2021 Test Beam activities for Dual Readout Calorimeter

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On behalf of the
IDEA Dual-Readout Calorimeter Collaboration

Introduction

Long term R&D project aiming by 2025 to test full hadronic containment prototype with partial SiPM readout

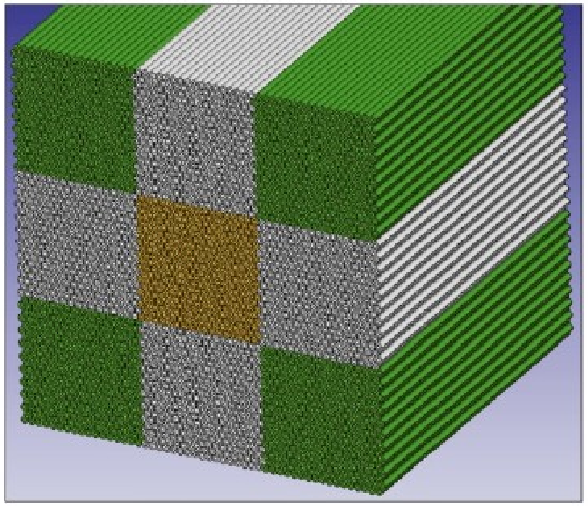
2020/21: Build and test in beam a em containment prototype (10x10cmx1m) DR fiber prototype partially equipped with SiPM. Aims:

- Start handling a scalable readout for SiPMs
- Consolidate EM performance
- Exploit mm-level space resolution for particle id and shower shape studies
- Tune detailed simulation

Two beam periods

- DESY (June) e^- beam 1-6 GeV
- CERN (August) e^+ beam 6-100 GeV

Prototype design

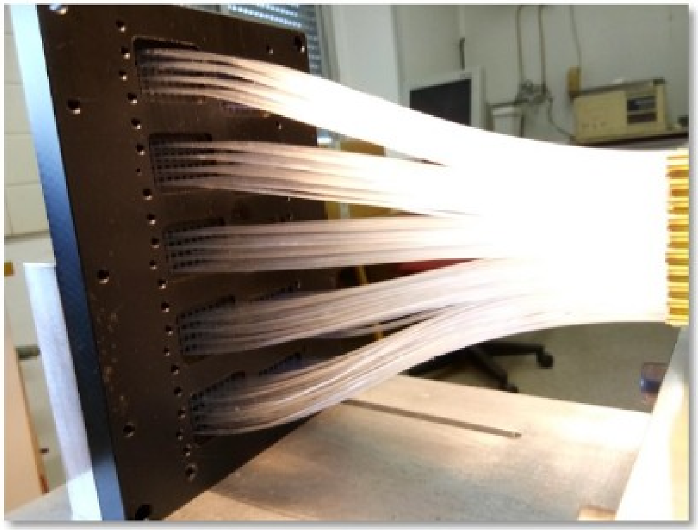


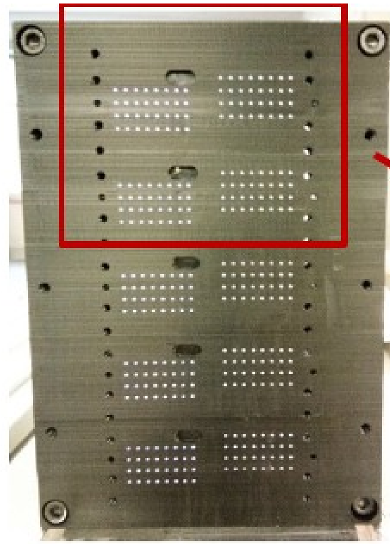
- EM-prototype (10x10x100 cm^3)
  - 9 modules made of 16 x 20 capillaries (160 C and 160 Sc)
  - Capillaries (brass): 2 mm outer diameter and 1.1 mm inner diameter
- EM-prototype readout
  - Each capillary of the central module is equipped with its own SiPM: highly granular readout
  - 8 surrounding modules equipped with PMTs (each module will use 1 PMT for C and 1 PMT for Sc fibres)

Scintillating fibres

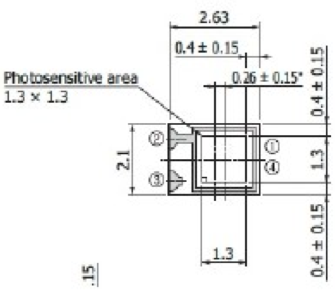
Cherenkov fibres

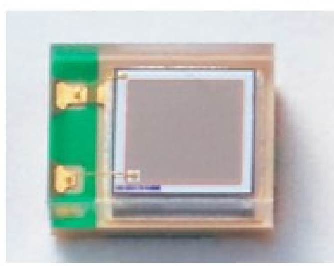
SiPM readout



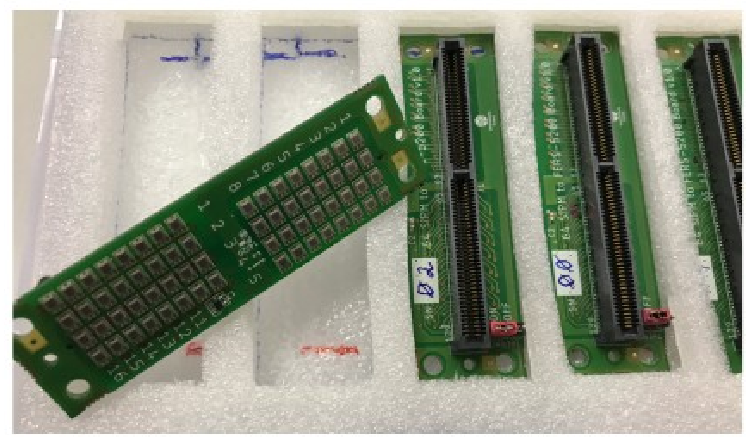


Dummy SiPM FEE board





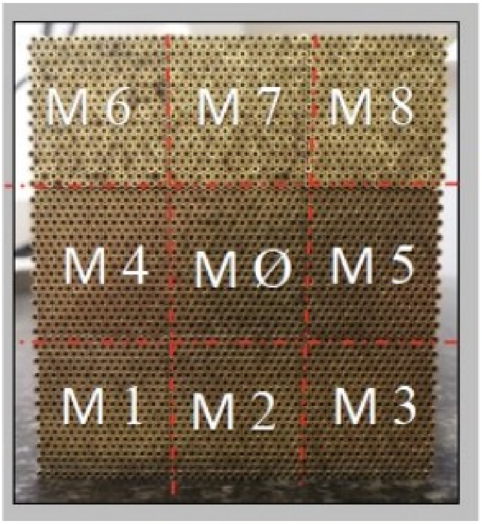
5 FEE Boards (320 SiPMs)

