# Compact pair spectrometer design and tracker update

- All beam effects turned on in this simulation study

Dhevan Gangadharan
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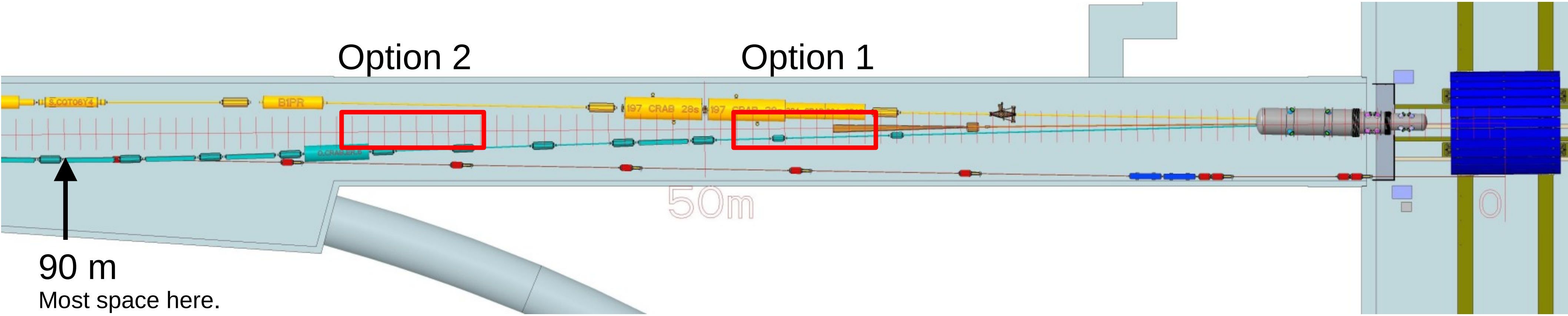
# Placement options for the Lumi Pair Spectrometer




90 m

Most space here.
Beyond this, electron beam moves again toward ion beam.

Placement Option 1 (**$Z_{sweeper}$ = - 40 m**):

- As close to the IP as possible (after the low-Q2 taggers).

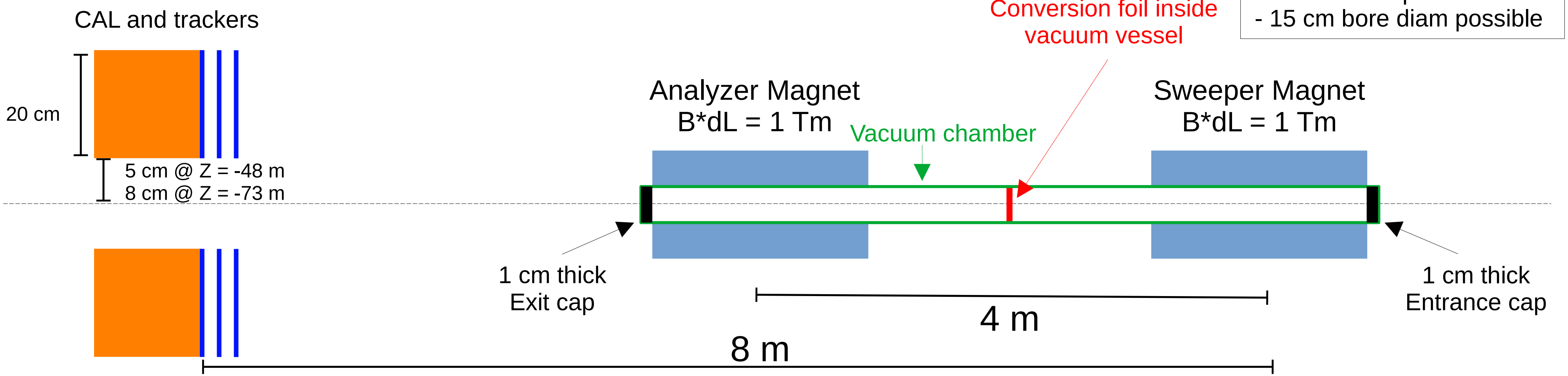
Placement Option 2 (**$Z_{sweeper}$ = - 65 m**) **Preferred**:

- Further down the tunnel where there's more space and less worries about fringe fields from our dipole magnets.
- May be beneficial to have a more diffuse photon beam. Easier to assess electron beam divergence to provide feedback to the accelerator.
- $Z_{sweeper}$ mainly determined by maximum realistic magnet bore size (15 cm bore diameters are possible)r.

Note that the ZEUS PS dipole magnet was 95 m from IP.

# Compact PS system (new baseline design?)

Compact system based on preliminary feedback from our magnet designer
- 1 T*m fields possible
- 15 cm bore diam possible

