ILD HCAL Calibration with Track Segments in Hadron Showers

Frank Simon, Shaojun Lu
MPI for Physics & Excellence Cluster 'Universe'
Munich, Germany

CALICE Collaboration Meeting, Daegu, South Korea, February 2009

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Calorimeter for ILC

Excellence Cluster Universe

Outline

- What about Cosmics?
- Reminder: Track segments in hadronic showers in the CALICE AHCAL
- Simulations for the full ILD barrel HCAL
- Luminosity needs for calibration: Rough estimates
- Summary, consequences for calibration strategy

Calibration: What about Cosmics?

- Cosmic muons are the classic particles for a MIP calibration: Can we use them?
  - Vertical Flux at surface ~160 Hz/m^2 above 1 GeV, ~20 Hz/m^2 above 10 GeV (only this will give us full penetration)

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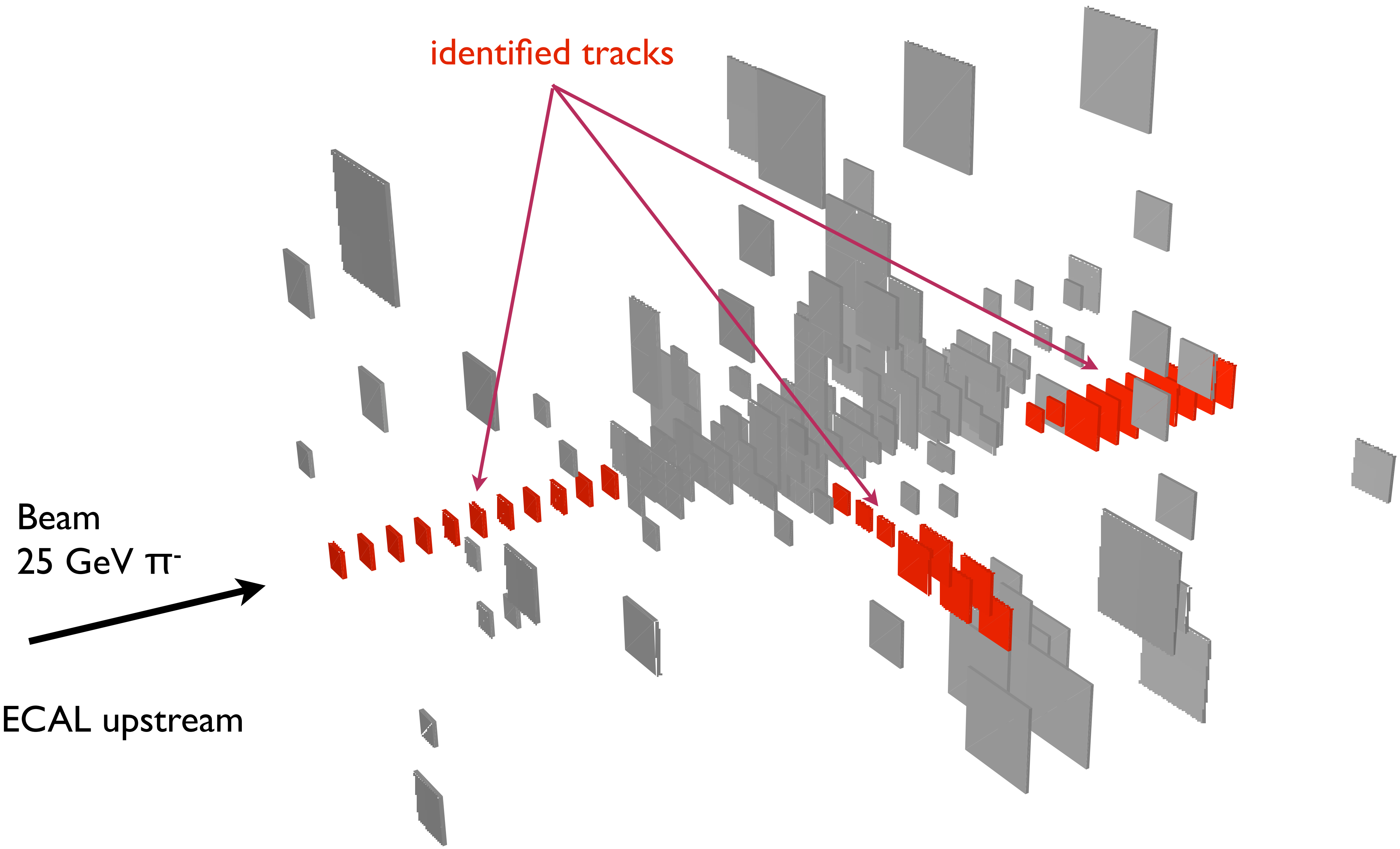
Alternative calibration scenarios are clearly necessary!

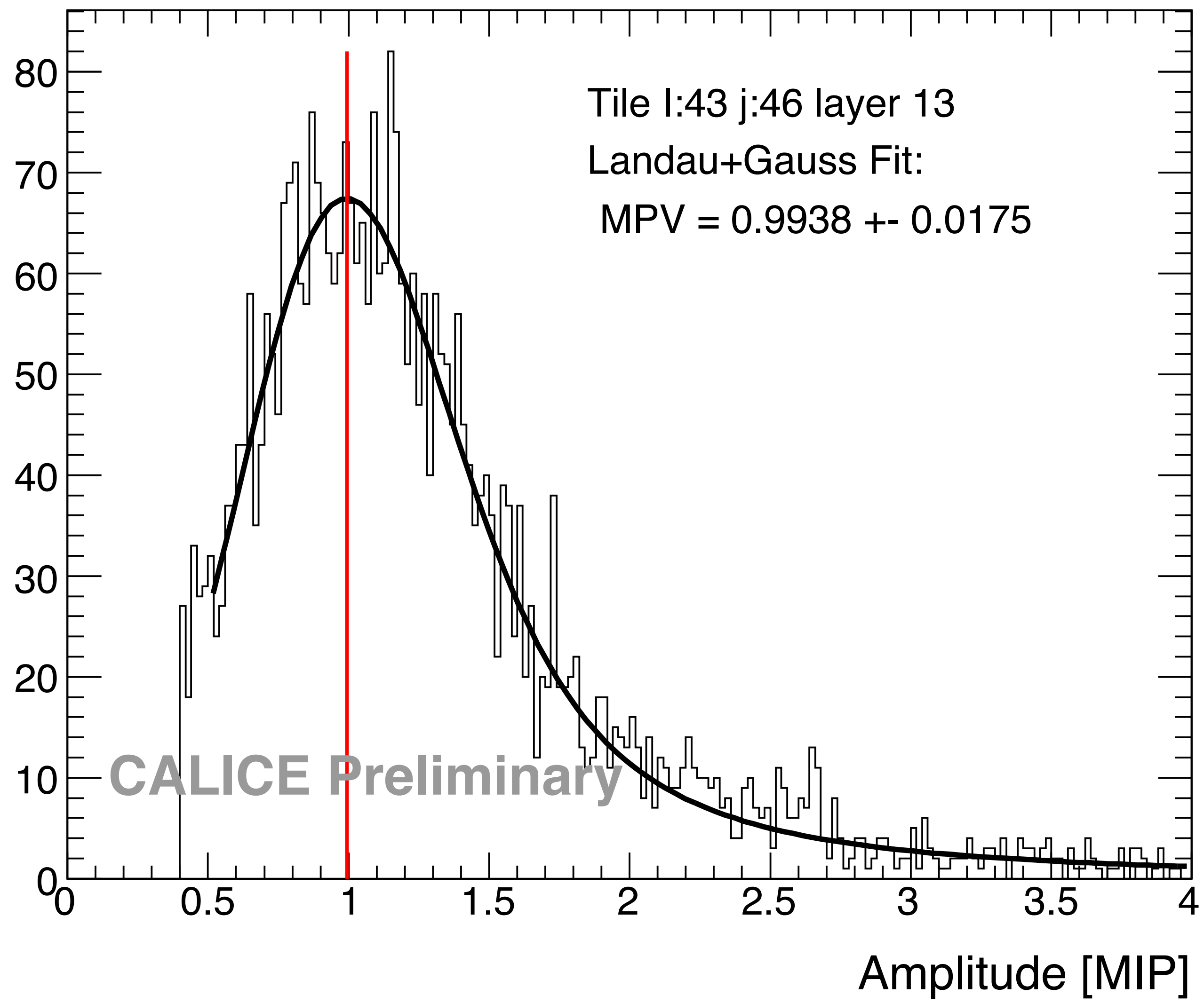
Reminder: Track Segments in Hadronic Showers in the CALICE HCAL

