

Far-Backward Pair Spectrometer

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[Pair Spectrometer Wiki Page:](#)

ePIC collaboration meeting
Warsaw, July 29th 2023

Measuring Luminosity at the EIC

Experimental Goal:

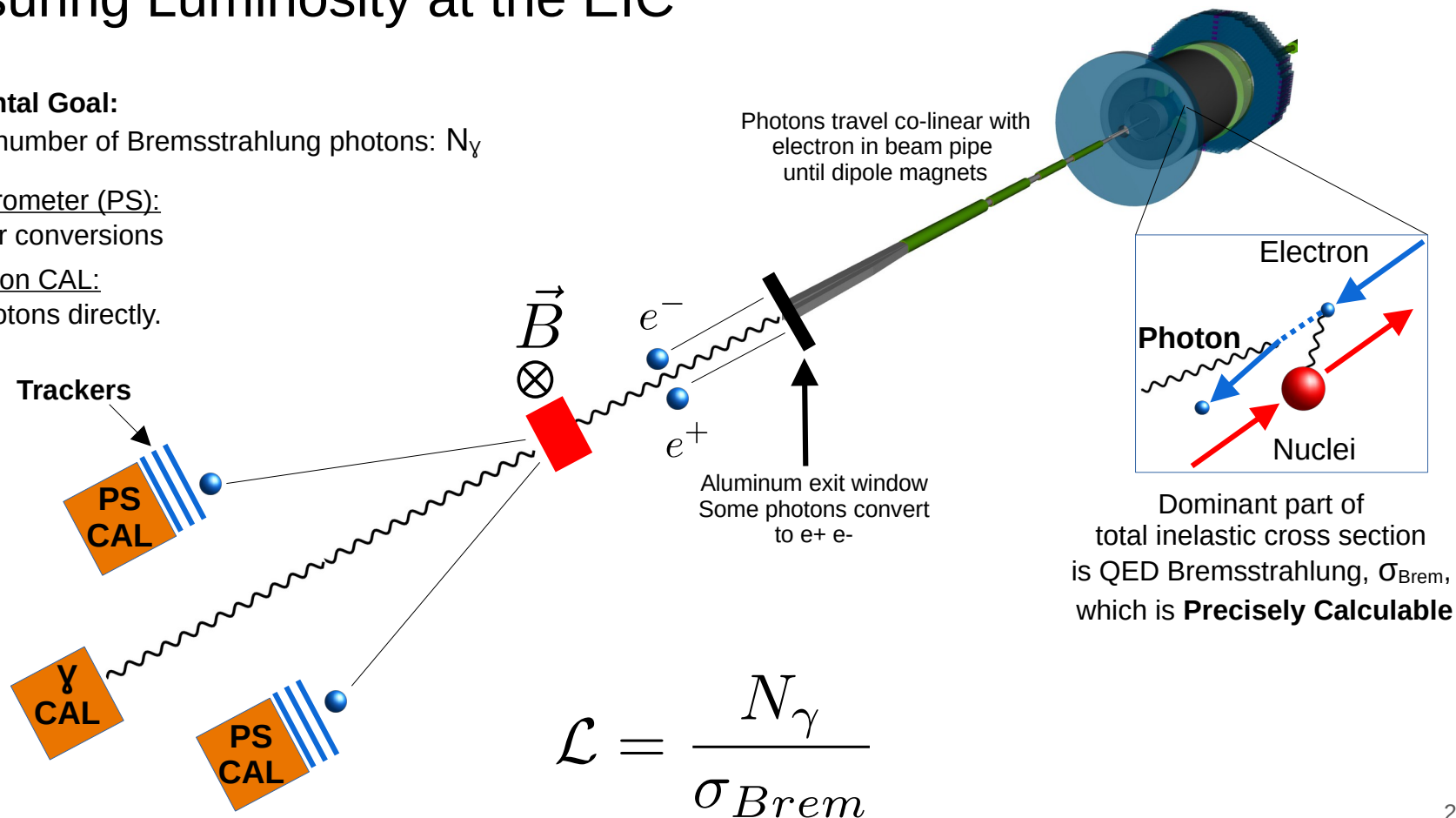
Count the number of Bremsstrahlung photons: N_γ

Pair Spectrometer (PS):

Counts pair conversions

Direct photon CAL:

Counts photons directly.



Lessons Learned from ZEUS Lumi Systematics

EIC Yellow Report Requirements:

- ~1% uncertainty for absolute luminosity.
- Less than 10^{-4} for relative lumi.

NIM A 744 (2014) 80-90

<u>Component</u>	<u>Sub-Component systematics</u>
Acceptance (1.6%: Total)	1.0%: Aperture and detector alignment
	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
Total	1.8%

Reduction routs for ePIC:

- 1) 5σ obstruction-free aperture
- 2) low-lumi runs with coincidences of low-Q2 tagger and pair spec.
Tagger critical for pair spec calibration/verification

With a well understood acceptance, 1% absolute lumi precision within reach.

For relative lumi, all systematics should cancel, and required statistical precision reached in less than 1 hour.

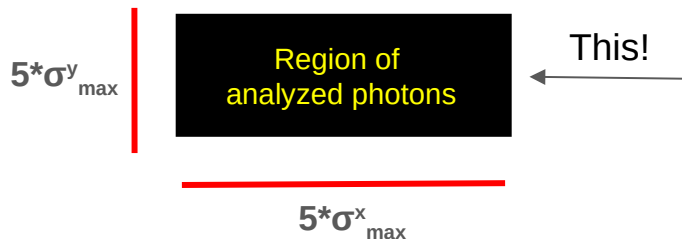
Photon Acceptance

Need to provide an unobstructed path for Bremsstrahlung photons to propagate from the IP to the lumi exit window, and then from the exit window to the Pair Spectrometer.

Photon beam width $\sigma(Z) = \Delta\theta$ (electron beam divergence) * Z .

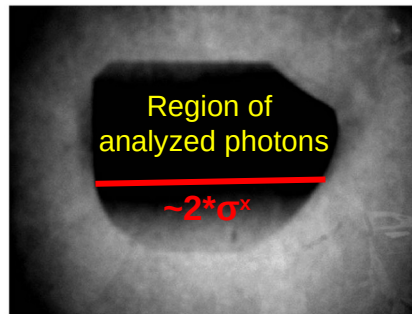
$3\sigma_{\text{Gaus}}$ covers 99.7% of population, but beam may not be Gaussian and it's preferable not to extrapolate.

