Low Energy Beam Diagnostics

Carsten P. Welsch

The Cockcroft Institute of Accelerator Science and Technology

University of Liverpool

DITANET Topical Workshop

"Low energy, low intensity beam diagnostics"
CERN Indico: 93294

Radioactive beams, slowed down beams, cryogenic rings and much more !

Outline

- What are the particular challenges ?
  - Example: Ultra-low energy storage ring (USR)
- Discussion of different instrumentation needs:
  - Beam current monitoring (basic),
  - Beam current monitoring (advanced),
  - Beam profile monitoring,
  - Focus: DITANET projects (posters !)
- Limitations, open questions.

The Cockcroft Institute of Accelerator Science and Technology

What‘s challenging (& interesting)?

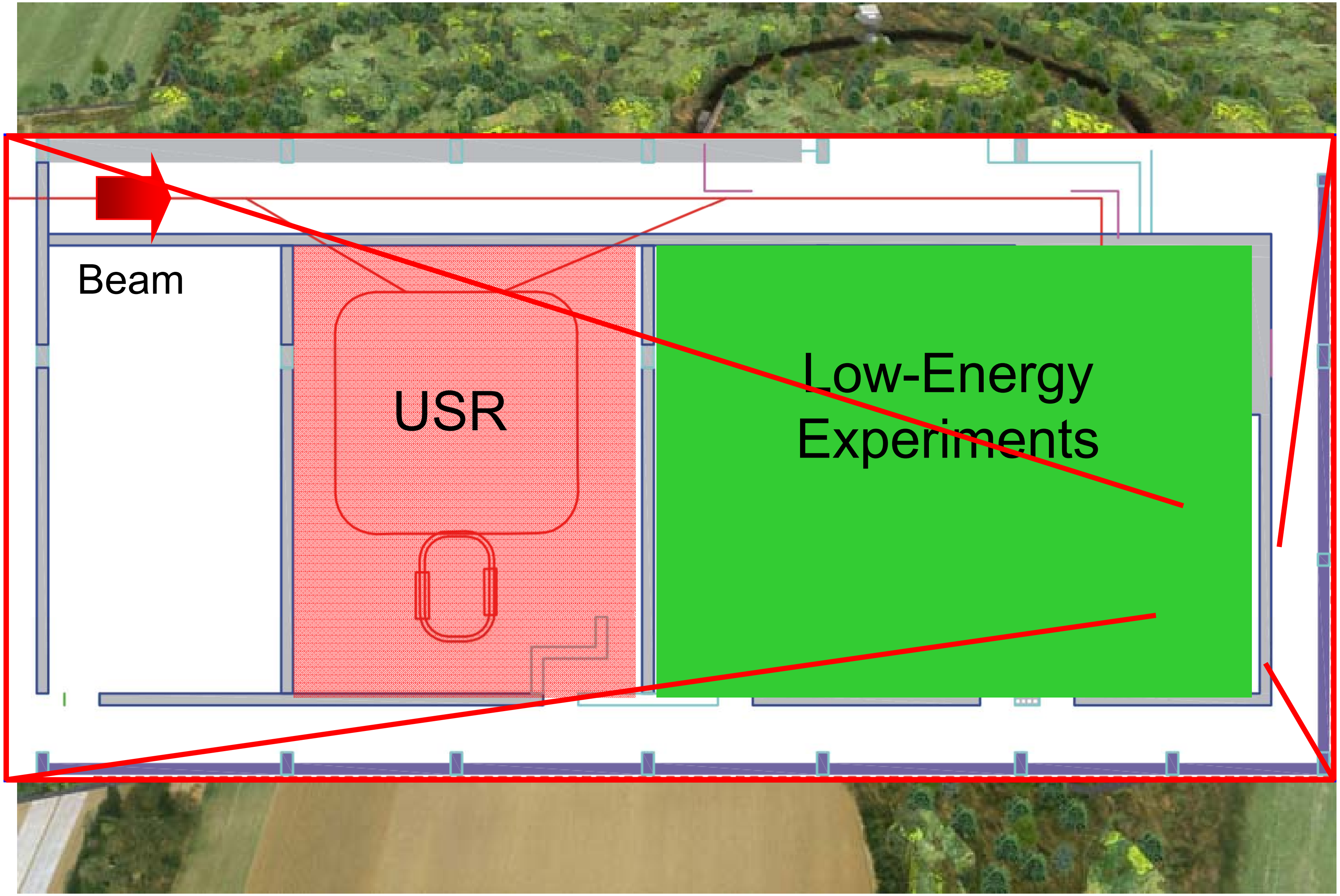
Low Intensity
=
Low signal levels

Low Energy
=
Insufficient Energy deposition

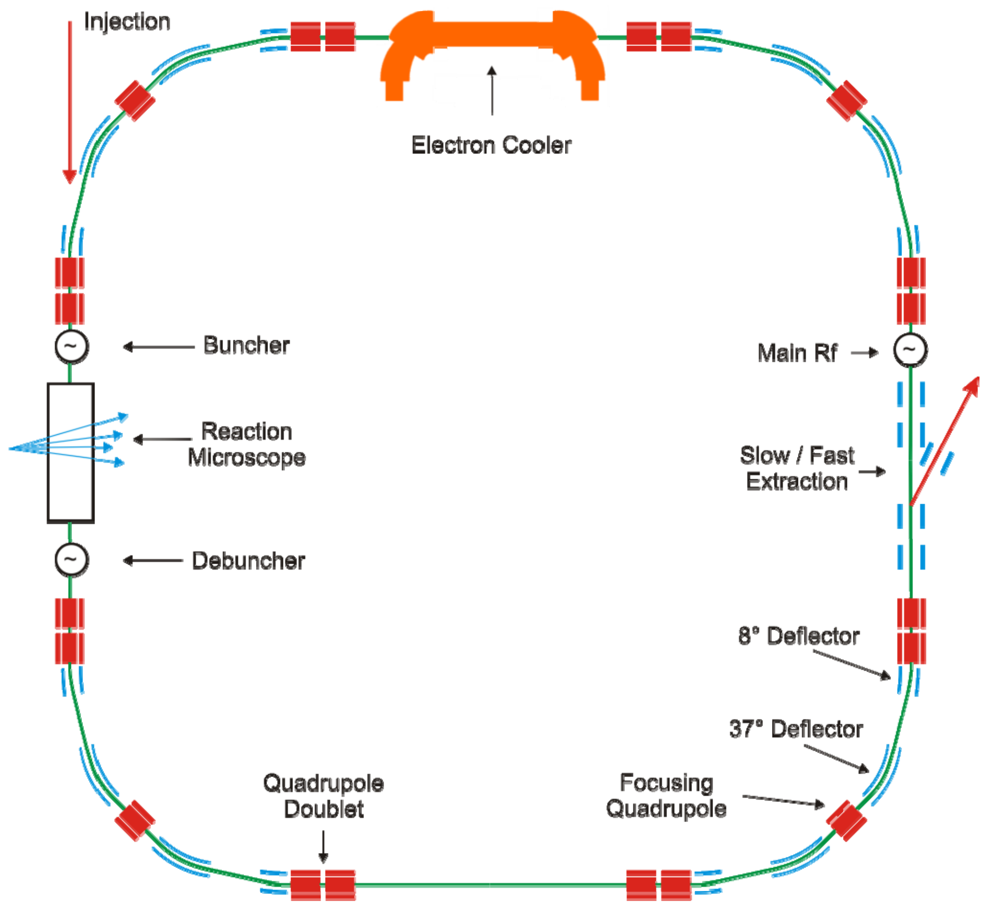
Strong impact from external sources

(fields, vibrations, etc.)

FLAIR @ Facility for Antiproton and Ion Research



Example: The USR



Energy	300 → 20 keV
β=v/c	0.025 → 0.006
f_{rev}	178 → 46 kHz
T_{rev}	5.6 μs → 21.8 μs
# ions	< 2×10^7
L_{bunch}	1 ns – DC beam
f_{RF}	1.78 MHz → 450 kHz
Charge per bunch	0.3 pC (@ 1/10 of intensity)
Extr. pbars (avg.)	5×10^5 – 10^6 pps

What do we need ?

- Basic instrumentation for machine commissioning
  - Position, current, profile (long./transv.)
  - Note: No antiprotons would be used !

- Basic instrumentation for machine operation
  - Same parameters, but with pbars

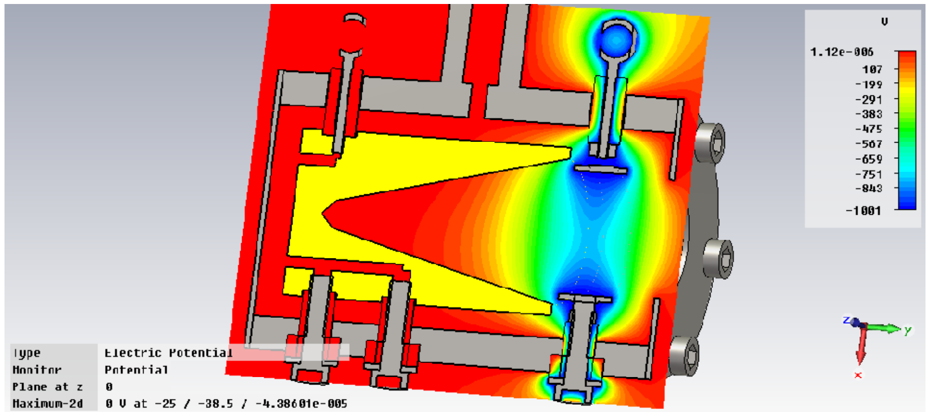
- Special diagnostics for machine operation
  - Least-invasive profile measurement

Beam Intensity

- Classic Solution: Faraday Cup

- Idea:
  - Stop beam,
  - Capture all charges,
  - Measure total charge.

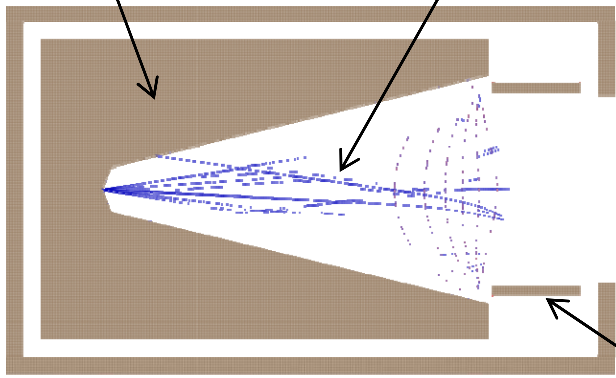
➡ Total intensity.

