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

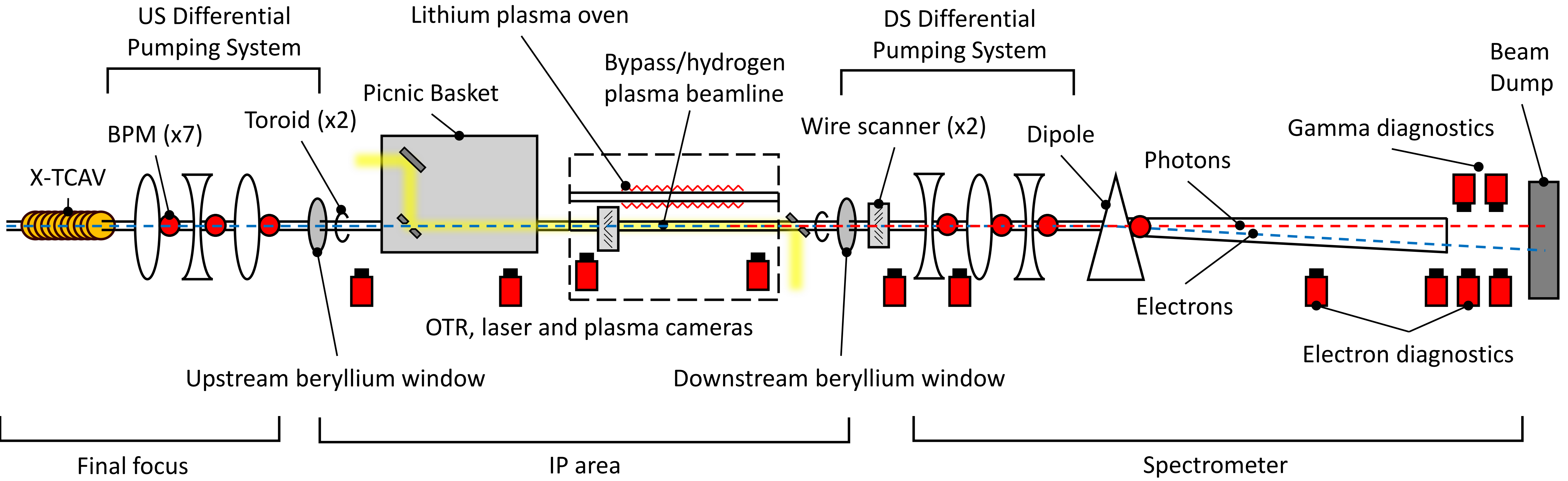
SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University

U.S. DEPARTMENT OF ENERGY

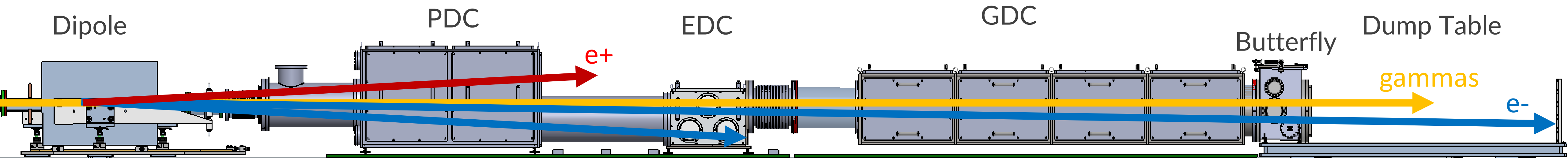
Experimental area overview

- 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*)

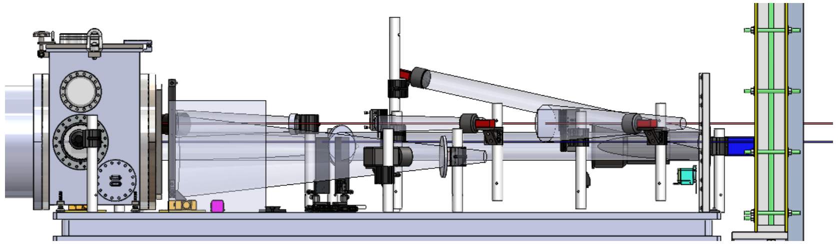


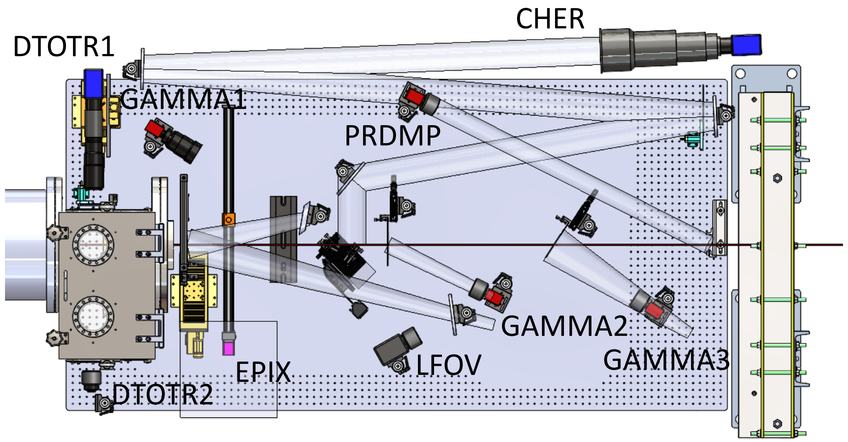
Result of significant coordination with users to support a diverse set of experimental requirements

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





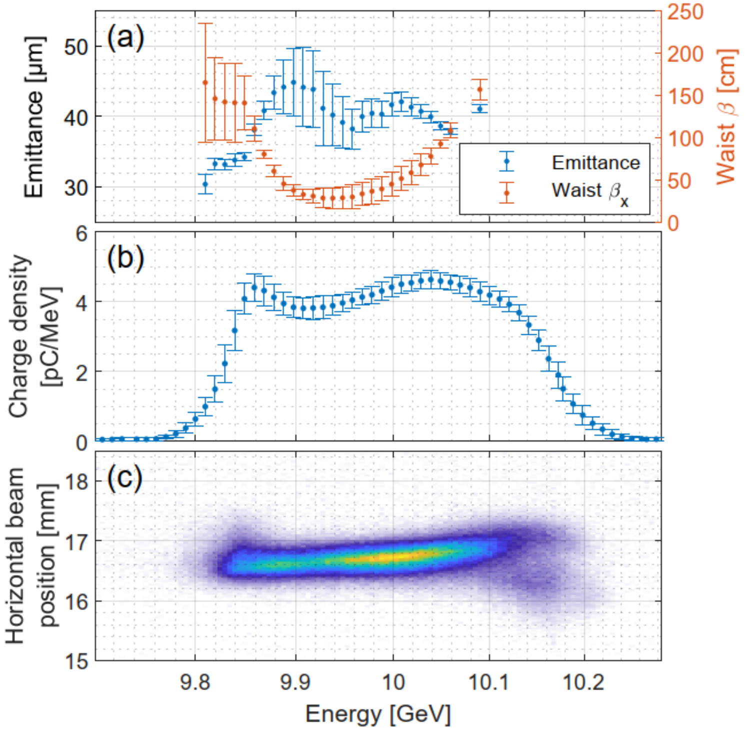
Dispersive and reimaging spectrometer enables energy resolved diagnostics for electrons, positrons, and photons

Electron diagnostics: Emittance

- **Dispersive quad scans**
  - Multi-shot measurement for $\epsilon_n(E)$ and $\beta_x(E)$

- **Single shot emittance measurements**
  - Emittance resolution down to ~5%
  - Provides β_x and waist location

