

Timing Measurements of the Hadronic Shower with Fast Scintillator Tiles

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Introduction & Overview

- Information about the time structure of hadronic showers in Tungsten is crucial for the development of a CLIC HCAL
 - 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

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 - 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

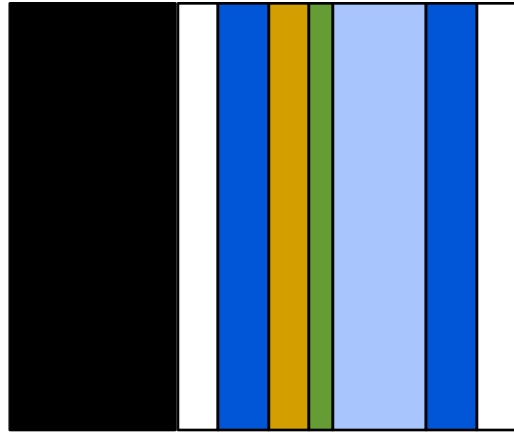
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Simulation Studies



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

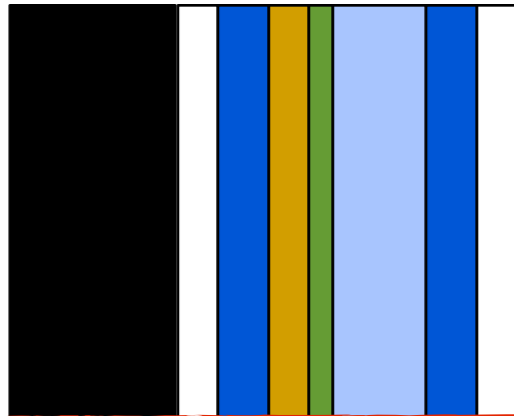
2 mm Steel

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)

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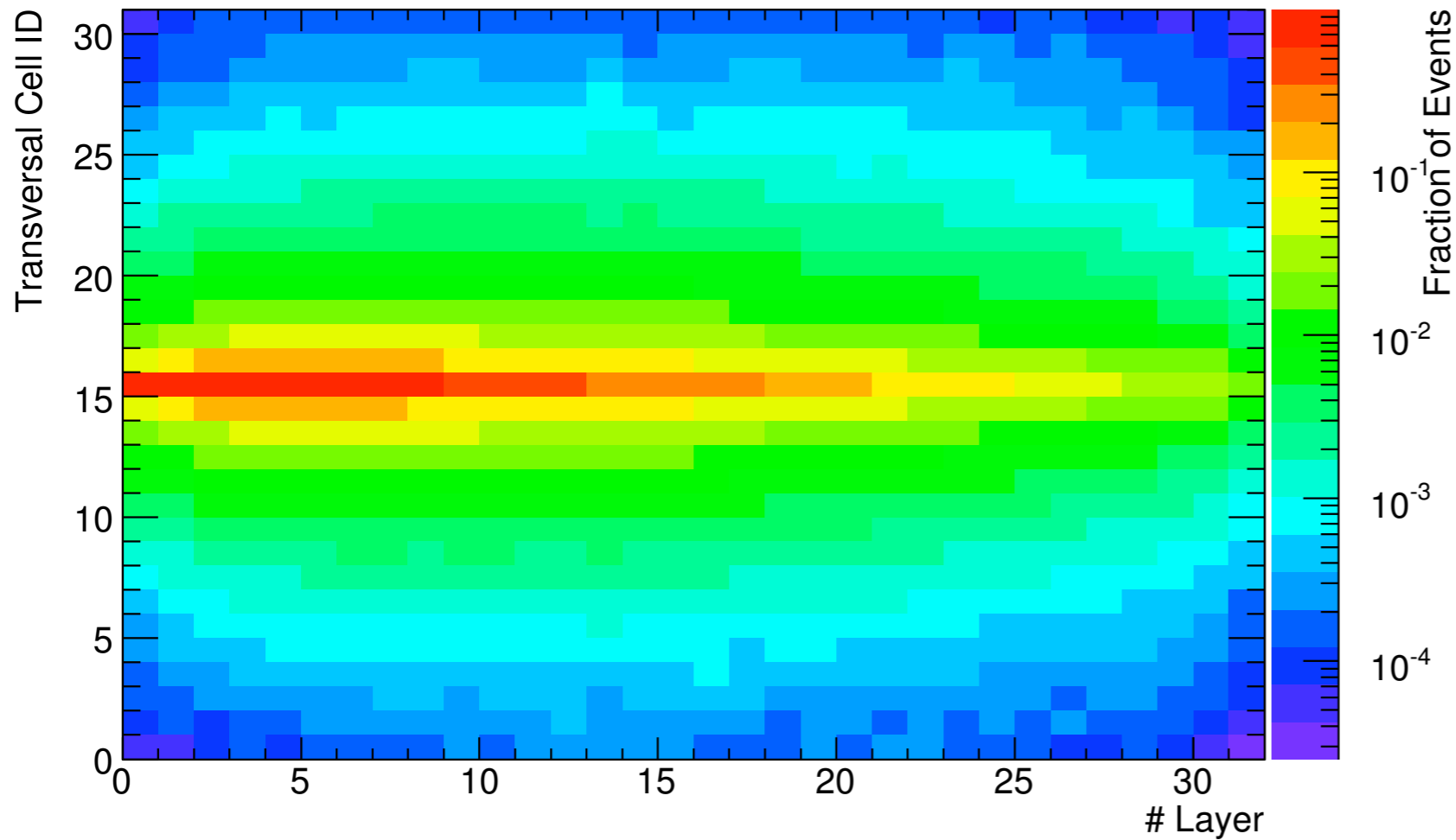
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Beware: No digitization, no description of detector effects, pure time and energy information from Geant4

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Simulations: Global Distributions - Hit Probability

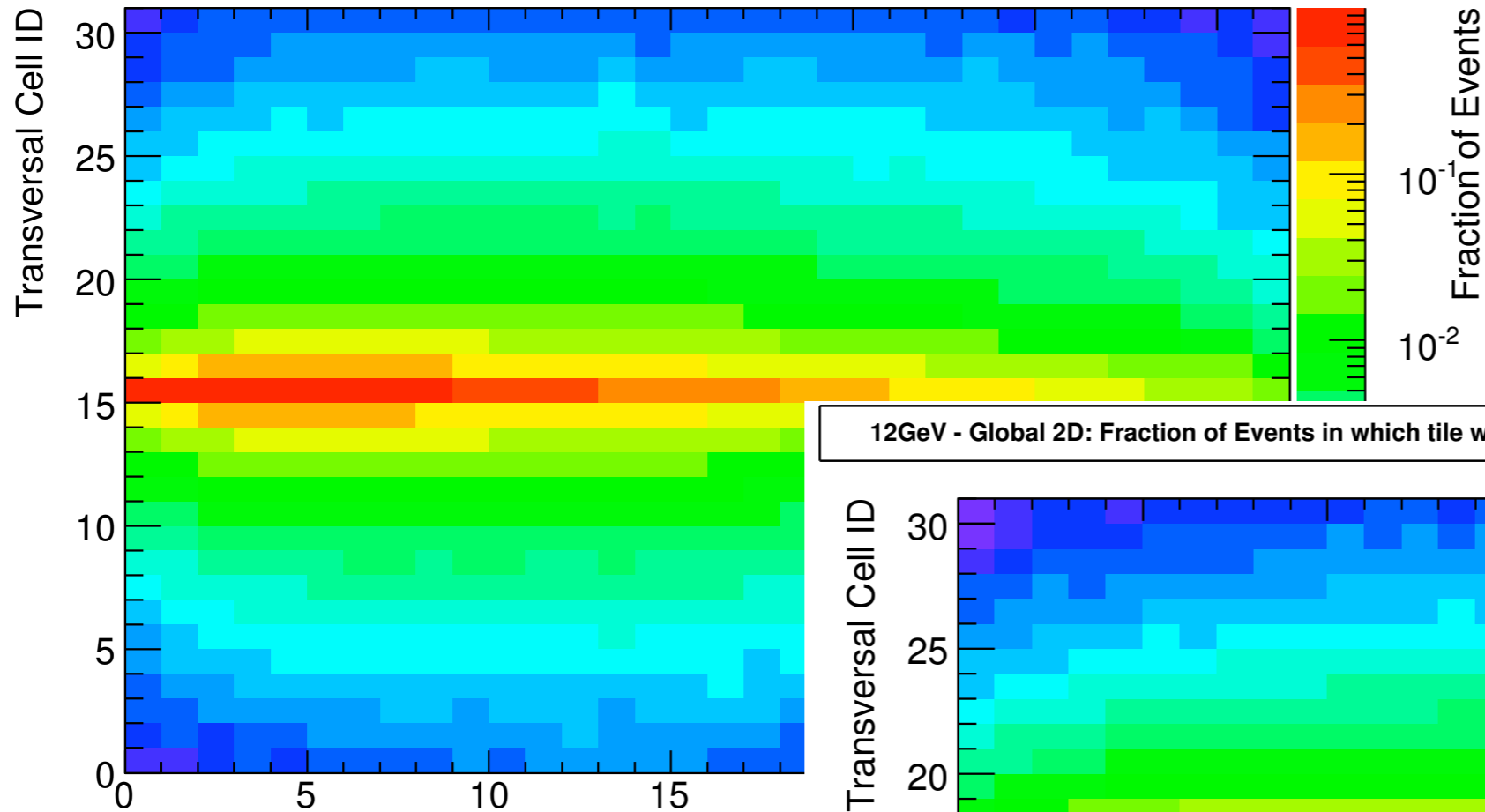
5GeV - Global 2D: Fraction of Events in which tile was hit (Total Edepos > 0.5MIP)_1



- Here: Full Calorimeter!

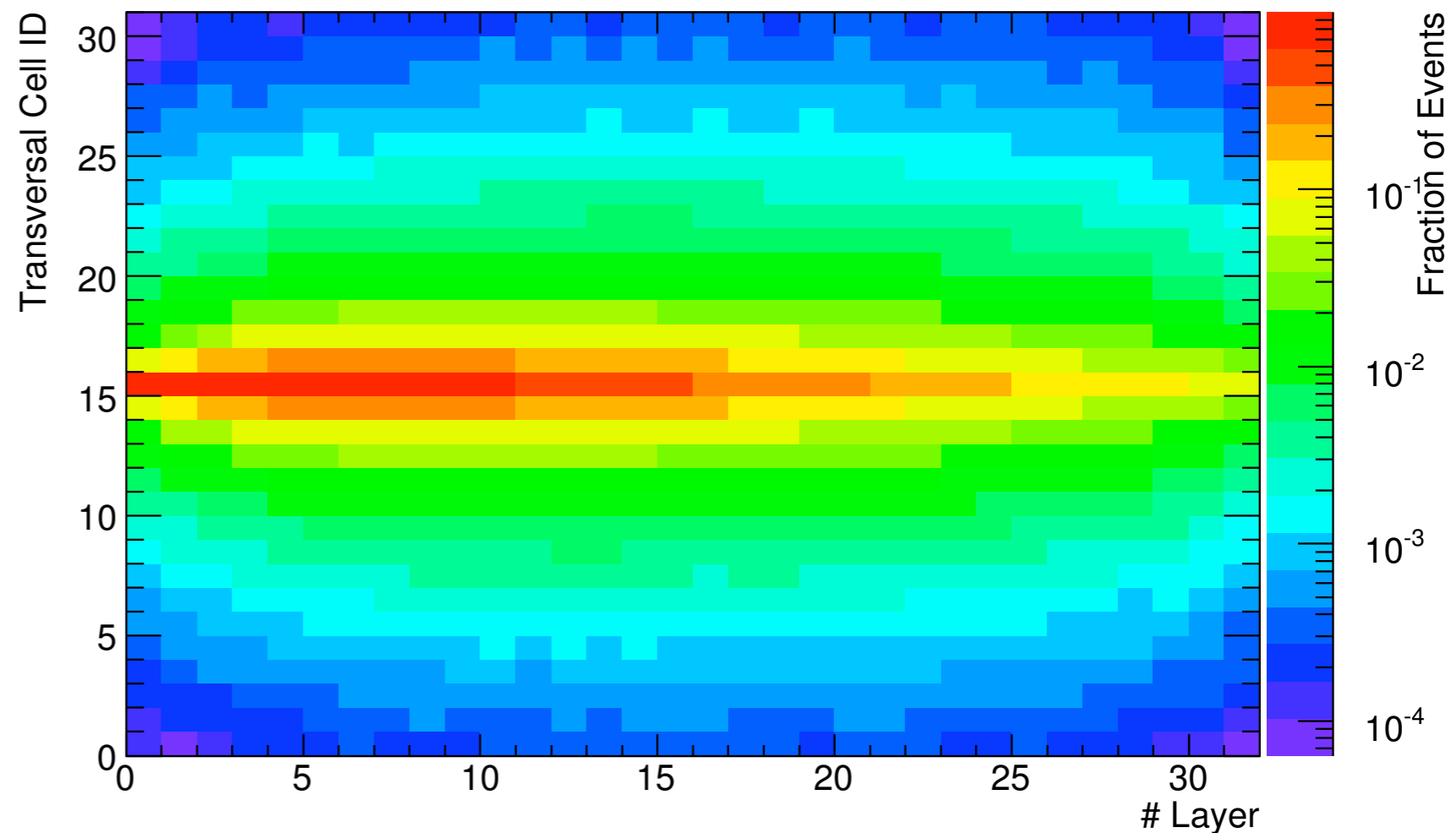
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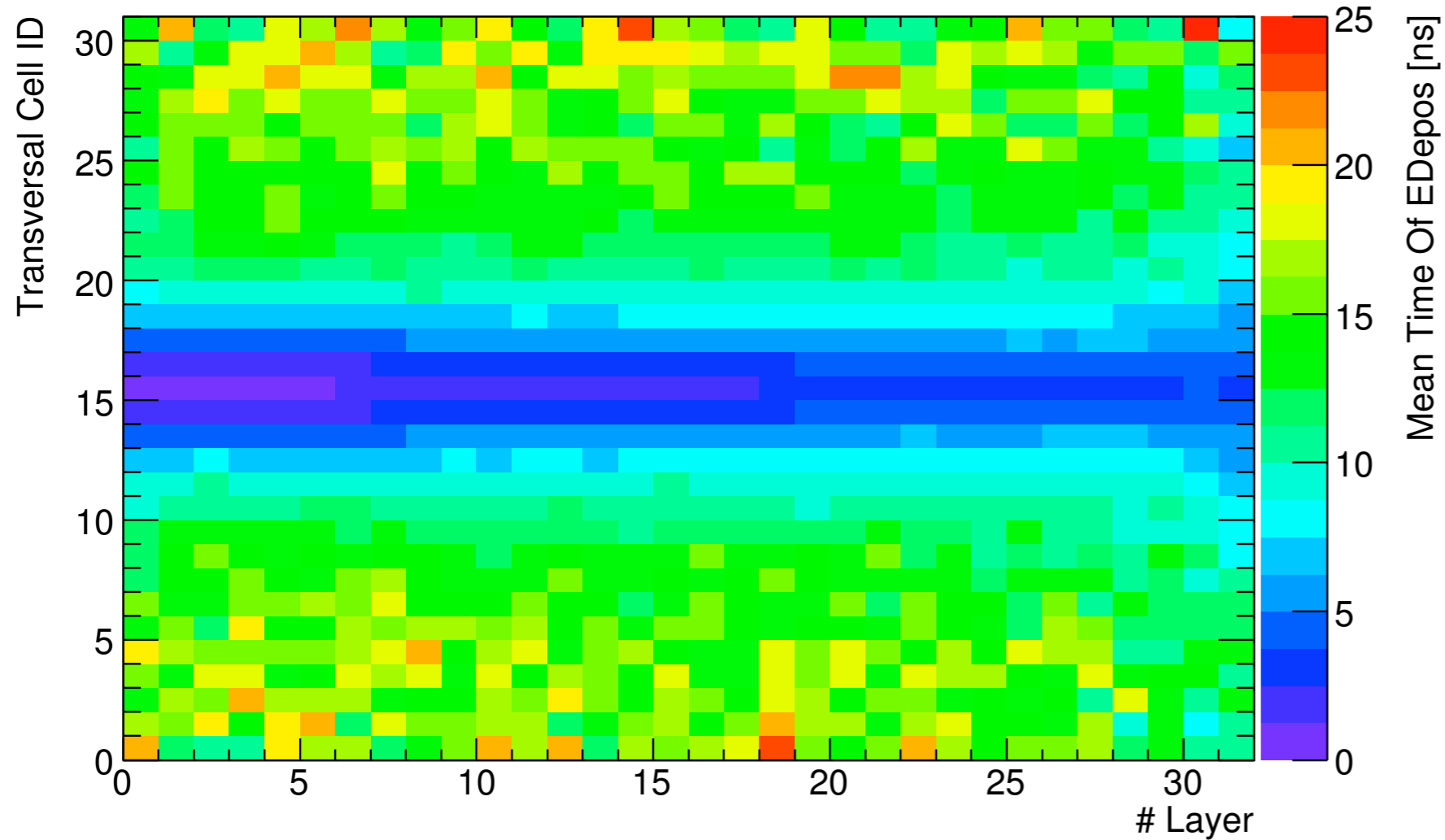
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12GeV - Global 2D: Fraction of Events in which tile was hit (Total Edepos > 0.5MIP)



Simulations: Global Distributions - Timing

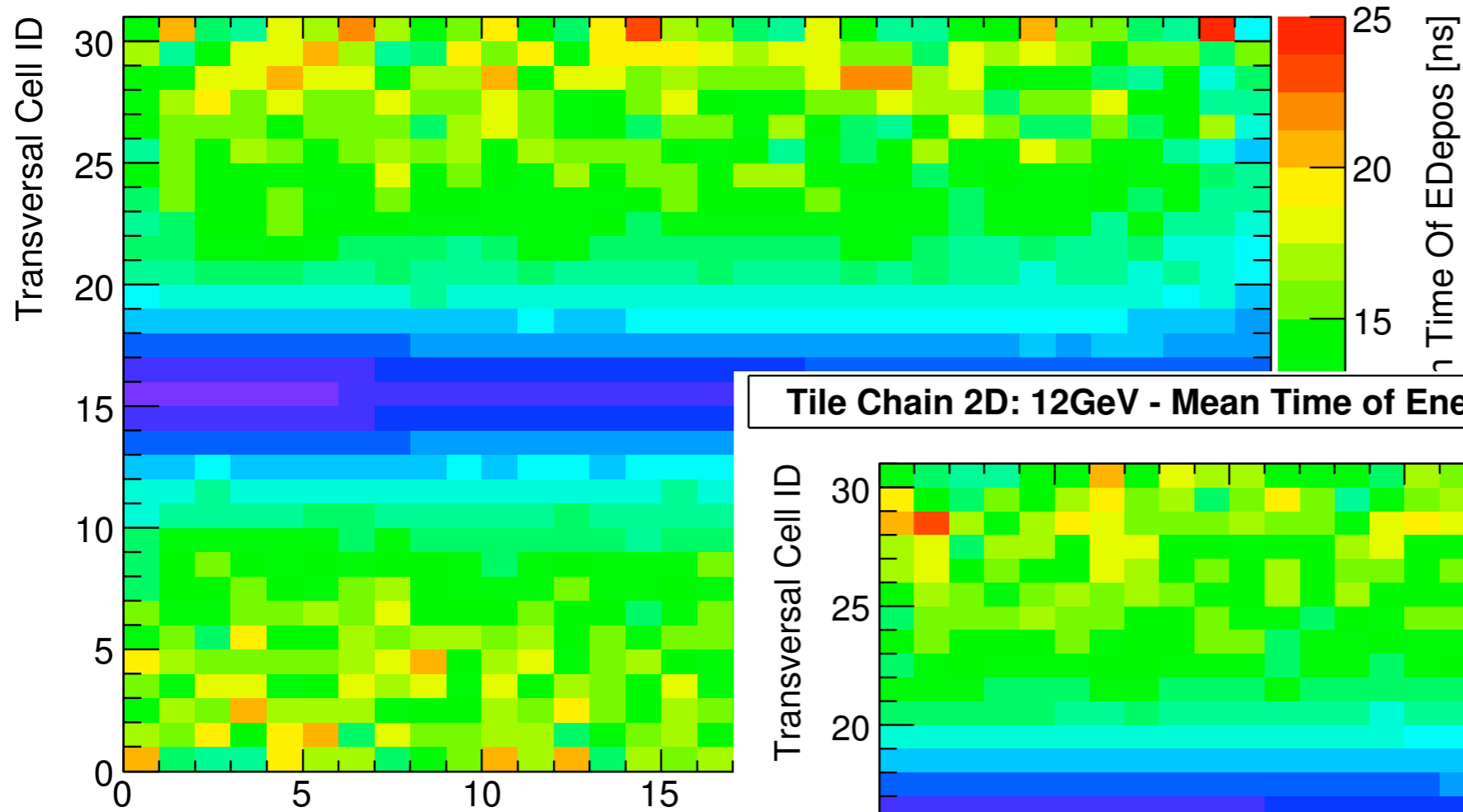
Tile Chain 2D: 5GeV - Mean Time of Energy Deposition



