Experimental Area, Diagnostics, and DPS

FACET-II
Facility for Advanced Accelerator Experimental Tests

FACET-II PAC Meeting 2022

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October 25-27, 2022

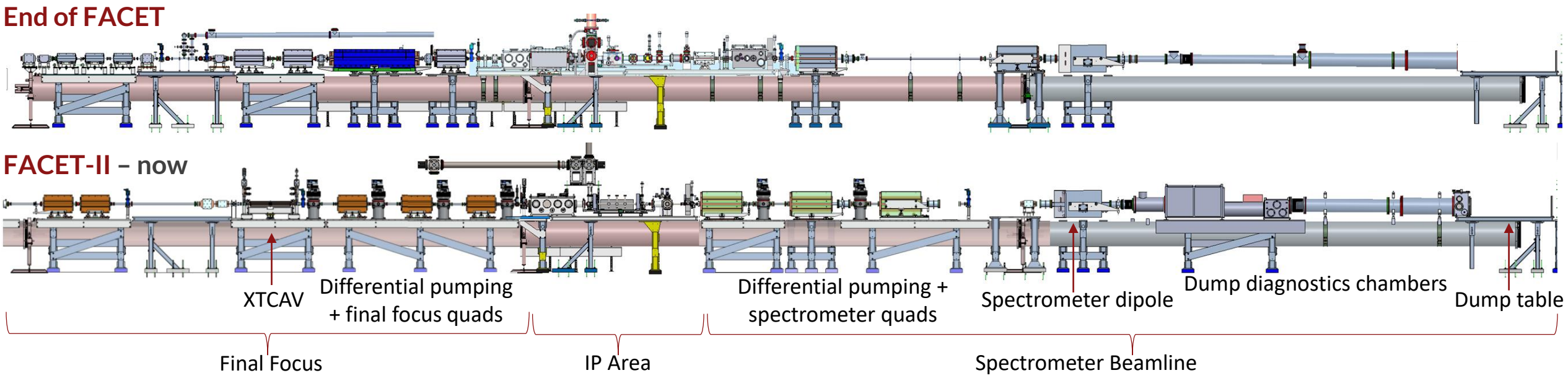
SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

Outline

- S20 beamline modifications
- Differential pumping system
- Spectrometer diagnostics
  - Electron and gamma diagnostics
  - Single shot LPS measurements
  - New diagnostics development

Evolution of the experimental area for the new FACET-II beams

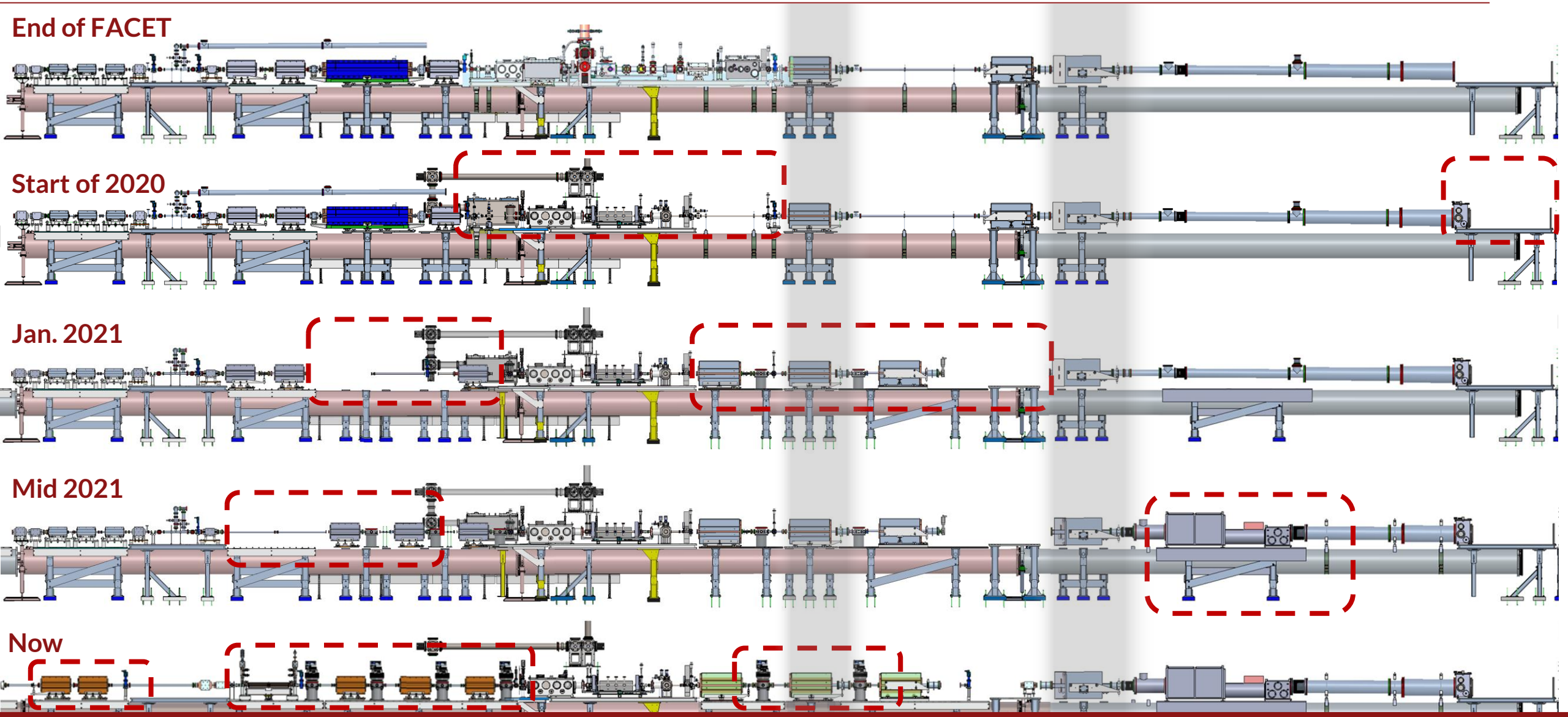


- Experimental area upgrades motivated by new beam parameters and user requirements
  - New photoinjector – smaller, round emittances
  - High peak current
  - New experimental laser delivery

Electron Beam Parameter		FACET Parameters	FACET-II Baseline	Operational Ranges
Final energy	[GeV]	23	10	4 – 13.5
Charge per pulse	[nC]	3	2	0.7 – 5
$\gamma\epsilon_{x,y}$ at S19	[µm]	100, 10	4.4, 3.2	3 – 6
Min bunch length	[µm]	20	1.8	0.7 – 20
Max peak current	[kA]	22	72	10 - 200

Significant coordination required between users, on site support, and beam operations to make this happen

Progression of S20 Beamline over the last 2 years

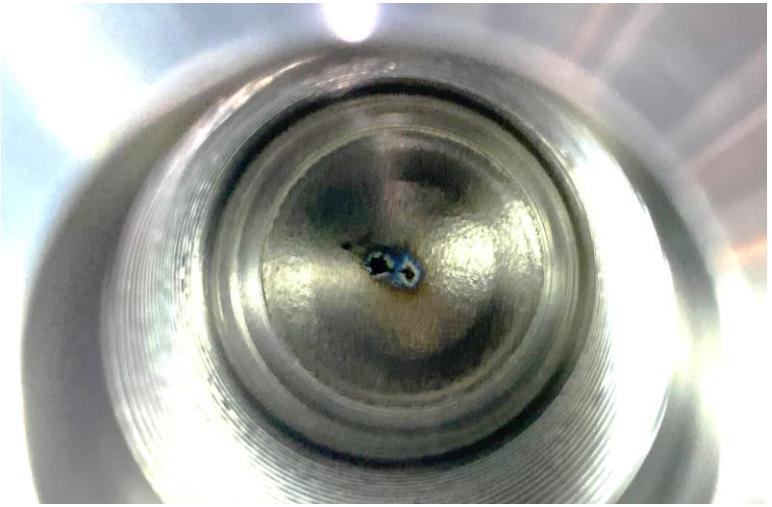


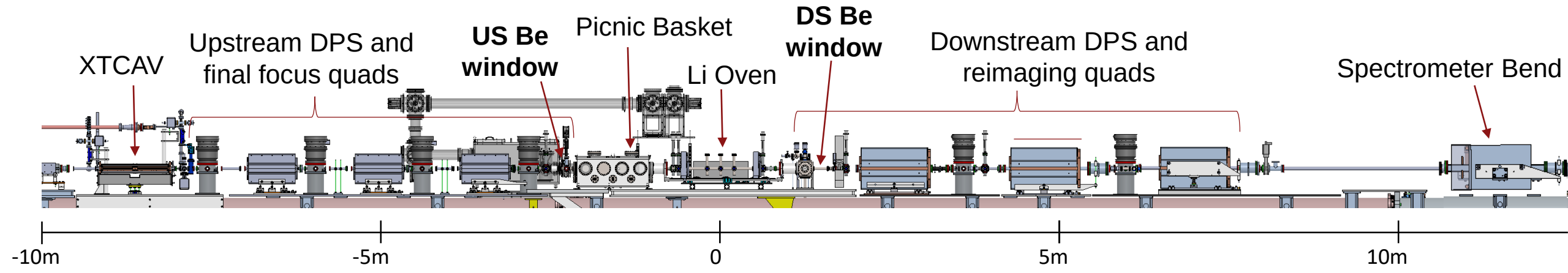
Work completed during PAMMs with beam delivery possible at every phase of installation

