IBIC 17
INTERNATIONAL BEAM INSTRUMENTATION CONFERENCE
Grand Rapids, Michigan, USA
20-24 August 2017

Beam Diagnostics for Low Energy Ion Beams

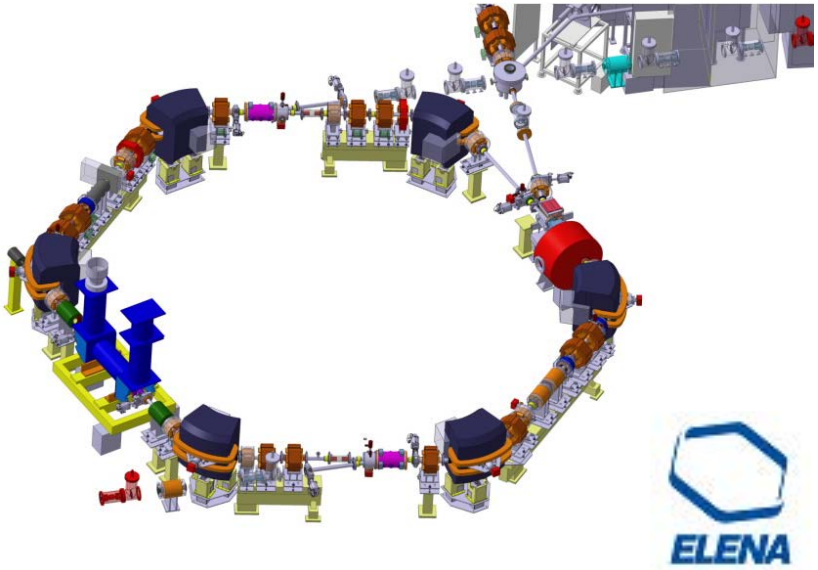
Carsten P Welsch

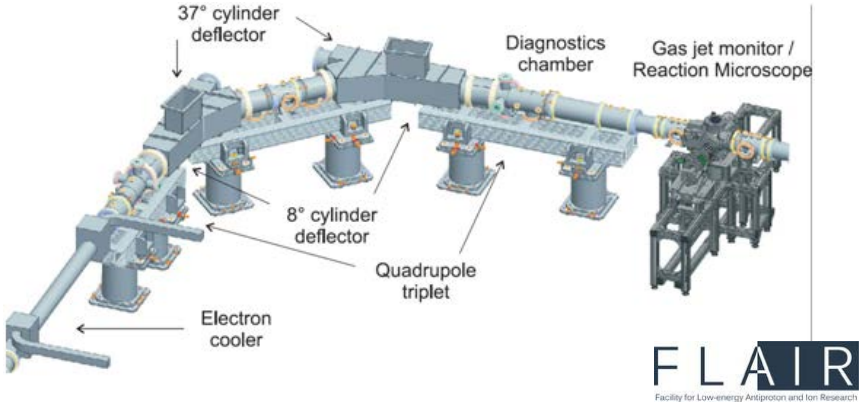
DITANET Workshop

- Low energy, low intensity beam diagnostics
- Proceedings available online.

- http://www.liv.ac.uk/ditanet
- https://indico.cern.ch/event/93294/

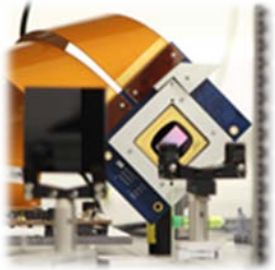
Setting the scene

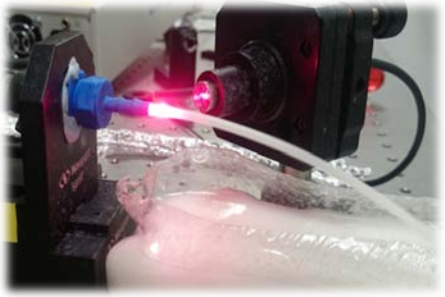


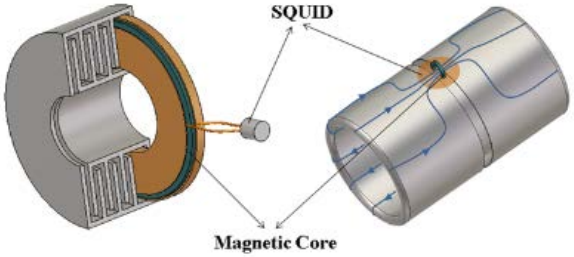


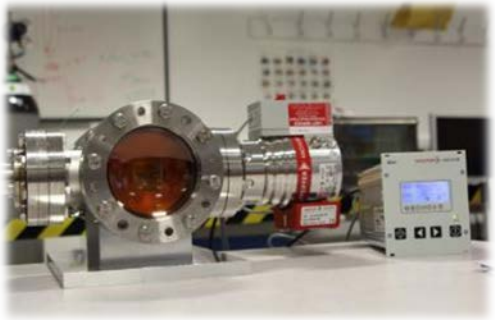
Parameter	Value
Beam energy	300 keV → 20 keV
Relativistic β = v/c	0.025 → 0.006
Revolution frequency	178 kHz → 46 kHz
Revolution time	5.6 μs → 21.8 μs
Number of particles	$<2 \cdot 10^7$ @ 20 keV
Bunch length	1 ns – DC beam
Effective in-ring rates	10^{10} – 10^{12} pps
Average extracted rates	$5 \cdot 10^5$ – 10^6 pps

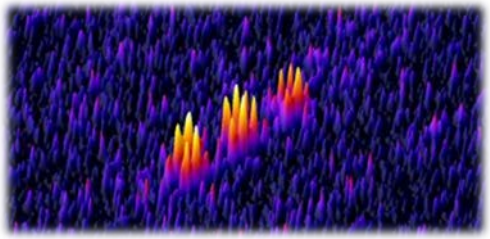
Diagnostics Requirements







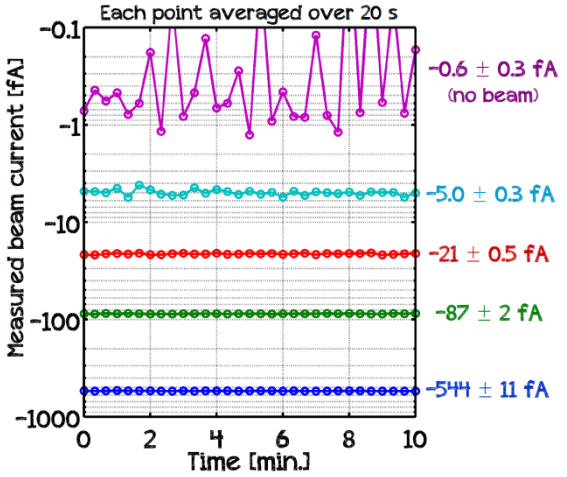




Aim: Fully characterize the beam during commissioning and later operation.

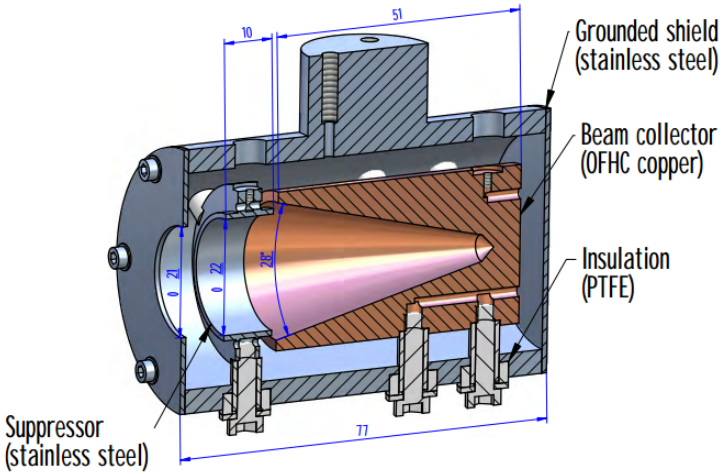
Beam Intensity

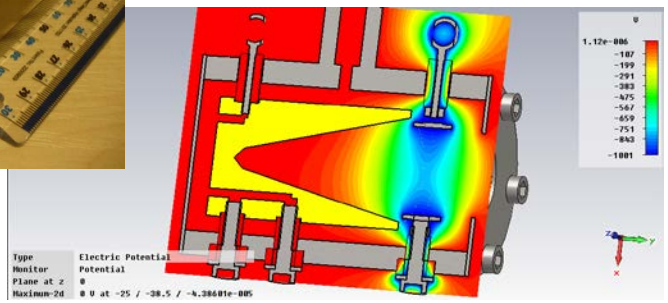
- Purpose-designed Faraday Cup
- Optimized for fA beams and noise suppressing
- Tool for machine commissioning and optimization – not for pbars



J. Harasimowicz, et al.,
Hyperfine Interact. (2009)

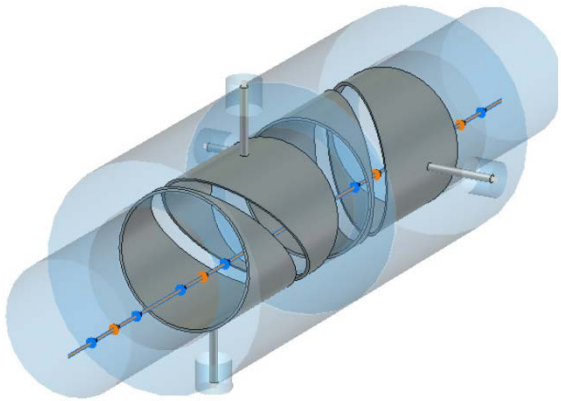
J. Harasimowicz, et al.,
Rev. Sc. Instr. **81** (9) (2010)

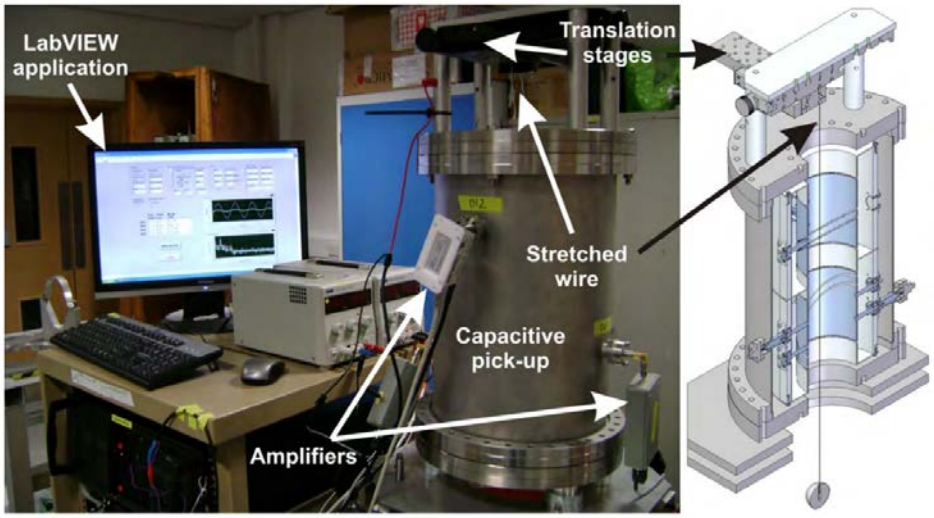


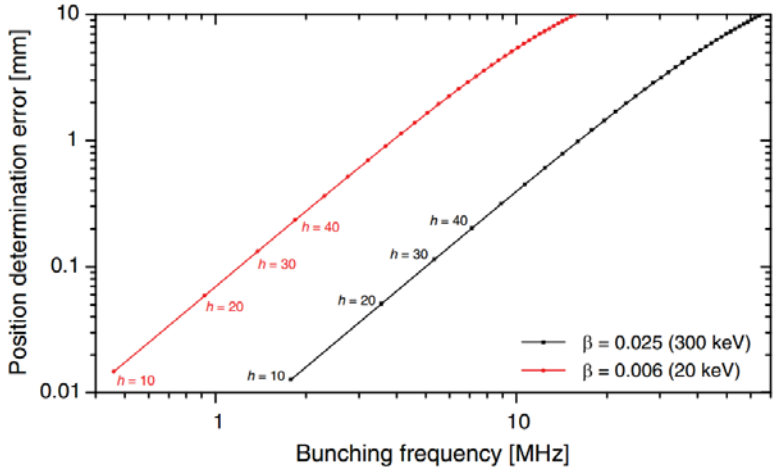


Beam Position

- Electrostatic pickup with diagonal cut chosen
- Full 3D numerical model – benchmarked against lab setup
- Optimized for signal quality.