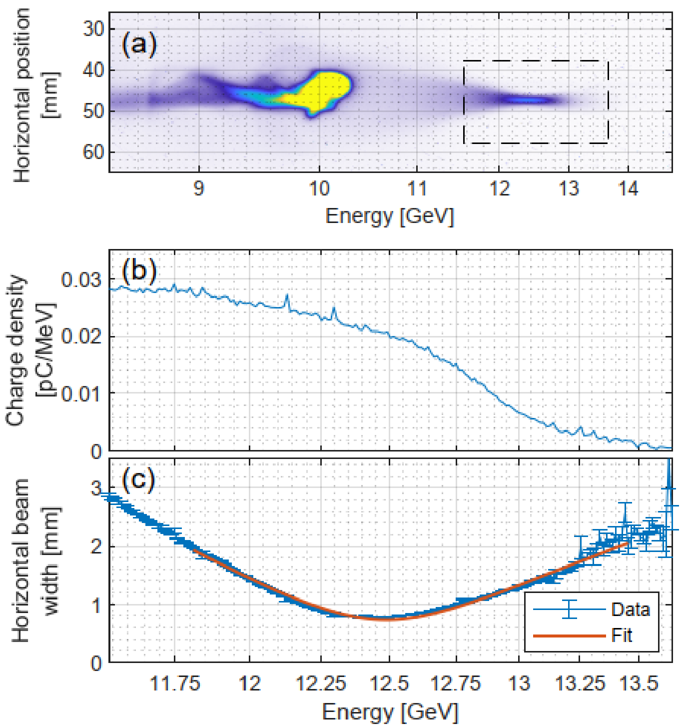
DTOTR2



◀ Summer 2022, compressed beam
Parameters across core:
- $\epsilon_{n,x} \sim 40$ µm
- $\beta_x \sim 30$ cm
- 3% FWHM energy spread

Summer 2022, first H_2 PWFA results ▶
Charge accelerated to 12.5 GeV:
- $\epsilon_{n,x} = 1400$ µm
- $\beta_x = 17.7$ cm
- $\Delta z = 0.7$ cm (*from Be window*)

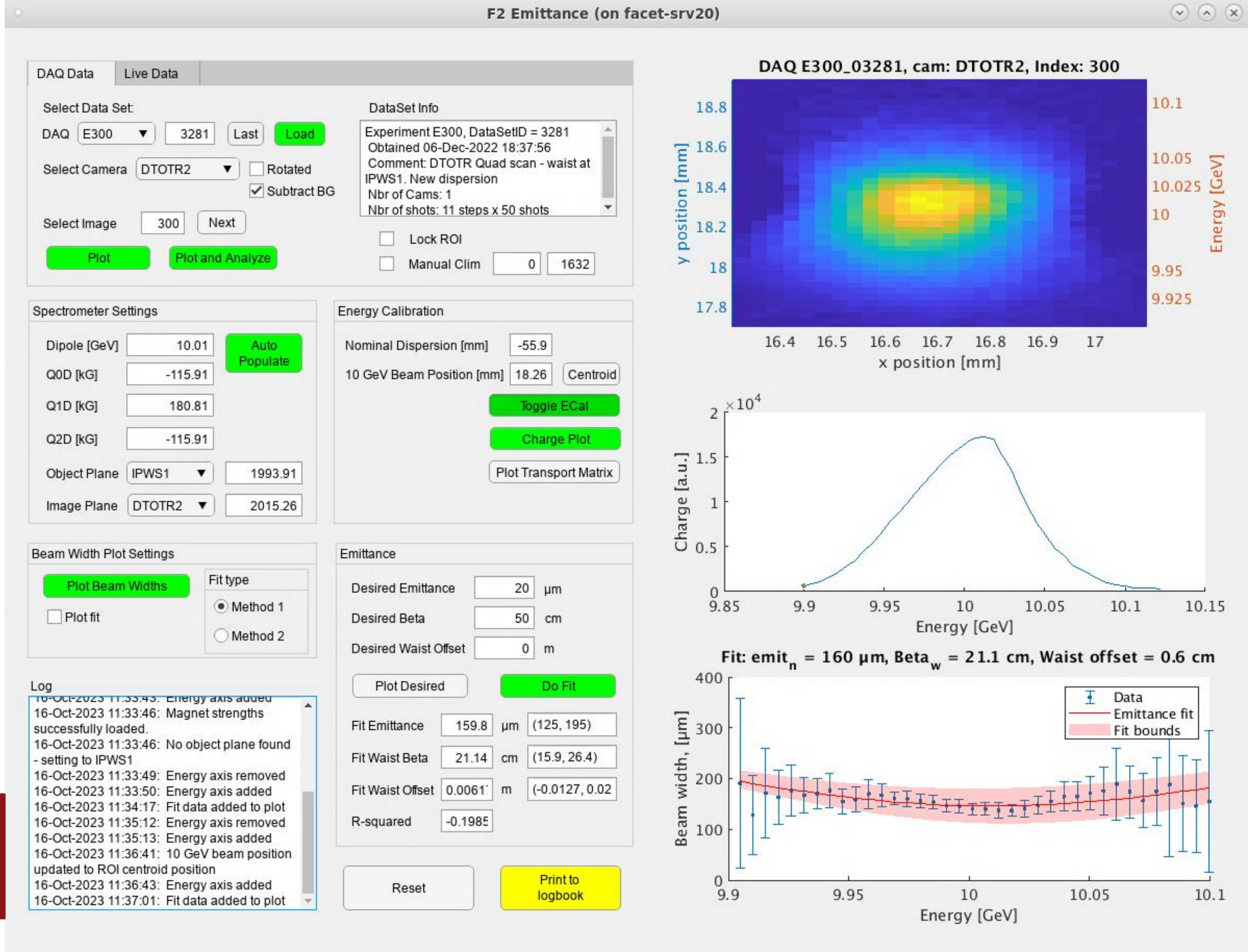
LFOV



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



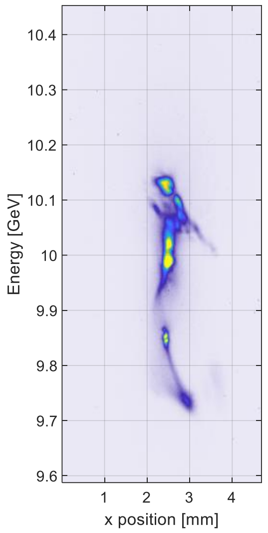
Developing standardized online analysis tools to ensure consistency in data analysis

Electron diagnostics: Energy

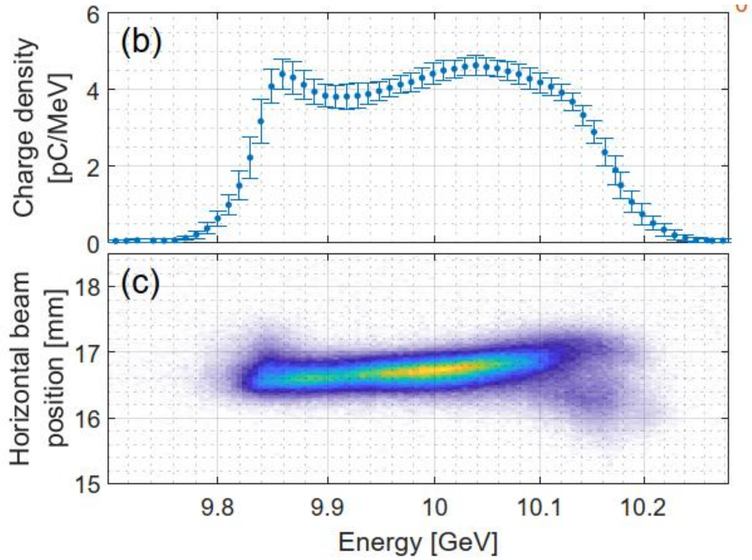
- **High resolution / in-vacuum screens**
  - DTOTR1 – High resolution
    - 4.5 um spatial res. → ~0.01% rel. energy res.
  - DTOTR2 – Mid field of view
    - 30 um spatial res → ~0.05% rel. energy res.

