Beam Gas Jet Fluorescence Monitor

Ray Veness

With thanks to:

E.Barrios, N.Chritin, R.Jones, R.Kersavan, P.Magagnin, G.Schneider, H.Schmickler @CERN

E.Martin, V.Tzoganis, C.Welsch, H.Zhang @Cockcroft Institute

P.Forck, S.Udrea @GSI

Contents

The Challenge for HL-LHC

- Co-linear beam profile measurements for HL-LHC
  - Proposed devices for active halo control with a hollow e-lens and long range beam-beam compensation both include a high intensity e- beam (upto 10 Amps) close to, or coaxial with the high energy LHC p+ beam.
  - These will need a non-invasive instrument for optimising the transverse profile (overlap) of one beam relative to the other
  - As the e- beam will need to be contained by a (superconducting) solenoid, this overlap monitor will need to operate in a strong solenoidal field, either in the main solenoid (2~4 T) or in the fringe field
  - The device would need to be installed in the LHC, integrated in some way in the SC solenoid

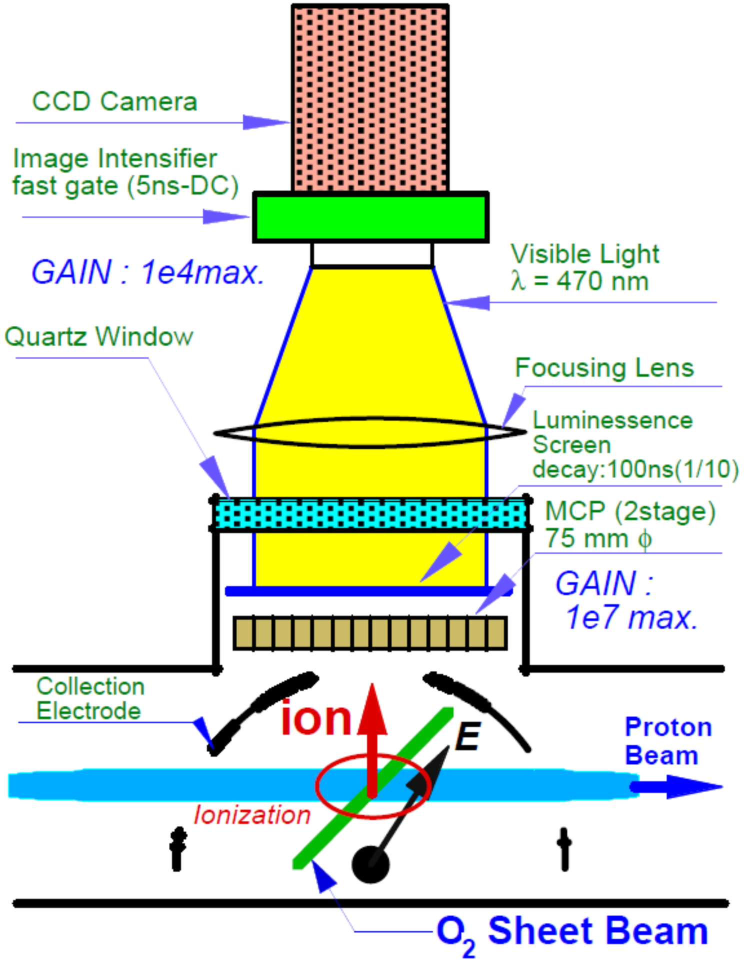
Summary of Gas Jet Collaboration

- Why?
  - Only viable non-invasive technique identified for the characterisation of high current electron beams in the presence of high intensity and energy proton beams
  - Important for development of electron lens components for hollow e-lens and LRBB compensator
- Objectives
  - Demonstrate production of a high density neutral gas sheet
  - Demonstrate detection using luminescence
  - Produce a system capable of equipping an e-lens test stand
  - Design, produce and test a prototype system that could be installed in the LHC
  - Collaboration partners
    - HL-LHC WP13 and UK collaboration (WP3 - Diagnostics)
      - Agreement in place for 50/50 funding of HL-LHC activities
      - Task 2 : Gas Jet Based Beam Monitor for HL-LHC
        - University of Liverpool & Cockcroft Institute
        - Design, Production and Test of a neutral gas sheet production device
    - GSI collaboration agreement
      - Design, production and test of a luminescence detection system for a neutral gas sheet monitor

Courtesy: Rhodri Jones

Gas Sheet Monitor

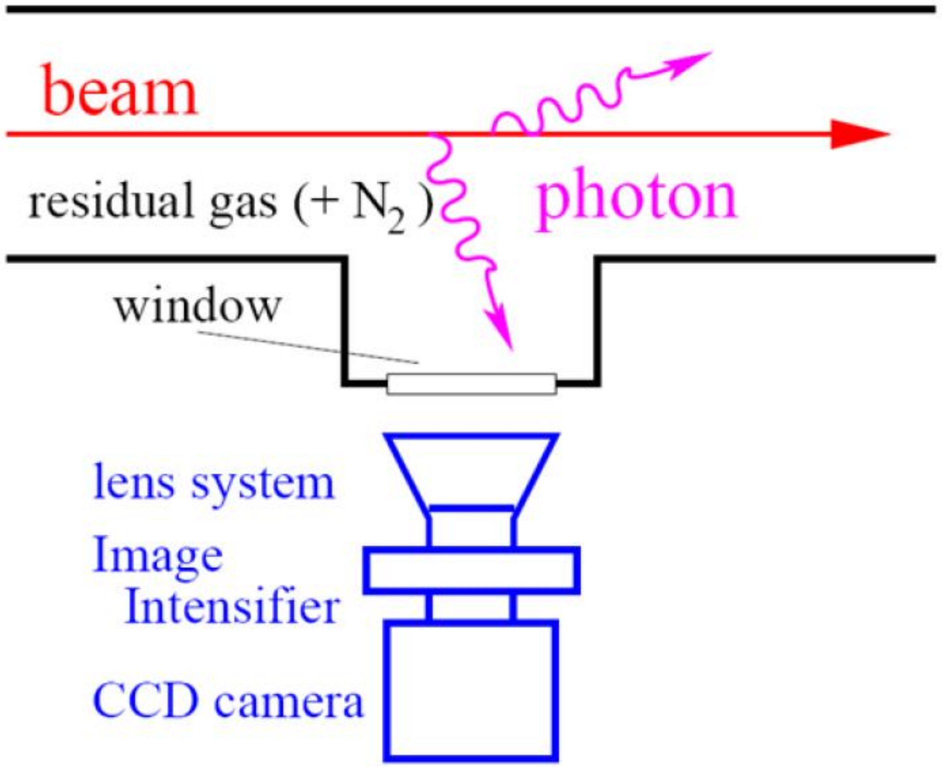
- Generate thin atom gas curtain,
- Ionize atoms with primary particle beam,
- Extract ions via electric field,
- Monitor on MCP, P screen.



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

Beam Induced Fluorescence Features @ GSI

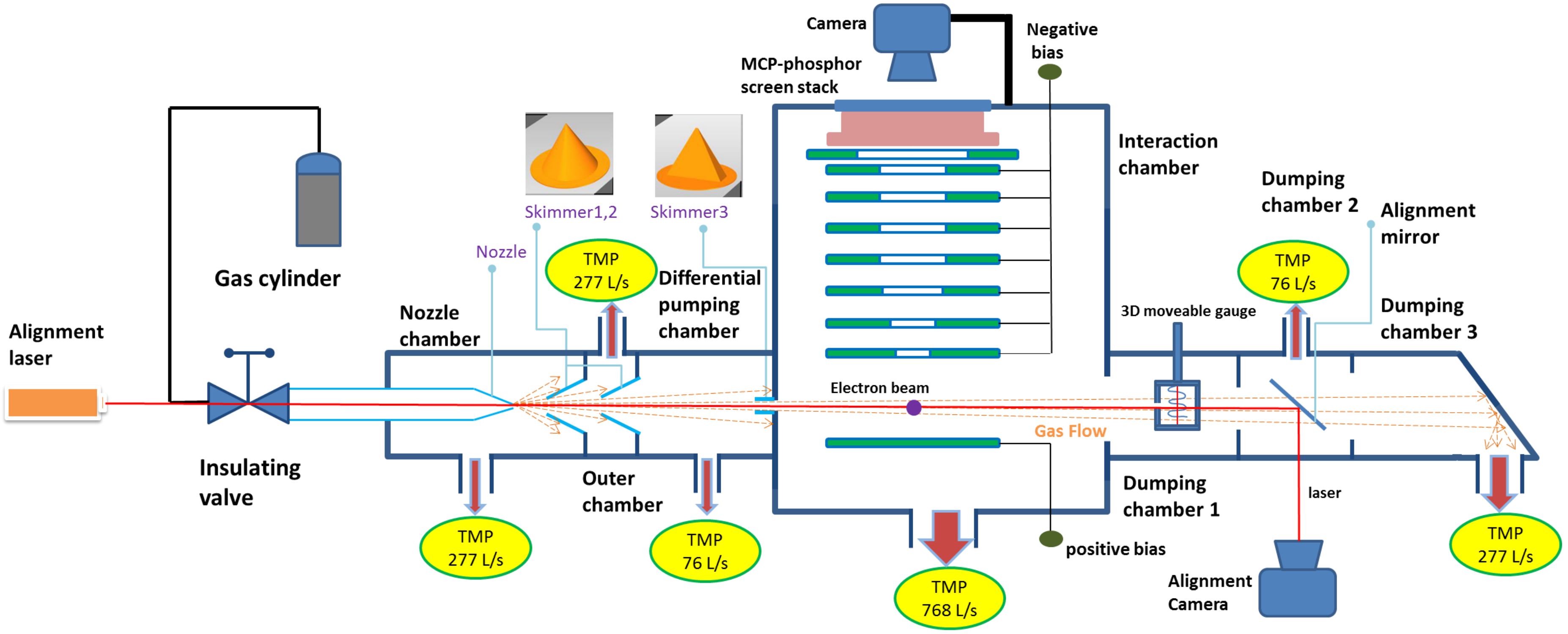
- Based upon the detection of photons emitted by residual or injected (low pressure) gas molecules
- Little influence on the beam
- Single pulse observation possible; down to ≈ 1 µs time resolution
- High resolution, e.g. 0.2 mm/pixel, can be easily matched to application
- Commercial image intensifier available
- Compact installation, e.g. 25 cm for both planes