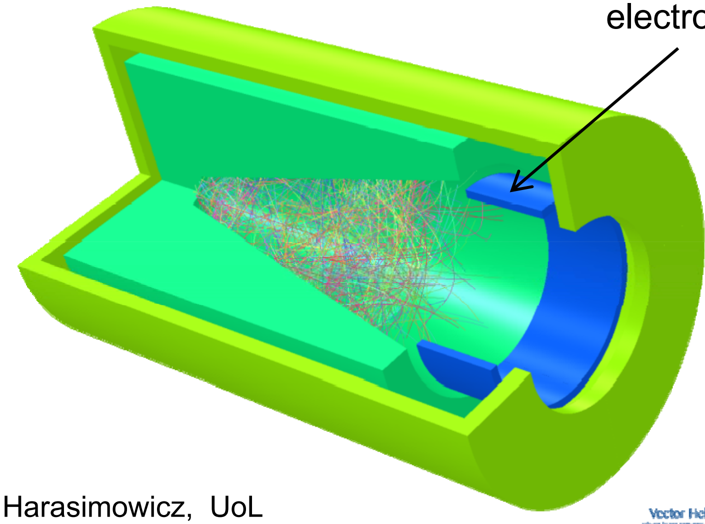


J. Harasimicz – poster today

Generic Layout of a Faraday Cup

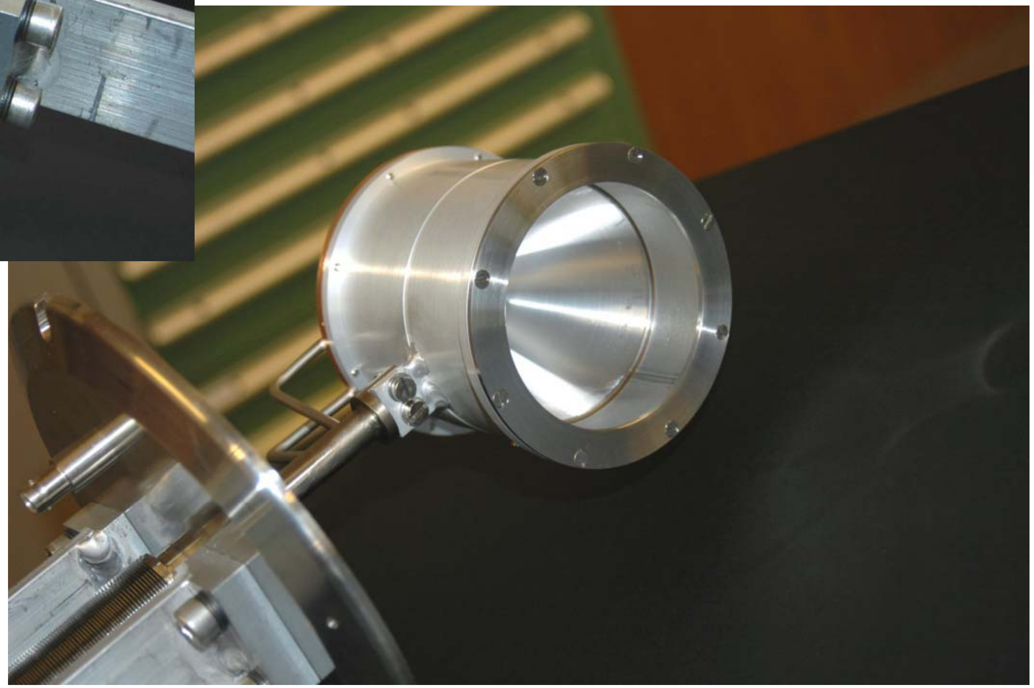
- Stop main beam in capture electrode,
- Secondary electrons are generated,
- Repelling electrode pushes secondary electrons back onto the electrode,
- Very low intensities can be measured, USR: fA !
- Limitations:
  - Beam energy ?
  - Sensitivity/noise ?
  - Antimatter ?





J. Harasimowicz, UoL
DITANET trainee

Faraday Cup with Water Cooling

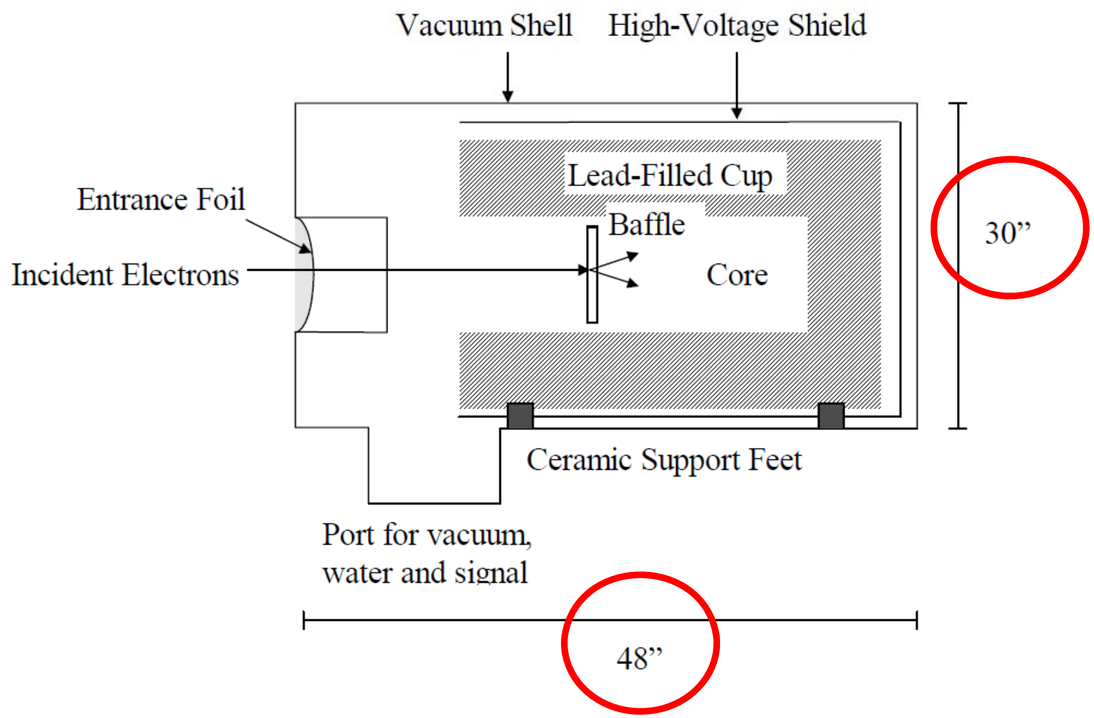


For higher intensities
water cooling may be needed

Source: U. Raich, CERN.

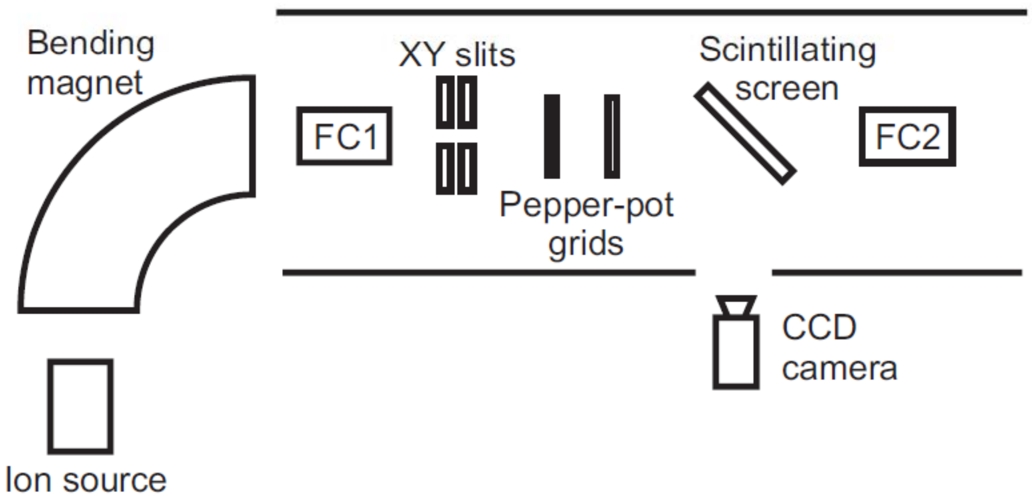
Faraday Cup: High Power Beams

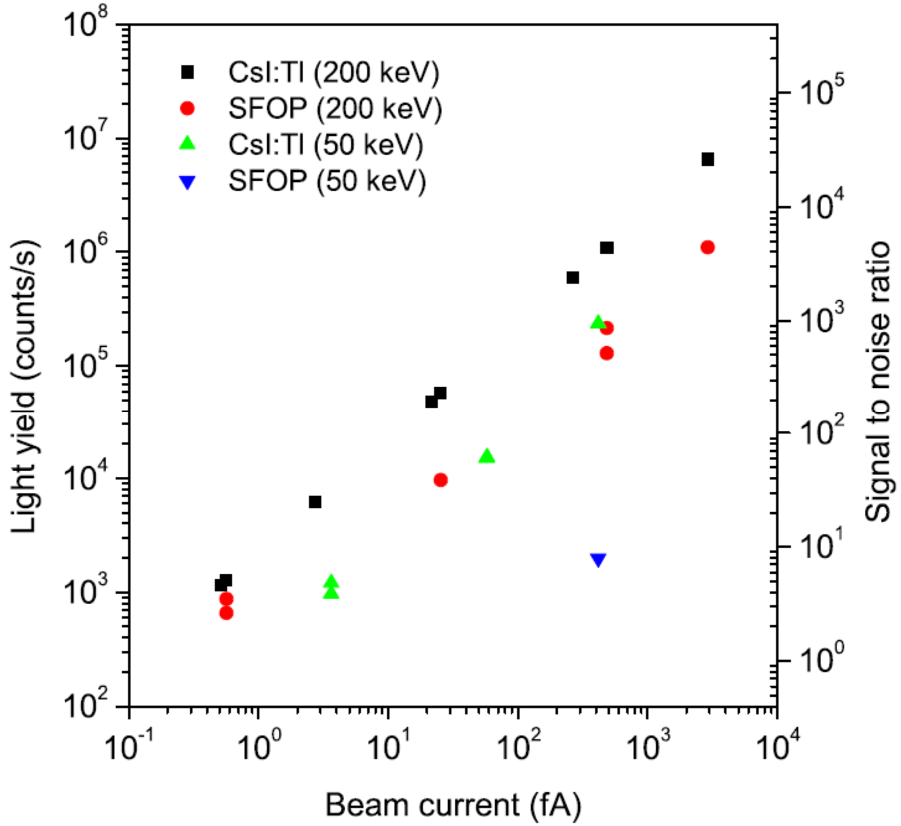
- 1 GeV @ 50 μA
- Need to dissipate 50 kW heat load !
- Error source ?
  - Entrance foil: Not all charges can be captured.



