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IDEA DUAL-READOUT CALORIMETRY HARDWARE

LORENZO PEZZOTTI – FCC WEEK 2018
On behalf of the INFN RD_FA COLLABORATION

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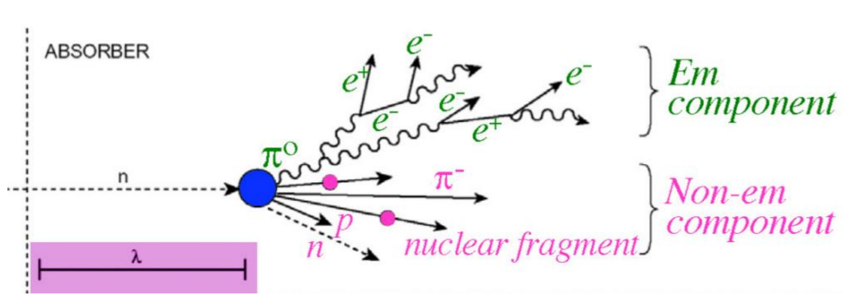
For a significant measurement of the Higgs boson couplings to the IVBs, it is mandatory to statistically separate the 4j final states from H → WW* and H → ZZ*, where the only discriminant is the W/Z invariant mass. This requires to reconstruct the IVB masses with a resolution of 3-4 GeV, i.e. a jet energy resolution of ~30%/√E. Such an energy resolution has already been achieved with calorimeters compensating through neutron boosting, for single hadron detection, but not for jets. Dual-readout calorimetry aims at providing such a performance with, at the same time, excellent electromagnetic resolution and particle id capabilities, without being affected by any of the drawbacks coming from neutron signal amplification. We present the recent development of a new light readout system based on Silicon PhotoMultipliers (SiPMs) that allows to sample showers with an unprecedented spatial resolution.

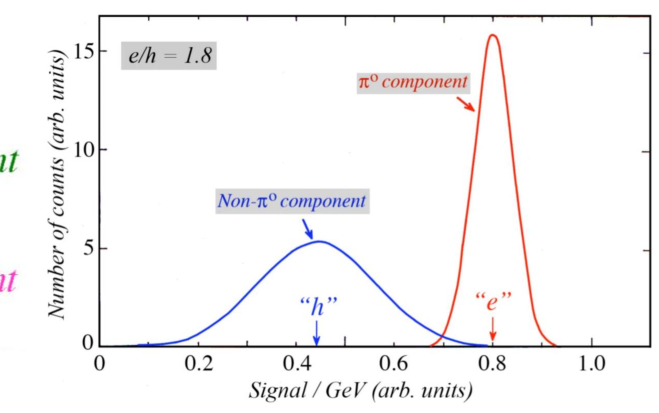
Dual-readout calorimetry

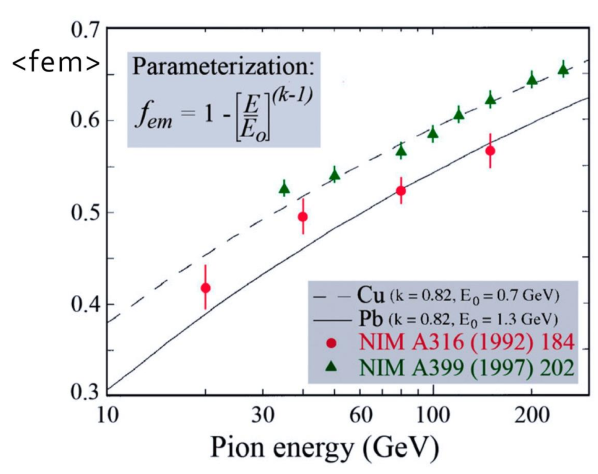
Shower induced by hadrons are made of two components:

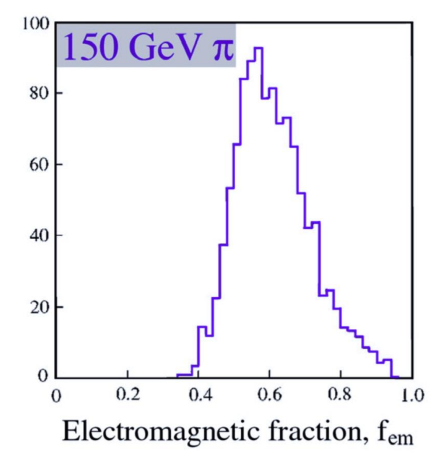
Electromagnetic component: electrons, positrons, photons (from π^0 decays)
Non-electromagnetic component: (Average values in lead)
charged hadrons (20%), nuclear fragments (25%), neutrons (15%), *invisible energy* (40%)

Usually, the calorimeter response to the two components is different (non compensation): $\frac{h}{e} \neq 1$







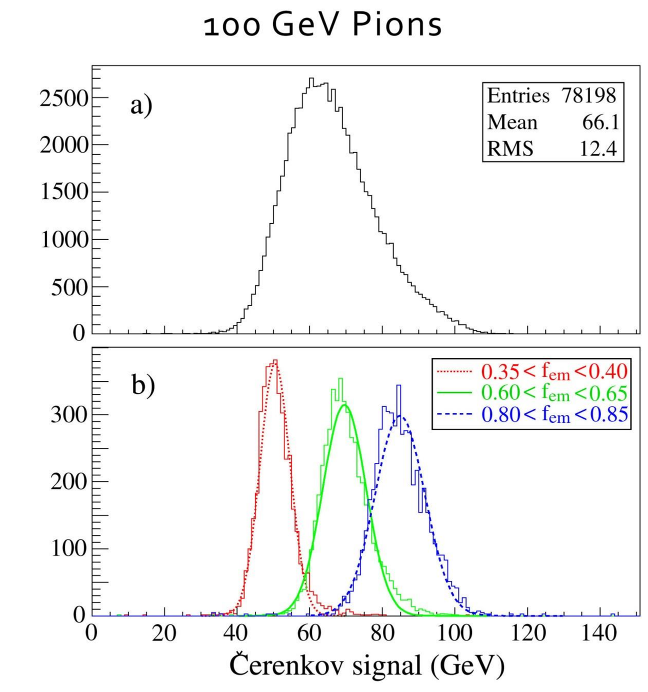


Akchurin N., Wigmans R., Nucl. Instr. and Meth. A490, 132 (2012)

The electromagnetic fraction, i.e. the fraction of the shower energy deposited by the electromagnetic component, has an asymmetric distribution and increases on average with the energy.
Non compensating calorimeters:

- have a resolution spoiled by fluctuations between these two components
- are non linear detectors
- have a non-gaussian response

100 GeV Pions



Akchurin N., et al., Nucl. Instr. and Meth. A 537, 537 (2004)

After a calibration with electrons, signals are given by:

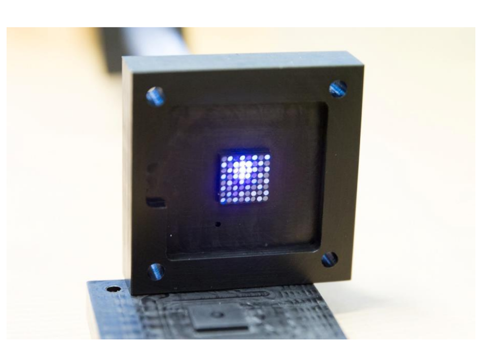
$$S = E\left[f_{em} + (h/e)_S(1 - f_{em})\right]$$
$$C = E\left[f_{em} + (h/e)_C(1 - f_{em})\right]$$
$$\frac{C}{S} = \frac{f_{em} + (h/e)_C(1 - f_{em})}{f_{em} + (h/e)_S(1 - f_{em})}$$

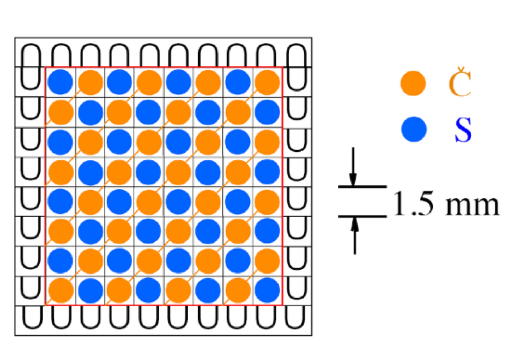
In a dual-readout fibre sampling calorimeter it is possible to measure, event by event, the electromagnetic fraction by means of two signals: **C:** Cherenkov photons produced in clear fibres
S: Photons produced in scintillating fibres