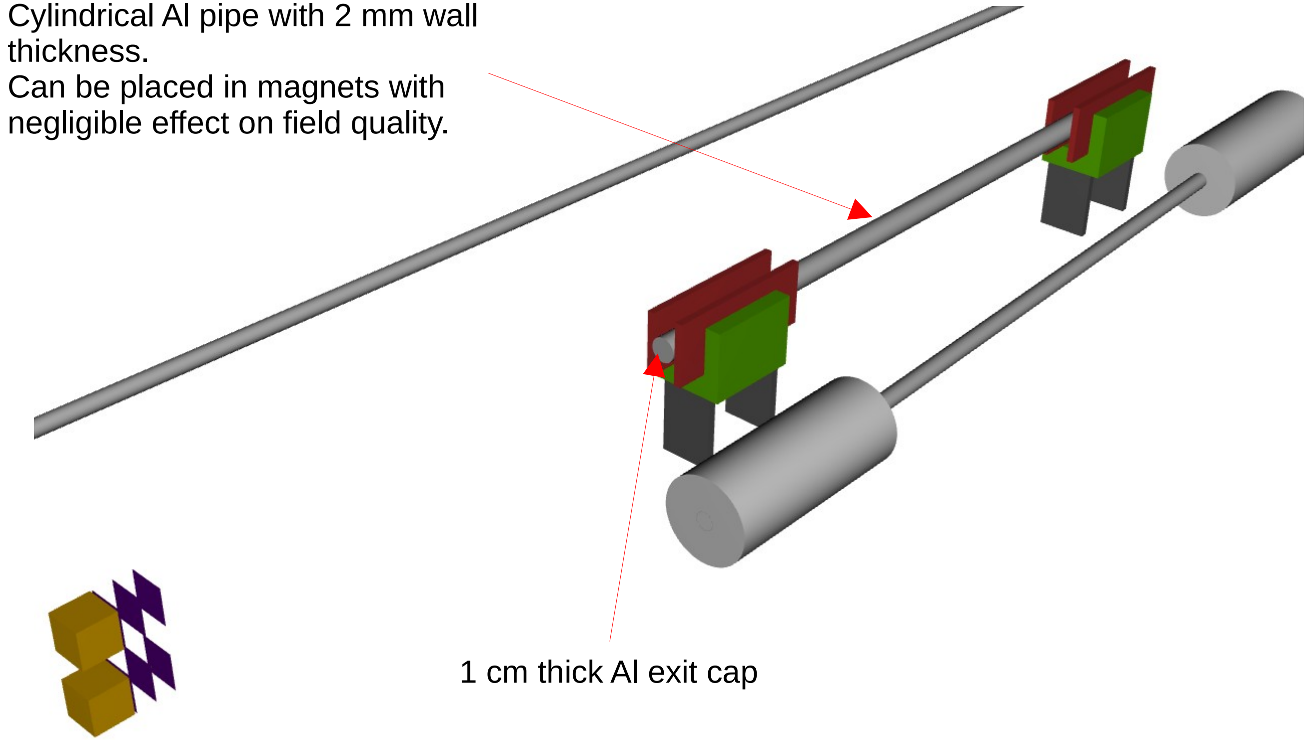



- Sweeping distance (considering sweeper field only):
  - For Option 1, 18 GeV electrons hit inner wall of analyzer magnet at 3 m from sweeper center.
  - For Option 2, it's after 4.4 m
  - **TODO:** need to study impact of all these swept electrons scattering off the magnet and still giving a signal in our detectors.
- Vacuum chamber (**not Helium**) can be an aluminum cylindrical pipe with wall thickness ~ 2 mm.
- Exit cap can be a flat plate 1 cm thick. **TODO:** investigate alternatives to reduce multiple scattering.
- Conversion foil will be inside vacuum: **TODO:** investigate the photon heat load and how to cool the foil.

# DD4hep implementation of compact PS system
# Option 2 location

Longitudinal view

Side view

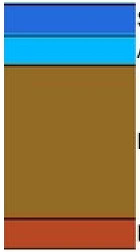


# Trackers

- Timepix might be a suitable technology for the Pair Spectrometer trackers.
- It will likely be used for the low-Q2 trackers.
- It has adequate pixel size (55 um), integration times (~> 100 ns), time resolution (< 10 ns), and material budget (~ 1% X0).
- However, Ken Livingston mentioned that Timepix might be overkill for the PS trackers since their occupancies will be much lower than the low-Q2 trackers. Maybe there's a cheaper technology that would satisfy our requirements...

## Timepix material budget

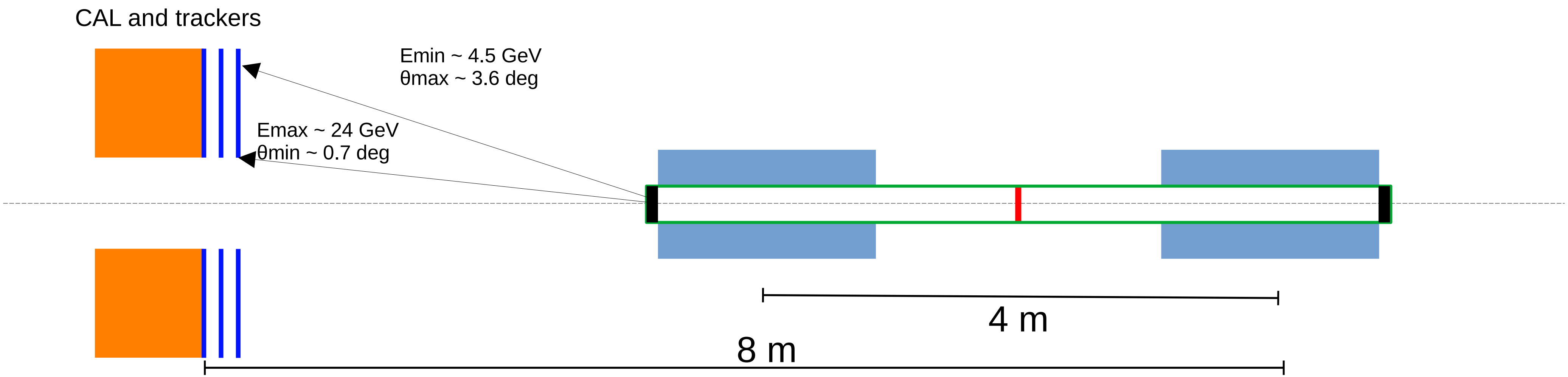
Tracking Layer



| Component | Material | X0(g/cm2) | Density(g/cm3) | X0(cm) | Depth(um) | Depth(X0) |
|---|---|---|---|---|---|---|
| Sensor | Silicon | 21.82 | 2.33 | 9.37 | 60.00 | 0.0006 |
| ASIC | Silicon | 21.82 | 2.33 | 9.37 | 100.00 | 0.0011 |
| PCB | FR4 | 31.85 | 2.00 | 159.30 | 200.00 | 0.0001 |
| Heat transfer | Copper | 12.86 | 8.96 | 1.44 | 100.00 | 0.0070 |

- This model for the material budget has been incorporated in the DD4hep PS trackers.
- Previous PS tracker studies had ~50% more material.

