Gas Sheet Ionization Diagnostic for Transverse Profile Measurement

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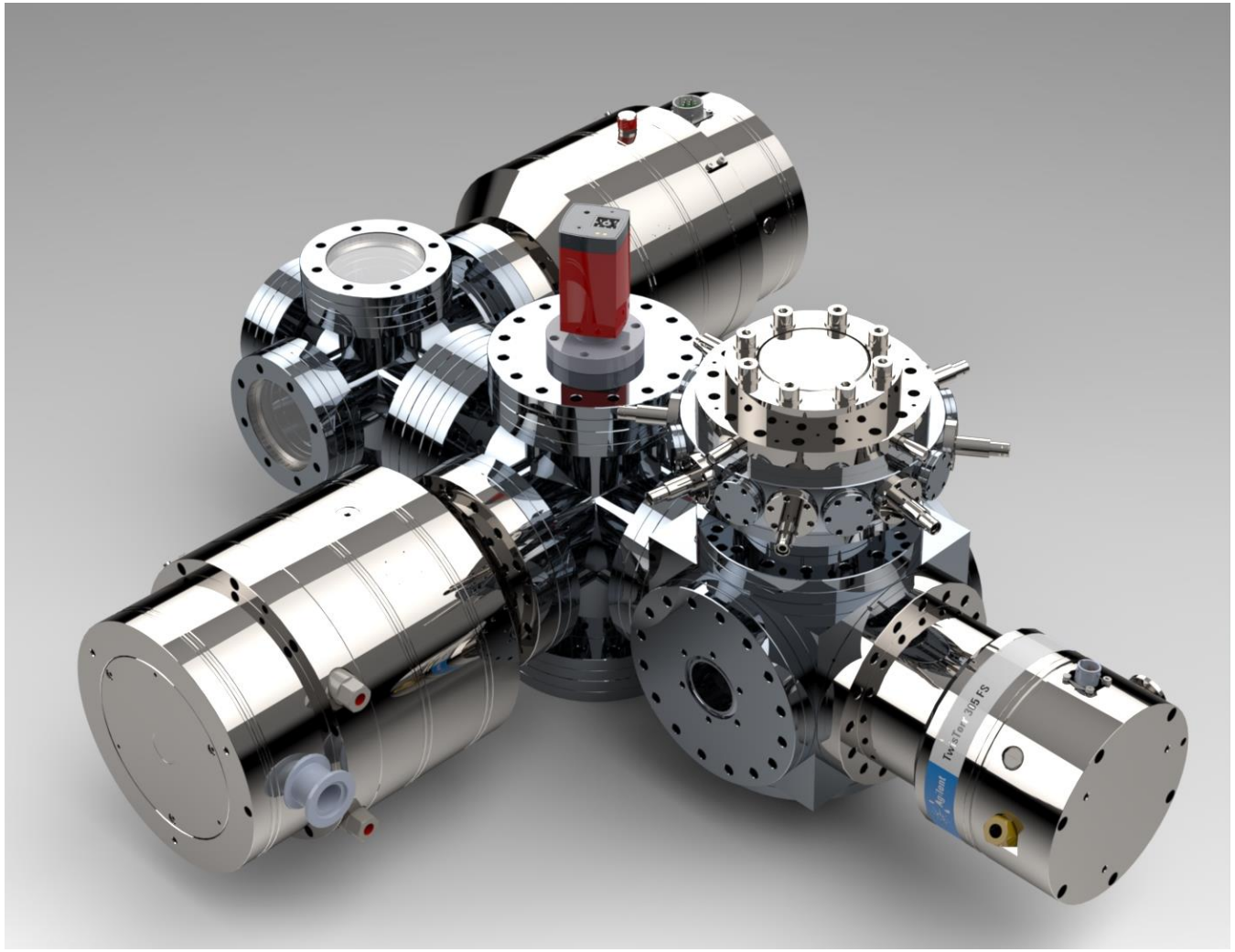
RadiaBeam

NAPAC 2022

Albuquerque, NM

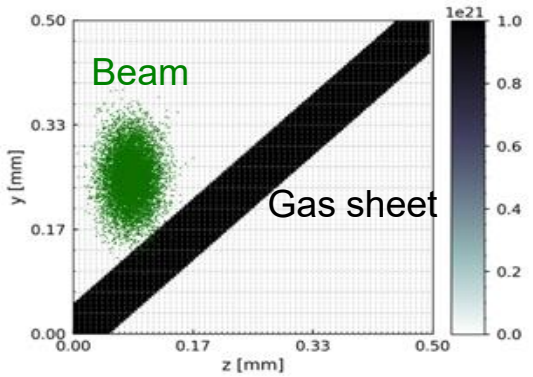
Overview

- Motivation
- Gas Sheet Ionization Monitor
- Gas Sheet Generation – Design
- Ionization Dynamics – Facet II
- Ion Microscope – Design
- Gas Sheet Generation – Validation
- Profile Reconstruction
- Commissioning Status
- Summary

