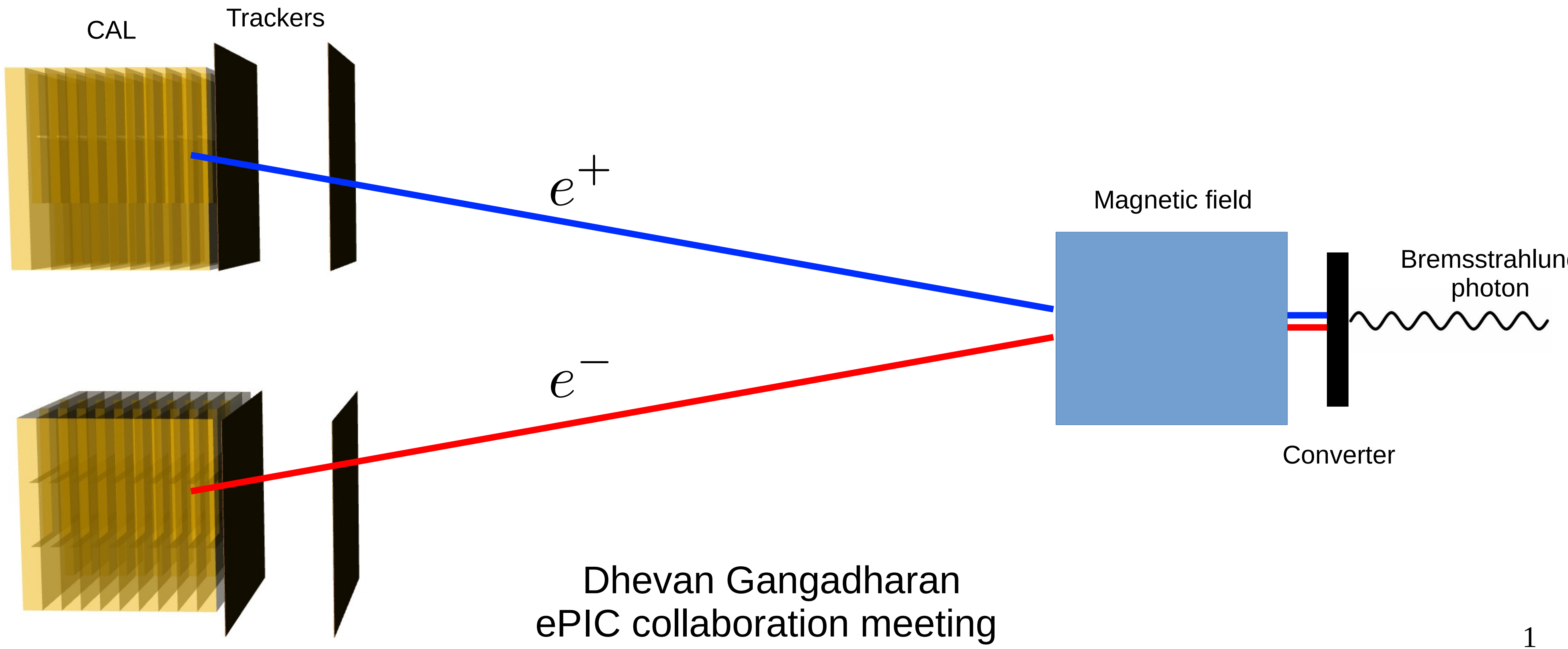
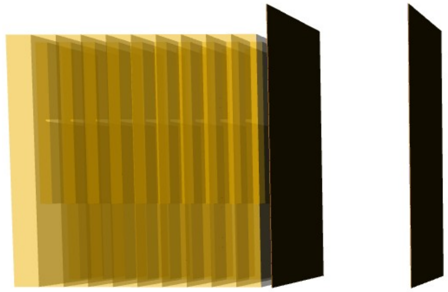
AC-LGAD Trackers for the Luminosity Pair Spectrometer



Dhevan Gangadharan
ePIC collaboration meeting
Jan 9th 2024

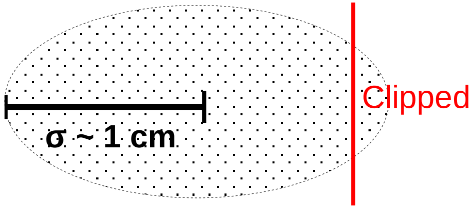
Why Does the Pair Spectrometer Need Trackers?



Precise determination of photon acceptance:

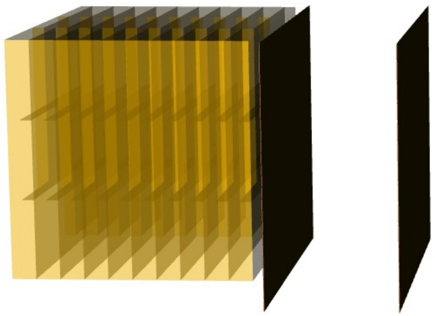
- precisely reconstruct photon position: X_γ & Y_γ
  Needed to extrapolate yield if photon beam is clipped.
- helps define CAL fiducial area (CAL edges are fuzzy).

Photon beam is macroscopic at converter (Z=-58 m).



Pileup mitigation:

- easy to distinguish multiphoton events with small pixels



Redundancy:

- CALs or trackers alone can determine the lumi. Better to have both.
- Online calibration tool for CALs.
- CALs are more robust: ~100% efficient
- Trackers are more precise in terms of photon energy and position resolution.

Why AC-LGAD?

Shared technology within ePIC:

- The PS would need at least 4 layers, each being 20 cm x 20 cm.
- We can "piggy-back" on the R&D work from TOF or the FF B0...

Pixel size:

- Need small pixels: 500 um / 5 / $\sqrt{12}$ = **30 um** is sufficient to achieve stated goals.

Timing information:

- AC-LGAD time resolution ~ **20 psec** easily allows to distinguish bunch crossings.
- Electron bunch is ~1 cm long → photon bunch is ~1 cm long → **30 psec**.
- Time separation between multiple photon conversions in same bunch crossing (pileup) ~ AC-LGAD time resolution. Timing info only provides a little extra help to mitigate pileup.

Material budget:

- Simulations suggest that the tracking distortion from ~1% X0 is not a problem.

Requirements

Photon position resolution, X_γ & Y_γ :

- Studies of how much the photon beam could be clipped, suggests δX_γ & δY_γ < 6 mm.

