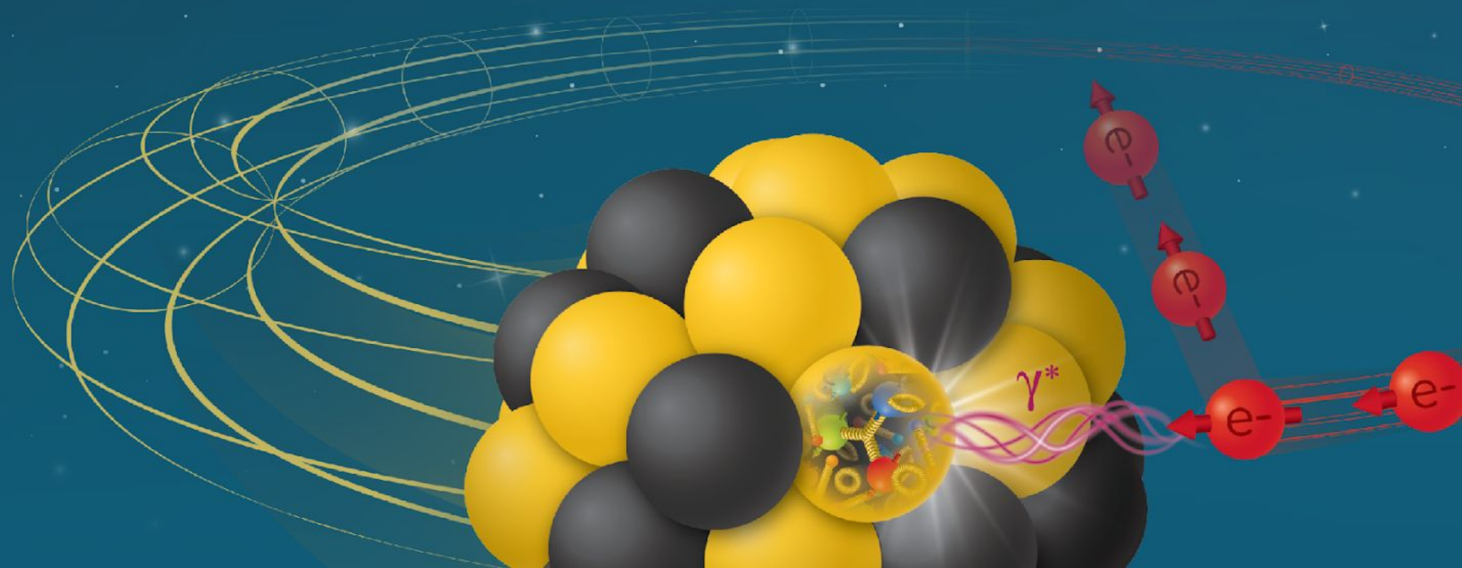
Far Backward Region

Low Q^2 Taggers
Direct Photon Detector
Pair Spectrometer

Nick Zachariou - for the Lumi and LowQ^2 Tagger WG

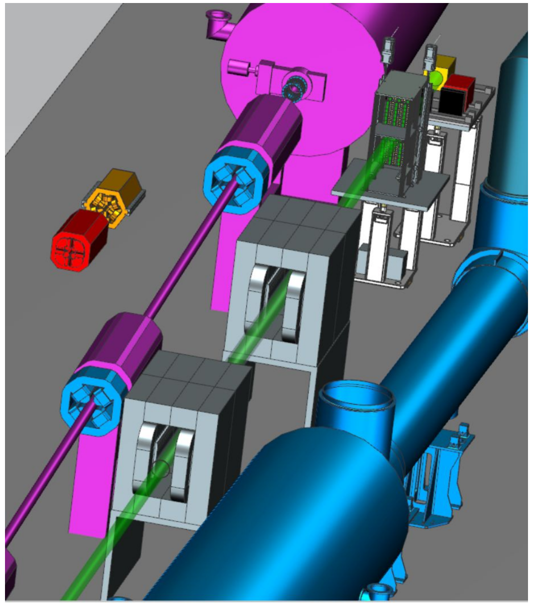
10th EIC DAC Review

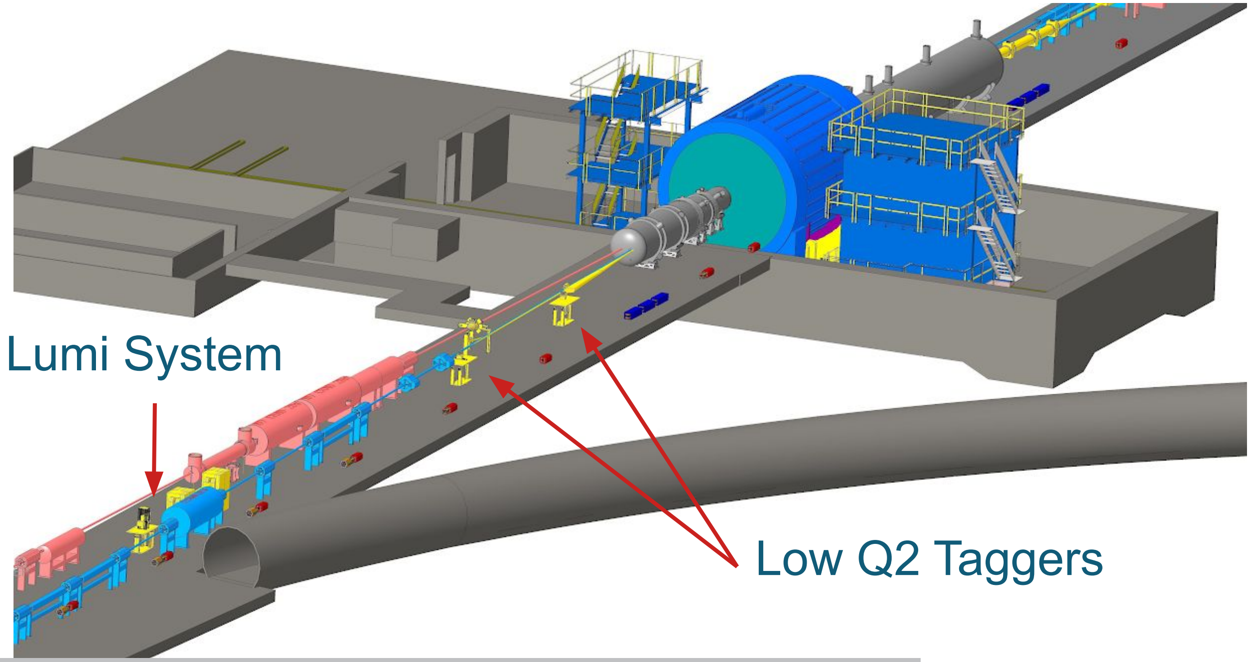
June 11th – 13th, 2025

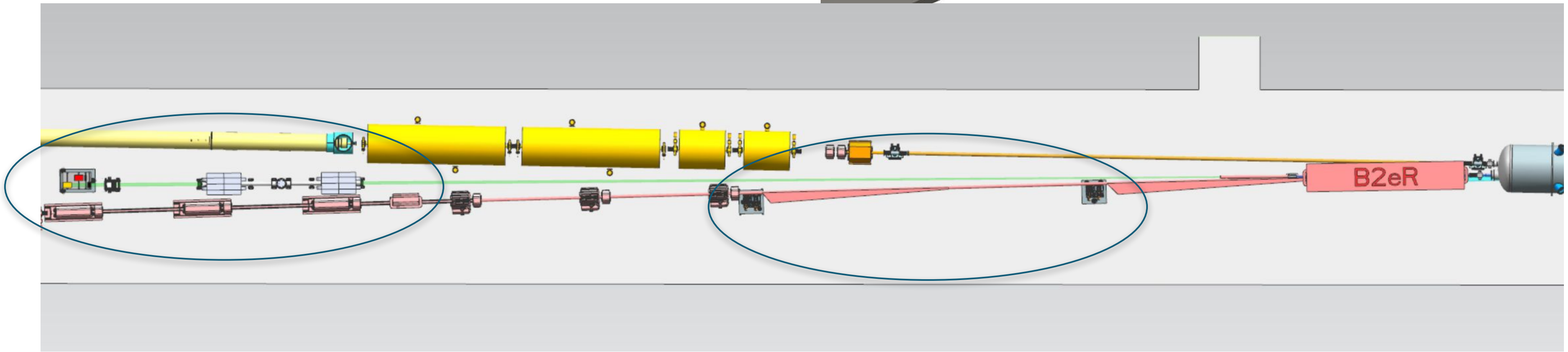


Electron-Ion Collider

The Far Backward Region

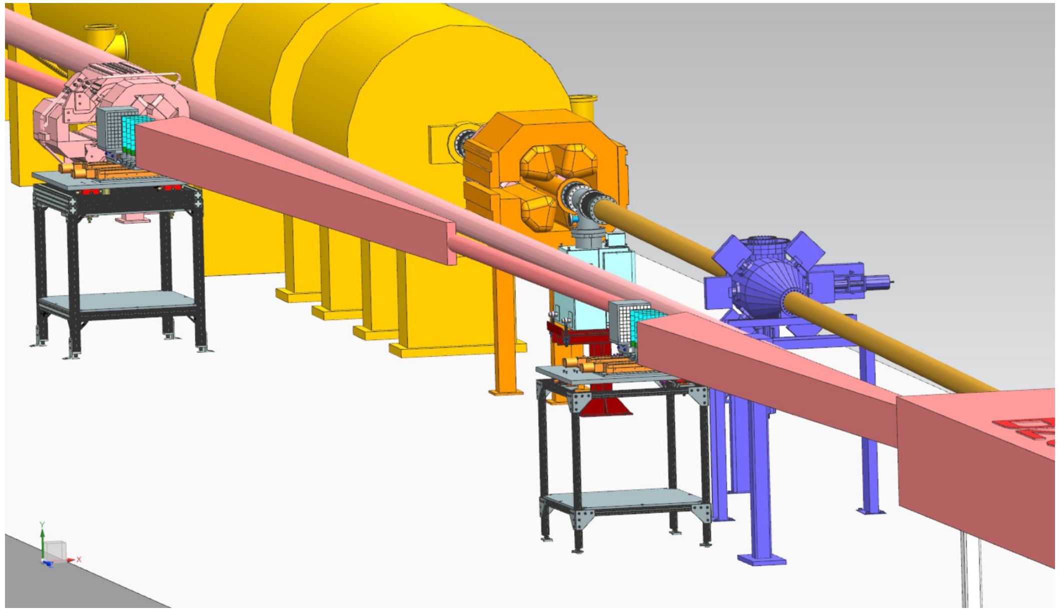






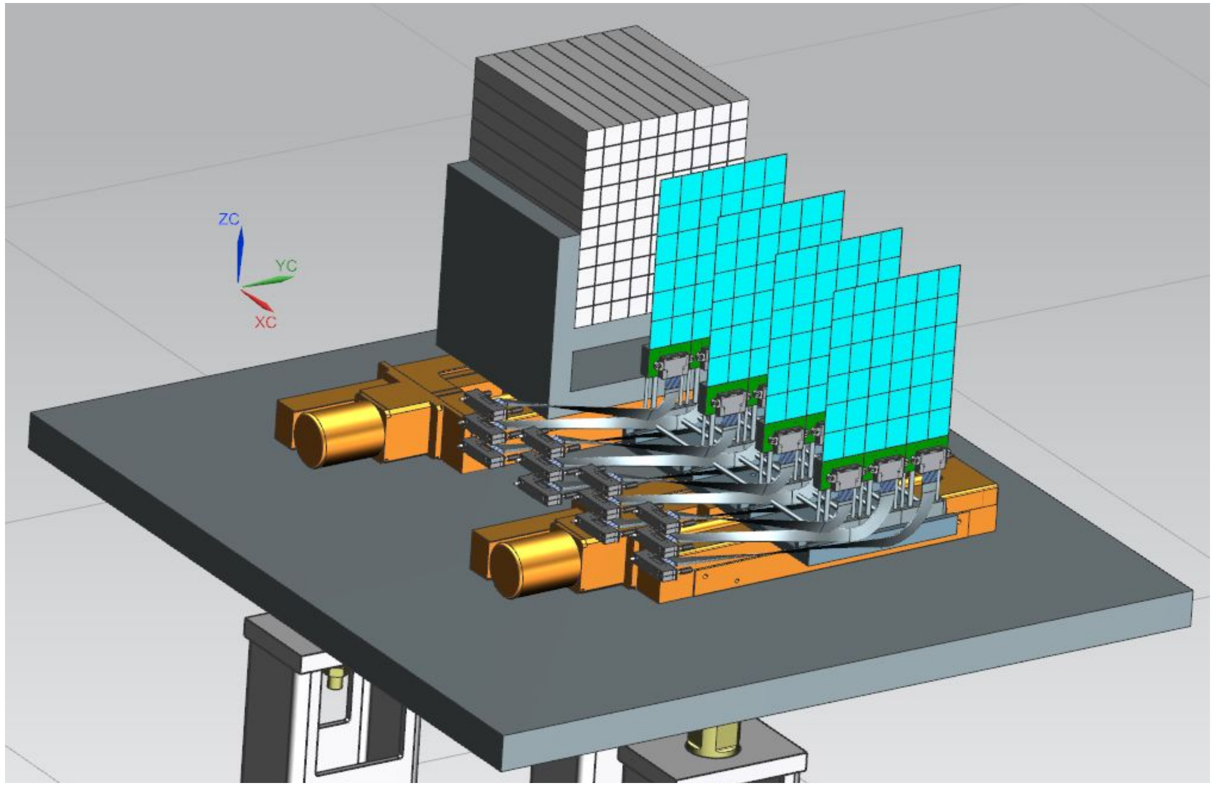
The Low Q^2 Taggers

Two detector stations placed along outgoing electron beamline



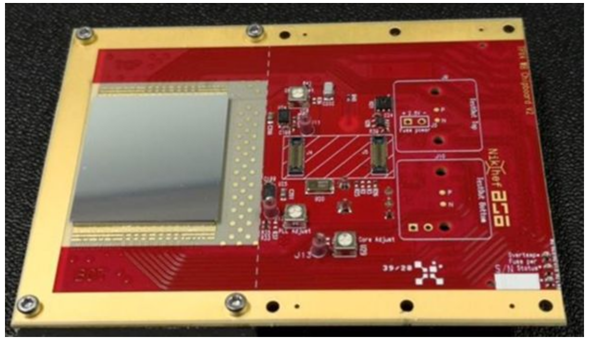
Calorimeter
Fiber sampling calorimeter (see Lumi)

Tracker
4 Layers of Timepix4 pixel detectors

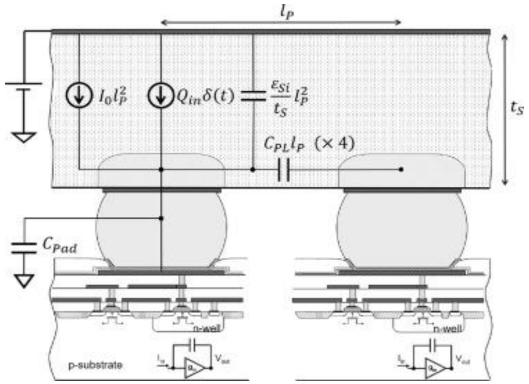


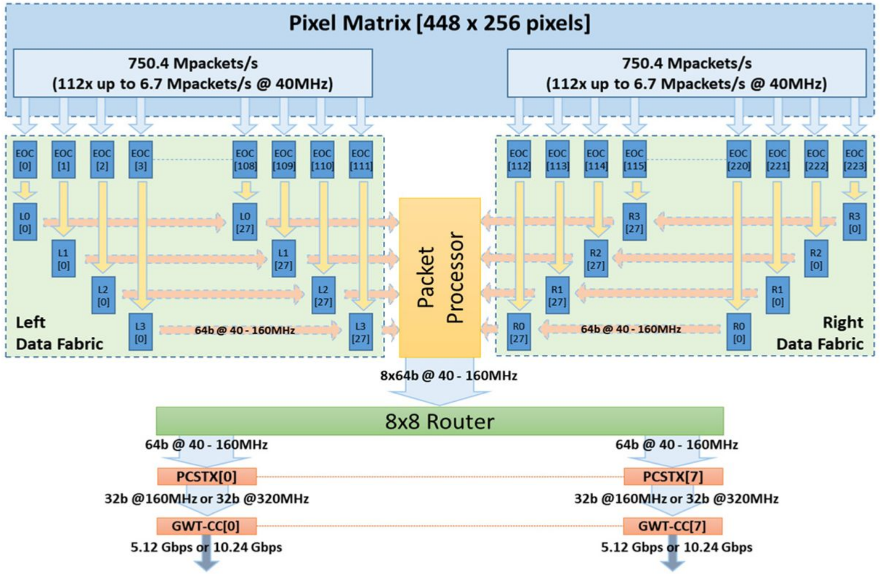
The Low Q^2 Taggers - Technology

- Timepix4 is the most recent ASIC from the CERN based Medipix collaboration.
- Hybrid pixel detector
