ePIC Far Backward Detector Systems

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University of York

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06/08/24

The EIC and ePIC

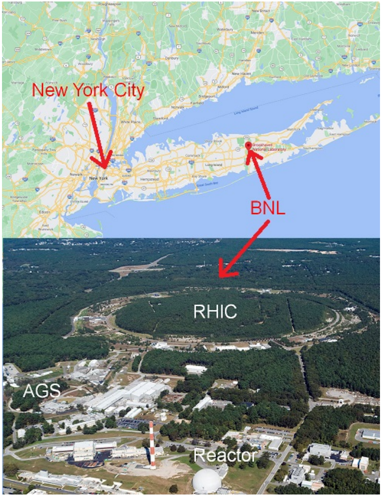

Figure - Brookhaven National Lab, `https://www.flickr.com/photos/brookhavenlab/` and Google Maps

- EIC is an upcoming (∼2030) accelerator based at BNL

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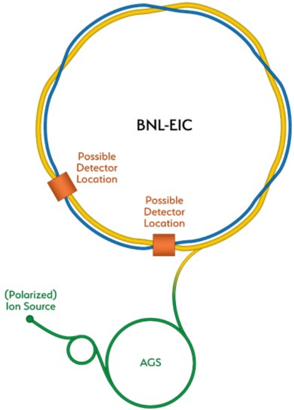

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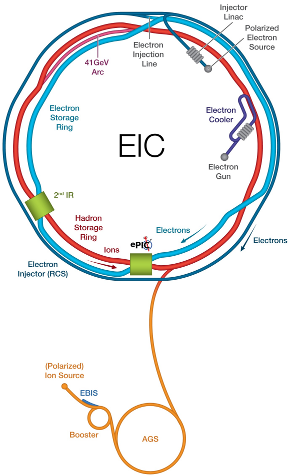

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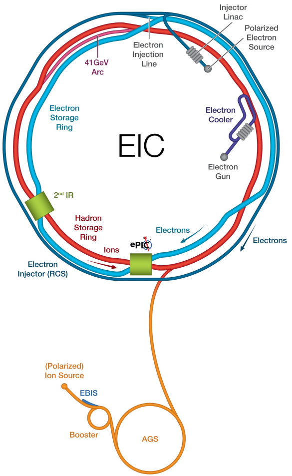

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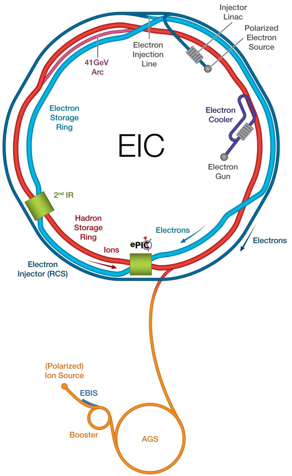

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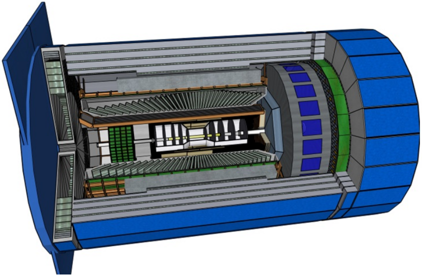
- Project detector → ePIC
  - **E**lectron-**P**roton/**I**on **C**ollider (ePIC)

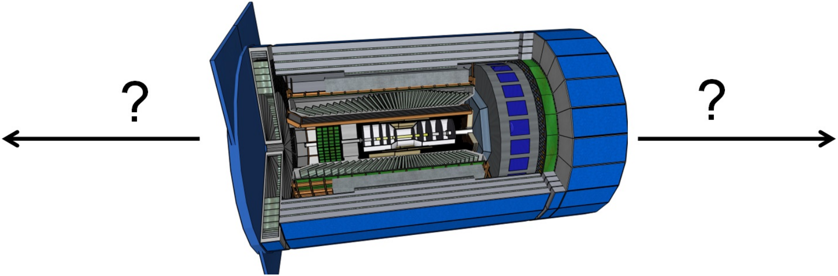
ePIC Detector

- Our “normal” picture of ePIC is something like this



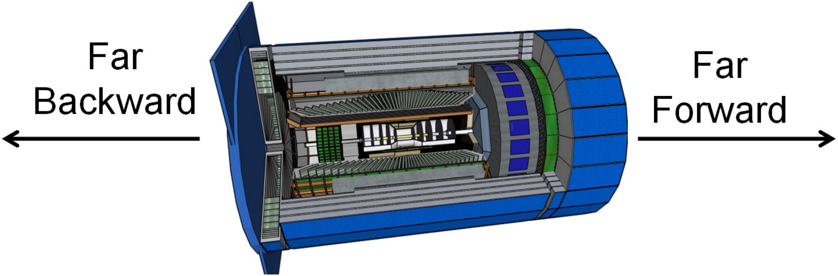
ePIC Detector

- But, this is just the central detector...



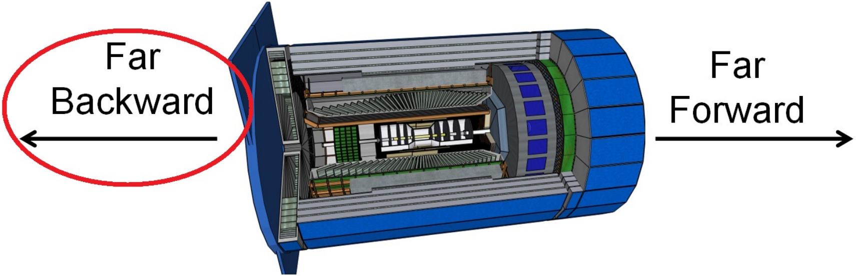
ePIC Detector

- Far forward (FF) and far backward (FB) detectors too!



