Luminosity Spectrometer

Dhevan Gangadharan & Aranya Giri (University of Houston)
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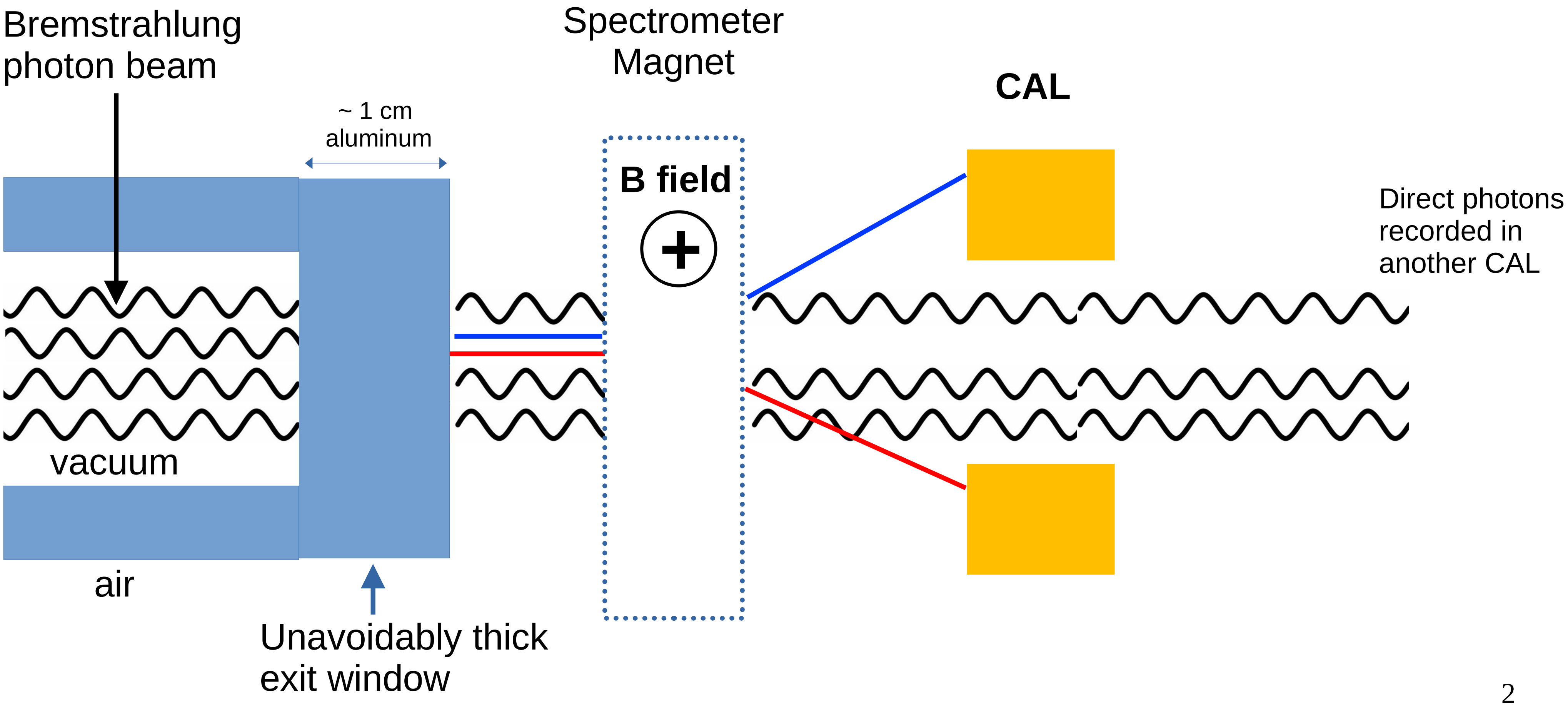
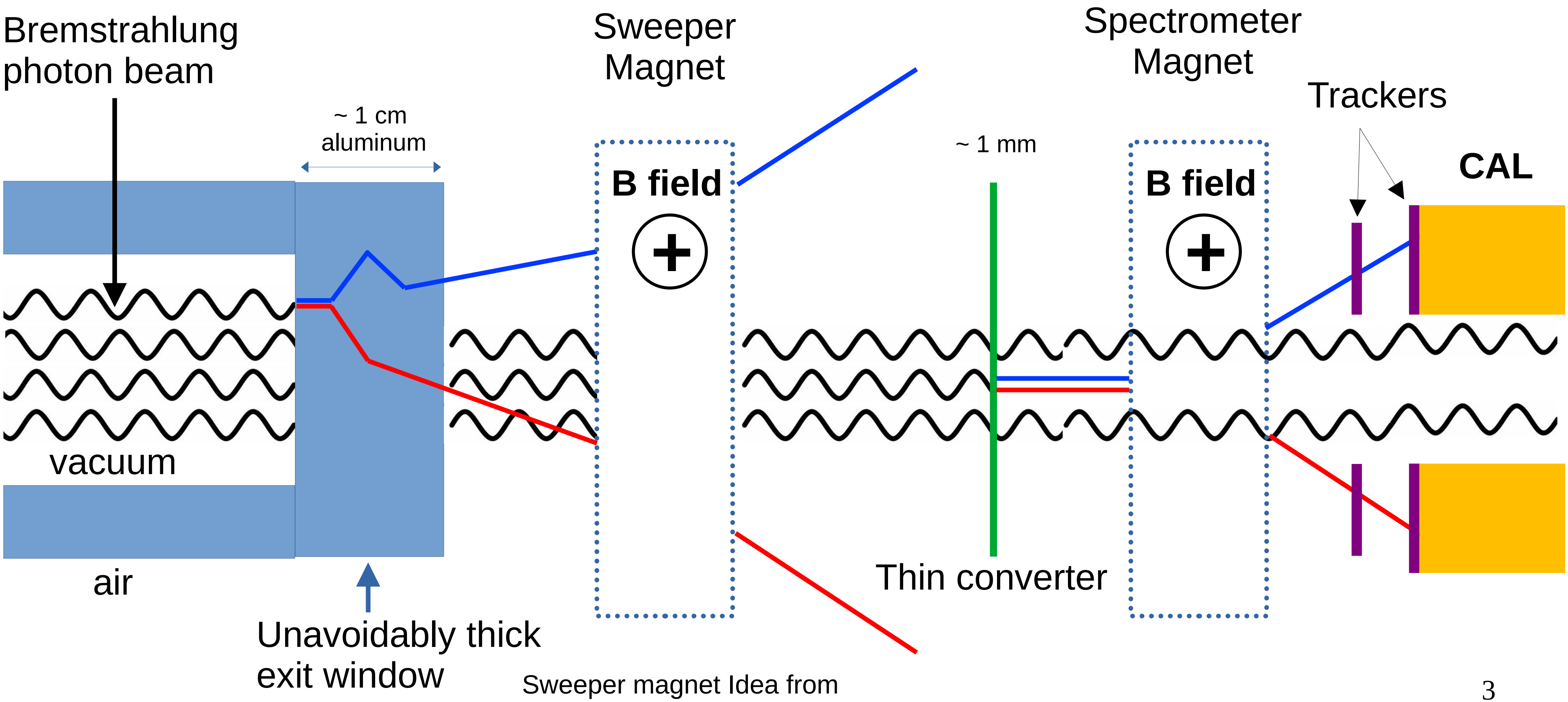
Basic idea of ZEUS spectrometer



