E-320: Current Status and Future Plans

A. Knetsch on behalf of the E-320 Collaboration

SLAC National Accelerator Laboratory

SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

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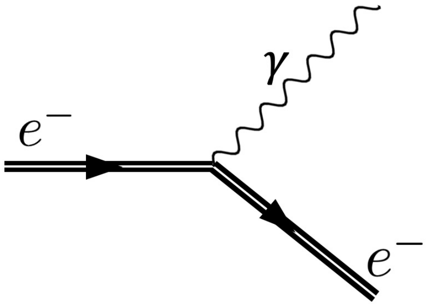
In the vicinity of strong electric fields the Dirac equation is modified

$$(i\hbar\gamma^{\mu}\partial_{\mu} - e\gamma^{\mu}A_{\mu}^{\text{ext}} - mc)\psi = 0$$

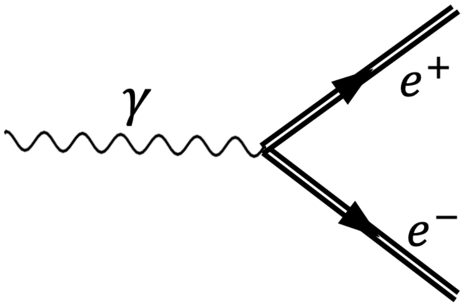
- Non linear inverse Compton scattering :

$$e^{-} + n\omega \rightarrow e^{-} + \gamma$$

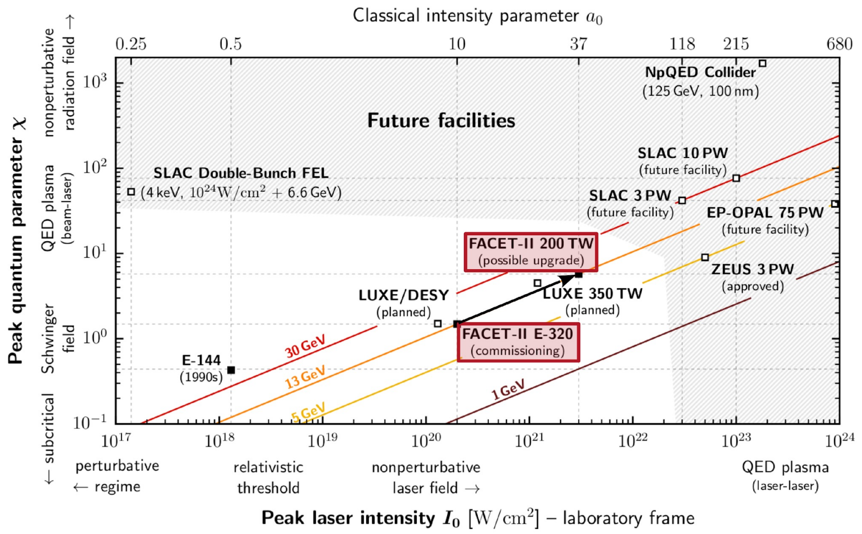


Non linear Breit-Wheeler pair creation :

$$\gamma + n\omega \rightarrow e^{-} + e^{+}$$



Leading parameters for laser-electron beam collsion experiments



Schwinger critical field

$$E_s = \frac{m^2 c^3}{e\hbar} \sim 10^{18}\,\frac{V}{m}. \qquad \chi = \frac{E}{E_s}$$

$\chi > 1$ marks onset of nonlinear effects

Laser-beam collisions

$$\chi = \gamma \frac{E}{E_s}$$

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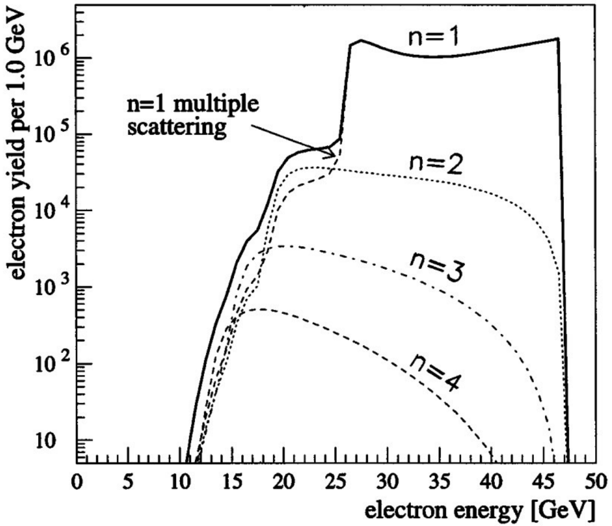
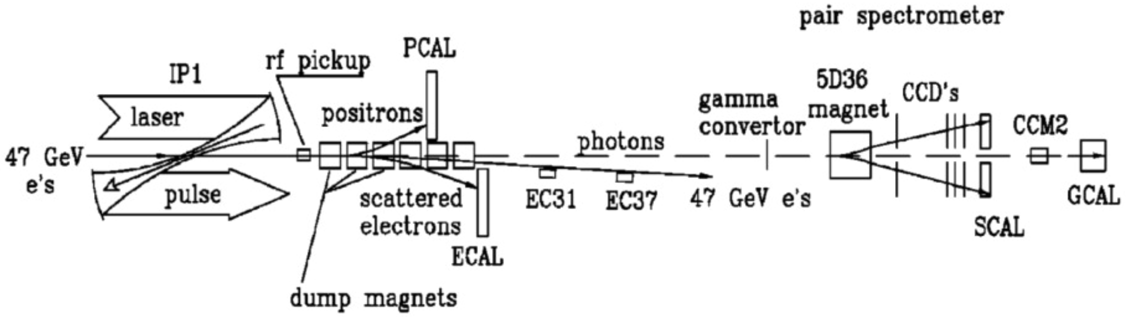
E-144: first observation of nonlinear Compton scattering



SLAC E-144 (simulation)

Bula et al., PRL 76 (1996)
Bamber et al., PRD 60 (1999)



E-144: observed onset of nonlinear effects

~ 50 GeV electrons + ~ 10^{18} W/cm^2 laser intensity: $a_0 \lesssim 0.5$, $\chi \lesssim 0.5$

Reaching extreme laser intensities: Lorentz boost

Yakimenko et al., PRAB 22, 101301 (2019)

