Istituto Nazionale di Fisica Nucleare

Dual-Readout Calorimetry

for High-Quality Energy Measurements

*Status report of the RD52 (DREAM) Collaboration**

Roberto Ferrari
INFN – Sezione di Pavia

CERN, LHCC Open Session, May 10, 2017

**DREAM (RD52) Collaboration:*
Cagliari, Cosenza, Como, Pavia, Pisa, Iowa State, TTU, Korea University

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

Goal:

Investigate + eliminate the factors that prevent us from measuring hadrons and jets with similar precision as electrons, photons

And thus develop a calorimeter that is up to the challenges of future experiments in particle physics

Outline:

- *New paper (hadronic performance)*
- *New experimental results (1 week in October 2016)*
- *Plans for the future*

Dual-Readout Method

What: avoid spoiling em resolution in order to get e/h = 1 (i.e. keep e/h > 1) *BUT* measure f_{em} event-by-event

→ *eliminate effects of fluctuations in f_{em} on calorimeter performance*

How:

1) exploit the fact that (e/h) values for a sampling calorimeter based on scintillation light or Čerenkov light are (very) different

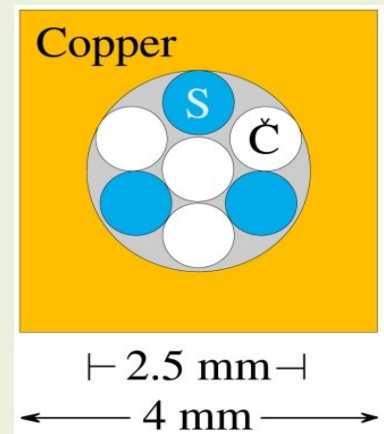
(e.g. protons contribute to S but not to Č signals)

2) calibrate separately S and Č response with electrons only

Dual-Readout w/ Sampling Fibre Calorimeters

2003
DREAM

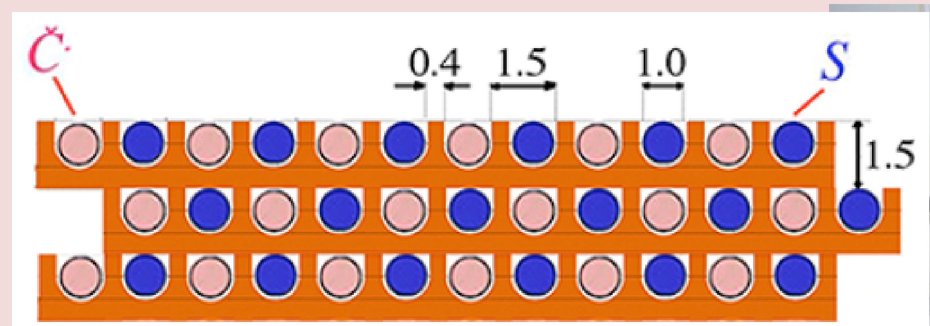
Copper
2m long, 16.2 cm wide
19 towers, 2 PMT each
Sampling fraction: 2%



2012
RD52

Copper, 2 modules

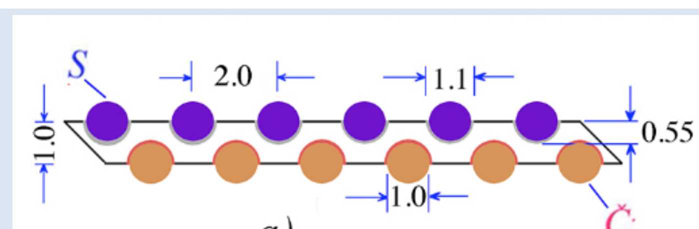
Each module: 9.3 * 9.3 * 250 cm^3
Fibers: 1024 S + 1024 C, 8 PMT
Sampling fraction: 4.5%, 10 λ_{int}

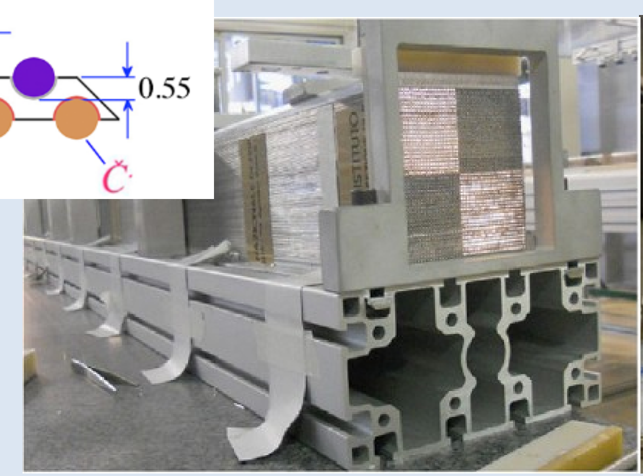


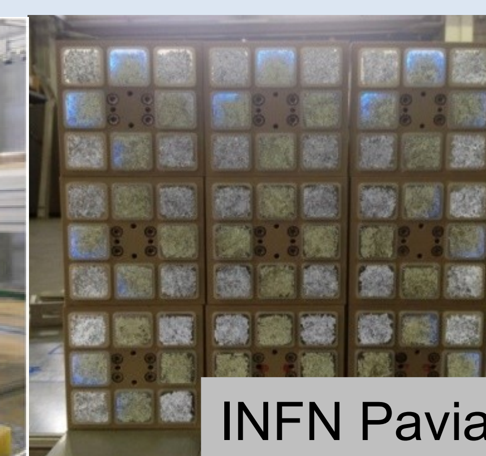
2012
RD52

Lead, 9 modules

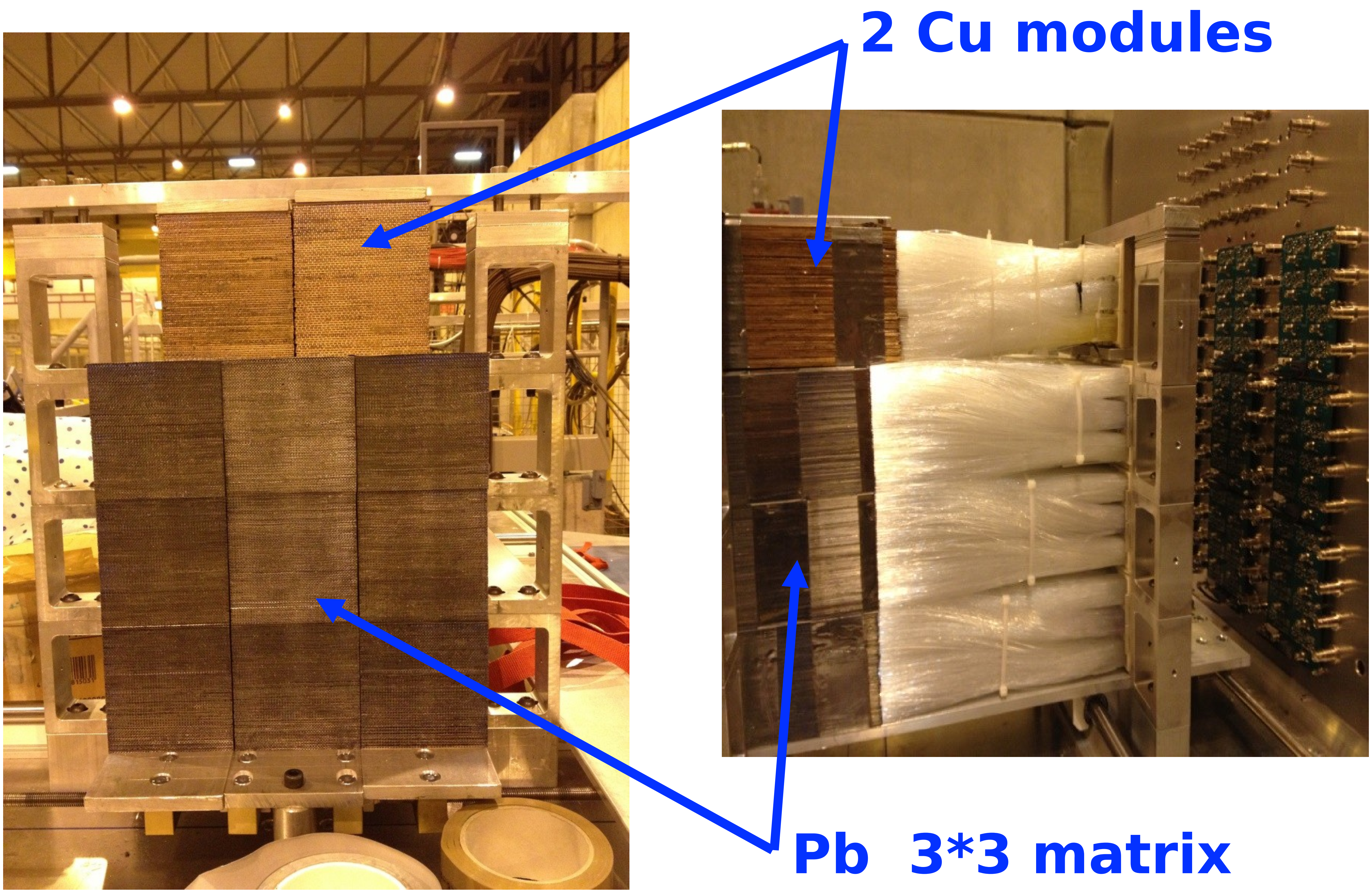
Each module: 9.3 * 9.3 * 250 cm^3
Fibers: 1024 S + 1024 C, 8 PMT
Sampling fraction: 5%, 10 λ_{int}