$5\sigma_{\text{max}}(Z)$ conical region should provide adequate acceptance.



Not this!

ZEUS photon aperture



This was the dominant source of uncertainties for the HERA luminosity

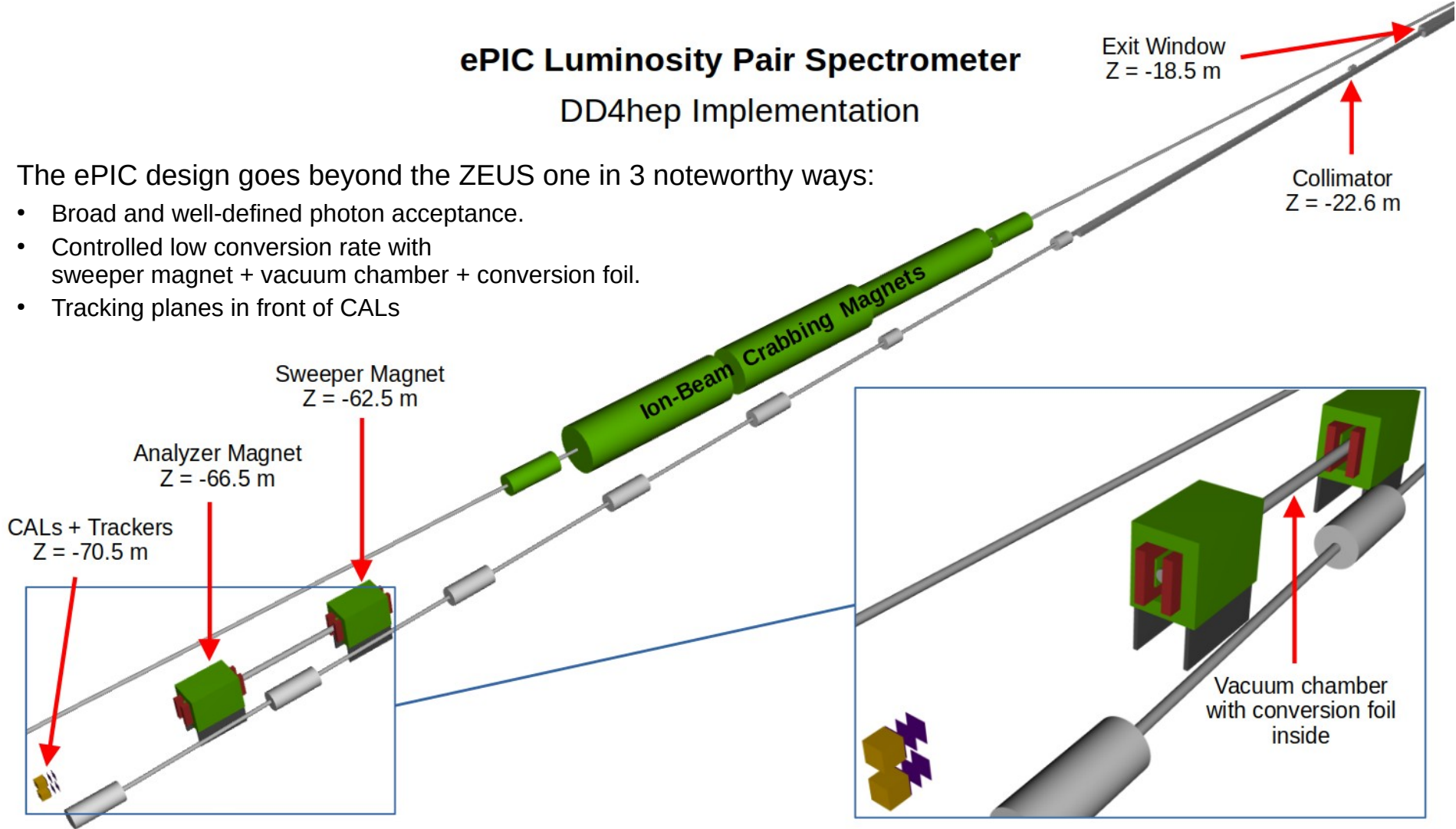
We need a simple and broad acceptance!

ePIC Luminosity Pair Spectrometer

DD4hep Implementation

The ePIC design goes beyond the ZEUS one in 3 noteworthy ways:

- Broad and well-defined photon acceptance.
- Controlled low conversion rate with sweeper magnet + vacuum chamber + conversion foil.
- Tracking planes in front of CALs



Design Considerations – System Placement

- The Pair Spectrometer system starts 62 m from the IP, and 43.5 m from the vacuum exit window.
- That's lots of air for the photons to travel through. The EM radiation length in air is 304 m.

$$P_{conv} = 1 - e^{-\frac{\Delta Z}{(X_0^{9/7})}} \approx 10\%$$

$$\begin{aligned} X_0^{\text{air}} &= 304 \text{ m} \\ \Delta Z &= 43.5 \text{ m} \end{aligned}$$

- 10% of the Bremsstrahlung photons will convert in air before arriving at the sweeper magnet.
- That's OK.
- The pair-conversion and Bremsstrahlung cross sections are cross channels of the **same** reaction.

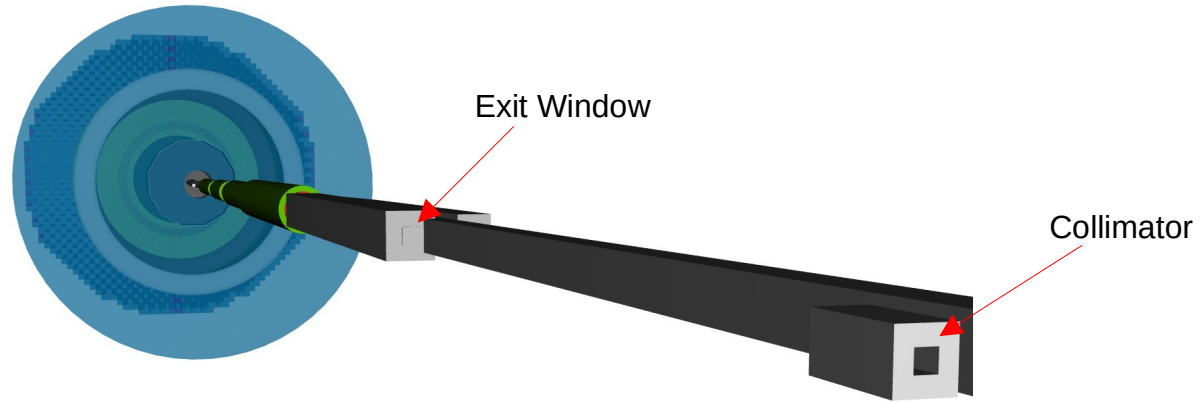
$$e^- + p^+ \rightarrow e^- + \gamma + p^+$$

$$\gamma + p^+ \rightarrow e^- + e^+ + p^+$$

- Bremsstrahlung cross section known to at least 0.2%. Conversion uncertainty $\sim 10\% * 0.2\% = \mathbf{0.02\%}$.

