Laser plasma particle acceleration activities at RRCAT, Indore

J. A. Chakera

Laser Plasma Section

Raja Ramanna Centre for Advanced Technology,

India – 452 013

Email: chakera@rrcat.gov.in

ICTS Programme on

Laser Plasma Accelerator Workshop

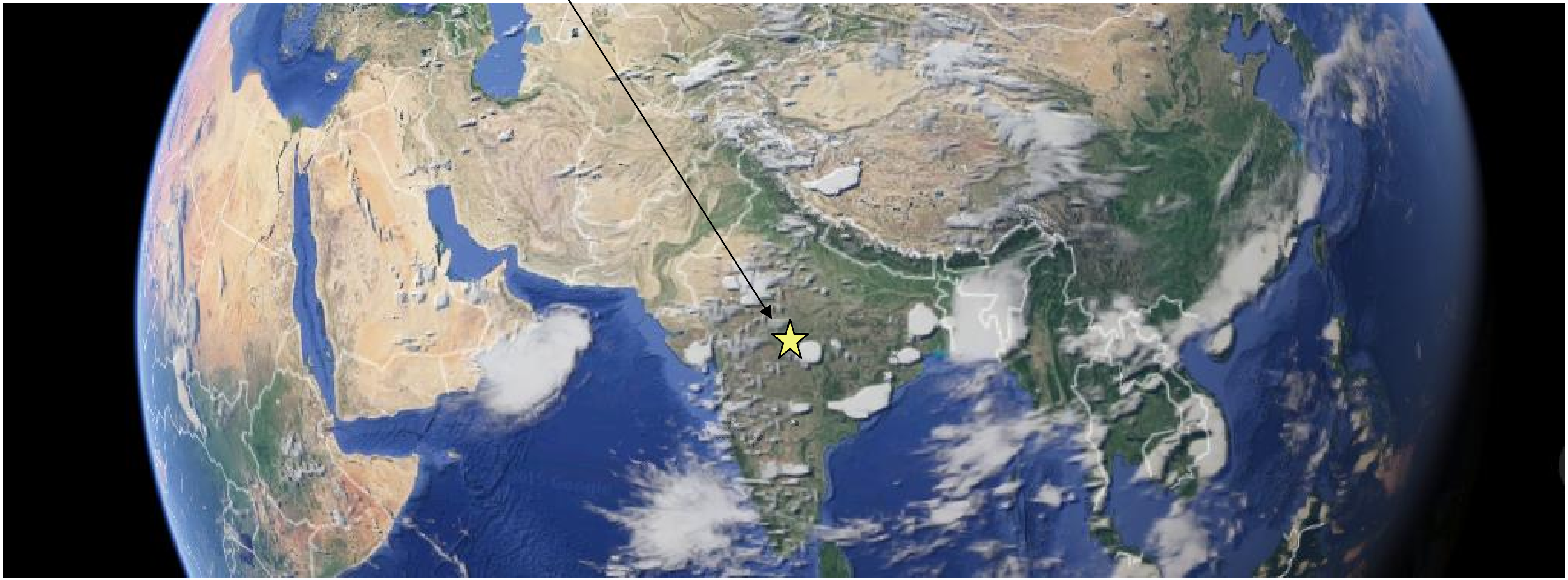
March 6 – 16, 2017, ICTS TIFR, Bangalore

Outline:

- Major activities at RRCAT
- Laser facilities at LPS, RRCAT
- Upcoming PW laser facility
- Recent studies on ion acceleration and results
- Conclusion

Introduction:

Raja Ramanna Centre for Advanced Technology (RRCAT)




Raja Ramanna Centre for Advanced Technology
RRCAT Guest House
Sukhniwas Lake
RRCAT

RRCAT Campus

Introduction:

The RRCAT is a premier institute having major facilities of Synchrotron radiation source and various types of Lasers. The Laser Plasma Section at RRCAT, Indore is pursuing laser matter interaction studies using various Ti:sapphire lasers viz. 10 TW and 150 TW laser systems. The centre soon will have 1 PW , 25 fs Ti:Sapphire laser. The group is involved in different aspects of ultrahigh intensity laser matter interaction studies such as LWFA, Ion acceleration in thin foil, neutron generation, TXRD, THz generation and HHG in plasma plumes.

A brief account of our recent studies on ion acceleration in thin foils is presented.

Outline:

- About RRCAT
- Major activities at RRCAT
- Laser facilities at LPS, RRCAT
- Upcoming PW laser facility
- Recent studies on ion acceleration and results
- Conclusion

10 TW, Ti:sapphire laser Facility

Laser Characteristics

Pulse duration : 45 fs

Max. peak power : 10 TW

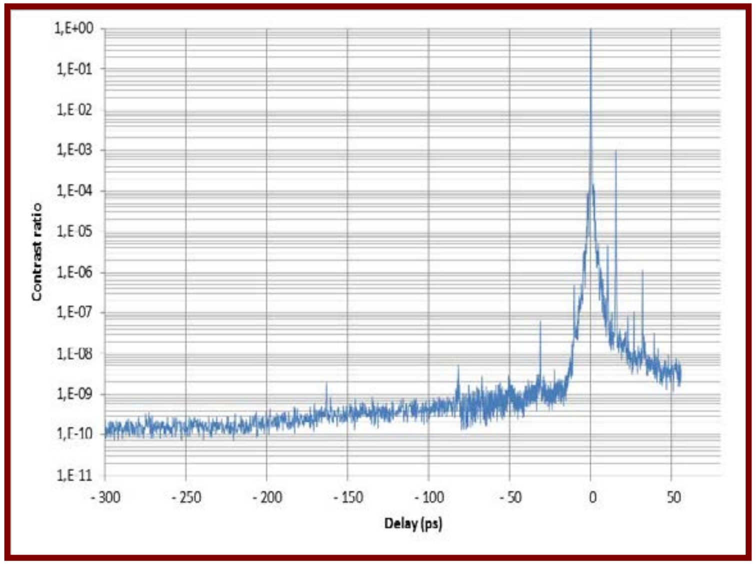
Max. rep rate : 10Hz

Wavelength : 800 nm

ASE ns prepulse contrast :$\sim 10^{-6}$

In operation since 2006 (Thales System)

150 TW, Ti:sapphire Laser at RRCAT



- *Contrast ratio at -300 ps before :1.10^{-10}*
- *Laser intensity at focus: ~ 10^{20} W/cm^2*

150 TW Laser Specifications

Pulse duration : 23 fs   Max. peak power : 150 TW

Max. rep rate : 5 Hz   Wavelength : 800 nm

In regular operational since 2015 (Amplitude System)

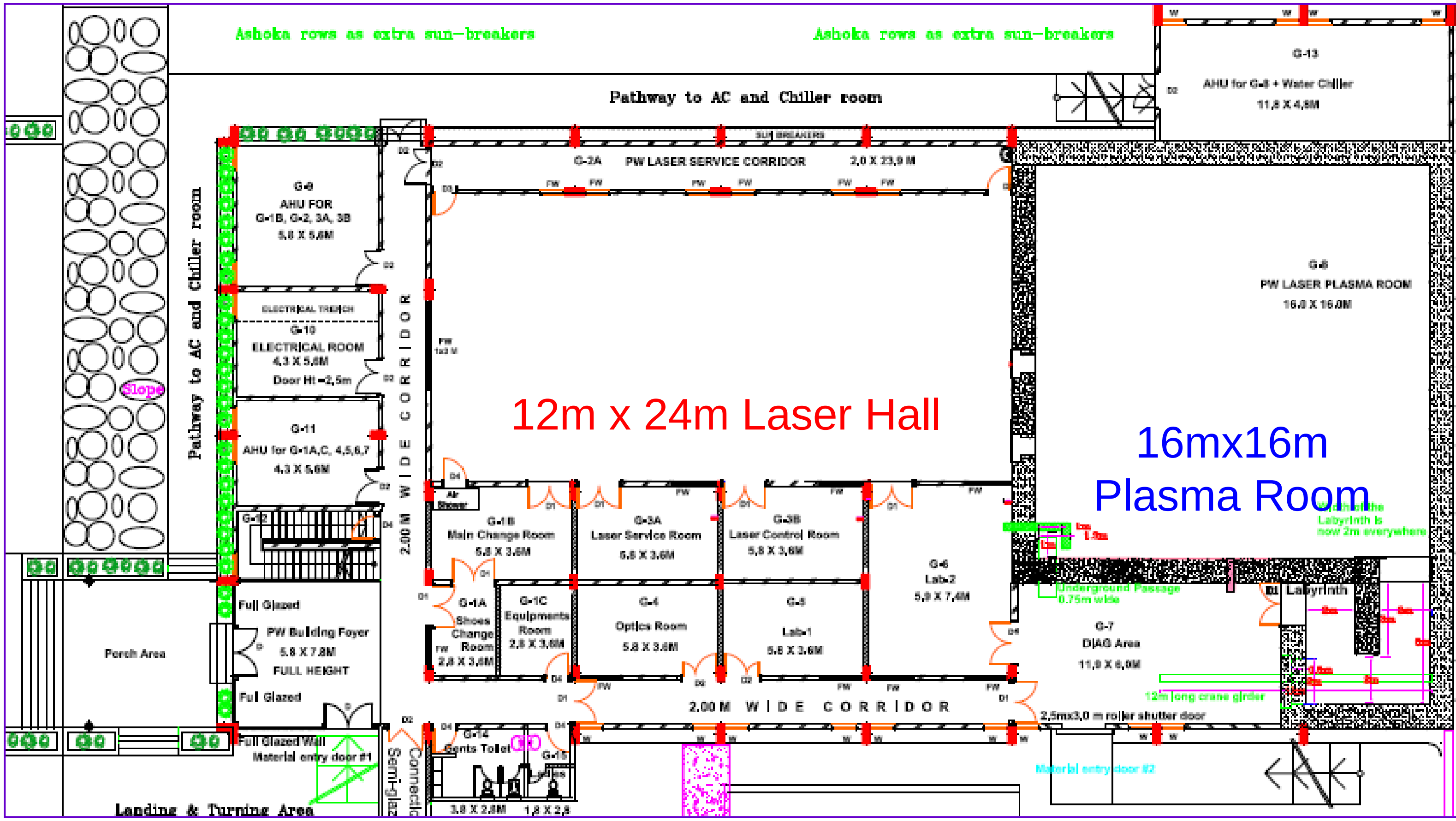
Outline:

- About RRCAT
- Major activities at RRCAT
- Laser facilities at LPS, RRCAT
- **Upcoming PW laser facility**
- Recent studies on ion acceleration and results
- Conclusion

Future Plans

Upcoming 1 PW Ti:sapphire laser system at RRCAT

(1PW, 25 fs Ti:sapphire laser installation is due Jan. 2018)