RD52 DR Fibre Calorimeters



New RD52 Paper

Hadron detection with a dual-readout fiber calorimeter

S. Lee[m], A. Cardini[c], M. Cascella[d], S. Choi[e], G. Ciapetti†[g], R. Ferrari[h], S. Franchino[i], M. Fraternali[f], G. Gaudio[h], S. Ha[e], J. Hauptman[j], H. Kim[m], A. Lanza[h], F. Li[j], M. Livan[f], E. Meoni[l], J. Park[m], F. Scuri[b], A. Sill[a] and R. Wigmans[a, 1]

[a] *Texas Tech University, Lubbock (TX), USA*
[b] *INFN Sezione di Pisa, Italy*
[c] *INFN Sezione di Cagliari, Monserrato (CA), Italy*
[d] *University College, London, UK*
[e] *Korea University, Seoul, Korea*
[f] *INFN Sezione di Pavia and Dipartimento di Fisica, Università di Pavia, Italy*
[g] *Dipartimento di Fisica, Università di Roma "La Sapienza" and INFN Sezione di Roma, Italy*
[h] *INFN Sezione di Pavia, Italy*
[i] *Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Germany*
[j] *Iowa State University, Ames (IA), USA*
[l] *Dipartimento di Fisica, Università della Calabria and INFN Cosenza, Italy*
[m] *Kyungpook National University, Daegu, Korea*
† *Deceased*

Abstract

In this paper, we describe measurements of the response functions of a fiber-based dual-readout calorimeter for pions, protons and multiparticle "jets" with energies in the range from 10 to 180 GeV. The calorimeter uses lead as absorber material and has a total mass of 1350 kg. It is complemented by leakage counters made of scintillating plastic, with a total mass of 500 kg. The effects of these leakage counters on the calorimeter performance are studied as well. In a separate section, we investigate and compare different methods to measure the energy resolution of a calorimeter. Using only the signals provided by the calorimeter, we demonstrate that our dual-readout calorimeter, calibrated with electrons, is able to reconstruct the energy of proton and pion beam particles to within a few percent at all energies. The fractional widths of the signal distributions for these particles (σ/E) scale with the beam energy as $30\%/\sqrt{E}$, without any additional contributing terms.

PACS: 29.40.Ka, 29.40.Mc, 29.40.Vj

Key words: Dual-readout calorimetry, Čerenkov light, optical fibers

[1] Corresponding author. Email wigmans@ttu.edu, fax (+1) 806 742-1182.

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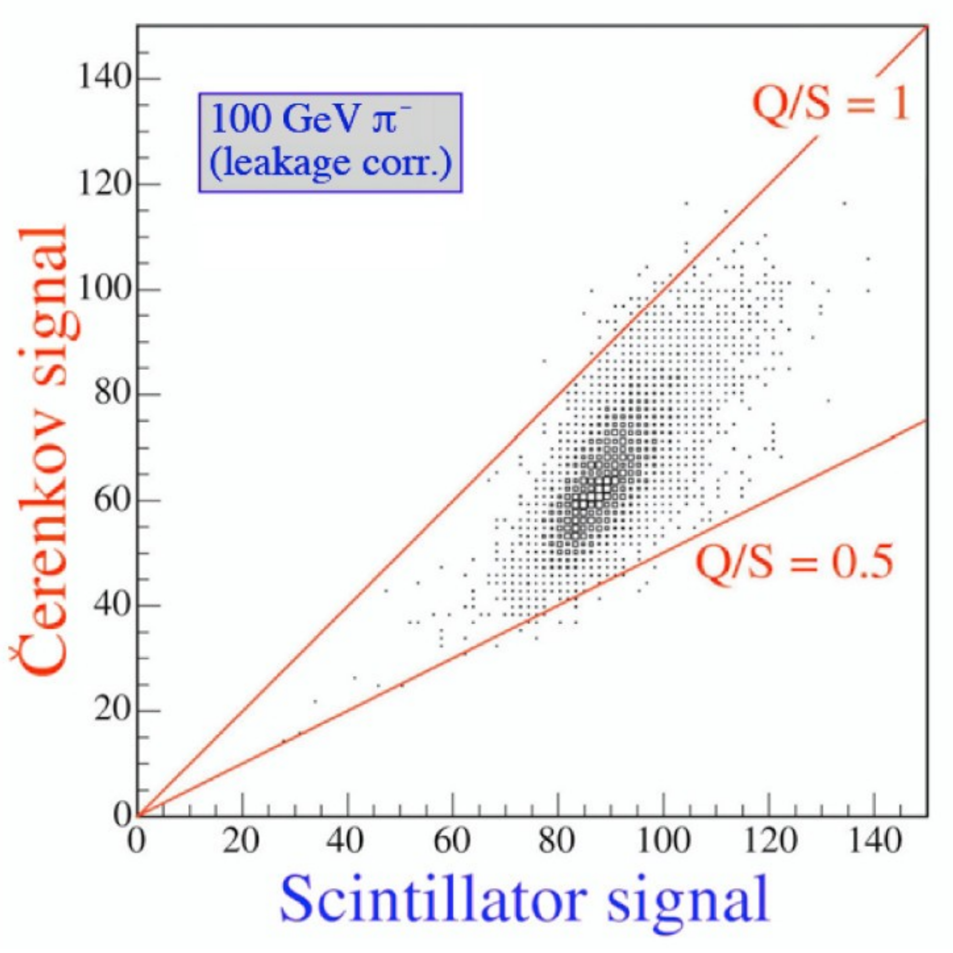
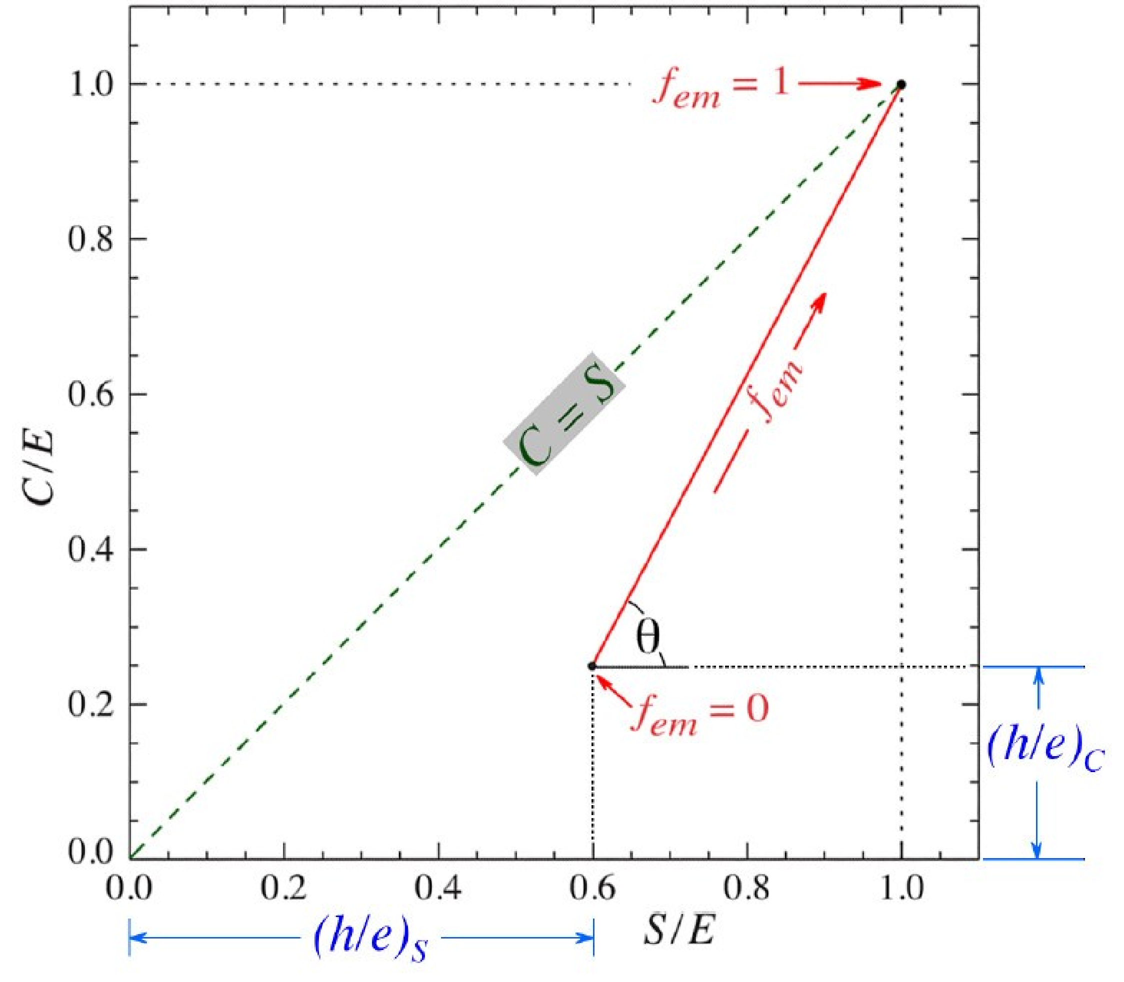
Principles of Dual Readout Calorimetry



