Compton and Pair Spectrometer Hardware Update

B. Naranjo, G. Andonian, J. Phillips, J. Rosenzweig, and M. Yadav

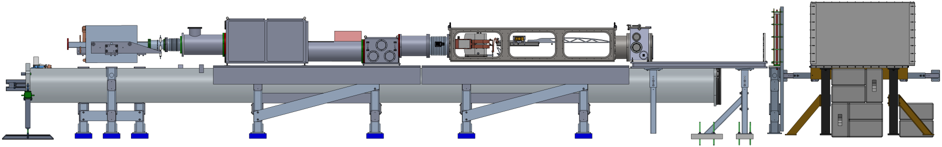
UCLA Dept. of Physics & Astronomy

C. Hast, K. Jobe, N. Majernick, and D. Storey

SLAC National Accelerator Laboratory

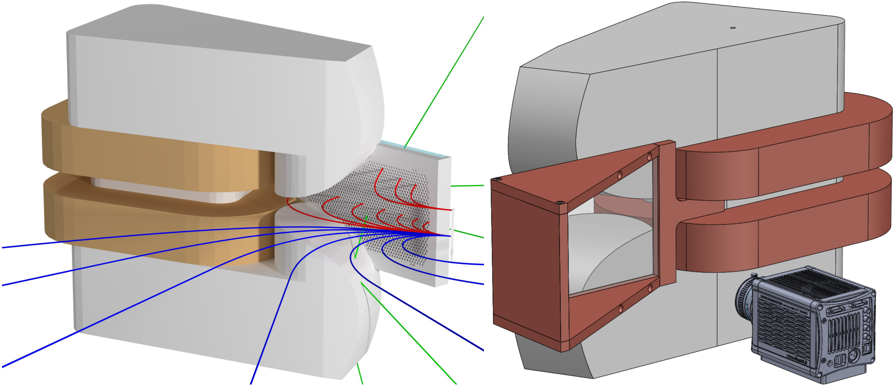
FACET-II User Meeting
SLAC National Accelerator Laboratory
2023 October 18

Gamma spectroscopy at FACET-II

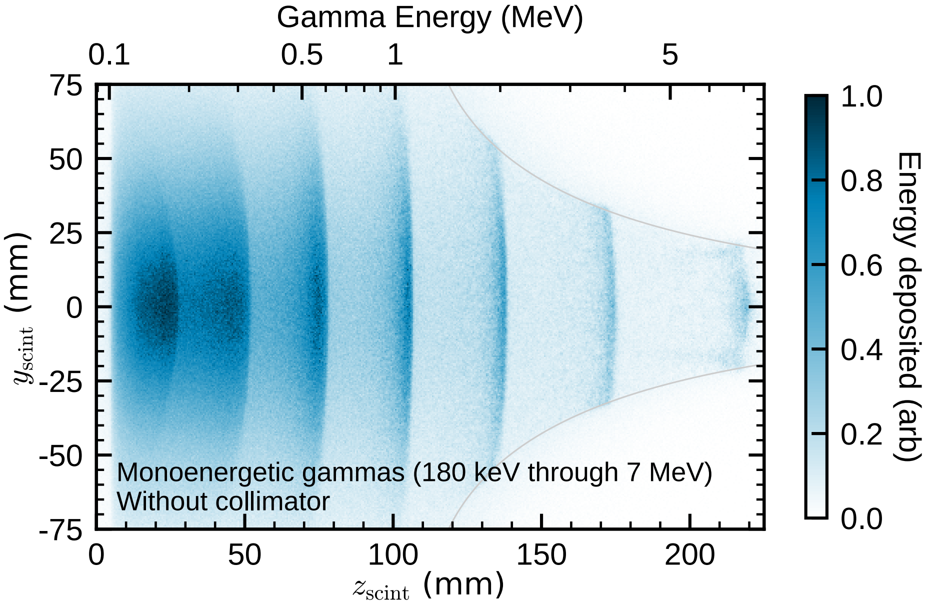


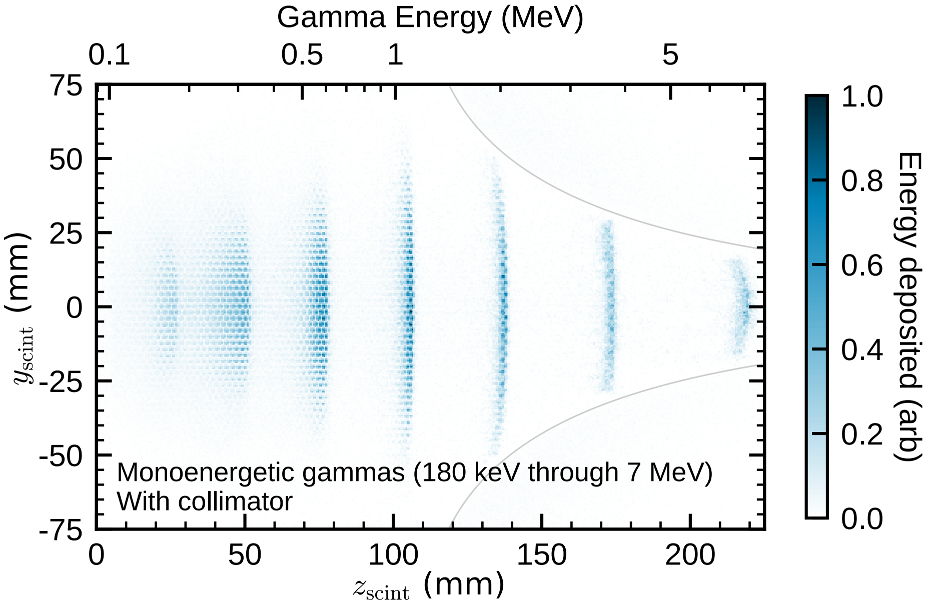
- New chamber for gamma spectroscopy (GDC) located between the EDC and the Butterfly Chamber.
- The Compton spectrometer (upstream) is optimized for gamma spectroscopy on the range 200 keV through 10 MeV.
- The pair spectrometer (downstream) is optimized for gamma spectroscopy on the range 10 MeV through 10 GeV.

