Results from LHC

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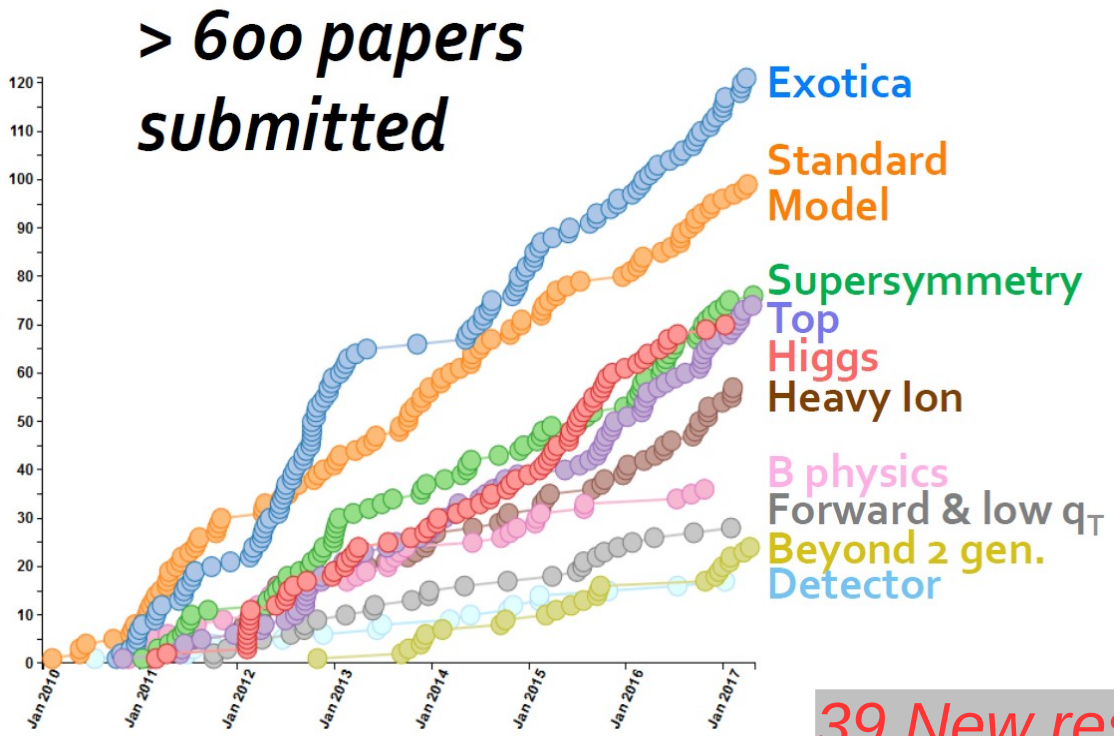
Plan of the talk

- CMS detector, performance
- Some SM measurements
- (mostly)CMS and ATLAS Searches
  - New results in Higgs search
  - New results in Searches for Supersymmetry
  - Other BSM searches: updates and new
- Conclusion

(Note: not a talk on behalf of CMS or ATLAS.)

CMS publications



39 New results Moriond 2017,

more for LHCP 2017

Status of LHC

- First stable beams are were produced in May
- 145 days of physics expected
- 2017 is a production year. Some challenges are to be faced to move towards HL-LHC era

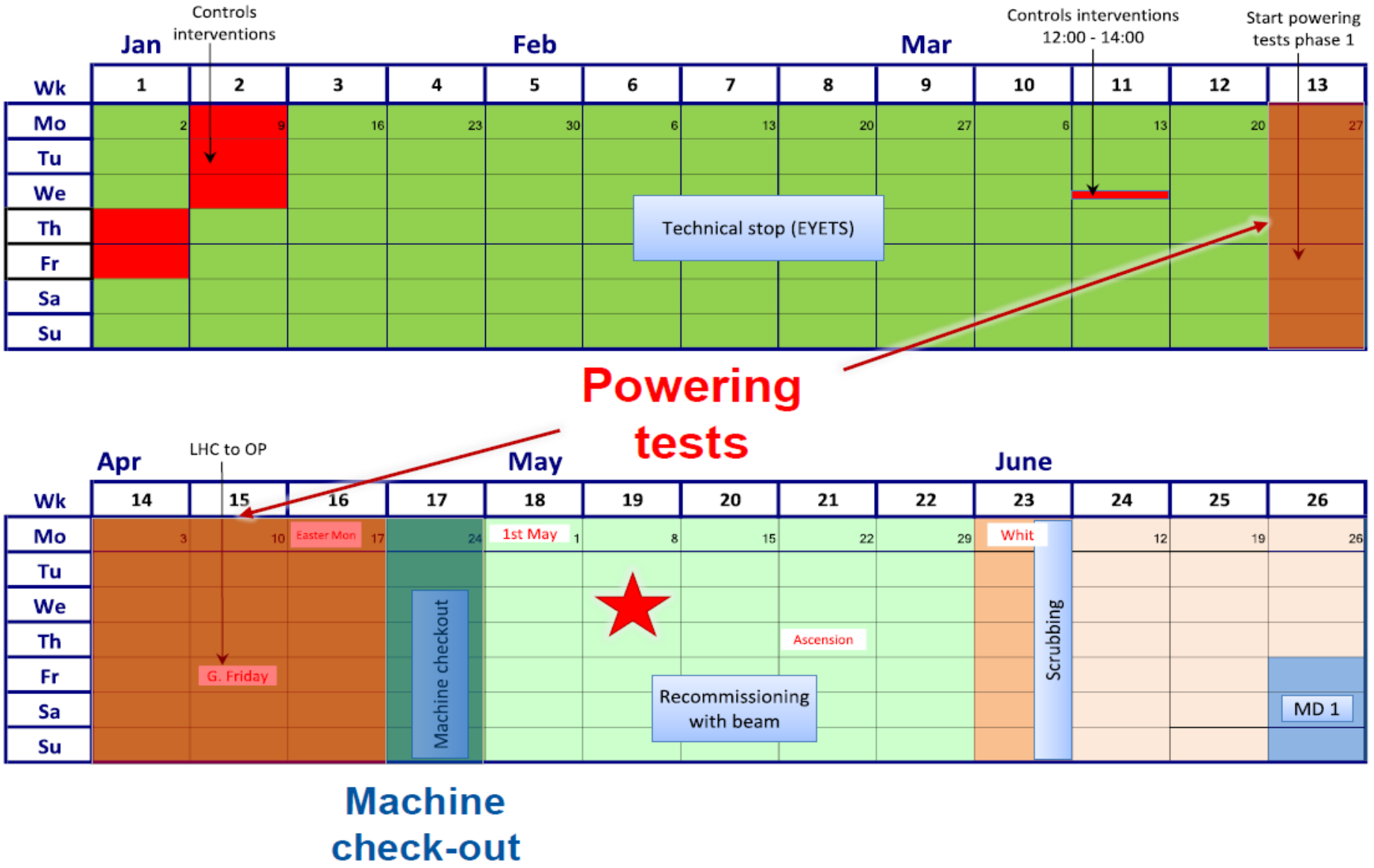
~90 fb^{-1} in 2017+18

See Matteo Solfaroli, LHCC 10 May, 2017, for details

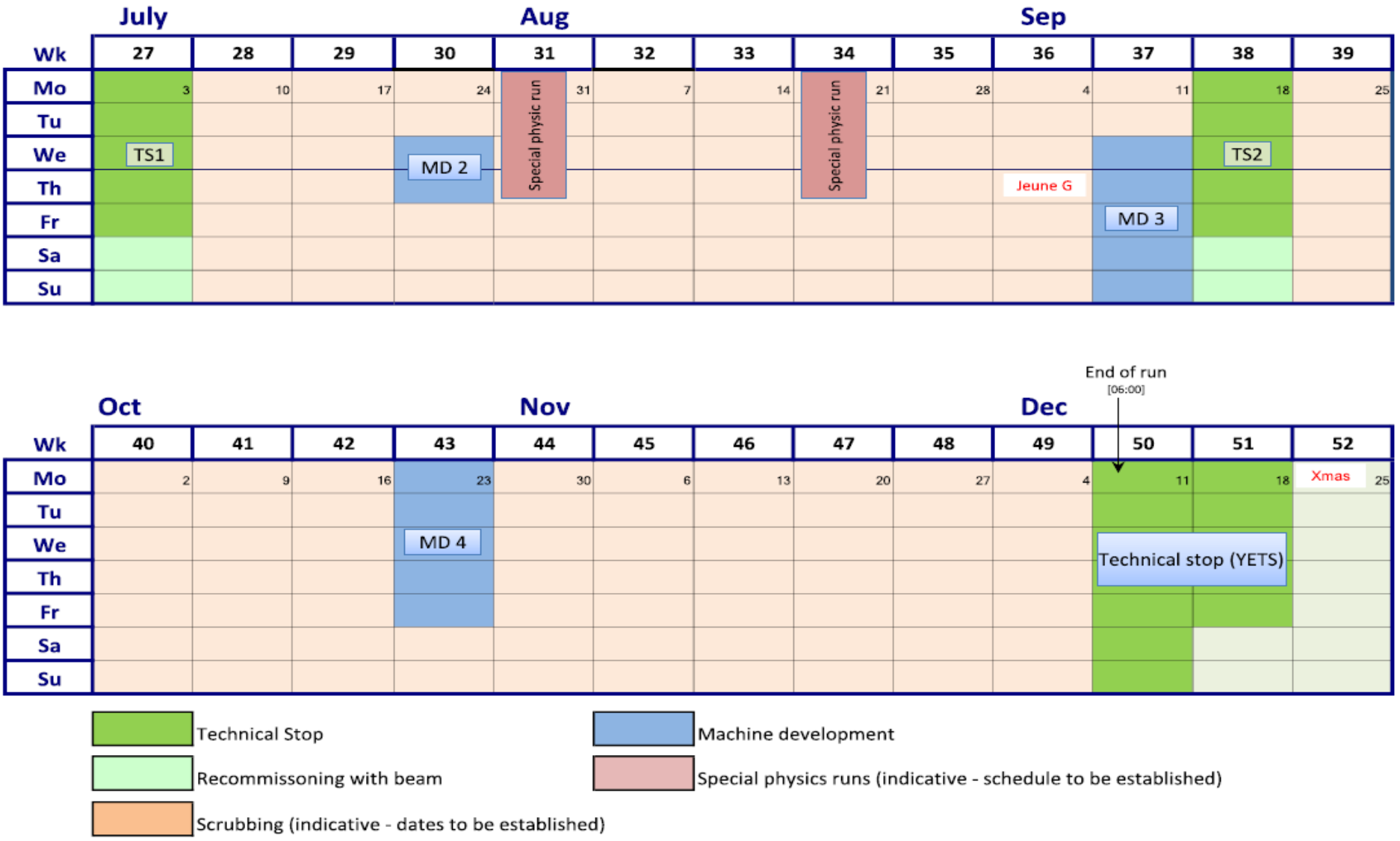
LHC schedule in numbers

Activity	#days	Ratio to total
Low beta p physics at 13 TeV	145	64%
Commissioning and intensity ramp-up (+ TS recovery)	39	18%
Machine Developments	15	7%
Technical Stops	10	4%
Special runs	8	4%
Scrubbing	7	3%

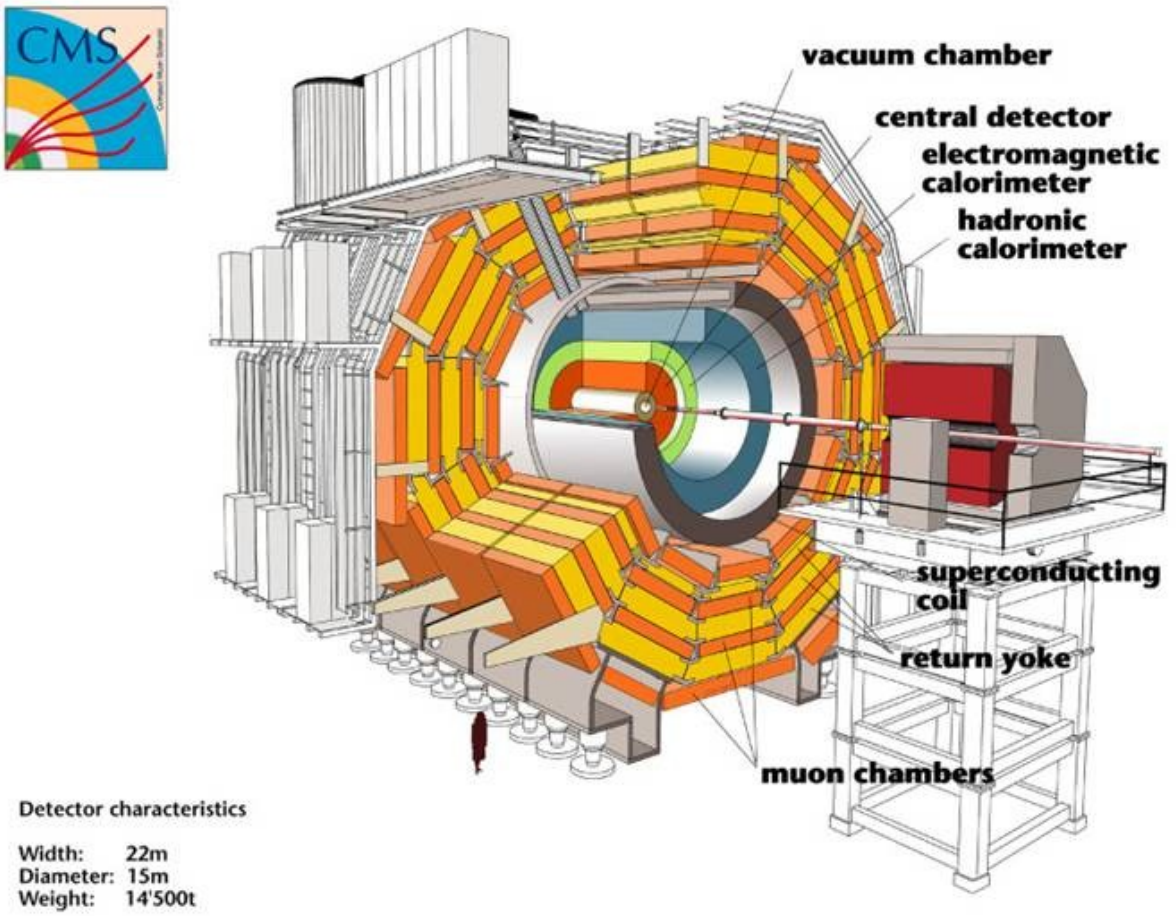
LHC schedule Q1 + Q2



LHC Schedule Q3 + Q4

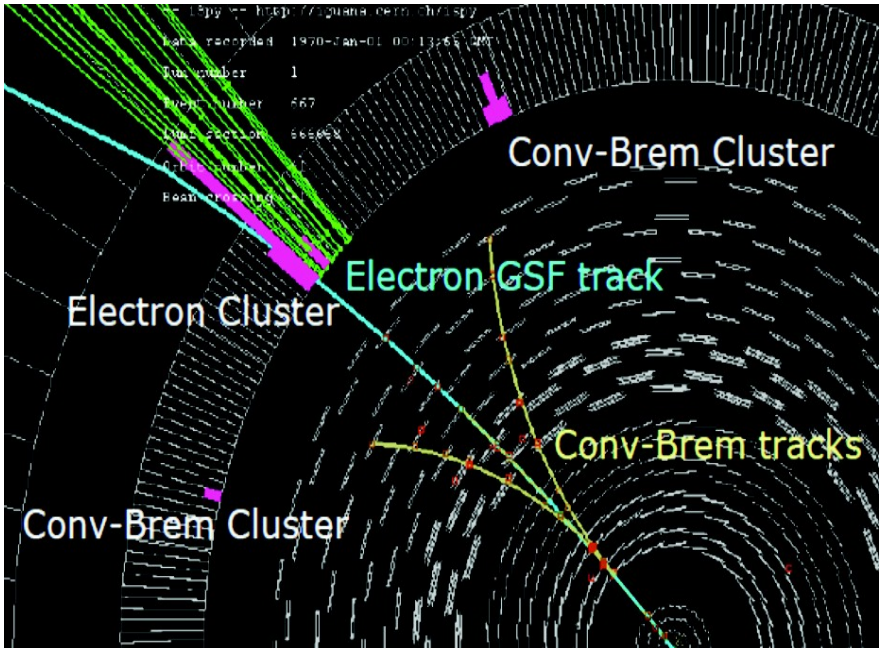


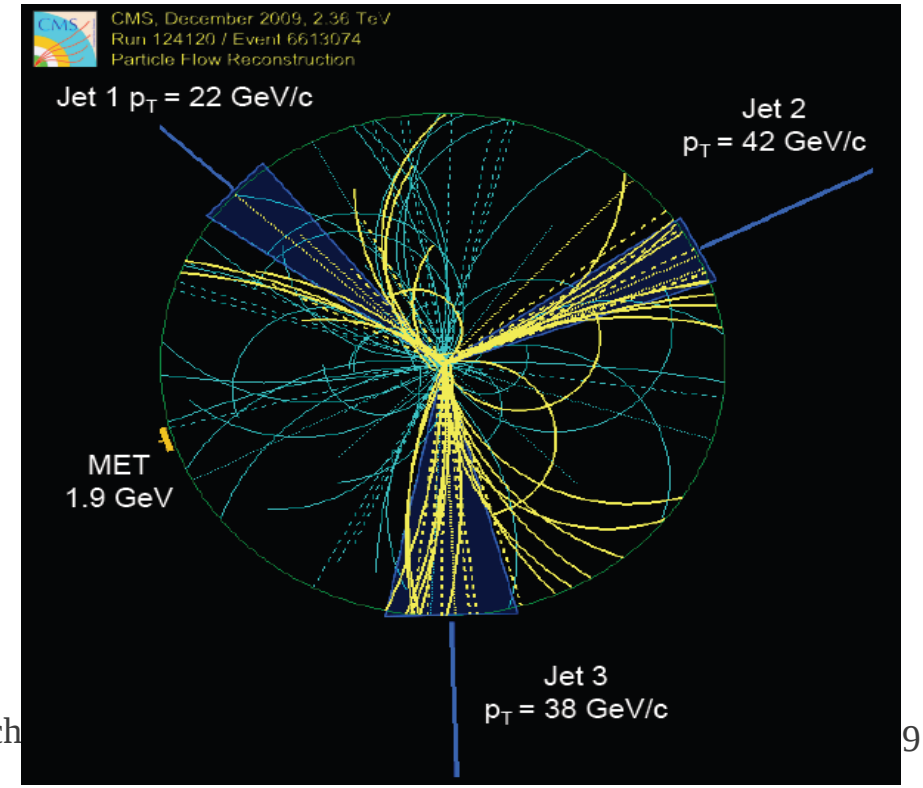
The CMS Detector



Particle Flow

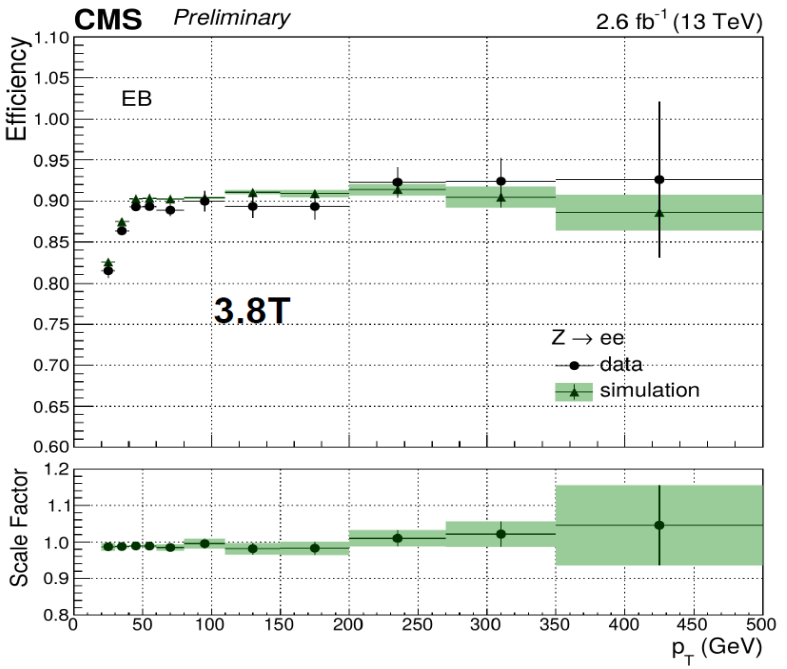
- Reconstruct all stable particles in CMS detector by linking responses of subdetectors
  - Photon, electron, muon, charged and neutral hadrons
  - Resulting list of particles can be used as if they came from a MC generator
  - Composite objects like jets, taus, MET can be reconstructed from the “PF candidates”

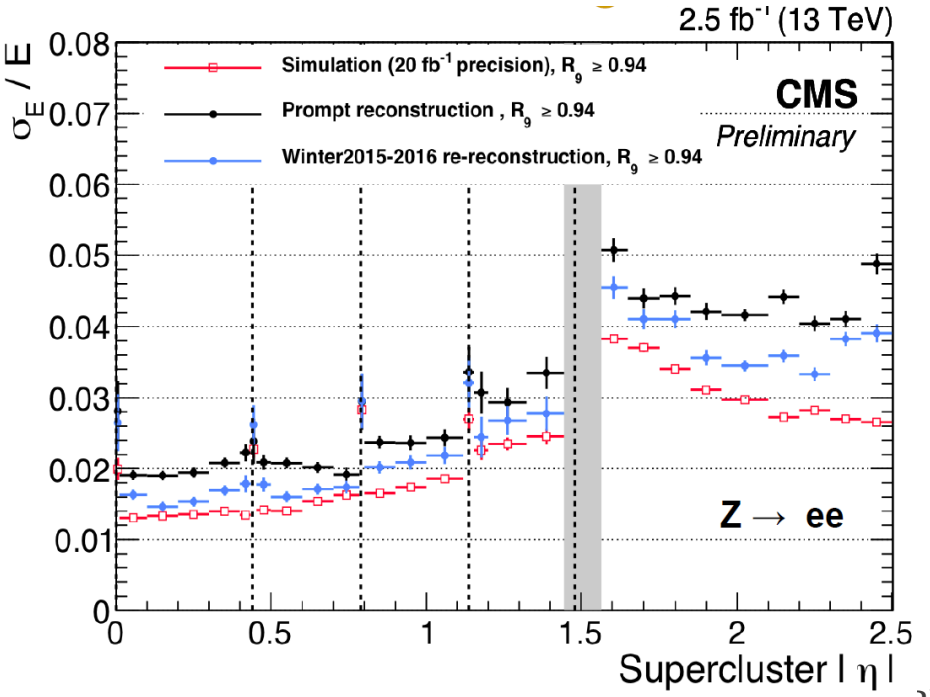


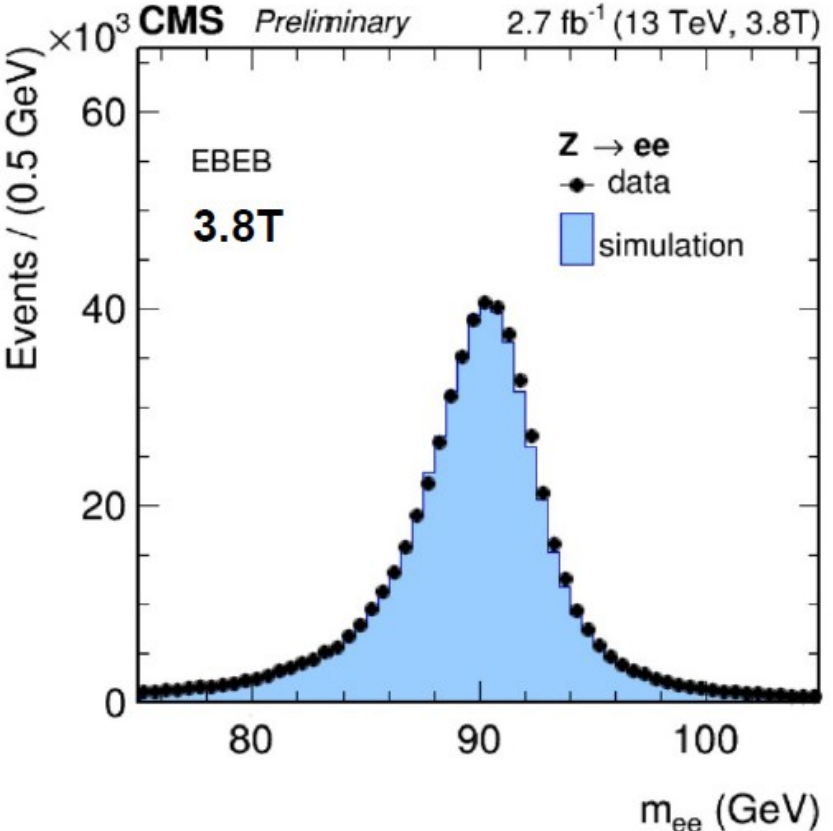


Electrons and photons

- Photon identification efficiency ~ 90%
- Photon energy resolution ~ 1% from Z to ee data

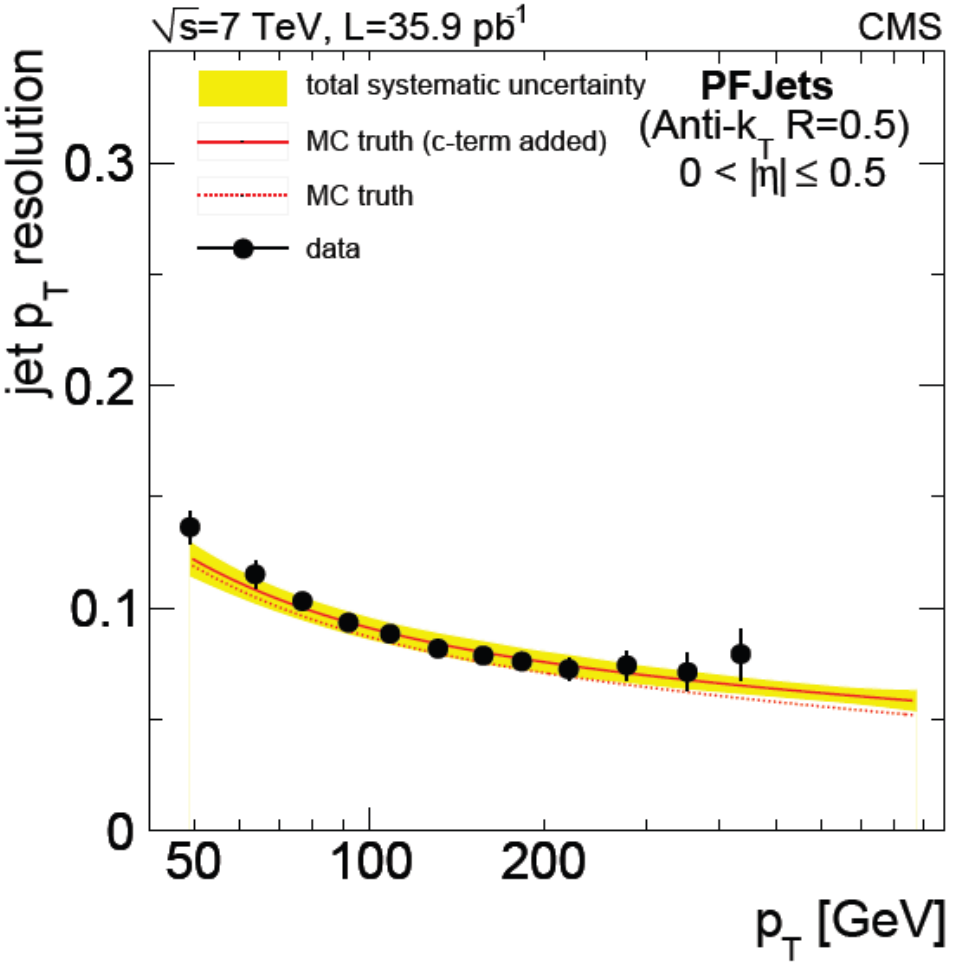






Jets

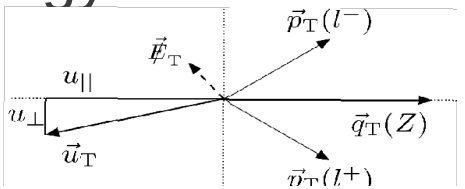
- Anti-KT with distance parameter 0.5
- CALO, JPT, PF
- PF jets clustered from PF candidate particles
- Resolution measured from MC and various energy balancing methods

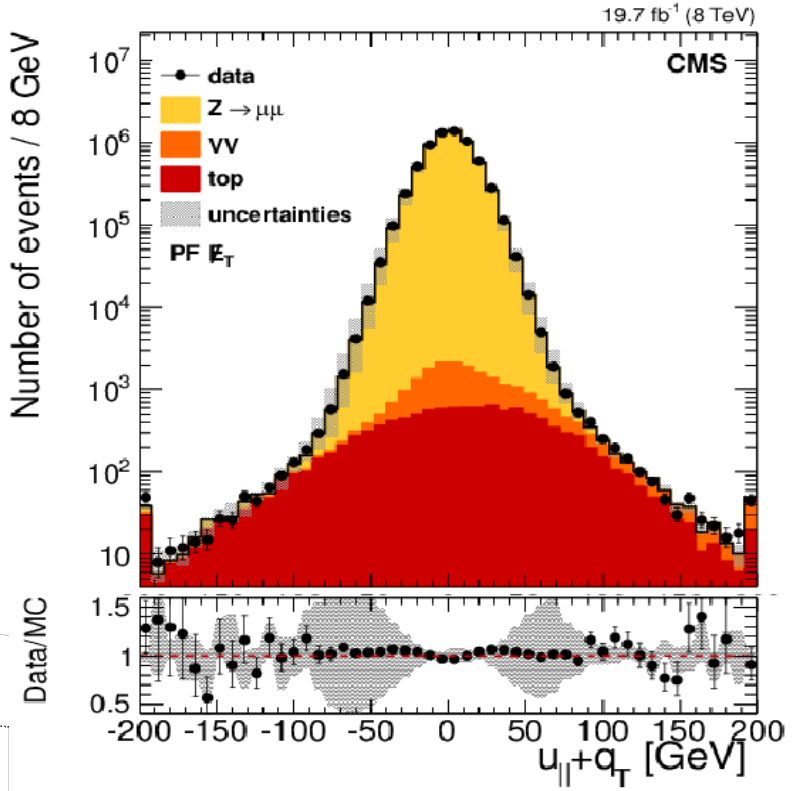


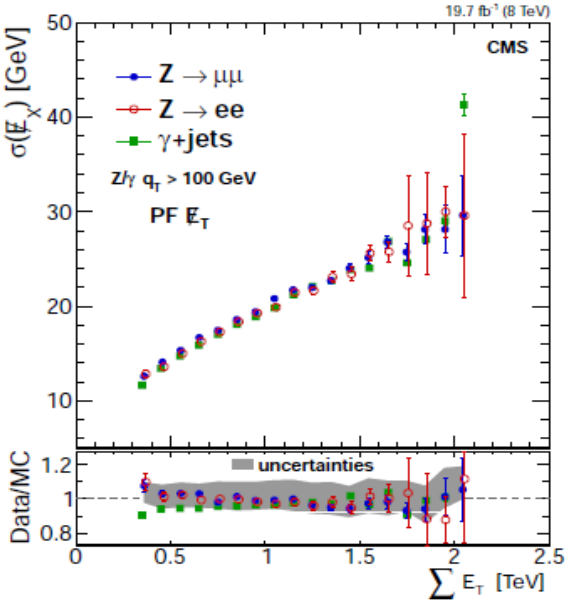
2011 JINST 6 P11002

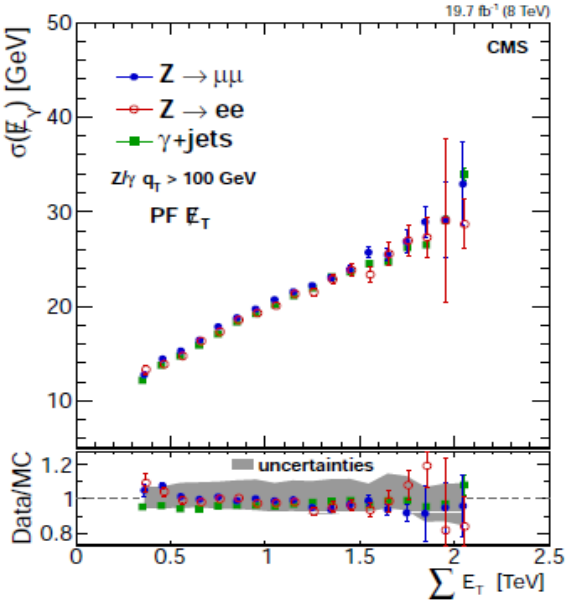
MET ($\not{E}_T$)

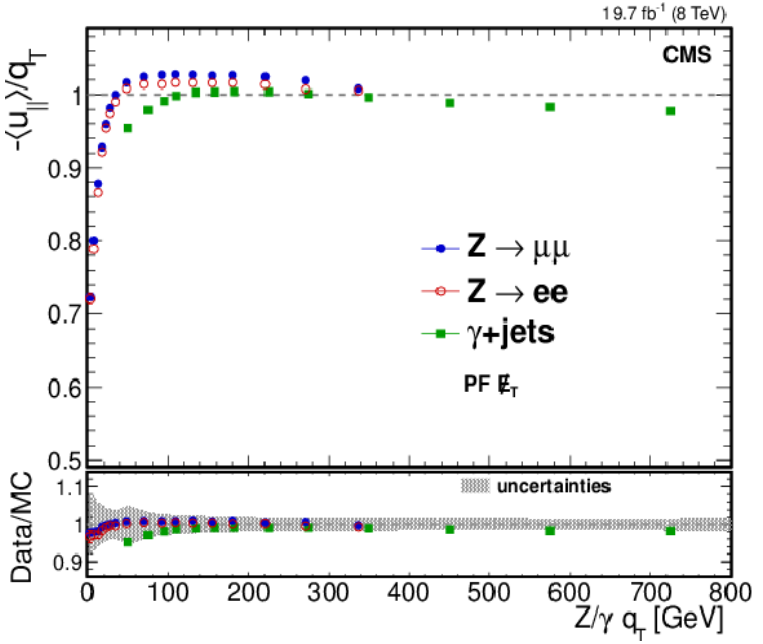
- Constructed from PF candidates
- Correted for various detector effects
- Dominated by jet enrgy resolution





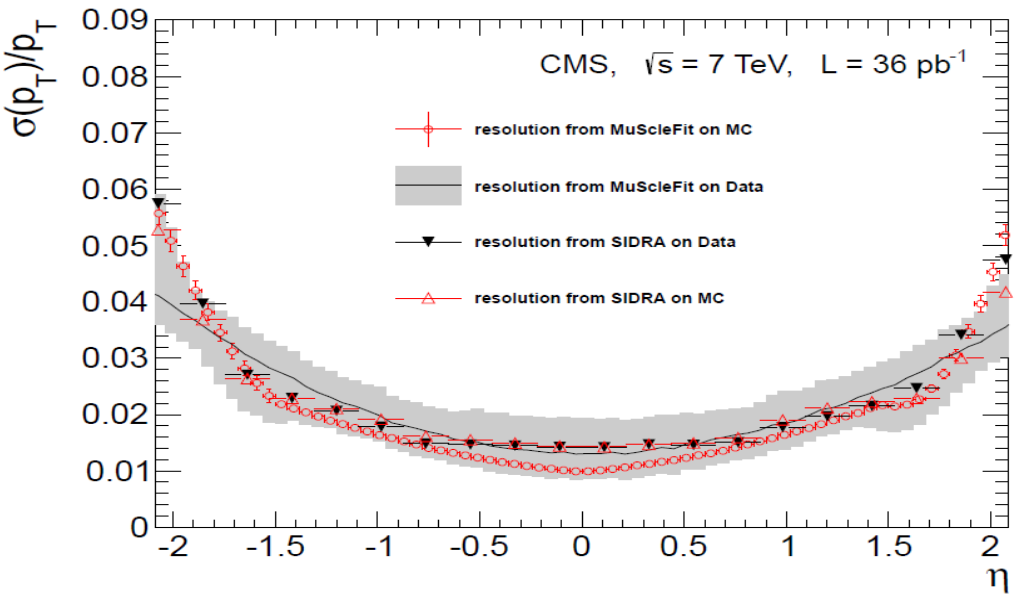






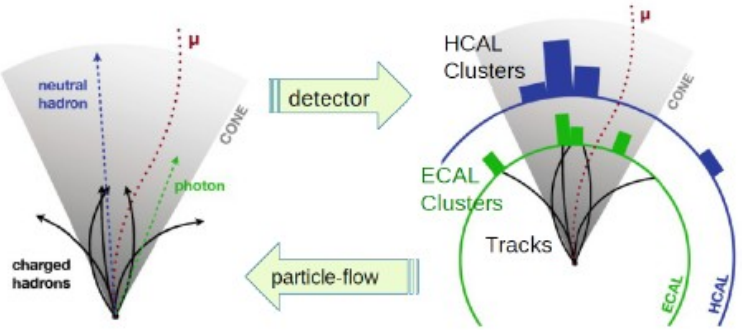
Muons

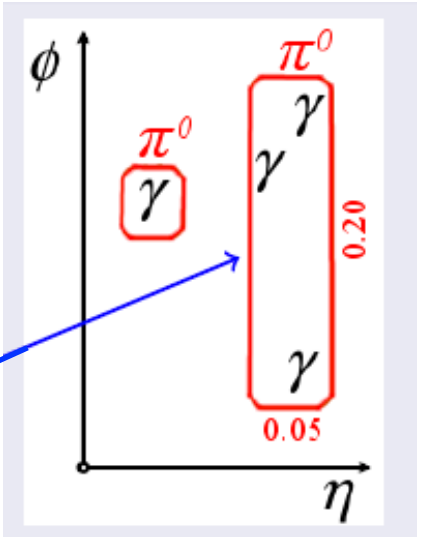
- 1-6% relative momentum resolution for pT<100GeV
- > 10% at a TeV
- > 1% hadron to muon fake probability
- Single muon trigger rates (much) better than 90% above a few GeV



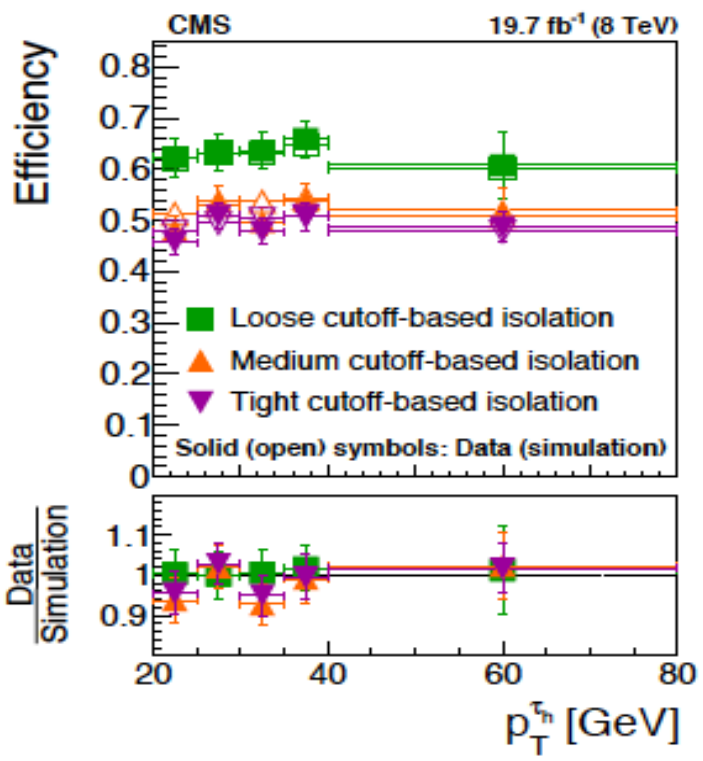
Taus: The HPS algorithm

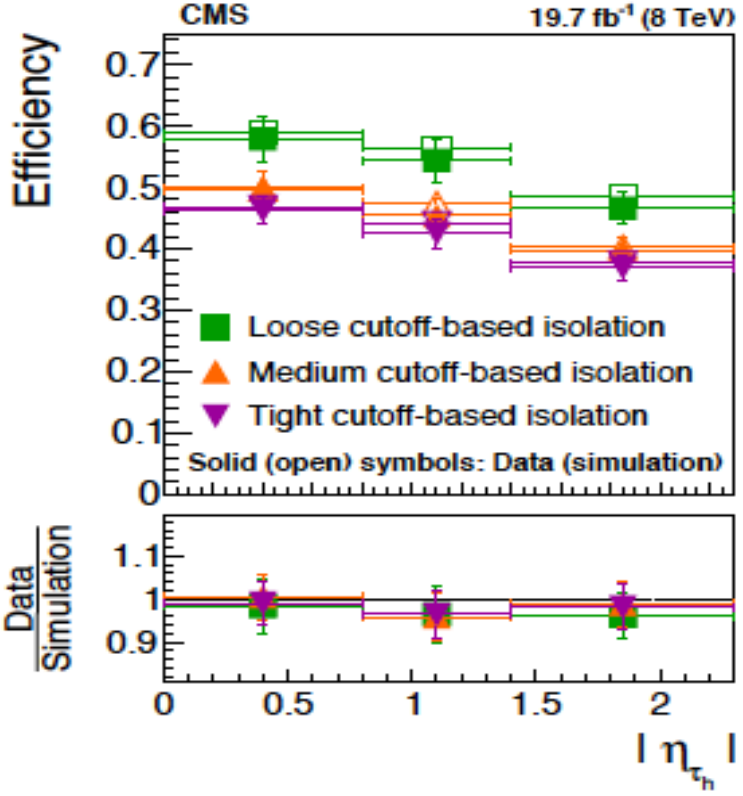
- charged hadrons reconstructed using PF algorithm
  - π0's are reconstructed in ECAL as strips
- Strips:
  - π0 -> γγ
  - Photon conversion in the tracker material
  - electron tracks bending in the magnetic field: broadening of the signal in the azimuthal direction
  - A strip of 0.05 in η and 0.2 in φ is built
  - Mass is required to be consistent with π0





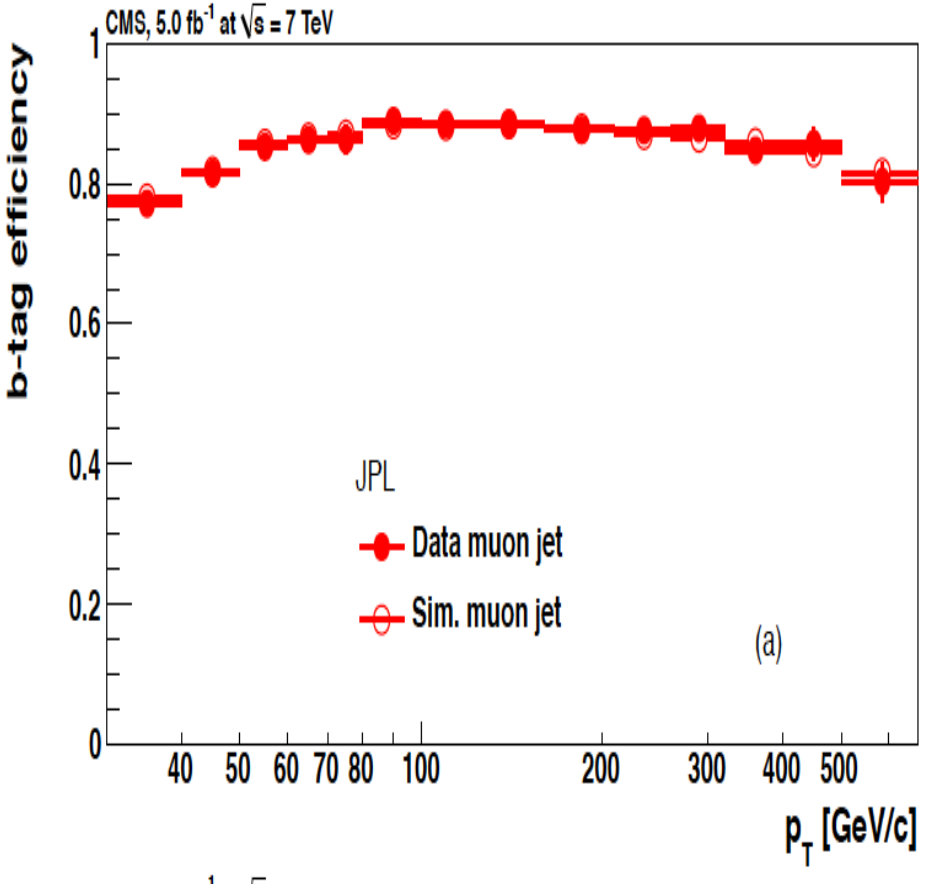
Tau efficiency





b-tagging efficiency

- The impact parameter (IP) of the track wrt the primary vertex is used to distinguish the decay product of the b hadron from the prompt tracks
- Algorithms:
  - Track counting: sorts tracks in a jet by decreasing value of IP significance
  - Jet probability (JP): uses estimate of the likelihood that all the tracks associated to the jet come from primary vertex
  - Jet B probability (JBP): same as JP, in addition, it gives more weight to the tracks with high IP significance



Profile Likelihood

ArXiv:physics 1007.1727v2

- Histogram of interest, and auxiliary measurement, used to construct Likelihood (Poisson statistics, u is signal strength, theta = nuisance parameters, here theta is b in each bin)

$$L(\mu,\boldsymbol{\theta}) = \prod_{j=1}^{N} \frac{(\mu s_j + b_j)^{n_j}}{n_j!} e^{-(\mu s_j + b_j)} \prod_{k=1}^{M} \frac{u_k^{m_k}}{m_k!} e^{-u_k} .$$

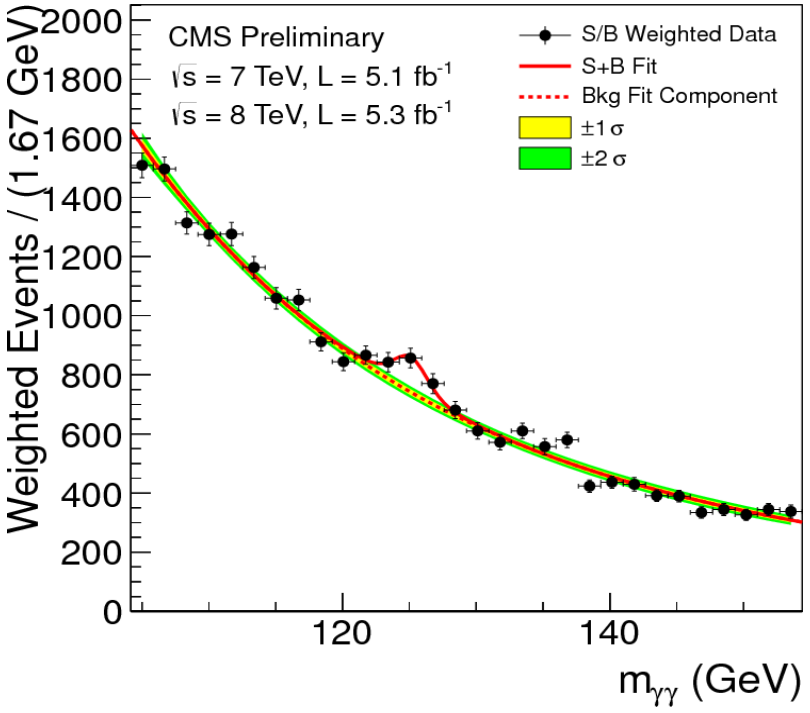
- Denominator: Likelihood at global minimum, Numerator: at a given mu, conditional maxima w.r.t. nuisance parameters

$$\lambda(\mu) = \frac{L(\mu,\hat{\hat{\boldsymbol{\theta}}})}{L(\hat{\mu},\hat{\boldsymbol{\theta}})} .$$

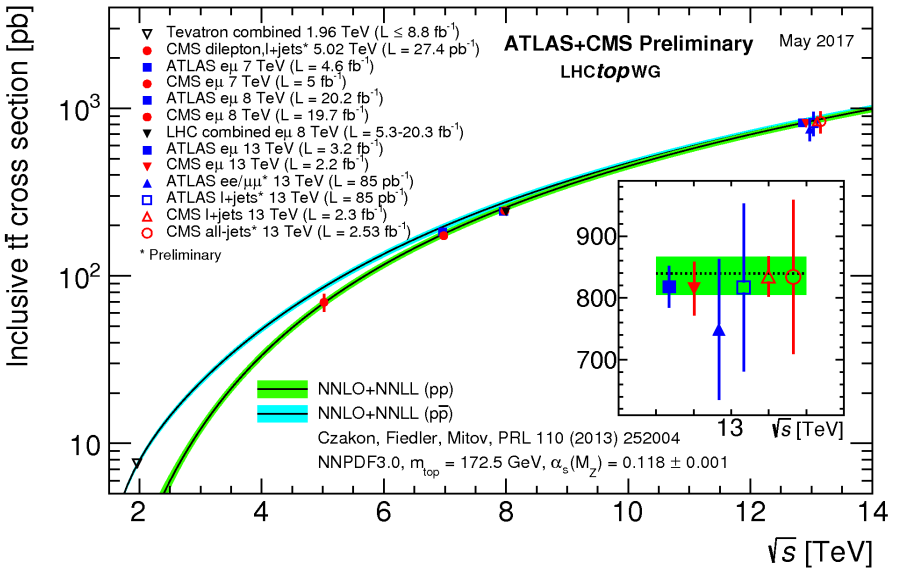
- Is between 0,1 by definition

$$t_\mu = -2\ln\lambda(\mu)$$

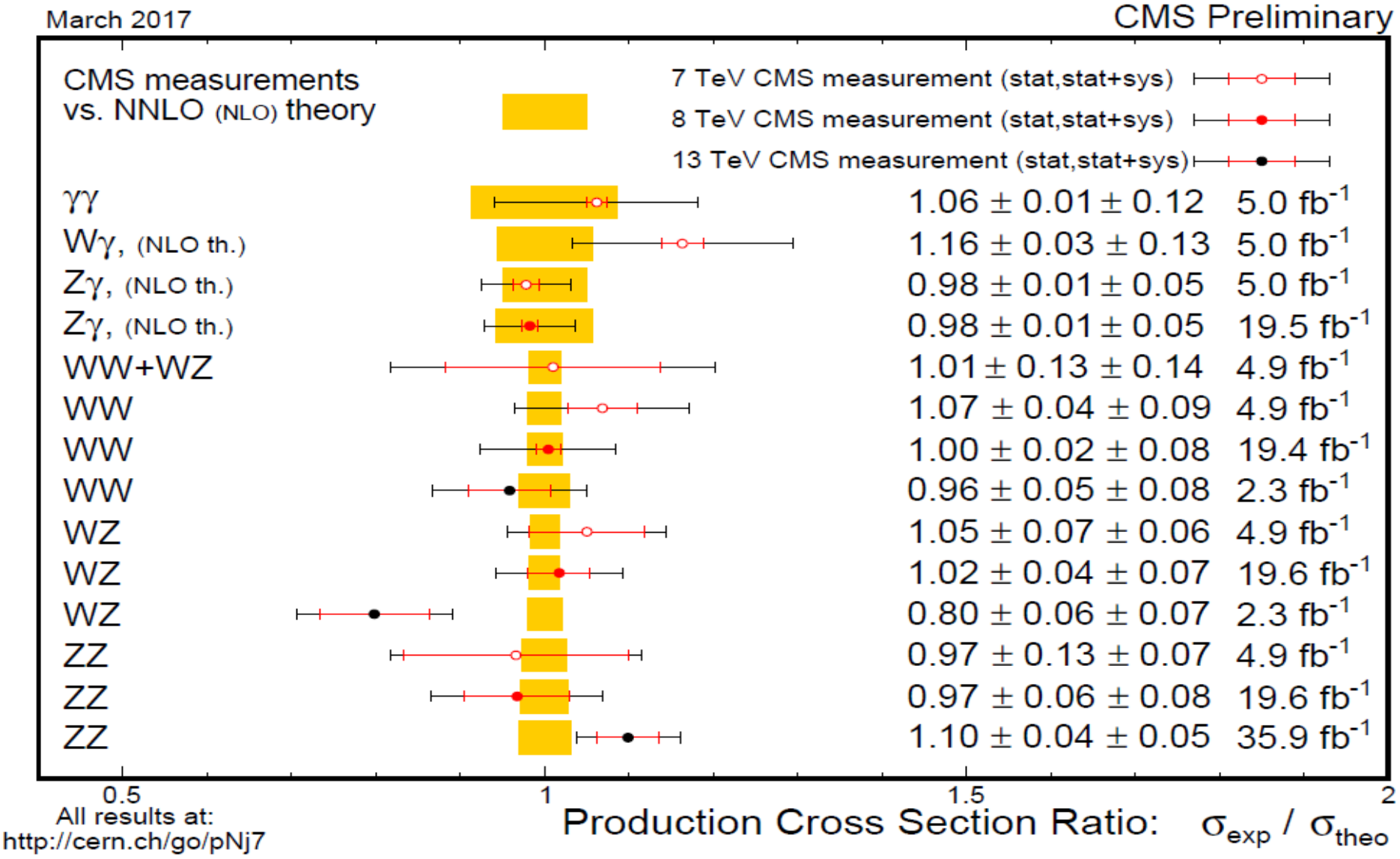
- tμ broadens due to presence of nuisance parameters



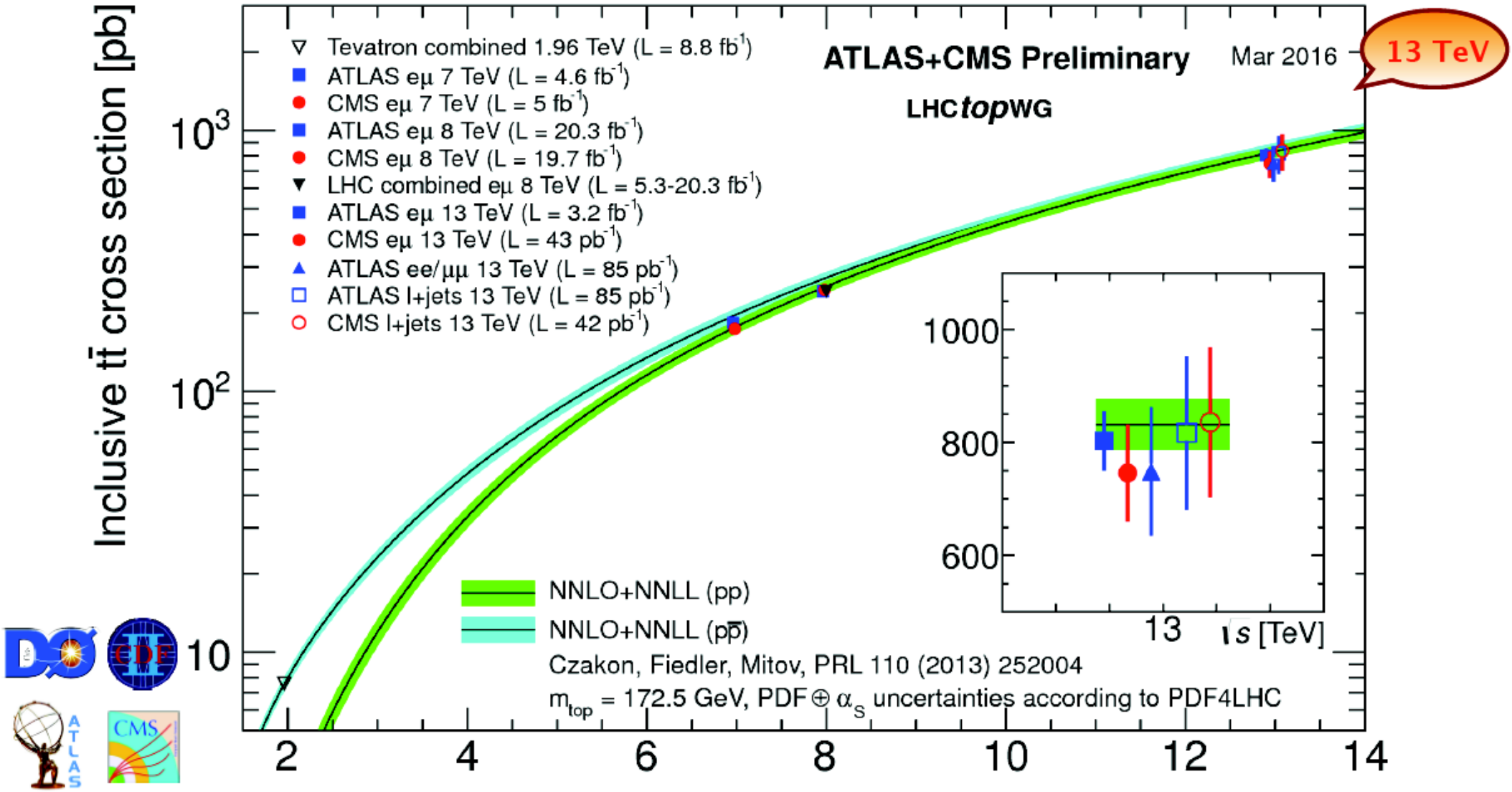
Standard model measurements



Di boson cross sections



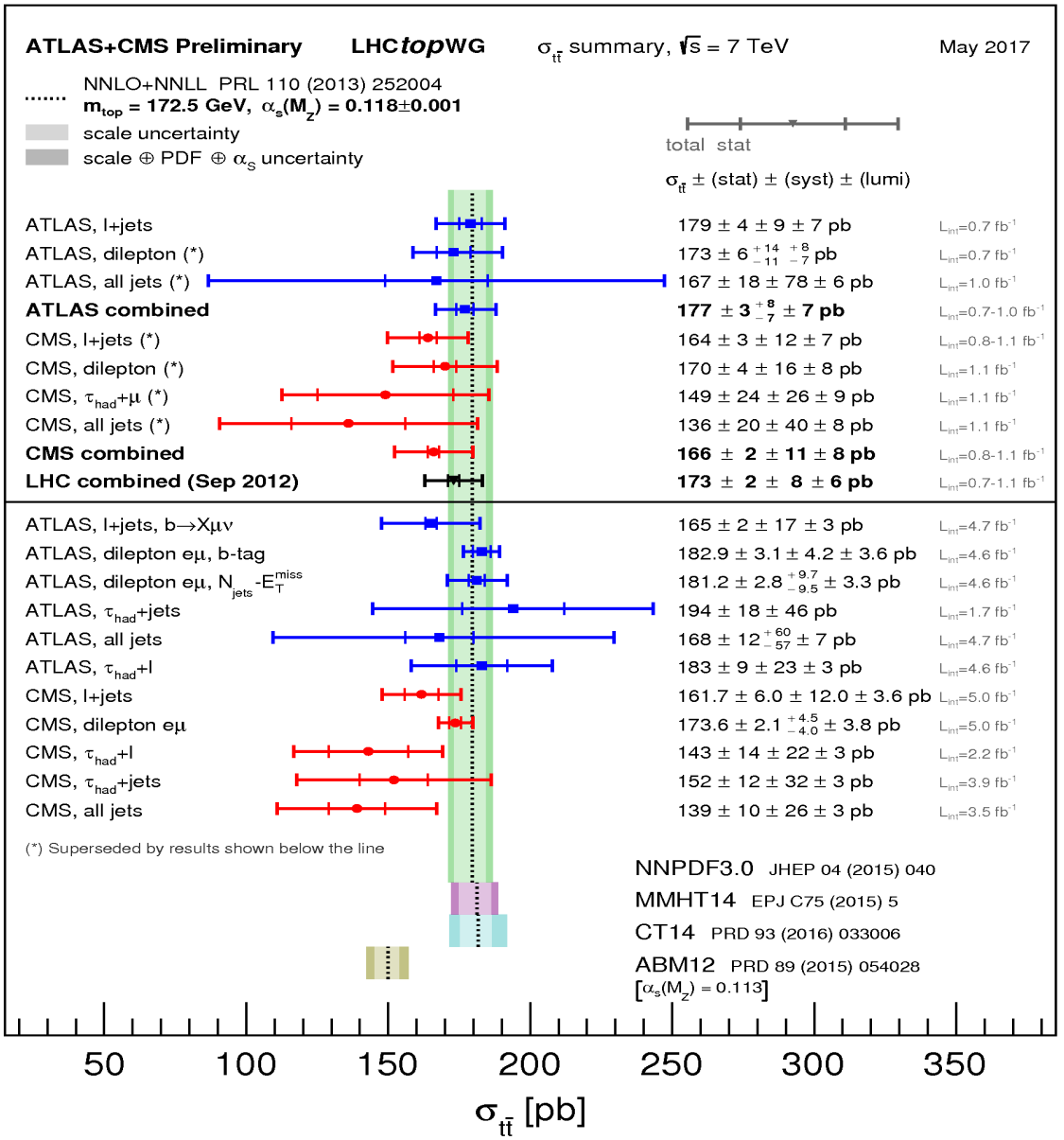
No evidence for anomalous couplings!



