Dual-Readout Calorimetry @ RD_FA Status Report

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on behalf of RD_FA/DR collaboration
30 August 2017

News since last presentation

a) RD52 testbeam at CERN with a small e.m. module

b) Work in progress with montecarlo simulations

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"*

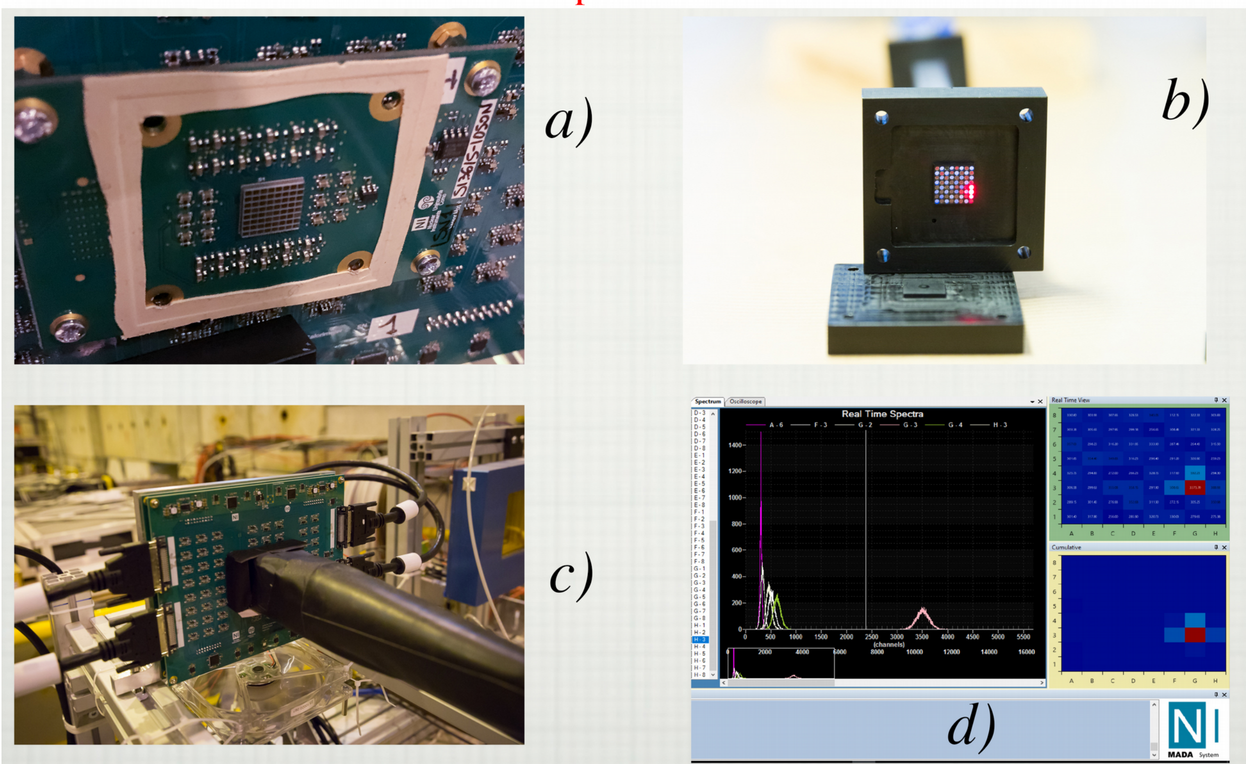
SiPM (potential) disadvantages:
- *signal saturation (digital light detector)*
- *cross talk between Čerenkov and scintillation signals*
- *dynamic range*
- *instrumental effects (stability, afterpulsing, ...)*

RD52 SiPM Readout

The very first SiPM test of a DR calorimeter (10/2016)

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)*

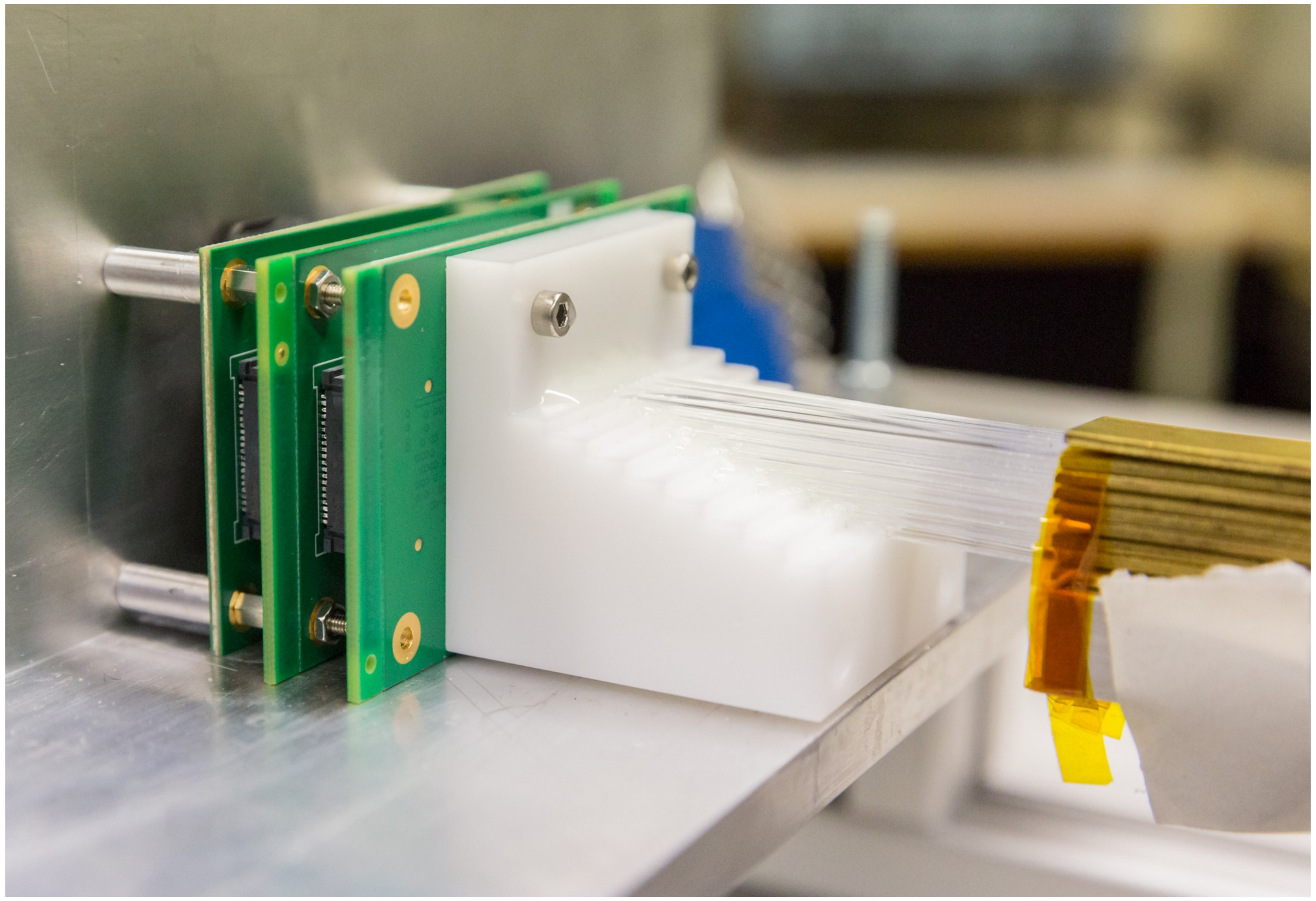
2016

a) 400 cells
b) 40% PDE

limitations:

- dynamic range saturation
- cross-talk (light leakage)

2017



a) 4 x dynamic range (1600 cells)
b) 25% PDE
c) photo-detection at 2 different levels

2017 Testbeam

New SiPM.s :

a) larger dynamic range:

from 50x50 μm^2, 400 cells → 25x25 μm^2, 1600 cells

b) lower PDE (lower fill factor)

→ avoid saturation ?

c) staggered fibre layout (readout at two different planes)

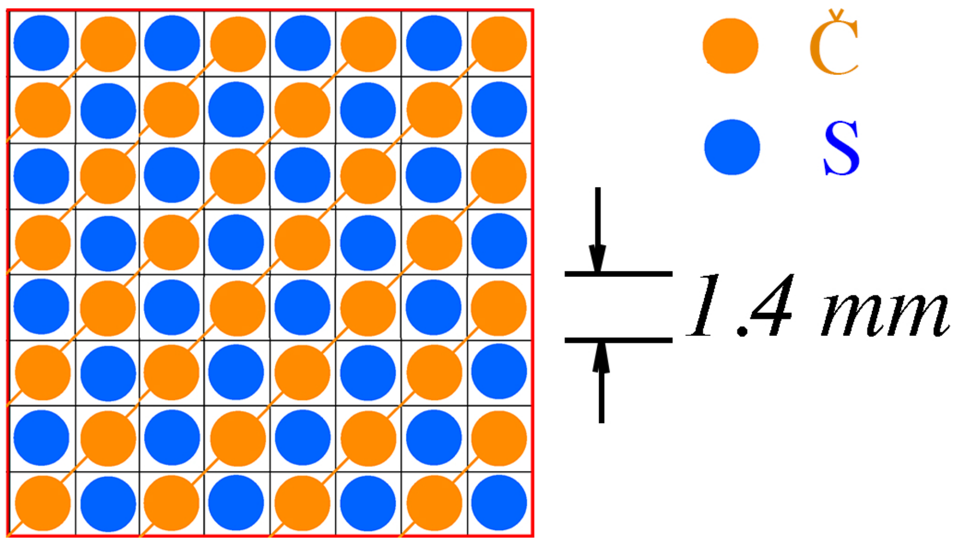
→ avoid light leakage ?