$$S = [\ f_{em} + (h/e)_s \times (1 - f_{em})\ ] \times E$$

$$C = [\ f_{em} + (h/e)_c \times (1 - f_{em})\ ] \times E$$



- Hadronic data points (S, C) are located around a straight (red) line

Dual Readout at Work

$$cotg\,\theta = \frac{1-(h/e)_S}{1-(h/e)_C} = \chi$$

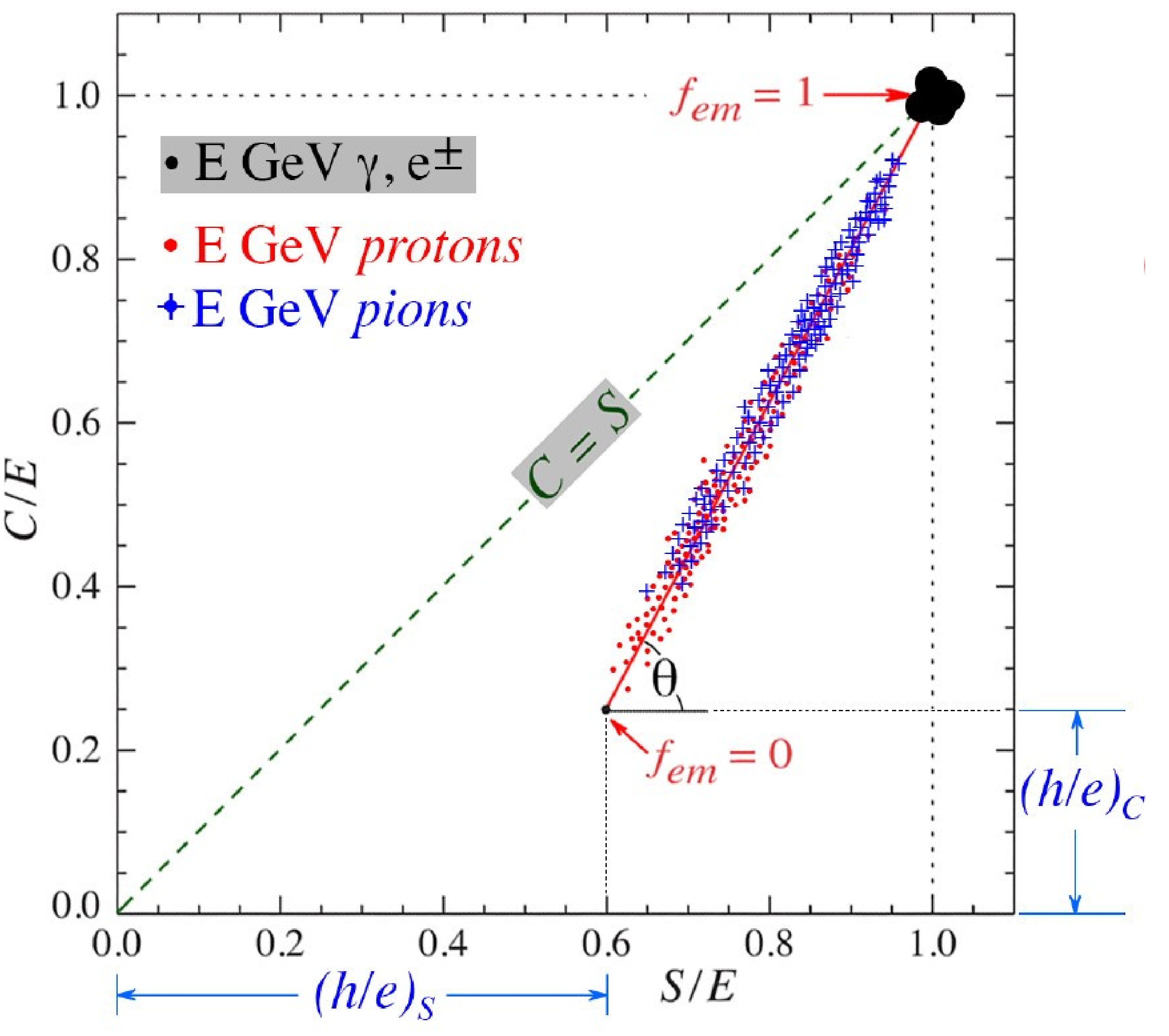
Θ, χ *independent of both*:

$i)$ *energy* (!)

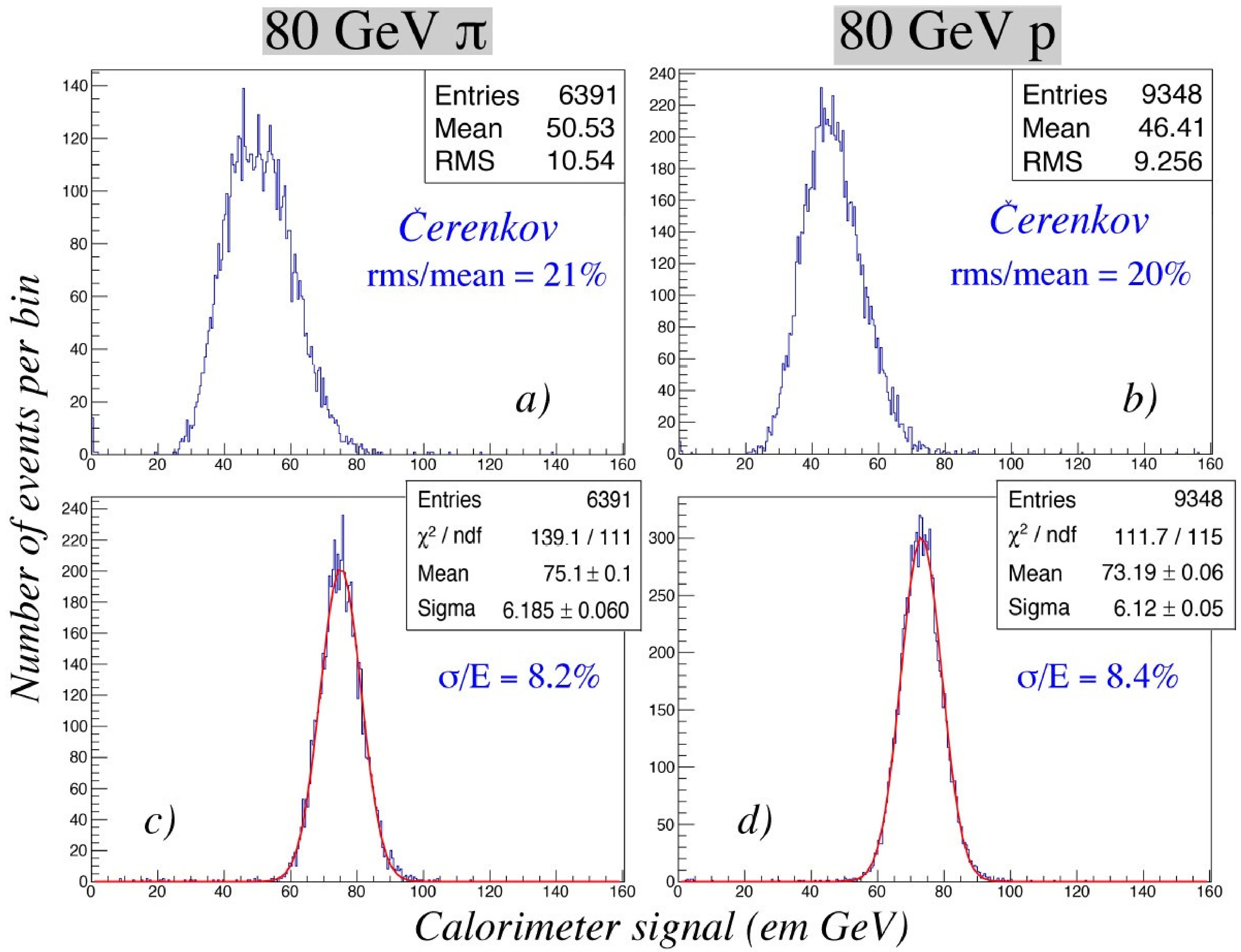
$ii)$ *type of hadron* (!!)

