The Cockcroft Institute
of Accelerator Science and Technology

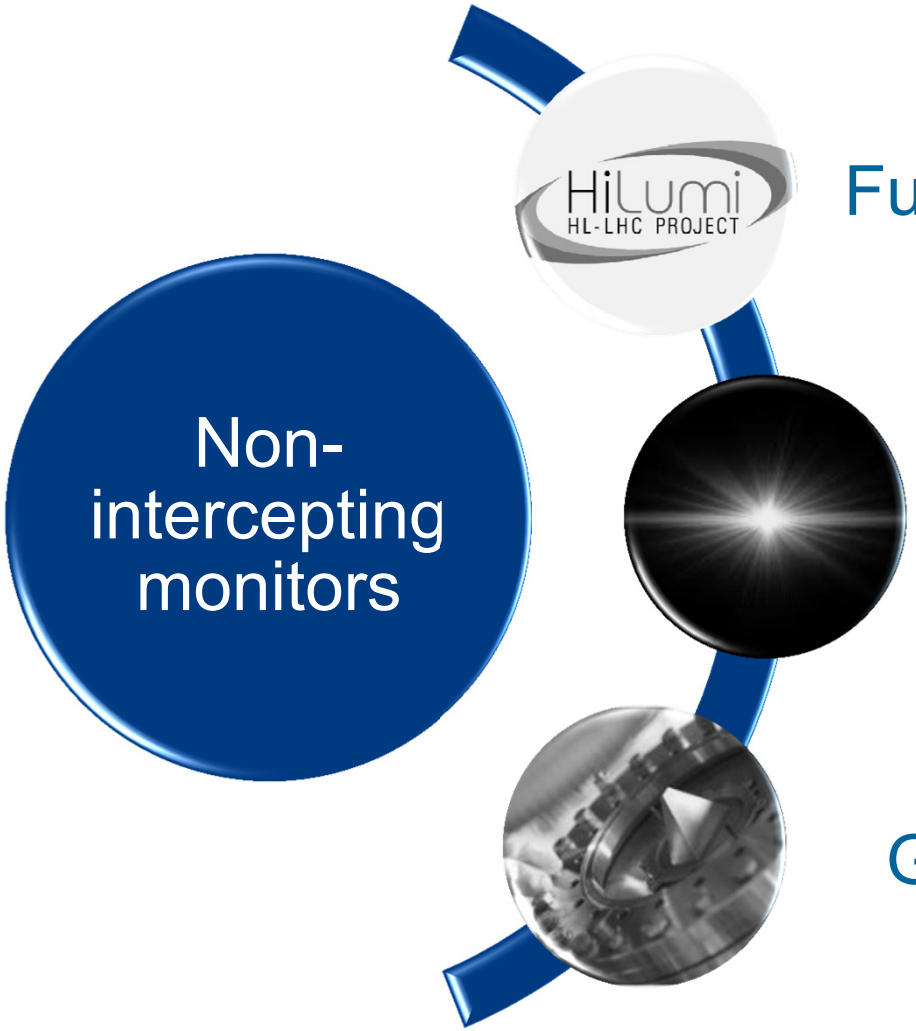
UNIVERSITY OF LIVERPOOL

Non-destructive Beam Profile Monitors

Prof Carsten P Welsch

Many thanks to: N.S. Chritin, E.B. Diaz, P. Forck, A. Jeff, O.R. Jones, K.U. Kühnel, E. Martin, M. Putignano, A. Rossi, G. Schneider, V. Tzoganis, S. Udrea, R. Veness and H.D. Zhang

Overview



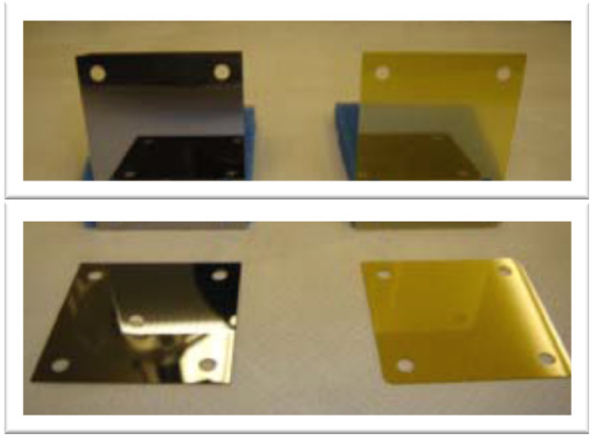
Future Challenges

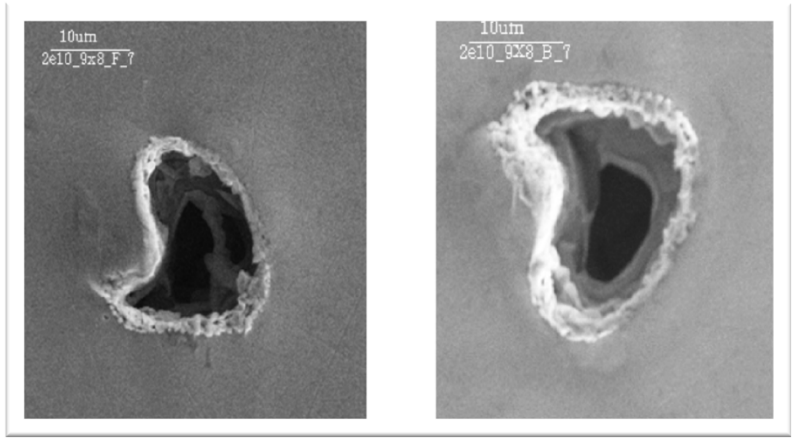
Imaging Techniques

Gas jet-based Techniques

Profile of High Energy/Intensity Beams

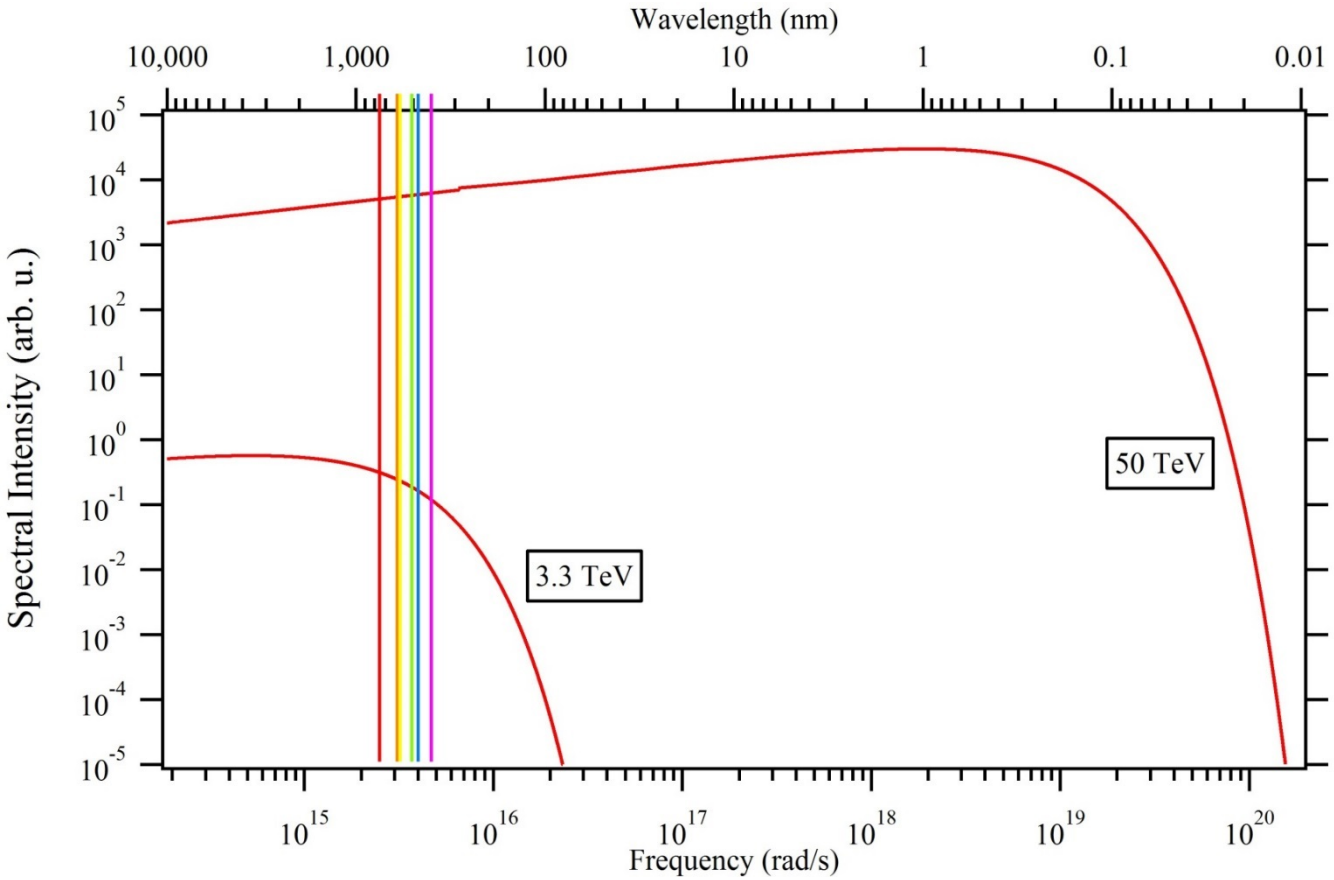
- Damage caused by the beam
- Ideally: Non-invasive.





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

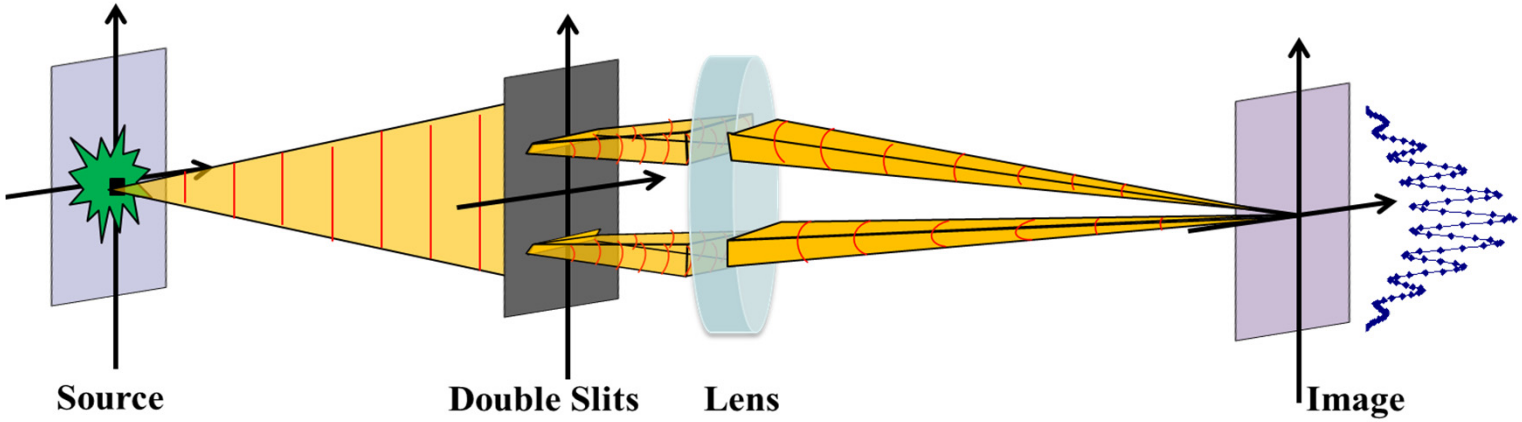
Synchrotron Radiation



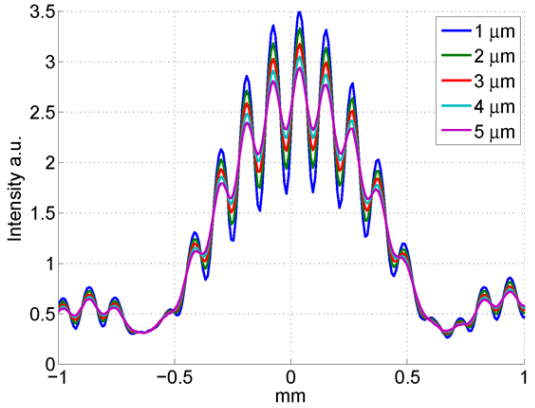
- In the visible ? Problem: Resolution (LHC).

Interferometry or Masking

- Goal: Overcome diffraction limit.

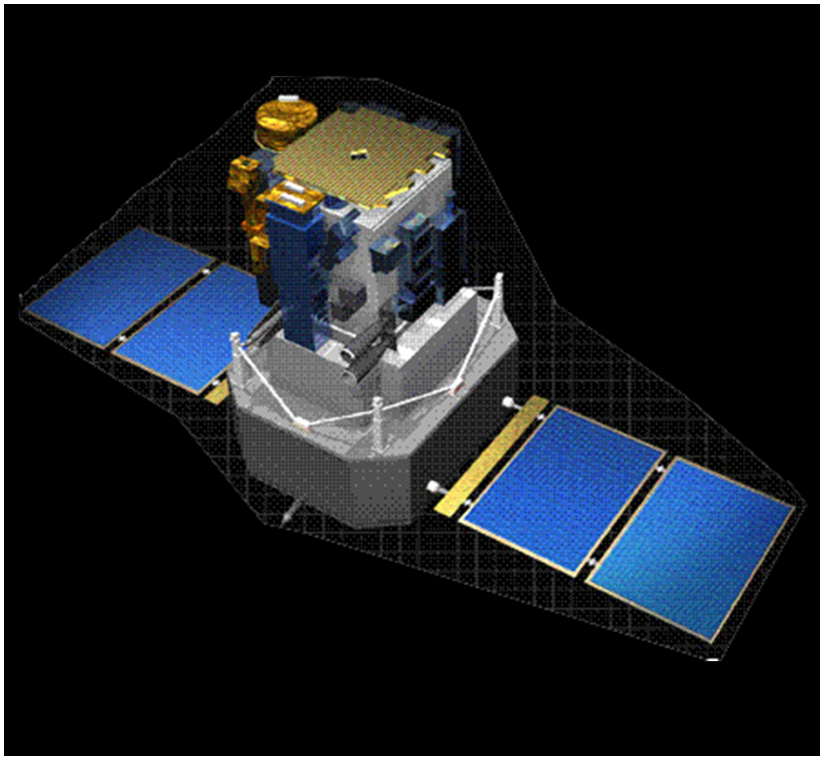


- Coronograph ?
- DMD-based system ?