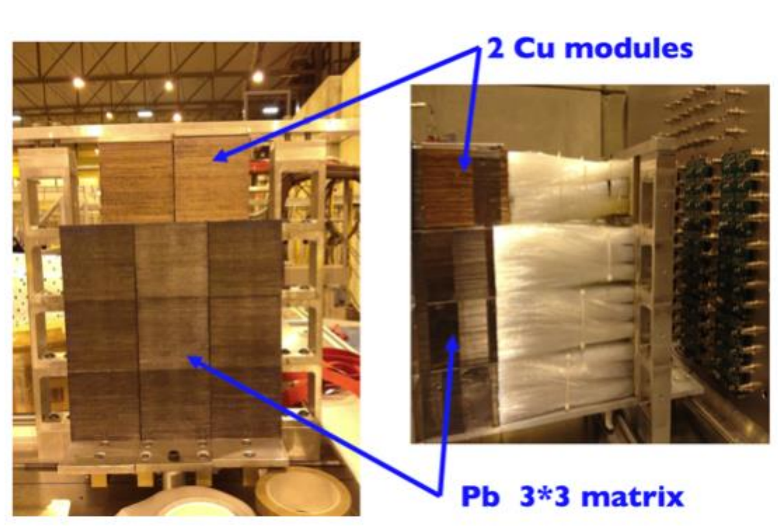
Dual-readout with SiPMs

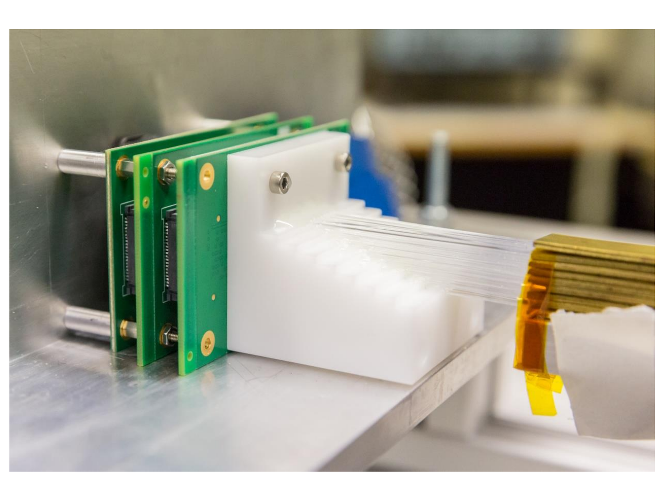
The brass (Cu[260]) calorimeter used for the beam test was 112 cm long, with a lateral cross section of 15 x 15 mm². The active part was composed of 64, 1 mm diameter, optical fibres, 32 scintillating (Kuraray SCSF-78) and 32 clear plastic (Mitsubishi SK40). Each fibre was interfaced to a SiPM[a].
Sensors were mounted, in chessboard-like arrangement, on a two-tier board, providing individual bias and on-board temperature measurement. The channels were read out with two Multichannel Analog to Digital Acquisition systems (MADA) [1]. Each board integrates 32 channels, with 80 MS/s and 14-bit ADCs, performing real-time charge integration.

ADVANTAGES OF SiPMs (respect to PMTs)
(1) Compactness
(2) Higher photon detection efficiency
(3) Magnetic field insensitivity
(4) Possibility to separate the calorimeter into longitudinal segments
(5) Independent readout of each fibre, allowing to sample showers with a millimetric resolution
(6) Potential combination of the dual-readout method with Particle Flow Analysis
DRAWBACKS response non-linearity, signal saturation effects and optical crosstalk between scintillating and Cherenkov fibres.