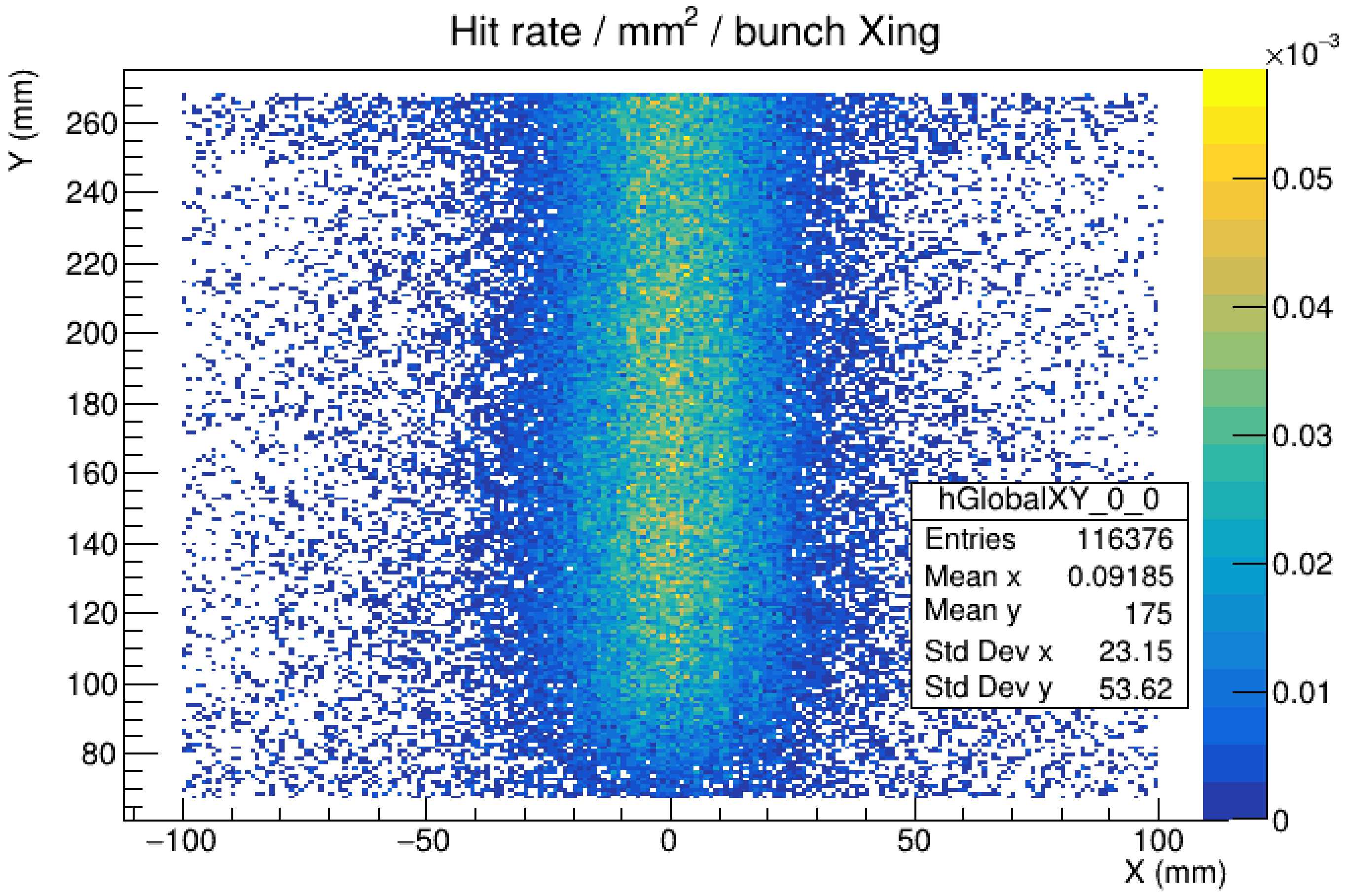
Photon energy resolution:

- Should be better than the PS CAL (~10% / $\sqrt{E}$). Trackers will calibrate PS CALs online.

Fake track rejection:

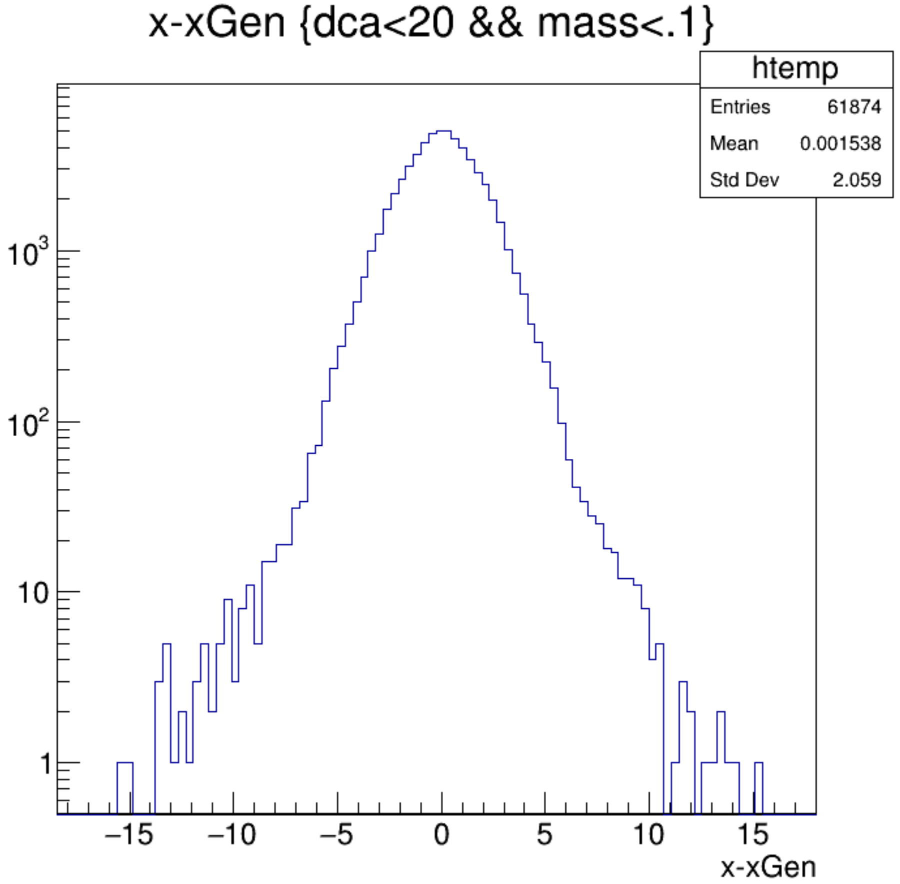
- 2-layer hodoscope saves on costs but requires cuts to isolate real tracks.
  DCA < 2 cm and M_{inv} < 0.1 GeV found to be effective.
- AC-LGAD noise rate ~30 Hz per pixel (30 msec). Bunch spacing is 10 nsec. So, a ~10^{-7} probability for a given pixel to fire as noise. Each sheet has 10^5 pixels → ~1% chance to have noise-induced track. Noise hits occur at random locations → dca to converter will be large (easy to reject).

