Dual-Readout Calorimetry

Milano, July 5th, 2018

RD_FA collaboration meeting

Roberto

Dual-Readout Calorimetry

1. dove stiamo …

2 stato collaborazione

3. programma (e budget) per 2019-2020

3-Year Goals

a) Detector/mechanics: build one (some) ~10×10×150 cm^3 module(s)

Copper grooving!

Need a reliable solution for massive production …

→ *Bronze ? Brass ? Other materials ?*

b) SiPM performance: linearity, dynamic range, noise, after pulses

c) UV-exclusive sensitive devices (e.g. SiC – few details in bkp slides)

d) signal readout/DAQ: signal aggregation/sum

→ *evaluate 64-channel ASIC-based modules*

d) performance assessment: full/fast simulations & Particle Flow analysis
(with and without preshower detector)

Other open issues:

When/How build a full-containment prototype ?

When/How develop projective geometry ?

Where are we ?

1. *CepC & FCCee CDR.s in progress*

2. *simulations → Lorenzo's talk*

3. *SiPM module → Massimiliano's talk*

4. *displaced-fibre module → Gabriella's talk*

5. *testbeam → Romualdo's talk*

but …

Copper/Brass vs. Lead

copper vs. lead

Copper	Lead
density = 8.96 gr/cm^3	density = 11.35 gr/cm^3
nuclear i.l. = 15.3 cm	nuclear i.l. = 17.6 cm
radiation l. = 1.44 cm	radiation l. = 0.561 cm
Molière radius = 1.57 cm	Molière radius = 1.60 cm

volume ratio = $(17.59/15.32)^3 = 1.15^3 = 1.51$

mass ratio = $1.51*(11.35/8.96) = 1.92$

brass vs. lead calorimeter

Brass:Fibres	*Lead:Fibres*
density = 4.57 gr/cm³	*density = 5.96 gr/cm³*
nuclear i.l. = 28.9 cm	*nuclear i.l. = 30.6 cm*
radiation l. = 2.96 cm	*radiation l. = 1.13 cm*
Molière radius = 2.96 cm	*Molière radius = 2.90 cm*

volume ratio $= (30.6/28.9)^3 = 1.06^3 = 1.19$

mass ratio $= 1.19*(5.96/4.57) = 1.55$

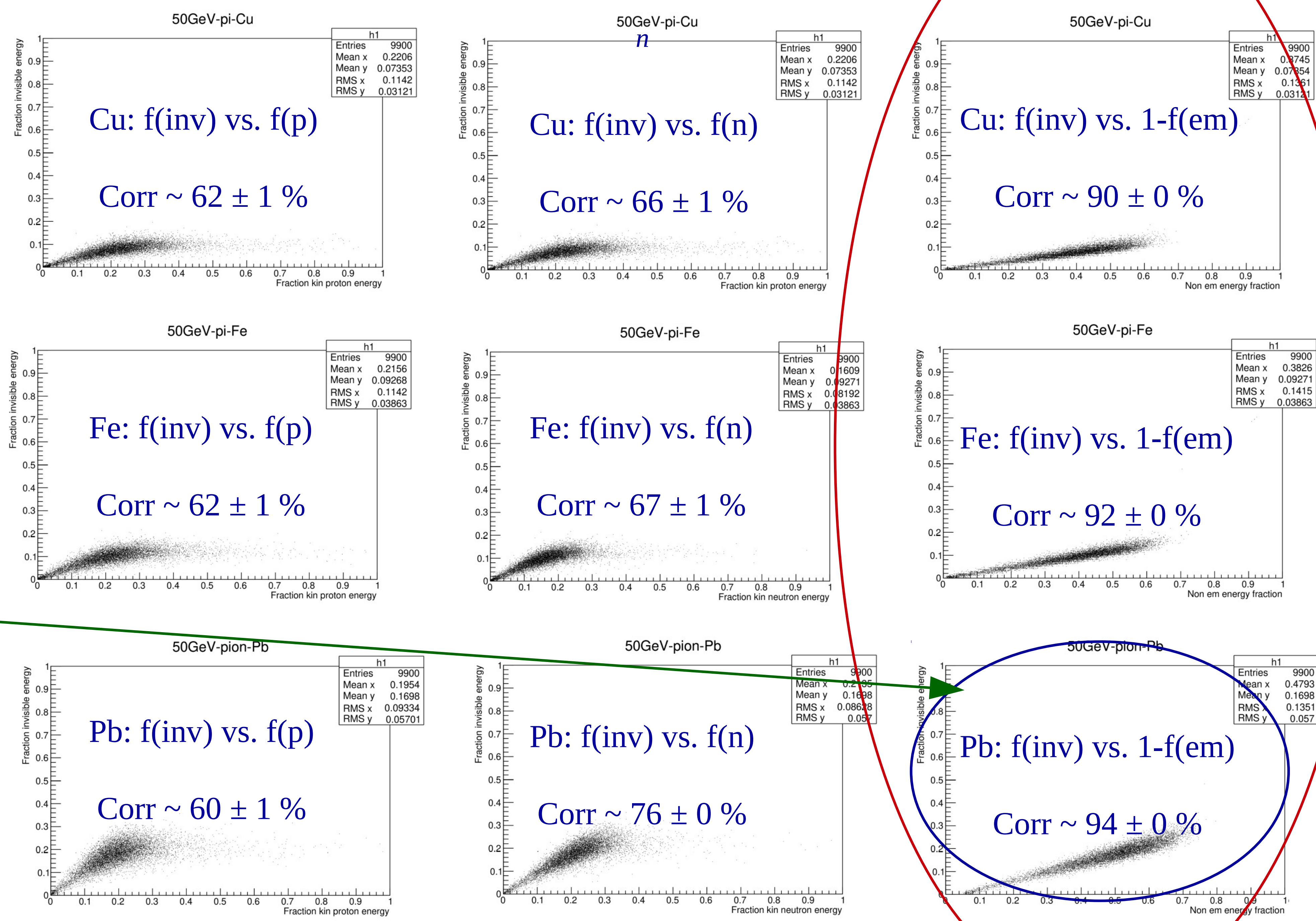
Invisible Energy (50 GeV π^-) - correlations