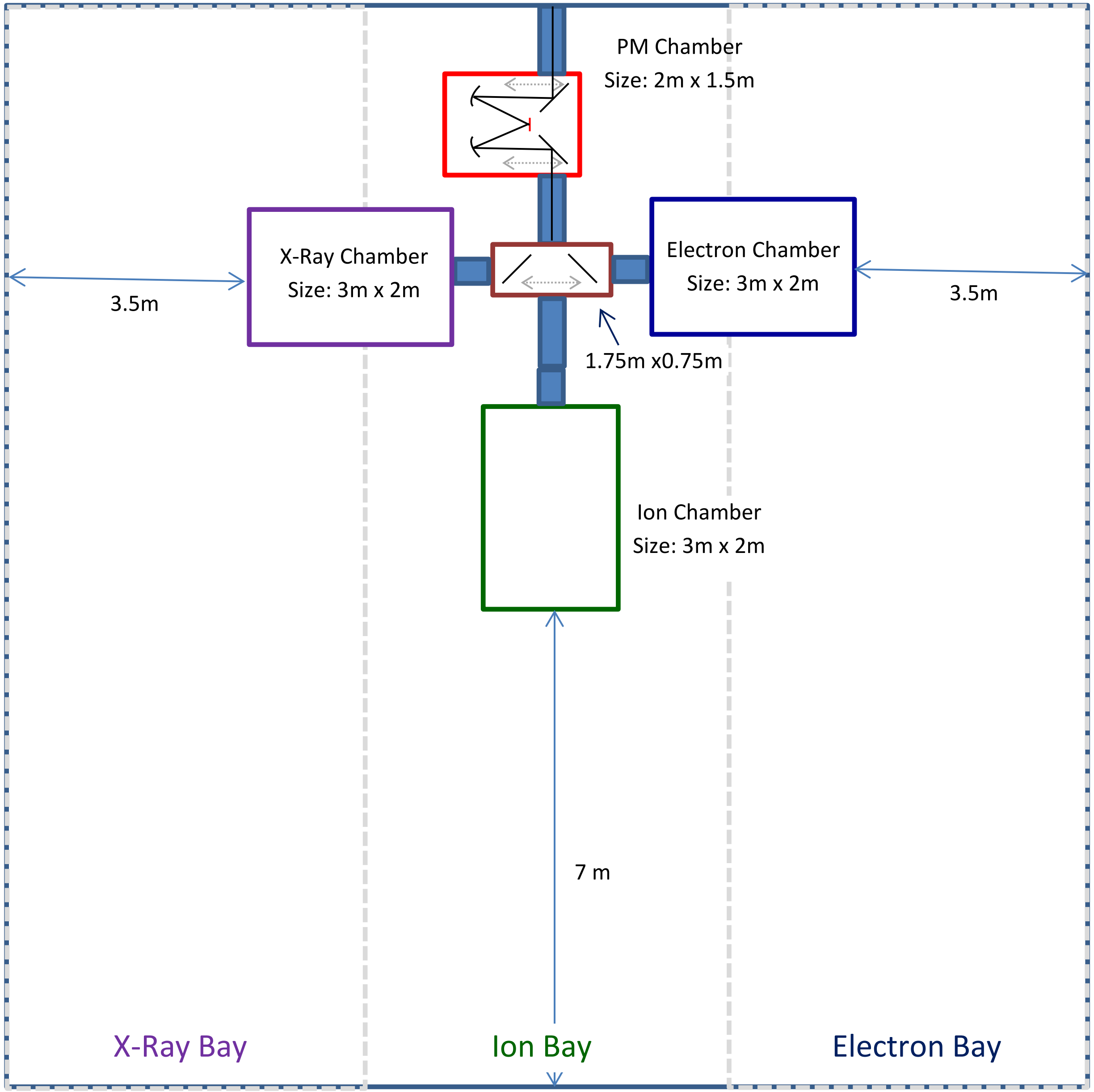
PW Laser building : Status

PW Laser hall

PW Laser interaction shielded area

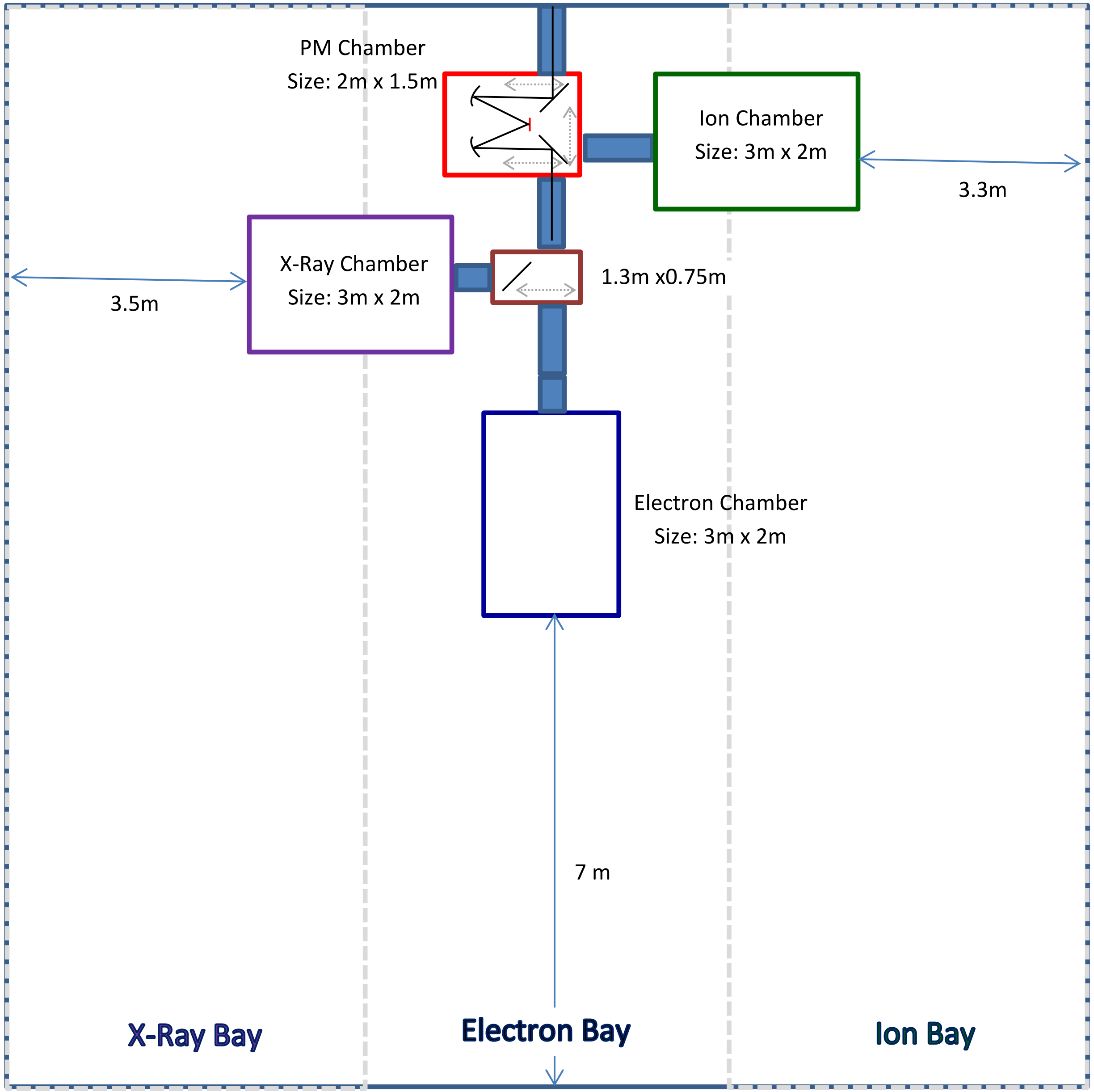
Lay out #1

Versatile for all chambers



Lay out #2

Ion chamber with always PM



Outline:

- About RRCAT
- Major activities at RRCAT
- Laser facilities at LPS, RRCAT
- Upcoming PW laser facility
- **Recent studies on ion acceleration and results**
- Conclusion

Why Ion beam ?

- Probing matter with intense ion beams yields valuable information about the material.
- Accelerated ion beam has been envisaged as a high potential tool in radiation oncology - localized heating without collateral damage.
- Ion beam based controlled fusion scheme.

- Ultrashort intense laser based ions sources – a potential alternative to conventional RF based ion accelerators.

Basic Ion acceleration mechanism

Target Normal Sheath Acceleration (TNSA)

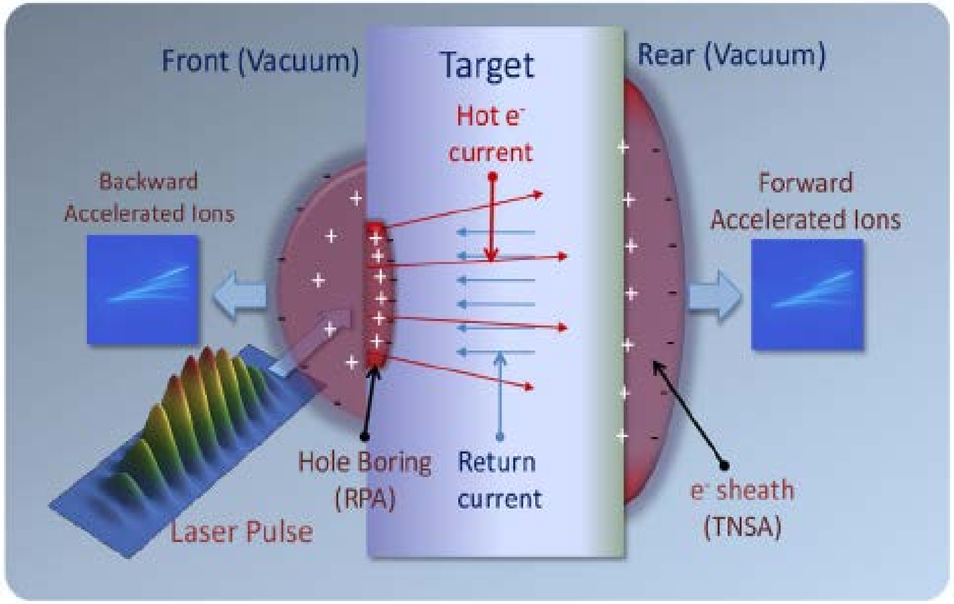
- "hot" e^- generated at the front reach the rear side
- e^- escaping from the rear side creates a charge imbalance

$$E_{accln} = T_h(eV) / e \max(\lambda_D, L_n)$$

$$T_h = 1 \text{ MeV and } \lambda_D \sim 1\mu m,$$

$$E_{sheath} \approx 10^{12} \text{ V/m}$$

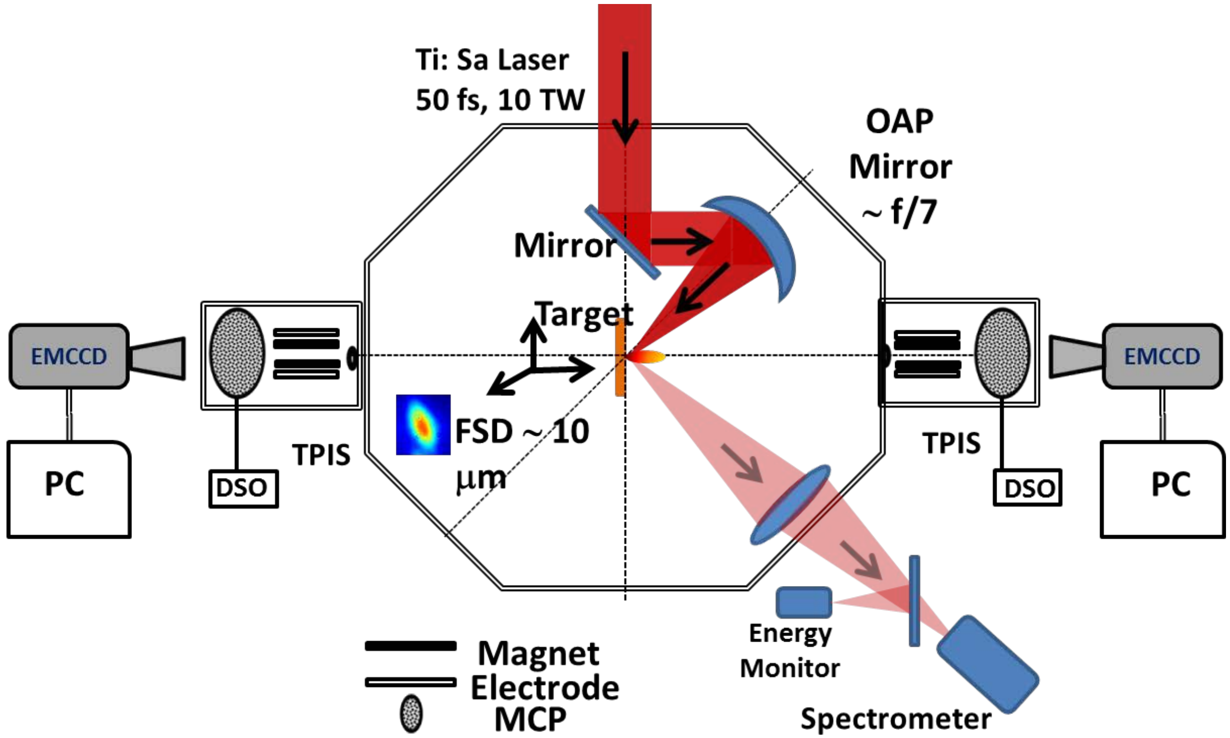
S. C. Wilks et al. POP (2001)



A. Machhi et. al. Rev. Mod. Phys. (2013)

- This huge field will back hold most of the escaping electrons, ionizes the atom at rear surface and start to accelerate ions
- So the test ion would acquire the energy $E_{ion} \approx Ze\, E_{sheath}\, \lambda_D \sim ZT_h$

Experimental setup



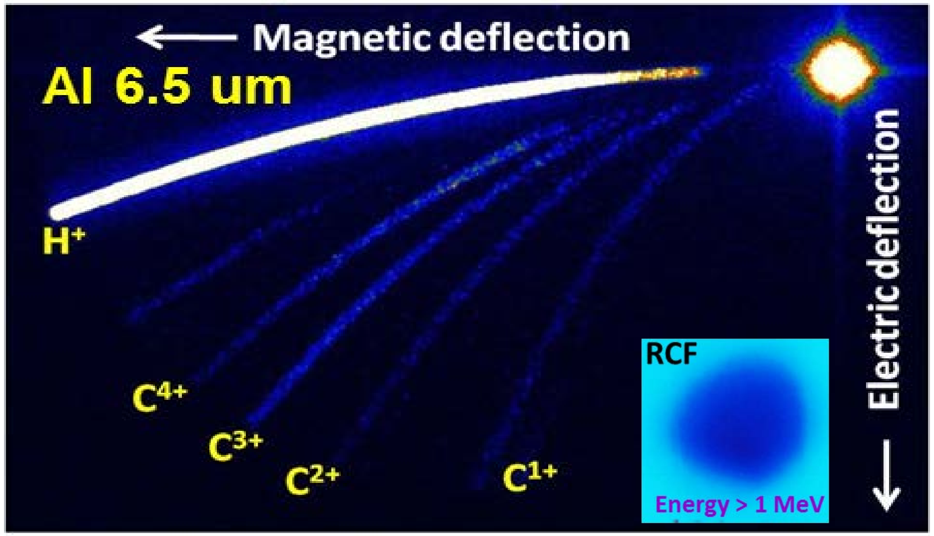
- ❖ Single shot acquisition of parabolic ion traces with MCP and EMCCD camera