USR: Screen Studies

- Realized in close collaboration with INFN-LNS



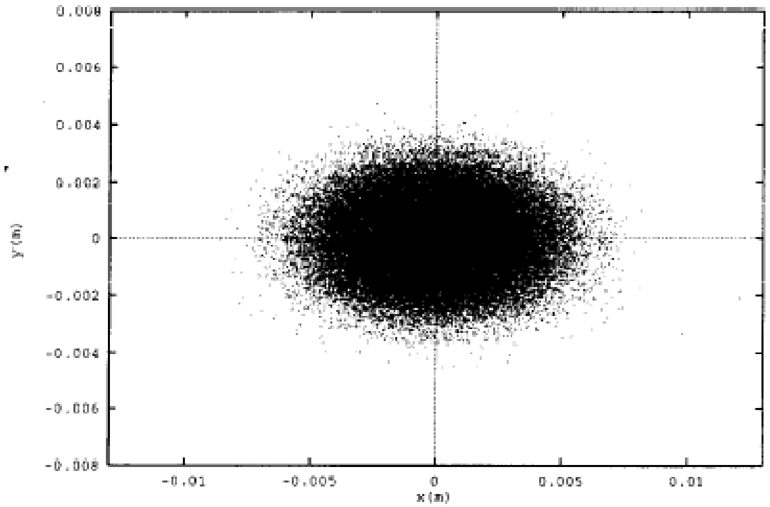


Tutorial !

J. Harasimowicz et al.,
Rev. Sci. Instr. 81 (10), 2010

Beam Halo Monitoring

Definition: What is 'Halo' ?

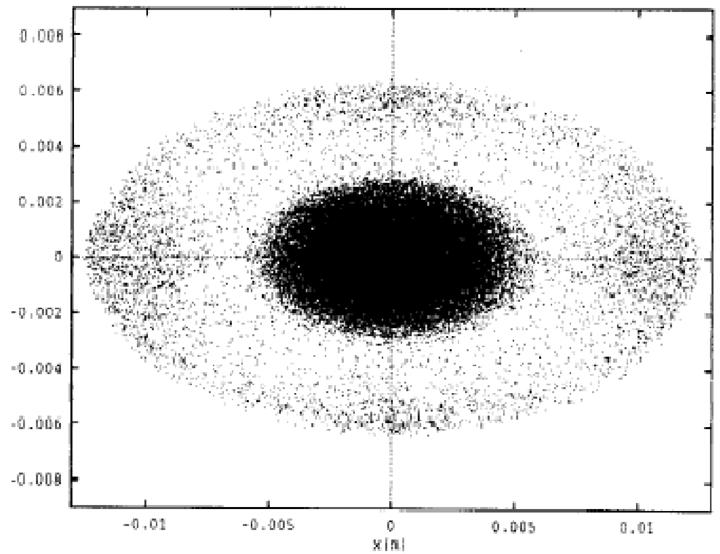


General definition difficult to make:

Accelerator physicists

Instrumentation specialists

Low density / difficult to measure

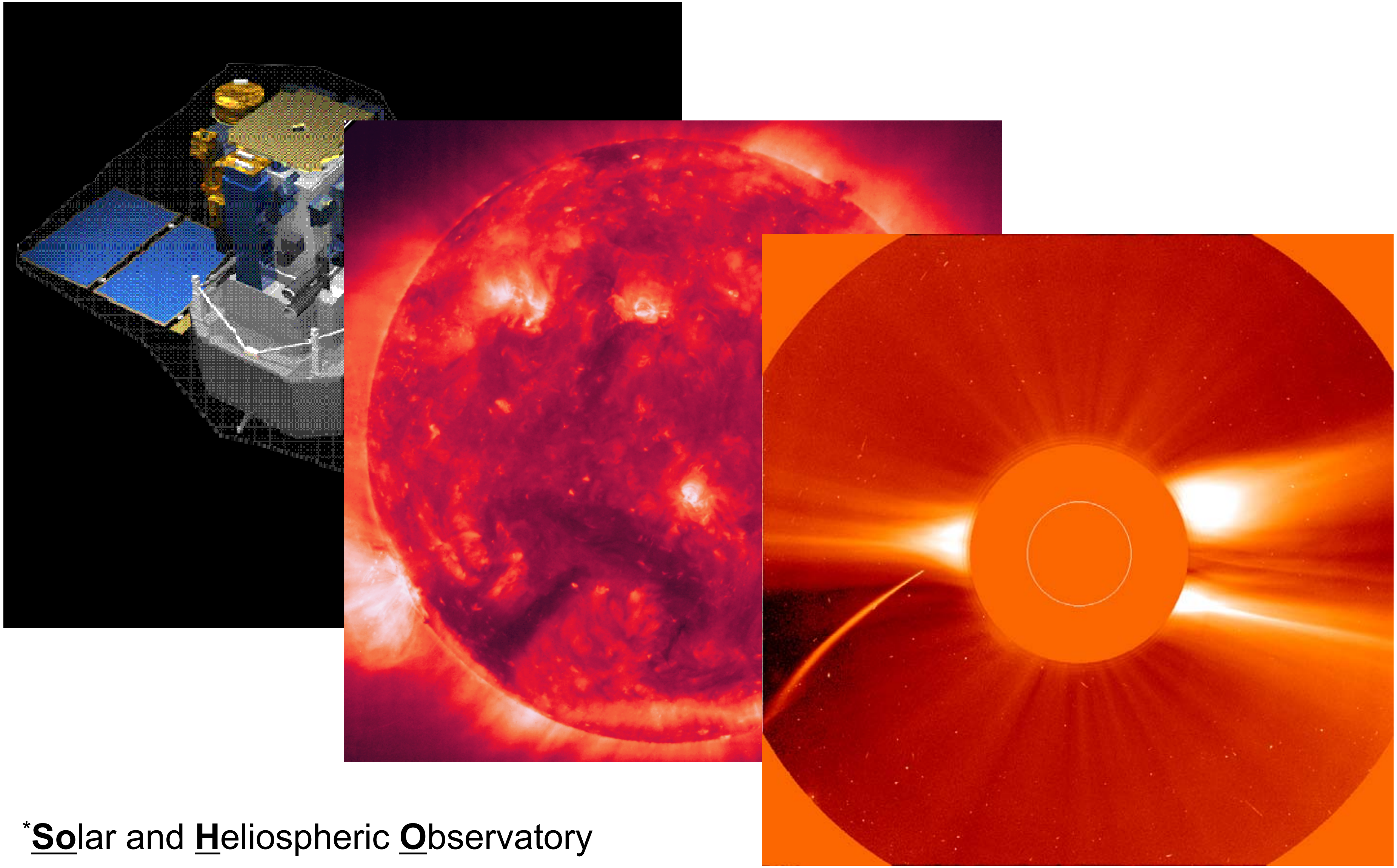


Problem

- Very high intensity in core:
  - Saturates pixels
  - Signal overflow to neighbouring pixels
  - Tail regions are being modified, wrong measurement.
- Concentrate measurement on tail region ONLY as this is the interesting part !

- How ??

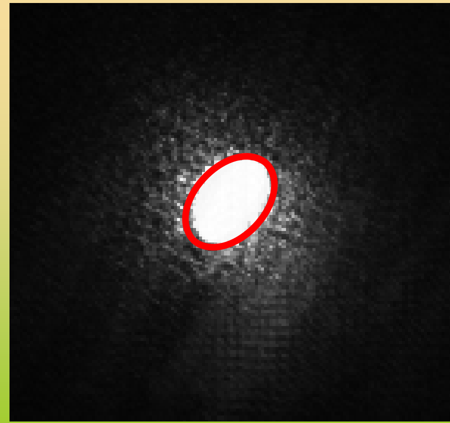
SOHO



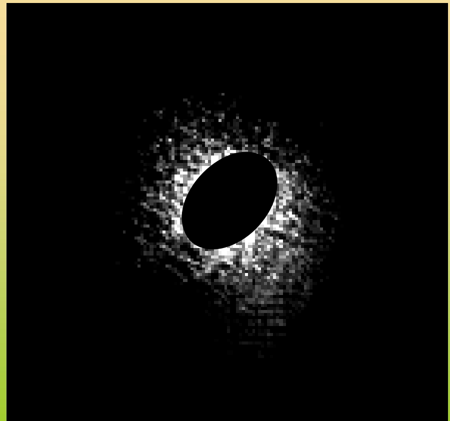
*<u>**So**</u>lar and <u>**H**</u>eliospheric <u>**O**</u>bservatory

