ePIC Far Backward Overview & Low Q^2 Prospects for Detector 2

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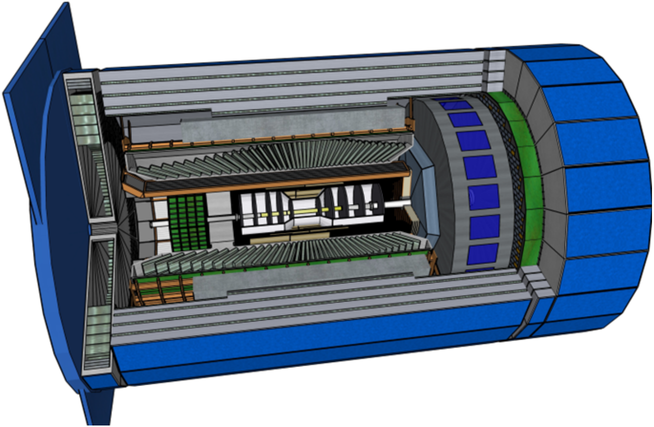
University of York

EICUG 2023
31/07/23

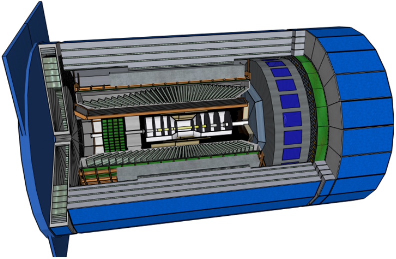
ePIC Detector

- Our "normal" picture of ePIC is something like this



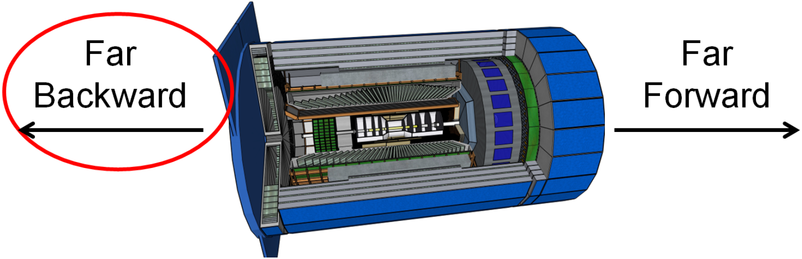
ePIC Detector

Far
Backward



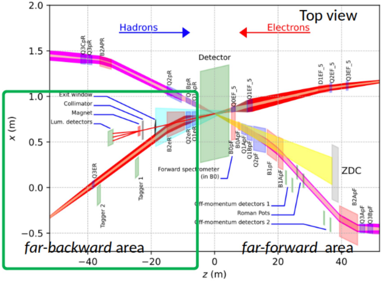
Far
Forward

ePIC Detector



Far Backward Region

- Relatively simple, but very important, set of detectors systems in this region
  - Luminosity monitors
  - Low Q^2 tagger



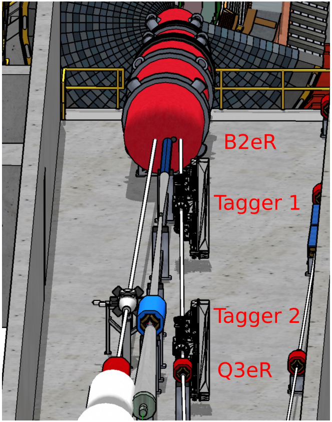


Figure - Igor Korover, MIT, ePIC Collaboration meeting January 2023

Luminosity monitoring systems for ePIC

Far Backward - Luminosity Monitors

- Luminosity measurements provide the required normalisation for all physics studies
  - Absolute cross sections
  - Combining run periods
  - Asymmetry measurements
    - Relative luminosity of different bunch crossings
- Require accuracy on the order of $\sim$**1%**

  Relative luminosity $> 10^{-4}$ precision

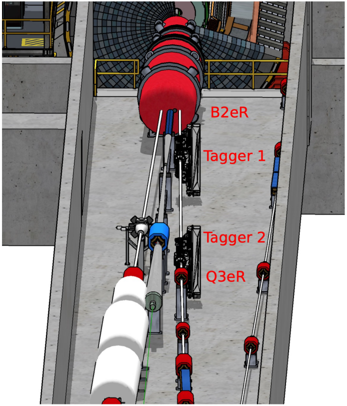


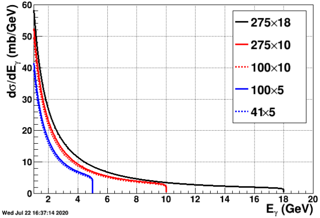
Figure - Igor Korover, MIT, ePIC Collaboration meeting January 2023

