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 Čherenkov radiator: 10 grooved lead glass plates ($\rho = 5.6$ gr/cm^3) 6.5mm x10mm x1050 mm readout by 8 or 6 WLS fibers
- Cerenkov light collection: WLS fiber optically coupled to glass
- Scintillation region ADRIANO 2014A: 10 scintillating plates, 2mm x 10mmx1000mm, 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 tg($\theta_{S/Q}$): due to WLS running longitudinally to cell axis ($\theta_{Cerenkov} < \theta_{Snell}$ 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 Č)
   - ~ 10^5 channels for typical 4π detectors
   - Can be calibrated with e^- only

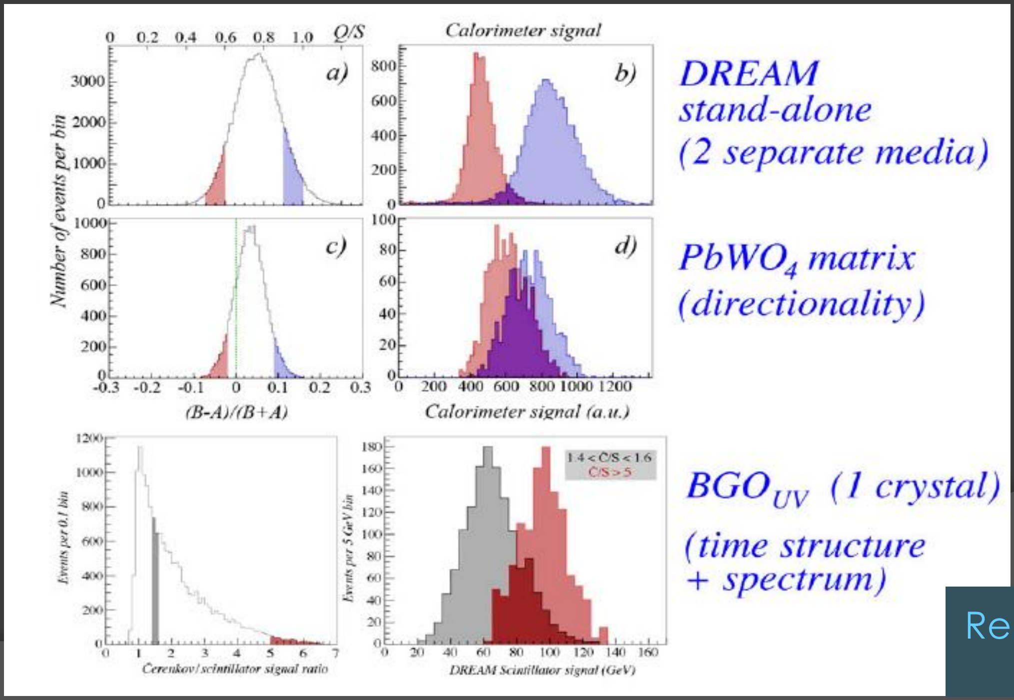
2. **Integrally active**
   - No passive absorber (glass + scintillating plastics)
   - It works as EM and Hadronic calorimeter at the same time

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

Hydrogen in plastic important element for neutron

Separation efficiency between S & Č components



Report form 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 (commercilly 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 amourphous rather than lattice structured*
- *Čherenkov light yield is high: need smart way to capture it*

ILCroot simulations

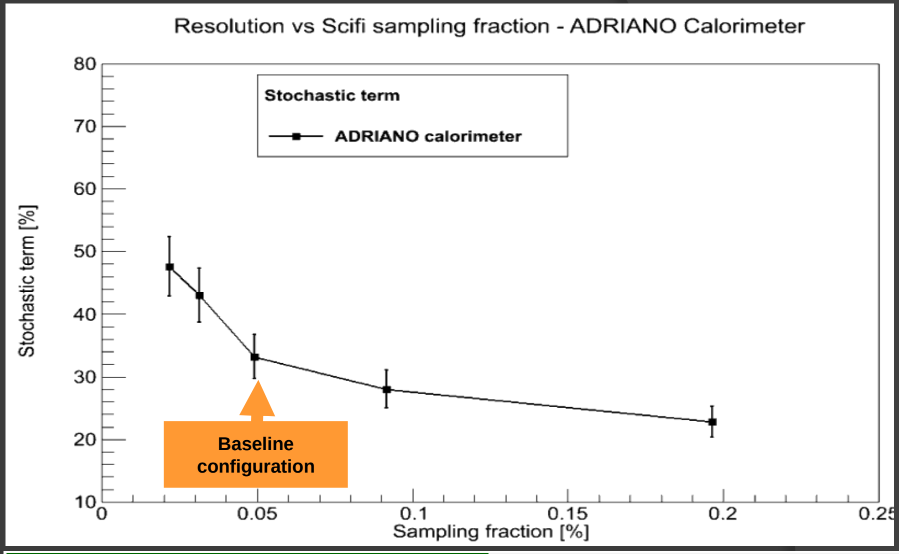
Pion beams

ADRIANO Simulations in ILCroot

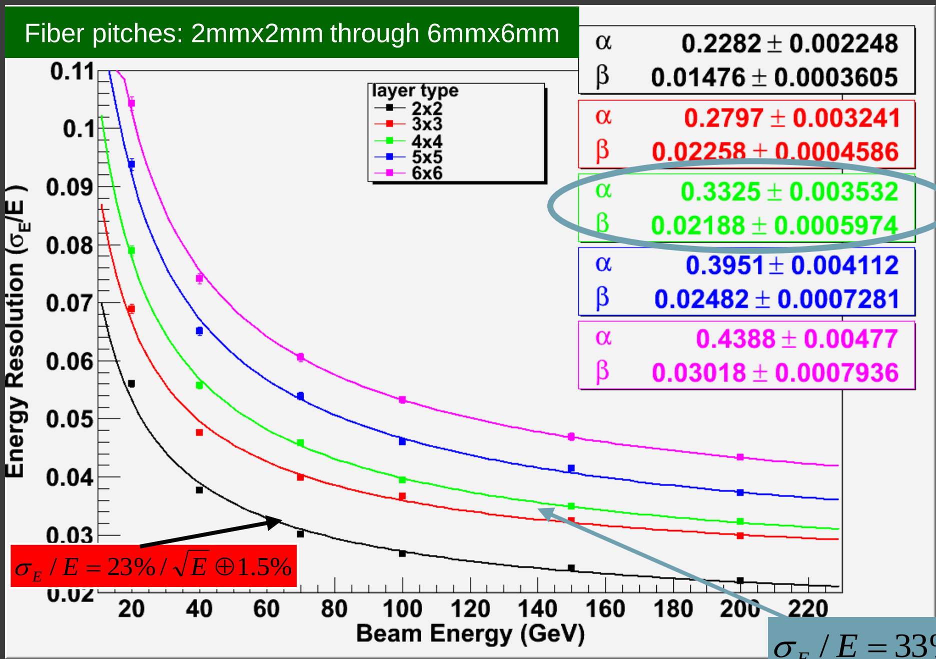
Integrally Active with Double side readout (*ADRIANO*)

Pitch [mm²] Diameter	2x2 1mm	3x3 1mm	4x4 1mm	5x5 1mm	6x6 1mm	4x4 1.4mm	4x4 2mm	4x4 capillry
$\langle pe_S/GeV \rangle$	1053	430	254	163	124	500	110	250
$\langle pe_C/GeV \rangle$	340	360	360	355	355	355	350	350

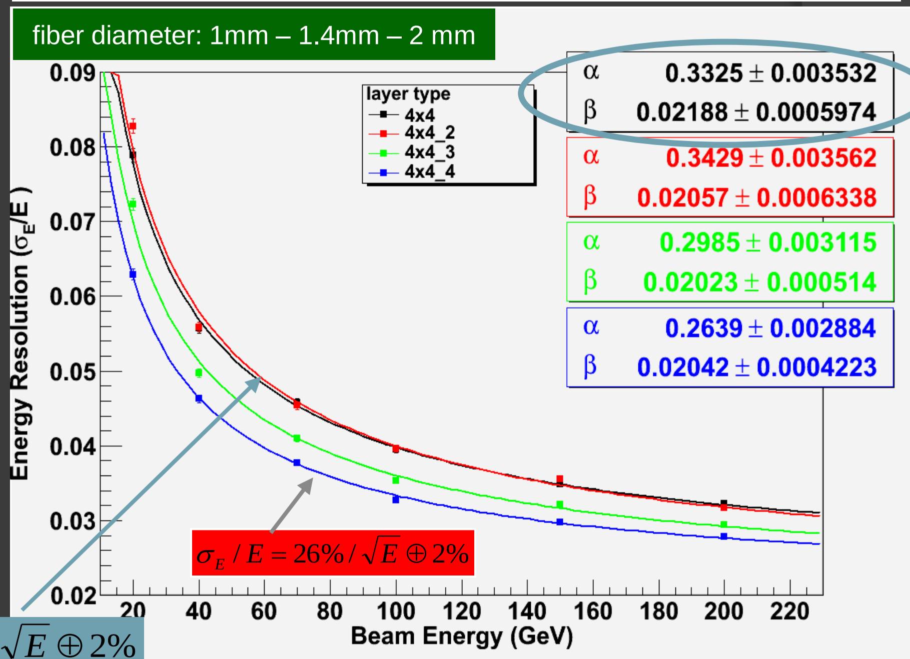
Baseline configuration
Active area/total detector surface = 8%



