FACET-II | Facility for Advanced Accelerator Experimental Tests

Spectrometer Diagnostics

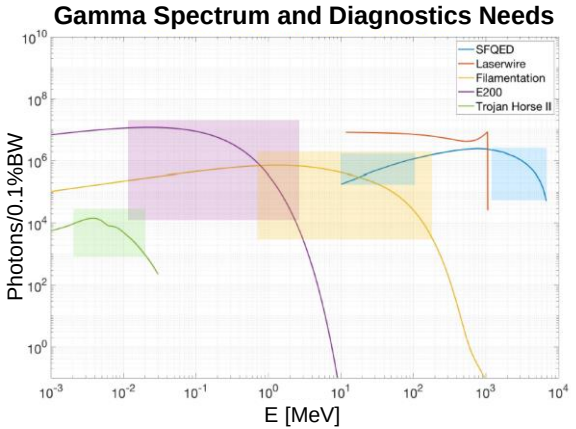
Doug Storey
October 26, 2020
SLAC National Accelerator Laboratory

U.S. DEPARTMENT OF ENERGY | Stanford University

SLAC NATIONAL ACCELERATOR LABORATORY

Experiment Requirements

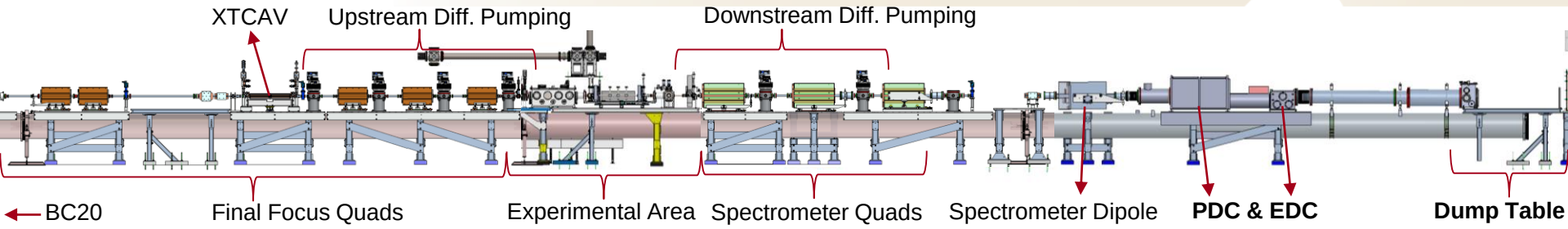
- Diagnostic needs determined through weekly “Particle and Gamma Detection” working group meetings.
- Gamma spectrums generated for each experiment to determine regions of interest and experimental requirements.
- Diagnostics developed in collaboration with users to accommodate common requirements and to distribute tasks.



	DTOTR	LFOV	CHER	G1	G2	G3	1-30 keV Bent Crystal	30-500 keV Bent Crystal	0.5-30 MeV Compton	0.001-10 GeV Compton+Pair
E300 – Two Bunch PWFA	Y	Y	Y	Y	HD	HD	O	HD	O	N
E302 – PWFA Wakefield	Y	Y	Y	Y	HD	HD	O	HD	O	N
E305 – Filamentation	Y	Y	Y	Y	Y	Y	O	HD	Y	HD
E310 – TH-II	Y	Y	Y	Y	O	O	RF		N	N
E320 – SFQED	Y	Y	Y	Y	Y	Y	N		HD	RF
E324 – Imaging	Y	Y	Y	Y	N	N	N	N	N	N

Y = “Required for beam time” N = “Not useful” RF = “Required for final run” O = “Optional, but useful” HD = “Not required for initial run, but highly desired”

Rebuilt FACET-II Experimental Area & Spectrometer



Dump Table:

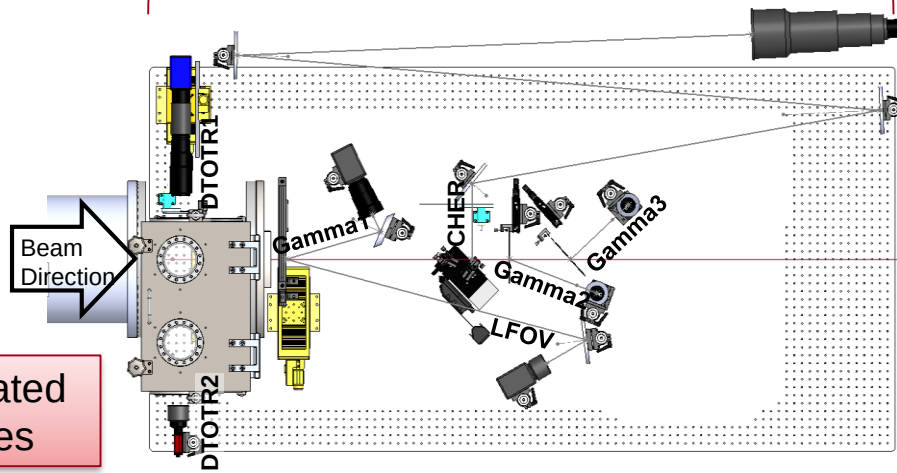
- Electron diagnostics down to ~5 GeV
- ~10 keV to 100 MeV Gamma diagnostics