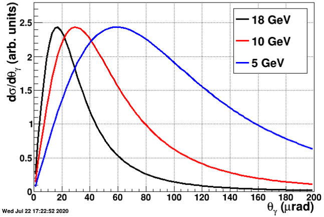
Luminosity Monitors - Measurements

- Use bremsstrahlung process to measure luminosity

$$e + p \rightarrow e + p + \gamma$$
$$e + A \rightarrow e + A + \gamma$$

- σ known precisely from QED
- γ strongly peaked in forward (e^- beam) direction
  - Beam divergence has a large effect - $\sim 200\mu$rad at IP6!
- Two luminosity monitor systems
  - **D**irect **P**hoton **D**etector (High rate calorimeter)
  - **P**air **S**pectrometer





Figures - EIC Yellow Report - Section 11.7.1, p575

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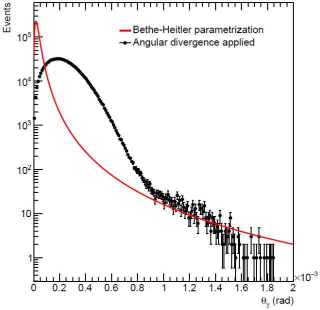


Figure - EIC Yellow Report - Section 11.7.1, p576

Direct Photon Detector

- In principle, direct bremmstrahlung photon measurement straightforward
- Could simply count photons above some energy cutoff
- Only possible at low luminosities
- At EIC luminosity, expect large number of photons
- At $\mathcal{L} \approx 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, expect about 23 hard photons per bunch crossing
- Two separate direct photon detectors proposed
  - One with excellent energy resolution, used only for special luminosity runs at low $\mathcal{L}$
  - One capable of withstanding $>$ 1 GHz rates, used for monitoring during nominal running
- DPD and PS highly complementary detectors, two independent measurements

Direct Photon Detector

- Use thick absorbers/filters to attenuate synchrotron radiation
- Studies underway to quantify dosage for photon detectors
- Latest design, fiber based calorimeter
- See talk by Krzysztof Piotrzkowski at 10:25 on 29/07/23 for more on the DPD/HRC

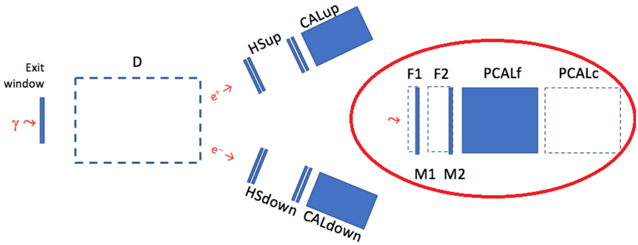


Figure - J. Nam, Temple University, ePIC Collaboration meeting January 2023

Pair Spectrometer

- Pair spectrometer outside of main synchrotron radiation fan
  - 5σ gap
- Some bremmstrahlung photons converted to e^+e^- pairs

