Direct Coupling of SiPMs to Scintillator Tiles for Imaging Calorimetry and Triggering

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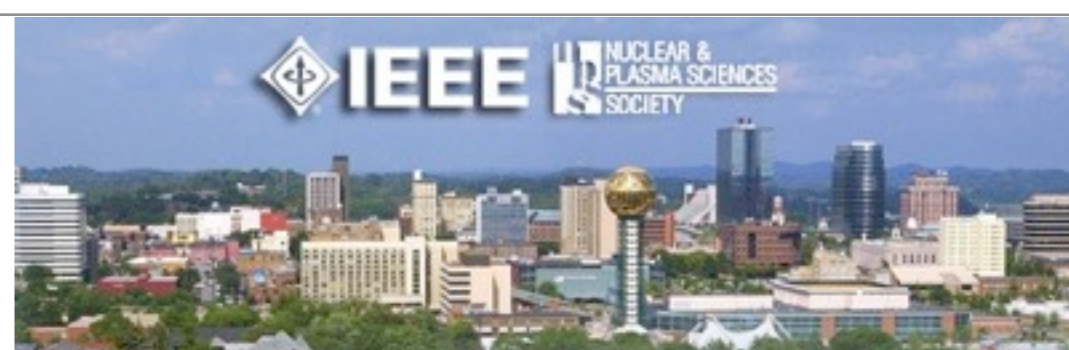

TUM LMU Excellence Cluster Universe

Applications in Triggering and Calorimetry

- Plastic scintillators are the classic detector for sampling calorimeters and for trigger systems:
  - Fast response to particles
  - Easy to work with
  - Affordable
  - ...

Recently: SiPMs as alternatives to photomultipliers for scintillator readout

- Competing requirements:
  - Trigger detectors need high efficiency
  - Calorimetry needs linearity and large dynamic range

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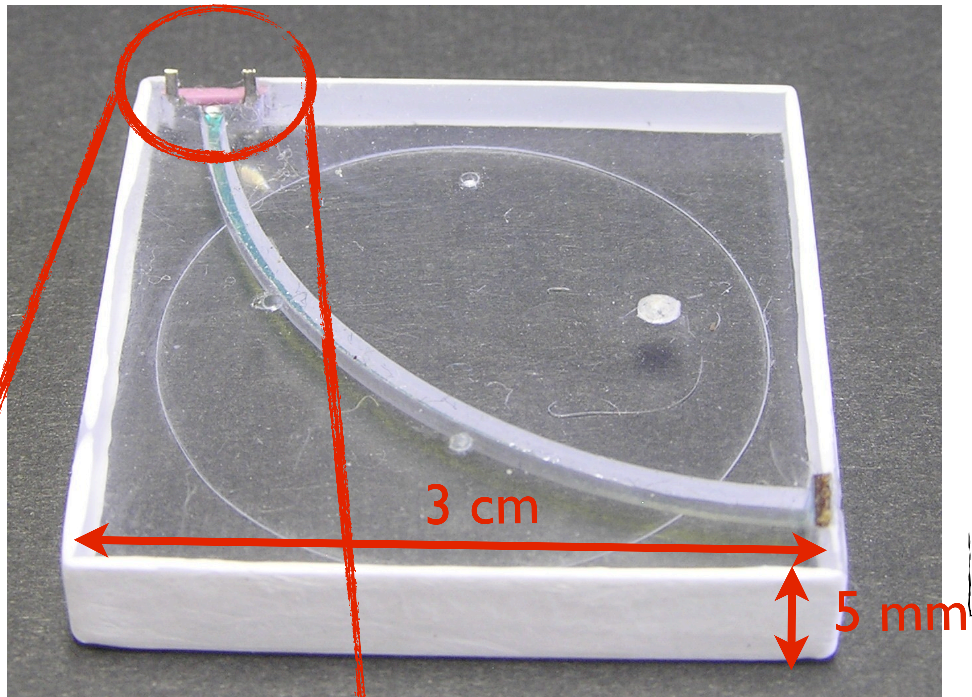
This talk:
- Scintillators for Imaging Calorimeters & ATLAS ALFA
- Fiberless coupling: Achieving uniformity and high signal amplitude
- Application for time structure studies

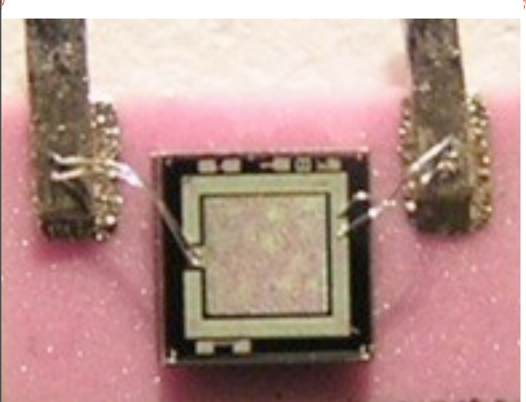
Scintillators for the CALICE Analog HCAL

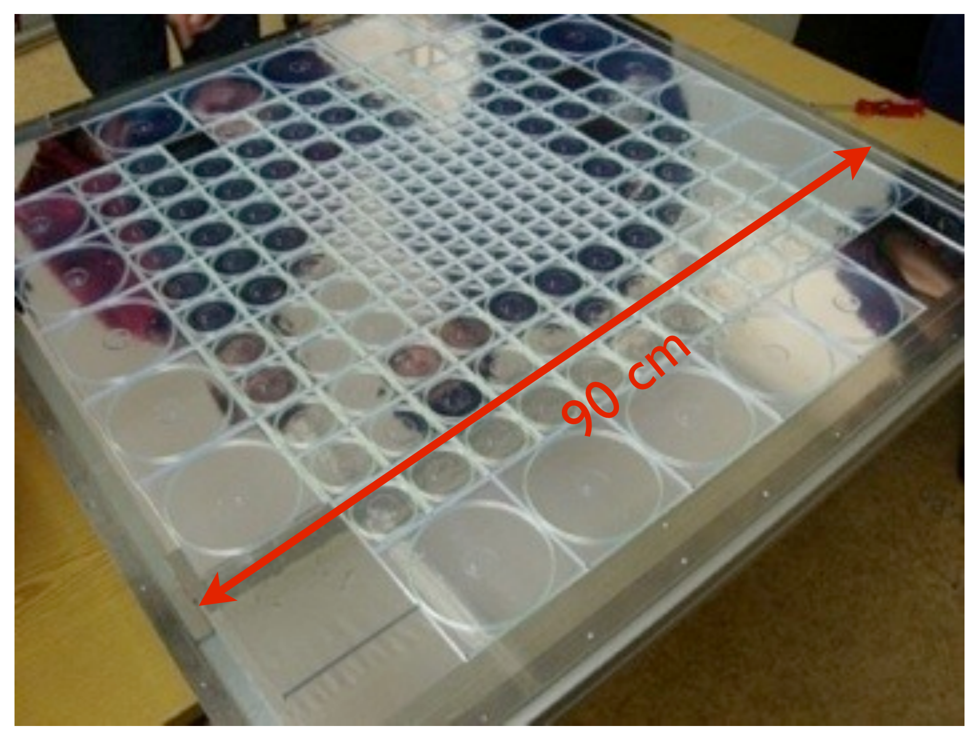
- The first large-scale use of SiPMs in particle physics:
  7608 scintillator tiles with embedded WLS fiber read out by SiPMs



First generation SiPMs had maximum sensitivity in the green spectral range: WLS fiber to match to the blue scintillation emission

Blue-sensitive SiPMs make the fiber unnecessary, but: helps to get uniform response!





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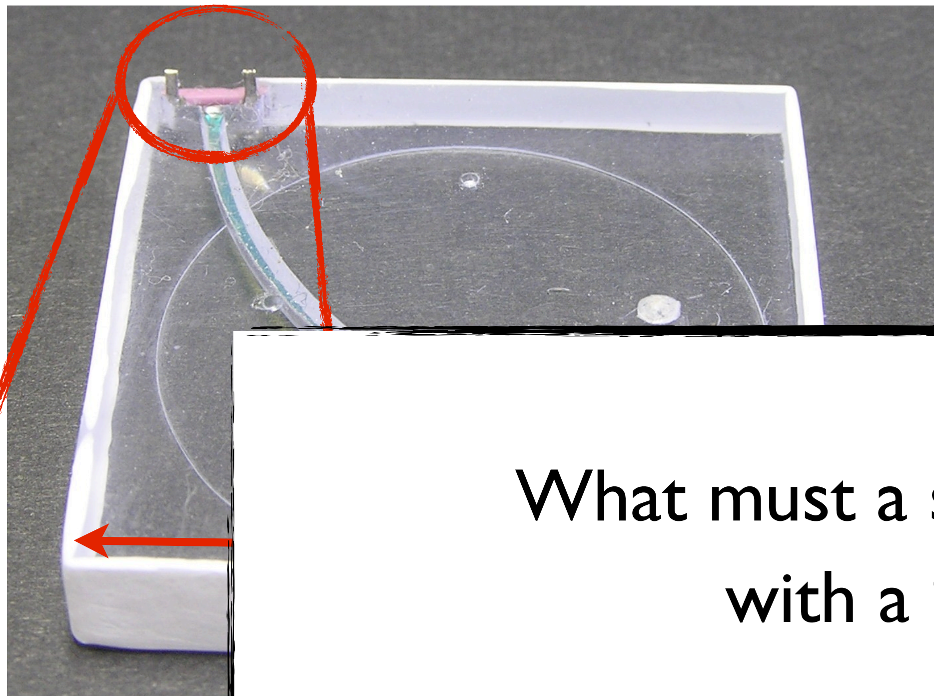

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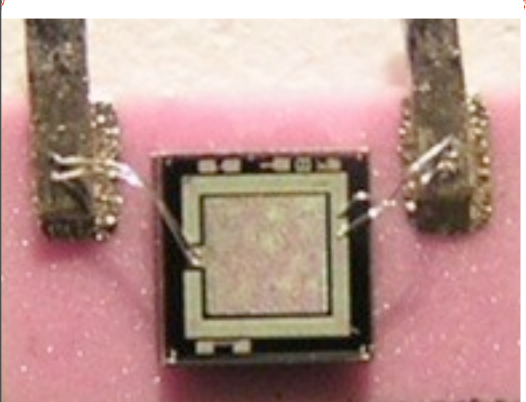
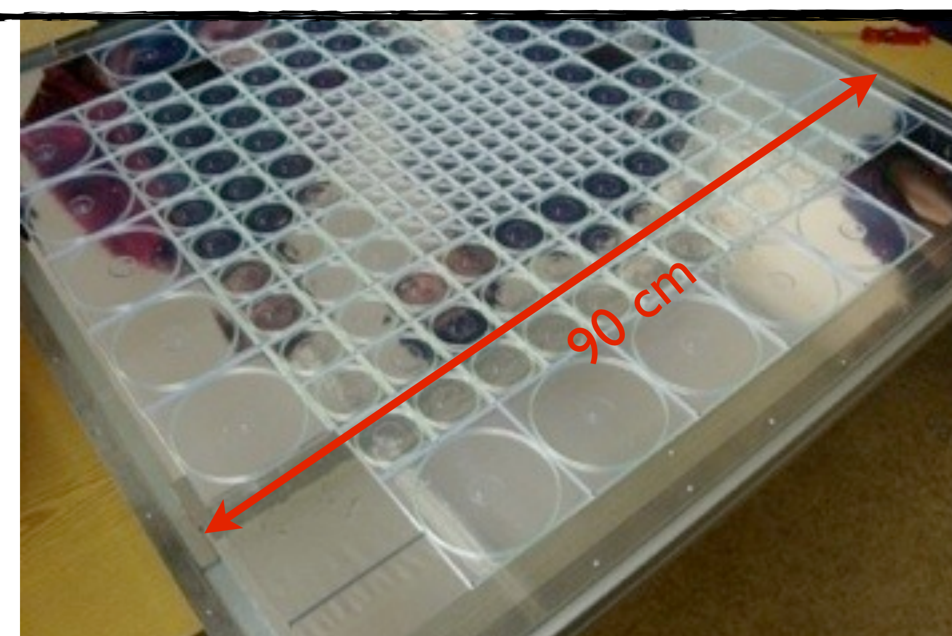
essary, but:

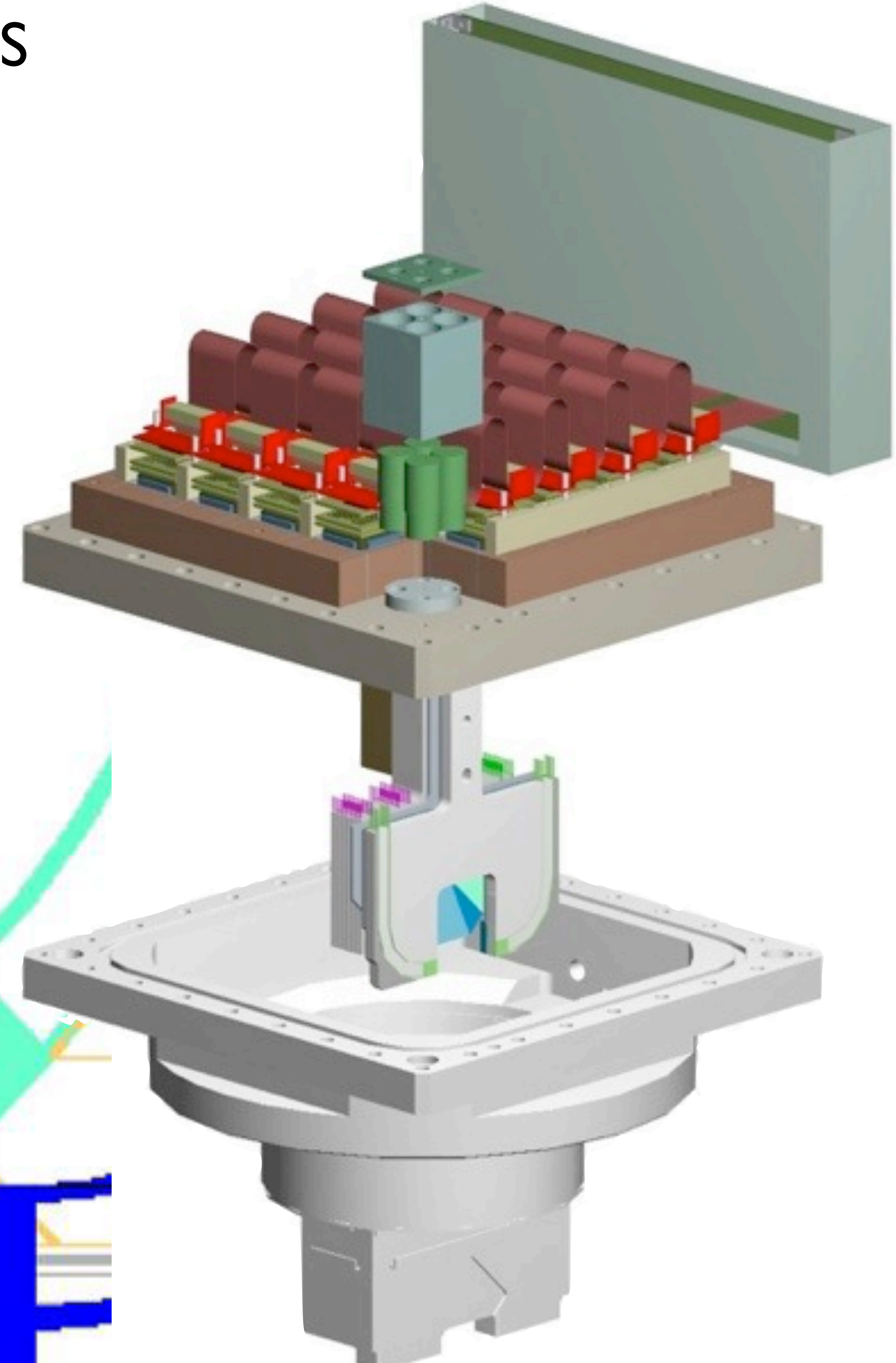
What must a scintillator tile look like to work with a SiPM without WLS Fiber?

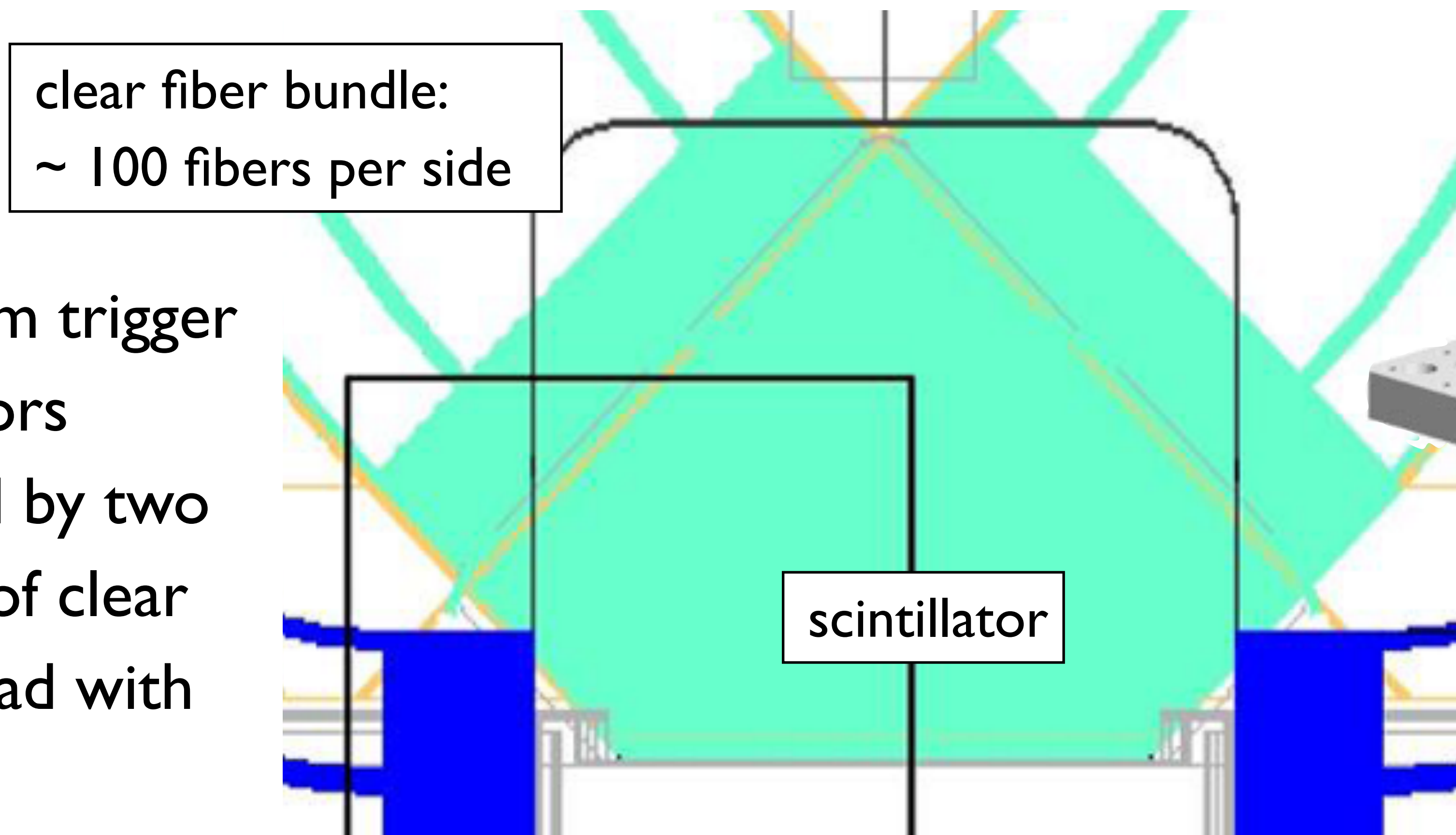




Scintillators for the ALFA Trigger

- ALFA: Absolute luminosity measurement for ATLAS
  - Low angle coulomb scattering, measured with a scintillating fiber tracker in Roman Pots in the LHC beam
  - Trigger provided by coincidence of two scintillators up and downstream of the tracking layers: Excellent uniformity mandatory!





