The Cockcroft Institute
of Accelerator Science and Technology

UNIVERSITY OF LIVERPOOL

Developments in Non-destructive Beam Profile Monitors

Prof. Carsten P. Welsch

Overview

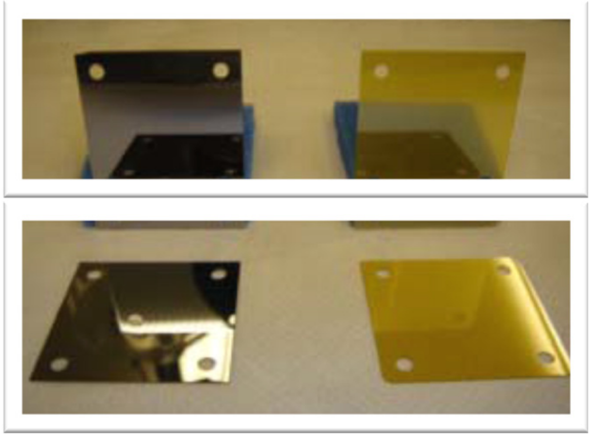
Non-intercepting monitors

Future Challenges

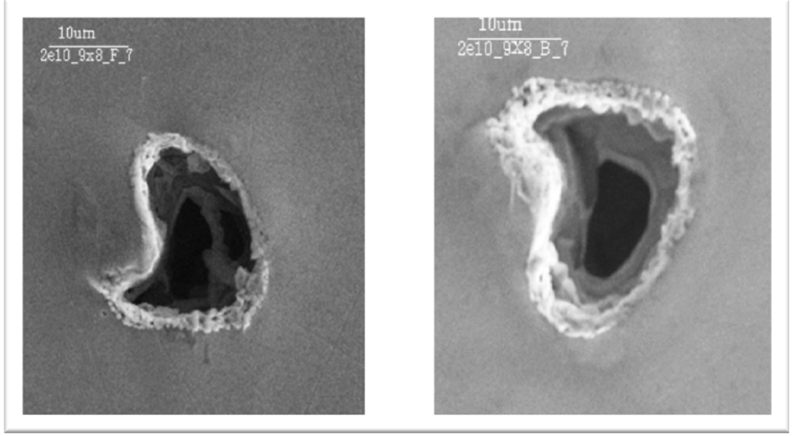
Imaging Techniques

Jet-based Techniques

Profile of High Intensity/Energy Beams

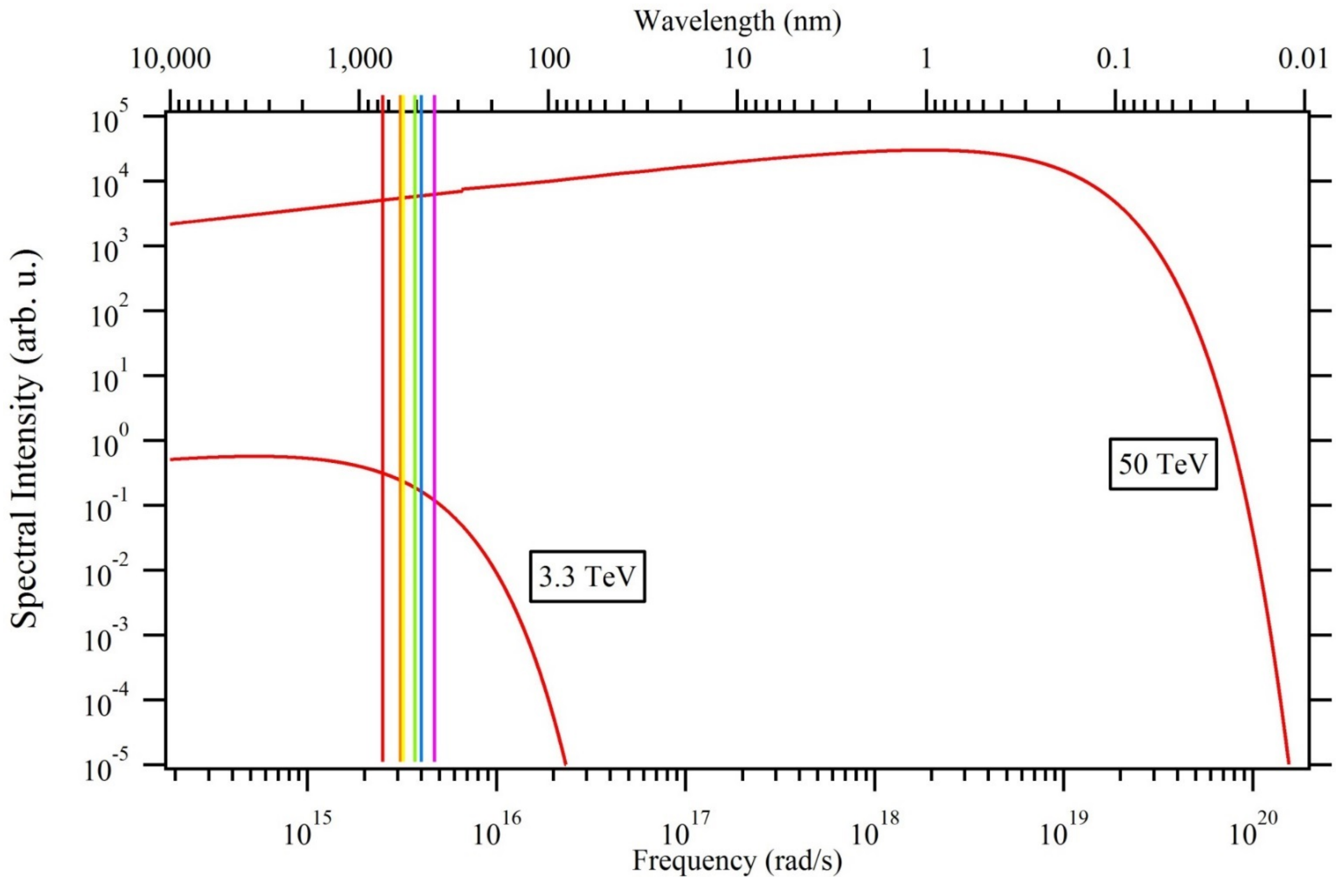


- Damage caused by the beam
- Ideally: Non-invasive.



- Relevant for HLLHC, FCC, CLIC, ESS, etc.

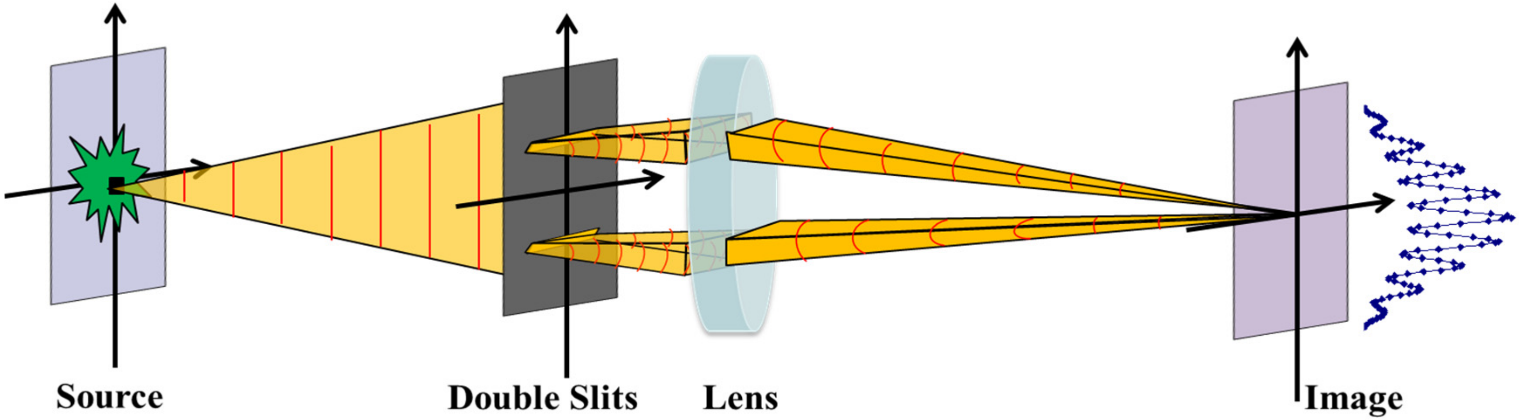
Synchrotron Radiation



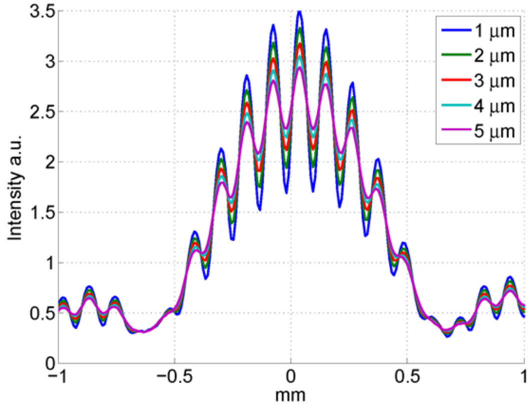
- In the visible ? Problem: Resolution (LHC).

Interferometry or Masking

- Goal: Overcome diffraction limit.

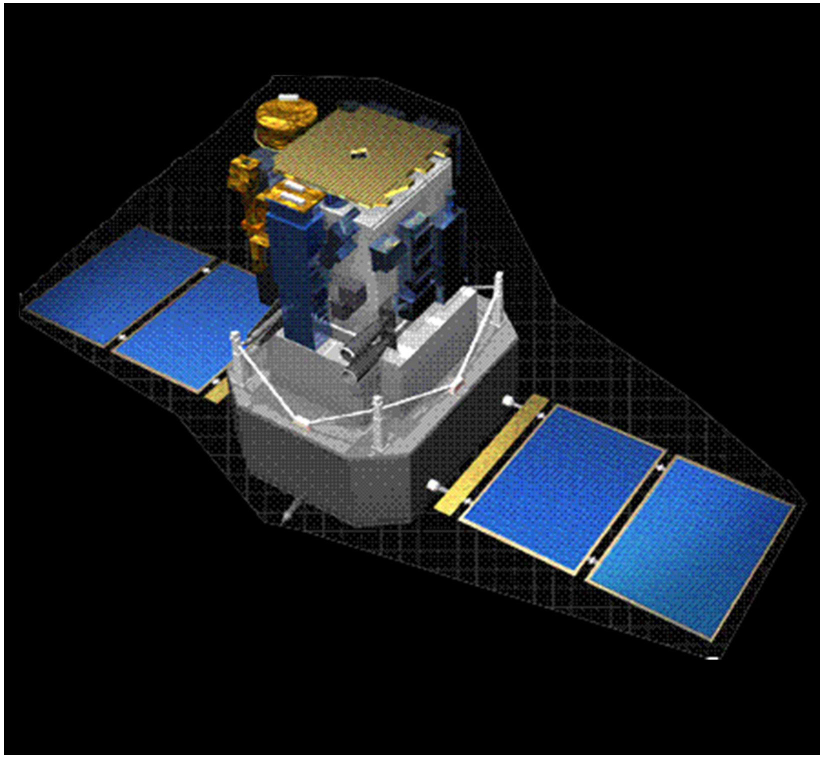


- Coronograph ?
- DMD-based system ?