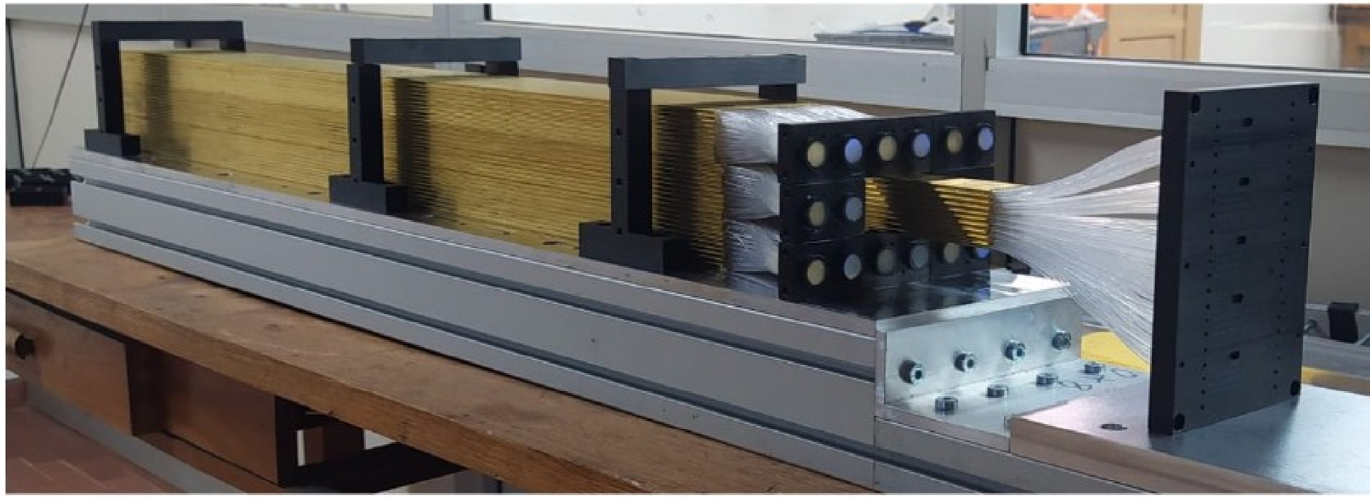


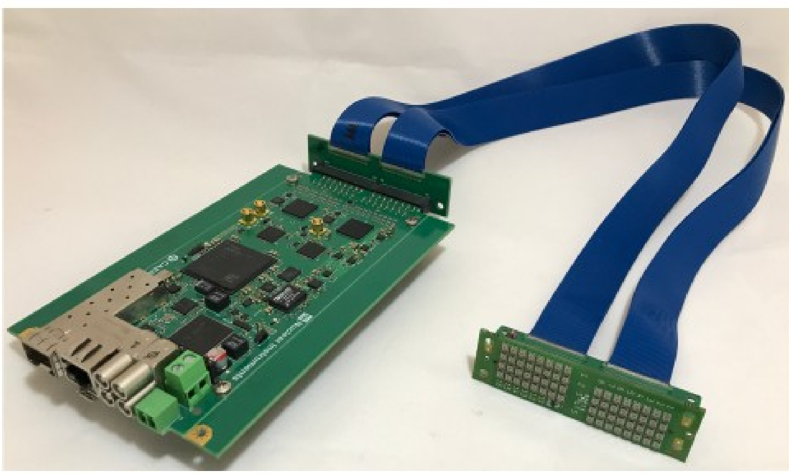
Hamamatsu SiPM: S14160-1315 PS

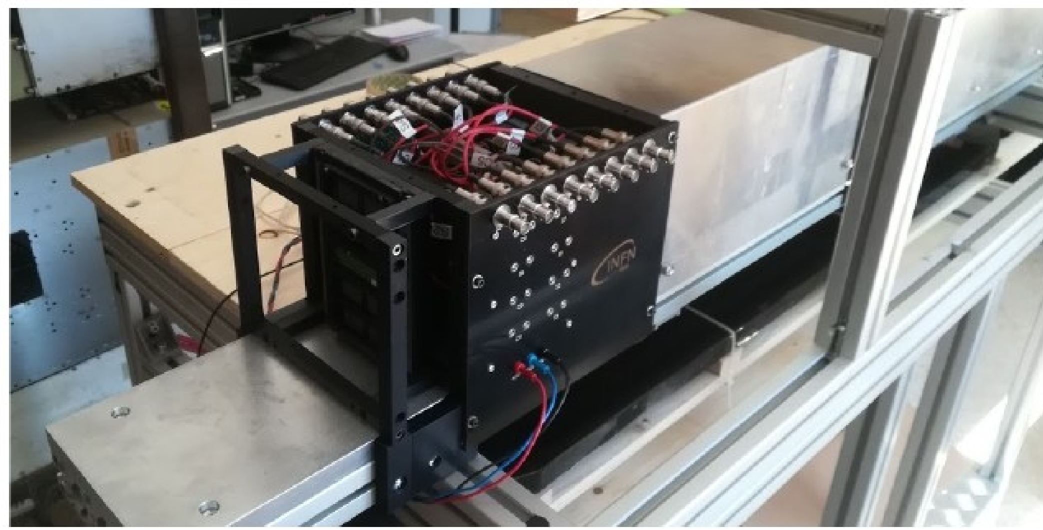
Cell size: 15 μm

Assembled prototype





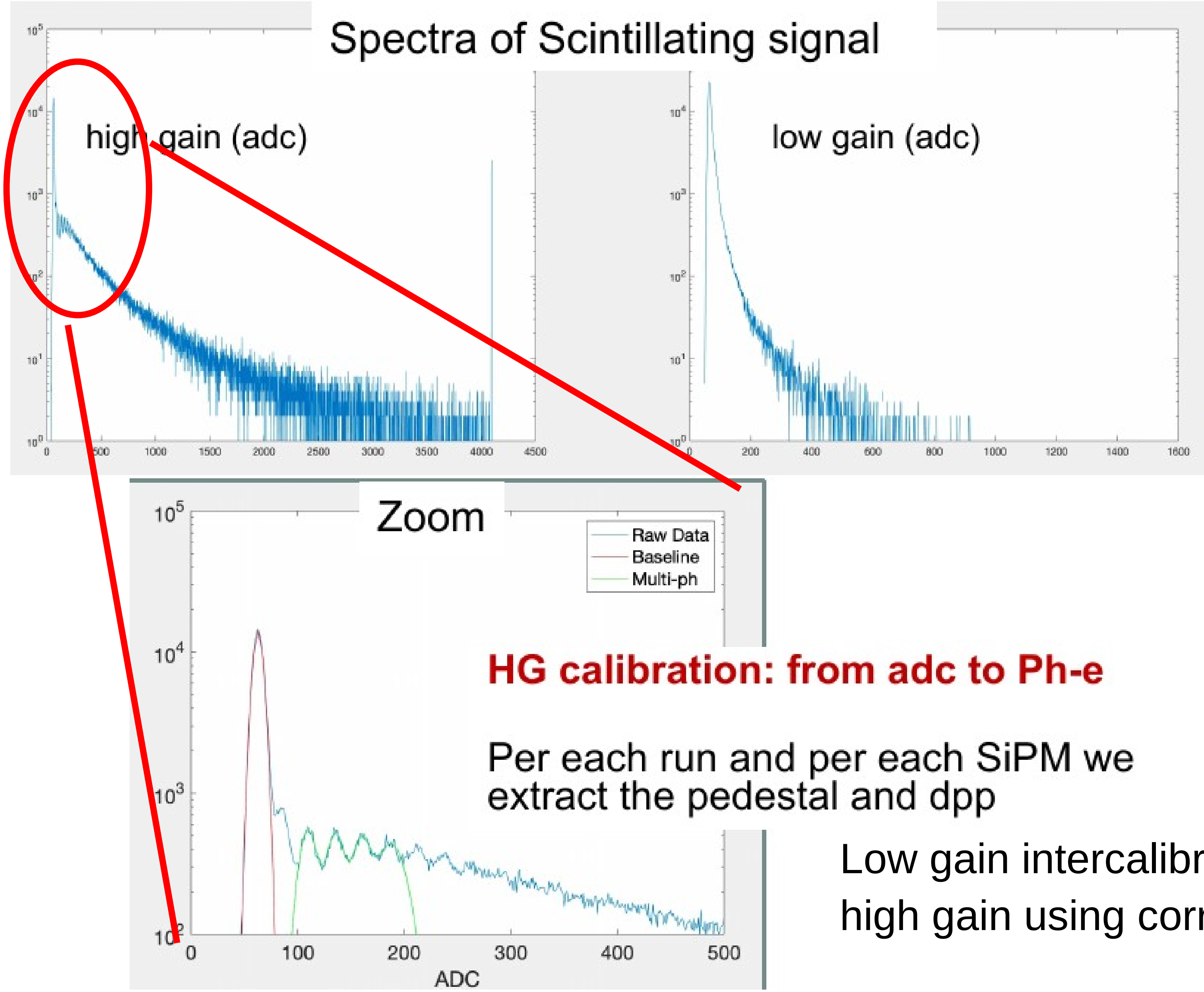




DESY Test Beam

- Trigger based on Coincidence of two scintillators
- SiPM readout system running in self-triggered mode with majority algorithm.
- Trigger from scintillators used to flag and store data on disk
- Tracker triggered by scintillators

SiPM calibration: ADC to Ph-e



HG calibration: from adc to Ph-e

Per each run and per each SiPM we extract the pedestal and dpp

Low gain intercalibrated with high gain using correlation plots

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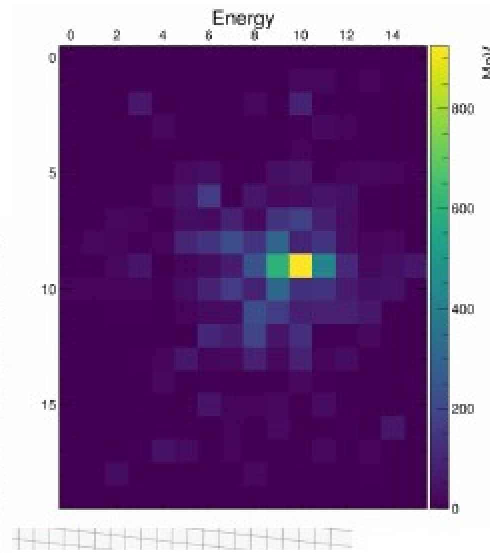
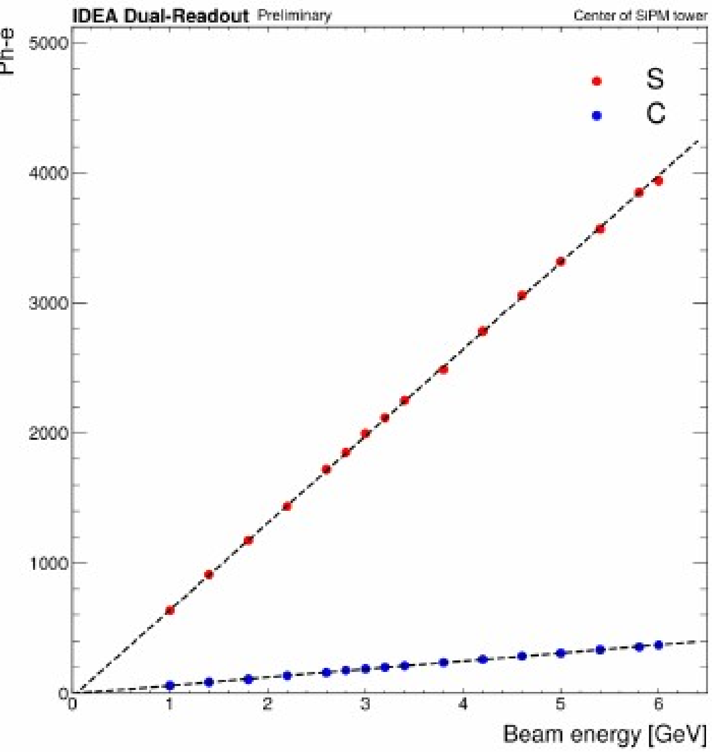
Calibration: Ph-e to GeV

