

PRELIMINARY RESULTS FROM THE TEST BEAM OF TWO ADRIANO PROTOTYPES FOR ILC

Corrado Gatto (INFN)

On behalf of

T1015 Collaboration

LCWS2014

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Fermilab
+
INFN
Collaboration

ADRIANO: A Dual-Readout Integrally Active Non-segmented Option

ADRIANO

2014




ADRIANO: A Dual-Readout Integrally Active Non-segmented Option

- Absorber and Čerenkov radiator: 10 grooved lead glass plates ($\rho = 5.6 \text{ gr/cm}^3$) 6.5mm x 10mm x 1050 mm readout by 8 or 6 WLS fibers
- Čerenkov light collection: WLS fiber optically coupled to glass
- Scintillation region ADRIANO 2014A: 10 scintillating plates, 2mm x 10mm x 1000mm, readout by 6 WLS
- Scintillation region ADRIANO 2014B: scintillating fibers, dia. 1mm, pitch 3.9 mm (total 200/cell) optically separated from glass
- Readout: Hamamatsu 647 PMT's and SiPM from BKF and STM
- CoG z-measurement: time division applied to SCSF81J fibers or glass (readout with 3.2 Gsa/s digitizer)
- Small $\text{tg}(\theta_{S/Q})$: due to WLS running longitudinally to cell axis ($\theta_{\text{Čerenkov}} < \theta_{\text{Snell}}$ for slower hadrons).

- Fully modular structure
- 2-D with longitudinal shower CoG via light division techniques

Rationale Behind ADRIANO Project

1. **Dual-readout calorimeter**

- Compensation evt-by-evt  smaller σ_E/E
- $\sigma_E/E \propto 1/\sqrt{E}$
- Particle ID (from S vs \check{C})
- $\sim 10^5$ channels for typical 4π detectors
- Can be calibrated with e^- only

2. **Integrally active**

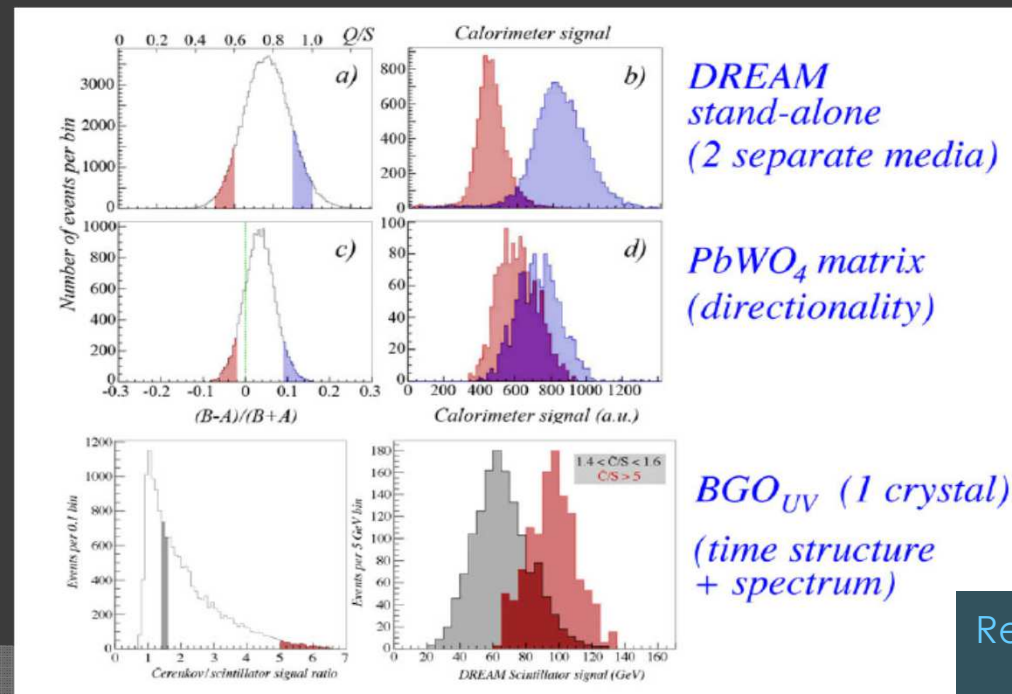
- No passive absorber (glass + scintillating plastics)
- It works as EM and Hadronic calorimeter at the same time

Rationale Behind ADRIANO Project (cont'd)

- Scintillating and Cerenkov light in *OPTICALLY SEPARATED MEDIA*: ->non-homogeneous detector
 - Use the absorber as Cerenkov component of dual-readout
 - Use scintillating fibers for the second component
 - Control the scintillation/Cerenkov with appropriate pitch between fibers

Separation efficiency between S & Č components

Hydrogen in plastic
important
element for
neutron



Report from DREAM
Collaboration

Rationale Behind ADRIANO Project (cont'd)

- Use heavy glasses rather than crystals

	Glass	Crystals
Light production mechanism	Only Cerenkov (minor fluorescence with some SF glasses)	Cerenkov + scintillation
Stability vs ambiental (temperature, humidity, etc)	Excellent	Varies, but generally poor
Stability vs purity	Very good if optical transmittance is OK	Very poor
Longitudinal size	Up to 2m	20-30 cm max
Cost	0.4-0.8 EUR/cm ³	10-100 EUR/ cm ³
Time response	prompt	Slow to very slow (with exceptions)
n _d	1.85-2.0 (commercially available) 2.25 (experimental)	1.85-2.3
Density	6.6 gr/cm ³ (commercially available) 7.5 gr/cm ³ (experimental)	Up to 8-9 gr/cm ³
Radiation hardness	Medium (recoverable via UV annealing for Pb-glass) or unknown (for Bi-glass)	varies

- Glasses are amorphous rather than lattice structured
- Čerenkov light yield is high: need smart way to capture it

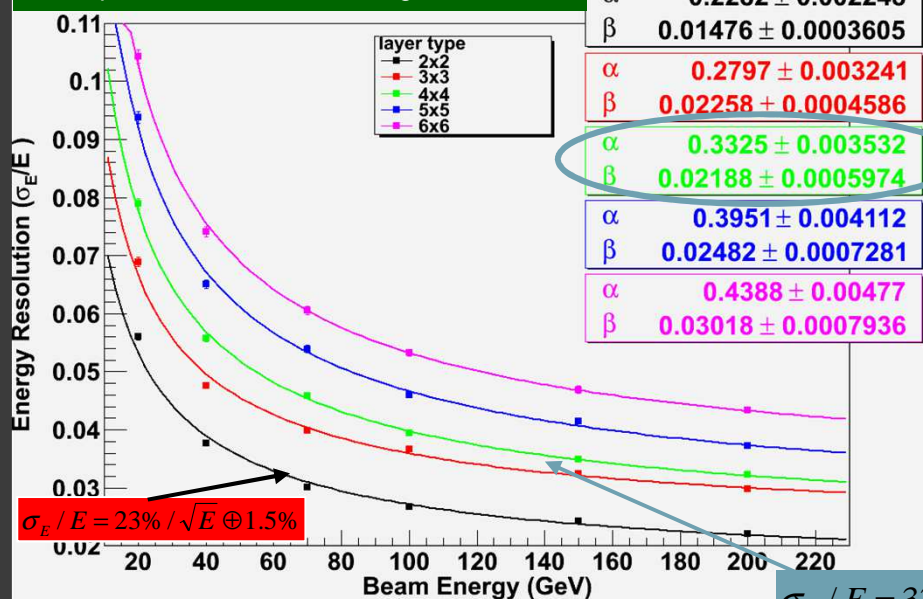
ADRIANO Simulations in ILCroot

Integrally Active with Double side readout (ADRIANO)

Pitch [mm ²]	2x2	3x3	4x4	5x5	6x6	4x4	4x4	4x4
Diameter	1mm	1mm	1mm	1mm	1mm	1.4mm	2mm	capillary
$\langle pe_s / \text{GeV} \rangle$	1053	430	254	163	124	500	110	250
$\langle pe_c / \text{GeV} \rangle$	340	360	360	355	355	355	350	350

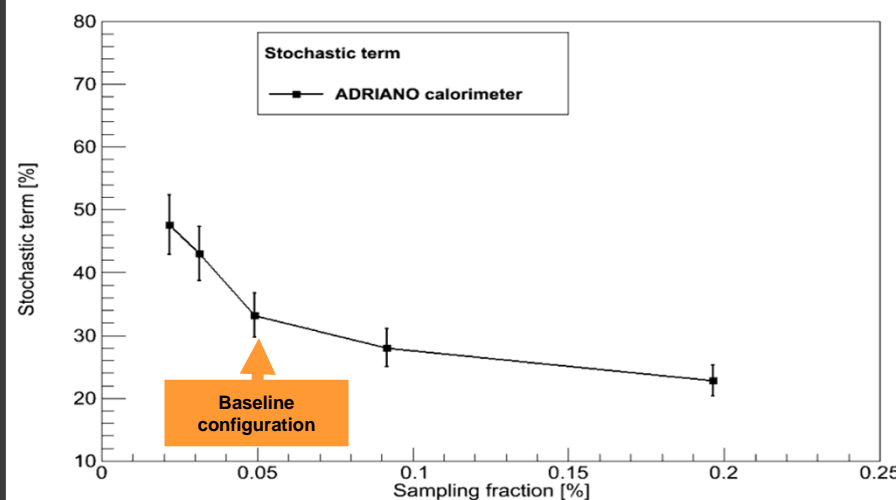
Baseline configuration
Active area/total detector surface = 8%

Fiber pitches: 2mmx2mm through 6mmx6mm

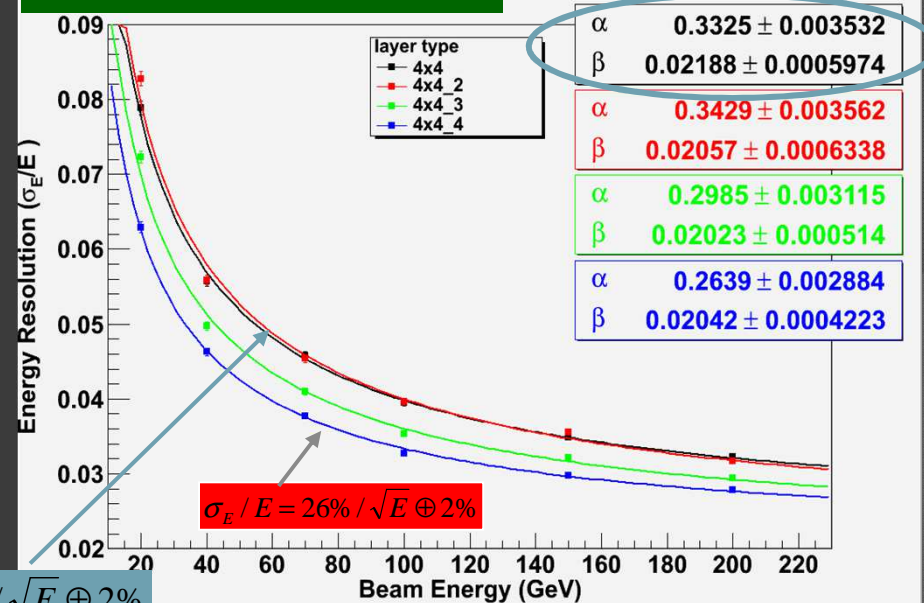


$\sigma_E/E = 33\% / \sqrt{E} \oplus 2\%$

Resolution vs Scifi sampling fraction - ADRIANO Calorimeter



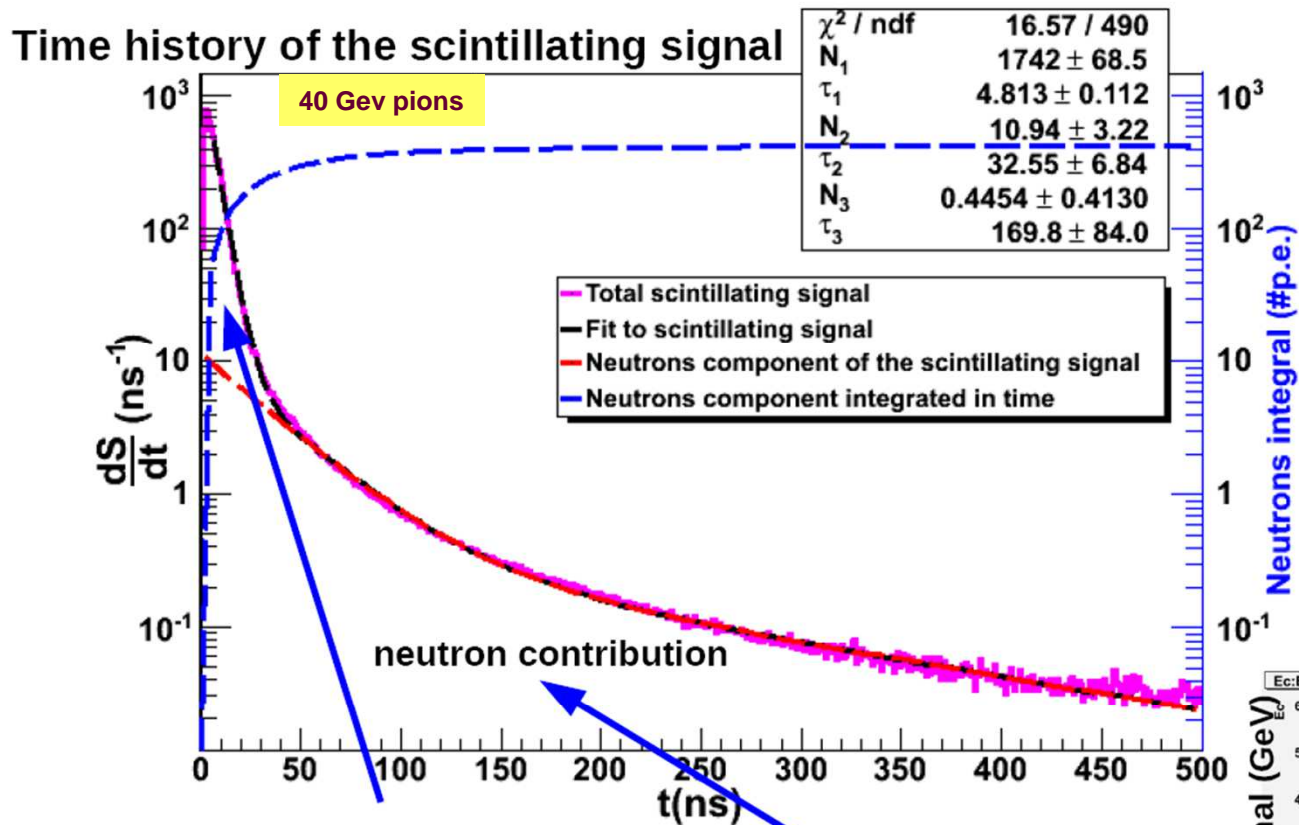
fiber diameter: 1mm – 1.4mm – 2 mm



All numbers include the effect of photodetector QE

From Dual to Triple Readout

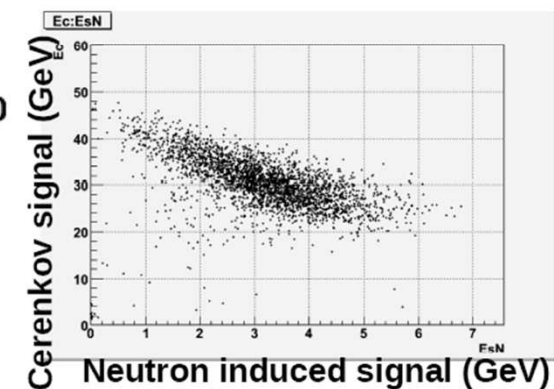
Disentangling neutron component from waveform



