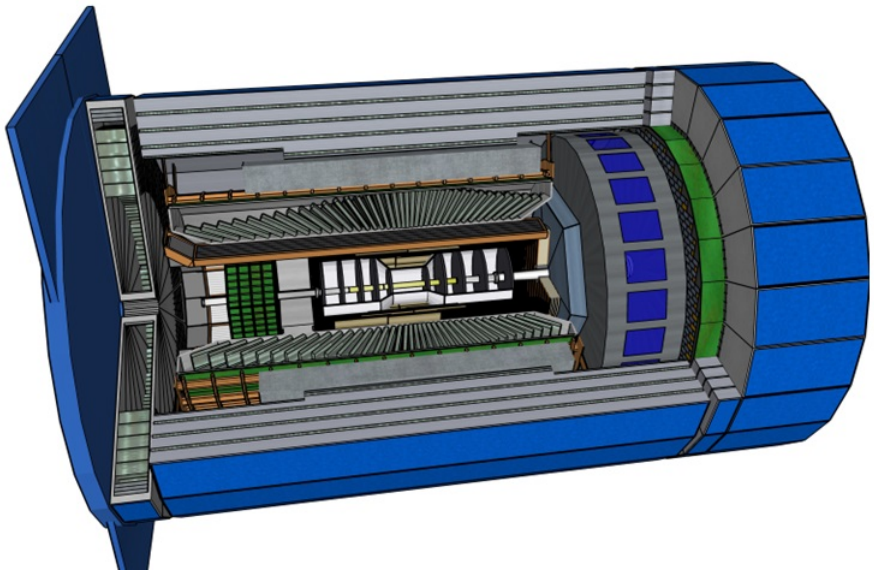
ePIC Luminosity Monitoring Systems

Stephen JD Kay
University of York

EIC UK 2025
09/12/25

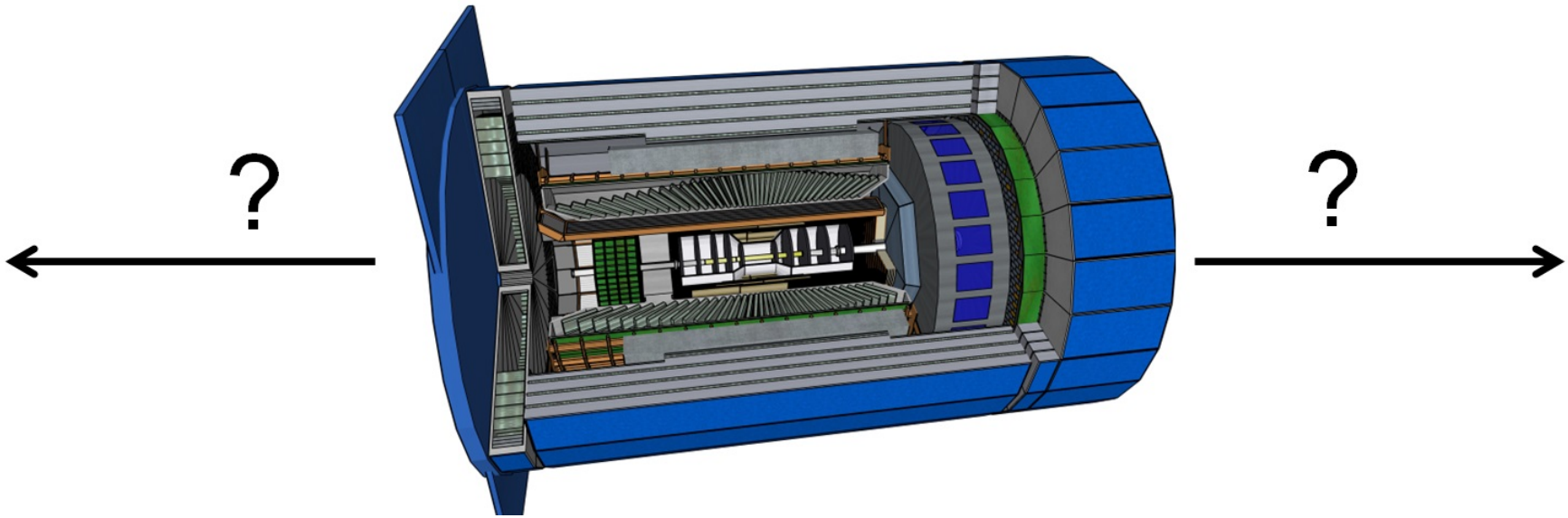
ePIC Detector

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



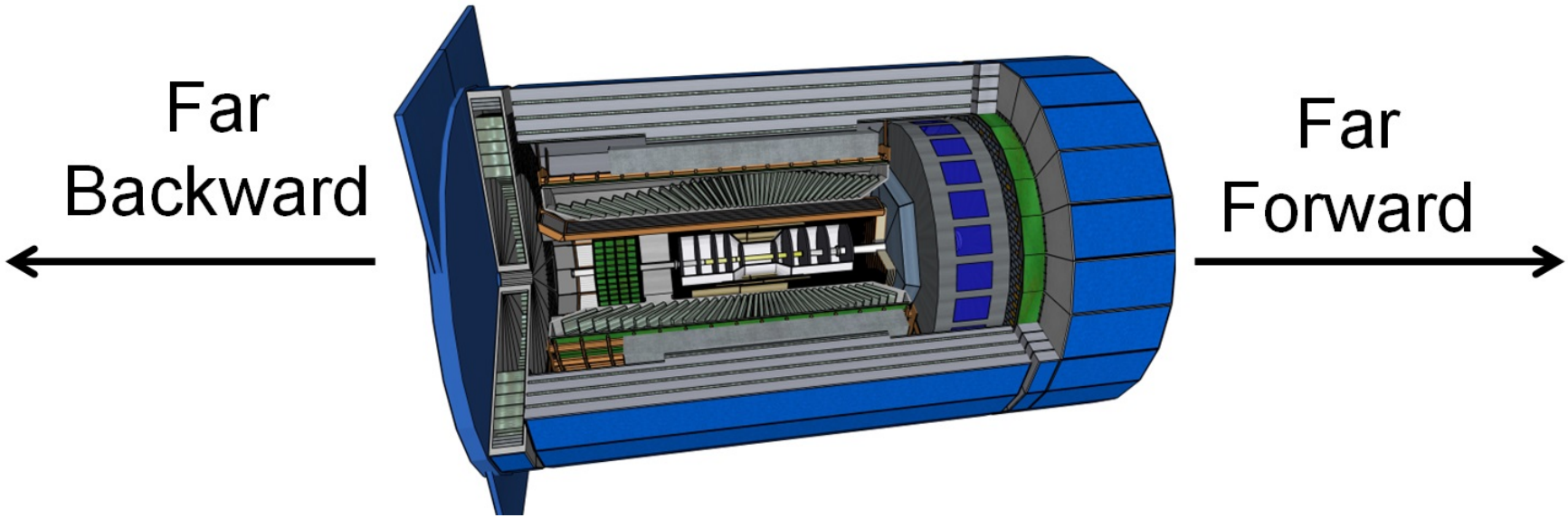
ePIC Detector

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



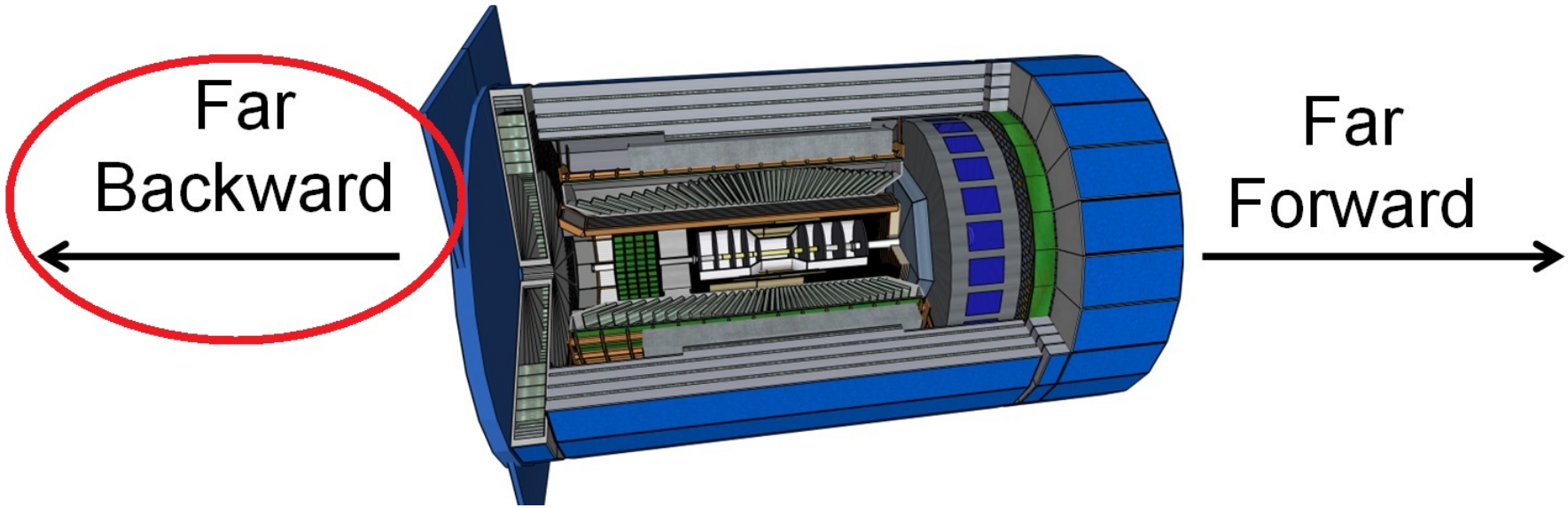
ePIC Detector

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



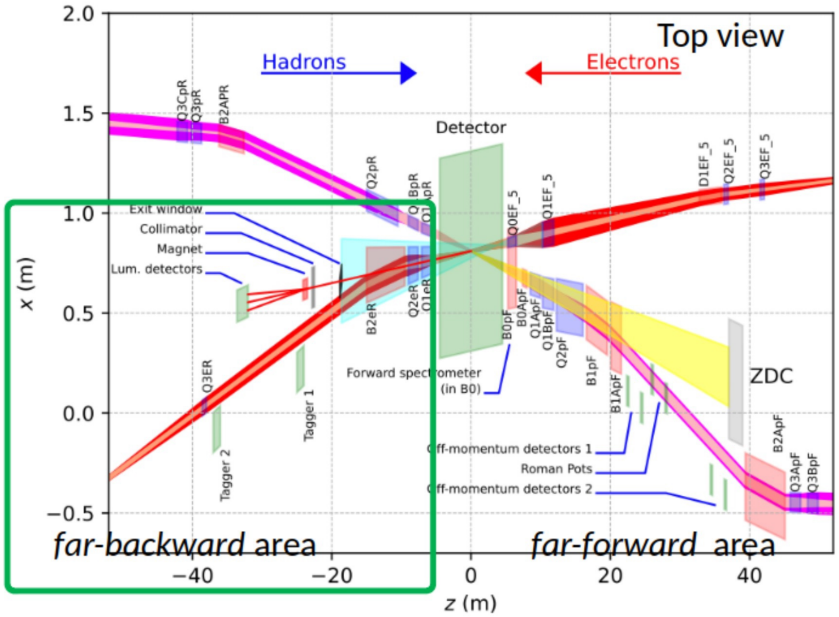
ePIC Detector

- Lots of UK involvement in the FB region!



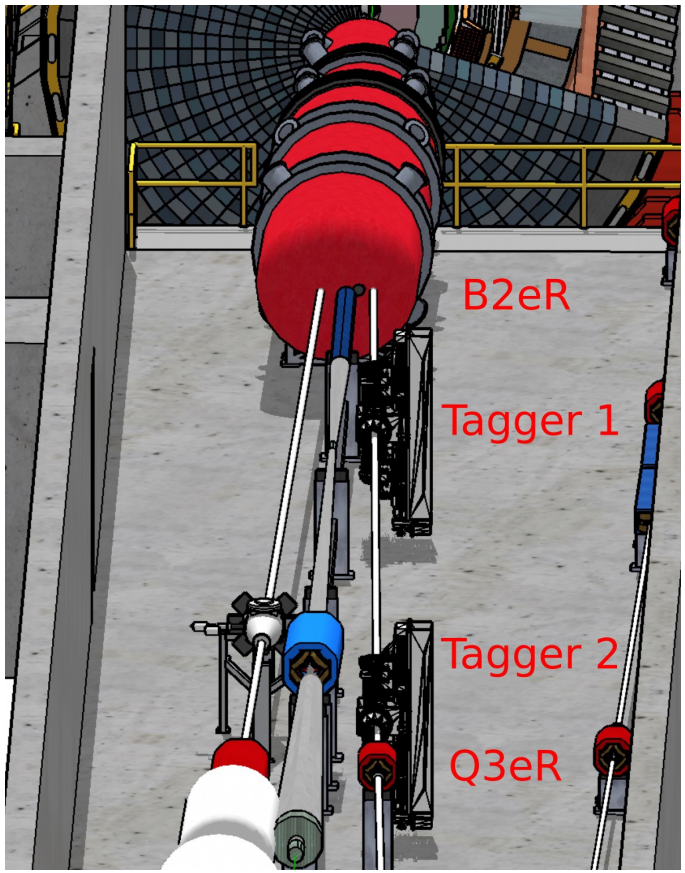
Far Backward Region

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



Far Backward Region

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



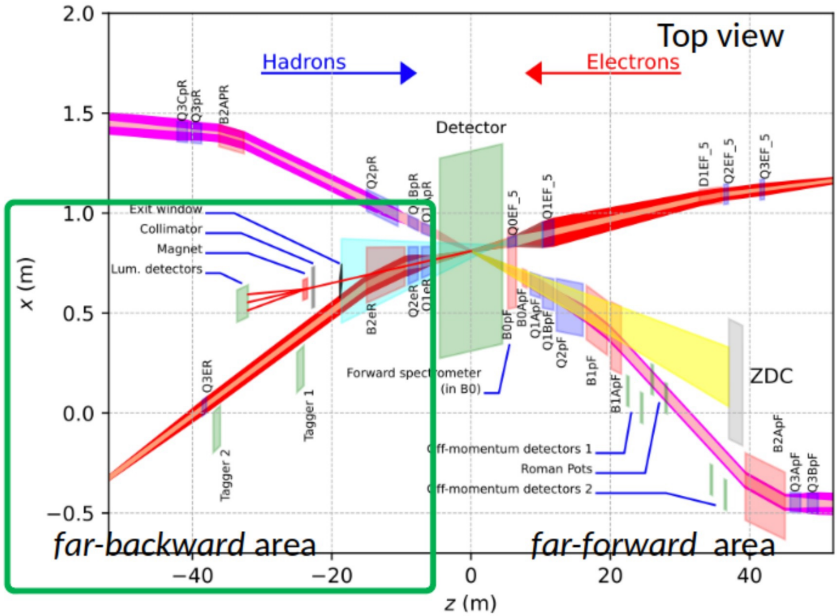
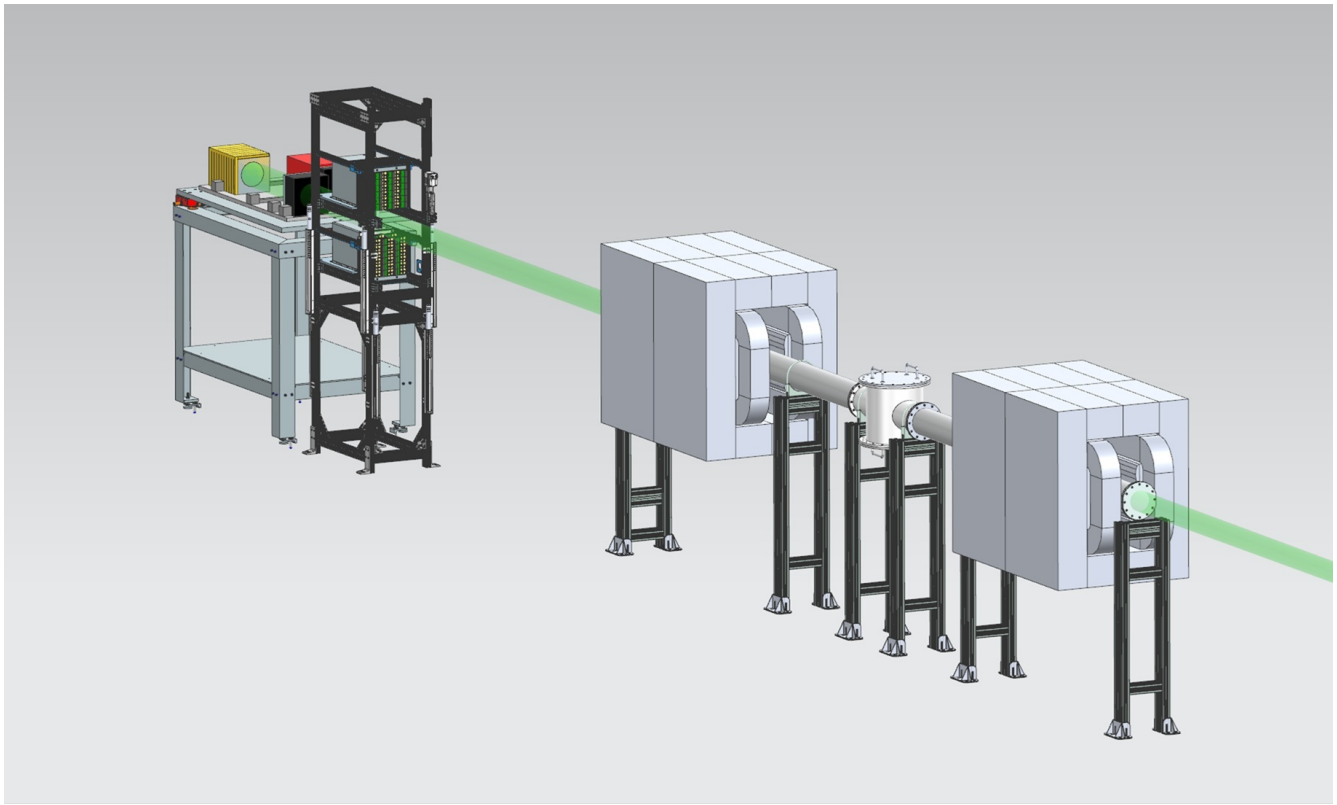