# Tracker energy resolution should be improved with more compact system

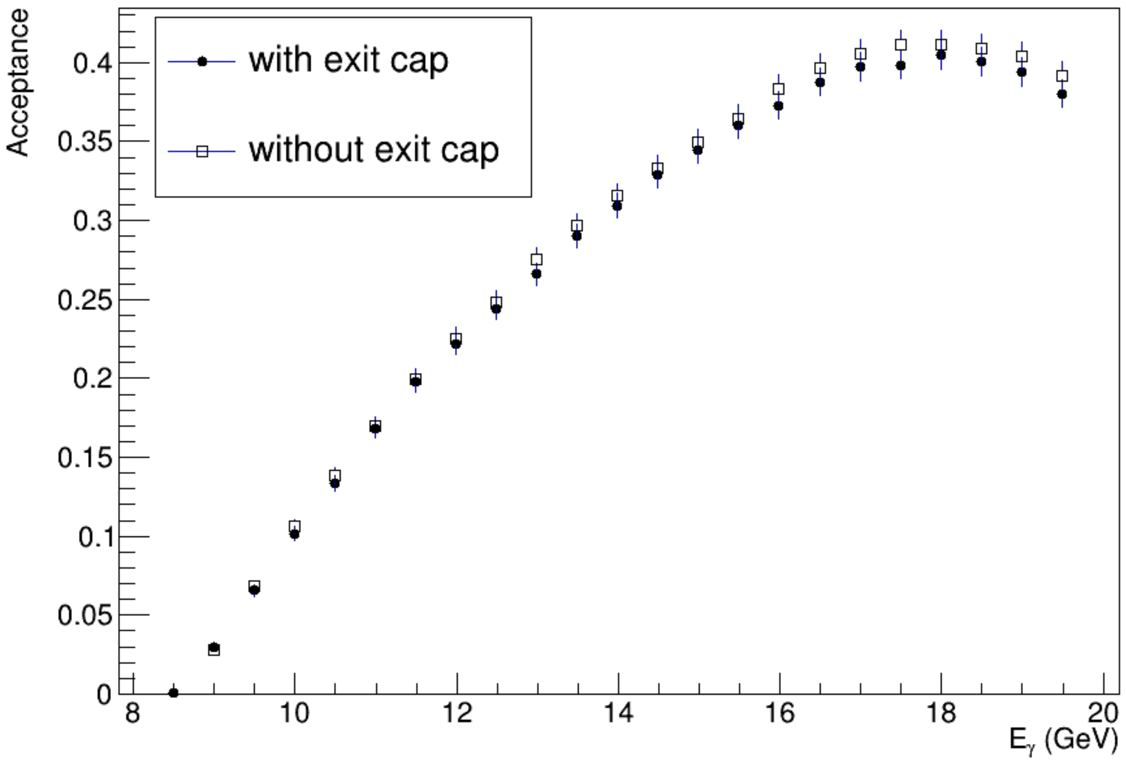



- Angles of tracks are more than 2x larger with the more compact system.
- Material budget of tracking layers ~50% reduced wrt previous studies.

The next slides will reassess the tracker performance with this compact design (occupancies, pointing resolutions, energy resolutions).

Special attention given to the effect of the exit cap.

# Tracker Acceptance



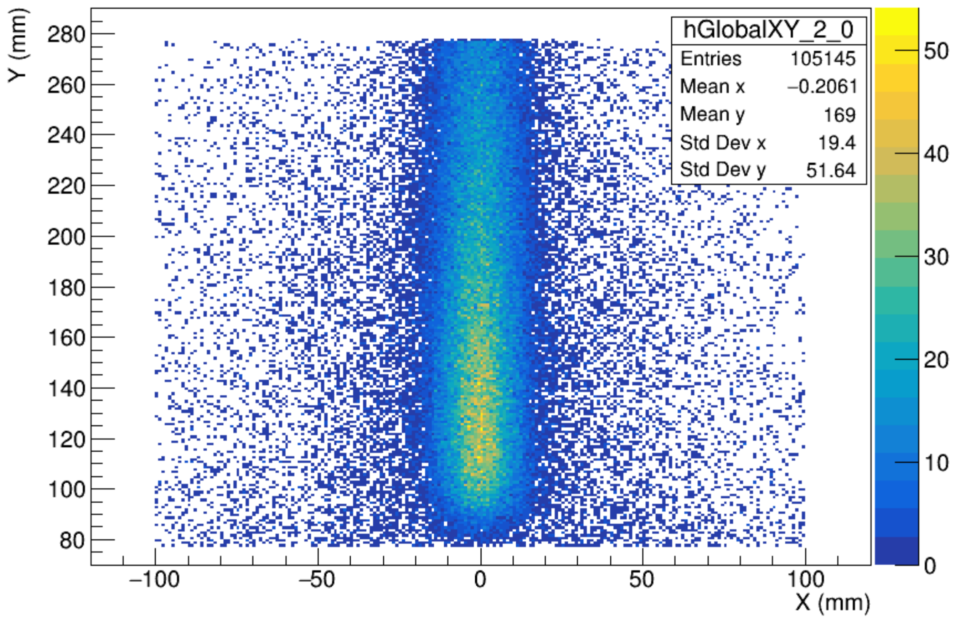

- Simulated energies ranged from 5 to 19 GeV

- ignore the error bars.

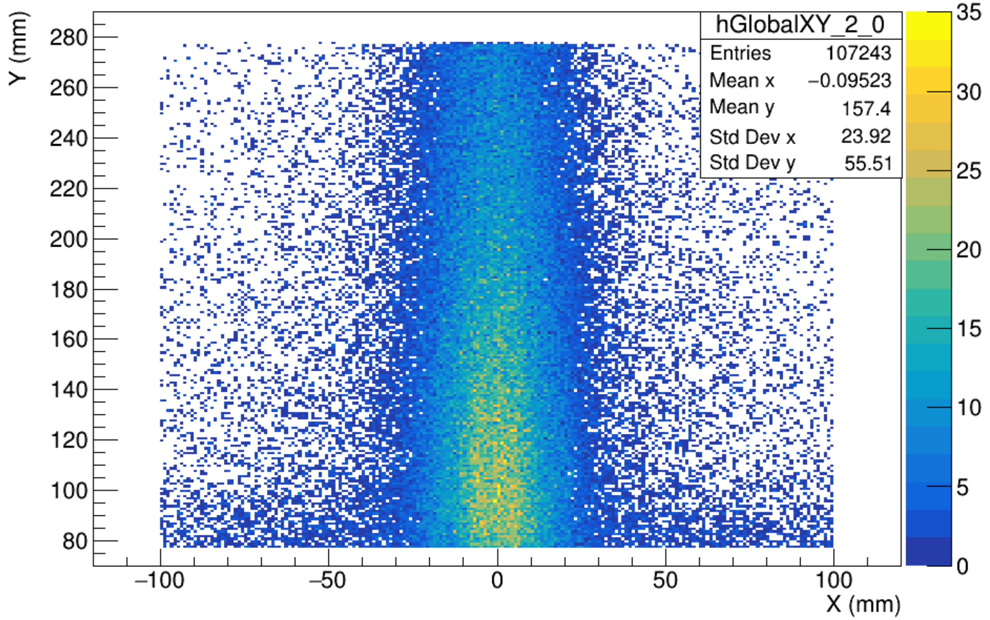
- The exit cap makes only a slight alteration to the acceptance.

