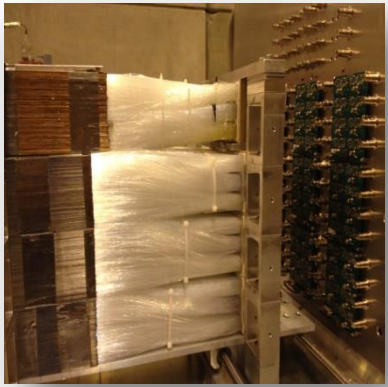
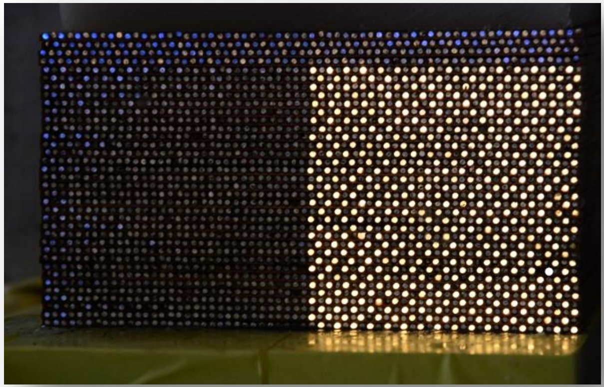
RD52 DREAM

RD52 Status report
Dual Readout Calorimetry

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**On behalf of the RD52 Collaboration*

126th LHCC Meeting, open session, CERN, 25/5/2016

RD52 goal

RD52 is a generic detector R&D project, not linked to any experiment

Goal:

- Investigate and eliminate factors that prevent us from **measuring hadrons and jets with similar precision as electrons and photons**
- Develop a calorimeter that is up to the challenges of future particle physics experiments

Dual-Readout Calorimetry

Dual REAdout Method (DREAM):

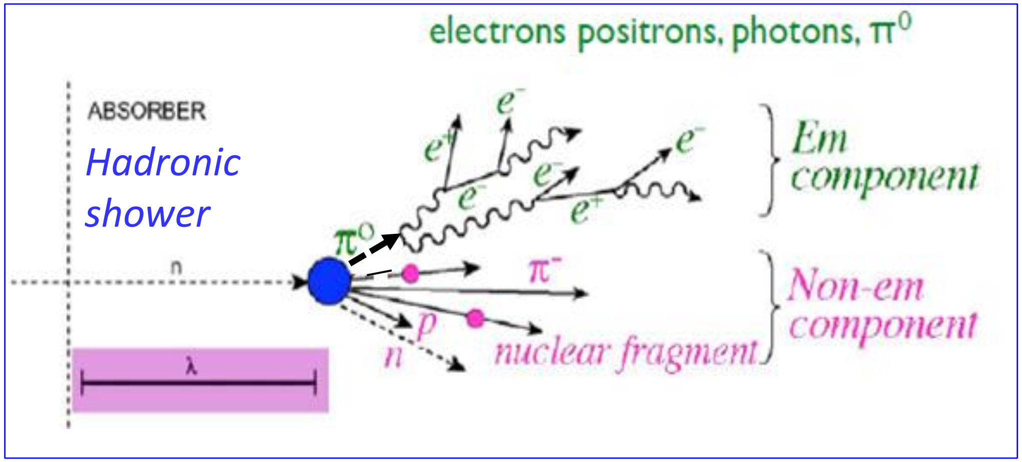
Simultaneous measurement, during shower development, of:

- Scintillation light (dE/dx charged particles)
- Cherenkov light (em part of the shower)

→ Measurement, event by event, of em fraction of hadron showers

→ Reduction of fluctuations in em fraction

Same advantages as for compensating calorimeters (e/h=1), without their limitations (sampling fraction, integration volume, time)



Result:

- Correct hadronic energy reconstruction (detector calibrated with electrons)
- Linearity
- Good energy resolution for hadrons and jets
- Gaussian response functions

RD52 DREAM

Results since 2015 LHCC

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The small-angle performance of a dual-readout fiber calorimeter

CrossMark

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Published in 2016, most of the results already presented last year

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ABSTRACT

The performance of the RD52 dual-readout calorimeter is measured for very small angles of incidence between the 20 GeV electron beam particles and the direction of the fibers that form the active elements of this calorimeter. The calorimeter response is observed to be independent of the angle of incidence for both the scintillating and the Čerenkov fibers, whereas significant differences are found between the angular dependence of the energy resolution measured with these two types of fibers. The experimental results are on crucial points at variance with the predictions of GEANT4 Monte Carlo simulations.

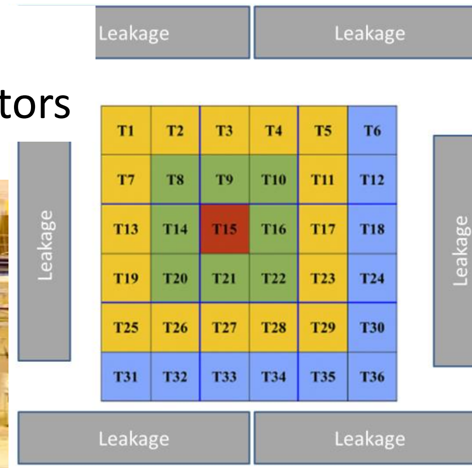
+ 2 in preparation (data taken during test beam Nov 2015)

- **Hadron detection** with a dual-readout fiber calorimeter
- **Characteristics of the light** produced in a dual-readout fiber calorimeter

Hadron detection with RD52 fiber calorimeter

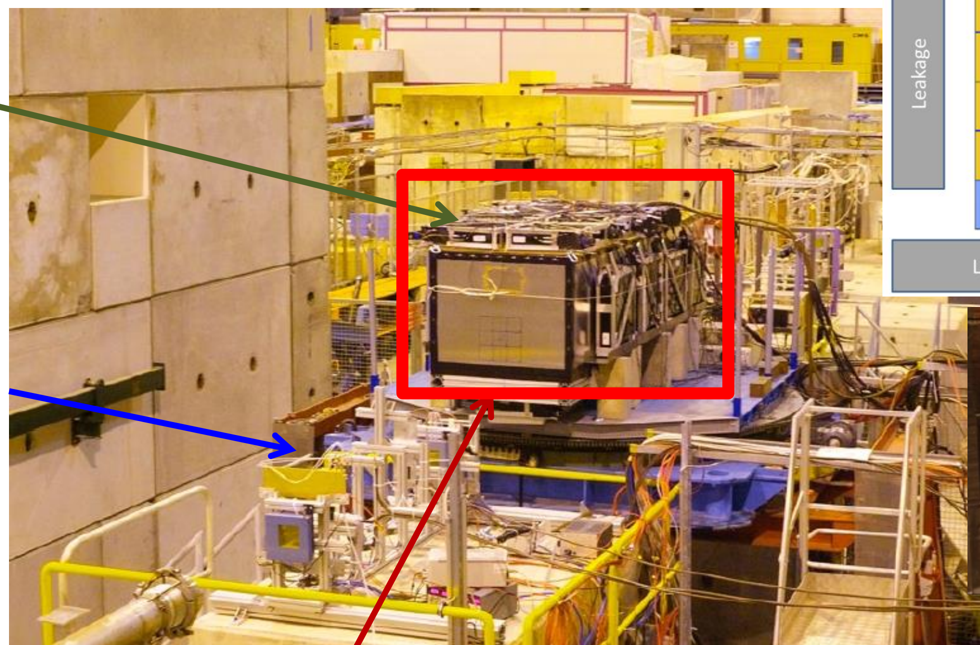
Experimental setup (H8)

72 towers,
20 leakage detectors



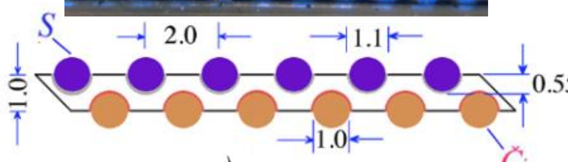
Scintillators to detect leaking showers (20)

Trigger, tracking, preshower, interaction target



RD52 Pb prototype (INFN Pavia)
3*3 Pb modules, each of them:

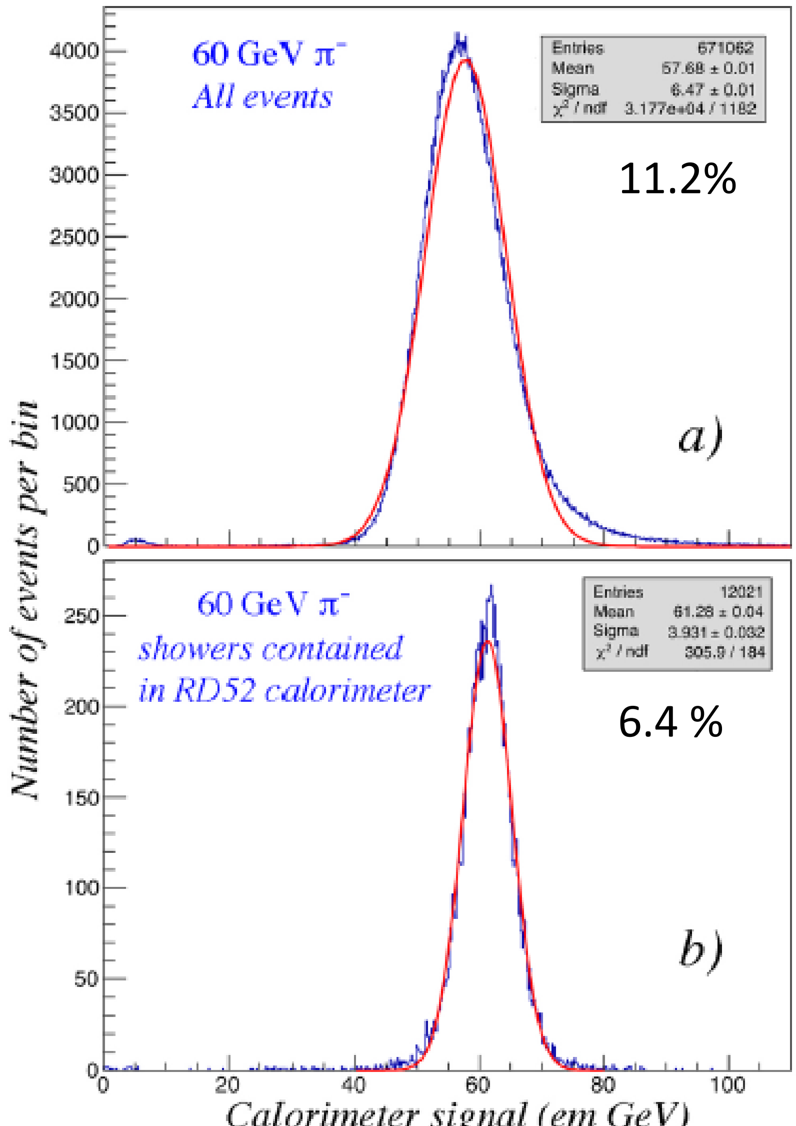
- 9.3 * 9.3 * 250 cm^3 (10 λint)
- Fibers: 1024 S + 1024 C, 8 PMT
- Optimized sampling fraction: 5%



Hadron detection with RD52 fiber calorimeter

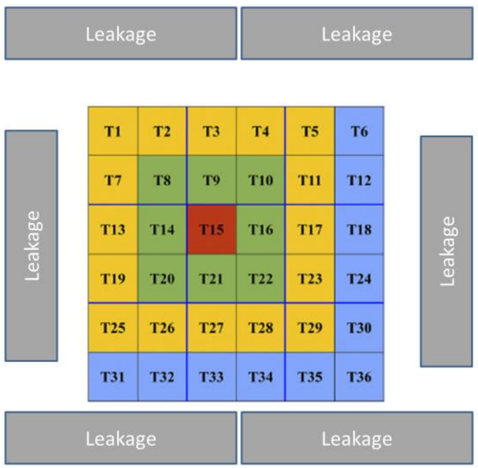
Hadronic energy resolution

Preliminary



Dominated by

- **leakage fluctuations**



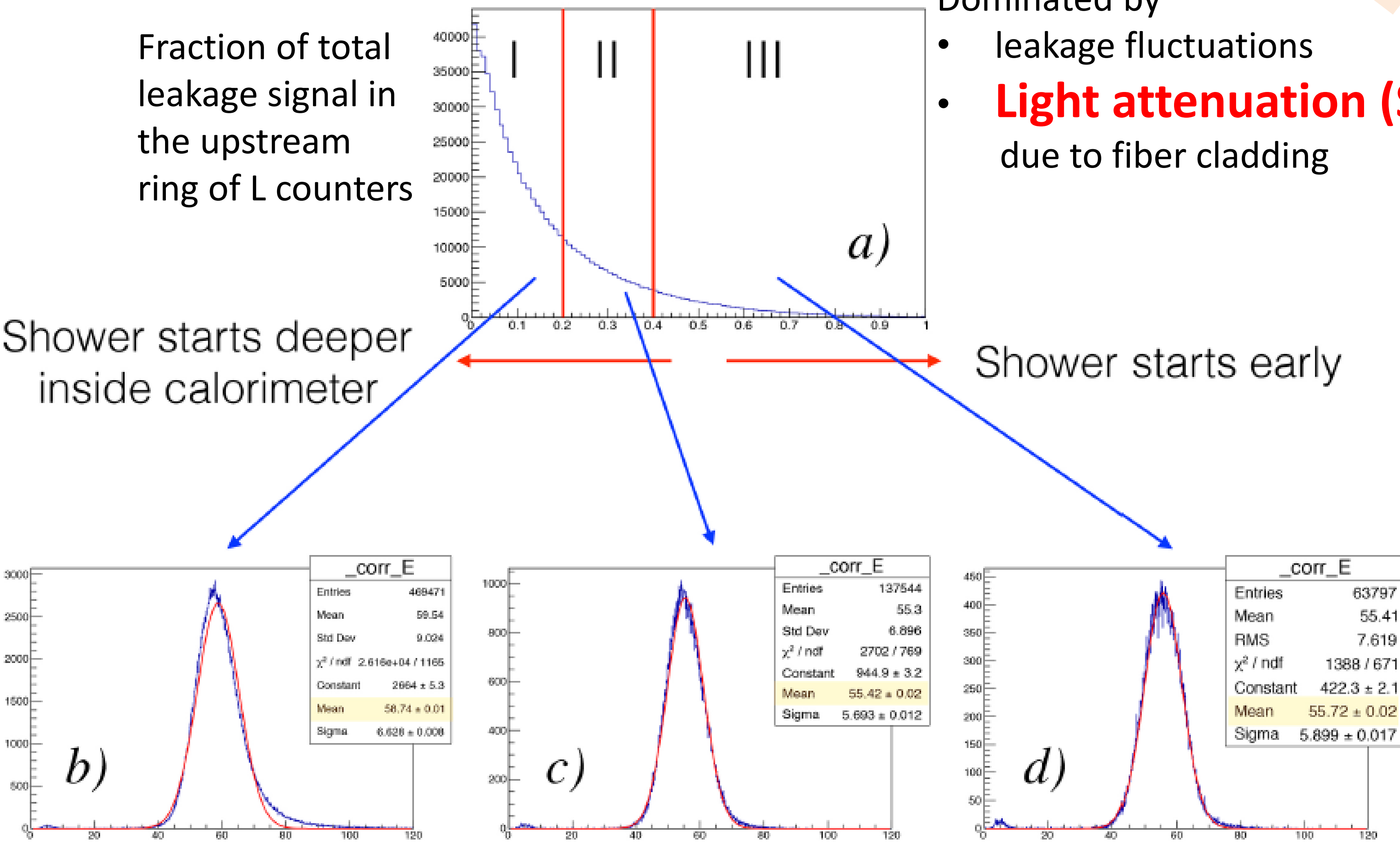
Analysis of each energy in progress

RD52 DREAM

Hadronic energy resolution

Preliminary

Dominated by
- leakage fluctuations
- **Light attenuation (S)** due to fiber cladding

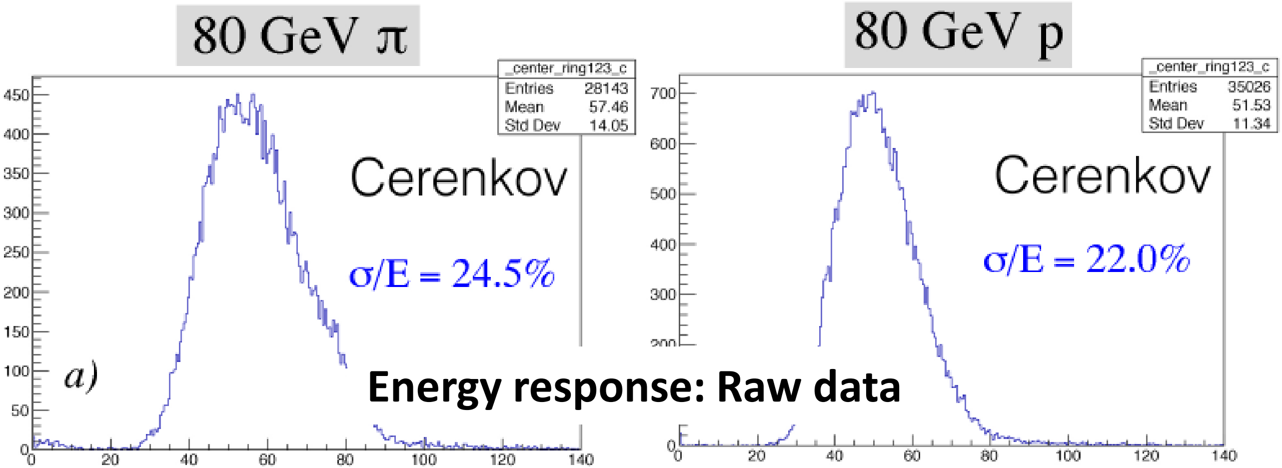


Dual-readout calorimeter signal for 60 GeV pions

Hadron detection with RD52 fiber calorimeter

Proton/Pion comparison

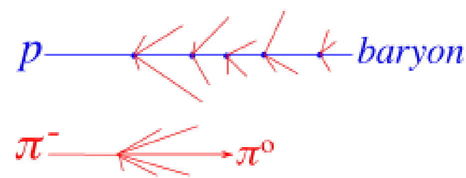
Preliminary



Energy response: Raw data

π showers:

- more em fraction
- more fluctuations



Hadron detection with RD52 fiber calorimeter

Proton/Pion comparison

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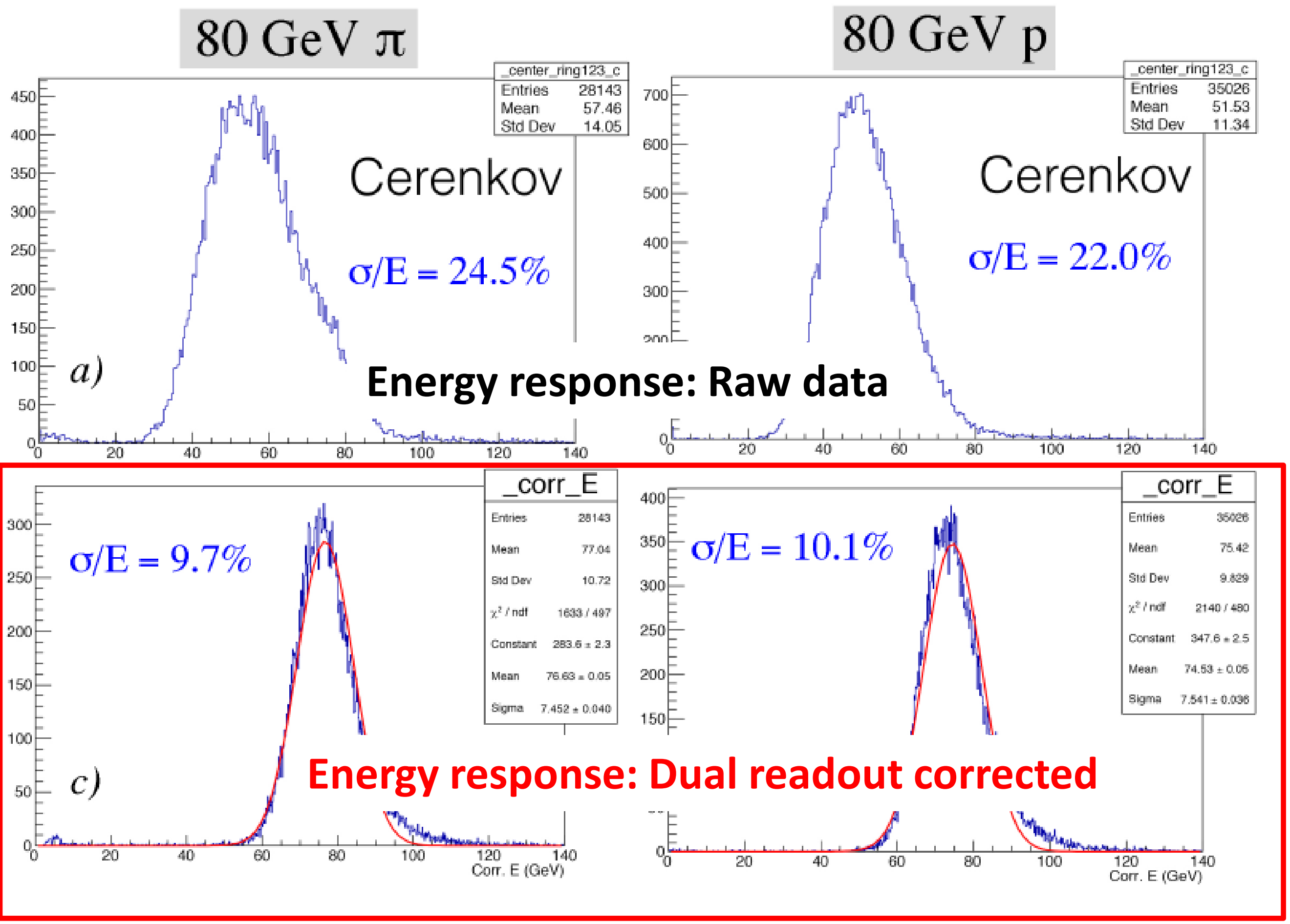

π showers:

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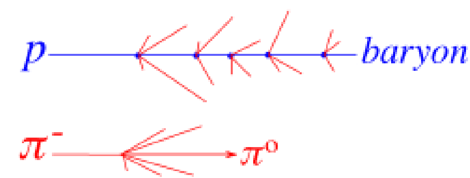
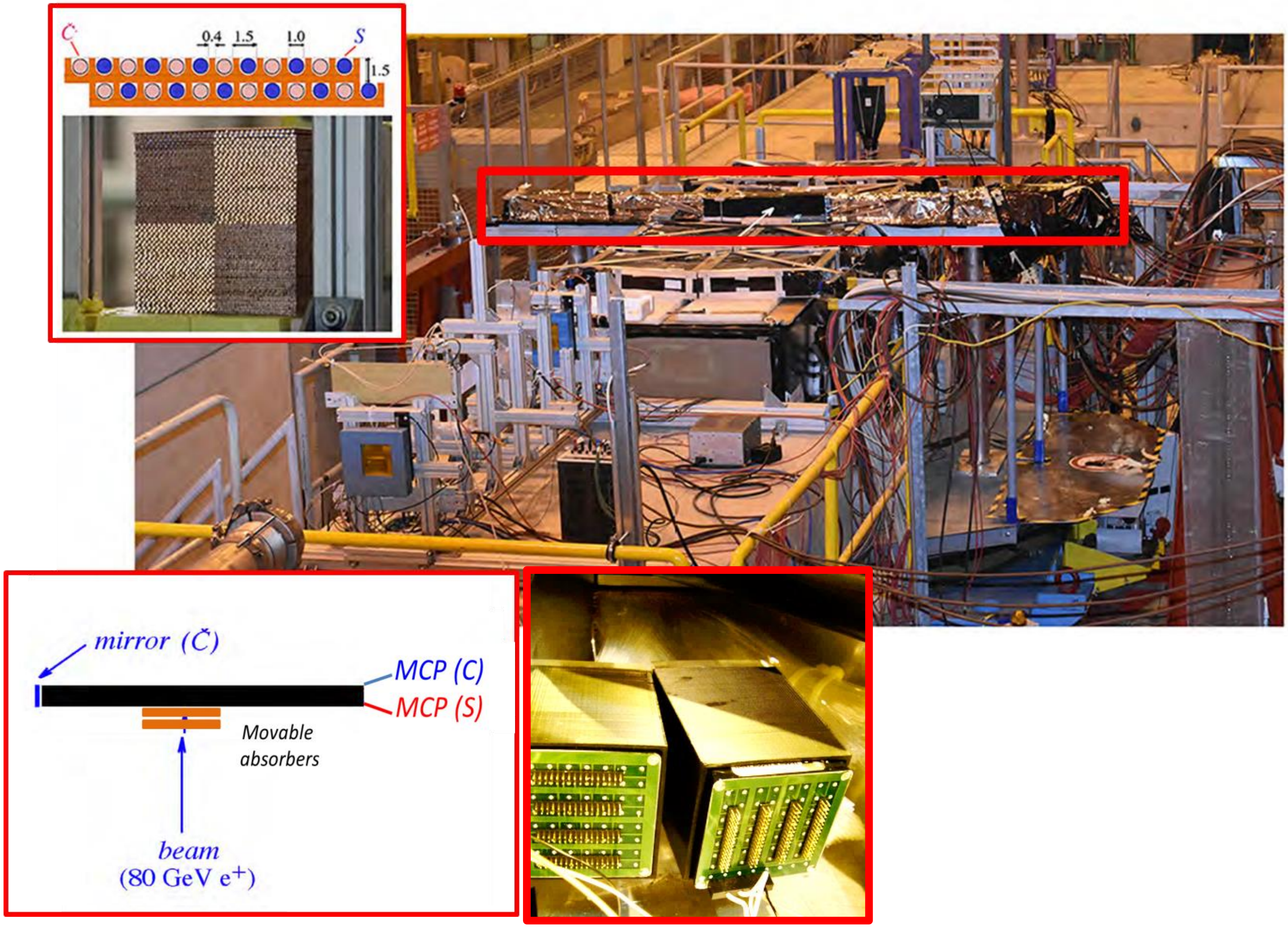