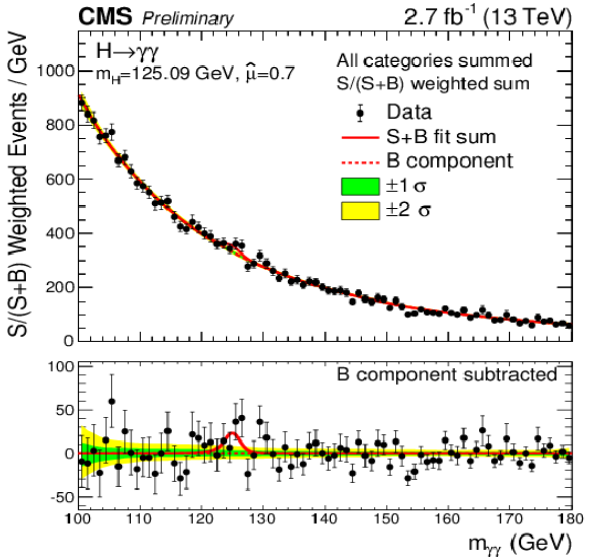
→ agreement with SM prediction

See talk by Christian Schwanenberger in LHC Ski 2016 for more details

top pair cross sections



SM Higgs measurements



Higgs to diphoton rediscovery

HIG-15-005

David Sperka, Moriond QCD,2016

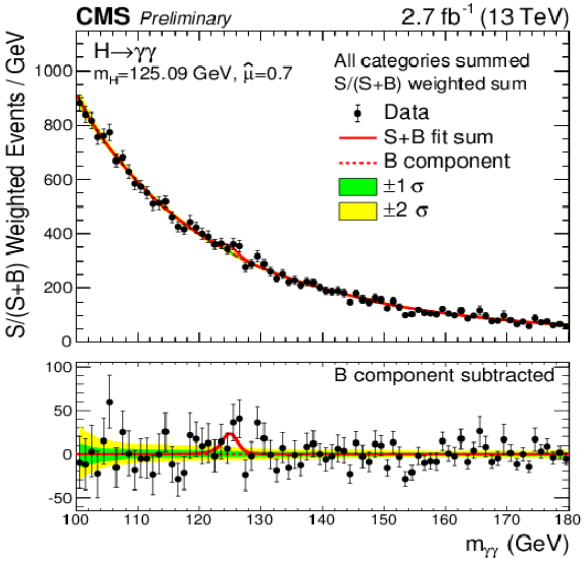
- MVA based analysis (vertex, photon id, kinematics)
- Background from sideband fit
- Categories:
- ttH leptonic/hadronic
- VBF
- 4 untagged
- Expected (MH=125.09 GeV)

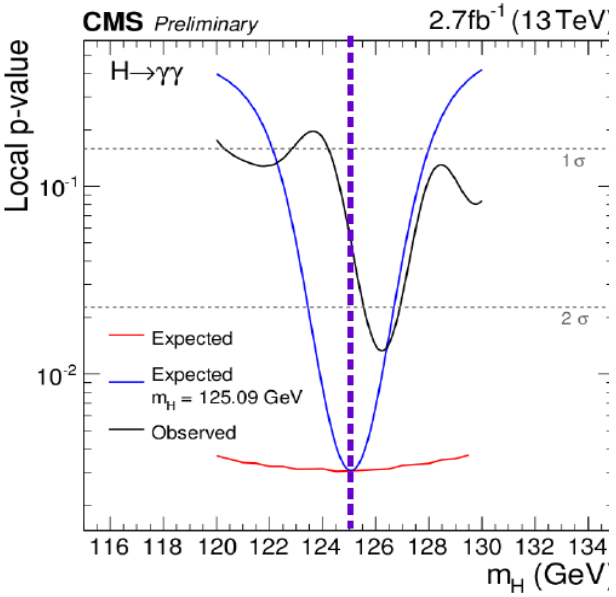
$2.7\ \sigma$

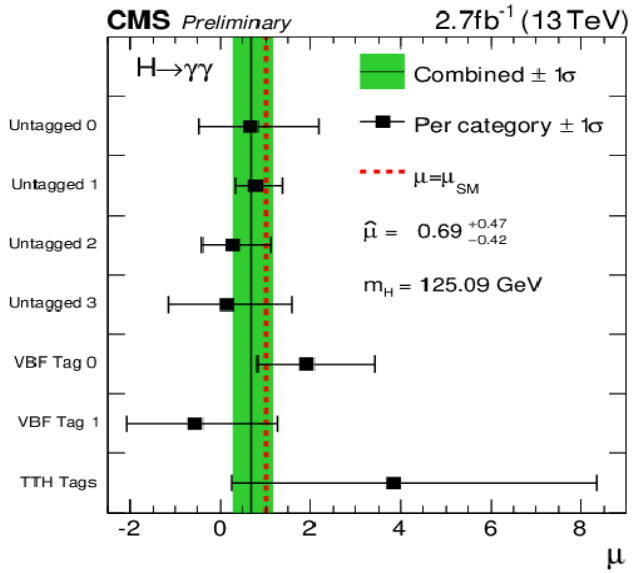
- Observed

$1.7\ \sigma$

- Best Fit





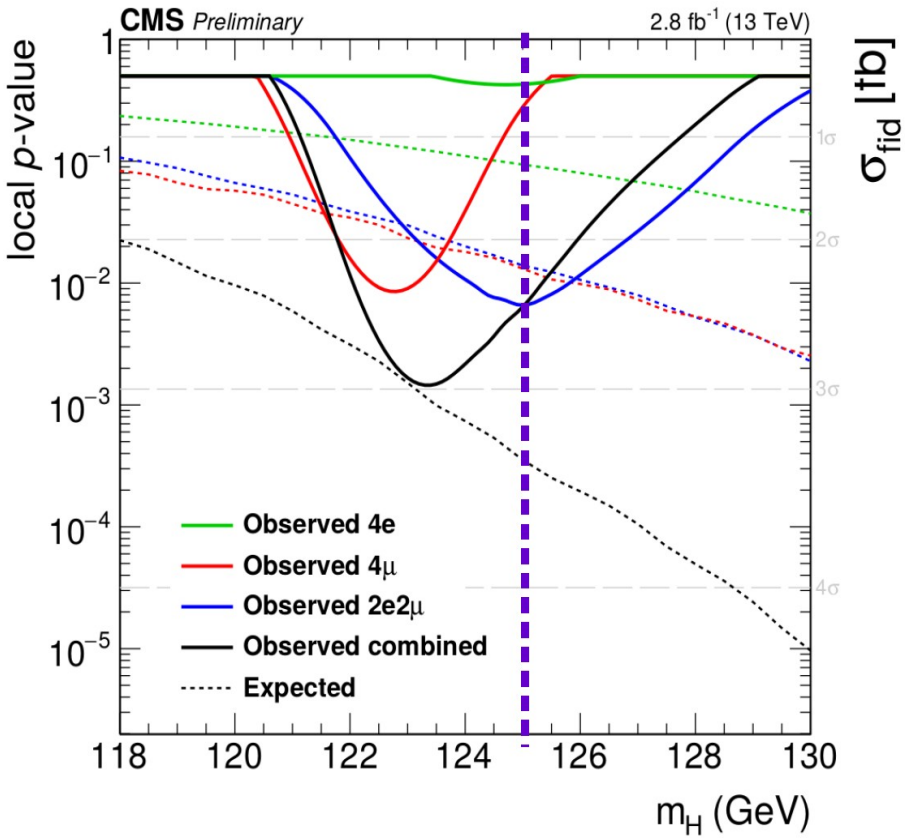


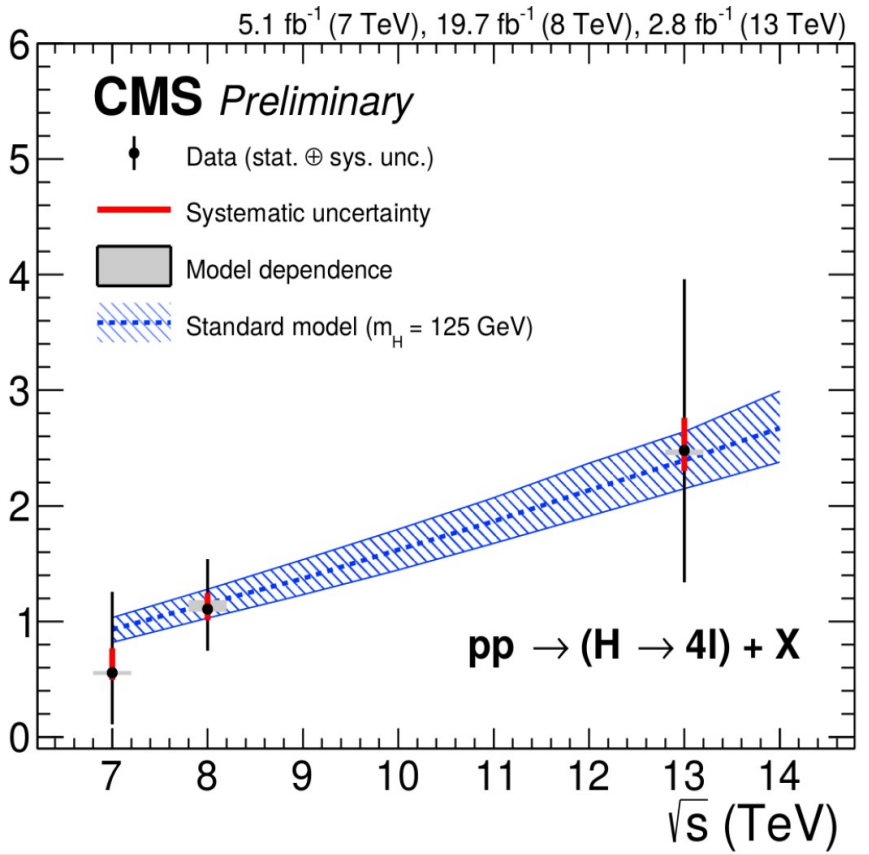
$\mu = 0.69^{+0.47}_{-0.42}$ $\mu_{\mathrm{ggH,t\bar{t}H}} = 0.43^{+0.80}_{-0.84}$ $\mu_{\mathrm{VBF,VH}} = 1.99^{+2.62}_{-2.45}$

Higgs rediscovery

$H \to ZZ \to 4\ell$ (13 TeV)

HIG-15-004





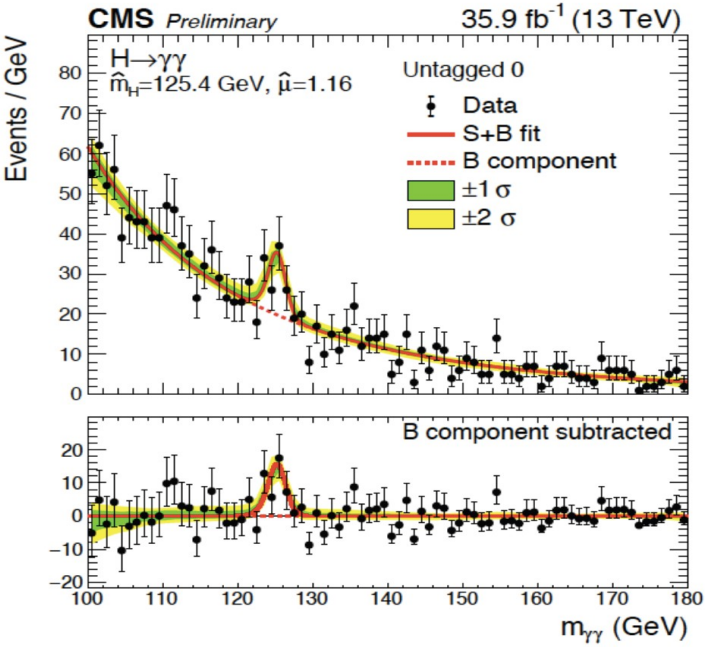
Significance: 2.5σ (3.4σ) obs. (exp.) at $m_{\mathrm{H}} = 125.09$ GeV

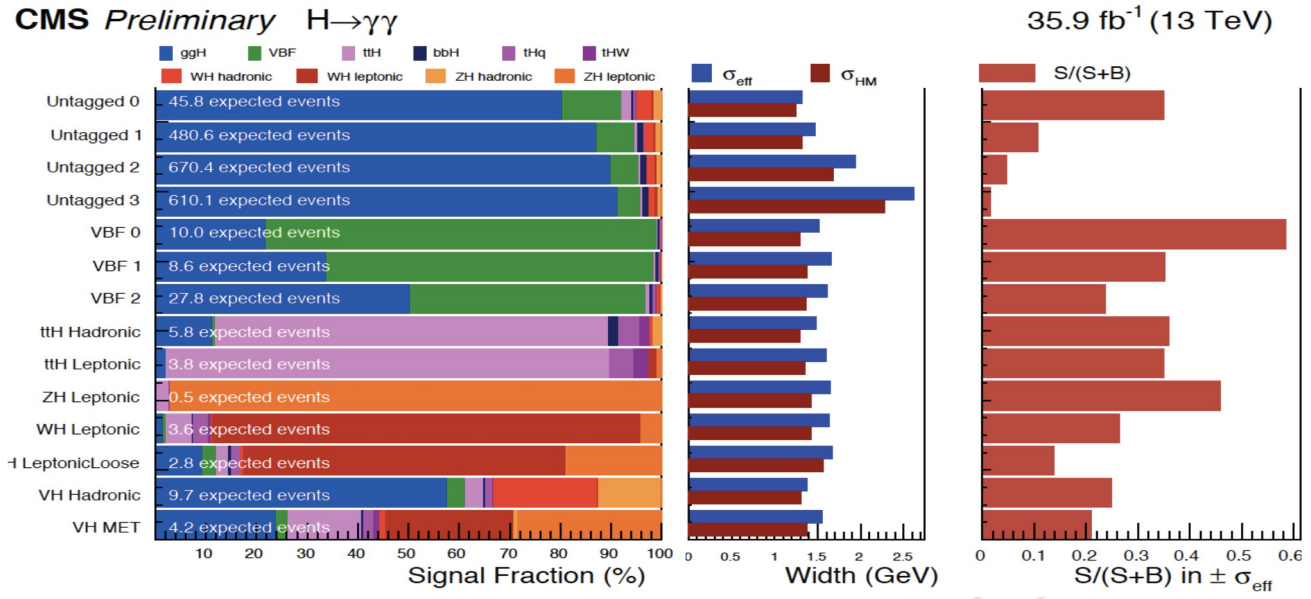
$\mu = 0.82^{+0.57}_{-0.43}$ $\mu_{\mathrm{ggH,t\bar{t}H}} = 0.95^{+0.64}_{-0.49}$ $\mu_{\mathrm{VBF,VH}} = 0.0^{+2.5}_{-0.0}$ $m_{\mathrm{H}} = 123.4^{+0.8}_{-0.7}$ GeV

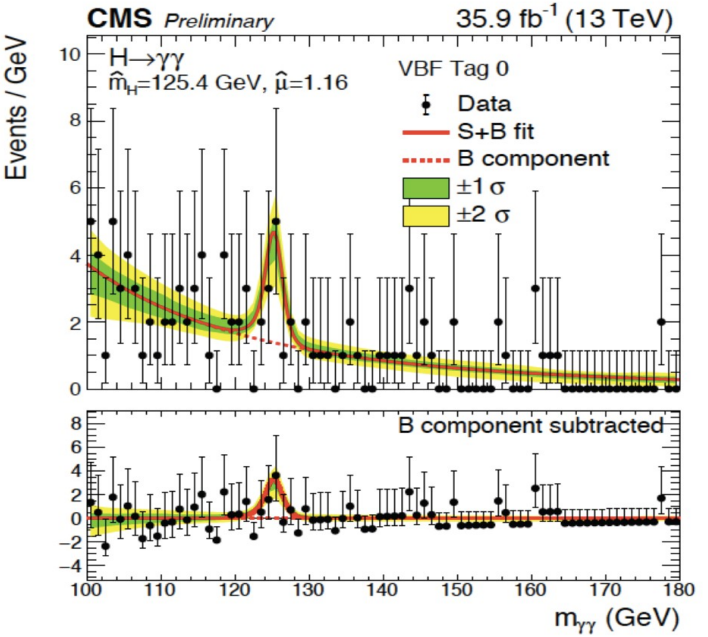
$\sigma_{\mathrm{fid.}} = 2.48^{+1.46}_{-1.13}(\mathrm{stat.})^{+0.28}_{-0.18}(\mathrm{sys.})^{+0.01}_{-0.04}(\mathrm{model\ dep.})$ fb $\sigma^{\mathrm{SM}}_{\mathrm{fid.}} = 2.39 \pm 0.25$ fb

Higgs to diphoton: Rediscovery

- Similar to run 1 analysis
- Categories in mass resolution and production channels for best sensitivity

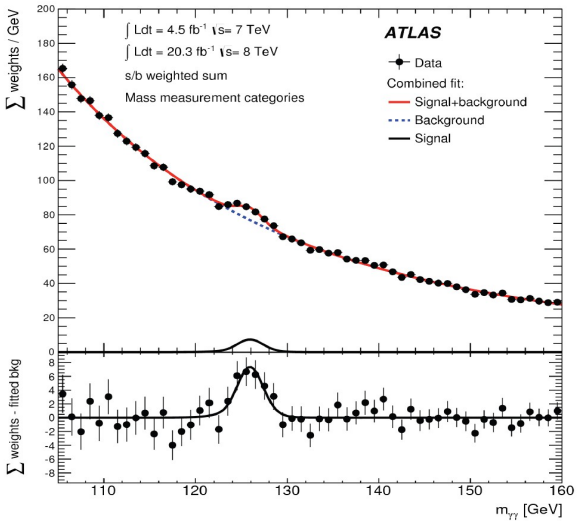


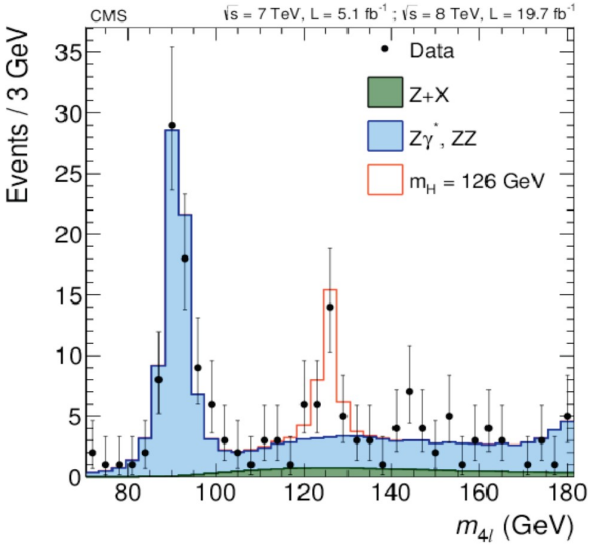


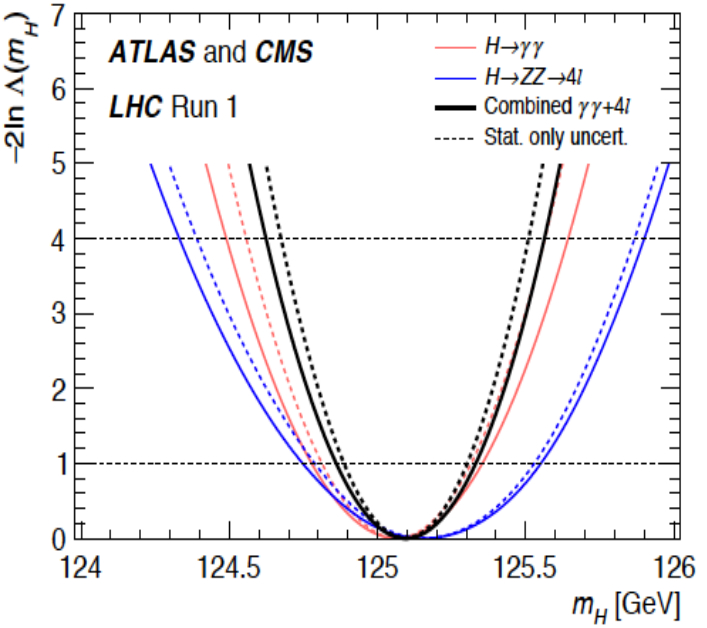


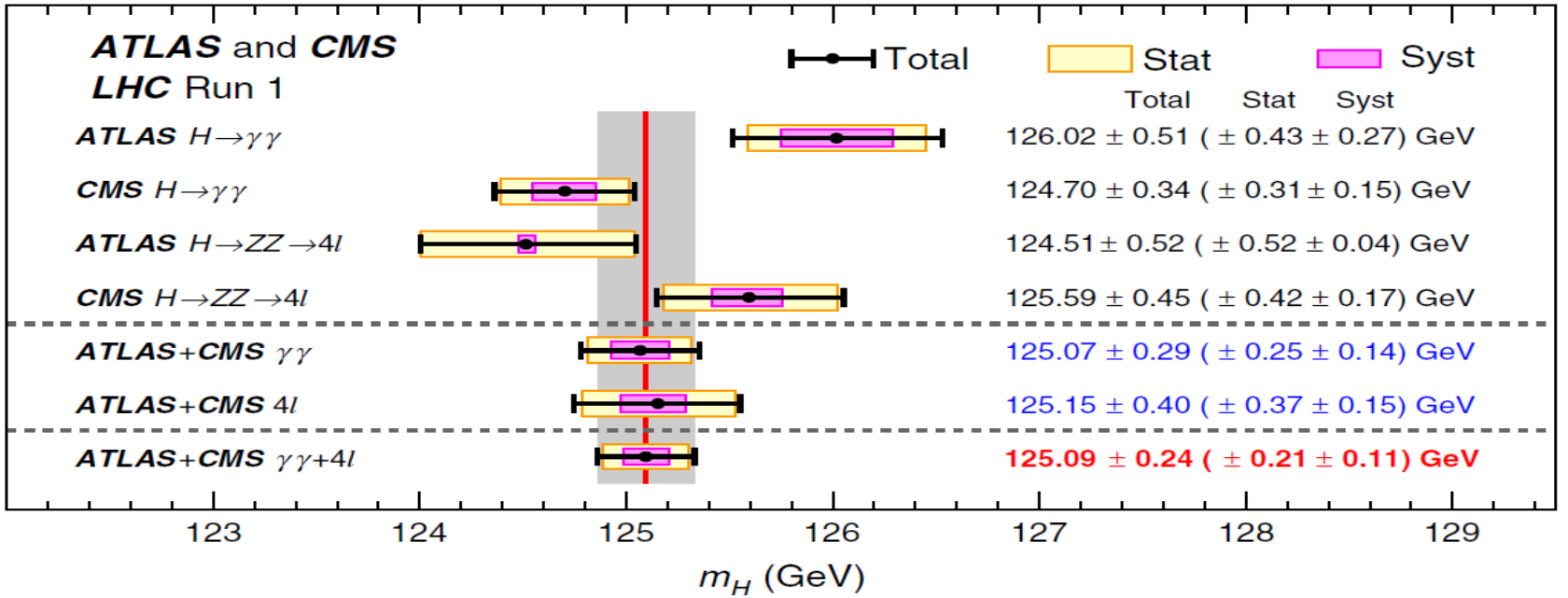
Higgs mass: CMS and ATLAS

PRL 114 (2015) 191803





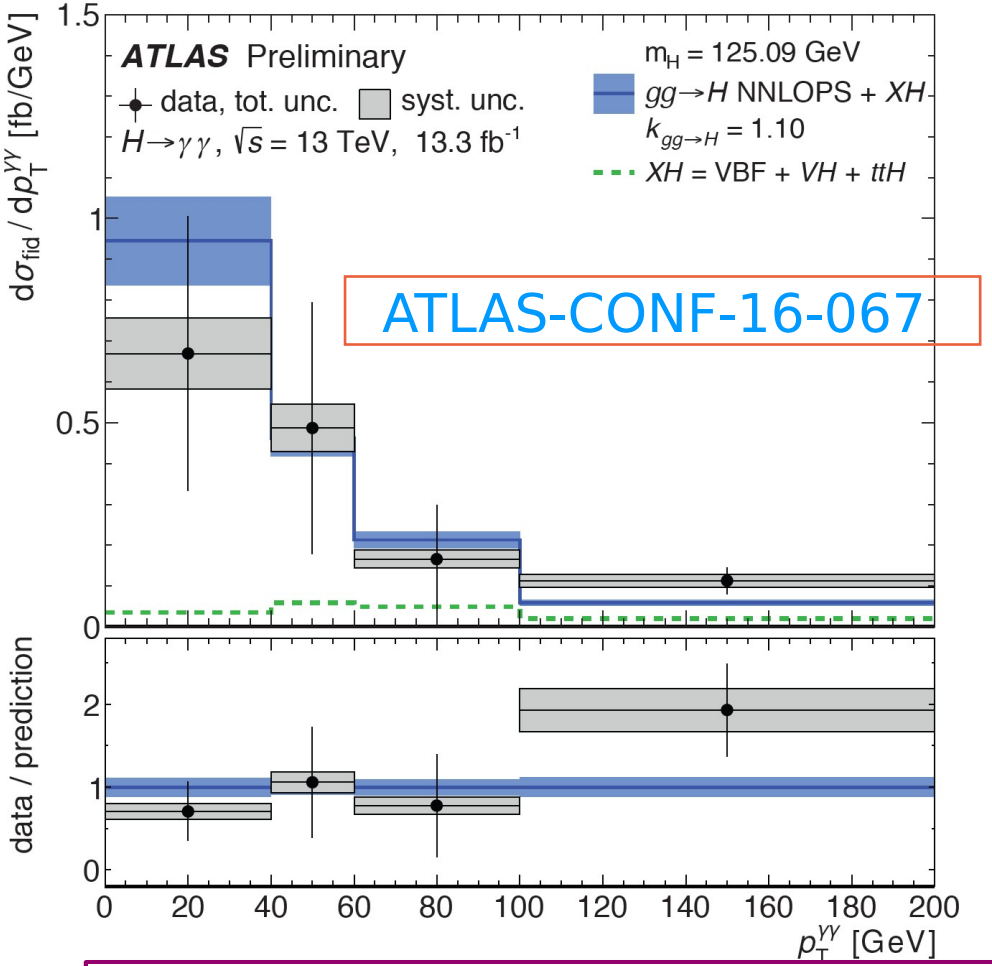




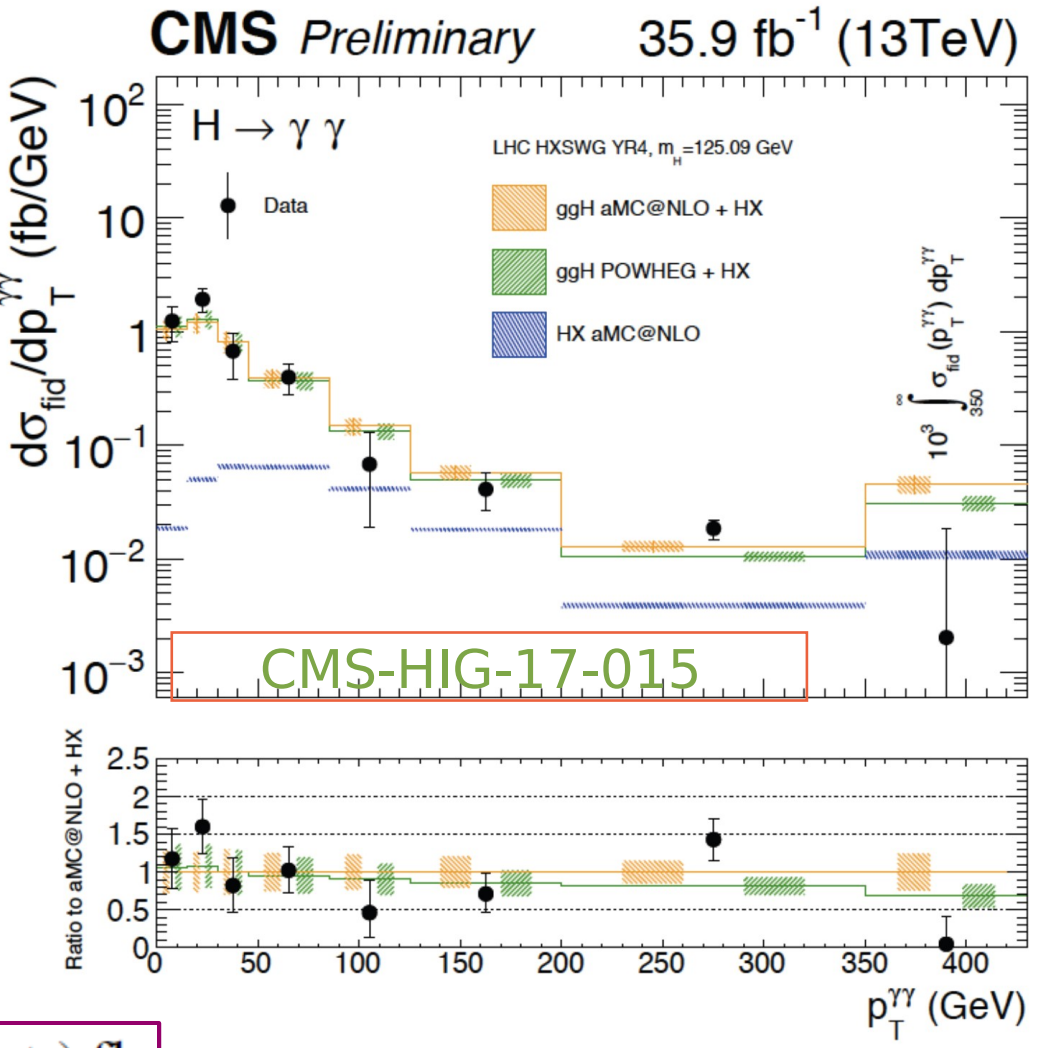
Higgs Mass

- Masured better than 0.2% precision
- Dominant systematics is from the energy/momentum scales of the final state particles
- Statistical uncertainty dominated

Fiducial and Differential Cross section



ATLAS-CONF-16-067



CMS-HIG-17-015

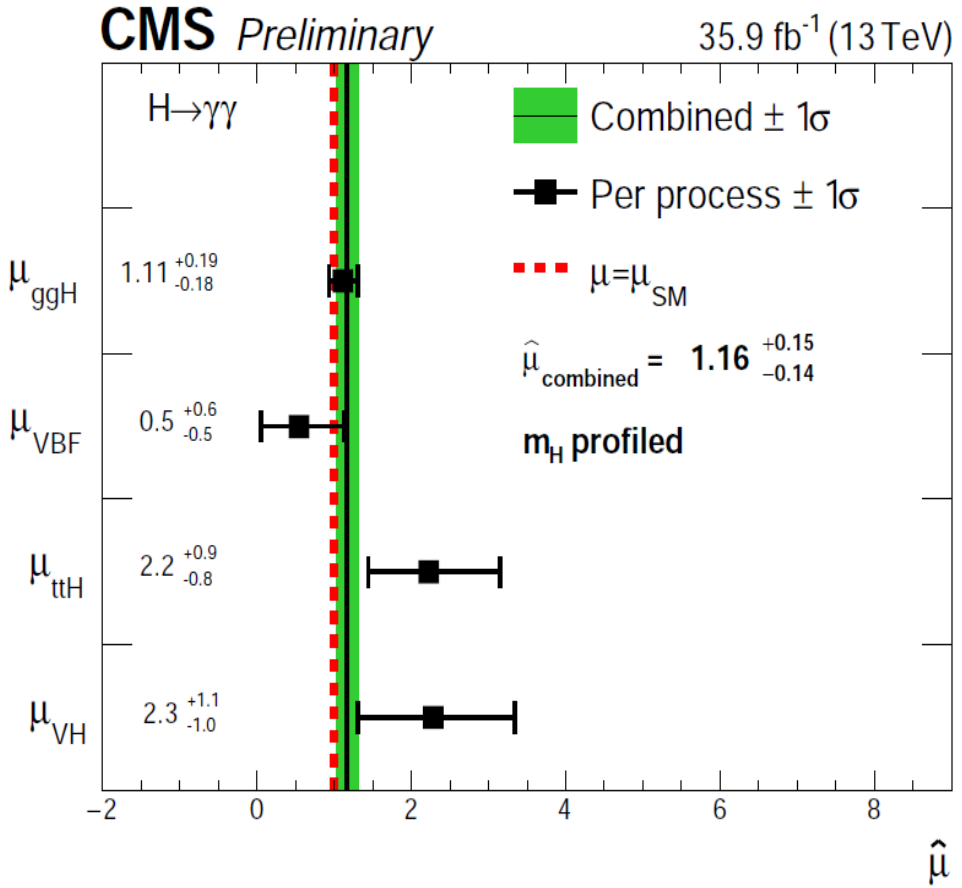
$$\sigma_{\text{fid}} = 43.2 \pm 14.9\,(\text{stat.}) \pm 4.9\,(\text{syst.})\,\text{fb}$$

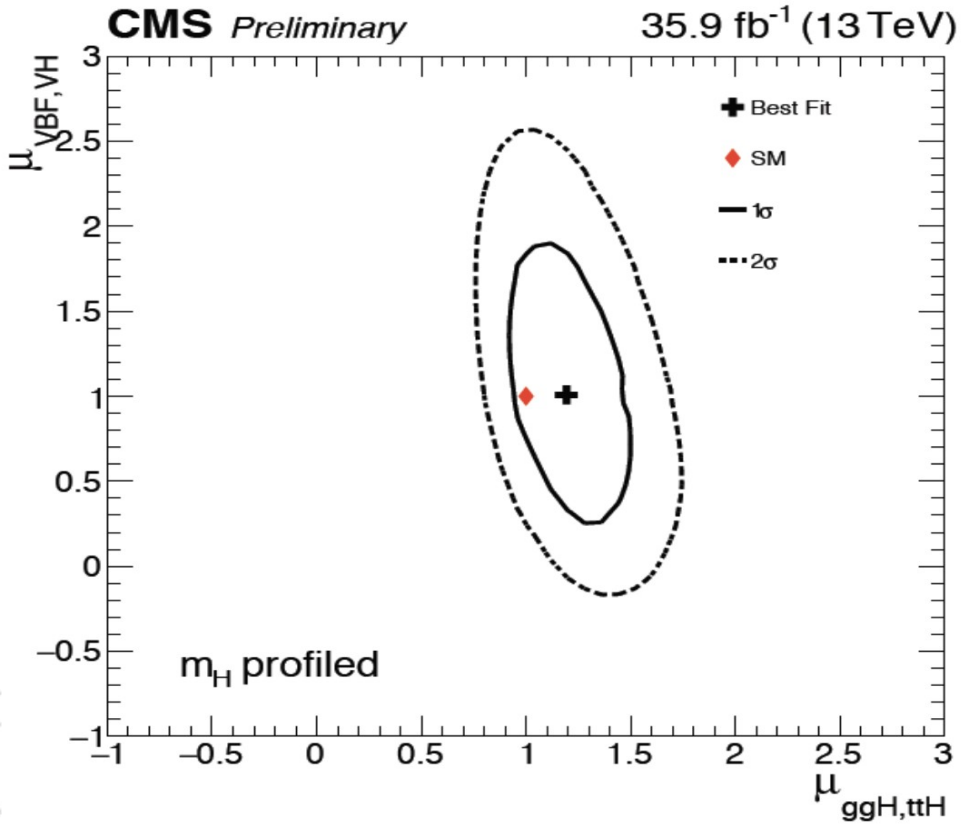
ATLAS SM expected $62.8\,^{+3.4}_{-4.4}\,\text{fb}$

CMS SM expected 75^{+4}_{-4}fb

$$\hat{\sigma}_{\text{fiducial}} = 84 \pm 11\,(\text{stat}) \pm 7\,(\text{syst})\,\text{fb} = 84^{+13}_{-12}\,(\text{stat+syst})\,\text{fb}$$

Signal strength: CMS @ 13 TeV



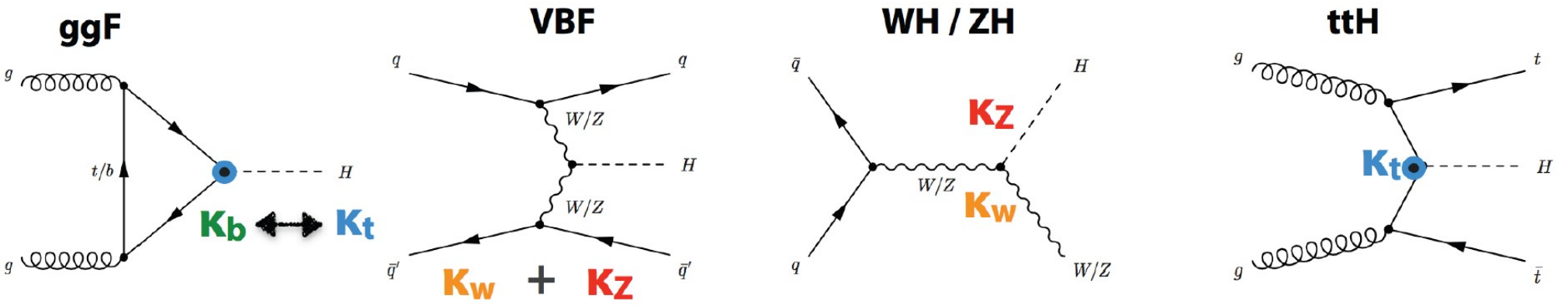


CMS-HIG-16-040

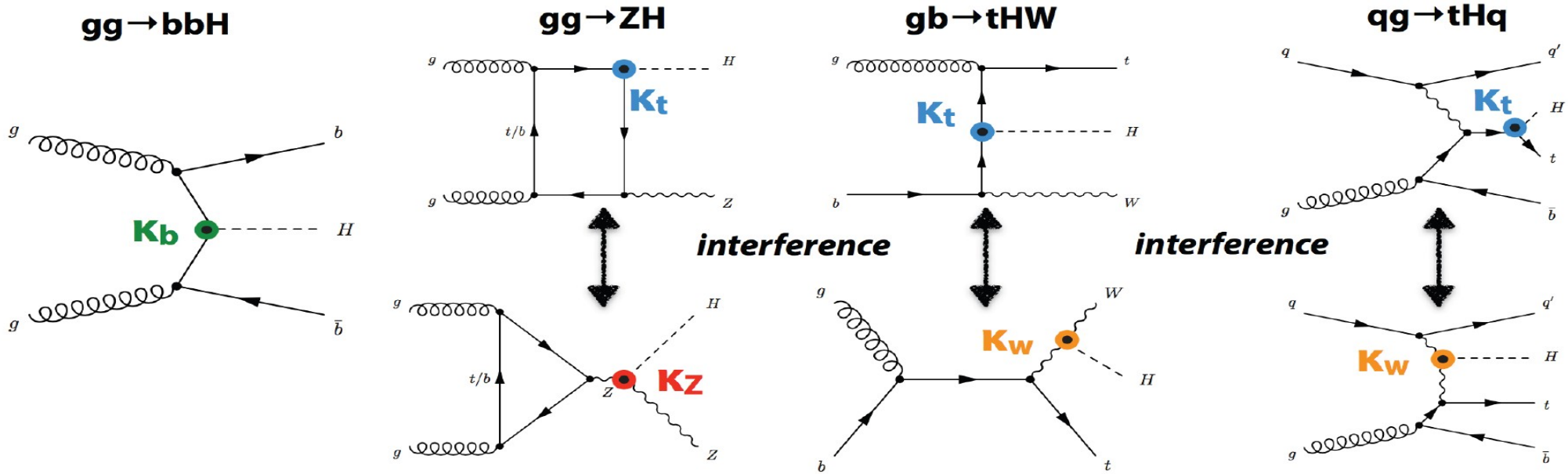
Higgs couplings

M. Chen, LHCP 2017

- Dominant



- Rare

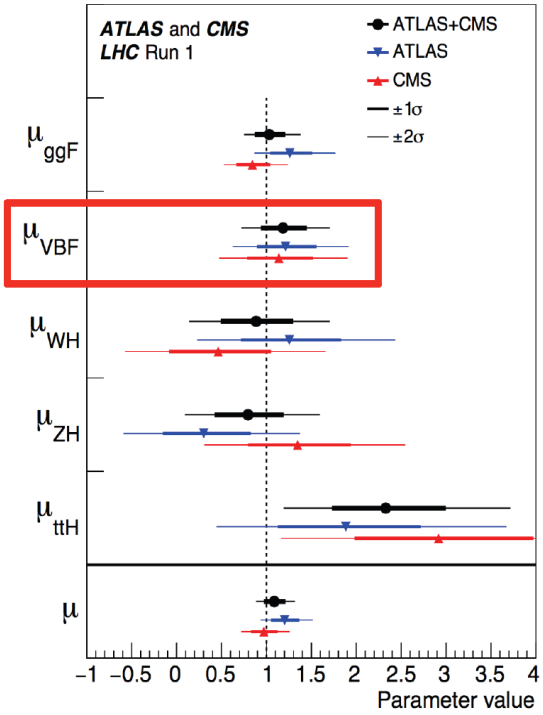


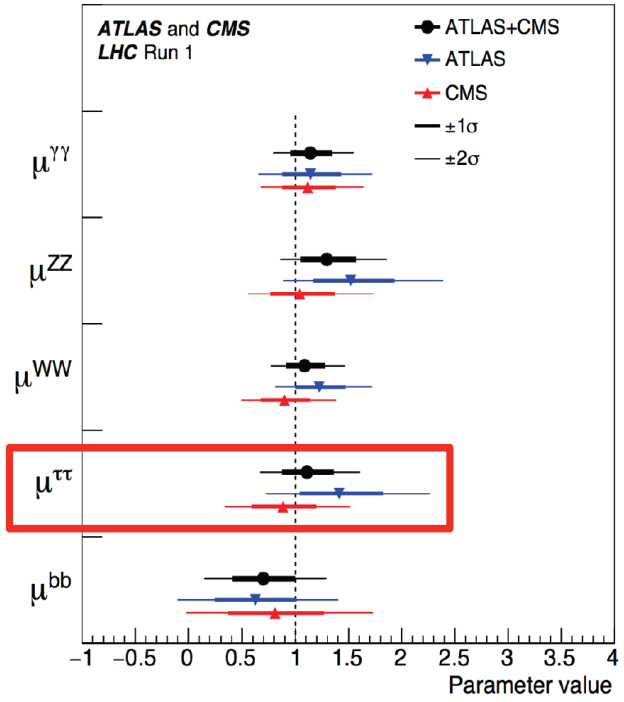
Mu and kappa: ATLAS + CMS run 1

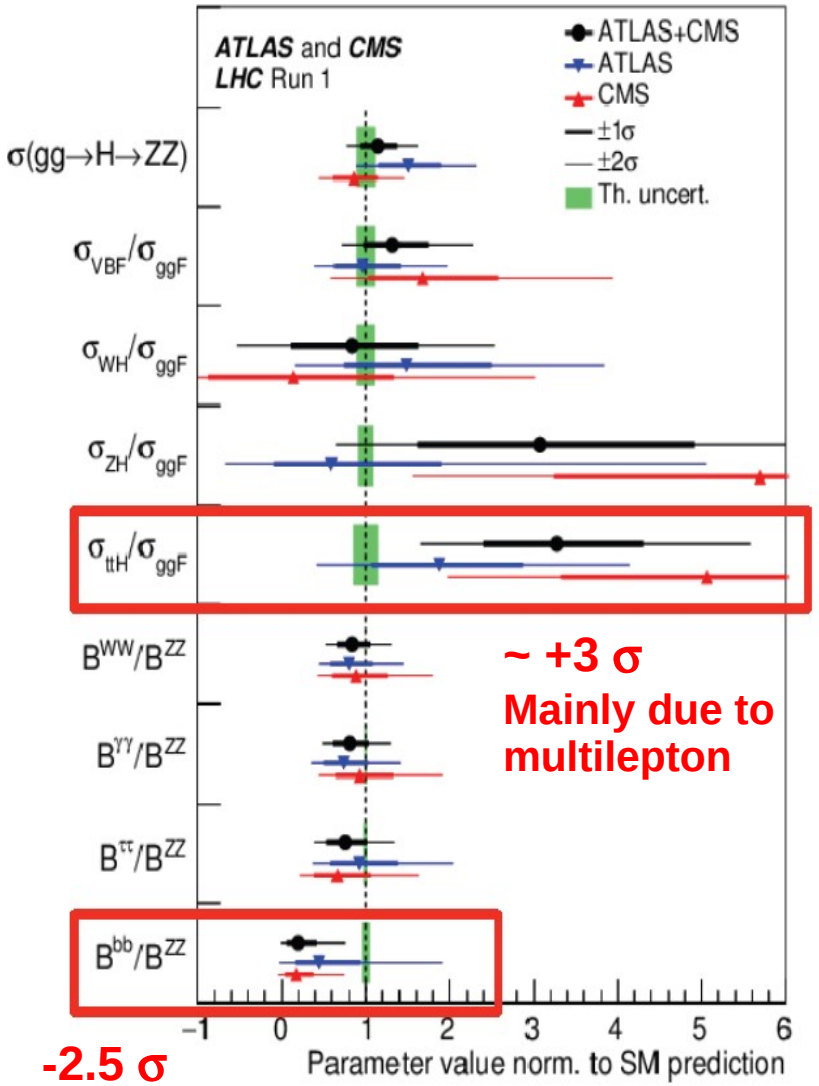
JHEP 08 (2016) 045

$$\kappa_j^2 = \sigma_j/\sigma_j^{SM} \quad \text{or} \quad \kappa_j^2 = \Gamma^j/\Gamma_{SM}^j$$

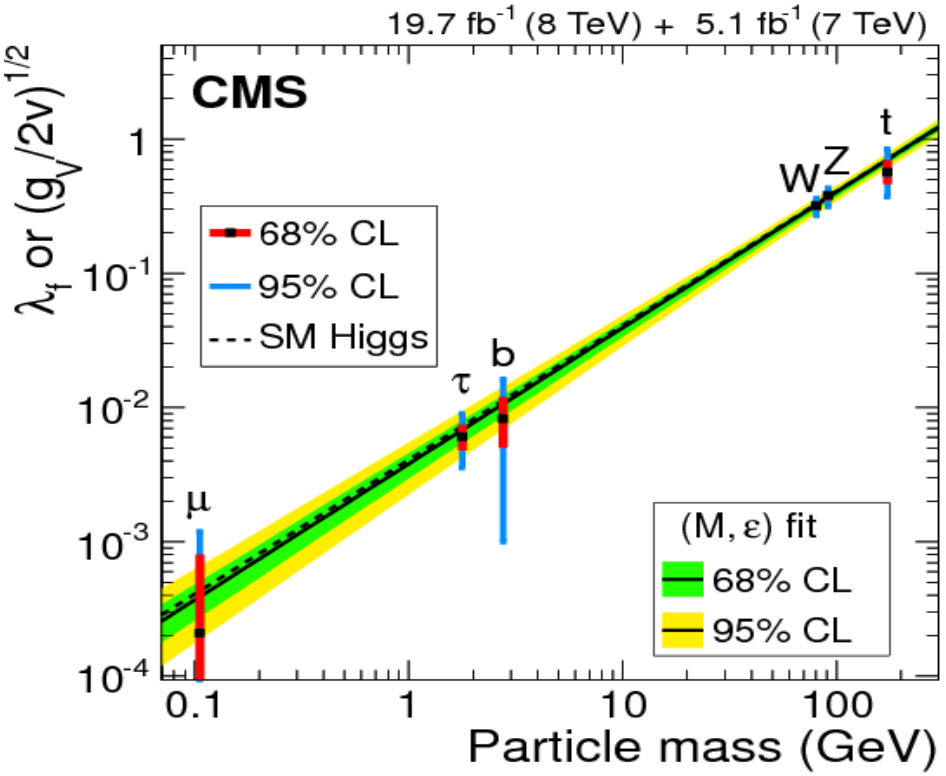
VBF and tau tau established by combining CMS and ATLAS

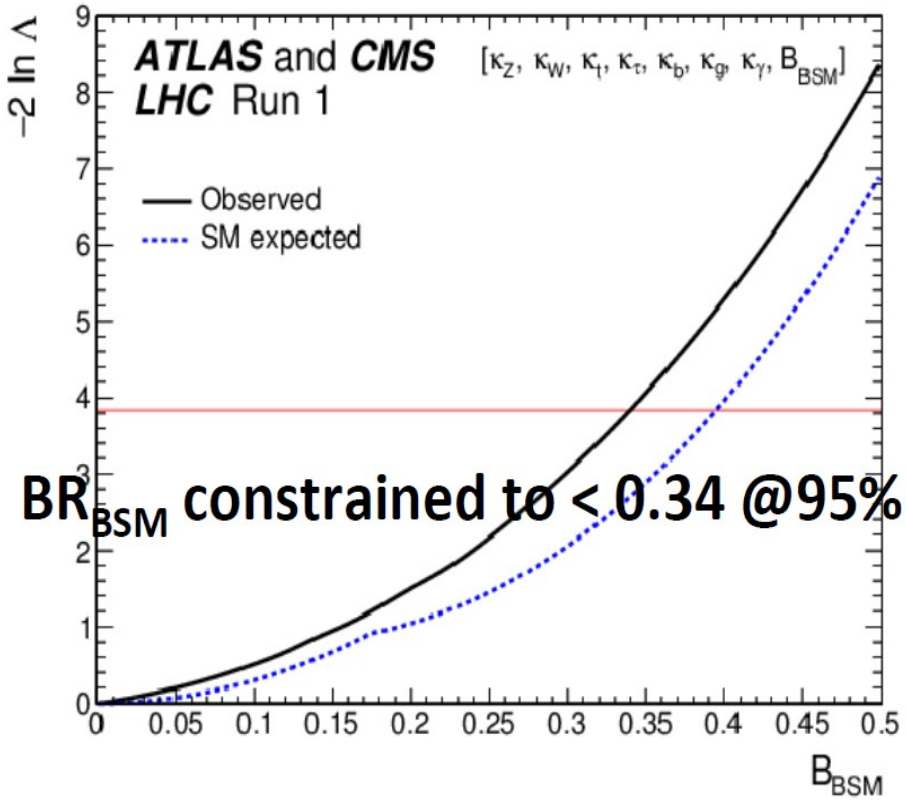






Higgs couplings



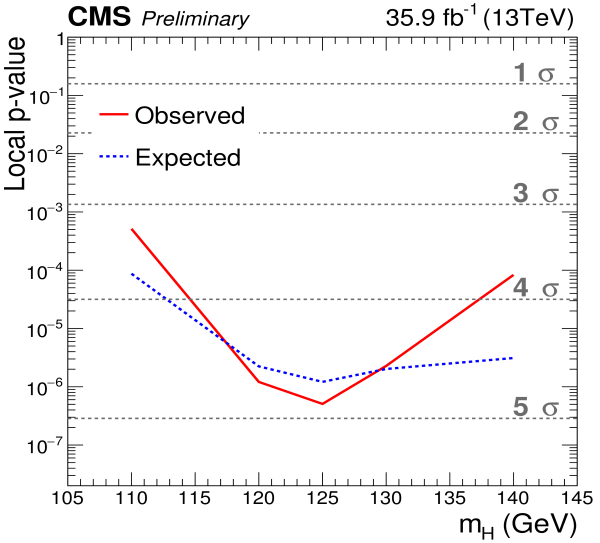


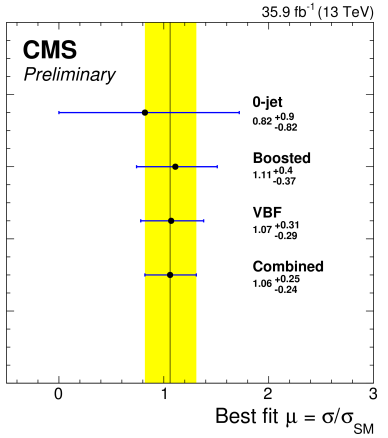
BR_{BSM} constrained to < 0.34 @95% CL

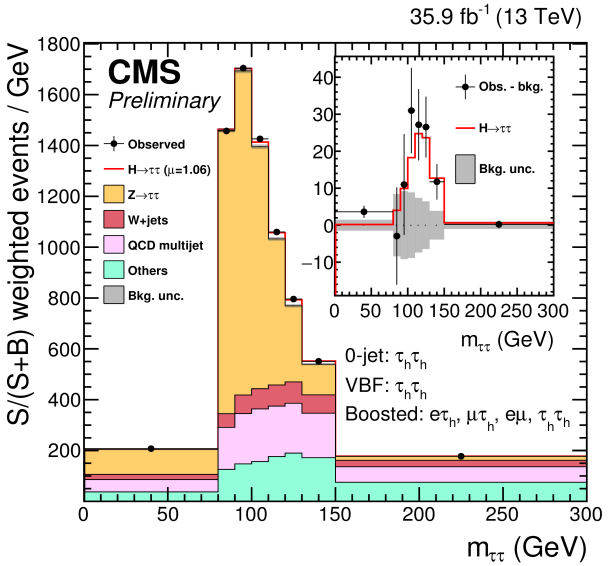
Higgs to tau tau

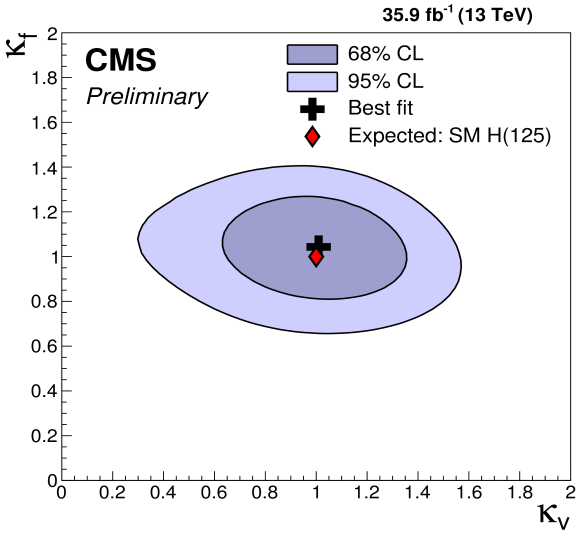
- Higgs to tau tau observed @ 4.9 σ (4.7 σ expected) at MH = 125 GeV

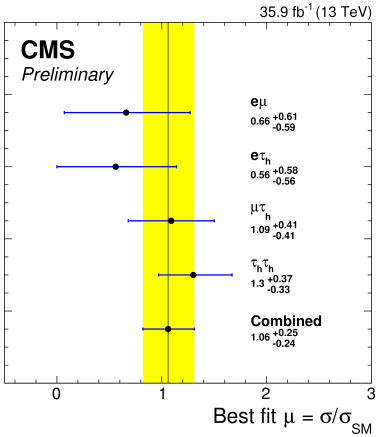
  (3.4 σ observed in run 1)











CMS-HIG-16-043

Higgs to top Yukawa

JHEP 08 (2016) 045

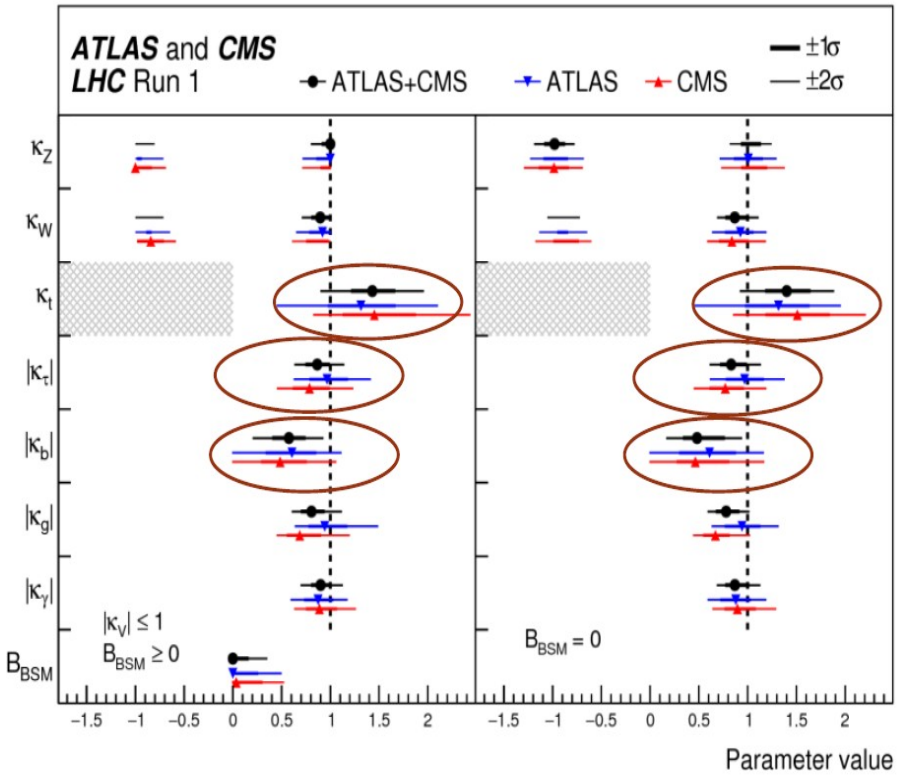
- Coupling to fermions constrained by run 1 measurements. $\kappa_i^2 = \frac{\Gamma^i}{\Gamma^i_{SM}}$
- H to bb, ttH not yet observed, inderect limits

ATLAS+CMS Run 1

Significance	Expected	Observed
H→ττ	5.0σ	5.5σ
H→bb	3.7σ	2.6σ
ttH	2.0σ	4.4σ

	No BSM	BSM in loops
κ_τ	$\mathcal{O}(15\%)$	$\mathcal{O}(15\%)$
κ_b	$\mathcal{O}(25\%)$	$\mathcal{O}(20-30\%)$
κ_t	$\mathcal{O}(15\%)$	$\mathcal{O}(30\%)$

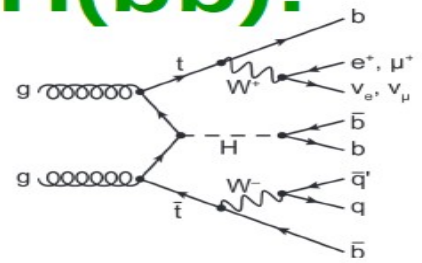
Georges Aad - LHCP 2017



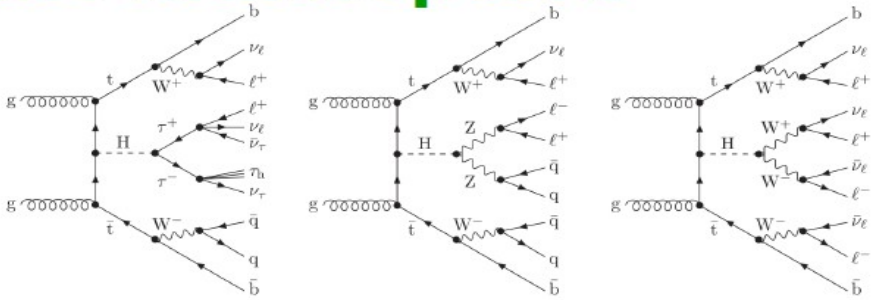
ttH @ 13 TeV early results

HIG-15-005
HIG-15-008
HIG-16-004

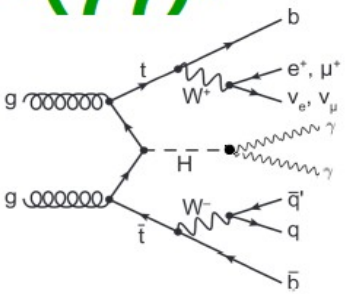
ttH(bb):

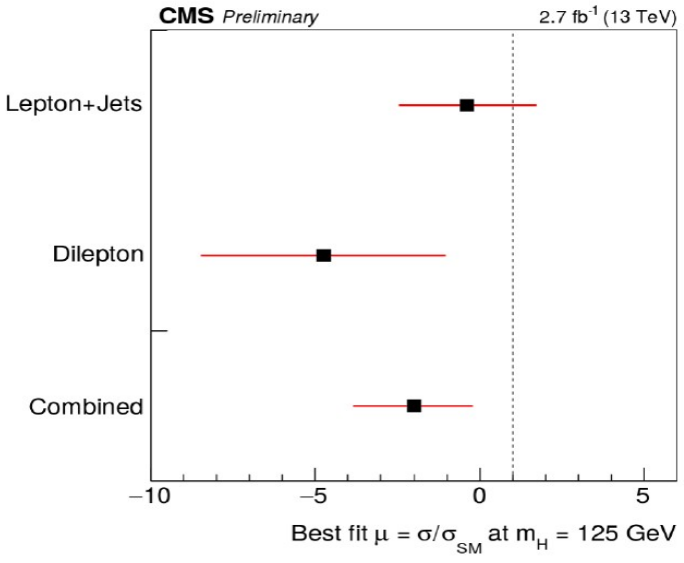


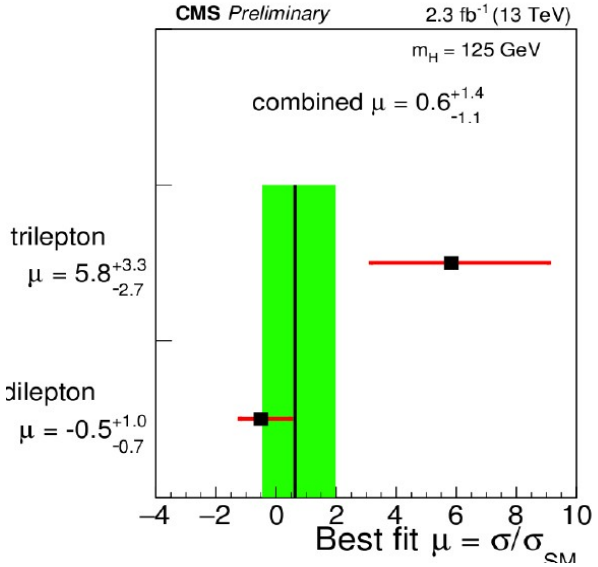
ttH multilepton:

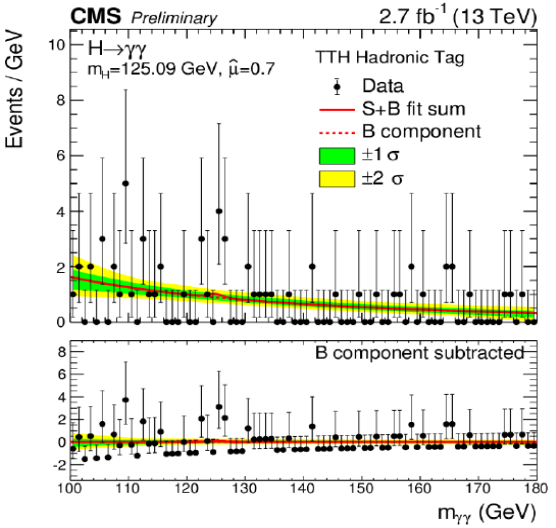


ttH(γγ):









$$\sigma/\sigma_{\rm SM} = -2.0^{+1.8}_{-1.8}$$
$$\sigma/\sigma_{\rm SM} < 2.6 \quad (3.6 \text{ exp.})$$

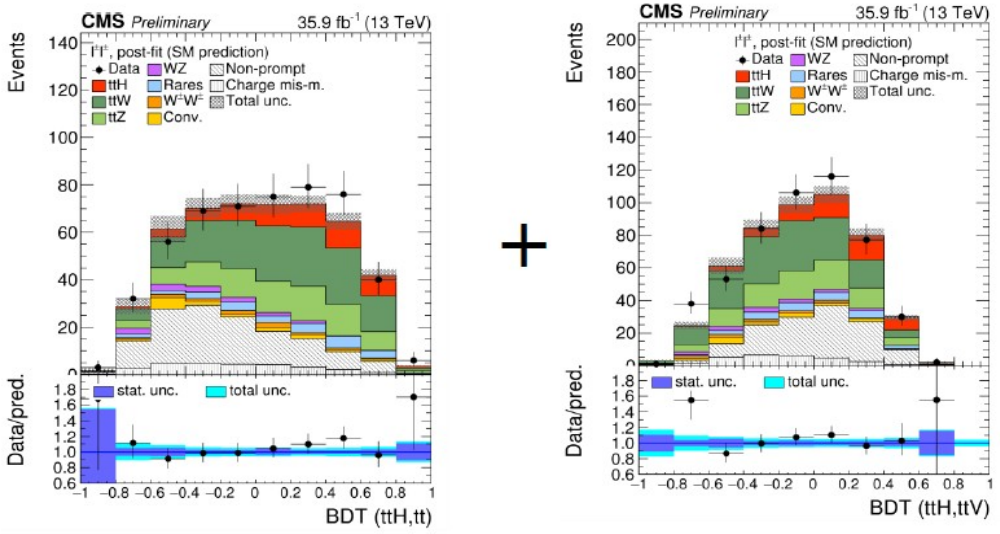
$$\sigma/\sigma_{\rm SM} = 0.6^{+1.4}_{-1.1}$$
$$\sigma/\sigma_{\rm SM} < 3.3 \quad (2.6 \text{ exp.})$$

