Time development of showers in a Tungsten-HCAL

Calice Collaboration Meeting – Casablanca 2010

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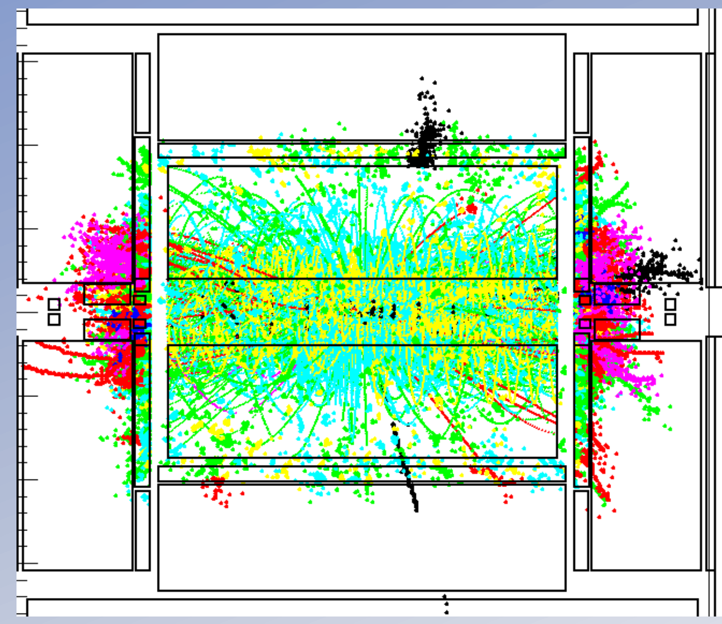
Outline

- Introduction: The Need for Timing at CLIC
- ILD vs. CLIC_ILD: A Comparison (Mark Thomson)
- The Road to a first Timing Measurement: T3B Simulations
- Summary

INTRODUCTION:
THE NEED FOR TIMING AT CLIC

Challenges to a CLIC Calorimeter



Calorimetry at CLIC is challenging:

1. Multi-TeV collision energies require a very dense absorber to contain particle showers

   → The solution (?): **Tungsten**

   $$\frac{X_0(W)}{X_0(Fe)} = 0.2 \qquad \frac{\lambda_I(W)}{\lambda_I(Fe)} = 0.6 \qquad \frac{\rho(W)}{\rho(Fe)} \approx 2.4$$

2. CLIC Bunch Separation: 0.5ns

   # BX/Bunch Train: 312 (in 156ns)

   → need event time stamping to reject background from $\gamma\gamma$-Interactions

   → require good time resolution in ALL detectors, also in the calorimeters

Is Tungsten suitable for that?

The Problem:

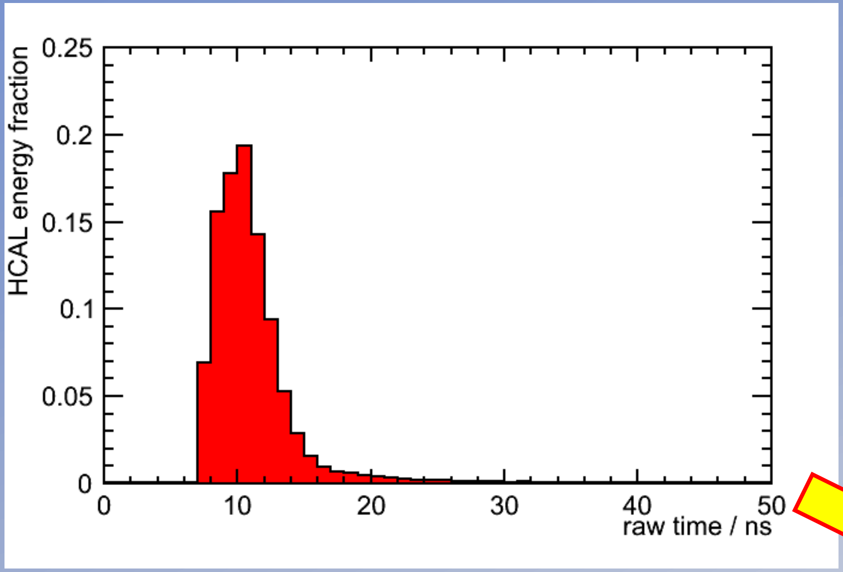
1. Showers are not instantaneous (e.g. slow neutron component)
2. Need to consider Time of flight of jet particles to the calorimeter

Optimal Time Stamping Precision is a balance between rejecting background and integrating the energy of a shower

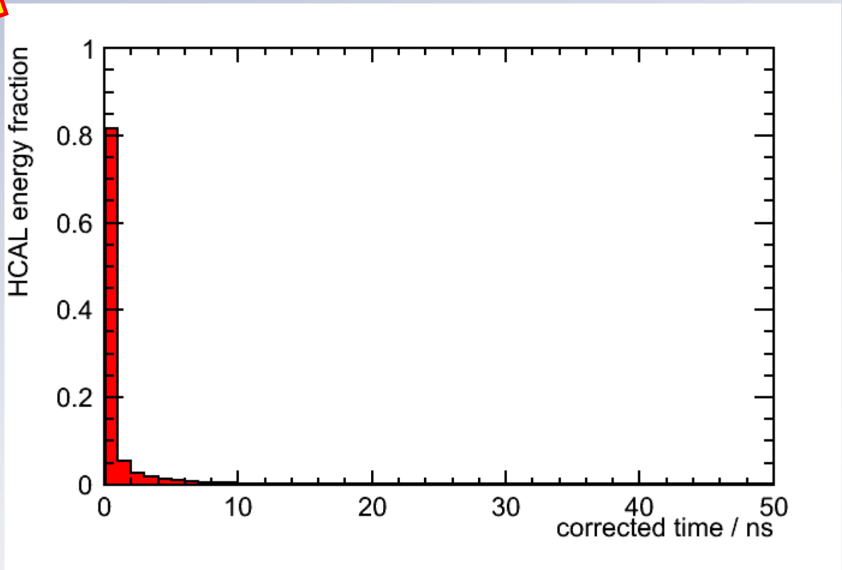
ILD VS. CLIC ILD: A COMPARISON

Timing at ILD: Steel HCAL

ILD Steel-Scintillator HCAL: Timing for 250 GeV Jets:

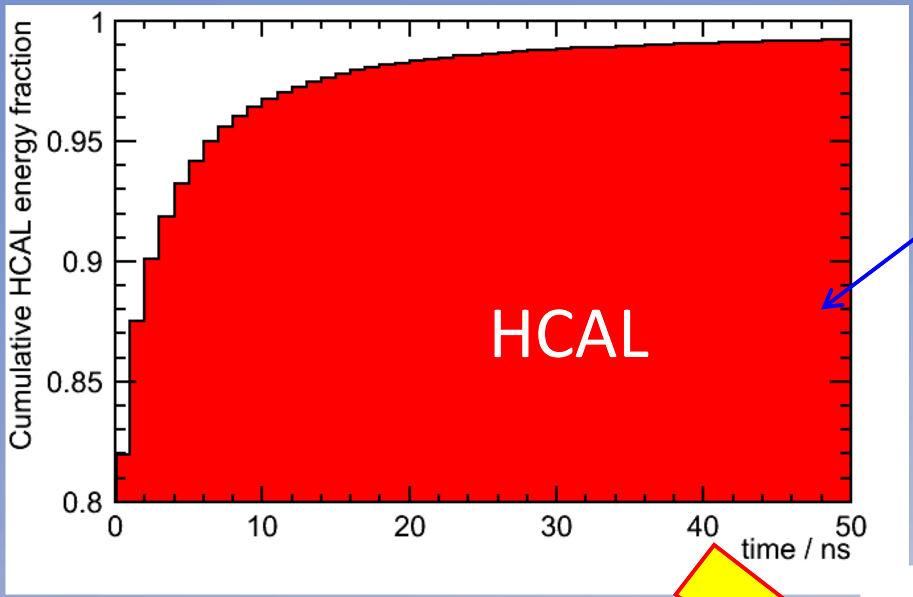


- Distribution dominated by time of flight to HCAL
- Long tail from low energy neutrons out to ~1 μs



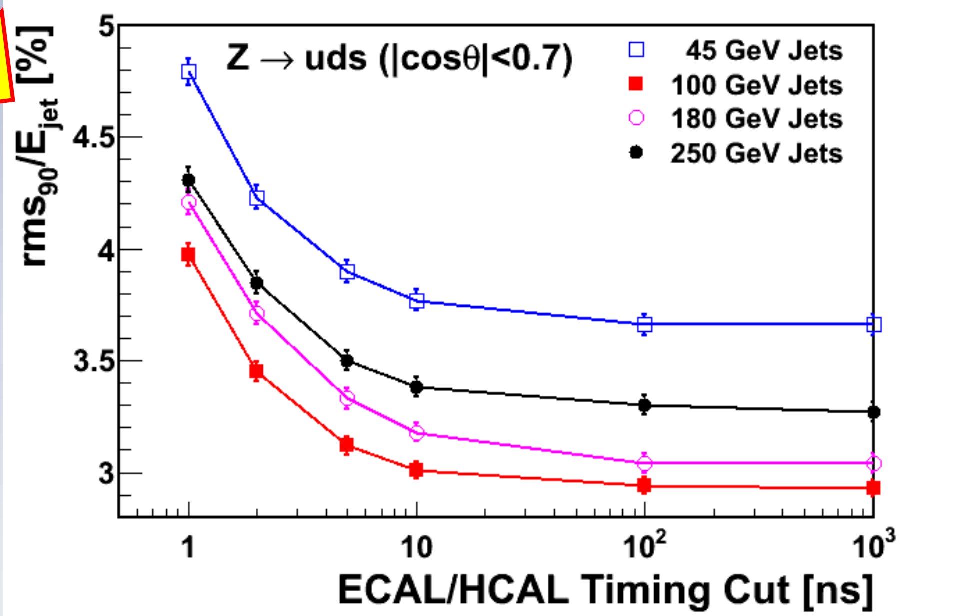
- Correct for time of flight using hit position assuming propagates at speed of light
- 90 % of energy deposited in first few ns

Timing at ILD: Steel HCAL



Corrected for ToF

- 95 % of energy in 10 ns
- 99 % in 50 ns



- Suggests optimal timing window in range 5-10 ns

Now consider Tungsten

What about Tungsten?

- Iron is particularly stable
- Tungsten: both #n and #p far from closed shells

→naively would expect more nuclear interactions with Tungsten

↓↓↓

Problem: expect longer time profile (decays, secondary interactions)

Furthermore: not clear how well modeled in Geant 4

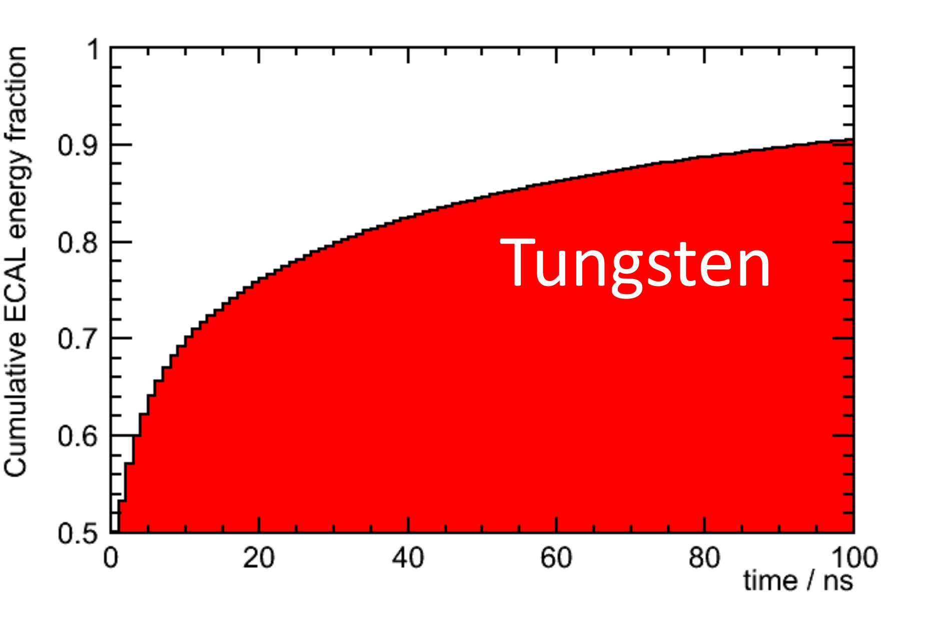
Study with CLIC_ILD model:

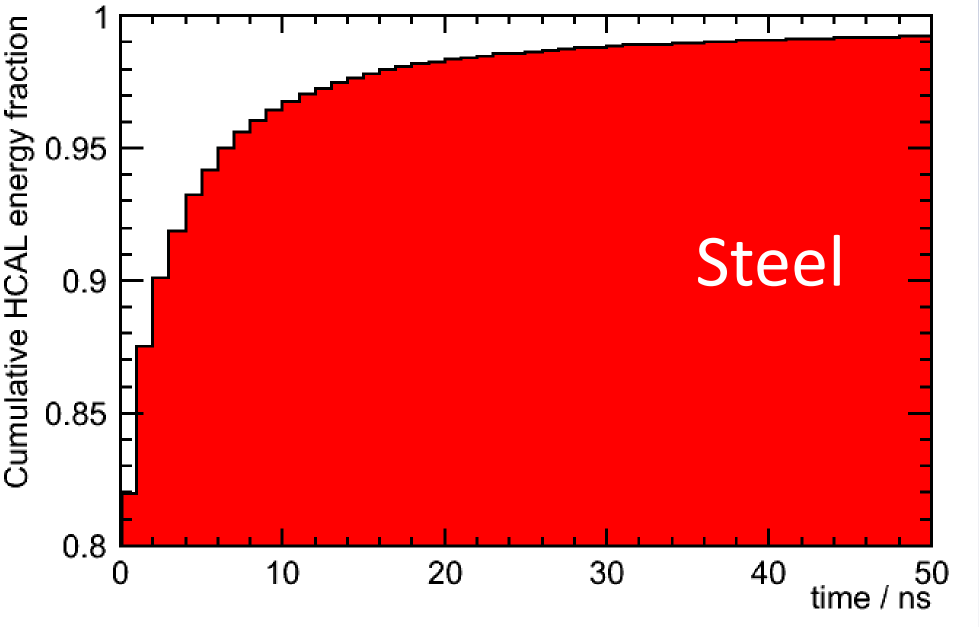
- generated single K_Ls (QGSP_BERT)
- uses 0.3 MiP cut
- rejection of very isolated hits

Tungsten vs Steel: 25 GeV K_L

Tungsten is much "slower" than Steel

- only 80 % of energy in 25 ns
- only 90 % in 100 ns
- how much due to thermal n ?





Tungsten vs Steel: 25 GeV K_L

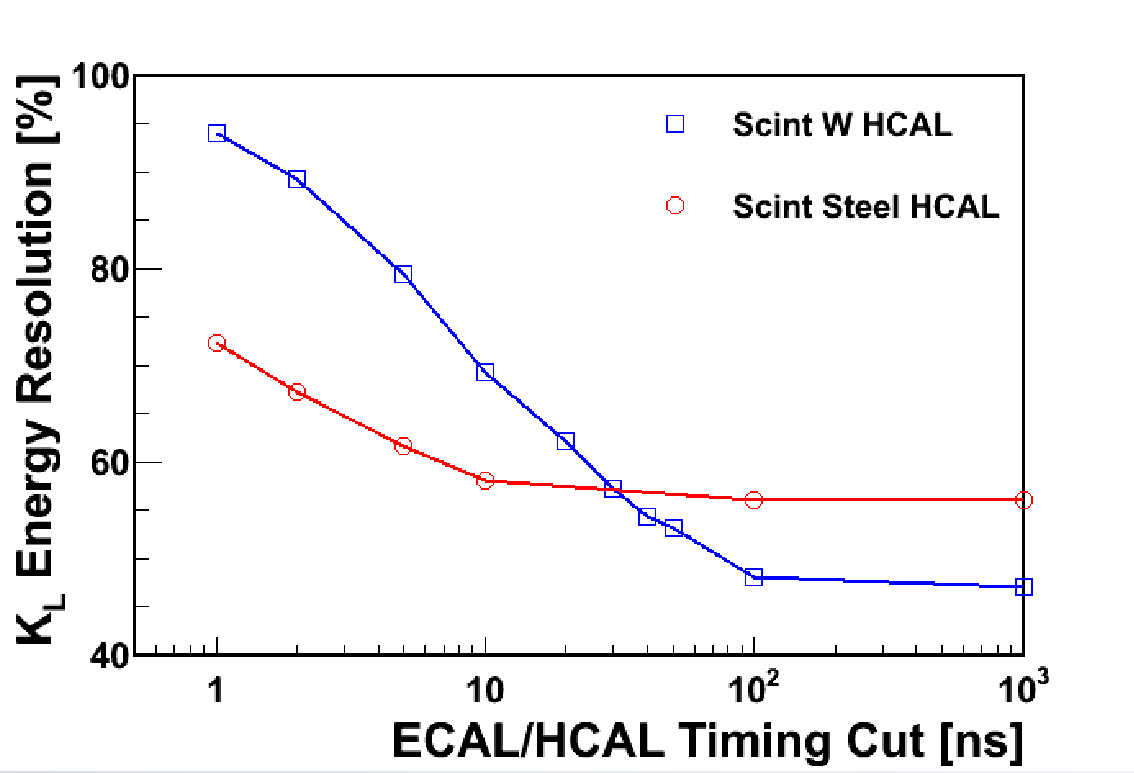
Study HCAL energy resolution vs time window for Tungsten vs Steel:

Dependence much stronger for W HCAL

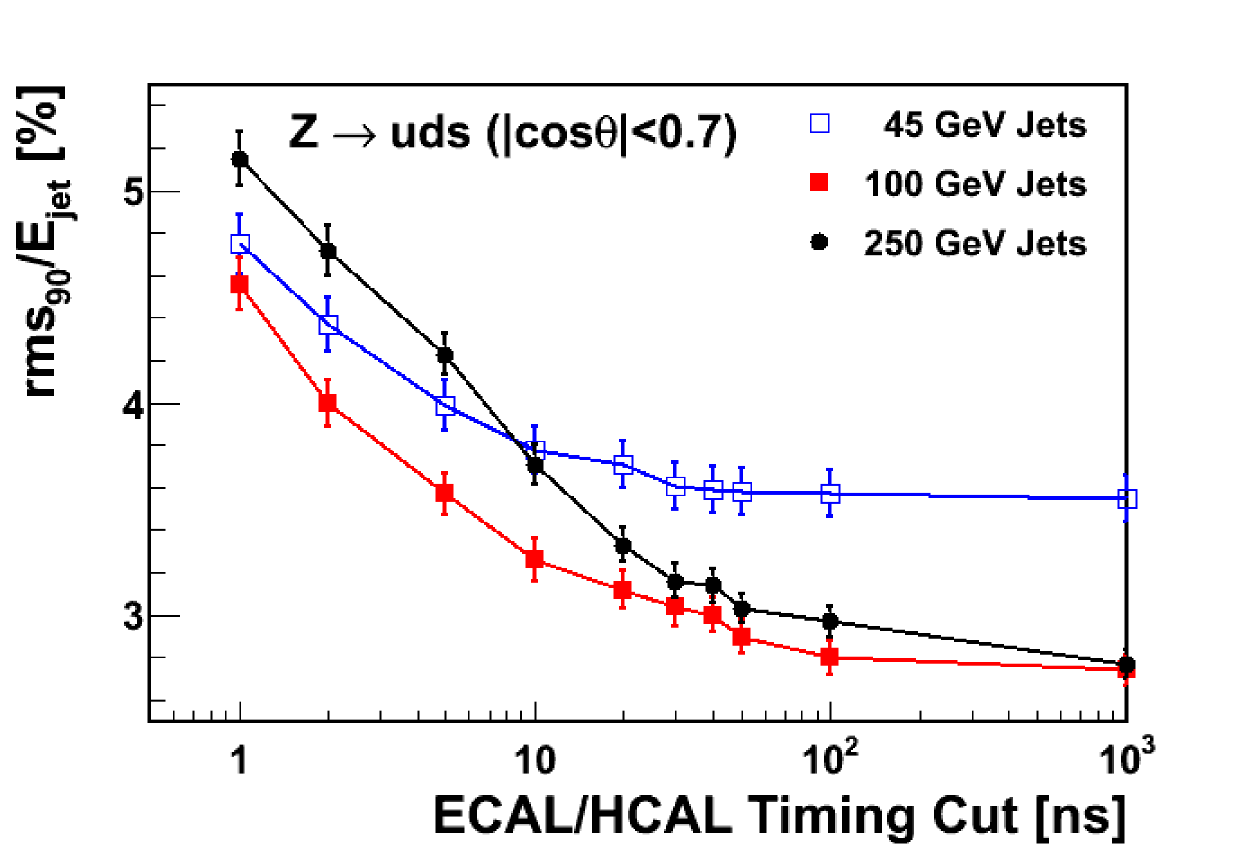
→reflects larger time spread

For decent HCAL performance, i.e. $60\,\%/\sqrt{E}$

→need to integrate over 20ns !



PFA Performance vs time cut: uds



- For no time cut (1000 ns) peformance of CLIC_ILD very good
  - somewhat better than ILD (thicker HCAL, larger B)
- For high(ish) energy jets – strong dependence on time cut
  - suggests time window of > 10 ns
  - need something like 50 ns to get into “flat region”

THE ROAD TO A FIRST TIMING MEASUREMENT: T3B SIMULATIONS

CALICE AHCAL Test Beam

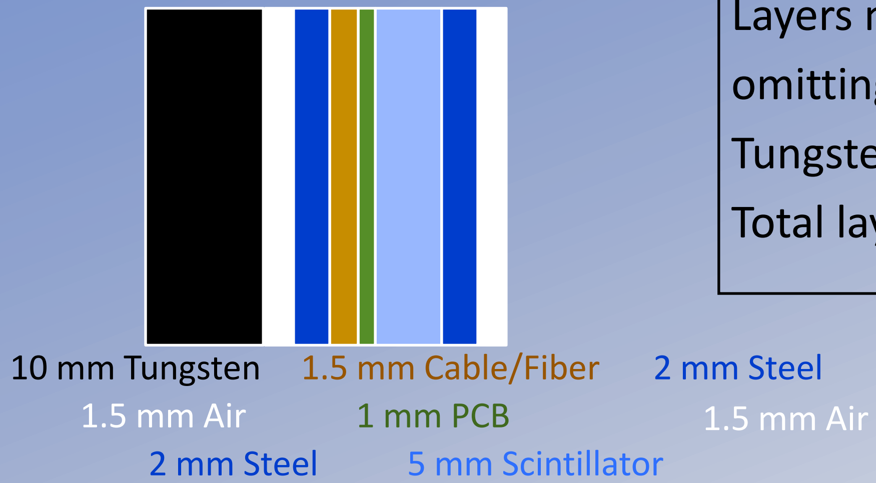
- CALICE Program at CERN T9 test beam area at PS:
  - Beginning of Sept.: Successful installation of Scintillator Tile Cassettes with Tungsten absorber plates (area T7)
  - Sept.-Okt.: (ongoing) Calibration with Muon Data and performance optimization
  - 8.-22.Nov.: 3D study of hadron showers in a highly granular W-HCAL

Tungsten Timing TestBeam

- T3B Program (MPI with kind support of AHCAL group)
  - Install 1 timing layer consisting of a strip of 15 Scintillator Tiles behind the AHCAL (successfully tested during AHCAL installation period)
  - Readout cells with fast digitizers → 1.25GSa/sec (=800ps sampling)
  - Aim: Obtain first time resolved measurements of hadronic shower → November
  - Needs synchronisation with CALICE event trigger to determine the shower start (successfully tested during AHCAL installation period)

Simulations

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



Layers modeled after CALICE Geometry description, omitting 3M foil layer

Tungsten: 94% W, 4% Ni, 2% Cu, density 17.6 g/cm^3

Total layer thickness: 24.5 mm

- **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

Simulations

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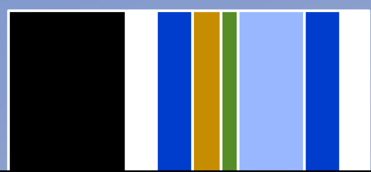


Layers modeled after CALICE Geometry description, omitting 3M foil layer

Tungsten: 94% W, 4% Ni, 2% Cu, density 17.6 g/cm^3

Beware: No digitization, no description of detector effects

Pure time and energy information from Geant4

- <u>Simulations</u>:
  - 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

- <u>Analysis</u>:

  - Assume one horizontal "strip" of 3 x 3 cm^2 scintillator cells (31 cells)

    (in reality we will have 15 cells, location to be chosen)