Setup #1 at Cockcroft

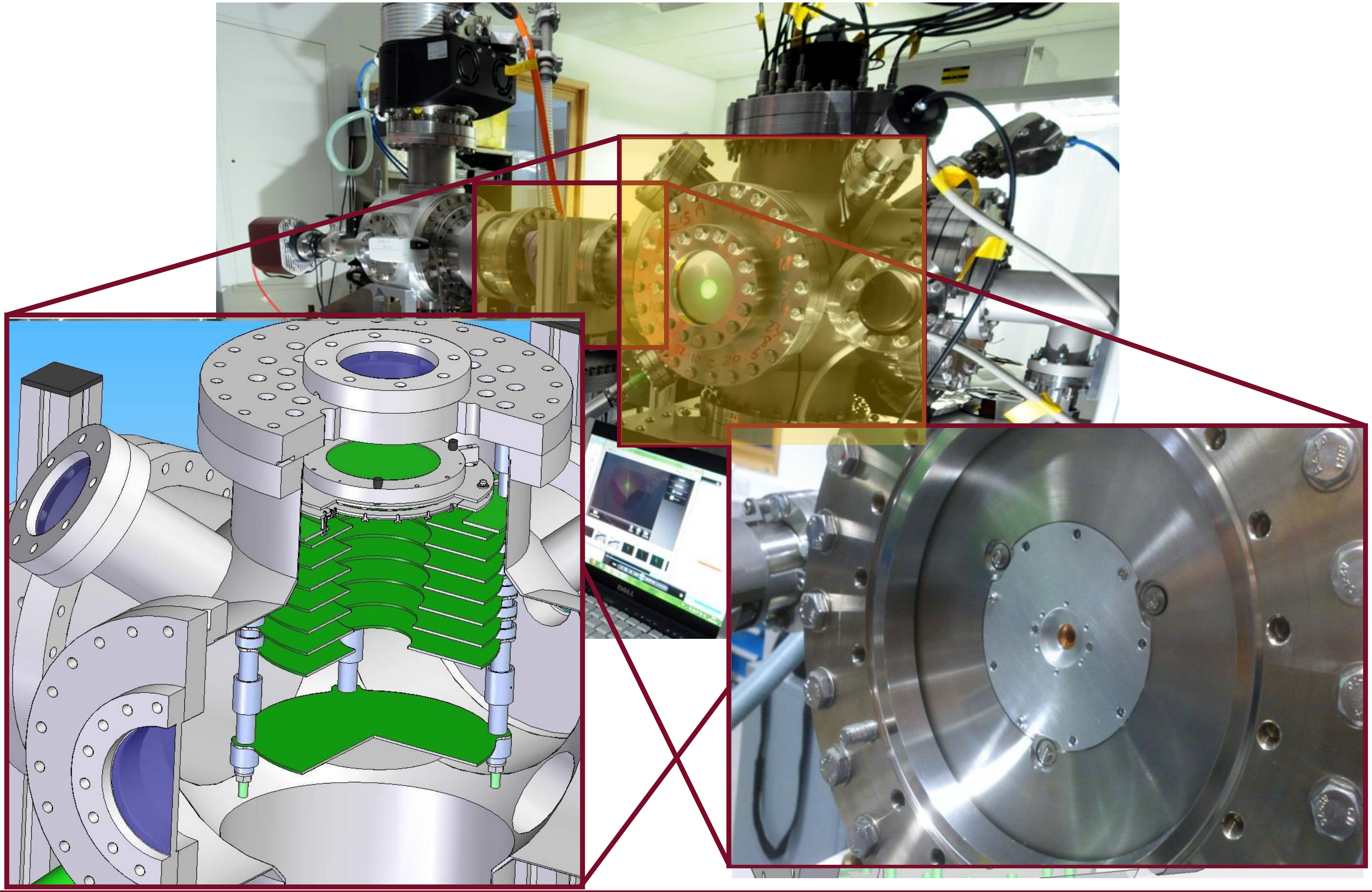
Using Beam-Gas Ionisation

Setup

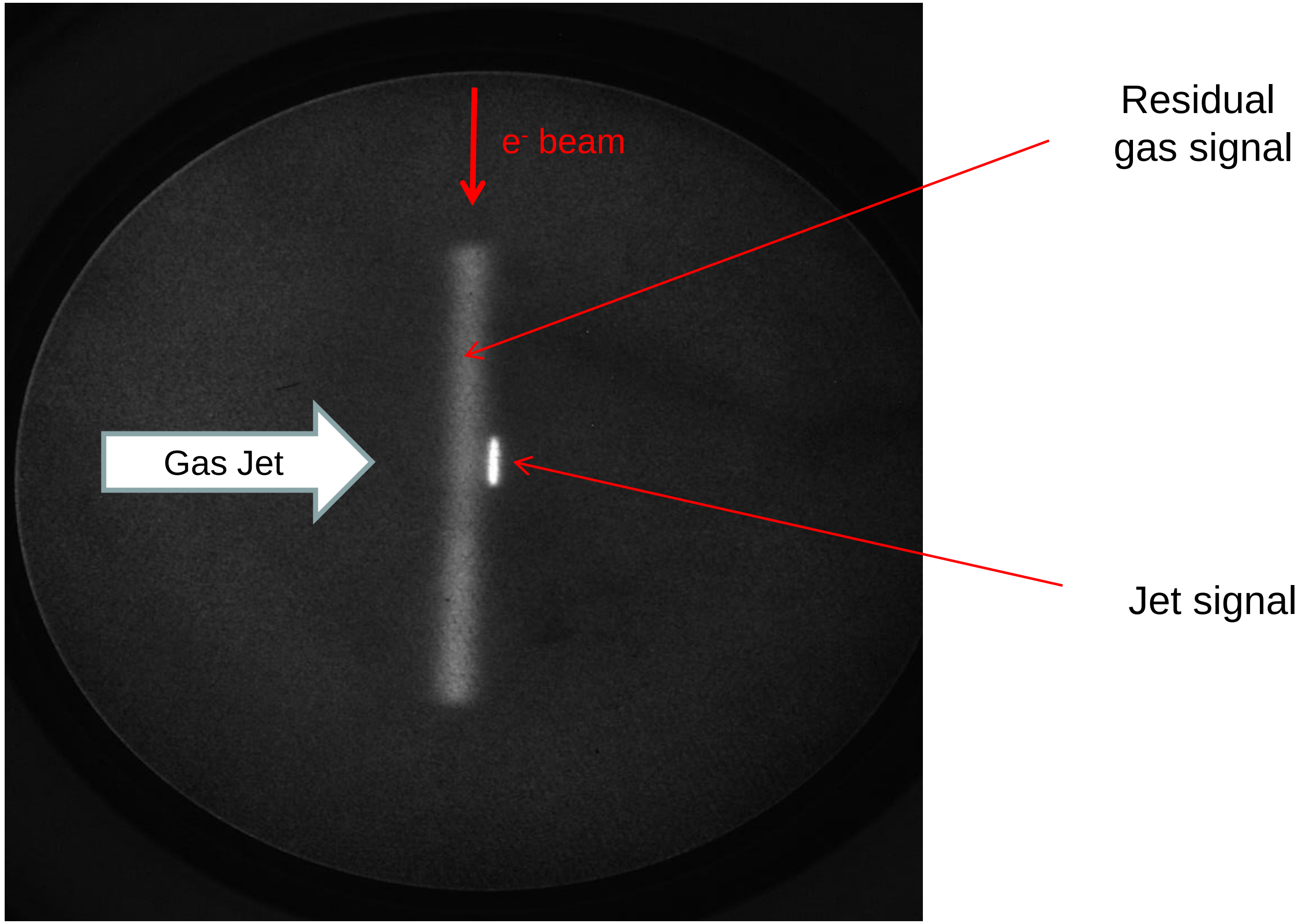


Camera
Negative bias
MCP-phosphor screen stack
Interaction chamber
Dumping chamber 2
Alignment mirror
Gas cylinder
Skimmer1,2
Skimmer3
Nozzle
TMP 277 L/s
Differential pumping chamber
TMP 76 L/s
3D moveable gauge
Dumping chamber 3
Nozzle chamber
Alignment laser
Electron beam
Gas Flow
Insulating valve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

