

Experimental Area

Electron and Gamma Diagnostics,
Differential Pumping System and Li Oven

FACET-II User Meeting 2023

Doug Storey / Associate Staff Scientist

October 17-19, 2023

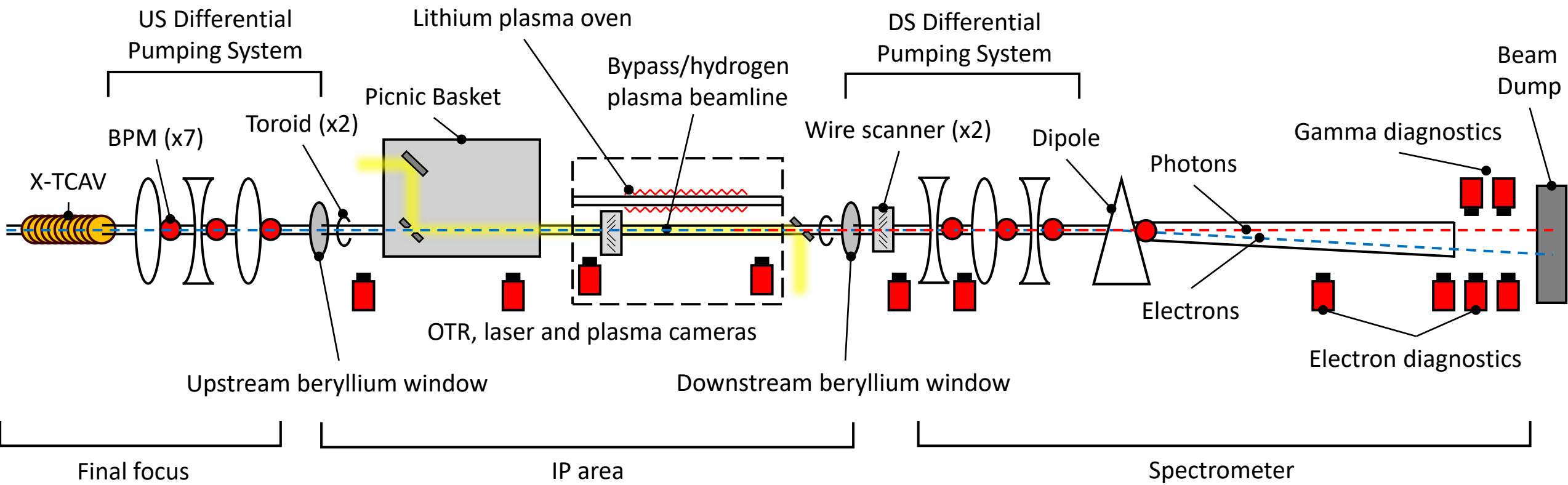


FACET-II

Facility for Advanced
Accelerator Experimental Tests

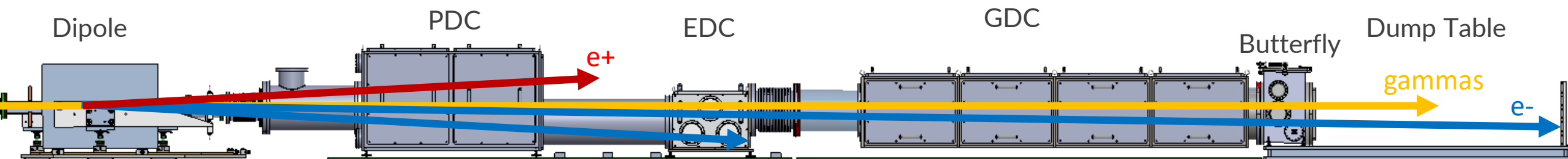
Experimental area overview

- Diagnostics, plasma sources, and DPS detailed here: <https://arxiv.org/abs/2310.06215>
 - D. Storey, C. Zhang, P. San Miguel Claveria, G. J. Cao *et al.*, **Wakefield Generation in Hydrogen and Lithium Plasmas at FACET-II: Diagnostics and First Beam-Plasma Interaction Results** (*submitted for publication*)



Result of significant coordination with users to support a diverse set of experimental requirements

Spectrometer beamline



- **Electrons**

- 1 GeV to >20 GeV at dump table, ~250 MeV+ at EDC chamber

- **X-rays and γ photons**

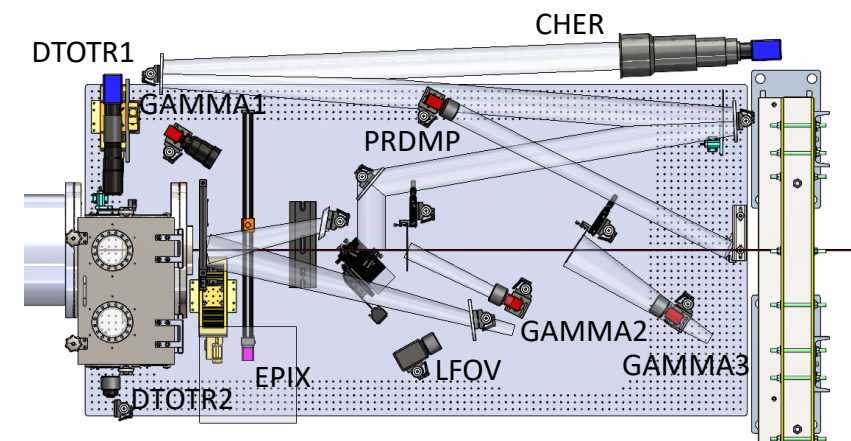
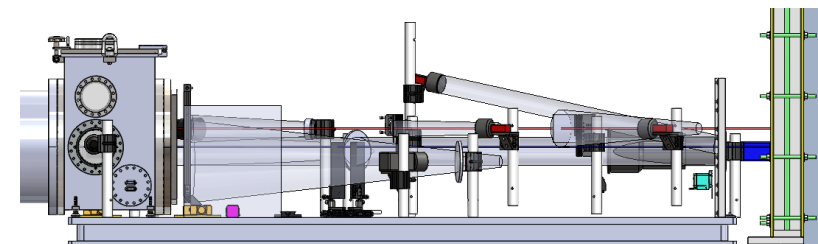
- Gamma 1/2 screens on the dump table
- new spectrometers under development for GDC

- **UV photons**

- Extracted at EDC chamber, new XUV spectrometer under development

- **Positrons:**

- 2.5 - 6 GeV in air after PDC, larger range in PDC in future

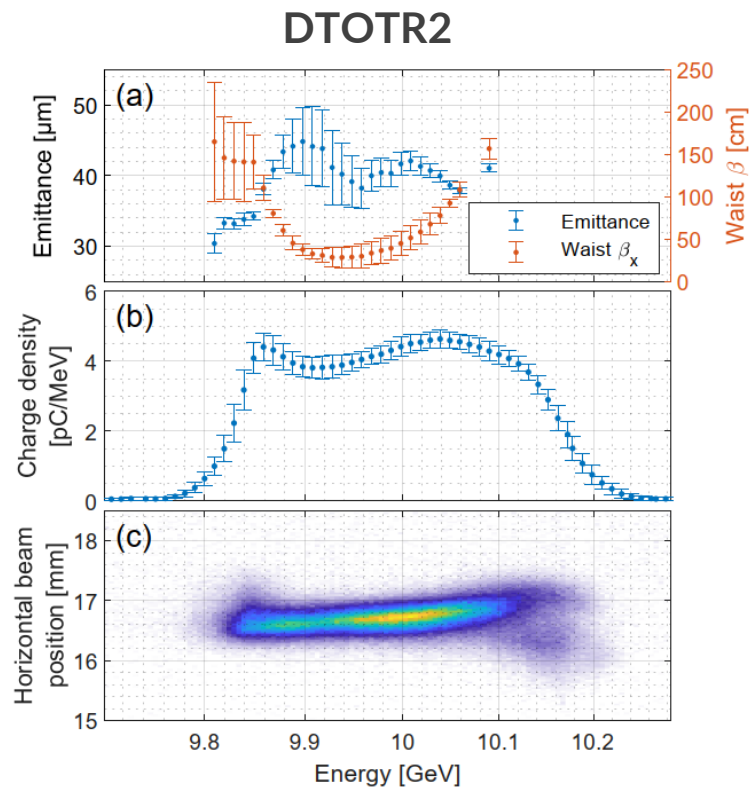


Dispersive and reimaging spectrometer enables energy resolved diagnostics for electrons, positrons, and photons