Negligible contribution to lumi systematics.

Design Considerations – Exit Window and Collimator



Exit Window (Z = -18.5 m)

- It should have a simple geometry: constant effective thickness vs X and Y.
- Thickness and chemical composition (a% Al + b% Si + ...)
needs to be precisely known before installation!
- Conversion rate in exit window can also be determined in special low-lumi runs by turning off the sweeper magnet

Collimator (shortly after the exit window)

- Just a block of steel to shield our downstream detectors from unnecessary radiation damage.
- It defines the outer limits of our acceptance (aperture size).
- Should have an opening half-width of $5 * \Delta\theta_{\max} * Z = 5 * 211\text{e-}6 \text{ rad} * 22.6 \text{ m} = 2.4 \text{ cm}$

Design Considerations – Dipole Magnets

Sweeper & Analyzer Dipole Magnets Requirements

- Large $\int B_x \cdot dz \sim 1 \text{ Tm}$ to keep our system compact
- 15 cm bore diameter: 5σ unobstructed photon acceptance
- Fringe fields at electron beam pipe < 10 Gauss

New magnets are to be built.

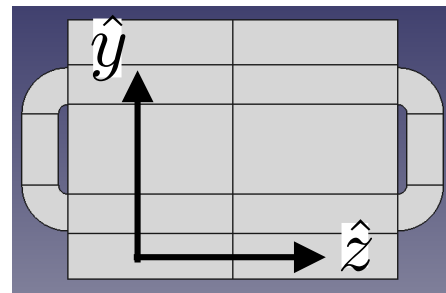
Magnet designer Peng Xu (BNL)

has designed and simulated the magnets for us.

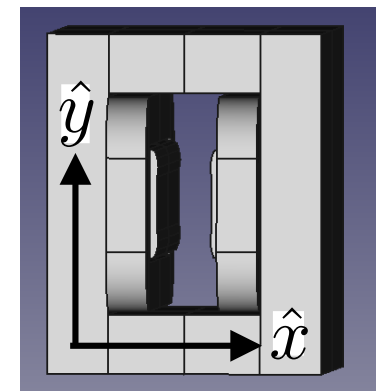
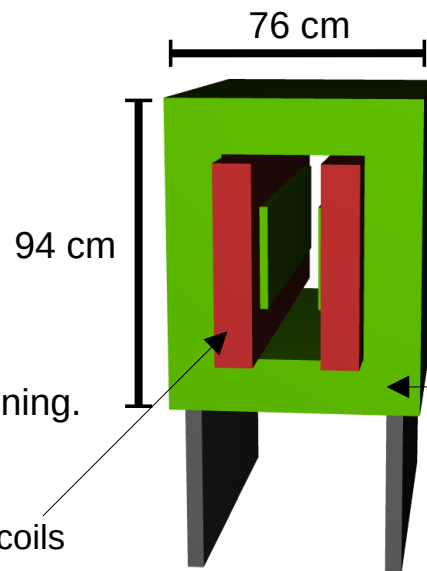
Design properties:

- 1.2 m long with field reaching about 0.8 T
- 15 cm bore diameter
- Fringe field at electron beam pipe < 4 Gauss.
- 6 metric tons each, excluding leg supports.
- Pre-covid cost: ~\$3 per kg of soft iron, including machining.
> \$20k per magnet.

Peng's CAD model



DD4hep model



DD4hep model by
Justin Chan (UH)

Design Considerations – Vacuum Chamber

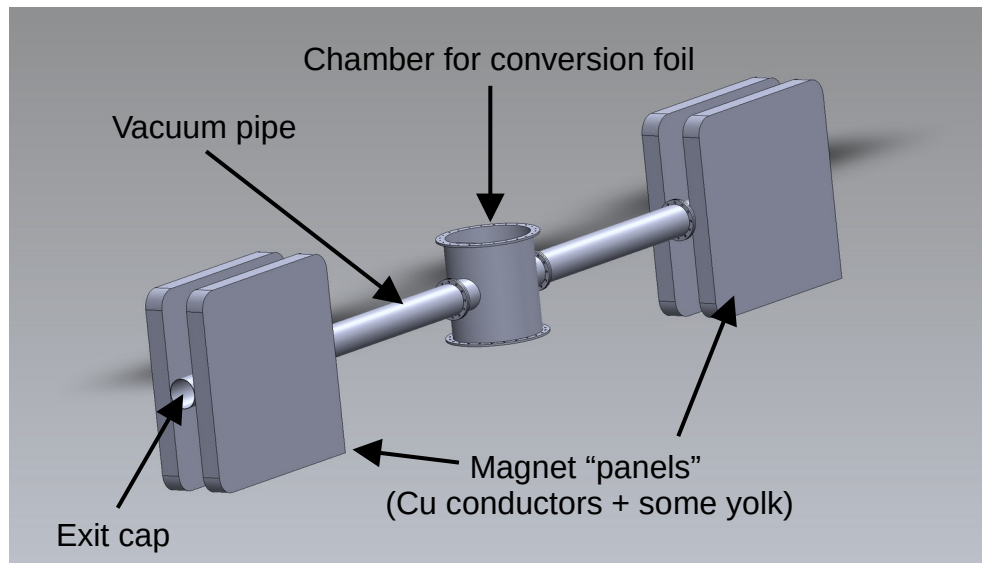
Vacuum chamber ($-67 \text{ m} < Z < -62 \text{ m}$)

- Allows us to precisely control the $Bx \cdot dz$ for the conversion electrons. Conversions in air in magnet smear the $Bx \cdot dz$.
 - Easier to get a well defined electron acceptance.
- Foil inside allows us to precisely control the rate of conversions by varying its thickness
 - Avoids pileup.