$f(E)_{proton}$ → $f(E)_{neutro}$ → $1 - f_{em}$ →

Brass

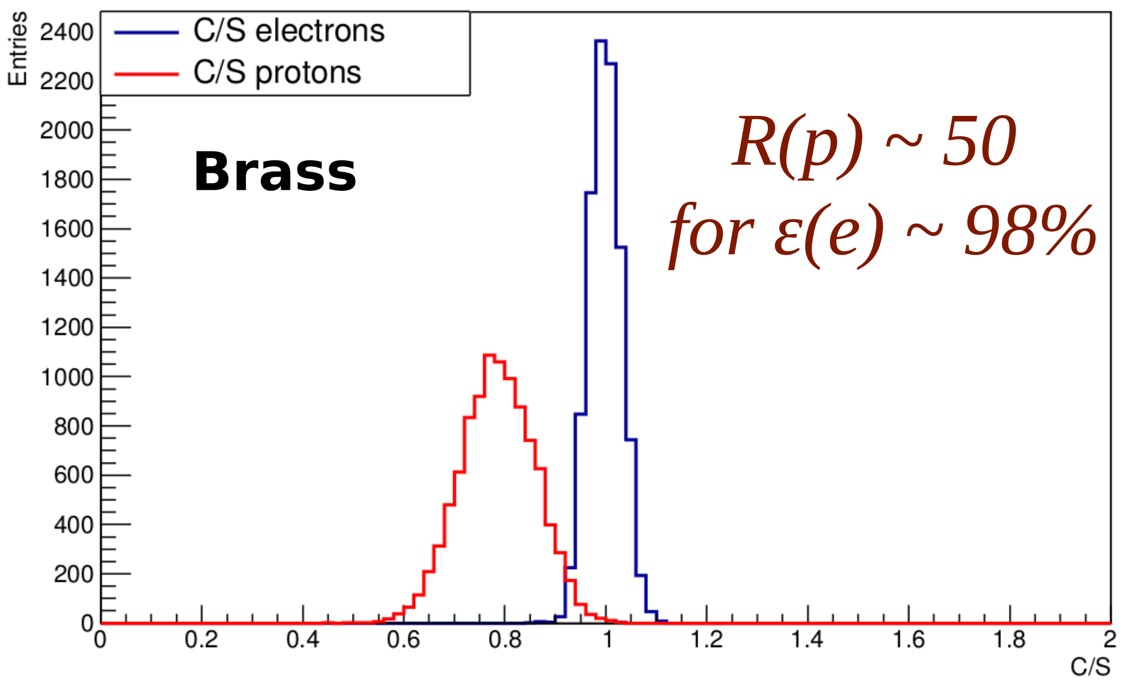
Iron

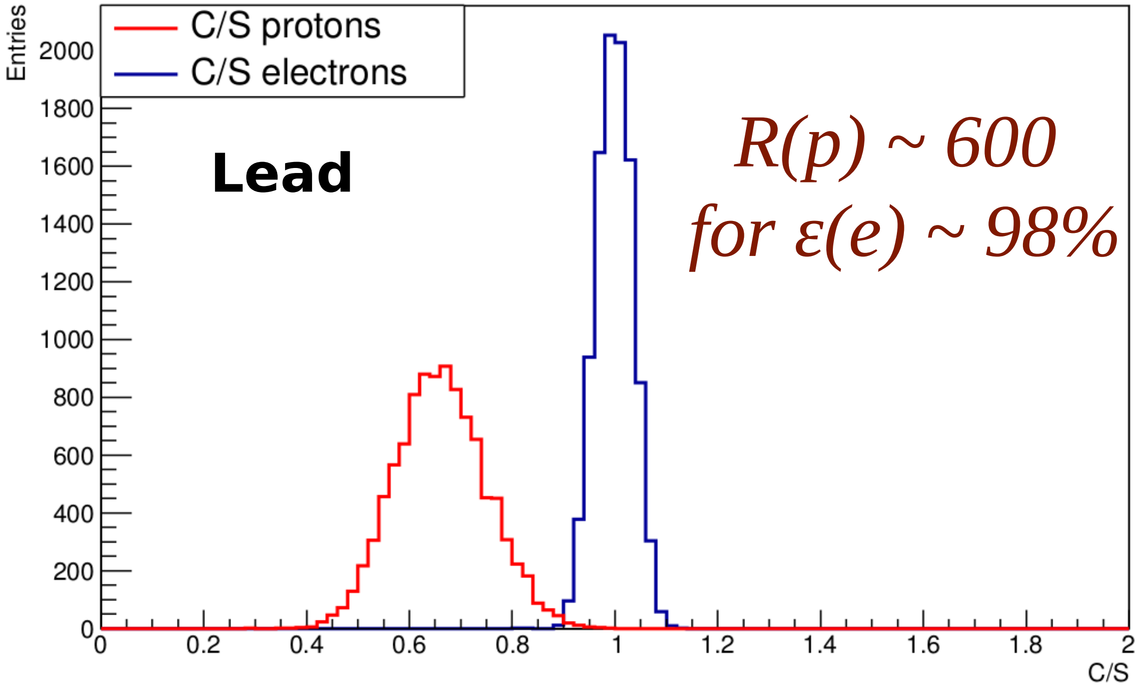
Lead



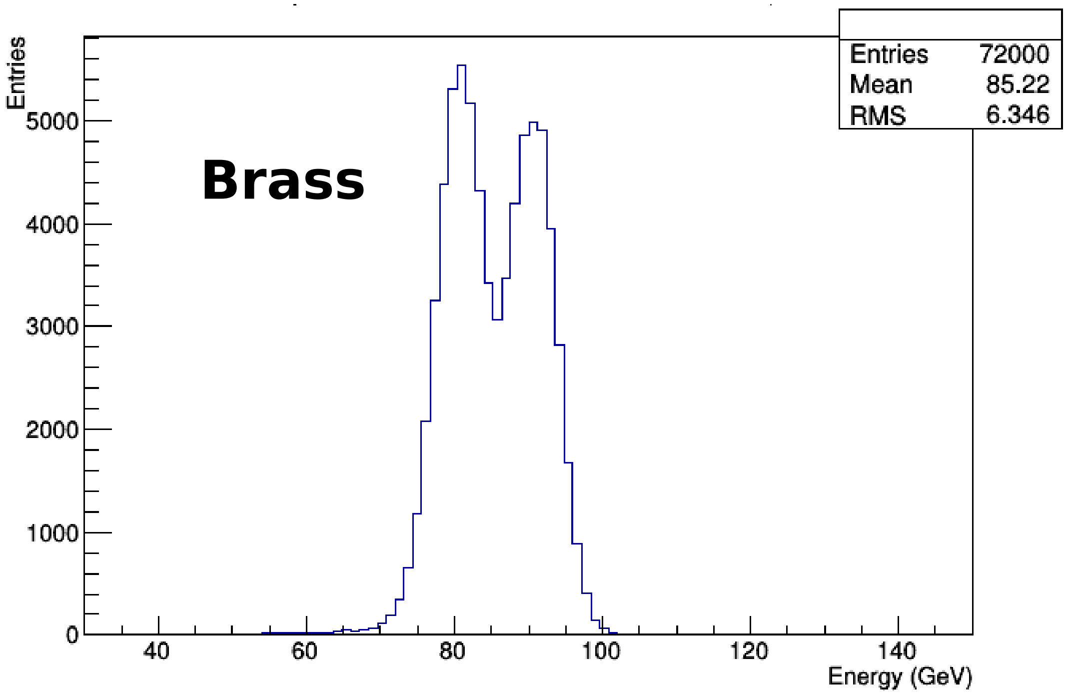
Particle Id & W/Z - Brass vs. Lead

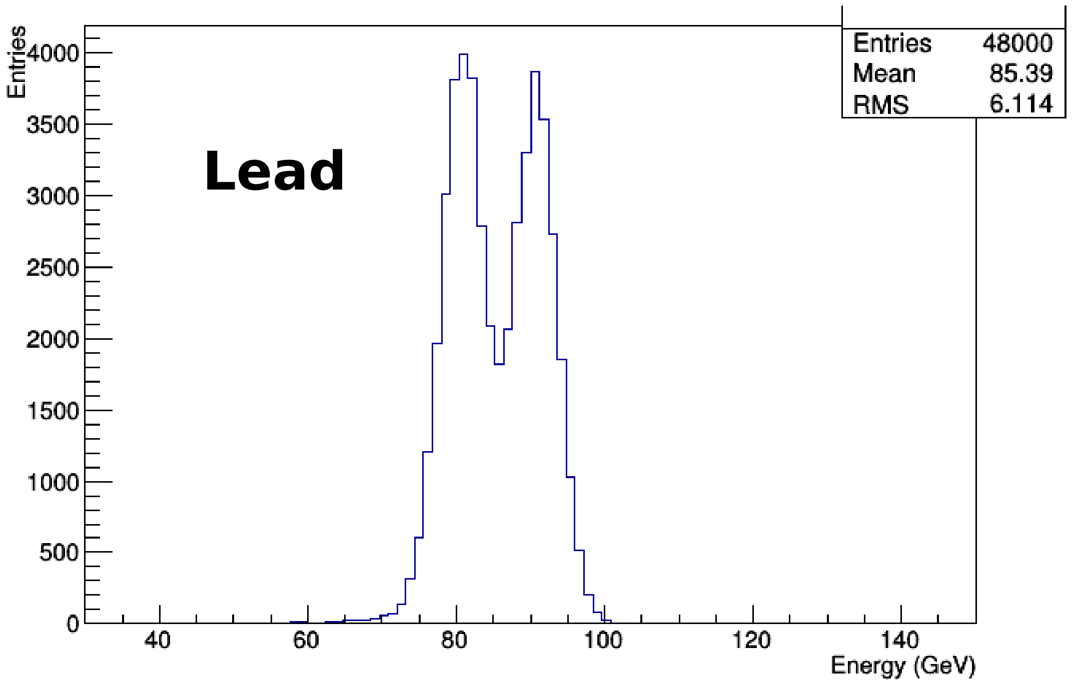
C/S ratio for 80 GeV e^- and p





Multiple hadrons, 81 & 91 GeV

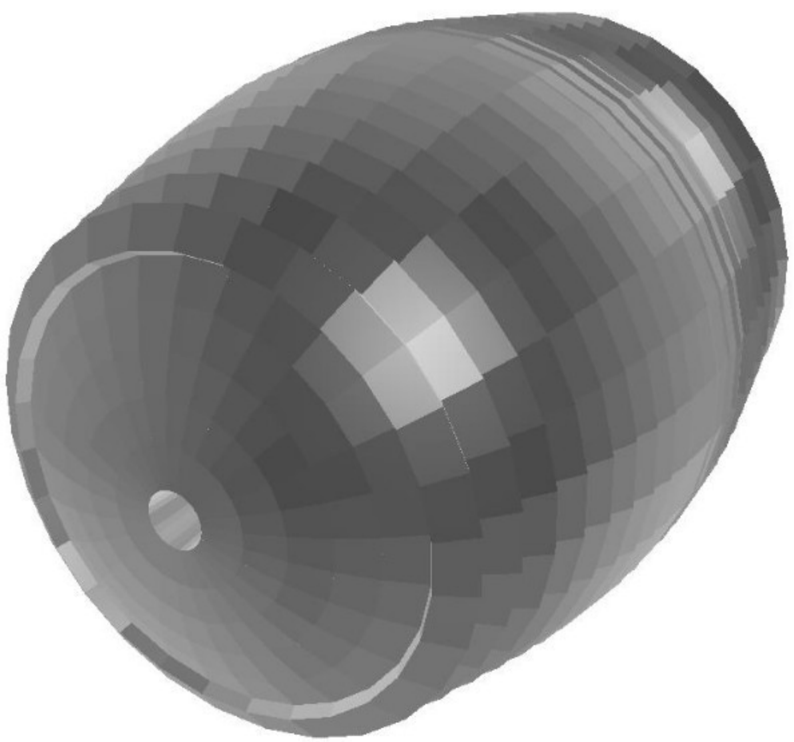


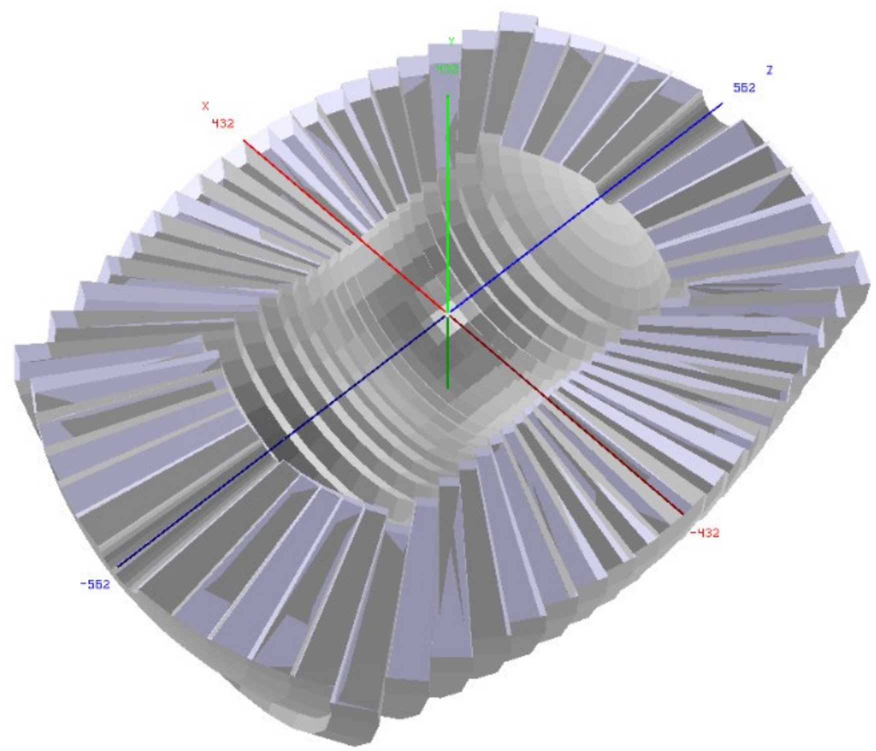


4π Simulations

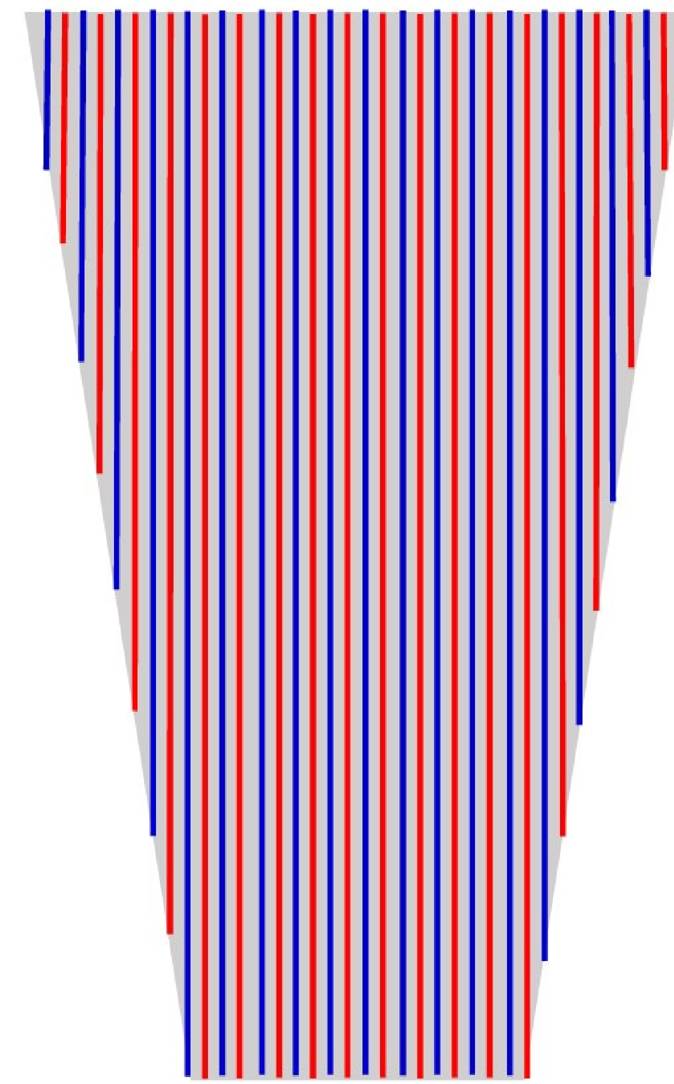
4π Simulations

Dual-readout calorimeter description for CepC/FCCee simulation sw:



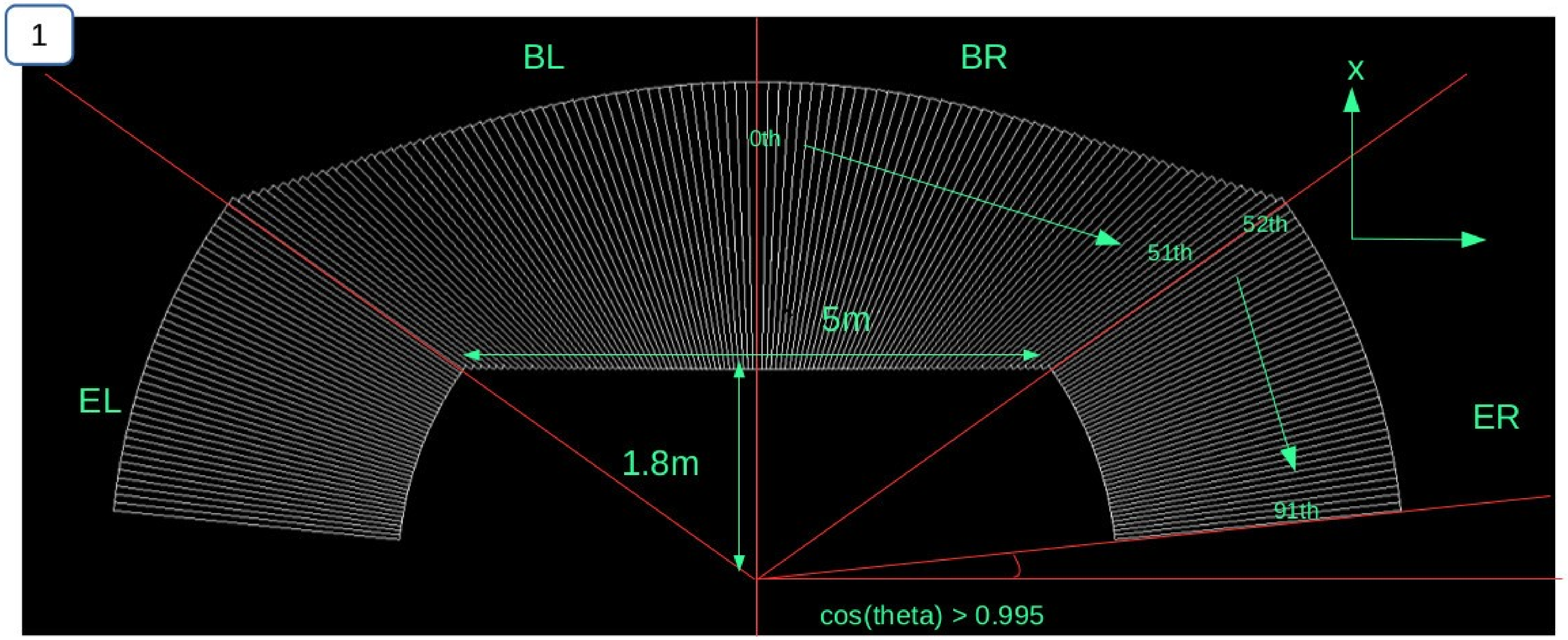


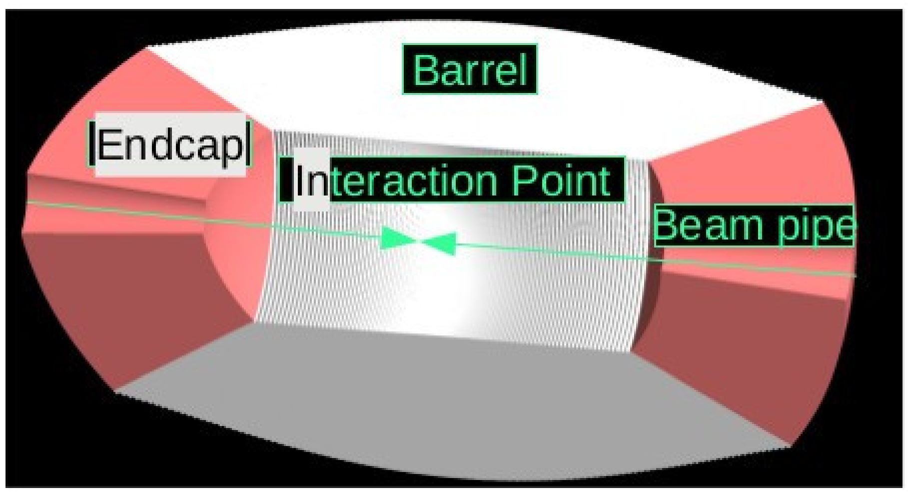
a) full coverage
b) projective geometry



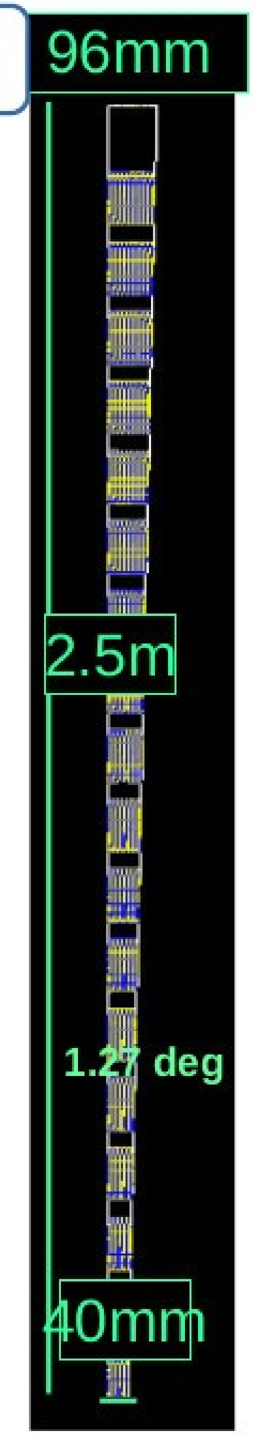
Wedge Geometry

1





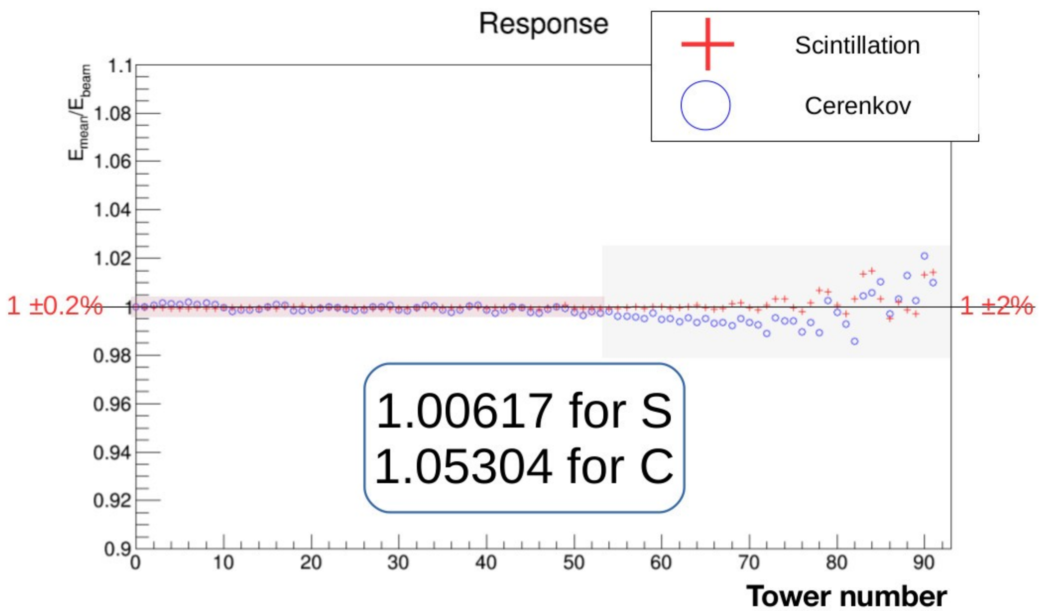
3

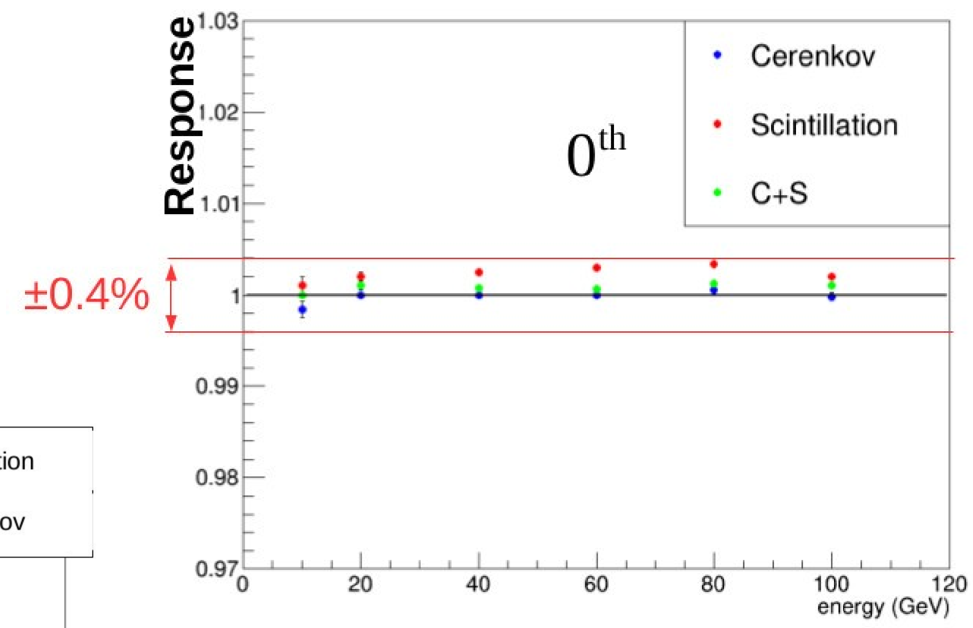


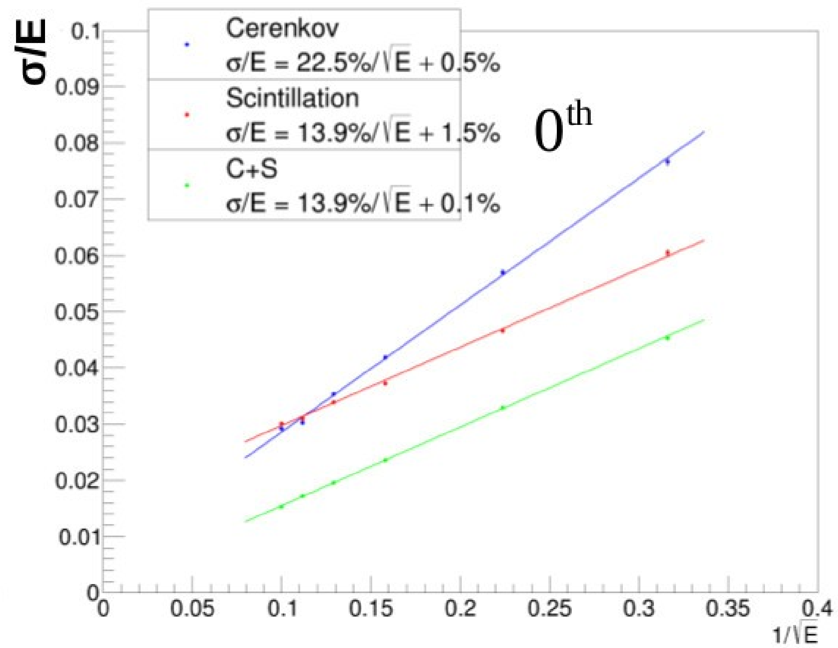
Čerenkov light yield set to 30 p.e./GeV

Calibrated w/ 20 GeV e⁻ beam @ [1º, 1.5º]

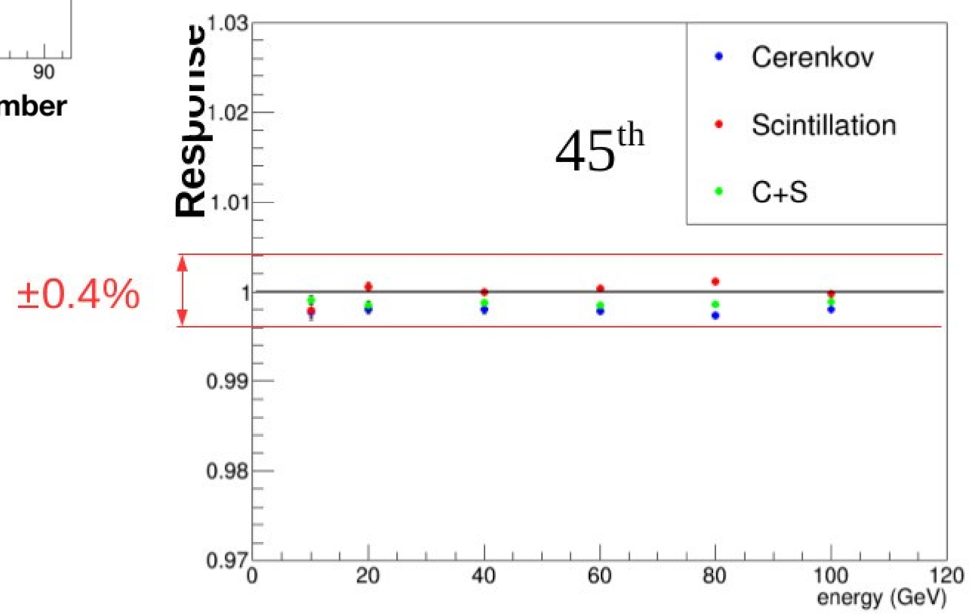
em Performance

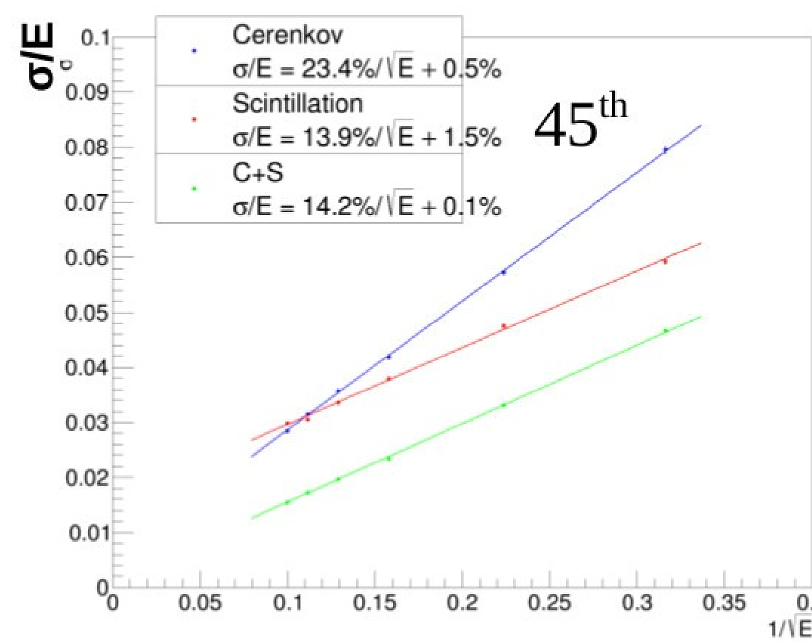






$\sigma/E \sim 14.0\% / \sqrt{E} + 0.1\%$





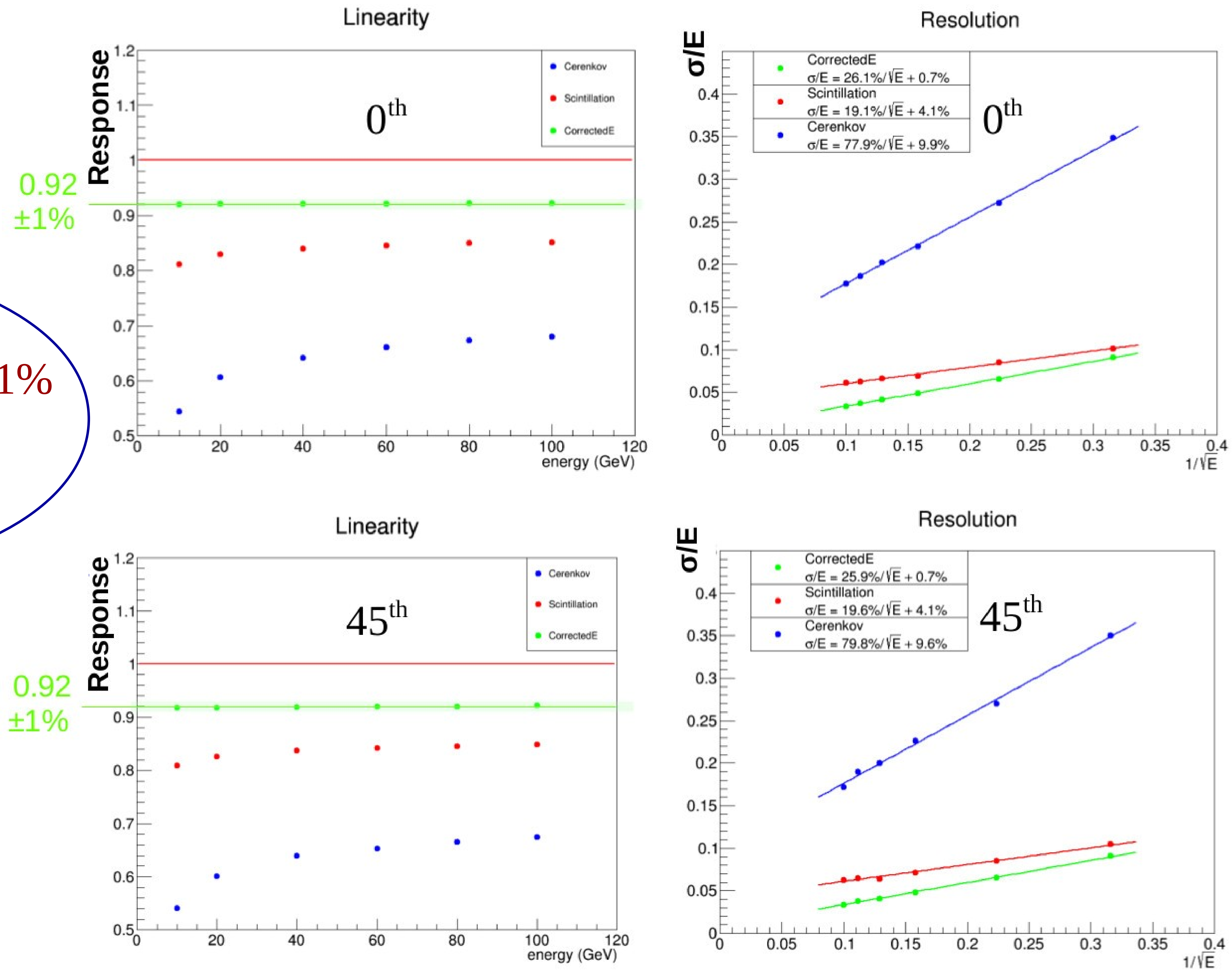
