CALOR 2018

UNIVERSITY OF OREGON

Dual-readout fibre-sampling calorimetry with SiPM light sensors

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On behalf of the

RD52 Collaboration

INFN RD_FA Collaboration

INFN

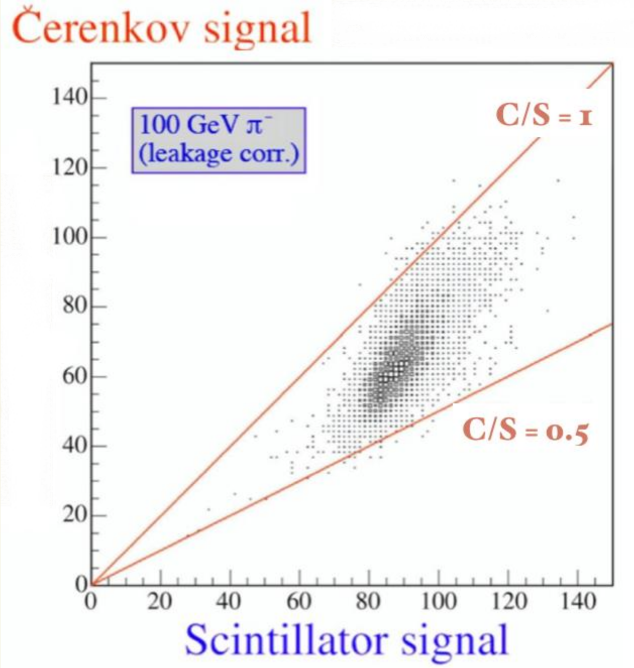
Dual-readout calorimetry

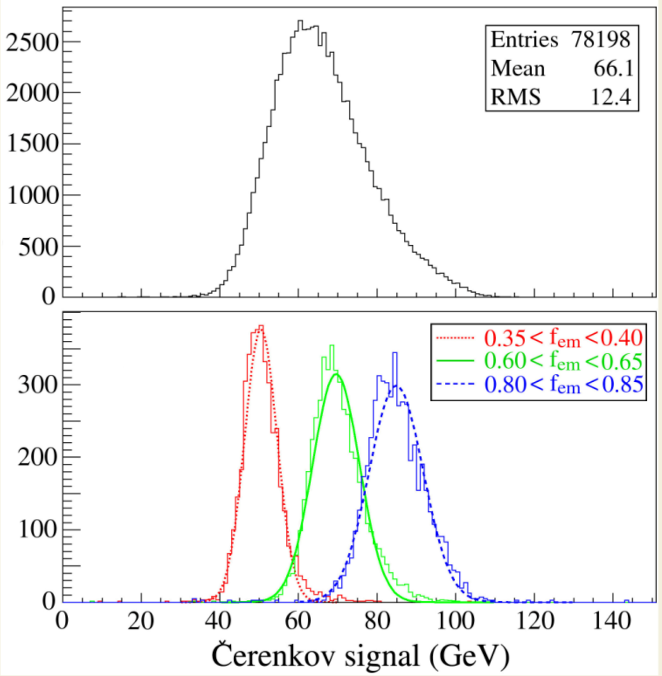
We measure f_{em} event by event by means of two independent sampling processes: Cherenkov and scintillation light production.

$$C = E\left[f_{em} + \frac{1}{(e/h)_C}(1-f_{em})\right]$$

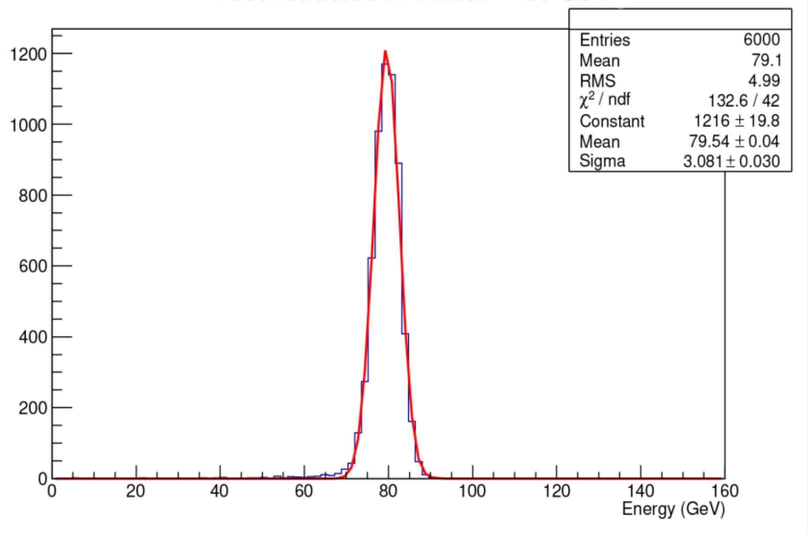
$$S = E\left[f_{em} + \frac{1}{(e/h)_S}(1-f_{em})\right]$$

This eliminates f_{em} fluctuation effects on the calorimeter performance.
more details in following Sehwook Lee's talk…





80 GeV π^- - Geant4 simulation



Tests of a dual-readout fiber calorimeter with SiPM light sensors

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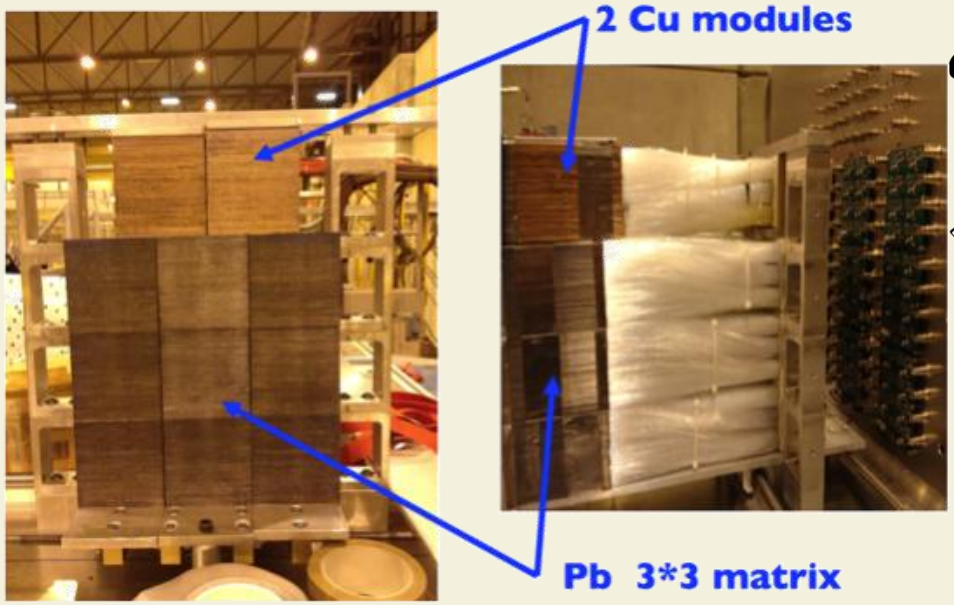
Outlook

- What we beam-tested?
- Dual-Readout with SiPM?
- Is it a plus?