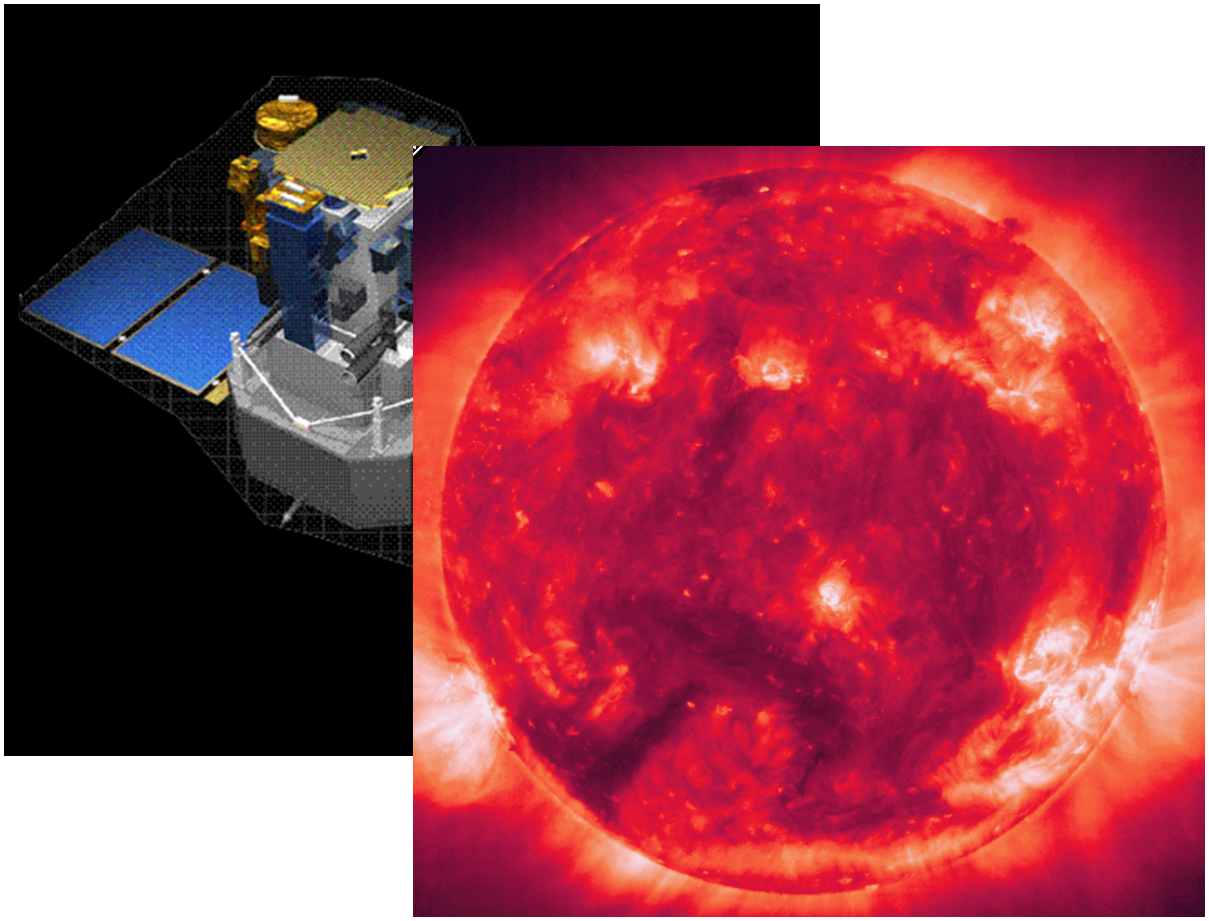
Thanks to G. Trad, A. Jeff

SOHO



*__So__lar and __H__eliospheric __O__bservatory

SOHO



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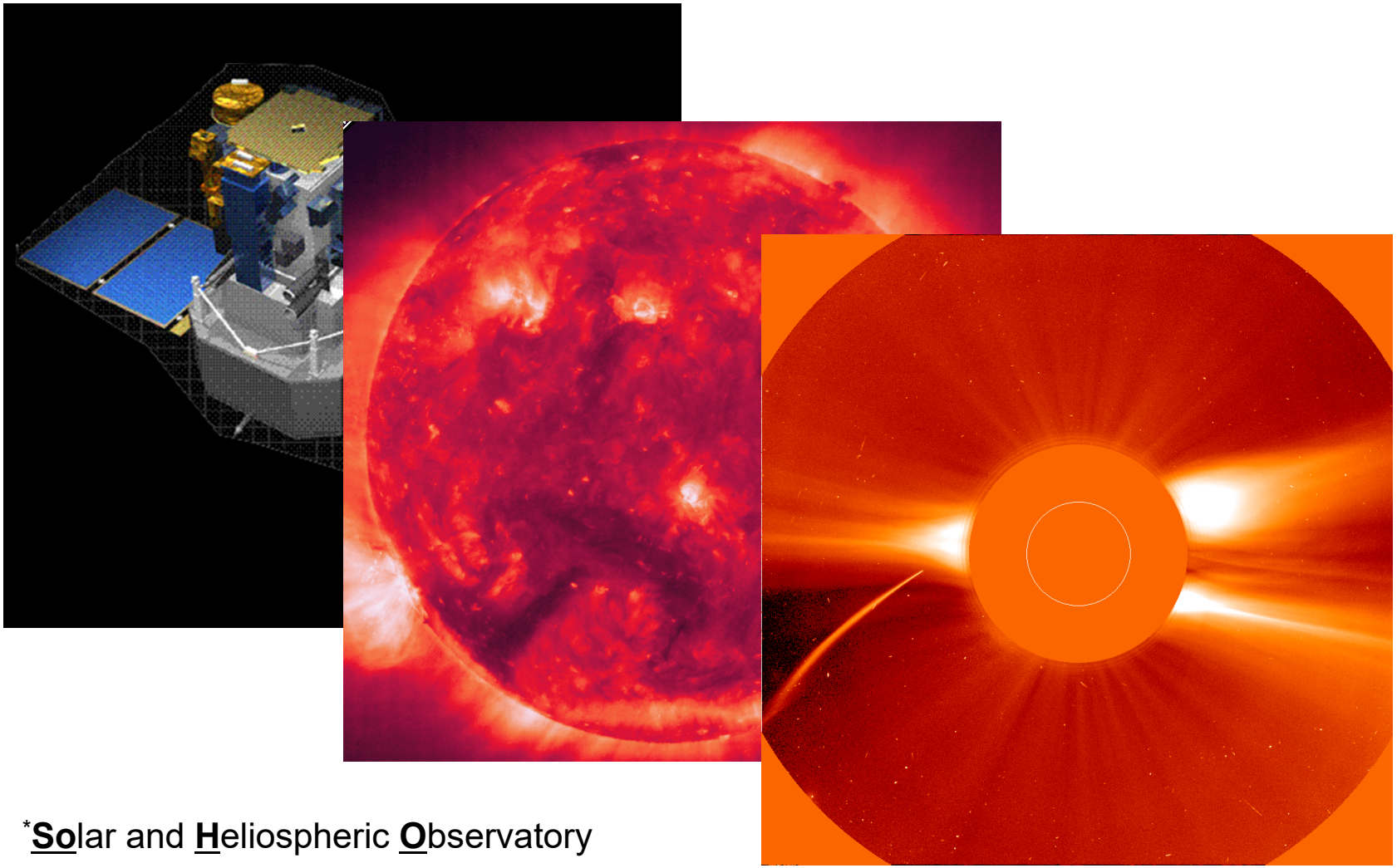
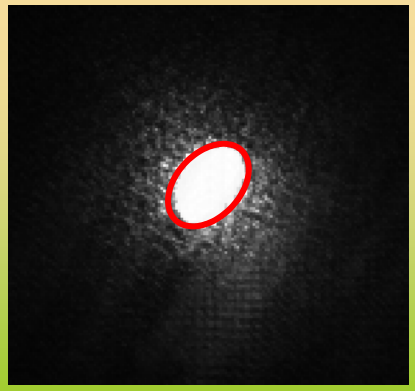
SOHO



*Solar and Heliospheric Observatory

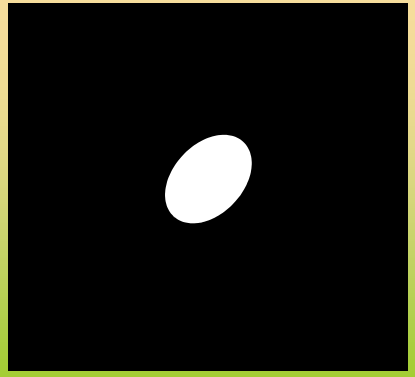
Halo Monitoring: Core Masking

(1) Aquire profile



(2) Define core

(4) Re-Measure

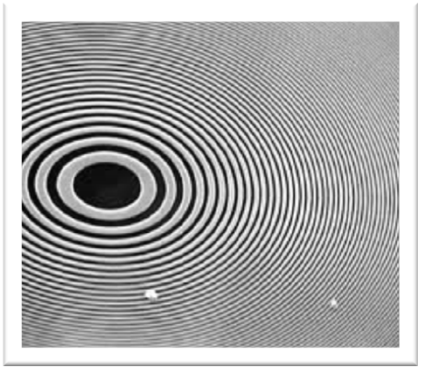


(3) Generate mask

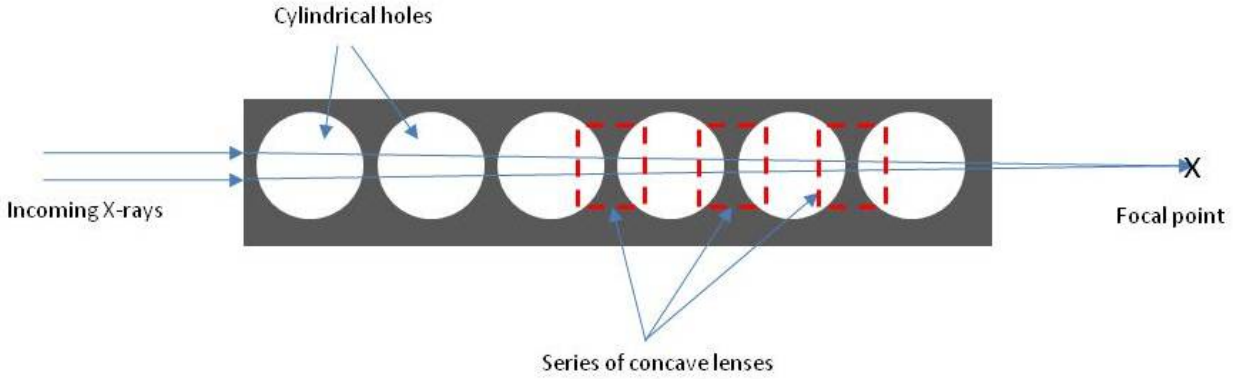
J. Egberts, et al.,
JINST **5** P04010 (2010)
H. Zhang, R. Fiorito, et al.,
Phys. Rev. STAB 15 (2012)

From Synchrotron Light Sources

- Fresnel zone plates



- Compound refractive lens



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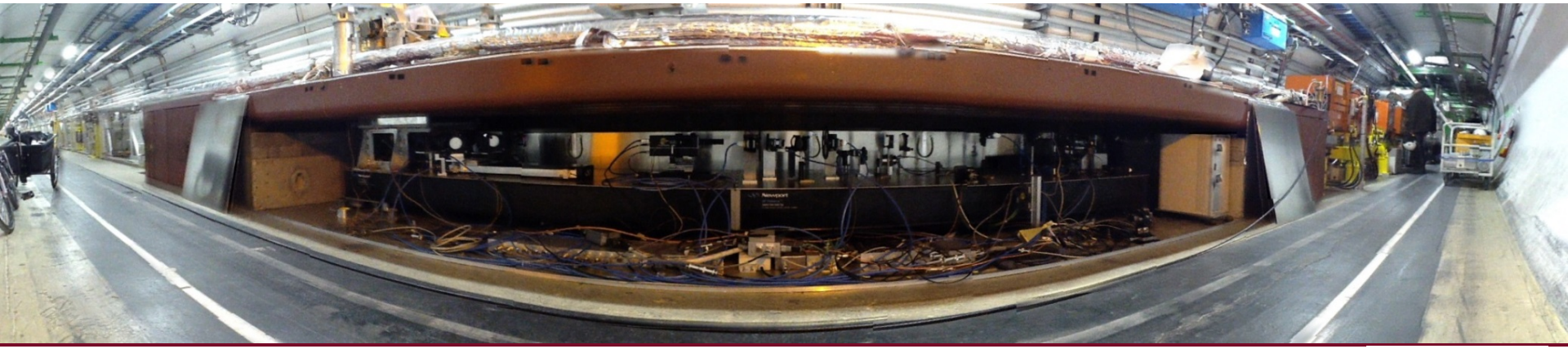
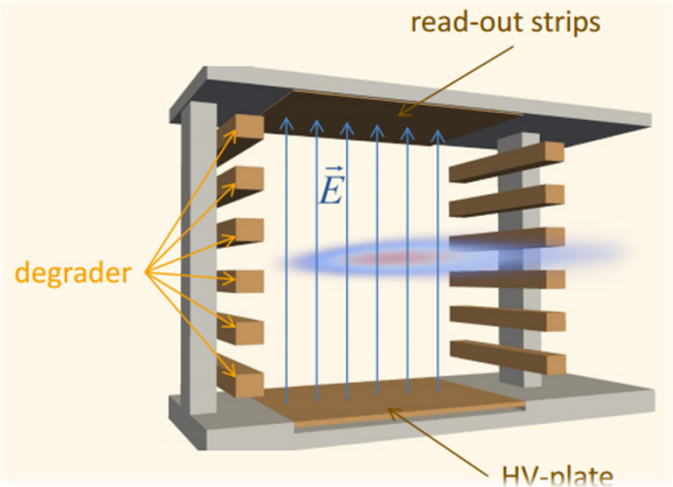
Challenges

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

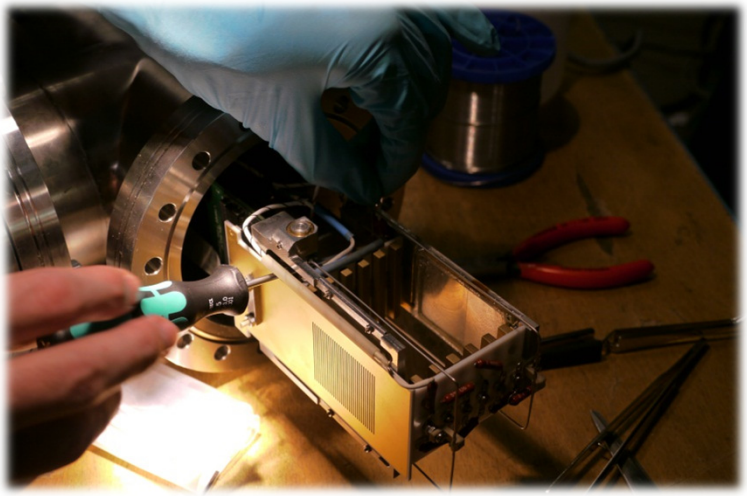
- Depth of field issues: ~ ρ/γ
  - Requires undulator to produce (soft) X-rays



Ionization Profile Monitor (IPM)