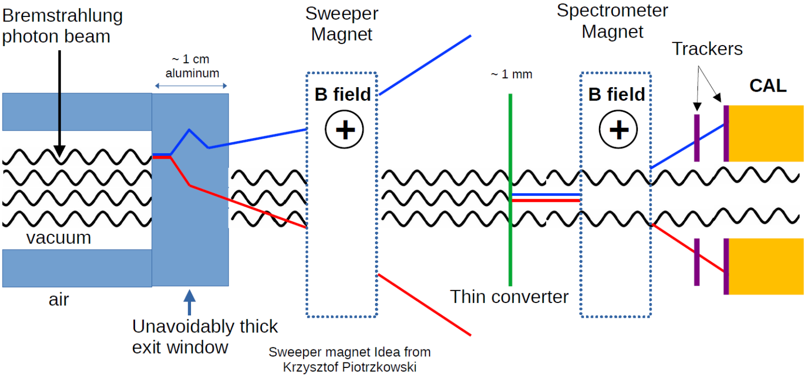


Figure - D. Gangadharan, University of Houston

Pair Spectrometer

- Conversion foil within vacuum pipe, between magnets

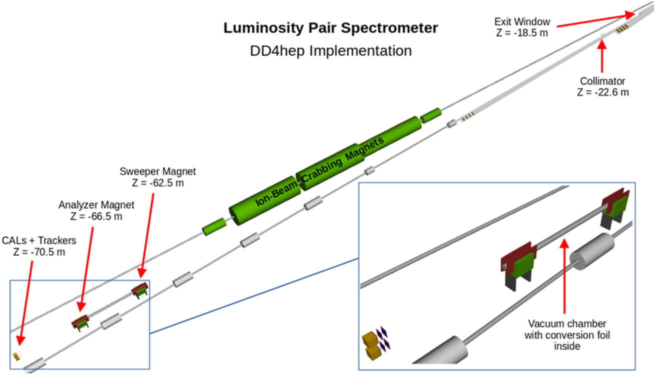


Figure - D. Gangadharan, University of Houston

Pair Spectrometer - Overview

- Based upon recent feedback from magnet designers, 1 Tm fields and 15 cm bore diameter possible
- New baseline design with sweeper magnet $\sim$ 65 m from IP
- See Dhevan's talk at 10:45 on 29/07/23 for more on this updated design!

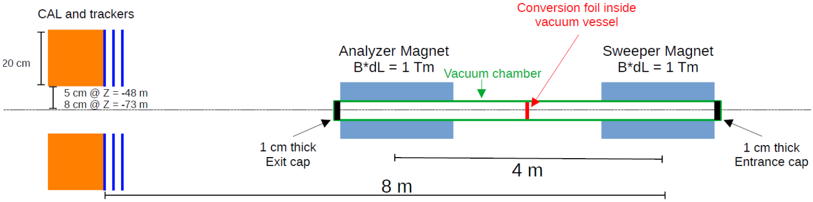
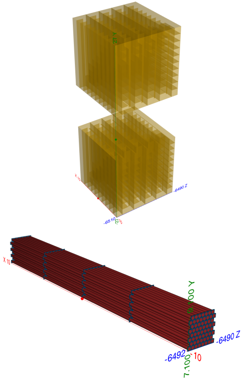


Figure - D. Gangadharan, University of Houston

Pair Spectrometer - Calorimeters, WSciFi

- Updated design - tungsten scintillating fiber calorimeter(WSciFi)
  - W powder and epoxy with embedded fiber grid
- Tweak volumetric ratio between W/SciFi to adjust many parameters
  - Radiation length
  - Molière radius
  - Sampling fraction
  - Energy resolution
- Studying new XY fiber design
  - 3D shower profile possible
  - Potential AI/ML applications



Figures - A. Giri, University of Houston

- See Aranya Giri's talk at 11:40 on 23/07/24 for more info and the latest on simulations!

Pair Spectrometer - Calorimeters, WSciFi

- Preliminary design ideas based upon sPHENIX calorimeters
- Recent R&D work by O.Tsai
  - doi:10.1088/1742-6596/404/1/012023
- Learn from this for ePIC lumical construction

- Beyond luminosity monitoring, FB detectors needed for some physics channels

Figure - doi:10.1088/1742-6596/404/1/012023

Far backward physics, quick examples

Far Backwards - Physics

- Far backward detectors also enable some unique physics measurements
- Meson spectroscopy
  - J/ψ, XY etc
- Example final state
  - J/ψ + π^+ + π^- + e' and nucleons
- Events at both low Q^2 and t
- $\int \mathcal{L}$ at EIC very high
  - Study rare exclusive processes, not accessible at HERA

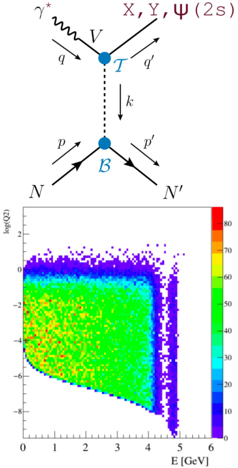
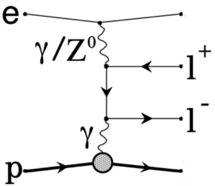