Differences vanishes if dual readout corrected energy

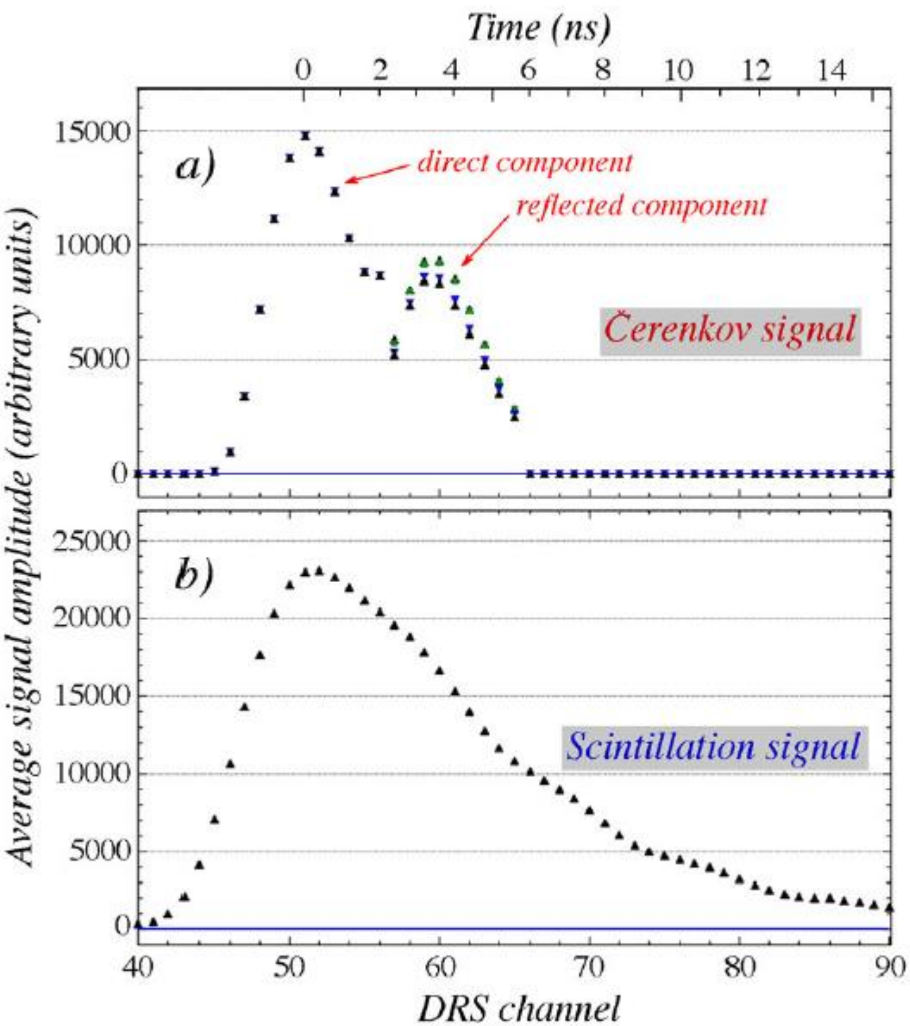
Characteristics of the light produced in a dual-readout fiber calorimeter

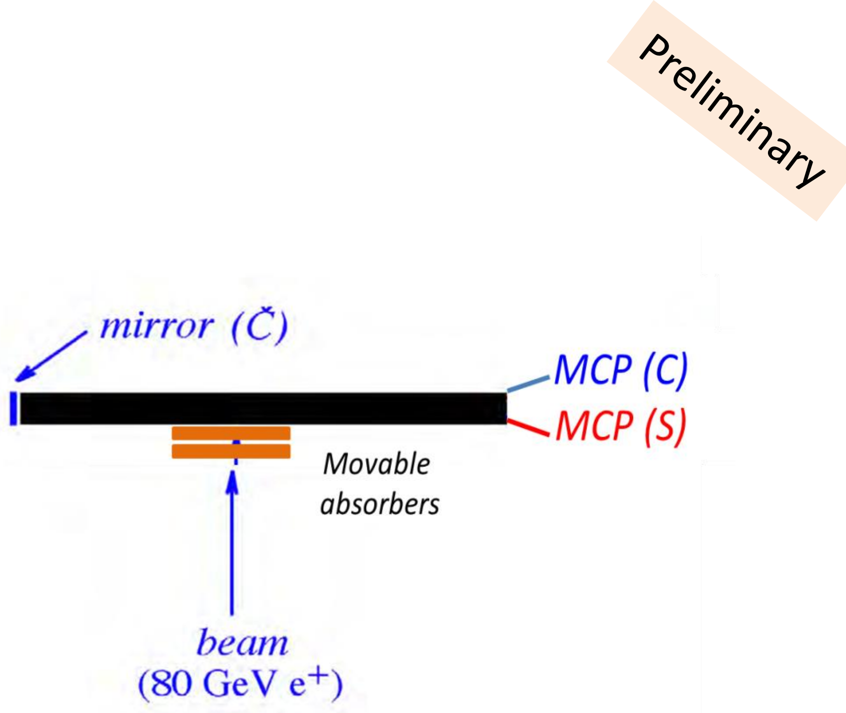
Experimental setup (H8)



Characteristics of the light produced in a dual-readout fiber calorimeter

MCP + DRS readout for fast signals

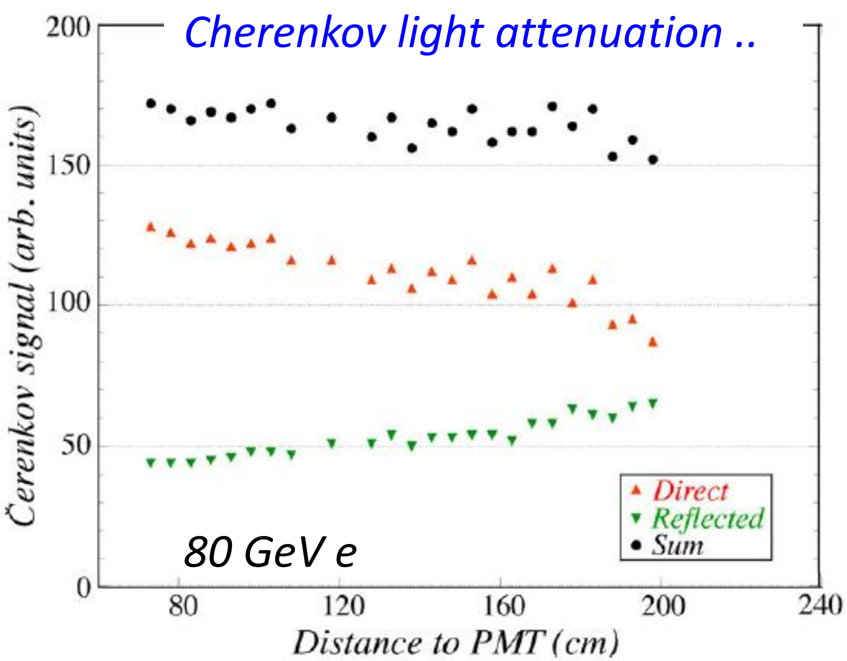


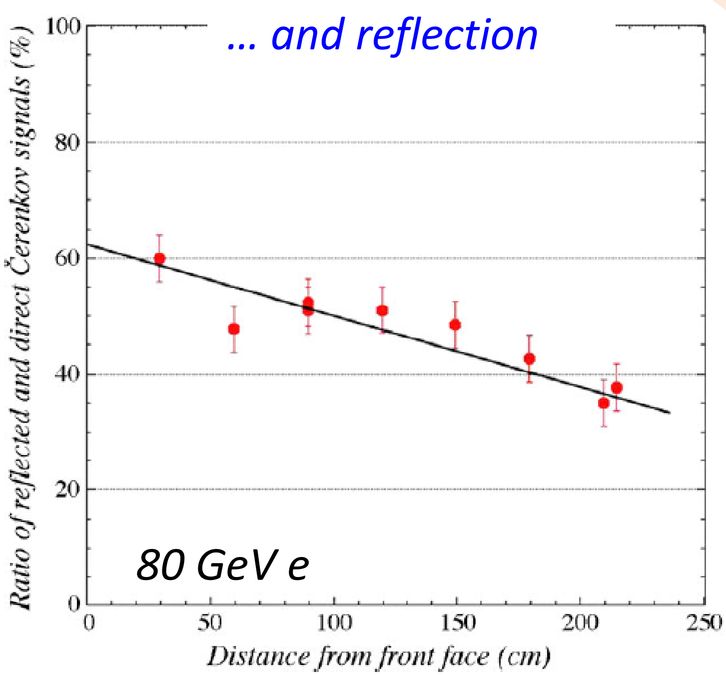


Characteristics of the light produced in a dual-readout fiber calorimeter

Measurement of C fiber characteristics

Preliminary





Analysis in progress

2016 test beam plans (2 weeks October)

1) **Measure proton/π differences in time signal time structure** (Pb matrix + DRS readout)
   Can calorimeter data be used to identify p/ π event by event?

