IF06: Precise Timing

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Max-Planck-Institute for Physics

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FÜR PHYSIK

White Paper:
Precision timing for collider-experiment-based calorimetry

Editors: Sergei Chekanov (ANL), Frank Simon (MPP)

- Applications of Timing
- System Options
- Technologies

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Precision timing for collider-experiment-based calorimetry

Editors: S. V. Chekanov[1], F. Simon[2]

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Applications of Timing in Calorimetry

Object and Event Reconstruction

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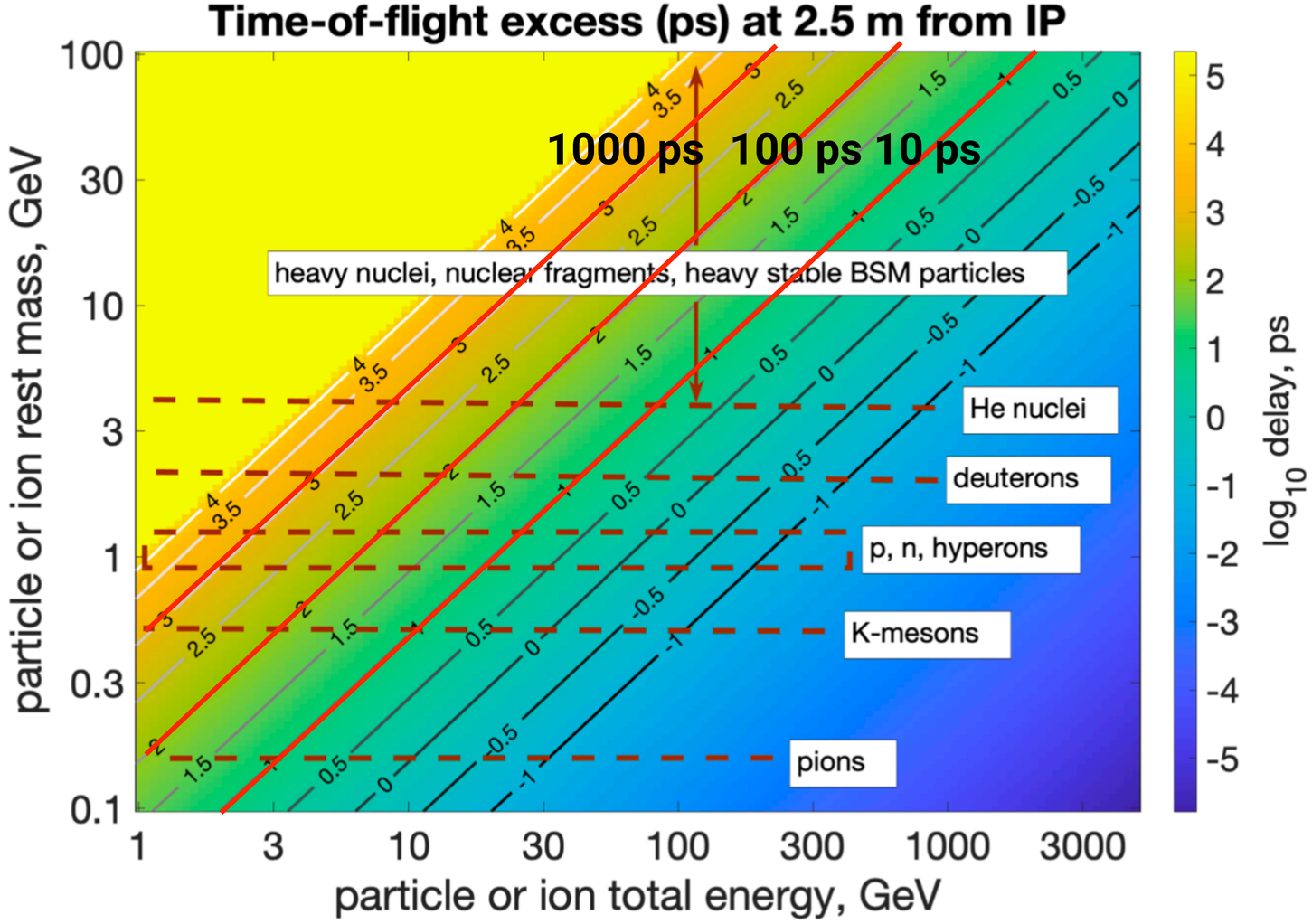
- Particle identification - combining energy and time (and momentum for charged particles):