Halo Monitoring: Core Masking

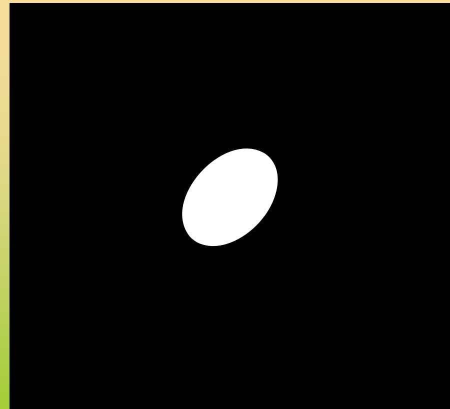
(1) Aquire profile



(2) Define core



(4) Re-Measure

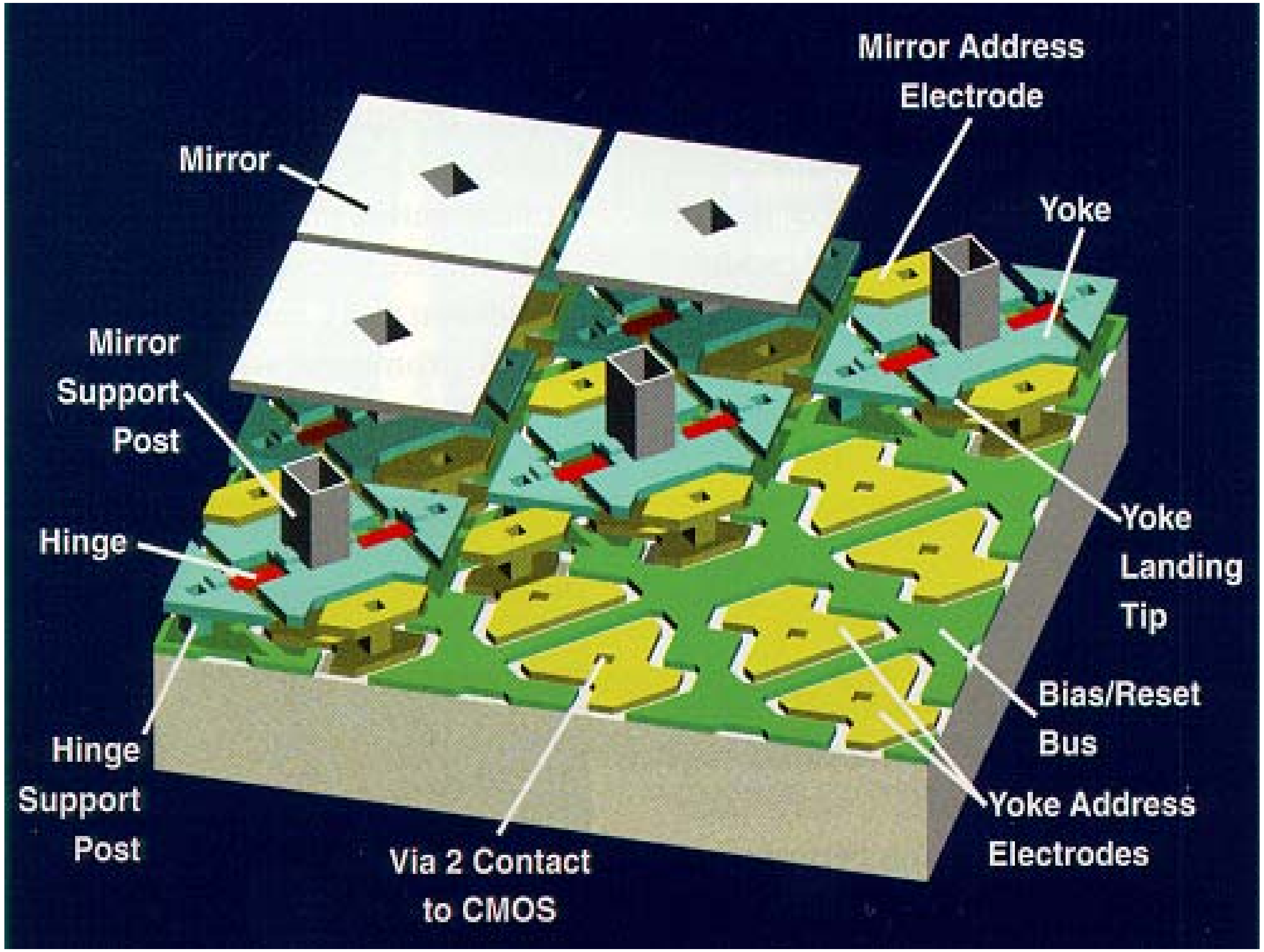


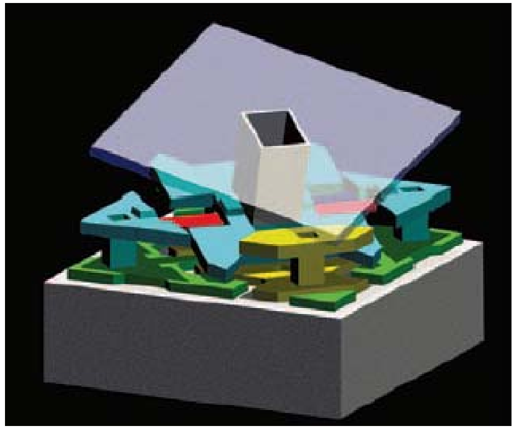
(3) Generate mask

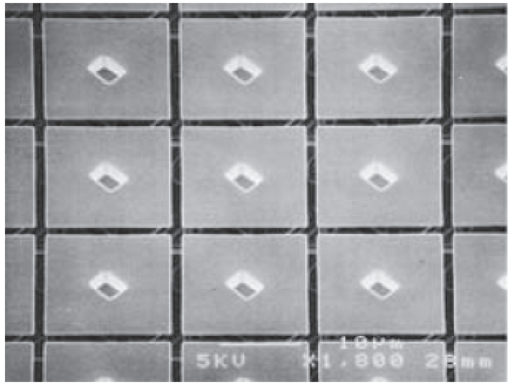
C.P. Welsch et al.,
Proc. SPIE (2007)

J. Egberts, et al.,
JINST **5** P04010 (2010)

Basis: Micro Mirror Array (TI)

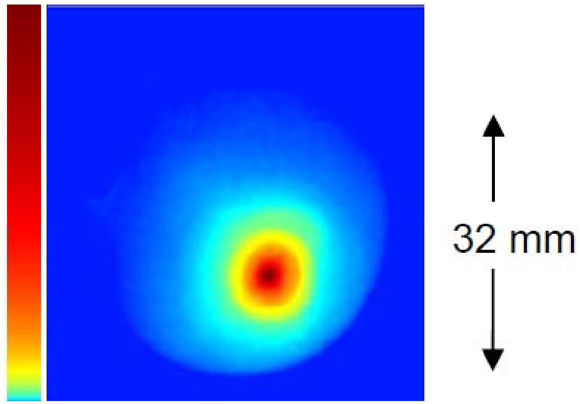






Measurements at UMER

- 10 keV e^- beam, Phosphor screen
- iCCD camera
- Verification of earlier lab measurements
- Reconstruction of beam profile with DR of 10^5
- Effects from diffraction on DMA are minimal



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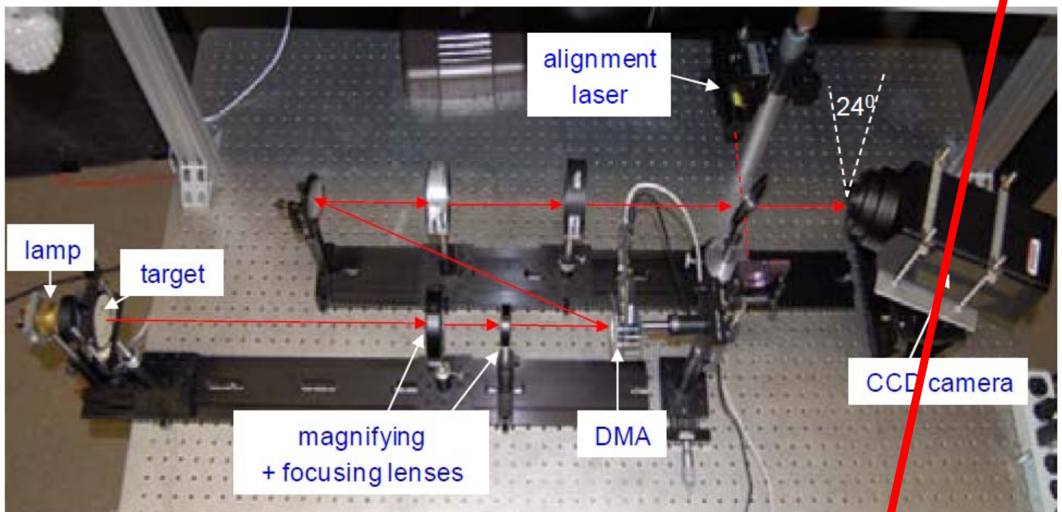


R. Fiorito, et al., Proc. BIW
C.P. Welsch et al. IPAC 2010

Cryogenic Current Comparator (CCC)

Absolute Current Measurement

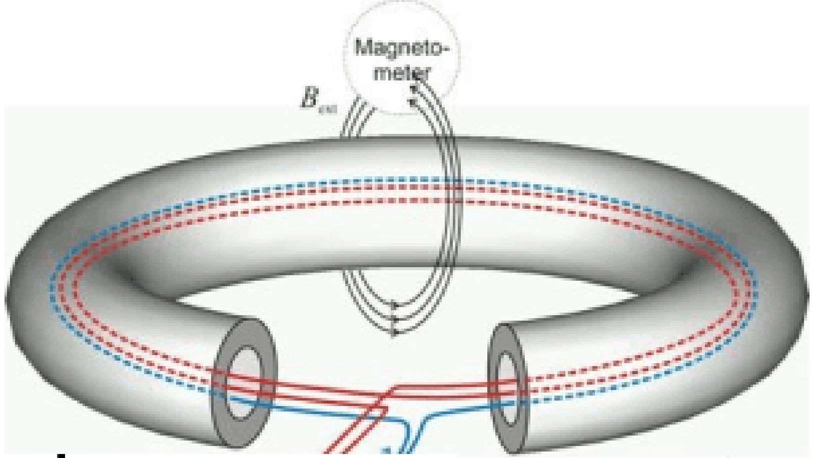
- Highly desirable !
  - Callibration of other monitors,
  - Direct link to experimental output.

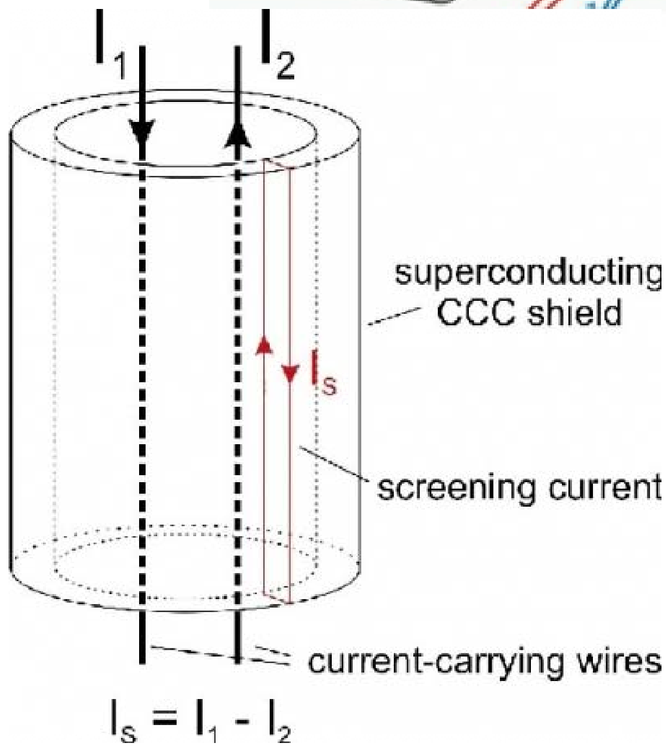
- Challenges:
  - Signal levels VERY low,
  - Signal/noise critical,
  - Isolation against vibrations, rf noise
  - ...many more...

Cryogenic Current Comparator

The CCC consists of:

- SC pickup coil,
- High efficient SC shield,
- High performance SQUID measurement system.





Harvey, Rev. Sci. Instrum. **43** (1972)
Poster: Febin Kurian

SQUID

Superconducting QUantum Interference Device

- Most sensitive magnetic flux detector,

The working principle makes use of:

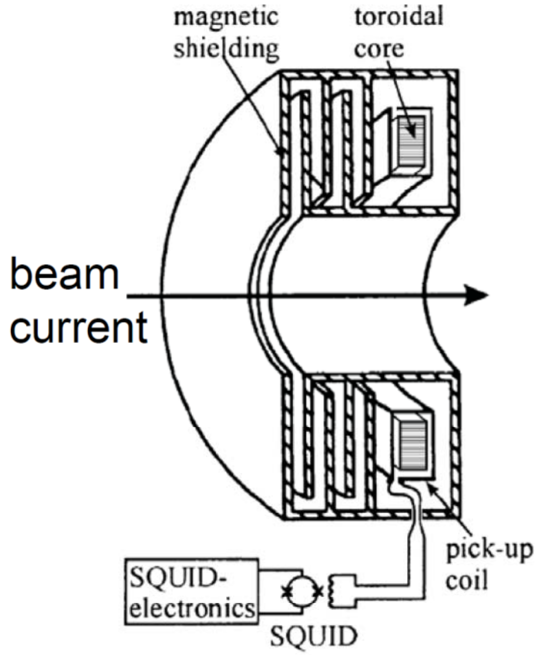
- Superconductivity,
- Flux quantization in SC rings,
- Josephson effect.