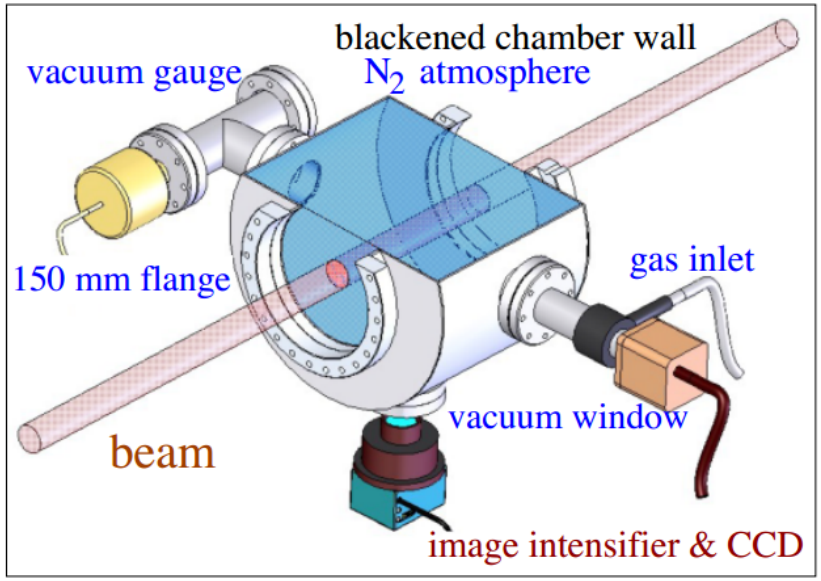


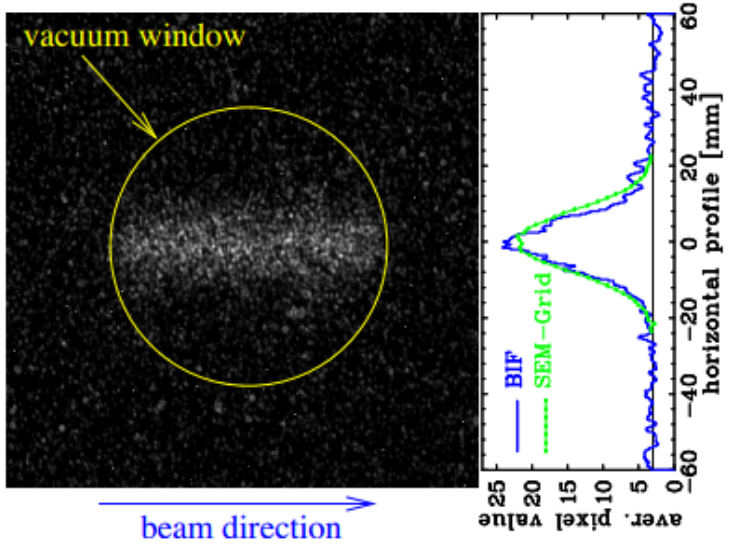
Souce: J. Egberts, CEA



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

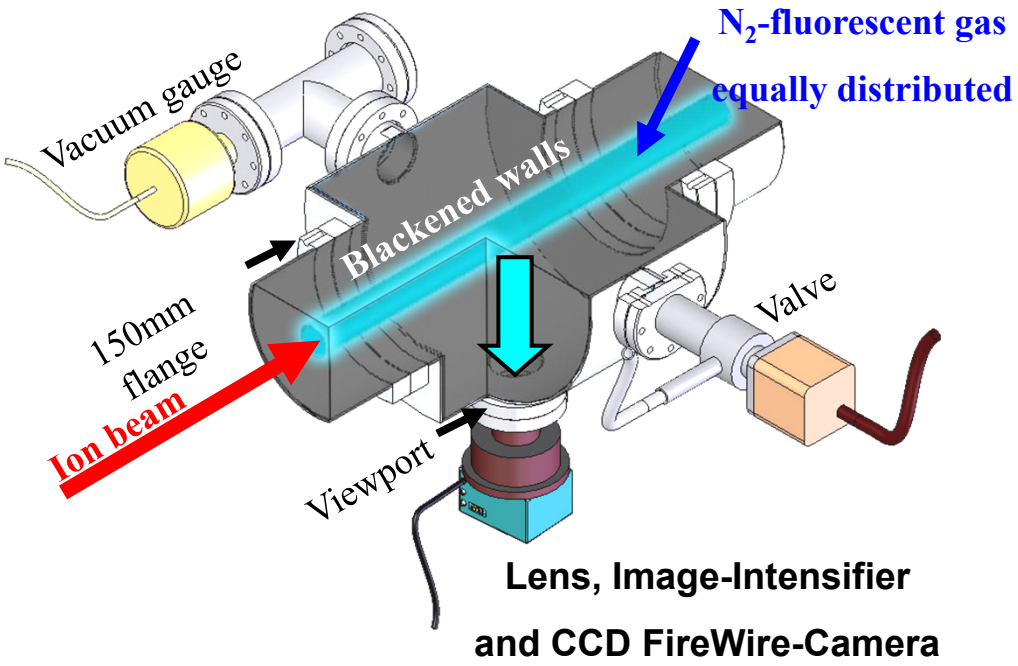
Beam Induced Fluorescence (BIF)

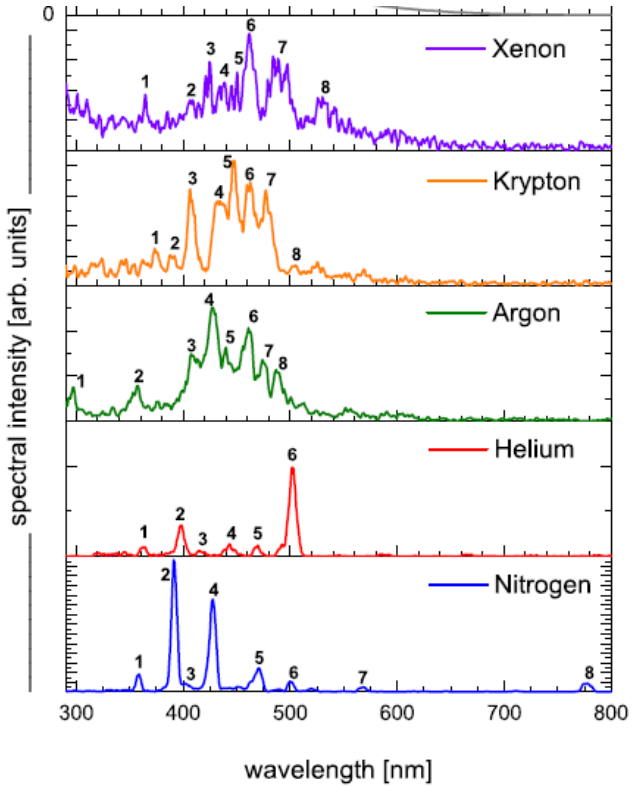




- Measures light from rest gas, excited by beam
- Challenges:
  - Very low cross sections
  - Isotropic light emission
  - Rest gas pressure requirements

Fluorescence Monitor Principle





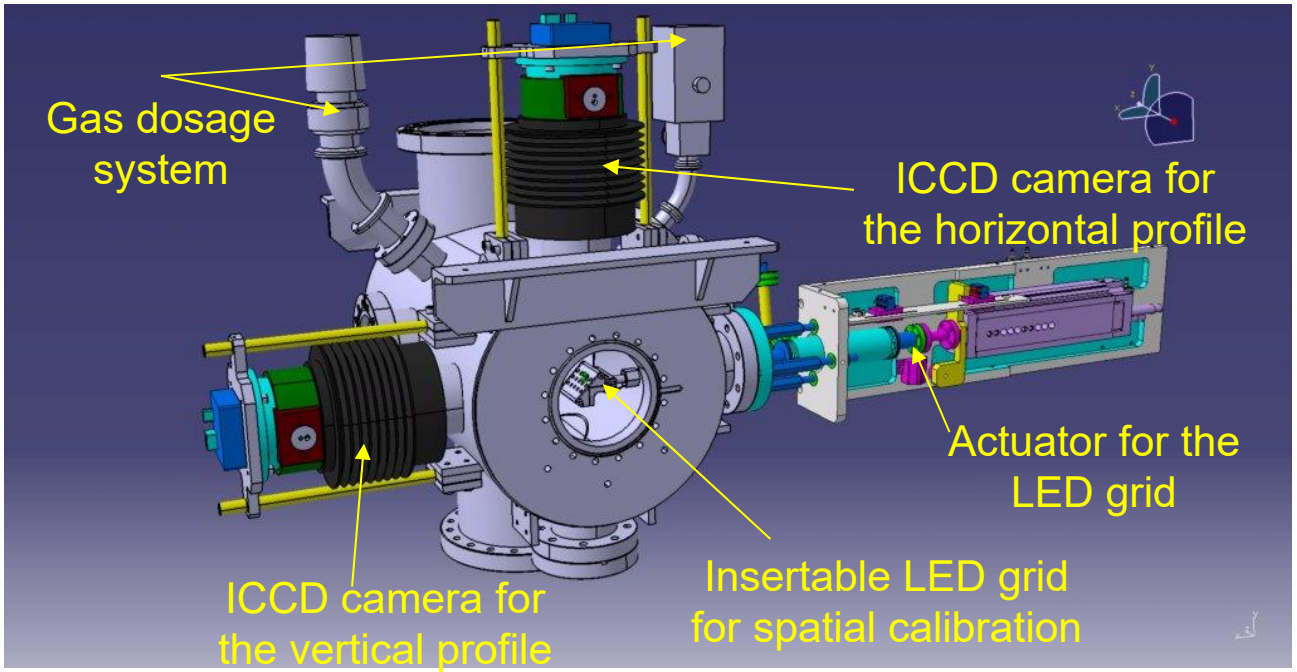
P. Forck et al., *Beam induced fluorescence profile monitor developments*, Proc. HB2010

- 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.

BIF Monitors @ GSI

Six BIF stations at the GSI LINAC:

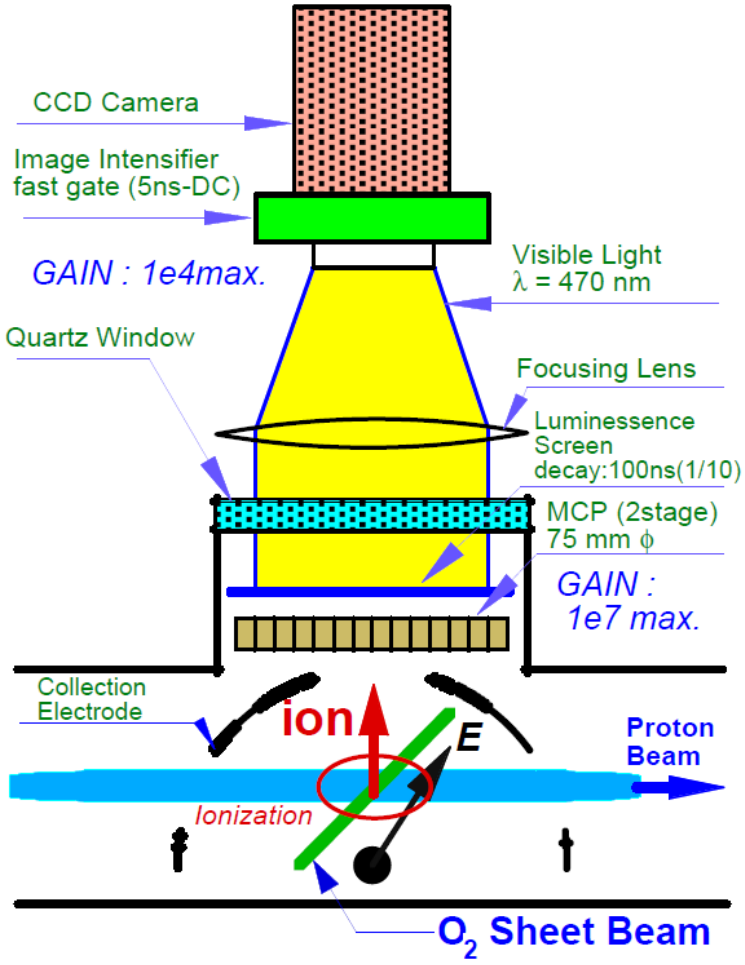
- 2 x image intensified CCD cameras each
- Optics with reproduction scale 0.2 mm/pixel
- Insertion length only 25 cm for both directions
- Single macro-pulse observation