Light from trigger scintillators collected by two bundles of clear fibers, read with PMTs

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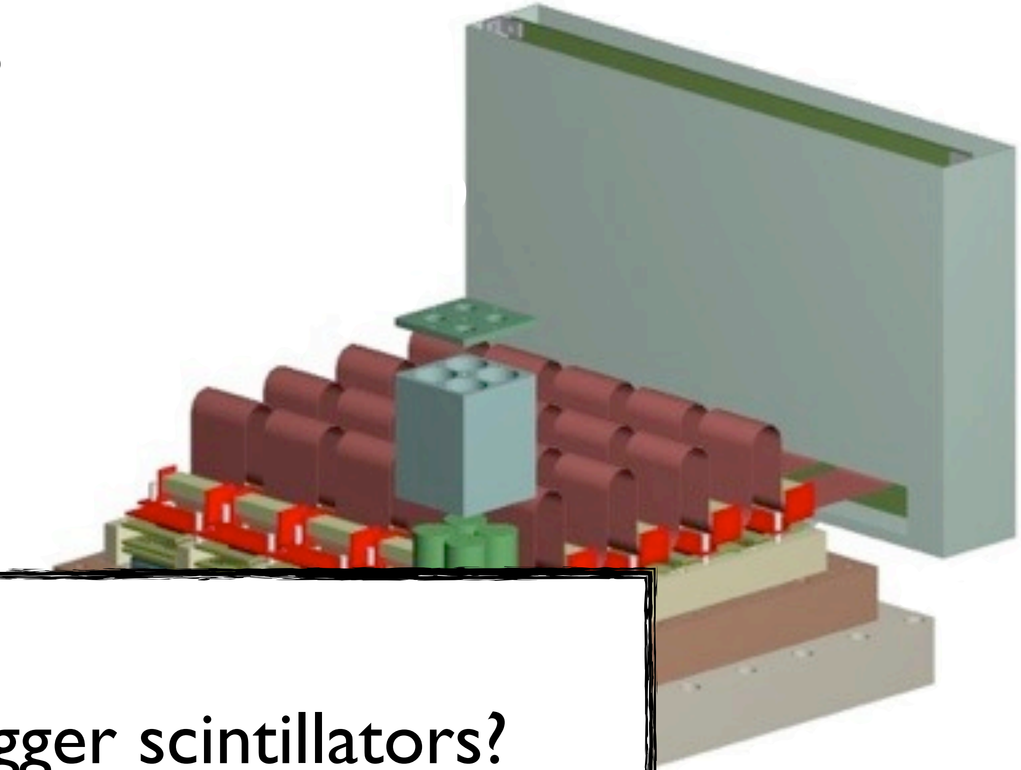
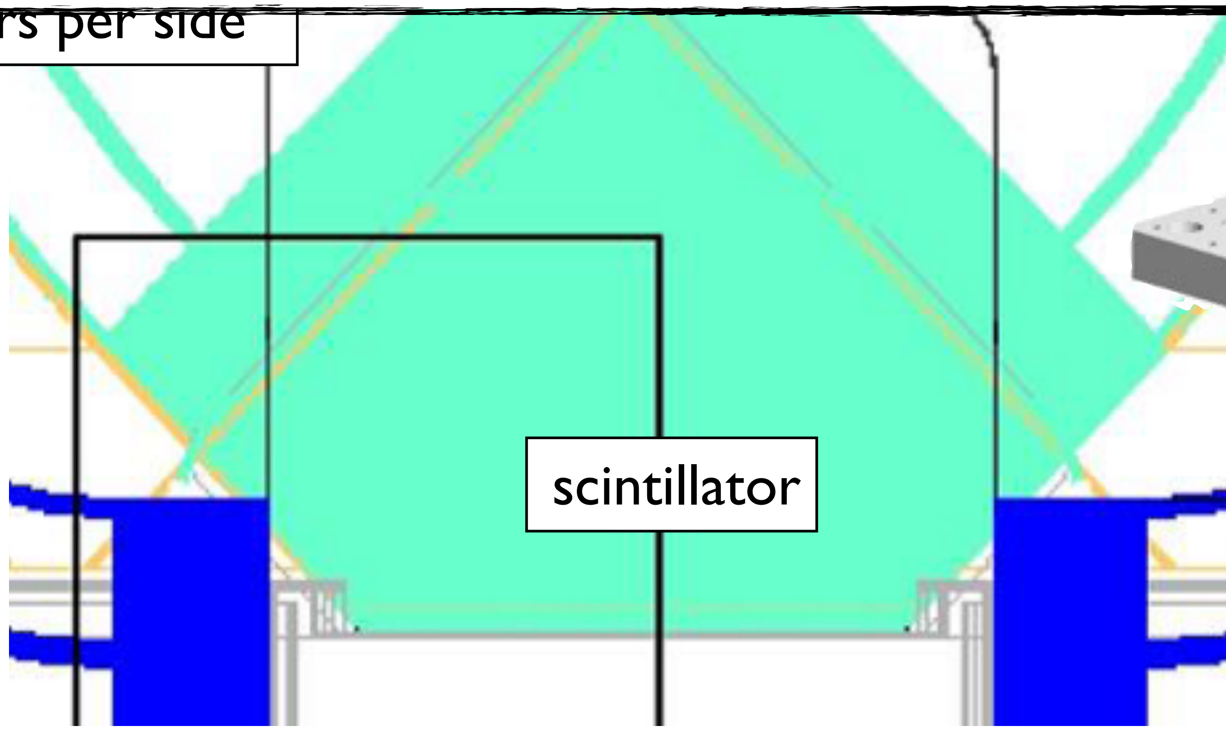
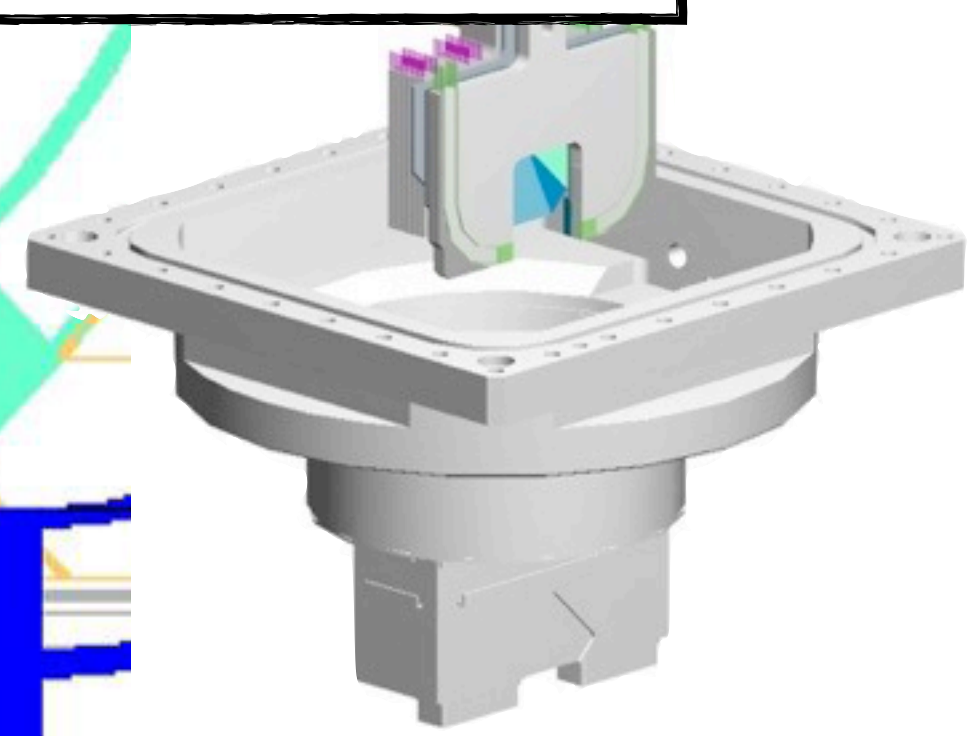


Can SiPMs be used to read out the trigger scintillators?

clea
~ 100 fibers per side

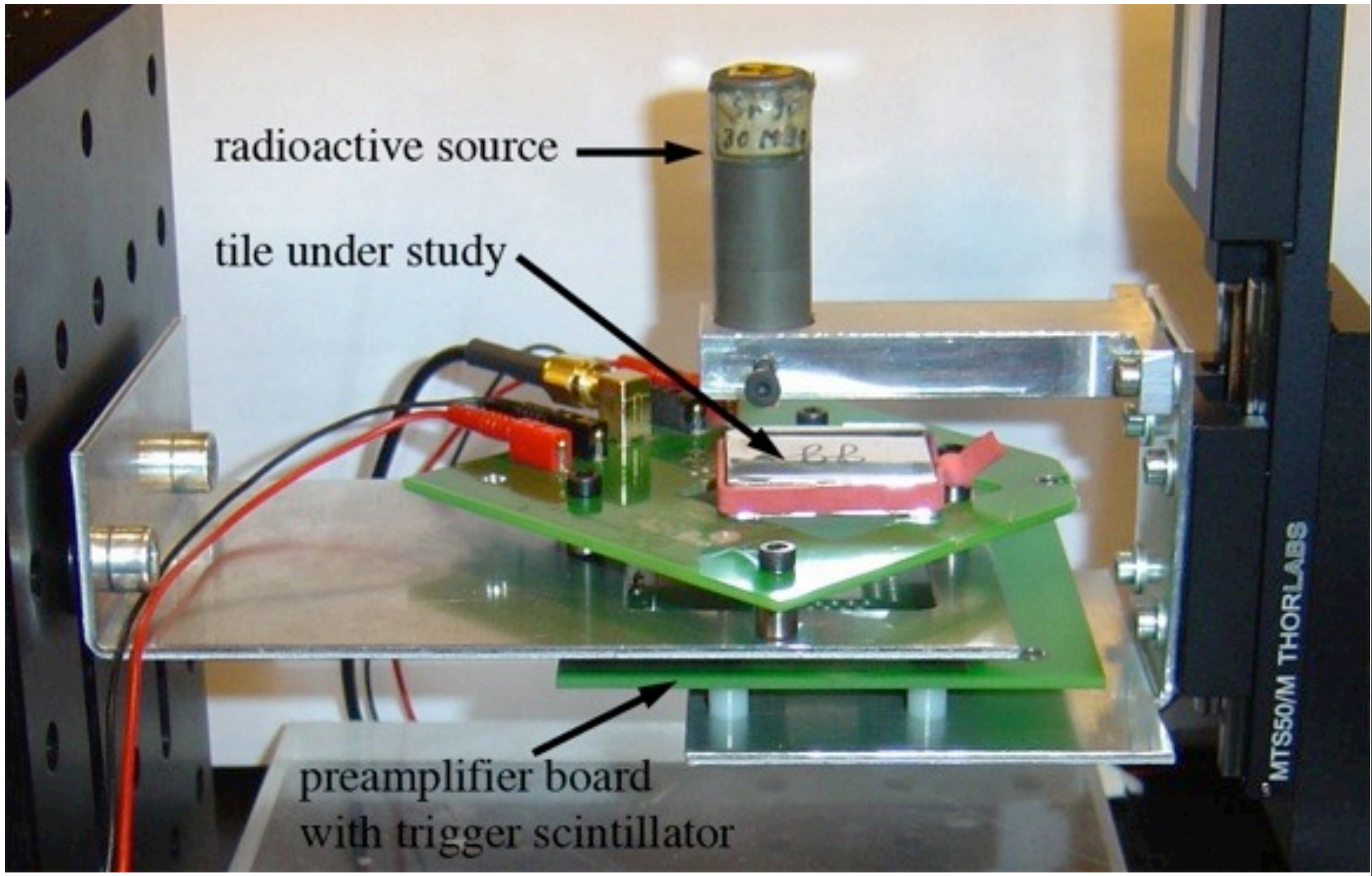
Light from trigger scintillators collected by two bundles of clear fibers, read with PMTs





Fiberless Coupling of SiPMs: Test Setup

- Test stand: Scanning of source across tile surface
  - ^{90}Sr source, ~ 2.2 MeV endpoint
  - Tile readout with 1 mm^2 MPPC25P
- Readout with fast oscilloscope & preamp



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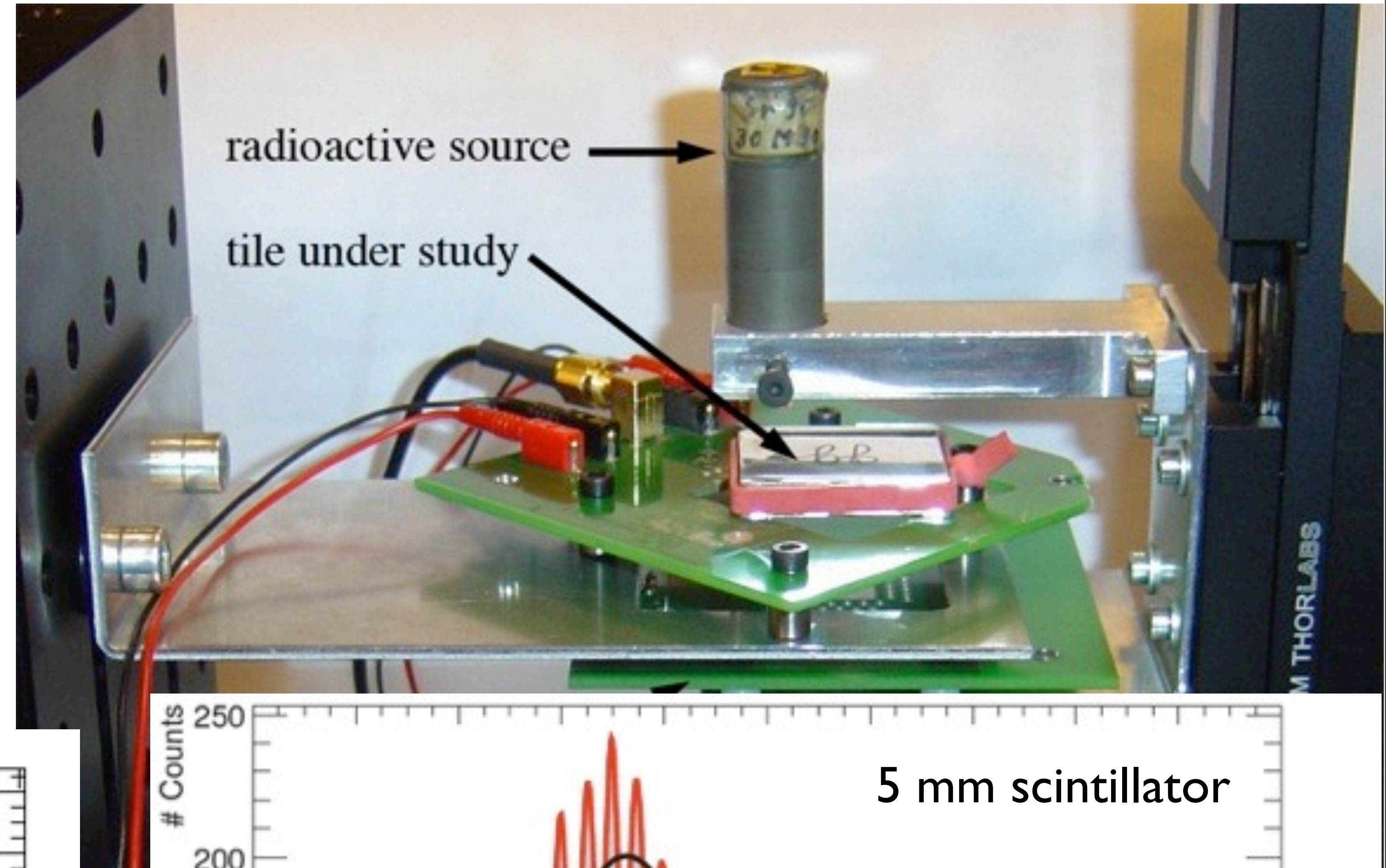
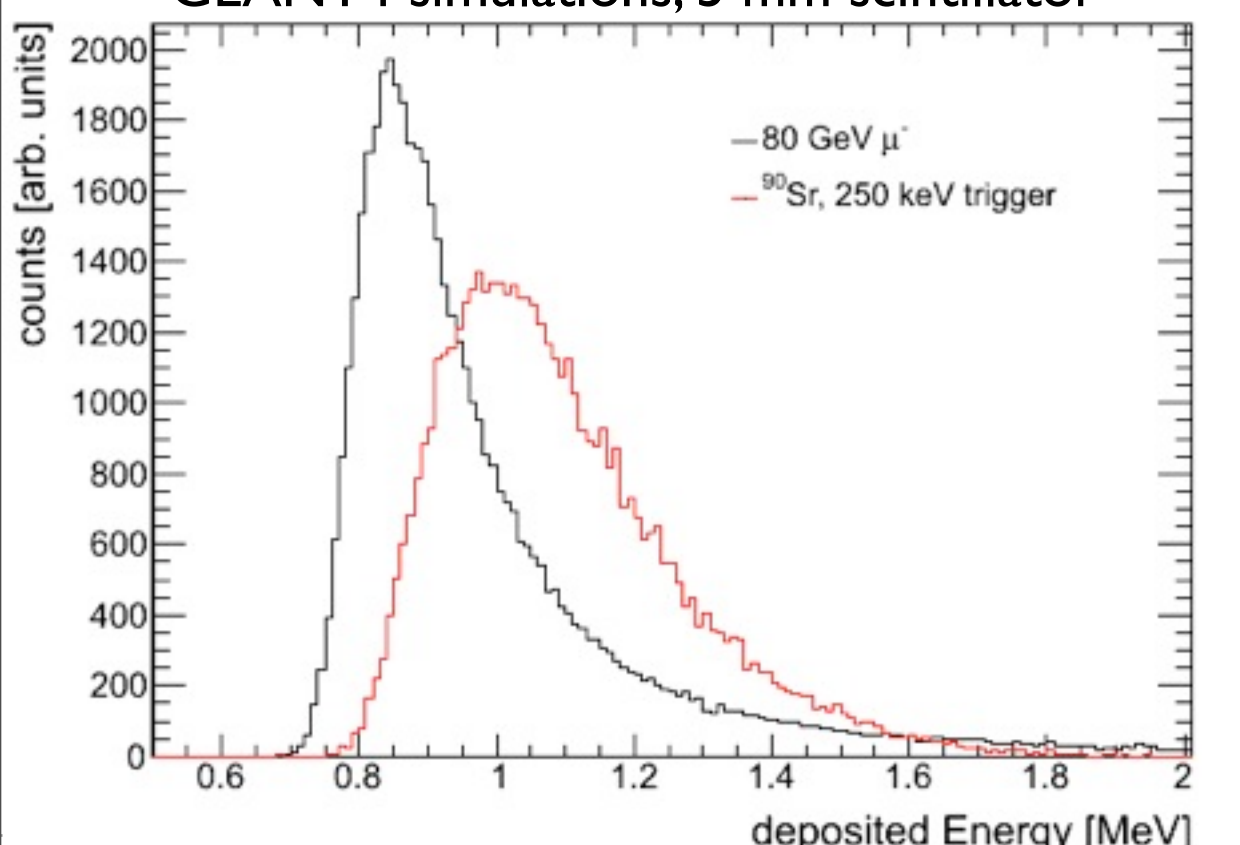
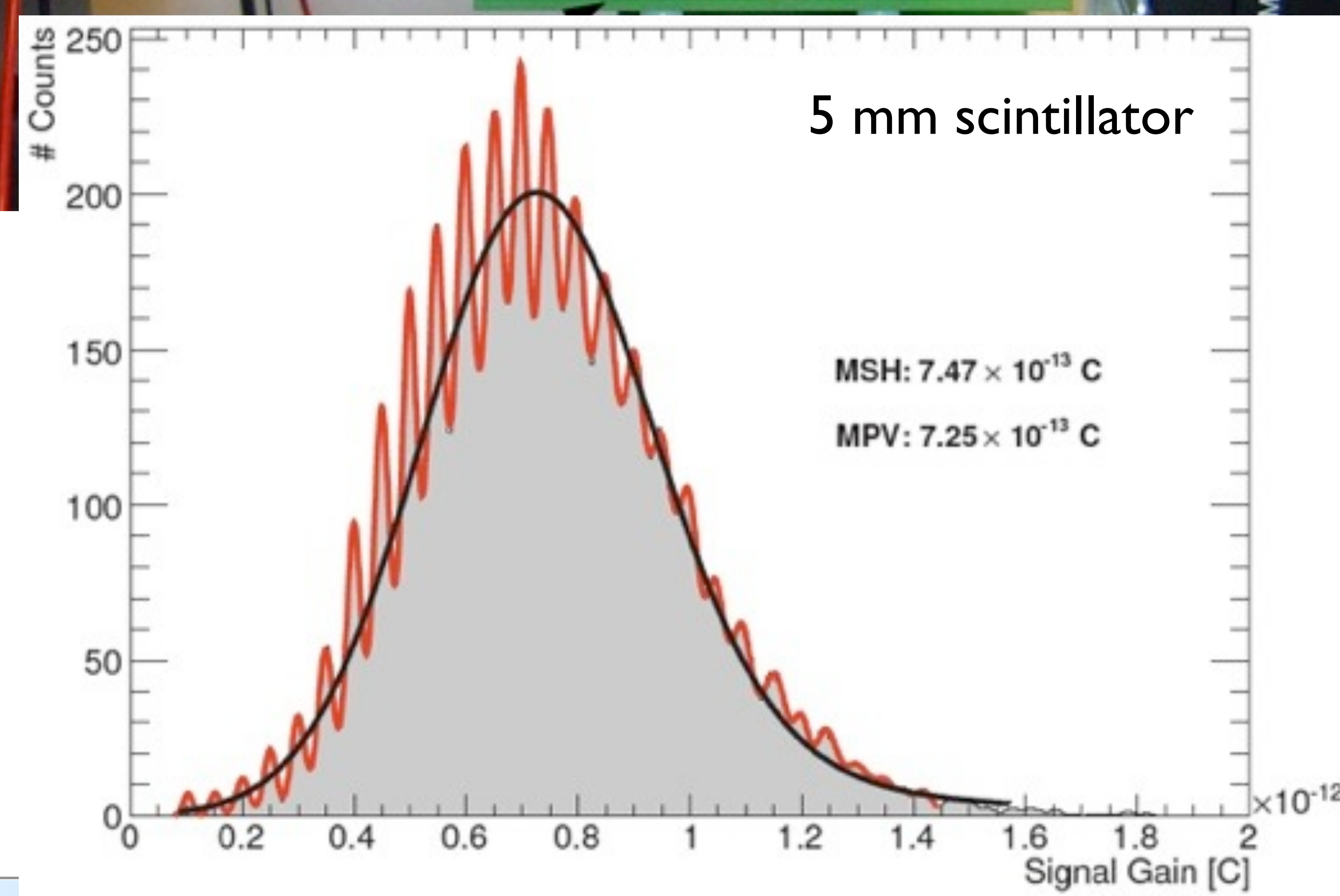