Magnetic Compton Spectrometer



- Beryllium converter
- As shown, readout is Hamamatsu ORCA-Fusion BT viewing scintillator.
- 3D-printed tungsten collimator used to improve sub-MeV gamma readout, where the Compton cross-section becomes less forward-peaked.


Gamma Energy (MeV)
0.1
0.5
1
5
75
50
25
0
-25
-50
-75
y_{scint} (mm)
0
50
100
150
200
z_{scint} (mm)
Monoenergetic gammas (180 keV through 7 MeV)
Without collimator
1.0
0.8
0.6
0.4
0.2
0.0
Energy deposited (arb)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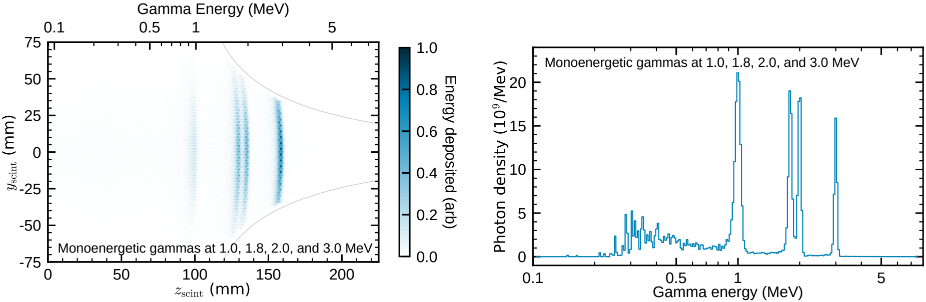
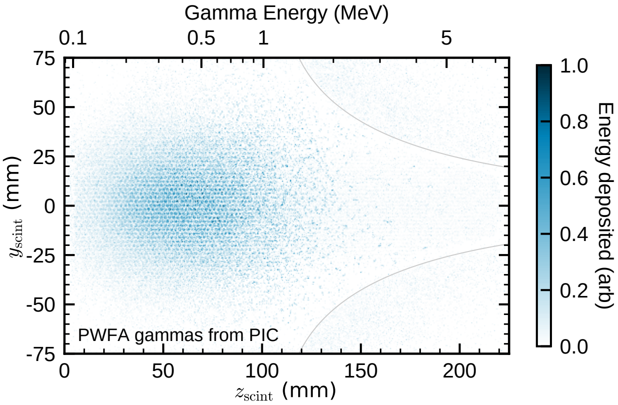
Monoenergetic gammas (180 keV through 7 MeV)
With collimator
1.0
0.8
0.6
0.4
0.2
0.0
Energy deposited (arb)

Maximum Likelihood-Expectation Maximization (ML-EM)



- ML-EM[1] is used as baseline for spectral reconstruction.
- Recovers gamma lines with energy resolution on the order of 1%.

[1] Shepp and Vardi, *IEEE Trans. Med. Imaging* **1**, 113 (1982)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0.1
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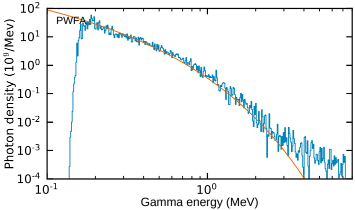
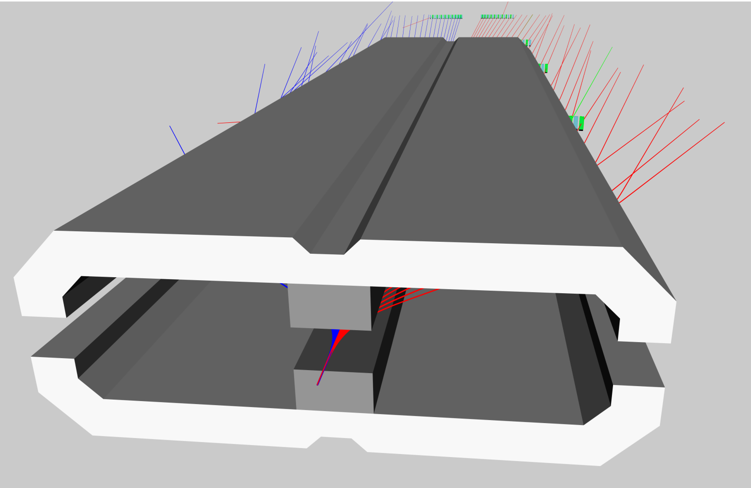
y_{scint} (mm)
0
50
100
150
200
z_{scint} (mm)
PWFA gammas from PIC
1.0
0.8
0.6
0.4
0.2
0.0
Energy deposited (arb)


PWFA
Photon density (10^9/Mev)
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-1}
10^0
Gamma energy (MeV)

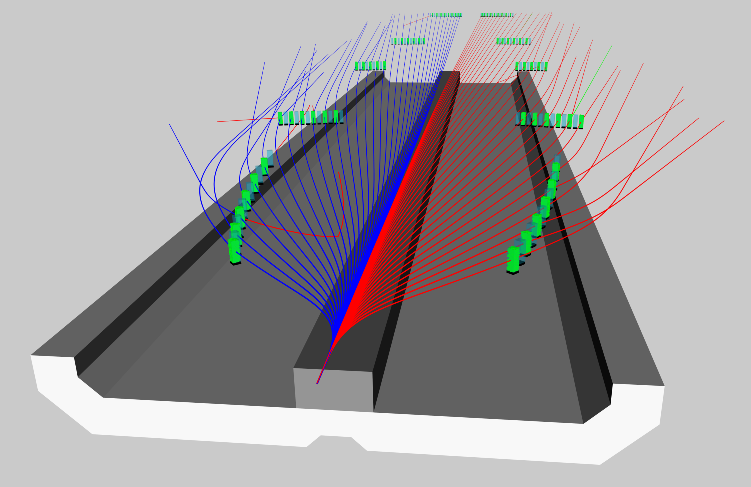
Pair spectrometer (10 MeV through 10 GeV)



Using a split yoke:

- Allows pair-converted positrons and electrons to escape magnet, instead of being absorbed in the outer yoke wall, reducing background x-ray signal.
- Allows optimal placement of Cherenkov cells, with faces normal to incoming trajectories and generous uniform logarithmic spacing in energy.