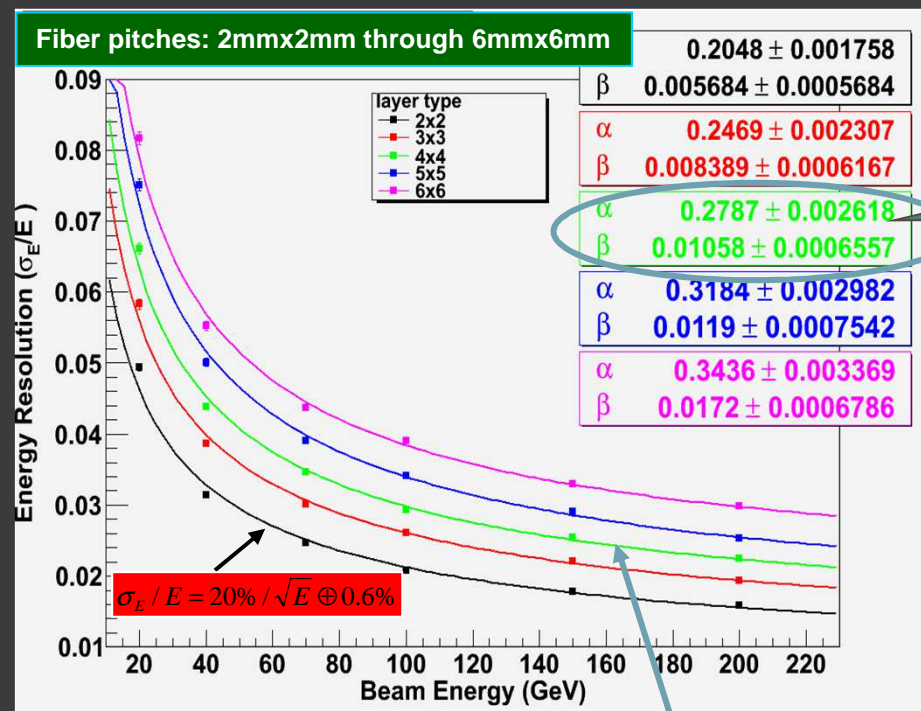
• The distribution has been fitted with a triple exponential function.

• After 50 ns only neutrons contribute to the signal.

$$E_{\text{shower}} = \frac{S_{\text{fast}} - \chi C}{1 - \chi} + \xi S_{\text{slow}}$$



ADRIANO in Triple Readout configuration

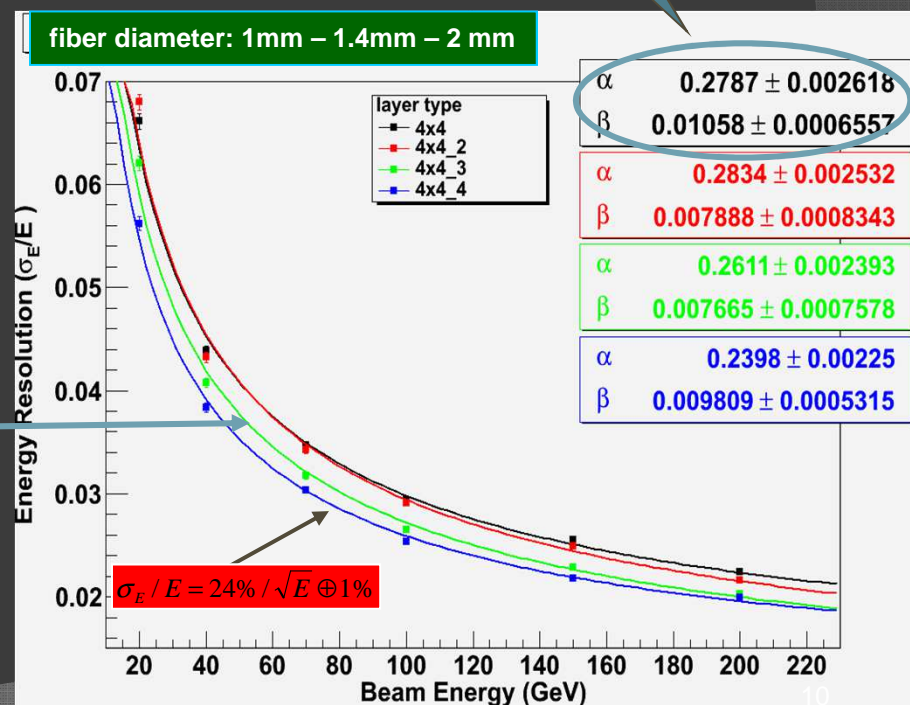


Baseline configuration
Active area/total detector surface = 8%

$$\sigma_E / E = 28\% / \sqrt{E} \oplus 1\%$$

Compare to ADRIANO in
Double Readout configuration

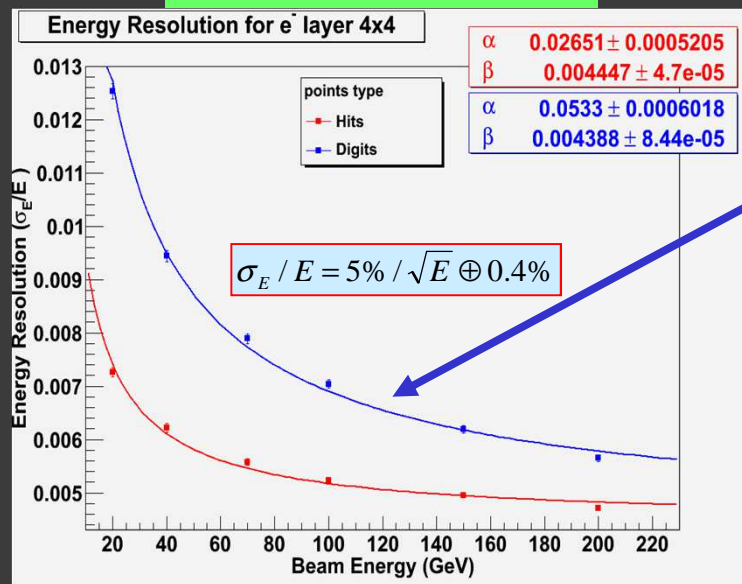
$$\sigma_E / E = 33\% / \sqrt{E} \oplus 2\%$$



ADRIANO EM Resolution (with and without instrumental effects)

- Compare standard Dual-readout method vs Čerenkov signal only (after electron-ID)
- Blue curve includes instrumental effects. Red curve is for perfect readout

Use only Čerenkov light

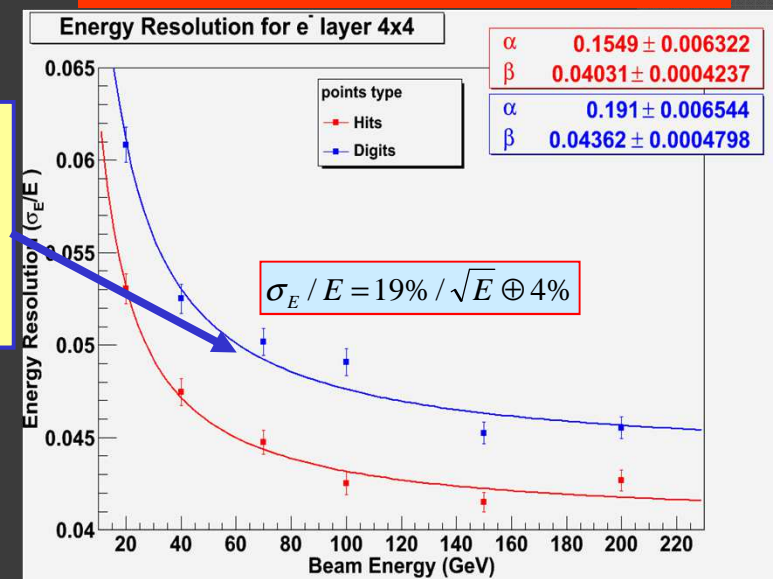


Blue curve includes:

- SiPM's ENF
- Constant noise
- Fiber non-uniformity
- 14 bit ADC
- 3pe threshold

ILCroot simulations

Dual-readout (scintillating+Čerenkov)



- Using Čerenkov signal only for EM showers gives $5\%/\sqrt{E}$ energy resolution while full fledged dual-readout gives only $19\%/\sqrt{E}$ (including FEE effects)

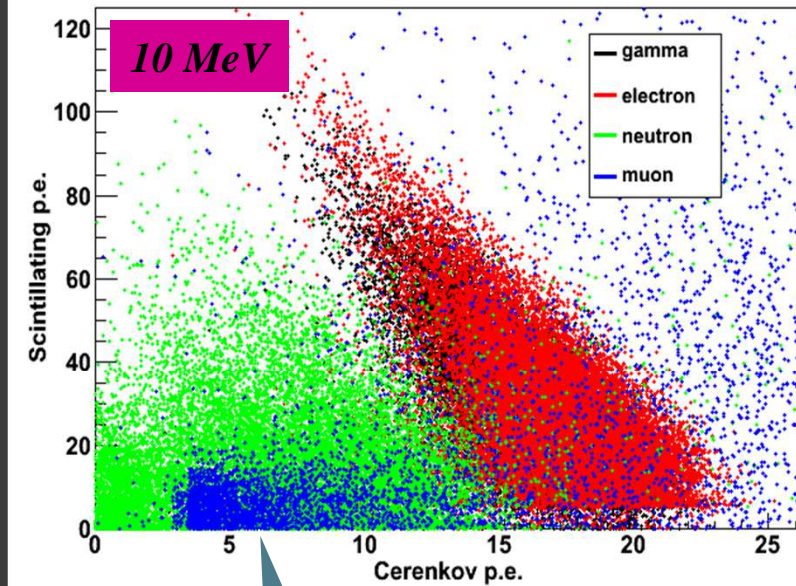


ADRIANO does not need a front EM section

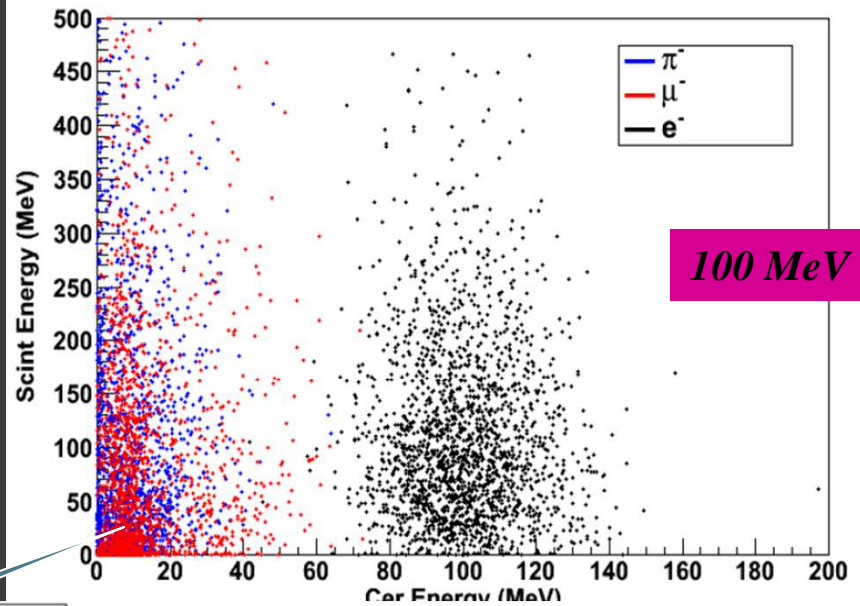
If Čerenkov lighth yield is large enough

Particle ID with ADRIANO

S vs C p.e. @ 10 MeV

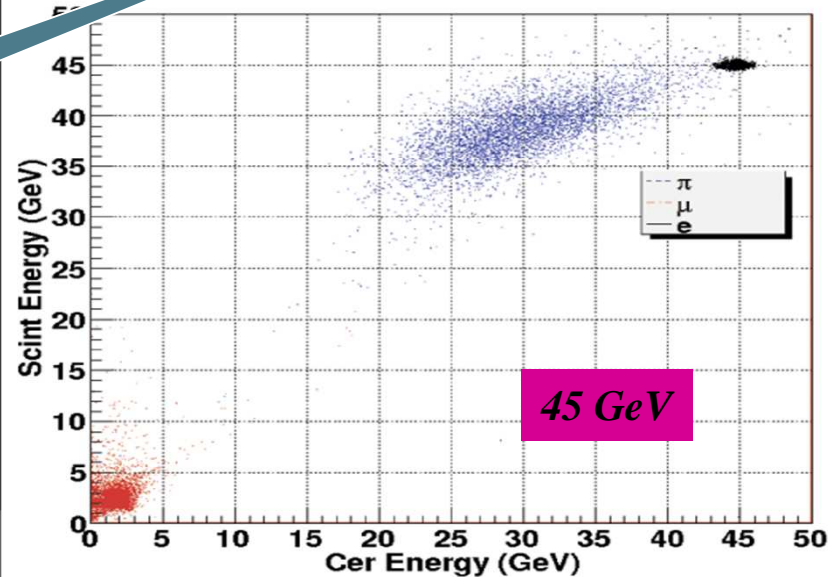


Cer Energy vs Scint Energy



ADRIANO for
ORKA

Cer Energy vs Scint Energy



T1015 R&D Program

- Seven test beam at FTBF by the summer 2014: 15 ADRIANO prototypes of different sizes and configurations. One test beam in November 2014
- 4 glass type: lead and bismuth based + scintillating Ce doped glass
- 4 glass coatings: TiO_2 , Silver paint, clear acrylic, BaSO_4
- 3 WLS fibers: Y11 (1.2mm) & BCF92 (1.0, 1.2 mm)
- 1 Scintillating fiber: SCSF81
- 1 scintillating plate: 2mm thick extruded (thinnest ever extruded)
- 4 scifi coating: TiO_2 , BaSO_4 , Silver paint, Al sputter
- Several optical glues (mostly homemade)
- Many photodetectors: SiPM (IRST, STM, round, square, etc.) & 3 PMT (P30CW5 , R647, H3165)
- 4 light coupling systems: direct glass + direct WLS + 4 light concentrators

Goals are:

- *Maximize light yield (Cerenkov)*
- *Measure parameters for Montecarlo simulations*
- *Hopefully test the dual-readout concept (size limited)*