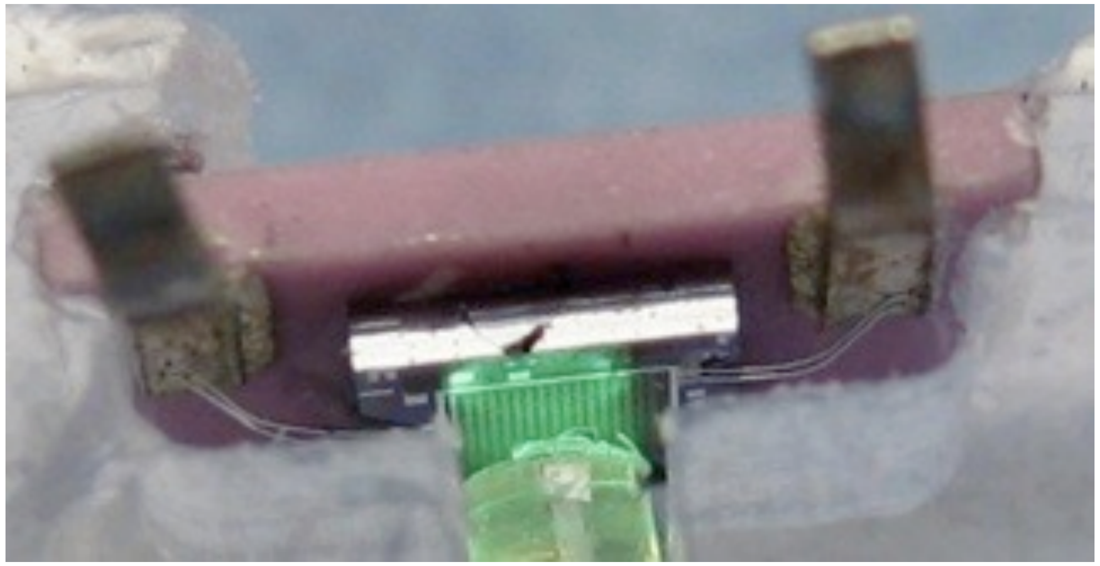
GEANT4 simulations, 5 mm scintillator

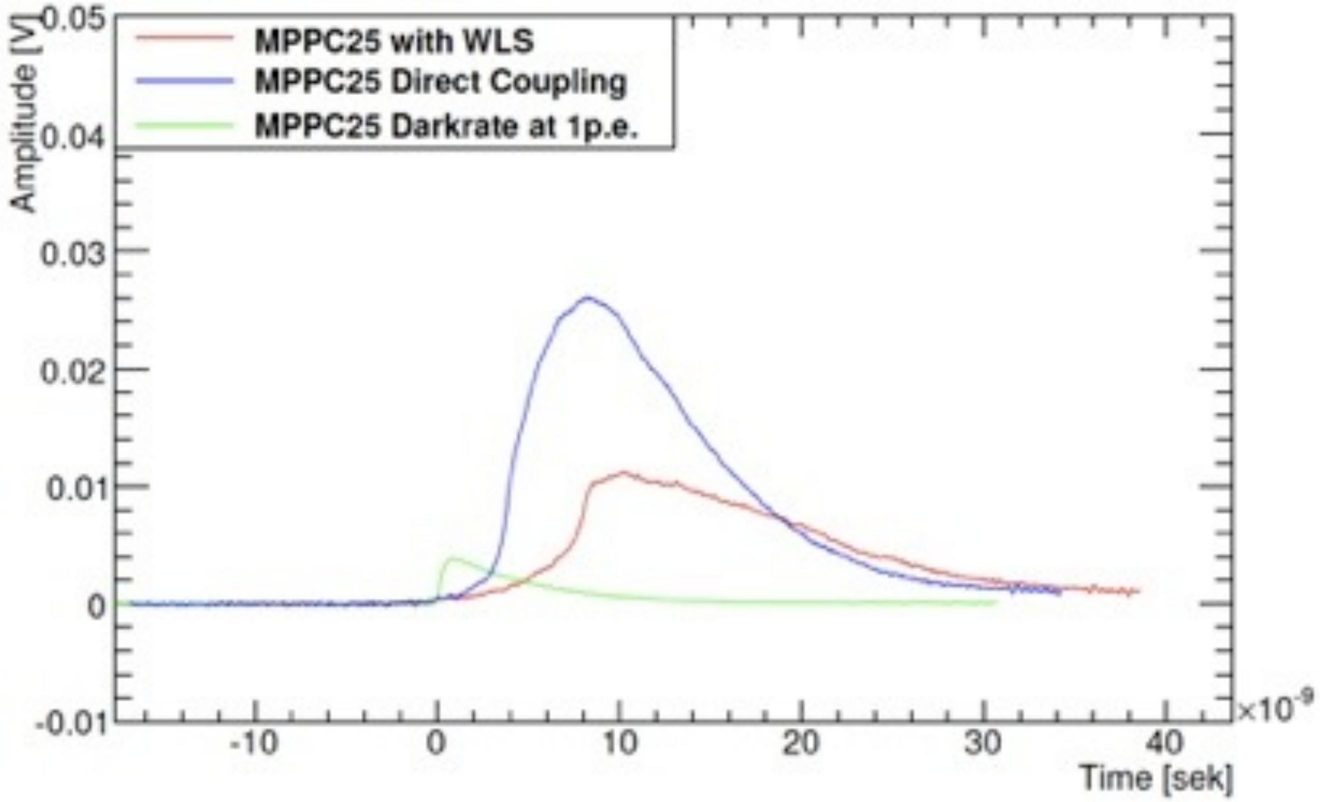




Advantages of going Fiberless

- Mechanical simplicity:
  - Easier (and cheaper) scintillator fabrication: No fiber to embed
  - Reduced alignment requirements: Matching of fiber to SiPM active area a critical issue



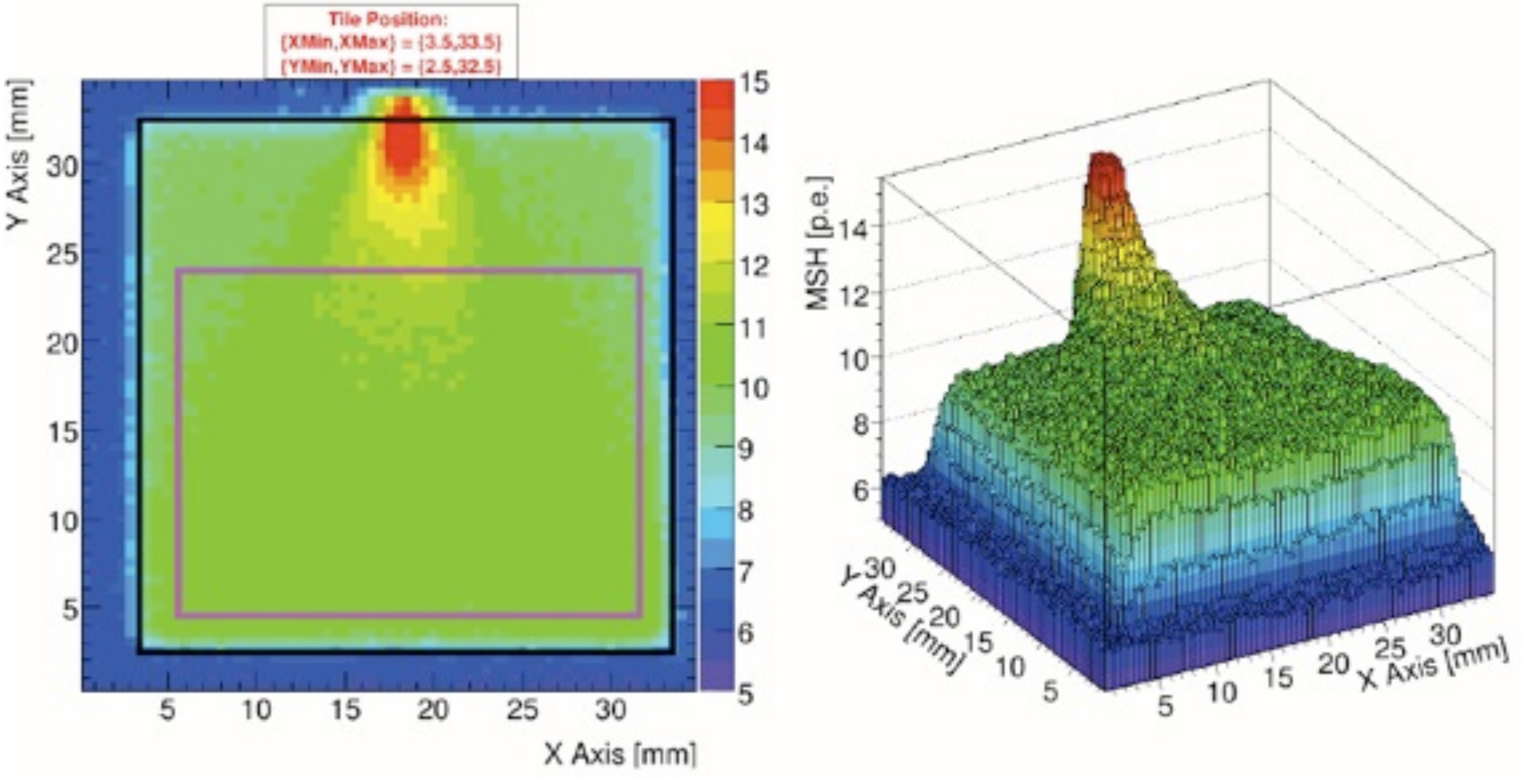


~ x2 faster response without WLS

- Faster response
  - Elimination of additional time constant of WLS fiber
- ▸ Important for timing-critical applications - triggering, time structure measurements

Non-Uniformity with directly coupled SiPMs

- Direct coupling made simple: Just stick a SiPM on the side face of tile (5 mm thick)



Strong non-uniformity, significantly increased response close to SiPM coupling position

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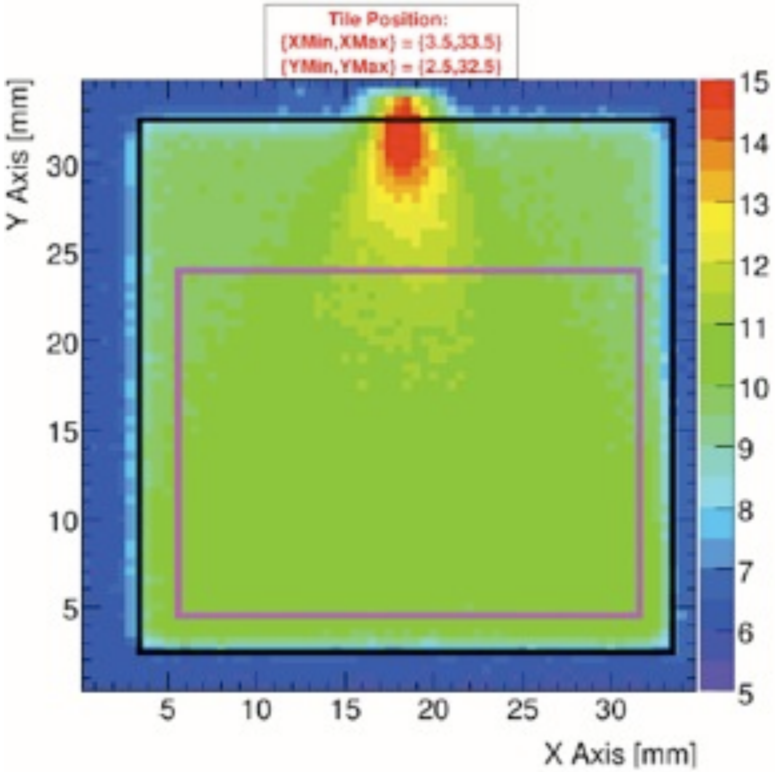
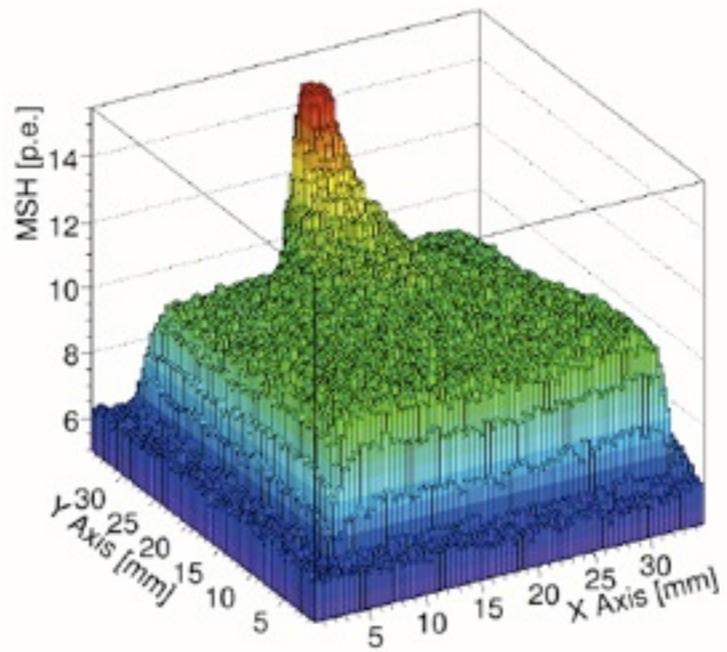
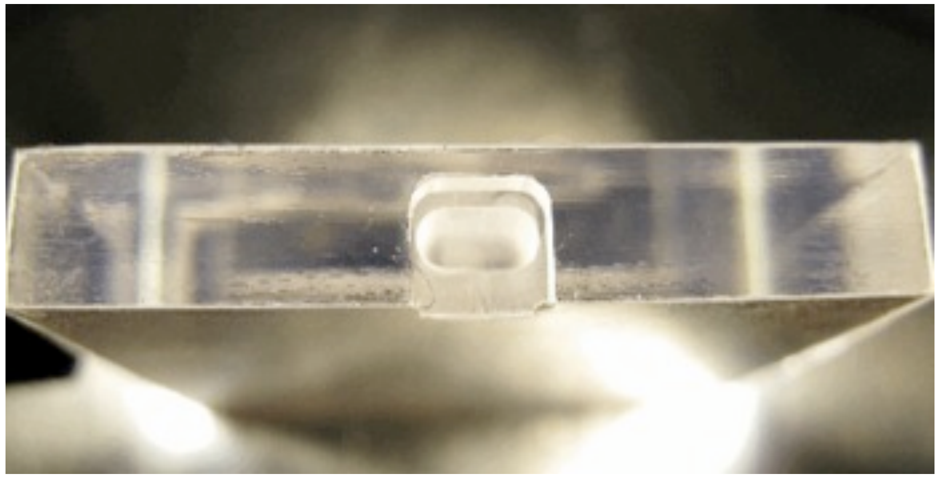
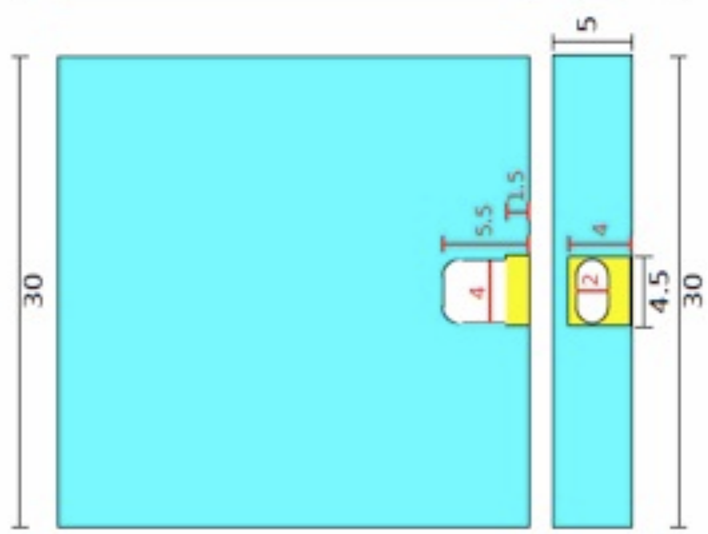