# Tracker Occupancies

Placement option 1 (close to IP)



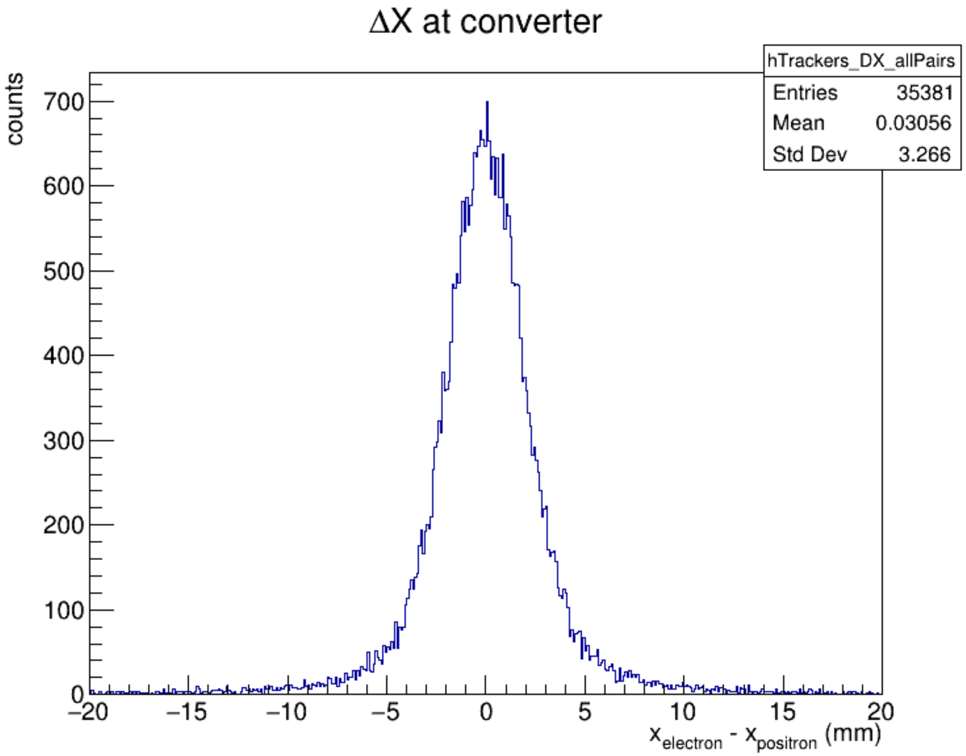

Placement option 2 (far from IP)



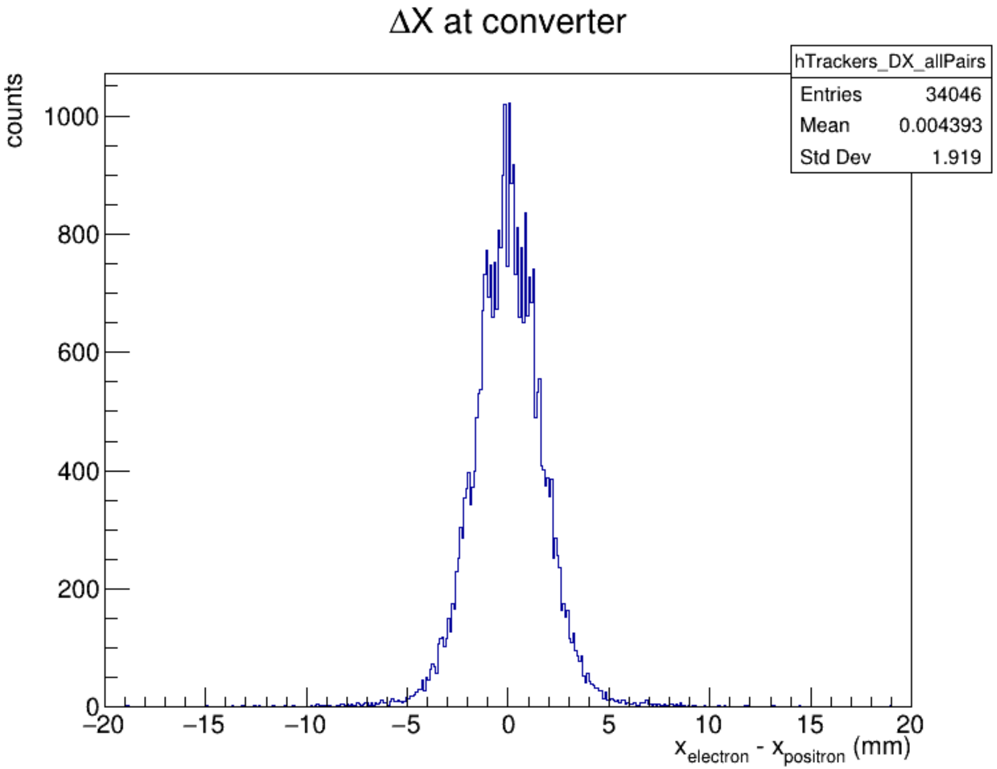

- The width of these distributions can tell us how wide to make our detectors.
- They look very similar with and without the exit cap.

