# Luminosity Detector
# Pair Spectrometer

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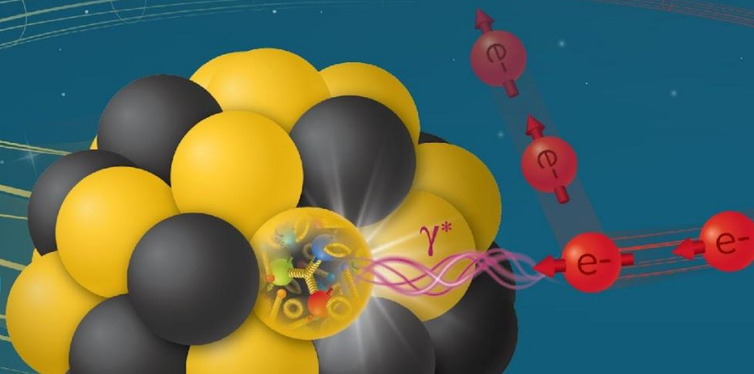
EIC Preliminary Design & Safety Review of the EIC Auxiliary Far-Forward/Far-Backward Detectors
February 12th, 2024



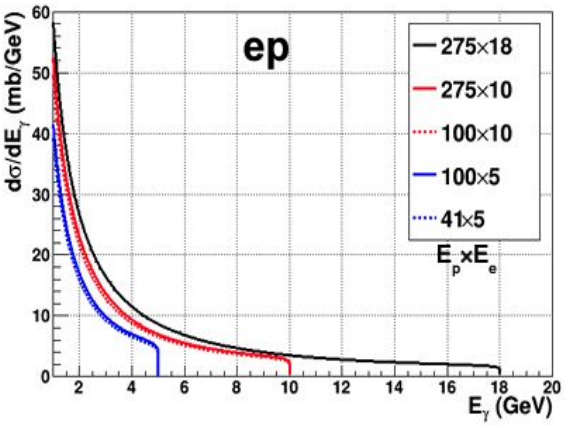

Electron-Ion Collider

# LUMI Process: Bremsstrahlung

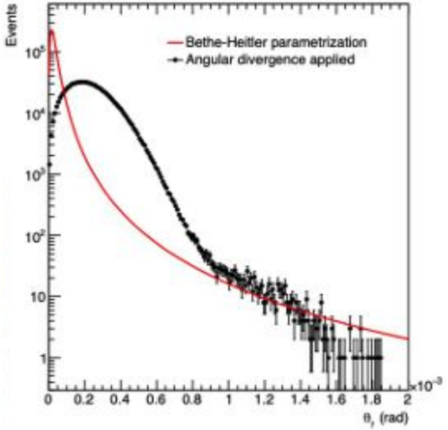
**Bremsstrahlung processes**
**ep → epɣ, eA → eAɣ**

- $\sigma_{BREMS}$ precisely known from QED (~0.5%) Bethe-Heitler 1934
- At EIC both beams are polarised
  - $\sigma_{BREMS}$ polarised component negligible (D. Gangadharan EPJA 59:303 (2023))
- Large $\sigma_{BREMS}$ ⇒ 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 0º
- Dominated by e-beam divergence
- Diagnostic for beam steering, tuning



# *Requirements*

## Physics:

- Precise determination of absolute luminosity at 1% level
- Precise determination of relative luminosity at $10^{-4}$ level
  - Spin-sorted lumi for different polarisation orientations  double BSA unc. @ RHIC $10^{-4}$ (Phys. Rev. D 93, 011501(R) (2016))
- Complementarity and redundancy (direct photon, and pair spectrometer sensitive to different systematics)

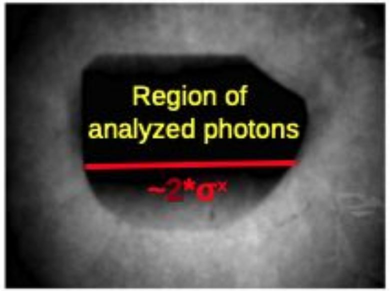
## Detector: Pair Spectrometer (PS):