F. Becker (GSI) et al., Proc. DIPAC'07, C. Andre (GSI) et al., Proc. DIPAC'11, IBIC'14

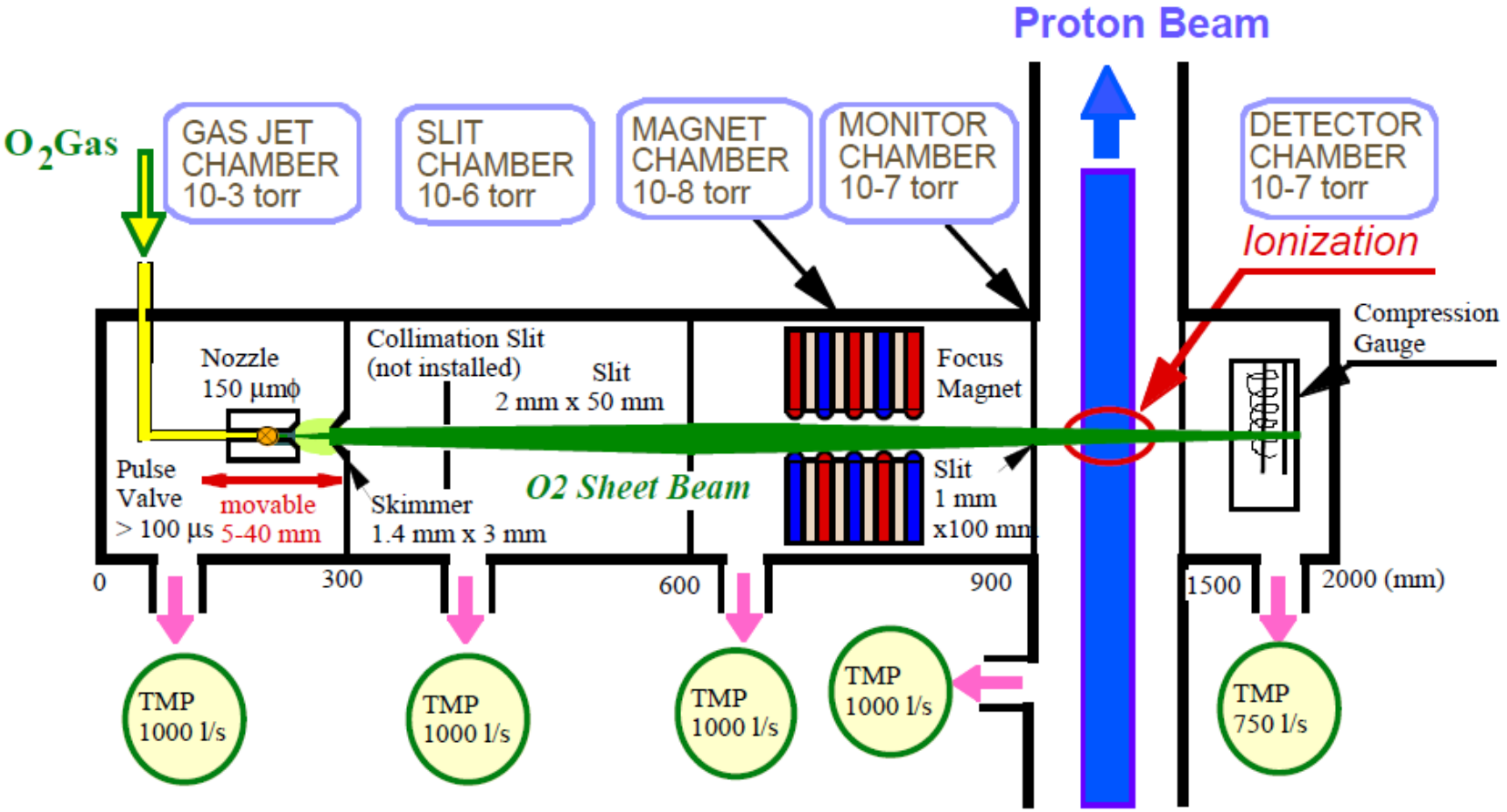
Gas Sheet Monitor

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



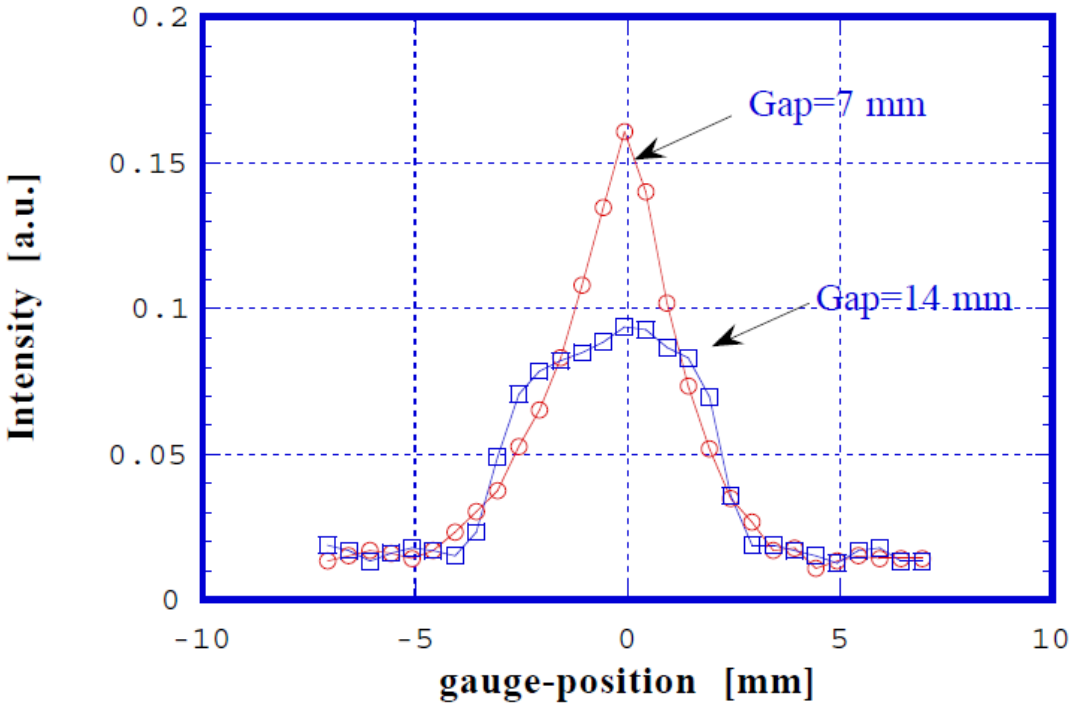
Y. Hashimoto et al., Proc. Part. Acc. Conf., Chicago (2001)

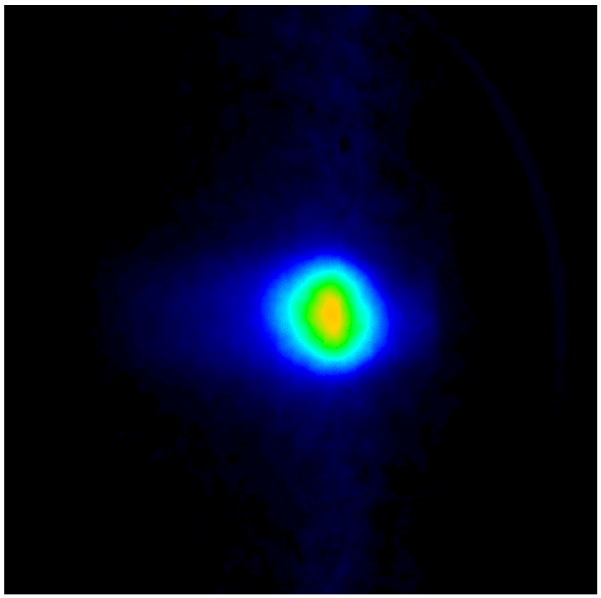
How to Generate the Jet ?

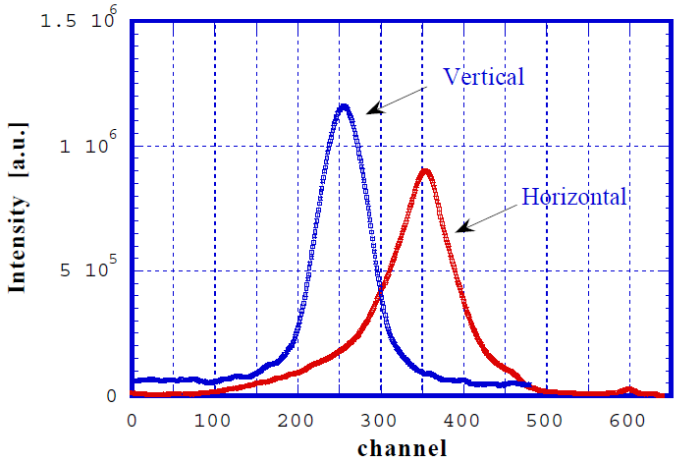


Y. Hashimoto et al., Proc. Part. Acc. Conf., Chicago (2001)

Experimental Data







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

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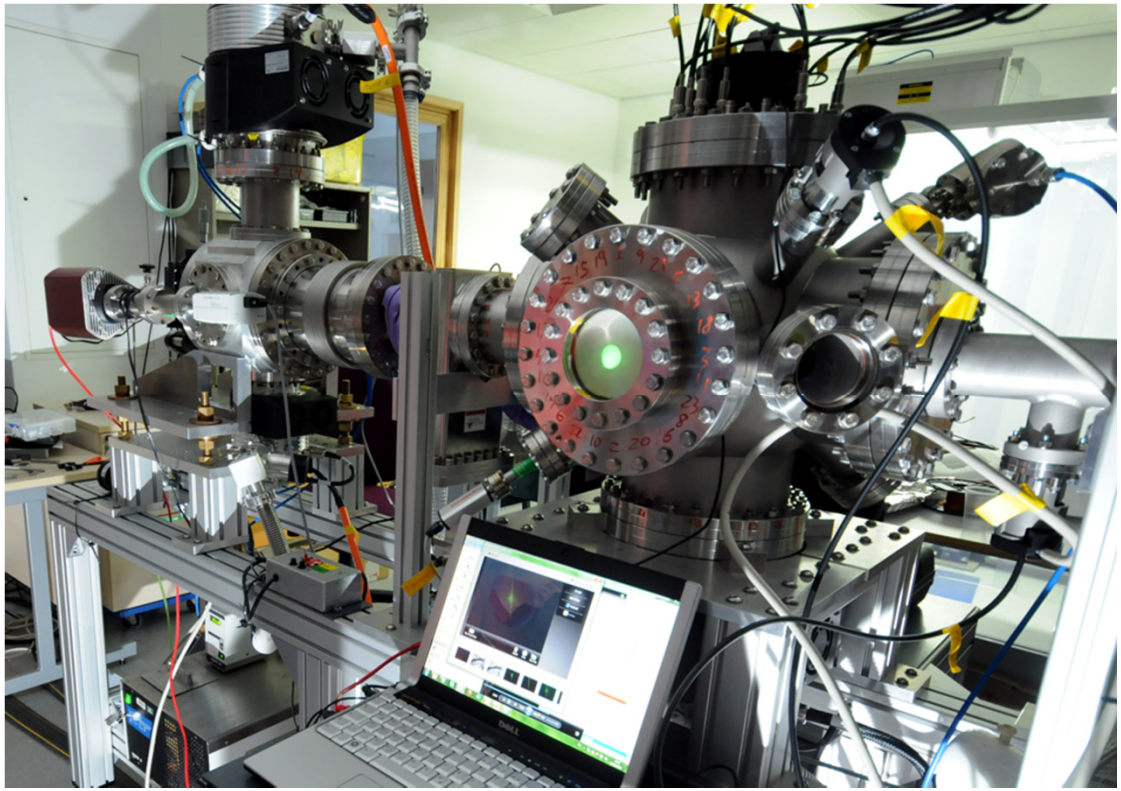
Setup @ Cockcroft Institute



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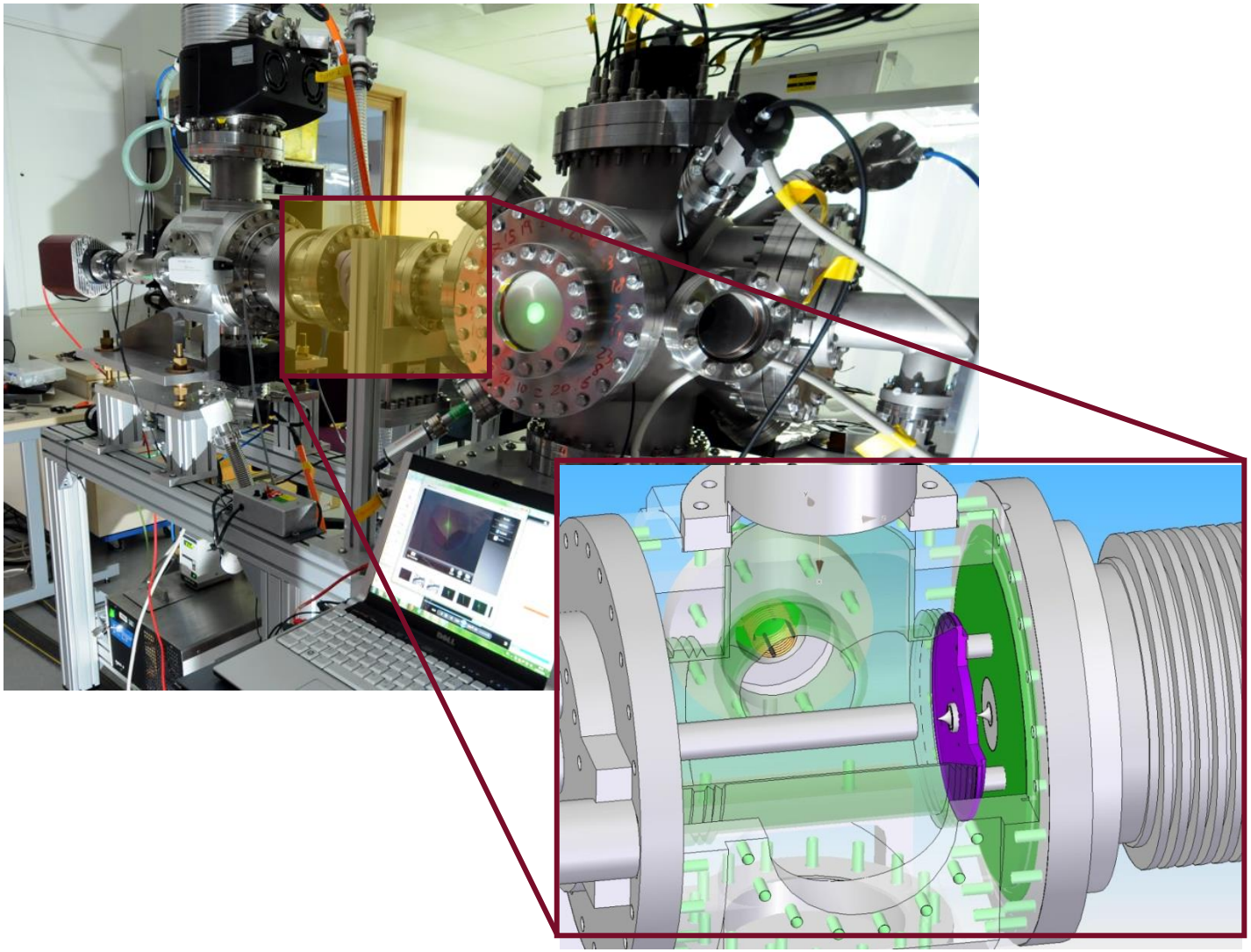