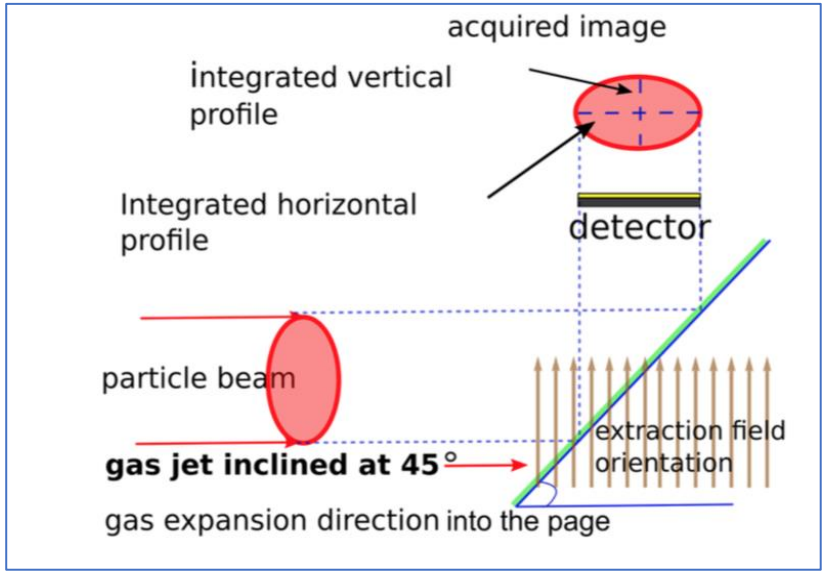


Motivation

- High-intensity beams present unique challenges in transverse profile diagnostics
- Single-shot, regenerative diagnostic
- “Gas sheet ionization monitor”
  - Generate a gas sheet, or “curtain” with nozzles and beam skimmers
  - 45˚ curtain for both axes projections in a single shot
  - Main particle beam ionizes neutral gas
  - Ions imaged by an “ion microscope”
  - Resolve high-intensity beams



Beam-gas interaction



Y. Hashimoto, et al, Proc. PAC 2001, Chicago, USA (2001)
V. Tzoganis, et al, *PRAB* **20**, 062801, 2017

Gas Sheet Ionization Monitor

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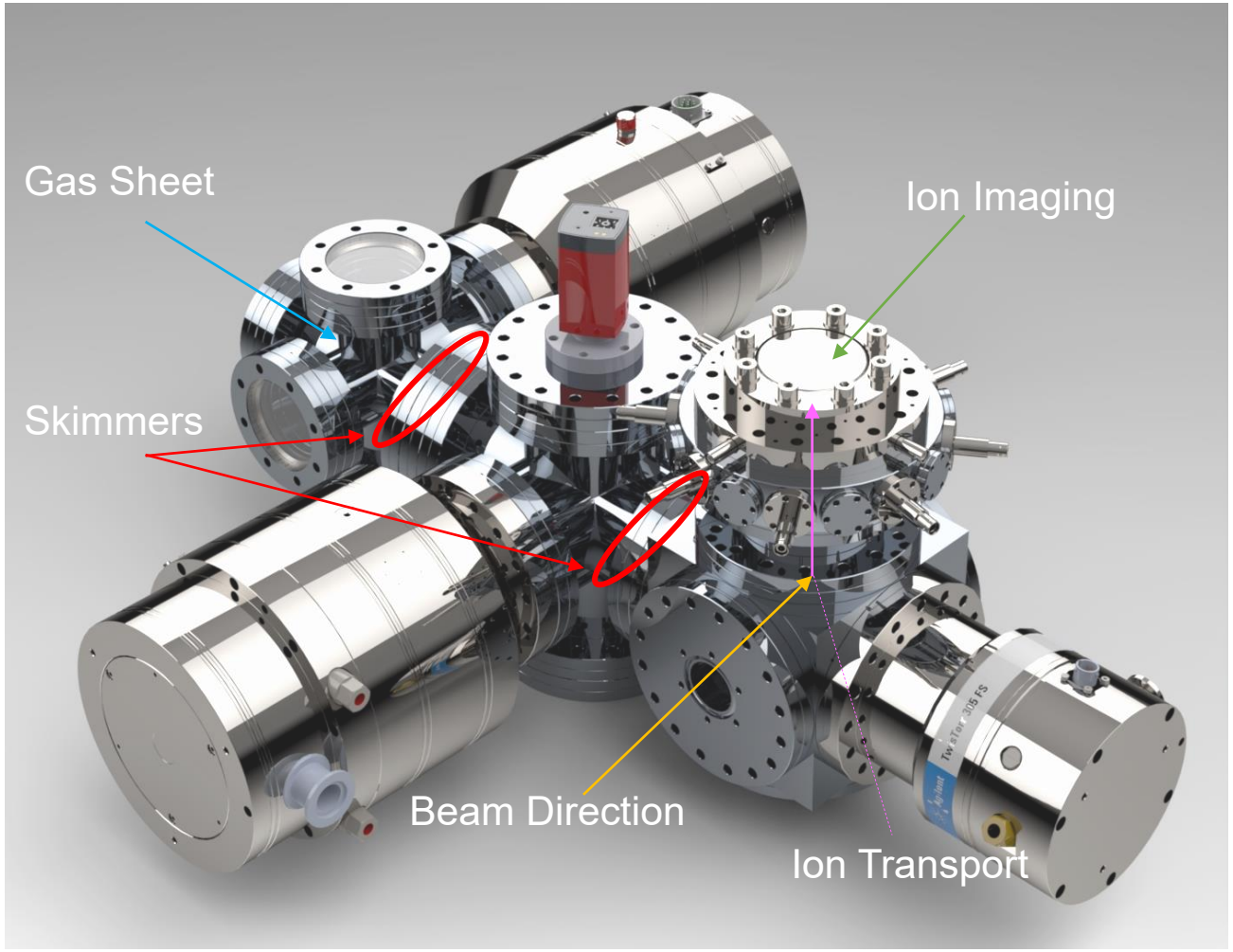
- Gas sheet generation, vacuum considerations
  - Externally triggered, remote controlled Piezo-valve for tunable gas pulse
  - Modular system accepts many skimmer sizes
  - High-capacity pumping
- Ionization and extraction/imaging
  - Tunable electrostatic lens array
  - Microchannel plate / Phosphor screen
- Data analysis and ML beam reconstruction