Studies underway by Igor:

- Exit cap optimization (thickness and material)
 - minimize $e^+ e^-$ multiple scattering.
- Conversion foil thickness and cooling method. Must withstand synchrotron rad heating.
- Vacuum pressure:
 - First, compare conversion rates:
 - 1 mm Al conversion foil: $P_{\text{conv}} = 0.9\%$.
 - 5 m of STP air (10^3 mbar) inside $P_{\text{conv}} = 1.3\%$
 - To reduce conversions in air to well below 1% that of foil, we need a **vacuum with $< 1 \text{ mbar}$** .
Note that vacuum near the IP = 10^{-9} mbar

Igor Korover (MIT & Tel Aviv University)

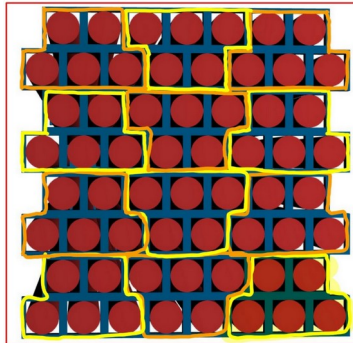
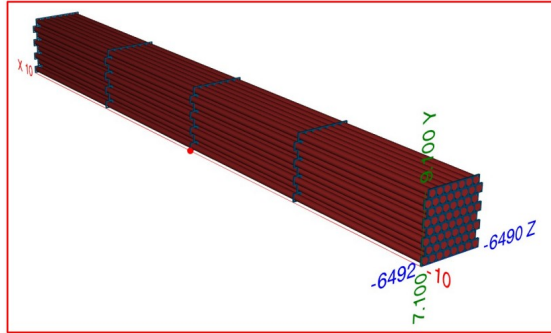
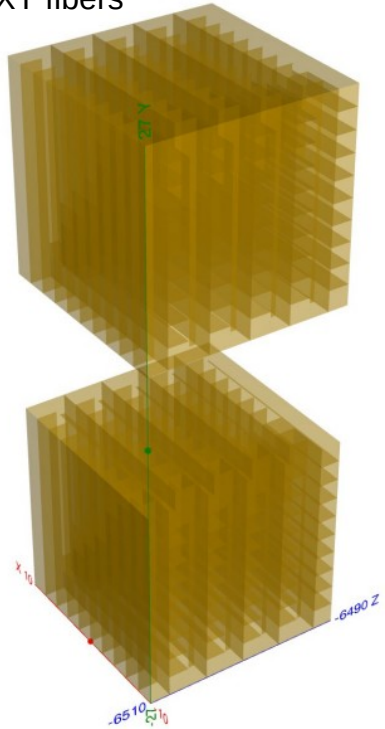


July 11th 2023 PS meeting

Design Considerations - CALs

Design by Aranya Giri

2D
XY fibers

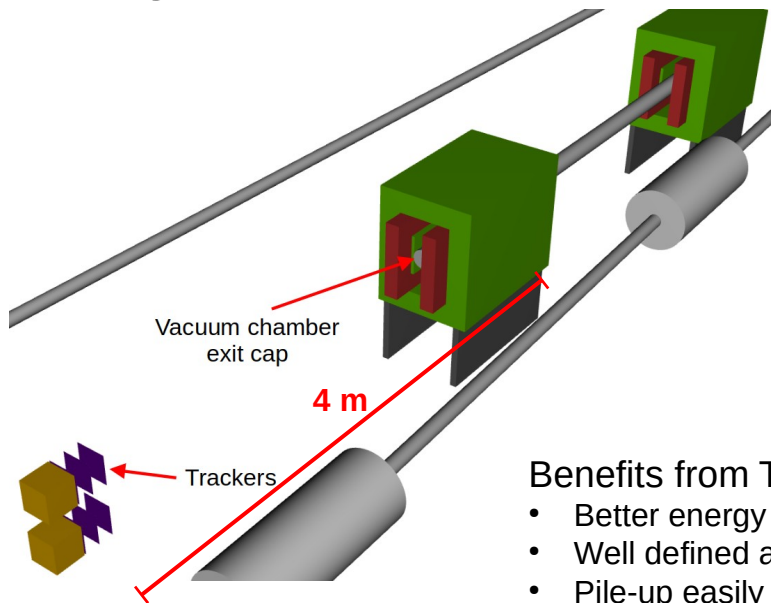


Construction of each module can follow the method of Oleg Tsai, W-powder + epoxy infused into a bundle of scintillating fibers (like fECAL). We are exploring a 2D XY fiber design: more detailed shower profiling.

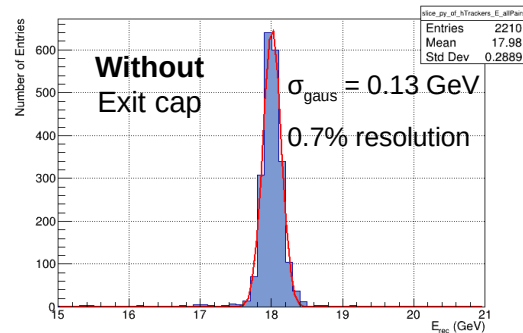
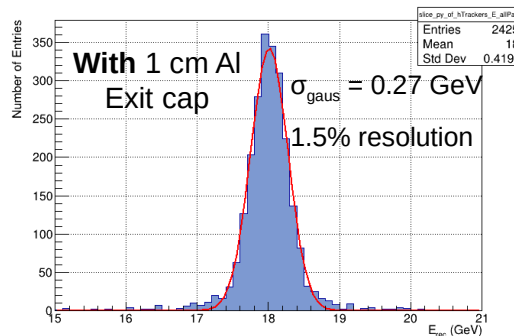
- Calorimeter size - $20 \times 20 \times 20 \text{ cm}^3$
- Alternating Layer of Y-rot and X-rot module
- Each Layer has 10 modules
- Module size - $2 \times 2 \times 20 \text{ cm}^3$
- Fiber Size - radius - 0.1 cm , height - 20 cm
- Fiber # in a module - 60
- W-Scifi Ratio - 1 : 1
- Fiber Holder
 - Material - Brass
 - thickness - 0.05 cm
 - 5 x Fiber Holders 5 cm apart
- 5 closest fibers are bundled to make a single readout channel.