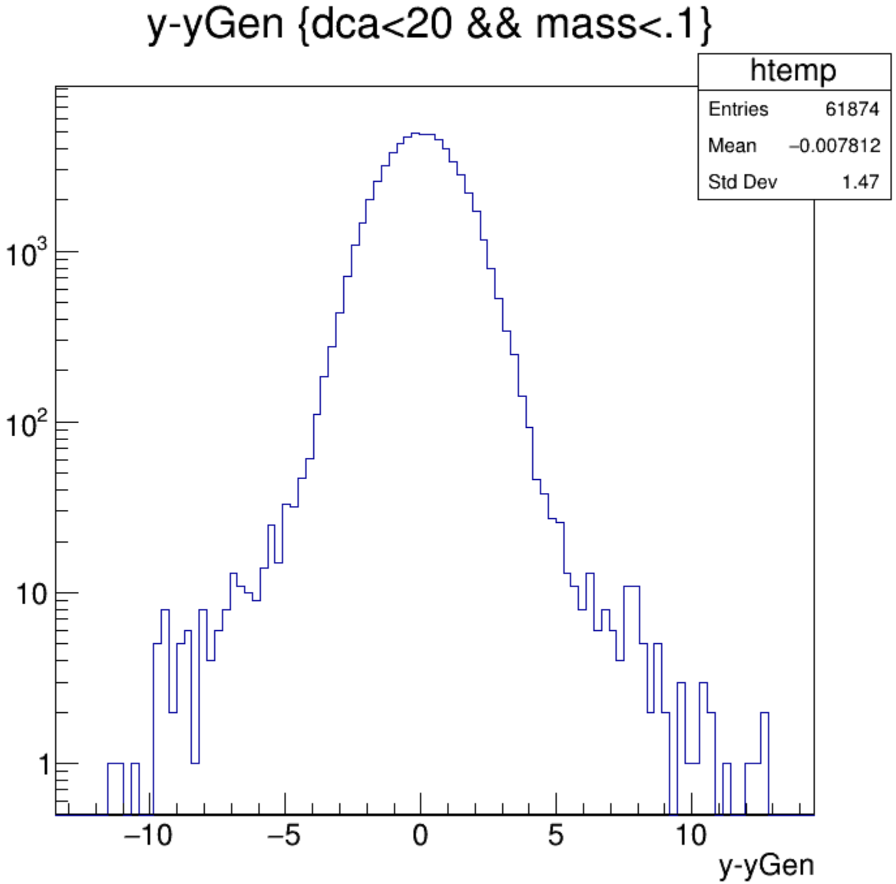
Tracker Occupancies



- Hit rate for e-Au 10 x 110: Maximum Bremsstrahlung rates
- Beam effects included.
- Hits concentrated in narrow vertical band.
- Rates per pixel very low. Large sensor integration times not a problem.

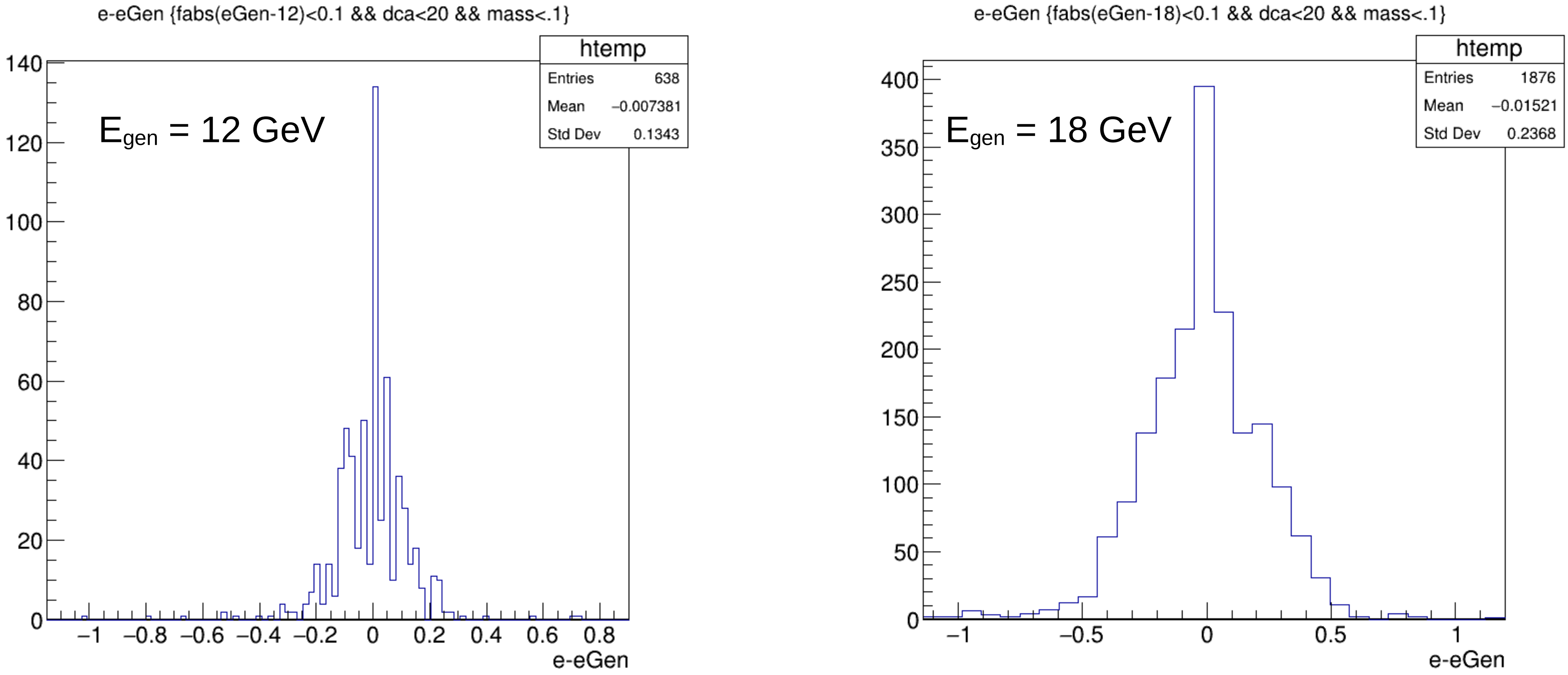
Tracker Performance: photon X_γ and Y_γ resolutions





- Photon X and Y resolutions ~ 2 mm.
- Satisfies requirements

Tracker Performance: photon energy resolutions



- Energy resolutions ~1%. Better at low E (larger slope in trackers). Opposite wrt CALs.
- Easily satisfies requirements.