Electron diagnostics: Emittance

- **Dispersive quad scans**

- Multi-shot measurement for $\epsilon_n(E)$ and $\beta_x(E)$



◀ Summer 2022, compressed beam
Parameters across core:

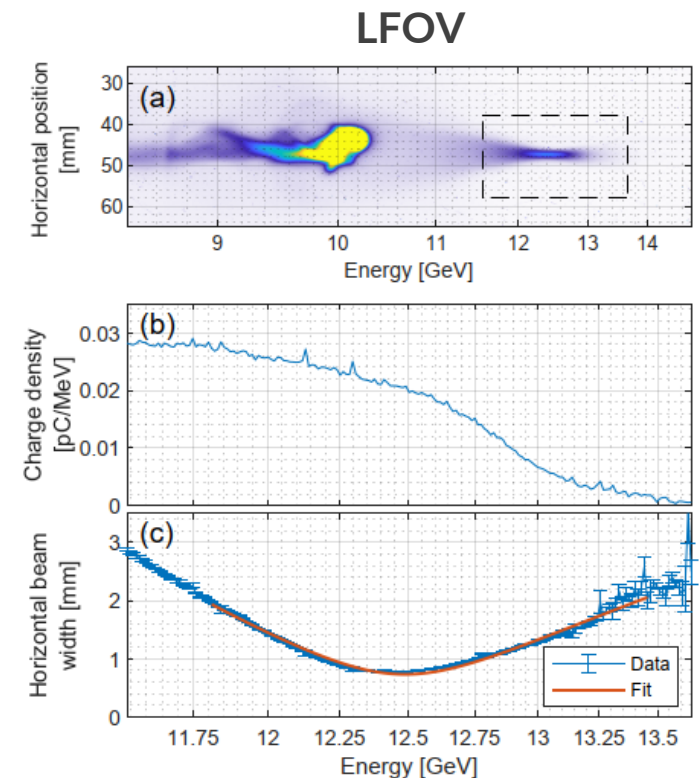
- $\epsilon_{n,x} \sim 40 \mu\text{m}$
- $\beta_x \sim 30 \text{ cm}$
- 3% FWHM energy spread

Summer 2022, first H₂ PWFA results ▶
Charge accelerated to 12.5 GeV:

- $\epsilon_{n,x} = 1400 \mu\text{m}$
- $\beta_x = 17.7 \text{ cm}$
- $\Delta z = 0.7 \text{ cm}$ (from Be window)

- **Single shot emittance measurements**

- Emittance resolution down to $\sim 5\%$
- Provides β_x and waist location



Development and characterization of these diagnostics is ongoing

Electron diagnostics: New online emittance diagnostic app

- Project by SULI intern Samuel Kresch
- Performs single-shot emittance analysis for saved DAQ, or live image data

F2 Emittance (on facet-srv20)

DAQ Data | Live Data

Select Data Set:
 DAQ: E300 | 3281 | Last | Load

Select Camera: DTOTR2 | Rotated: | Subtract BG:

Select Image: 300 | Next | Plot | Plot and Analyze

DataSet Info
 Experiment E300, DataSetID = 3281
 Obtained 06-Dec-2022 18:37:56
 Comment: DTOTR Quad scan - waist at IPWS1. New dispersion
 Nbr of Cams: 1
 Nbr of shots: 11 steps x 50 shots

Lock ROI: | Manual Clim: 0 | 1632

Spectrometer Settings
 Dipole [GeV]: 10.01 | Auto Populate
 Q0D [kG]: -115.91
 Q1D [kG]: 180.81
 Q2D [kG]: -115.91
 Object Plane: IPWS1 | 1993.91
 Image Plane: DTOTR2 | 2015.26

Energy Calibration
 Nominal Dispersion [mm]: -55.9
 10 GeV Beam Position [mm]: 18.26 | Centroid
 Toggle ECal | Charge Plot | Plot Transport Matrix

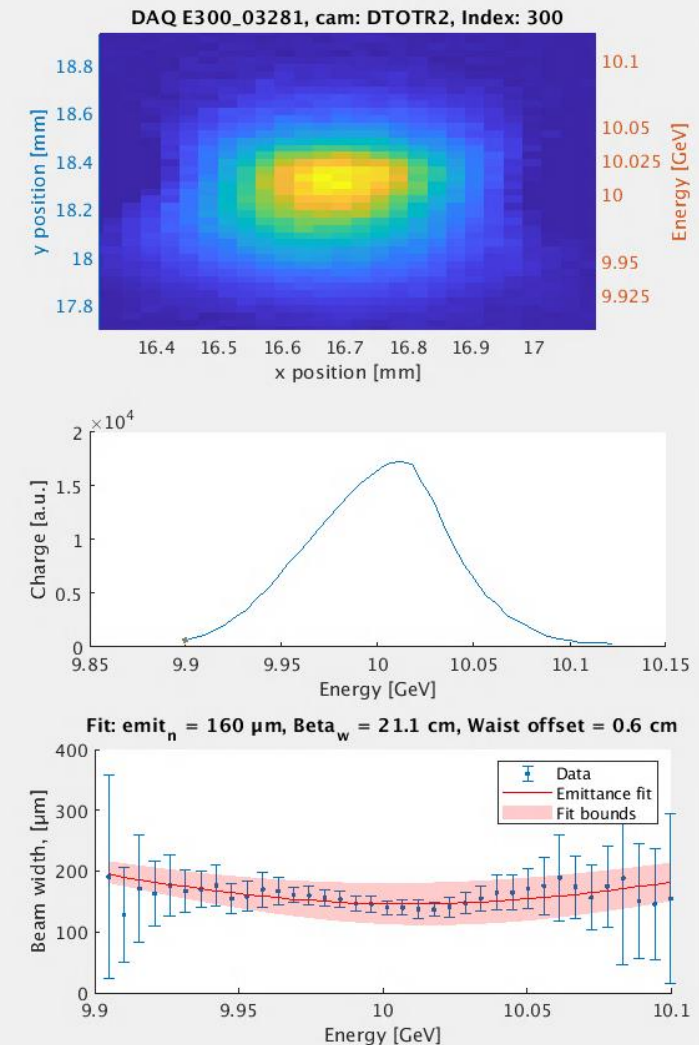
Beam Width Plot Settings
 Plot Beam Widths | Plot fit: | Fit type: Method 1

Emittance
 Desired Emittance: 20 μm
 Desired Beta: 50 cm
 Desired Waist Offset: 0 m
 Plot Desired | Do Fit

Fit Results
 Fit Emittance: 159.8 μm (125, 195)
 Fit Waist Beta: 21.14 cm (15.9, 26.4)
 Fit Waist Offset: 0.0061 m (-0.0127, 0.02)
 R-squared: -0.198E

Reset | Print to logbook

Log
 16-Oct-2023 11:33:45: Energy axis added
 16-Oct-2023 11:33:46: Magnet strengths successfully loaded.
 16-Oct-2023 11:33:46: No object plane found - setting to IPWS1
 16-Oct-2023 11:33:49: Energy axis removed
 16-Oct-2023 11:33:50: Energy axis added
 16-Oct-2023 11:34:17: Fit data added to plot
 16-Oct-2023 11:35:12: Energy axis removed
 16-Oct-2023 11:35:13: Energy axis added
 16-Oct-2023 11:36:41: 10 GeV beam position updated to ROI centroid position
 16-Oct-2023 11:36:43: Energy axis added
 16-Oct-2023 11:37:01: Fit data added to plot

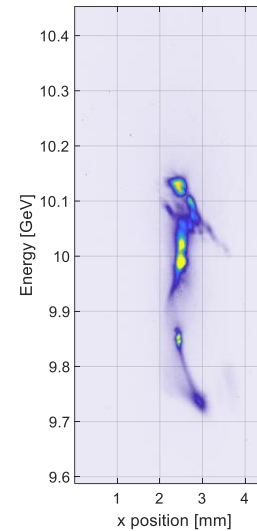


Developing standardized online analysis tools to ensure consistency in data analysis