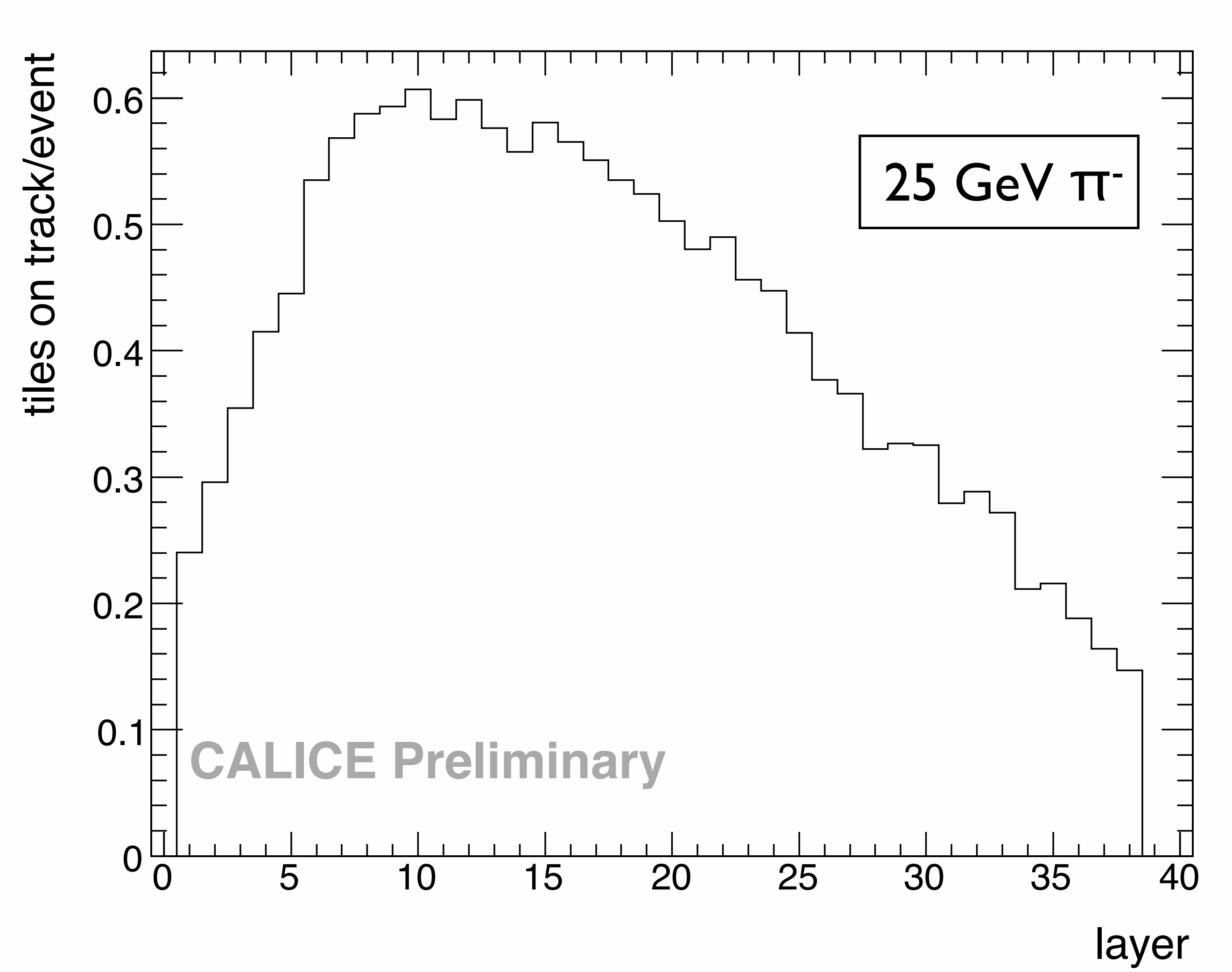
Tracking in Hadronic Showers works in HCAL!



- Find tracks from isolated hits (tiles that don't have energy deposits in their next neighbors on the same layer)

Cells on Tracks: Amplitudes (Muons & Hadrons)





- Track finding applied to Muon runs and Hadron runs:
  - clean spectrum of energy deposit in both cases
  - Most probable value extracted with a Landau+Gauss fit

Expansion to ILD

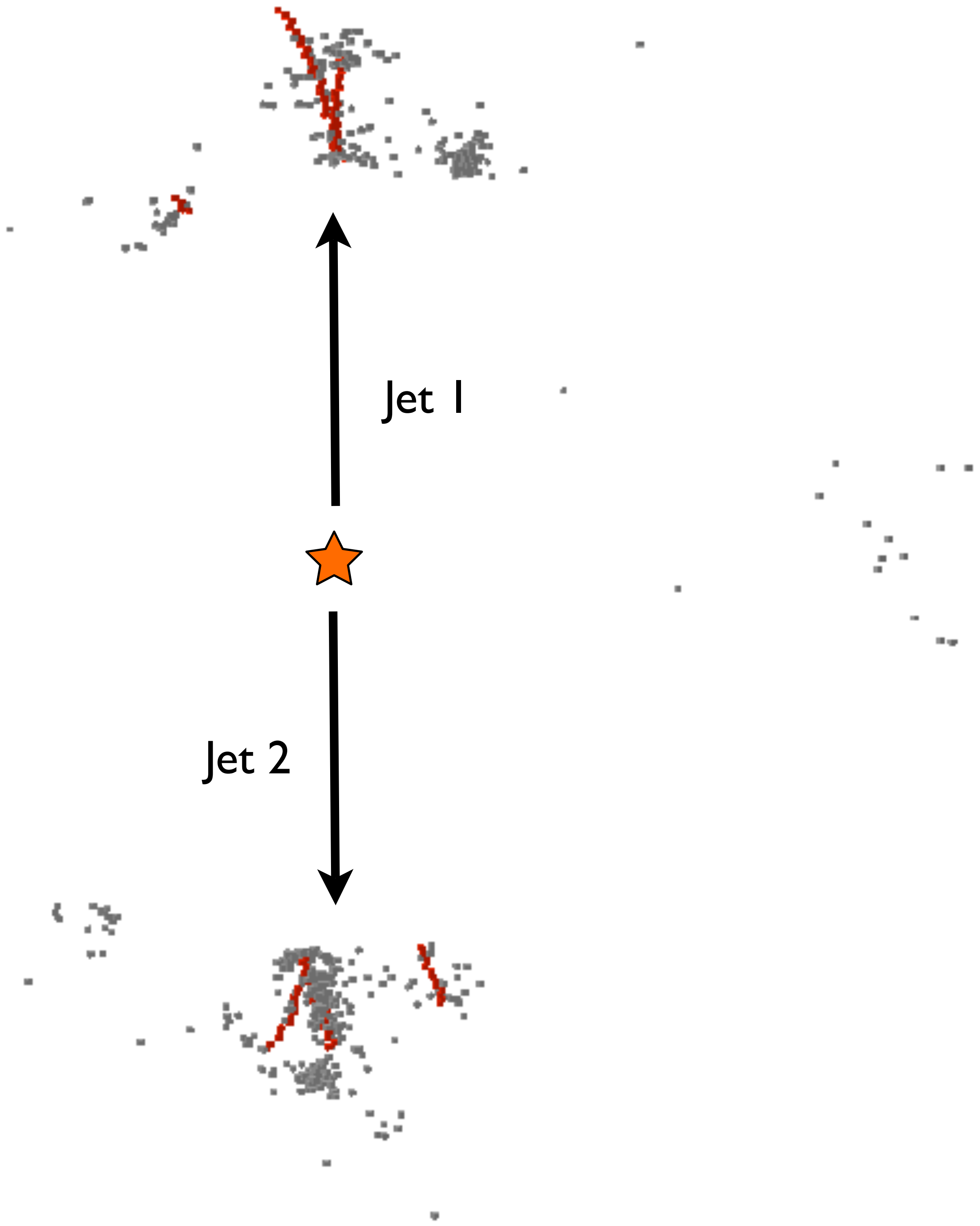
MC Studies in the ILD Detector

- Simulation with the ILD detector geometry
  - Digitization not used, only use raw G4 energy deposits in the scintillator cells

- Tracking algorithm slightly optimized for tracking within ILD: improved acceptance for curved and inclined tracks compared to the algorithm used for the CALICE AHCAL
  - Currently no tracking across module boundaries, no use of data from other detectors (besides HCAL Barrel)

- Simulated $e^+e^- \rightarrow$ qqbar and $e^+e^- \rightarrow \mu^+\mu^-$ via Z exchange (real Z in the case of 91.2 GeV)