Pair spectrometer (10 MeV through 10 GeV)



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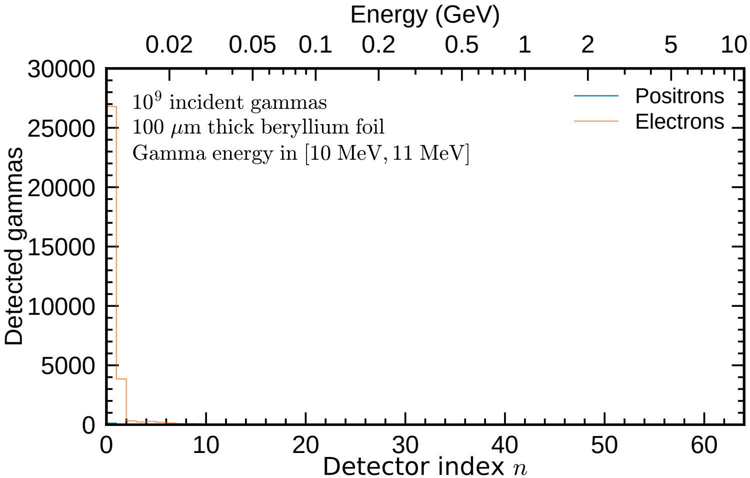
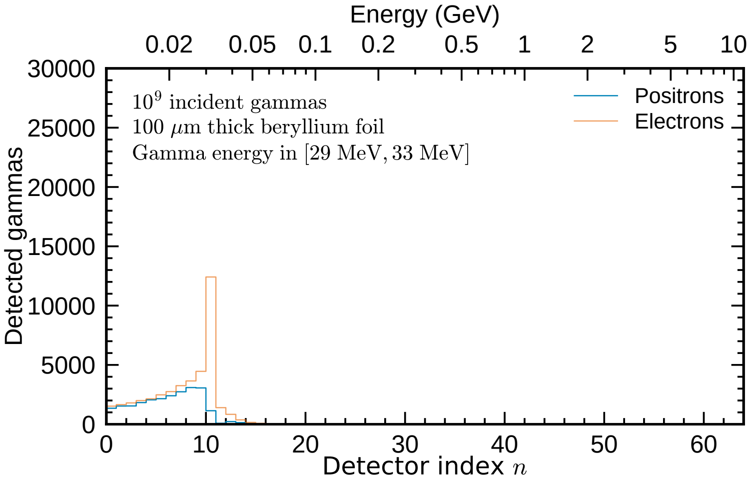


- End-to-end Geant4 simulation
- Simulated spectrometer response is used as basis for spectral deconvolution
- Note that at low gamma energies (< 40 MeV for a beryllium converter), the spectrometer is behaving as a Compton spectrometer including subtraction of pair-produced background.

Simulated spectrometer response



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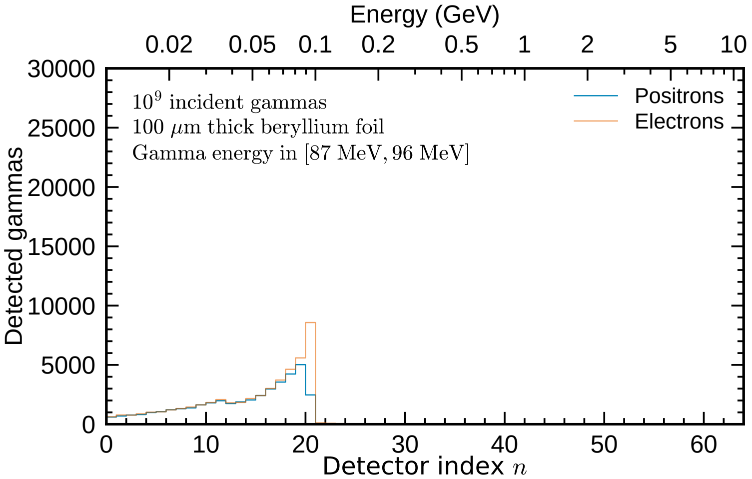

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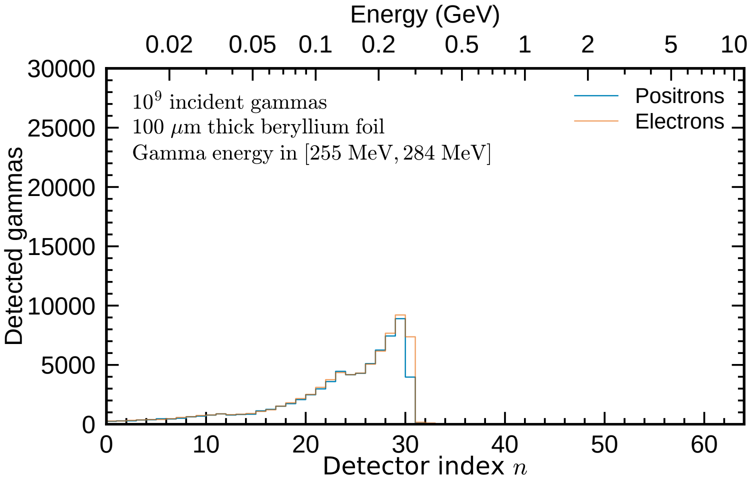