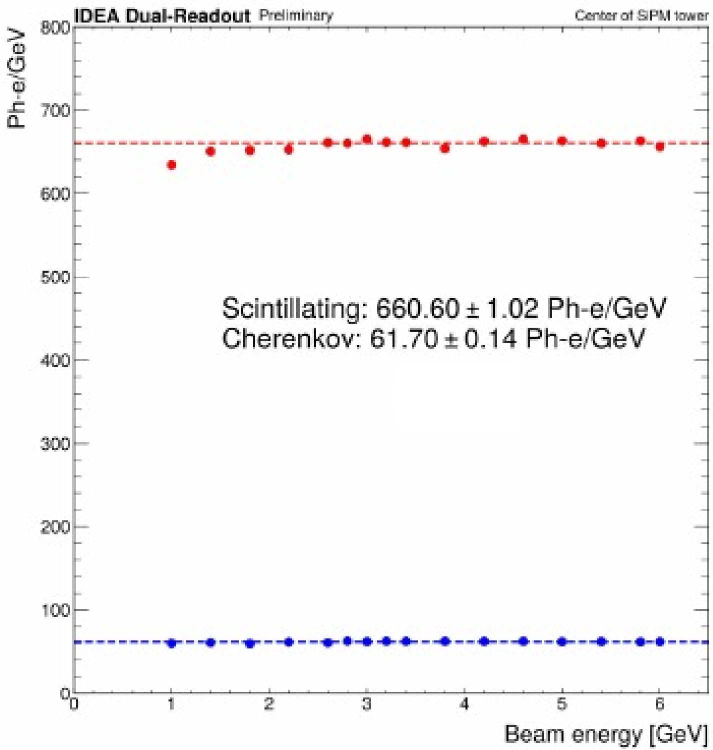
Sum the light detected by all SiPM event-by-event

From distribution extract energy calibration and linearity

- Event selection requiring leading fiber placed in centre of tower (4x4 cell)
- Assumed containment 70% (to be evaluated with simulation)







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CERN Test Beam

H8 Beam line

- Calorimeter:
  - 8 towers with PMT RO
  - 1 tower with SiPM RO
- Auxiliary detectors
  - 2 Cherenkov counters
  - 2 delay wire Chambers
  - Preshower
  - Muon counter
- Trigger
  - 2 scintillators + veto

Software setup for analysis

Raw data handling workflow

As two DAQ systems are involved for PMTs and SiPMs, the workflow looks like this:

Raw Data Handling

Raw ASCII Data as DAQ Output
for PMTs and auxiliaries

↓

Rootified raw data output
for PMTs and auxiliaries

Rootified raw data output for SiPMs

↑

.dat files as raw data output for SiPMS

Data Merging

Stored events from the
two DAQs are synchronized
by taking into account
the random pedestal events
and stored in a dedicated
root merged file.

→

**Calibration and
High-Level Abstraction**

Calibration constants are
applied for
ADC to GeV conversion,
final information is saved in a
high-level-object (class)
ready for analysis.

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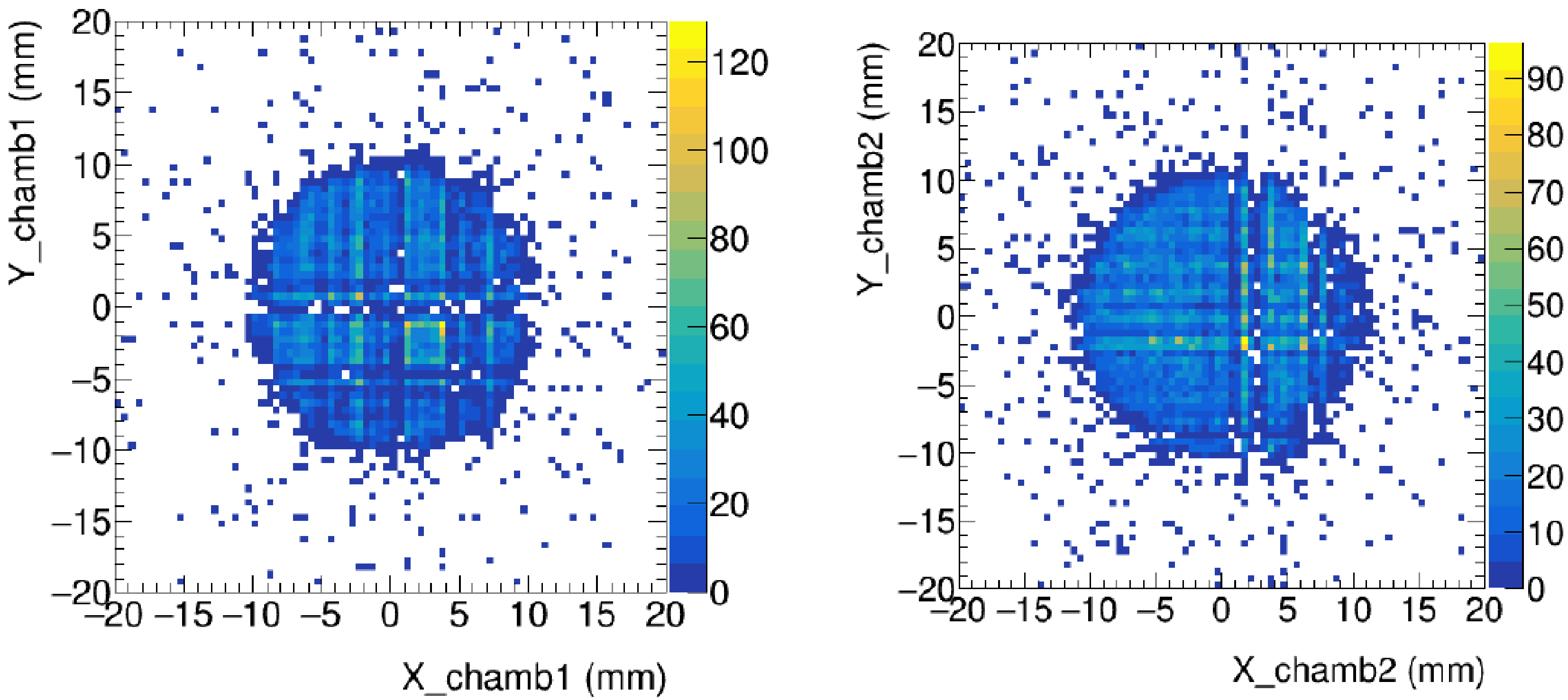
Beam cleaning



Two SPS DWC at 499 (Ch1) and 322 (Ch2) cm from calo face

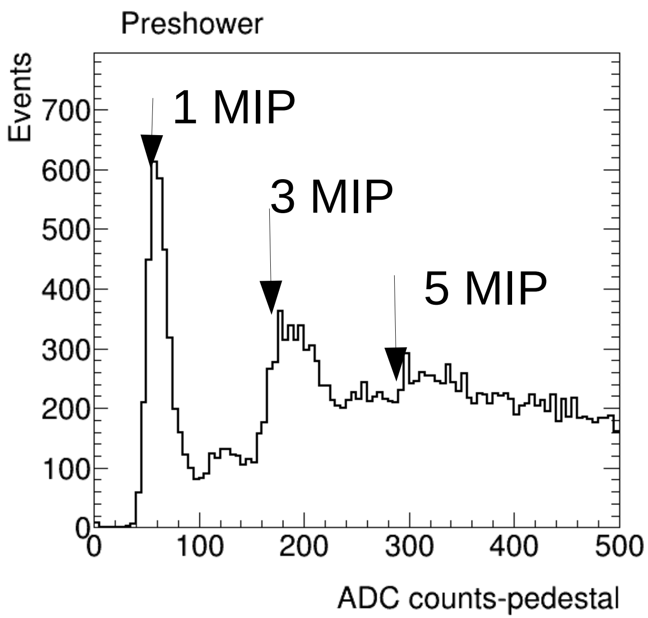
Structure due to hardware problem in the chambers