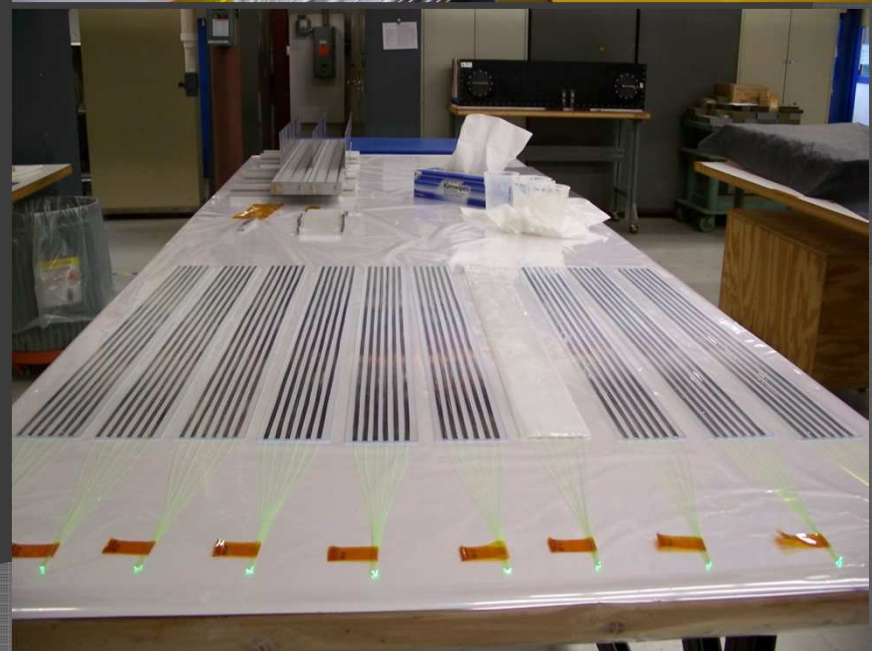
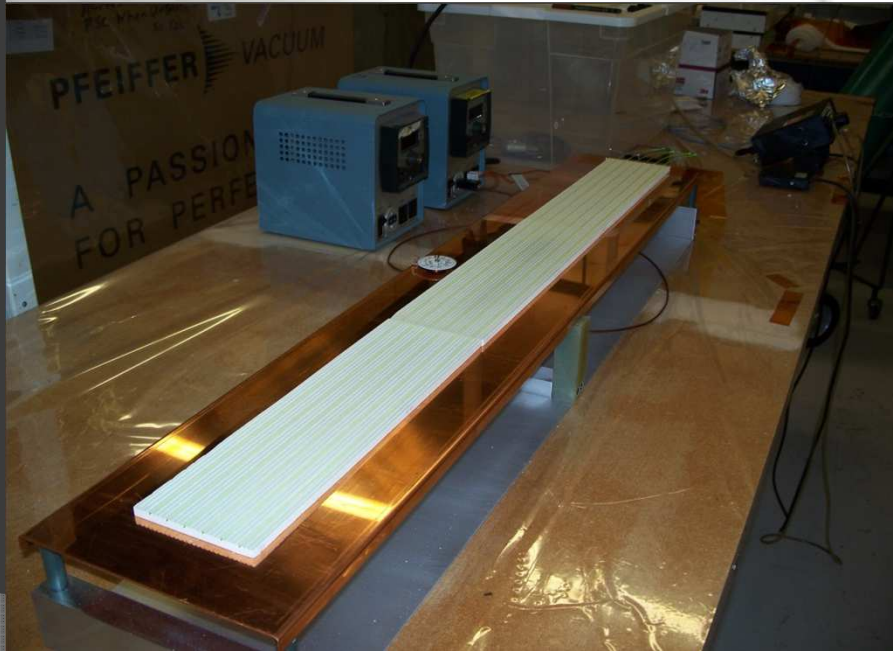
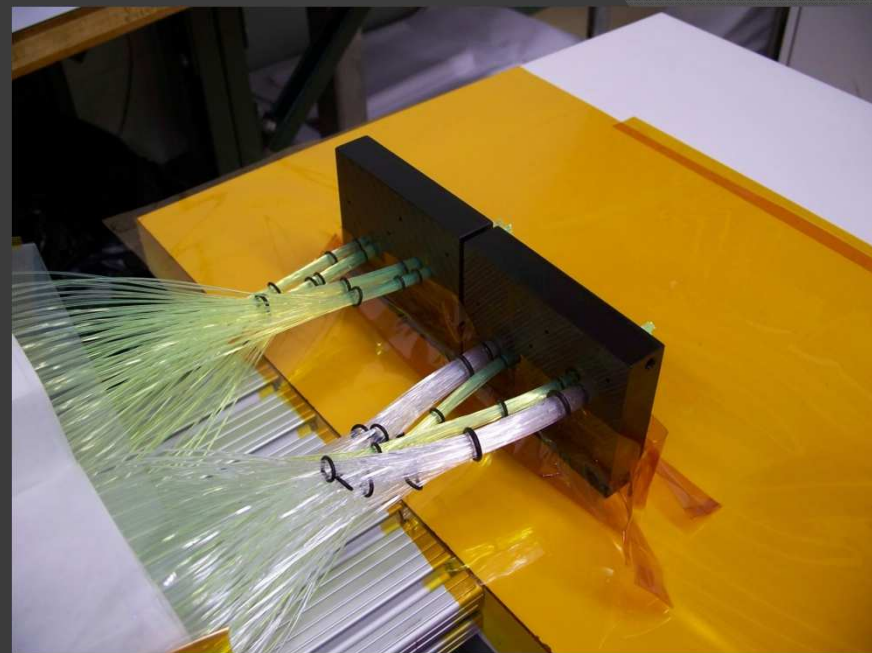
ADRIANO 2014

Detector construction

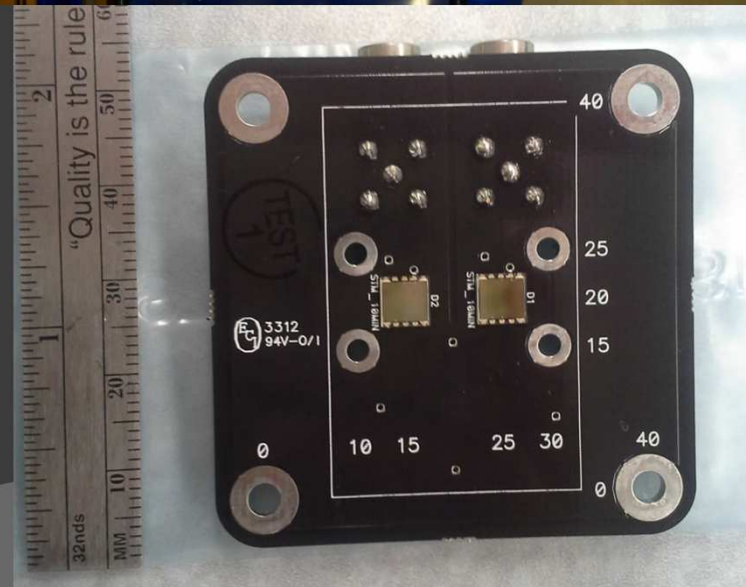
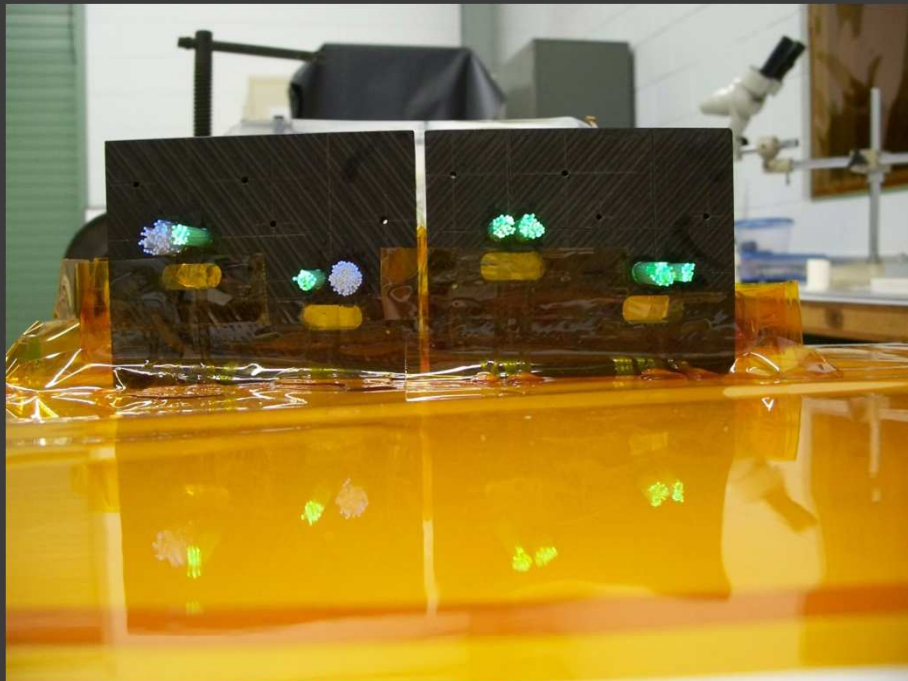


ADRIANO 2014

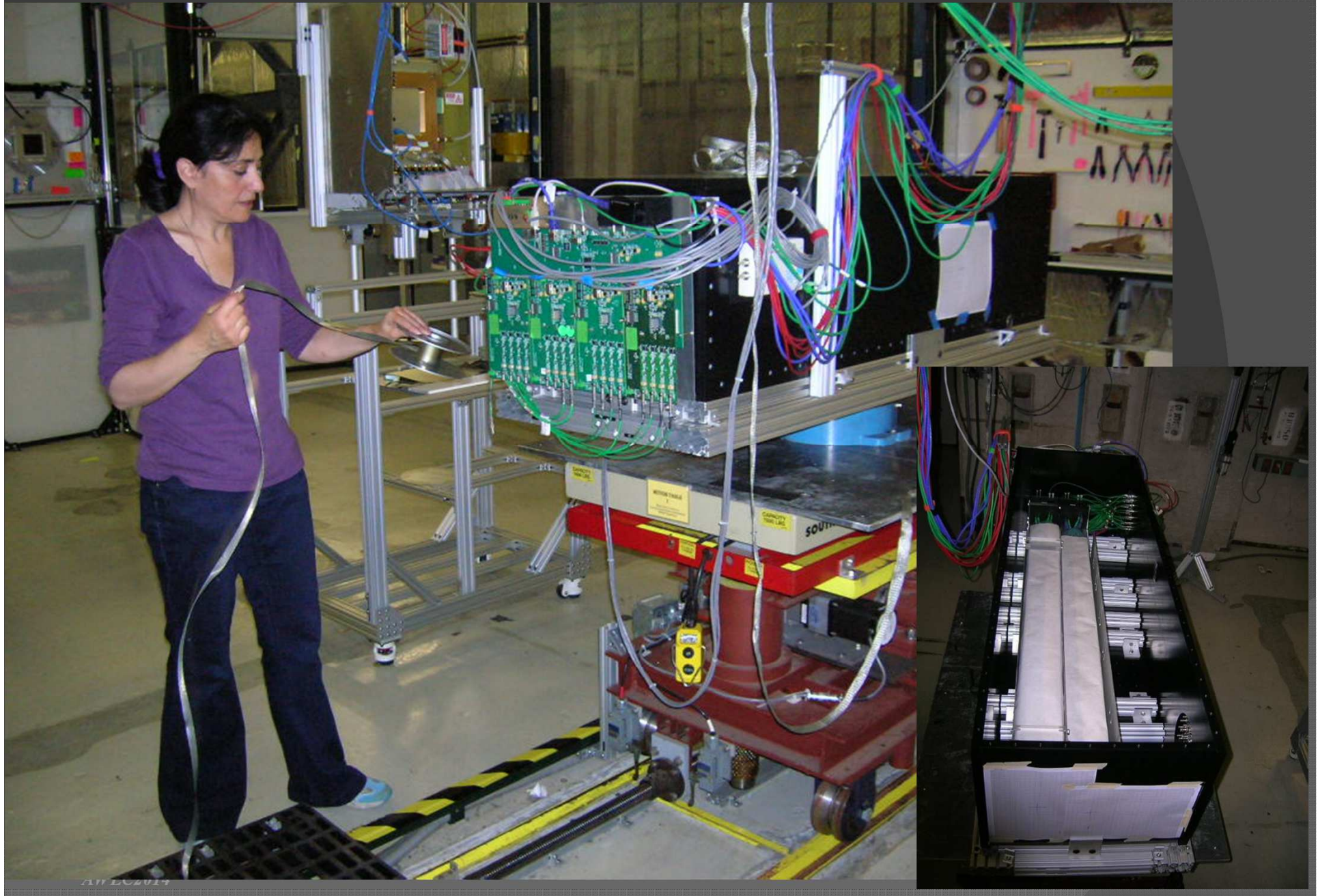
Detector assembly



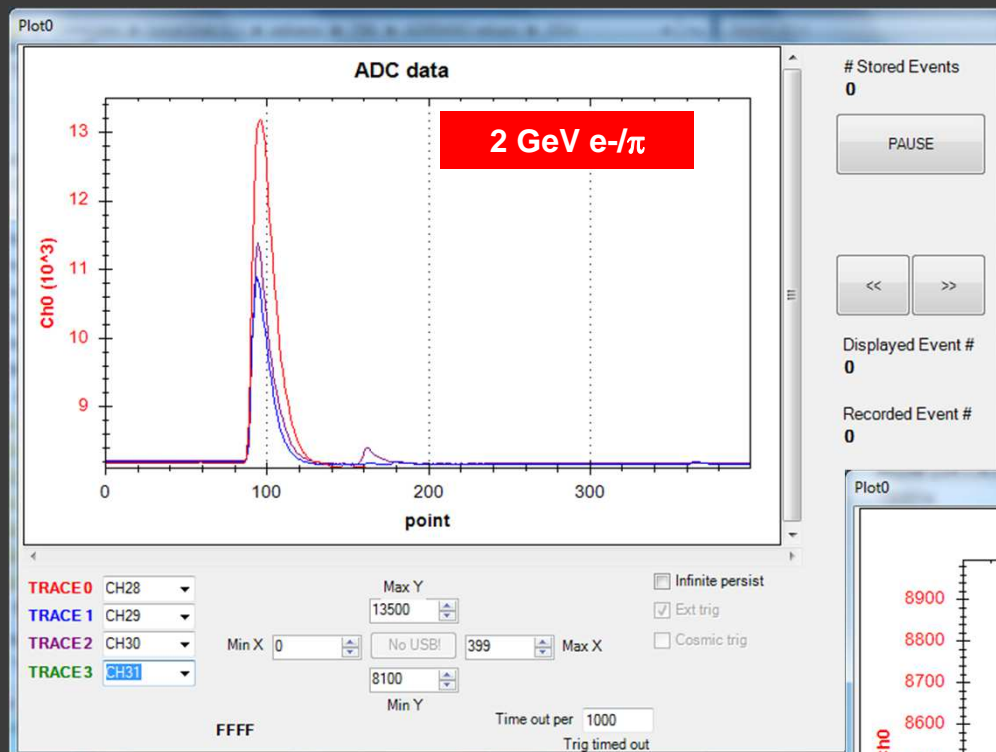
ADRIANO 2014



2014 Test Beam Setup at FTBF

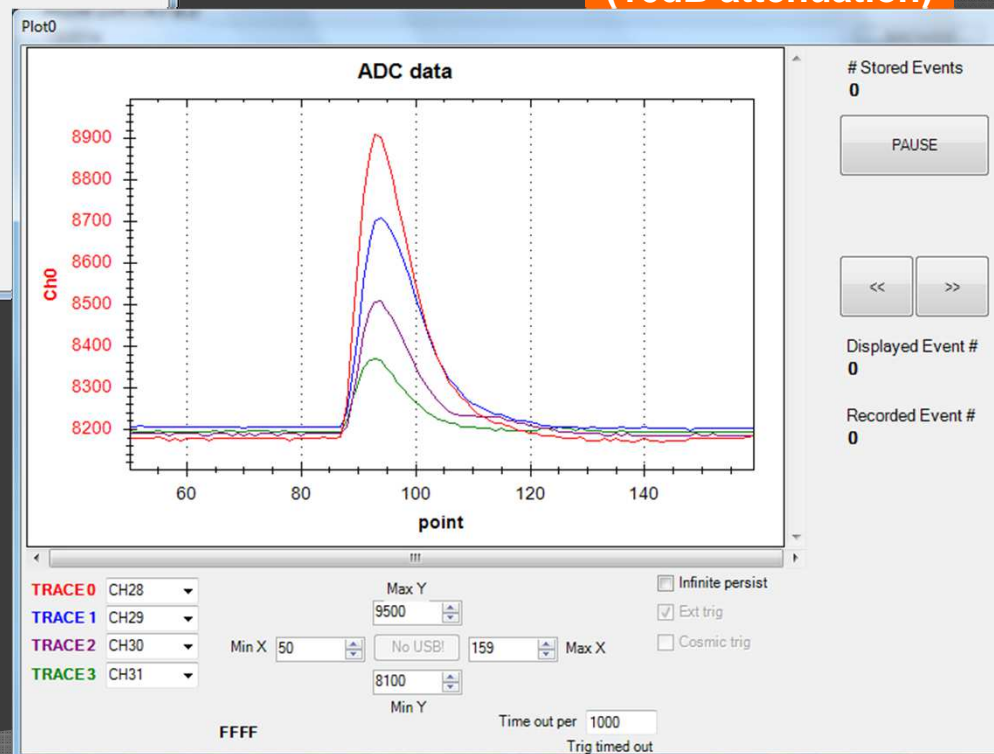


Waveforms from TB4 DAQ (FTBF)