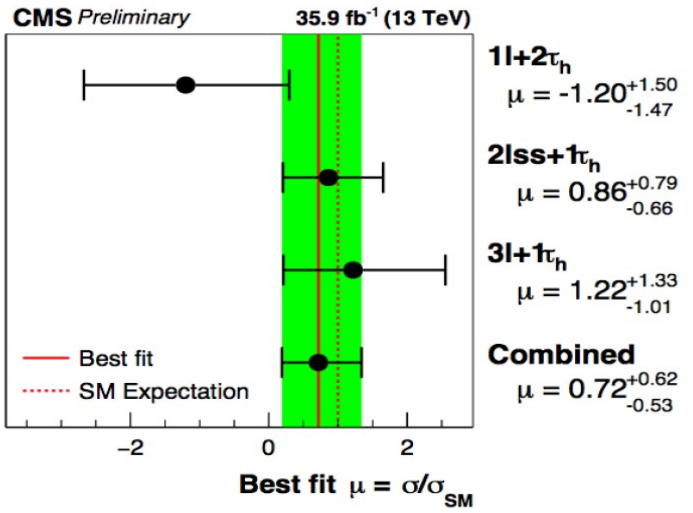
$$\sigma/\sigma_{\rm SM} = 3.8^{+4.5}_{-3.6}$$

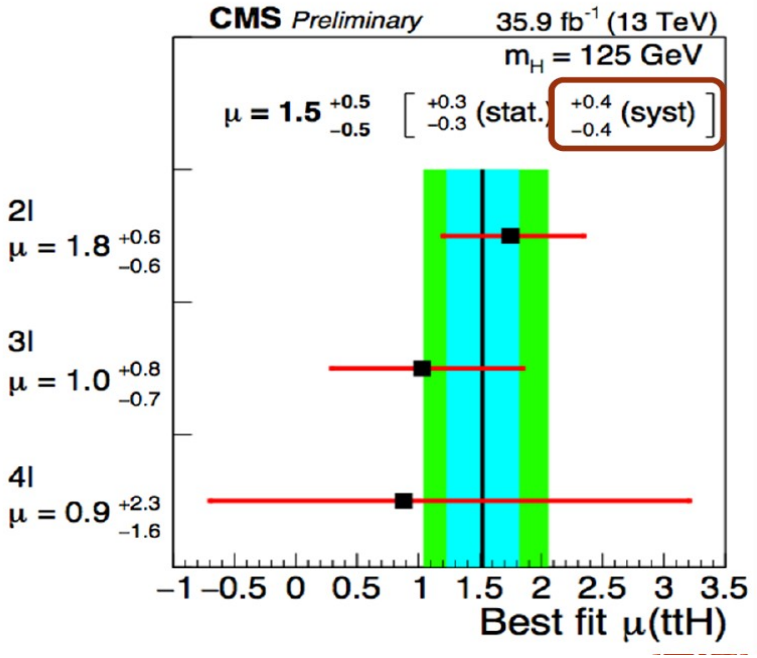
ttH @ 13 TeV, leptonic (WW*,ZZ*,ττ)

ATLAS-CONF-2016-058 CMS PAS HIG-17-003
CMS PAS HIG-17-004

- **CMS observes 3.3 σ evidence with 35.9 fb^{-1}**





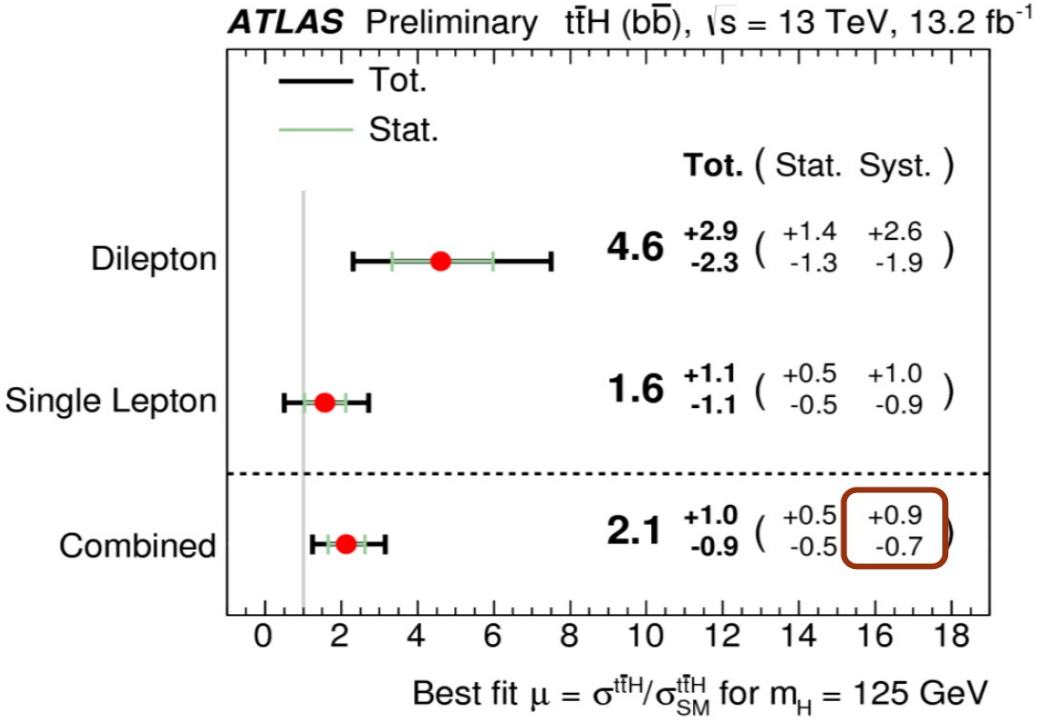


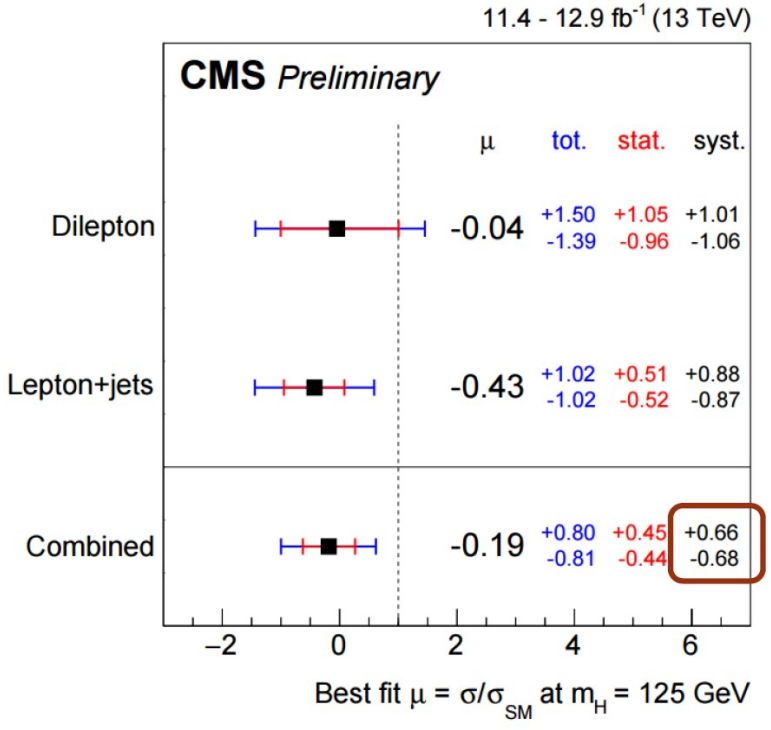
ttH to $b\bar{b}$ @ 13 TeV

ATLAS-CONF-2016-080 CMS PAS HIG-16-038

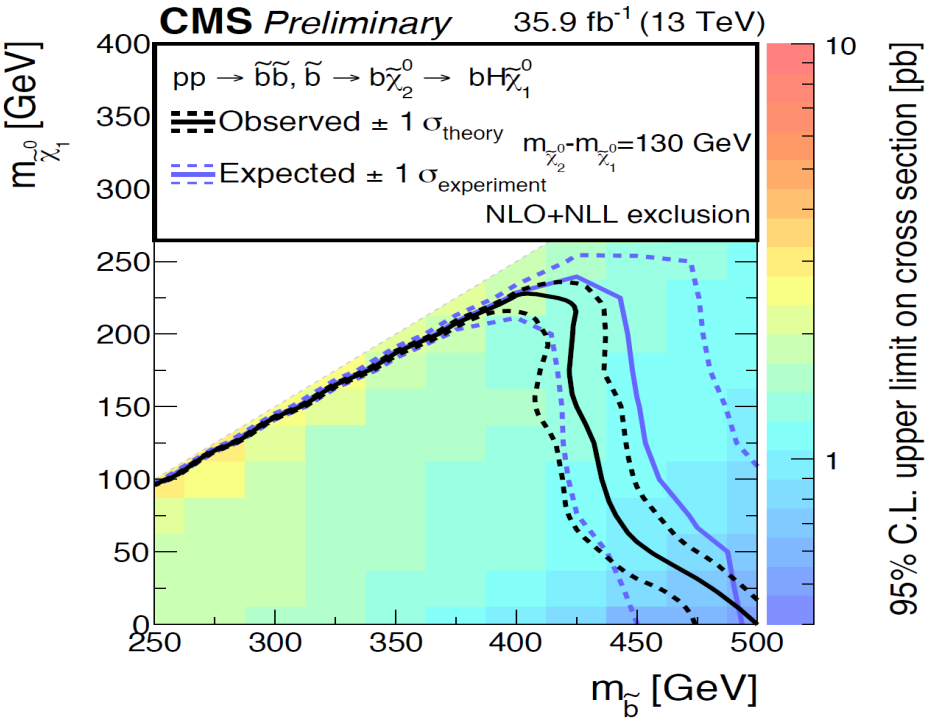
Georges Aad - LHCP 2017

- Basic $t\bar{t}$ selection + b jets categories + MVA in signal rich region
- Sensitivity increased from RUN 1
- 2 σ level not reached

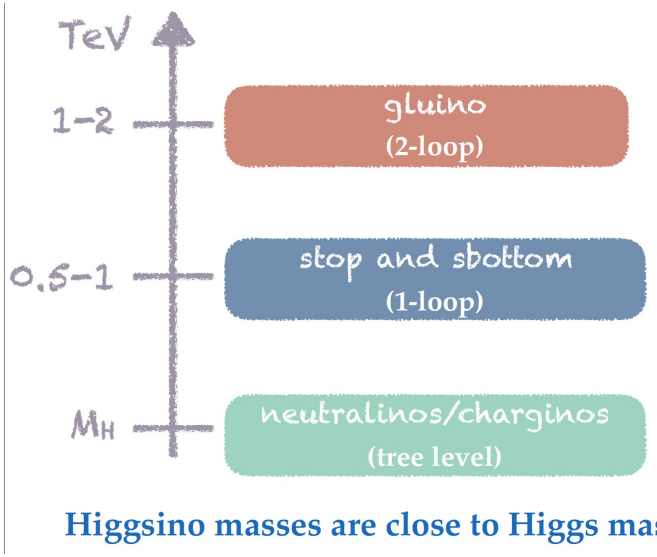


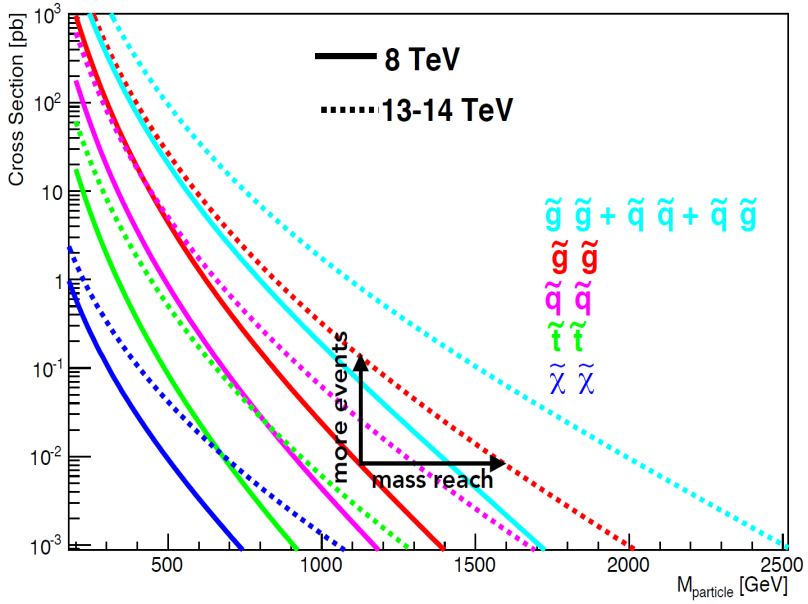


Search for Supersymmetry



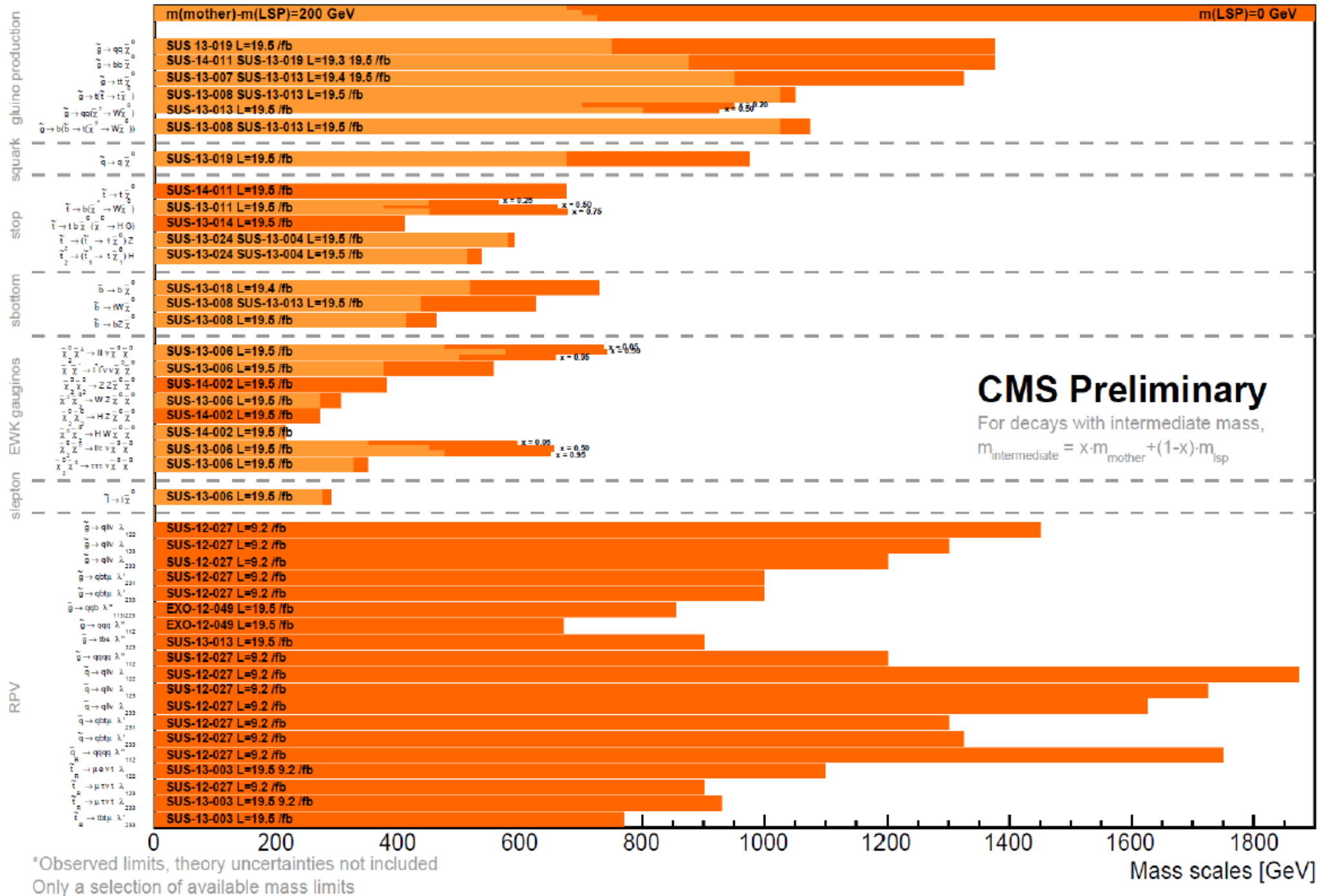
SUSY search strategy at LHC





- Focus on strongly produced processes.
  - *Large gain from increased parton luminosity at 13 TeV*
- Start from inclusive sqark, gluino searches
- Move to focussed stop, sbottom searcehs, electroweakinos

See: John Paul Chou, Moriond 2016
Cristian H. Pena, DM@LHC 2017


Summary of CMS SUSY Results* in SMS framework
ICHEP 2014
m(mother)-m(LSP)=200 GeV
m(LSP)=0 GeV
gluino production
squark
stop
sbottom
EWK gauginos
slepton
RPV
SUS 13-019 L=19.5 /fb
SUS-14-011 SUS-13-019 L=19.3 19.5 /fb
SUS-13-007 SUS-13-013 L=19.4 19.5 /fb
SUS-13-008 SUS-13-013 L=19.5 /fb
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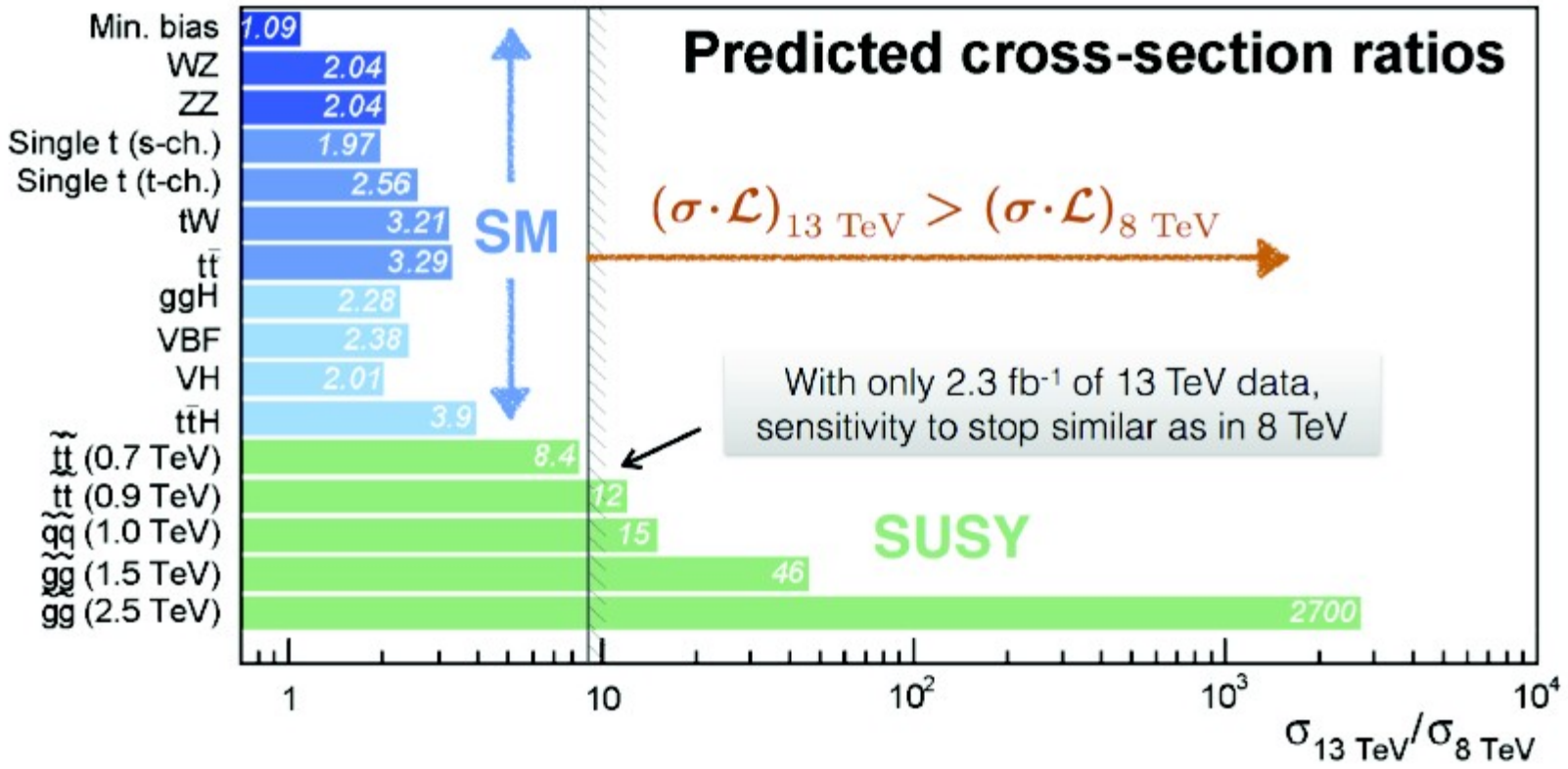
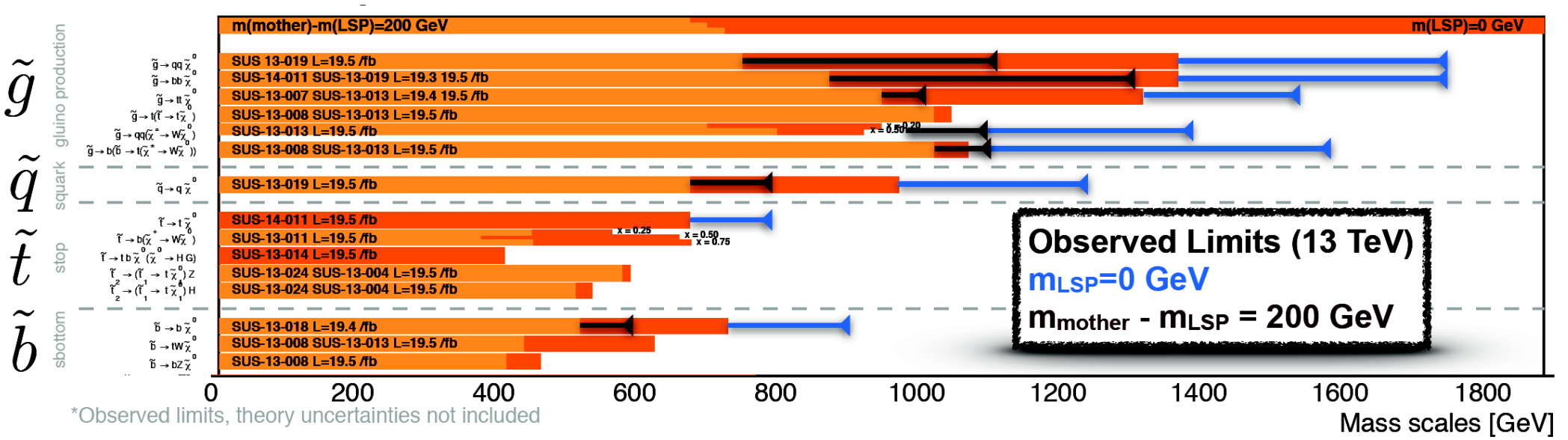
SUS-12-027 L=9.2 /fb
SUS-13-003 L=19.5 9.2 /fb
SUS-13-003 L=19.5 /fb
CMS Preliminary
For decays with intermediate mass,
m_intermediate = x·m_mother +(1-x)·m_lsp
0
200
400
600
800
1000
1200
1400
1600
1800
Mass scales [GeV]
*Observed limits, theory uncertainties not included
Only a selection of available mass limits

SUSY searches @13 TeV



- Search in all accessible channels
- Focus on stop, sbottom, gluino

SUSY hadronic summary 2015

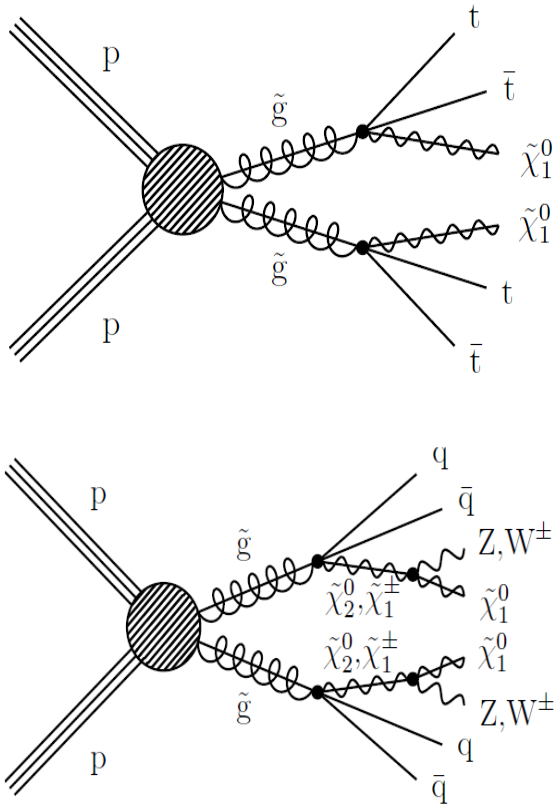


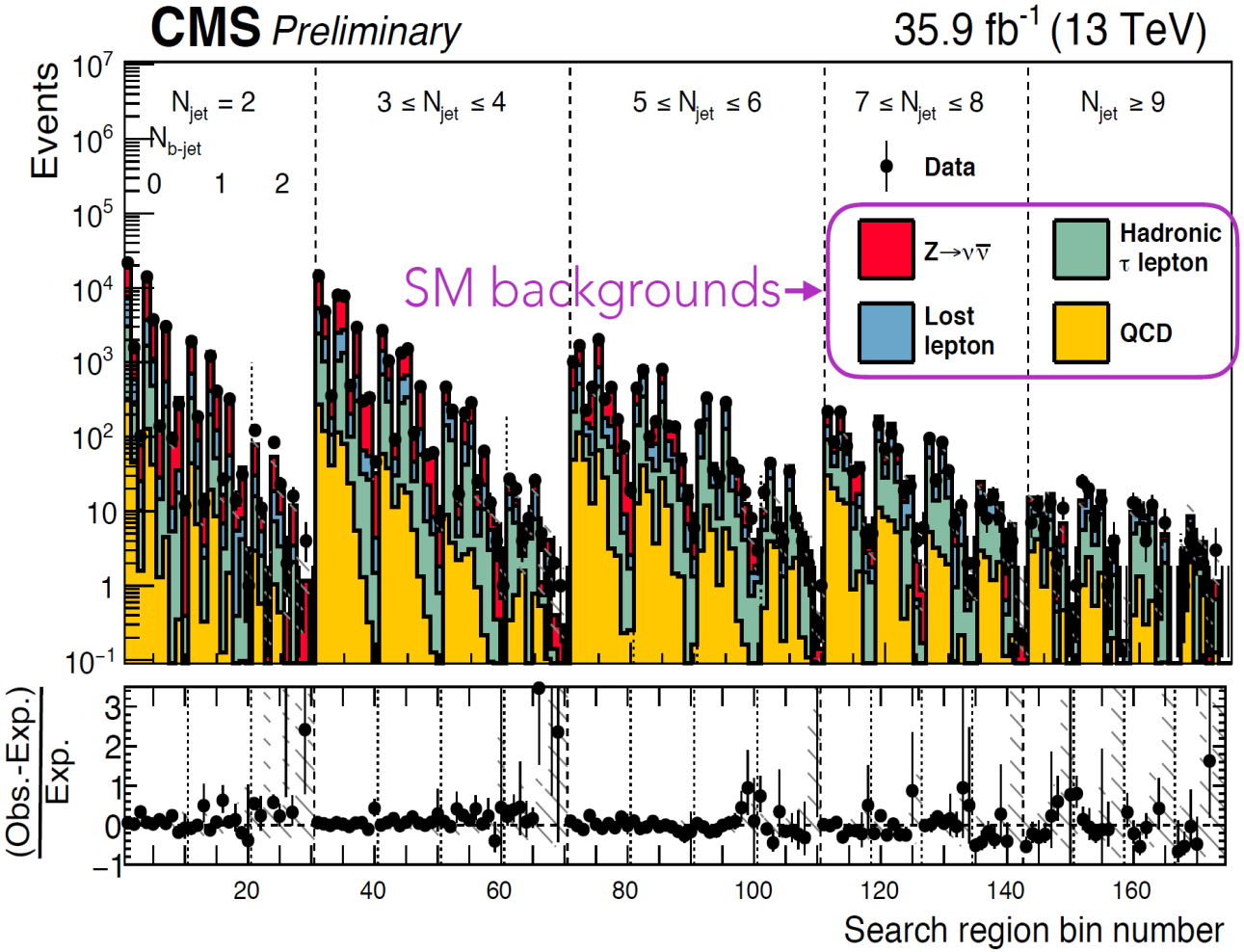
- 2016 = 10X opportunity

CMS multijet, zero lepton

- 174 regions in N_{jets}, $N_{b\text{-}jets}$, H_T,H_T^{miss}

CMS-SUS-16-033





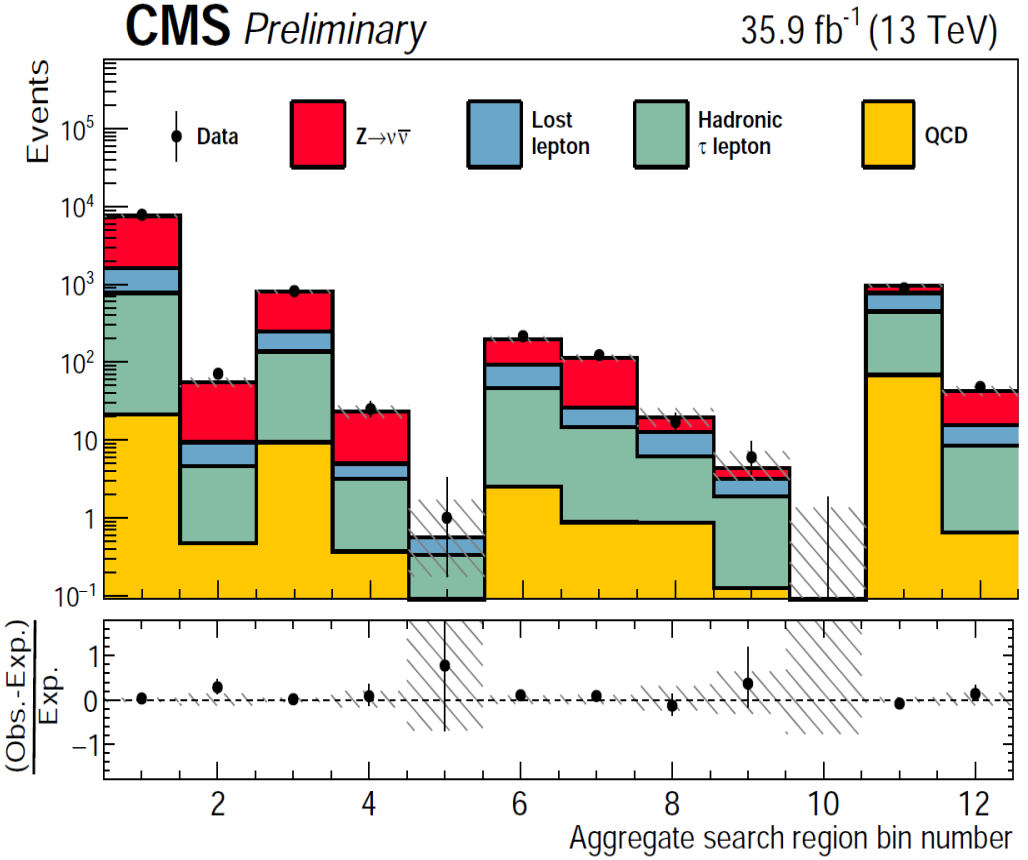
No significant excess

CMS multijet + 0 lepton

CMS-SUS-16-033

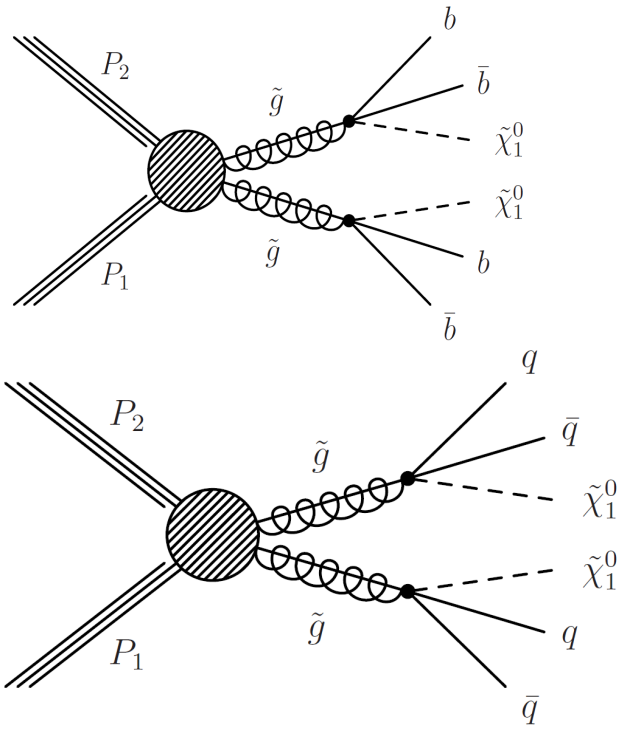
- New analysis added
- 12 search regions

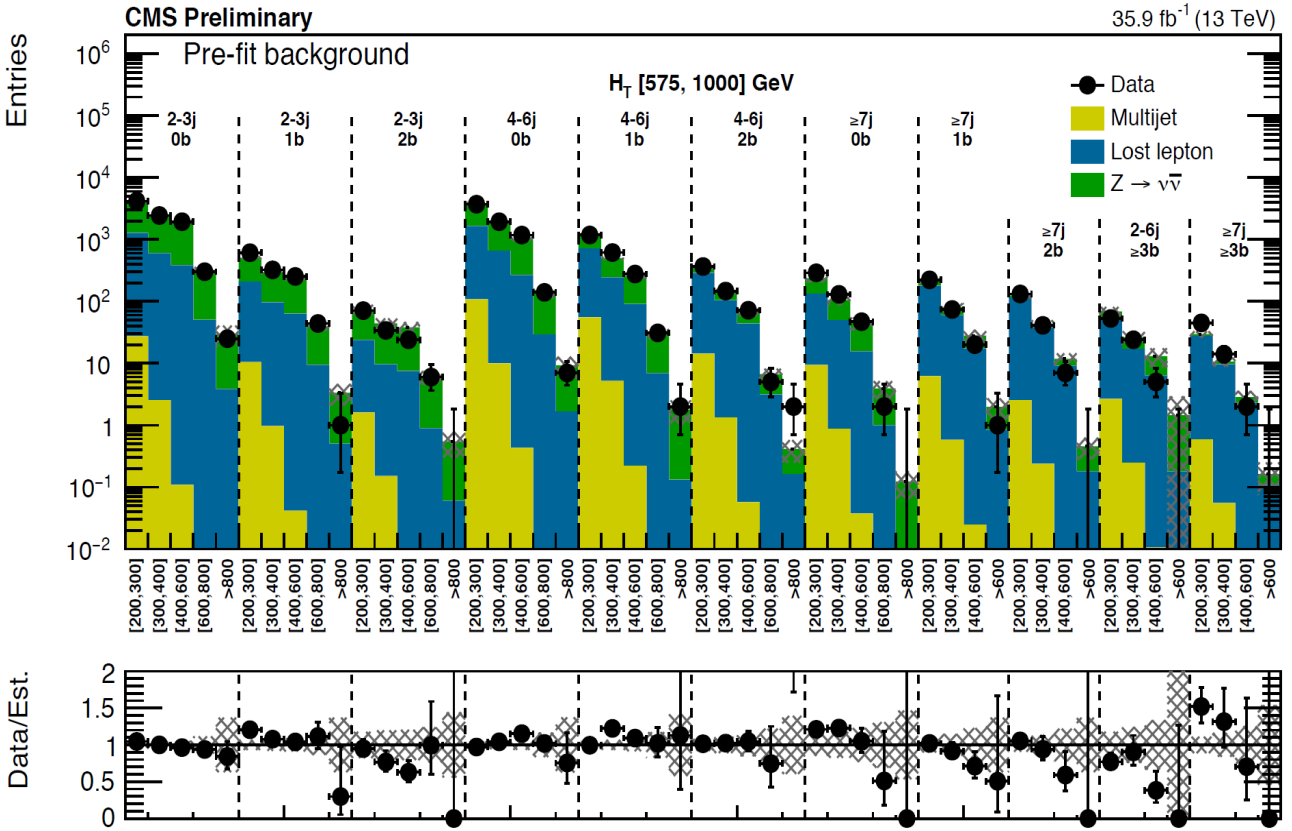
No significant excess



CMS multijet + 0 lepton

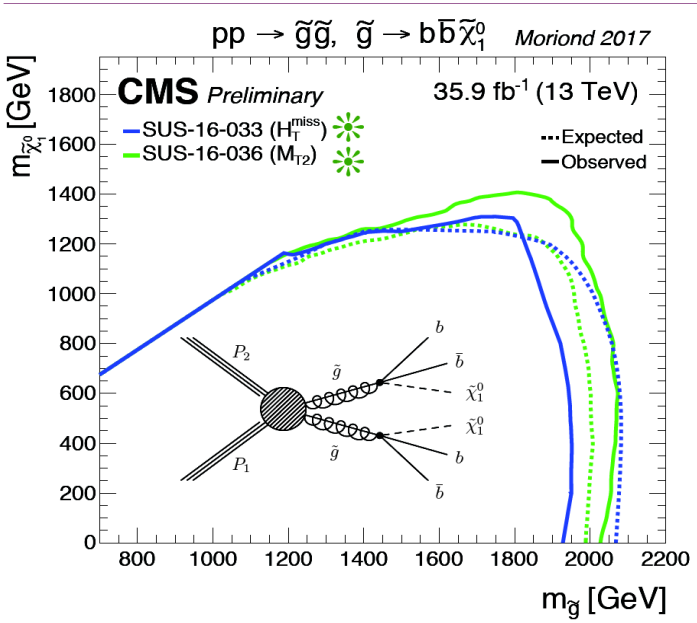
$$M_{T2} = \min_{\vec{p}_T^{\,missX(1)} + \vec{p}_T^{\,missX(2)} = \vec{p}_T^{\,miss}} \left[\max\left(M_T^{(1)}, M_T^{(2)} \right) \right]$$

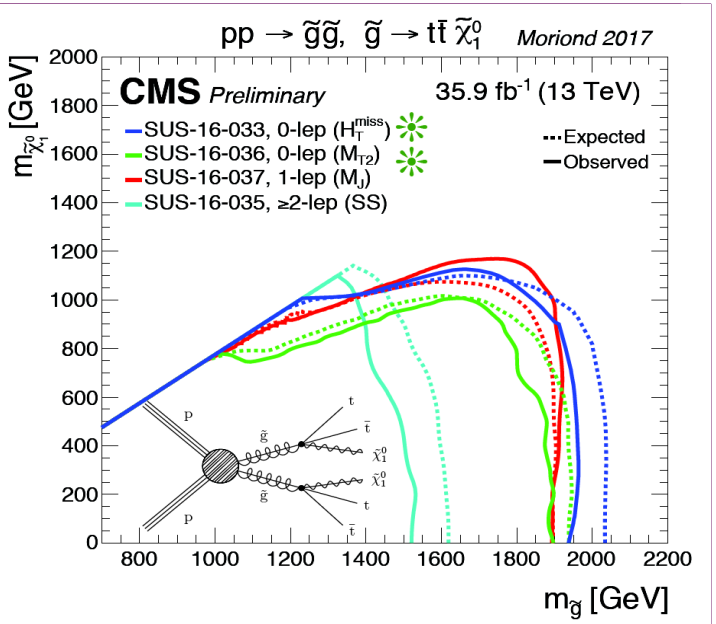


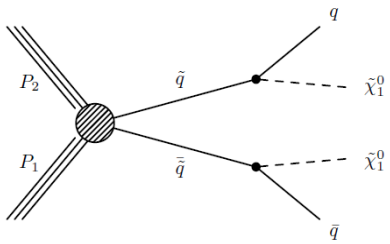


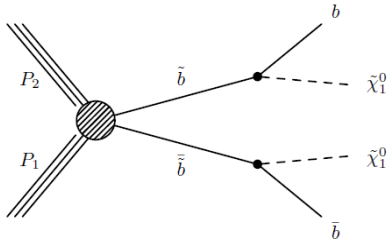
No significant excess

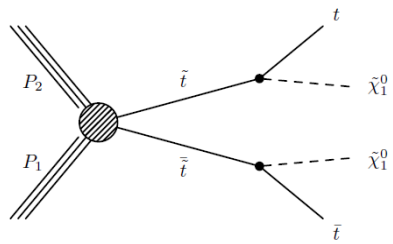
CMS summary of exclusions

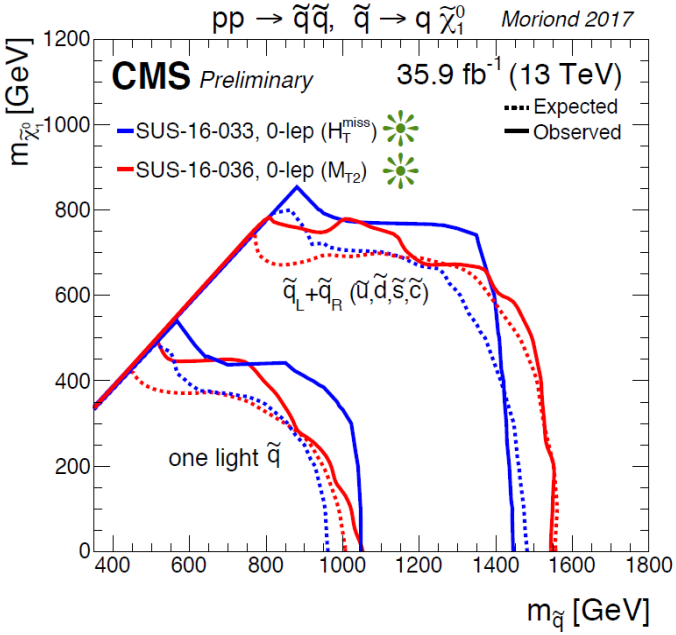


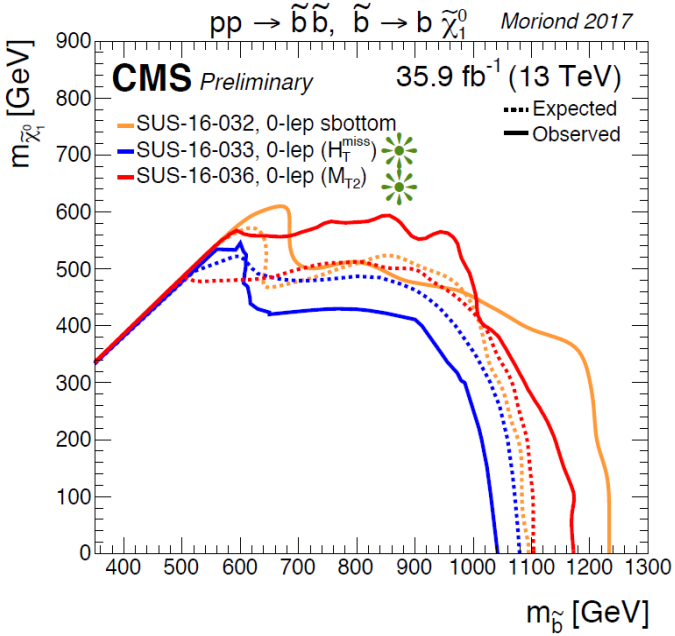


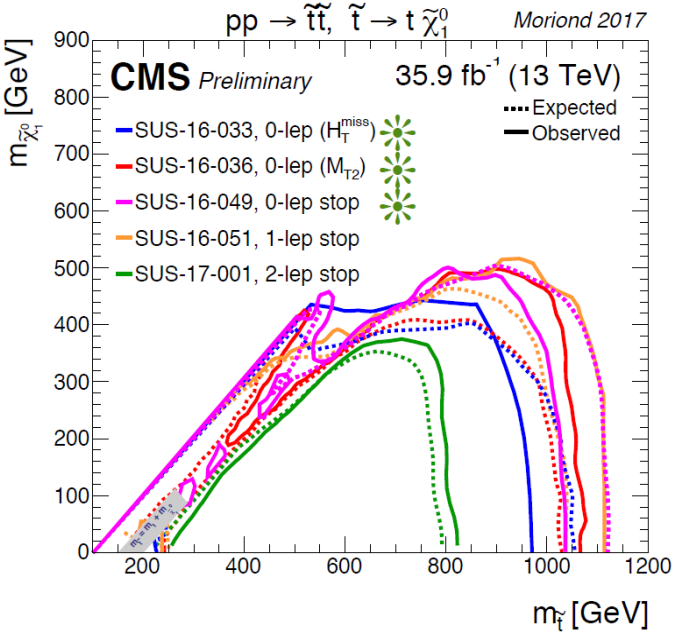






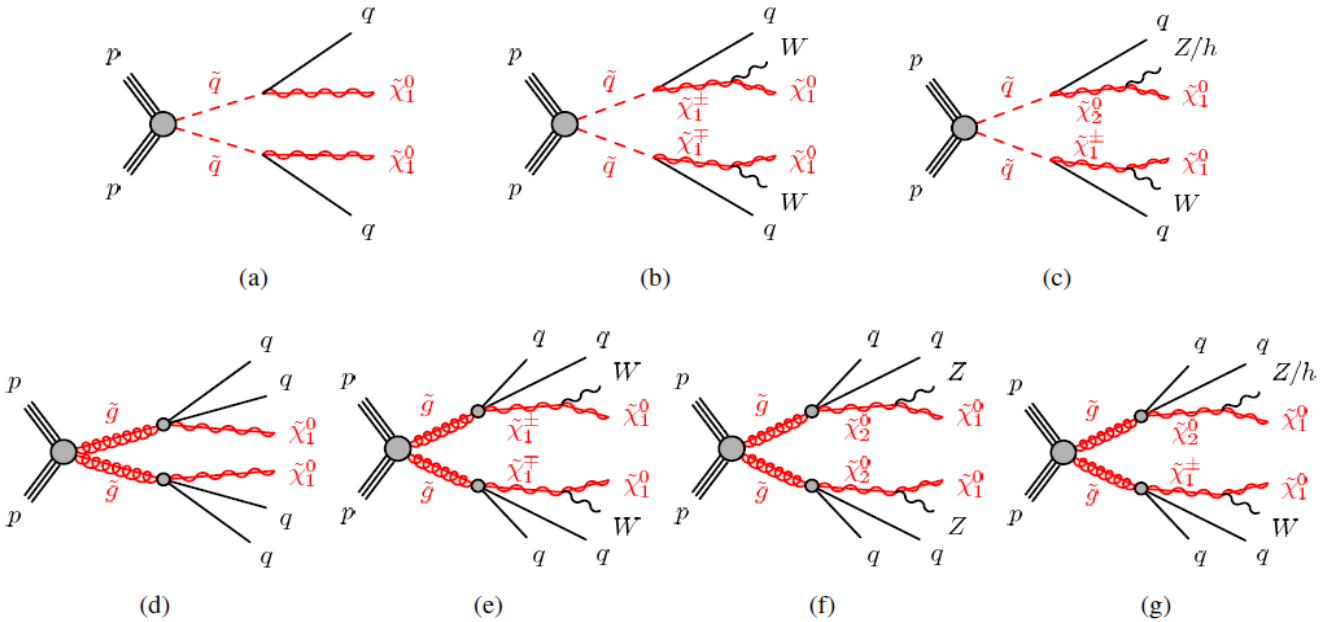




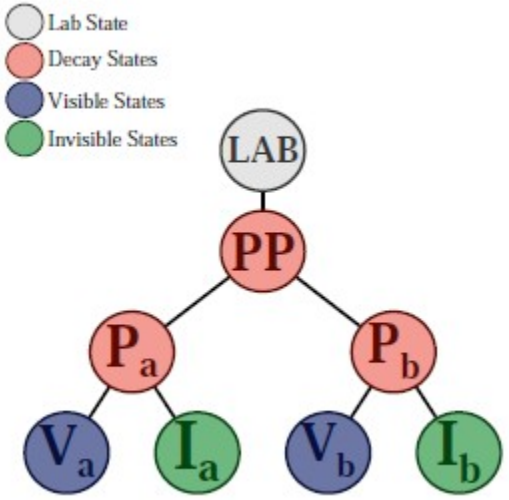


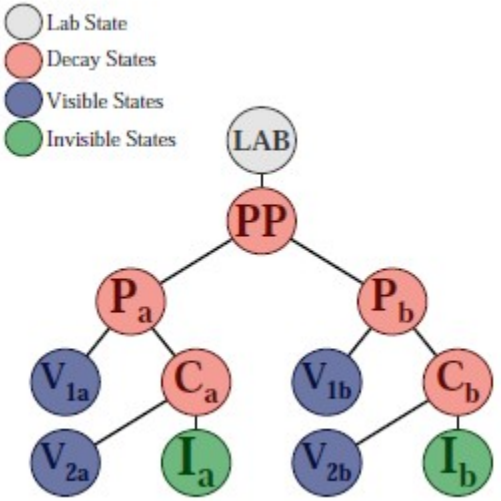
ATLAS squarks and gluinos with jets + MET

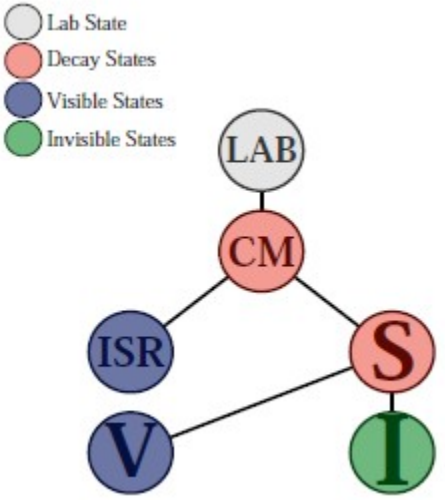
ATLAS-CONF-2017-022



Recursive Jigsaw Reconstruction (RJR) – recover partially, lost kinematic information



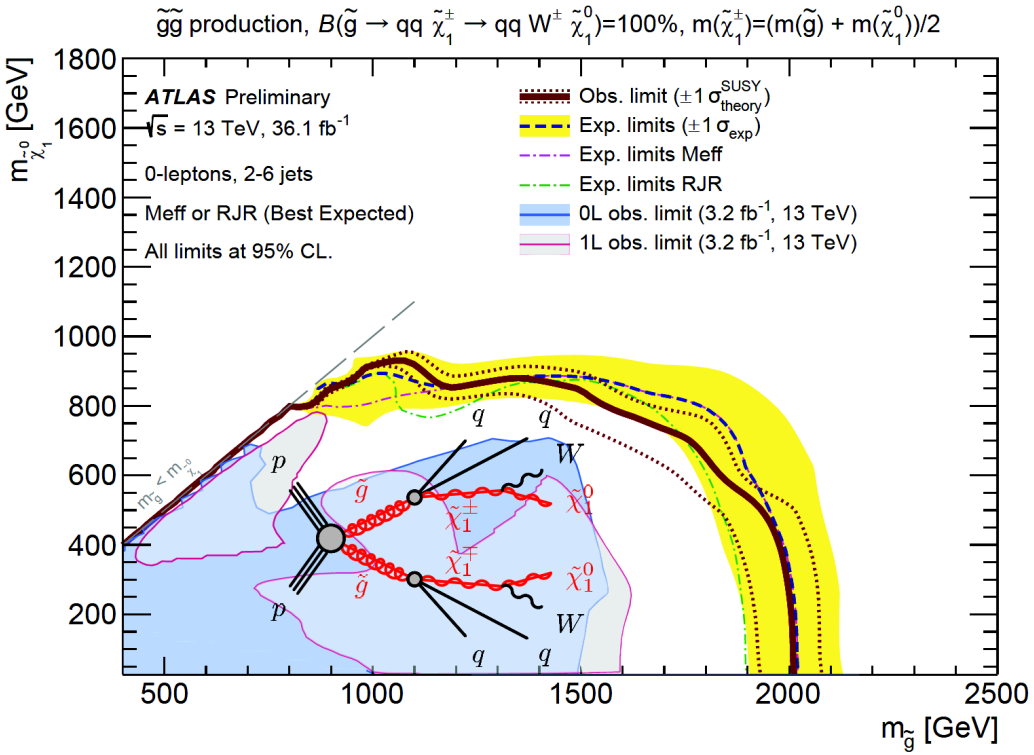


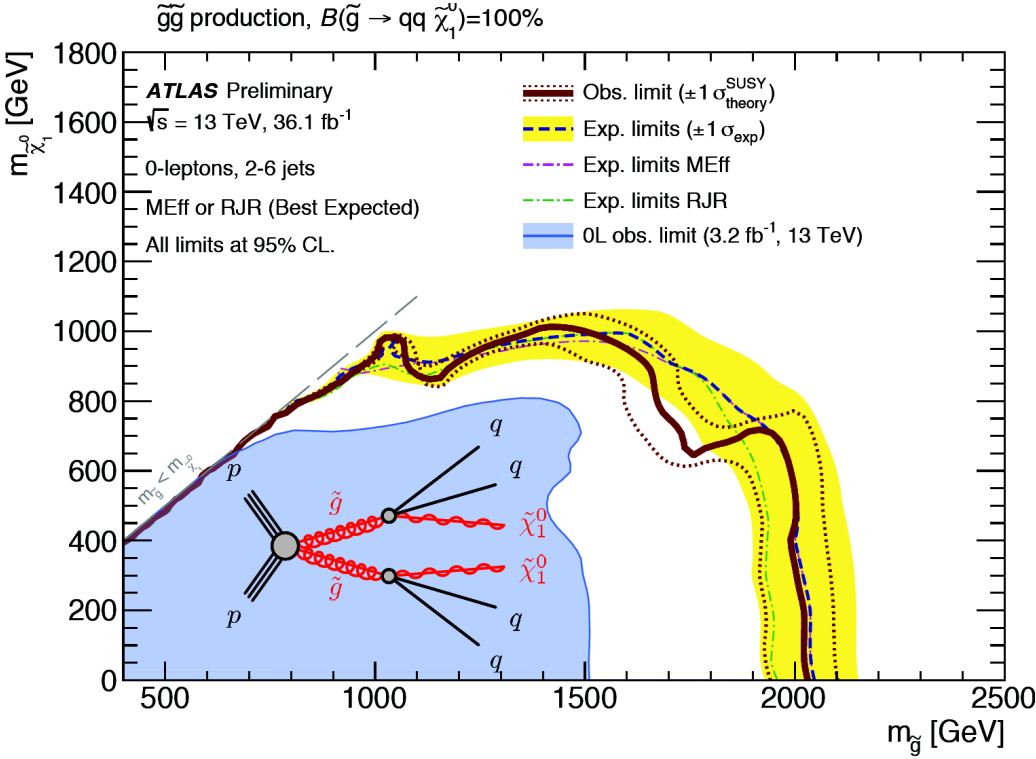


]

Limit on gluino mass

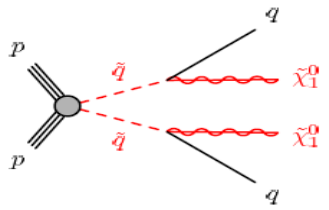
Best of Meff and RJR limits

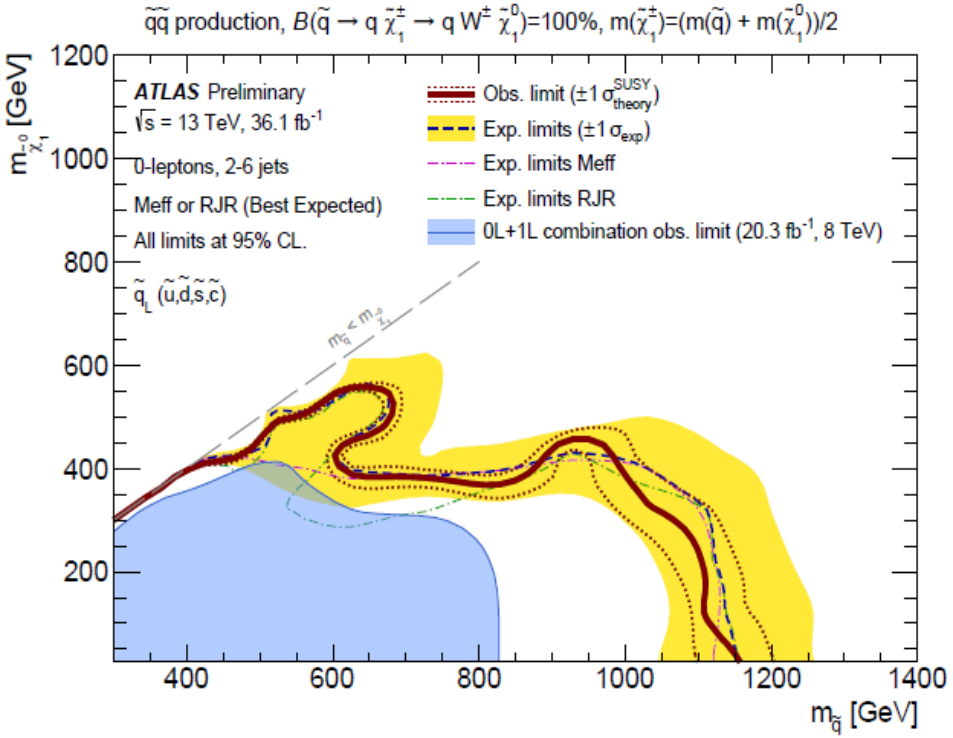




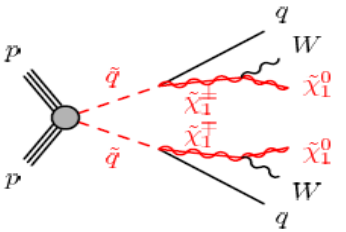
- Gluino mass excluded upto ~ 2 TeV (500 GeV improvement from 2015

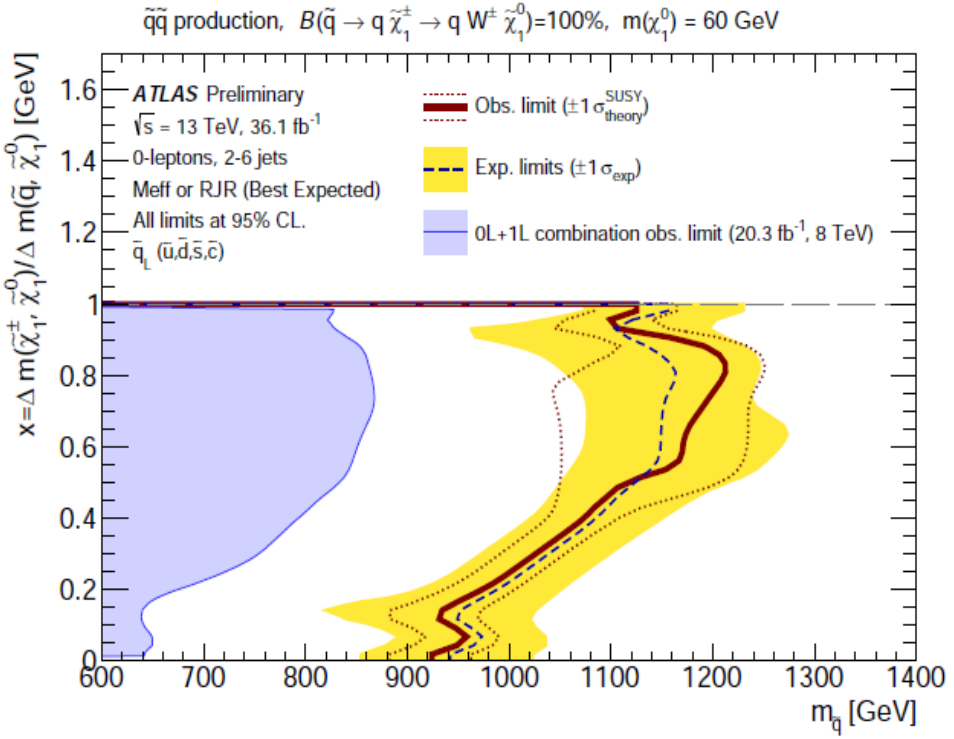
Limits on squark mass





- excluded squark mass upto 1.6 TeV (500 GeV improvement from 2015 ~400 GeV



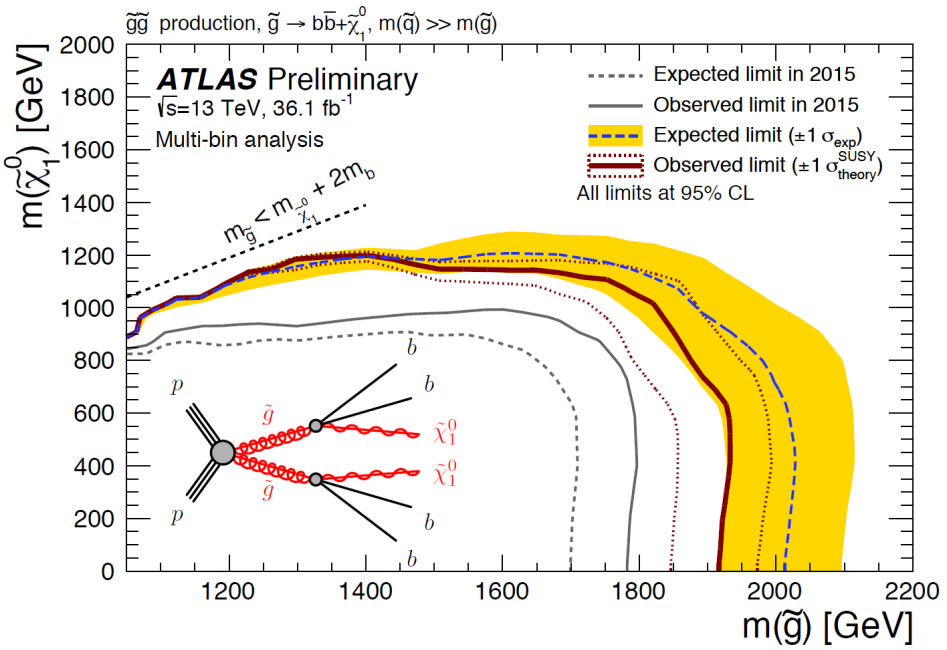


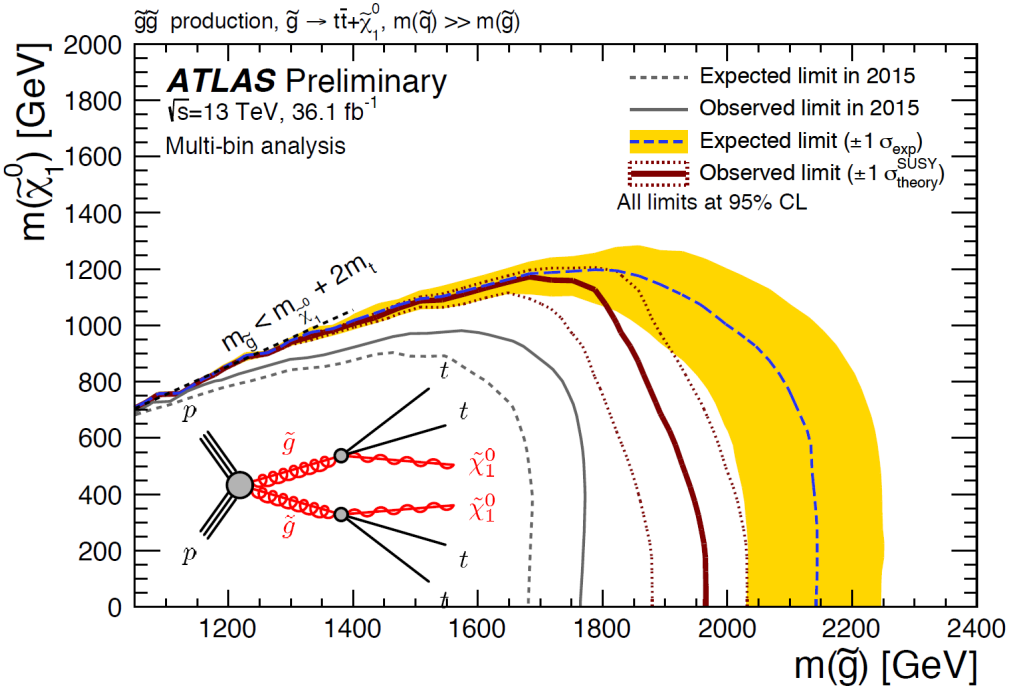
- excluded squark mass upto 1.2 TeV (500 GeV)