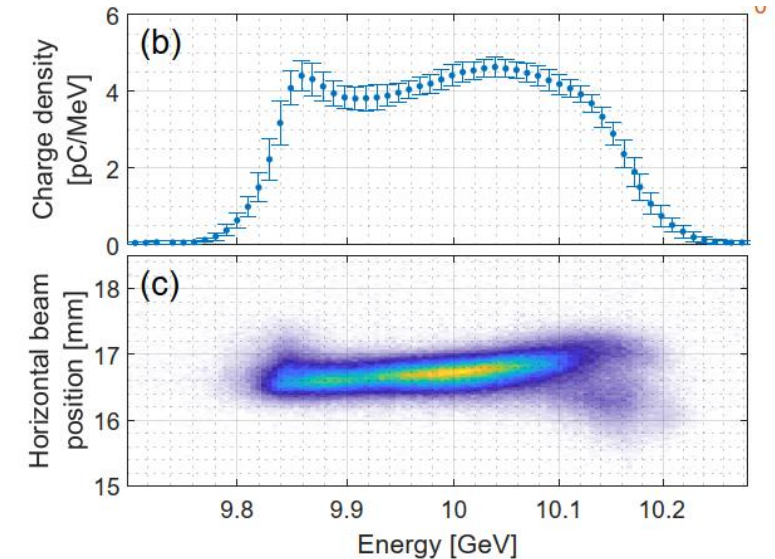
Electron diagnostics: Energy

- **High resolution / in-vacuum screens**
 - DTOTR1 – High resolution
 - 4.5 μm spatial res. \rightarrow $\sim 0.01\%$ rel. energy res.
 - DTOTR2 – Mid field of view
 - 30 μm spatial res \rightarrow $\sim 0.05\%$ rel. energy res.
- **Large bandwidth / Large field of view**
 - LFOV and CHER
 - Covers the 1 GeV to 20+ GeV range
 - LFOV uses a DRZ-Fine scintillator
 - CHER has much higher damage threshold
 - EDC_SCREEN
 - Extends measurement range to 250 MeV

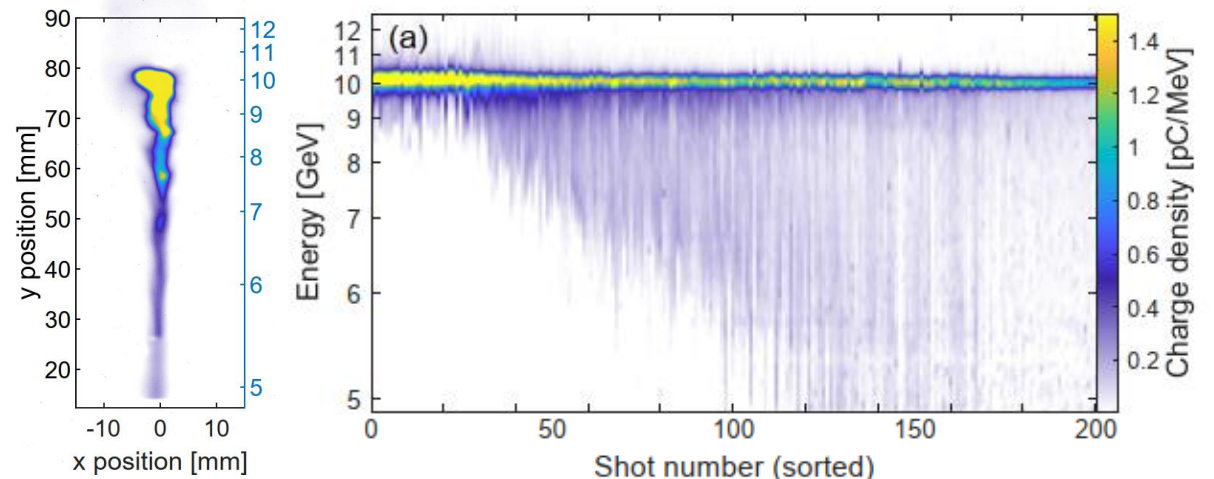
DTOTR1



DTOTR2 – med resolution



LFOV – large BW – Energy depletion with H₂ PWFA



Electron diagnostics: Longitudinal diagnostics

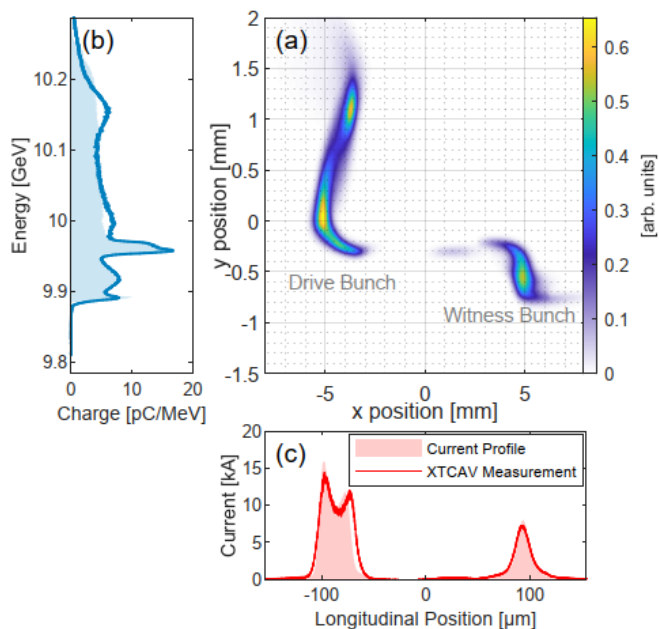
- **XTCAV**

- Located in the final focus and streaks in x-direction
 - Nominal longitudinal resolution down to 1 μ m (\sim 3fs)
- Vertical dispersion gives LPS in single shot
 - Energy resolution: \sim 0.01%

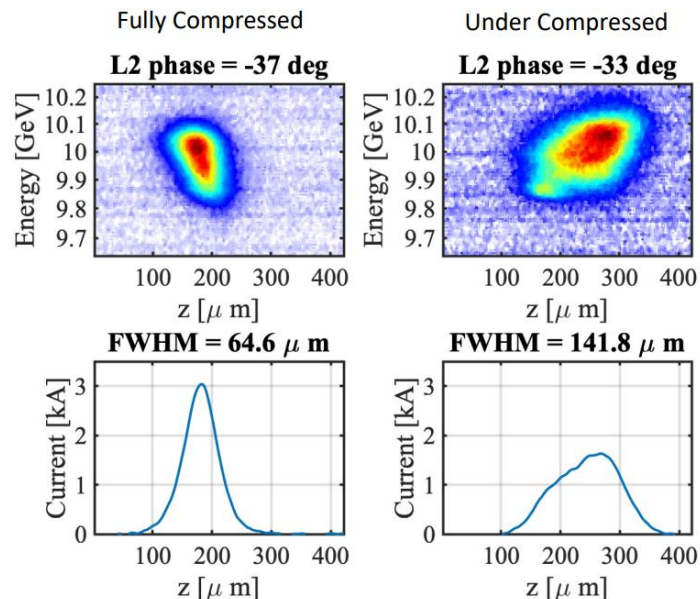
- **Additional non-invasive diagnostics:**

- S20 bunch length monitor (not yet)
- EOS: see Claire's upcoming talk
- SYAG: energy distribution in BC20