PDC/EDC:

- ~2 to 5 GeV electron and positron diagnostics

Status:

- Dump table ~90% complete
- New PDC/EDC chambers delivered in Dec., installation in Jan.
- New PDC/EDC diagnostics under development by E-320 group



FACET-II is being upgraded with a mix of new and updated hardware to provide the required diagnostic capabilities

Electron diagnostics: DTOTR

Purpose: High resolution in-vacuum electron OTR profile monitor

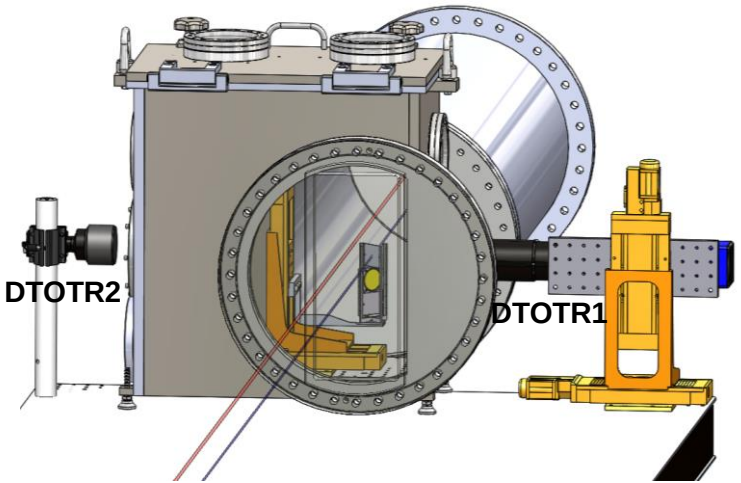
Main uses:

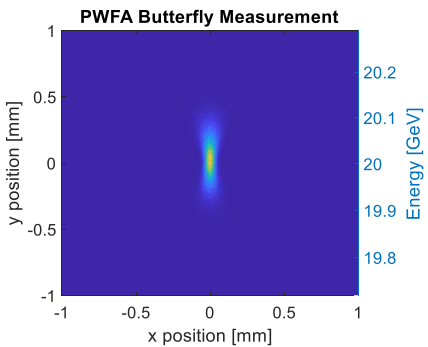
- Primary post-IP emittance diagnostic
- LPS measurements with TCAV

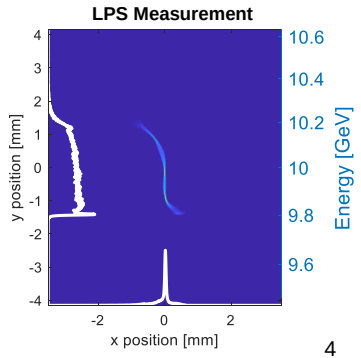
Specifications:

- Screen: YAG or polished titanium plate for OTR
- Camera: PCO Edge5.5 w. Nikon 200mm f/4
- Field of View: 7mm x 8.4mm (±30mm)
- Energy Range: ~2 GeV FOV (E-300)
- Resolution: 4.5 µm imaging → 0.01% energy res.

- DTOTR2 is a complimentary large FOV alternative







DTOTR Emittance Diagnostic

Butterfly emittance measurement

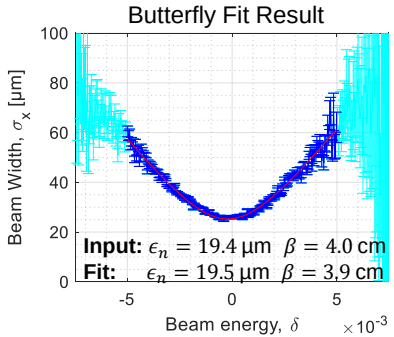
- Single shot measurement of the projected emittance down to the scale of ~1 mm-mrad
- **Resolution:** <5% emittance resolution for measuring matched beams at plasma exit
- **Limitations:** Phase mismatch, existing correlations can impact the measurement

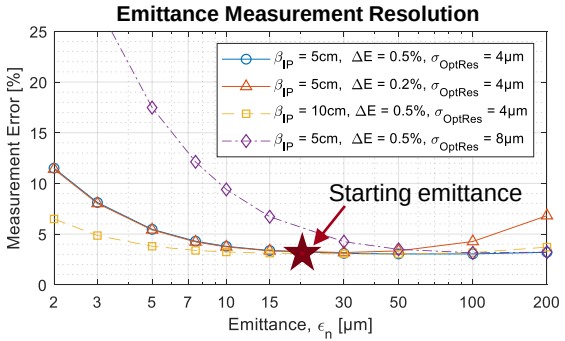
Dispersive quad scan emittance measurement