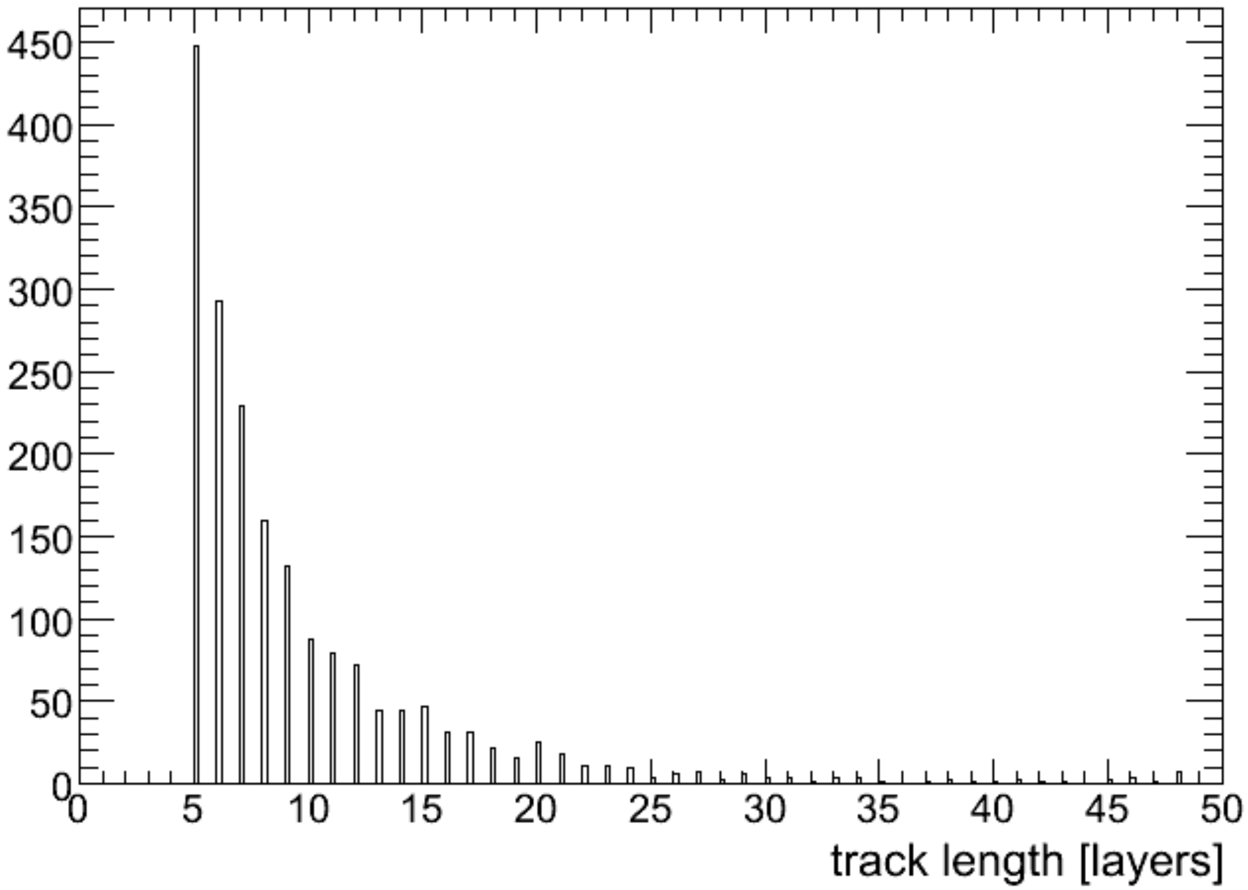
Expansion to ILD: MC Study

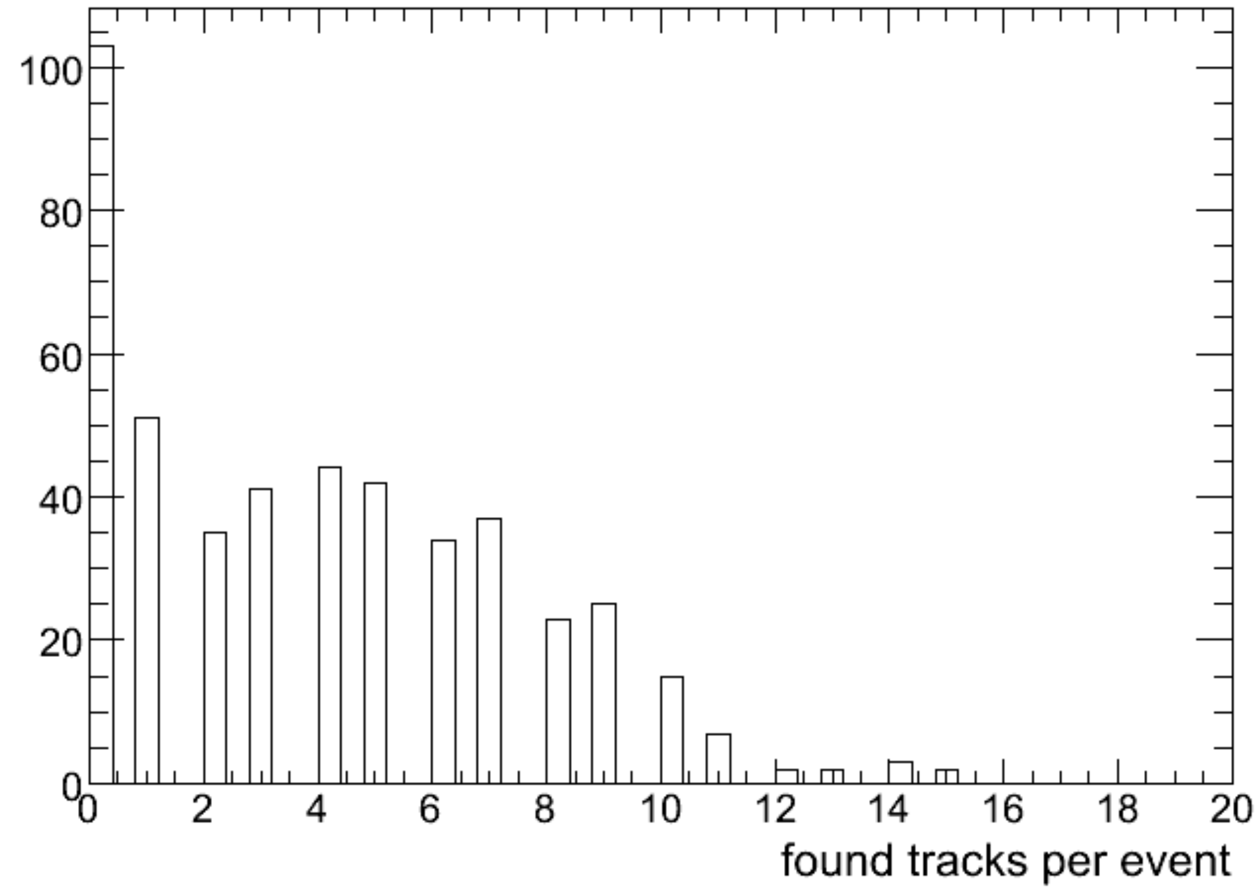


$Z^0 \rightarrow q\bar{q}$ @91.2GeV

- All hits in the HCAL barrel are shown
  - Two clean back-to-back jets
- Total number of found tracks: 8

Properties of Tracks: Z Resonance





$$Z^0 \rightarrow q\bar{q}\ @91.2\mathrm{GeV}$$

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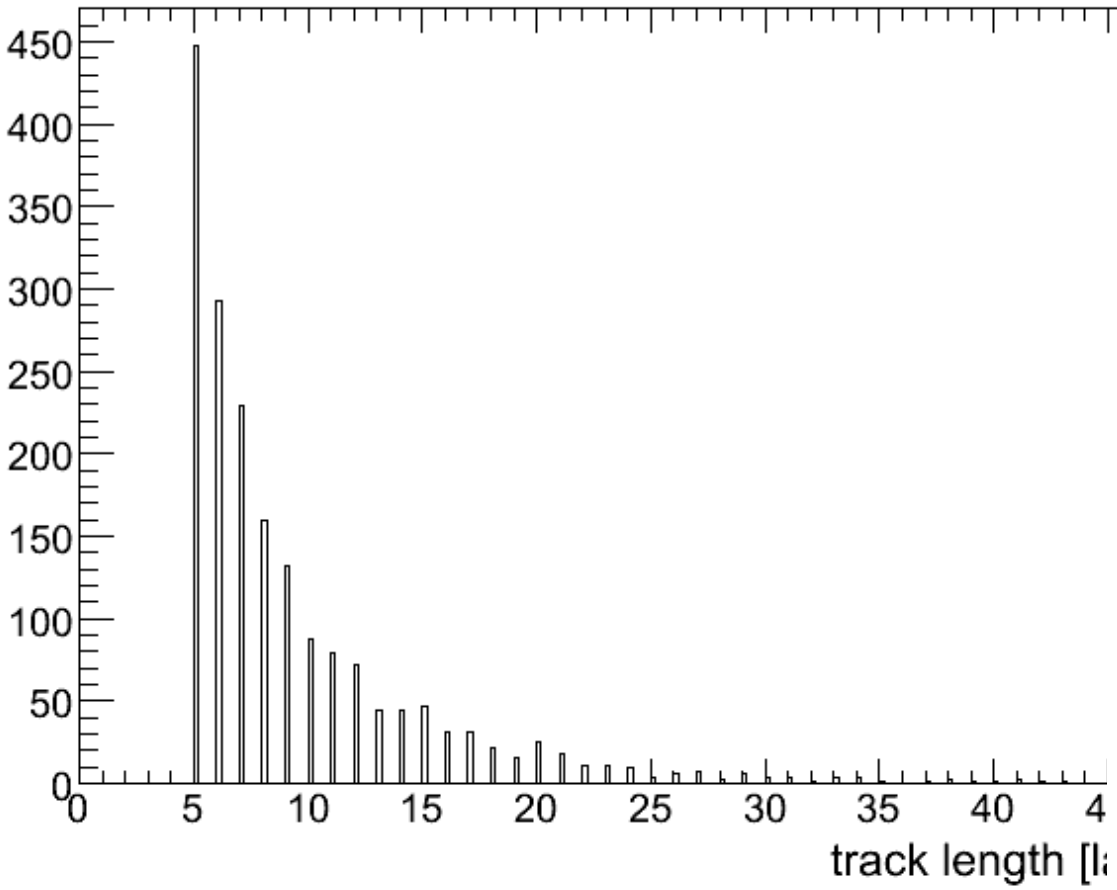