  - Sensor separate from the electronics
  - Can select sensor based on requirements
- 448x512 array of 55μm square pixels
  - 6.94 cm^2 sensitive area
  - Data driven readout – Only reads pixels which register a hit
  - 4 side buttable using TSV technologies – Read out through bottom of chip rather than wire bonds allowing tiled layer of detectors.
- 200 ps - Time of arrival clock binning
- 25 ns - Time over threshold clock binning (energy measurement)
- Up to 16, 10.23 Gbps readout lines
  - 64-bit event packet.
  - 10.8 kHz maximum (average) rate per pixel.
  - Absolute maximum single pixel rate limited by 25 ns clock



Timepix4 wire bonded to Nikhef carrier board





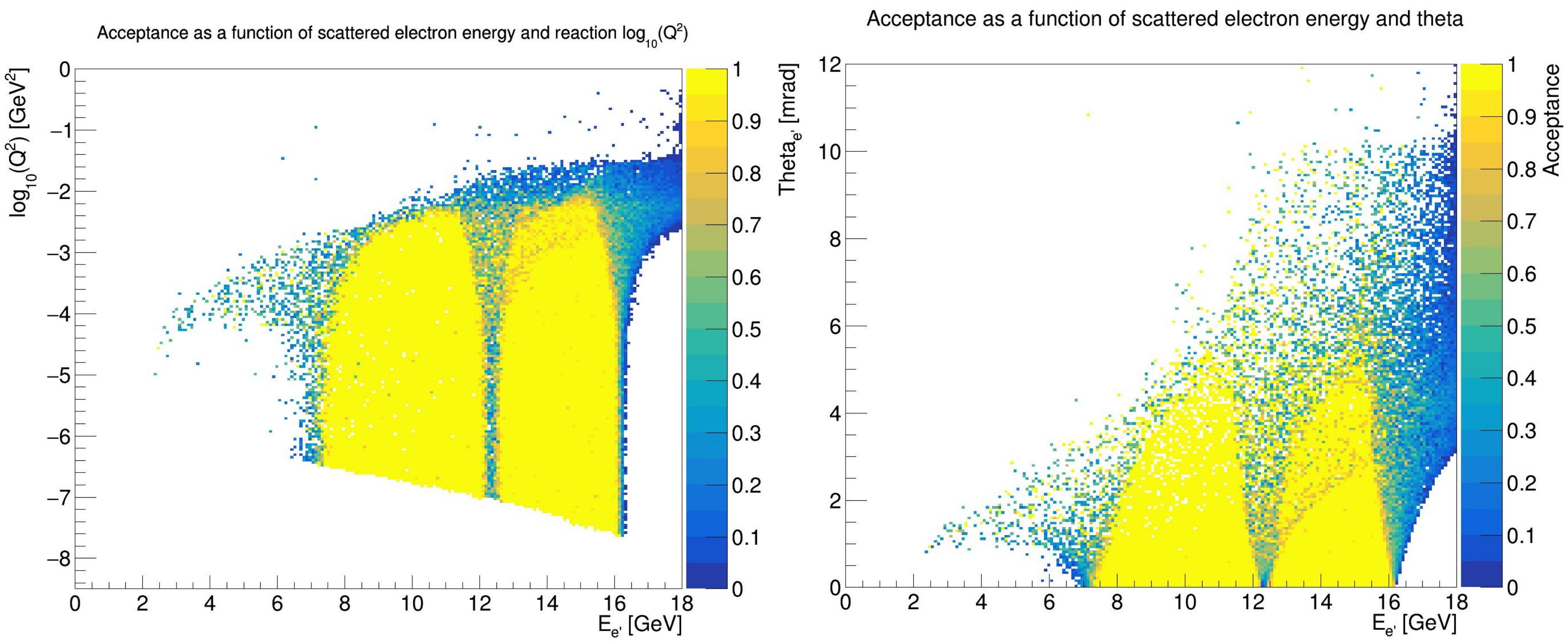
Readout path for periphery on one side. From: Timepix4, a large area pixel detector readout chip which can be tiled on 4 sides providing sub-200 ps timestamp binning - IOPscience