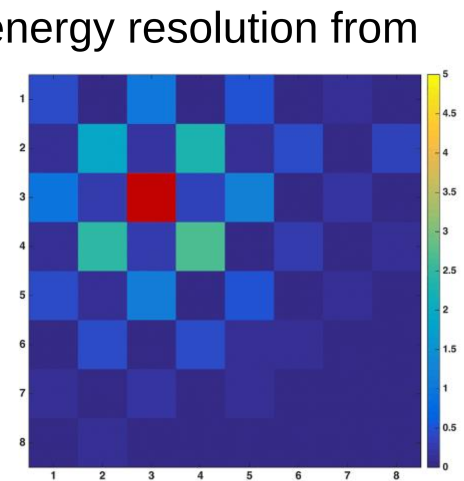






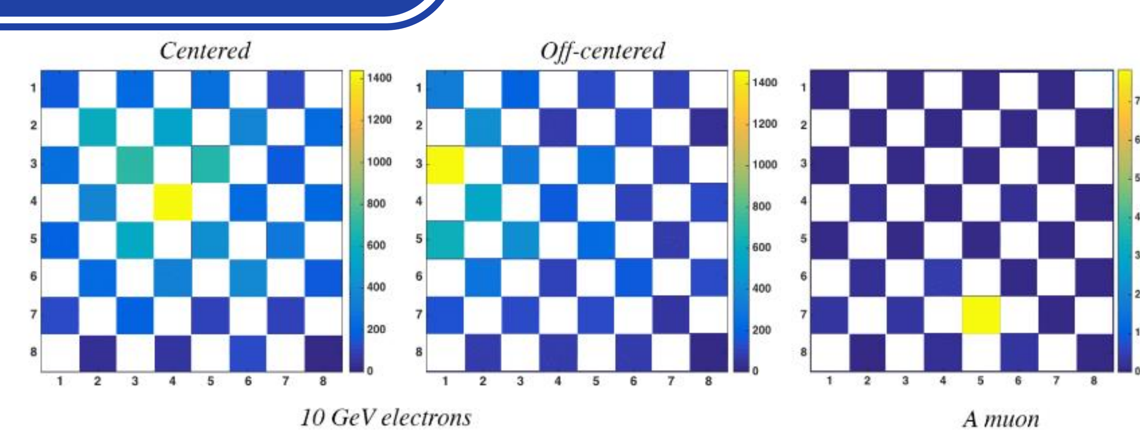
RESULTS (Cherenkov) [3]
We verified that the Cherenkov light yield (28.4 fired cells/GeV) for electromagnetic showers is constant over the 6–125 GeV energy range. By taking into account an average shower containment of ~36% the expected light yield is **~70 fired cells/GeV**, 2.3 times larger than what estimated with PMTs [2]. This increase alone, keeping the same geometry, improves the stochastic term in the e.m. energy resolution from ~14%/√E to **~10%/√E**.

The optical crosstalk was estimated by illuminating a scintillating fibre (covering all the others) with a pulsed LED (PicoQuant PDL 800). The distribution of the Cherenkov signals has a mean value that is **~0.3%** of the scintillating signal. This is an upper limit for the optical crosstalk.