Fiber pitches: 2mmx2mm through 6mmx6mm



fiber diameter: 1mm – 1.4mm – 2 mm



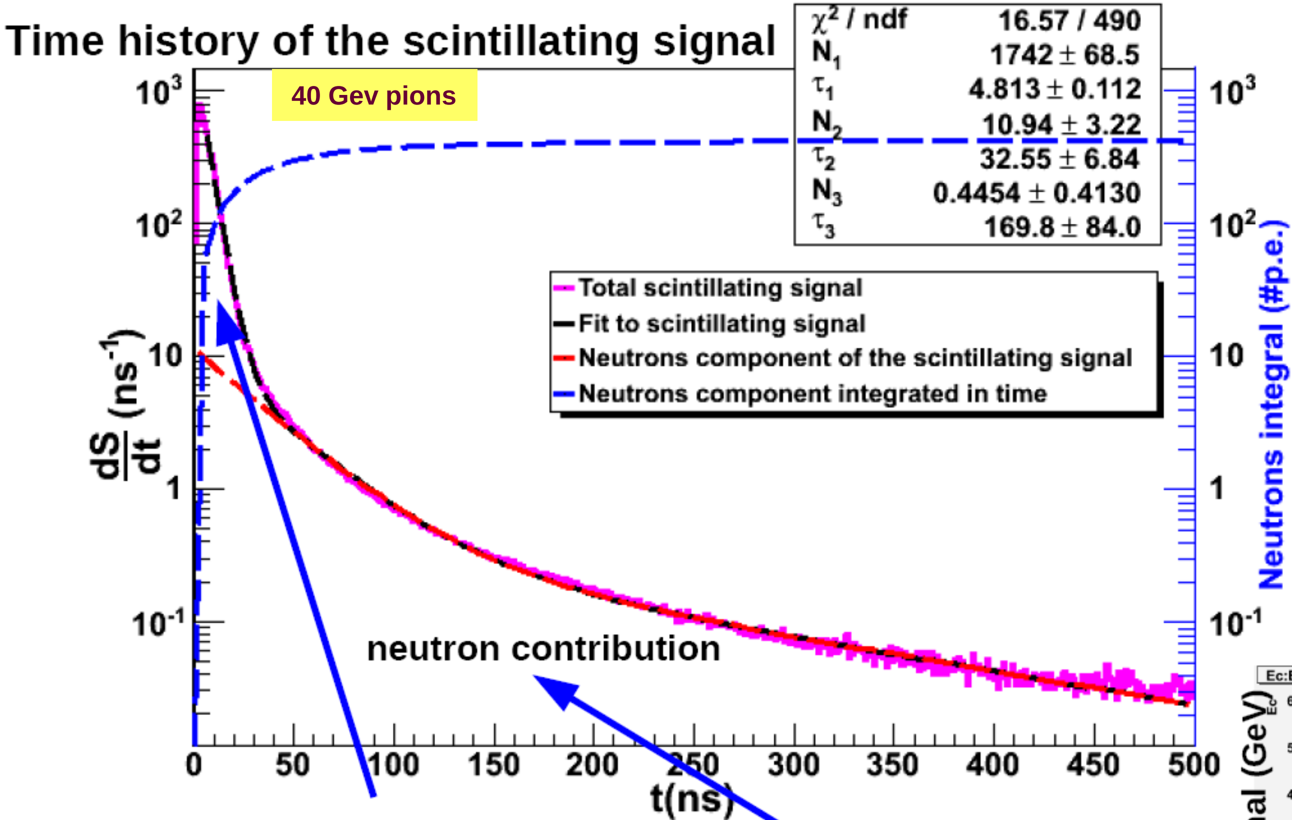
$\sigma_E / E = 33\% / \sqrt{E} \oplus 2\%$

All numbers include the effect of photodetector QE

ILCroot simulations

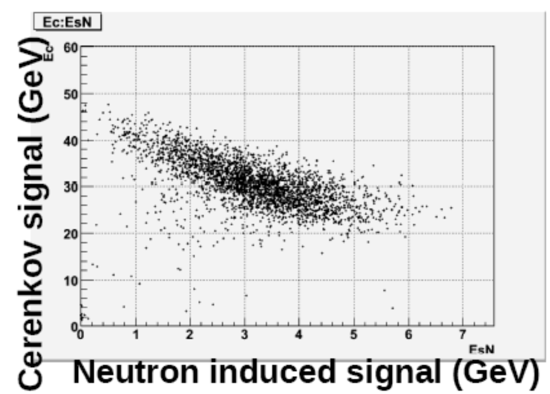
From Dual to Triple Readout

Disentangling neutron component from waveform

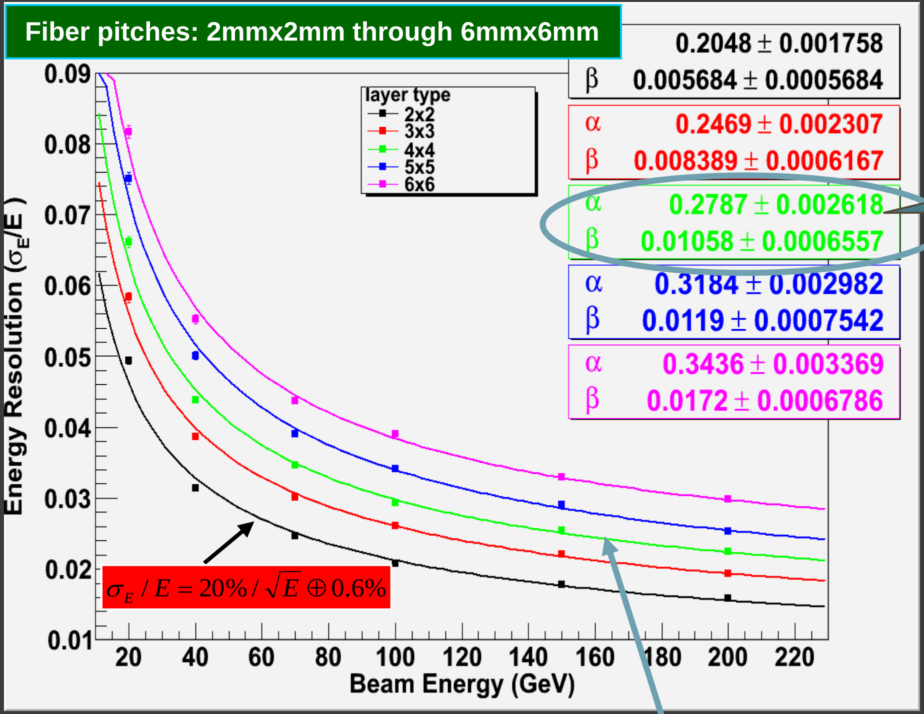


- The distribution has been fitted with a triple exponential function.
- After 50 ns only neutrons contribute to the signal.

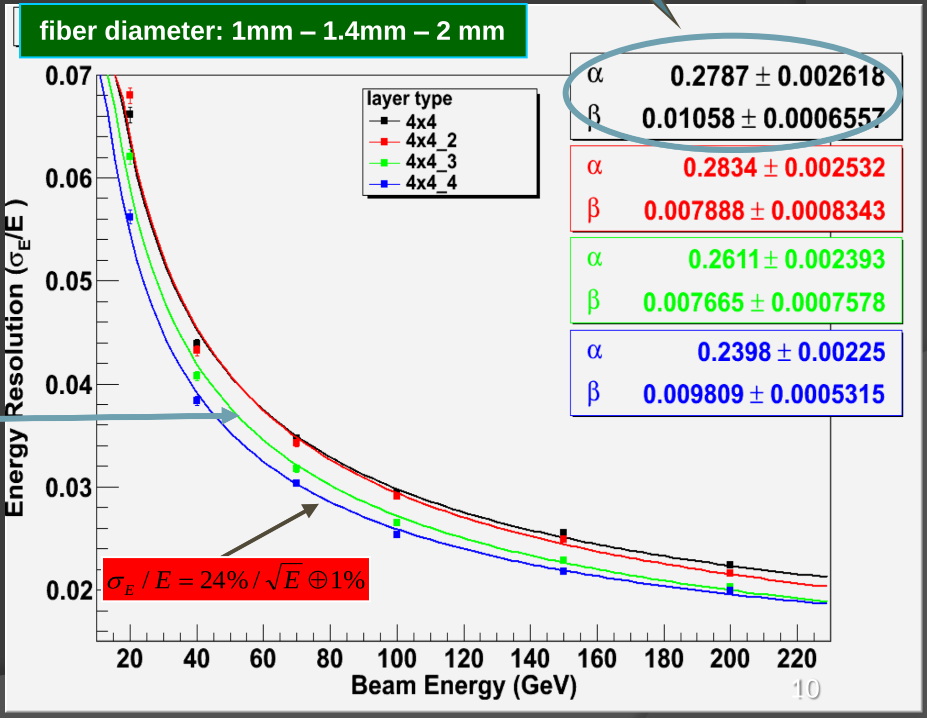
$$E_{shower} = \frac{S_{fast} - \chi C}{1-\chi} + \xi S_{slow}$$