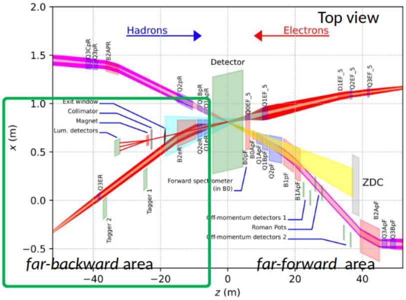
ePIC Detector

- Will focus on the FB region



Far Backward Region

- Relatively simple, but very important, set of detectors systems in this region



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

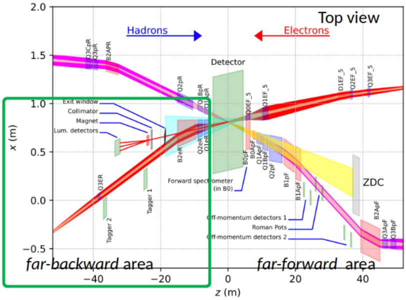
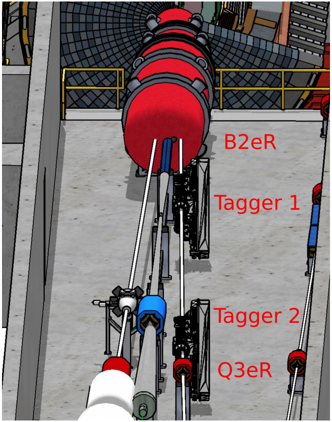


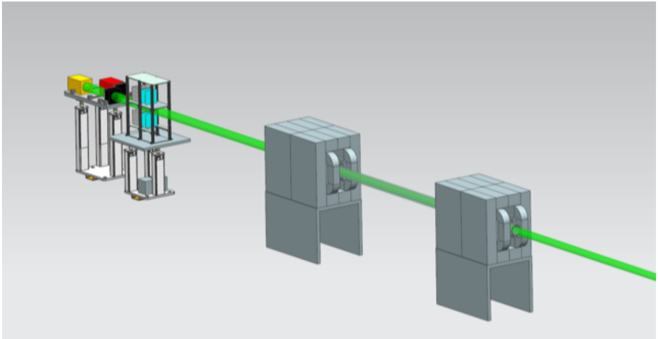
Figure - Igor Korover, MIT, ePIC Collaboration meeting January 2023



Luminosity monitoring systems for ePIC

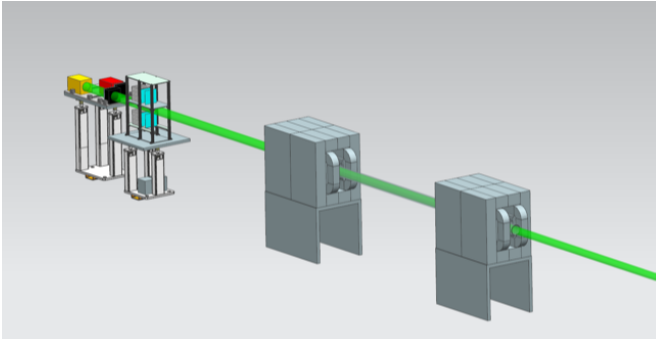
Far Backward - Luminosity Monitors

- Luminosity → normalisation for all physics studies



Far Backward - Luminosity Monitors

- Luminosity → normalisation for all physics studies
  - Absolute cross sections
  - Combining run periods
  - Asymmetry measurements
    - Relative luminosity of different bunch crossings



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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%**	

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- With reductions, 1% absolute lumi precision within reach

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- Use bremsstrahlung process to measure luminosity

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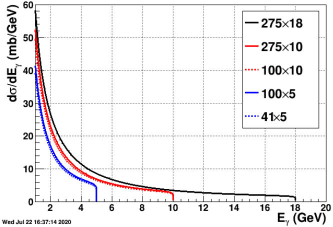

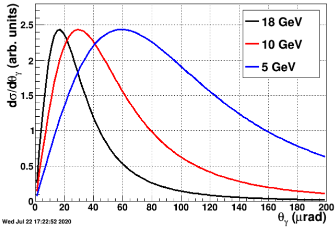

Figures - EIC Yellow Report - Section 11.7.1, p575

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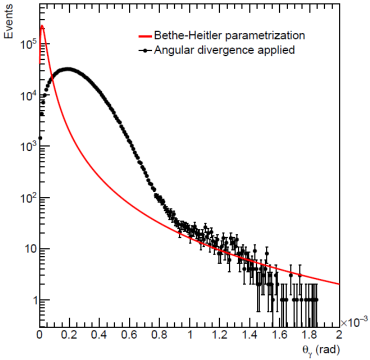

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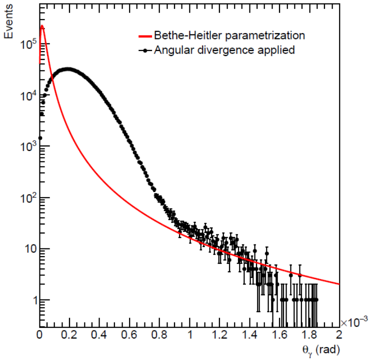
  - **D**irect **P**hoton **D**etector (High rate calorimeter)
  - **P**air **S**pectrometer