Data taking w/ electrons and muons (energy scans and position scans)

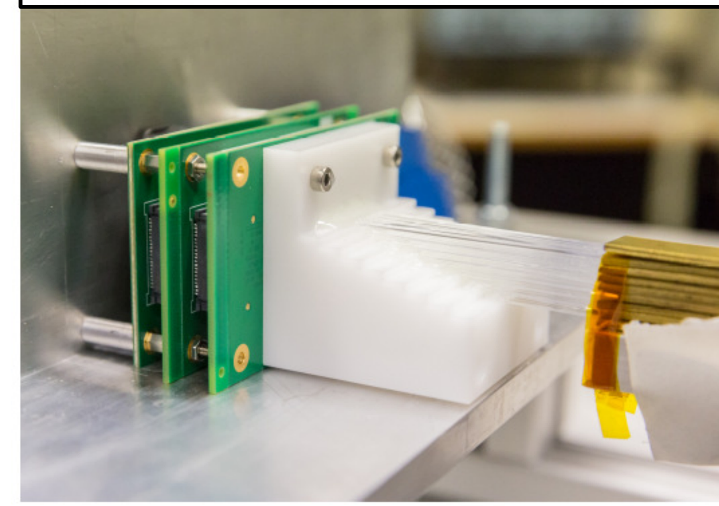
2017 Testbeam Layout

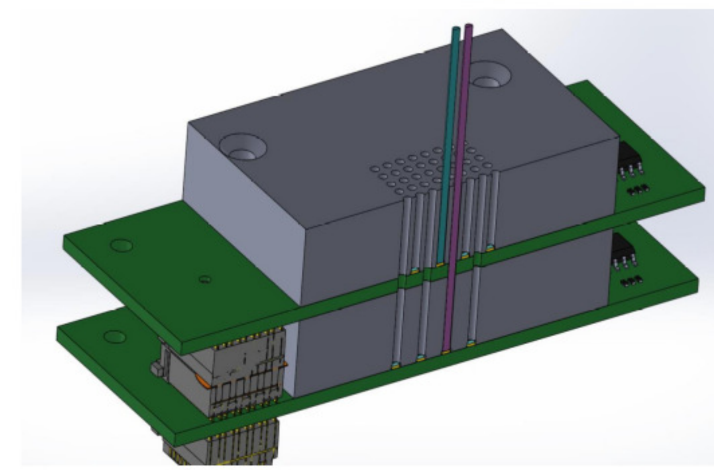
Brass module, dimensions: ~ 112 cm long, 12 x 12 mm²

section

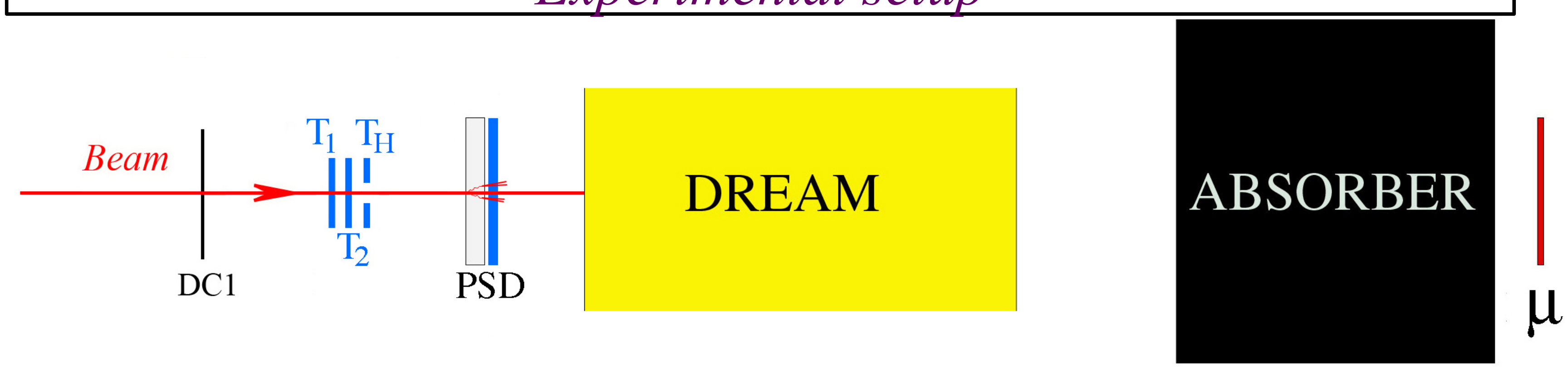


Back





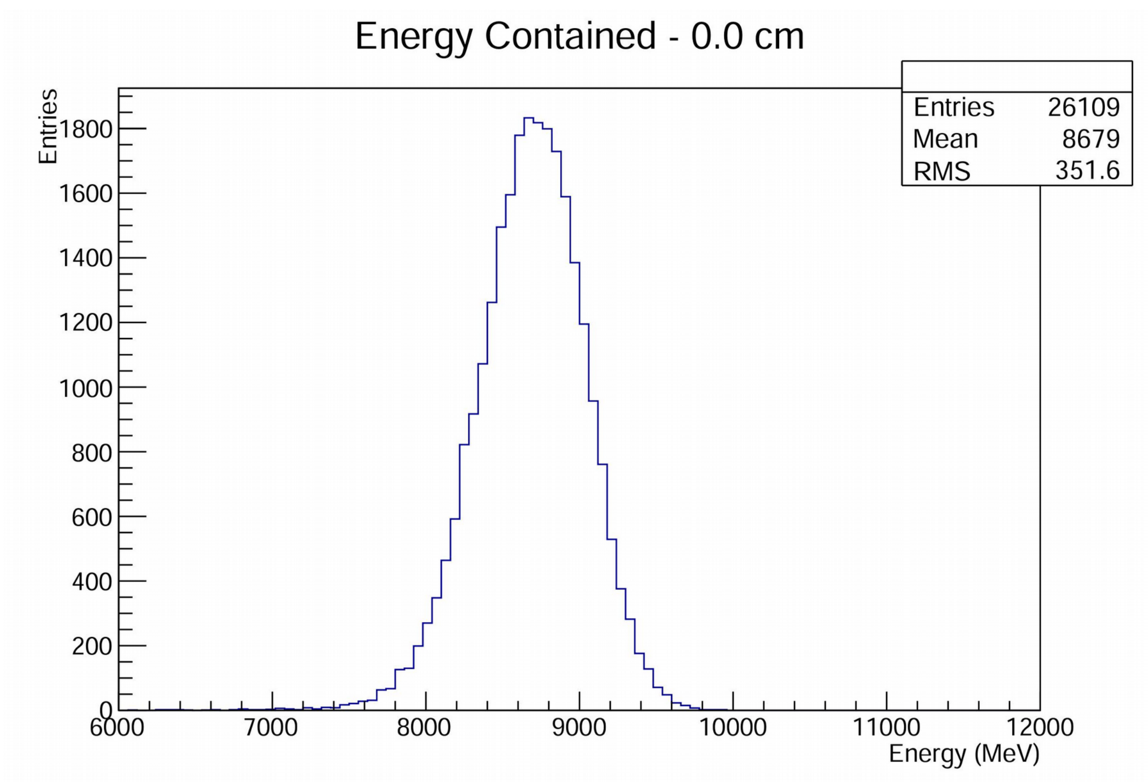
Experimental setup



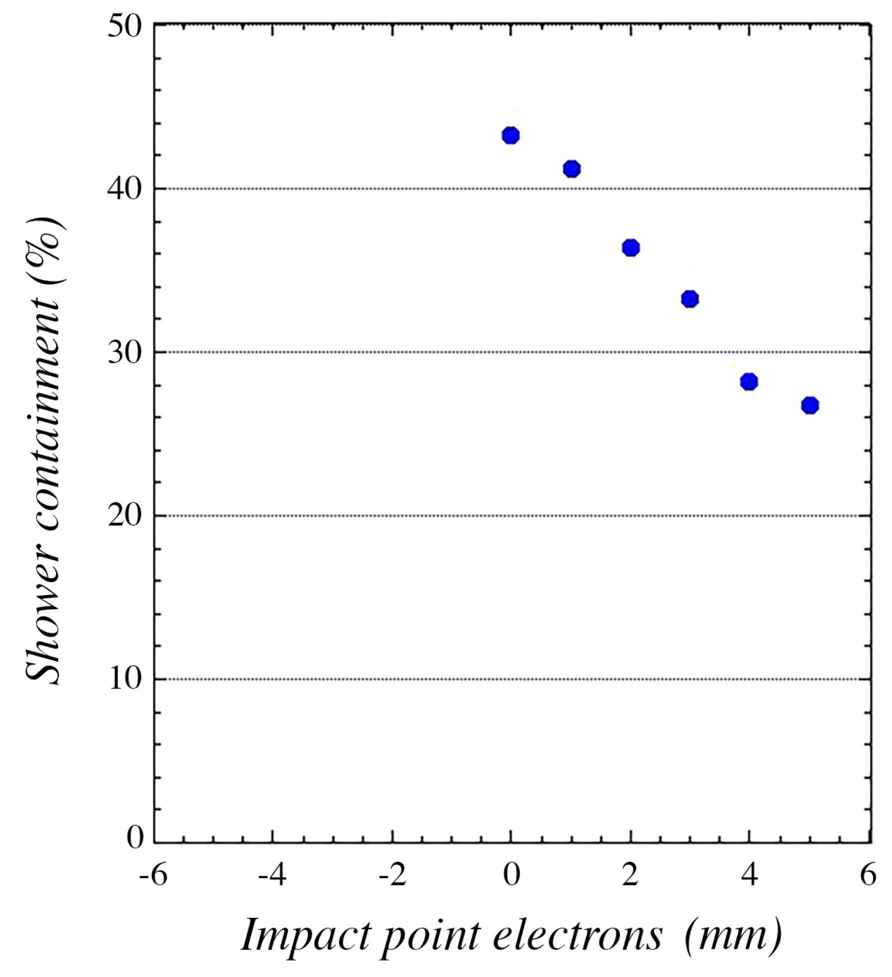
Trigger : $(T_1 \cdot T_2 \cdot \overline{T_H})$

Shower Containment (MC) – 20 GeV electrons

Centered events (MC) : ~43% shower containment

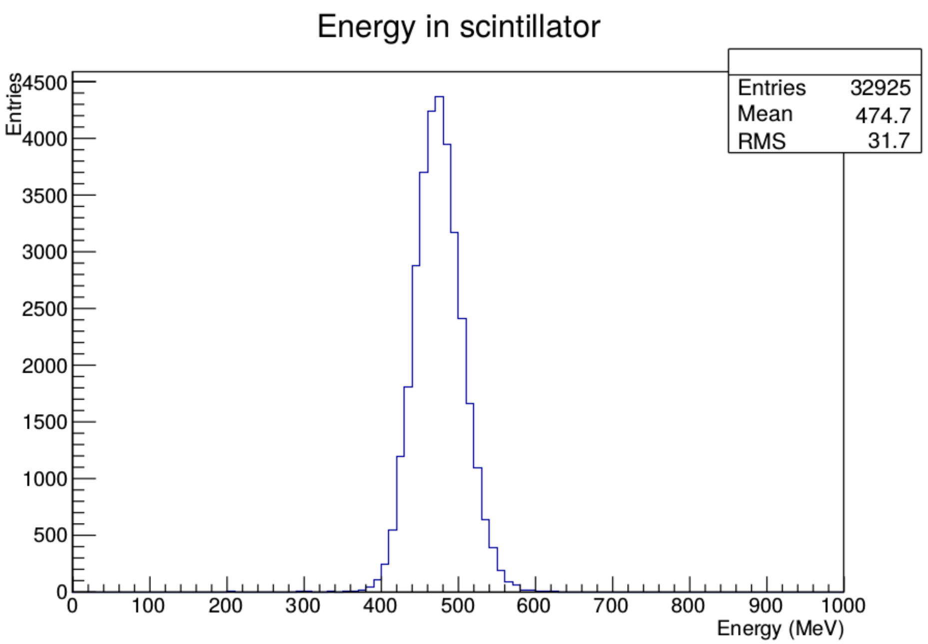


containment .vs. impact point (MC)