Gas Sheet Generation - Design

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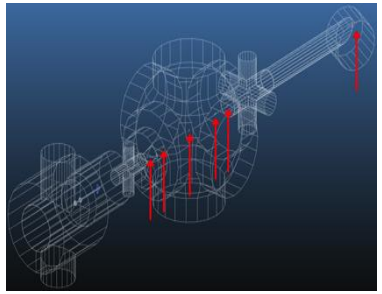
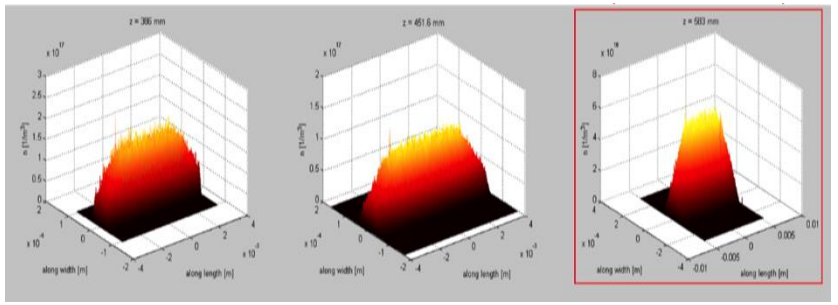
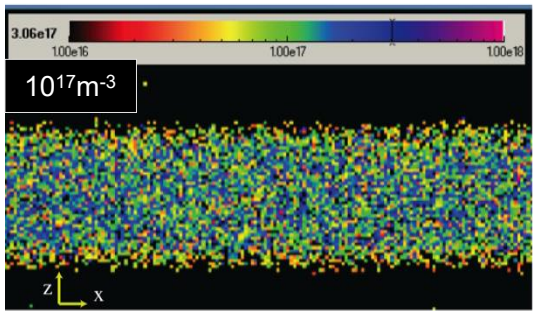
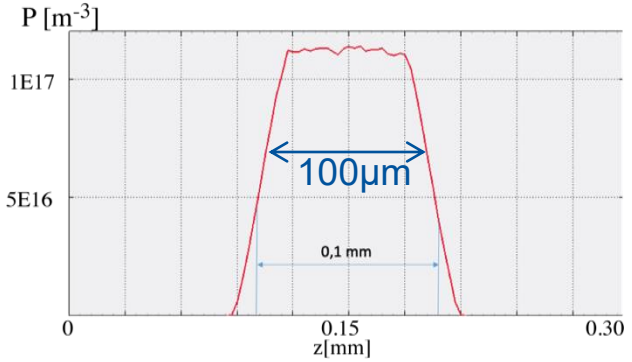
Optimization of gas density profile: (Molflow+)

- Example to study effect of skimmer size/shape/locations
- Compact design to maintain distribution at IP



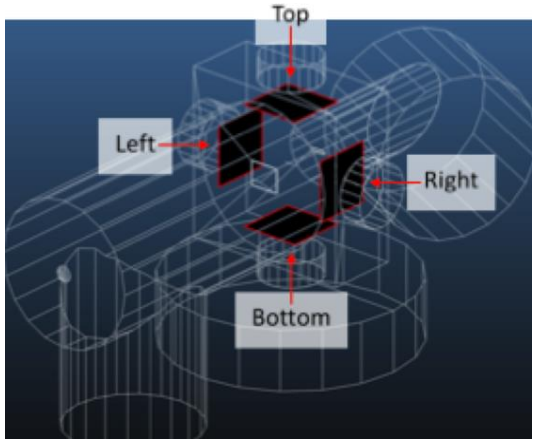






Differential pumping: (Molflow+)

- Strict UHV requirements determine pump speed and placement



Vacuum levels near IP (mbar)

	Min	Max	Av
Top	1,66E-09	4,49E-09	3,14E-09
Bottom	1,65E-09	4,13E-09	2,64E-09
Left	2,09E-09	4,54E-09	3,20E-09
Right	1,73E-09	4,50E-09	3,19E-09

Ionization Dynamics - FACET II

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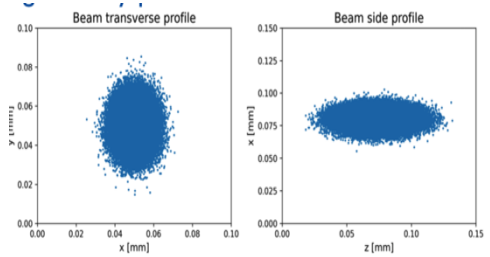
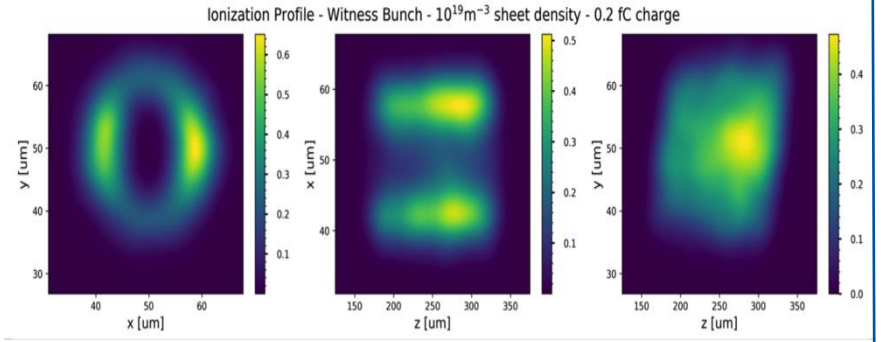
Configuration 1: drive/witness

Q = 0.5nC
σ_x= 5μm,
σ_y = 7.5μm,
σ_z = 14μm
Peak field
~20GV/m



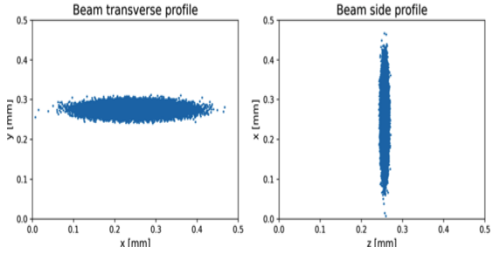


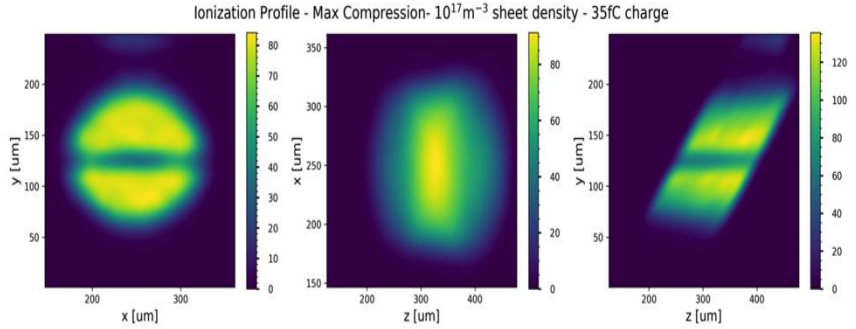
N_2 gas sheet
Density = $10^{19}m^{-3}$
Thickness = 150μm
Q_{ions} = 0.2 fC (10^3 ions)