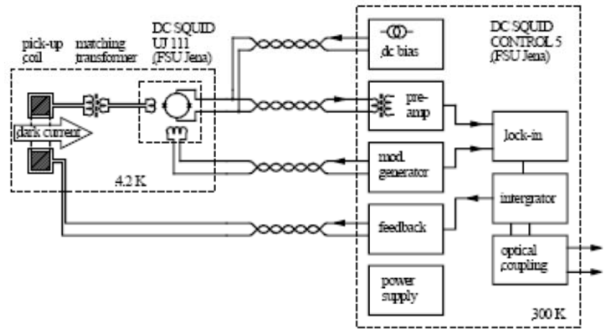
A SQUID consists of a SC ring with one or two weak links (*Josephson tunnel junctions*).

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)

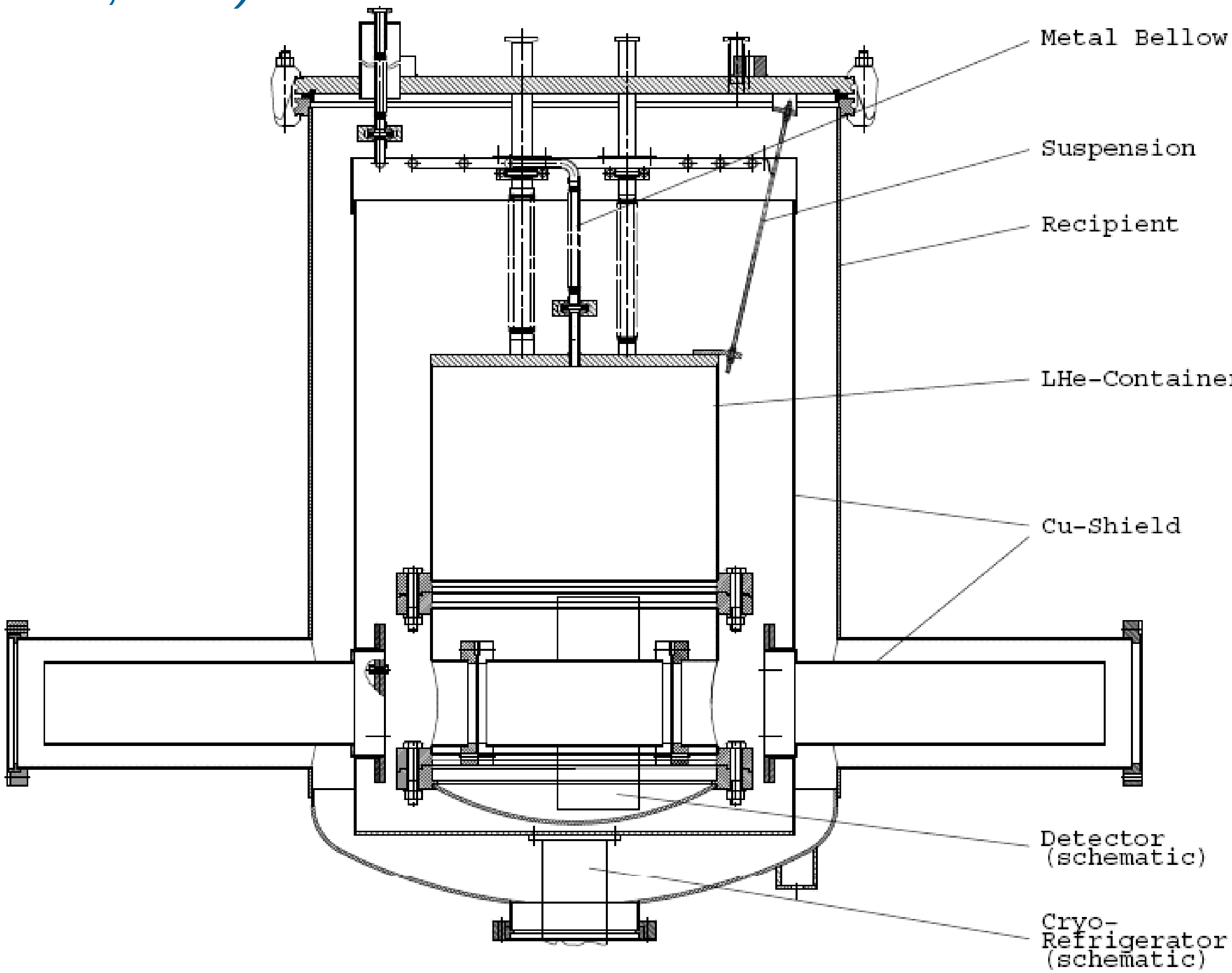




M. Schwickert

Prototype @ GSI

- GSI prototype *(A. Peters, 1997)*



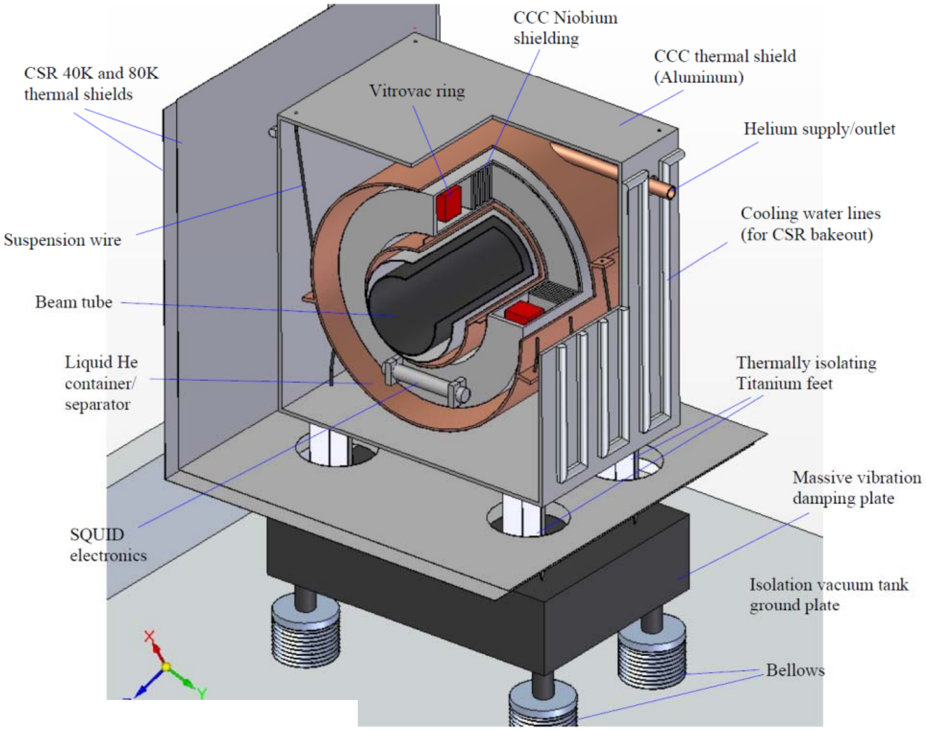
Resolution:

250 pA/√Hz

→ **8 nA (1 kHz readout)**

→ **2×10^9 U^{28+}/s**

More recently...



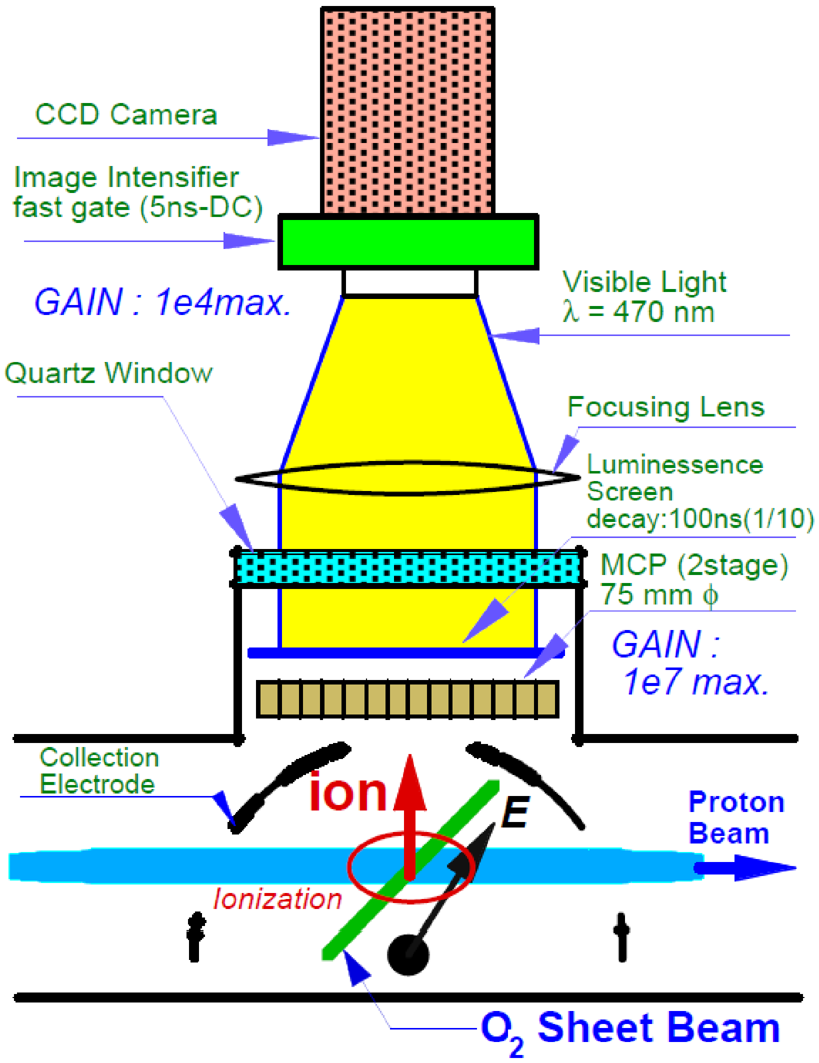
Poster: Febin Kurian

2D (least destructive)