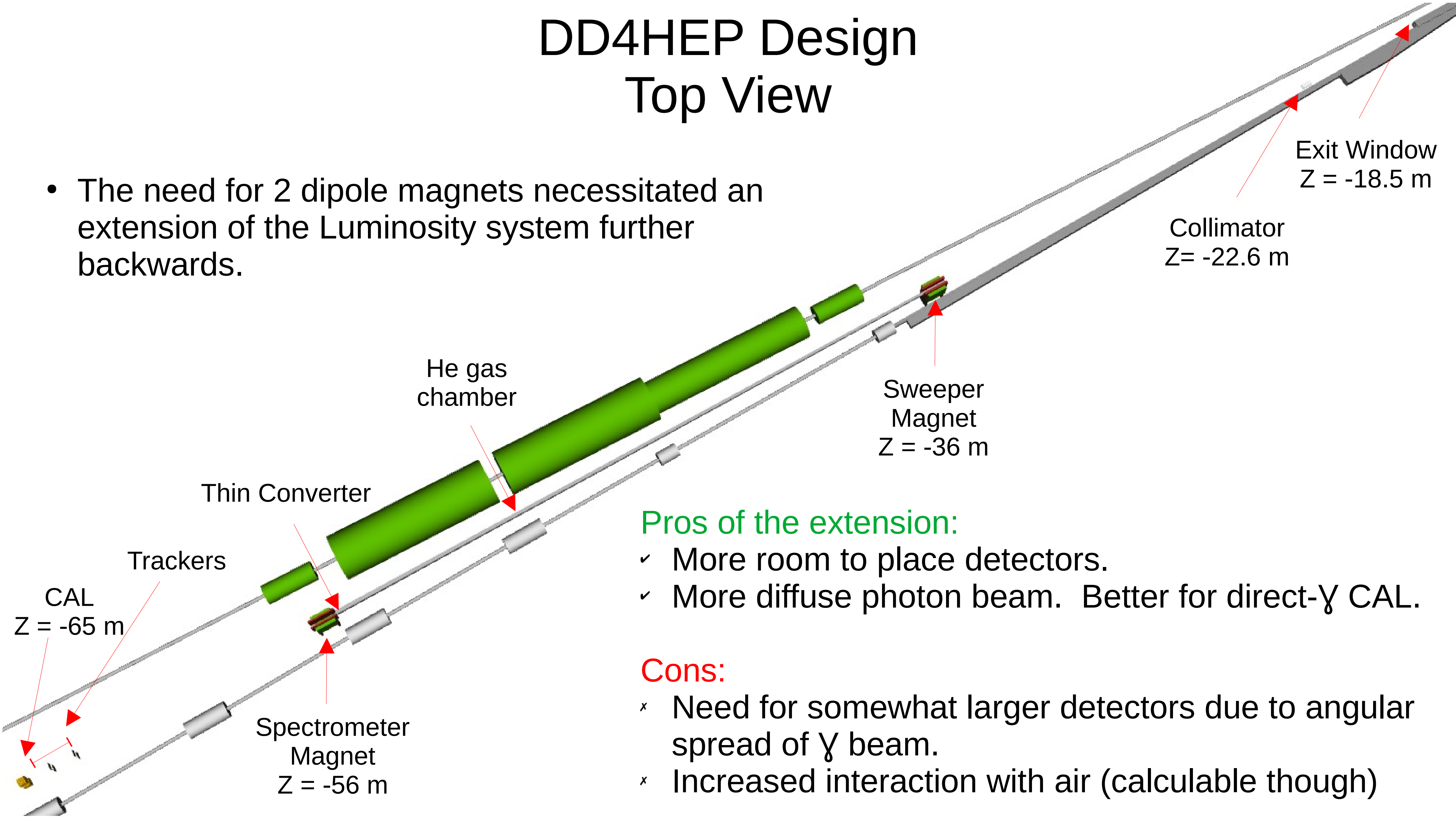
New work-in-progress design of **ePIC** spectrometer



Sweeper magnet Idea from
Krzysztof Piotrzkowski

DD4HEP Design
Top View

- The need for 2 dipole magnets necessitated an extension of the Luminosity system further backwards.



Pros of the extension:

✔ More room to place detectors.