- Lower end of acceptable statistics
- High gain MCP
- Thicker gas sheet

Configuration 2: max compression

Q = 1.4 nC
σ_x = 49μm,
σ_y = 8.5μm,
σ_z= 3.5μm
Peak field
~50GV/m





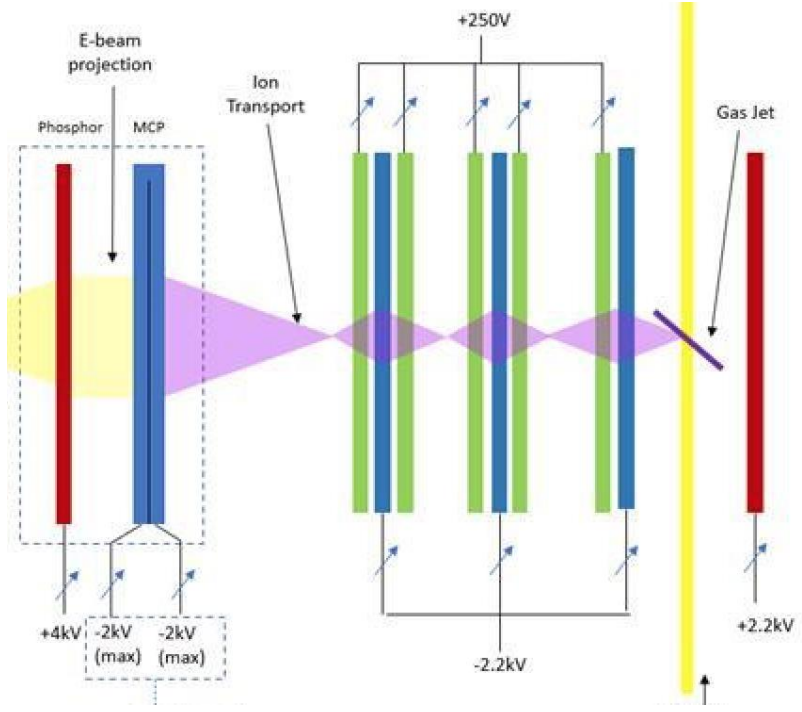
N_2 gas sheet
Density = $10^{17}m^{-3}$
Thickness = 150μm
Q_{ions} = 35 fC (>10^5 ions)

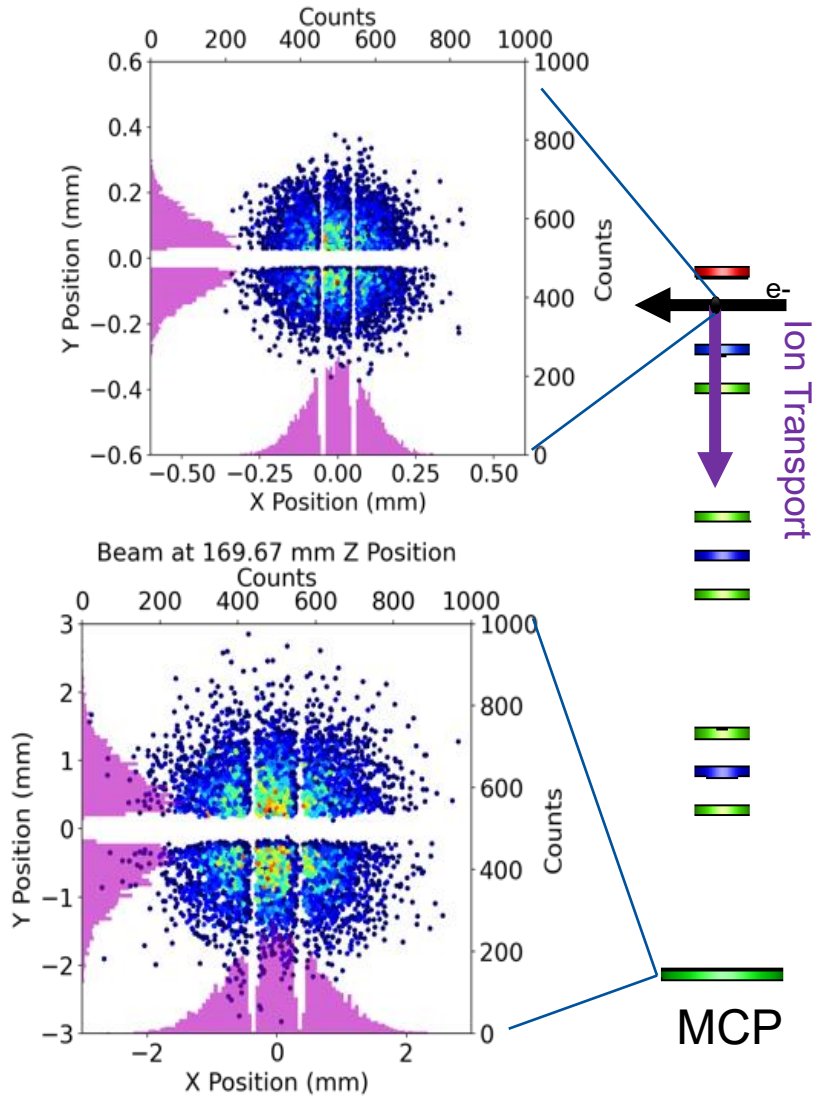
- Substantially larger yield
- Reduced densities
- flexibility
- Gas sheet tunability