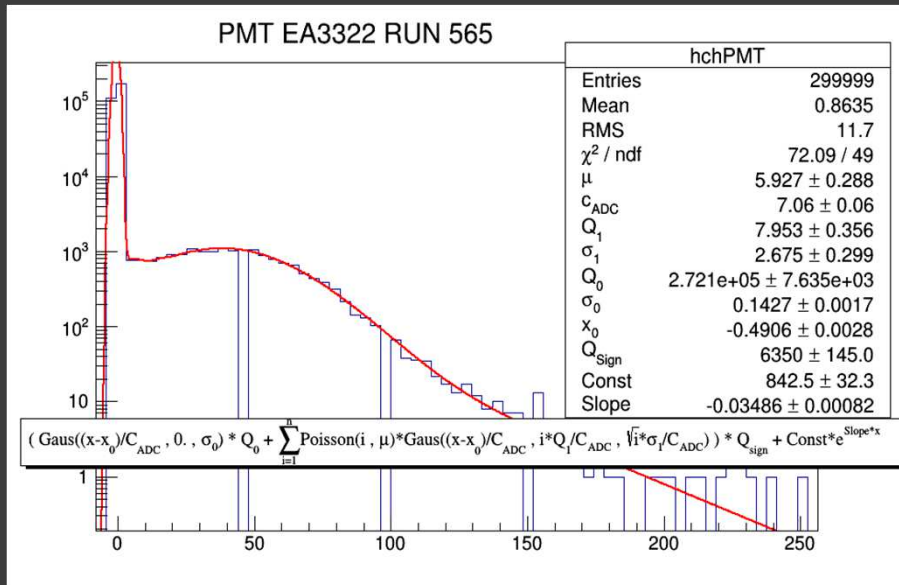
ADRIANO 2014A

ADRIANO 2014B
(16dB attenuation)



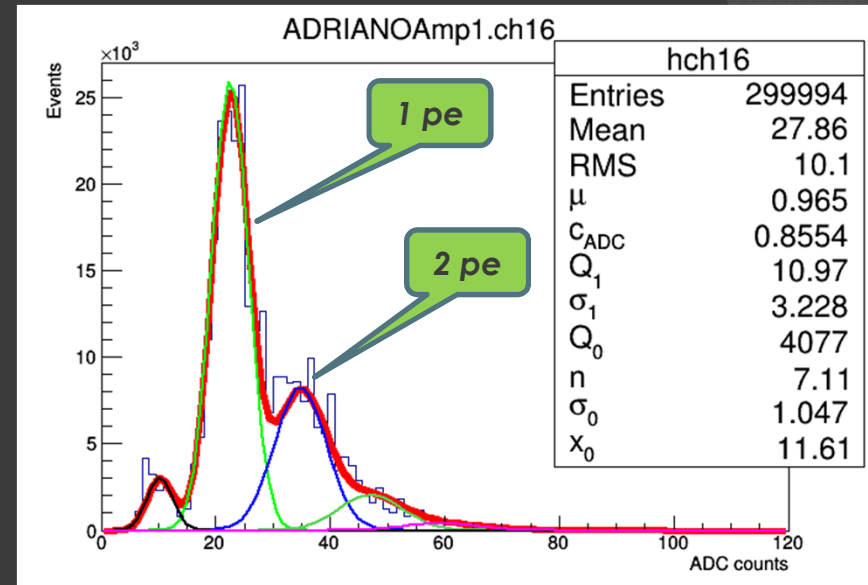
PMT's and SiPM Calibration

PMT Calibration



UV based fast LED with fast pulser
Fit with Bellettini et al. function

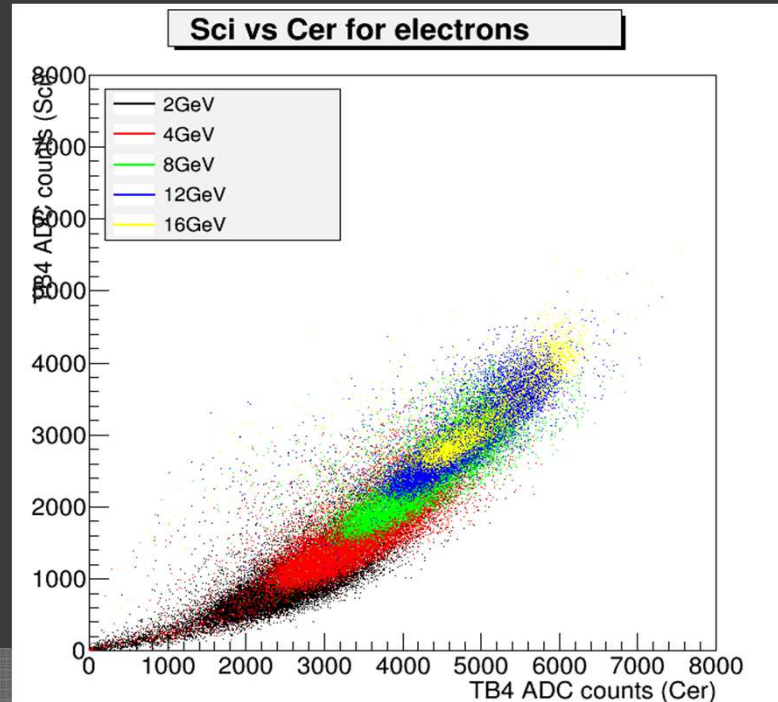
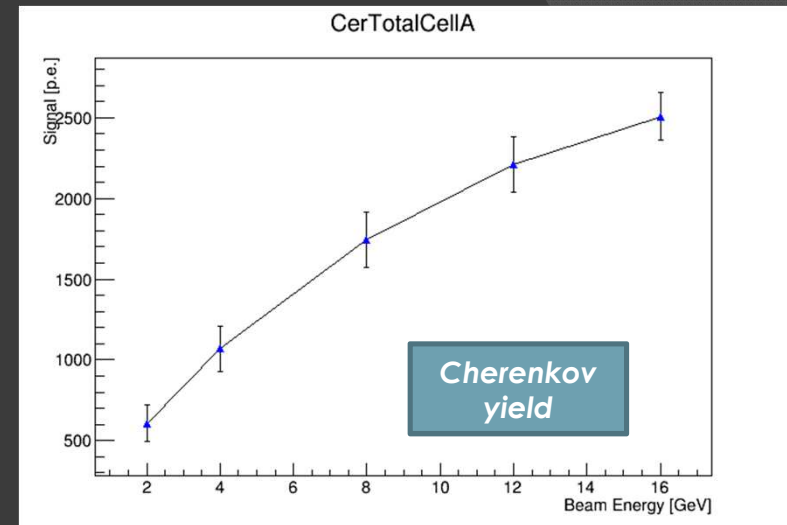
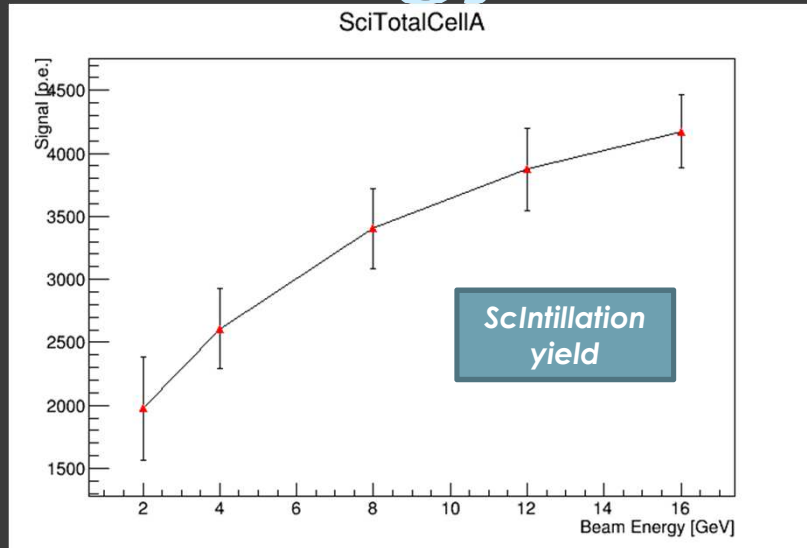
SiPM Calibration



Spurious pulse – 1 pe
Fit with 2 gaussians + poisson

$$\left(\text{Gaus}\left(\frac{x-x_0}{C_{\text{ADC}}}, 0, \sigma_0\right) * Q_0 + \sum_{i=1}^n \text{Poisson}(i, \mu) * \text{Gaus}\left(\frac{x-x_0}{C_{\text{ADC}}}, i * Q_1 / C_{\text{ADC}}, \sqrt{i} * \sigma_1 / C_{\text{ADC}}\right) \right) * Q_{\text{sign}} + \text{Const} * e^{\text{Slope} * x}$$

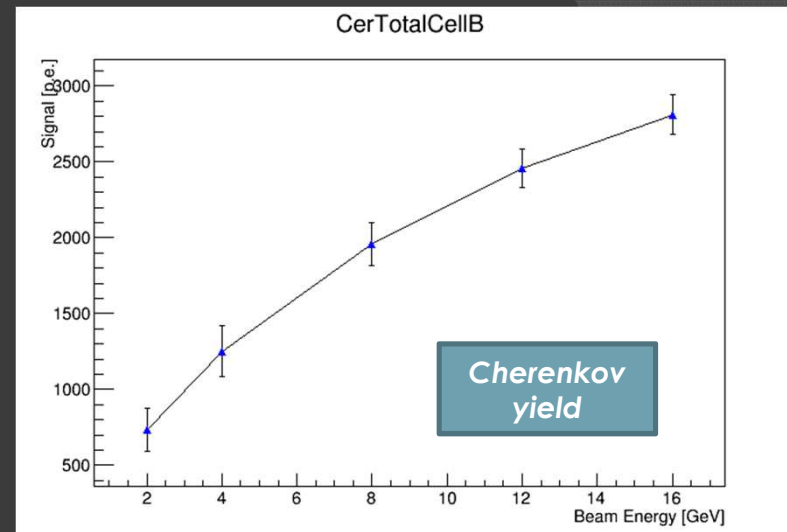
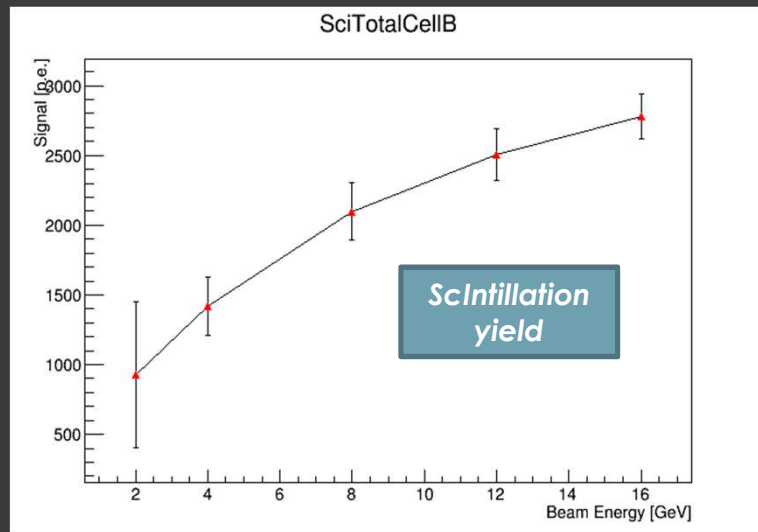
Energy scan with electrons