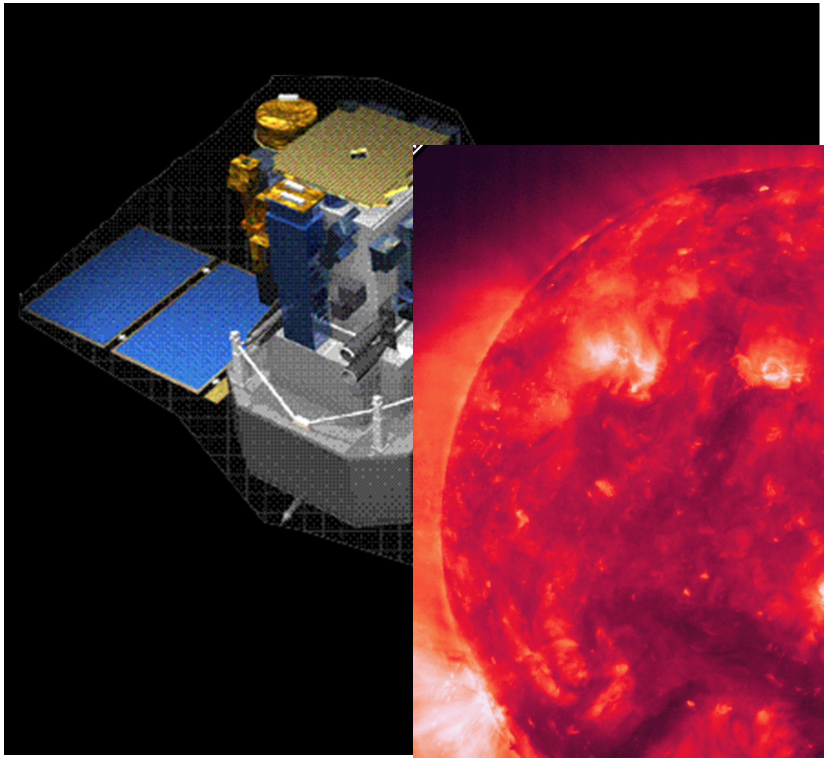
Thanks to G. Trad, A. Jeff

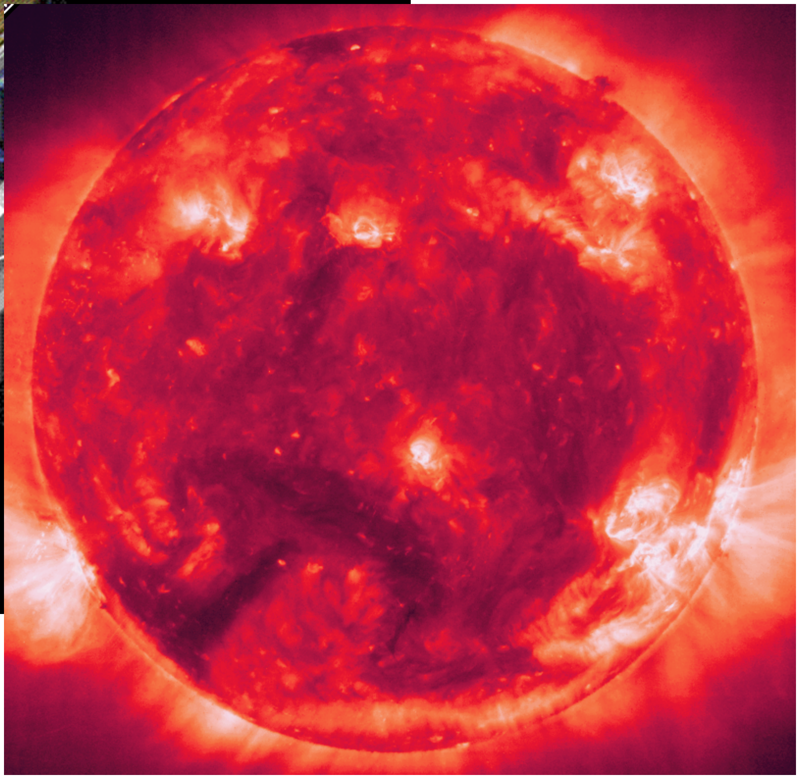
SOHO



*__So__lar and __H__eliospheric __O__bservatory

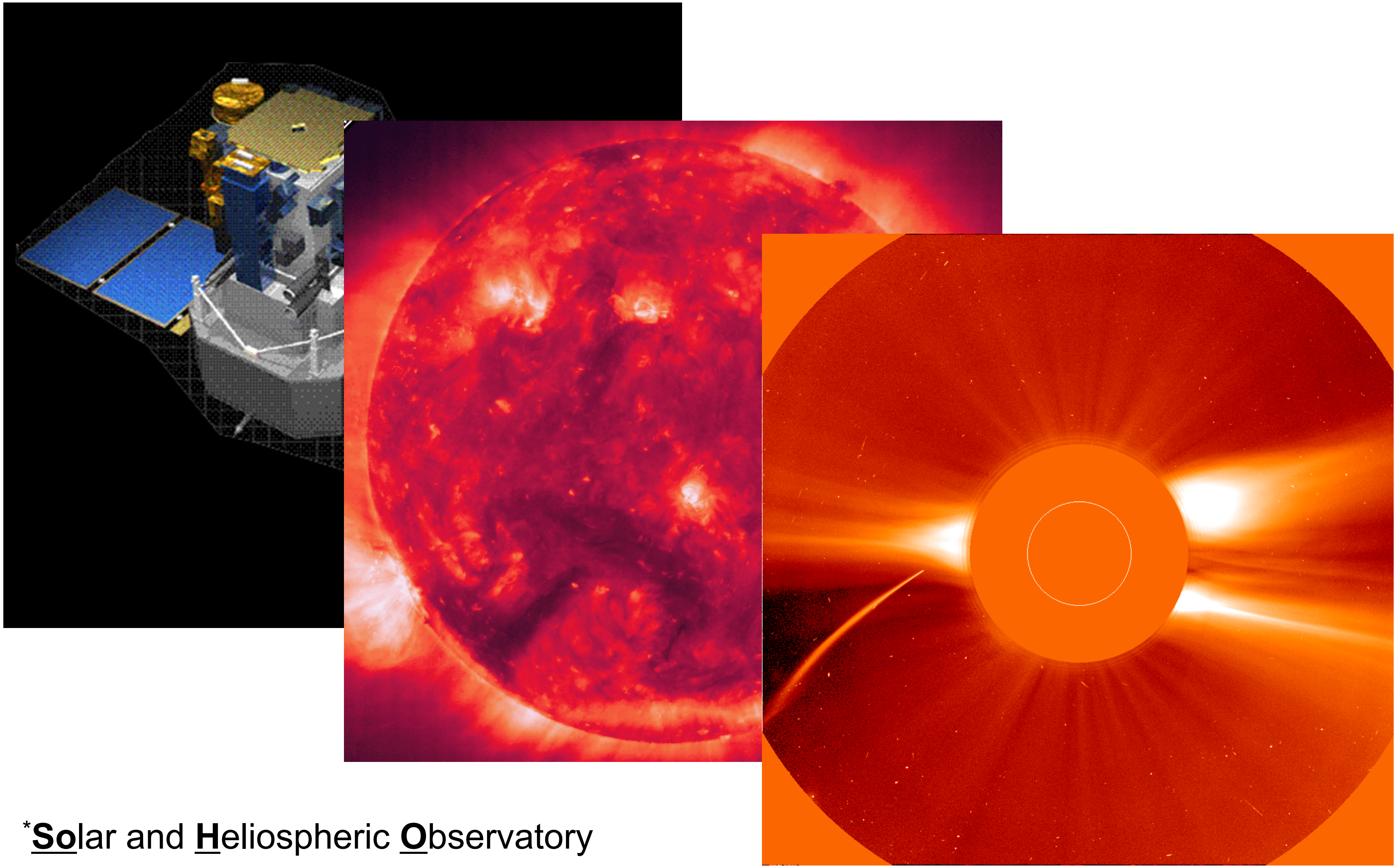
SOHO





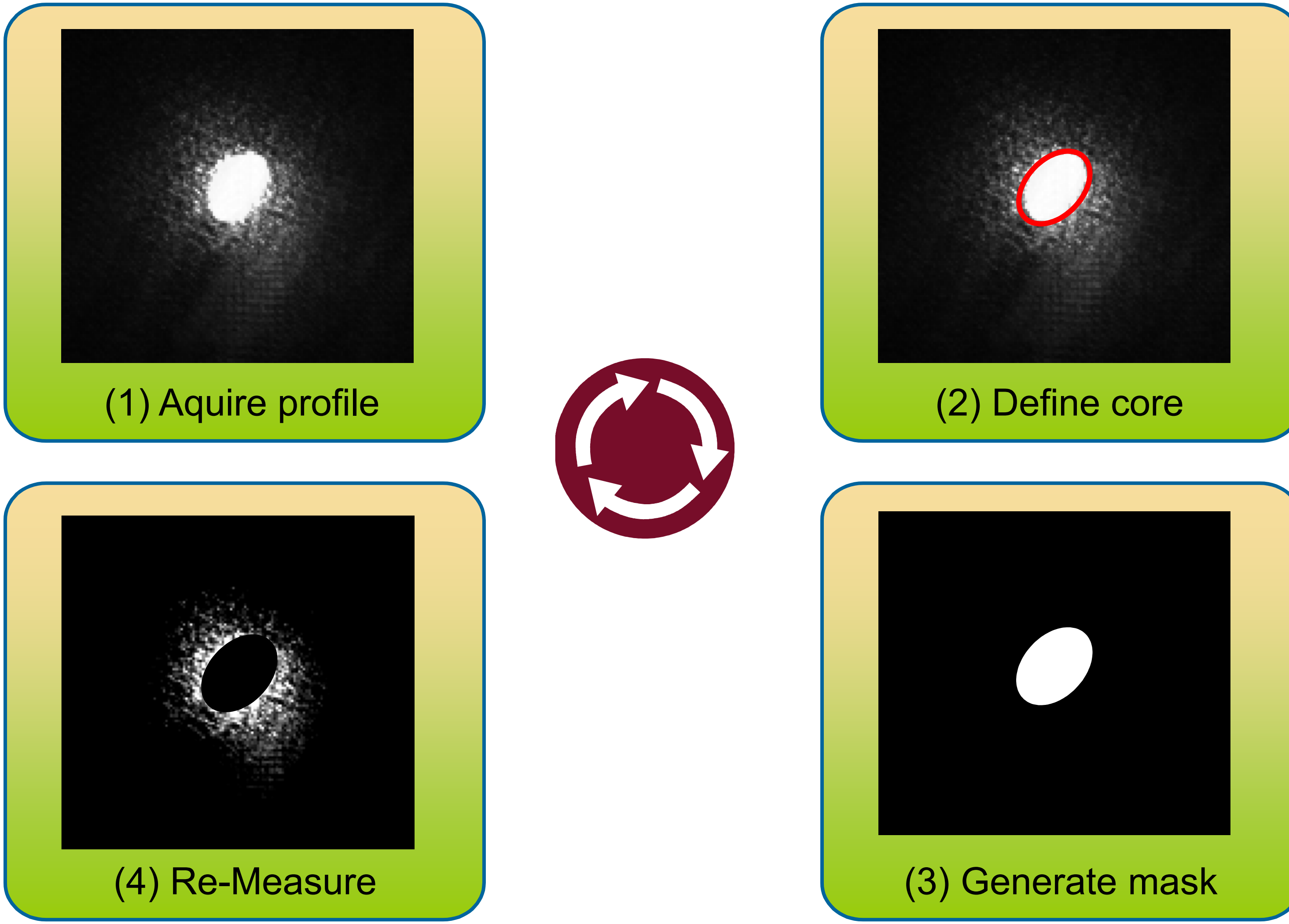
*__So__lar and __H__eliospheric __O__bservatory

SOHO



*Solar and Heliospheric Observatory

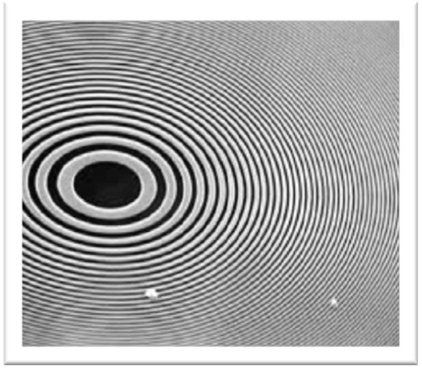
Halo Monitoring: Core Masking



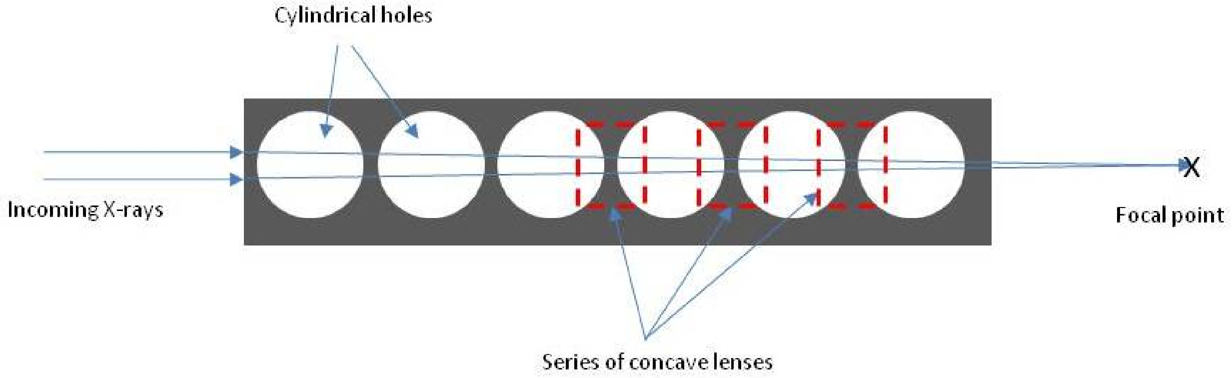
J. Egberts, et al.,
JINST **5** P04010 (2010)
H. Zhang, et al.,
Phys. Rev. STAB 15 (2012)

From Synchrotron Light Sources

- Fresnel zone plates



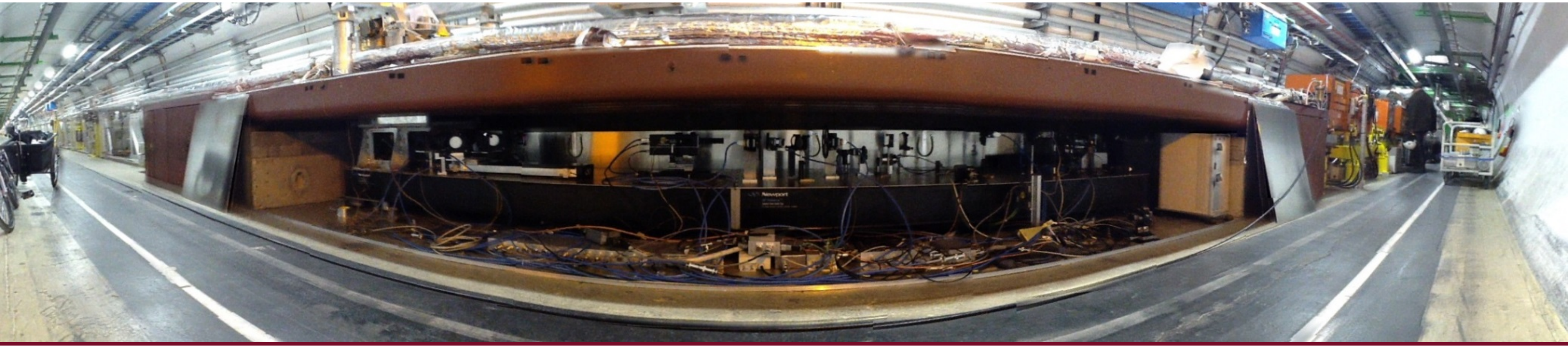
- Compound refractive lens



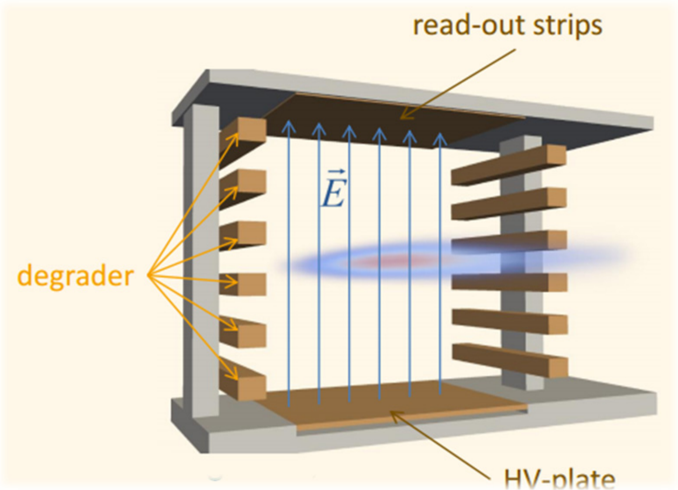
Challenges

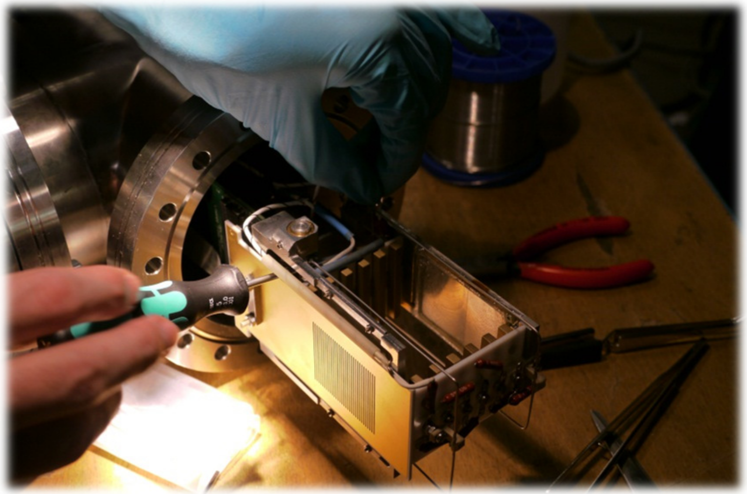
- Need to separate radiation from beam
- Large bending radius = large distances (> 100 m)