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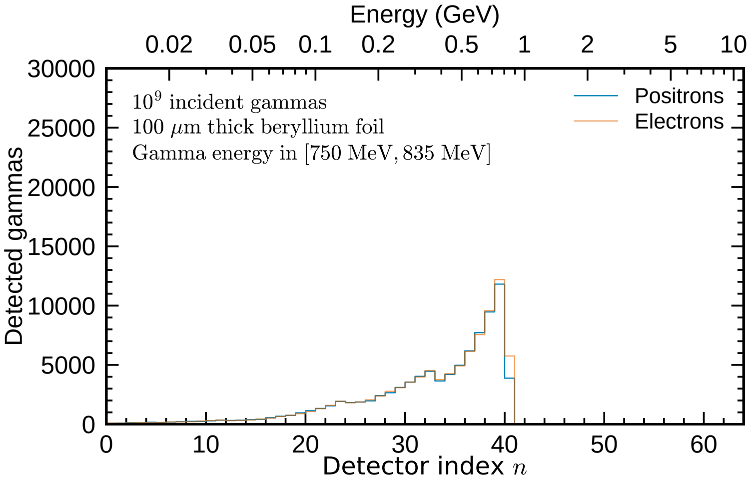

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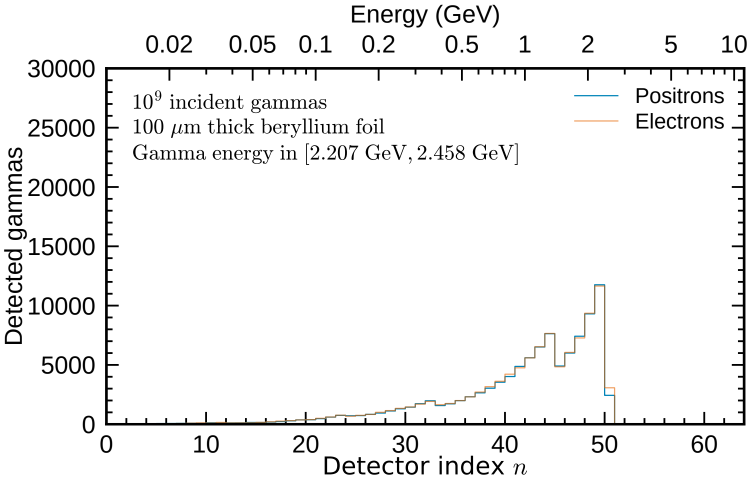

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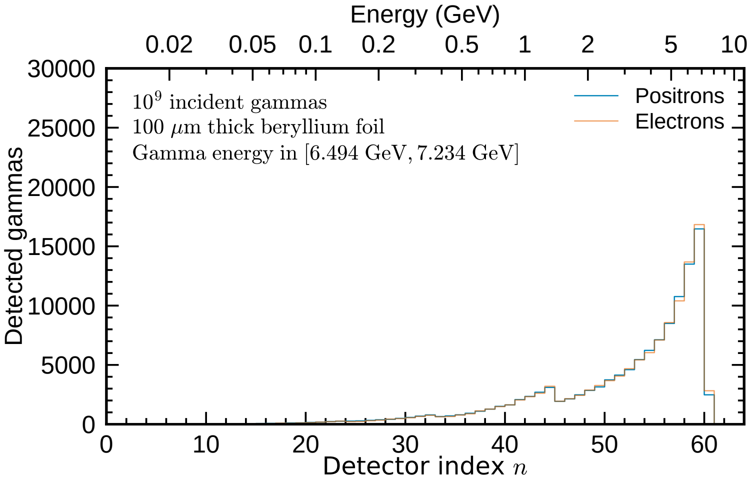

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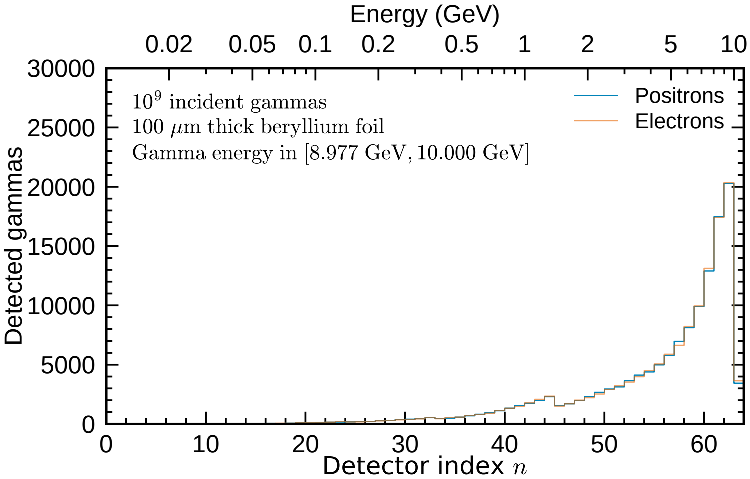

