Searches with unusual objects

Sourabh Dube

Jets at LHC at ICTS

25/1/2017

Outline

- Usual and Unusual objects
- Categories of unusual-object searches
  - Description of some searches

Usual Objects

- What do I mean by usual? *(in the context of searches)*

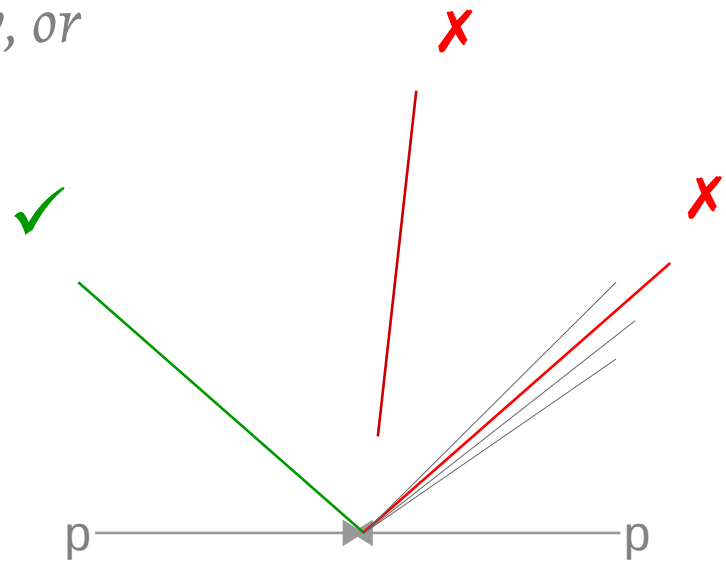
Usual Objects

- What do I mean by usual?
- When I say 'lepton', you know what I mean completely.

Usual Objects

- What do I mean by usual?
- When I say 'lepton', you know what I mean completely.

Mostly it means leptons arising from W/Z decay, or BSM, but looking like those from W/Z



Usual Objects

- What do I mean by usual?
- When I say 'lepton', you know what I mean completely.

Eur. Phys. J. C (2016) 76:317
DOI 10.1140/epjc/s10052-016-4149-y

THE EUROPEAN PHYSICAL JOURNAL C

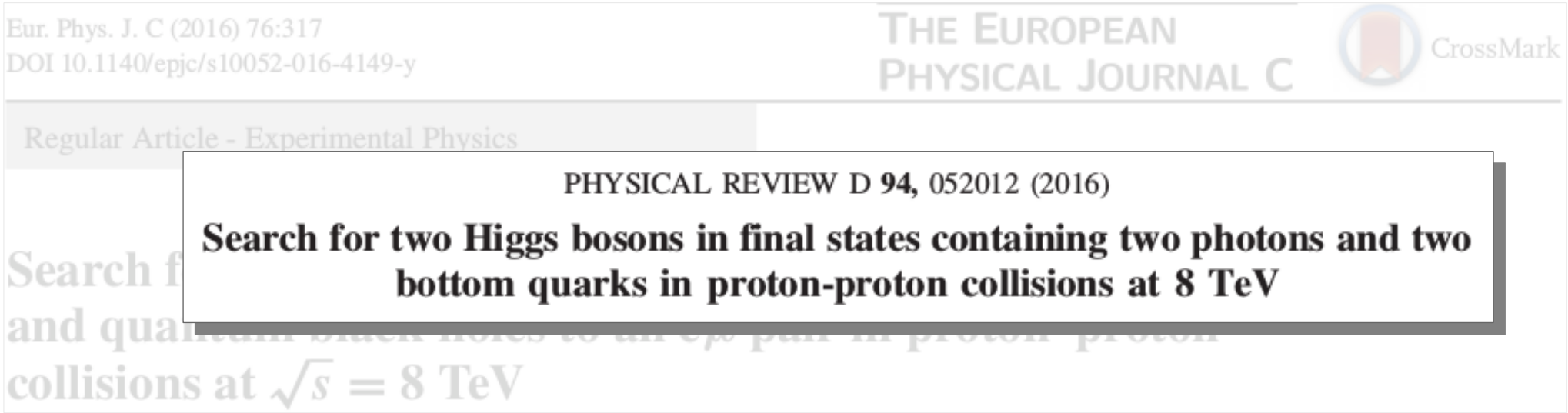
CrossMark

Regular Article - Experimental Physics

Search for lepton flavour violating decays of heavy resonances and quantum black holes to an eμ pair in proton–proton collisions at $\sqrt{s} = 8$ TeV

Usual Objects

- What do I mean by usual?
- When I say 'lepton', you know what I mean completely (*or photon, or jet*)

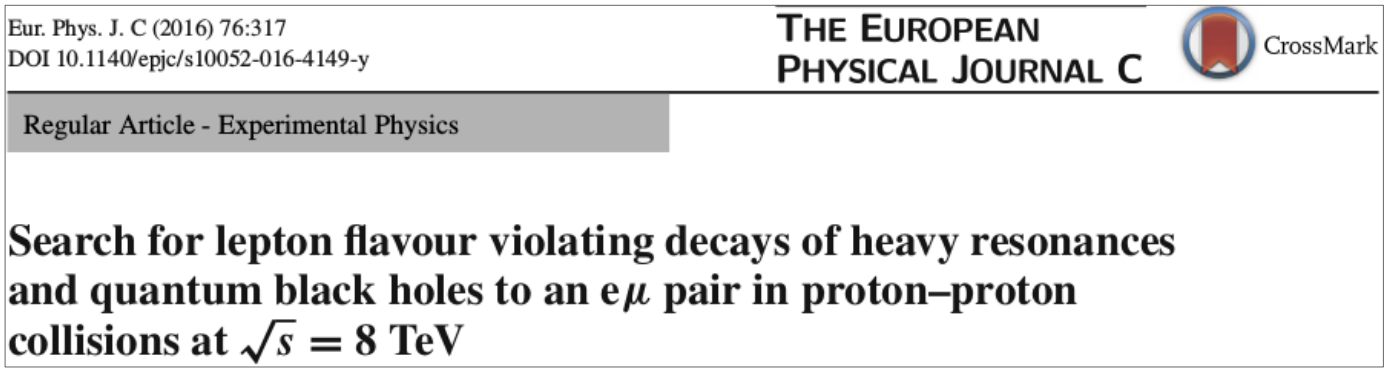


Usual Objects

- Additionally, when the final state is known – you can reasonably state what the major backgrounds will be.

Usual Objects

- Additionally, when the final state is known – you can reasonably state what the major backgrounds will be.



Eur. Phys. J. C (2016) 76:317
DOI 10.1140/epjc/s10052-016-4149-y

THE EUROPEAN PHYSICAL JOURNAL C

CrossMark

Regular Article - Experimental Physics

Search for lepton flavour violating decays of heavy resonances and quantum black holes to an eμ pair in proton–proton collisions at $\sqrt{s} = 8$ TeV

Usual Objects

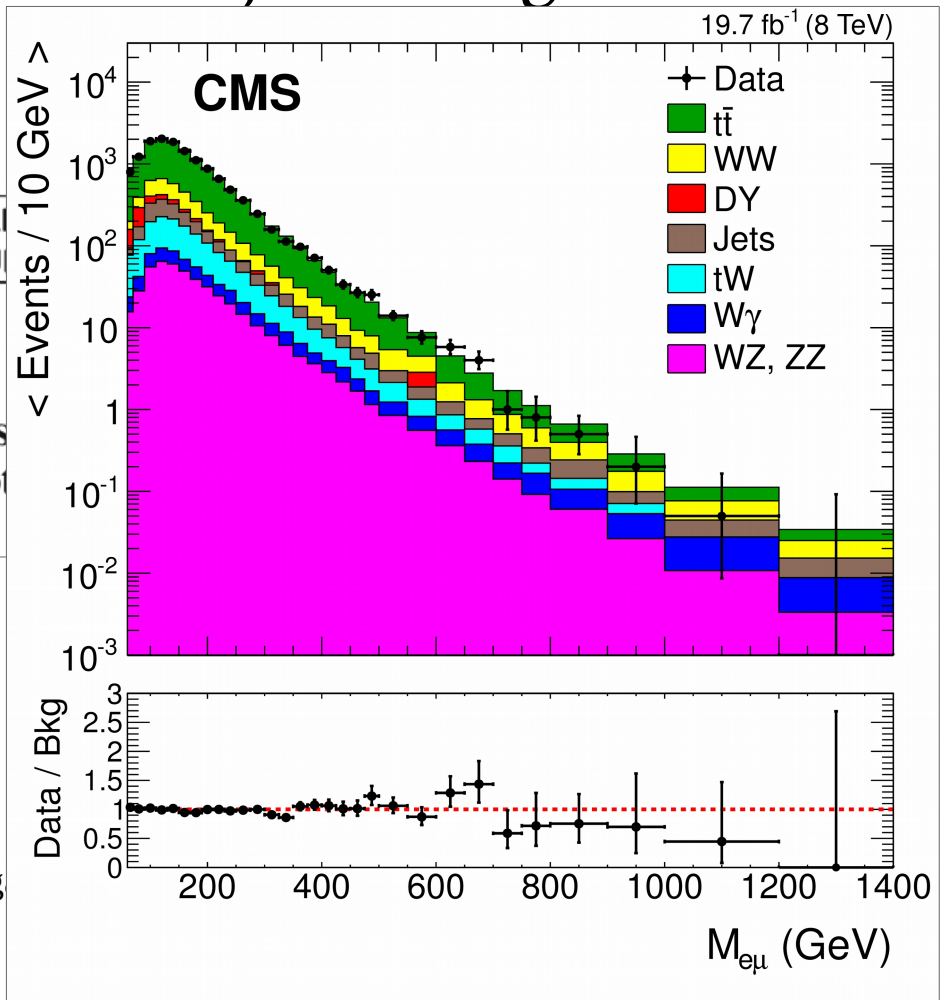
- Additionally, when the final state is known – you can reasonably state what the major backgrounds will be.

Eur. Phys. J. C (2016) 76:317
DOI 10.1140/epjc/s10052-016-4149-y

THE EUROPEAN PHYSICAL JOURNAL

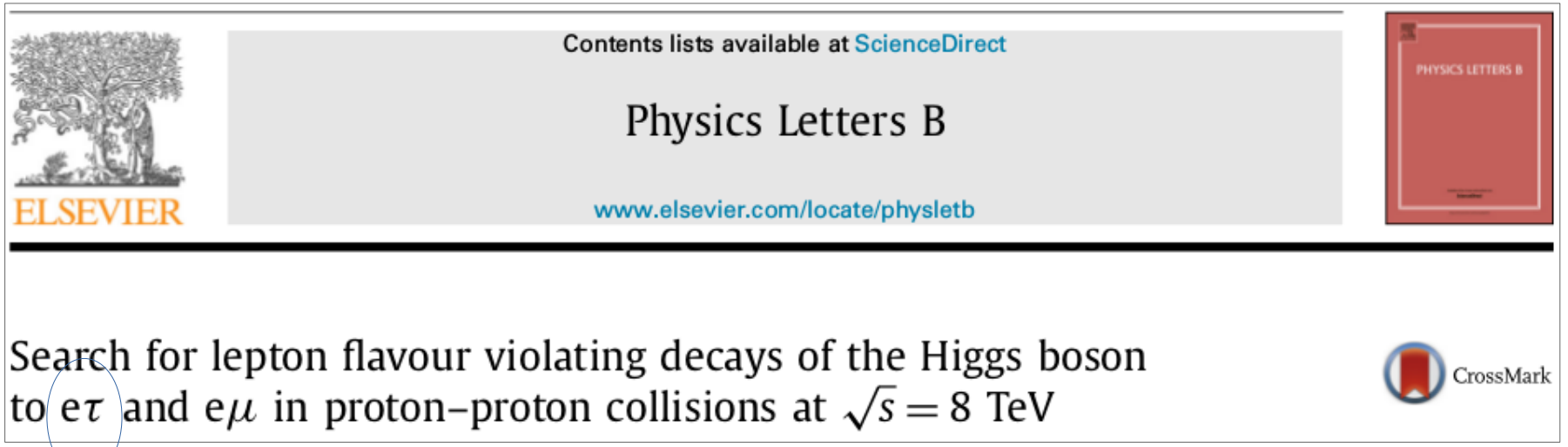
Regular Article - Experimental Physics

Search for lepton flavour violating decays of heavy res and quantum black holes to an eμ pair in proton–prot collisions at $\sqrt{s} = 8$ TeV



Usual Objects

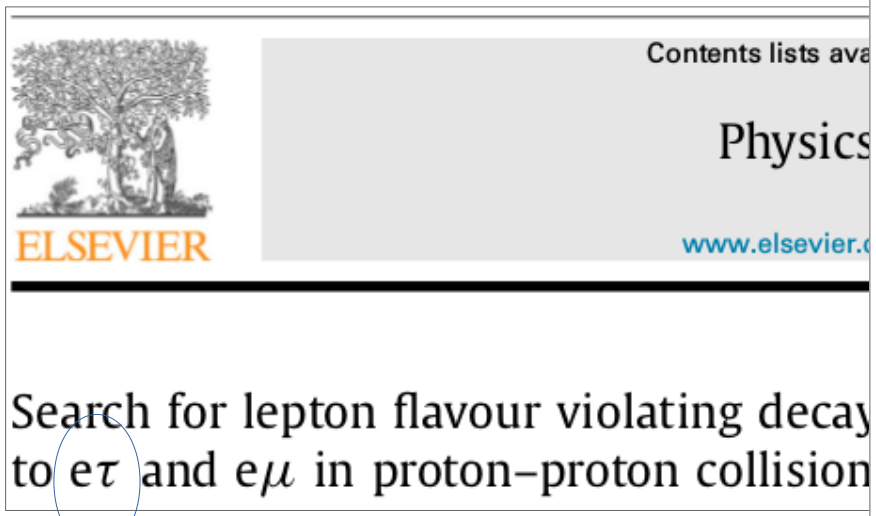
- Additionally, when the final state is known – you can reasonably state what the major backgrounds will be.