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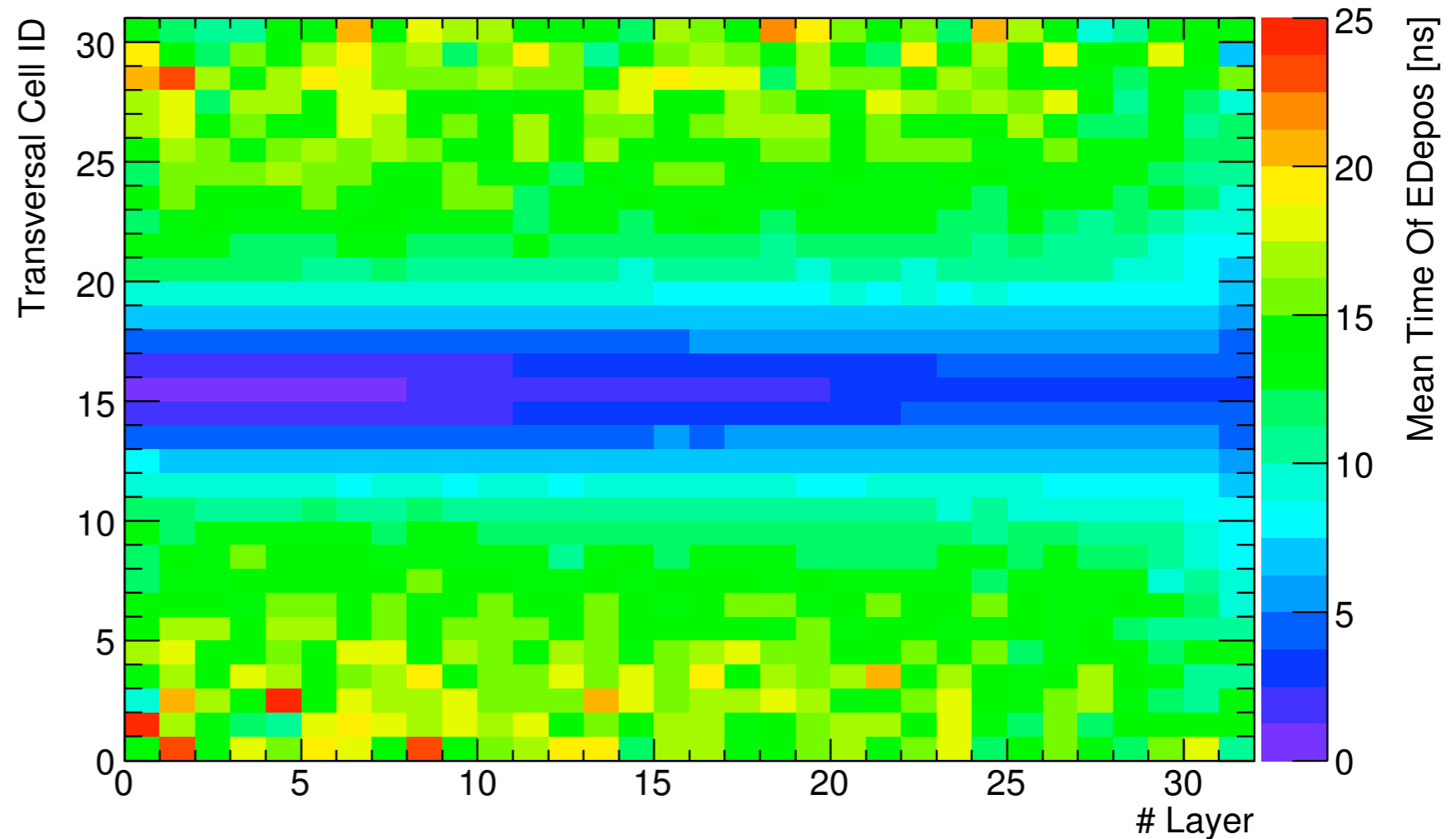
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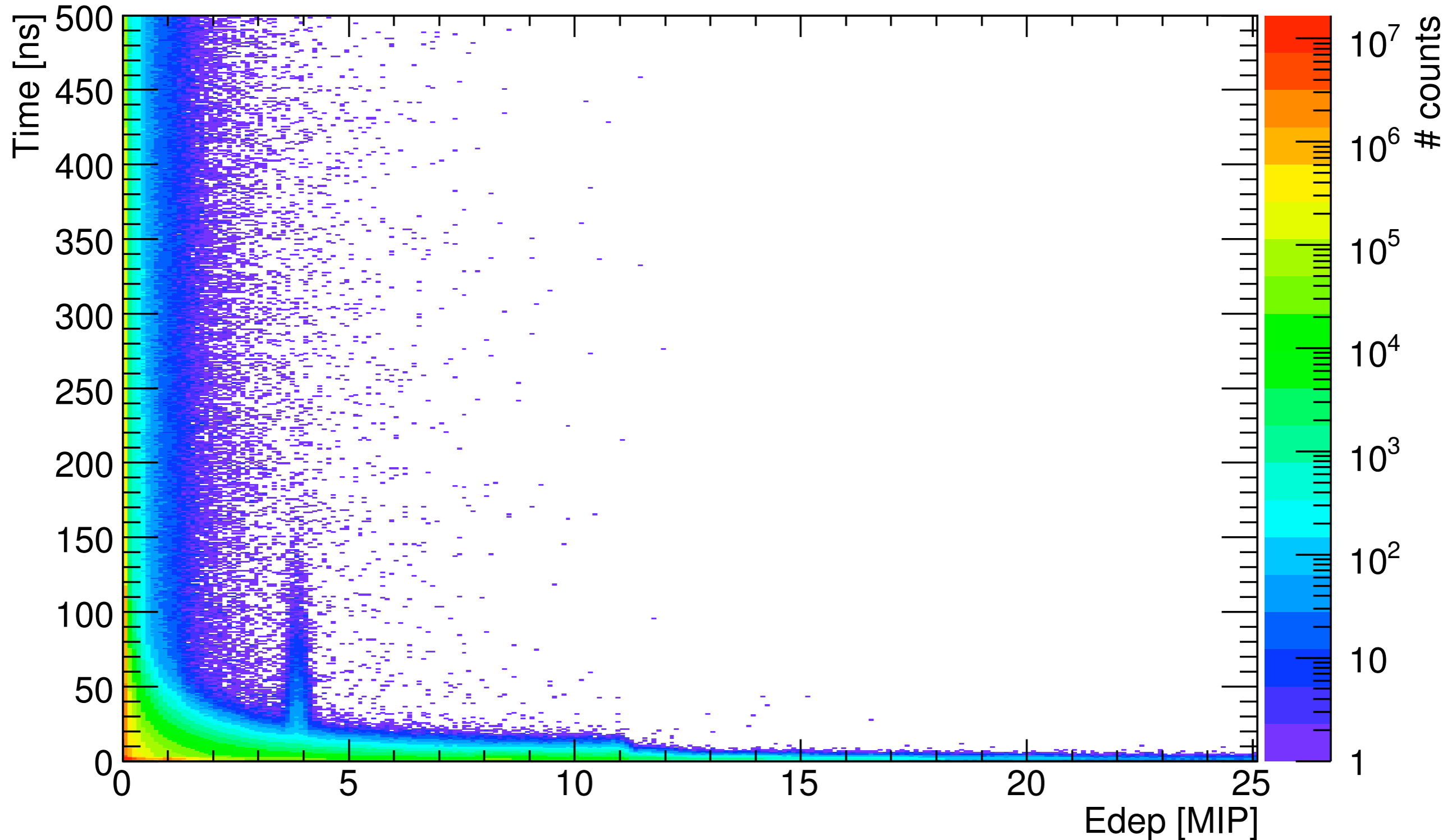
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Time Structure of Energy Deposits

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

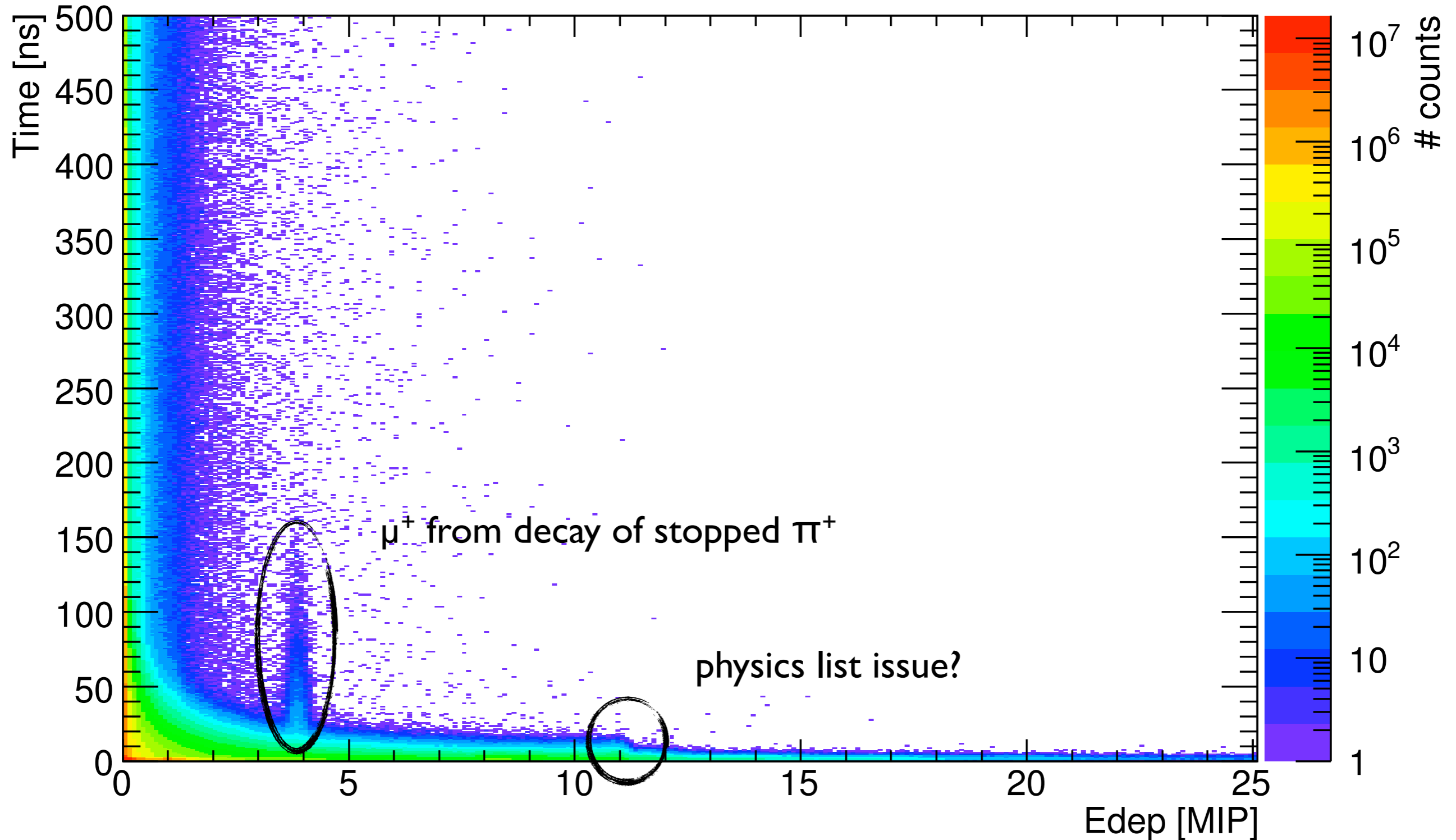
• Global:All Hits



Time Structure of Energy Deposits

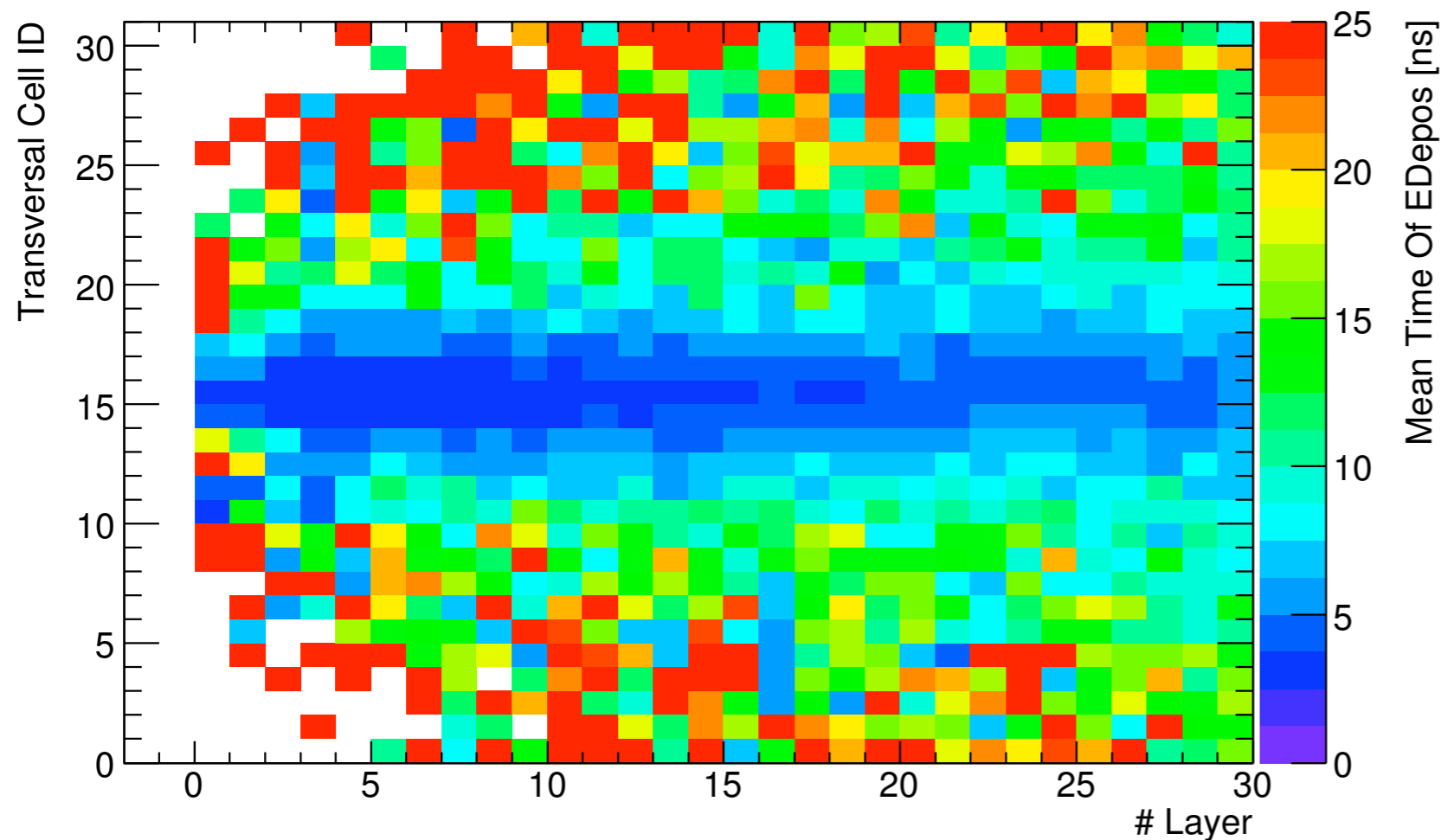
Global 2D: 12GeV - # vs. Edep vs. Time

• Global:All Hits



Timing Profiles: Correlation with HCAL - 12 GeV

ShowerStartFinder ON - Select TileChain Layer 30: 12GeV - Mean Time of Energy Deposition



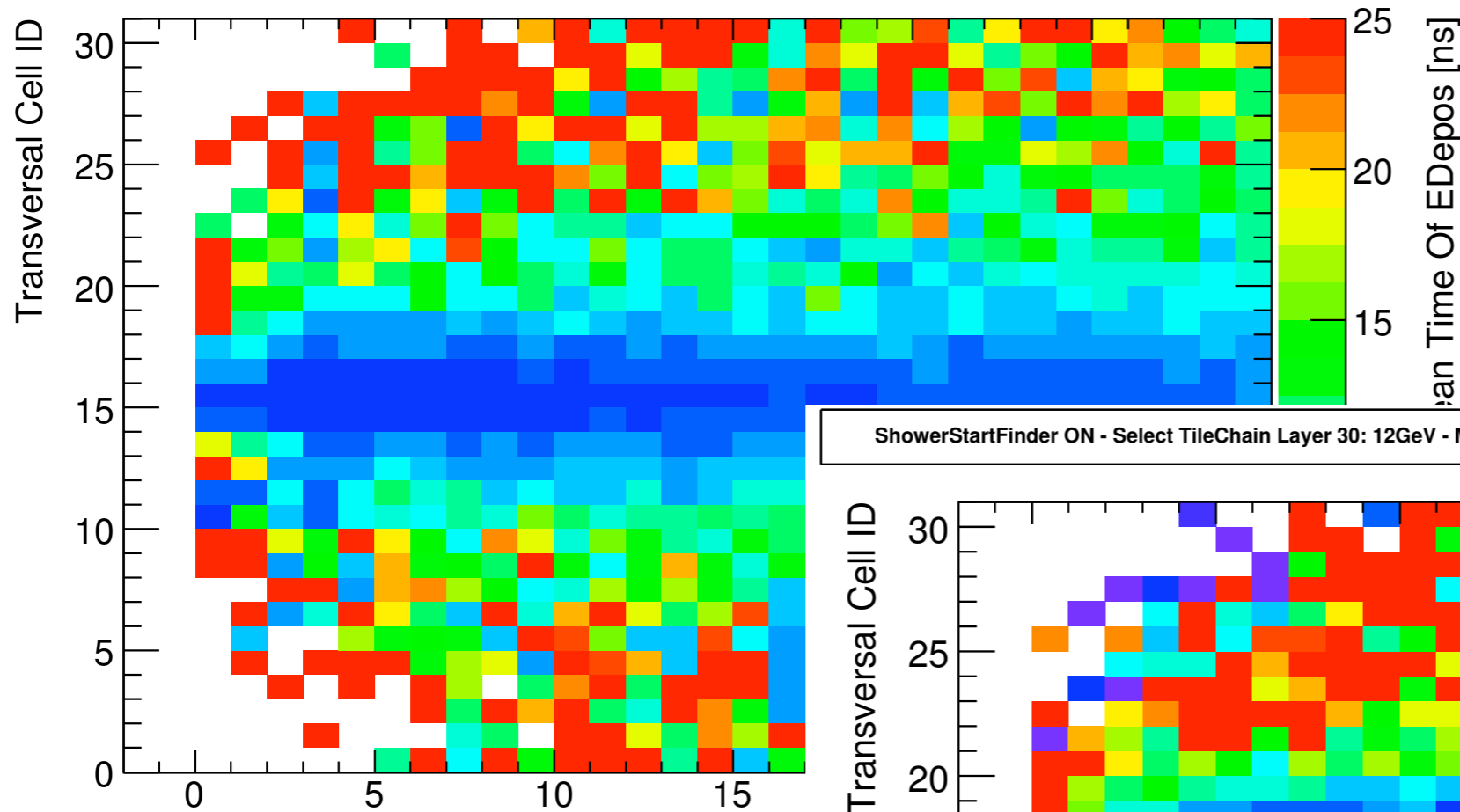
- Assumption: Timing strip in layer 30 (start at 0), correlation with HCAL events to determine shower start event by event