- Energy resolution < 15%/sqrt(E)
- Good timing resolution ~5 ns (sufficient to resolve bunches 10.15 ns)
- Tracker dimensions larger than CAL to enable acceptance determination
- Less than 5 mm photon position resolution from trackers ($X_\gamma$ and $Y_\gamma$)
- Unobstructed photon aperture
- High accuracy in converter chemical composition (~0.3%)

# What we learned from Zeus

| Cause | Uncertainty in luminosity |
|---|---|
| Vertical alignment and $y_\gamma$ measurement | 2.5% |
| Photon conversion rate | 2% |
| Pile-up | 0.5% |
| Deadtime measurement | 0.5% |
| Theoretical Bethe–Heitler cross-section | 0.5% |
| Dipole magnetic field | Small |
| Trigger threshold correction | Small |
| Total | 3.5% |

ZEUS photon aperture



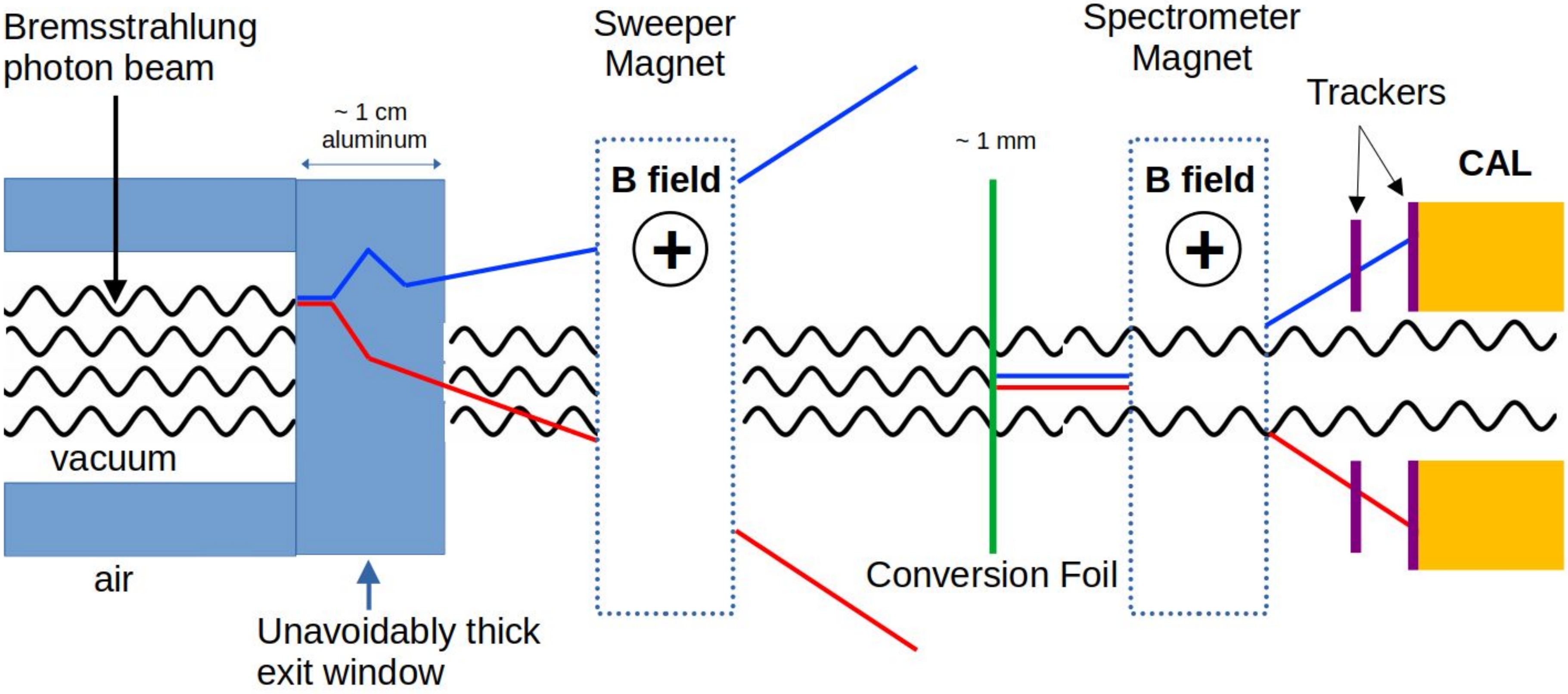

This was the dominant source of uncertainties for the HERA luminosity

Not a simple, well-defined photon acceptance (fuzzy)