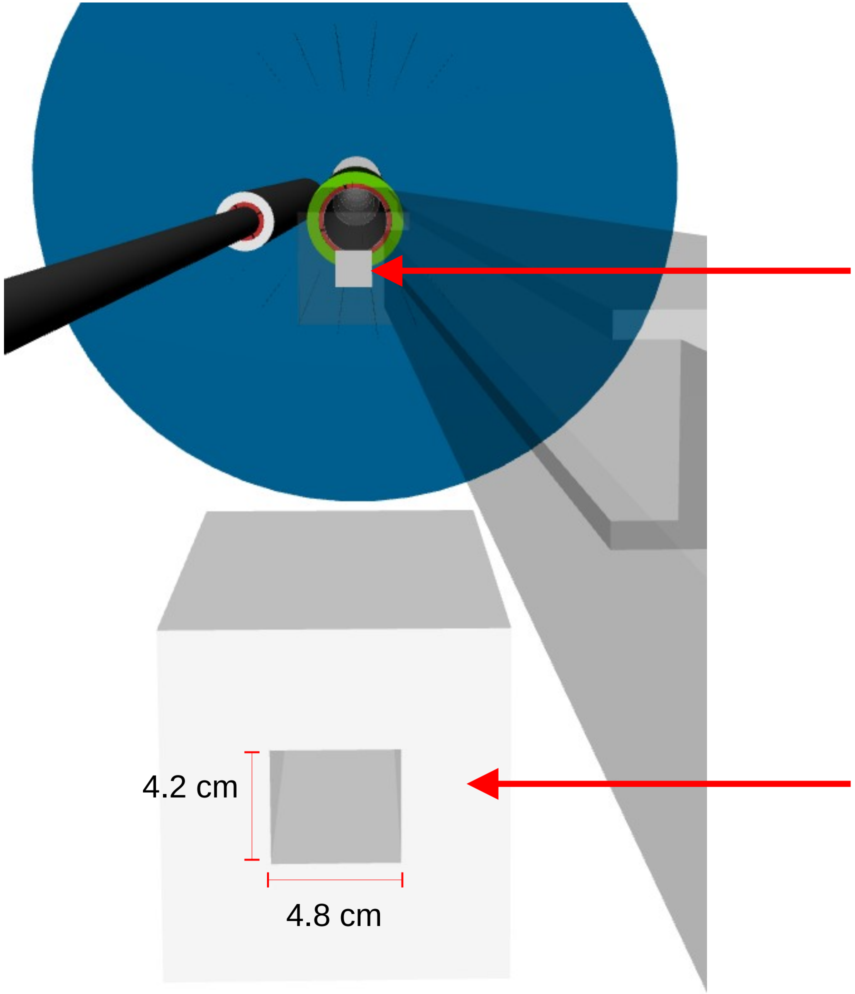
✔ More diffuse photon beam. Better for direct-ɣ CAL.

Cons:

✗ Need for somewhat larger detectors due to angular spread of ɣ beam.

✗ Increased interaction with air (calculable though)

DD4HEP Design



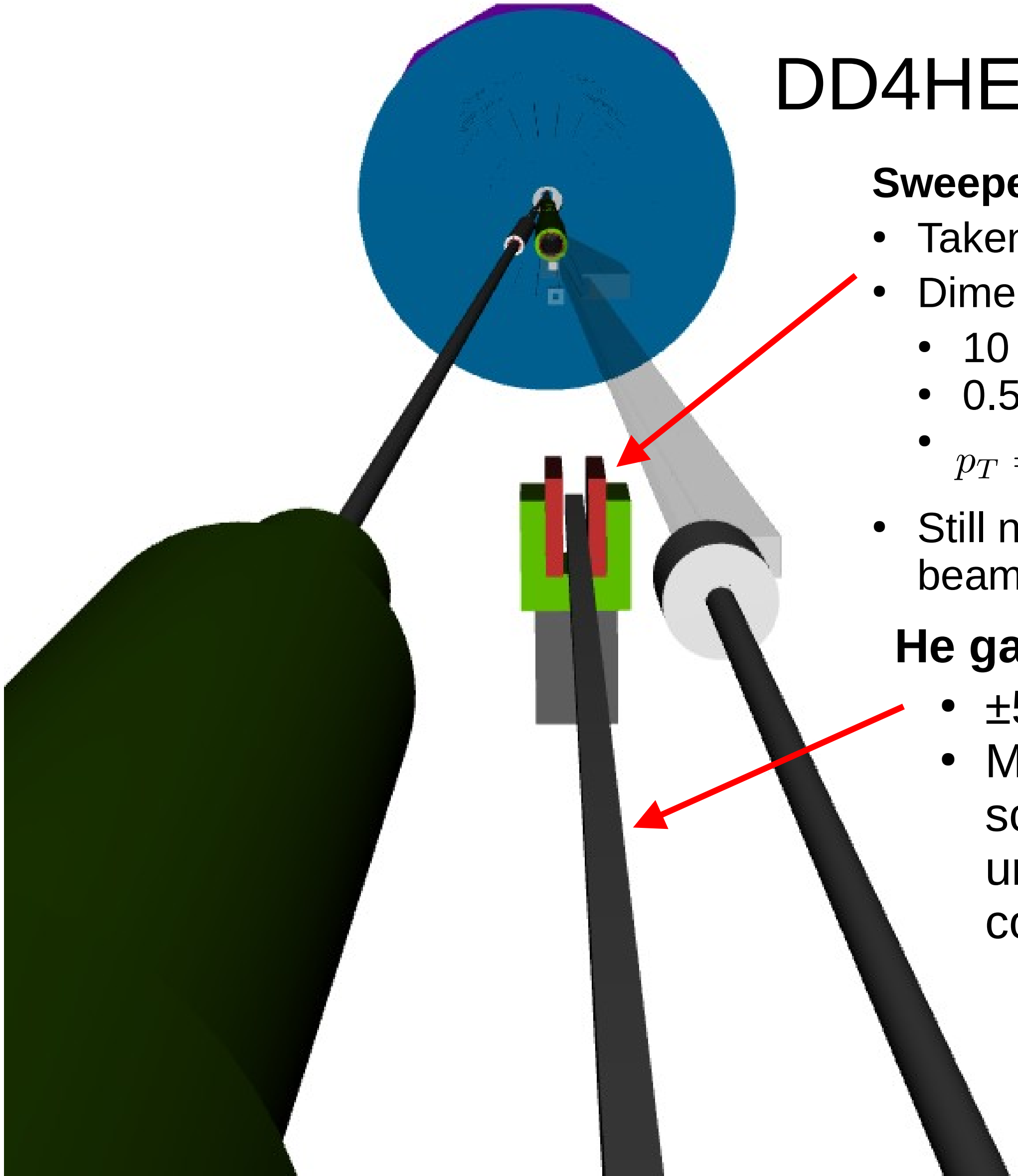
Exit Window

- Taken to be Aluminum, 1 cm thick
- Thickness and composition needs to be accurately known in order to account for the lost photons

Collimator

- Steel block to remove stray particles that may damage other components further downstream.
- Opening size defines phase space of measured photons: taken to be 5σ ~ ±2.4 cm.