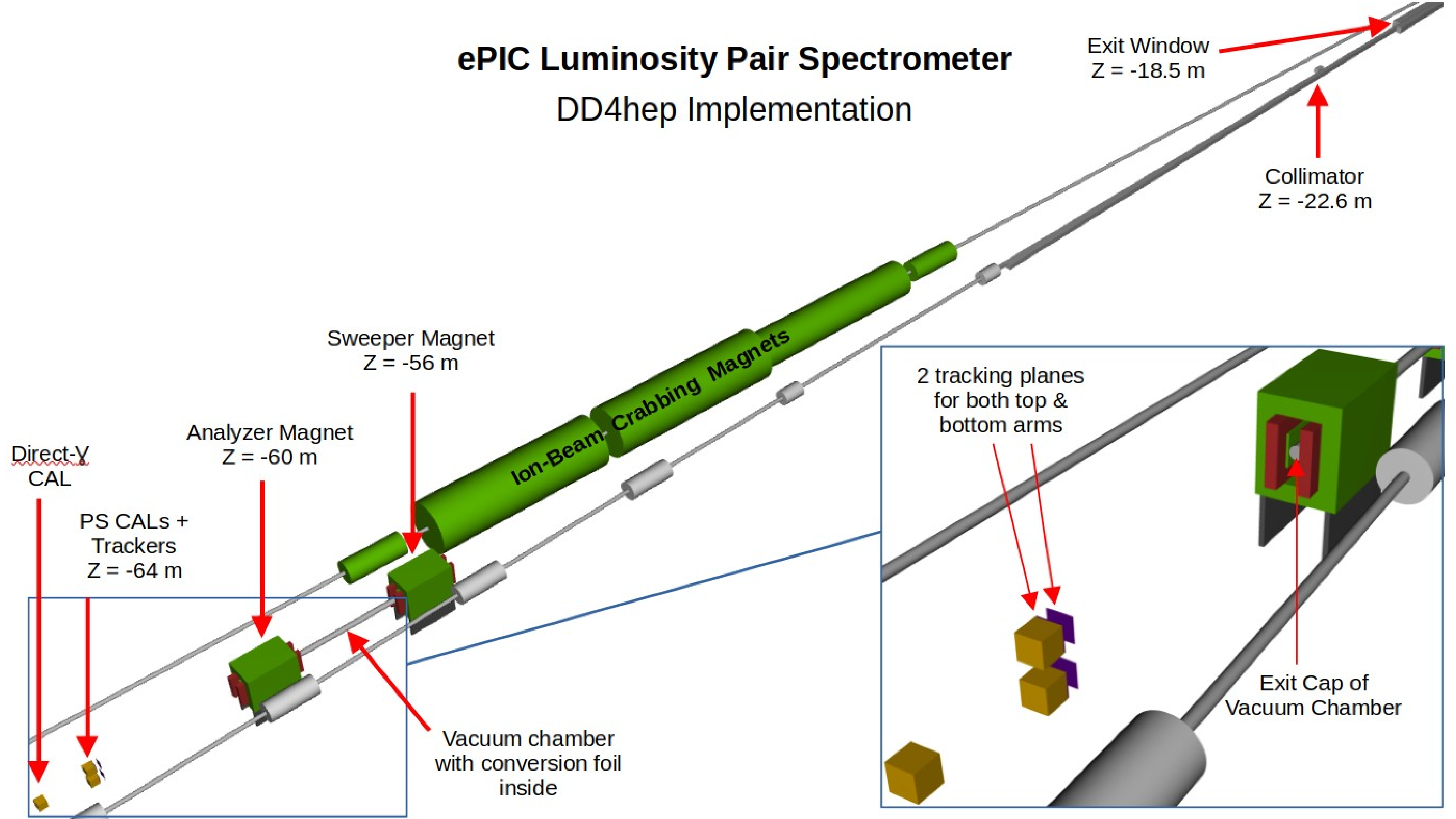
Remarks

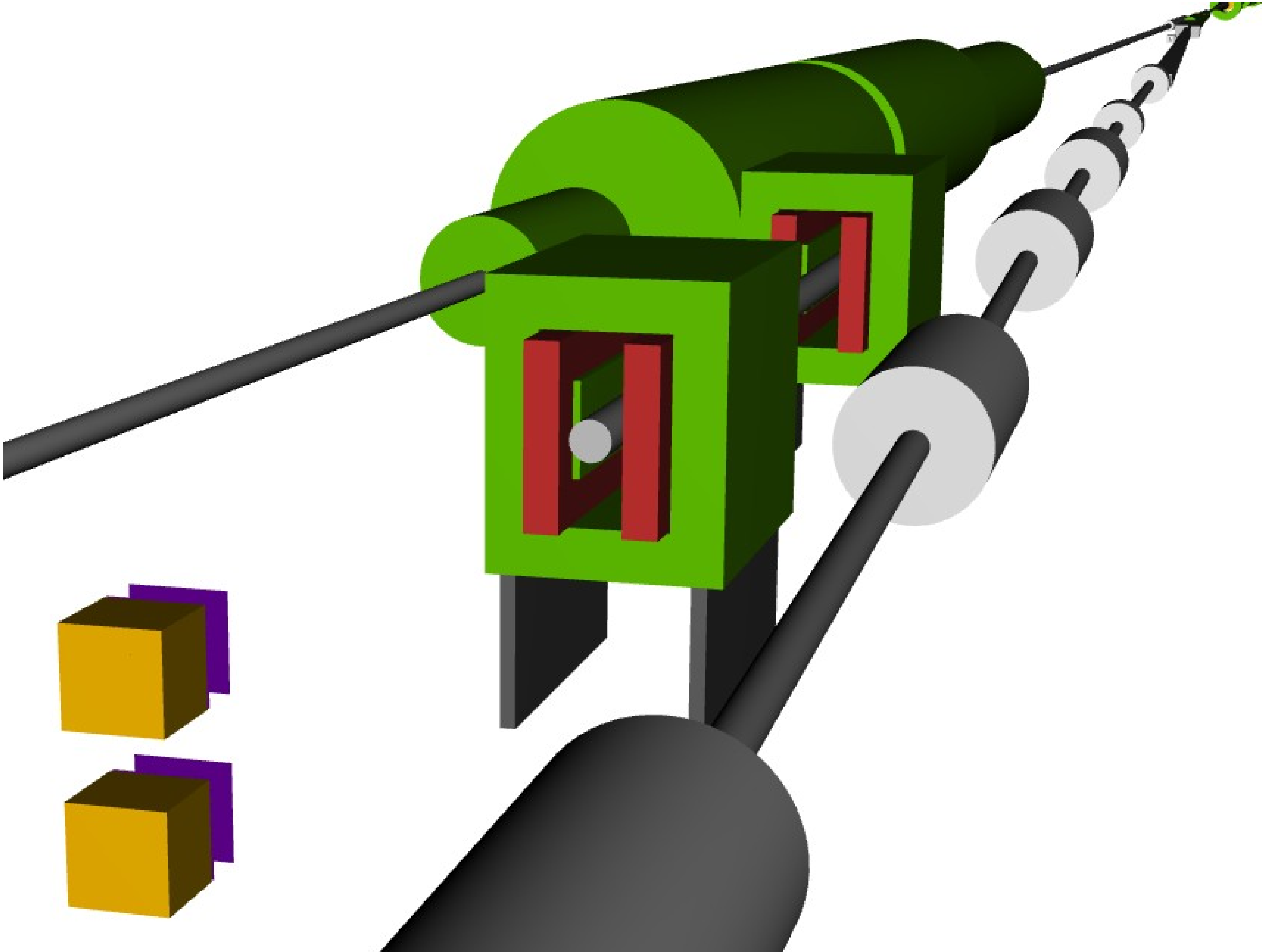
- AC-LGADs are a suitable technology for the Pair Spectrometer tracker.
- A 2-layer (“bare-bones”) hodoscope should suffice, although with cuts in place.
- Reconstructed photon energy and position resolutions satisfy our requirements.

To Do

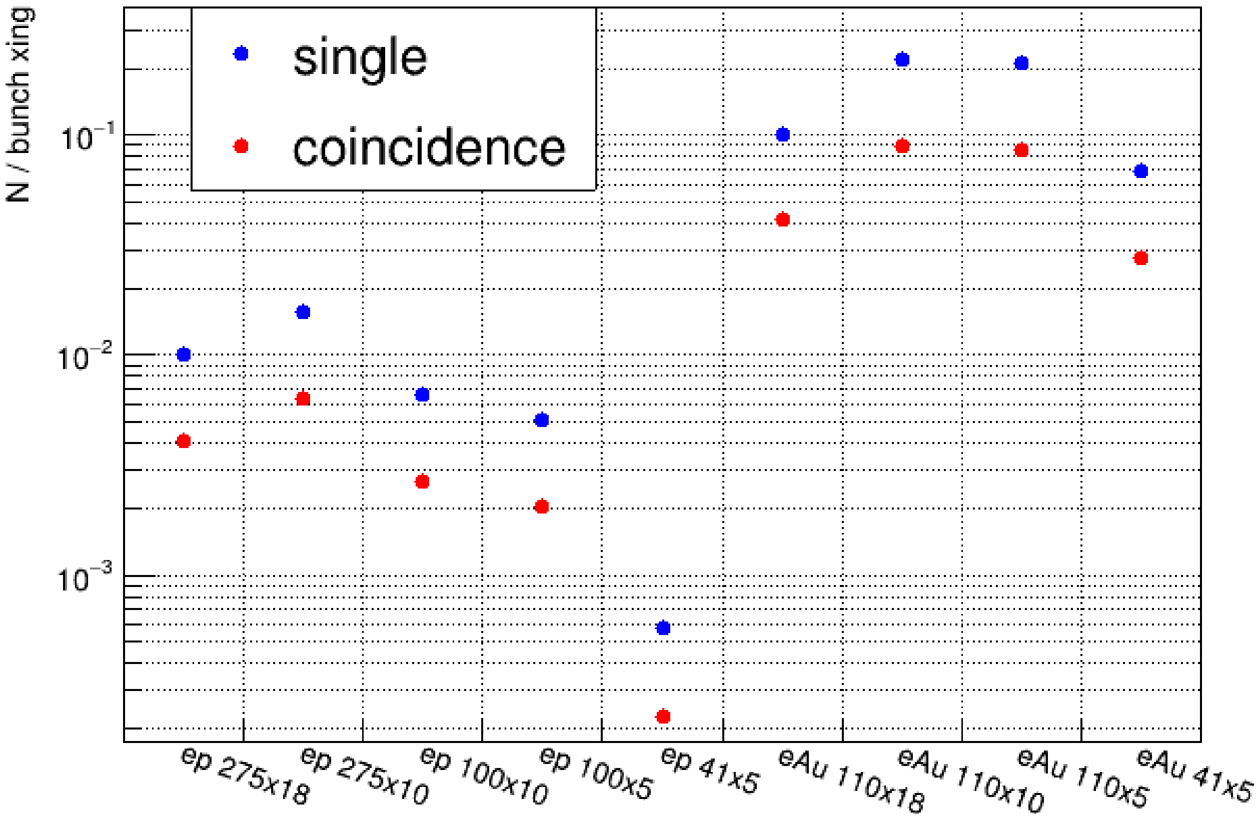
- Calculate tracking efficiency (with cuts) & fake-track rates.
- Check performance of trackers in multi-conversion events (pileup):
  - With 1 mm Al converter foil, expect ~0.2 electrons per bunch crossing on average in eA. Not certain that a 1 mm foil can withstand synchrotron heat load.
  - Thicker converters → more conversions.