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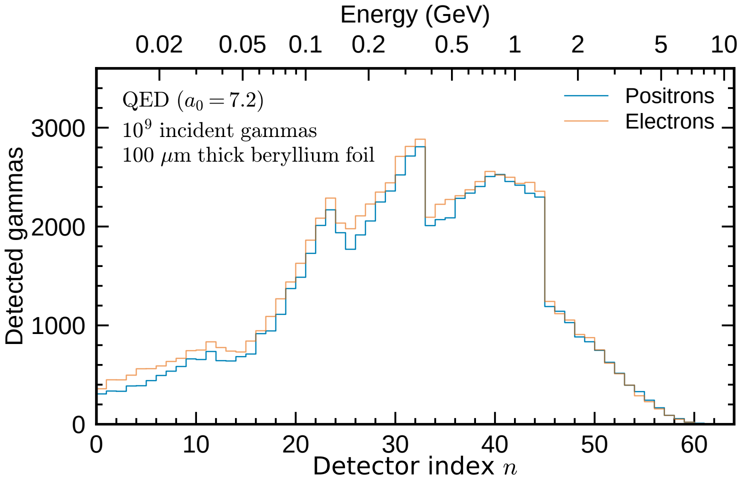
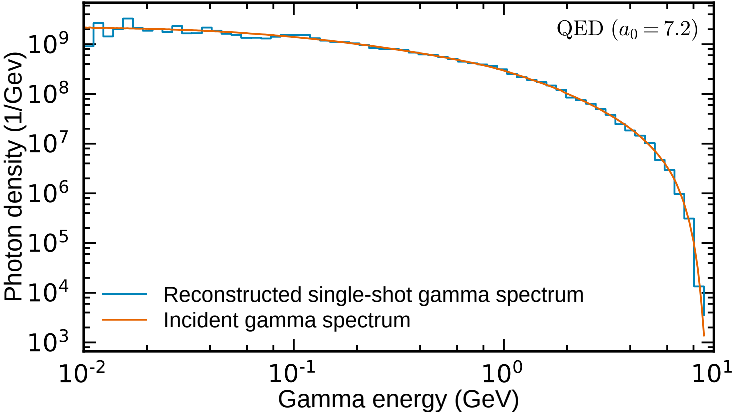
Single-shot spectral reconstruction

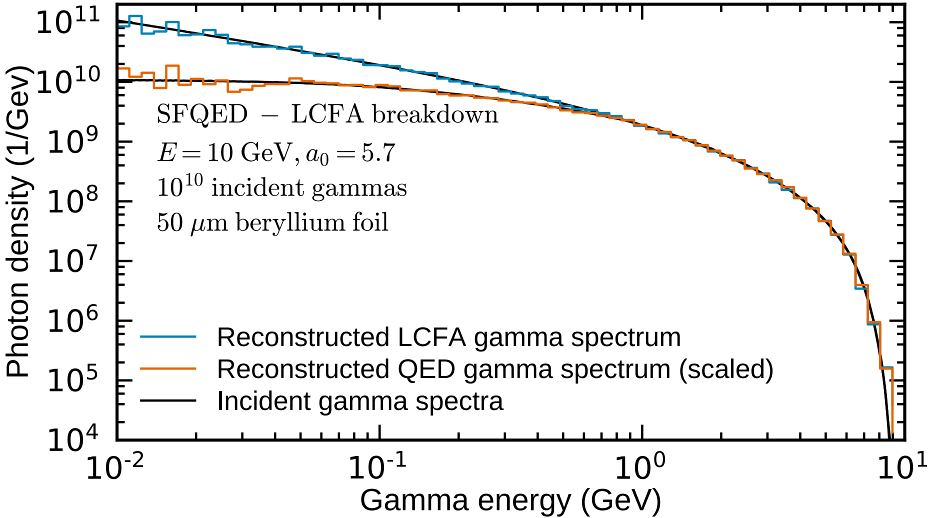


- Raw detector response from 10^9 incident gammas taken from simulated SFQED spectrum.
- Nice amount of signal distributed throughout the SiPM array – plenty of signal without saturating SiPMs.



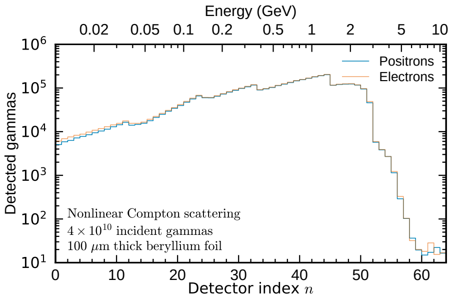
- Blind reconstruction using maximum likelihood-expectation maximization (ML-EM)[2].
- Converges rapidly without need for regulation.
- Correctly recovers both spectrum and intensity of incoming radiation.

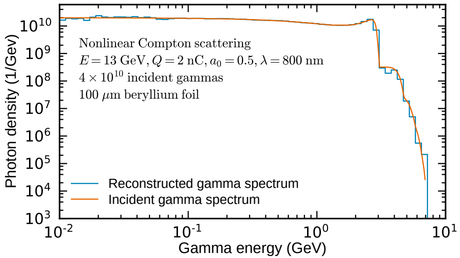
[2] Shepp and Vardi, *IEEE Trans. Med. Imaging* **1**, 113 (1982)



- Formation length for photons increases with decreasing photon energy. This leads to a breakdown of the local constant field approximation (LCFA) at low energies. Pair spectrometer resolves this breakdown.

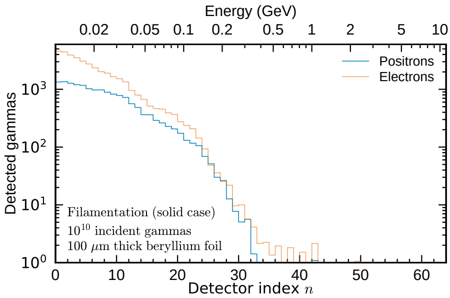
Nonlinear Compton scattering

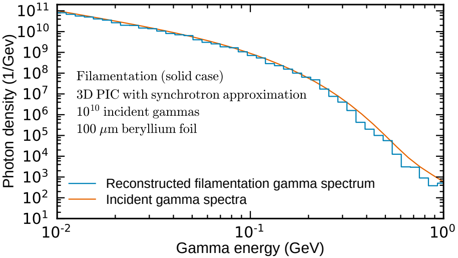




- Raw detector multi-shot readout on left and reconstructed spectrum on right.
- Resolve harmonics in reconstructed spectrum.