- **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

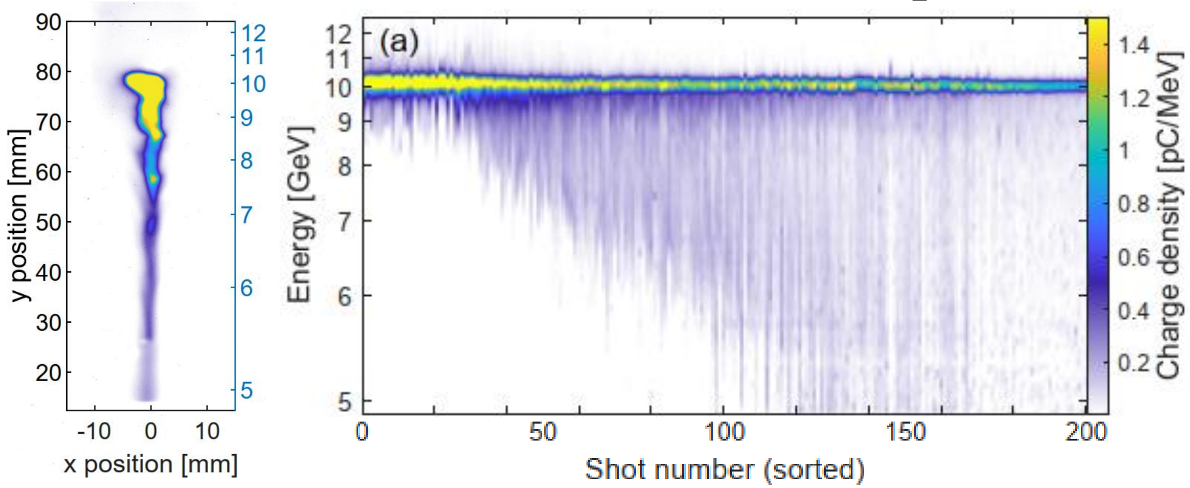
DTOTR1



DTOTR2 – med resolution



LFOV – large BW– Energy depletion with H_2 PWFA

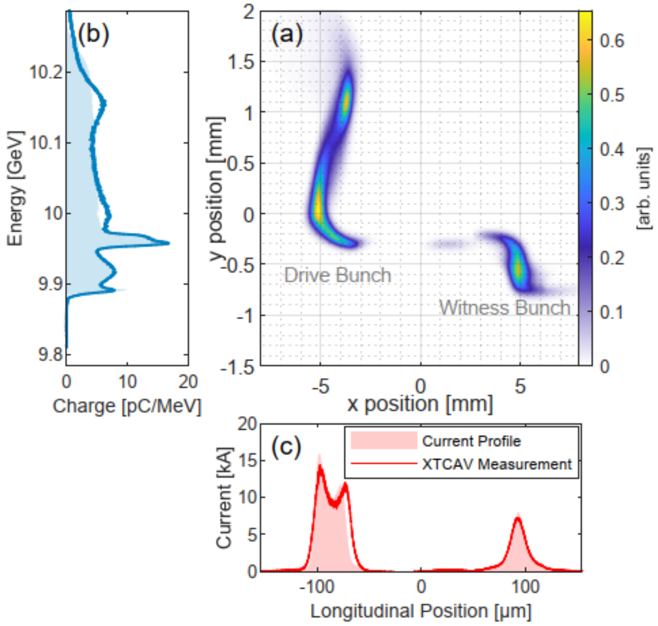


Electron diagnostics: Longitudinal diagnostics

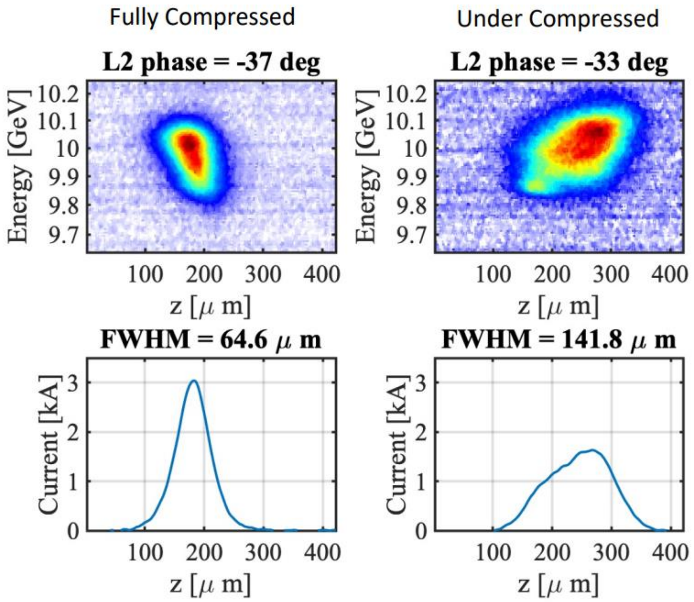
- **XTCAV**
  - Located in the final focus and streaks in x-direction
    - Nominal longitudinal resolution down to 1um (~3fs)
  - Vertical dispersion gives LPS in single shot
    - Energy resolution: ~0.01%