ATLAS: Gluino mass limit from 3rd generation

ATLAS-CONF-2017-021

Assume 100% BR





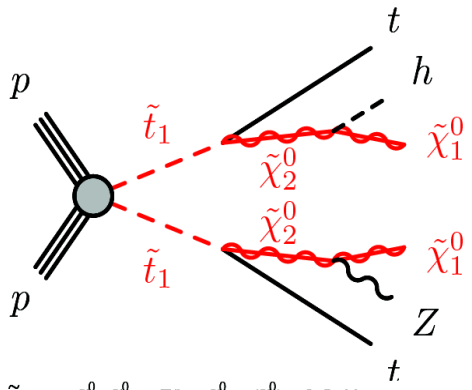
excluded gluino mass upto ~ 2 TeV (500 GeV improvement from 2015 ~400 GeV

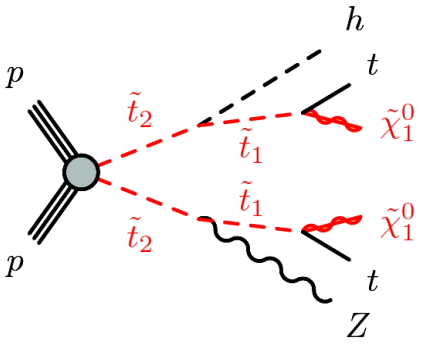
Floating BR reduces limit below 1.5 TeV

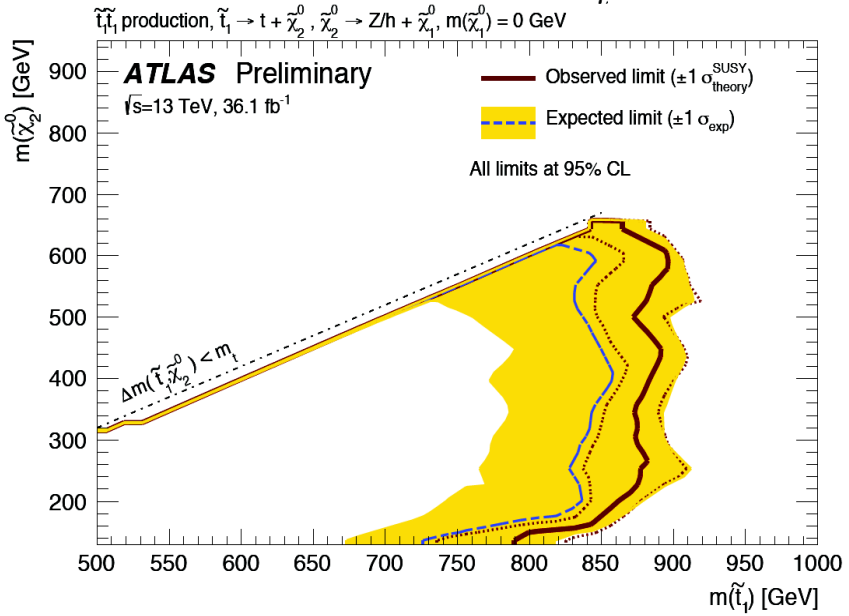
ATLAS stop search

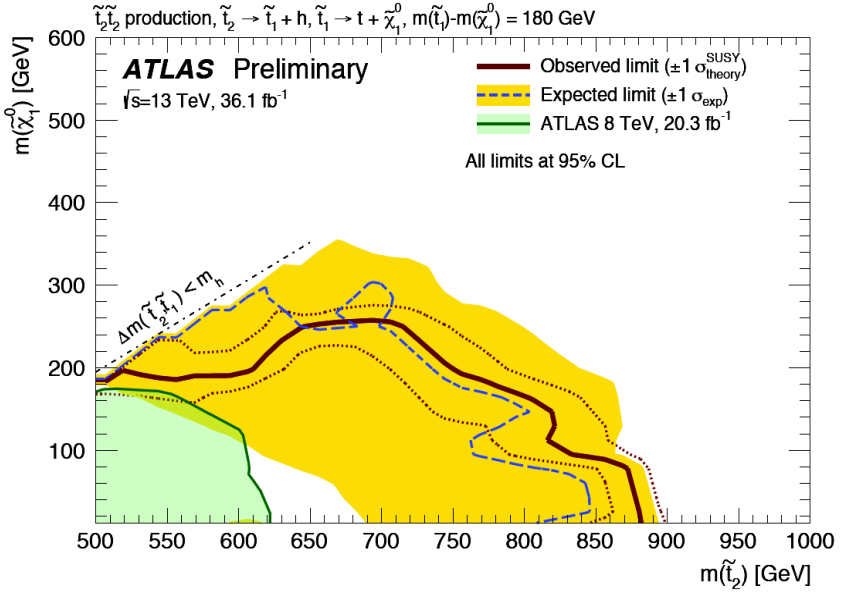
ATLAS-CONF-2017-019

3 leptons + b or 1 lepton + 4 b





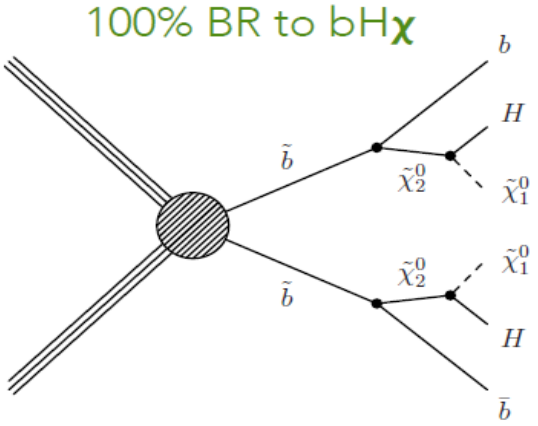


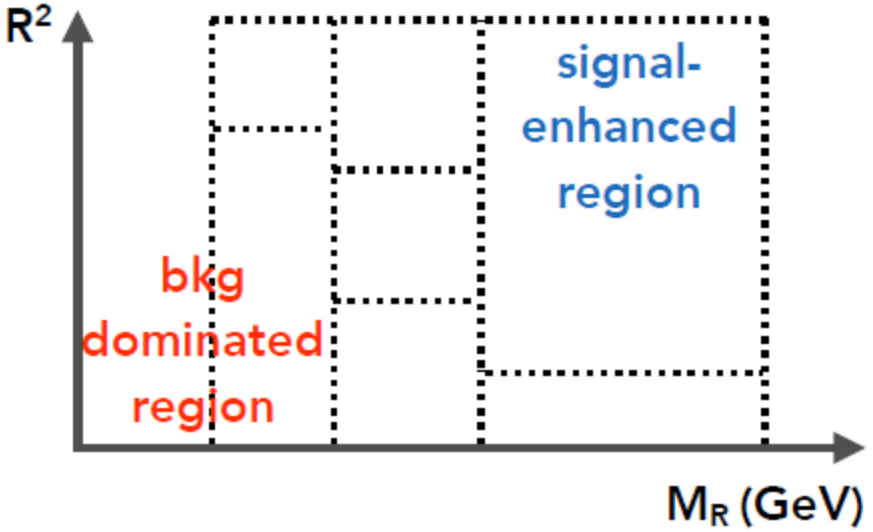


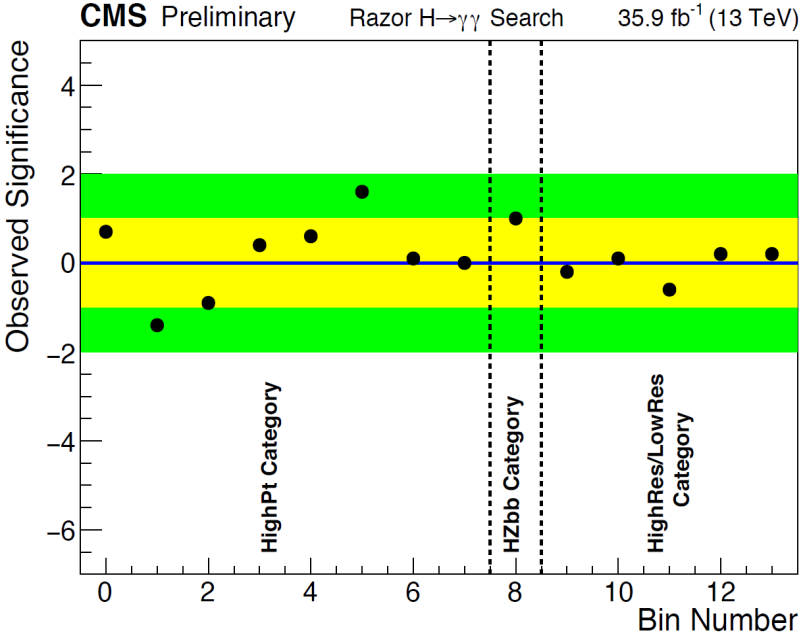
CMS sbottom to H+b+MET

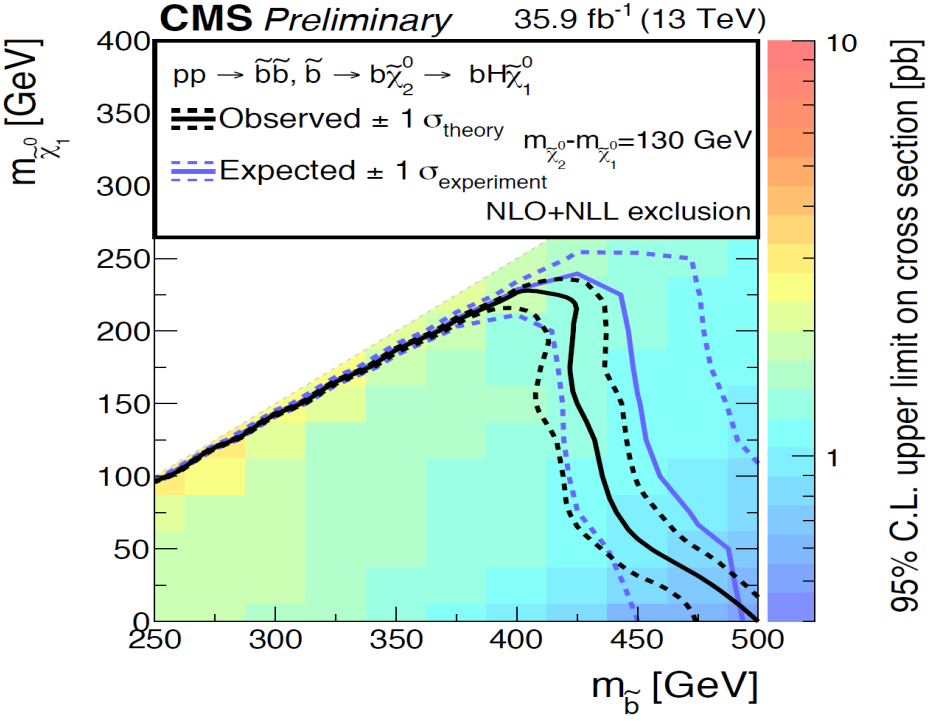
H->gg + jets + MET

Razor variables



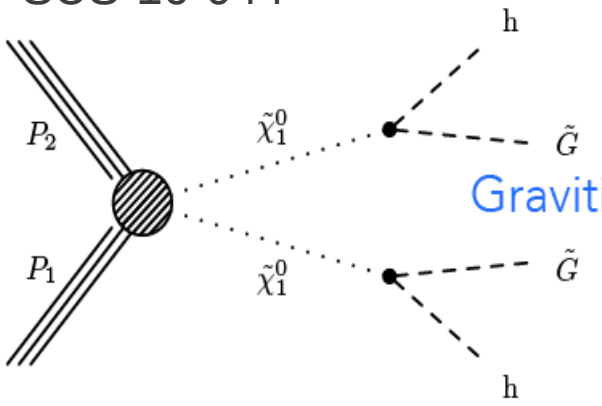






CMS Higgsino search

SUS-16-044



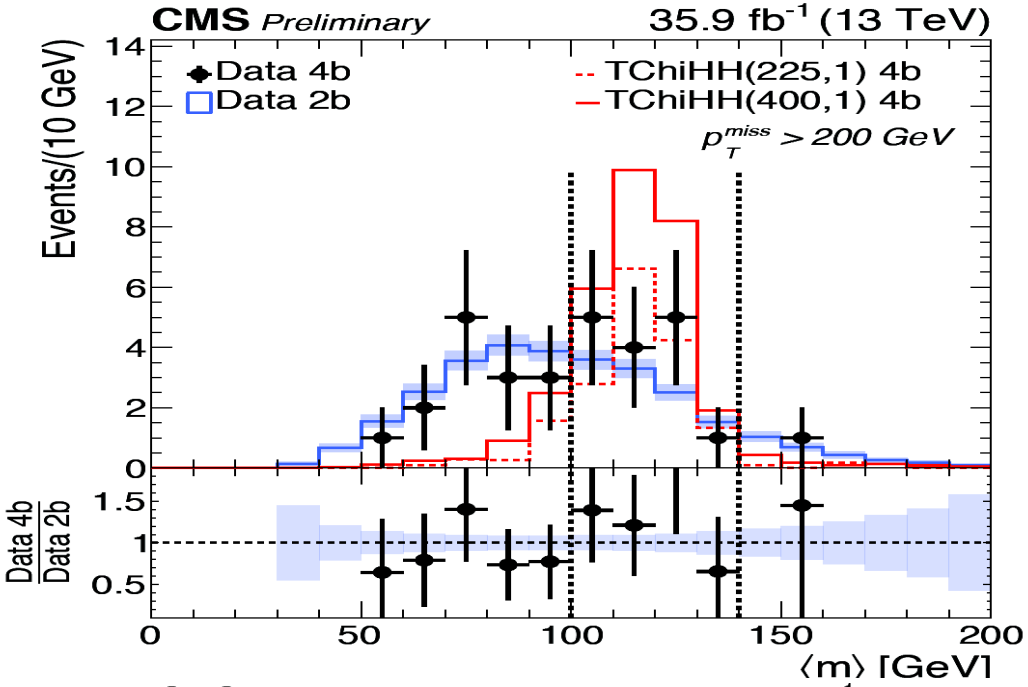
Gravitino LSP (1 GeV)

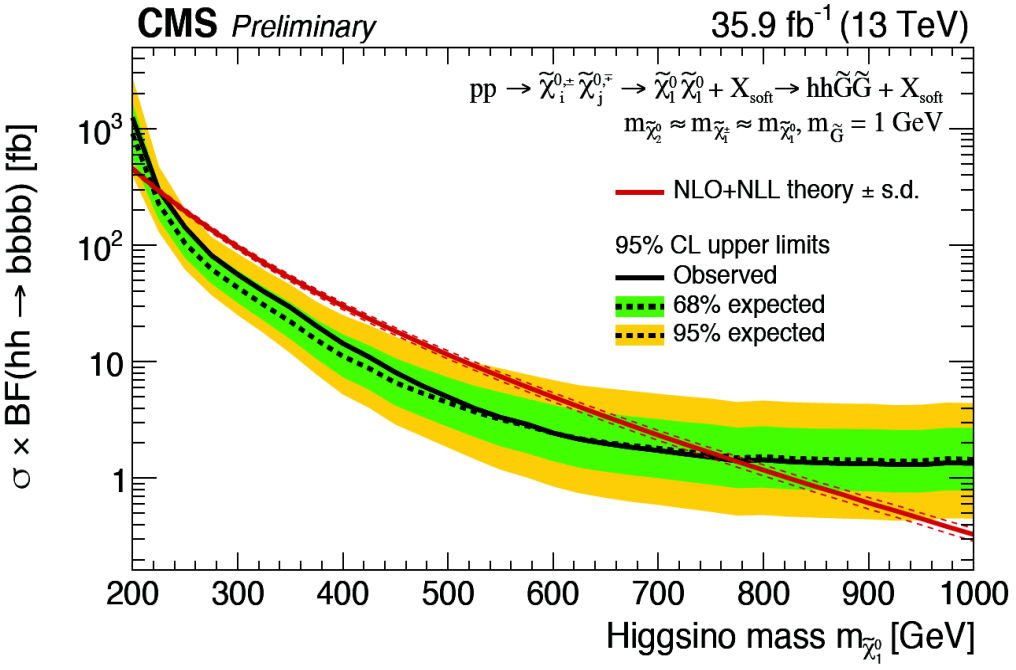
$$\langle m \rangle \equiv \frac{m_{H_1} + m_{H_2}}{2}$$

$$\Delta m \equiv |m_{H_1} - m_{H_2}|$$

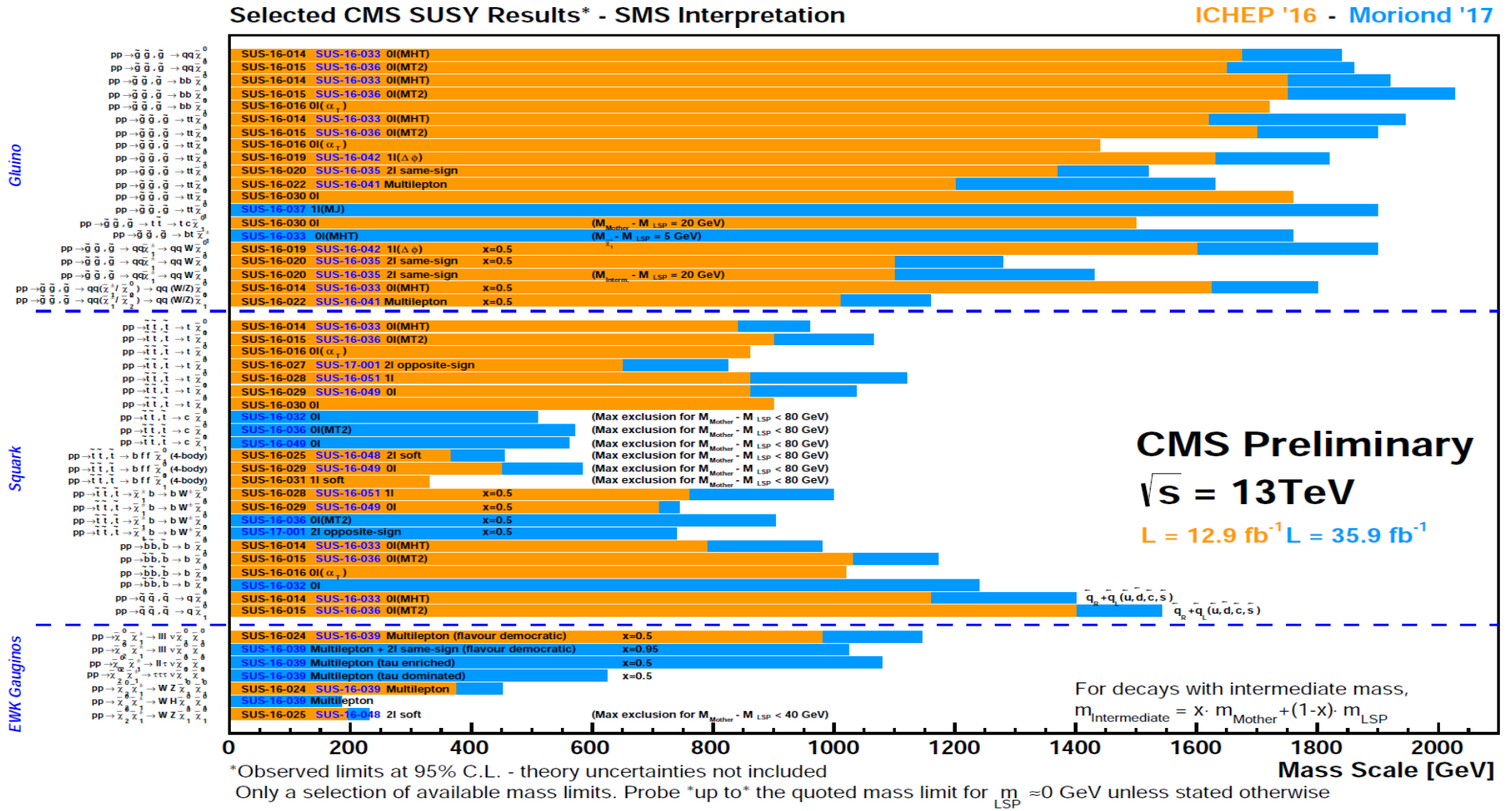
hh->bbbb + MET

Exclude Higgsino mass in (225,770) GeV

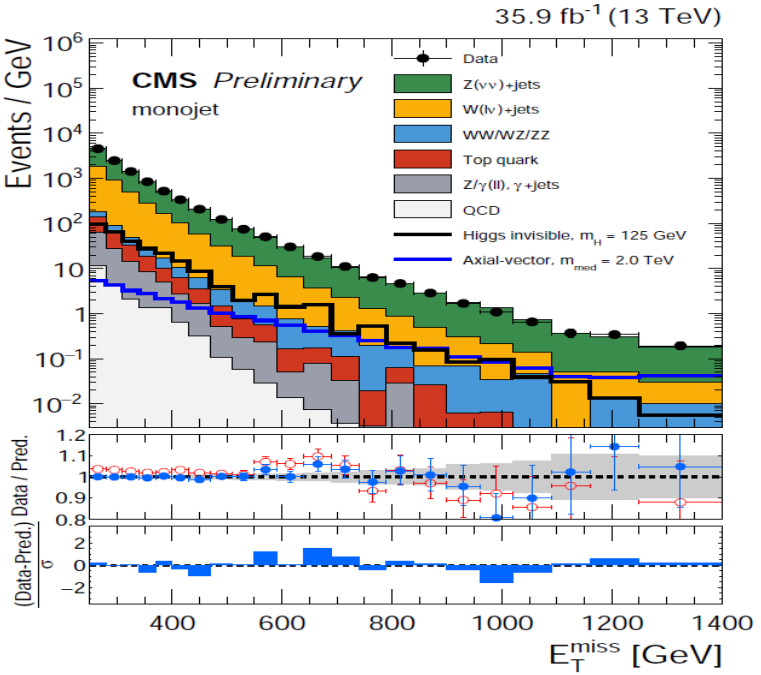




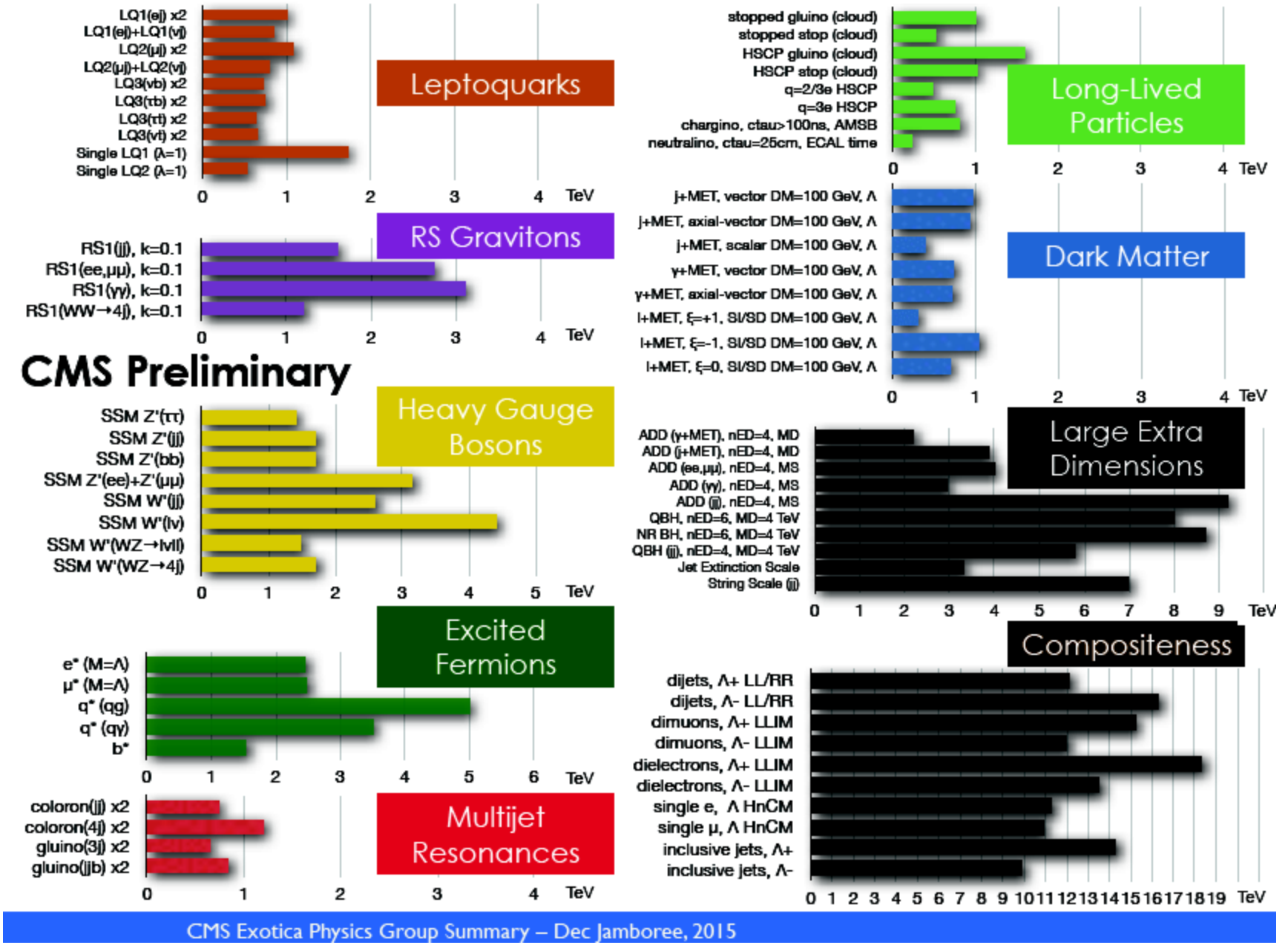
SUSY searches @ 13 TeV after 35 fb^{-1}



Other BSM Searches (Exotica)

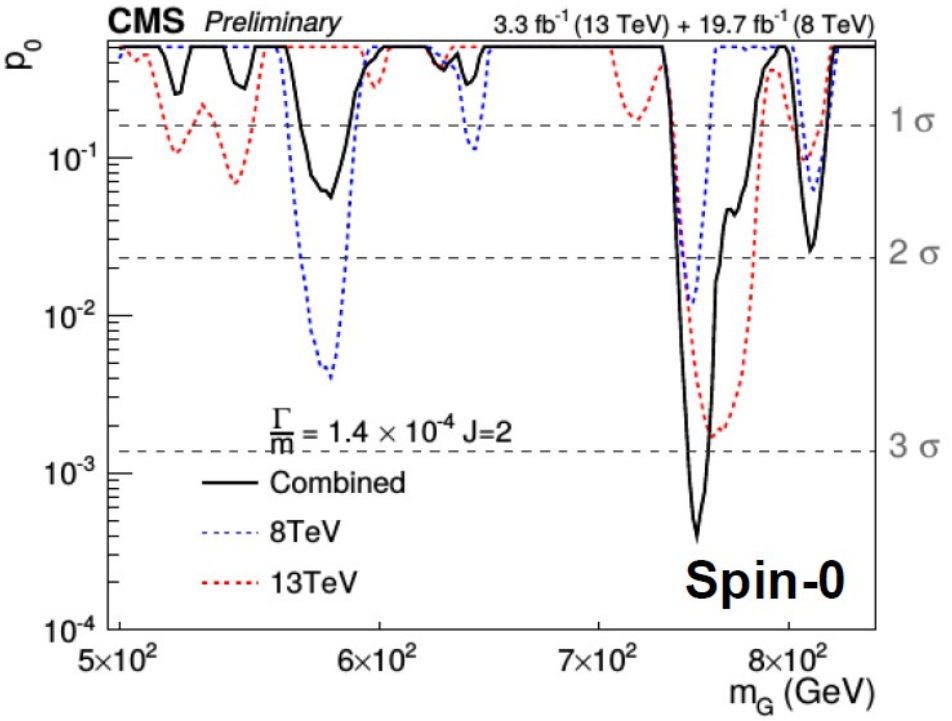


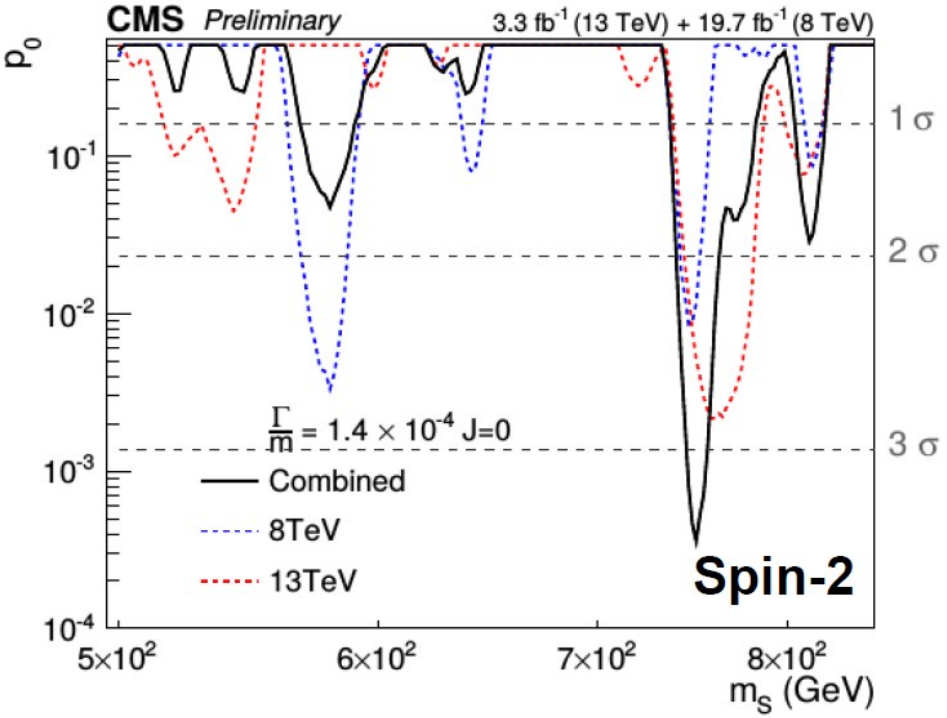
8 new analyses in CMS wih full 2016 data !



High mass diphoton

- Largest excess @ **M_x =750 GeV, narrow** width
- **3.4 sigma** local significance
- **1.6 sigma** global in range 500-3500 GeV

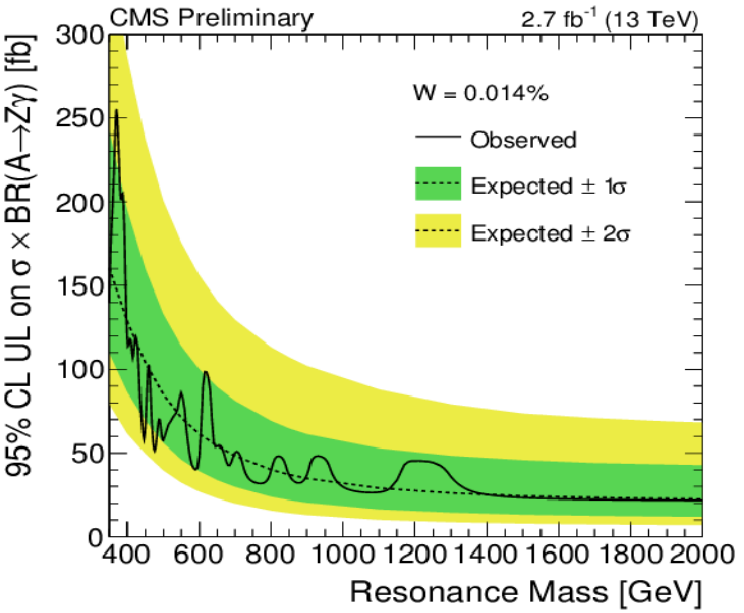


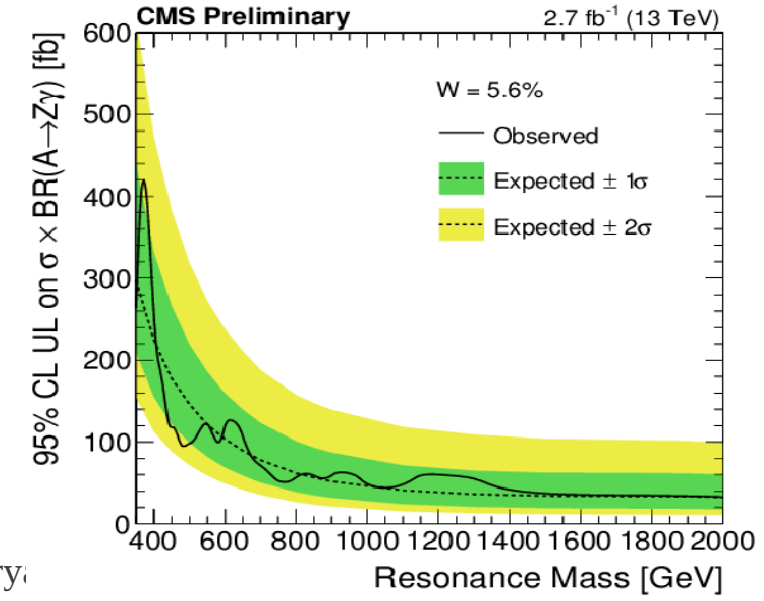


High-mass resonances in Zγ → e+e−γ/μ+μ−γ final states @ 13 TeV

EXO-16-019

- Higgs to diphoton style analysis
- Unbinned likelihood fit of background sideband
- Supported by an independent cut and count analysis
- No excess seen

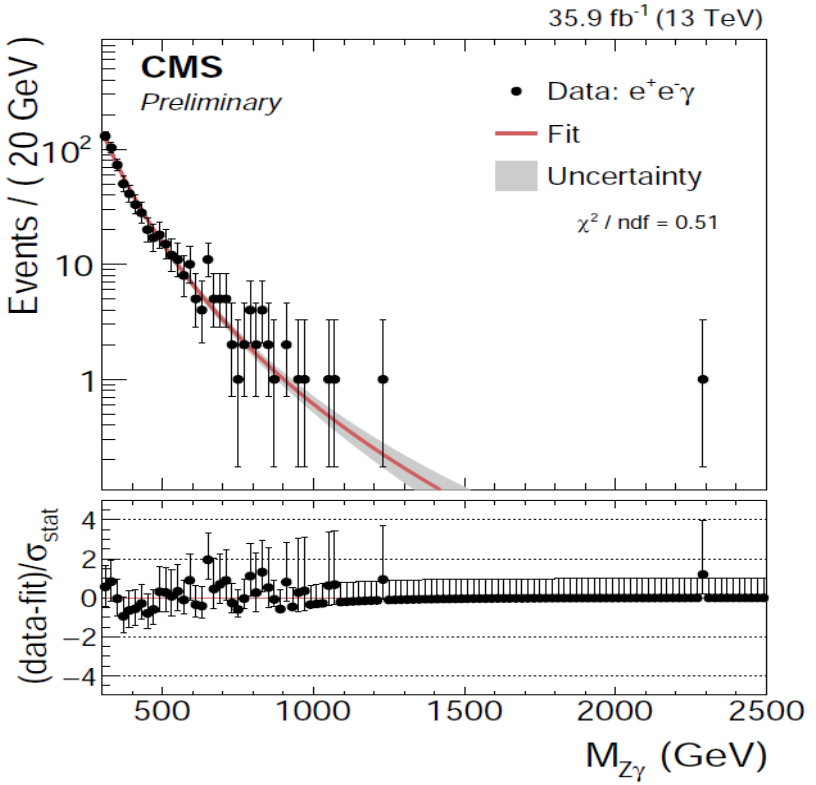


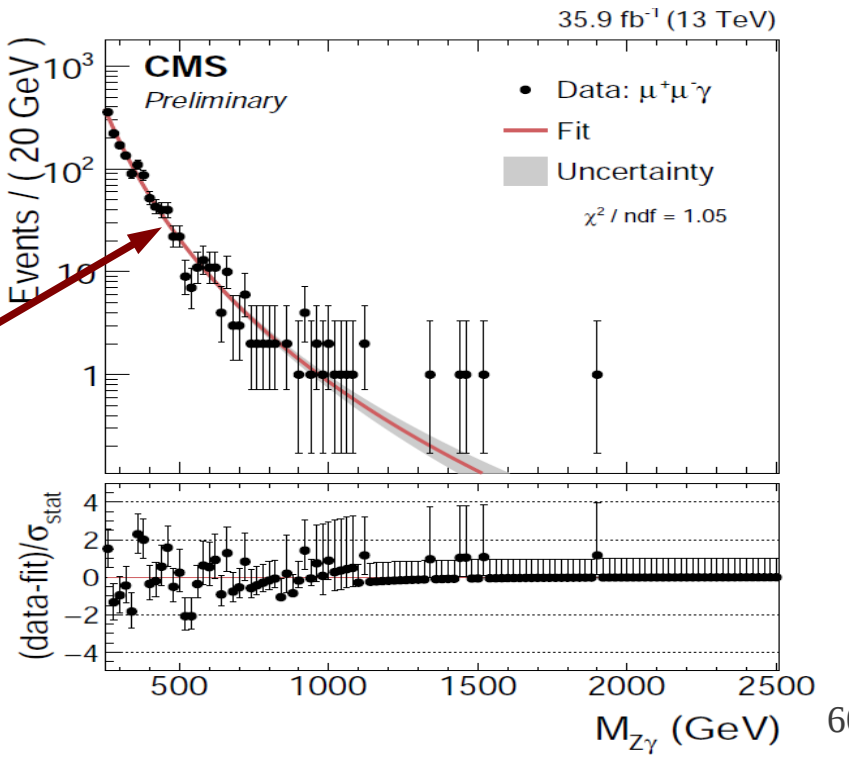


CMS high mass resonance to Zγ

CMS-EXO-17-005

- Leptonic and hadronic final states
- Hadronic final state categorized in b-tagged and anti-b tagged based on subjettiness ratio
- Two categories in light quark jets

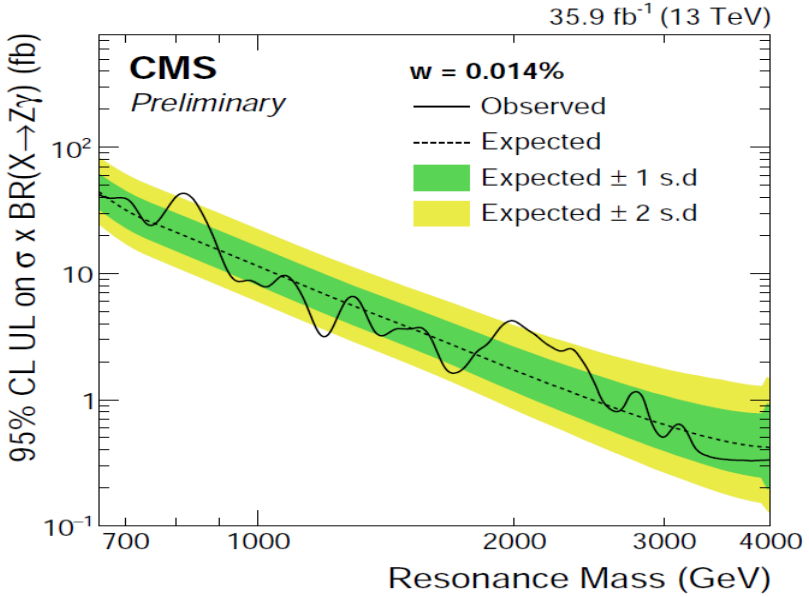




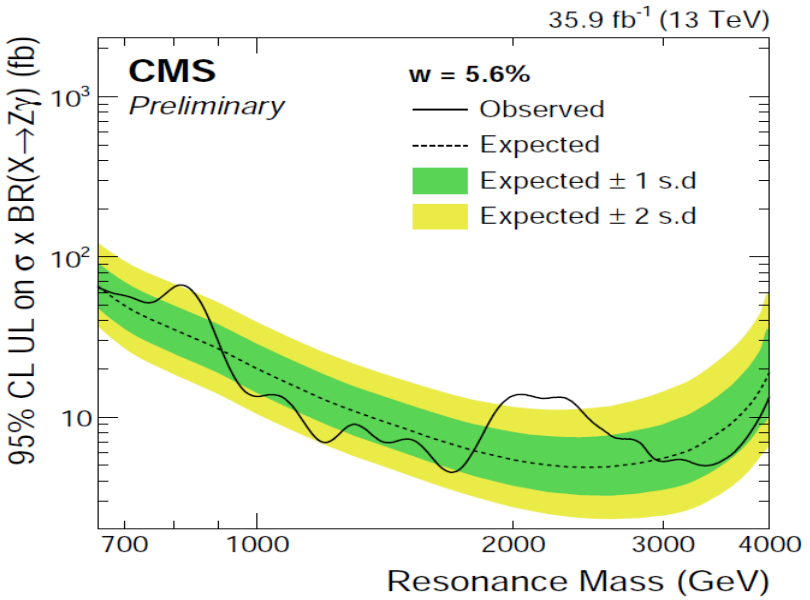
$$\frac{dN}{dM_{Z\gamma}} = P_0 \times (M_{Z\gamma}/\sqrt{s})^{P_1+P_2\times\log(M_{Z\gamma}/\sqrt{s})}$$

CMS high mass resonance to Zγ

Hadronic: b-tag + tau21 + antitau 21

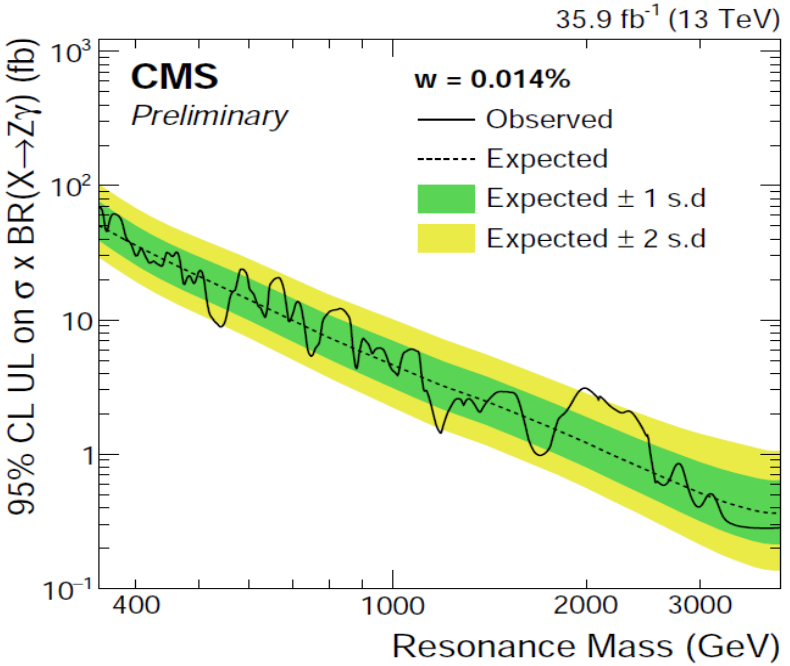


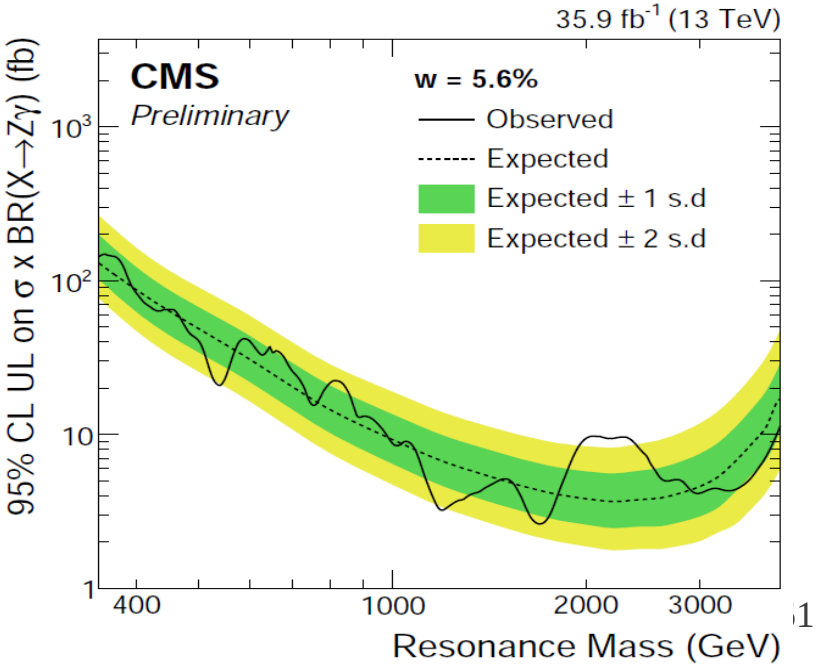
(a) $\frac{\Gamma}{m} = 0.014\%$: combined limit



(b) $\frac{\Gamma}{m} = 5.6\%$: combined limit

Hadronic + leptonic (e, μ)

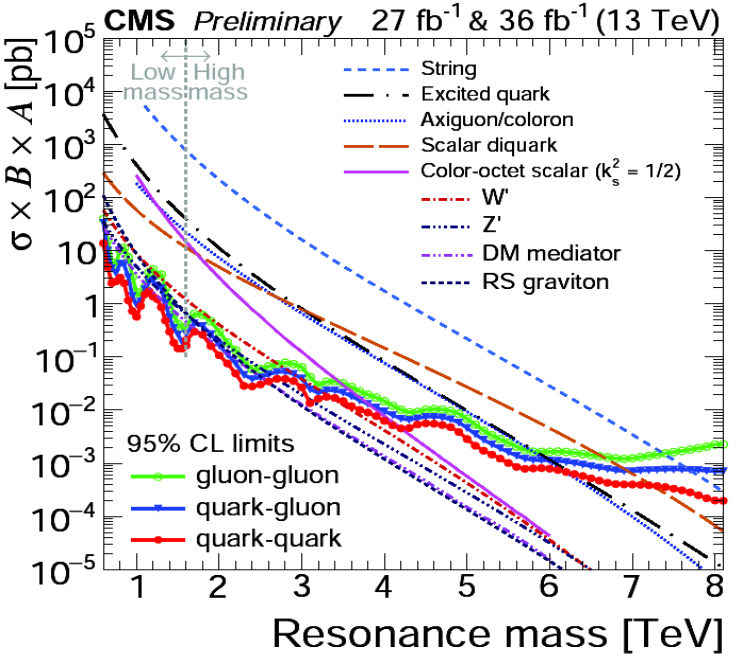


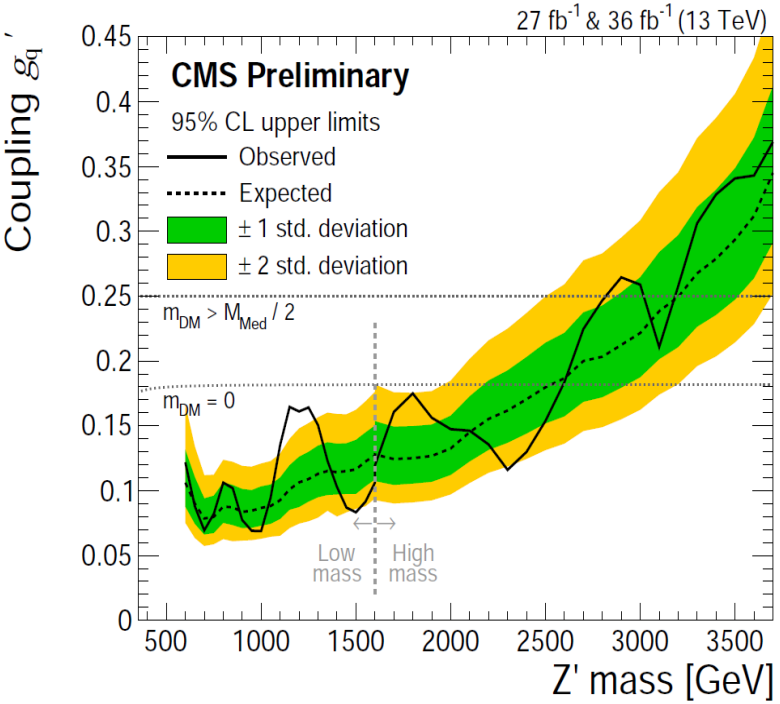


CMS Search for dijet resonance

CMS-EXO-16-056

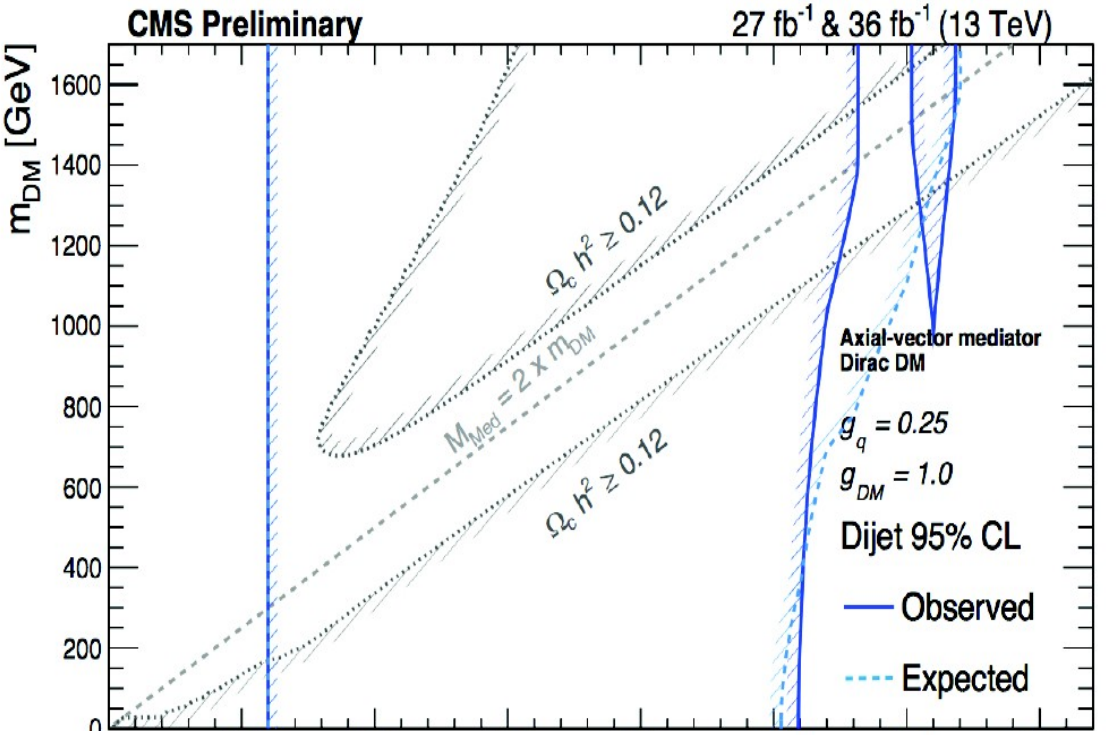
- Excludes masses:
- String resonances > 7.7 TeV
- Scalar diquarks > 7.2 TeV
- Axigluons, colorons > 6.1 TeV
- Excited quarks > 6.0 TeV
- Color octet scalars > 3.4 TeV
- W', Z' > 3.3, 2.7 TeV
- RS gravitons > 1.7 TeV and outside [2.1,2.5] TeV

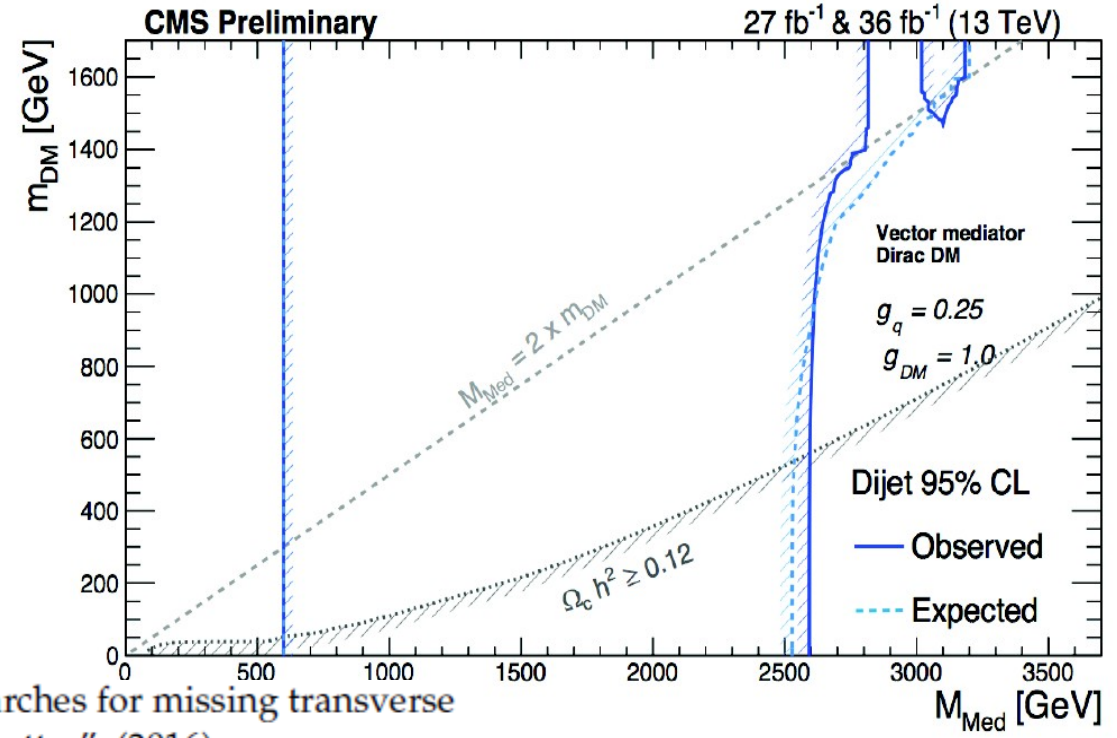




CMS dijet resonance

And DM mediator > 2.6 TeV
(* in simplified model, spin 1 mediator, coupling only to quarks)

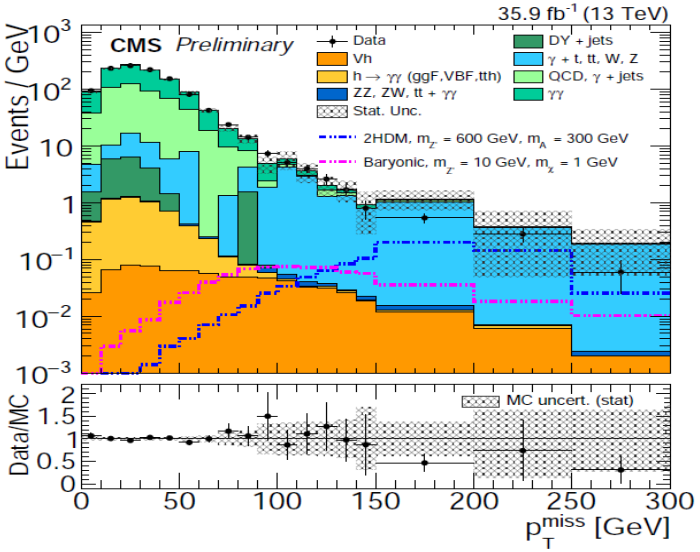


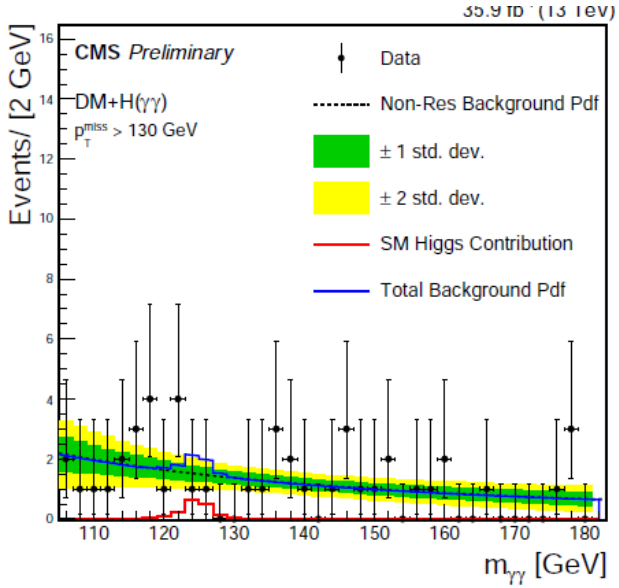


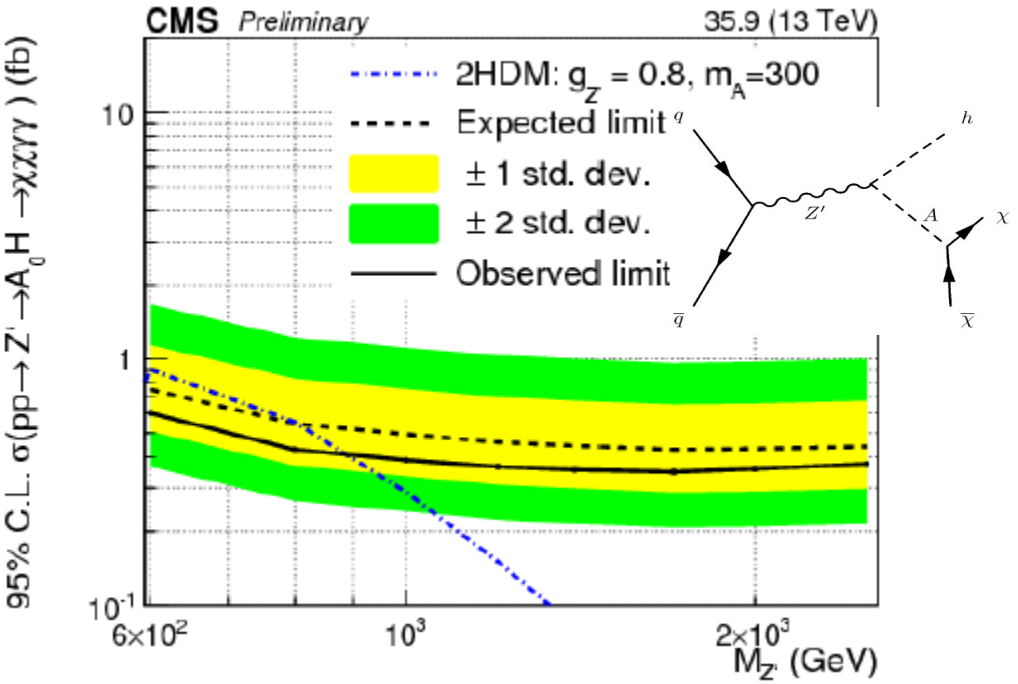
* A. Boveia et al., "Recommendations on presenting LHC searches for missing transverse energy signals using simplified *s*-channel models of dark matter", (2016). arXiv:1603.04156.