Figure - Igor Korover, MIT, ePIC Collaboration meeting January 2023

Far Backward - Luminosity Monitors



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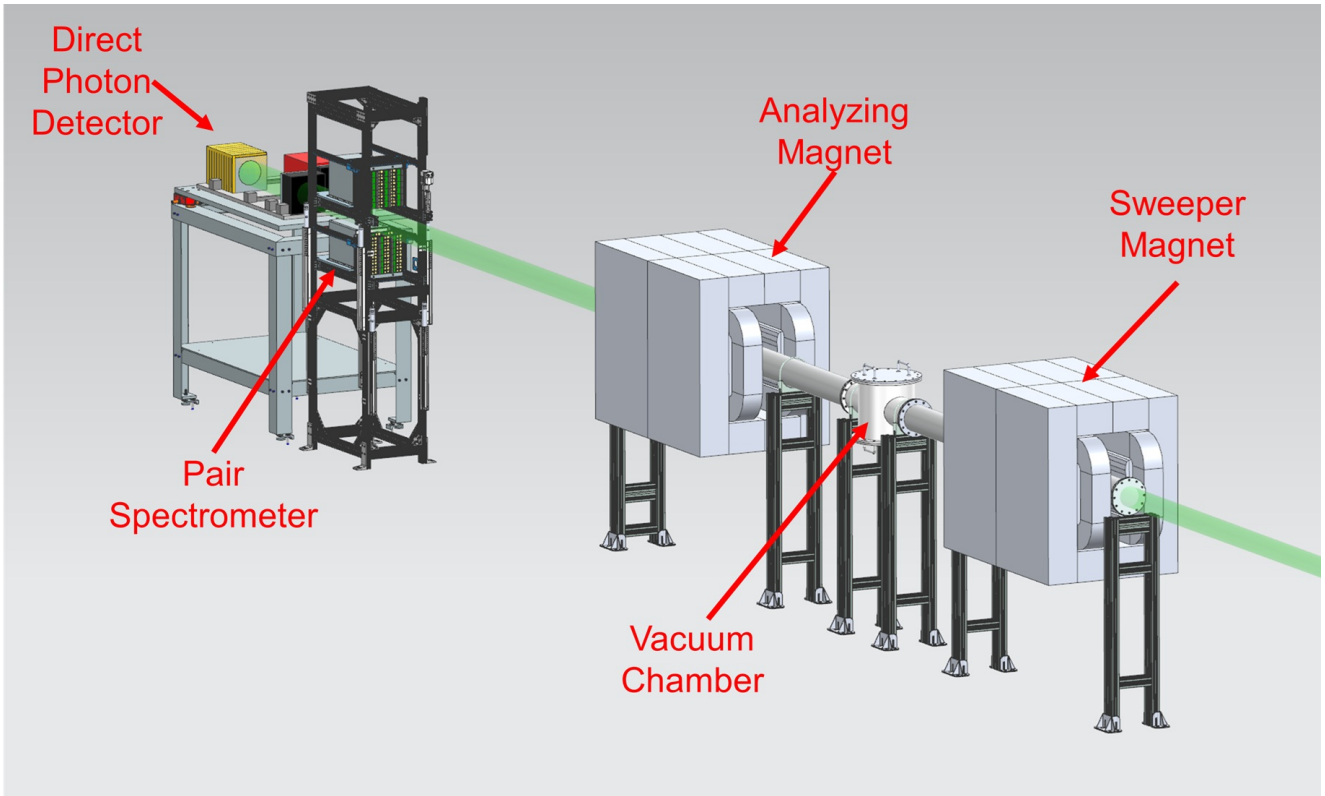
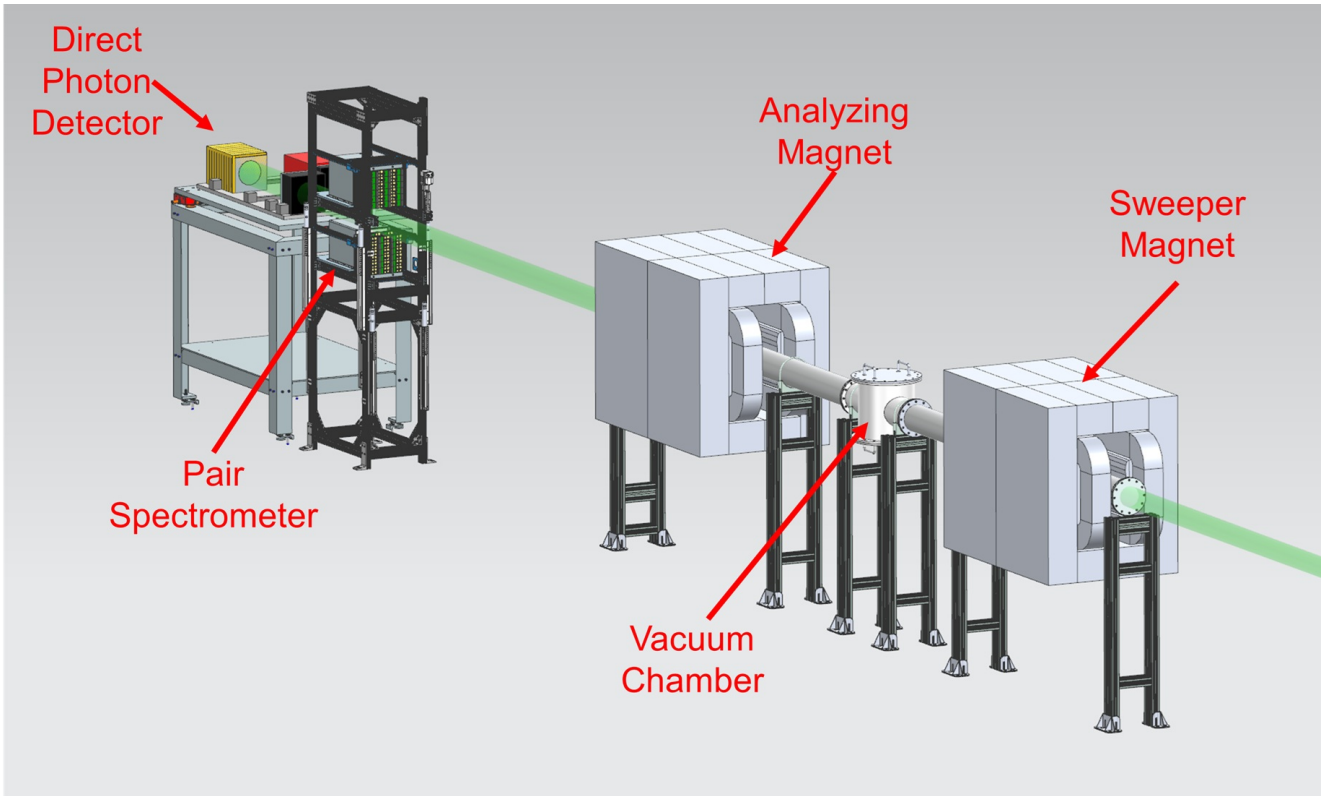


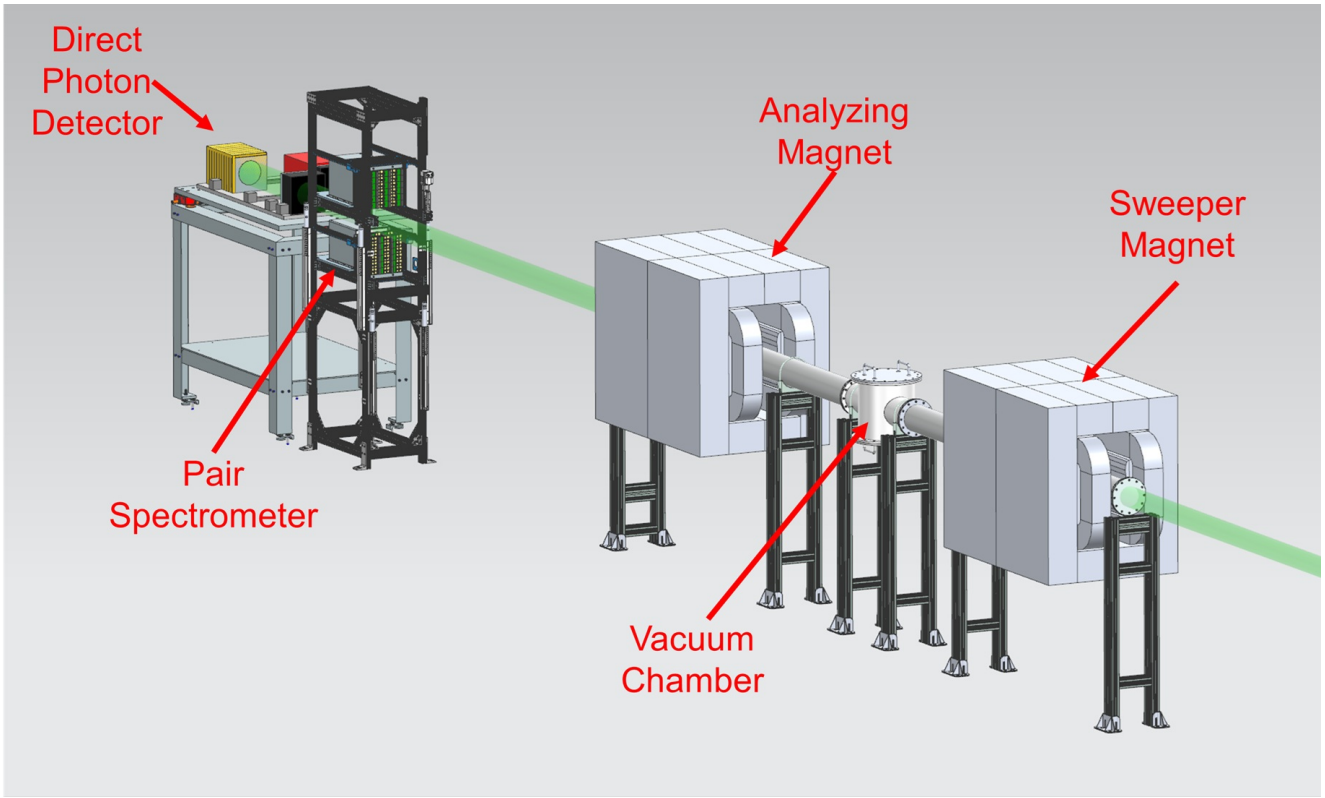
Far Backward - Luminosity Monitors

- Luminosity $\rightarrow$ normalisation for all physics studies



Far Backward - Luminosity Monitors

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



Luminosity Requirements and Systematics

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Cause	**Uncertainty contribution**
Vertical alignment and y_γ measurement	0.5 - 1 %
Photon conversion rate	0.5 - 1 %
Pile-up	0.0 - 0.2 %
Deadtime measurement	0.5 % **[kept same as ZEUS]**
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- With reductions, $\sim$1% absolute lumi precision within reach

Luminosity Monitors - Measurements

- Use bremsstrahlung process to measure luminosity

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

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Figures - EIC Yellow Report - Section 11.7.1, p575

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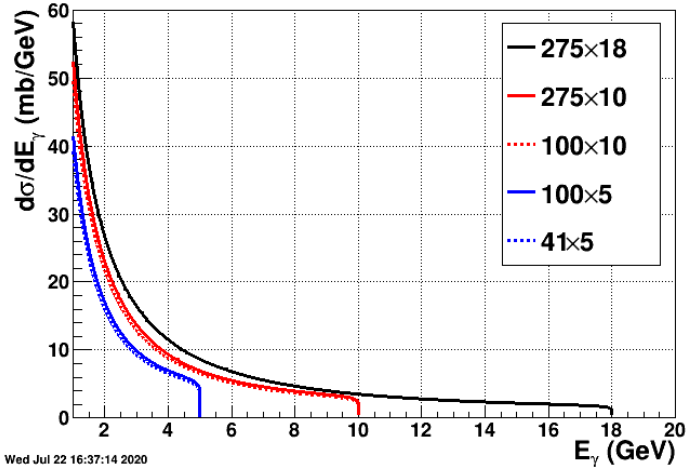

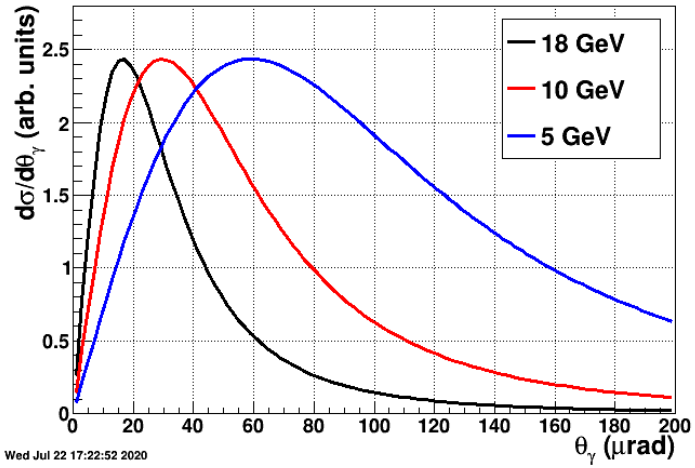

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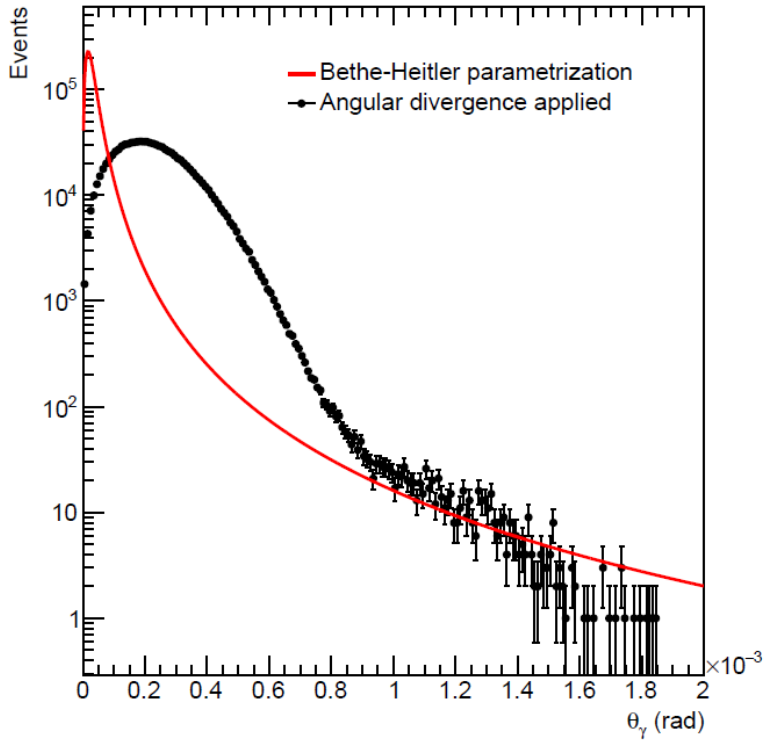

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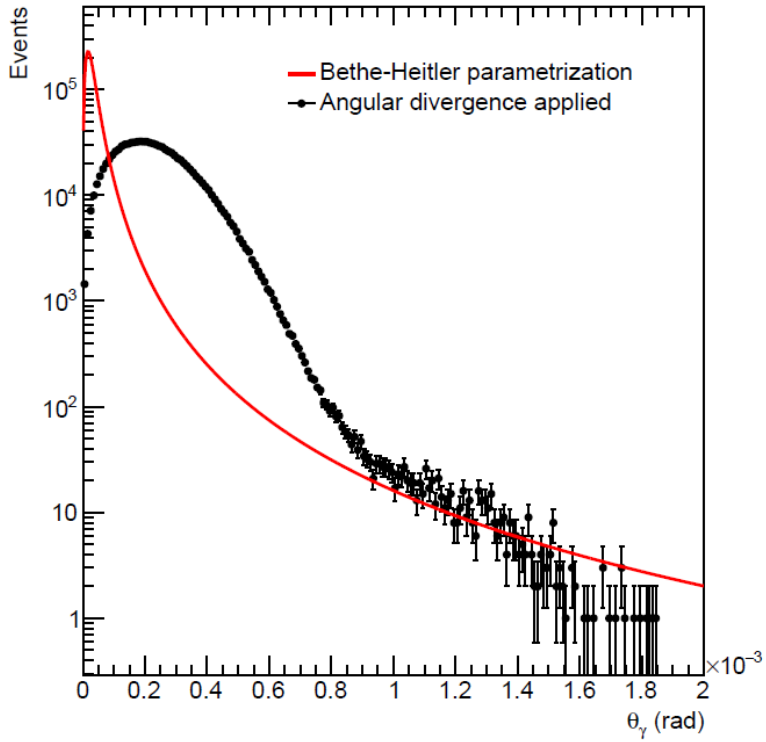
  - **D**irect **P**hoton **D**etector
  - **P**air **S**pectrometer



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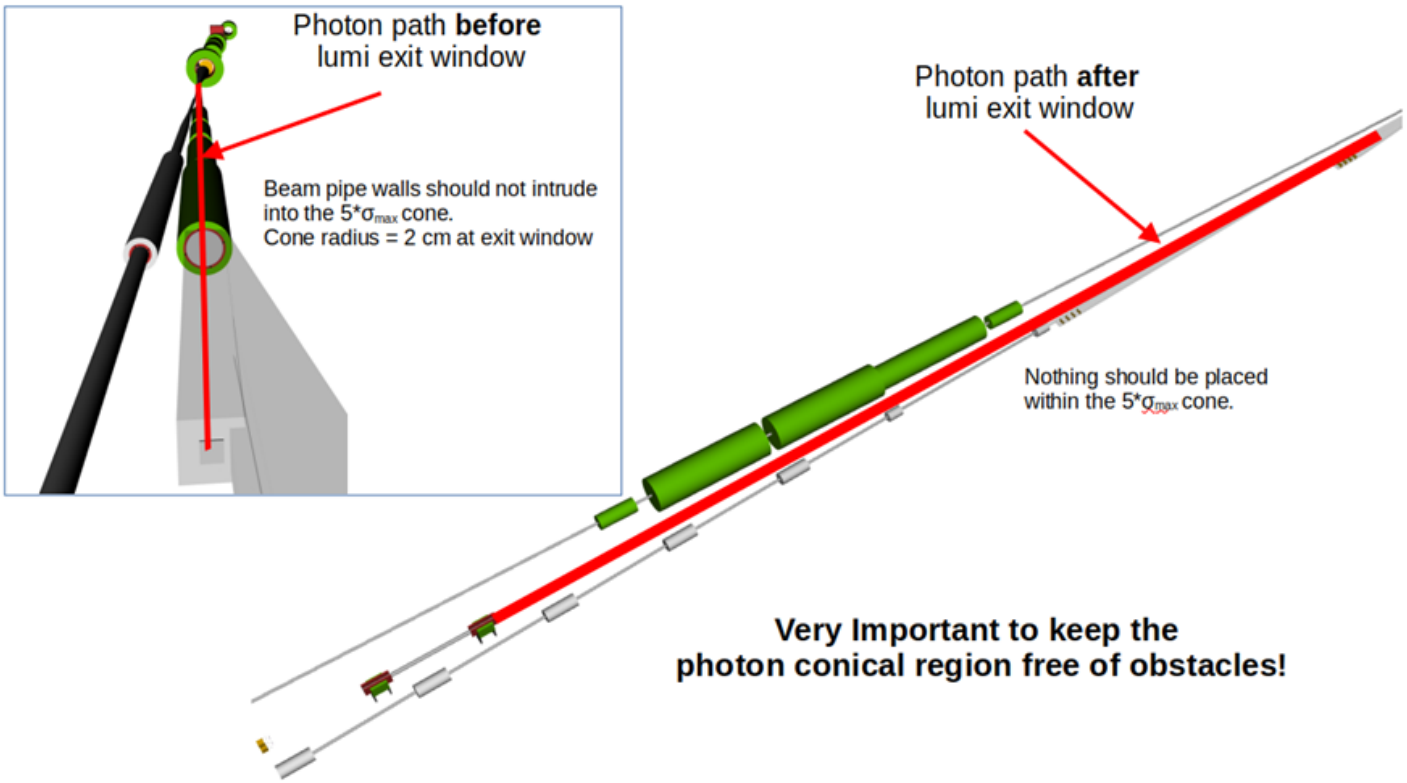
  - One used only for special luminosity runs at low $\mathcal{L}$
    - Use same calorimeter design as pair spectrometer!
  - One capable of withstanding > 1 GHz rates, used for monitoring during nominal running at high $\mathcal{L}$
- Use a complementary **P**air **S**pectrometer too