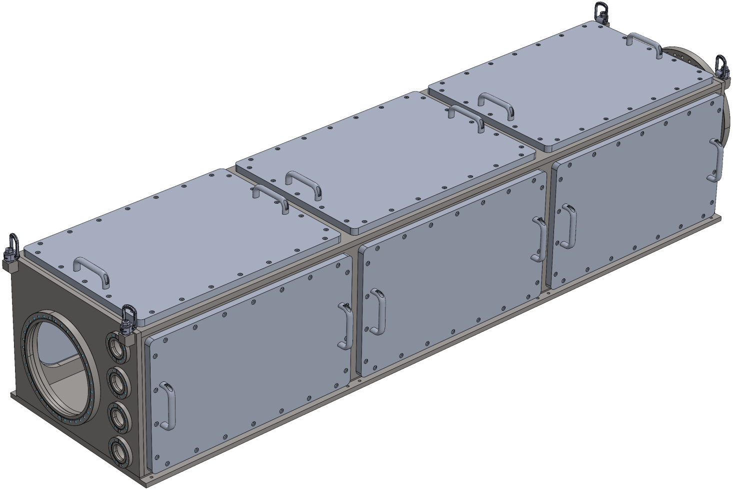
Filamentation (E305)





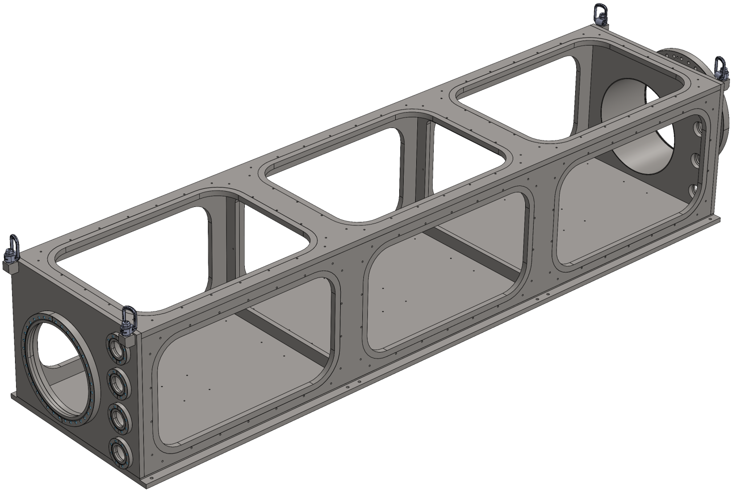
- Raw detector single-shot readout on left and reconstructed spectrum on right.
- Only about one in 100 of the incident gammas is above 50 MeV, so the spectrometer's response is mostly in its Compton region, as can be seen by the large excess of low-energy electrons.

GDC: Paneled design



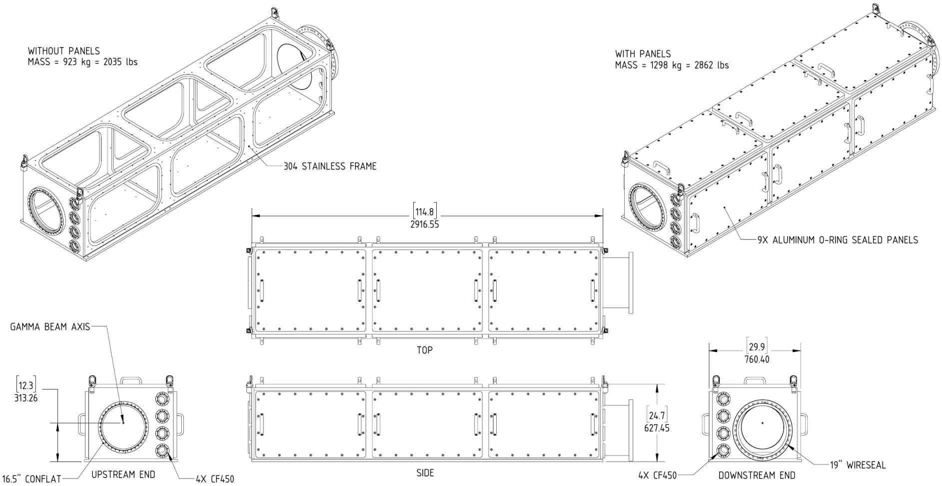
- GDC = Gamma Detection Chamber
- Stainless frame with nine O-ring sealed aluminum panels (similar to EDC/PDC).

GDC: Paneled design



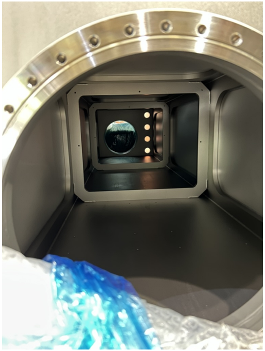
- Interior stiffening ribs
- Upstream 16” Conflat flange and downstream 19” Wireseal flange
- Eight auxiliary CF450s

GDC: Dimensions



- SLAC design review held with D. Storey, C. Hast, and K. Jobe
- Obtained multiple quotes. Placed order from Nor-Cal.
- Fabricated in Germany, with approved metric modifications.

GDC: Delivered to SLAC

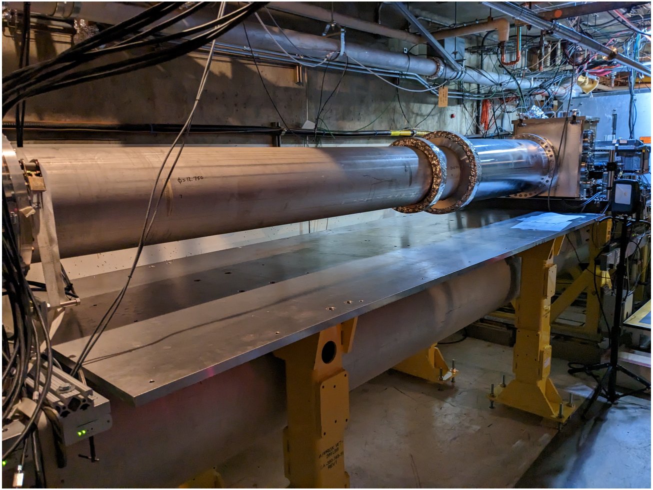


- Delivered to SLAC.