  Online monitoring of reflected beam energy and spectrum

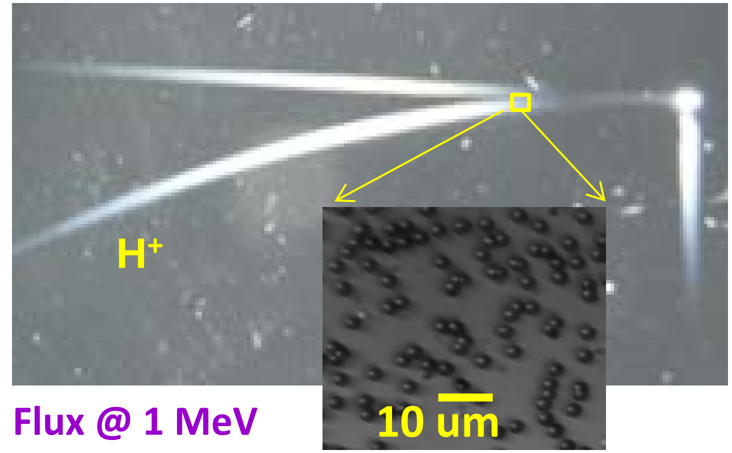
- ❖ Online monitoring of reflected laser pulse energy & spectrum

Typical TPIS Spectra

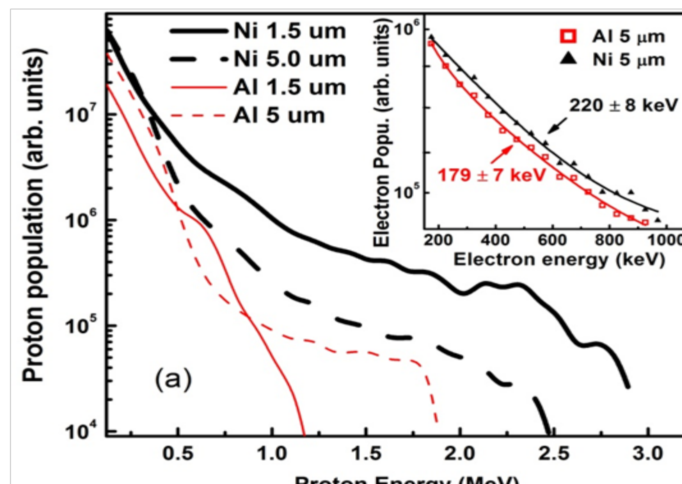
Typical parabolic ion traces captured with TPIS



Proton trace on CR-39 detector



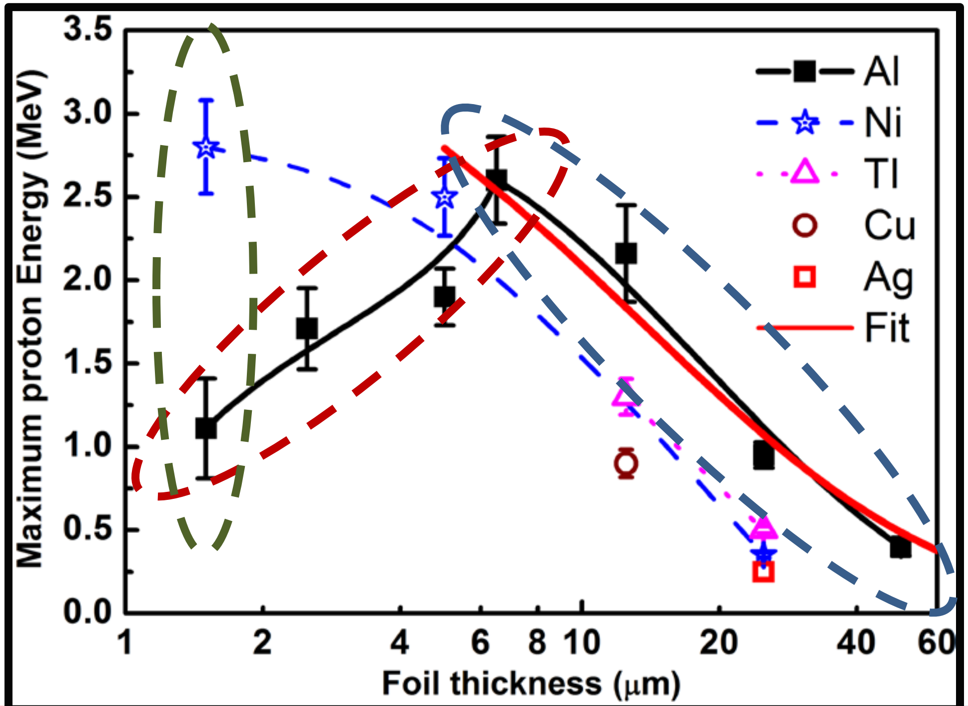
Proton and electron energy spectrum from Ni and Al foils

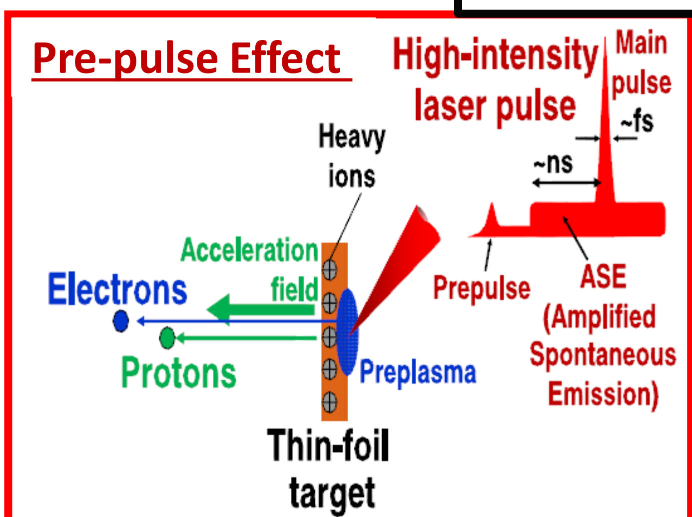


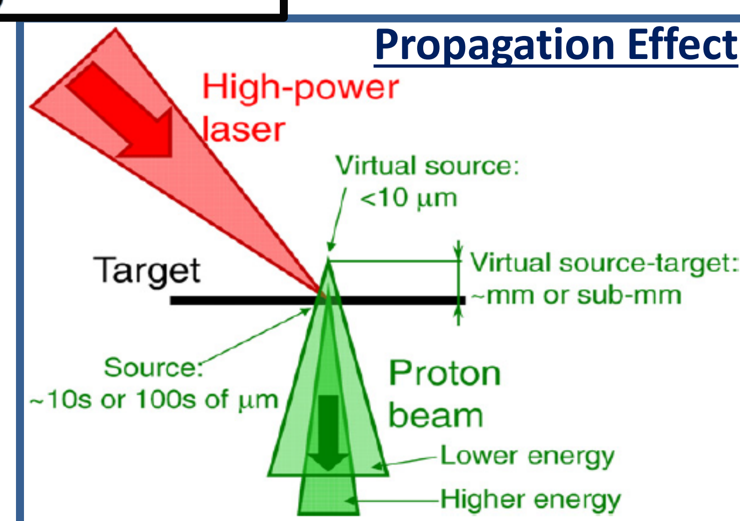
- ❑ Protons and lighter atoms preferentially accelerated
- ❑ Typical of TNSA characteristics
- ❑ Ni yields more proton energy compared to Al

Phys. Rev. E 90, 023103 (2014)