SiPMs *vs.* PMTs

Thanks to its ultimate hadron energy resolution a dual-readout fibre-sampling calorimeter is a good candidate for future e^+e^- colliders (FCC-ee, CepC). However, …



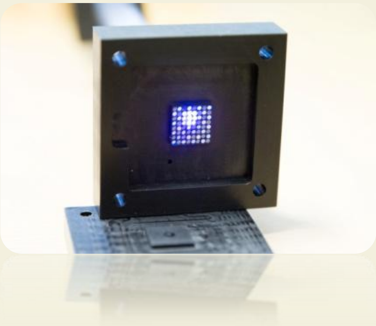
Using a SiPM readout

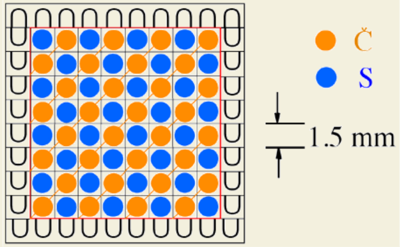
- ✓ Compact readout: a single SiPM directly coupled to each fiber
- ✓ Magnetic field insensitive
- ✓ Higher photon detection efficiency (PDE) (Cherenkov photoelectrons are a limiting factor both for hadronic and electromagnetic energy resolutions)
- ✓ Unprecedented 2-dimensional shower spatial sampling

- ? Signal saturation
- ? Optical crosstalk between Cherenkov and scintillating signals

What we (beam) tested

A brass (Cu260) module, 112 cm long, 15 x 15 mm^2 wide (12 x 12 mm^2 active area), housing 1 mm diameter clear and scintillating fibers (32 + 32) with a pitch of 1.5 mm.





Geometry	X_0 = 29 mm, R_M = 31 mm
Module	39 X_0 deep, 0.22 R_M wide
Geant4	45% electromagnetic energy containment

Delay Wire Chamber	selects events in central region
Trigger	$T_1 \bullet T_2 \bullet \mathrm{not}(T_H)$
Preshower	identifies e^-
Muon counter	identifies μ^-

Data taken with

e- @ 6, 10, 20, 30, 40, 50, 60, 80, 100, 125 GeV

μ- @ 50, 60, 125 GeV

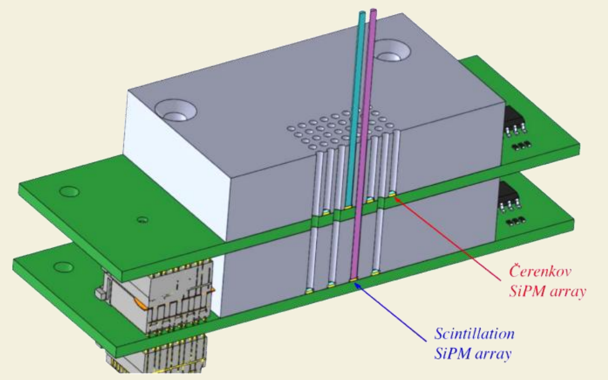
SiPM readout… handling cross talk

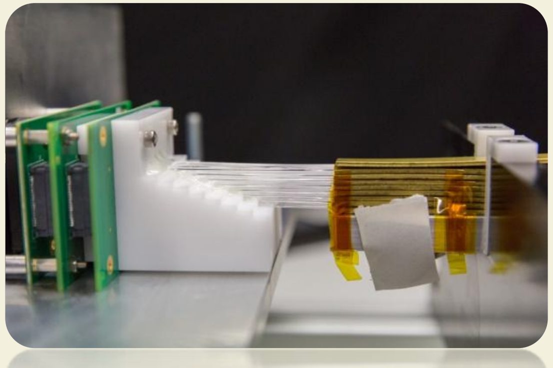
Each of the 64 fibers was interfaced to a single SiPM… we had to separately readout (S and C) signals that differ by a factor ~60.

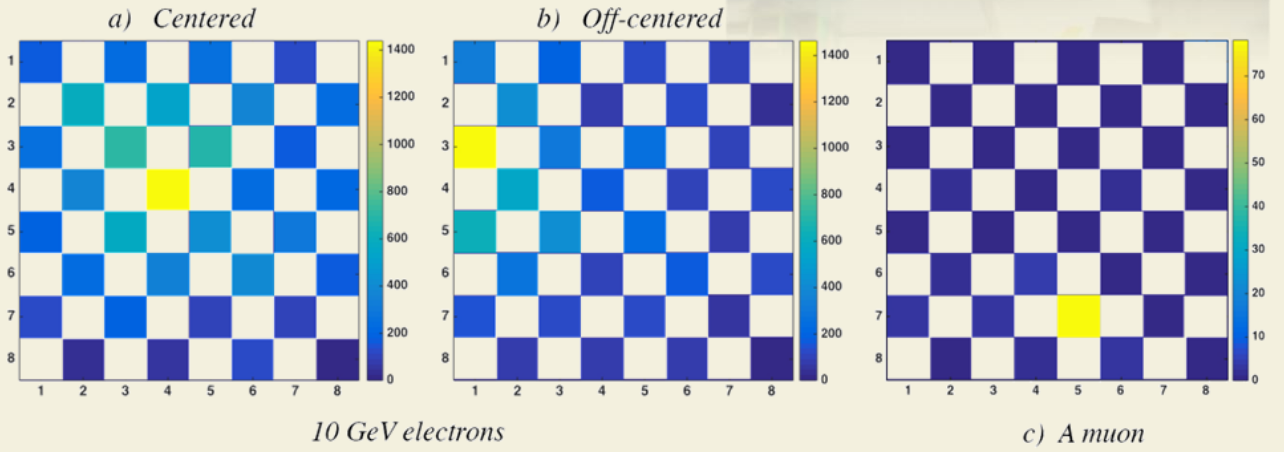
…the easiest way was to mount the sensors on a two-tier structure with a chessboard-like arrangement.

SiPM specifics

HAMAMATSU S13615-1025	
Sensitive area	1×1 mm^2
Cell pitch	25 μm
No. of pixels	1584
Peak Photon Detection Efficiency	25%
Breakdown voltage V_{br}	53 V
Recommended operational voltage V_{op}	V_{br} + 5V
Gain at V_{op}	7×10^5
Dark Count Rate at V_{op}	50 kps
After Pulse Rate at V_{op}	2 - 3%
Optical Crosstalk at V_{op}	1%







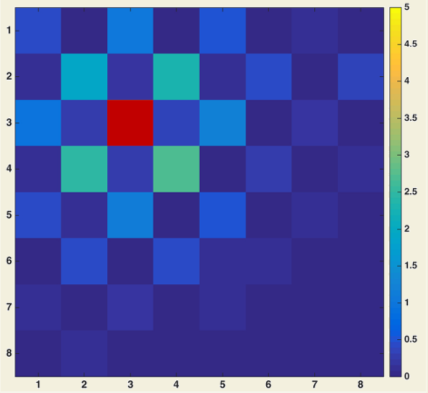
Optical crosstalk – two measurements

Using a LED

lighting up a single fibre and masking the others…

$0.3\% \pm 0.1\%$

of scintillation photons detected as Cherenkov photons.