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

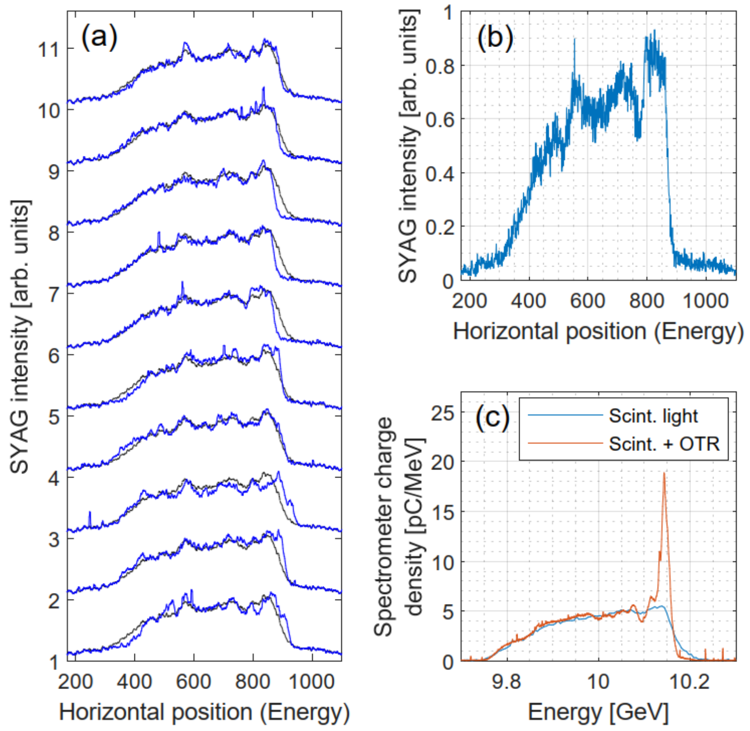
Simulated XTCAV measurement



2022 - L2 compressions scans



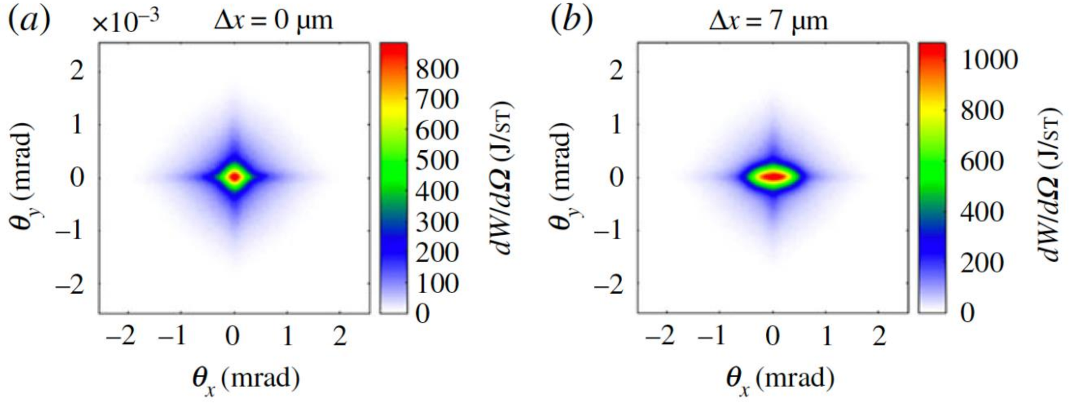
(a, b) SYAG, (c) DTOTR1 and 2



Gamma diagnostics: Intensity and spectra

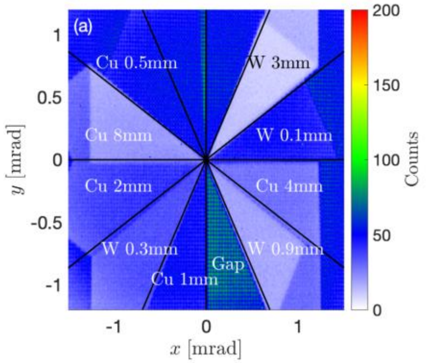
- Design and first results detailed here: https://arxiv.org/abs/2310.05535v1
  - P. San Miguel Claveria, *et al.*, **Commissioning and first measurements of the initial X-ray and γ-ray detectors at FACET-II**, *Proc. of AAC'22*.
- **Gamma1:** uniform DRZ scintillator or CsI array (0.5mm pixels)
  - Provides 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

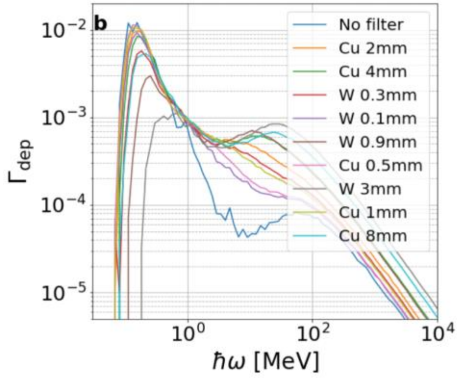


GAMMA2

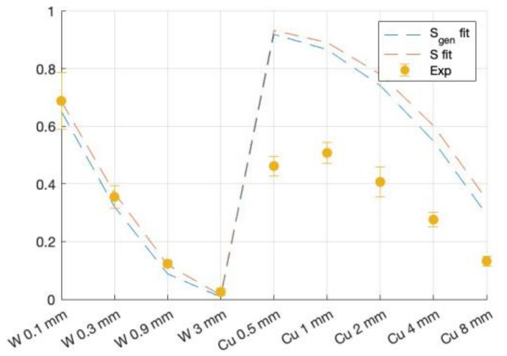
Raw image + filters



Spectral response

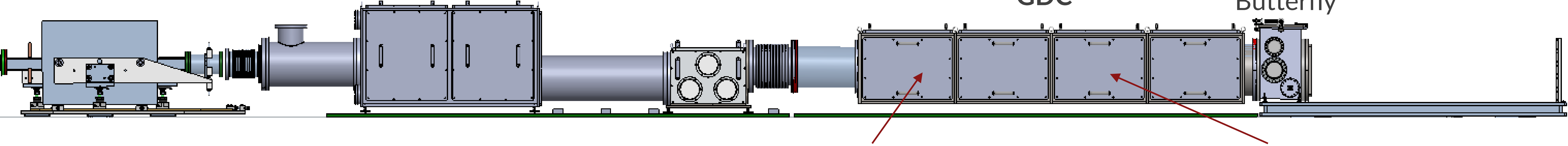


Fit: synch. rad spectrum with $E_c = 65$ keV

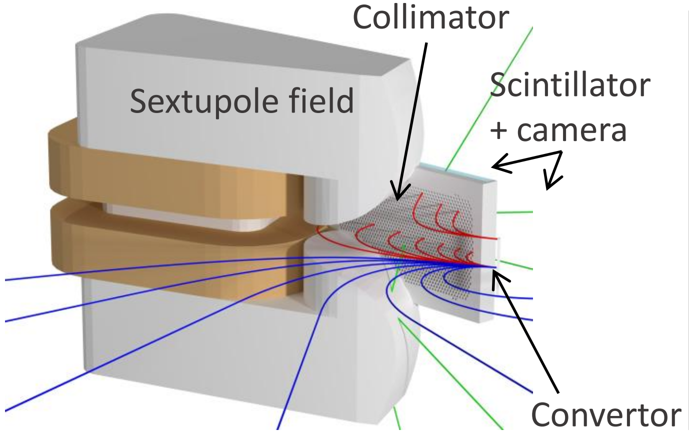


Gamma diagnostics commissioned and instrumental for PWFA, SFQED and more

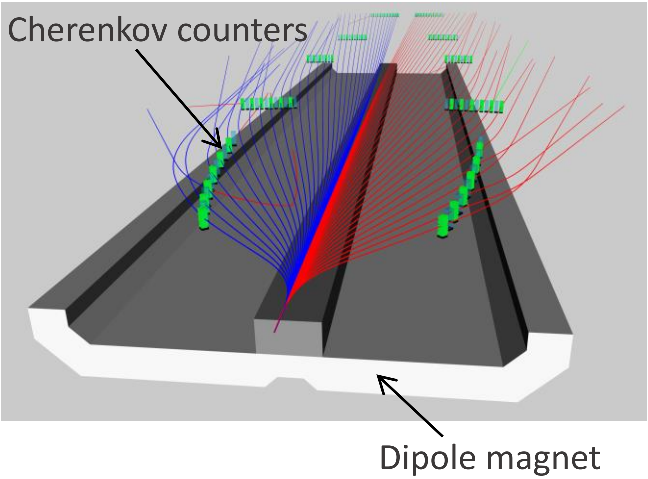
Gamma diagnostics: Up and coming



Compton Spectrometer



Pair Spectrometer



Design Credit: B. Naranjo (UCLA)

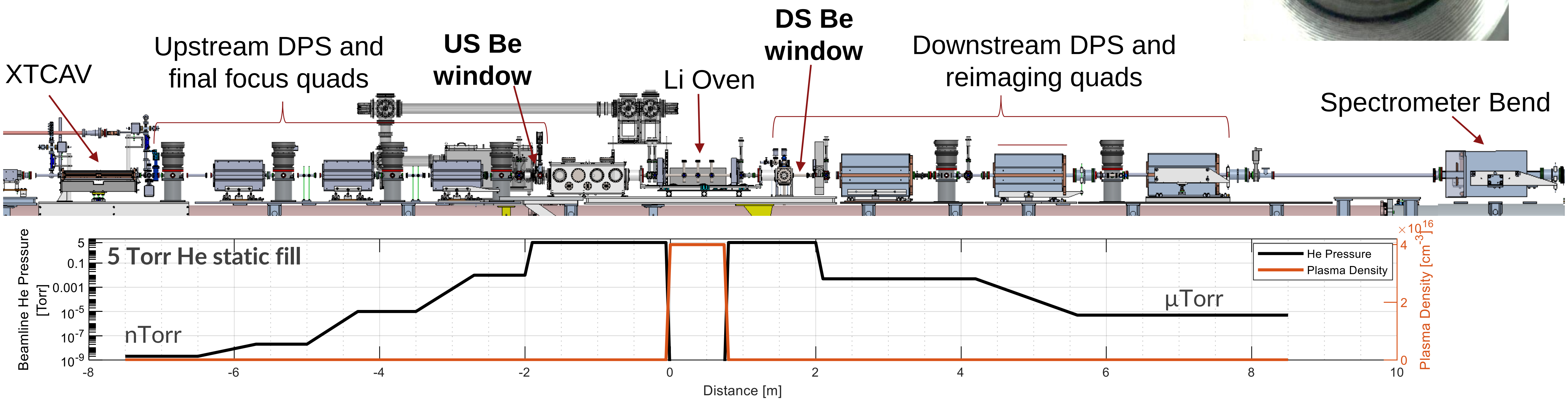
- Compton spectrometer: single-shot gamma spectrometer
  - Range of 200 keV – 20 MeV
  - Secondary capability to resolve angle-energy double differential
- Pair spectrometer:
  - Measure gamma spectrum to 10 GeV
- More details in talk by Brian on Wed. afternoon