Strong non-uniformity, significantly increased response close to SiPM coupling position

➾ The strategy: reduce material close to coupling position, improve light collection through embedding of SiPM and light diffusion



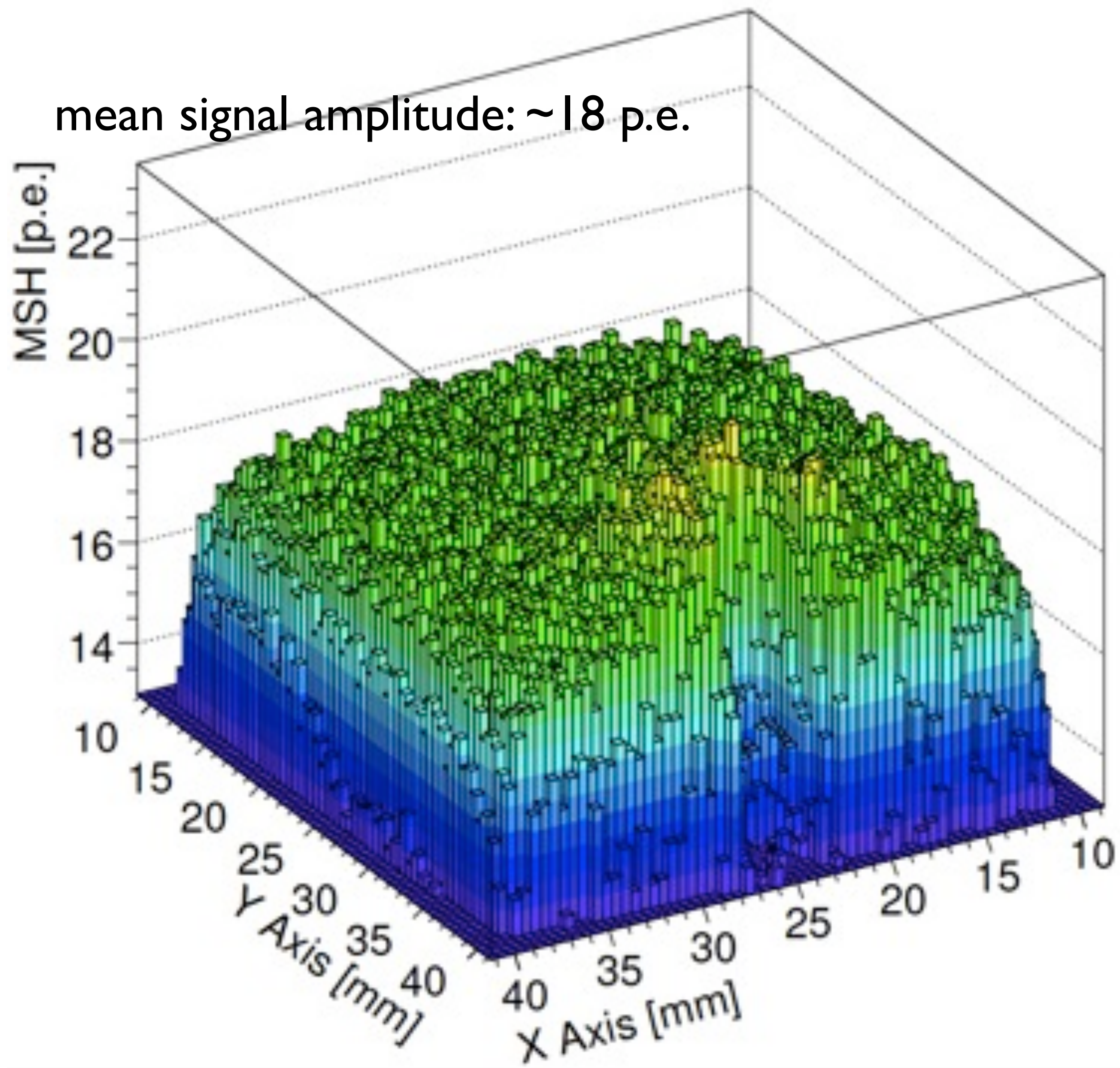


Add a “dimple” at the SiPM coupling position: Drilled into the tile

Obtaining Uniformity

- Dimple, SiPM embedded in Tile
  - High degree of uniformity
  - 50% increased signal yield compared to naive direct coupling

mean signal amplitude: ~18 p.e.



Obtaining Uniformity

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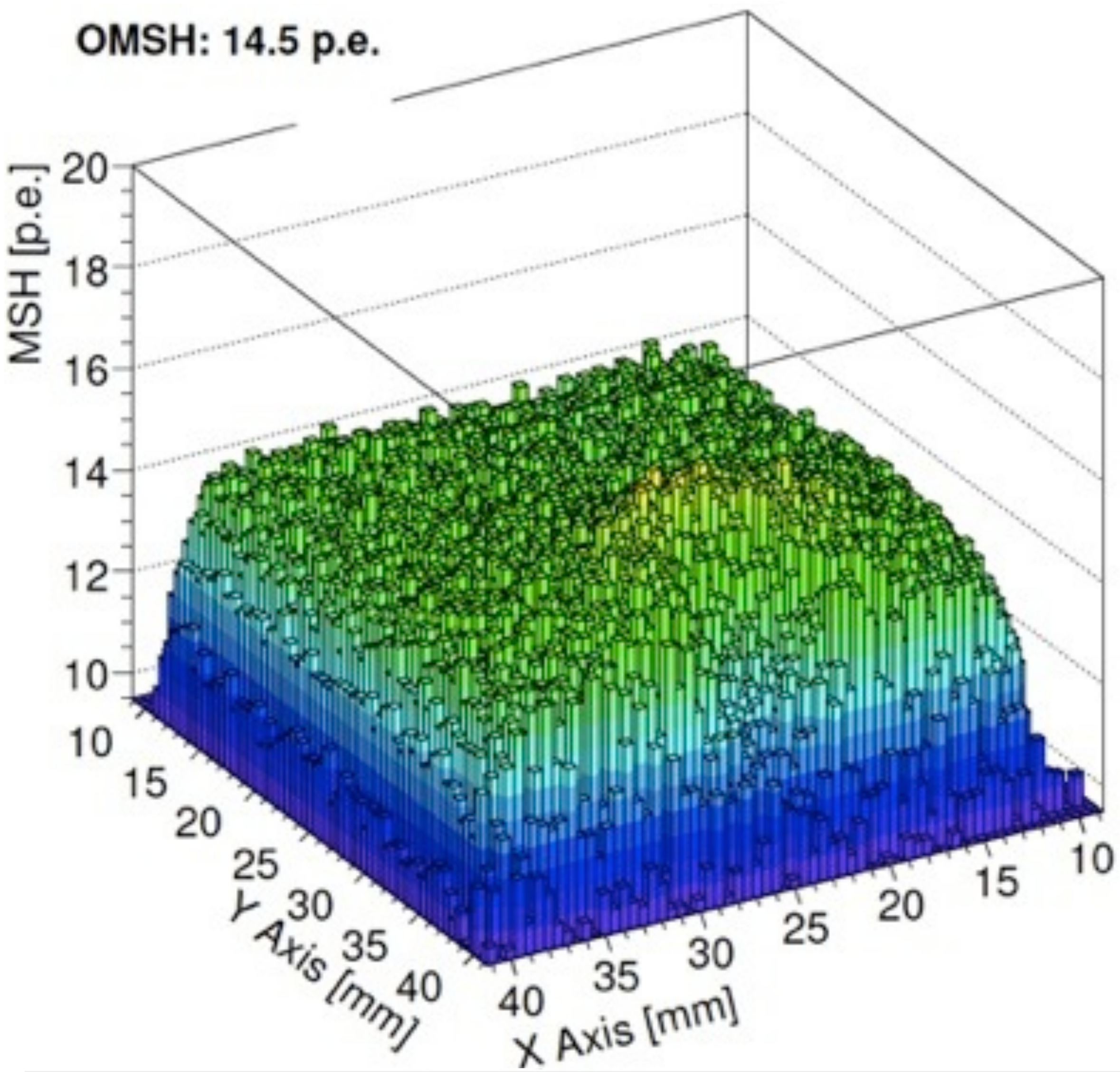
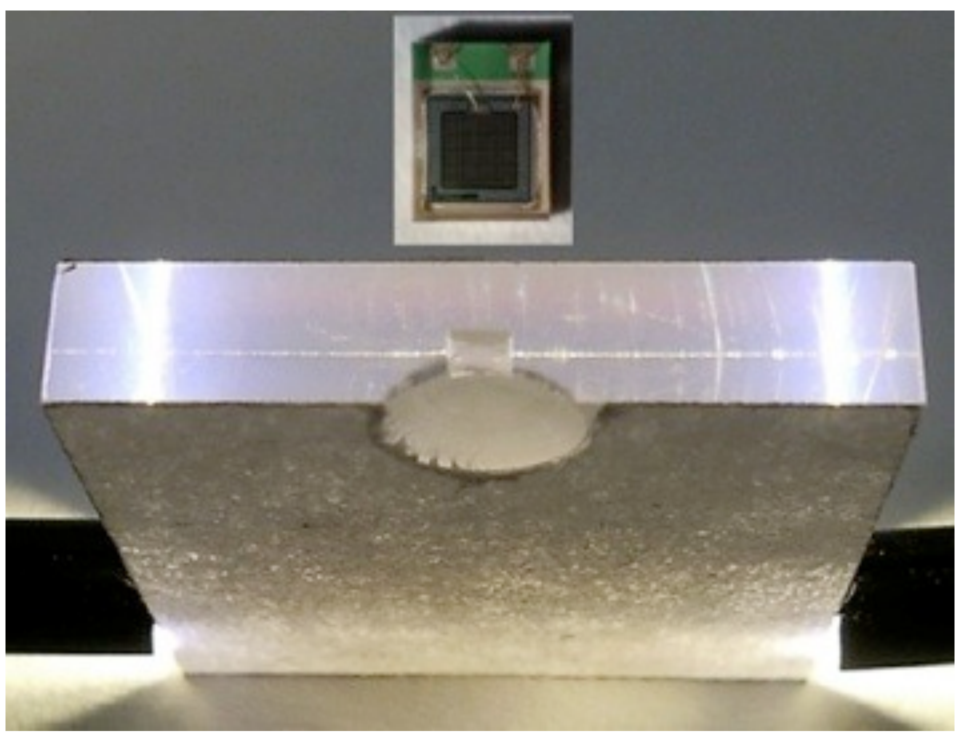
  - 50% increased signal yield compared to naive direct coupling
- Further studies: Spherical hole
  - Avoid signal drop at SiPM position
  - Easier for molding: Mass production

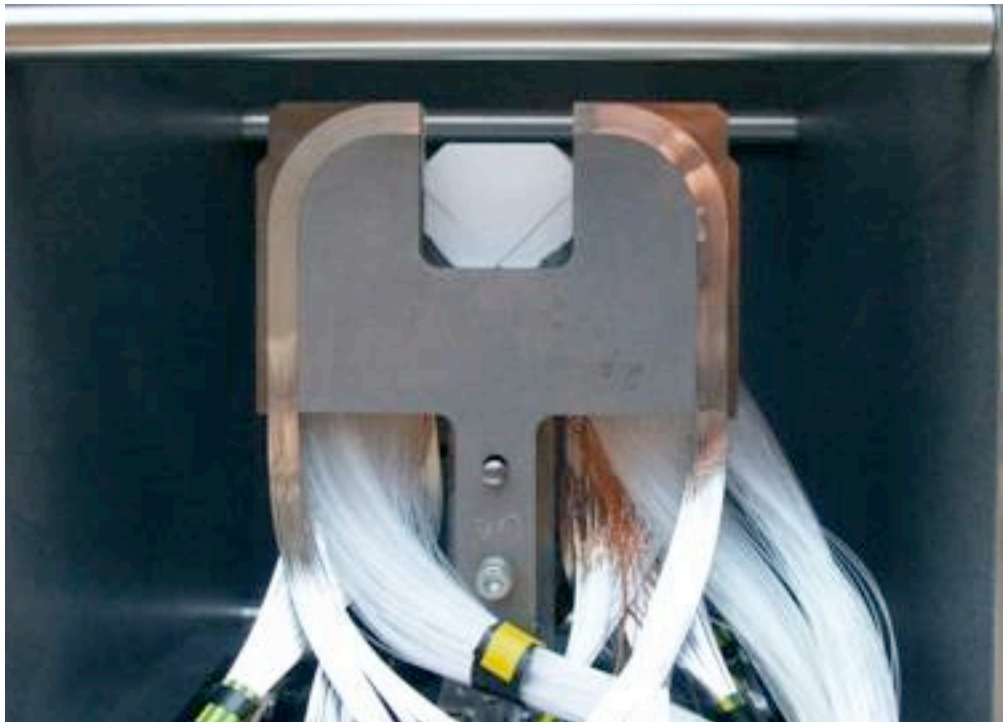




- Excellent uniformity achieved
- Signal amplitude ~20% less than for original dimple concept: Well within requirements for calorimetry

Scintillators with SiPMs for Triggering in ALFA

- Fiber readout takes up lots of real estate in the roman pots - A compact solution is attractive
  - Easiest to achieve for trigger tiles
    Here: Feasibility study for potential upgrade, baseline detector with PMTs will be installed in LHC this Winter
- Key challenge: Perfect uniformity of trigger required: Measurement of count rate profiles!



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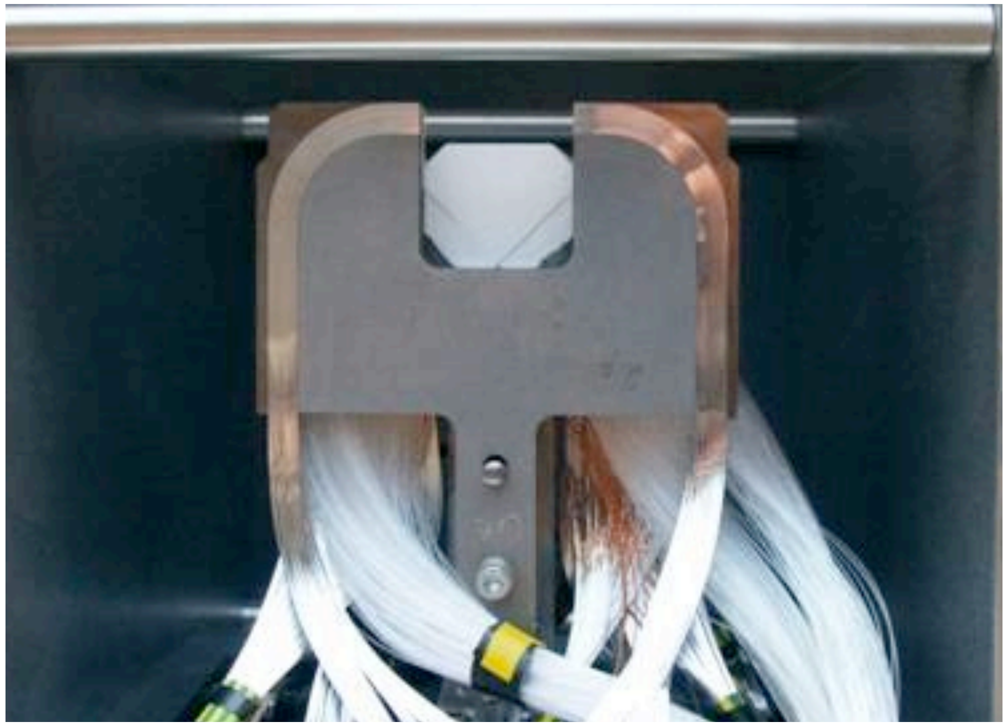
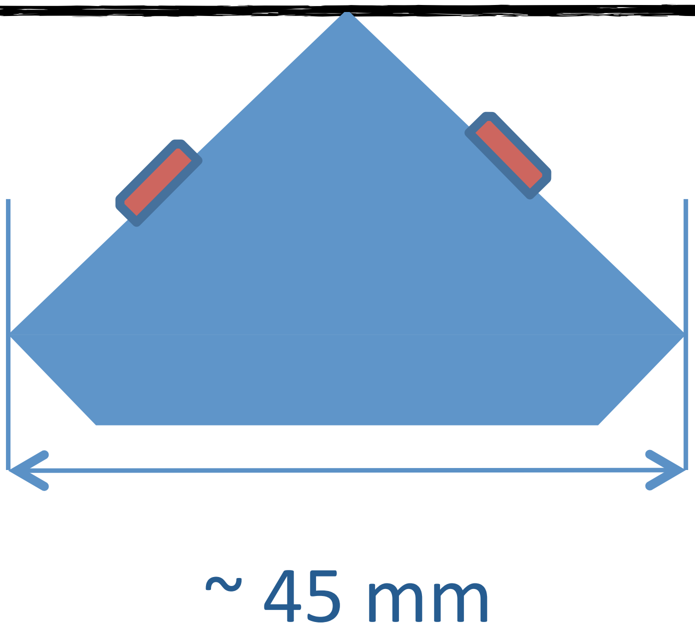


➯ Level of uniformity that can be achieved with fiberless (or fiber) coupling of SiPMs not sufficient: Have to guarantee full trigger efficiency for minimum ionizing particles