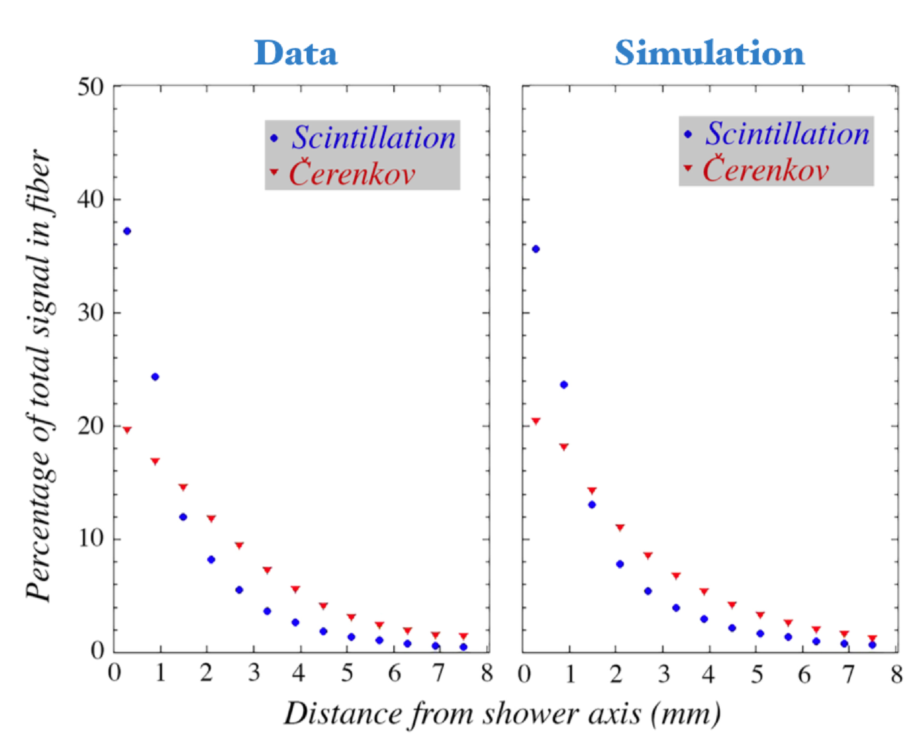


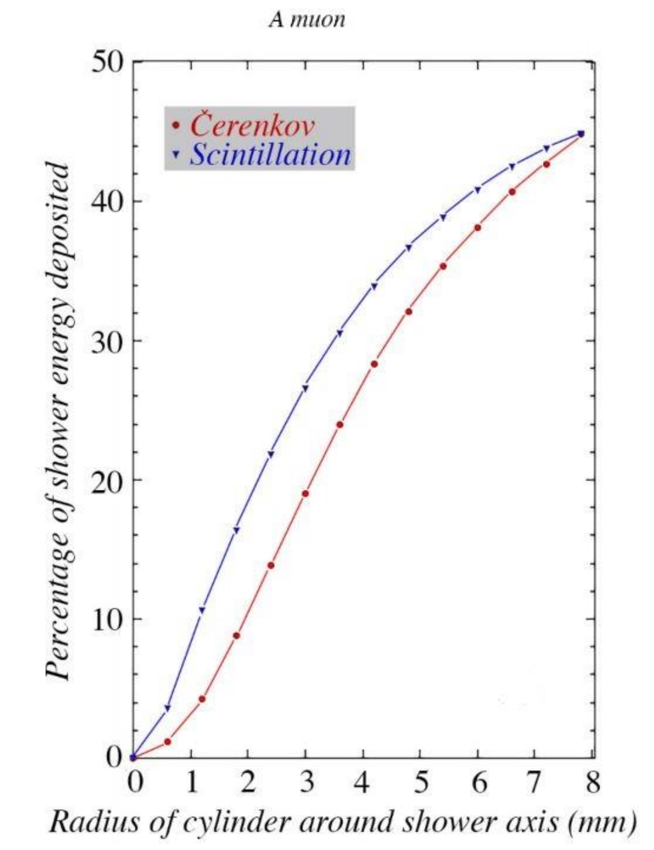
[a] **HAMAMATSU S13615-1025:** active area:1x1 mm², pitch: 25 µm, 1584 cells/sensor, V_{br}: 52.5 V, V_{op}: V_{br} + 5, Peak Photon Detection Efficiency: 25%, Gain at V_{op}: 7x10⁵, Dark Count Rate at V_{op}: 50 kps; Optical Cross talk at V_{op}: 1%