Require beam radius in two chambers<10 cm and

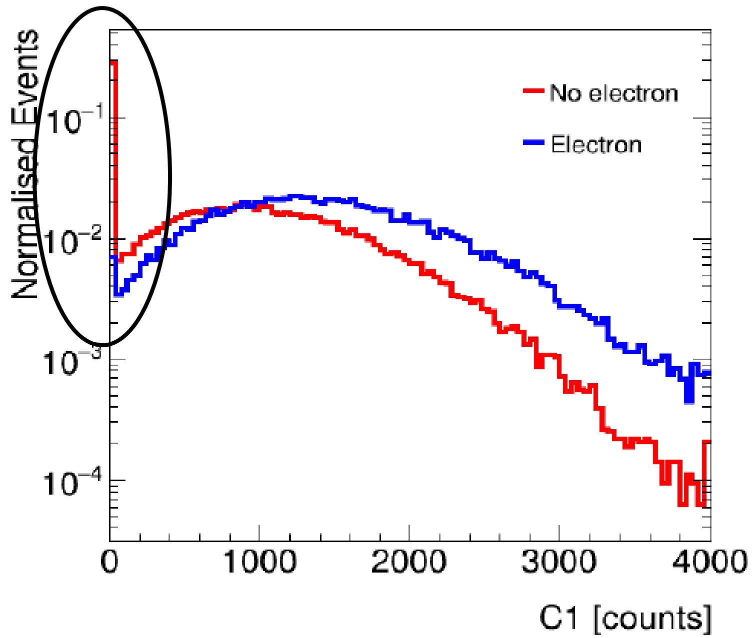
|xch2-xch1|<3 cm and |ych1-ych2|<3 cm to ensure beam collimation

Electron ID

Preshower detector and two SPS Cerenkov detectors



Distribution of counts in preshower
For events with firing Cerenkov detectors
And energy in calo compatible with beam energy



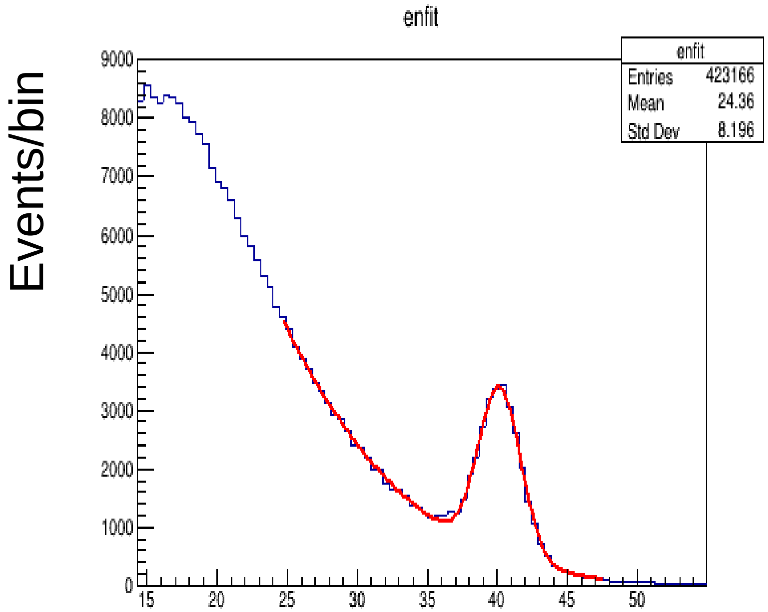
Distribution of counts in Cerenkov Detector.

Electron: >3 mip in PS, energy in calo compatible with beam

No electron <3 mip in PS, energy in calo much smaller than beam energy

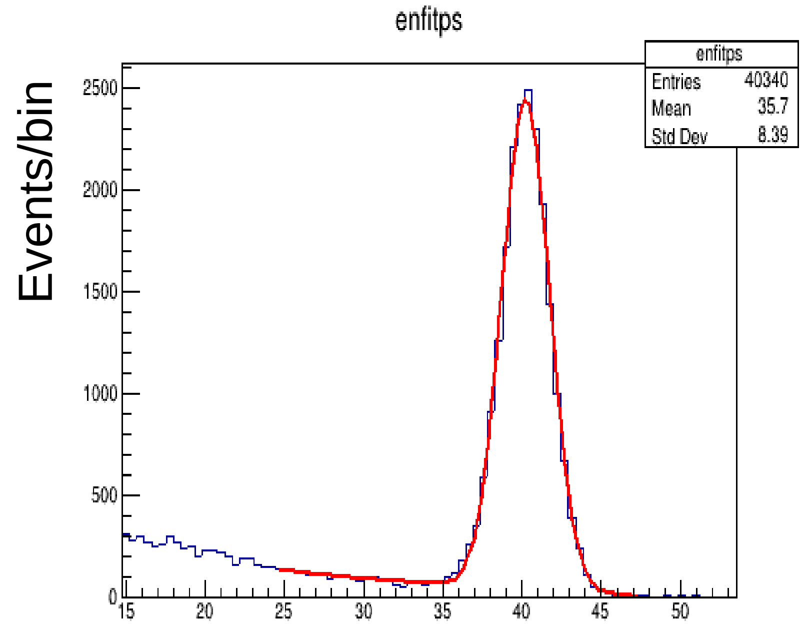
Energy distributions at 40 GeV

Plot linear combination of sum of energies in SiPM and PMT cells minimizing resolution



Energy in calo [GeV]

Only beam profile cuts



Energy in calo [GeV]

Beam profile cuts + 3 MIP in preshower

For each energy: electron content of beam by fitting 3[rd] degree polinomial+gaussian and taking the ratio of the integral of the gaussian to the number of entries

Quality of SPS beam

Energ y	Events	Events good beam	Nele	Fract.
10	79k	61k	34k	0.56
20	352k	289k	79k	0.27
30	302k	251k	31k	0.13
40	1523k	1270k	71k	0.060
60	488k	402k	9.6k	0.024
80	697k	563k	10.8	0.019
100	512k	424k	5.7k	0.013

Poor beam purity at high energies.

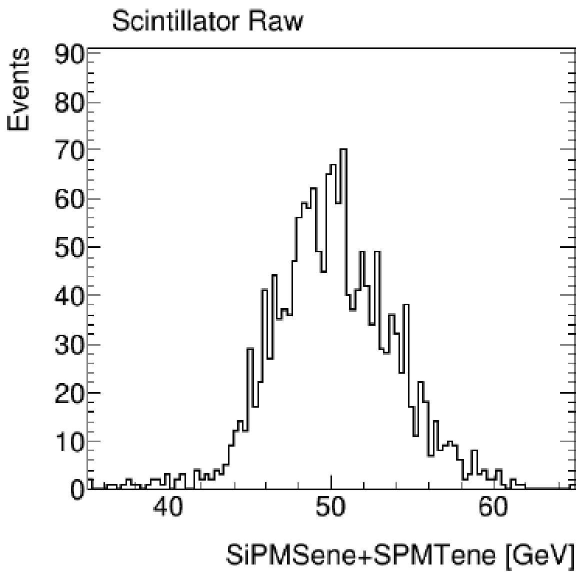
Requiring 3 MIPs in preshower obtain purity from 95 to 98%

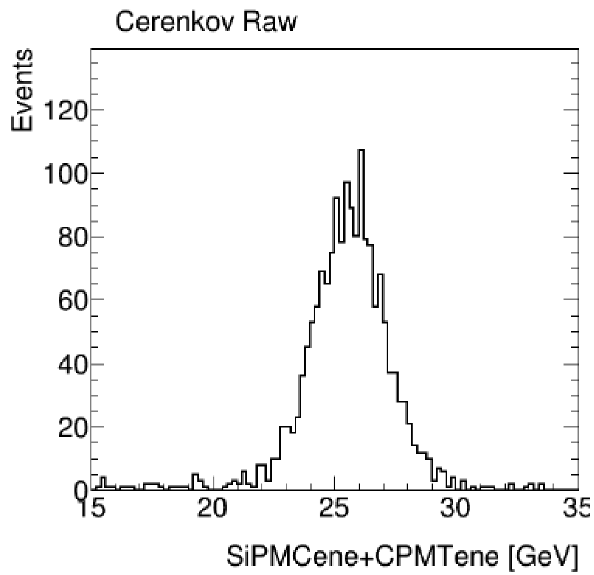
In energy range within 3 sigmas of peak

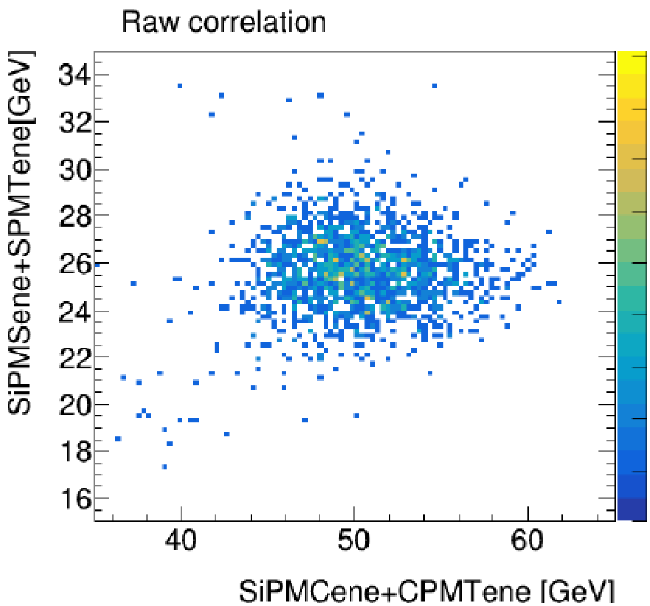
Preliminary baseline extraction of calo performance