Figure - Igor Korover, MIT, ePIC Collaboration meeting January 2023

Far Backwards - Physics

- Dilepton production channels
  - Utilises FF and FB detectors



- FB taggers detect e'
  - $\pi - \theta_e <$1 mrad
- Scattered proton in FF
  - $\theta_p <$ 6 mrad
- All lepton pairs, $e^{\pm}$, $\mu^{\pm}$, $\tau^{\pm}$ can reach central detector

- Background for J/ψ or υ production
- $\mu^{\pm}$ sensitive to proton charge radius
- Opportunity for data-driven calibrations with two-photon exclusive processes

Figure - Igor Korover, MIT, ePIC Collaboration meeting January 2023

ePIC Low Q^2 Tagger

Low Q^2 Tagger - Overview/Positioning

- Two tagger detectors along outgoing e^- beam pipe
- Roughly -20 m and -36 m from IP

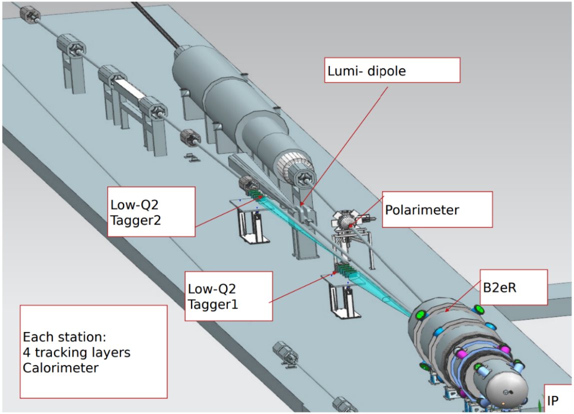
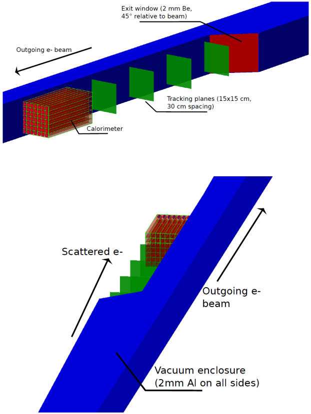


Figure - J. Adam, CTU Prague, ePIC Collaboration meeting July 2023

Low Q^2 Tagger

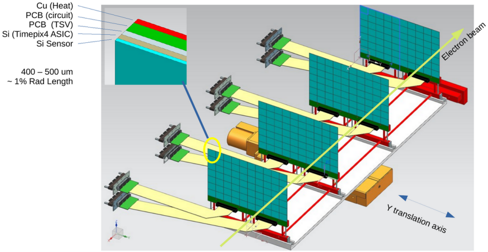
- Quasi-real tagging (low Q^2), $\theta_e < 10$ mrad
  - $Q^2 \sim 10^{-2}$ GeV^2
- Detector goals
  - Large acceptance ($> 10\%$)
  - Good energy resolution $\leqslant 1\%$
  - Reconstruction of scattering plane (polarisation)
- Two tagger modules
- Timepix4+SPIDR4 detectors
- Investigating neural networks for kinematic reconstruction



Figures - J. Adam, CTU Prague, ePIC Collaboration meeting July 2023

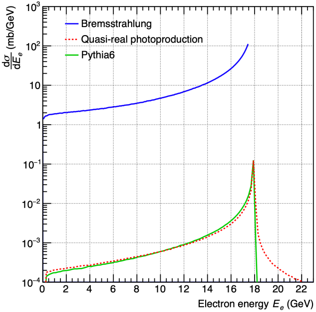
Low Q^2 Tagger - Detail

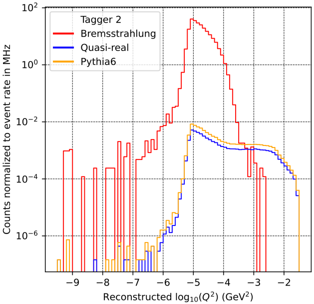
- 4 tracking layers per station, $\sim$ 30 cm apart
- Timepix4 + Si hybrids, 55x55 μm pixels, 448x512 pixels per sensor (6.94 cm^2)
- 2 ns timing resolution
- Singles rate capability high, $>$ 20 kHz per 55 μm pixel