The need for a differential pumping system (DPS)

- Solid vacuum windows do not survive FACET-II beam intensities near the IP
- Plasma sources require a range of gas conditions up to 5 Torr of helium or hydrogen
- Key requirements:
  - XTCAV requires UHV to avoid RF breakdown
  - Spectrometer requires HV to avoid emittance growth

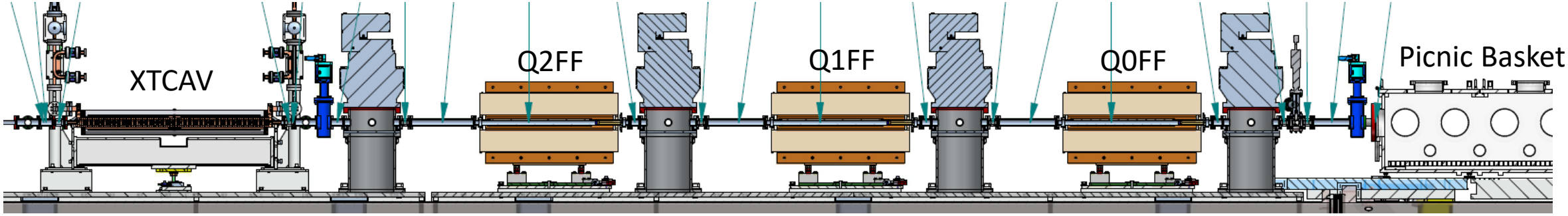
Upstream Be window after the 2022 run

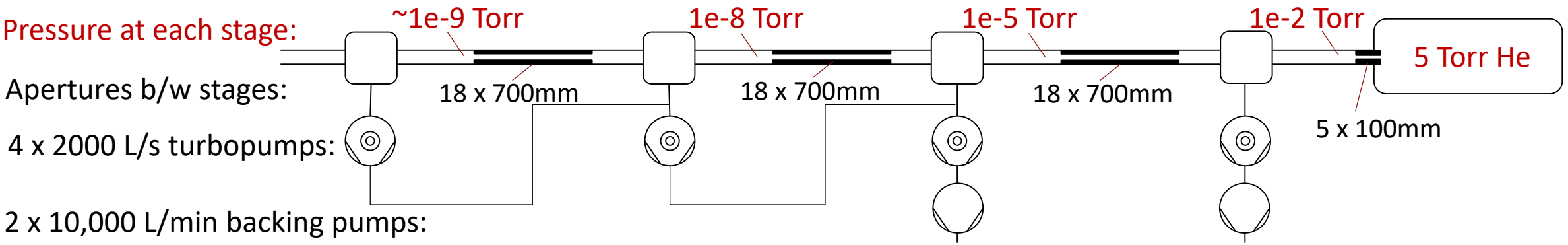




FACET-II extreme beam conditions require differential pumping

Design of the upstream differential pumping system





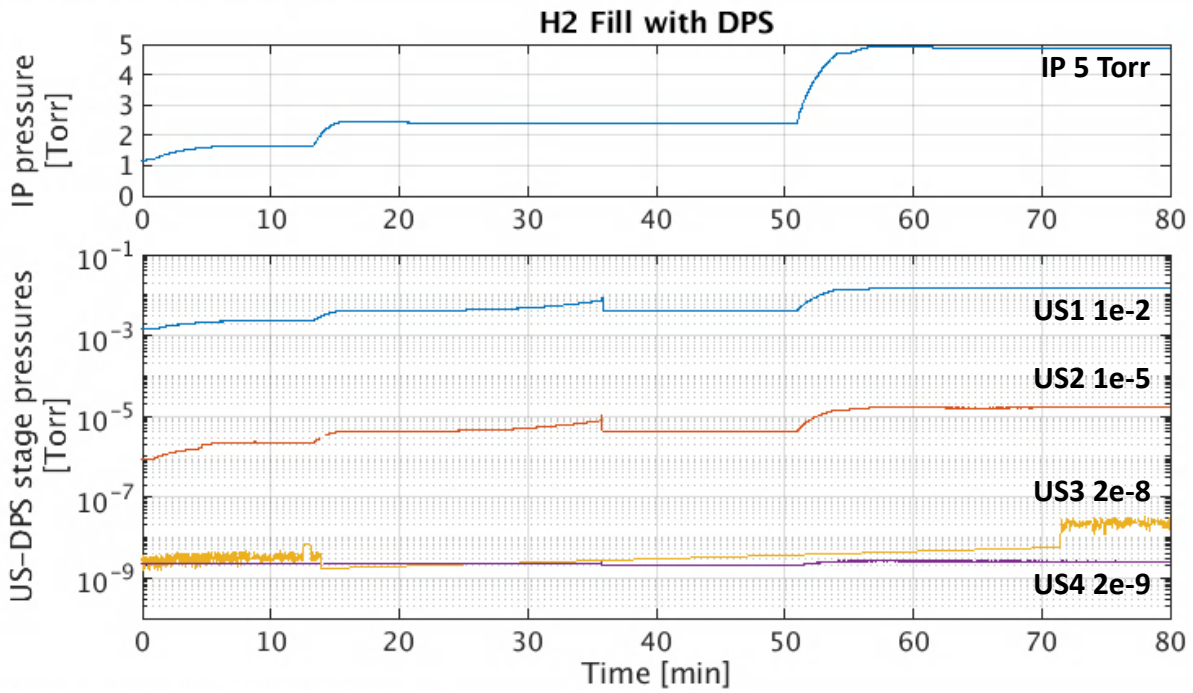
- Four operating states that will require no hardware changes between
- Supports static fill and gas jet operation

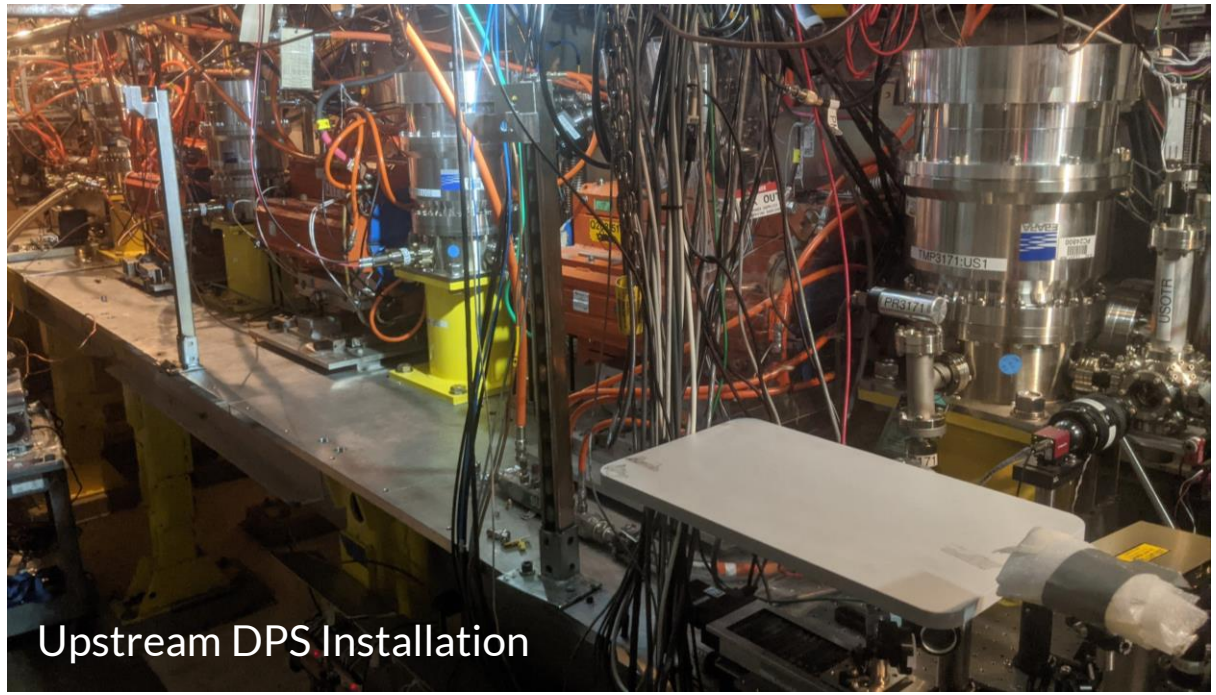
State:	Gas:	Pressure:
0: High vacuum	none	High vacuum at IP
1: Li oven	He	$\leq$ 5 Torr
2: H2 plasma	H_2	$\leq$ 5 Torr
3: Gas jets	He, H_2	10^{-4} Torr background