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

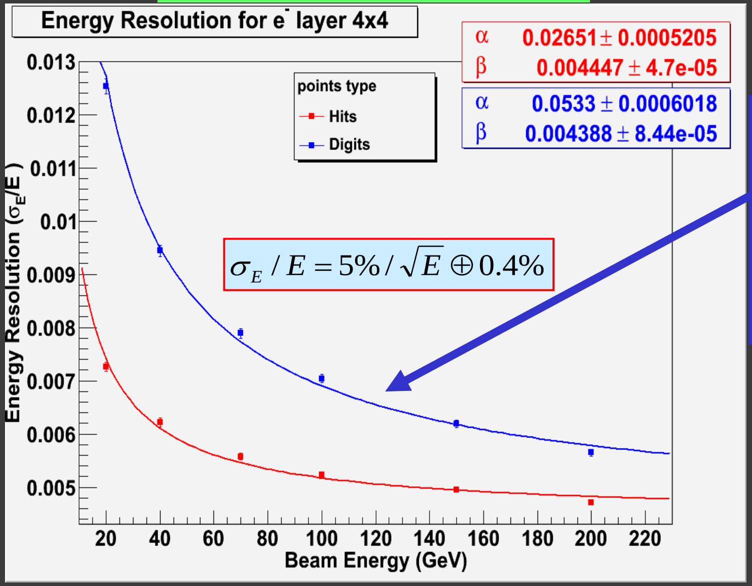
$$\sigma_E / E = 33\% / \sqrt{E} \oplus 2\%$$

ILCroot simulations

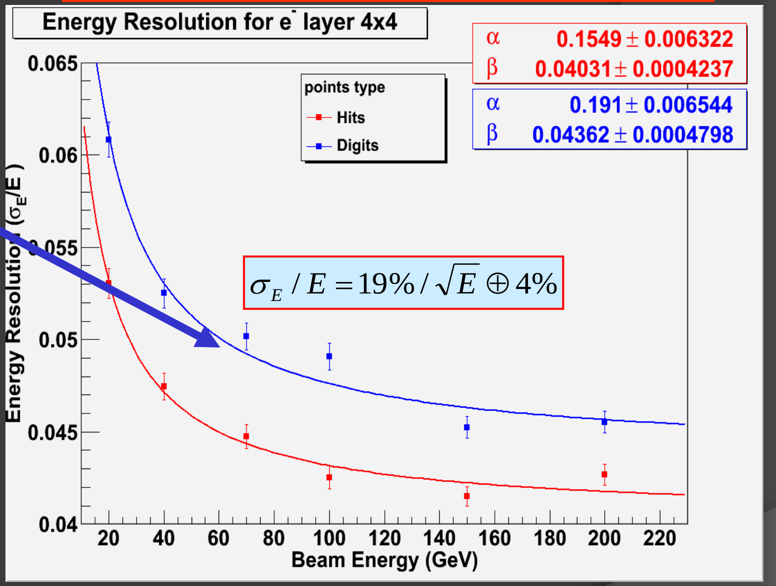
ADRIANO EM Resolution (with and without instrumental effects)

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

Use only Cerenkov light



Dual-readout (scintillating+Cerenkov)



Blue curve includes:

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

ILCroot simulations

- Using Čerenkov signal only for EM showers gives 5%/√E energy resolution while full fledged dual-readout gives only **19%/√E** (including FEE effects)

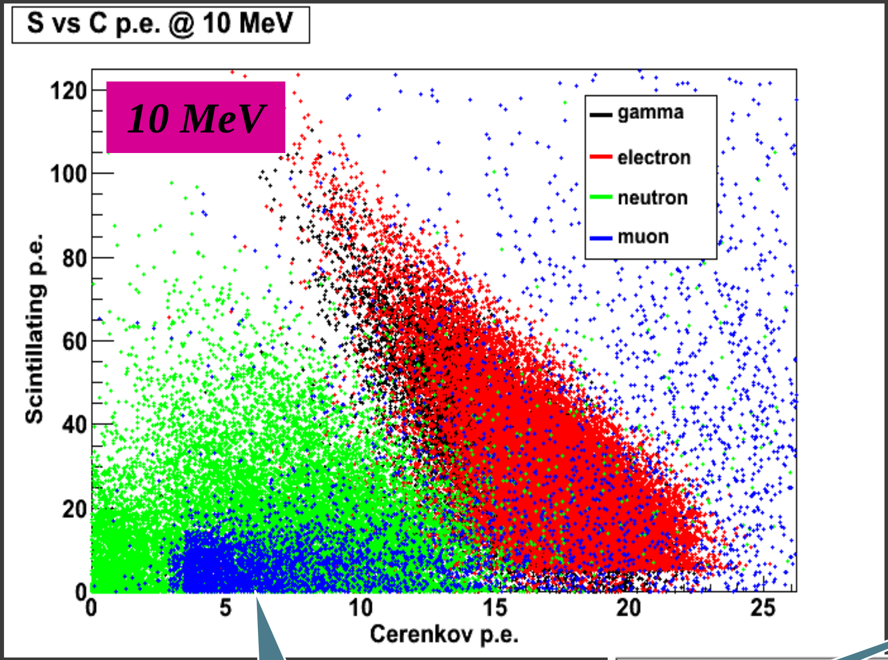
ADRIANO does not need a front EM section