University of York In kind contribution (awaiting decision on proposal)

Design Considerations - Trackers



Energy Resolutions for 18 GeV electrons



Benefits from Tracking Planes in front of CALs:

- Better energy resolutions attainable than from CALs.
- Well defined acceptance, no “fuzzy” edges as with CALs.
- Pile-up easily identified and treated.
- Tracks allow rejection of background particles (beam-gas) and assessments of the electron beam divergence.

3 Timepix4 tracking planes assumed so far, but given the rough \$2M price tag, we will explore the performance with 2 or even just 1 plane (acceptance and pile-up treatment only).

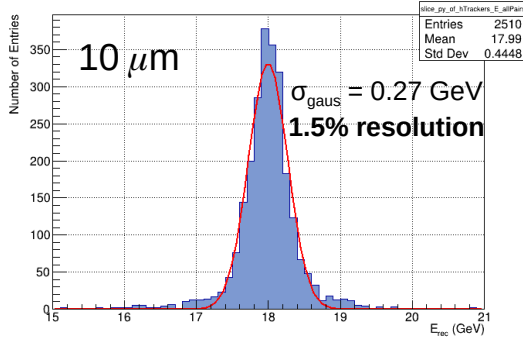
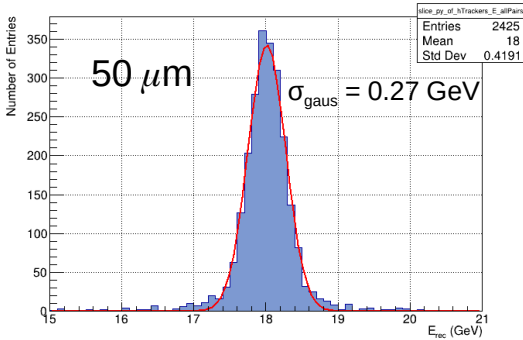
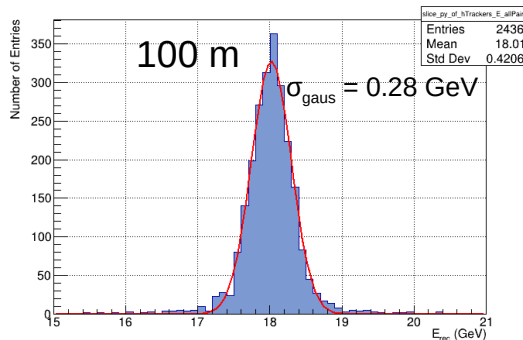
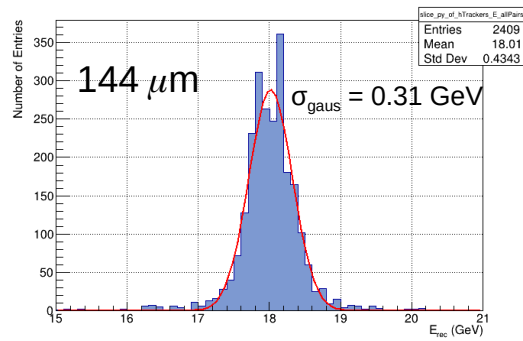
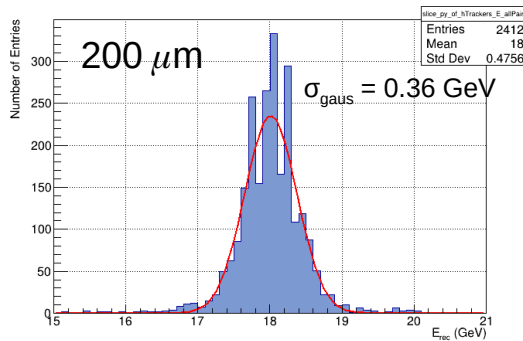
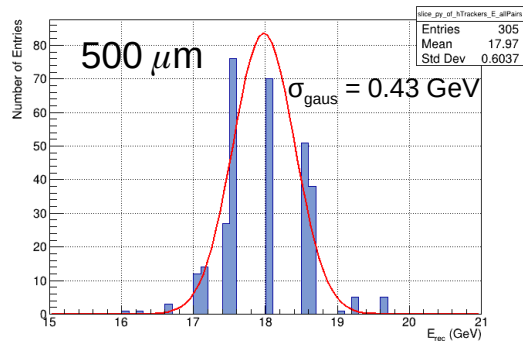
In principle, either trackers or CALs alone can do the job, but having both is advantageous

Concluding Remarks

- EIC bremsstrahlung rates will be much higher than those at HERA.
 - More sophisticated pair spectrometer design wrt ZEUS needed for precise lumi at the EIC.
- Having a simple and broad photon acceptance is very important for the Lumi program.
 - No obstructions to our $5\sigma(Z)$ conical photon beam, please.
- New dipole magnets (sweeper + analyzer) have been designed that satisfy our requirements.
 - Allows our system to be quite compact.
 - Awaiting final calculation of field maps by Peng Xu.
- CAL design will follow the W-powder + SciFi design used in the forward ECAL.
 - 2D XY fiber design being considered.
- Tracking planes provide many benefits to the system and should to be included.
 - Number of planes needed to be determined.
- Side note: electron bunches with no colliding ion bunch (pilot bunches) are required for measurements of beam-gas backgrounds to the lumi measurements.