Select electrons with 3MIP in preshower

Tight beam spot: |X_ch2|<2mm, |Y_ch2|<3 mm to minimize impact point effects







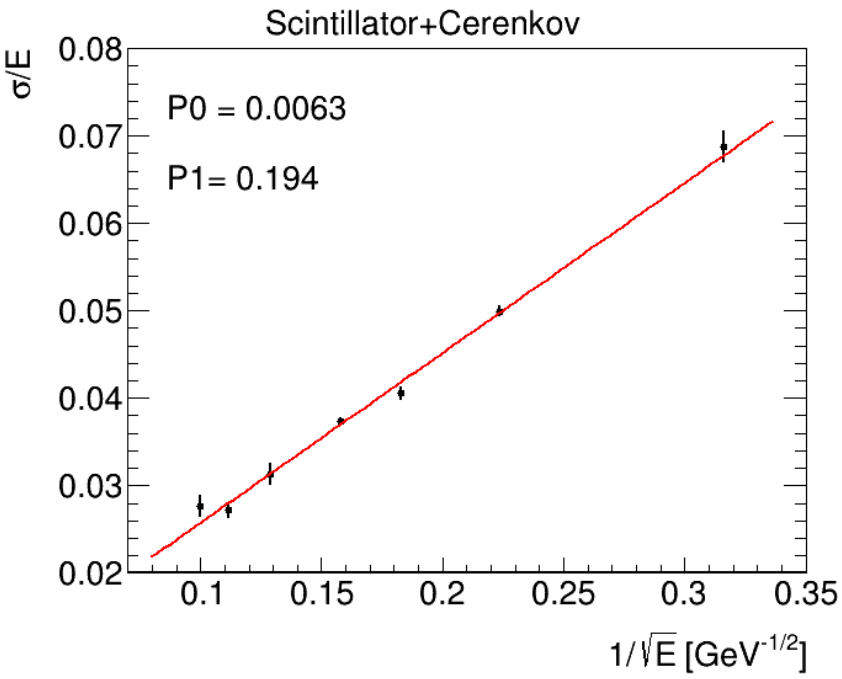
Use 5 measurements:

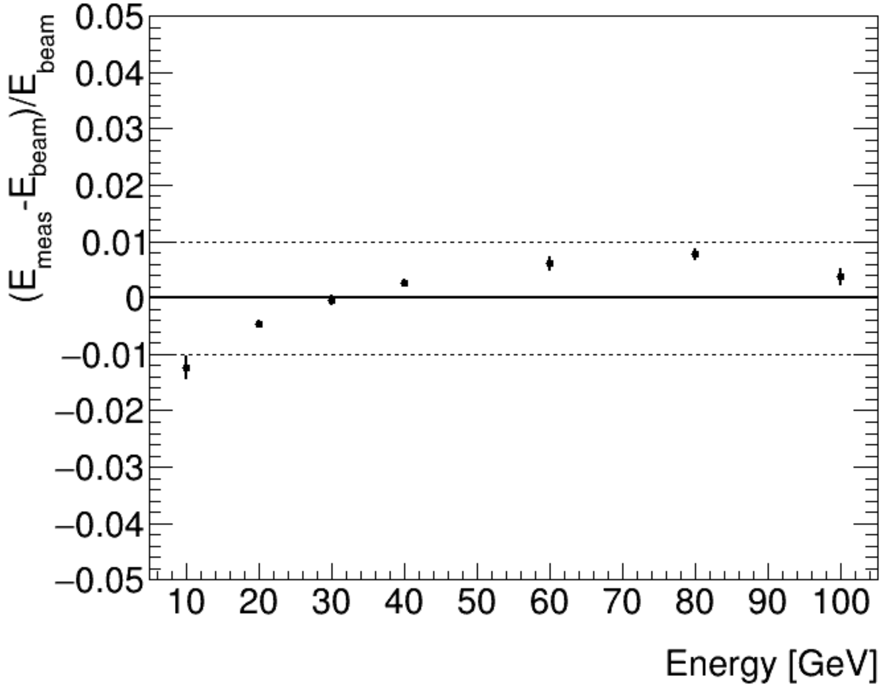
Preshower signal, Sum of energy in SiPMs (Scint. and Cerenkov),

Sum of energy in PMS (S snd C)

Find linear combination of 5 measurements minimising RMS of distribution,

Preliminary performance result

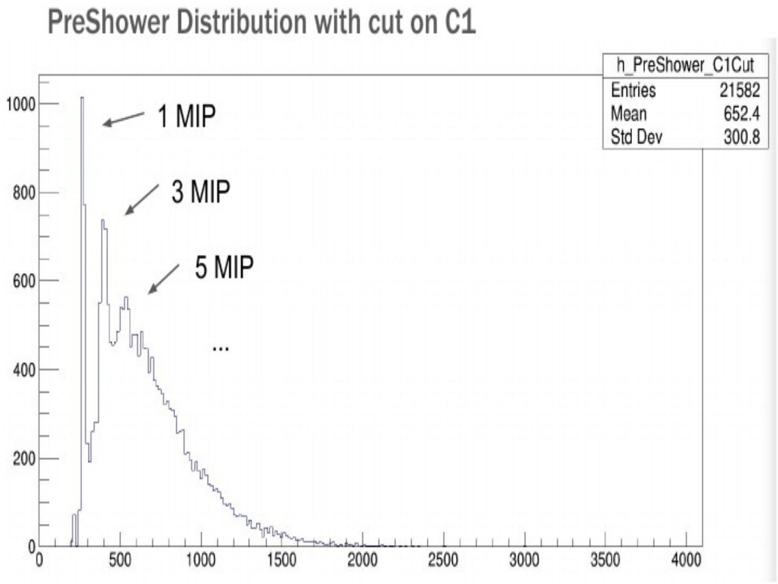




Mediocre resolution result, but only preliminary baseline exercise:

- Calculate the 'perfect' expected resolution from full simulation
- Understand and if possible correct sources of fluctuation in setup: Geometrical effects, equalisation of light response for all cells, beam line

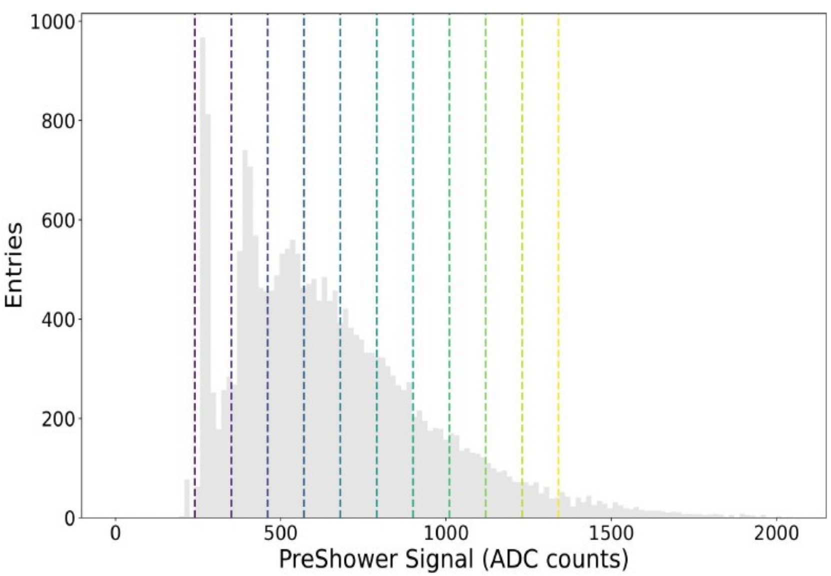
Impact of preshower on energy measurement