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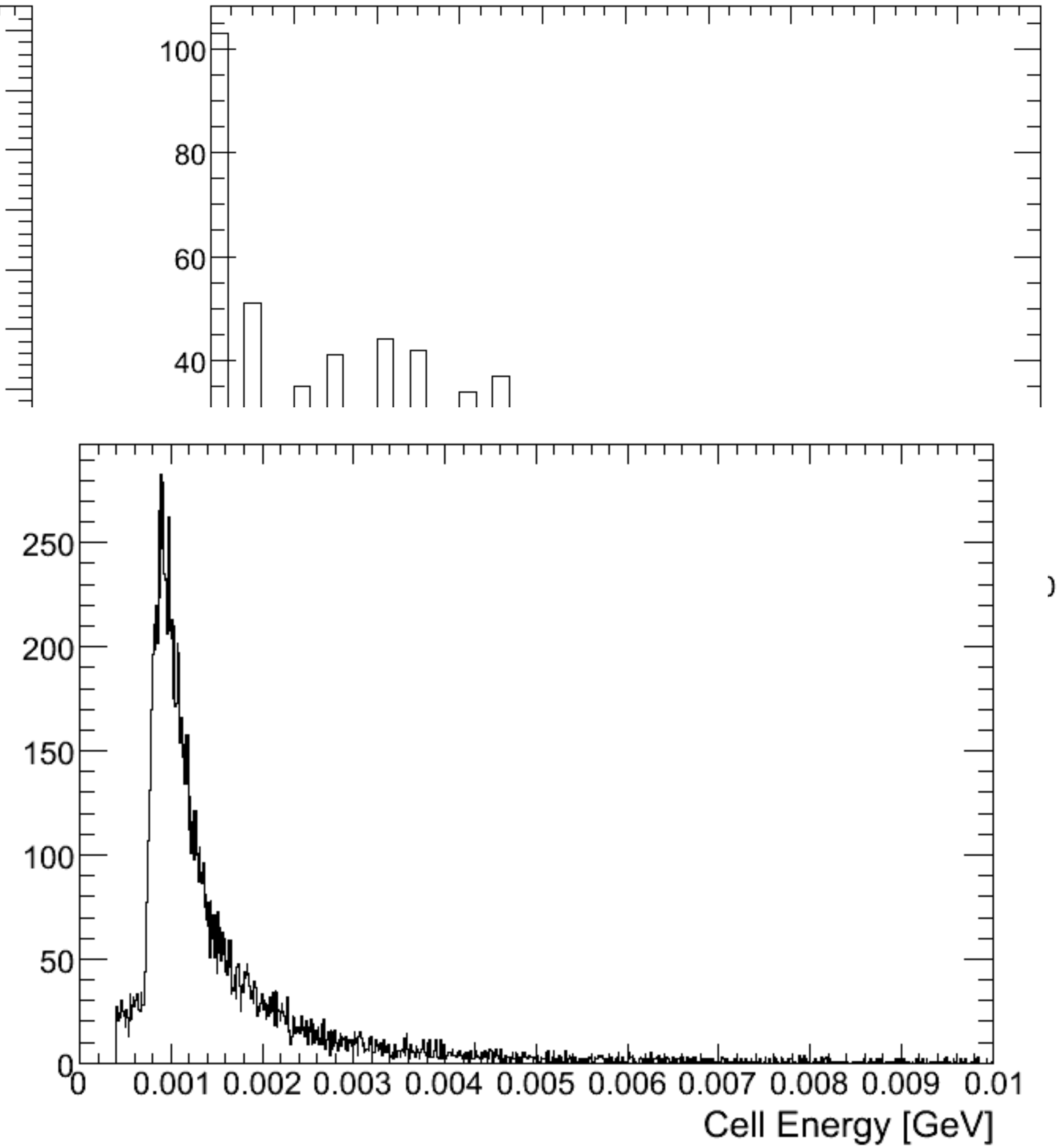
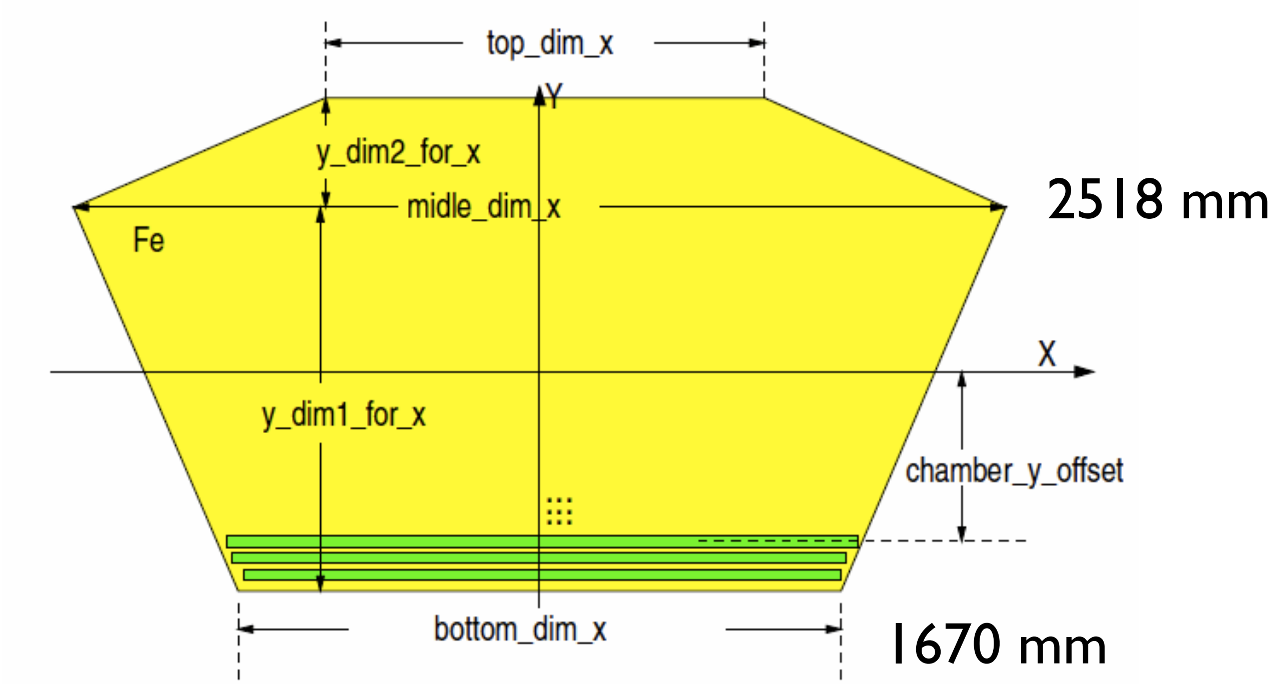


So: How much is needed?

- For a good calibration (e.g. very well defined MIP peak): ~ 1000 Entries per cell

Rough ballpark estimate:



The ILD HCAL module: average x dimension ~ 2094 mm, corresponds to 70 cells of 30 x 30 mm^2

Length in z: 2350 mm, corresponds to 78 cells

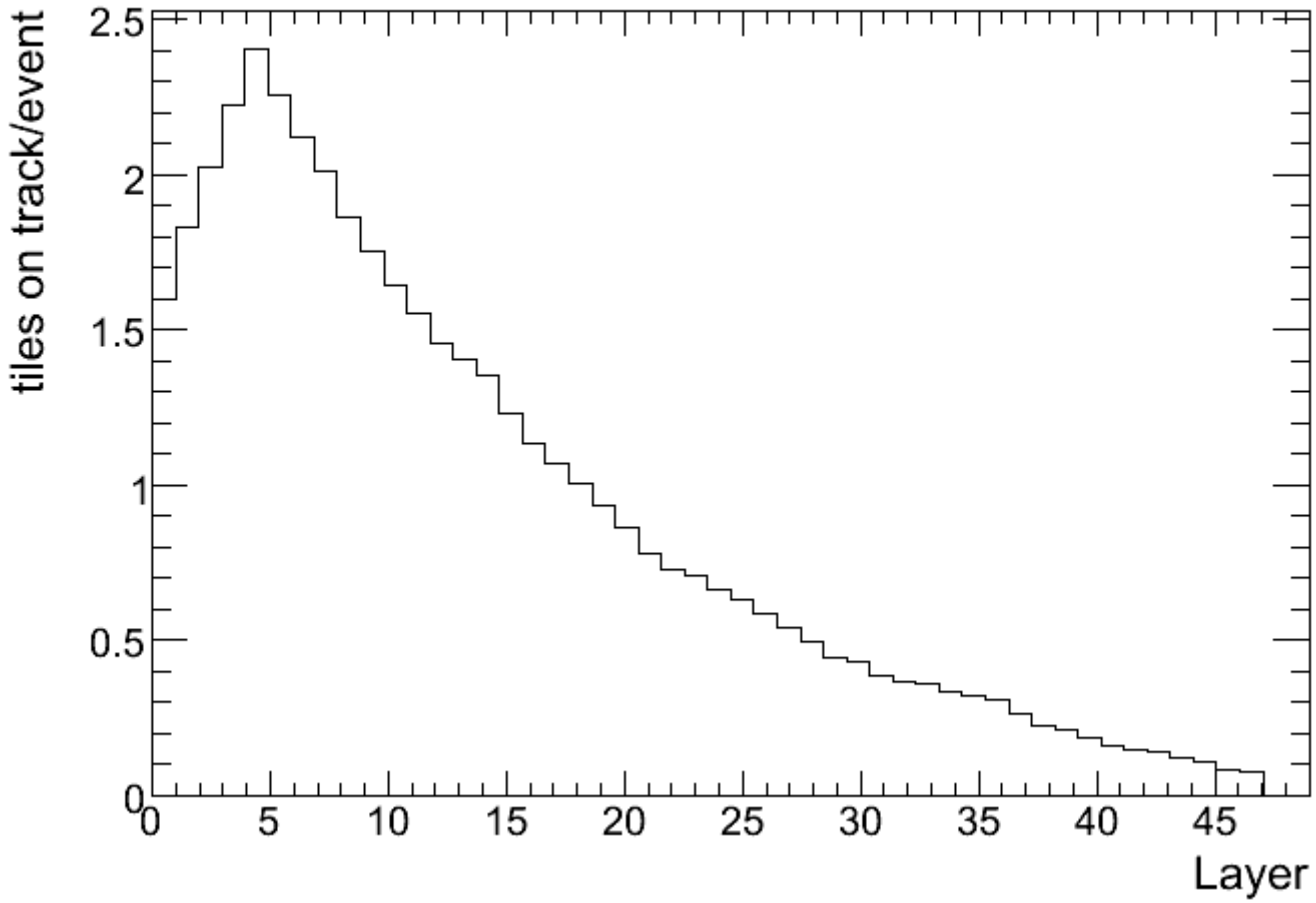
➯ On average 5460 cells per layer, with 16 modules (2 rings a 8 modules): ~ 90k cells / layer

➯ To get 1000 tracks per cell on average: 90 M tracks per layer

How much do we get?