Backup

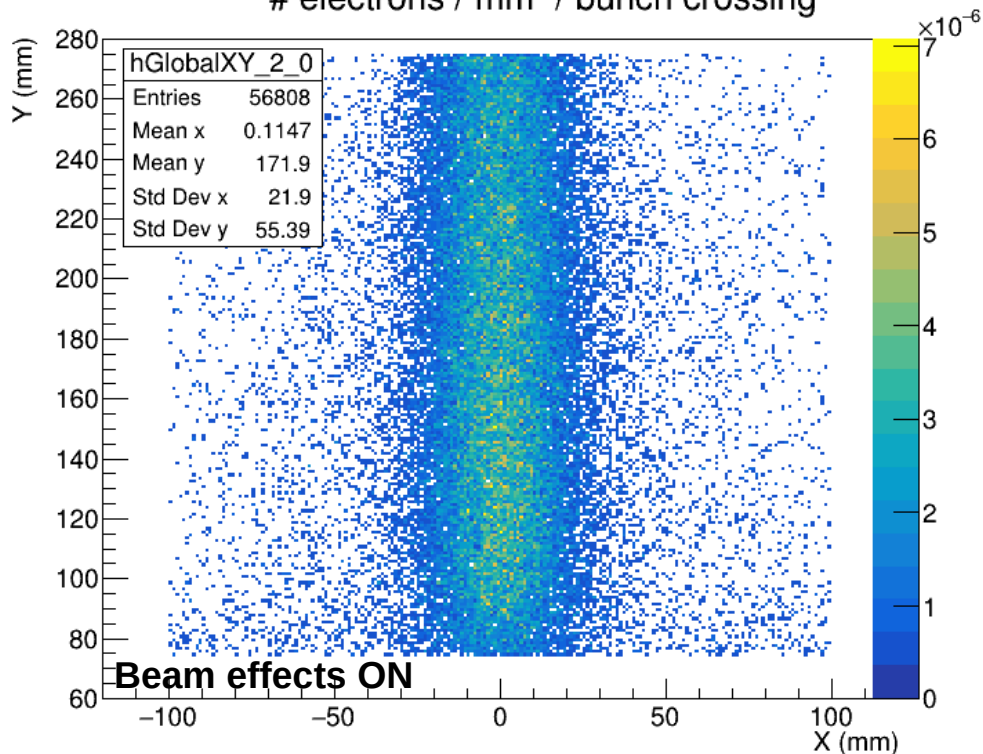
Trackers - Pixel Size and Energy Resolutions



- Clear discretization effects visible for “large” pixels, due to small angular range of tracks: $\sim 0.7^\circ$ to $\sim 4^\circ$.
Note, charge-sharing effects would improve E resolutions somewhat.

ep 18x275 (44 ns bunch spacing)

electrons / mm² / bunch crossing



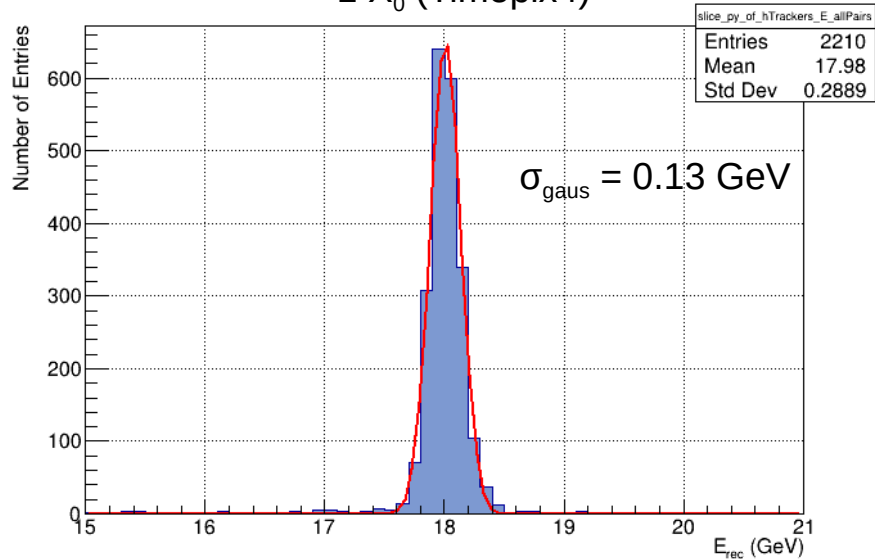
~ 10^{-5} electrons per mm² per bunch crossing.

~ 10^{-5} electrons per 55 μ m pixel per bunch crossing in the “brightest” eA setting.

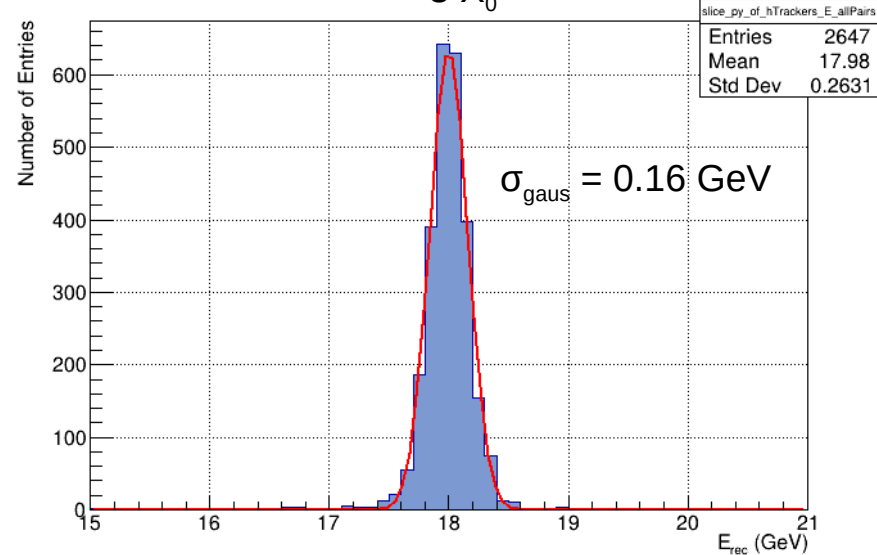
**Large sensor integration times
are not a problem (even μ sec level).**

50 μm without exit cap

1 X_0 (Timepix4)



3 X_0



No stringent requirement on the sensor material budget.

Summary of Tracker Requirements

Total sensor Area	$2 \text{ sets} * 3 \text{ layers} * 20 \text{ cm} * 20 \text{ cm} = 2,400 \text{ cm}^2$
Pixel size	$\sim 50 \text{ um}$
Material budget	no stringent requirements
Integration times	no stringent requirements
Time resolution	$\sim \text{nsec}$, to distinguish bunch crossings

Considered technologies for the Trackers:

- **Timepix4 (preferred option so far)**
- Microstrips (quote from a company on next slide)
- AC-LGAD
- AstroPix
- MAPS

Microstrip sensors

For what its worth...here is a price quote I obtained for microstrips that might suite our needs

Product Catalogue



Micron Semiconductor Limited

Units 1-5 Royal Buildings
85 Marlborough Rd
Lancing
West Sussex
United Kingdom
BN15 8SJ
Tel: +44 1903 755252

Company Registration No: 1694255 England
VAT No: GB 376 8710-14
EORI No: GB 376 8710 14000