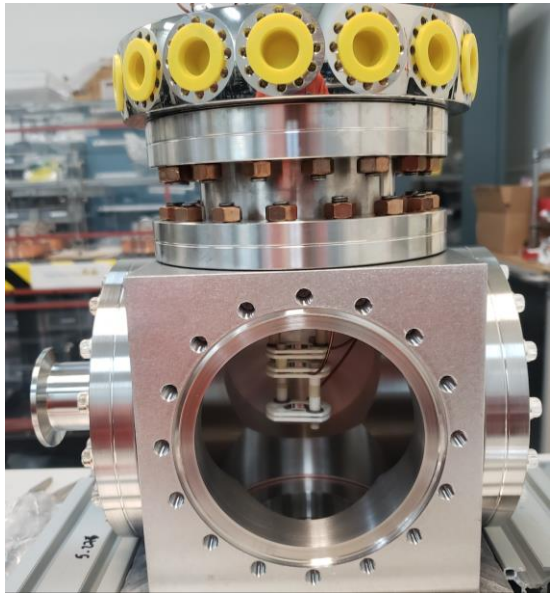
WARP simulations: Impact and field ionization considered for different regimes

Ion Microscope - Design

- Transport and magnify generated ion beam to Multi-Channel Plate (MCP) detector
- Simulated fields and ion beam transport in CST
- Tested magnification imaging ability with test beam with random initial transverse velocity
- Design magnification: 8x

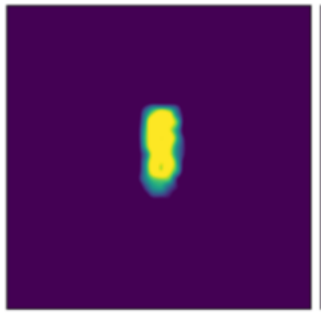




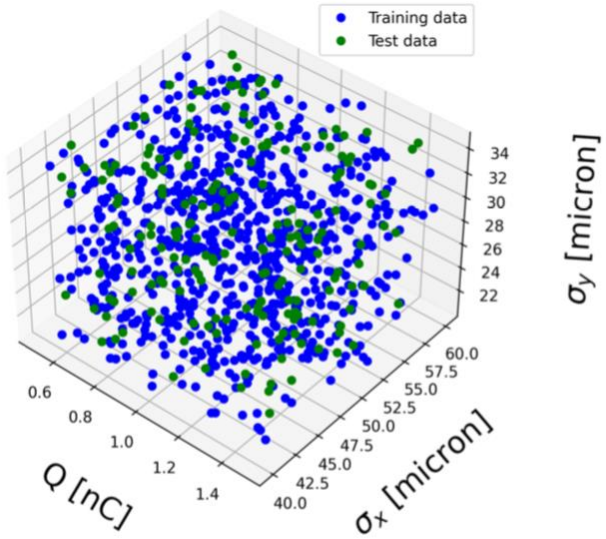


Profile Reconstruction

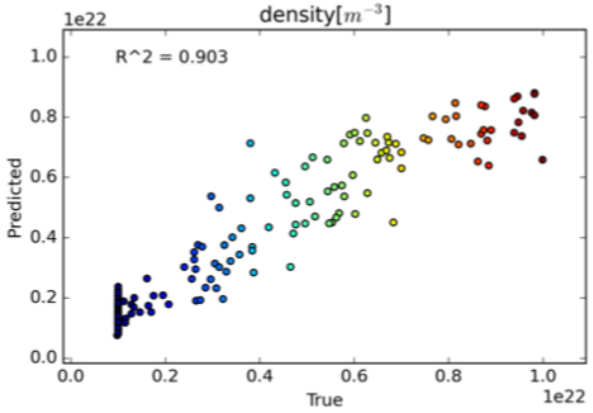
- Test data for surrogate model (WARP)
  - Variances in Q, σ_x, σ_y, σ_z, n_p
- Convolutional neural network (CNN)
- Robust performance of CNN
- Further enhancement when constraints enforced (e.g. from experimental measurements)