# Tracker Pointing Resolutions
# Placement Option 2 (far from IP)

**With** 1 cm thick Al exit cap




**Without** 1 cm thick Al exit cap

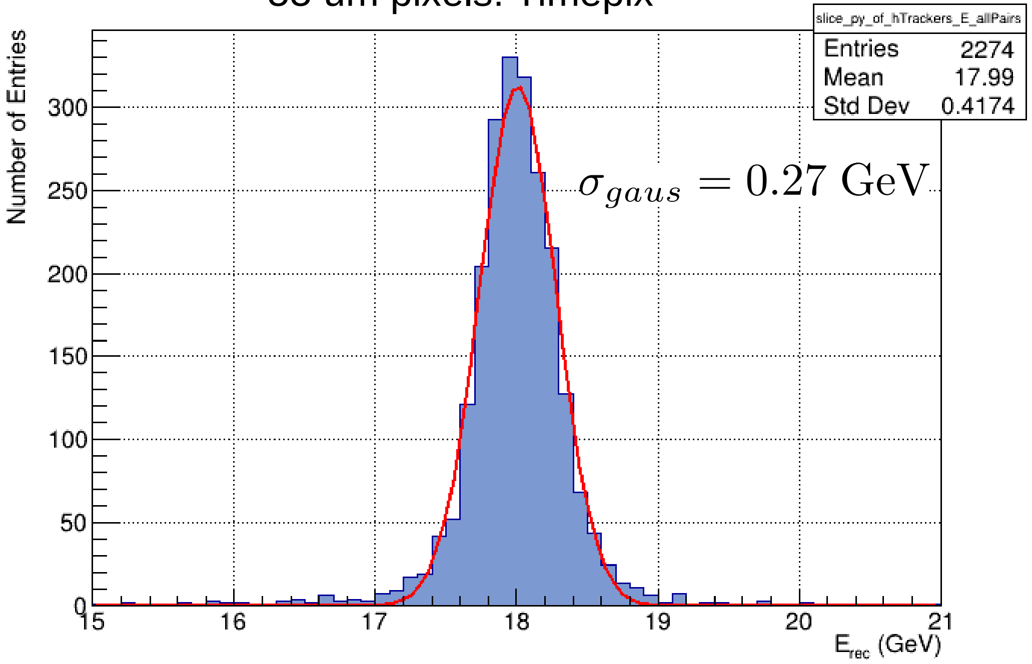



- Resolution of photon conversion location is about 3 mm (with exit cap) and 2 mm (without exit cap).
- Important to reject backgrounds and to provide feedback on the electron beam divergence.

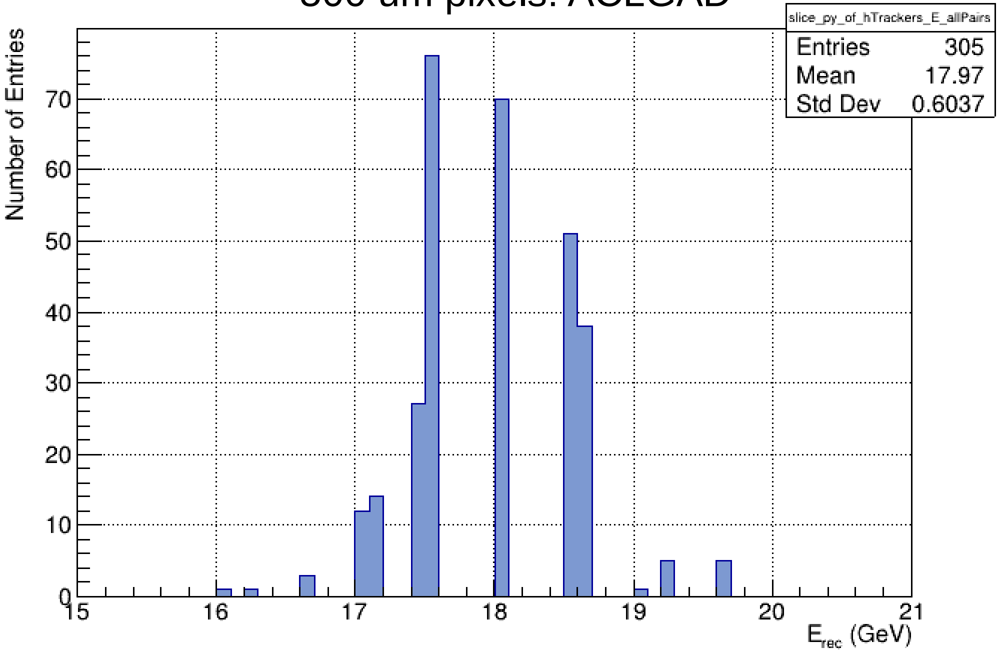
# Tracker Energy Resolutions
# Placement Option 2 (far from IP)

$$E^{\gamma}_{gen} = 18 \text{ GeV}$$

55 um pixels: Timepix




500 um pixels: ACLGAD

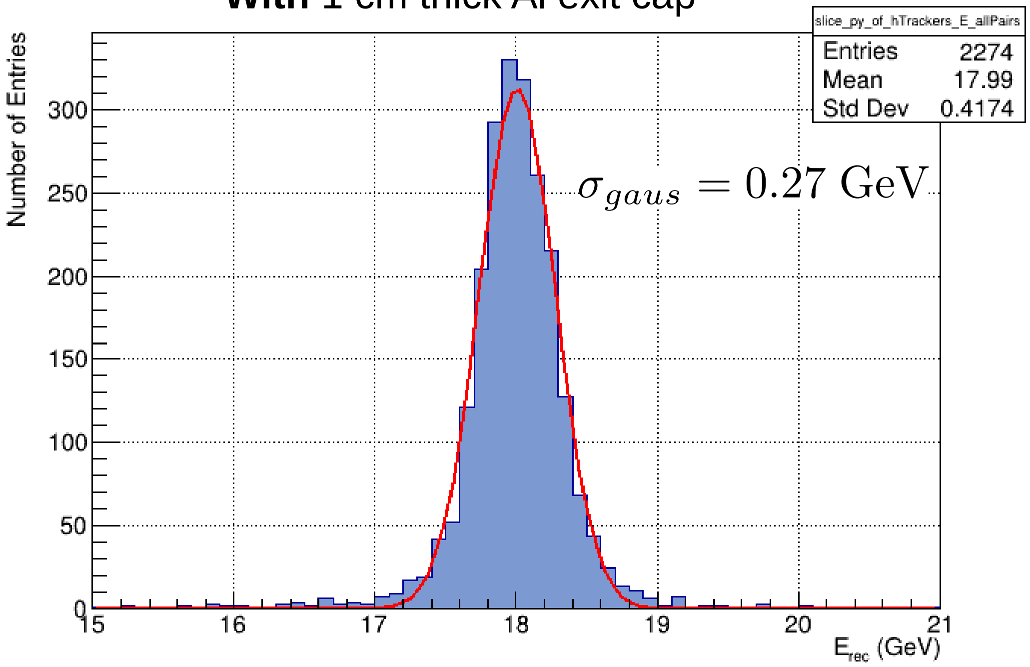



- Large pixels show clear discretization effects. Note, didn't take into account 1/Sqrt(12) reduction of effective pixel size arising from a pulse shape analysis.
- ACLGAD pixel sizes not suitable for the **small angular range** in the PS trackers.