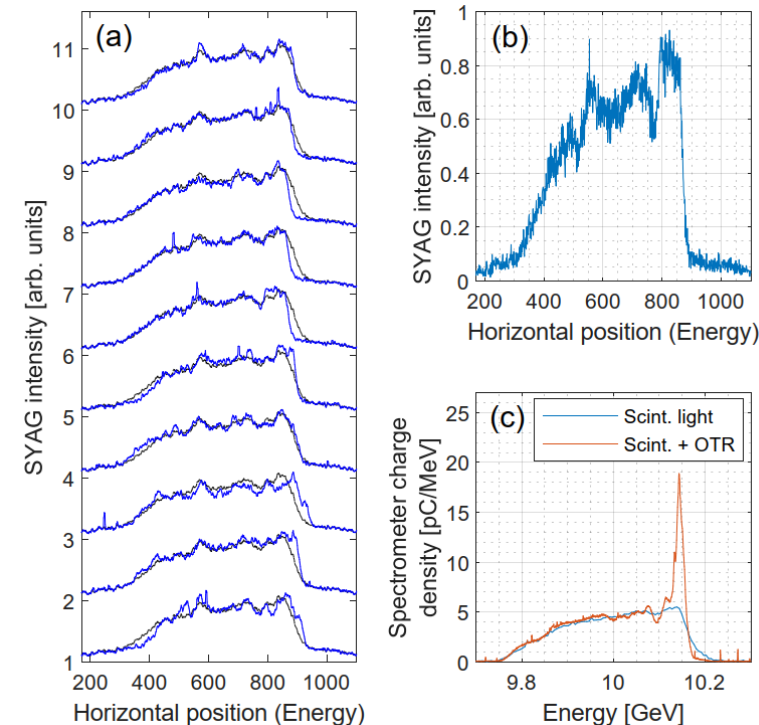
Simulated XTCAV measurement



2022 - L2 compressions scans



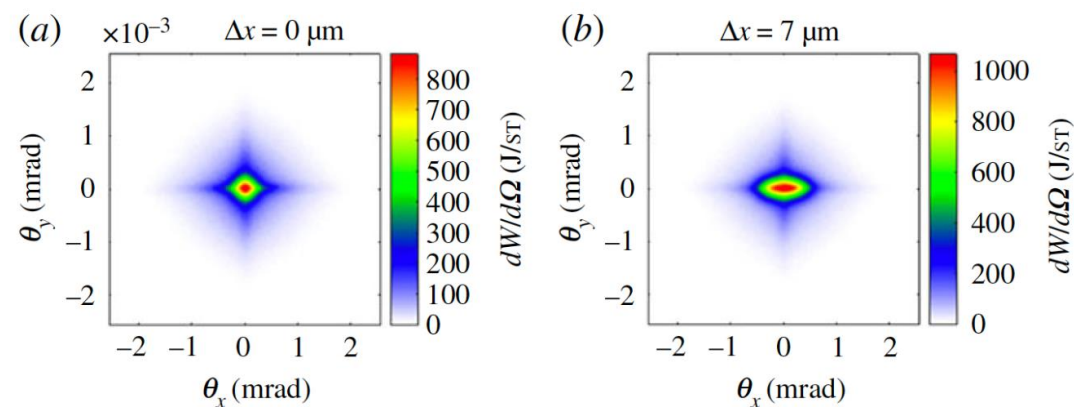
(a, b) SYAG, (c) DTOTR1 and 2



Gamma diagnostics: Intensity and spectra

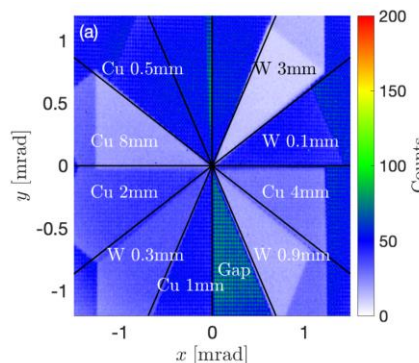
- Design and first results detailed here: <https://arxiv.org/abs/2310.05535v1>
 - P. San Miguel Claveria, *et al.*, **Commissioning and first measurements of the initial X-ray and γ -ray detectors at FACET-II**, *Proc. of AAC'22*.
- **Gamma1**: uniform DRZ scintillator or CsI array (0.5mm pixels)
 - Provides angular profile and intensity
- **Gamma2**: DRZ scintillator behind multi-material/thickness converter
 - Information on gamma spectra

GAMMA1 – Betatron radiation from PWFA (sim.) with witness bunch (a) aligned, and (b) offset

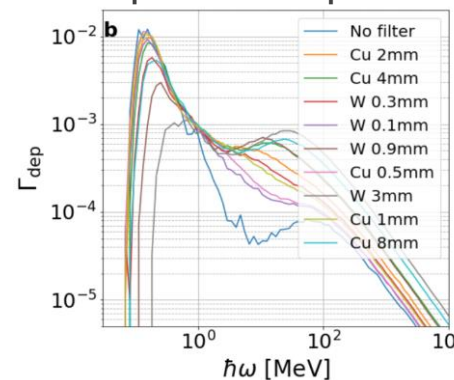


GAMMA2

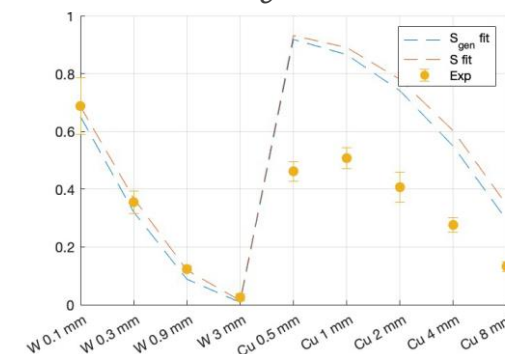
Raw image + filters



Spectral response

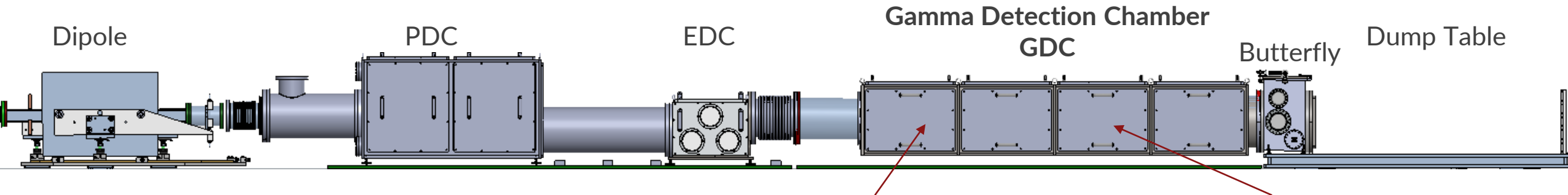


Fit: synch. rad spectrum with $E_c = 65$ keV

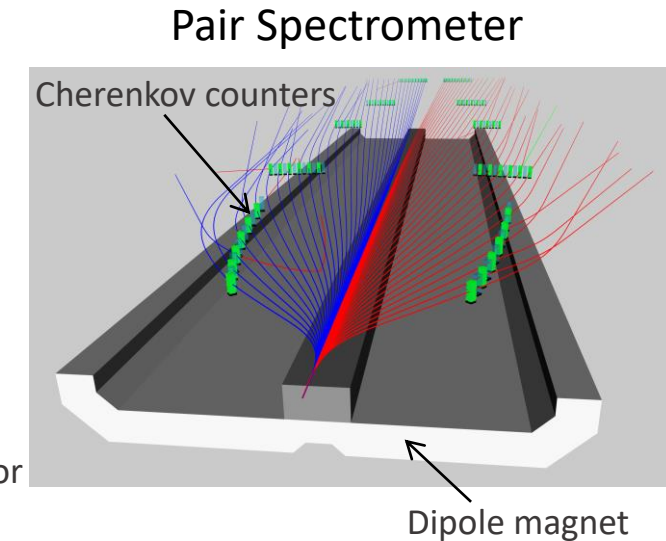
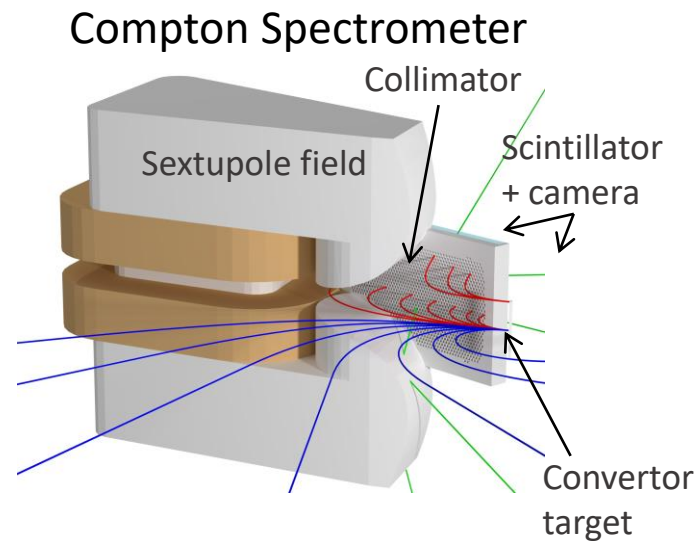