DD4HEP Design

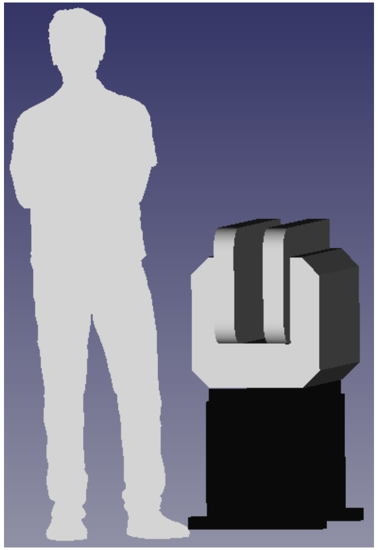


Sweeper Magnet

- Taken to be the same as the ZEUS design
- Dimensions extracted from a CAD drawing.
  - 10 cm opening (~±7σ photon beam) .
  - 0.5 T horizontal B field (electrons go up and down)
  - $p_T = 0.3\,BdL = 0.3(\frac{\mathrm{GeV}}{\mathrm{T\ m}}) * 0.5\mathrm{T} * 0.78\mathrm{m} = 0.117\,\mathrm{GeV}$
- Still need to ensure fringe field < 10 Gauss @ electron beam.

He gas chamber

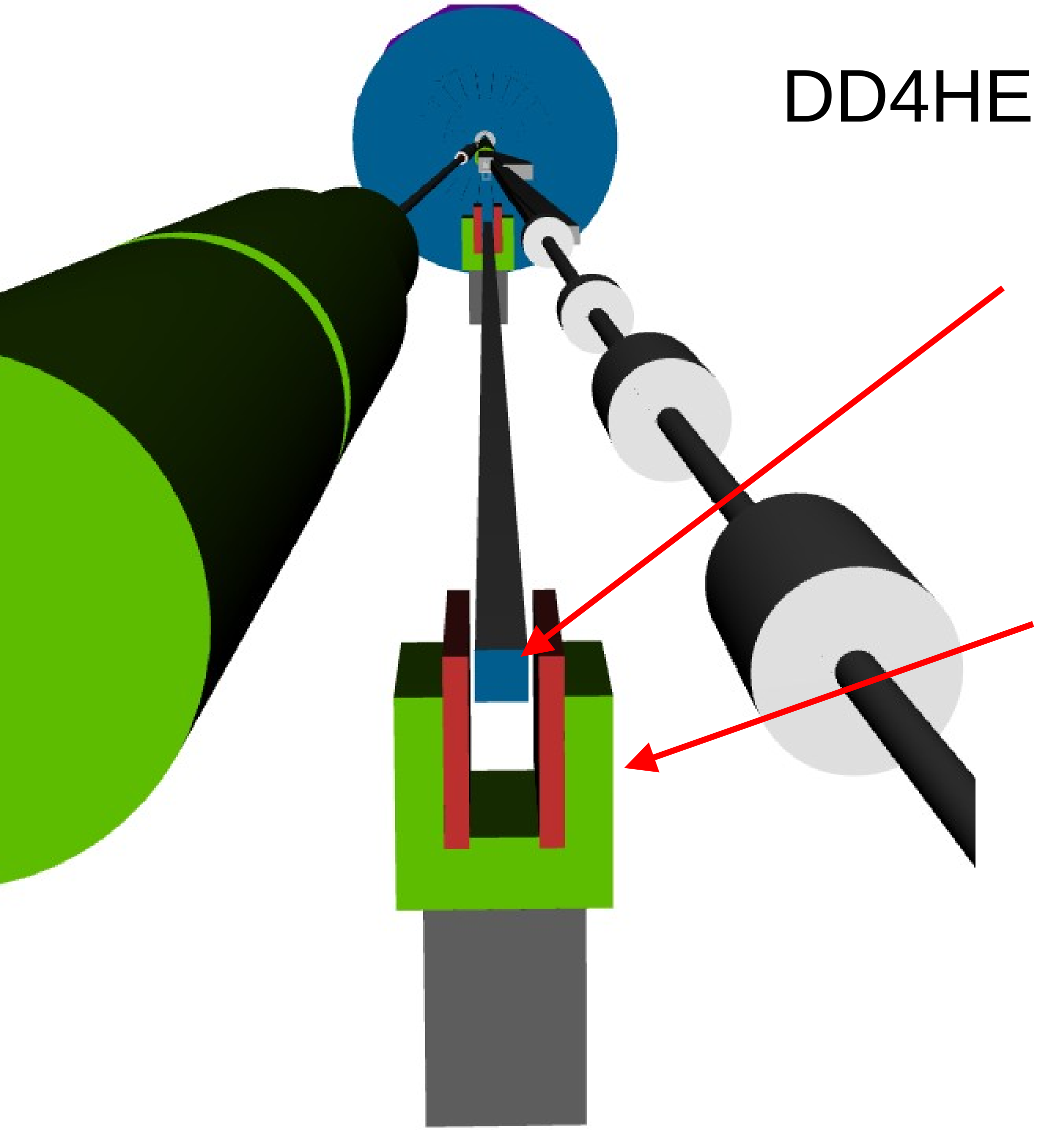
- ±5σ dimensions
- Minimizes multiple scattering and unwanted conversions