profile measurements

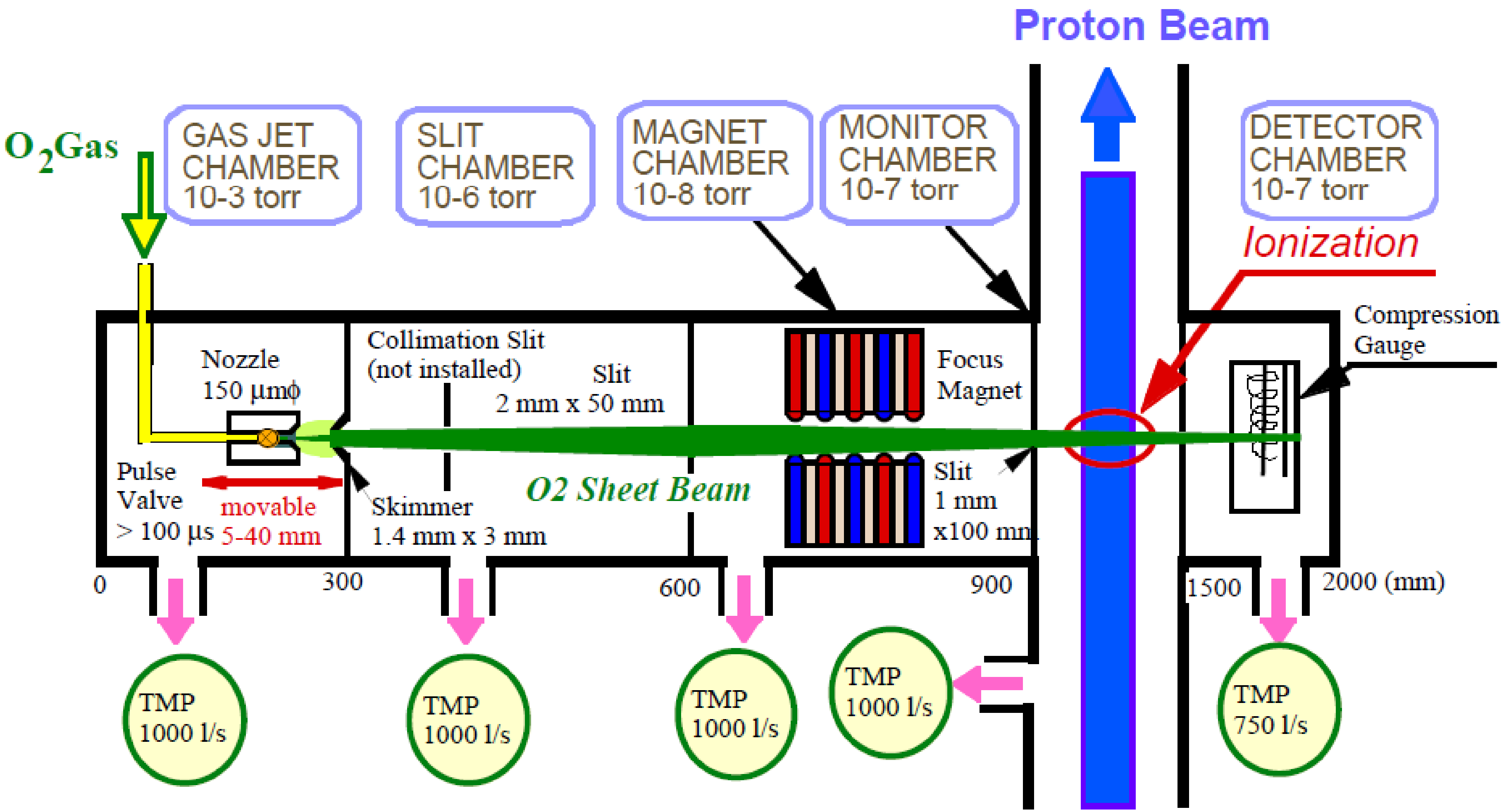
The idea: Gas Sheet Monitor

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



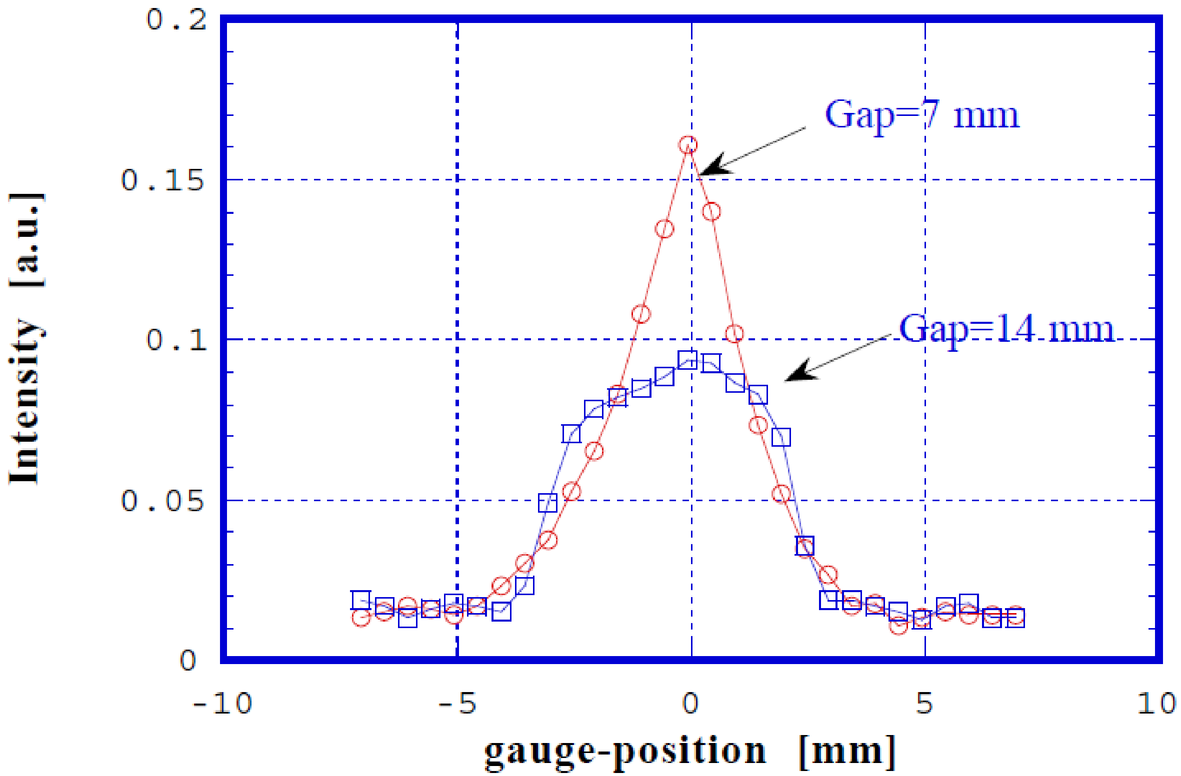
Y. Hashimoto et al., Proc. Part. Acc. Conf., Chicago (2001)

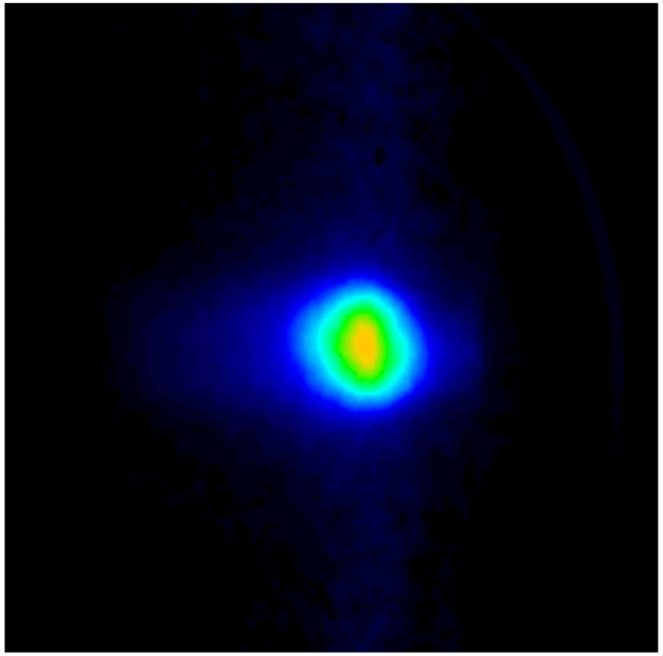
How to Generate the Jet ?