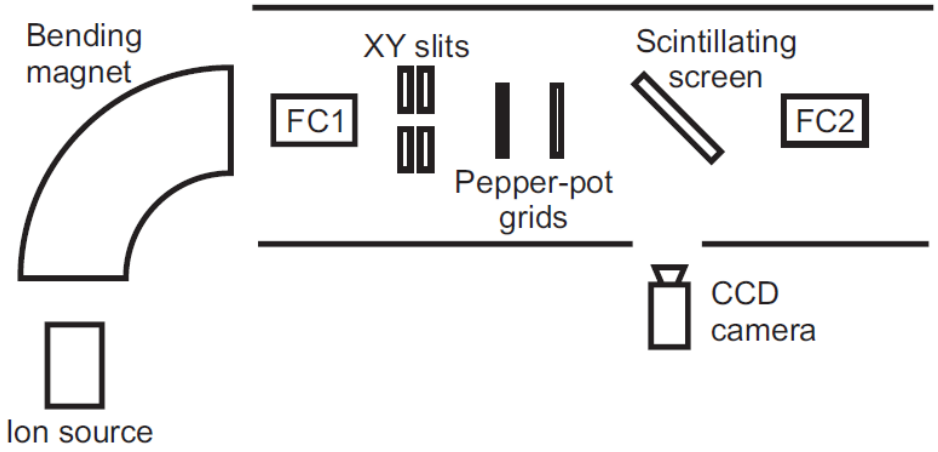


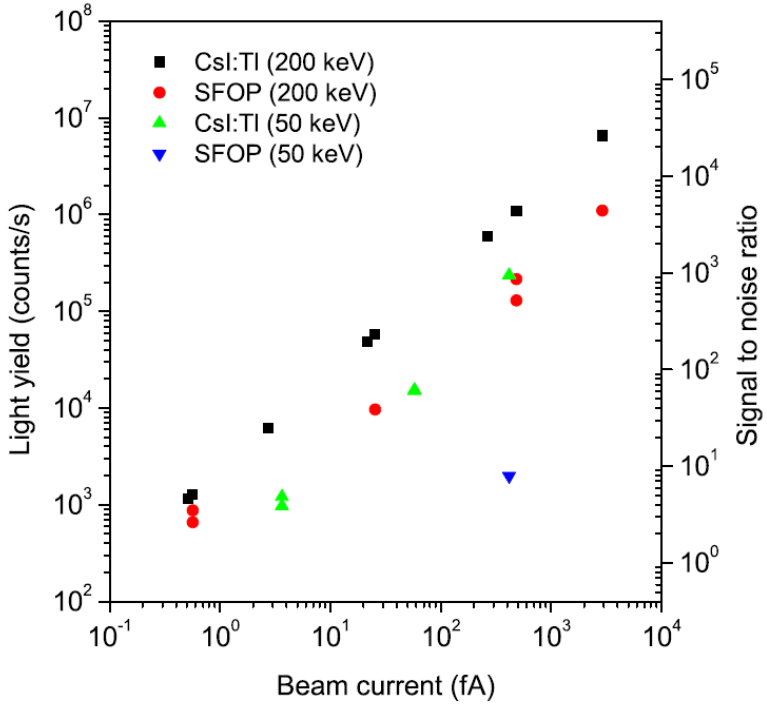


J. Harasimowicz, et al., Phys. Rev. STAB **16** (2013)

Beam Profile

- Challenge: Low energy deposition, low photon yield, etc.
- Tested various scintillators with low energy proton beams
- Realized in close collaboration with INFN-LNS

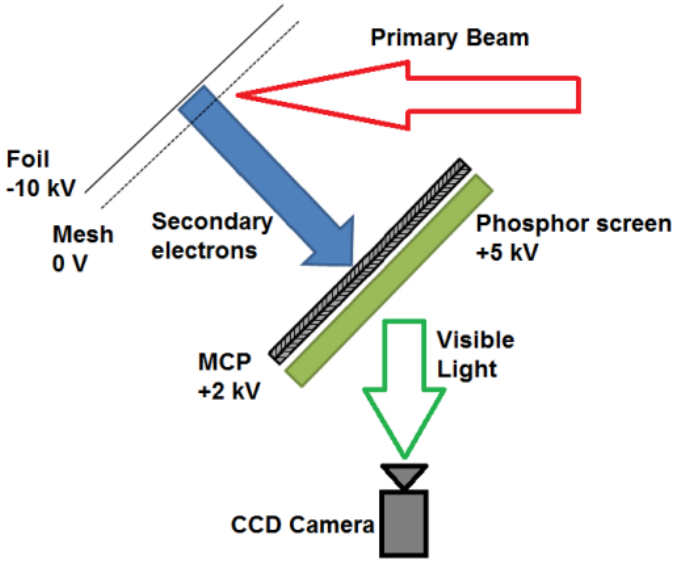




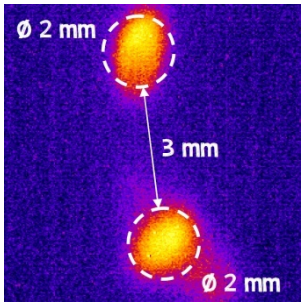
J. Harasimowicz, et al., Rev. Sc. Instr. **81** (9) (2010)

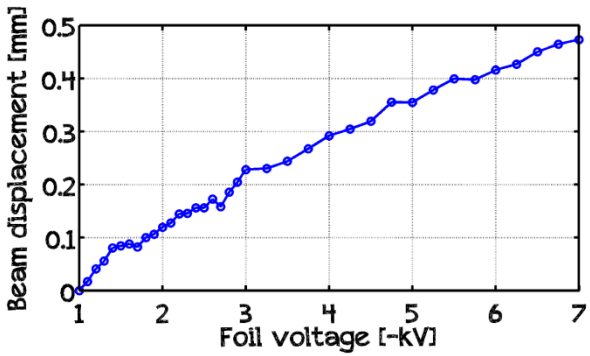
Secondary Emission Monitor

- Alternative for transverse profile measurement;
- Based on earlier designs
- Tested in measurements with 200 keV proton beams at INFN
- Allowed benchmarked of simulations
- Reaction to pbars ?

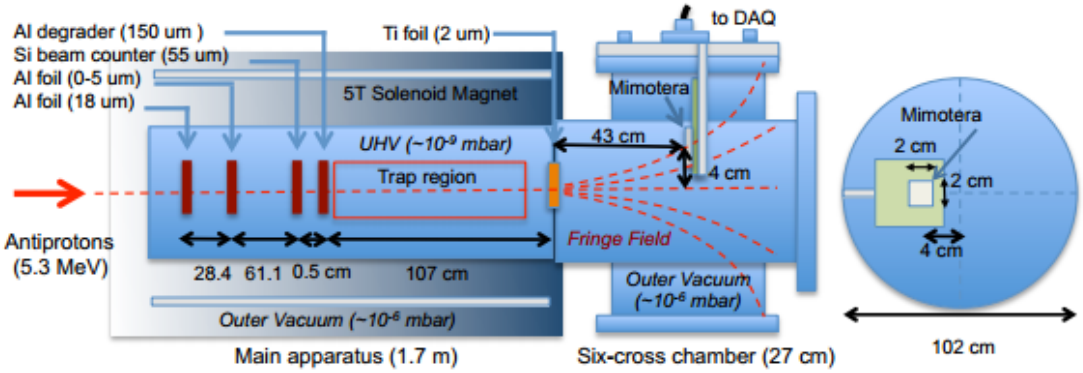


- Next step: AEgIS setup.



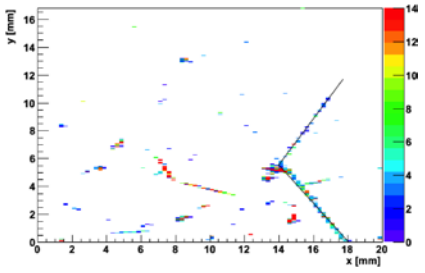


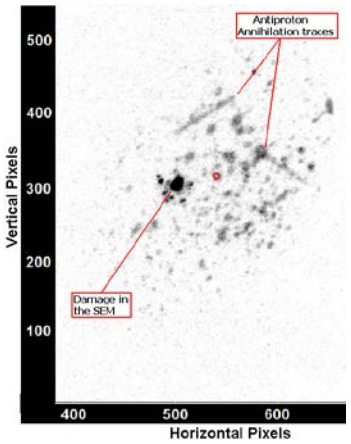
Setup @ AEgIS



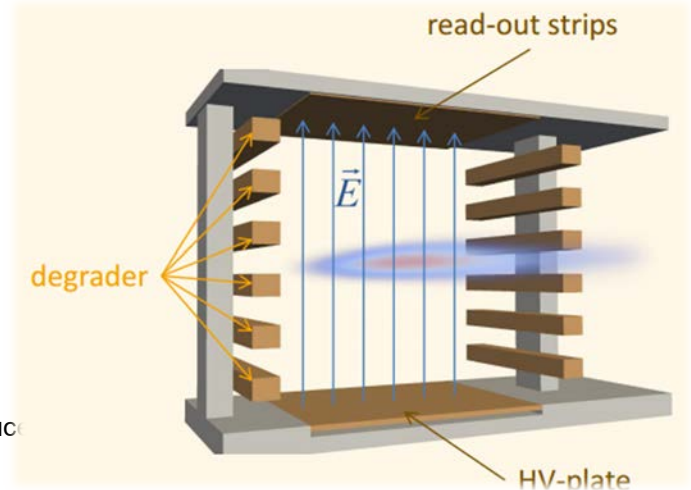
- Crutial for detailed detector and diagnostics tests
- Tested: Secondary emission monitors, Silicon pixel and strip detectors.

J. Harasimowicz, et al., Rev. Sc. Instr. **81** (9) (2010)
J. Harasimowicz, et al., Phys. Rev. STAB **16** (2013)
A. Sosa, et al., Hyp. Inter. (2014)
S. Aghiona, et al., JINST 8 P08013 (2013)
S. Aghiona, et al., JINST 8 P06020 (2013).