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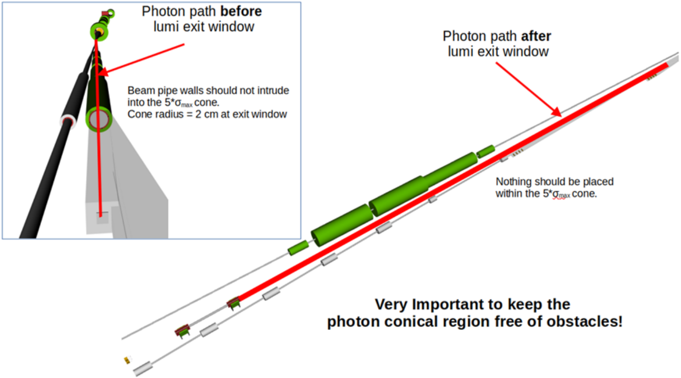
- Use a complementary **P**air **S**pectrometer too

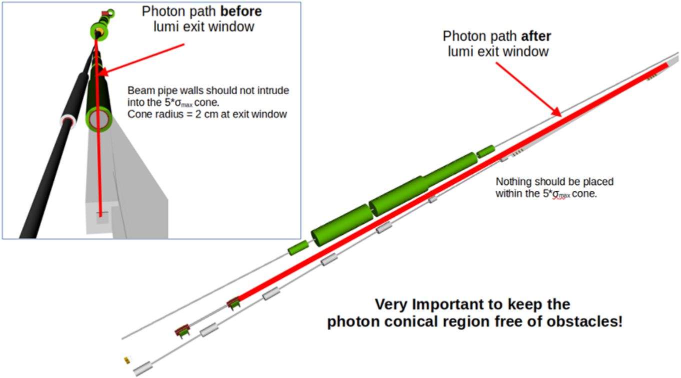
Luminosity Monitoring Region



Figures - D. Gangadharan, University of Houston

Luminosity Monitoring Region

- Conversions in air before vacuum pipe, negligible effect



Figures - D. Gangadharan, University of Houston

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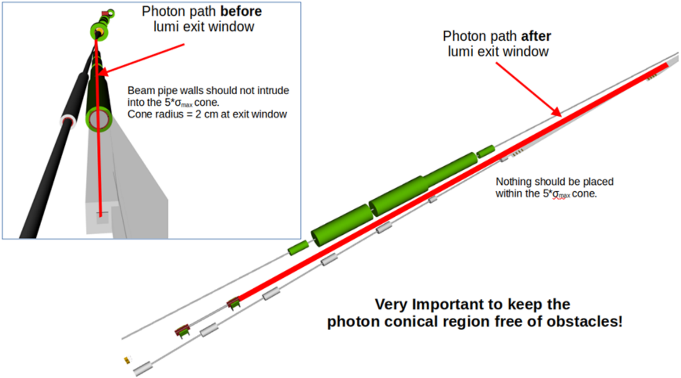
  - $< 0.02\%$ contribution to systematics



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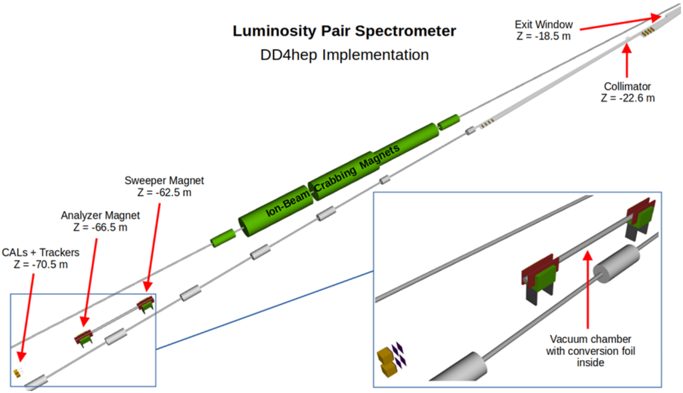
- Conversion foil within vacuum pipe, between magnets



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Direct Photon Detector

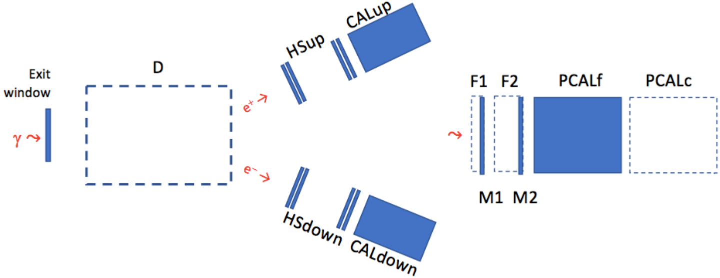

Figure - J. Nam, Temple University, ePIC Collaboration meeting January 2023

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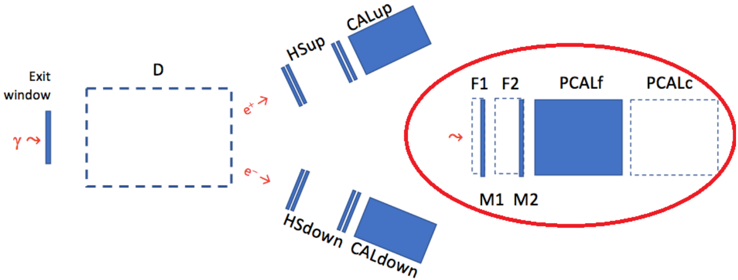