Gamma diagnostics commissioned and instrumental for PWFA, SFQED and more

Gamma diagnostics: Up and coming



- Compton spectrometer: single-shot gamma spectrometer
 - Range of 200 keV – 20 MeV
 - Secondary capability to resolve angle-energy double differential
- Pair spectrometer:
 - Measure gamma spectrum to 10 GeV
- More details in talk by Brian on Wed. afternoon



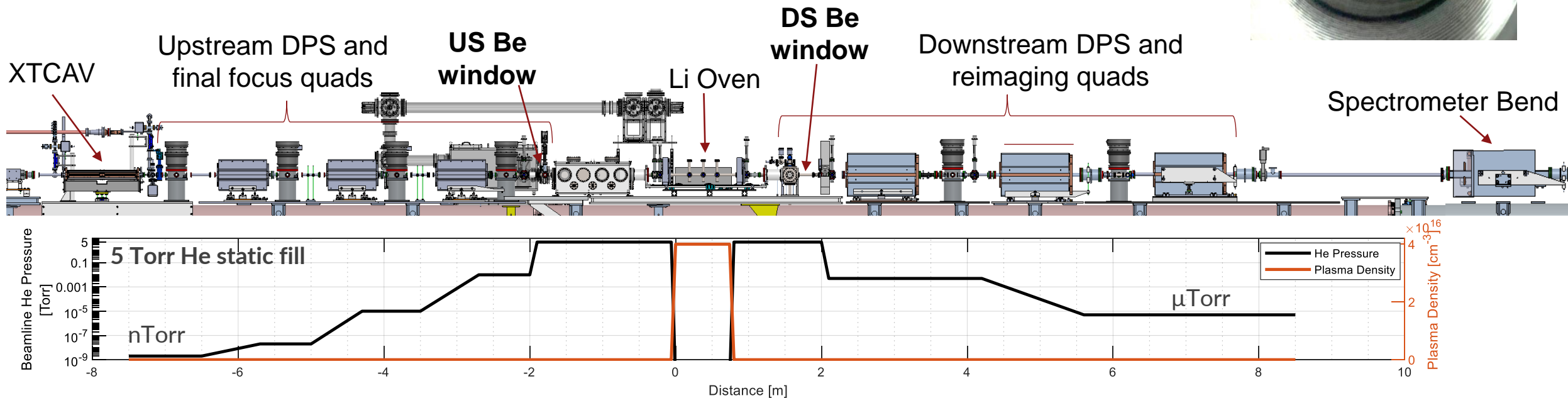
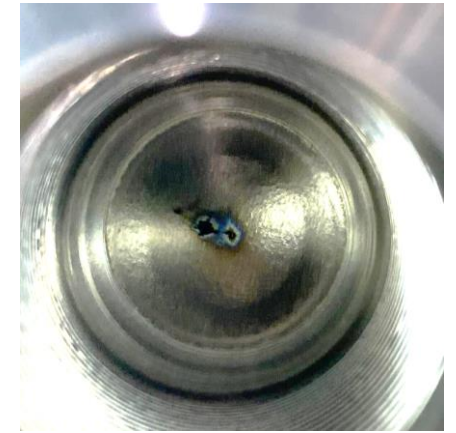
Design Credit: B. Naranjo (UCLA)

New diagnostics will enable increased range and spectral sensitivity for gamma measurements

Differential Pumping System (DPS)

- The FACET-II beam drills holes through solid materials near the IP
 - We have $\sim 200\ \mu\text{m}$ “beam-aligned” holes in the US and DS Be windows
- DPS allows gas pressures up to 10 Torr in the IP
 - Supports gas jets and static fill for Li and H_2 plasmas
 - Windowless transmission for low background (not yet fully implemented)

Upstream Be window after the 2022 run



Differential pumping system critical to allow gas delivery to IP for gas jets and plasma sources

DPS operating modes

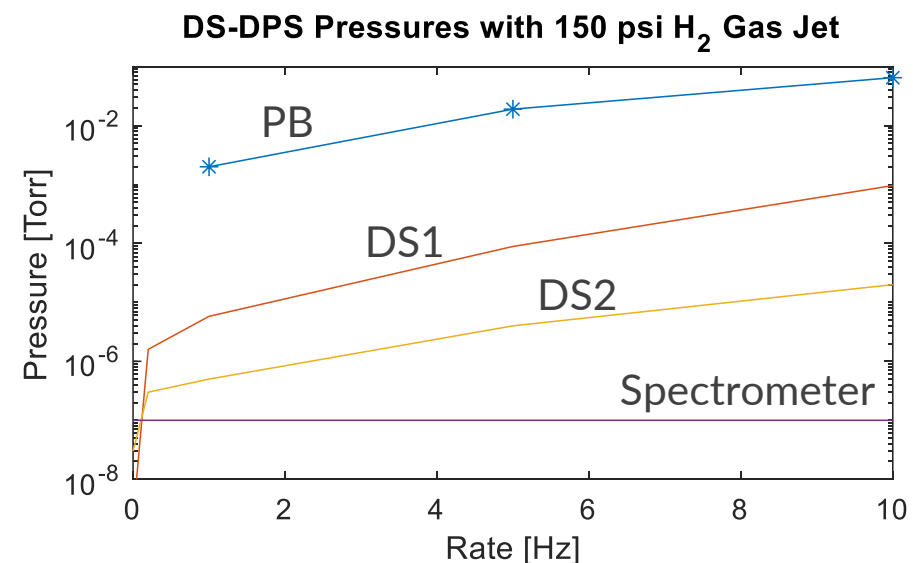
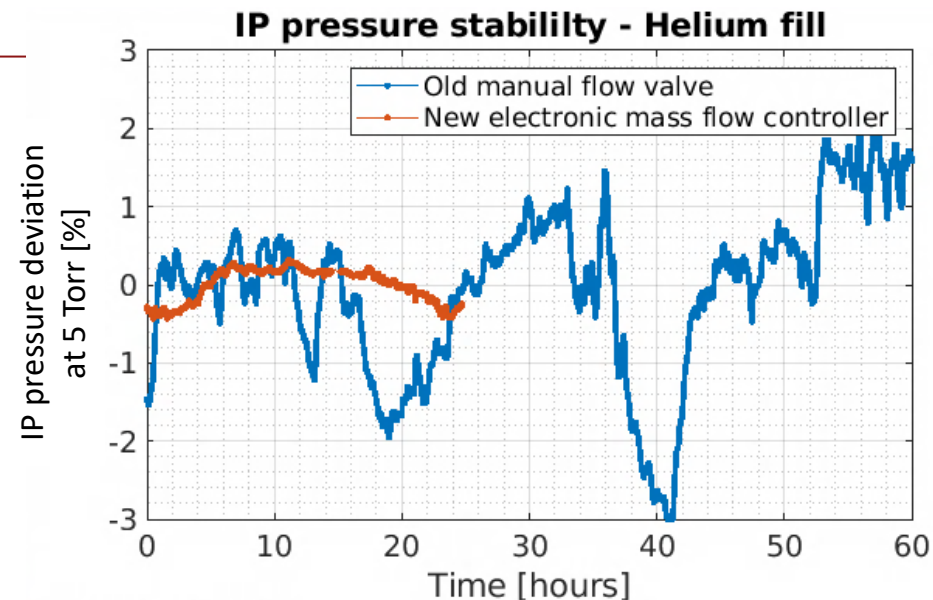
- **Static fill:**

- He or Ar up to 10 Torr, H₂ up to 5 Torr
- Pressure stability < 0.5% over 24 hours
 - Mass flow controller implemented by SULI intern Samara Steinfeld

- **Gas jets:**

- Hydrogen or helium, up to 1200 psi backing pressure
- Rates up to 10 Hz, limited by
 - 1) Background pressure in PB
 - 2) Beamline pressure (DPS limit)