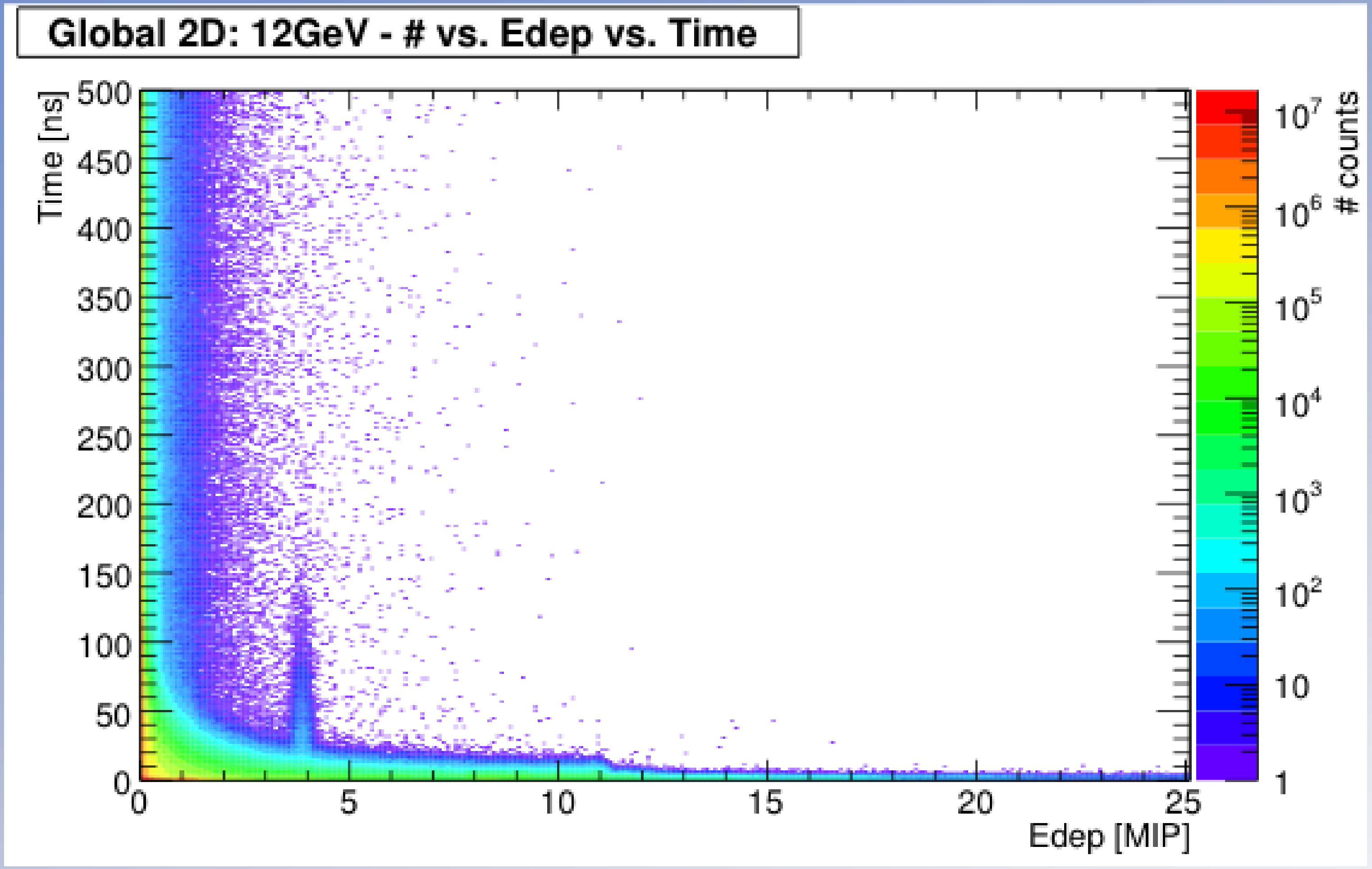
    - Focus on time stamp and hit energy
    - Find start point of the hadron shower:

      → Determine strip position relative to shower start

      → Reconstruct the timing of the shower development

  - For next Slide: Analysis of All active Layers → boost in statistics

Rich Time Structure in a Tungsten Calorimeter
Problem for a Timing HCAL?



Measuring a distribution like this requires enormous statistics

→In Test Beam Experiment: Probably not measurable in this detail, but

→Standalone run would increase the DAQ rate

Rich Time Structure in a Tungsten Calorimeter
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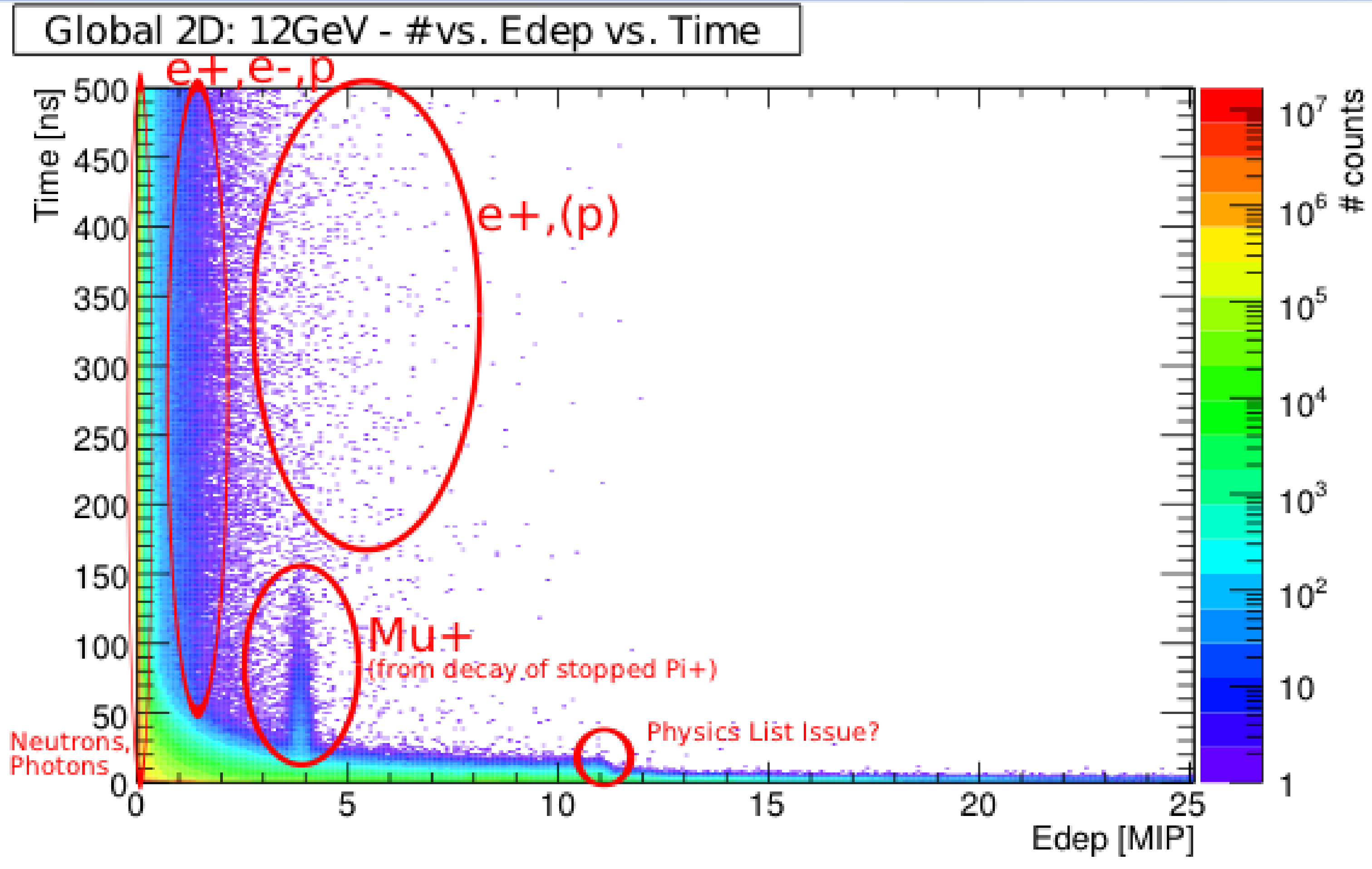