CAD drawing obtained from Yulia Furletova

Implemented in DD4HEP by Justin Chan

DD4HEP Design



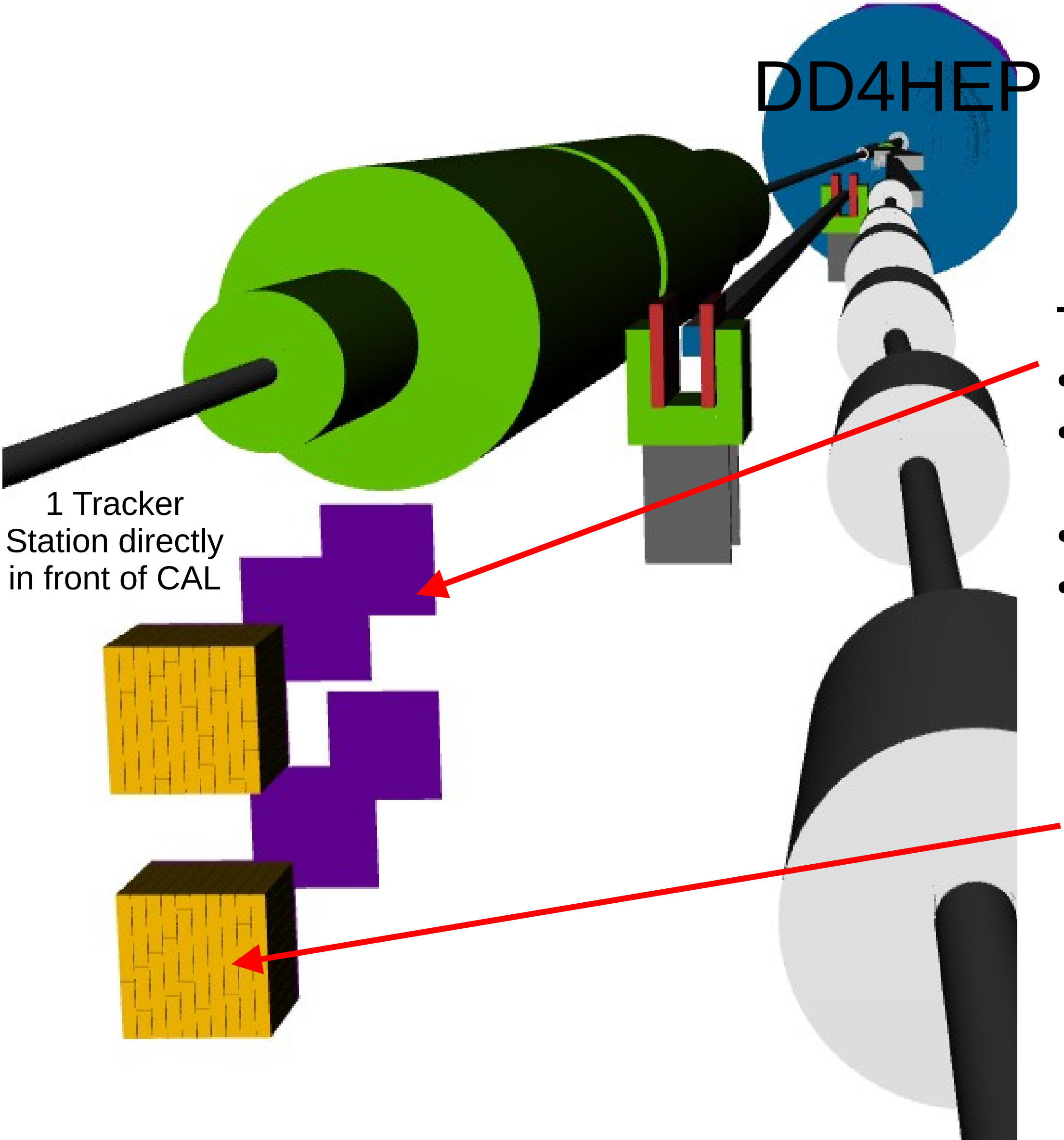
Converter

- Taken to be Aluminum, **1 mm thin**
- Thickness and composition needs to be accurately known in order to account for the conversions

Spectrometer Magnet

- Taken to be the same as the Sweeper Magnet: 0.5 T horizontal B field.
- Placed just after the converter.
- 12 cm opening also provides ~±6sigma clearance for direct-ɣ beam.
- $p_T = 0.3\,BdL = 0.3(\frac{\mathrm{GeV}}{\mathrm{T\ m}}) * 0.5\mathrm{T} * 0.78\mathrm{m} = 0.117\,\mathrm{GeV}$