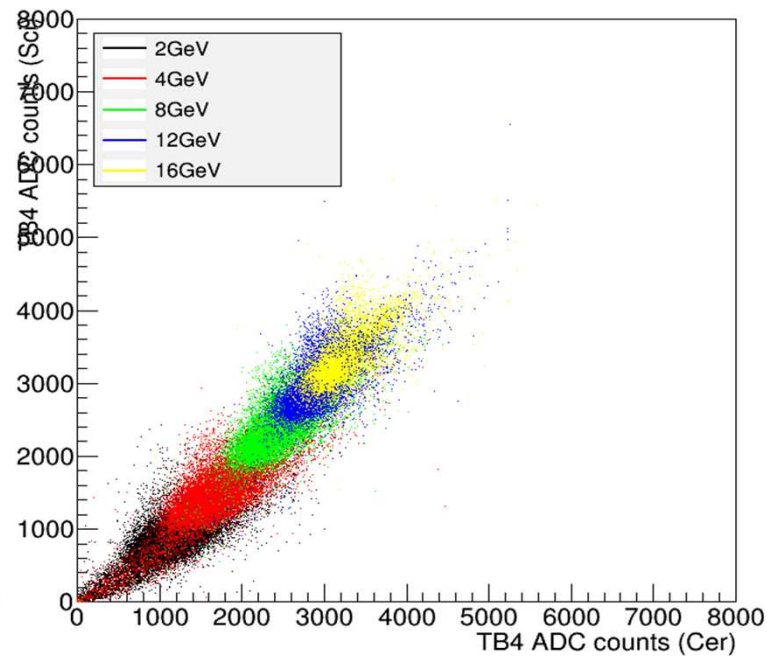
ADRIANO 2014A

- Electrons selected with Cherenkov systems at FTBF

Energy scan with electrons



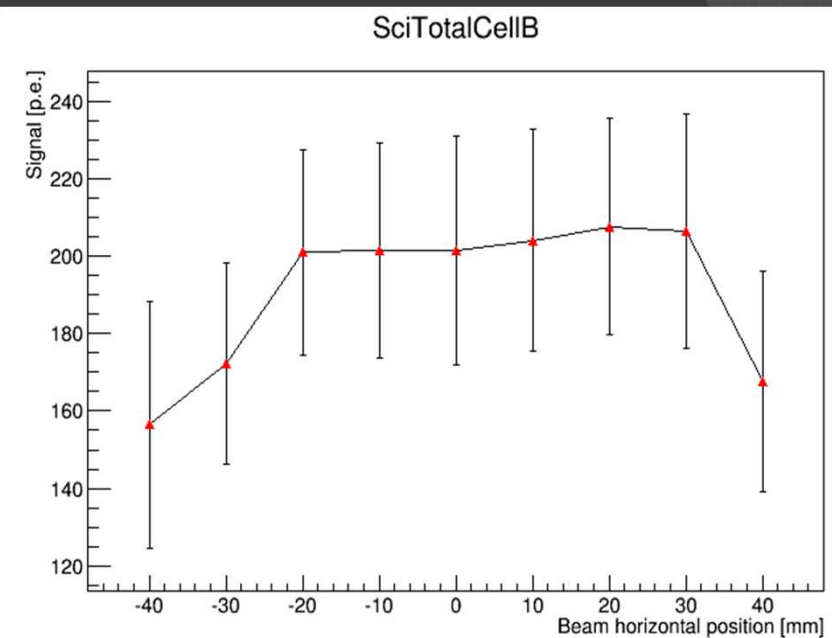
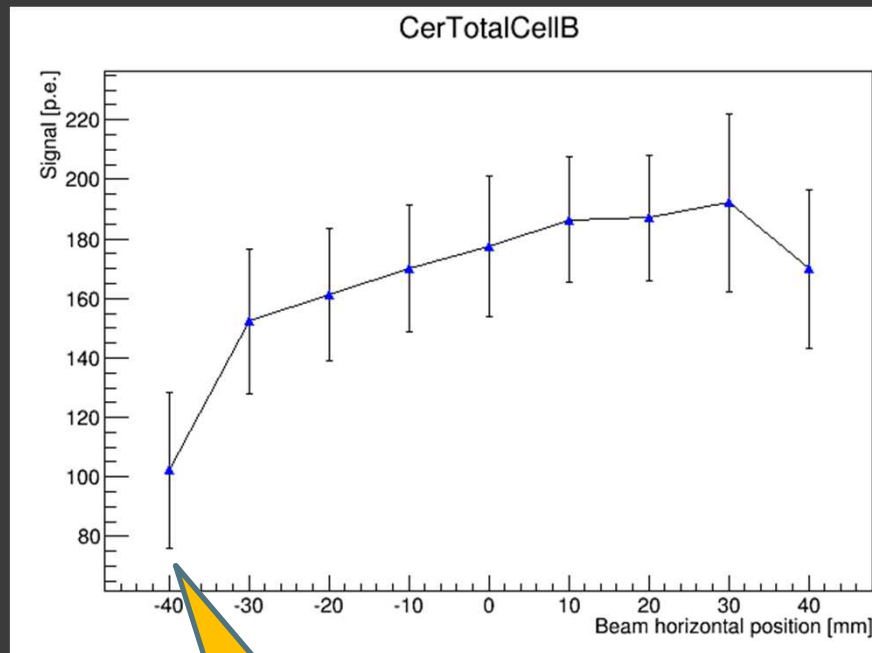
Sci vs Cer for electrons



ADRIANO 2014B

- Electrons selected with Cherenkov systems at FTBF

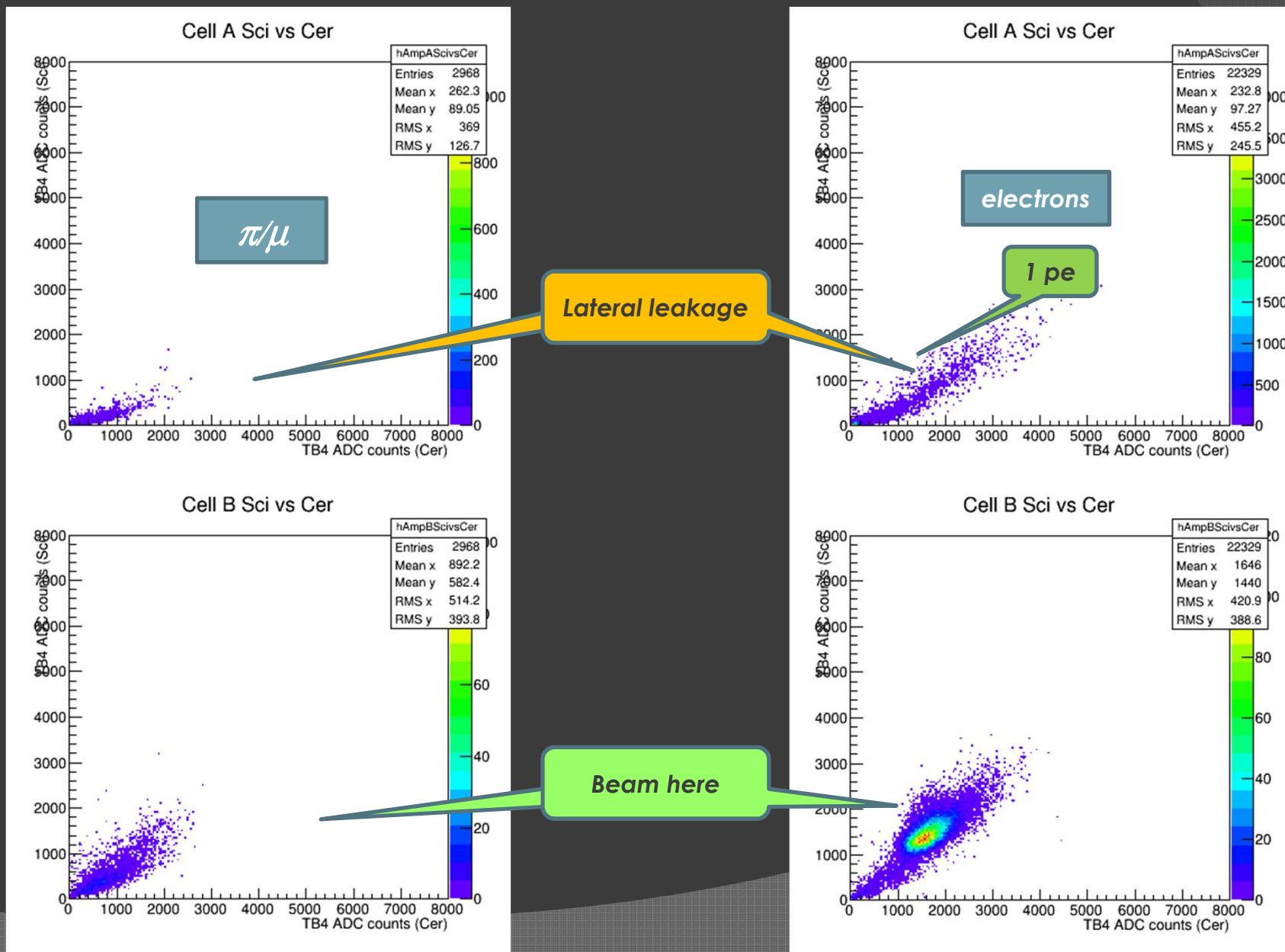
Horizontal scan with mixed beam ($e/\pi/\mu$): ADRIANO 201B



Lateral leakage

*Readout from glass appears to be not uniform.
Further investigations are required*

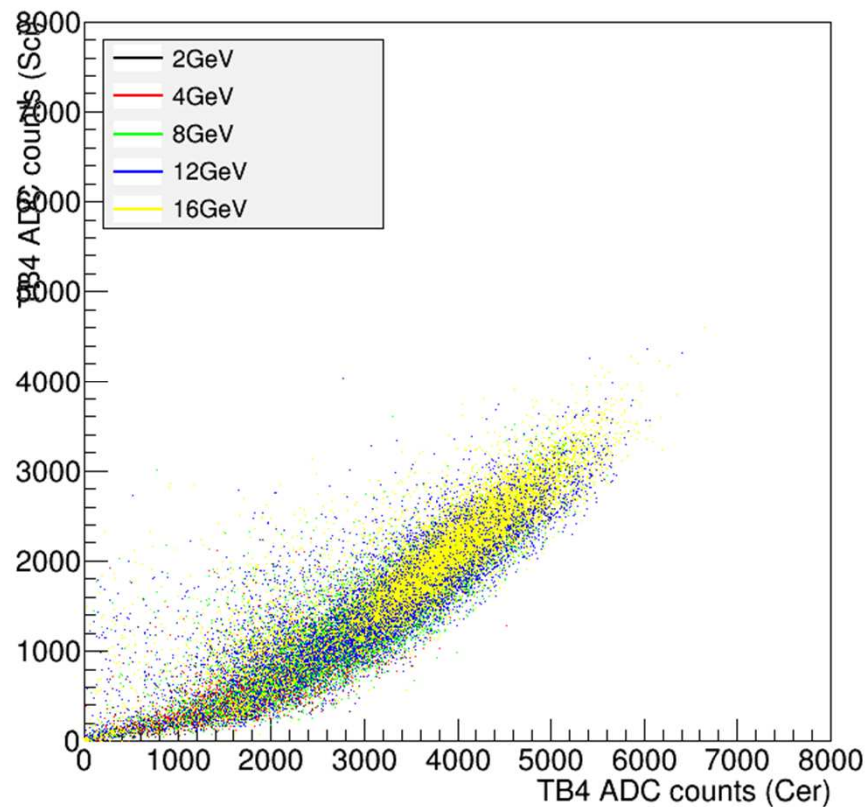
Hadrons vs EM showers: ADRIANO 2014 B



Hadrons scatter plots showers: ADRIANO 2014A and 2014B

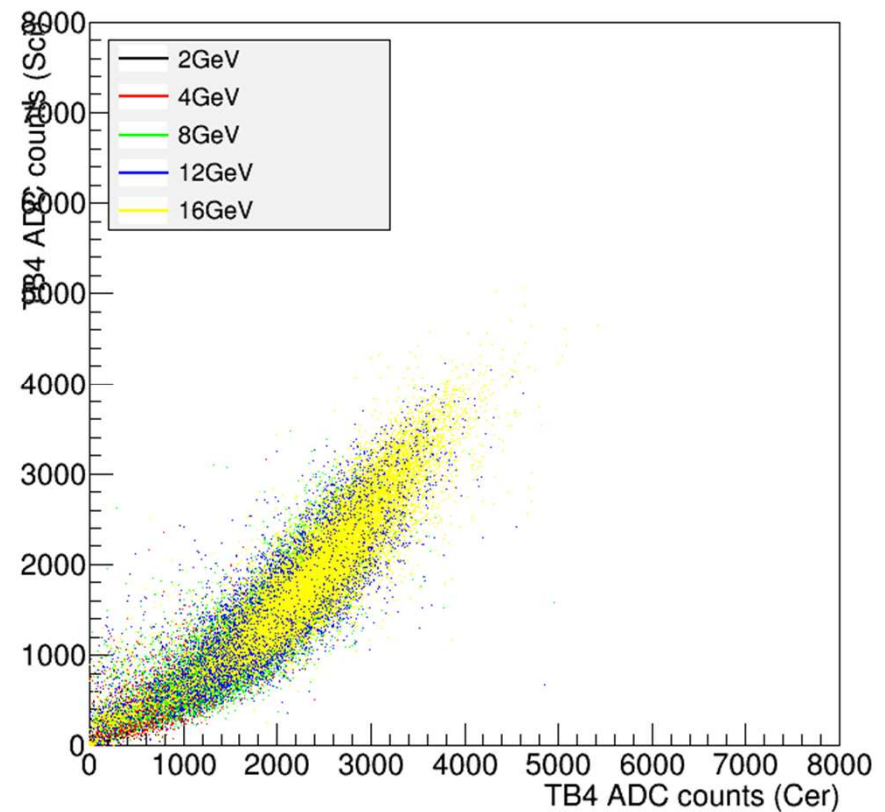
ADRIANO 2014A

Sci vs Cer for pions



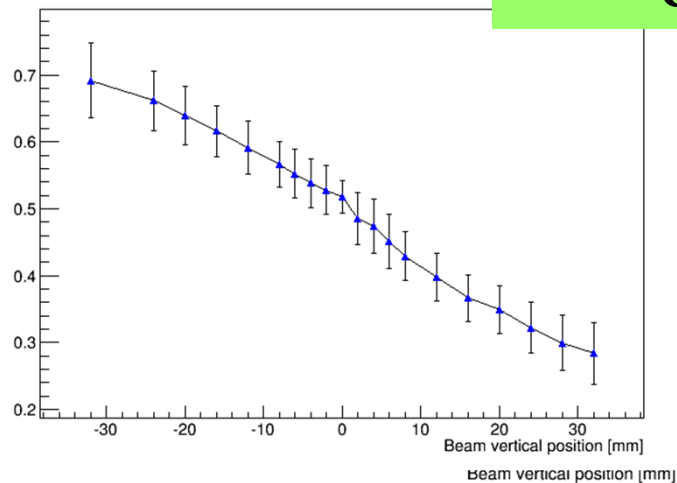
ADRIANO 2014B

Sci vs Cer for pions



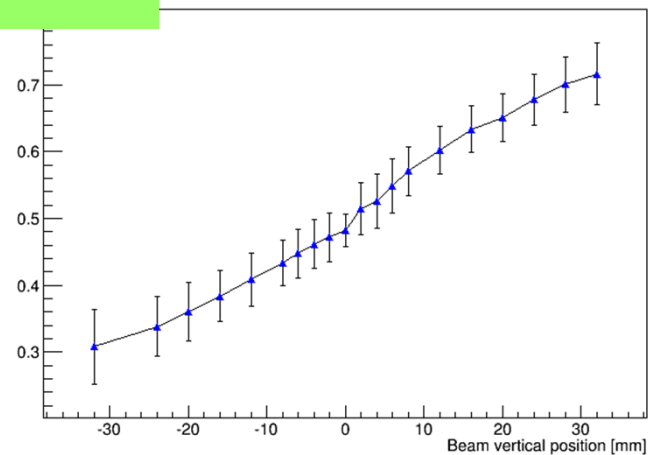
Vertical Scan with Protons: ADRIANO 2014B top half vs bottom half

CerBottom/CerTotal CellB

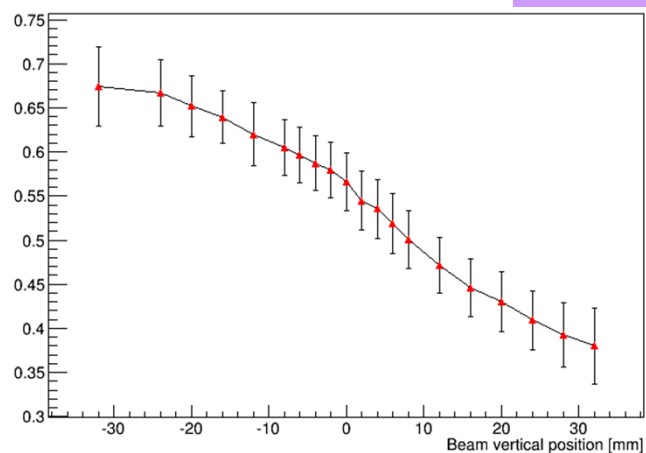


Cherenkov

CerTop/CerTotal CellB

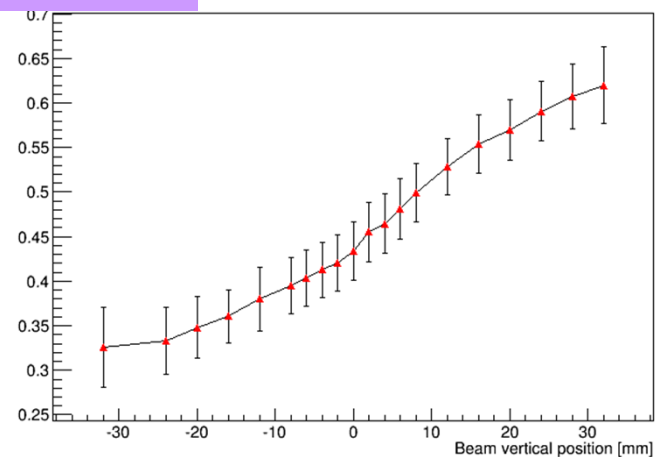


SciBottom/SciTotalCellB



Scintillation

SciTop/SciTotalCellB



Position resolution with light COG < 1 cm

Detector Response

	ADRIANO 2014A	ADRIANO 2014B
Scintillation L.Y.	1000 pe/GeV	450 pe/GeV
Cherenkov L.Y.	300 pe/GeV	350 pe/GeV
% scint. energy	6.0% @ 4 GeV	1.14% @ 4 GeV
% Cher. energy	94% @ 4 GeV	98.86% @ 4 GeV
% visible energy	89.7% @ 4 GeV	89.7% @ 4 GeV
Scint. pe/deposited energy [MeV]	0.215 GeV@ 4gev Or 18 pe/MeV	0.041 GeV@ 4gev or 44 pe/ MeV
Cher. pe/deposited energy [MeV]	3.37 GeV@ 4gev Or 0.36 pe/MeV	3.52 GeV@ 4gev Or 0.4 pe/MeV

Light yield goals achieved!