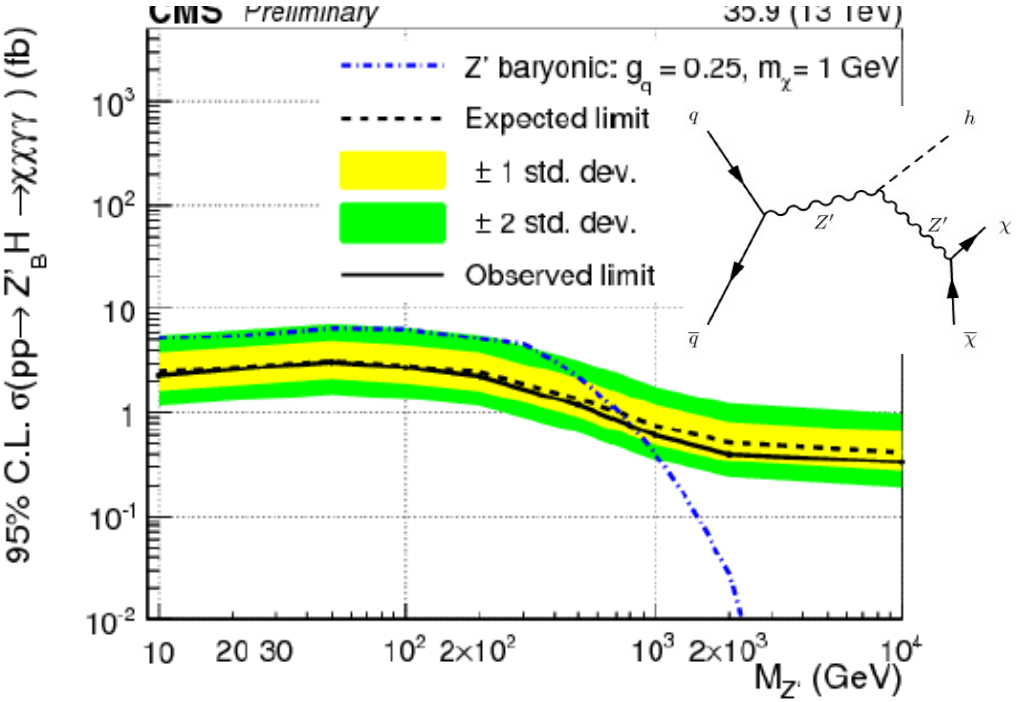
CMS Higgs + DM

CMS-EXO-16-054



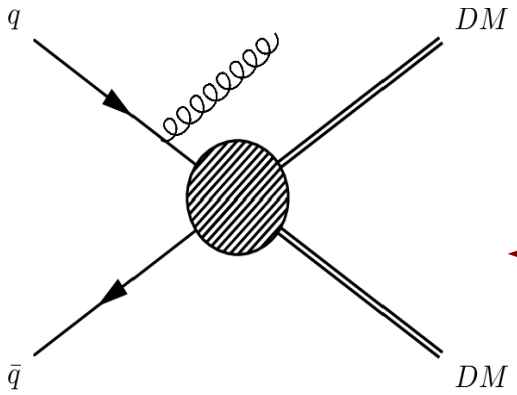






H to γγ (peak at 125 GeV)+ large MET

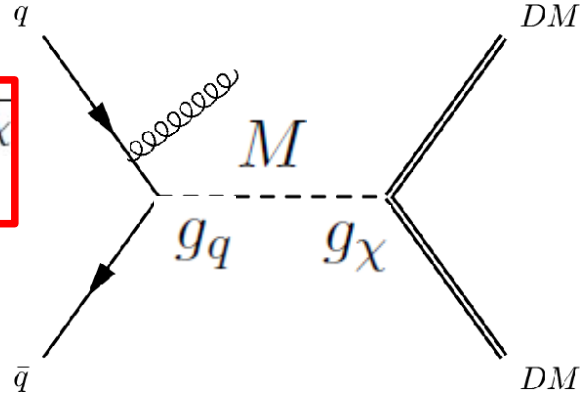
Monojet + MET



DM EFT

$\Lambda = M/\sqrt{g_q g_\chi}$

$Q_{\rm tr} < M$



DM MED

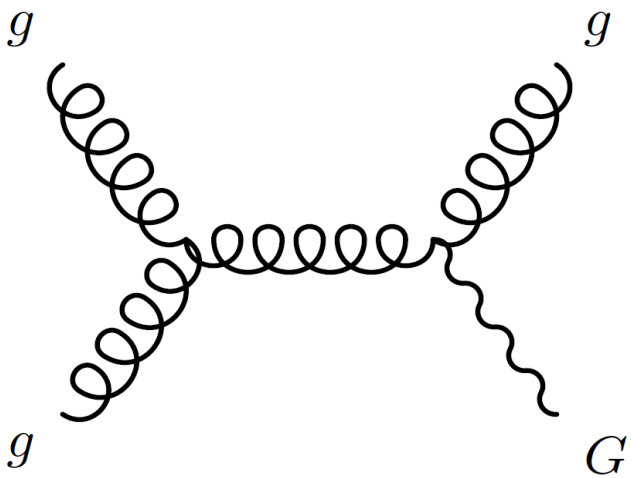
perturbative

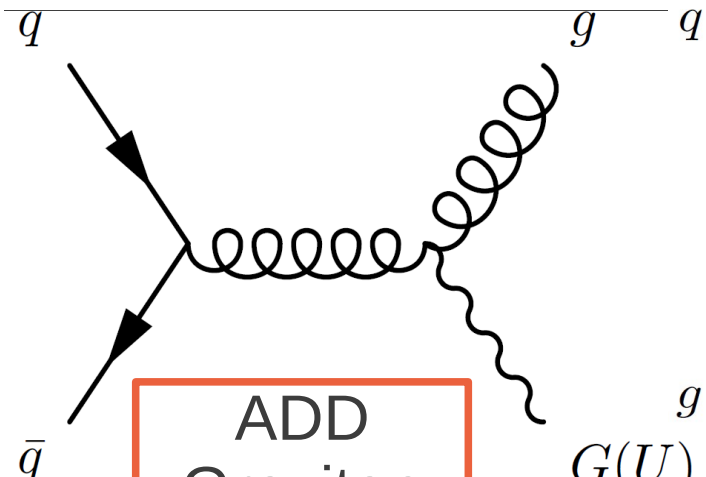
$g_{q,\chi} < 4\pi$

$\Lambda > \frac{Q_{\rm tr}}{\sqrt{g_q g_\chi}} > \frac{Q_{\rm tr}}{4\pi}$

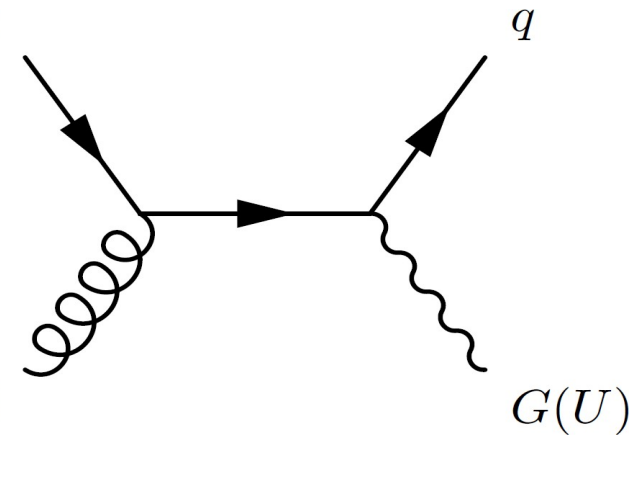
s-channel

$\Lambda > \frac{m_{\rm DM}}{2\pi}$

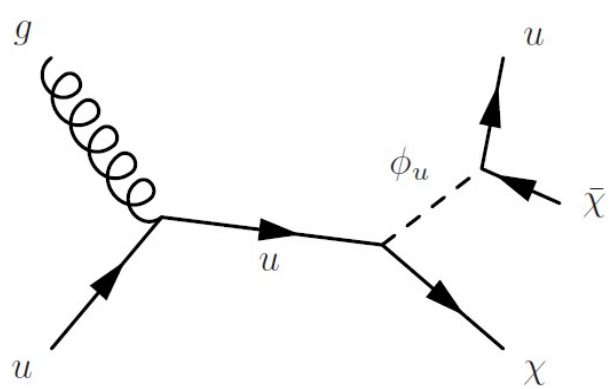


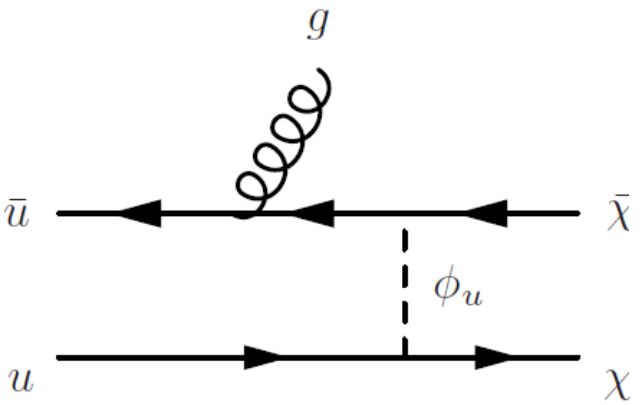


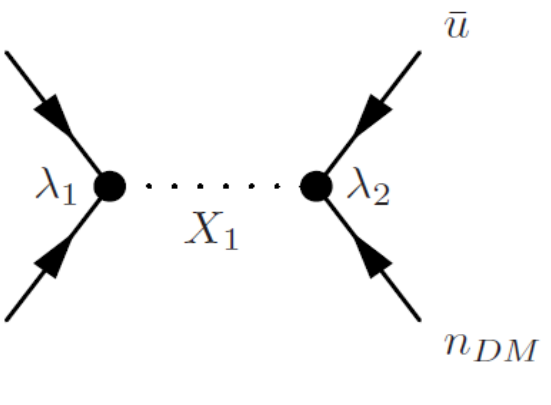
ADD Graviton

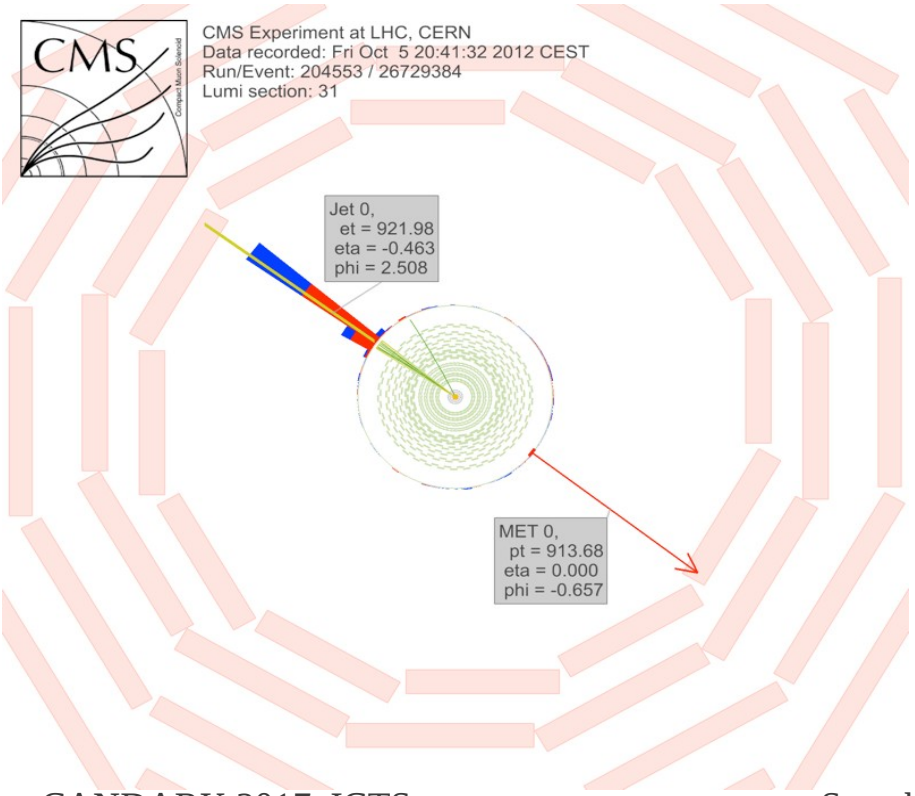


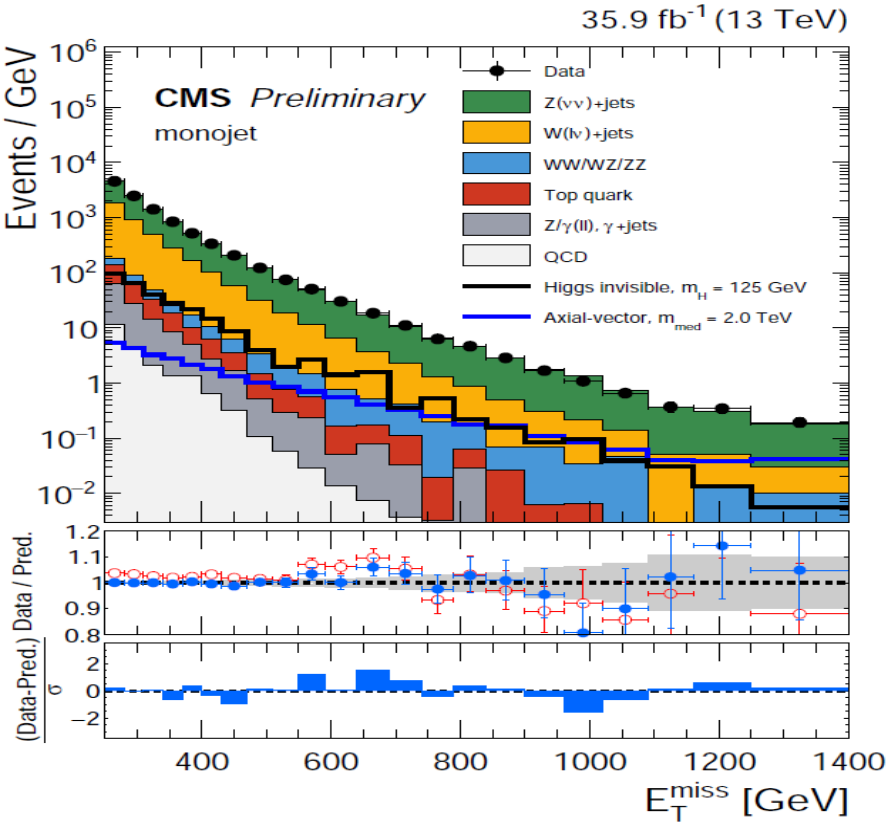
CMS monojet @ 13 TeV



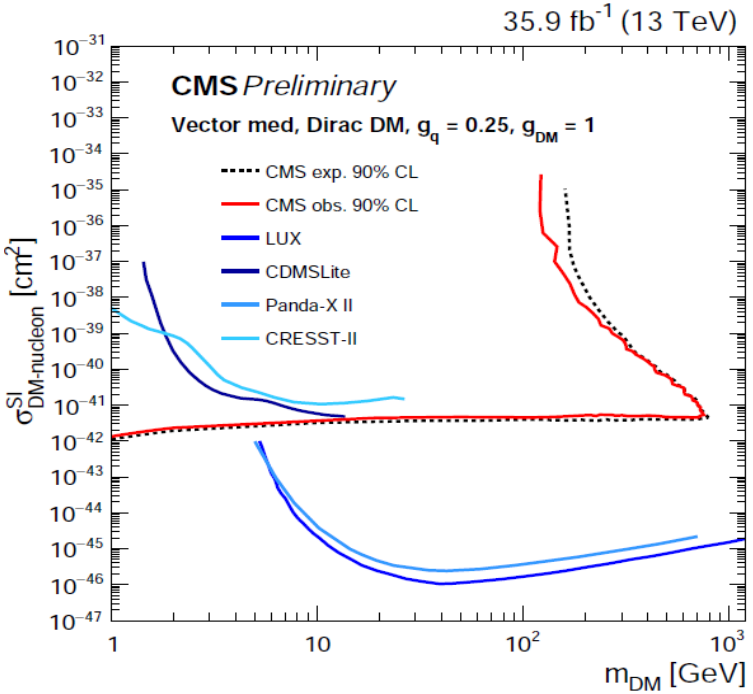


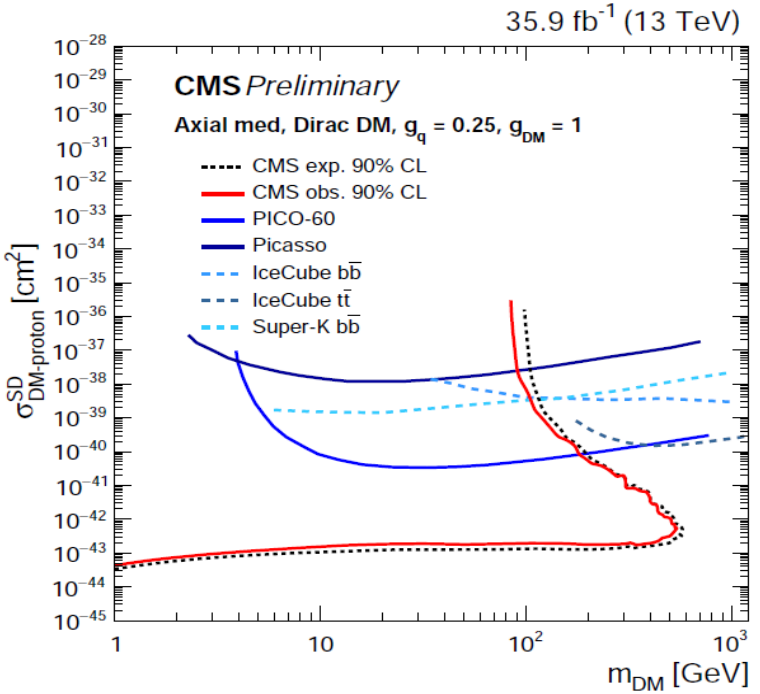




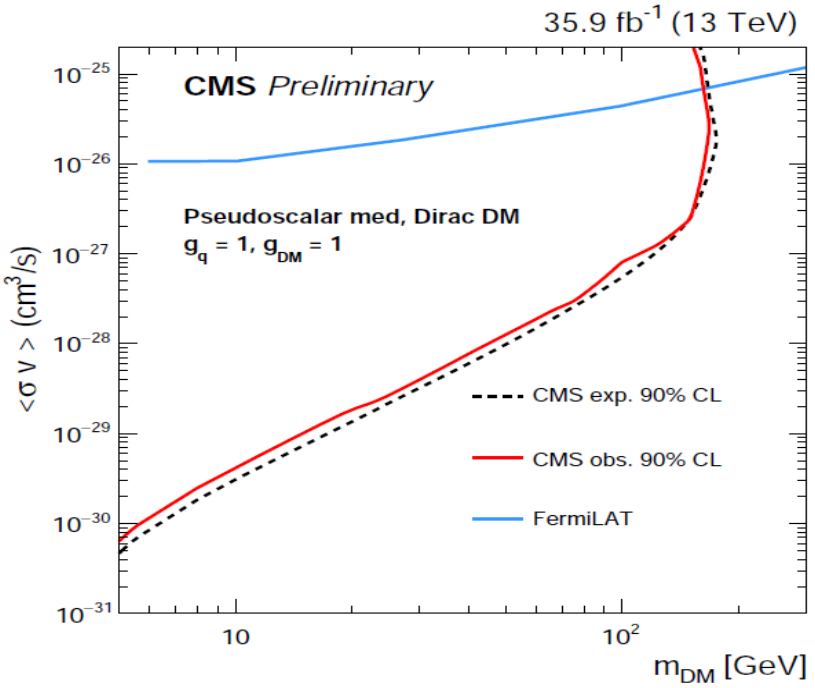


CMS monojet @ 13 TeV

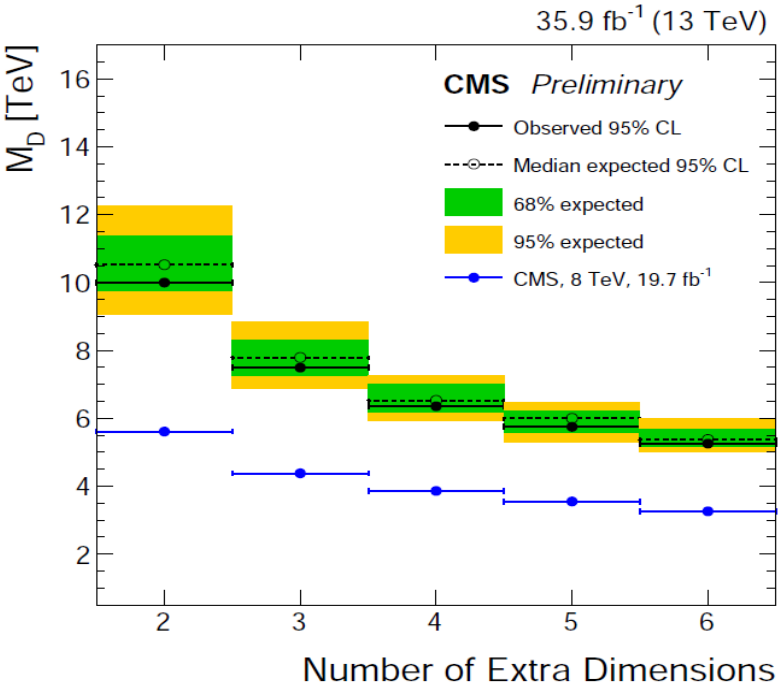


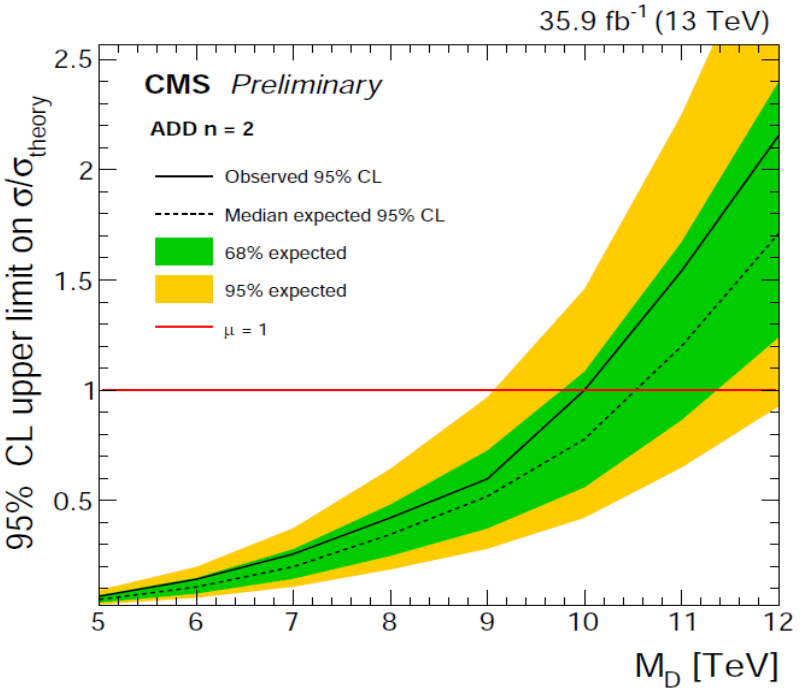


- For pseudoscalar mediator bound is on velocity averaged DM annihilation cross section
- Quark scattering suppressed at low velocities
- Compared with FermiLAT

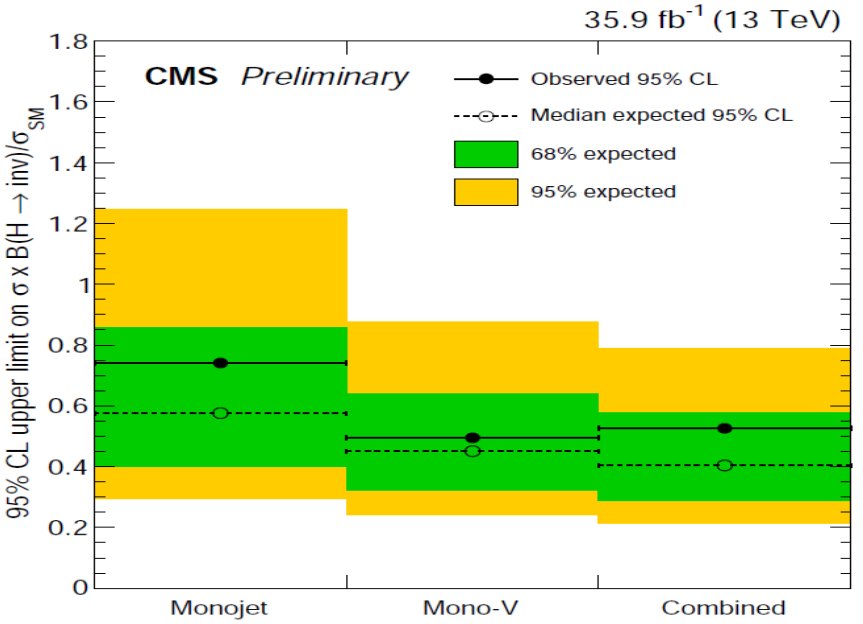


Monojet: other bounds



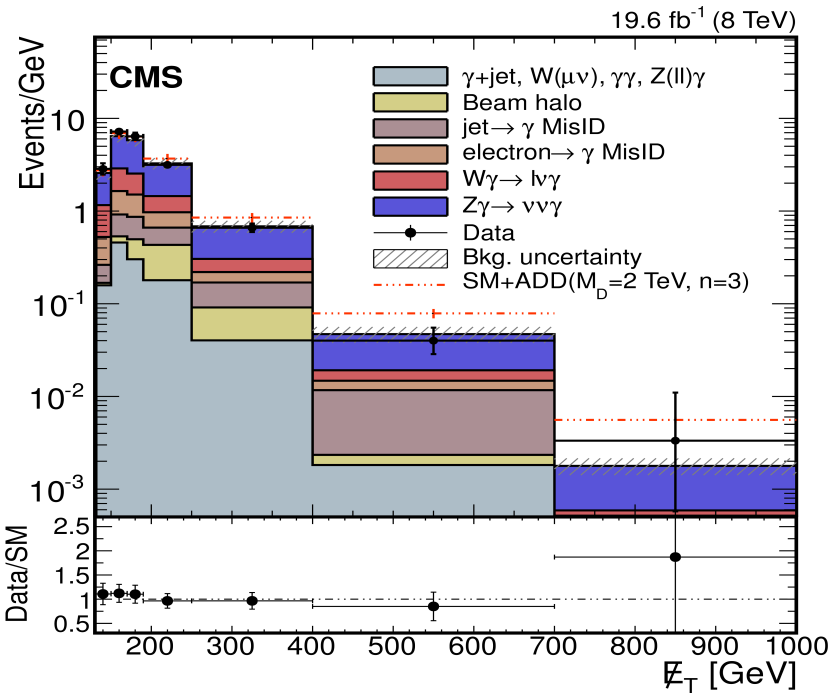


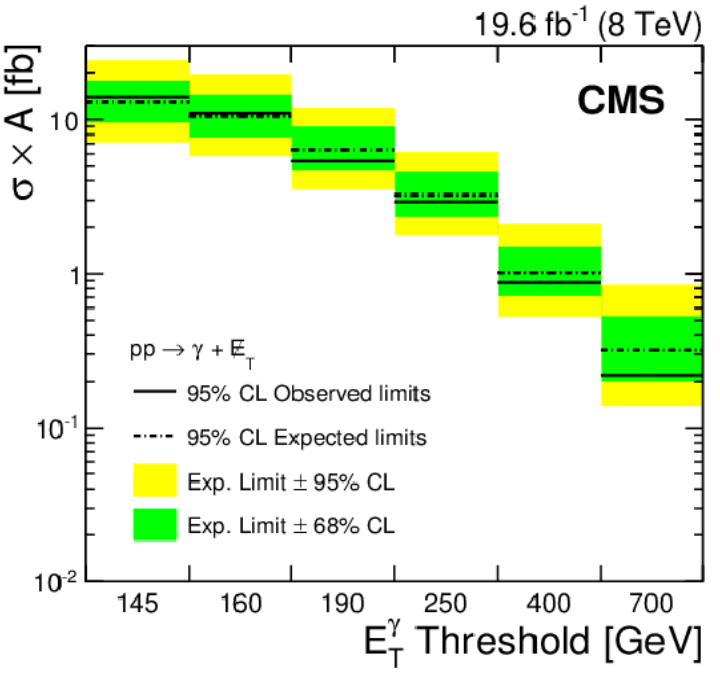
- M_D > 10 TeV, 5.5 TeV for n = 2,6 (> 6 TeV for n = 2, from Run 1)
- $BR_{invisible}$ > 0.3 @ 95% CL for SM higgs



Monophoton

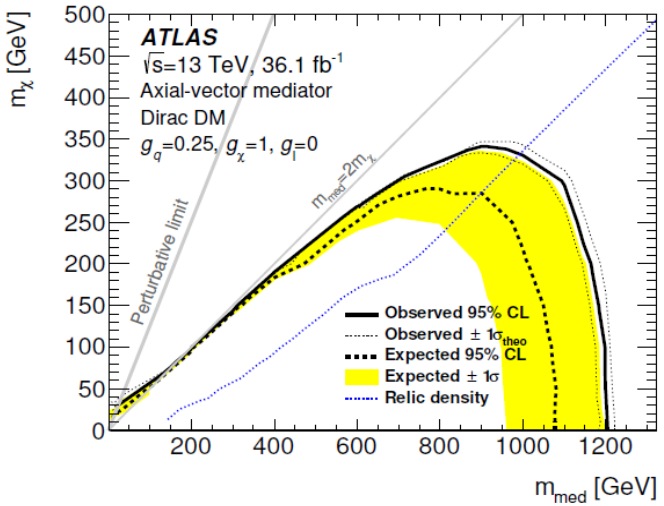
- Photon pT > 150 GeV
- Met > 135 GeV
- No jet
- No lepton
- Discriminator for beam halo, cosmics, anomalous ECAL signals

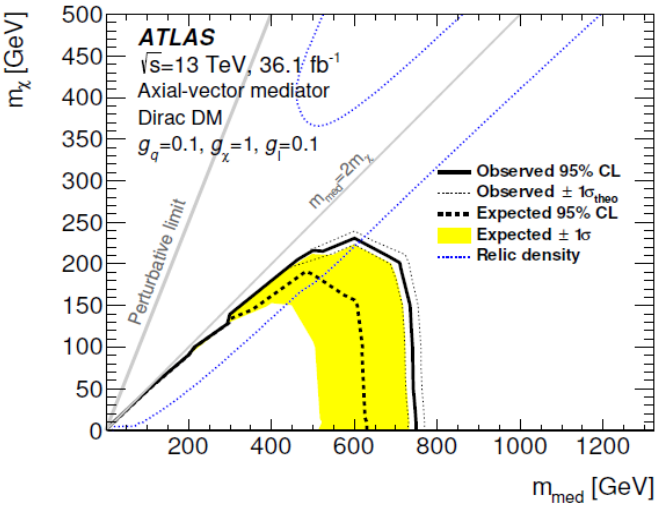


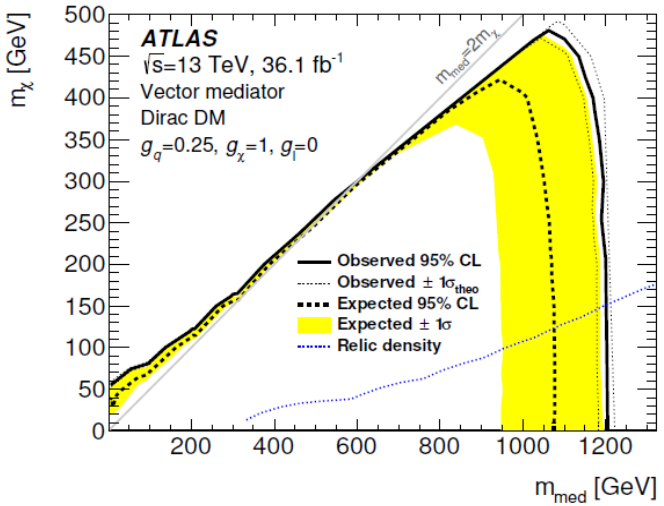


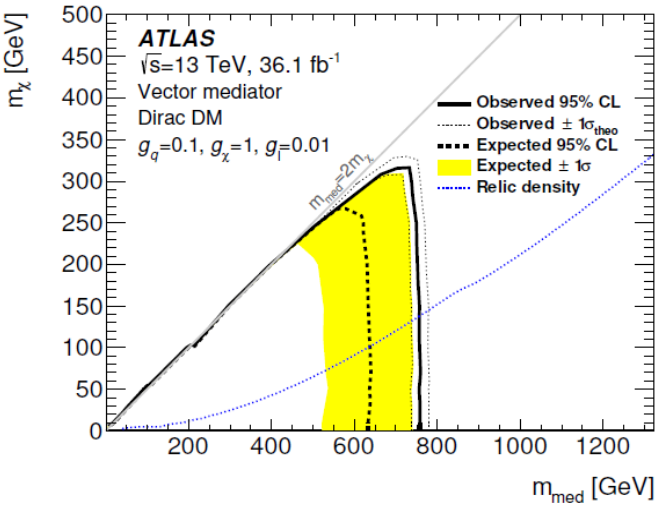
ATLAS Monophoton @ 13 TeV

ATLAS, arXiv:1704.03848







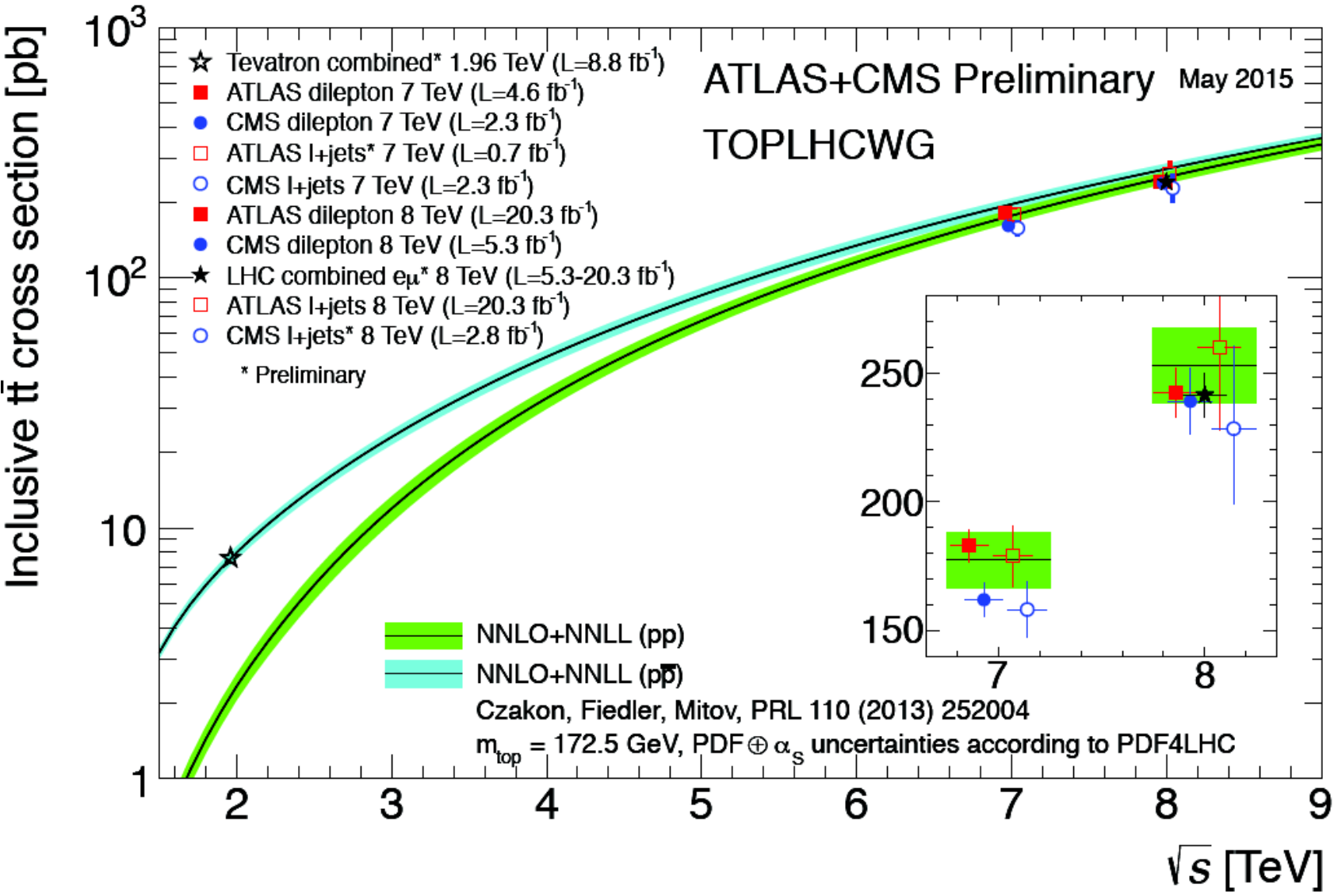


Conclusion

- Many new results @ 13 TeV
- Higgs properties establishes an SM like Higgs
- Early excess in diphoton channel faded away
- Higgs + no new physics (so far!)
- Look forward for 2017-18 data

backup

top pair cross sections



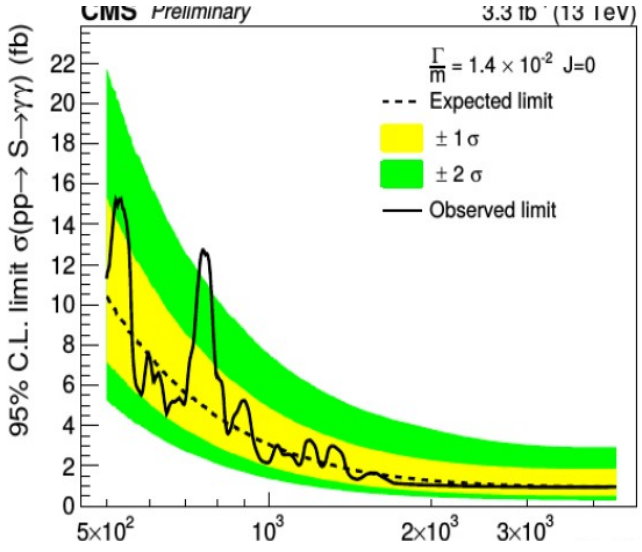
±5.7% (theo)

±3.9% (eμ)

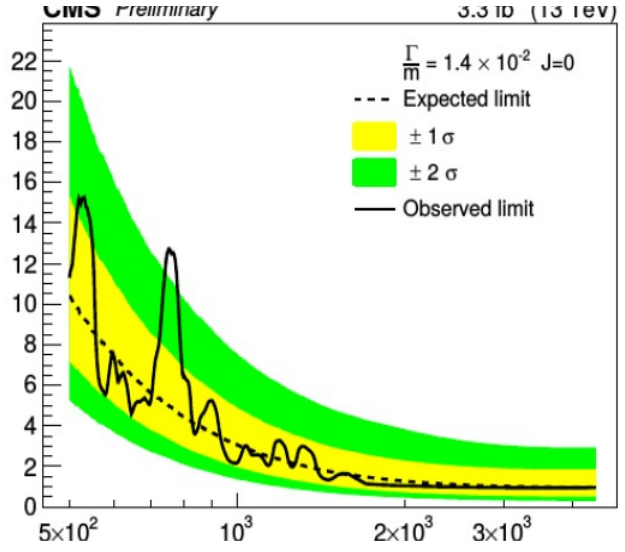
High mass diphoton

Frequentist, unbinned likelihood

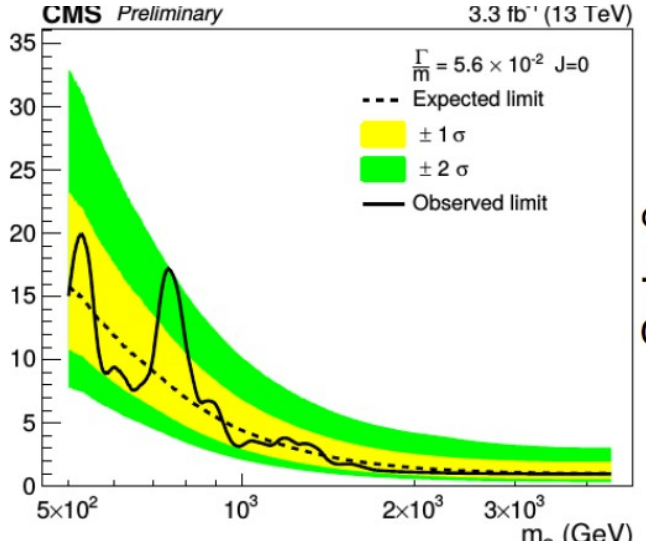
$$L(\mu,\theta)=\prod_{i=1}^{N_{events}}\left[\ \mu S(m_i|\theta_S)\ +\ B(m_i|\theta_B)\ \right]\cdot Poisson\left(N_{events}|N_B+\mu N_S\right)$$



$\Gamma/m = 1.4\times10^{-4}$

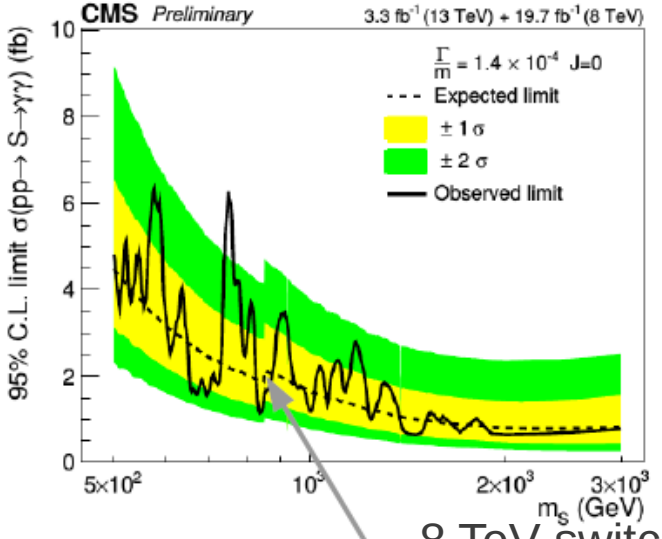


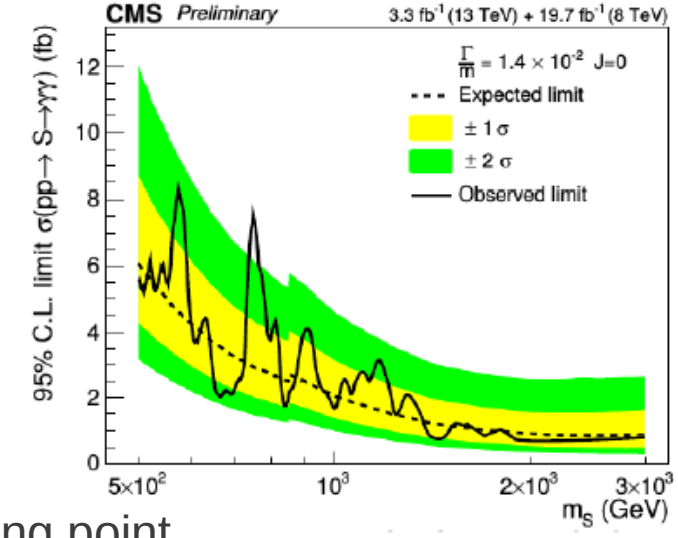
$\Gamma/m = 1.4\times10^{-2}$

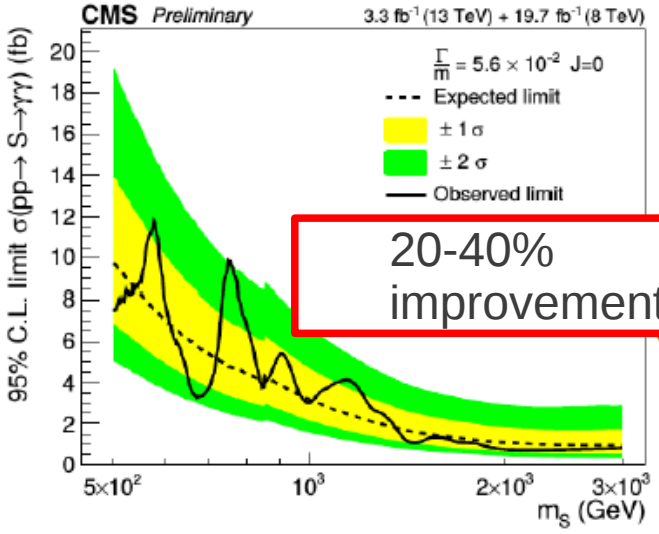


$\Gamma/m = 5.6\times10^{-2}$

Spin 0







20-40% improvement

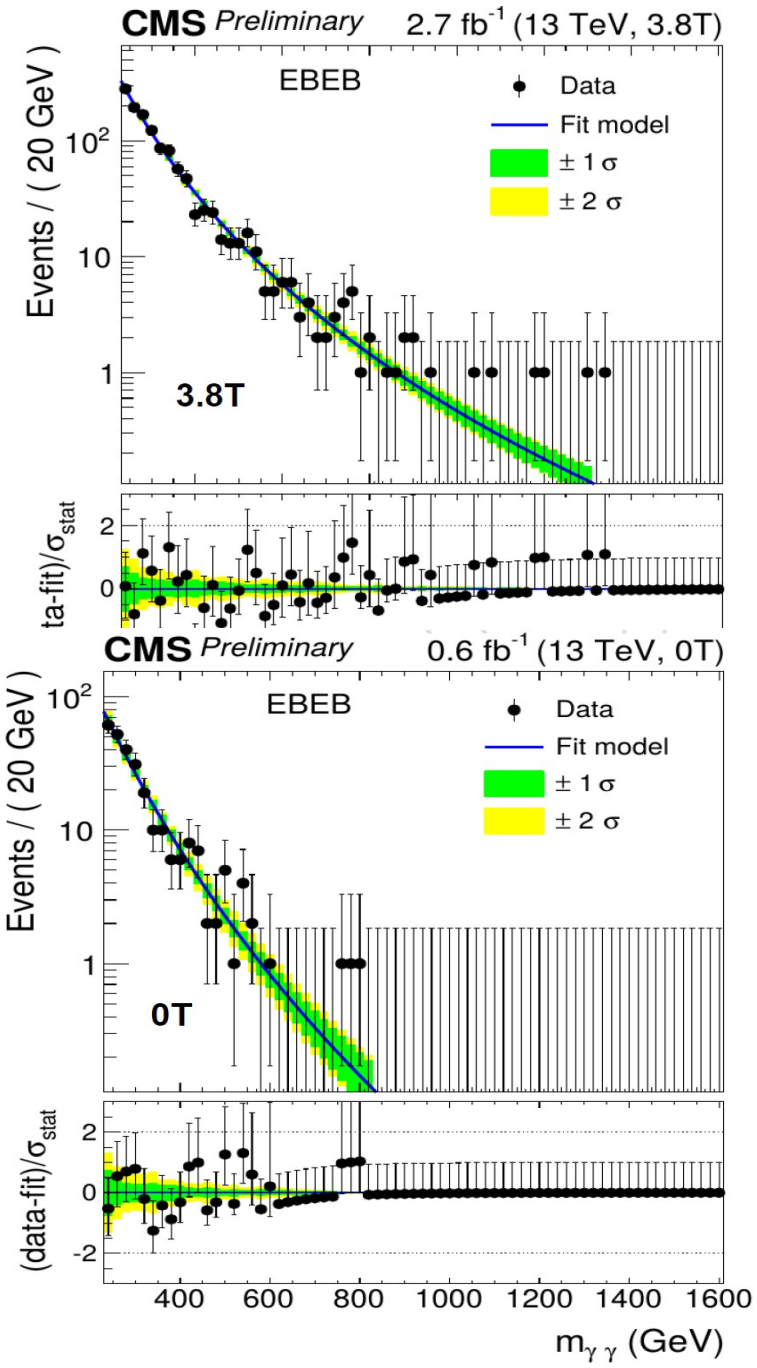
8 TeV switching point

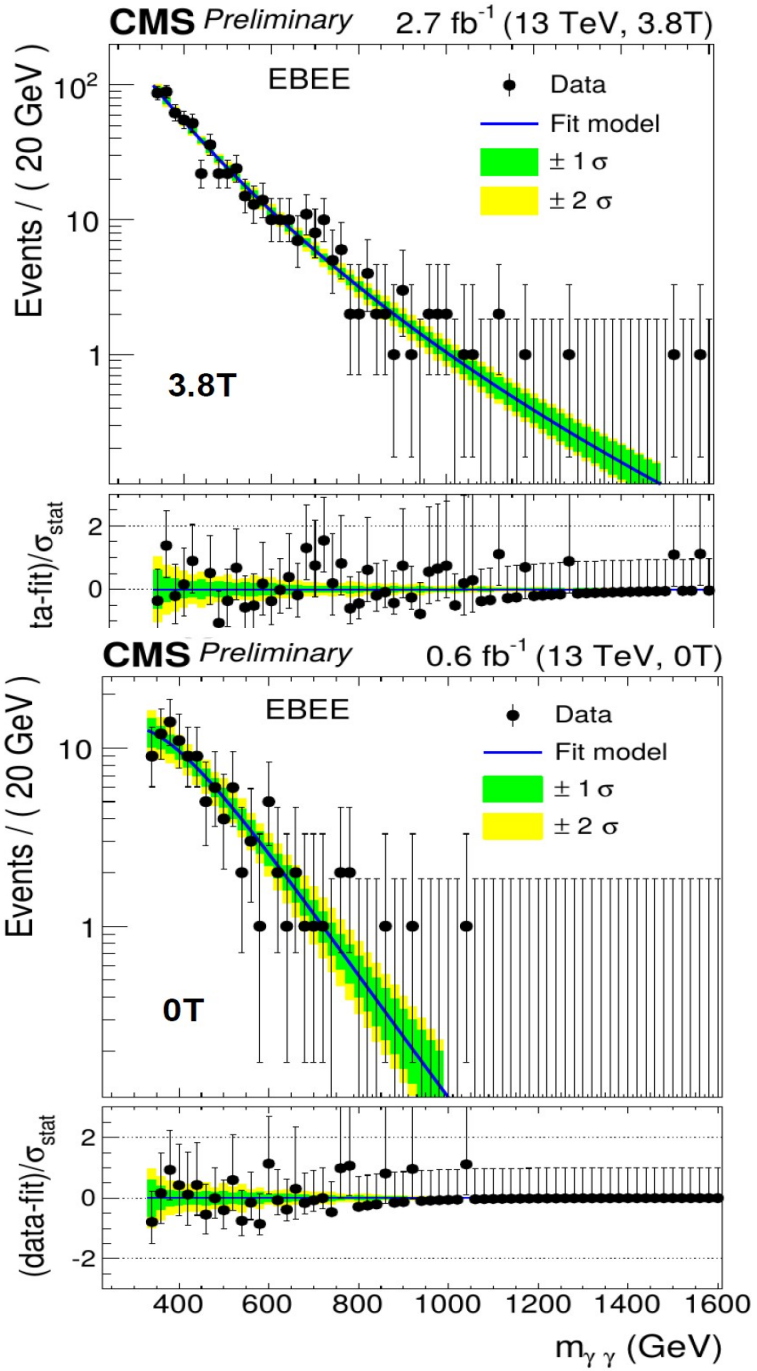
High mass diphoton

EXO-16-018

- Signal model: lineshape X detector resolution
- Background model:

$$f(m_{\gamma\gamma}) = m_{\gamma\gamma}^{a+b\cdot\log(m_{\gamma\gamma})}$$





Higgs papers by May 2016

- **(Re)Discovering H(125):**
  - H→4ℓ (13 TeV) HIG-15-004
  - H→γγ (13 TeV) HIG-15-005
  - ttH→multileptons (13 TeV) HIG-15-008
  - ttH→bb (13 TeV) HIG-16-004
- **Search for BSM Higgs production:**
  - BSM Summary (8 TeV) HIG-16-007 NEW!
  - H→ZZ→4ℓ (13 TeV) HIG-15-004
  - H→ZZ→2ℓ2ν (13 TeV) HIG-16-001
  - H→Z(ℓℓ)A(bb) (13 TeV) HIG-16-010 NEW!
  - X→HH→bbττ (13 TeV) HIG-16-013
  - X→HH→bbbb (13 TeV) HIG-16-002 NEW!
- **Double-Higgs Production**
  - HH→bbττ (8 TeV) HIG-15-013
  - HH→bbττ (13 TeV) HIG-16-012
  - HH→bbγγ (8 TeV) HIG-13-032 (submitted to PRD)
- **Exotic Decays of H(125)**
  - H→μμbb (8 TeV) HIG-14-041
  - H→μμττ (8 TeV) HIG-15-011
  - Z(ℓℓ)H(invisible) (13 TeV) HIG-16-008

Strategy @ 13 TeV

Focused on strongly produced SUSY

Largest gain from 13TeV parton luminosity

Started from *inclusive* searches: M_{T2}, α_T, H_T^{miss}, Razor Updated

compare data to SM estimates across a large phase space, look for excesses

- No excess is observed, extract limits on cross-section x branching-ratios
- Preliminary results presented in December 2015

New New for Moriond QCD

then moved to *targeted* searches: stop and sbottom

similar background estimation techniques, but fine-tuned selection

- First results of 3rd generation searches showed at Moriond

All results available from: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

H_T^{miss}	SUS-15-002, arXiv:1602.06581
α_T	SUS-15-005
M_{T2}	SUS-15-003, arXiv:1603.04053
Razor	SUS-15-004

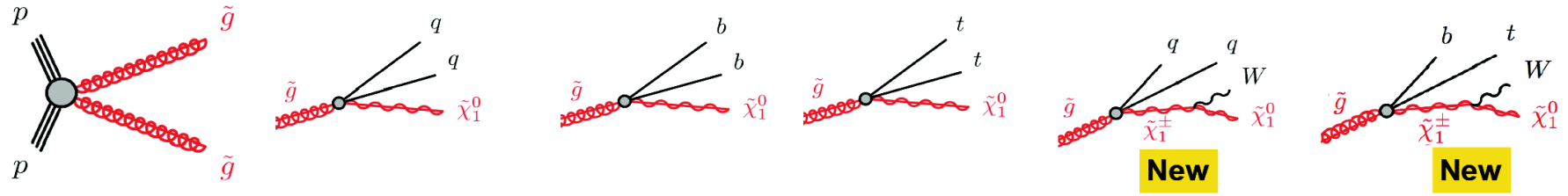
stop	SUS-16-007
sbottom	SUS-16-001
Further Interpretations (Dec. 2015 Analyses)	SUS-16-004
γγ+MET	SUS-15-012

SUSY Hadronic search channels

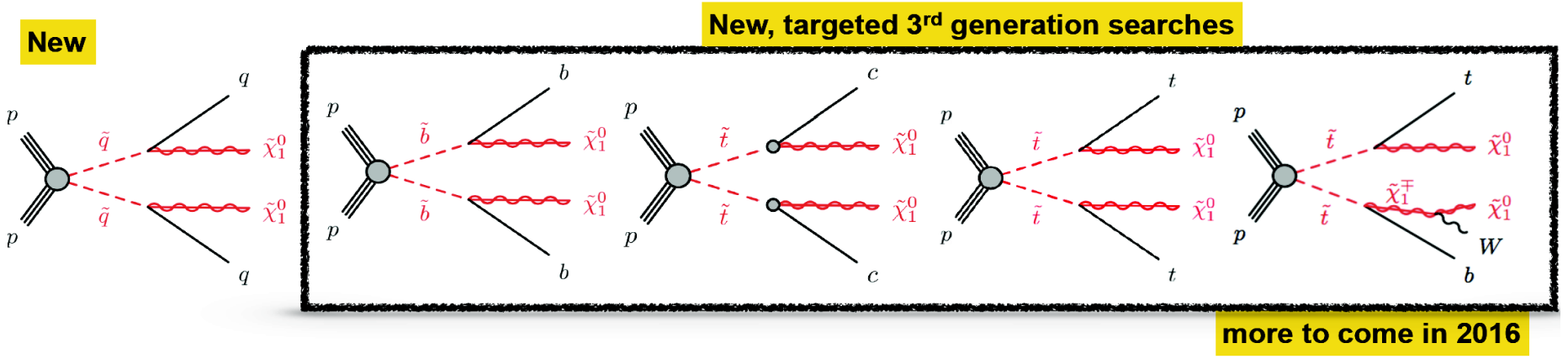
- Look for pair production with simple decay chain
- Exclusion in M_produced-M_LSP plane

Gluino pair-production:

Several decay modes, all relevant depending on squark mass spectra and branchings



Squark pair-production and decays:



SUSY Hadronic search

- Lepton veto to remove W's
- MET related quantities to reject multijets

$$H_{\mathrm{T}}^{\mathrm{miss}} = \left| -\sum_{jets} \vec{p}_{\mathrm{T}} \right| \approx E_{\mathrm{T}}^{\mathrm{miss}}$$

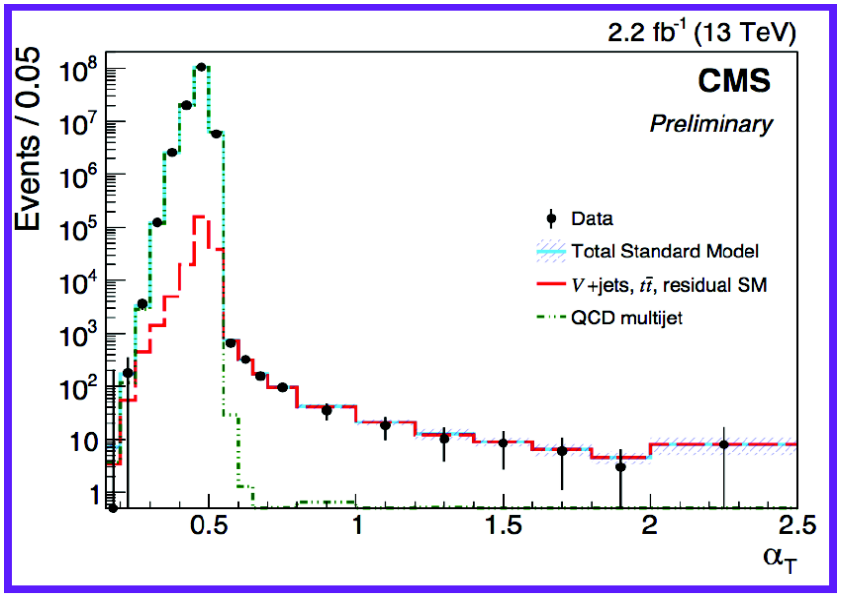
$$M_{\mathrm{T2}} \approx \sqrt{2p_{\mathrm{T}}^{\mathrm{J1}} p_{\mathrm{T}}^{\mathrm{J2}} (1 + \cos\Delta\phi_{1,2})}$$

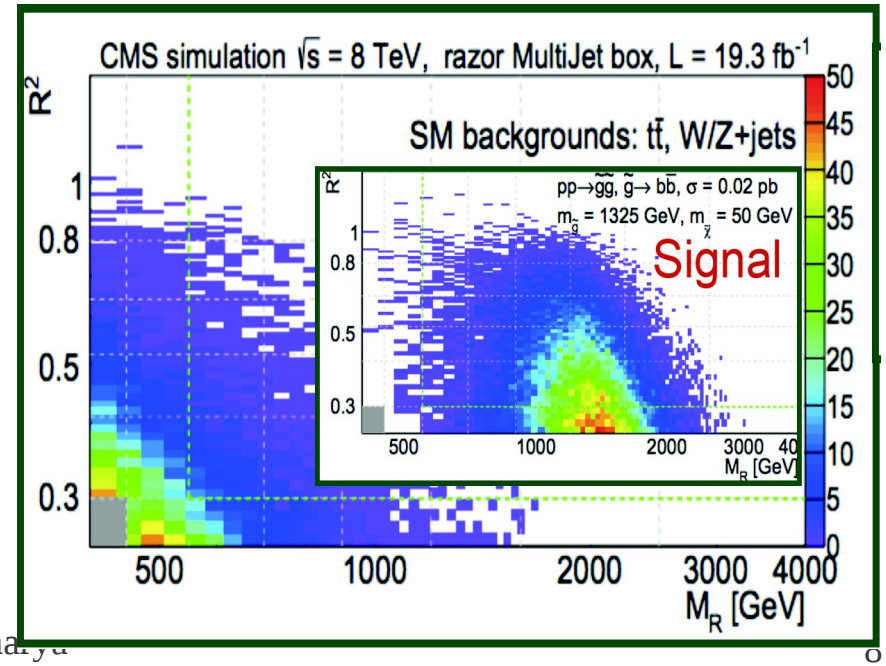
$$\alpha_{\mathrm{T}} \approx \sqrt{\frac{p_{\mathrm{T}}^{\mathrm{J2}}}{2p_{\mathrm{T}}^{\mathrm{J1}}} \frac{1}{(1 - \cos\Delta\phi_{1,2})}}$$

Razor:

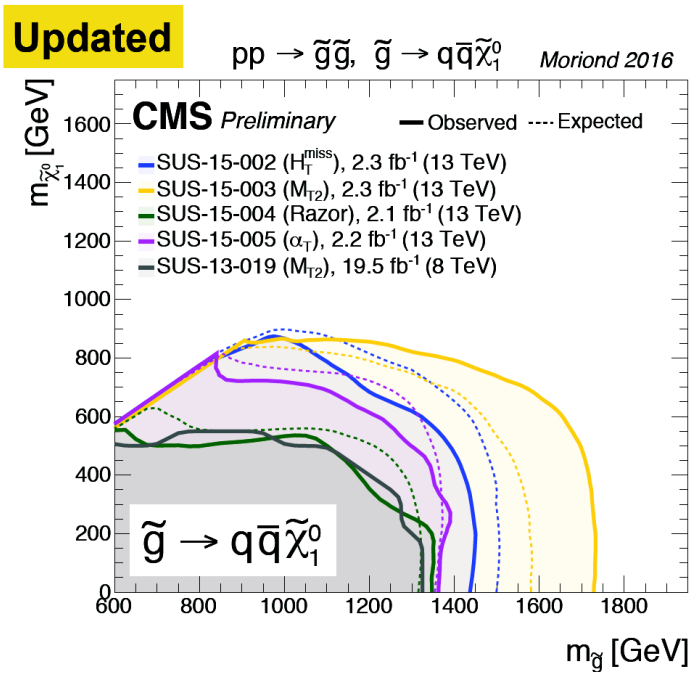
$$\mathrm{R}^2 \approx \frac{E_{\mathrm{T}}^{\mathrm{miss}} (p_{\mathrm{T}}^{\mathrm{J1}} + p_{\mathrm{T}}^{\mathrm{J2}} + E_{\mathrm{T}}^{\mathrm{miss}})}{2M_{\mathrm{R}}^2}$$

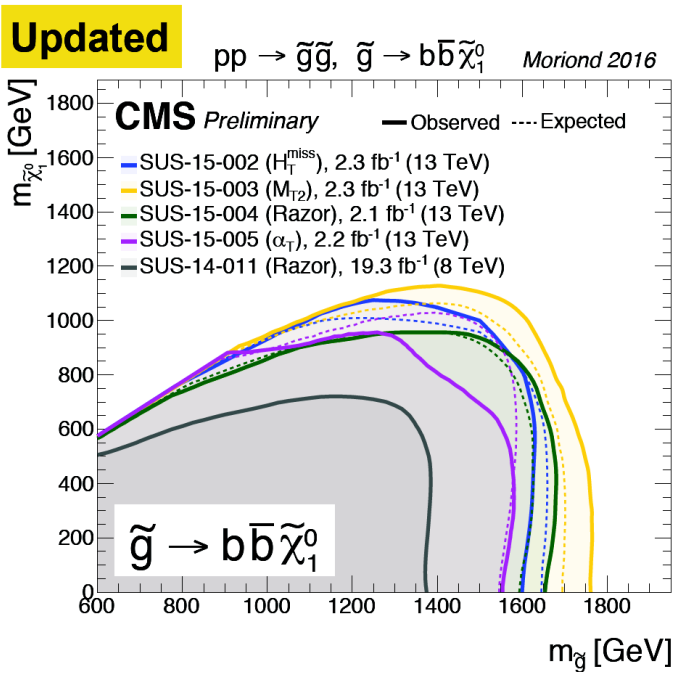
$$M_{\mathrm{R}}^2 = m_{\mathrm{J1,J2}} + (E_{\mathrm{T}}^{\mathrm{miss}})^2$$