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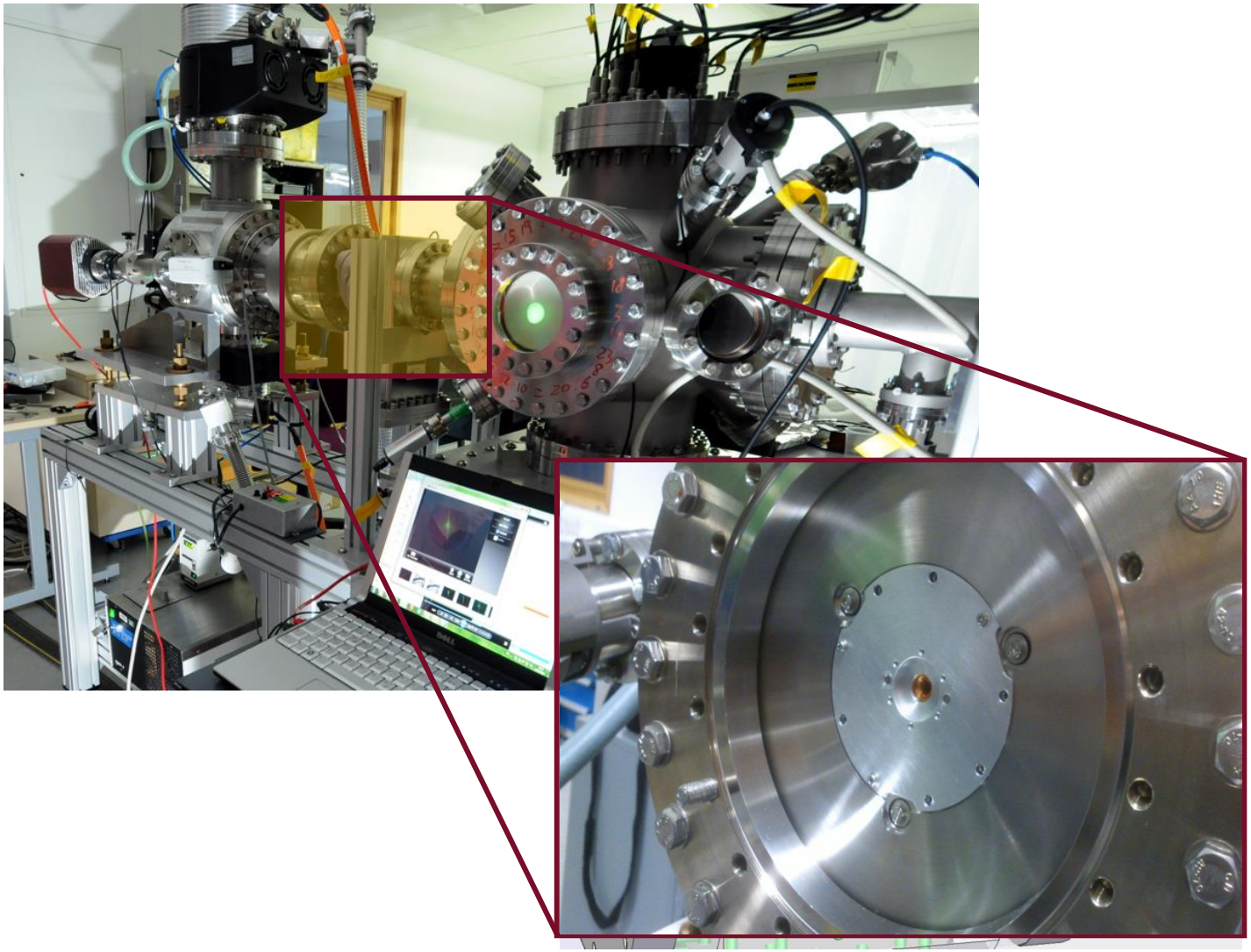
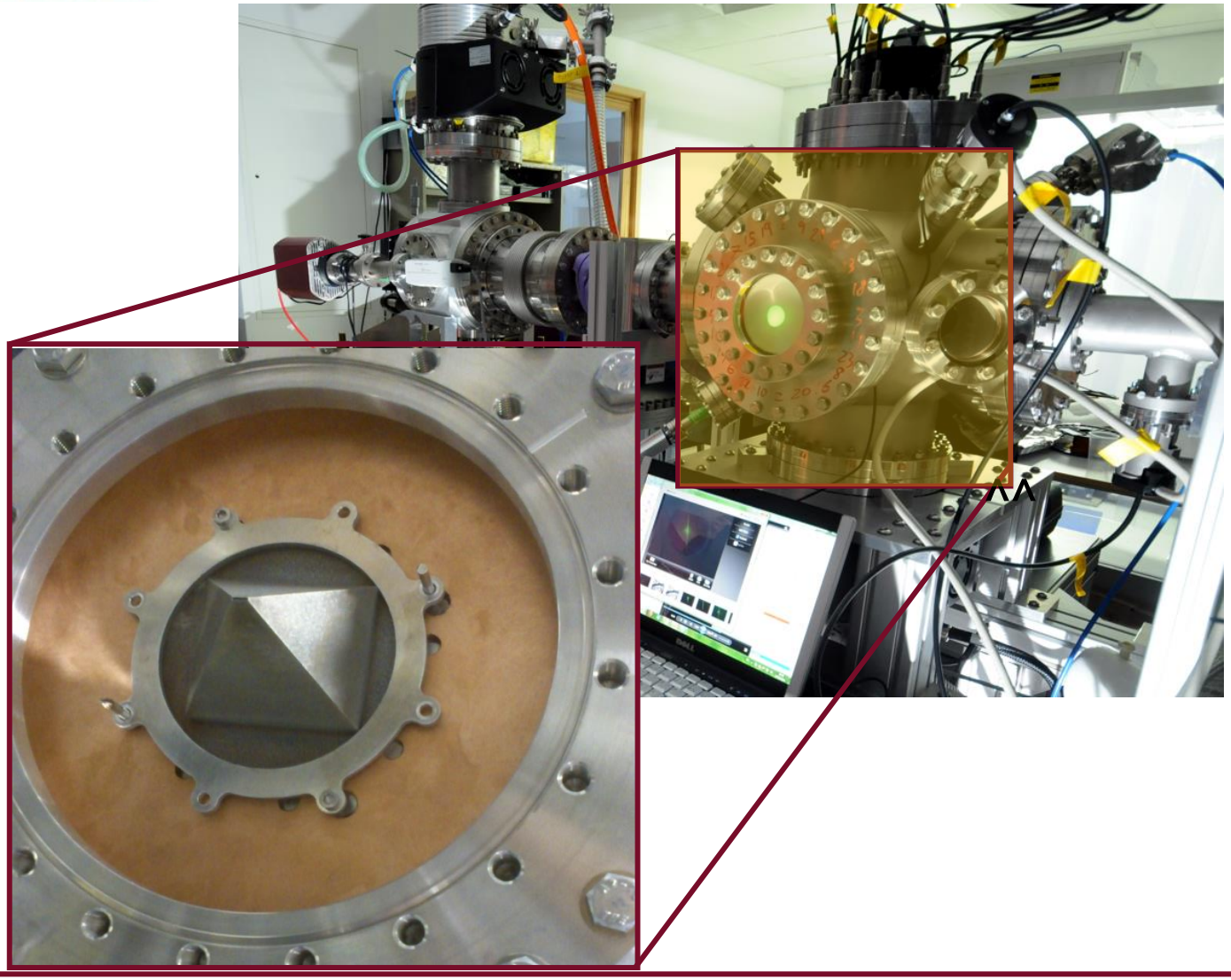
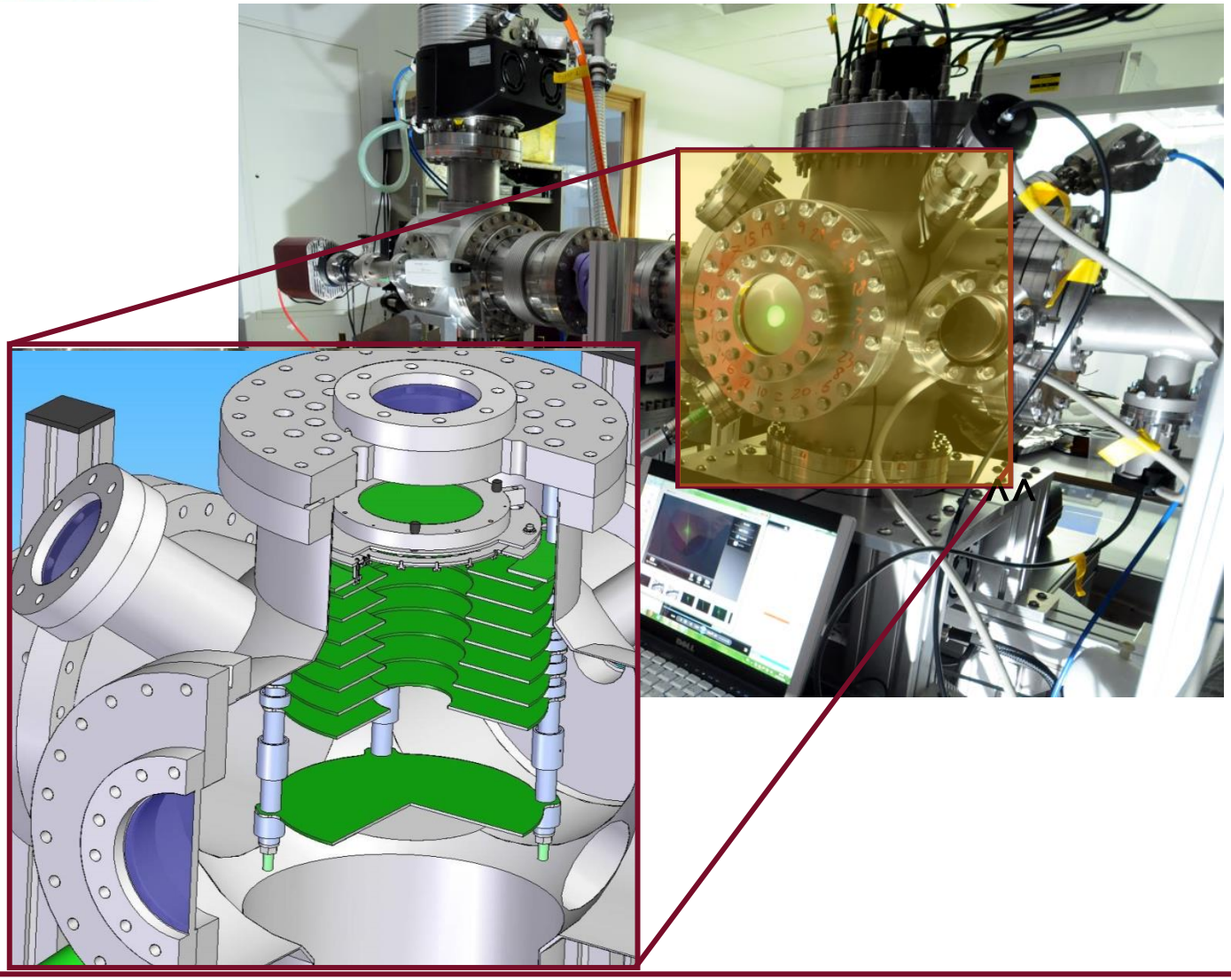


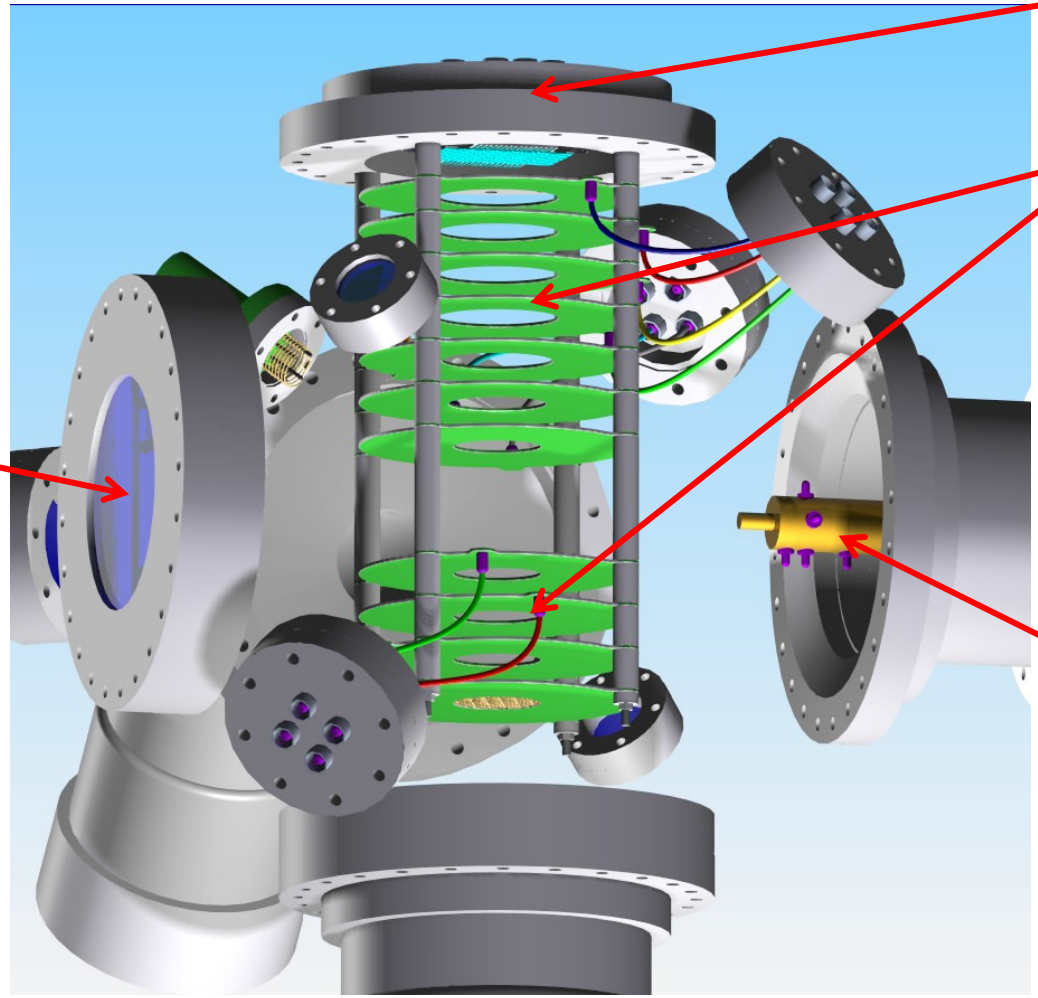
Setup @ Cockcroft Institute



Setup @ Cockcroft Institute



Zoom: Main chamber



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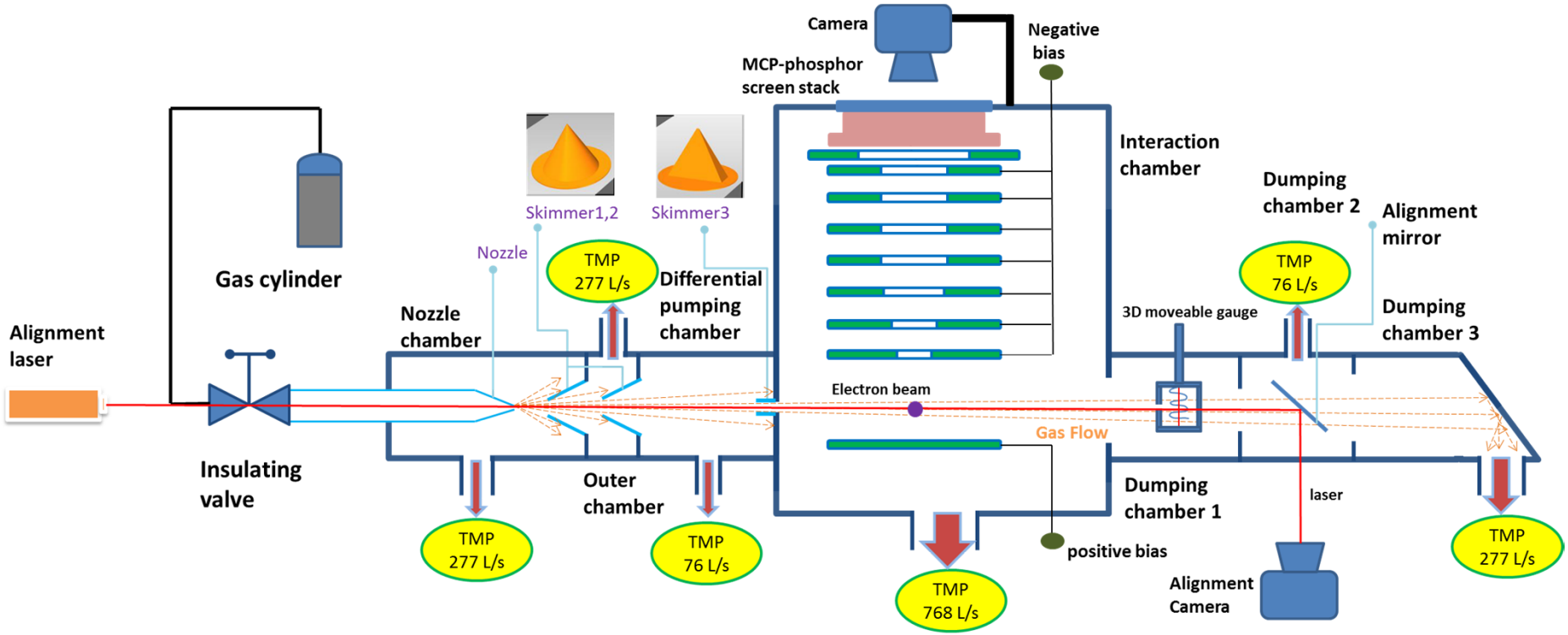
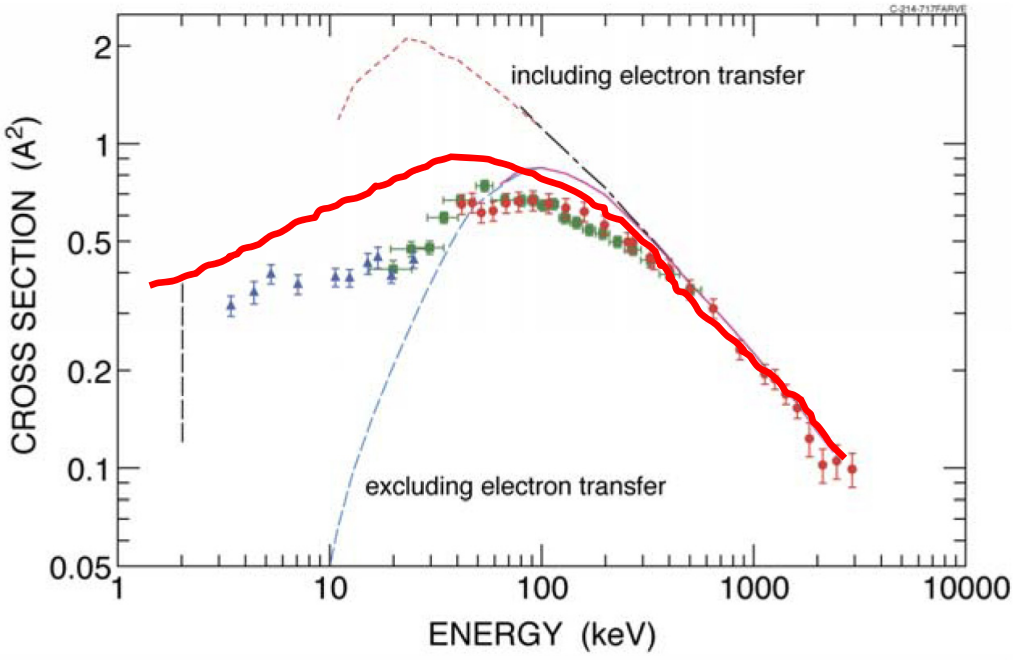
Setup