- With a few 10 ps time resolution, particle ID above the pion mass becomes possible
- Particular potential for heavy hypothetical particles: Larger time offsets
  - Standalone in the calorimeter with at least two precise timing layers, for particles without known production vertex

Applications of Timing in Calorimetry

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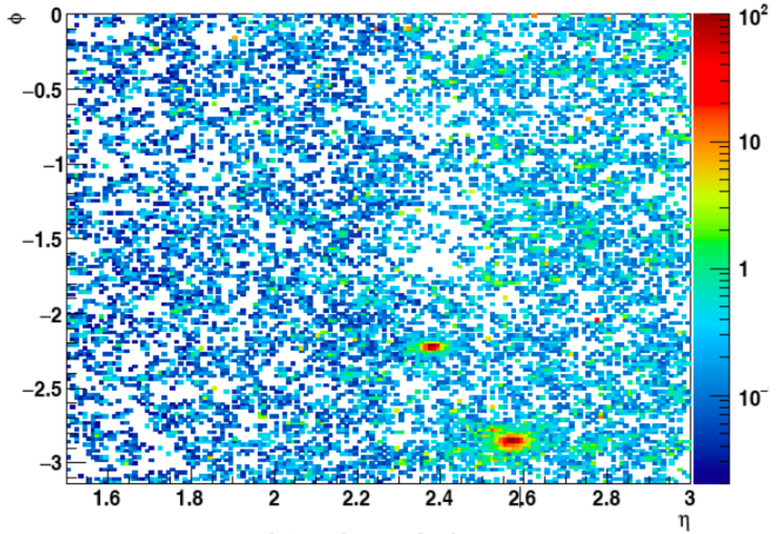
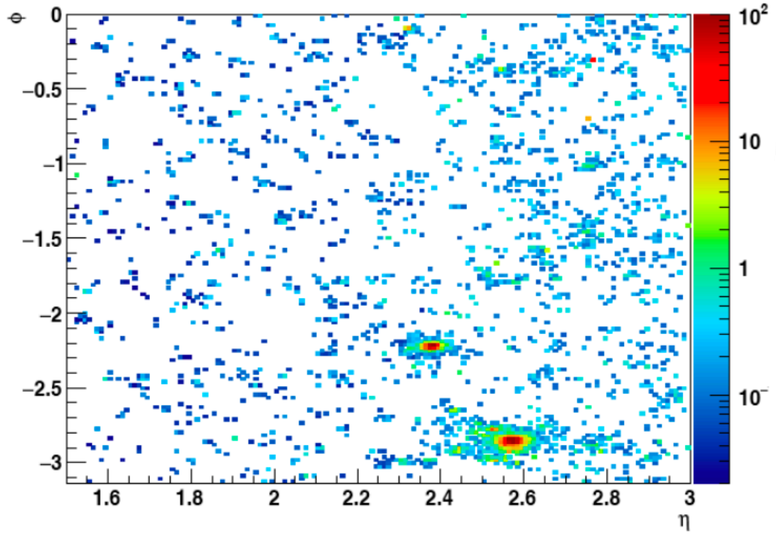


CMS HGCAL

timing cut



- Pattern reconstruction and pileup rejection
  - Timing on the few 10 ps level enables to reject pileup (particles from the same BX, but slightly out of time / position wrt interesting collision)
    - At FCC-hh: 5 - 10 ps required to reach HL-LHC-like conditions
  - Timing also cleans up hadronic activity: Narrow core of em subshower, much wider hadronic activity, neutron halo

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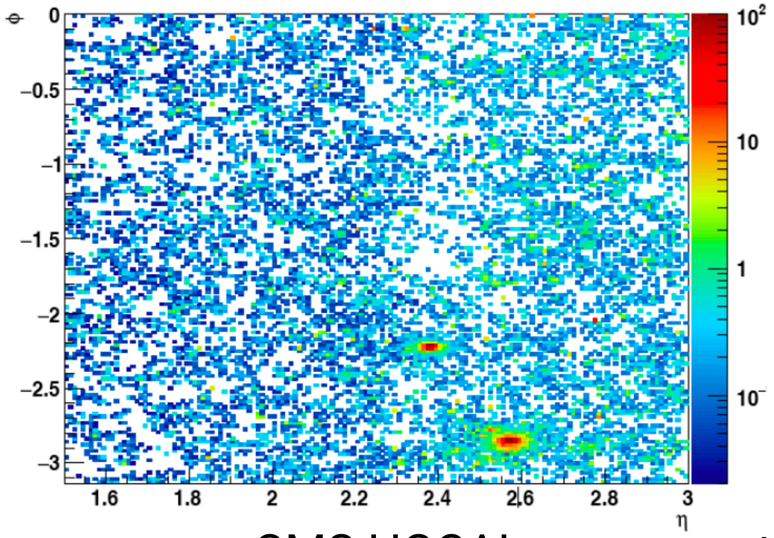