- Study at full energy: 500 GeV

$$e^+e^- \rightarrow Z^0 \rightarrow q\bar{q} \text{ @ } 500\text{GeV}$$



- Average over all events, no requirement that jets actually go into the Barrel
- High statistics in the first few layers, then a fast drop to later layers: Made worse by the presence of the strong magnetic field

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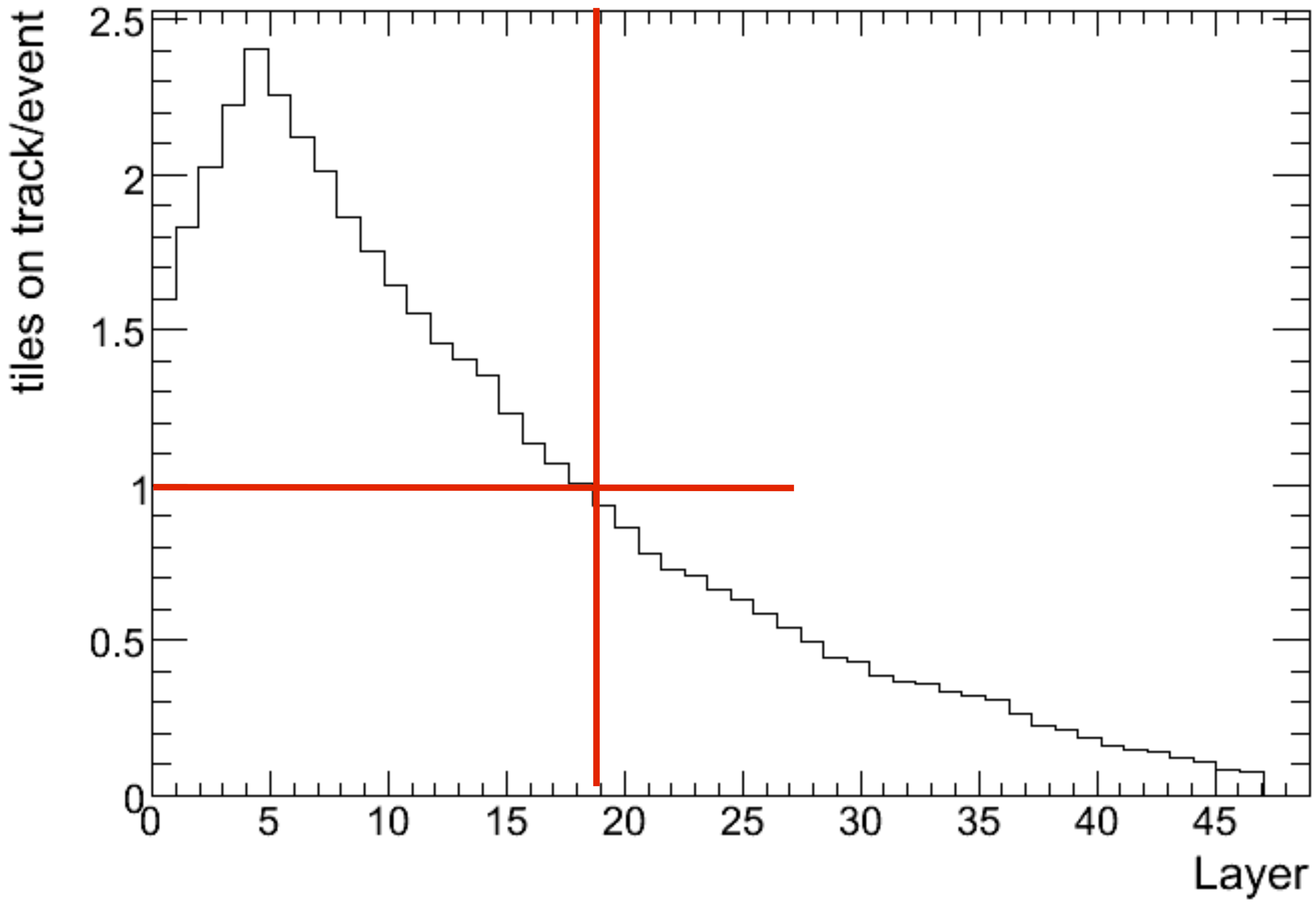

> 1 Track / layer out to layer 18 (counting from 0)

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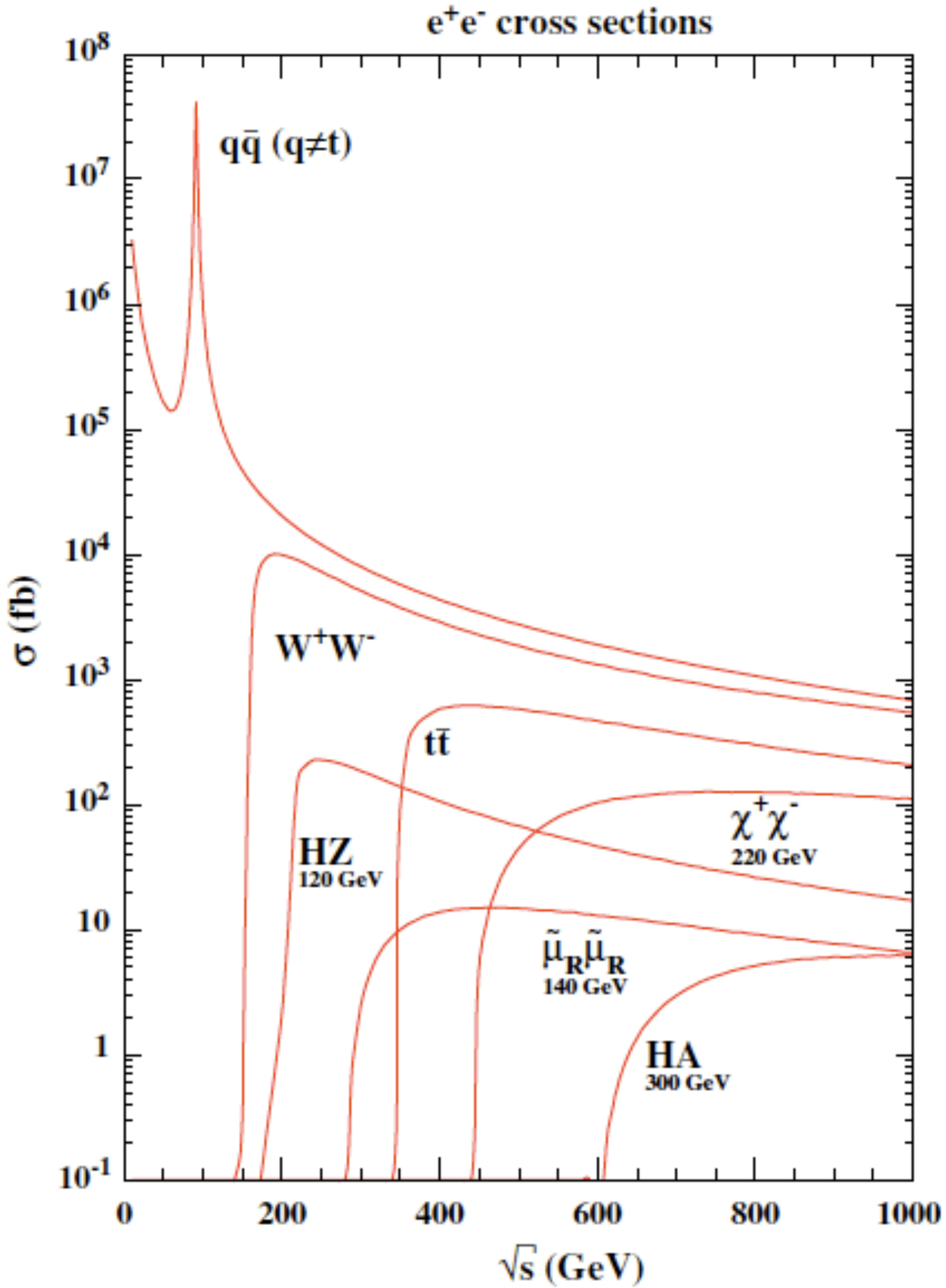
What Integrated Luminosity is needed?

