Timing Measurements in the Tungsten Prototype

Frank Simon, Christian Soldner
MPI for Physics & Excellence Cluster 'Universe'
Munich, Germany

CALICE AHCAL Meeting, DESY, July 5th, 2010

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

Calorimeter for ILC

LMU Excellence Cluster Universe

Introduction & Overview

- Information about the time structure of hadronic showers in Tungsten is crucial for the development of a CLIC HCAL: High background at high energies, combined with time structure of beam, requires time stamping
  - Time structure depends on the active medium (sensitivity to neutrons): Need scintillators to evaluate an analog HCAL
  - Directly coupled scintillator tiles read out with fast digitizers can be used for detailed measurements of the time structure of the shower in selected positions in the calorimeter

Introduction & Overview

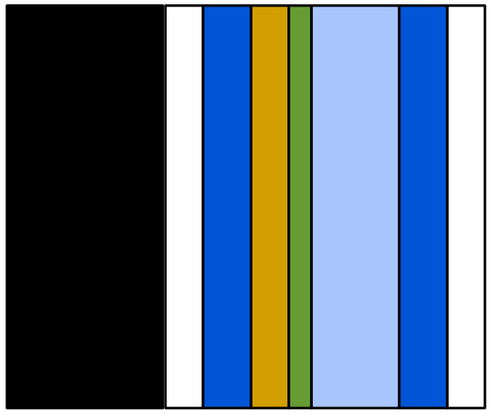
- Information about the time structure of hadronic showers in Tungsten is crucial for the development of a CLIC HCAL: High background at high energies, combined with time structure of beam, requires time stamping
  - Time structure depends on the active medium (sensitivity to neutrons): Need scintillators to evaluate an analog HCAL
  - Directly coupled scintillator tiles read out with fast digitizers can be used for detailed measurements of the time structure of the shower in selected positions in the calorimeter

- Overview:
  - The Physics Case: Simulations, planned run modes
  - Hardware Options

The Physics Case
-
Simulation Studies

Simulations

- Simulated a reasonable approximation of the W HCAL:
  - 32 layer calorimeter



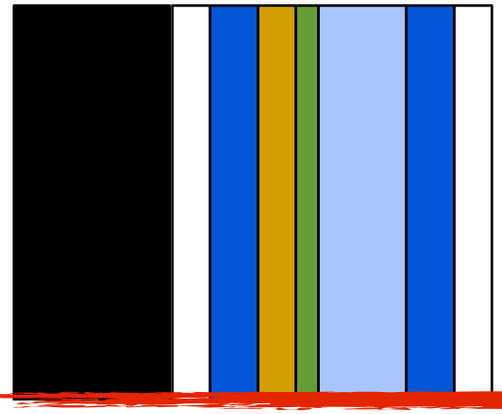
Layers modeled after CALICE Geometry description, omitting 3M foil layer (2 x 115 μm Polystyrole, same atomic composition as Scintillator)
Tungsten: 94% W, 4% Ni, 2% Cu, density 17.6 g/cm^3
Total layer thickness: 24.5 mm

10 mm Tungsten 1.5 mm Cable/Fiber 2 mm Steel
1.5 mm Air 1 mm PCB 1.5 mm Air
2 mm Steel 5 mm Scintillator

- Simulations:
  - Geant4.9.0 , Physics List QGSP_BERT_HP (to be repeated with new Geant4)
  - 200 k events π^- at 3 GeV, 5 GeV, 7 GeV, 10 GeV, 12 GeV
- Analysis:
  - Assume one horizontal "strip" of 3 x 3 cm^2 scintillator cells (31 cells) vertically centered read out, layer position flexible (in reality we will have 16 cells, location to be chosen)

Simulations

- Simulated a reasonable approximation of the W HCAL:
  - 32 layer calorimeter



Layers modeled after CALICE Geometry description, omitting 3M foil layer (2 x 115 µm Polystyrole, same atomic composition as Scintillator)
Tungsten: 94% W, 4% Ni, 2% Cu, density 17.6 g/cm^3
Total layer thickness: 24.5 mm

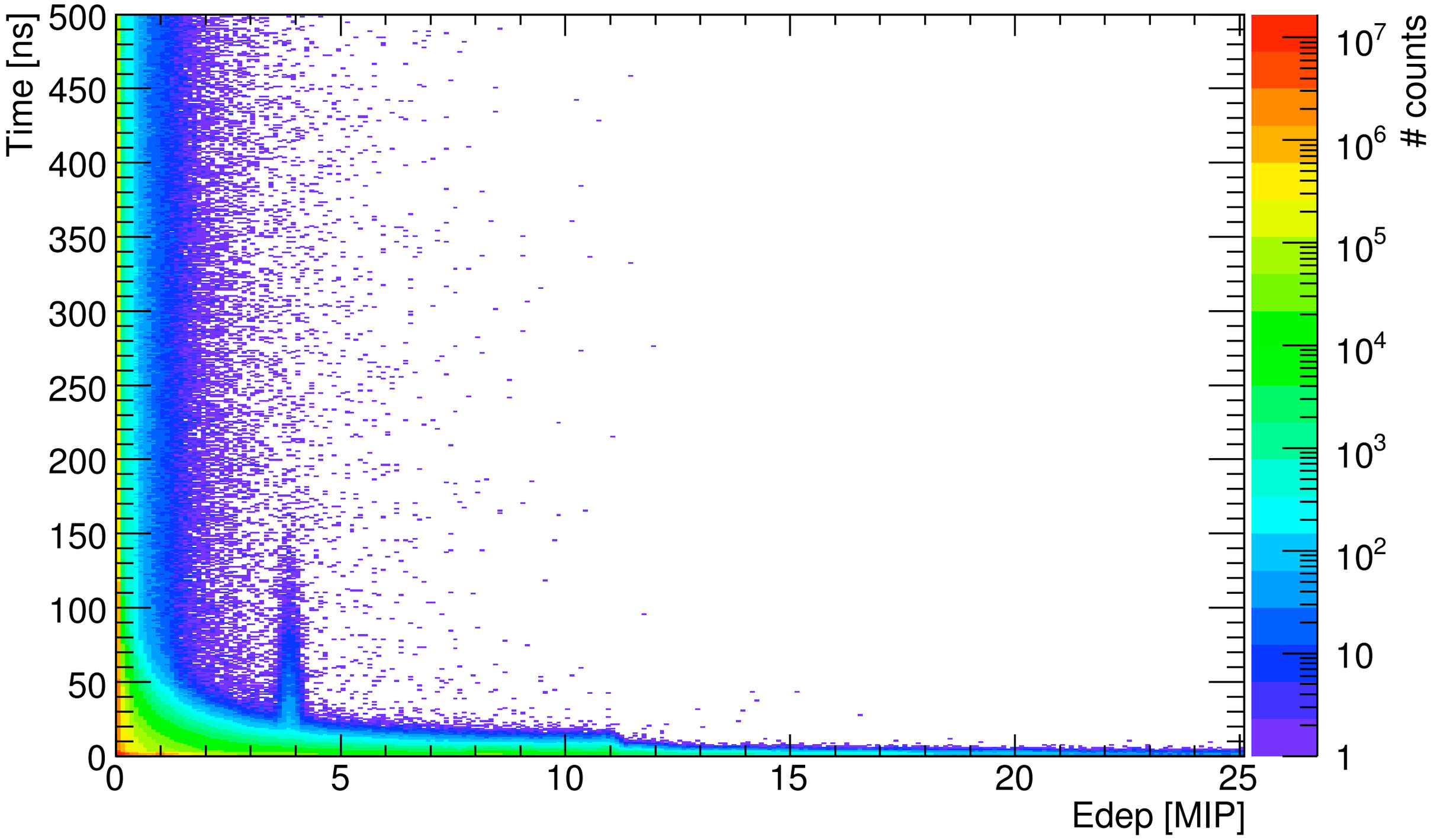
Beware: No digitization, no description of detector effects, pure time and energy information from Geant4

- Sim
  - Geant4.9.0 , Physics List QGSP_BERT_HP (to be repeated with new Geant4)
  - 200 k events π^- at 3 GeV, 5 GeV, 7 GeV, 10 GeV, 12 GeV
- Analysis:
  - Assume one horizontal "strip" of 3 x 3 cm^2 scintillator cells (31 cells) vertically centered read out, layer position flexible (in reality we will have 16 cells, location to be chosen)

Rich Time Structure in a Tungsten Calorimeter

Global 2D: 12GeV - # vs. Edep vs. Time

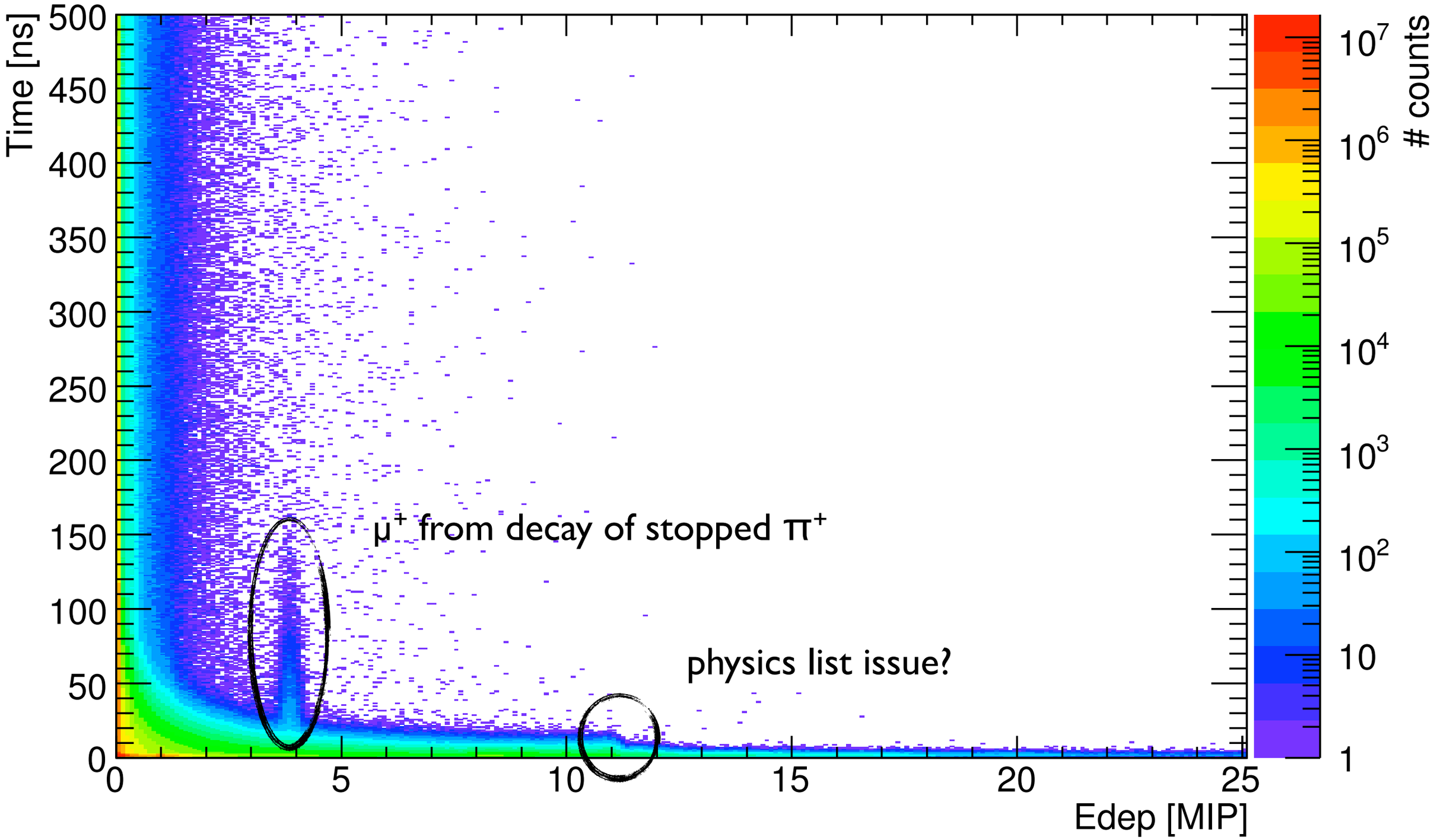
- Global: All Hits



Rich Time Structure in a Tungsten Calorimeter

Global 2D: 12GeV - # vs. Edep vs. Time

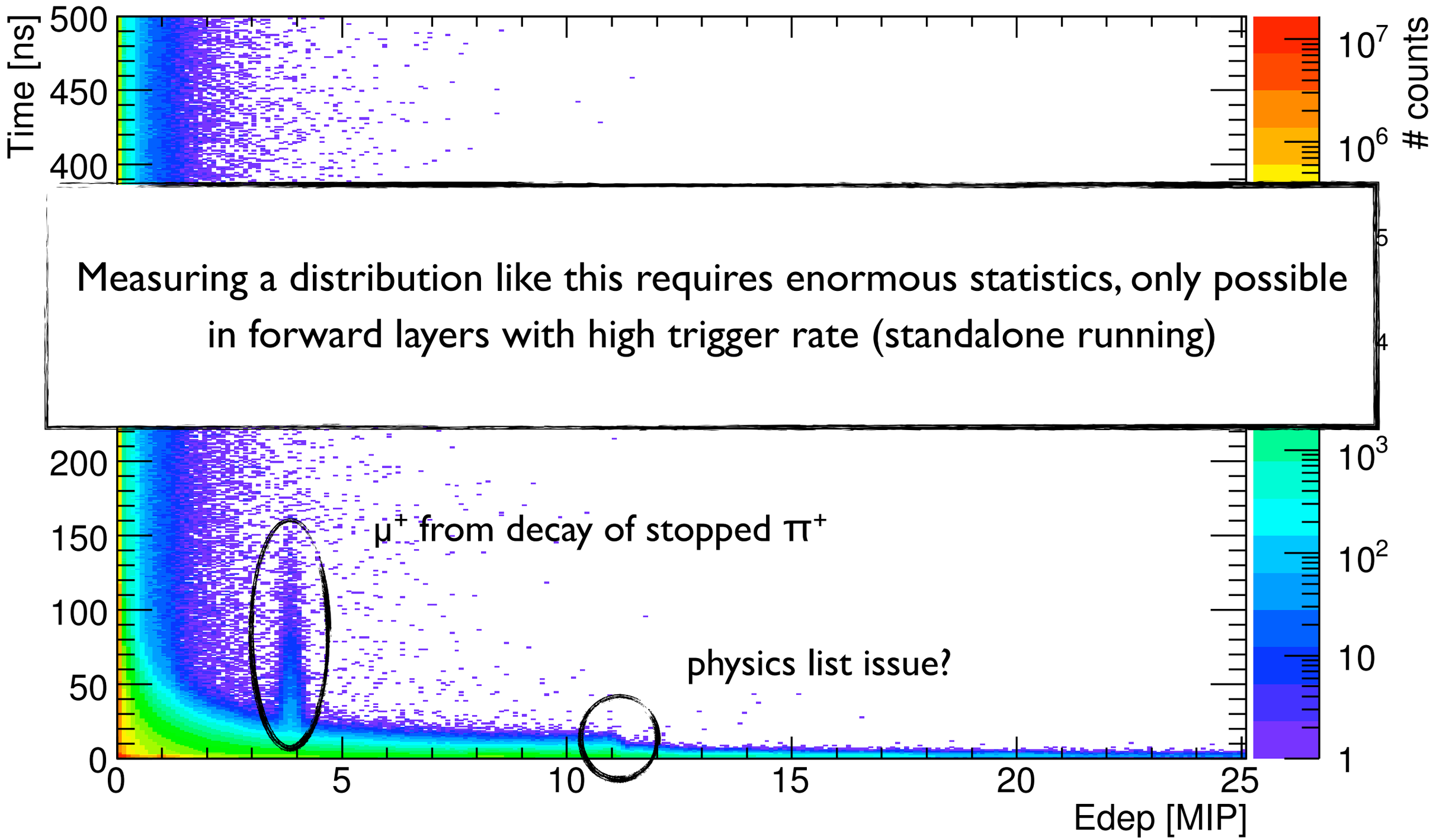
- Global: All Hits



Rich Time Structure in a Tungsten Calorimeter

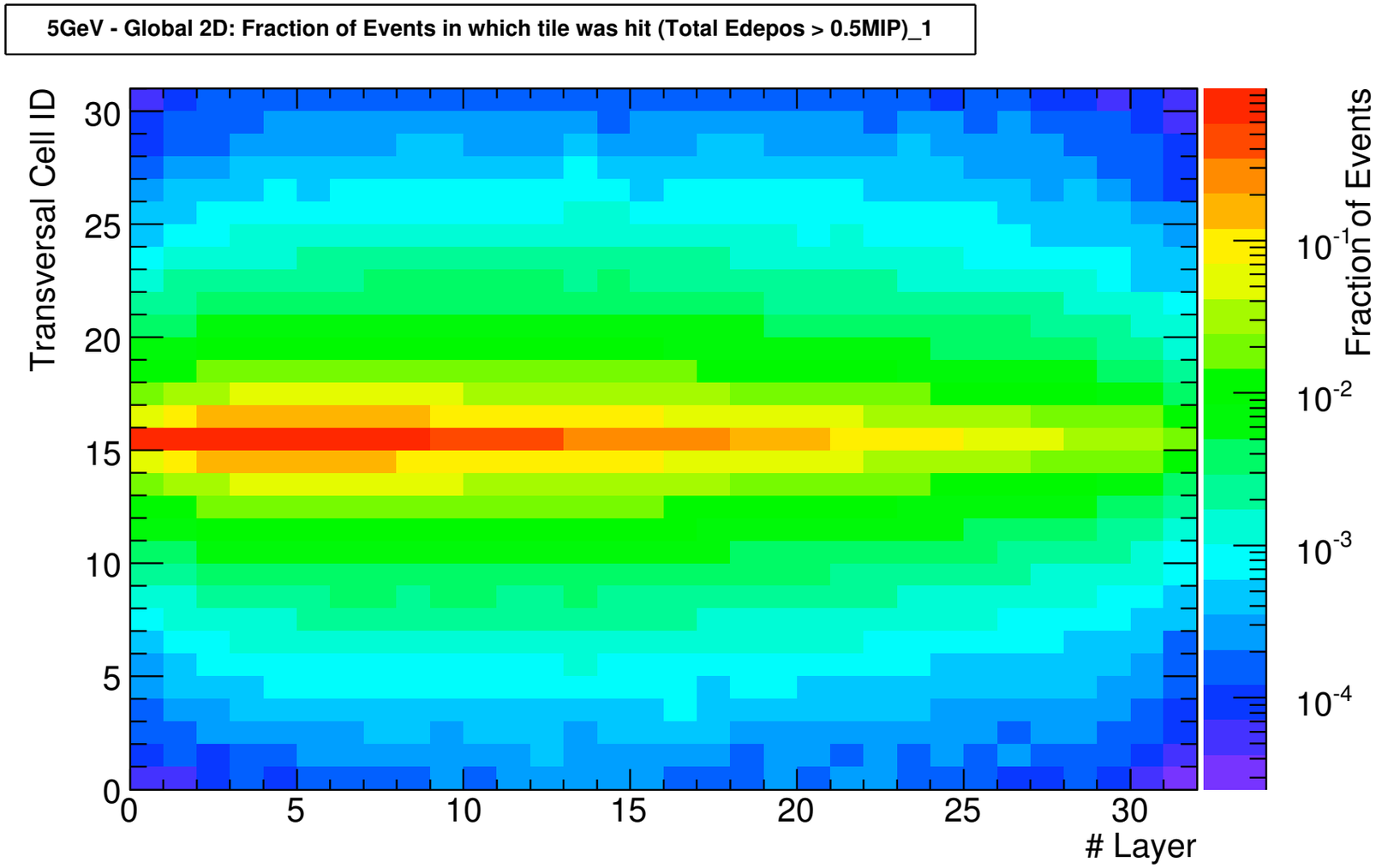
Global 2D: 12GeV - # vs. Edep vs. Time

- Global: All Hits



Measuring a distribution like this requires enormous statistics, only possible in forward layers with high trigger rate (standalone running)