- Depth of field issues: ~ ρ/γ
  - Requires undulator to produce (soft) X-rays



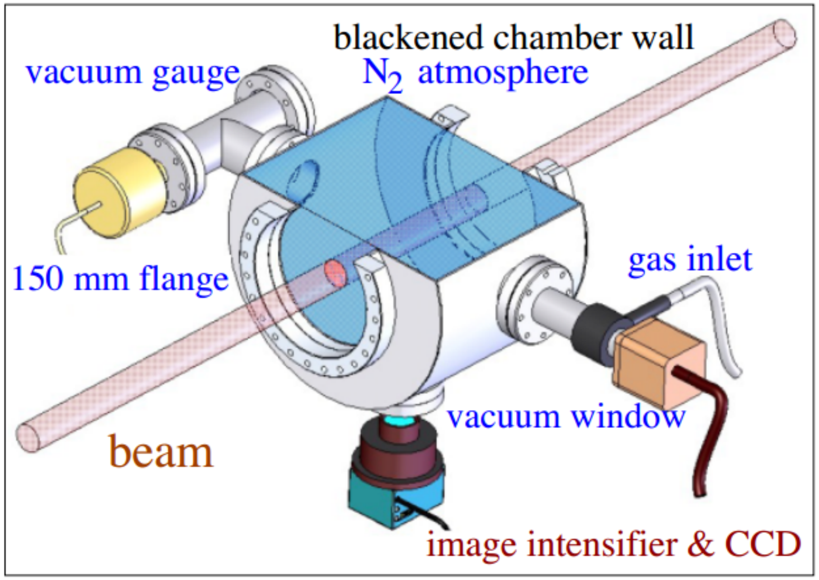
Ionization Profile Monitor (IPM)

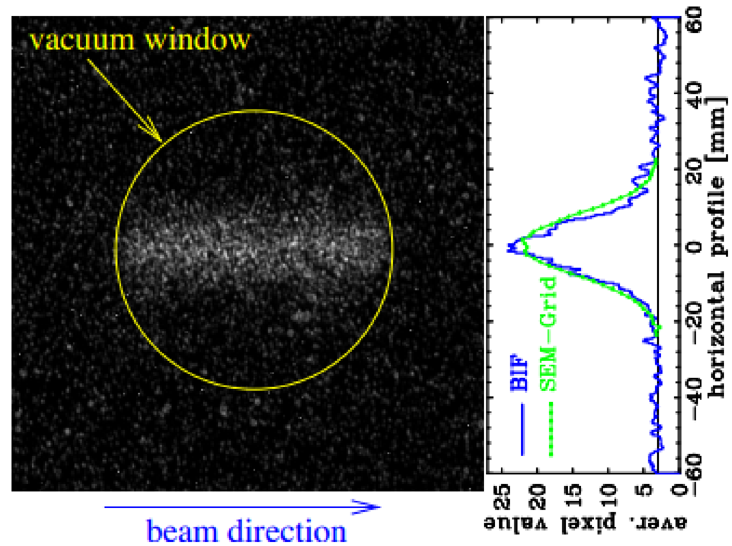




- Based on ionization of rest gas
- Challenges
  - Required residual gas pressure
  - 1D beam profile ‚only‘

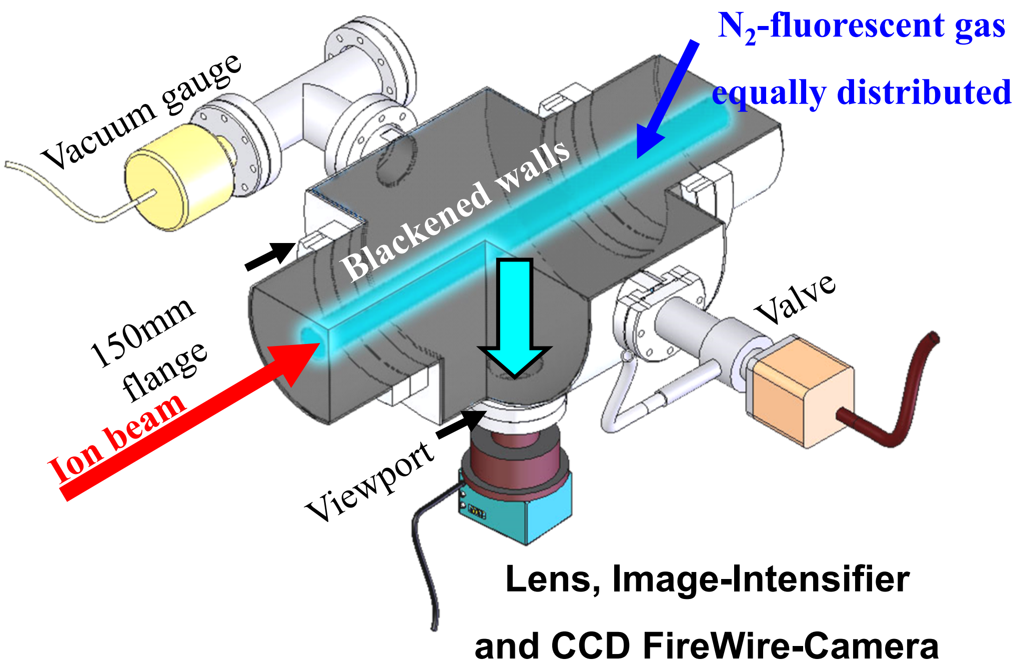
Beam Induced Fluorescence (BIF)

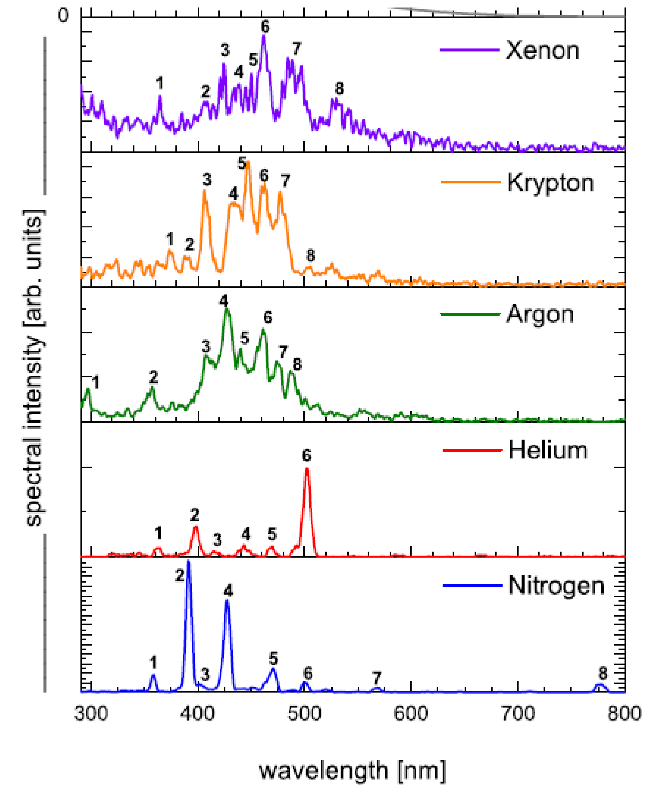




- Measures light from rest gas, excited by beam
- Challenges:
  - Very low cross sections
  - Isotropic light emission
  - Rest gas pressure requirements

Fluorescence Monitor Principle



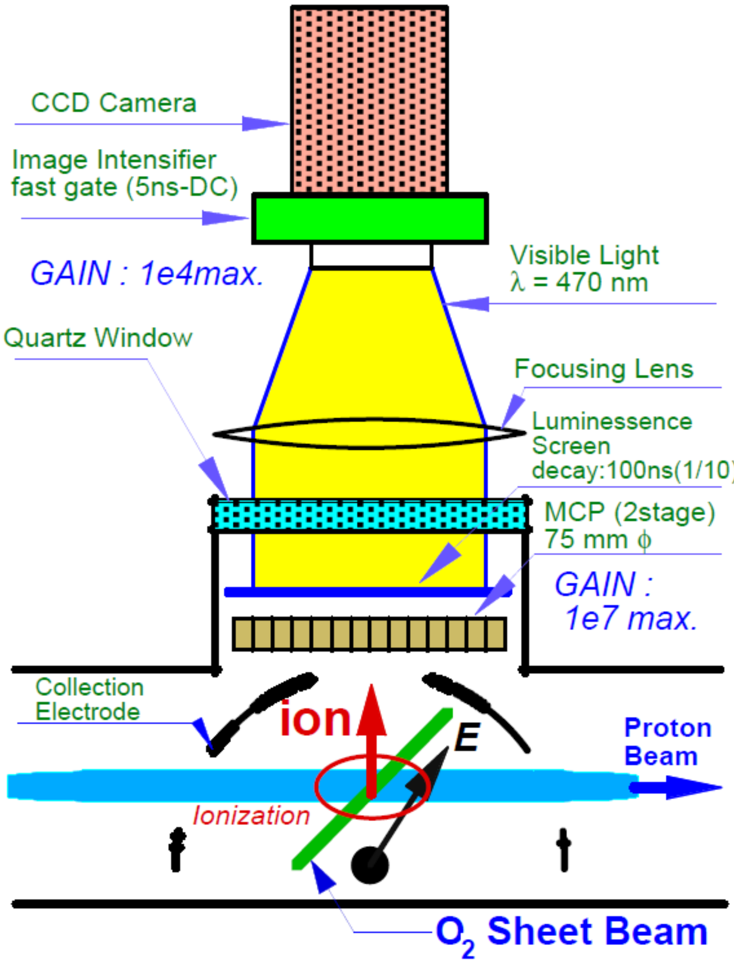


P. Forck et al., *Beam induced fluorescence profile monitor developments*, Proc. HB2010

- Gas molecules are excited by the beam and emit a photon when returning to the ground state.
- Emission wavelength is determined by the gas species
- The relaxation time is typically 10s or 100s of ns.

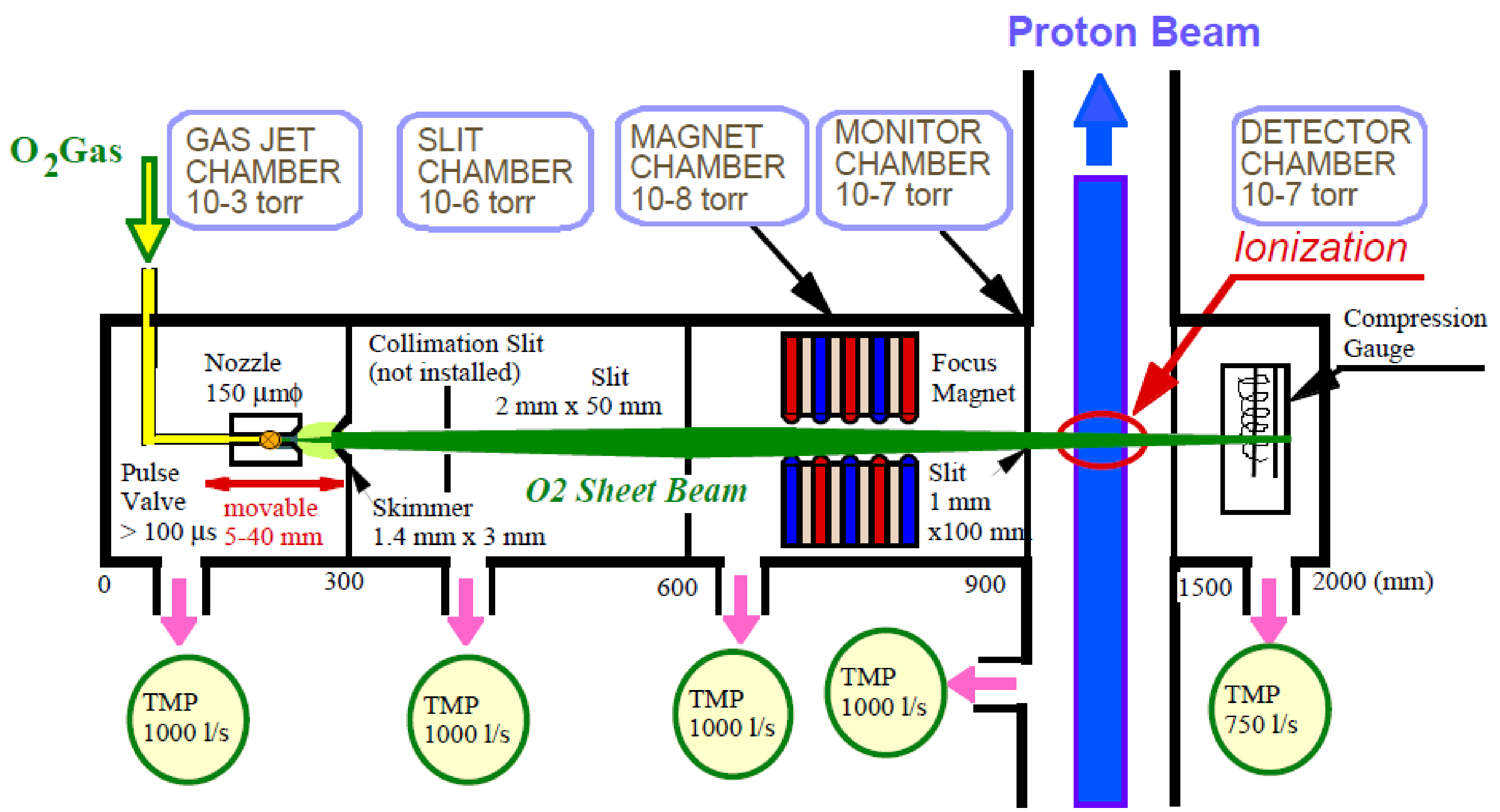
Gas Sheet Monitor

- Generate thin atom gas curtain,
- Ionize atoms with primary particle beam,
- Extract ions via electric field,
- Monitor on MCP, P screen.