GDC: Test pumpdown

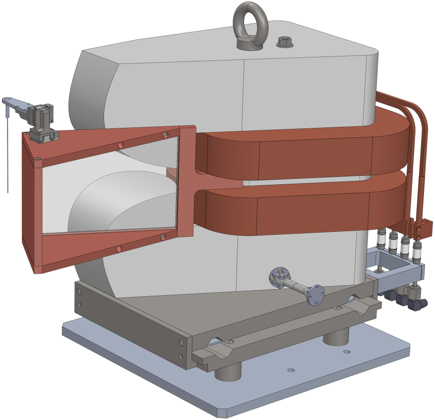
- Test pumpdown at SLAC

GDC: Installation



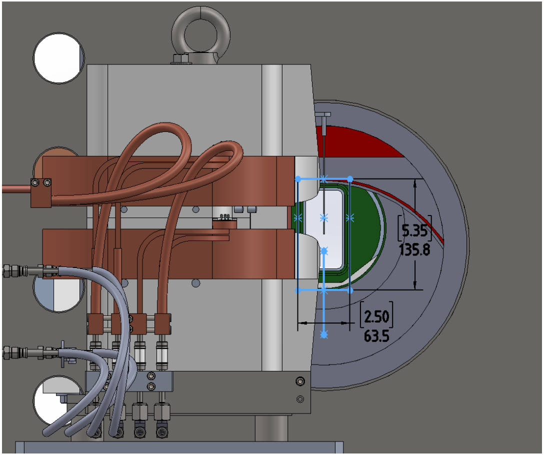
- To be installed here, between the EDC and the Butterfly Chamber.
- Support table is new. Same design as the PDC/EDC support table.
- Chamber installation pending arrival of Compton spectrometer.

Compton: Overview



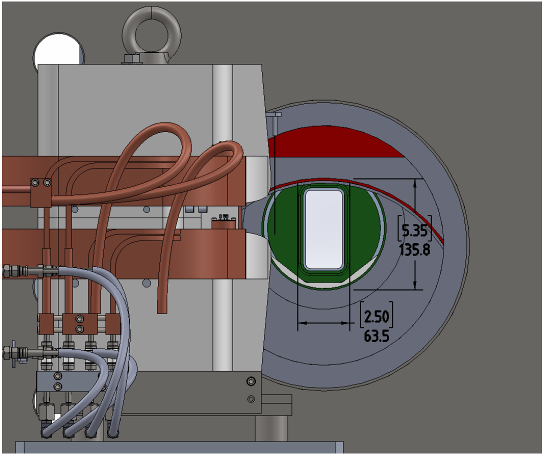
- Spectrometer is lowered into chamber pre-assembled.
- Converter target mounted on an XY stage.
- Magnet coil windings have 1/8” bore for water cooling.
- Stage, supported on 1” silicon nitride balls, has a total travel of 75mm to move spectrometer off-beam when not in operation.
- Total weight of magnet plus stage = 650 pounds.
- Rolling friction estimated to be under 50 pounds. Need to test.

Compton: Keep-outs

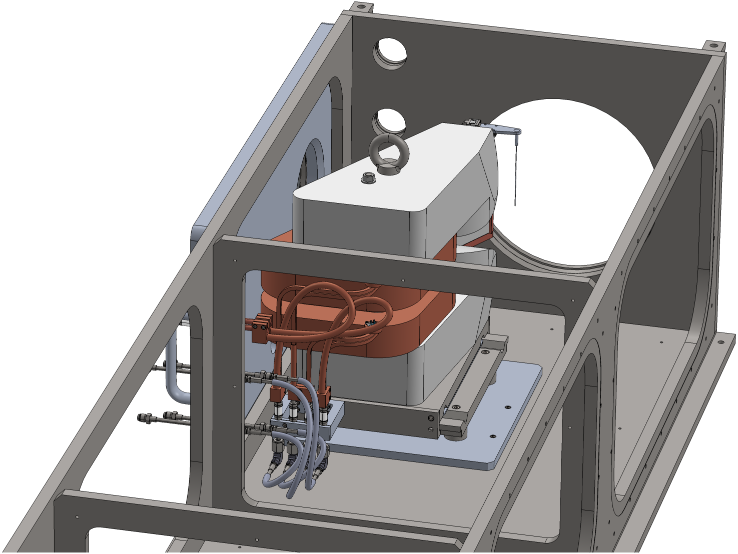


- Spectrometer shown in “on-beam” position.
- Beryllium converter is shown suspended into gamma beam from above.
- Range of deflected primary beam shown.
- Blue region shows the spectrometer’s keep-out region when not in operation.