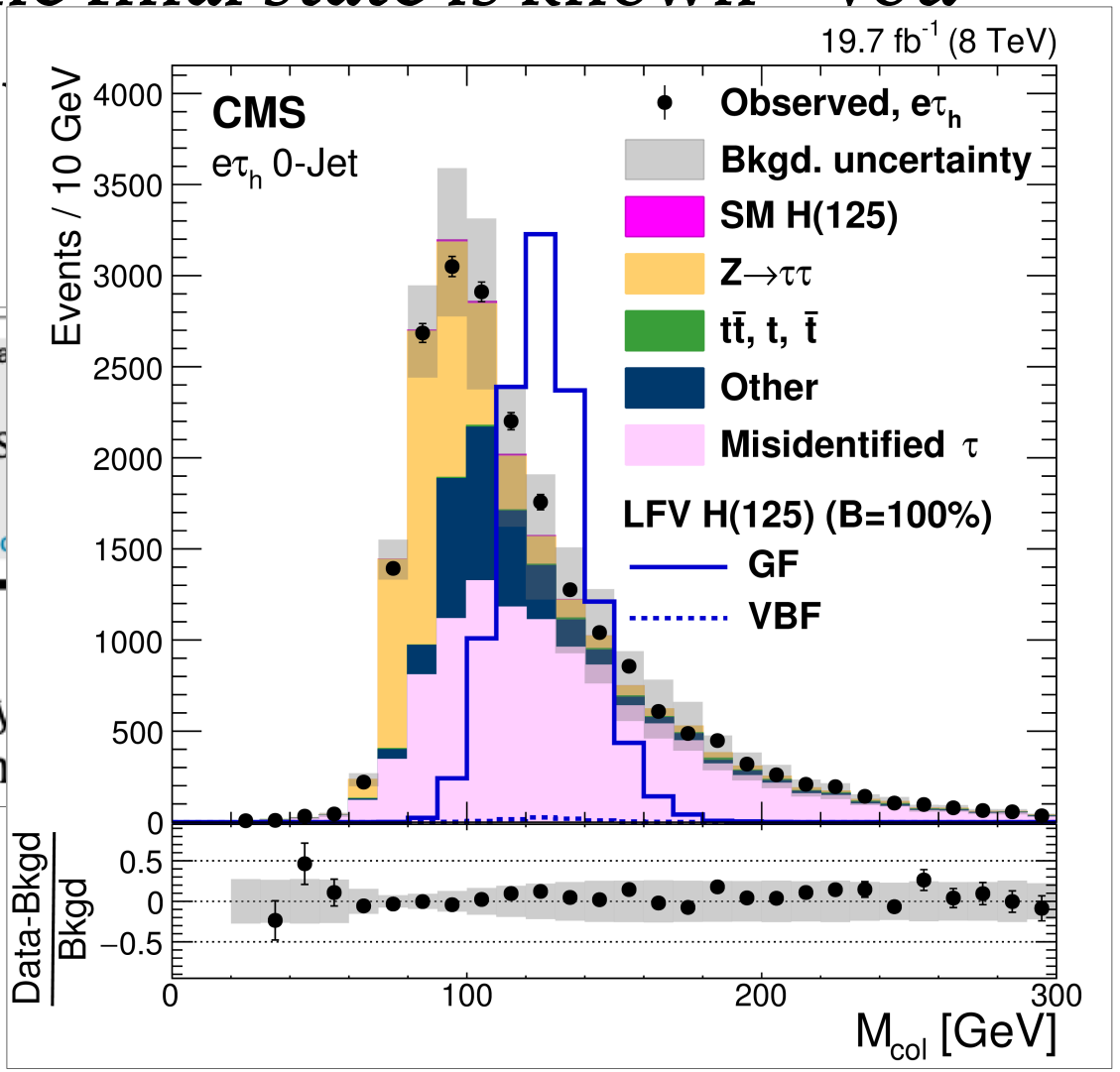
Physics Letters B 763 (2016) 472–500

Usual Objects

- Additionally, when the final state is known – you can reasonably state what will be.



Physics Letters B 763 (2016) 472–500



Unusual Objects

- Where lepton, or diphoton (*etc.*) needs additional qualifications to be appreciated

  (displaced photon, non-isolated lepton, ...)

- Where list of backgrounds needs second thoughts

Categorizing unusual objects

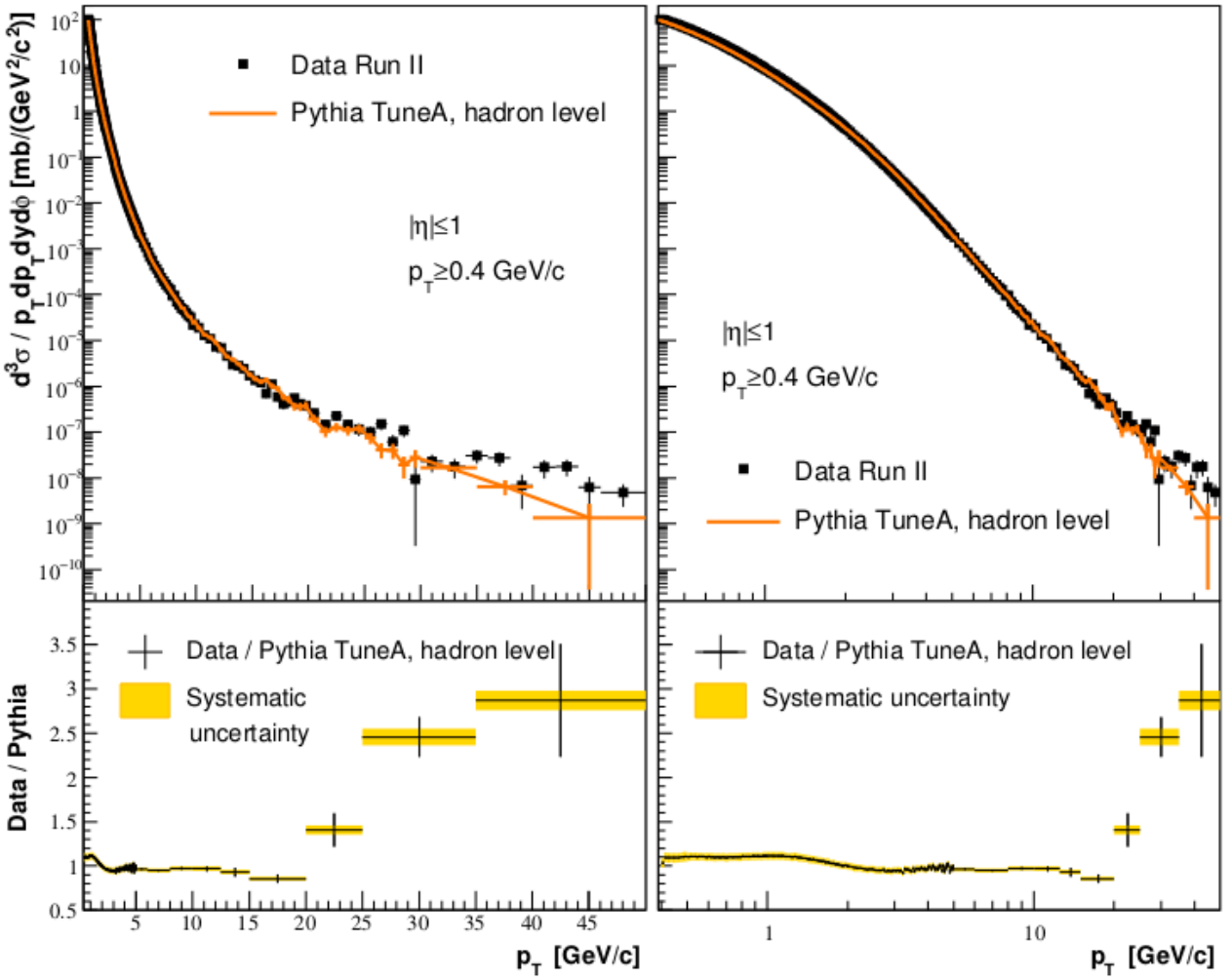
- Displacement
  - Leptons, Photons, Jets
- 'Jets' of leptons, photons
- Long-lived, stopped, disappearing
- Charge (Fractional, Large,...)
- Others

Categorizing unusual objects

Searches

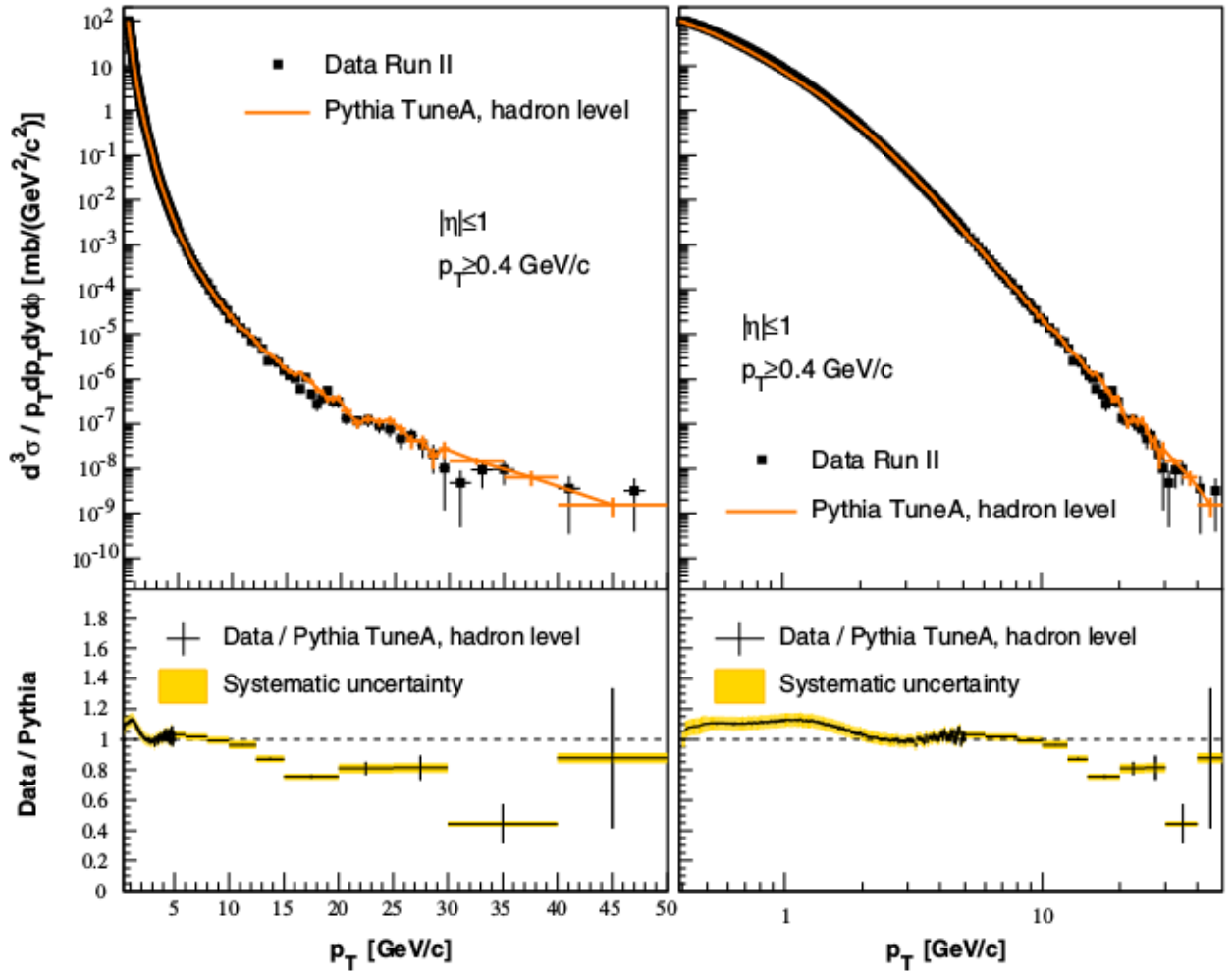
- Displacement
  - Leptons, Photons, Jets
- 'Jets' of leptons, photons
- Long-lived, stopped, disappearing
- Charge (Fractional, Large,...)
- Others

CDF Particle Production



Phys.Rev.D79:112005,2009;