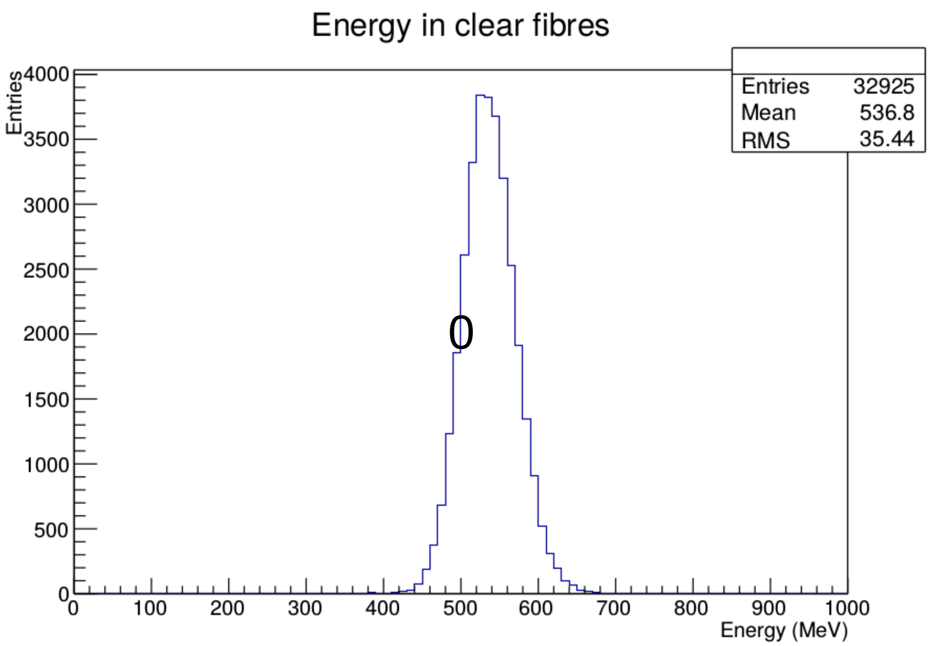


Sampling Fraction (MC) – 20 GeV electrons

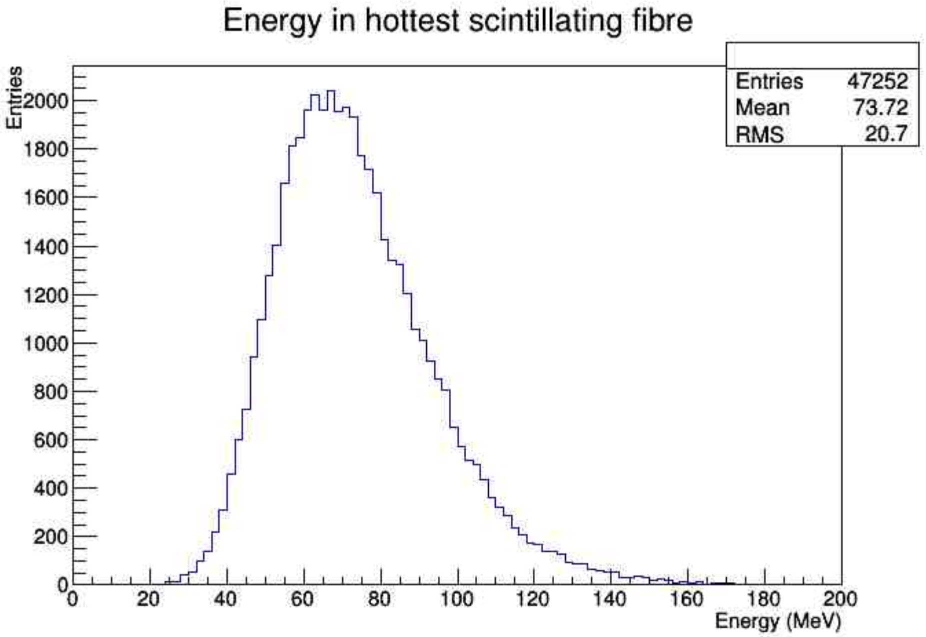
Scintillating fibres: ~5.5%



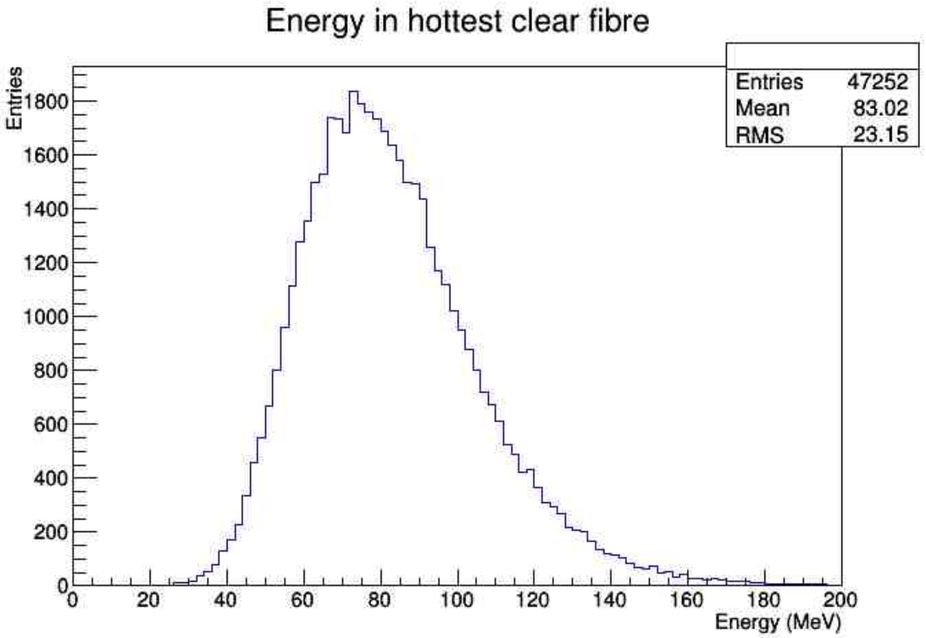
Cherenkov fibres: ~6.2%



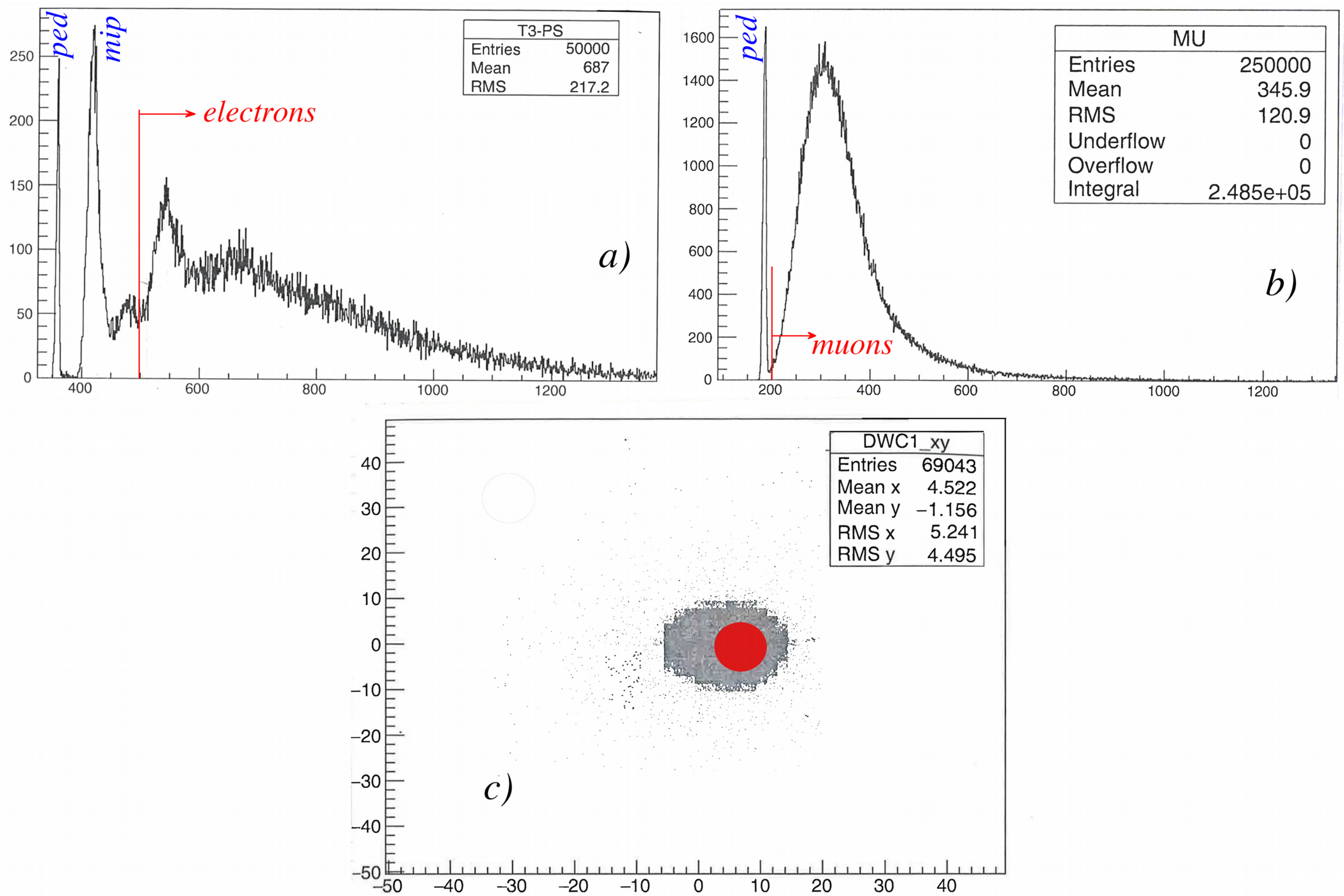
Energy in hottest S fibre