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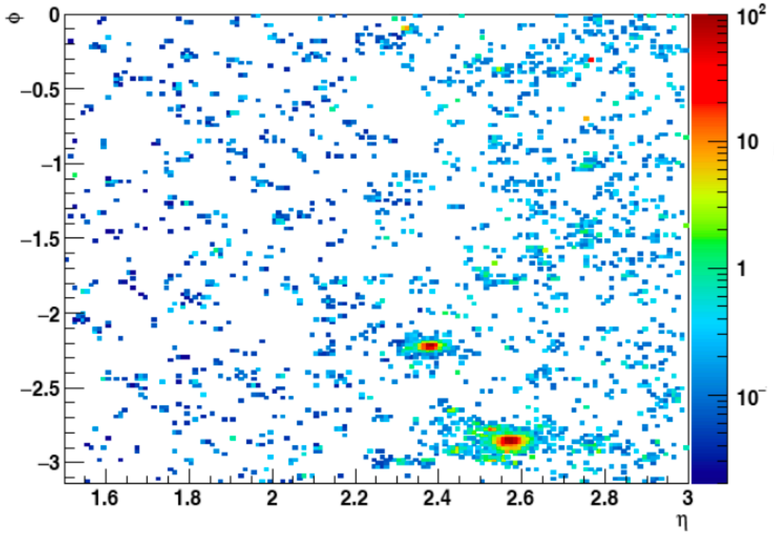

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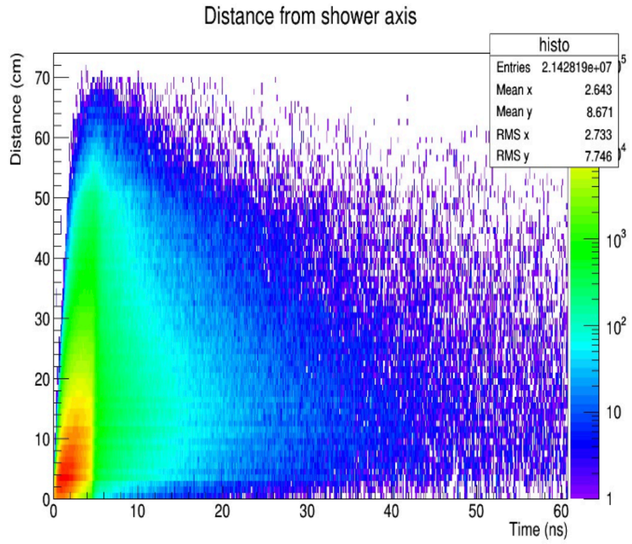
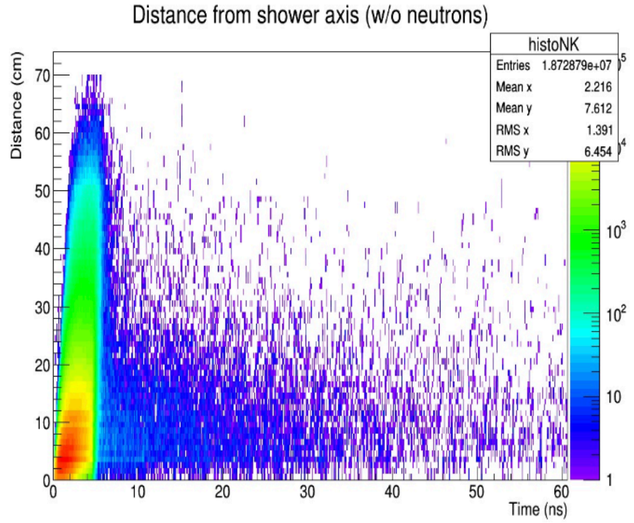
Illustrated for gaseous HCAL (CALICE SDHCAL):