15 Prototypes tested: Performance Summary

Prototype	Year	Glass	gr/cm ³	L. Y./GeV	Notes
5 slices, machine grooved, unpolished, white	2011	Schott SF57HHT	5.6	82	SiPM readout
5 slices, machine grooved, unpolished, white, v2	2011	Schott SF57HHT	5.6	84	SiPM readout
5 slices, precision molded, unpolished, coated	2011	Schott SF57HHT	5.6	55	15 cm long
2 slices, ungrooved, unpolished, white wrap	2011	Ohara BBH1	6.6	65	Bismuth glass
5 slices, scifi silver coated, grooved, clear, unpolished	2011	Schott SF57HHT	5.6	64	15 cm long
5 slices, scifi white coated, grooved, clear, unpolished	2011	Schott SF57HHT	5.6	120	
2 slices, plain, white wrap	2011	Ohara	7.5	-	DAQ problem
10 slices, white, ungrooved, polished	2012	Ohara PBH56	5.4	30	DAQ problems
10 slices, white, ungrooved, polished	2012	Schott SF57HHT	5.6	76	
5 slices, wifi Al sputter, grooved, clear, polished	2012	Schott SF57HHT	5.6	30	2 wls/groove
5 slices, white wrap, ungrooved, polished	2012	Schott SF57HHT	5.6	158	Small wls groove
ORKA barrel	2013	Schott SF57	5.6	In prog.	BCF92
ORKA endcaps	2013	Schott SF57	5.6	In prog.	BCF92
10 slices – 6.2 mm thick, scifi version	2014B	Schott SF57	5.6	350	molded
10 slices – 6.2 mm thick, sci-plate version	2014A	Schott SF57	5.6	300	molded

Analysys is still ongoing, all L.Y. results subject to change

New Glasses R&D in T1015

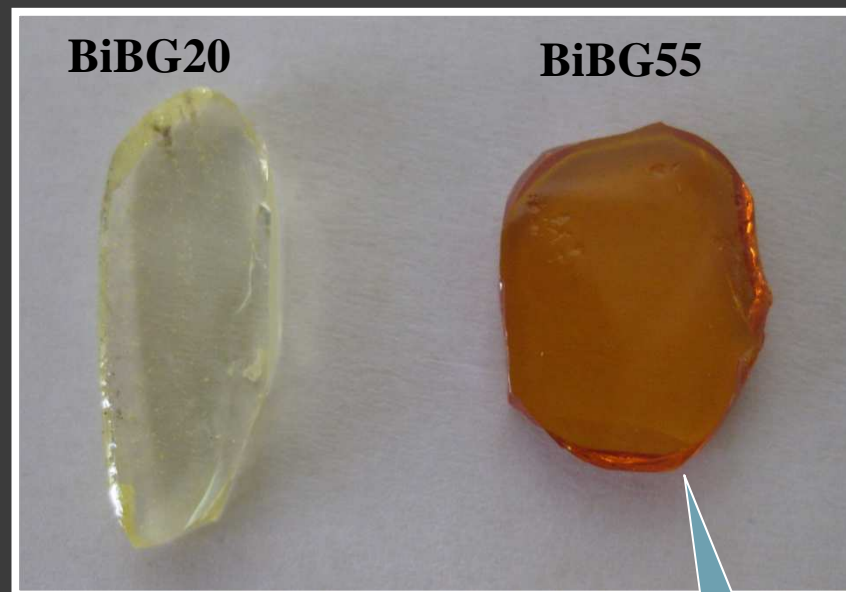
- ⦿ Research mostly carried at Department of Materials and Environmental Engineering at Uni-Modena (Italy)
- ⦿ Heavy glasses with **no-Pb** (Cerenkov only)
 - Mostly **Bi** based (heavier, less environmental issues, higher n_D , lower softening point for molding)
 - WO_2 under study (just purchased a 1600 °C furnace)
 - Goal is $>8 \text{ gr/cm}^3$
- ⦿ Rare earths doped scintillating heavy glasses:
 - Ba-Bi-B matrix to accomodate Ce_2O_3 :
 - Density achieved up to now: 7.5 gr/cm^3 (see next slide)
 - Several rare earth oxides tested: Dy_2O_3 promising
 - Lithium content for neutron sensitivity



Bismuth Borate Glasses BiB-G

Goal High density glasses by melt quench method

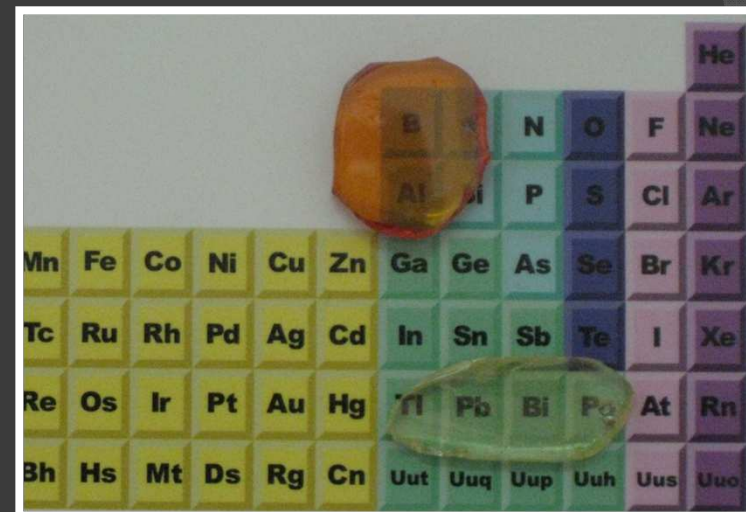
- Two compositions (BiBG20 and BiBG55) with different Bi_2O_3 content



Bi_2O_3 mol%



Dark color due to Bi_2O_3
not pure enough



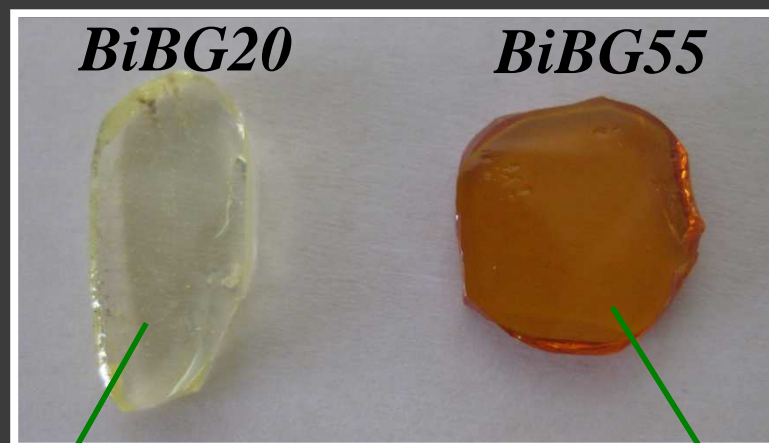
DENSITY

Glass	ρ (g/cm ³)
BiBG 20	4.57
BiBG 55	7.48

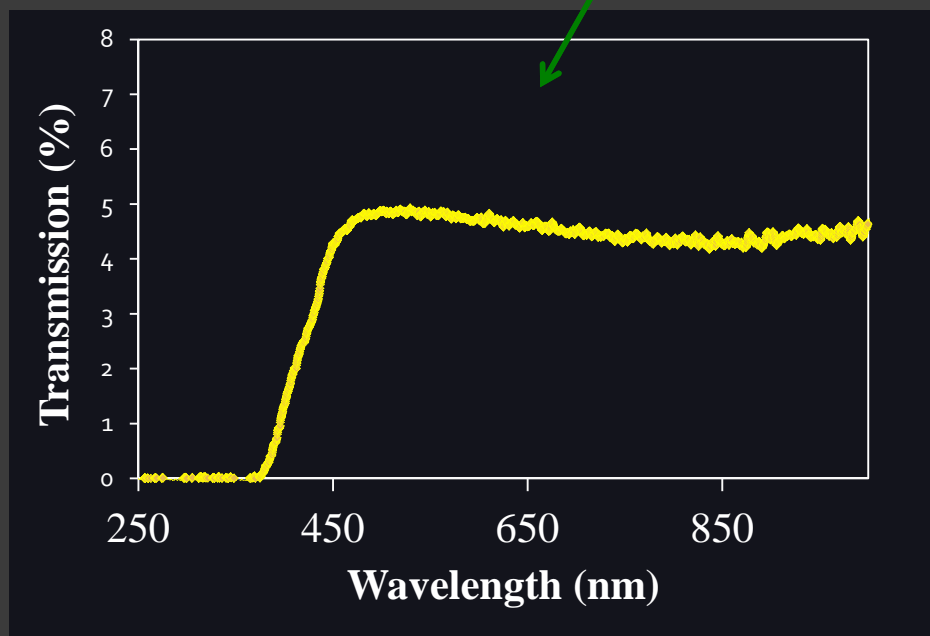
exp.error ± 0.01



Transmission Spectra

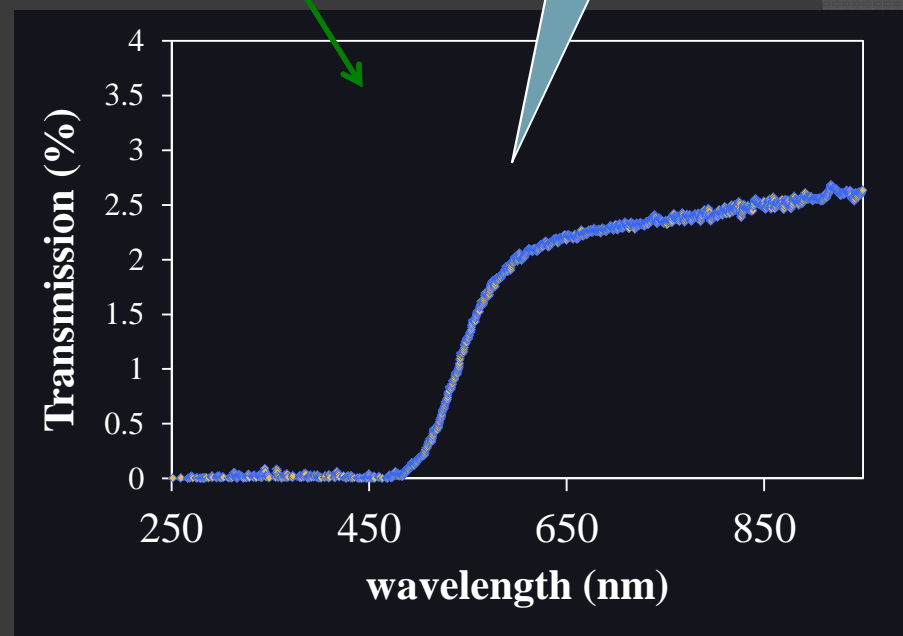


No absorption bands



thickness c.a 0.3 cm

AWLC2014



thickness c.a 0.3 cm

Rare Earth Heavy Glasses

- Rare earths oxides + Ho_2O_3 + ZnO + P_2O_5 + B_2O_3 + SiO_2
- R.e. considered: CeO_2 , Dy_2O_3 , Nd_2O_3 , Pr_6O_{11} , Er_2O_3

Composition	Density (g/cm ³)
CeO_2	3,3776
Pr_6O_{11}	3,7445
Dy_2O_3	3,8851
Er_2O_3	4,0690
Nd_2O_3	4,2441

Conclusions & Future Prospects

- T1015 started operation in 2010. Expected to conclude in 2015.
- 15 detectors successfully built and tested. 1 under construction.
- **We have mastered the technique of collecting light from glass with WLS fibers: 360 pe/GeV reached with ADRIANO 2014B.**
- Cerenkov light yield more than adequate for 25-30%/sqrt(E) calorimetry. We have shown that it can be used for EM calorimetry as well
- COG technique gives an effective granularity of about 1 cm²

What's next:

- LDRD proposal in preparation on Organically Doped Scintillating Glasses (A. Mazzacane et. al)
- New proposal to INFN on new glass technologies for HEP:
 - ADRIANO2 (Cerenkov + scintillating glass)
 - ADRIANO in triple readout mode
- Two new prototypes already planned:
 - ADRIANO 2014C (lead glass + scintillating fibers ribbon)
 - ADRIANO 2015 (z-readout)

**Under
construction**

Backup Slides

Adding the 3rd Dimension info with light division methods

- Determine Center of Gravity of showers by ratio of front vs back scintillation light
- It works because $\lambda_{811} = 3.5$ m
- Similar to charge division methods in drift chambers with resistive wires
- A technique already adopted by UA1 and ZEUS

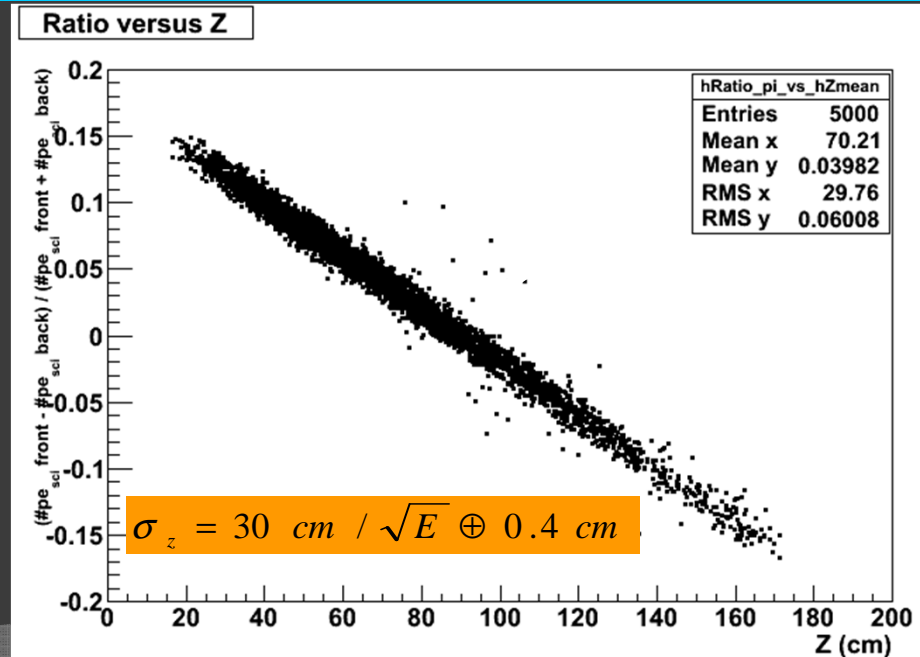
100 GeV pions

Instrumental effects included in ILCroot :

- SiPM with ENF=1.016
- Fiber non-uniformity response = 0.6% (scaled from CHORUS)
- Threshold = 3 pe (SiPM dark current < 50 kHz)
- ADC with 14 bits
- Constant 1 pe noise.