DD4HEP Design



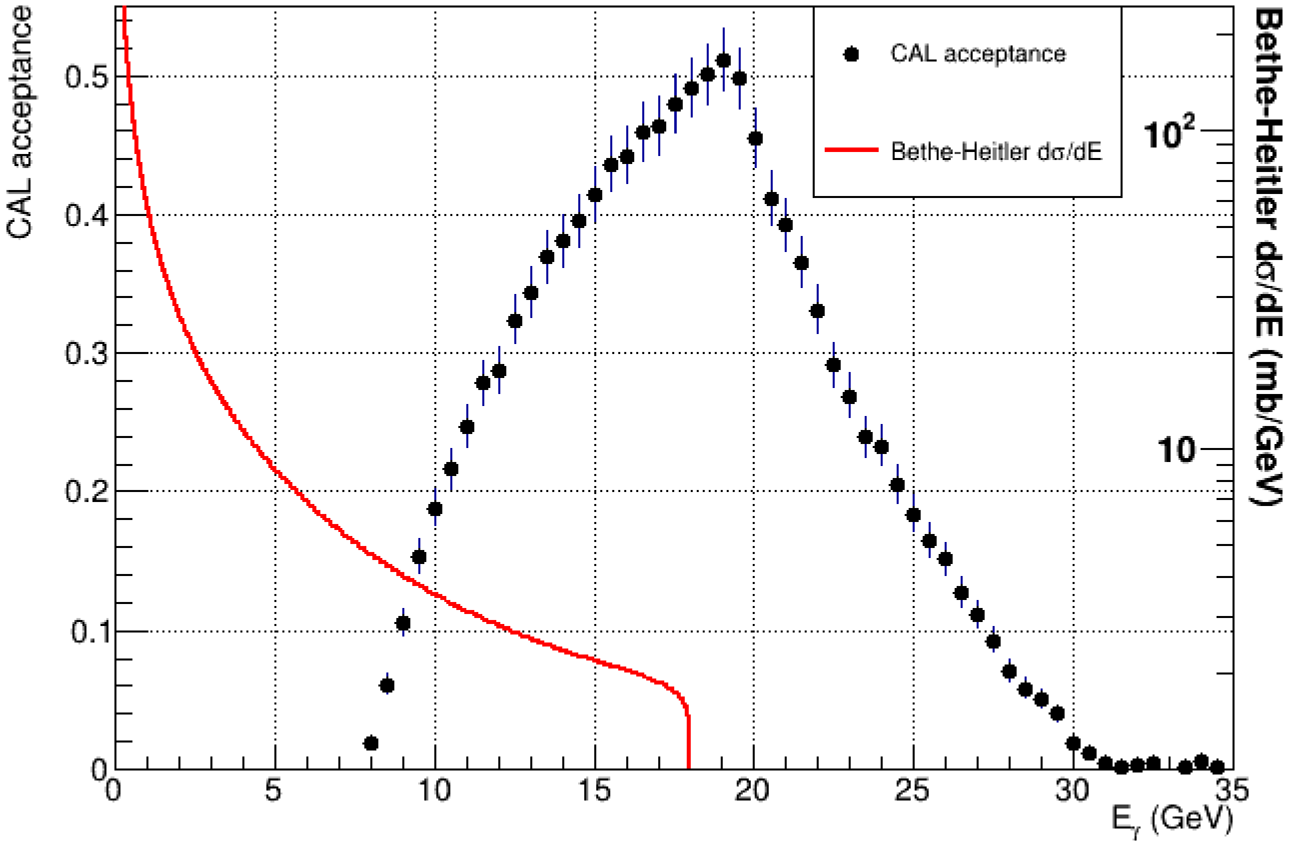
Trackers

- 3 stations with a top & bottom plane each.
- ±5σ gap between top and bottom for direct photon passage.
- 20 cm x 20 cm transverse dimensions
- 0.3 mm SiliconOxide (sensor) + 0.14 mm Copper (ASIC+cooling approximation): ~1% $\boldsymbol{X}_0$

Calorimeter

- Taken to be PbWO4 with same module dimensions as scattered electron CAL
  - 2 cm x 2 cm x 20 cm.
- ±5σ gap between top and bottom for direct photon passage.

CAL acceptance



- Shape of acceptance governed by geometry of spectrometer arm
- Current design with nominal B=0.5 T favors high end of spectrum
- One can “slide” the acceptance to the left by decreasing B

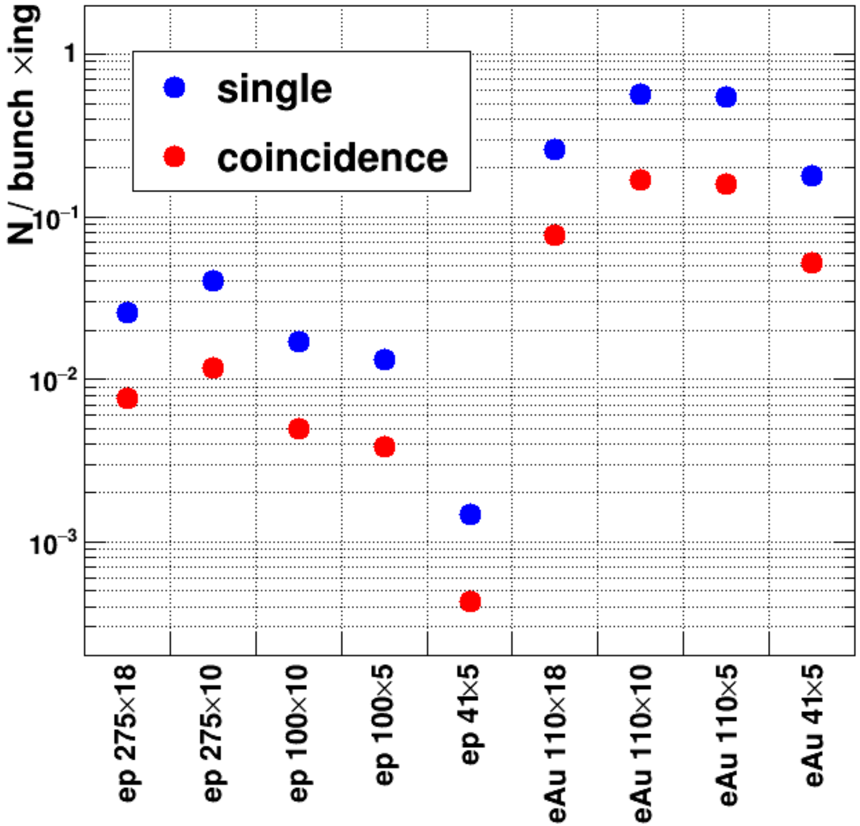
eA (very high Bremstrahlung)
- Use a large B

ep
- Use a smaller B

Expected Rates of electrons at spectrometer CALs

Bethe-Heitler formula for unpolarized ep Bremstrahlung

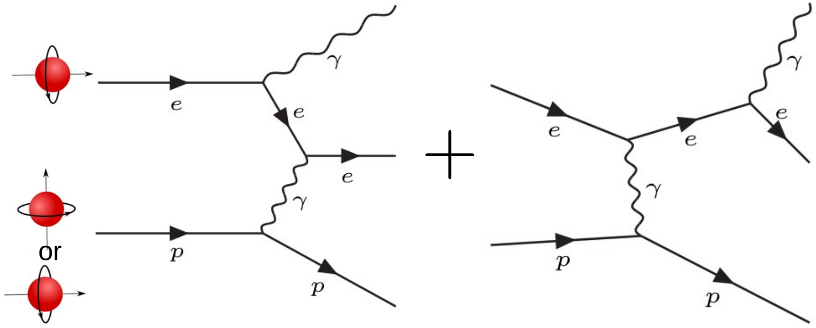
$$\frac{d\sigma}{dE_\gamma} = 4\alpha Z^2 r_e^2 \frac{E'_e}{E_\gamma E_e}\left(\frac{E_e}{E'_e} + \frac{E'_e}{E_e} - \frac{2}{3}\right)\left(\ln\frac{4E_pE_eE'_e}{m_pm_eE_\gamma} - \frac{1}{2}\right)$$



- 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

Calculation of Polarized Bremstrahlung



- Bethe & Heitler first derived the cross section for bremstrahlung in 1934, but for unpolarized projectile and targets.
- Steps to calculate the polarized cross section outlined in Lifshitz QED textbook (section 93).

Before calculating the polarized cross section, a re-derivation of the unpolarized double-differential cross section has been done:

1) Write out Feynman amplitudes, square them, and work through the Dirac algebra.