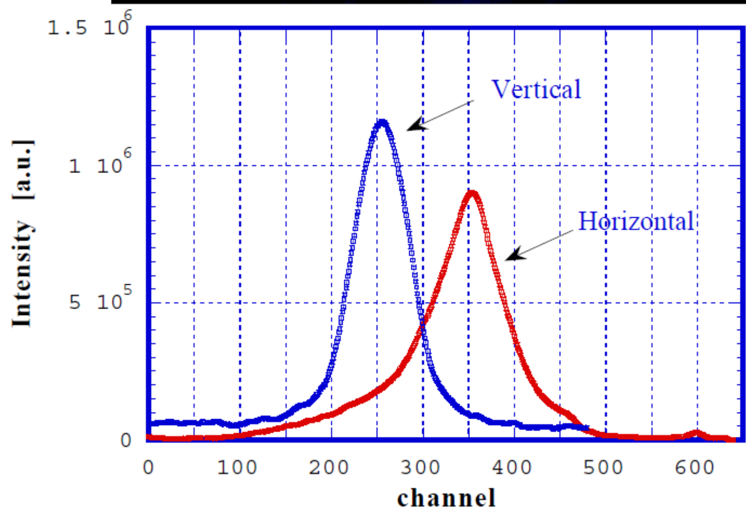


Y. Hashimoto et al., Proc. Part. Acc. Conf., Chicago (2001)

Experimental Data



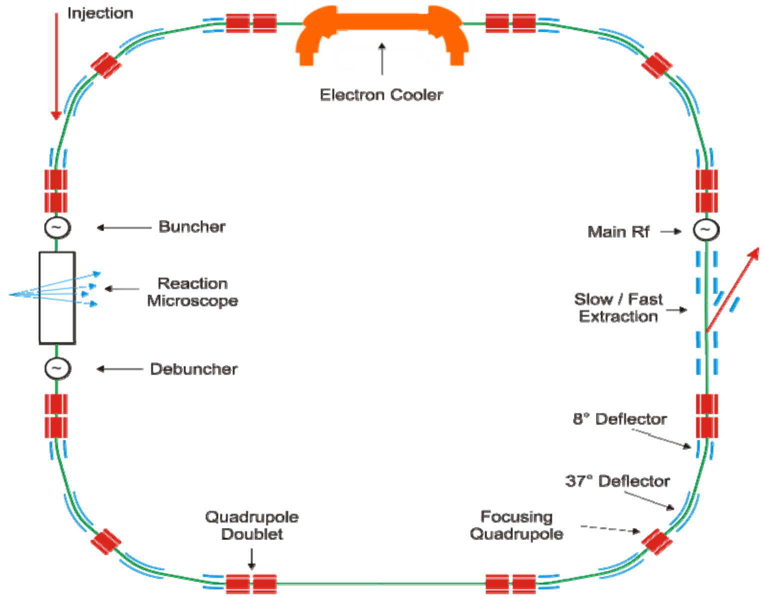




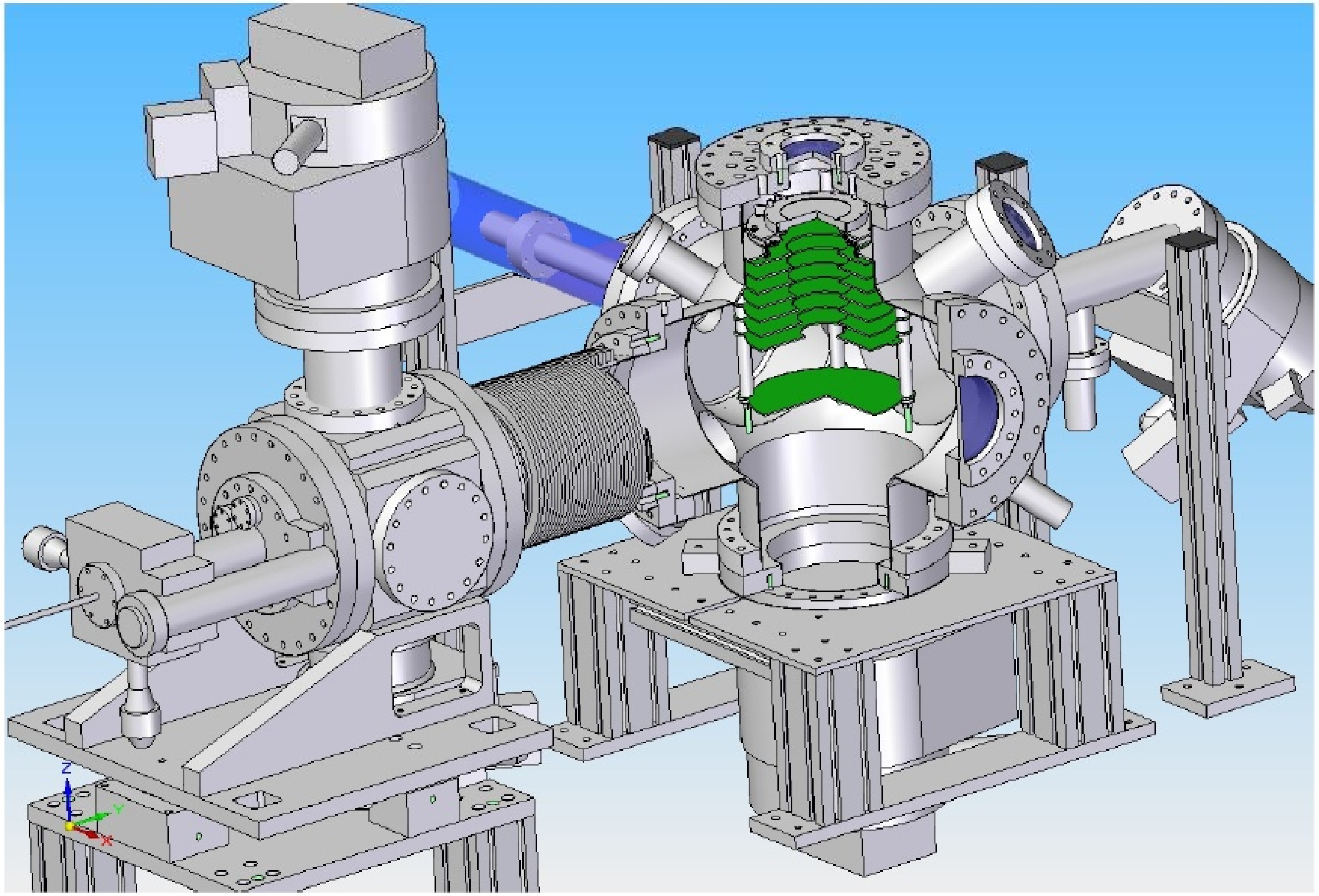
Y. Hashimoto et al., Proc. Part. Acc. Conf., Chicago (2001)

Is this ready for low energies ?

- Designed for 10 MeV proton beams,
- Magnetic field B > 2 T,
- Pressure: 10^{-7} mbar
  - » No !!!