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

Shower start determined analogous to CAN-01 I: 3 consecutive layers with a total of > 5 hits, > 8 MIP, first layer of this block of 3 is counted as shower start

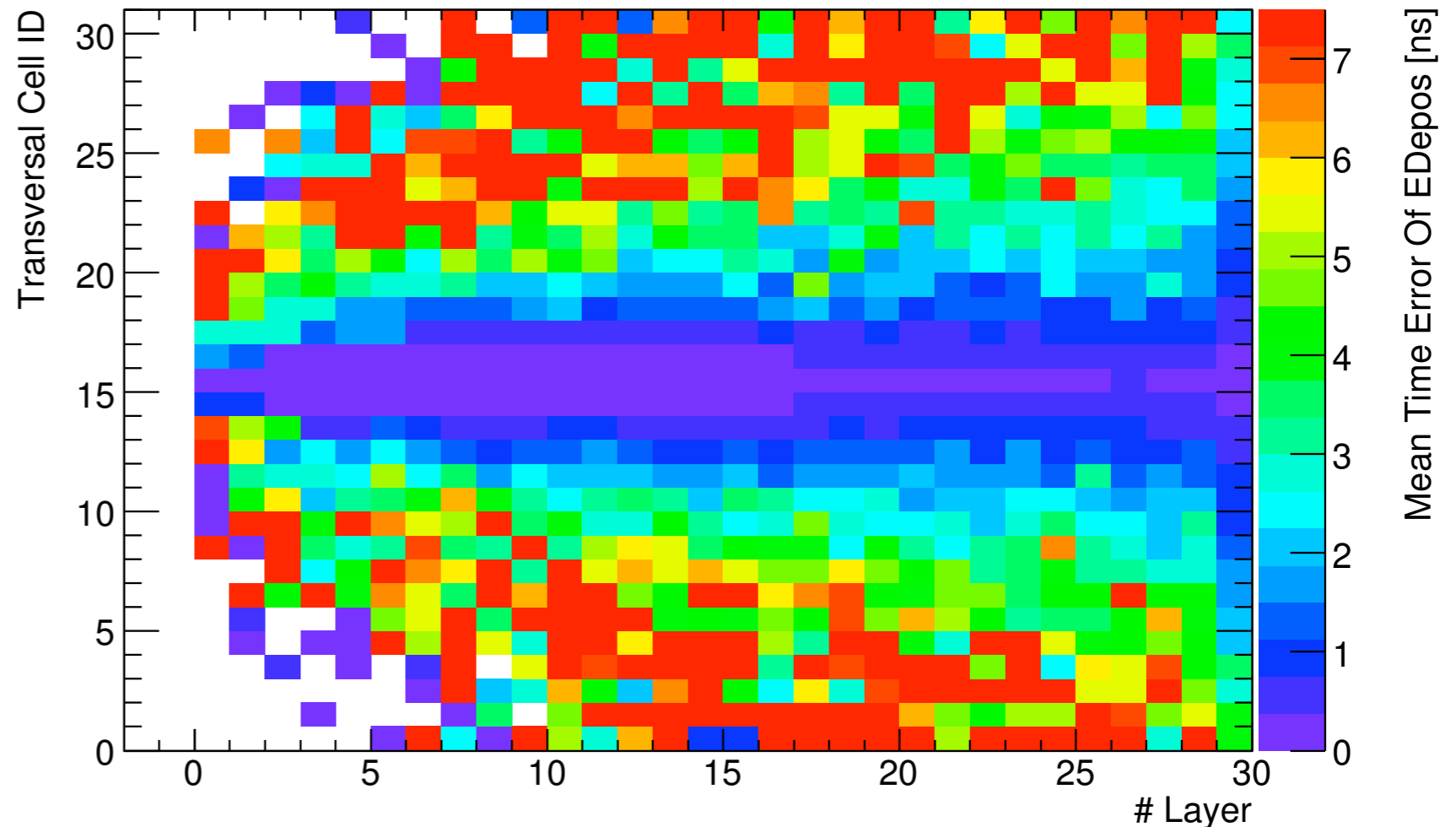
Timing Profiles: Correlation with HCAL - 12 GeV

ShowerStartFinder ON - Select TileChain Layer 30: 12GeV - Mean Time of Energy Deposition



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

ShowerStartFinder ON - Select TileChain Layer 30: 12GeV - Mean Time Error of Energy Deposition

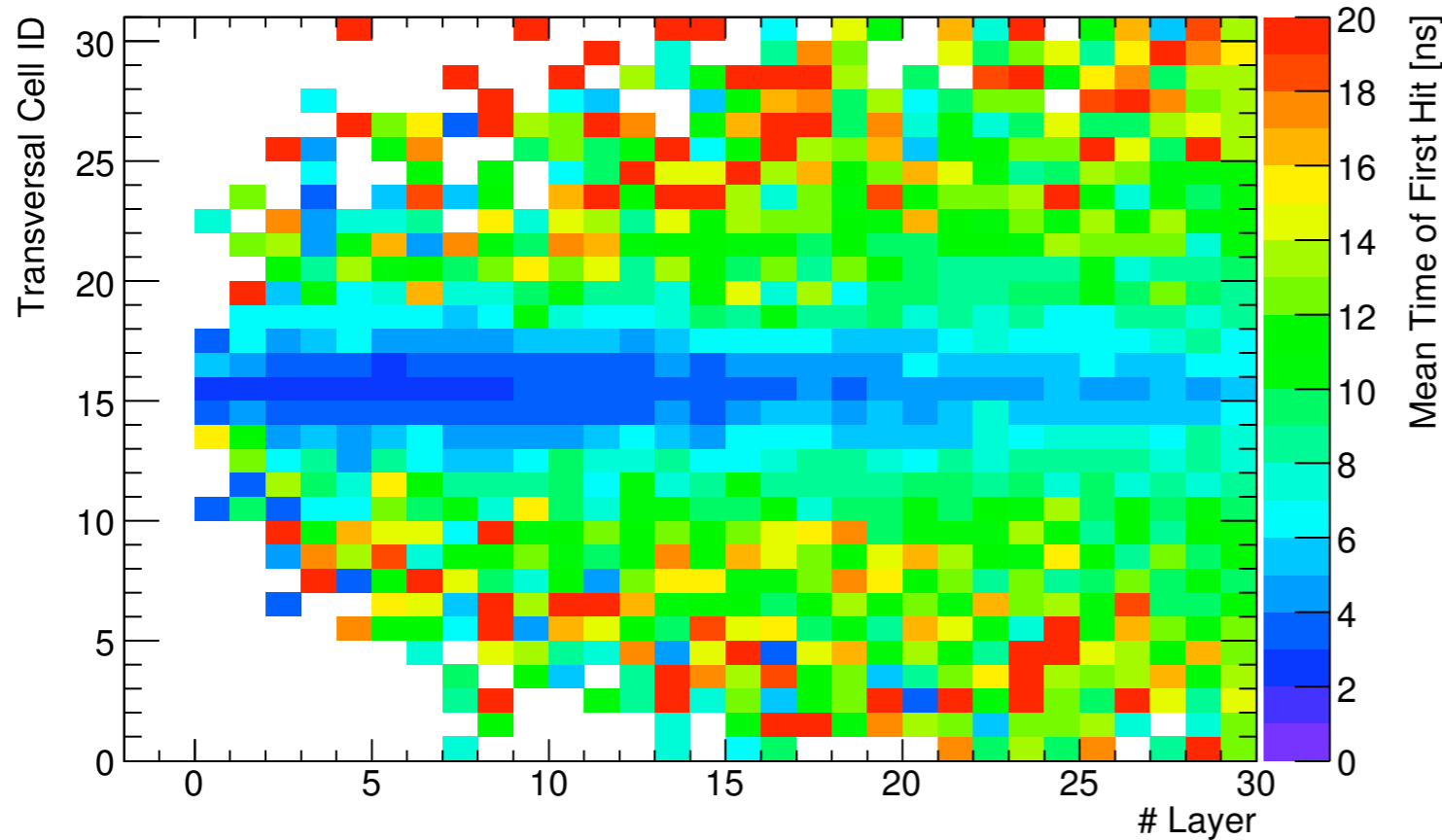


⇒ Relative to shower start a full (averaged) showers is possible

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

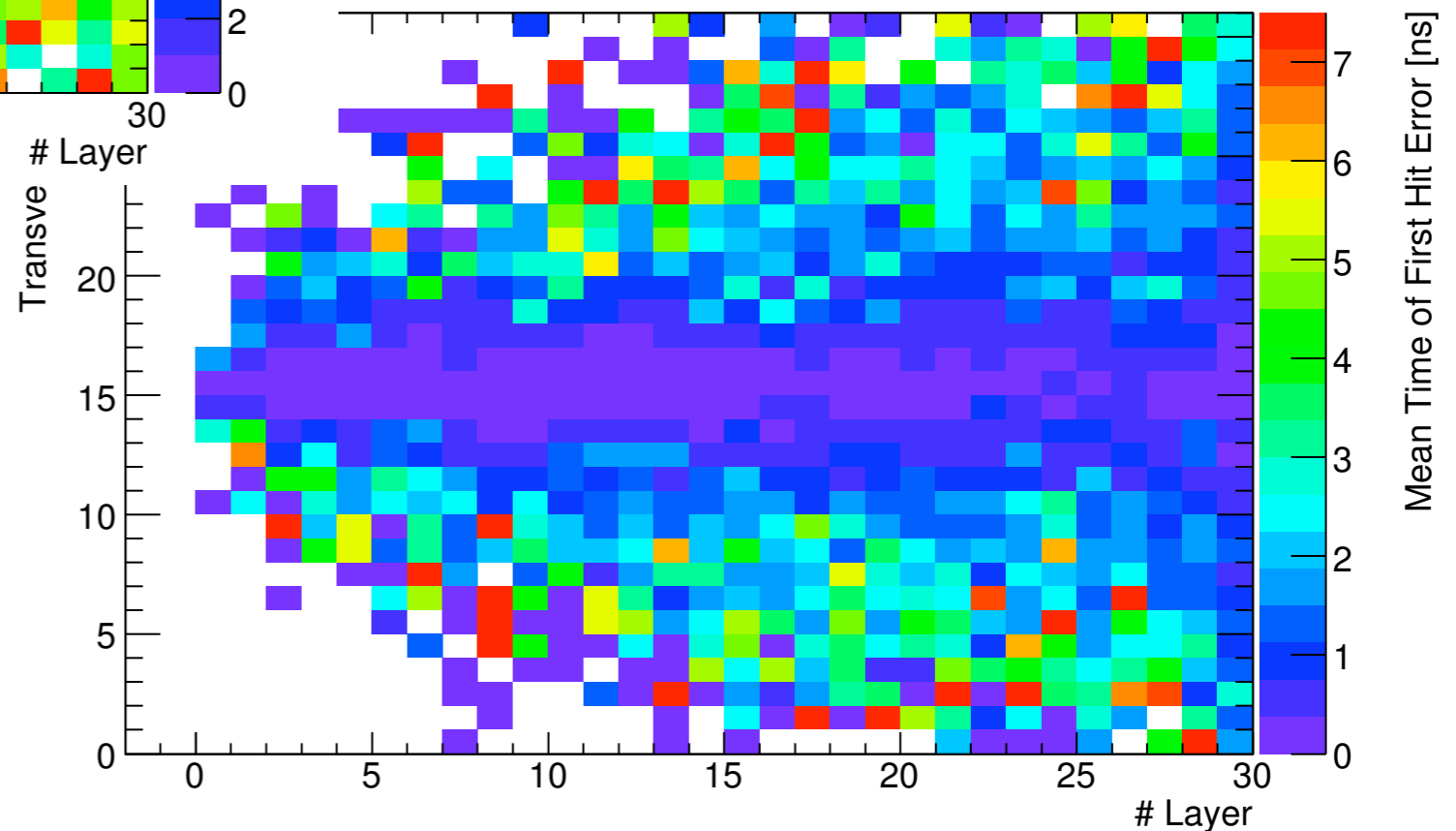
Timing Profiles: Time of First Hit (12 GeV)

ShowerStartFinder ON - Select TileChain Layer 30: 12GeV - Mean Time of First Hit (Cell Energy > 0.3MIP)



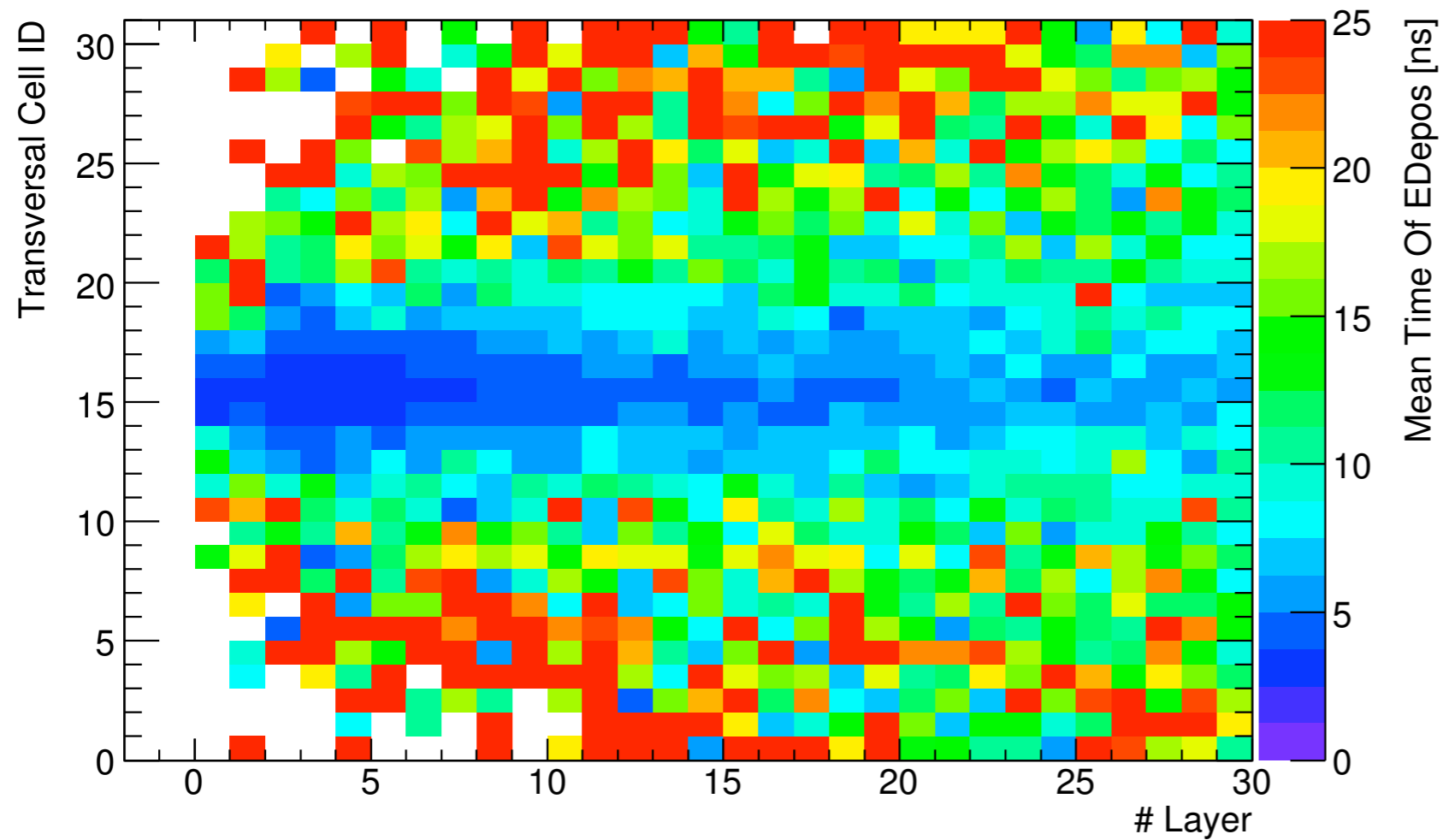
- First time of energy deposit for a cell that has a total energy above 0.3 MIP, as a function of shower start position

Select TileChain Layer 30: 12GeV - Mean Time of First Hit Error



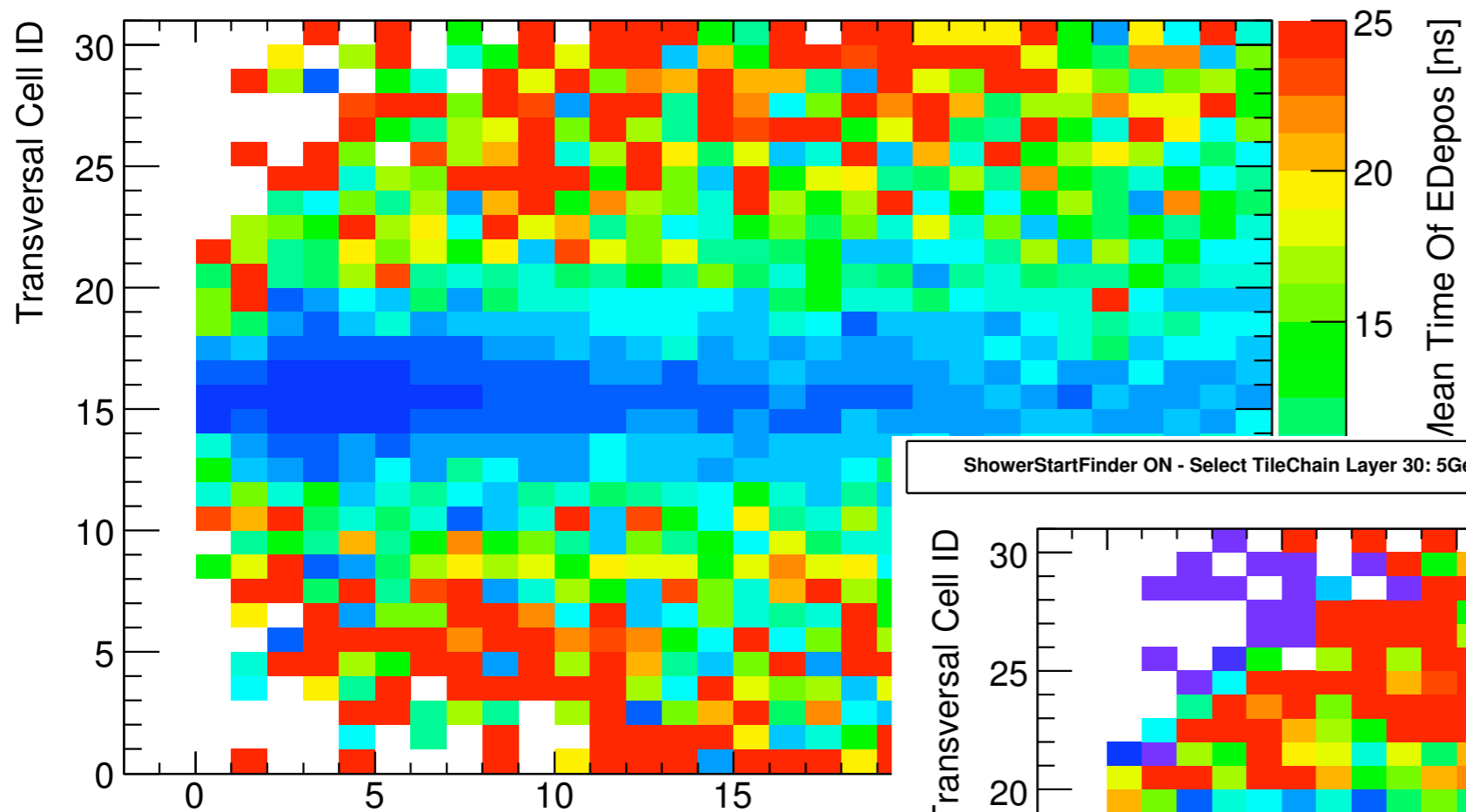
Timing Profiles: Correlation with HCAL - 5 GeV