$$E = \frac{S - \chi C}{1 - \chi}$$

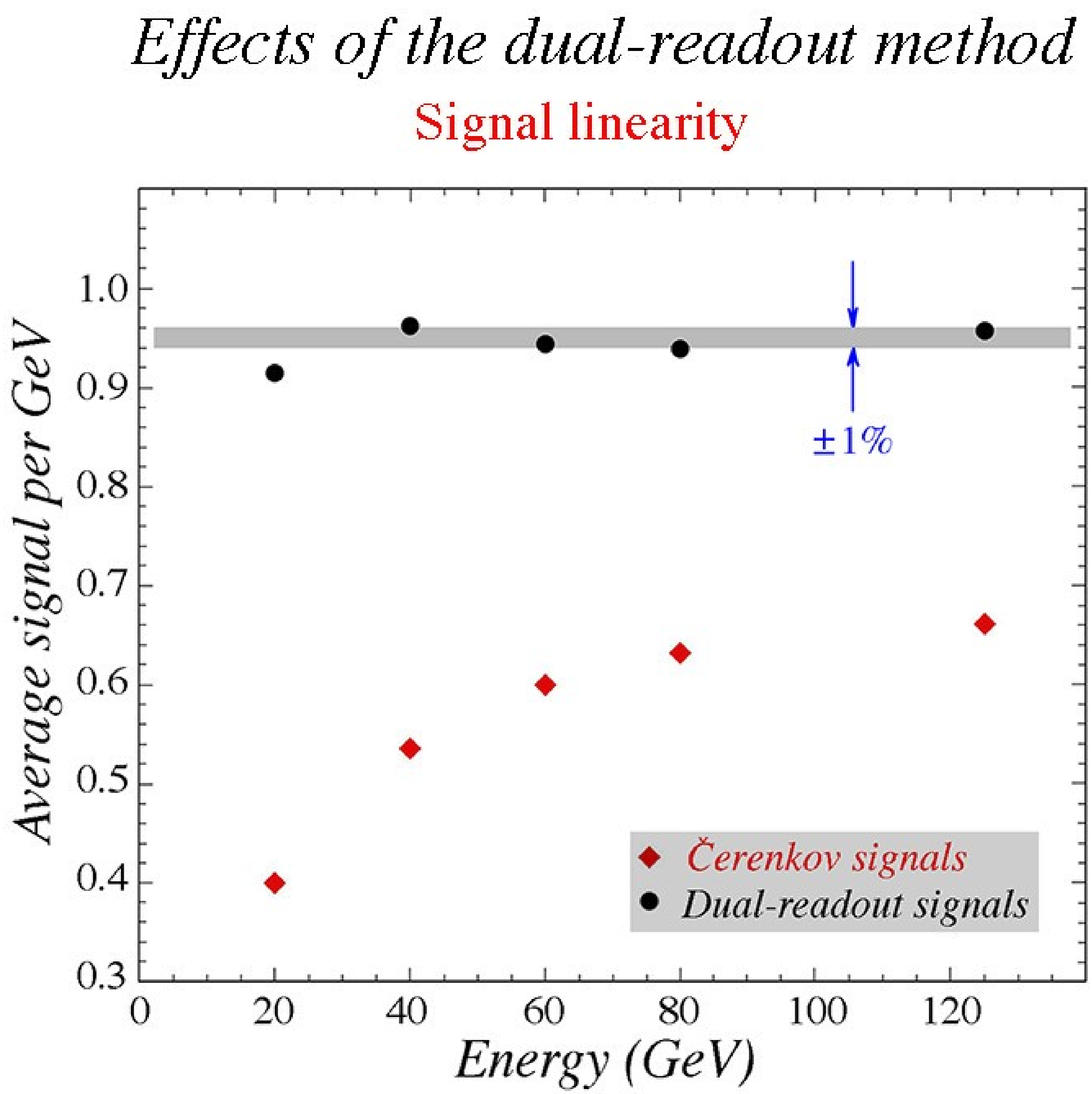
is universally valid



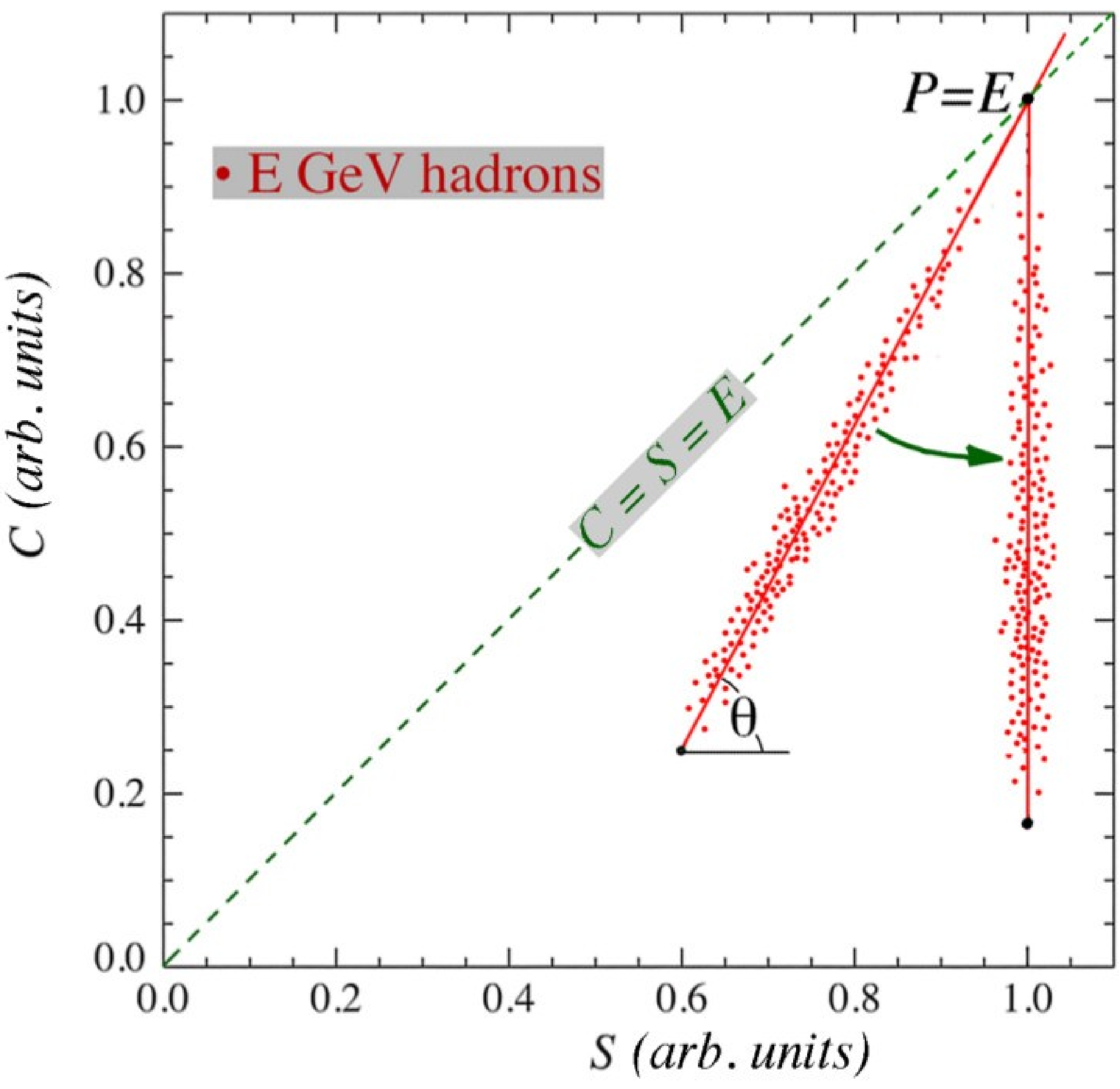
Dual Readout at Work (2)