Setup @ Cockcroft Institute



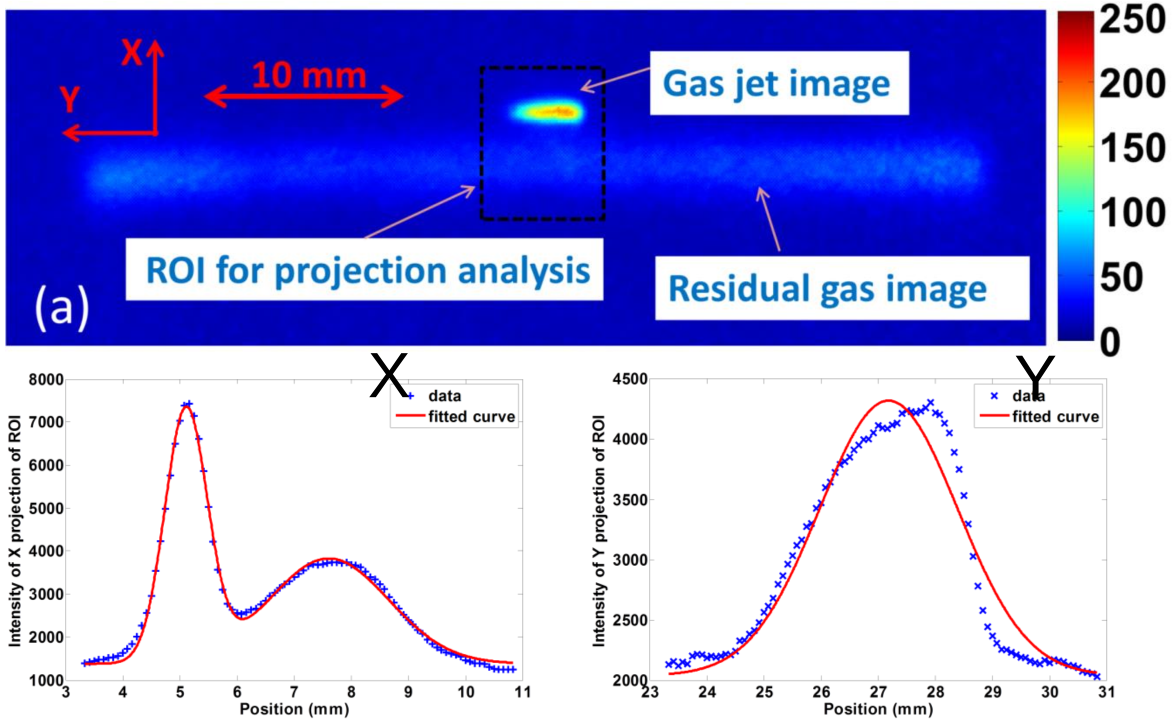
Results @ CI

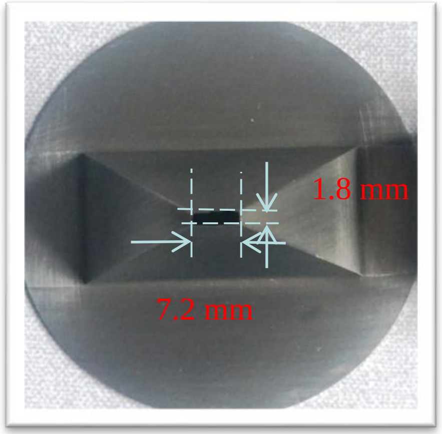


V. Tzoganis, et al.,
APL **104** 204104 (2014)

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

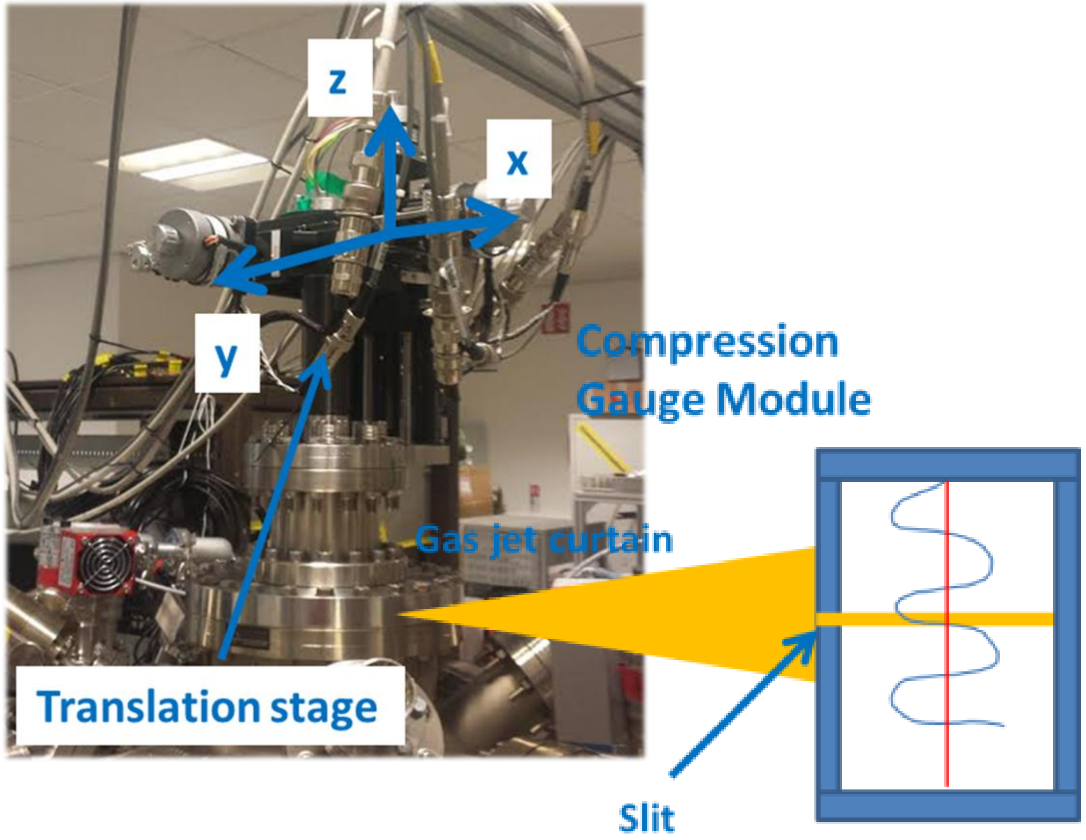
Example Measurement 1

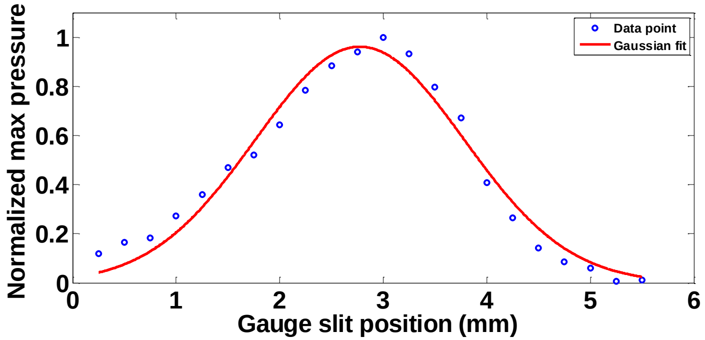




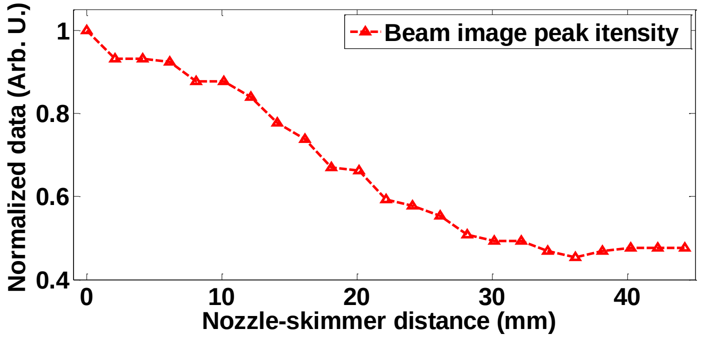
Jet Studies

- Apply 3D movable ion gauge to scan through jet





Vertical scan – yields profile

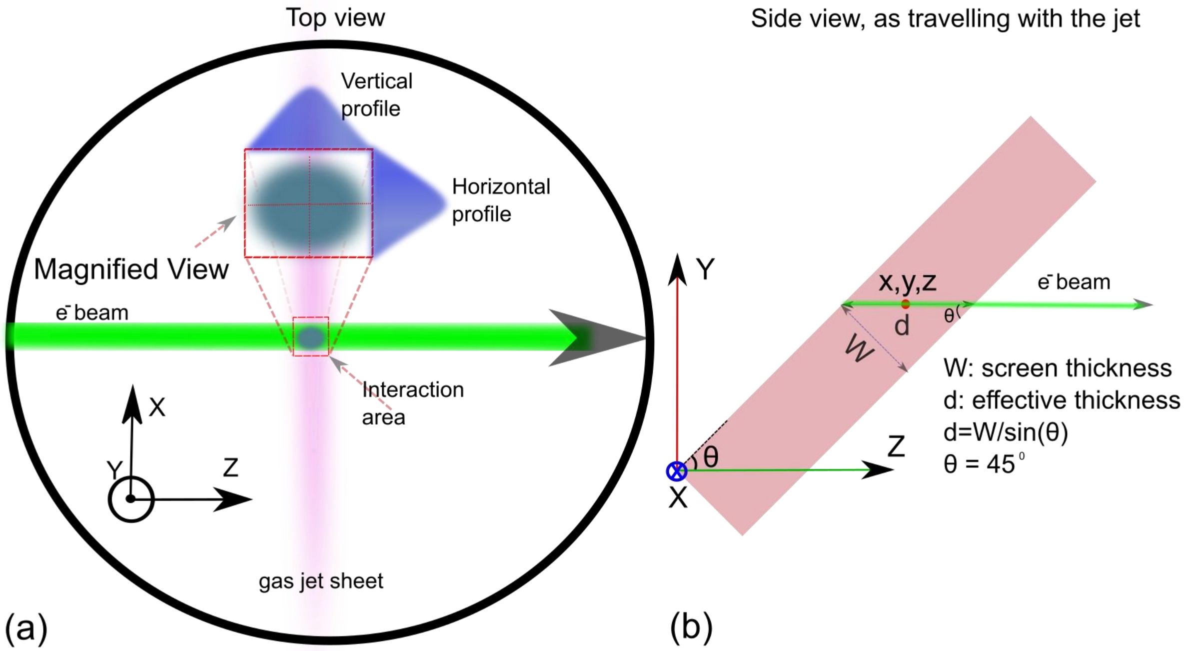


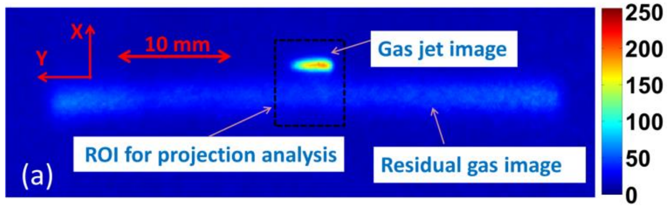
Identify Mach disk location

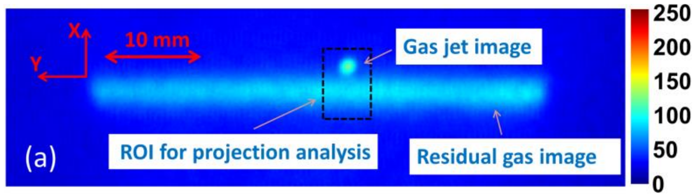
H. Zhang, et al., Phys. Rev. AB (2016), *submitted*

Resolution

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



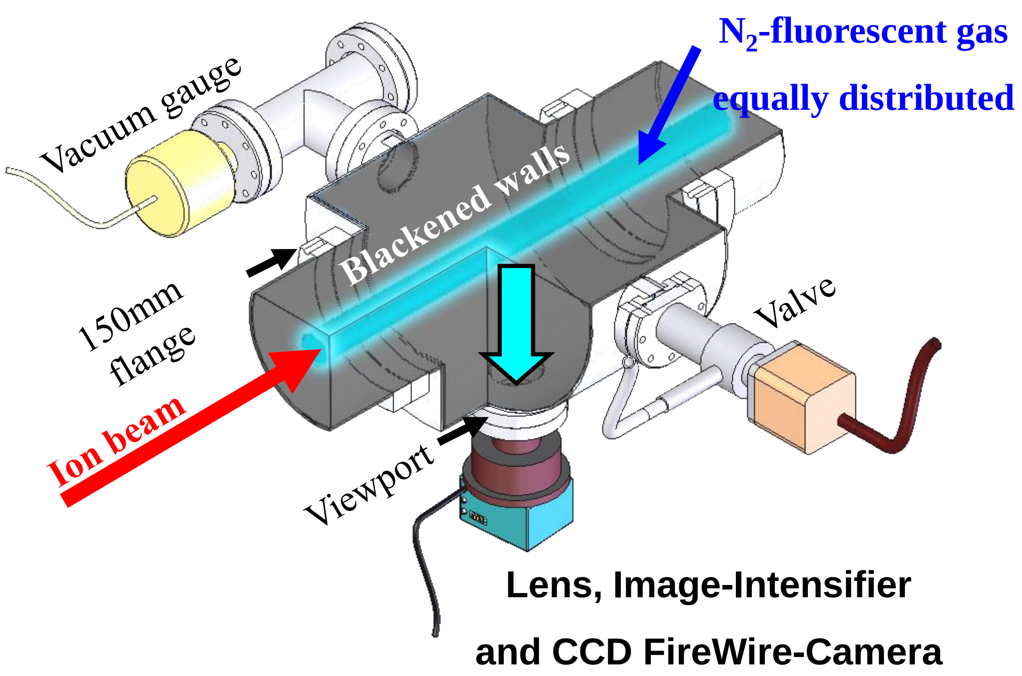


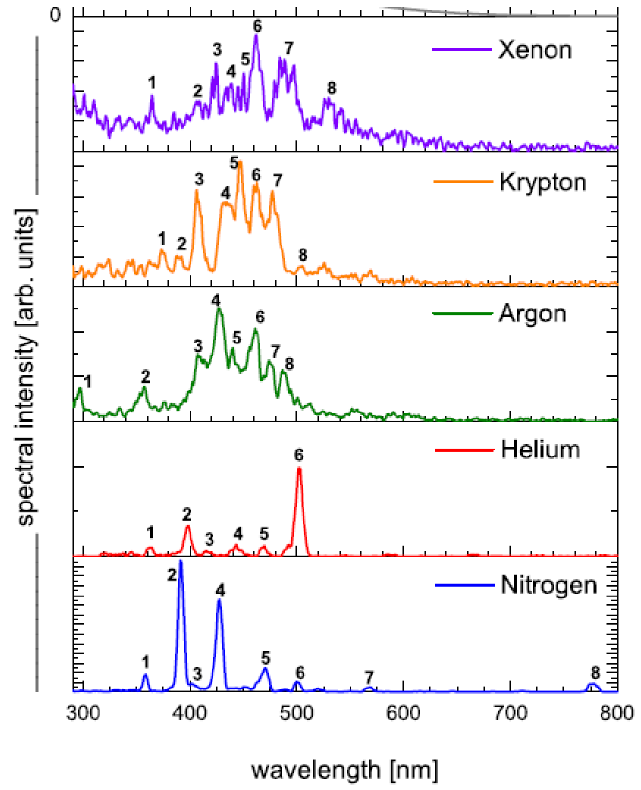


Benefit from Jet and BIF !

- Generate light in collision between gas jet and beam
- Detect photons and measure profile
- R&D challenges:
  - Monitor integration (location, cryostat,…)
  - Optimum location, e.g. do we have to measure inside the solenoid?
  - Gas condensation, extraction and choice of species,…
  - Achievable resolution of optics and anticipated signal levels
- We are optimizing this idea towards HLLHC application with CERN and GSI.
- 2 monitors planned for 2017 and 2019.

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.

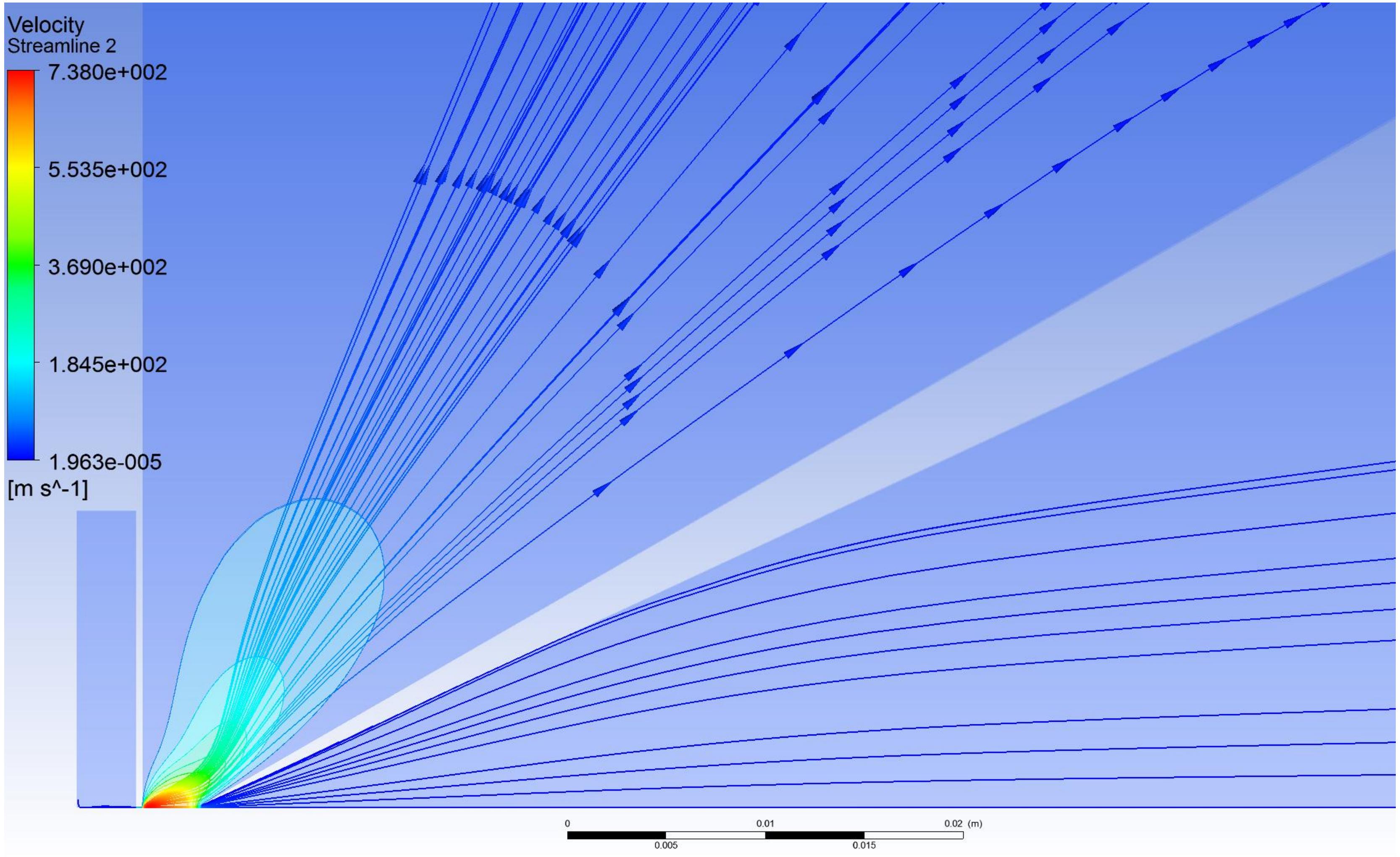
Gas Dynamics Studies

Simulation issues

- Pressure range spans 11 orders of magnitude
  - Gas nozzle inlet at 10 Bar, Interaction chamber at ~10^{-7} mbar
  - Transition from viscous to molecular flow regimes mean the same physical models cannot be used over the whole flow
- Geometric details also range over 4 to 5 orders of magnitude
  - Nozzles from ~30 µm with transport over ~ 1 m
  - Tends to require numerical models with large numbers of elements, so computationally demanding