- To get high statistics (e.g. ~1000+ tracks per cell) to layer 18, 90 M events are needed



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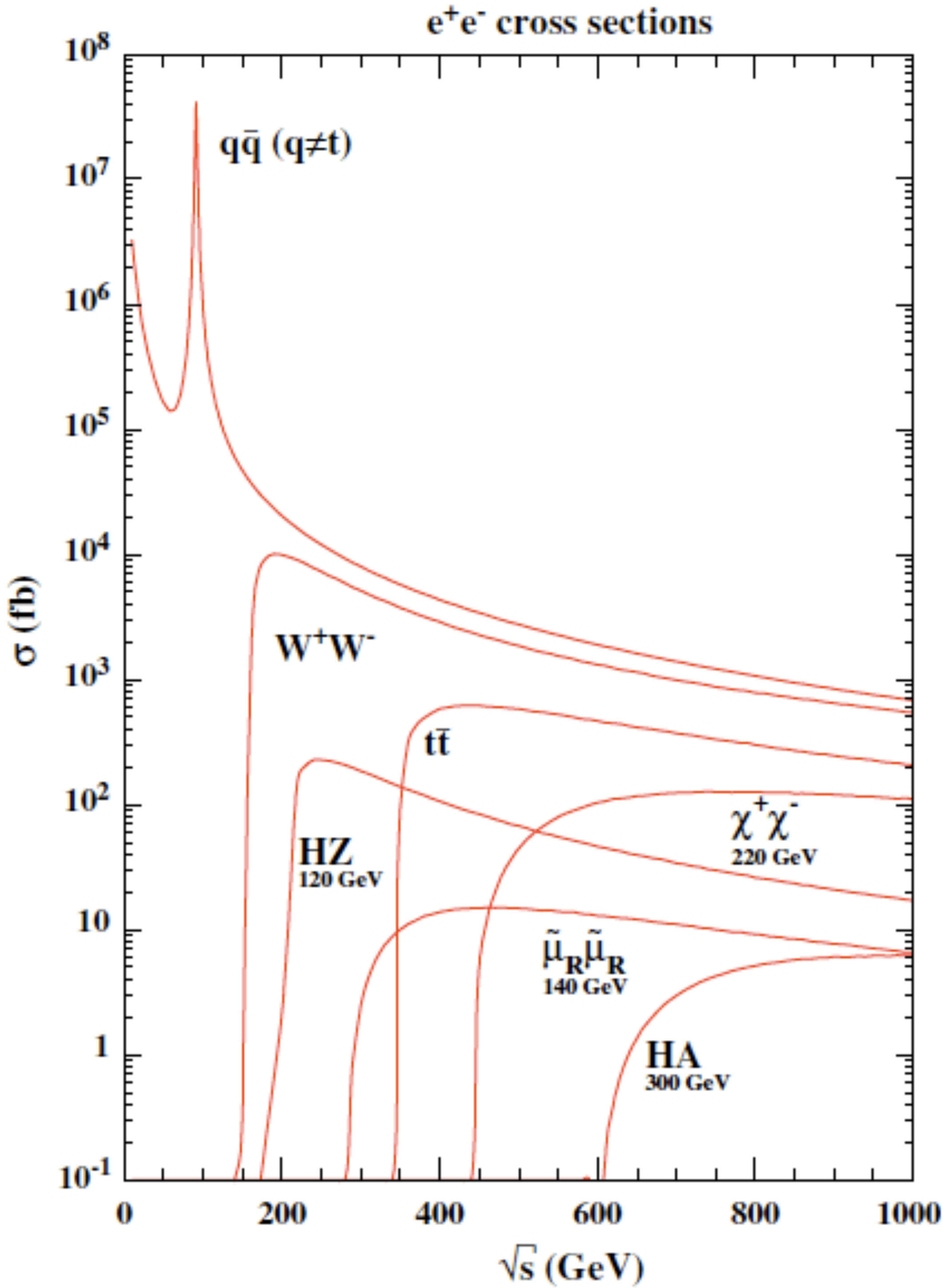

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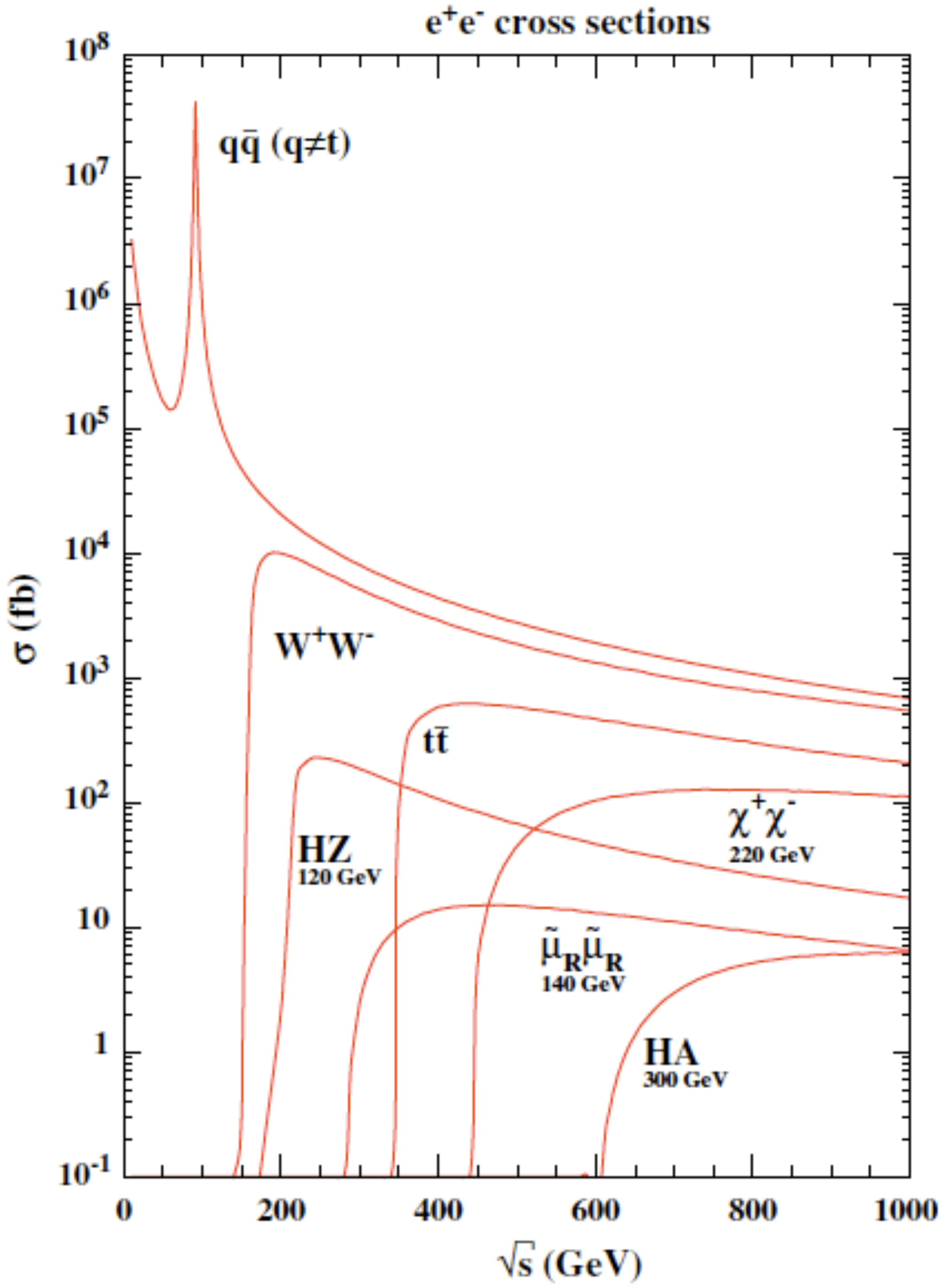