Energy in hottest C fibre



Data Selection and Tagging



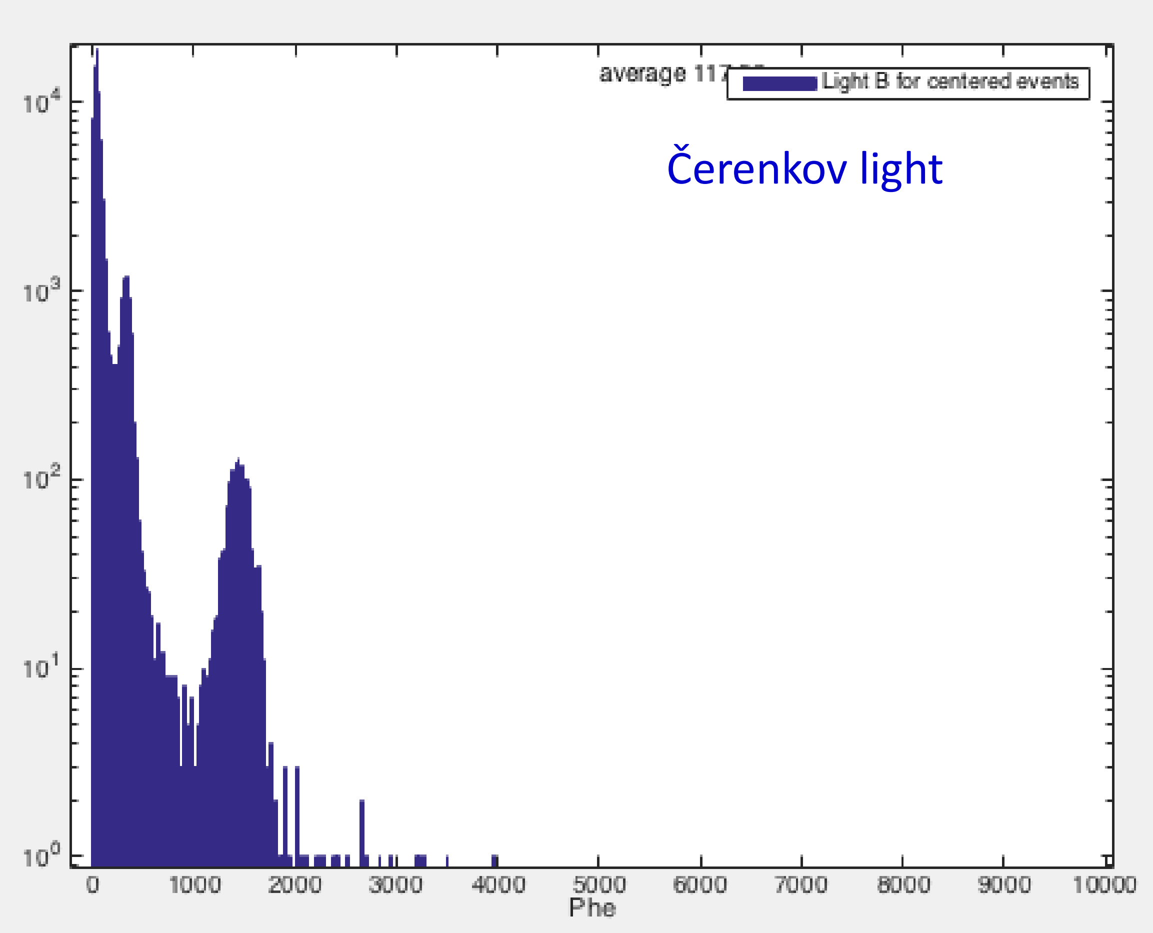
Preshower detector and Muon counter: select electrons or muons

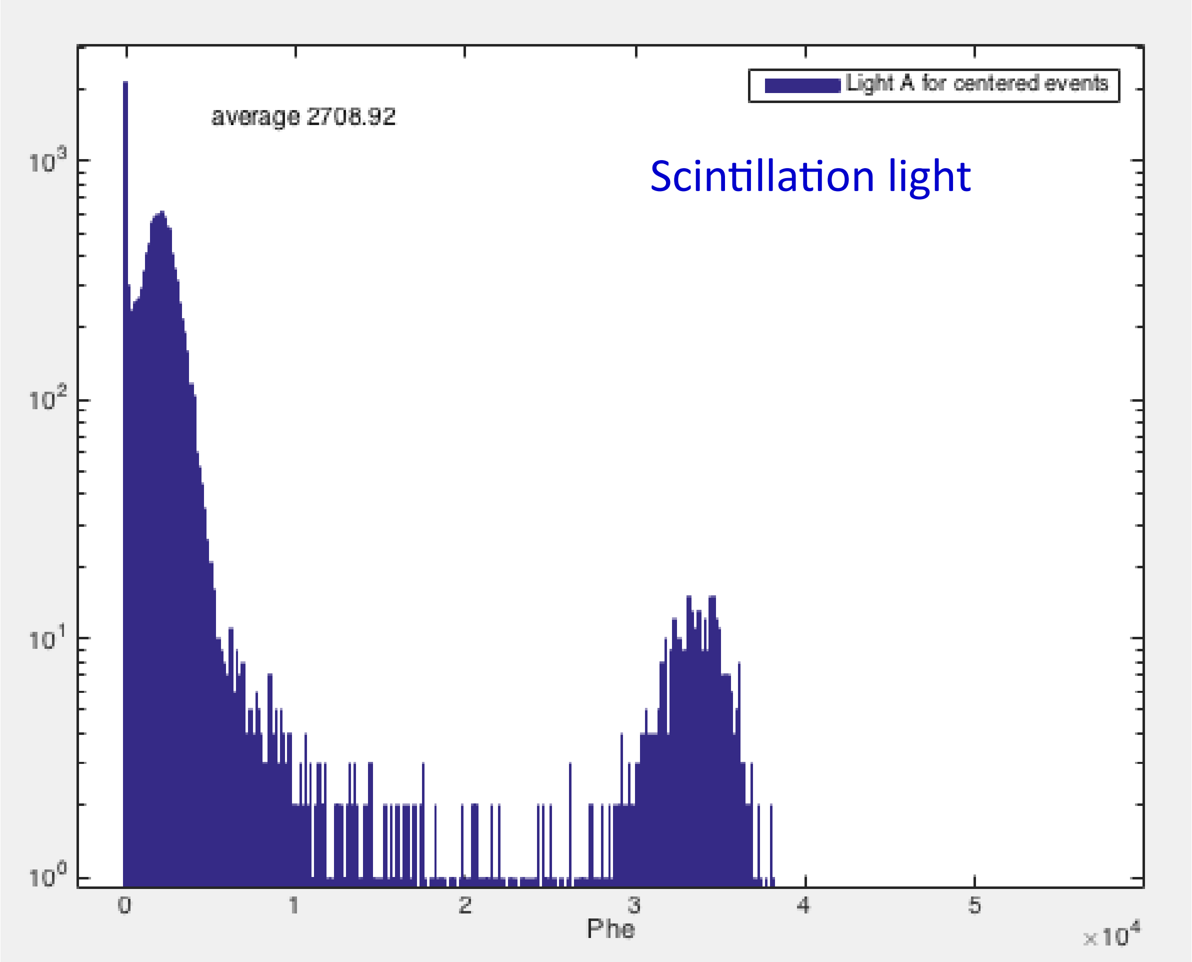
Delay Wire Chamber: select events in central region

RD52 Preliminary Results (2017)