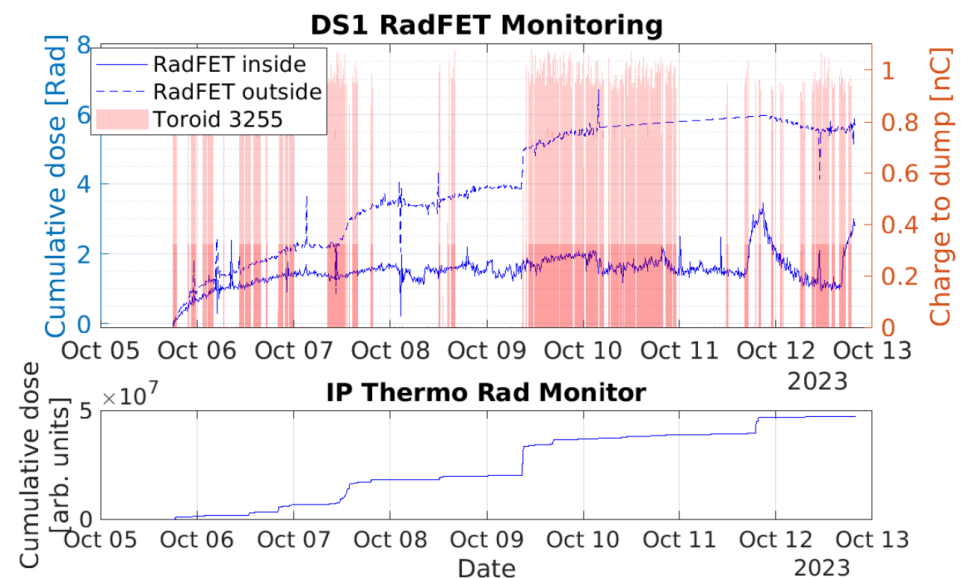
State:	Gas:	Pressure:
0: High vacuum	none	High vacuum at IP
1: Li oven	He	≤ 10 Torr
2: H ₂ plasma	H ₂	≤ 5 Torr
3: Gas jets	He, H ₂	1200 psi, up to 10 Hz



Improvements to DPS

- Radiation shielding
 - >3 tons of lead and poly shielding placed around roughing pumps
 - No radiation faults since shielding added
 - Improvements to “watcher” from SULI intern Samara Steinfeld
- Purge gas added to improve H2 pumping efficiency
 - Increased static fill range from 2 Torr to 5 Torr
 - Increased rate available for gas jets
- New mass flow valve for improved static fill stability
 - Allows for remote operation, better stability

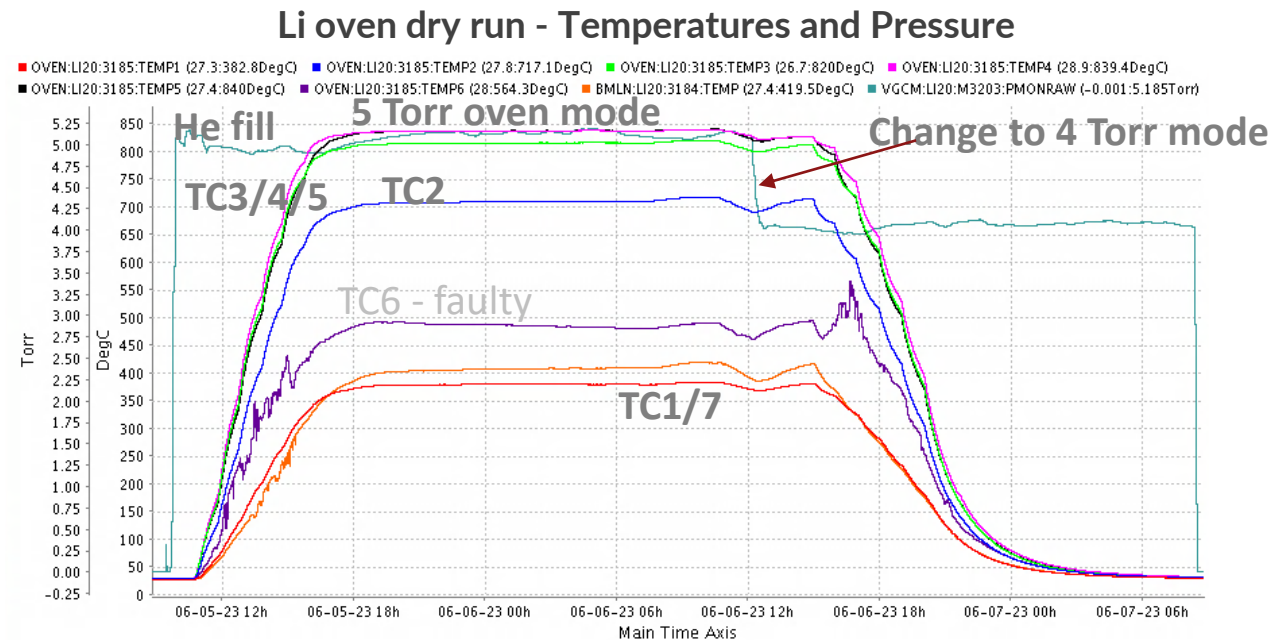
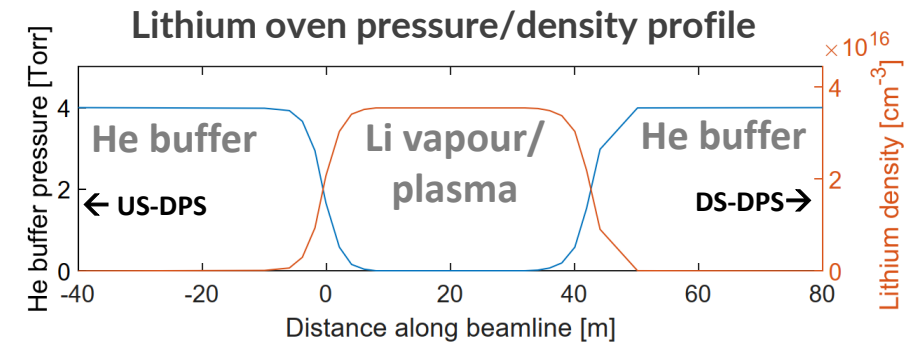
Rad shielding of DS1 roughing pump



DPS is now more robust than in the previous run

Lithium plasma oven operation with DPS

- IP pressure is very robust to DPS failures
 - No single DPS failure affects the IP pressure
 - No DPS failures since lead shielding added
 - Need more experience with high-loss conditions
- Pressure stability < 0.5% of 24 hours
 - 0.5% diurnal temperature swing
 - 0.1% stability over hour time scale
- Dry-run of Li oven with DPS (no beam)
 - Operated at 5 Torr for >20 hours



Nearly ready to start testing the lithium plasma oven with beam!

Documentation on confluence

- Updated how-to pages can be found here:
 - [How to perform a static fill](#)
 - [Lithium oven procedure](#)
 - [How to operate the gas jets](#)

Pages / FACET-II Home / How-to articles

How to use the gas jets

Created by Storey, Doug Wesley, last modified on Oct 02, 2023

These are the new instructions for how to use the gas jets. This procedure will supersede the "How to use gas jets" and "How to DPS with gas jets" pages.

- Hardware requirements:
- Step-by-step guide
 - 1. Prepare the DPS system
 - Figure 1: Nominal vacuum state, before gas jet operations
 - Figure 2: Gas jet control panel
 - 2. Prepare the gas delivery
 - NOTE ABOUT CHANGING THE REGULATOR
 - Figure 3: Gas bottle and fill line
 - Figure 4: Drain line and scroll pump
 - Figure 5: IOTA controller and it's correct set up
 - 3. How to operate the jet
 - TROUBLESHOOTING:
 - THINGS TO WATCH OUT FOR:
 - Figure 6: Beamline pressures under nominal conditions with H2 gas
 - 4. How to reduce pressure or get into safe state to move the gas jet assembly
 - 5. How to shut down after gas jet operation at end of shift or before changing gas species/regulator
 - 6. Return DPS to nominal state
- Maximum operating rates
- Related articles

Step-by-step guide

1. Prepare the DPS system

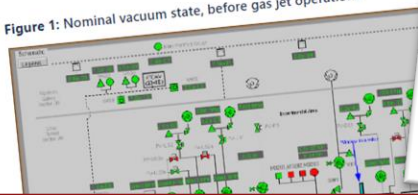
1. Verify both US-DPS and DS-DPS pumps are running and operating as normal.
 - a. Also check VPIO:LI20:3164 to ensure the ion pump is on.
 - b. Figure 1 shows how the DPS looks under nominal operation.

Hardware requirements:

1. Gas bottle of selected gas species. Needs to have >1200psi if you plan to run to high.
2. N2 available in the 6 pack if you plan to run with H2
3. Regulator - there are multiple available
 - a. 100 to 1200 psiG (max 3000psiG, but we only run up to 1200)
 - b. -30psiG - ?? psi (for low pressure, and the ability to run to real 0, not

Note: Approval to operate with hydrogen needs to be given. The authorization here:
https://docs.google.com/document/d/13LvuOP7FBSUg4rawcie_g3stOF0nirf4Z/
 For any testing, we use helium. Particularly for testing when in access - except following a reviewed and approved procedure.