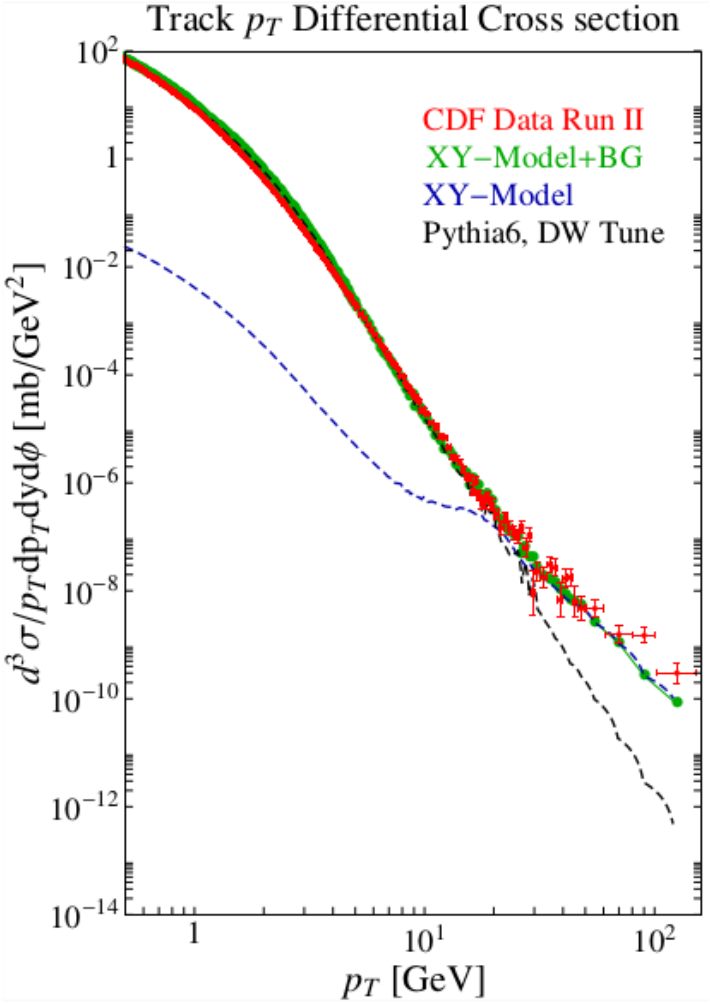
CDF Particle Production



Phys.Rev.D79:112005,2009;
Erratum-ibid.D82:119903,2010

Odd Tracks

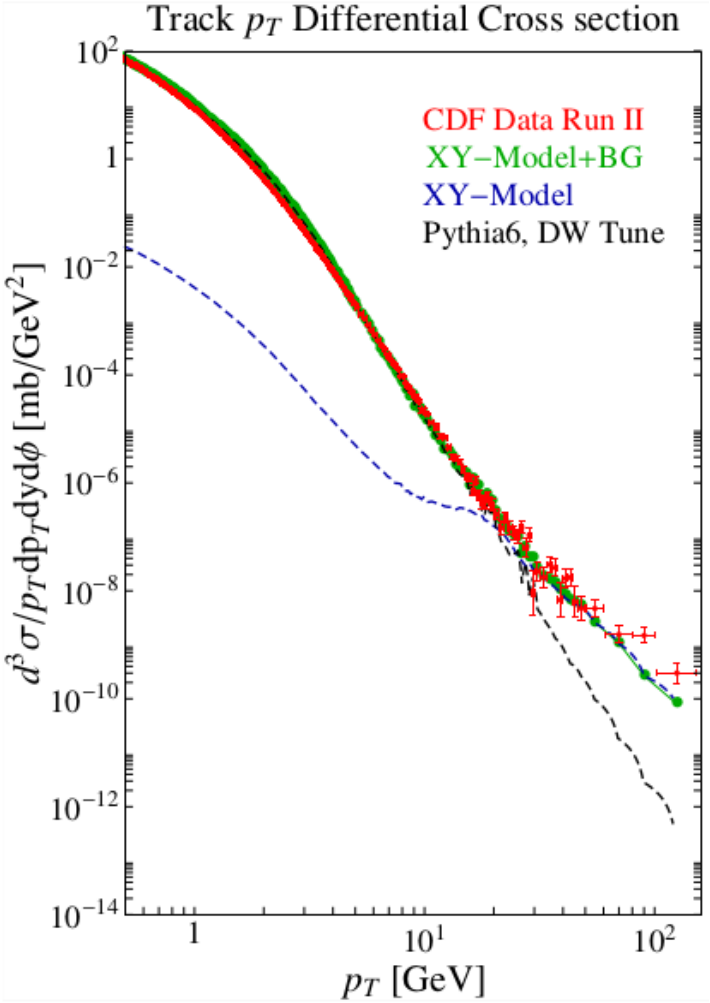
1103.3016



Meade, Papucci, Volansky:

Odd Tracks

1103.3016



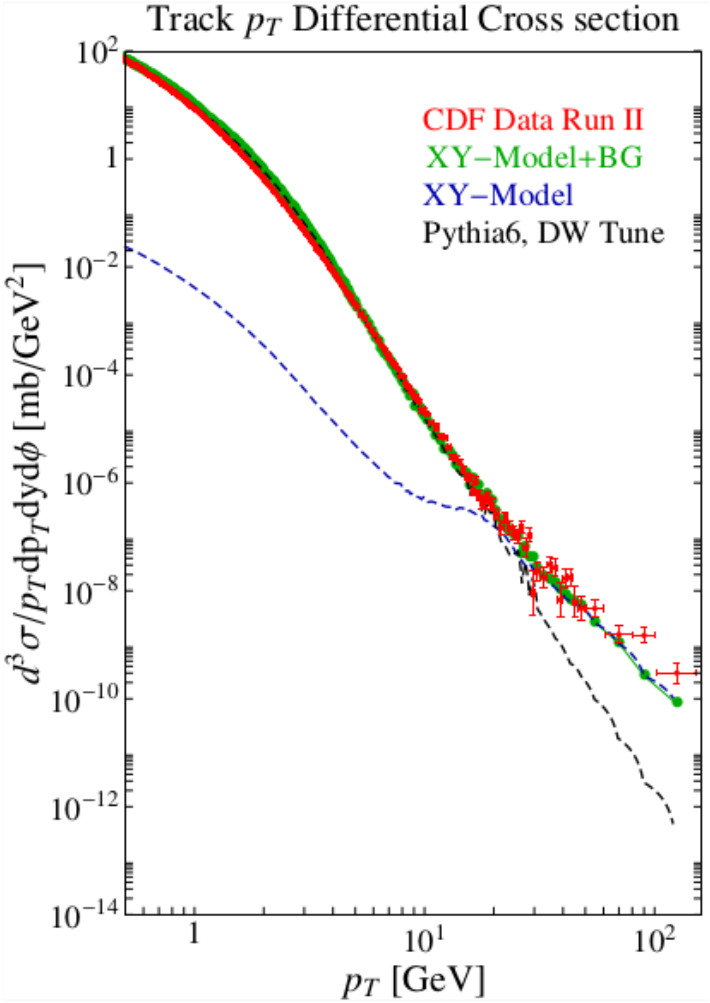
Meade, Papucci, Volansky:

New Odd Tracks (NOTs)

- Kinks
- Displaced vertices
- Anomalous dE/dx
- Anomalous timing
- Intermittent hits
- Anomalous curvature
- Stub tracks

Odd Tracks

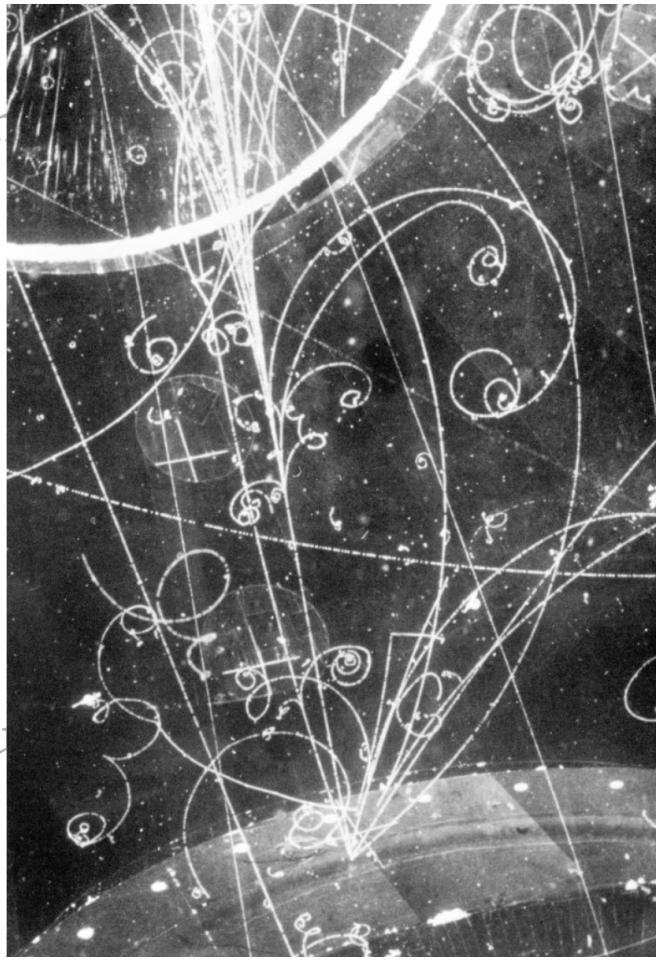
1103.3016



Meade, Papucci, Volan

New Odd Tracks

- Kinks
- Displaced vertices
- Anomalous dE/dx
- Anomalous timing
- Intermittent hits
- Anomalous curvatu
- Stub tracks



CDF: Phys.Rev.D79:112005,2009; Erratum-ibid.D82:119903,2010

https://astrobites.org/2016/08/02/leaving-on-a-jet-stream/

Fractionally charged Particles

1210.2311

Look for massive fermions L_q with charge $q = 2e/3, e/3$

Neutral under $SU(3)_C$, $SU(2)_L$ – couple only to photon, Z

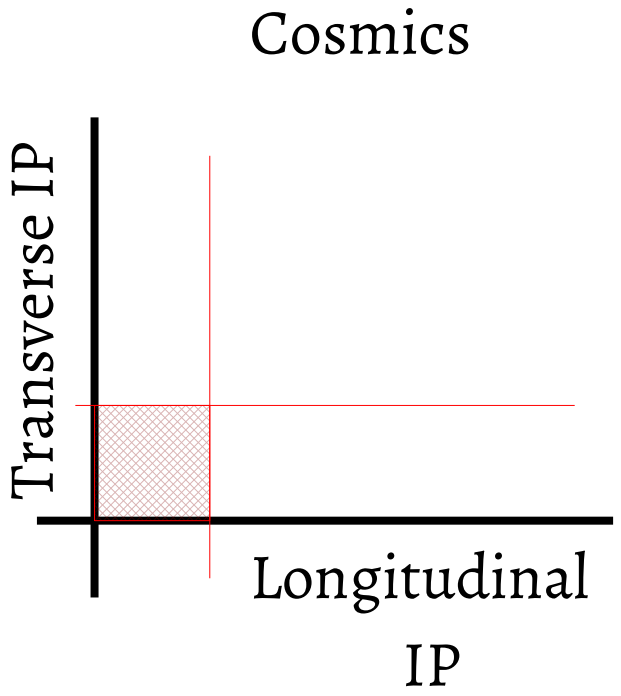
These are isolated tracks in the detector (use the tracker) –
but with anomalously low ionization energy losses.
Use dE/dx (signal amplitude/path length) in det. Module ($\propto q^2$)

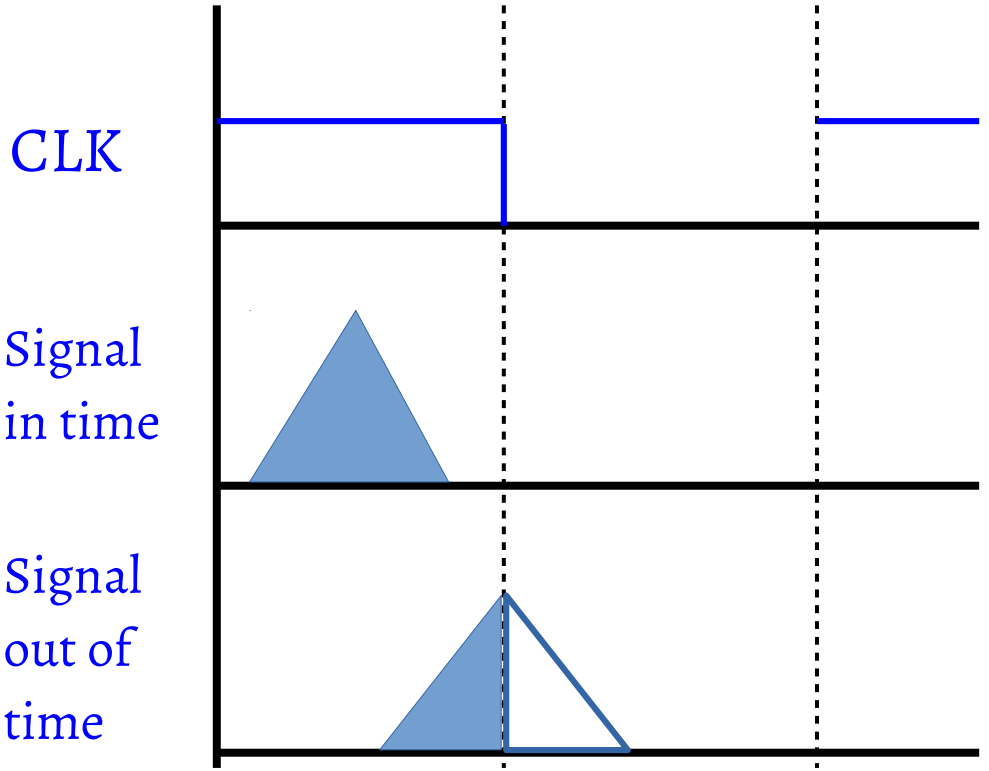
Trigger: Use a single muon trigger with pT>40 GeV
(But this 40 GeV is for $|q|=1$ particles)... so threshold is
L2/3 (27 GeV), L1/3 (13 GeV)

Backgrounds?