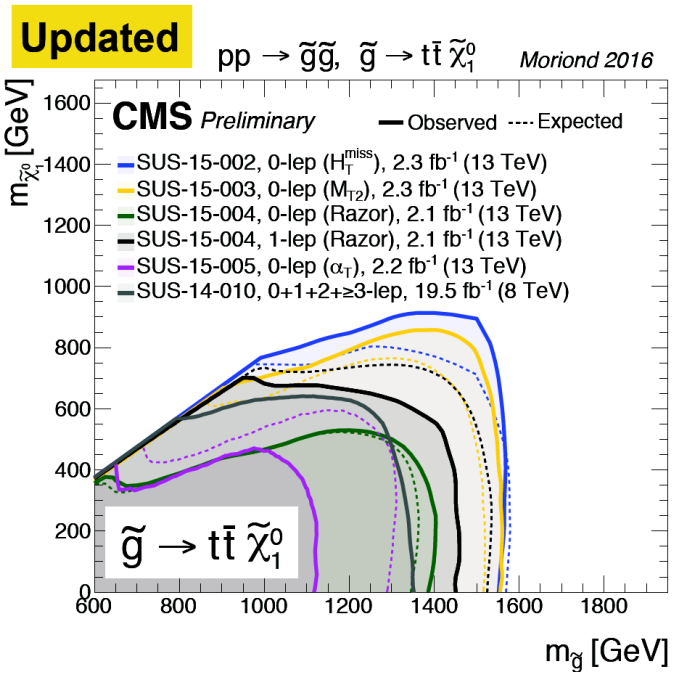




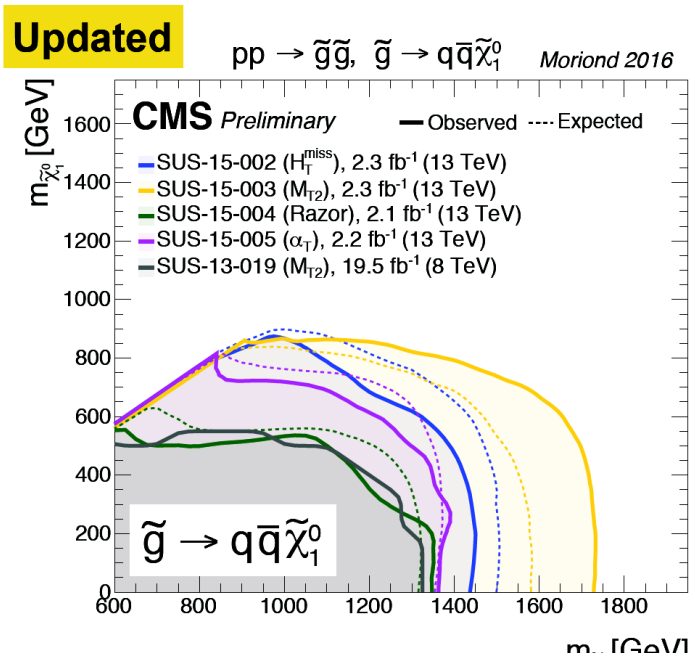
Gluino searches

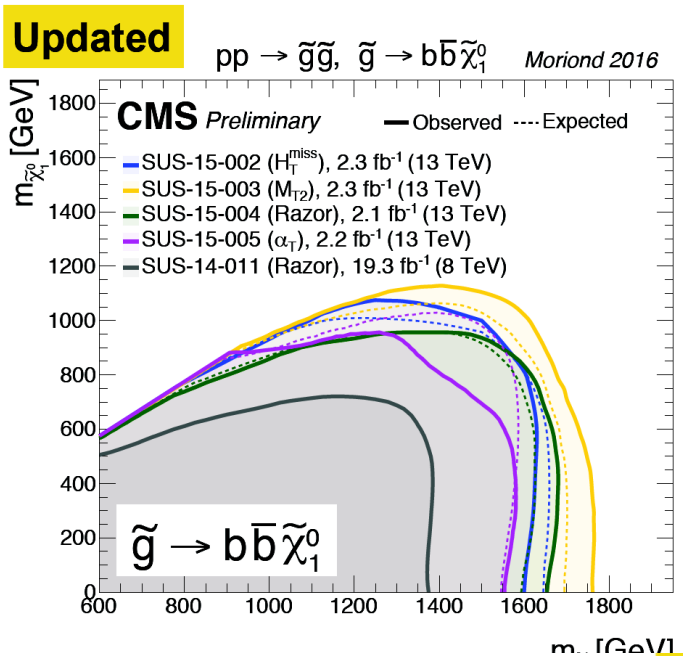


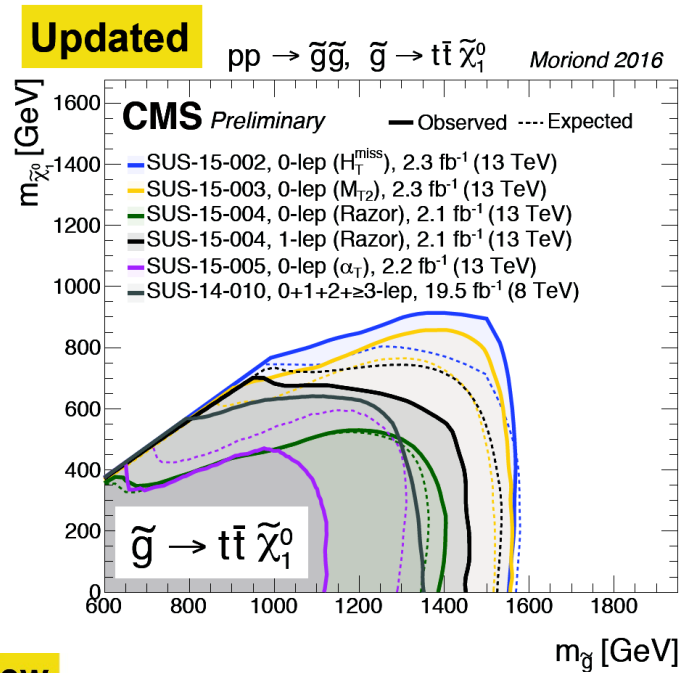




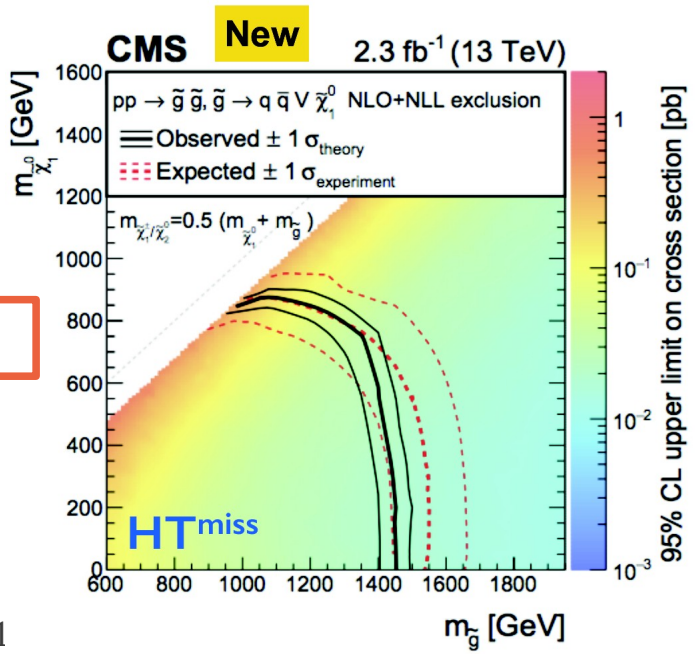
Gluino searches

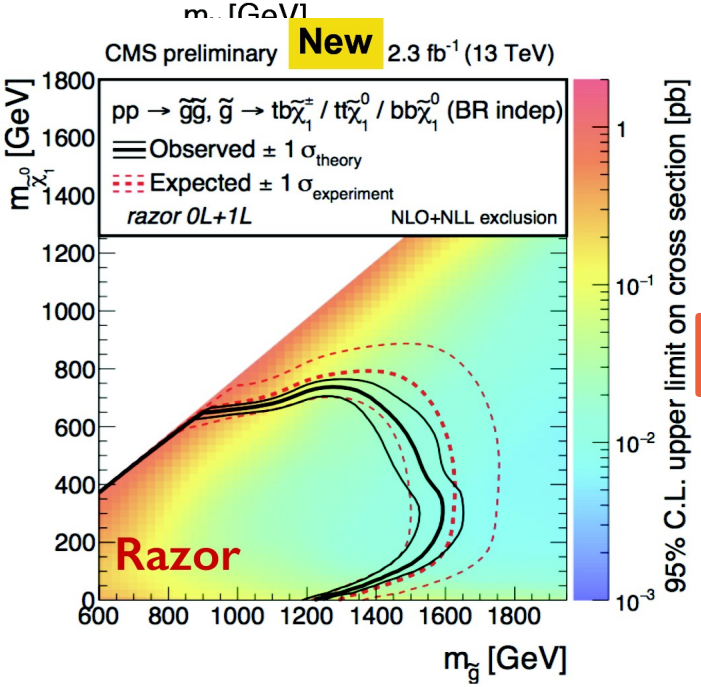






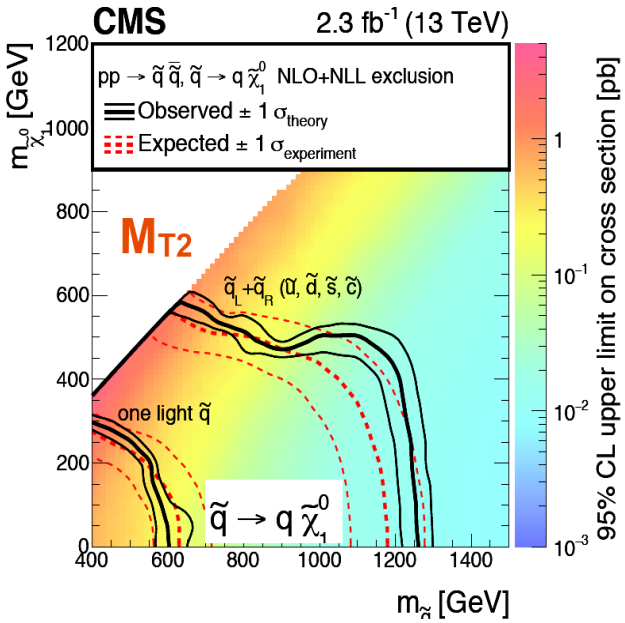
SUS-16-003

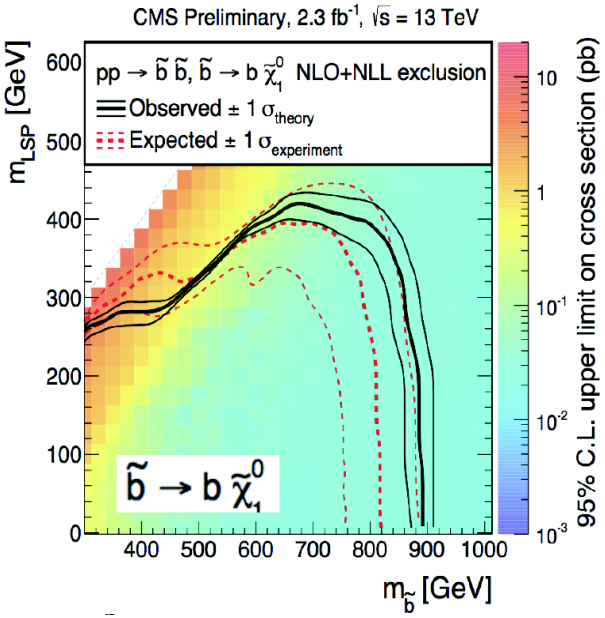


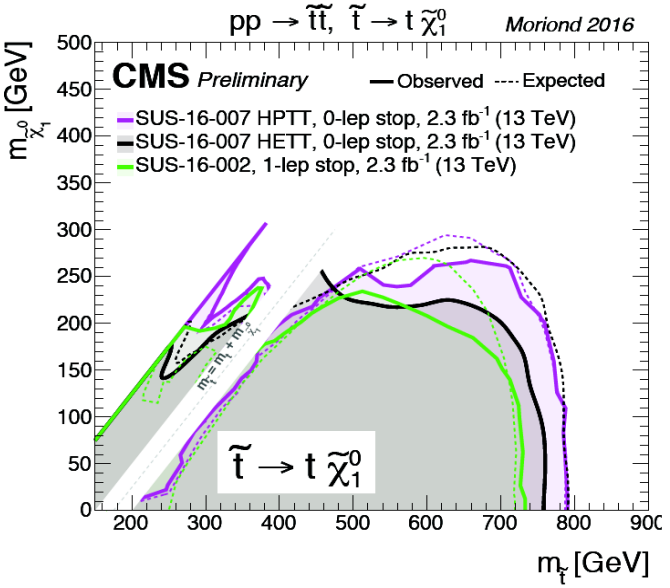


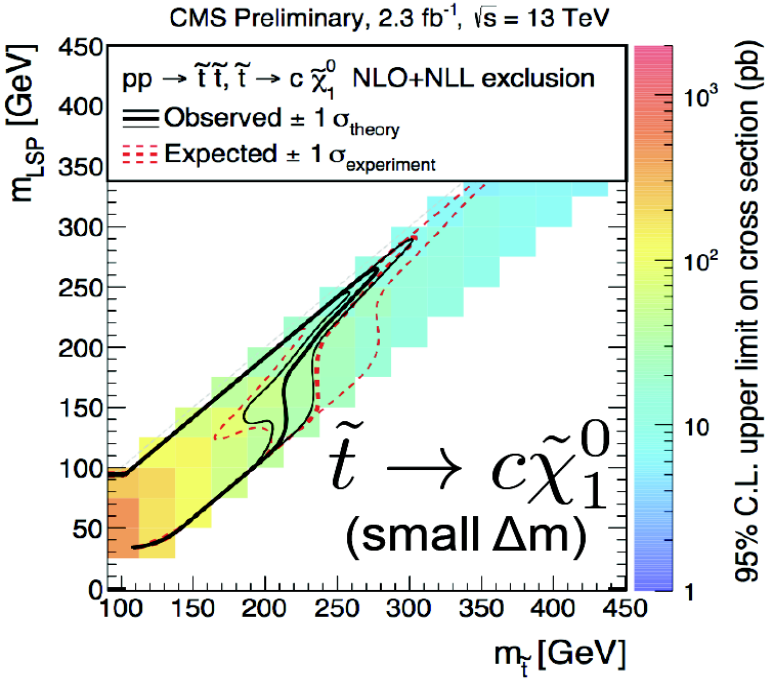
SUS-16-004

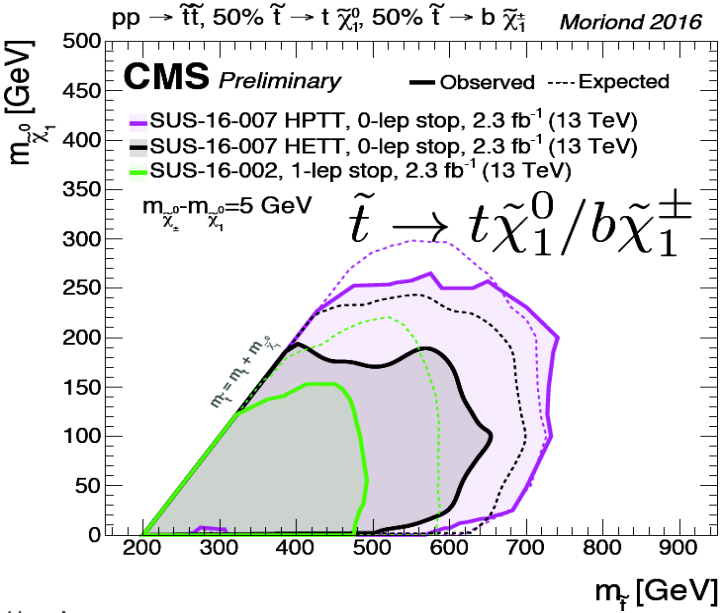
Stop Searches





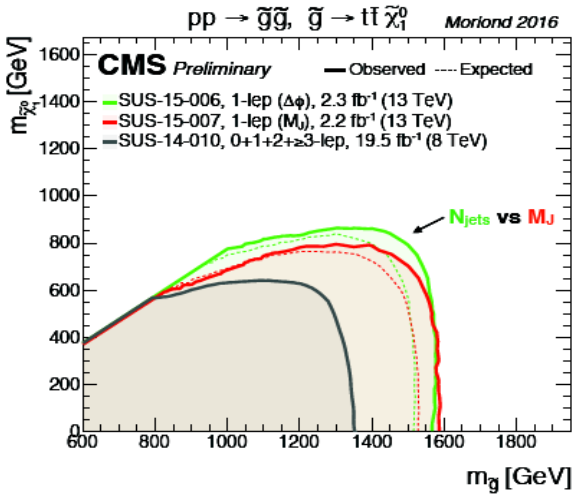


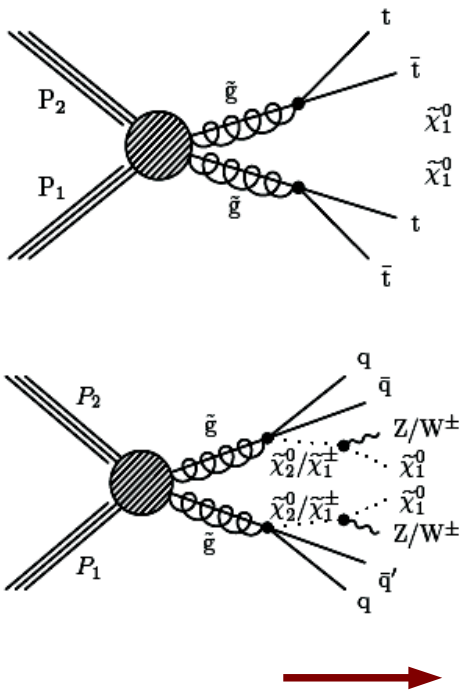


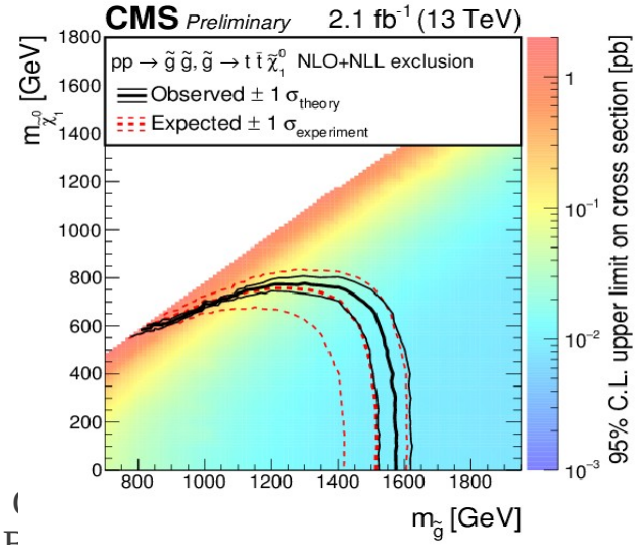


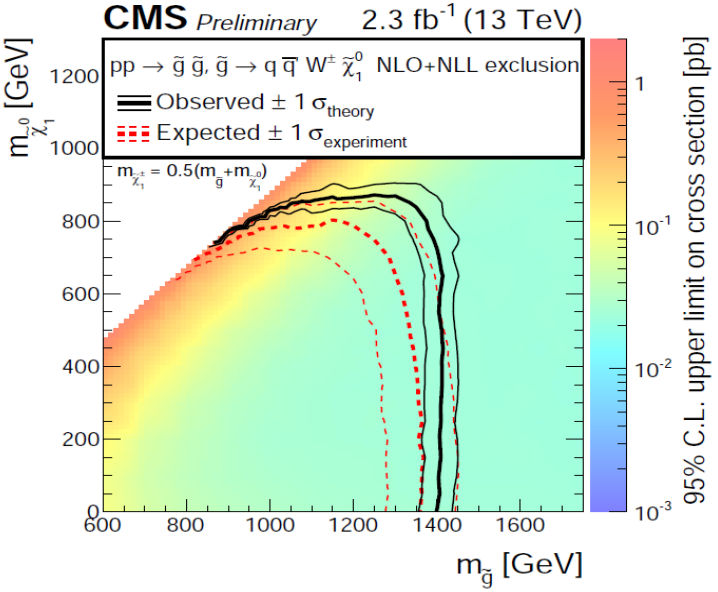
Single lepton gluino limits @ 13 TeV

PAS-SUS-15-007,
PAS-SUS-15-006







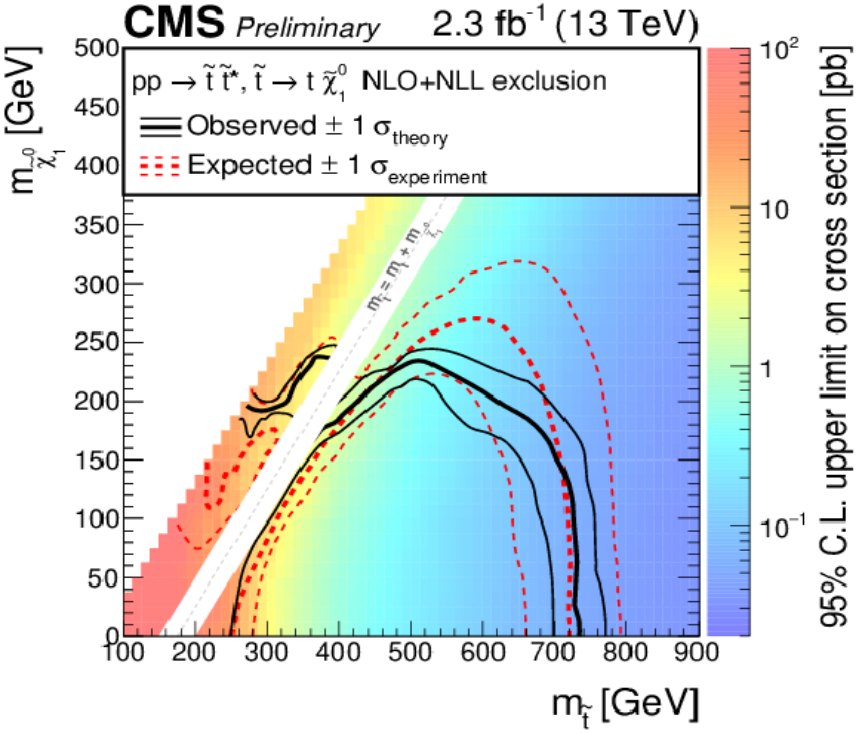


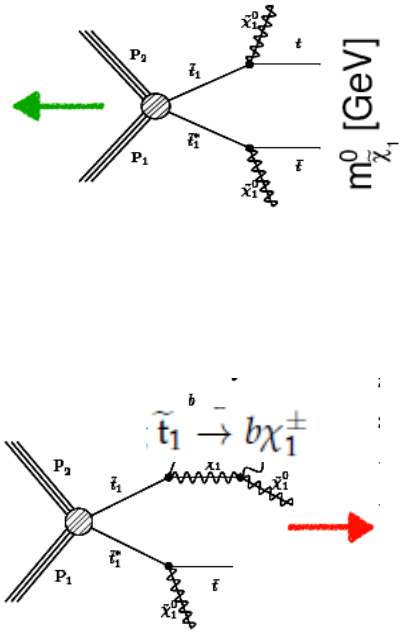
- T5q4WW model
- 0 b analysis

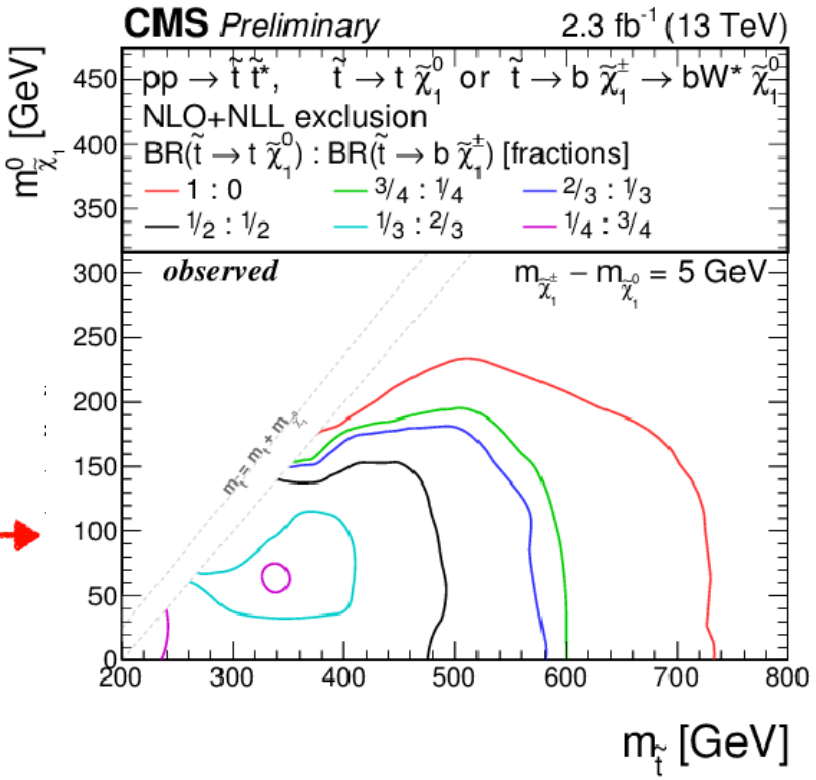
$$m_{\tilde{\chi}_1^{\pm}} = 0.5\left(m_{\tilde{g}} + m_{\tilde{\chi}_1^0}\right)$$

Single lepton stop search

PAS-SUS-16-002







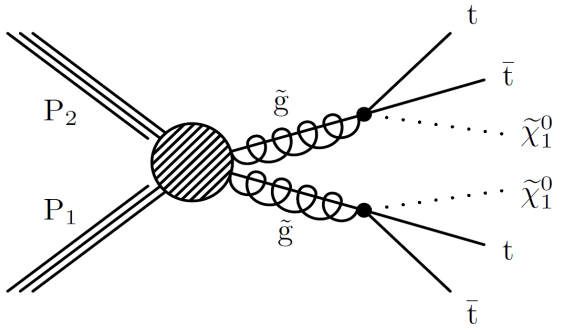
Limits on direct stop production with 100% B.R.

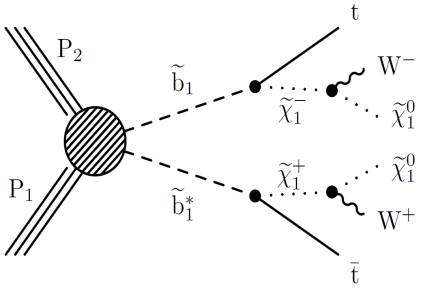
- Run I limit 650 GeV (790 GeV from most sensitive channel)

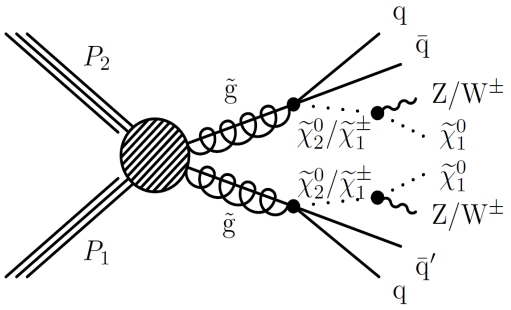
- Assume chargino nearly degenerate with LSP
- Limit worsens with increasing B.R. $\tilde{t}_1 \to b\chi_1^{\pm}$

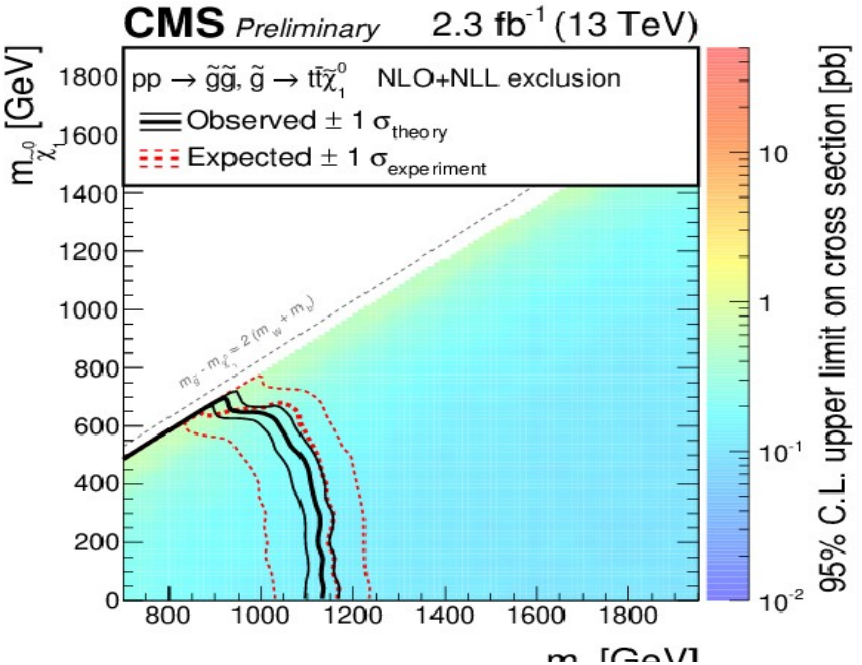
SUSY with Multileptons @ 13 TeV

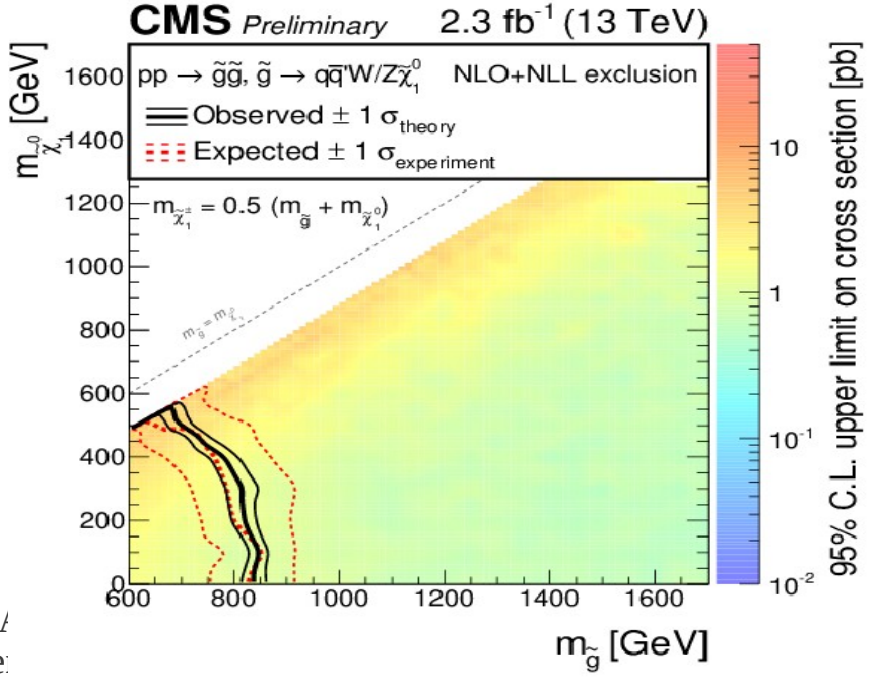
PAS-SUS-16-003

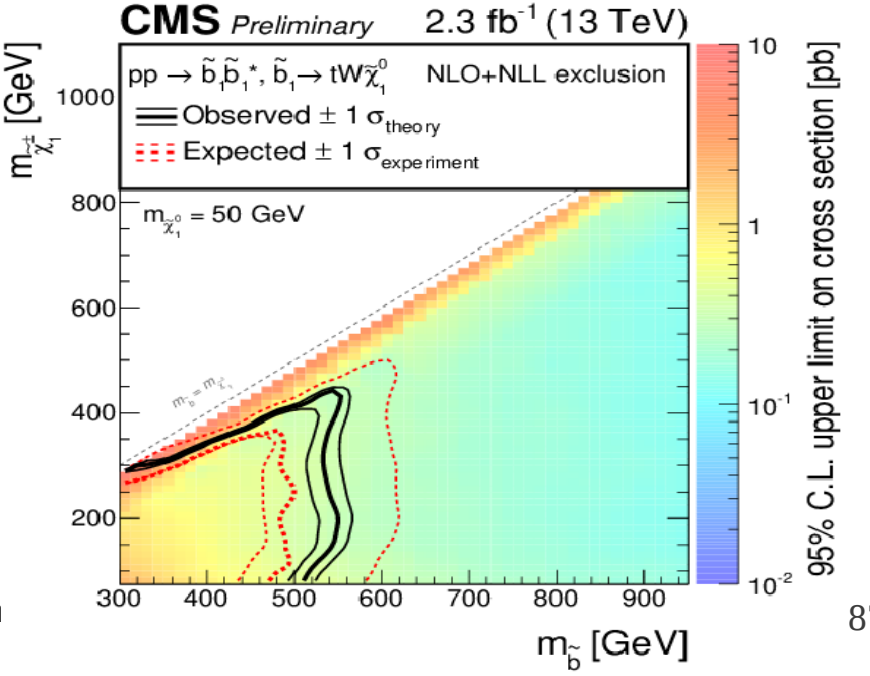








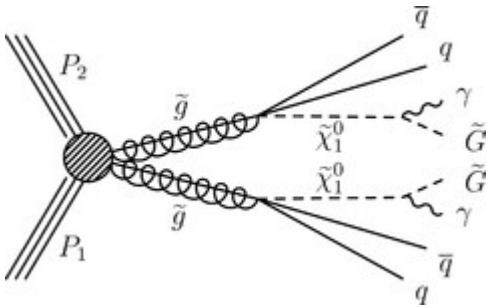


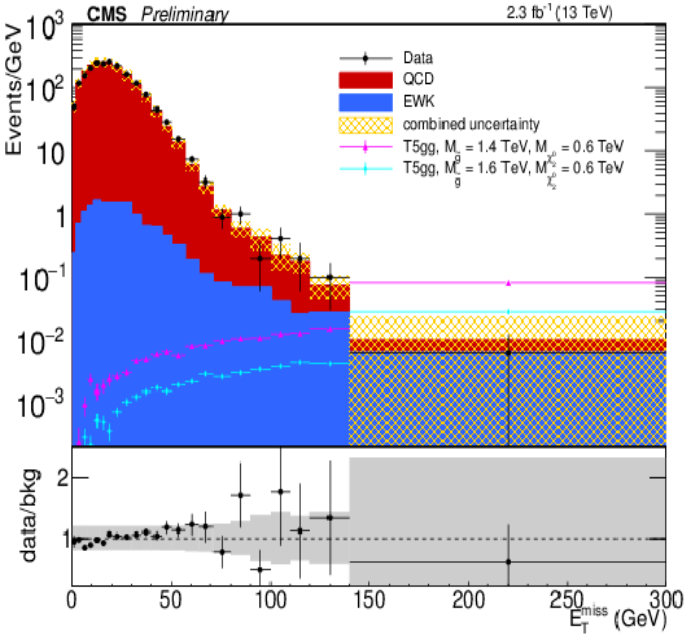


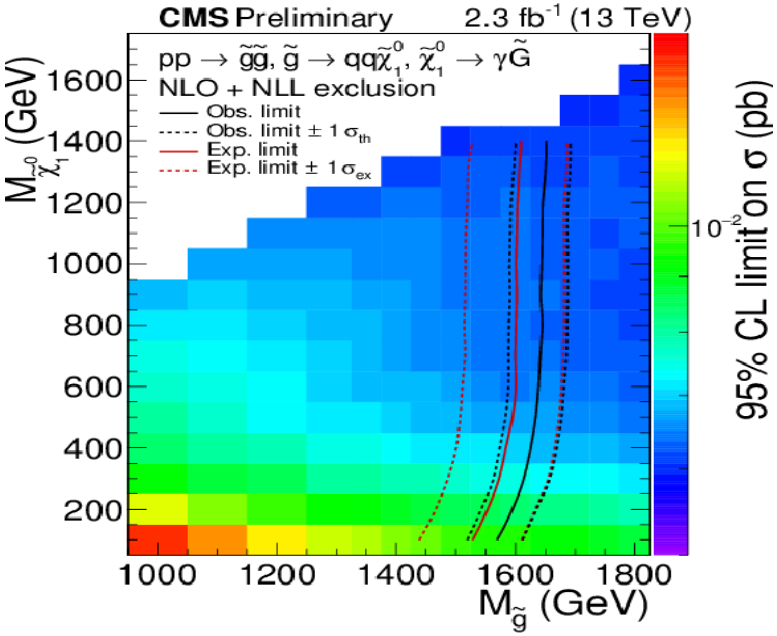
SUSY with photons @ 13 TeV

SUS-15-012

- At least two photons > 40 GeV
- MET > 100 GeV
- No constraints on number of jets
- General Gauge Mediated breaking with Gravitino LSP



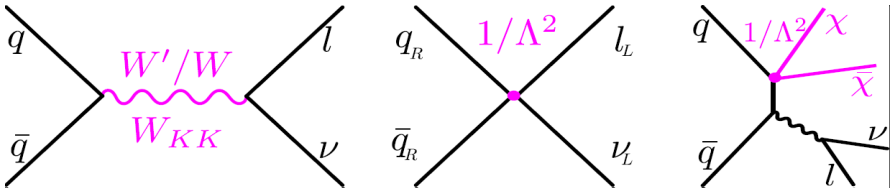


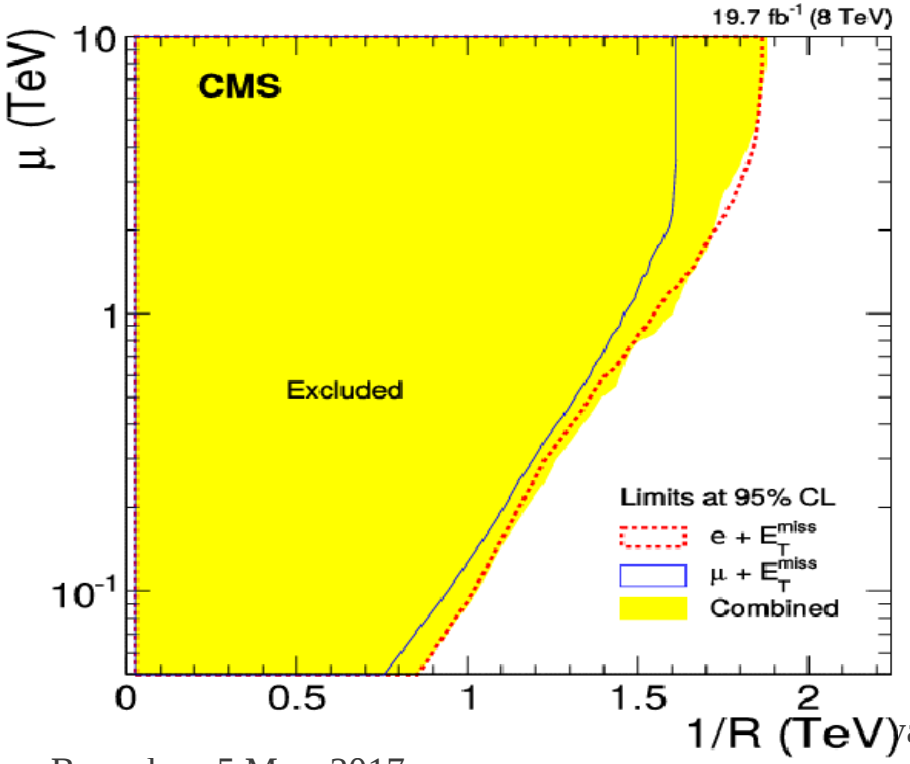


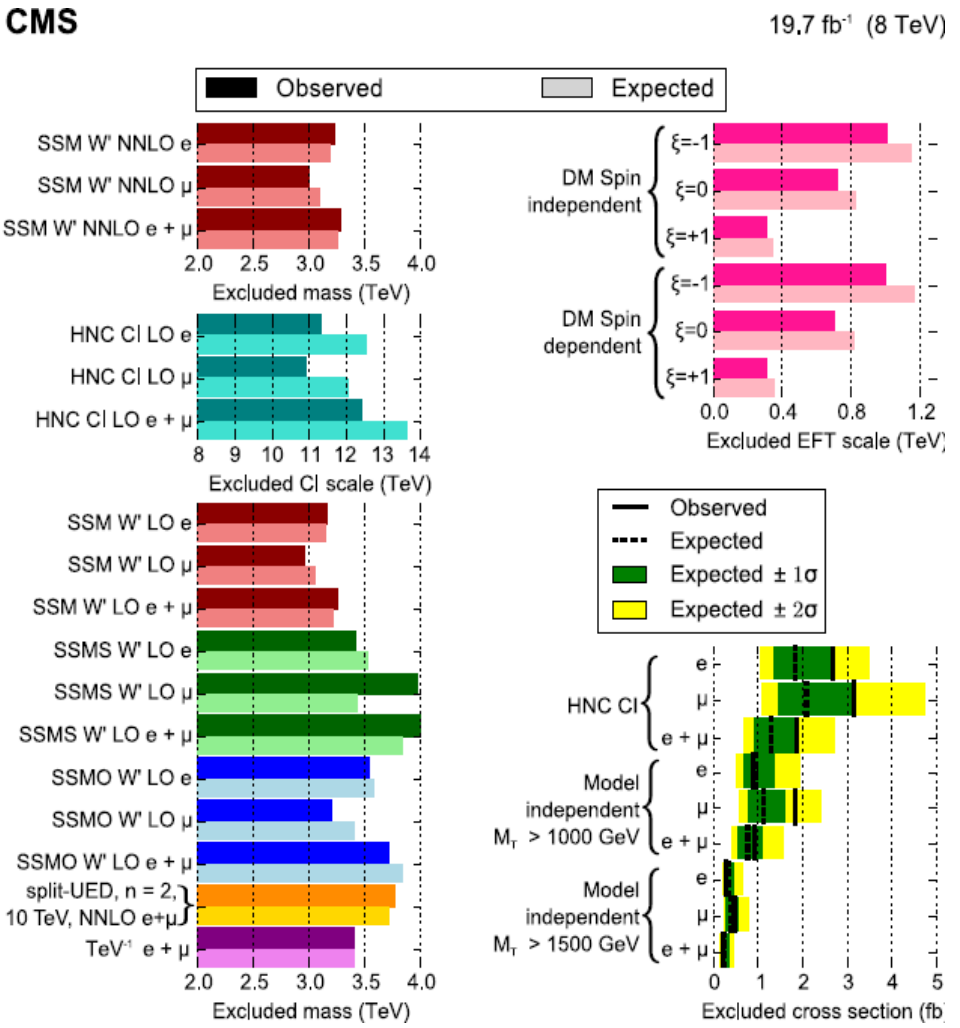
Search for physics beyond the standard model in final states with a lepton and missing transverse energy in proton-proton collisions at s√ = 8 TeV