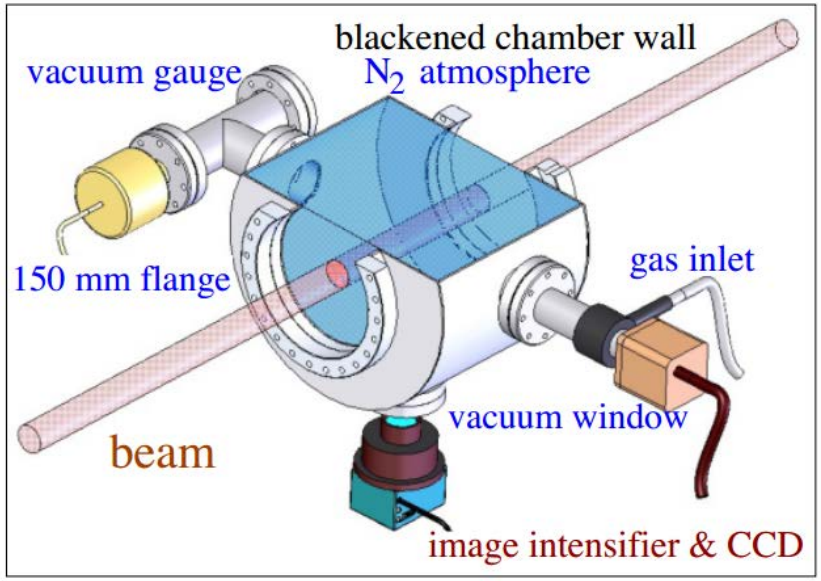
Ionization Profile Monitor (IPM)

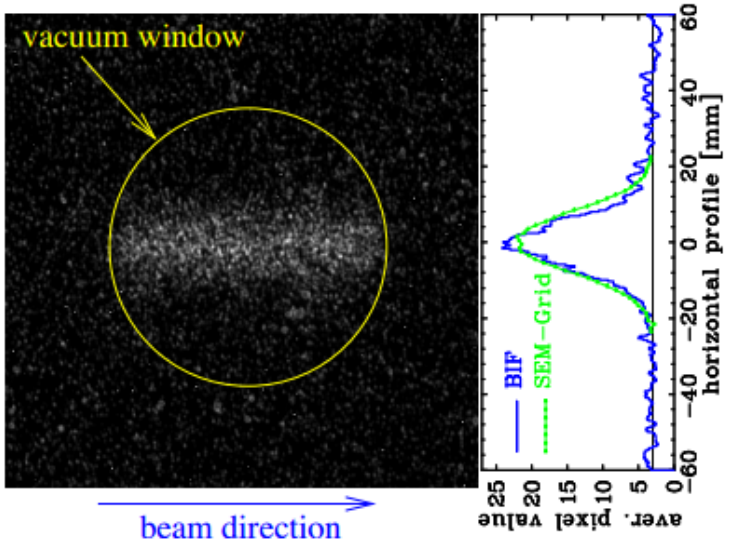


Souc

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

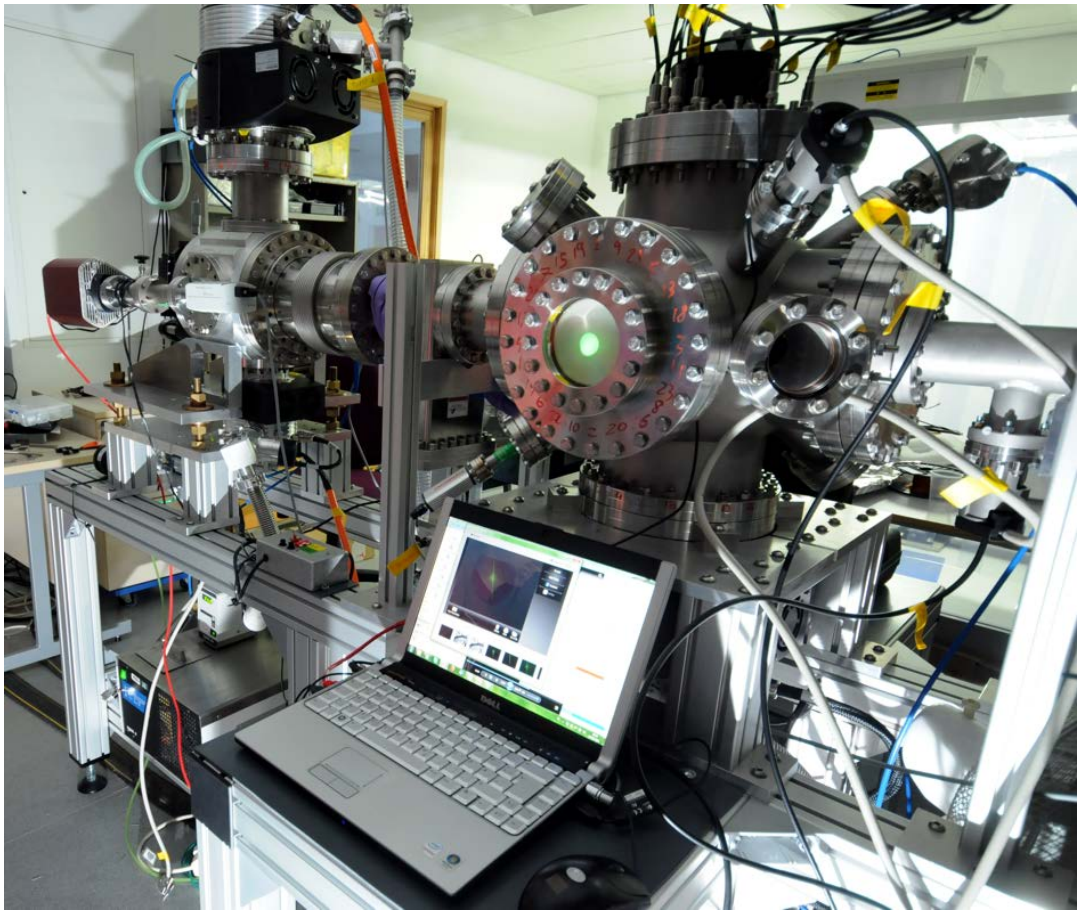
Beam Induced Fluorescence (BIF)





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

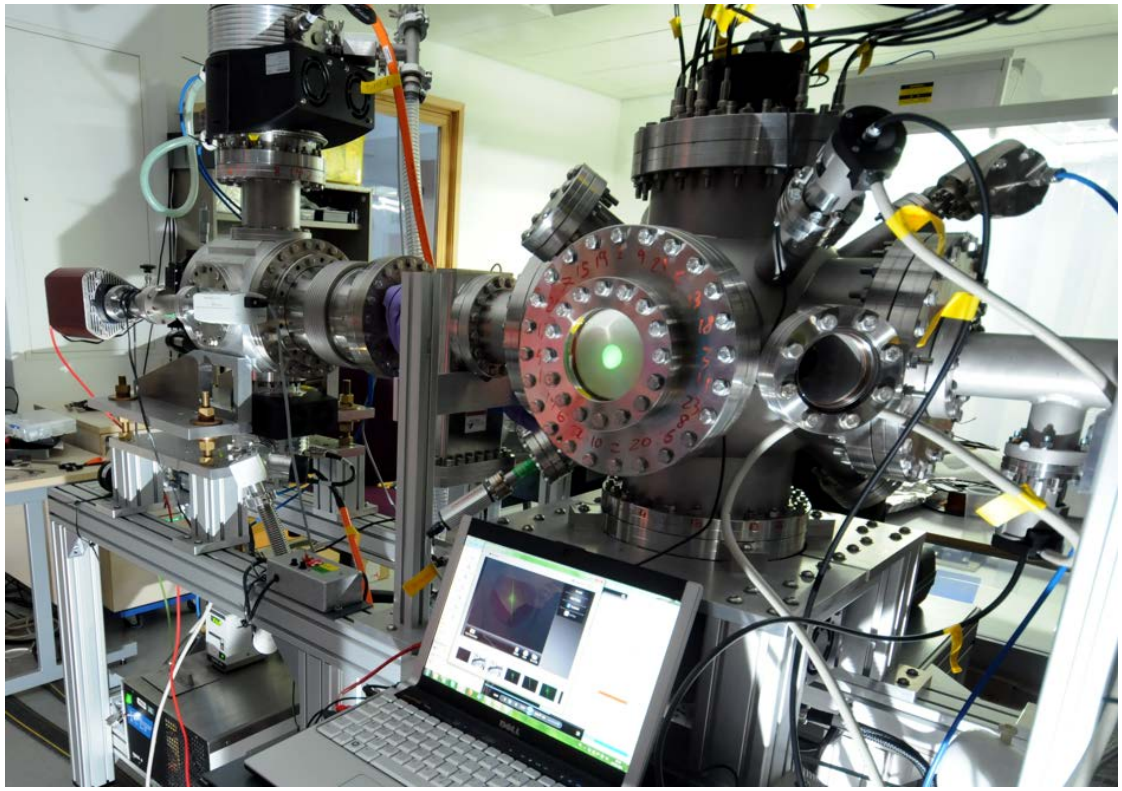
Gas Jet Monitor



- Setup @ CI;
- Gas jet, IPM and BIF;
- Designed for use with low energy pbars:
  - Profile monitor
  - Collision studies.
- Excellent tool for studies into jet properties.

M. Putignano, C.P. Welsch, Nucl. Instr. Meth. A 667 (2012)
V. Tzoganis, C.P. Welsch, Apl. Phys. Letters (2014), V. Tzoganis, C.P. Welsch, et al., VACUUM (2014)
V. Tzoganis, et al., Phys Rev AB 20, 062801 (2017)

Setup @ Cockcroft Institute



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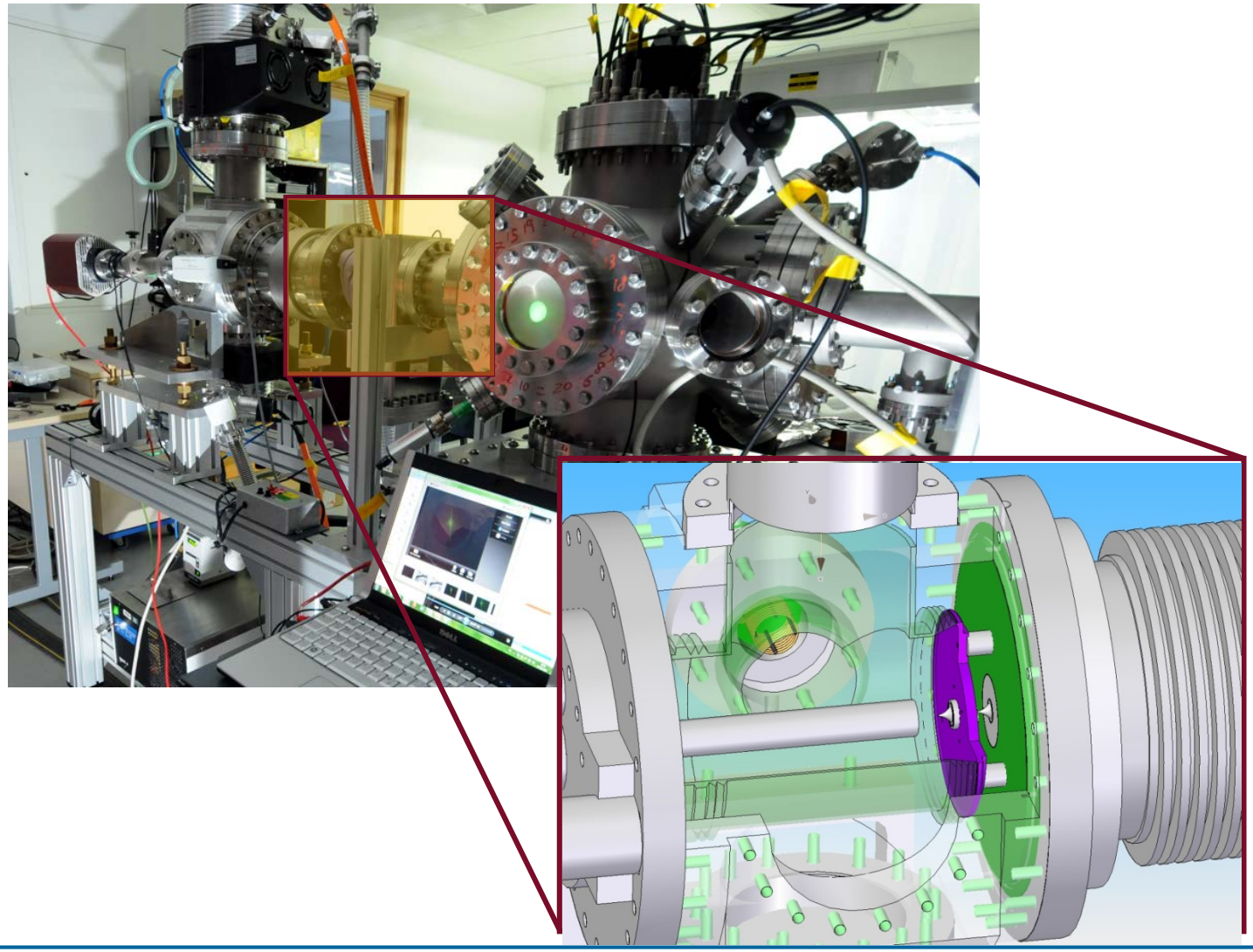

