

Investigation of the Time Structure of Showers in a Tungsten HCAL

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MPI for Physics & Excellence Cluster 'Universe'
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Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)



Calorimeter for ILC



Excellence Cluster
Universe

Outline

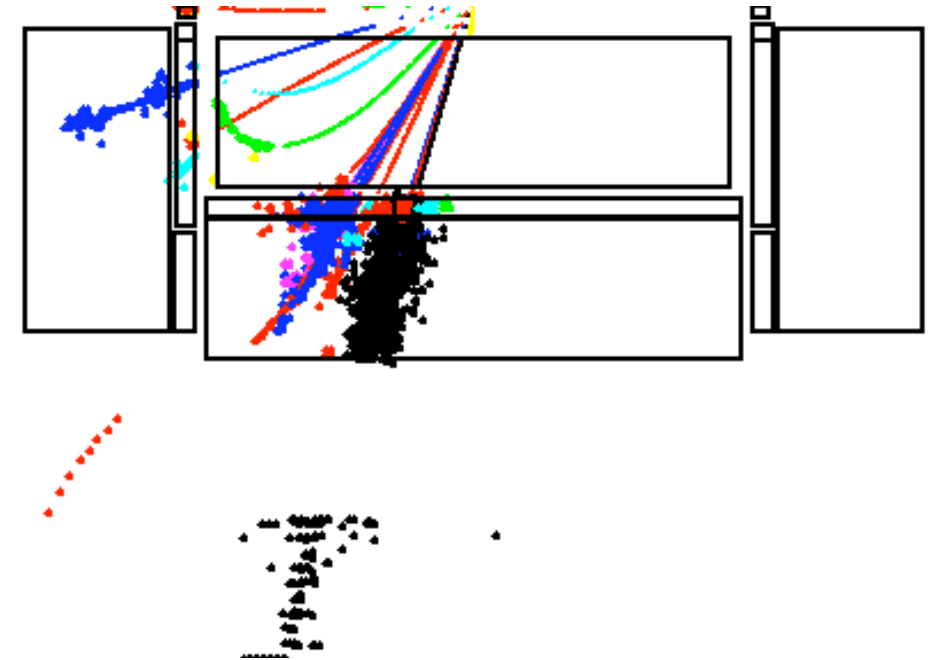
- Hadron Calorimetry at CLIC: Competing Requirements
- The Time Structure of Hadronic Showers
- Prospects for a First Measurement: T3B
- Summary & Outlook

Hadron Calorimetry at CLIC

- The key CLIC feature: High Energy!
 - 3 TeV energy means in principle up to 1.5 TeV jets

Shower containment and leakage is a crucial issue

- ⇒ A (very) deep hadron calorimeter is needed
- ⇒ Use compact absorbers to limit the detector radius: Tungsten a natural choice

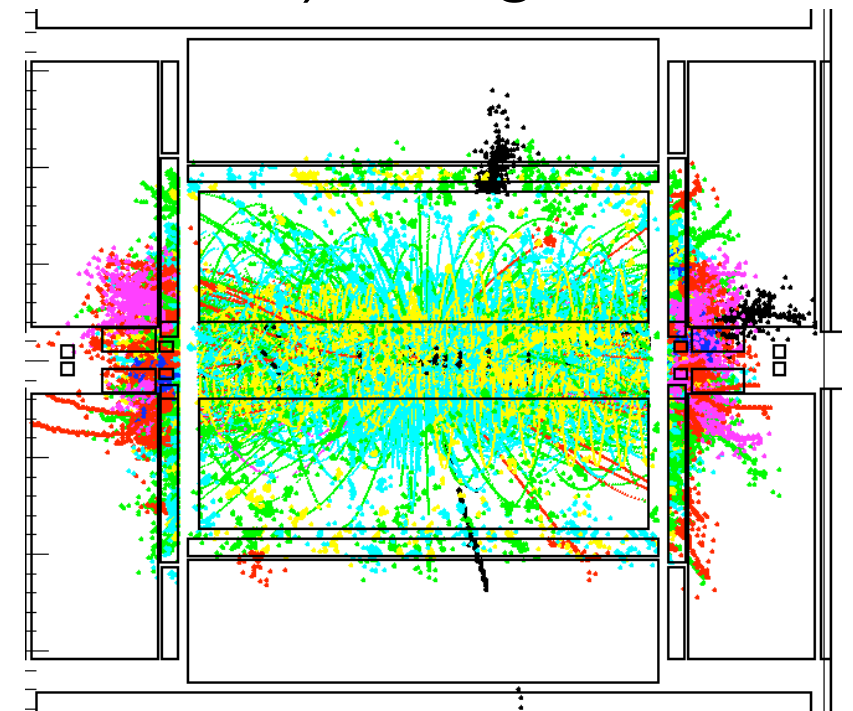
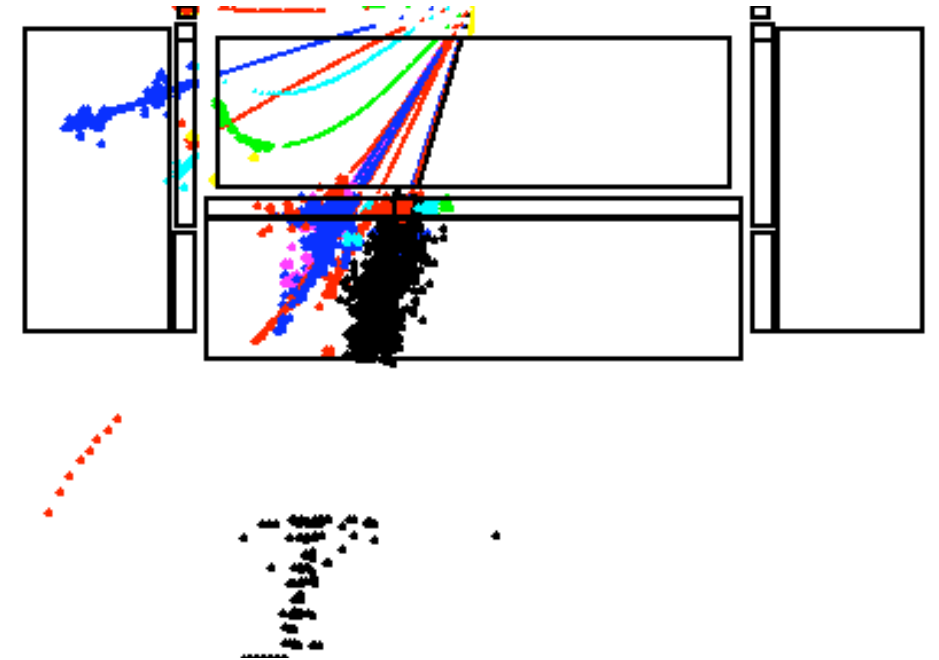


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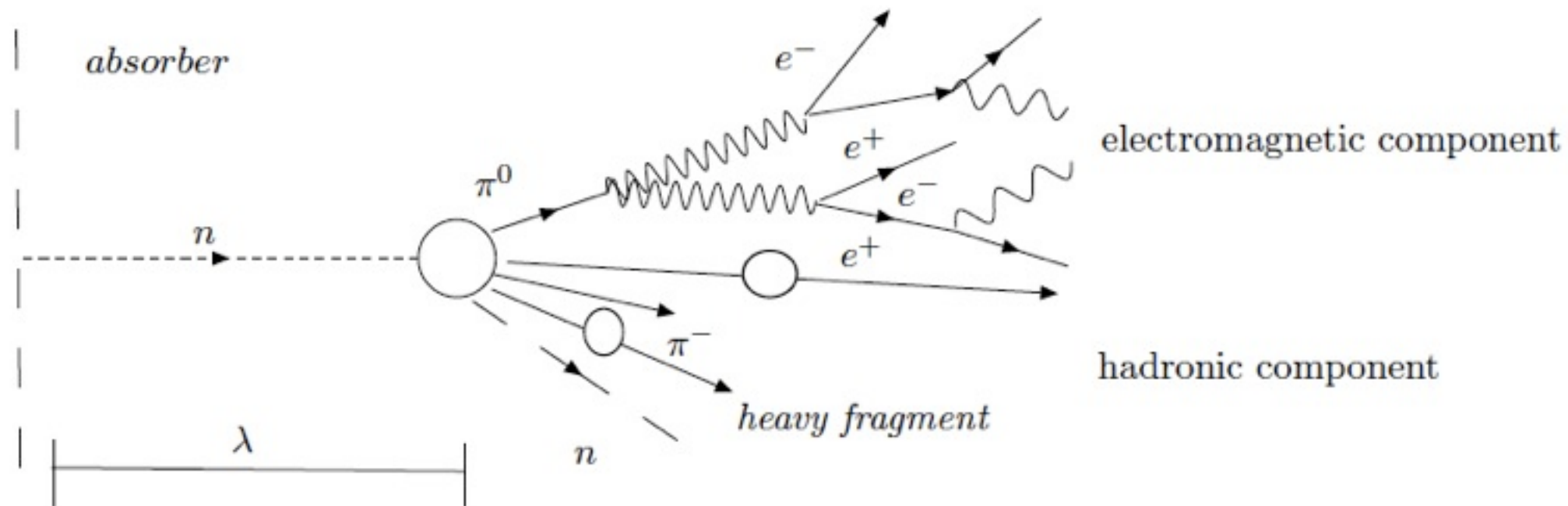
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- ⇒ A (very) deep hadron calorimeter is needed
- ⇒ Use compact absorbers to limit the detector radius: Tungsten a natural choice
- Key challenge (linked to high energy and machine-specific issues): Background
 - $\gamma\gamma \rightarrow$ hadrons substantial:
 - ~ 9 hadrons/bunch crossing in the barrel region (5.8 GeV / bunch crossing)
 - extreme bunch crossing rate: every 0.5 ns
- ⇒ Very good time resolution in all detectors important to limit impact of background!