FACET-II | Facility for Advanced Accelerator Experimental Tests

FACET-II electron beam parameters

- Up to 2 nC bunch charge
- ~ 10 GeV beam energy
- Bunch length (rms) < 100 µm

FACET-II laser parameters

- ~ 300 mJ on target
- ~ 60 fs pulse length
- $a_0 > 1$
- $\chi \sim 1$

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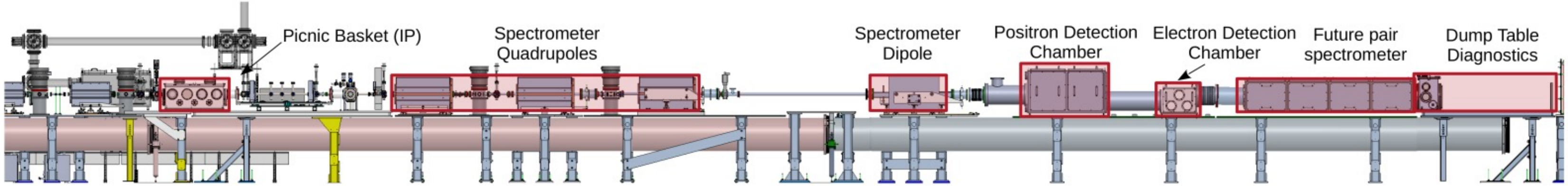
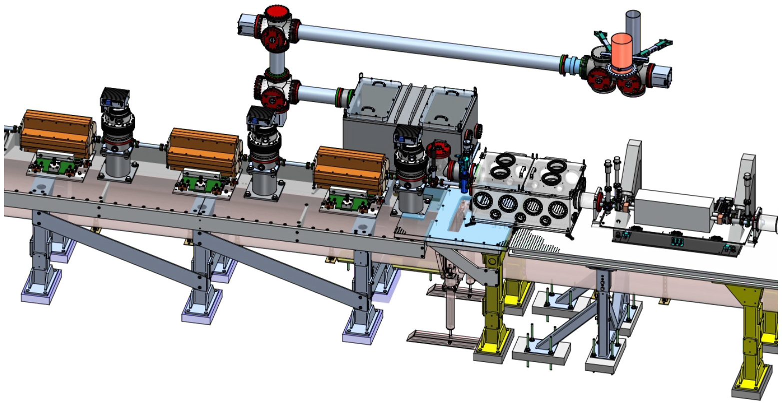
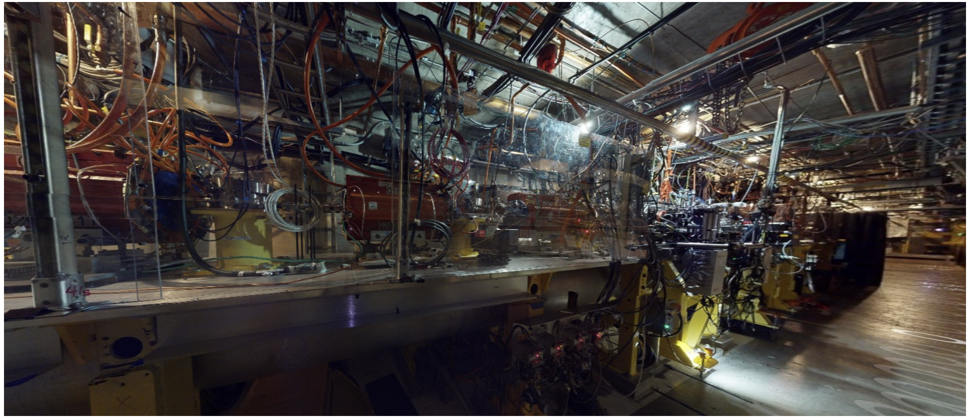
FACET-II experimental area







3D walkthrough
https://my.matterport.com/show/?m=E6rRJHvAB27

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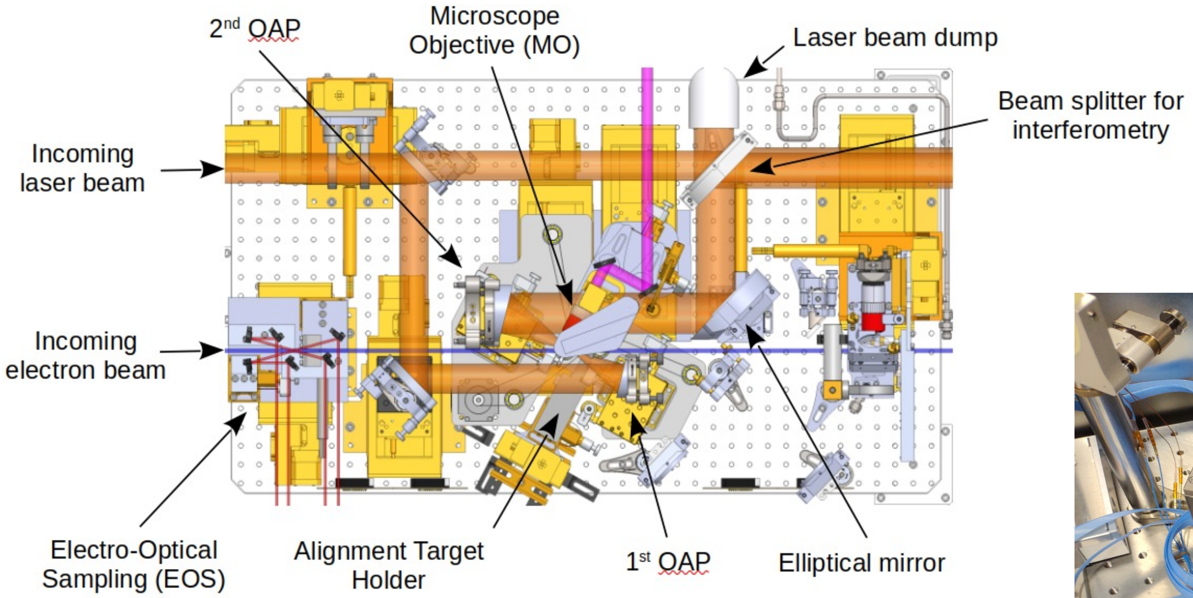
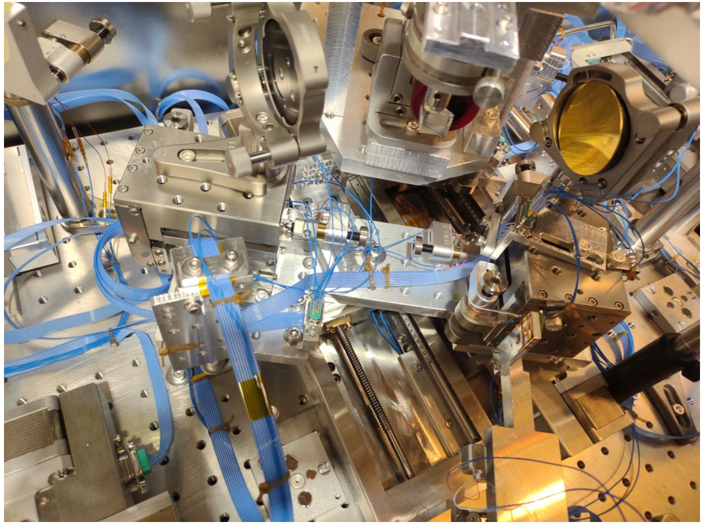
E-320 interaction point (IP)