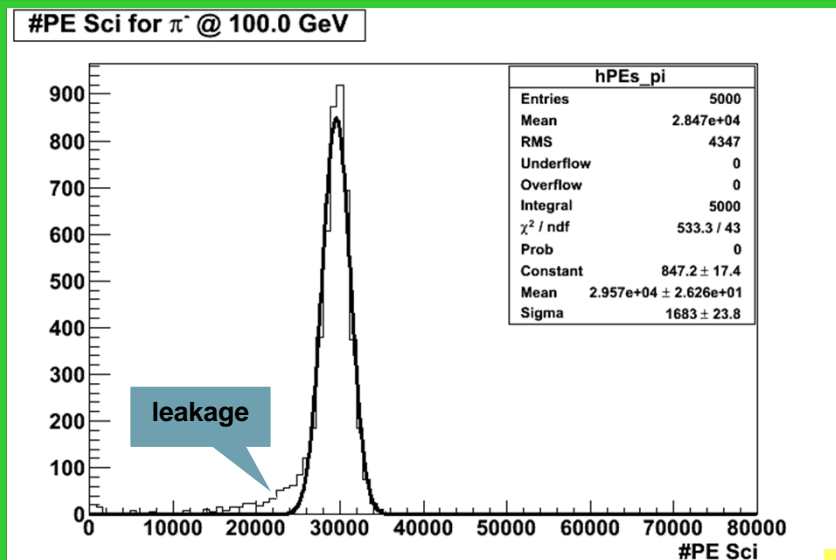
ILCroot simulations

Front vs back Scintillation light vs true shower CoG

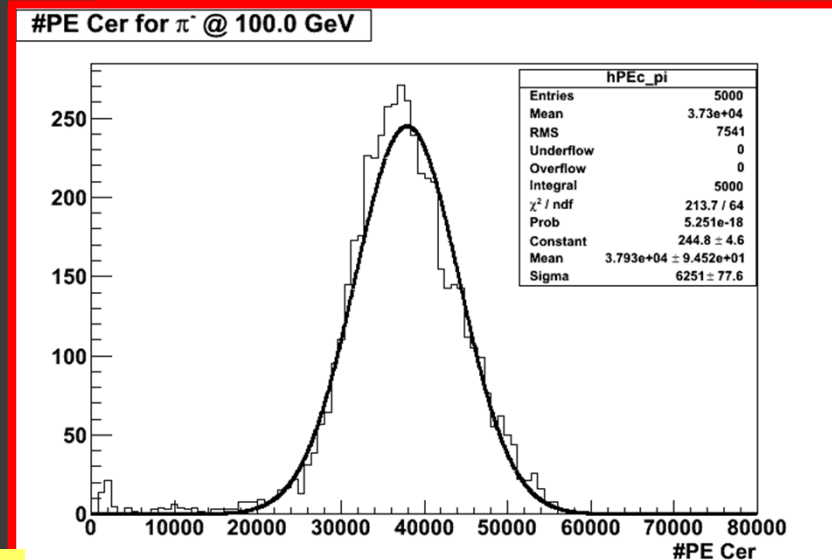


Leakage in 180 cm long *ADRIANO* module

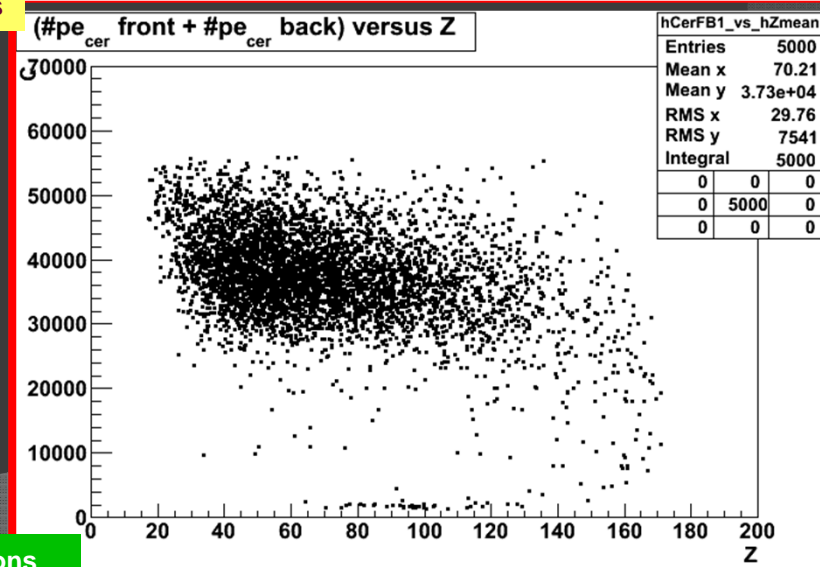
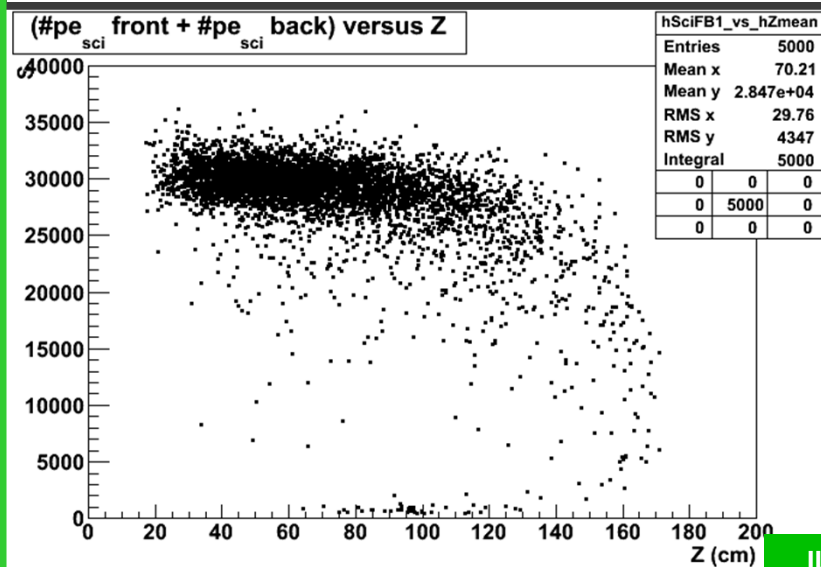
Uncorrected scintillating signal



Uncorrected Cerenkov signal



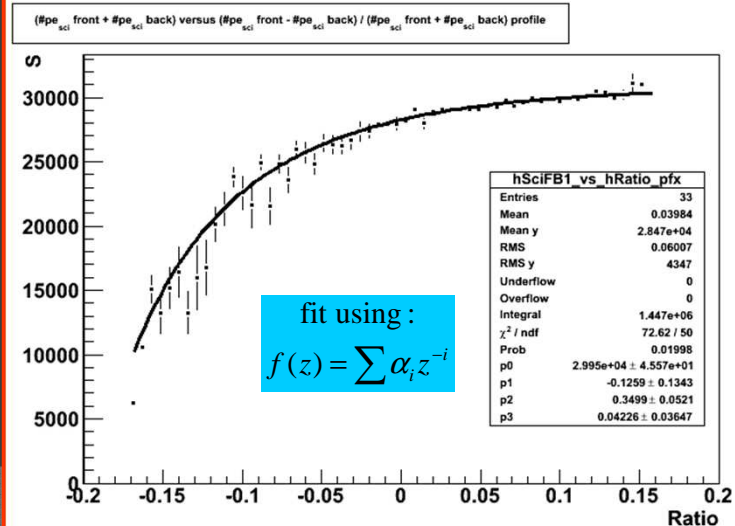
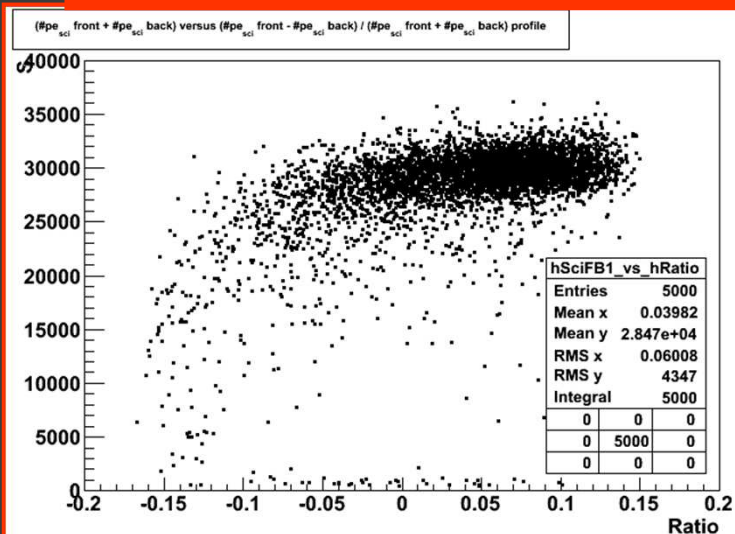
100 GeV pions



ILCroot simulations

Applying leakage corrections from CoG measured with a light division

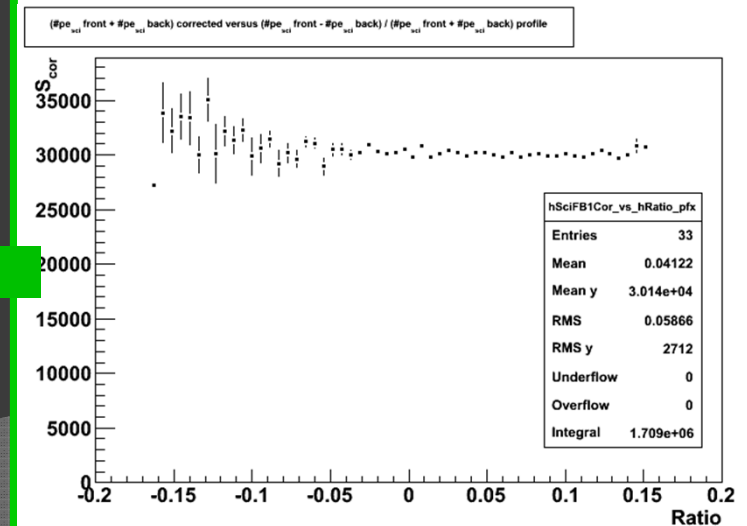
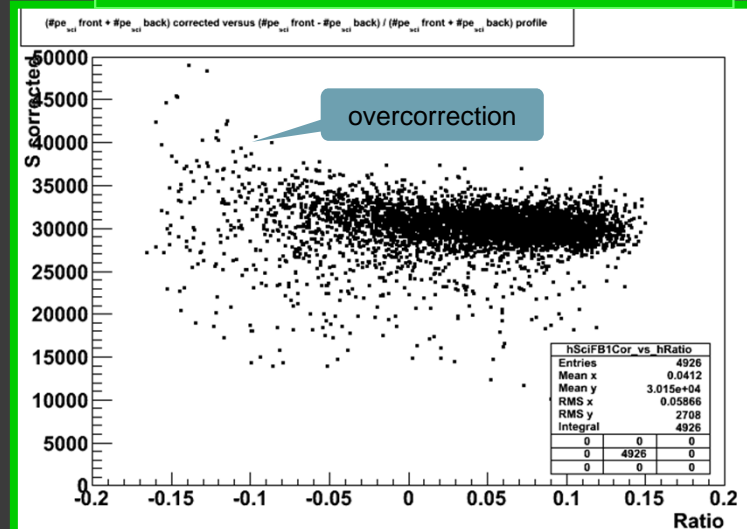
Uncorrected scintillating signal



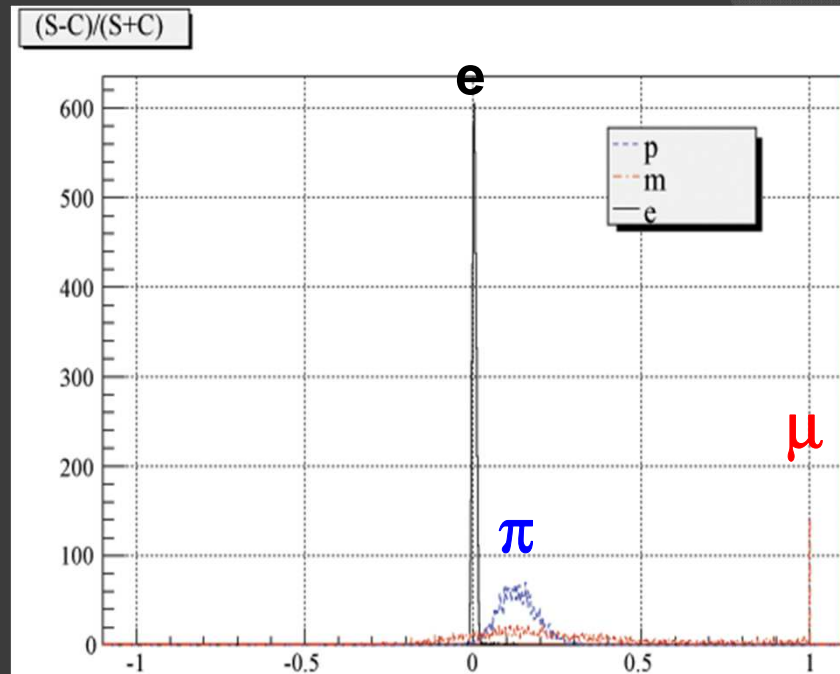
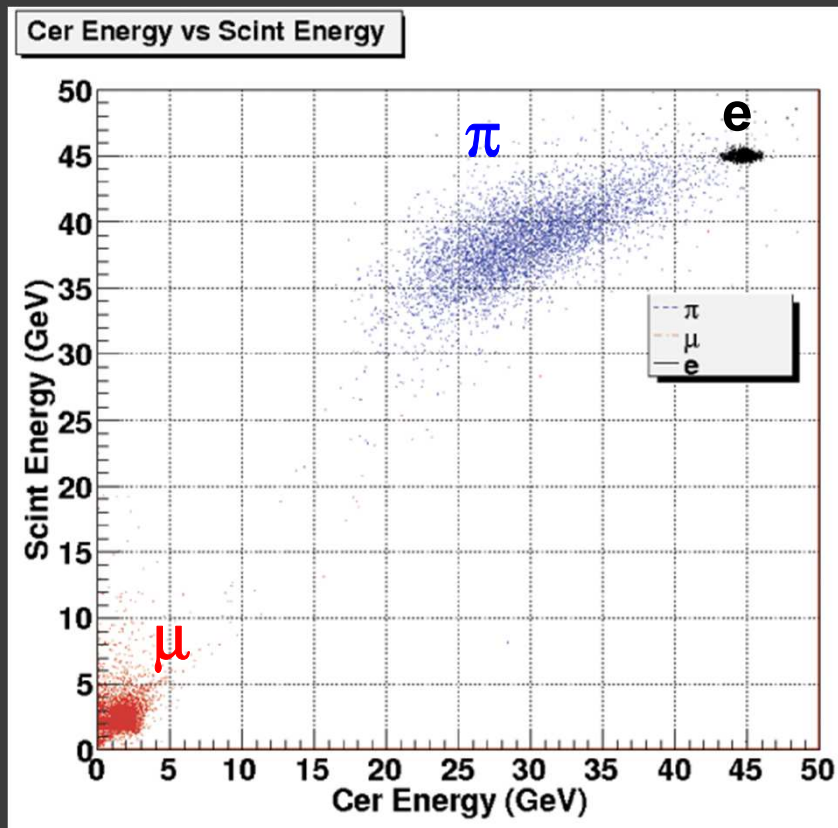
100 GeV pions