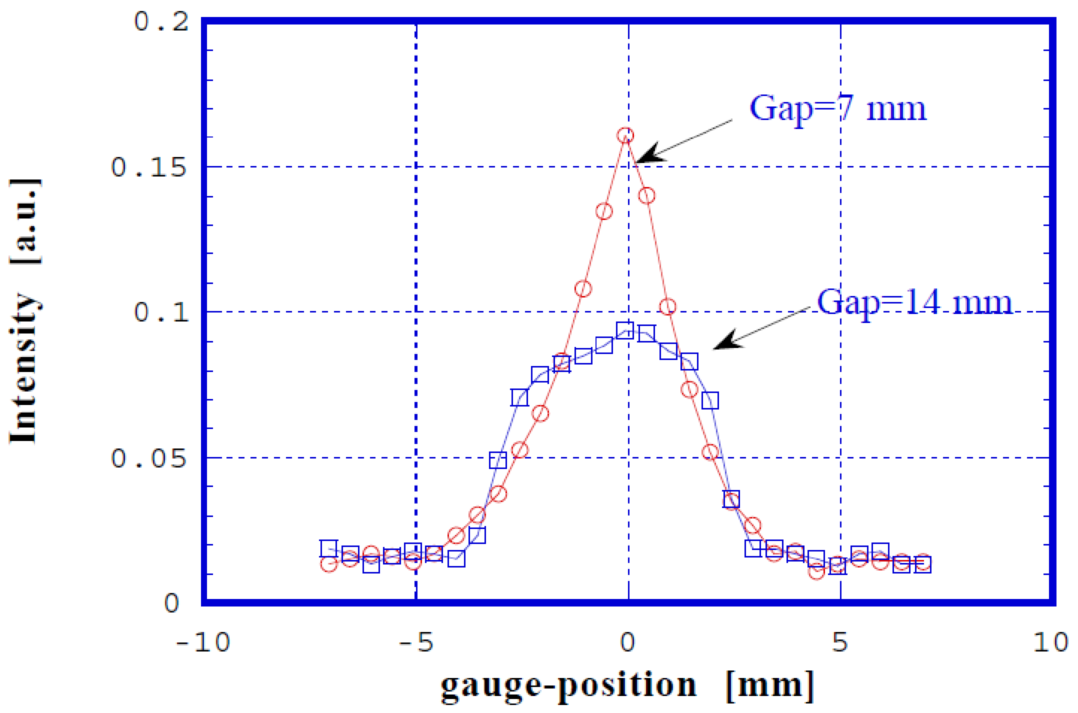
Y. Hashimoto et al., Proc. Part. Acc. Conf., Chicago (2001)

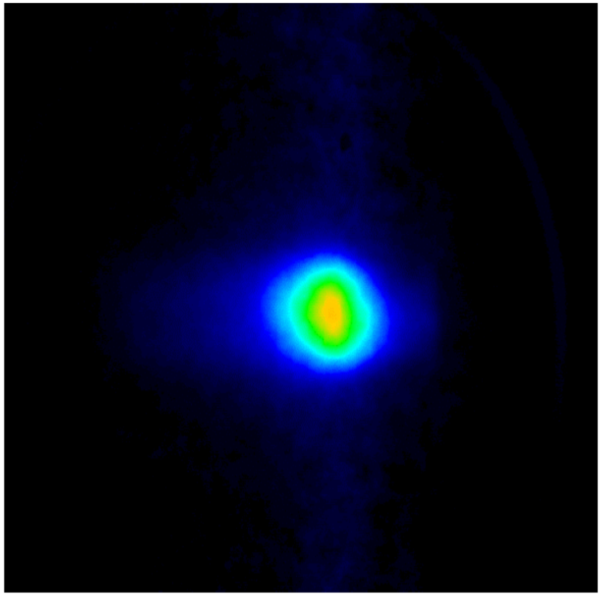
How to Generate the Jet ?