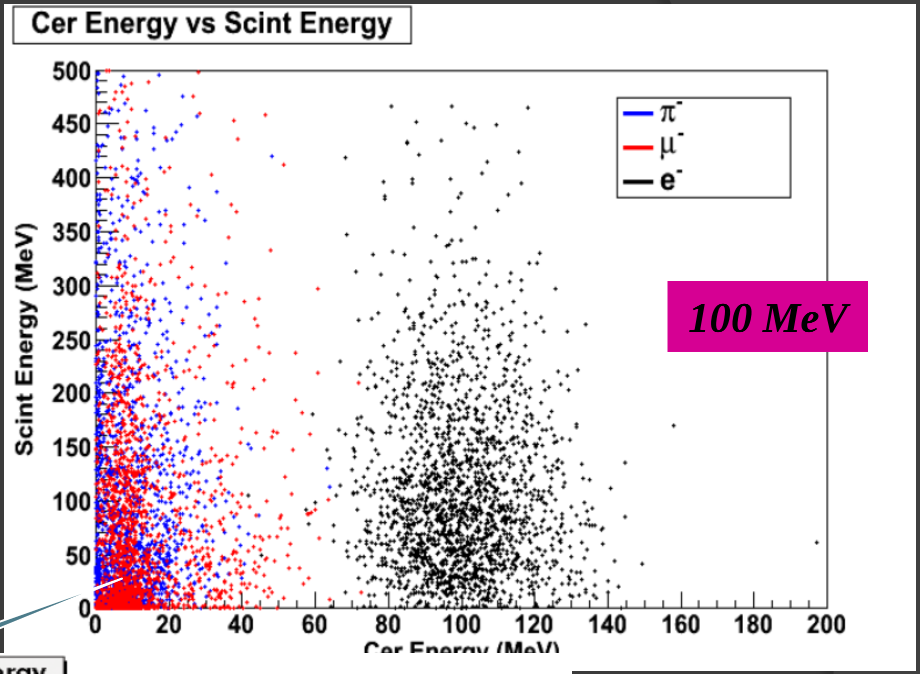
If Čerenkov ligth yield is large enough

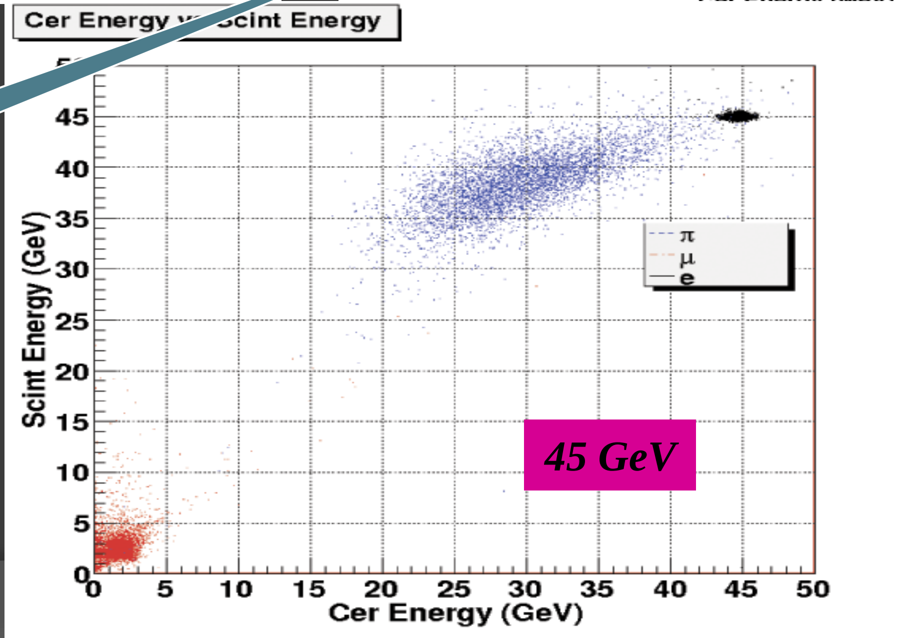
Anna Mazzacane
Vito Di Benedetto

ILCroot simulations

Particle ID with ADRIANO







ADRIANO for ORKA

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: TiO2, 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: TiO2, BasO4, 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:

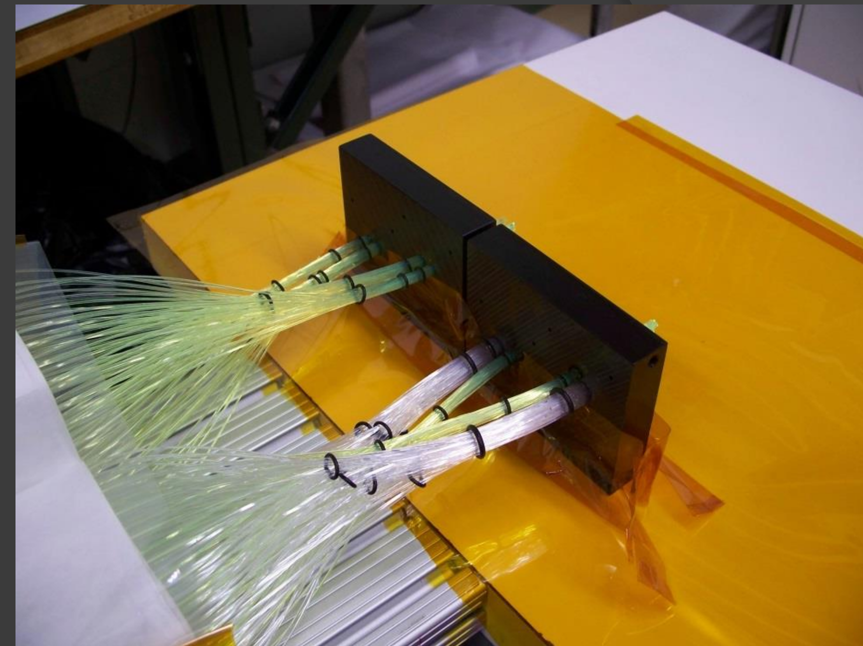
- *Maximize light yield (Cerenkov)*
- *Measure parameters for Montecarlo simulations*
- *Hopefully test the dual-readout concept (size limited)*