Current laser parameters

MPA output	0.6-0.8 J
Transport efficiency	0.88 %
Probe splitter	0.8 %
Compressor	0.7 %
Compressor window	0.96 %
Energy on target	**0.28-0.38 J**

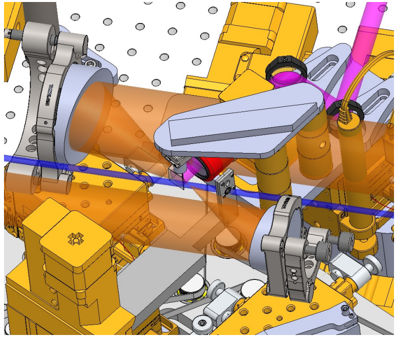
Beam diameter	40 mm
f#	~2
wavelength	0.8 μm
Spot size (FWHM)	2-3 μm
Pulse duration	~60 fs
Strehl ratio	~0.5

$$a_0 \approx 0.60\,\mu\mathrm{m}^{-1}\lambda\sqrt{2I_0/(10^{18}\,\mathrm{Wcm}^{-2})}$$

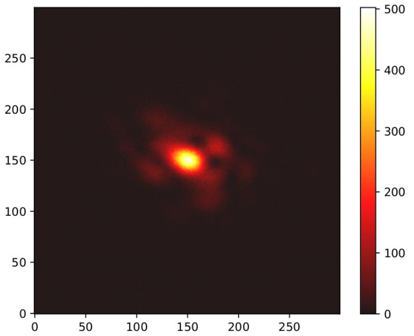
$$I_f \approx 0.7812\frac{\mathcal{E}_L}{\mathrm{FWHM}^2\tau_0}$$

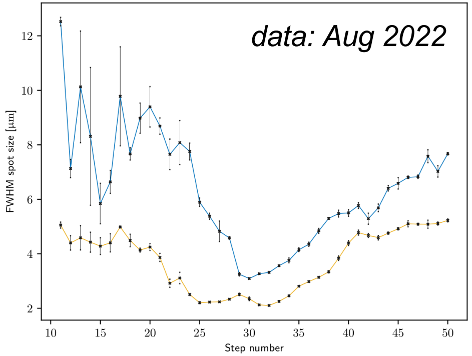
Peak intensity (Airy disk)

Expected achievable: ≳3x10^{19} W/cm^2 (a_0≳4)



Laser focused by OAP in the tunnel

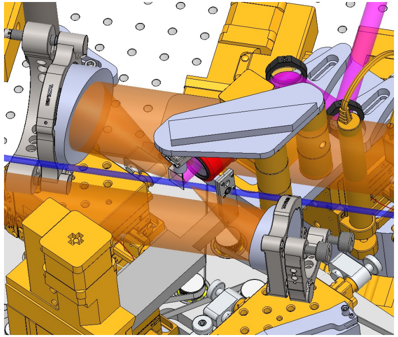


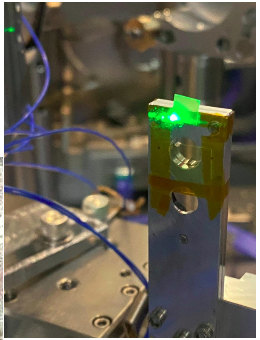


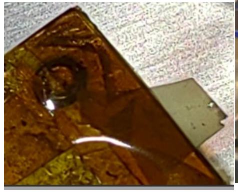
Focal scan: wavefront aberrations clearly visible

Study by Junzhi Wang, Robert Ariniello, et al.

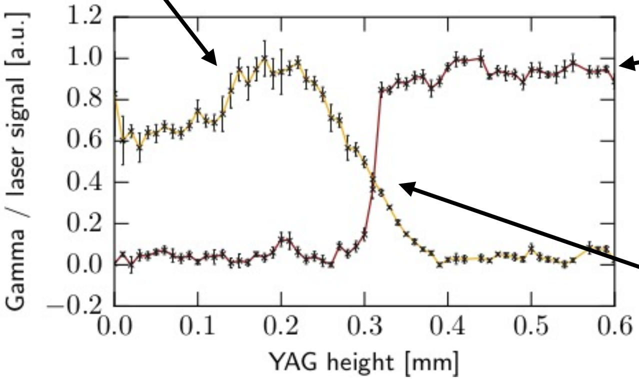
Finding spatial overlap: knife-edge scan