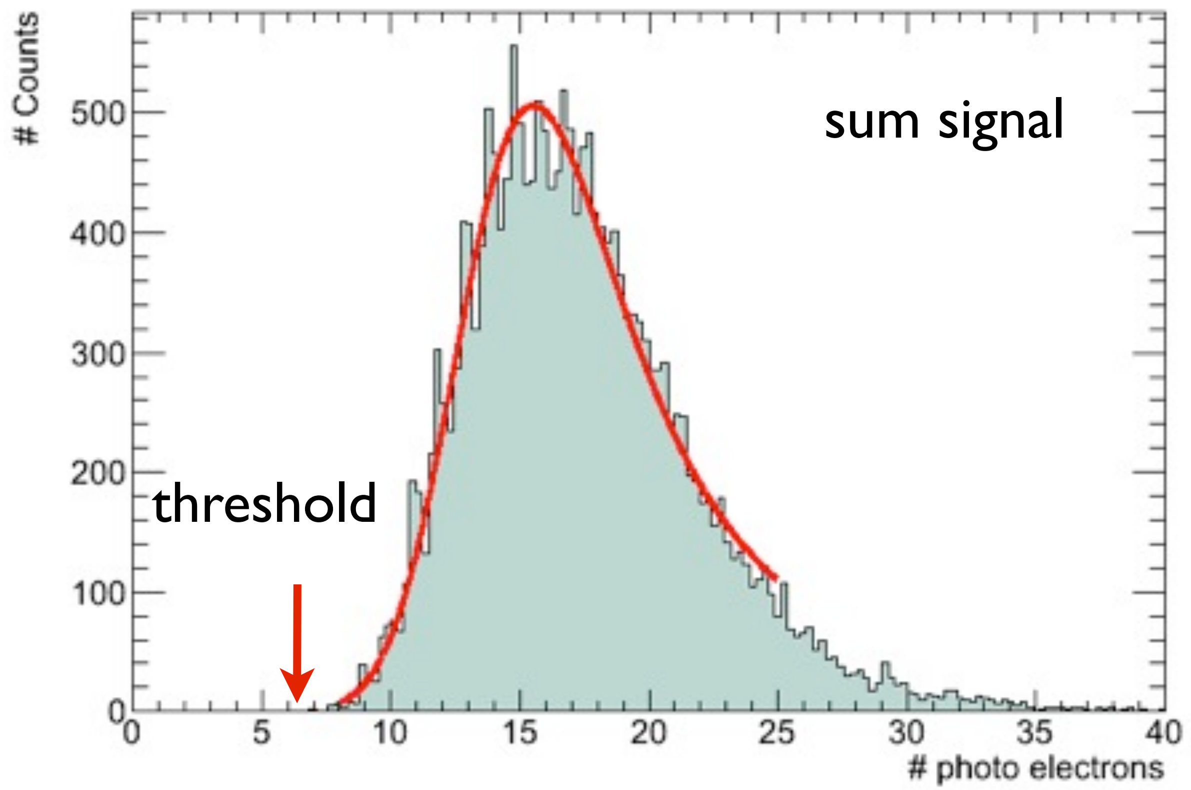
ALFA trigger scintillator tiles have about the same size as the tiles in the CALICE HCAL (3mm thickness)

Increased signal yield by readout with two SiPMs per tile



SiPM Readout of ALFA Tiles

- Initial tests with 2 MPPC25P (1 mm^2)
- Insufficient signal amplitude: noise threshold set to 3 p.e. on each SiPM



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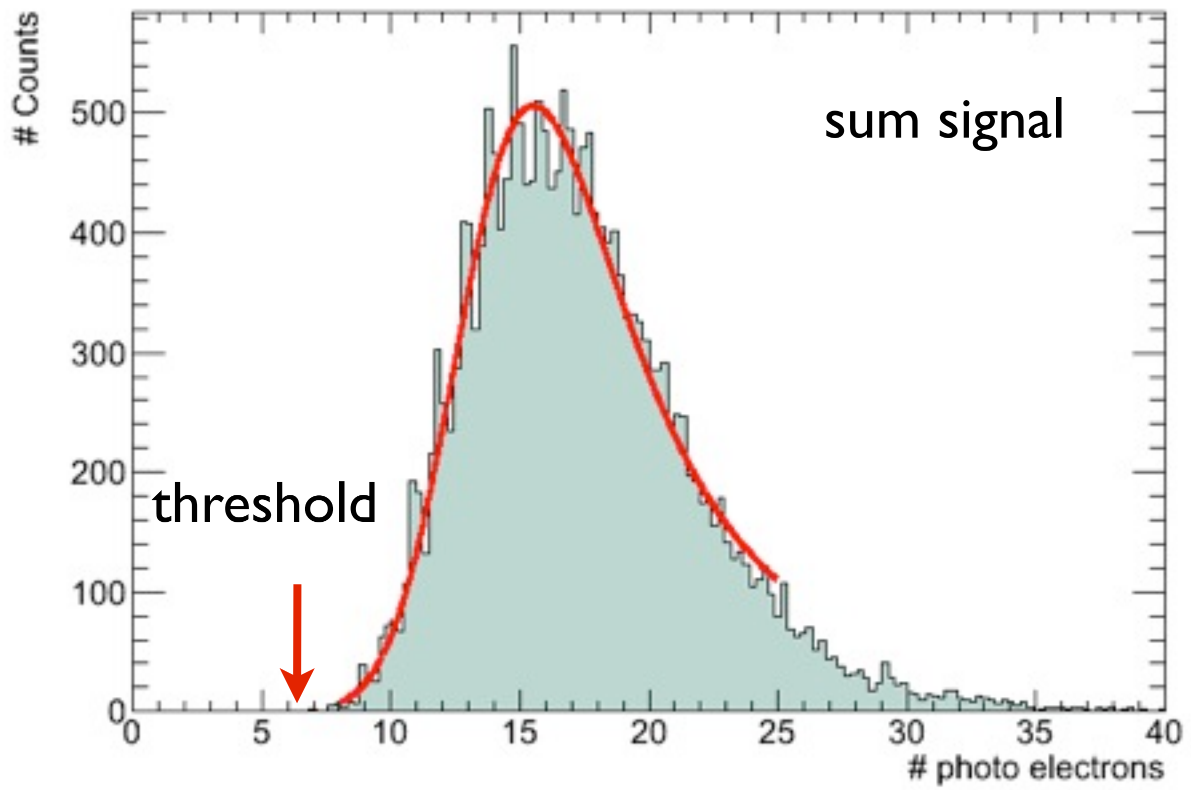
➯ use larger pixels for increased photon detection efficiency



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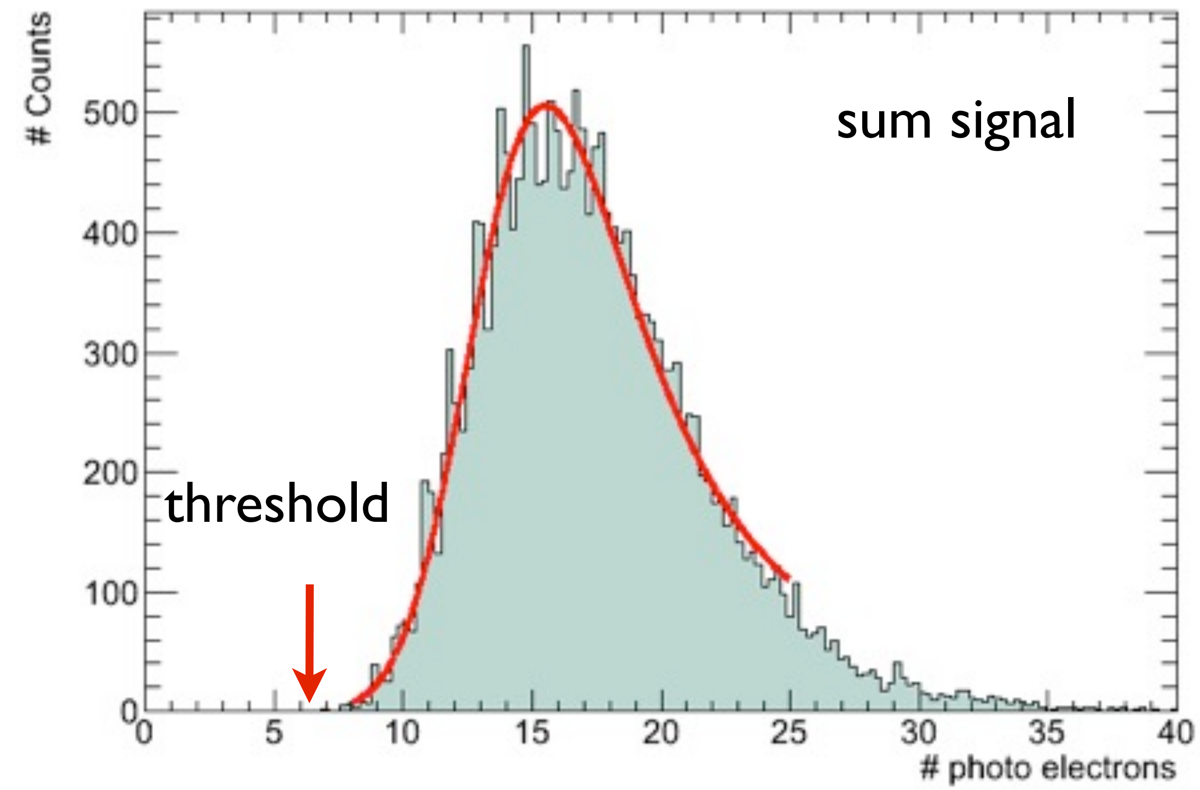
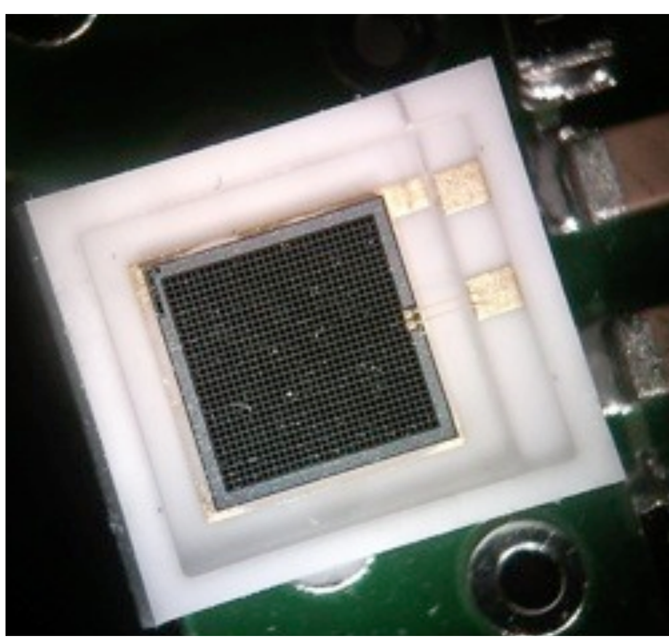
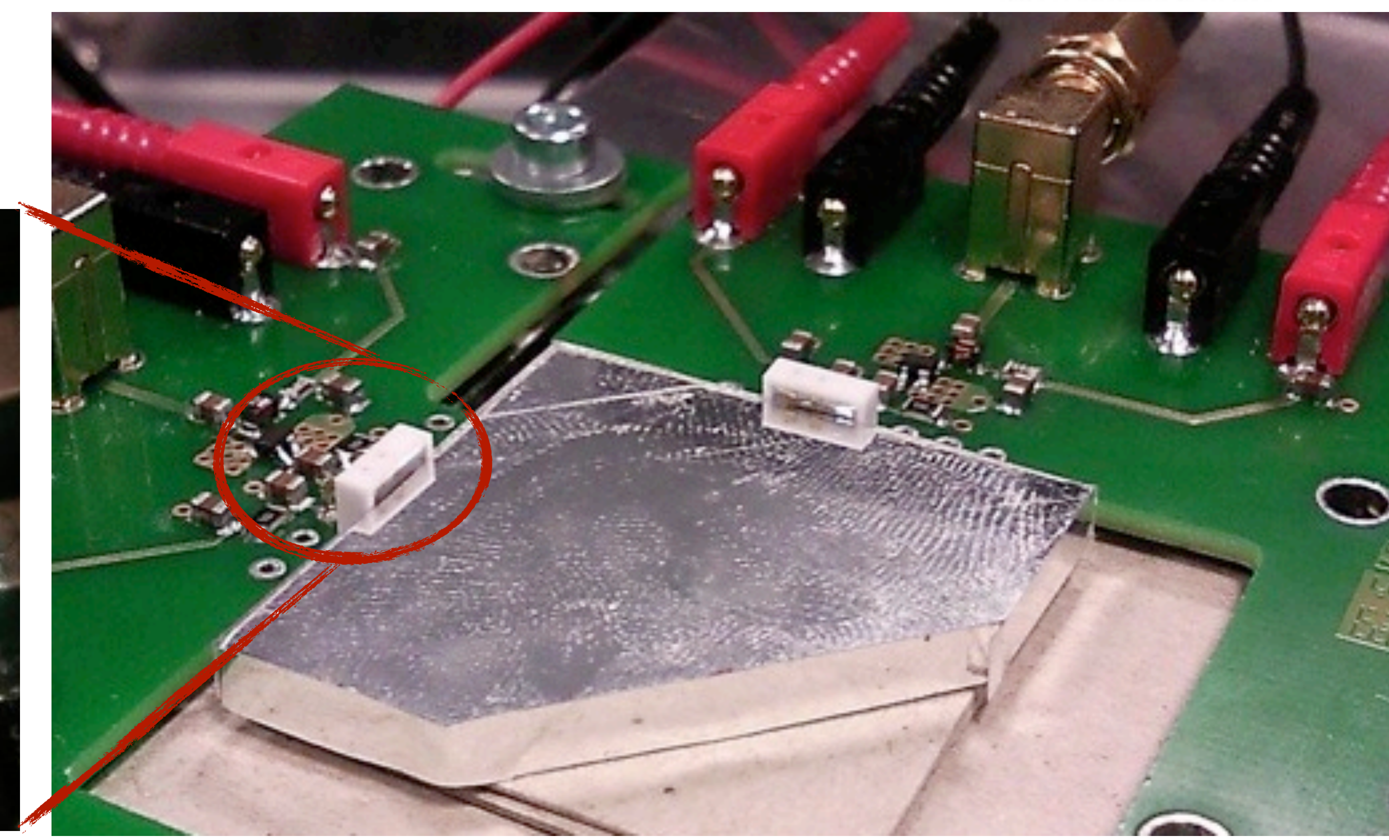


Use MPPC50C, 3x 3 mm^2:

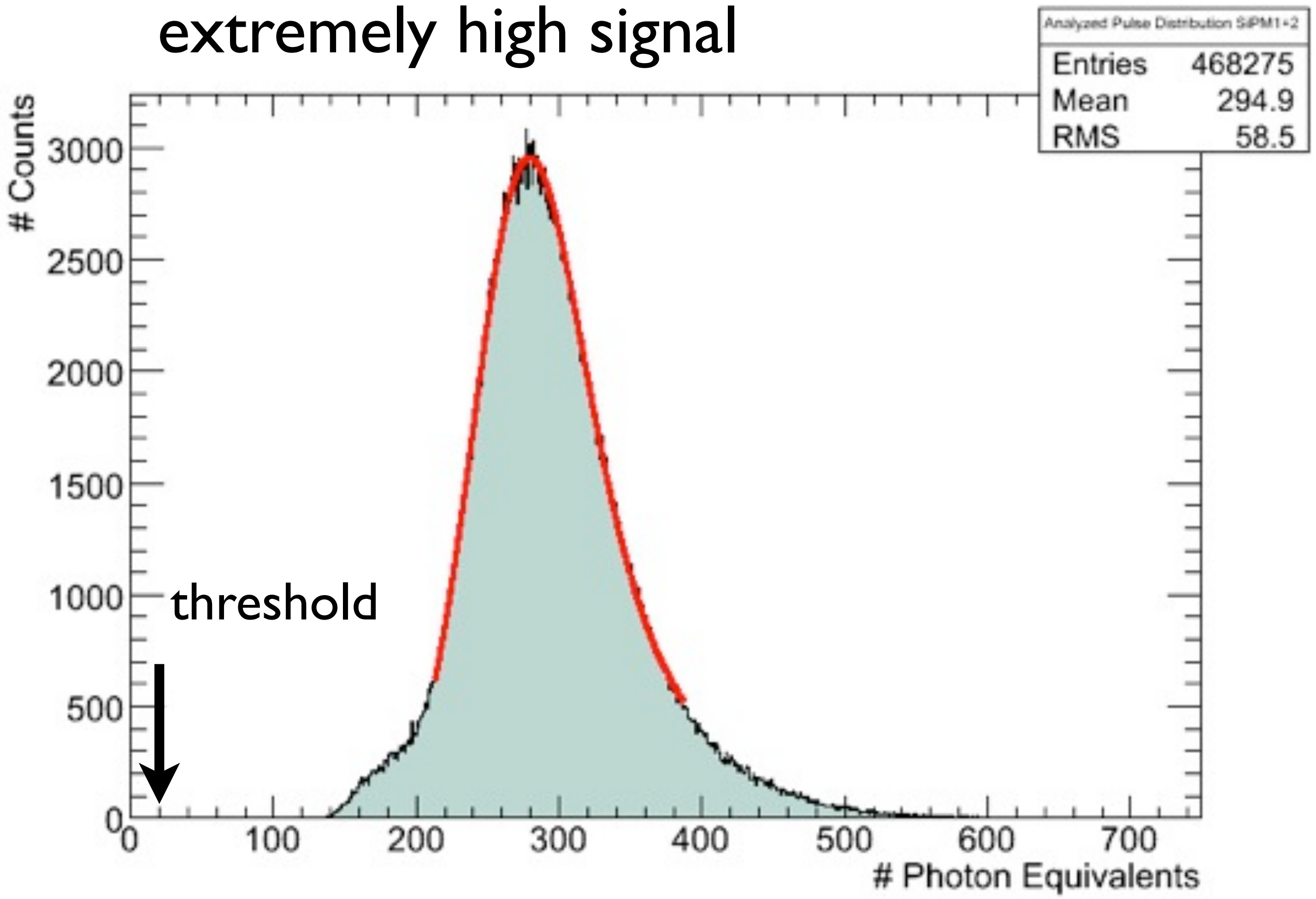
x2 in PDE, x9 in collection area, but: increased noise level