V. Tzoganis, H. Zhang, et al., Phys. Rev. AB (2017).

Ionization Cross Sections

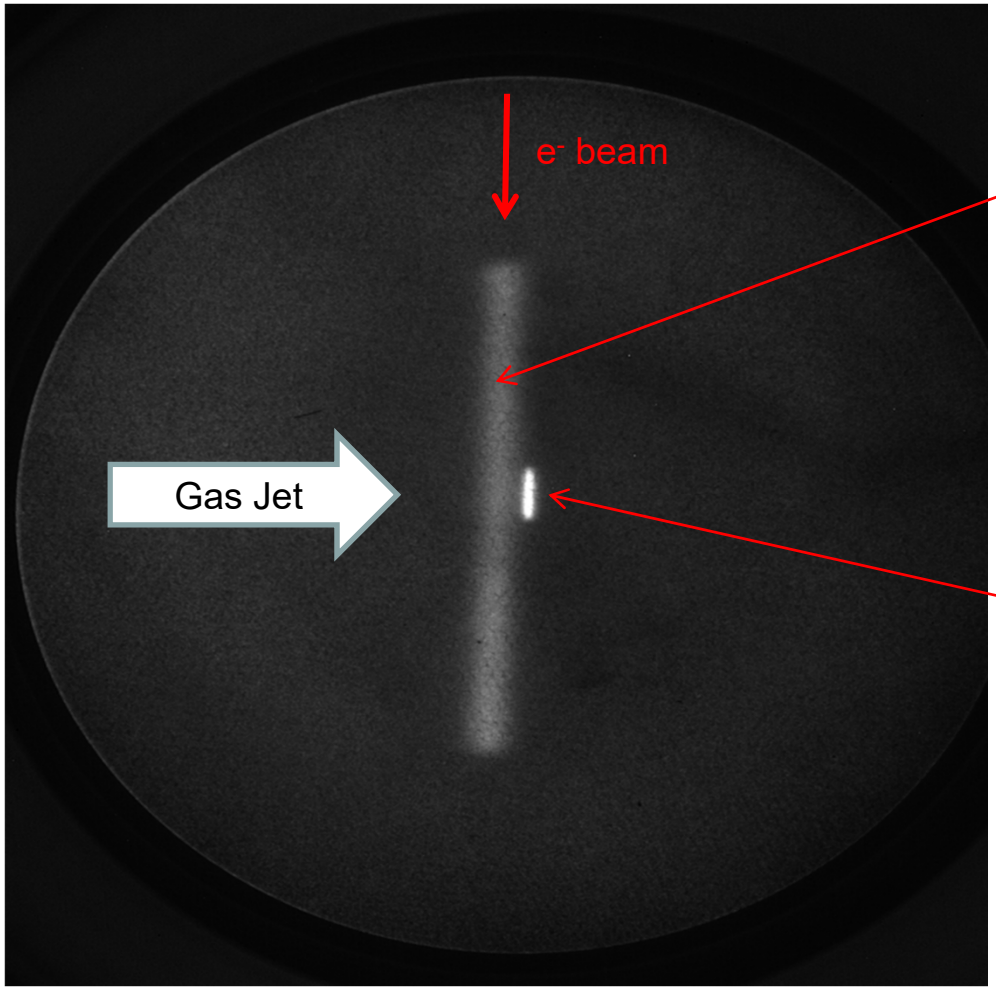
- Can be exotic, e.g. single ionization of helium by antiproton impact



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

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

Experimental Results @ CI



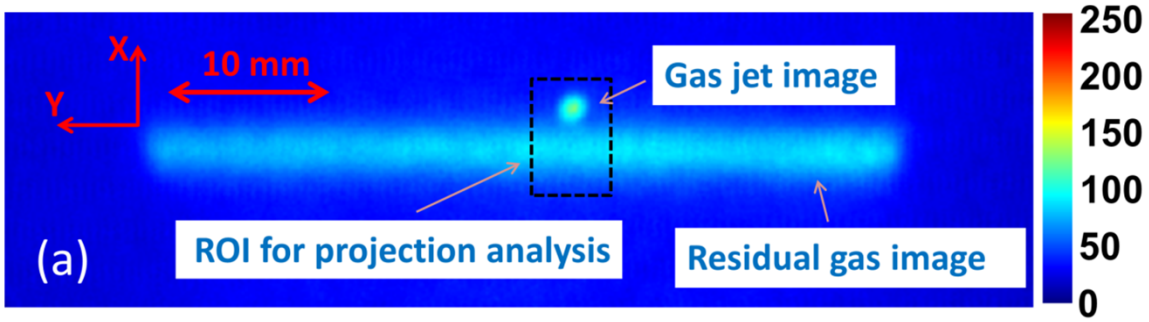
Residual gas signal

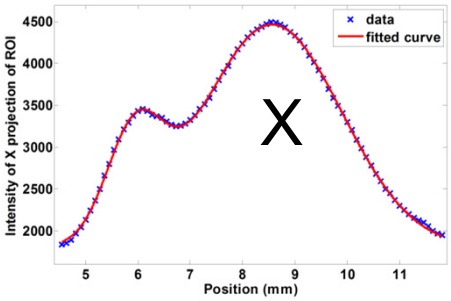
Jet signal

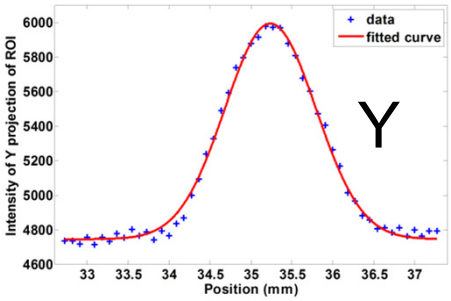
V. Tzoganis, et al.,
APL **104** 204104 (2014)

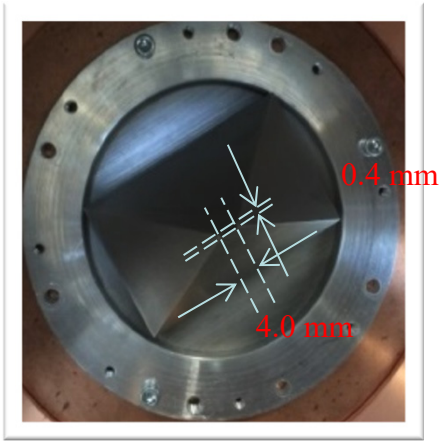
V. Tzoganis, et al.,
VACUUM (2015)

Example Measurement



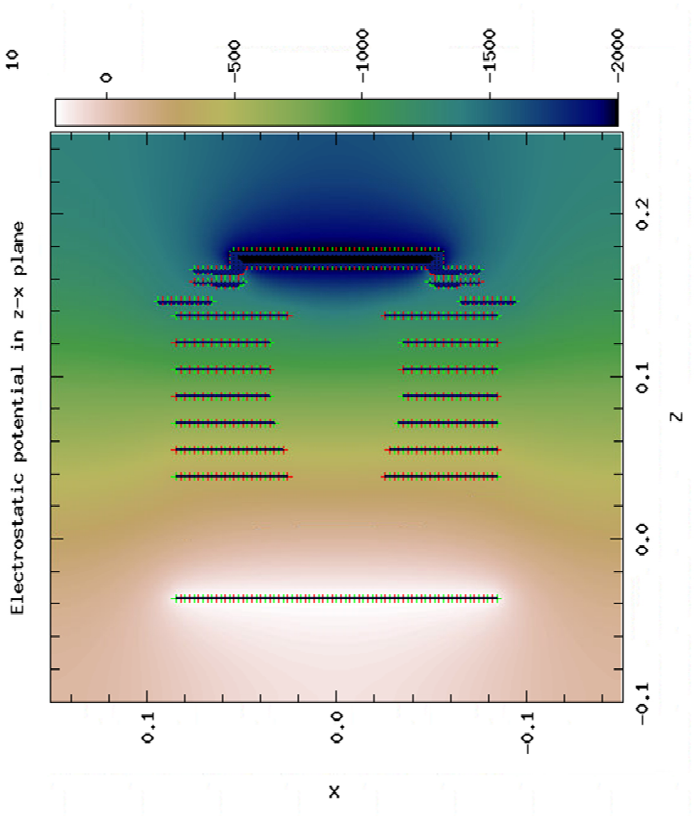


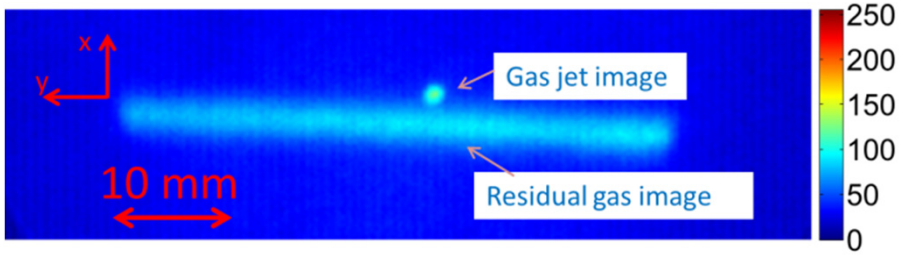


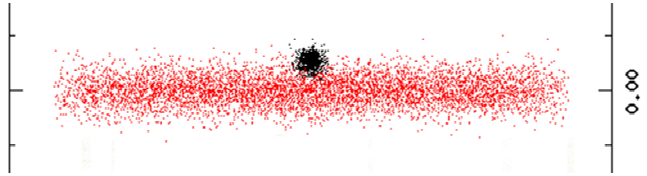


Understanding the Jet

- Simulations using the CST and WARP codes





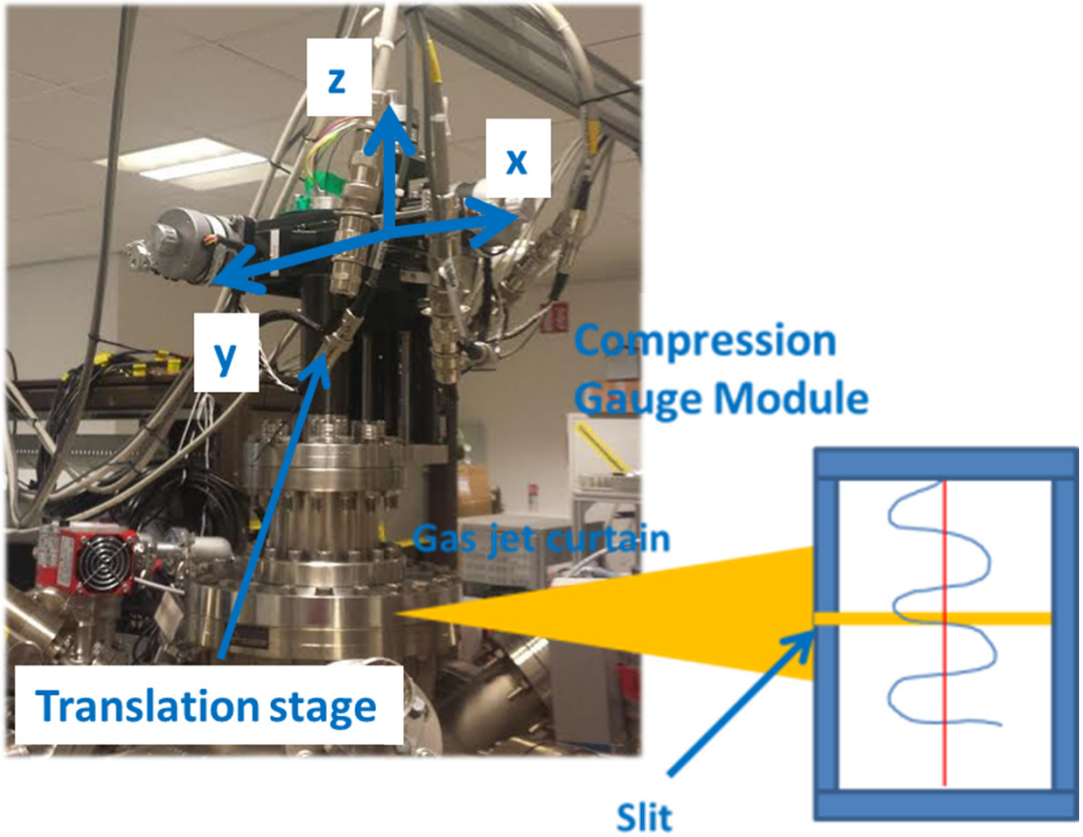


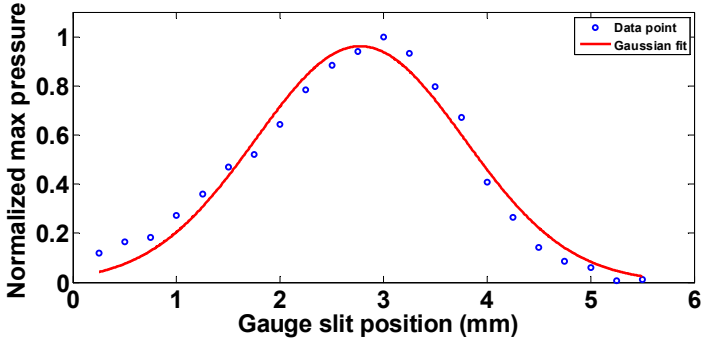
Unit(mm)	Experiment	Simulation
σ_x	0.56 ± 0.02	0.57
σ_y	0.53 ± 0.03	0.61
σ_x (residual gas)	1.52 ± 0.07	1.23