64 Hamamatsu SiPM
1x1 mm^2
25x25 µm^2 cell
1600 cells
nominal detection efficiency 25%

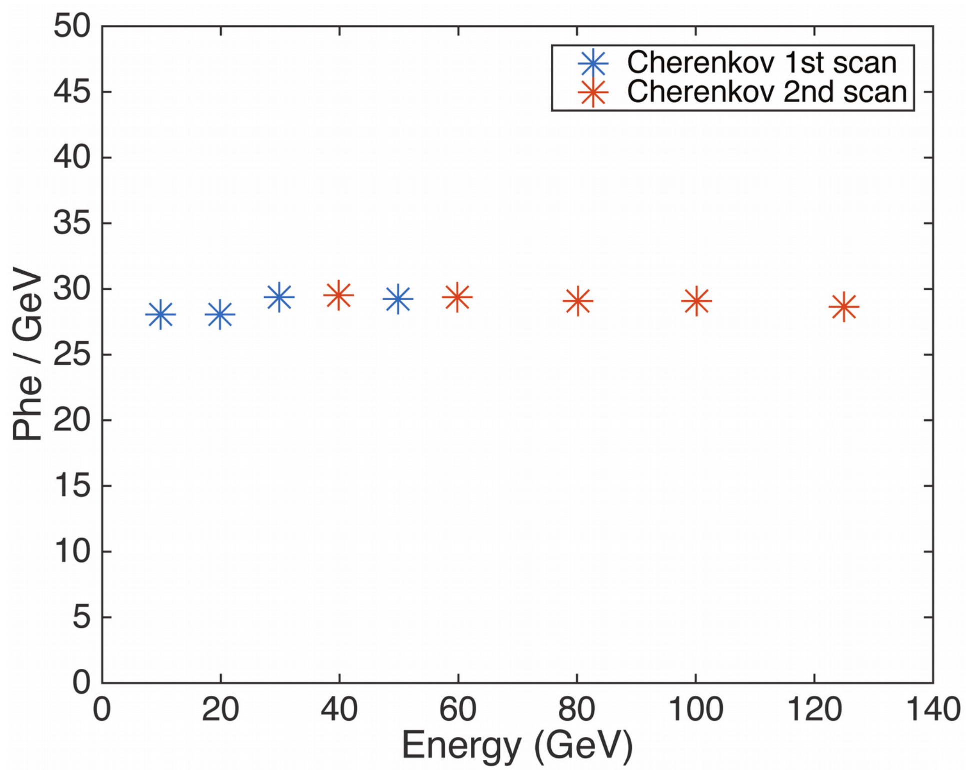
50 GeV electron beam





Preliminary Results (2017) – Cherenkov Signals

Number of Photoelectrons per GeV .vs. Beam Energy



→ *no saturation in Cherenkov signals*

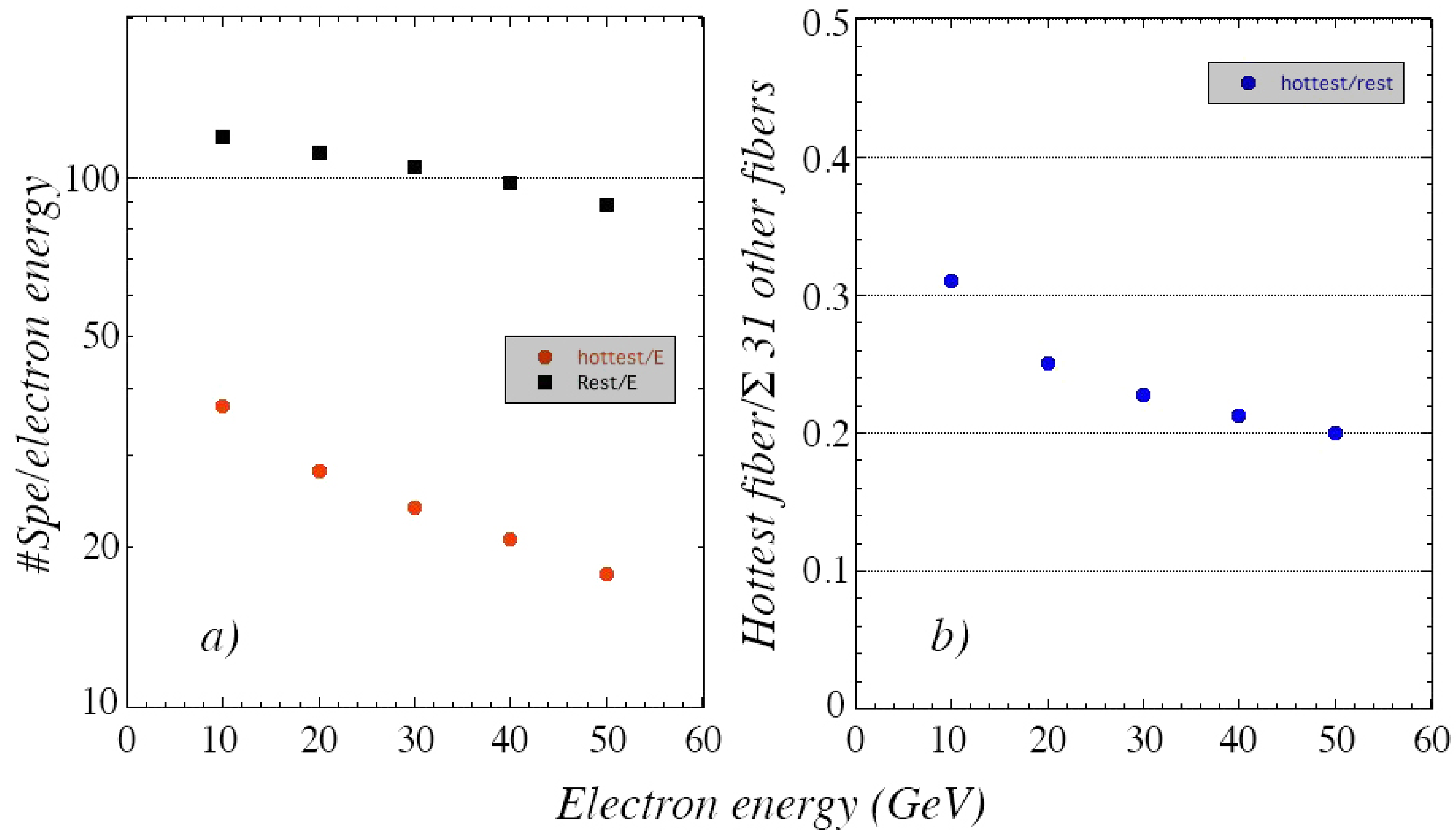
→ *average shower containment independent of energy*

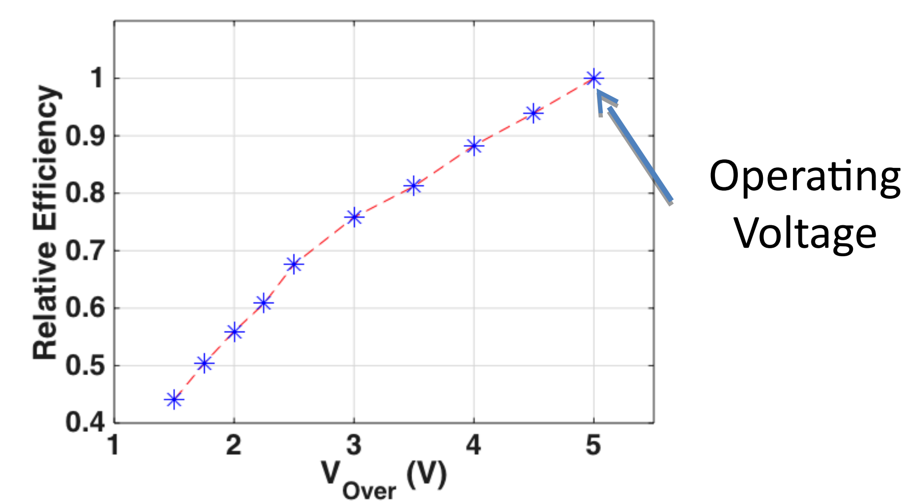
Preliminary Results (2017) – Scintillation Signals

Number of p.e. / GeV in all fibres but hottest one

Number of p.e. / GeV in hottest fibre

Ratio hottest/all



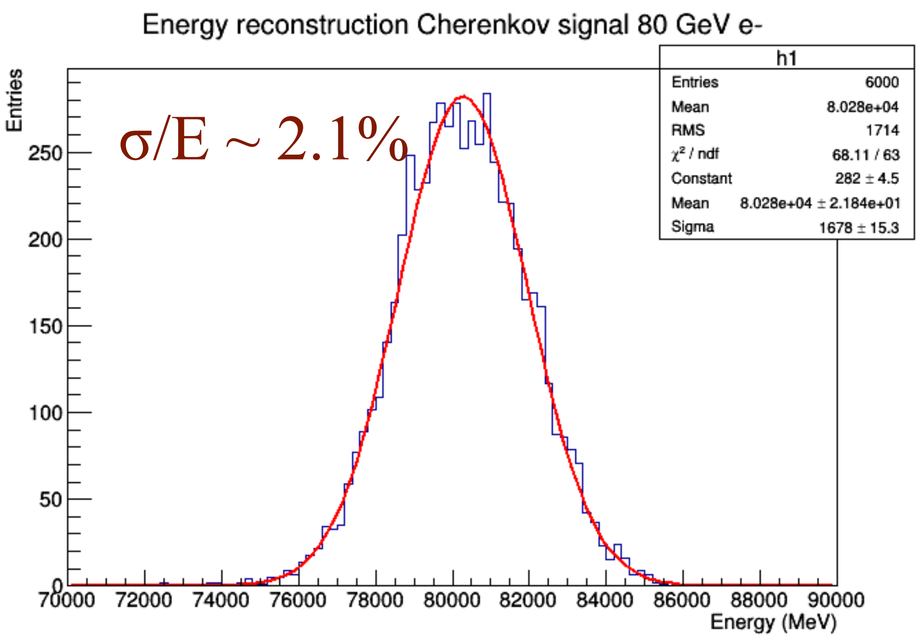


**** Take care: bias voltage lowered by 5 V → PDE very low! ****

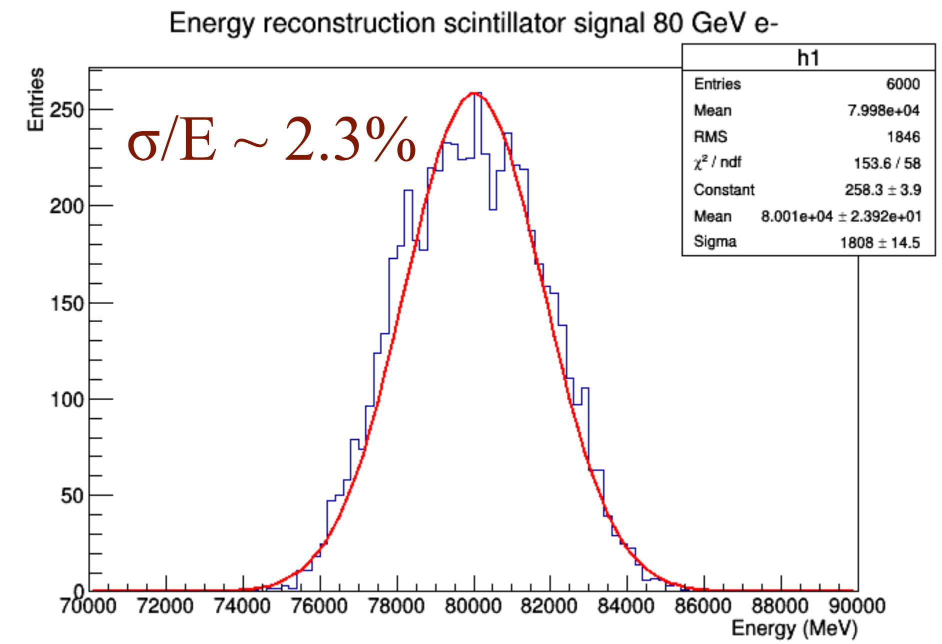
Geant4 Resolution(s) (e.m. performance)