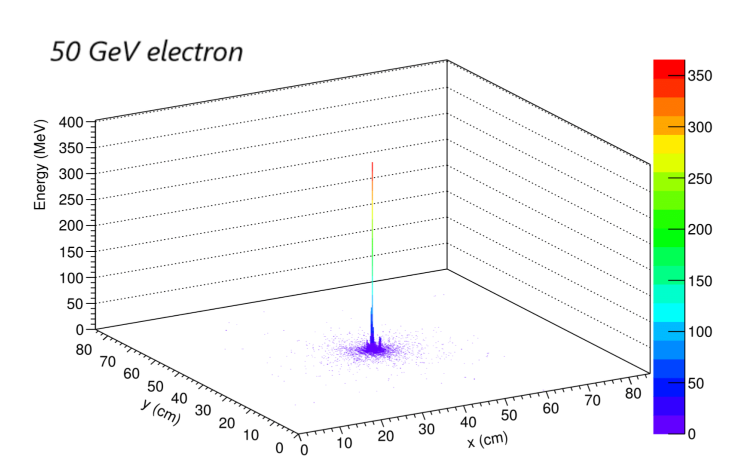
Spatial Resolution
Data & Geant4



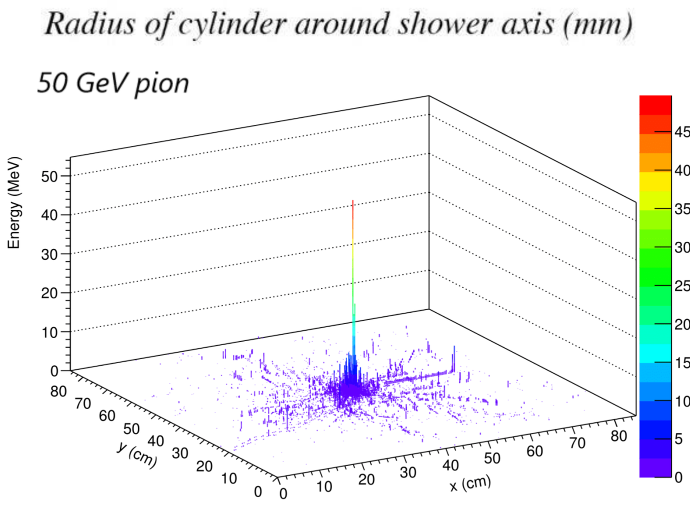
Data Scintillating fibres event display



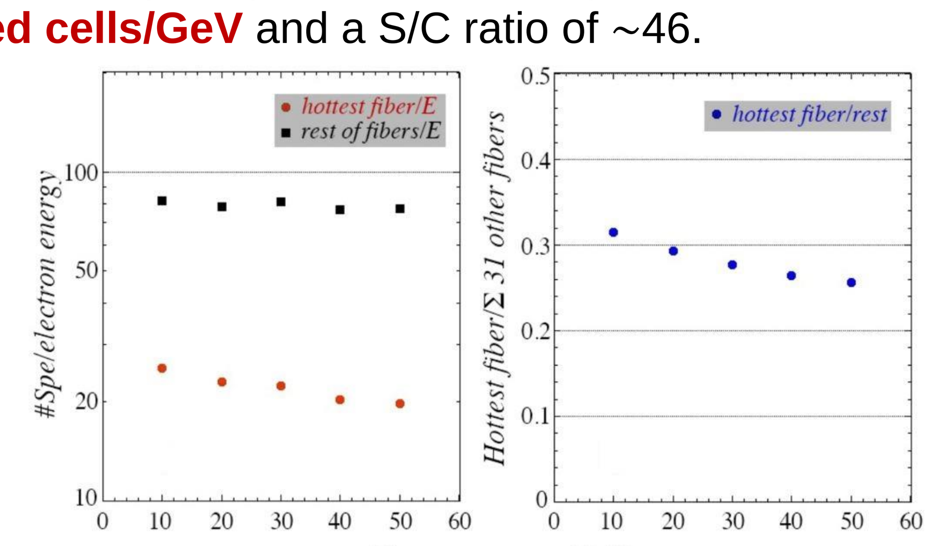




Geant4



RESULTS (Scintillation) [3]
For the scintillation signal SiPMs saturation and response non linearity are major concerns. Even with a PDE of ~2.0% we experienced a decrease of about a factor 2 in the "hottest" fibre and ~25% in the remaining 31. By correcting for occupancy saturation we almost completely restored linearity and estimated a scintillation light yield of **~3000 fired cells/GeV** and a S/C ratio of ~46.



[1] http://www.nuclearinstruments.eu/sipm.html
[2] N. Akchurin *et al.*, Nucl. Instr. and Meth. A735 (2014) 130
[3] M. Antonello *et al.*, Tests of a dual-readout fiber calorimeter with SiPM light sensor, NIM preprint

All the DREAM/RD52 publications are available at:
http://www.phys.ttu.edu/ dream/index.html