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 ~200 µm "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

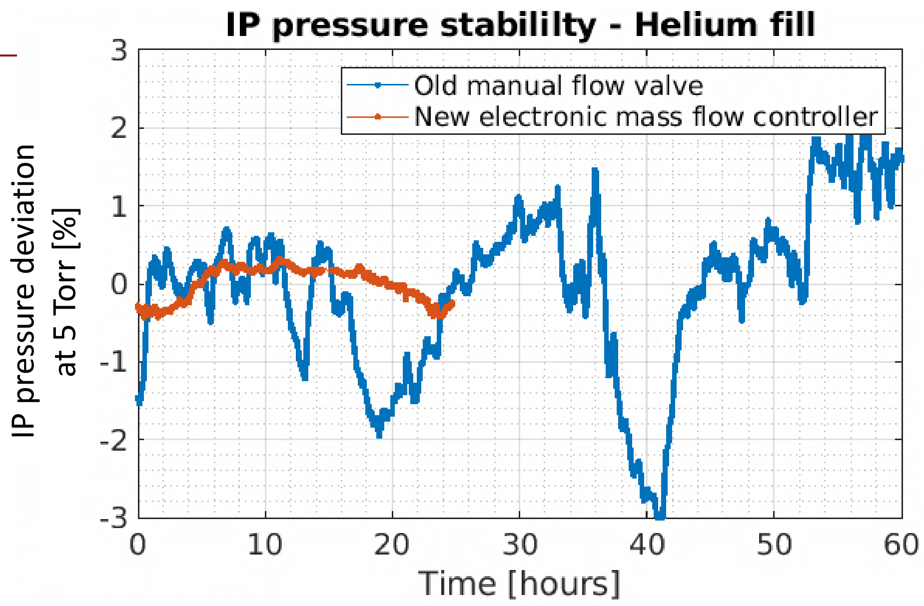


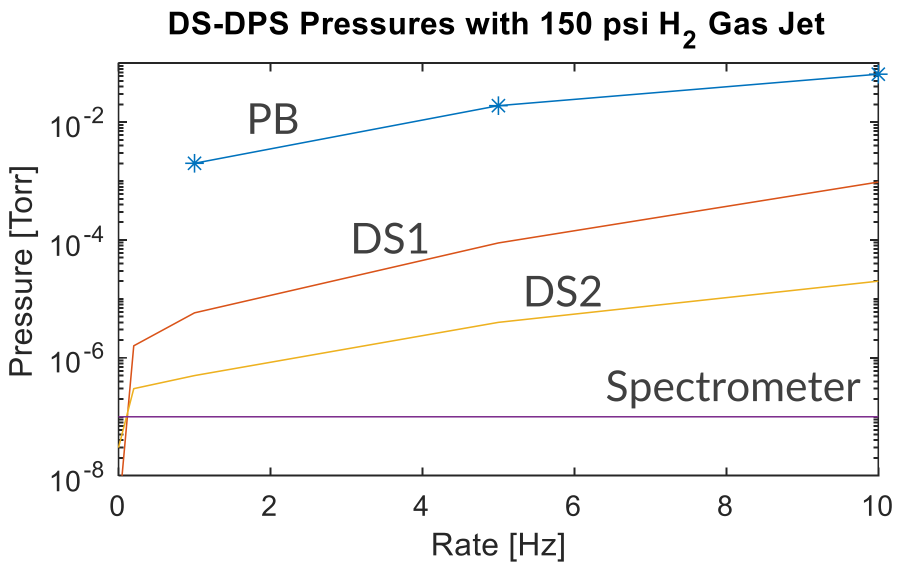
Differential pumping system critical to allow gas delivery to IP for gas jets and plasma sources

DPS operating modes

- **Static fill:**
  - He or Ar up to 10 Torr, H_2 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: H2 plasma	H_2	≤ 5 Torr
3: Gas jets	He, H_2	1200 psi, up to 10 Hz

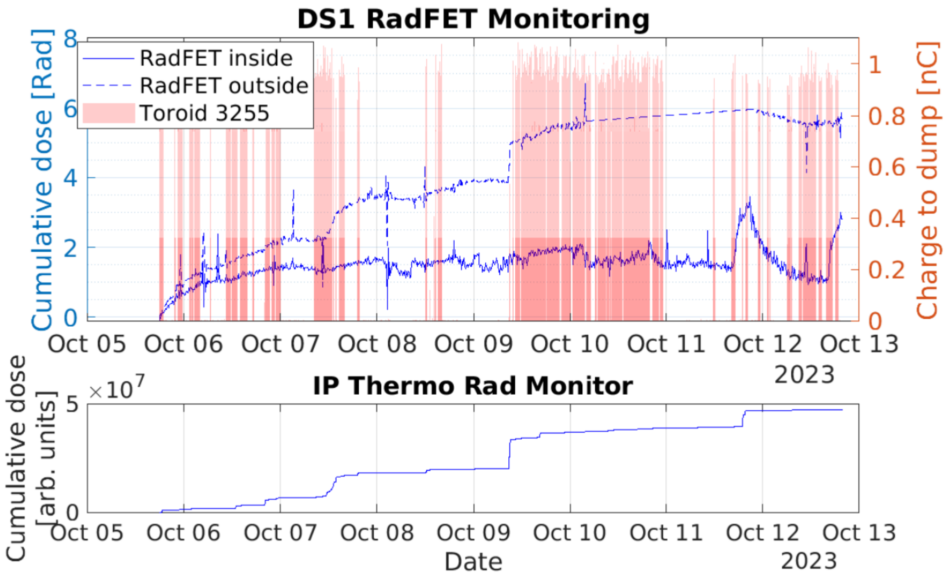




Improvements to DPS

- 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



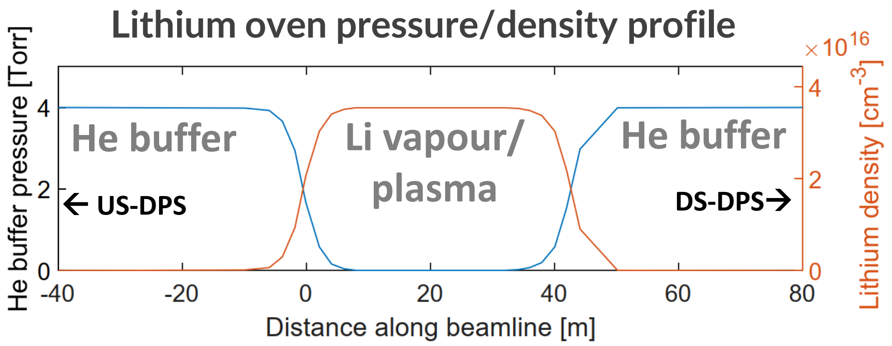
DPS is now more robust than in the previous run