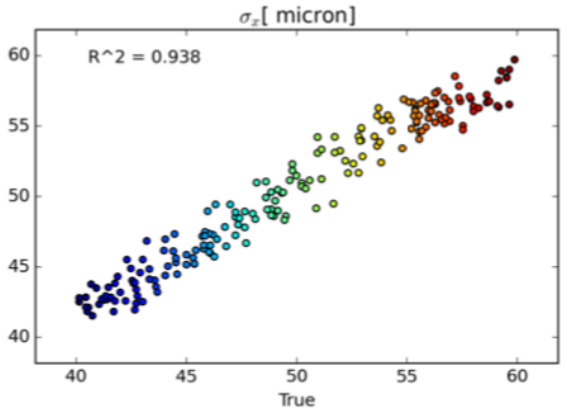


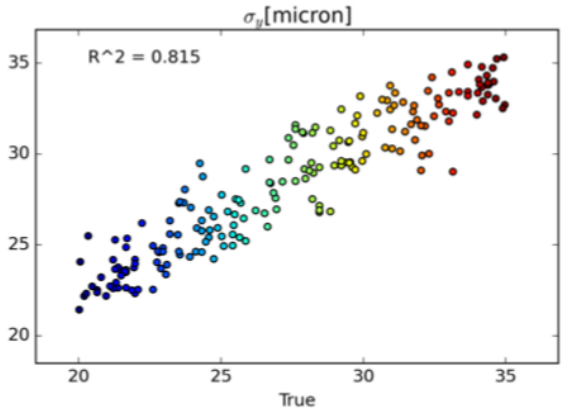
Sample beam



3D parameter space



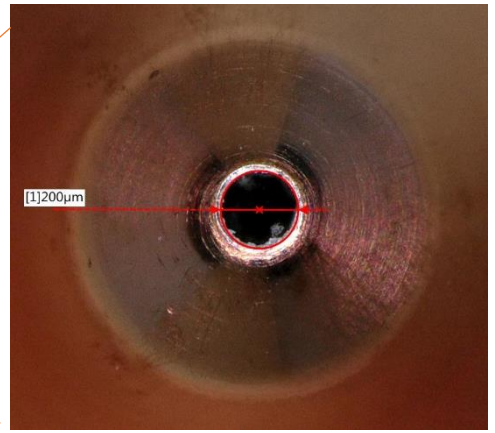




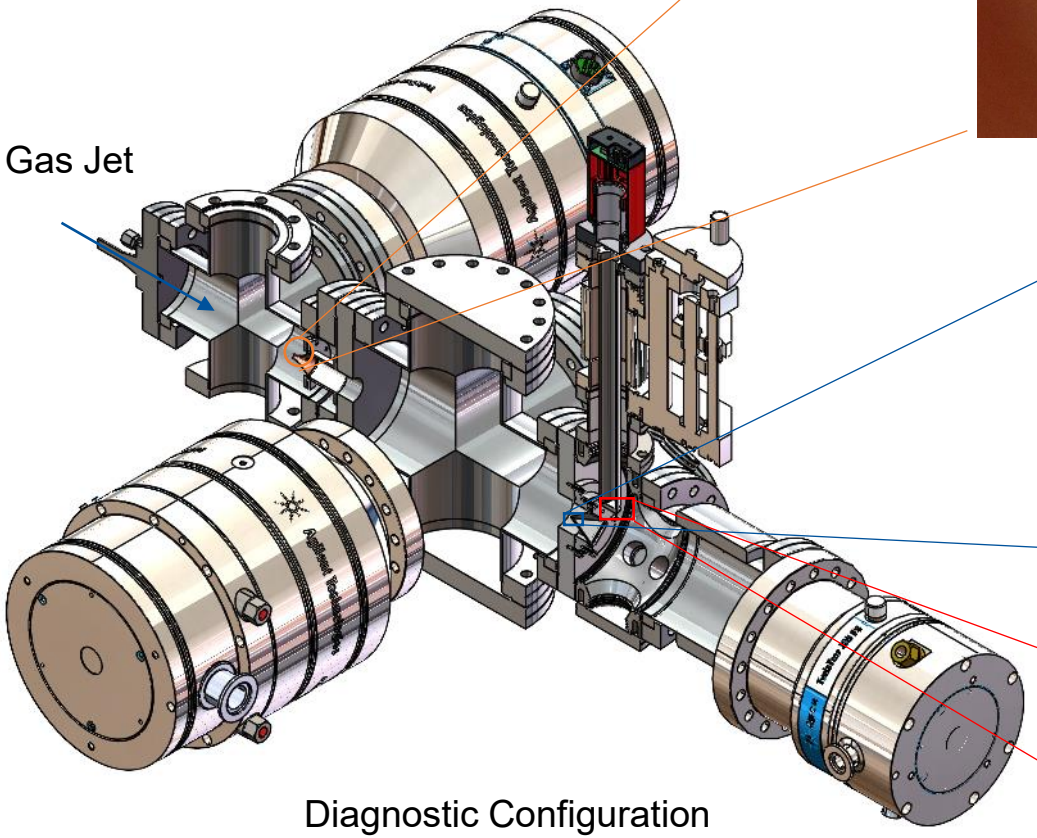
Performance plots: surrogate model vs truth, and relative R^2 values

Gas Sheet Generation - Validation

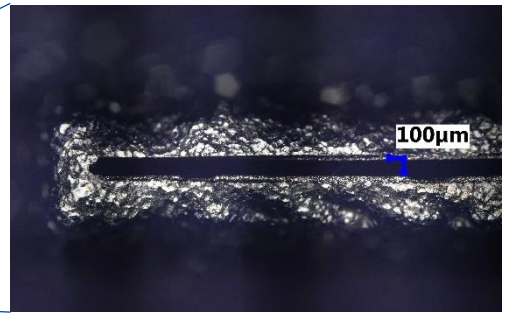
- Bench tests
  - Fast recovery of vacuum after gas sheet operation (N_2)
  - Gas density profile agrees for various skimmer sizes