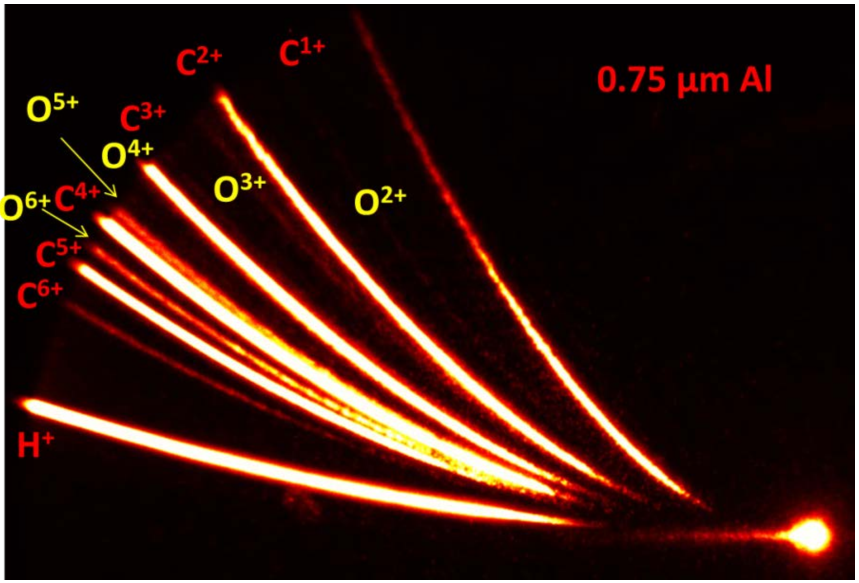
Optimum foil thickness for 10 TW Laser

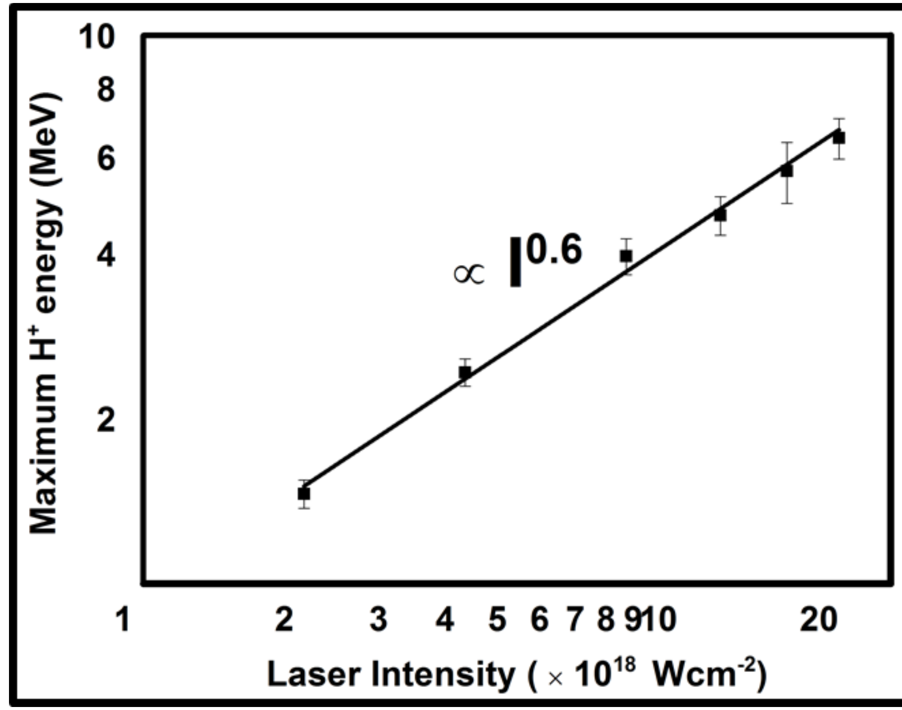


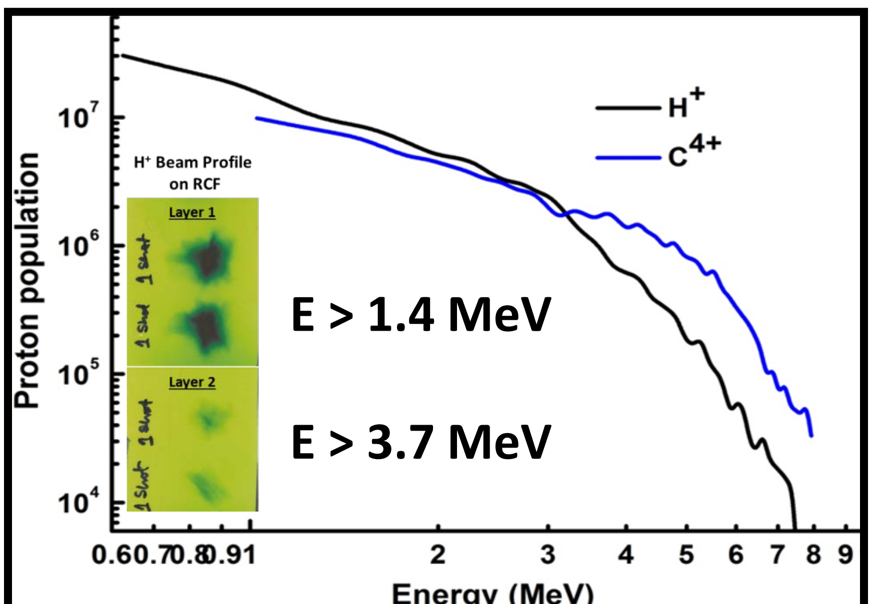


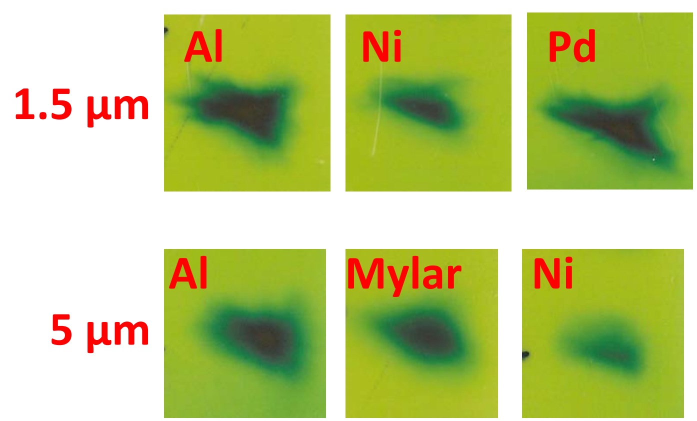


Recent results with 150 TW



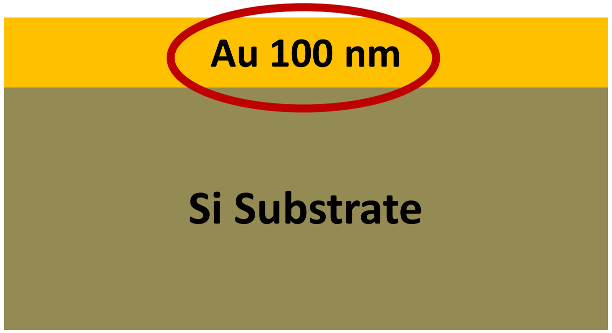


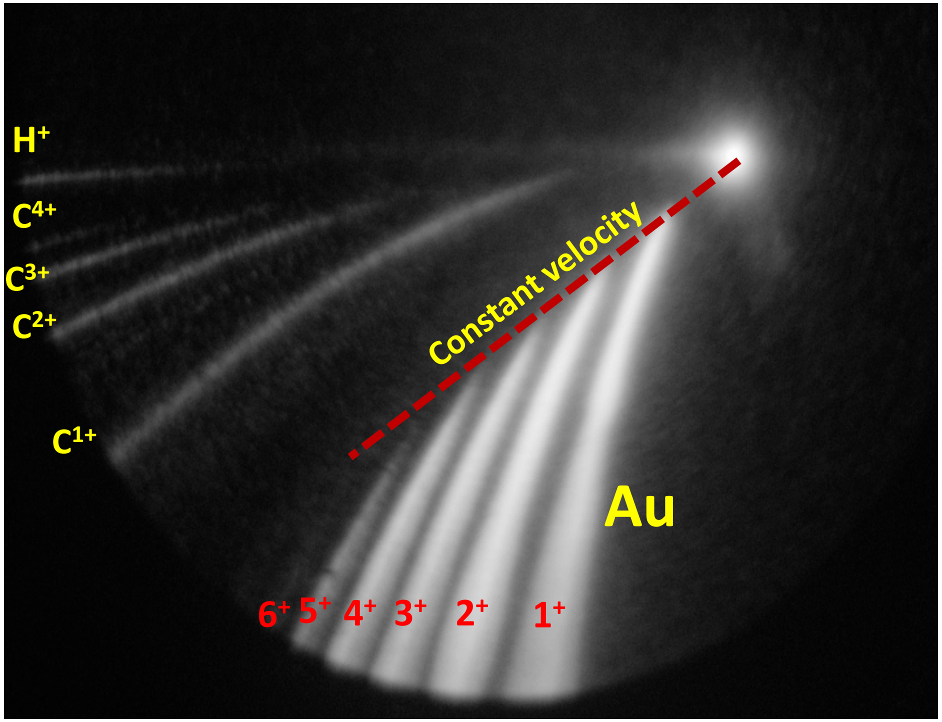




Heavy ion Acceleration

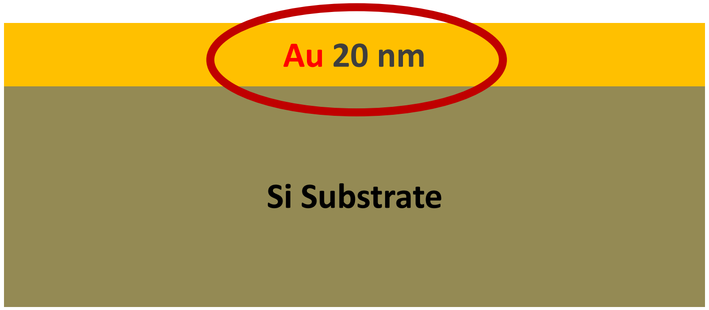
Au ion spectrum recorded from the front side

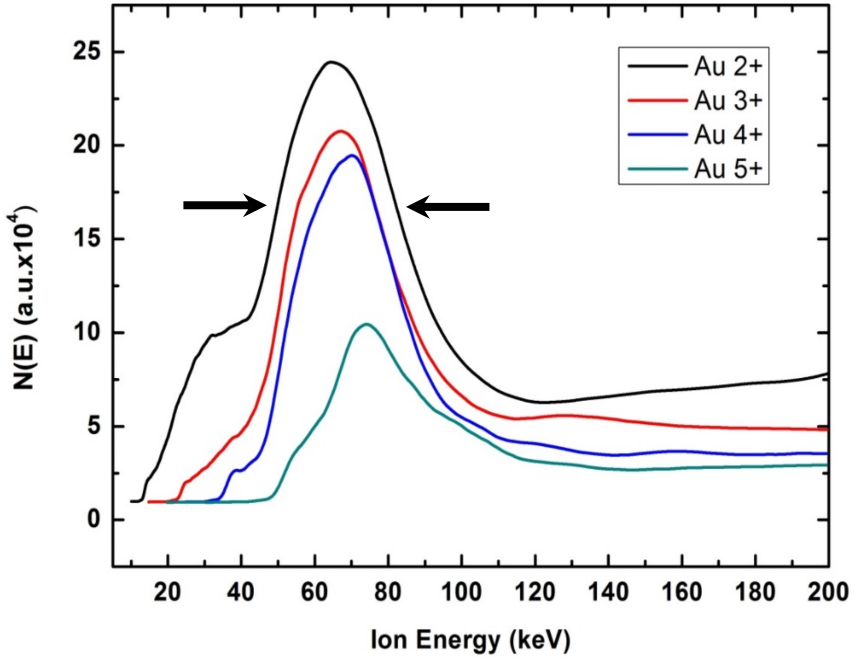


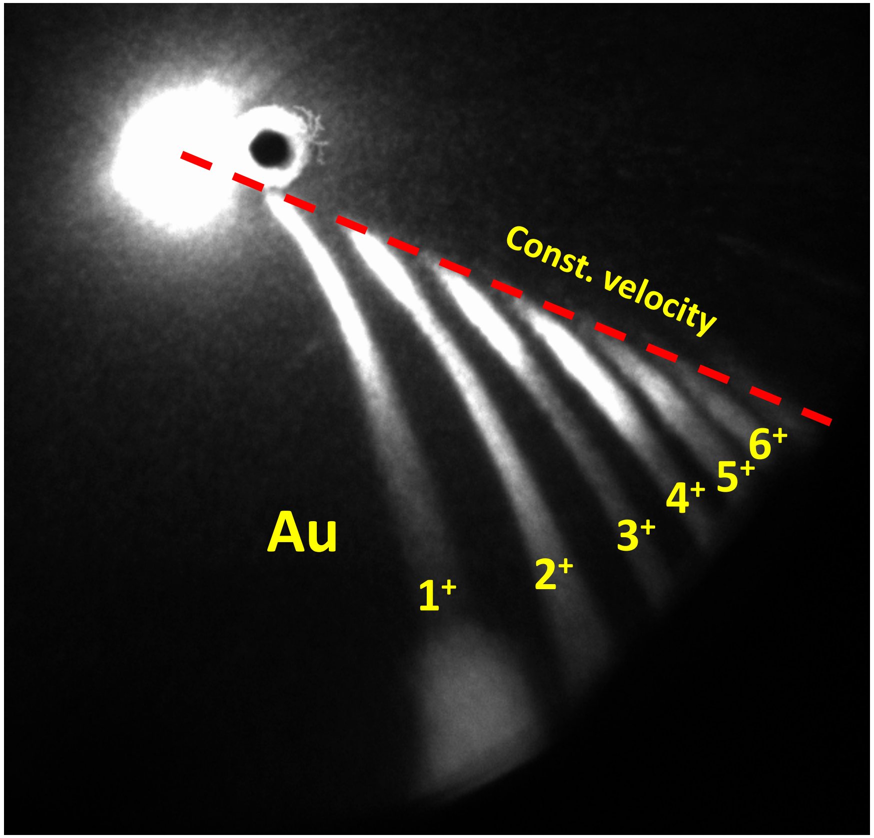


- **Au ions of *different charge states* having *<u>same maximum energy</u>***
- ***Uncharacteristic of <u>TNSA</u>***

Ion acceleration from Au coated target



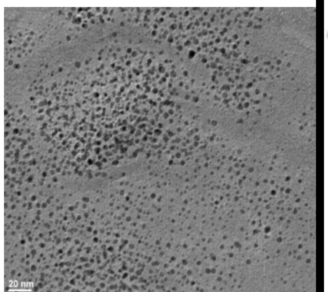




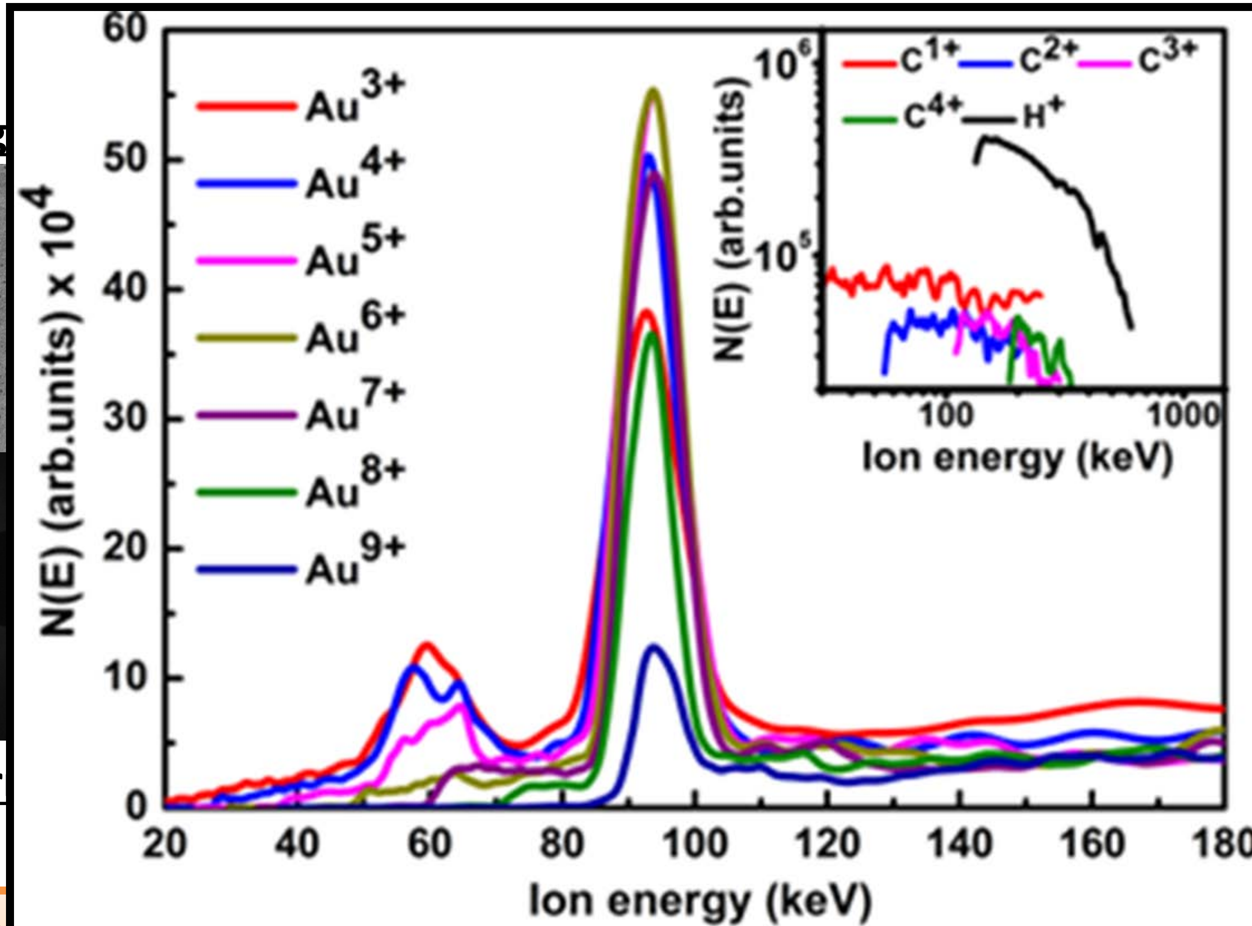
❖ ***Appearance of quasi-monoenergetic emission***