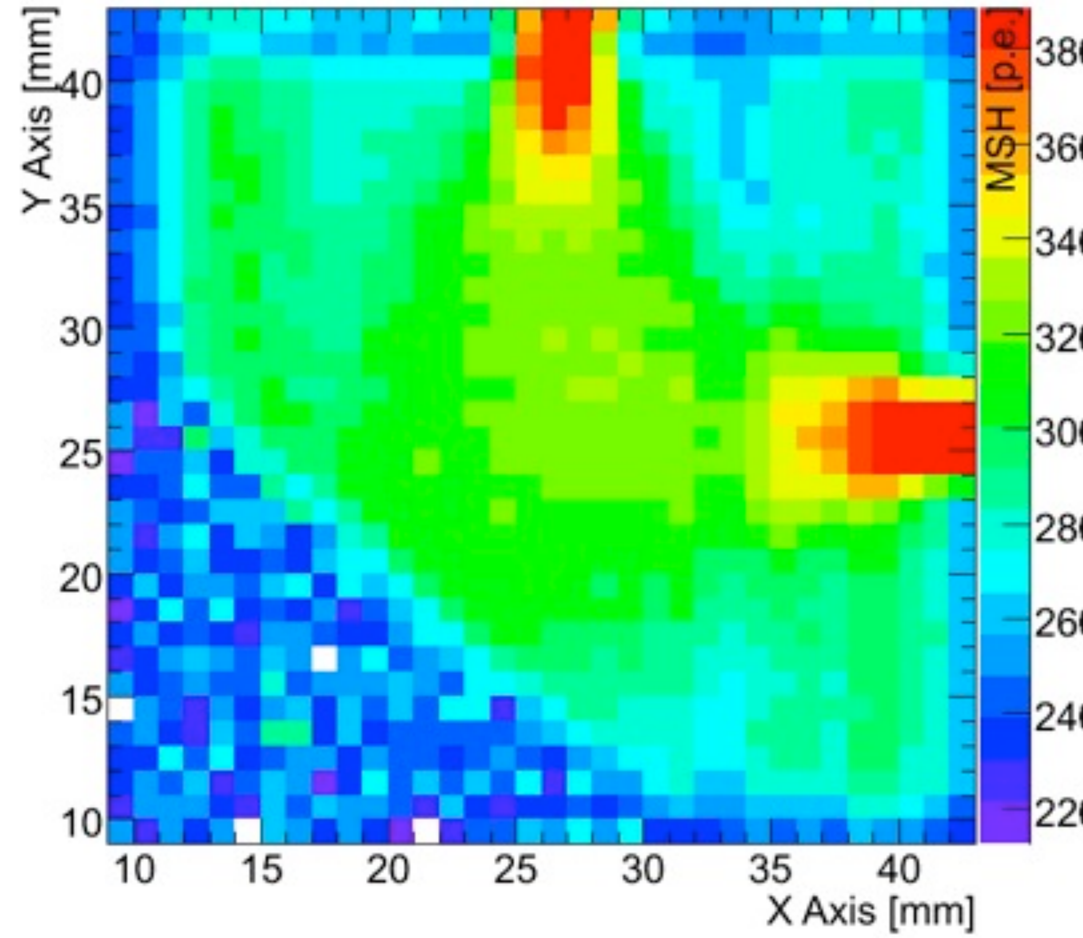




SiPM Readout of ALFA Tiles: Response

- Noticeable non-uniformity, but: extremely high signal





threshold at 10 p.e. per SiPM

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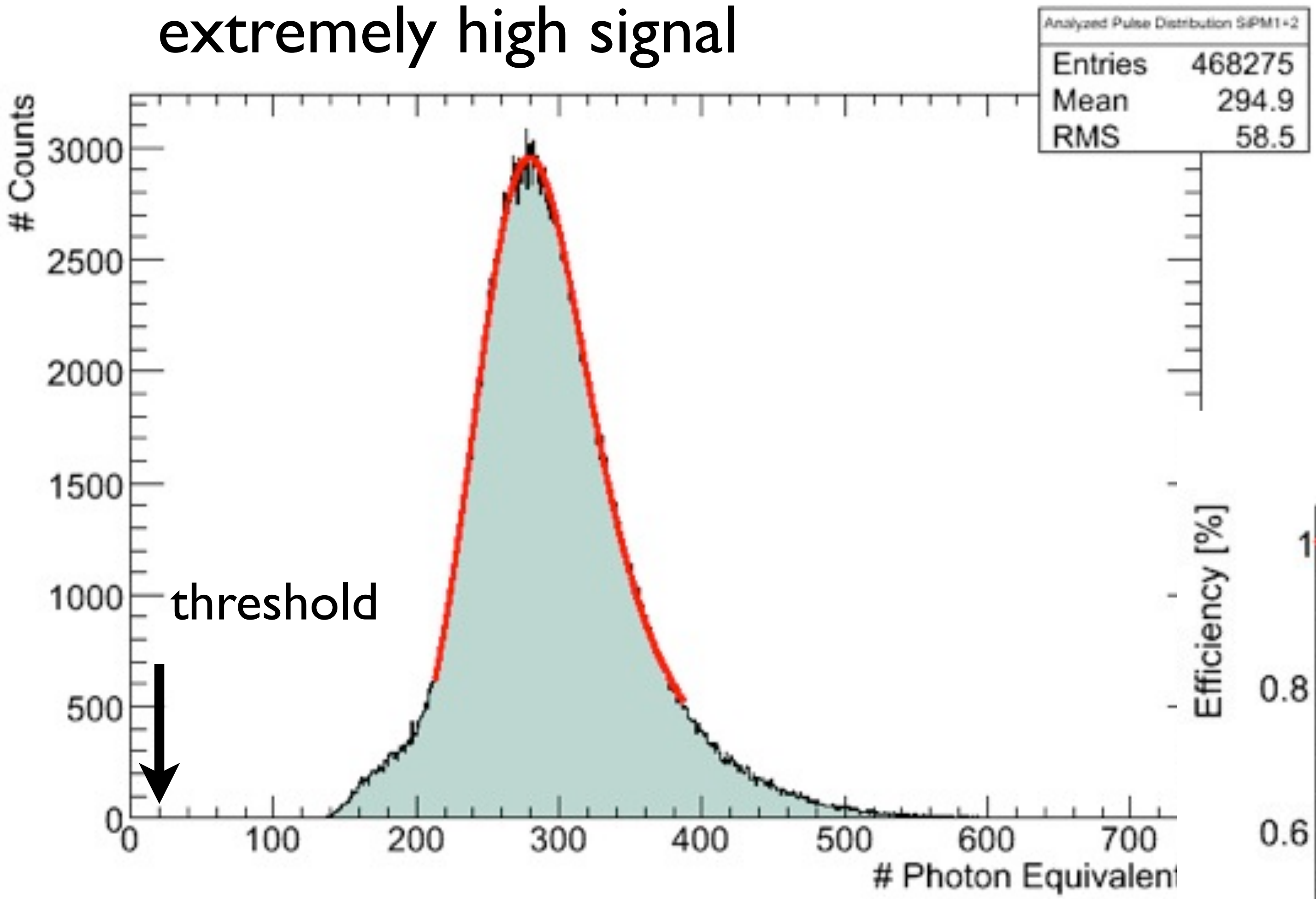

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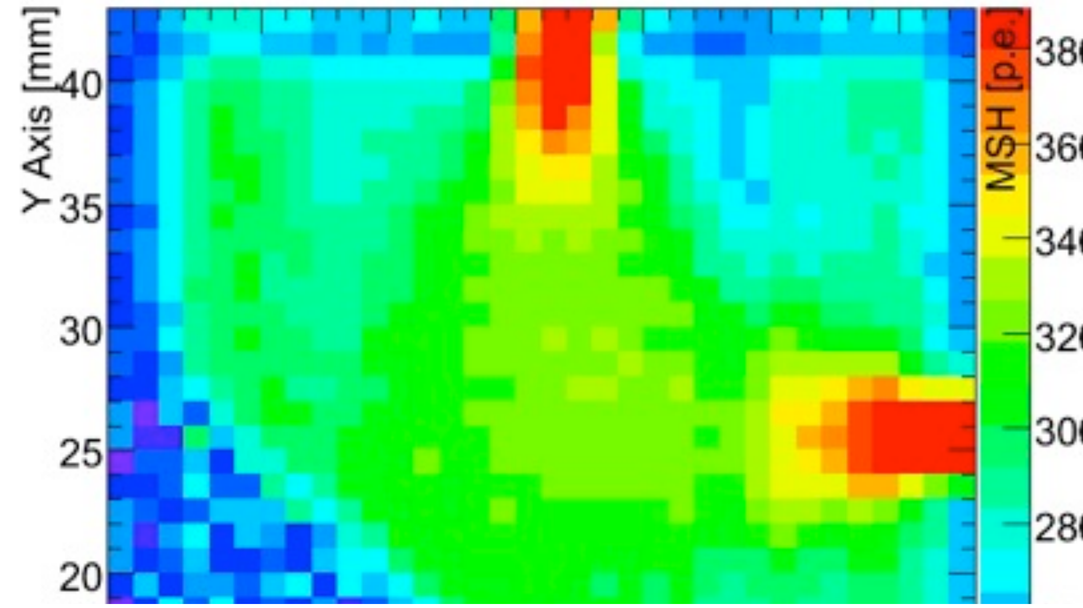
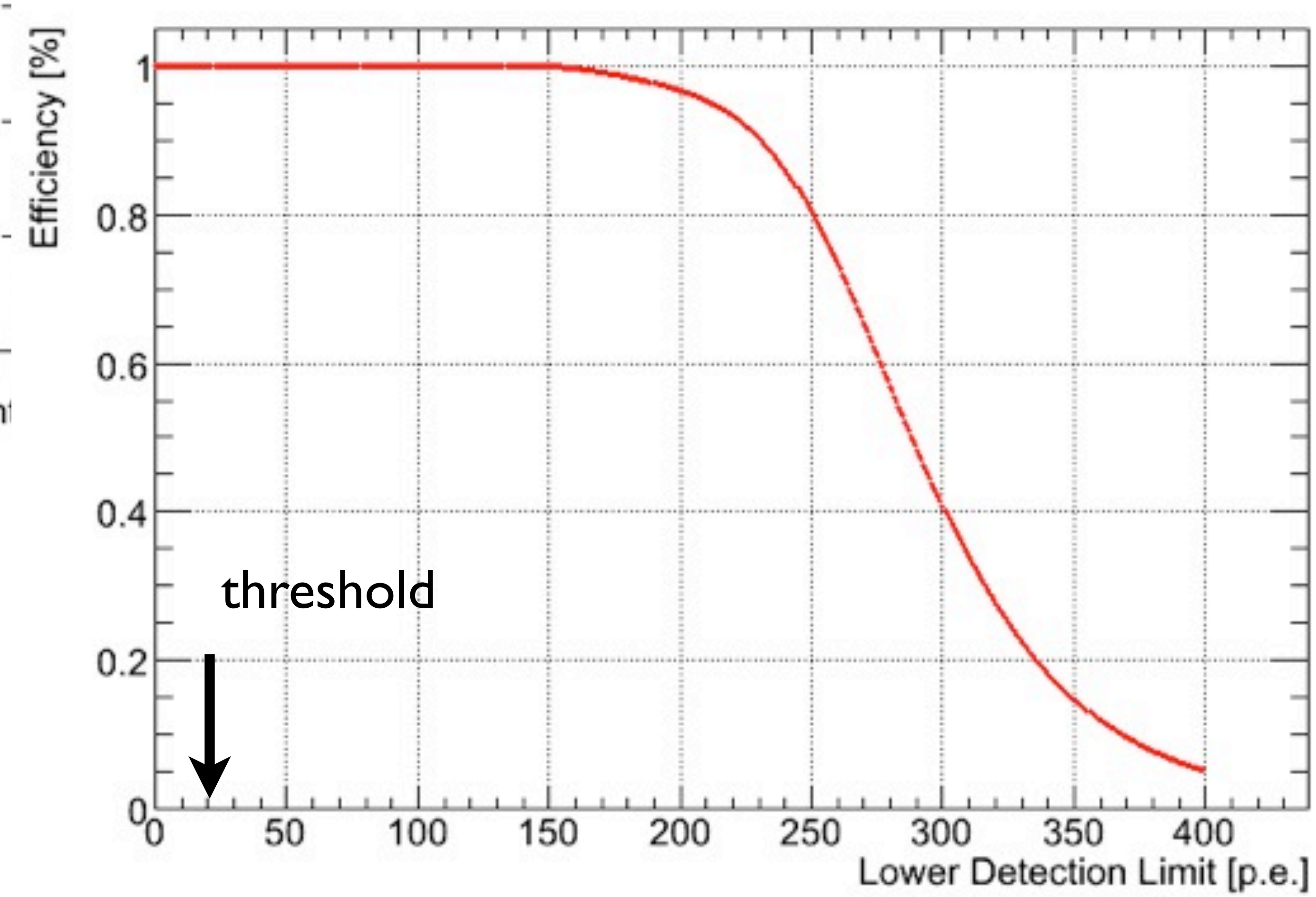
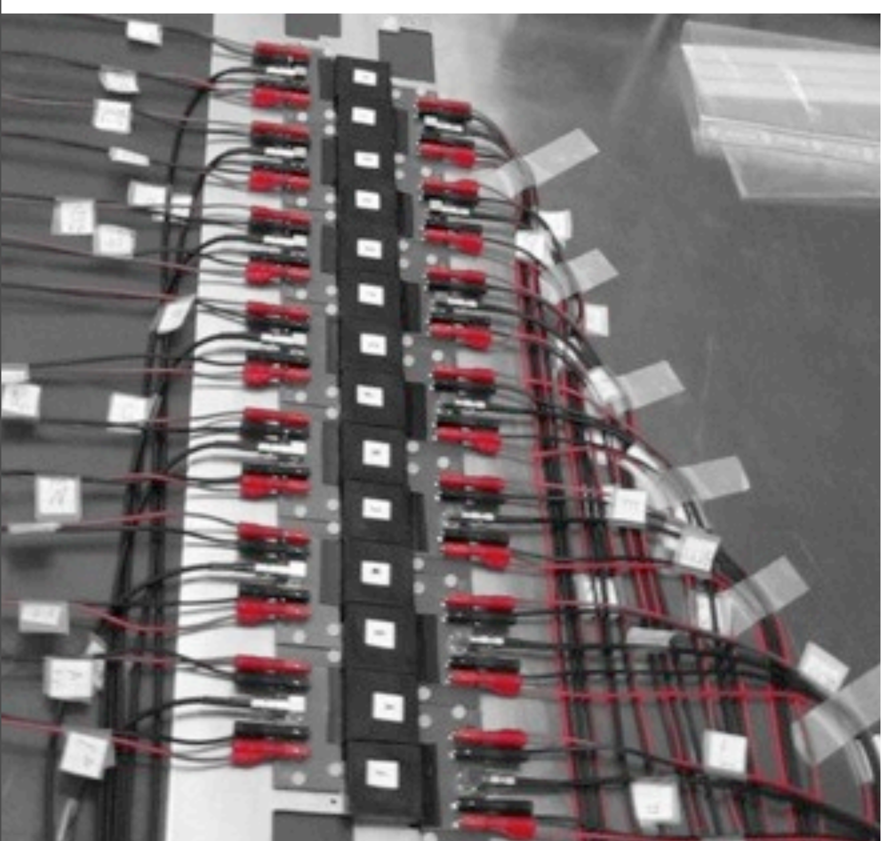


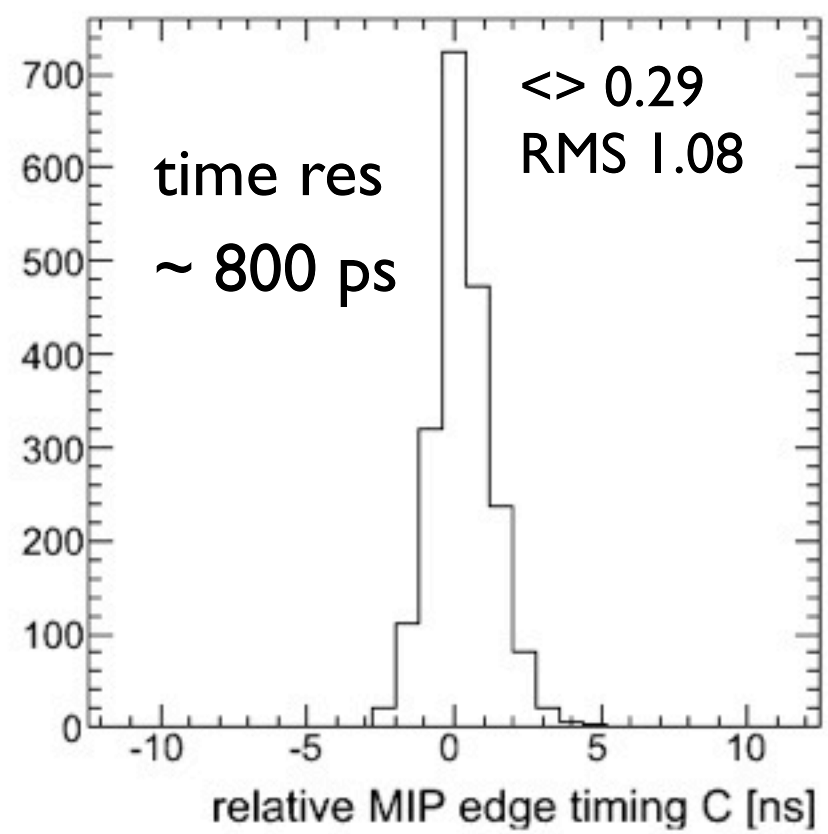


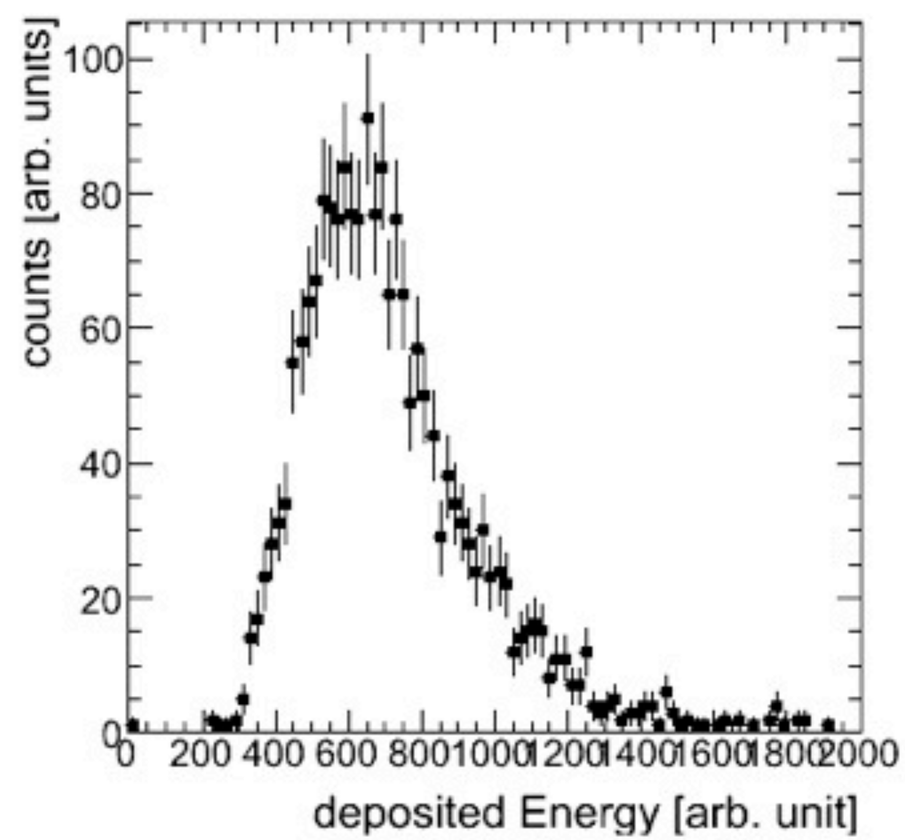
signal far above threshold:
Full efficiency for MIPs with a comfortably large margin

Fiberless Coupling: Immediate Applications

- First measurement of time structure of hadronic showers in a Tungsten HCAL
  - Under study in the context of CLIC, a 3 TeV e^+e^- collider
- The experiment: 15 scintillator tiles with 1 mm^2 MPPC50P read out by 1.25 GS oscilloscopes, 2.0 μs record length per event
- Test beam at CERN PS, together with the 30 layer CALICE Tungsten HCAL: Hadron running beginning today!
- First results from commissioning with muons