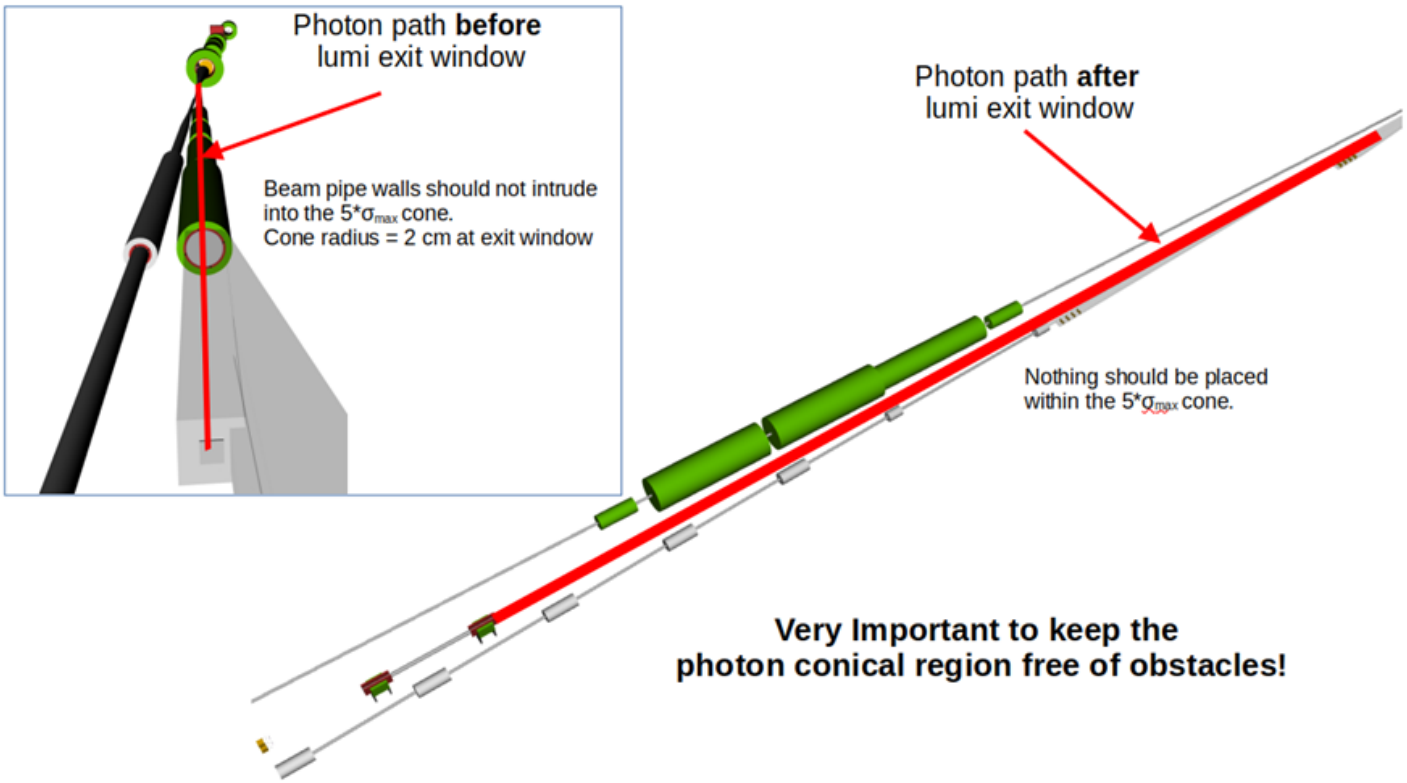
Luminosity Monitoring Region



Figures - D. Gangadharan, University of Houston

Luminosity Monitoring Region

- Conversions in air before vacuum pipe, negligible effect



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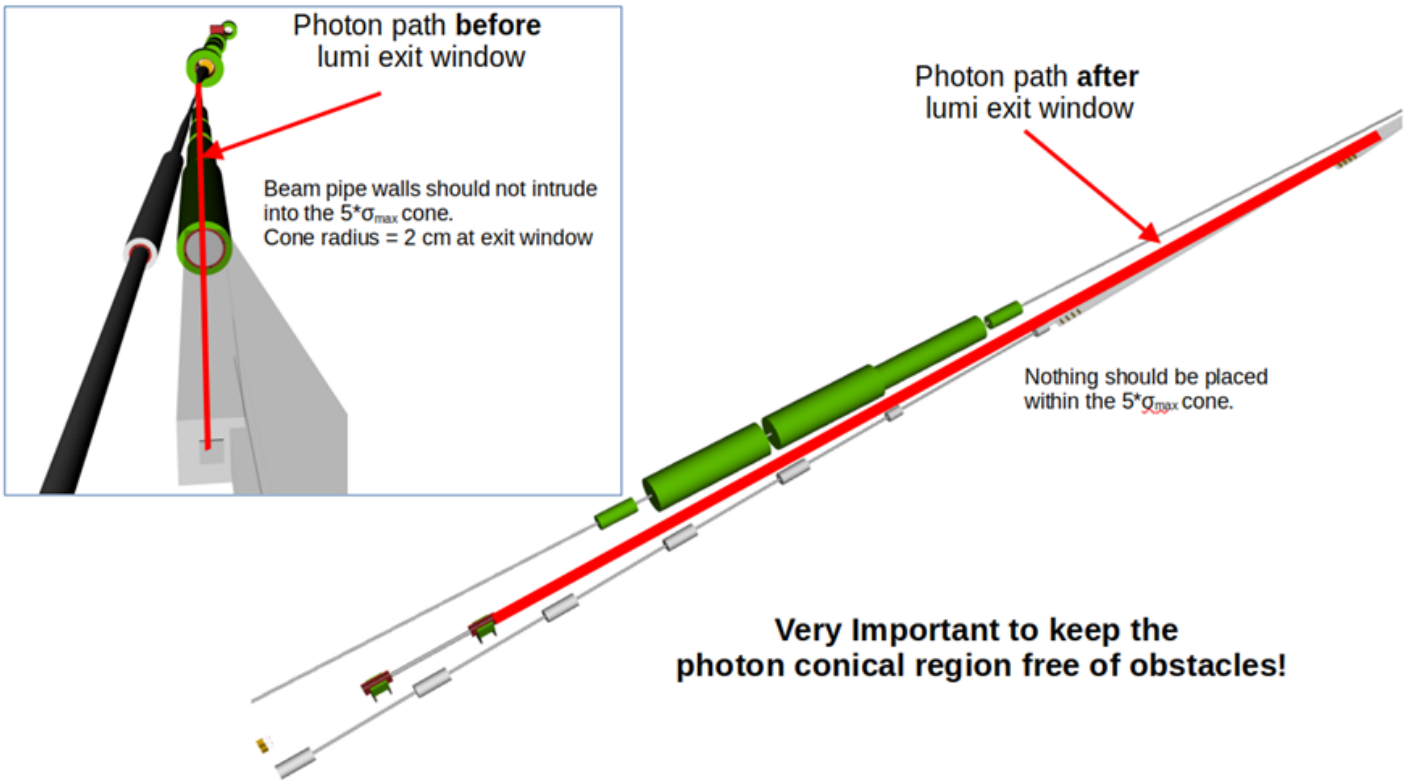
  - $< 0.02\%$ contribution to systematics



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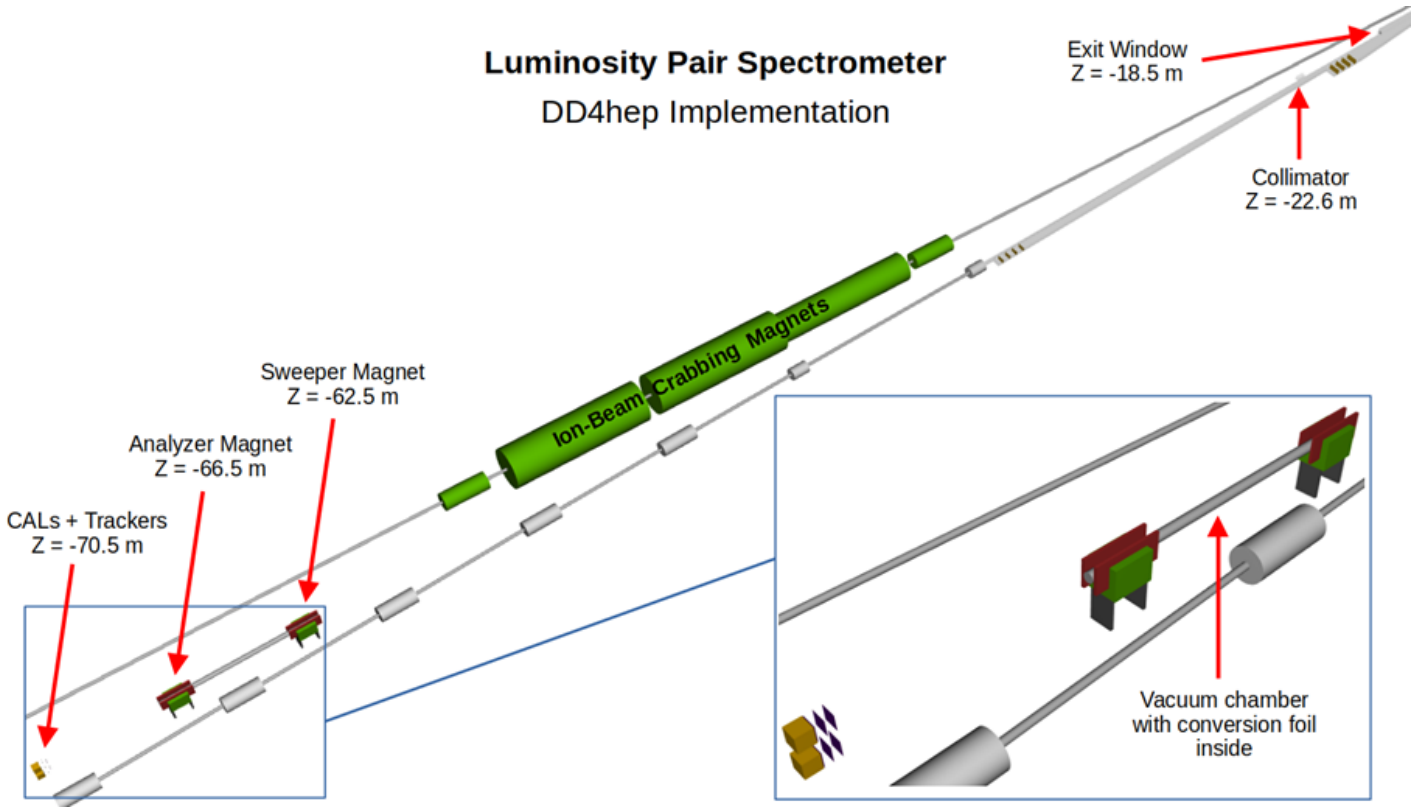
Luminosity Monitoring Region

- Conversion foil within vacuum pipe, between magnets



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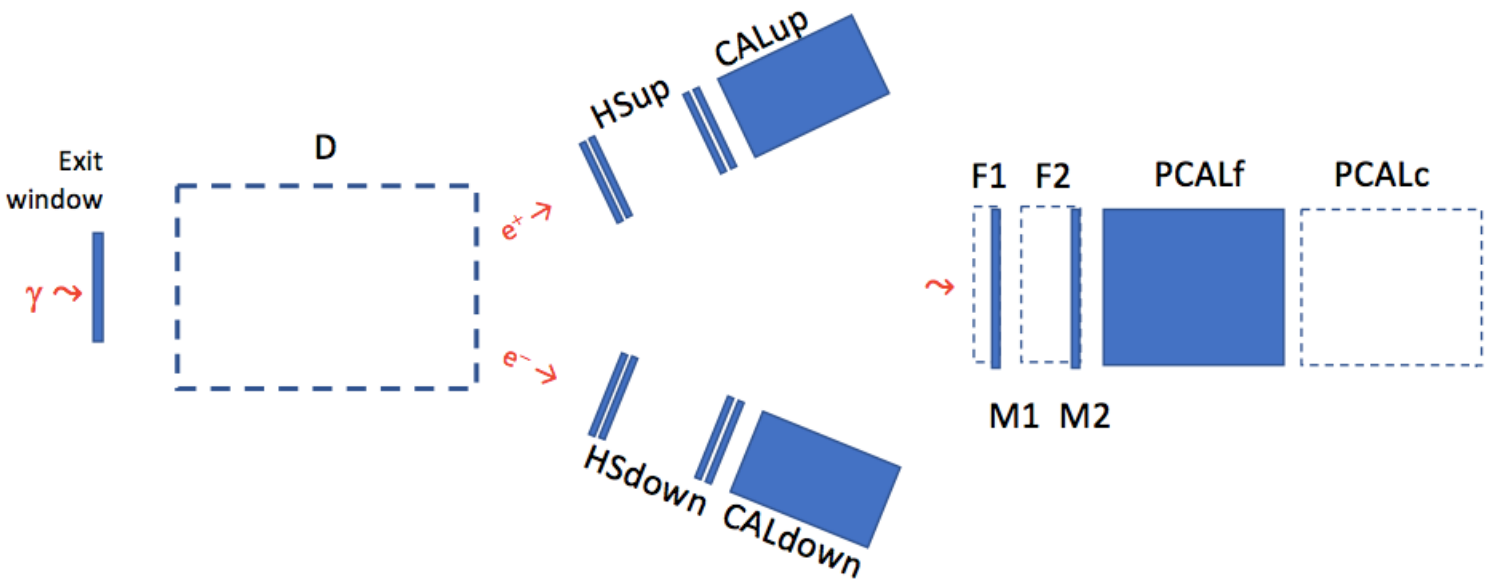

Figure - J. Nam, Temple University, ePIC Collaboration meeting January 2023

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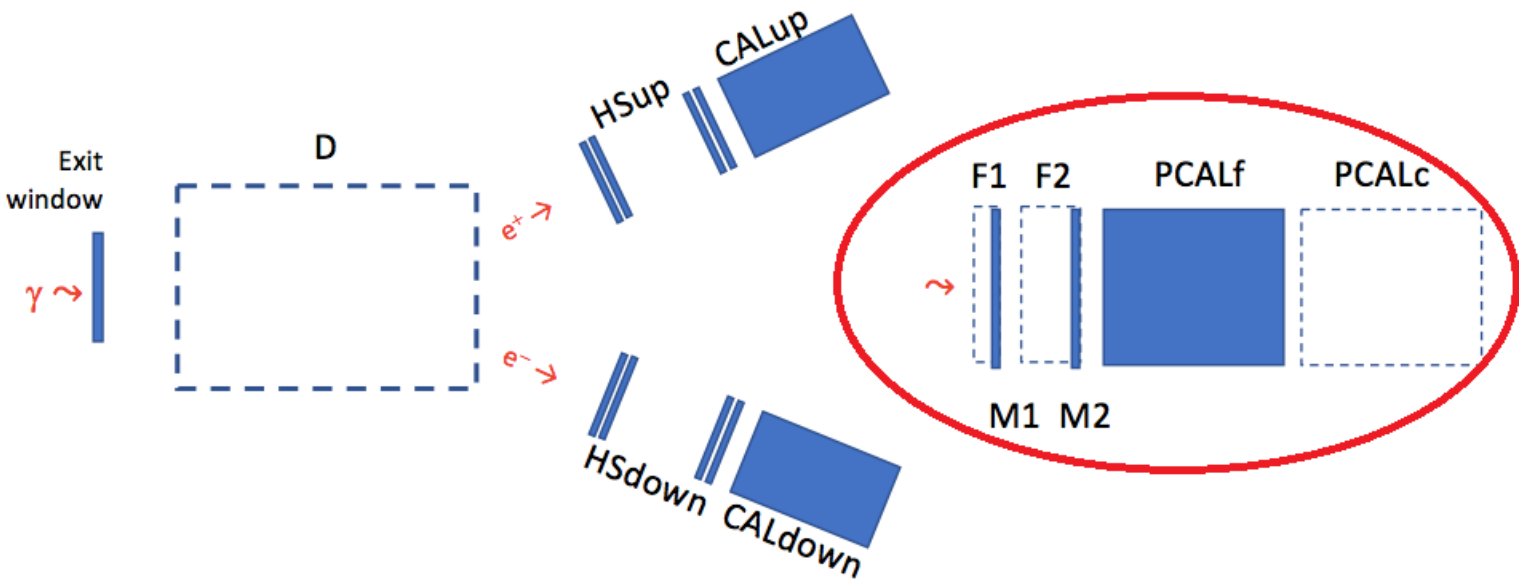

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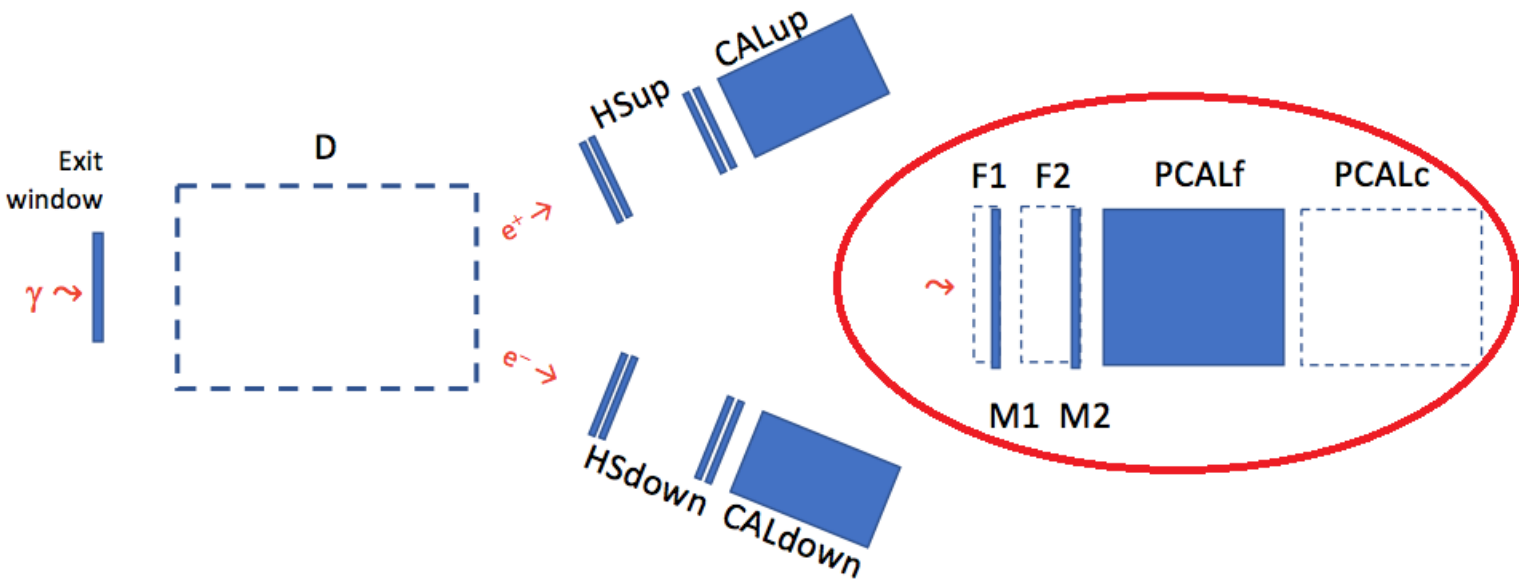
Direct Photon Detector