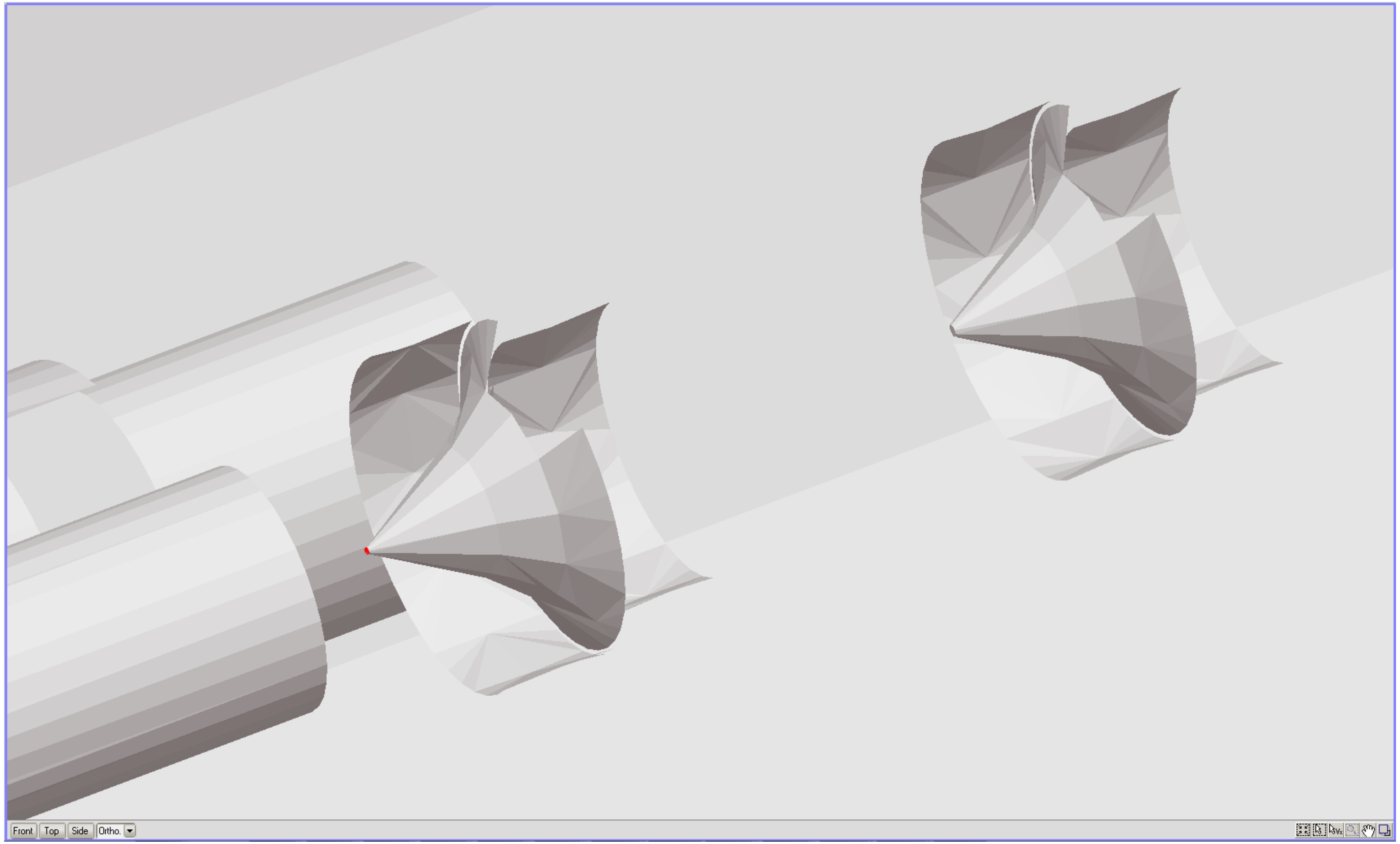
CFD simulation with 1st skimmer and $p_{NC} = 0.88\ [Pa]$ everywhere

- Velocity distribution and streamlines



Molflow+ Model:

3. Molflow+ model (simplified);

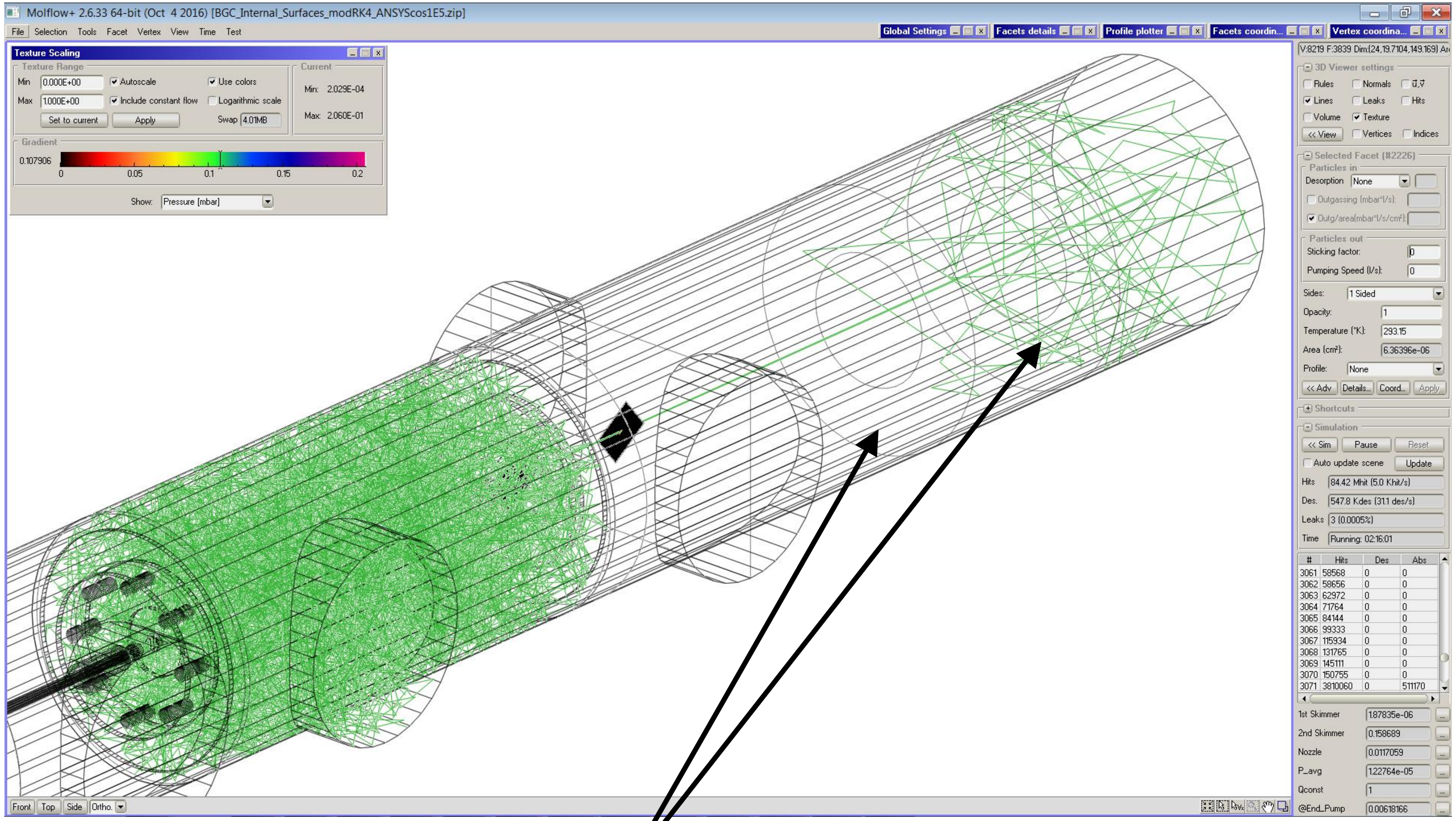


Closer view into the first skimmer area; the little red dot is the inlet surface simulating the viscous-flow distribution as calculated by P. Magagnin;

Courtesy: Roberto Kersevan

Molflow+ Model:

3. Molflow+ model (simplified);

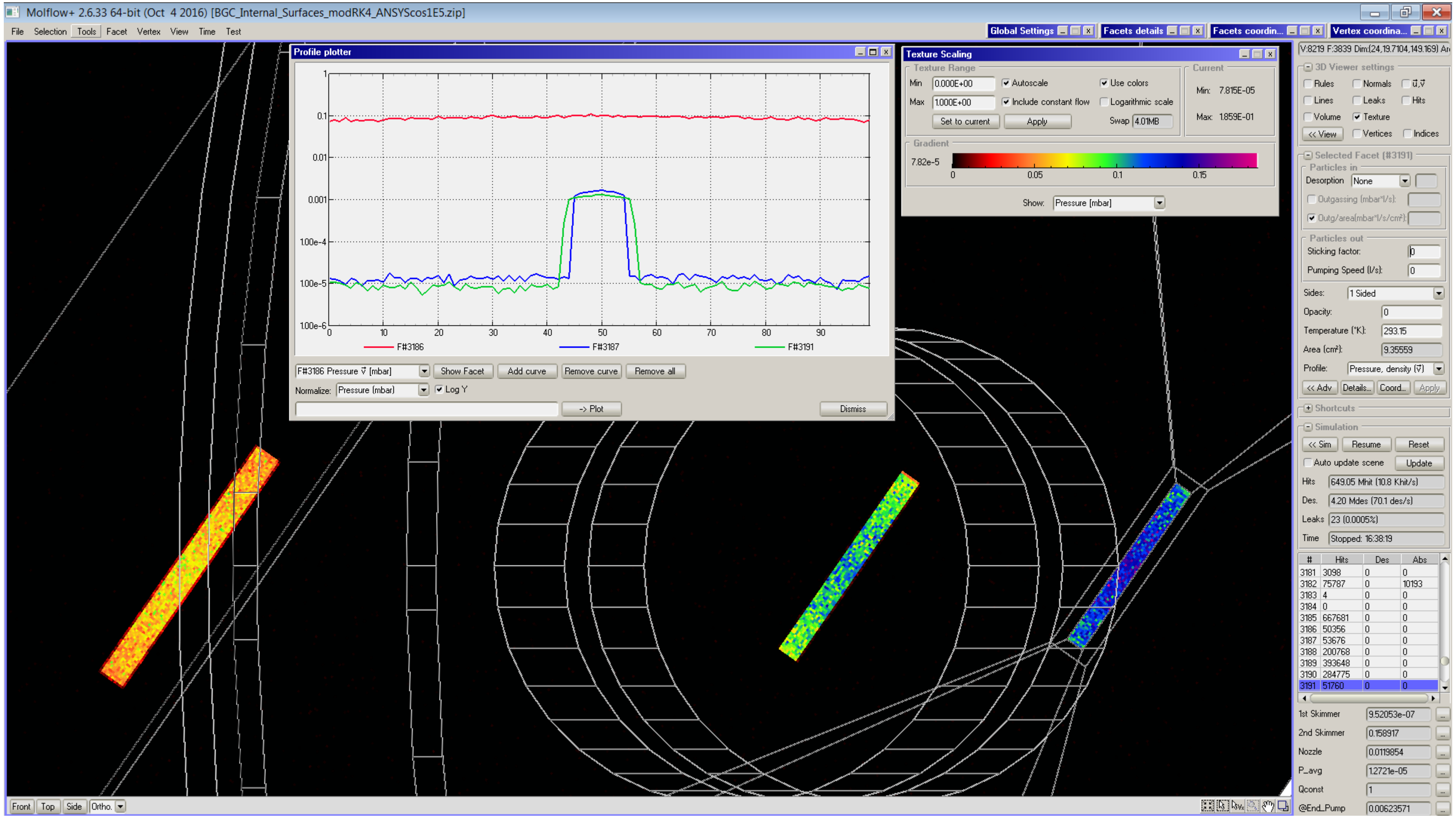


Ray-tracing with Molflow: **two baffles** have been placed in front of the "dump" area turbo pump, to reduce backscattering from it;

Courtesy: Roberto Kersevan

Molflow+ Model:

3. Molflow+ model (simplified);

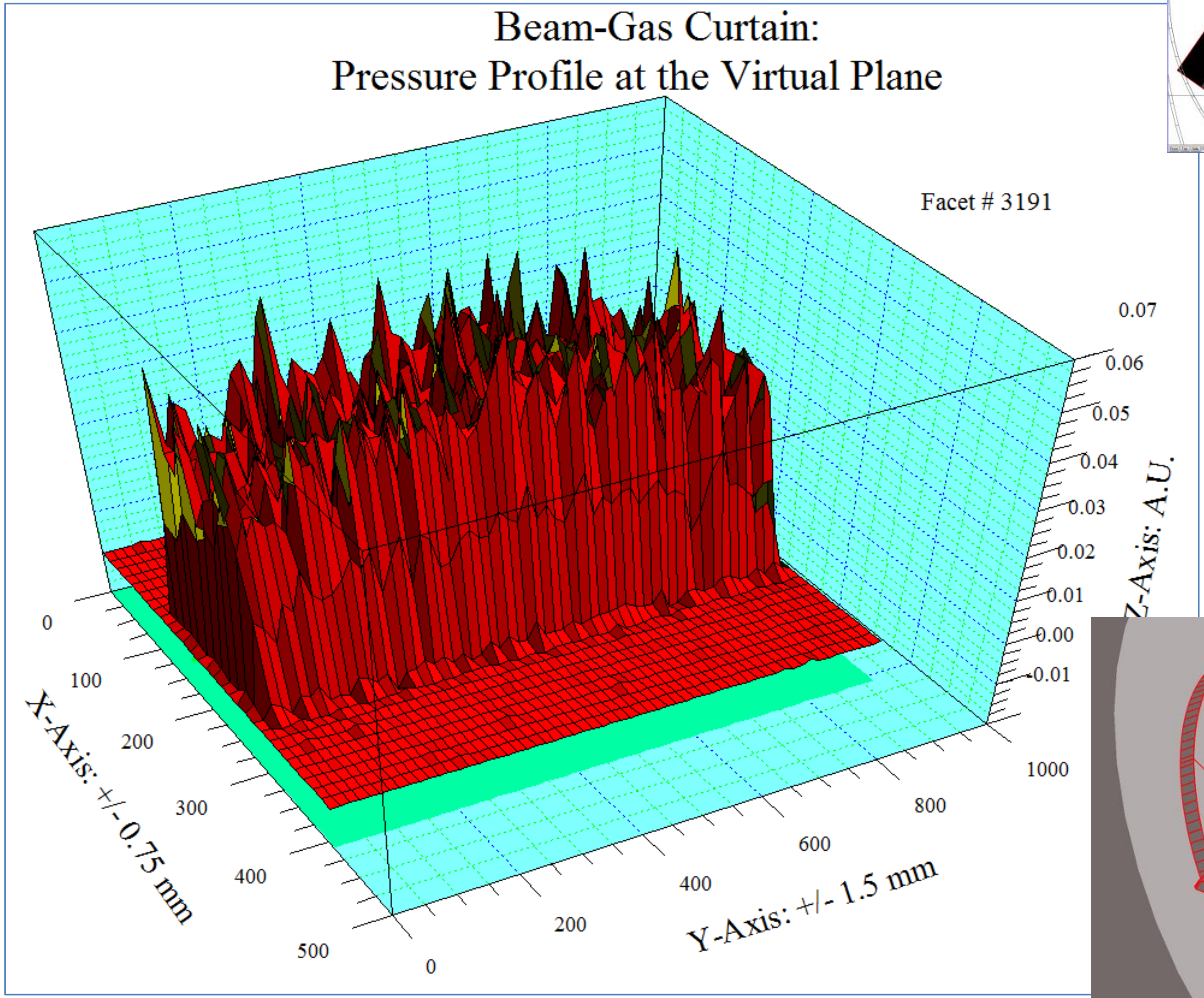


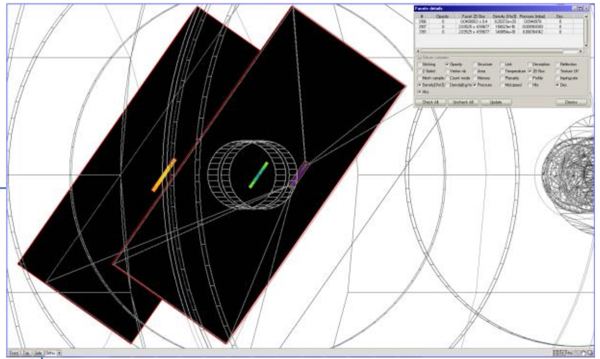
- Close-up view of the textured surfaces;
- Right-to-Left: entrance to nozzle (red profile on inset), base of nozzle (blue), and interaction region (green); The horizontal axis on inset plots is longest side of textured rectangles; Red: 4x0.4 mm^2 nozzle inlet; Blue and Green: 20.4 x 46.0 mm^2;

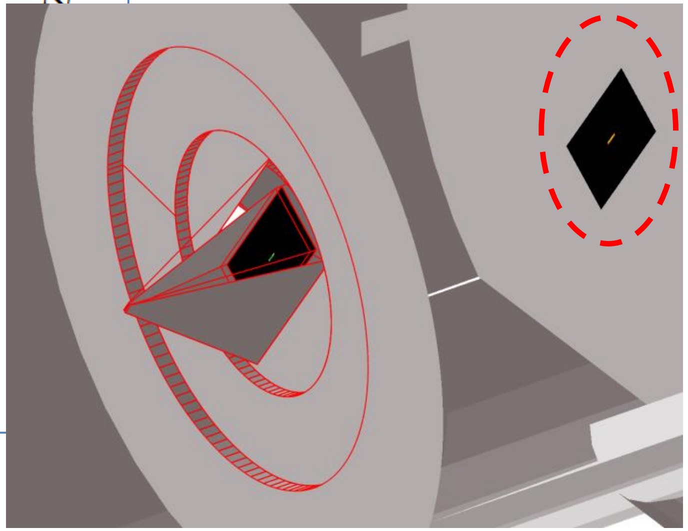
Courtesy: Roberto Kersevan

Molecular Distributions

3. Molflow+ model (simplified);







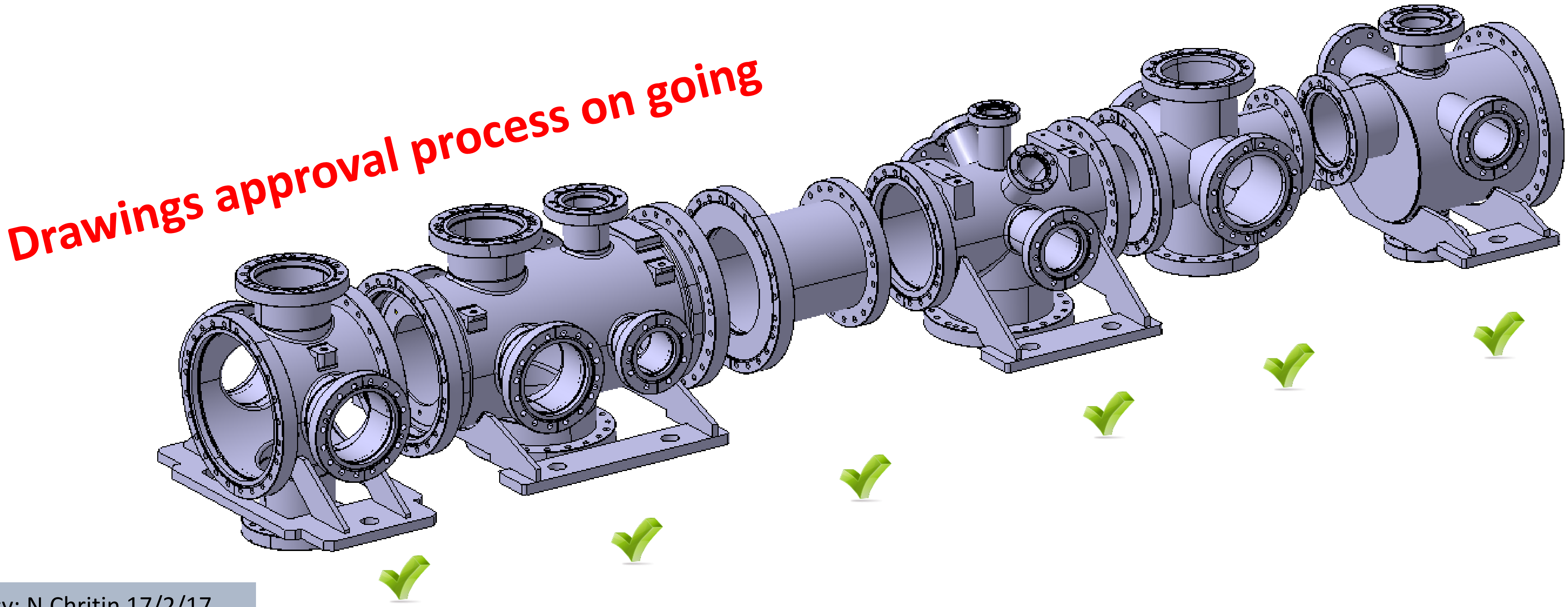
- Facet # 3191: rectangle on virtual facet →

Courtesy: Roberto Kersevan

Recent Progress

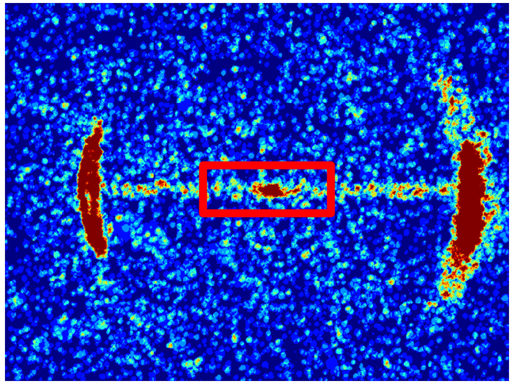
Beam Gas Curtain: Current status

- Vacuum chambers :
  - Drawings ready (LHCBGCAA0002 / 0004 / 0005 / 0006 / 0007 / 0010)