2) Integrate over scattered electron angles and photon’s azimuthal angle.

3) Take ultra-relativistic and small-angle limit (p ~ ε , θ <~ m/ε), δ = θ ε/m.

Lifshitz Eq 93.16

$$\frac{d^2\sigma}{d\omega d\delta} = 8Z^2\alpha r_e^2 \frac{1}{\omega}\frac{\varepsilon'}{\varepsilon}\frac{\delta}{(1+\delta^2)^2}\left(\left[\frac{\varepsilon}{\varepsilon'}+\frac{\varepsilon'}{\varepsilon}-\frac{4\delta^2}{(1+\delta^2)^2}\right]\ln\frac{2\varepsilon\varepsilon'}{m_e\omega}-\frac{1}{2}\left[\frac{\varepsilon}{\varepsilon'}+\frac{\varepsilon'}{\varepsilon}+2-\frac{16\delta^2}{(1+\delta^2)^2}\right]\right)$$

Unpolarized spinor simplification

$$\frac{1}{2}\sum_{spins} u(p)\bar{u}(p) = \frac{1}{2}(\gamma p + m)$$

Polarized case

$$u(p)\bar{u}(p) \rightarrow \frac{1}{2}(\gamma p + m)(1-\gamma^5(\gamma\, s))$$

Contains beam polarization

Summary

- New luminosity spectrometer design implemented in DD4HEP.
- With new design (sweeper magnet + thin converter), pileup is greatly suppressed.
- Preliminary estimates for energy resolutions from trackers and CALs have been given.
  - Synergy with taggers: special low-luminosity runs are planned to cross calibrate spectrometer CAL and taggers. Full detection of $e+p \rightarrow e+p+\gamma$

Next steps

- Check the fringe-field strength of Lumi dipole magnets to confirm < 10 Gauss @ beams.
- Optimize placements/sizes of trackers and CAL.
- Further investigate feasibility & benefit of an extended He^2 gas chamber.
- Implement a clusterizer to more appropriately extract hit centers & deal with residual pileup.

Backup

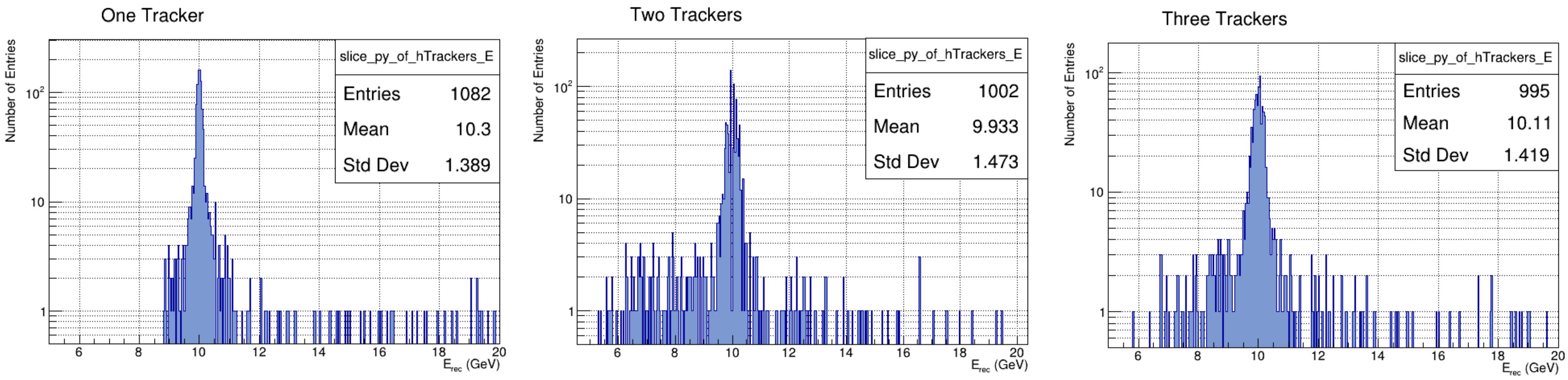
Tracker Energy reconstruction

Slope of track obtained from the least-squares linear regression formula

NIM Phys Res A 565 (2006) 572-588

$$\tan\theta = \frac{N\sum z_i y_i - \sum z_i \sum y_i}{N\sum z_i^2 - (\sum z_i)^2} \qquad E_{e\pm} = \frac{p_T}{\sin\theta} = \frac{0.3\int B_x\,dz}{\sin\theta} \qquad E_\gamma = E_{e-} + E_{e+}$$