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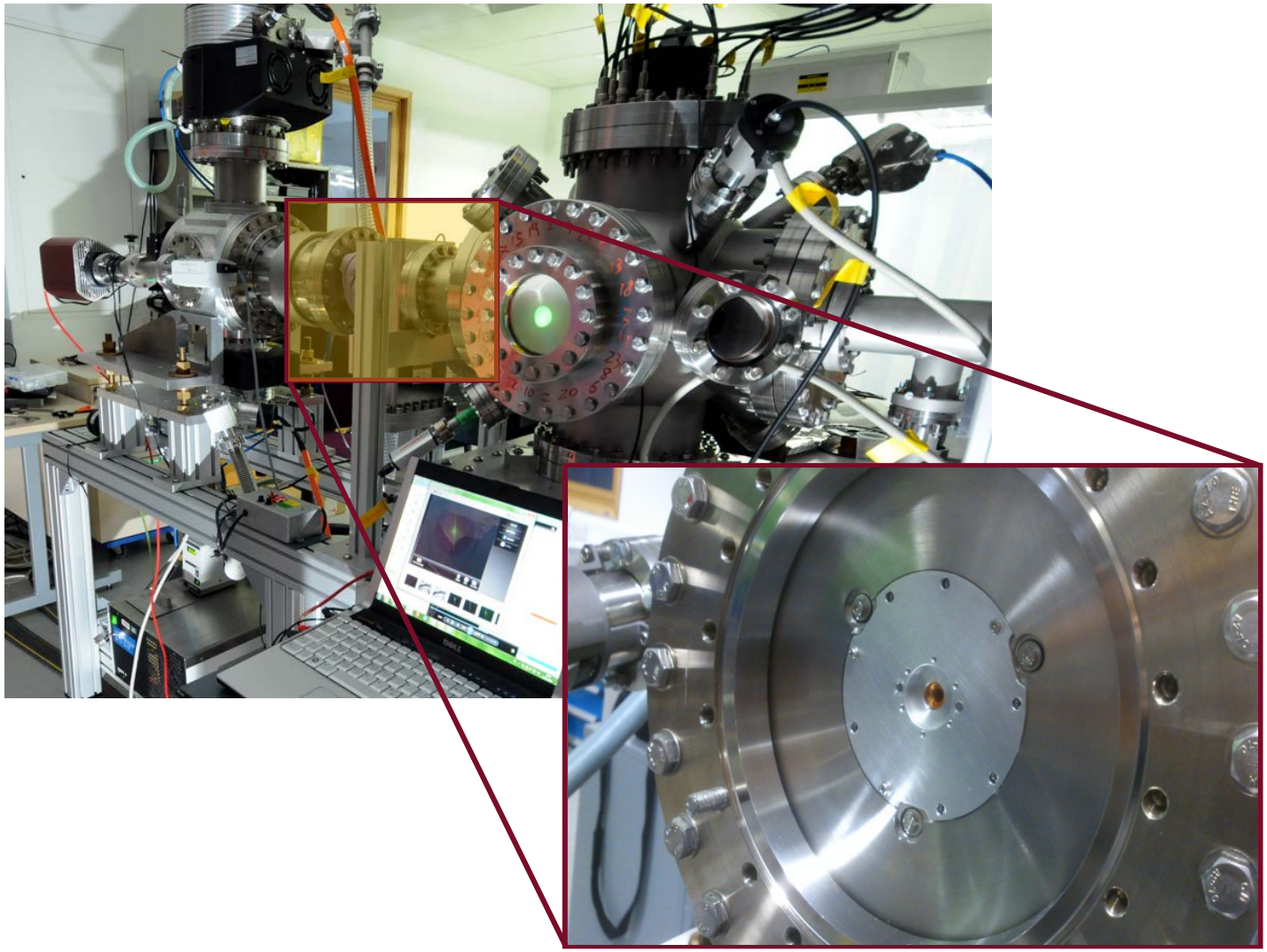

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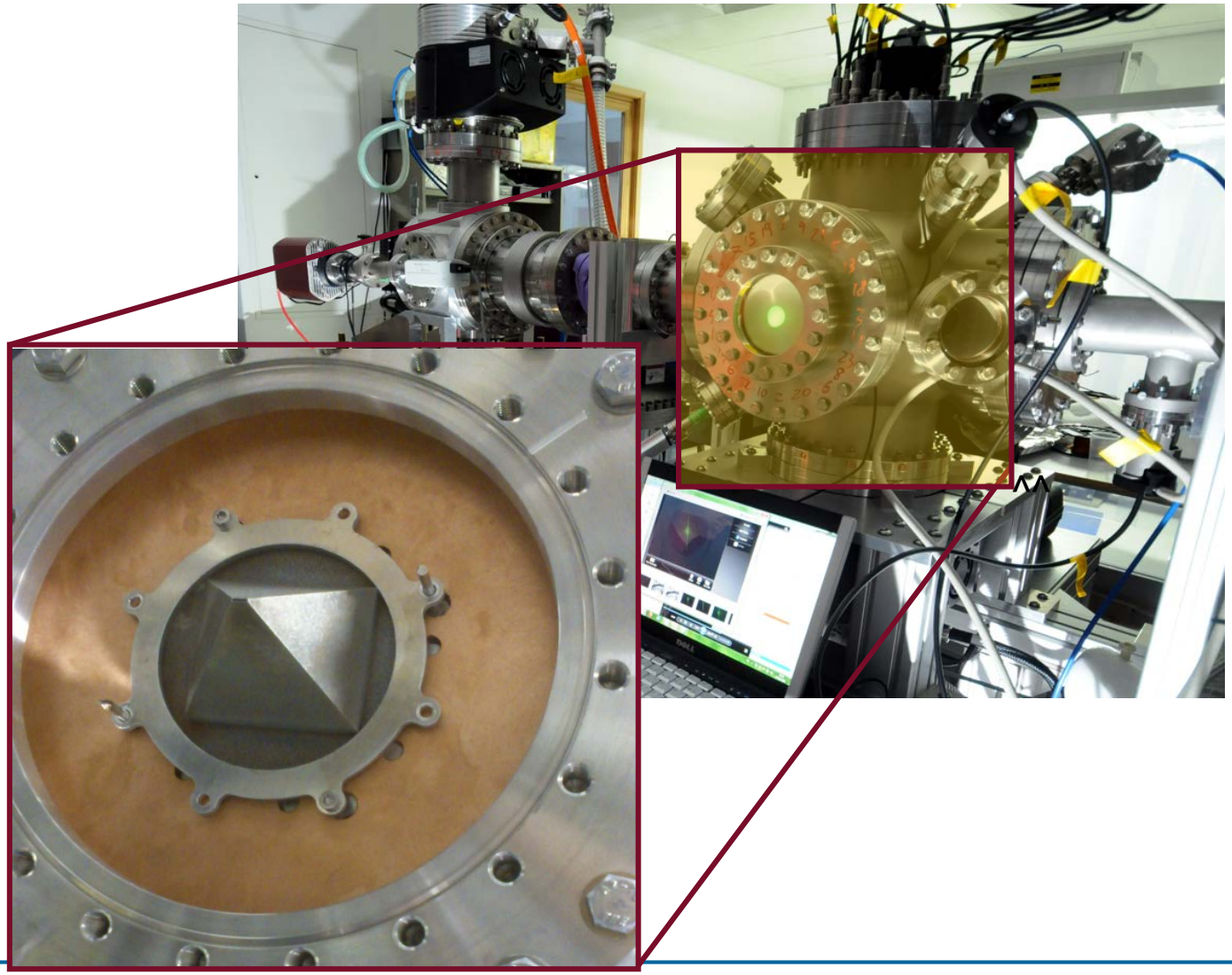