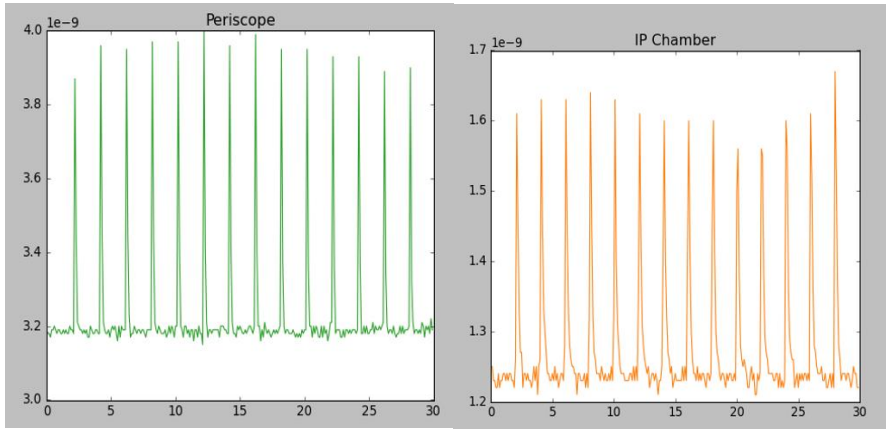
Gas Jet



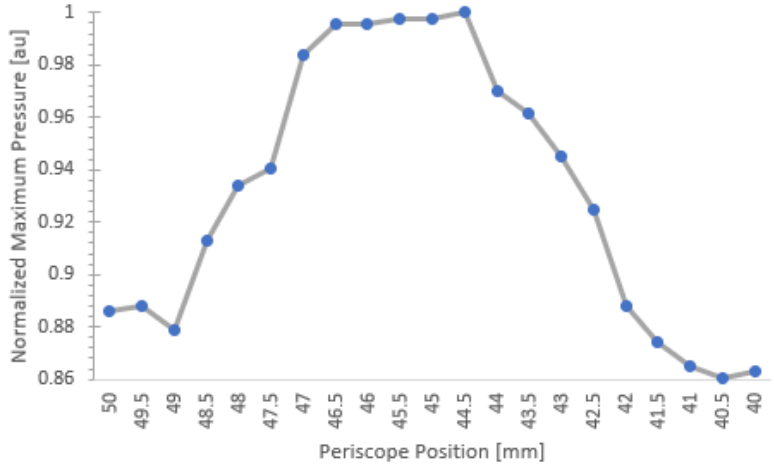
Diagnostic Configuration



1mm “Bulldozer” Collector



Vacuum Readings – 0.5 Hz



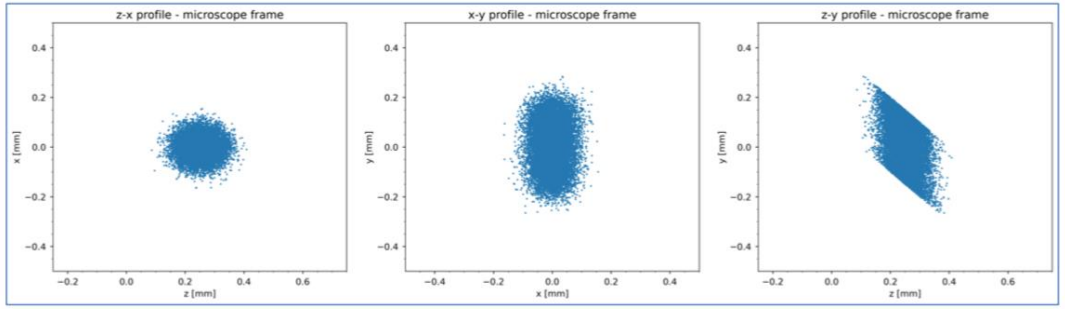
Gas Profile at Diagnostic

Commissioning Status

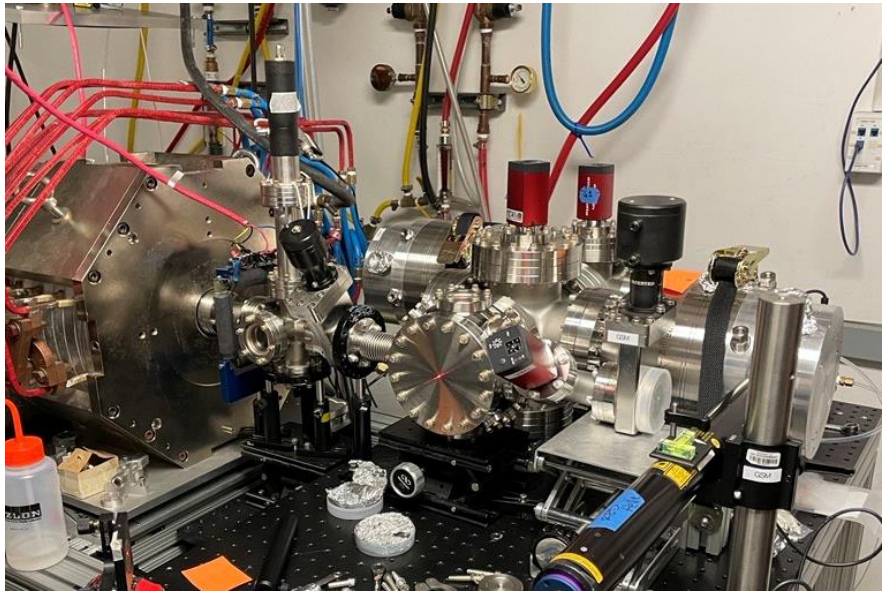
- UCLA Pegasus beamline
  - Validate results with well-diagnosed beams
  - Impact ionization dominates
  - Expected 9 fC charge (~55k ions)
  - Resolvable on MCP/phosphor
- Status
  - Installed on beamline, vacuum <E-9
  - Ion microscope commissioned on dedicated laser stand

Pegasus Beam
$\sigma_x = \sigma_y = 40$ μm
$\sigma_z = 200$ μm
Q = 0.1nC

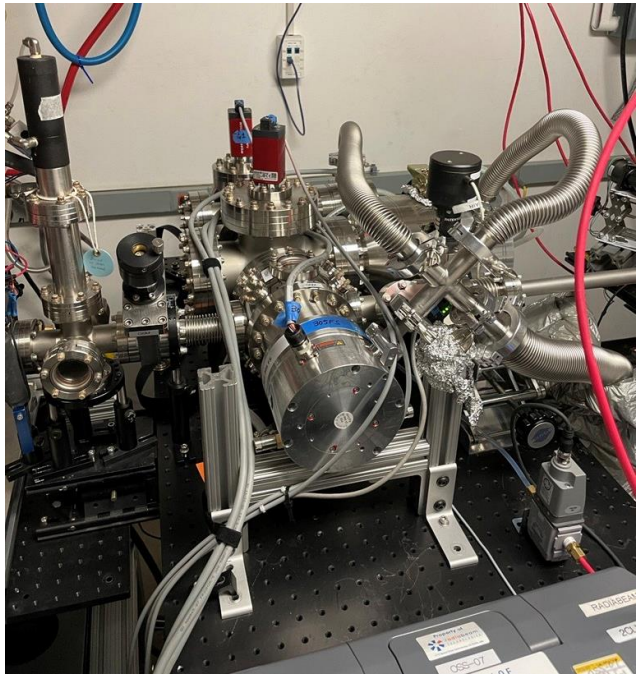
Gas Sheet
$n_{N2} = 10^{14}$ cm^{-3}
$L_{N2} = 150$ μm
$\theta = 45^{\circ}$