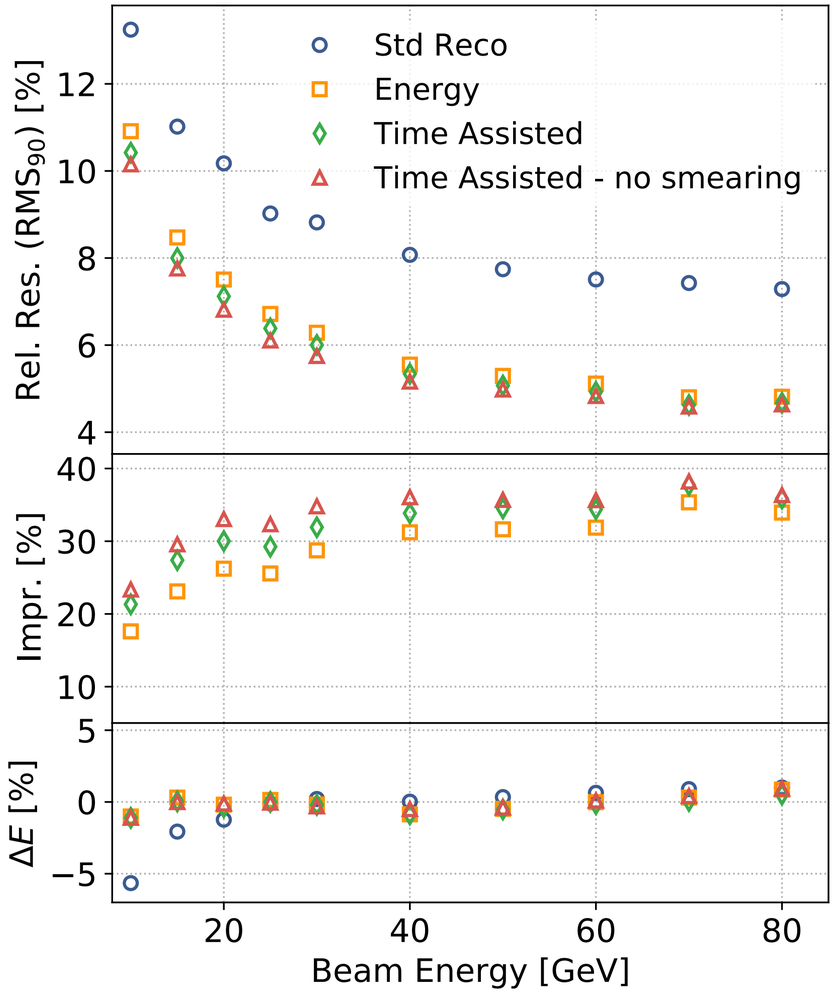




Applications of Timing in Calorimetry

Hadronic Energy Reconstruction

- Hadronic energy reconstruction in non-compensating calorimeters



- Using time in software compensation: Exploiting delayed nature of neutron signals, which track hadronic activity.
  1 ns resolution helps, slight further potential when reaching the ~ 100 ps level (on cell-by-cell basis)