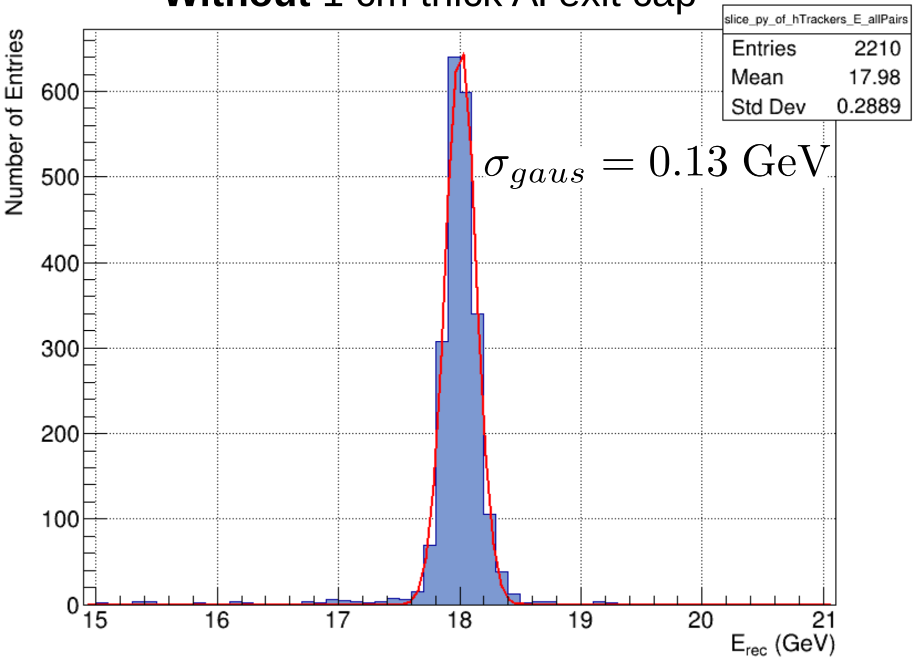
# Tracker Energy Resolutions
# Placement Option 2 (far from IP)

$$E_{gen}^{\gamma} = 18\ \mathrm{GeV}$$

**With** 1 cm thick Al exit cap



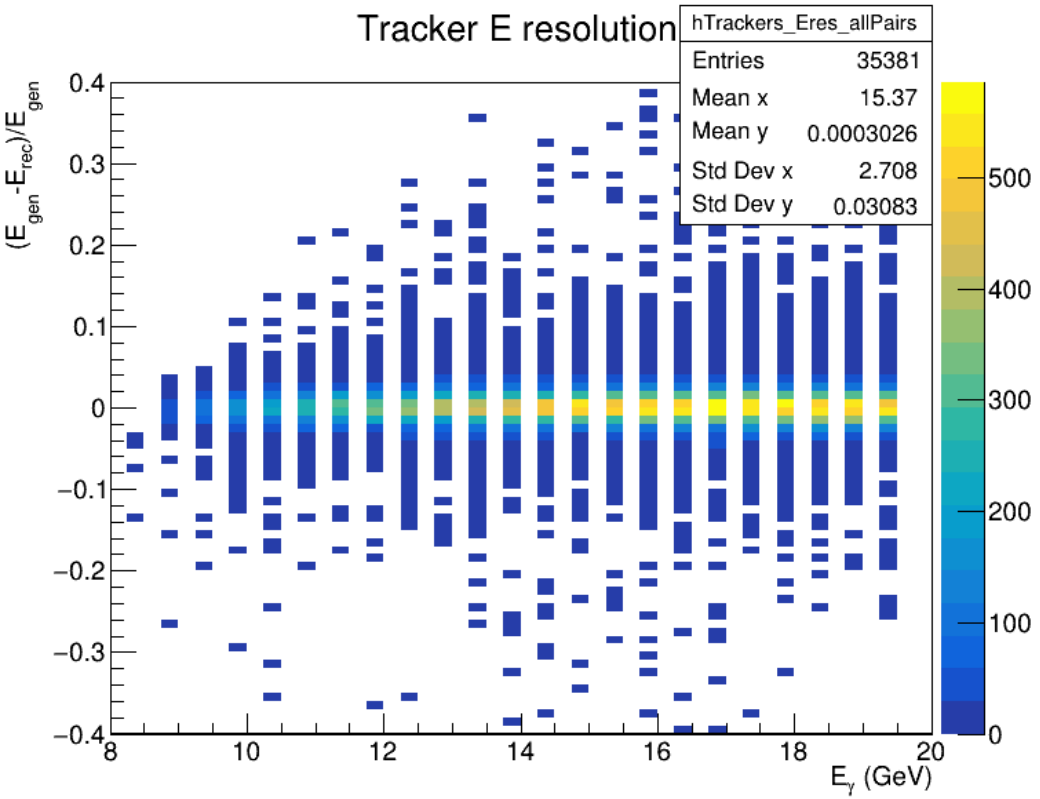

**Without** 1 cm thick Al exit cap



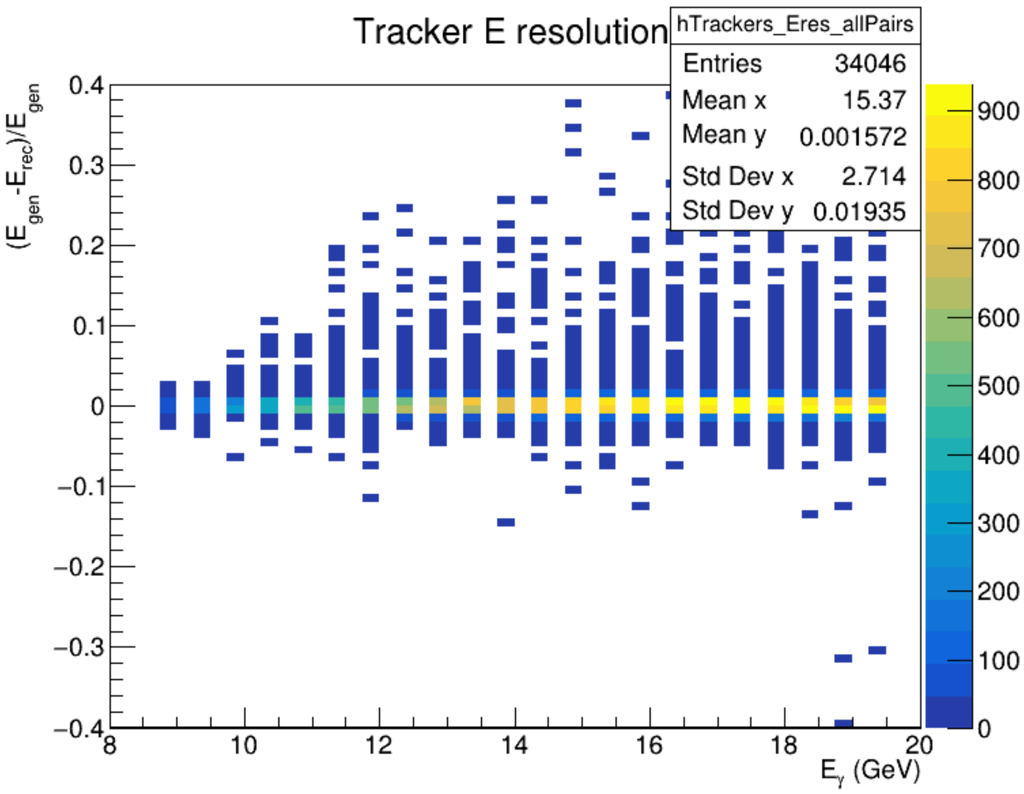

- % level resolutions! Likely better resolution than any CAL.