The Low Q^2 Taggers - Simulations

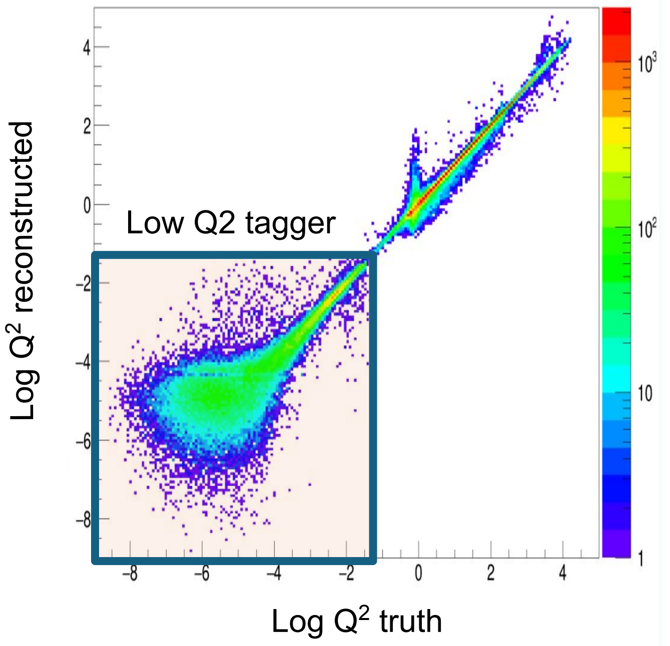
Simulation includes all mechanical components, beam smearing.
Not beam gas, synchrotron radiation.

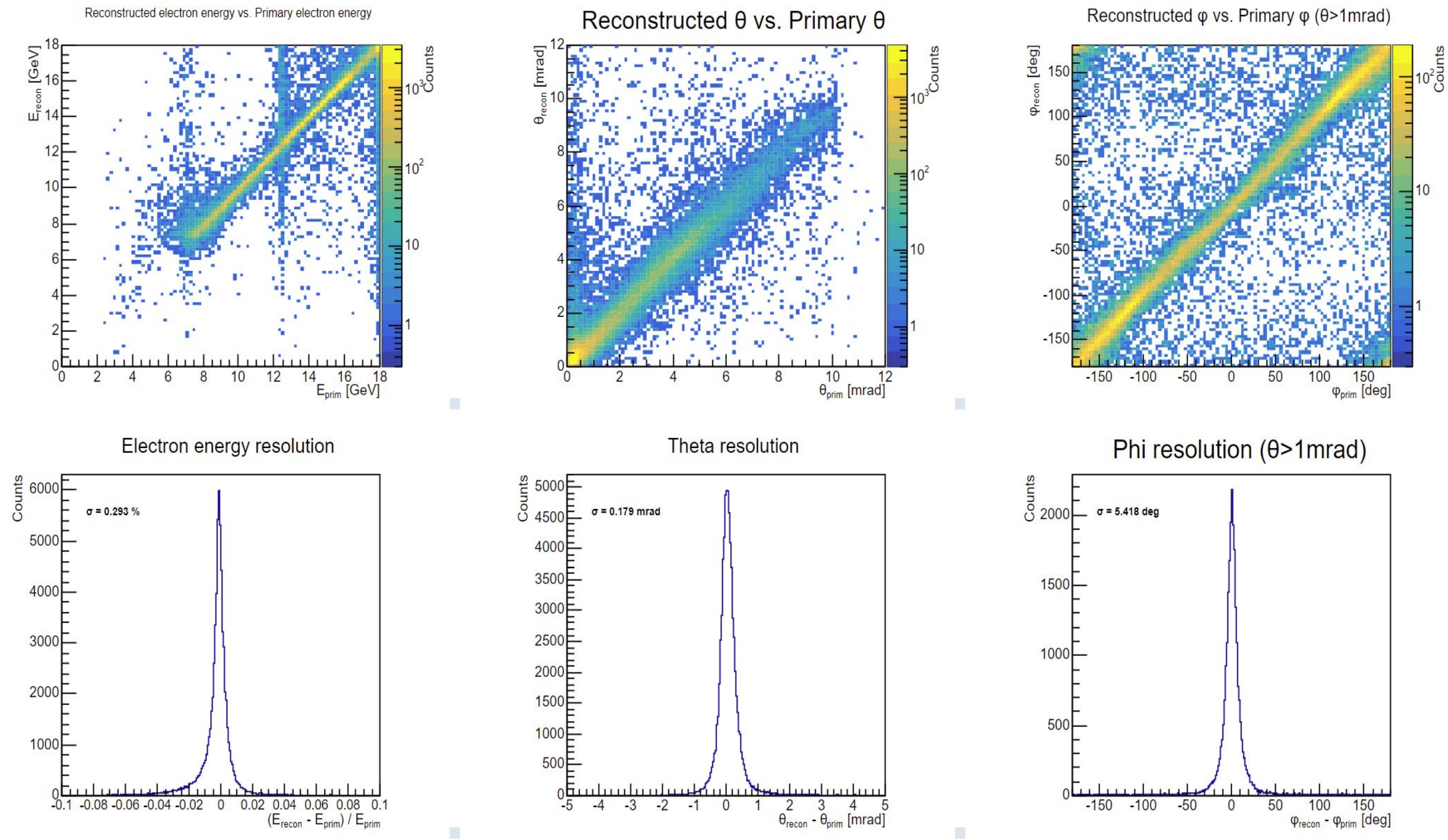
% scattered electrons reconstructed in tagger :

- 10% from all collisions
- 15% of all electrons < 11 mrad (Low Q^2)



The Low Q^2 Taggers - Simulations



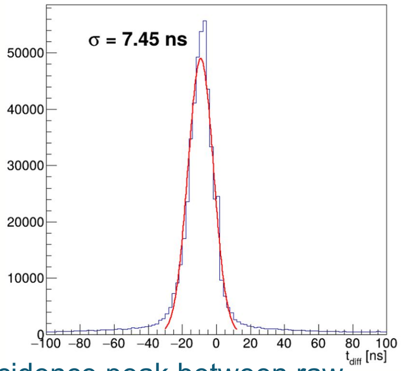


Integrated resolutions of reconstructed particles

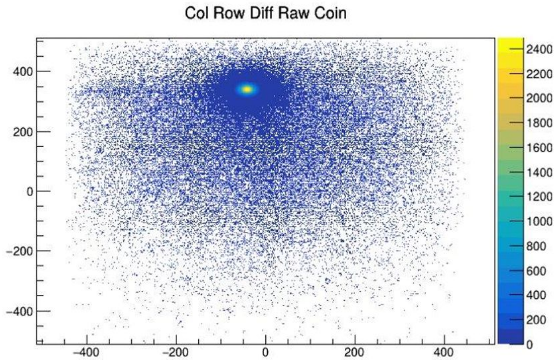
E_{σ} = 0.3 %
θ_{σ} = 0.2 mrad
Φ_{σ} = 5 deg

The Low Q^2 Taggers - Beam Tests

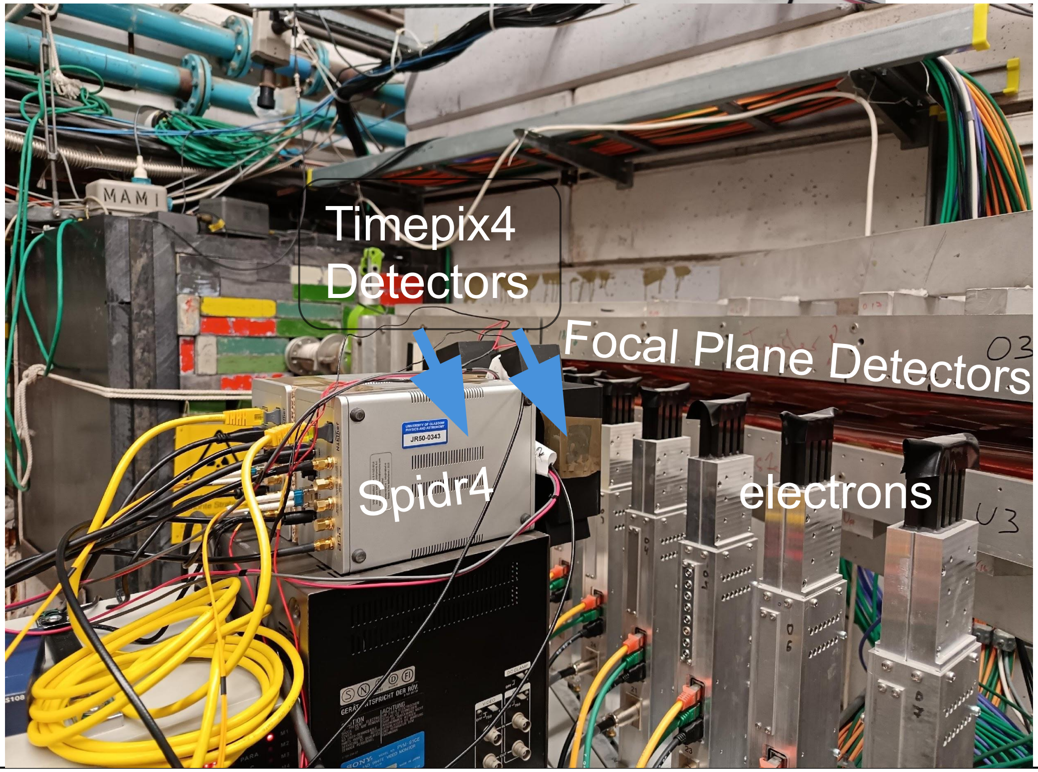
- Test beamtime @ MAMI (February 2025)
  - Demonstrated two synchronized SPIDR4 readouts with Timepix4 detectors.
  - Measured cluster from minimum ionizing electrons at incline.
  - Tested range of thresholds for efficiency and cluster size.
- Future Tests Planned - Summer/Autumn 2025
  - Readout rate using noise.
  - Test configuration for maximum throughput without affecting efficiency.
  - 4-Layer SPIDR4 telescope beam tests.
- Further Tests - 2026 onwards
  - ePIC DAQ integration @ JLAB
  - Radiation hardness tests with Nikhef