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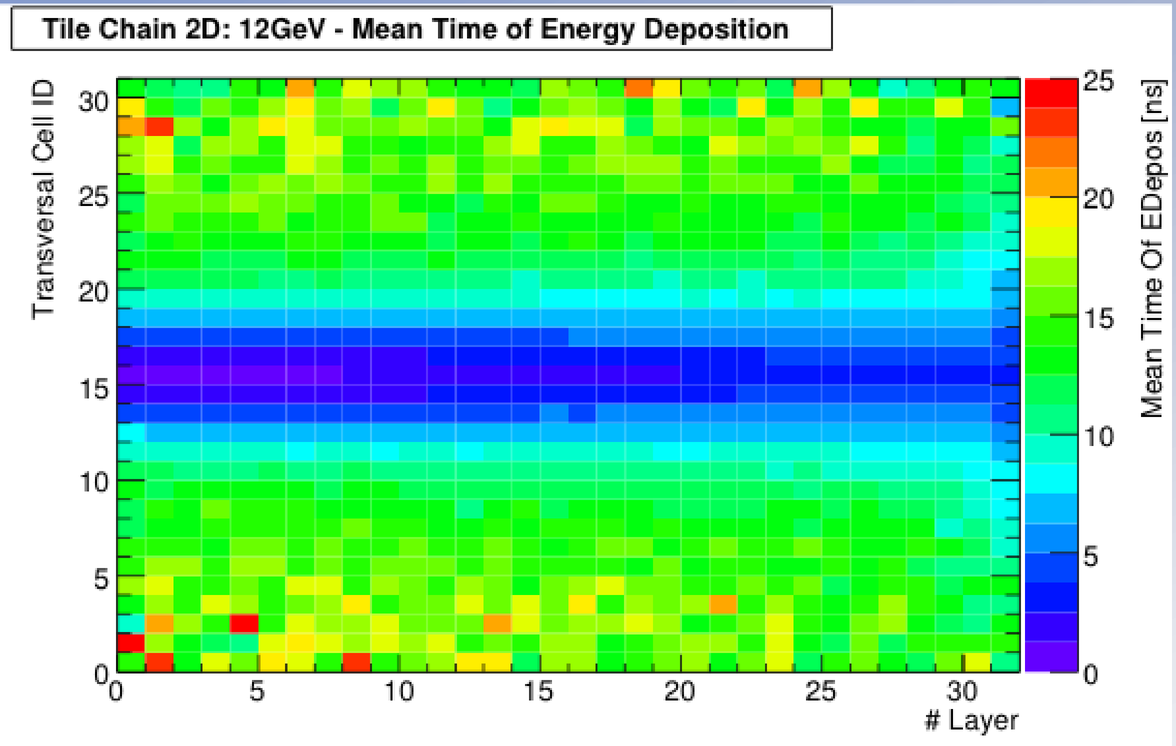
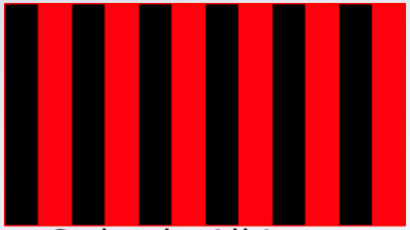
Timing of Hadronic Showers
Mean time of Edep, Mean Time of first Hit