Dual Readout at Work (3)



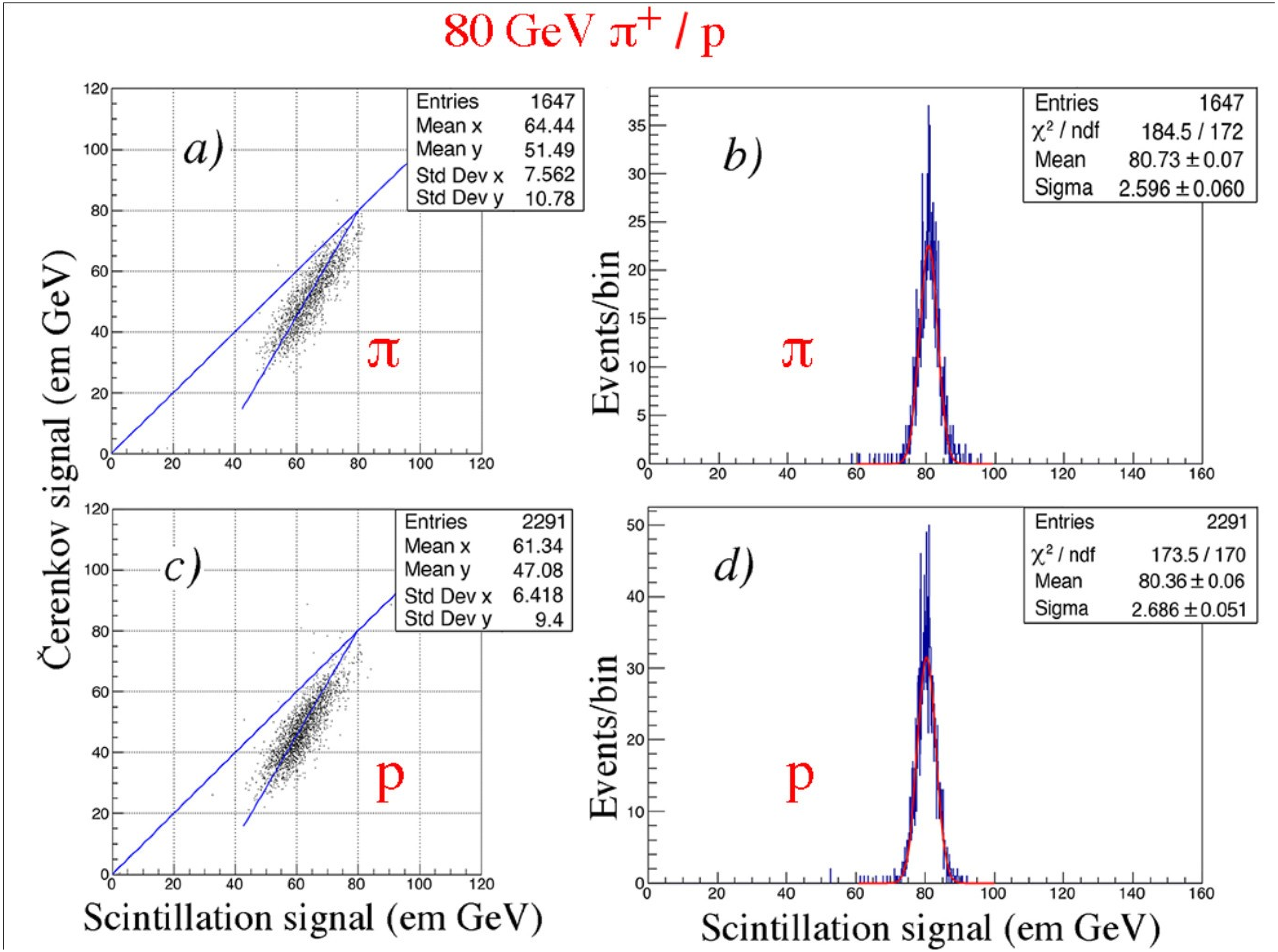
the Rotation Method



- *Fit experimental data with a straight line*
- *Determine coordinates of P (intersection with C=S line)*
- *Rotate data points about P over angle* $(90^{\circ} - \theta)$
- *Project data points on horizontal (S) axis*

θ is independent of E
and particle type!!
⟶ Don't need this info!!