Coincidence peak between raw clusters. Calibration will bring this below 1 ns

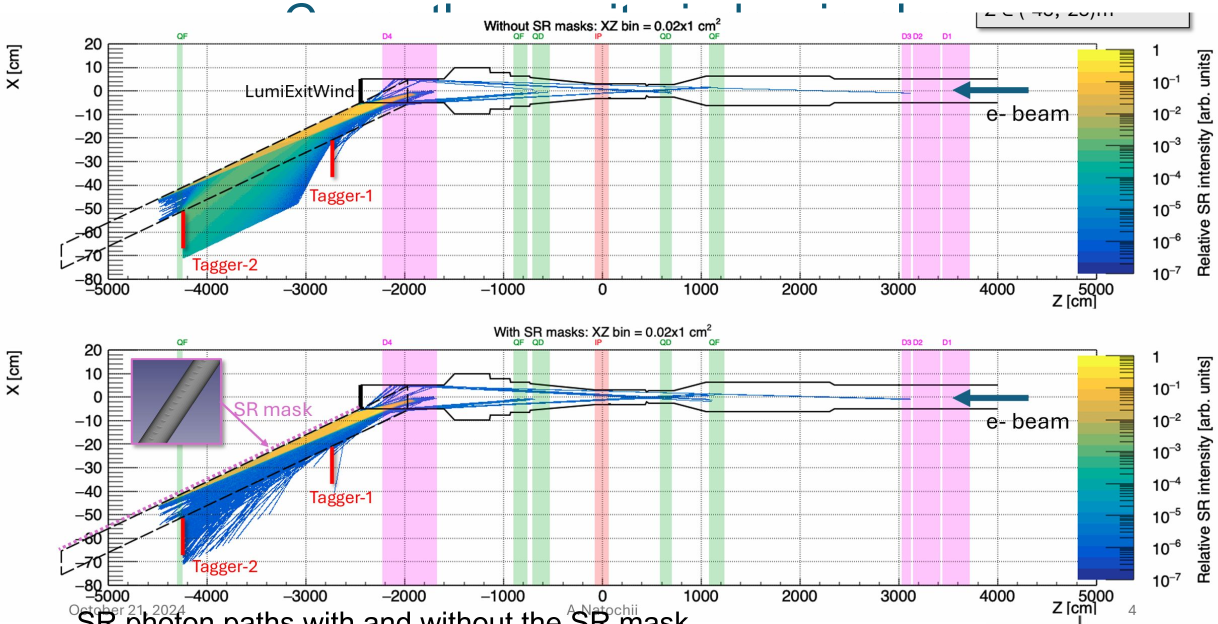


Position difference in pixels. Detectors pitched at 12 degrees



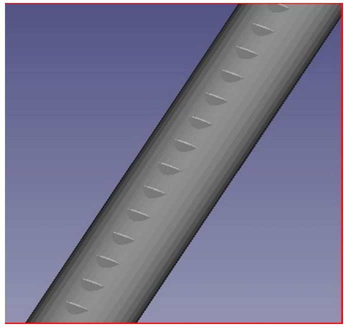
The Low Q^2 Taggers - Integration

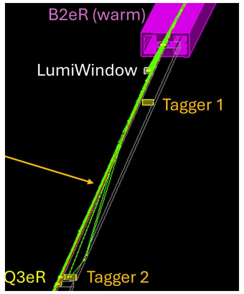
- The ESR lattice between the IP and Far-Backward detectors is still undergoing revisions.
- Beam pipe design still needs to be finalized,

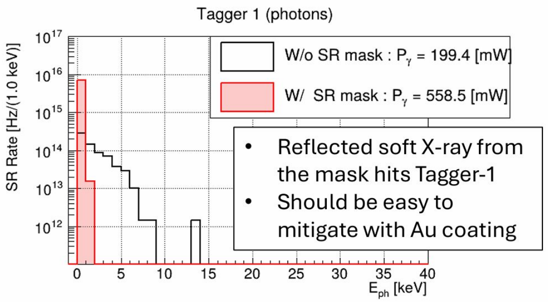


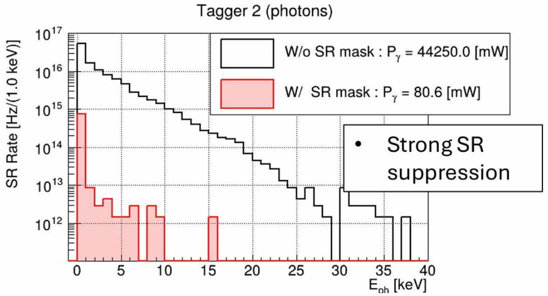
SR photon paths with and without the SR mask

Synchrotron Studies (Andrii Natochii)

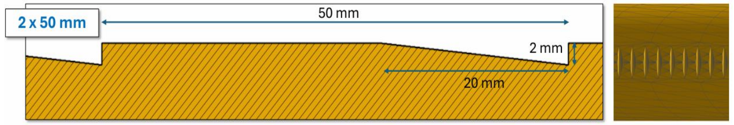




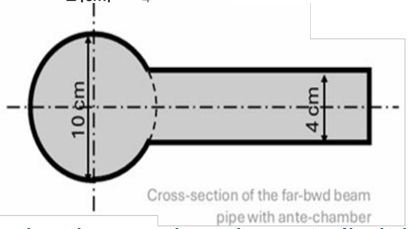




Energy spectrum of SR hitting taggers



Sawtooth mask along inside beam pipe to stop SR reflections



Ante-chamber beam pipe shape to limit beam impedance

The Lumi System

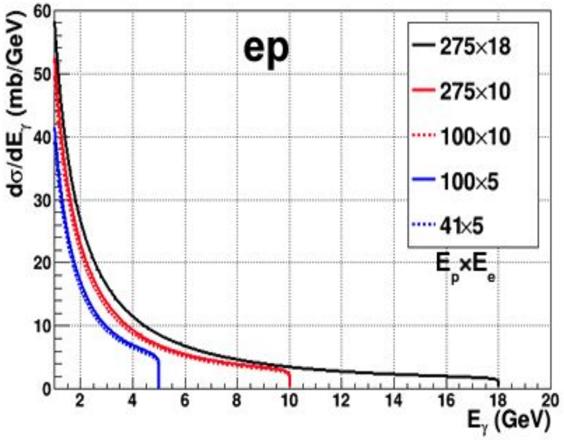
Bremsstrahlung processes

ep → epɣ, eA → eAɣ

- σ_{BREMS} precisely known from QED (~0.5%) Bethe-Heitler 1934
- At EIC both beams are polarised
  - σ_{BREMS} polarised component negligible EPJA 59:303 (2023))
- Large σ_{BREMS} ⇒ high statistics
- Lumi significantly higher than HERA (100x - 1000x)