## ePIC mitigations

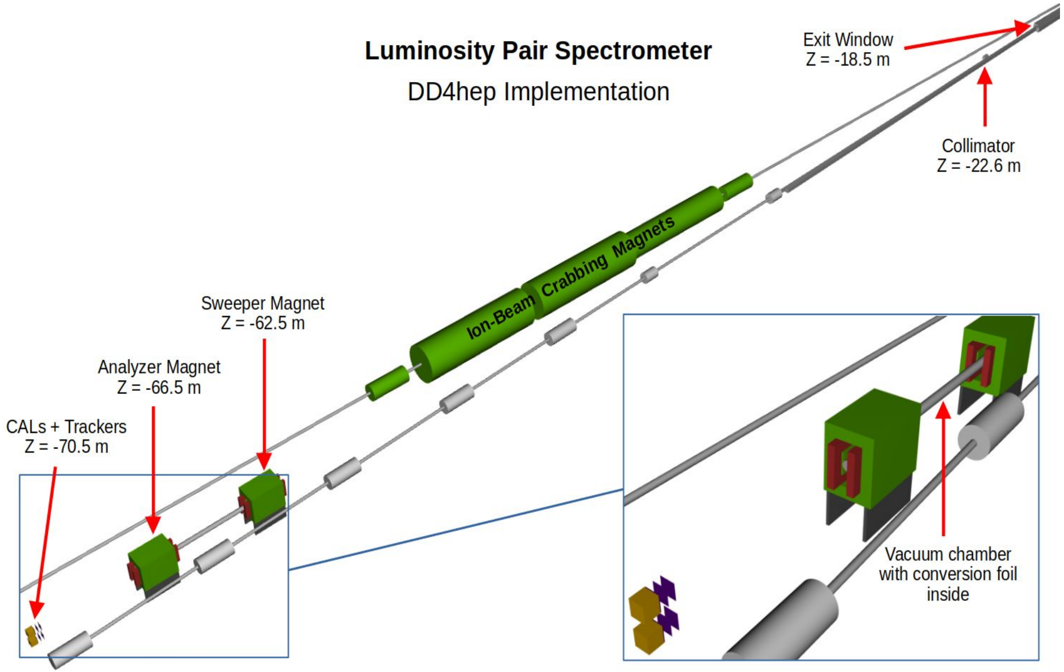
- Obstruction-free aperture
- System redundancy (Low $Q^2$ coincidences, tracker info)
- Systematic handles (sweeper magnet and adjustable analysing magnet)
- Trackers/Cal dual operation for self-calibration
- Precisely known chemical composition of all conversion materials (exit window and conversion foil).
- Dedicated thin conversion foil

# Experimental Approach



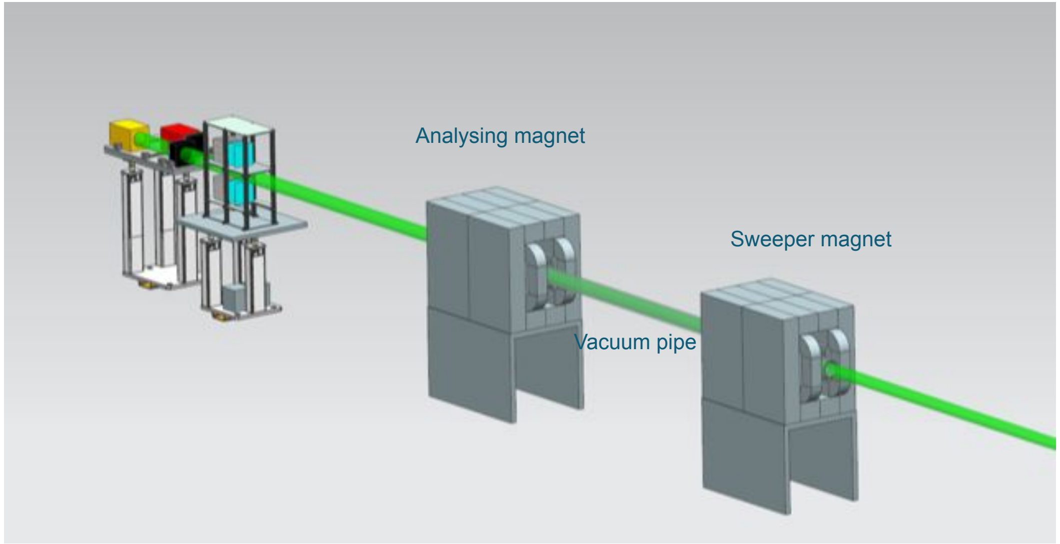
# *Far Backward region -- Exit Window, collimator*