had Performance

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

with $\chi = 0.29$

E(rec)/E(beam) ~ 92% ± 1%

σ/E ~ 26% / √E + 1%



SiC photodiodes

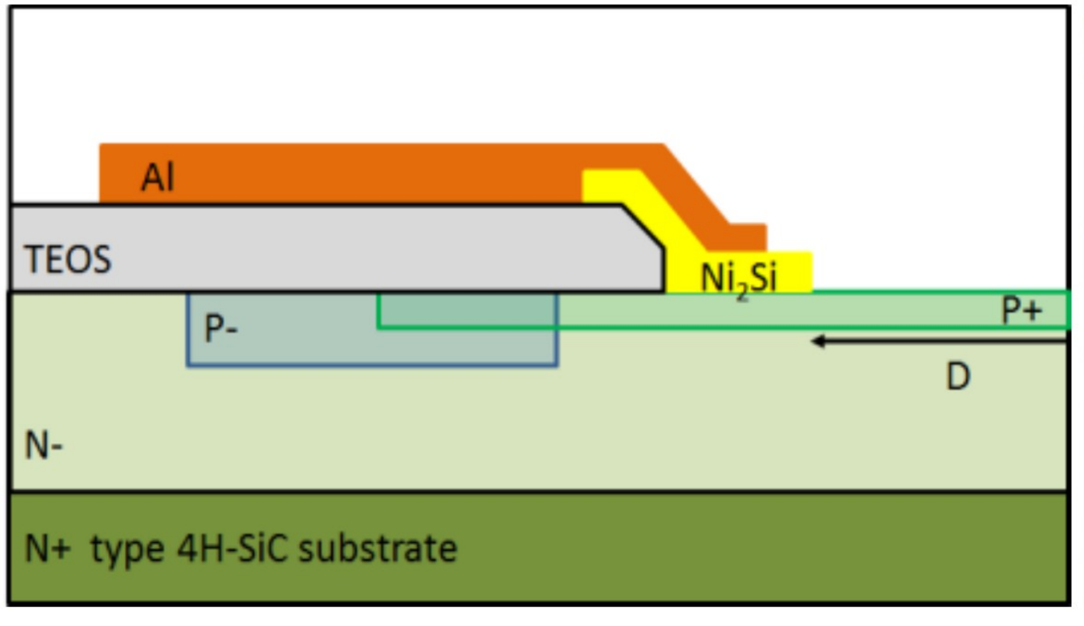
SiC Avalanche photodiodes for UV detection (CT/FI/CNR)

- Postdoc position going to be called in Catania for RD-FA

- PRIN proposal presented end of March to realize an APD array

- SiC APD prototype already realized in Catania within the CLASSIC R&D project:
  → suffers elevated lateral leakage soft breakdown. New lateral structures foreseen to solve the problem.