ShowerStartFinder ON - Select TileChain Layer 30: 5GeV - Mean Time of Energy Deposition

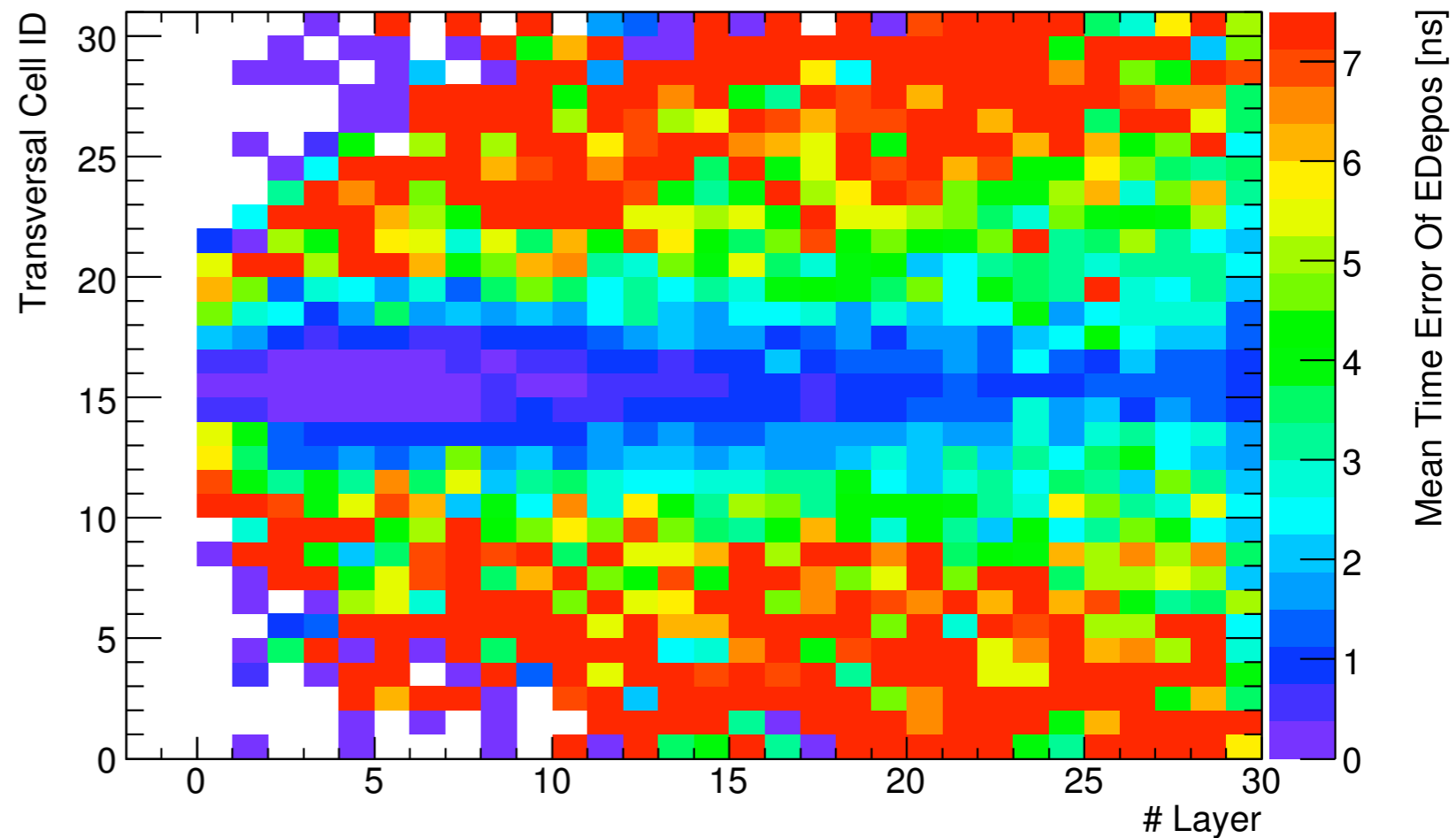


Timing Profiles: Correlation with HCAL - 5 GeV

ShowerStartFinder ON - Select TileChain Layer 30: 5GeV - Mean Time of Energy Deposition



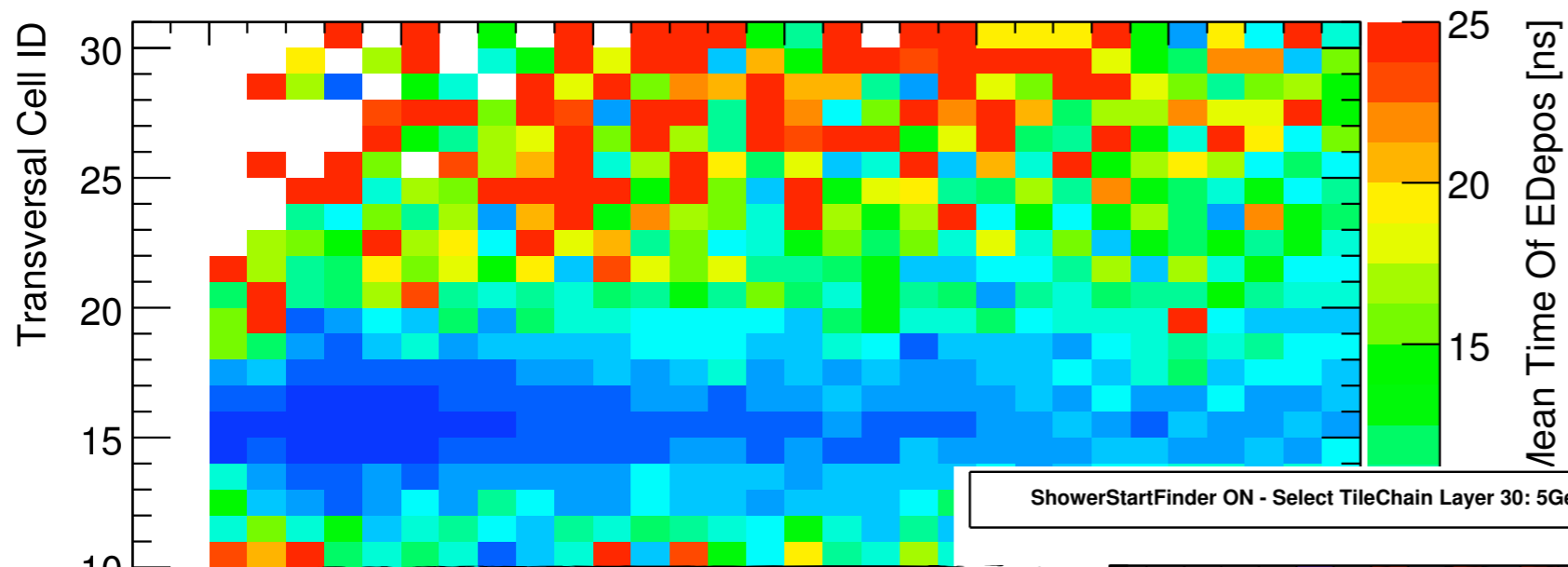
ShowerStartFinder ON - Select TileChain Layer 30: 5GeV - Mean Time Error of Energy Deposition



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

Timing Profiles: Correlation with HCAL - 5 GeV

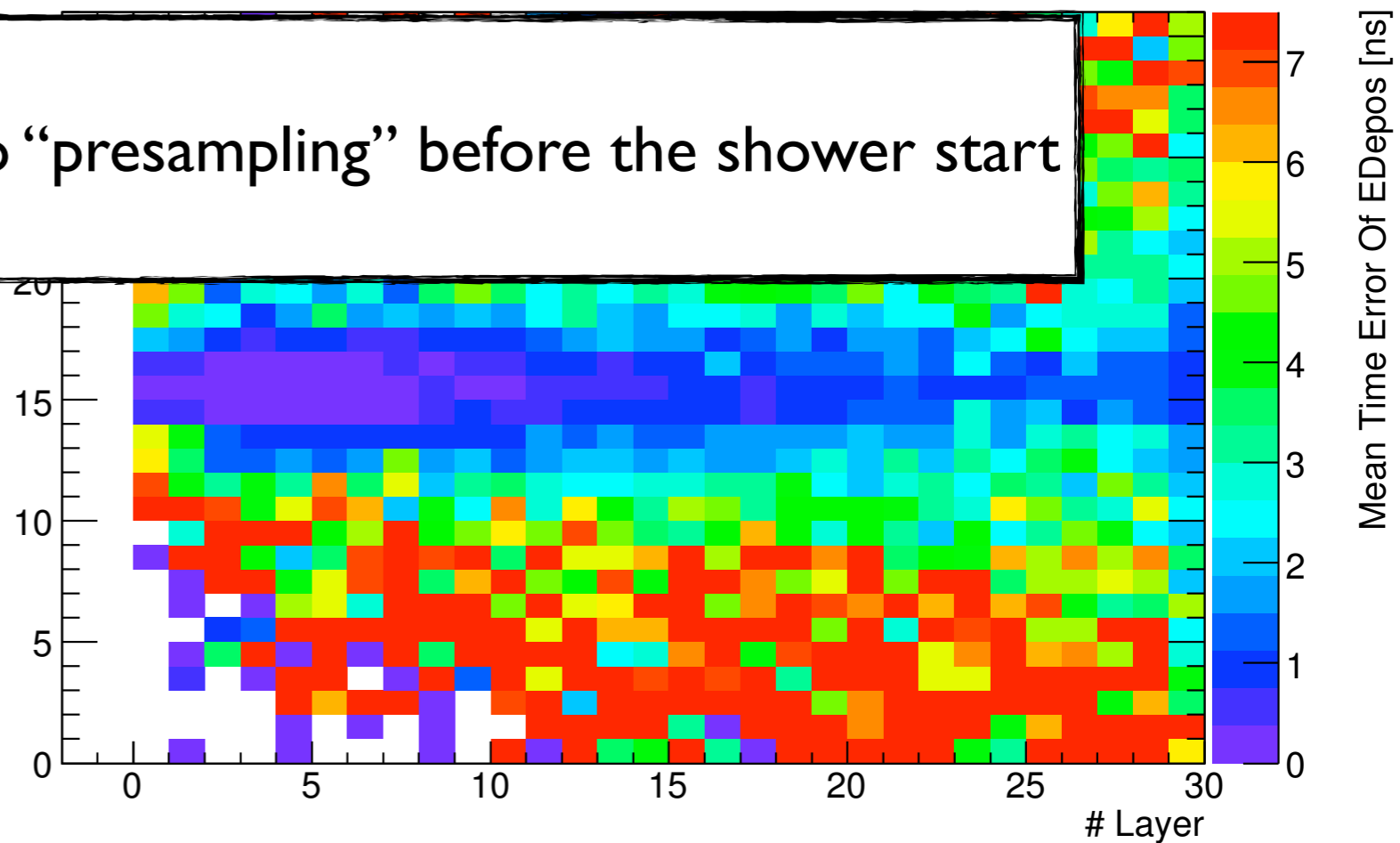
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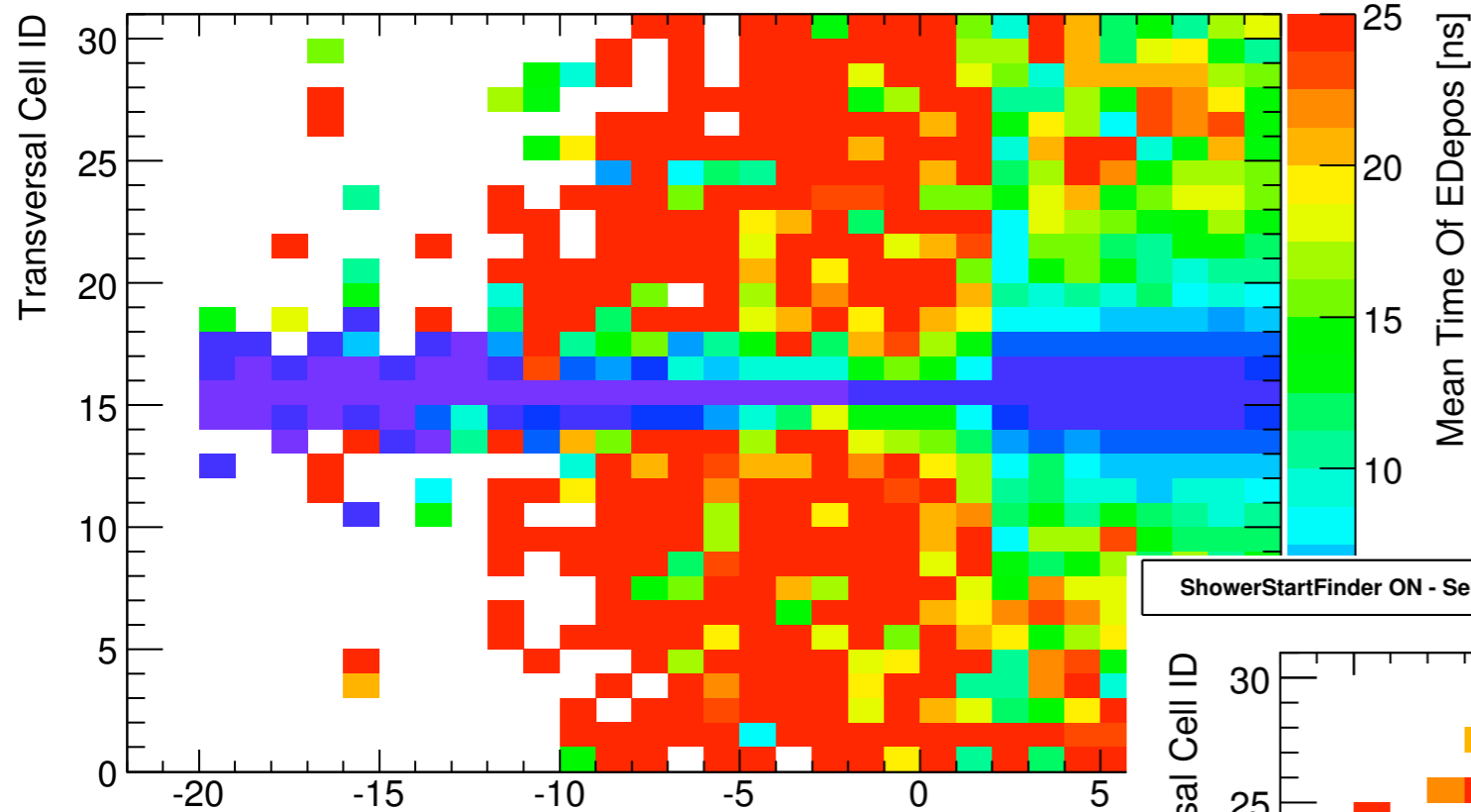
In General: In Layer 30 no “presampling” before the shower start

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



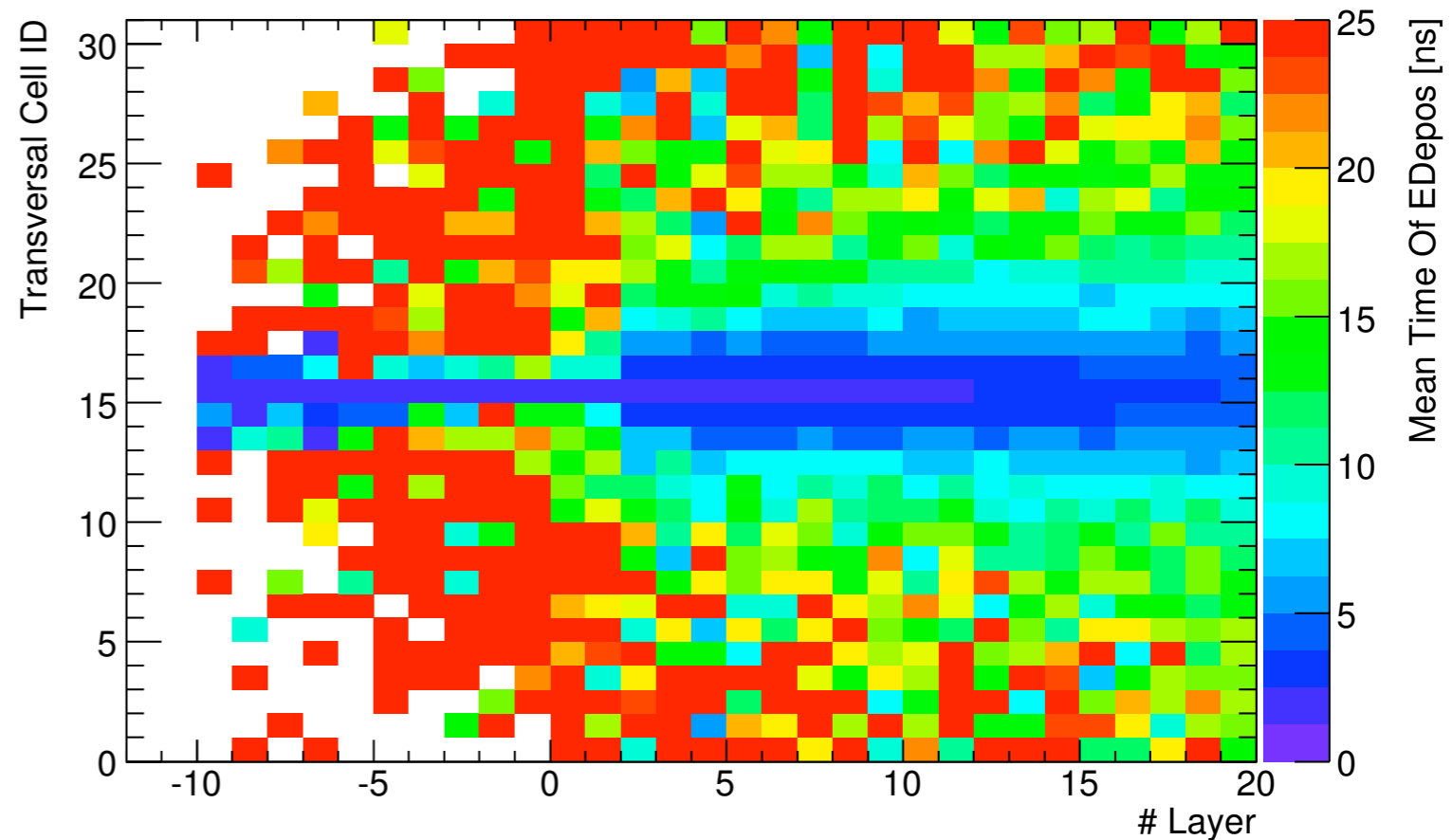
Timing Profiles: Moving the Timing Strip (12 GeV)