Fractionally charged Particles

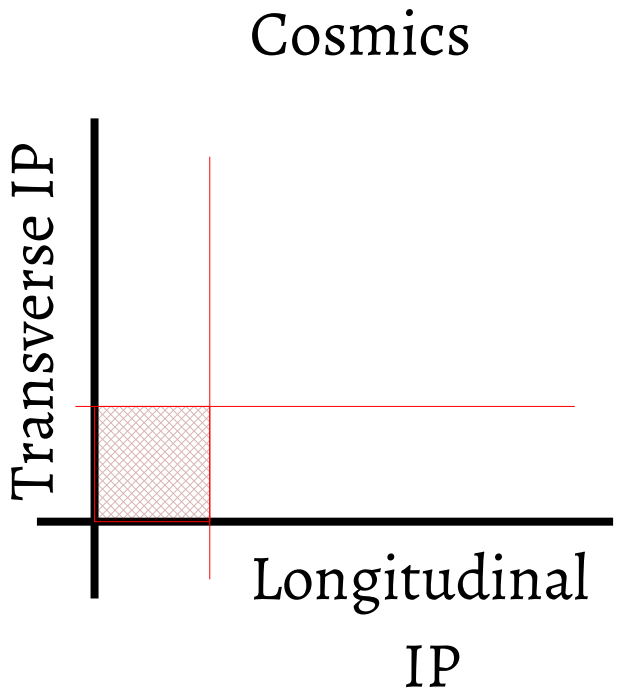
1210.2311

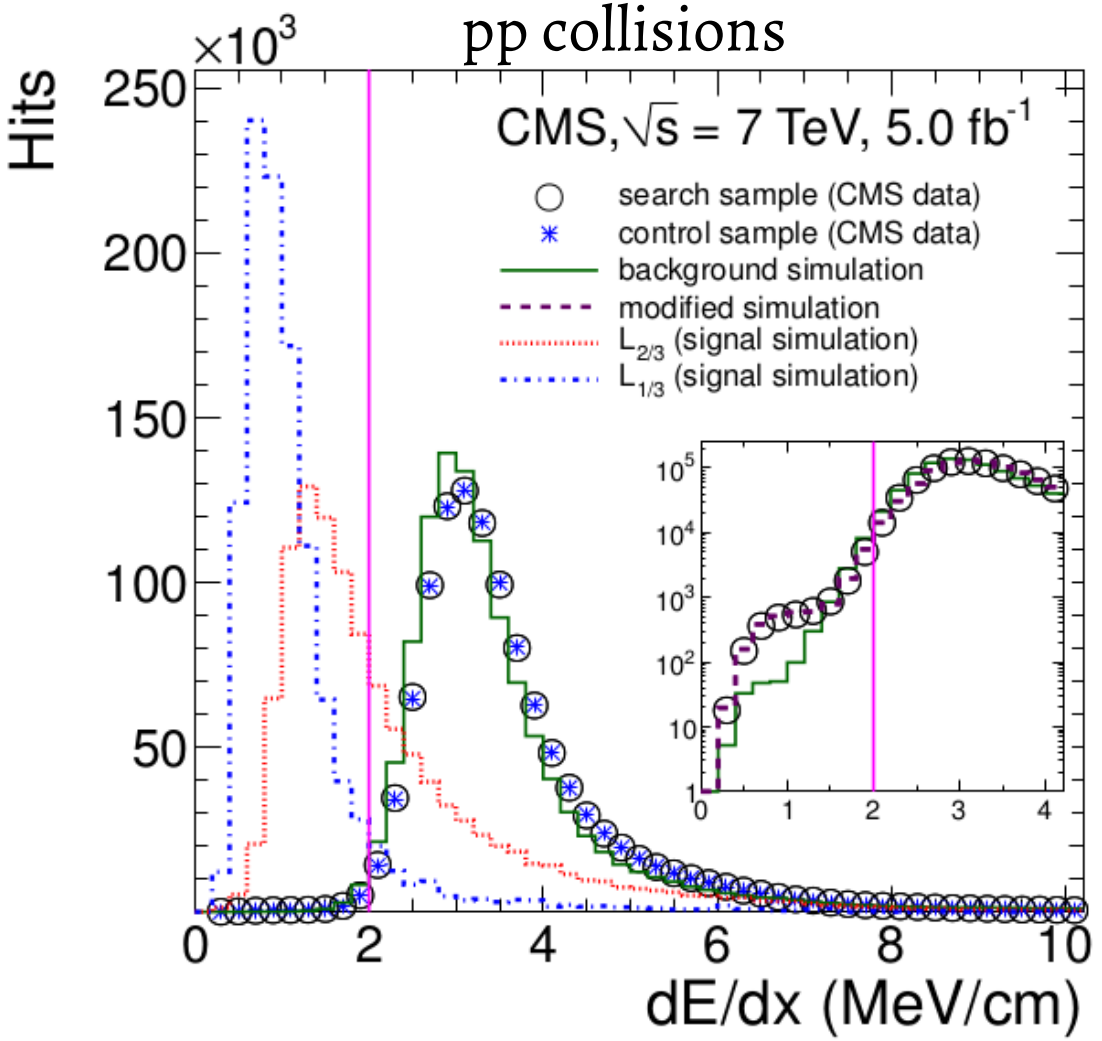




Fractionally charged Particles

1210.2311





Heavy Stable Charged Particles

1305.0491

Look for anomalously large dE/dx

Heavy particles, v less than c

Lepton-like or hadron-like

Heavy Stable Charged Particles

1305.0491

Look for anomalously large dE/dx

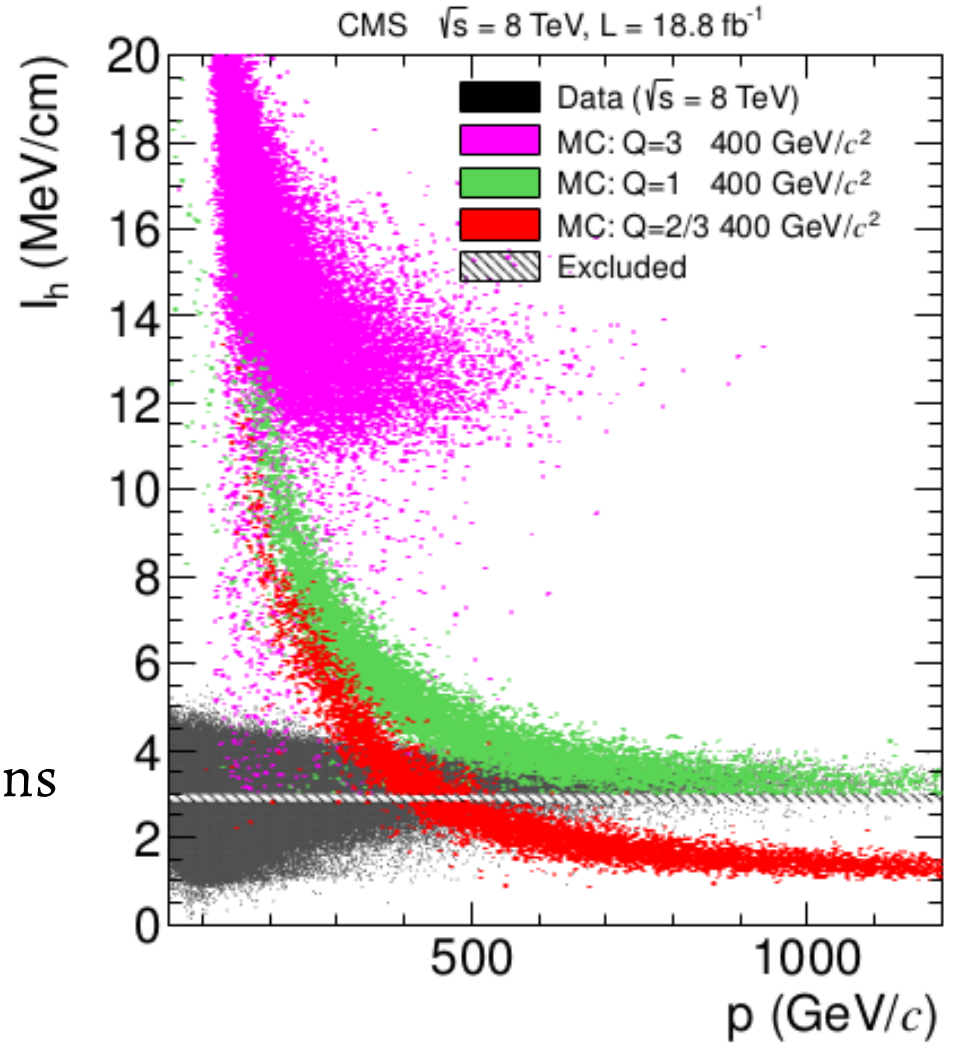
Heavy particles, v less than c

Lepton-like or hadron-like

I_h is dE/dx estimator,

TOF gives $\beta^{-1} = 1 + c\delta_t/L$

Backgrounds from random fluctuations in measured energy depositions, timings of SM particles



Large charge Particles

1509.08059

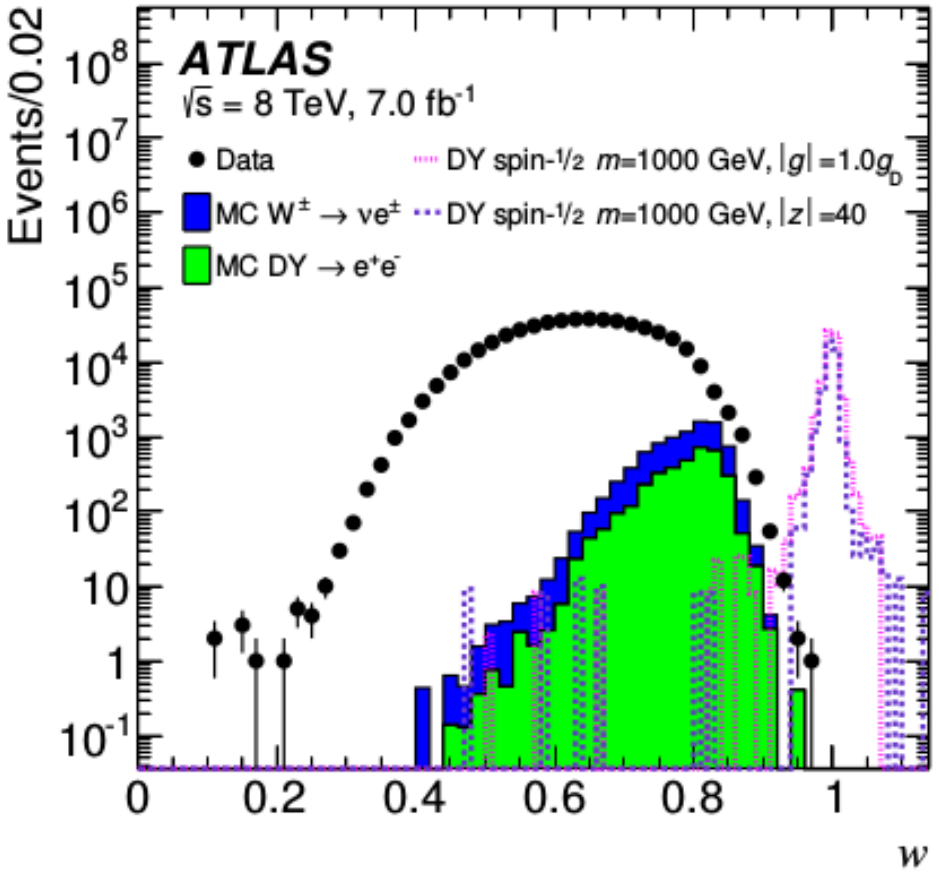
Magnetic monopoles!
In terms of ionization loss, q≈68e