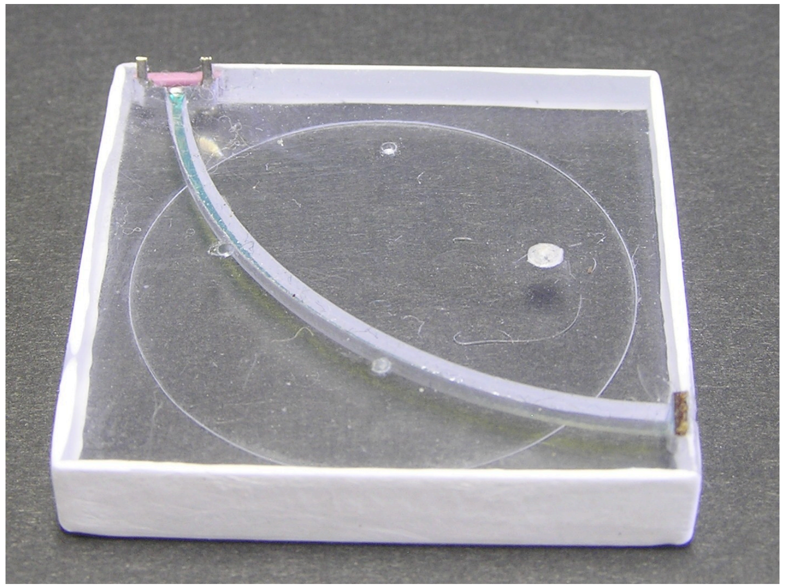


Summary & Outlook

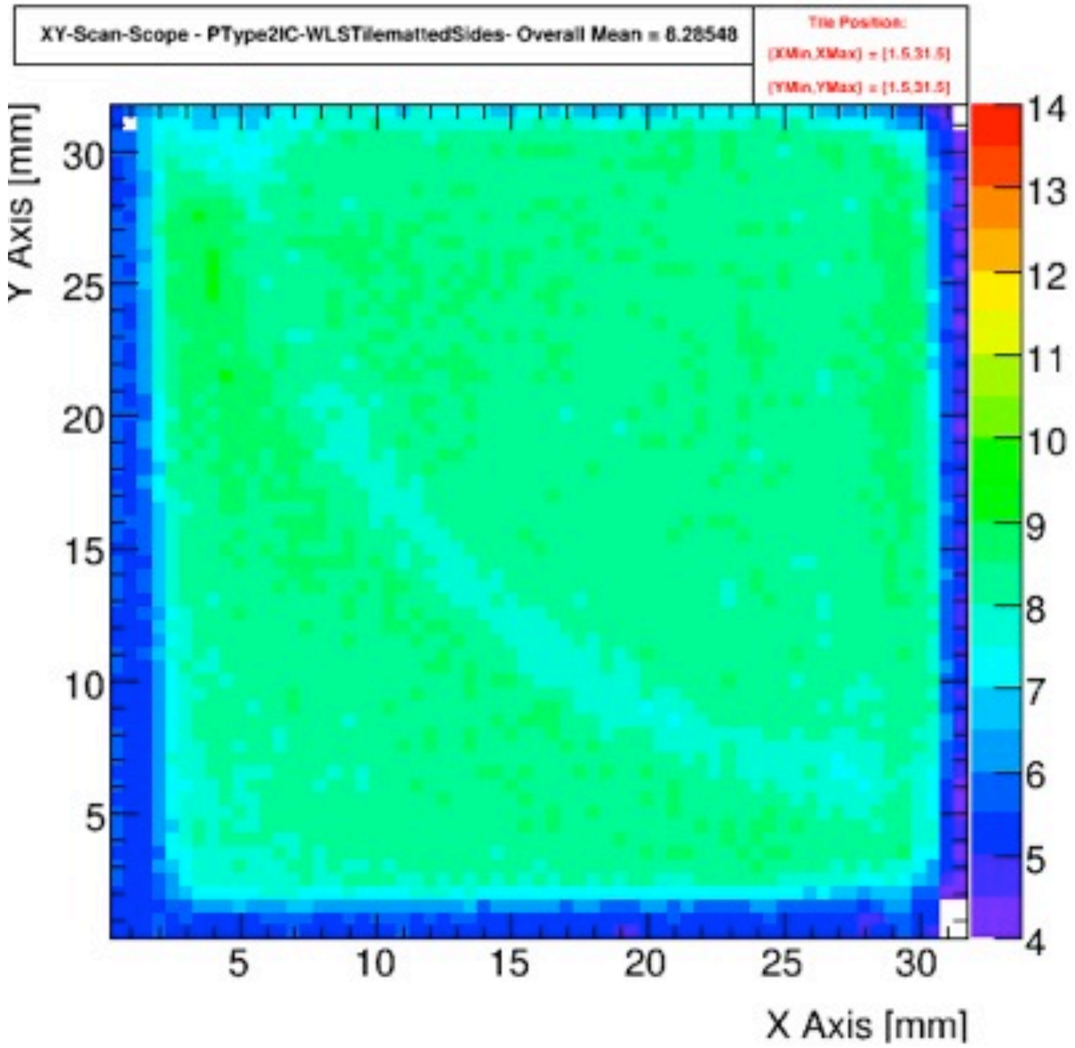
- Scintillators with SiPM readout are powerful tools in particle physics
  - Fiberless coupling is possible, offers mechanical advantages and fast signals
- High degree of response uniformity can be achieved with special shaping of the coupling position - Satisfies requirements of Imaging Hadronic Calorimeters
- Full efficiency for MIPs can be obtained with larger sensors
  - Under consideration as a possible upgrade of ATLAS ALFA - Requires studies of electronics and potential RF pick-up close to the LHC beam
- Directly read out scintillator tiles are used to study the time structure of hadronic showers in a Tungsten calorimeter

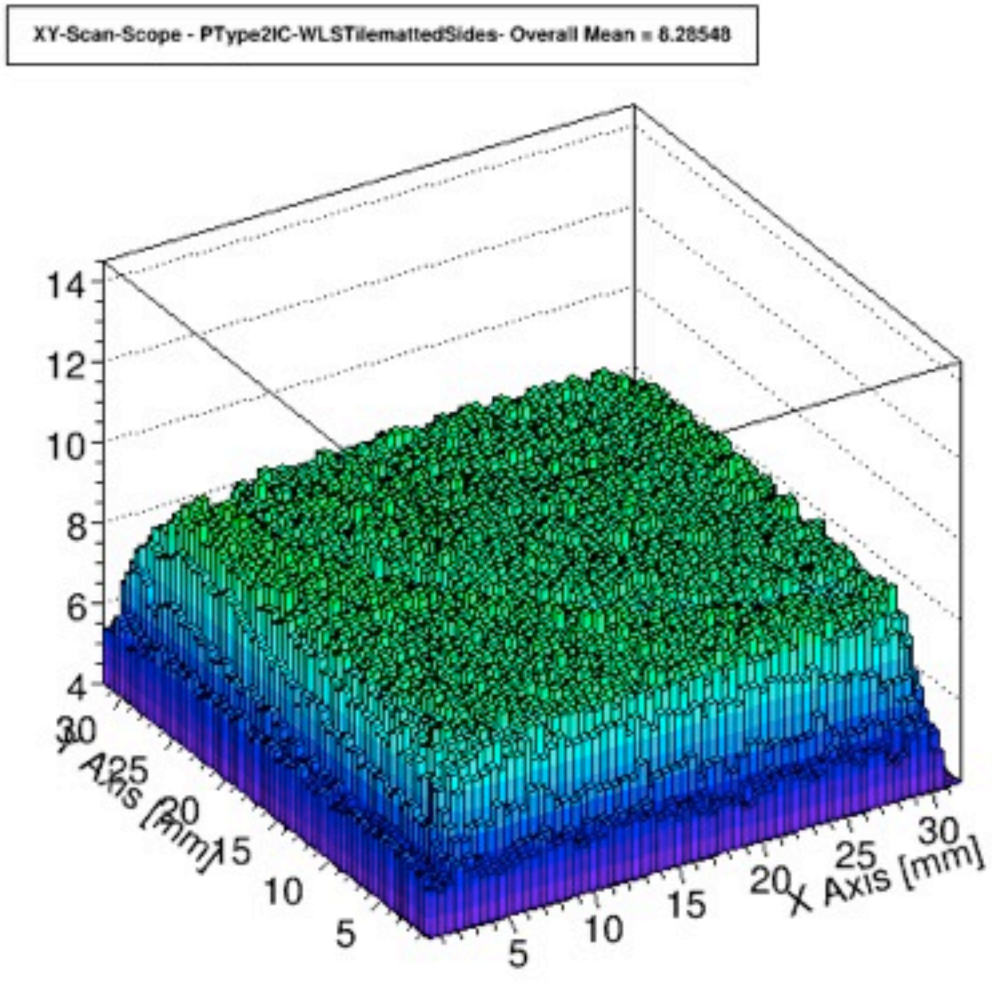
Backup

A Quick Look at the Old Tiles



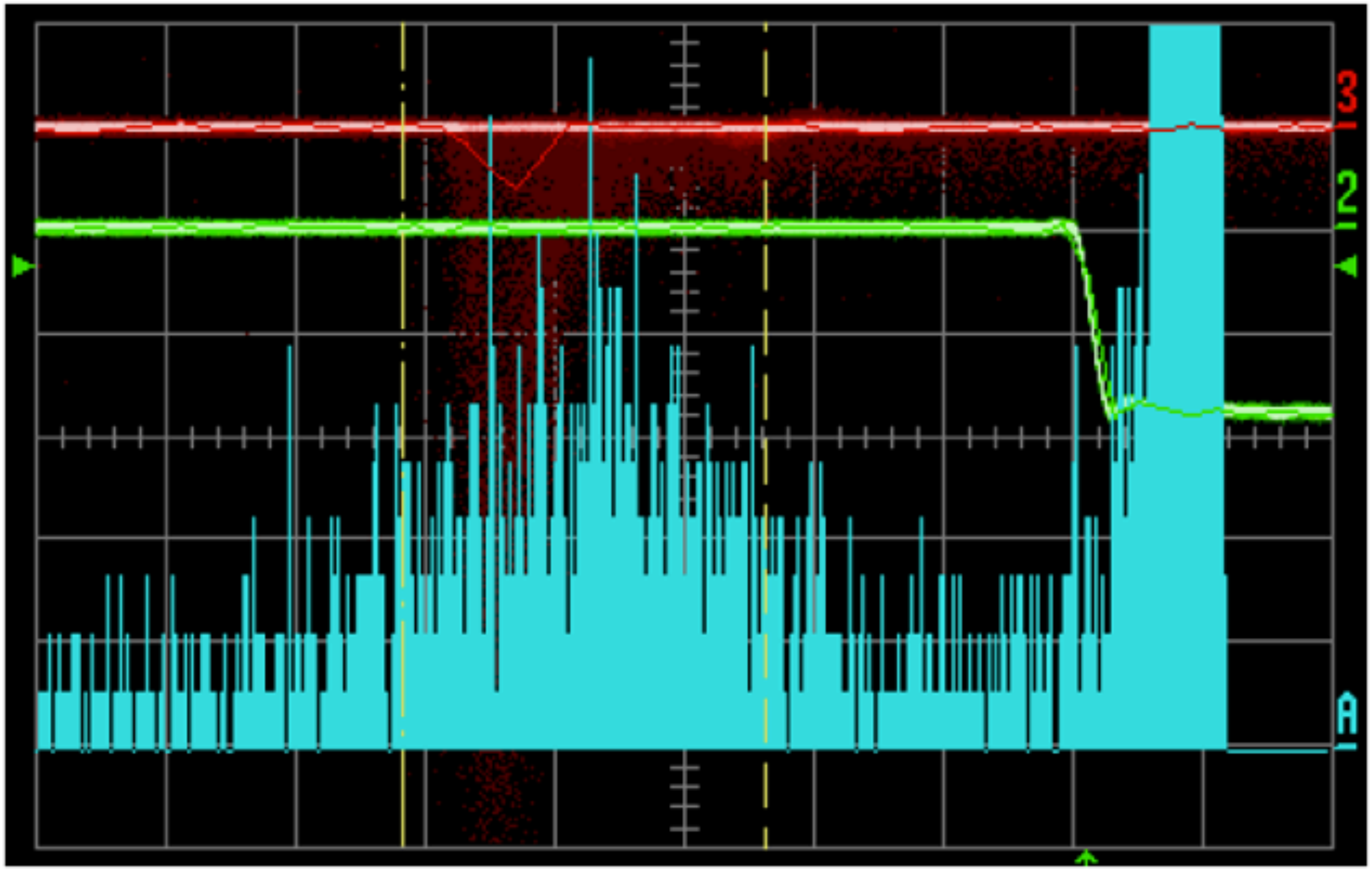
- Tile from 1st generation prototype with WLS fiber, read out with MPPC25P
  - Reduced signal amplitude (mean: 8.3 p.e.): sensitivity of MPPC not matched to fiber emission
  - Excellent uniformity: 78% within 5% of mean, 88% within 10% (not corrected for edge effects)





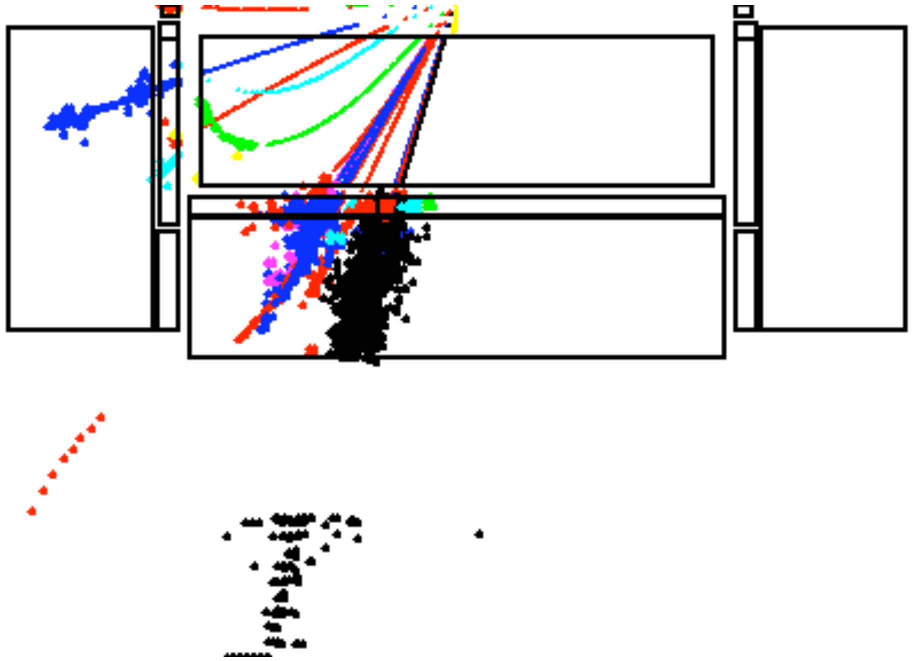
ALFA: PMT Readout

- ALFA trigger tiles with clear fibers & PMT readout: Test with cosmic muons
  - Signal amplitude ~ 40 p.e.



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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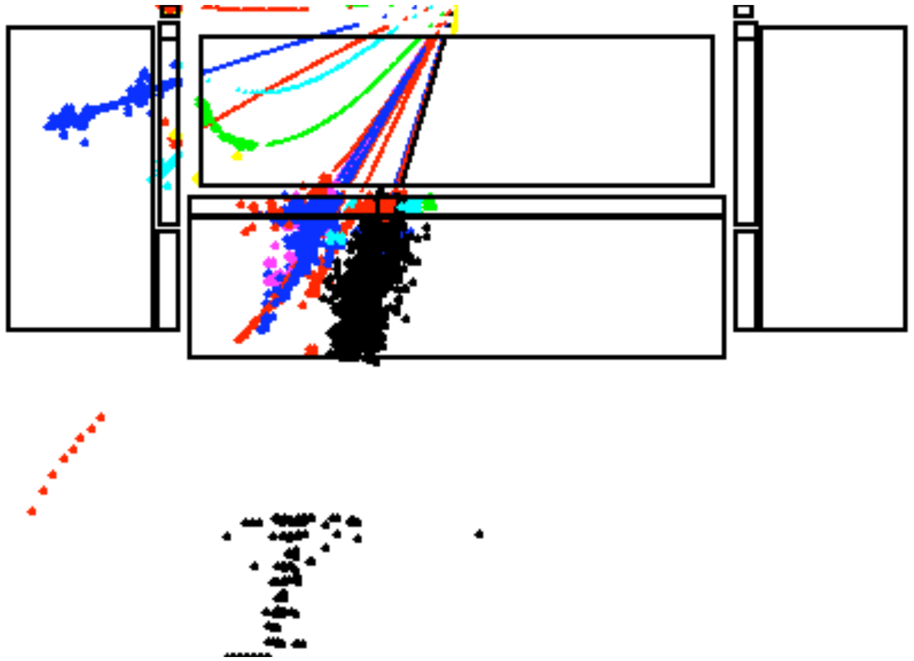
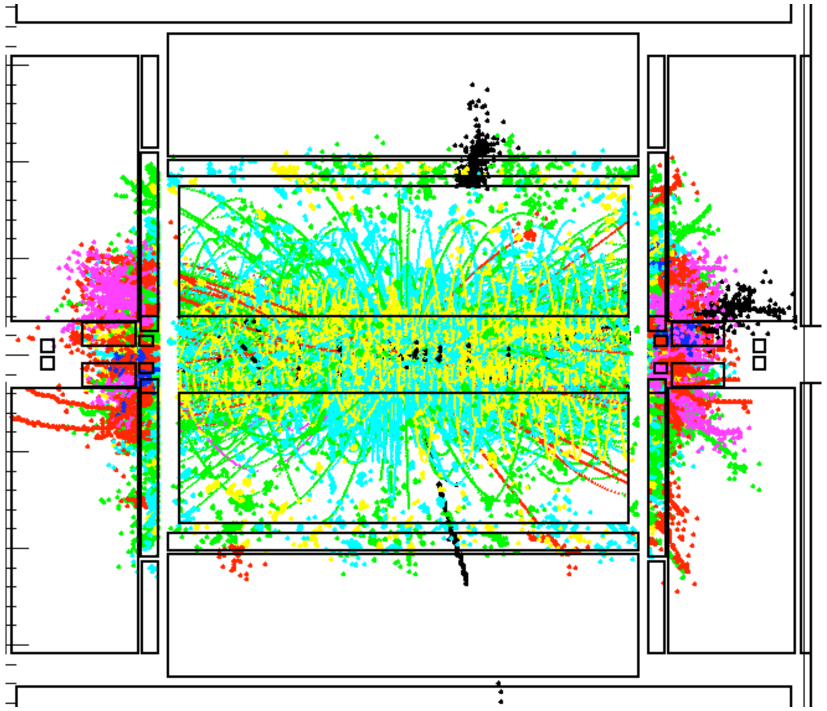