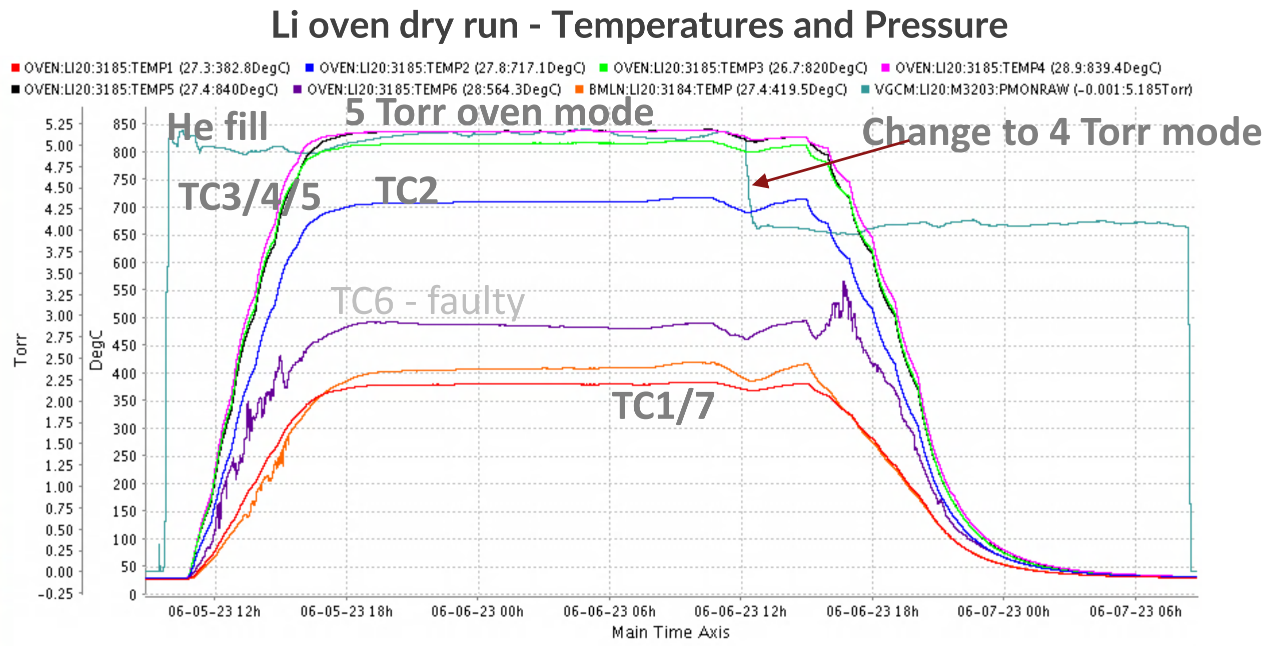
Lithium plasma oven operation with DPS

- 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

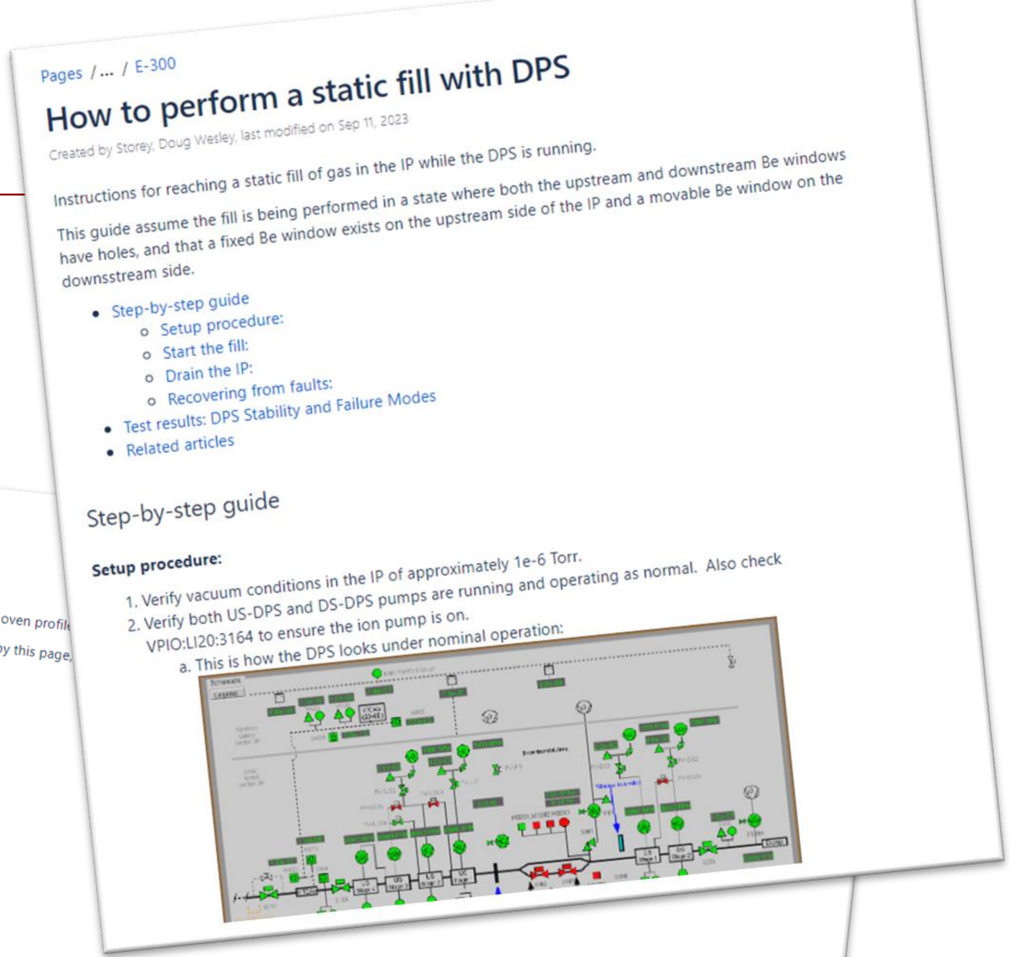


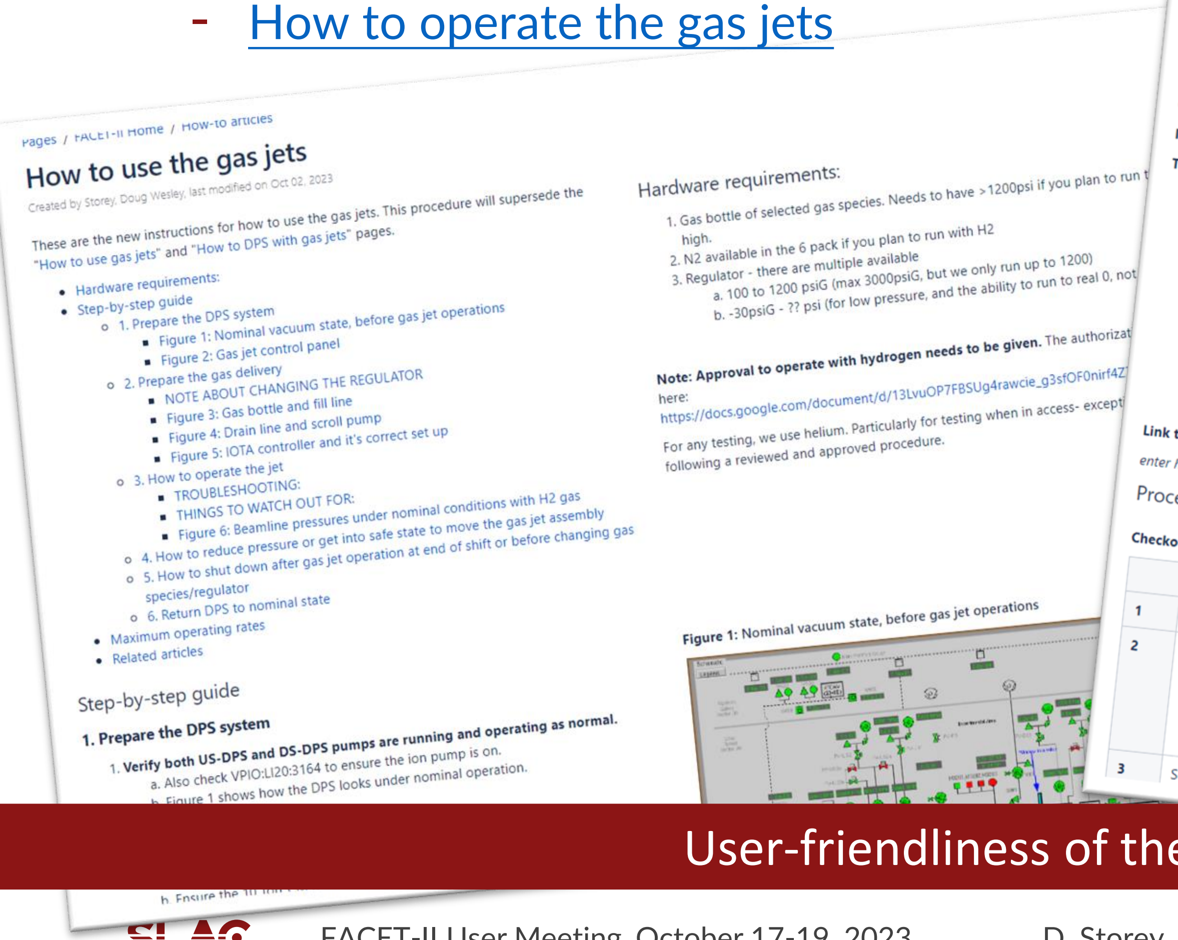


Nearly ready to start testing the lithium plasma oven with beam!

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](#)