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Direct Photon Detector

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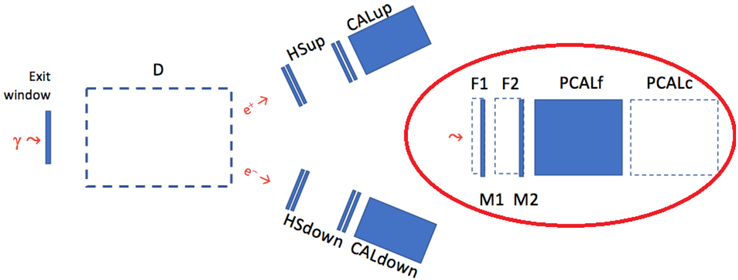

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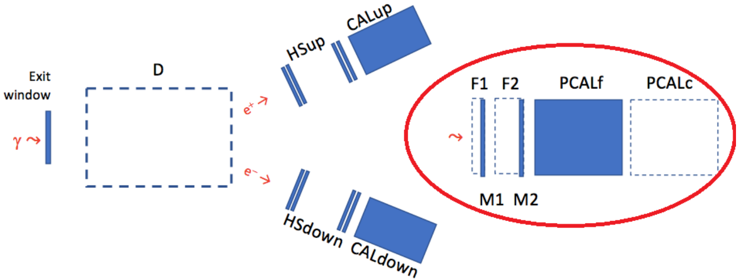

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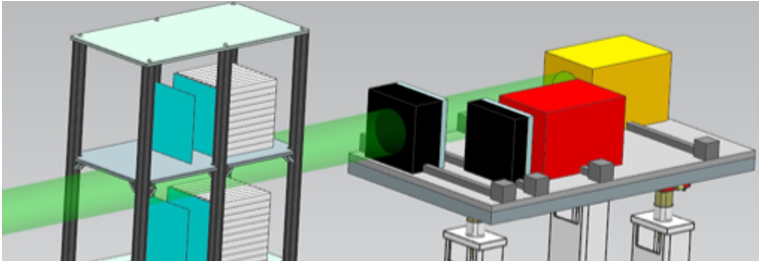
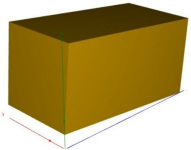
- For 18 GeV e^{-}, may need $\sim$35 cm graphite absorbers to absorb synchrotron radiation
- Paper on radiation studies in preparation

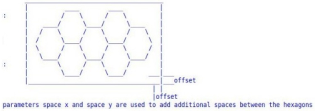


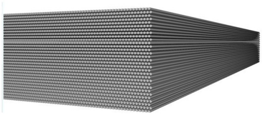
Direct Photon Detector - Details

- Latest design - spaghetti calorimeter (quartz fiber based)

5 degree







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

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- Inclined to avoid events directly hitting (and propagating along) direction of fiber

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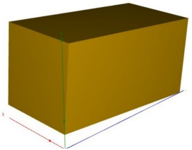

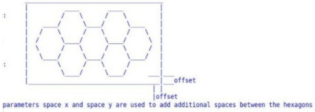

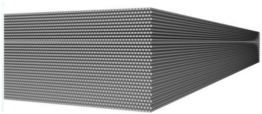

Pair Spectrometer Overview

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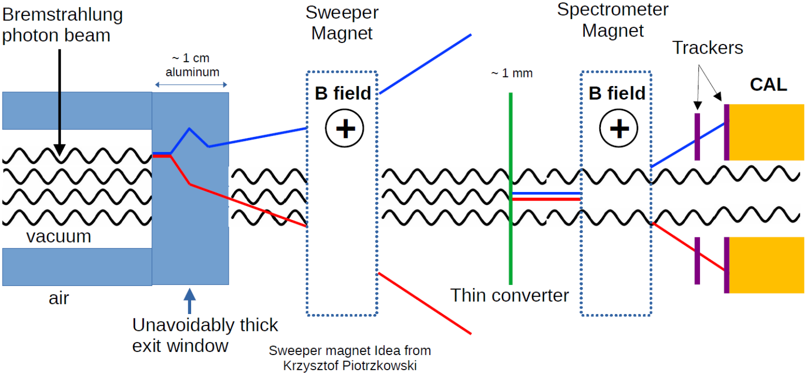

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  - Segmented readout, disentangle pileup
  - $\sim$ ns timing resolution, bunch-by bunch $\mathcal{L}$

Pair Spectrometer - Magnet Design and Positioning

- Based upon recent feedback from magnet designers, 1 Tm fields and 15 cm bore diameter possible

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- New baseline design with sweeper magnet $\sim$ 65 m from IP

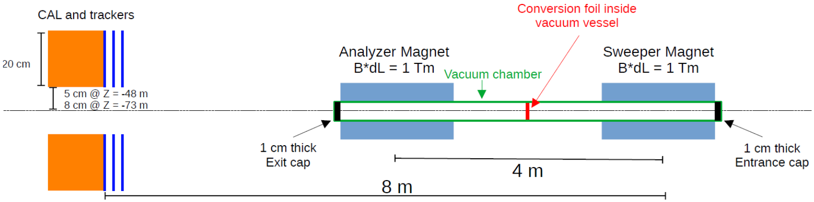
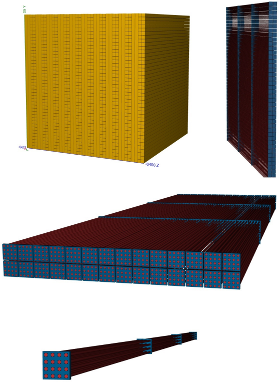


Figure - D. Gangadharan, University of Houston

- Updated design - tungsten scintillating fiber calorimeter (WSciFi)