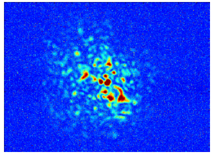


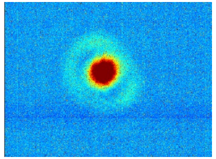




bremsstrahlung:
e-beam on YAG







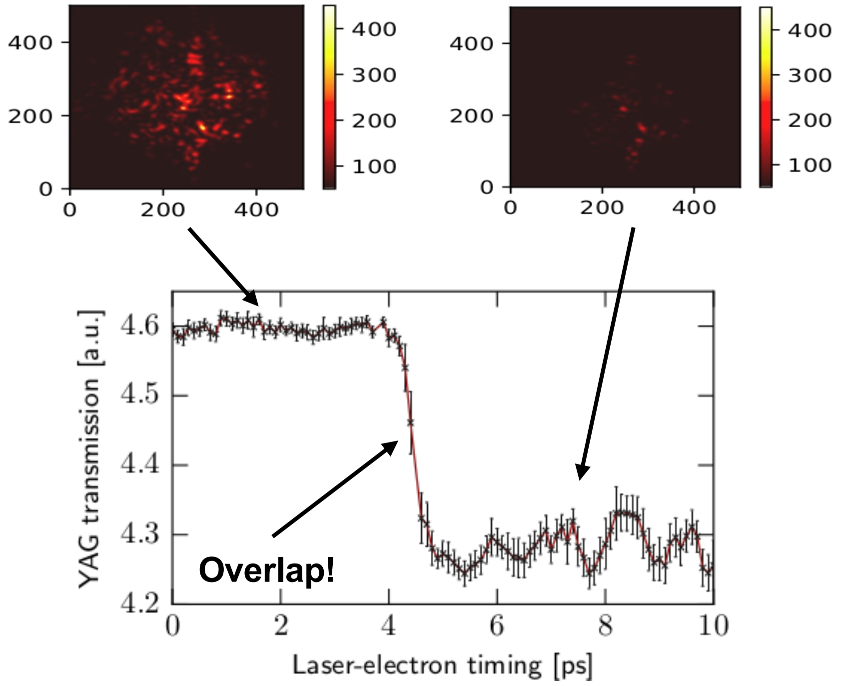
laser spot: fully blocked by YAG (left)
vs. direct transmission (right)

Overlap!

YAG position scan: up/down and left/right (analogue)
gamma signal (dump) & laser spot (MO camera)

E-320 run on August 19, 2022 (dataset 2918)

Finding temporal overlap: YAG-timing tool

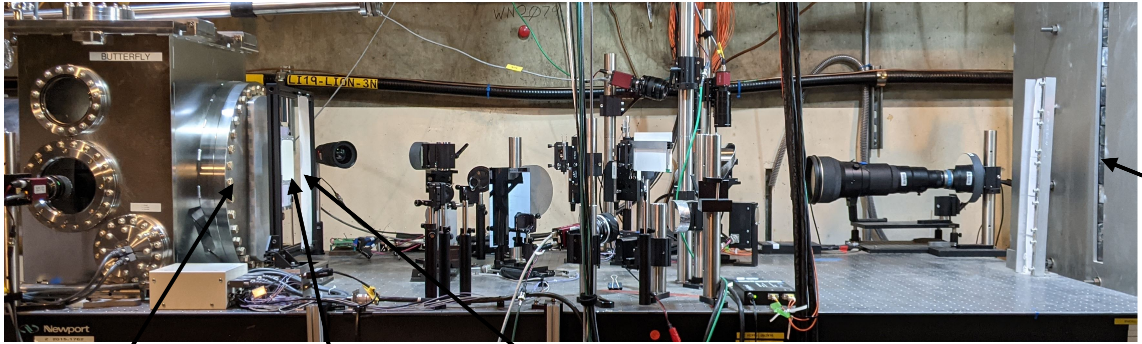


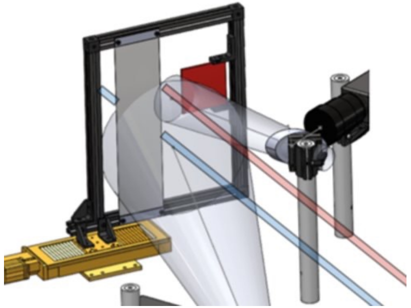
E-320 run on August 19, 2022 (dataset 2925)

- e-beam arrives early: carriers are induced
- Laser transmission is reduced
- Rise time: $\lesssim$ 1ps, carrier lifetime: $\gtrsim$ 100 ps
- 10 ns window covered with only 100 shots
- Transition marks synchronous time-of-arrival between electron beam and laser

Inspired by LCLS timing tool: *Sato et al., J. Syn. Rad. 26, 647 (2019)*

Dump-table diagnostics (electron + gamma)



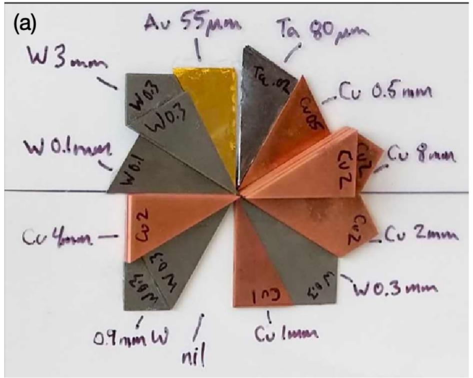


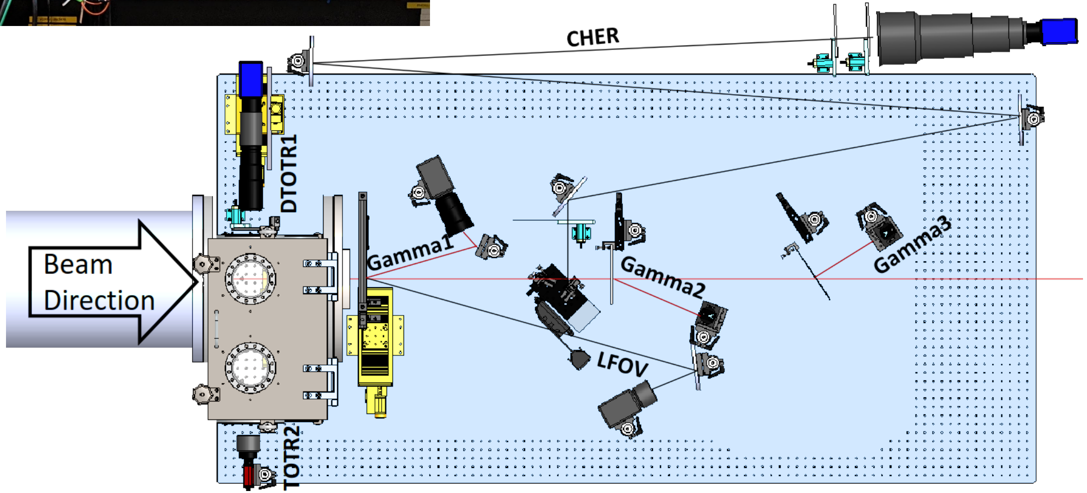
beam dump entrance

exit window

CsI (gammas)

DRZ/Lanex (electrons)