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

DPS performance during tests and in operation

- DS-DPS fully installed in January 2022
- Failure of the Be window fast tracked the installation of the US-DPS to July 2022
  - Straw apertures are not installed, but "holey" Be windows are left in place



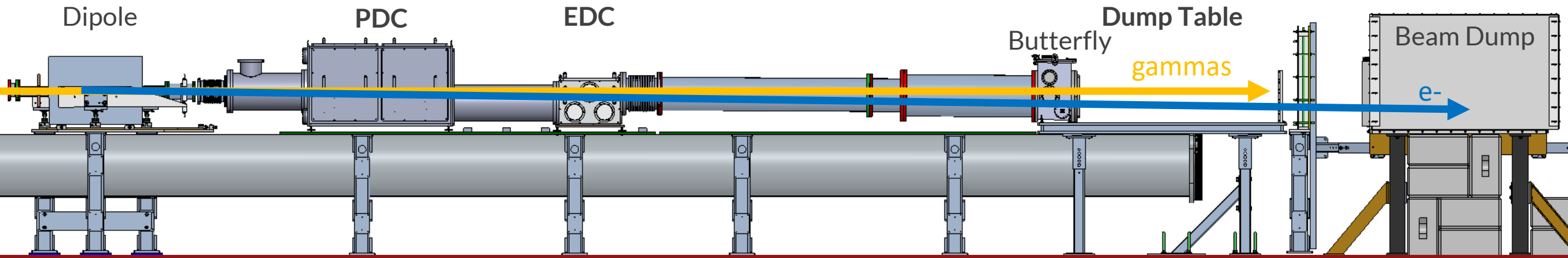


- Performance
  - Max IP pressure of 5 Torr He or H2 available
  - Gas jet operation with up to 10 Hz rep rate
  - ~1e-9 Torr retained at XTCAV

Successful demonstration of DPS capabilities and regular use during the experimental run

Spectrometer overview

- Spectrometer beamline contains the main post-IP electron beam and photon diagnostics for all experiments
  - Focusing triplet reimages electrons to diagnostics located before the dump
  - Dipole bend disperses the beam vertically
  - 3 main diagnostics regions:
    - "Dump table"
    - Positron and Electron detection chambers – PDC/EDC
    - Compton and pair spectrometers (under development)

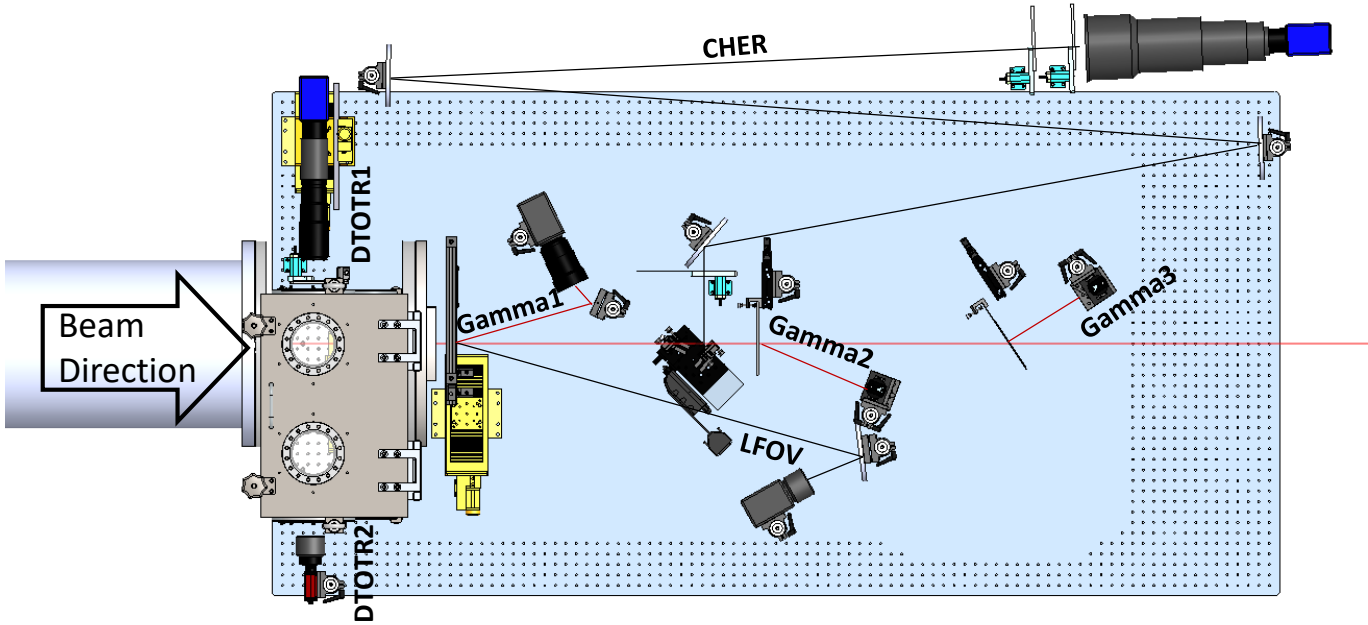


Developed in close collaboration with the User community to satisfy a diverse set of requirements

Dump table electron beam and photon diagnostics

- Electron beam diagnostics
  - **DTOTR** – high resolution, single shot emittance and TCAV measurements
    - Nominal sub-μm emittance resolution
    - few fs longitudinal resolution
  - **LFOV** and **CHER**– large field of view electron profile monitors using scintillator/Cherenkov light
    - 0.4% energy resolution

- Photon diagnostics:
  - **Gamma1**: photon profile monitor
  - **Gamma2** and 3: spectral information from <100keV to 10's of MeV



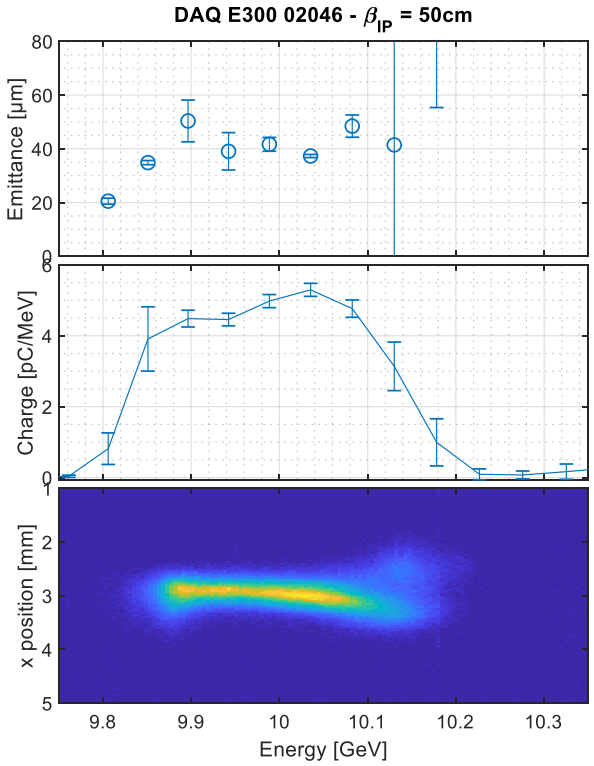
Diagnostics have been commissioned and put to regular use in experimental runs

Emittance and beam profiles

- Commissioning of spectrometer diagnostics performed in conjunction with experimental programs
  - Dispersive quad scans for emittance measurements return reasonable emittance estimates
  - Commissioning of the single shot “butterfly” emittance measurements is ongoing

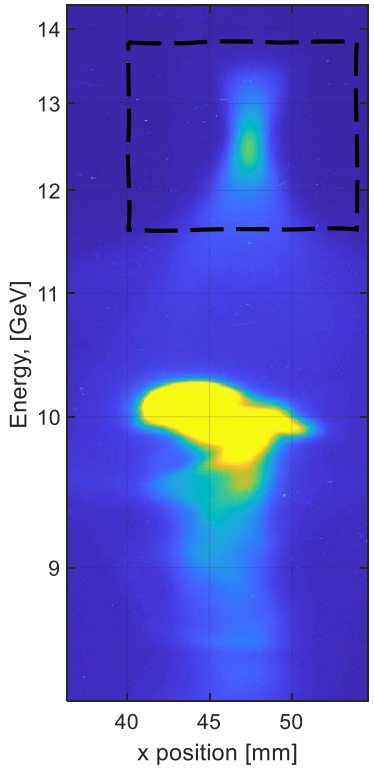
Dispersive quad scans:

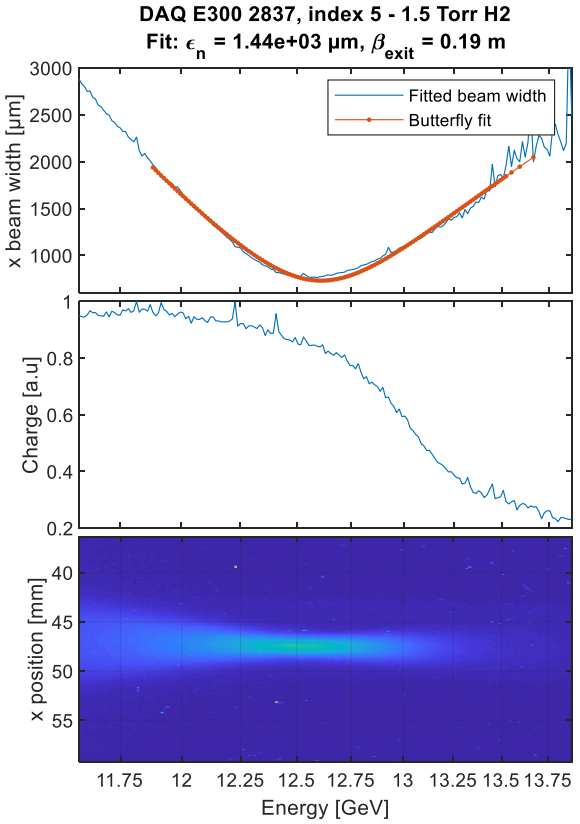
- Using DTOTR2
- S19 emittance measured at 45 μm
- Spectrometer measured 40-50μm



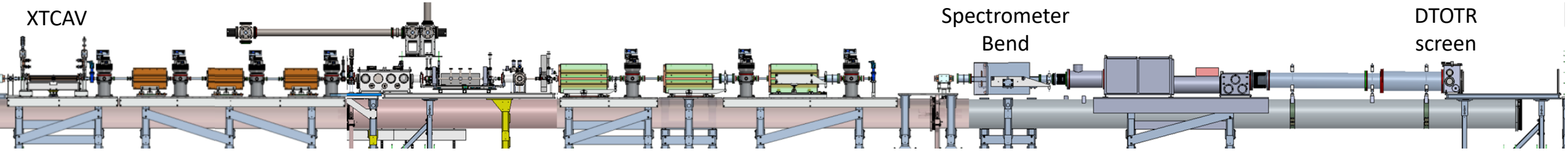
Single shot emittance of PWFA accelerated charge:

- Using LFOV
- 10’s pC/GeV of charge at ~13 GeV
- Single shot emittance of 1.4e3 μm
- Waist located with mm precision

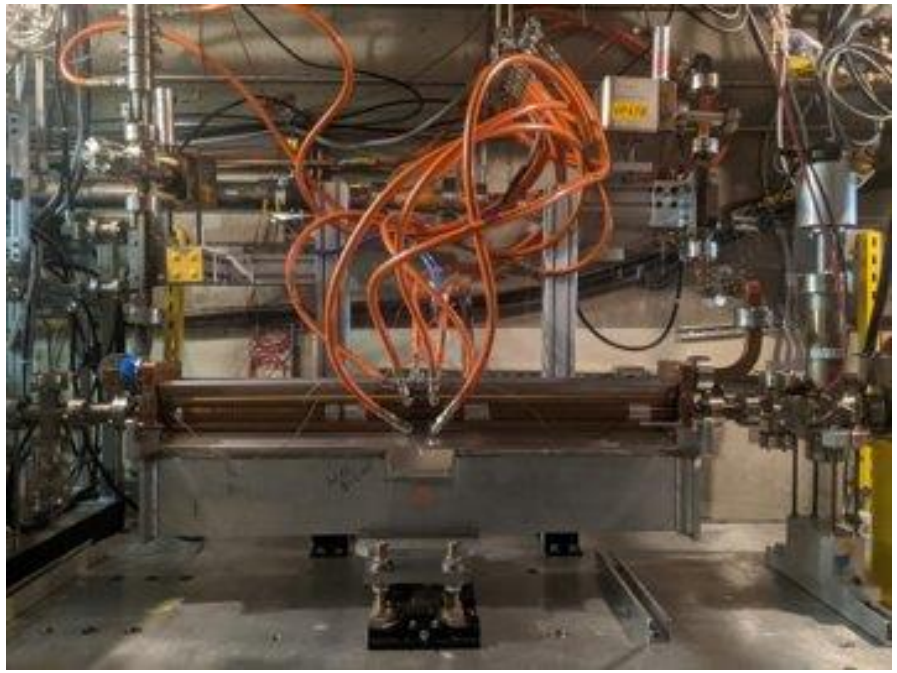


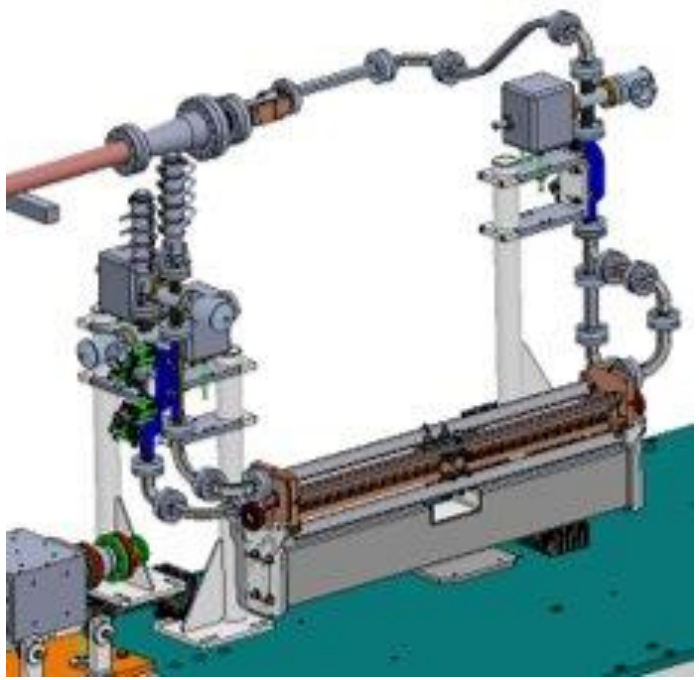


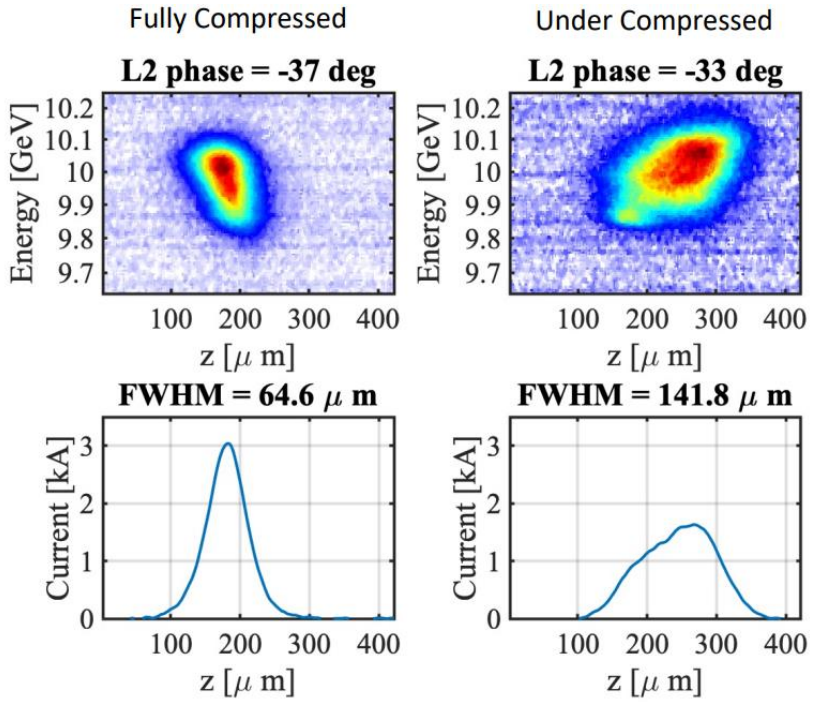
TCAV Longitudinal Phase Space measurements



- XTCAV moved to Final Focus and rotated to streak in x-direction
- Vertical dispersion at dump table allows for measurement of LPS in single shot