E-Mail: sales@micronsemiconductor.co.uk
www.micronsemiconductor.co.uk

Description	Quantity	Unit Price	VAT	Amount USD
DDD5 (DS) 300 2M/2M AC coupled chip only detectors	120.00	5000.00	Zero Rated	600000.00
NRE custom dedicated test and shipping trays for sample testing, shipping and storage	120.00	175.00	Zero Rated	21000.00
NRE masks	2.00	1850.00	Zero Rated	3700.00
NRE probe cards; 128 channels	2.00	1250.00	Zero Rated	2500.00
NRE copy masks	12.00	650.00	Zero Rated	7800.00
NRE Silicon 5K - 10K N Type <1-0-0> 6 inch	100.00	150.00	Zero Rated	15000.00
Prices US dollars FOB destination				
		Subtotal		650000.00
		Total Zero Rated		0.00
		TOTAL USD		650000.00

DDD5 dual sided Si microstrips

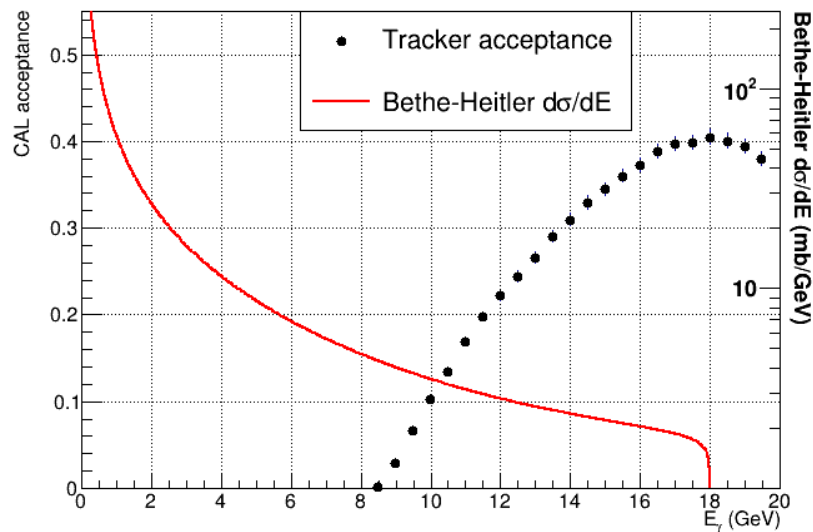
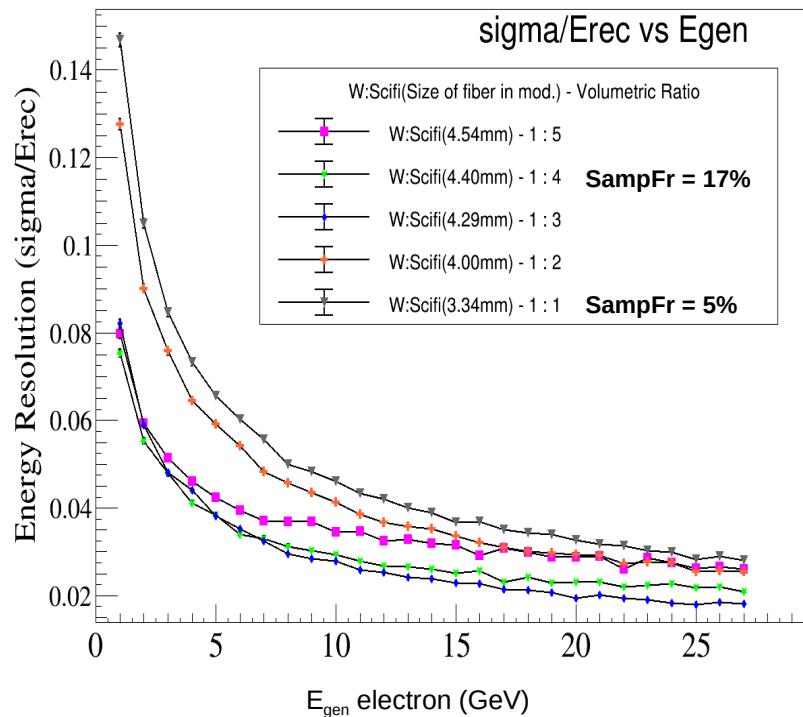
- 50 um pitch

- orthogonal dual sided strips
not sure if readouts from both sides could be read out from one end

- 2 cm x 12 cm chips (need 120 of them)

This price doesn't include ASICs, assembly, etc.
Appropriate total could be well over \$1M.

Current CAL design results (fibers running along X & Y)



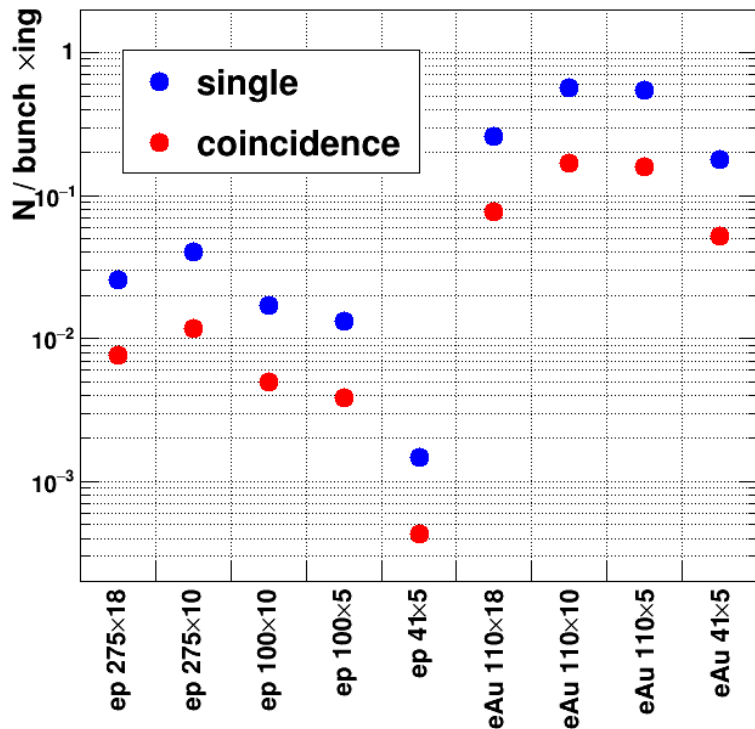
- For the most “bright” eA runs, we want such an acceptance to keep the rates low.
- For dimmer ep runs, we can shift the acceptance curves to the left by lowering our B fields.