2016 test beam plans (2 weeks October)

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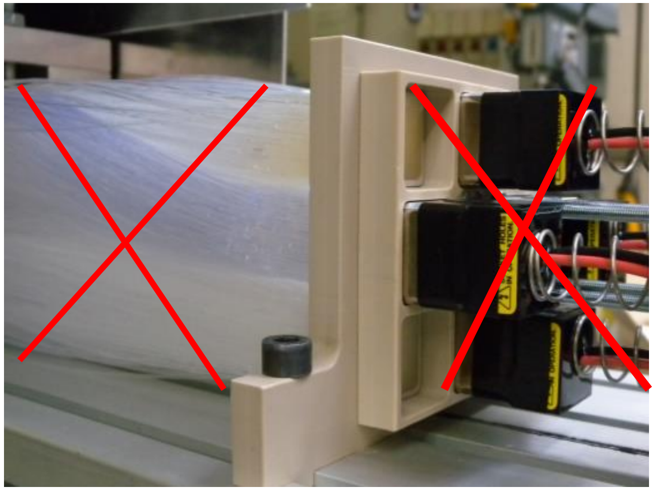
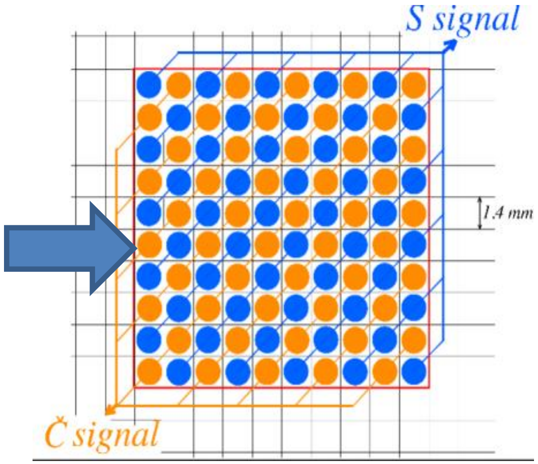
Can calorimeter data be used to identify p/ π event by event?

2) **Test SiPM readout on a new small Cu module. Proof of principles**
- Get rid of the "fiber forest" antennas
- RO closer to the end face
- Transversal segmentation as small as needed
- Possible longitudinal segmentation
- Possible operation in magnetic field

Important for a 4π calorimeter



Fiber bunches + **PMT**



SiPM matrix coupled to end of detector

2016 test beam preparation

Practical problem:

two kind of fibers , very different light yields:

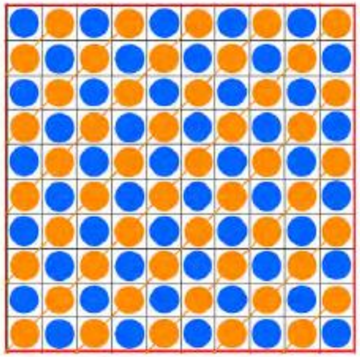
C: ~50 p.e./GeV (large efficiency)

S: ~1000 p.e./GeV (large dynamic range)

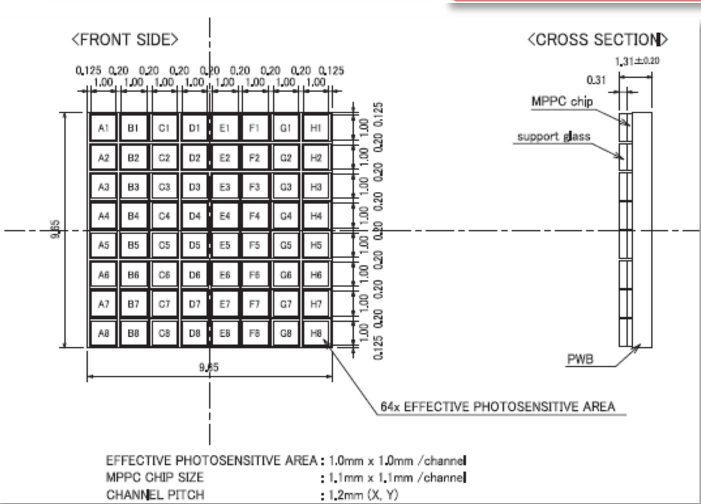
Ongoing preparation :

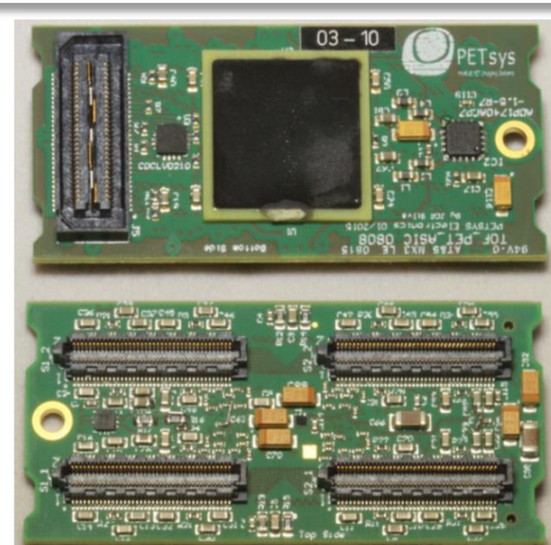
- two small modules (skived Cu) 15*15*100 cm^3, 10*10 fibers. (Iowa State University)
- Hamamatsu: matrix 8*8 SiPm 1mm^2
- M.Caccia (Como) in charge of readout board

Hopefully everything will be ready to be tested in October 2016 testbeam (<u>still not 100% granted</u>)



HAMAMATSU PRELIMINARY



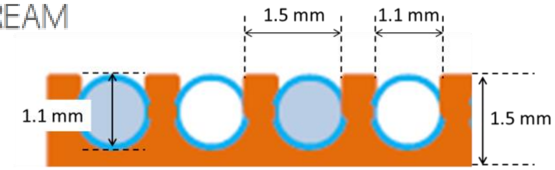


Long term plans

Idea to build a **full containment Cu dual readout calorimeter** (same structure as the few tested modules).

On the way of finding the **best technology to machine 1 mm grooves in Cu**. Need to be industrial compatible to lower prices

Toward industrial Cu production



- geometry: high grooves density, sampling fraction (5%)
- Cu as absorber for energy resolution performances
- Reduce inhomogeneity (constant term at high E)
- Cu not easy to be machined

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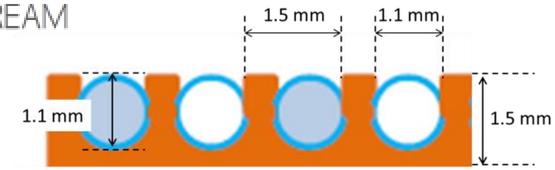

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Cu grooving techniques investigated:

Abandoned for Cu

- **Rolling**
- **Extrusion**

(Used techniques for Pb calo: KLOE, ATLAS LAr, SPACAL)

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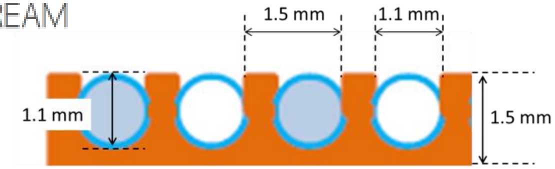

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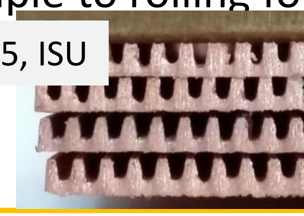
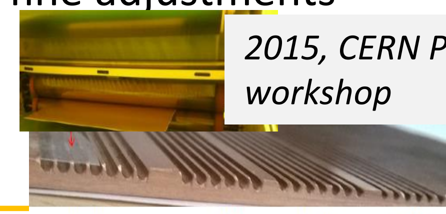
Promising To be more investigated, better if couple to rolling for fine adjustments

- **Water jet** (industrially compatible)
- **Chemical milling** (industrially compatible)

2015, ISU



2015, CERN PCB workshop



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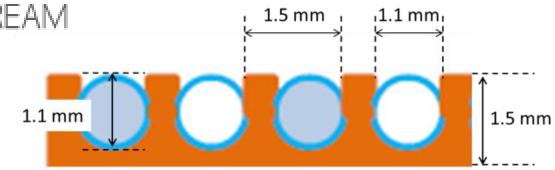

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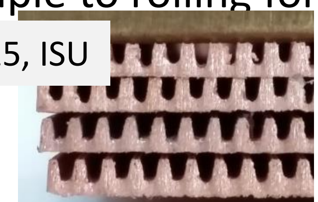
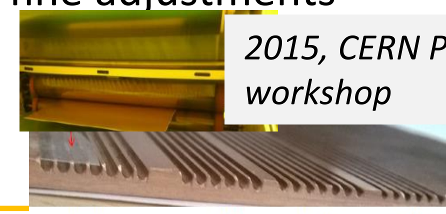


2015, ISU

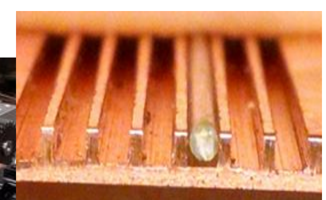


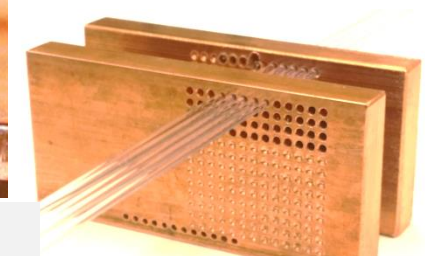
2015, CERN PCB workshop

Used

- <u>**Saw scraping**</u> with rotating calibrated disks (not industrially compatible)
- **Skiving** (used for a small prototype but not imperfect and expensive)
- **Drilling**

2012, INFN Pisa RD52 prototypes





2016, ISU. ongoing trials

Long term plans

Idea to build a full containment Cu dual readout calorimeter
(same structure as the few tested modules).