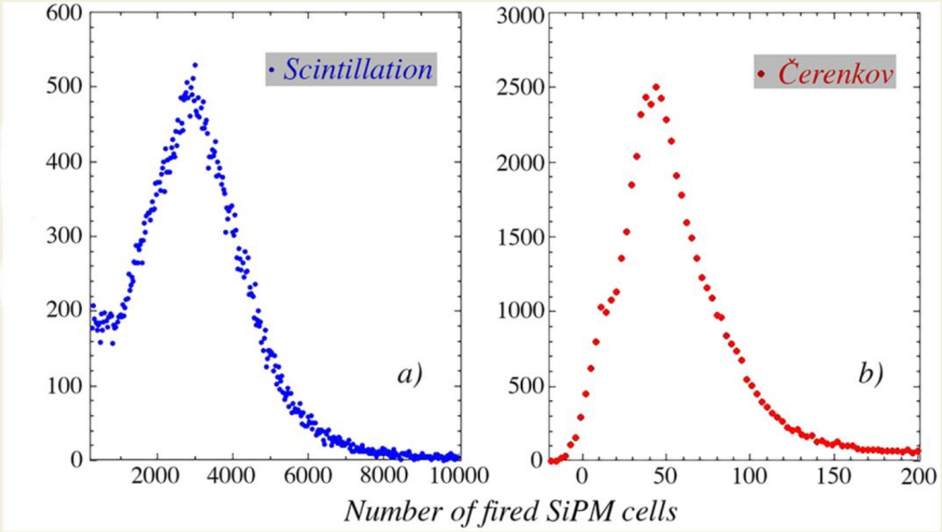
Average of 10000 events

Using muons

and looking at the radiative component (bremsstrahlung) only in the Cherenkov fibers…

0.4%

of scintillation photons detected as Cherenkov photons.

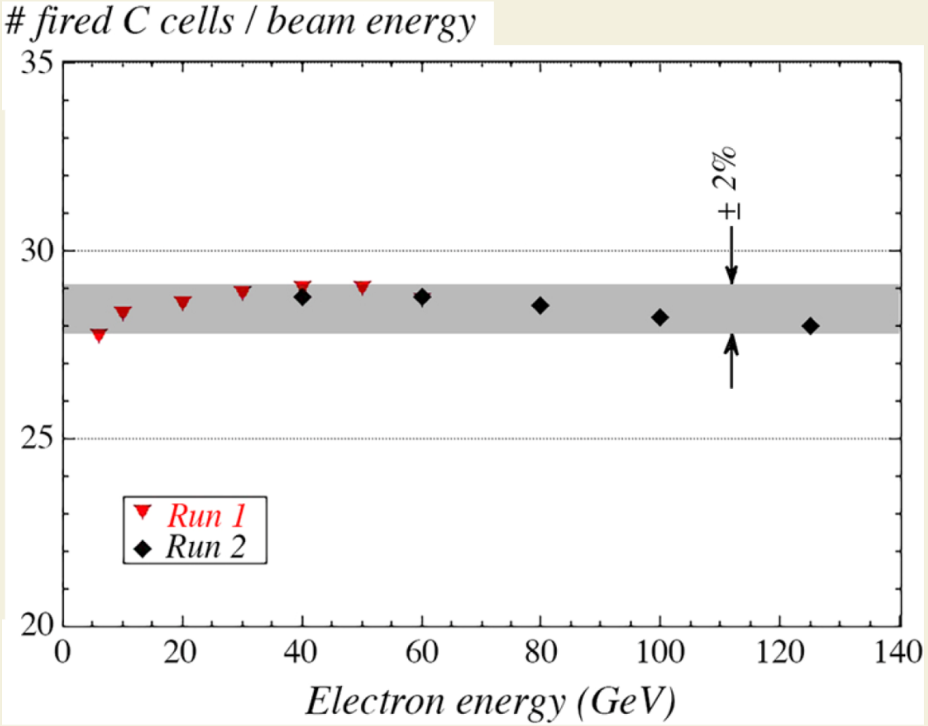


Cherenkov light yield

28.6 Cpe/GeV 2% linear from 10 to 125 GeV.
This indicates that:

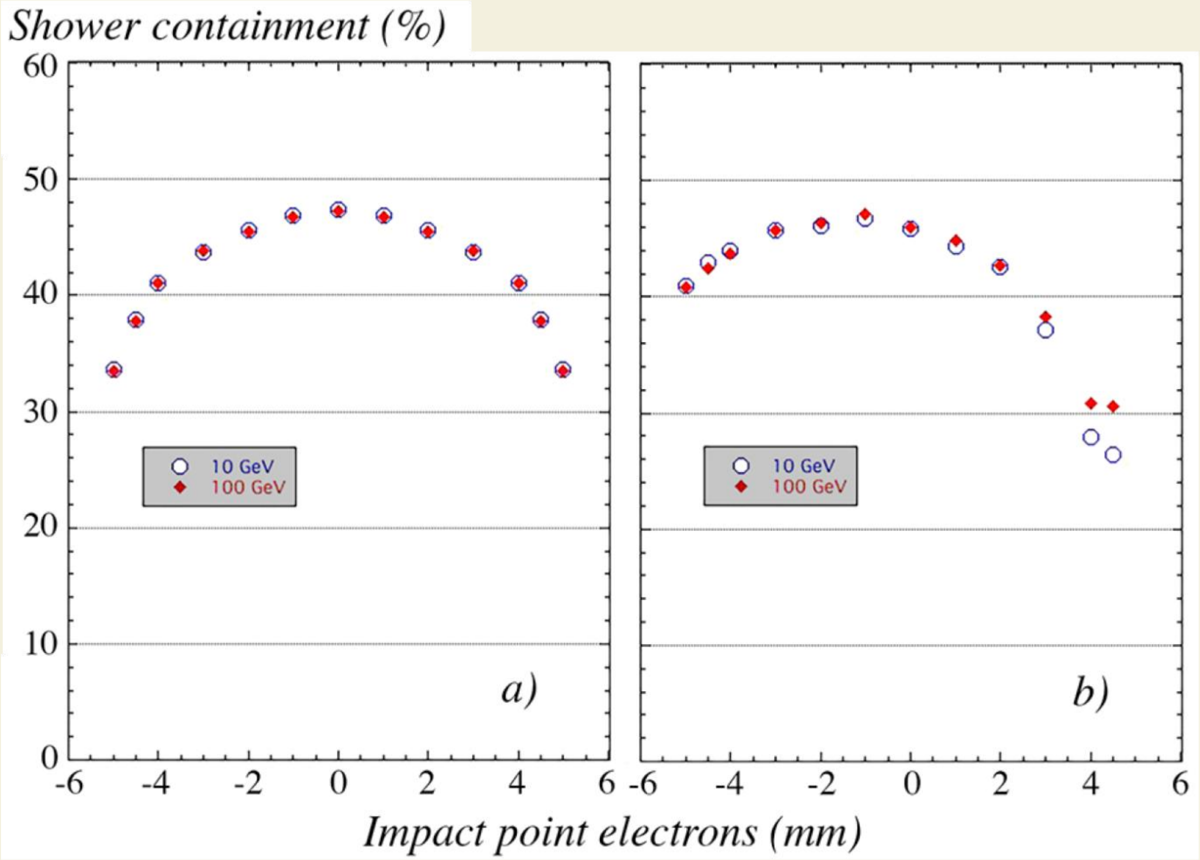
1) There was no saturation in the Cherenkov signal
2) The average shower containment was independent of the electron energy
3) Correcting for 45% energy containment and optical crosstalk we estimate ~54 Cpe/GeV, two times larger than PMTs!

…but, what if energy containment is not constant and saturation is masking this effect?



Energy containment

To be able to correctly estimate light yields we have to be sure that energy containment does not depend on beam energy. Geant4 nicely confirmed it.