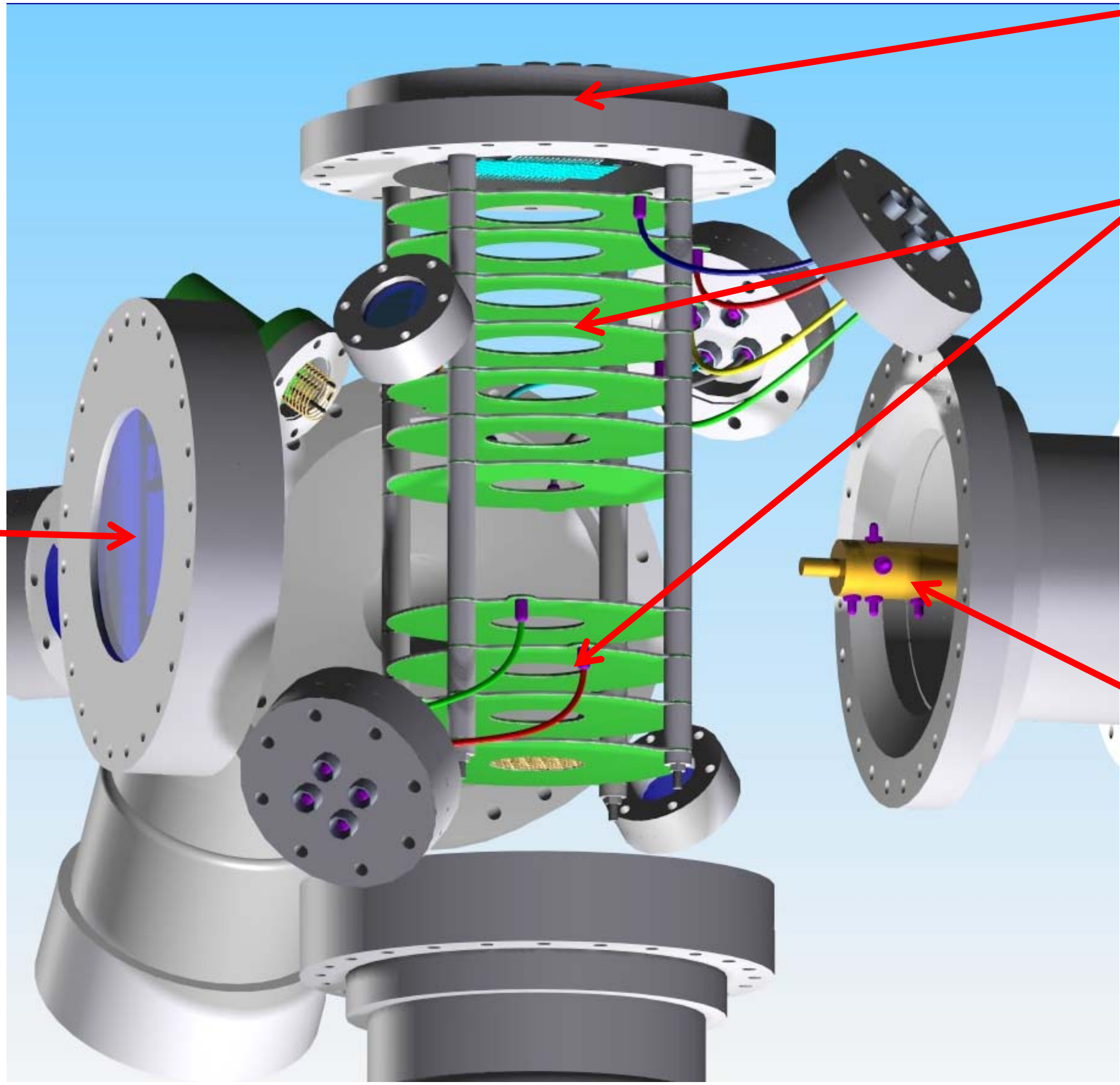


Curtain Jet w/o Magnetic Field



M. Putignano et al., Hyperfine Interact. (2009)
M. Putignano et al., Proc. BIW and IPAC (2010)

Zoom: Main chamber



MCP

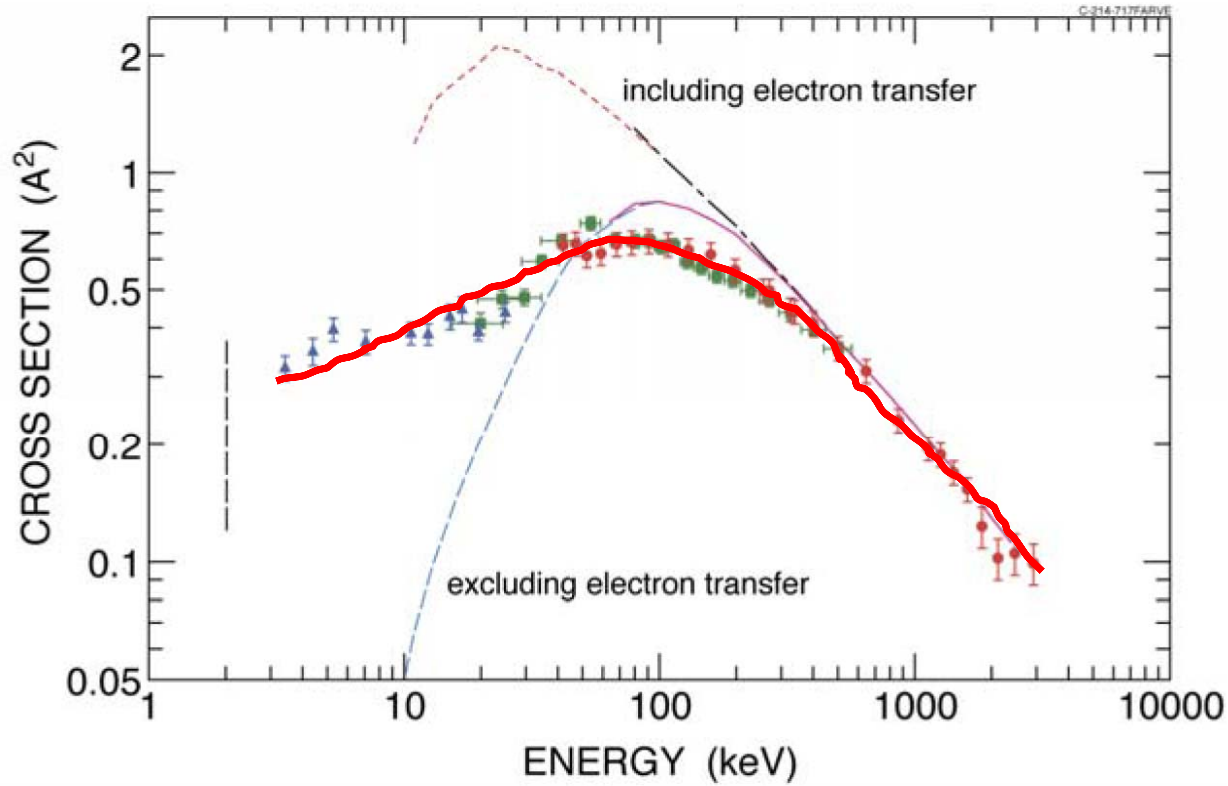
Extraction electrodes

Phosphor coated window

e^- gun

Ionization Cross Sections

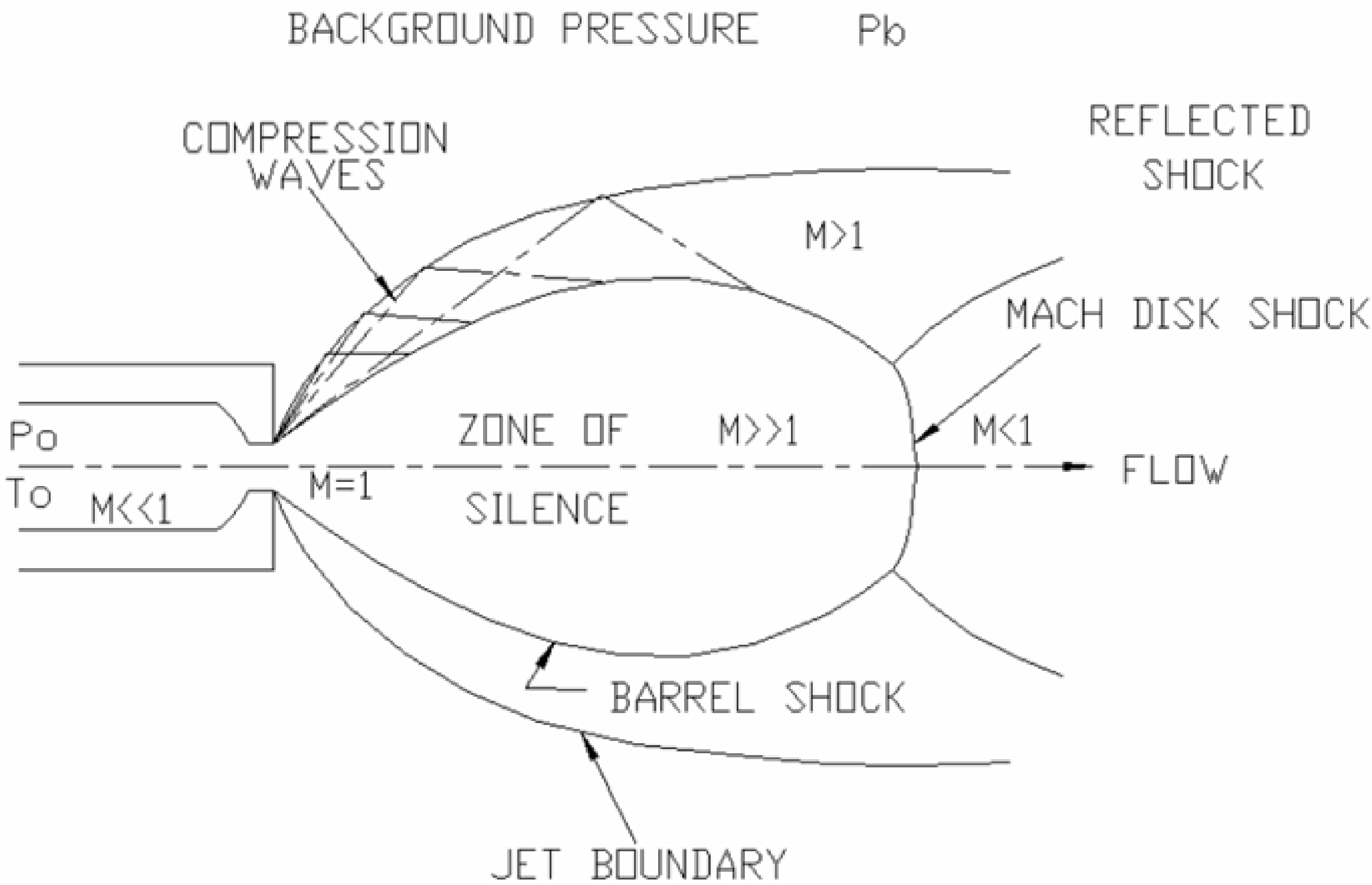
- Single ionization of helium by antiproton impact



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

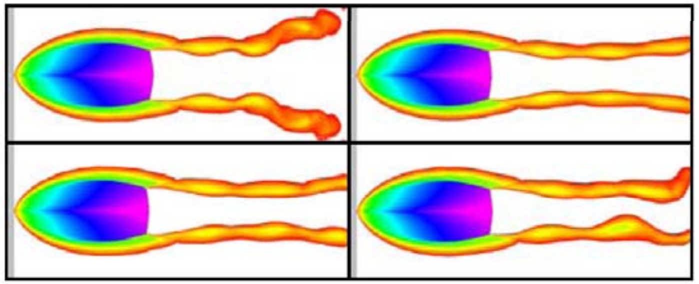
H. Knudsen, Hyperfine Interactions **109** (1997) 133–143
H. Knudsen, Journal of Physics:Conf. Series **194** (2009) 012040

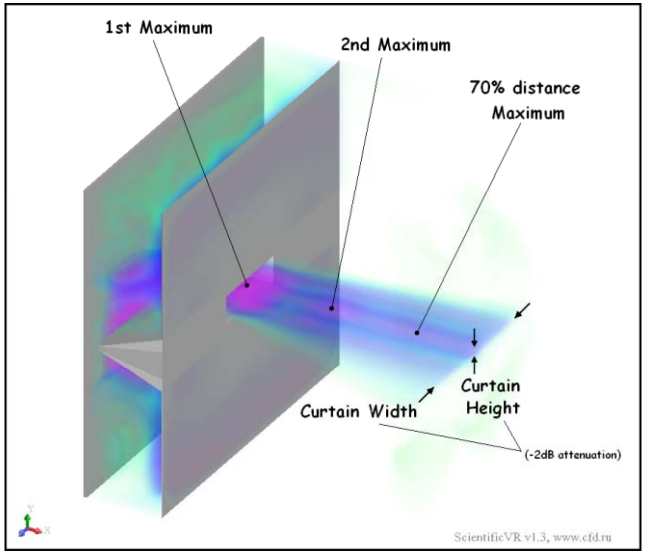
Jet Generation



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

Numerical Investigations with GDT

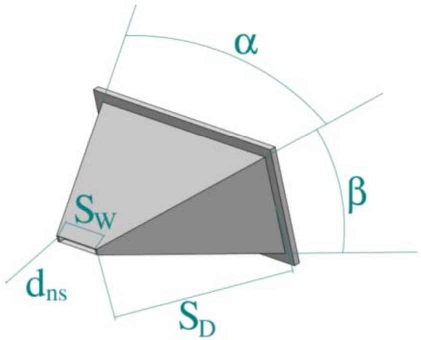




M. Putignano et al.,
Proc. DIPAC 2009, BIW 2010

- System optimization and trends analysis

	Mach N.	D	W
α	↘	↘	↗
β	↘	⤴	→
SW	↘	↘	↗
SD	(α)	⤴	⤵
Dist	⤵	(α, β)	(α, β)

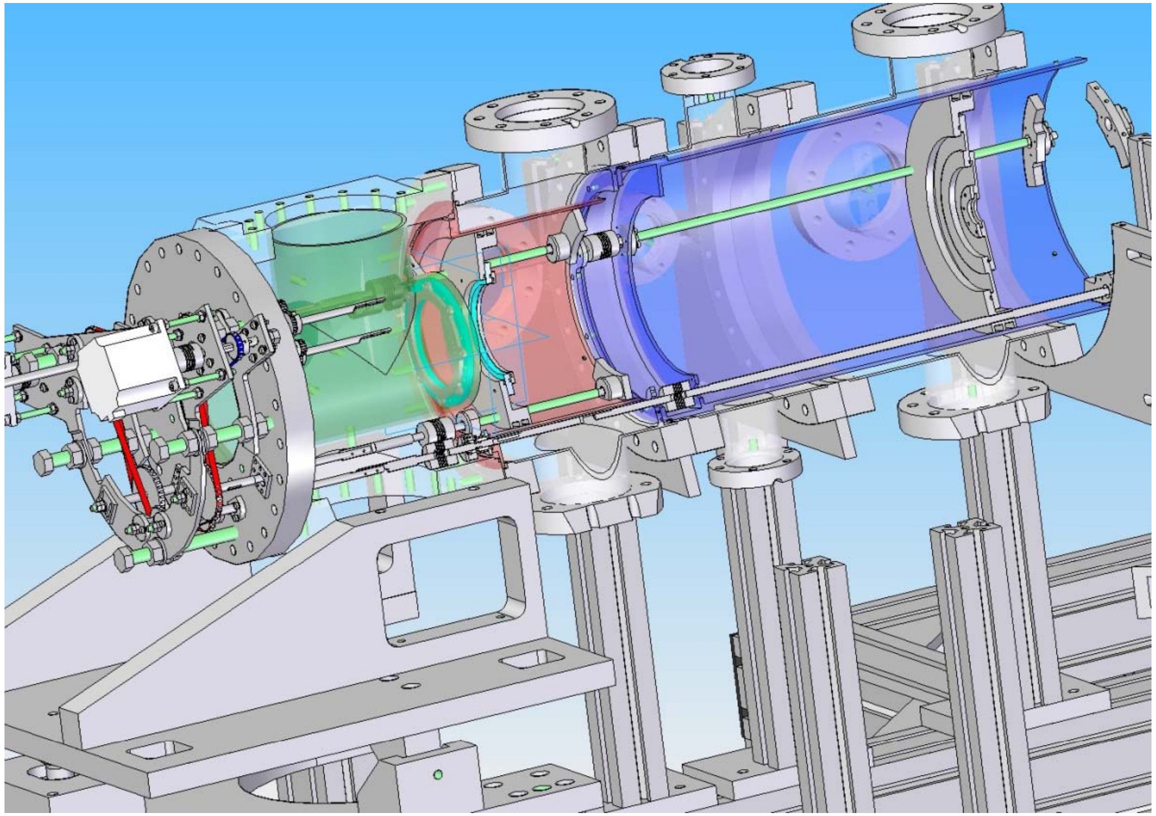


Ongoing: Flexible nozzle/skimmer system for benchmarking GDT.

Poster

Benchmarking of Simulations

- Movable skimmer, summer 2011.



Summary

- Low energy beam diagnostics pushes technology and techniques to the limits,
- Established instrumentation needs to be „re-developed“ to provide required resolution,
- International effort, close collaboration is key.

- Full details: See Workshop Homepage

CERN Indico: 93294

Thank you for your attention !!