Hadronic Showers: Complex (Time) Structure

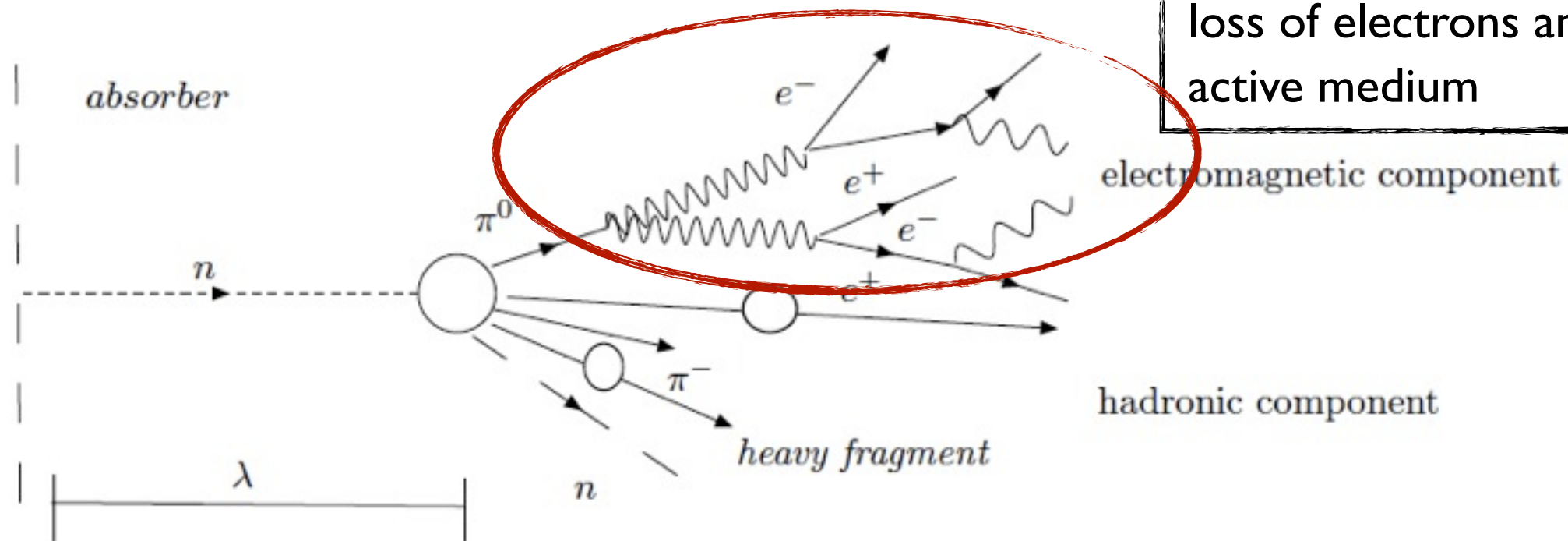
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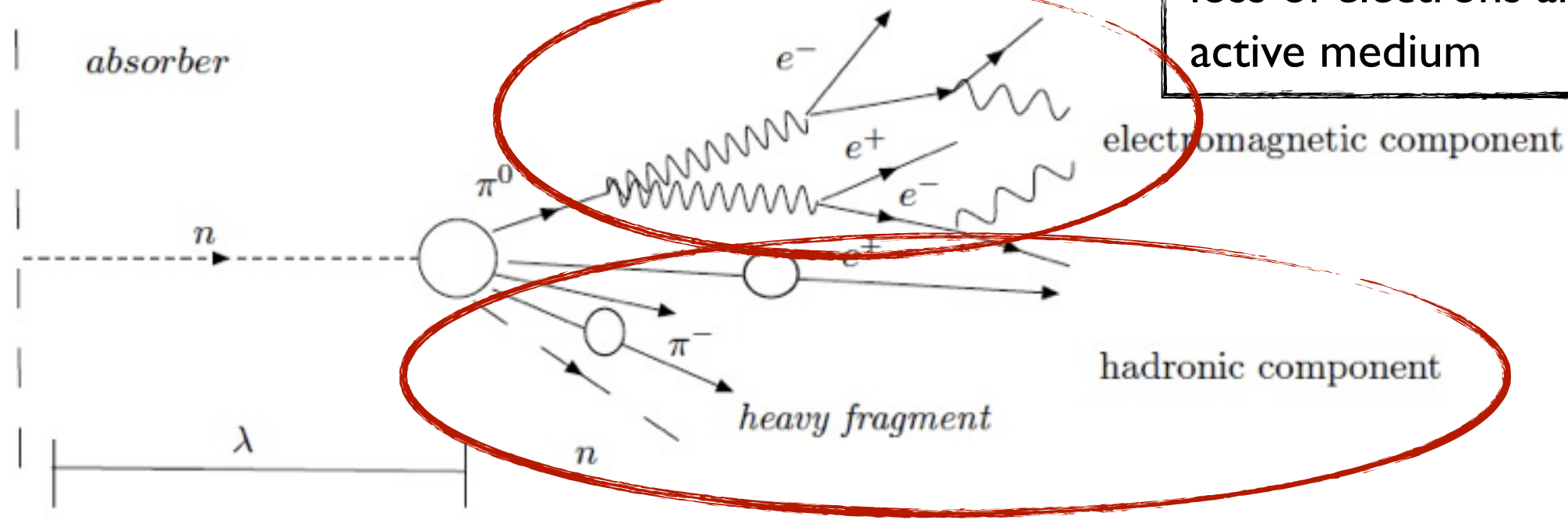
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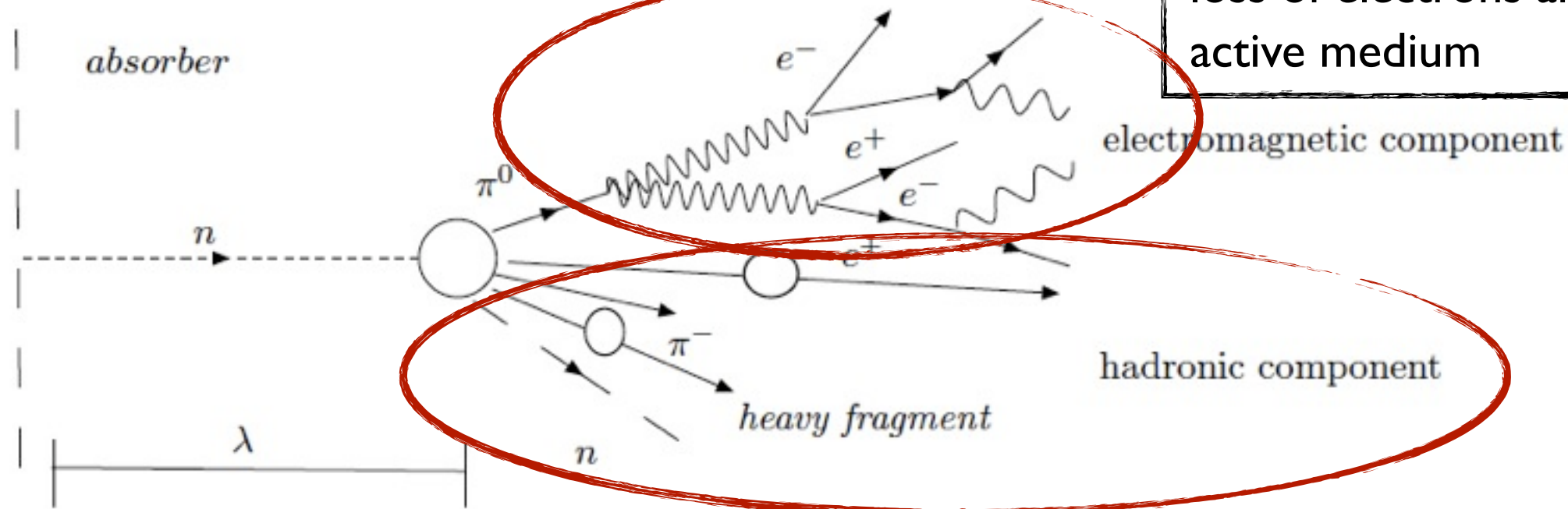