- **Unobstructed photon path (5 σ)**
- **Exit window**
  - Simple geometry with uniform thickness and well-known composition
  - Conversion rate well established (special runs with sweeper magnet off)
- **Collimator**
  - Shield detectors from unnecessary radiation
  - Defines the outer limits of our acceptance (5σ → ~5 cm radius at our detectors)
- **Sweeper magnet to remove pair conversions from the thick exit window**
  - Multiple scattering in thick exit window degrades resolution of measurement: Sweep these away.
  - Also rates from thick exit window will be very large: might lead to pileup.



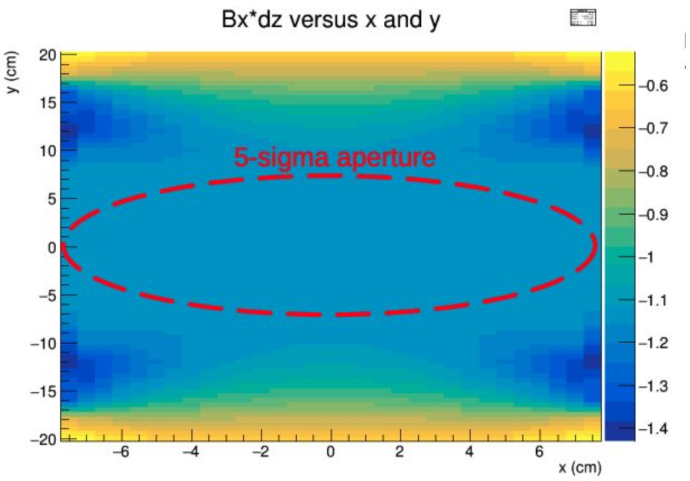
# Far Backward region - Converter, Vacuum, and analysing magnet

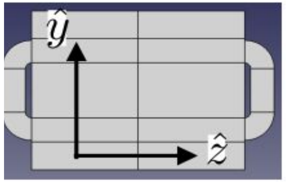
- **Vacuum Chamber**
  - Key to minimise conversions in air *within dipole magnets*
  - Requirements:
    - Diameter 5σ beam size
    - Thin exit cap (Beryllium 1.4%$X_0$)
- **Thin Aluminum converter**
  - Placed within vacuum pipe in between Sweeper and Analyzer magnet.
  - 1 mm thin→ 1% conversion rate
  - Precise and accurate determination of conversion rate
- **Tunable magnetic field**
  - Large and uniform Bdl (~1Tm)
  - Allows additional handle on rates
  - Adjustable acceptance coverage for PS

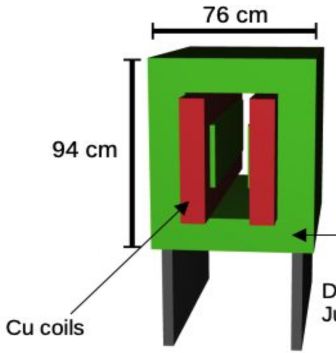


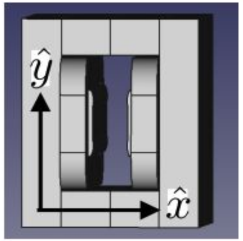
# Dipole magnets

- **Sweeper & Analysing Magnet Requirements**
  - Large $\int B_x\,dz \sim 1$ Tm to keep system compact
  - 15 cm bore diameter: 5σ unobstructed photon acceptance
- **Properties (Designer: Peng Xu)**
  - 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