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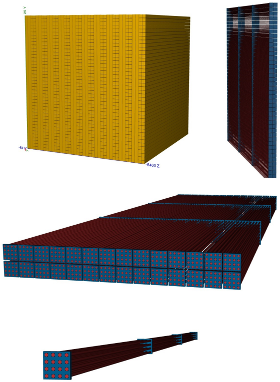

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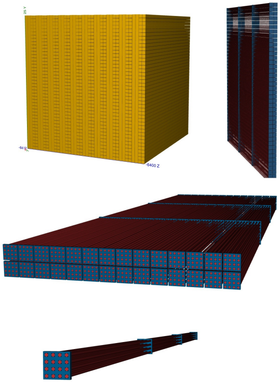

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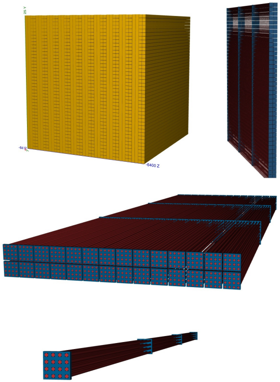
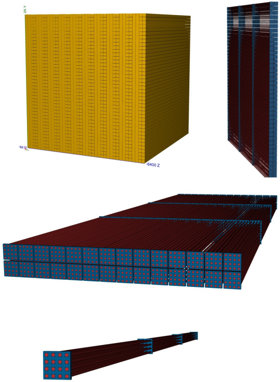
- XY orientated fiber design



Pair Spectrometer - Calorimeters, WSciFi

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



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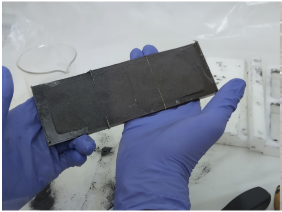
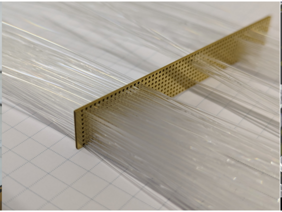
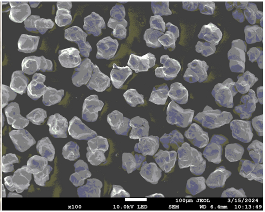

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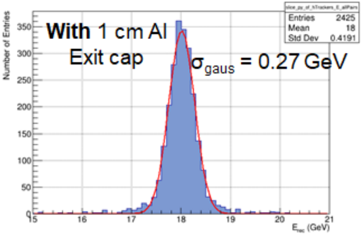

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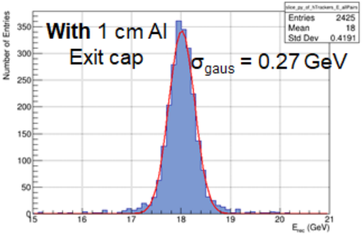

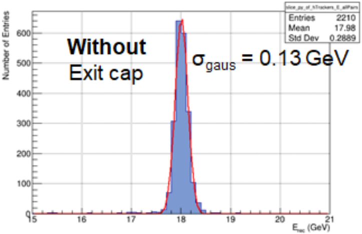

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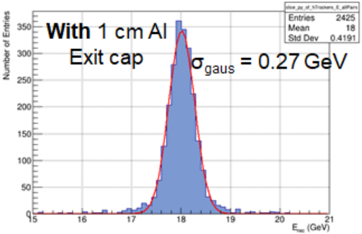
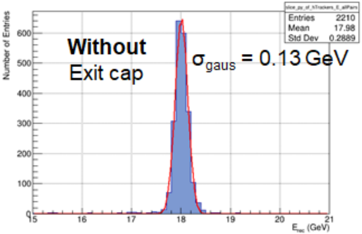
- Likely AC-LGAD pixel detector
  - Synergy with other systems using this technology

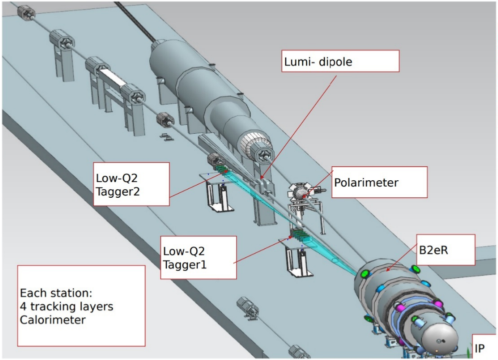




ePIC Low Q^2 Tagger

Low Q^2 Tagger - Overview/Positioning

- Two tagger detectors along outgoing e^- beam pipe



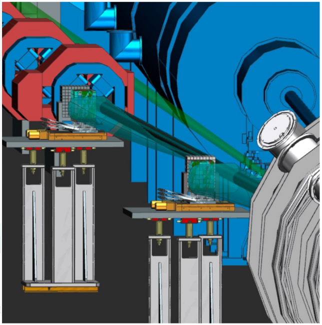


Figure - J. Adam, CTU Prague, ePIC Collaboration meeting July 2023, S. Gardner, University of Glasgow, EIC UK Meeting 2024

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- Two tagger detectors along outgoing e^- beam pipe
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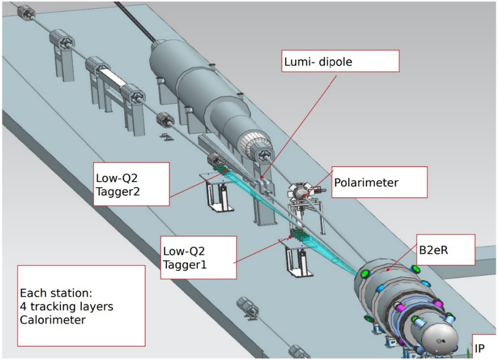