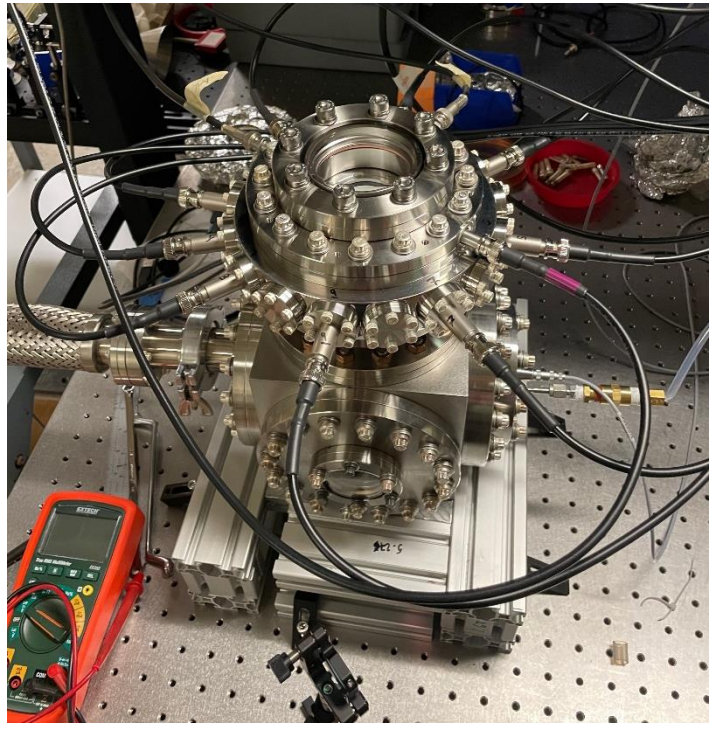


WARP simulations for Pegasus parameters



GSM at Pegasus

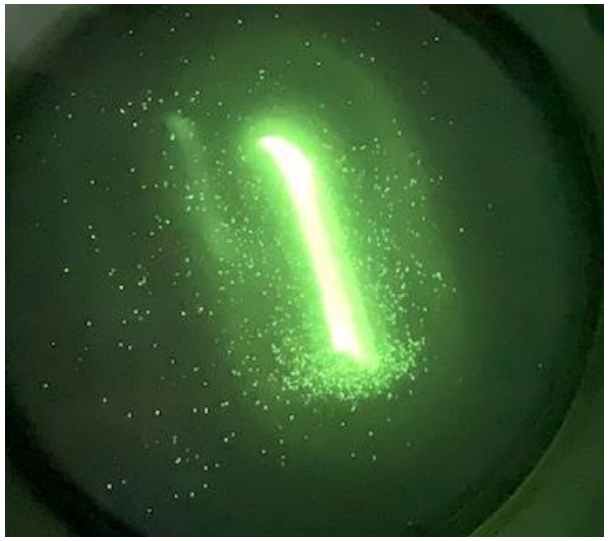




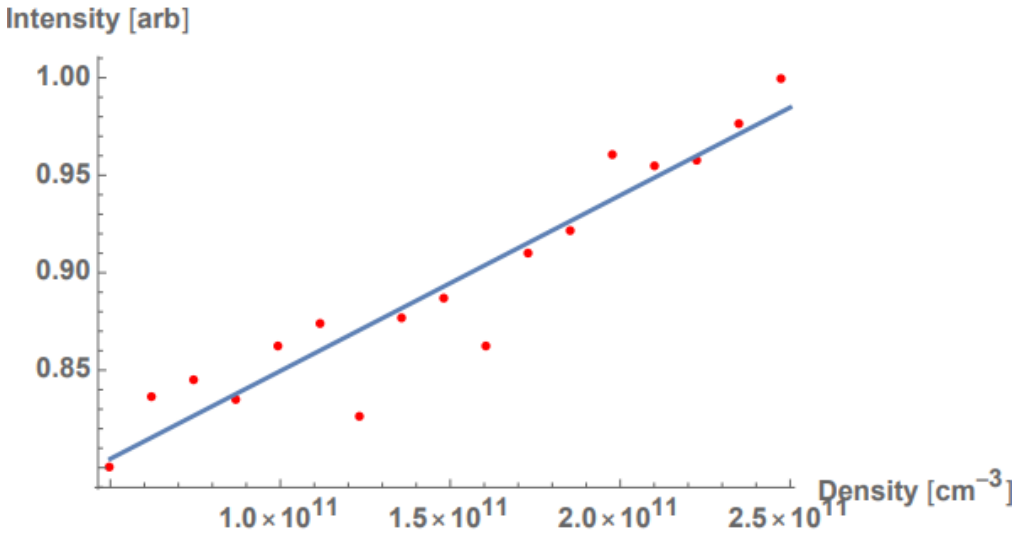
Microscope Commissioning

Summary

- GSM is viable diagnostic
- Bench tested individual components
  - Skimmers / pumping
  - Ion microscope
  - Reconstruction methods
- First tests at Pegasus UCLA
- Next tests at SLAC FACET II
  - High intensity
- Opportunities for integration in beamline feedbacks with machine learning
  - Unique source of beam information



Initial Ion Capture on Phosphor Screen



Integrated Phosphor Intensity vs. Gas Density

Acknowledgements

N. Burger, G. Andonian, T. Hodgetts, D. Gavryushkin, J. Penney, A.L. Lamure, N. Norvell, M. Ruelas (RadiaBeam), A. Diaw, N. Cook, C. Hall (RadiaSoft), A. Marinelli, D. Cesar, M. Hogan, V. Yakimenko (SLAC), P. Denham, D. Garcia, P. Musumeci, A. Ody (UCLA), C. Welsch, M. Yadav (Univ. Liverpool)

This work supported by Grant No. **DE-SC0019717**