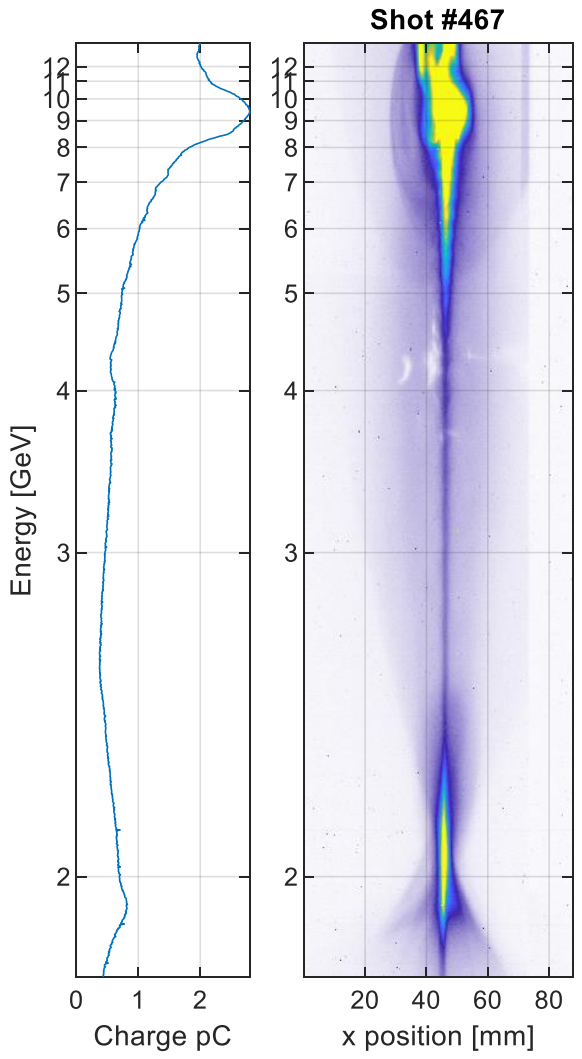


Electron spectrometer measurements

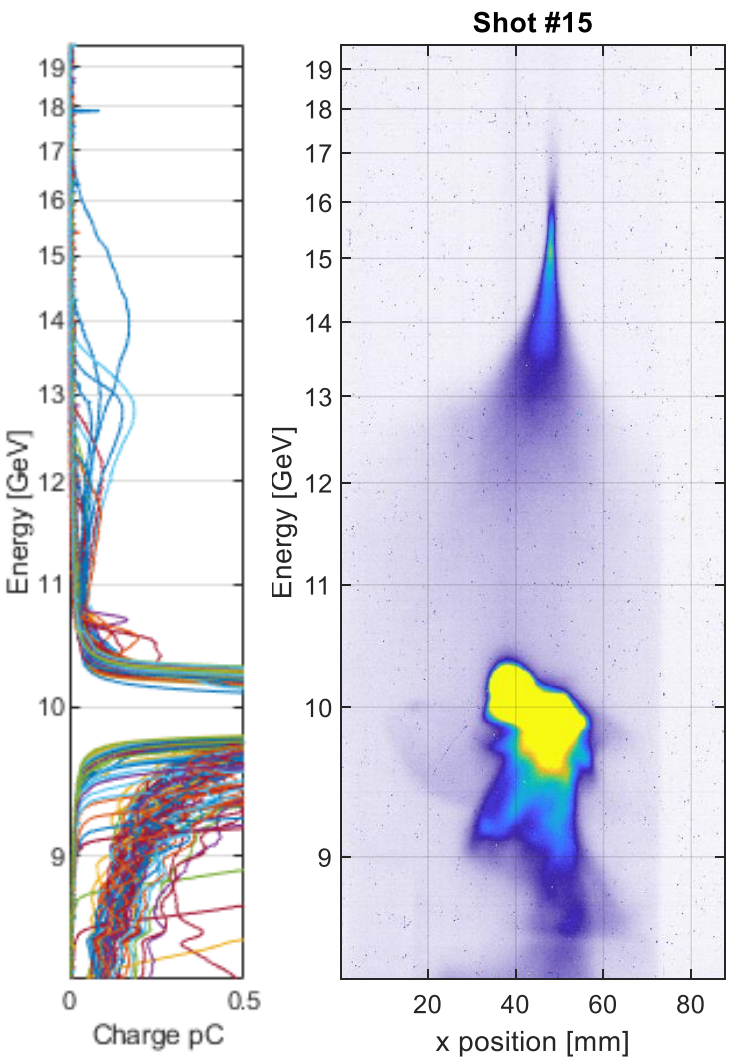
- Electron energy spectra acquired by LFOV and CHER
  - Plots show E300 data from beam-ionized H2 plasma
- Energy resolution of <1%
- Range of ~2 GeV to >20 GeV

- Ongoing work:
  - Understanding contribution to steering from spectrometer quads
  - Formalizing energy calibration for general use

Energy Depletion



Acceleration via PWFA

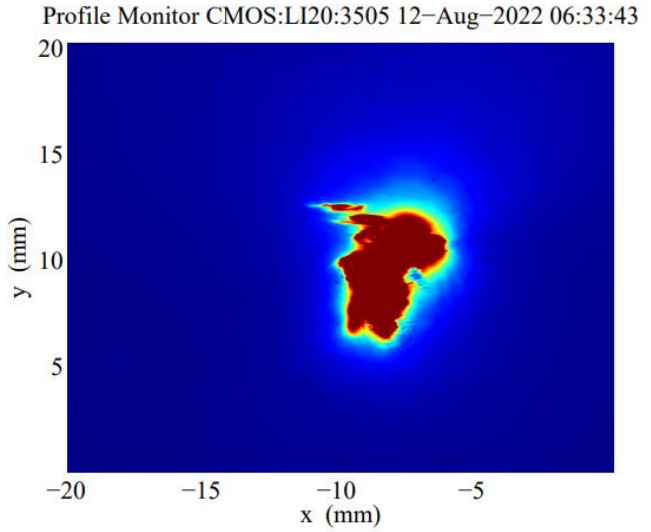


Coherent OTR and mitigation strategies

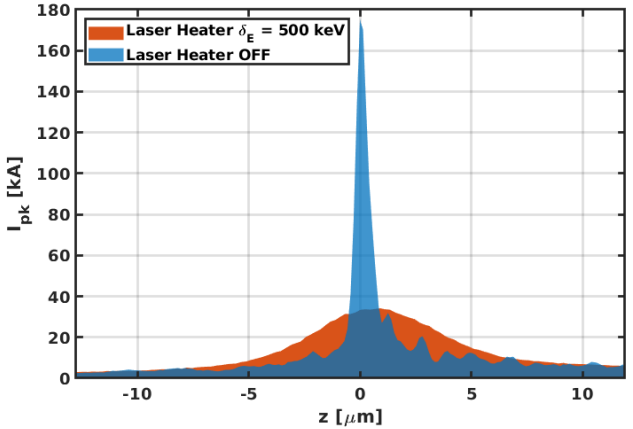
- COTR visible on all IP and dump OTR and YAG screens
- Presumed source is microbunching

- Mitigation:
  - Imaging the back side of a YAG crystal has been effective
    - Adding reversed YAG for DTOTR1
  - Blue pass filters to block long wavelength COTR
    - Added to a single IP camera, but only partially successful
  - Laser heater will be used to suppress microbunching