- Multi-shot emittance measurement using a quad scan
- **Resolution:** Good resolution, useful for low energy spread beams, provides info on matching condition
- **Limitations:** Relies on beam stability

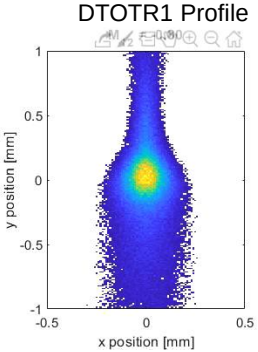
New high resolution diagnostics support sub-μm precision measurements of μm scale emittances

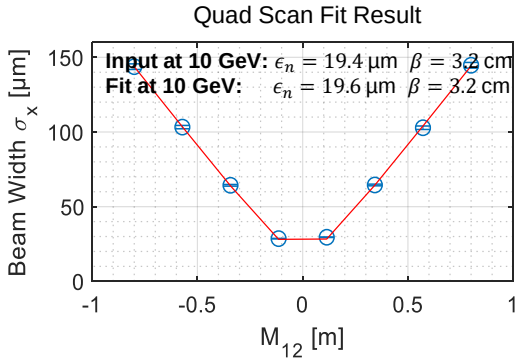
Sample Butterfly Measurement





Sample Dispersive Quad Scan





Electron diagnostics: LFOV and CHER

LFOV – Large field of view profile monitor

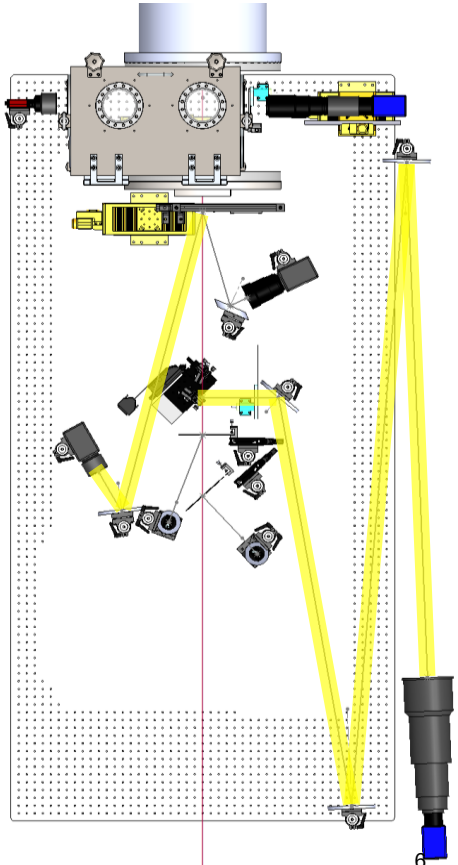
Specifications:

- Screen and camera: DRZ Fine + Orca Flash
- Field of view: 10cm x 30cm
- Imaging resolution: ~150 µm (pixel size)
- Energy Range: Down to ~5 GeV
- Minimum detectable charge: 1×10^{-5} pC/pixel (with SNR>10)

CHER – Electron spectrometer

Specifications:

- Screen and cameras: Cherenkov light from 5cm gap
- Camera: PCO Edge w. Nikon 600mm f/4
- Field of view: 5 x 16 cm FOV
- Imaging resolution: ~230 µm
- Energy Range: ~5 to 24 GeV
- Energy resolution: 0.4%

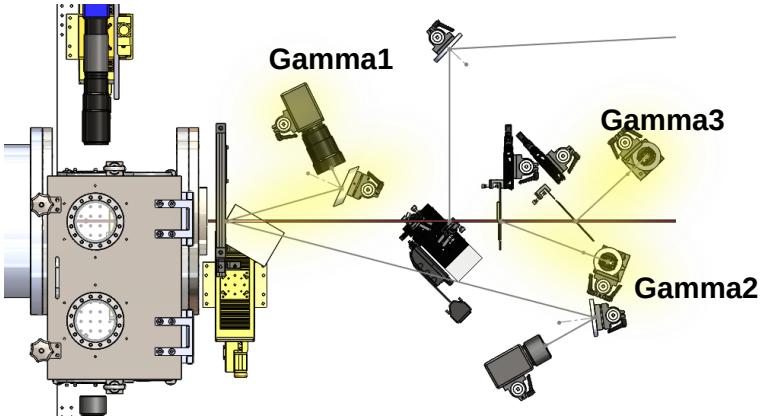


General purpose electron diagnostics available to all experimental users that remains mostly unchanged from FACET

Gamma diagnostics: Gamma1

Gamma1 – Photon profile monitor

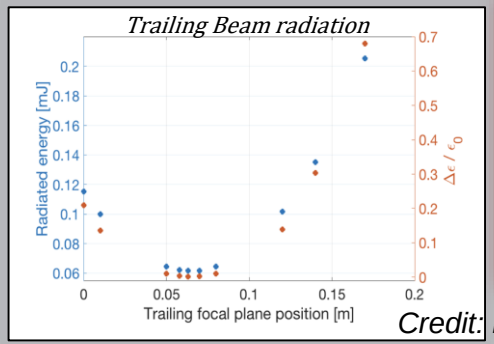
- Photon integrated signal:
  - PWFA: Correlated with beam matching dynamics
  - Spatio-temporal alignment
- Photon angular distribution:
  - PWFA: e^- beam *x-y* symmetry and trailing beam offsets.
  - E320 - SFQED: a_0 value.