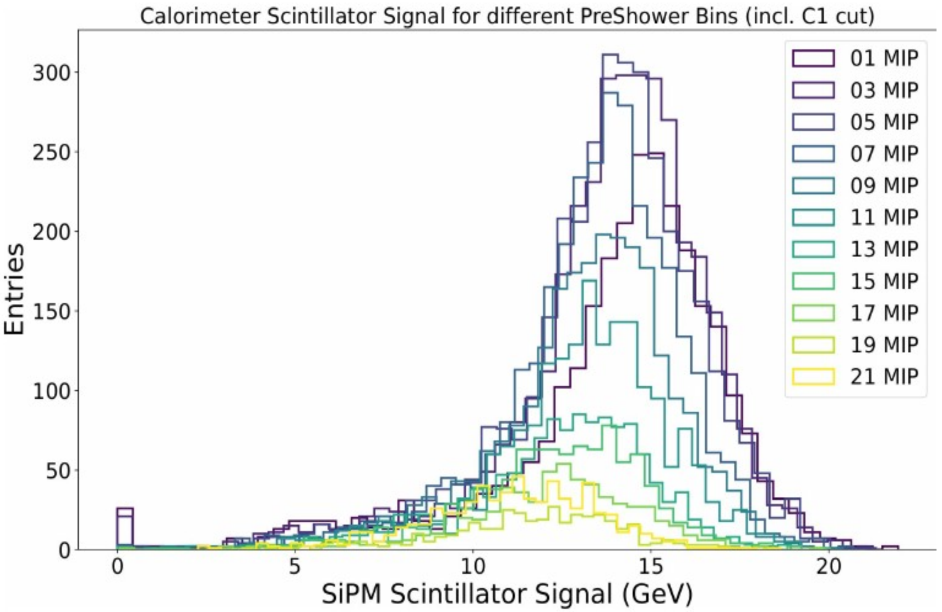


A Loeschcke Centeno

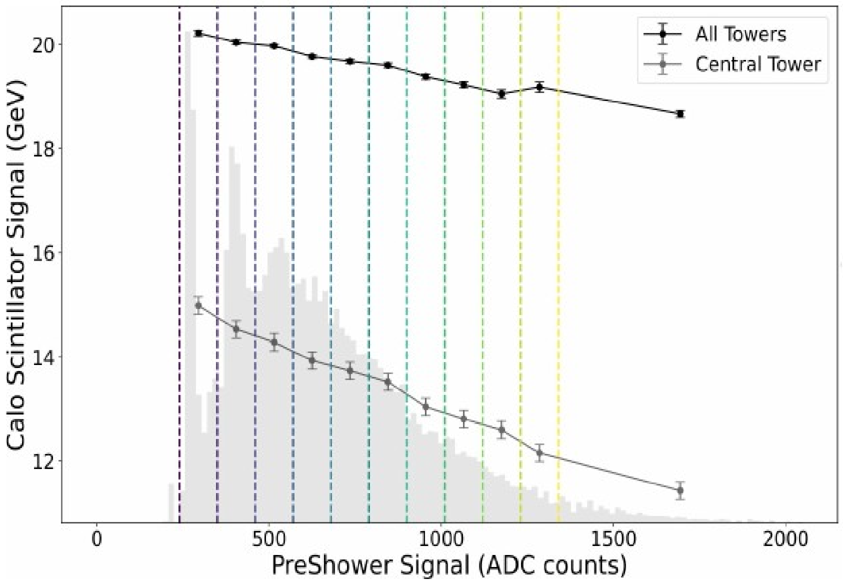
20 GeV e+:

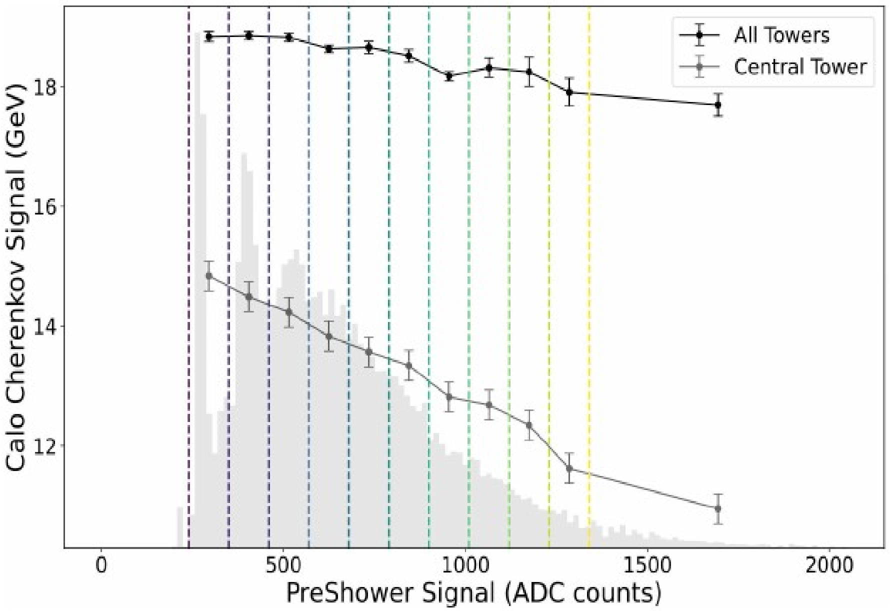
- Require signal in Cerenkov 1
- Bin the response of preshower
- For each bin fit gaussian part of distribution of sum of SiPMs or of sum of SiPMS and PMs





Containment effect





Very large effect on containment of central tower

Significant effect on full calorimeter

Additional resolution term for this effect

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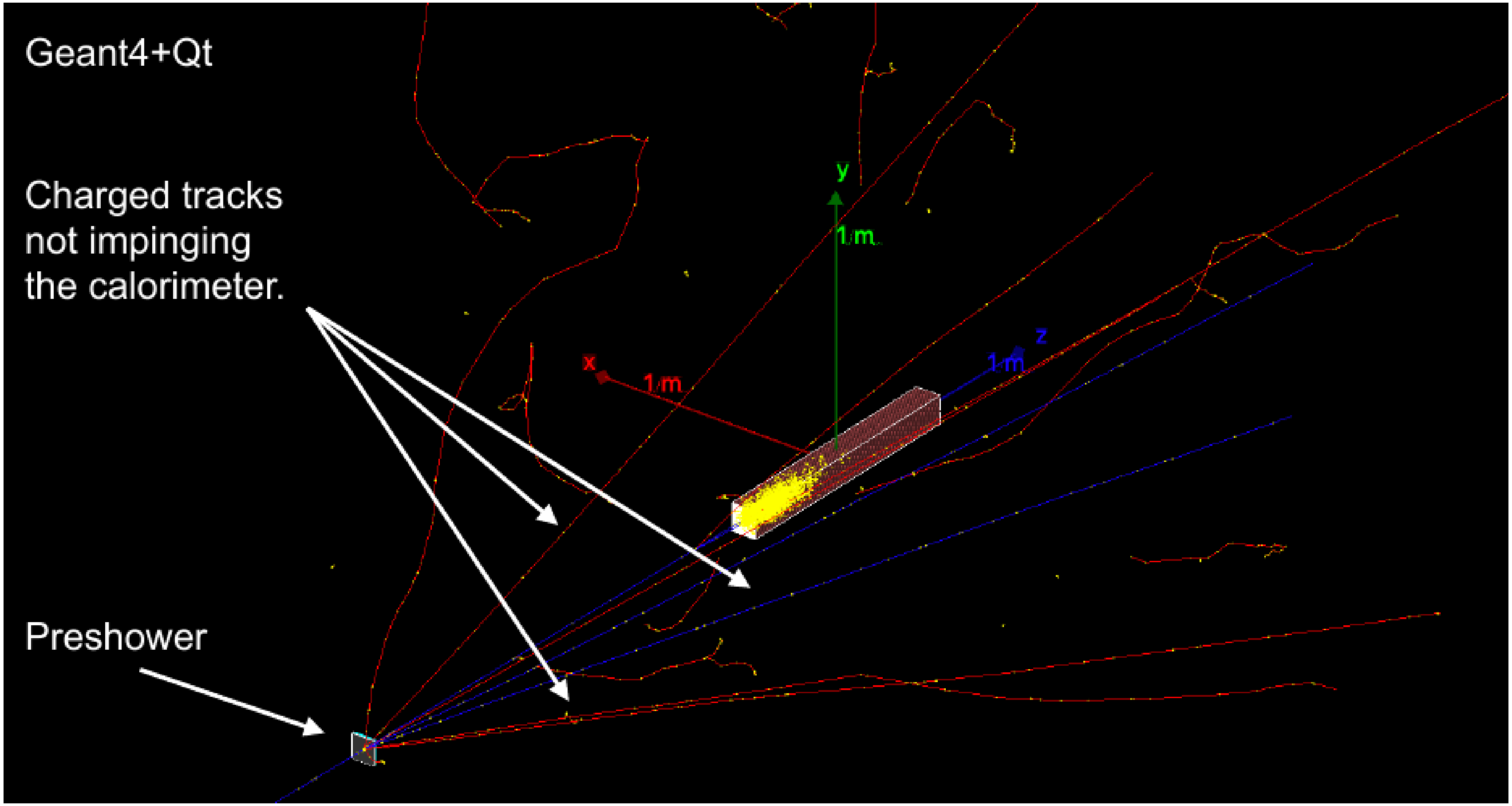
Comparison to simulation