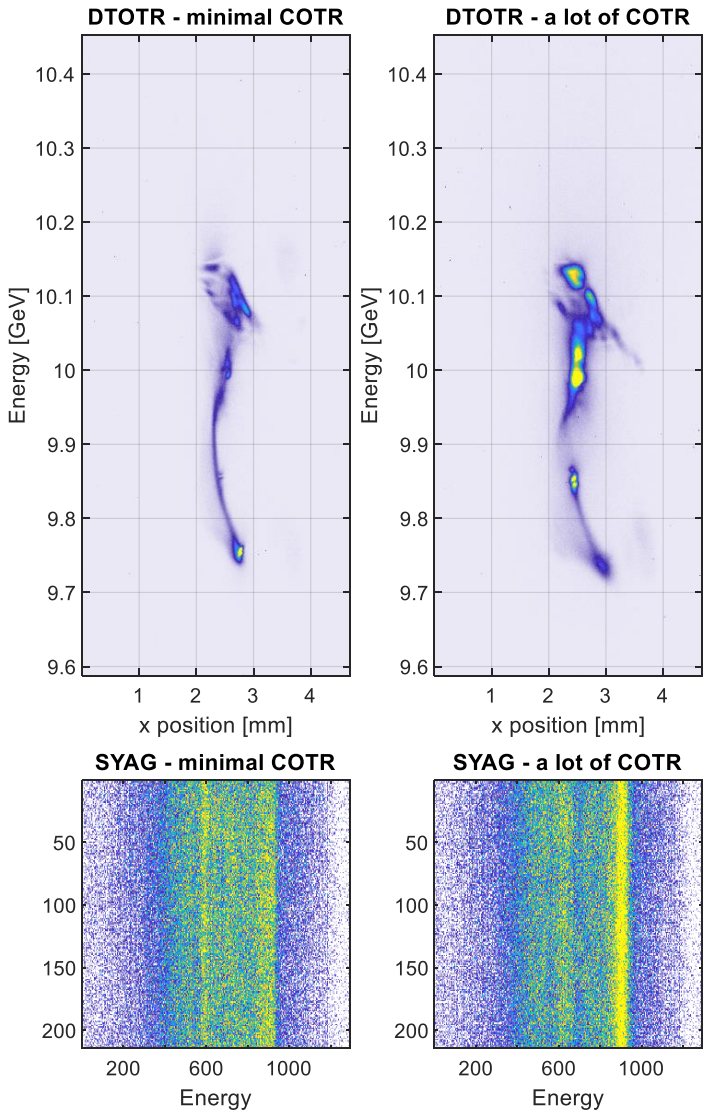
DTOTR1 – full COTR saturation



Microbunching suppressed by LH



COTR and SYAG/energy correlation

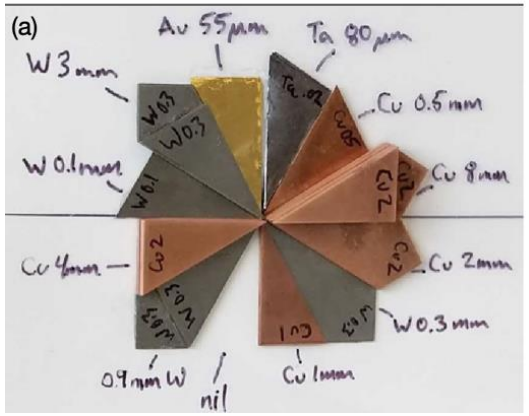


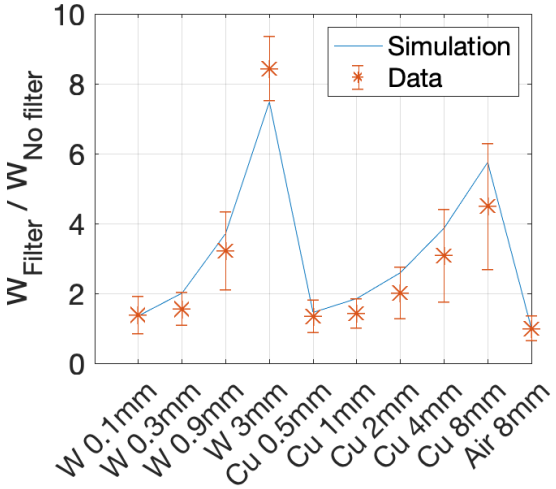
Gamma1/2 first results

- Gamma 1 provides intensity and angular profile
- Gamma2 provides spectral information

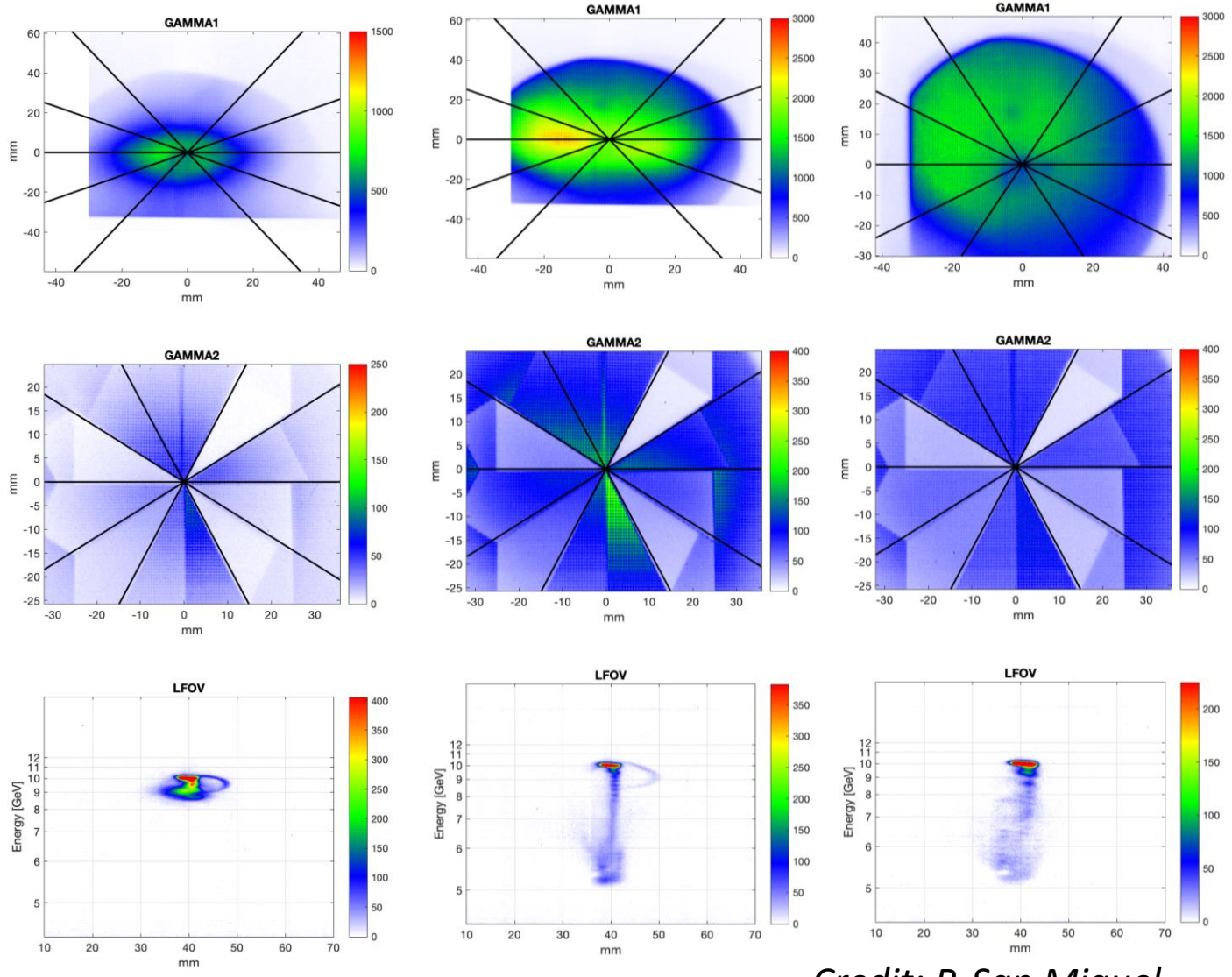
- Lower – Commissioning using bremsstrahlung photons
- Right – Raw data from E300, H2