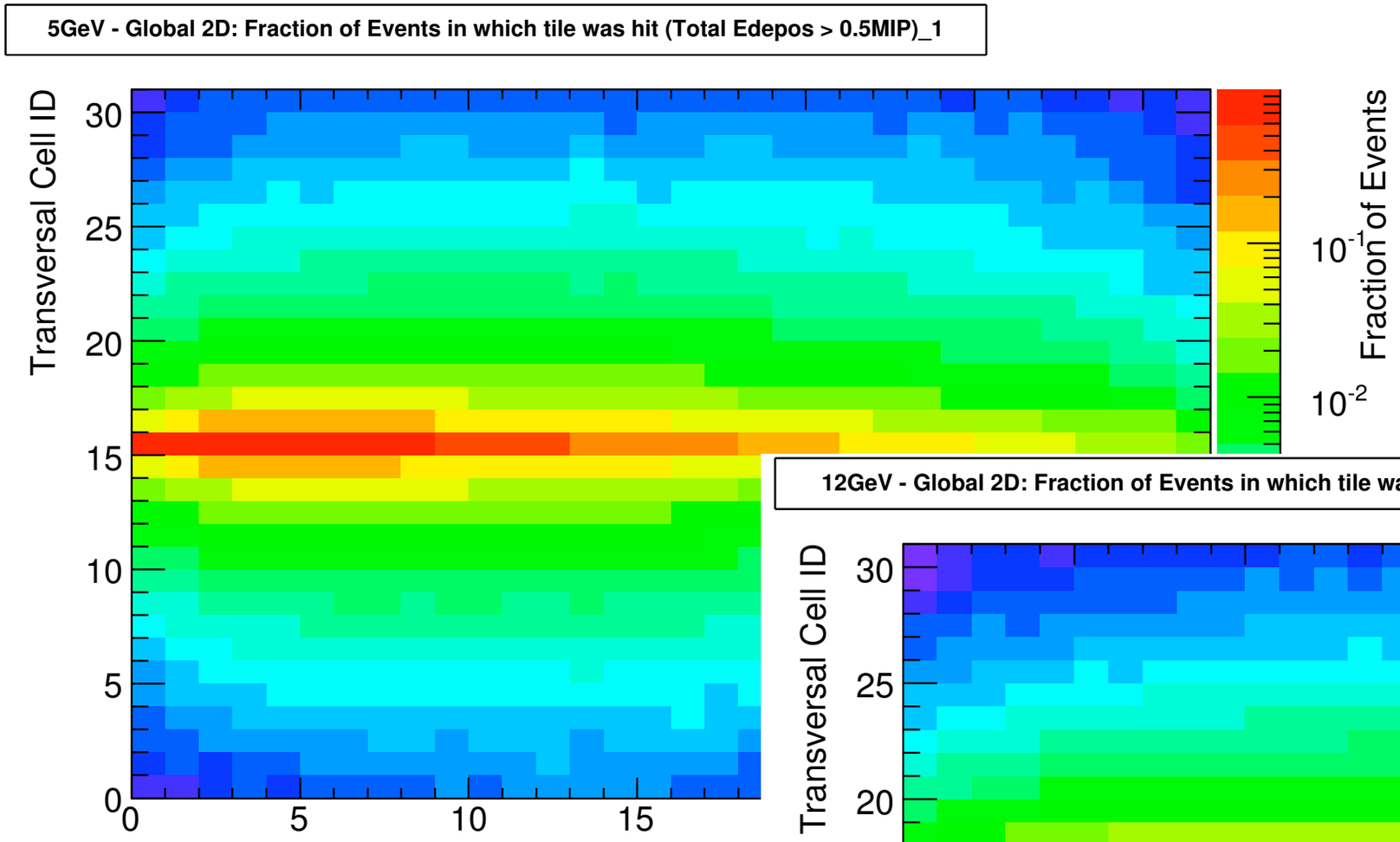
Simulations: Global Distributions - Hit Probability



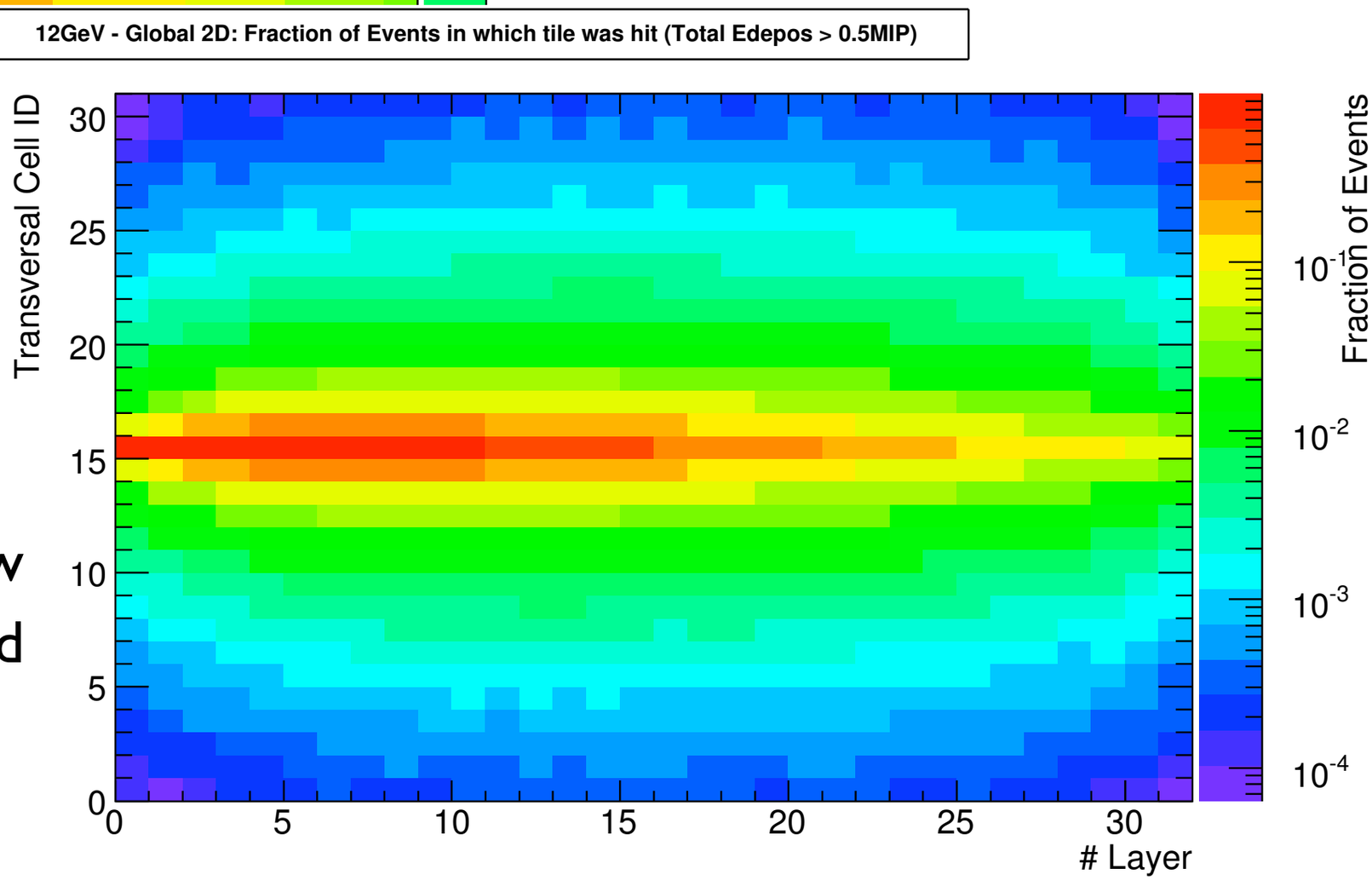
- Here: Full Calorimeter!

- The downside of being the parasite (and having just a few channels): Statistics at the end of the calorimeter is low!

Simulations: Global Distributions - Hit Probability

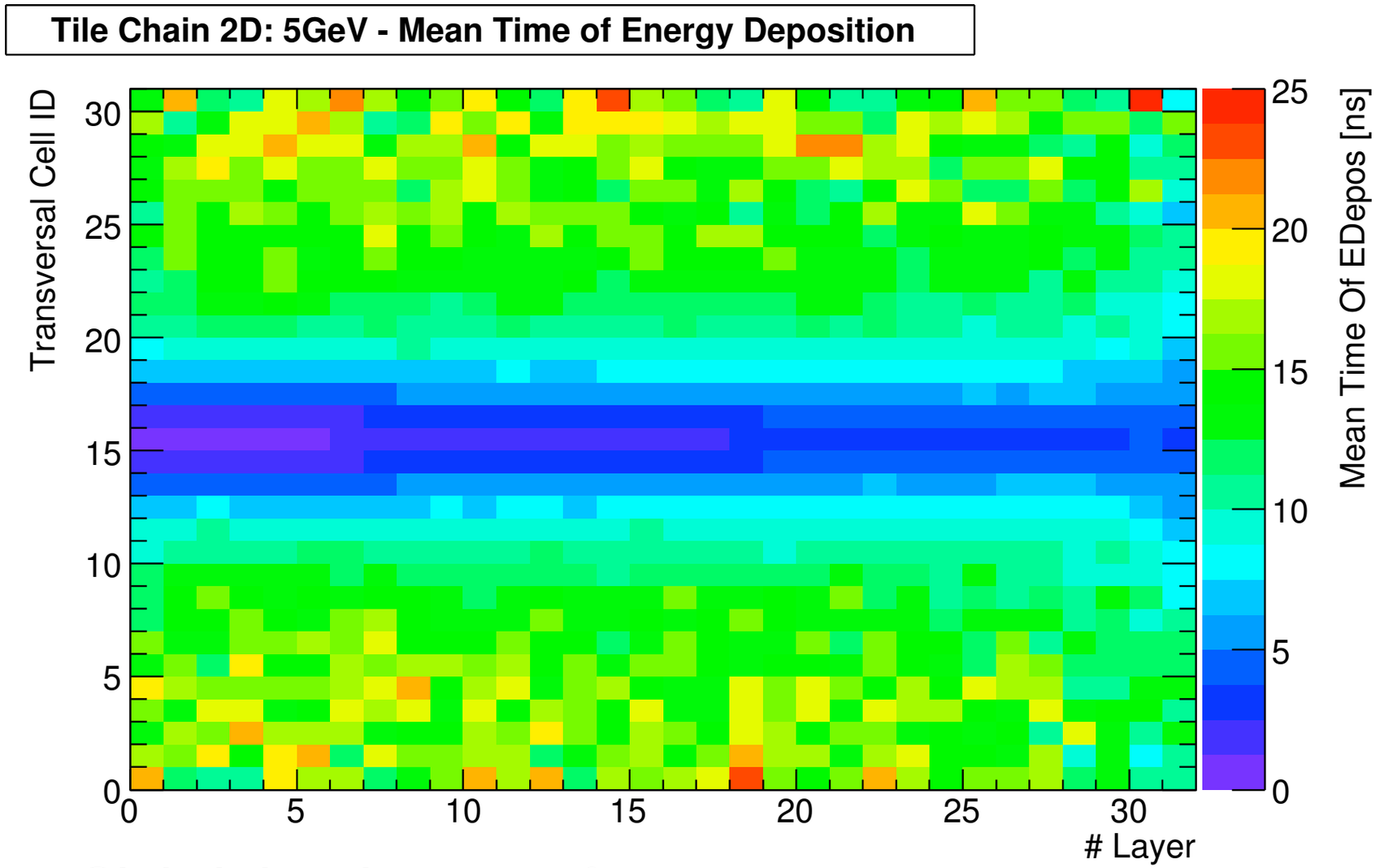


- Here: Full Calorimeter!



- The downside of being the parasite (and having just a few channels): Statistics at the end of the calorimeter is low!

Simulations: Global Distributions - Timing

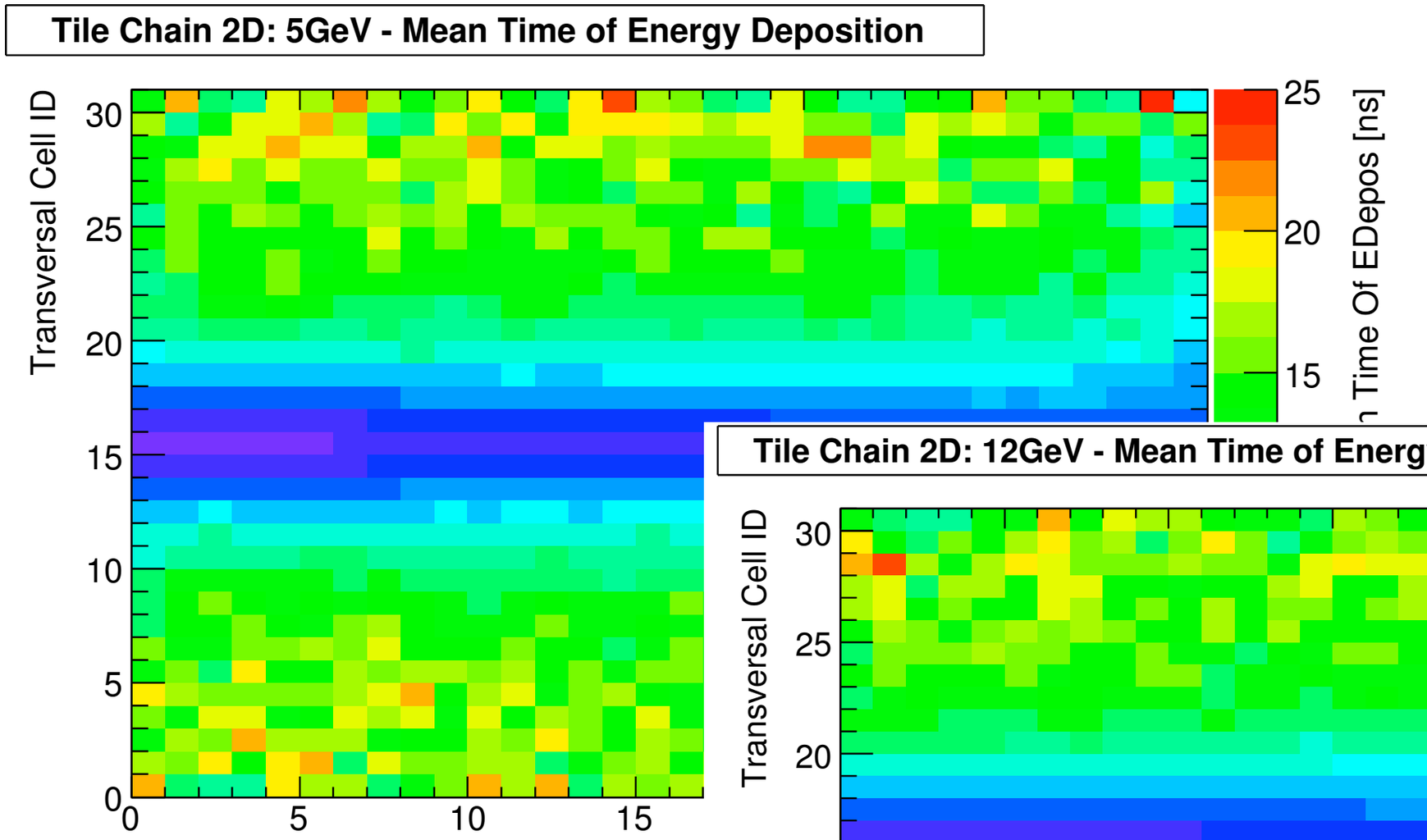


- Here: Full Calorimeter!

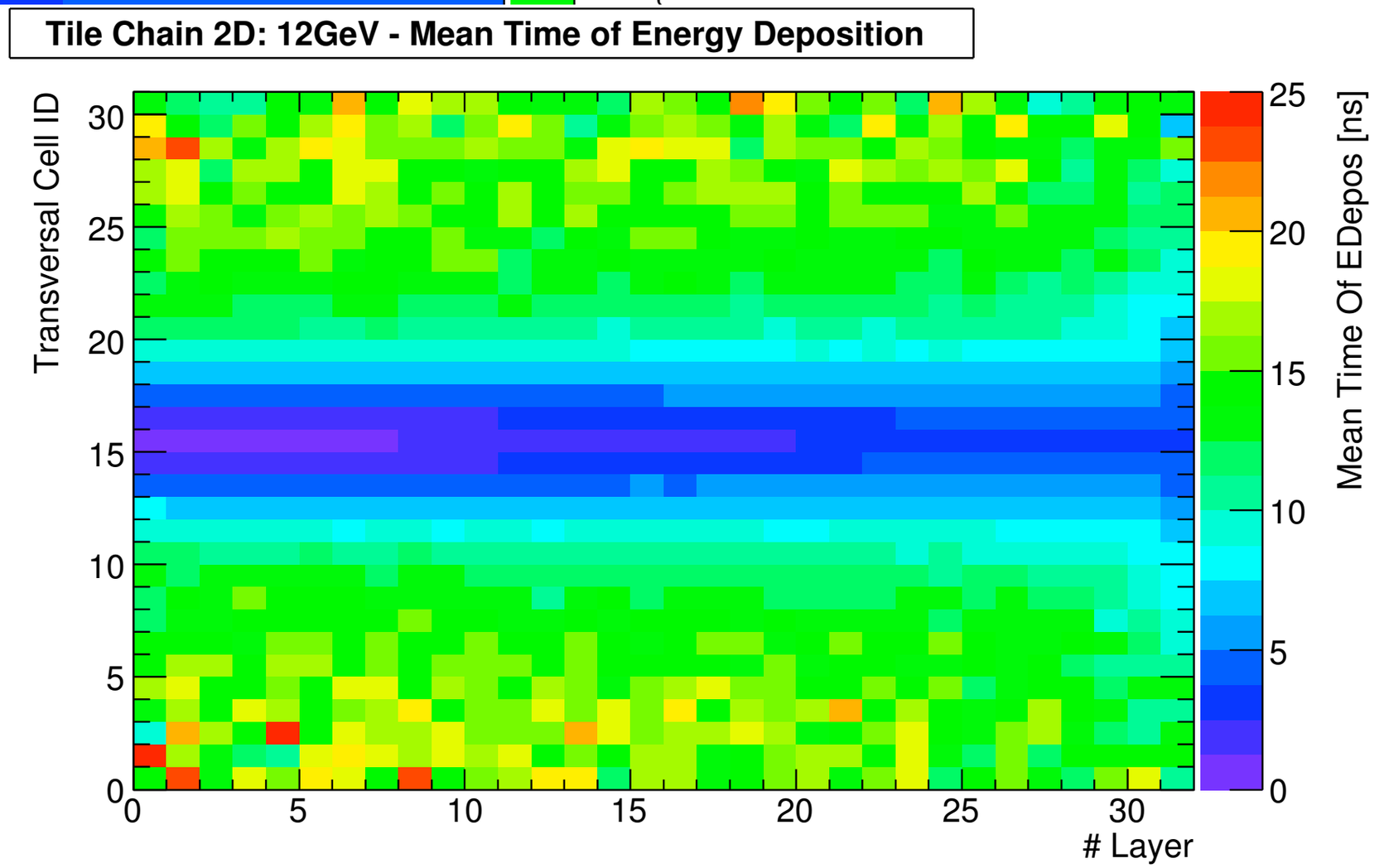
- Global distributions of mean time: could be measured by moving the Timing Strip

Simulations: Global Distributions - Timing

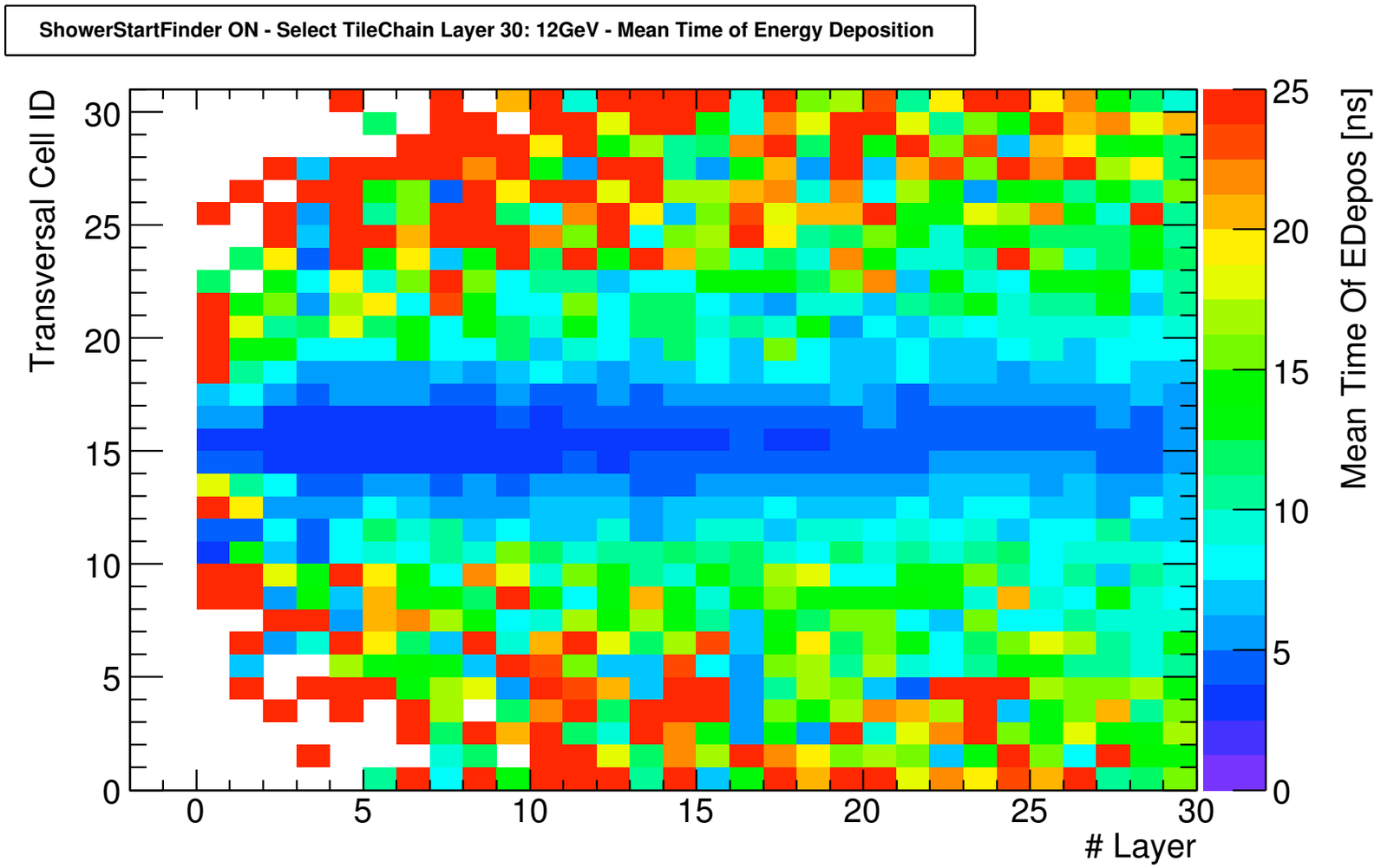
- Here: Full Calorimeter!