On the way of finding the best technology to machine 1 mm grooves in Cu.
Need to be industrial compatible to lower prices

Problem: no new funding, few resources

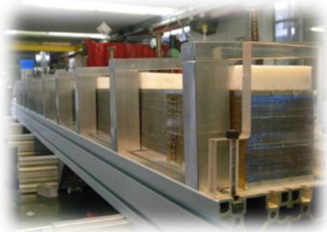
Since beginning of RD52 project (2012) tested almost everything one can do with relatively small prototypes (dual readout crystals, fiber calorimeters).

A future experiment interested in dual readout calorimetry could complete the work, starting from solid basis.

From RD52 fiber prototypes to a 4π calorimeter

Best solution found:

- Copper Dual Readout (em + had) fiber calorimeter
- high fiber filling fraction
- not longitudinally segmented
- read out with fast electronics (< ns)



RD52 DREAM

From RD52 fiber prototypes to a 4π calorimeter

Best solution found:

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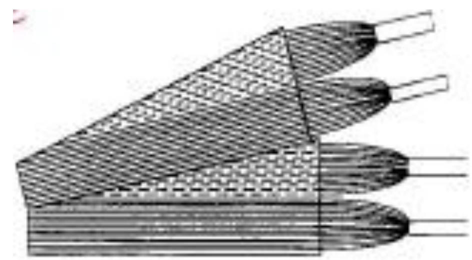
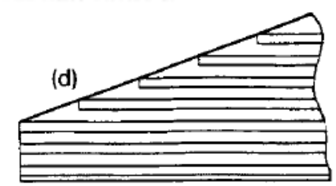
Suggestions on what needs to be done/completed..

- Projective geometry *(NIM A337 (1994) 326- 341)*
- Use/optimization of SiPm
- Rad hardness Cherenkov clear fibers
- Industrial production of grooved Copper
- Custom fast electronics
- …





More Slides

Choice of the RD52 fiber calorimeters components

Scintillating fibers :

doped SCSF-78, (produced by Kuraray) *+ YELLOW filter* to eliminate effect of self absorption in the short wavelength region (λatt >5m)

Cherenkov fibers :

PMMA based SK40 (produced by Mitsubishi), measured λatt ~ 6m. Good numerical aperture

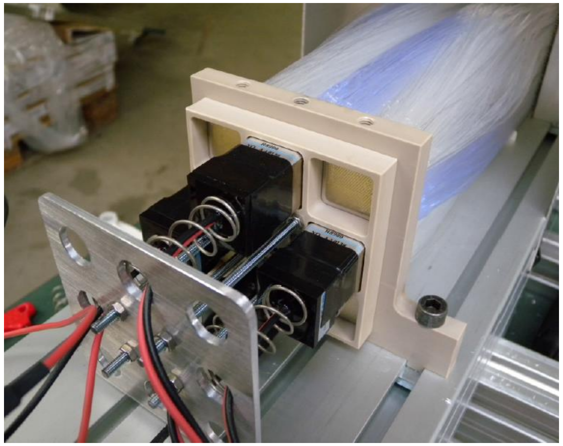
Aluminized front end (in only one Cu prototype). With Sputtering, at Fermilab.

- more C light,
- more uniform response as a function of interaction depth
- With precise time information, possible to know the interaction depth

Phototubes:

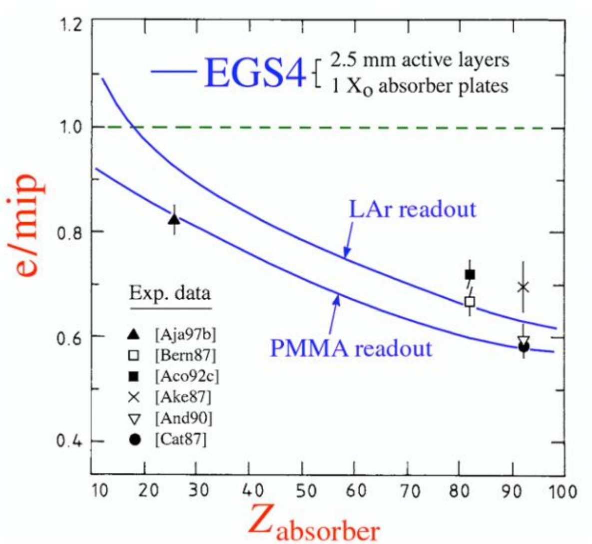
Hamamatsu R8900, a 10-stage, super-bi alkali photocathode , 21 mm size of active area.

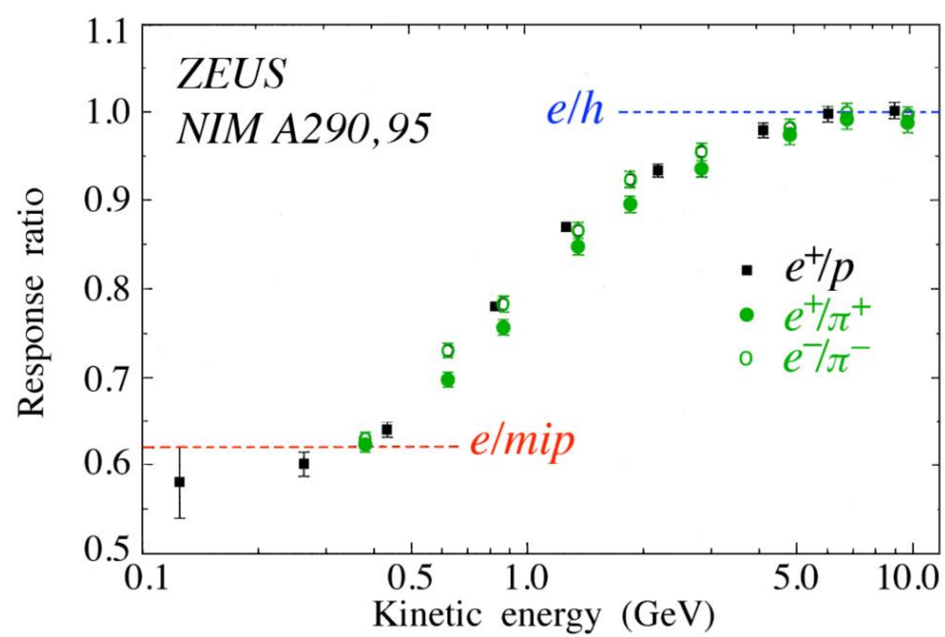
- Largest possible ratio (85%)between the photocathode surface and the total surface to minimize dead zones between towers;
- Squared section cathode to have the best fiber packing