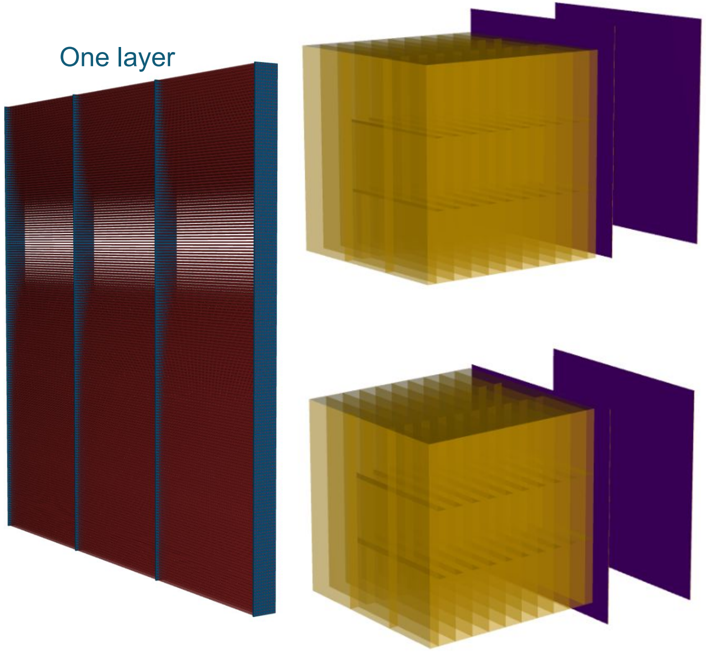
DD4hep model by Justin Chan (UH)

# Pair Spectrometer - 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*
- **Meets all requirements**

- Dimensions 18x18x18 $cm^3$
- Radiation length ~ 8 mm
- 20 layers → $23X_0$
- Scintillating Fiber 0.5 mm diameter (Kuraray or Luxium -- samples for tests) - (see backup slide 19 for specs)
- Epoxy: DE NEEF or Epotek 301-1
- W-Scifi Ratio: 4:1 → Density 10.95 $g/cm^3$

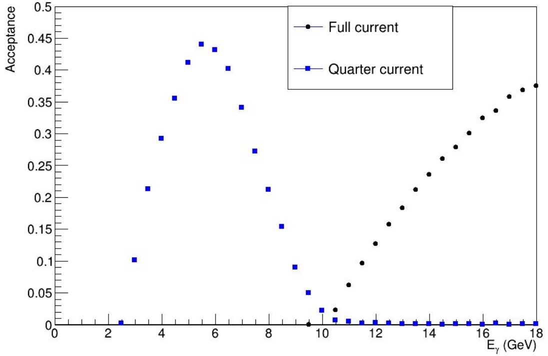


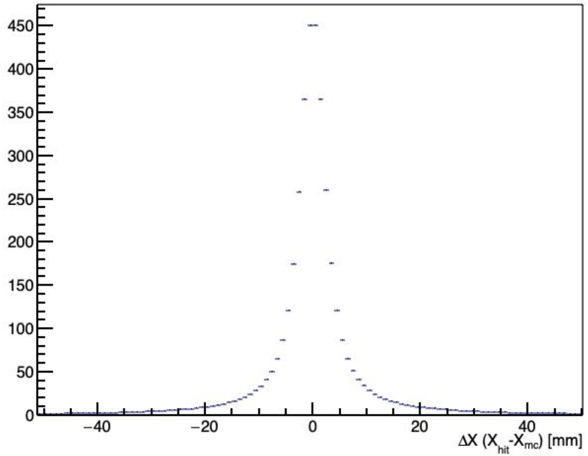

*O D Tsai et al 2012 J. Phys.: Conf. Ser. 404 01202

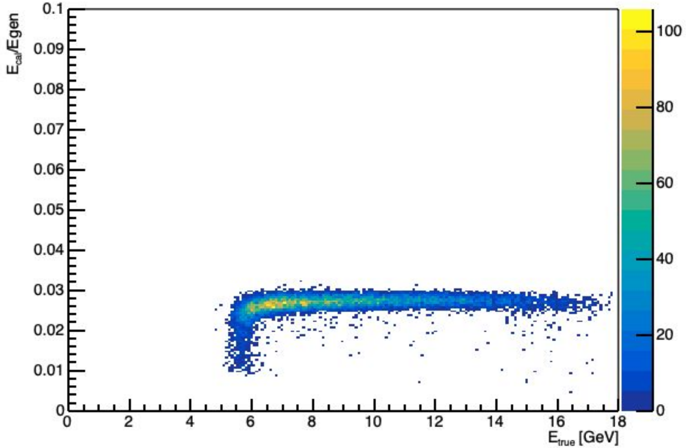
# Pair Spectrometer - Calorimeters

## Simulation studies

- Moliere radius ~1.5 cm (0.9 cm for pure W)
- Sampling fraction ~3%
- Linear response
- Energy resolution
  - Stochastic term 10% / sqrt(E)
- Shower profile determination
  - Position resolution ~ 2 mm
- Tunable acceptance with different magnet currents