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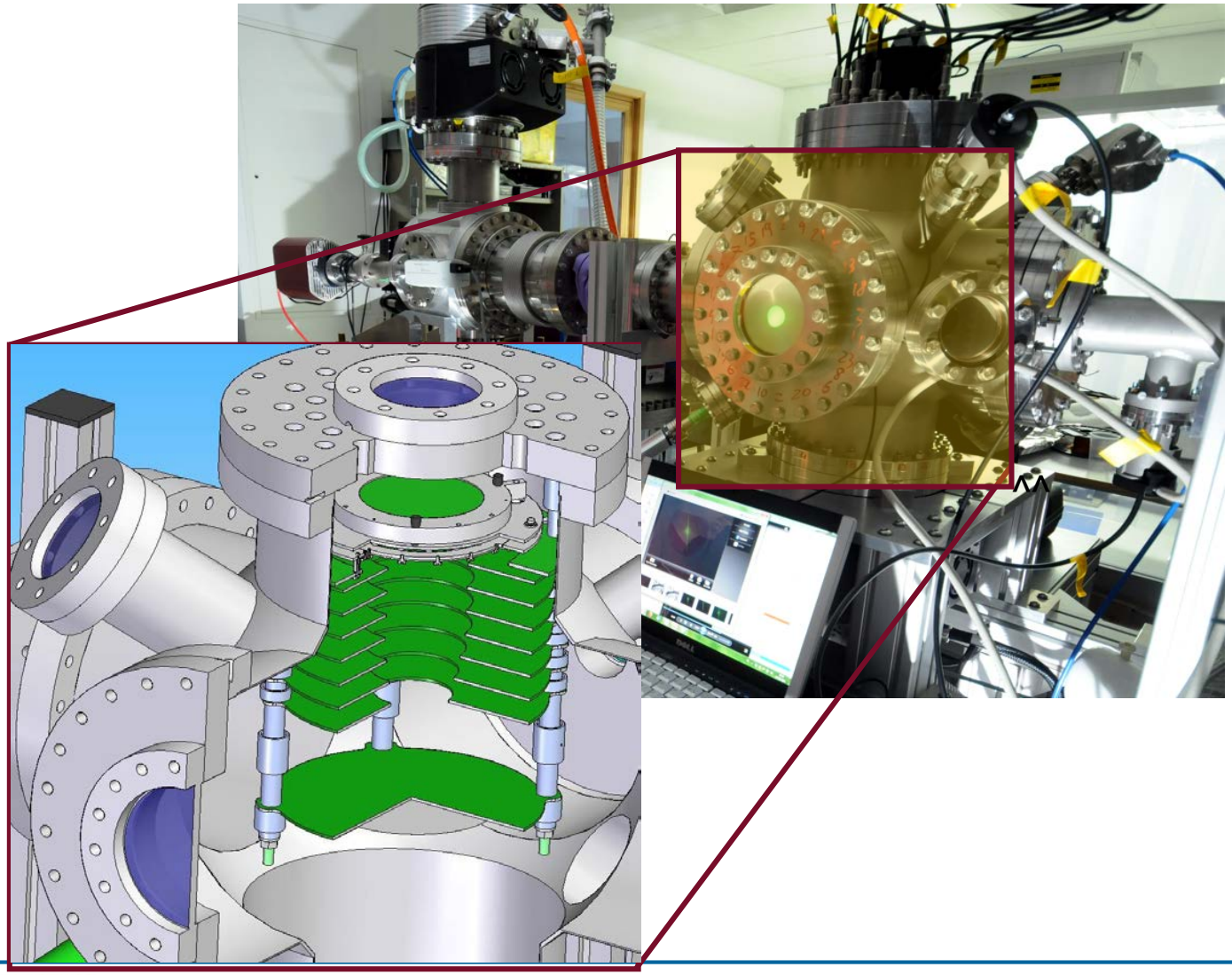
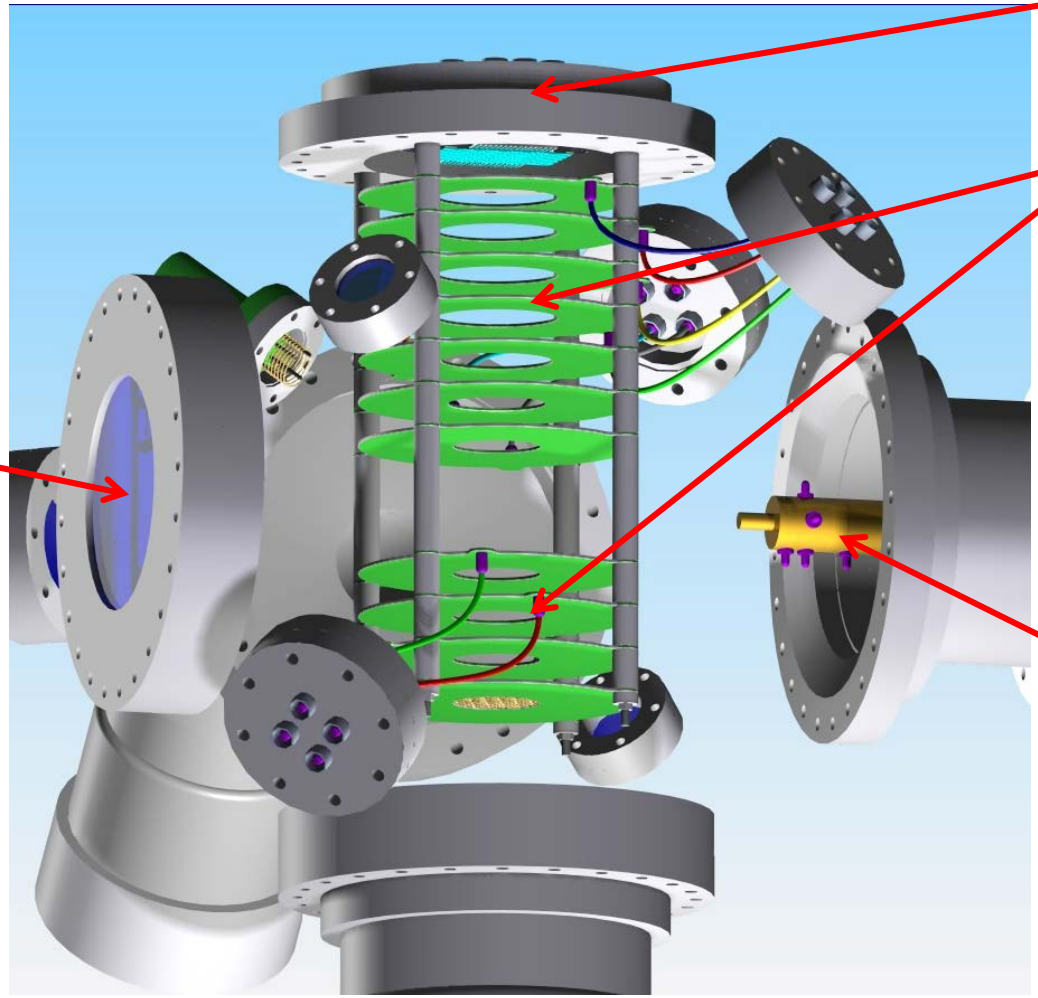
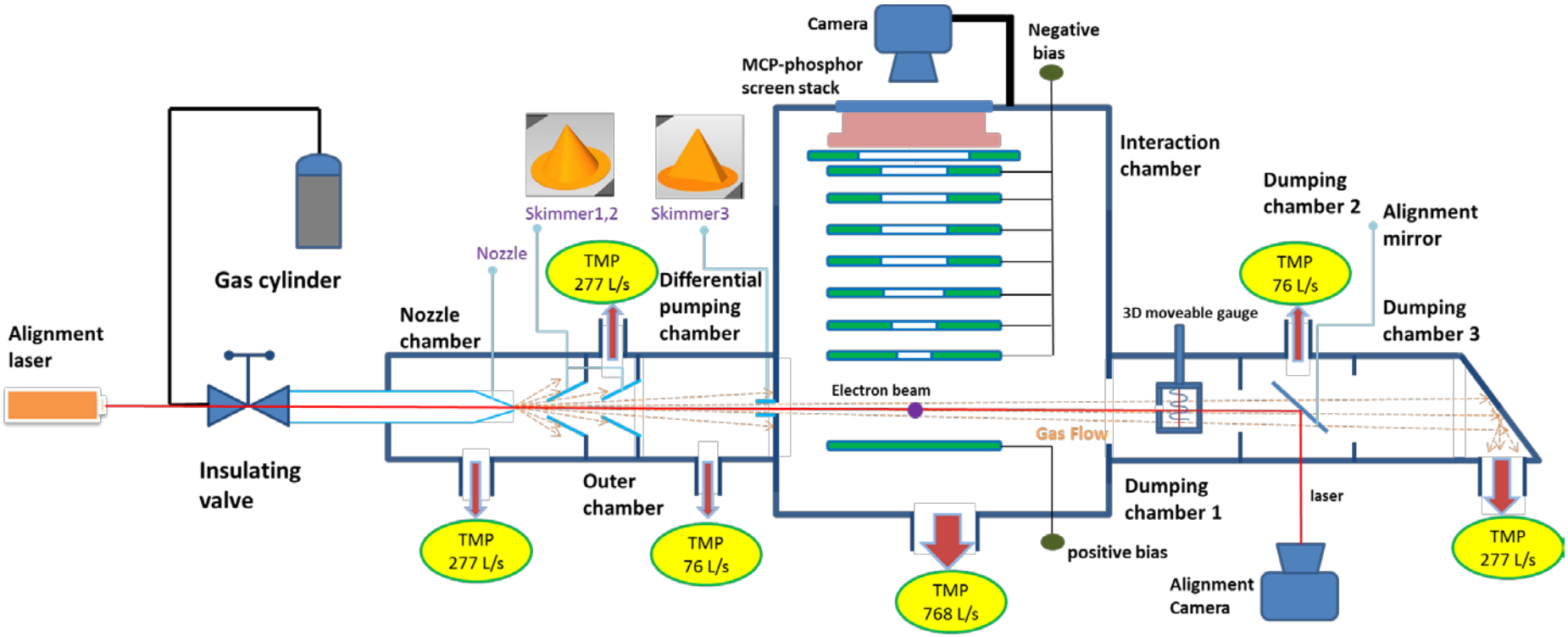