- Latest high rate design, quartz fiber based calorimeter



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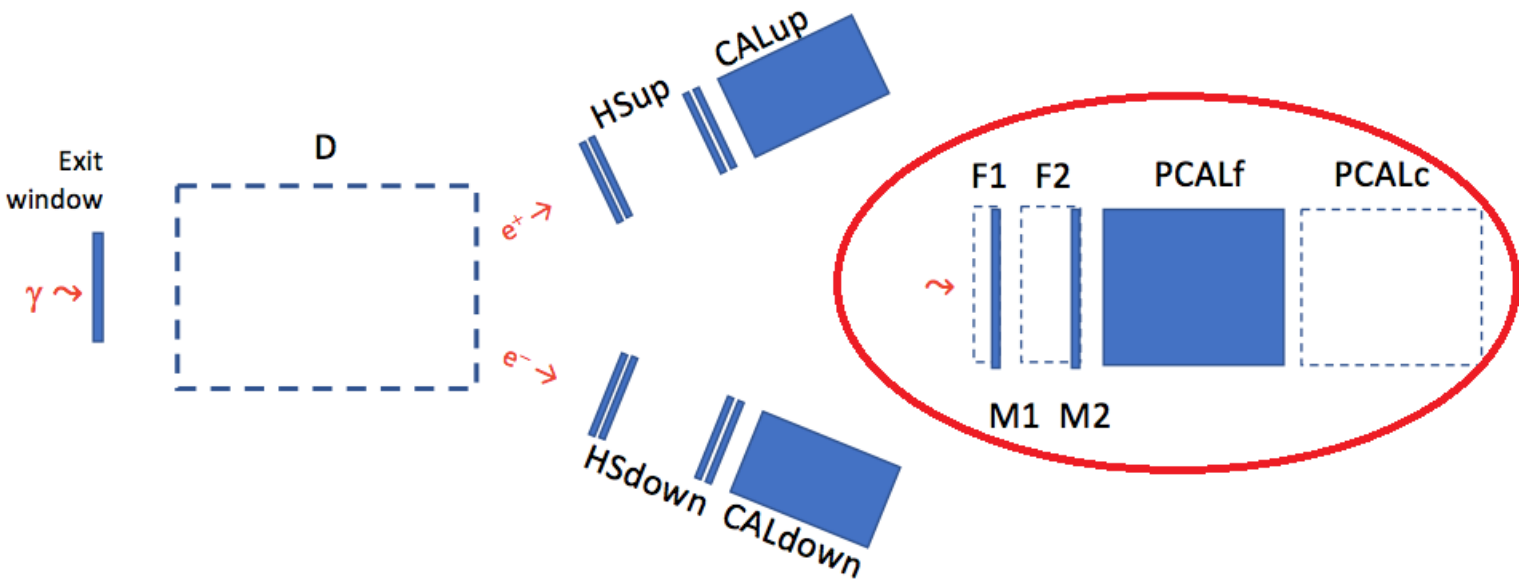

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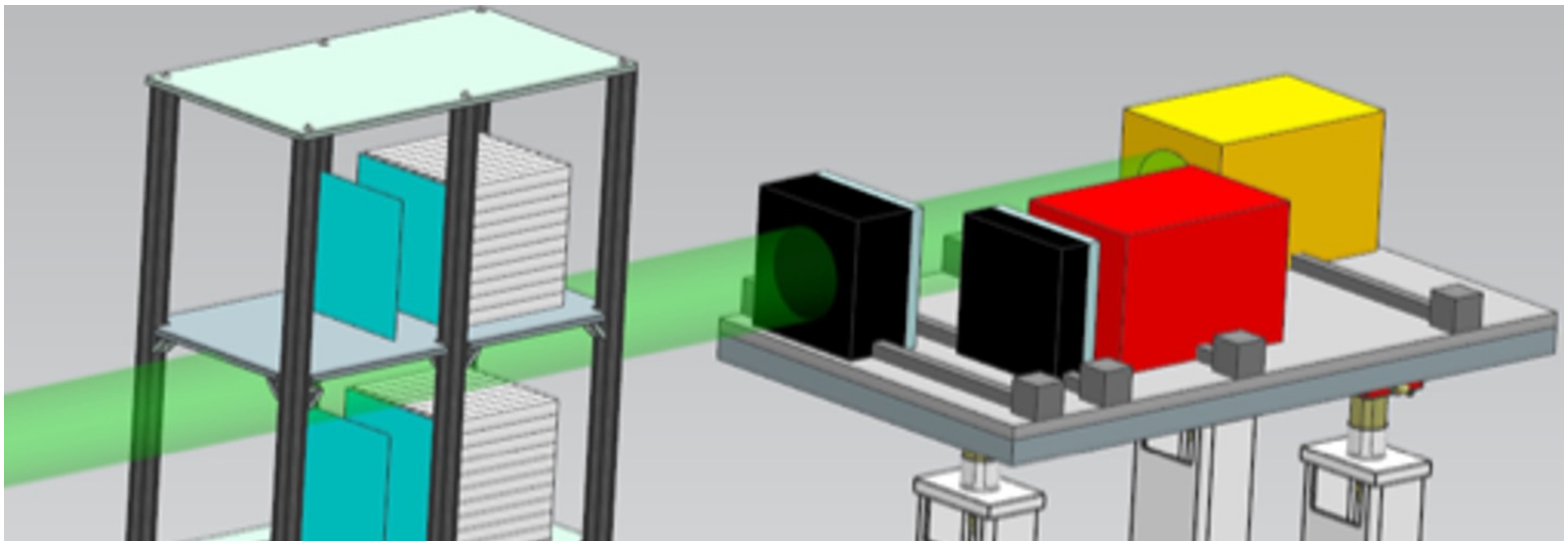
- For 18 GeV e^-, graphite absorbers to absorb synchrotron radiation
- Recent paper on simulation of detector demonstrates performance at high photon multiplicities



https://doi.org/10.48550/arXiv.2510.05259

Direct Photon Detector - Details

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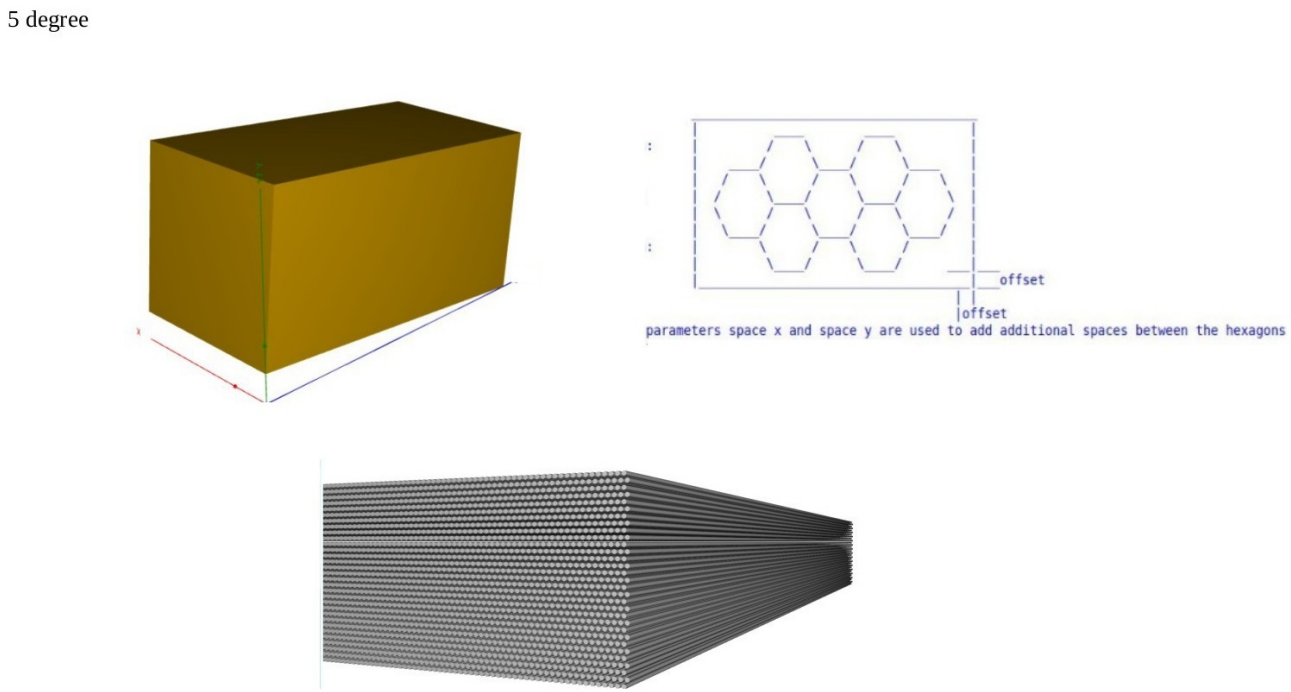
- Detect Cherenkov radiation from EM shower along fibers



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

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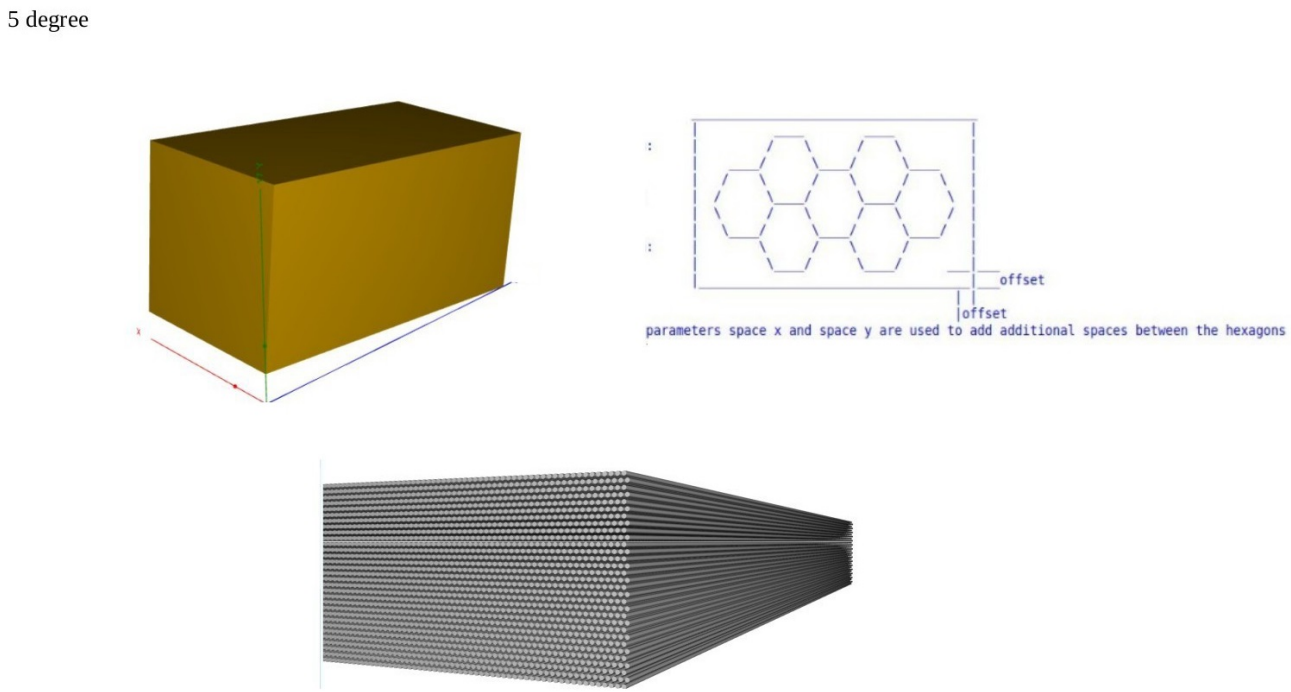

Pair Spectrometer Overview

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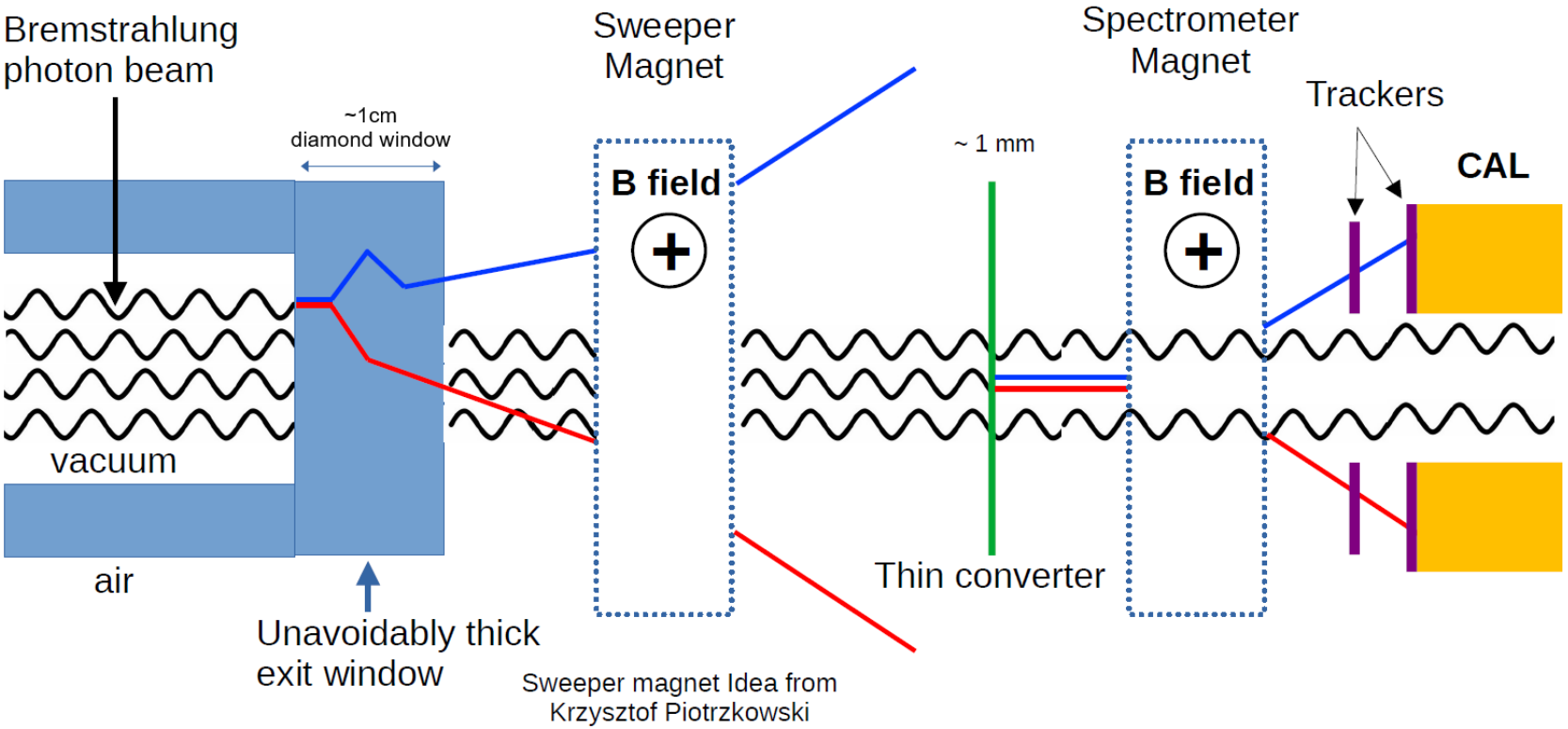

Figure - D. Gangadharan, University of Houston

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

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

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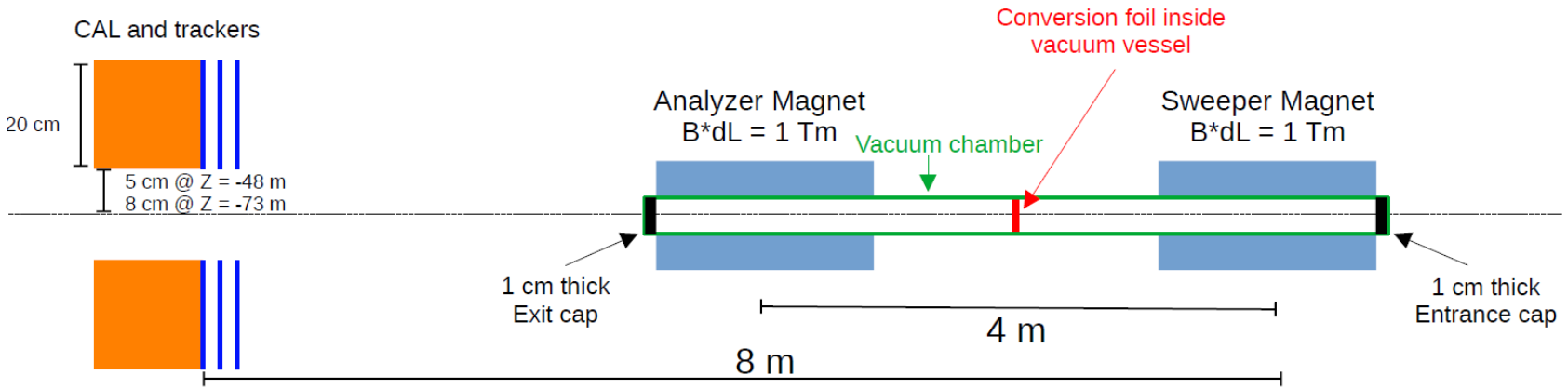
- New baseline design with sweeper magnet $\sim$ 55 m from IP



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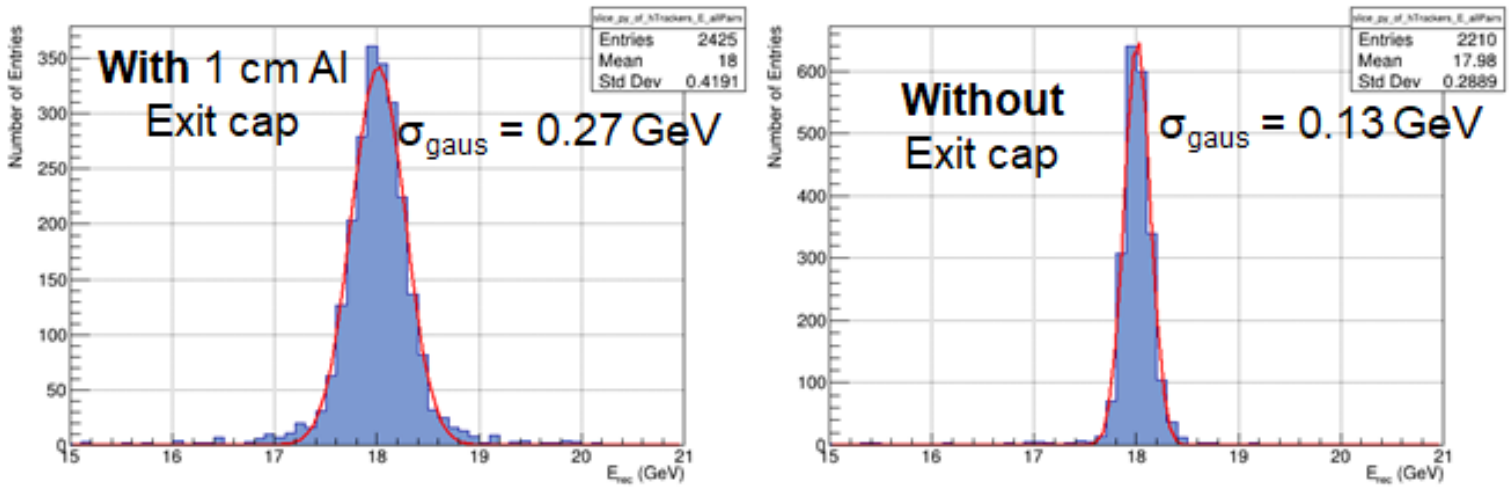

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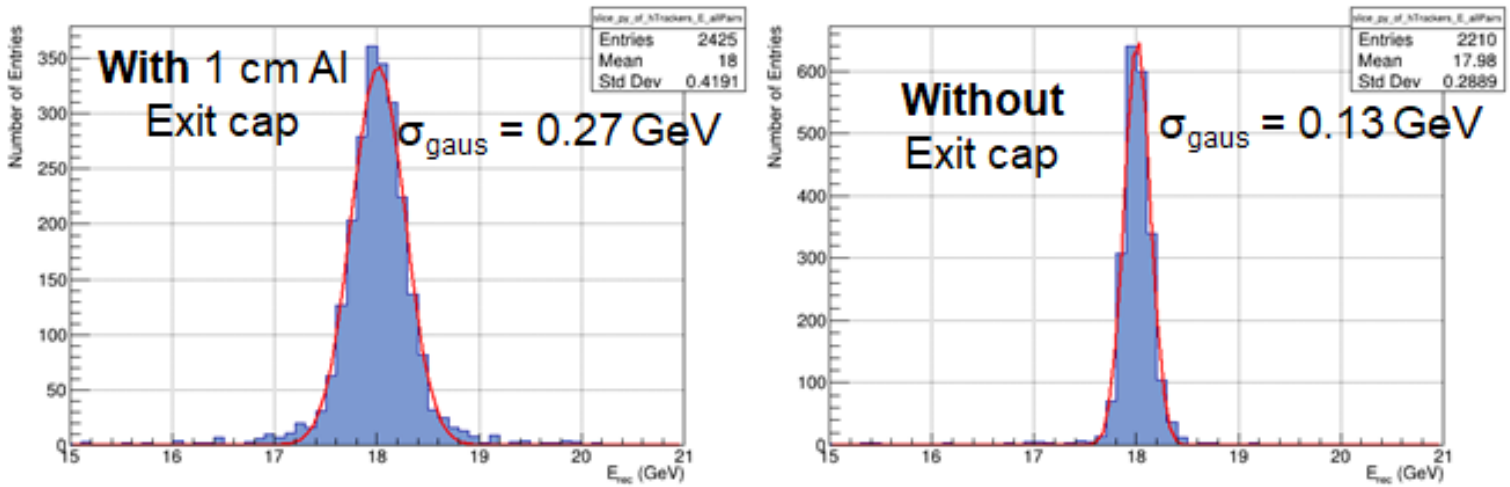