ShowerStartFinder ON - Select TileChain Layer 10: 12GeV - Mean Time of Energy Deposition



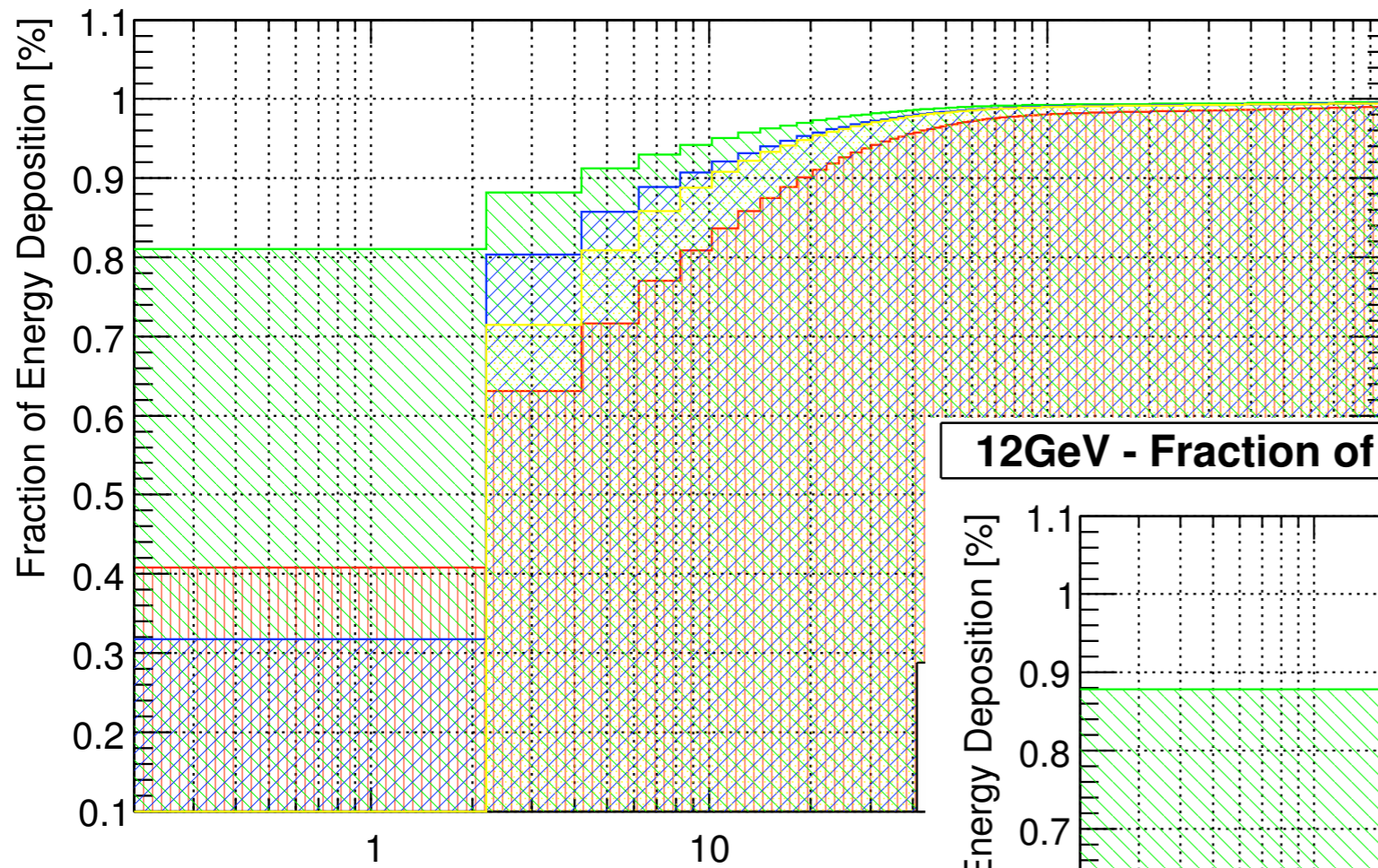
- Moving of the Timing Strip allows to study early region of the shower with higher precision

ShowerStartFinder ON - Select TileChain Layer 20: 12GeV - Mean Time of Energy Deposition



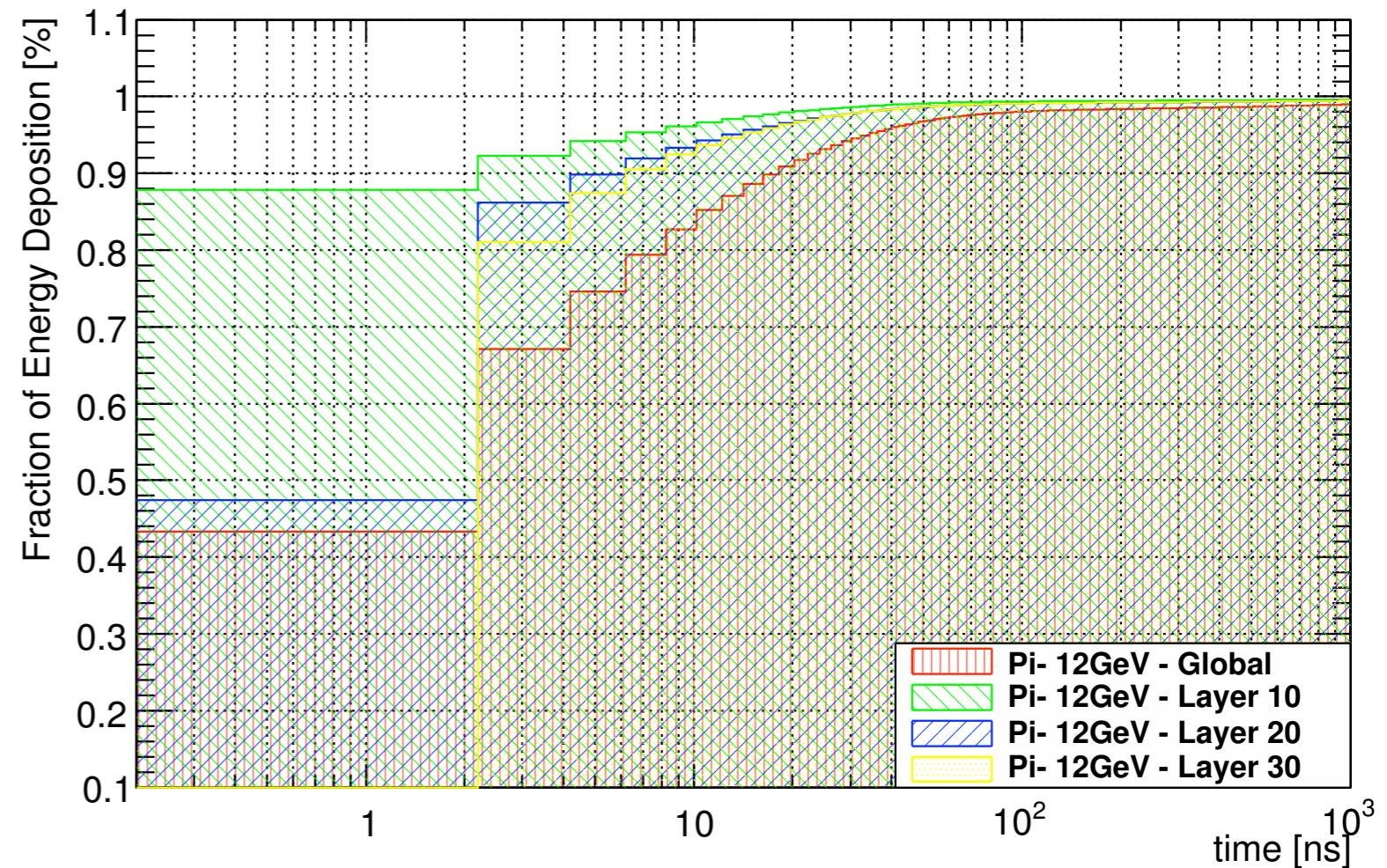
Integration time: Time to Collect Full Energy

5GeV - Fraction of Total Energy Deposition



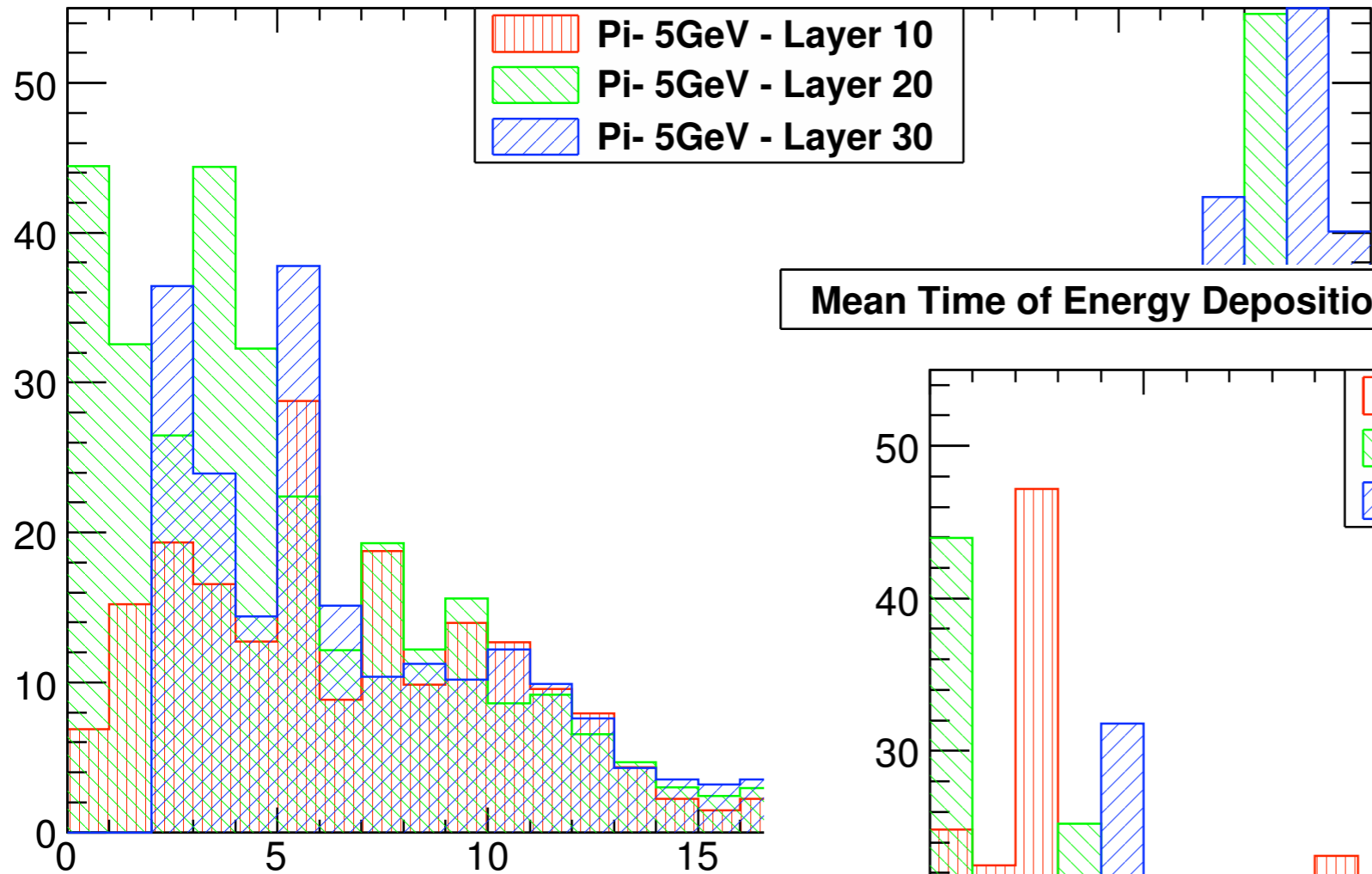
- Significant fraction of the event energy arrives late, longitudinal distribution energy dependent