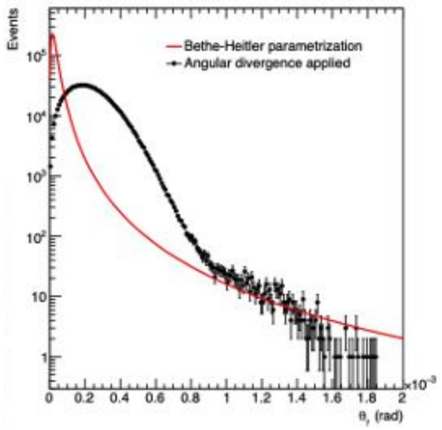
ɣ energy spectrum

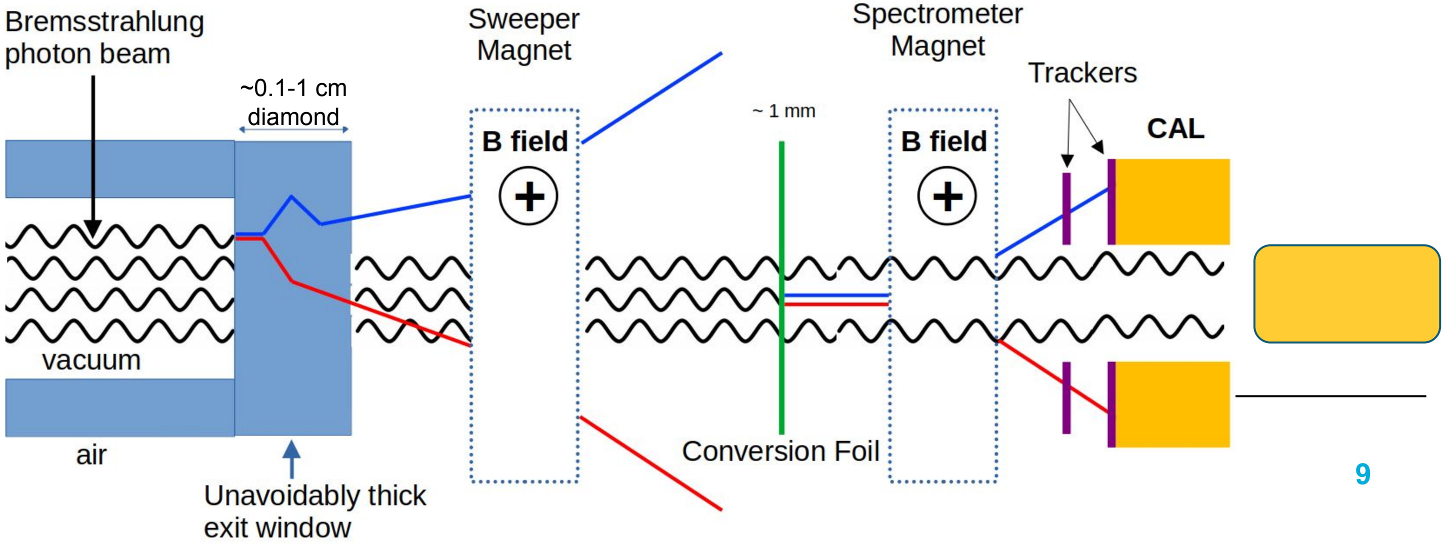
- Diverges $E_\gamma \to 0$
- Endpoint @ $E_\gamma = E_{e\text{-beam}}$
- Nuclei $\sigma_{eA} = Z_A^2 \cdot \sigma_{ep}$



ɣ angular distribution

- Strongly peaked @ beam 0°
- Dominated by e-beam divergence
- Diagnostic for beam steering, tuning

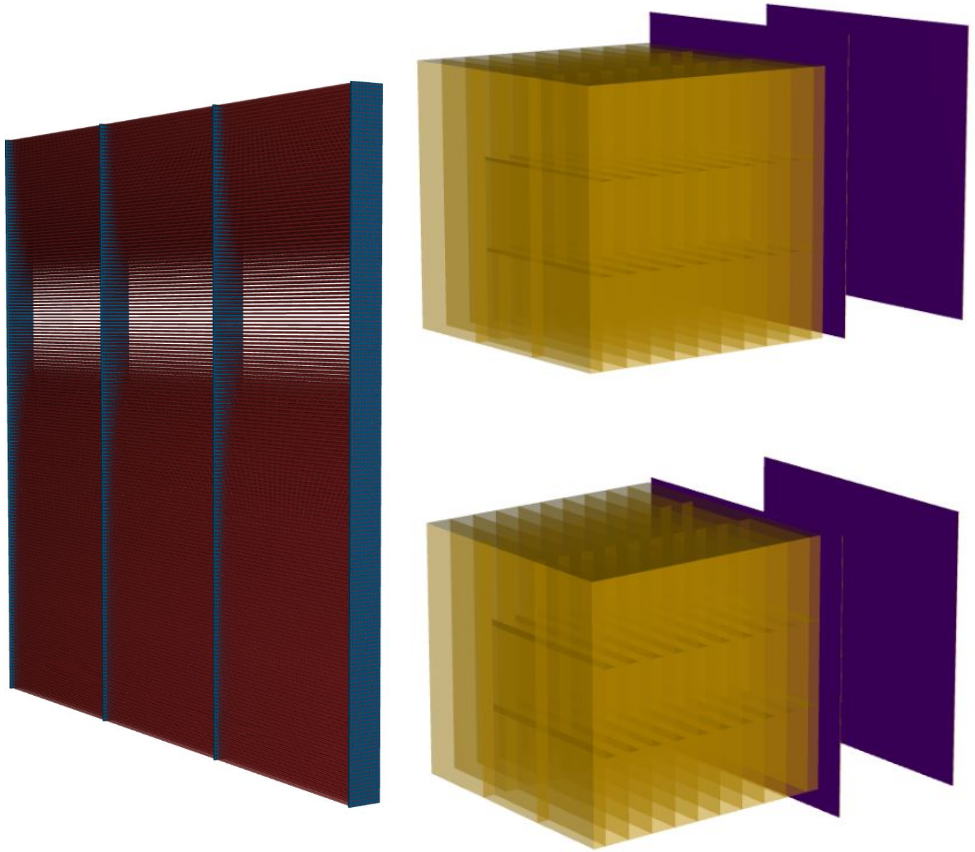




The Lumi Systems - Calorimeters

Technology of choice: Scintillating Fiber Calorimeter

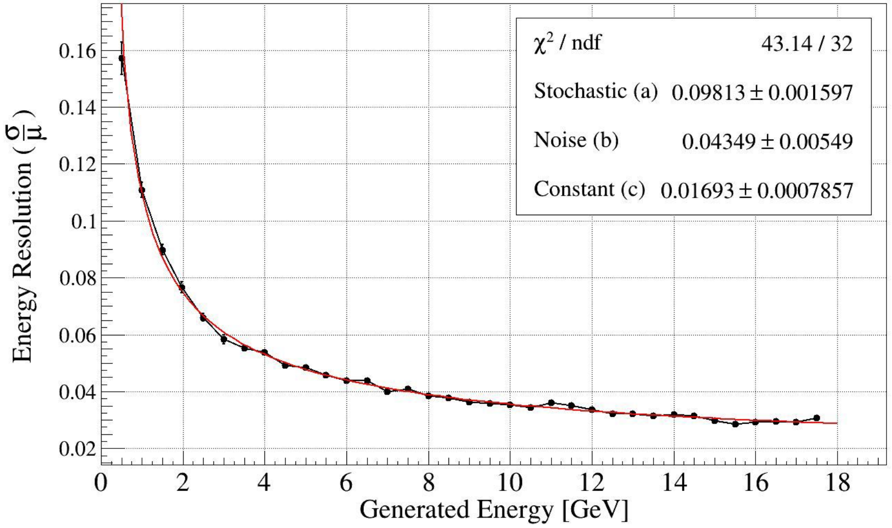
  - W-powder + epoxy infused into a bundle of scintillating fibers
  - Technology utilised in ePIC (fECAL)
  - Existing R&D and expertise*
- Dimensions 18x18x18 cm^3
- Radiation length ~ 8 mm
- 20 layers → $23X_0$
- Scintillating Fiber 0.5 mm diameter (Kuraray or Luxium -- samples for tests)
- Epoxy: DE NEEF or Epotek 301-1
- W-Scifi Ratio: 4:1 → Density 10.95 g/cm^3

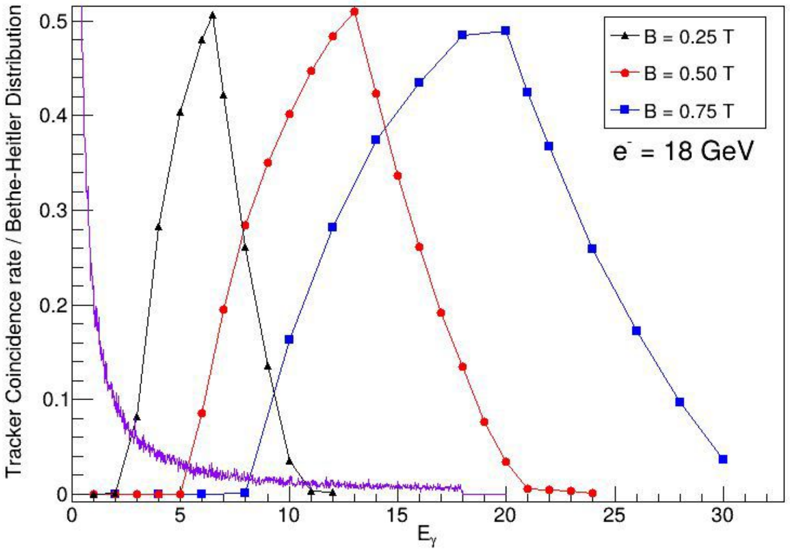


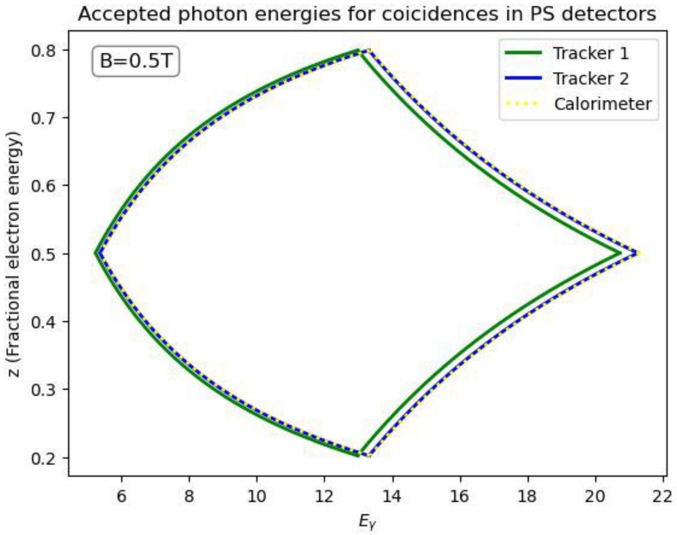
*O D Tsai et al 2012 J. Phys.: Conf. Ser. 404 01202

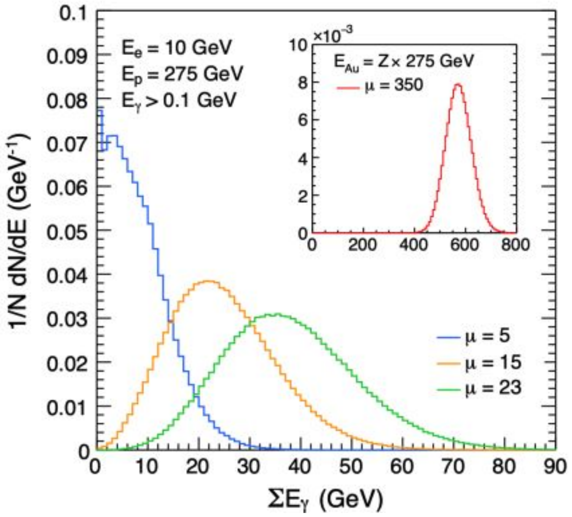
The Lumi System - Calorimeters

- Acceptance, position/energy resolution and sampling fraction well studied in simulation
- Energy resolution of ~9.8%/√E
    - ZEUS was 17%/√E
- Latest design has ~2% sampling fraction
- Expect ~80 photons/SiPM in EM shower
- Well understood acceptance
- Understood Synchrotron contribution