Applications of the Rotation Method

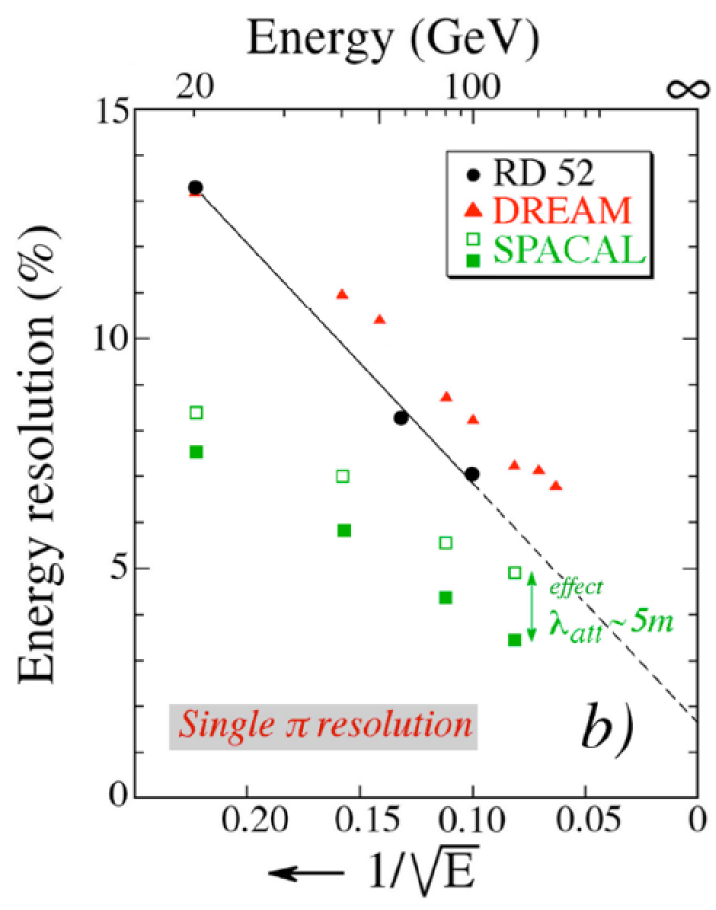


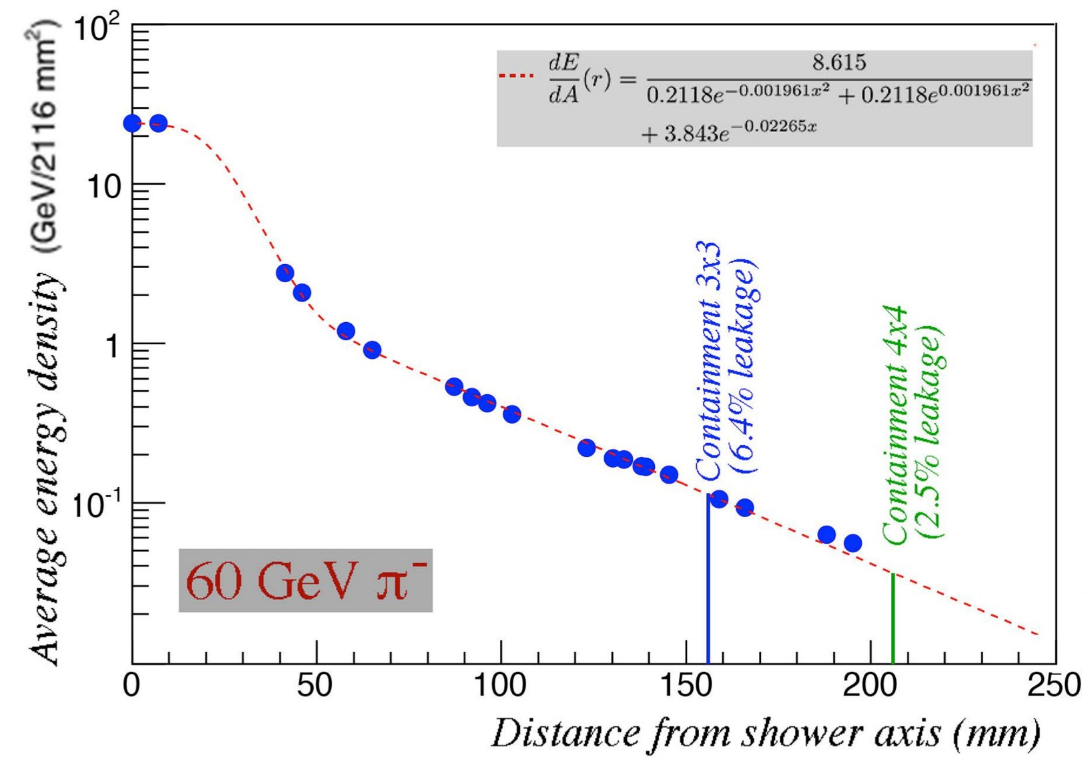
Single-Particle Hadronic Resolution

Hadronic Resolution
(Pb Module)

$$\frac{\sigma}{E} = \frac{53\%}{\sqrt{E}} + 1.7\%$$

to be corrected for:
- light attenuation
- lateral leakage



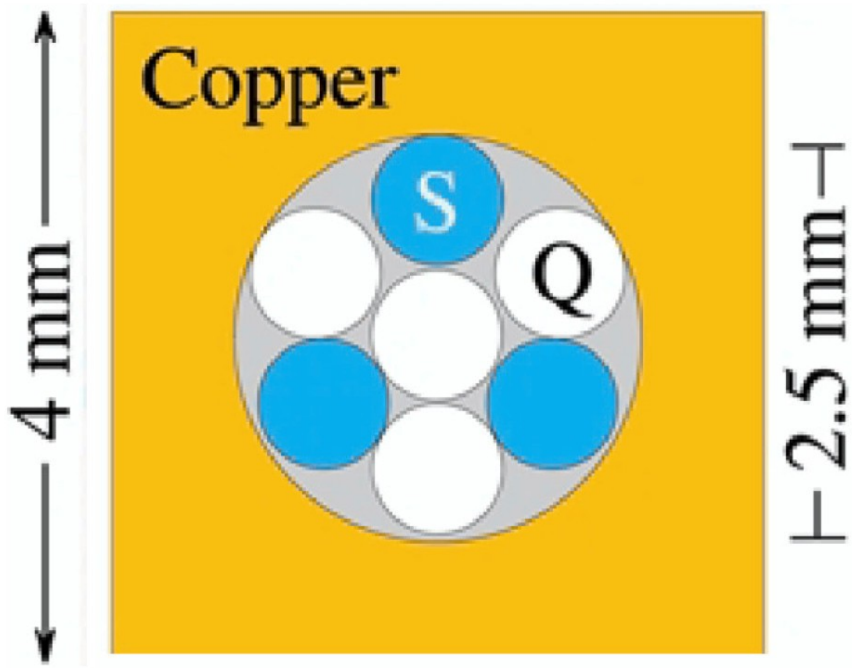


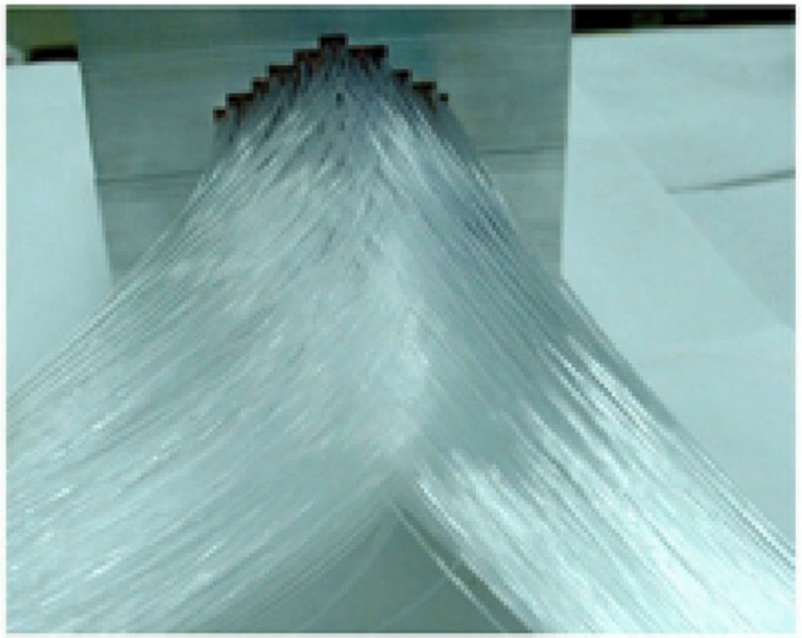
jet energy resolution ~ few % at ~100 GeV

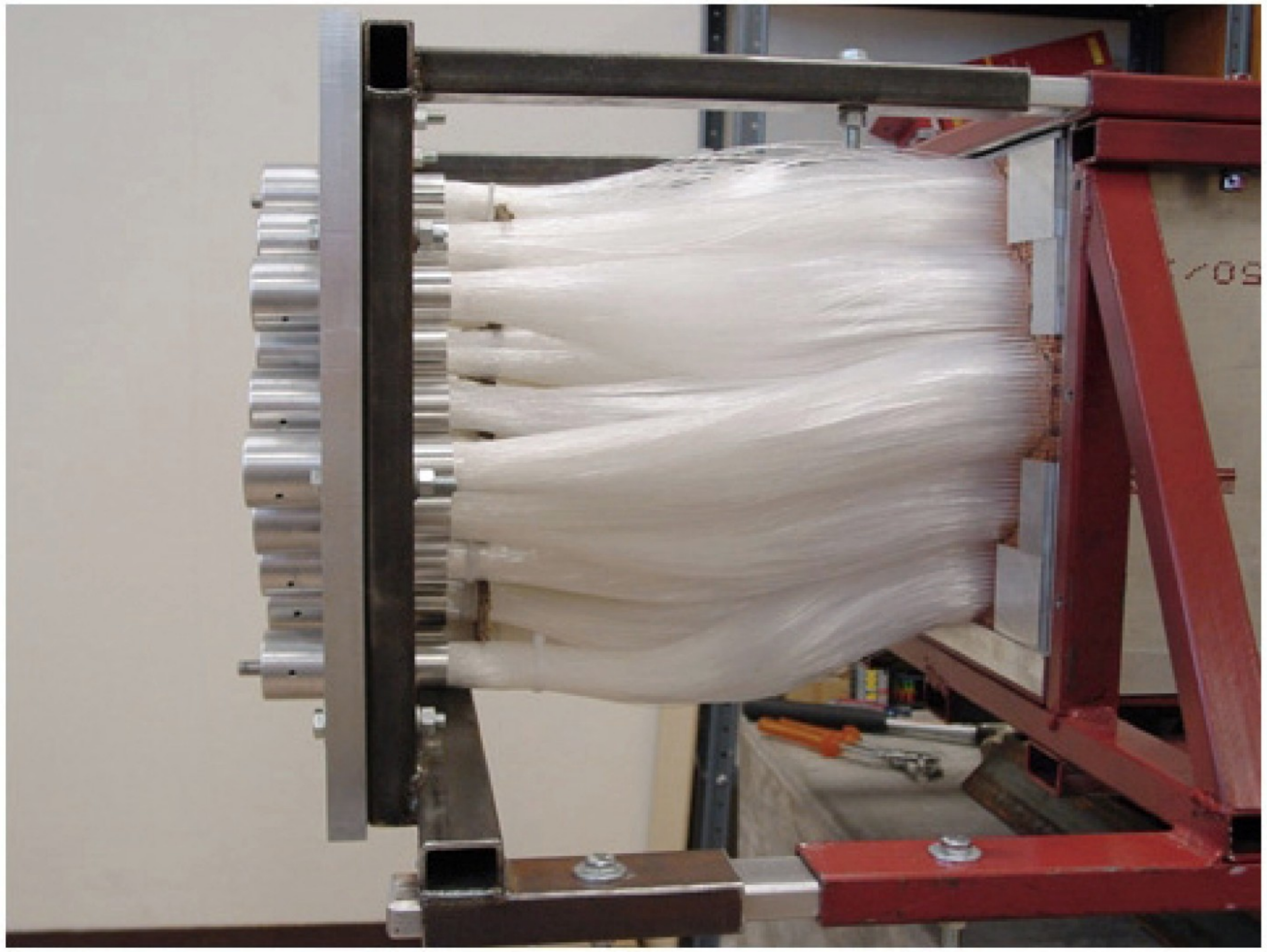
(4th Concept Detector LOI quotes 30%/√E for jets)