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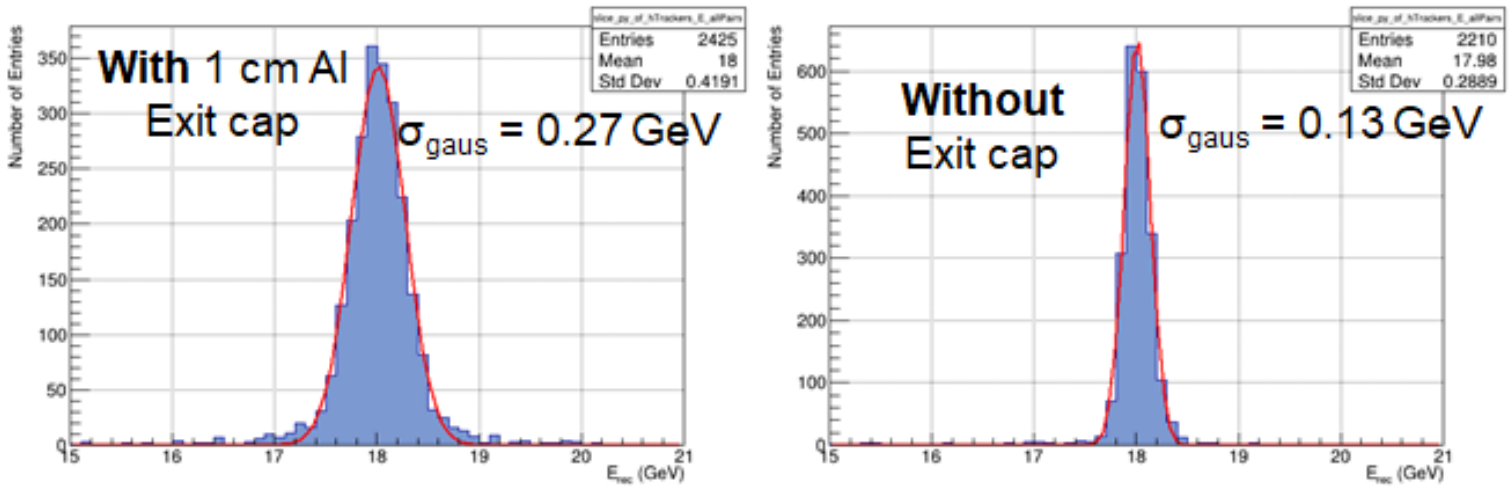
- AC-LGAD pixel detector
  - Synergy with other systems using this technology



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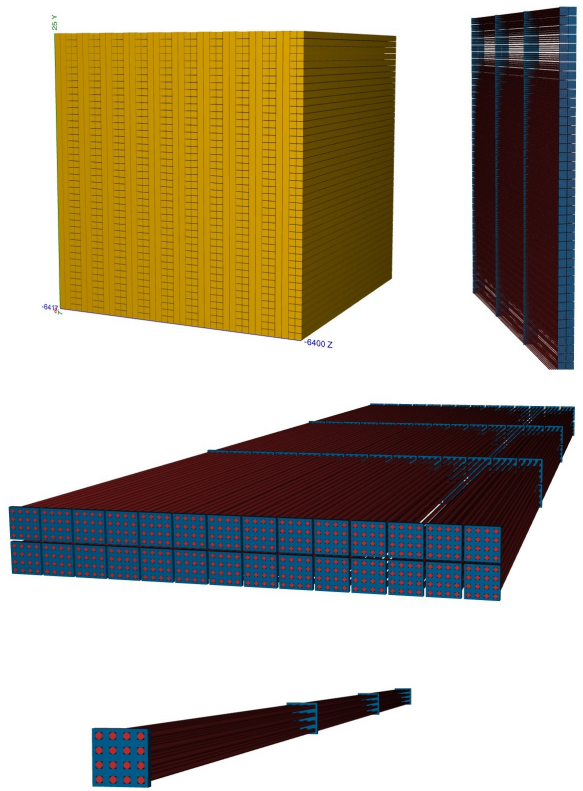

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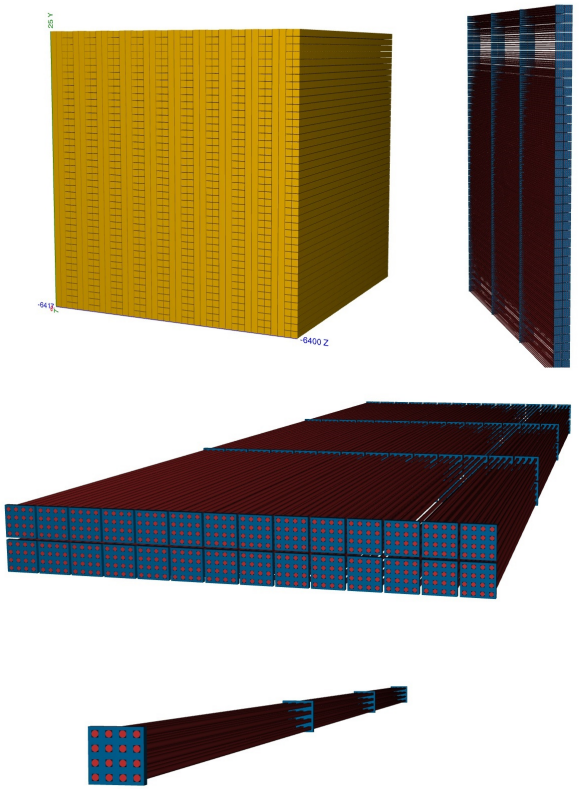

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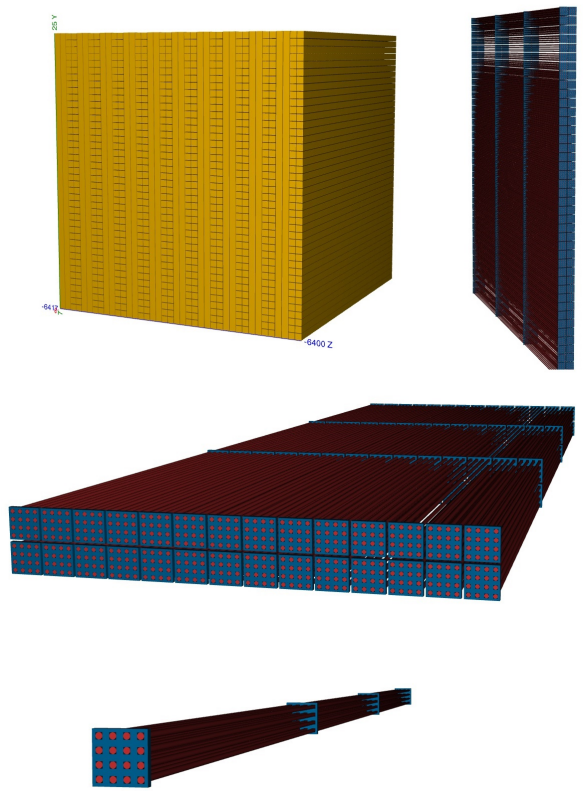

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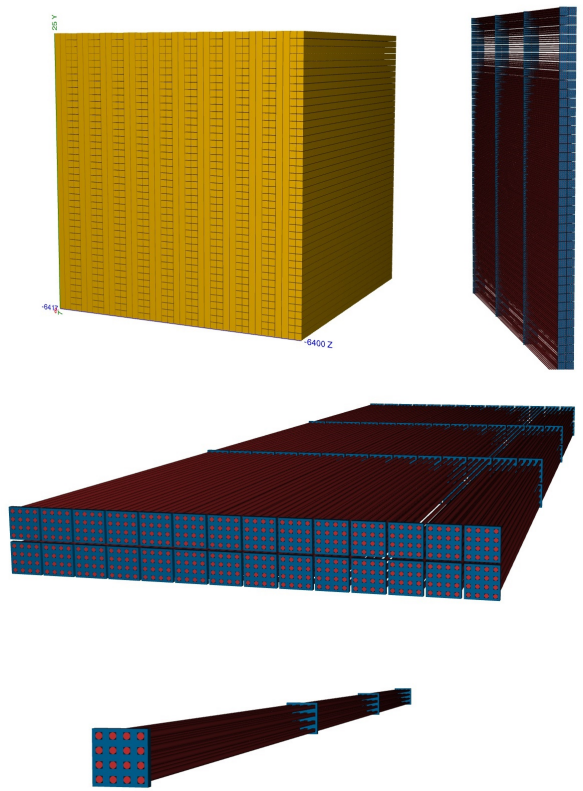

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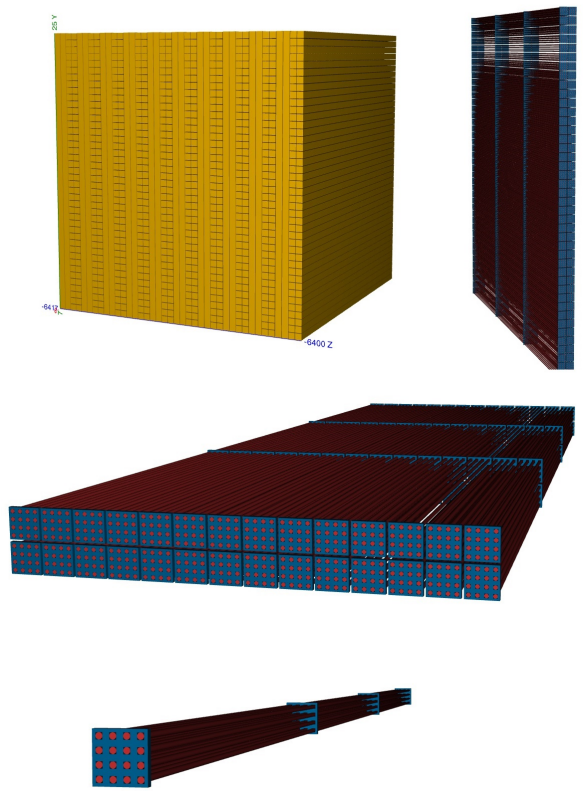
  - Potential AI/ML applications



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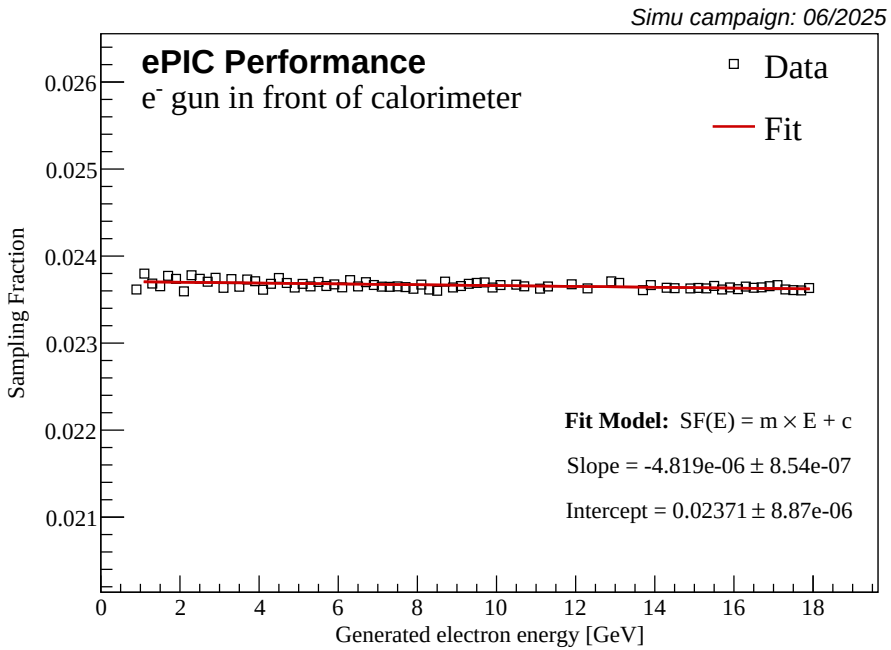

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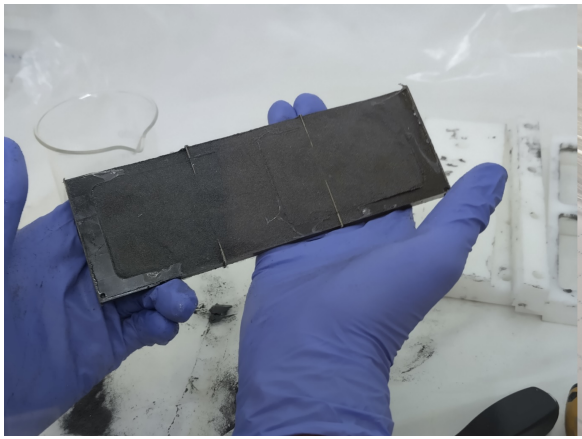

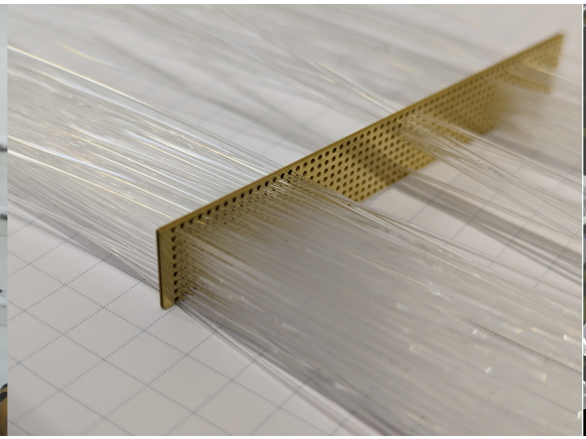

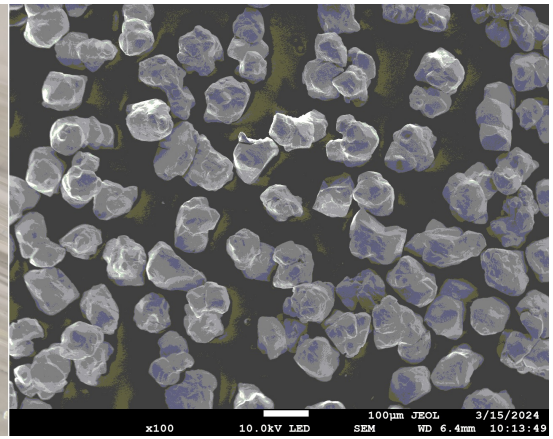

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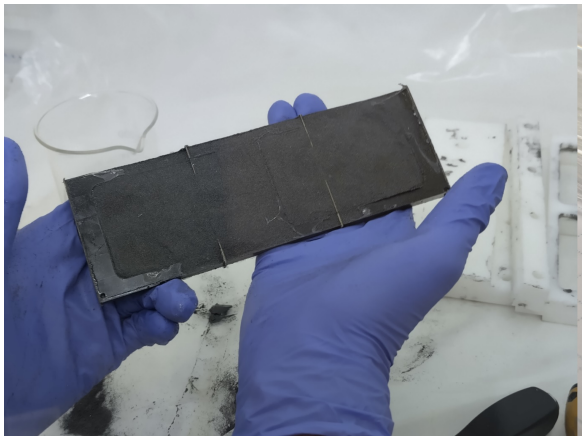
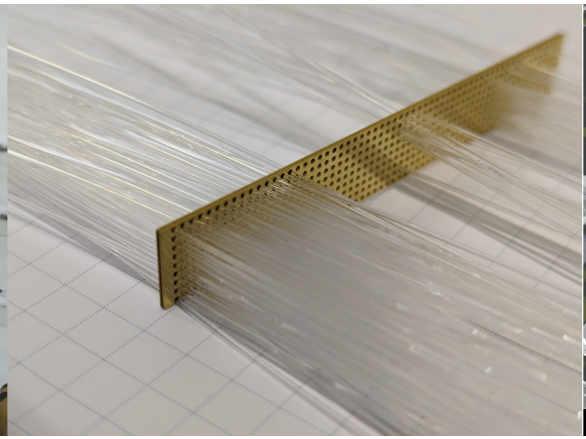
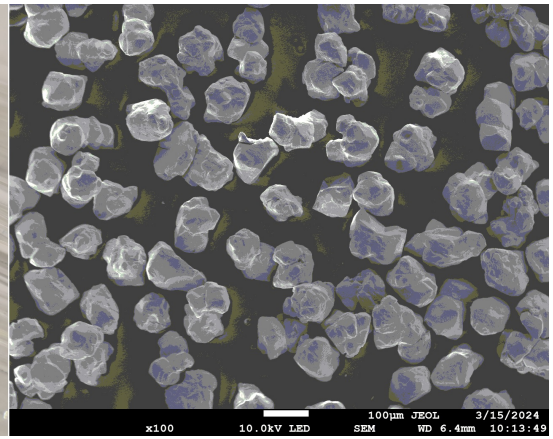




Pair Spectrometer Calorimeter - Prototype Construction

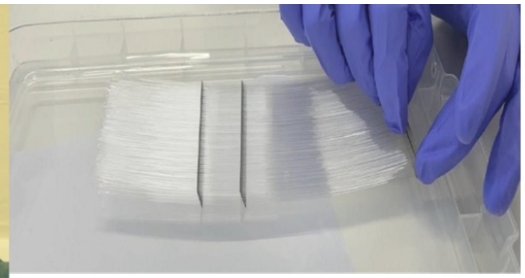
- Basic sketch of construction process...