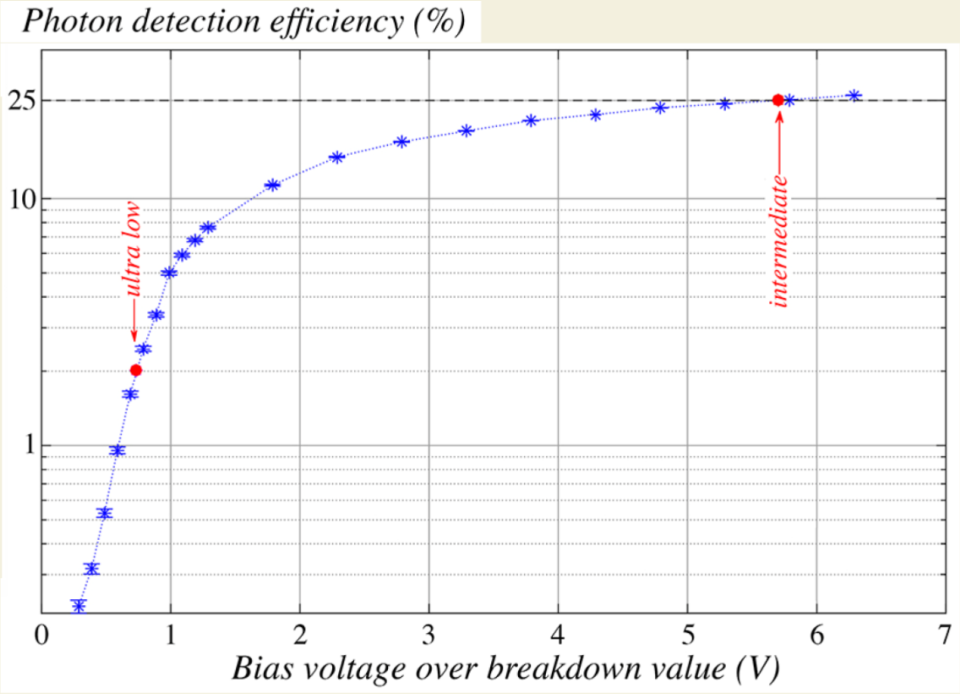
Scintillation light yield and saturation

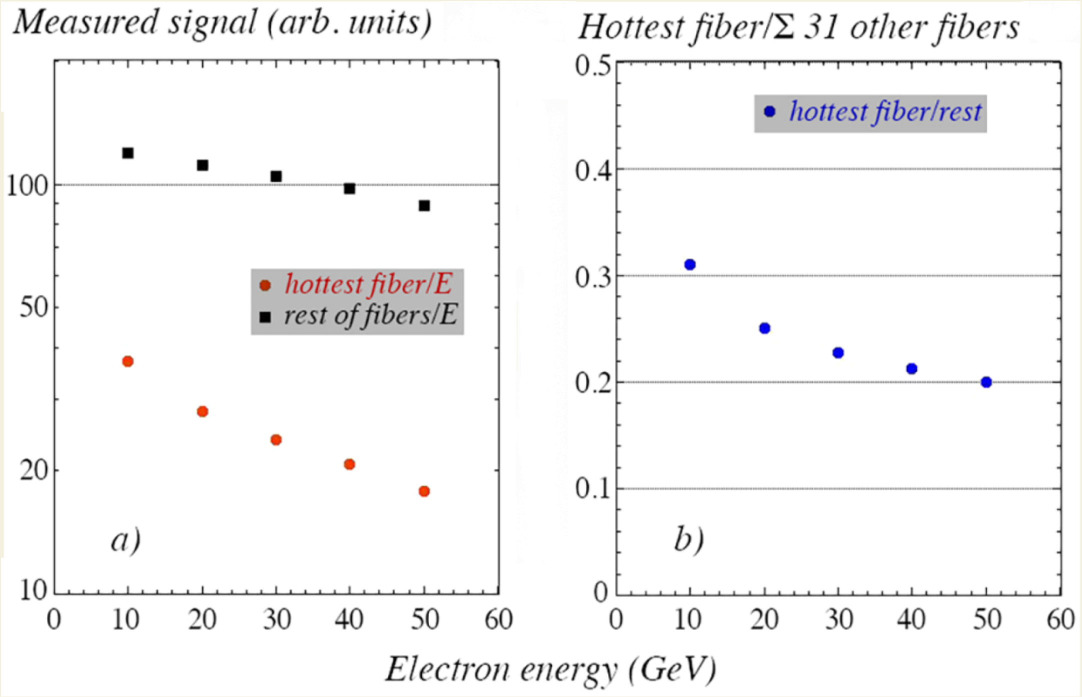
We first set the PDE in a ultra low regime ~2%. However,

in the 10 – 50 GeV range:

1) The signal in the hottest fiber decreased by more than a factor 2

2) The other 31 decreased by 25% …why?

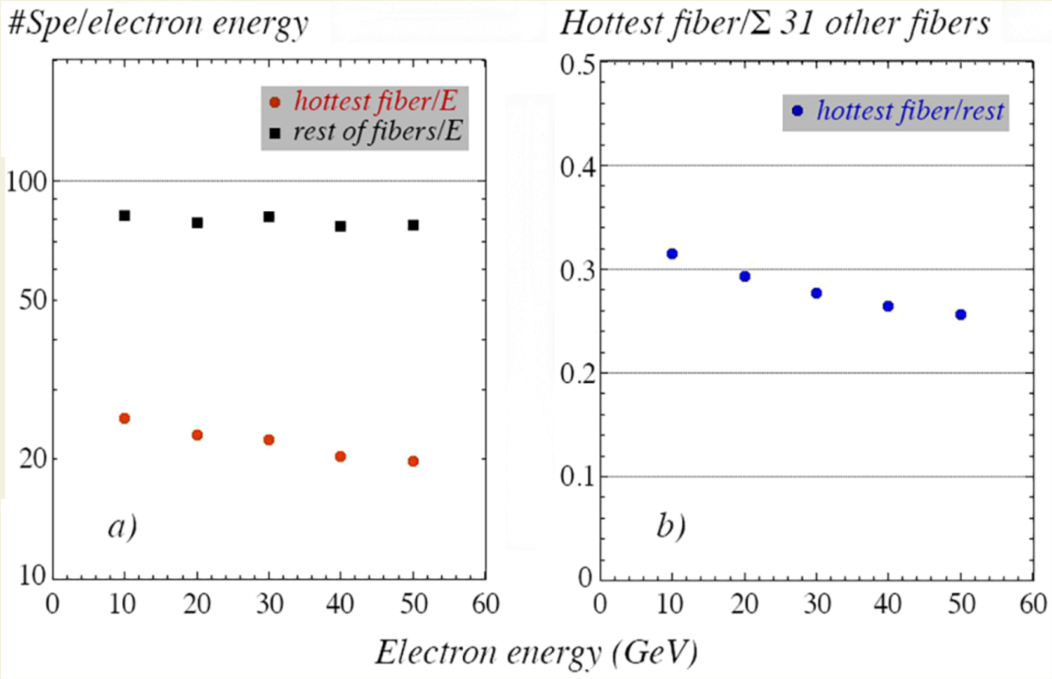




Occupancy correction

When dealing with so many photons one has to take into account the possibility that more photons hit a single cell at (almost) the same time: occupancy correction is needed!

$$N_{fired} = N_{cells} \times \left[1 - exp\left(-\frac{N_{photons} \times PDE}{N_{cells}}\right)\right]$$



We estimated a scintillation light yield of ~3200 Spe/GeV, 50 times larger than the Cherenkov one.