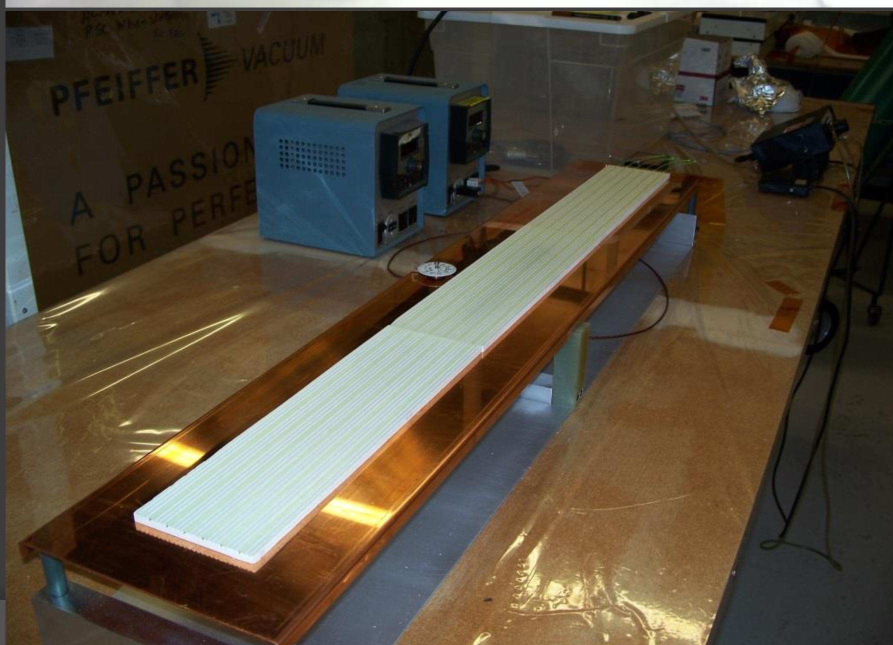
ADRIANO 2014

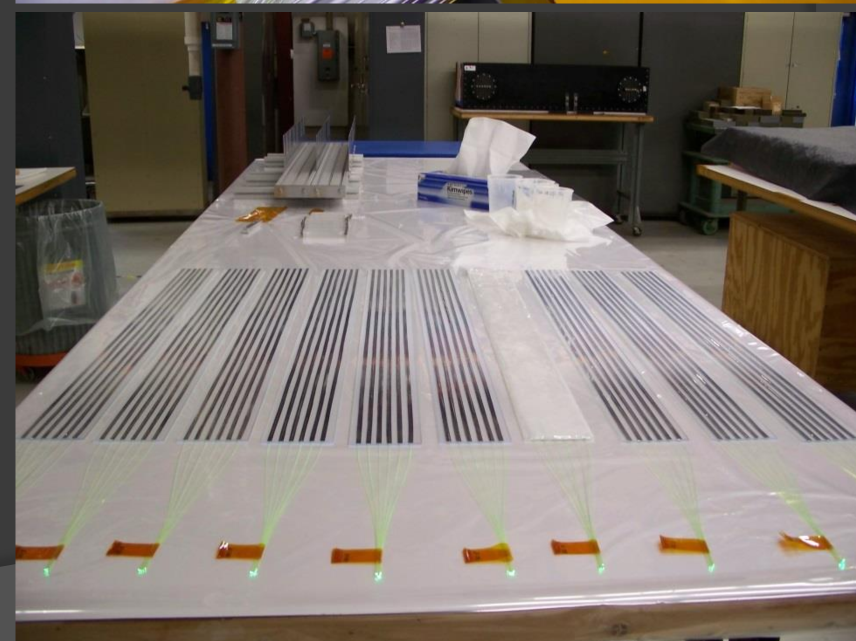
Detector construction

ADRIANO 2014

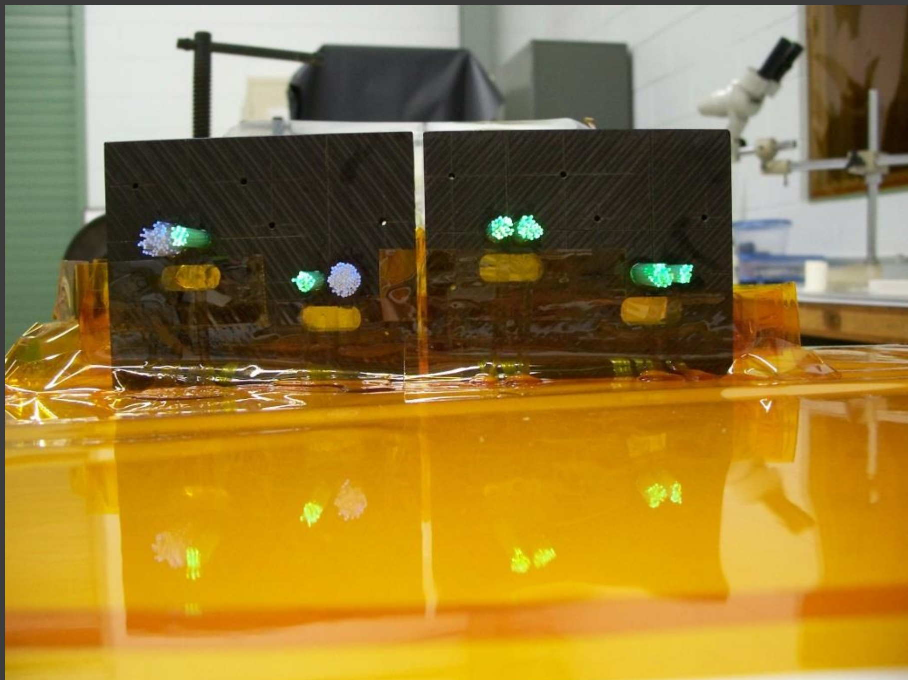
Detector assembly

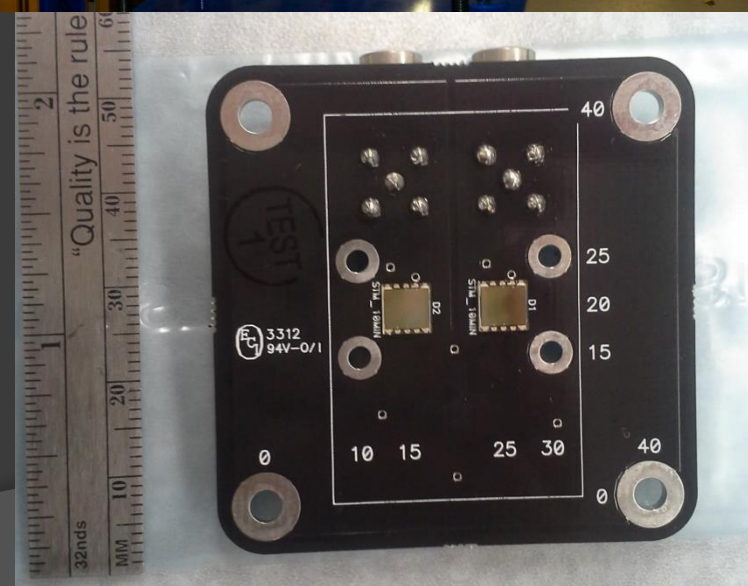




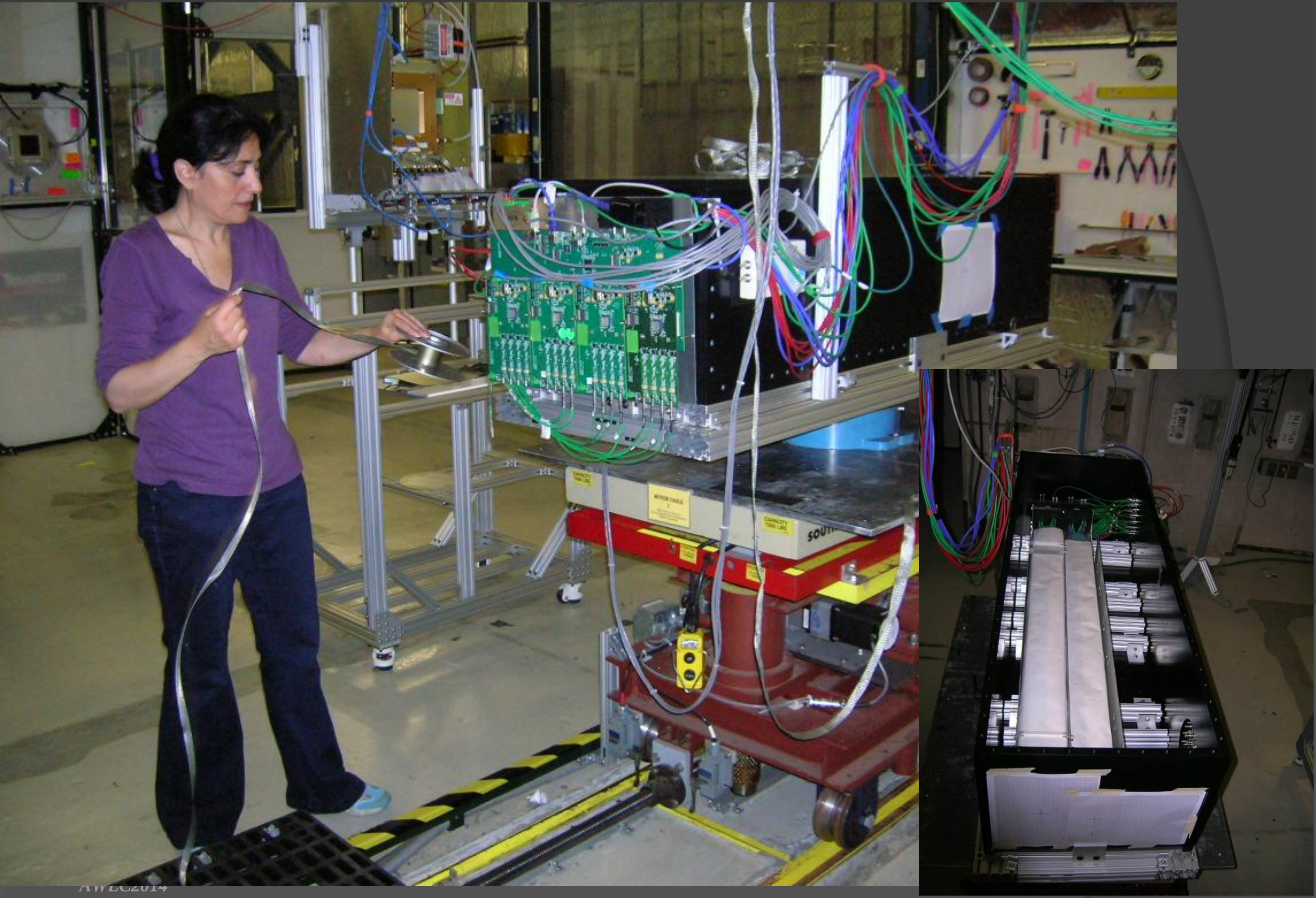


ADRIANO 2014

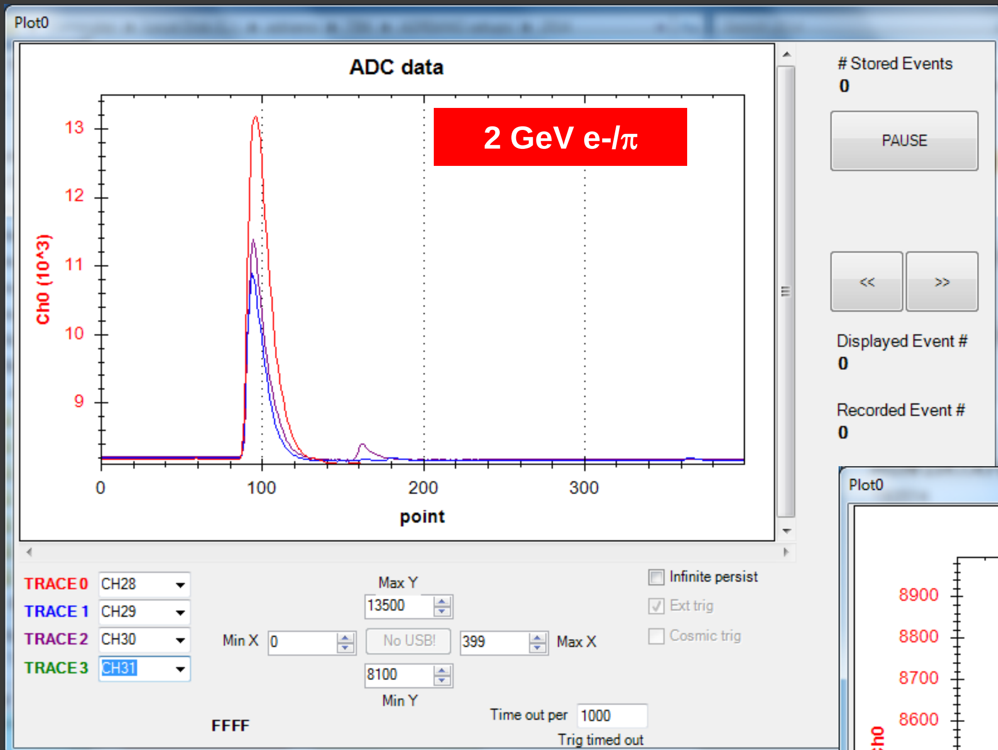




2014 Test Beam Setup at FTBF

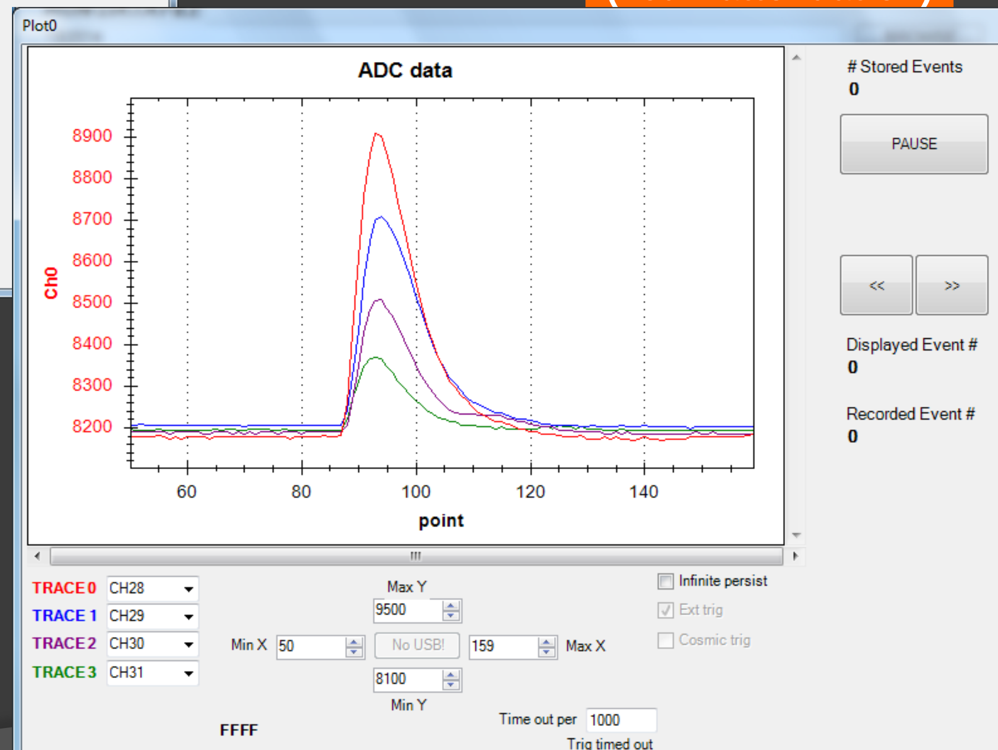