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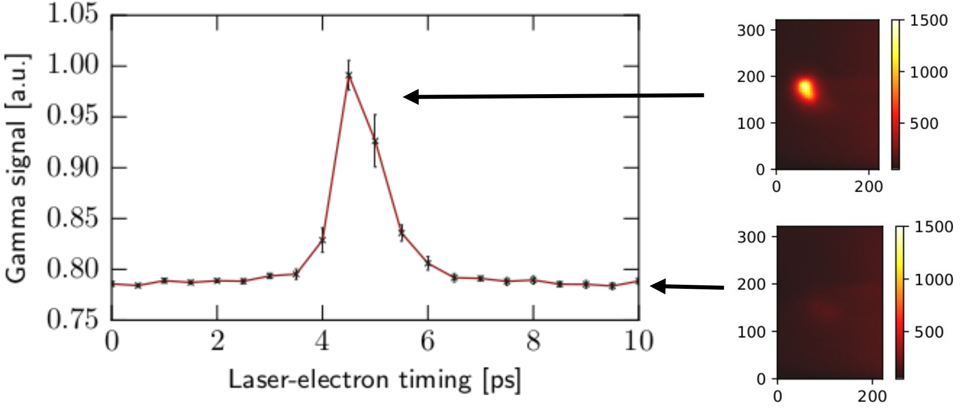
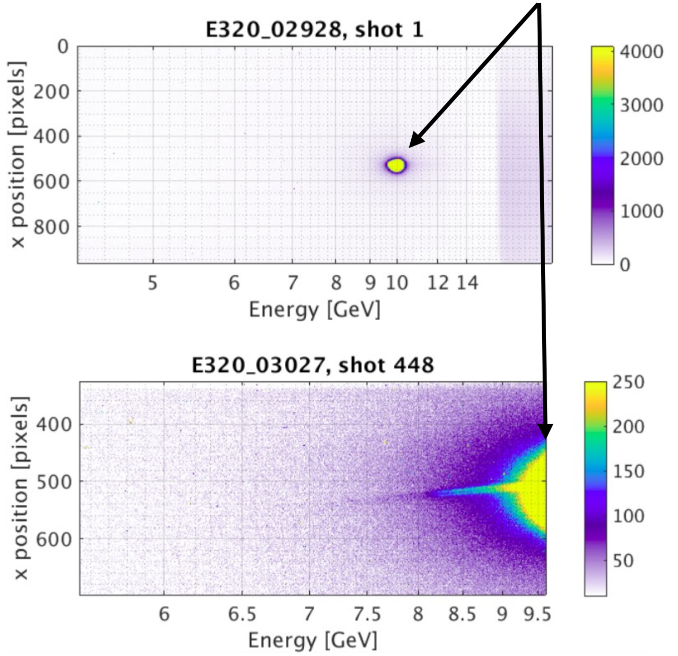
First successful collisions (August 2022)



Gamma signal: electron-laser relative timing

main e-beam: (filter removed for 2nd plot saturation)



Electron spectrum:
net absorption of 1&2 laser photons

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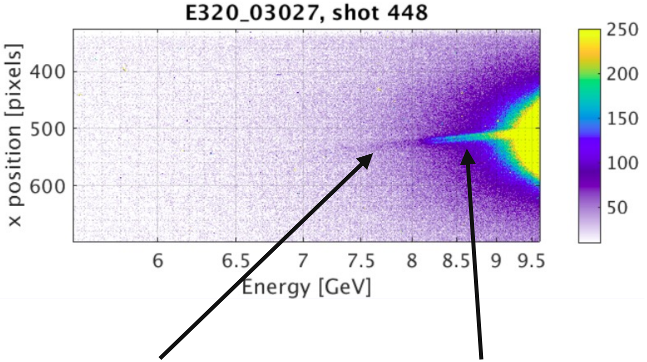
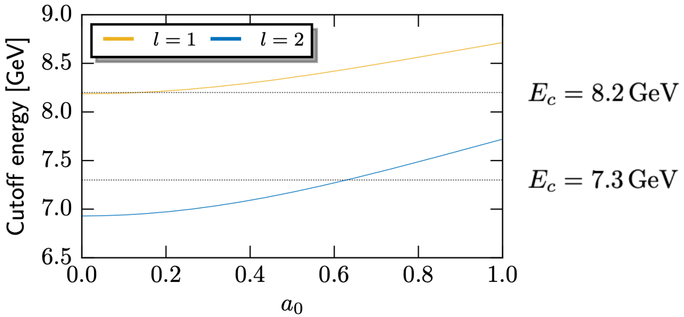
Estimation of the (peak) laser intensity (2022 beamtimes)



two-photon (l=2) and **one-photon** (l=1)
Compton scattering

Conservation of quasi-momentum
(linear polarization)

$$k'^{\mu} = lk^{\mu} + q^{\mu} - q'^{\mu}, \quad q^{\mu} = p^{\mu} + \frac{m^2 a_0^2}{4pk} k^{\mu}, \quad q'^{\mu} = p'^{\mu} + \frac{m^2 a_0^2}{4p'k} k^{\mu}$$



$$a_0 = 0.6 \pm 0.1$$

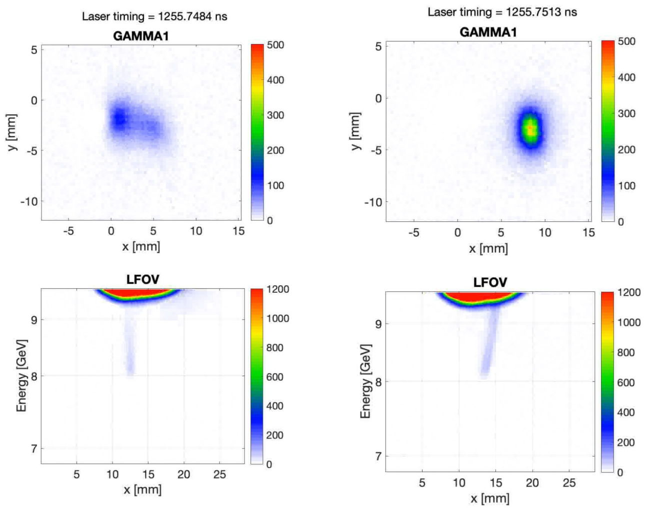
$$I_0 = 8 \times 10^{17}\,\mathrm{W/cm^2}$$