Figure 1: Nominal vacuum state, before gas jet operations



Pages / ... / E-300

Li Oven Turn on Procedure

Created by Storey, Doug Wesley, last modified on Jun 09, 2023

Goal of this procedure: Enter oven mode and reach desired oven profile

Instructions: To keep track of changes to the procedure - copy this page

Table of Contents:

- Procedure
 - Checkout and setup
 - Procedure for oven turn on
 - Procedure for oven shut down
 - Emergency shut down procedure
- Figures:
 - Useful material
 - Li oven sketch with TC locations
 - Li density profiles

Link to elog summary:
[enter here](#)

Procedure

Checkout and setup

	Procedure	Execution notes
1	Record goal density and helium buffer pressure	
2	Set 10 Torr gauge set points to plus and minus 1 Torr of desired pressure <ul style="list-style-type: none"> ◦ Note: the hysteresis value is where the trip occurs, the lower value is where the fault will clear 	
3	Set the 1000 Torr gauge setpoint to 20 Torr	

Pages / ... / E-300

How to perform a static fill with DPS

Created by Storey, Doug Wesley, last modified on Sep 11, 2023

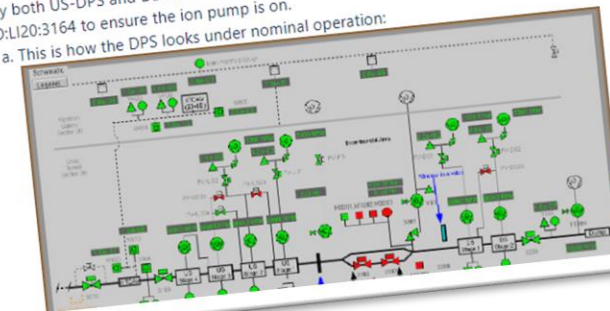
Instructions for reaching a static fill of gas in the IP while the DPS is running. This guide assume the fill is being performed in a state where both the upstream and downstream Be windows have holes, and that a fixed Be window exists on the upstream side of the IP and a movable Be window on the downstream side.

- Step-by-step guide
 - Setup procedure:
 - Start the fill:
 - Drain the IP:
 - Recovering from faults:
 - Test results: DPS Stability and Failure Modes
 - Related articles

Step-by-step guide

Setup procedure:

1. Verify vacuum conditions in the IP of approximately 1e-6 Torr.
2. Verify both US-DPS and DS-DPS pumps are running and operating as normal. Also check VPIO:LI20:3164 to ensure the ion pump is on.
 - a. This is how the DPS looks under nominal operation:



Figures:

Useful material

- E300 Google Drive folder
- How to perform a static fill with DPS
- TDK-Lambda GEN100-15 oven heater power supply manual

Li oven sketch with TC locations

User-friendliness of the DPS improving with experience

Conclusions

- Comprehensive set of spectrometer diagnostics has been defined, built, and commissioned through extensive collaborations with Users
- The differential pumping system supports gas jets, static fill, and the delivery of high intensity, low emittance beams to User programs
- Improvements to robustness and usability have greatly improved performance and reliability
- Successful demonstration of the lithium oven operation supported by DPS
- Diagnostics, plasma sources, and DPS detailed here:
<https://arxiv.org/abs/2310.06215>



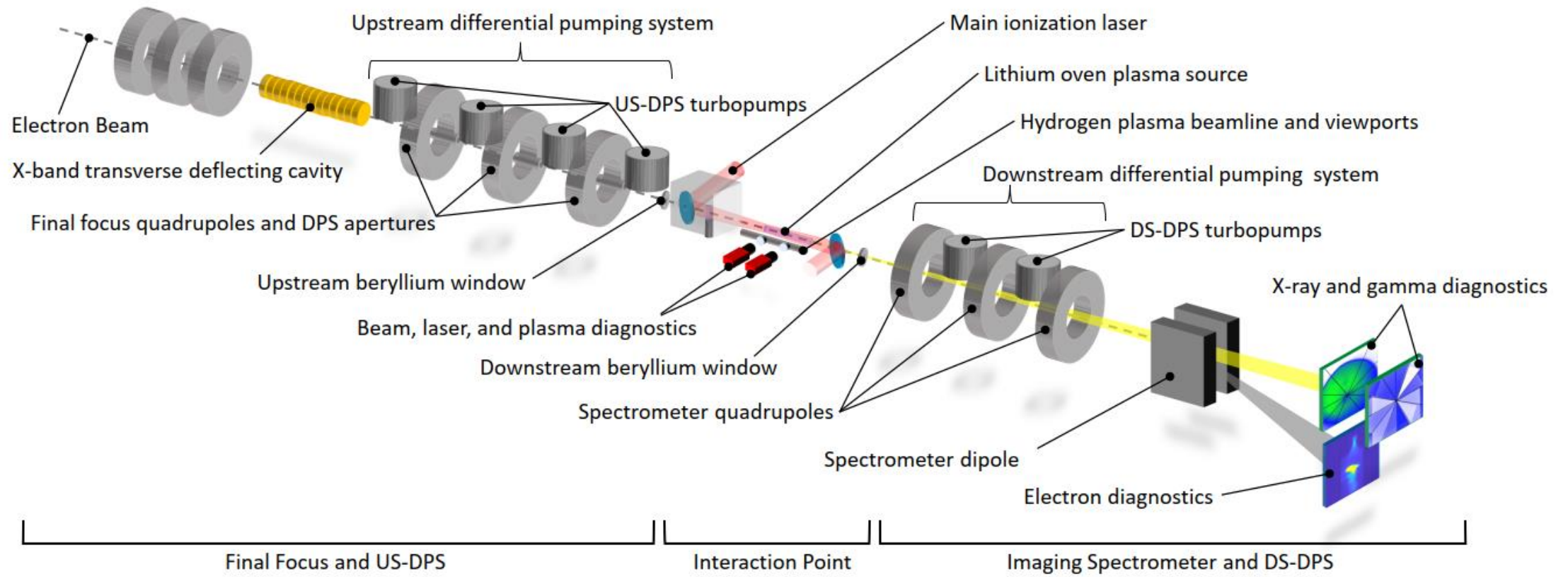
Questions?

FACET-II User Meeting 2023

October 17-19, 2022

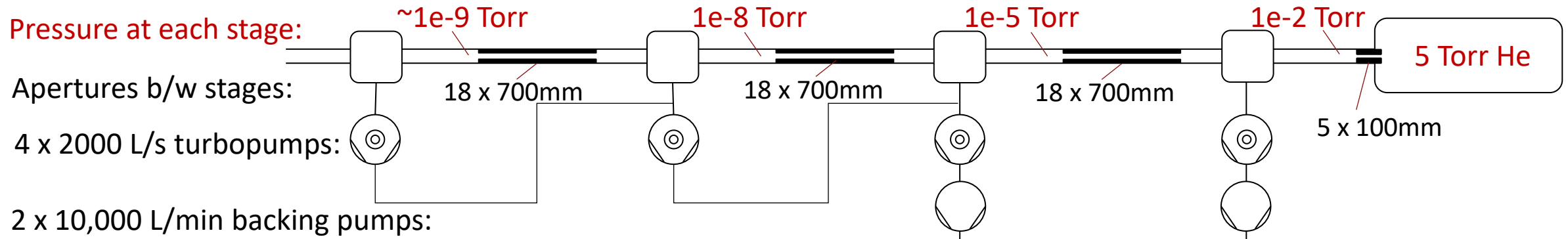
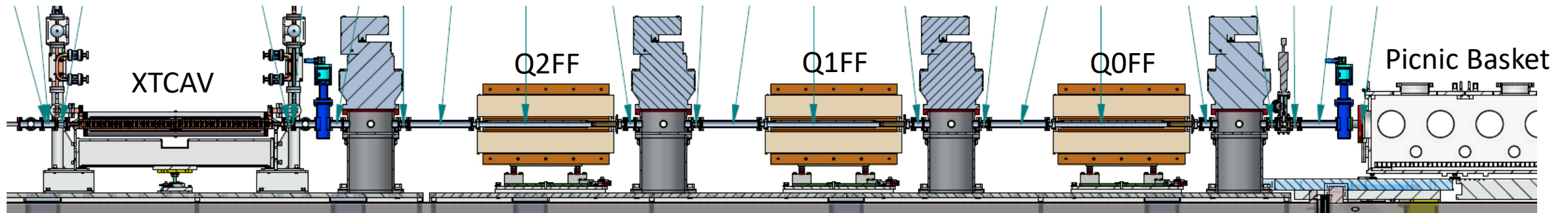
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Developed to satisfy a diverse set of experimental requirements