- instantaneous component: charged hadrons detected via energy loss of charged hadrons in active medium
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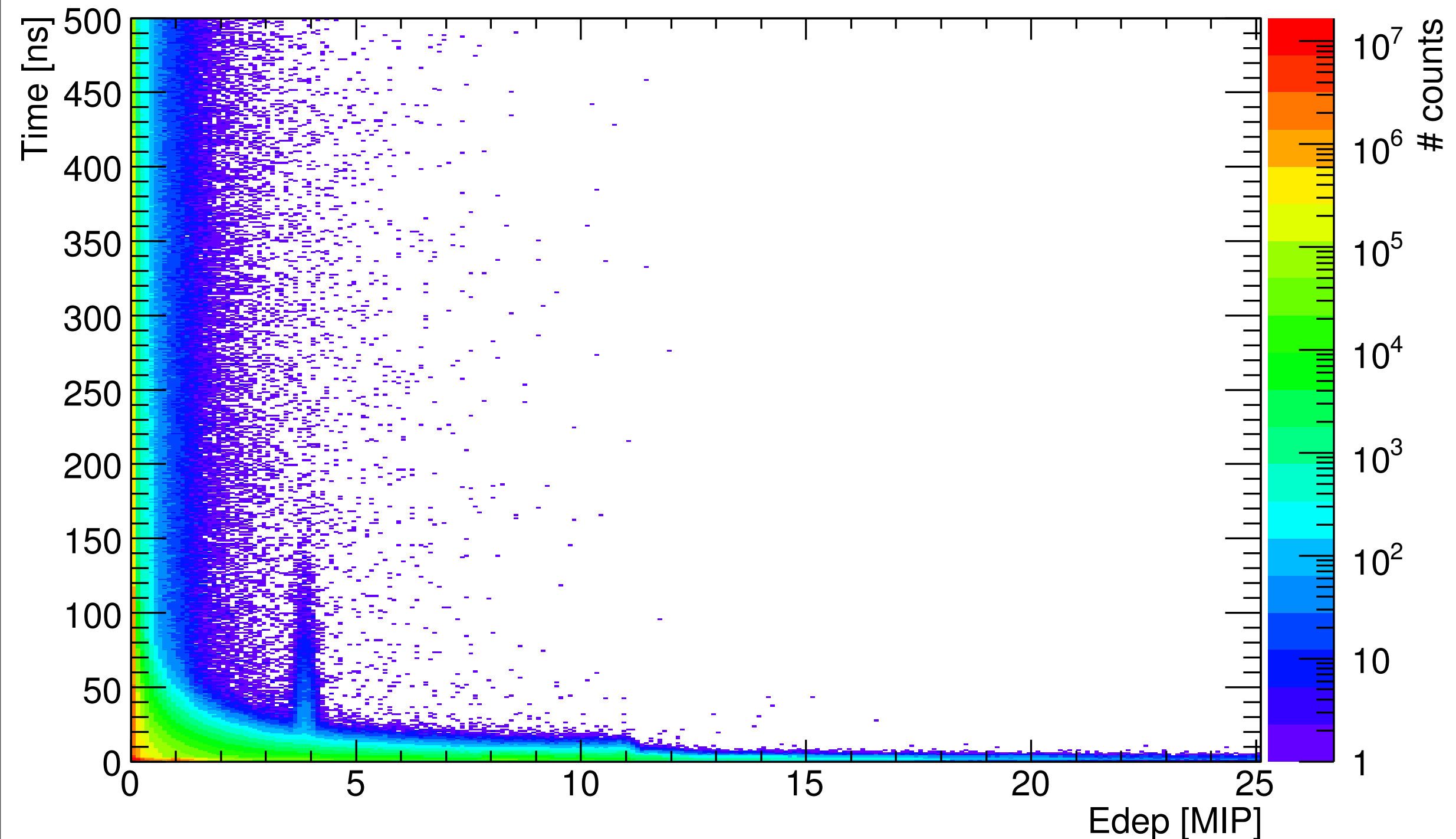


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- ⇒ Importance of delayed component strongly depends on target nucleus
- ⇒ Sensitivity to time structure depends on the choice of active medium

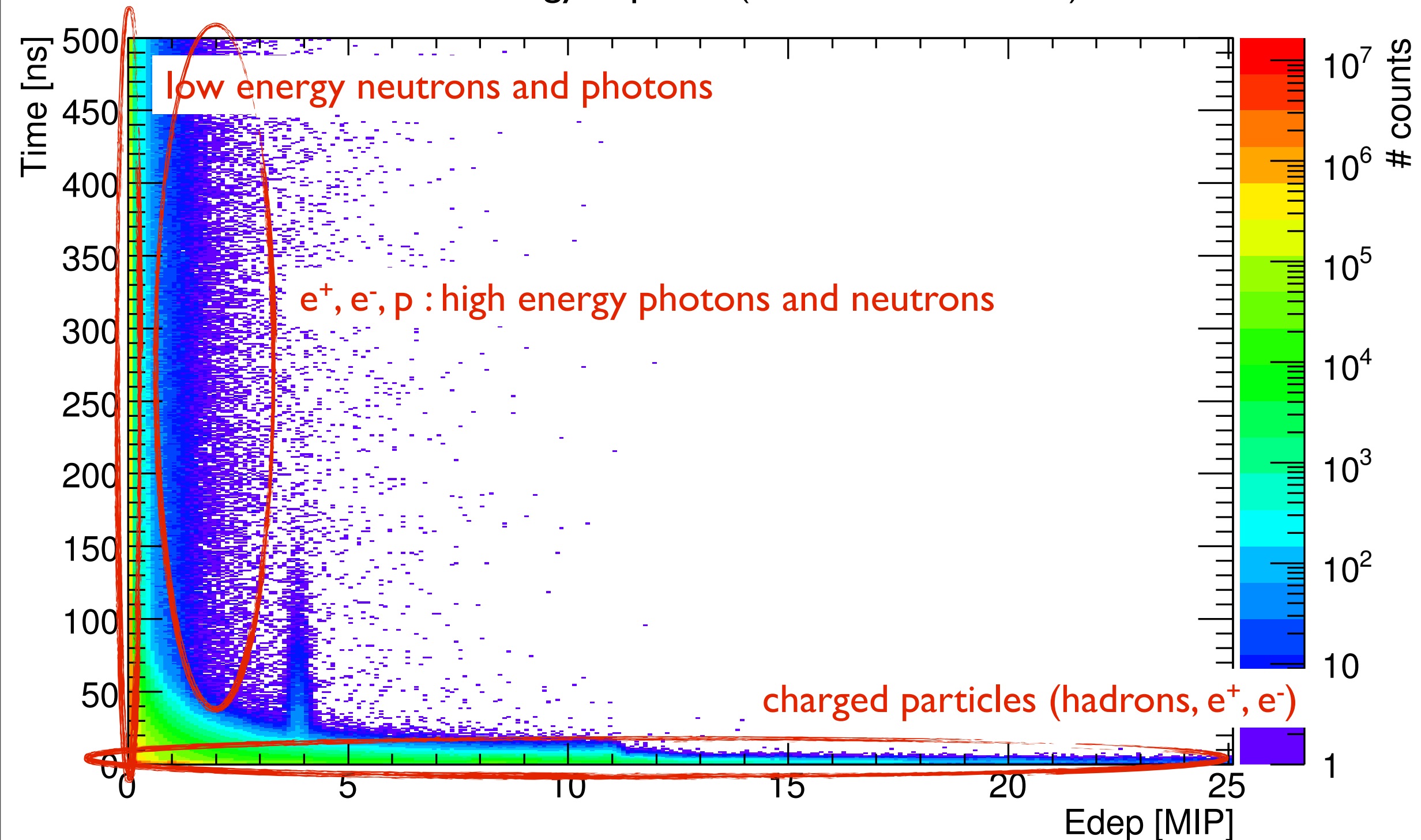
A Look at Geant4:Time Distribution

- Geant4 simulation of a 30 layer Scintillator-W calorimeter (QGSP_BERT)
 - Time distribution of energy deposits (no detector effects!)



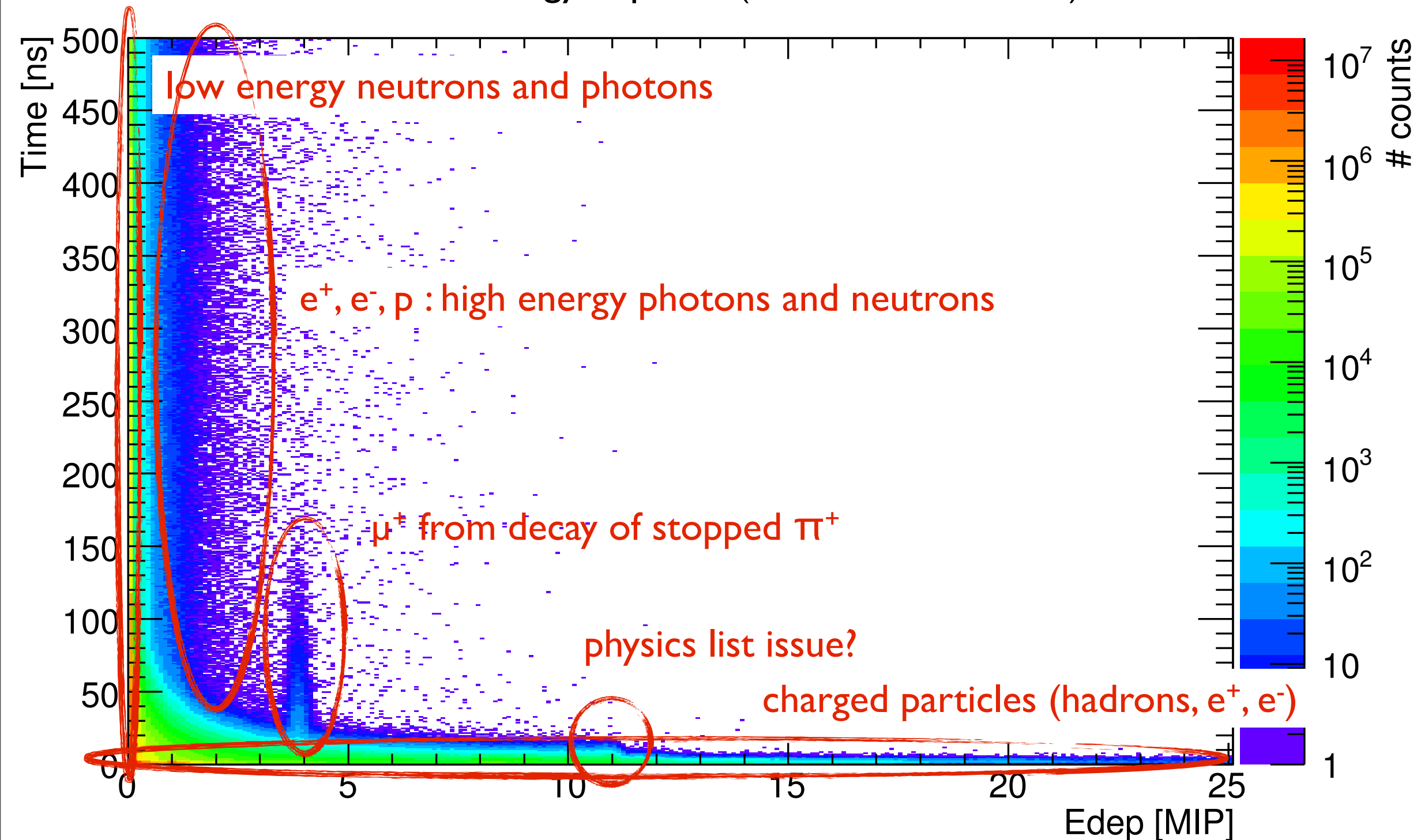
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T3B: An Experiment for a First Study of the Time Structure