Pair Spectrometer Calorimeter - Prototype Construction

- Populate stack of meshes with fibers
- Now use a dedicated fiber holder/dropper

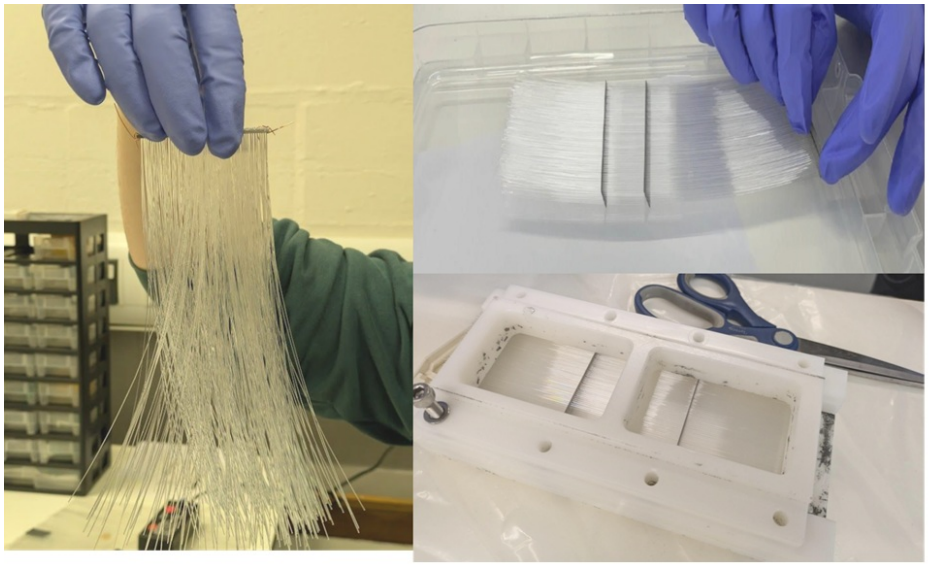
Pair Spectrometer Calorimeter - Prototype Construction

- Separate meshes (Alex's favourite part)
- Must be done **extremely** carefully



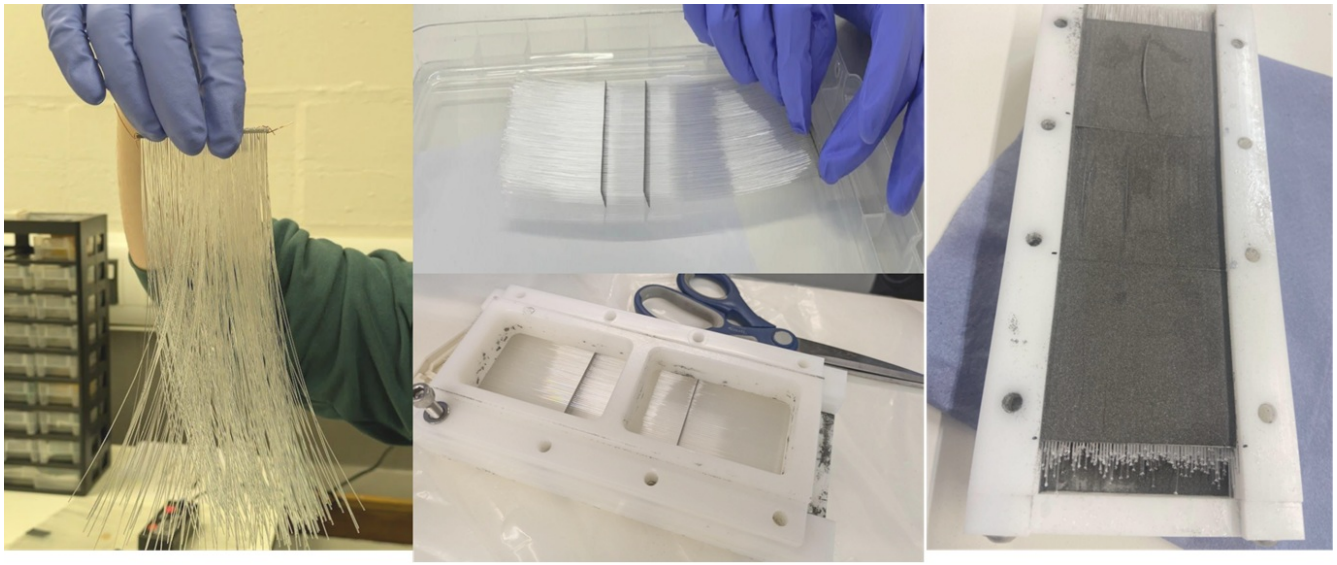
Pair Spectrometer Calorimeter - Prototype Construction

- Insert meshes into slots in mould
- Lesson Learned - Seal the ends



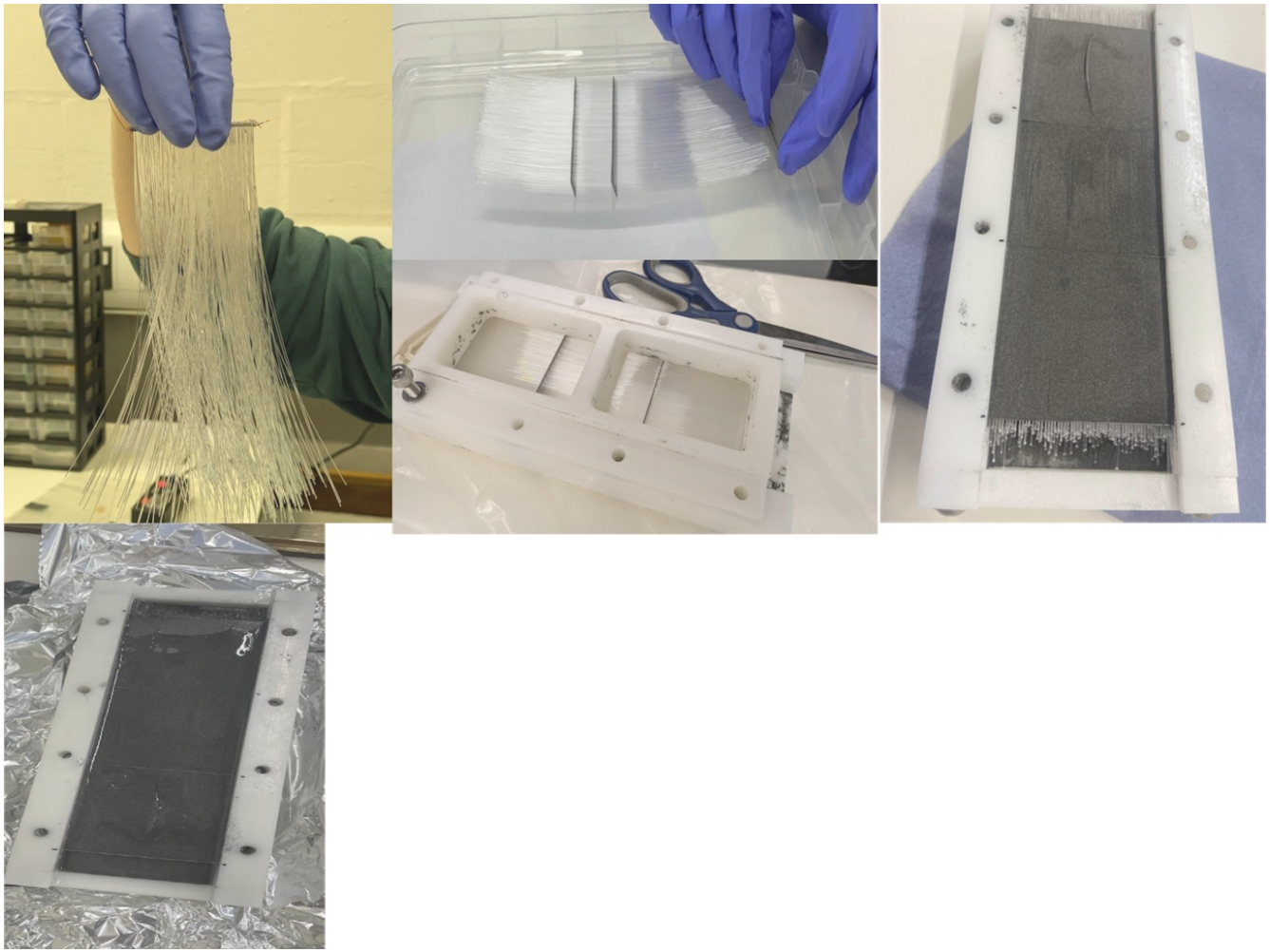
Pair Spectrometer Calorimeter - Prototype Construction

- Pour tungsten powder over fiber array



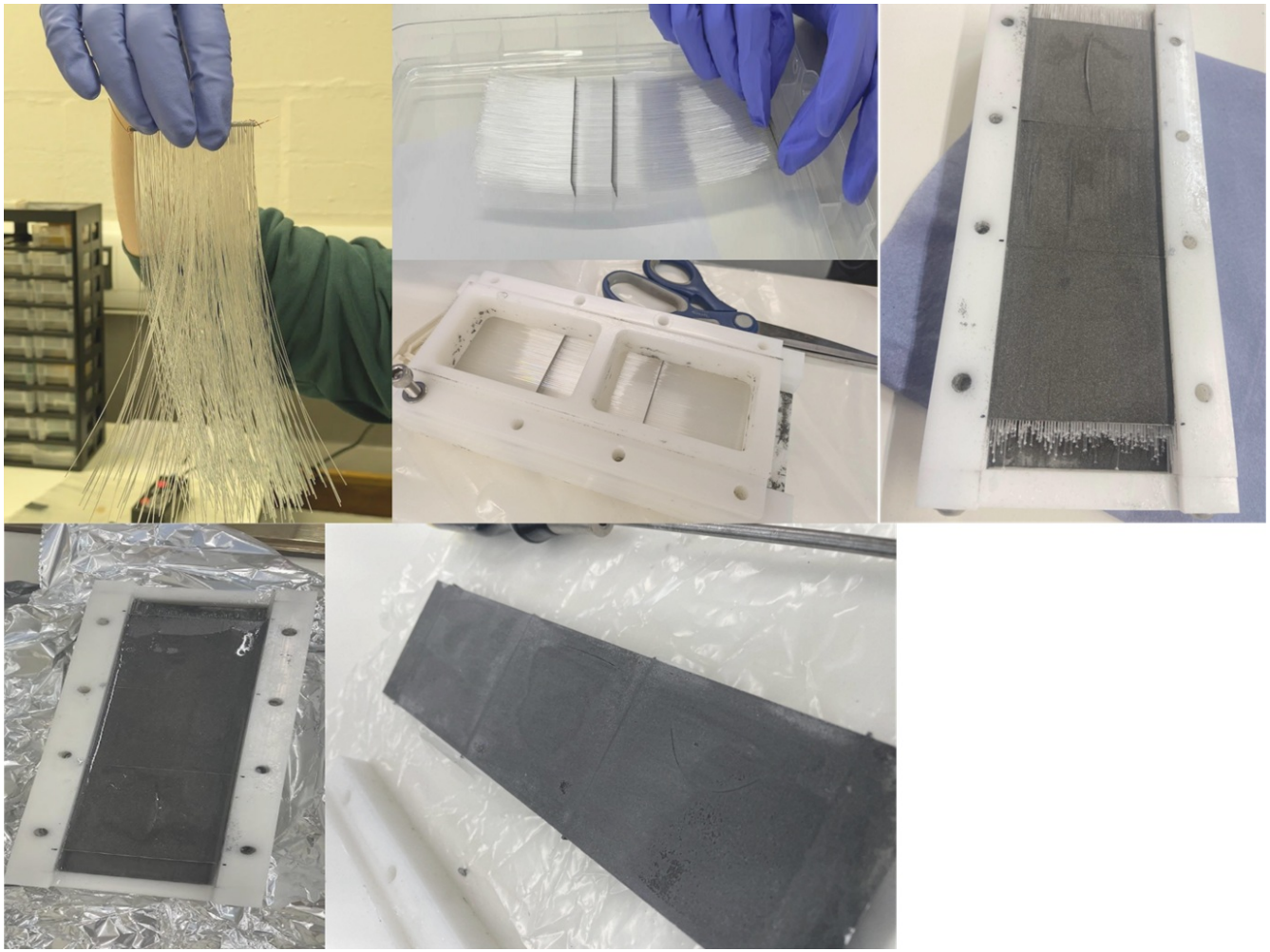
Pair Spectrometer Calorimeter - Prototype Construction

- Mix and pour epoxy over tungsten/fiber array
- Pour in 25 ml batches, use a vibrating table



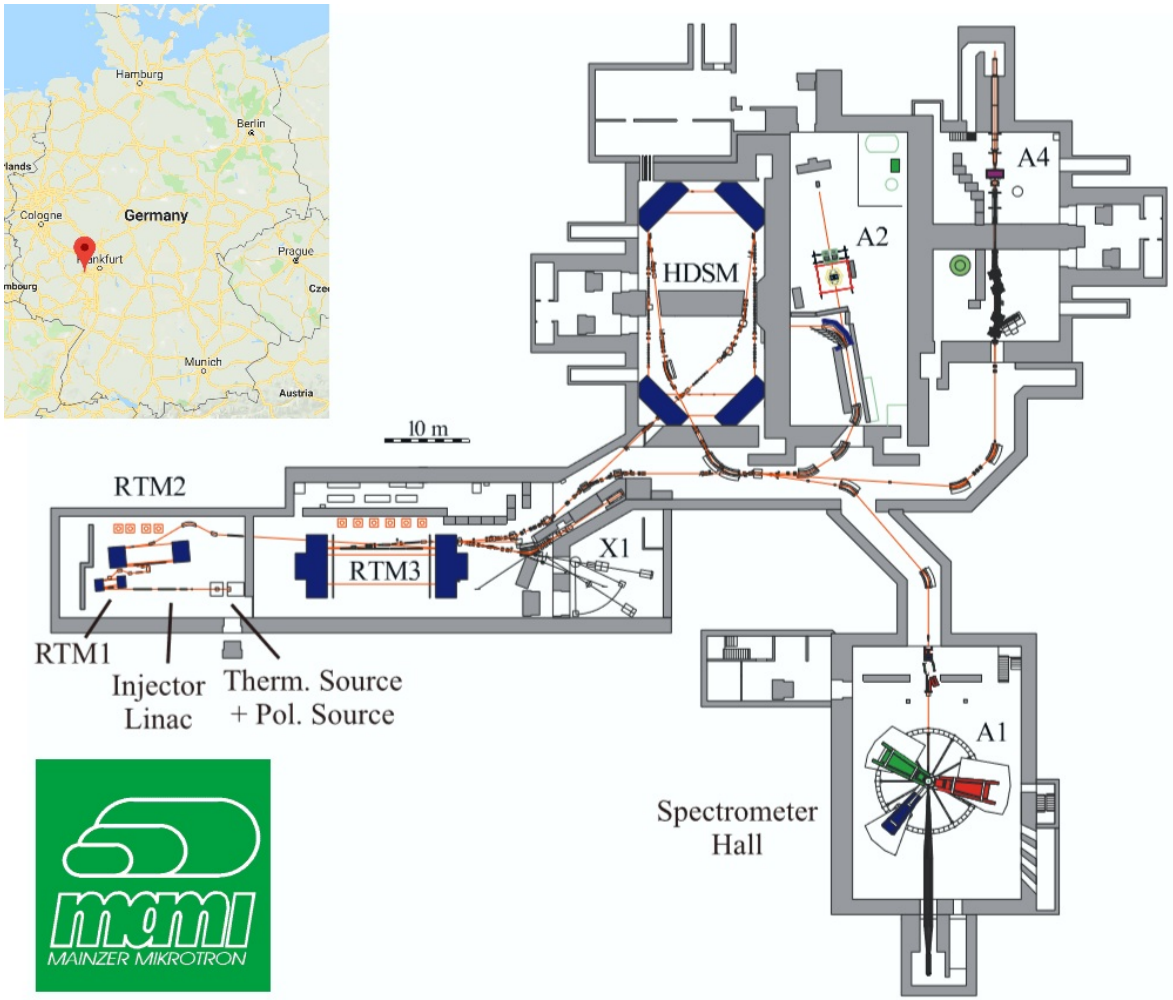
Pair Spectrometer Calorimeter - Prototype Construction

- Cure epoxy for $\sim$2 hours at $50 - 60^{\circ}$C, remove from mould
- Lesson learned - Place under vacuum before curing



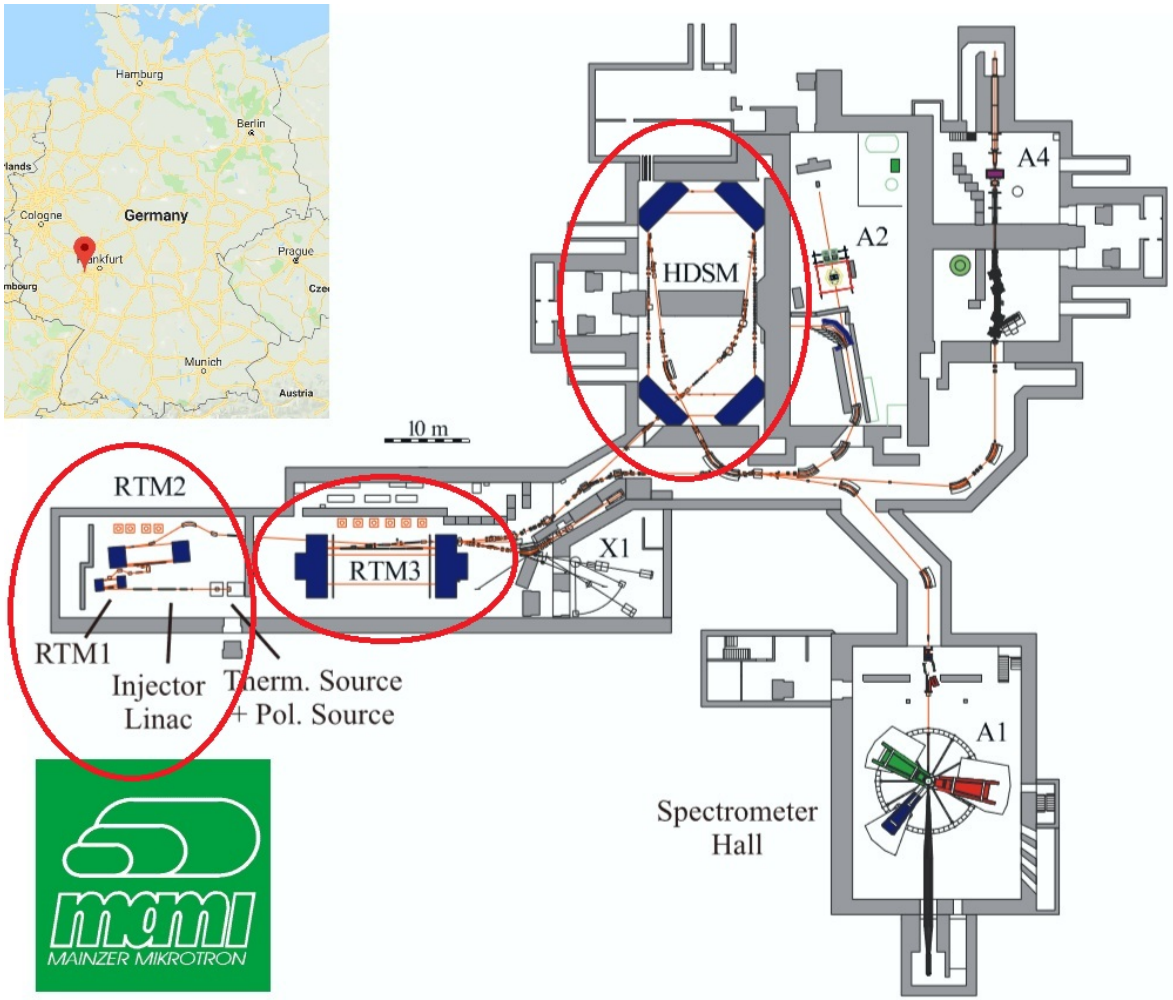
PSCal - Prototype Testing at Mainz

- Beam tests at the Mainz Microtron, MAMI, in Mainz Germany



PSCal - Prototype Testing at Mainz

- Series of microtrons deliver up to $\sim 1.6\ GeV\ e^-$ beam



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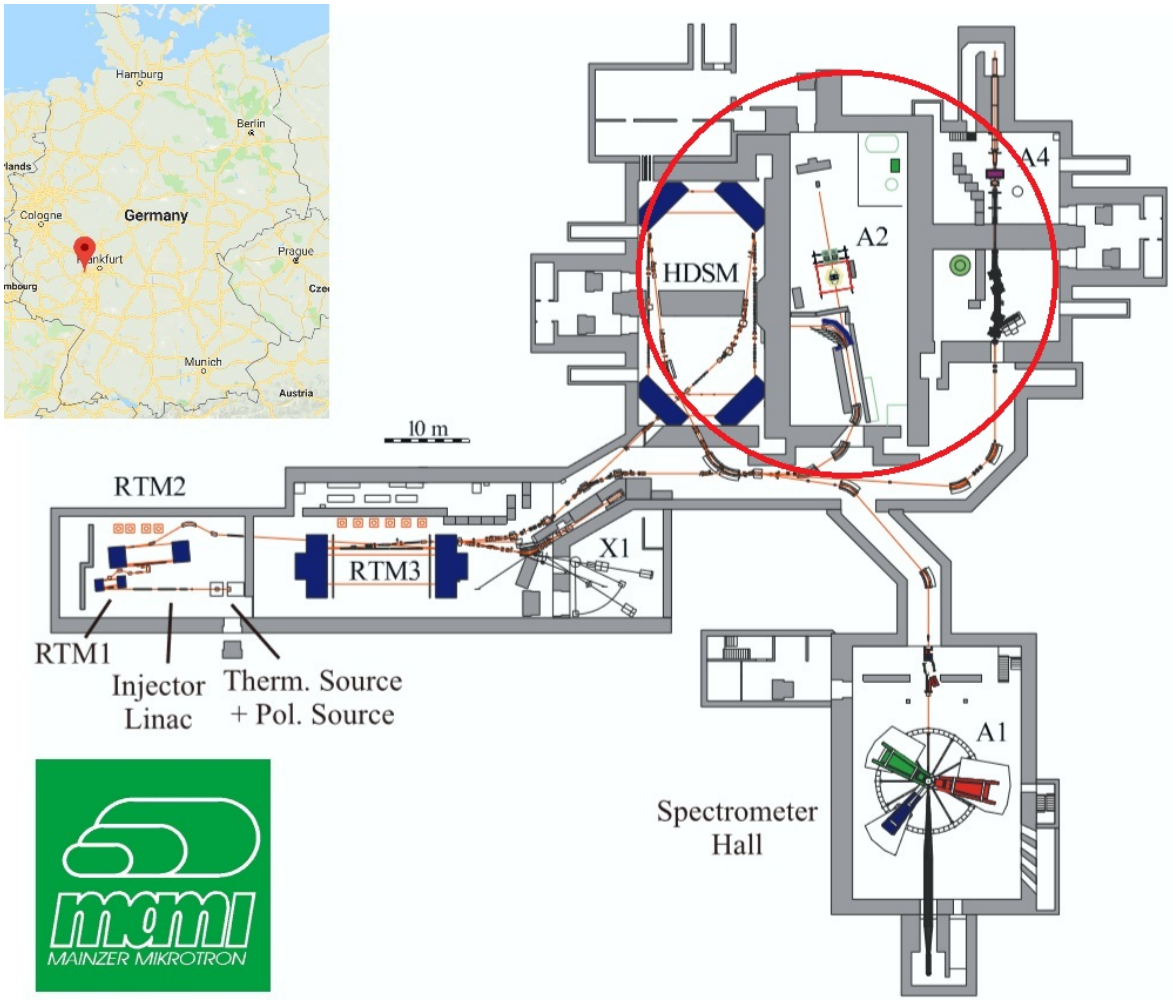
- Beam tests in A2 hall