CMS-EXO-12-060 ; CERN-PH-EP-2014-176

Phys. Rev. D 91 (2015) 092005



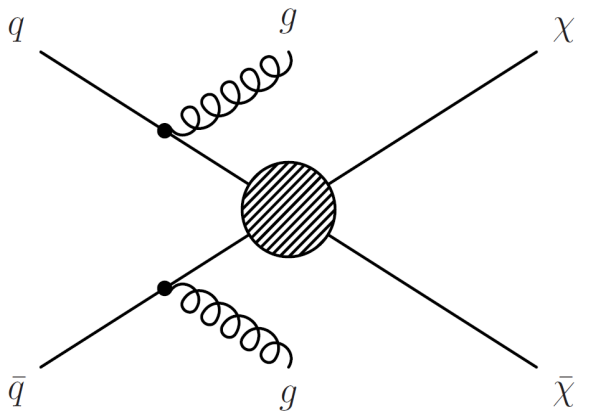


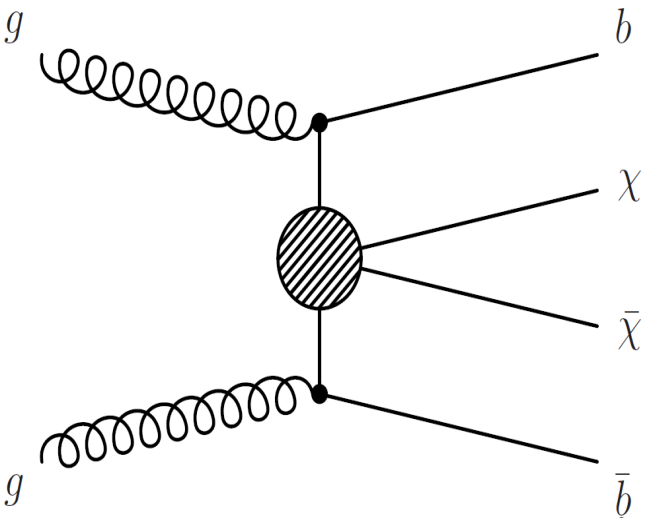


Dark matter razor analysis

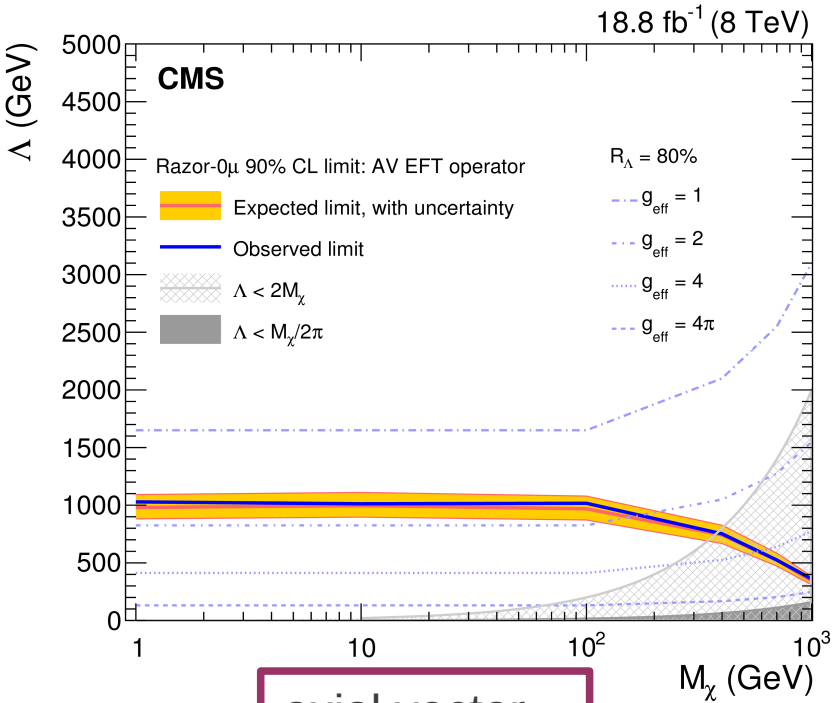
EXO-14-004

- Two Jets
- No leptons
- Razor variables used
- Separate analysis for b-jets

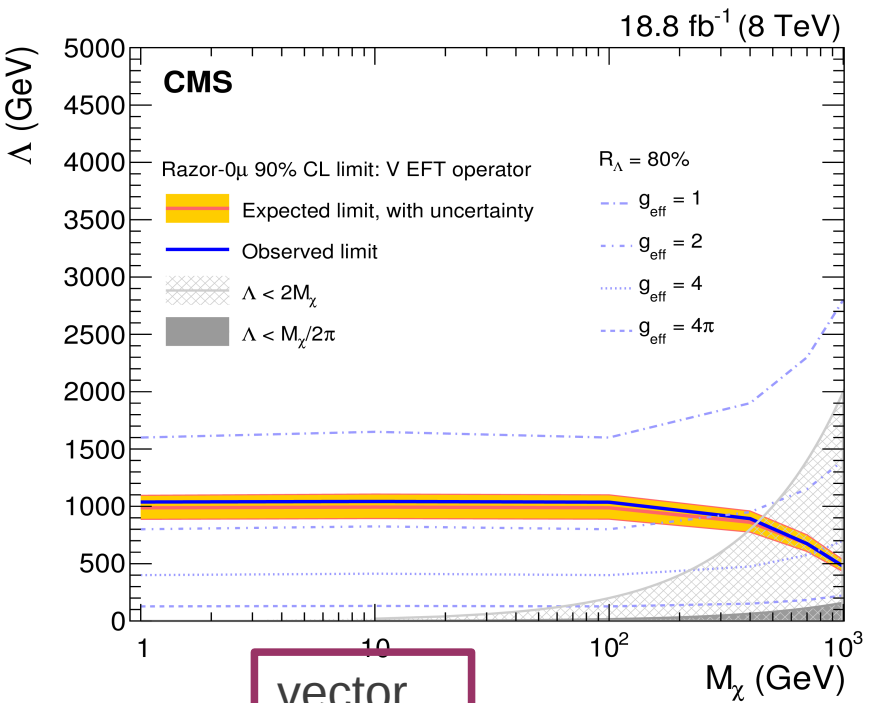




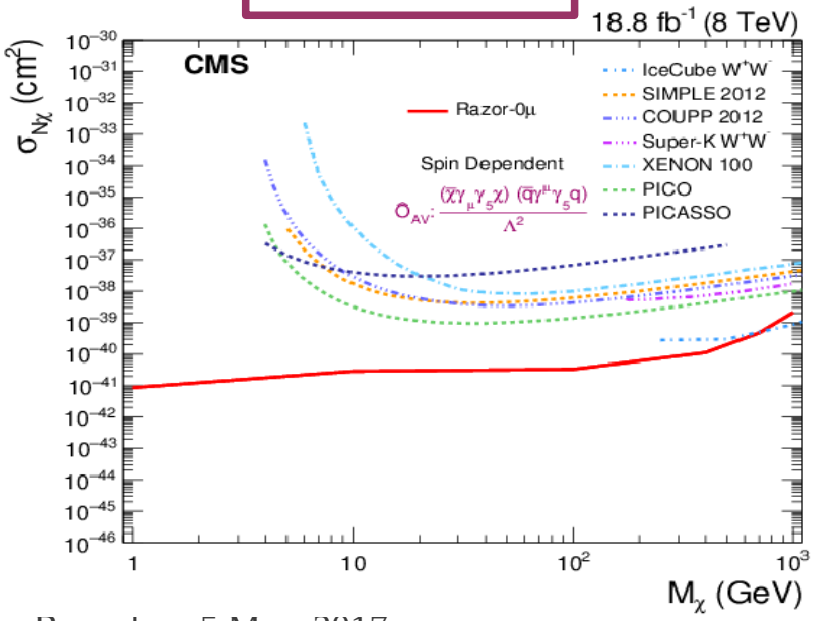
Dark matter razor analysis

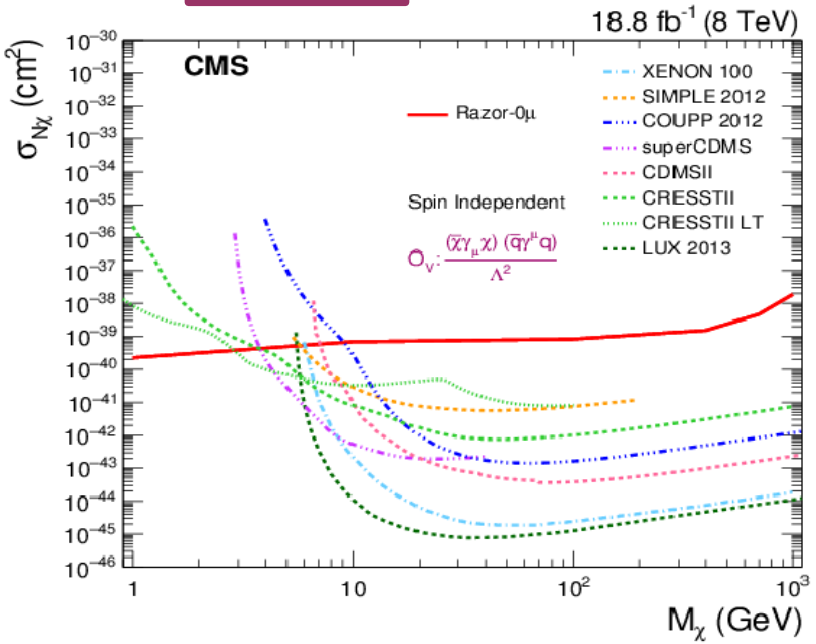


axial vector

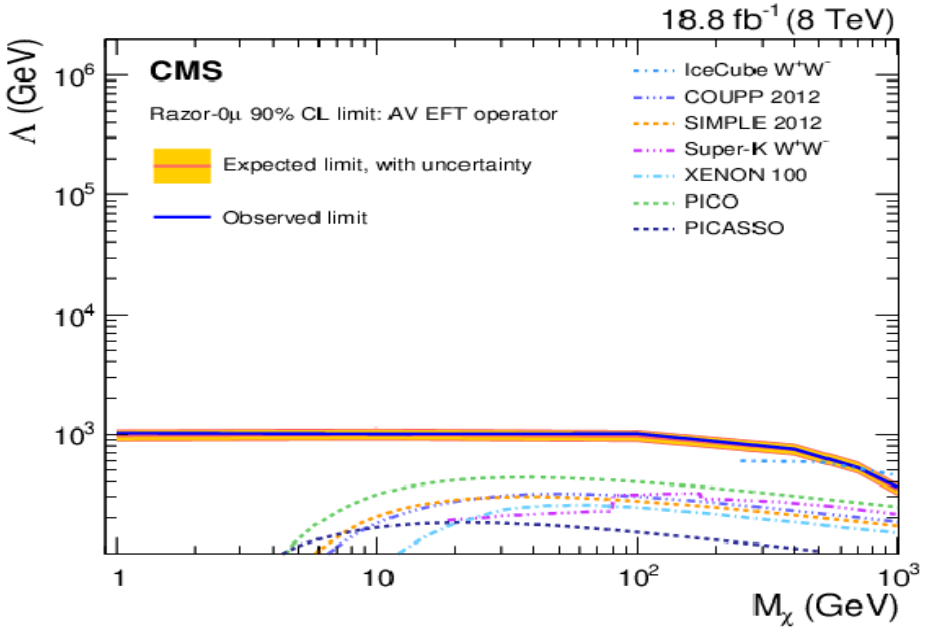


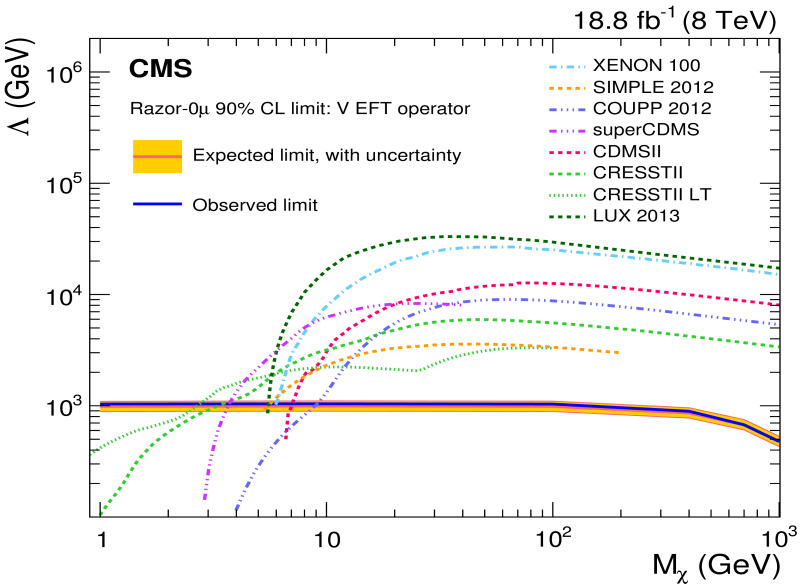
vector

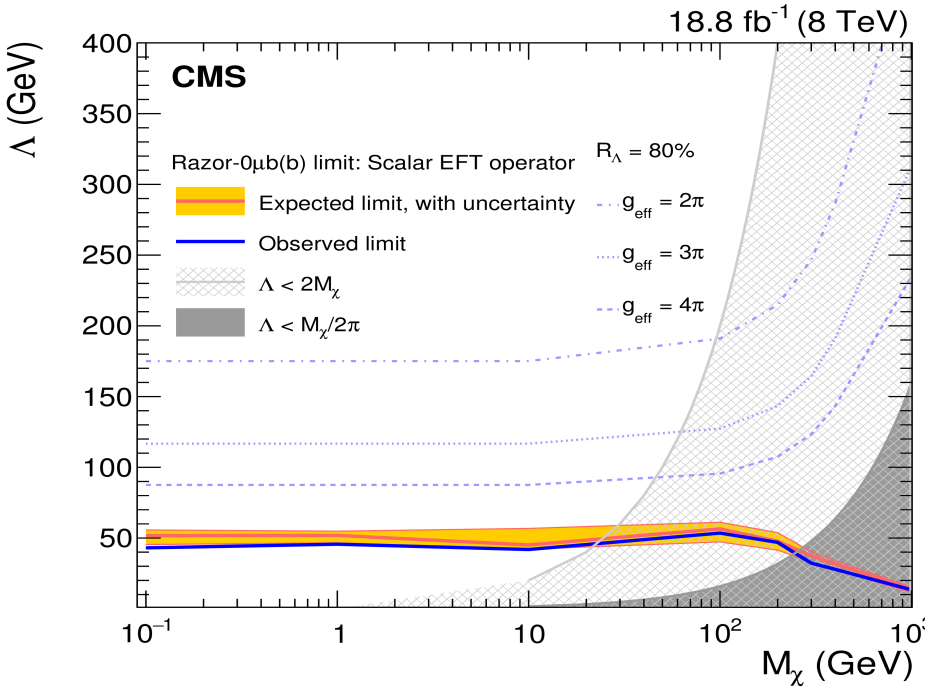


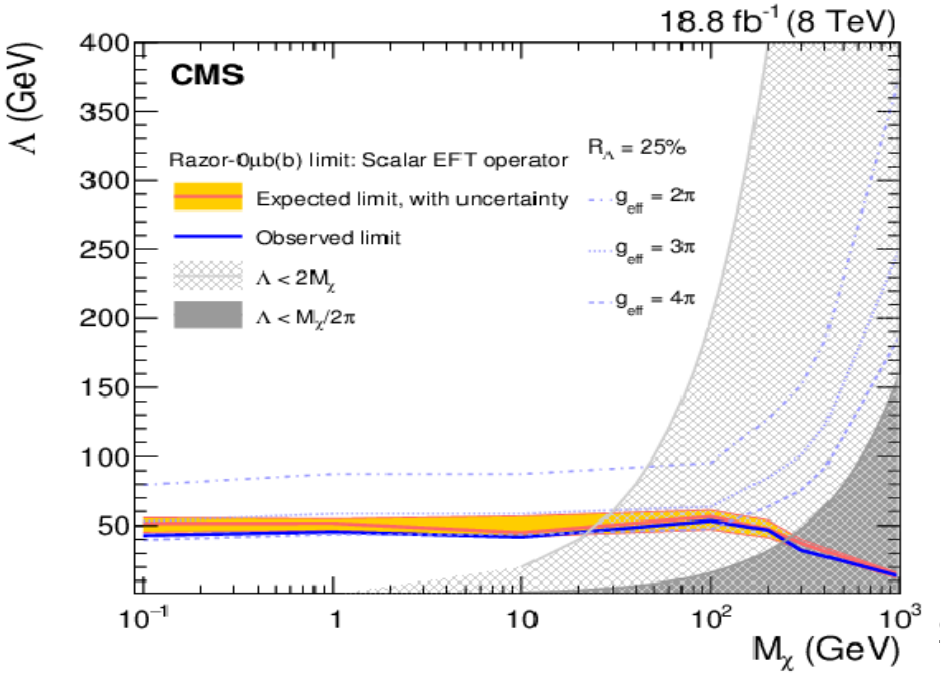


Dark Matter razor analysis



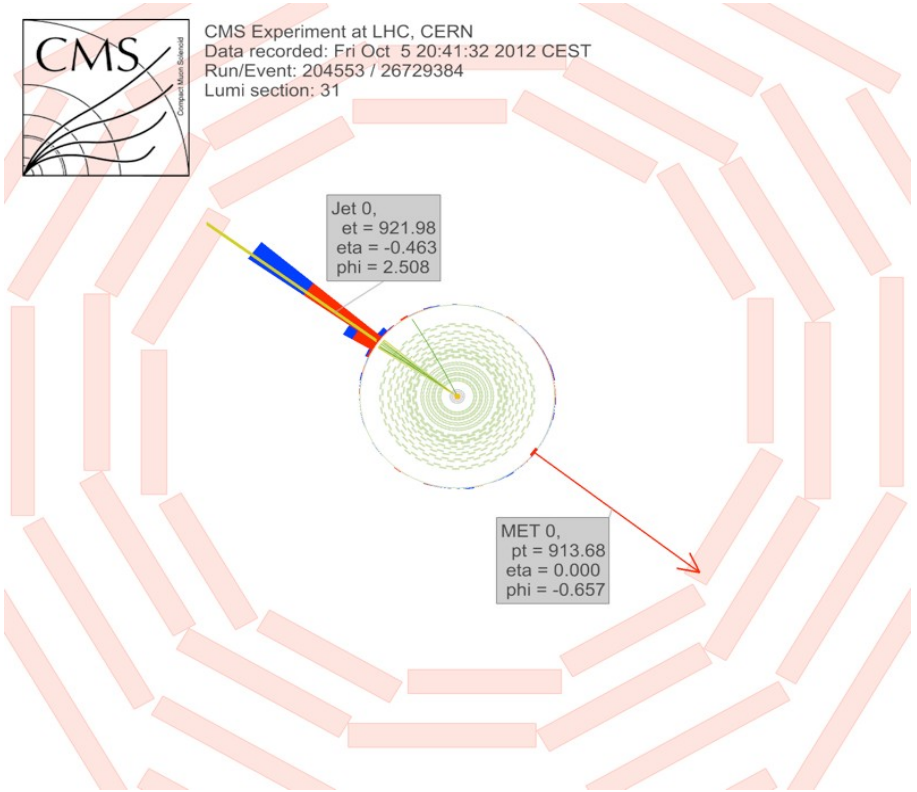


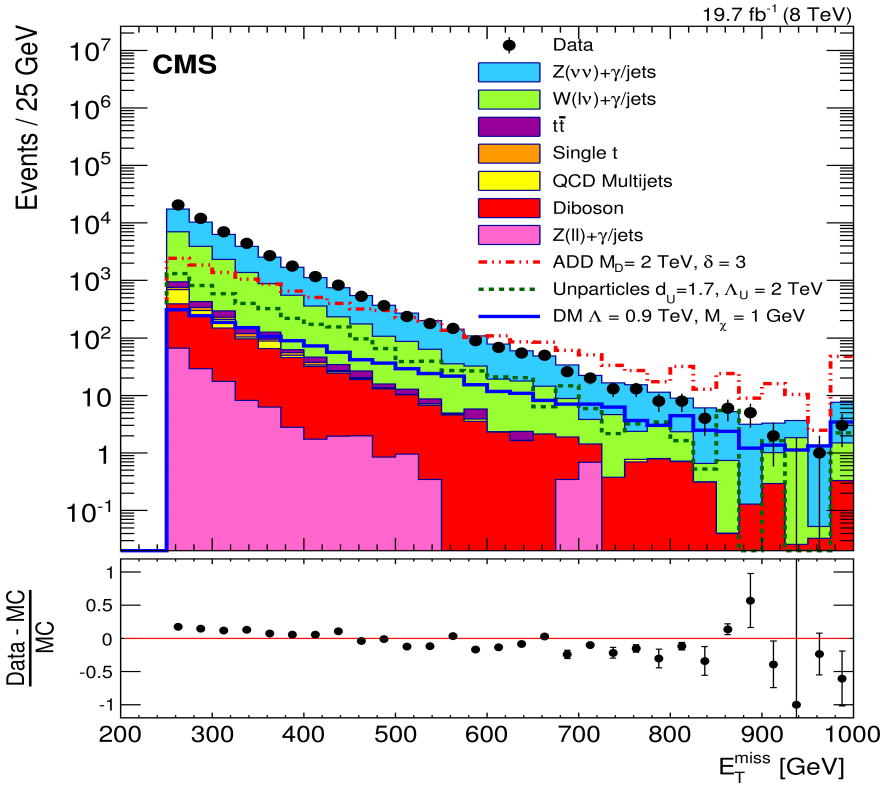


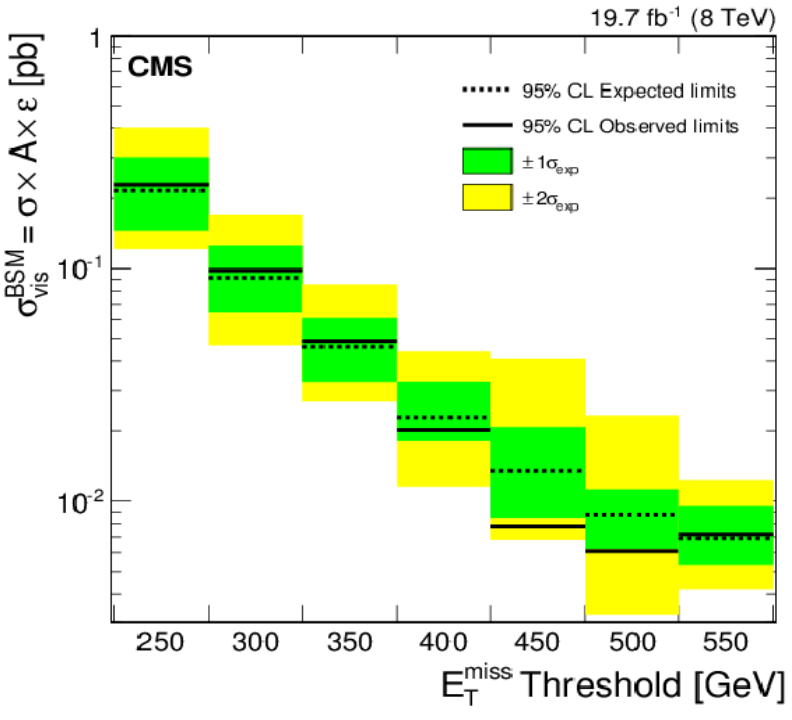


Bhat

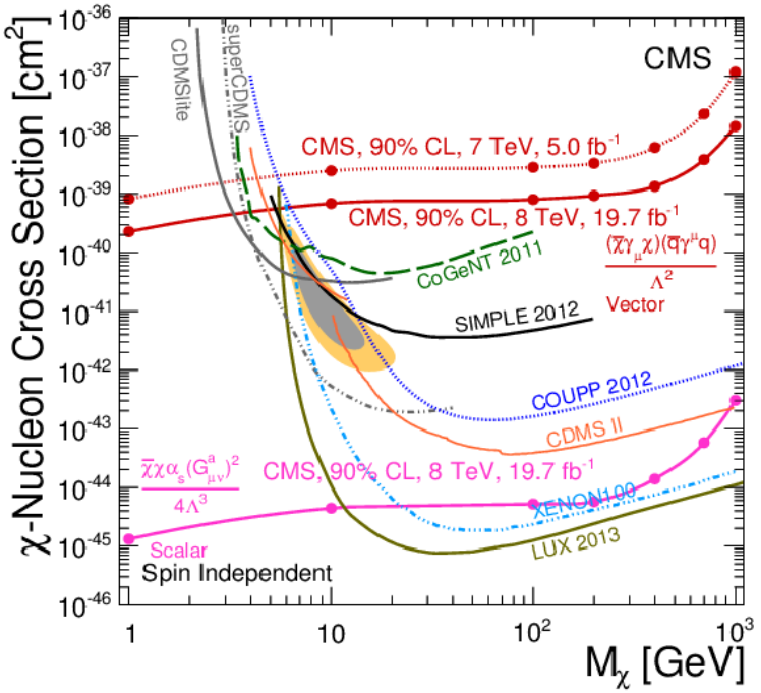
Monojet + MET @ 8 TeV

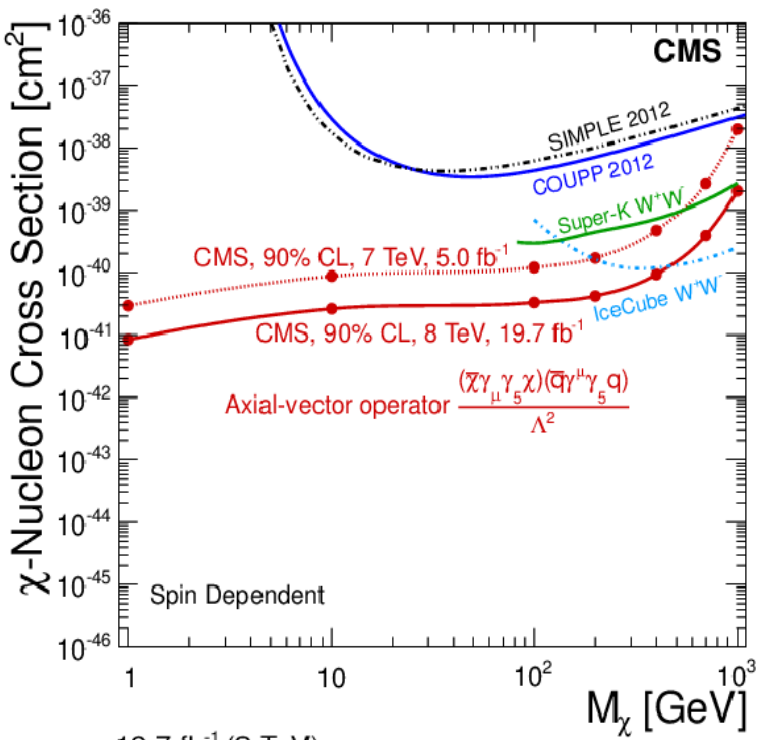


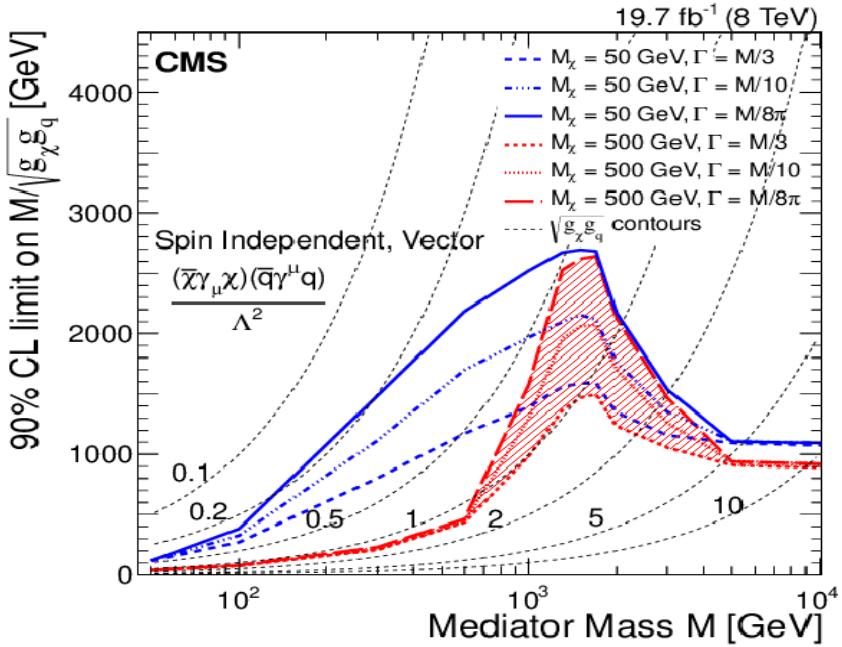




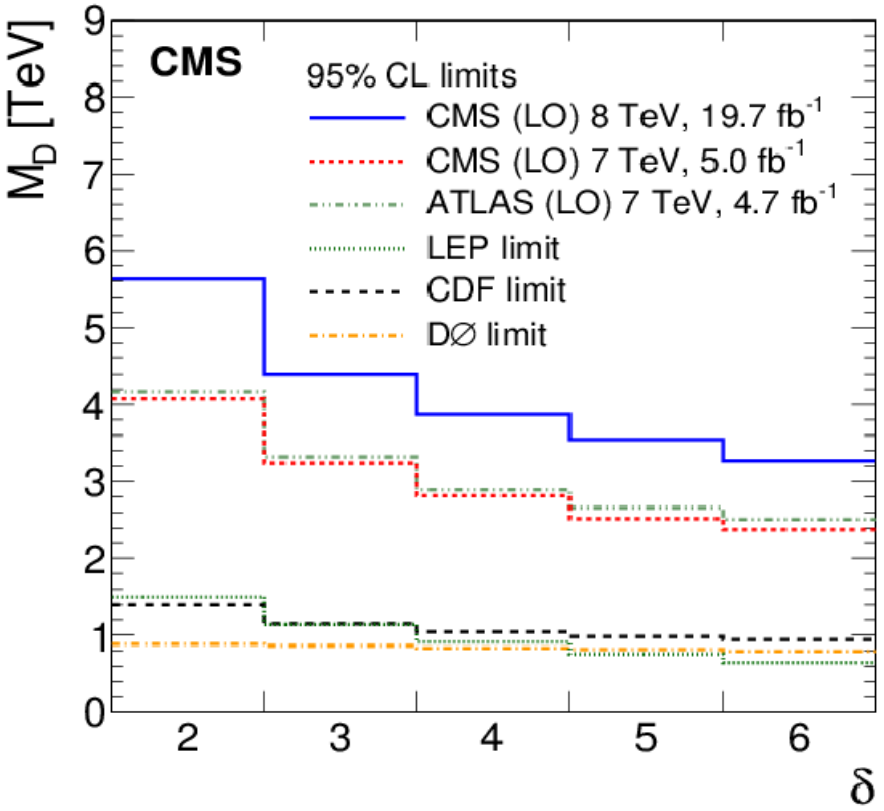
Monojet

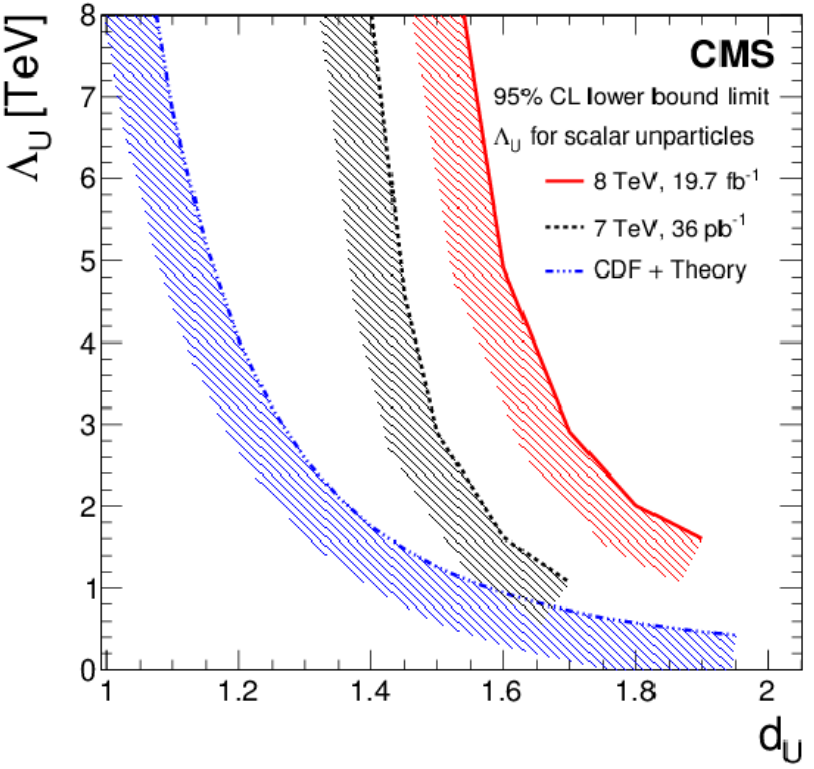

CMS
CDMSlite
superCDMS
CMS, 90% CL, 7 TeV, 5.0 fb^{-1}
CMS, 90% CL, 8 TeV, 19.7 fb^{-1}
$\frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$ Vector
CoGeNT 2011
SIMPLE 2012
COUPP 2012
CDMS II
$\frac{\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2}{4\Lambda^3}$
CMS, 90% CL, 8 TeV, 19.7 fb^{-1}
XENON100
LUX 2013
Scalar
Spin Independent
χ-Nucleon Cross Section [cm^2]
M_χ [GeV]


CMS
SIMPLE 2012
COUPP 2012
Super-K W^+W^-
CMS, 90% CL, 7 TeV, 5.0 fb^{-1}
IceCube W^+W^-
CMS, 90% CL, 8 TeV, 19.7 fb^{-1}
Axial-vector operator $\frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5 q)}{\Lambda^2}$
Spin Dependent
χ-Nucleon Cross Section [cm^2]
M_χ [GeV]


19.7 fb^{-1} (8 TeV)
CMS
M_χ = 50 GeV, Γ = M/3
M_χ = 50 GeV, Γ = M/10
M_χ = 50 GeV, Γ = M/8π
M_χ = 500 GeV, Γ = M/3
M_χ = 500 GeV, Γ = M/10
M_χ = 500 GeV, Γ = M/8π
$\sqrt{g_\chi g_q}$ contours
Spin Independent, Vector
$\frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$
0.1
0.2
0.5
1
2
5
10
90% CL limit on $M/\sqrt{g_\chi g_q}$ [GeV]
Mediator Mass M [GeV]

Monojet extra dim, unparticle

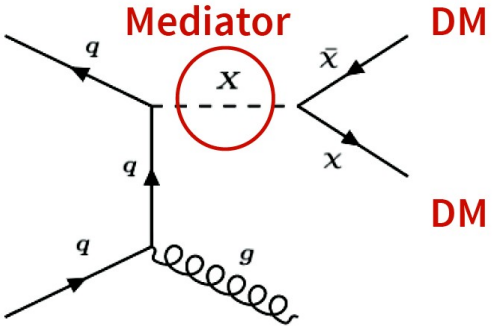


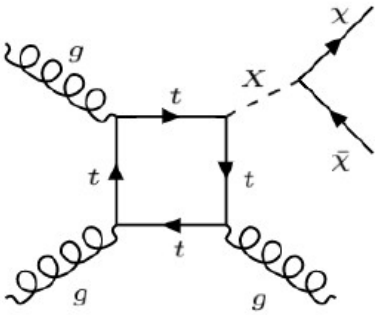


Monojet @13 TeV

EXO-15-003

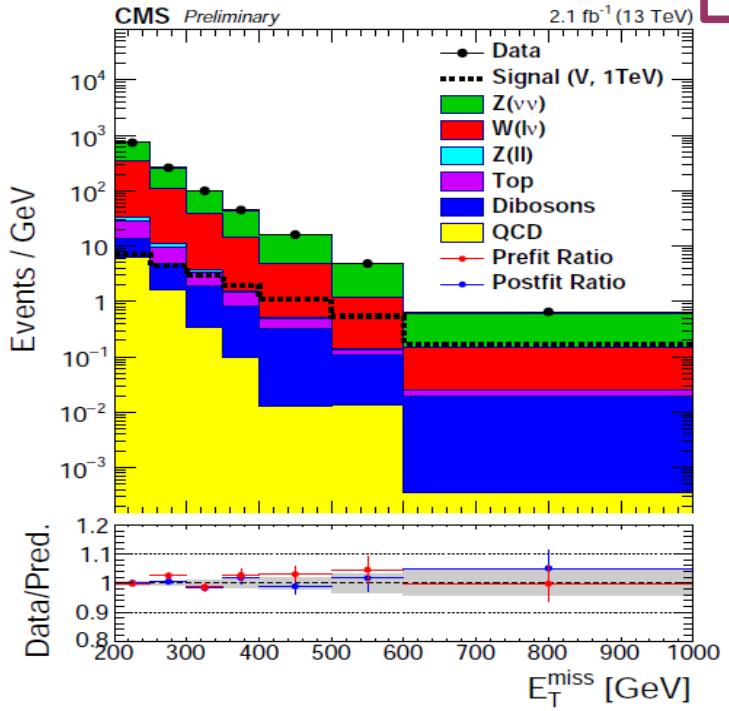
- Central high pT jet + large MET
- Lepton, b-jet veto
- Large azimuthal opening between jet-MET

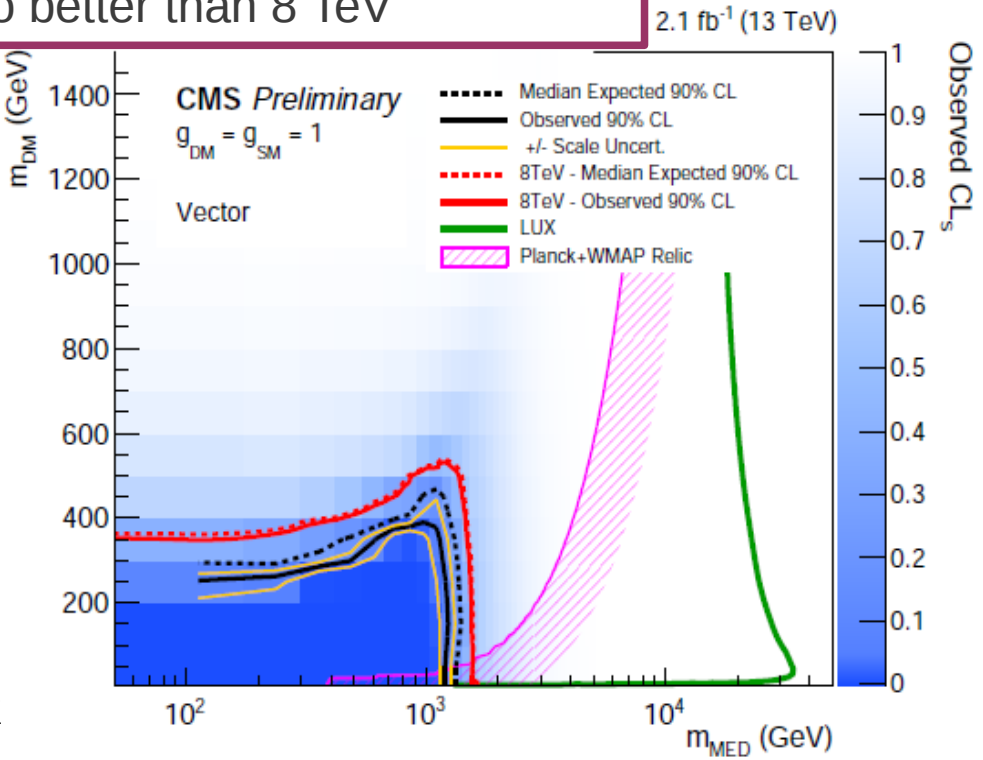




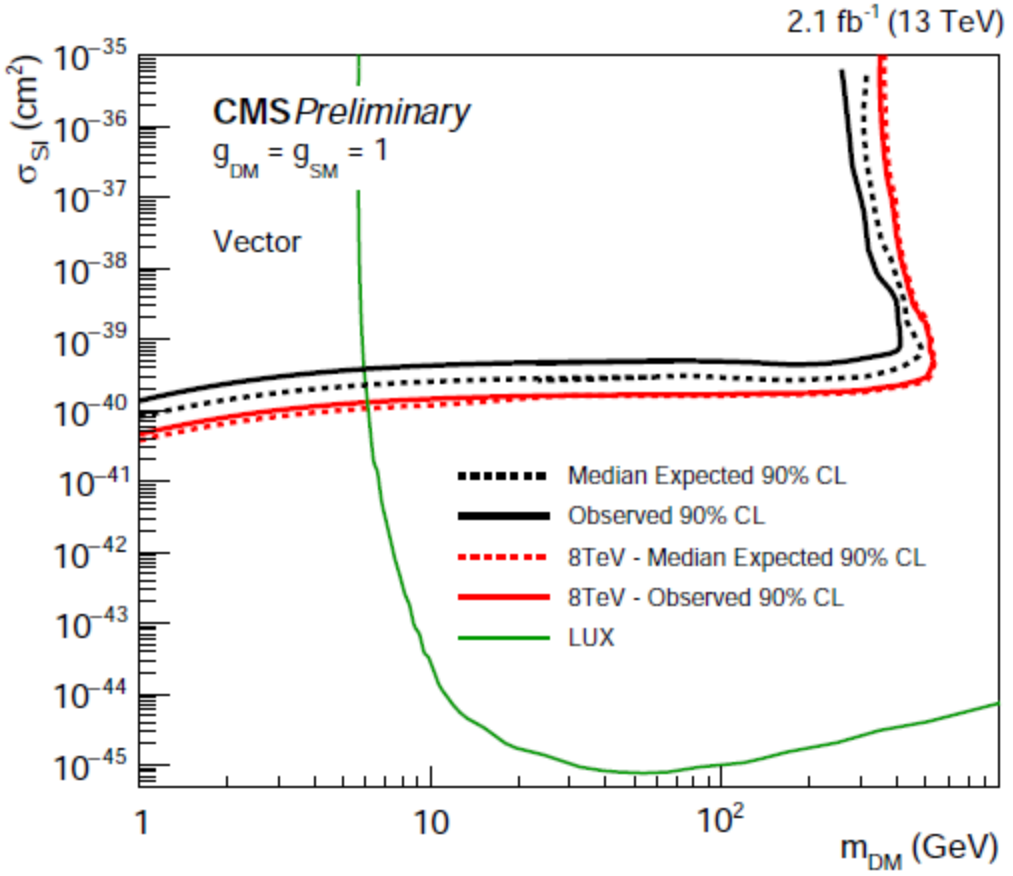
90% upper limit on signal strength

Yet to do better than 8 TeV



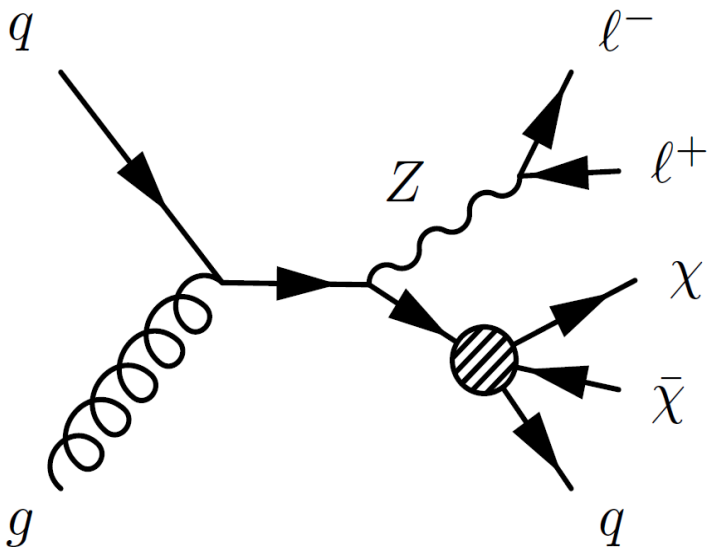


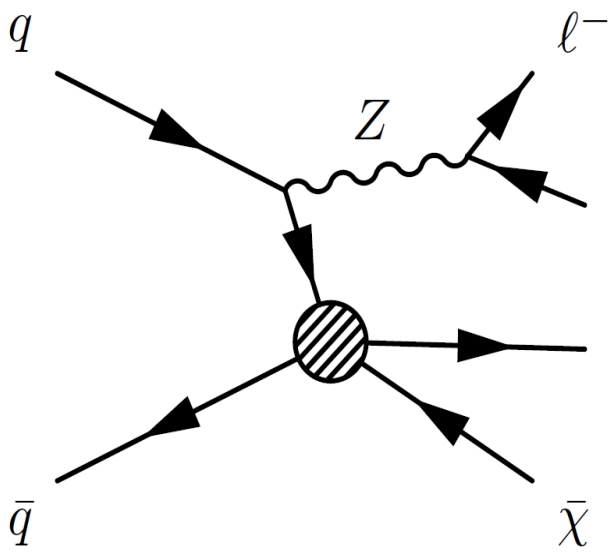
Monojet @13 TeV

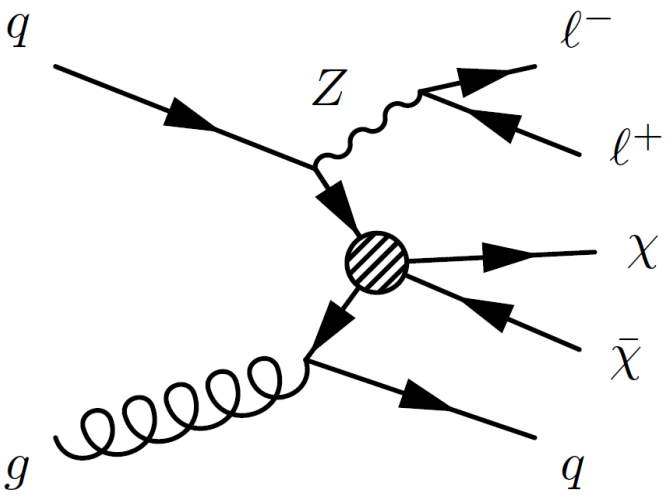


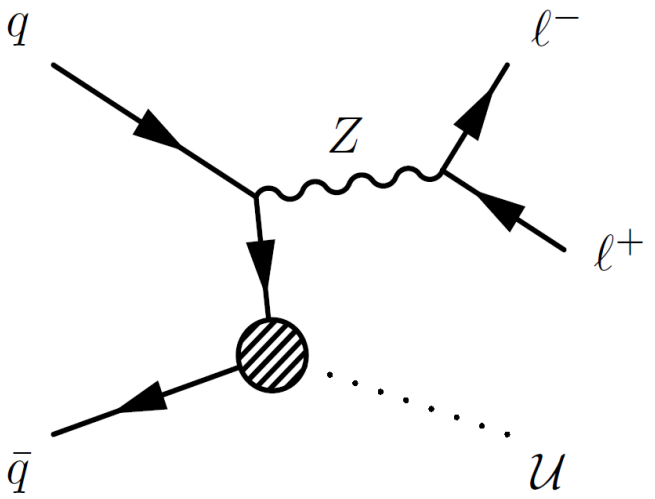
Couplings taken to be unity

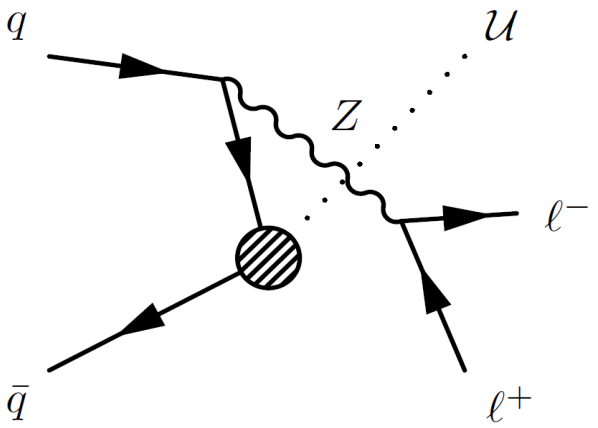
Mono Z @ 8 TeV


q
ℓ^-
Z
ℓ^+
χ
$\bar{\chi}$
g
q

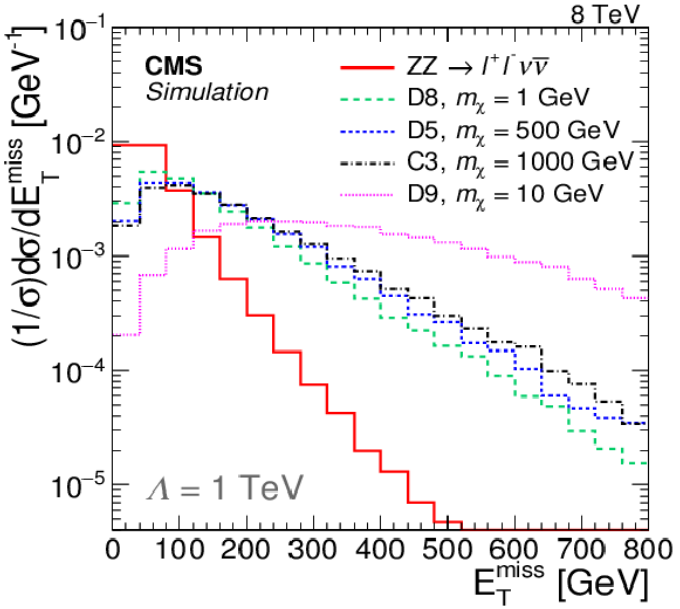

q
ℓ^-
Z
q
$\bar{q}$
$\bar{\chi}$

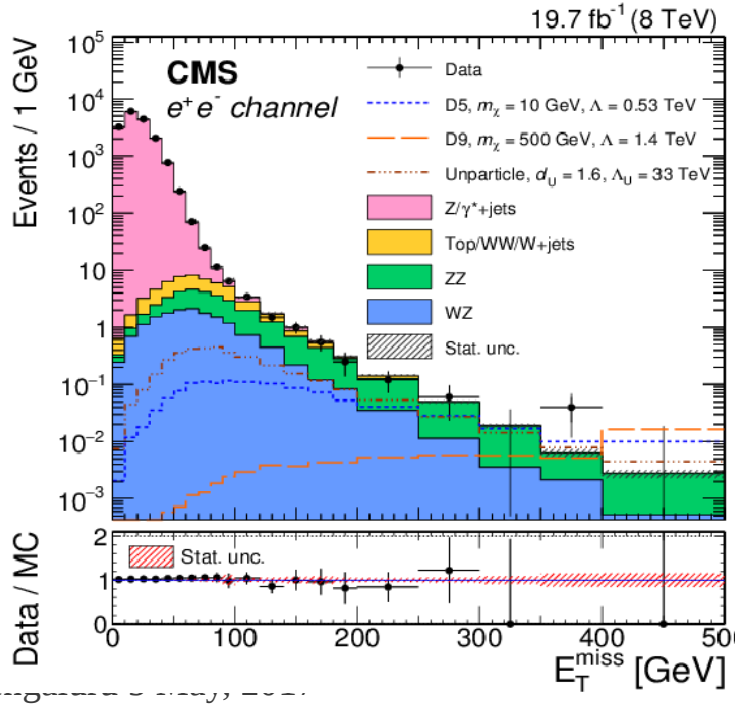

ℓ^-
Z
ℓ^+
χ
$\bar{\chi}$
g
q

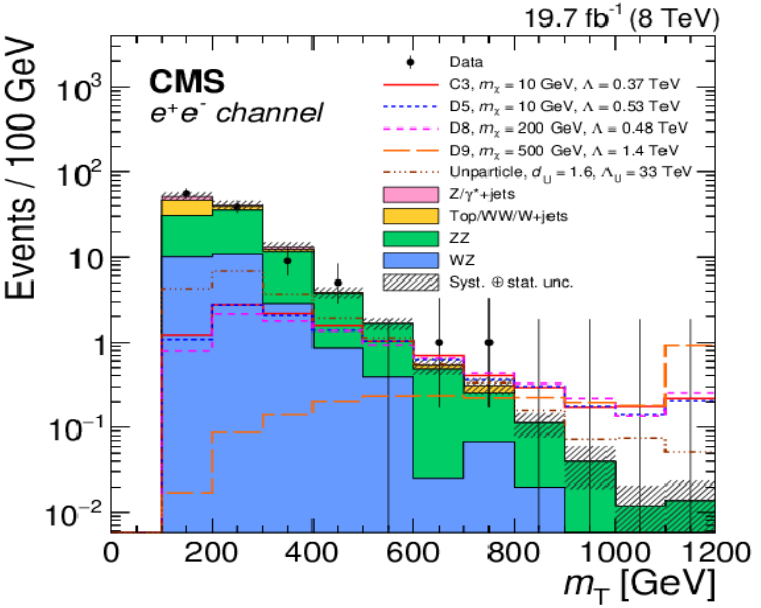

q
ℓ^-
Z
ℓ^+
$\bar{q}$
$\mathcal{U}$


q
$\mathcal{U}$
Z
ℓ^-
$\bar{q}$
ℓ^+

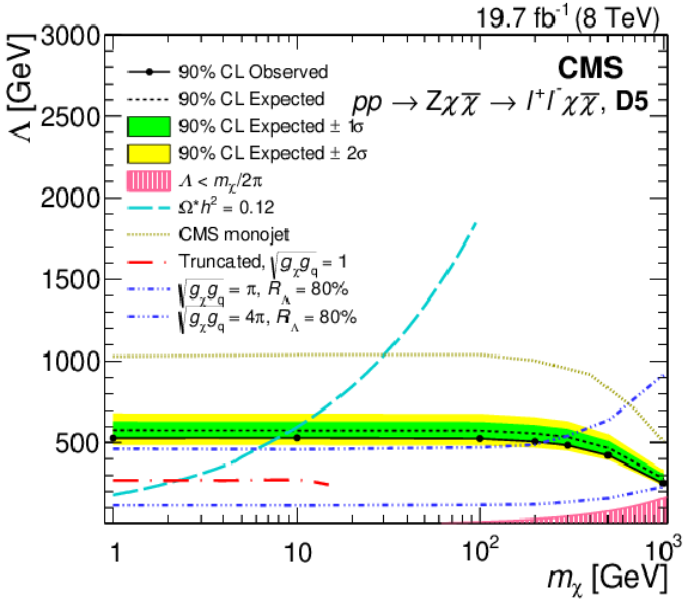
Mono-Z @ 8 TeV

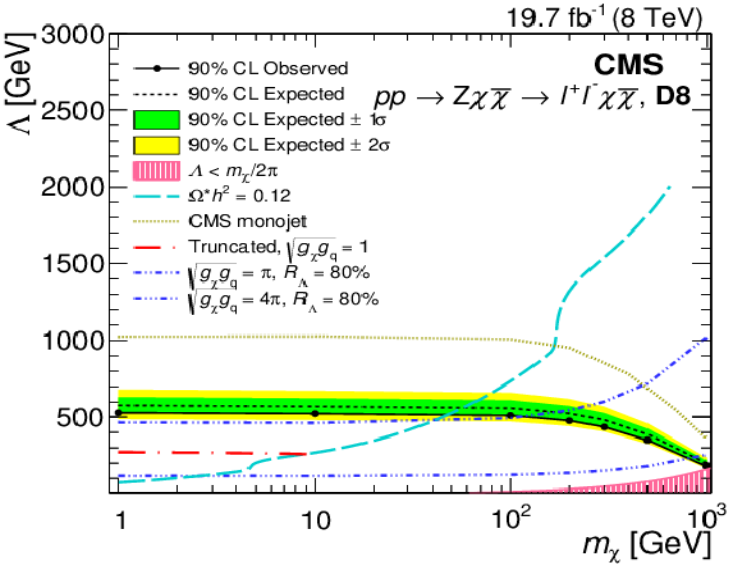

8 TeV
CMS
Simulation
$ZZ \to l^+l^-\nu\bar{\nu}$
D8, m_χ = 1 GeV
D5, m_χ = 500 GeV
C3, m_χ = 1000 GeV
D9, m_χ = 10 GeV
Λ = 1 TeV
$(1/\sigma)d\sigma/dE_T^{miss}$ [GeV^{-1}]
E_T^{miss} [GeV]

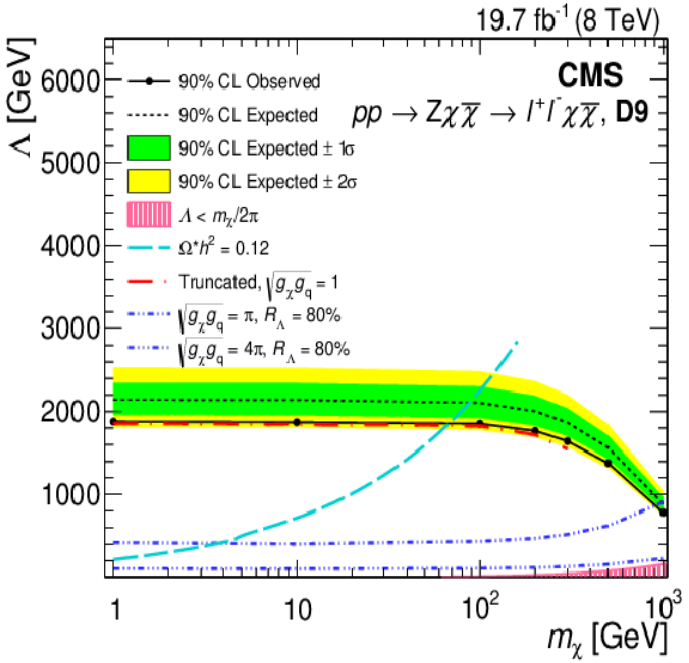

19.7 fb^{-1} (8 TeV)
CMS
e^+e^- channel
Data
D5, m_χ = 10 GeV, Λ = 0.53 TeV
D9, m_χ = 500 GeV, Λ = 1.4 TeV
Unparticle, d_U = 1.6, Λ_U = 33 TeV
Z/γ^*+jets
Top/WW/W+jets
ZZ
WZ
Stat. unc.
Events / 1 GeV
Data / MC
E_T^{miss} [GeV]

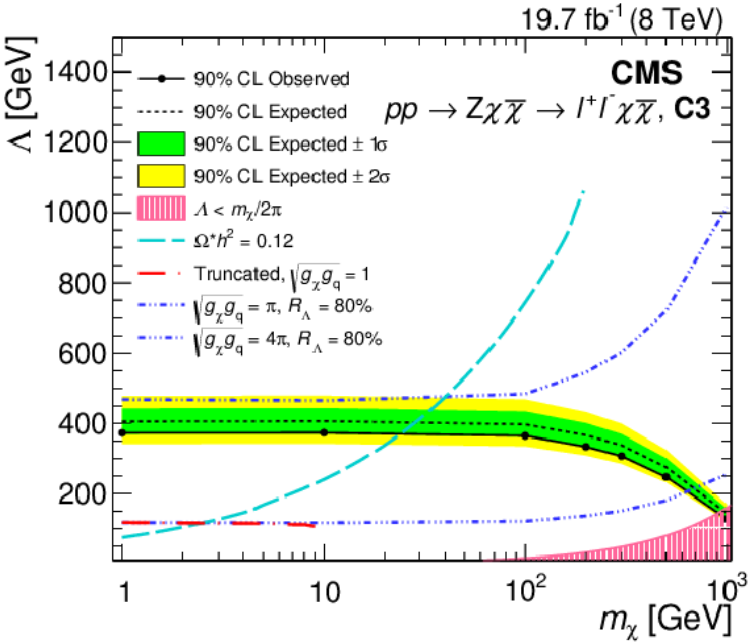

19.7 fb^{-1} (8 TeV)
CMS
e^+e^- channel
Data
C3, m_χ = 10 GeV, Λ = 0.37 TeV
D5, m_χ = 10 GeV, Λ = 0.53 TeV
D8, m_χ = 200 GeV, Λ = 0.48 TeV
D9, m_χ = 500 GeV, Λ = 1.4 TeV
Unparticle, d_U = 1.6, Λ_U = 33 TeV
Z/γ^*+jets
Top/WW/W+jets
ZZ
WZ
Syst. ⊕ stat. unc.
Events / 100 GeV
m_T [GeV]

Mono Z @ 8 TeV

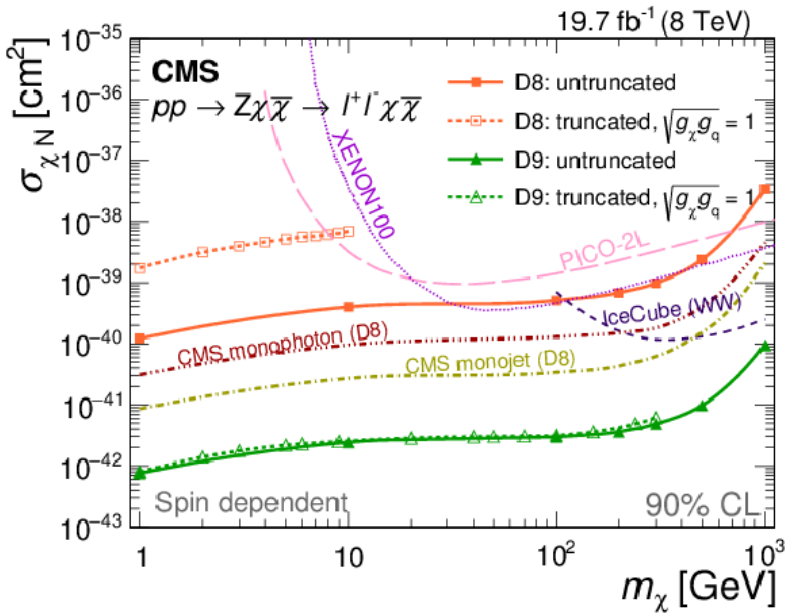

19.7 fb^{-1} (8 TeV)
CMS
$pp \to Z\chi\bar{\chi} \to l^+l^-\chi\bar{\chi}$, D5
90% CL Observed
90% CL Expected
90% CL Expected ± 1σ
90% CL Expected ± 2σ
$\Lambda < m_\chi/2\pi$
$\Omega^*h^2 = 0.12$
CMS monojet
Truncated, $\sqrt{g_\chi g_q} = 1$
$\sqrt{g_\chi g_q} = \pi$, $R_\Lambda = 80\%$
$\sqrt{g_\chi g_q} = 4\pi$, $R_\Lambda = 80\%$
Λ [GeV]
m_χ [GeV]

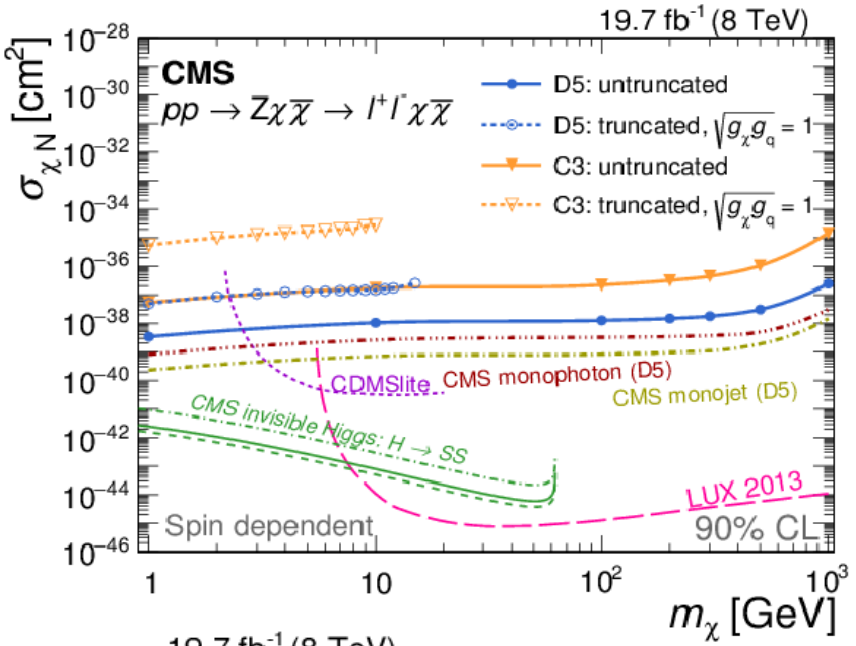

19.7 fb^{-1} (8 TeV)
CMS
$pp \to Z\chi\bar{\chi} \to l^+l^-\chi\bar{\chi}$, D8
90% CL Observed
90% CL Expected
90% CL Expected ± 1σ
90% CL Expected ± 2σ
$\Lambda < m_\chi/2\pi$
$\Omega^*h^2 = 0.12$
CMS monojet
Truncated, $\sqrt{g_\chi g_q} = 1$
$\sqrt{g_\chi g_q} = \pi$, $R_\Lambda = 80\%$
$\sqrt{g_\chi g_q} = 4\pi$, $R_\Lambda = 80\%$
Λ [GeV]
m_χ [GeV]

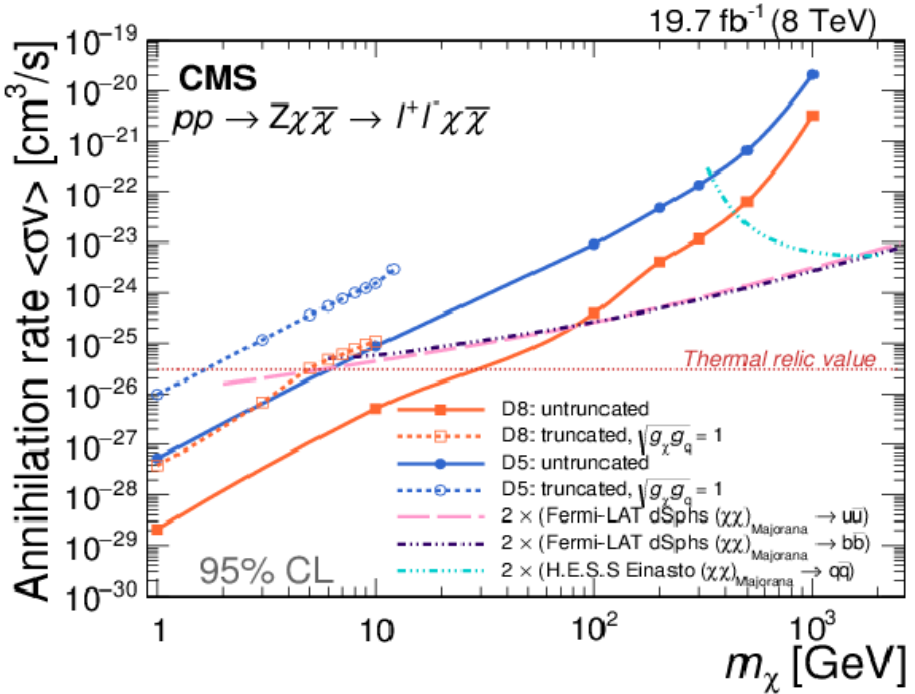

19.7 fb^{-1} (8 TeV)
CMS
$pp \to Z\chi\bar{\chi} \to l^+l^-\chi\bar{\chi}$, D9
90% CL Observed
90% CL Expected
90% CL Expected ± 1σ
90% CL Expected ± 2σ
$\Lambda < m_\chi/2\pi$
$\Omega^*h^2 = 0.12$
Truncated, $\sqrt{g_\chi g_q} = 1$
$\sqrt{g_\chi g_q} = \pi$, $R_\Lambda = 80\%$
$\sqrt{g_\chi g_q} = 4\pi$, $R_\Lambda = 80\%$
Λ [GeV]
m_χ [GeV]


19.7 fb^{-1} (8 TeV)
CMS
$pp \to Z\chi\bar{\chi} \to l^+l^-\chi\bar{\chi}$, C3
90% CL Observed
90% CL Expected
90% CL Expected ± 1σ
90% CL Expected ± 2σ
$\Lambda < m_\chi/2\pi$
$\Omega^*h^2 = 0.12$
Truncated, $\sqrt{g_\chi g_q} = 1$
$\sqrt{g_\chi g_q} = \pi$, $R_\Lambda = 80\%$
$\sqrt{g_\chi g_q} = 4\pi$, $R_\Lambda = 80\%$
Λ [GeV]
m_χ [GeV]

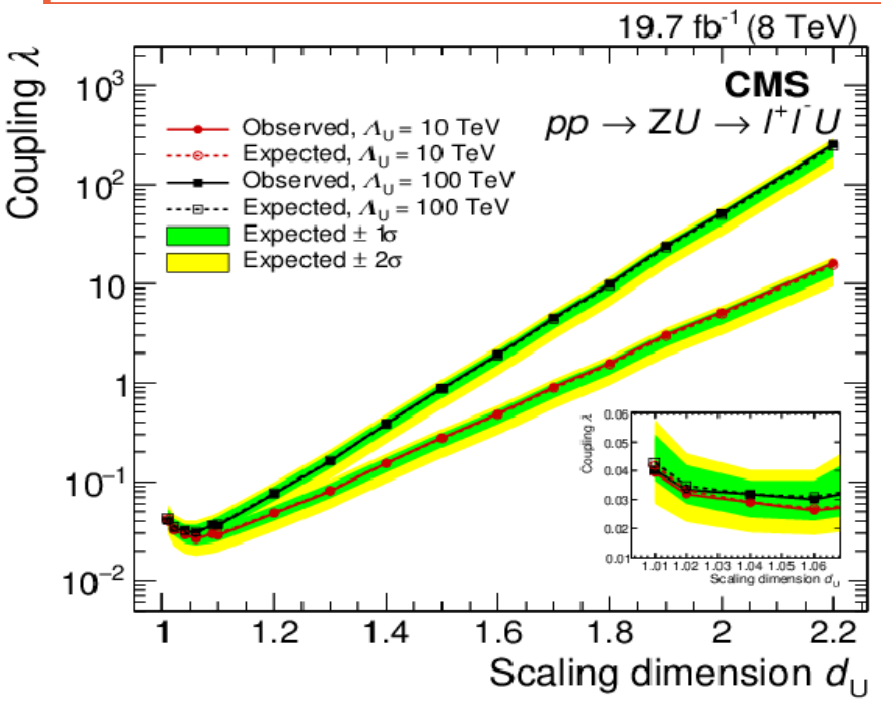
Mono-Z

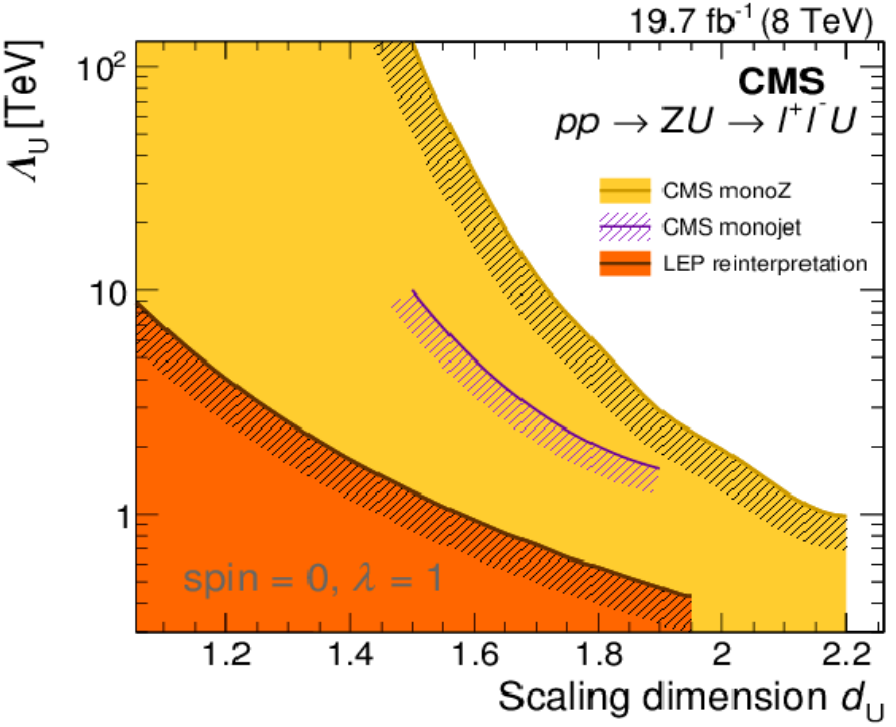

19.7 fb^{-1} (8 TeV)
CMS
$pp \to Z\chi\bar{\chi} \to l^+l^-\chi\bar{\chi}$
D8: untruncated
D8: truncated, $\sqrt{g_\chi g_q} = 1$
D9: untruncated
D9: truncated, $\sqrt{g_\chi g_q} = 1$
XENON100
PICO-2L
IceCube (WW)
CMS monophoton (D8)
CMS monojet (D8)
Spin dependent
90% CL
$\sigma_{\chi N}$ [cm^2]
m_χ [GeV]

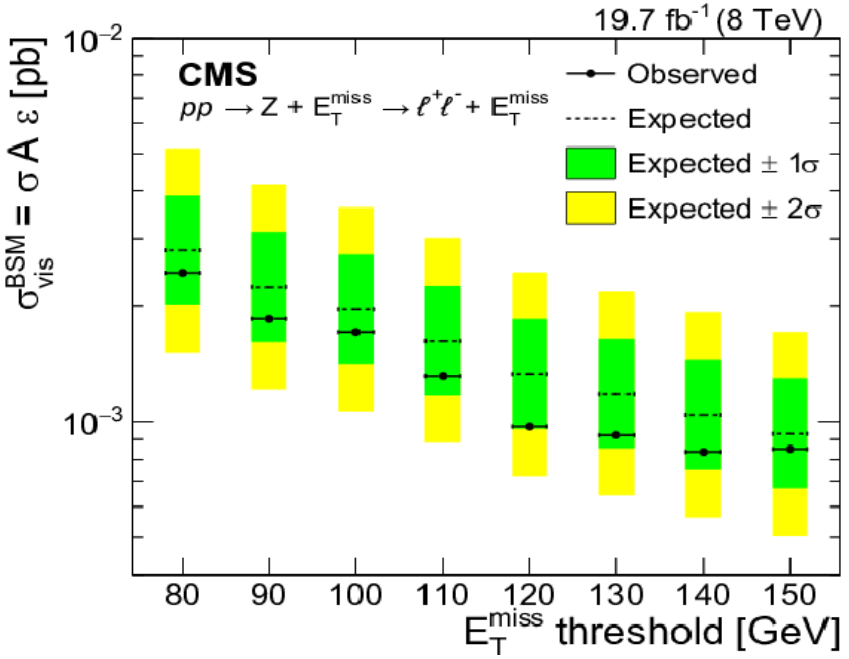

19.7 fb^{-1} (8 TeV)
CMS
$pp \to Z\chi\bar{\chi} \to l^+l^-\chi\bar{\chi}$
D5: untruncated
D5: truncated, $\sqrt{g_\chi g_q} = 1$
C3: untruncated
C3: truncated, $\sqrt{g_\chi g_q} = 1$
CDMSlite
CMS monophoton (D5)
CMS monojet (D5)
CMS invisible Higgs: $H \to SS$
LUX 2013
Spin dependent
90% CL
$\sigma_{\chi N}$ [cm^2]
m_χ [GeV]


19.7 fb^{-1} (8 TeV)
CMS
$pp \to Z\chi\bar{\chi} \to l^+l^-\chi\bar{\chi}$
Thermal relic value
D8: untruncated
D8: truncated, $\sqrt{g_\chi g_q} = 1$
D5: untruncated
D5: truncated, $\sqrt{g_\chi g_q} = 1$
2 × (Fermi-LAT dSphs $(\chi\chi)_{Majorana} \to u\bar{u}$)
2 × (Fermi-LAT dSphs $(\chi\chi)_{Majorana} \to b\bar{b}$)
2 × (H.E.S.S Einasto $(\chi\chi)_{Majorana} \to q\bar{q}$)
95% CL
Annihilation rate <σv> [cm^3/s]
m_χ [GeV]

Mono-Z


19.7 fb-1 (8 TeV)
CMS
pp → ZU → l+l-U
Observed, Λ_U = 10 TeV
Expected, Λ_U = 10 TeV
Observed, Λ_U = 100 TeV
Expected, Λ_U = 100 TeV
Expected ± 1σ
Expected ± 2σ
Coupling λ
Scaling dimension d_U

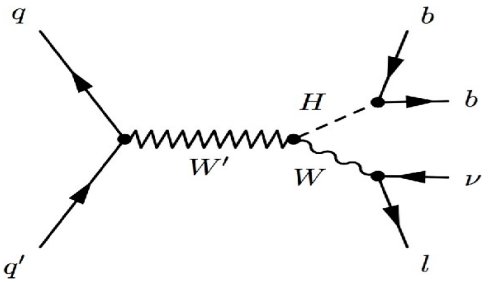

19.7 fb-1 (8 TeV)
CMS
pp → ZU → l+l-U
CMS monoZ
CMS monojet
LEP reinterpretation
spin = 0, λ = 1
Λ_U [TeV]
Scaling dimension d_U

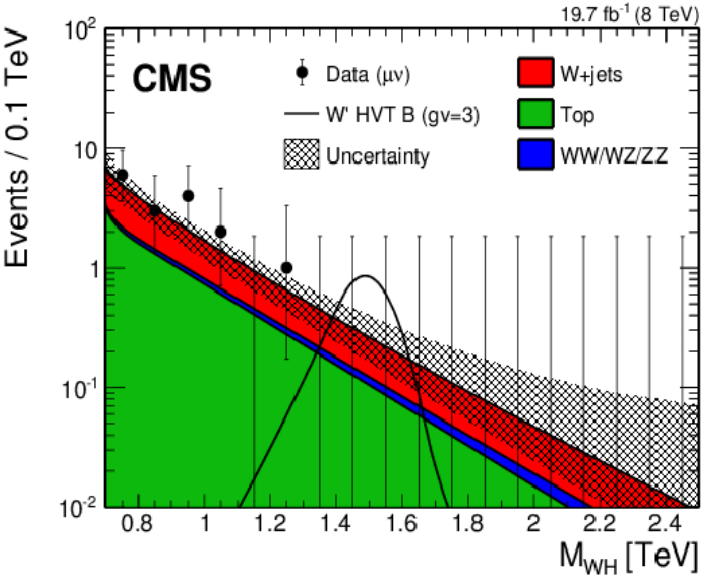

19.7 fb-1 (8 TeV)
CMS
pp → Z + E_T^miss → ℓ+ℓ- + E_T^miss
Observed
Expected
Expected ± 1σ
Expected ± 2σ
σ_vis^BSM = σ A ε [pb]
E_T^miss threshold [GeV]

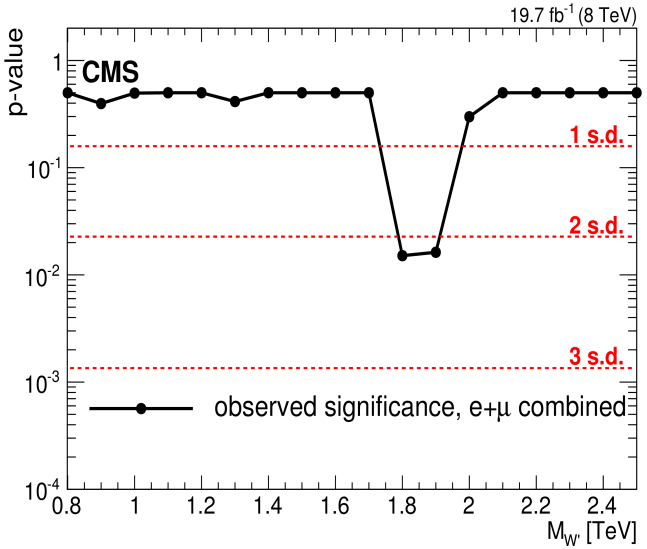
Search for massive WH resonances decaying into the $\ell\nu b\bar{b}$ final state at $s\sqrt{}$= 8 TeV

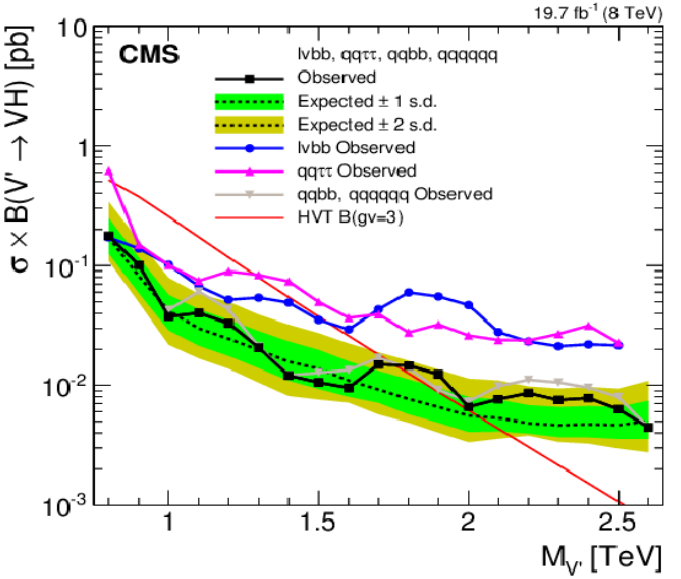
- exo-14-010

- B 's reconstructed as a single jet
- Tagged by substructure
- In HVT model limit of
- 1.5 TeV on W' mass

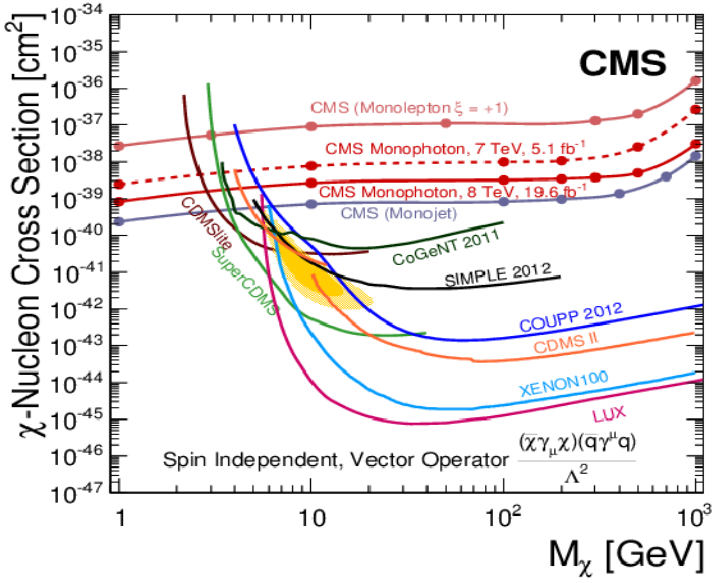


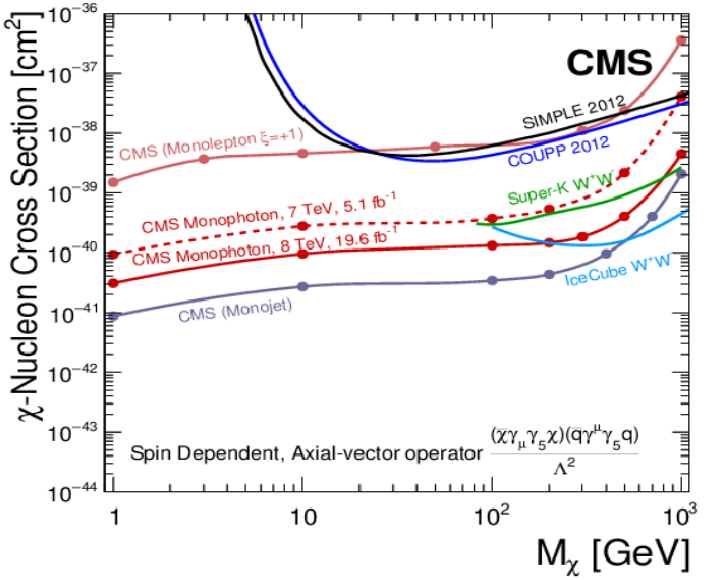


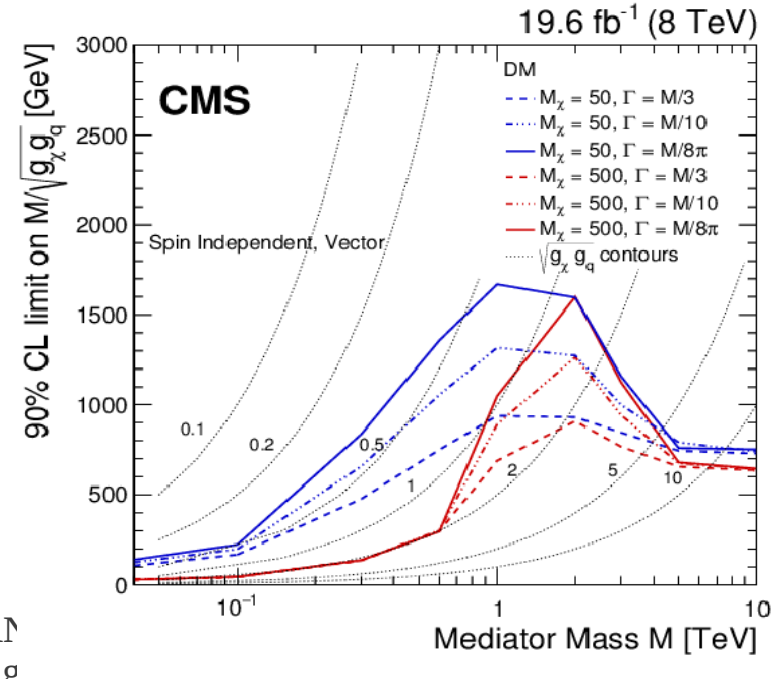




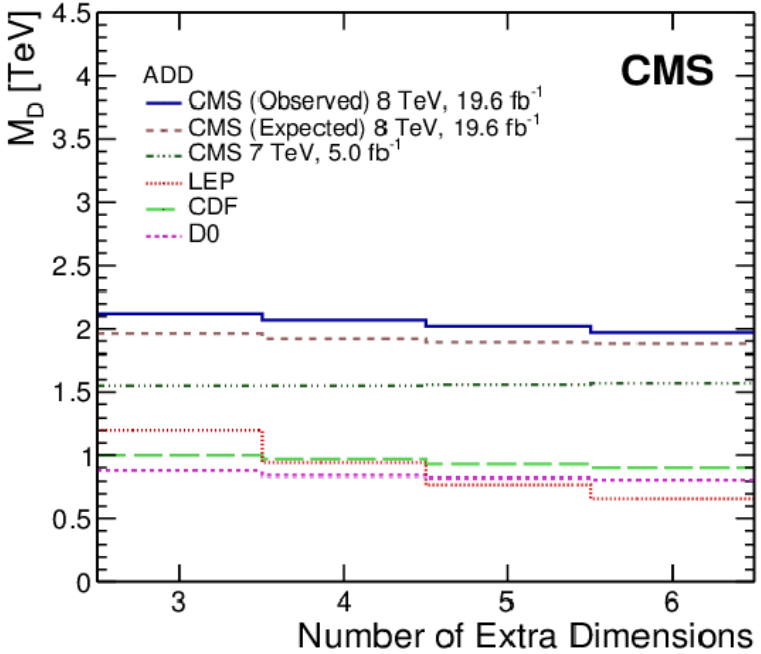
Monophoton

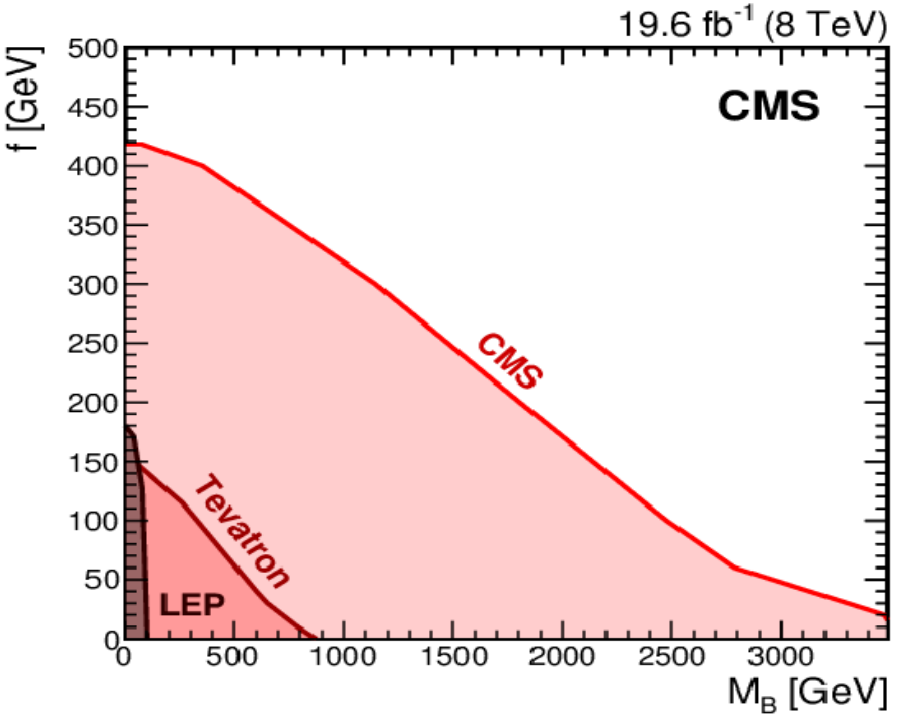

CMS
CMS (Monolepton ξ = +1)
CMS Monophoton, 7 TeV, 5.1 fb-1
CMS Monophoton, 8 TeV, 19.6 fb-1
CMS (Monojet)
CoGeNT 2011
SIMPLE 2012
COUPP 2012
CDMS II
XENON100
LUX
CDMSlite
SuperCDMS
Spin Independent, Vector Operator (χγμχ)(qγμq)/Λ2
χ-Nucleon Cross Section [cm2]
Mχ [GeV]