Zoom: Main chamber



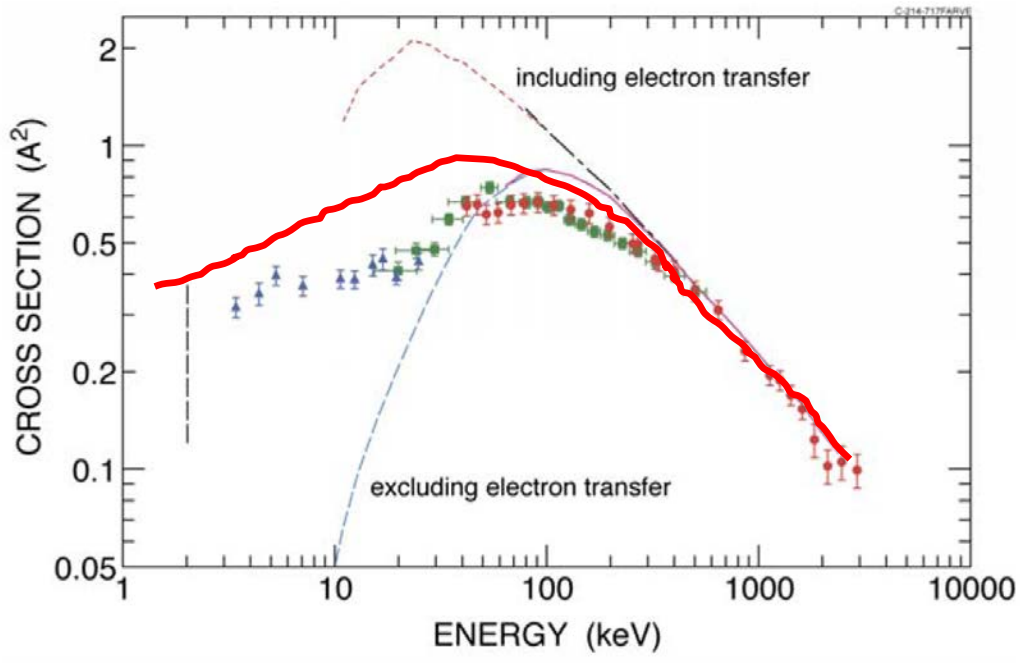
Setup



V. Tzoganis, et al., Phys Rev AB 20, 062801 (2017)

Ionization Cross Sections

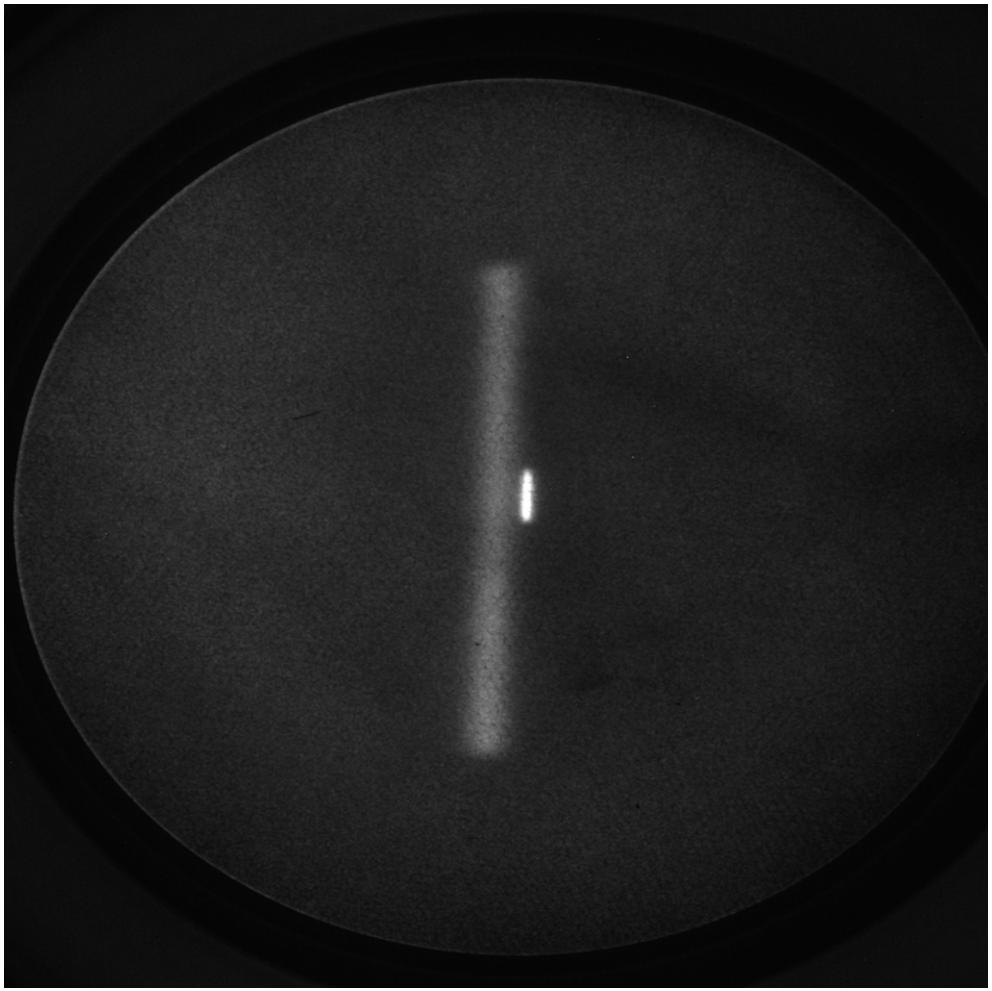
- Can be exotic, e.g. single ionization of helium by antiproton impact



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

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

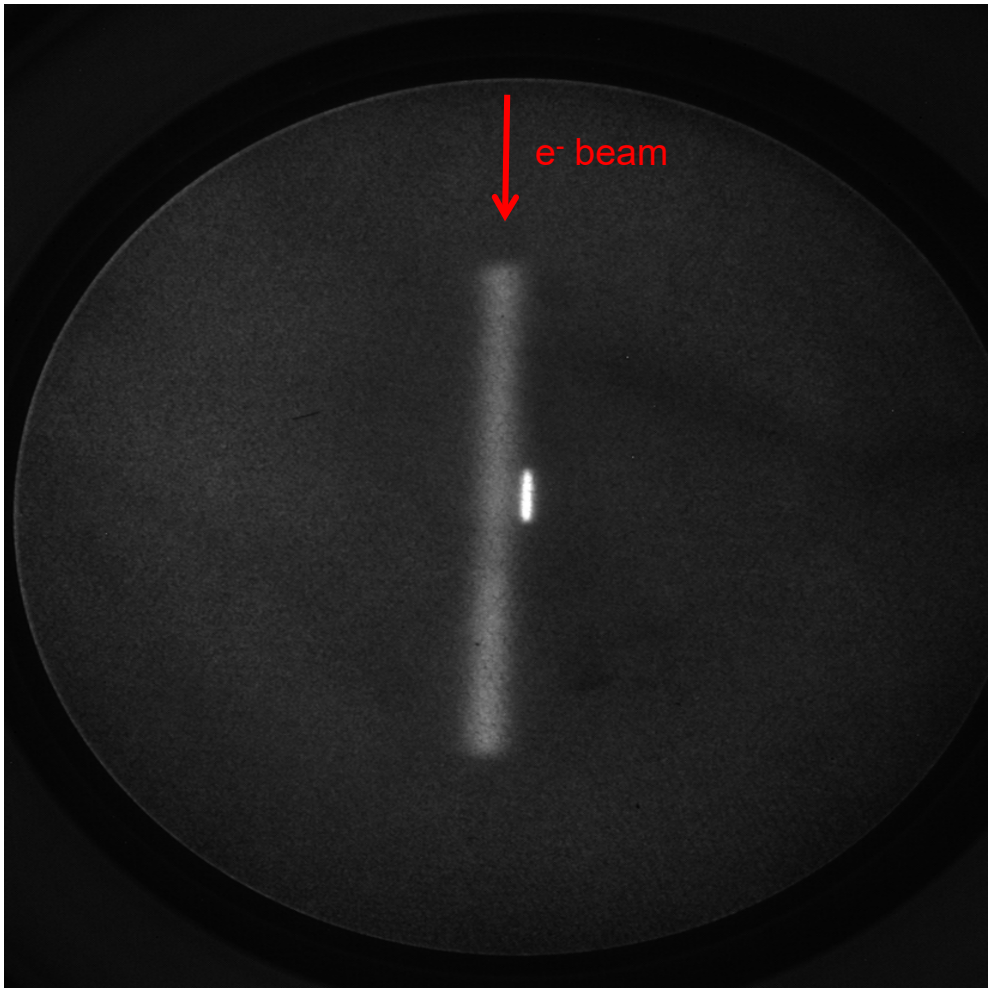
Experimental Results @ CI



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

V. Tzoganis, et al.,
VACUUM (2014)

Experimental Results @ CI



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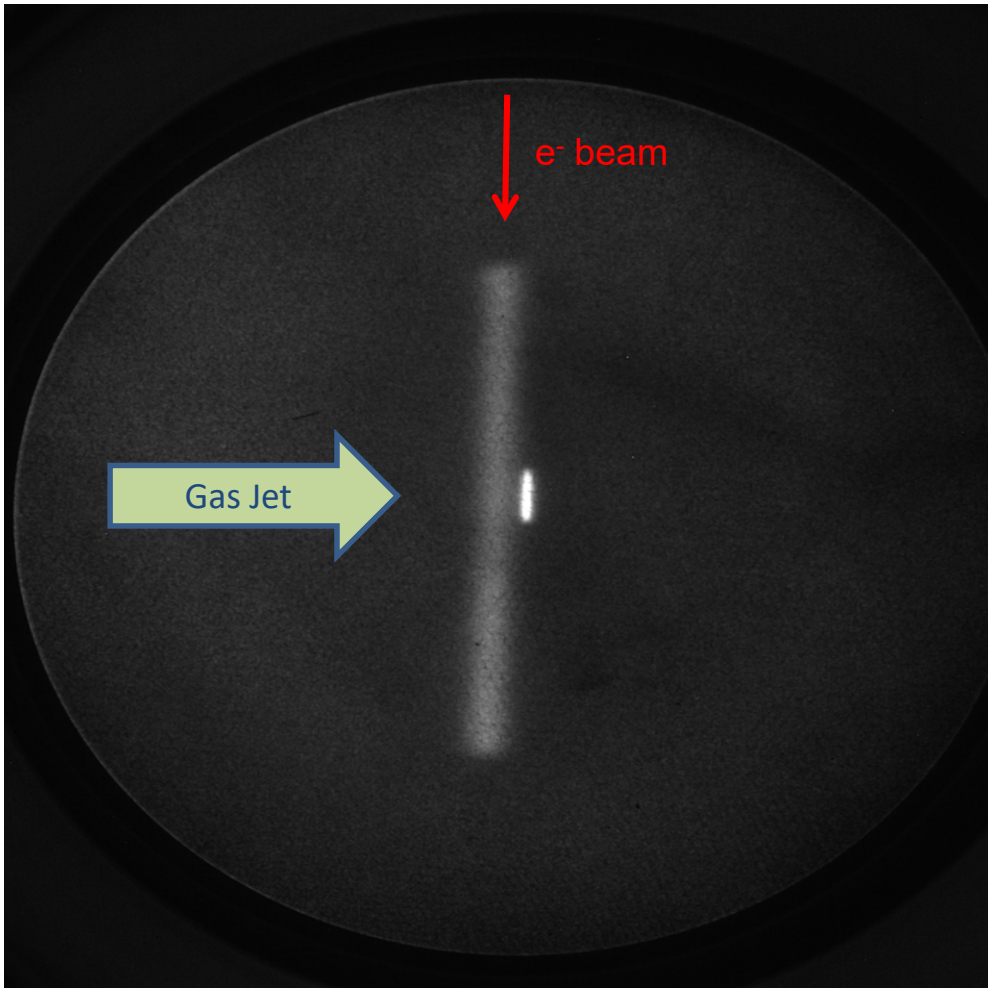
VACUUM (2014)

Experimental Results @ CI



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VACUUM (2014)