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

Facility for Advanced Accelerator Experimental Tests

Questions?

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Experimental area overview

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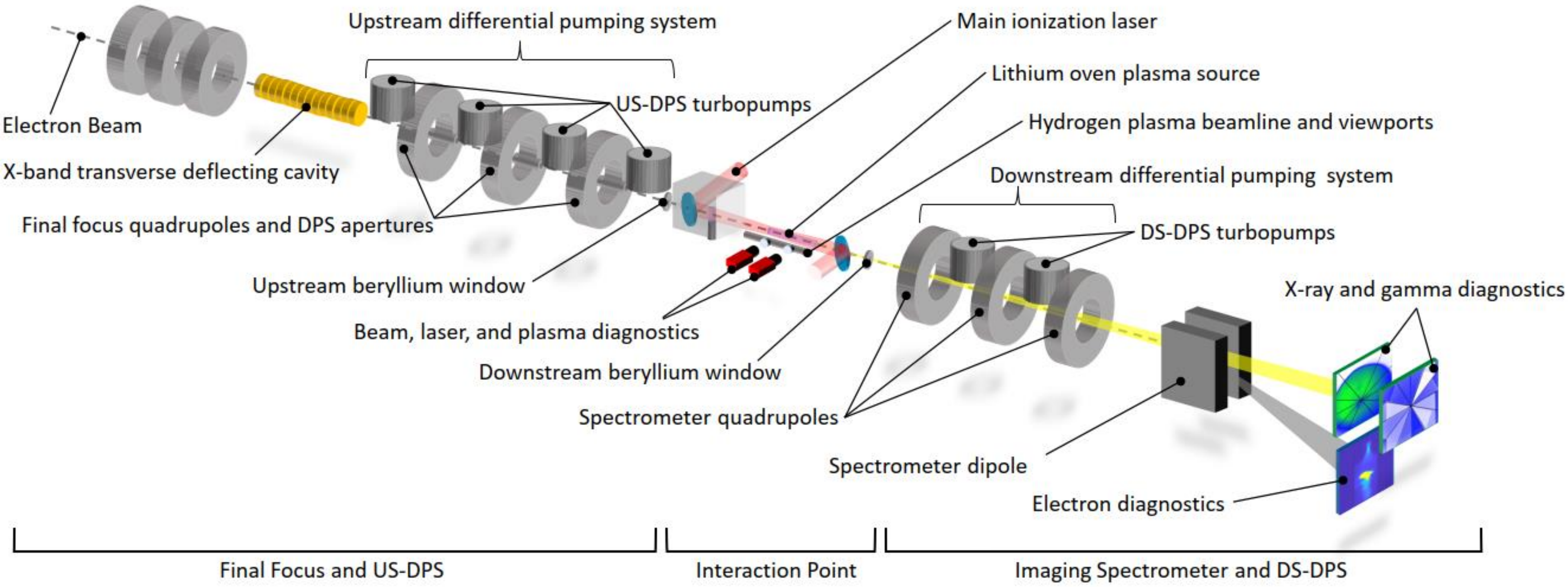
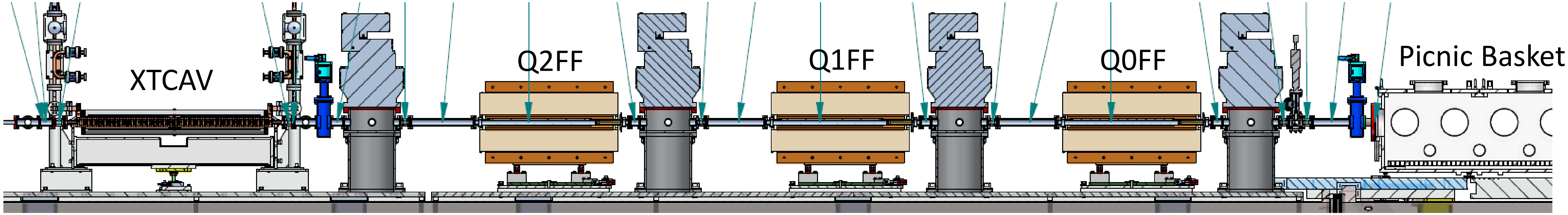
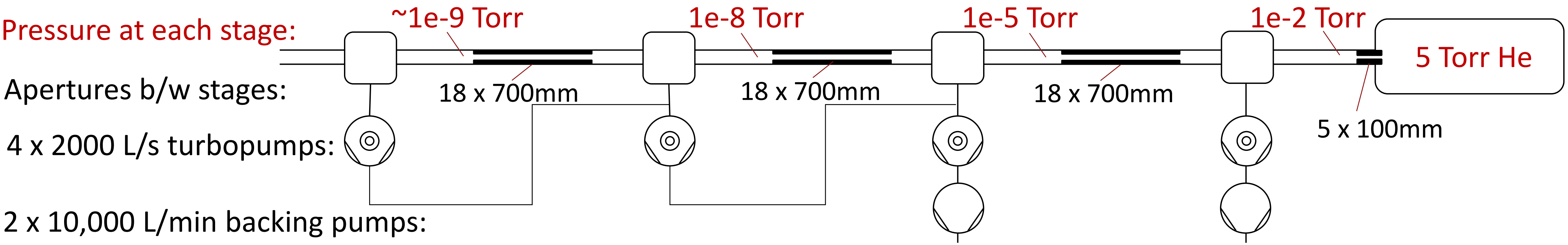