Waveforms from TB4 DAQ (FTBF)



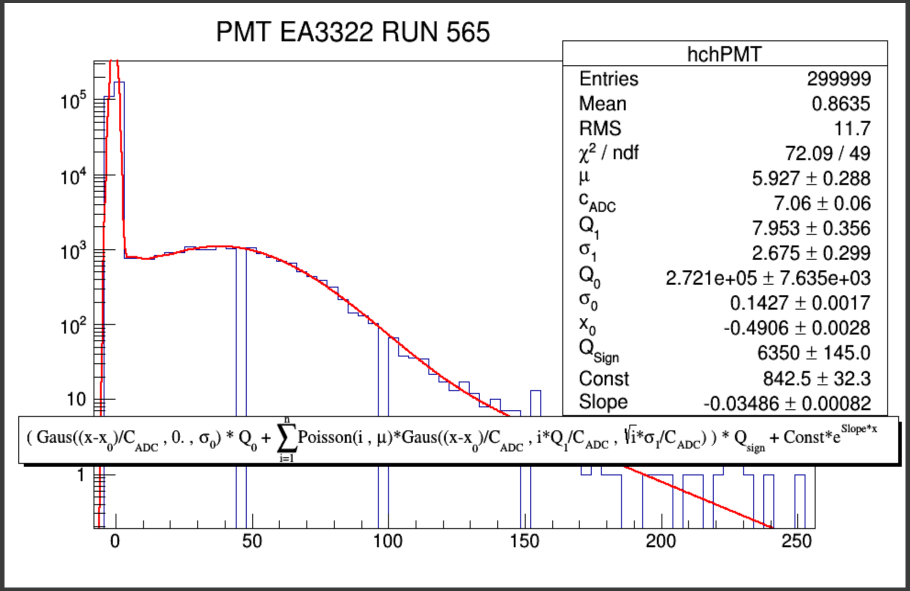
ADRIANO 2014A

ADRIANO 2014B
(16dB attenuation)

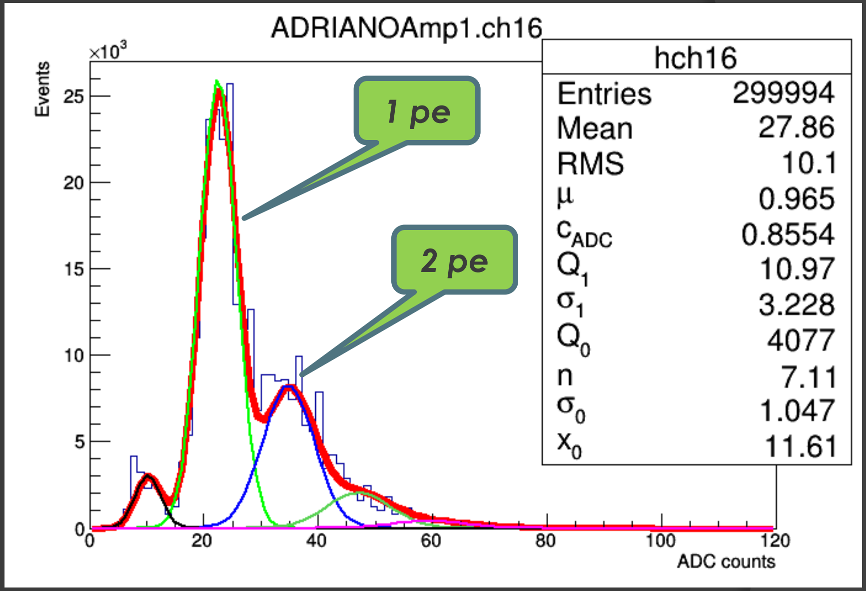


PMT's and SiPM Calibration

PMT Calibration



SiPM Calibration

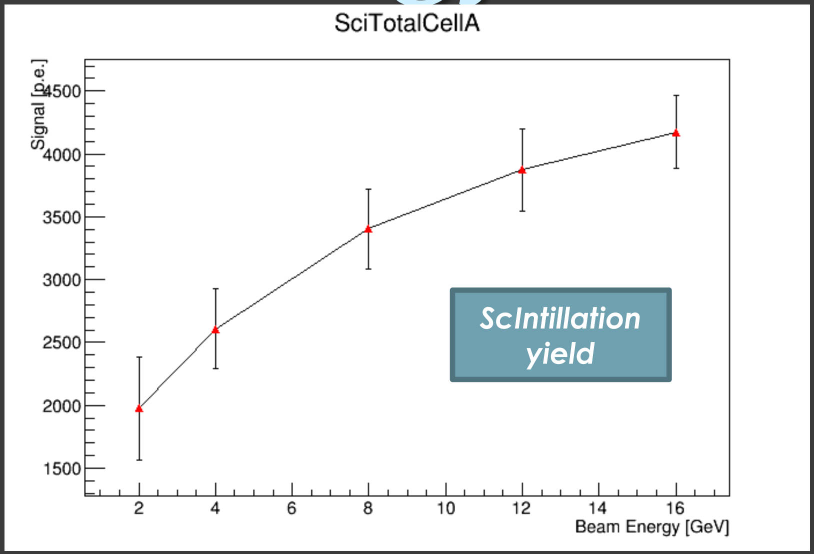


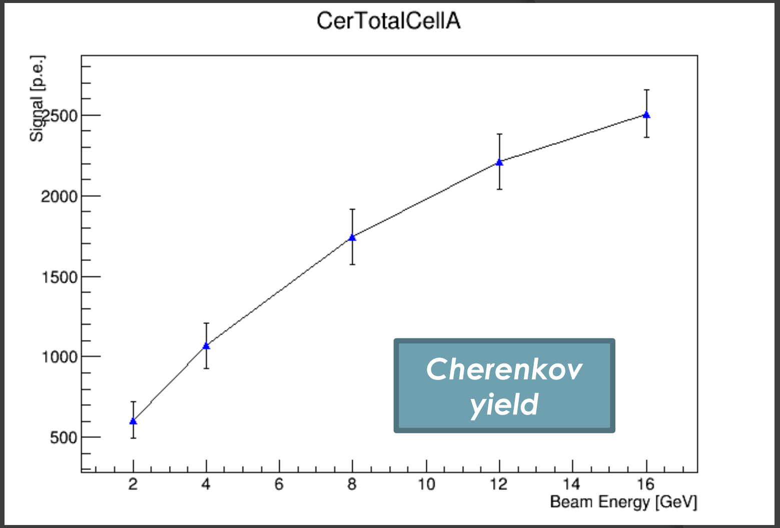
UV based fast LED with fast pulser
Fit with Bellettini et al. function