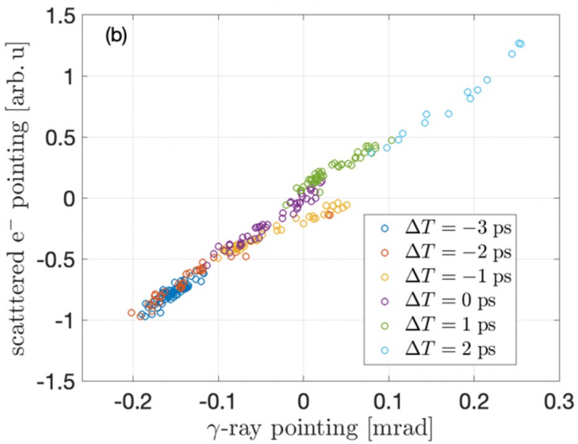
- $a_0 < 1$ can be estimated from cutoff energies
- Indication to improve laser quality and pulse length
- Extensive efforts ongoing to improve wavefront

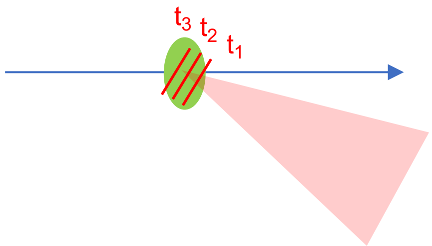
Laser improvements: J. Wang, R. Ariniello, B. O'Shea, A. Knetsch

Study byTatiana Smorodnikova

Laser-wire-like results from a timing scan







- Laser-to-beam timing scans transverse collision location
- Correlation found between x_{col} θ_{photon} and $\theta_{e,scat.}$
- Electron beam has x-x‘ corellation at collision point
- → E-beam is not at waist

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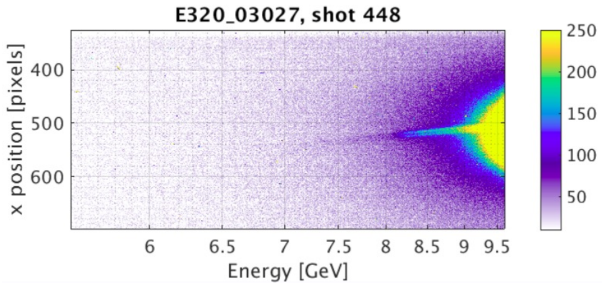
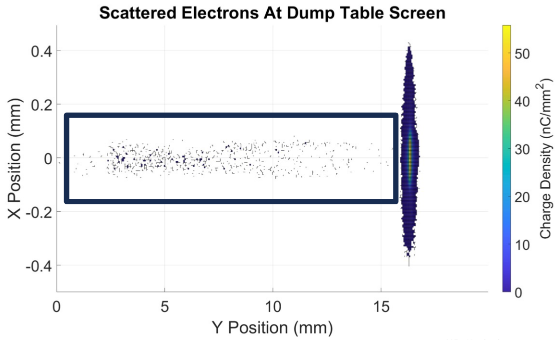
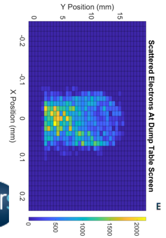
P. San Miguel Claveria et al. AAC Proceedings 2020

Start-2-end modelling

The LUCRETIA Project







- Fast collision code developed
- Calculates 6D phase spaces of electrons and photons after IP (Klein-Nishina)
- E-beam Start-2-end simulation of FACET-II Linac with GPT and Lucretia
- Hand-shake between Lucretia and collision code to include experimental magnet settings an
- Virtual experiment with virtual diagnostics.

Preliminary result:

- Double-line feature might origin in off-waist location

Study by Rafi Mir Ali

Future plans

Future: shot-to-shot high-intensity diagnostic

MO focal imaging: only possible at low intensities

beam splitter
(≲1:≳99)

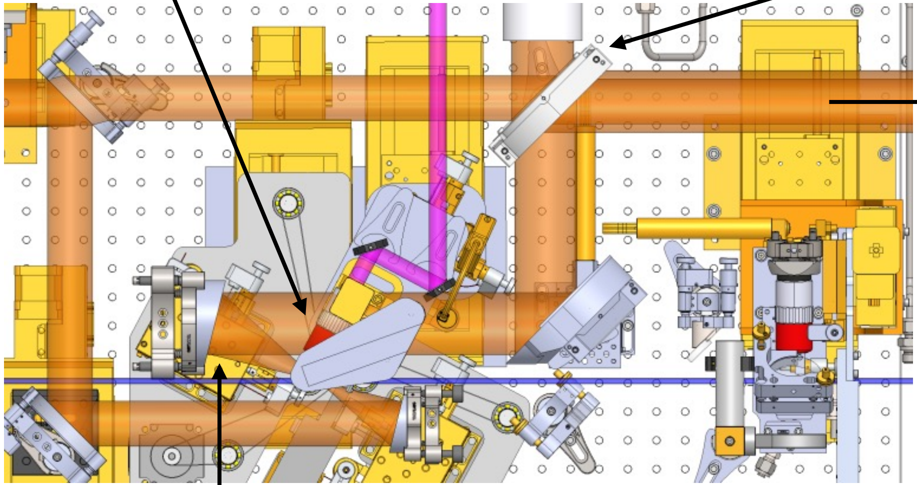
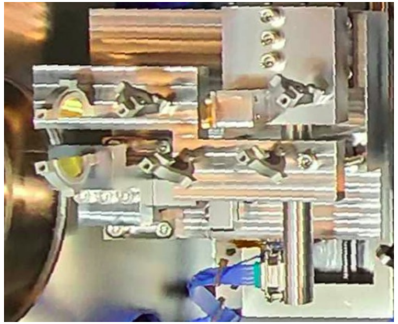


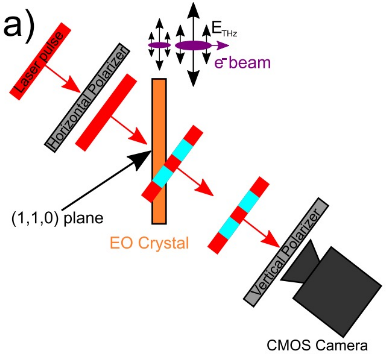
image of focal spot
is formed outside
the PB with a lens