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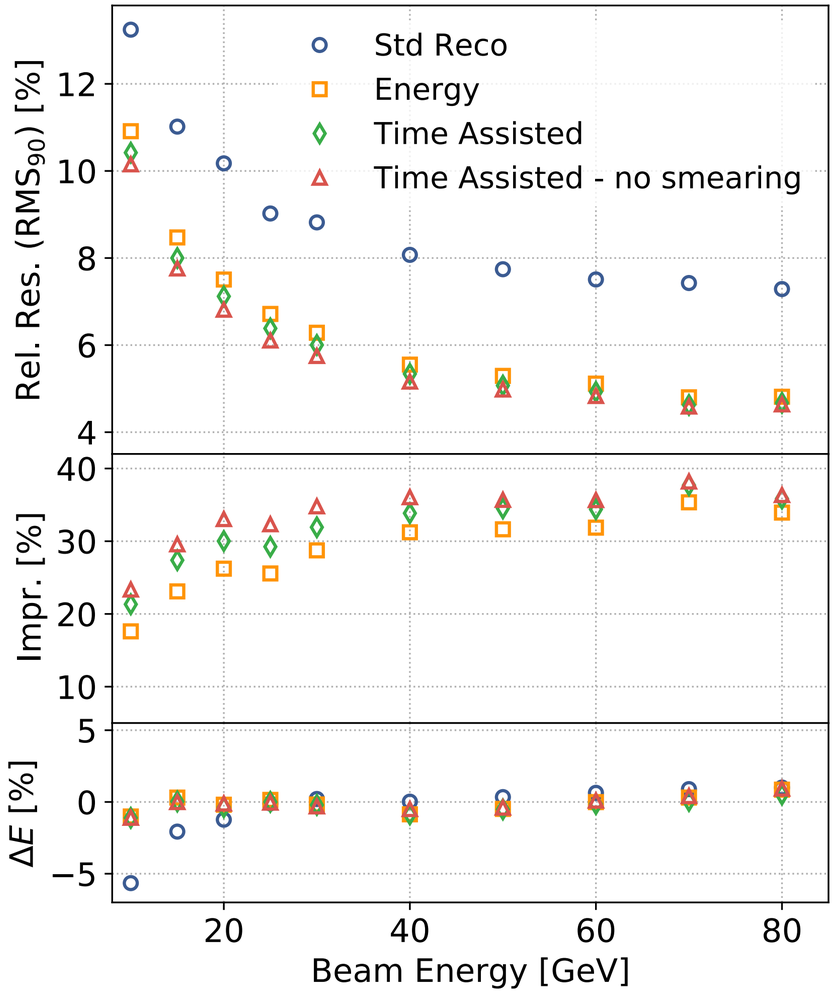
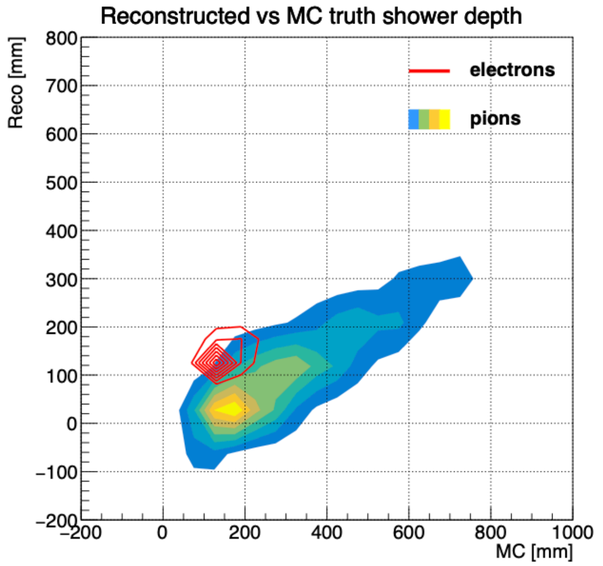
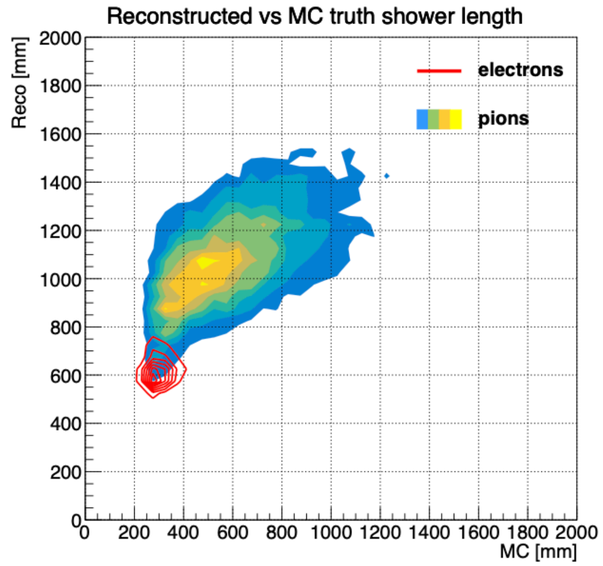


- Using time in software compensation: Exploiting delayed nature of neutron signals, which track hadronic activity.
  1 ns resolution helps, slight further potential when reaching the ~ 100 ps level (on cell-by-cell basis)
- As a means of reconstructing the shower profile in longitudinally unsegmented DR calorimeters