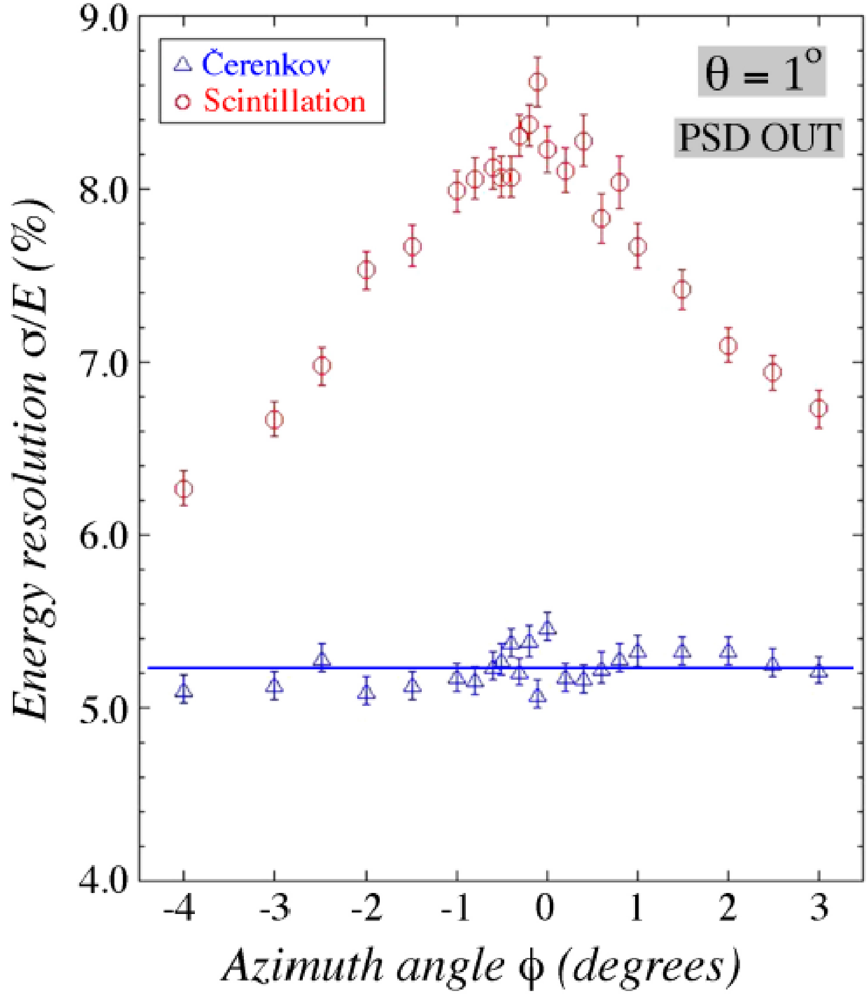
Absorber choice: Cu vs Pb

- *Detector mass:* $\lambda_{Cu} = 15.1$ *cm*, $\lambda_{Pb} = 17.0$ *cm*
  Mass $1\lambda^3$ *: Cu/Pb = 0.35*
- *e/mip* ⟶ *Čerenkov light yield Cu/Pb ~ 1.4*
  (Showers inefficiently sampled in calorimeters with high-Z absorber)
- *Non-linearity at low energy in calorimeters with high-Z absorber*
  Important for jet detection



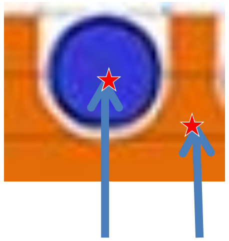


Small-angle em performance



Em showers very narrow at the beginning;
Sampling fraction depends on the impact point (fiber or dead material)

If particles enter at an angle the dependence disappears



Fluctuations on different impact point

Effect NOT seen in Cherenkov signals since early part of the shower do not contribute to the signal (outside numerical aperture C fibers)

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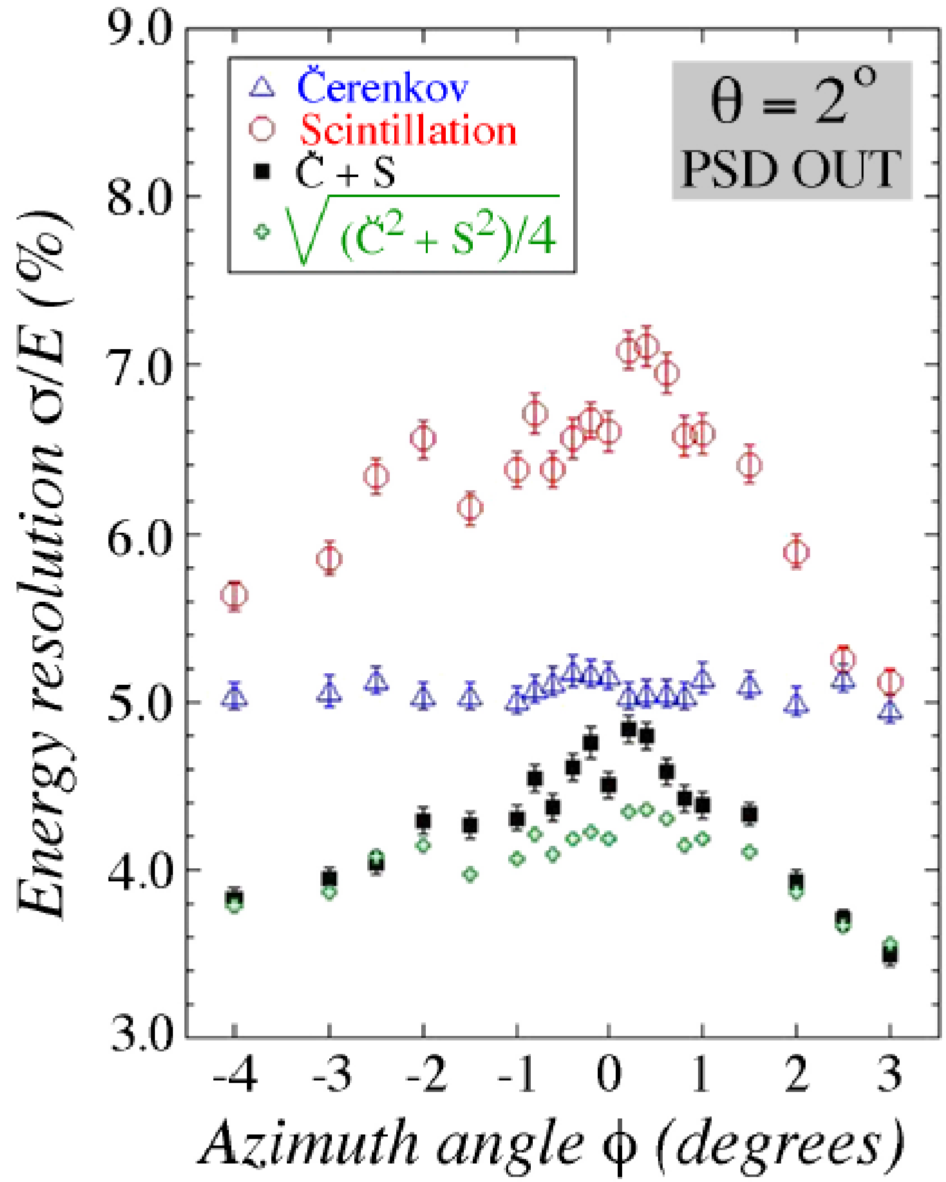
Small-angle em performance

S, C: sample INDEPENDENTLY the em showers

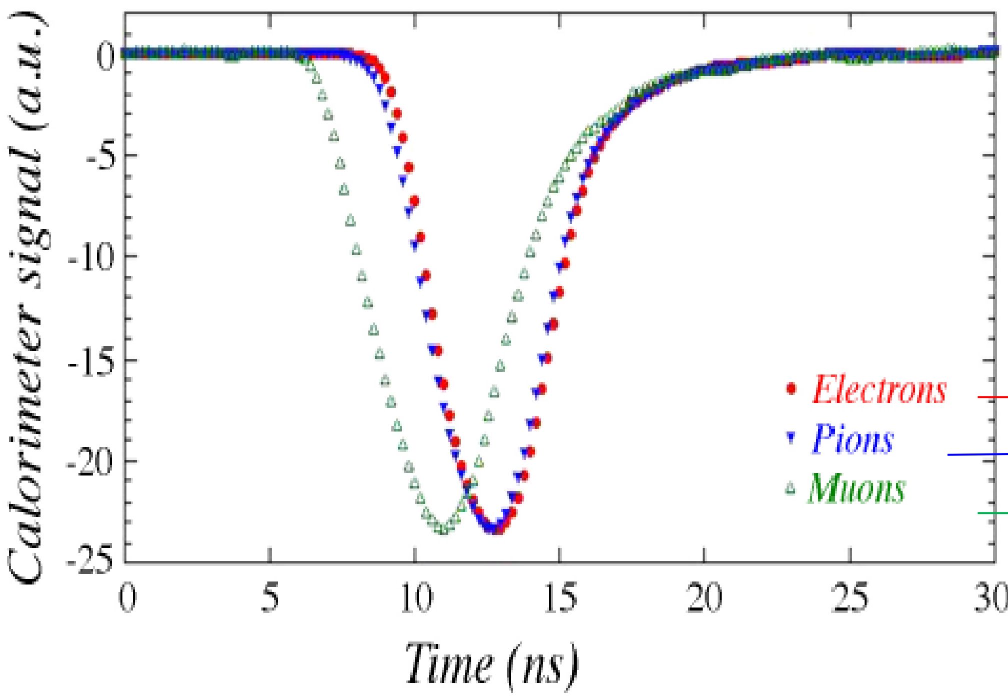
→ We can sum their contributions
→ em energy resolution improves by a factor √2

Good em energy resolution



Time structure (1)

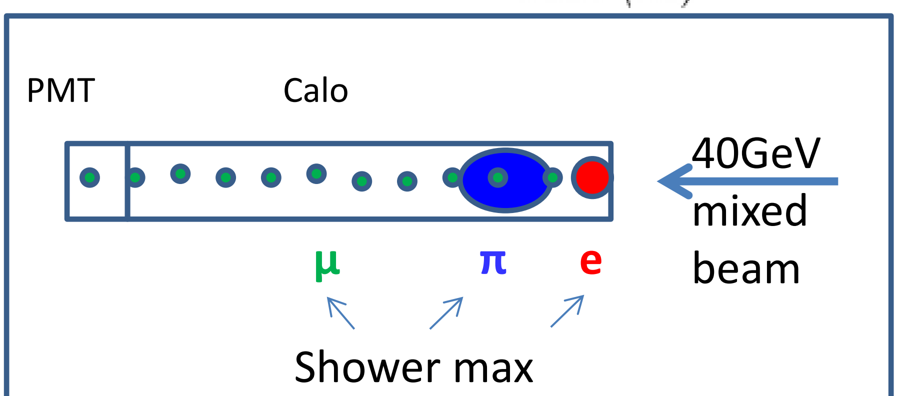
Average Cherenkov signal (40 GeV mixed beam)
from tower around the beam axis