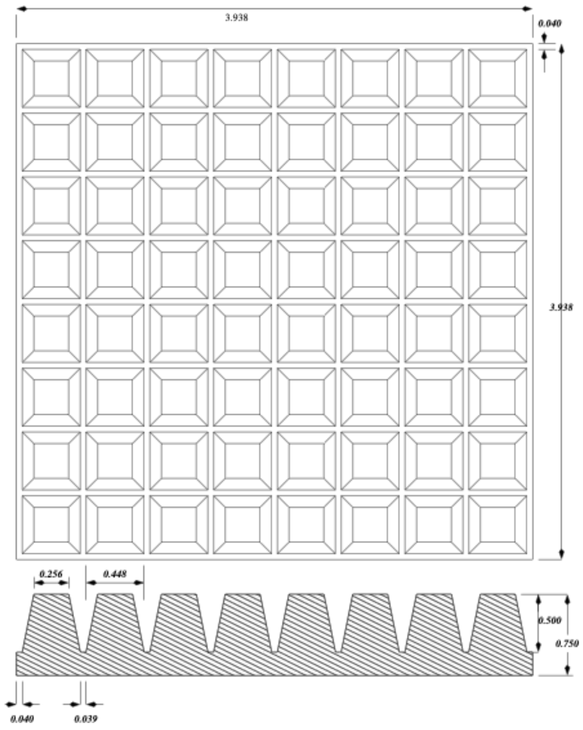


# Pair Spectrometer - Calorimeters

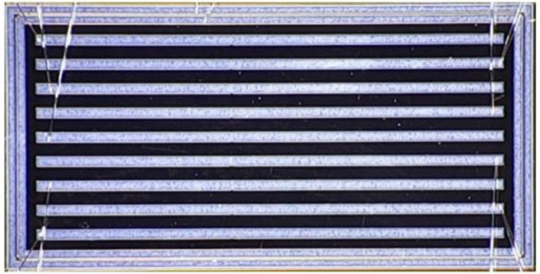
- Fibers Kuraray or Luxium (sample for tests)
- Readout
  - 900 3x3mm Hamamatsu SiPMs per Calorimeter (options to be evaluated)
  - Optical guides - Following design by O. Tsai that maximises light collection efficiency
- Support Structure designed by University of York
- No significant space requirement/constraints
- High rate (~0.1 event / bunch crossing) dictates FEE different from FeCAL. Support from UoY technicians and UCLA.