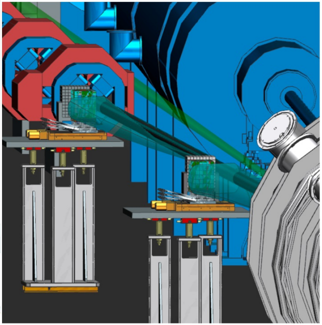

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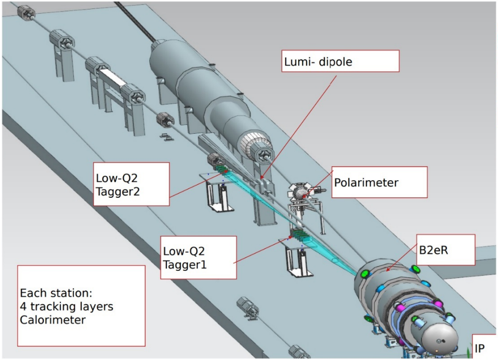
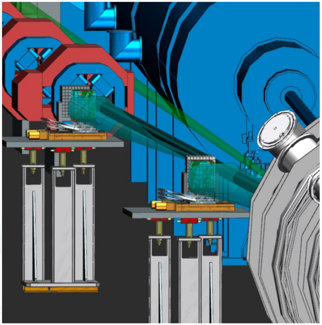
- Integration with beamline/beampipe **critical**





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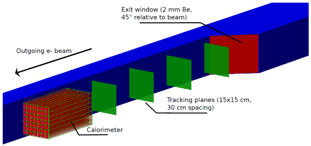

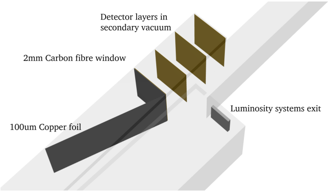

Figures - J. Adam, CTU Prague, ePIC Collaboration meeting July 2023, S. Gardner, University of Glasgow

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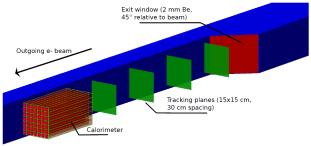
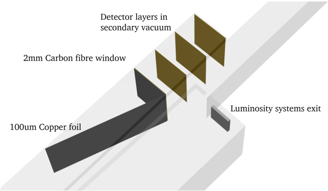
- Investigating neural networks for kinematic reconstruction





Low Q^2 Tagger - Tracking Station Details

- 4 tracking layers per station, $\sim$ 30 cm apart
- Timepix4 + Si hybrids, 55x55 μm pixels, 448x512 pixels per sensor (6.94 cm^2)

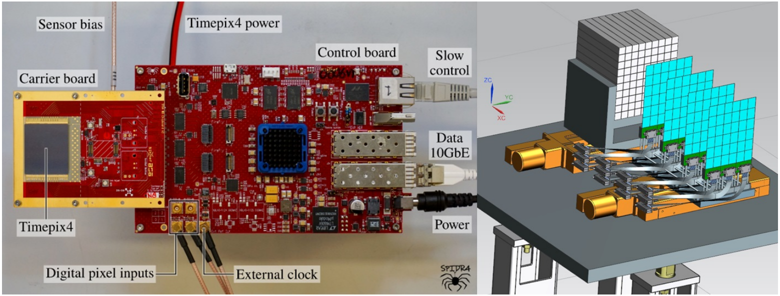


Figure - S.Gardner, University of Glasgow, EIC UK Meeting 2024

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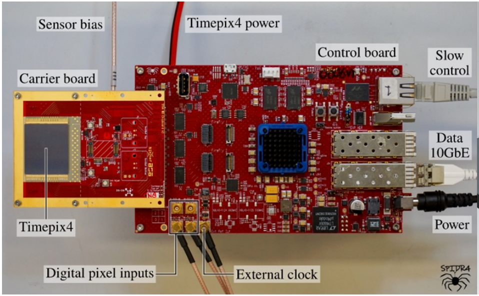
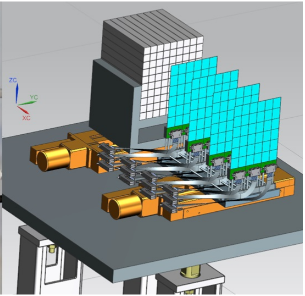
- 2 ns timing resolution
- Singles rate capability high, $>$ 20 kHz per 55 μm pixel





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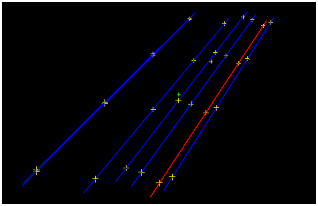

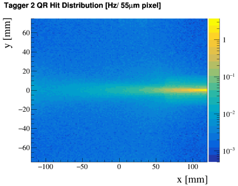

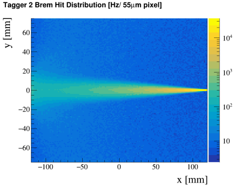

Figures - S.Gardner, University of Glasgow, ePIC Collaboration meeting January 2023