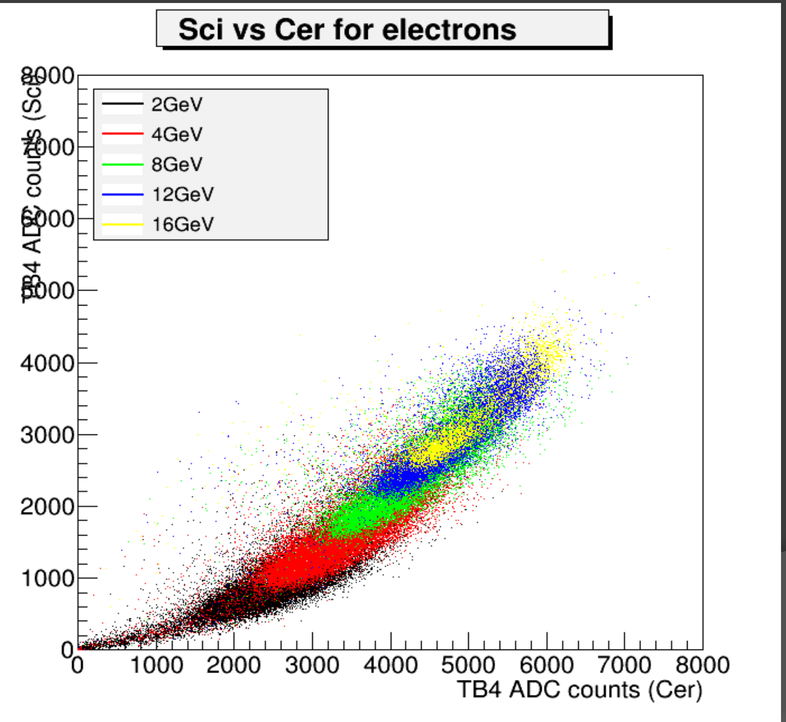
Spurious pulse – 1 pe
Fit with 2 gaussians + poisson