Jet resolution should also be studied coupled w/ tracking information (high granularity → "particle-flow friendly")

The PMT readout of the DREAM calorimeter







PMT .vs. SiPM Readout

SiPM advantages:

- *compact readout (no fibres sticking out)*
- *longitudinal segmentation possible*
- *operation in magnetic field*
- *larger light yield (# of Čerenkov p.e. limits resolution)*
- *very high readout granularity → particle flow "friendly"*

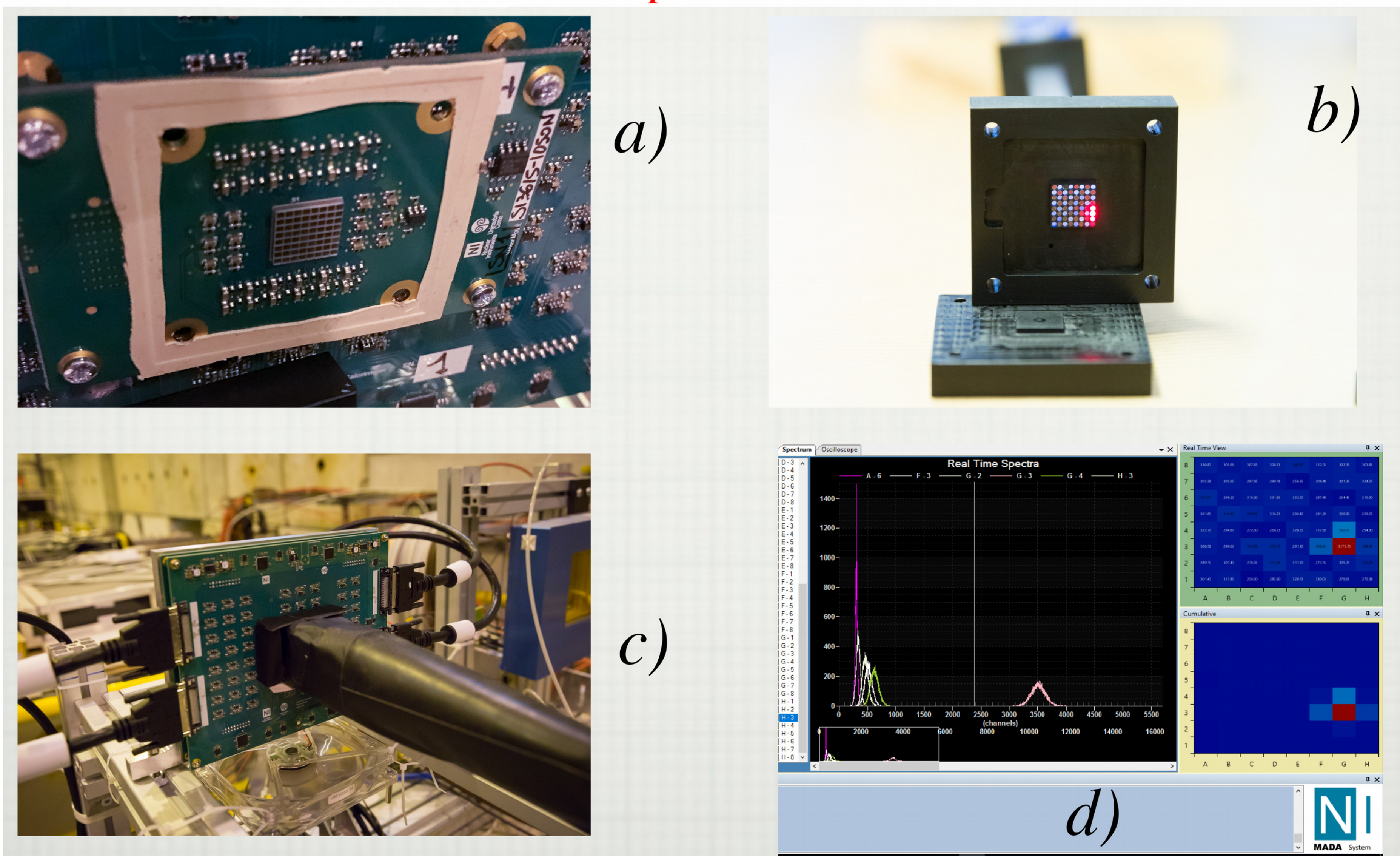
SiPM (potential) disadvantages:

- *signal saturation (digital light detector)*
- *cross talk between Čerenkov and scintillation signals*
- *dynamic range*
- *instrumental effects (stability, afterpulsing, ...)*

First SiPM RD52 Readout

8 x 8 array of 1 mm^2 Hamamatsu SiPMs, 50 μm pixels (400/SiPM)

1 fiber per SiPM



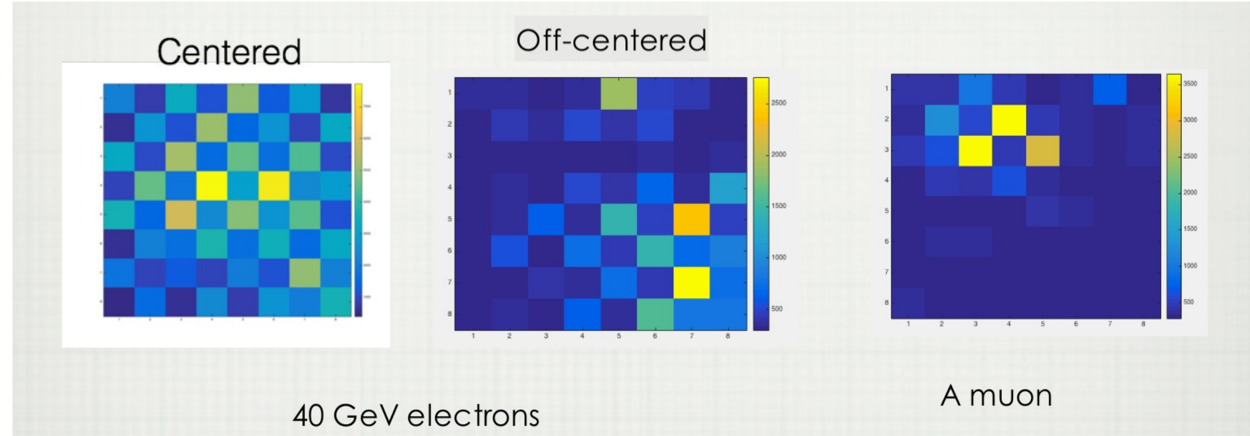
MODULE 1: *All channels equipped* (32 scintillating + 32 Čerenkov fibers)

MODULE 2: *Only Čerenkov fibers connected (32)*

First SiPM RD52 Readout

Event displays in 8x8 mm² regions →

Showering electrons deposit 50% of their energy in this region



A short summary of the data taking conditions:

- two modules, both based on the array with 50 μm pitch cells:
  - module 1: both scintillating and Cherenkov fibres connected to the pixels of the array
  - module 2: Cherenkov fibers only were connected

driven by two main reasons:

- the saturation of the sensors connected to the scintillating fibres
- the study of the optical cross talk