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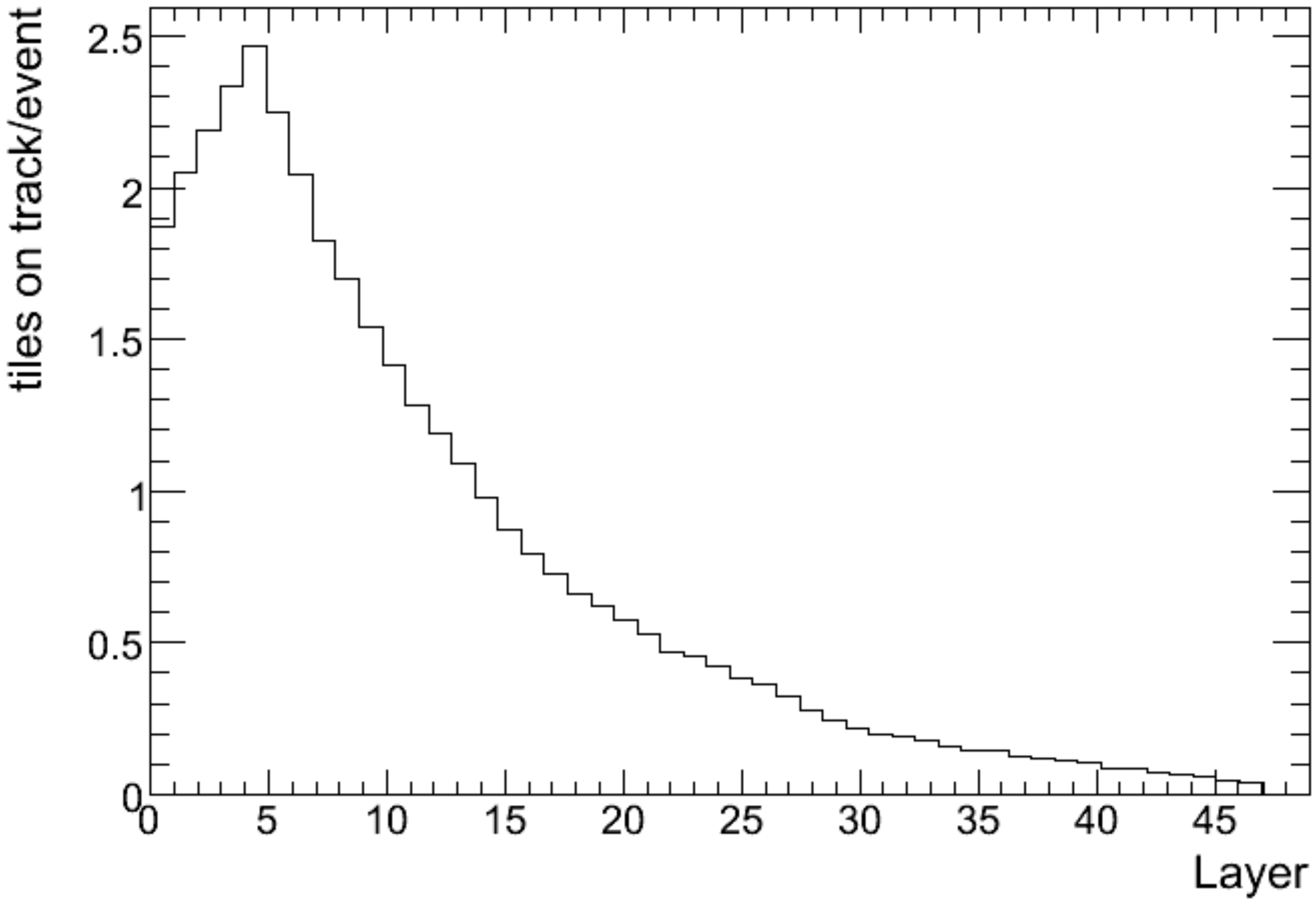
... no need to say more... but anyway:

at L = 2 x 10^{34} $cm^{-2}s^{-1}$: ~1.7 fb^{-1}/day

➩ 50 years of continuous operation at peak luminosity...

The Hope: Z-Resonance Running



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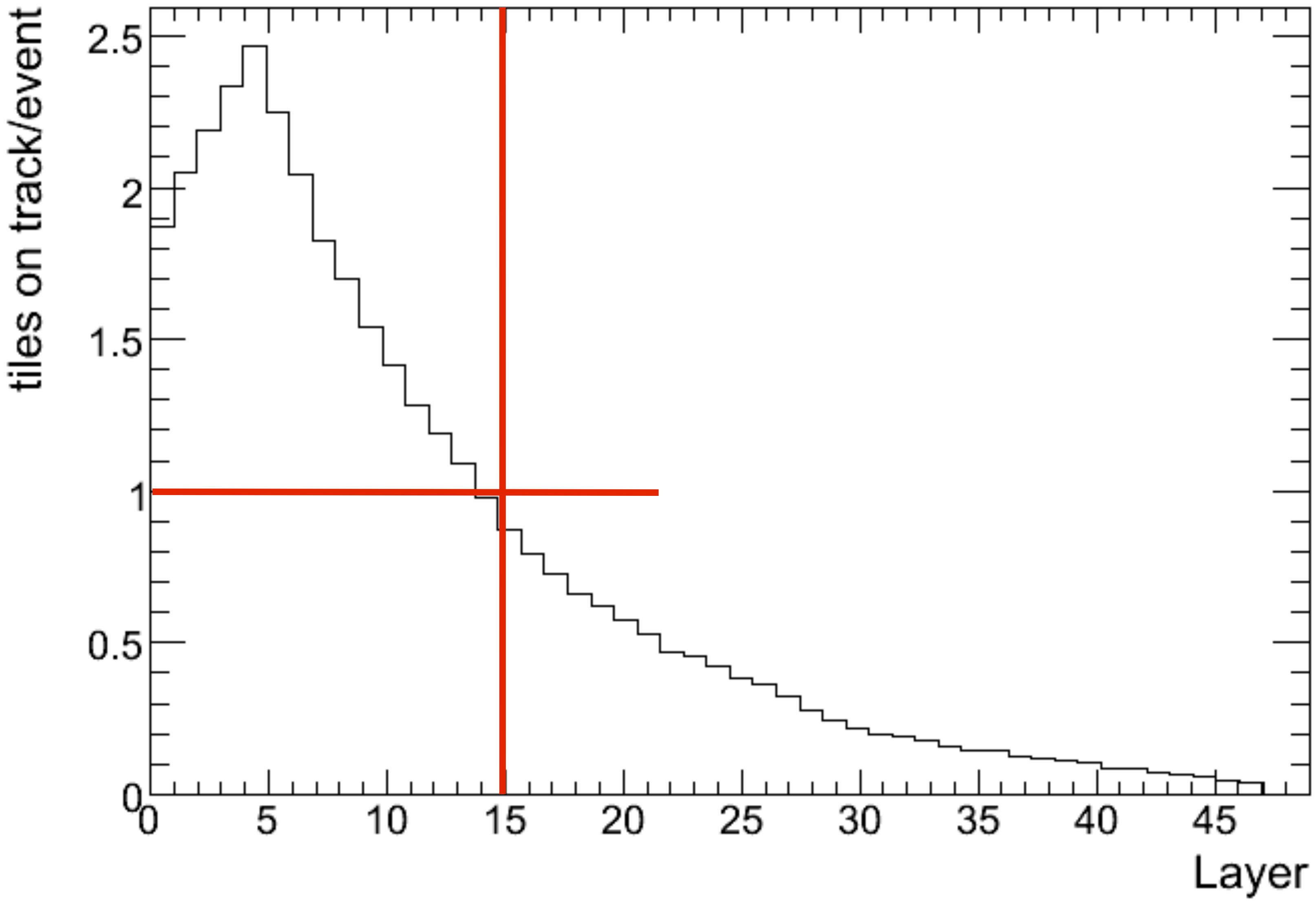

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Z Resonance: Required Luminosity

- Needed event count the same for 500 GeV and Z-Resonance running: ~ 90 M events

$$\sigma(e^+e^- \to q\bar{q}) \text{ @ } 91.2\text{GeV} \sim 30\,\text{nb}$$

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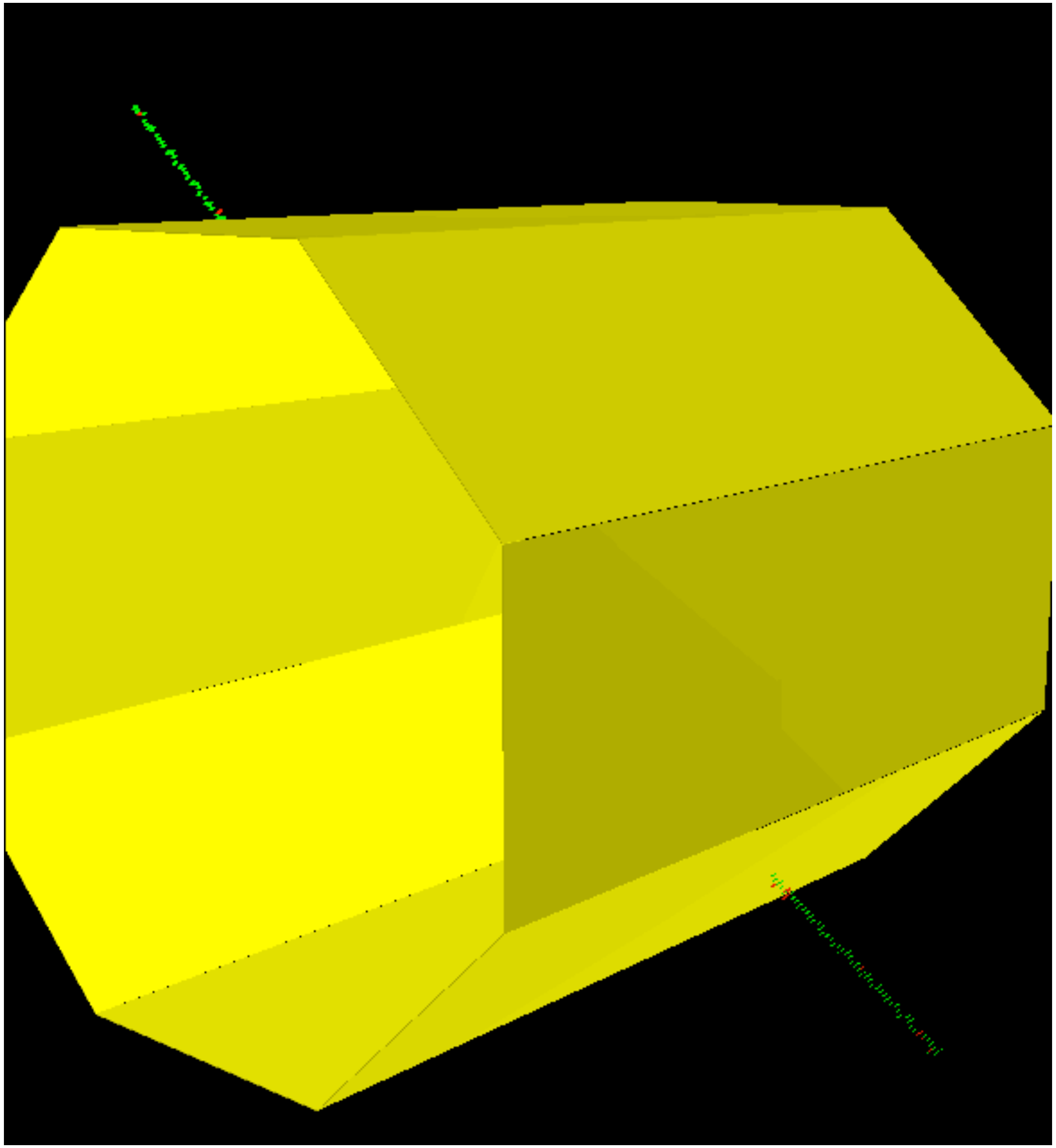
➯ lowering of statistics requirement per cell, potential increase in track finding efficiency (not a lot to be expected), and possibly ganging of cells, in particular in later layers, can bring this number down to something that might actually be reasonable: With high luminosity at the Z pole, we might be in business after a day or so...