V. Tzoganis, H. Zhang, et al., Phys. Rev. AB (2017).

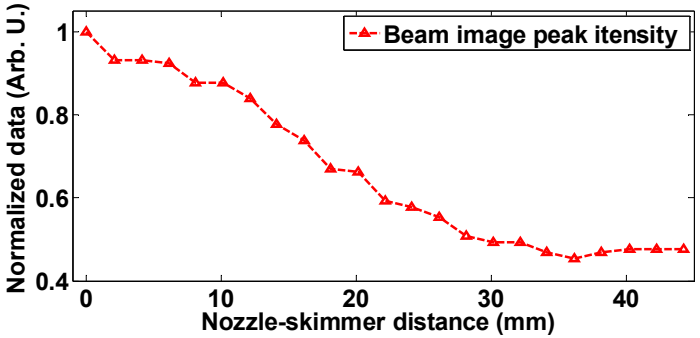
Jet Studies

- Apply 3D movable ion gauge to scan through jet





Vertical scan – yields profile

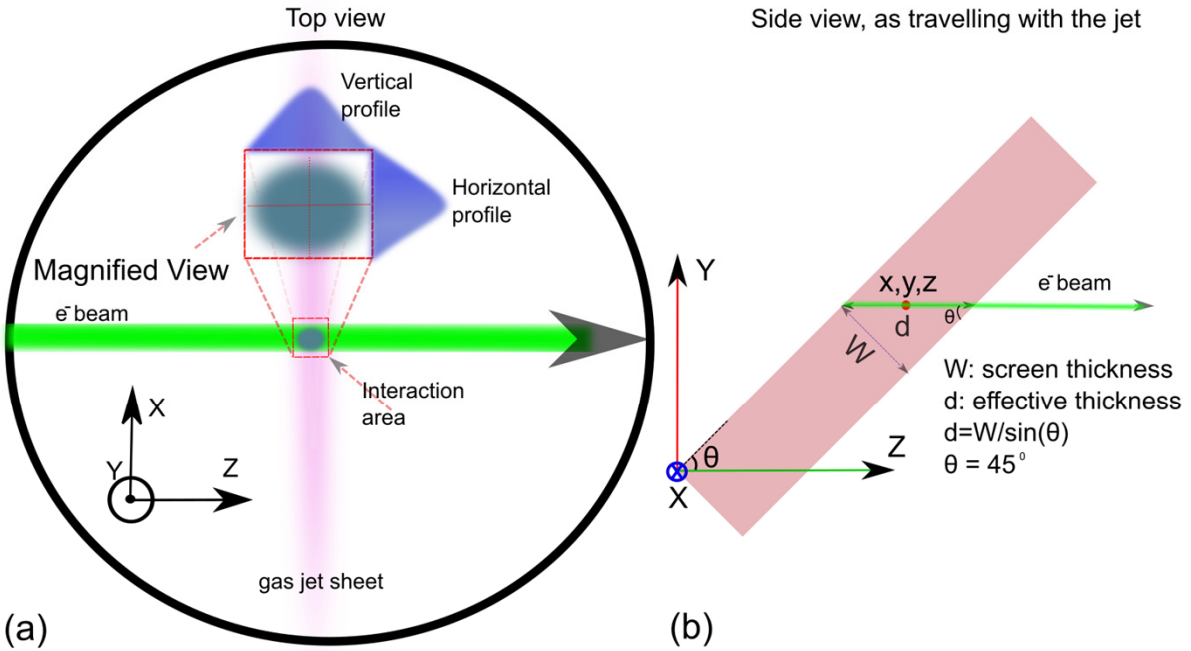


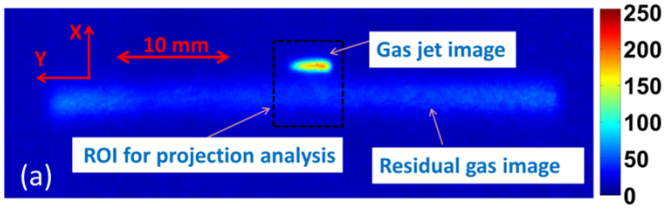
Identify Mach disk location

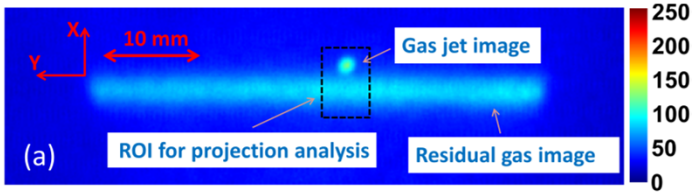
V. Tzoganis, H. Zhang, et al., Phys. Rev. AB (2017).

Resolution

- σ_{CCD} = 90 μm
- σ_{MCP} = 80 μm
- Jet thickness

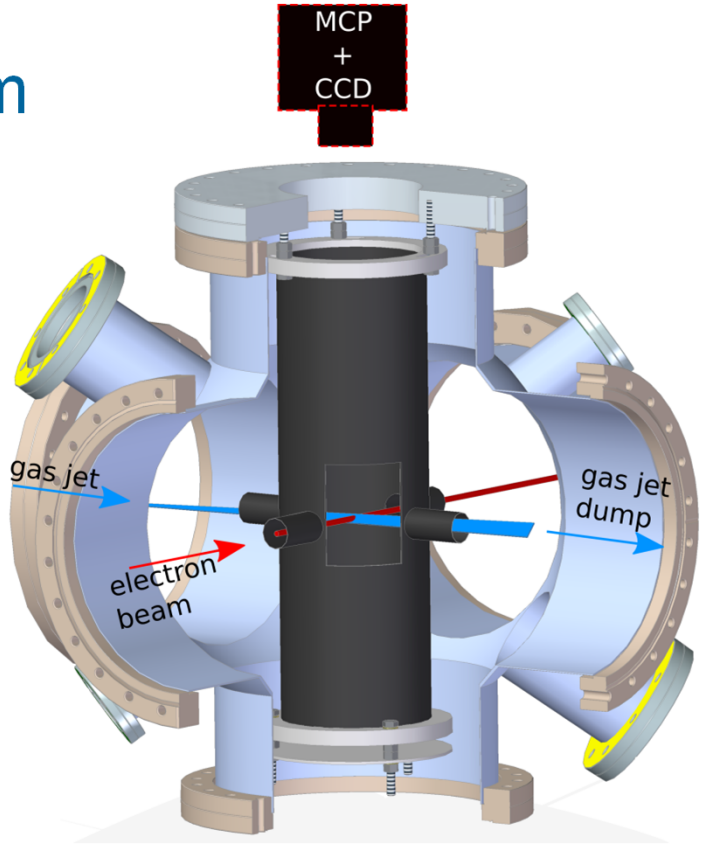






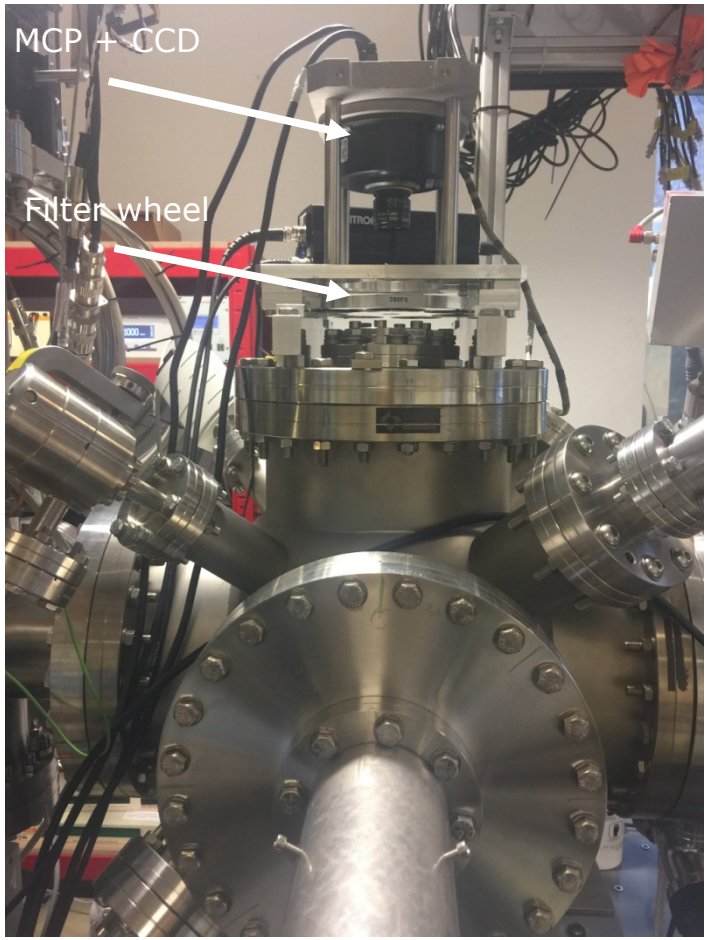
Benefit from Jet and BIF

- Generate light in collisions between gas jet + primary beam
- Detect photons to measure profile



- R&D challenges:
  - Monitor integration (location, EM fields, cryostat,…)
  - Optimum location, e.g. do we have to measure inside the solenoid?
  - Achievable resolution of optics and signal levels

Setup at the Cockcroft Institute



BIF Setup

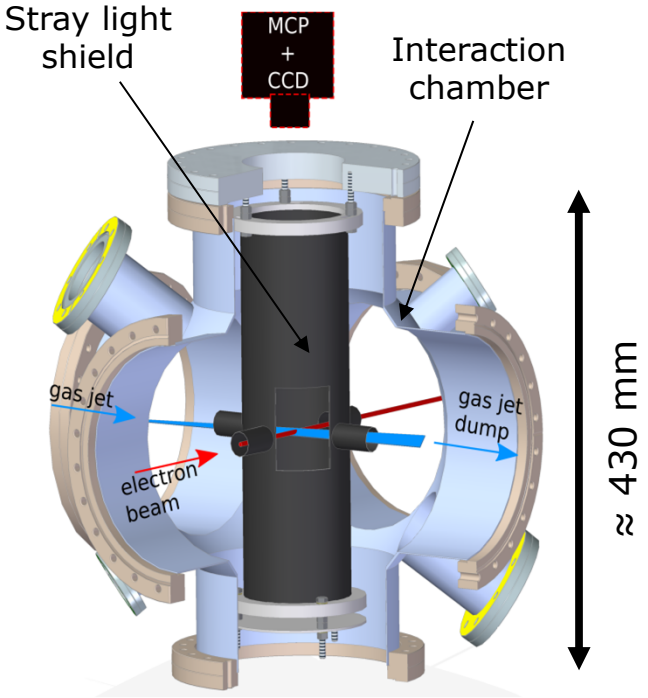
- Proxivision image intensifier with chevron double MCP
- Basler A311f CCD camera
- Pentax B2528-UV objectiv, f=25 mm, F#=2.8-16, transmission band 230–800 nm
- Filter wheel with 10 nm bandwidth filters at 337, 390, 430 & 470 nm

Gas Jet

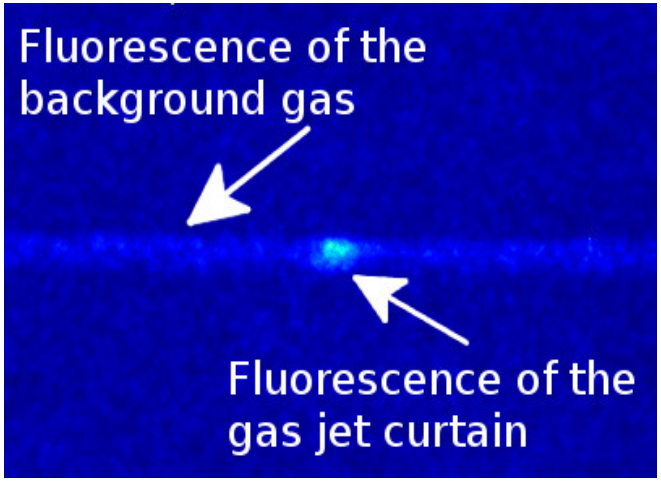
- N_2
- Density ≈ $2.5 \cdot 10^{10}$ cm^{-3}
- Thickness ≈ 0.4 mm
- Width ≈ 4 mm

Electron beam

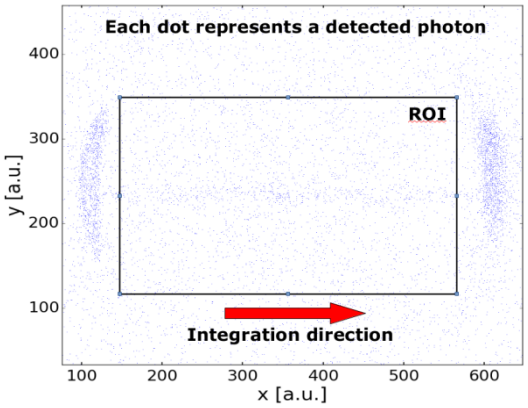
- E < 5 keV
- I < 10 μA
- Φ ≈ 1 mm

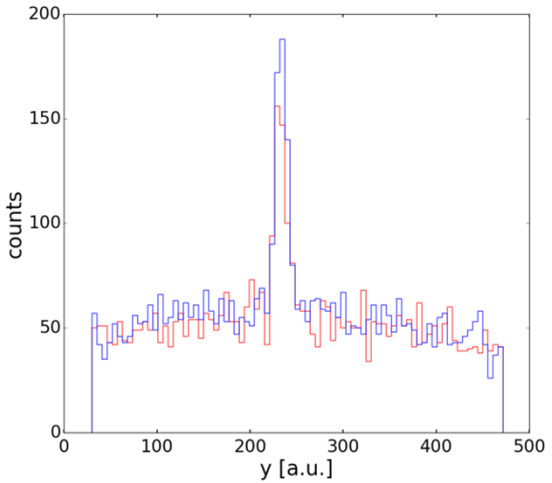


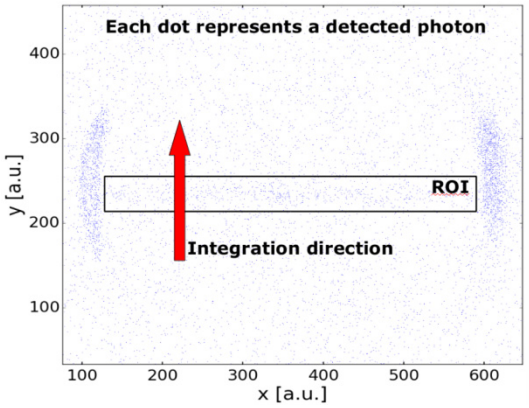
Experimental Results

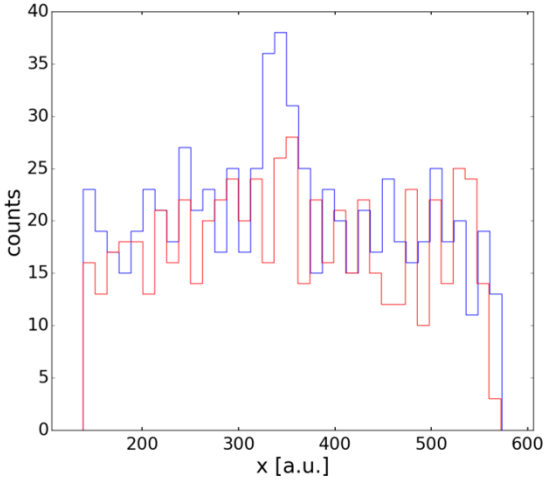


Nitrogen gas jet, integration over $t_{int} \approx 8000$ s.
e^- beam energy was 3.5 keV and current approx. 7 μA.