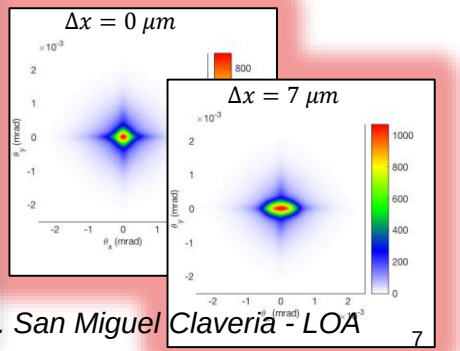
Specifications:

- Screen: CsI Array or DRZ-Fine
- Camera: Orca Flash w. Nikon 50mm f/1.4 lens
- Field of View: 10cm x 10cm
- Resolution: 0.5 x 0.5mm^2 CsI pixel size (20 µrad)
  50 µm imaging pixel size (2 µrad)

Correlation b/w betatron radiation and PWFA emit. growth



Drive + trailing bunch betatron radiation angular distributions

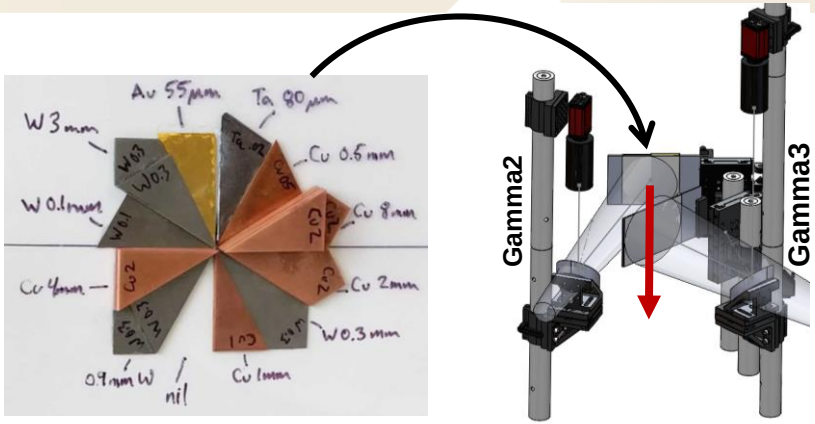


Credit: P. San Miguel Claveria - LOA

Gamma diagnostics: Gamma2/3

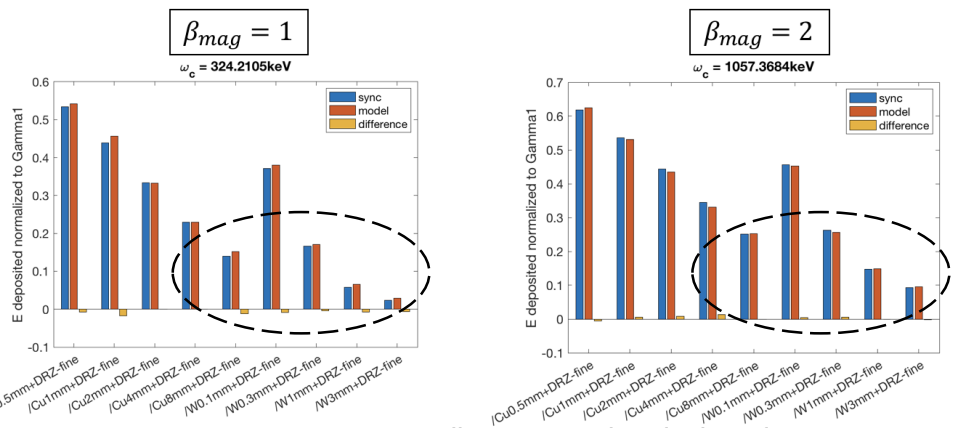
Gamma2 and Gamma3 – 10keV-100MeV spectral measurements

- DRZ screens located downstream of a set of step filters and one Ross pair arranged in a “camembert” filter wheel.
  - Gamma2 measures conversion rates
  - Gamma3 measures transmission rates



Analysis:

- Image intensity behind each filter material varies with the spectral content of the incident gammas
- Comparison to GEANT4 simulations provide an estimate of the corresponding critical frequency
- Example shown for analysis of E300 PWFA case:

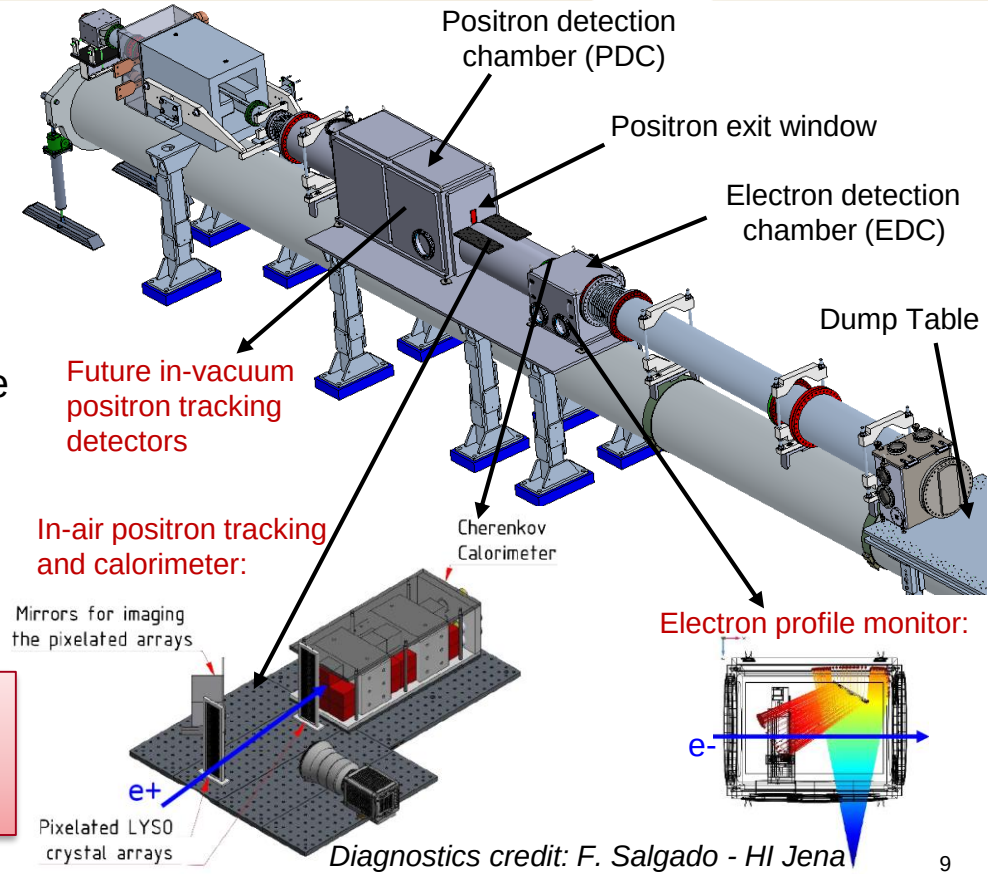


Gamma diagnostics at the dump table provide robust intensity and spectral information

Credit: P. San Miguel Claveria - LOA

Positron and Electron Detection Chambers

- Multi-use vacuum chambers to allow for detection of low energy electrons and positrons
  - Reconfigurable chamber walls for maximum flexibility
  - Maintains the current electron and gamma apertures
- Diagnostics being developed by members of the E-320 collaboration
  - ~2-6 GeV positron tracking detectors
  - Positron calorimeter
  - ~2-8 GeV electron profile monitor

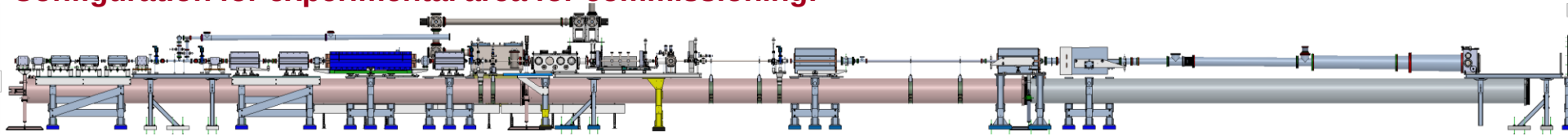


Provides simultaneous single-particle detection of positrons and low energy electron detection, complimentary to the dump table diagnostics

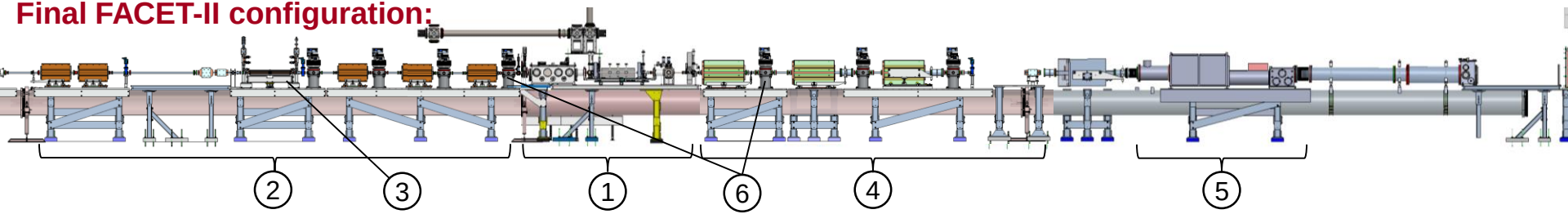
Diagnostics credit: F. Salgado - HI Jena

Final Focus and Spectrometer rebuild

Configuration for experimental area for commissioning:



Final FACET-II configuration:



Experimental area rebuild:

1) IP equipment install:
2) Final Focus quad reconfiguration:
3) XTCAV rotated and moved from BC20:
4) Spectrometer doublet to triplet:
5) PDC and EDC chambers:
6) Differential Pumping System:

Status and timeline:

Complete vacuum to dump now, fully instrumented Dec./Jan.