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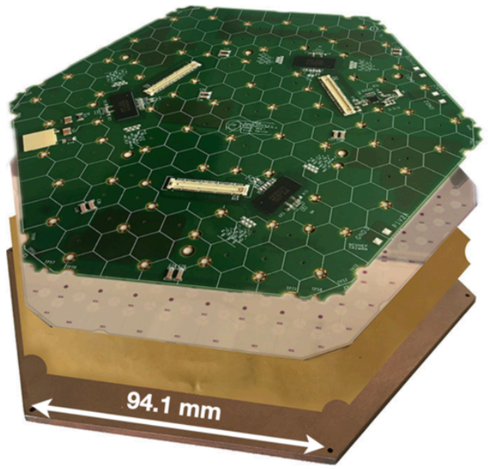
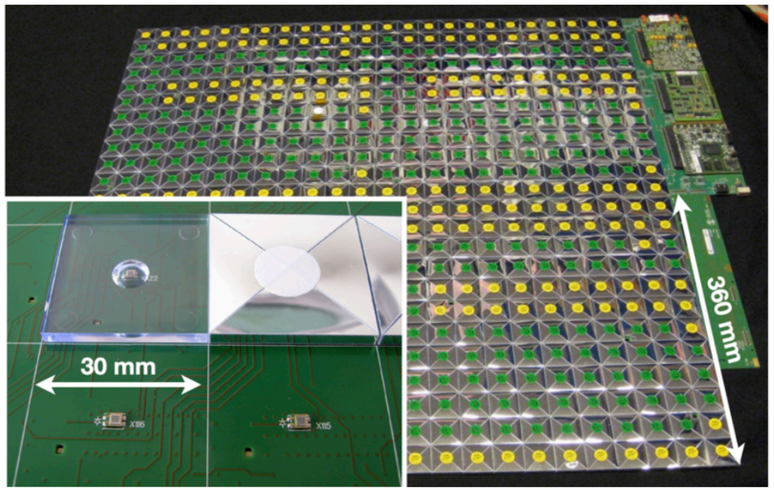
System Options

Volume Timing vs Timing Layers

- ***Volume timing***: good time resolution on the cell level in highly granular calorimeters
  - requires technologies that can provide this timing; significant implications for electronics
  - potential compromises in timing for objects