- Global distributions of mean time: could be measured by moving the Timing Strip



Timing Profiles: Correlation with HCAL - 12 GeV

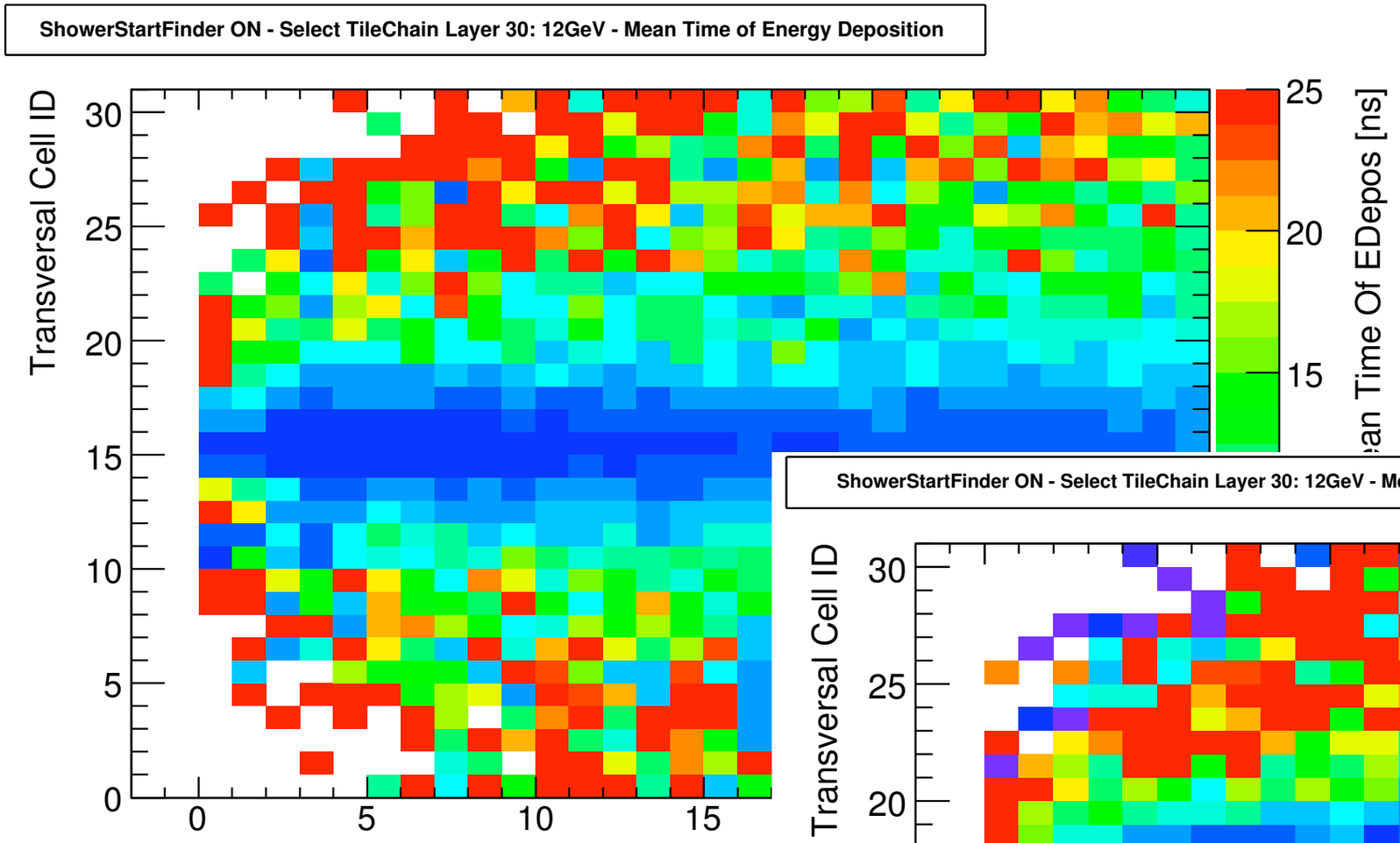


- Assumption: Timing strip in layer 30 (start at 0), correlation with HCAL events to determine shower start event by event

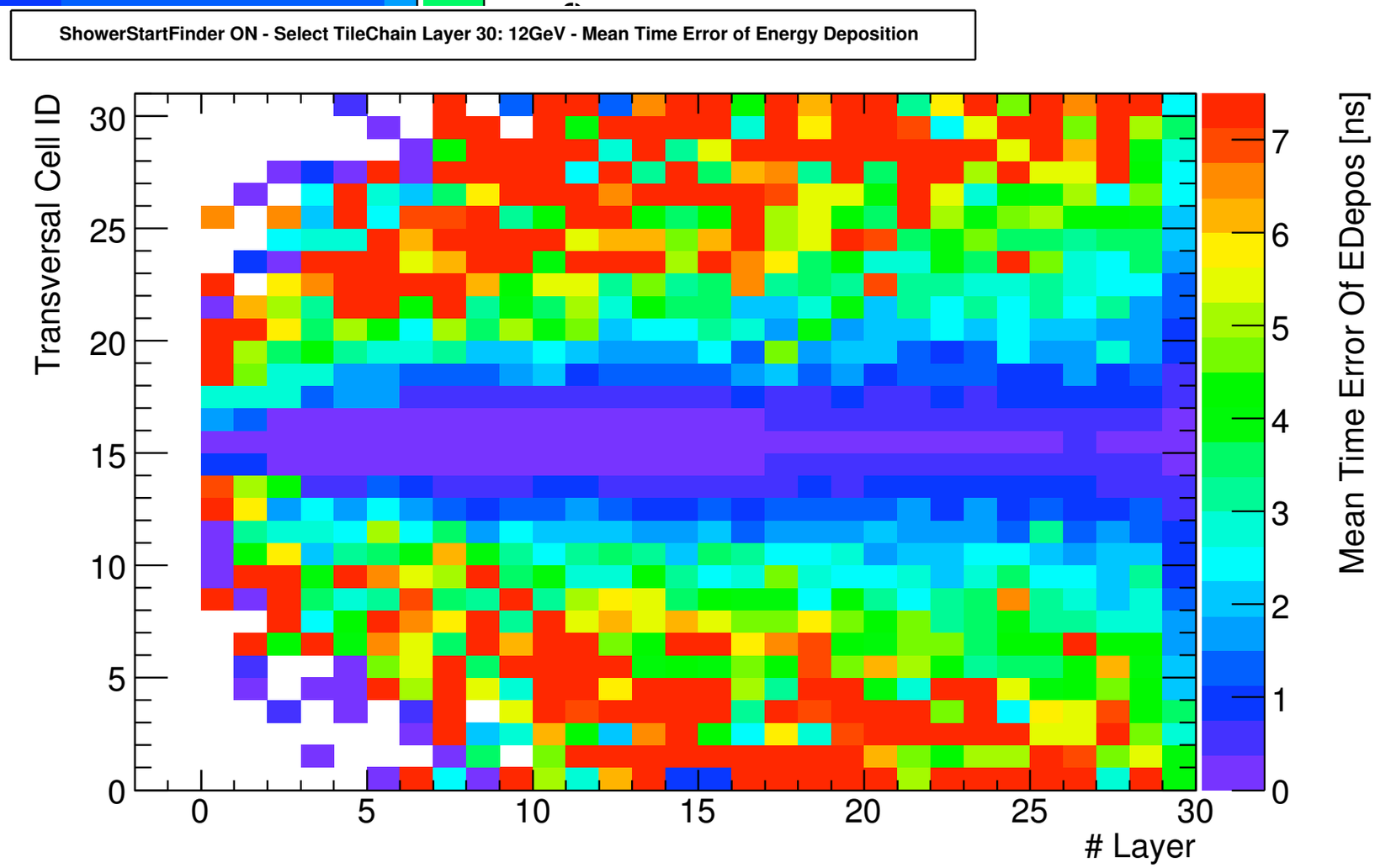
⇨ Relative to shower start a full mapping of the time structure of (averaged) showers is possible

Shower start determined analogous to CAN-011: 3 consecutive layers with a total of > 5 hits, > 8 MIP, first layer of this block of 3 is counted as shower start

Timing Profiles: Correlation with HCAL - 12 GeV



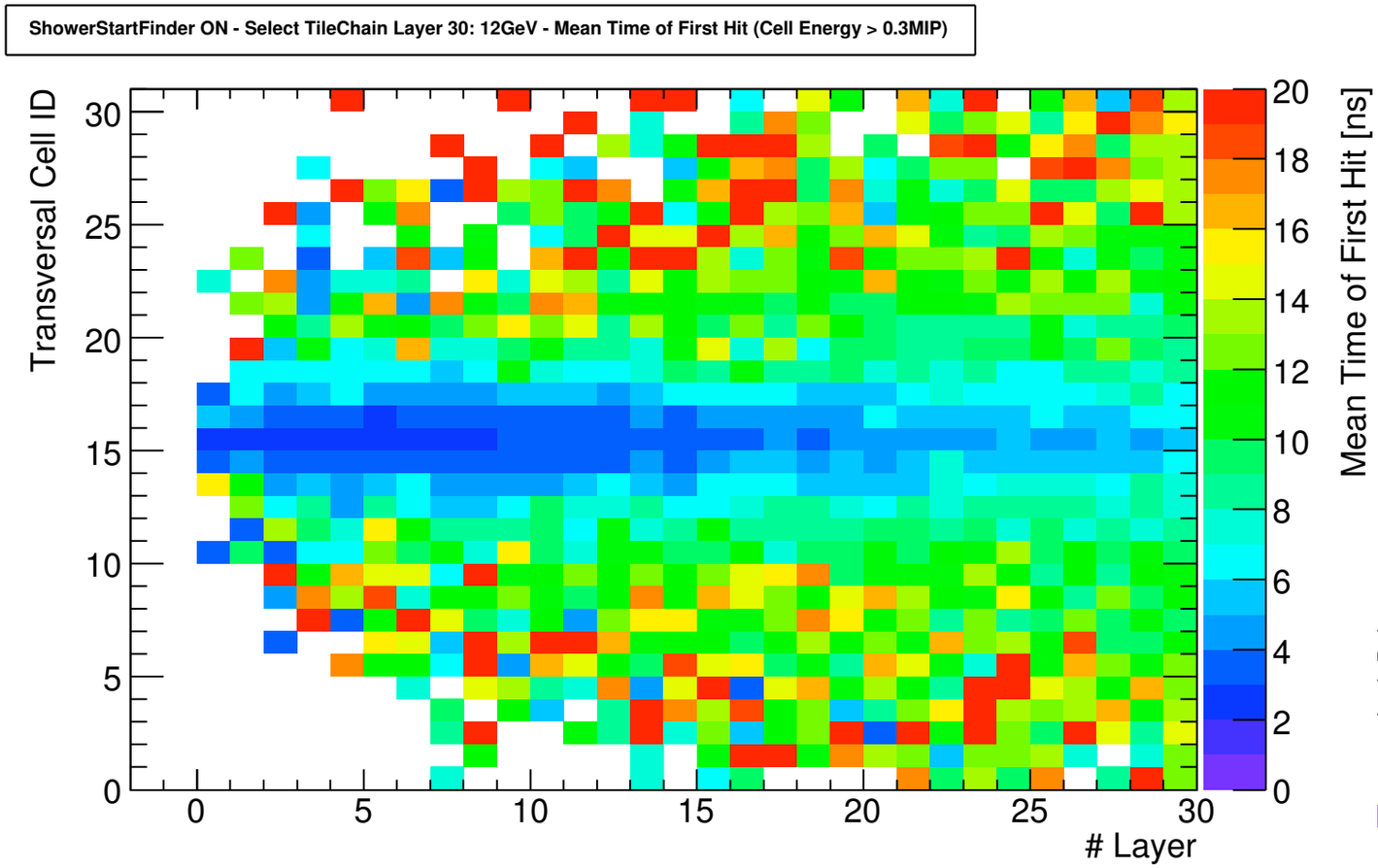
- Assumption: Timing strip in layer 30 (start at 0), correlation with HCAL events to determine shower



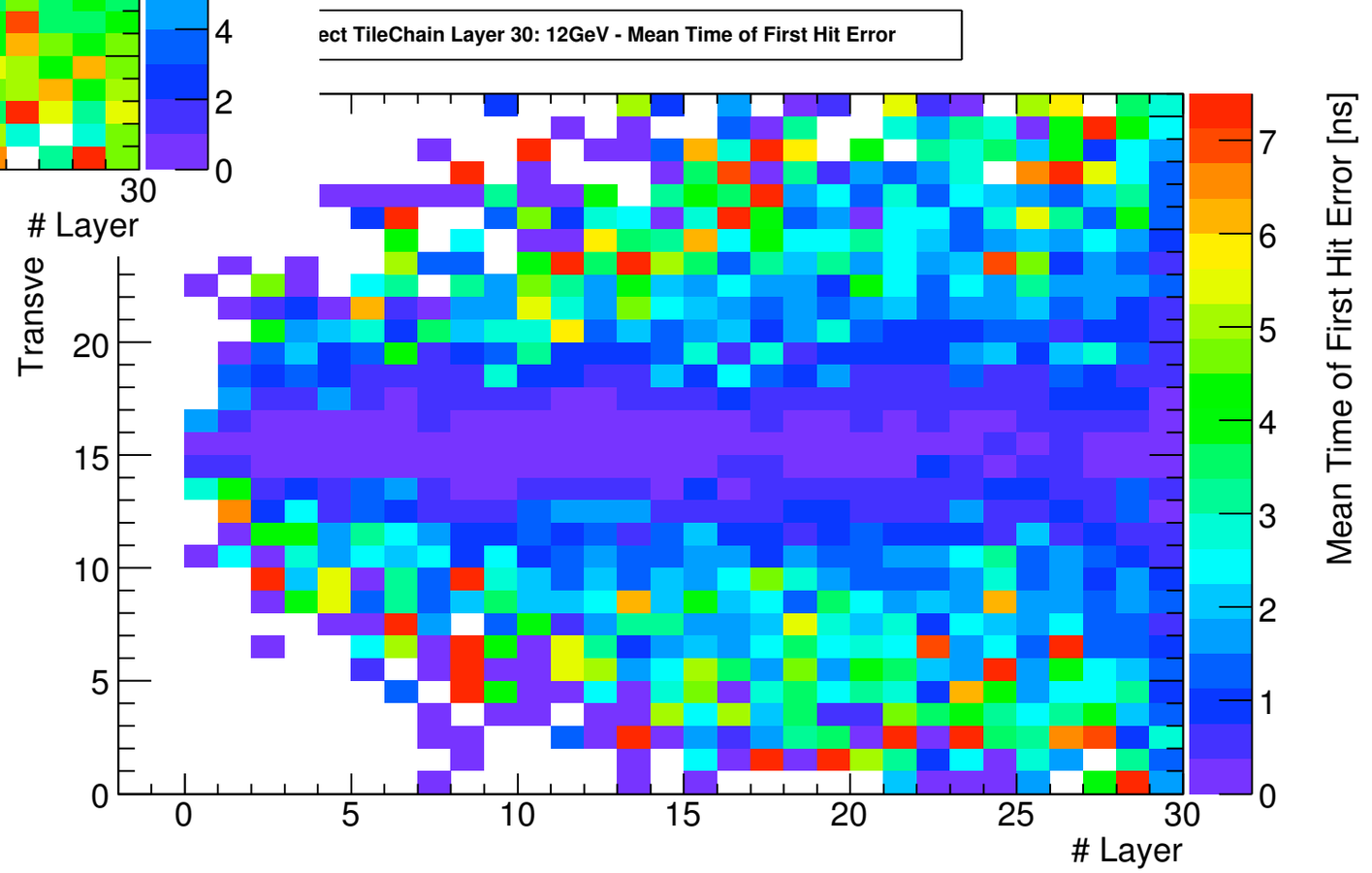
⇨ Relative to shower start a ful (averaged) showers is possible

Shower start determined analog layers with a total of > 5 hits, > is counted as shower start

Timing Profiles: Time of First Hit (12 GeV)