Design of the upstream differential pumping system

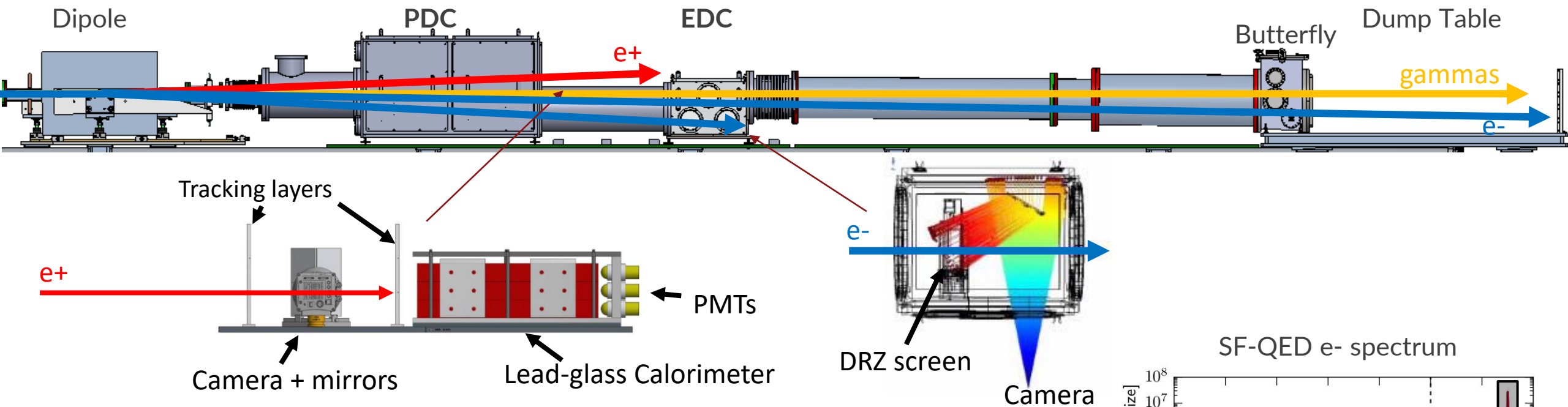


- Four operating states that will require no hardware changes between
- Supports static fill and gas jet operation

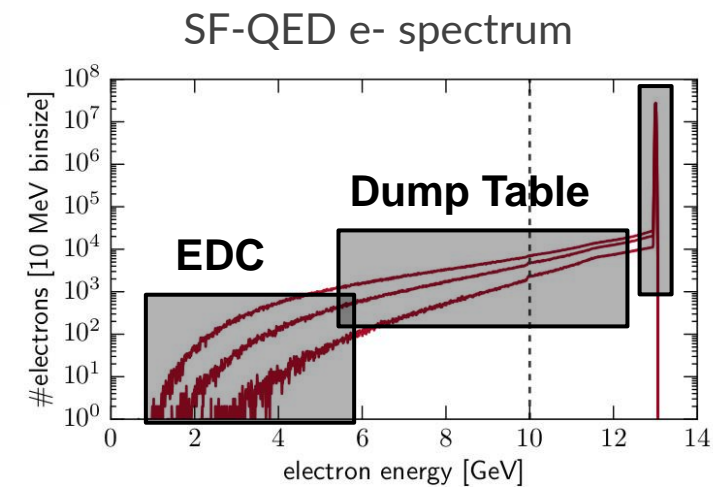
State:	Gas:	Pressure:
0: High vacuum	none	High vacuum at IP
1: Li oven	He	≤ 5 Torr
2: H ₂ plasma	H ₂	≤ 5 Torr
3: Gas jets	He, H ₂	10^{-4} Torr background

Differential pumping system critical to allow gas delivery to IP for gas jets and plasma sources

Positron and Electron Detection chambers

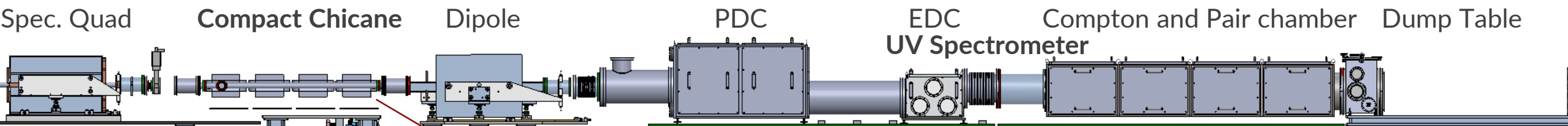


- Tracking, profiles, and calorimetry for low energy electrons and positrons
 - PDC chamber: e^+ tracking and calorimetry – 2.5-6 GeV
 - EDC chamber: e^- profile monitor – 1-6 GeV
- Development driven by the E320 collaboration

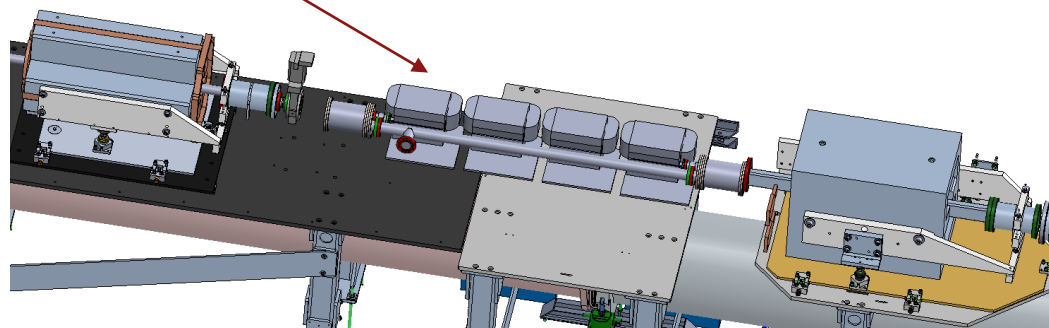


New low energy diagnostic capabilities and multipurpose, adaptable chambers installed

Compact chicane for testing compression of plasma chirped beams

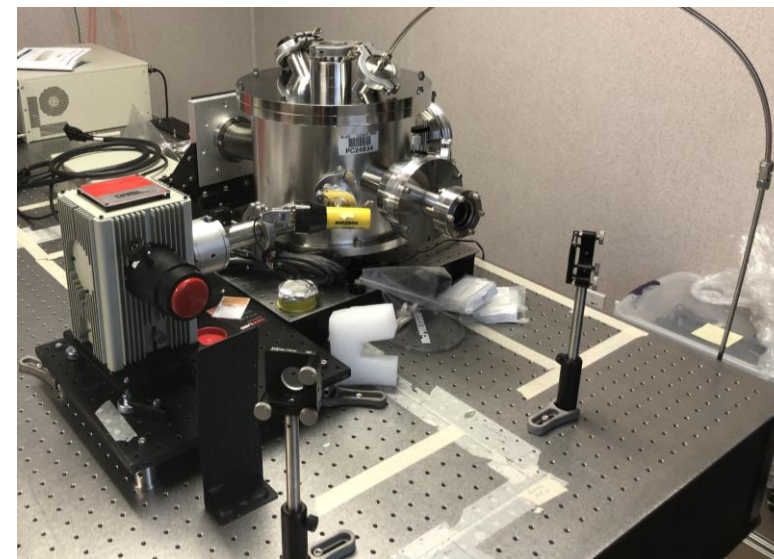


Compact chicane:



- Chicane enables extreme compression of e- beams to nm duration and coherent XUV generation
- Chicane retracts out of the beamline to restore max aperture
- Development led by E-338 collaboration
 - UV spectrometer is being installed on the EDC chamber for initial tests

UV Spectrometer testing - E338



Credit: C. Emma