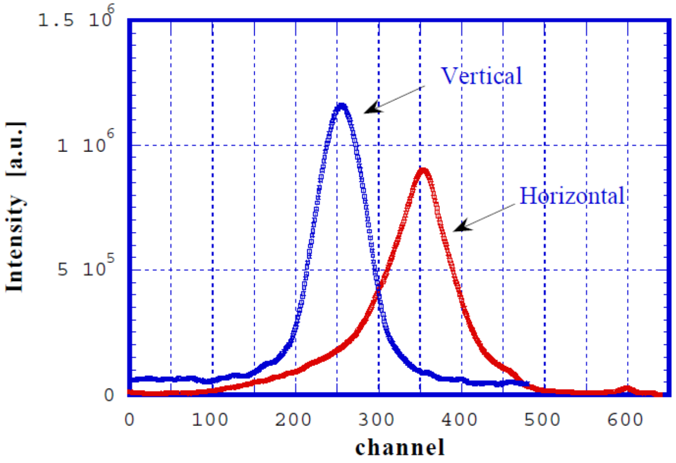


Y. Hashimoto et al., Proc. Part. Acc. Conf., Chicago (2001)

Experimental Data

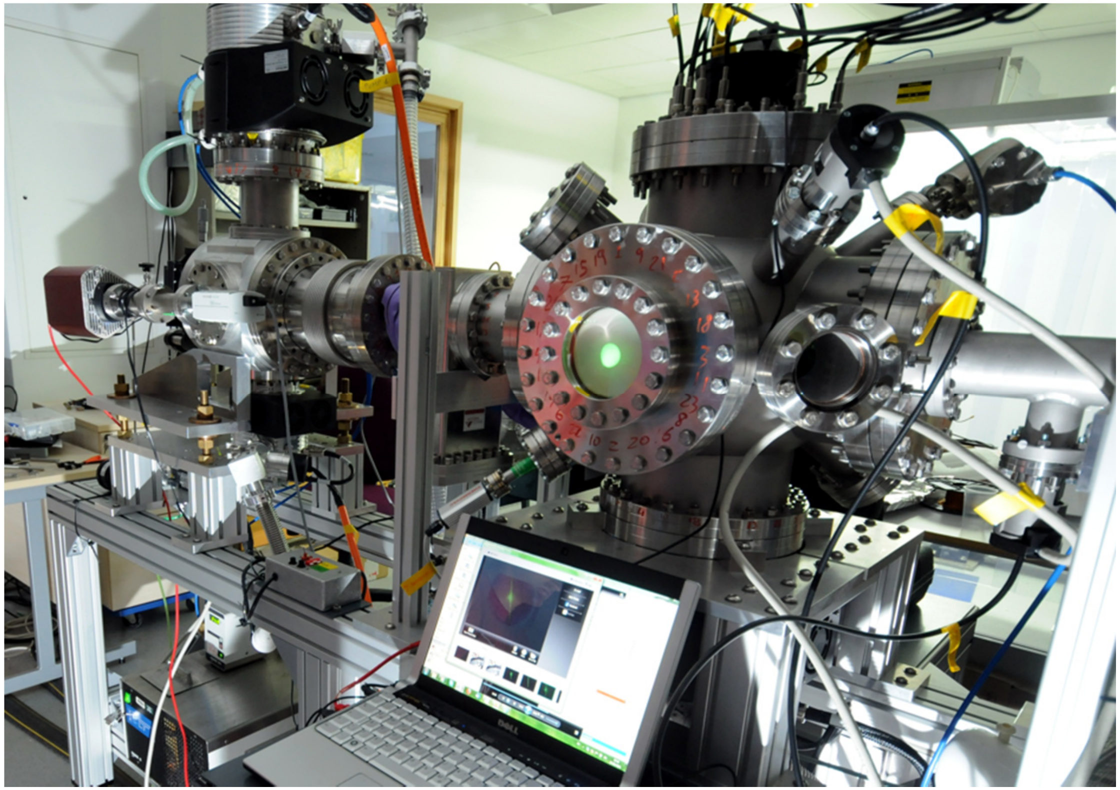




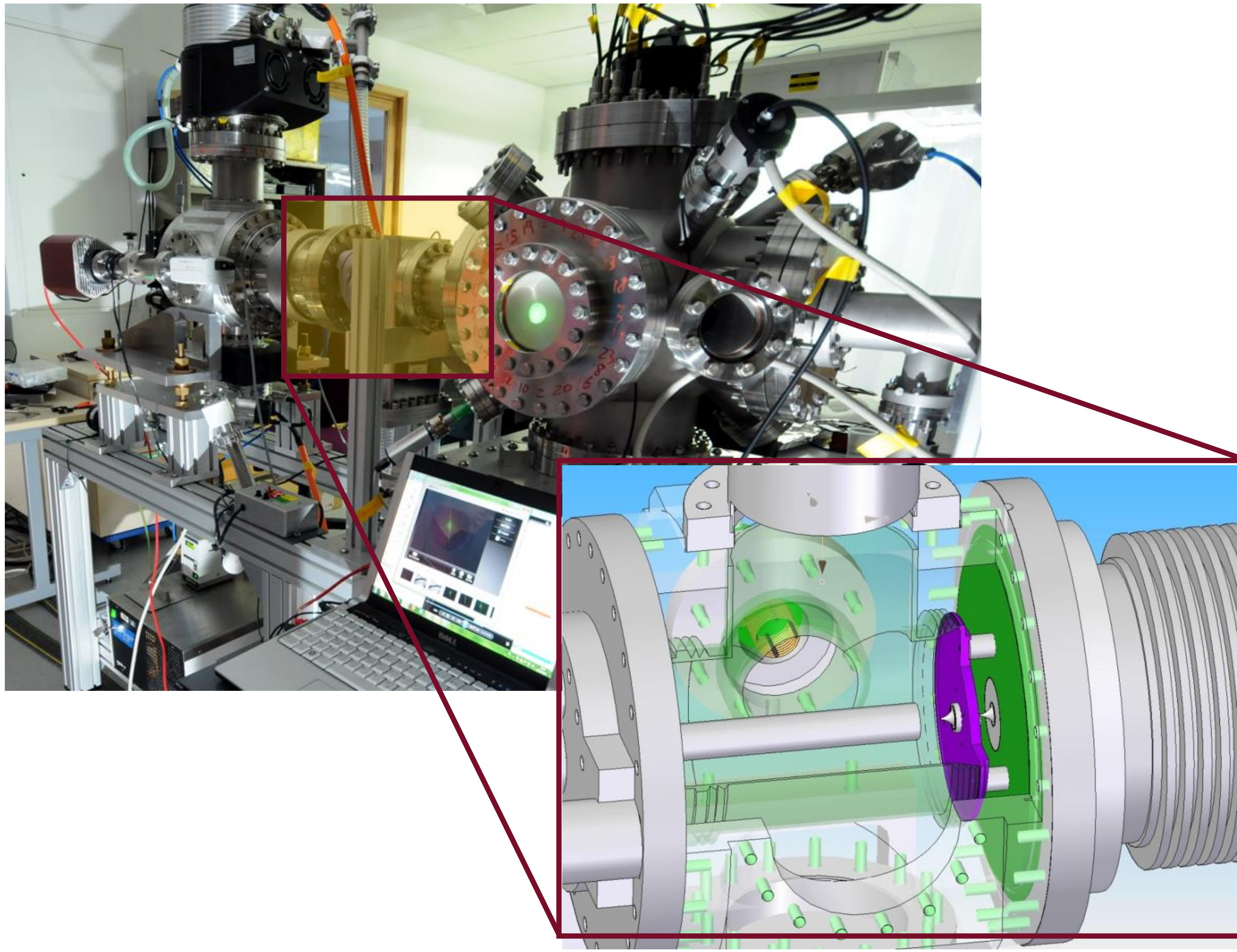


Y. Hashimoto et al., Proc. Part. Acc. Conf., Chicago (2001)

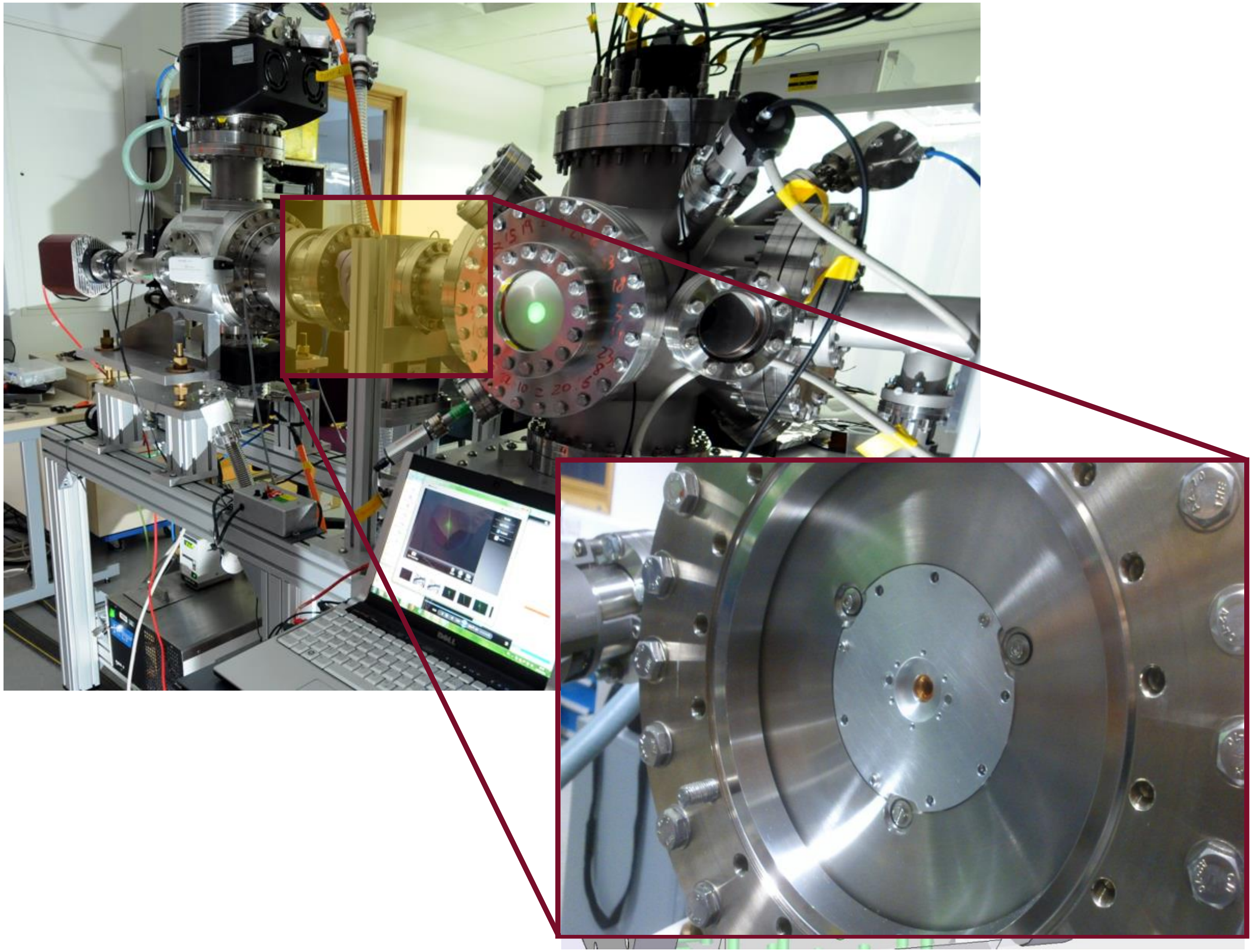
Setup @ Cockcroft Institute



Setup @ Cockcroft Institute



Setup @ Cockcroft Institute



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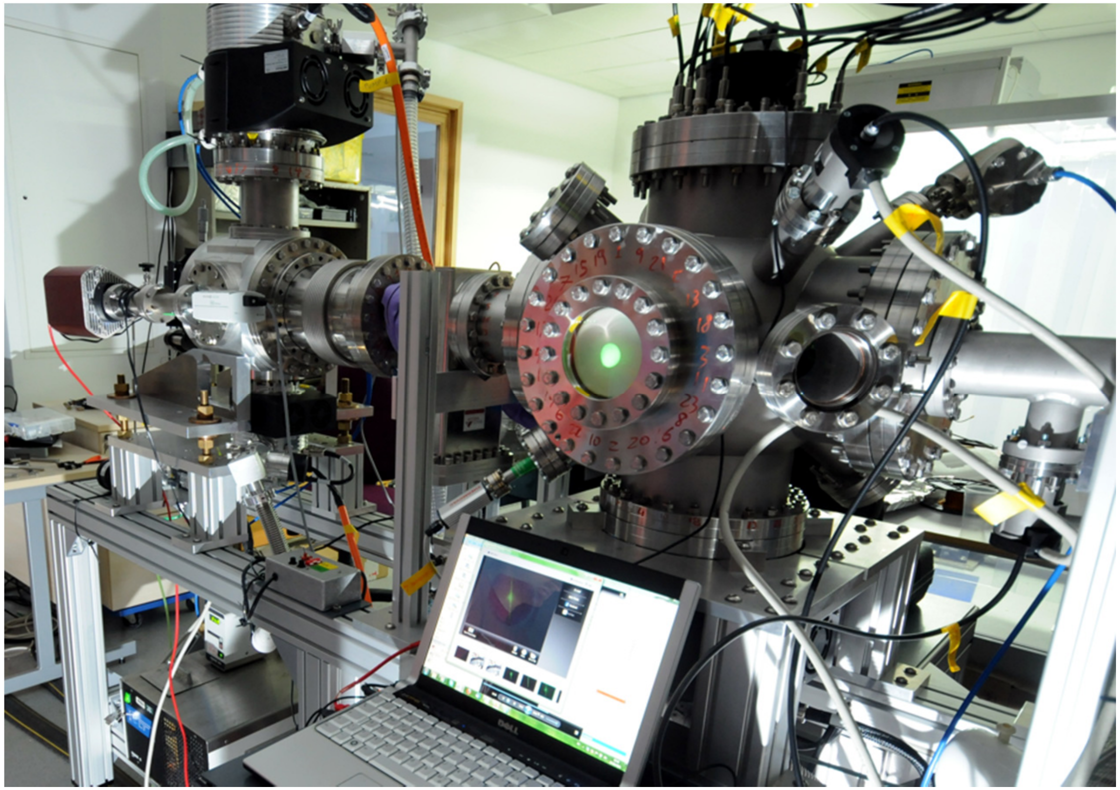
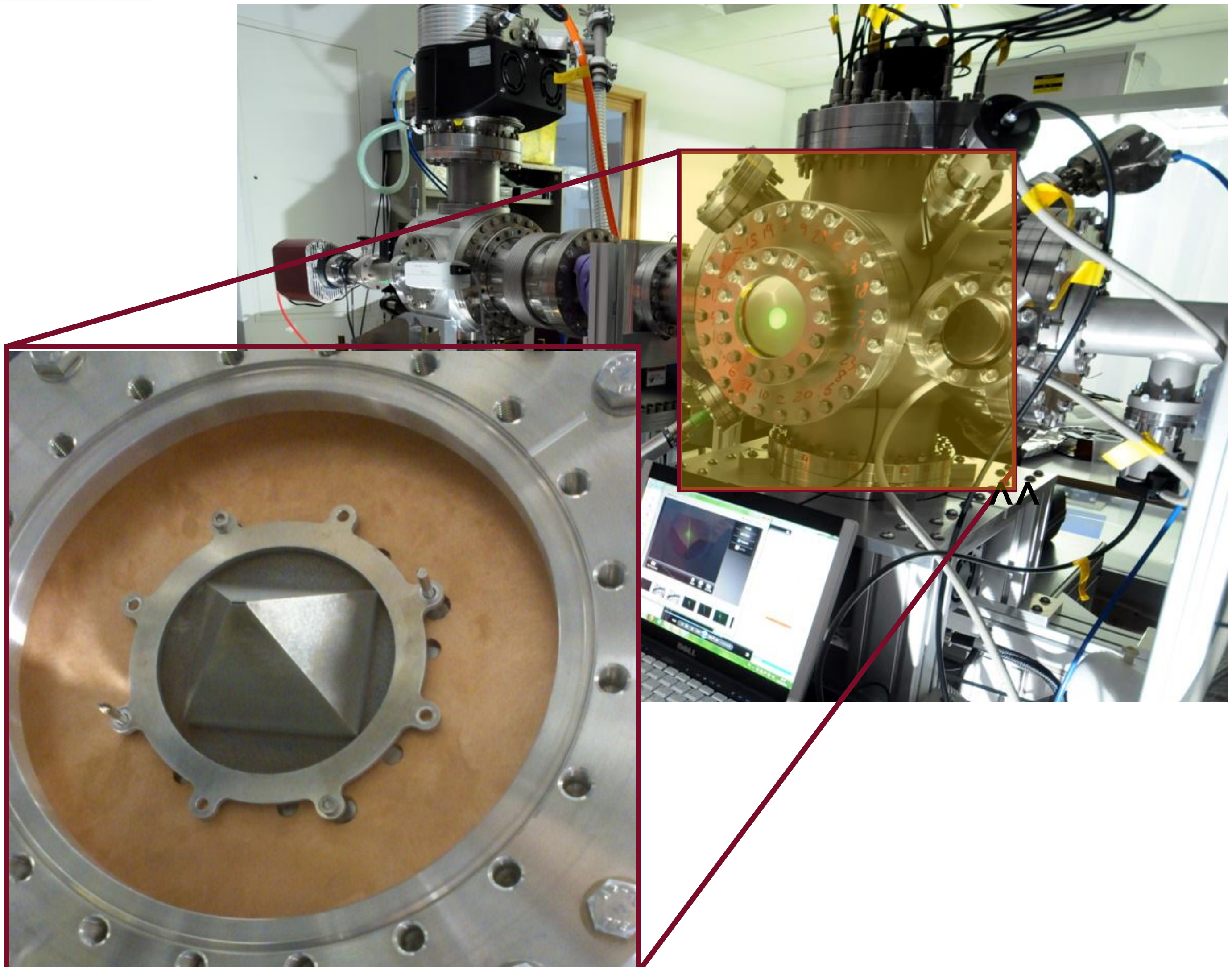
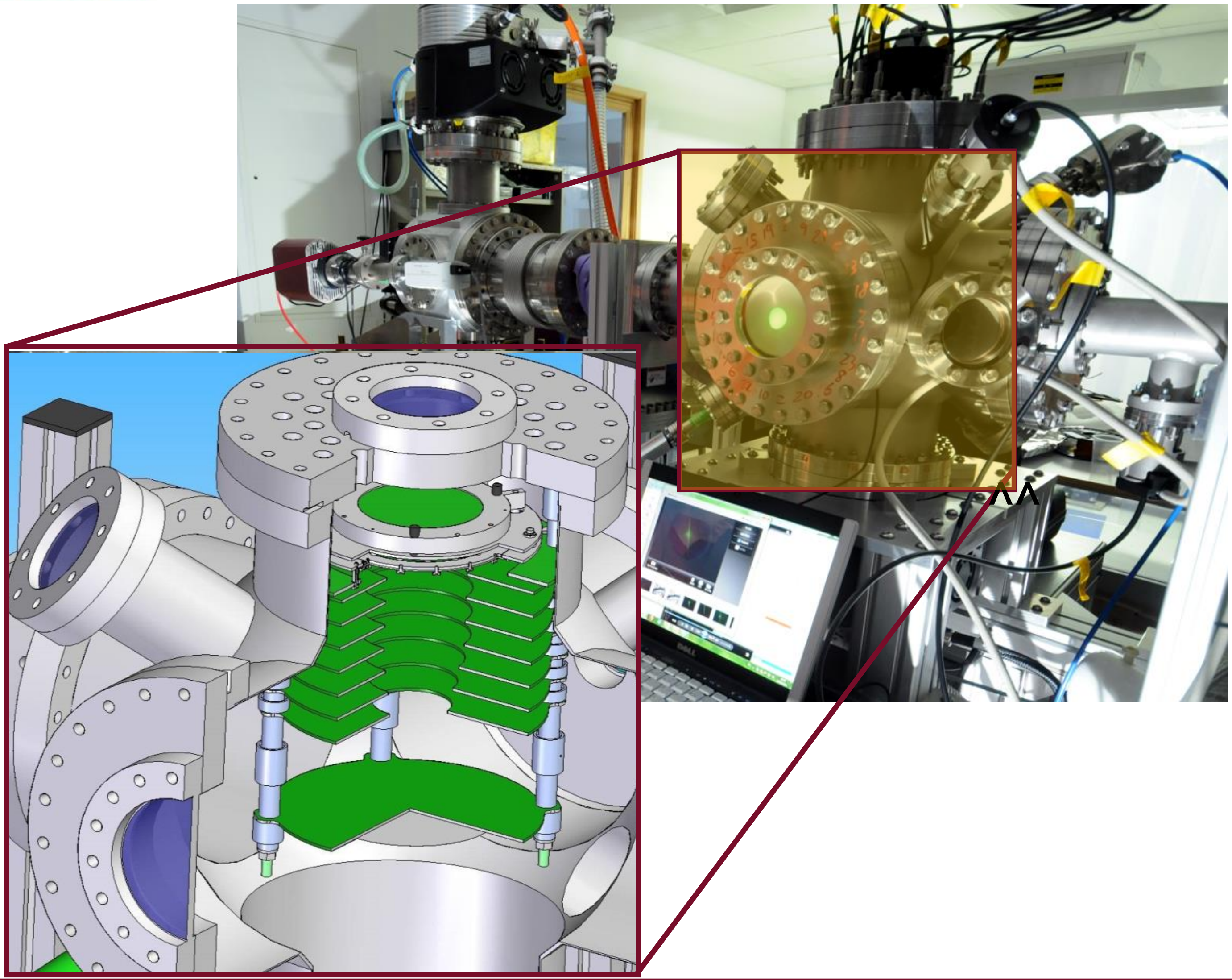
Setup @ Cockcroft Institute