Quasi-monoenergetic Heavy Ions

TEM Imag

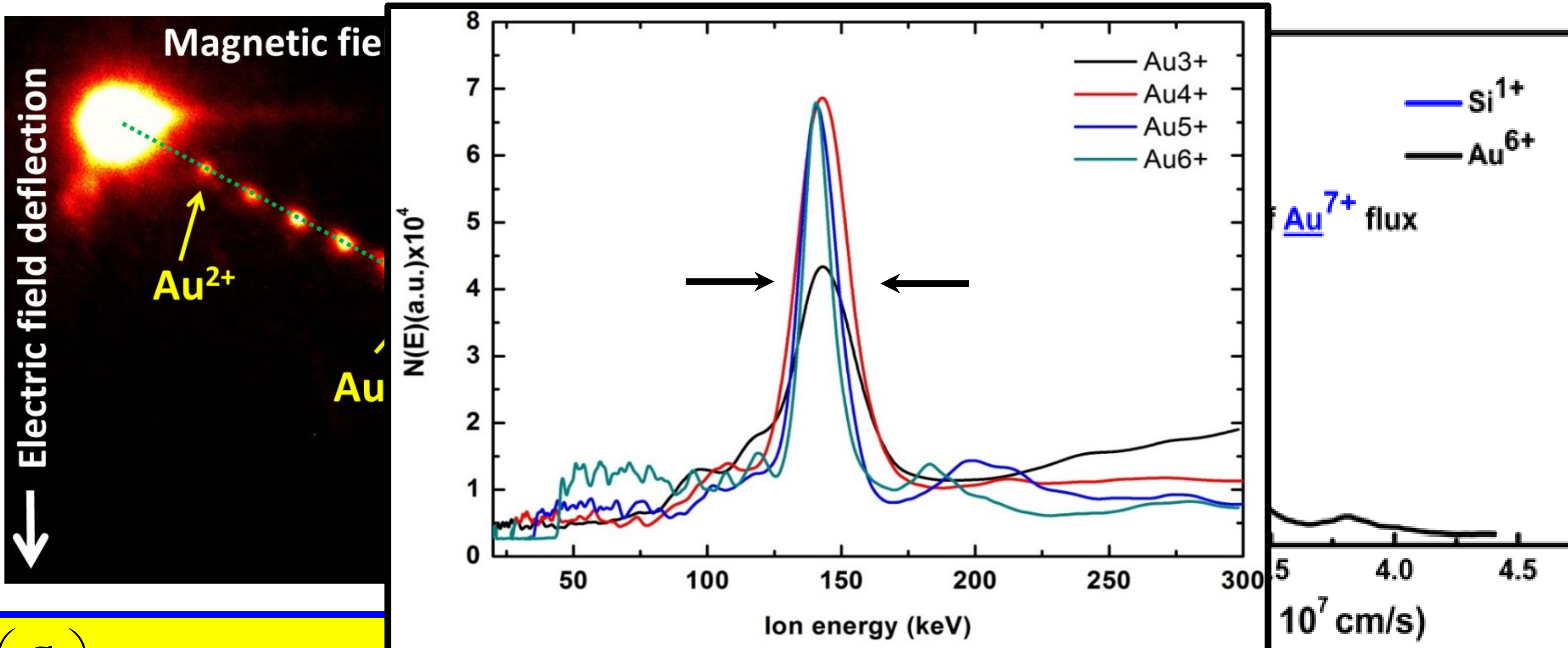


SAED Patter



- ❖ Target Composition: 3 – 8 nm AuNPs embedded in 30-40 nm thick C film on Al
- ❖ Simultaneous detection of two different Acceleration Process
- ❖ TNSA / Coulombic process characterized by continuous energy spectra
- ❖ Non-Coulombic Acceleration: All the charged states of Gold have same energy

With a different substrate (Si)

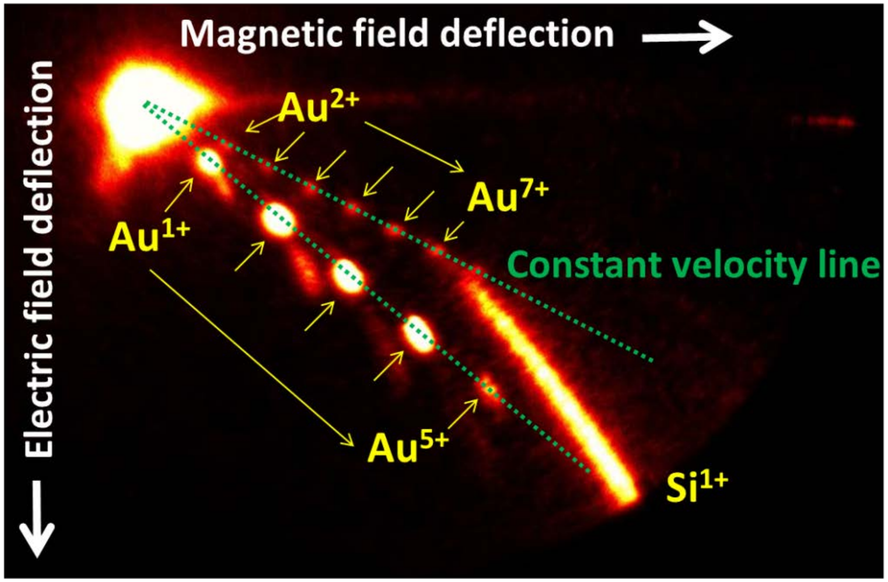


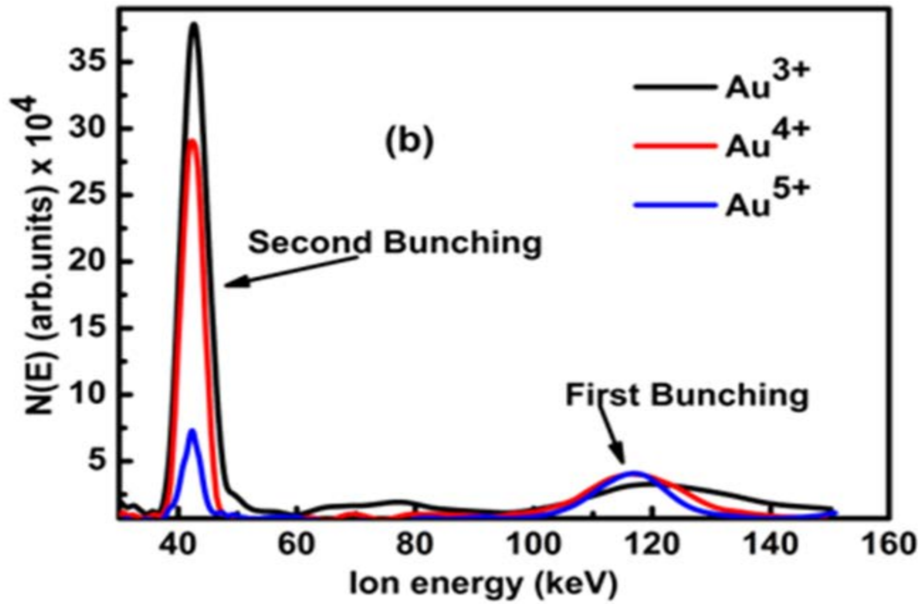
$$\left(\frac{q}{m}\right)_{Si^{1+}} = (28.086)^{-1} = 0.0356$$

$$\left(\frac{q}{m}\right)_{Au^{7+}} = \left(\frac{196.97}{7}\right)^{-1} = (28.138)^{-1} = 0.0355$$

- Substrate (Si) shows continuous trace
- Embedded Au Nano-Particles reveals mono-energetic feature
- Matches well with the expected Overlap of parabolic trajectories