- CALICE is currently testing a first Tungsten HCAL
 - 30 layers with 10 mm Tungsten (94% W, 4% Ni, 2% Cu, density 17.6 g/cm³) absorber
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- T3B (Tungsten Timing Test Beam)
 - Goal: Measure the time structure of the signal within hadronic showers in a Tungsten calorimeter with scintillator readout
 - Use a (very) small number of scintillator cells, read those out with high time resolution
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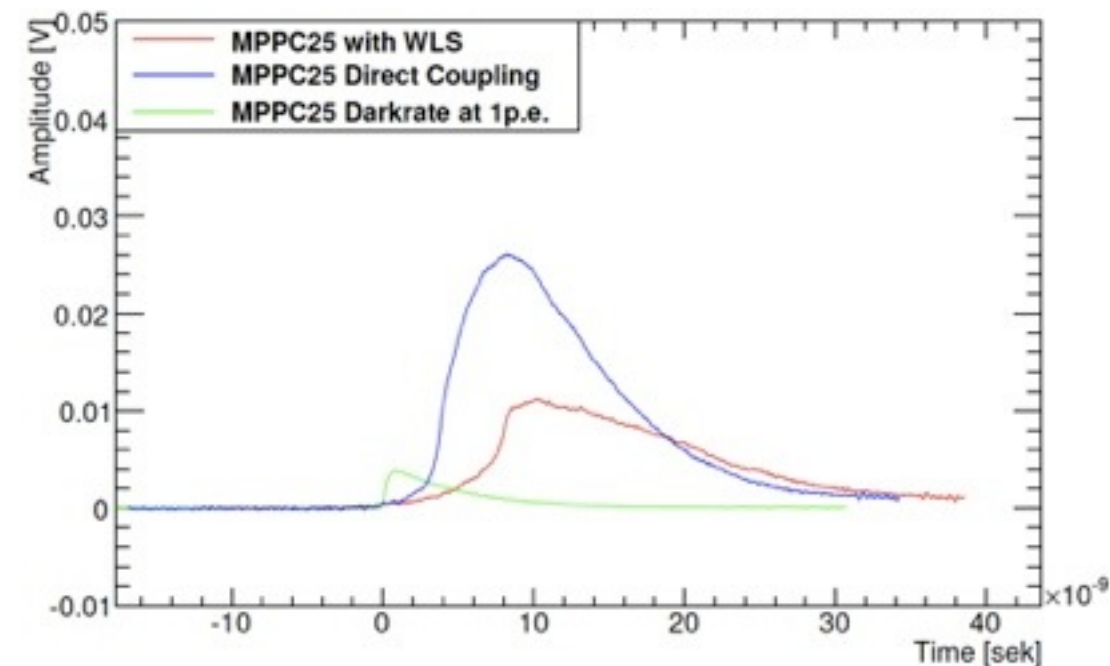
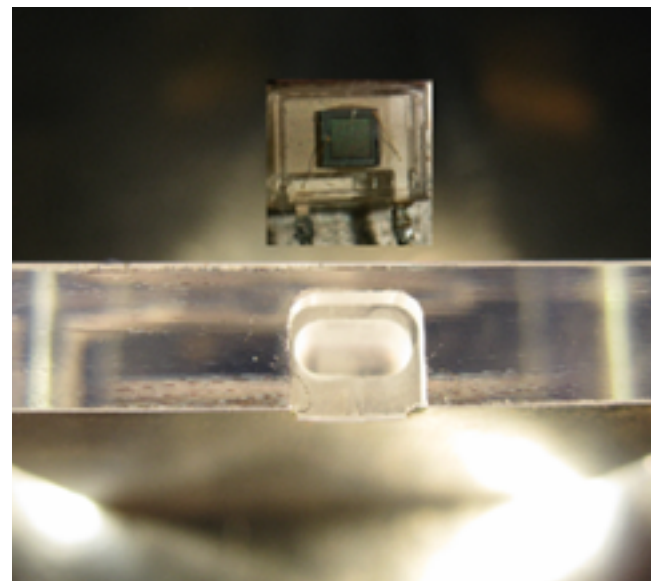
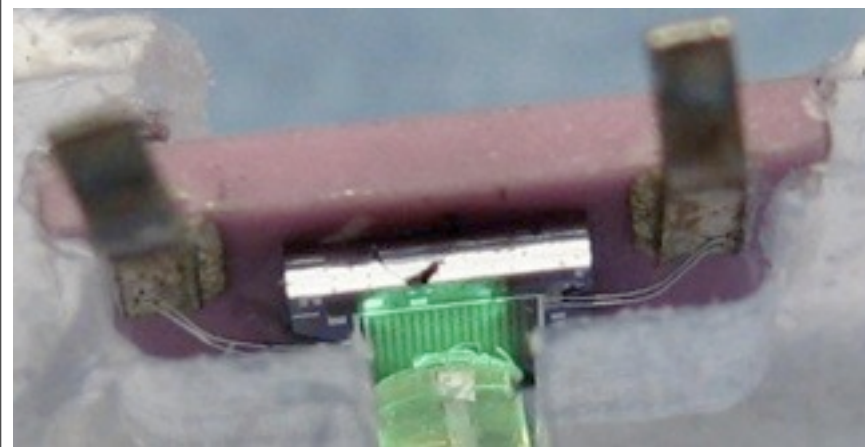
⇒ First information on time structure, possibility for comparisons to Geant4, but:
no complete “4D” shower reconstruction!

T3B Technology: Scintillators and Photon Sensors

- Important features for timing measurement:
 - Fast response (good time resolution!)
 - Large signal (allows detection of small individual energy deposits)

Fiberless coupling of photon sensor to scintillator: Eliminate time constant of WLS

- ▶ Requires blue sensitive photon sensors
- ▶ Requires special shaping of coupling position to obtain uniform response over tile



~ x2 faster response without WLS

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Choice of photon sensor: Number of pixels

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- ▶ T3B will sit behind 3λ of Tungsten: Extremely high signals very rare, main interest in small energy deposits

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For T3B: Hamamatsu MPPC50C

- ▶ 400 pixels, with a size of $50 \times 50 \mu\text{m}^2$
- ▶ For a ^{90}Sr source: Mean signal height ~ 30 p.e.
- ▶ For muons in beam (real MIPs): ~ 26 p.e., consistent with ^{90}Sr observations

T3B Technology: DAQ

- Key requirements:
 - Fast sampling to allow for single photon resolution: ~ 1 GHz or more
 - Long acquisition window per event: $2 \mu\text{s}$ or more
 - Fast trigger rate: faster than the CALICE HCAL, $>$ a few kHz

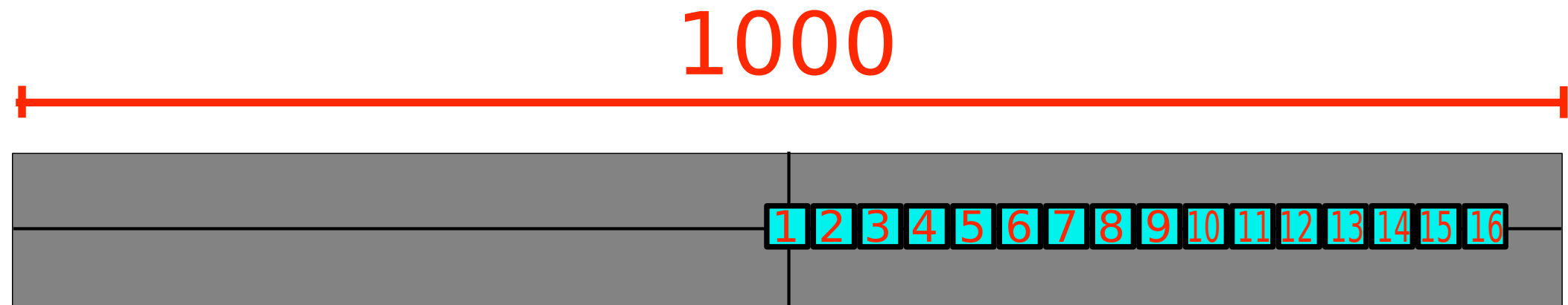
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- Adopted solution for T3B: PicoScope 6403
 - 1.25 GHz sampling for 4 channels per unit
 - 1 GB buffer memory (shared between channels)
 - Burst trigger mode: Maximum rate determined by window length:
 ~ 500 kHz for $2 \mu\text{s}$ acquisition window
 - 8 bit vertical resolution
 - Control & Readout via USB