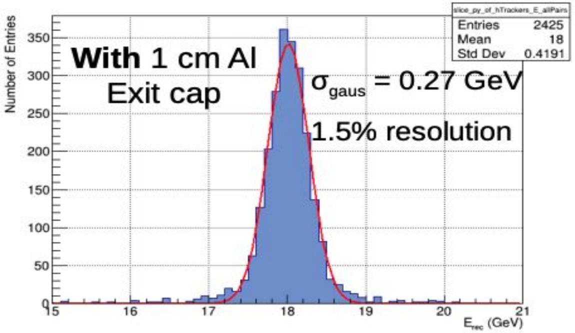


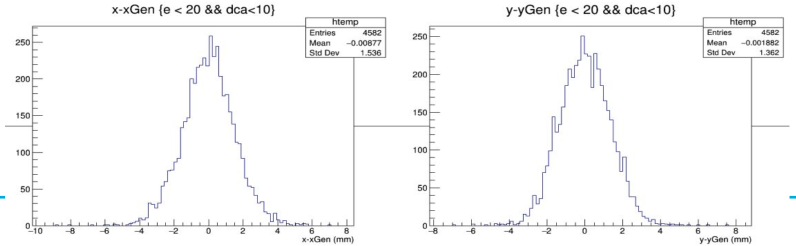
# *Tracker design*

- Trackers provide redundancy to the CALs
- Trackers enable precise photon acceptance determination (major uncertainty at ZEUS)
- Mitigates multiple hits
- Allow for a precise energy calibration (2%) for CALs
- Technology choice: AC-LGAD strips
  - Strip sensors, with strip pitch 500 μm. 30 μm position resolution with charge sharing and 1/√12.
    → 2 mm photon position resolution
  - Technology of choice for different systems in ePIC (Synergy with BTOF)
  - 2 stations per calorimeter
    (2 layers per station: X and Y orientation)
  - Small material budget (~1% $X_0$ per layer):
    low multiple scattering
    = good angle resolution
    = good E resolution.

**HPK Strip Sensor (4.5x10 mm²)**



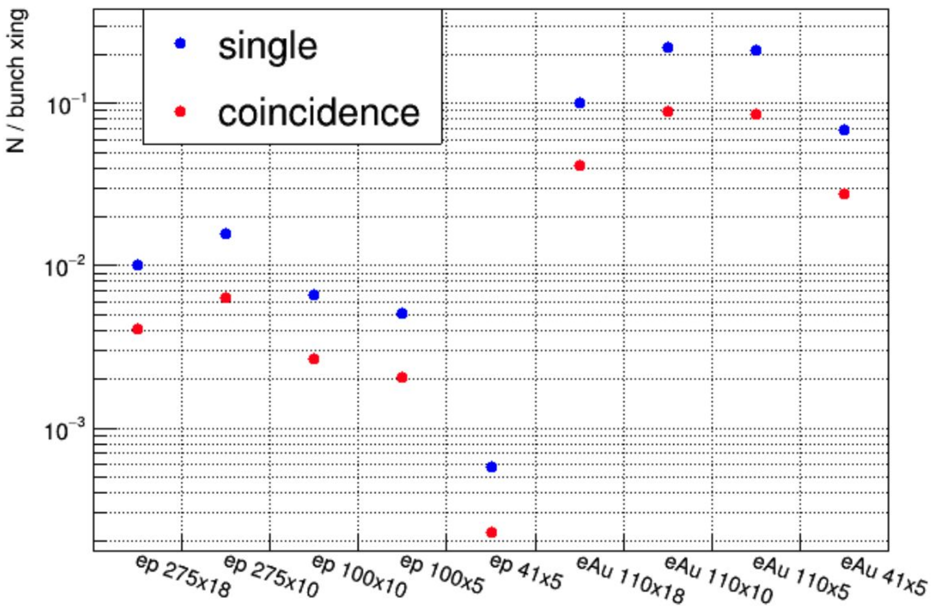


# *Expected Signal Rates*

Determined using nominal luminosity accounting for

- 1 cm conversion at exit window (9% 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



# Quality assurance

- Expertise within ePIC collaboration (technologies of choices used in other parts of ePIC)
  -- Synergies with fECAL and BTOF
- Continuous progress review by ePIC Technical and Integration Council
- Engineering tests soon underway building on existing work done by O. Tsai
- Initial tests planned for 2024/2025
- Development of full documentation for test and commissioning

# Health and safety

- We will be using the appropriate Radiation Safety measurements as dictated by the University of York and Brookhaven national Laboratory.
- Construction: The University has extensive ES&H measures in placement that need to be followed in all our labs and ensure Radiation, Chemical, and Electrical safety, as well as proper occupational Health and safety measures
    - Use of fume boxes, protective equipment for hands/eyes/body.
    - The university ensures all personnel working within the labs have the appropriate training to ensure adherence to these safety protocols.

We will strictly follow the laboratory safety procedure for electrical safety (HV supply) and ensure that all equipment is mechanically secure.

Trip hazards from cabling will be minimised by proper cable routing.

Ear protection and proper signage will indicate clearly areas of high-magnetic field.

No fire risk is anticipated from scintillating fibers as these are enclosed within the calorimeter.