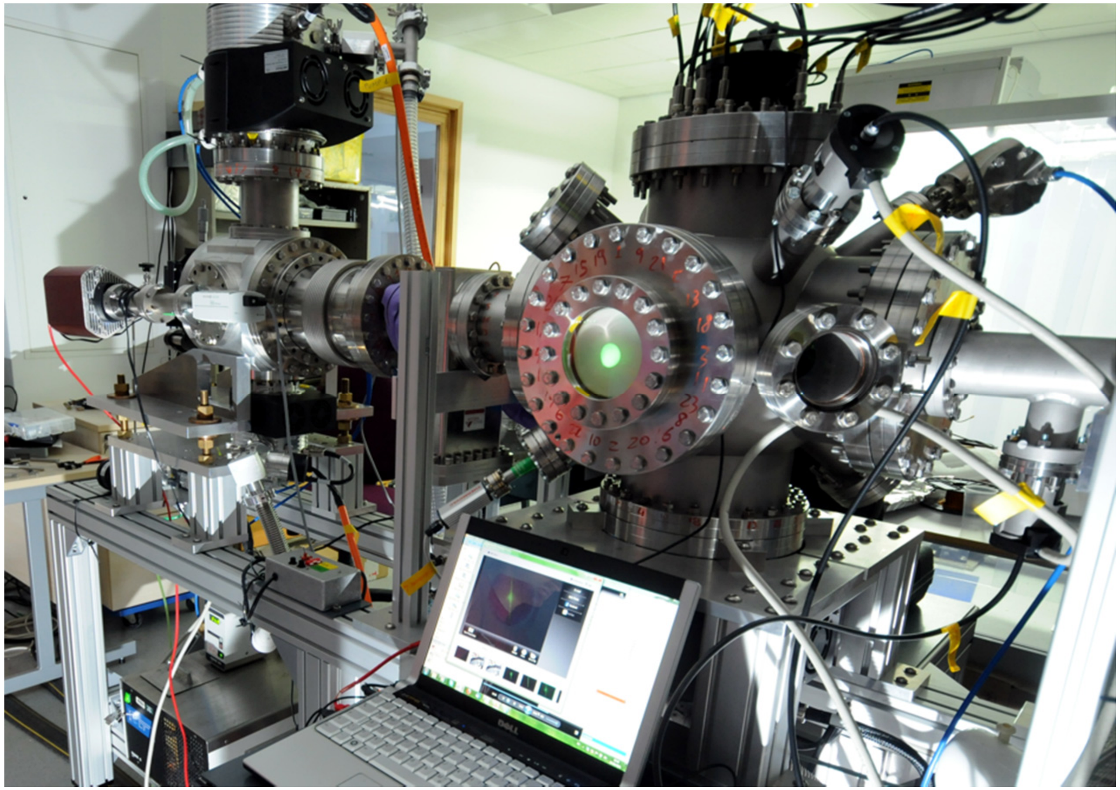
Setup @ Cockcroft Institute



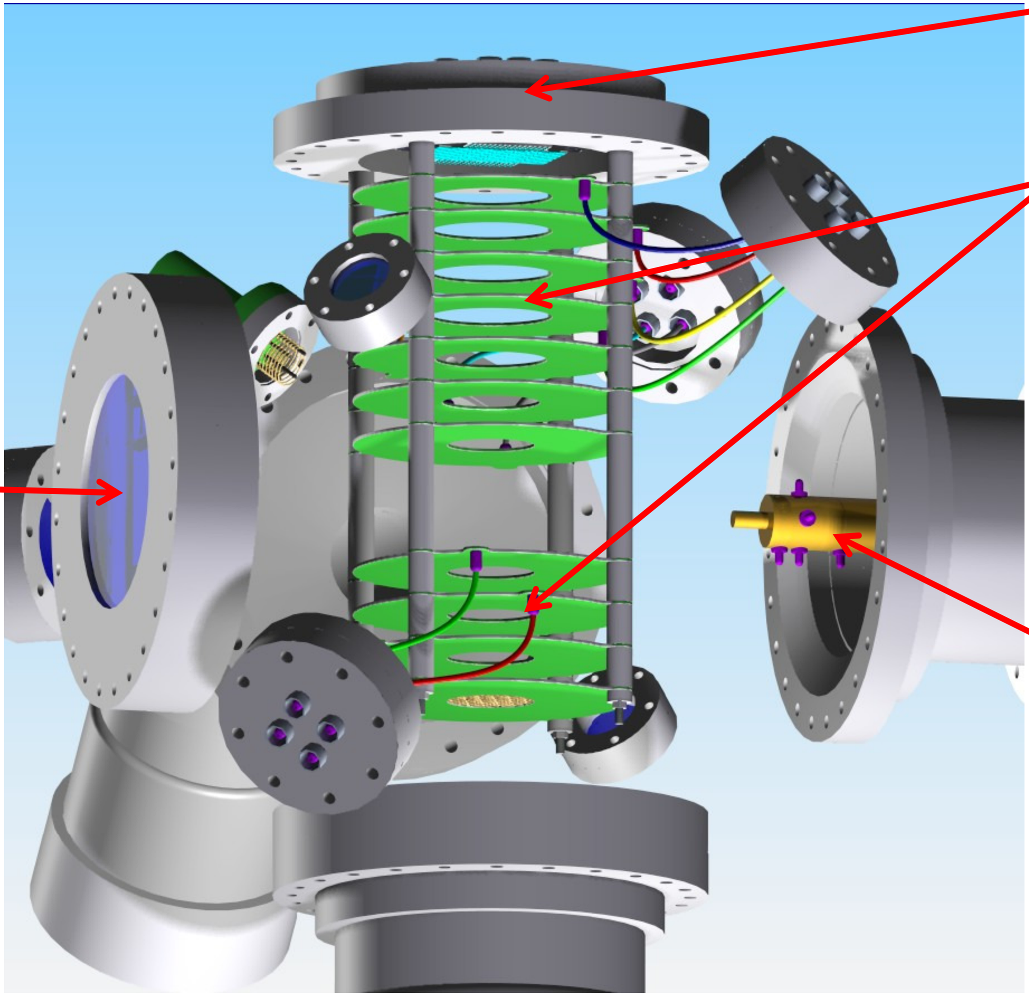
Setup @ Cockcroft Institute



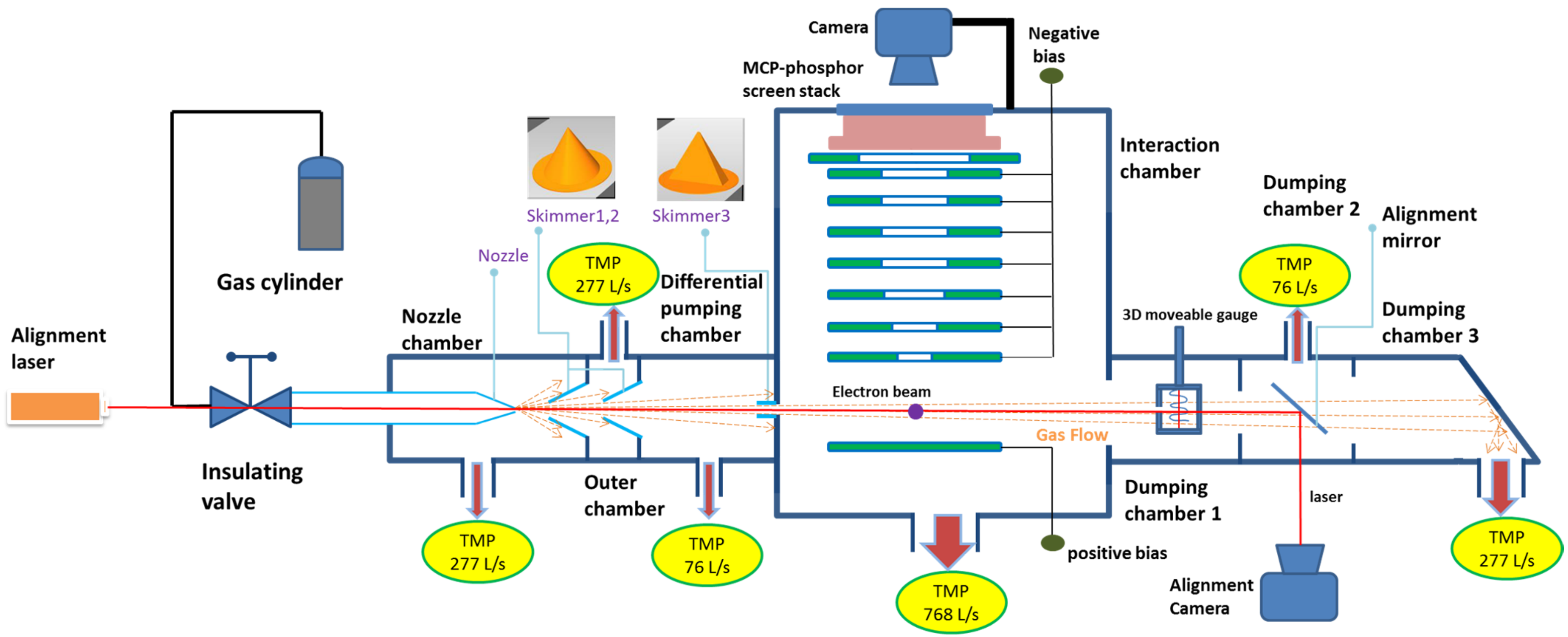
Setup @ Cockcroft Institute



Zoom: Main chamber

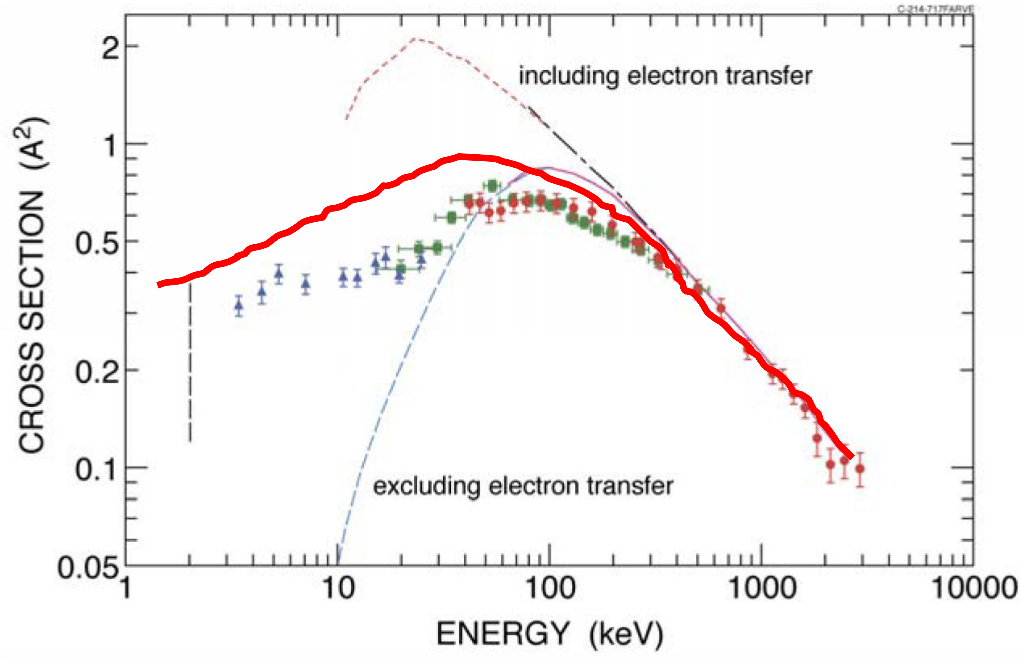


Setup


Camera
Negative bias
MCP-phosphor screen stack
Gas cylinder
Skimmer1,2
Skimmer3
Interaction chamber
Dumping chamber 2
Alignment mirror
Nozzle
TMP 277 L/s
Differential pumping chamber
TMP 76 L/s
3D moveable gauge
Dumping chamber 3
Alignment laser
Nozzle chamber
Electron beam
Gas Flow
Insulating valve
Outer chamber
Dumping chamber 1
laser
TMP 277 L/s
TMP 76 L/s
TMP 768 L/s
positive bias
Alignment Camera
TMP 277 L/s

Ionization Cross Sections

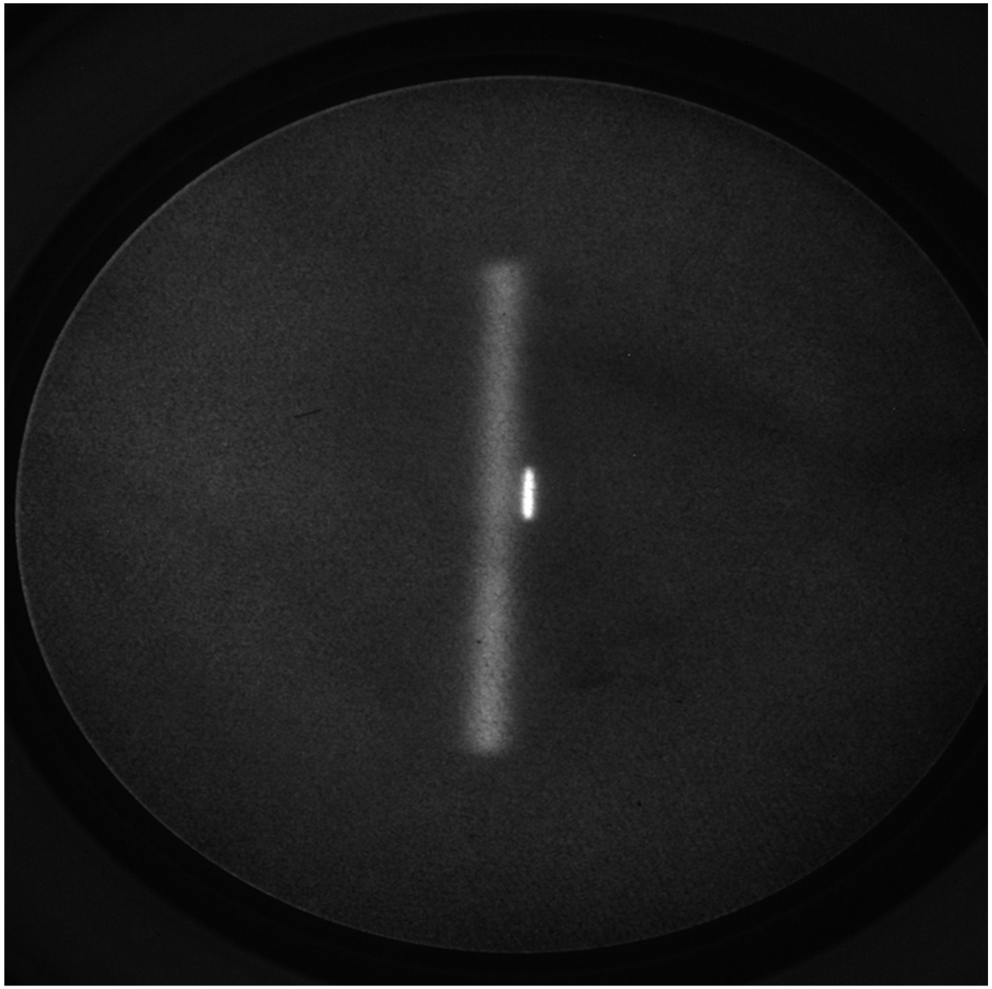
- Can be exotic, e.g. single ionization of helium by antiproton impact



$$\#_{Events} = \frac{\#_{ions}}{C} \cdot v \cdot \sigma(E) \cdot \rho_{target} \cdot w_{target}$$

H. Knudsen, Hyperfine Interactions **109** (1997) 133–143
H. Knudsen, Journal of Physics:Conf. Series **194** (2009) 012040