Shower containment and leakage is a crucial issue

➯ A (very) deep hadron calorimeter is needed

➯ Use compact absorbers to limit the detector radius: Tungsten a natural choice

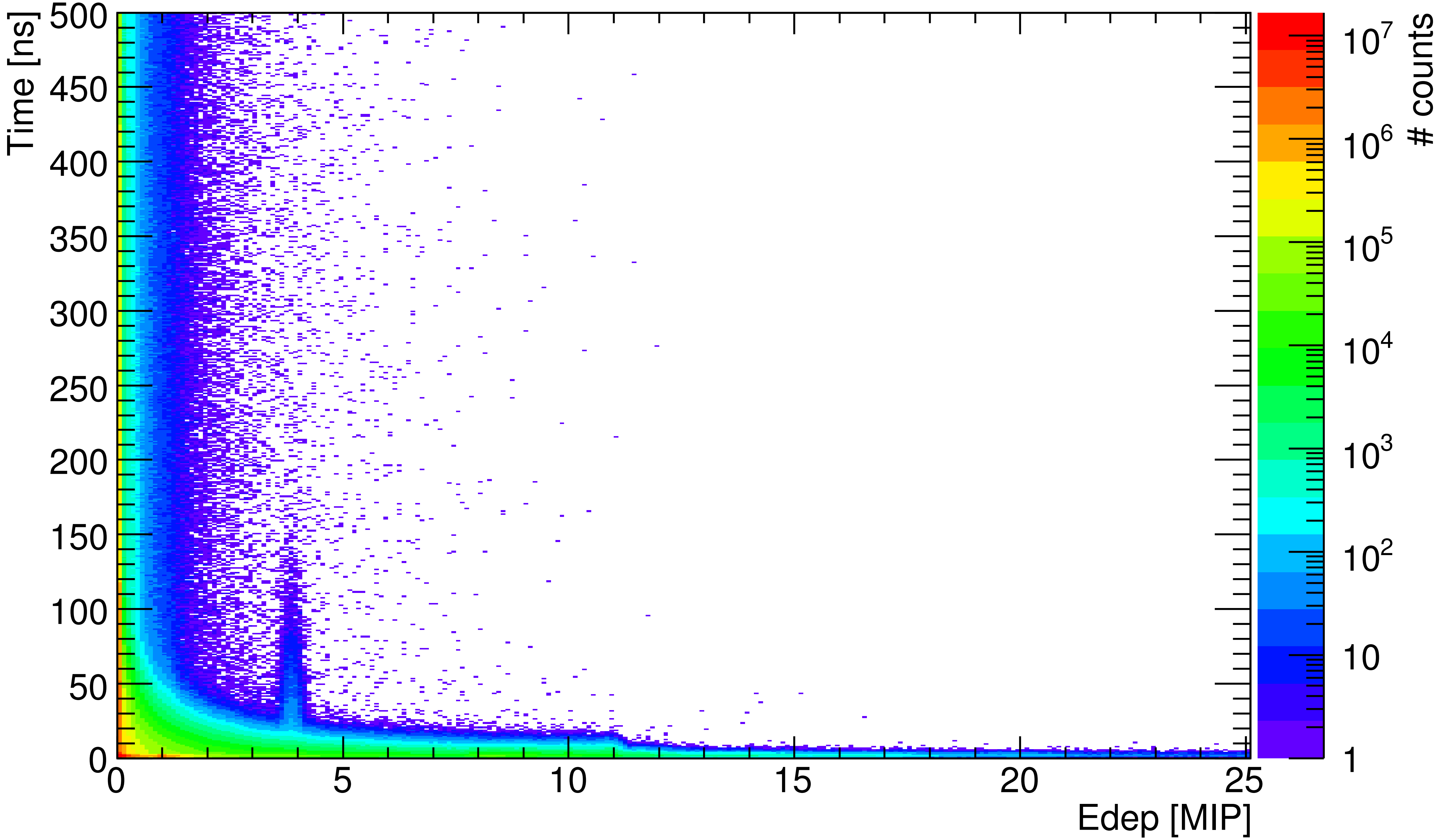
- Key challenge (linked to high energy and machine-specific issues): Background
  - $\gamma\gamma \rightarrow$ hadrons substantial:
    ~ 9 hadrons/bunch crossing in the barrel region
    (5.8 GeV / bunch crossing)
  - extreme bunch crossing rate: every 0.5 ns



➯ Very good time resolution in all detectors important to limit impact of background!

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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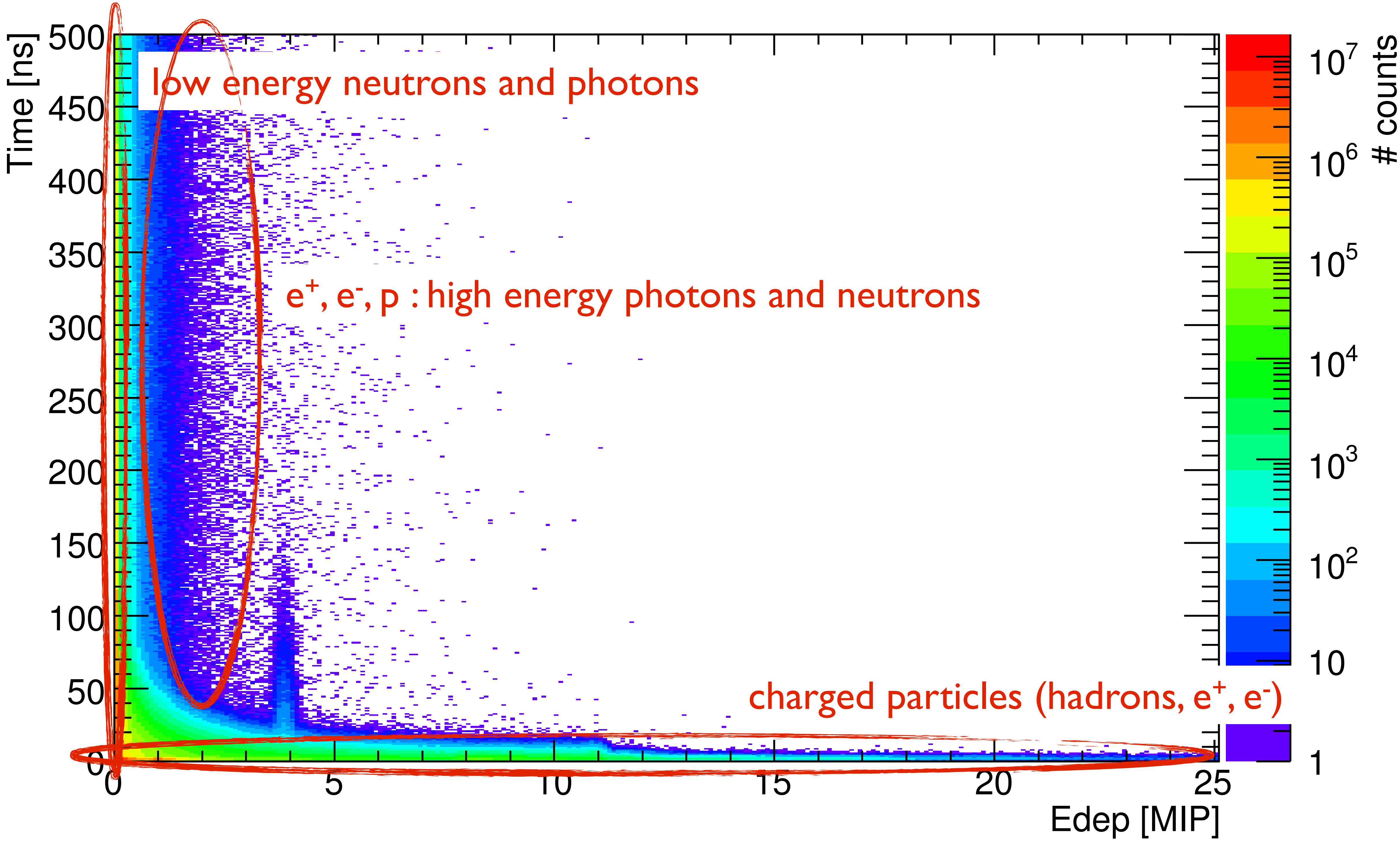

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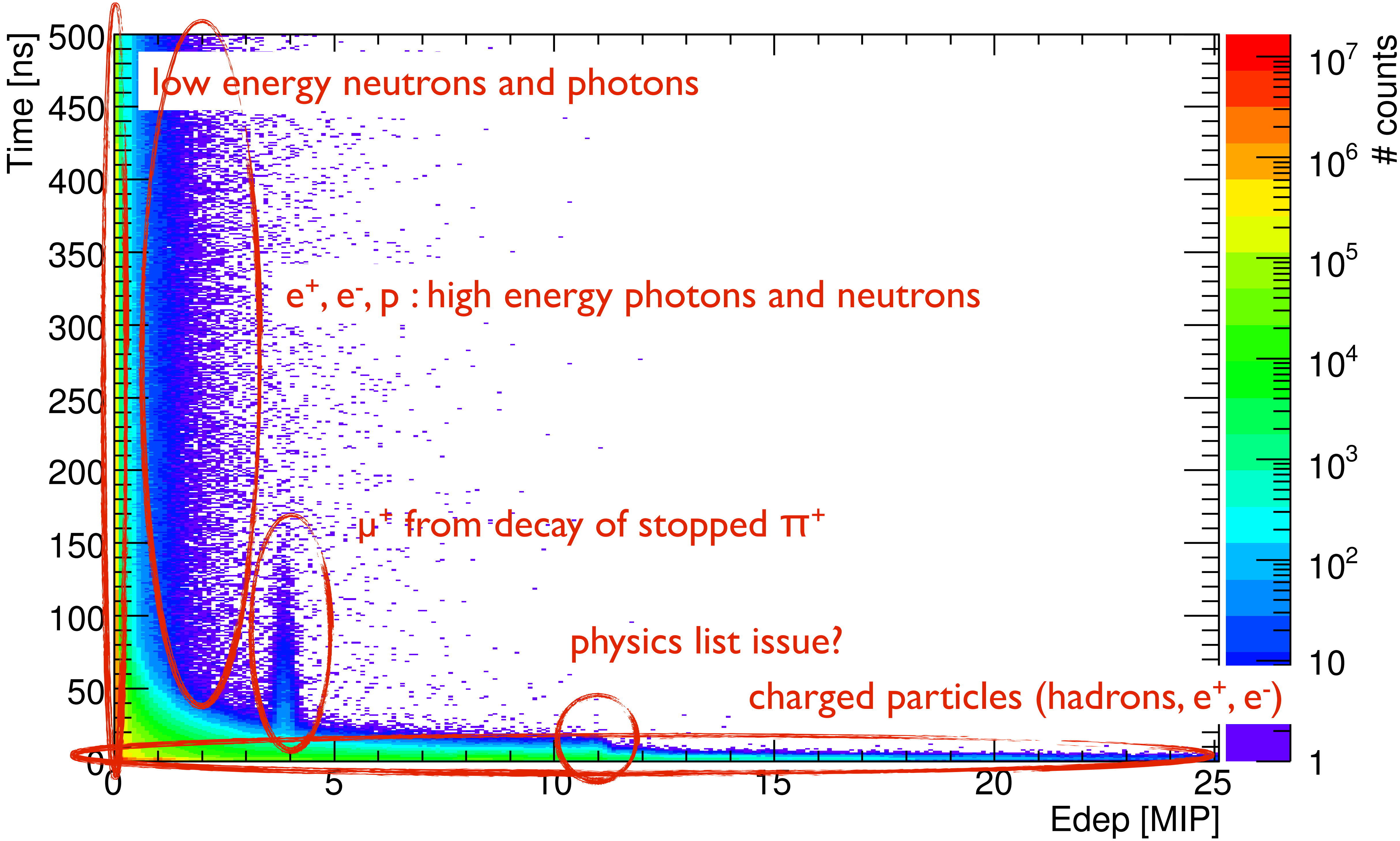

T3B Technology: Scintillators, Photon Sensors

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

Choice of photon sensor: Number of pixels

- Compromise between amplitude and dynamic range
- T3B will sit behind 3 λ 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 x 50 μm^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 μs or more
  - Fast trigger rate: faster than the CALICE HCAL, > a few kHz

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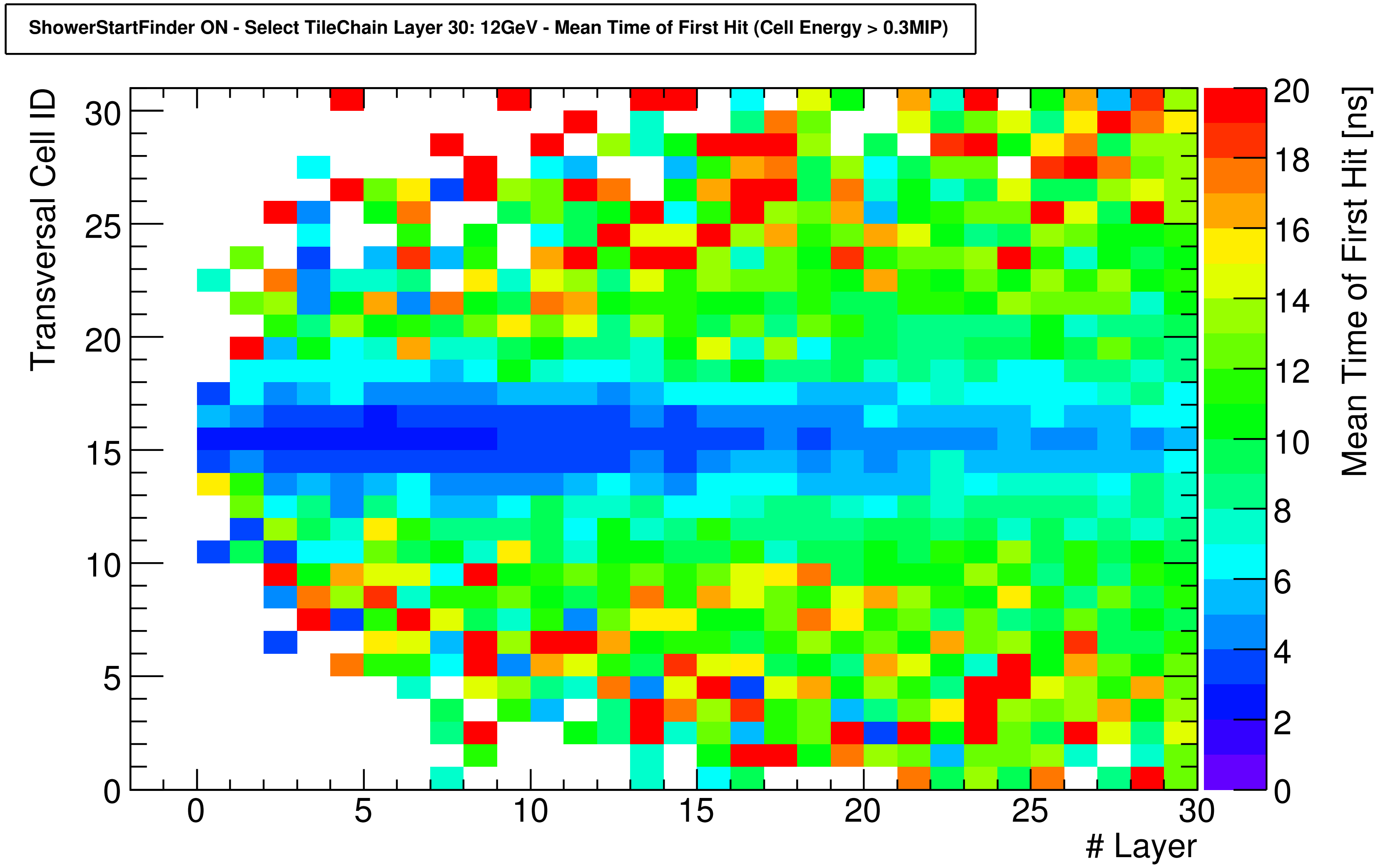
- Key requirements:
  - Fast sampling to allow for single photon resolution: ~ 1 GHz or more
  - Long acquisition window per event: 2 μs or more
  - Fast trigger rate: faster than the CALICE HCAL, > a few kHz
- Adopted solution for T3B: PicoScope 6403
  - 1.25 GHz sampling for 4 channels per unit
  - 1 GB buffer memory (shared between channels)
  - Burst trigger mode: Maximum rate determined by window length: ~ 500 kHz for 2μs acquisition window
  - 8 bit vertical resolution
  - Control & Readout via USB

T3B: 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



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

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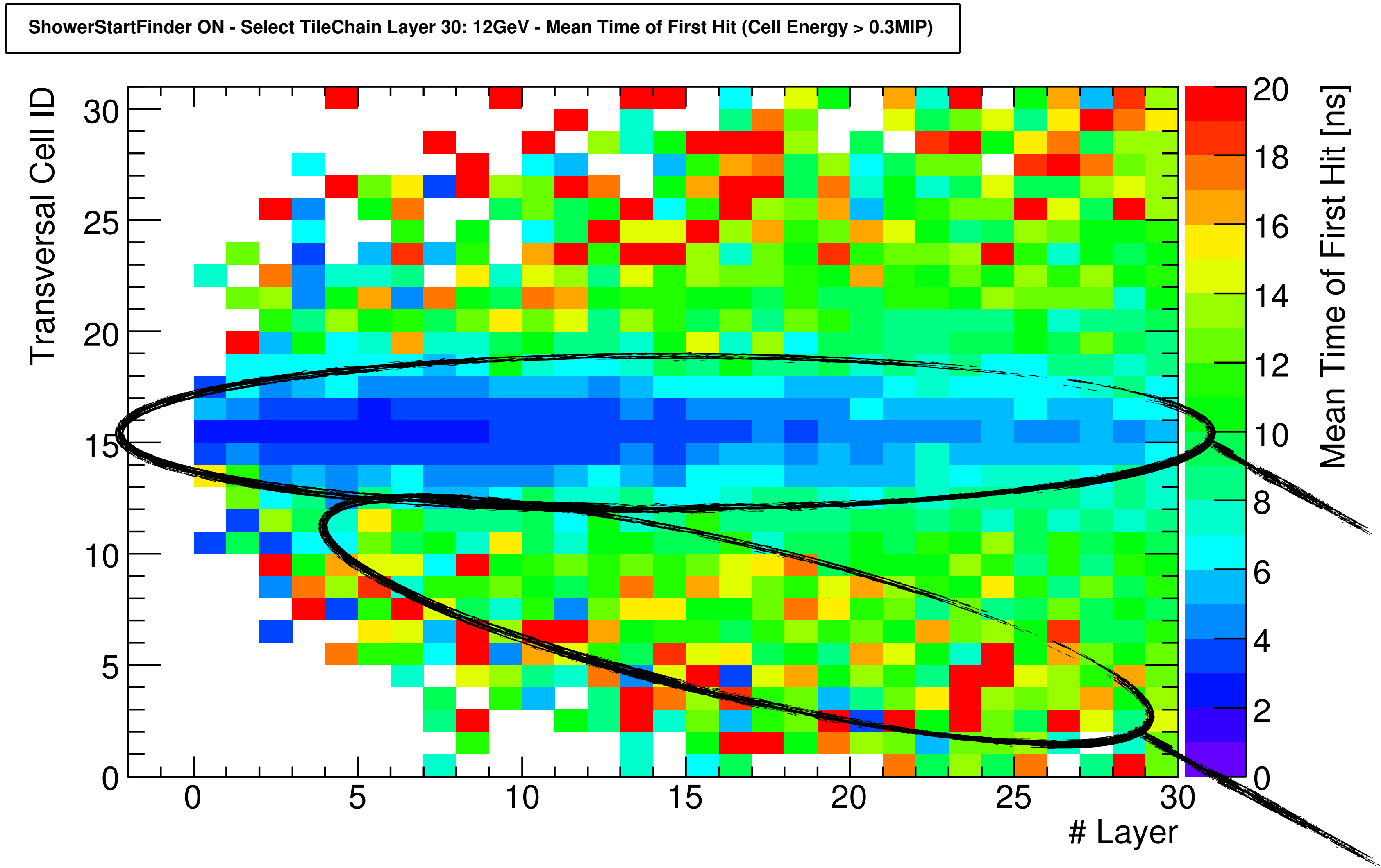

Average time of first hit (for cells which reach an energy > 0.3 MIP in the event)

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

outside the shower core, late deposits quickly become important