12GeV - Fraction of Total Energy Deposition

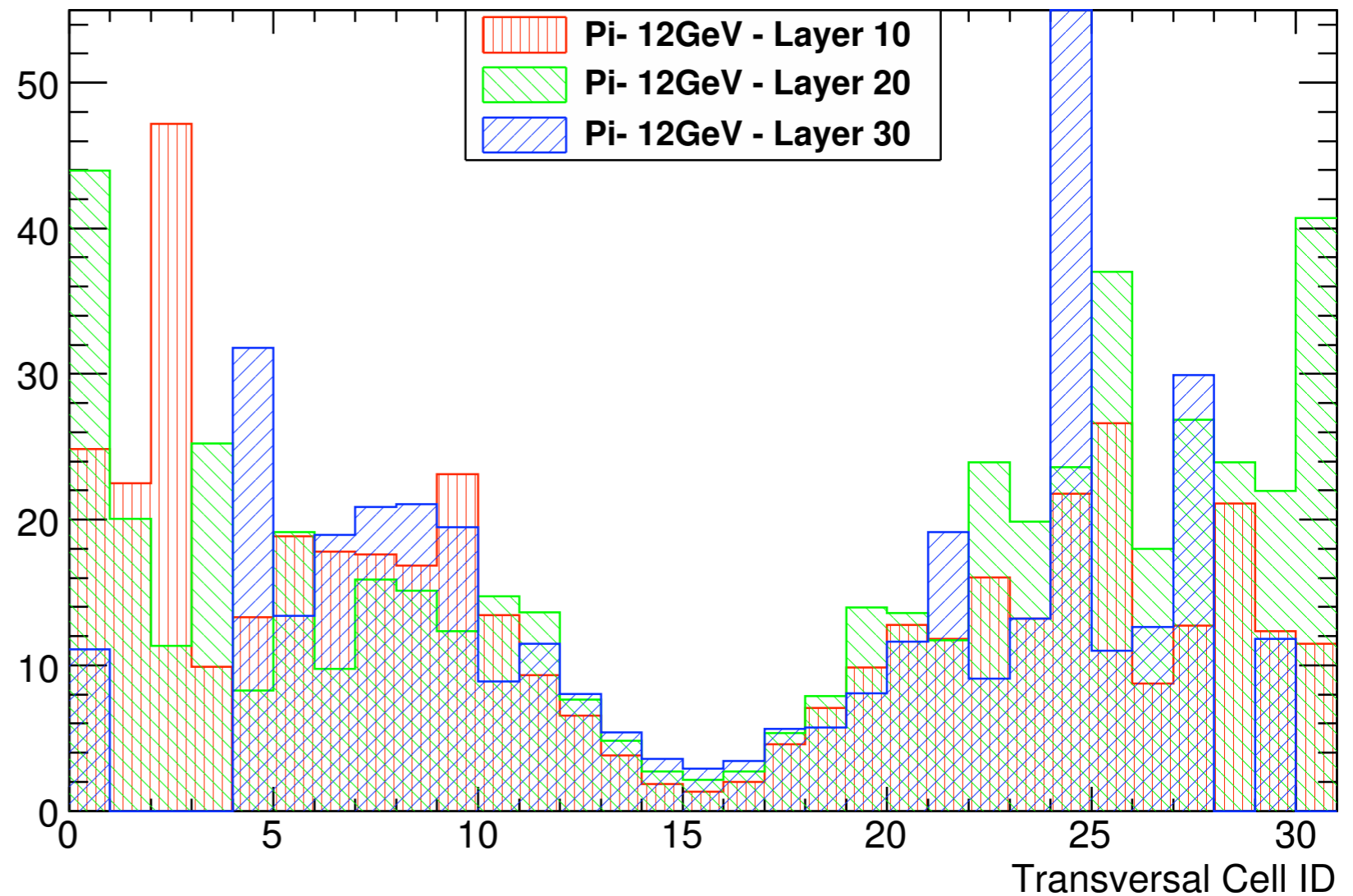


Transverse Time Profile, 5 Layers after Shower Start

Mean Time of Energy Deposition - 5. Layer after Shower Start

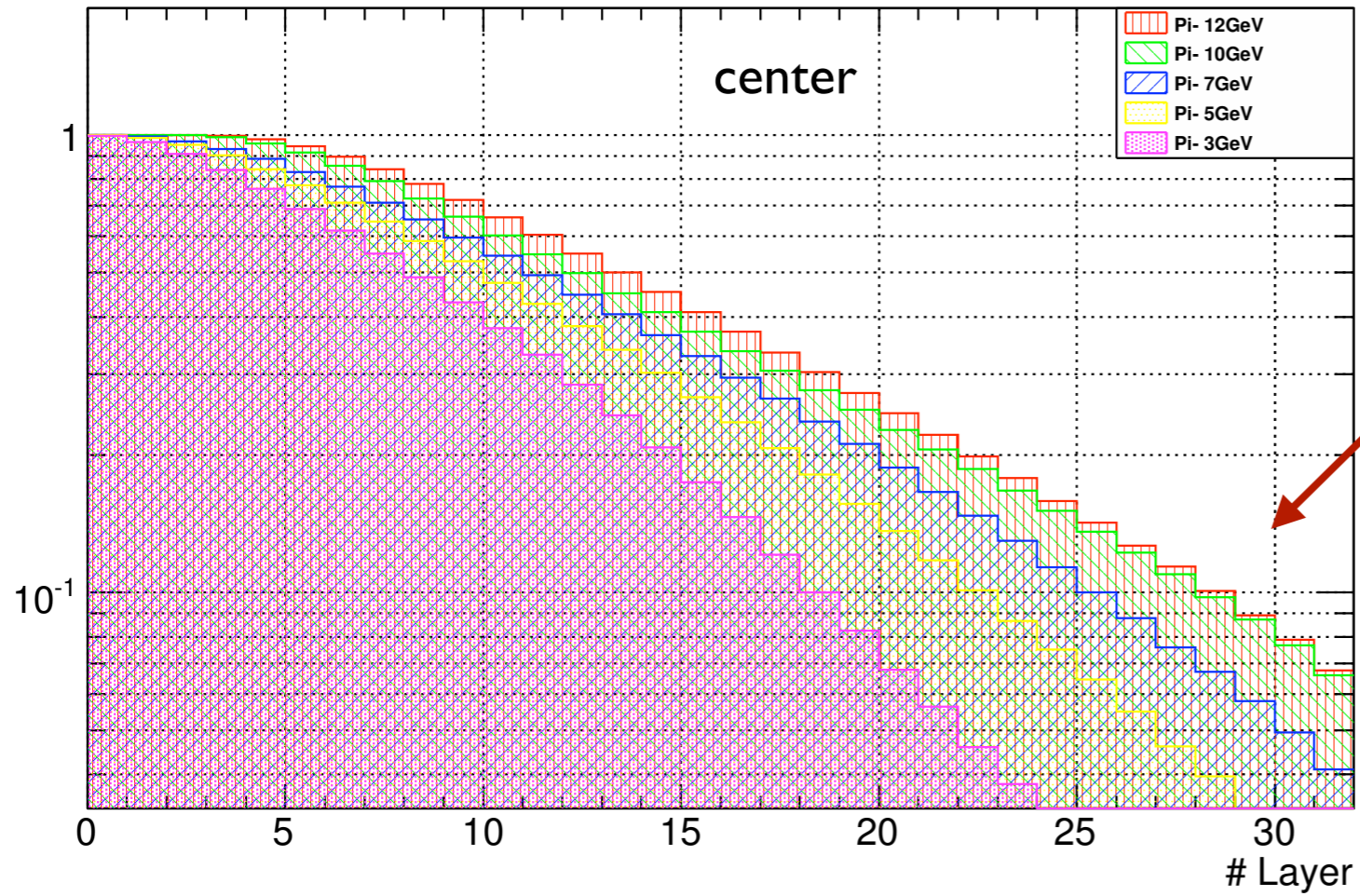


Mean Time of Energy Deposition - 5. Layer after Shower Start



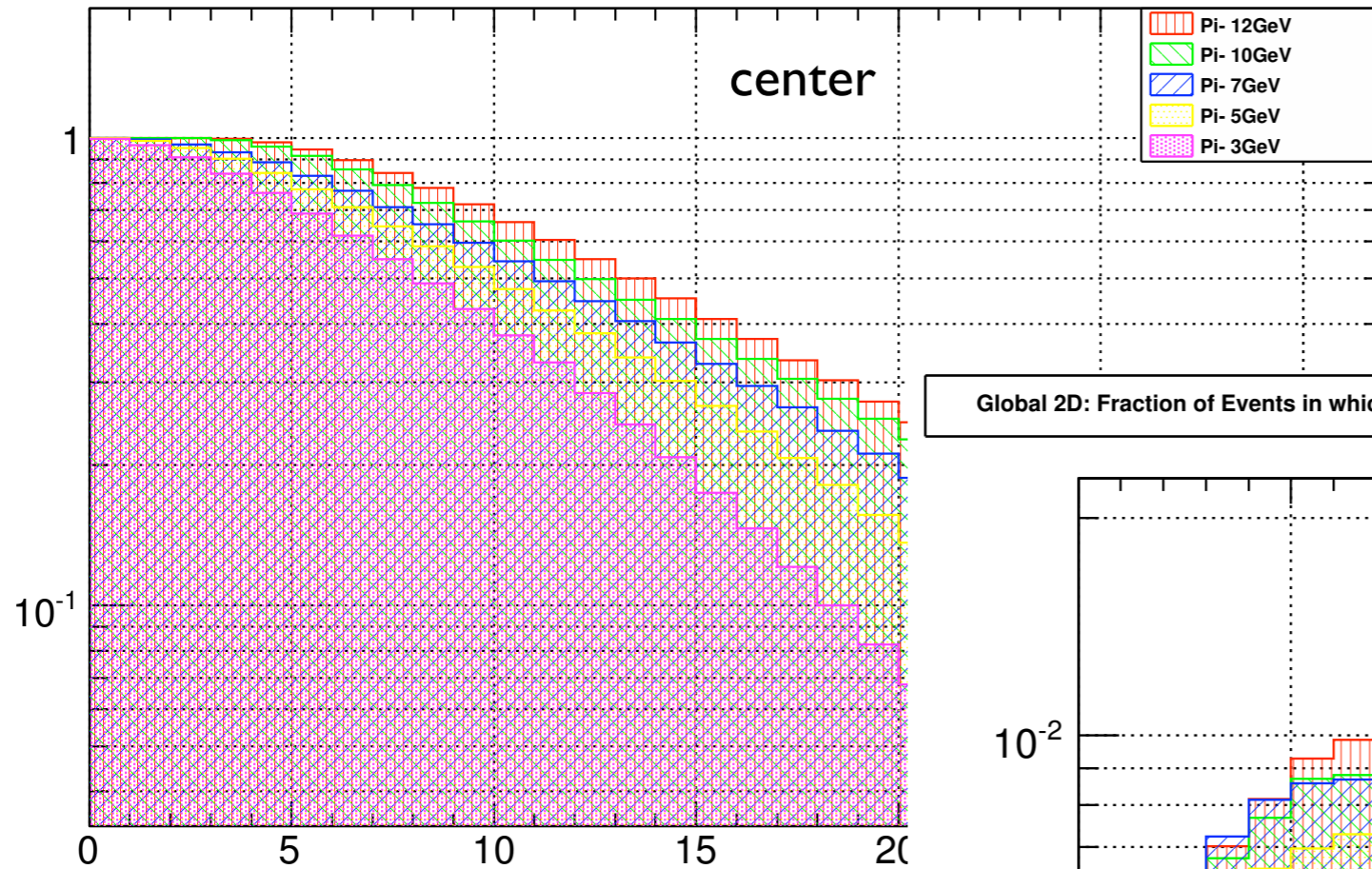
Statistics: Hit Probability of Cells

Global 2D: Fraction of Events in which tile was hit (Total Edepos > 0.5MIP) -> Lateral Tile Position 15

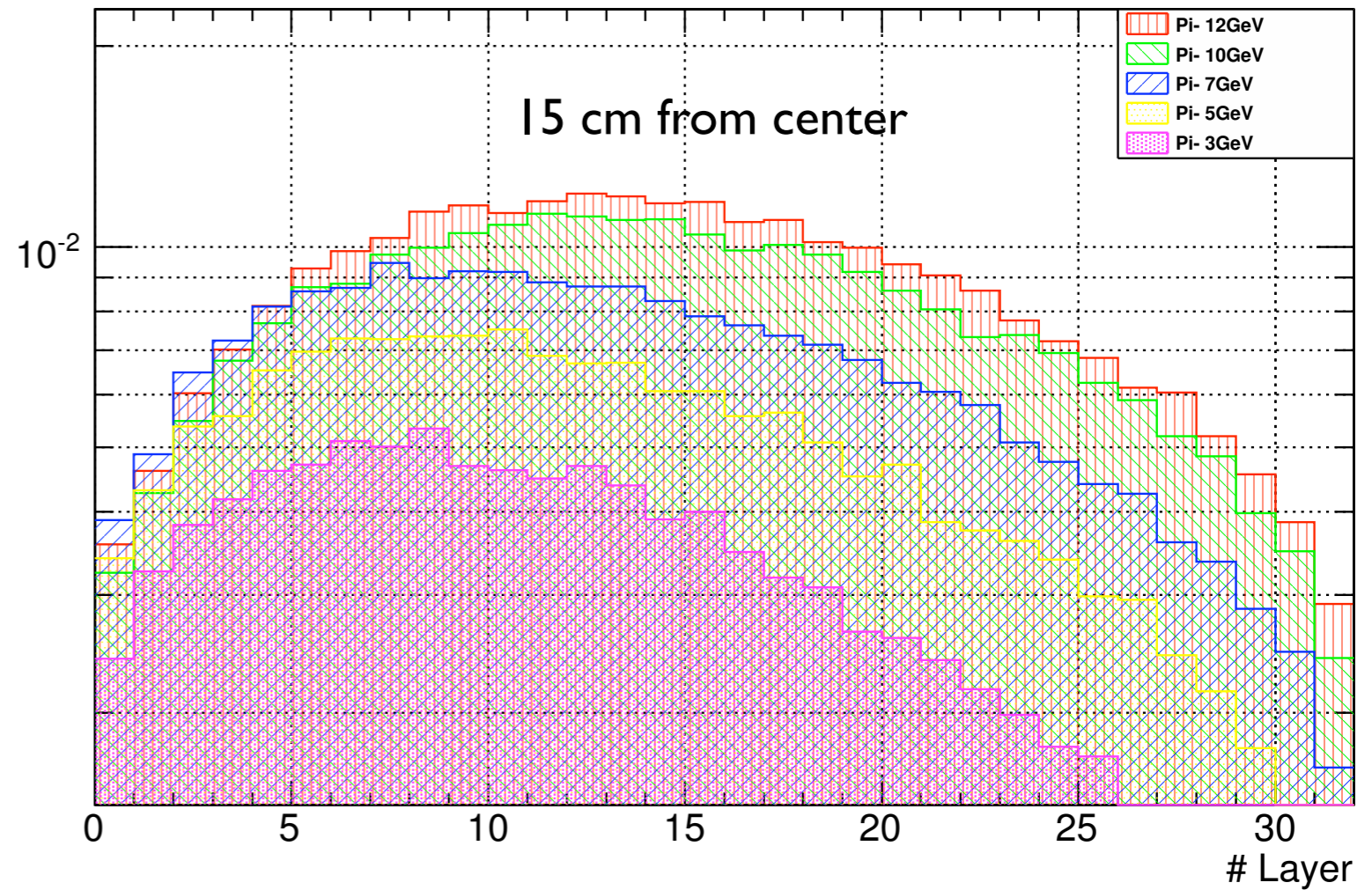


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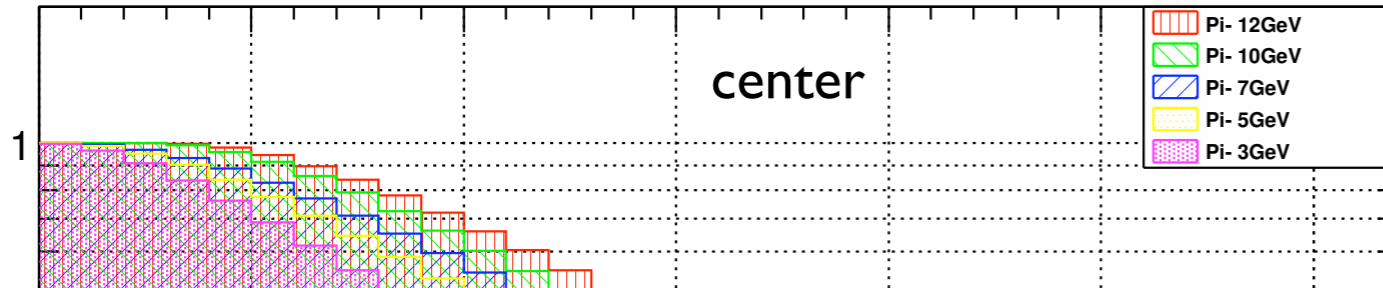


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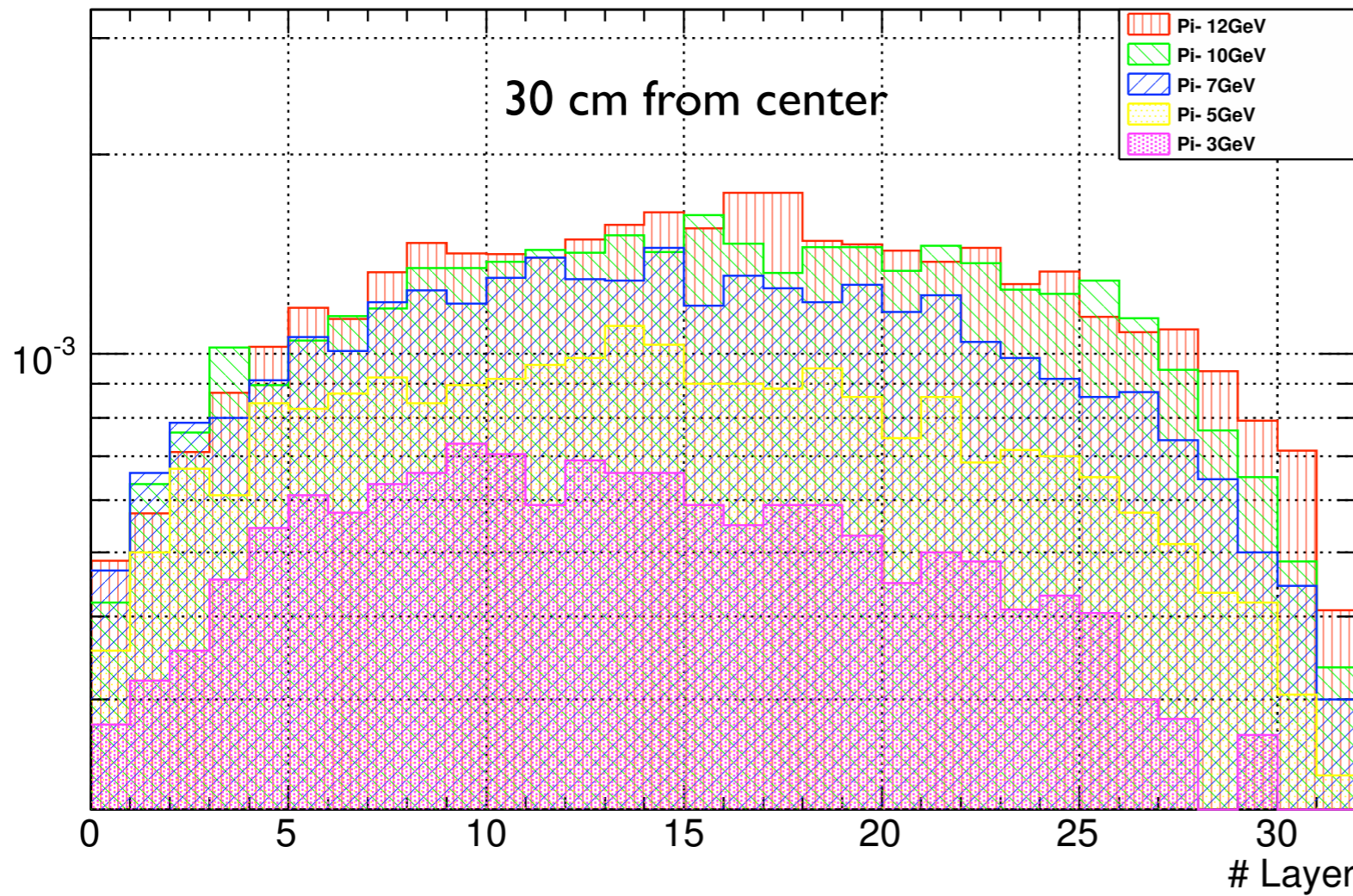


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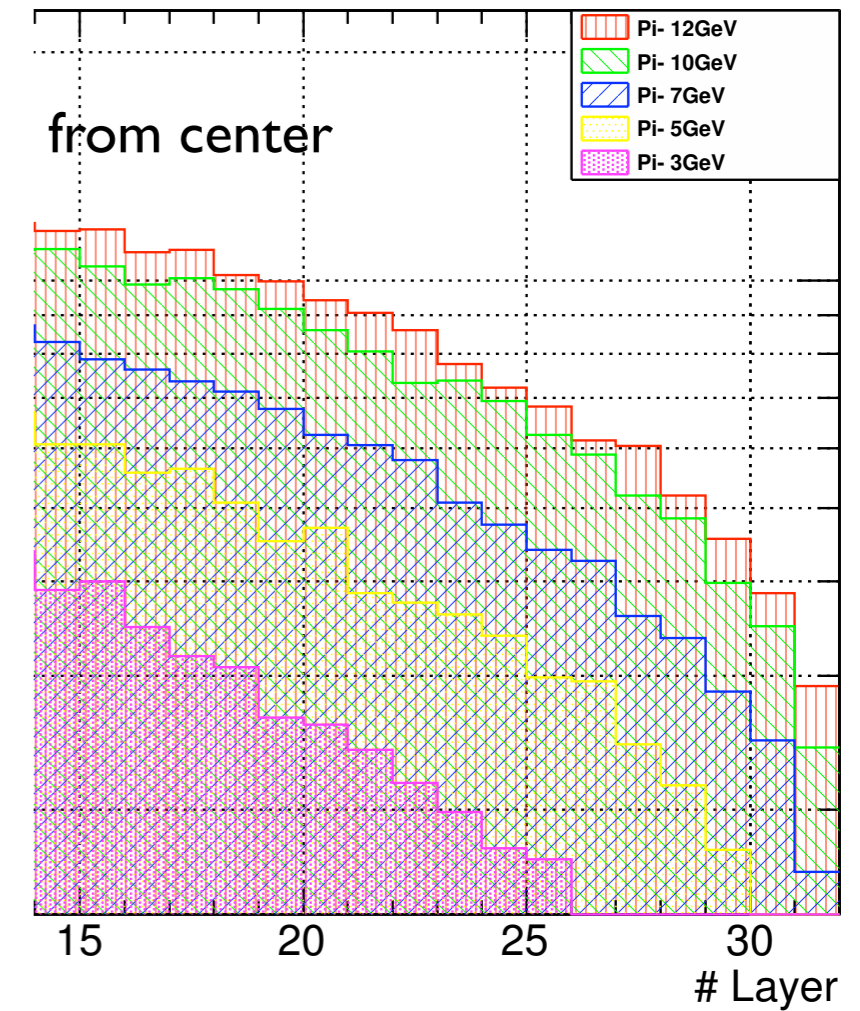


Global 2D: Fraction of Events in which tile was hit (Total Edepos > 0.5MIP) -> Lateral Tile Position 25



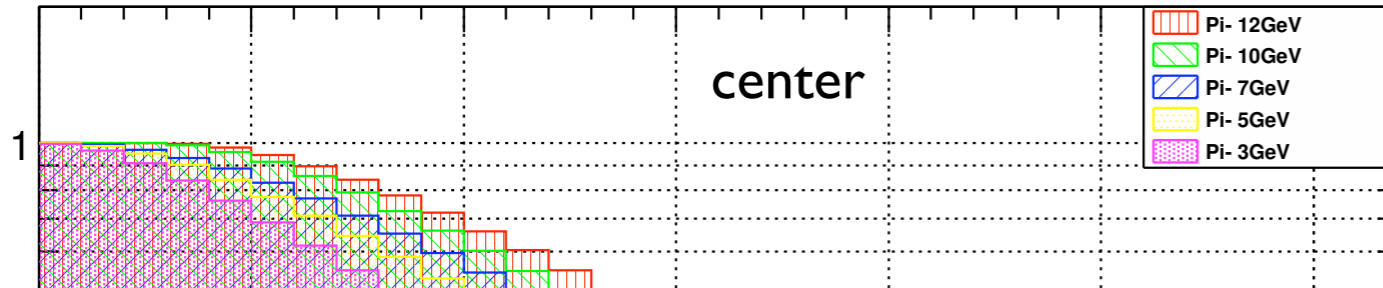
nominal position

> 0.5MIP) -> Lateral Tile Position 20



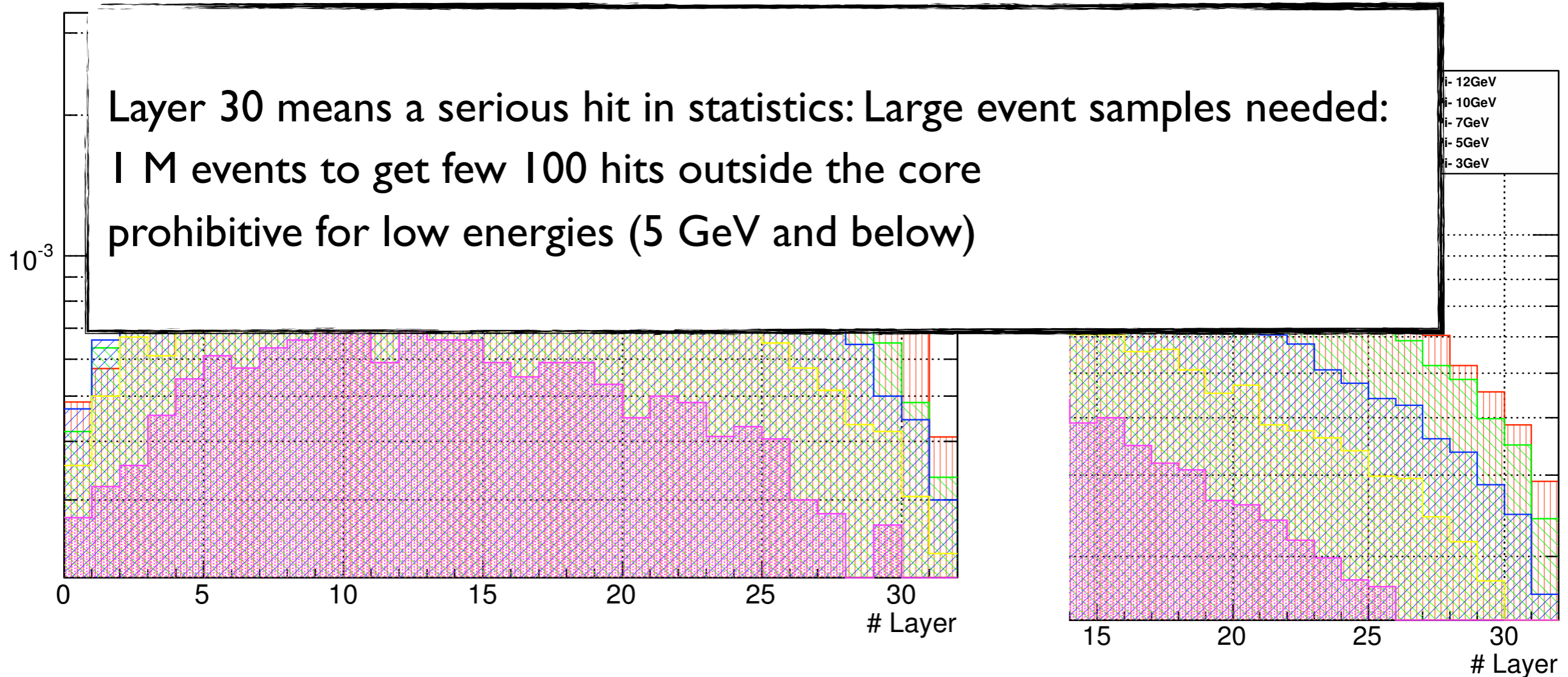
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Global 2D: Fraction of Events in which tile was hit (Total Edepos > 0.5MIP) -> Lateral Tile Position 15