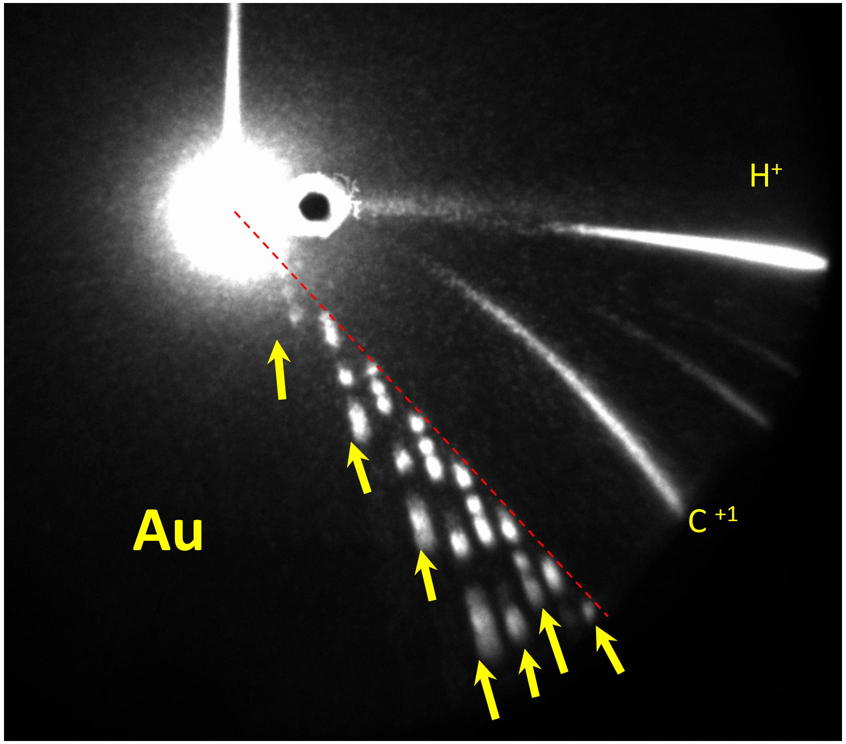
Double Bunching of Heavy Gold Ions

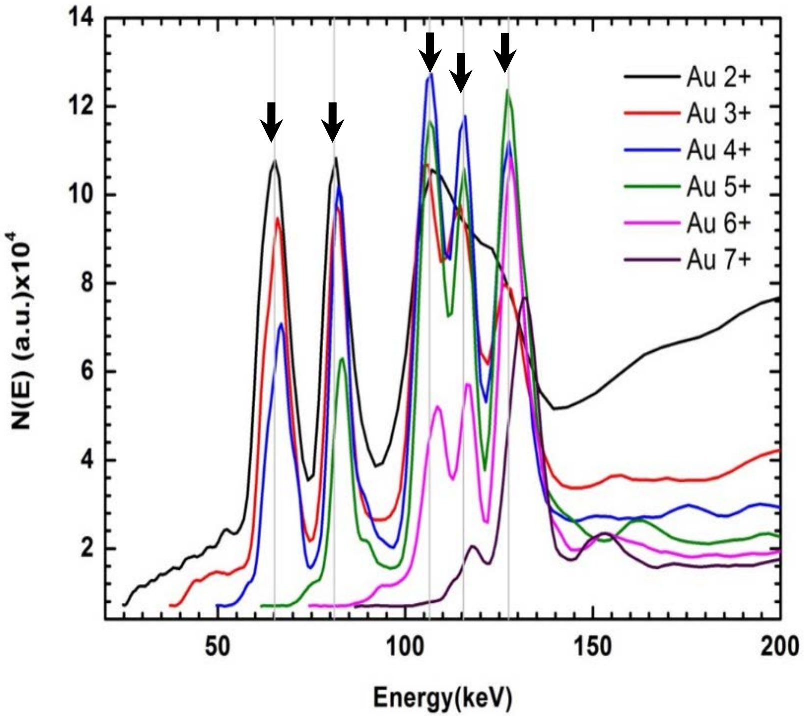




❖ Two distinct sets of gold ion bunches observed on many occasions

Multiple Bunching of Heavy Gold Ions



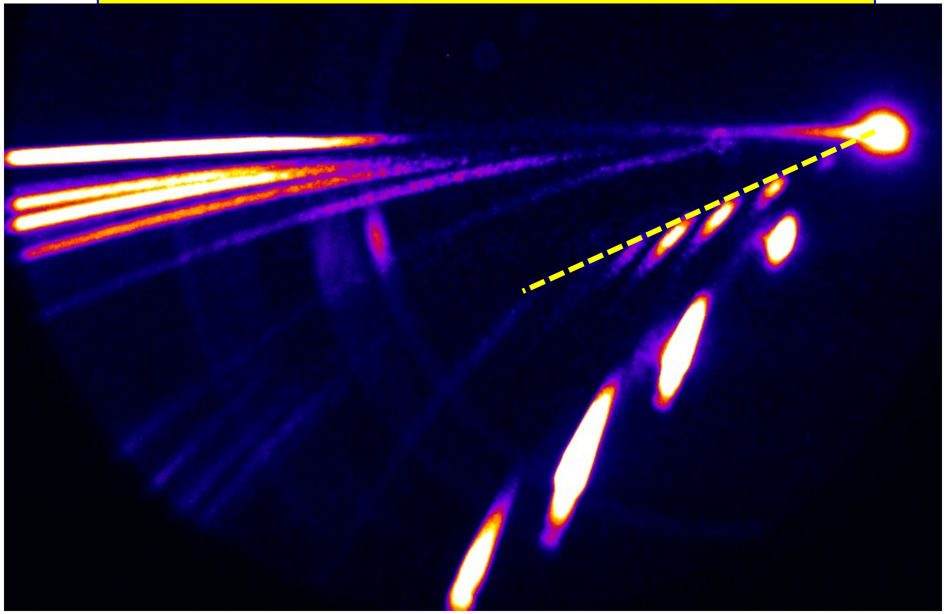


Multiple Quasi Mono-energetic features

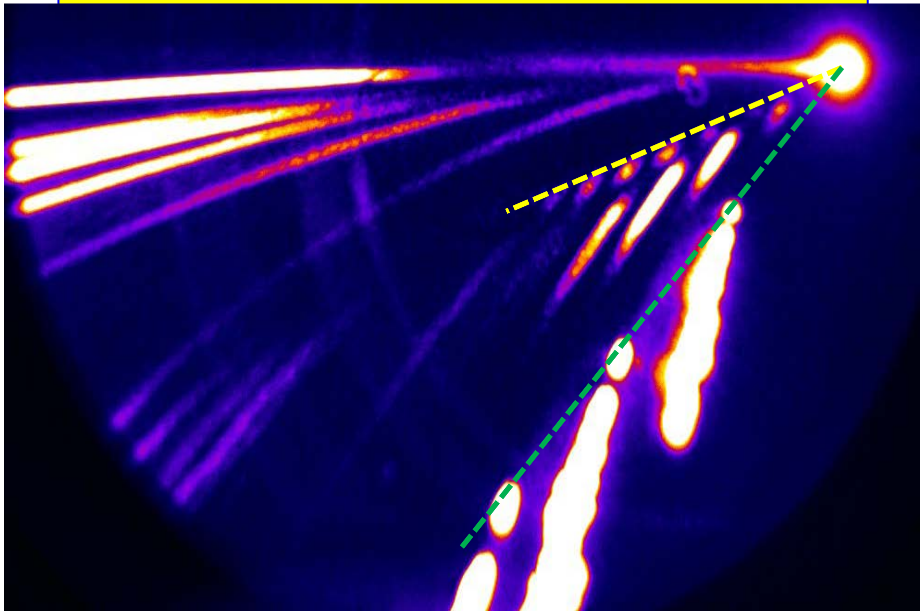
First Experimental demonstration

Validation of Simulation

Single Layer of C & Au on Al



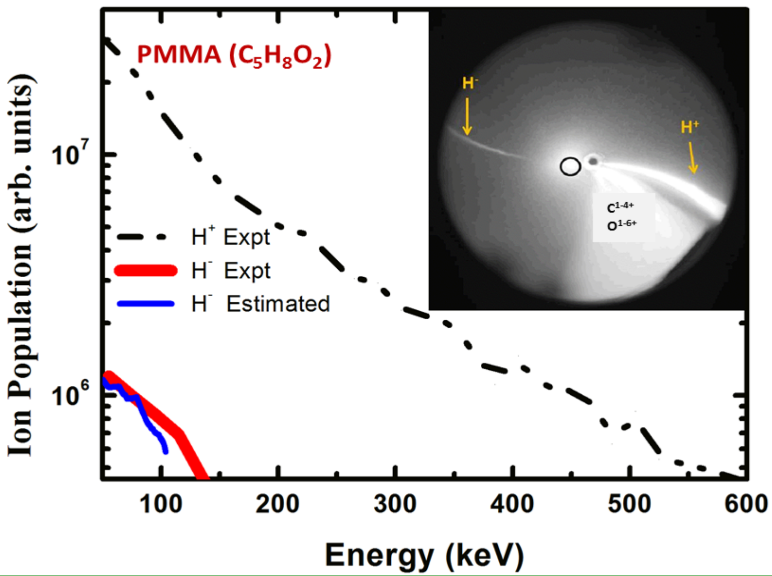
Double Layer of C & Au on Al

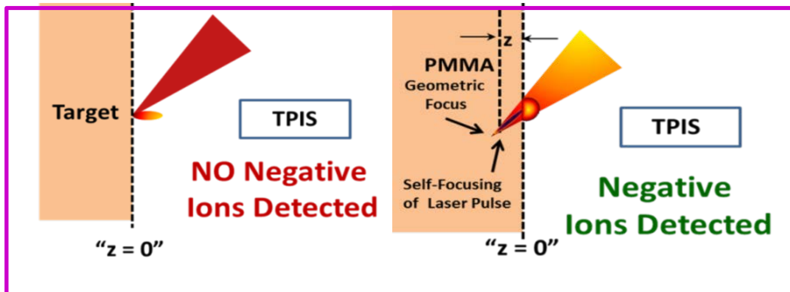


- **Experiments on Layered targets based on the prediction of 1D Hydrodynamic Simulation yield consistent Heavy Gold Ion Bunching**
- **Highly Reproducible**

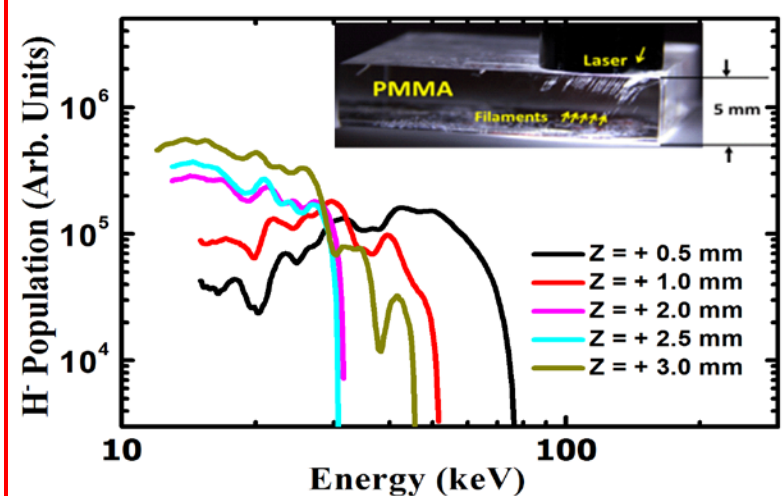
Negative Ion and Neutral Atom Acceleration

Negative ions from laser interaction with transparent hydrogen containing solids

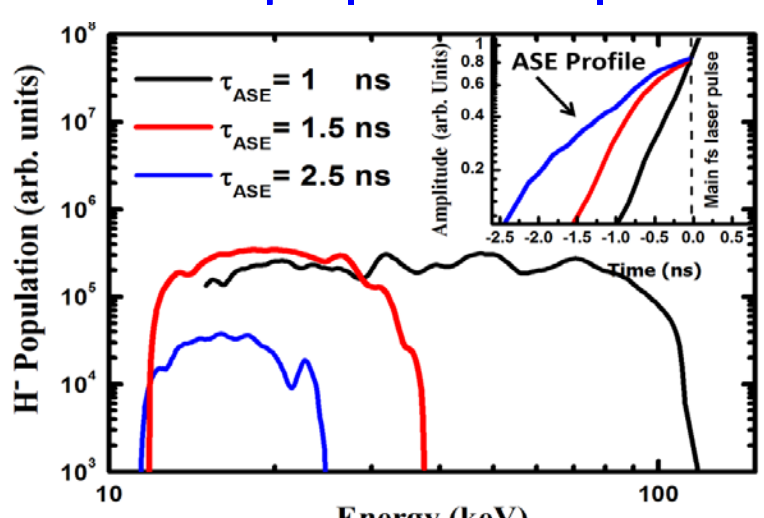




Effect of laser focusing conditions



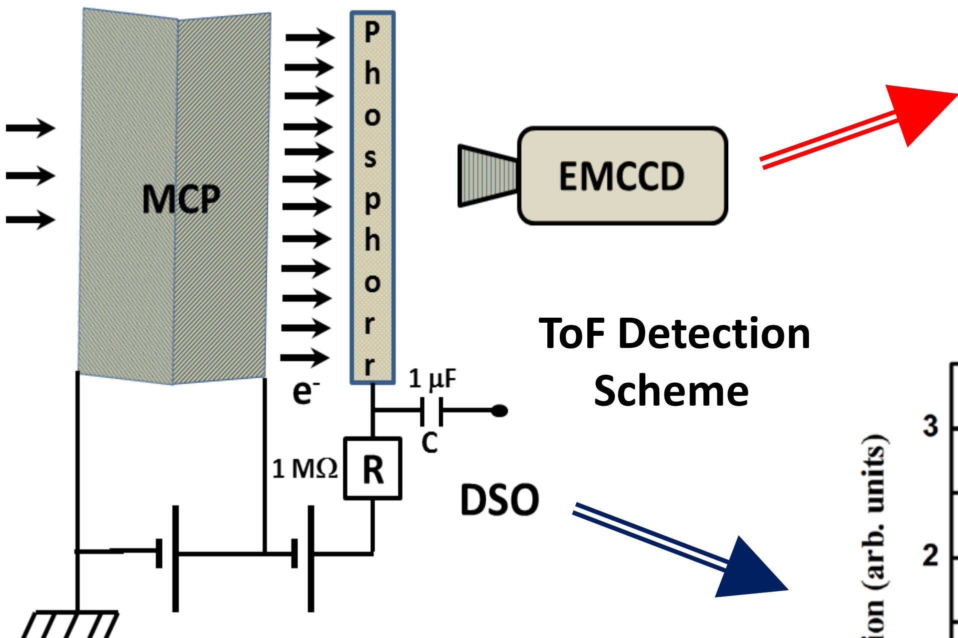
Effect of pre-pulse on H^- spectrum

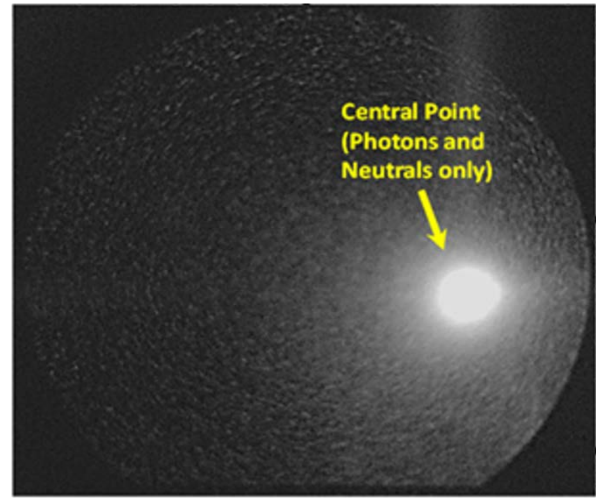


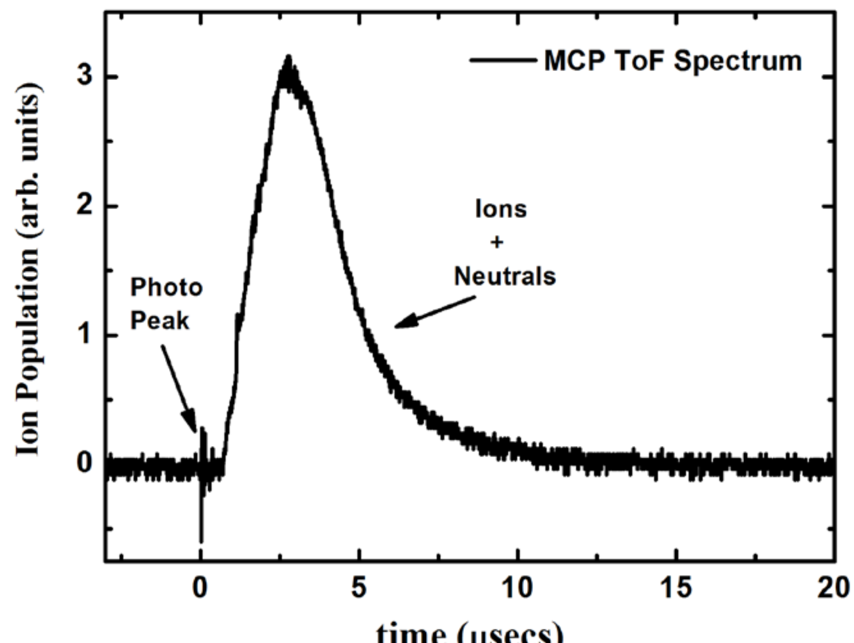
- First time observation of H^- with solid target.
- Negative H^- ion flux $\sim 8 \times 10^{11}$ H^-/ sr
- Order of magnitude lower laser intensity.
- Dependence of laser focusing conditions.
- Drastic reduction in presence of pre-pulse.

Phys. Rev. E 92, 051103 (R) (2015)

How to detect Neutral atoms using TPIS ?