Parts are being collected. Rebuild in January

Spring/Summer 2021

Parts are being collected. Rebuild starting December

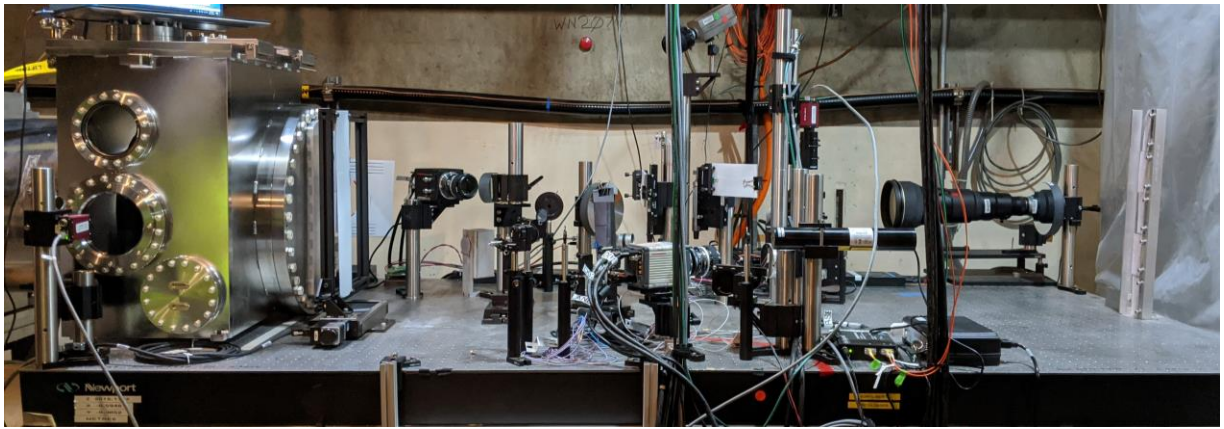
Chamber fabrication nearing completion. Install in January

Beamline parts to be installed in January, pumps by Feb/March

Summary

- Spectrometer diagnostics have been developed and implemented in collaboration with the experimental users
- The Dump Table will be ready to receive beam by the end of the week
- New diagnostic capabilities are being added though the installation of significant new hardware to come online in early 2021

Present Dump Table Installation



Backups

Butterfly Emittance Diagnostic - DTOTR

DTOTR1 specs:

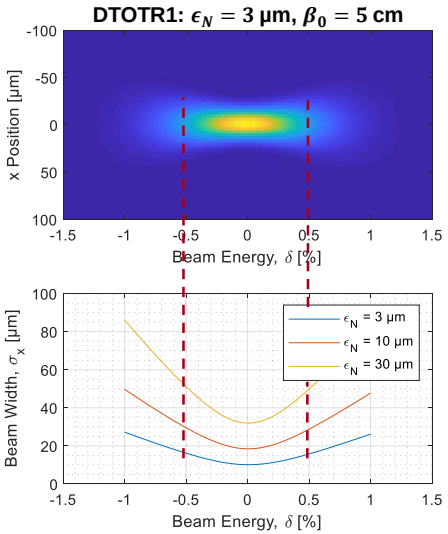
- Screen: YAG or polished titanium plate for OTR
- Camera: PCO Edge5.5 w. Nikon Nikkor 200mm f/4
- Field of View: 7mm x 8.4mm (±30mm)
- Resolution: 4.5 µm imaging → 0.01% energy resolution