# Summary

- Requirements well defined
- Technologies of choice (Scifi Cal and AC-LGADS) satisfy all requirements
- Detector setup mitigates systematics (lessons from Zeus)
  - Sweeper magnet
  - Thin converter (ability to have different converters)
  - Vacuum pipe (mitigating conversions in air within magnetic field)
  - Unobstructed photon acceptance
- Engineering test soon underway (Mainz 2024)
- Optimisation ongoing utilising DD4HEP simulations

# *Extras*

# *Fiber Specification*

A. Light yield shall exceed 8000 photons/MeV

B. Diameter mean value and variation shall be 0.47 +/- 0.004 mm, RMS ≤0.02 mm.

C. Attenuation length for blue light > 3m.

D. Batch to batch or lot to lot variation of light yield <10%.

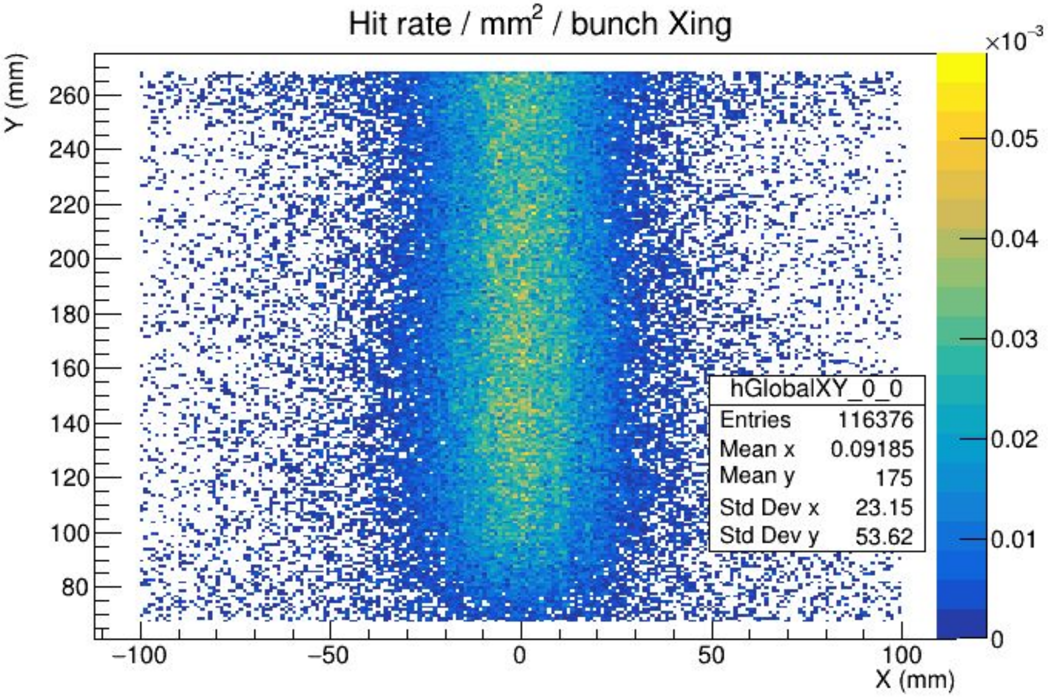
E. Emission spectrum in blue-green light

F. Scintillation decay time <3ns

Luxium BCF10 https://www.mi-net.co.uk/product/scintillating-fiber/

Kuraray https://www.kuraray.com/products/psf

# *Tracker Occupancies*




- Hit rate / mm^2 / bunch crossing for max bremsstrahlung rates in e-Au 10x110.
- Hits concentrated in narrow vertical band. But band may move for different EIC beam configurations.

# Radiation hardness

- Calorimeter components do not require hardness studies
  - Epoxy tested to 15 MRad→ no degradation in mechanical properties
  - SiPM to light guide coupling → Silicone, selected by CMS in 2002 used for STAR FCS
  - Scintillating fibers → Radiation hard. Do not expect to see noticeable changes in LY or transparency
- Plans for SiPM irradiation following feCAL studies
- No space constraints → Can easily shield FEE

# Plans for engineering test articles

- Engineering tests will follow well established procedures developed by O. Tsai (FeCAL)
- Materials are ordered and anticipate module construction to commence ASAP
  - Epoxy (left) and brash mesh (all) acquired
  - Fiber sample acquired (right)
    - Tested with mesh (right)
  - Tungsten powder sample acquired
  - Construction mould design in progress

- Work is needed to establish FEE
- Initial test to be performed at MAINZ in 2024