So what?

It is possible to perform
dual-readout fibre-sampling
calorimetric measurements
with SiPM light sensors

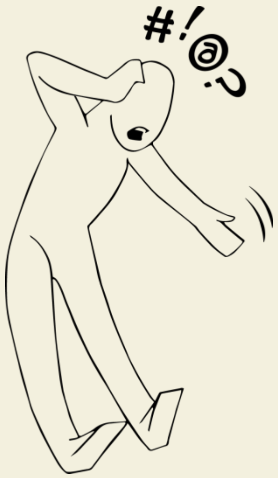
Is it a plus?

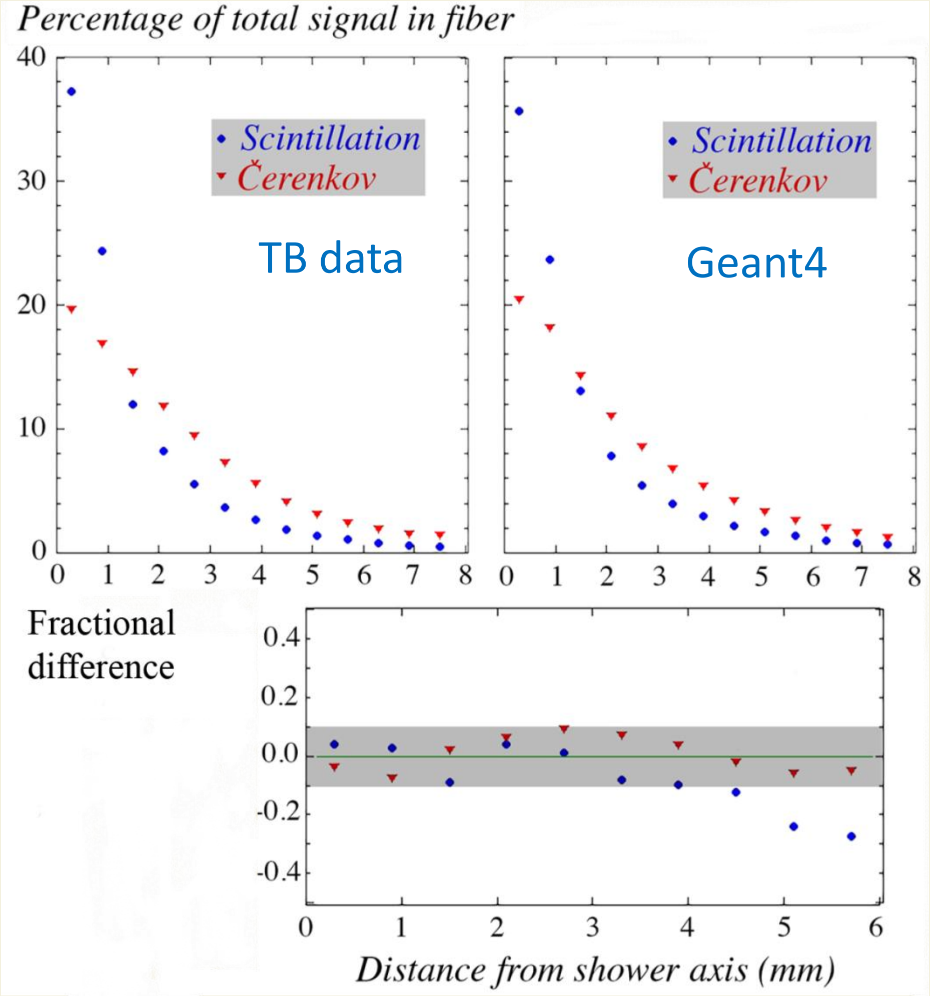
Lateral shower profiles

SiPMs enable us to sample electromagnetic showers, very close to the shower axis, with an unprecedented detail.

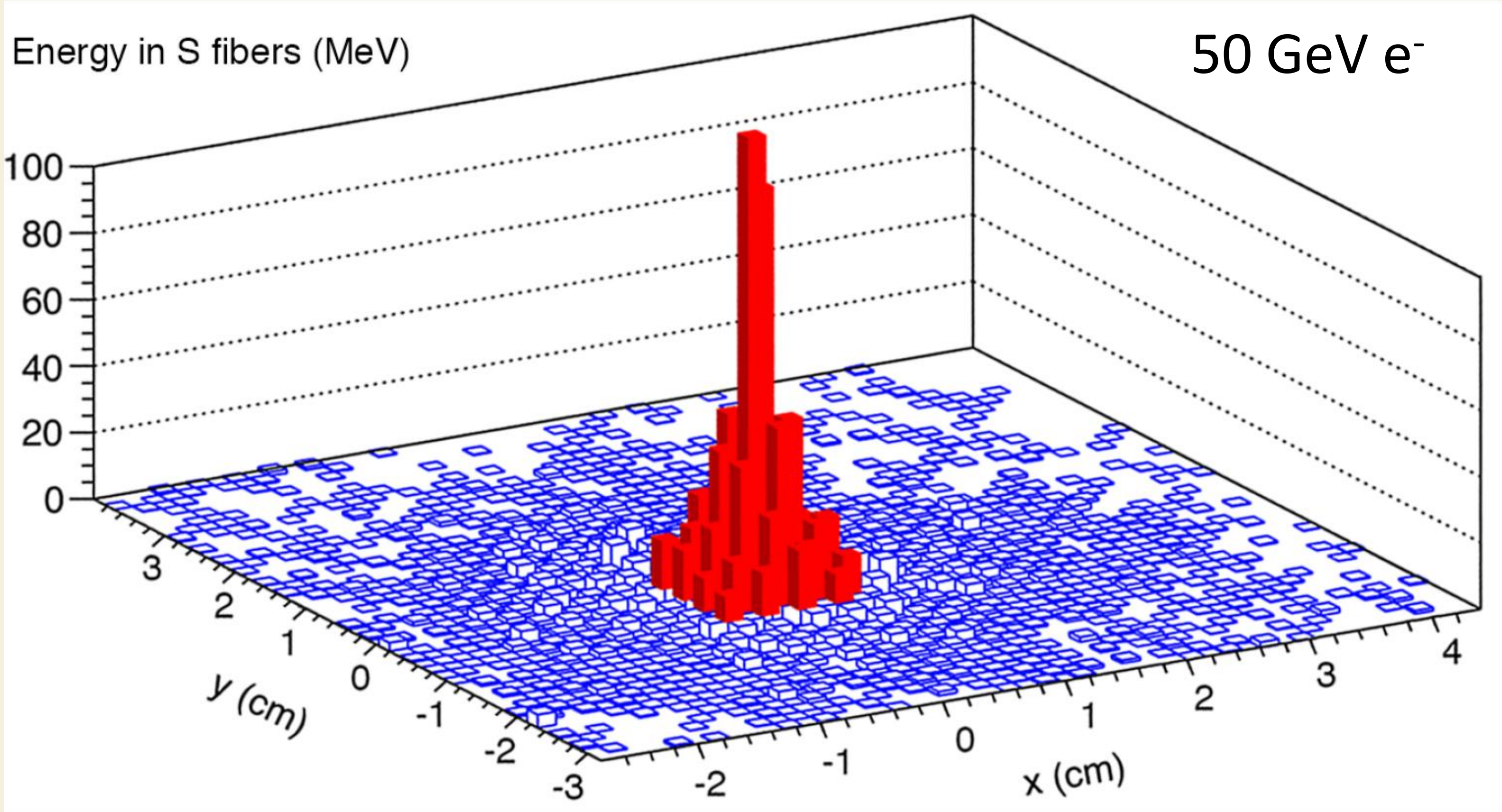
$$\bar{x} = \frac{\Sigma_i x_i E_i}{\Sigma_i E_i} \qquad \bar{y} = \frac{\Sigma_i y_i E_i}{\Sigma_i E_i}$$