ILCroot simulations

Corrected scintillating signal



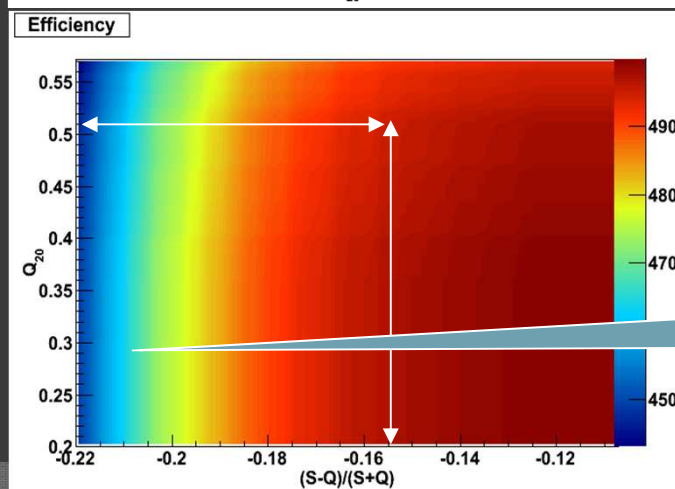
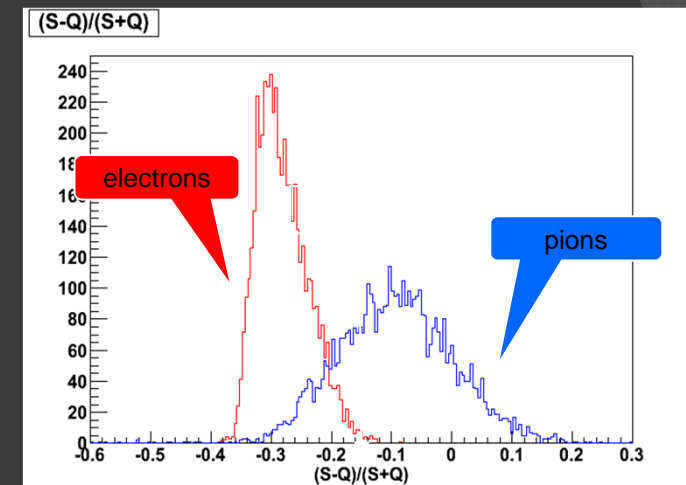
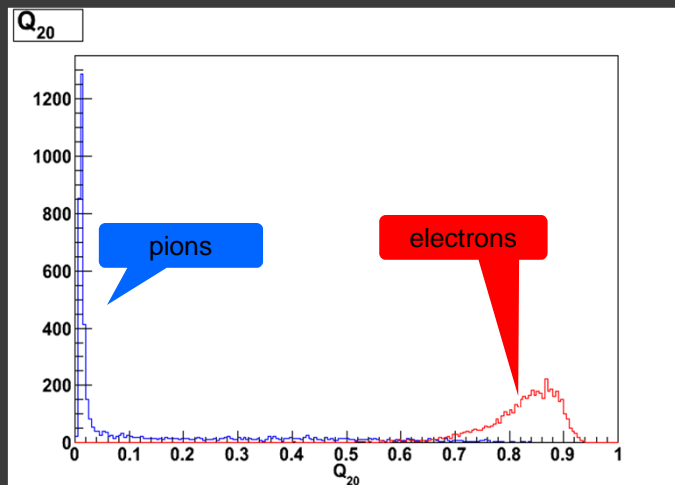
Particle Identification in Dual Readout calorimeters



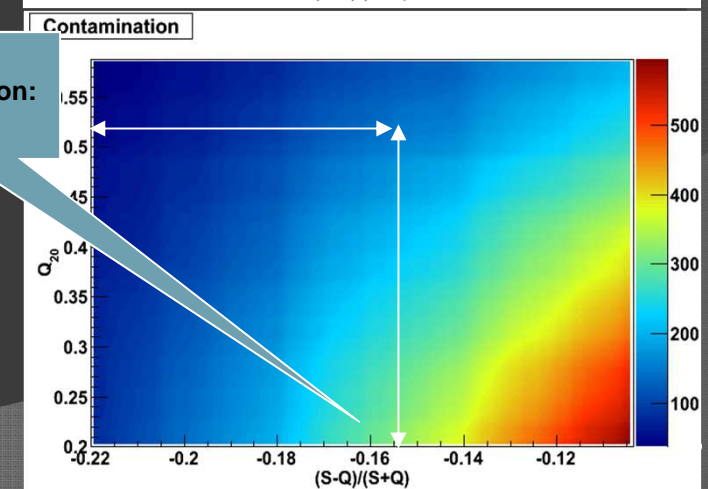
45 GeV particles

Identifying EM Showers in *ADRIANO*

- Use Q_{20} fibers and $(S-Q)/(S+Q)$ to disentangle EM particles from hadrons
- Use E_{Cerenkov} from heavy glass ONLY for EM showers



Electron
efficiency:
99.0%



Pion
contamination:
3%

Calibration à la DREAM

- E_S and E_C for electron beam is equivalent to pion beam when $fem=1$

Step 1

$$\begin{cases} E_S = \left[fem + \frac{(1-fem)}{\eta_S} \right] \cdot E_{HCAL} \\ E_C = \left[fem + \frac{(1-fem)}{\eta_C} \right] \cdot E_{HCAL} \end{cases}$$

for electrons

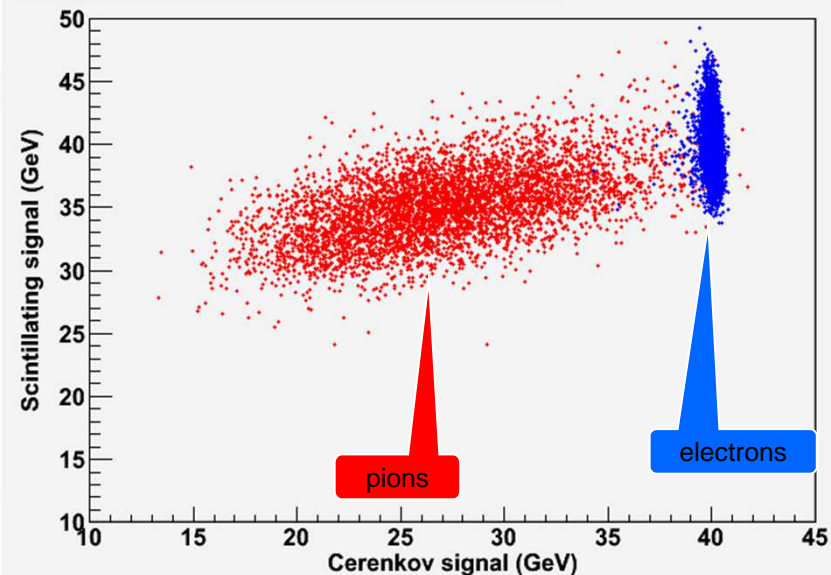
$$\begin{cases} E_S = E_{HCAL} \\ E_C = E_{HCAL} \end{cases}$$

- Final calibration with pion beam
minimize

Step 2

$$E_{HCAL} = \frac{\chi^2(E_{HCAL} - E_{beam})}{\frac{\eta_S \cdot E_S \cdot (\eta_C - 1) - \eta_C \cdot E_C \cdot (\eta_S - 1)}{\eta_C - \eta_S}}$$

Sci vs Cer signal for π^- and e^- @ 40 GeV



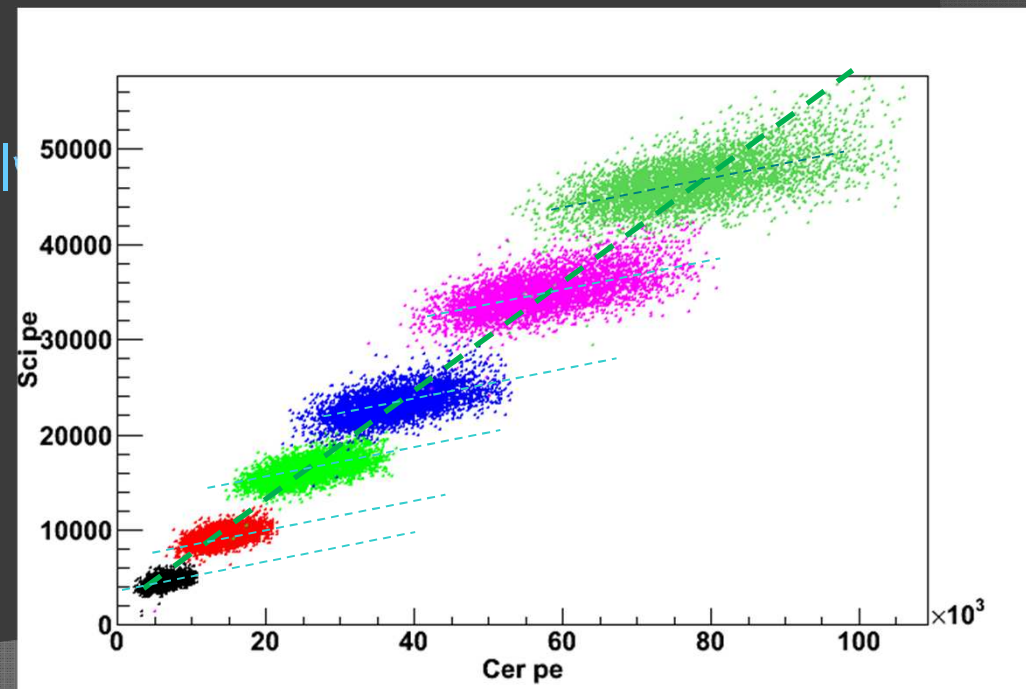
Calibration à la TWICE

- Take advantage of the fact that η_s and η_c are expected to be (almost) energy independent
- Use a sample of n pions of **ANY** known energy
- For the i -th pion rewrite the dual readout equation as:

$$\frac{\hat{S}_i}{E_i} = \alpha - \beta \frac{\hat{Q}_i}{E_i}.$$

$$\beta = \frac{\sum_1^n (\hat{Q}_i/E_i)(\hat{S}_i/E_i) - 1/n \sum_1^n (\hat{Q}_i/E_i) \sum_1^n (\hat{S}_i/E_i)}{\sum_1^n (\hat{Q}_i/E_i)^2 - 1/n (\sum_1^n \hat{Q}_i/E_i)^2}$$

$$\alpha = 1/n \sum_1^n (\hat{S}_i/E_i) - \beta/n \sum_1^n (\hat{Q}_i/E_i)$$

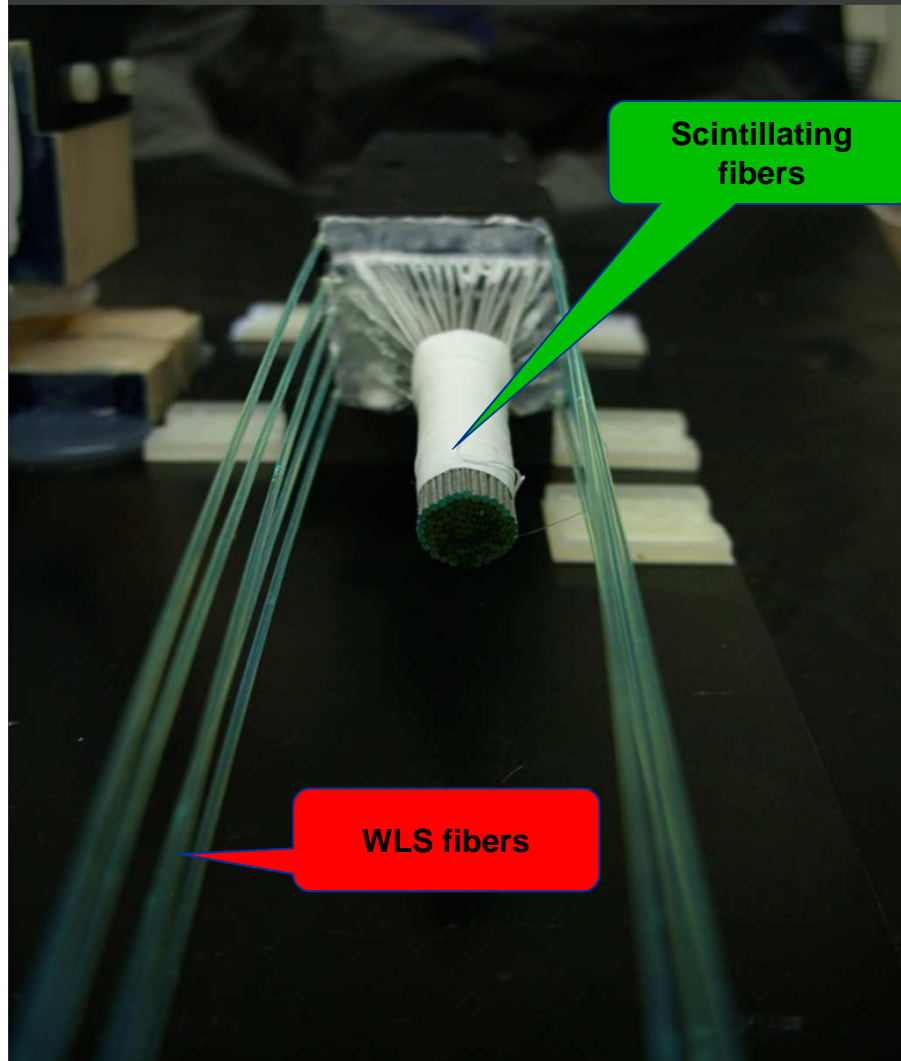


Department of Materials and Environmental Engineering



ADRIANO Applications

Dual-readout Calorimetry
(compensate e/h fluctuations)



Imaging Calorimetry
(spatially resolve the shower in 3D)