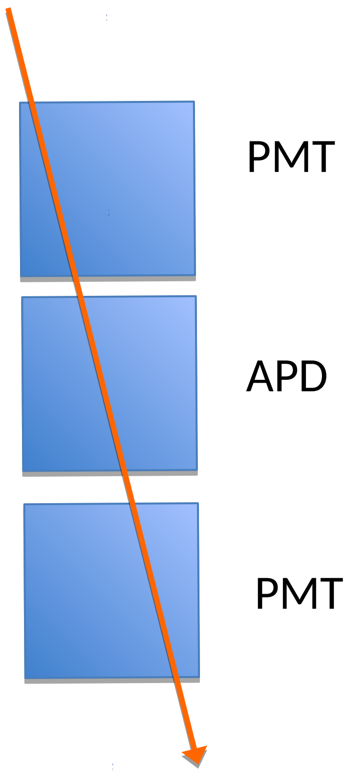
- While waiting financial support to upgrade our prototype, commercial devices have been tested too.



Cosmic rays test for a 100 μm SiC APD

Single-Pixel SiC APD

3×3×3 cm^3 BaF scintillators vertically aligned;
photon yield ≈ 10^5/event



- APD relative rate (PMT×APD×PMT coincidences/PMT×PMT coincidences)

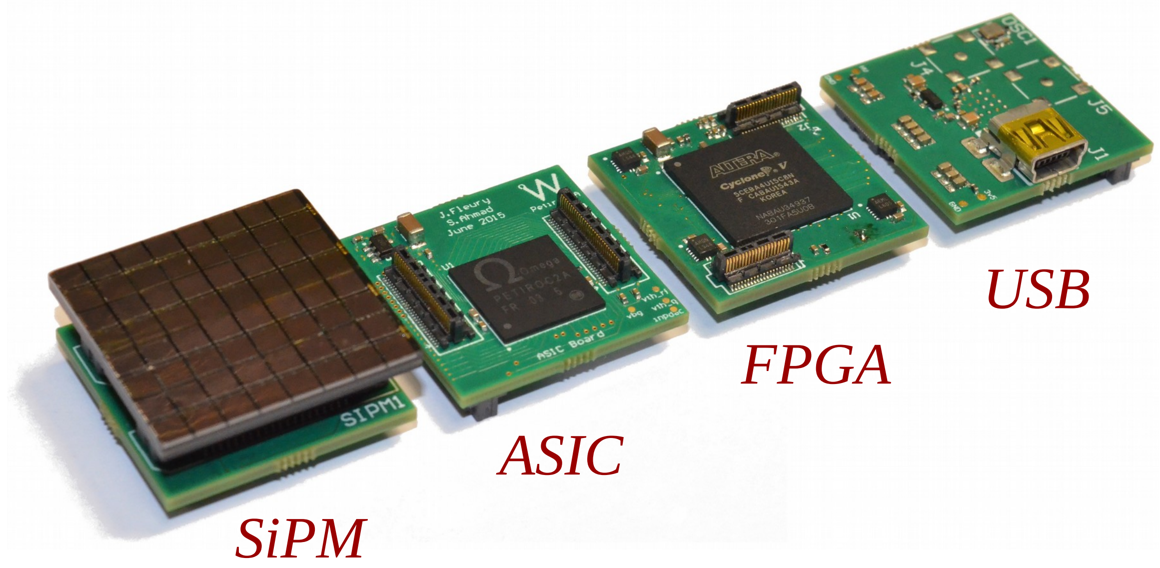
≈ 1% after background subtraction

→ an array of thousand SiC-APD units would give 100% efficiency and a hopefully linear behaviour vs light intensity

Readout ASIC

Readout

would like to get:



first step: ASIC

weeroc catalogue:

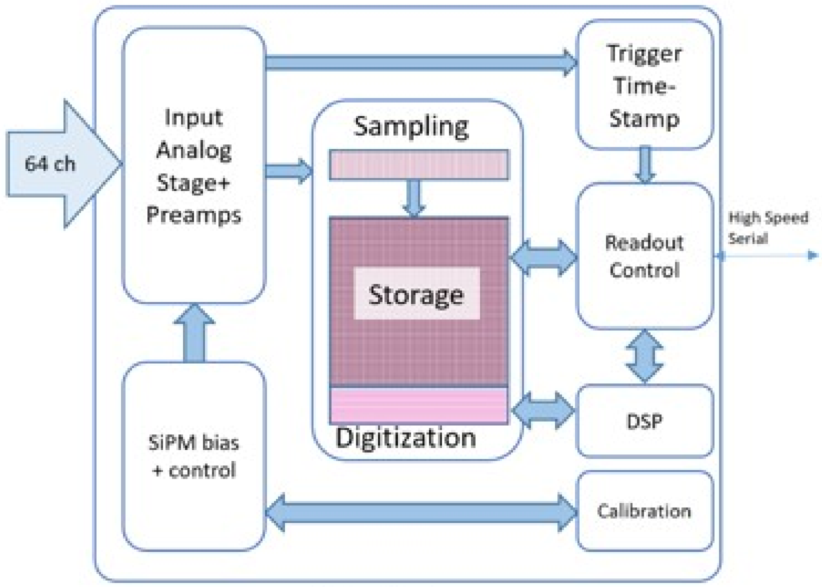
Chip	Detector	Ch	Polarity	Dyn Range	Specificities
SPIROC	SiPM	36	>0	10 fC - 300 pC	36 HV SiPM tuning (8 bits), Internal 12-bit ADC for charge and time measurement
EASIROC	SiPM	32	>0	10 fC - 300 pC	32 HV SiPM tuning (8 bits), 32 trigger outputs
CITIROC	SiPM	32	>0	10 fC - 300 pC	32 HV SiPM tuning (8 bits), 32 trigger outputs
PETIROC	SiPM	32	<0	100fC – 300 pC	32 HV SiPM tuning (8 bits), 32 trigger outputs, Internal 10-bit ADC for charge and time measurement (25 ps)
TRIROC	SiPM	64	Both	100 fC- 300 pC	64 HV SiPM tuning (8 bits), 64 trigger outputs, Internal 10-bit ADC for charge and time measurement (25 ps)

Digital solution ?

SiREAD

Silicon photomultiplier REadout, Automated calibration and Detection

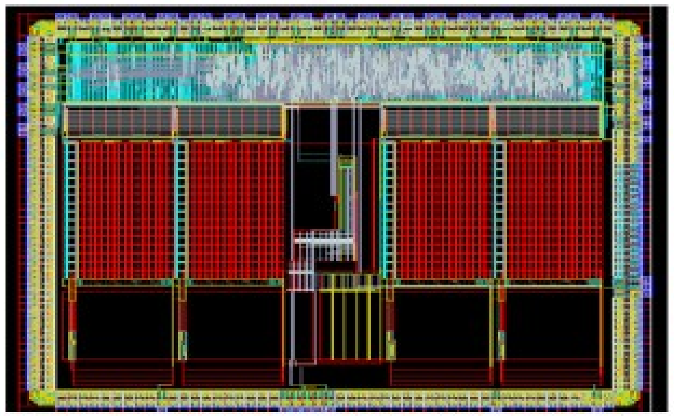
Nalu Scientific, LLC.
2800 Woodlawn Dr. Ste 298
Honolulu, HI 96822
info@naluscientific.com
Nalu Scientific
Data Acquisition Systems



SiREAD block diagram

SiREAD Parameter	Specifications
Channels	64
Sampling rate	1-4 GSa/s
Storage samples/ch	4096
Analog bandwidth	0.7-1.1 GHz
RMS voltage noise	<1mV
Dynamic range	10-11 bits
Signal voltage range	2.1 V
ADC on chip	12 bits
Readout	Serial LVDS
Power consumption	20-40 mW/ch

Key Features:
- ✓ Giga-sample/sec full waveform sampling
- ✓ High density (64 channels)
- ✓ SiPM bias trim
- ✓ Deep buffer (4k Samples)
- ✓ Dead-timeless for kHz trigger rates
- ✓ User friendly: can operate using a CPU
- ✓ Low cost CMOS process, Low-power



SiREAD layout- 4 ch prototype

declared to provide ~40-80 ps timing accuracy

Collaboration

Collaboration/Declarations of Interest

Long list … seems promising …

INFN: Catania, Firenze, Milano (Como), Pavia, Pisa

(11-15 people, >= 2.5 FTE)

UK: University of Sussex

CERN

US: TTU, Iowa State

Korea: Kyungpook KNU, Seoul SNU

China: IHEP, CAS, Nankai

(but in some cases just single individuals)

Nevertheless some breakdown seems to be already effective ...

Spending profile

3-Year Spending Profile

		2018	2019	2020		Totale
CT	SiC	3.5	3.5	4		11
	totale CT	3.5	3.5	4		11
PV	servizi TB	3	3	3		9
	laminazione Rame	5				5
	DAQ	10				10
	modulo rame		10	10		20
	fibre		10	10		20
	totale PV	18	23	23		64
MI	SiPM	5	15	15		35
	FE	7.5	7	10		24.5
	totale MI	12.5	22	25		59.5
	Gran totale	34	48.5	52		134.5

Main Steps

Mechanics:

2018: small (~ few cm^2) module production (5 ke)

2019-2020: 5×5 - 10×10 cm^2 module (10+10 ke)

Sensors:

2018:

(100-200) SiPM with 10000 pixels, 10×10 μm^2, price: ~ 30 e/SiPM

SiC ~ 1 wafer production and test

2019-2020:

O(1000) SiPM ~ 30 kE

SiC ~ 2-3 wafer production and test

Electronics:

→ *SiPM tailored multi-channel ASIC.s*

→ *test channel grouping / adding (1, 3, 5, 6 channels summed up → Wigmans)*

the big issue !