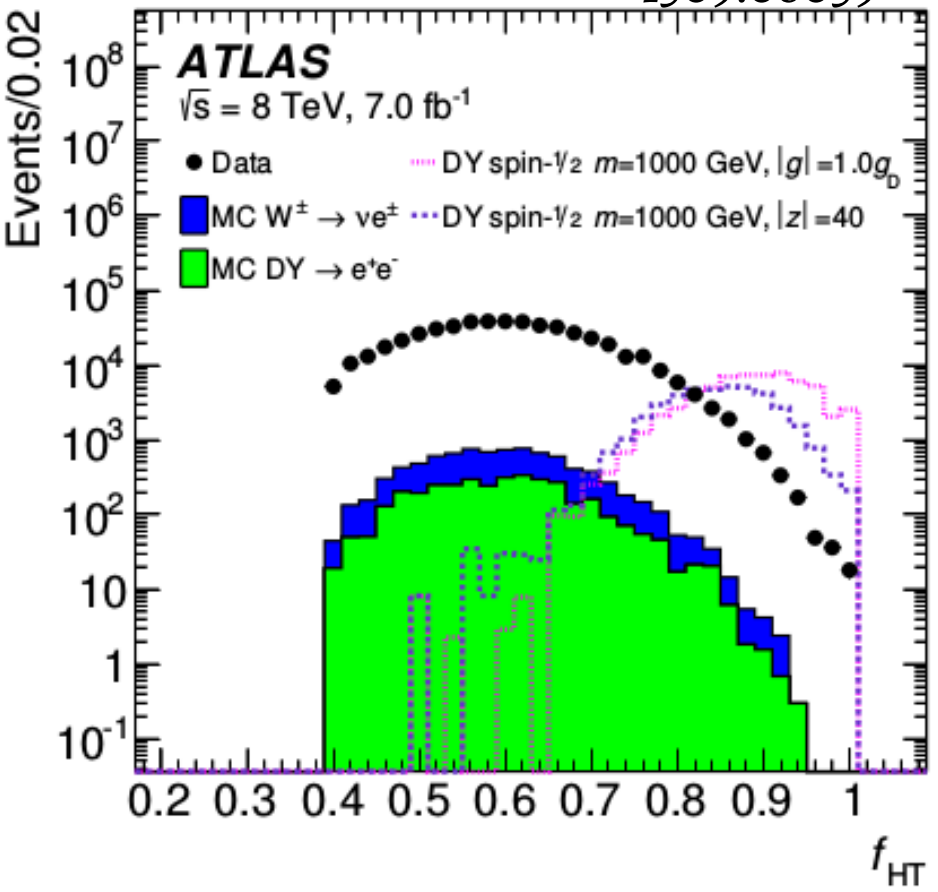
ATLAS makes use of its TRT and uses HT (high threshold) hits
HT ionization ≈ 3 x MIP

Dedicated Trigger
Calorimeter + TRT HT hits (total and fraction of total)

Large charge Particles

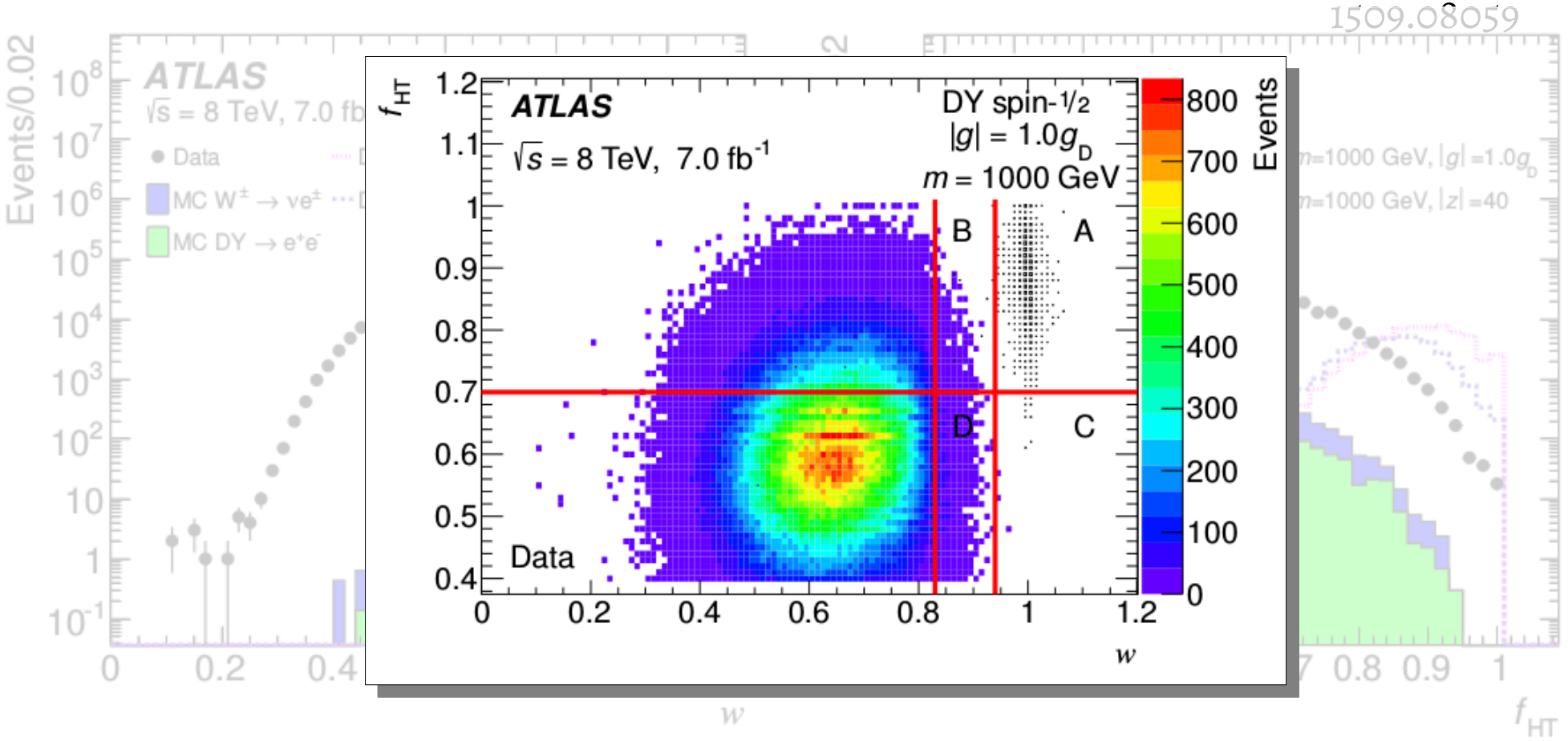
1509.08059





- f_{HT} is fraction of TRT HT hits in 'road'
- w is mean of EM energy dispersion seen in presampler, EM1, EM2 (fraction of total energy contained in most energetic cells)

Large charge Particles



- f_{HT} is fraction of TRT HT hits in 'road'
- w is mean of EM energy dispersion seen in presampler, EM1, EM2 (fraction of total energy contained in most energetic cells)

Disappearing Tracks

1310.3675, 1411.6006

Charged particle daughters are unobservable... the track disappears

$$\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0 \pi^{\pm}$$

If the chargino and neutralino are close in mass, the pion is soft

50 GeV prompt/isolated track, with < 10 GeV deposit in calorimeter

This track has missing outer hits in the tracker

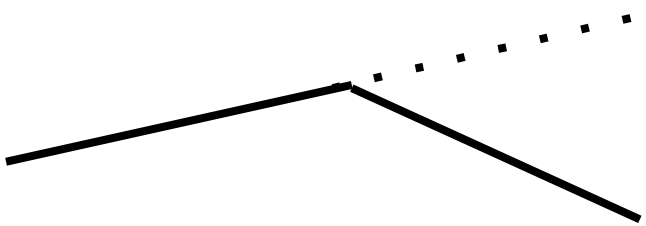
Trigger on ISR jet + MET (the track is not reconstructed as anything)

Disappearing Tracks

1310.3675, 1411.6006

Trigger on ISR jet + MET (the track is not reconstructed as anything)

Backgrounds are thus QCD multijet + inefficient ele, mu, tau recon.



Electron that brems hard

$$\pi^+ + n \longrightarrow \pi^0 + p$$

Charged hadron loses charge

Reduce multijet as usual (no b2b jets, MET not aligned with j1/j2)

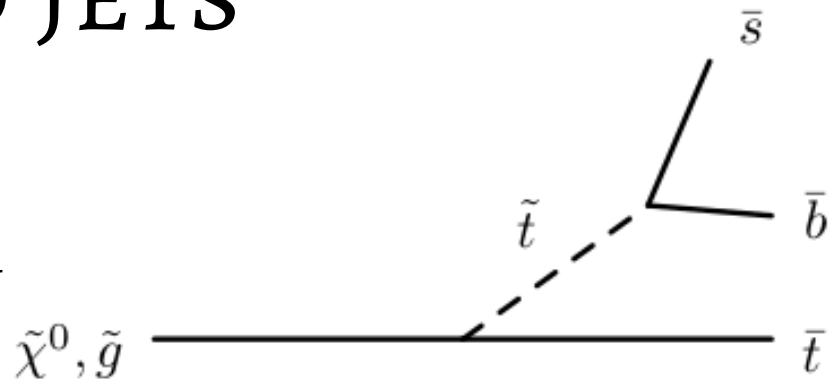
Estimate others by control region × inefficency

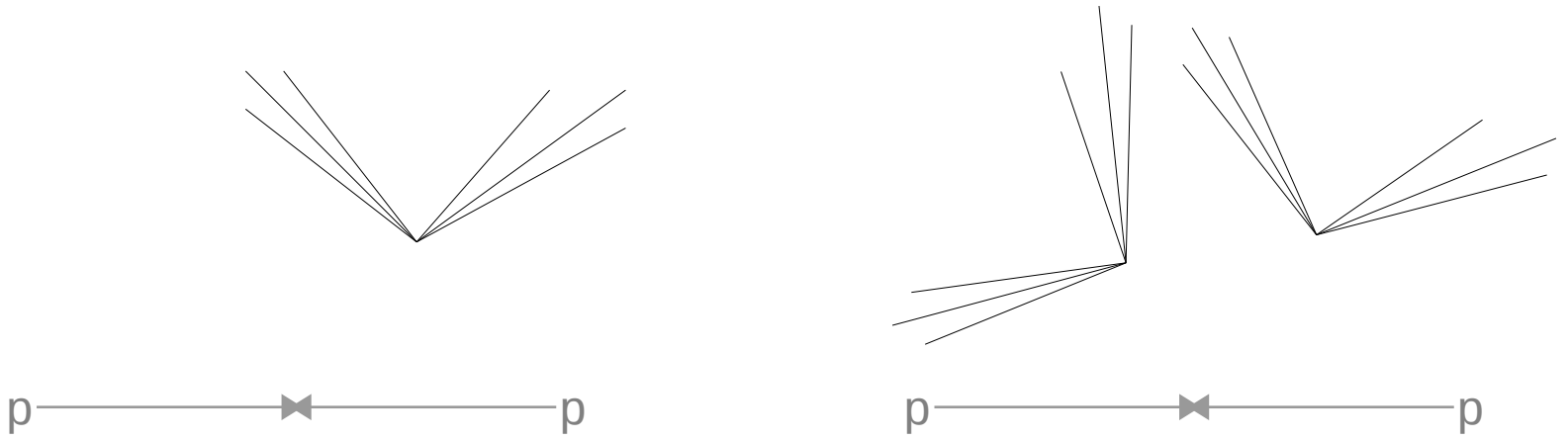
Displaced Jets

Long lived neutral particle decaying to qq

Long lived gluino/neutralino decay

Signature: jets emanating from a displaced vertex

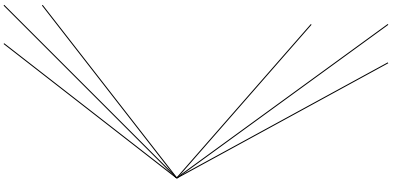




1411.6530, 1610.05133, ...

Displaced Jets

1411.6530

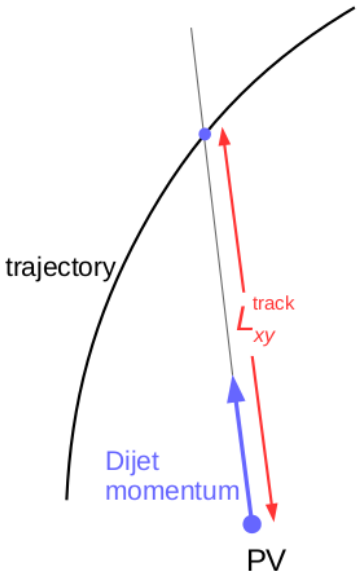


Dedicated displaced jet trigger:
Calo jets with H_T selection. Must have associated displaced tracks, carrying most of the jet's energy