# Tracker Energy Resolutions
# Placement Option 2 (far from IP)

**With** 1 cm thick Al exit cap




**Without** 1 cm thick Al exit cap




- Energy resolution is mostly constant.

# Remarks

<u>New baseline design</u>

- Propose to make this new compact design (slide 3) the baseline in DD4hep
  - 8 m long (Sweeper to CALs)
  - Timepix sensors for the tracking layers (1% material budget, 55 um pixel size)
  - Vacuum chamber stretching in between Sweeper and Analyzer magnet
    - 1 cm thick Al entrance and exit caps
    - Thin conversion foil inside the vacuum.

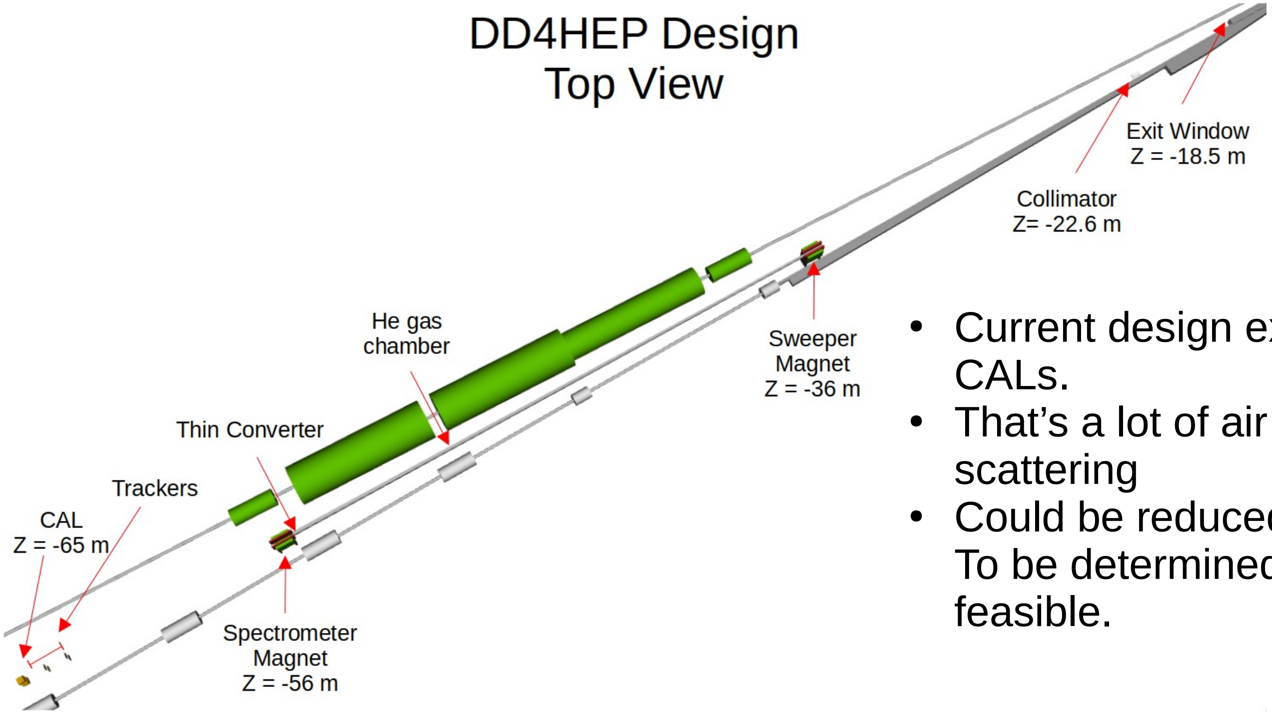
<u>Route to Improvement</u>

- Tracker pointing and energy resolutions are roughly twice as good without the Al exit cap.  Worth studying alternative materials and geometrical designs of the exit cap to reduce multiple scattering

# Backup

# Sweeper and Analyzer Magnets

- Peng Xu from BNL will design 2 new bore magnets for us.
- Preliminary discussions with Elke & Rolf suggest that fields of ~ 1 T and lengths of ~ 1m are feasible. Thus we can get B*dL = 1 Tm (over 3x the ZEUS magnet).
- With a sweeper + analyzer, we will have an **effective B*dL of 2 Tm**.
- Thus, the Pair Spectrometer can be made much more compact.




- Current design extends almost 30 m from sweeper to CALs.
- That's a lot of air → extra conversions and multiple scattering
- Could be reduced with a long Vacuum/He chamber. To be determined if a thin exit window is mechanically feasible.