2019-2020 → no testbeam at CERN

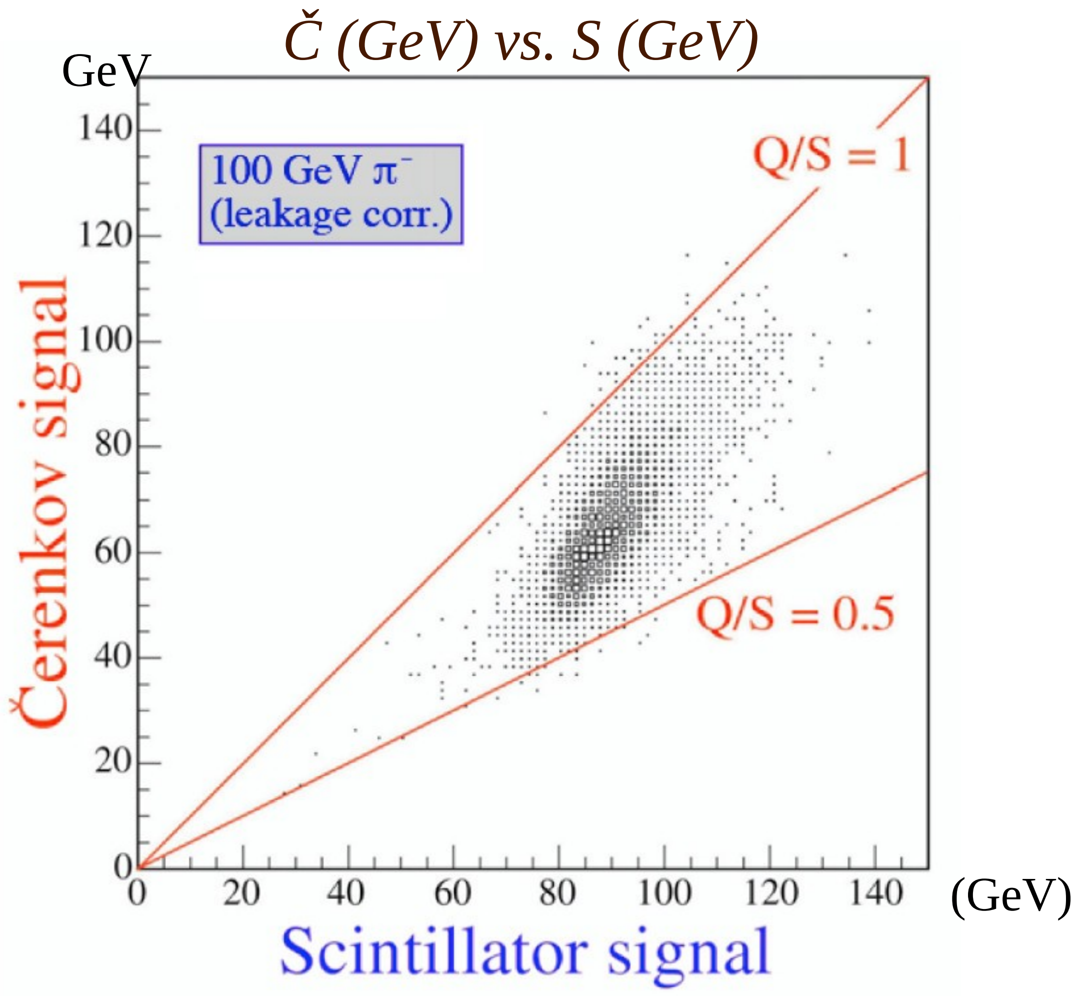
1) need to clear-up experimental area & control room

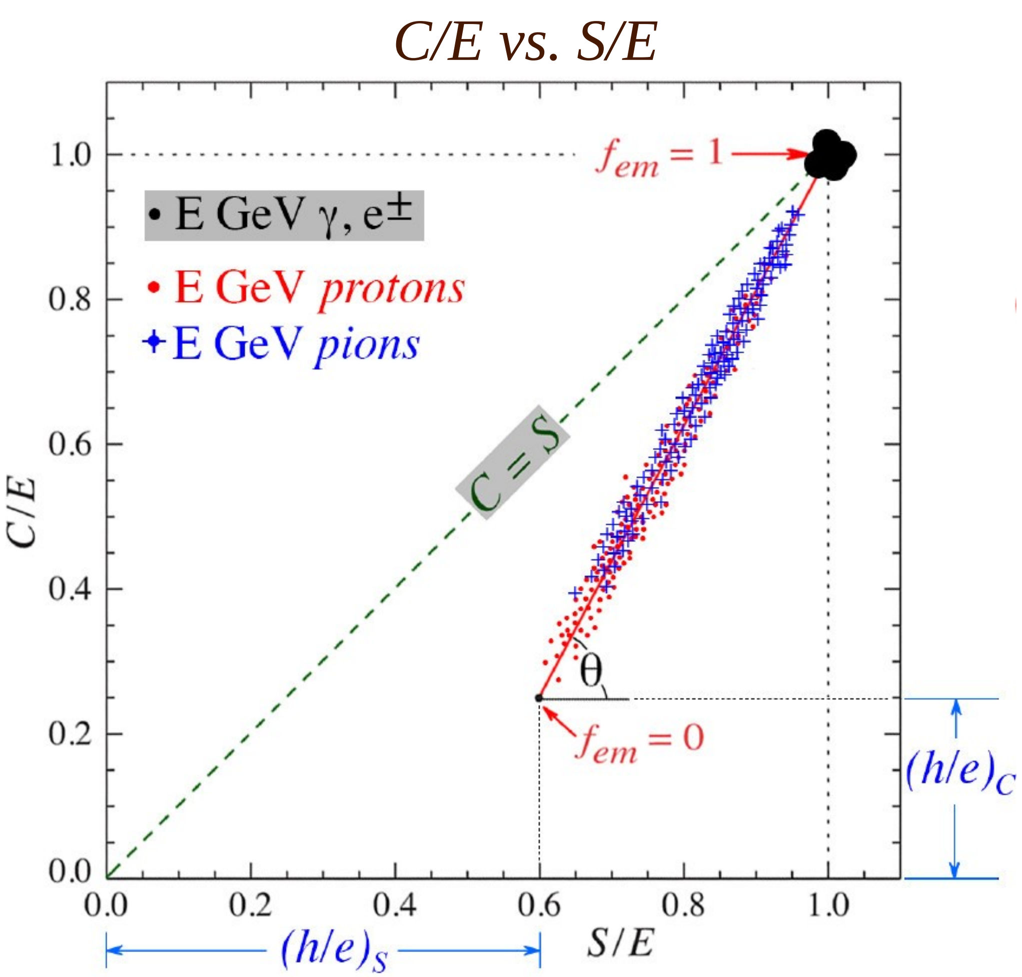
2) need a plan B (Fermilab ?)

3) additional costs ?

Backup

The Alchemy





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

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

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 (!!)

DREAM/RD52 … an historical perspective

Homogeneous Calorimeter	Sampling Calorimeter
Possibility to solve light yield and sampling fluctuation problem. Need to separate C and S light.	Two types of fibers, either sensitive to Cherenkov and Scintillation Separated by construction
2007-11 **Crystals DRC** ***Single Xtals, prove of principles*** • $PbWO_4$ + Pr, Mo doped $PbWO_4$ • BGO • BSO *NIM A 638 (2011) 47* *NIM A 640 (2011) 91* *NIM A 621 (2010) 212* *NIM A 604 (2009) 512* *NIM A 593 (2008) 530* *NIM A 595 (2008) 359* ***Matrixes + DREAM, em section*** • $PbWO_4$ • Doped $PbWO_4$ • BGO *NIM A 598 (2009) 710* *NIM A 686 (2012) 125* *NIM A 610 (2009) 488* *NIM A 584 (2008) 273*	*2003 - 11* **DREAM Cu-fiber** *NIM A 533 (2005) 305* *NIM A 536 (2005) 29* *NIM A 537 (2005) 537* *NIM A 548 (2005) 336* *NIM A 550 (2005) 185* *NIM A 581 (2007) 643* *NIM A 598 (2009) 422* *2010* **Pb - Tile DRC** *INST 9, (2014) C05009* *2012- 16* **Cu, Pb Fiber DRC** *NIM A 762 (2014) 110* *NIM A 735 (2014) 120* *NIM A 735 (2014) 130* *NIM A 808 (2016) 41*

INFN CSN V (2008-2012)

1) DRC (2008-2009): crystals

2) New-DREAM (2010-2012): crystals → Pb/Cu + fibres

Experience with homogeneus (crystal) prototypes:

a) For C and S separation, crystals need *non conventional readout*

→ results not good as w/ standard EM calorimetry

b) Extraction of pure C and S signals implies

- *Large suppression of Č light yield* (optical filters)
- *Issue with Č light due to UV self absorption*

→ lower performance wrt fibre-sampling solutions

Pb/Cu fibre-sampling studies

2012 t.b.: issues with noise and ADC response for low signals

→ *actions/consequences:*

1) (Agostino) add low-noise preamp
2) (CAEN) fix charge integrator (V792AC and V862AC) QDC.s
3) no reliable results for hadronic showers

2013-2014: long shutdown (no testbeam)

2015: first results on hadronic performance

2016: 1 cm^2 *em* prototype w/ SiPM readout *(400, 50×50 μm^2, cells)*

→ *saturation, light leakage*

2017: 1 cm^2 *em* prototype w/ SiPM readout *(1600, 25×25 μm^2, cells)*

→ *non-linearity, (maybe marginal) light leakage*

Our assumptions

1) study of hadronic performance - so far - very crude

2) since 2012, no INFN support → efforts just for testbeam support

3) simulations - so far - very crude as well → need validation

4) design and study of a real detector limited to 4^{th} Detector Concept

5) growing interest for a circular e+e- machine at ZH “pole”

6) detector readout and longitudinal segmentation need to be addressed

(h/e) and χ factors

f_{em} = MC truth (total energy deposited by e^+ and e^-)

E = average contained energy

C, S = signals

either:

$f_{em} \rightarrow 0$: C/E, S/E → (h/e)

or:

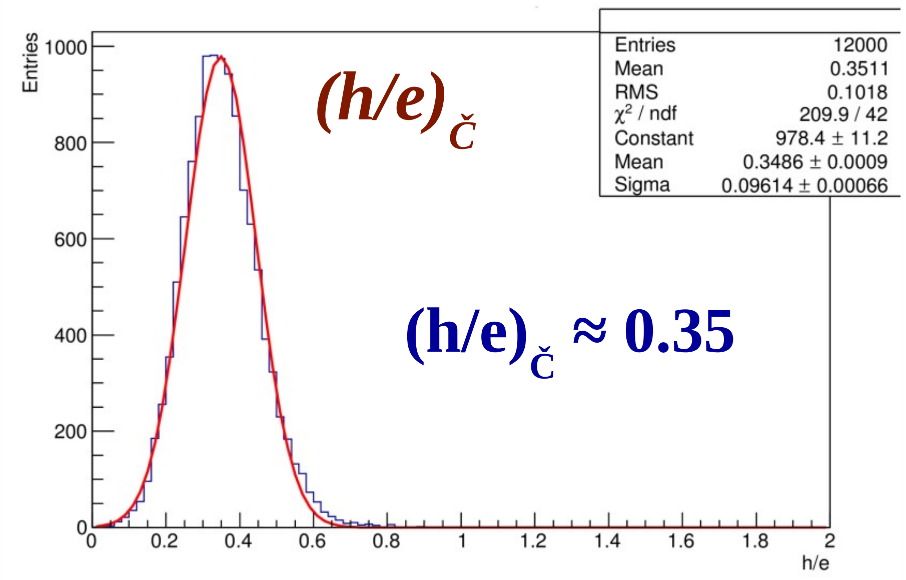
$$(h/e)_{Č} = (C/E - f_{em}) / (1 - f_{em})$$