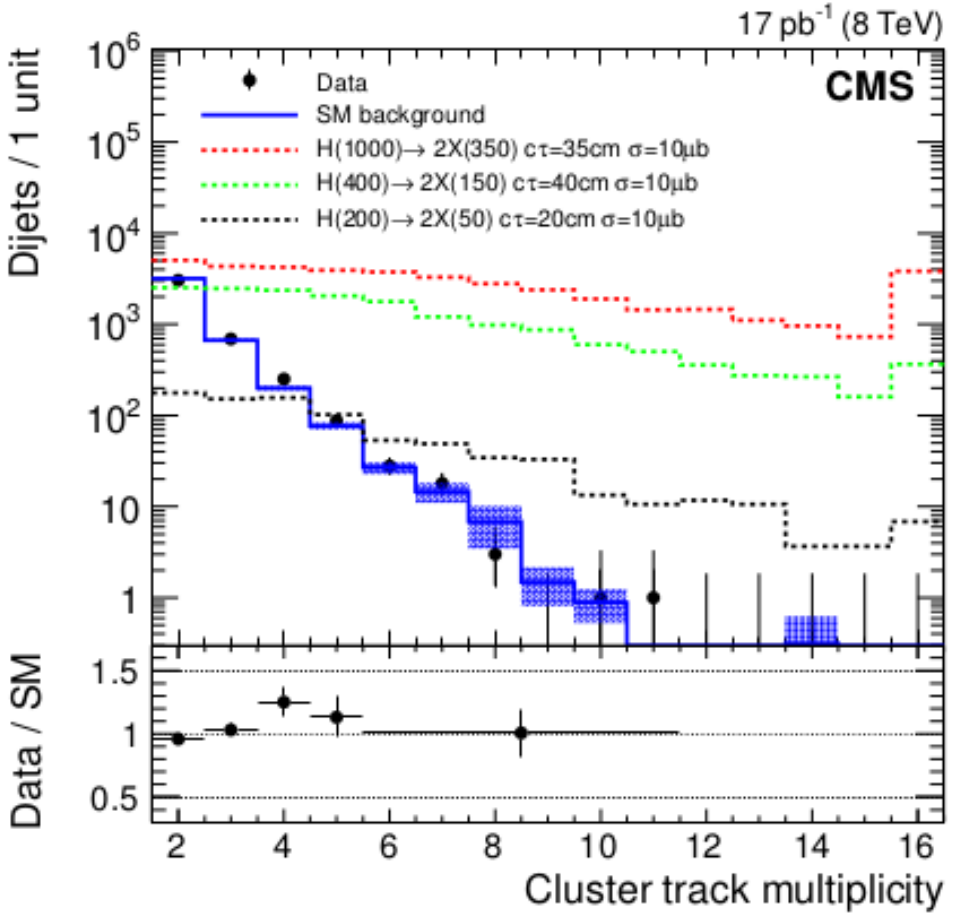
Require HT > 325, with two 60-GeV jets
Displaced tracks from both jets fitted to one vertex
Secvtx away from pvtx ($L_{xy}^{sig} > 8$)

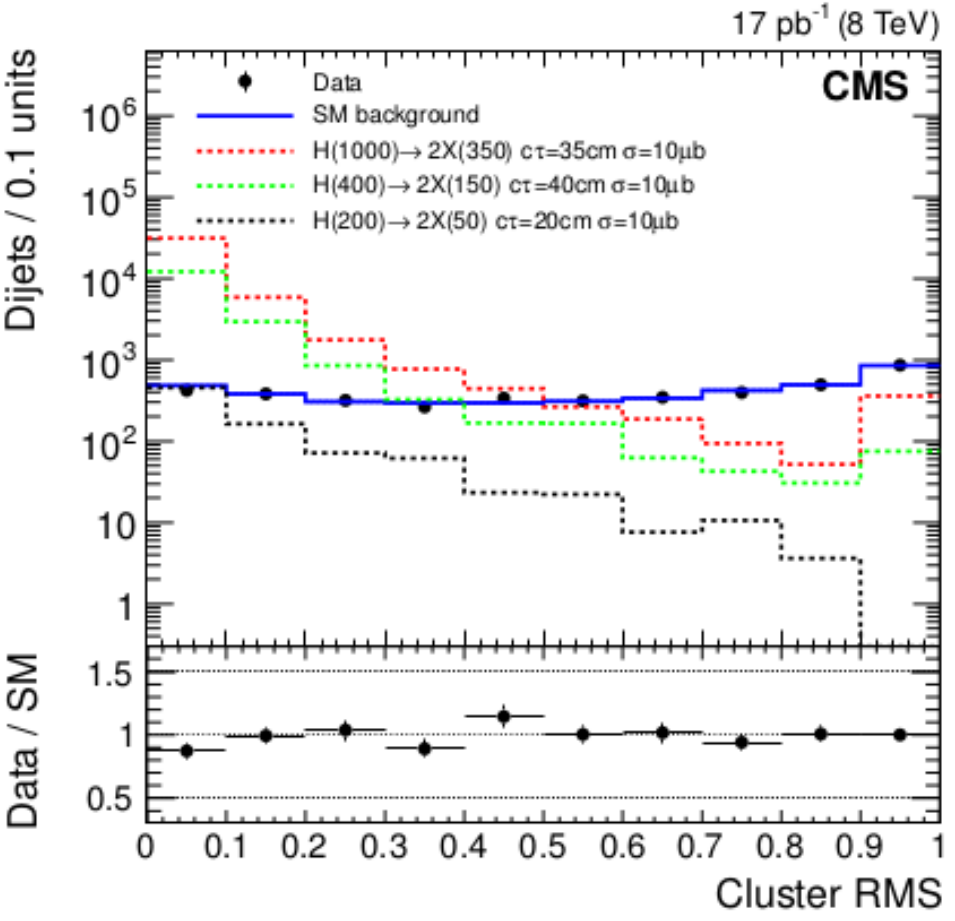
In addition, construct likelihood discriminant from

- Secvtx Ntracks
- Cluster Ntracks
- RMS L_{xy}^{trk}, w.r.t L_{xy}
- Pointing of secvtx tracks vs dijet momentum



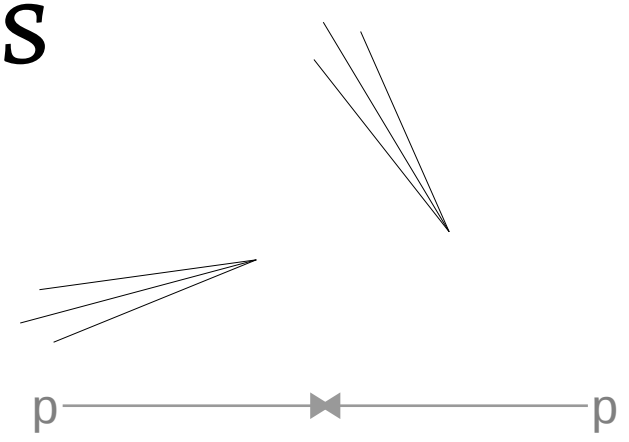
Displaced Jets





Displaced Jets

1610.05133



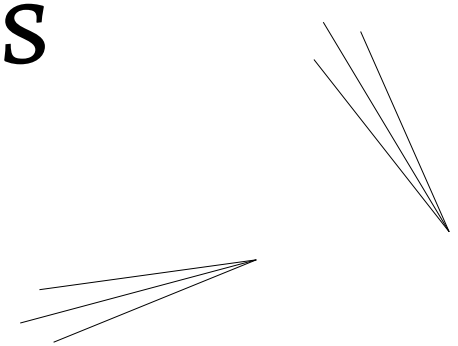
Pair produced long-lived gluino

Look for a pair of jets, each from a displaced vtx

Trigger on 4 calojets (60 GeV)

Displaced Jets

1610.05133

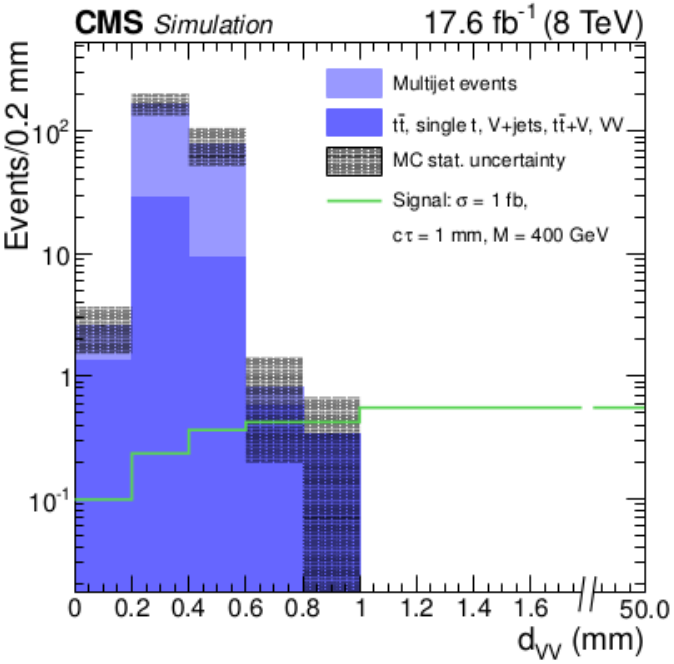


Pair produced long-lived gluino

Look for a pair of jets, each from a displaced vtx
Trigger on 4 calojets (60 GeV)

H_T>500 GeV
Form disp. vertices from disp. tracks, with requirements to ensure jets have disp tracks
Require =2 displaced vertices
Require large separation between them

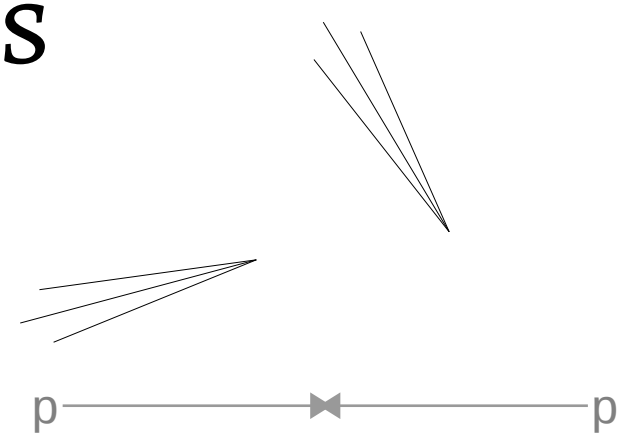
d_{VV} > 600 mm is signal region

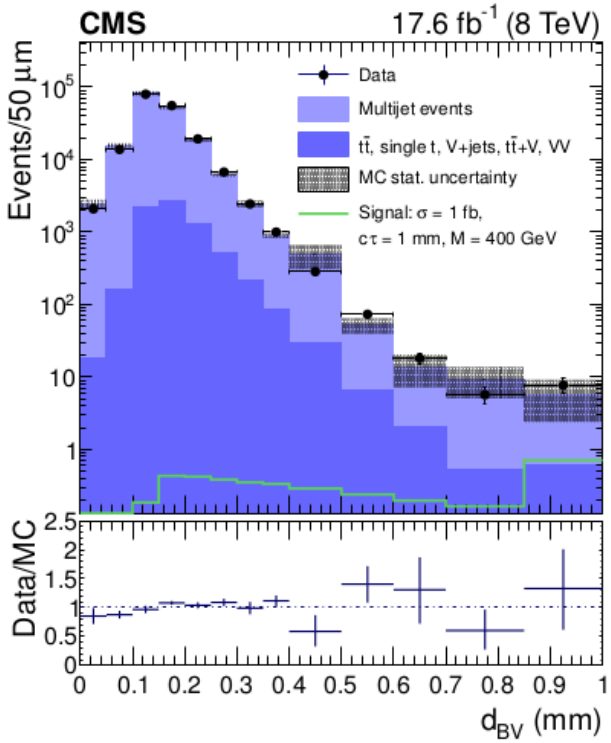


Displaced Jets

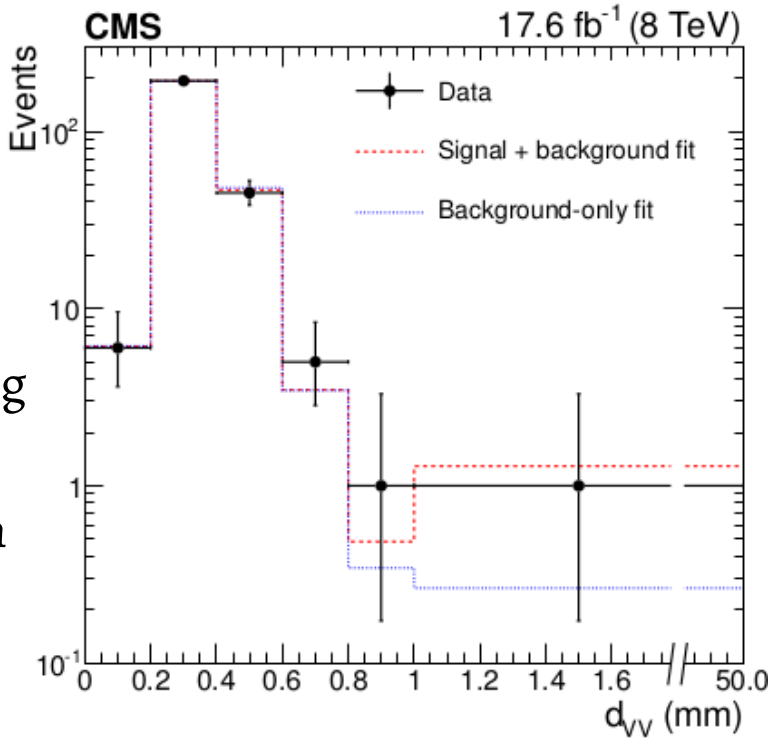
1610.05133

Use one-vtx events to build a template for distance between two vertices

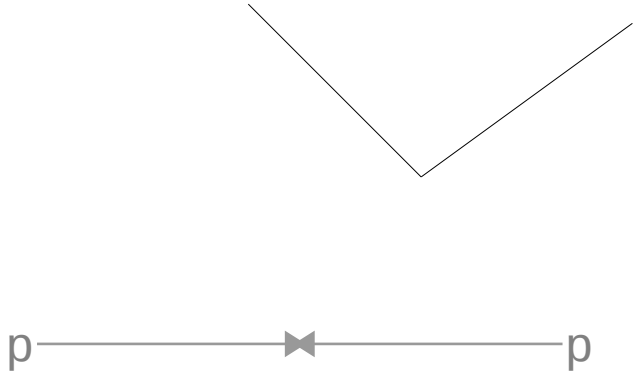




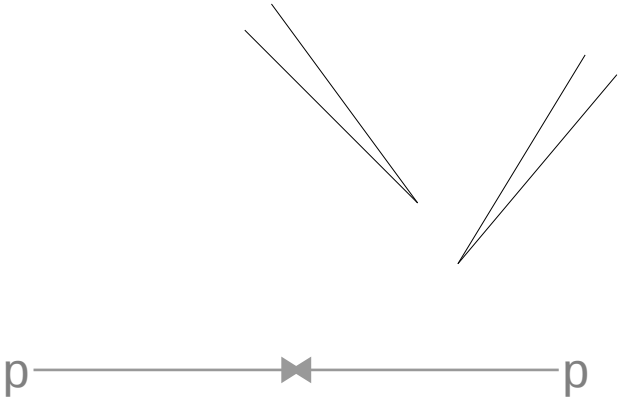
Excess corresponding to p-values of 0.05-0.14 for cτ 0.3-30 mm



Displaced Leptons



1411.6977, 1504.05162, ...