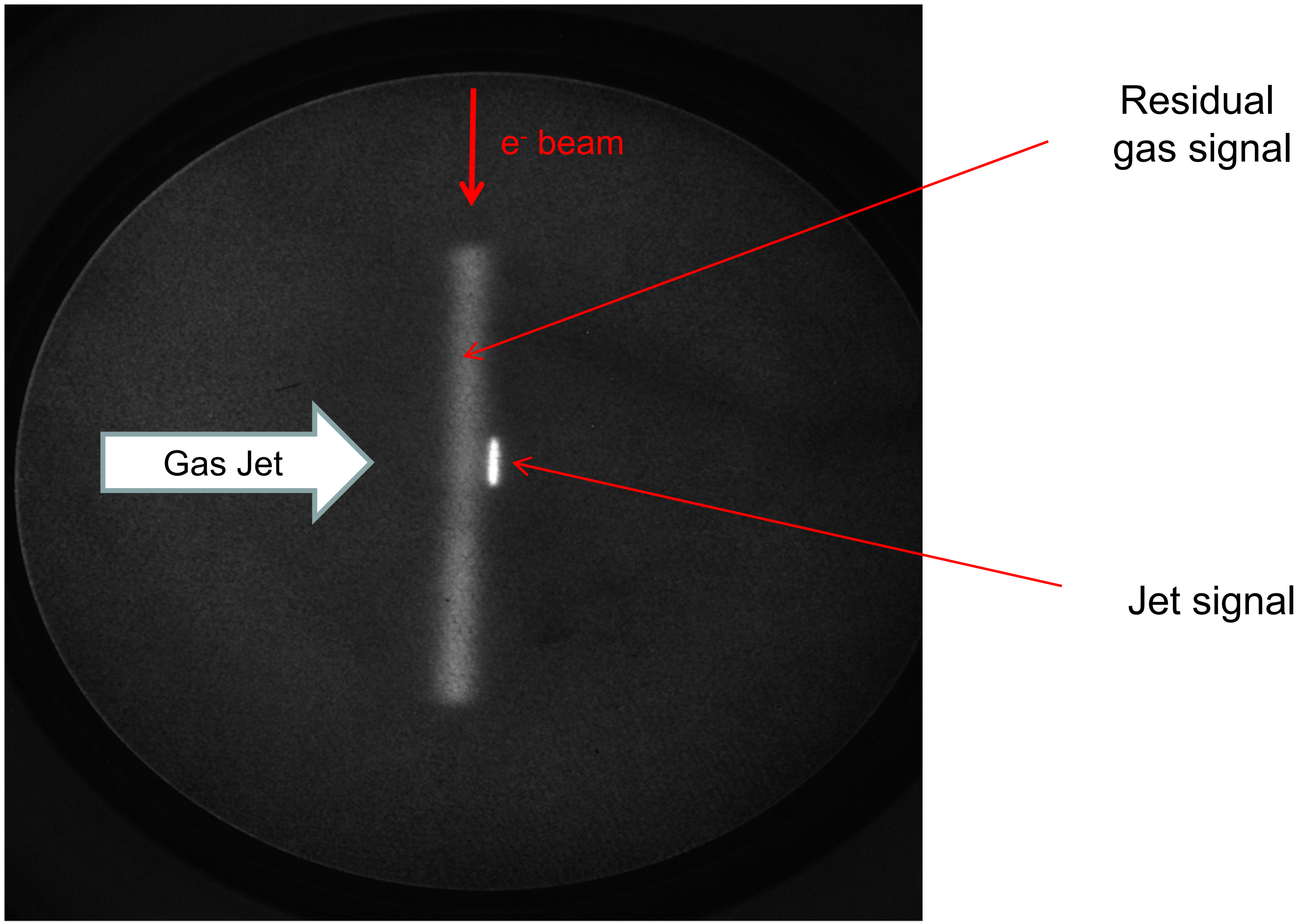
Results @ CI



V. Tzoganis, et al.,
APL **104** 204104 (2014)

V. Tzoganis, et al.,
VACUUM (2015)

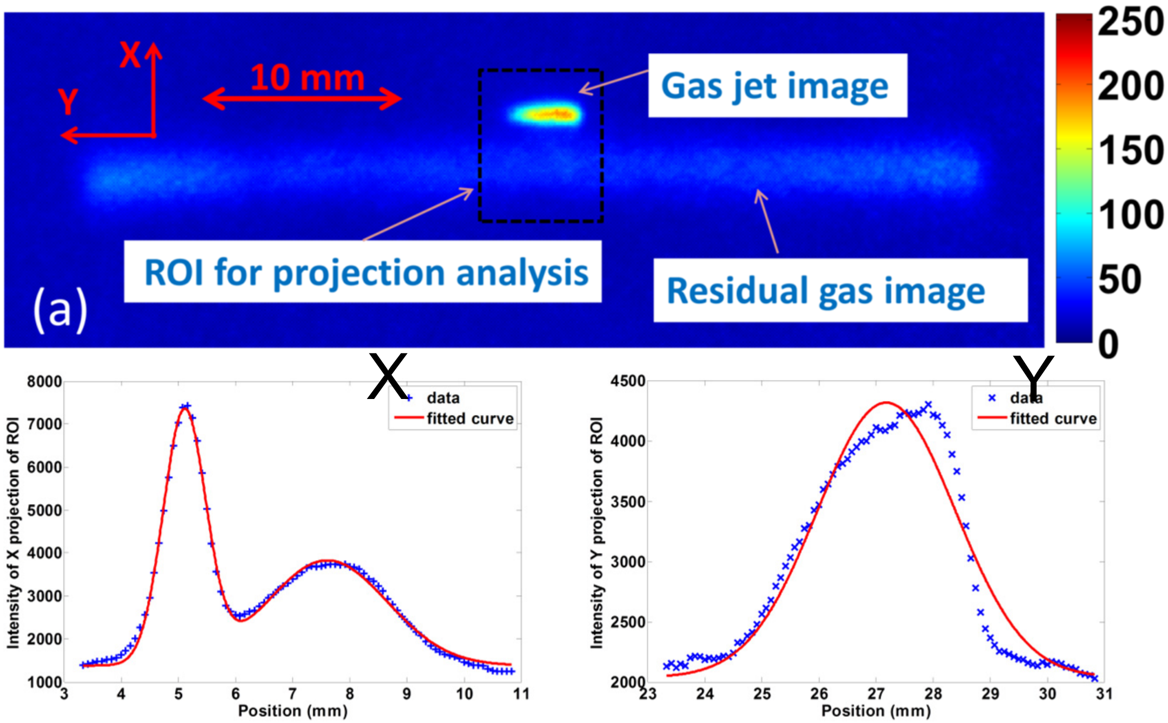
Results @ CI

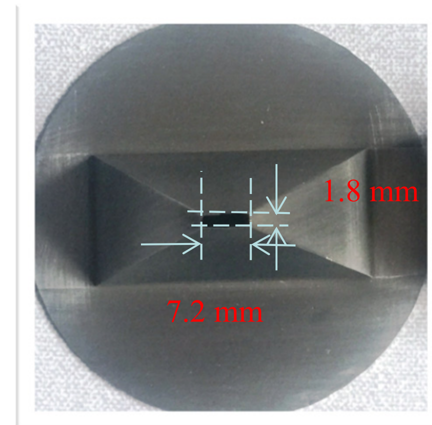


V. Tzoganis, et al.,
APL **104** 204104 (2014)

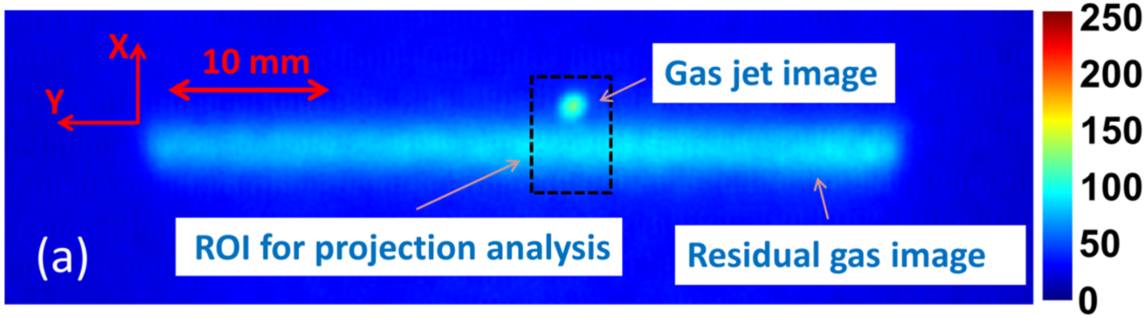
V. Tzoganis, et al.,
VACUUM (2015)

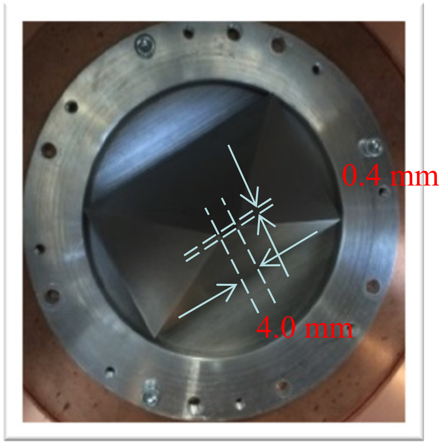
Example Measurement 1

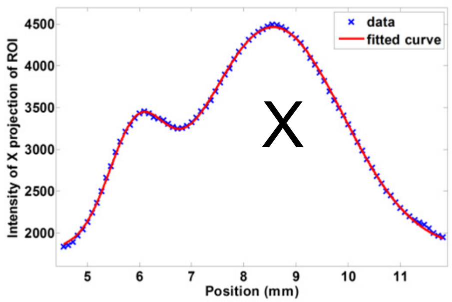


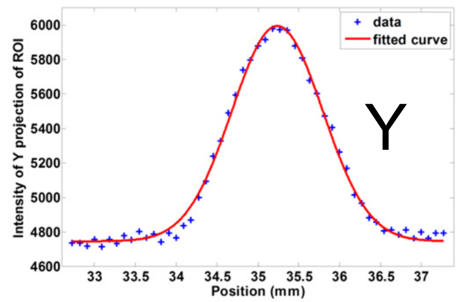


Example Measurement 2



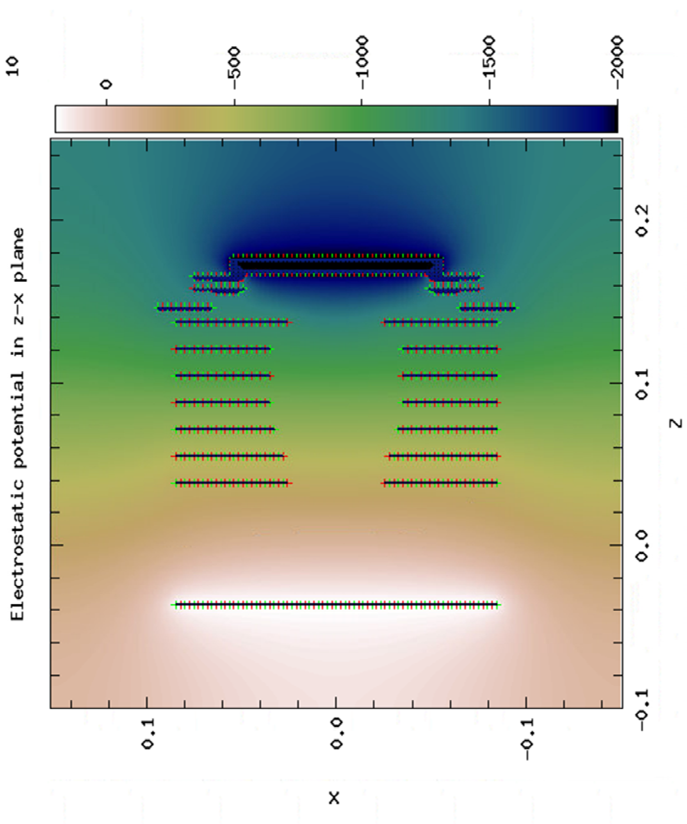


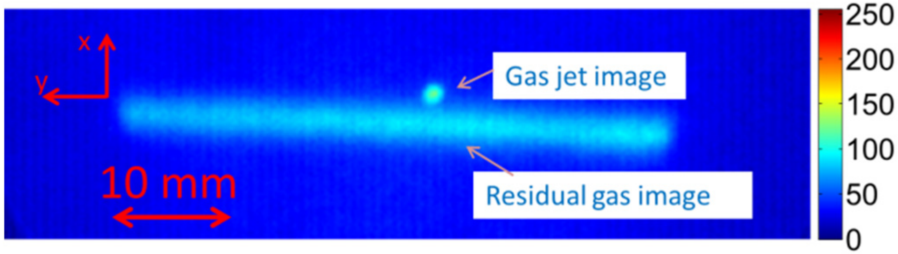


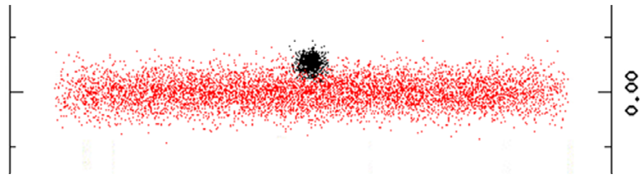


Understanding the Jet

- Simulations using the CST and WARP codes



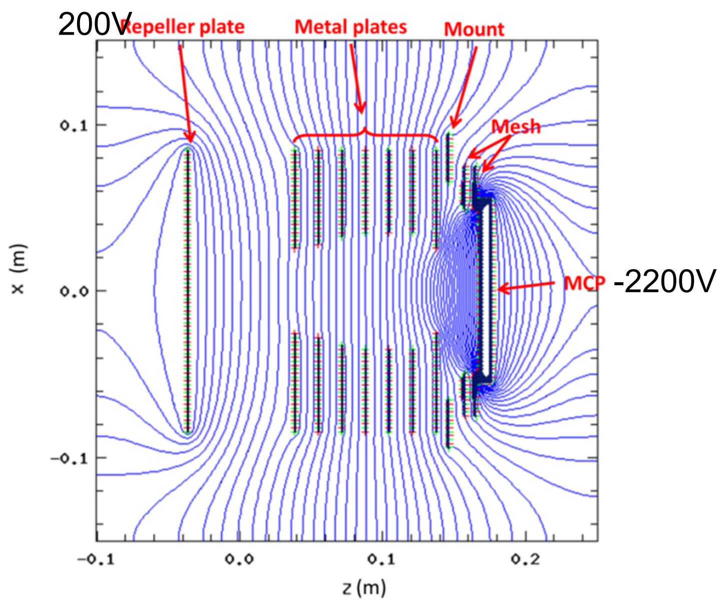


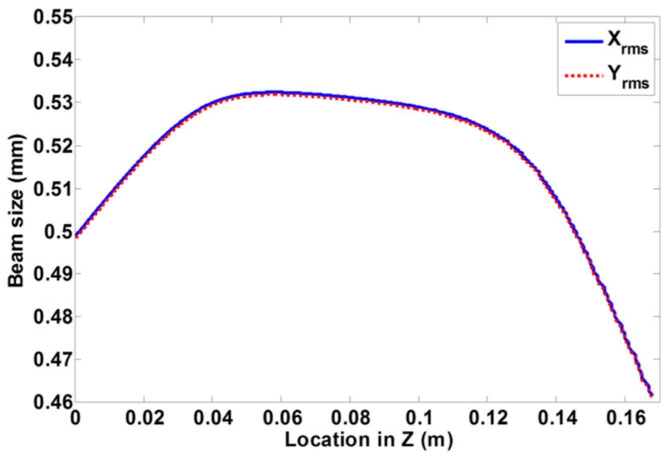


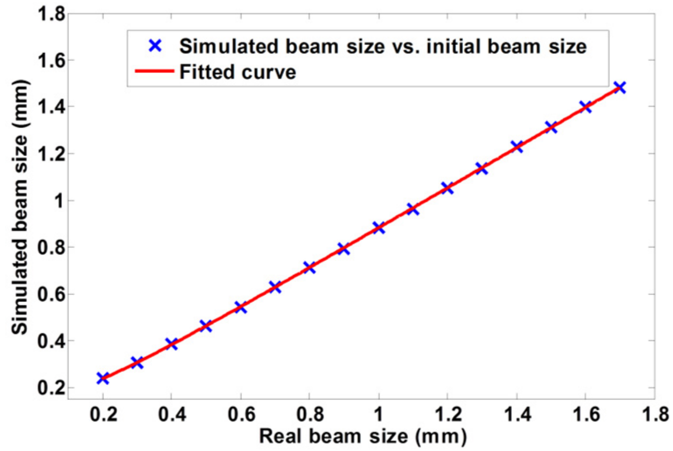
Unit(mm)	Experiment	Simulation
σ_x	0.56 ± 0.02	0.57
σ_y	0.53 ± 0.03	0.61
σ_x (residual gas)	1.52 ± 0.07	1.23