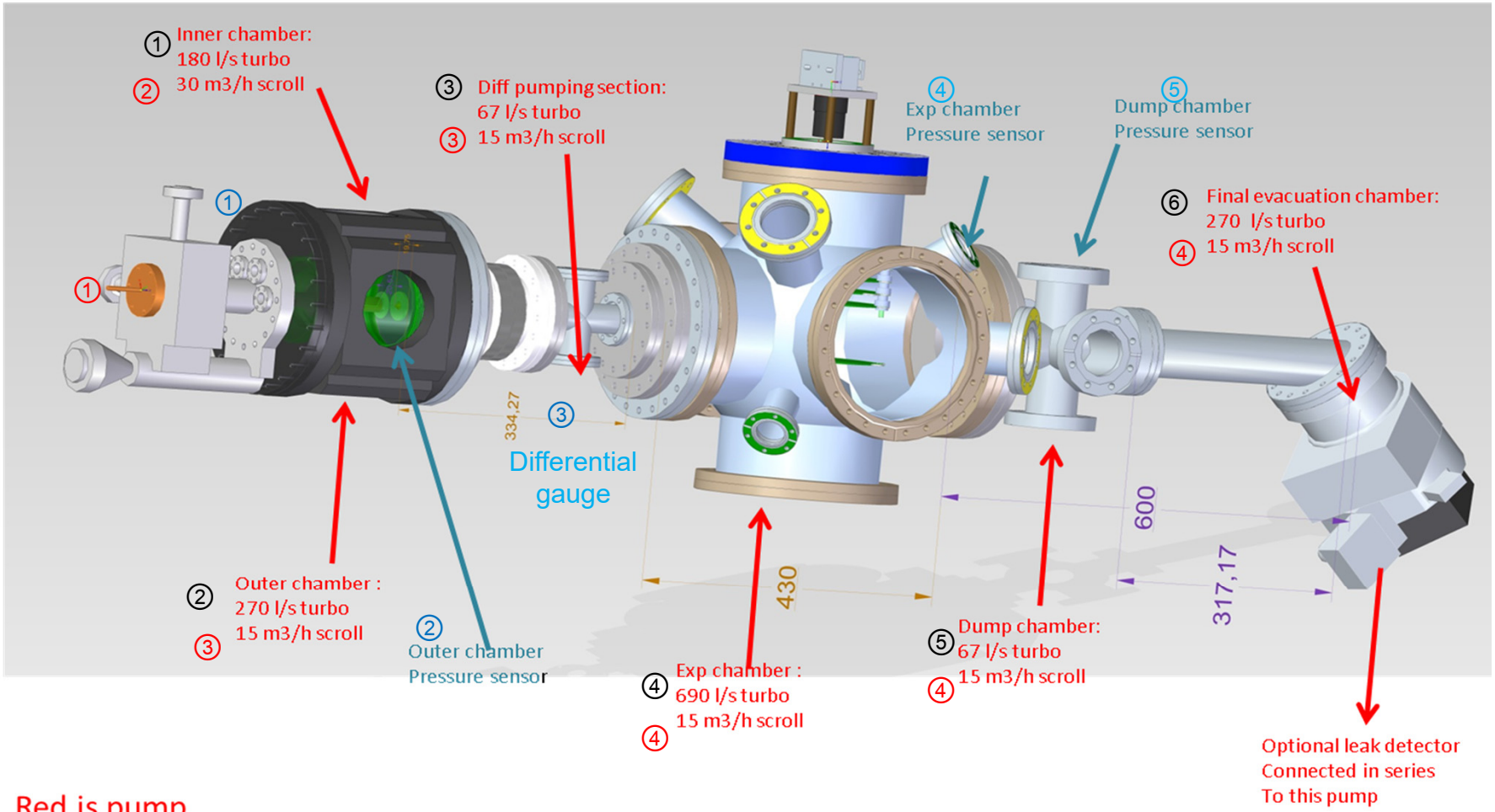






Images to the left have been obtained by centroiding, $t_{int} \approx 1000$ s.
Red histograms: measurement without gas jet.
Blue histograms: measurement with gas jet.

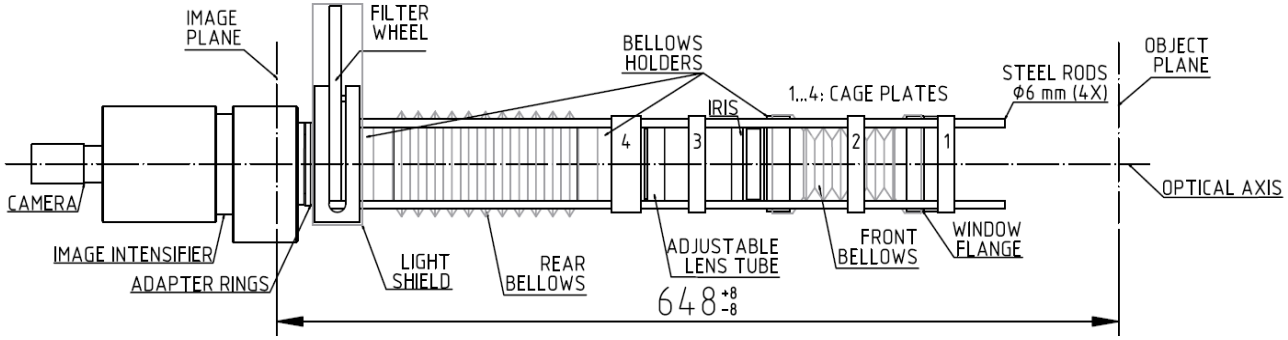
Mechanical Design



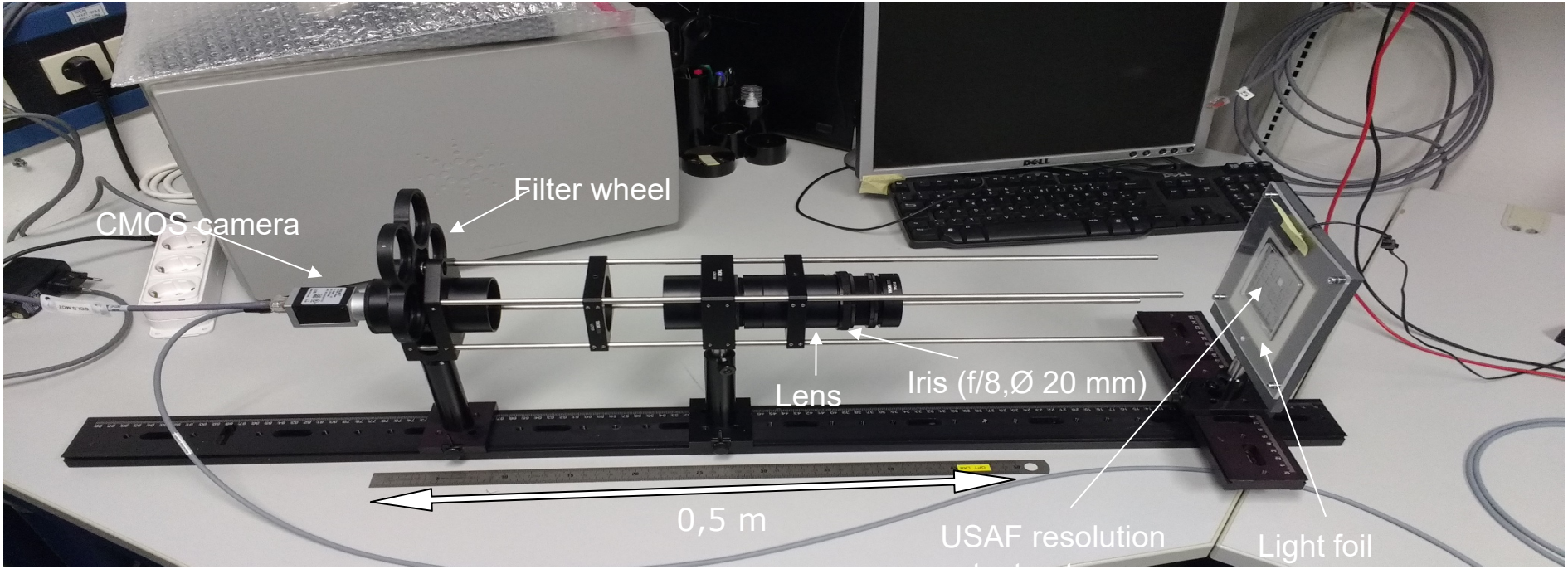
Red is pump

Blue is pressure sensor

Optical System Optimization



S. Udrea, GSI



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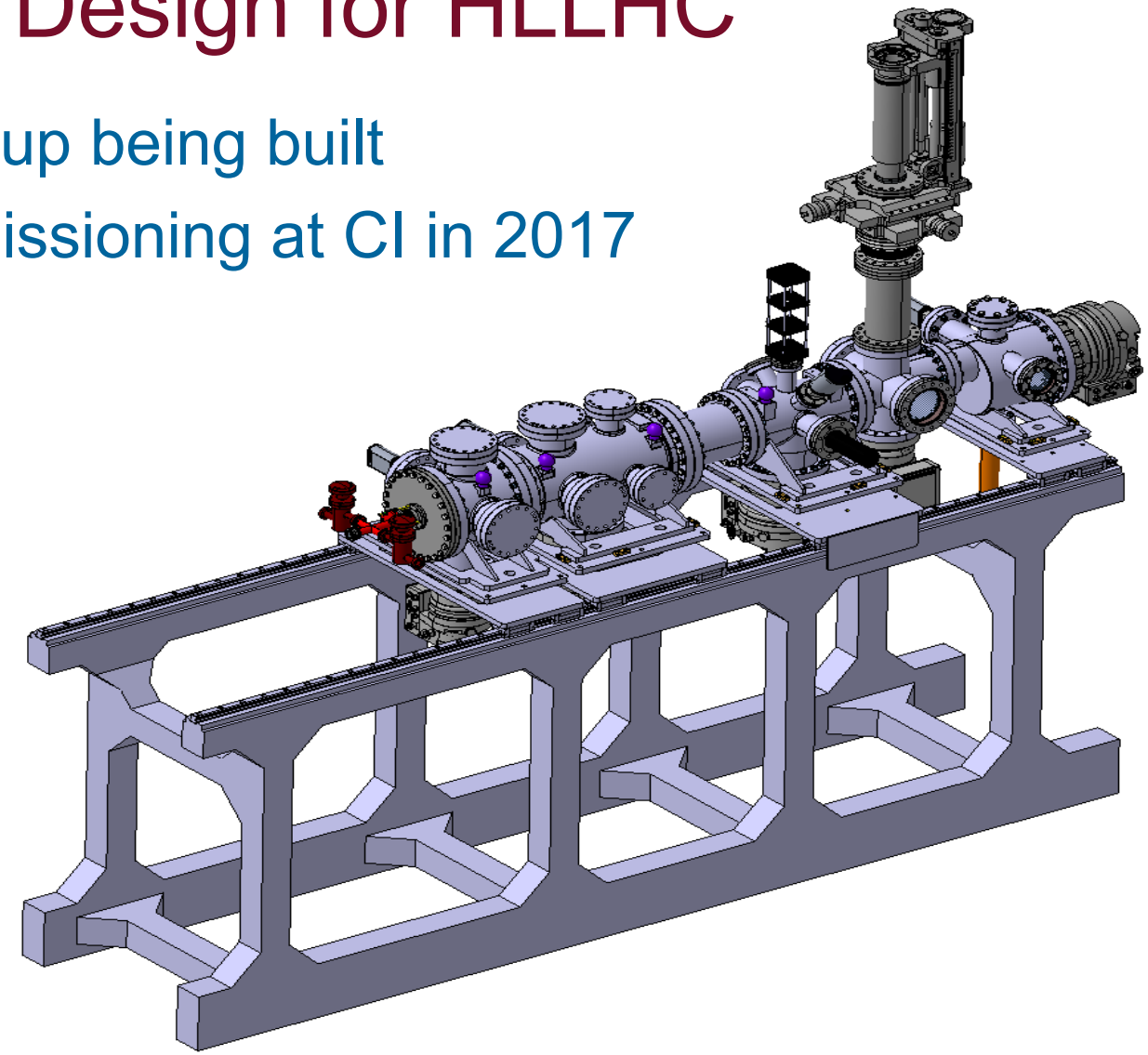
Design for HLLHC

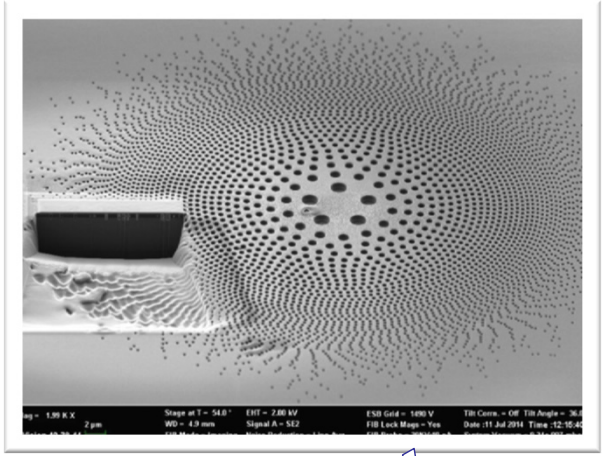
- 2nd setup being built
- Commissioning at CI in 2017

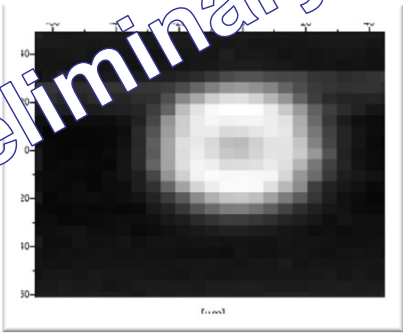


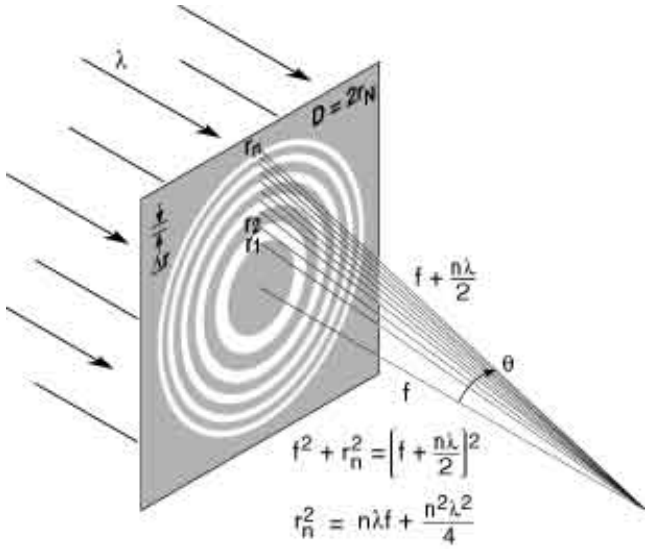
N. Chritin, CERN

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 and spatial resolution.

Thanks for your attention !

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