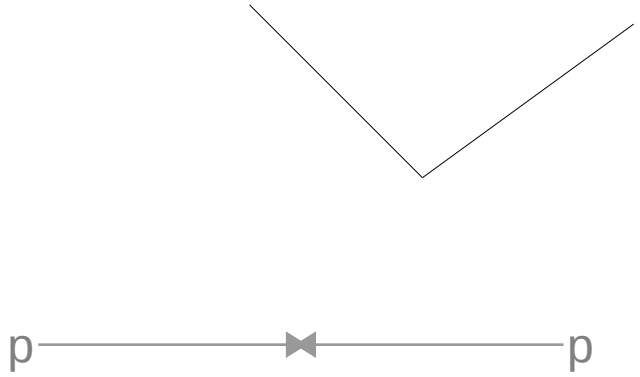
1409.0746, 1212.5409, ...

Displaced Leptons

1411.6977, 1504.05162, ...

$$H \to XX, X \to \ell^+\ell^-$$

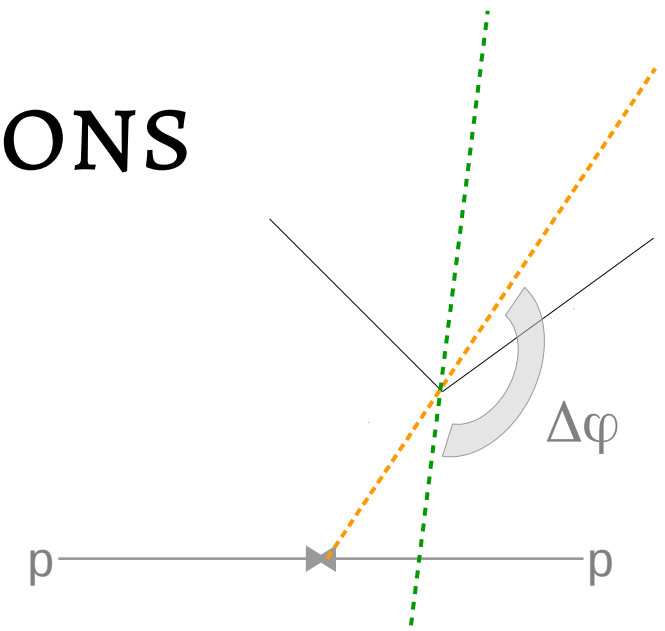
$$\tilde{q} \to q\tilde{\chi}^0, \tilde{\chi}^0 \to \ell^+\ell^-\nu$$



Displaced Leptons

1411.6977, 1504.05162, ...

$$H \rightarrow XX, X \rightarrow \ell^+\ell^-$$
$$\tilde{q} \rightarrow q\tilde{\chi}^0, \tilde{\chi}^0 \rightarrow \ell^+\ell^-\nu$$



Select isolated OS dimuons (26/26), dielectrons (40/25) with large impact parameters, and consistent with emerging from one vertex.
Backgrounds are SM dilepton which appear displaced due to resolution issues

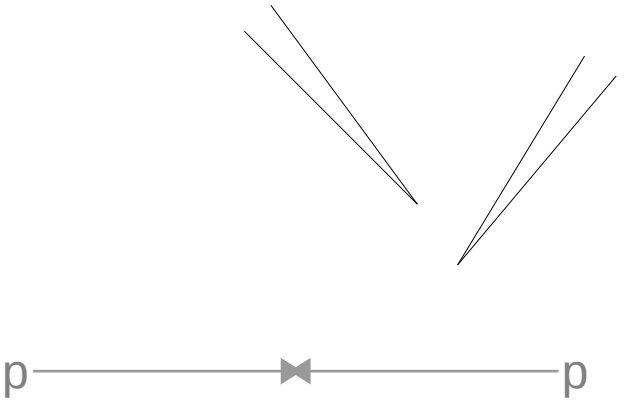
Require $M_{ll} > 15$ GeV

Require $\Delta\varphi < \pi/2$ for signal (invert for control sample)

Use impact parameter significance to scale control to signal region

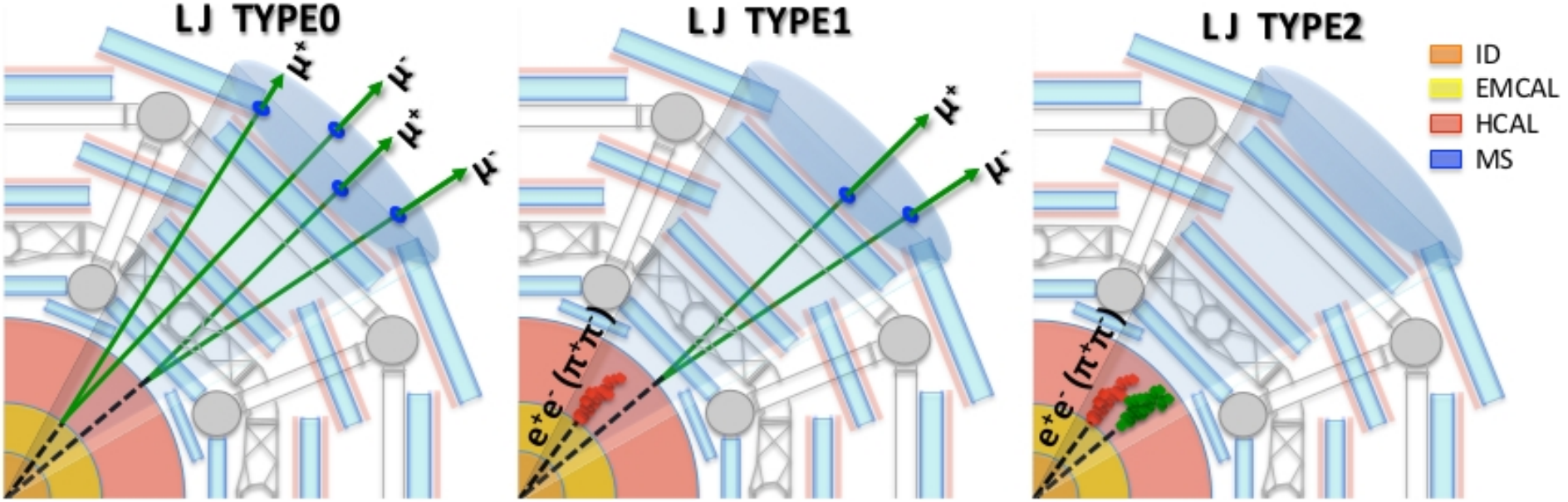
Displaced Lepton-Jets

1409.0746, 1212.5409, ...



Light (boosted) dark photons decaying to pair of electrons or muons or pions

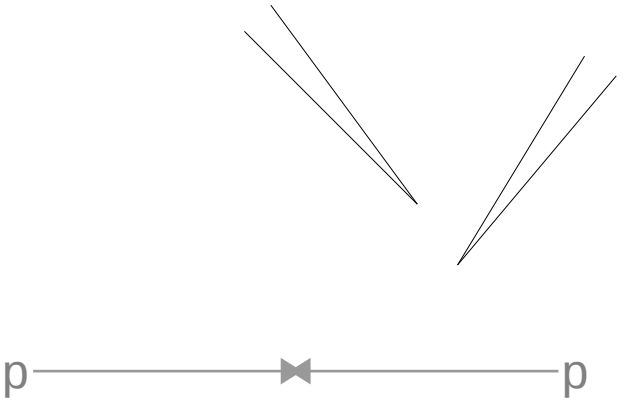
Signal studied using LJ gun MC generator

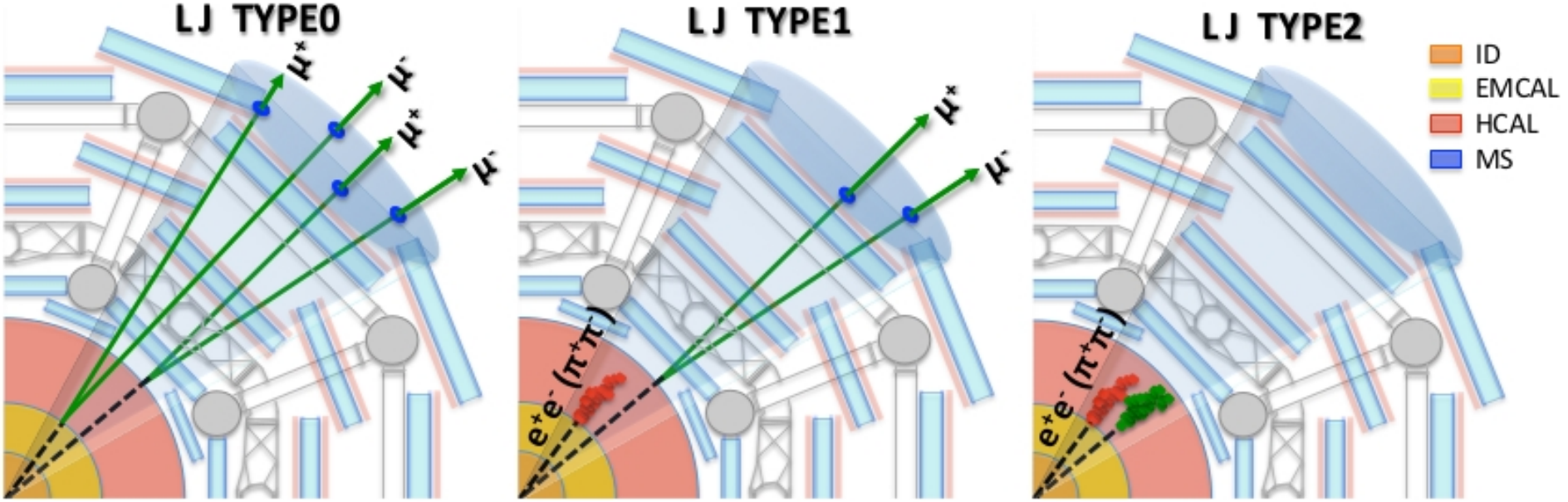


Displaced Lepton-Jets

1409.0746, 1212.5409, ...

Electron/pion clustered using antikt4 algorithm
Then muons, jets clustered into LJ using fixed cone algorithm (R=0.5)

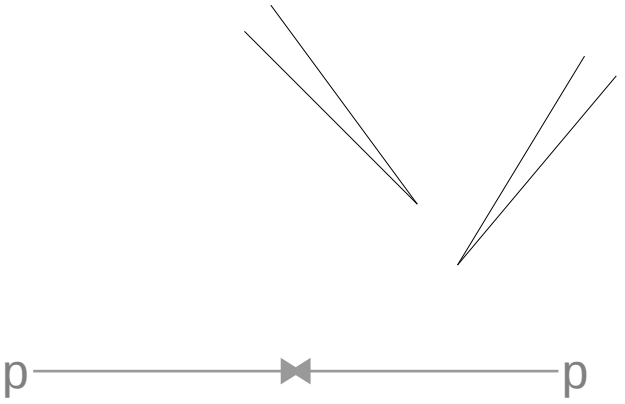




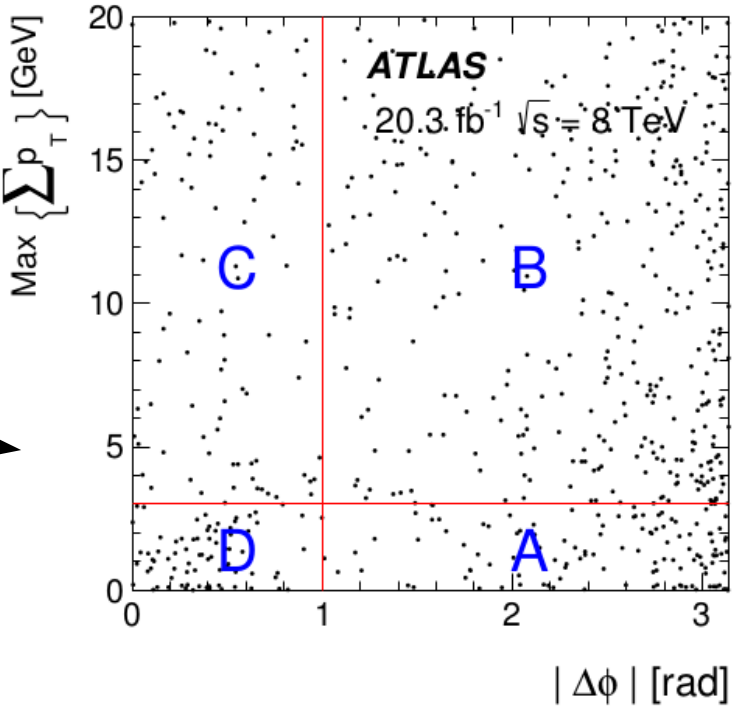
Displaced Lepton-Jets

1409.0746, 1212.5409, ...