A Look at Muons



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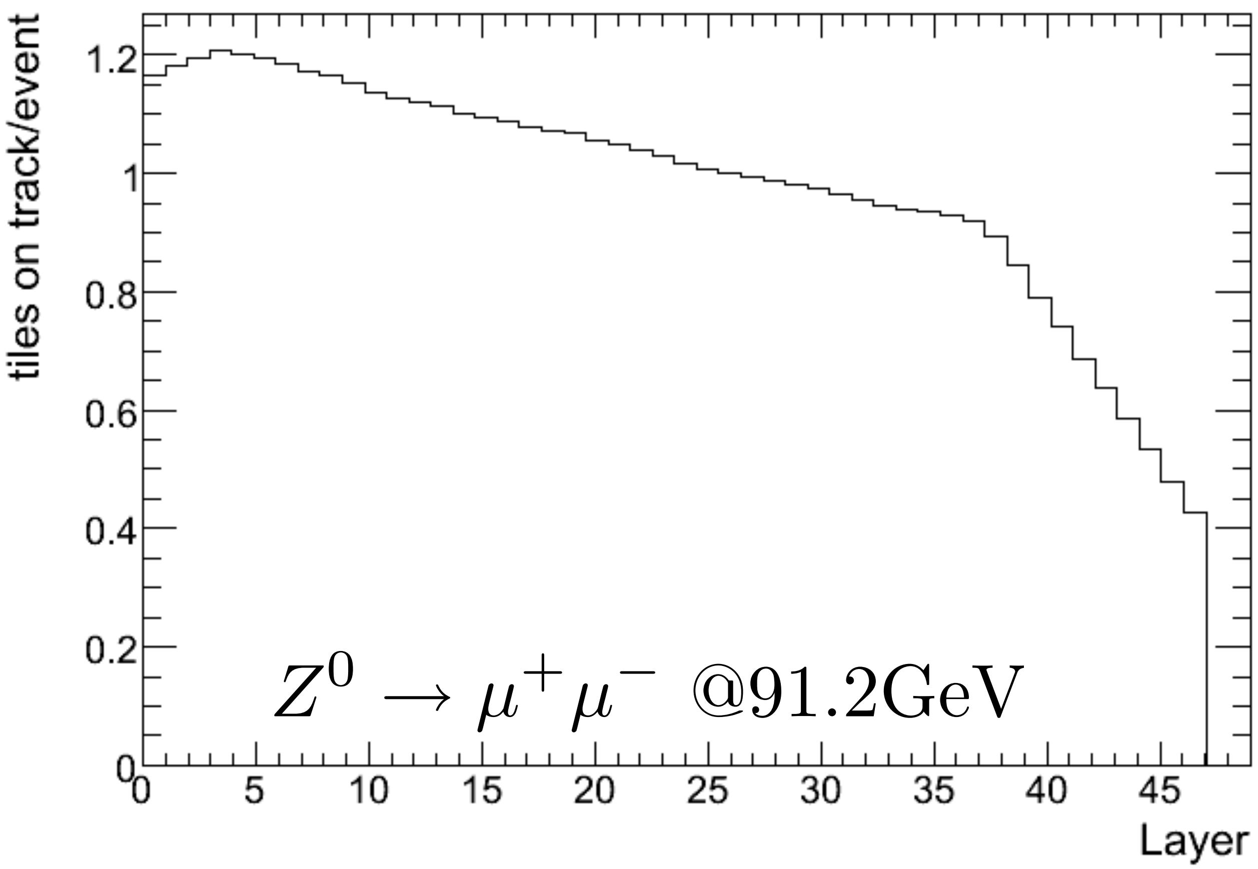
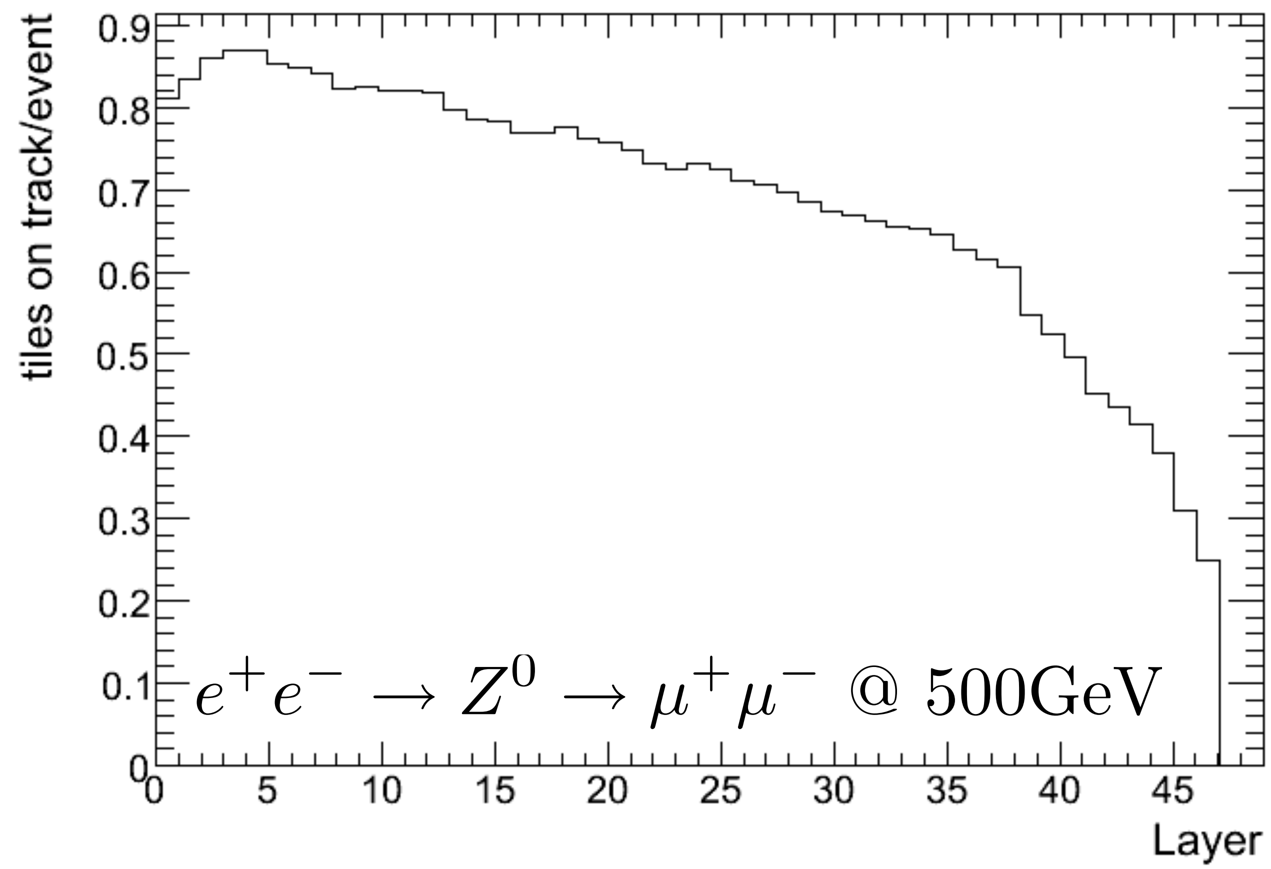
- Typically beautiful back to back Muons!

Di-Muon Events: Beautiful Tracks, Lousy Statistics





- Muons penetrate the whole calorimeter: Good statistics almost to the last layer
- But: BR(Z^0) in Muons: 3. 37%, Hadrons: 69.9% ➩ Factor 20 more hadronic evens than Muons
    - At 500 GeV the ratio is more favorable, but the overall cross section is much too low anyway...

Summary and Consequences for Calibration

- Track segments in Hadronic Showers can be found both in real CALICE data and in ILD MC, the tracks are of high quality, can be used for calibration
- The ILD studies suggest than several 10 M events are needed to get sufficient statistics in most cells of the HCAL to provide a precise intercalibration
- ▸ Impossible to reach at 500 GeV (> 10 ab^{-1})!
- ▸ Cross section at Z-Pole more favorable: a few fb^{-1} provide sufficient stats

- Still: Might be too much to allow for a precise cell-by-cell intercalibration using hadronic data (depending in actual Z-Pole Lumi and time available to collect calibration data)
  - ▸ Cell-by-cell intercalibration with MIPs with beam tests of each module, module-to-module calibration with hadronic tracks with real data events can then be obtained very quickly
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Track segments in hadronic showers are viable calibration tools, both for granular calibrations at the Z pole and coarser long-term monitoring at full energy.