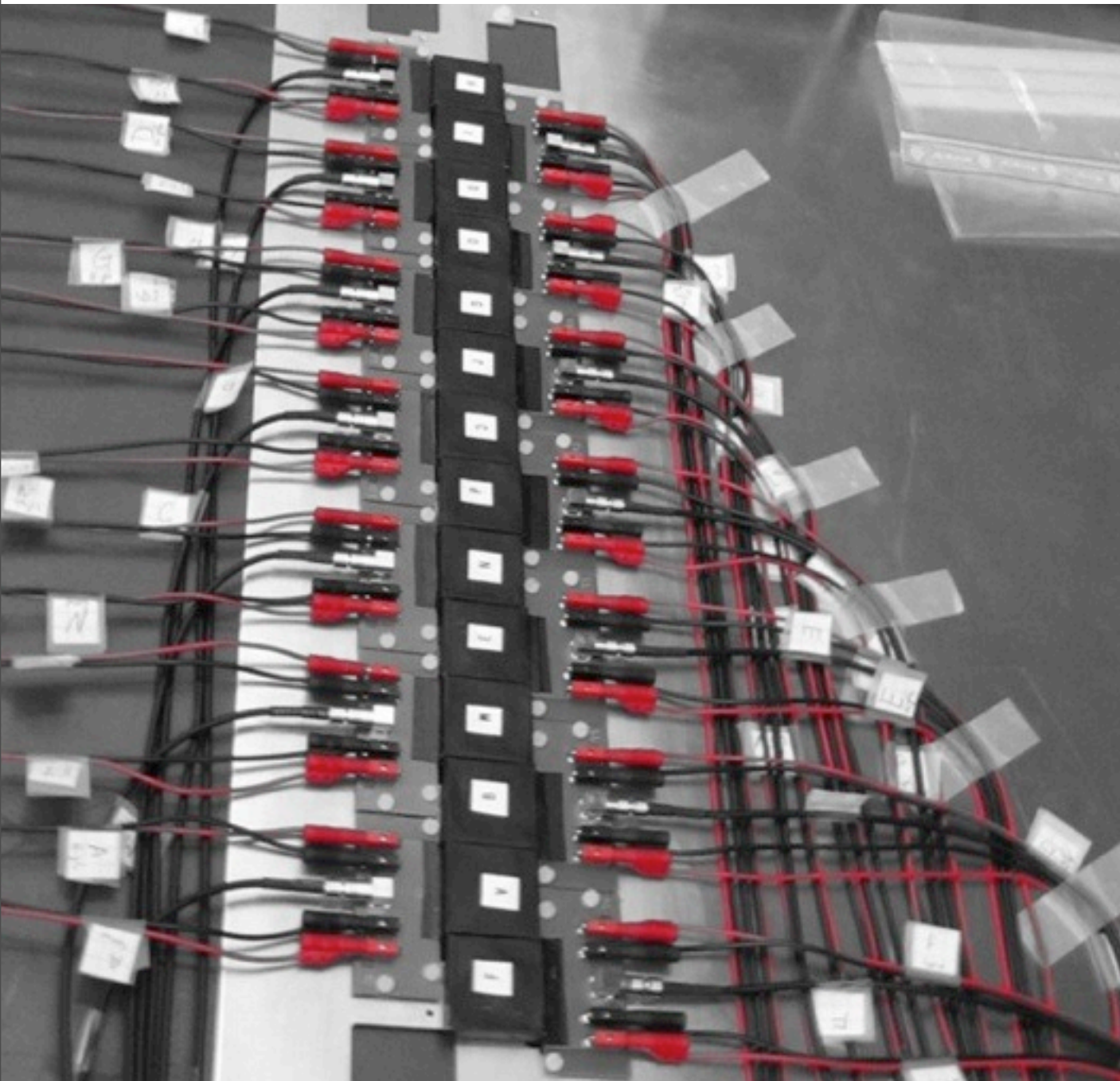
Putting it together: The T3B Setup

- A maximum of 16 channels, 4 readout units: one strip from the center of the calorimeter to the outer edge

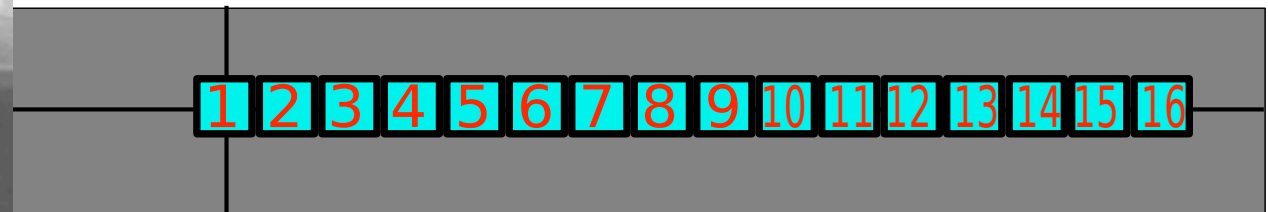


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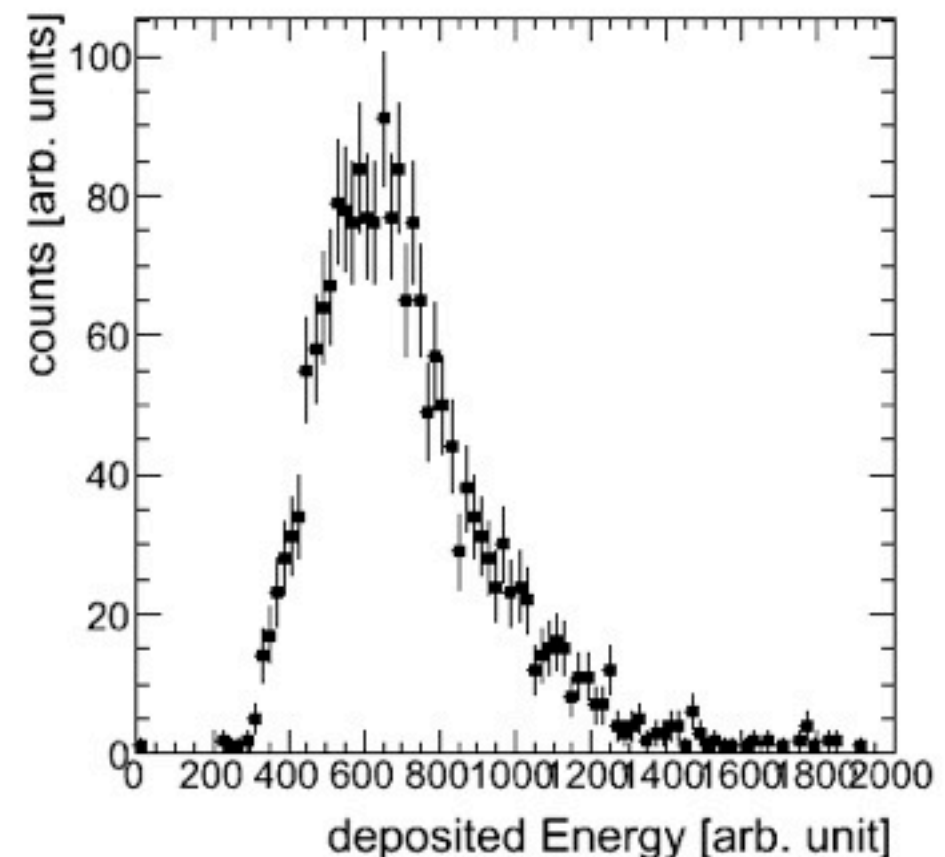
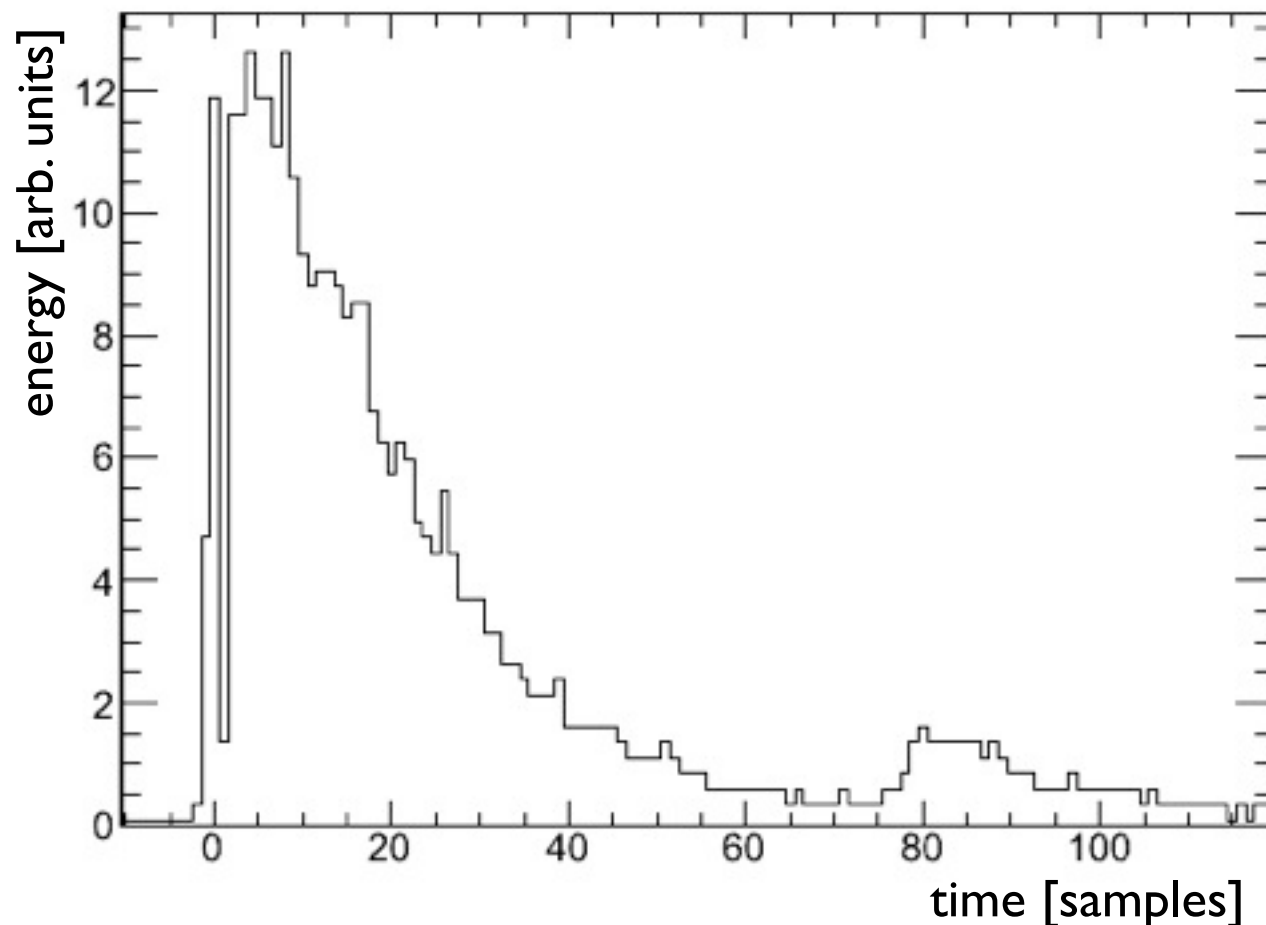
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- Separate powering for each channel: adjust voltage to the SiPM working point channel by channel
- Mechanical support given by Al-structure, easy installation in W calorimeter structure