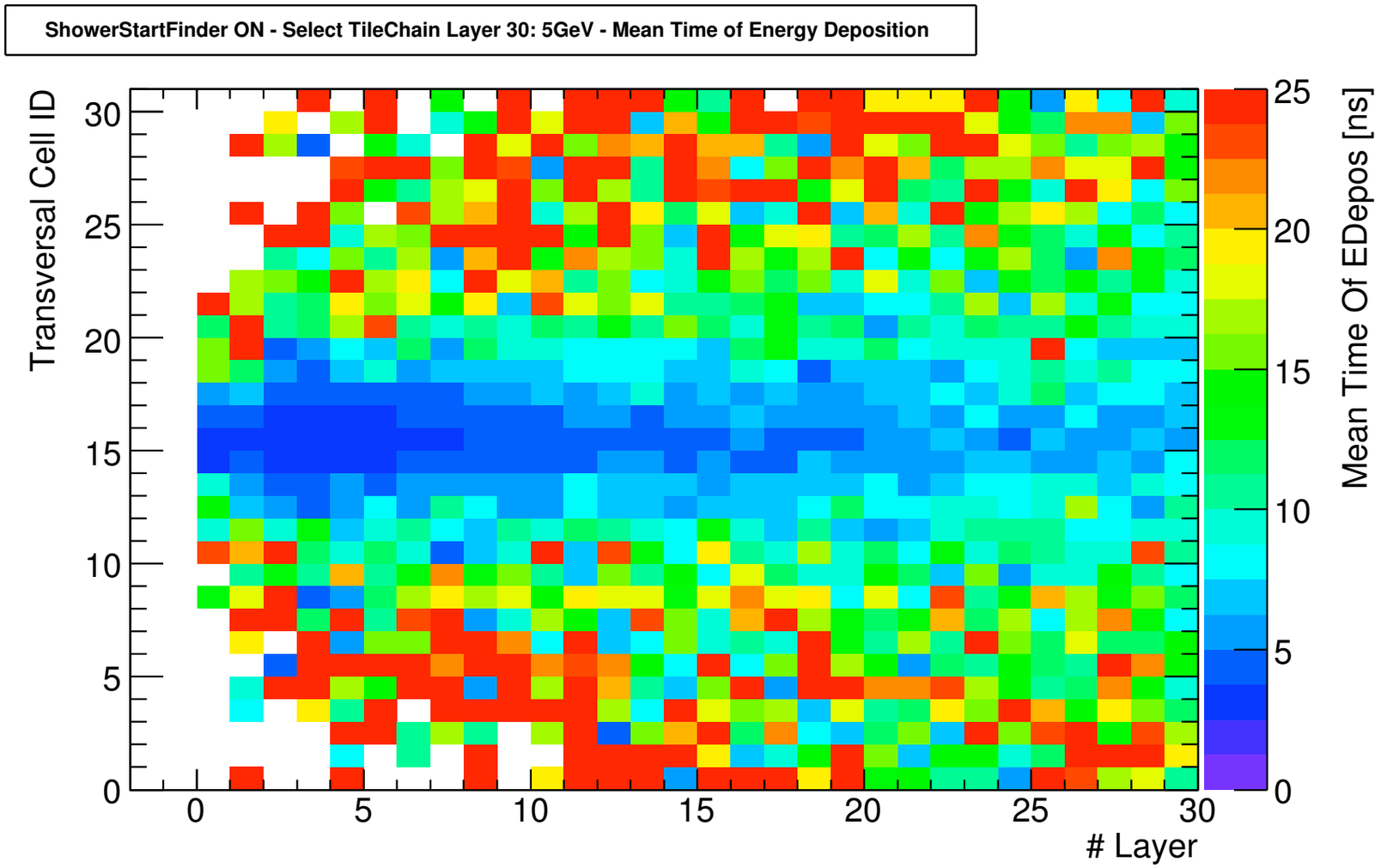


- First time of energy deposit for a cell that has a total energy above 0.3 MIP, as a function of shower start position

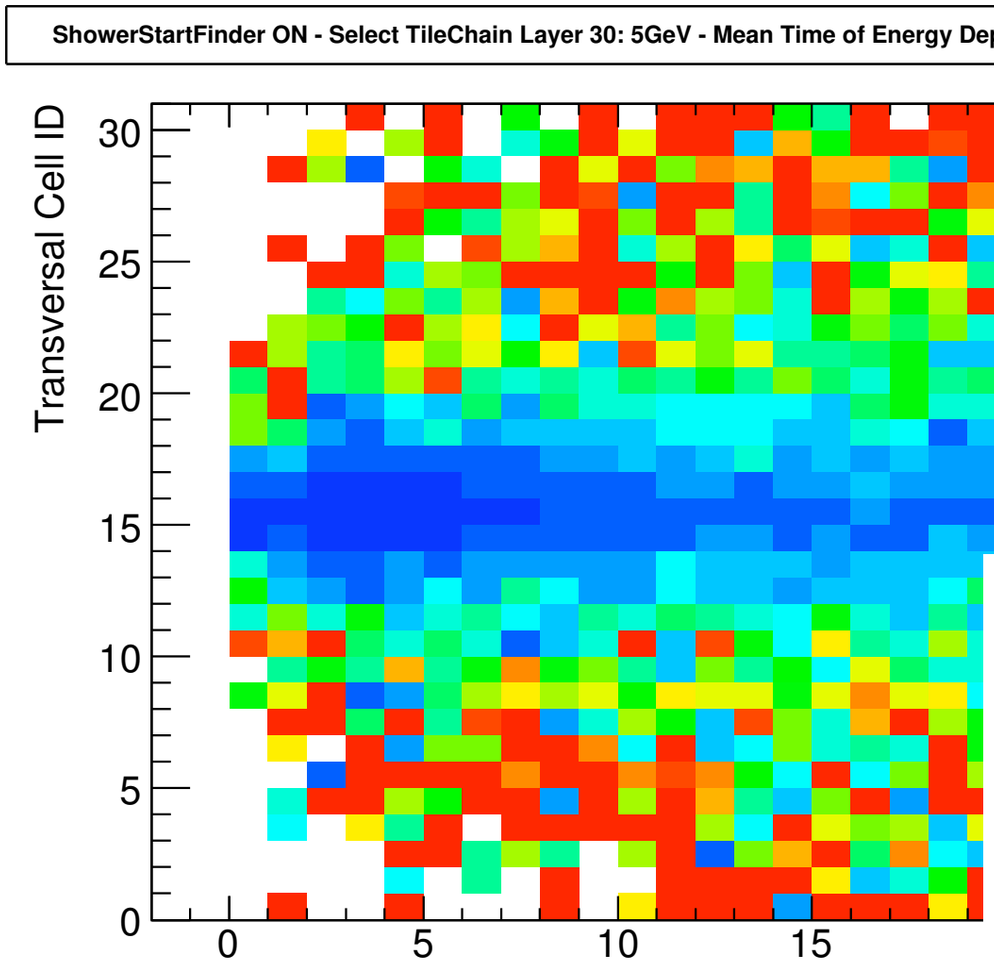


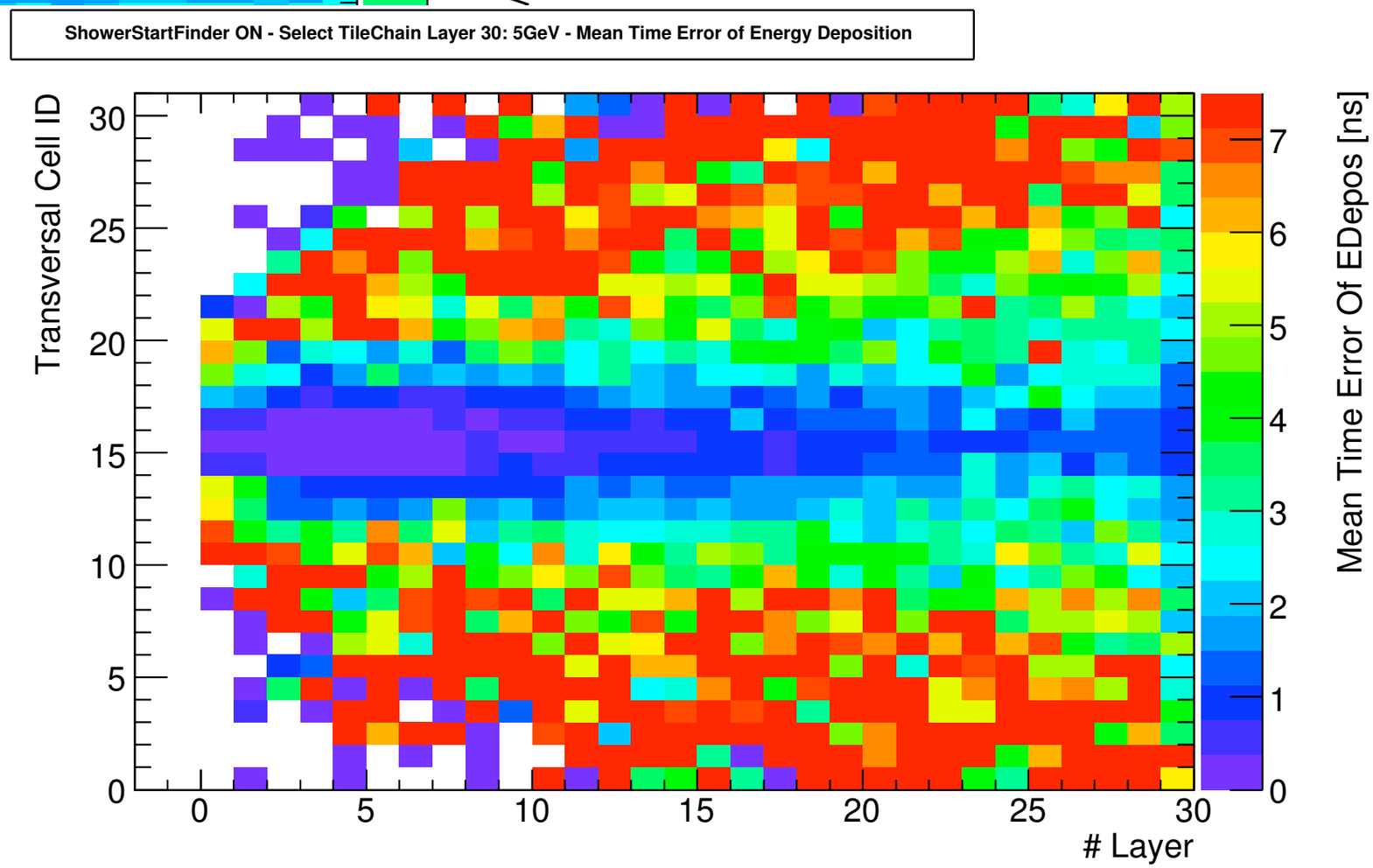
Frank Simon (frank.simon@universe-cluster.de)

Timing Profiles: Correlation with HCAL - 5 GeV



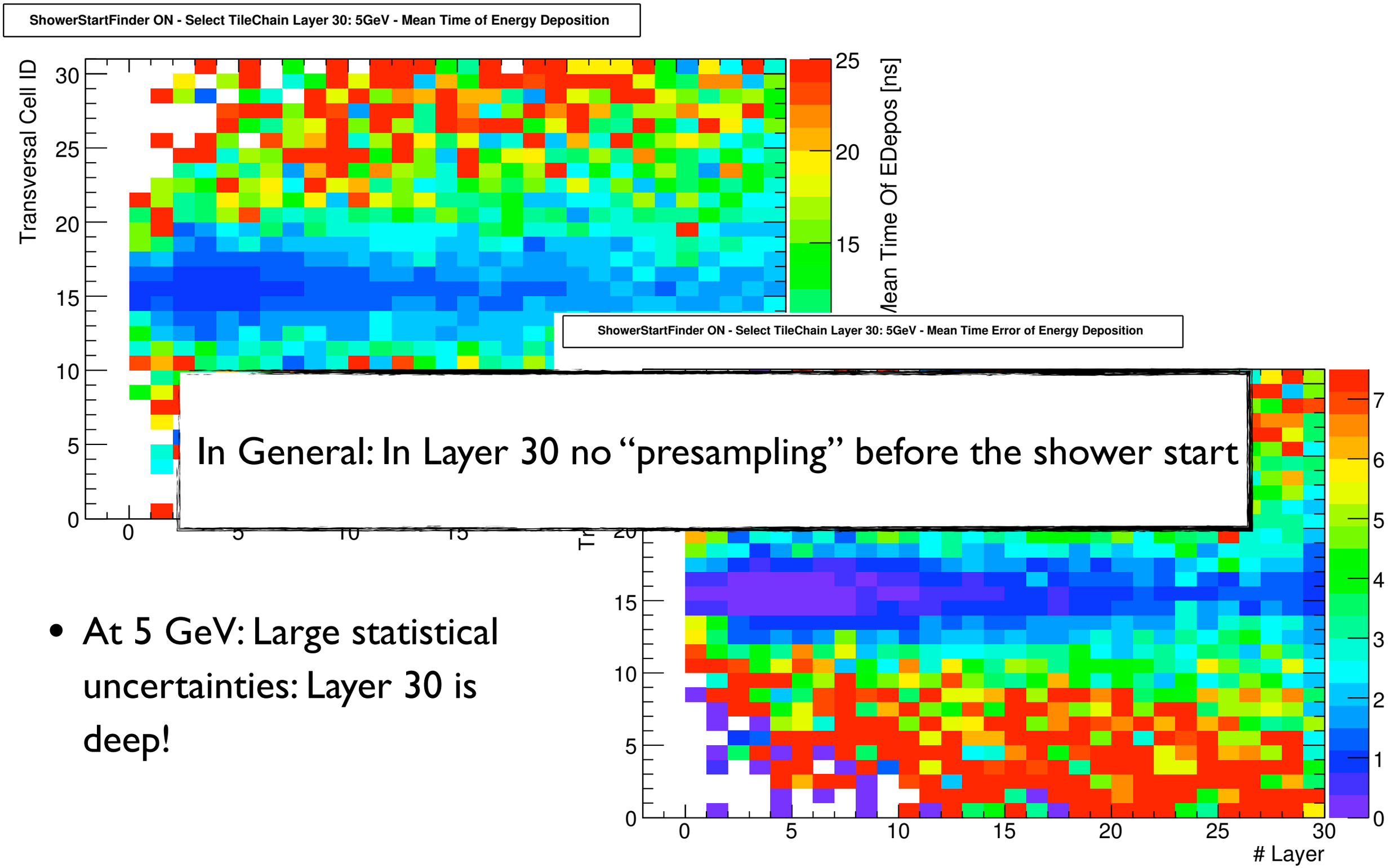
Timing Profiles: Correlation with HCAL - 5 GeV





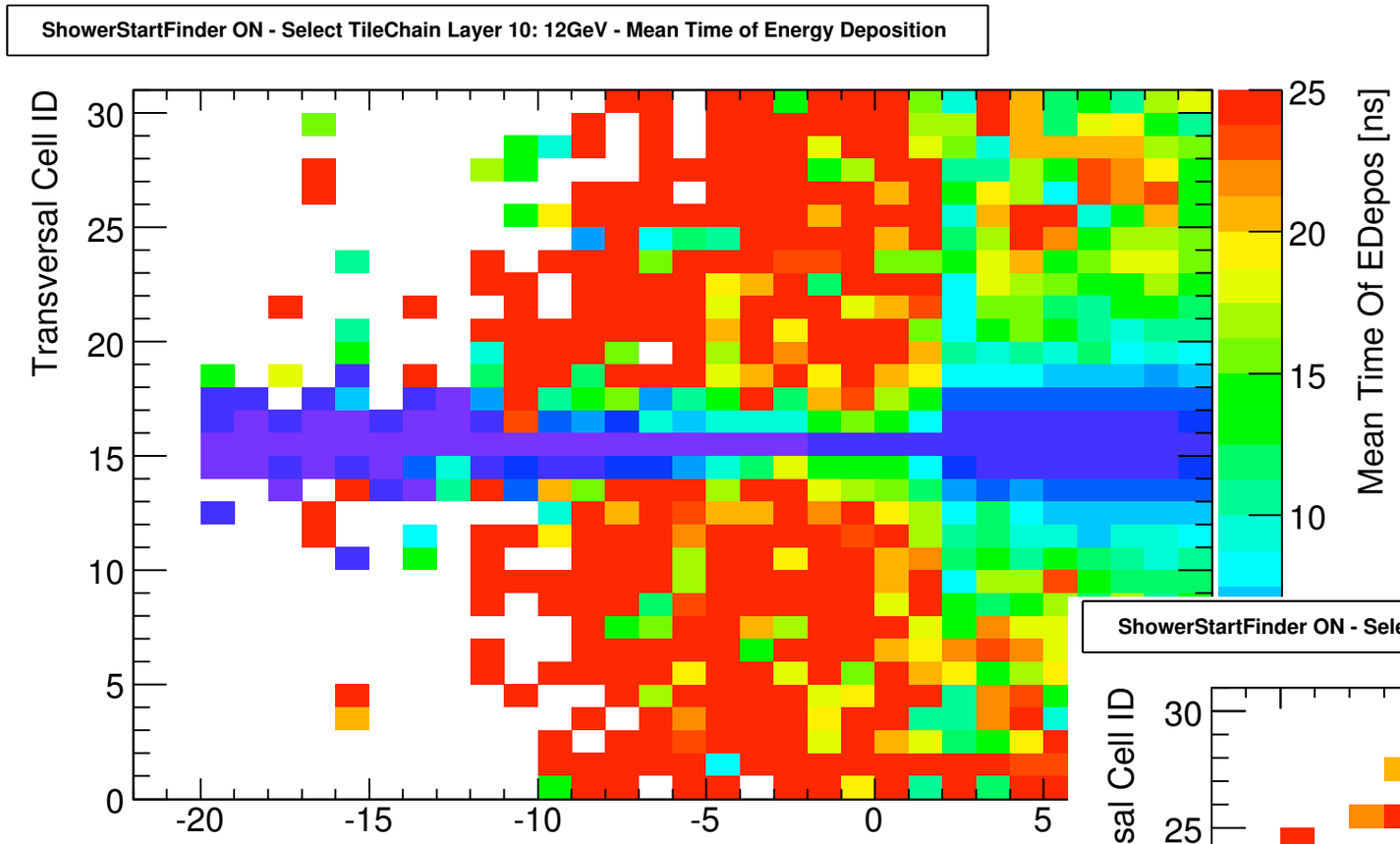
- At 5 GeV: Large statistical uncertainties: Layer 30 is deep!

Timing Profiles: Correlation with HCAL - 5 GeV



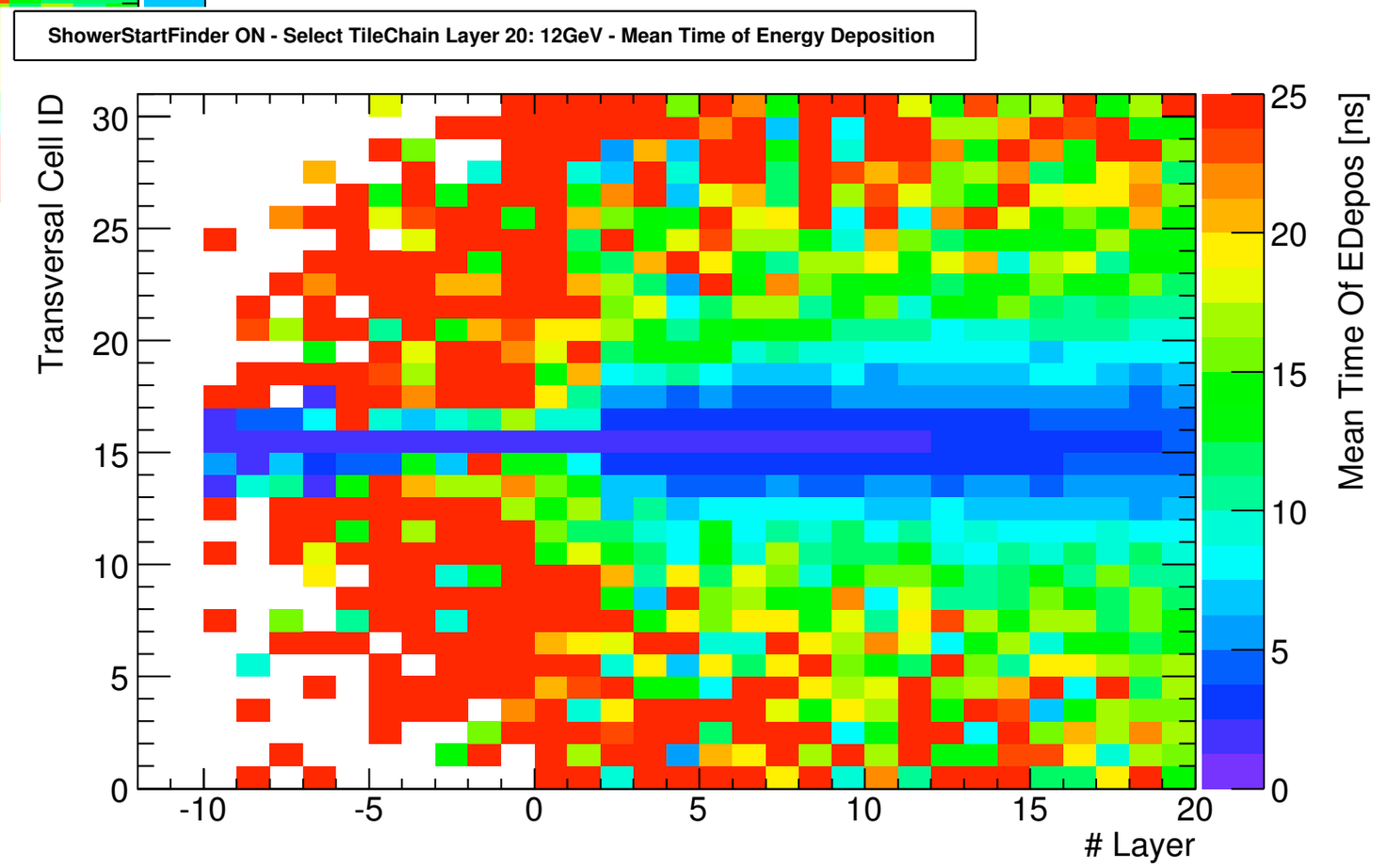
- At 5 GeV: Large statistical uncertainties: Layer 30 is deep!