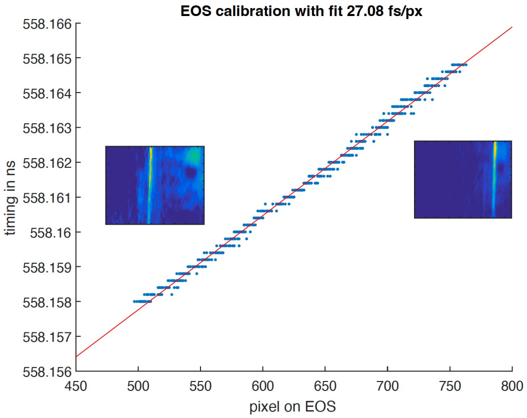
- Aim: re-image focal spot for each shot
  alignment of the 2nd OAP becomes critical
- Use interferometry to align OAP pair
  we know that "errors" are due to the actual
  focus and not the mis-alignment of OAP2

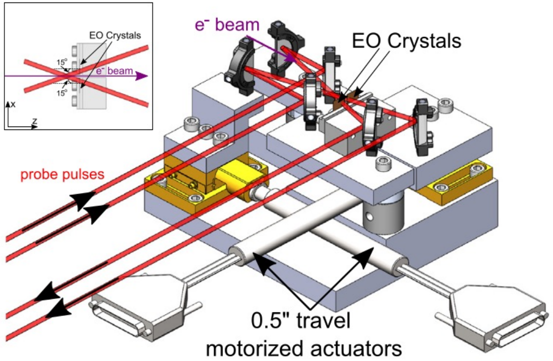
High-intensity diagnostics: 2nd OAP re-images the focal spot

shot-to-shot timing information via EOS (UC Boulder)







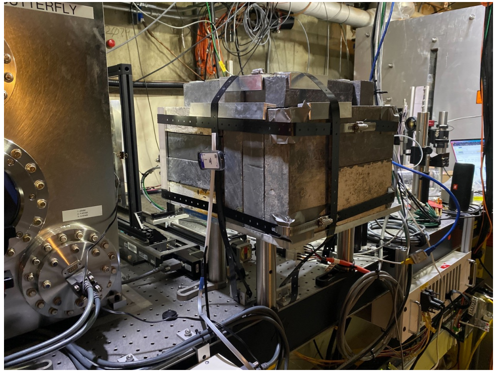


EOS installed in the picnic basket

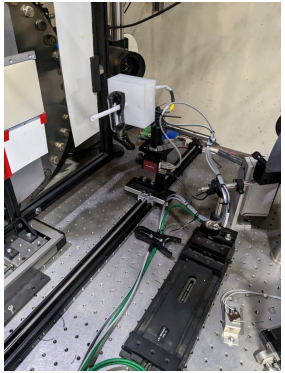
- electro-optical sampling (EOS) measures relative time-of-arrival between laser and e-beam
- Shot-to-shot non-invasive time-stamping

Hunt-Stone et al., NIMPRA 999, 165210 (2021)

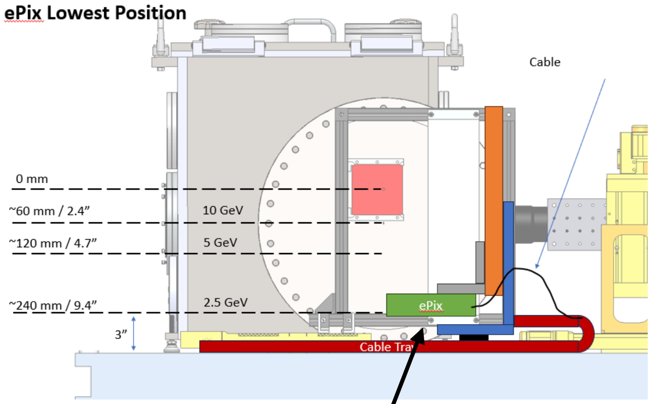
Near-term goal: deploy a silicon-pixel detector with better SNR



shielding to keep ePix safe during “high radiation times”



currently installed: radiation sensor



ePix module provided by the SLAC detector group (Chris Kenney et al.)

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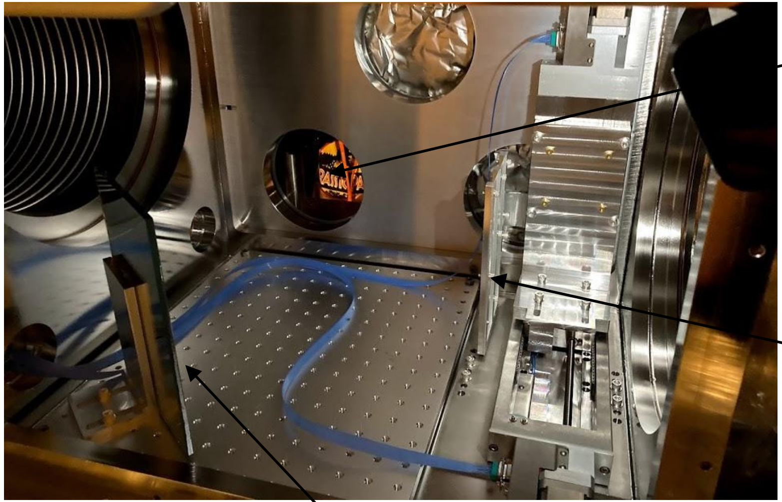
Main contributors: Aimé Matheron, Sébastien Corde, Robert Holtzapple, Doug Storey