80 GeV Performance

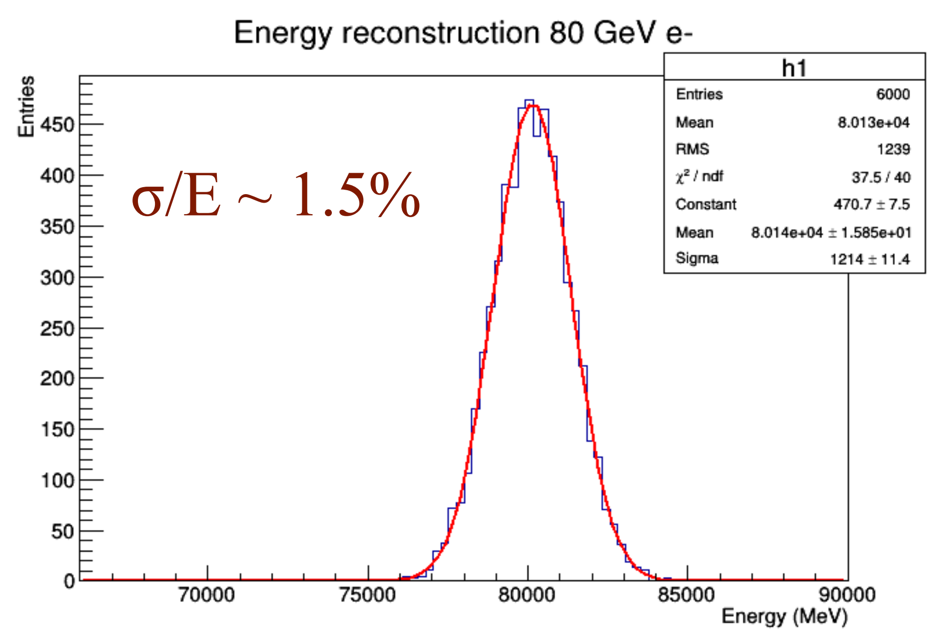
Čerenkov only



Scintillation only

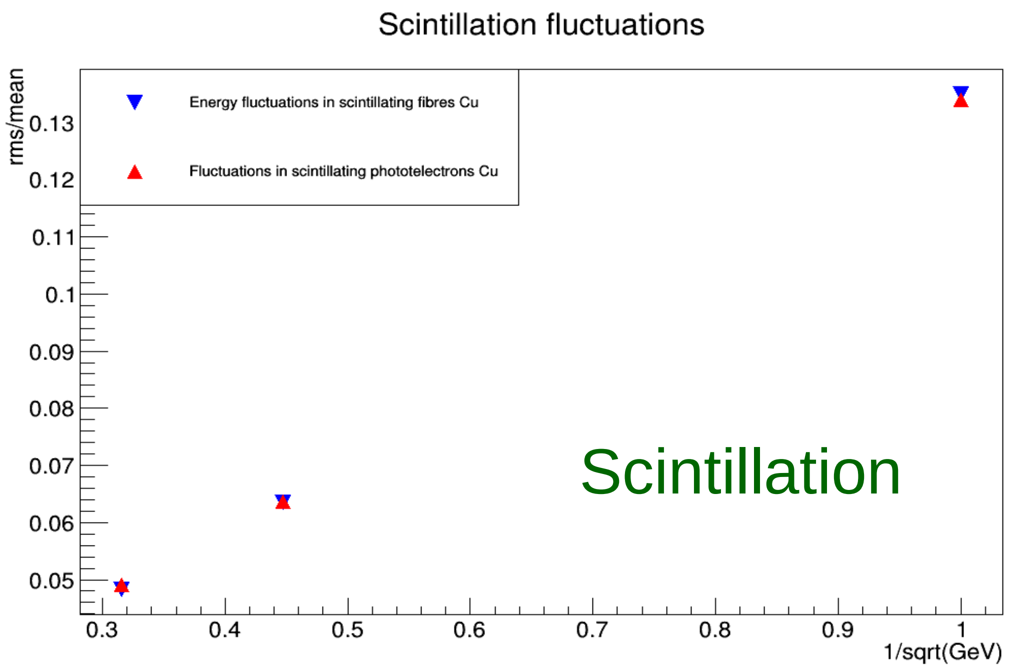


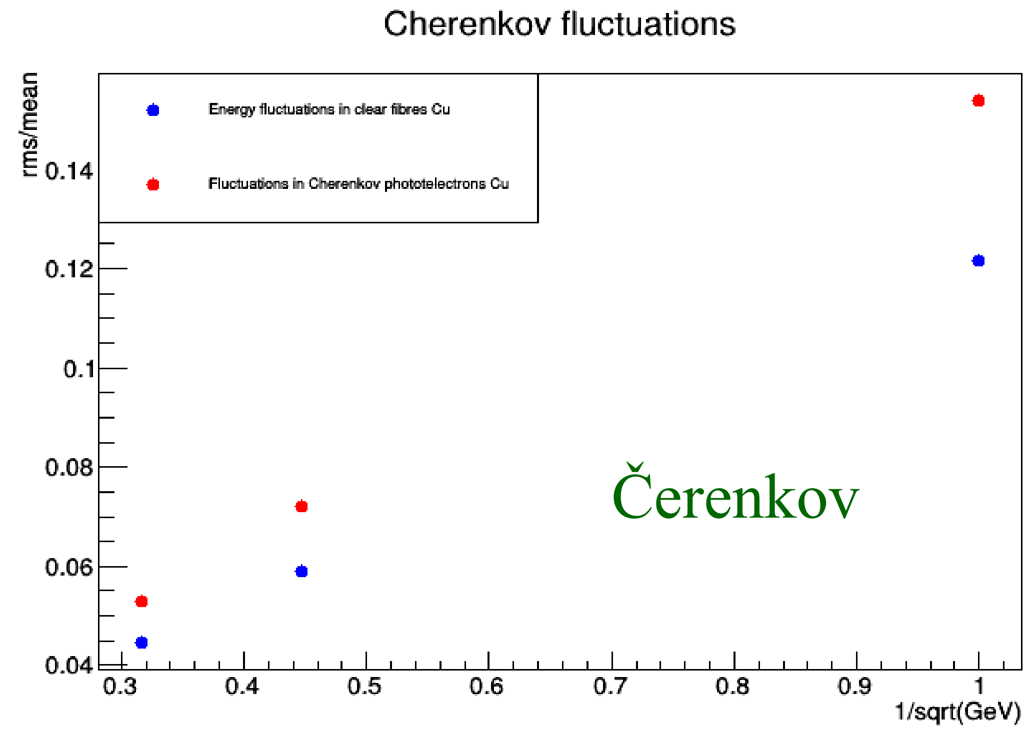
S+C



Geant4 e.m. Performance

Energy deposition and p.e. number fluctuations





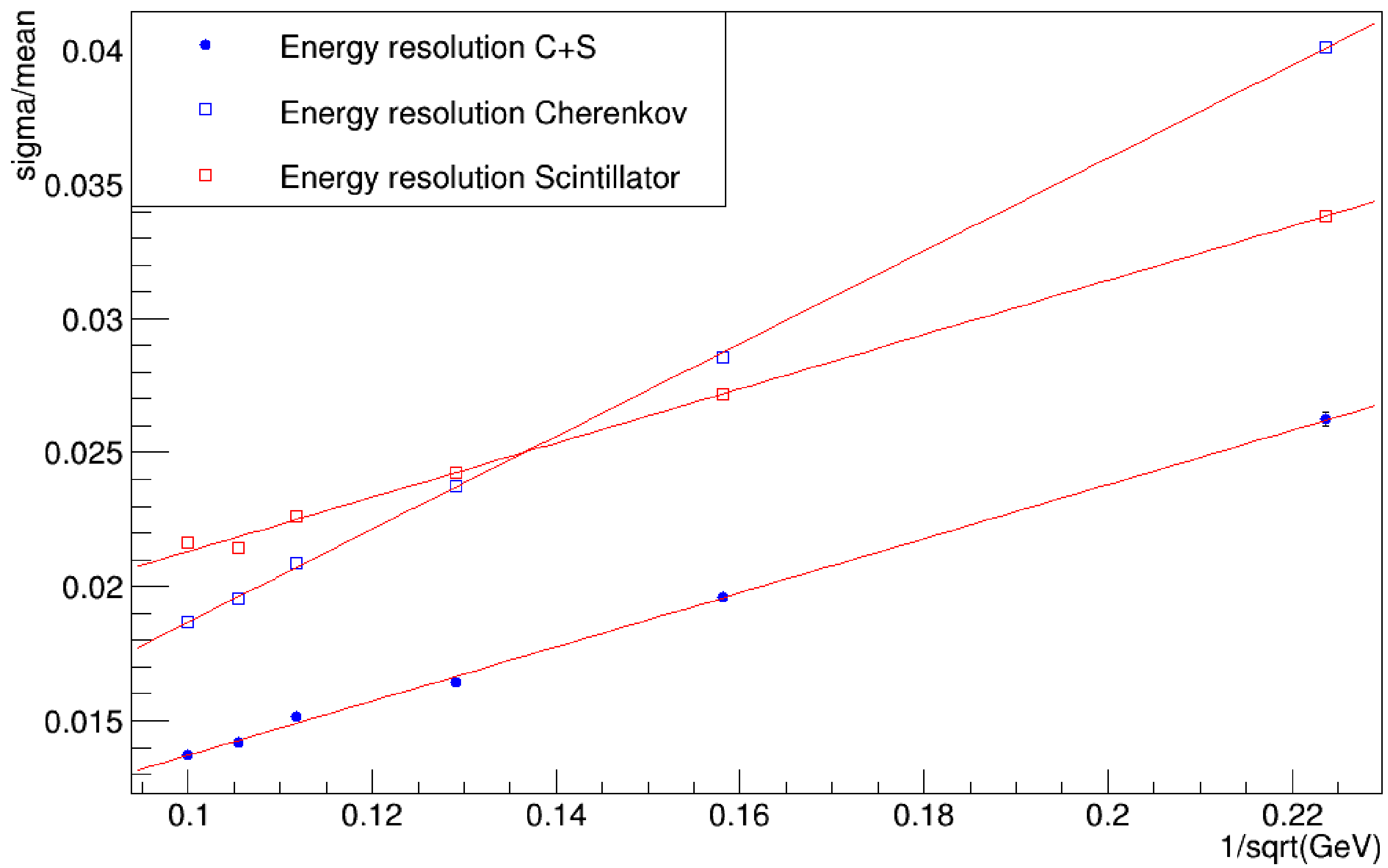
Scintillation: ~5500 p.e. / GeV
→resolution driven by fluctuations in energy depositions

Cherenkov: ~108 p.e. / GeV
→resolution driven by fluctuations in p.e. number

Sampling fluctuations impact on resolution:

$$\frac{\sigma}{E} = 2.7\% \times \frac{\sqrt{1/0.113}}{\sqrt{E}} = \frac{8.0\%}{\sqrt{E}}$$

E.M. Resolution(s)



S-only: 10.1%/√E+1.1%

Č-only: 17.3%+0.1%

Č+S: 10.1%/√E+0.4%<

Geant4 Hadronic Performance

Work started …

10-20 GeV protons simulated

Need production of scintillation light (Birks saturation effects in scintillation)