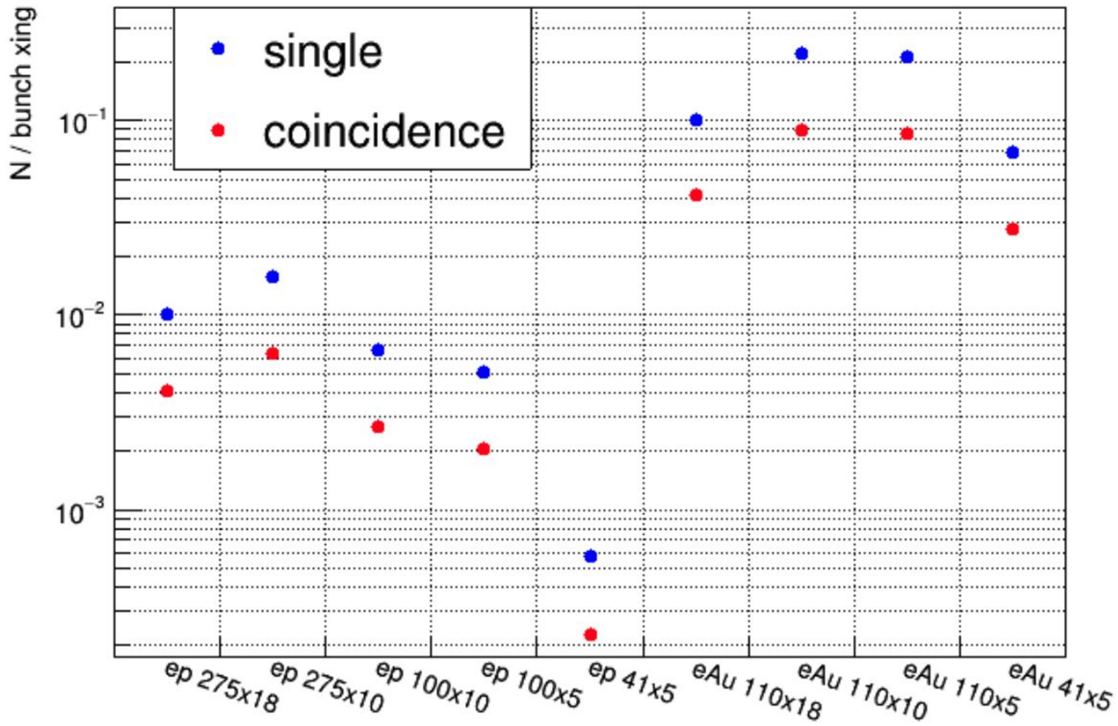






The Lumi System - PS Calorimeters Rates

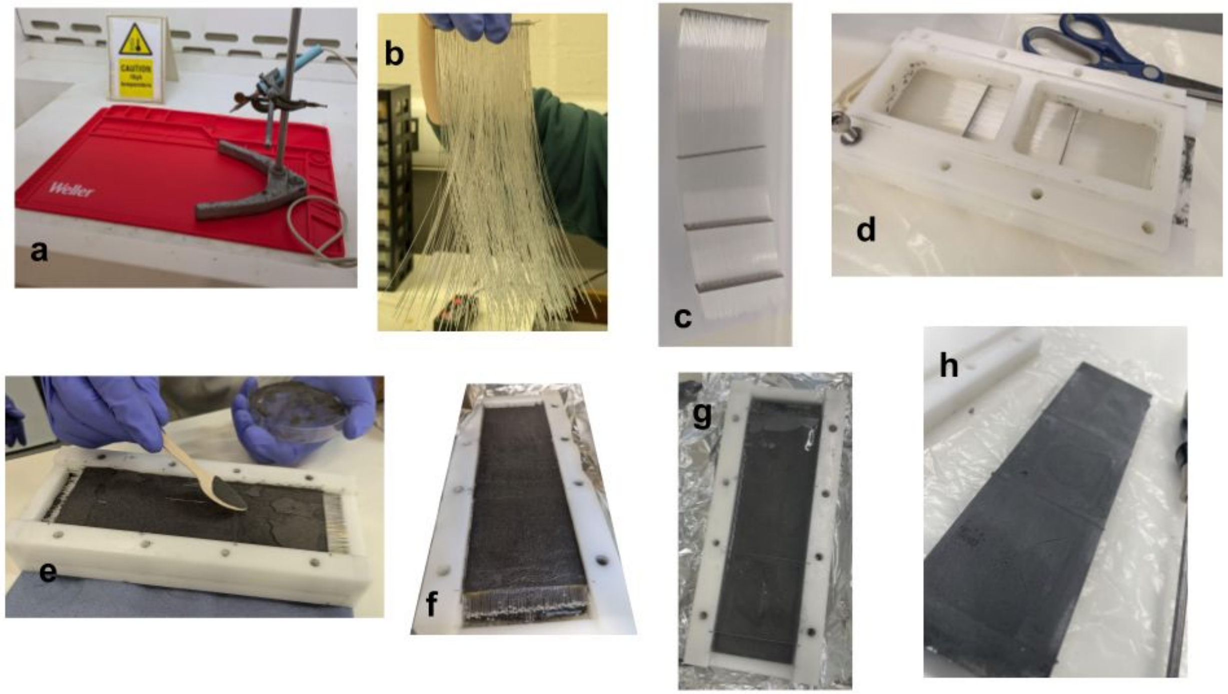
- Determined using nominal luminosity
- accounting for
- Conversion at exit window (<1% conv prob)
  → swept away
- 37 m Air (9%)
  → swept away
- 1 cm Al Vacuum chamber entrance cap (9%)
  → swept away
- 1 mm Al Conversion foil (1%)
  → detected in PS
- At most ~0.2 electrons per bunch crossing on average

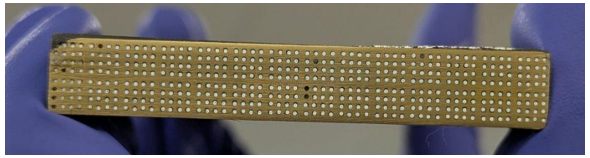


The Lumi System - Calorimeters

Production protocol established

- Fiber preparation
- Populating Fiber mesh with fiber holder design
- Meshes and fibres placed into the mould and secured
- Premeasure tungsten powder is added to the mould. Vibration table helps evenly distribute tungsten
- Epoxy is poured over the mould and mould is placed in vacuum chamber, helping trapped air to escape
- Module is baked in a low temperature oven
- Tile is then machined to predetermined dimensions

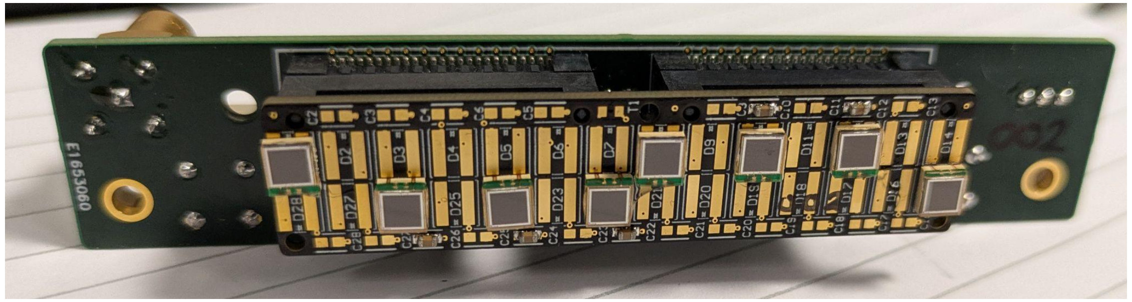


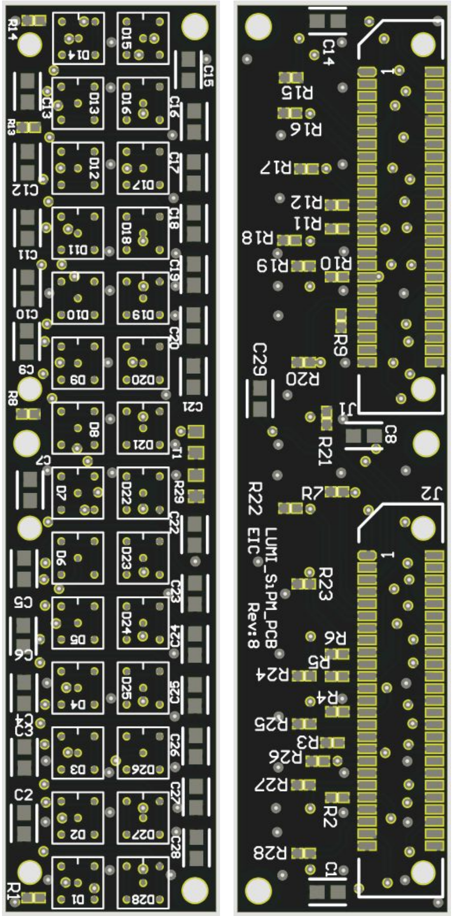


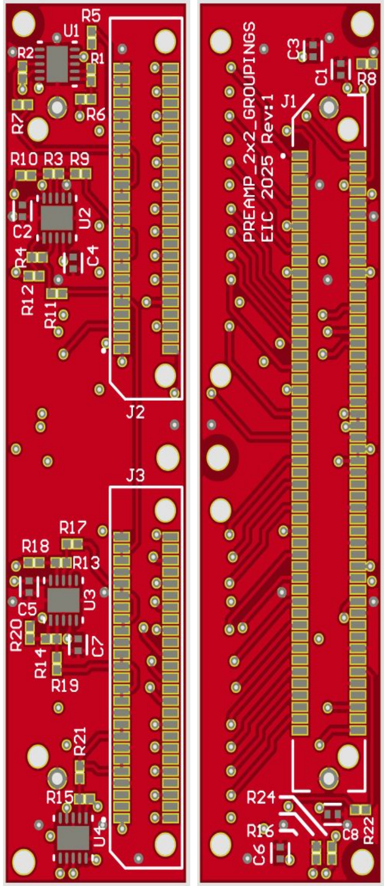
The Lumi System - Calorimeter FEE

FEE in development

- SiPM PCB board - iteration 4
  - S14160-3050HS SiPMs
  - 28 per PCB board
  - Can group in 2x2 for front/rear layers which see smaller signals
  - Reduce readout channels