Timing Profiles: Moving the Timing Strip (12 GeV)

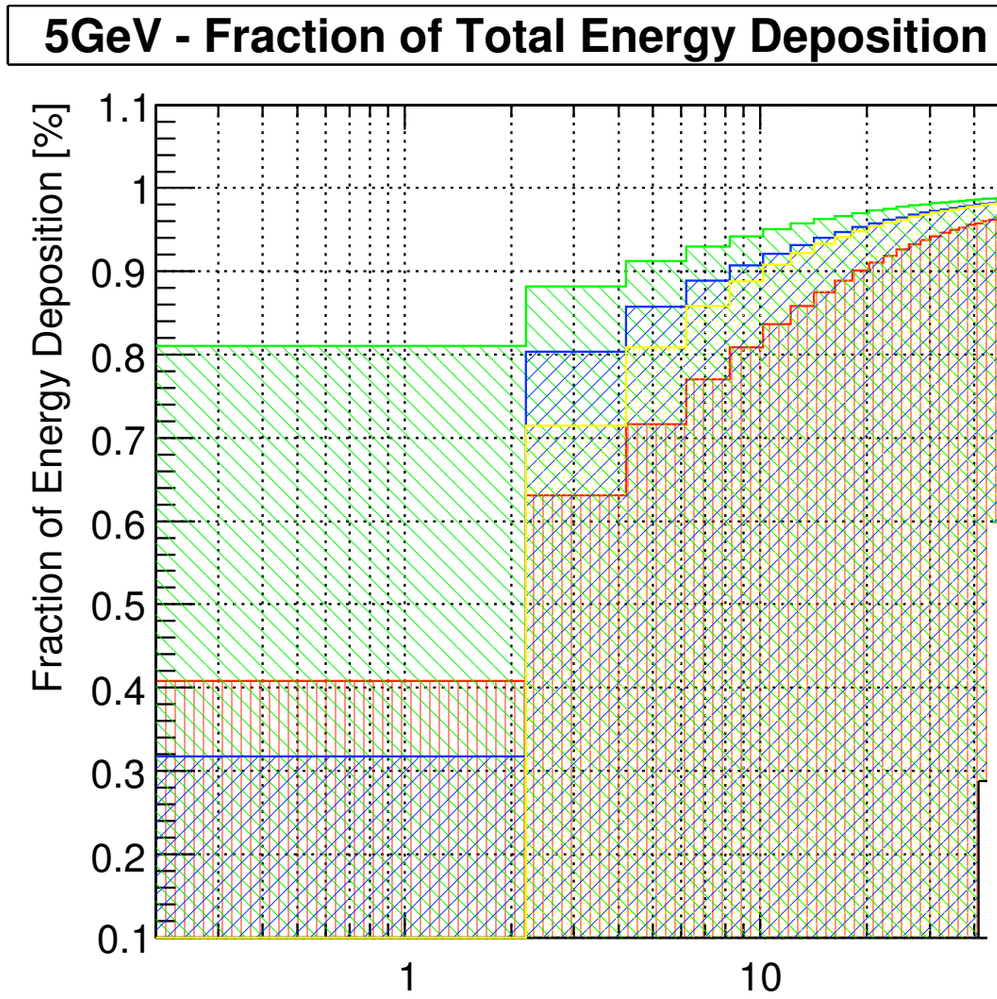


- Moving of the Timing Strip allows to study early region of the shower with higher precision

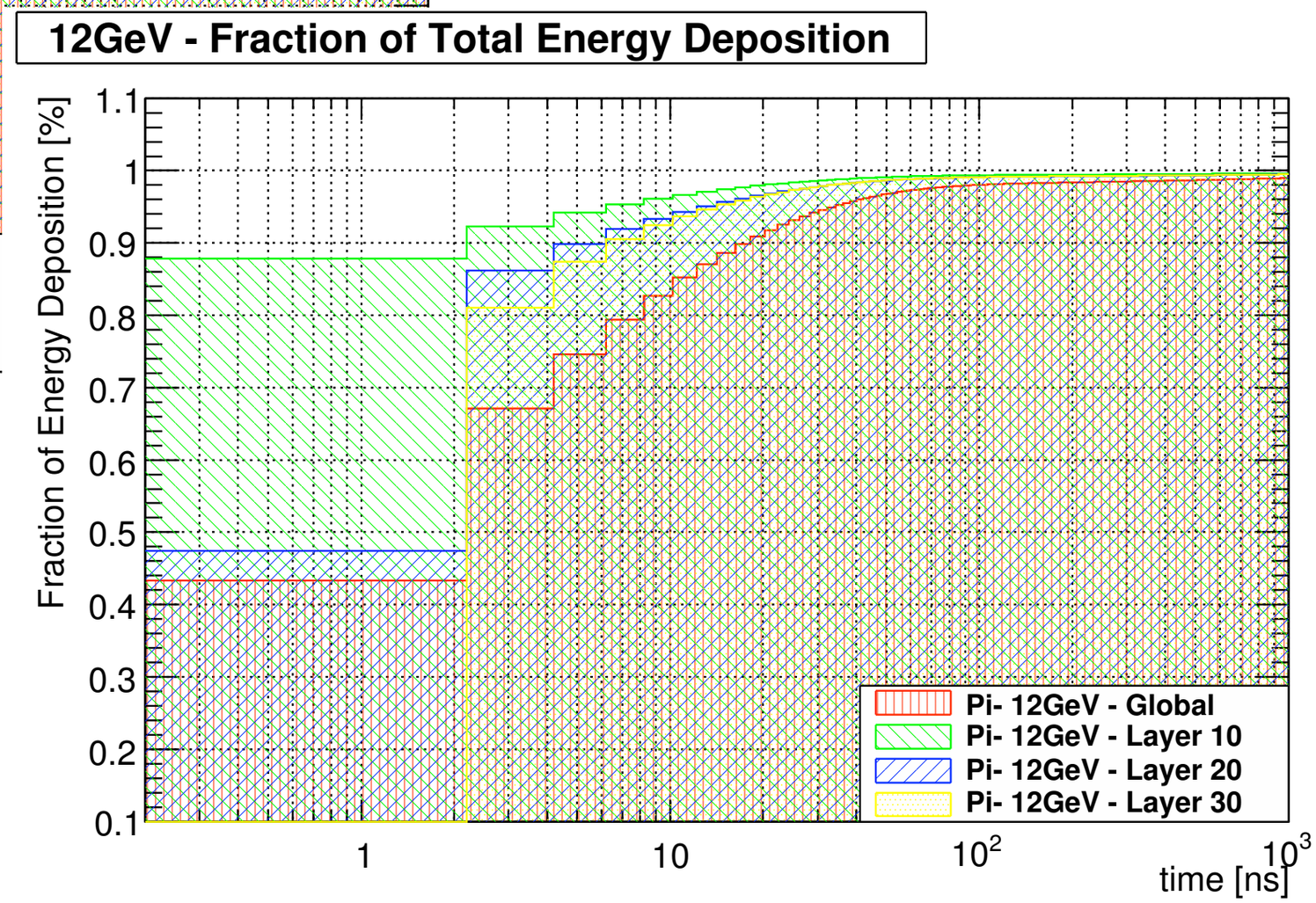
- Adds also "presampling" if layers behind the timing strip remain functional



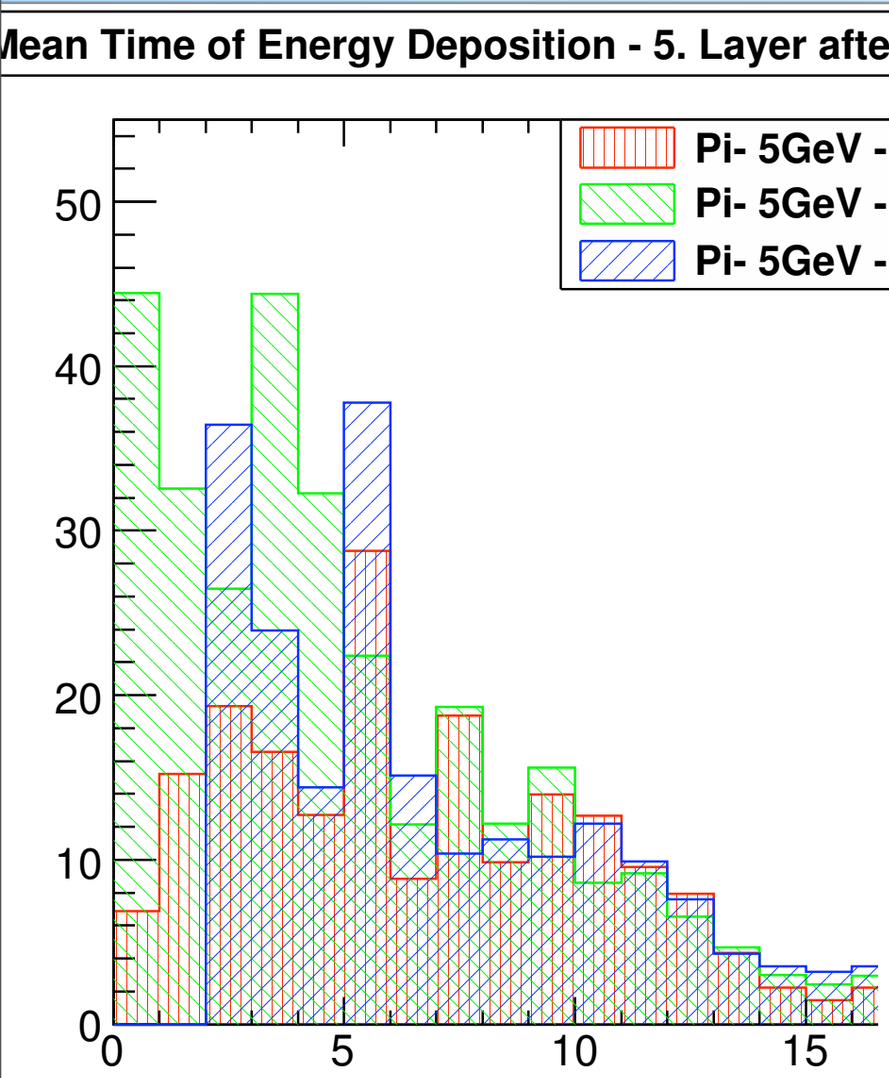
Integration time: Time to Collect Full Energy

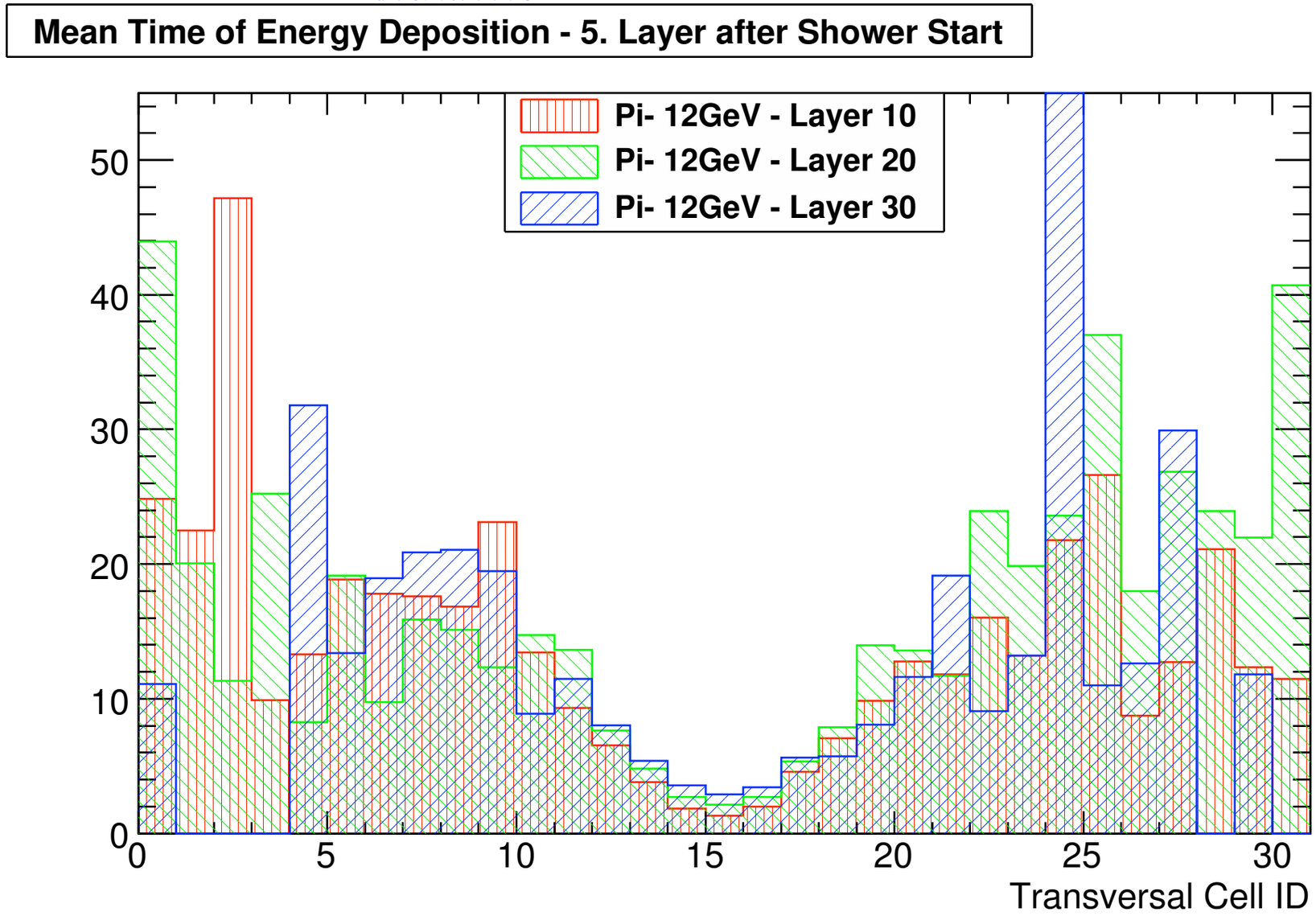


- Significant fraction of the event energy arrives late, longitudinal distribution energy dependent