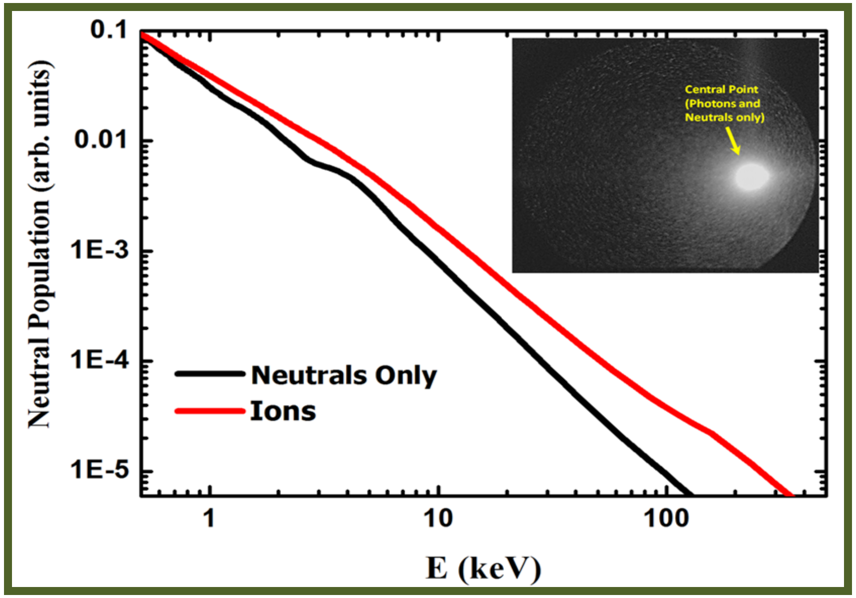




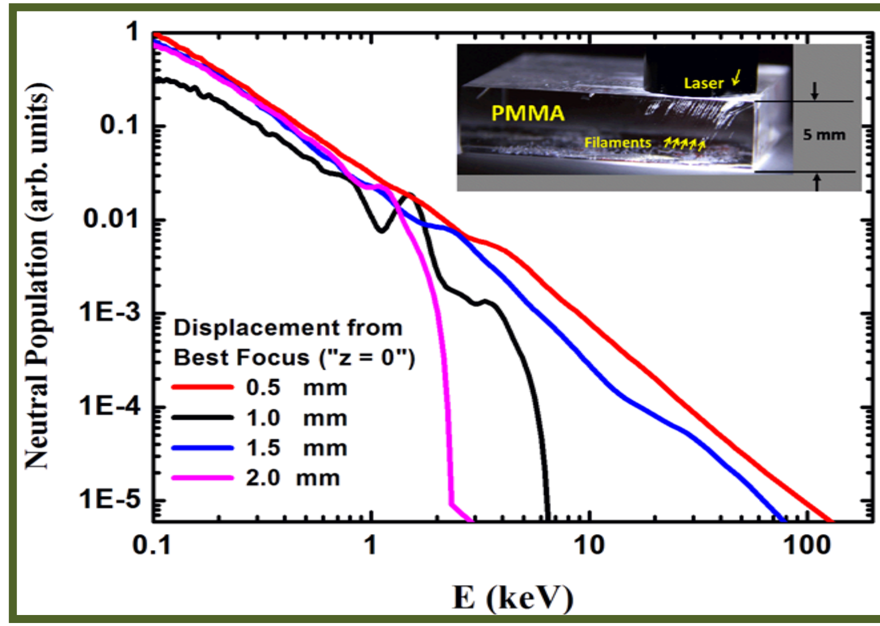


$$E = \frac{1}{2} m \frac{l_{ToF}^2}{t_{arr}^2}$$

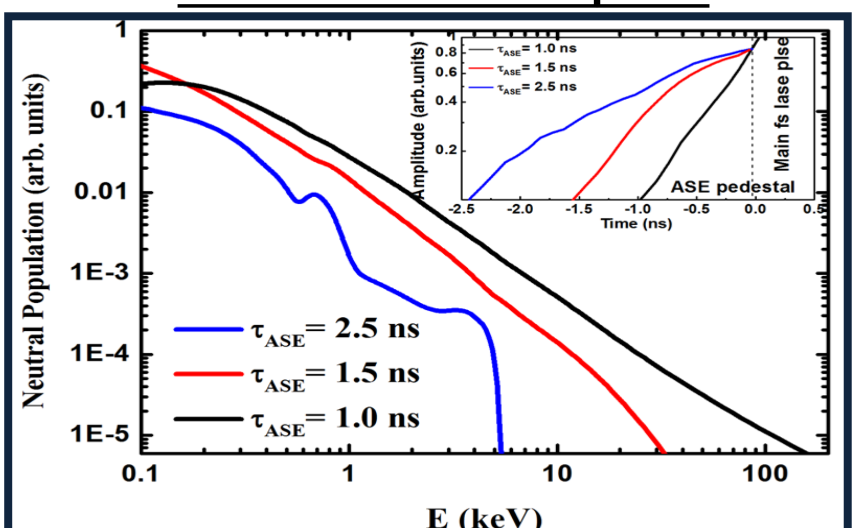
Neutral atom generation from laser interaction with transparent hydrogen containing solids



Effect of Laser Focusing Conditions

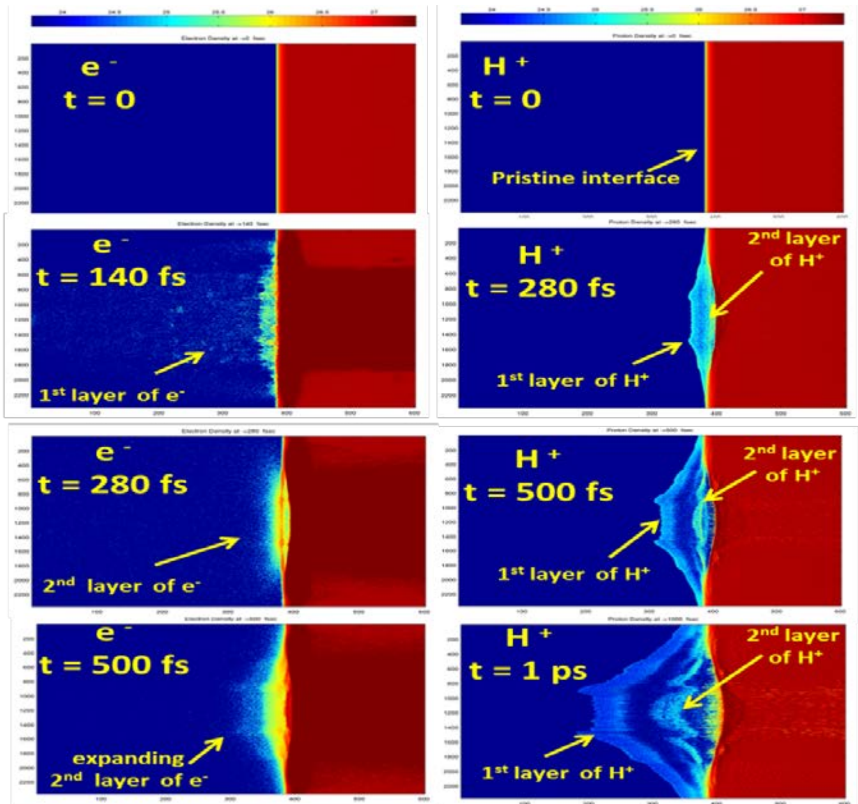


Effect of Laser Pre-pulse

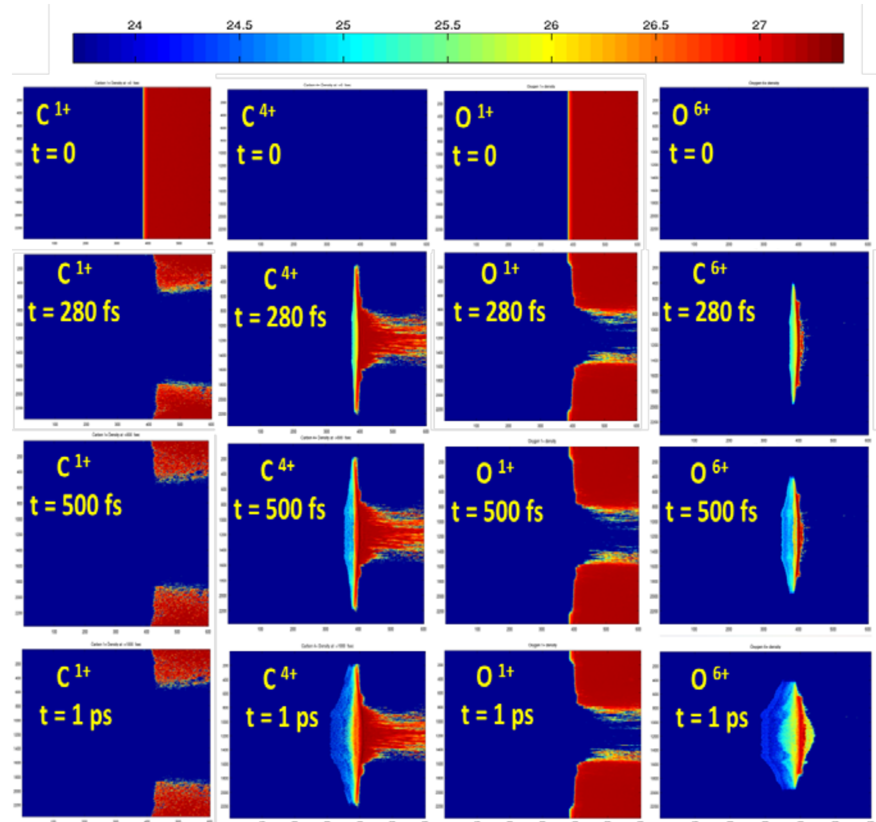


- First time observation of H^0 with solid target.
- Dependence of laser focusing conditions.
- Drastic reduction in presence of pre-pulse.

Origin of H^- and H^0



Time evolution of e^- & H^+



Time evolution of C & O ions

Conclusions

- **RRCAT is premier institute with state of art ultra high intensity laser facilities viz. 10 and 150 TW.**
- **By end of 2018 , 1 PW Tis:apphire laser will be in operation**
- **Strong group pursuing research in areas of laser plasma based particle accelerators**

Results on ion acceleration

- Demonstration of Bunched Heavy Ion (Au^{n+}) acceleration from Intense, ultra-short laser produced plasmas
- Hydrodynamic expansion of gold inhibited by carbon layer yields mono-energetic gold ion emission (non TNSA mechanism)
- First report of energetic (> 100 keV) Negative Ion generation and Neutrals from transparent solids

Acknowledgements:

P. A. Naik, Director RRCAT

Colleagues:
A. Upadhyay, S. Bagchi, M. Tayyab

Ti:sapphire laser team:
R. A. Khan, R. A. Joshi, R. K. Bhat, Ankit Singhla

Mechanical team:
P. K. Tripathi, R. P. Kushwaha, S. Sebastine, K. C. Parmar, D. Karmakar

Electronics support by Laser Electronic Support Division

Collaborators:
D. K. Avasthi, IUAC, Delhi
B. Ramakrishna. IIT Hydrabad

Thank You for your attention.

How Laser Pulse forms plasma ?