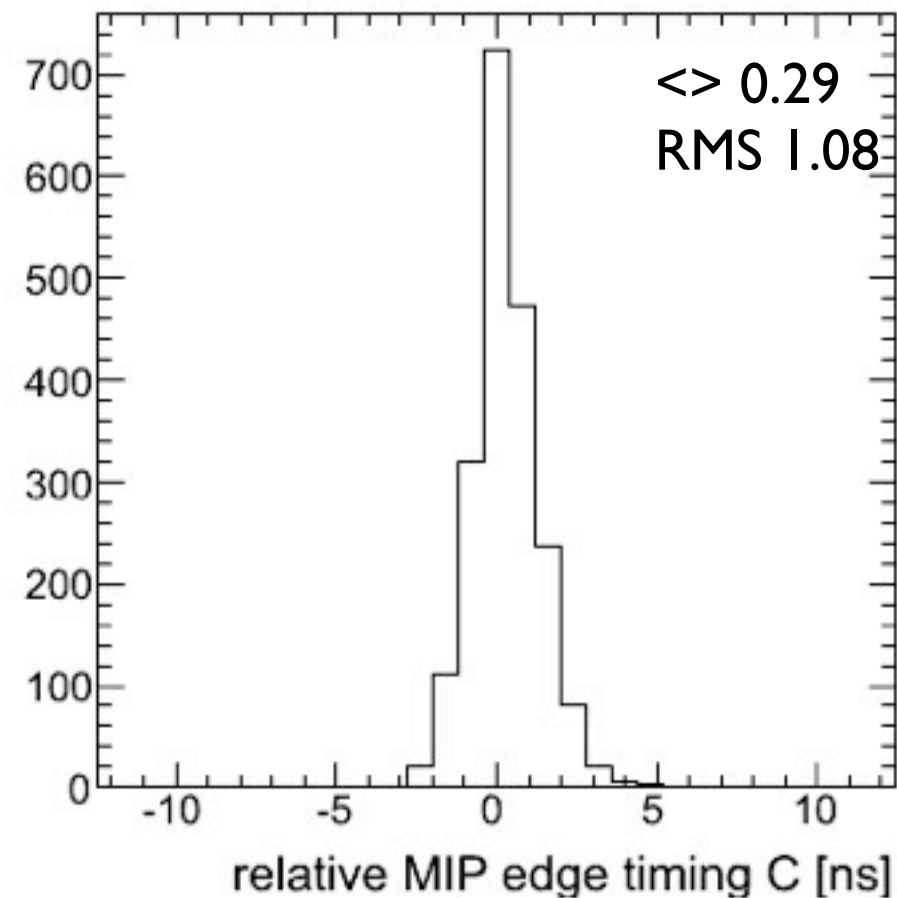
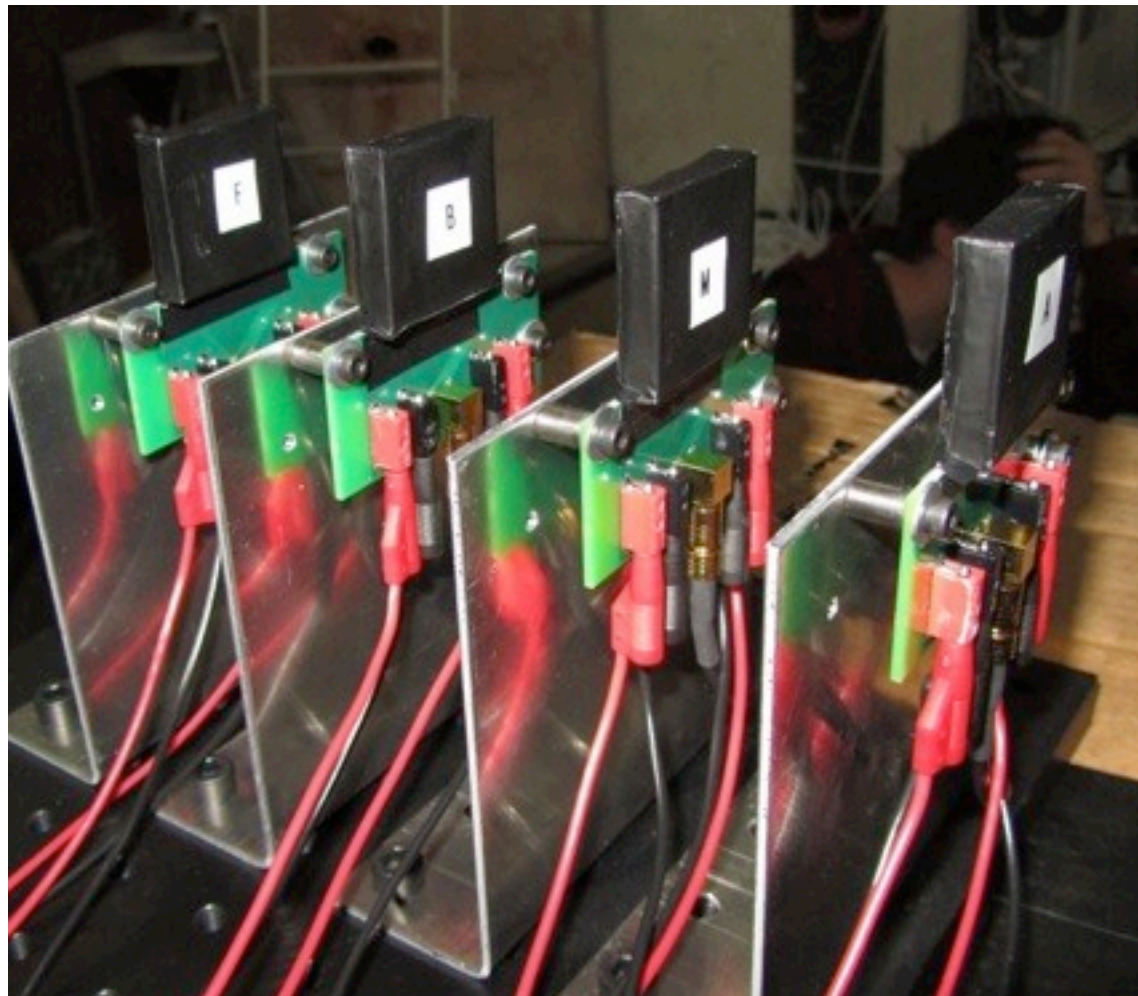
First Commissioning Results: Muon Signals

- 1 week commissioning campaign at CERN PS in September:
Low intensity muon beam
- Key result: Demonstrated capability to synchronise T3B Data taking with CALICE, crucial to use shower information from WHCAL in T3B analysis
- First muon signals observed



First Commissioning Results: Timing

- Measurement of intrinsic time jitter of T3B DAQ system: ~ 400 ps (in part given by the sampling frequency)
- Time resolution of scintillator tiles with SiPMs studied with special muon telescope setup of four T3B tiles