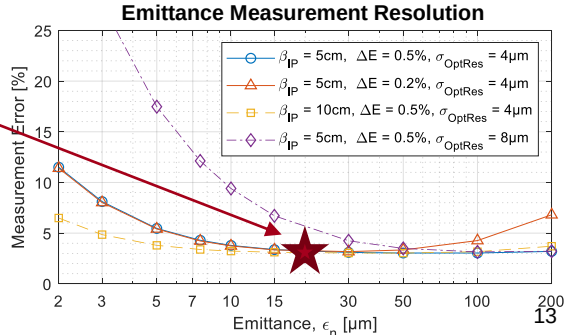
Butterfly emittance measurement

- Single shot emittance measurement – use fit to get ϵ_n and β

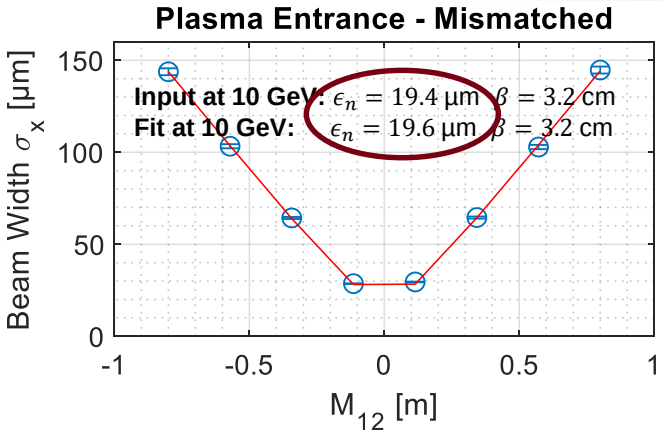
$$\left(\sigma_x(\delta)\right)^2 = \frac{\epsilon_n}{\gamma_b}\left[M_{11}(\delta)^2\beta_0 - 2M_{11}(\delta)M_{12}(\delta)\alpha_0 + M_{12}(\delta)^2\left(\frac{1+\alpha_0^2}{\beta_0}\right)\right]$$

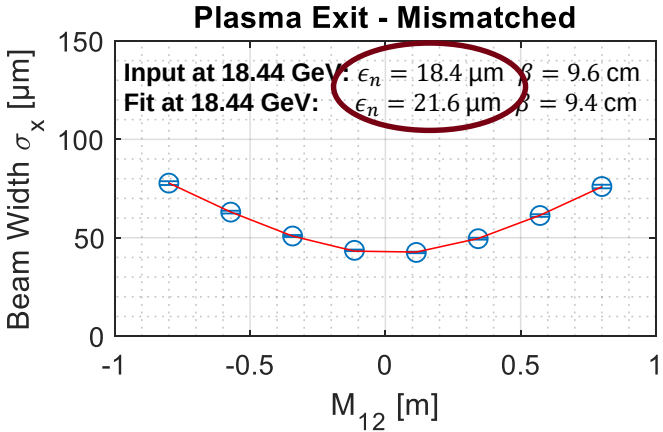
- **Resolution:** <5% emittance resolution, for measuring matched beams at plasma exit
- **Limitations:** Phase mismatch, existing correlations in the beam properties





Dispersive Quad Scan Emittance Measurement



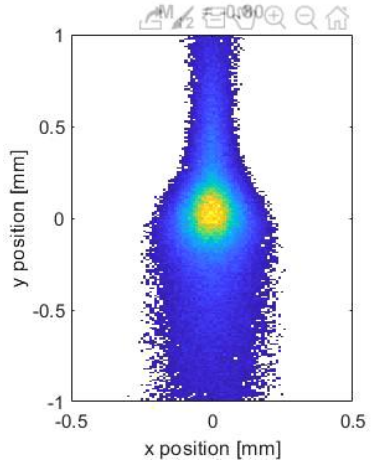


This is a multi-shot measurement that can be used as an alternative to the butterfly measurement:

- Scan the spectrometer quads to scan over R_{12} and image the beam on DTOTR1
- Fit the beam width at a single energy using M_{12} and M_{11}:

$$(\sigma_x(M_{12}))^2 = \frac{\epsilon_n}{\gamma_b}\left[M_{11}^2\beta_0 - 2M_{11}M_{12}\alpha_0 + M_{12}^2\left(\frac{1+\alpha_0^2}{\beta_0}\right)\right]$$

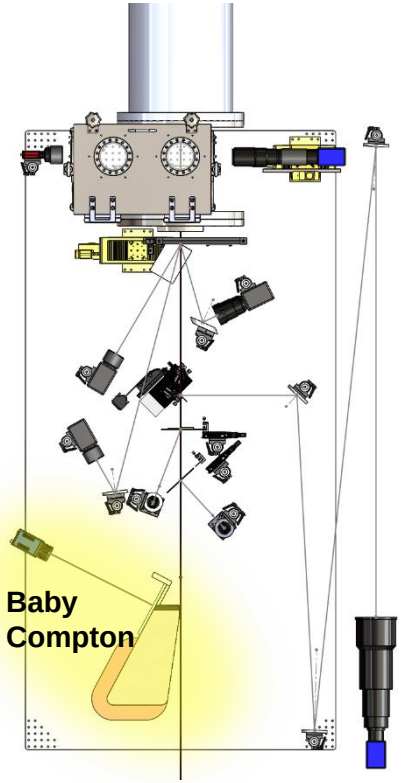
Quad Scan:

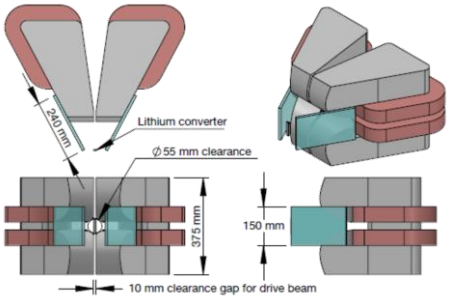


Key points:

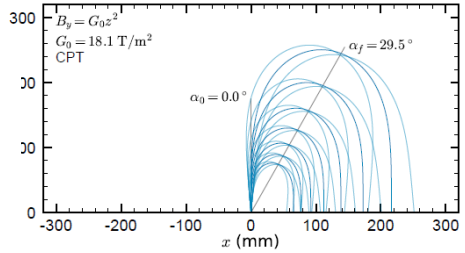
- Can determine the $\epsilon_n(E)$ and $\beta(E)$
  → provides information on matching condition
- Useful during beam commissioning for low energy spread beams, and cross-checking the butterfly emittance measurement
- Main limitation: relies on beam stability

Compton Spectrometer (UCLA)

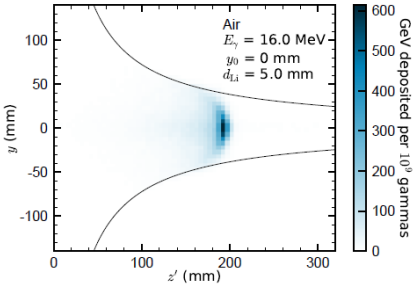




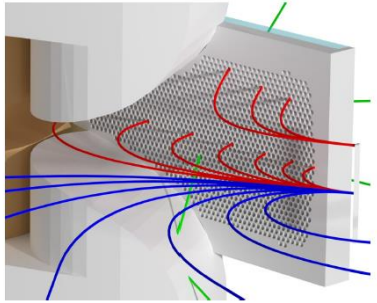
Dimensions including optional positron readout



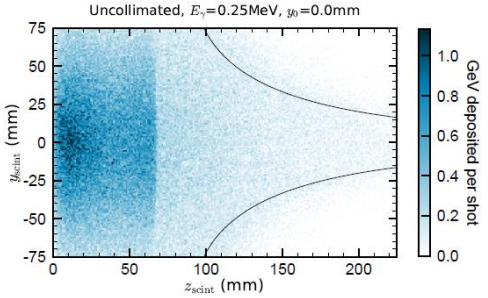
Focusing in horizontal plane



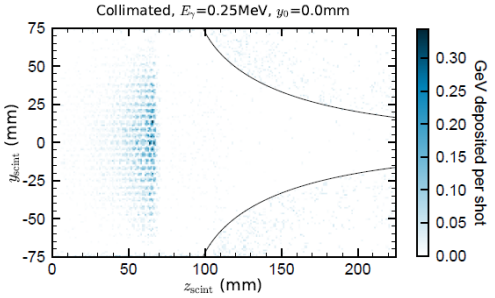
16 MeV gammas incident on lithium



Electron collimator (3D printed tungsten)



250 keV gammas (without collimator)



250 keV gammas (with collimator)

- Nominal gamma spectroscopy range from 200 keV through 20 MeV.
- Optional positron readout to subtract pair background from Compton spectrum.
- Sextupole design allows compact spectrometer with high dynamic range.
- Lengths scale with cube root of electron momenta.

Slide courtesy of B. Naranjo, UCLA

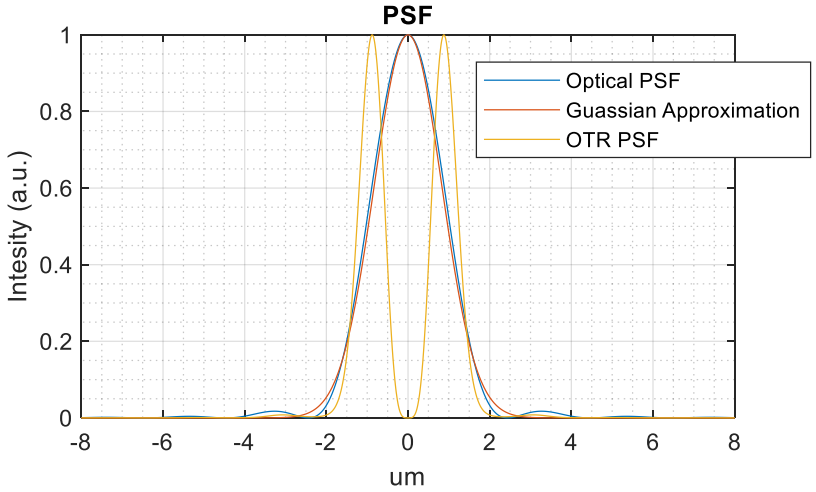
OTR PSF

For case of:

- 50mm aperture at 200mm FD
- 10 GeV
- 500nm light

- Normal diffraction resolution of ~1.5 um

- OTR PSF is donut-like
  - Width on order of: 2-3 um
  - Less than pixel size
    → resolution is still dominated by pixel size, not PSF



Pixel size