CMS
CMS (Monolepton ξ=+1)
SIMPLE 2012
COUPP 2012
Super-K W+W-
CMS Monophoton, 7 TeV, 5.1 fb-1
CMS Monophoton, 8 TeV, 19.6 fb-1
IceCube W+W-
CMS (Monojet)
Spin Dependent, Axial-vector operator (χγμγ5χ)(qγμγ5q)/Λ2
χ-Nucleon Cross Section [cm2]
Mχ [GeV]


19.6 fb-1 (8 TeV)
CMS
DM
Mχ = 50, Γ = M/3
Mχ = 50, Γ = M/10
Mχ = 50, Γ = M/8π
Mχ = 500, Γ = M/3
Mχ = 500, Γ = M/10
Mχ = 500, Γ = M/8π
√gχ gq contours
Spin Independent, Vector
90% CL limit on M/√gχ gq [GeV]
Mediator Mass M [TeV]

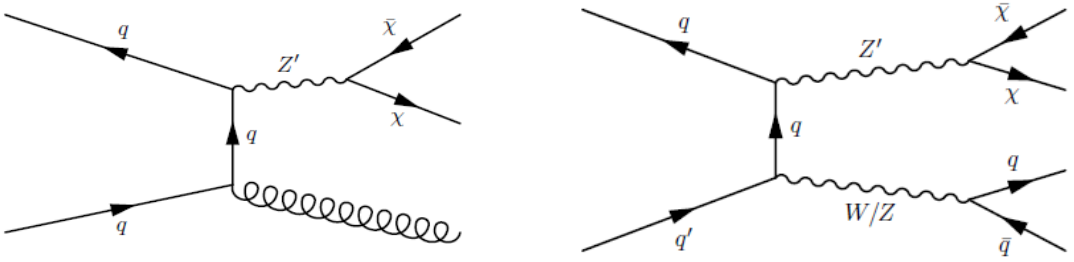
Monophoton: graviton and branon

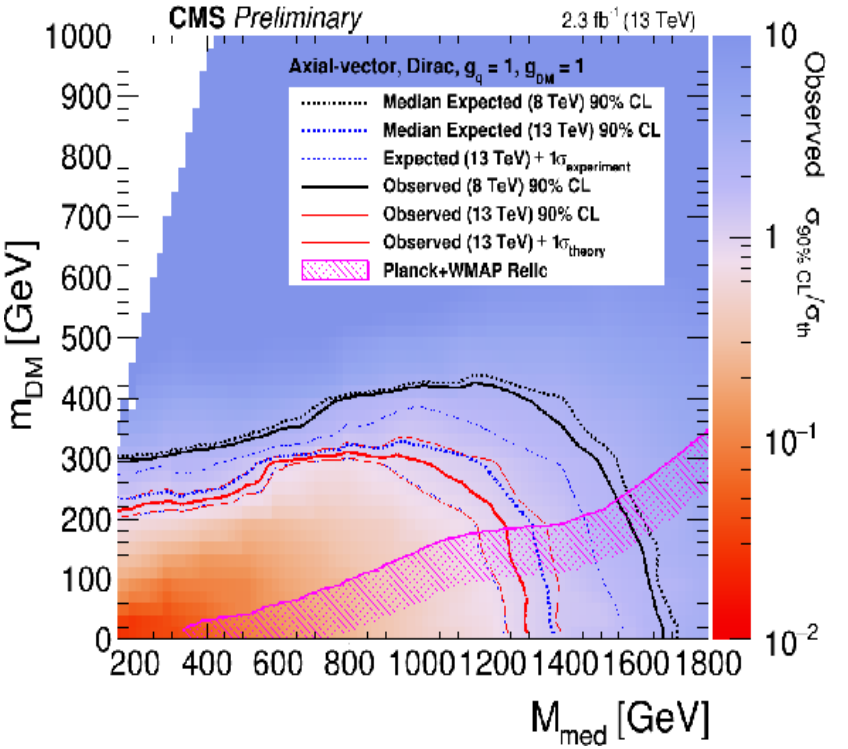


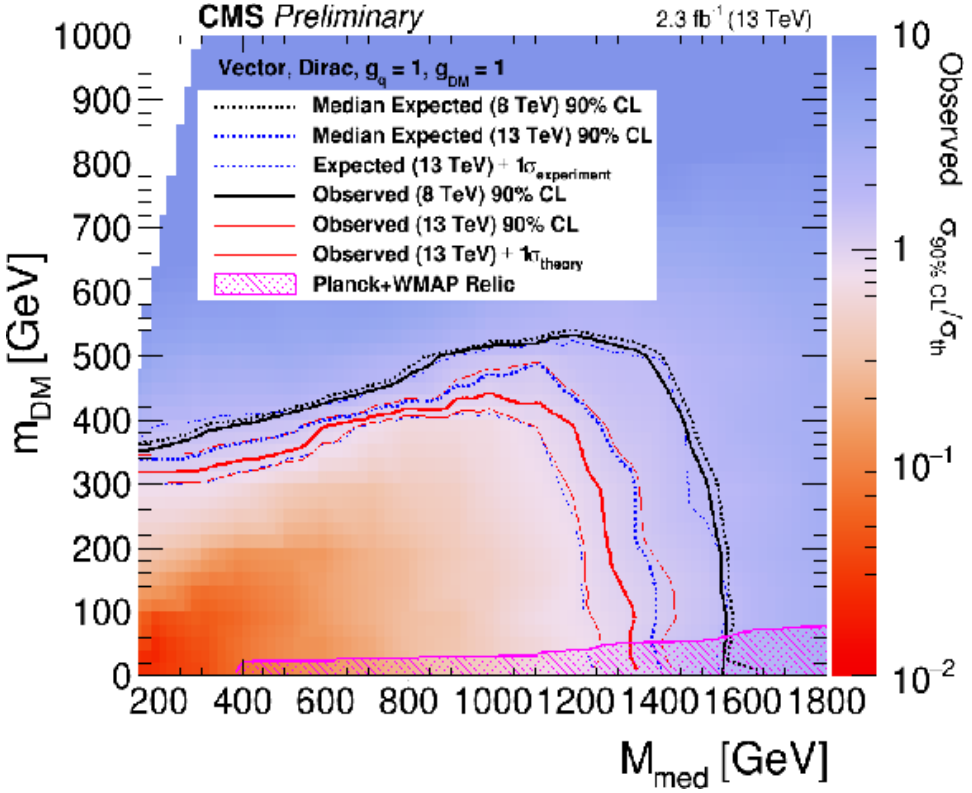


Mono jet and mono V(hadronic) @ 13 TeV

NEW!! EXO-16-018

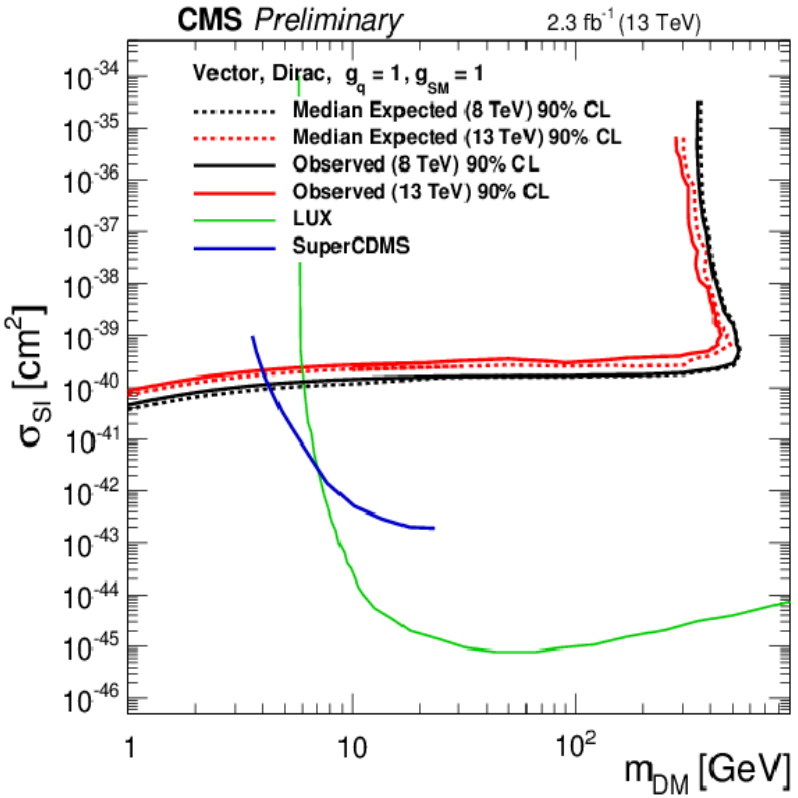


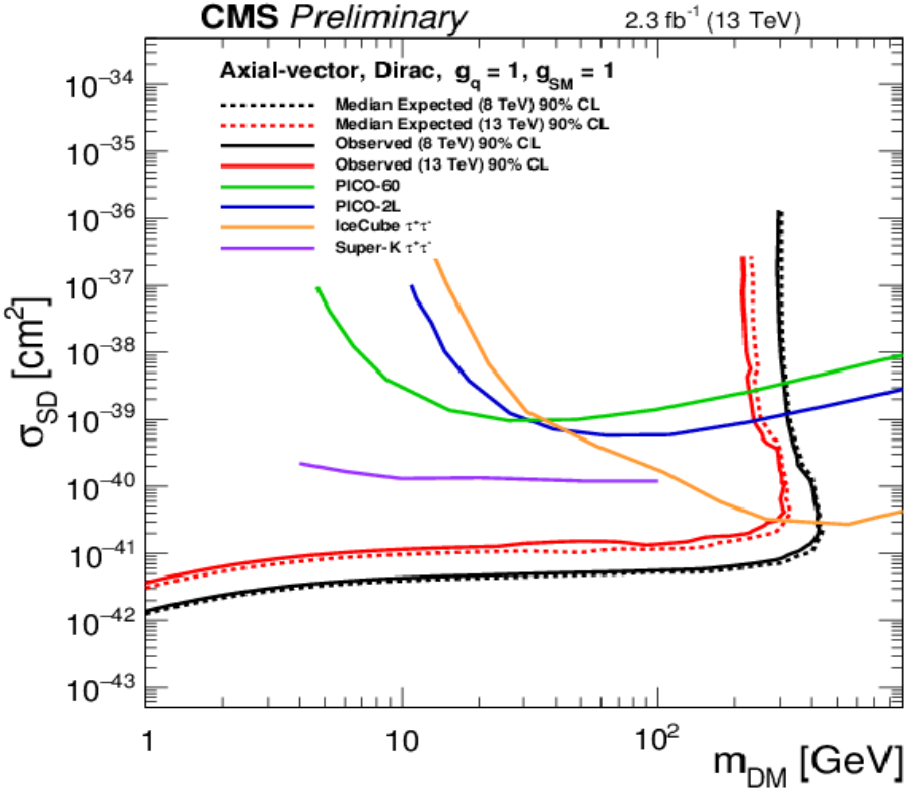




- Jet + MET(>90 GeV)
- For mono-V jet substructure (pruned mass, N-jettiness) used
- Couplings taken as unity

Mono jet and mono V(hadronic) @ 13 TeV



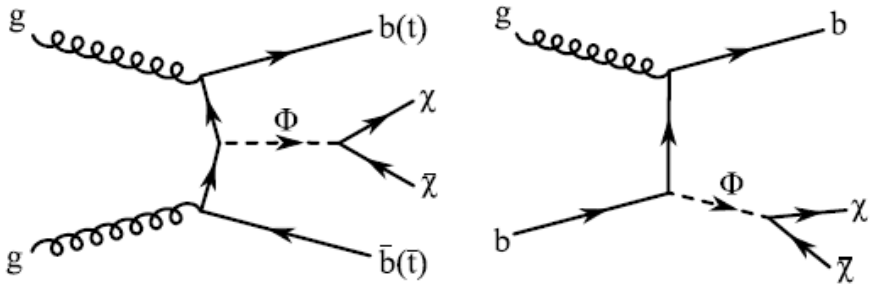


DM + Heavy Flavor

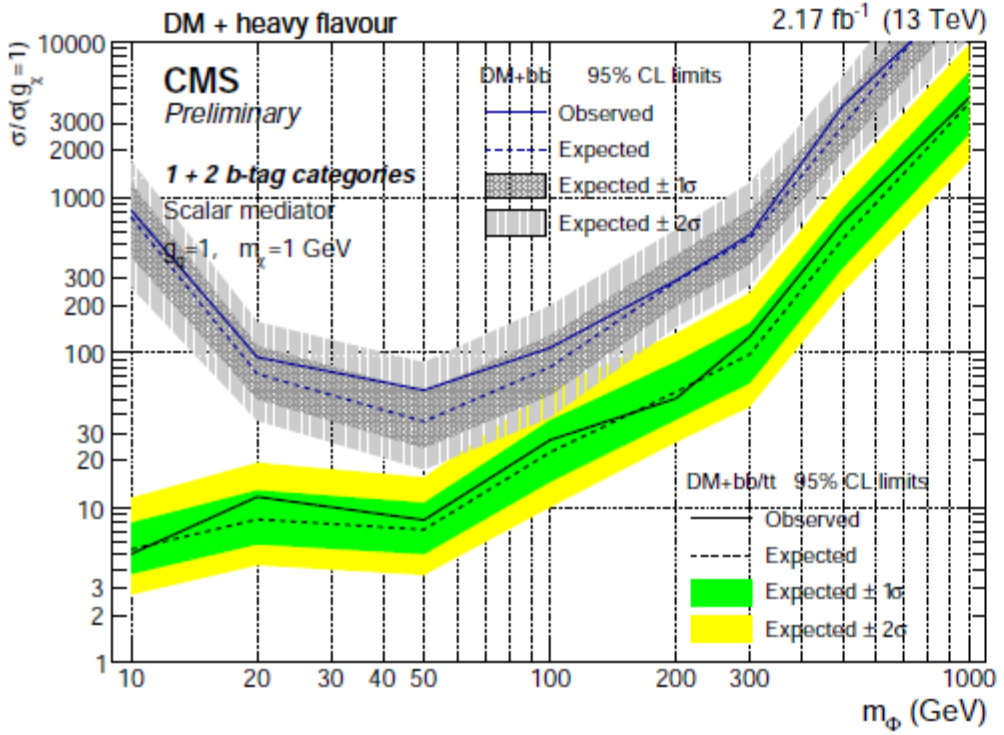
NEW!!

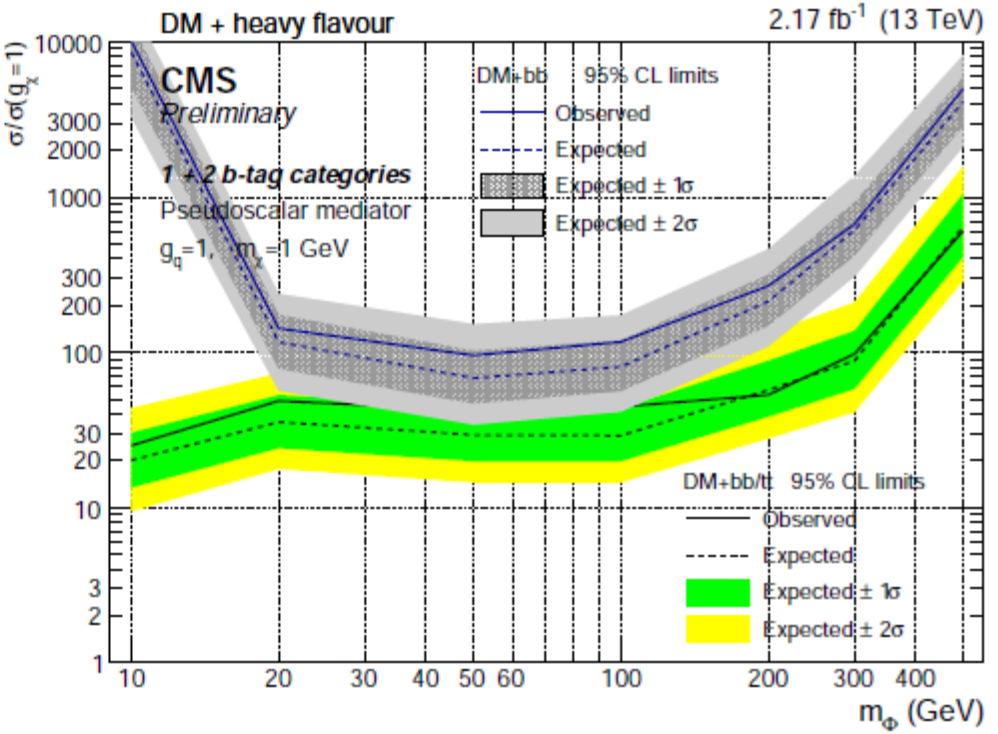
B2G-15-007

- **MET + b + lepton veto**
- Sample divided in categories of b jet multiplicity
- Signal extracted from MET spectrum

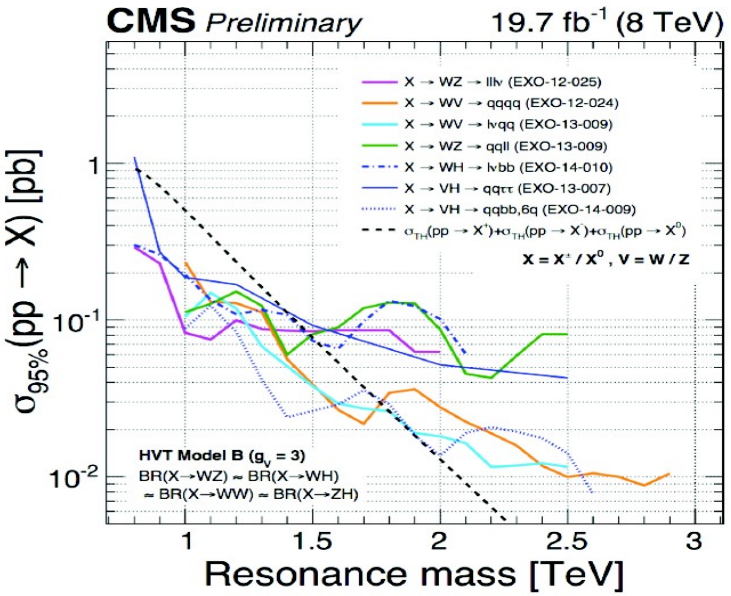


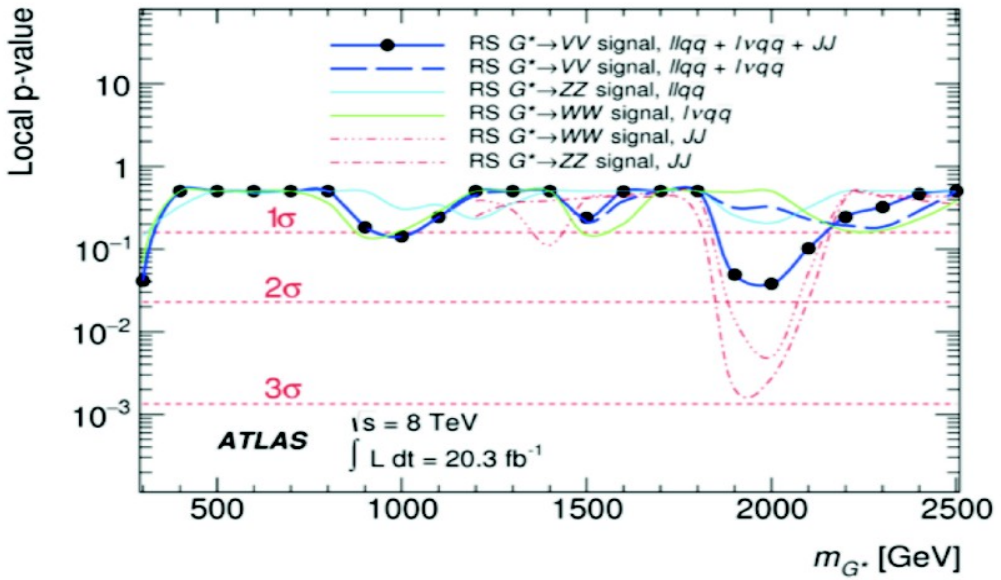
- Scalar/pseudoscalar mediator
- Signal efficiency strongly depends on mediator mass (10^{-6} to 10^{-2} for mass 10 GeV to 1 TeV)



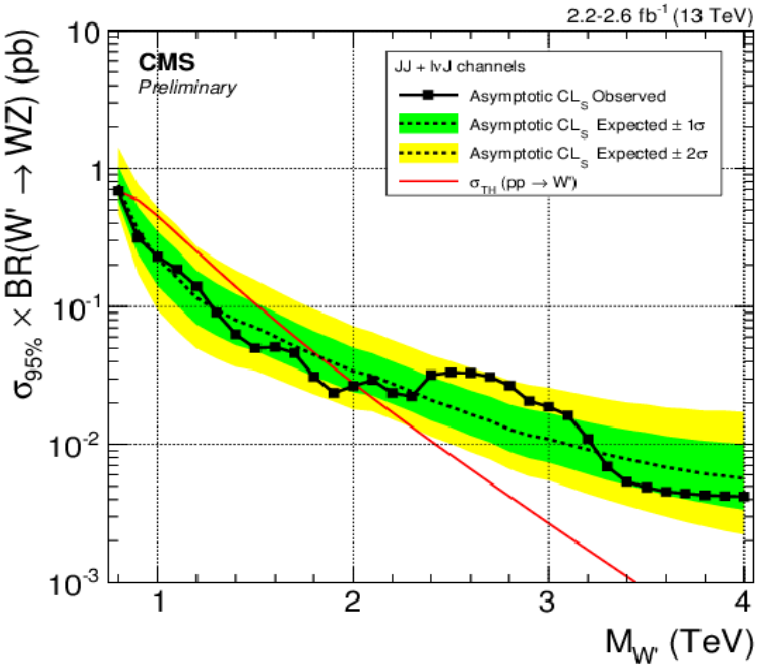


CMS diboson: 8 to 13 TeV



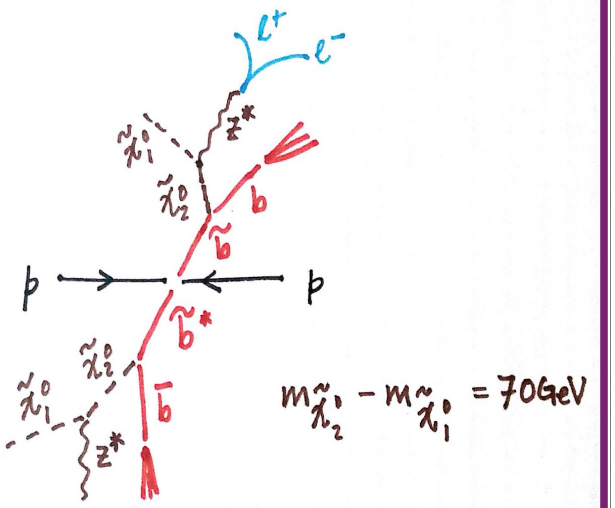


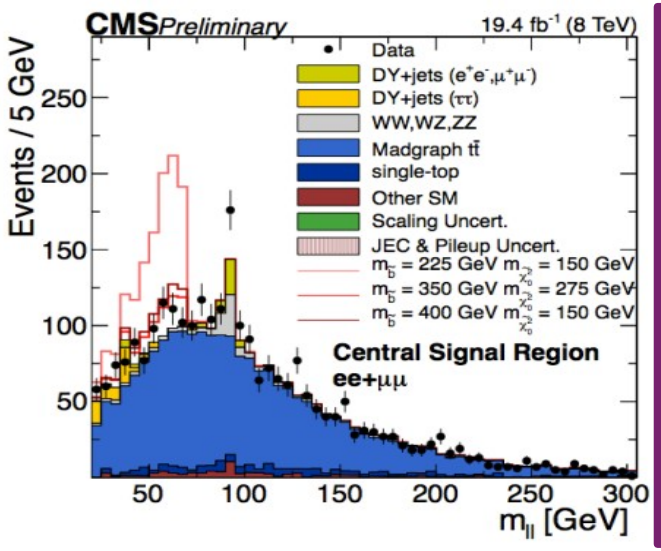
- massive narrow resonances decaying to pairs of W and Z
- Spin-1, spin-2 resonances < 0.8 TeV
- WW, WZ, or ZZ to ℓνqq or qqqq



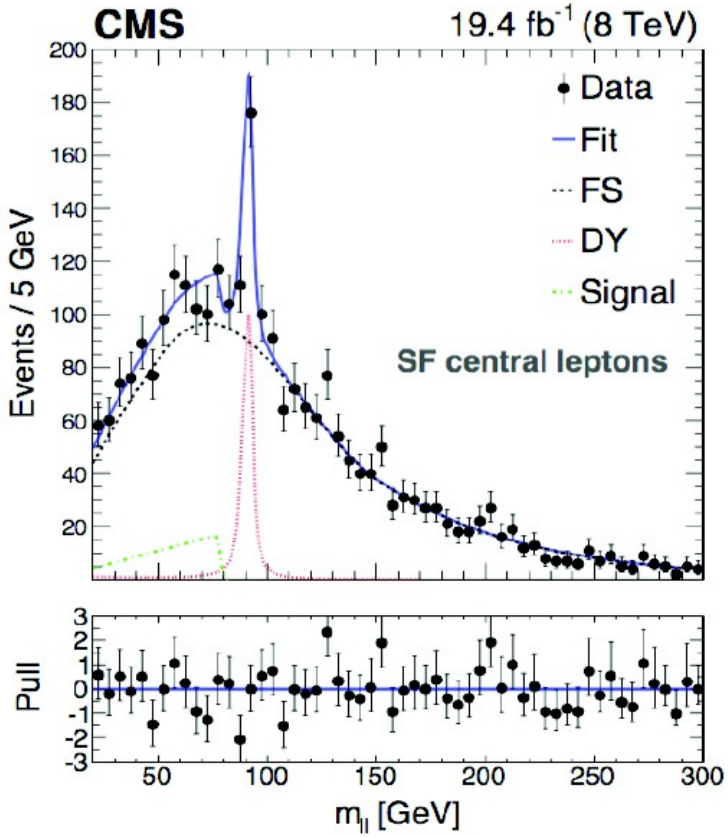
Dilepton OSSF @ 8 TeV

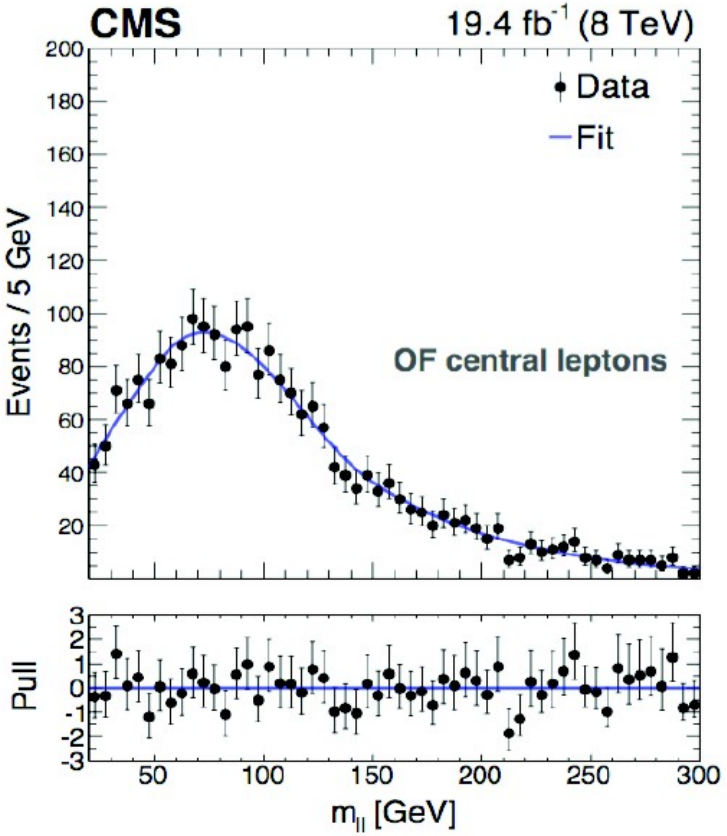
JHEP 04 (2015) 124





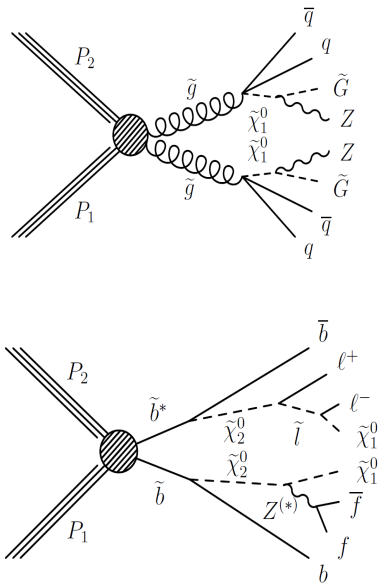
- Best fit edge:78.7 +-1.4 GeV
- Local p-value with -2logQ statistic is 0.009
- Gaussian one sided tail probability → 2.4 sigma
- No look-elsewhere effect

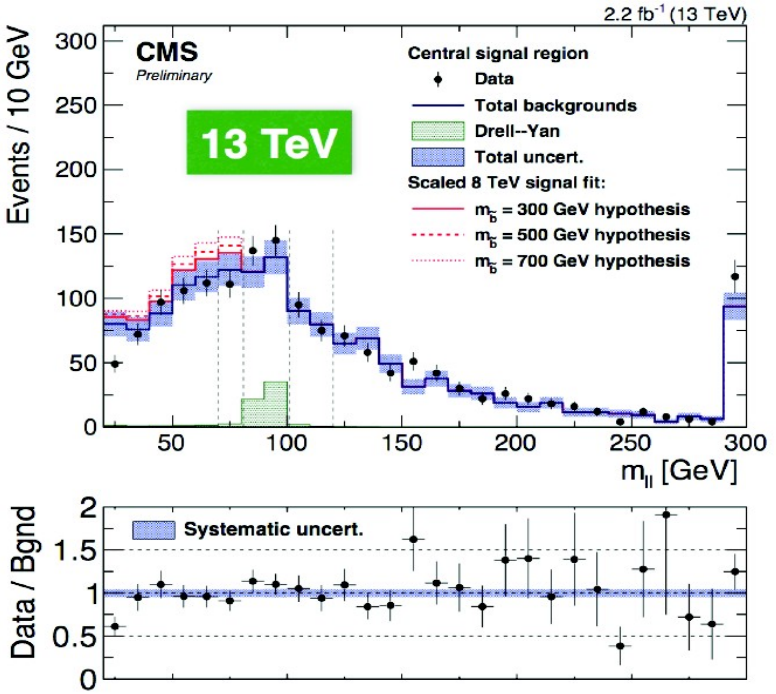


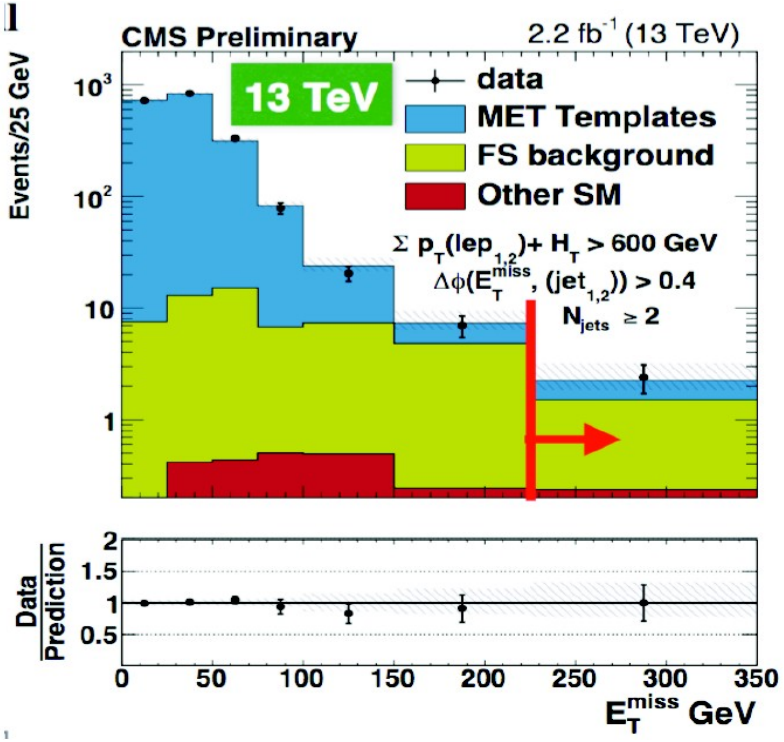


Search for new physics in final states with two opposite-sign same-flavor leptons, jets and EmissT in pp collisions at s√= 13 TeV

SUS-15-011







- Should see 61 events offshell
- 57 is upper limit

- Should see 12 events offshell
- 9 is upper limit

High mass diphoton search

Ref	Title	M_X	interpreted as	
			spin-0	spin-2
PLB 750 (2015) 494	Search for diphoton resonances in the mass range from 150 to 850 GeV in pp collisions at √s = 8 TeV	150-850GeV	✔	✔
EXO-12-045	Search for High-Mass Diphoton Resonances in pp Collisions at √s = 8 TeV with the CMS Detector	0.5-3TeV	✘	✔
EXO-15-004 Dec'15	Search for new physics in high mass diphoton events in proton-proton collisions at √s = 13 TeV	0.5-4.5TeV	✘	✔
EXO-16-018 NEW	Search for new physics in high mass diphoton events in **3.3 fb^{-1}** of proton-proton collisions at √s=13 TeV and combined interpretation of searches at √s=8 TeV and 13 TeV.	0.5-4.5TeV	✔	✔

P. Mussella, Moriond EWK,2016

High mass diphoton

- Compatibility of 8 and 13 TeV

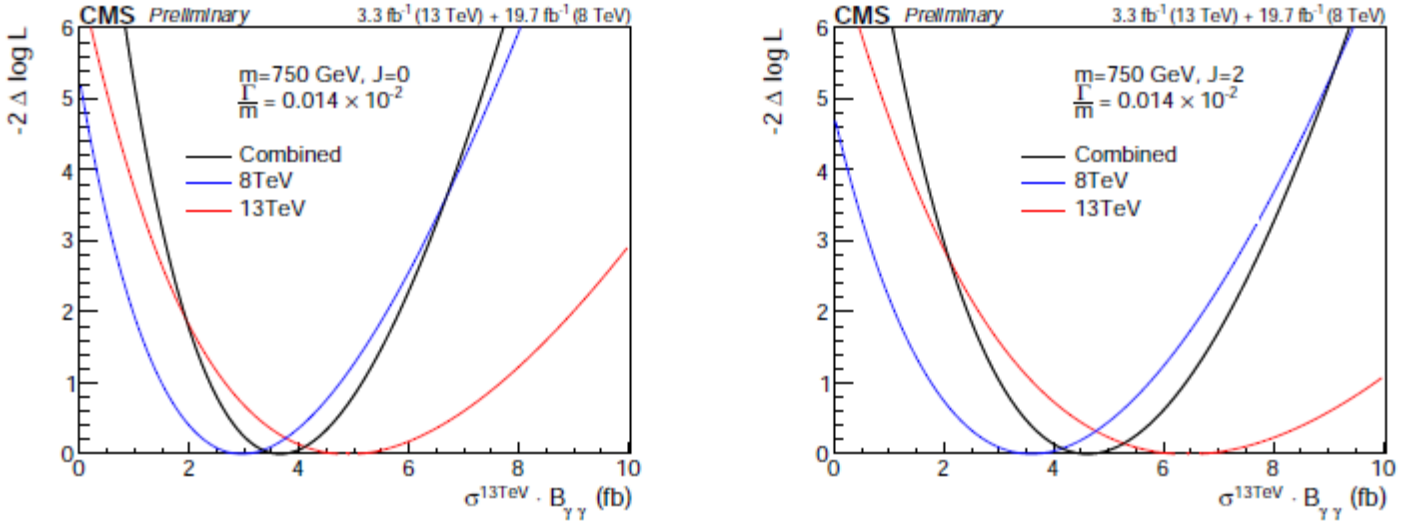
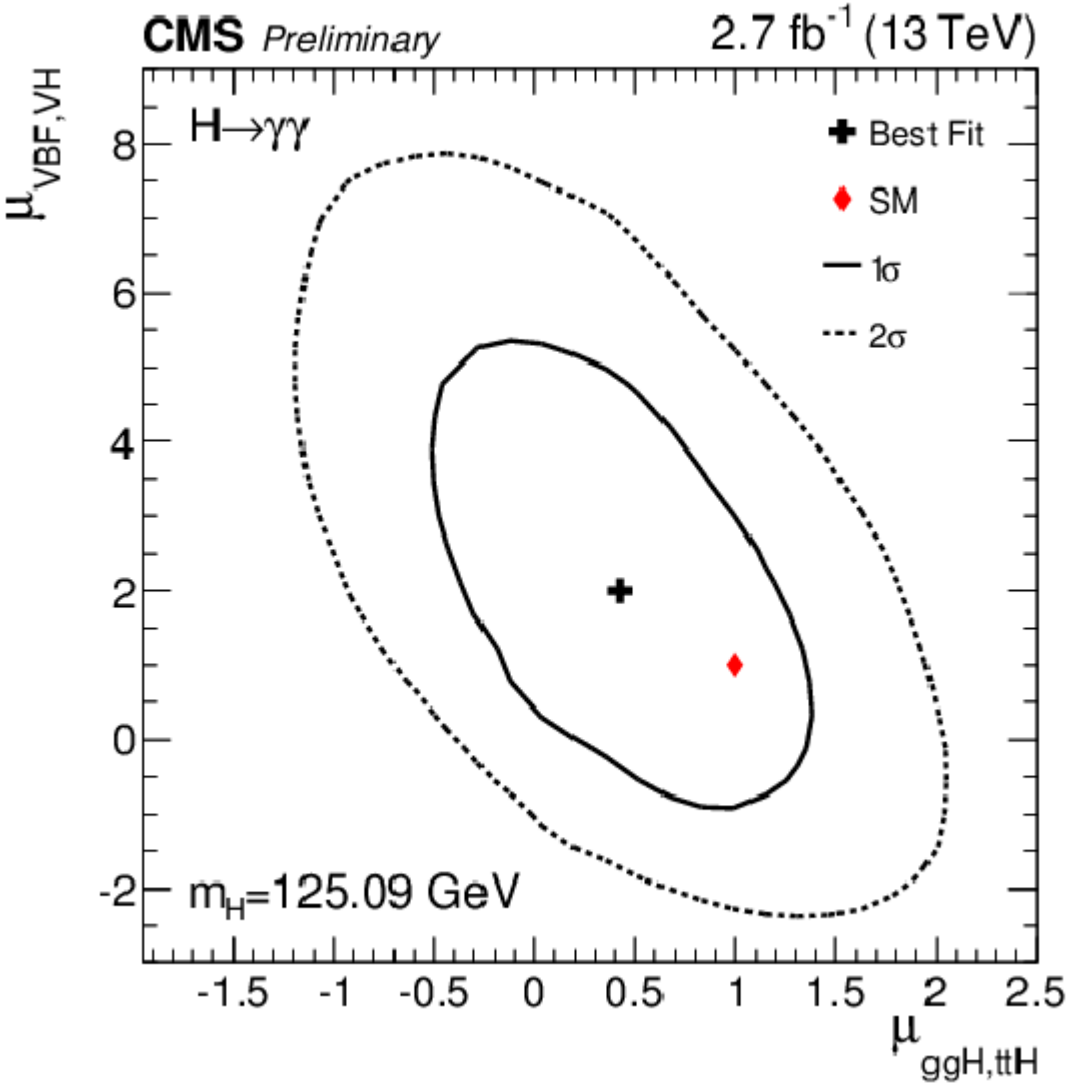


Figure 10: Likelihood scan for the cross section corresponding to the largest excess in the combined analysis of the 8 and 13 TeV datasets. The left (right) column corresponds to the scalar (RS graviton) signals. The 8 TeV results are scaled by the expected ratio of cross sections in each scenarios.

Higgs to diphoton



Rediscovering H(125)

H→ZZ→4ℓ (13 TeV): Analysis Overview

HIG-15-004

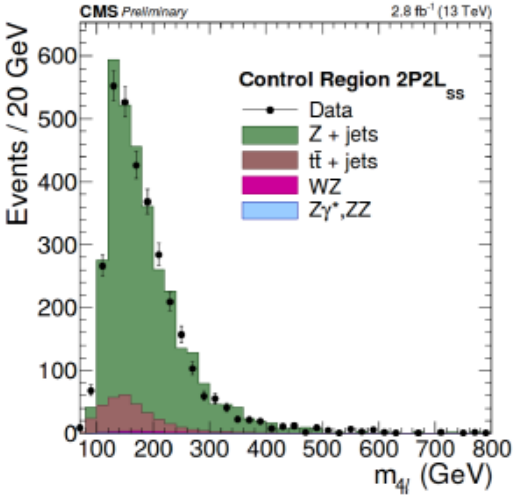
- Excellent mass resolution:
  - Calibrated using $Z \to \ell\ell$
- Very High Signal/Background
  - ZZ bkg. scaled to NNLO pred.
  - Reducible bkg. from data (two methods)
- Event Categorization:
  - 2 jets + $\mathcal{D}_{\rm jet} > 0.5$: VBF tagged
  - Other events: Untagged
- ME Discriminant in likelihood:

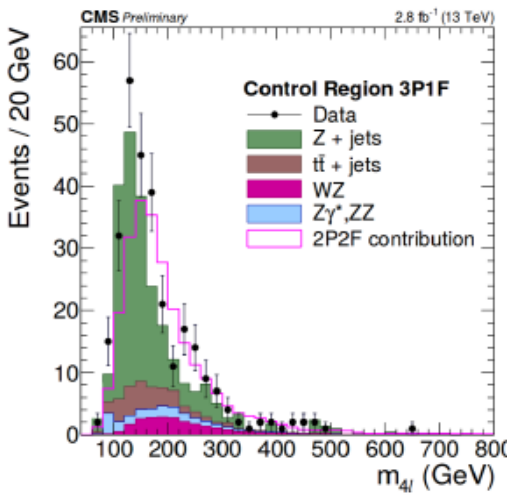
$$\mathcal{L}_{2D}(m_{4\ell}, \mathcal{D}^{\rm kin}_{\rm bkg}) = \mathcal{L}(m_{4\ell})\mathcal{L}(\mathcal{D}^{\rm kin}_{\rm bkg}|m_{4\ell})$$

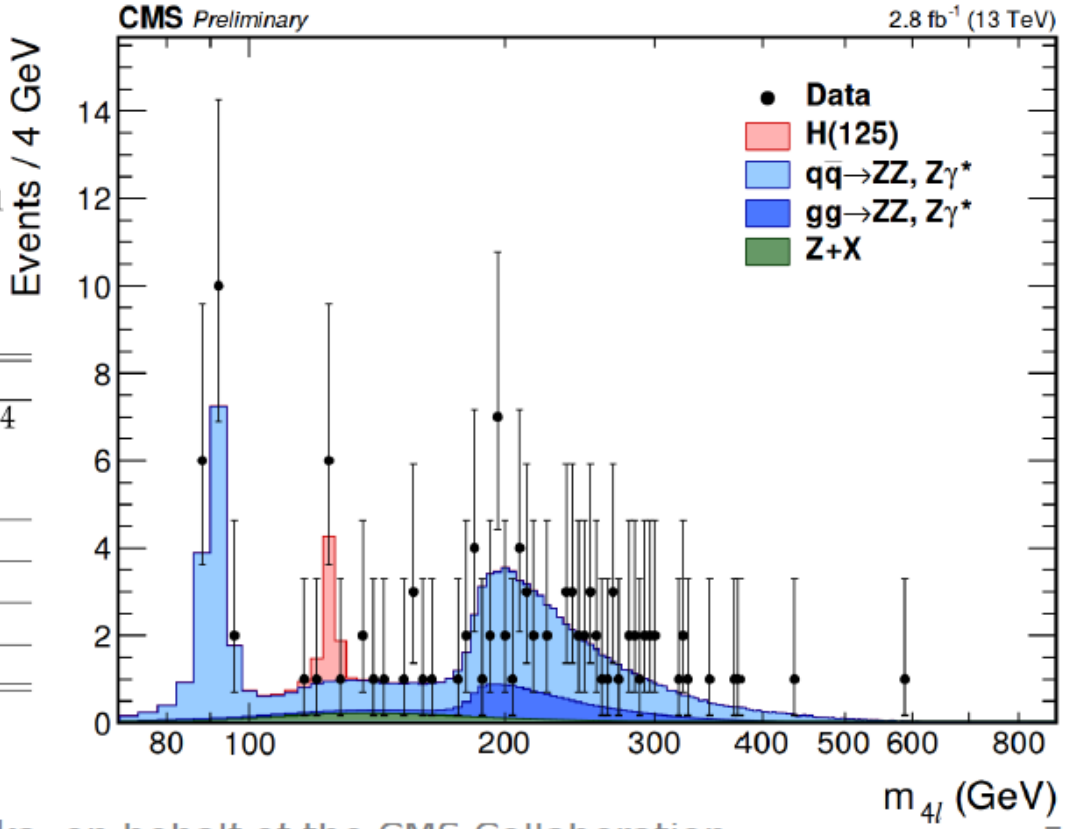
$$\mathcal{D}^{\rm kin}_{\rm bkg} = \left[1 + \frac{\mathcal{P}^{\rm q\bar{q}}_{\rm bkg}(\vec{\Omega}^{H\to 4\ell}|m_{4\ell})}{\mathcal{P}^{gg}_{\rm sig}(\vec{\Omega}^{H\to 4\ell}|m_{4\ell})}\right]^{-1} \quad \mathcal{D}_{\rm jet} = \left[1 + \frac{\mathcal{P}_{\rm HJJ}(\vec{\Omega}^{\rm H+JJ}|m_{4\ell})}{\mathcal{P}_{\rm VBF}(\vec{\Omega}^{\rm H+JJ}|m_{4\ell})}\right]^{-1}$$

Channel	4e	4μ	2e2μ	4ℓ
$q\bar{q} \to ZZ$	0.33 ± 0.03	0.75 ± 0.05	0.92 ± 0.07	2.00 ± 0.14
$gg \to ZZ$	0.04 ± 0.01	0.08 ± 0.01	0.07 ± 0.01	$0.18^{+0.03}_{-0.02}$
Z+X	$0.17^{+0.15}_{-0.09}$	0.19 ± 0.08	0.26 ± 0.10	$0.62^{+0.20}_{-0.16}$
Sum of backgrounds	$0.54^{+0.16}_{-0.10}$	1.02 ± 0.09	1.25 ± 0.13	$2.80^{+0.25}_{-0.22}$
Signal ($m_{\rm H} = 125$ GeV)	$0.91^{+0.11}_{-0.10}$	1.70 ± 0.15	2.21 ± 0.22	$4.82^{+0.44}_{-0.45}$
Total expected	$1.45^{+0.21}_{-0.16}$	2.72 ± 0.20	3.45 ± 0.29	$7.62^{+0.58}_{-0.56}$
Observed	1	3	4	8

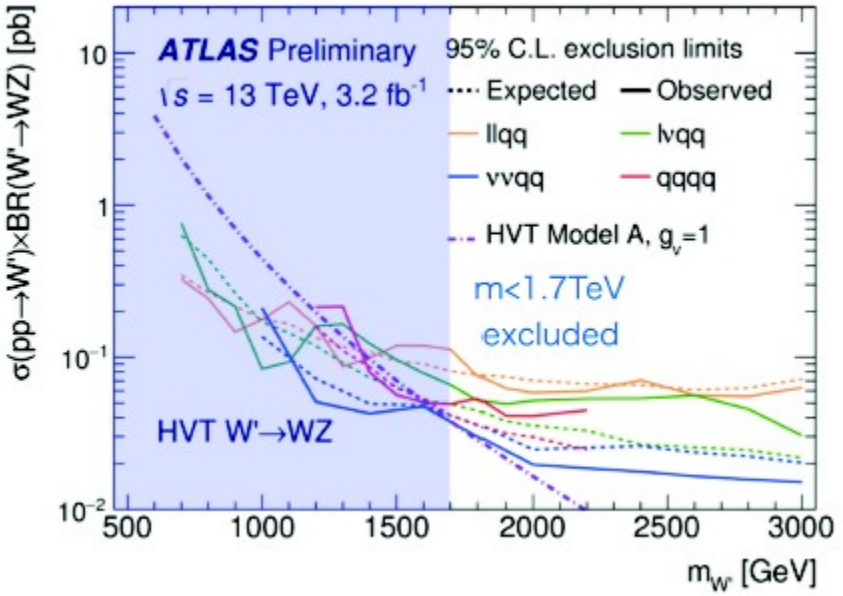
118 GeV < $m_{4\ell}$ < 130 GeV



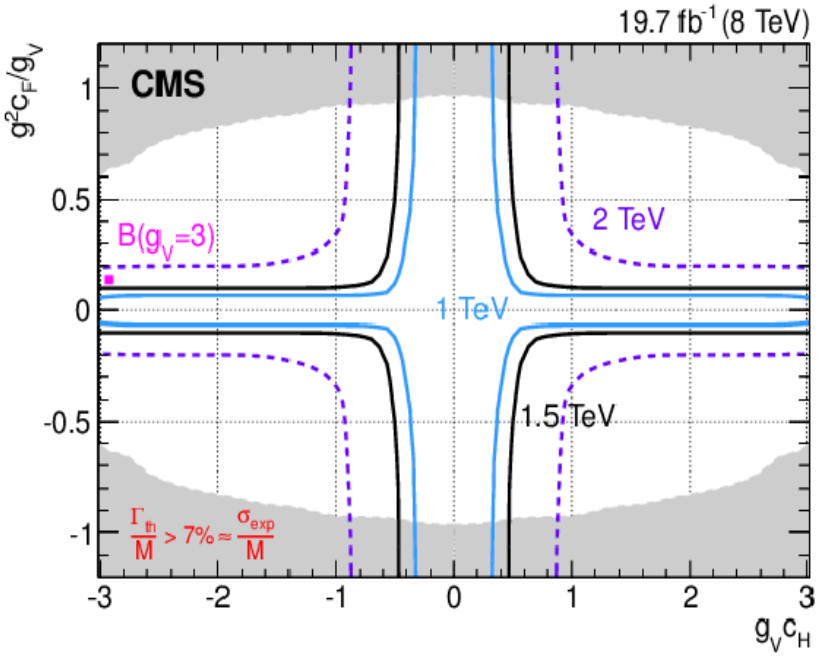




HVT Model

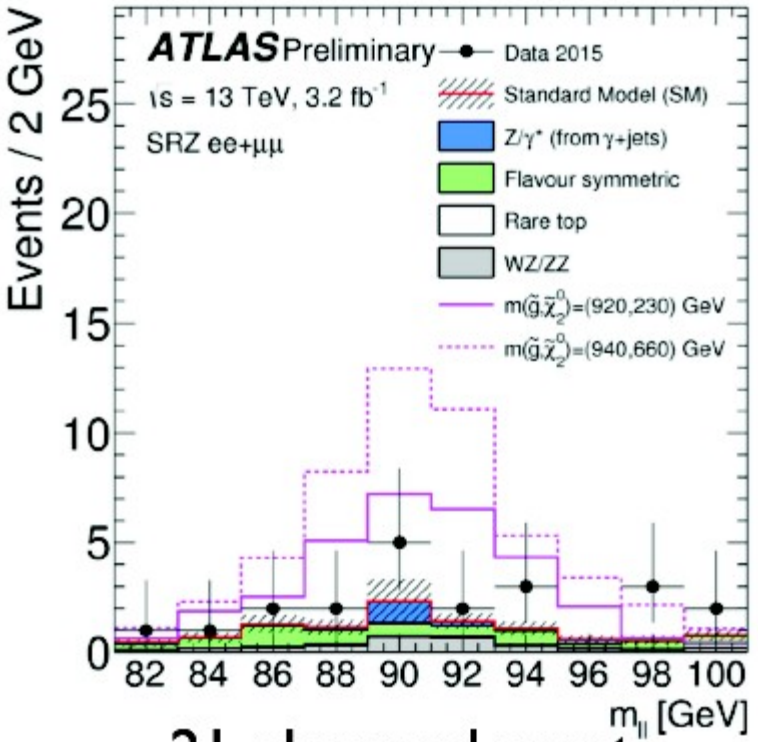


- exo-14-010



ATLAS dilepton excess

excess on-shell

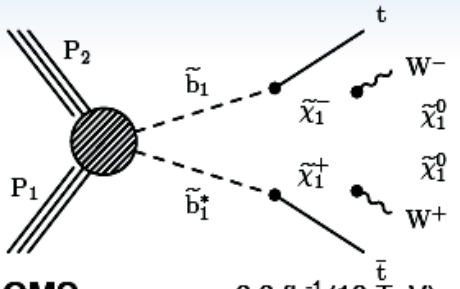


21 observed events with 10 expected (2.2σ)

2ℓ same-sign, ≥3ℓ: limits

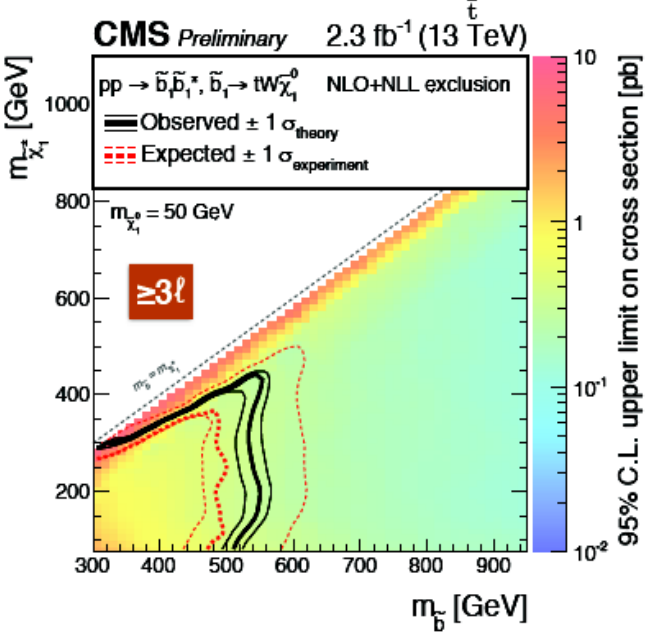
SUS-15-008 ≥2ℓ, SS

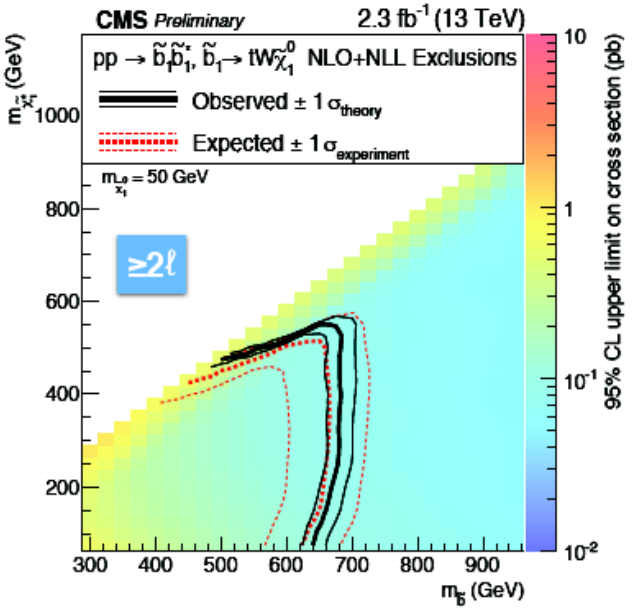
SUS-16-003 ≥3ℓ

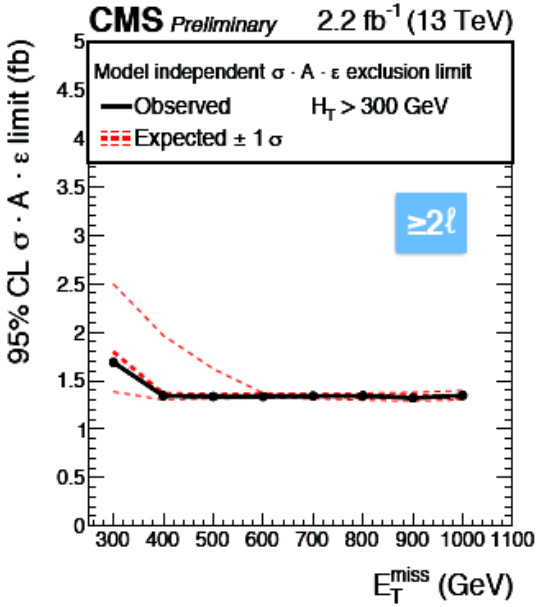


Limits on direct sbottom production

Excluded model-independent NP with σ•A•ε ~ 1.3 fb







Higgs singlet branching

$$
\begin{aligned}
\Gamma(\mathrm{h} \to X_{\mathrm{SM}} X_{\mathrm{SM}}) &= \cos^2\alpha\, \Gamma(\mathrm{h} \to X_{\mathrm{SM}} X_{\mathrm{SM}})_{\mathrm{SM}} \\
\Gamma(\mathrm{H} \to X_{\mathrm{SM}} X_{\mathrm{SM}}) &= \sin^2\alpha\, \Gamma(\mathrm{H} \to X_{\mathrm{SM}} X_{\mathrm{SM}})_{\mathrm{SM}} \\
\Gamma_{\mathrm{H}} &= \sin^2\alpha\, \Gamma_{\mathrm{H,SM}}(m_{\mathrm{H}}) + \Gamma(\mathrm{H} \to \mathrm{hh}) \\
\Gamma_{\mathrm{h}} &= \cos^2\alpha\, \Gamma_{\mathrm{h,SM}}(m_{\mathrm{h}})
\end{aligned}
$$

Figure 1. The photon p_T distribution for the candidate sample, compared with estimated contributions from SM backgrounds and a prediction from ADD for $M_D = 1TeV$ and $n = 3$.

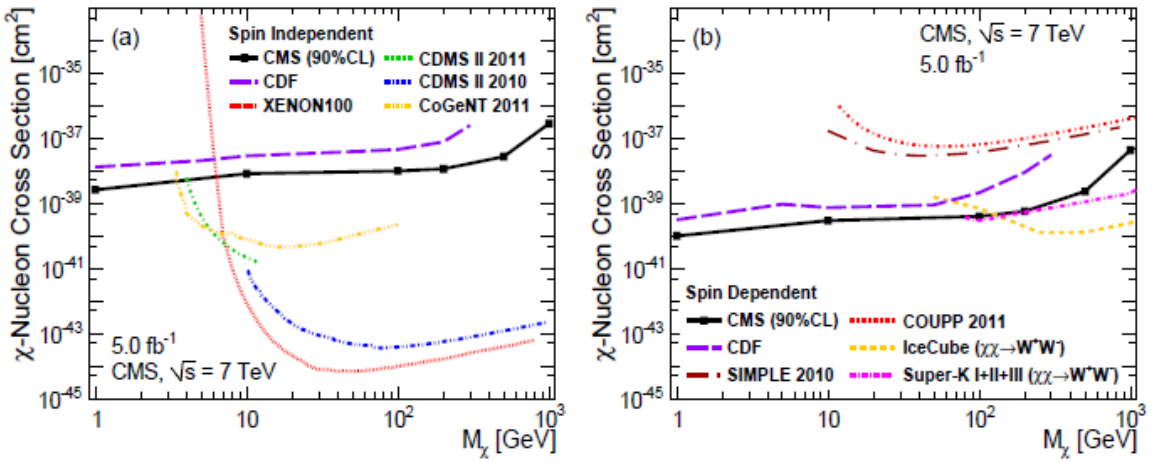


Figure 2. The 90% CL upper limits on the χ-nucleon cross section as a function of M_χ for (a) spin-independent and (b) spin-dependent scattering

11.1 ± 5.6 events.