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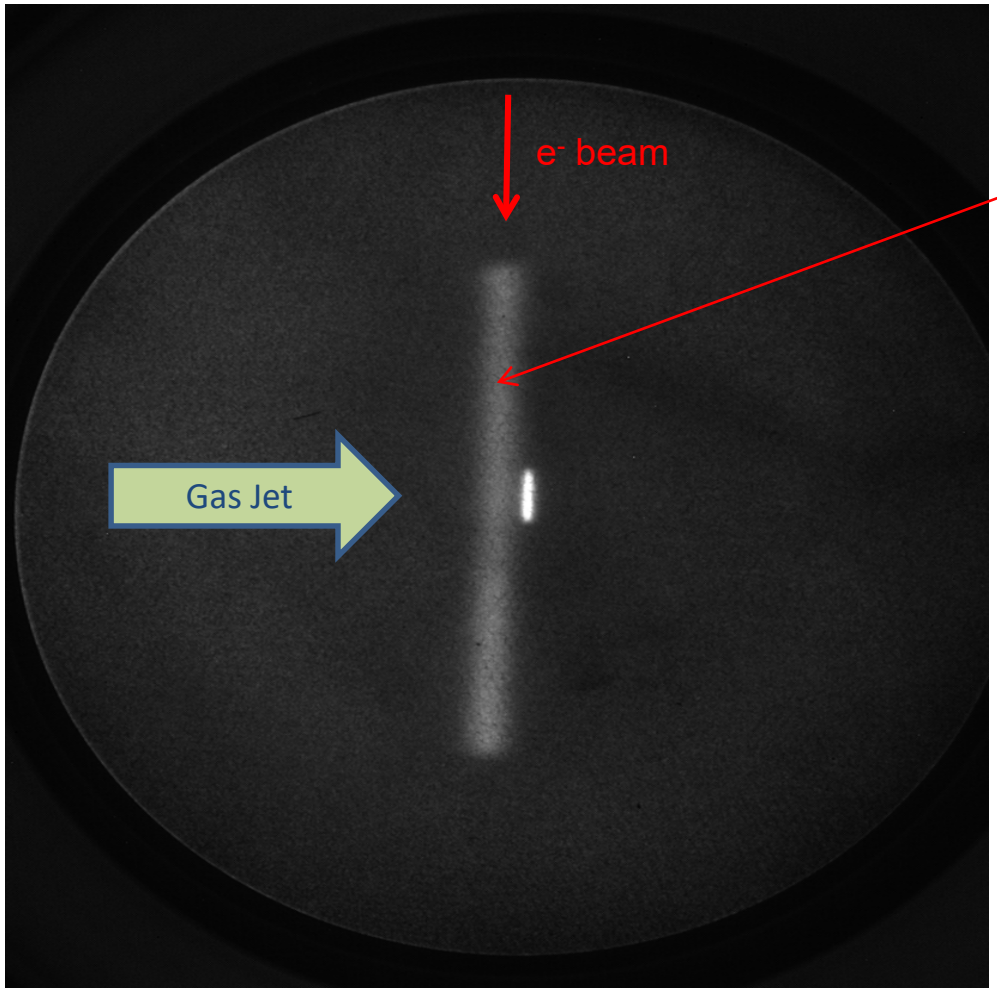
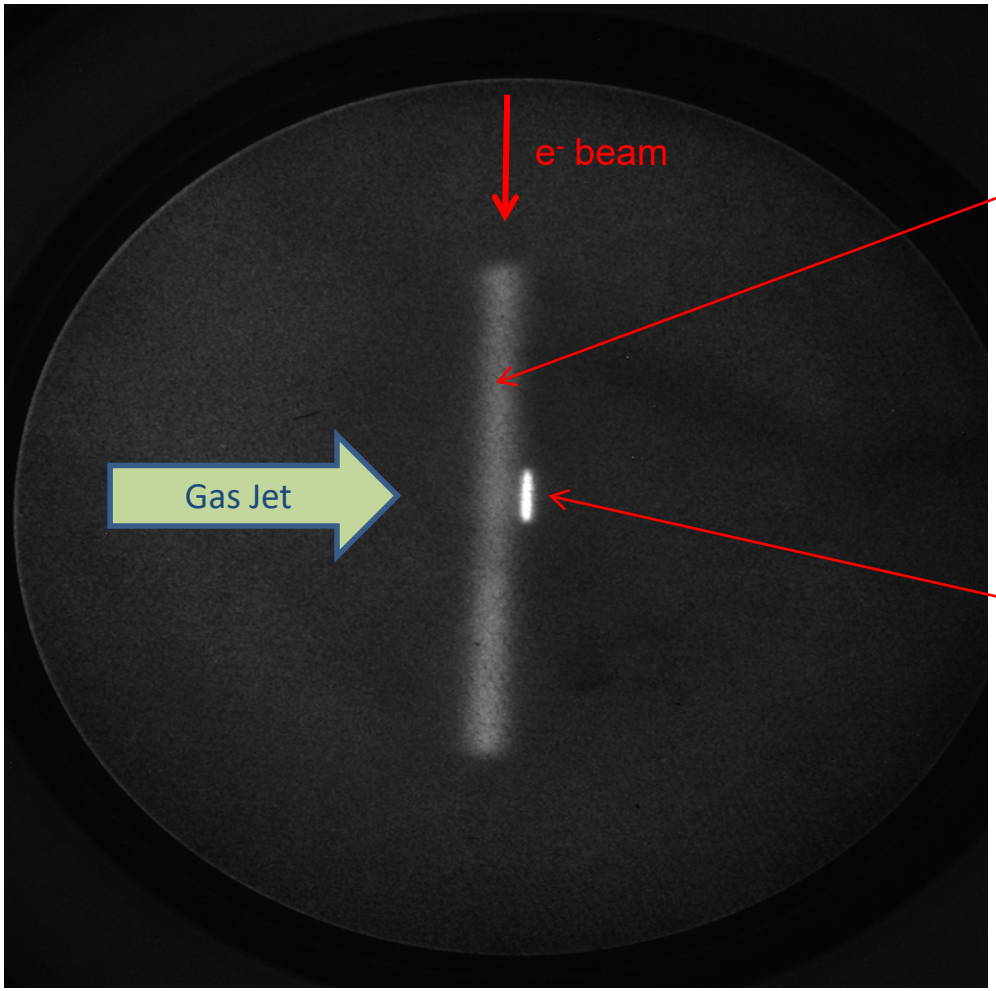


Residual gas signal

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

V. Tzoganis, et al., VACUUM (2014)

Experimental Results @ CI



Residual gas signal

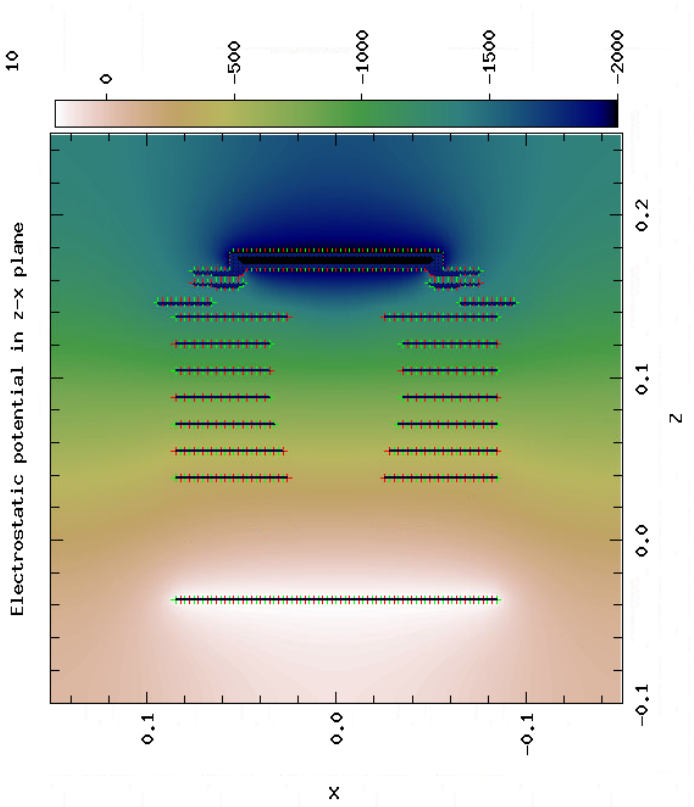
Jet signal

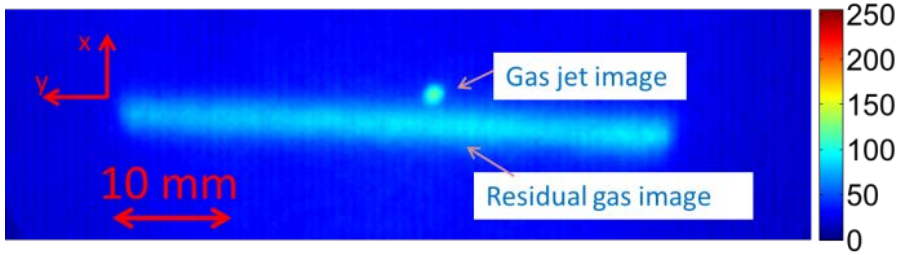
V. Tzoganis, et al.,
APL **104** 204104 (2014)

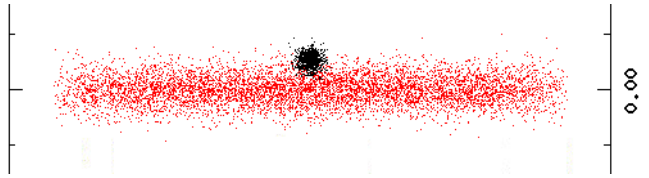
V. Tzoganis, et al.,
VACUUM (2014)

Understanding the Jet

- Simulations using the CST and WARP codes





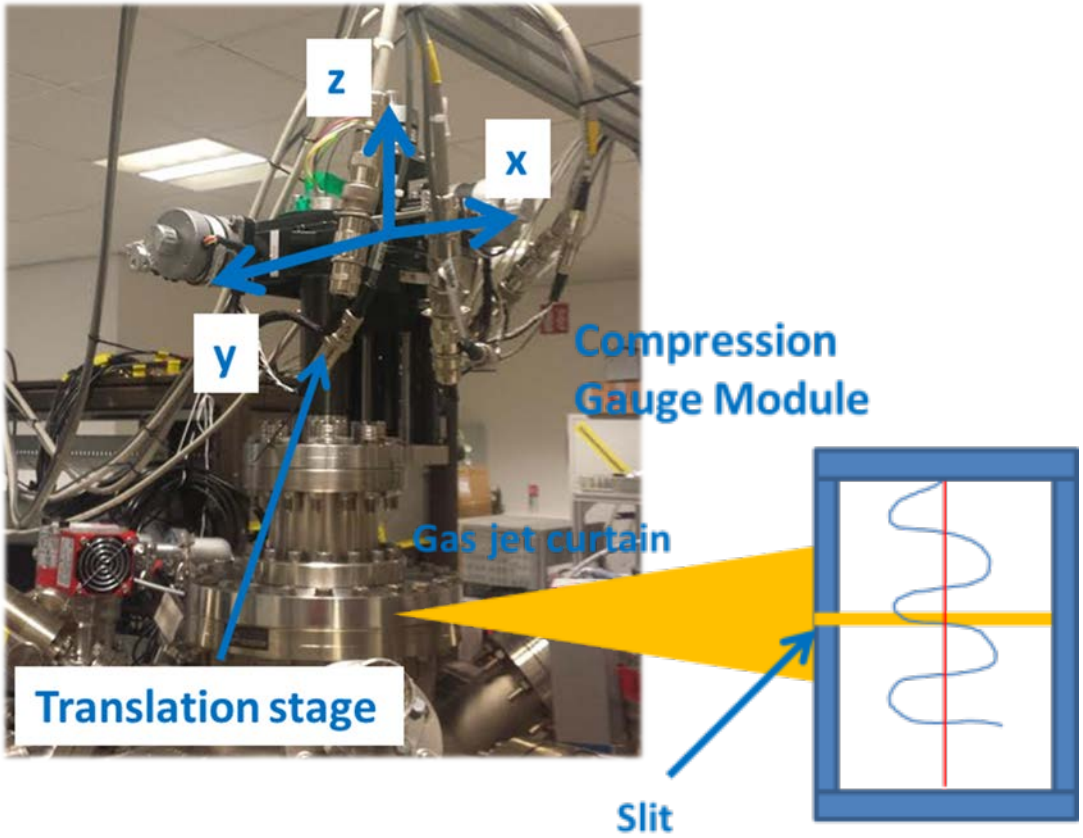


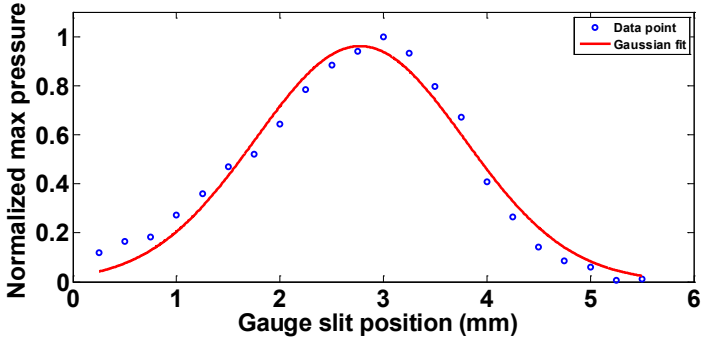
Unit(mm)	Experiment	Simulation
σ_x	0.56 ± 0.02	0.57
σ_y	0.53 ± 0.03	0.61
σ_x (residual gas)	1.52 ± 0.07	1.23