Still issues in understanding first results …

News asap

Note on dual readout calorimetry

Preliminary version distributed for internal feedback

Still missing few things

→ *release it within this week*

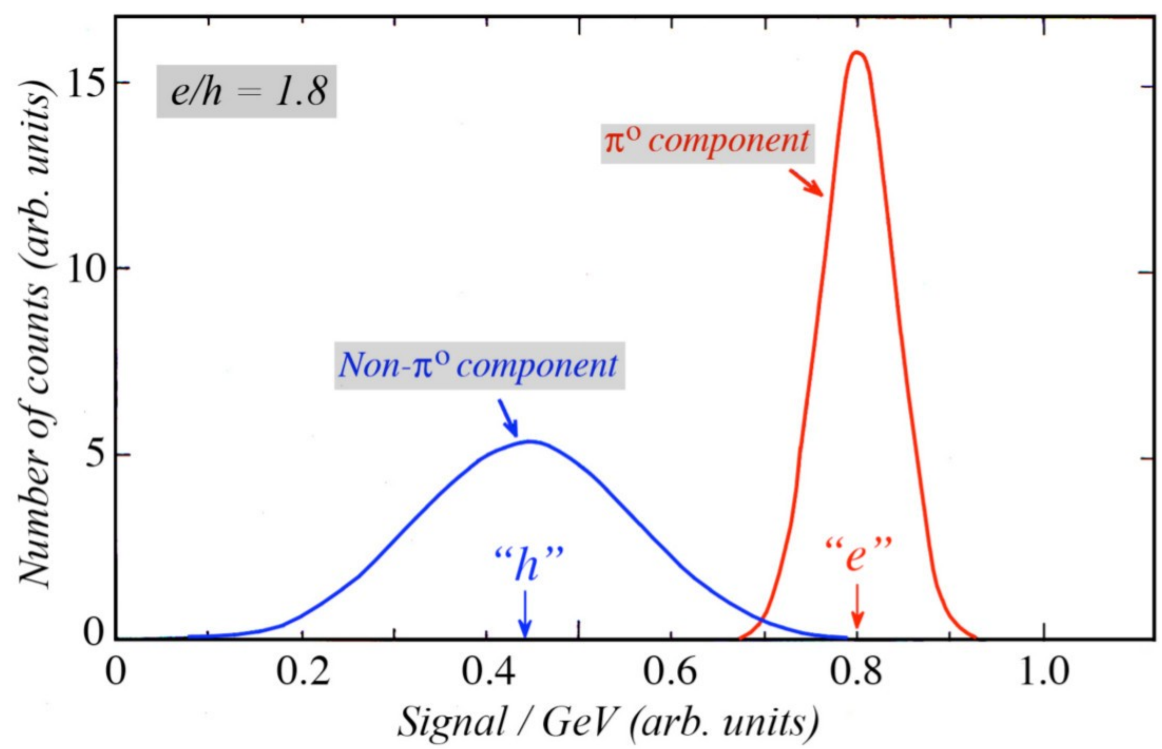
Contents

BACKUP

Dual-Readout Calorimetry

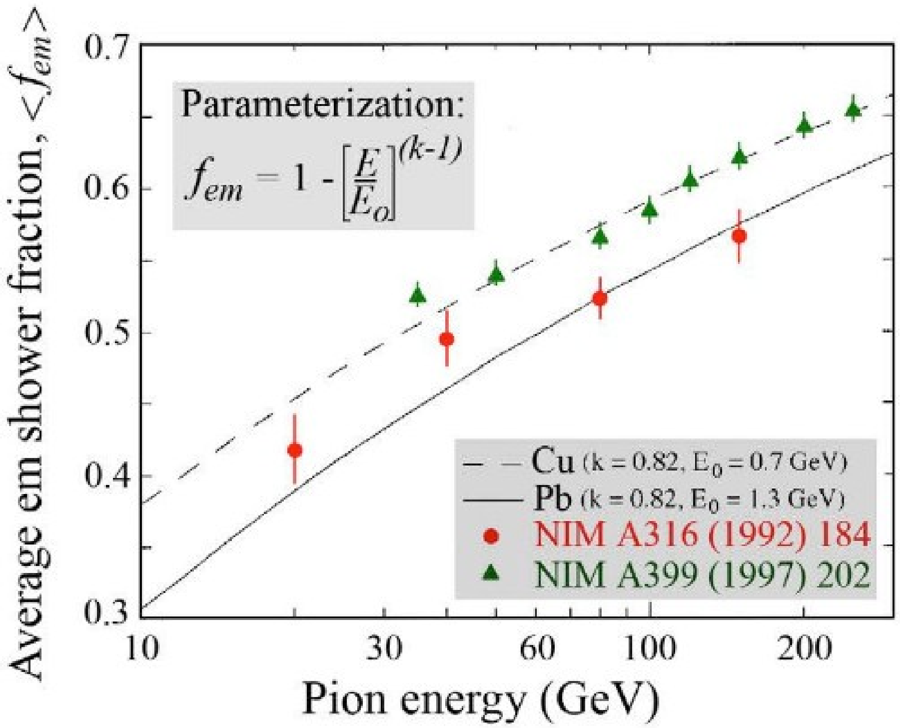
Hadronic showers develop both e.m. and hadronic components that are sampled with different efficiency

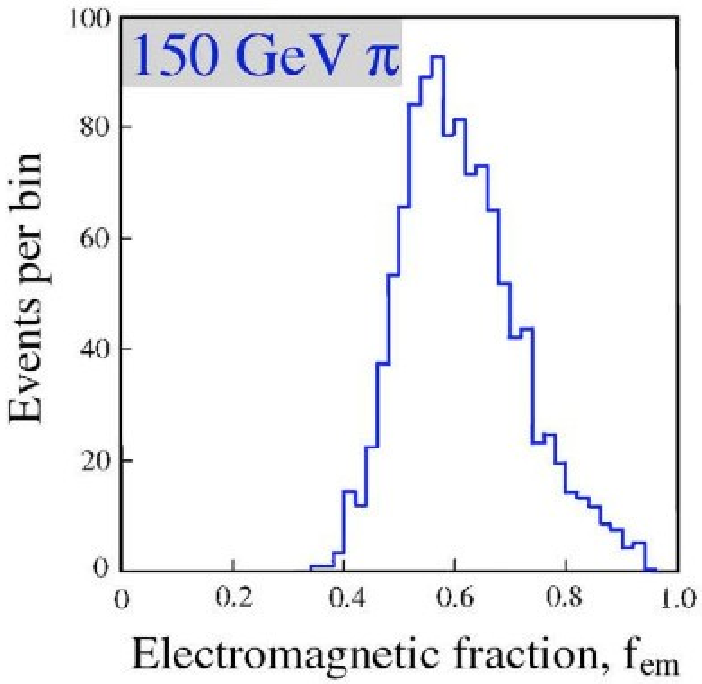
This effect is quantified in the e/h ratio
(in the plot e/h ≈ 1.8)



Electromagnetic Shower Fraction, f_{em}

f_{em} changes with energy and type of "mother" particle and with age ("depth") of shower





Idea: use two independent processes (scintillation and Čerenkov light emission) having very different e/h values to eliminate f_{em}

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

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

How it works

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

is universally valid

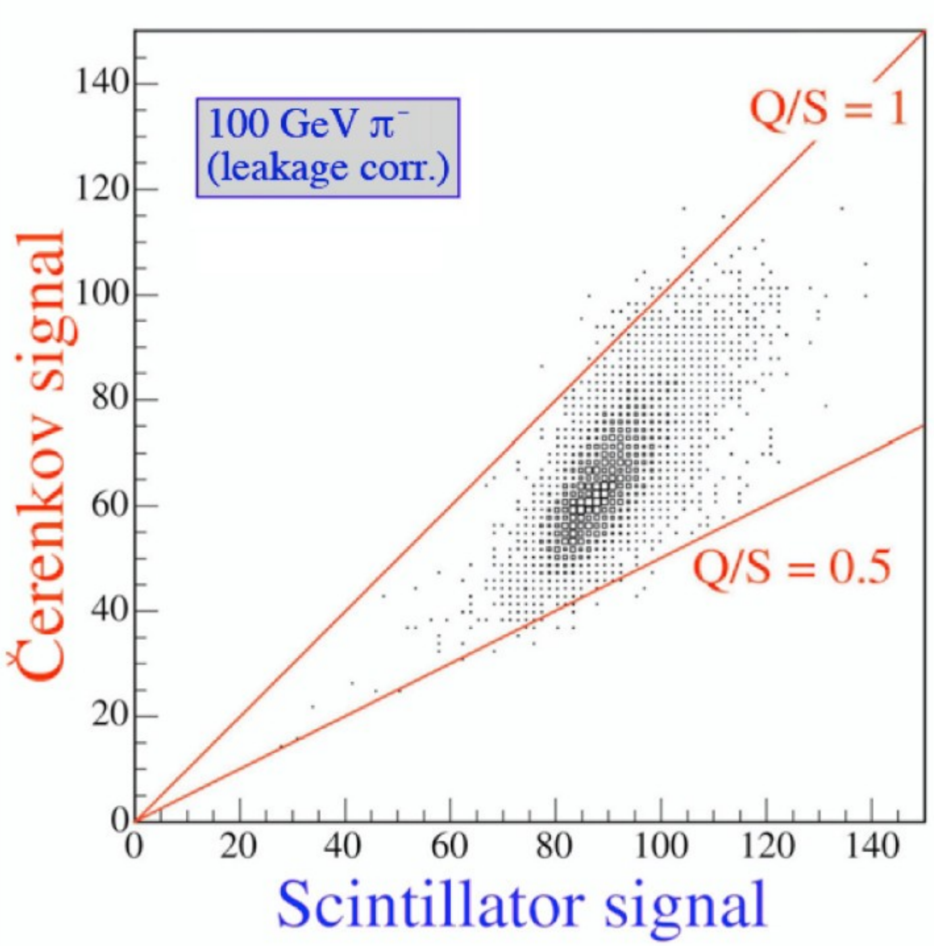
$$cotg\,\theta = \frac{1-(h/e)_S}{1-(h/e)_C} = \chi$$

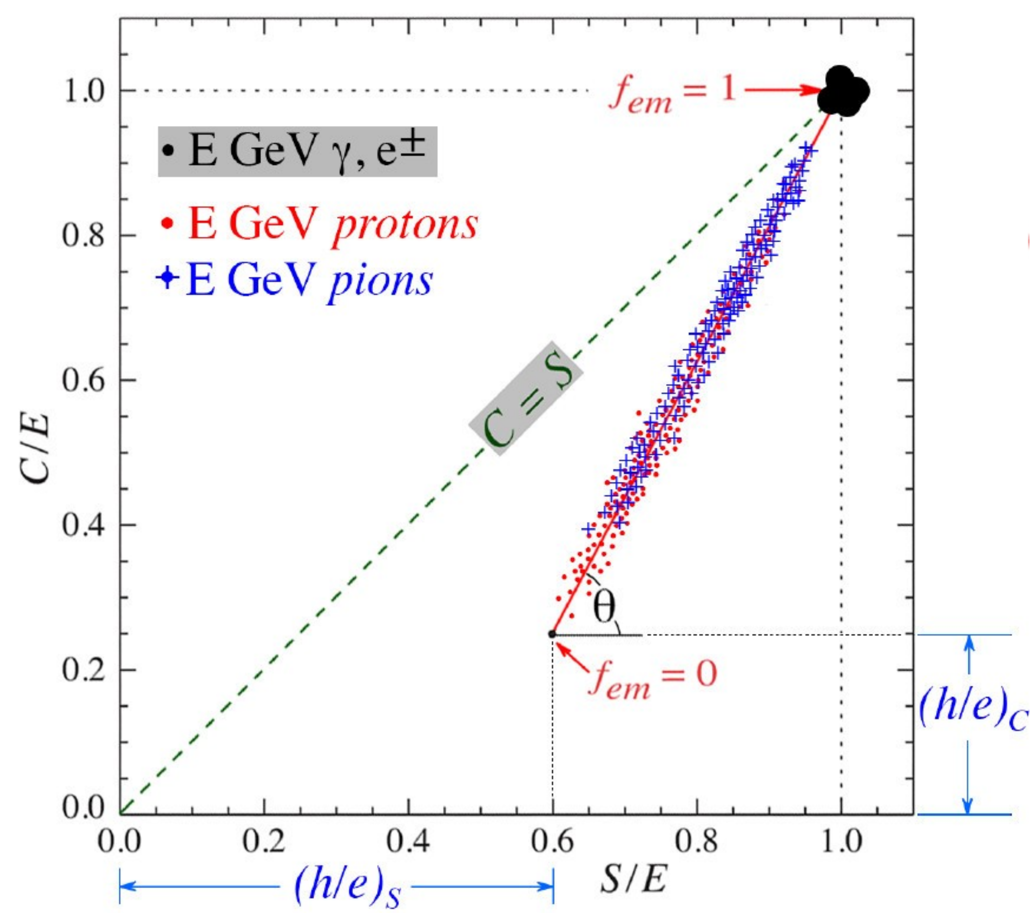
Θ, χ *independent of both*:

i) energy (!)

ii) type of hadron (!!)