Backup


ePIC Luminosity Pair Spectrometer
DD4hep Implementation
Exit Window
Z = -18.5 m
Collimator
Z = -22.6 m
Ion-Beam Crabbing Magnets
Sweeper Magnet
Z = -56 m
Analyzer Magnet
Z = -60 m
Direct-γ
CAL
PS CALs +
Trackers
Z = -64 m
Vacuum chamber
with conversion foil
inside
2 tracking planes
for both top &
bottom arms
Exit Cap of
Vacuum Chamber



PS Rates



Takes into account conversions from:

- 1 cm Al Exit Window (8% conversion) (swept away)
- 37 m air (9%) (swept away)
- 1 cm Al Vacuum chamber entrance cap (8%) (swept away)
- 1 mm Al conversion foil (1%) (**enters PS**)

Toy MC simulation

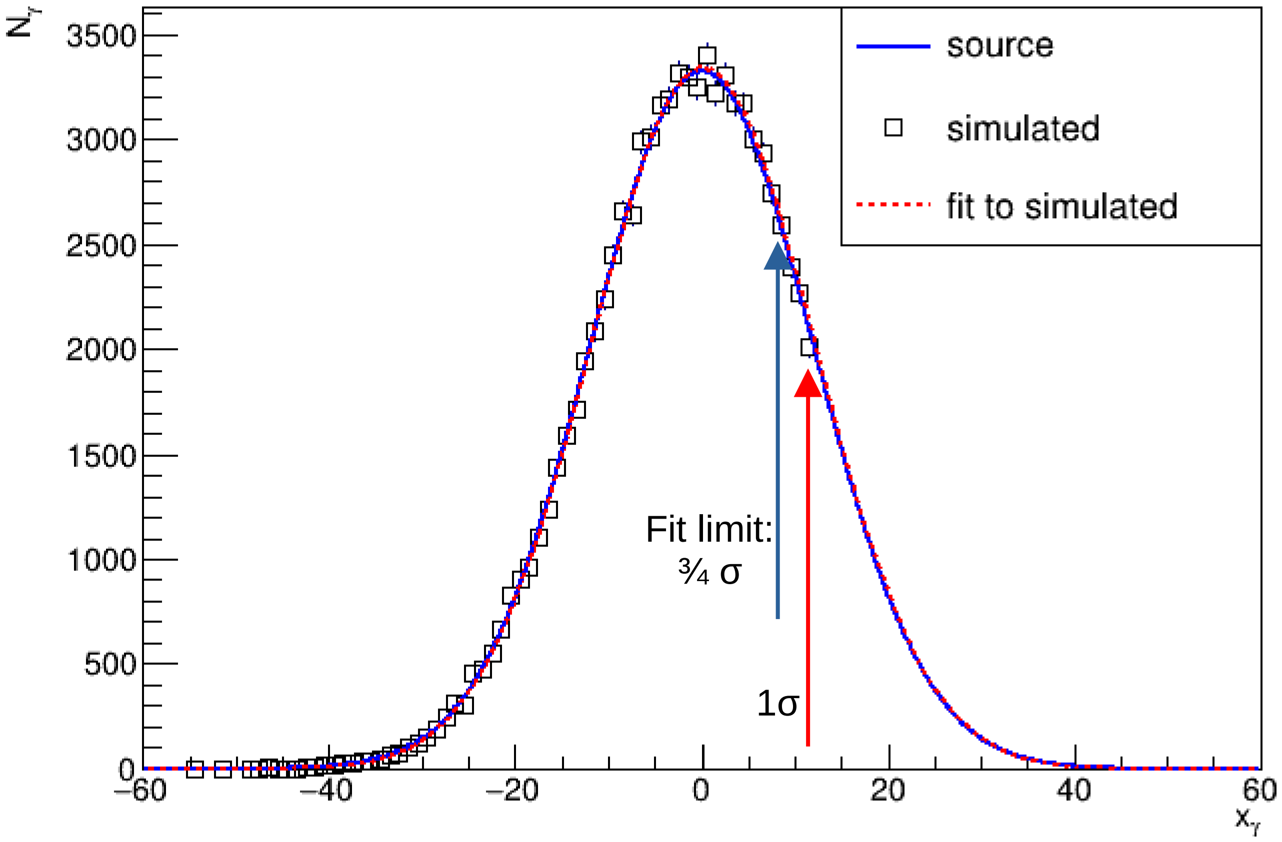
Source photon X_γ distribution taken as a Gaussian with
$\sigma = \delta\theta * Z = (211e\text{-}6 \text{ rad}) * (58 \text{ m}) = 12 \text{ mm}$

1) Randomly sample X_γ from the source
2) Clip one side by $N\sigma$
3) Smear X_γ by resolution
4) Fill a histogram with smeared X_γ
5) Fit the histogram with Gaussian and compare it's yield to that of the source

This is done for truncated $N\sigma$ between 0 and 5 from center of Gaussian, and for X_γ resolutions from 0 to 20 mm.

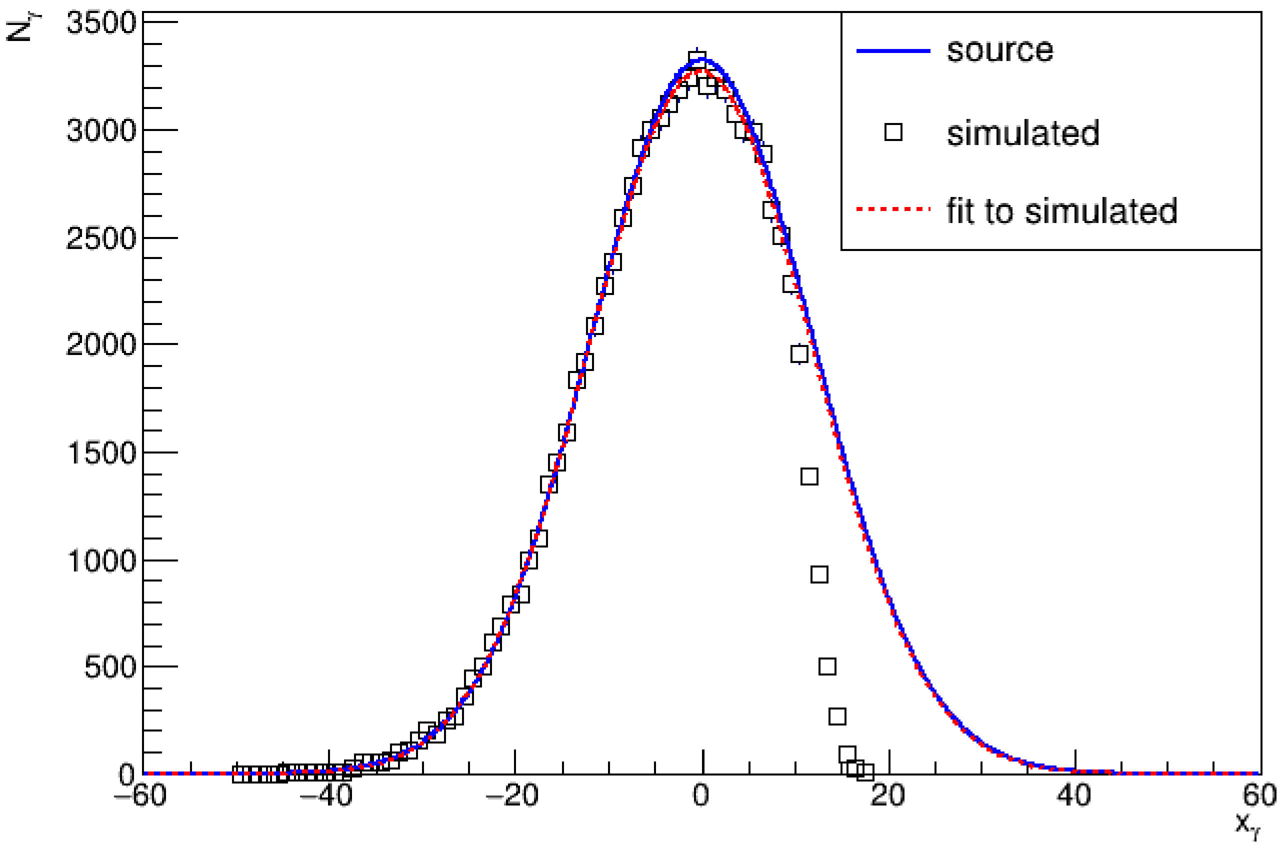
Fitting the clipped & smeared distribution causes non-Gaussian features.
Best fits obtained by fitting from -5σ to ¾ $N\sigma_{clipped}$