Intense light field

↓

Instantaneous ionization

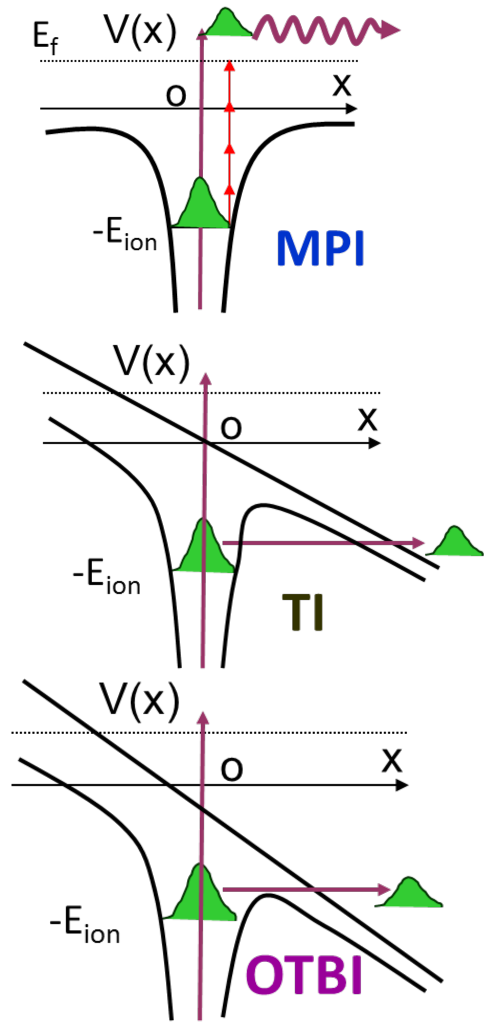
↓

Acceleration of electrons by light

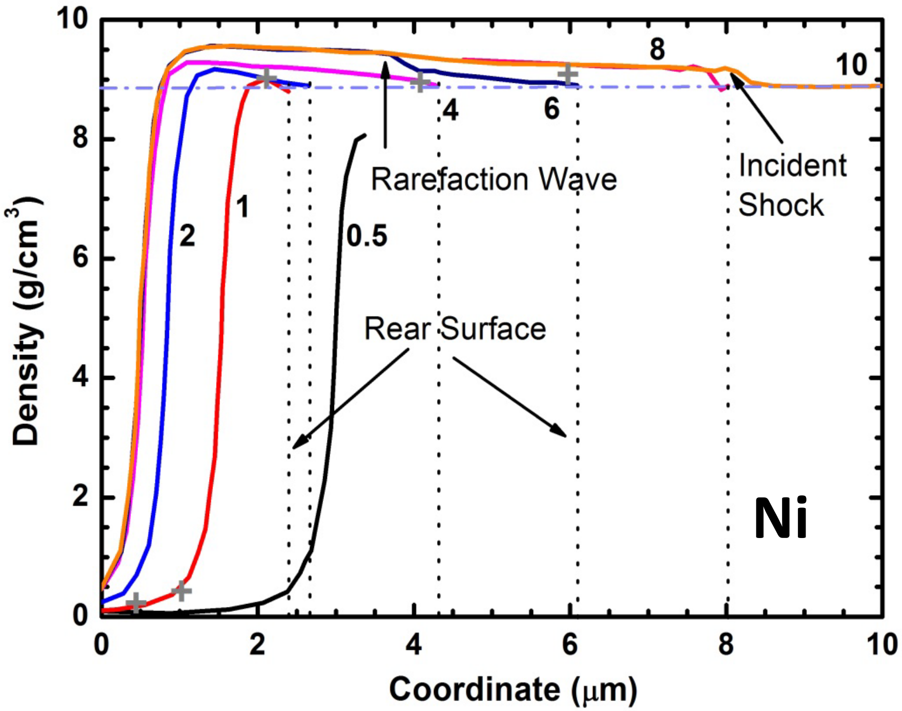
↕

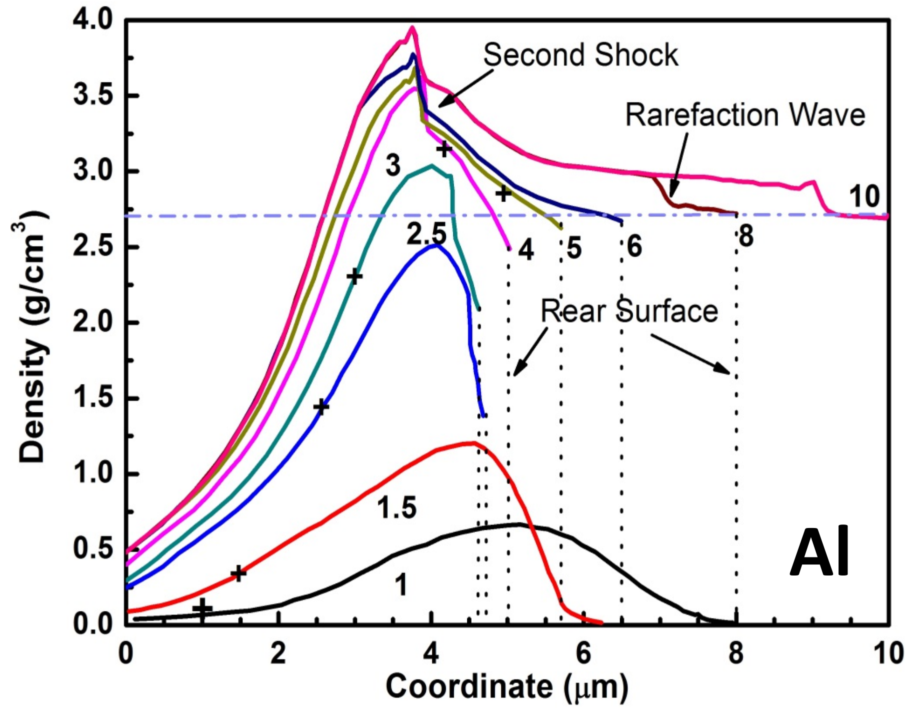
Absorption of light by collisional and collective processes

Hot dense plasma → “hot” electrons



MULTI-1D Simulation Results

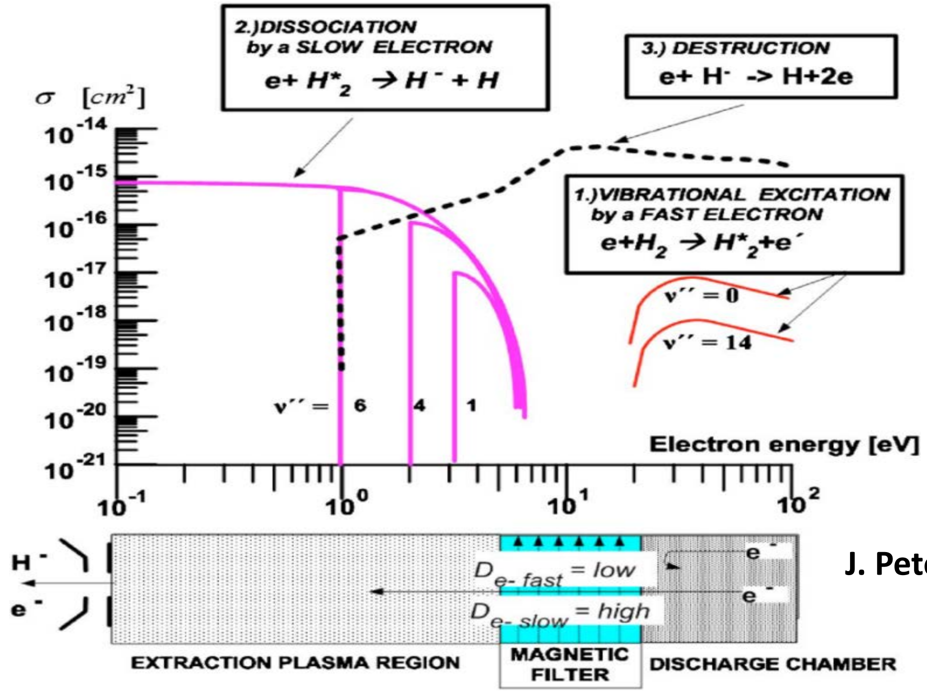




- ❑ Simulation results vindicates the experimental observation
- ❑ In case of Al, the rear surface of the foil survives beyond 6 μm thickness
- ❑ For Ni, Thicknesses above 1 μm suffice to withstand the laser pre-pulse

Conventional Negative Ion Sources

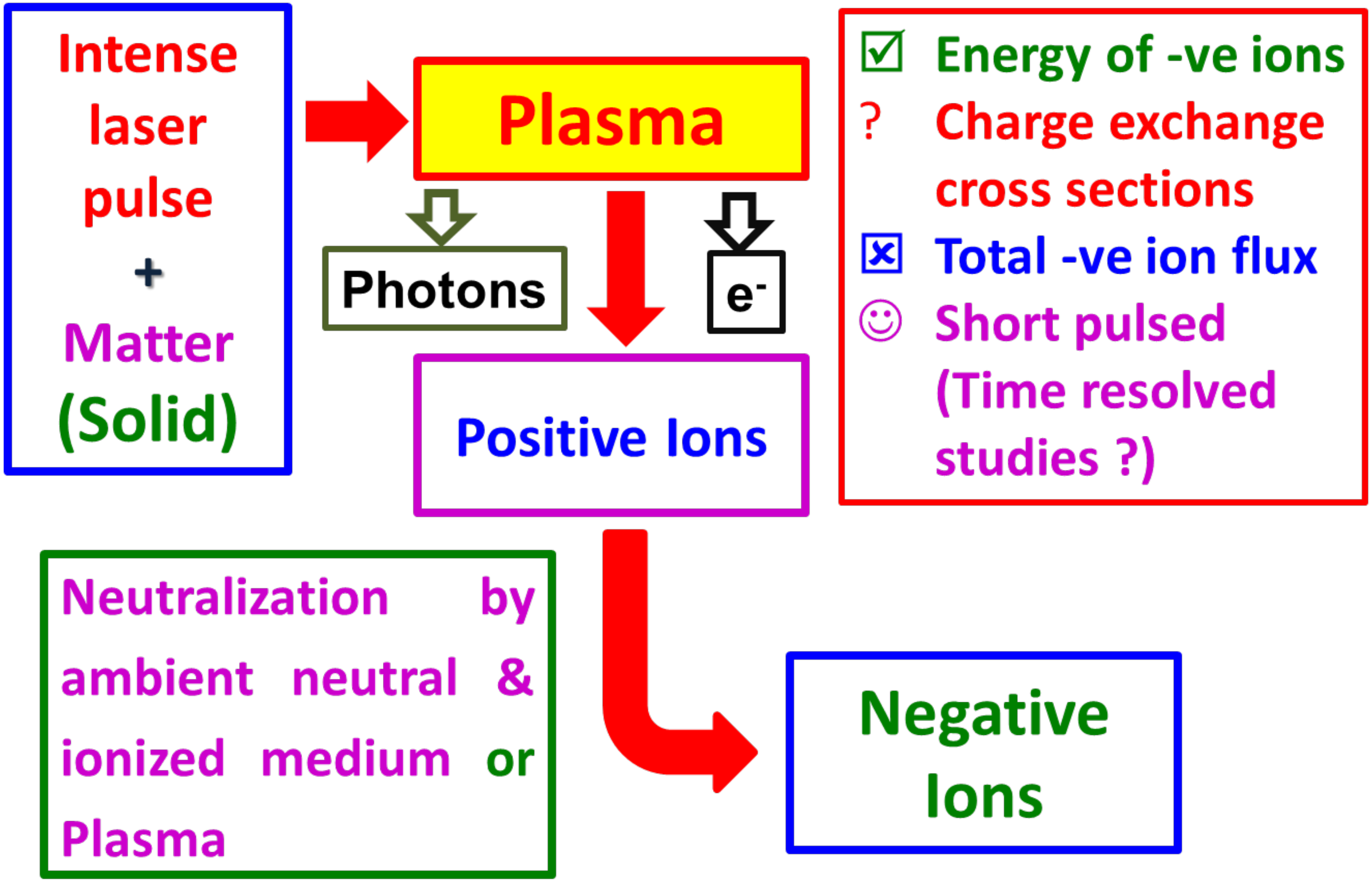
Element	electron Affinity (eV)
H	0.7542
He	< 0
Li	0.6182
Be	< 0
B	0.277
C	1.2629
N	< 0
O	1.462
F	3.399



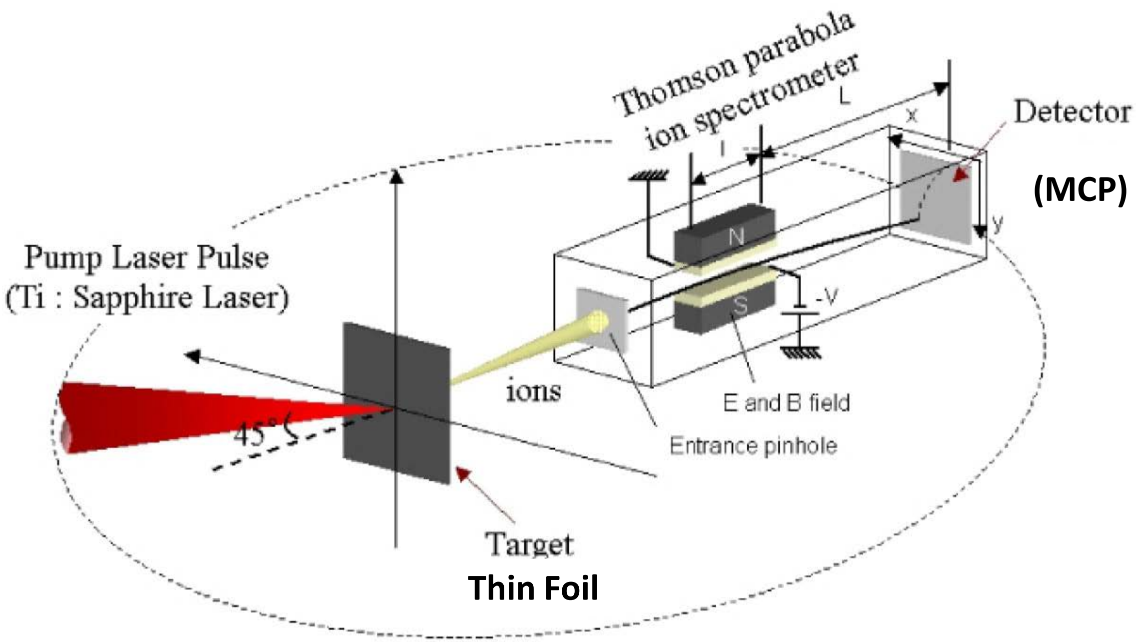
J. Peters RSI 2008

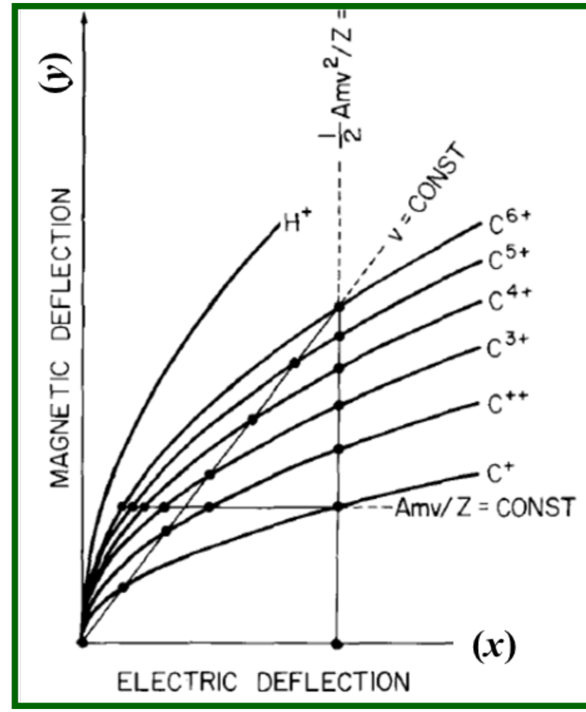
- Surface & Volume Sources
- Single or multistep excitation
- Dissociate attachment of vibrationally excited state dominates over other processes

A counter-intuitive approach



Thomson Parabola Ion Spectrograph (TPIS)





$$x = (q\,E\,l/mv^2)\,(L + l/2)$$

$$y = (q\,B\,l/mv)\,(L + l/2)$$

$$y^2 = K*(\underline{q/m})*x$$

$$K = f\,(l, L, E, B) : \text{Constant}$$

- Simultaneous application of parallel E & B: Charge particle moving under two forces acting in perpendicular
- Unambiguous Identification different charged states with energy distribution
- Detection of <u>+Ve</u>, <u>-Ve</u> ions & <u>neutrals</u> from single diagnostics