Depth shower max ~ 5cm

Depth shower max ~ 25cm

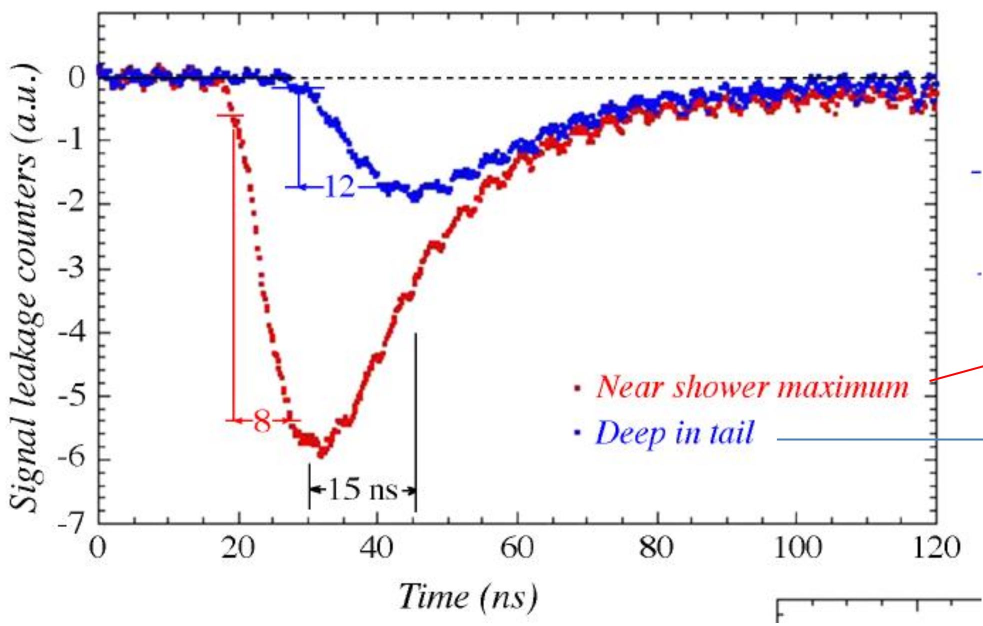
Average depth light production ~125 cm



Particle ID possibility
in longitudinally unsegmented detector.

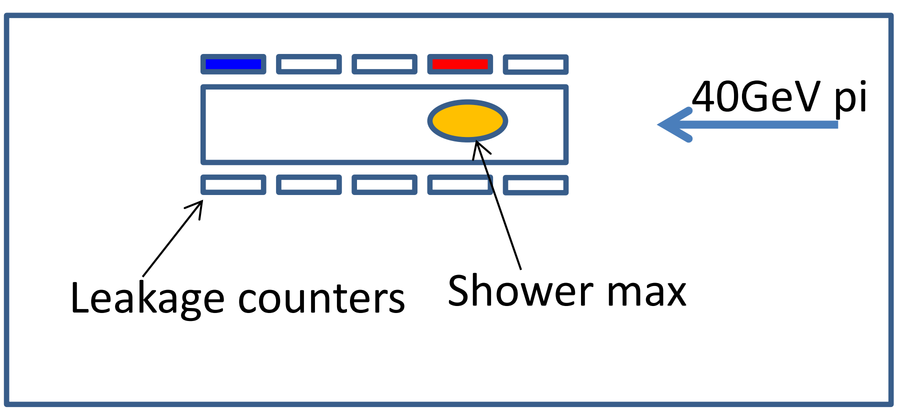
Time structure (2)

Comparison signal shape leakage counters (average signal)



Prompt charged shower particles escaping the calorimeter

Signal produced by recoiled protons from elastic neutron scattering
time constant 10-20 ns

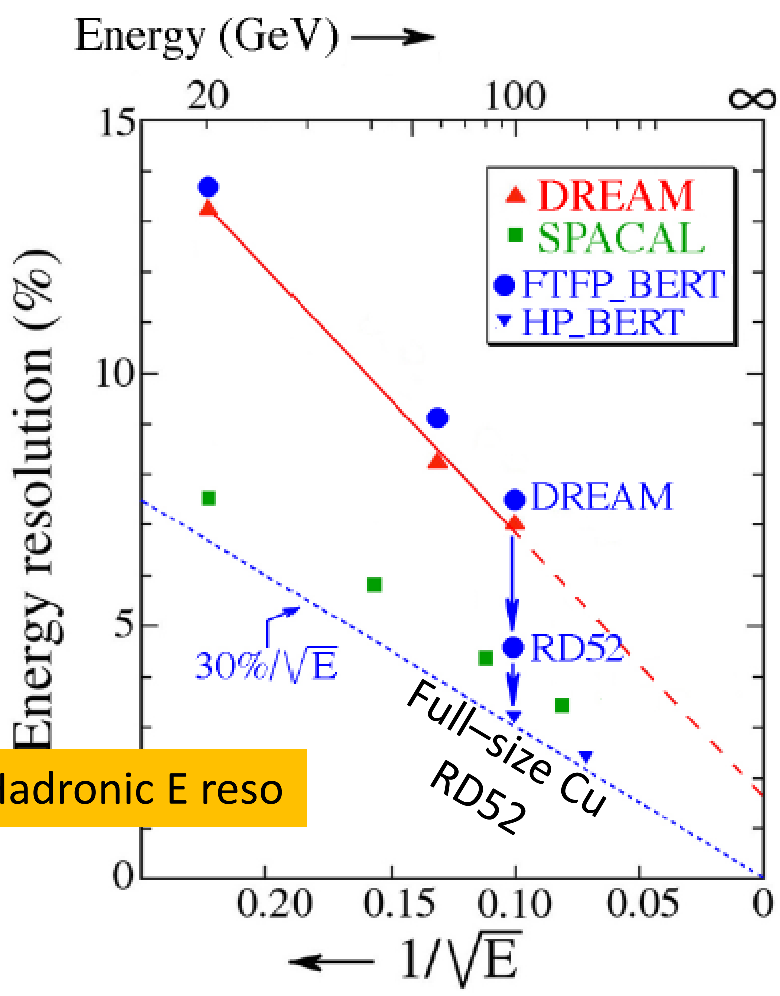


Sensitivity to the neutrons
→ Possible to improve resolution

Monte Carlo simulations

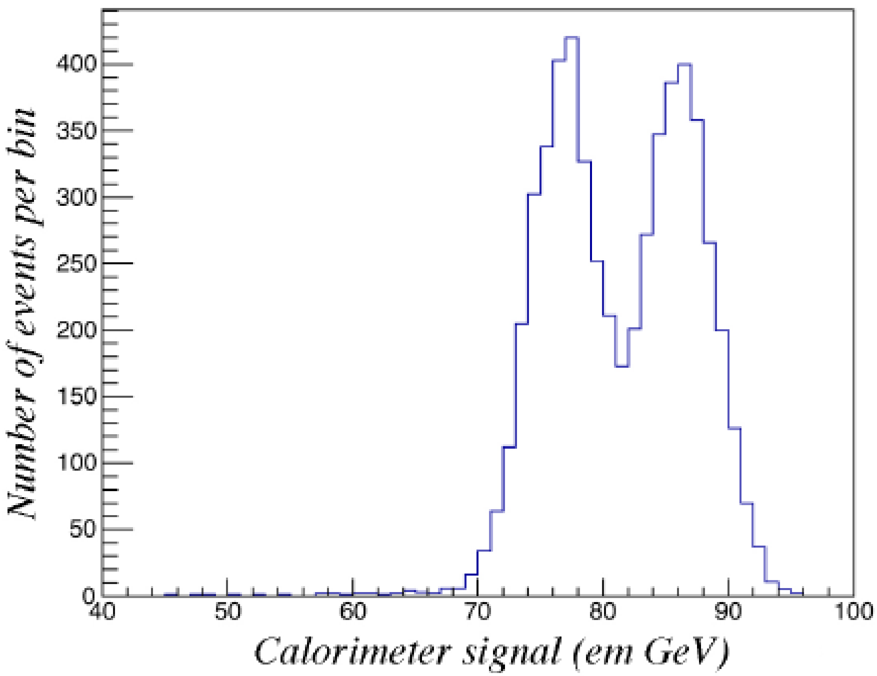
Nucl. Instr. Meth. A762 (2014) 100 DREAM method simulated with GEANT4

2015: Repeated some of these simulations with high precision version of had. showers (neutrons followed in details)



Hadronic E reso

W/Z hadronic decay separation, high precision GEANT4 full-size Cu RD52



Goal for future e+e- accelerators