Low Q^2 Tagger - Quasi Real Photoproduction

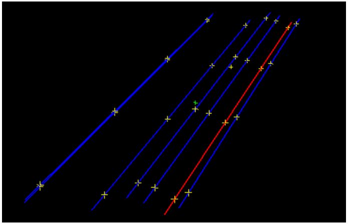
- Clean photoproduction signal over a limited region
  - $10^{-3} < Q^2 < 10^{-1}$ (GeV/c^2)
- Large background from Bethe-Heitler bremsstrahlung
  - High event rates
  - Mitigate with good tracking and Q^2 resolution



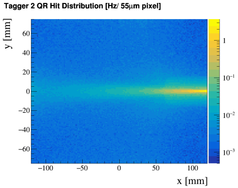


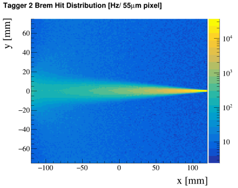
Low Q^2 Tagger - Reconstruction

- Typical bunch crossings at 18x275
  - ~12 electrons
  - ~7 accepted by tagger 2
  - 95% reconstruction efficiency



- Quasi-real e^- scattering event amongst bremsstrahlung e^-
- Max rate per pixel - ~20 kHz





Figures - S.Gardner, University of Glasgow, ePIC Collaboration meeting January 2023

Low Q^2 Tagger - Q^2 Reconstruction

- Two different ML algorithms give similar results
- Reconstruct tracks with e' kinematics
- Q^2 from e' energy and θ
- Compare to truth info in taggers and central detector

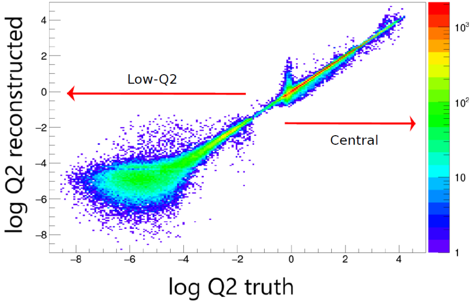
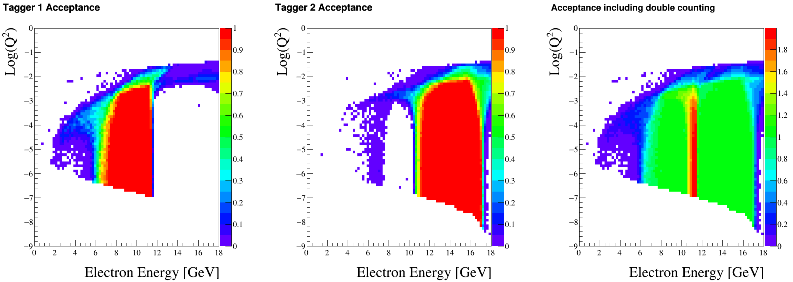


Figure - J. Adam, CTU Prague, ePIC Collaboration meeting July 2023

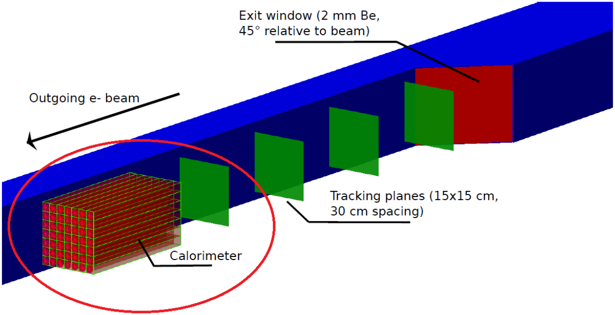
Low Q^2 Tagger - Acceptance

- Acceptance for each tagger station
- Overall acceptance, including double counting region
  - Double counting region only possible if both taggers in same vacuum
  - Also requires no calorimeter
  - Gap in acceptance if double counting region not available



Low Q^2 Tagger - Calorimeter

- For ePIC, calorimeter still in baseline design
  - Being costed
- Some open questions/challenges
  - Needs to handle very high rates
  - Taggers already provide very high resolution
    - Could degrade if exit windows too thick.



So, what could detector 2 do differently?