$$r_i = \sqrt{(x_i - \bar{x})^2 + (y_i - \bar{y})^2}$$

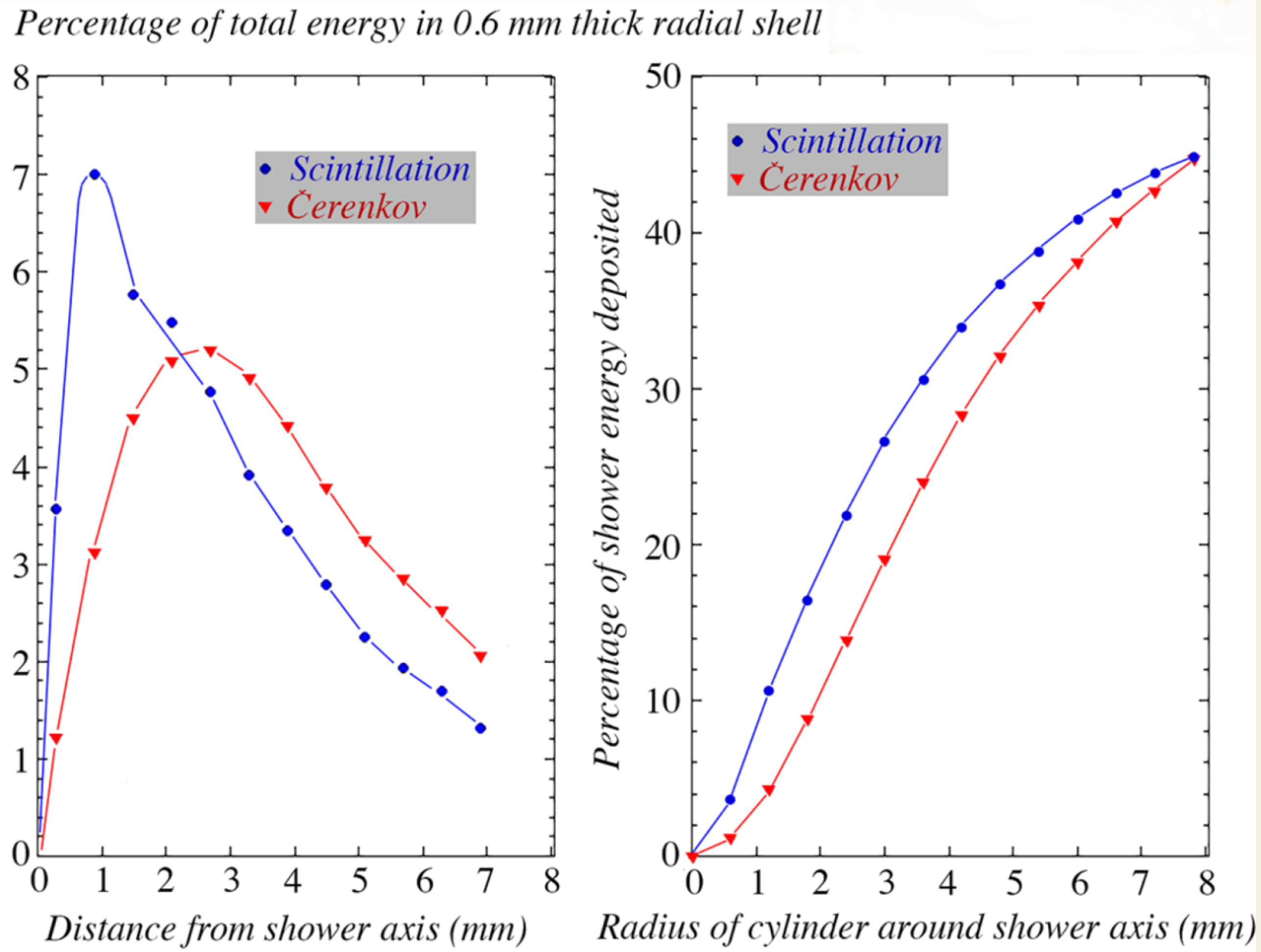




Geant4 shows us…



Radial shower profiles

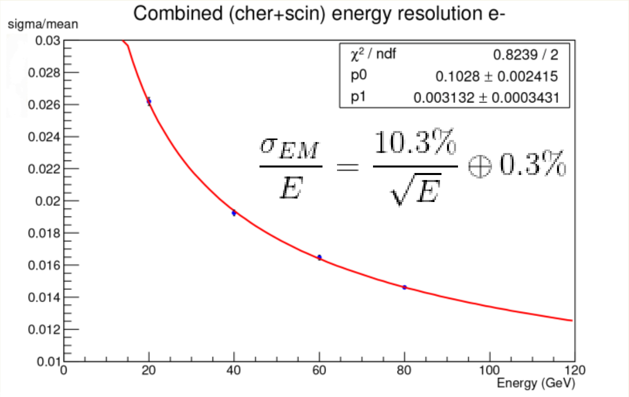


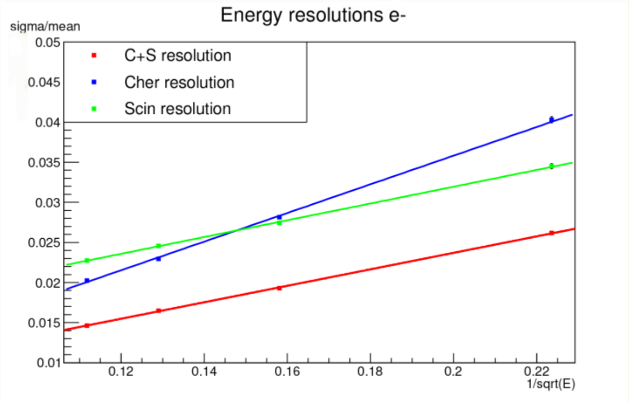
10% of an electromagnetic shower energy is deposited within 1 mm from the shower axis, i.e. in a single fiber.

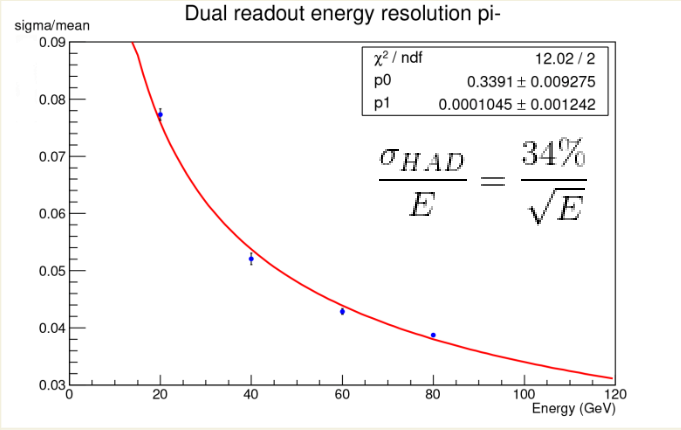

2SLIDES
TO GO!