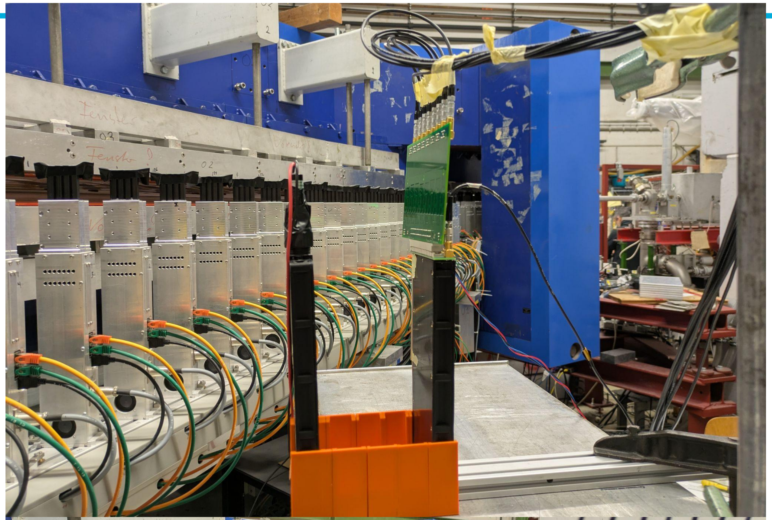


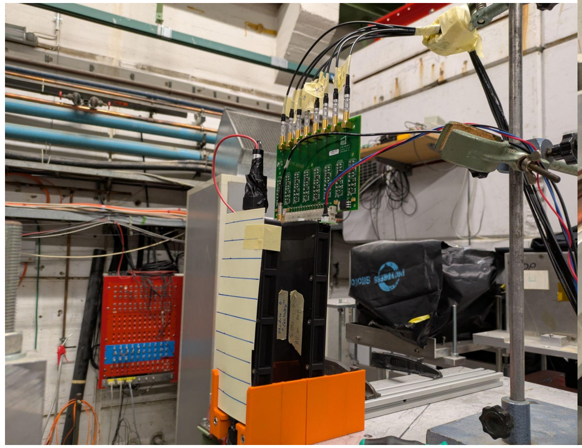
Older prototype with 8 SiPM readout for testing

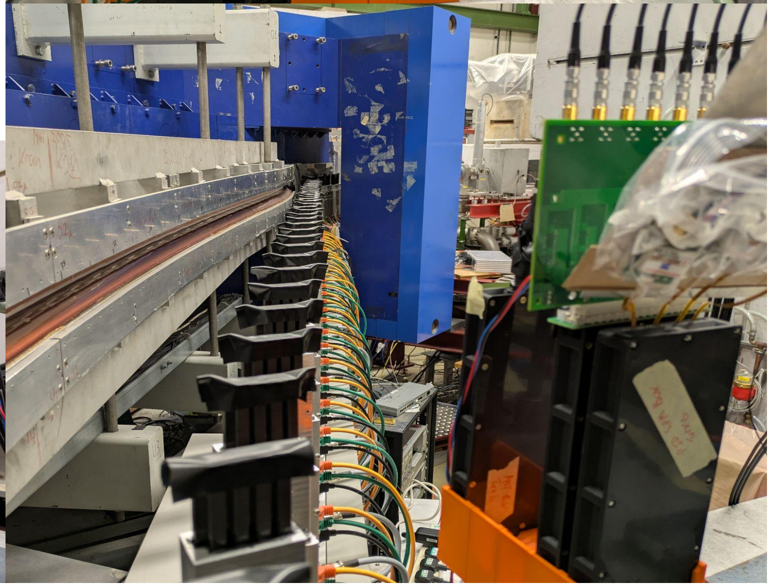
The Lumi System - Test Beam

Performance Validation

- 5 days of beam time at the MAMI facility in Mainz, Germany
  - Tests with both electrons and real photons
  - Energies on the order of 500 MeV
  - Analysis ongoing

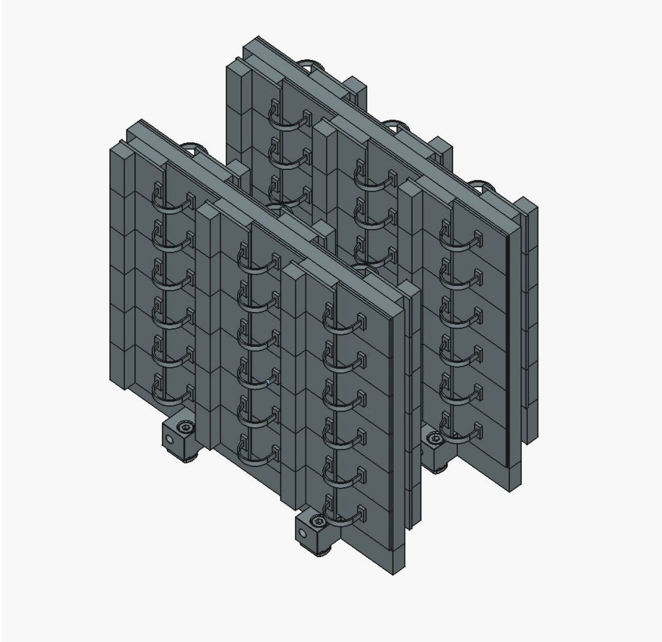






The Lumi System - Tracker (PS)

Detector technology: Pixel AC-LGAD, 500 μm pixel pitch.



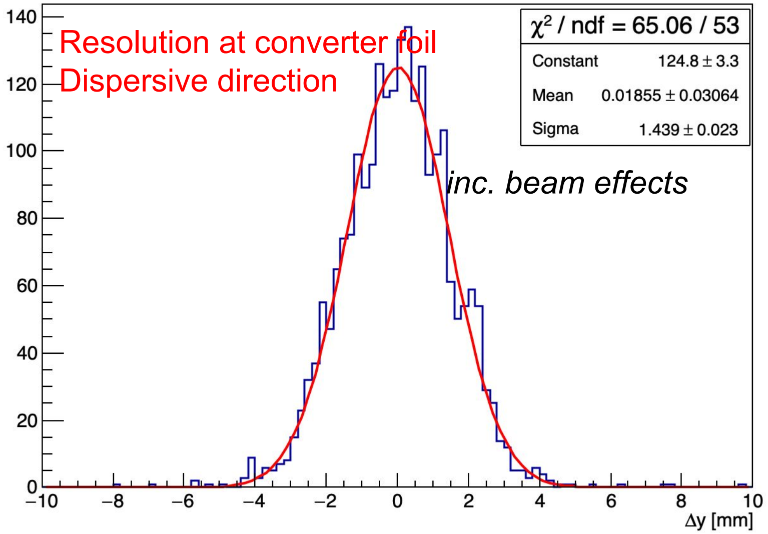
Two planes per section (up/down). Estimated cost of $0.93M

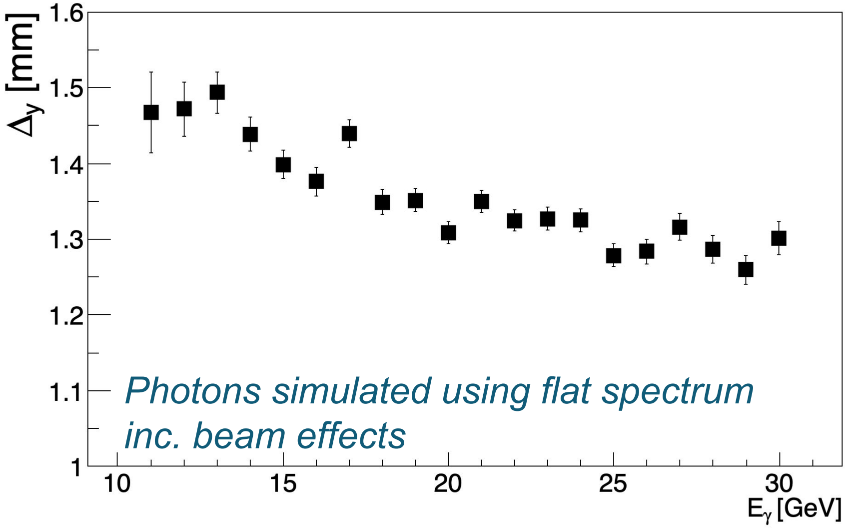
Active detector area of each plane: 18x18 cm^2

Maximal readout channels: 590K

Possible reduction in channels in non-dispersive direction by factor 2 (combining outputs)

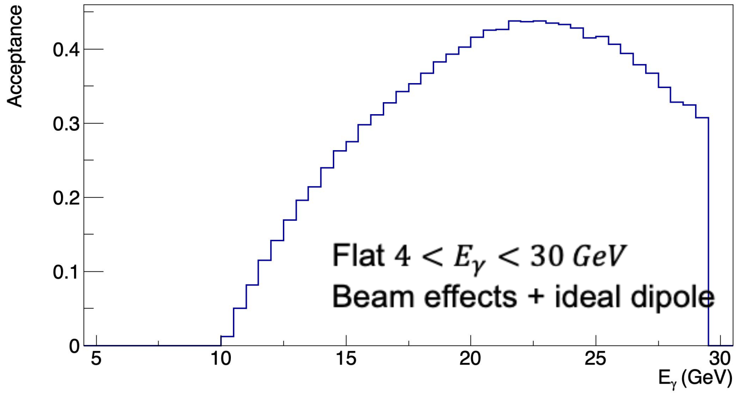
Position resolution (assuming charge sharing < 100 μm)