Detector 2 - Low Q^2 Tagger - Ideas/Options

- Include the low Q2 tagger calorimeter
  - "Distinctive" if ePIC drops the low Q^2 tagger calorimeters
  - Need to decide if this is "worth" doing or not in either case
- Decision between in/out of vacuum is a big one
  - Det2 could deliberately go the other way
- Try to bridge the acceptance gap in e' energy and Q^2 reach between central detector and low Q^2 tagger
  - More on this in the next talk!
- Acceptance gap is consequence of the magnet configuration and arrangement
  - Low energy e^- are bent into the dipoles
  - Low(ish) Q^2 e^- go into the beampipe
- Broad solutions to this include
  - A "B0" equivalent, a detectors inside the magnet
  - A beampipe with a significantly larger radius
  - Neither option is straightforward

Detector 2 - Low Q^2 Tagger - Ideas/Options

- To improve high energy acceptance, get detectors as close to the beam as possible
  - Challenging! Radiation environment, vacuum, detector access concerns...
  - If this is worked in early, more likely
  - Integrated active/passive radiation monitoring critical
- For some physics channels, filling the acceptance gap between Q^2 0.1 and 0.01 is very important
- For others channels, getting lots of events with energies as close to the beam energy is more crucial
  - Lots of events near threshold
  - These events have zero energy γ
  - This would again, likely mean detectors within the beamline vacuum

Summary

- Far backward detectors vital for luminosity monitoring and for some physics measurements
- ePIC luminosity monitoring systems in advanced stage of development
  - Pair spectrometer R&D testing very soon!
  - Need complementary independent detectors at IP8?
- ePIC low Q^2 tagger design progressing
  - Calorimeter or not?
  - In or out of vacuum?
  - Exit window materials?
- Prospects for detector 2 strongly dependent upon final IP design
  - Change the shape of the beampipe?
  - Detector in beampipe?
  - Taggers closer to beampipe?

Thanks for listening, any questions?

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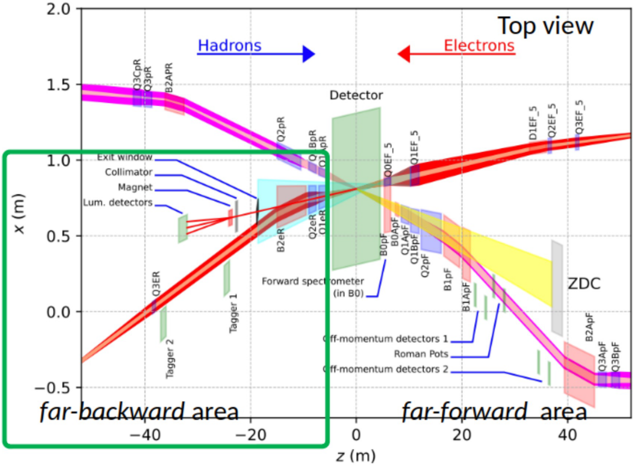
Backup Zone

IP6 Overview



Luminosity Requirements and Systematics

- Yellow Report Requirements
  - $\sim$1% uncertainty for absolute luminosity
  - Less than 10^{-4} for relative luminosity
- Compare to Zeus lumi systematics

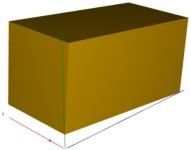
Component	**Sub-Component systematics**	**ePIC Improvements**
Acceptance (**1.6%: Total**)	1.0%: Aperture and detector alignment	5σ obstruction free aperture. Low lumi runs with coincidences of low-Q^2 tagger and pair spec
	1.2%: X-position of photon beam	
Photon conversion in exit window (**0.7%: Total**)	0.1%: Thickness	
	0.3%: chemical composition	
	0.6%: photon conversion cross section	
RMS-cut correction (**0.5%: Total**)	Rejection of proton gas interactions	Greatly reduced for ePIC – trackers with good pointing resolution
Total	**1.8%**	

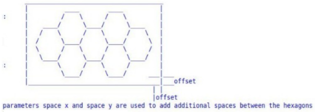
- With reductions, 1% absolute lumi precision within reach

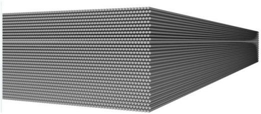
Luminosity Requirements and Systematics

- Latest design - spaghetti calorimeter (fiber based)
- Inclined to avoid events directly hitting (and propagating along) direction of fiber

5 degree







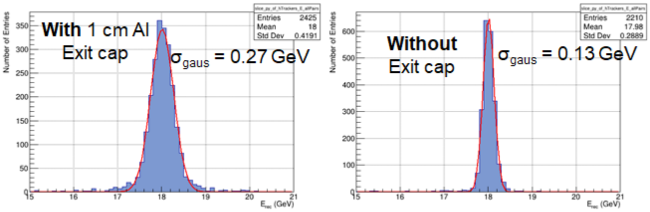
Figures - Yasir Ali, AGH UST, Krakow (modified)