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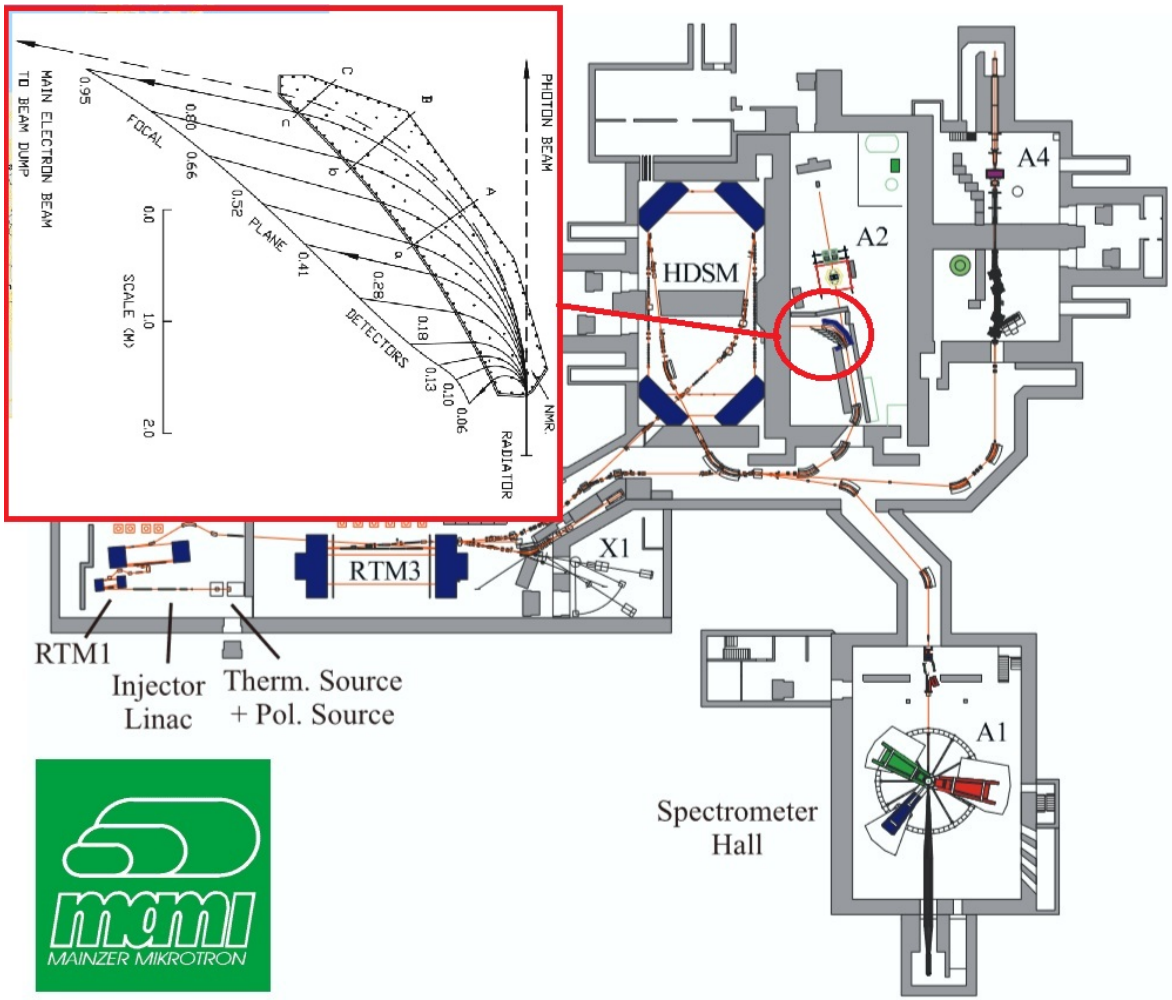
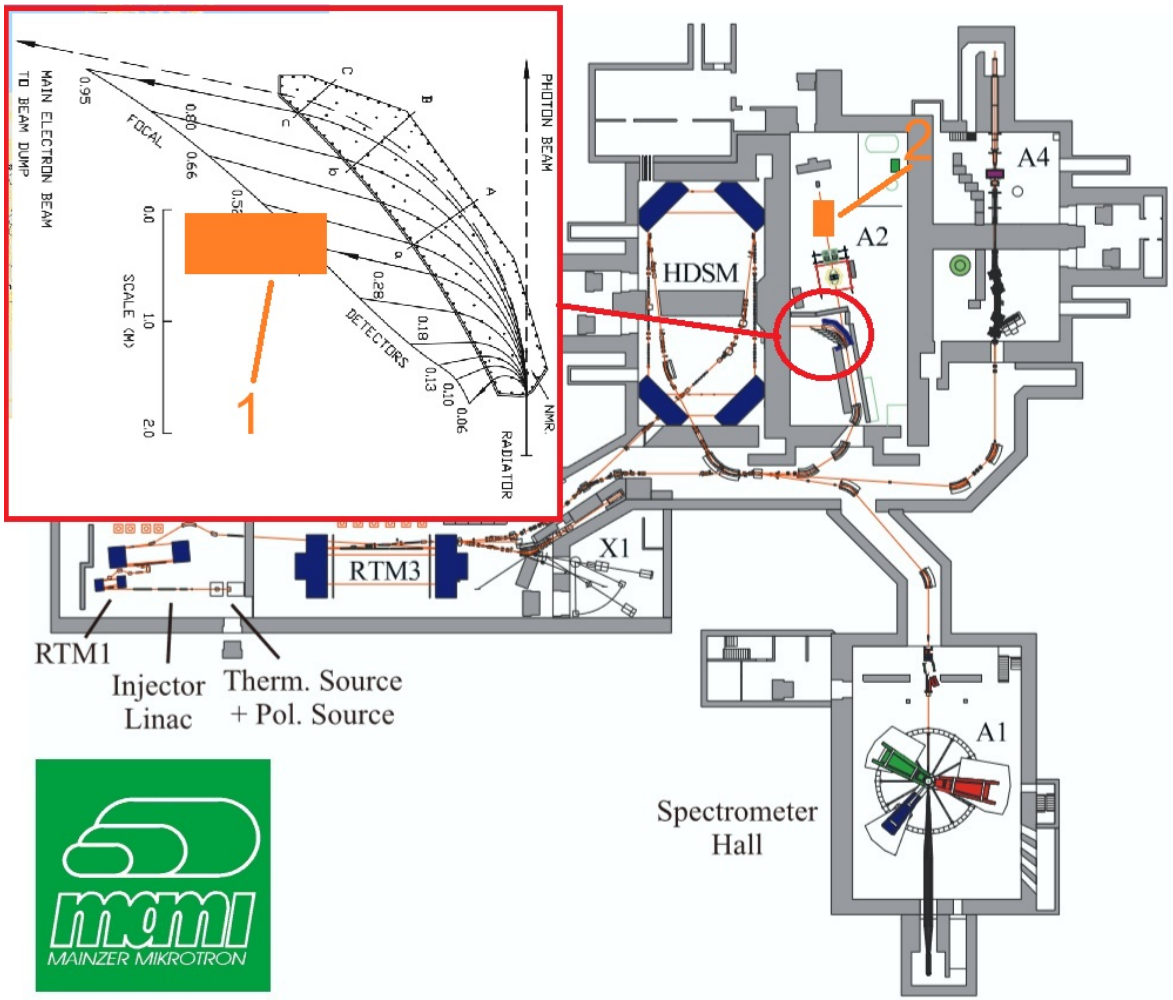
- e^- beam on radiator $\rightarrow$ real γ beam (tagger detects $e^{-\prime}$)



PSCal - Prototype Testing at Mainz

- Two options, place along tagger FP (e^-), 1, or in γ beam, 2



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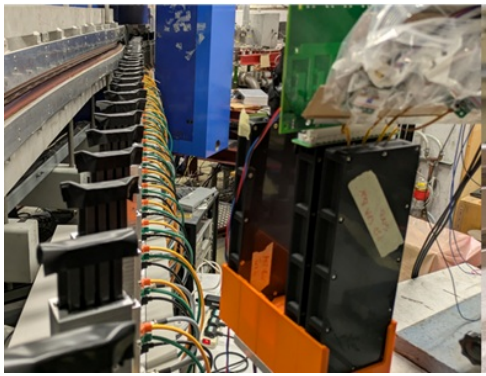
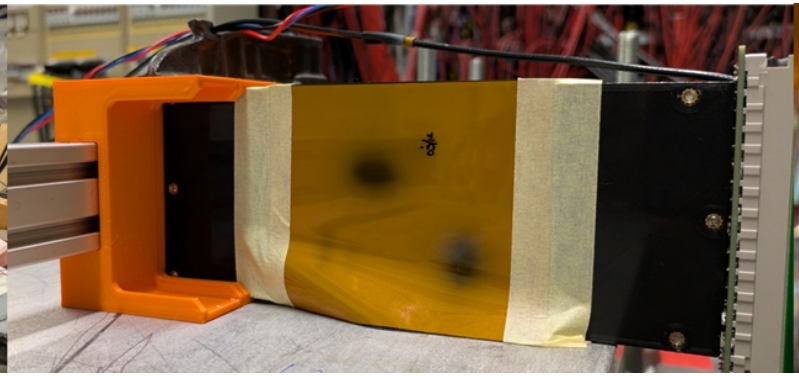
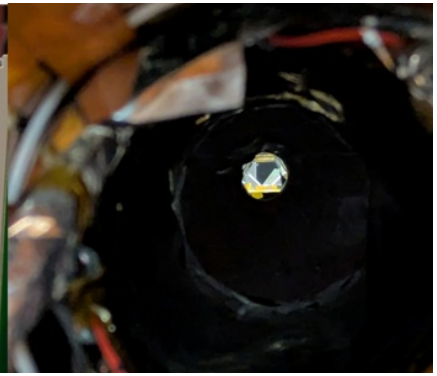

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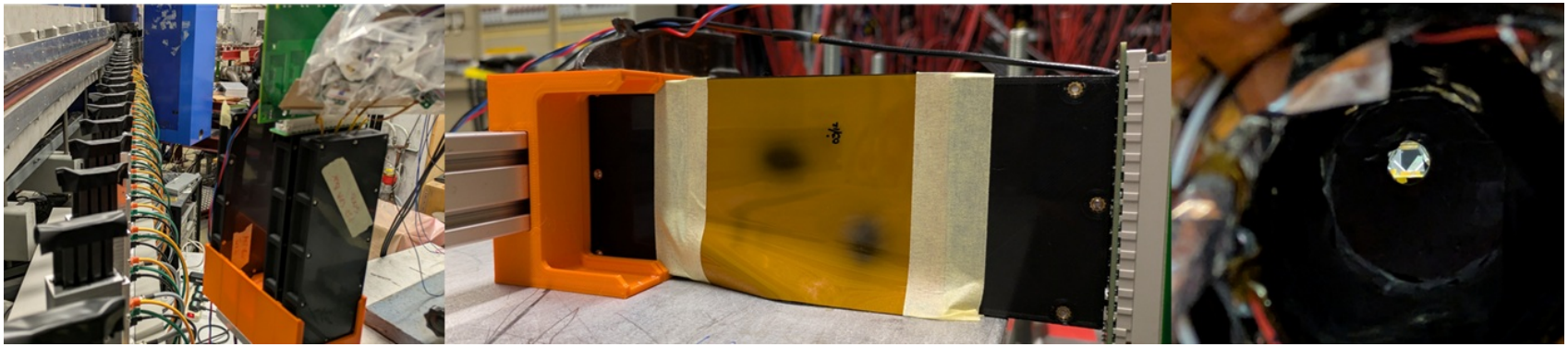

- Hampered by readout... but, saw clear rate dependent signal

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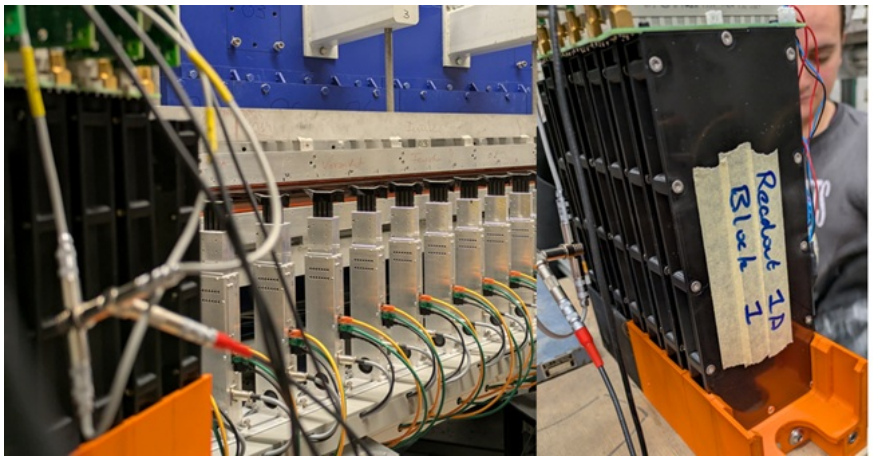

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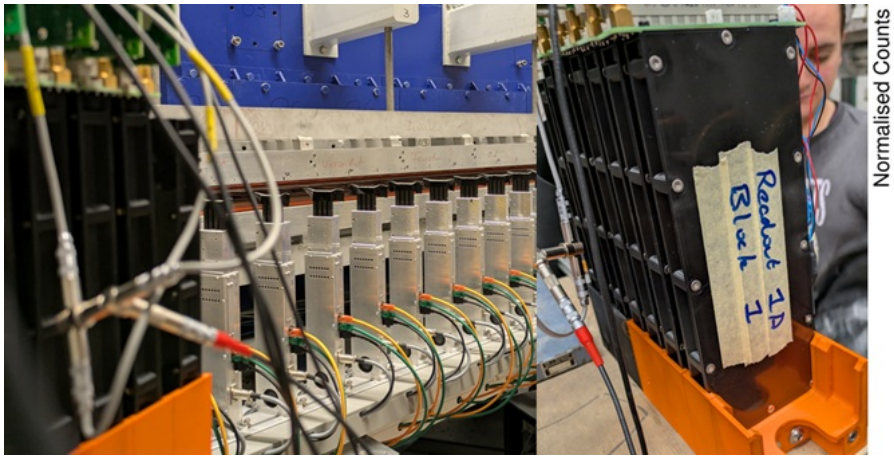

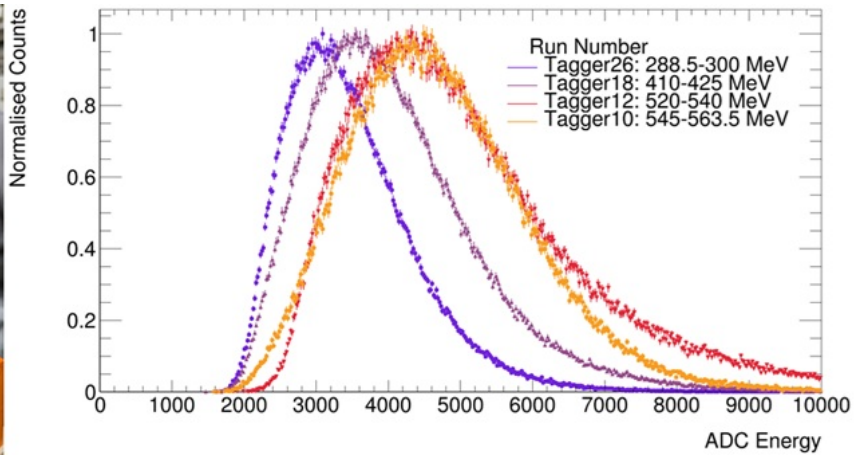

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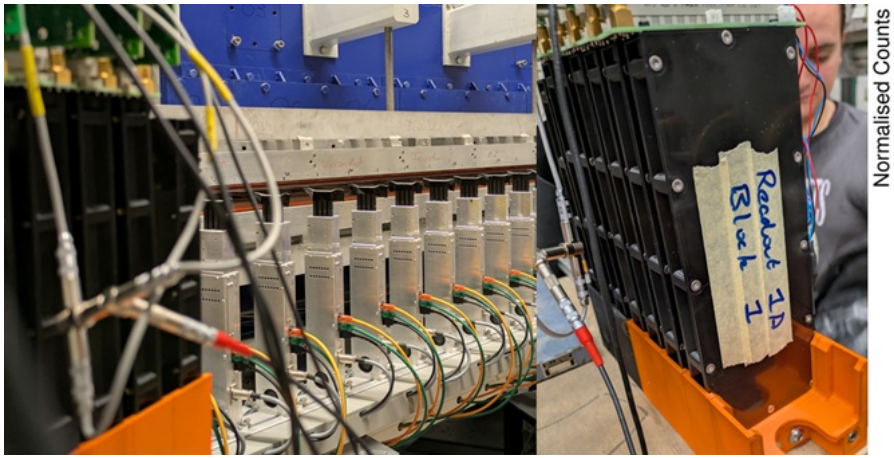