H. Zhang, et al., Phys. Rev. AB (2016), *submitted*

External field and image broadening



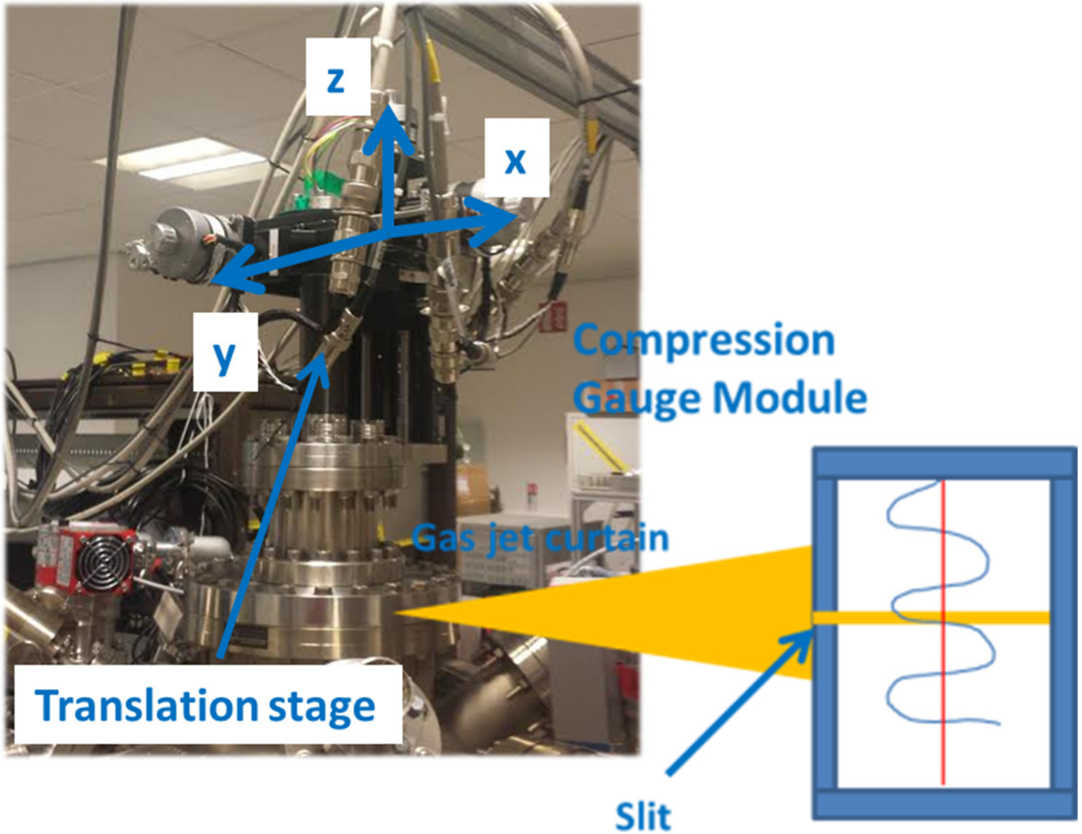


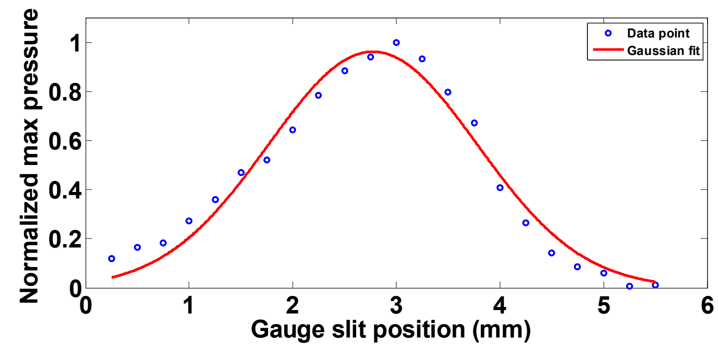


$$\sigma_{measured} = \sqrt{M^2 \cdot \sigma_{real}{}^2 + \sigma_{thermal}{}^2}$$

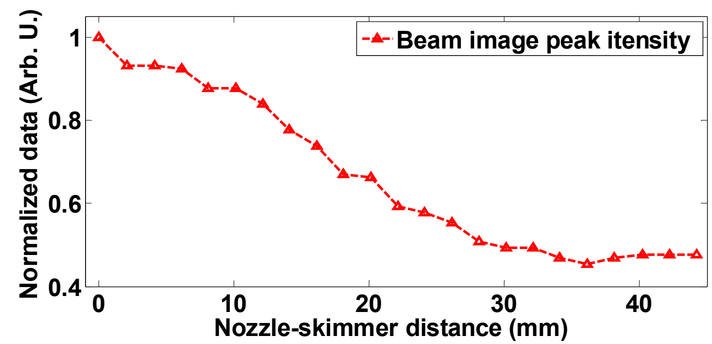
Jet Studies

- Apply 3D movable ion gauge to scan through jet





Vertical scan – yields profile

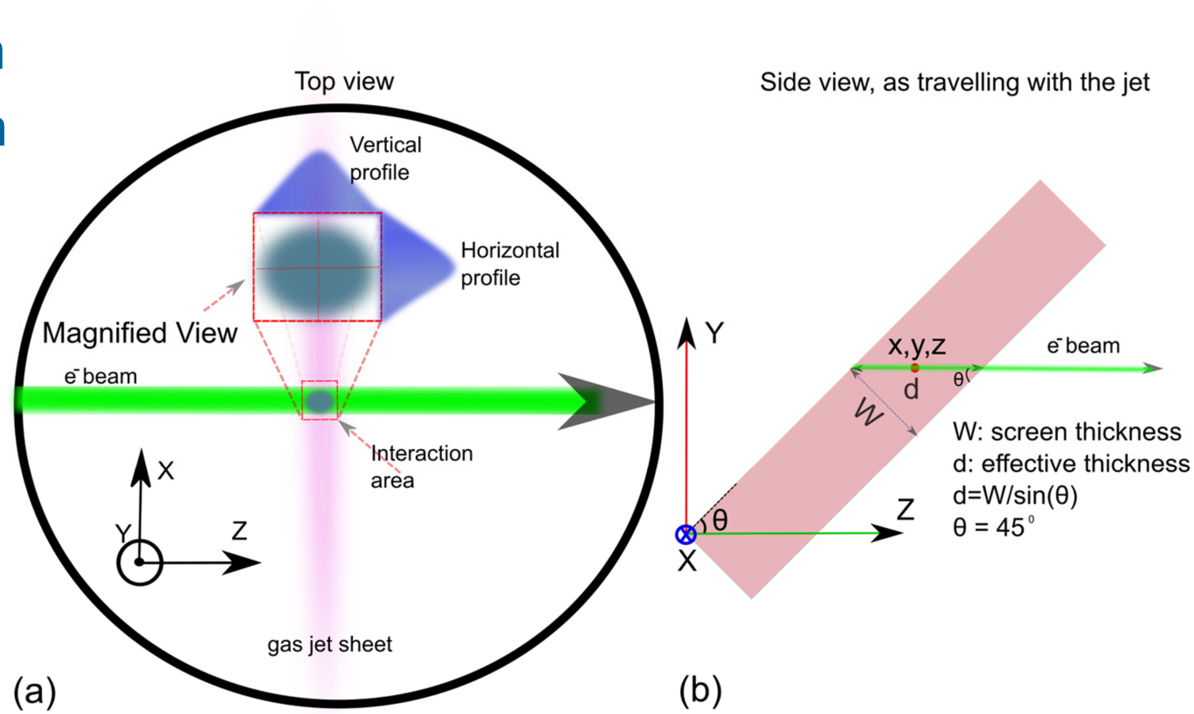


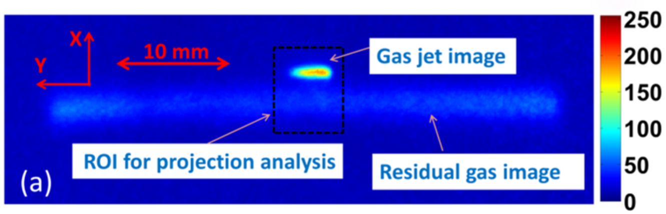
Identify Mach disk location

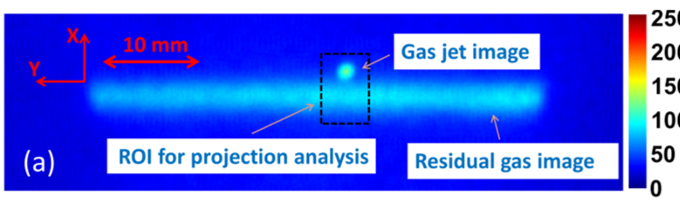
H. Zhang, et al., Phys. Rev. AB (2016), *submitted*

Resolution

- $\sigma_{CCD} = 90\ \mu m$
- $\sigma_{MCP} = 80\ \mu m$
- Jet thickness



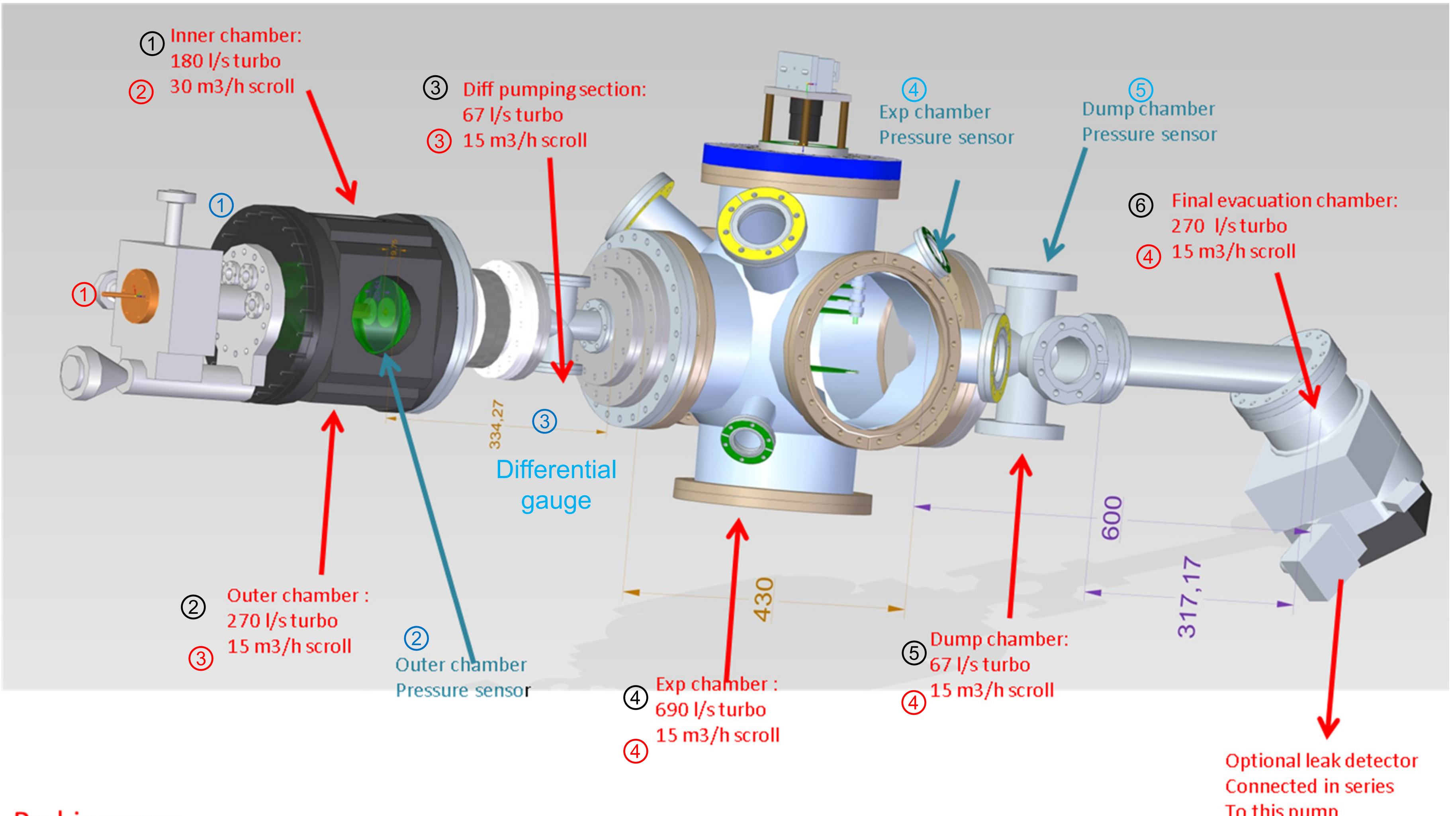




Benefit from jet and BIF ?!

- Generate electrons/ions or light in collisions between gas jet and beam to be measured
- Detect electrons/ions or photons and measure profile
- R&D challenges:
  - Monitor integration (location, EM fields, cryostat,…)
  - Optimum location, e.g. do we have to measure inside the solenoid?
  - Gas condensation, space charge issues,…
  - Achievable resolution of optics and signal levels
- Optimize towards specific application:
  - Medical, HLLHC, etc. applications

Mechanic Design (DRAFT)

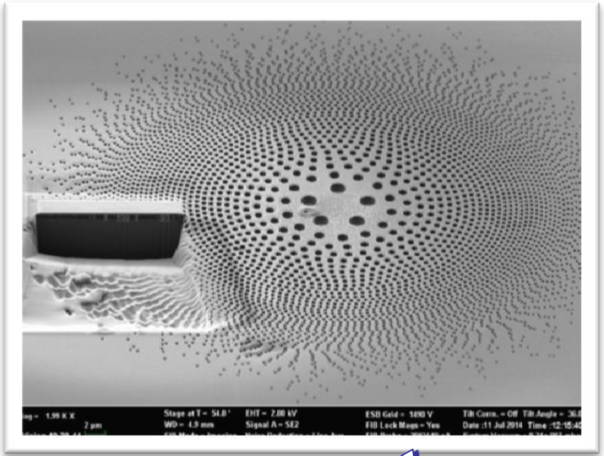


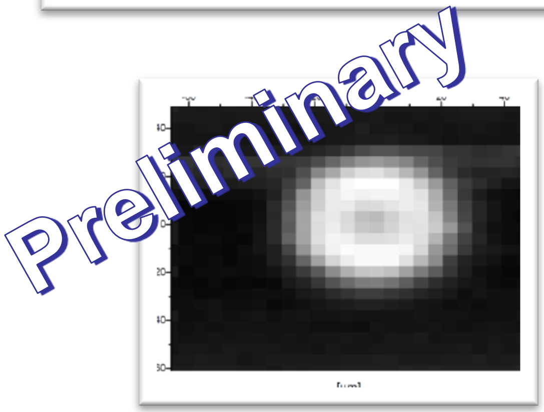
Red is pump

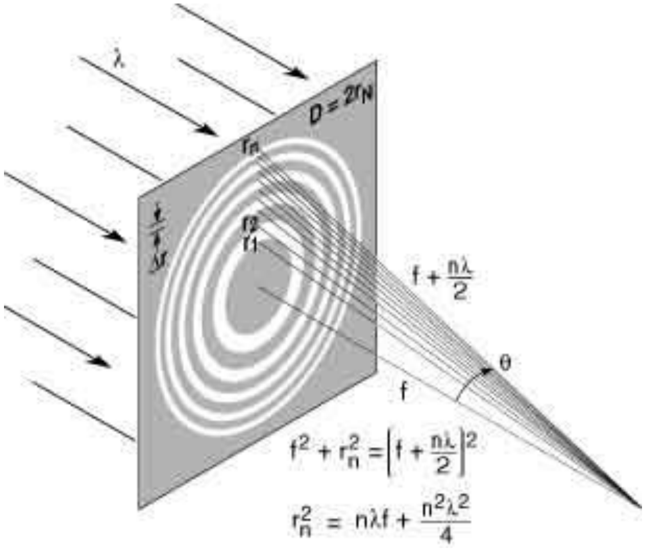
Blue is pressure sensor

Alternative: Gas Jet Wire ?

- Similar idea to laser wire
- Challenge mm focus







Fresnel Zone Plate

Summary

Next-generation machines requires new diagnostics solution to cope with beam energy and intensity

Optical techniques offer many opportunities, but are also limited by a number of effects

Gas jet-based monitors can operate in XHV environments, are least-invasive and provide good time/spatial resolution.

Thanks for your attention !