Developed to satisfy a diverse set of experimental requirements

Design of the upstream differential pumping system



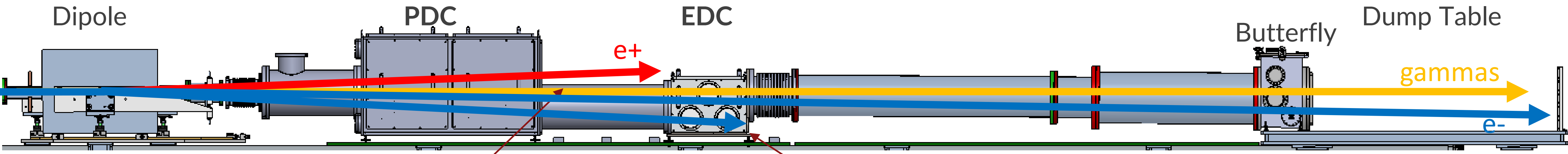


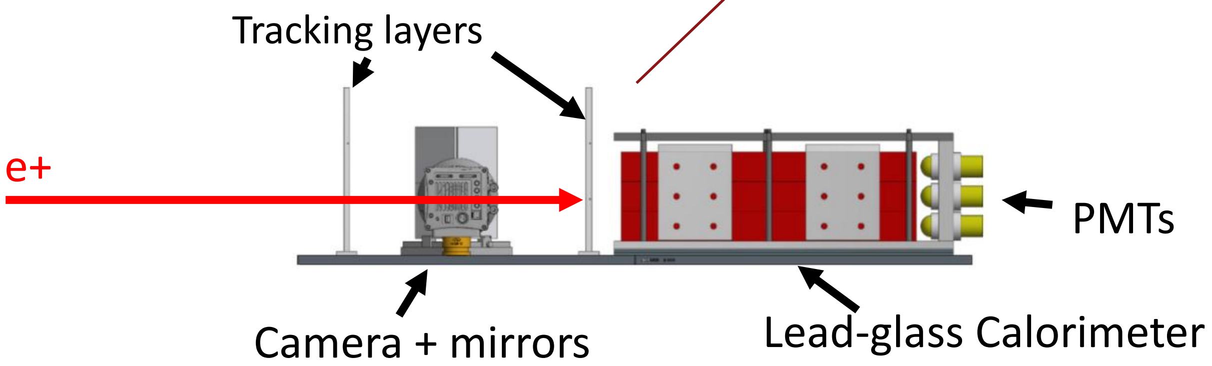
- Four operating states that will require no hardware changes between
- Supports static fill and gas jet operation

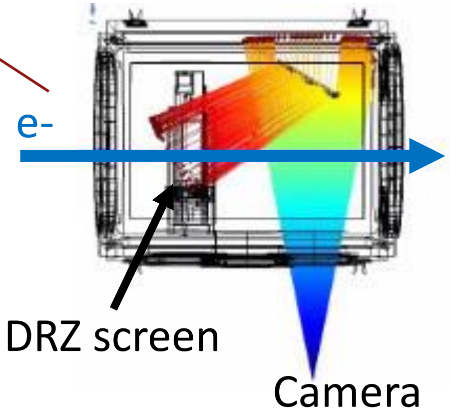
State:	Gas:	Pressure:
0: High vacuum	none	High vacuum at IP
1: Li oven	He	$\lesssim$ 5 Torr
2: H2 plasma	H_2	$\lesssim$ 5 Torr
3: Gas jets	He, H_2	10^{-4} Torr background

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

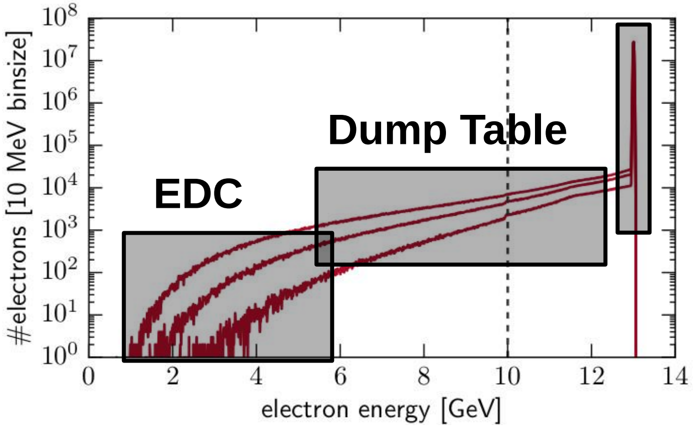
Positron and Electron Detection chambers







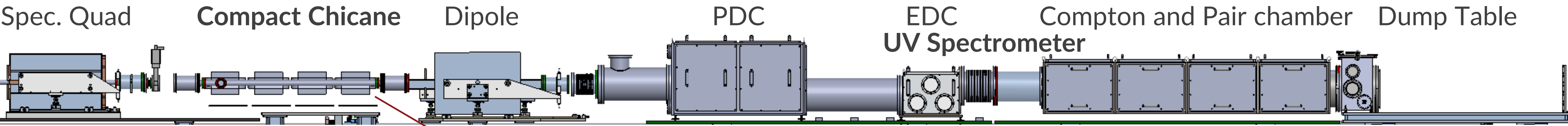
SF-QED e- spectrum



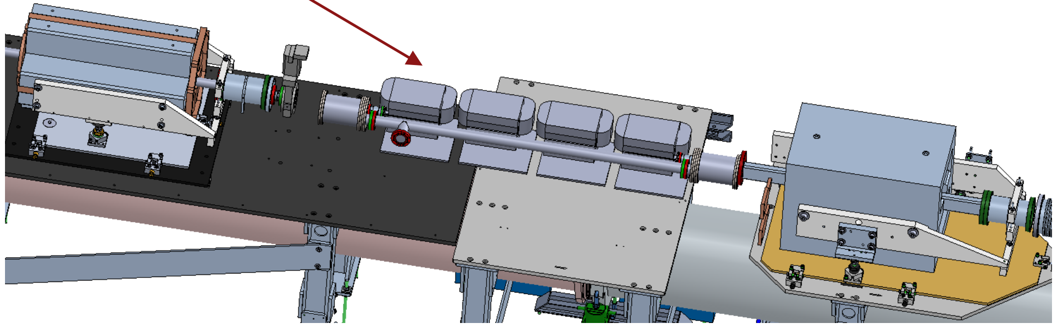
- Tracking, profiles, and calorimetry for low energy electrons and positrons
  - PDC chamber: e+ tracking and calorimetry – 2.5-6 GeV
  - EDC chamber: e- profile monitor – 1-6 GeV
- Development driven by the E320 collaboration

New low energy diagnostic capabilities and multipurpose, adaptable chambers installed

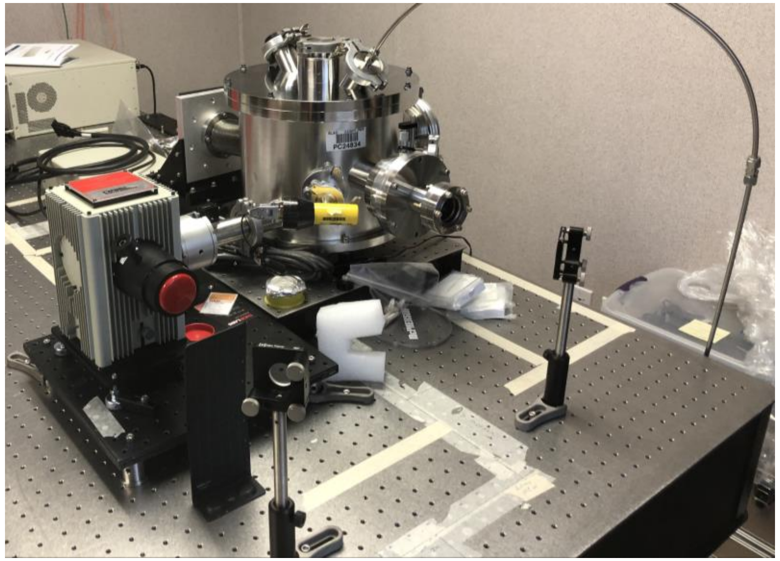
Compact chicane for testing compression of plasma chirped beams



Compact chicane:



UV Spectrometer testing – E338



Credit: C. Emma

- 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