Global: No shower start finder, Assume timing strip in all layers



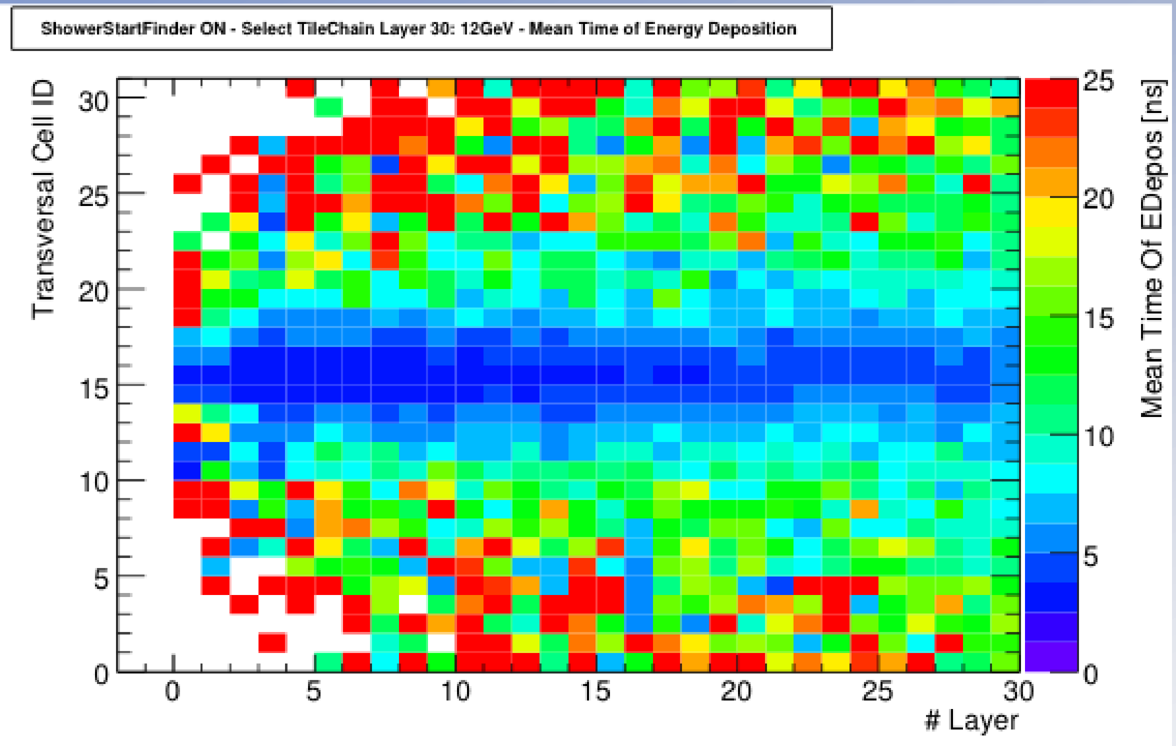


Strips in All Layers

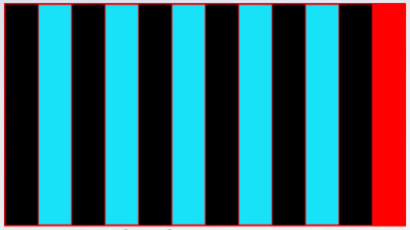
Timing of Hadronic Showers
Mean time of Edep, Mean Time of first Hit

Global: No shower start finder, Assume timing strip in all layers

→ Switch on shower start finder, Timing strip in layer 30
Full mapping of the time structure of (averaged) showers 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



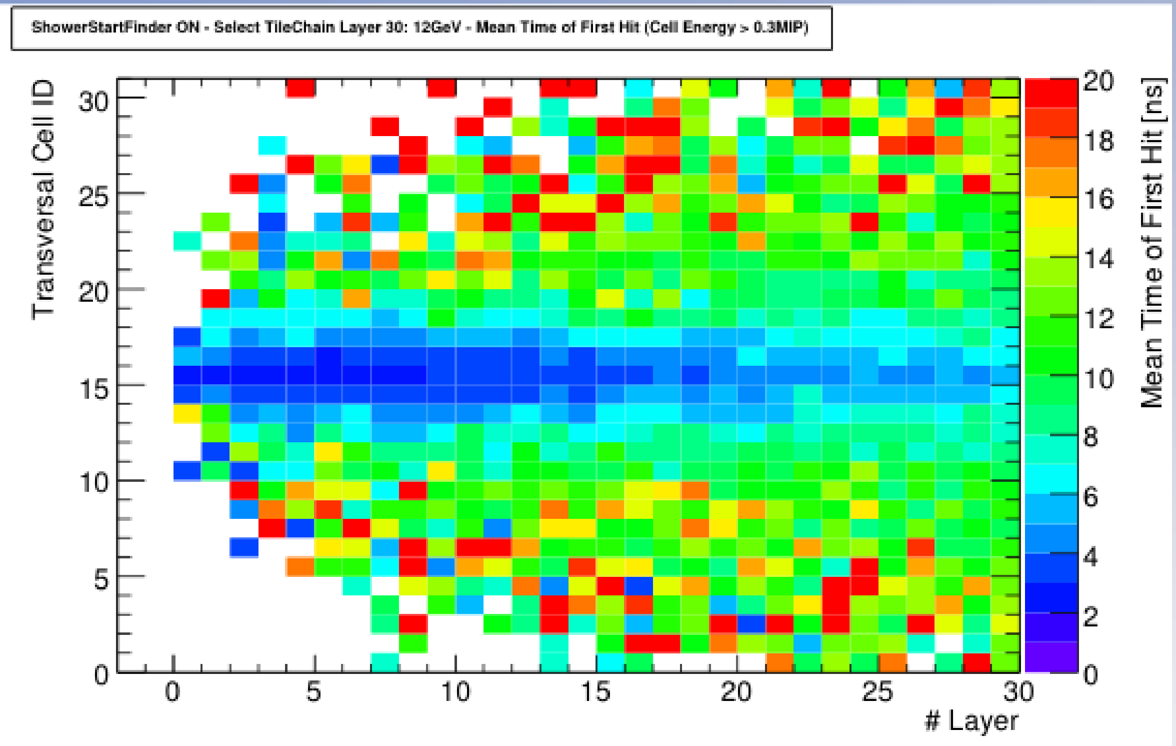
Strip in Layer 30

Timing of Hadronic Showers
Mean time of Edep, Mean Time of first Hit

Global: No shower start finder, Assume timing strip in all layers

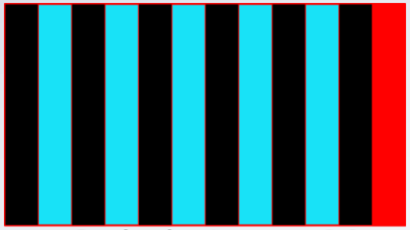
→ Switch on shower start finder, Timing strip in layer 30
Full mapping of the time structure of (averaged) showers possible

→ Mean Time of first Hit (cell energy > 0.3MIP demanded)