# Considerations of pair spectrometer longitudinal placement

Fraction converted before sweeper

$$N^{\gamma}_{sweeper} = N^{\gamma}(1-f)$$

$$f = 1 - e^{-Z/\lambda}$$

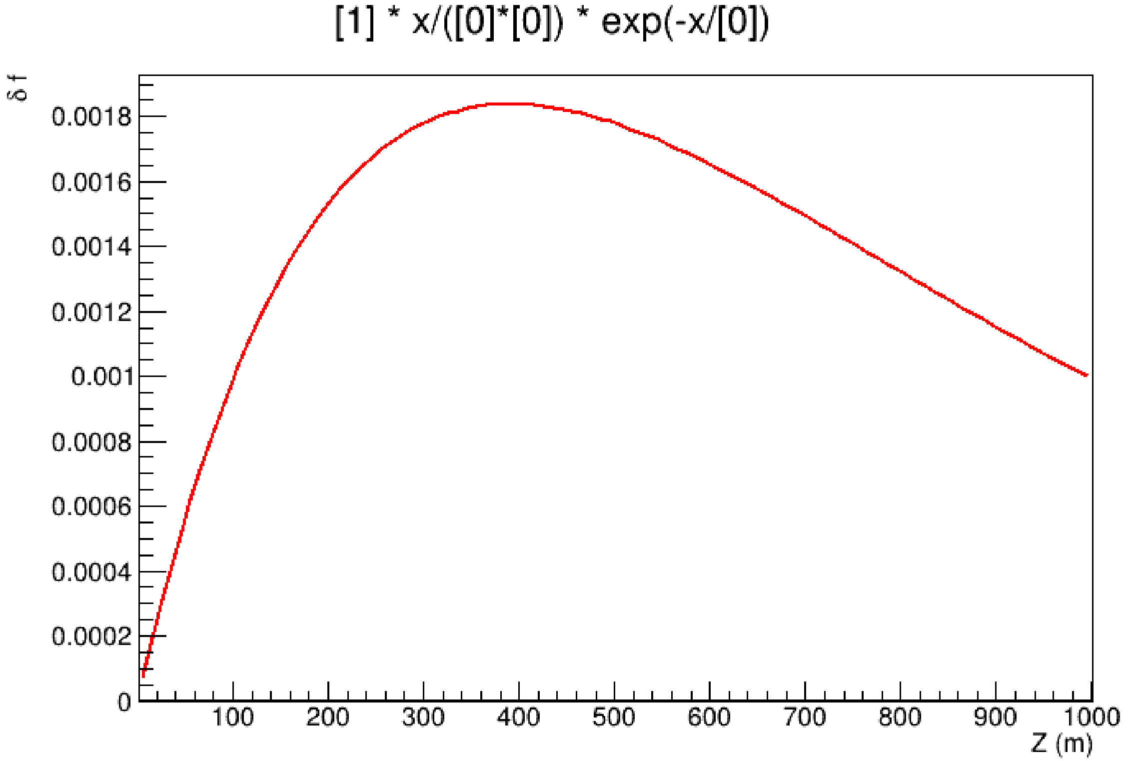
$$\delta f = |\frac{df}{d\lambda}| = \frac{Z}{\lambda^2} e^{-Z/\lambda} \delta\lambda$$

From the PDG book, for air

$$\lambda \approx \frac{9}{7} X_0 = 391\, m$$

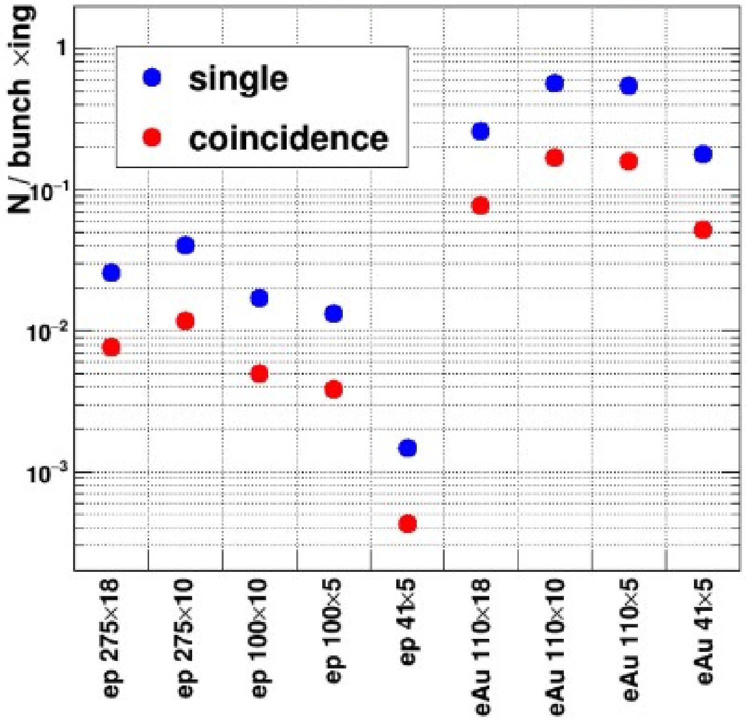
Assume the uncertainty is at the same scale as for conversion in Aluminum.

$$\delta\lambda \approx 0.005\, \lambda$$



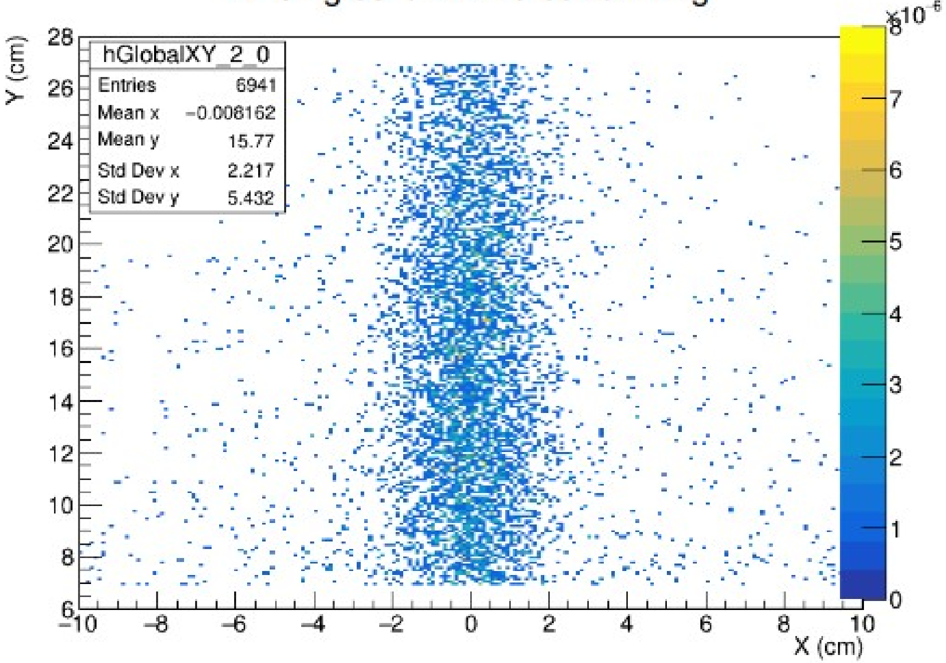
# Expected Rates

Overall rates given current design




Differential rates for ep 275x18 (top trackers):
N "singles" / mm2 / bunch xing

Includes beam effects




CALs:

- Moliere radius defines the granularity of the readout (~ 2 cm). Two CALs of 20cm x 20cm yields 200 readout channels.
- Differential rate per 2cm x 2cm readout channel:
  For ep 275x18 it is < 1e-3 per bunch xing.
  For eA 110x10 it is < 2e-2 per bunch xing.

Trackers:

- Rates per pixel are tiny. MAPS sensors with small material budget and ~1 μsec integration times might be feasible.