Generated E_γ = 10 GeV

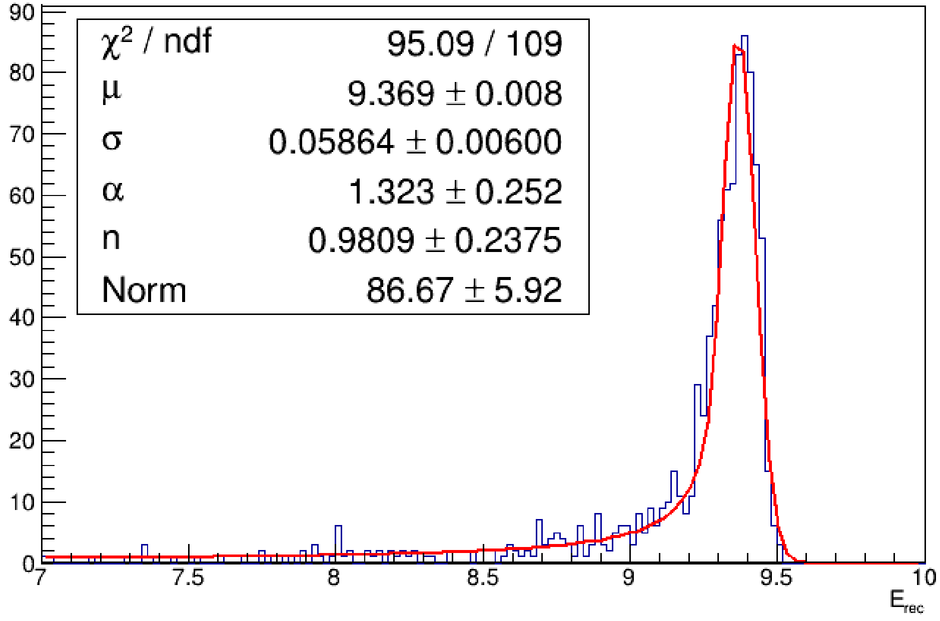


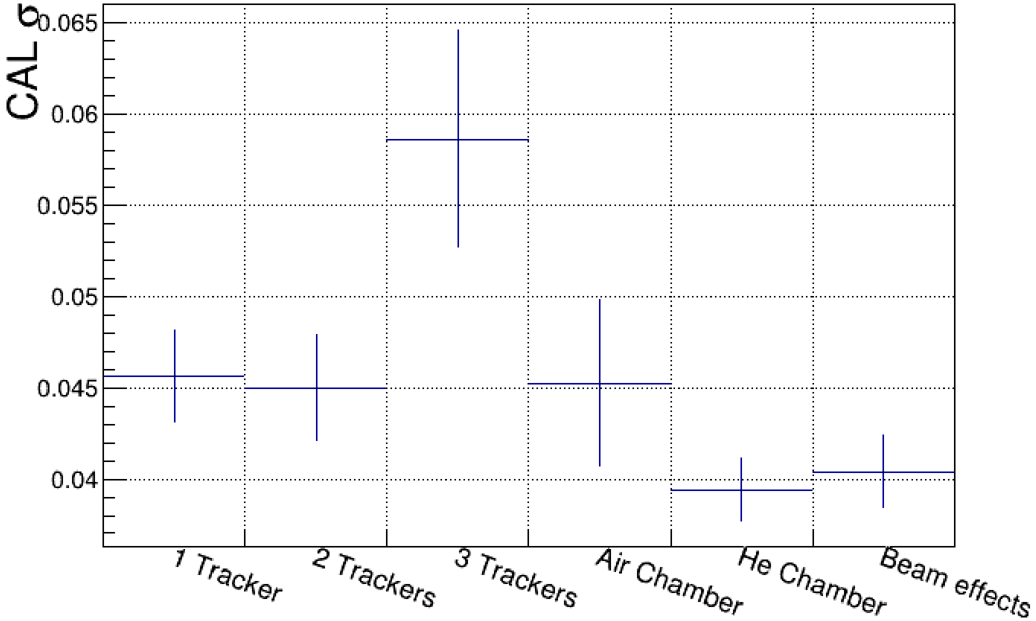
- More tracking layers leads to more multiple scattering (of course).

CAL Energy reconstruction

Crystal Ball fit used: Gaussian + power law tail

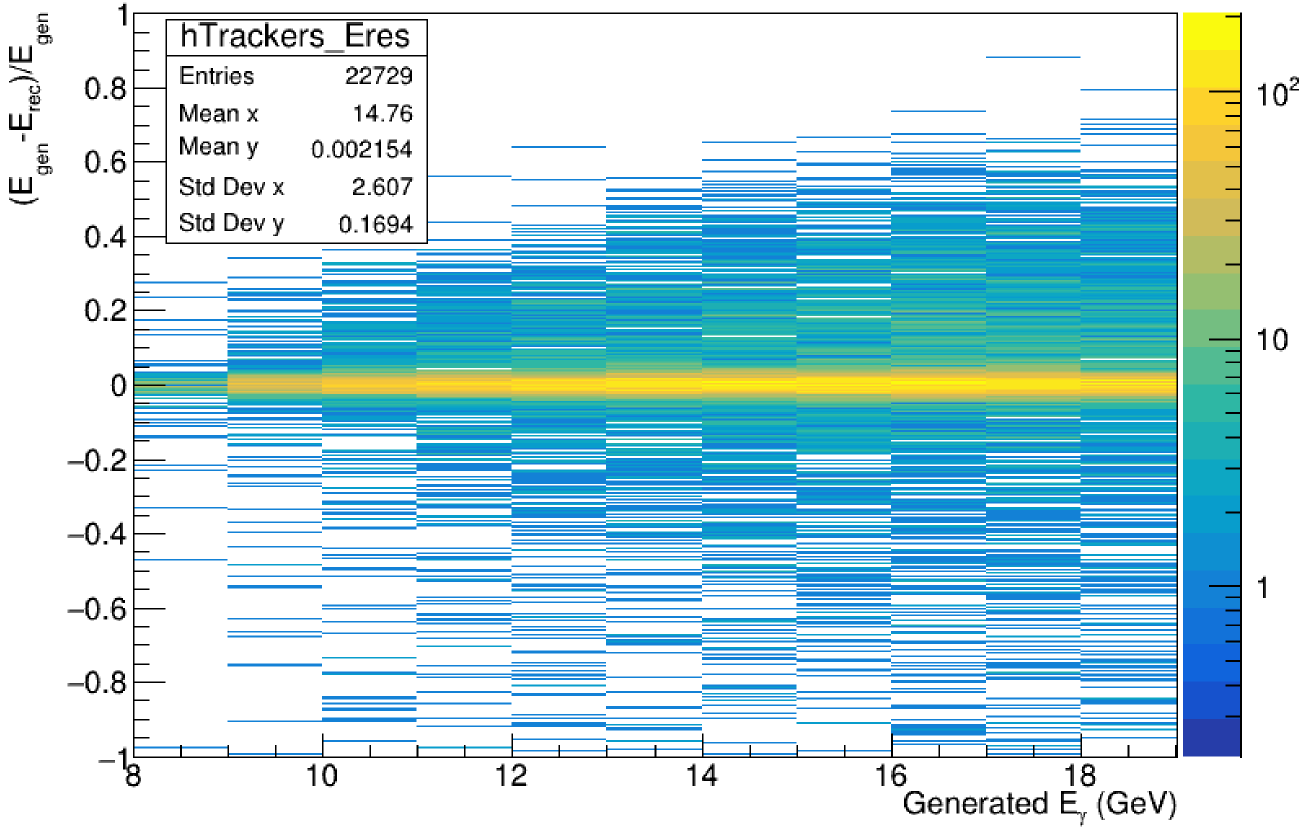
E_{gen} = 10 GeV





- No observable difference in CAL energy resolution with these configurations.

Tracker relative Energy reconstruction



3 Tracker planes

Bethe-Heitler

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