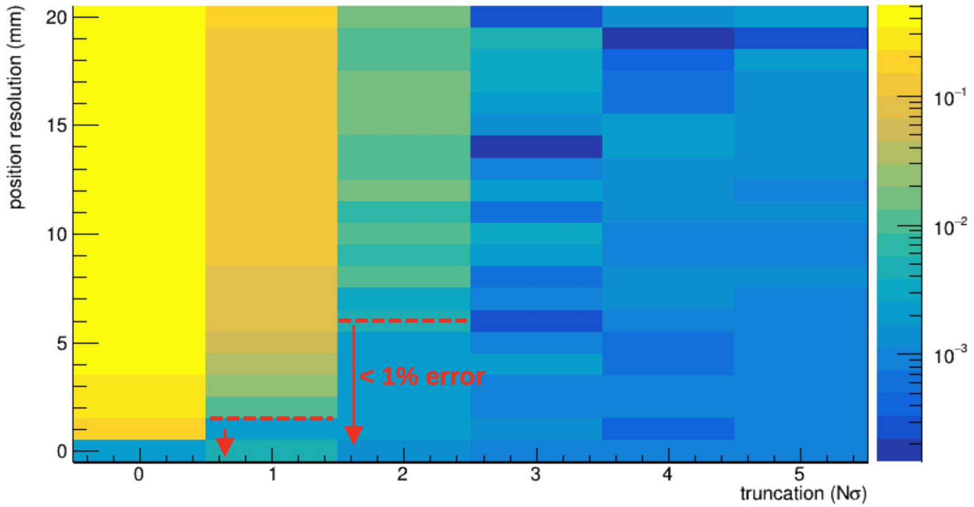


The Lumi System - Tracker (PS)

Tracker acceptance (positron and electron arms combined)



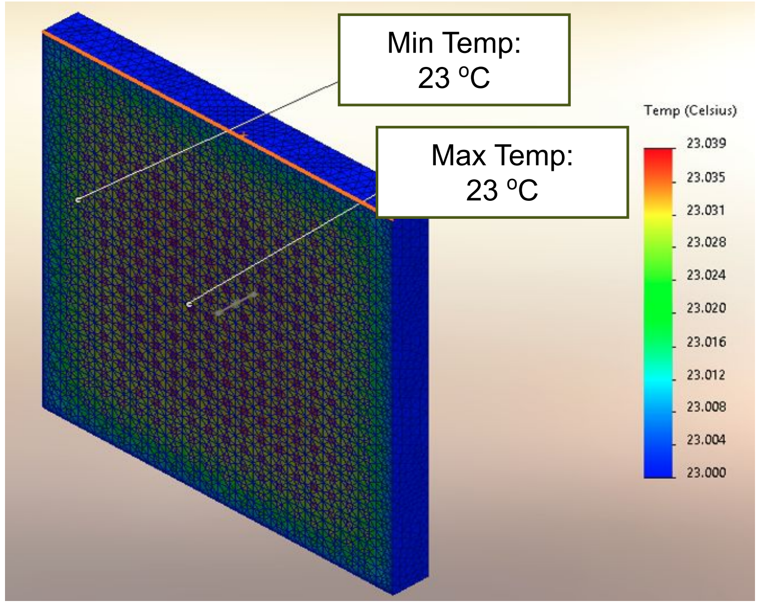
Position resolution vs truncation of the beam



For 2σ truncation, 6 mm resoltion is needed

Tracker heating – negligible

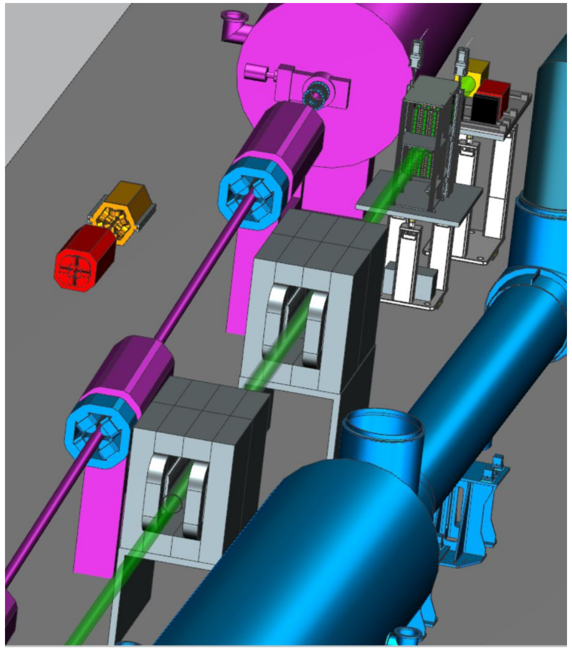
Assuming 1 mW per channel

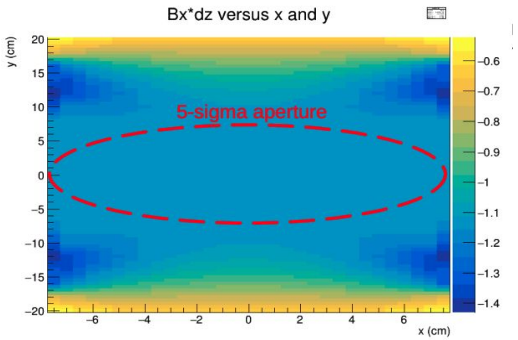


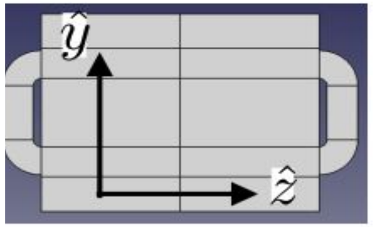
Strong synergies with fToF system
(see dedicated fToF talk)

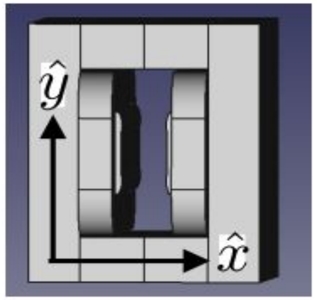
The Lumi System - Beamline and Magnets

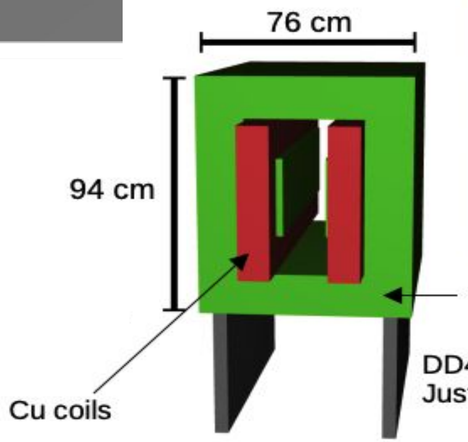
- **Sweeper & Analysing Magnet Requirements**
  - Large $\int B_x\, dz$ ~ 1 Tm to keep system compact
  - 15 cm bore diameter: 5σ unobstructed photon acceptance
- **Properties (Designer:Sandesh Gopinath)**
  - 1.2 m long with field of 0.8 T
  - 15 cm bore diameter
  - Uniform field
    - 1σ: $\langle B_x dz \rangle$=-1.1385 Tm and std 0.00005 Tm
    - 5σ: $\langle B_x dz \rangle$=-1.1395 Tm and std 0.0015 Tm





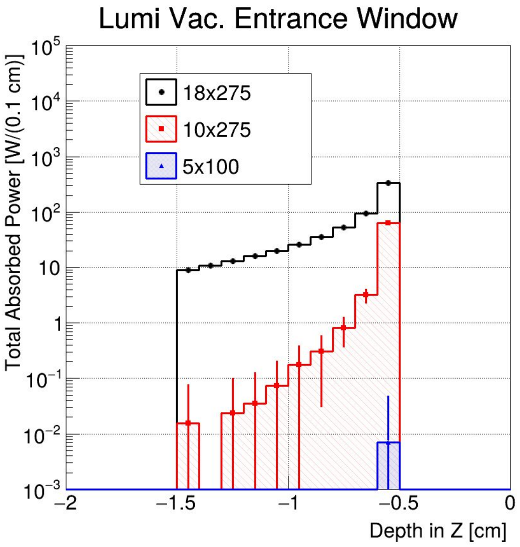






Backgrounds - Synchrotron Radiation

- Recent changes to beamline to reduce Synchrotron Radiation (SR) load
- Lumi exit window studied in detail
    - Thin diamond window now proposed to withstand SR heat load
- SR load on window reduced significantly
- Minimal impact on Luminosity system
    - ~1-2% loss of BH photons depending upon chosen thickness of diamond exit window)
- **Remaining SR load on lumi system is minimal**
    - ~600W on lumi entrance window in "worst" case conditions



Beam Energy [GeV]	Max. Absorbed Power Density [W/mm²]			Total Absorbed Power [W]		
	Entrance Window	Exit Window	Converter Foil	Entrance Window	Exit Window	Converter Foil
5 x100	< 0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01
10 x275	0.21	0.01	< 0.01	67.50	0.05	< 0.01
18 x275	2.06	0.07	< 0.01	611.71	19.28	0.26

In Summary

Points to Address

- LMS for Calorimeters
- Establish Far Backward Beam pipe and as well as study effect from entrance/exit windows
- Establish Converter specifications
- Magnet design according to specifications
- Calorimeter Enclosure
- Electron Beampipe design still needs to be finalized, optimizing:
  - Beam impedance, Beam vacuum, Synchrotron power and rates on luminosity exit window.
  - Low-Q2 Tagger acceptances.

Synchrotron in Far Backward