Dependence of energy containment on preshower signal ascribed to Broadening of early starting shower in preshower detector, verify with full simulation of full testbeam setup

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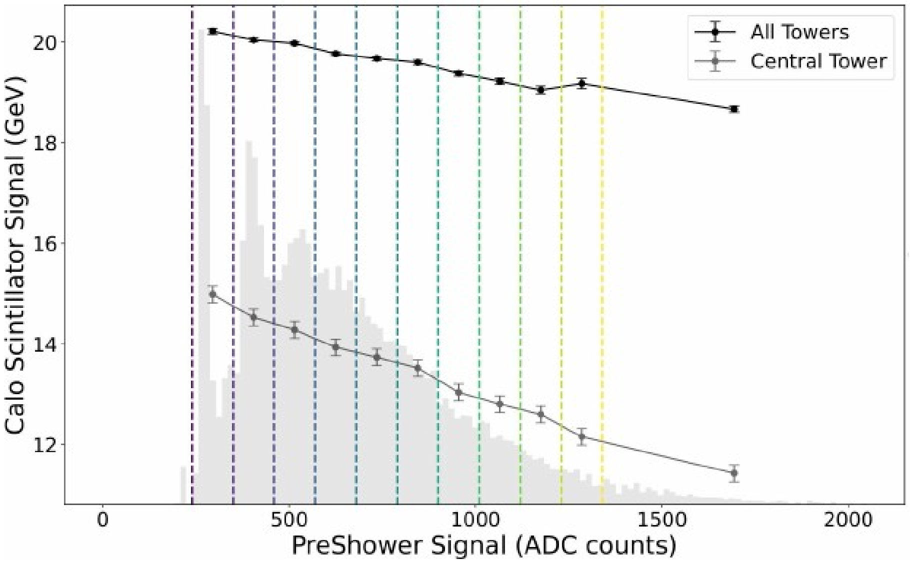

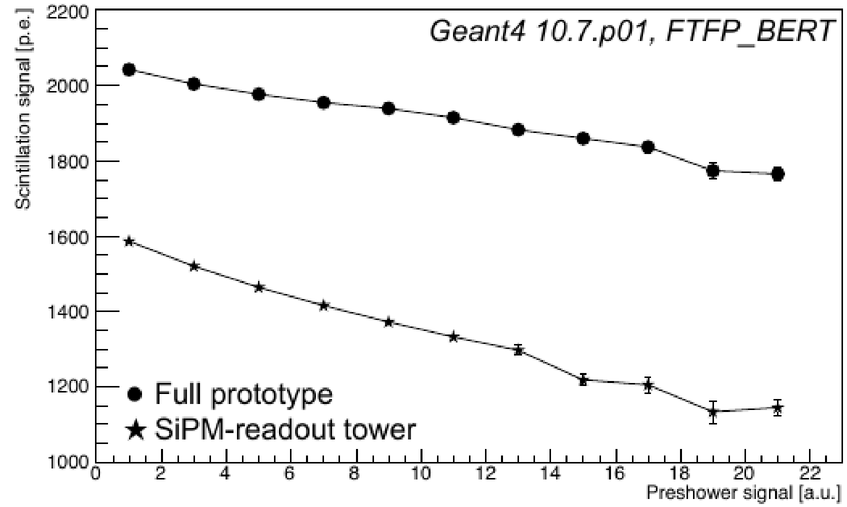

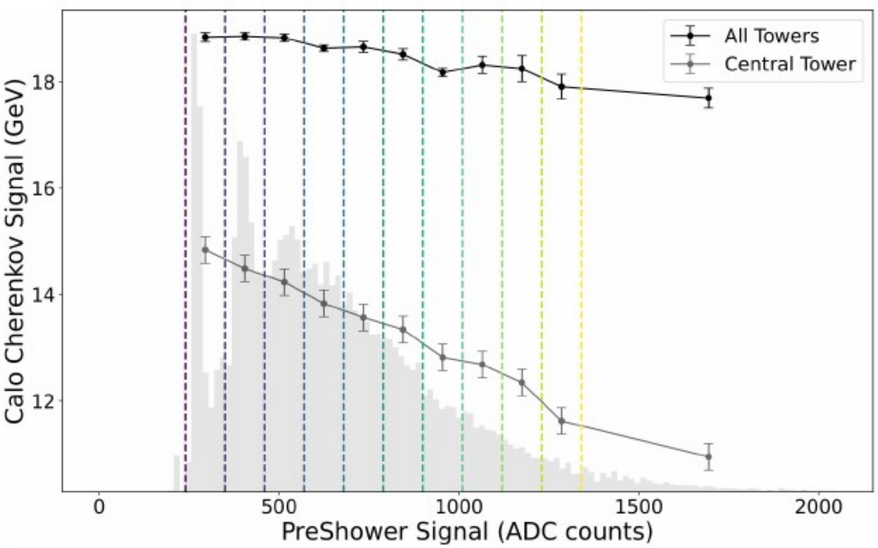

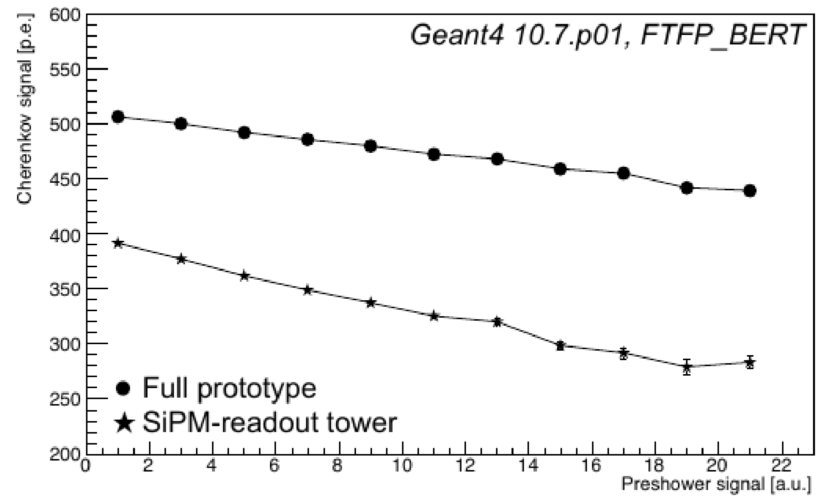

Dependence of shower containment from preshower signal confirmed by full simulation

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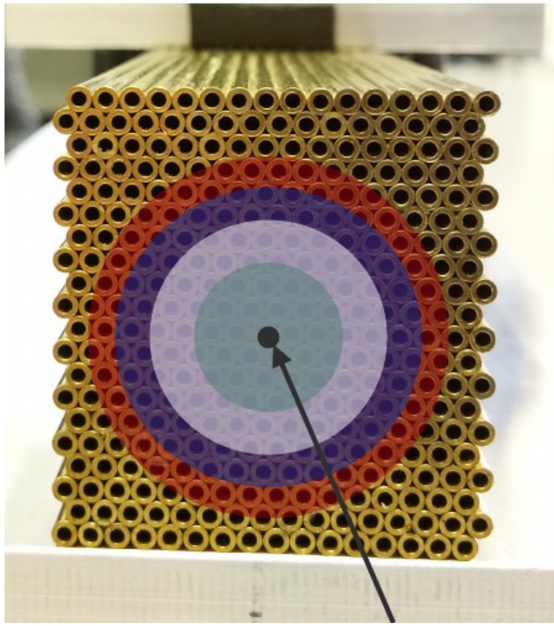
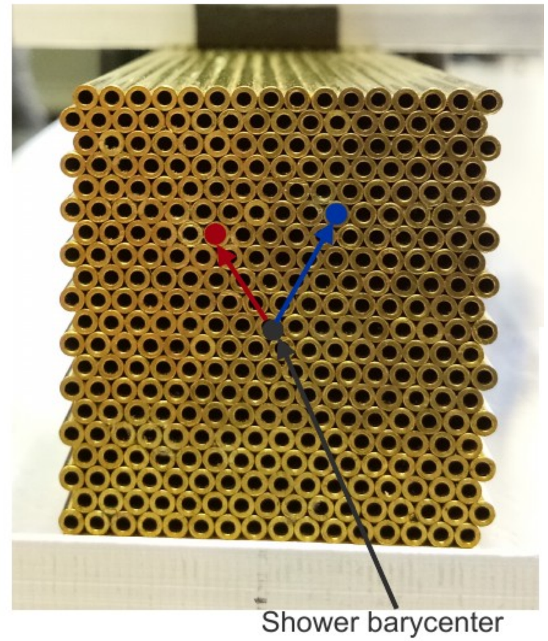
Measurement of shower shape