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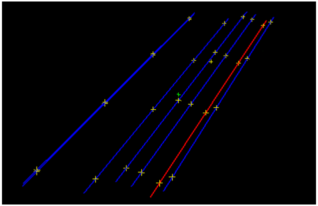
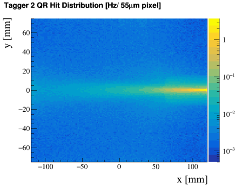
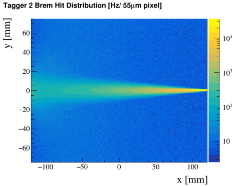


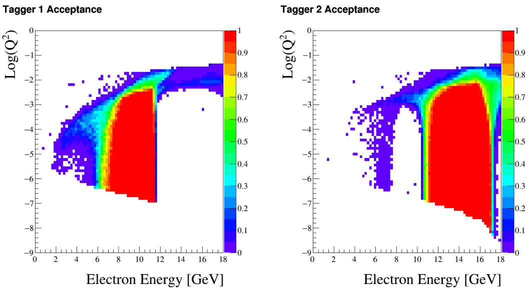




- Quasi-real e^- amongst bremsstrahlung e^-
- Max rate per pixel - $\sim$20 kHz

Low Q^2 Tagger - Acceptance

- Acceptance for each tagger station



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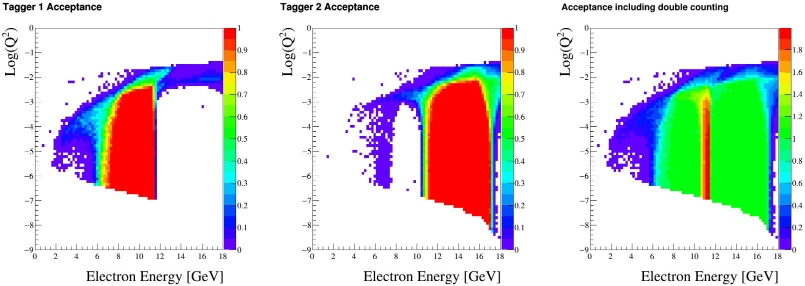

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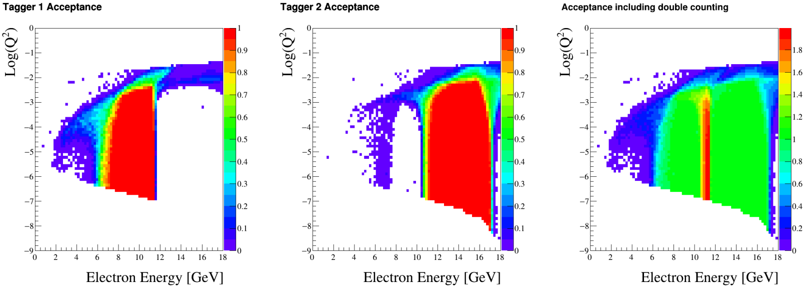
  - Also requires no calorimeter
  - Gap in acceptance if double counting region not available



Far backward physics, quick examples

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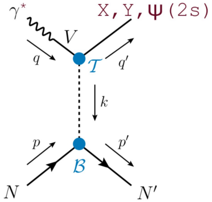

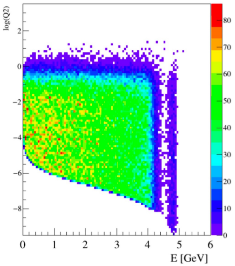

Figures - Igor Korover, MIT, ePIC Collaboration meeting January 2023

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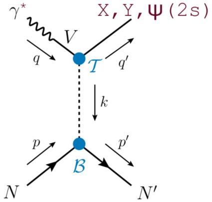

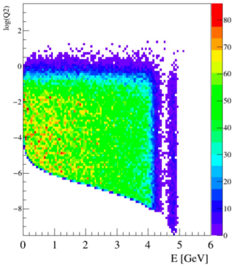

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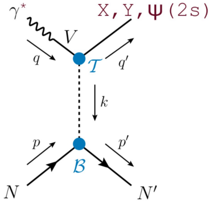
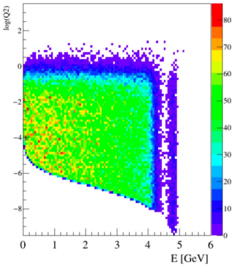
- $\int \mathcal{L}$ at EIC very high
  - Study rare exclusive processes, not accessible at HERA





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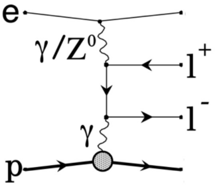

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Figure - Igor Korover, MIT, ePIC Collaboration meeting January 2023

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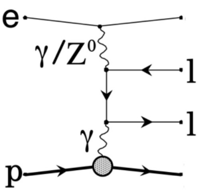

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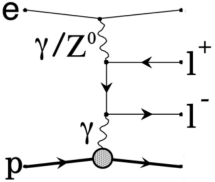

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- Background for J/ψ or υ production
- $\mu^{\pm}$ sensitive to proton charge radius
- Opportunity for data-driven calibrations with two-photon exclusive processes

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  - Detailed simulations for beamline integration ongoing
  - Calorimeter incorporation under assessment

Thanks for listening, any questions?