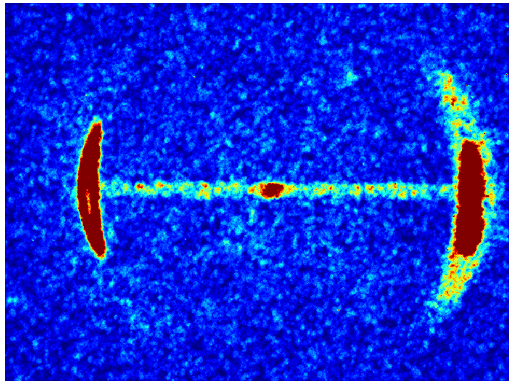


Courtesy: N.Chritin 17/2/17

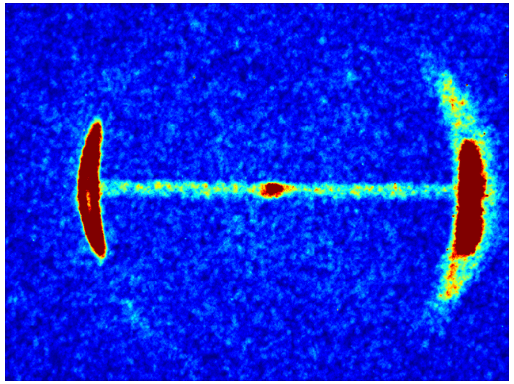
Integration time



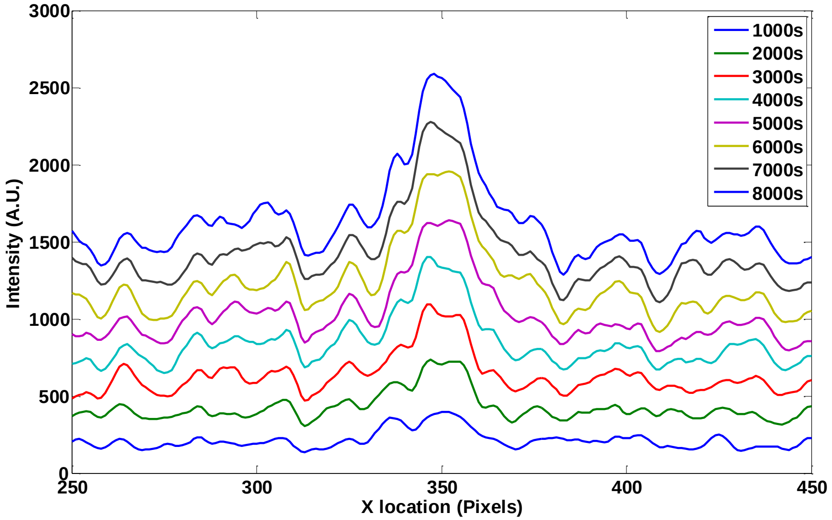
1000s

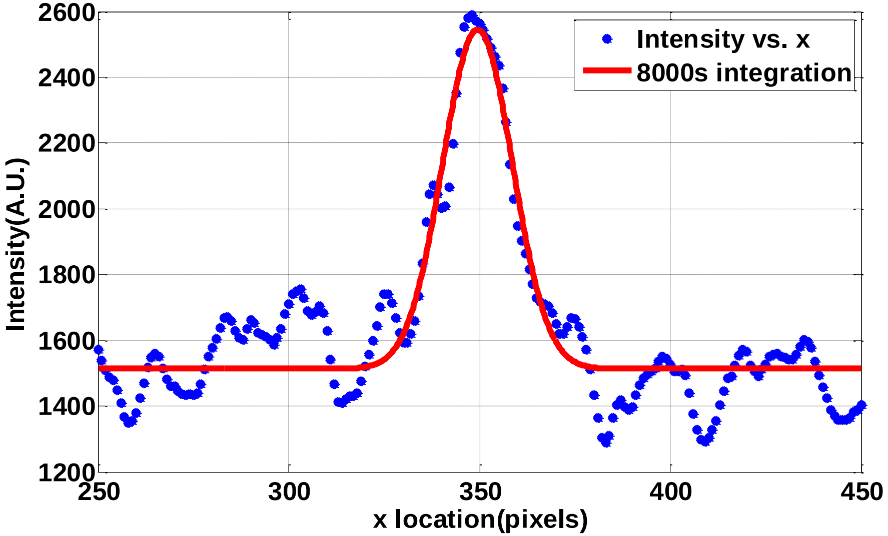


4000s



8000s

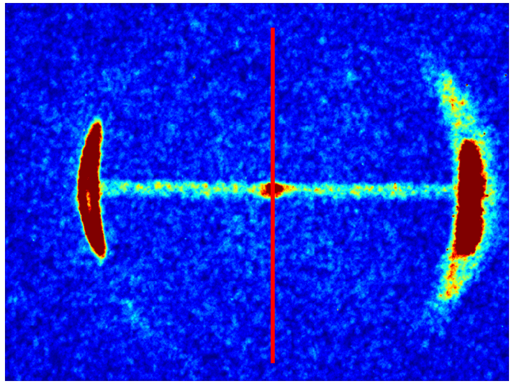


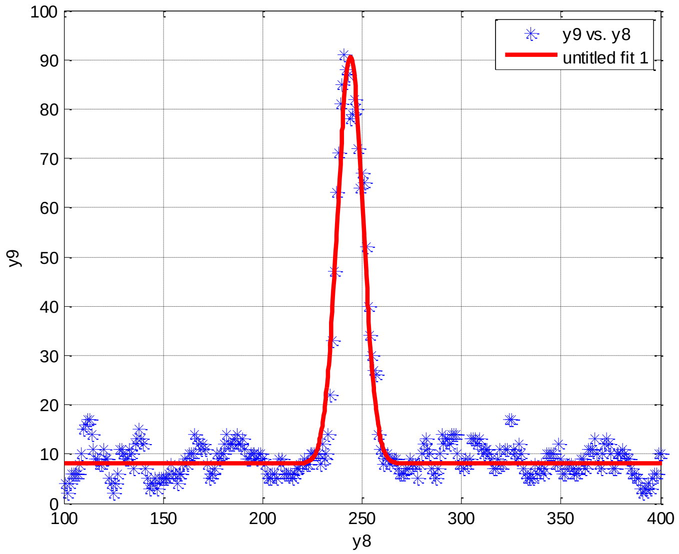


H.Zhang, 16/12/16

hao.zhang@cockcroft.ac.uk

Y line scan





a	82.42
b	244.1
c	6.45
d	8.084
R2	0.9321

⇨ 1.41 mm

Next Steps

Main challenges for HL-LHC

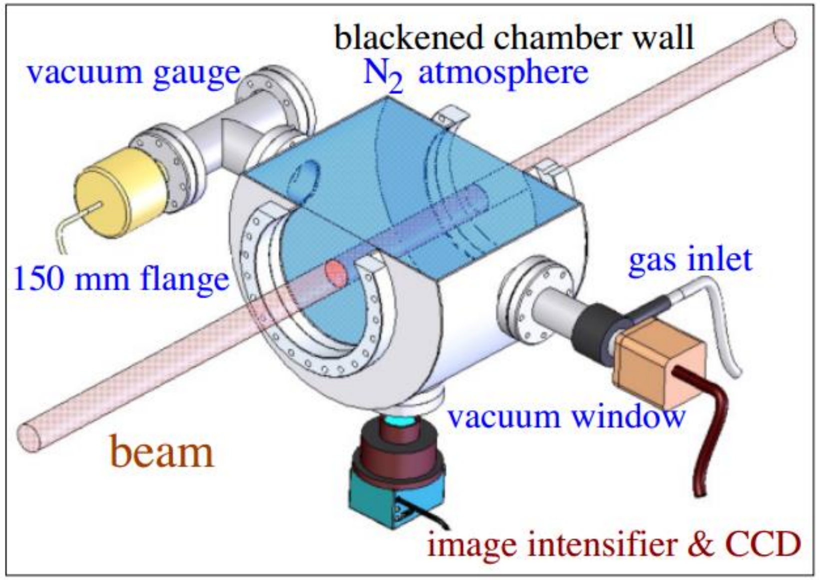
- Performance challenges
  - Integration time
  - Precision achievable in the gas and electro-magnetic environment
- Instrument challenges for HL-LHC
  - Integration into/around the SC solenoid
  - Vacuum issues (pressure, gas species N2 vs. Ne)
  - Instrument size and maintainability

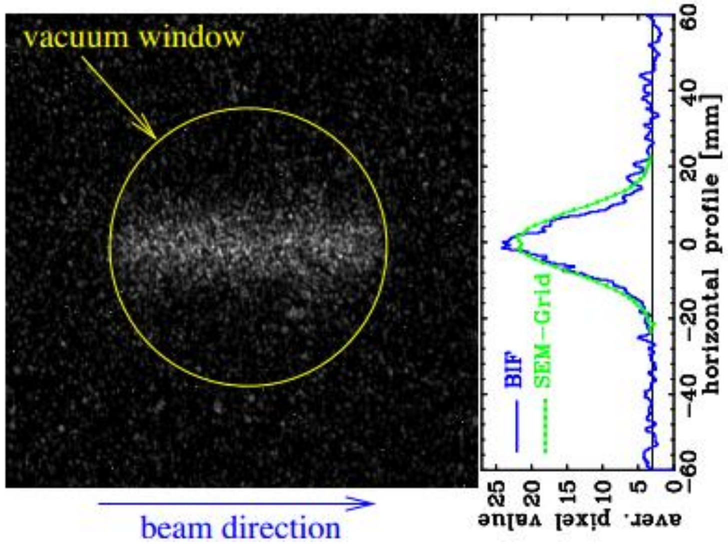
Project research goals in 2017

- Cockcroft
  - Assemble and commission the #2 test stand with new, higher intensity e-gun
  - Commission instrumentation (Mass spec…)
  - Demonstrate results with BIF then start to quantify performance
  - Simulation work: Beam-gas simulations
- GSI (upto 30/6/17)
  - Deliver optical system for BIF to Cockcroft and participate in commissioning
  - Deliver report on BIF with different gas species (in particular Ne)
- CERN
  - Complete mechanical design of #2 test stand (skimmer production and alignment)
  - Integration studies with the SC solenoid and HL-LHC
  - Continue studies of gas dynamics (high pressure-low pressure)
  - Longer-term studies targeted at FCC (gas jet scanner)

Backup Material

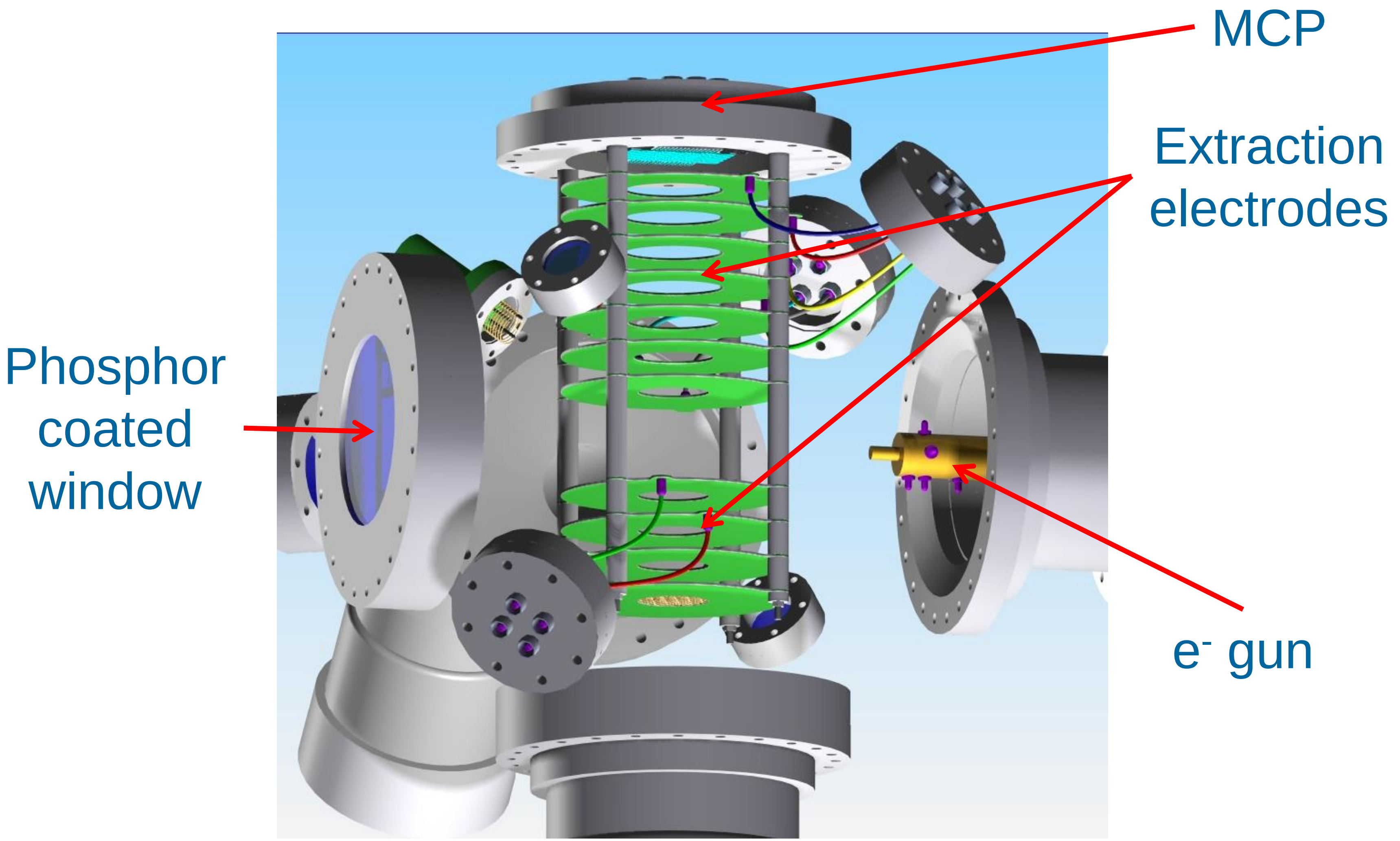
Beam Induced Fluorescence (BIF)





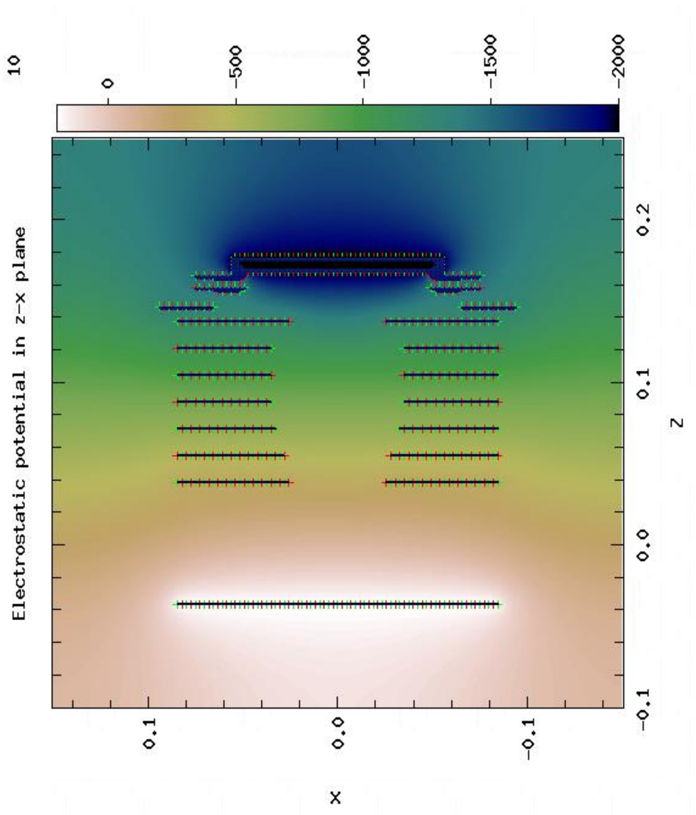
- Measures light from rest gas, excited by beam
- Challenges:
  - Very low cross sections
  - Isotropic light emission
  - Rest gas pressure requirements