Pair Spectrometer - General Requirements

- Exit window and conversion foils
  - Well known composition and thickness of exit window and conversion foils
    - Foil needs to withstand heat load!
- Sweeper and analyser magnets
  - $BdL \approx 1\ \mathrm{Tm}$, compact system, $\sim 15\ \mathrm{cm}$ bore diameter
    - Allows placement far from central region
  - Small fringe fields
  - Good vacuum for minimal air conversions
- Calorimeter
  - $17\%/\sqrt{E}$ energy resolution sufficient
    - Based upon ZEUS experience
  - Segmented readout, disentangle pileup
  - $\sim$ ns timing resolution, bunch-by bunch $\mathcal{L}$

Pair Spectrometer - Trackers

- Trackers could be used to obtain $\sim 1\%$ energy resolution
- Resolution strongly affected by end cap thickness and material
- Excellent tracking possible
  - Excellent energy resolution
  - Excellent pointing resolution
- Still need to choose technology, same as Low Q^2 tagger



Figures - D. Gangadharan, University of Houston

Pair Spectrometer

- Conversions in air before pipe, negligible effect
    - $< 0.02\%$ contribution to systematics

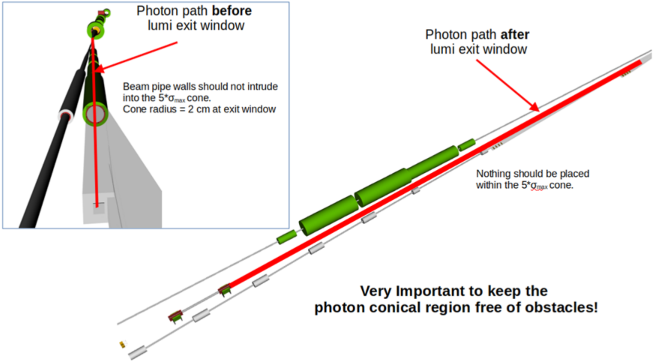
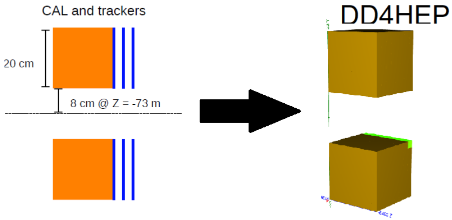


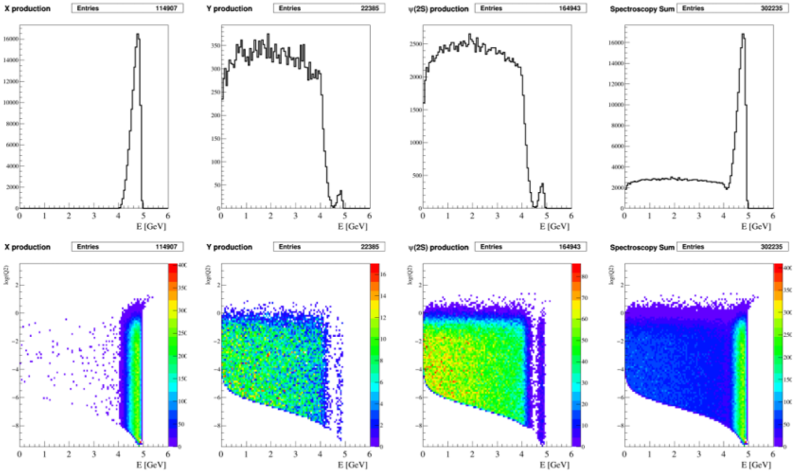
Figure - D. Gangadharan, University of Houston

Pair Spectrometer - Calorimeters

- Calorimeter is fairly simple design
  - Two $\sim 20\mathrm{cm}^3$ calorimeters
  - Vertically separated from direct γ, $\pm 5\sigma$
- Current baseline design in ePIC DD4HEP simulation uses segmented $PbWO_4$ calorimeters
- See talk by Aranya Giri at 11:40 on 23/07/24 for more info and the latest on simulations!



Far Backwards - Physics, Spectroscopy Distributions



Figures - D. Glazier, University of Glasgow