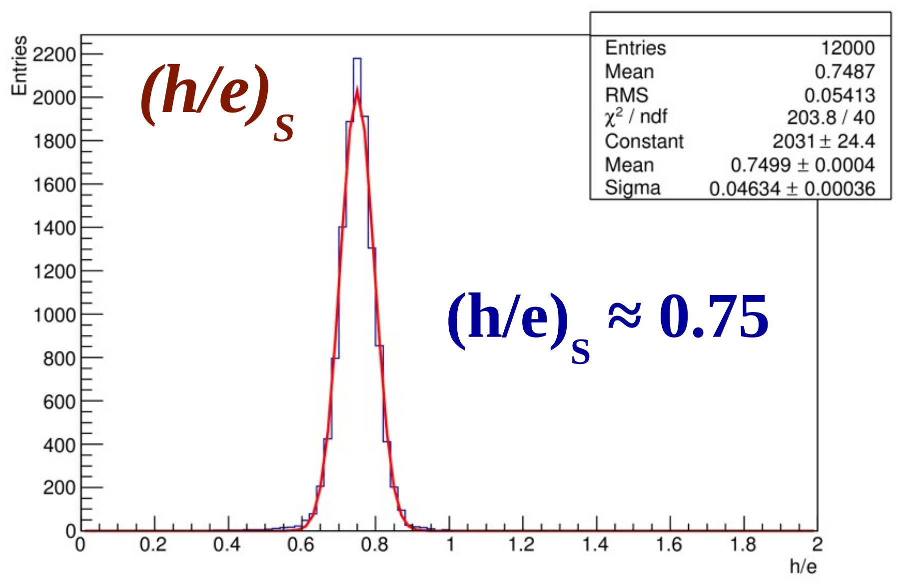
$$(h/e)_{S} = (S/E - f_{em}) / (1 - f_{em})$$

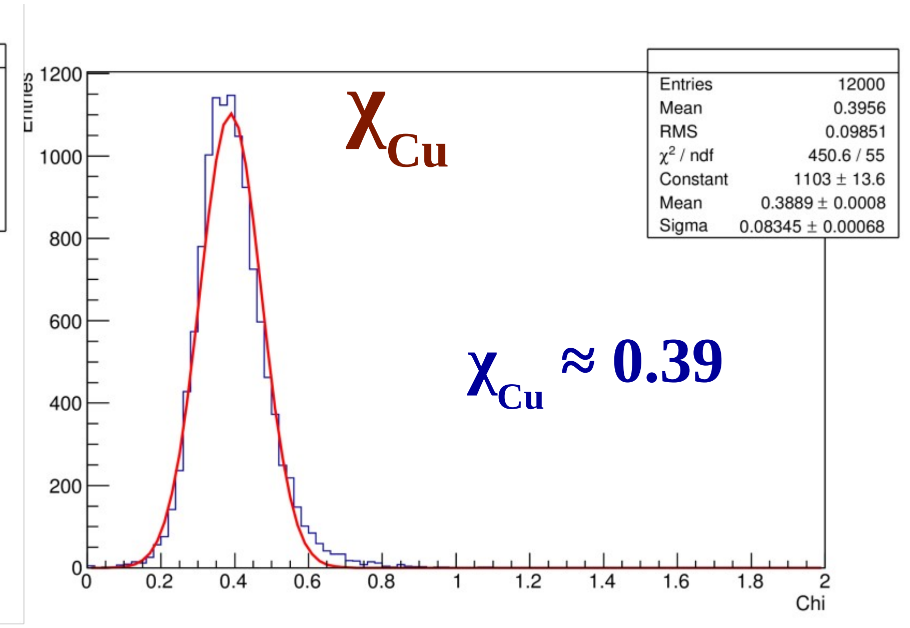
while:

$$\chi = (1 - (h/e)_S) / (1 - (h/e)_{Č}) = (E - S) / (E - C)$$

(h/e) and χ factors



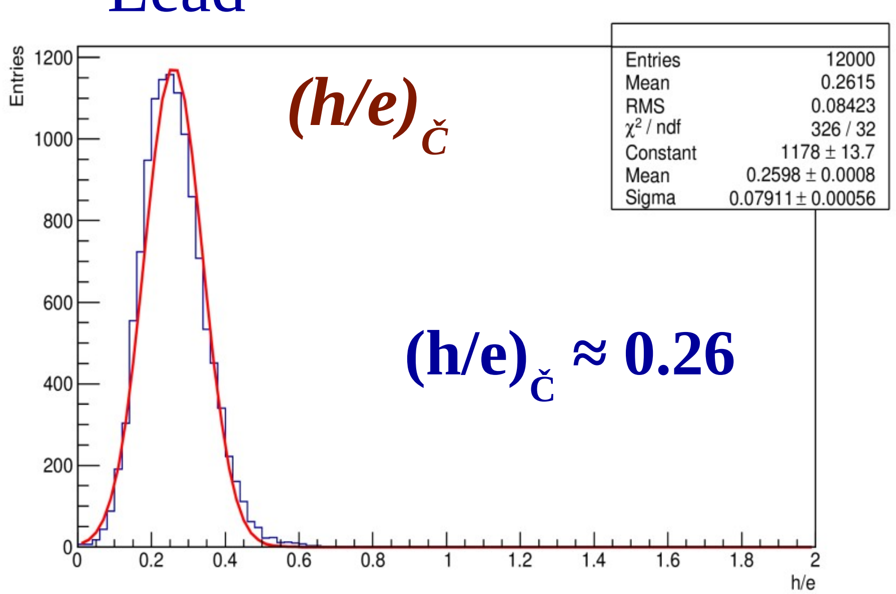


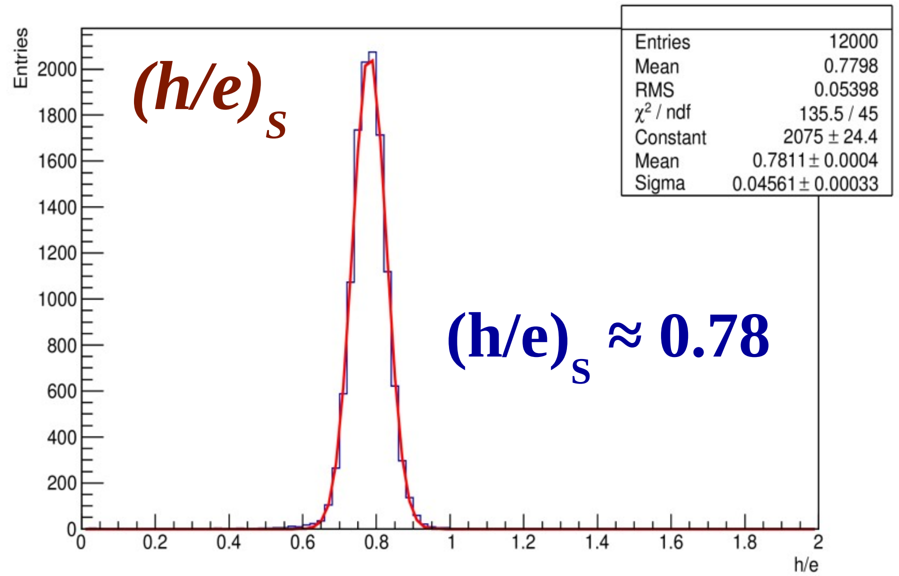


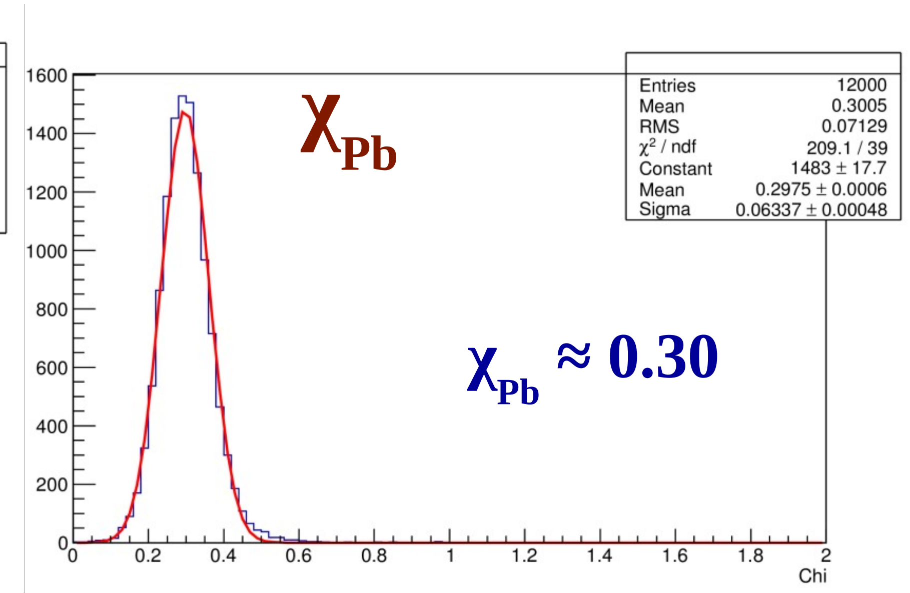
Copper →

80 GeV protons in Copper ↑ & Lead ↓

Lead →

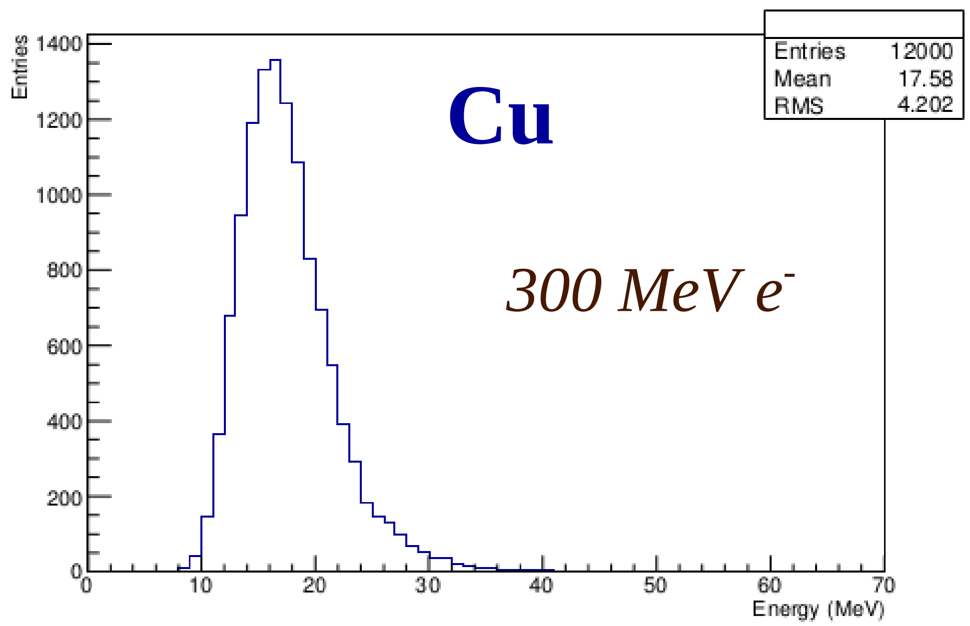


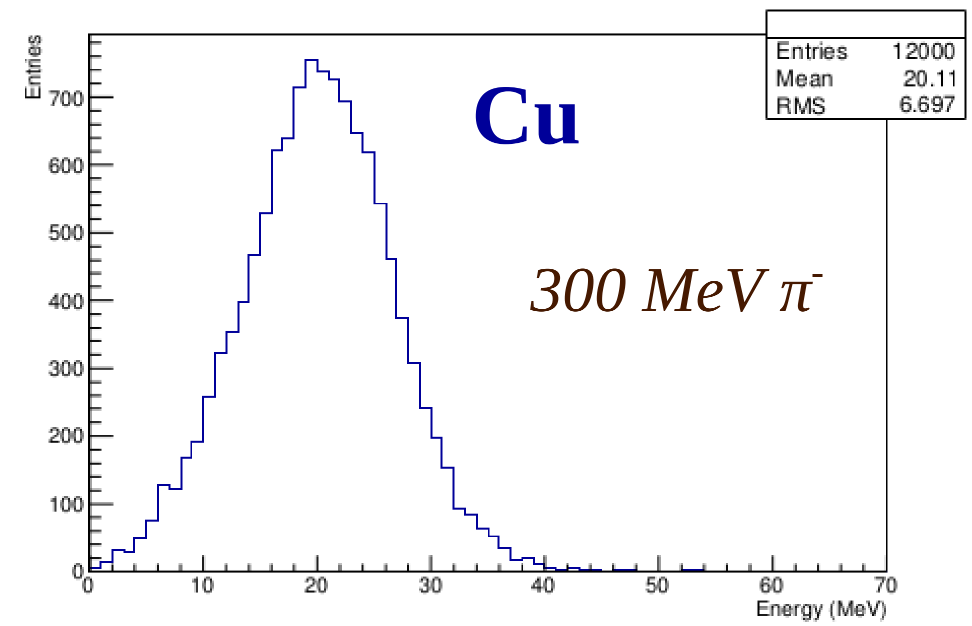


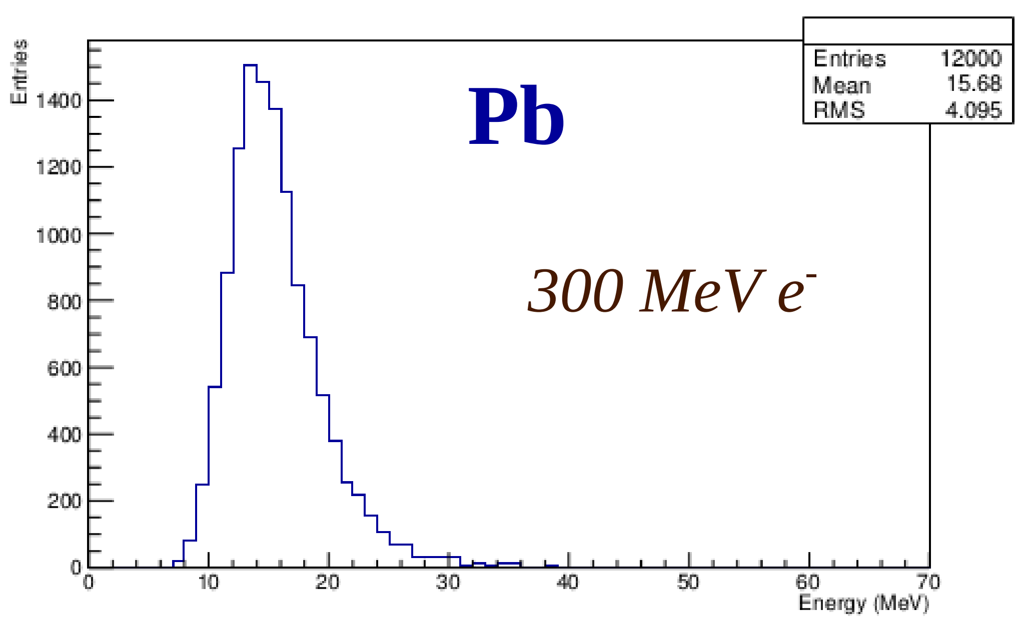


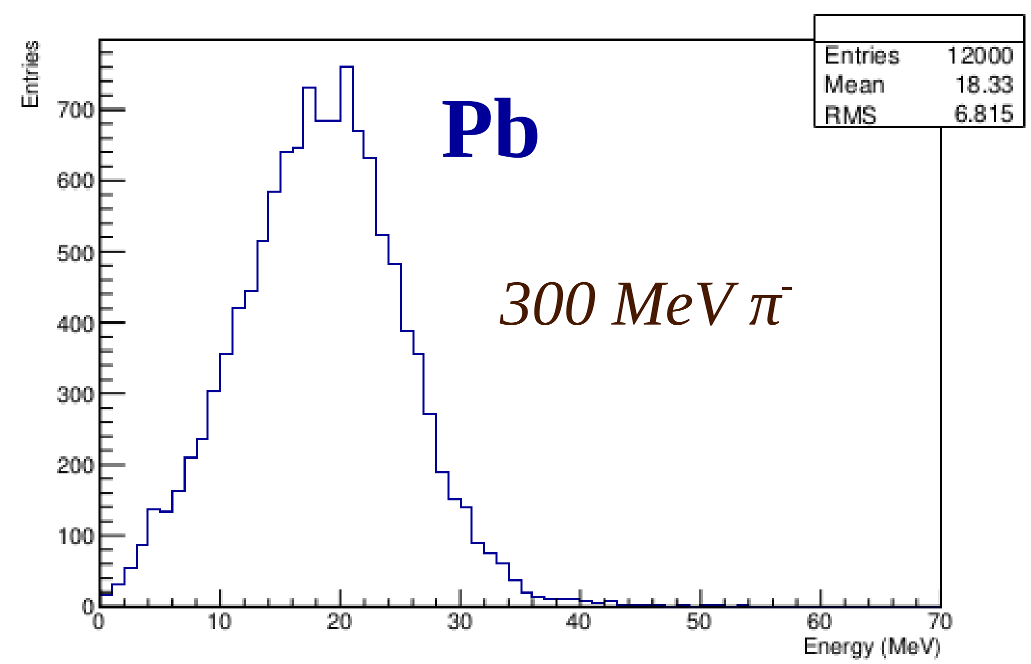
Low-energy performance - Copper vs. Lead

Energy deposited in scintillating fibres









longitudinal segmentation

in order to implement particle flow algorithms

3 possible ways:

a) a real segmentation (em and had compartiments)

b) dual (displaced) fibre arrangement

c) timing (ToT, ToA, peaking time)

Mechanics/Sensors/Electronics

Mechanics:

from ~O(~1 cm^2) → 5×5 / 10×10 cm^2 few modules

Sensors:

→ SiPM performance: go to 10×10 μm^2, 10000 pixels, sensors

→ follow developments on SiC devices (meant to be solar light blind and provide exclusive UV sensitivity) ?

Electronics:

search for SiPM tailored multi-channel ASIC.s

→ test channel grouping / adding (1, 3, 5, 6 channels summed up)

target: demonstrate the feasibility of a scalable solution made of ~10×10 cm^2 modules w/ 5000-10000 fibres, individually coupled to electronics

Readout

We have this:

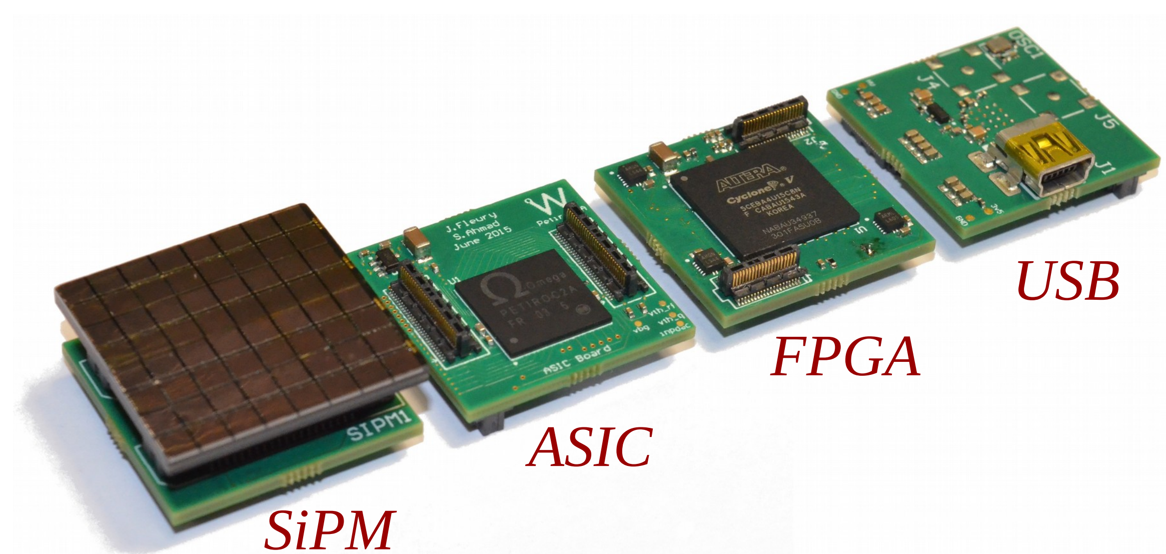
:-)

- *32-channel read out system*
- *FPGA based charge integration algorithm*
- *data: event timecode and integrated charge for all pixels*

  → need something more tailored (shorter integration time, time information, peak/charge ratio, ...)

but we would like this:

:-(



first step: ASIC (to be identified)

Conclusions

Preliminary results look very interesting, nevertheless what can be obtained in a real experiment has to be demonstrated/quantified

1) We believe we need (at least) a 3-year R&D plan on mechanics, frontend electronics, readout in order to develop a scalable solution made of:

a) ~10×10 cm^2 modules w/ 5000-10000 fibres,

b) individually coupled to photo-detectors

c) w/ data compression/reduction readout

d) feature-extraction processor (?), ...

2) G4 Simulations and test with beam … long list:

a) terminate Cu & Pb characterisation

b) evaluate impact of finite attenuation length

c) evaluate need/impact of longitudinal segmentation

d) jet ($\tau \rightarrow$ had) em/had component separation

e) performance in a realistic integrated 4π detector

f) physics performance (W, Z, H, ...)!

g) particle flow algorithms

+ G4 VALIDATION w/ RD52 lead prototype