Require 2 LJ's per event
Require large azimuthal separation ($\Delta\varphi>1$)
Background for LJ0 is cosmics (use IP cuts)
Background for LJ2 is multijet (use isolation)



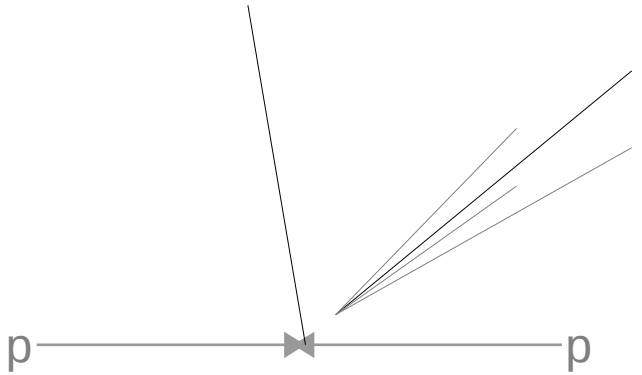
Estimate cosmics from empty BX, estimate DY/$t\bar{t}$ from MC, estimate multijet from ABCD method



Isolated+Nonisolated Muons

1308.4075

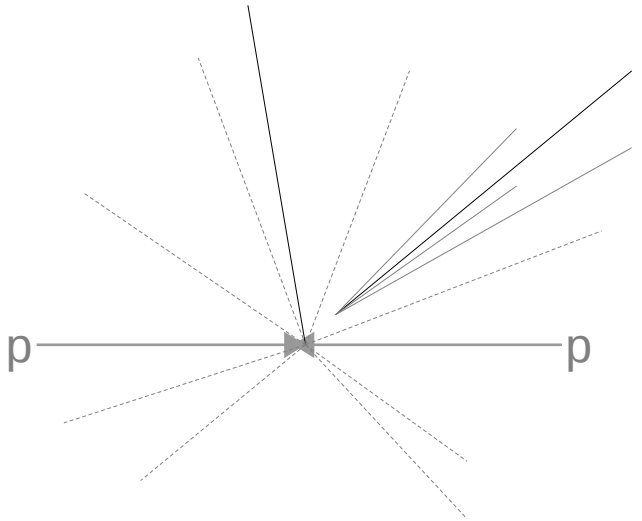
Require one loosely isolated hard muon
(pT>100 GeV, iso<20%),
+ one other muon of *same charge* as first one
(no requirements on isolation, or IP)

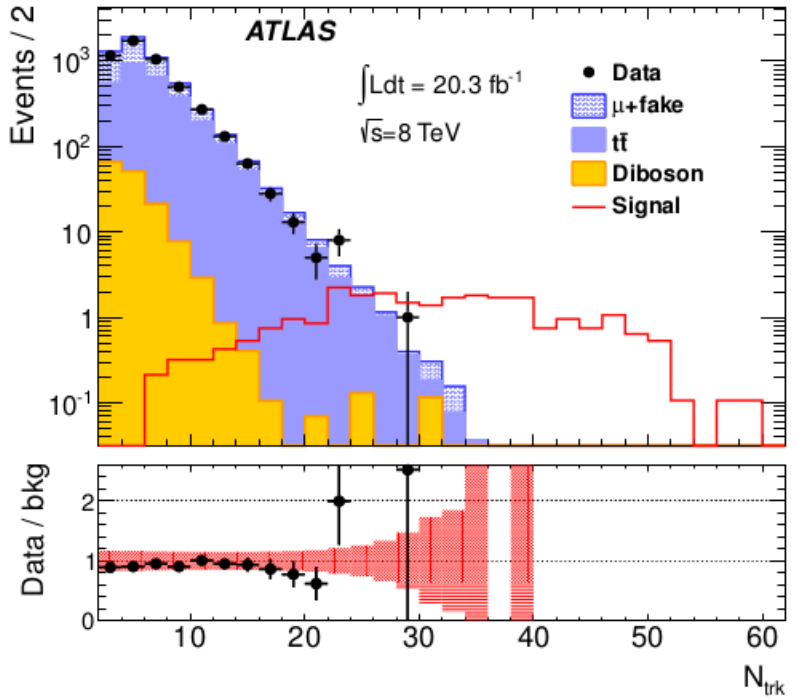


Isolated+Nonisolated Muons

1308.4075

Require one loosely isolated hard muon
(pT>100 GeV, iso<20%),
+ one other muon of *same charge* as first one
(no requirements on isolation, or IP)
+ many tracks (10 GeV each)

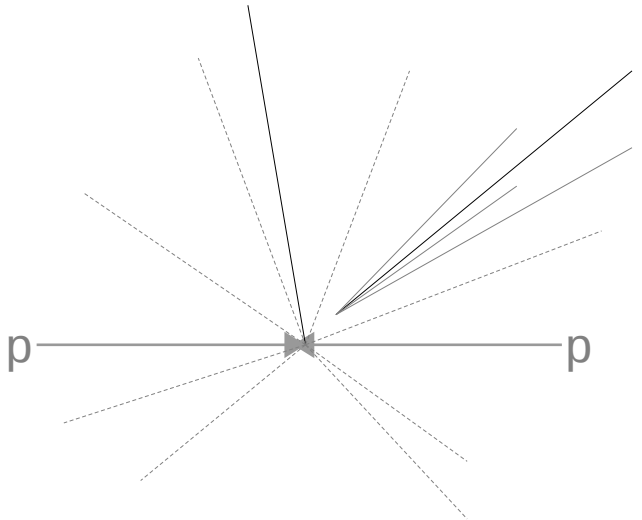


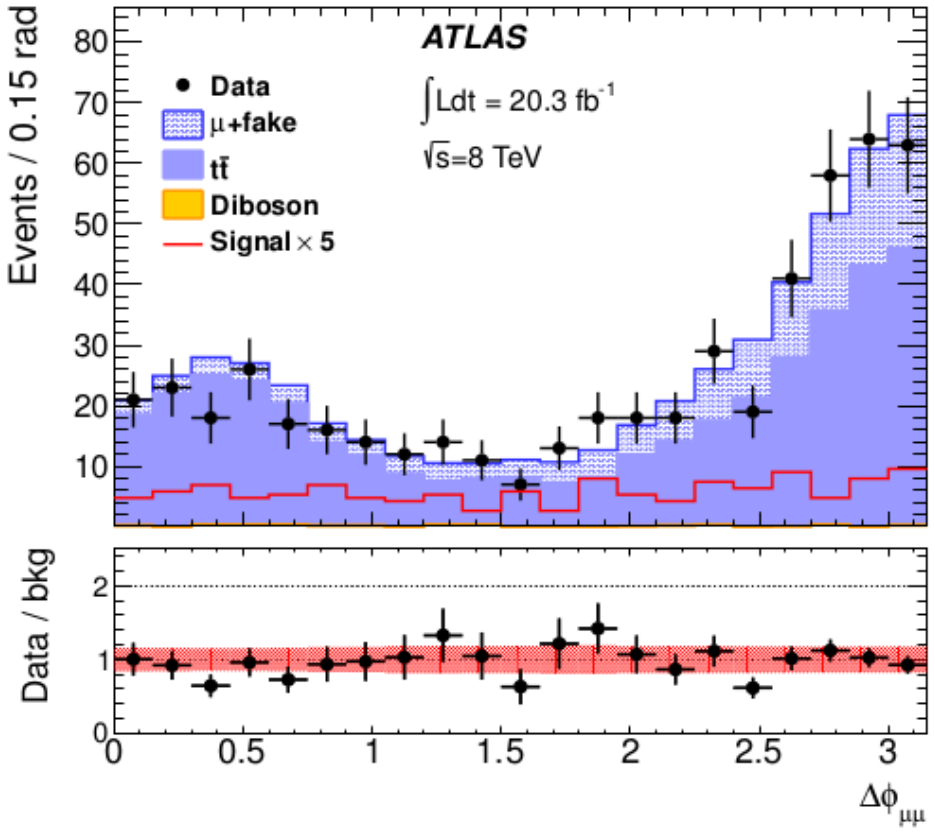


Isolated+Nonisolated Muons

1308.4075

Require one loosely isolated hard muon
(pT>100 GeV, iso<20%),
+ one other muon of *same charge* as first one
(no requirements on isolation, or IP)
+ many tracks (10 GeV each)

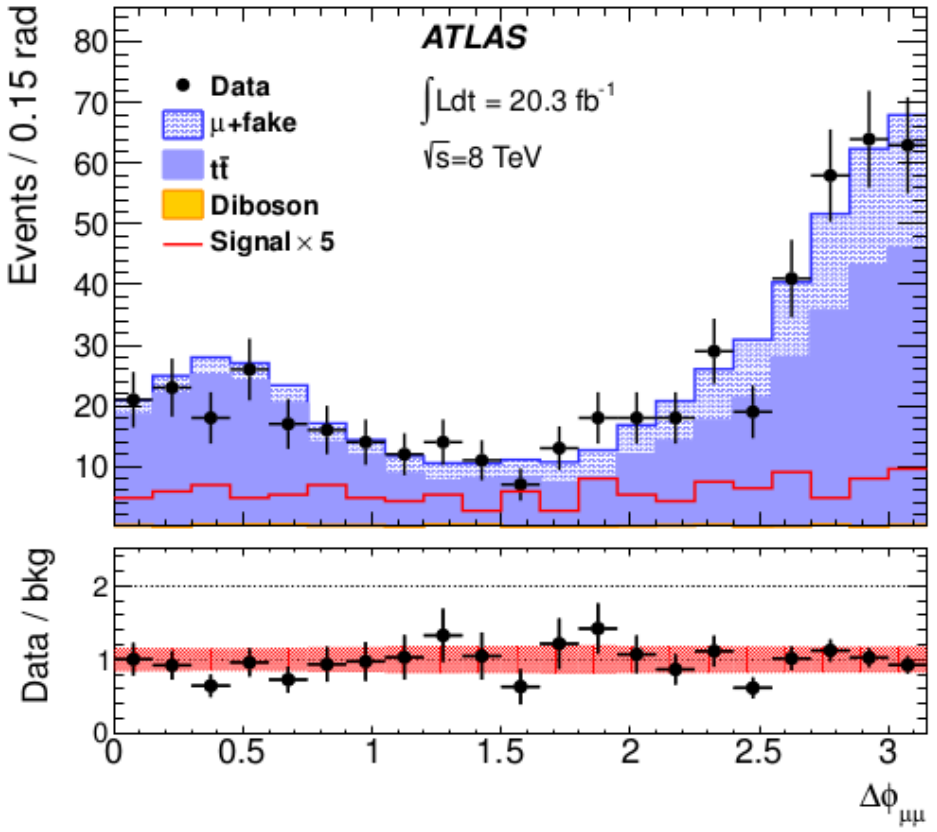


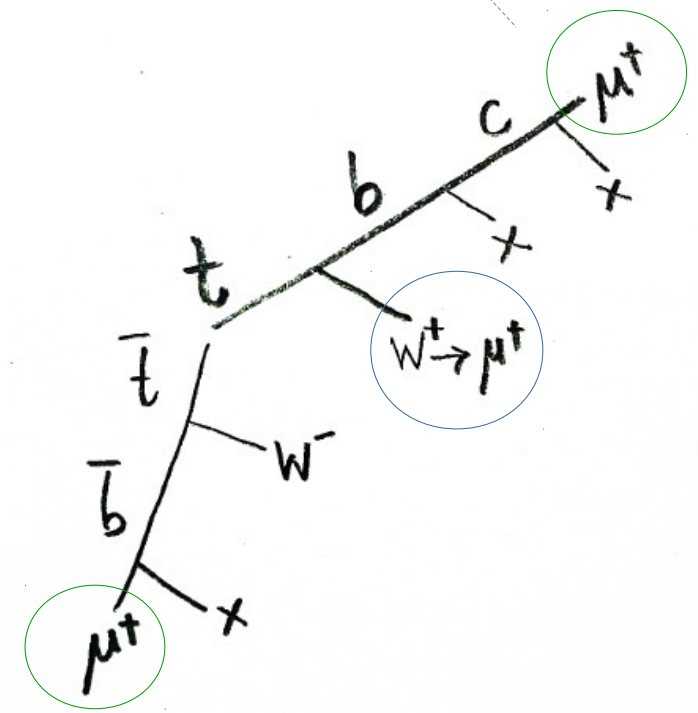


Isolated+Nonisolated Muons

1308.4075

Require one loosely isolated hard muon
(pT>100 GeV, iso<20%),
+ one other muon of *same charge* as first one
(no requirements on isolation, or IP)
+ many tracks (10 GeV each)





No BSM yet....

- We should keep expanding list of signatures
- Experimentalists are imaginative...

- But sometimes need theory to motivate a signature... *even if it sounds far-fetched!*