Detection of ‘low-energy’ electrons in the Electron Detection Chamber

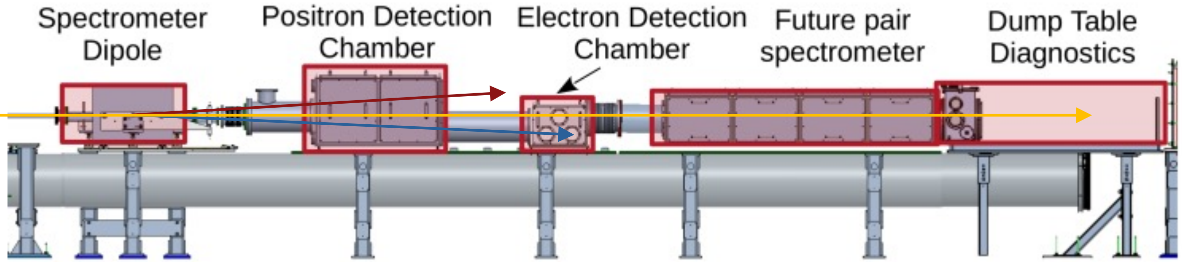


Camera outside

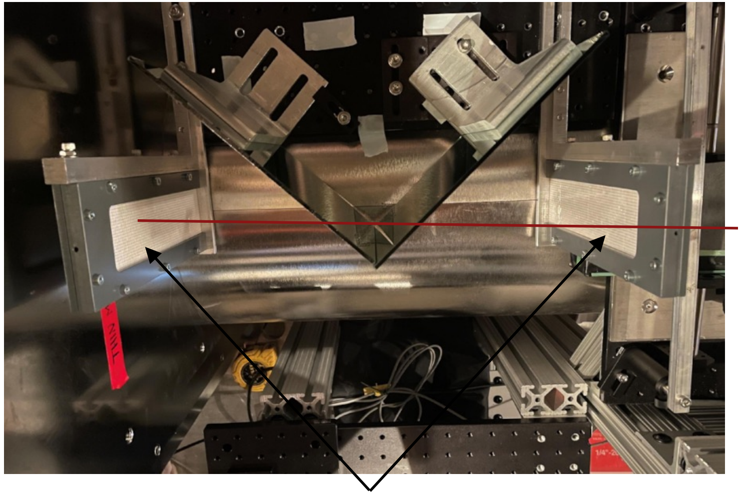
Holder for scintillator, mounted on x/y-stage (signal could be enhanced via shower in material)

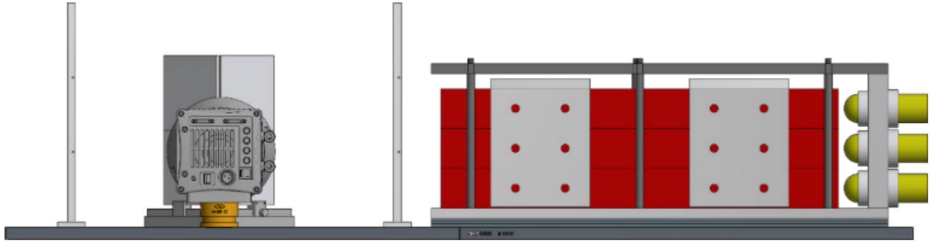
Mirror for 90°-imaging

Dipole deflection: electrons down, positrons up

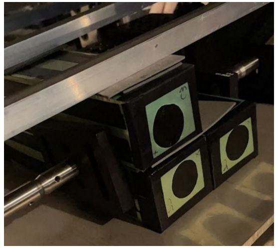


Single-positron detection (Jena group)

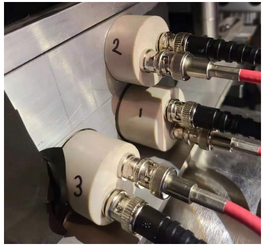




Tracking: mainly for background suppression
(currently LYSO; later: silicon-pixel detectors)



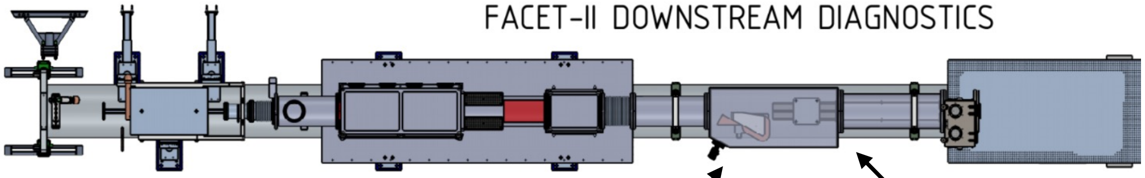
Cherenkov calorimeter
(currently lead glass;
future: lead fluoride?!)

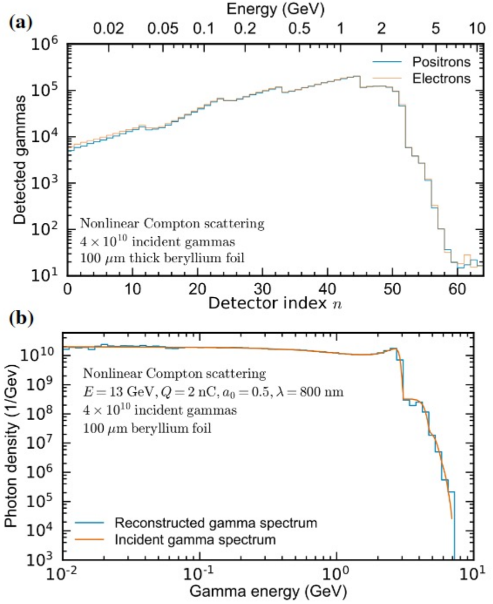


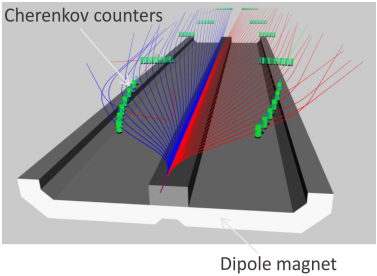
readout: PMTs

based on: *Salgado et al. NJP 24 (2021)*

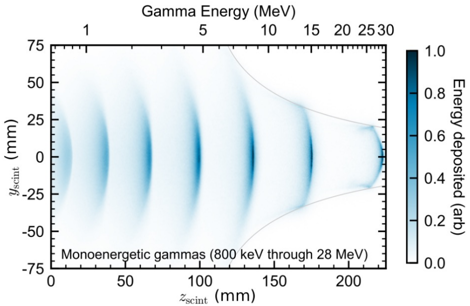
Future: Compton & gamma pair spectrometer (UCLA group)

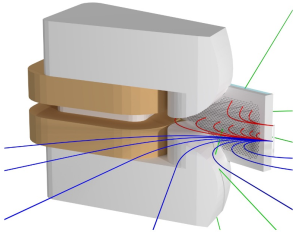






Gamma pair spectrometer: energies: 0.1-10 GeV
gamma spectrum can be reconstructed





Compton spectrometer: based on sextupole magnet, energies: 1-30 MeV

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B. Naranjo et al., IPAC2021 THPAB269, THPAB270 (2021)

Stanford/E-320 are looking for postdocs!

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Thank you for your attention