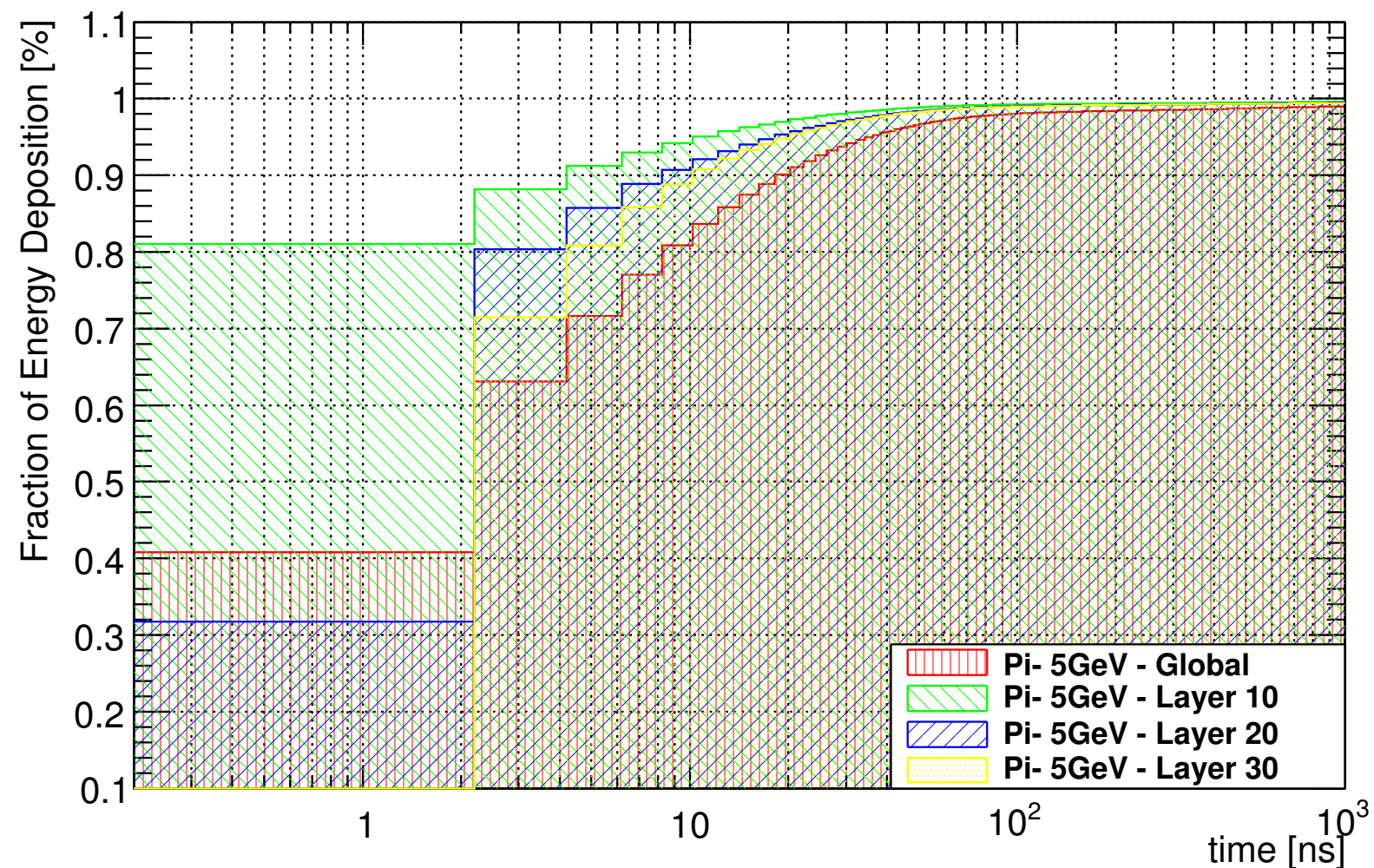


intrinsic time resolution for MIPs:
 ~ 800 ps

T3B Program: Planned Measurements - Global Timing

- Based on simulations of 30 layer WHCAL, using Geant4.8.0 & QGSP_BERT_HP
 - 200k negative pion events simulated
 - No digitization in simulation: Raw time information from Geant4, no inclusion of response of scintillator, photo sensor, DAQ (yet)
- With T3B behind the HCAL:
 - expect 90% (95%) of the complete energy within ~10 (20) ns

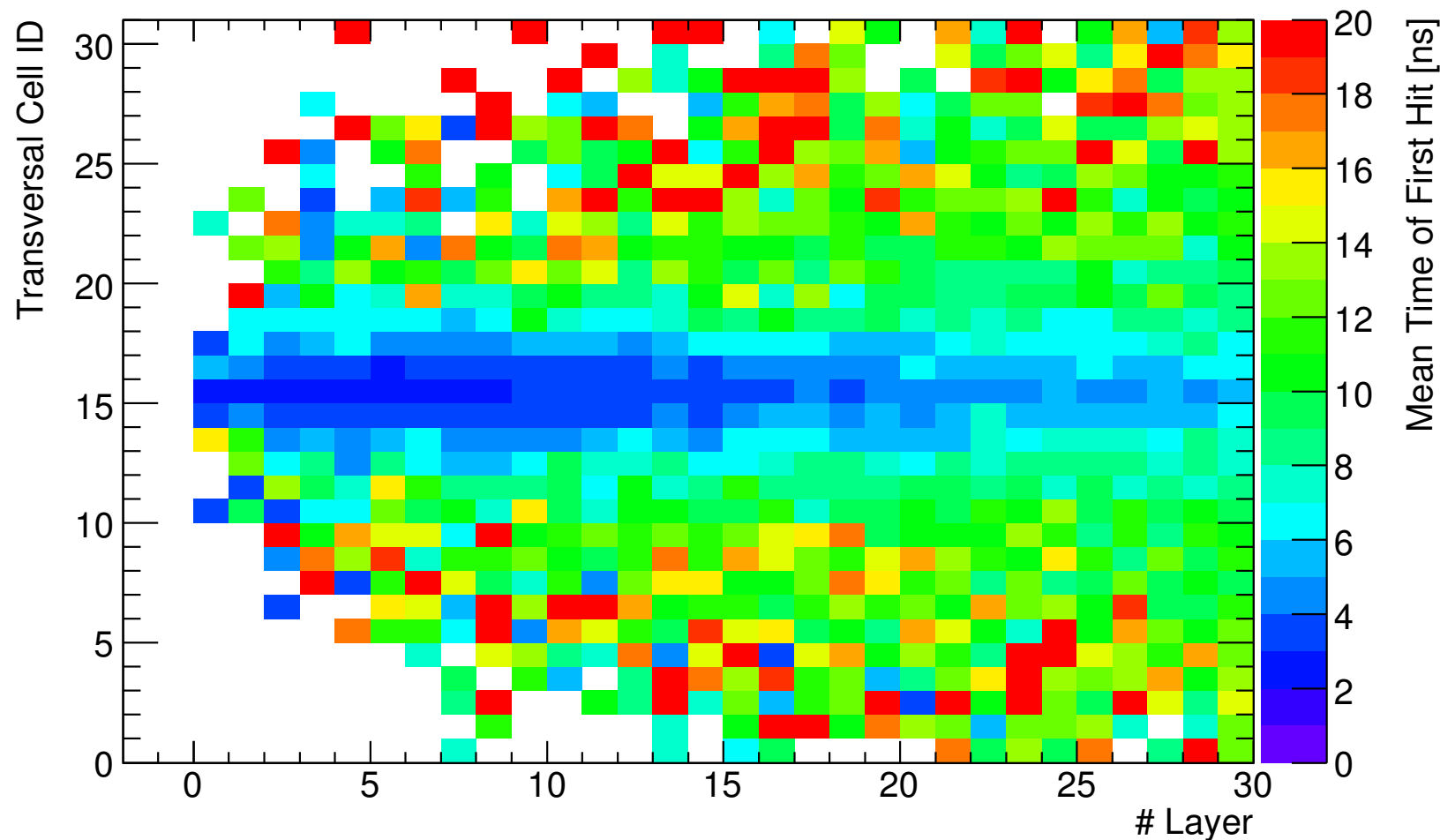
5GeV - Fraction of Total Energy Deposition



T3B Program: Planned Measurements - Time & Space

- Determine shower start point using full WHCAL data: Pin-point T3B location within the shower event by event
 - Allows the measurement of average time profiles over the full shower

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

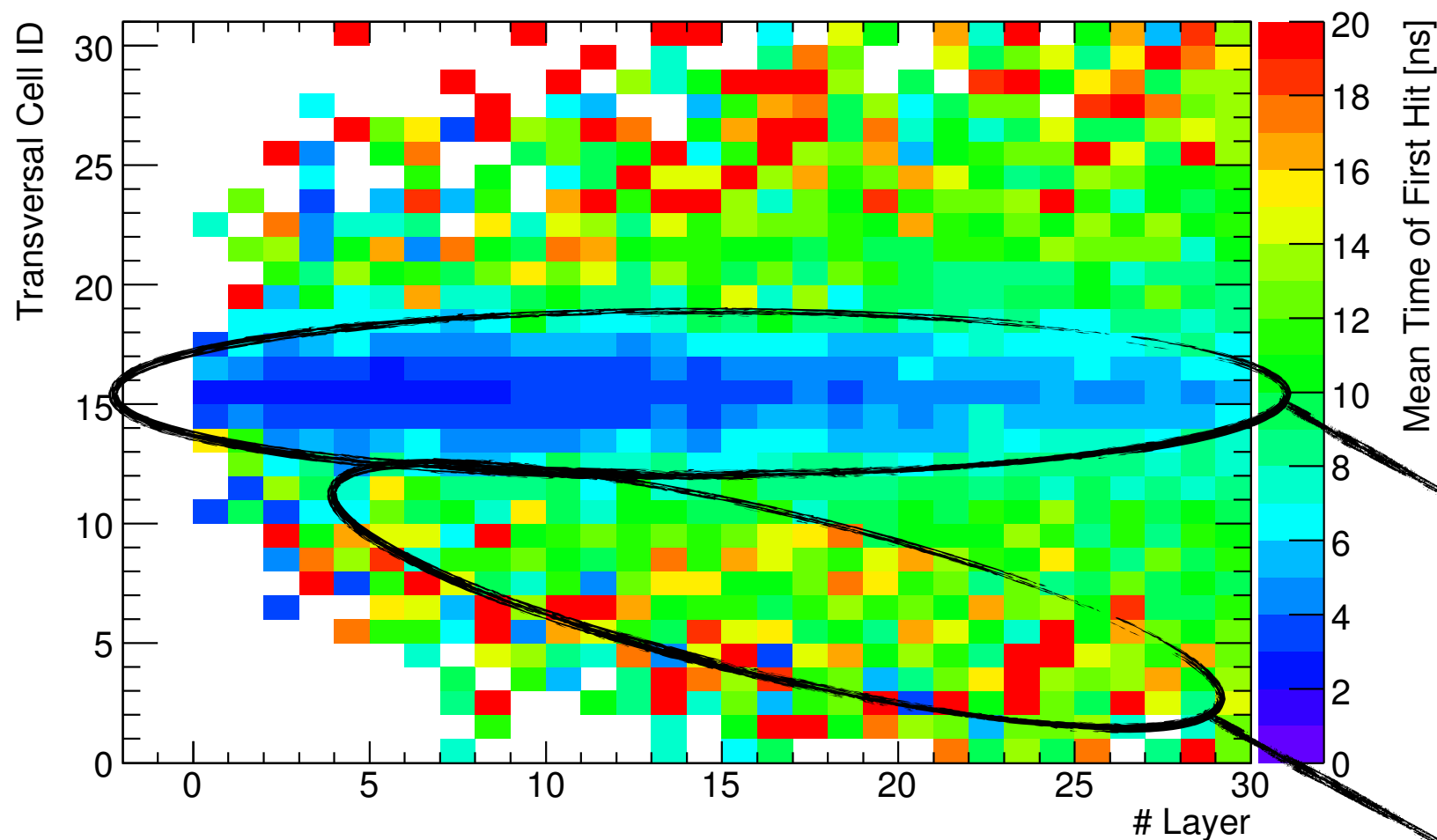


Average time of first hit (for cells which reach an energy > 0.3 MIP in the event)