- Need to study the how the Moliere radius changes with W:SciFi ratios (need to keep it small).

Expected Rates of electrons at spectrometer CALs

Bethe-Heitler formula for unpolarized ep Bremstrahlung

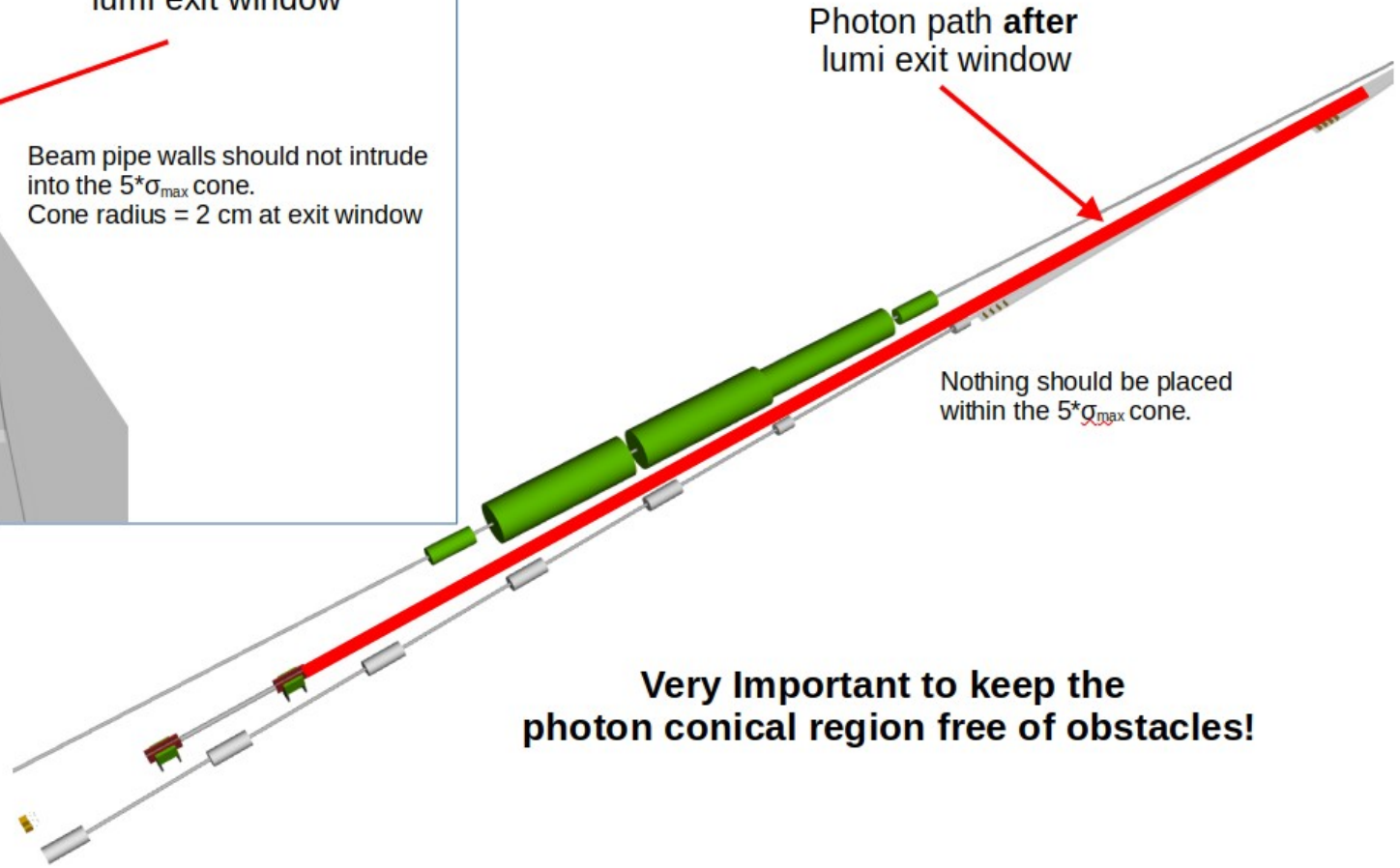
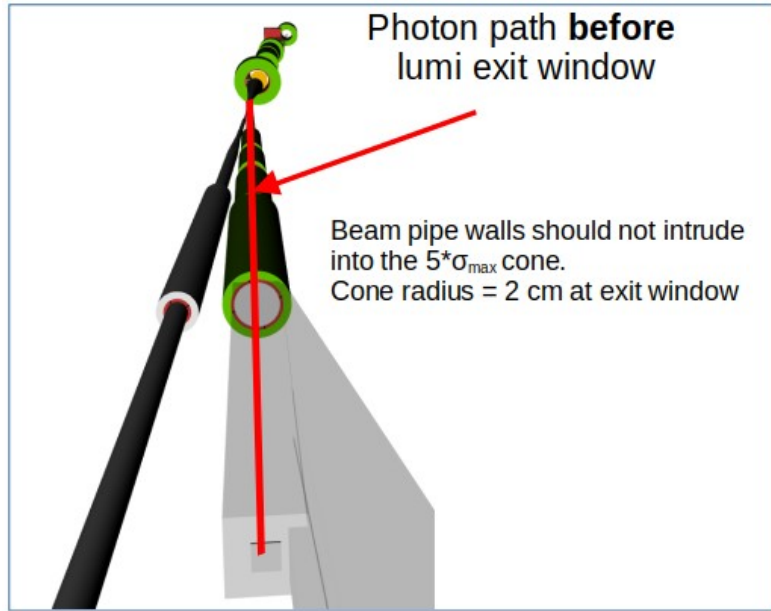
$$\frac{d\sigma}{dE_\gamma} = 4\alpha Z^2 r_e^2 \frac{E'_e}{E_\gamma E_e} \left(\frac{E_e}{E'_e} + \frac{E'_e}{E_e} - \frac{2}{3} \right) \left(\ln \frac{4E_p E_e E'_e}{m_p m_e E_\gamma} - \frac{1}{2} \right)$$



- Bremstrahlung σ is much larger for eAu than ep, but the bunch luminosity will be lower for eAu.
- These rates depend also on the design (acceptance) of the spectrometer CALs as well as the converter thickness (1 mm Al).
- **Pileup greatly suppressed with low conversion rate!**

See Bill Schmidke's [talk](#)
for studies assuming 10 mm converter

General Pair Spectrometer Requirements



Work Packages