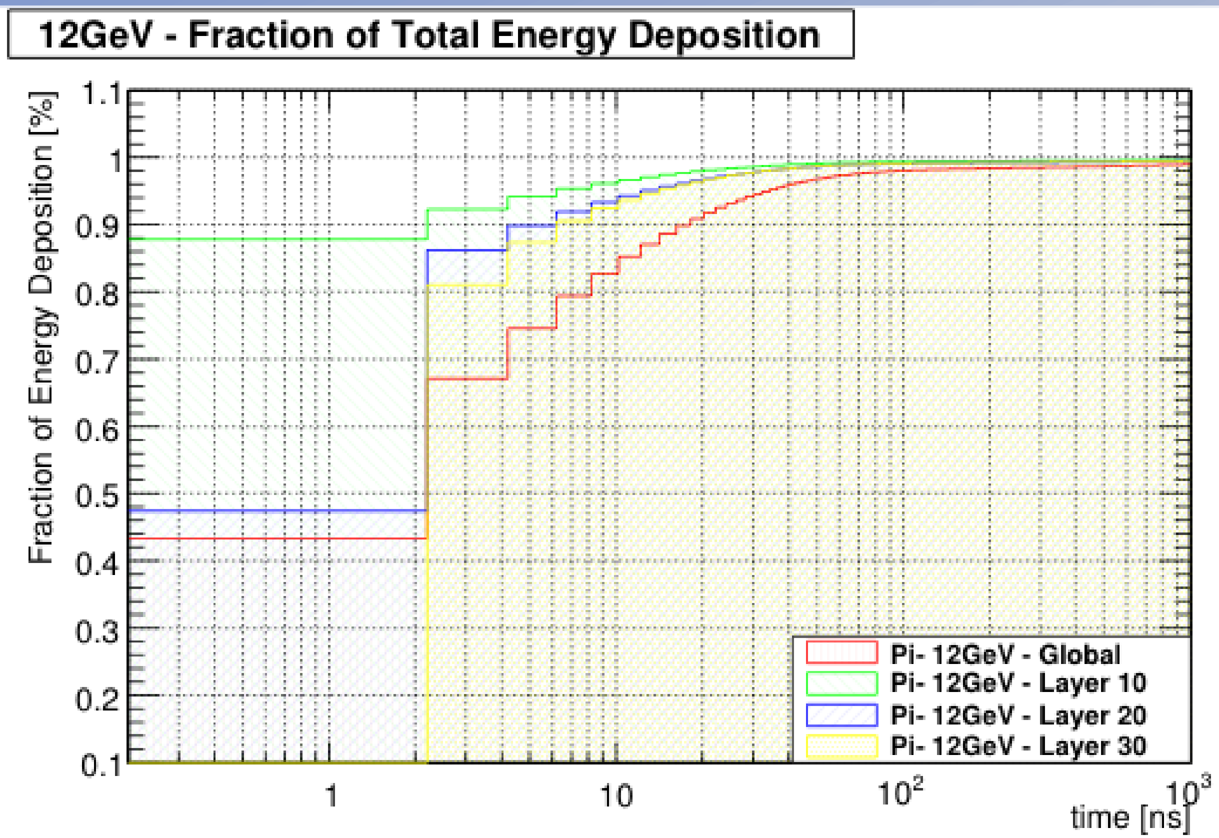
<u>Time of FH shows:</u>
Hadronic showers are slow
~10 ns outside shower core

<u>Challenge at CLIC:</u>
Use Time of FH to match Event approx. with bunch crossing



Timing of Hadronic Showers
Cumulative HCAL Energy fraction

Time resolved fraction of total Edep vs. Time:
→ Significant fraction of event energy arrives late
→ Dependent on position in HCAL

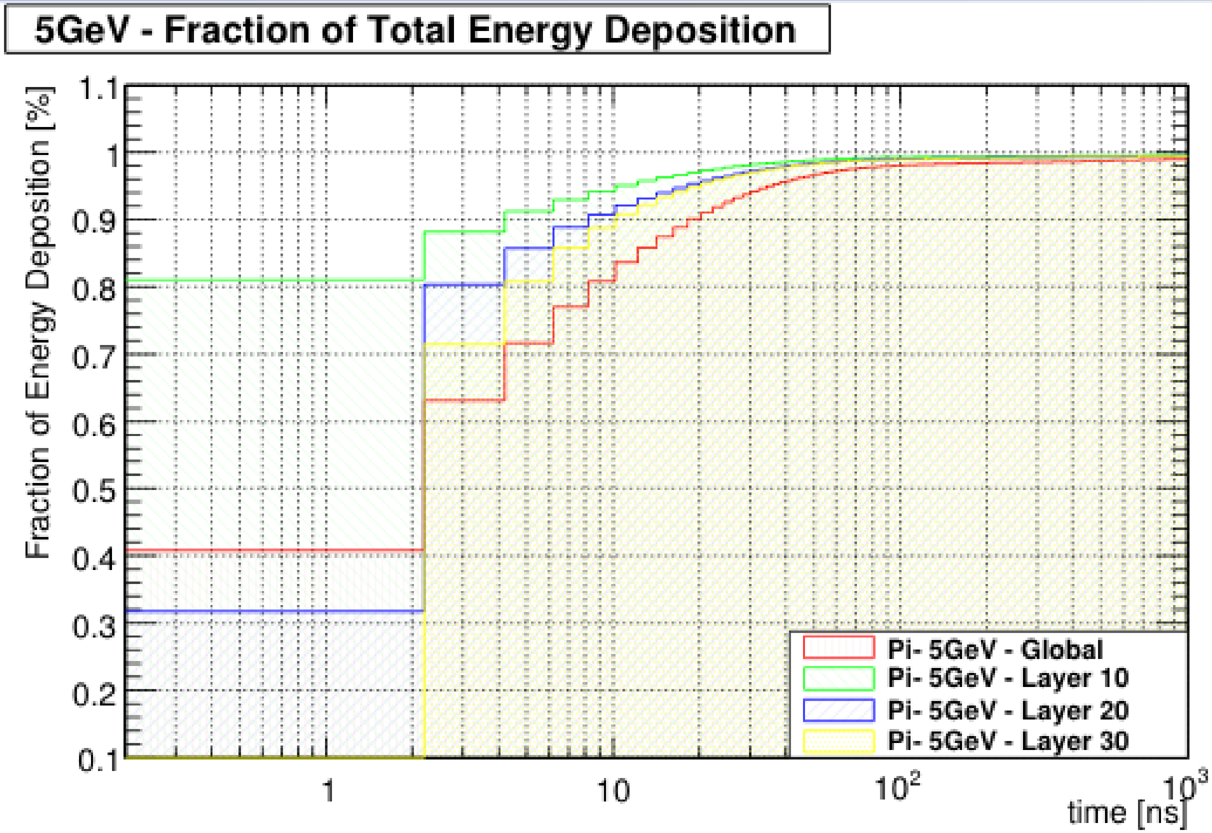


Global:
Only ~80% in first 10ns

Strip in Layer 30:
~90% in first 10ns

Timing of Hadronic Showers
Cumulative HCAL Energy fraction

Time resolved fraction of total Edep vs. Time:
→ Significant fraction of event energy arrives late
→Dependent on position in HCAL and the projectiles' energy
So far we have only simulations → might be uncorrect as never tested
We hope the T3B experiment can unearth the truth!



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Strip in Layer 30:
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SUMMARY

Summary

- Tungsten leads to a longer time distribution of hits
  - for “reasonable” performance need to integrate over 10s of ns
- Is Tungsten is reasonable choice for a CLIC HCAL absorber?
- Not clear at this stage – a number of questions
  - how good is simulation?
  - how much can be recovered offline?
    - i.e. integrate over some part of bunch train in reconstruction and
    - then tag BX for clusters

- Road to a first Shower Timing Experiment
  - A full timing study requires a completely instrumented W HCAL

    → Still a long way till we might get there!
  - Wide range of measurements possible with a single strip of scintillator tiles with time-resolved readout

    → Particularily powerful in combination with shower start information through Sync with CALICE HCAL

Special Thanks to:

- Mark Thomson

for providing valuable material for this talk