Science and Technology Facilities Council

stephen.kay@york.ac.uk

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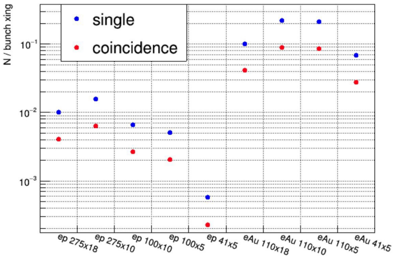
Backup Zone

Pair Spectrometer - Expected Rates

- Expected signal rates using nominal $\mathcal{L}$, accounting for -

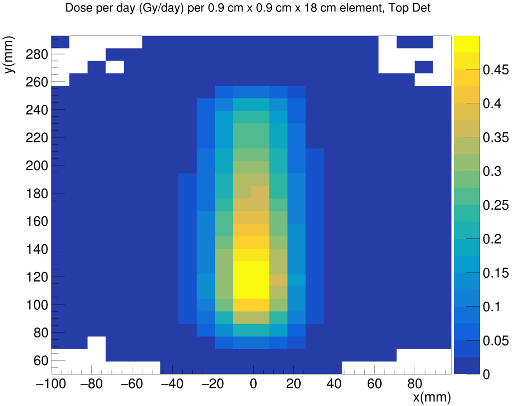
- 1 cm conversion at exit window, (9% conversion probability, swept away
- 37 m air, 9% conversion, swept away
- 1 cm Al vacuum chamber entrance cap, 9% conversion, swept away
- 1 mm Al conversion foil, 1%, detected in pair spec



- At most, $\sim$ 0.2 electrons per bunch crossing on average

Pair Spectrometer - Radiation Dose

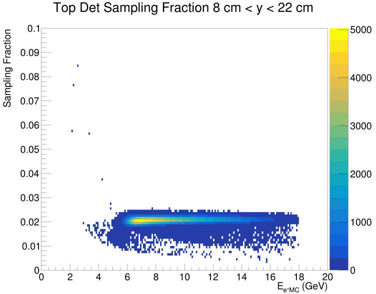
- Using DD4HEP simulation, evaluated dose
- In highest rate config, max fiber dose $\sim$ 1 MGy/100 fb^{-1}
- Dose is predominantly along a strip in middle of detector



Pair Spectrometer - Sampling Fraction

- Sampling fraction strongly depends upon W:SciFi ratio

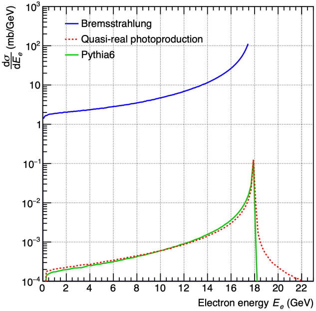
- 4 : 1 W:SciFi ratio in current design
- Yields ∼2% sampling fraction
- ∼18 cm×18 cm×18 cm detector
- $\sim 23X_0$
  - $X_0 \sim 8$ mm

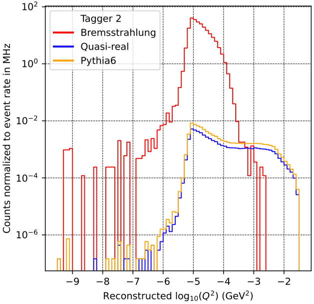


- Can quickly tweak design and re-evaluate sampling fraction and energy/position resolution with DD4HEP simulation

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 - 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

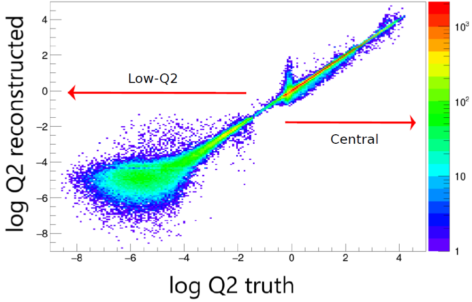
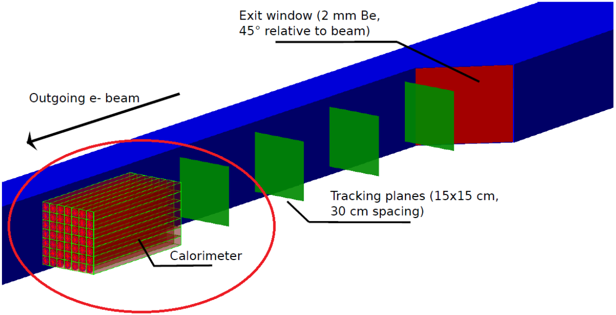


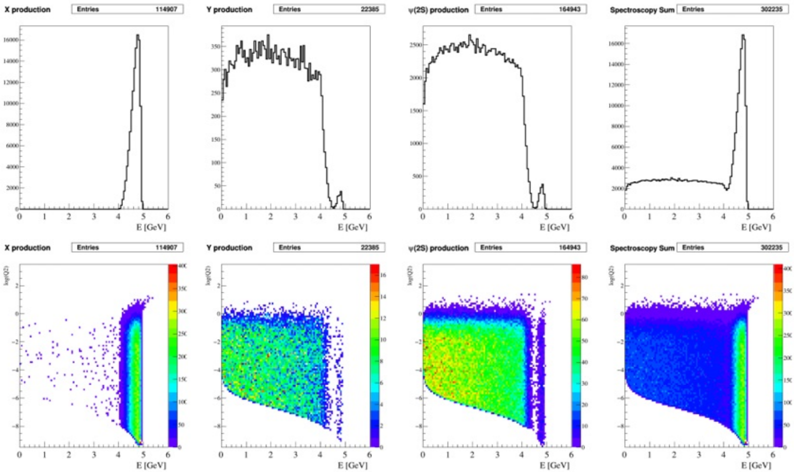
Figure - J. Adam, CTU Prague, ePIC Collaboration meeting July 2023

Low Q^2 Tagger - 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.



Far Backwards - Physics, Spectroscopy Distributions



Figures - D. Glazier, University of Glasgow

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