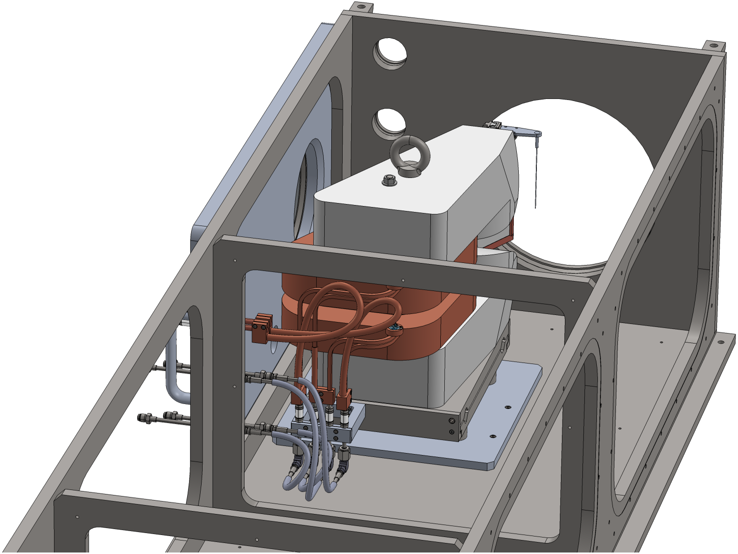
Compton: Keep-outs



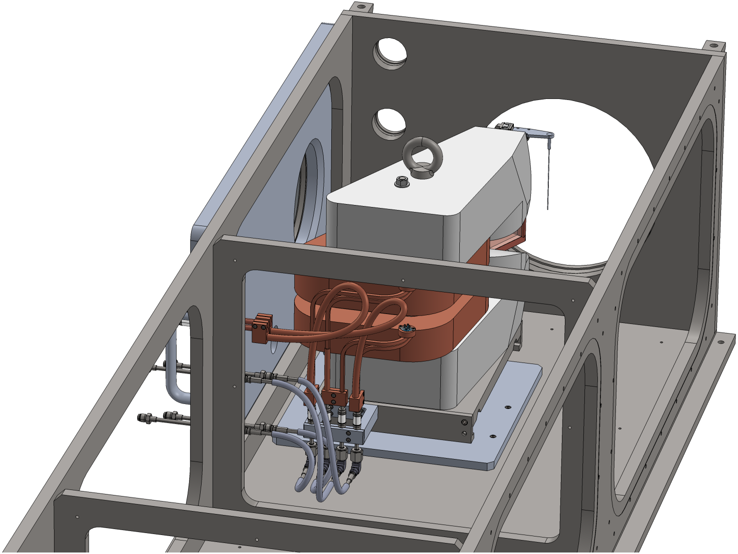
- Spectrometer shown in “fully retracted” position.
- Spectrometer moved completely out of the keep-out region. Total throw = 75mm.



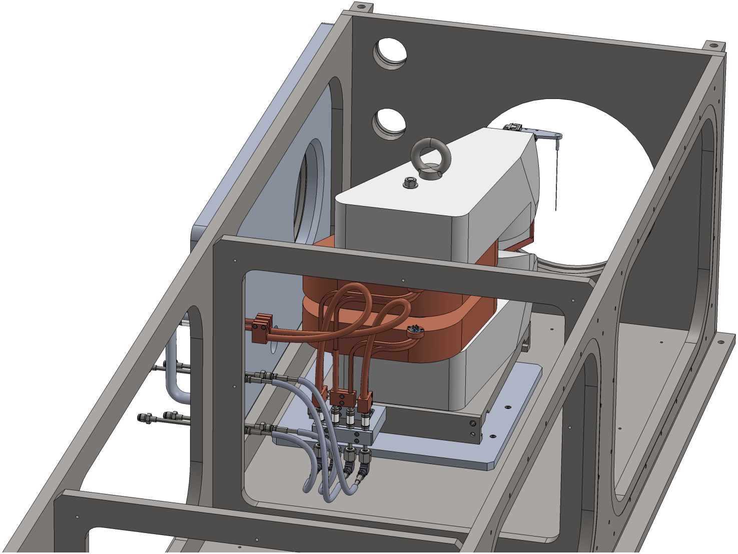
Fully retracted



Neutral position



On beam



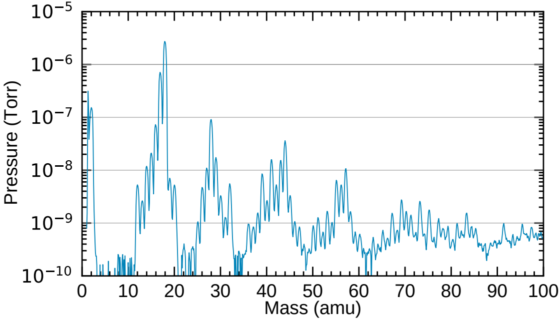
Fully inserted

Fabricated yoke and coil

- Yoke and coil are fabricated. Confirmed coil fits over yoke.

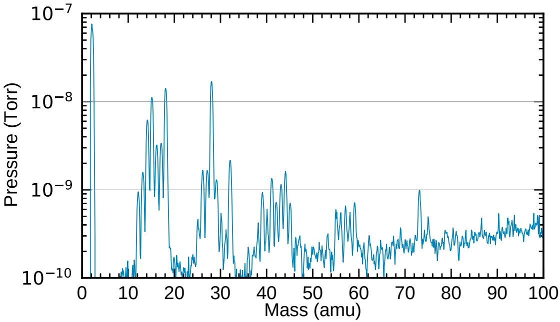
- Do a quick “worst-case scenario” vacuum test of coil: water-contaminated surfaces, uncapped cooling channel, Kapton outer-wrap, possible fingerprint or machine-oil contamination.
- Removed yellow label.
- Cut a few slit vents in the outer Kapton wrap.
- Wiped down outer surface with alcohol.

Magnet-coil vacuum testing



- After 24 hours of pumping at 250 lps, including a light bake-out at 120C, the pressure, as measured by a UHV BA gauge, was 6×10^{-7} Torr.
- As shown on the RGA scan, we are still water dominated at this point, but we also see a plenty of spikes above 40 AMU that we would not normally see in a clean system.

Magnet-coil vacuum testing



- After a few weeks of pumping out, a base pressure of 1.8×10^{-8} Torr was reached.
- Room temperature RGA scan, above, shows some possible hydrocarbon or adhesive contamination at the the level of 10^{-9} Torr. 73 AMU might indicate a silicone-based adhesive (PDMS monomer).
- Heating to 150C caused some elevation of the possible hydrocarbon peaks, but total pressure stayed below 10^{-7} Torr.