Gamma2 Filters



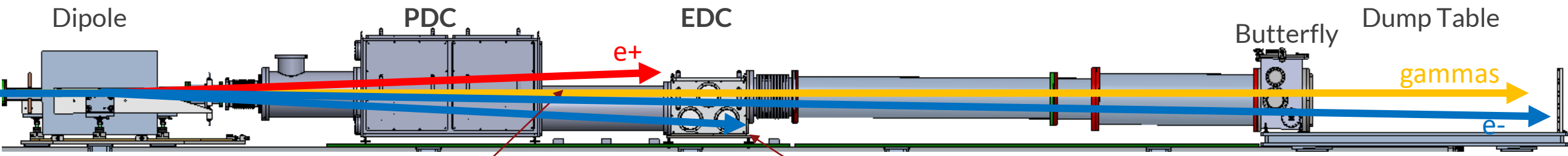


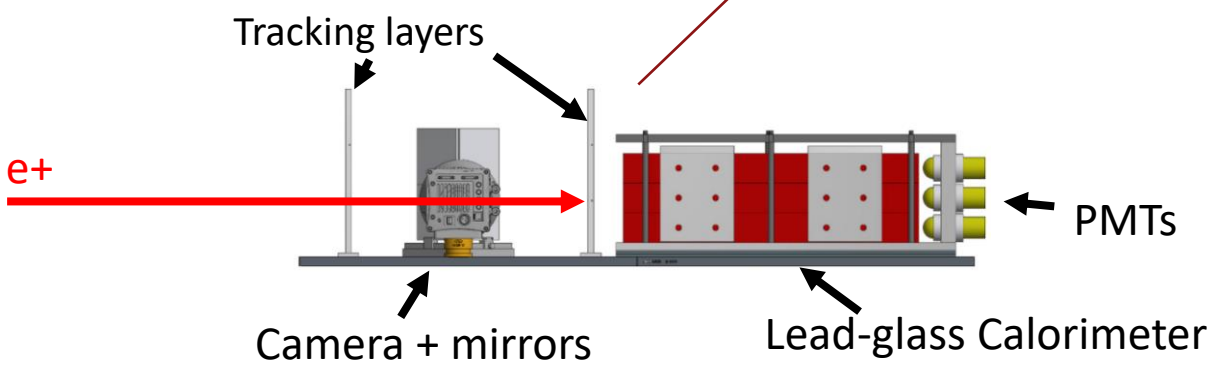
0.08 Torr | **0.3 Torr** | **1.5 Torr**

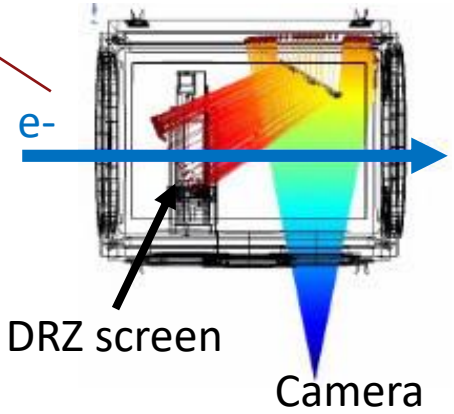


Credit: P. San Miguel

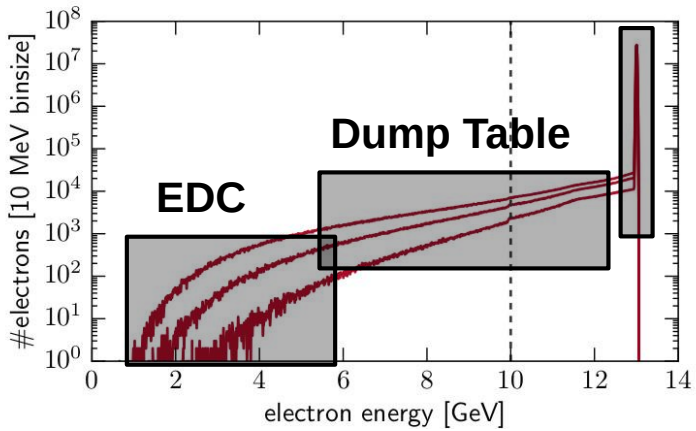
Positron and Electron Detection chambers







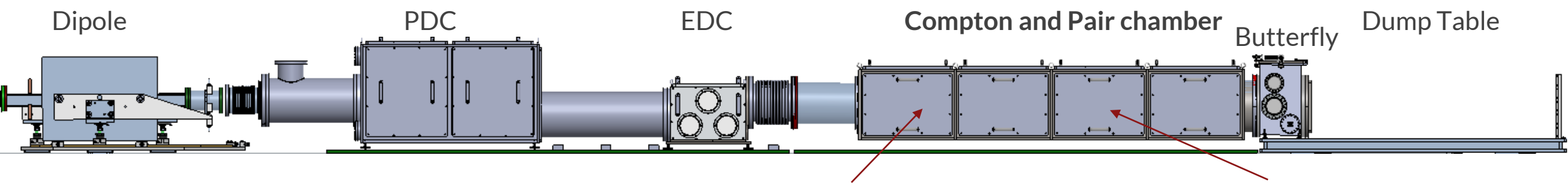
SF-QED e- spectrum



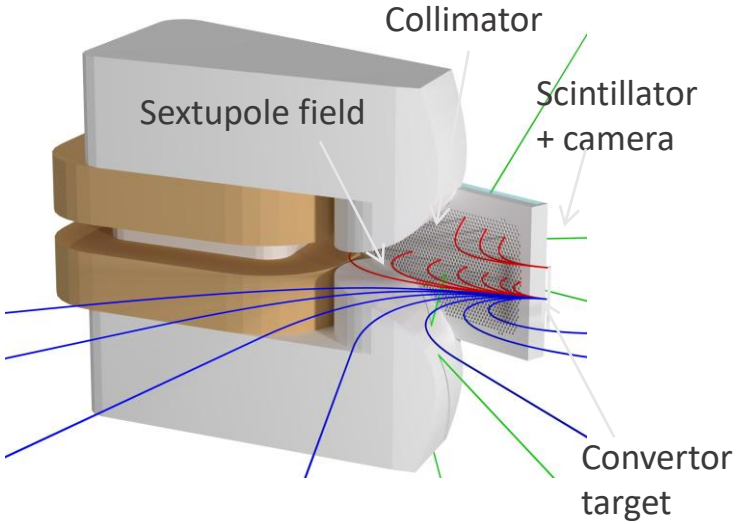
- Tracking, profiles, and calorimetry for low energy electrons and positrons
  - PDC chamber: e+ tracking and calorimetry – 2.5-6 GeV
  - EDC chamber: e- profile monitor – 1-6 GeV
- Development driven by the E320 collaboration

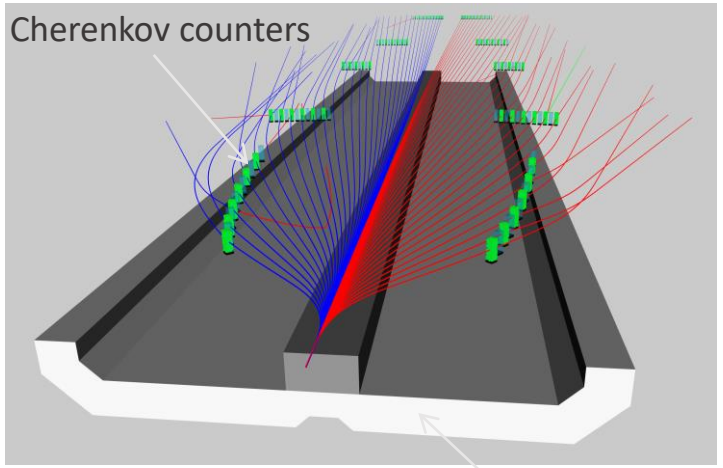
New low energy diagnostic capabilities and multipurpose, adaptable chambers installed

New Compton and pair spectrometers in progress



- Compton spectrometer:
  - 180 keV – 28 MeV energy double differential gamma spectrum
- Pair spectrometer:
  - Extends spectrum to 10 GeV
  - e-/e+ pairs analyzed by a dipole magnet and acrylic Cherenkov detectors



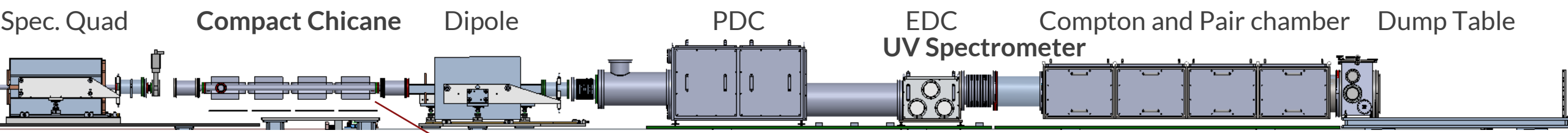


Design Credit: B. Naranjo (UCLA)

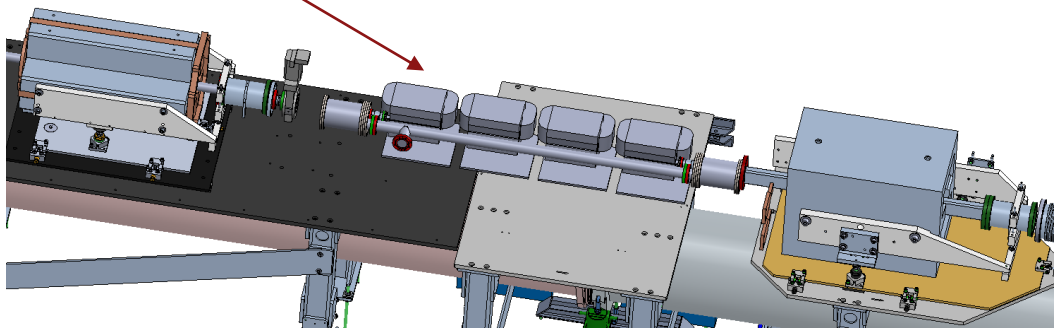
- Vacuum chambers reviewed and ready for purchase for installation in 2023

New diagnostics will extend the range and precision for measuring high energy gamma signals

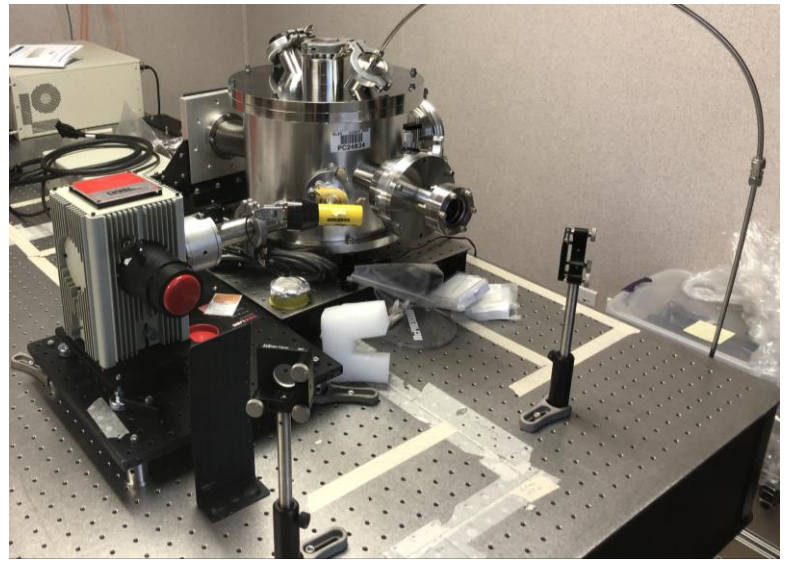
Compact chicane for testing compression of plasma chirped beams



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

Design ongoing and aiming for installation summer 2023

Summary

- Entire S20 experimental area rebuilt to meet the needs of the FACET-II science programs
- A differential pumping system has been installed to allow delivery of high intensity, low emittance beams to User programs
- Comprehensive set of spectrometer has been defined, built, and commissioned through extensive collaborations with Users
- More diagnostics are being added to further complement the spectrometer

FACET-II | Facility for Advanced Accelerator Experimental Tests

Questions?