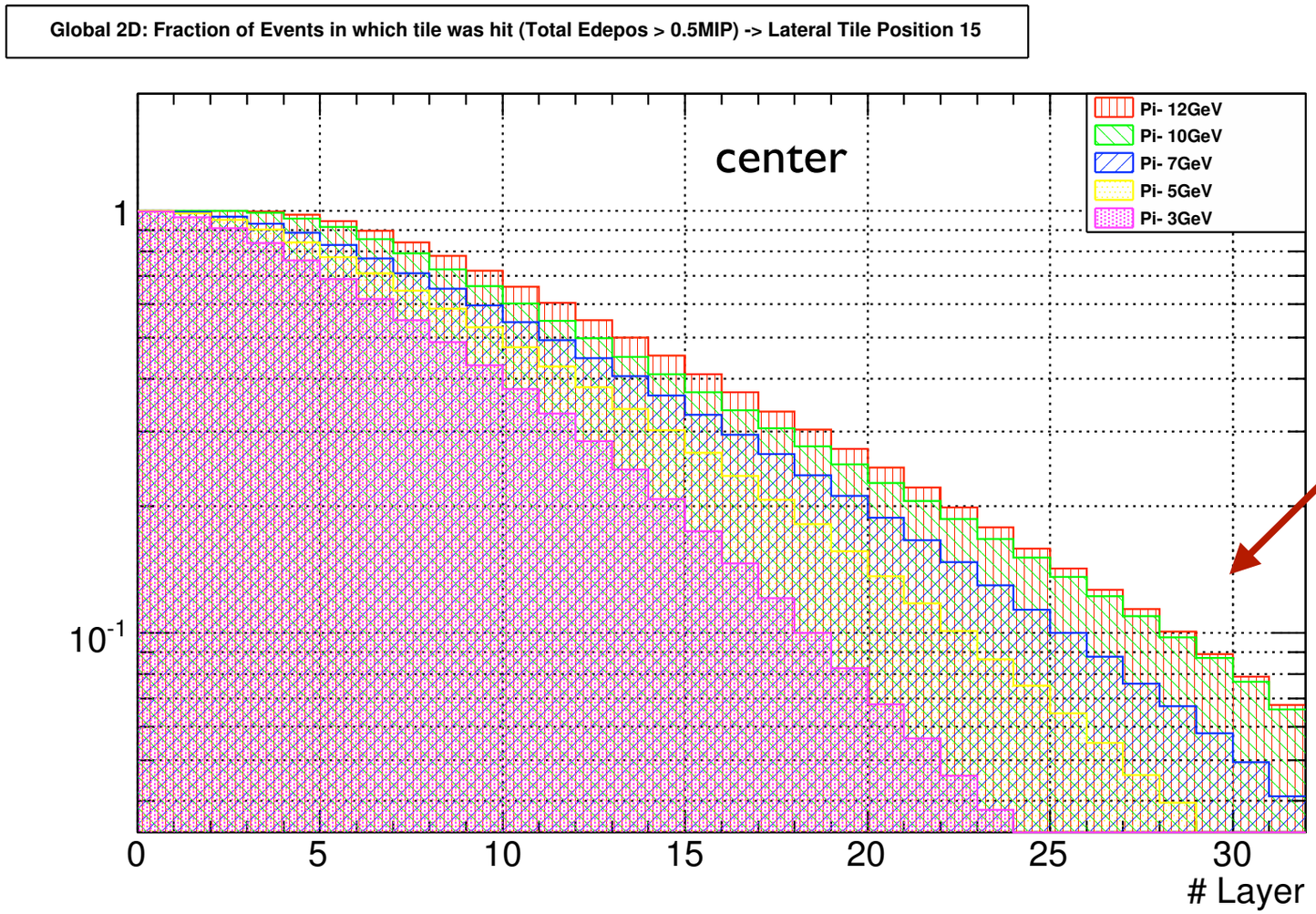


Transverse Time Profile, 5 Layers after Shower Start



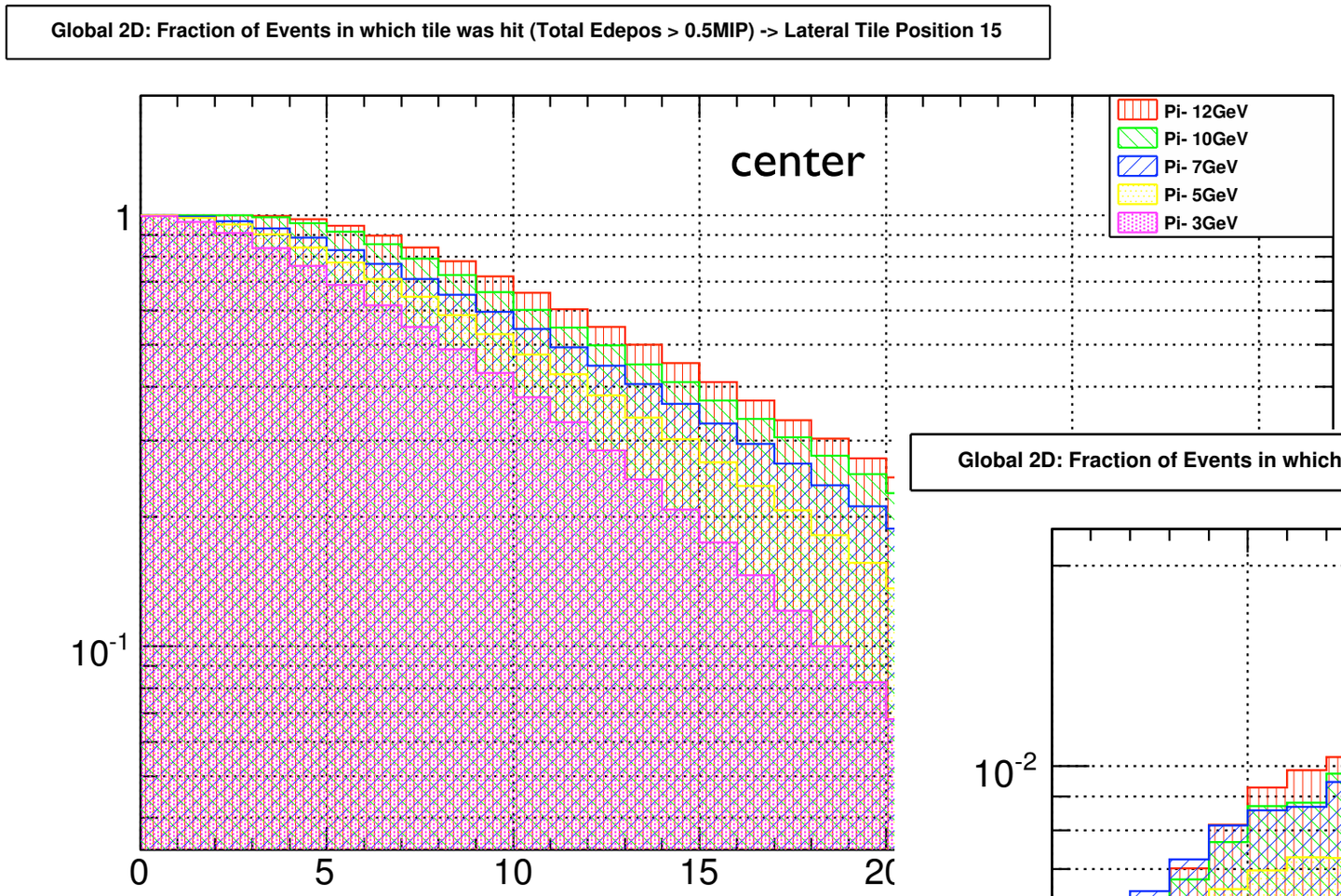


Statistics: Hit Probability of Cells

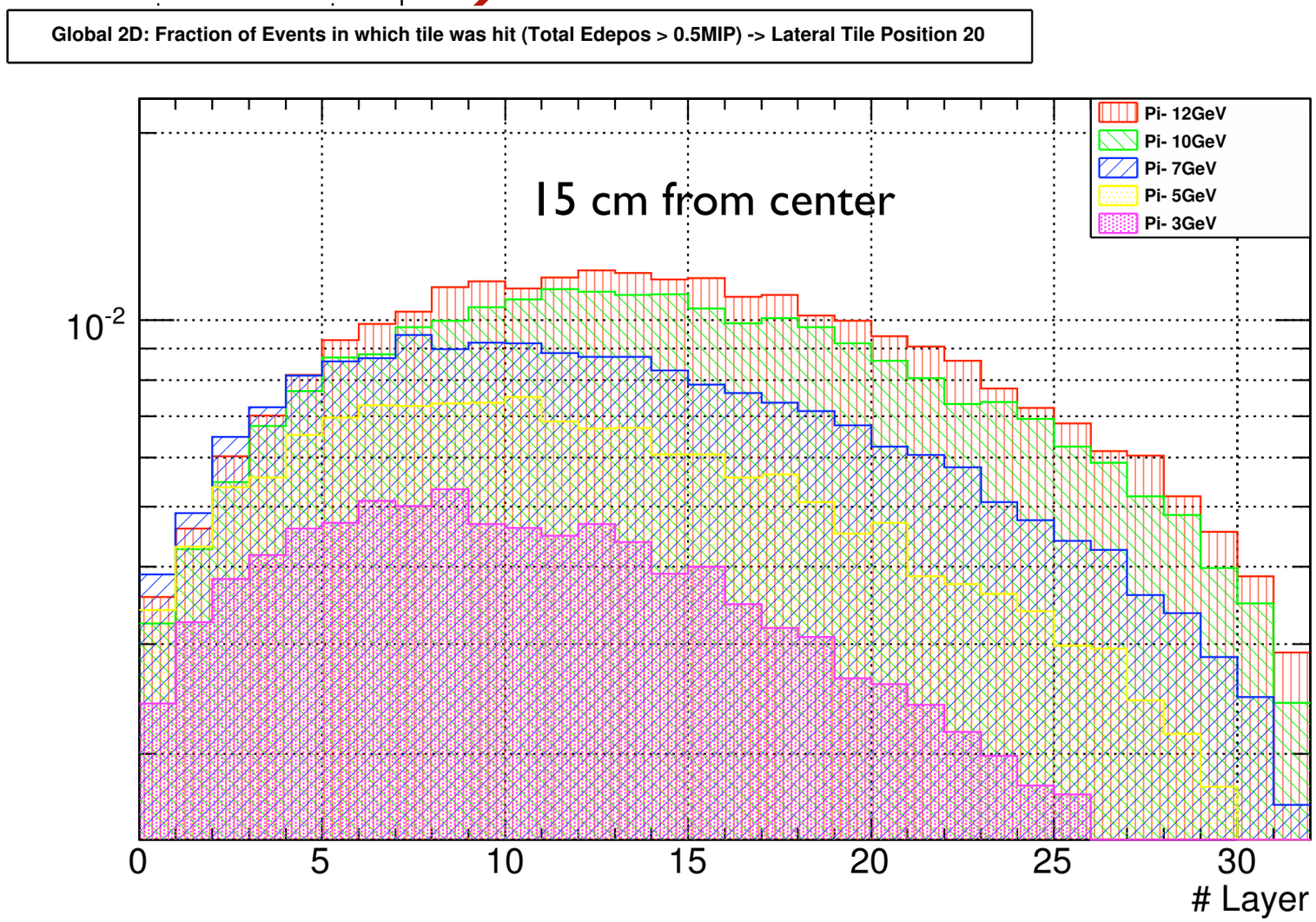


nominal position

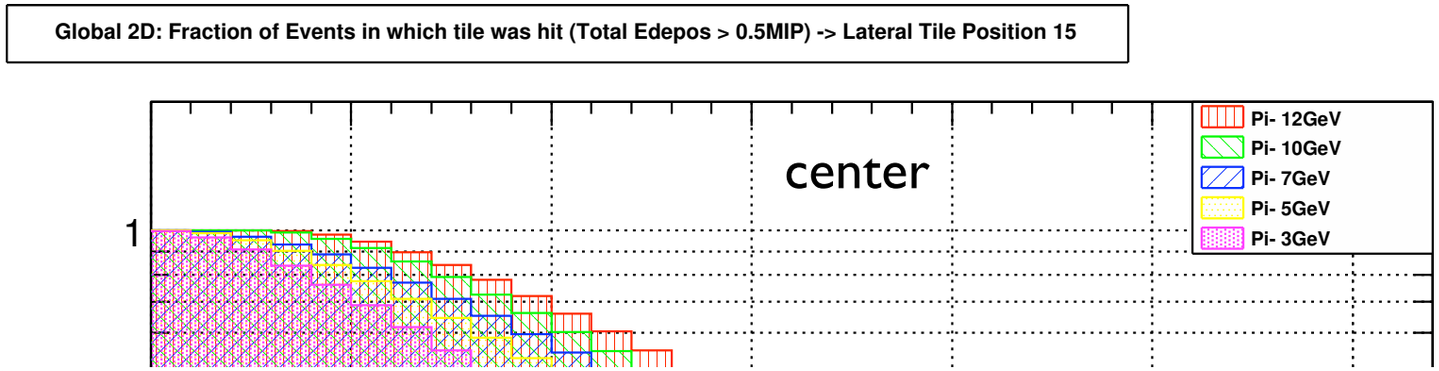
Statistics: Hit Probability of Cells



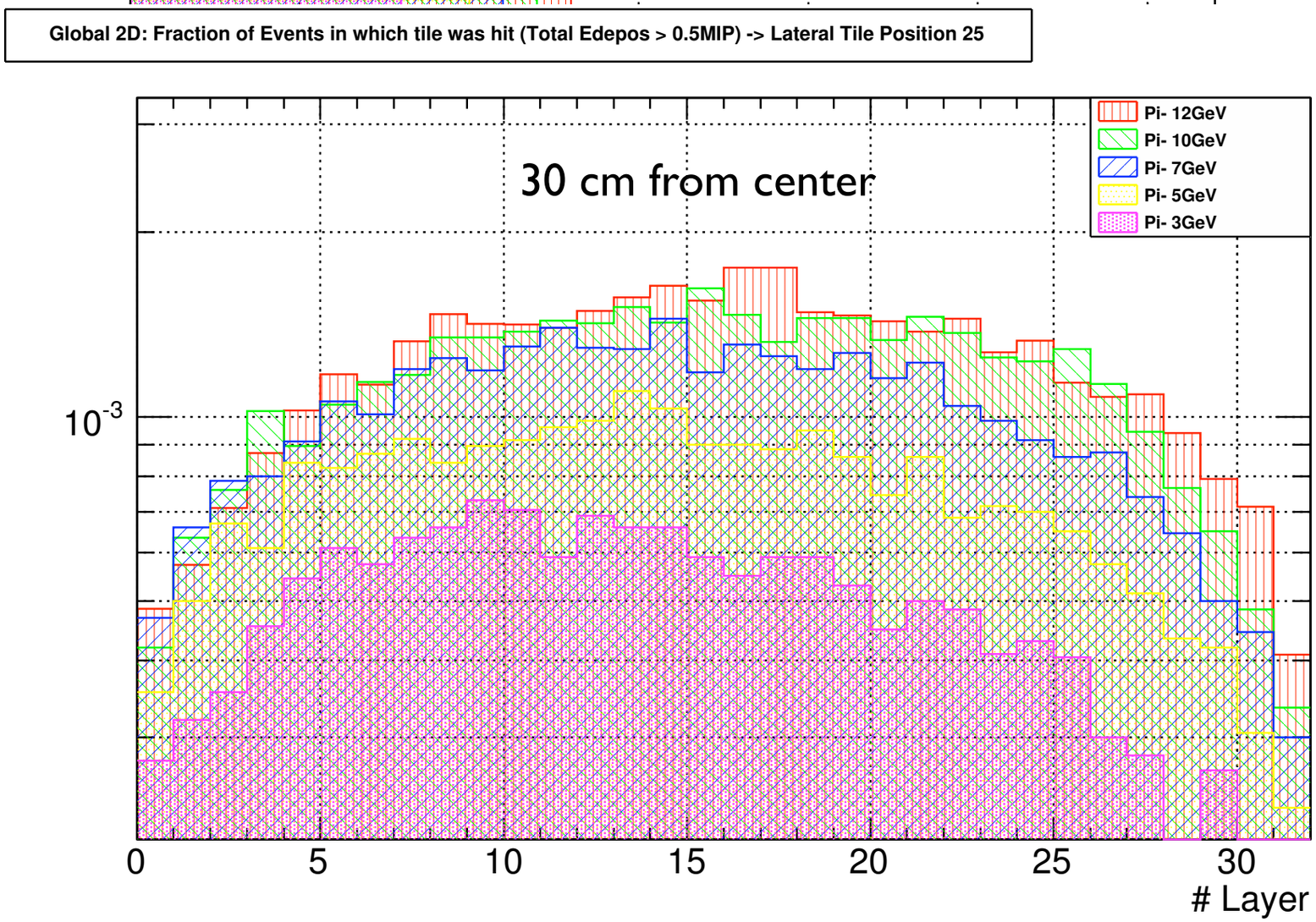
nominal position

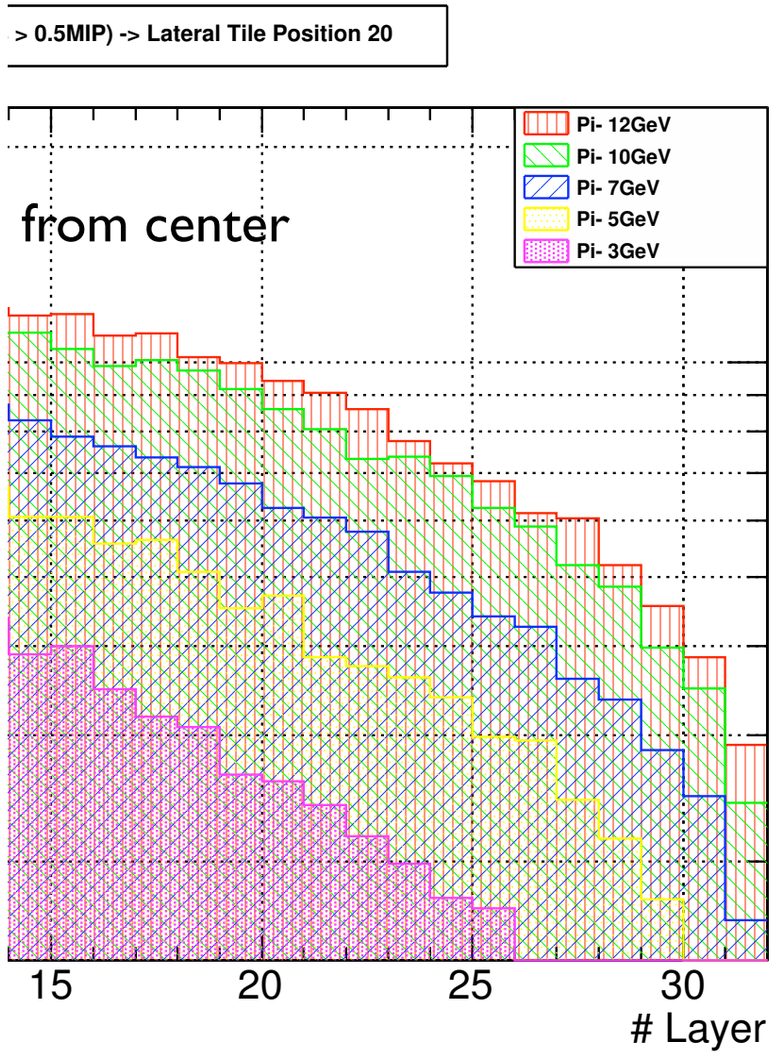


Statistics: Hit Probability of Cells

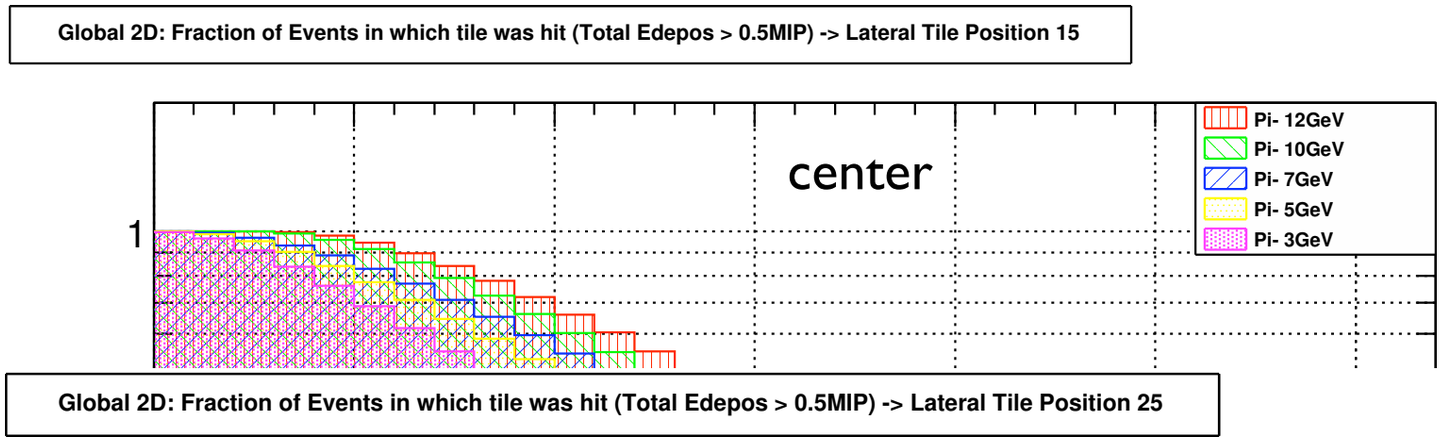


nominal position





Statistics: Hit Probability of Cells

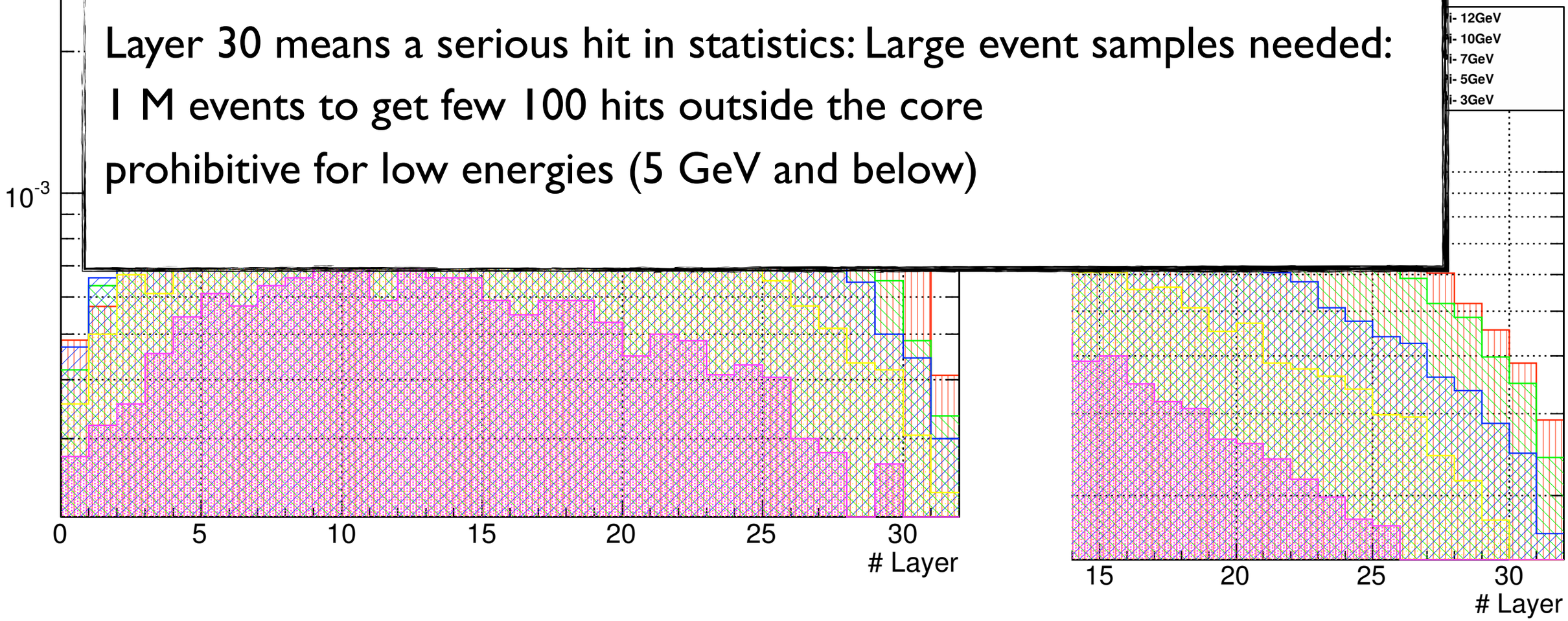


nominal position

Layer 30 means a serious hit in statistics: Large event samples needed:

1 M events to get few 100 hits outside the core

prohibitive for low energies (5 GeV and below)