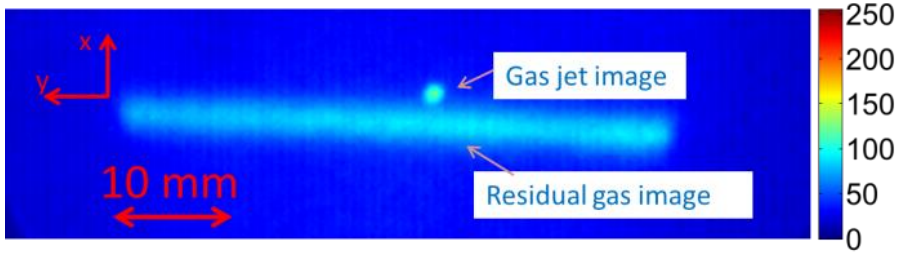
Zoom: Main chamber

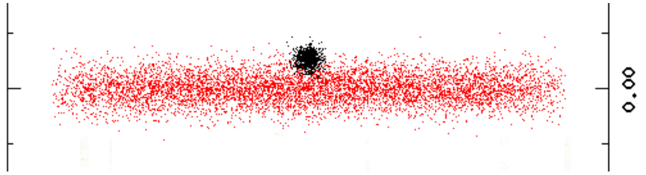


Understanding the Jet

- Simulations using the CST and WARP codes





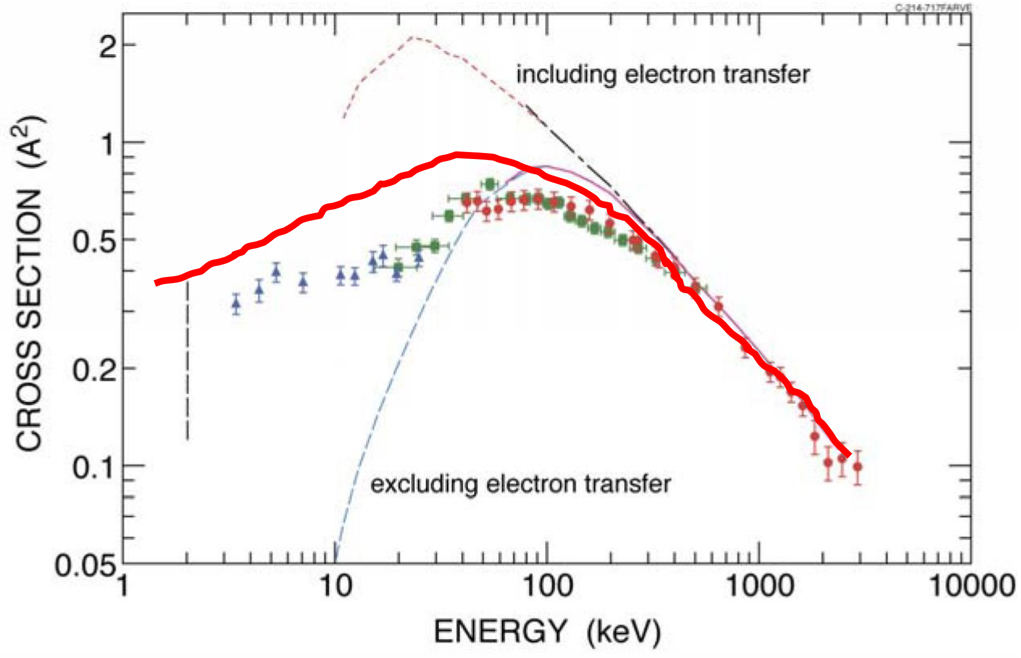


Unit(mm)	Experiment	Simulation
σ_x	0.56 ± 0.02	0.57
σ_y	0.53 ± 0.03	0.61
σ_x (residual gas)	1.52 ± 0.07	1.23

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

Ionization Cross Sections

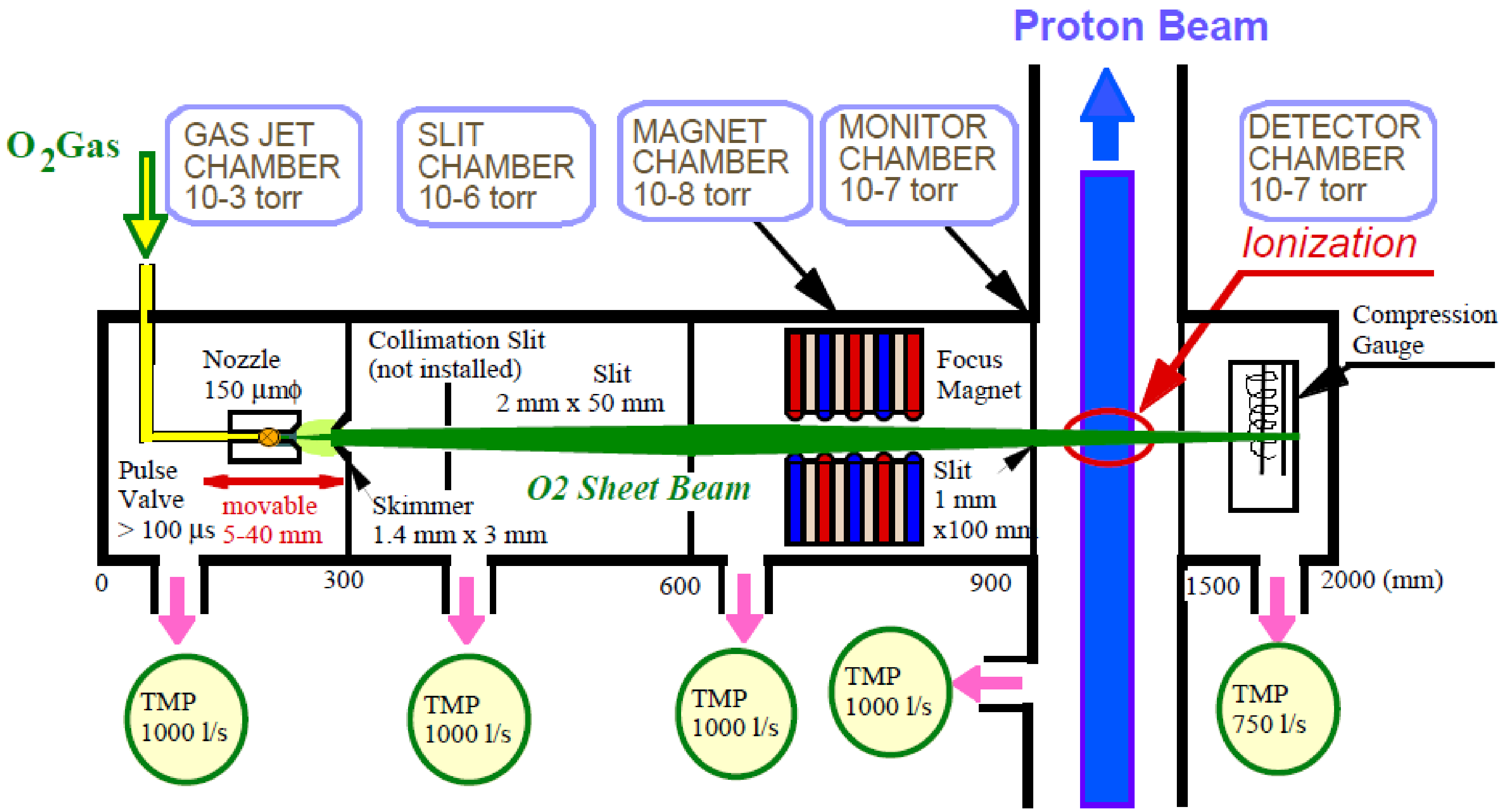
- Can be exotic, e.g. single ionization of helium by antiproton impact



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

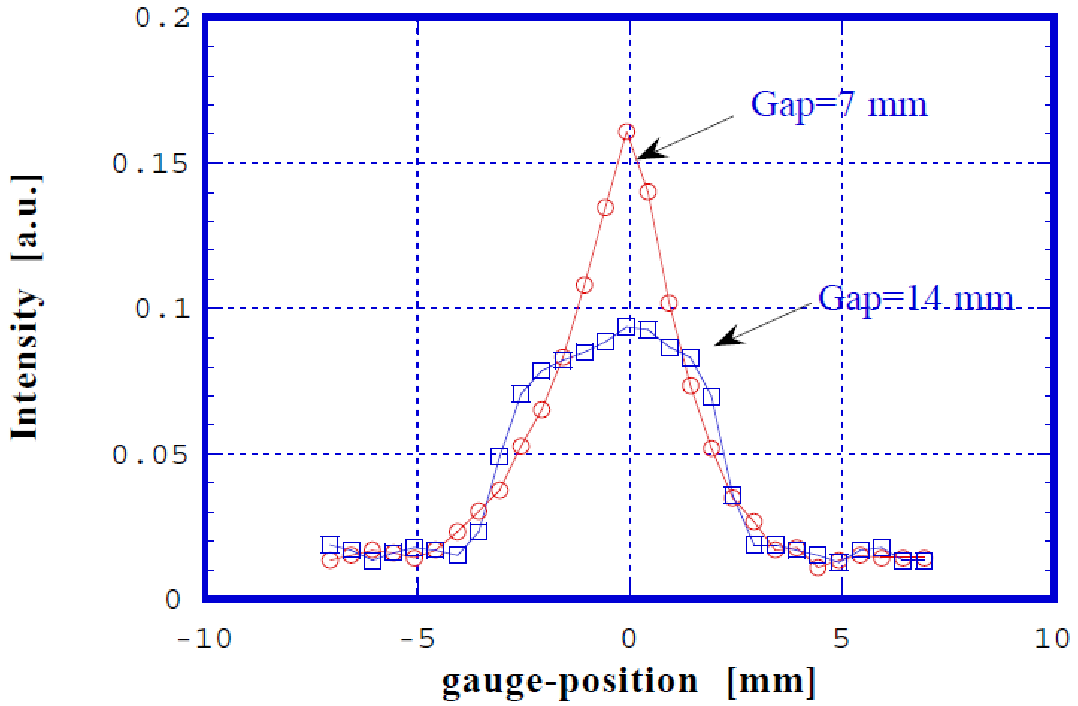
H. Knudsen, Hyperfine Interactions **109** (1997) 133–143
H. Knudsen, Journal of Physics:Conf. Series **194** (2009) 012040

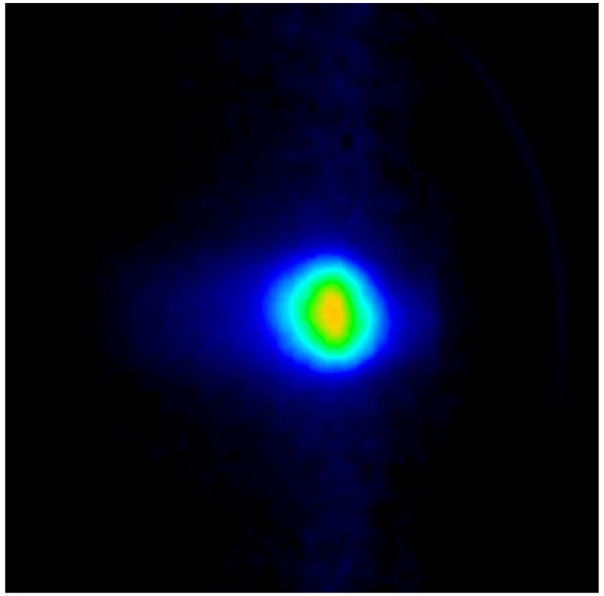
How to Generate the Jet ?