nominal position

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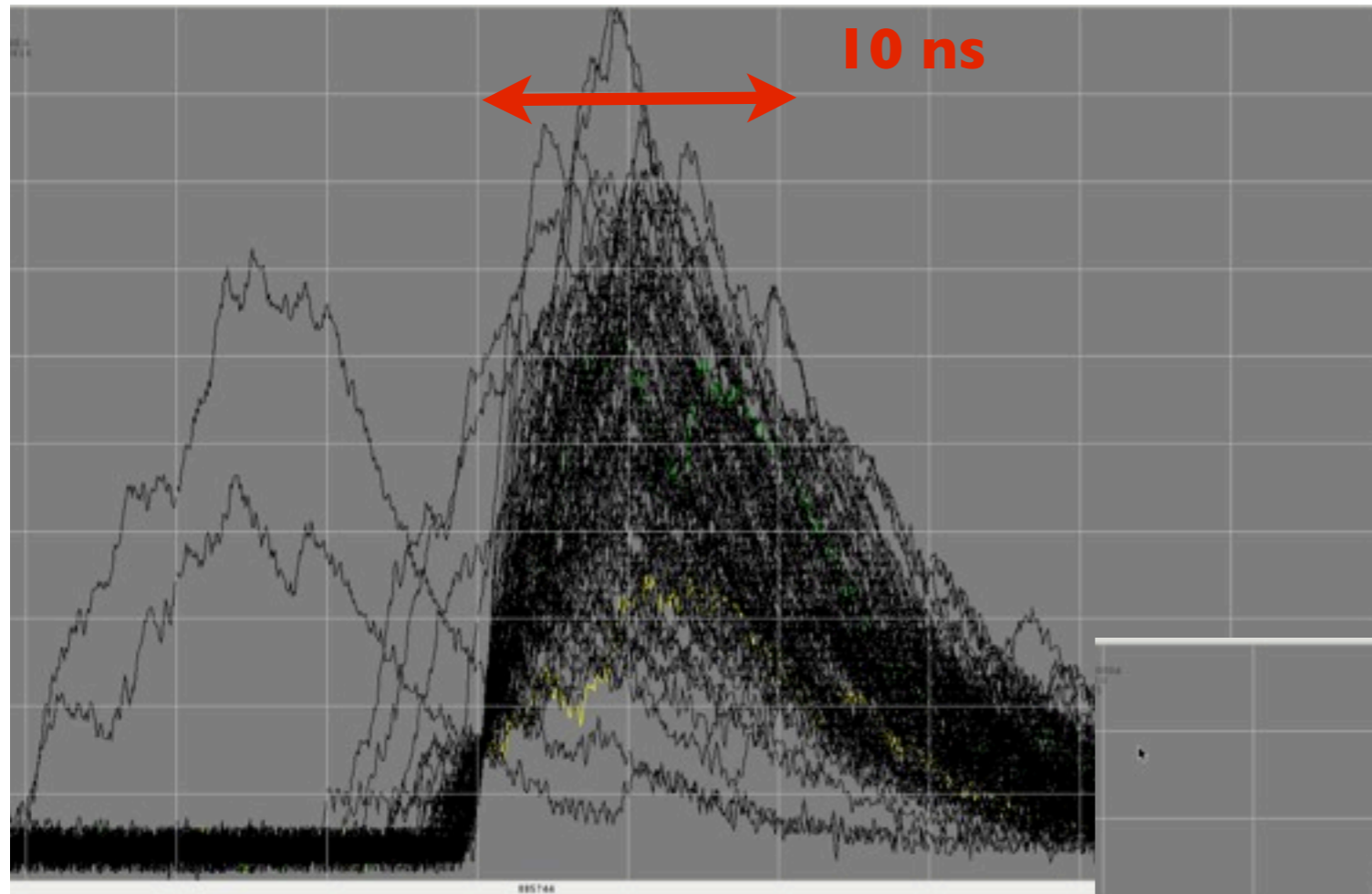


Run Plan

- Take 1 M events each at ~ 5 different energies, if possible with stable transverse beam position, vertical beam position centered on Timing Strip
 - Timing Strip located at the end of the calorimeter: Behind 30 absorber layers
- Ideal: One or two other longitudinal locations: layer 10, layer 20
 - In each location, take ~ 250 k events at several energies (3 should do)
- That way:
 - Possibility for stand-alone analysis of the timing data, providing first rough results quickly (good to make my funding source happy)
 - Thorough analysis including full correlation with HCAL data

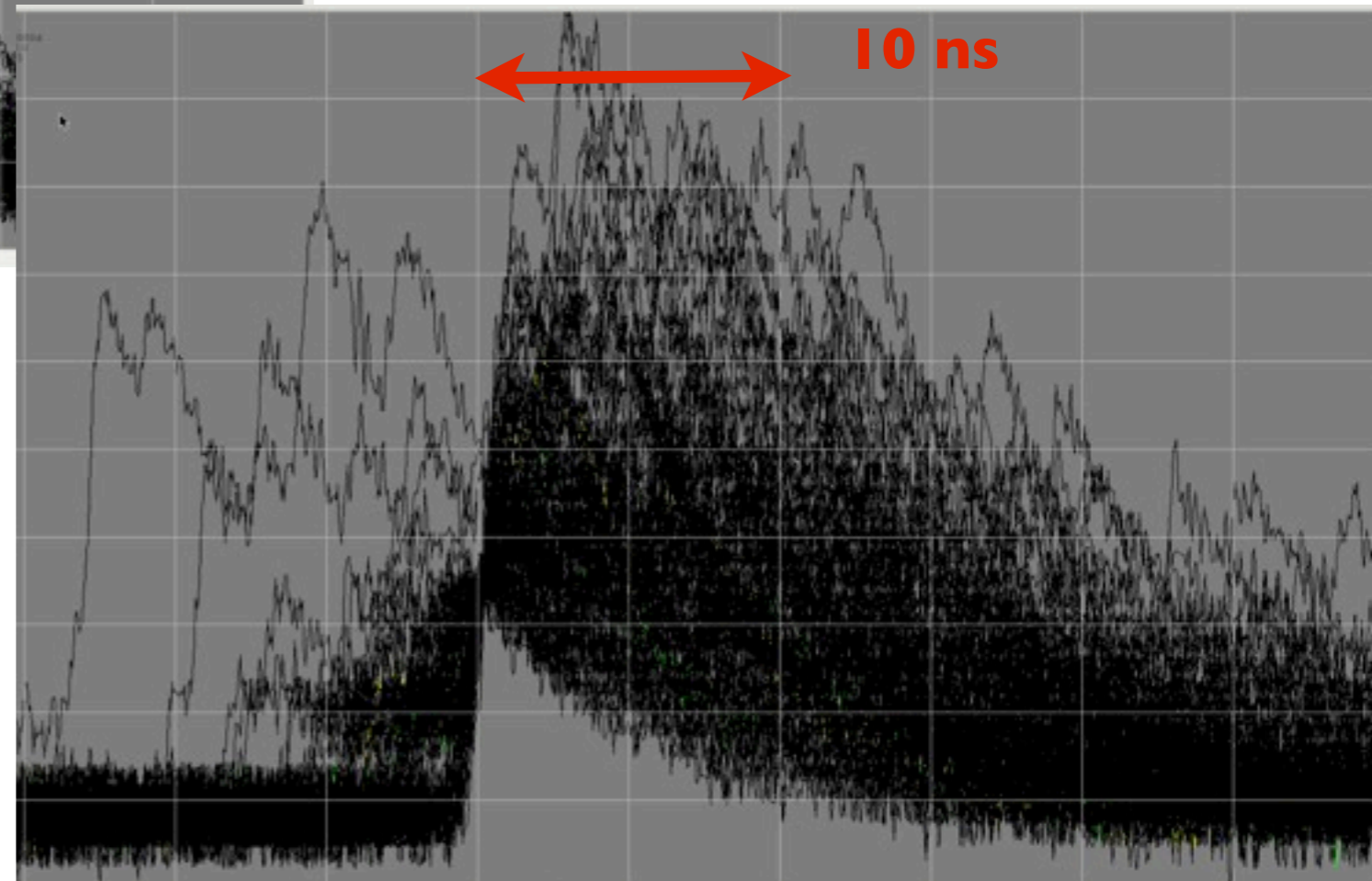
Hardware Options

Tile Response with and without Fiber



directly coupled tile

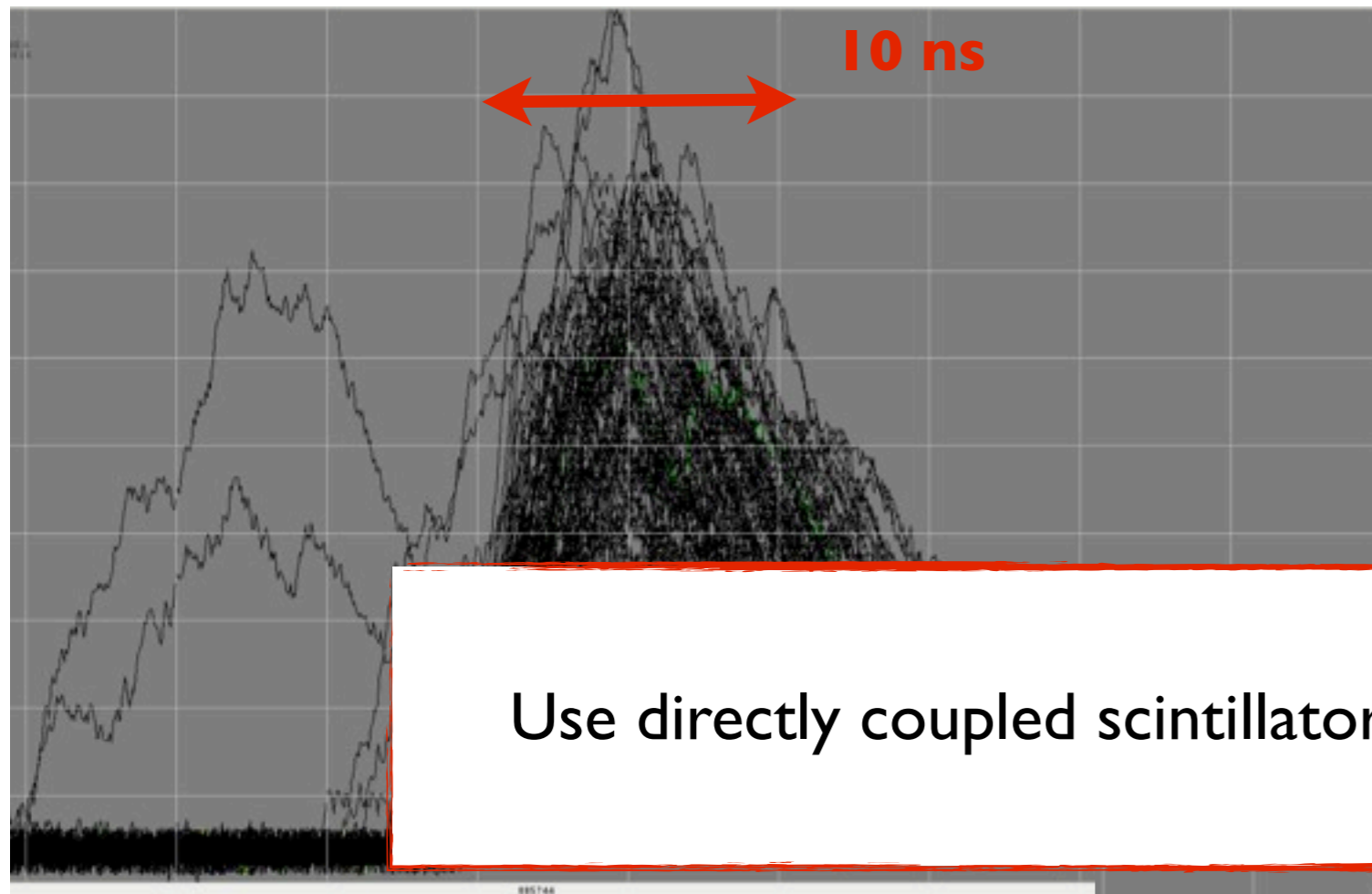
- ▶ fast peaking signal, pronounced peak
- ▶ sub-ns time resolution possible
- ▶ short integration times sufficient



CALICE 1st generation tile:
curved WLS fiber

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

Tile Response with and without Fiber



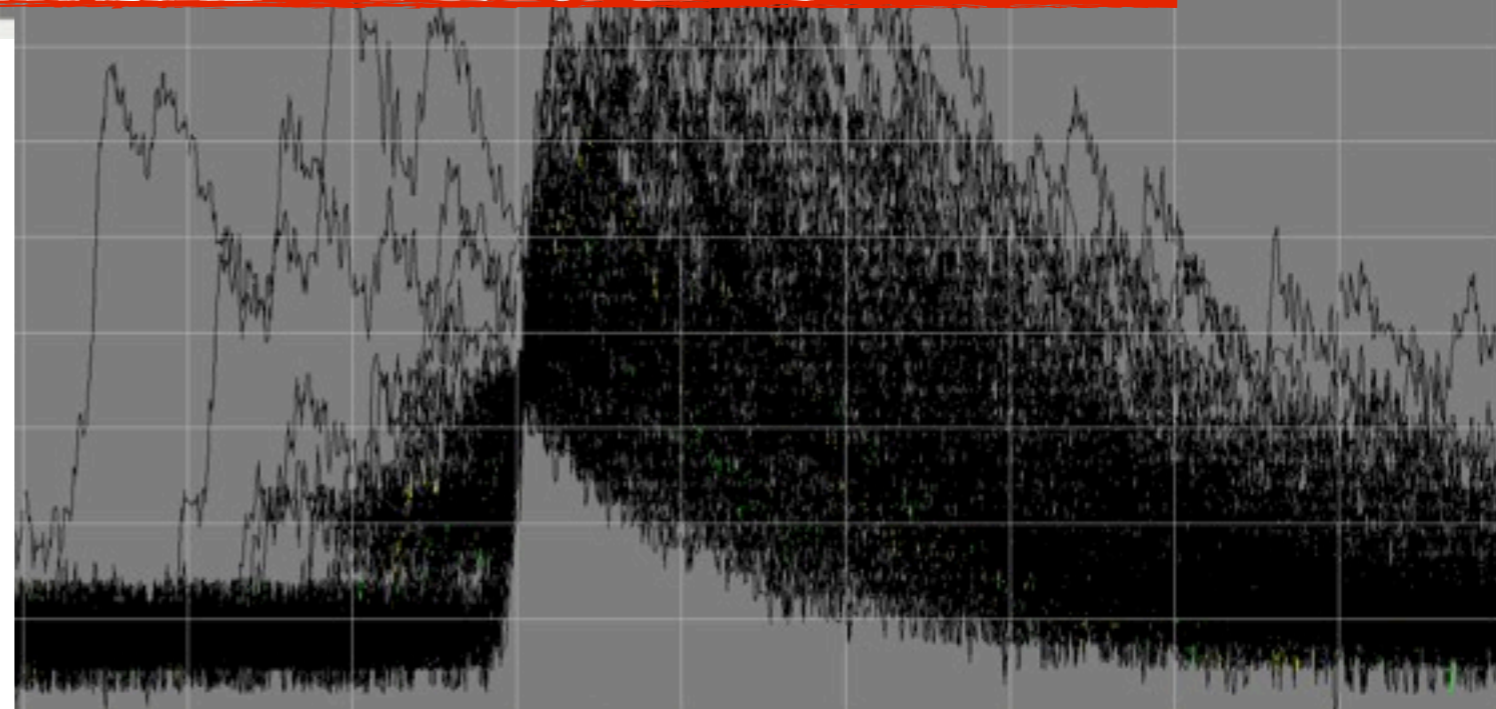
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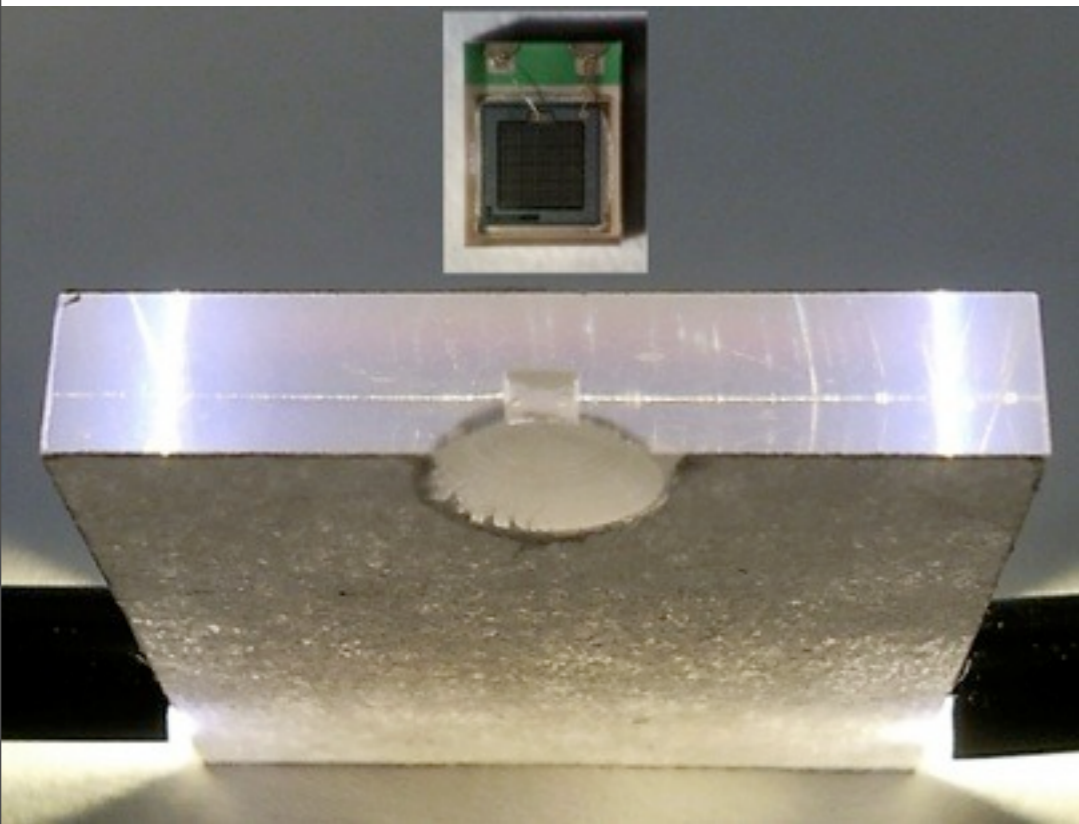
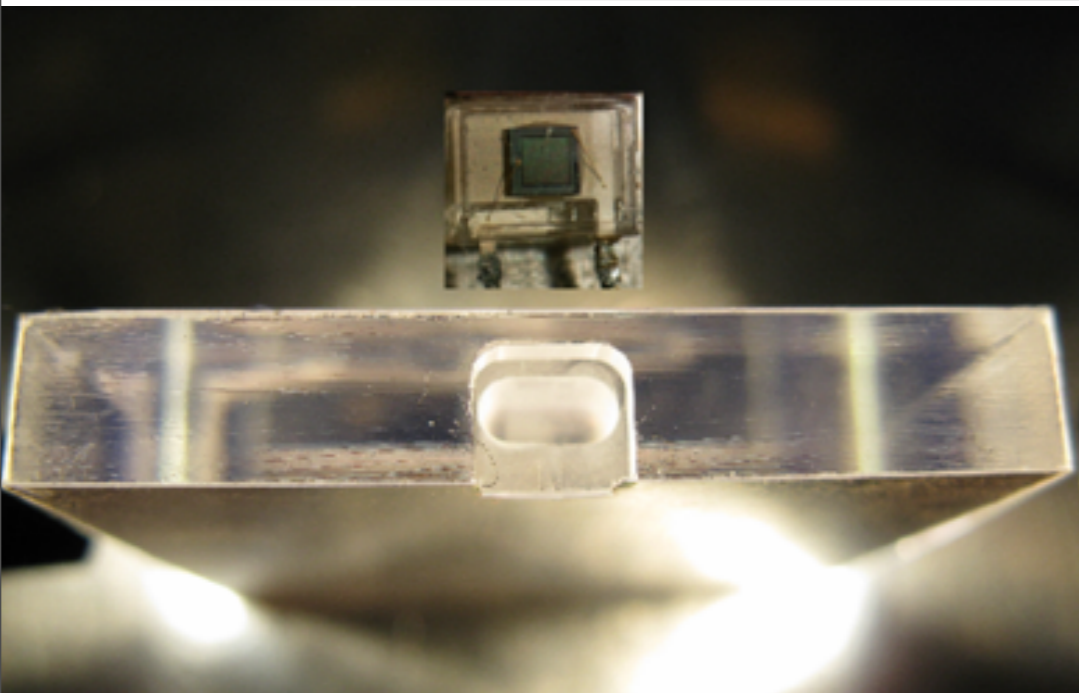
Use directly coupled scintillator tiles for timing studies!