Run Plan: Updated at CERN last Week

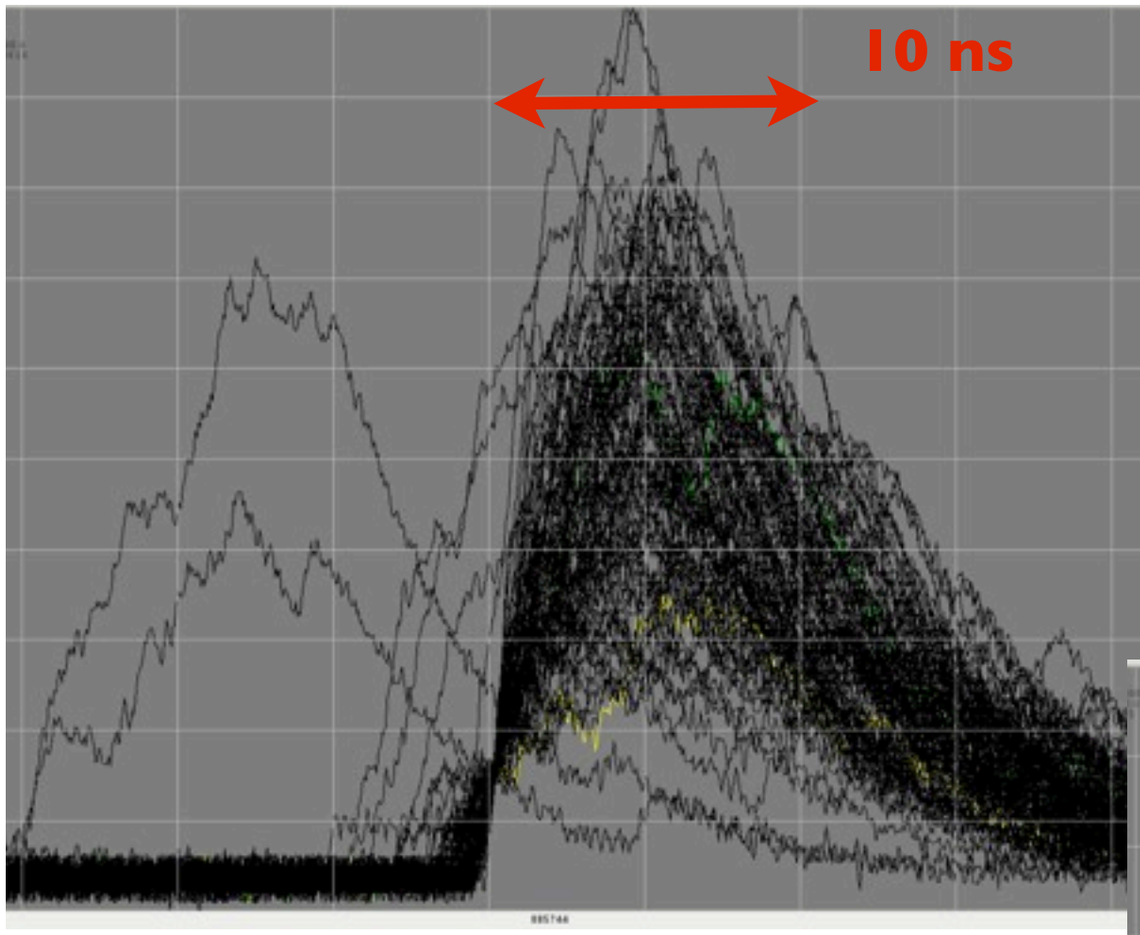
- Beam structure (tbc): Every 30 s one 300 ms spill (if we are lucky, more than one spill) - Means 10 Hz average rate with 1 kHz CALICE trigger rate
- Take highest possible statistics at ~5 different energies (3, 5, 7, 10, 12 GeV), beam vertically centered on Timing Strip
  - Timing Strip located at the end of the calorimeter: Behind 30 absorber layers, and behind one layer of Micromegas (essentially 4 mm of stainless steel)

- Ideal: One or two other longitudinal locations: layer 10, layer 20
  - In each location, take ~250 k events at several energies (3 should do): If we give up correlation with AHCAL, this could go very fast, larger datasets could be acquired

- That way:
  - Possibility for stand-alone analysis of the timing data, providing first rough results quickly
  - Thorough analysis including full correlation with HCAL data

Hardware Options

Tile Response with and without Fiber

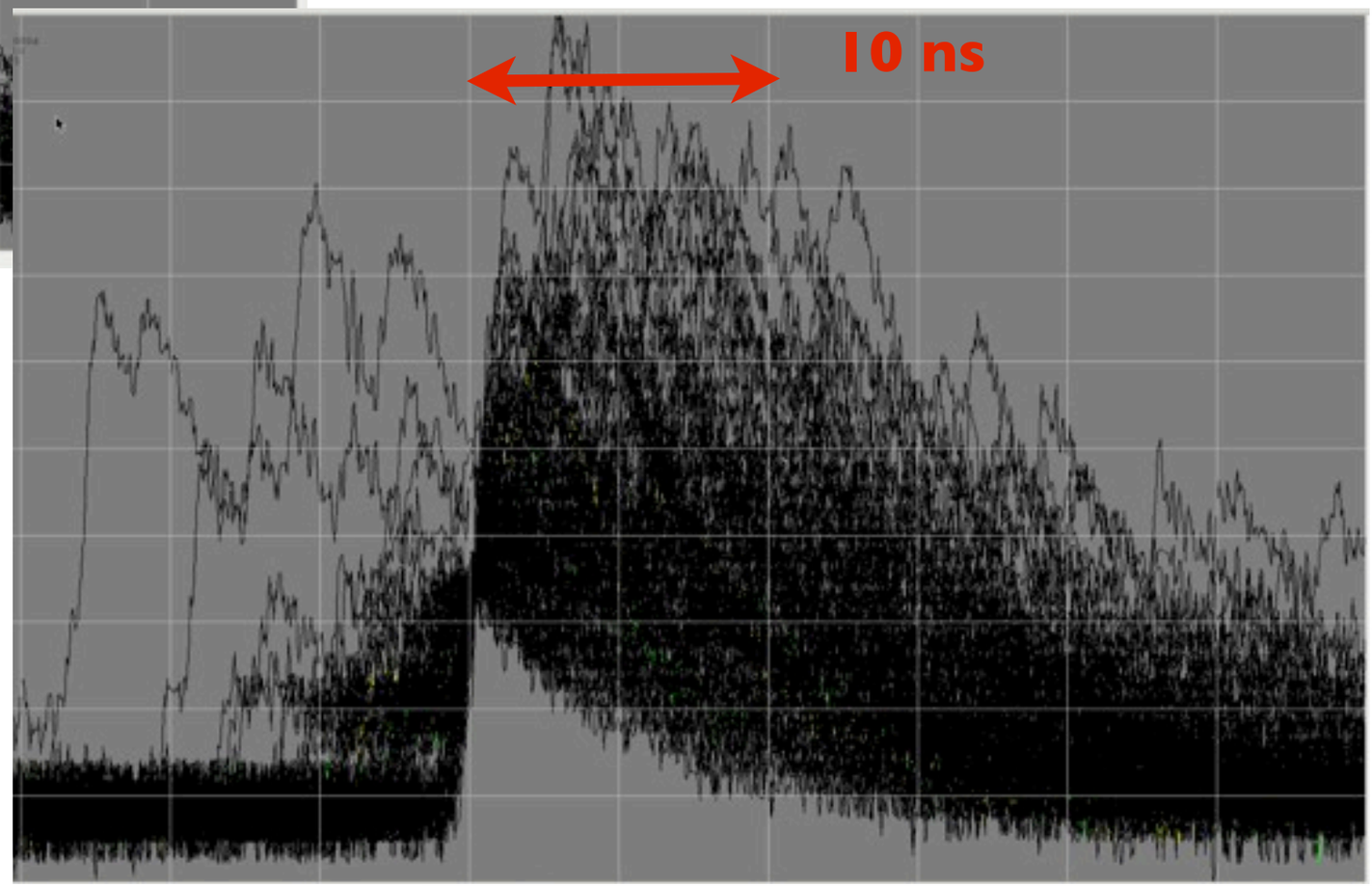


directly coupled tile

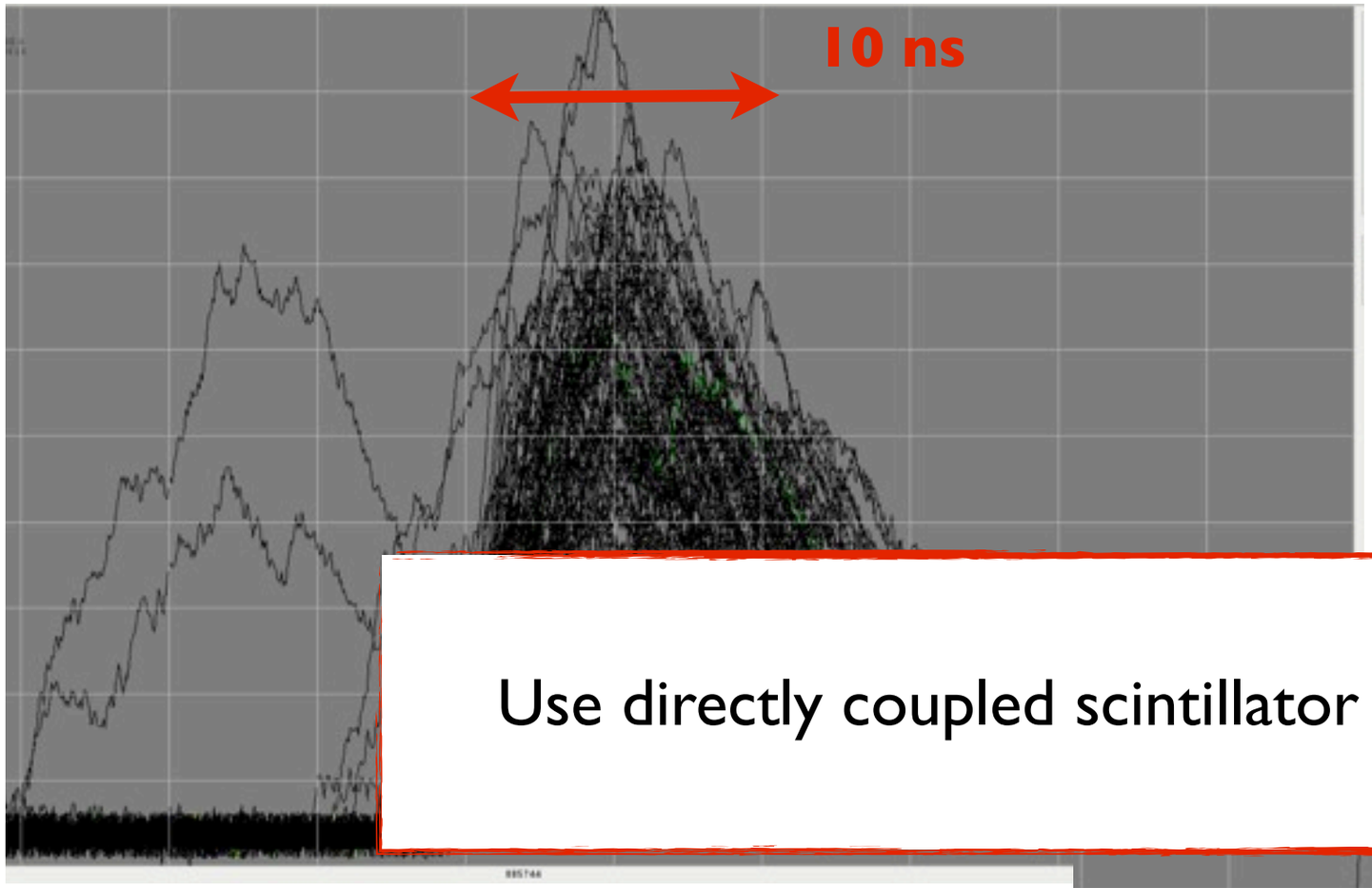
- fast peaking signal, pronounced peak
- sub-ns time resolution possible
- short integration times sufficient

CALICE 1st generation tile:
curved WLS fiber

- broad signal peak
- reasonable time resolution possible
- longer integration time needed



Tile Response with and without Fiber



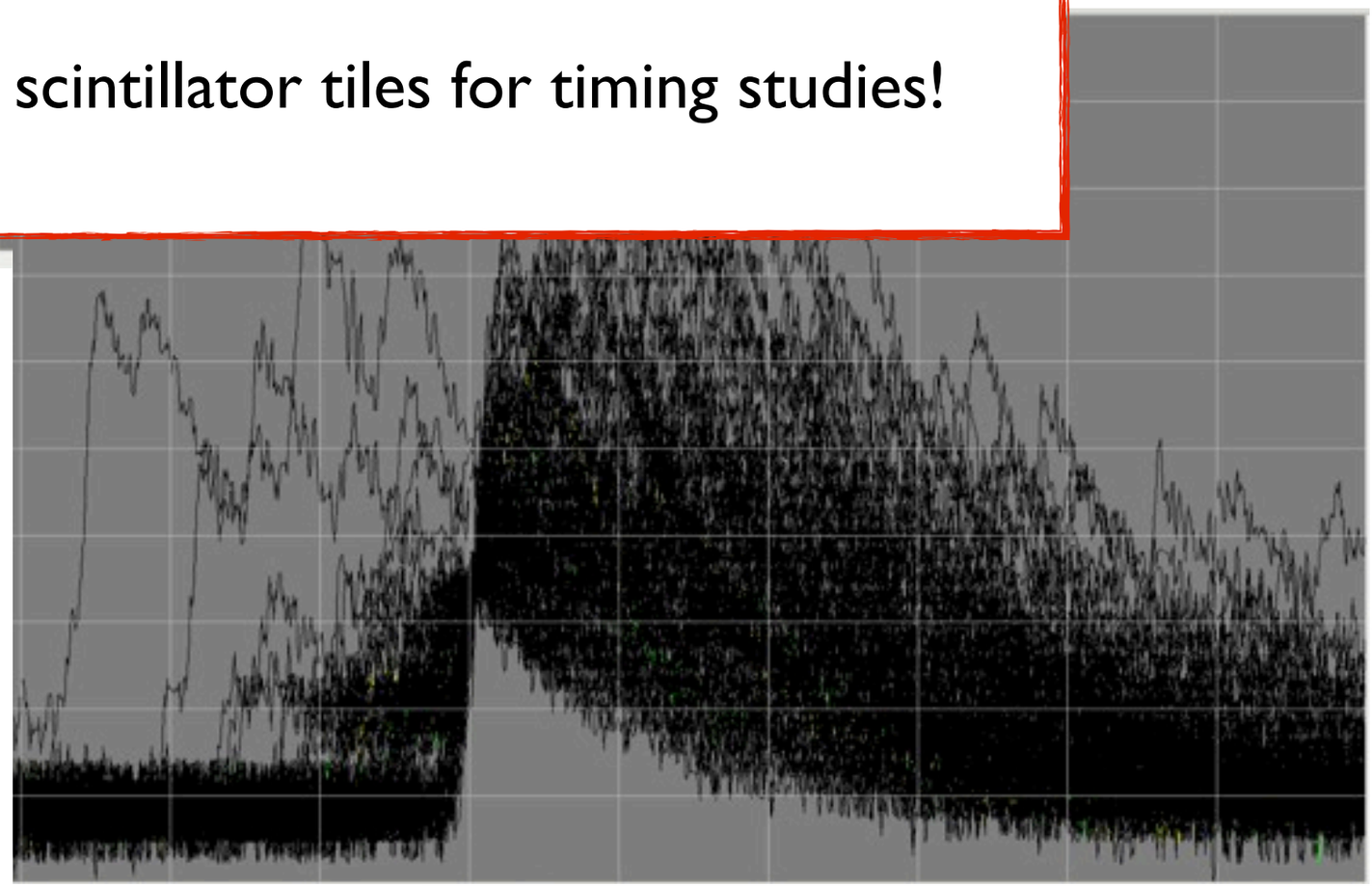
directly coupled tile

- fast peaking signal, pronounced peak
- sub-ns time resolution possible
- short integration times sufficient

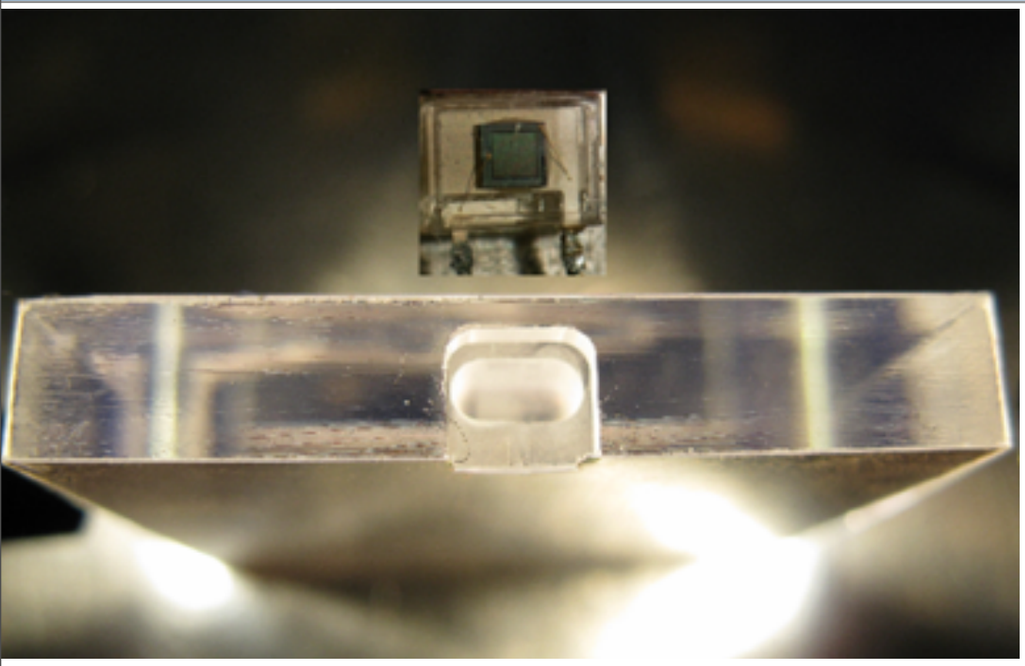
Use directly coupled scintillator tiles for timing studies!

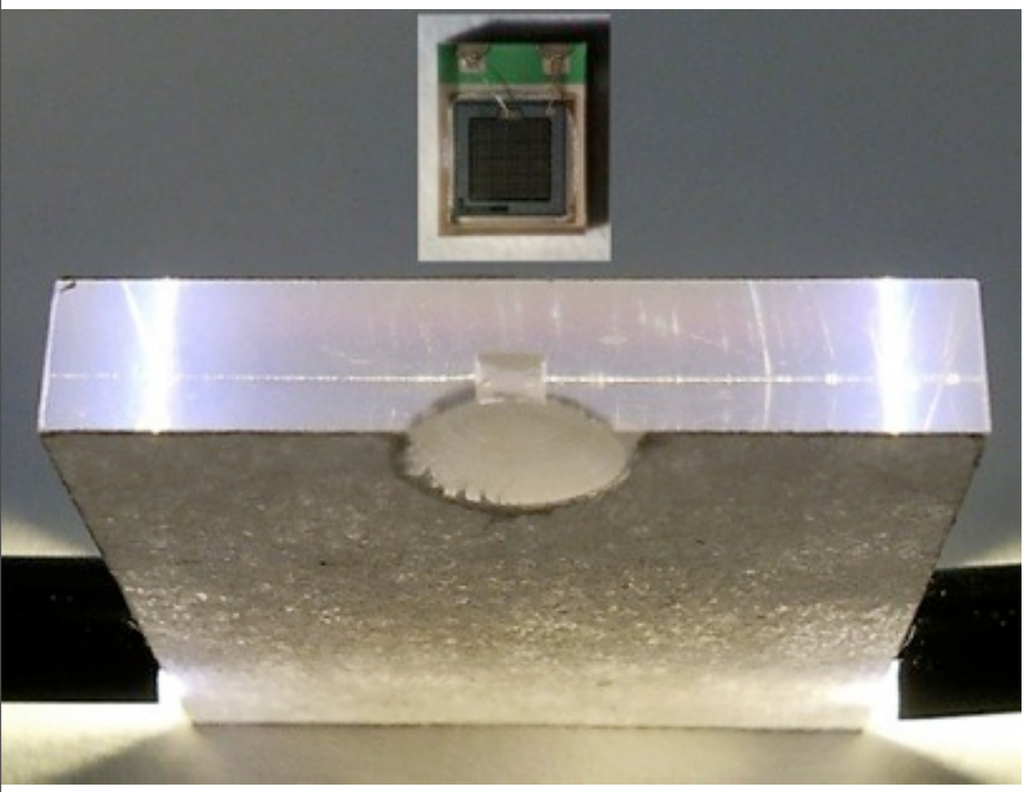
CALICE 1st generation tile:
curved WLS fiber

- broad signal peak
- reasonable time resolution possible
- longer integration time needed



Scintillators: Directly Coupled Tiles





- Active medium: 5mm thick scintillator tiles, read out by Hamamatsu MPPCs
- Special shape of scintillator at SiPM coupling position, two options under study
- Hamamatsu MPPCs: two possible pixel sizes: 25 x 25 μm^2 or 50 x 50 μm^2
  - Small pixels: larger dynamic range (not needed here), lower cross talk, dark rate
  - Large pixels: Higher photon detection efficiency (also small pixel MPPCs achieve 15 - 20 p.e. / MIP)
- ▸ Need to decide soon, order photo sensors