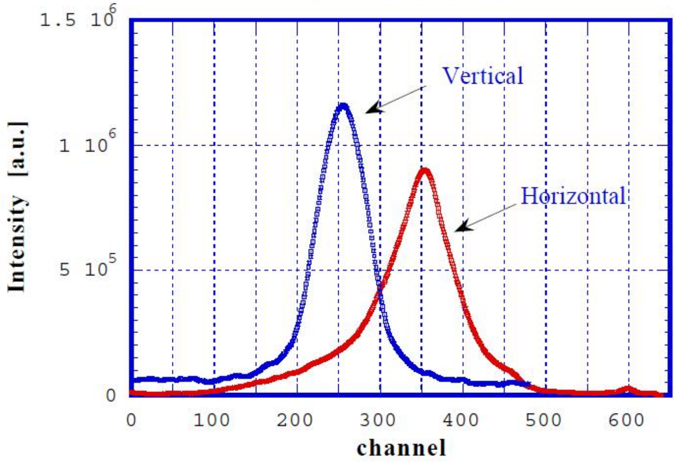


Y. Hashimoto et al., Proc. Part. Acc. Conf., Chicago (2001)

Experimental Data

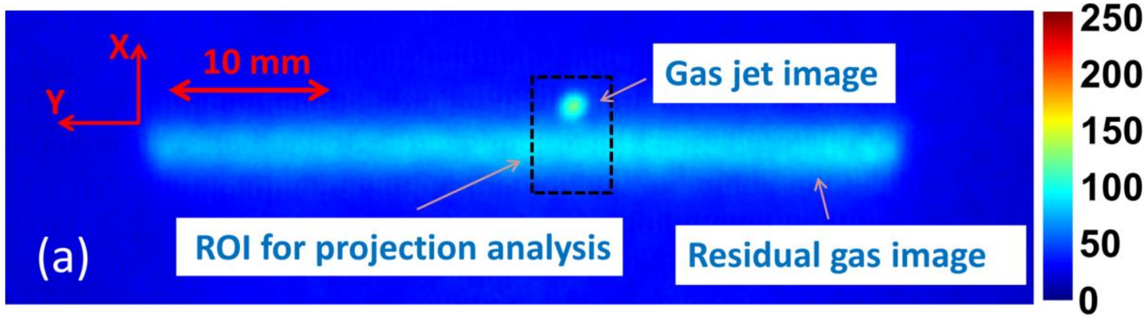


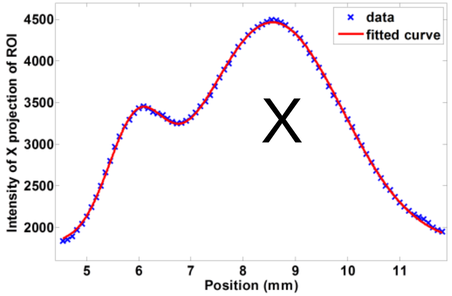


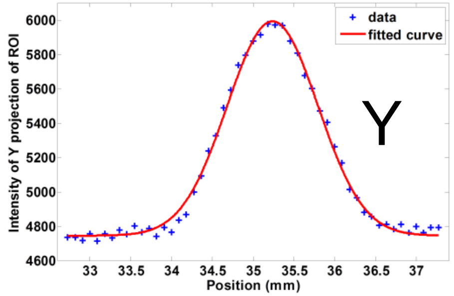


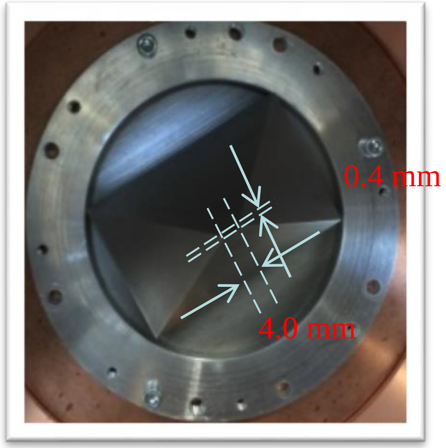
Y. Hashimoto et al., Proc. Part. Acc. Conf., Chicago (2001)

Example Measurement 2

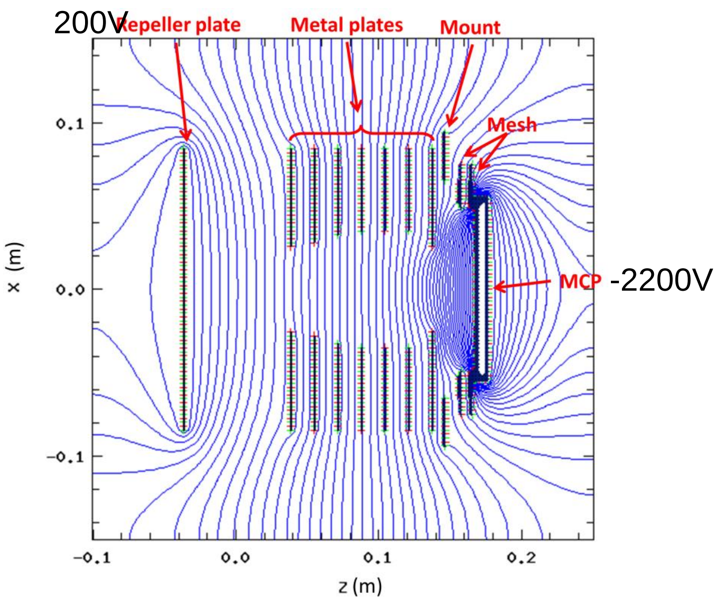




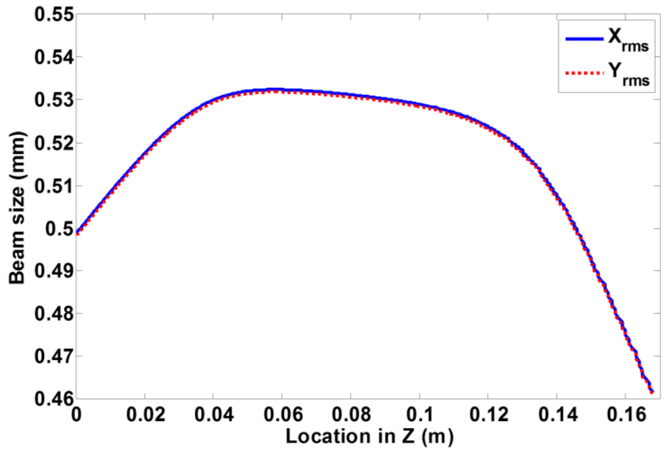


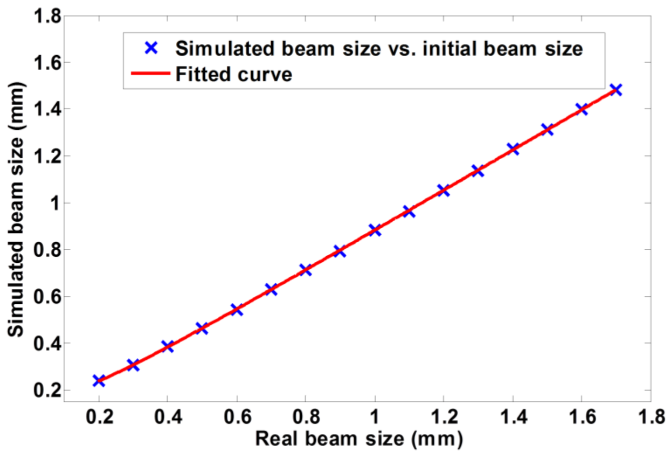


External field and image broadening

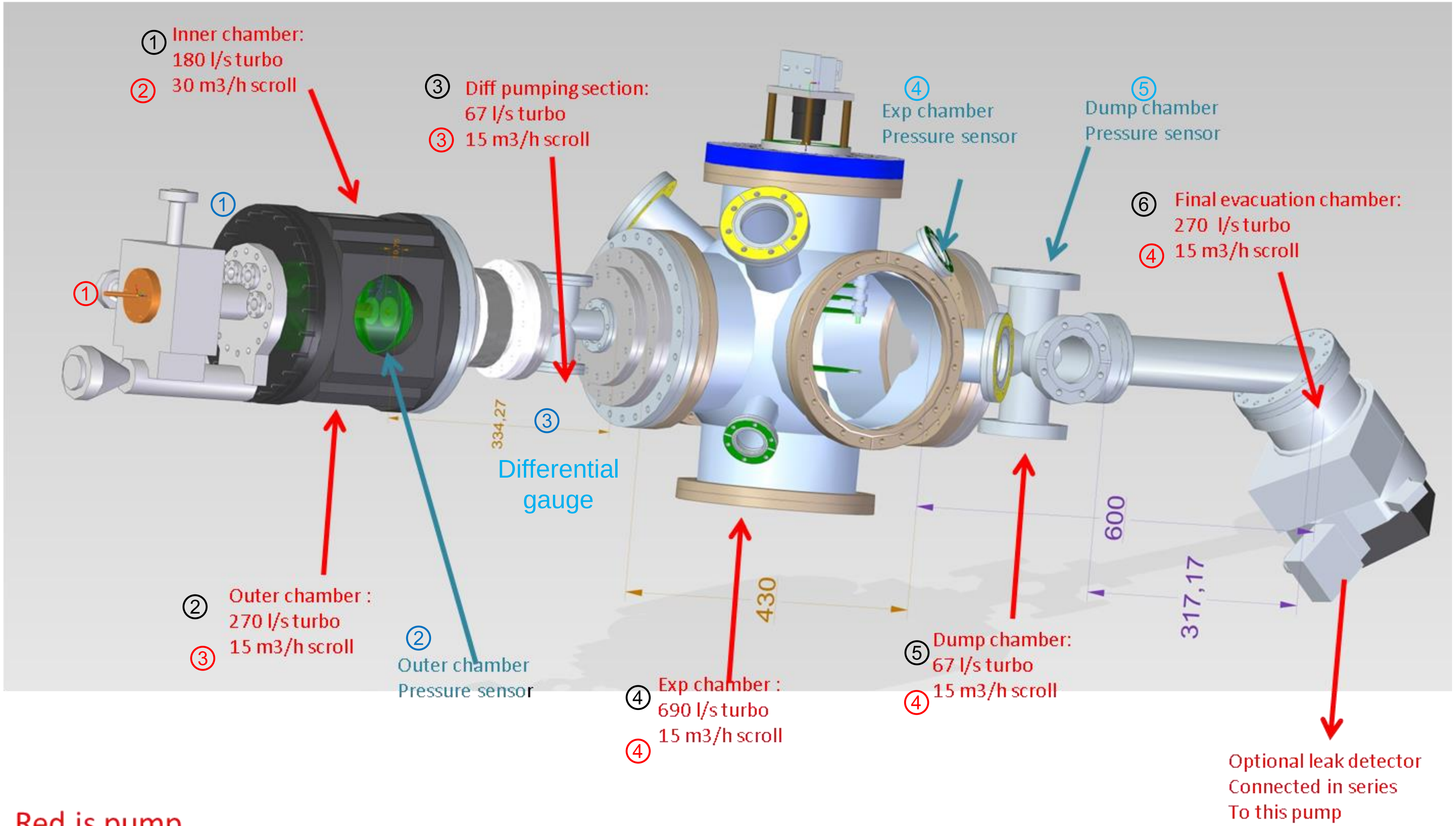


$$\sigma_{measured} = \sqrt{M^2 \cdot \sigma_{real}{}^2 + \sigma_{thermal}{}^2}$$





Mechanic Design (DRAFT)



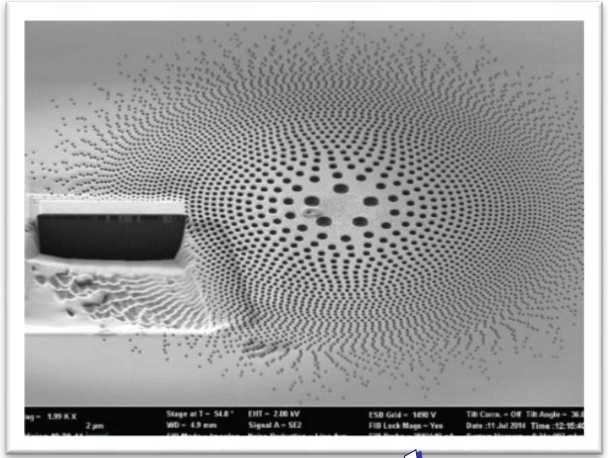
Red is pump

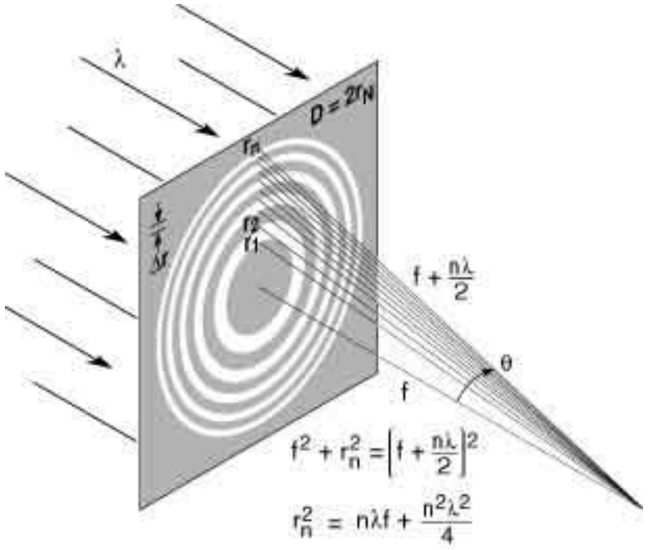
Blue is pressure sensor

The Cockcroft Institute
of Accelerator Science and Technology

Also considered: Gas Jet Wire ?

- Similar idea to laser wire
- Challenge mm focus





Fresnel Zone Plate