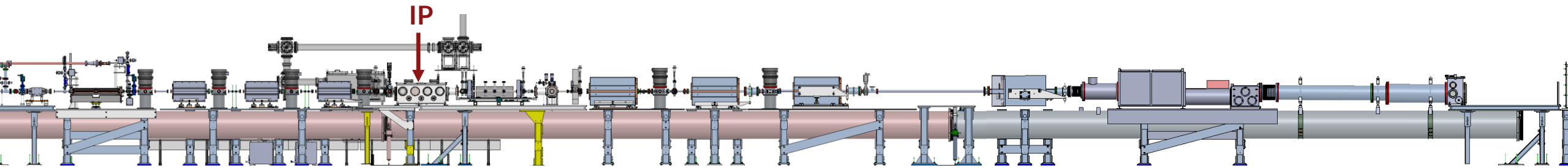
FACET-II PAC Meeting 2022

October 25-27, 2022

S20 Beam Delivery for FACET-II

- Reevaluated beam delivery in S20
  - Installed New Final Focus for smaller spot sizes at IP
  - Moved IP and removed one of the experimental tables
  - Redesigned laser compressor
  - T-cavity at a better location for measurements of x or y streak
  - Butterfly chamber for high resolution emittance and longitudinal profile measurements
  - Differential pumping to remove material in beam path
  - Space for 3 new tables / experiments

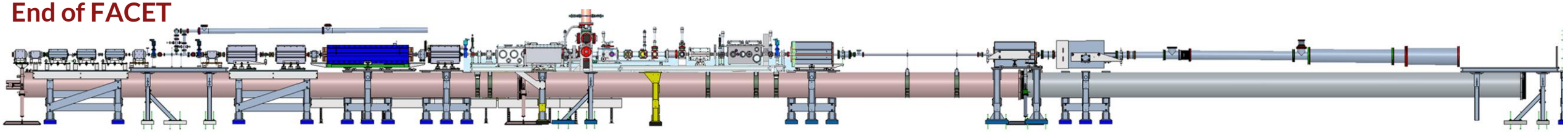
- Installation complete
  - Power supplies and Controls modifications complete
- Cooling water modifications complete
- Installations mostly during PAMM days
- All up and running



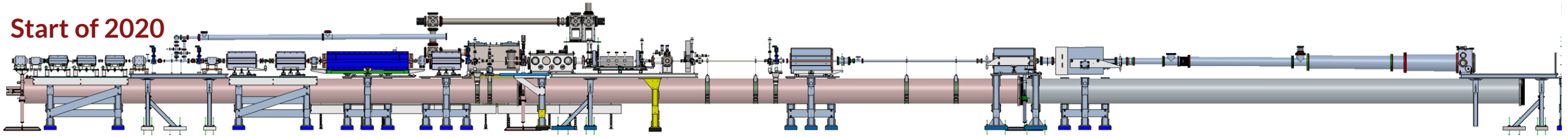
These installations were woven into the run plan to minimize down time

Progression of S20 Beamline over the last 2 years

End of FACET



Start of 2020

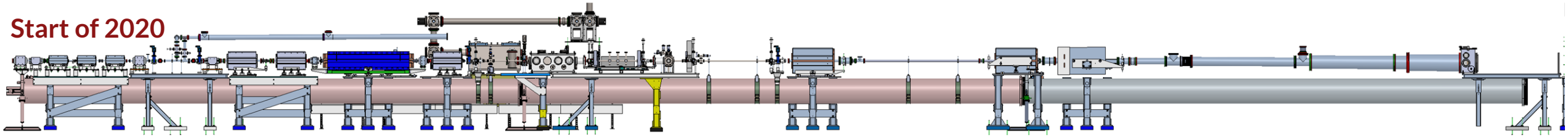


IP shortened, new laser transport line and compressor

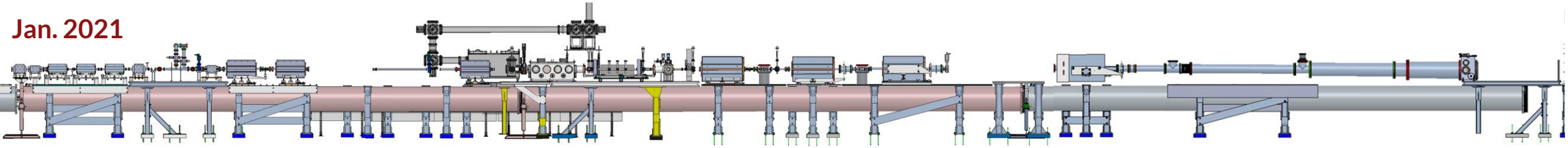
New “butterfly” chamber and dump table configuration

Progression of S20 Beamline over the last 2 years

Start of 2020



Jan. 2021



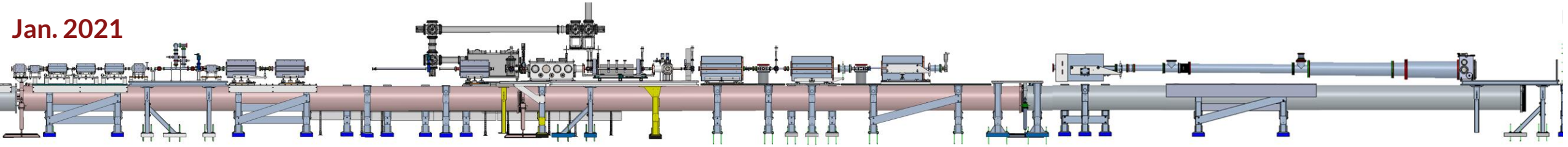
FF quads removed and replaced

Spectrometer quads reconfigured, new quad added

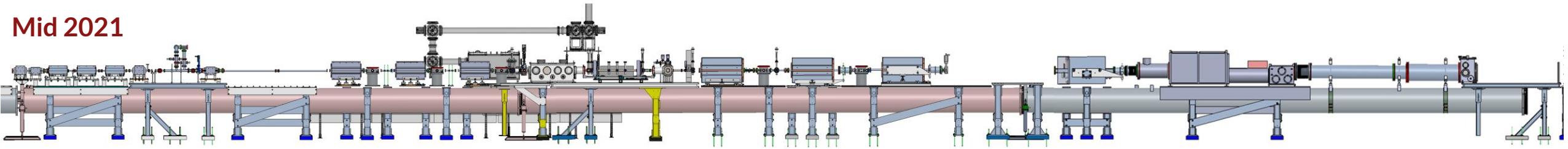
New tables installed in spectrometer

Progression of S20 Beamline over the last 2 years

Jan. 2021



Mid 2021



FF quads moved

PDC and EDC chambers installed

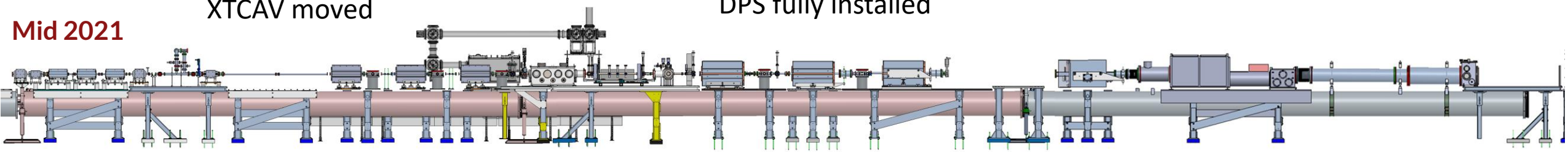
Progression of S20 Beamline over the last 2 years

More FF quads moved and power cables reconfigured

XTCAV moved

DPS fully installed

Mid 2021



Now