Excellent granularity of SiPM readout → detailed studies of EM shower shape





Two variables:

Radial profile: average signal in a radial shell centered on the beam axis

Lateral profile: average signal in a fiber located at a distance r from beam axis

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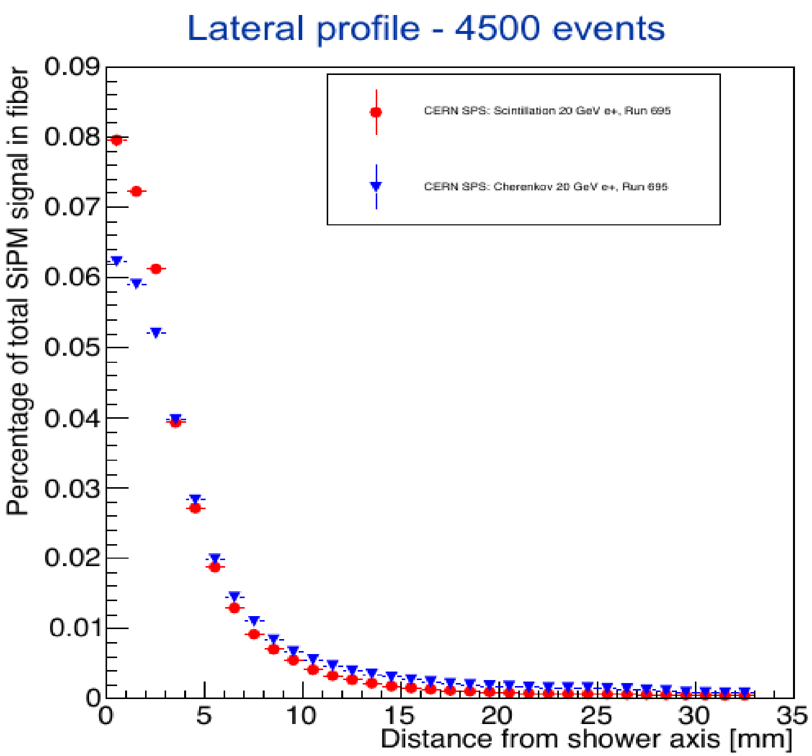
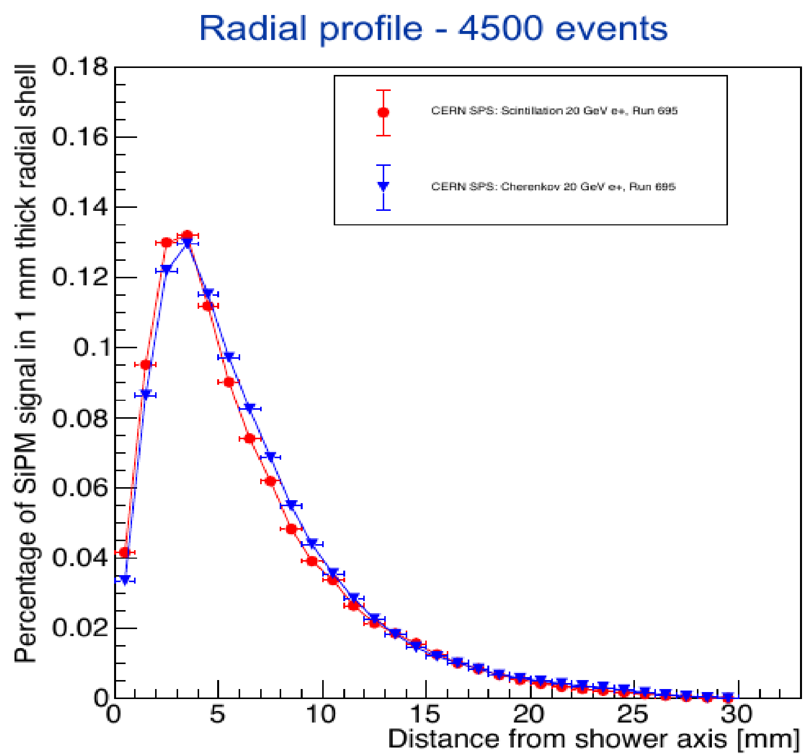
Shower shape: compare Scintillator and Cerenkov

20 GeV e+ profiles from 20 GeV run without preshower





Possible 1 mm sampling of shower up to 3 cm from beam axis
Difference in shape Scinitllator/Cerenkov already measured in previous test https://inspirehep.net/literature/1672363

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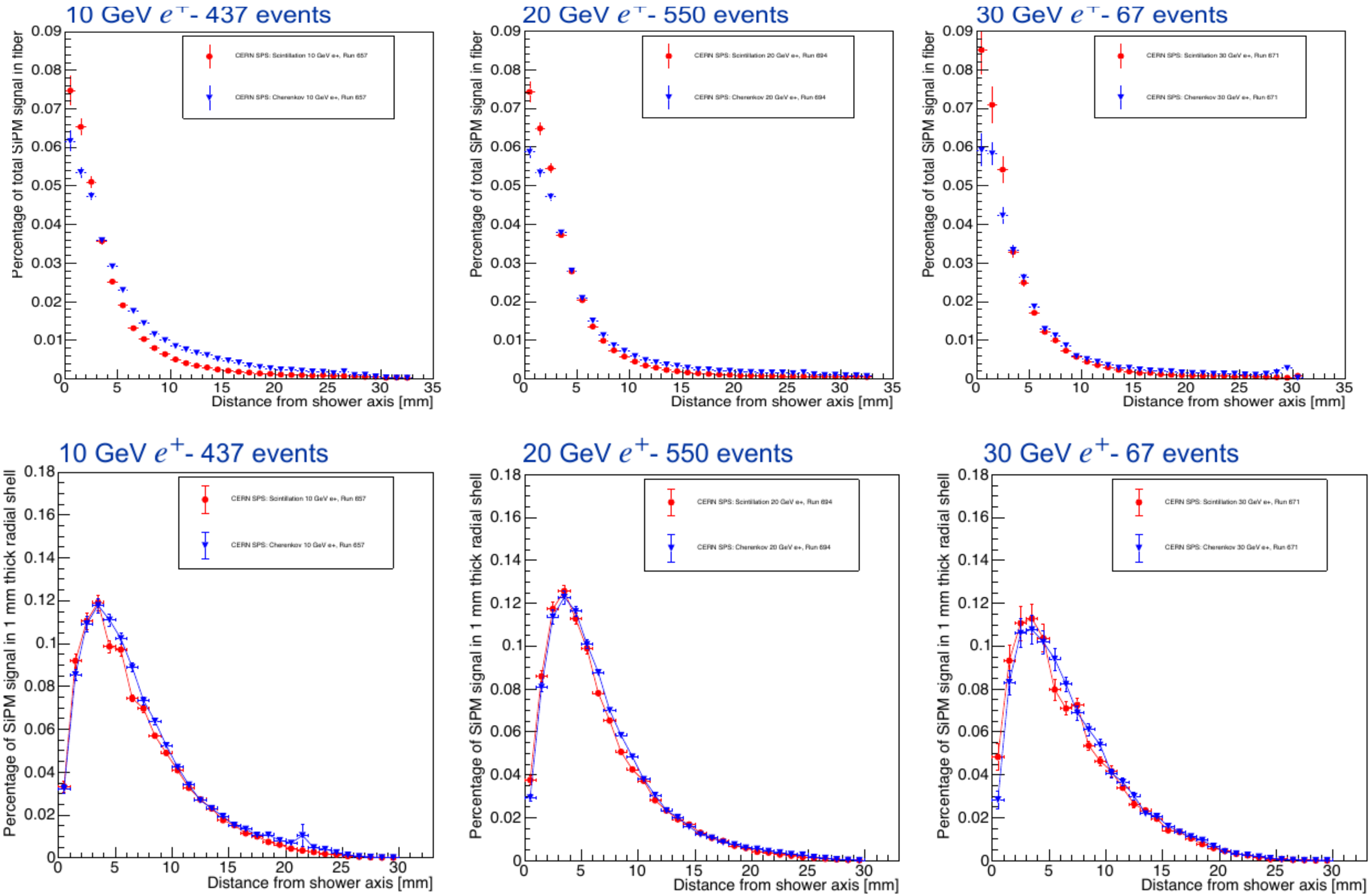
Energy dependence of shower shape



Shape approximately independent from energy

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Conclusions

EM containment DR module built and successfully tested in beam in 2021

Good data collected in two testbeam periods at DESY and CERN SPS

- Very rich and clean set of data up to 6 GeV from DESY
- Full energy scan available up to 100 GeV from CERN, but low statistics at high because of beam purity issues

Work ongoing to exploit these data, start already to see dividends from the very high granularity of the SiPM readout, many interesting studies in the pipeline

Still quite some work to master the complexity of the data and extract final performance figures

Backup