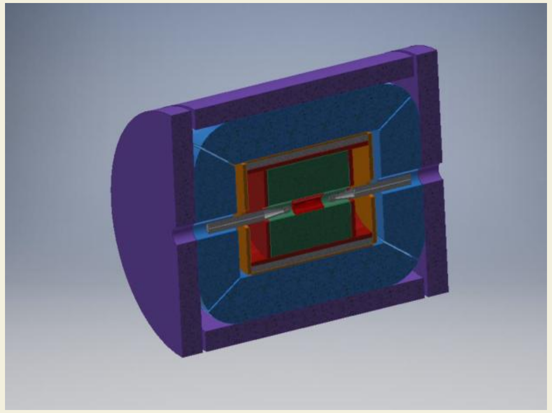
IDEA Detector

A dual-readout fiber calorimeter equipped with SiPMs is now part of the INFN IDEA Detector proposed for both CepC and FCC-ee and specifically tailored for e^+e^- colliders. Preliminary results from Geant4 simulation look interesting.



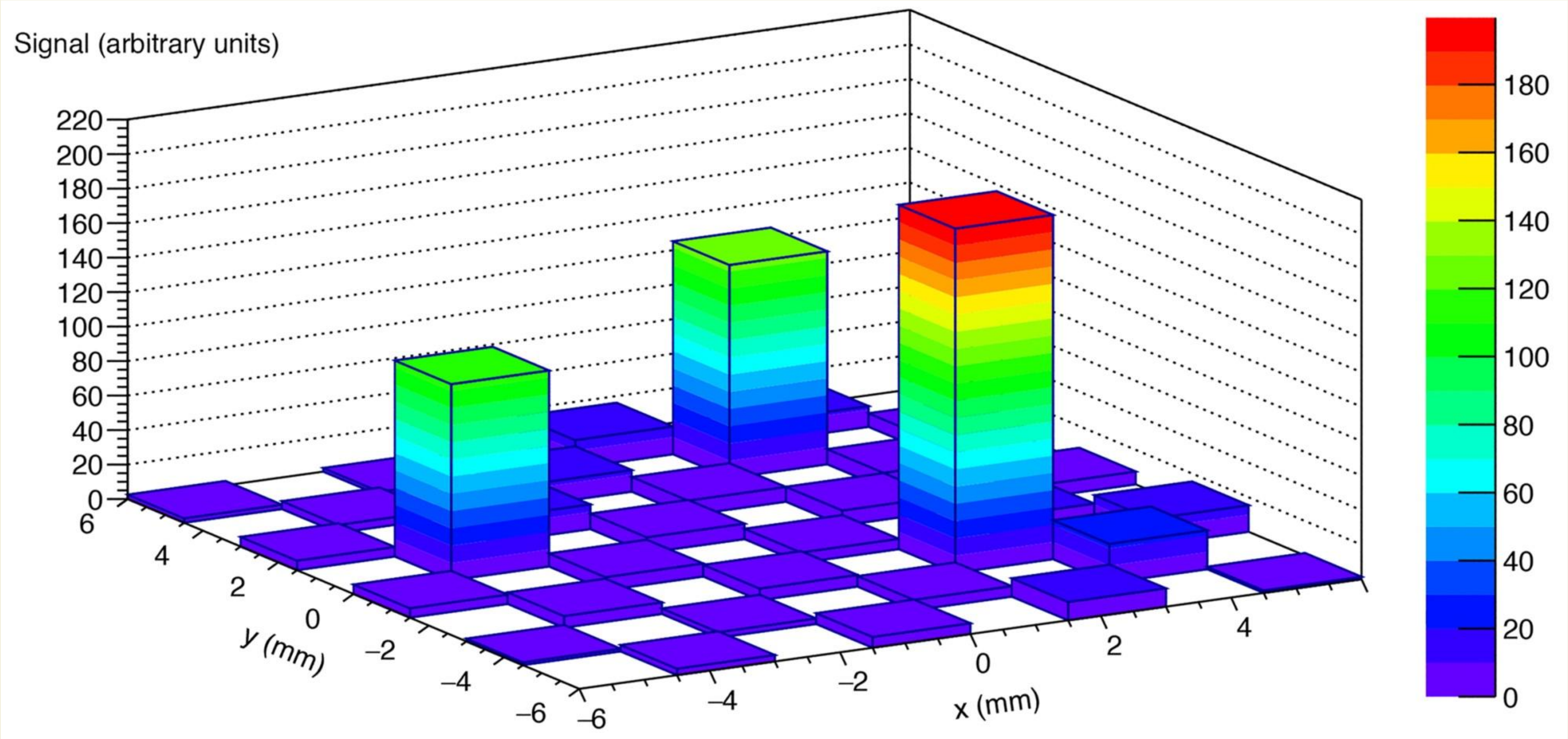






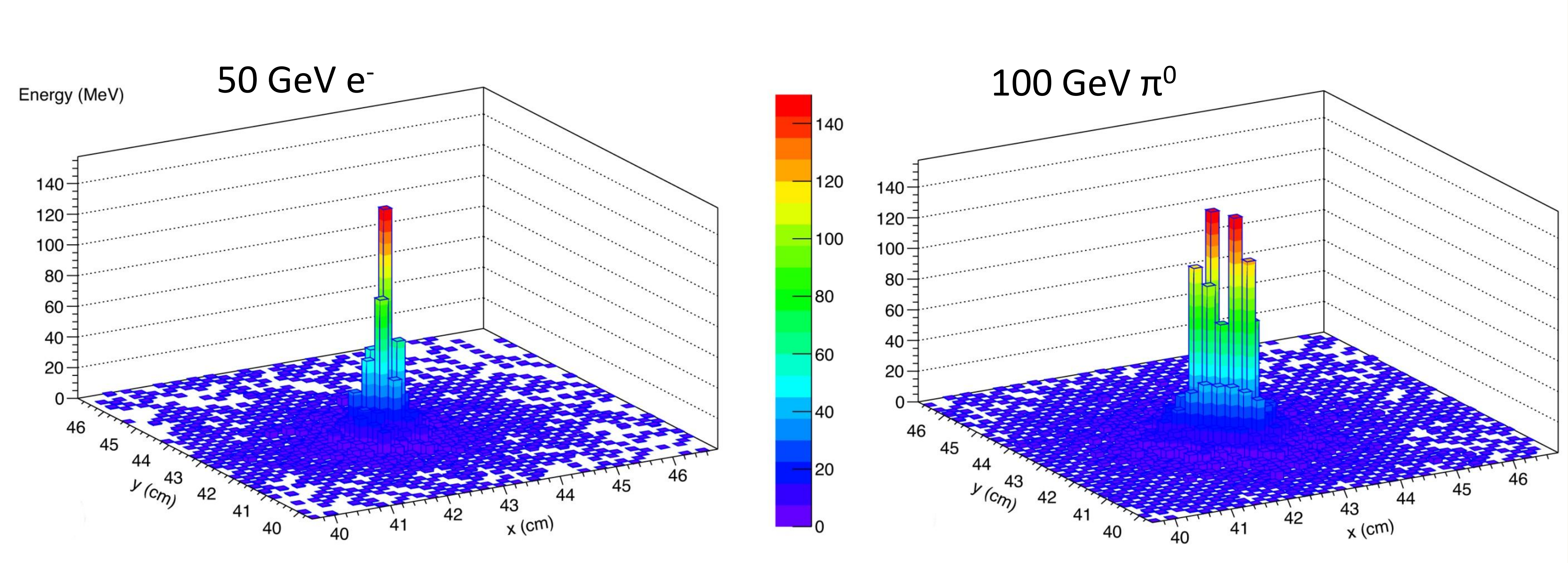
- Beam Pipe (R ~ 1.5 cm)
- VTX: 4-7 MAPS layers
- DCH: 4m long, R 30-200 cm
- Outer Silicon Layer
- SC Coil: 2 T, R ~ 2.1 m
- Preshower: ~ 1-2 X_0
- DR calorimeter: 2 m
- Yoke + muon chamber