1σ truncation,
perfect position resolution



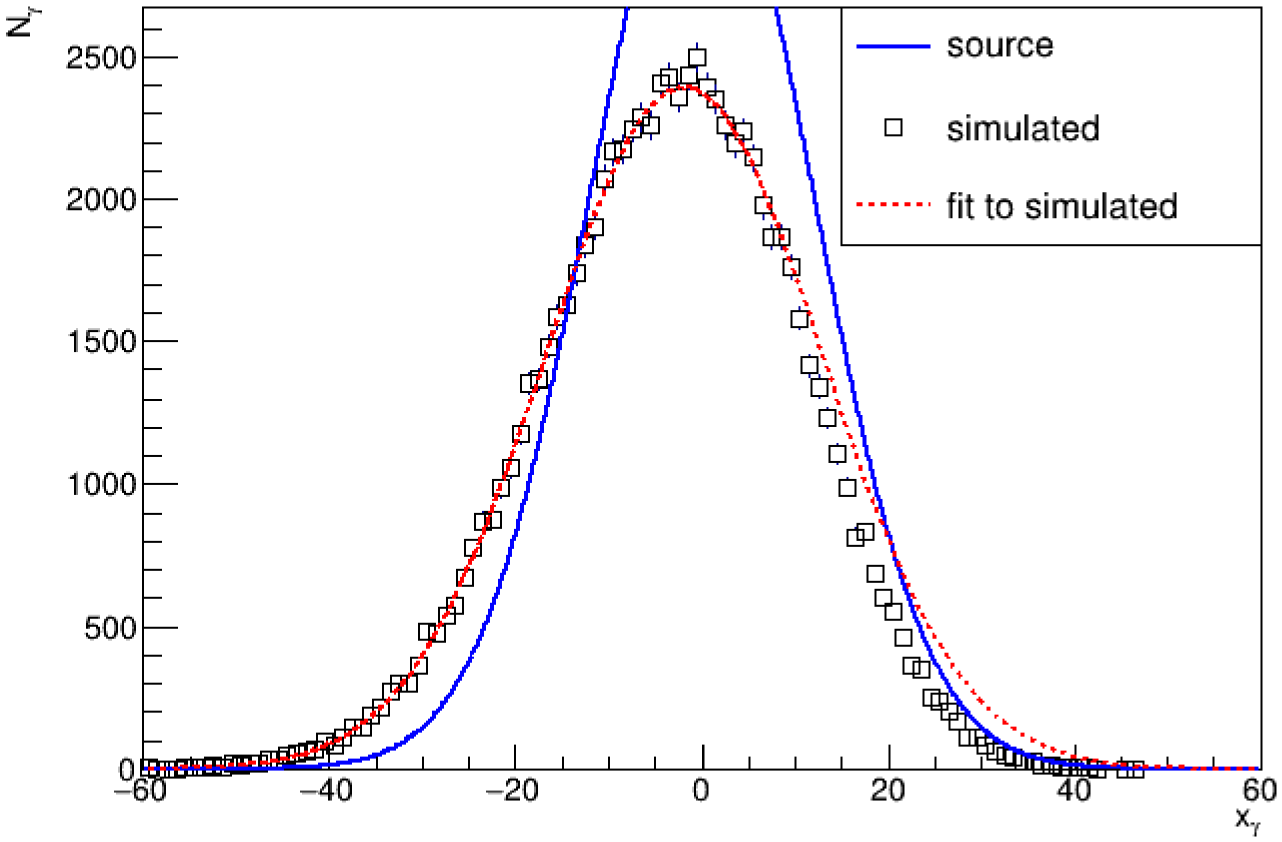
Acceptance error = 0.4%

1σ truncation, 2 mm position resolution



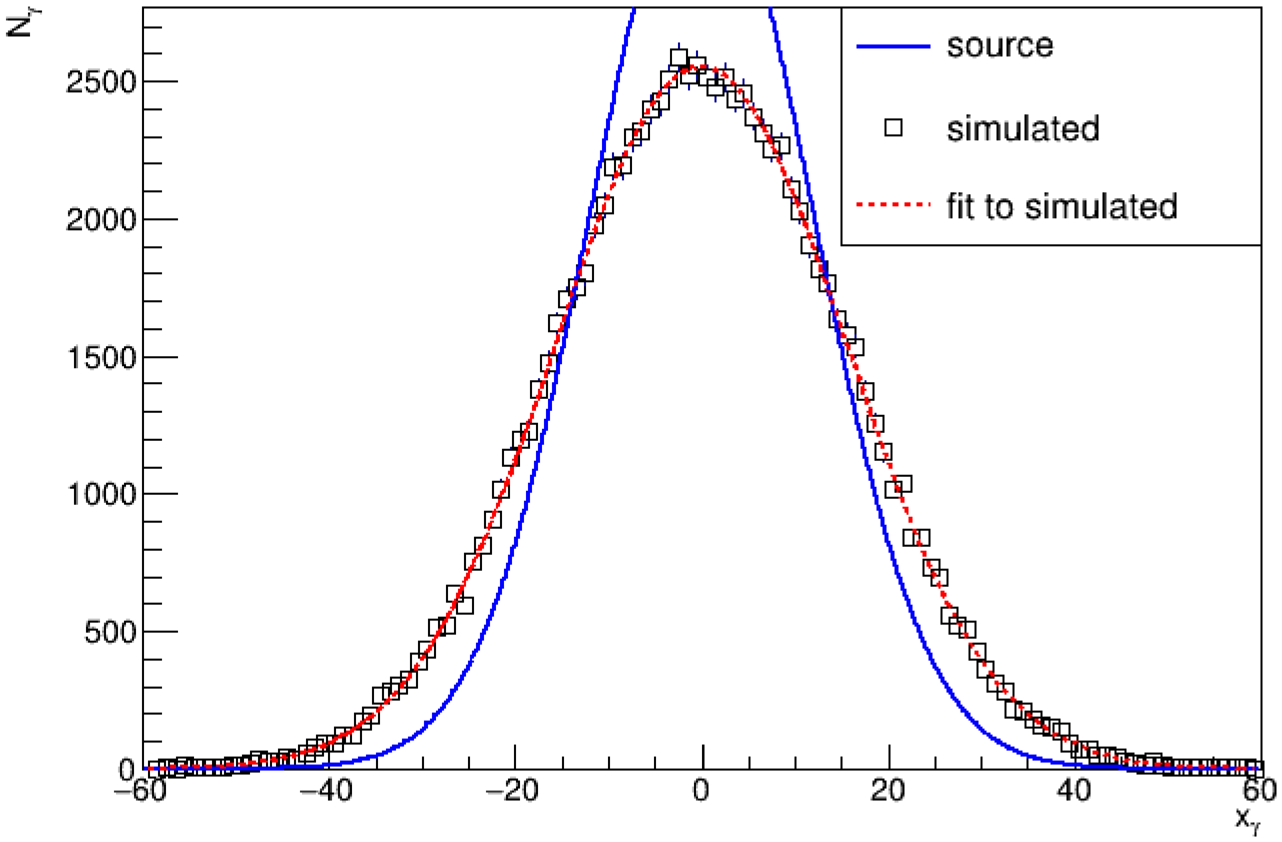
Acceptance error = 0.6%

1σ truncation, 10 mm position resolution



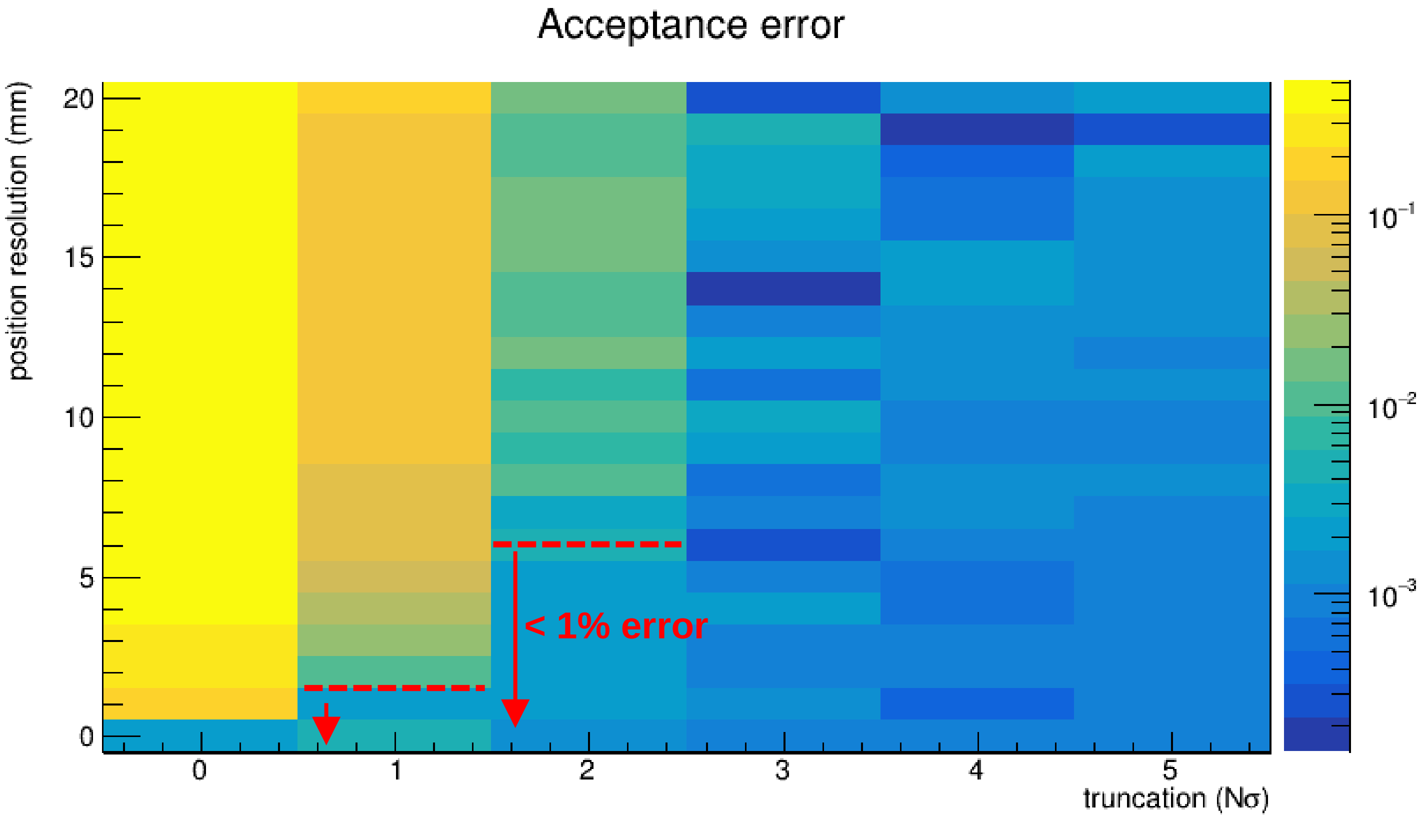
Acceptance error = 11%

3σ truncation,
10 mm position resolution



Acceptance error = 0.2%

Putting it all together



Acceptance error depends on truncation and position resolution.

How much truncation to expect??

Difficult to answer, but discussions with Christoph Montag suggest that Nσ=2 might be a reasonable max. Corresponds to a 630 urad angle of electron beam at IP.

- To achieve < 1% error, we need a X_γ resolution of **< 6 mm**.