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- ***Volume timing***: good time resolution on the cell level in highly granular calorimeters
  - requires technologies that can provide this timing; significant implications for electronics
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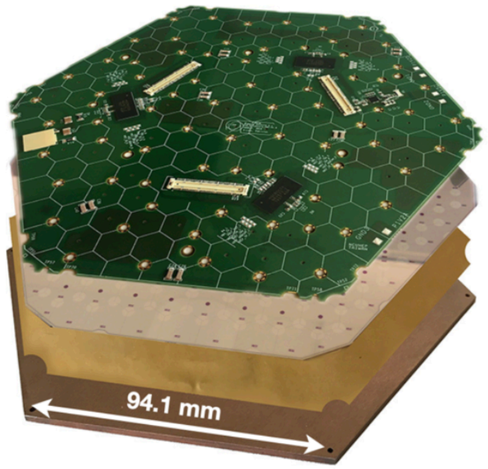
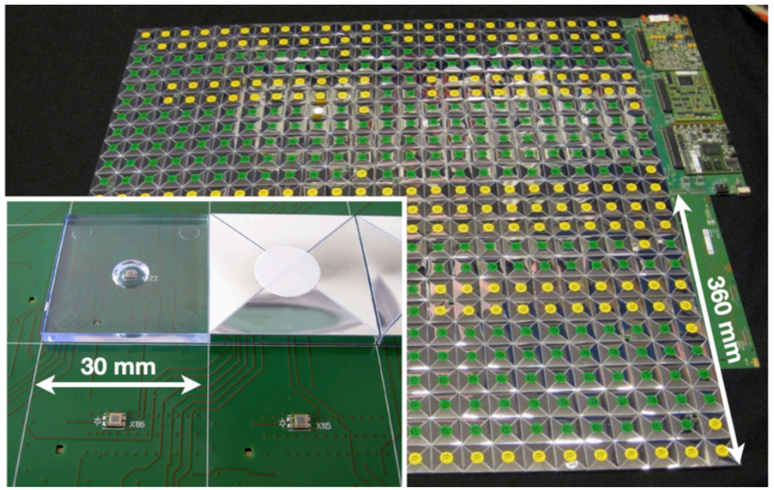
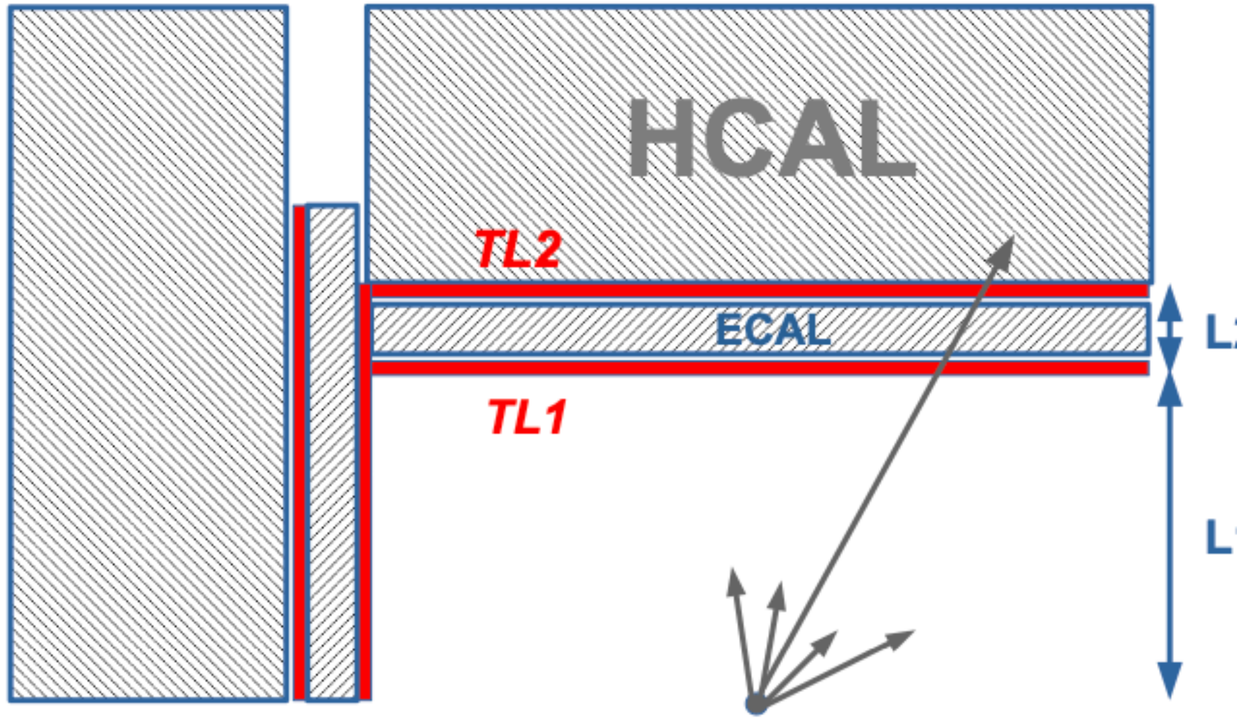
- ***Timing layers***: extreme timing in a few selected layers inside of the calorimeter system
  - can be combined with a wide range of technologies
  - excludes applications that require timing in the full shower volume, rather than on object level







Technologies

Some ideas - and points for discussion

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- Timing layers - 30 ps or less
  - LGADs
  - CMOS timing sensors
  - MCPs
  - Fast gas detectors
  - Very fast crystals + SiPMs (LYSO, …)
  - Microwave Cherenkov detectors
  - Ultra-fast Si detecteors

“the ps frontier”

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  - SiPM-on-Tile
  - RPCs, in particular MRPCs
  - Highly segmented crystal calorimeters
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A wide range of possibilities - choice will depend on application, performance needs, and cost.

Technologies

R&D Needs and Points for discussion

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- R&D needs - a selection:
  - Sensors: Improve time resolution, reduce cost
  - Electronics: Match sensor precision, while reducing power
    (power particularly critical for volume timing)
  - System aspects: Time synchronisation over full volume,
    stability, mechanical integration (particular challenge for timing layers),
    services (power, data, cooling…)

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Up for discussion:

What R&D needs to be done, which direction appears most promising?

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Up for discussion:

What R&D needs to be done, which direction appears most promising?

- Plus some discussion points (Questions from June 8, 2022):
  - How can precision timing be best used in PFA?
  - How can precision timing be best used in DRO?
  - What level of precision timing can make a real difference to calorimeter performance?
  - What are the potential benefits of moving "intelligence" into calorimeter front ends?
  - What are the benefits of AI for calorimeter reconstruction?