3 electrons in 1.2 cm^2



Thanks to this extremly high granularity three electrons are separated in only 1.2 cm^2.

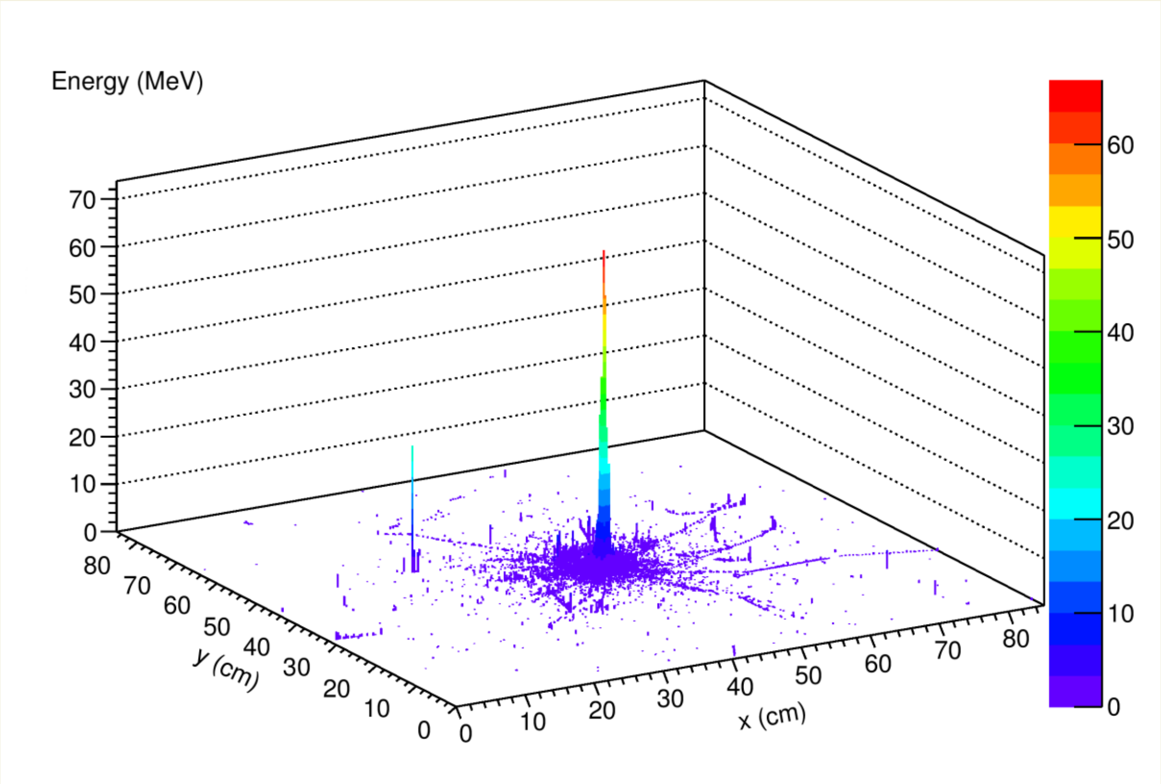
e^-/π^0 separation



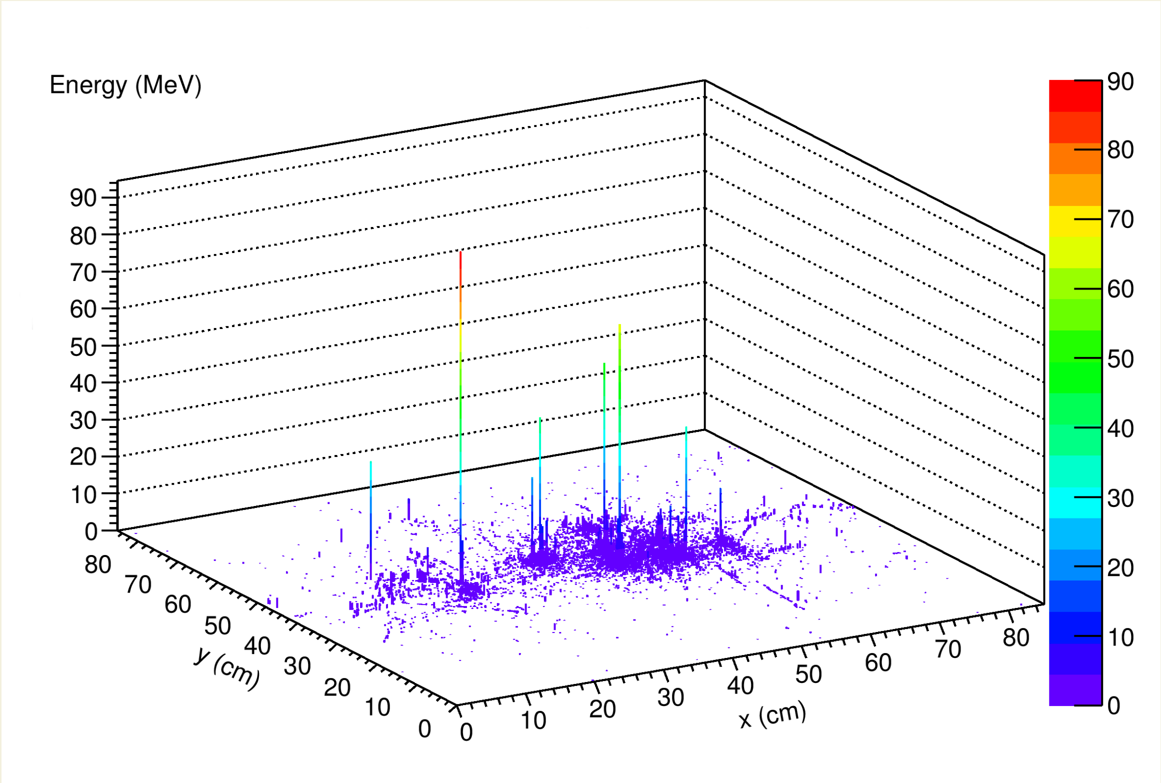
A 100 GeV π^0 decaying 2 m before the calorimeter can be identified as two electromagnetic showers.

Hadrons and Jets

80 GeV π⁻



100 GeV jet



Conclusion

We demonstrated the feasibility of using SiPMs as dual-readout calorimetry light sensors.

Huge step in order to exploit dual-readout calorimetry benefits at future e^+e^- experiments.