- recorded data:

Module 1

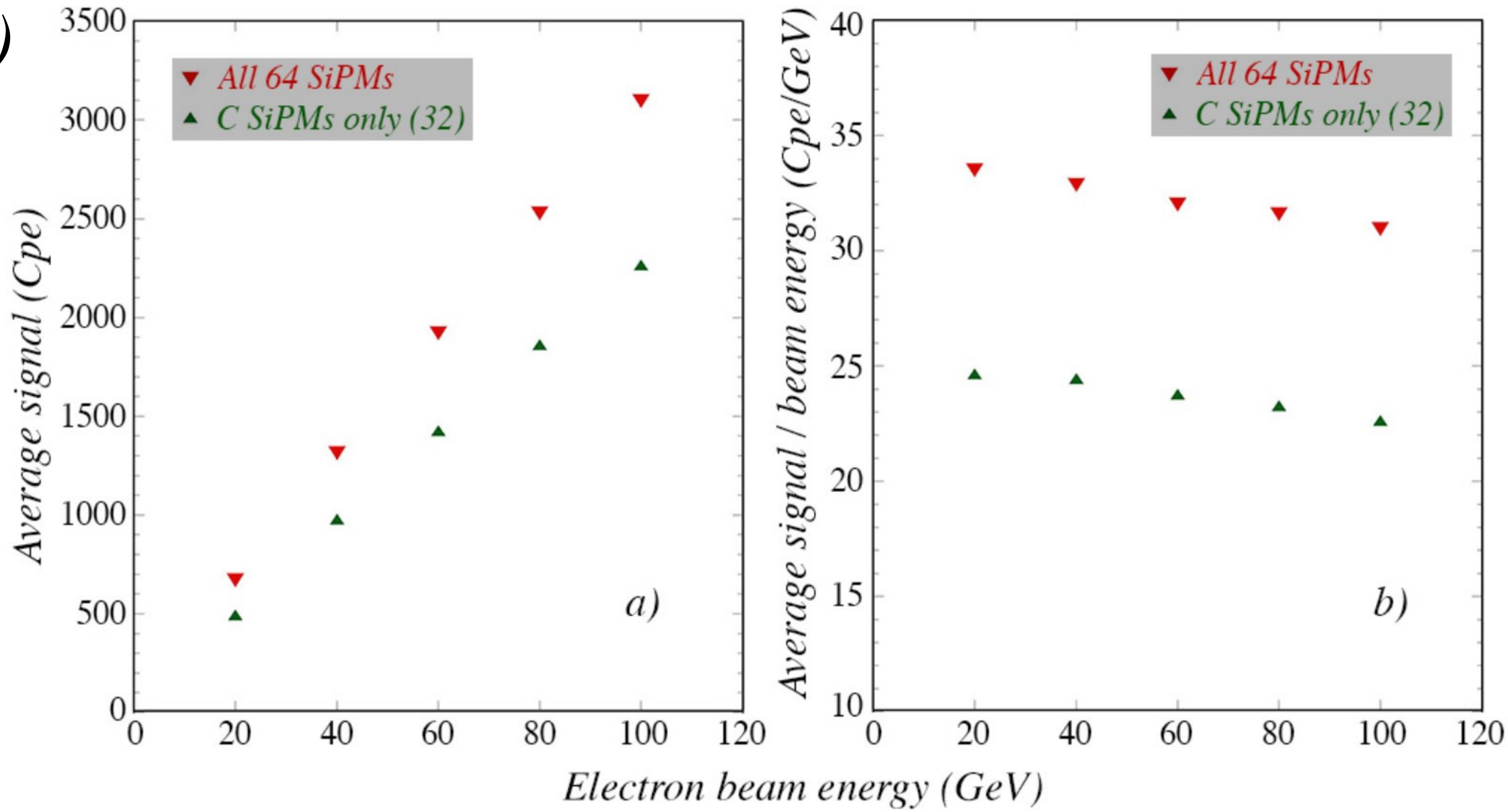
- **e^+:**
  - 20 GeV (> 54.000 events)
  - 40 GeV (> 146.000 events)
  - 60 GeV (> 173.000 events)
- μ^+: 180 GeV (> 100.000 events)

Module 2

- **e^+:**
  - 20 GeV (> 178.000 events)
  - 40 GeV (> 300.000 events)
  - 60 GeV (420.000 events)
  - 80 GeV (340.000 events)
  - 100 GeV (300.000 events)
- μ^+: 180 GeV (400.000 events)

Optical Cross Talk and Signal Saturation

(module 2)



Čerenkov light yield ~ 60-70 p.e./GeV (2 x PMT)

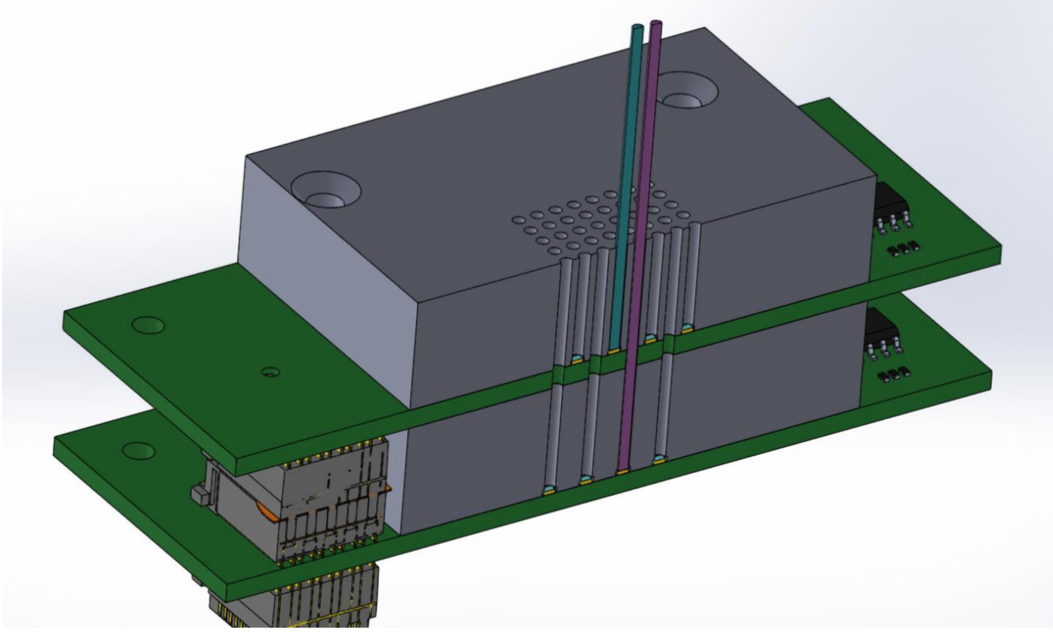
~ 25% optical x-talk to neighboring SiPM.s

~ 8% non-linearity due to saturation

2017 RD52 Plans

a) Eliminate x-talk by using separate SiPM arrays

crucial issue: fibre feed-thru



b) Eliminate / strongly reduce saturation effects by using SiPM with 4 x larger dynamic range (4 x smaller pixel area)

c) Possibly develop an electronic board to integrate up to 9 sensors in a single readout channel

Goals 2017 beam tests

In addition, we want to test two new full-scale copper-fiber calorimeter modules, built at Iowa State University (standard PMT readout)

For both components of our experimental program, we request electron beams, with energies from 10 - 100 GeV

More on Future

INFN initiative for R&D for future accelerators (RD_FA):
open a 3-year (2018-2020) working package on DR
→ first step: simulate a conceptual detector (IDEA) for CepC/FCCee

Activities already started (within RD52 groups and plans) ...
collaboration growing

Setting up collaboration with CepC people
in order to include the DR option in CepC CDR

Setting up collaboration with FCCee people (Gigi, Mogens)

Need a CERN official project!

2017 Simulation Plans

Fully simulate a testbeam copper module (w/ full optical propagation and conversion, at least for Čerenkov light)

Implement a 4π geometry description for the IDEA detector
→ estimate W/Z resolution capability

Evaluate combined performance w/ a $2X_0$ preshower (Si or MPDG) detector in front

a.o.b.

Copper grooving still an issue !

We don’t have yet a viable solution for massive production …

Thinking about bronze

Other issues:

When/How build a full-containment detector ?

When/How develop projective geometry ?

About the read-out of $O(10^3$-$10^4)$ fibres ?