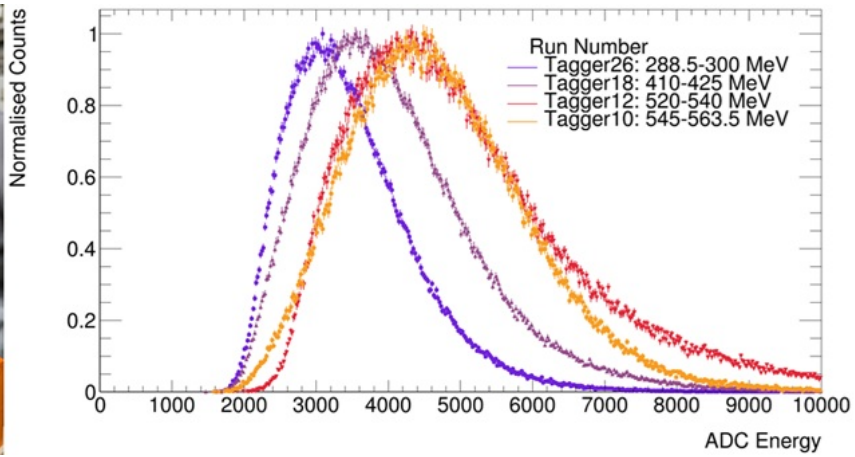

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- Need for more advanced readout clear

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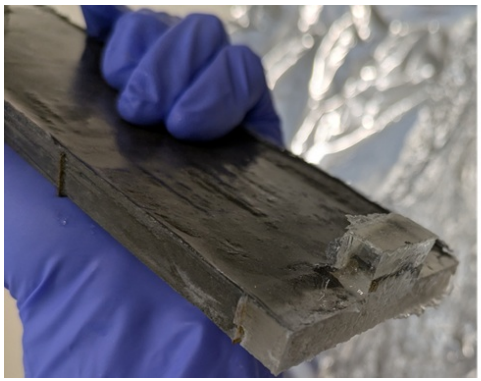
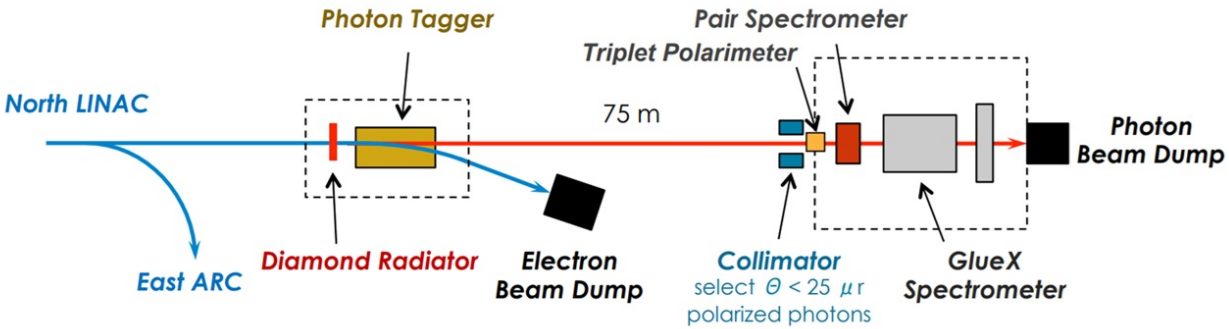
- Plan to run tests in Hall D, $\sim$ late spring 2026
  - $\sim$1-6 GeV e^- at pair spectrometer station





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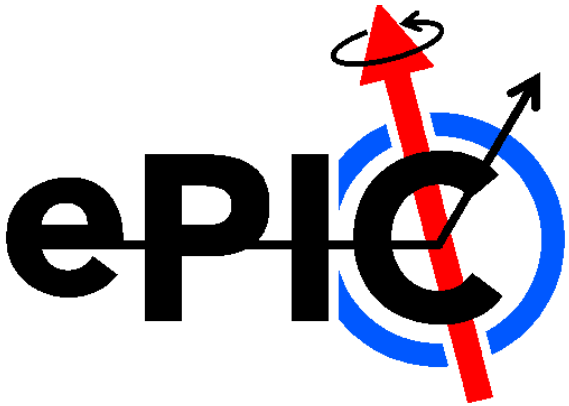
  - Prototype design and construction process finished
  - Utilised prototypes in two beam tests
- Applying lessons learned from prototyping phase to develop full production protocol and procedure
- On track for a further beam test next year and full production following this $\rightarrow$ Potentially 180+ modules to make!

Thanks for listening, any questions?



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Science and Technology Facilities Council

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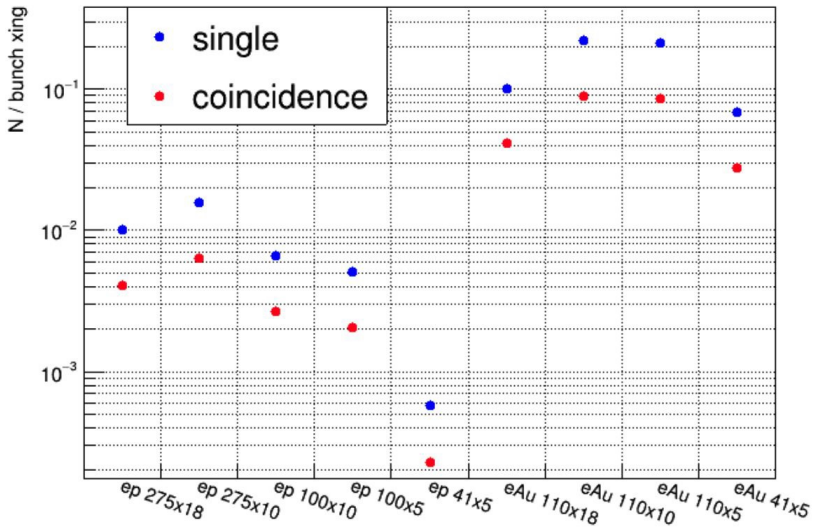
Backup Zone

Pair Spectrometer - Expected Rates

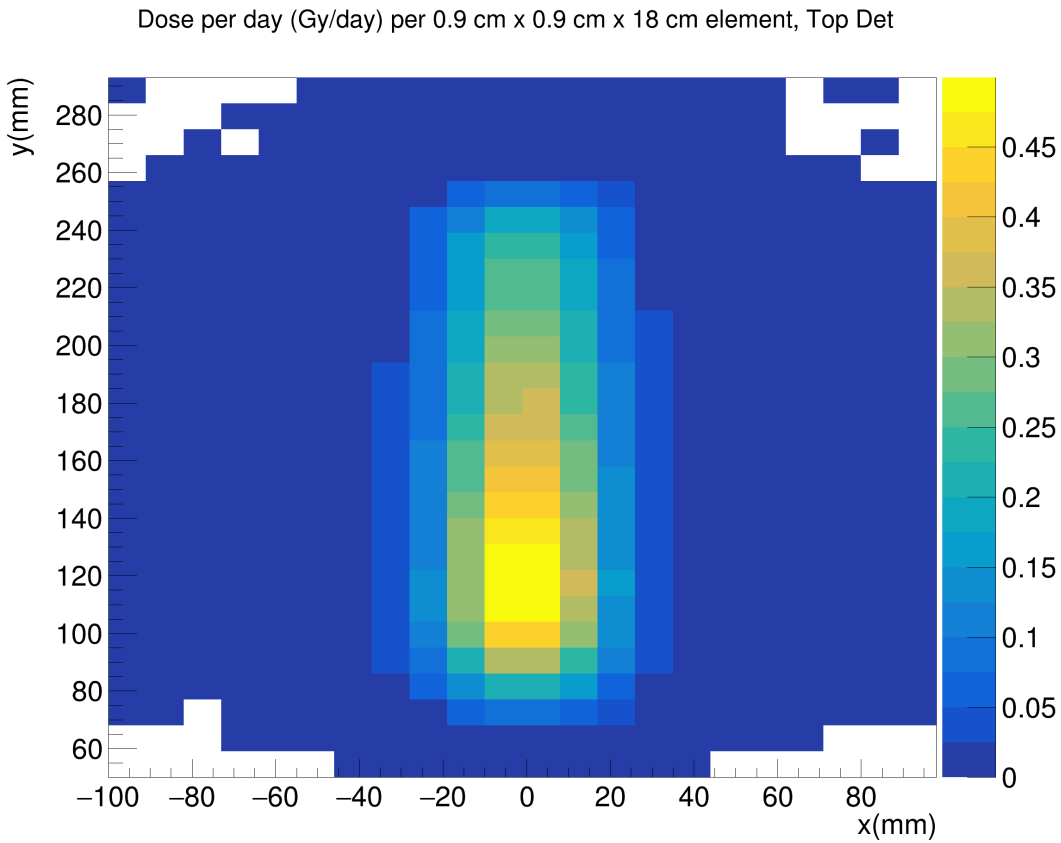
- Expected signal rates using nominal $\mathcal{L}$, accounting for -

- 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



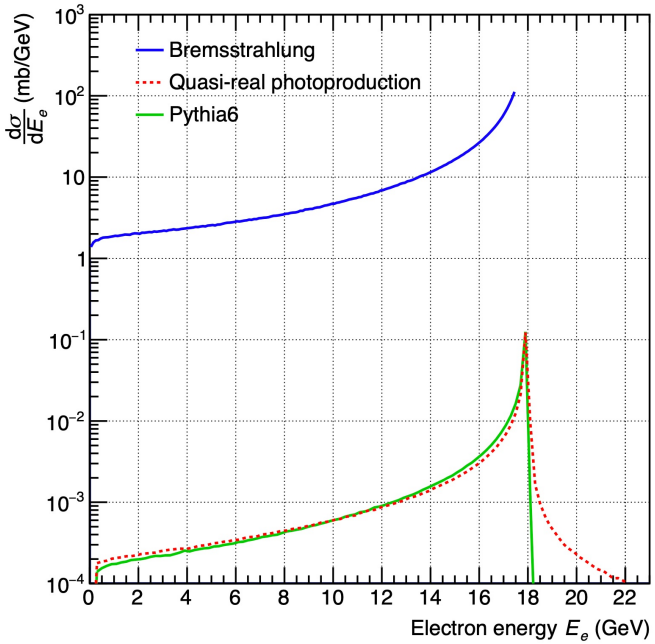
Pair Spectrometer - Radiation Dose

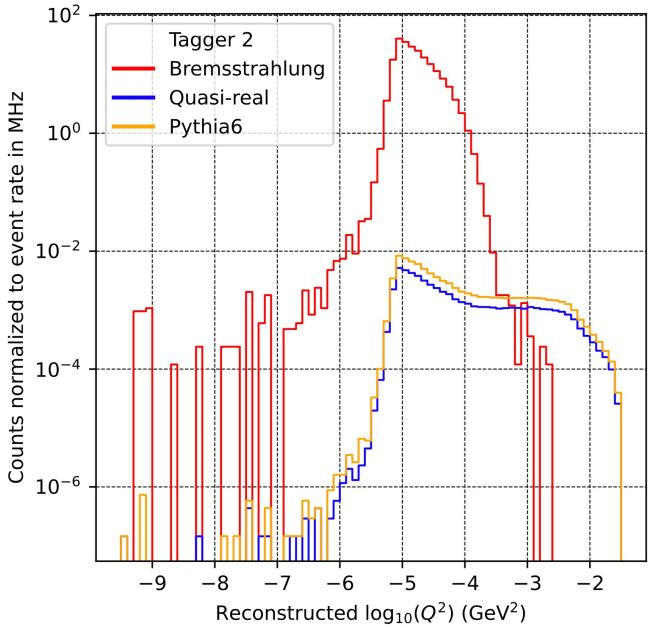
- Using DD4HEP simulation, evaluated dose
- In highest rate config, max fiber dose ~ 1 MGy/100 fb^{-1}
- Dose is predominantly along a strip in middle of detector



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

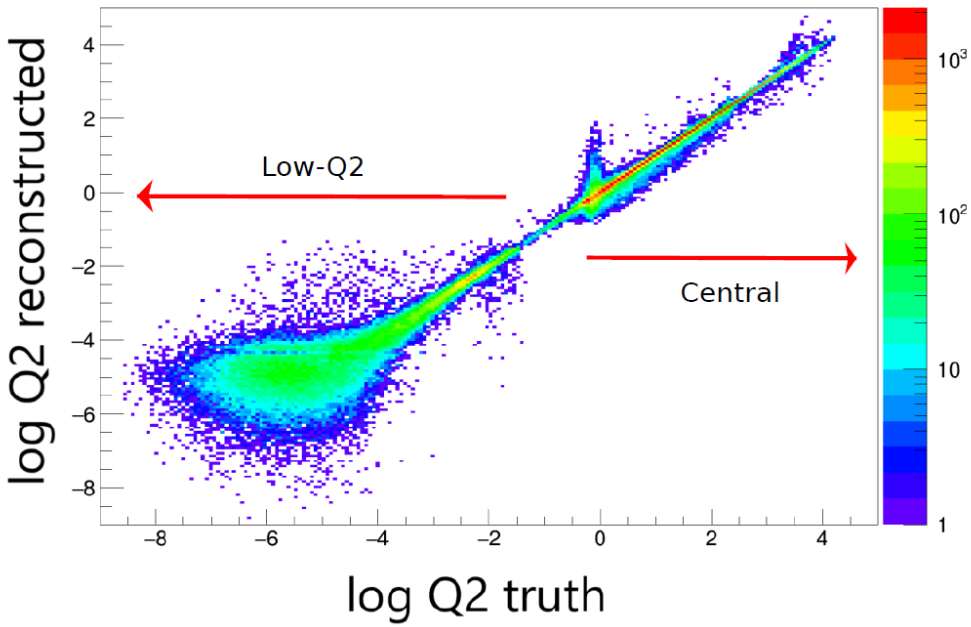
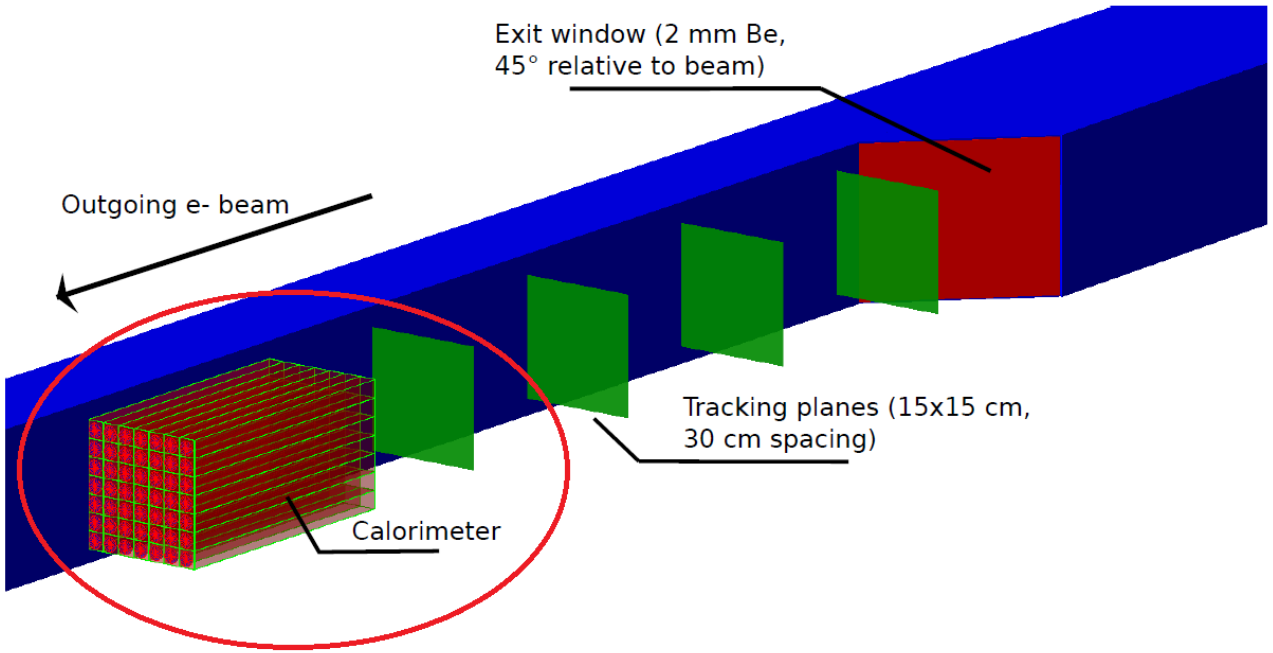


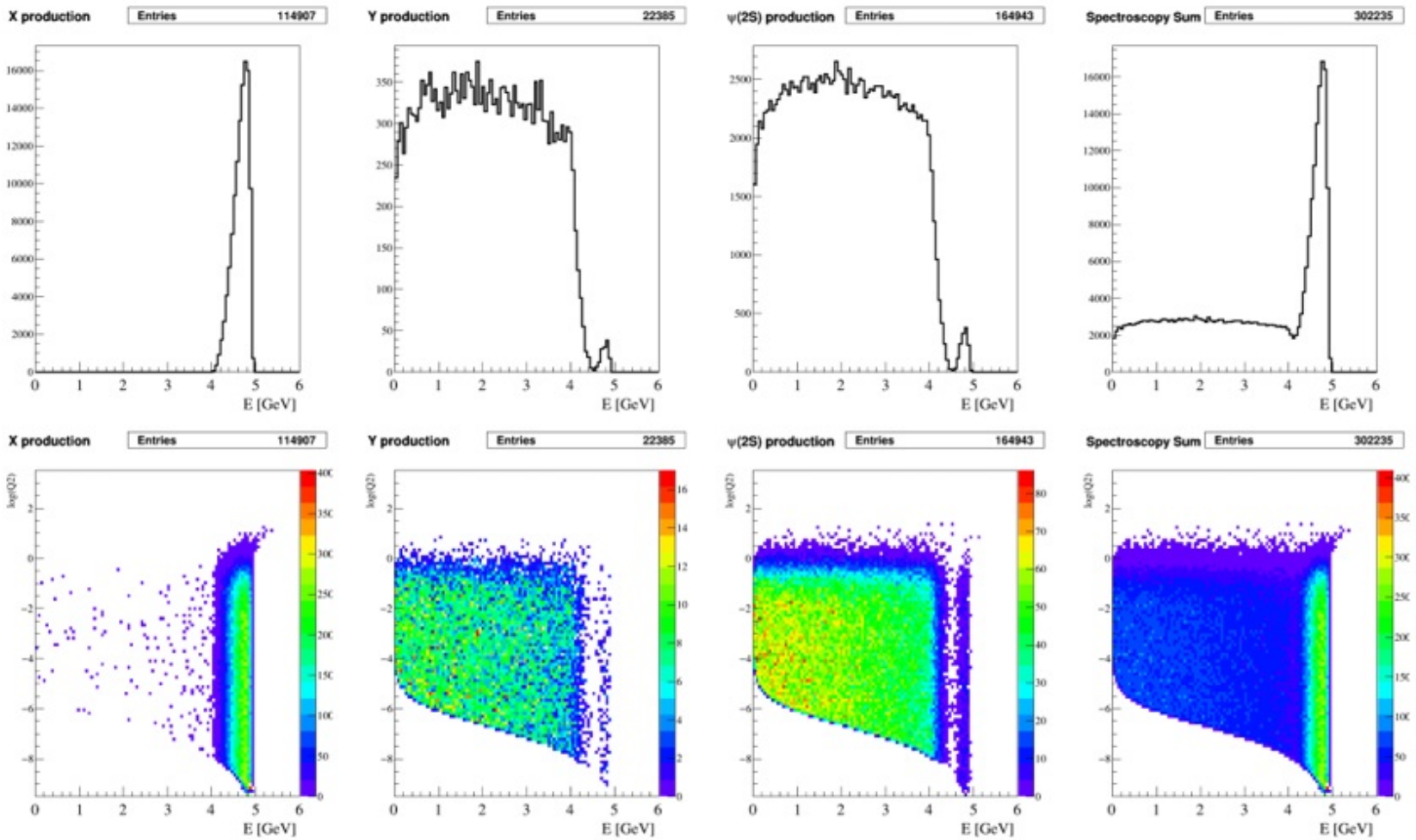
Figure - J. Adam, CTU Prague, ePIC Collaboration meeting July 2023

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