Hadronic data points (S, C) located around straight lines

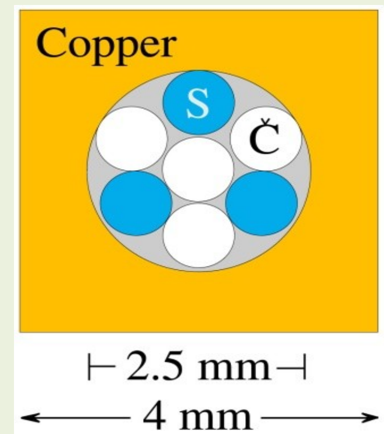




Dual-Readout w/ Sampling Fibre Calorimeters

2003
DREAM

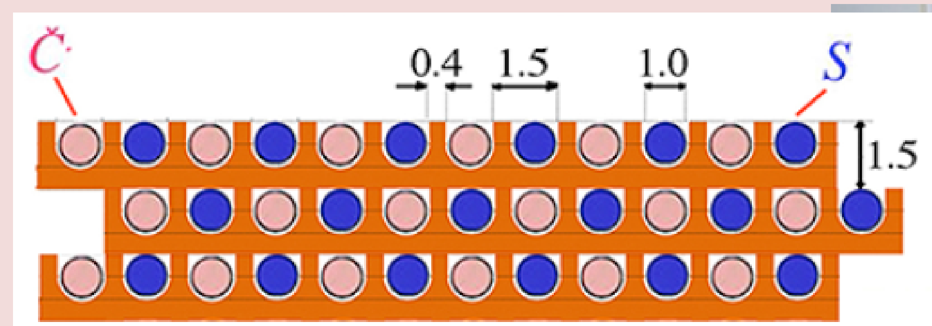
Copper
2m long, 16.2 cm wide
19 towers, 2 PMT each
Sampling fraction: 2%



2012
RD52

Copper, 2 modules

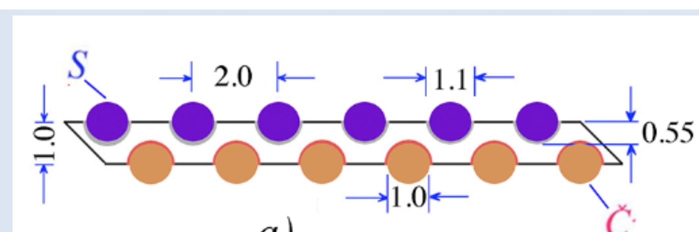
Each module: 9.3 * 9.3 * 250 cm^3
Fibers: 1024 S + 1024 C, 8 PMT
Sampling fraction: 4.5%, 10 λ_{int}

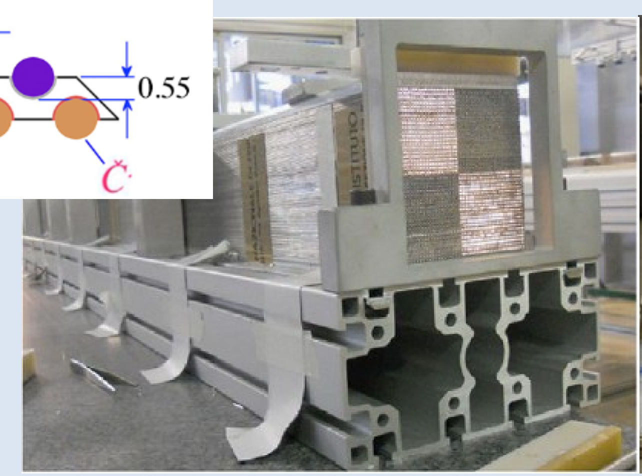


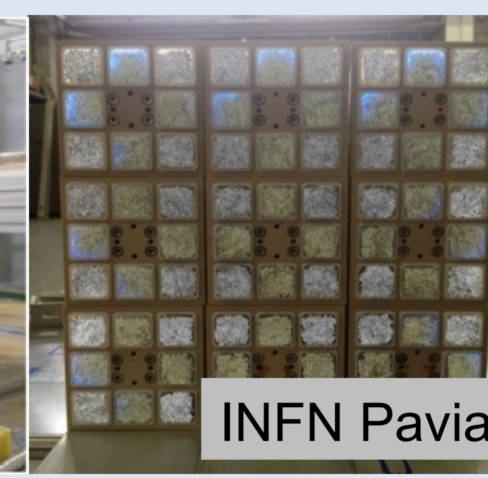
2012
RD52

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}





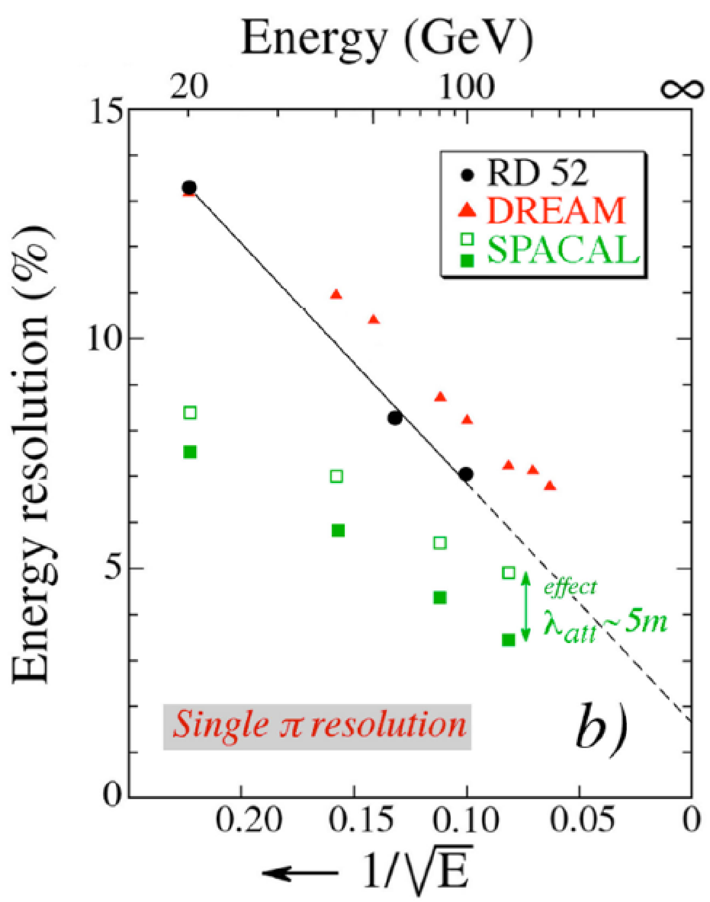


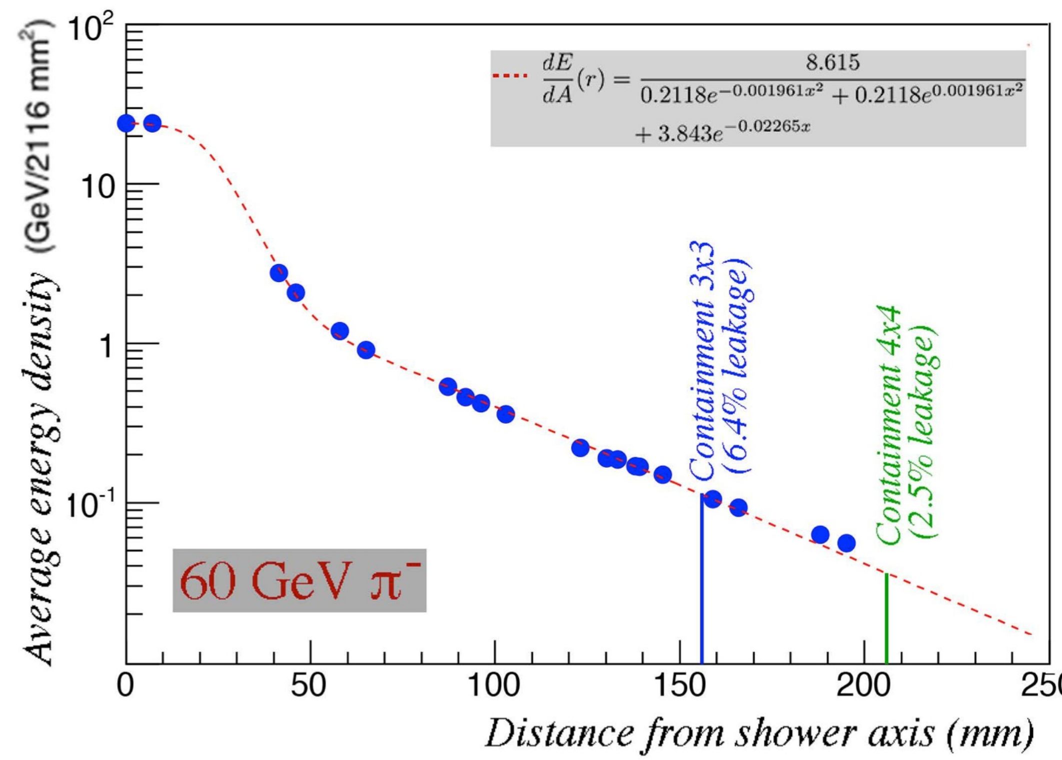
RD52 Single-Particle Hadronic Resolution

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")

Dual Readout at Work