V. Tzoganis, et al., Phys Rev AB 20, 062801 (2017)

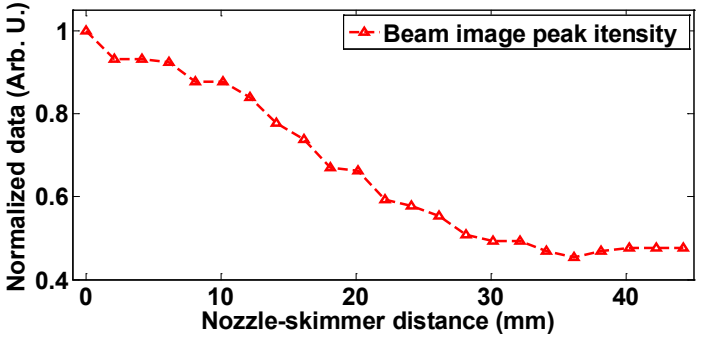
Jet Studies

- Apply 3D movable ion gauge to scan through jet





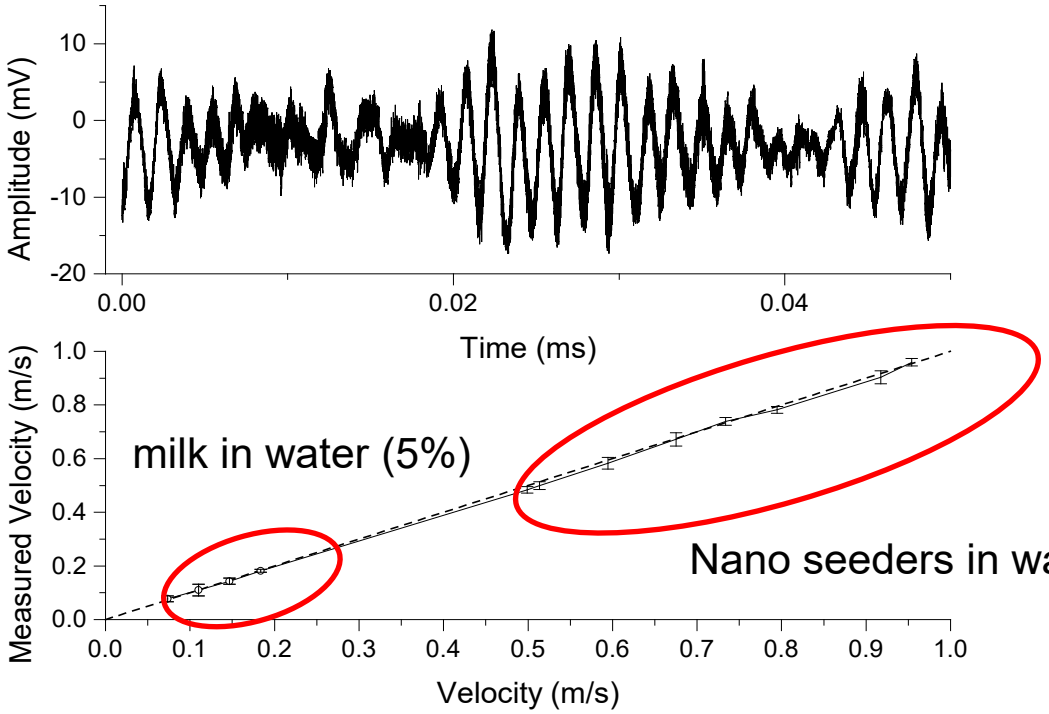
Vertical scan – yields profile



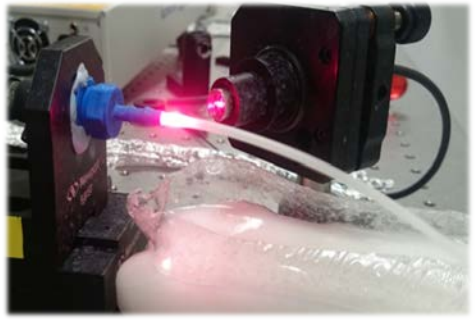
Identify Mach disk location

V. Tzoganis, et al., Phys Rev AB 20, 062801 (2017)

Laser Velocimetry



- Successfully tested with solids and fluids *(nano-particles seeding)*
- Improved resolution and max. limits by factor 10.



A. Alexandrova, et al.,
Optical Engineering (2015)
Nucl. Instr. Meth. A. (2016)

Absolute Current Measurement

Superconducting QUantum Interference Device

- Most sensitive magnetic flux detector,

The working principle makes use of:

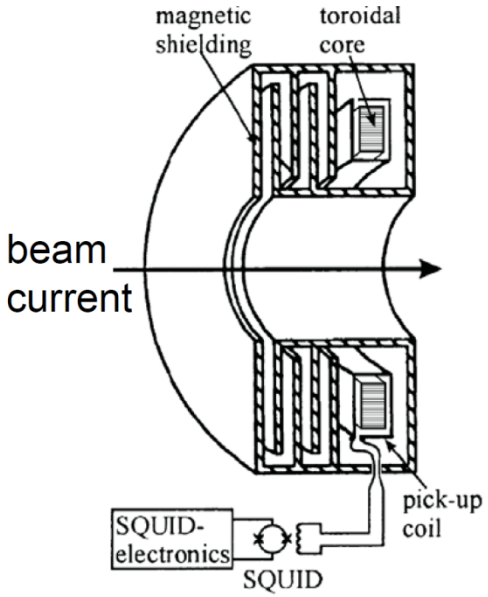
- Superconductivity,
- Flux quantization in SC rings,
- Josephson effect.

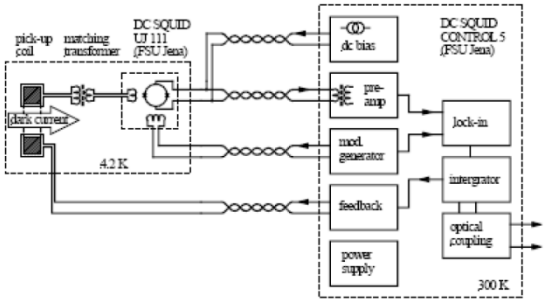
A SQUID consists of a SC ring with one or two weak links (*Josephson tunnel junctions*).

Measurement Principle

- Couple to azimuthal magnetic field,
- Screening current induced in SC coil with ferromagnetic core,
- DC SQUID for sensitive detection of coil magnetic field,
- Strong shielding against magnetic noise is key !

(14 ring cavities give 200 db shielding factor)





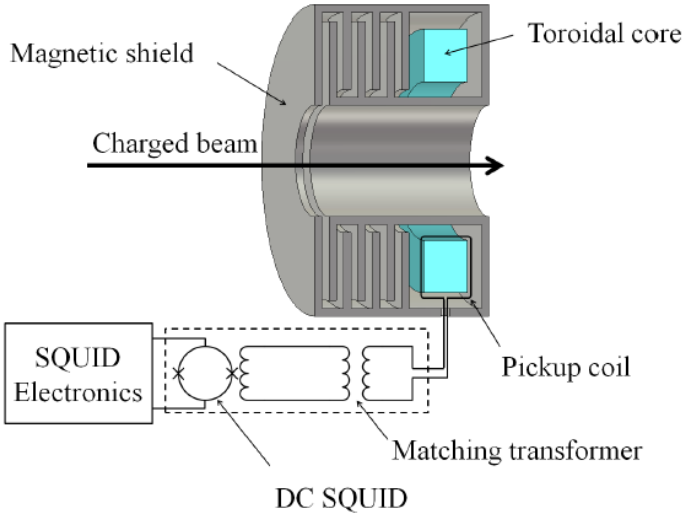
M. Fernandes, et al., Proc. IBIC (2015)
M. Fernandes, et al., Supercond. Sci. Technol. 30 (2017) 015001

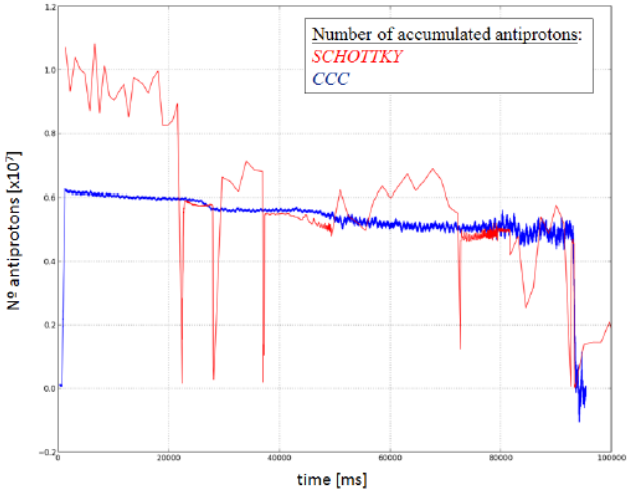
M. Schwickert

Cryogenic Current Comparator

- Absolute (!) current measurements with nA (!) resolution of bunched (!) beams.

TH2AB3

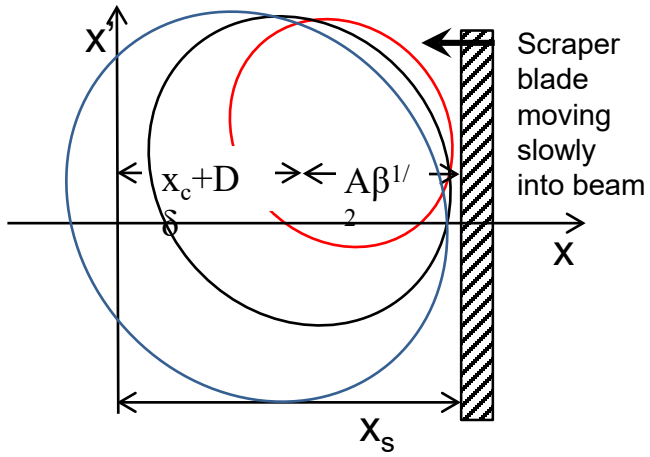




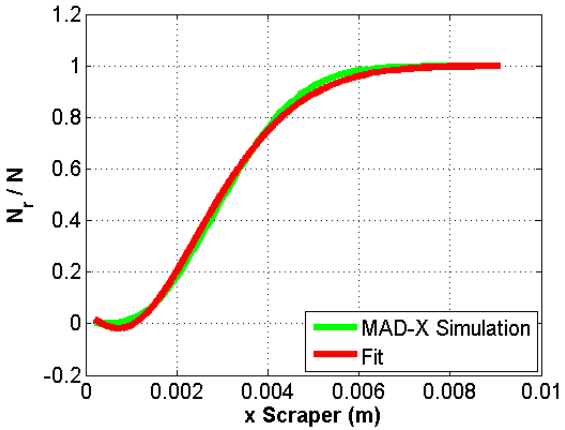
M. Fernandes, et al., Proc. IBIC (2015)
M. Fernandes, et al., Supercond. Sci. Technol. 30 (2017) 015001

Emittance Measurement

- Emittance measurements using a scraper
- Only emittance measurement technique @ ELENA
- Challenges: Effect of finite dispersion, systematic errors (diffusion, fast scraper)
- Custom codes for realistic simulation.



Being implemented and optimized as part of ELENA commissioning.



Ongoing developments

- Ultra-thin diamond detectors for position, profile and intensity measurements;
- Cryo detectors for detection of (down to) single particles;
- Optical diagnostics using DMD technology (profile, emittance);
- Liquid targets for beam tracking;
- CCC improvements;
- Enhancement of AEgIS test stand capabilities.

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Conclusion

- Combination of low energy and low intensity makes detailed diagnostics demanding;
- Demonstrated performance of all devices;
- (rather) basic instrumentation for initial operation, however, complex setups for advanced diagnostics.

Thanks for your attention

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Quarterly newsletter for the (wider) antimatter research community

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