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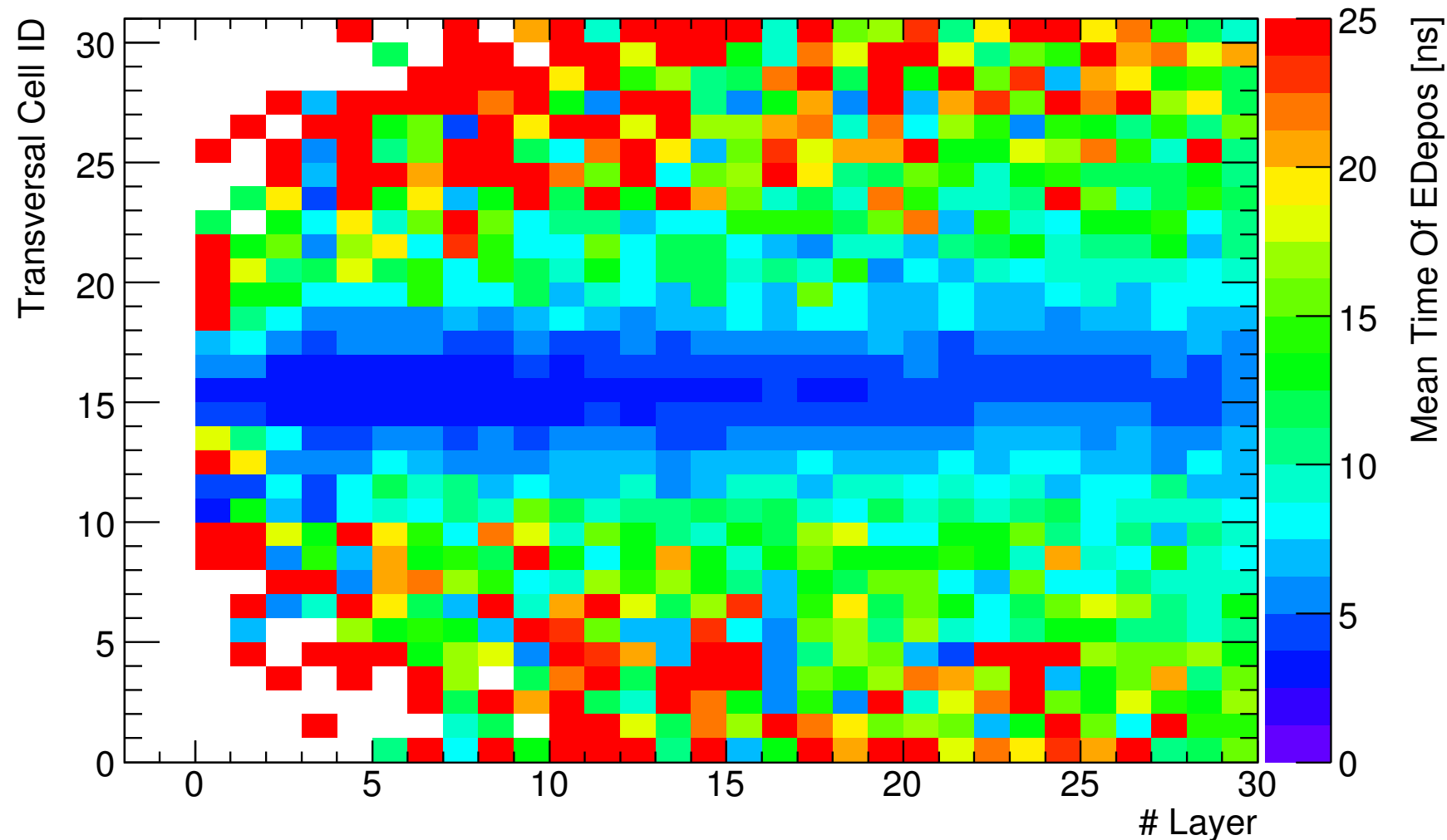
central shower region dominated by prompt deposits: time structure is mostly time of flight

outside the shower core, late deposits quickly become important

T3B Program: Planned Measurements - Time & Space

- Analogous: Mean time of all energy deposits, relative to the shower start

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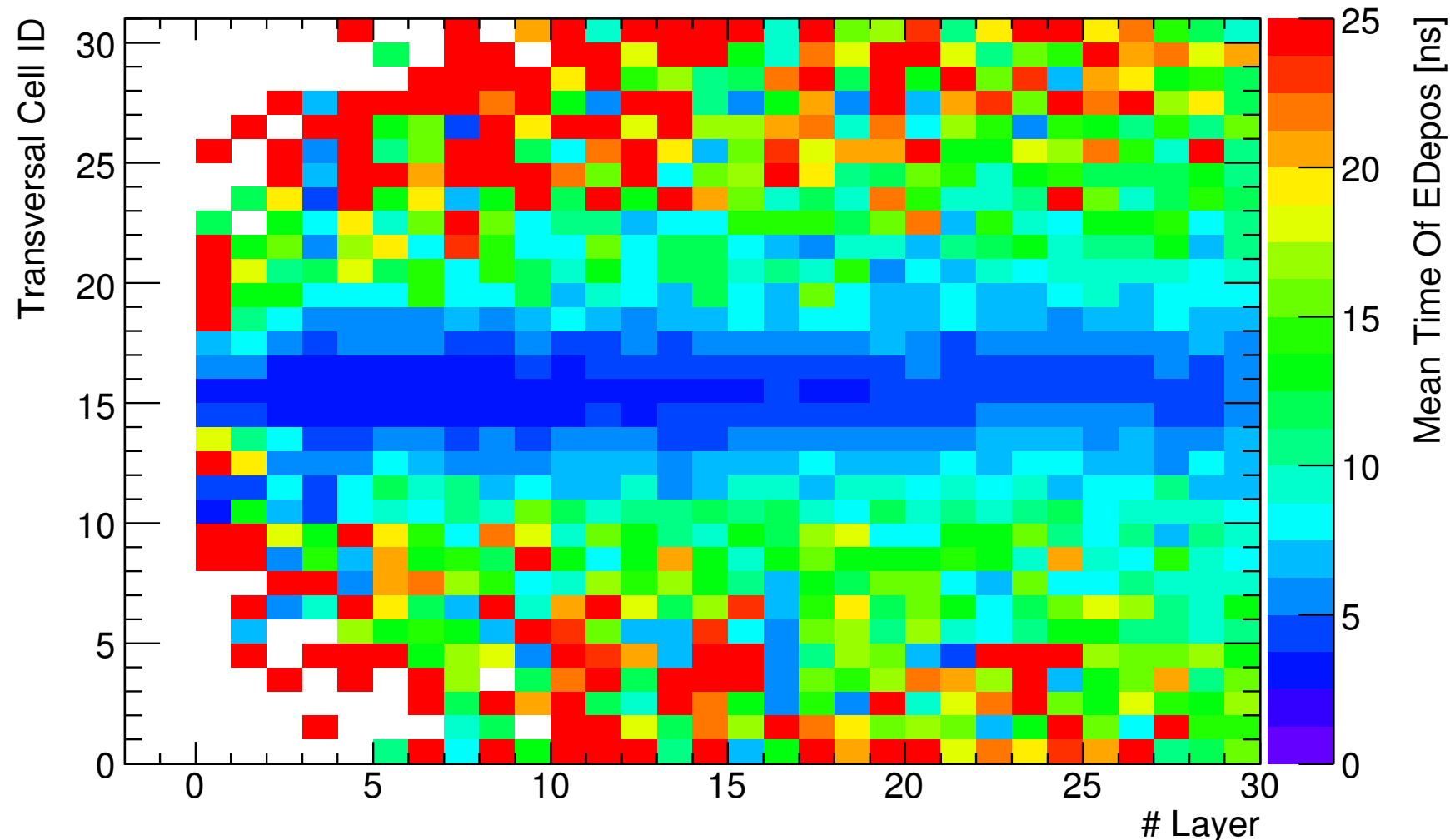


Shower core characterized by prompt energy deposits, delayed deposits contribute significantly ~ 10 cm and more away from the shower axis

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In general: T3B will look at space-resolved averages of time distributions, event by event studies need time resolution in all calorimeter cells

Summary & Outlook

- Time resolution is important at CLIC: High hadron background combined with 2 GHz bunch crossing frequency
- Hadronic showers are not instantaneous: Limits to the time resolution of the hadronic calorimeters
- In the upcoming test beam of a Tungsten HCAL, T3B will provide a first measurement of the averaged time structure of hadronic showers
- Event-to-event measurements of the time structure require a full “4D” calorimeter: Time resolution in every calorimeter cell
 - Possible with the next generation of CALICE AHCAL electronics, currently in production