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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: $25 \times 25 \mu\text{m}^2$ or $50 \times 50 \mu\text{m}^2$
 - 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 \sim 15 - 18 p.e., instantaneous \sim 12 p.e.)
- Limitations of the PicoScope amplifier: Large signals well beyond the set dynamic range (\sim 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. \sim 4 bit (problems beyond 15 MIP)
 - Medium gain: 11 MIP maximum, 1 p.e. \sim 2 bit (problems beyond 30 MIP)
 - Low gain: 22 MIP maximum, 1 p.e. \sim 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

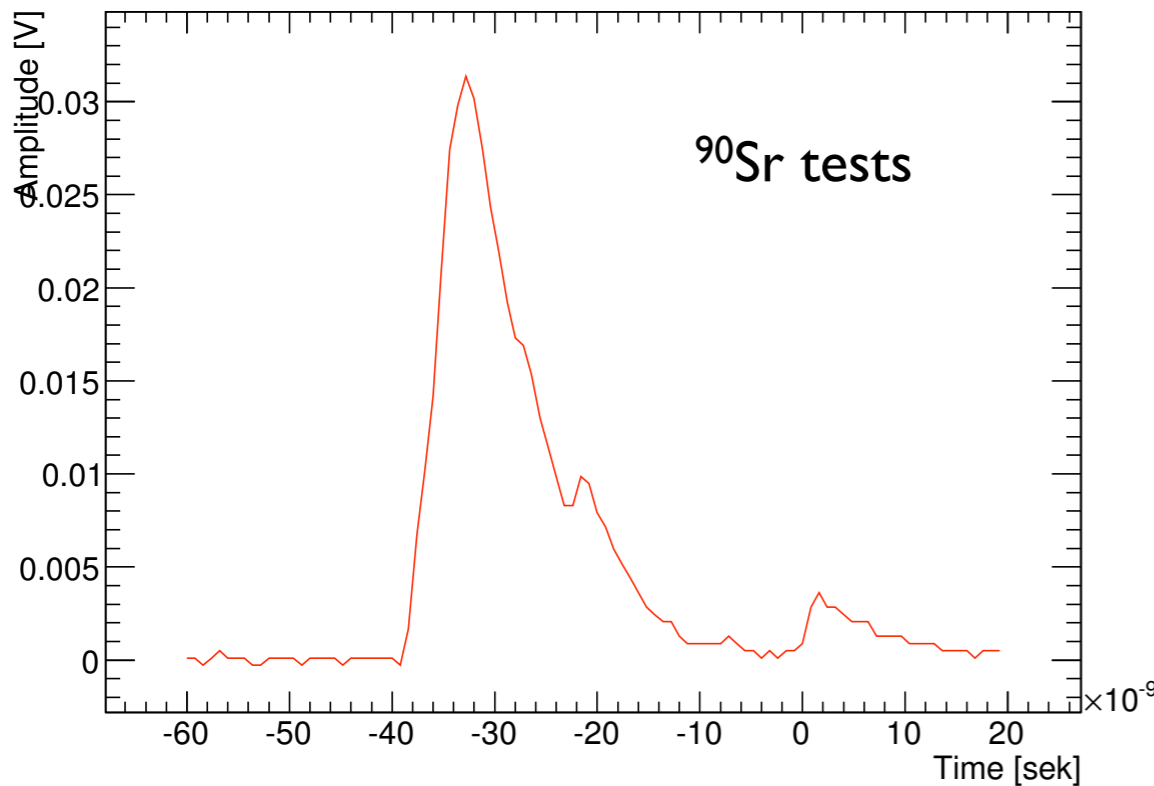
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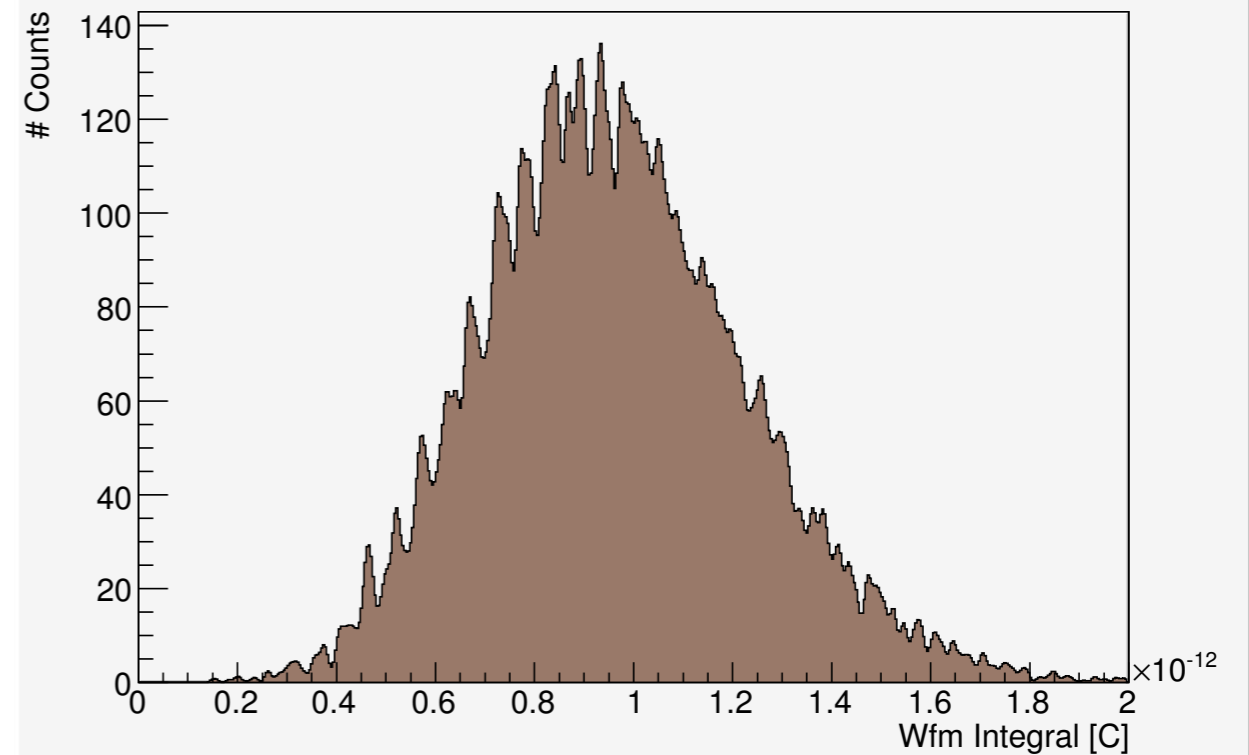
likely best option

Test Results

Triggered Wfm No 1 of CH1 - PicoScope_20kWfms_plusminus50mV_80ns



Distribution of Waveform Integral - plusMinus50mV

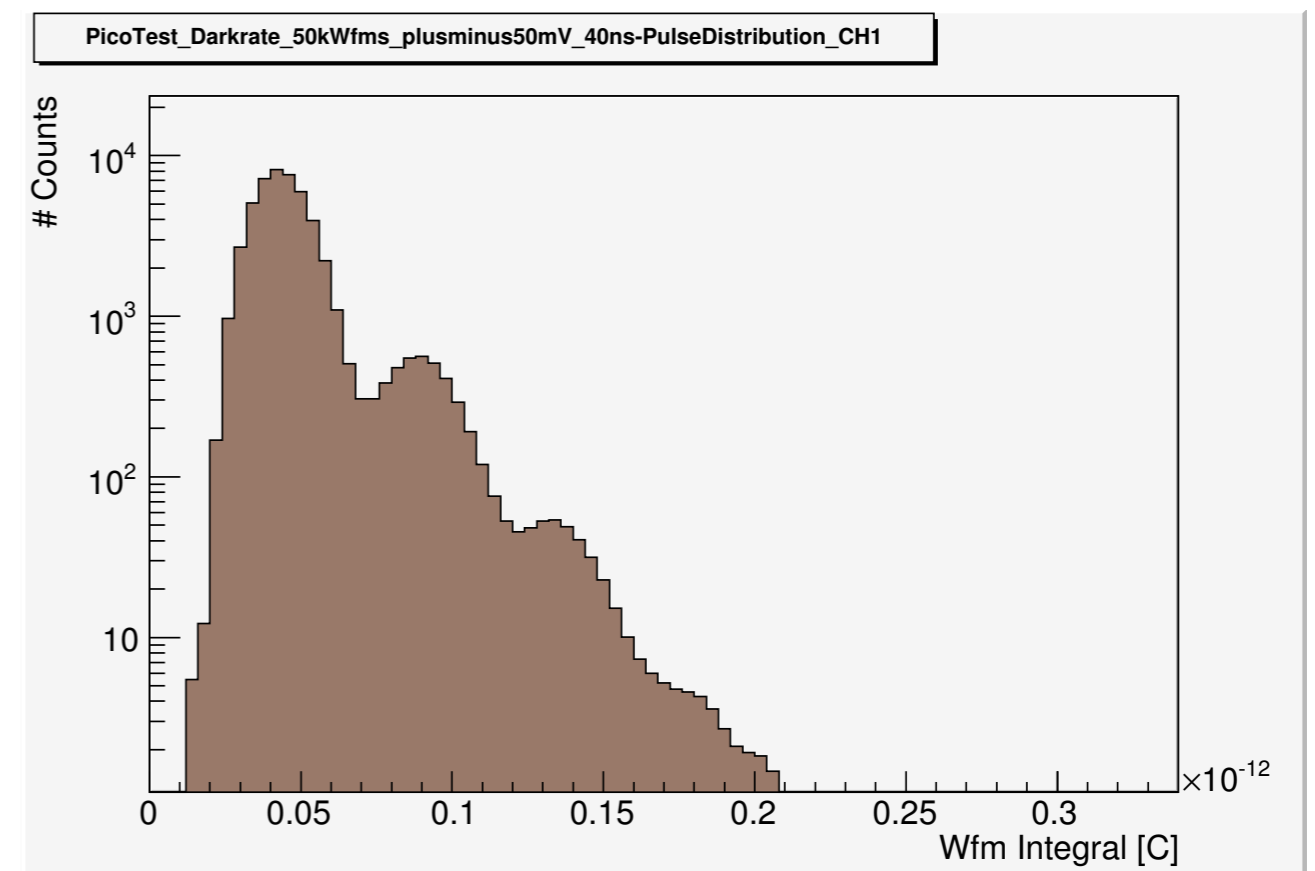
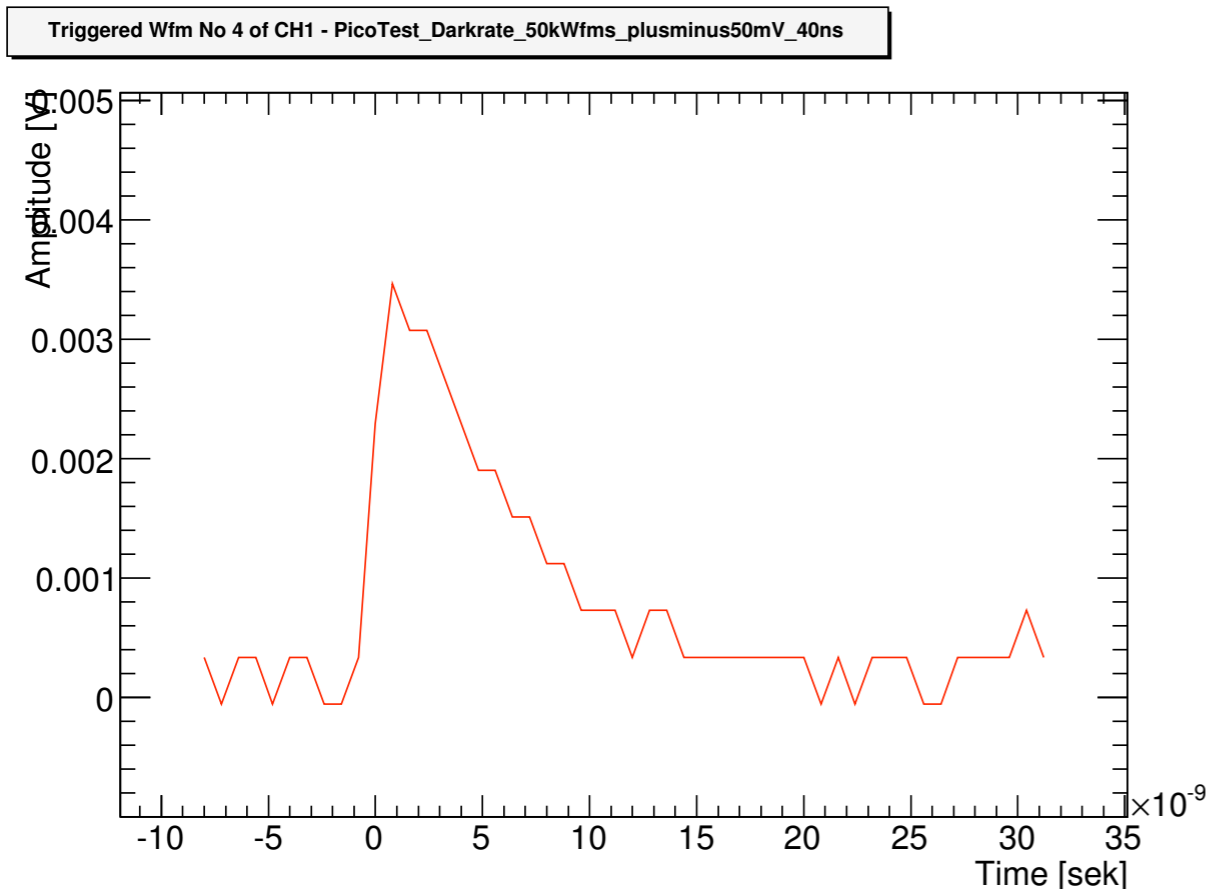


- Time resolution sufficient to resolve single p.e. peaks in sum signal
 - Here: extreme high gain: ± 50 mV, corresponds to 2.7 MIP dynamic range
- Planned physics mode: 2 μs acquisition window, acquire $\sim 3\text{k}$ events per spill with a trigger rate < 10 kHz, transfer data out between spills (60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

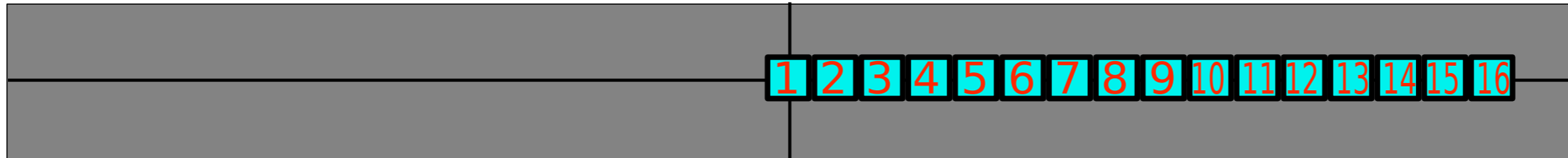


- Struck VME Digitizer SIS 3305
 - 8 ch digitizer cards, two cards in one mainframe
 - 1.25 GS/s in 8 ch mode
 - 1 GS shared memory per module
 - 2 GHz bandwidth
 - 10 bit vertical resolution
 - Trigger in/out
- Not tested yet, test unit expected in Munich in ~ 1 week, open questions:
 - Is high trigger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

Geometrical Arrangement

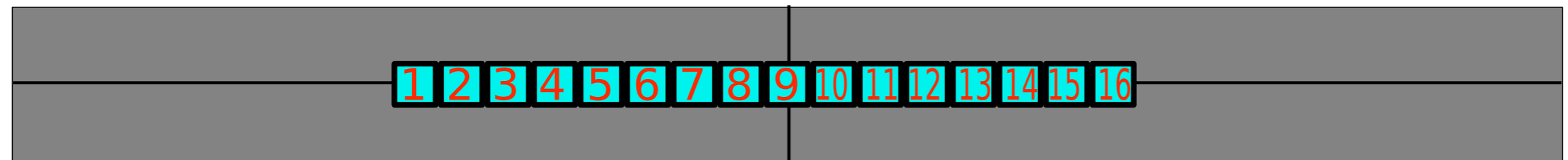
- 16 channels - 2 possible arrangements

1000



⇒ wide lateral coverage, high statistics needed

1000



⇒ 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

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⇒ Let's do it!