DAQ Option I: PicoScope 6403

- Tested in June in Munich

- 4 Channel Readout, up to 1.25 GS/Sec
- 1 GS buffer memory (shared)
- Rapid Shot: Acquire signals with up to 1MHz repetition rate
- External trigger
- USB readout
- Existing libraries for LabView, VisualStudio, fast response from manufacturers
- Size of an external HDD

Cons:

- 8-bit vertical resolution (ADC)
- clipping of very high signals can distort measurement
- 350MHz Bandwidth

Dynamic Range: Issues

- Ideally: Acquire Signals from 20 MIP down to 1- 2 p.e.
  - not achievable with 8-bit (1 MIP ~ 15 - 18 p.e., instantaneous ~ 12 p.e.)
- Limitations of the PicoScope amplifier: Large signals well beyond the set dynamic range (~ x 3 beyond limit) lead to distortions of the wave form

- Possible dynamic ranges (derived from ^{90}Sr signals used as MIPs)
  - High gain: 5.5 MIP maximum, 1 p.e. ~ 4 bit (problems beyond 15 MIP)
  - Medium gain: 11 MIP maximum, 1 p.e. ~ 2 bit (problems beyond 30 MIP)
  - Low gain: 22 MIP maximum, 1 p.e. ~ 1 bit (problems beyond 60 MIP)

- Potential approaches to avoid limit problem also for high gain (both not attractive):
  - external clipping of waveform
  - logarithmic amplifier (would also solve the dynamic range issue) but: Requires 16 amplifiers, complicated calibrations

Dynamic Range: Issues

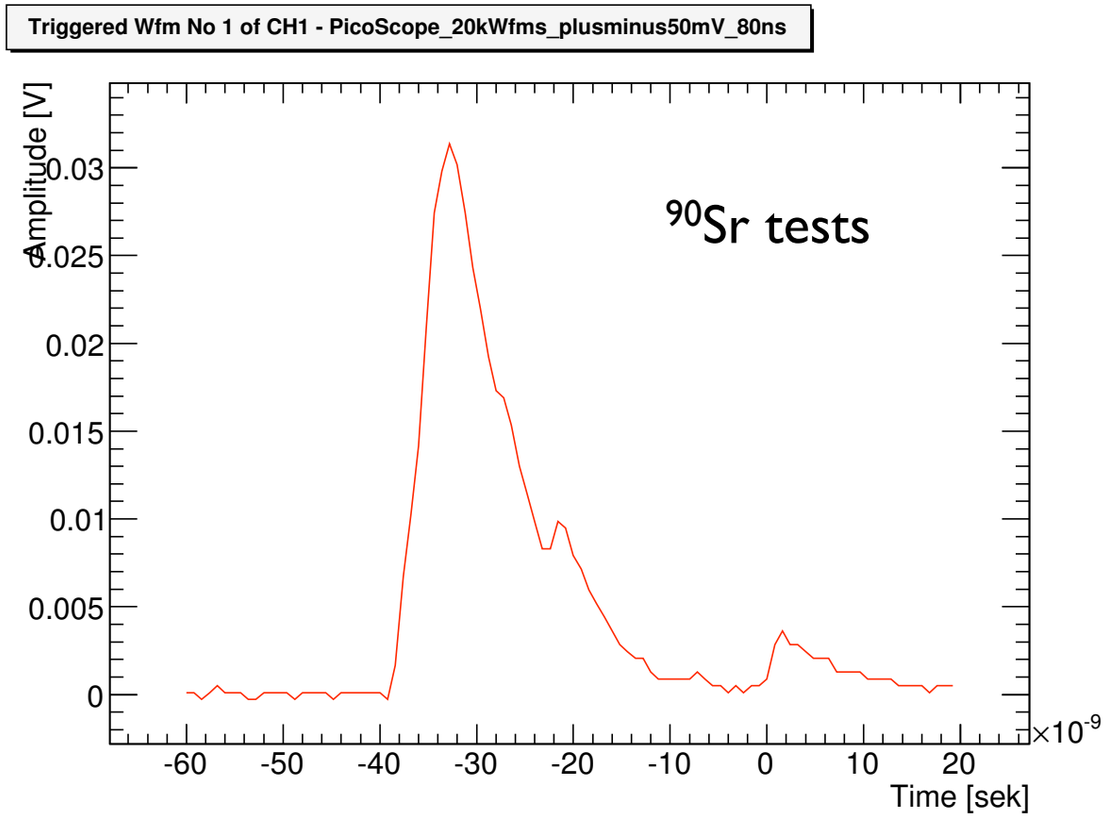
- Ideally: Acquire Signals from 20 MIP down to 1- 2 p.e.
  - not achievable with 8-bit (1 MIP ~ 15 - 18 p.e., instantaneous ~ 12 p.e.)
- Limitations of the PicoScope amplifier: Large signals well beyond the set dynamic range (~ x 3 beyond limit) lead to distortions of the wave form

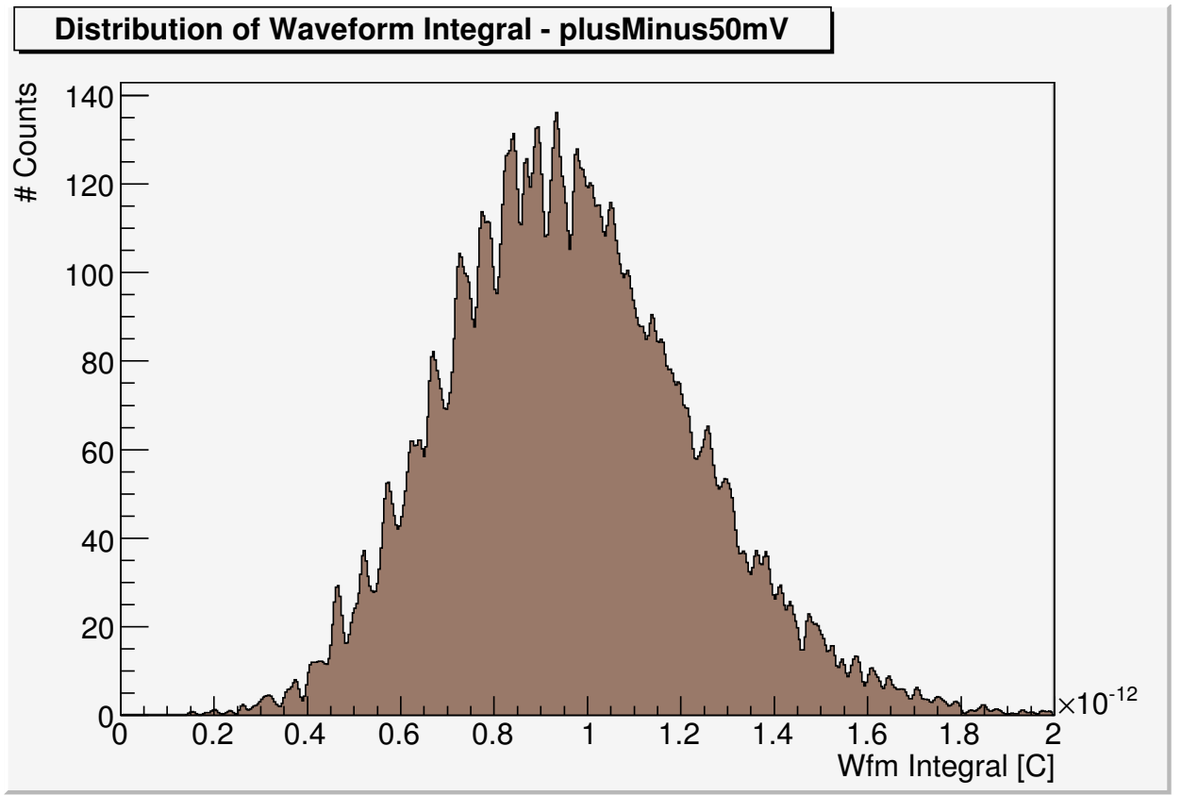
- Possible dynamic ranges (derived from ^{90}Sr signals used as MIPs)
  - High gain: 5.5 MIP maximum, 1 p.e. ~ 4 bit (problems beyond 15 MIP)
  - Medium gain: 11 MIP maximum, 1 p.e. ~ 2 bit (problems beyond 30 MIP)
  - Low gain: 22 MIP maximum, 1 p.e. ~ 1 bit (problems beyond 60 MIP)

likely best option

- Potential approaches to avoid limit problem also for high gain (both not attractive):
  - external clipping of waveform
  - logarithmic amplifier (would also solve the dynamic range issue) but: Requires 16 amplifiers, complicated calibrations

Test Results





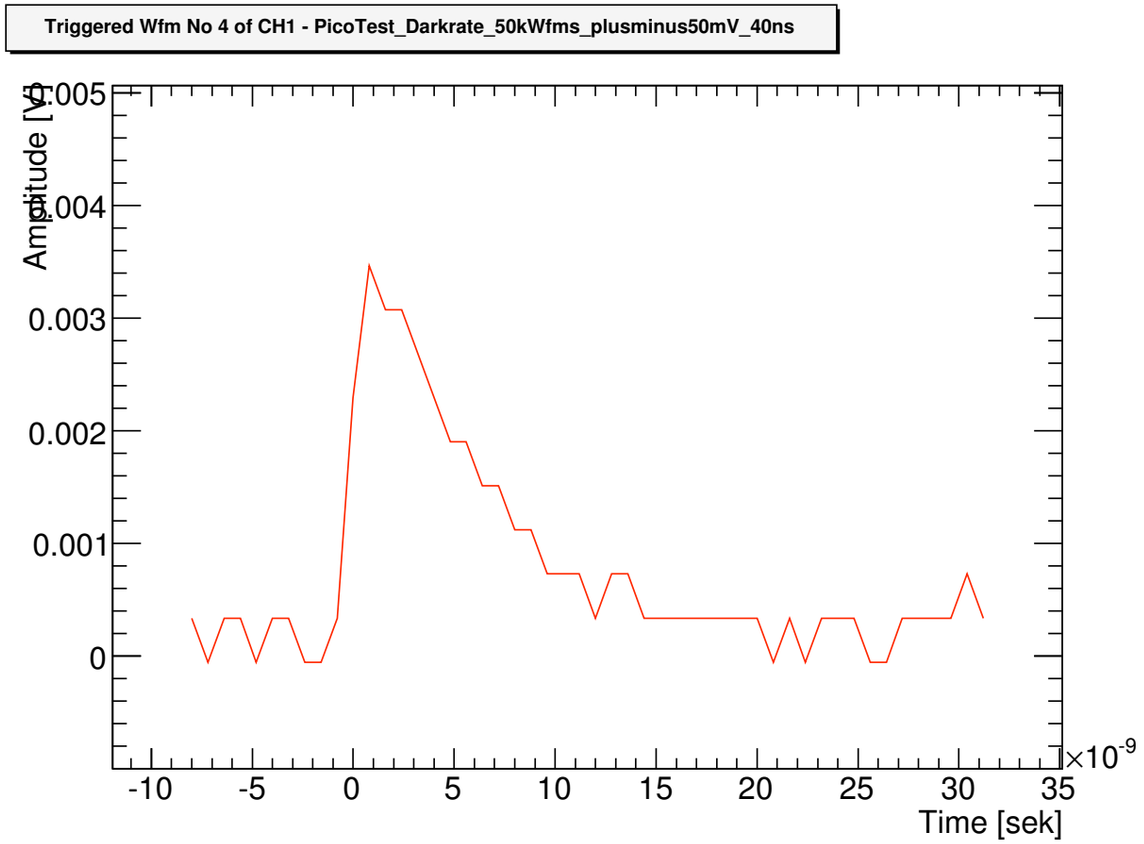
- Time resolution sufficient to resolve single p.e. peaks in sum signal
  - Here: extreme high gain: +- 50 mV, corresponds to 2.7 MIP dynamic range
- Planned physics mode: 2 µs acquisition window, acquire ~ 3k events per spill with a trigger rate < 10 kHz, transfer data out between spills (60 MB per unit)

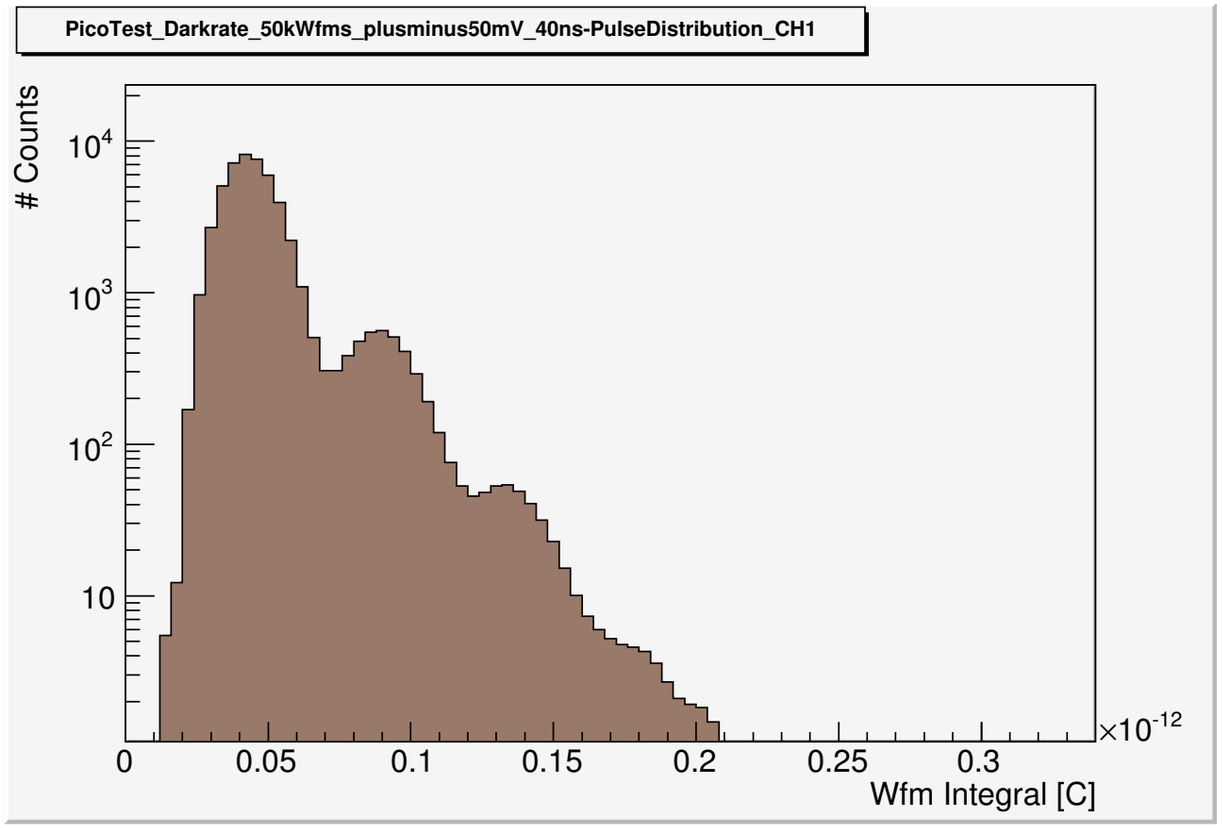
▸ Achieved in less than 8 s!

With trigger speeds up to several 100 kHz: Synchronisation with CALICE trigger should be unproblematic, use CALICE data for shower start finding, correlate with timing measurements

Test Results: Calibration Mode

- Monitoring of SiPM gain planned using dark pulses
  - acquire data with short time window (40 ns), internal trigger, high gain mode
  - Between spills or dedicated runs (a few thousand between spills could be realistic)





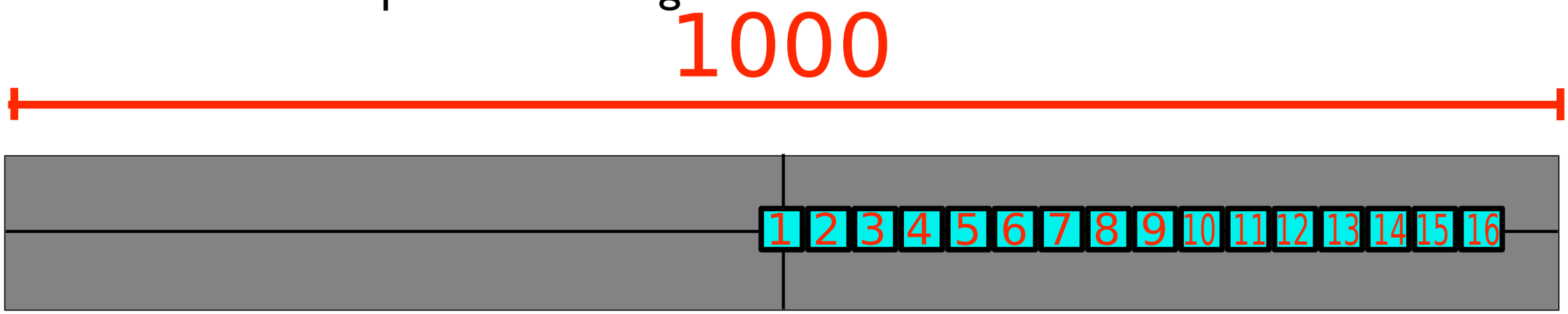
- In addition: Installation of temperature sensors to monitor temperature

DAQ Option II: Struck SIS 3305

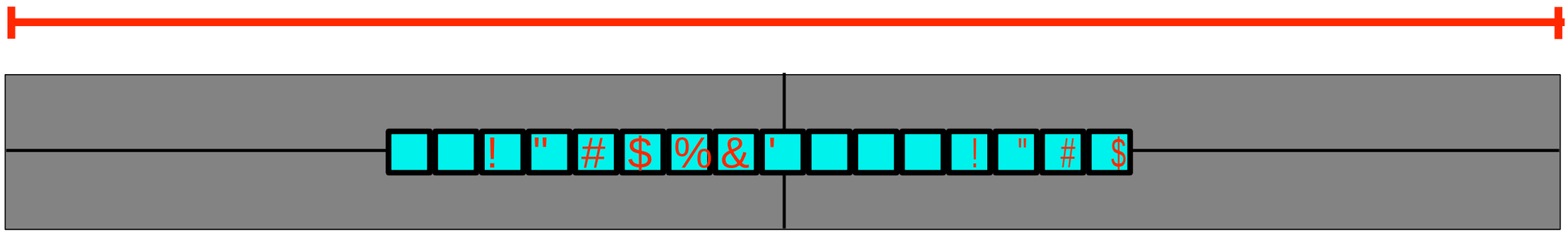
- Struck VME Digitizer SIS 3305
  - 8 ch digitizer cards, two cards in one mainframe
  - 1.25 GS/s in 8 ch mode
  - 1 GS shared memory per module
  - 2 GHz bandwidth
  - 10 bit vertical resolution
  - Trigger in/out
- Not tested yet, test unit expected in Munich in ~ 1 week, open questions:
  - Is high trigger rate, well above CALICE trigger rate, achievable?
  - General performance, quality issues?
  - Delivery time?
- Probably the better option, we'll have to see...

Geometrical Arrangement

- 16 channels - 2 possible arrangements



➪ wide lateral coverage, high statistics needed



➪ limited lateral coverage, moderate statistics requirements

- In addition: wider spacing, larger central tile...
- Final choice depends on run plan, beam parameters, expected statistics...

Summary

- Wide range of measurements possible with a single strip of scintillator tiles with time-resolved readout
  - Particularly powerful in combination with shower start information from AHCAL layers: Have to ensure that matching up of events is possible offline!

- First DAQ option investigated, satisfies (most) requirements
- Second option being tested next week

- Good news: Hardware funded from Excellence Cluster as a Special Project: 22 kEUR received, approximately sufficient for 16 channel DAQ system and SiPMs

Summary

- Wide range of measurements possible with a single strip of scintillator tiles with time-resolved readout
  - Particularly powerful in combination with shower start information from AHCAL layers: Have to ensure that matching up of events is possible offline!

- First DAQ option investigated, satisfies (most) requirements
- Second option being tested next week

- Good news: Hardware funded from Excellence Cluster as a Special Project: 22 kEUR received, approximately sufficient for 16 channel DAQ system and SiPMs

⇨ Alright, let's do it!