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

Energy scan with electrons



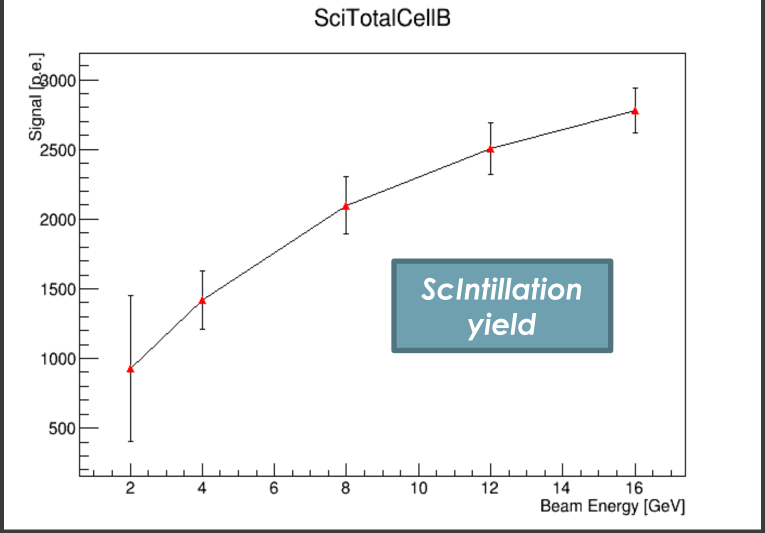


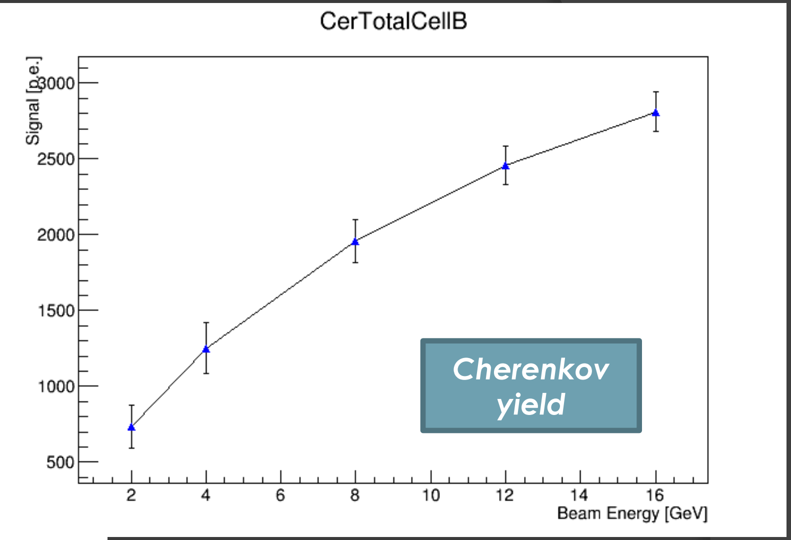


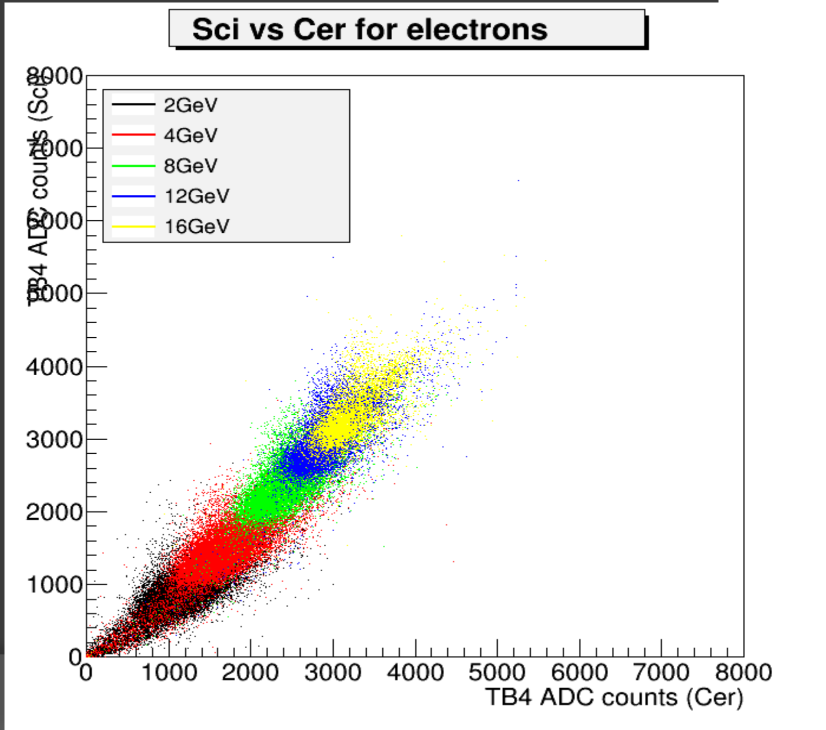
ADRIANO 2014A

- Electrons selected with Cherenkov systems at FTBF

Energy scan with electrons



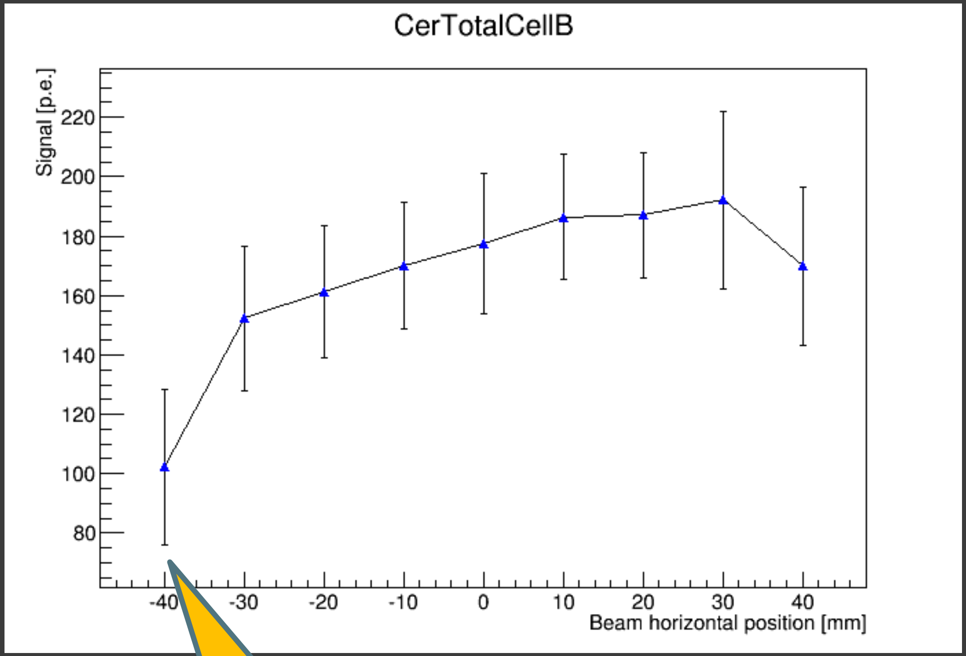


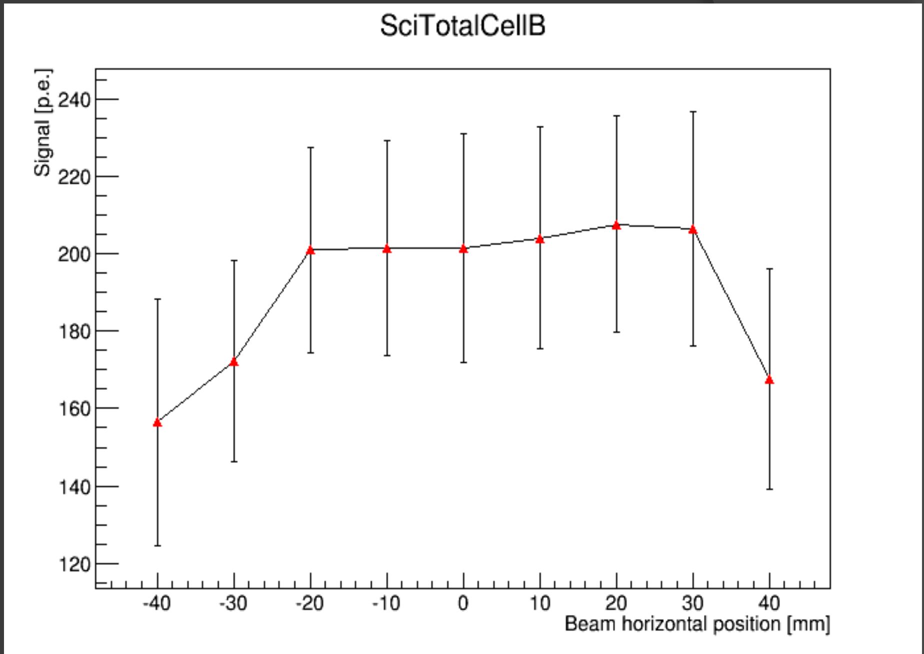


ADRIANO 2014B

- Electrons selected with Cherenkov systems at FTBF

Horizontal scan with mixed beam (e/π/μ): ADRIANO 201B

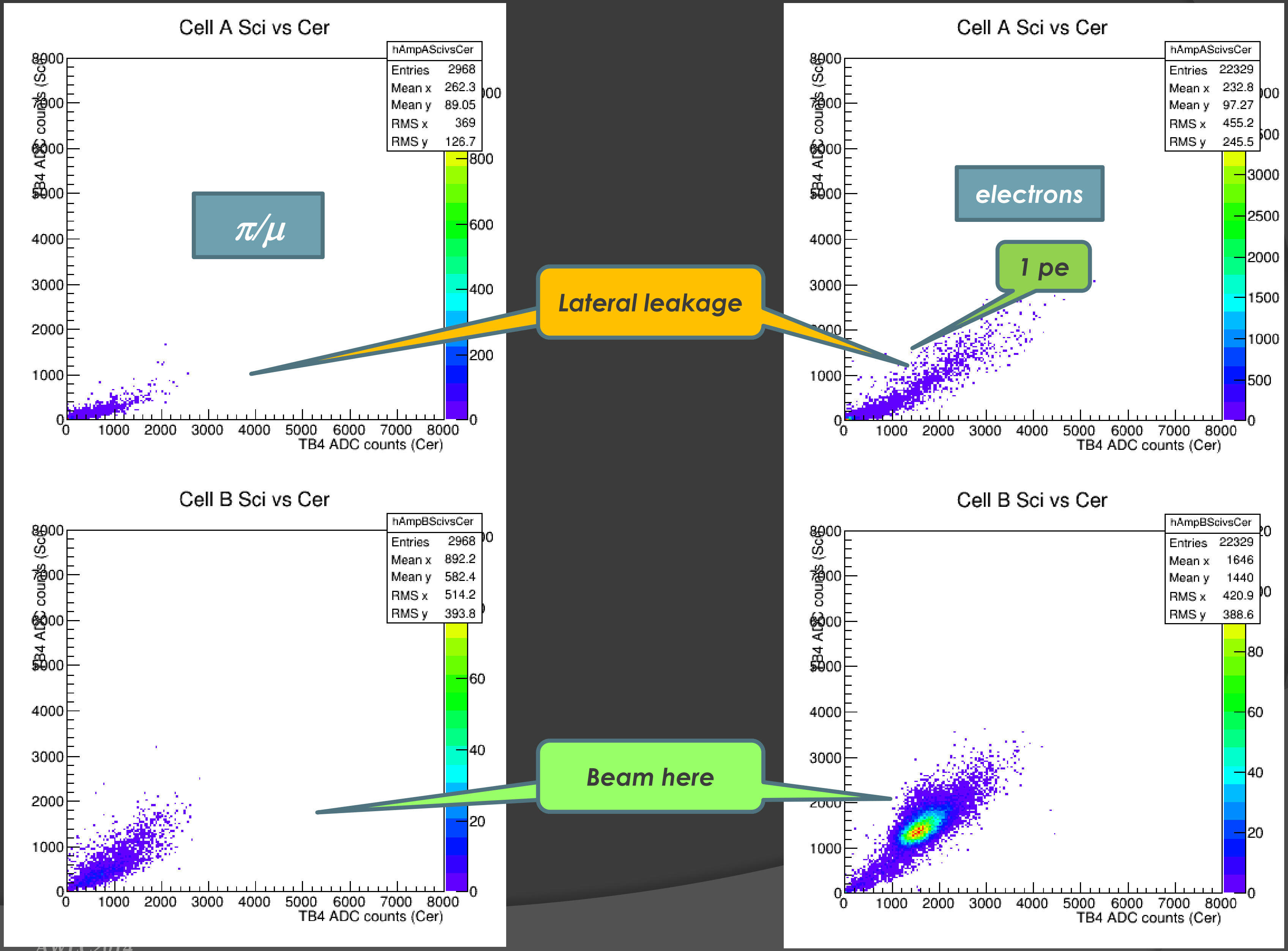




Lateral leakage

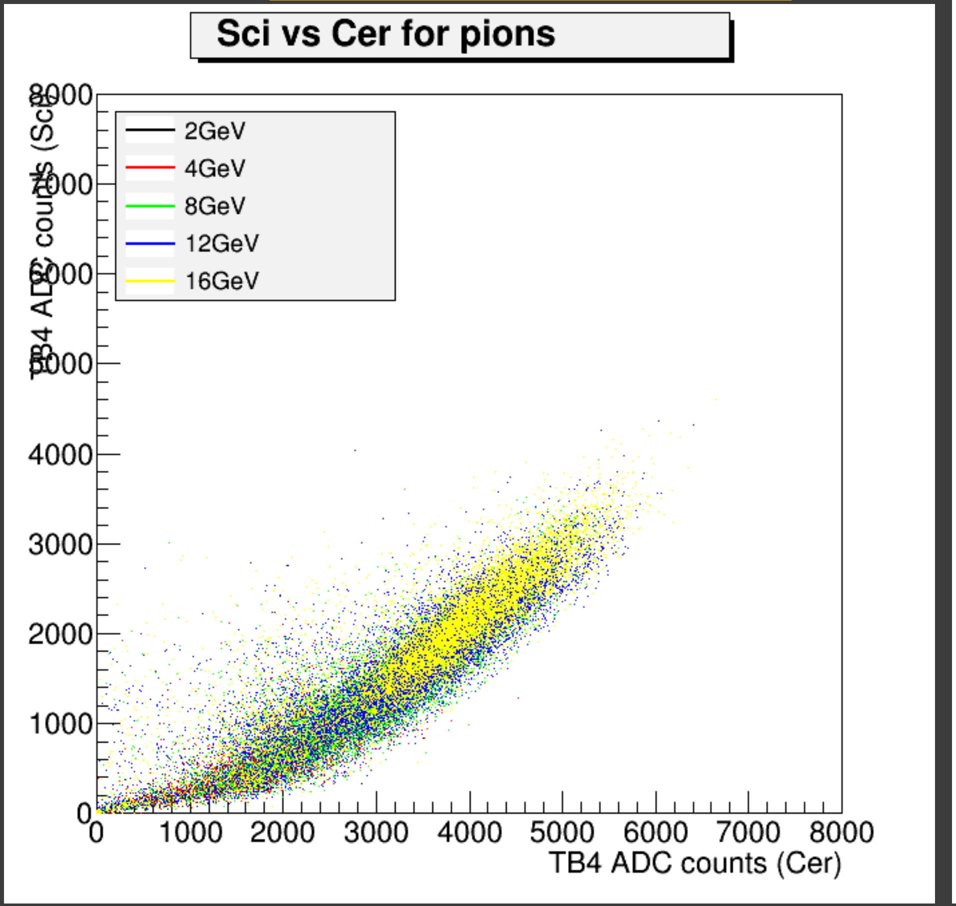
Readout from glass appears to be not uniform. Further investigations are required

Hadrons vs EM showers: ADRIANO 2014 B

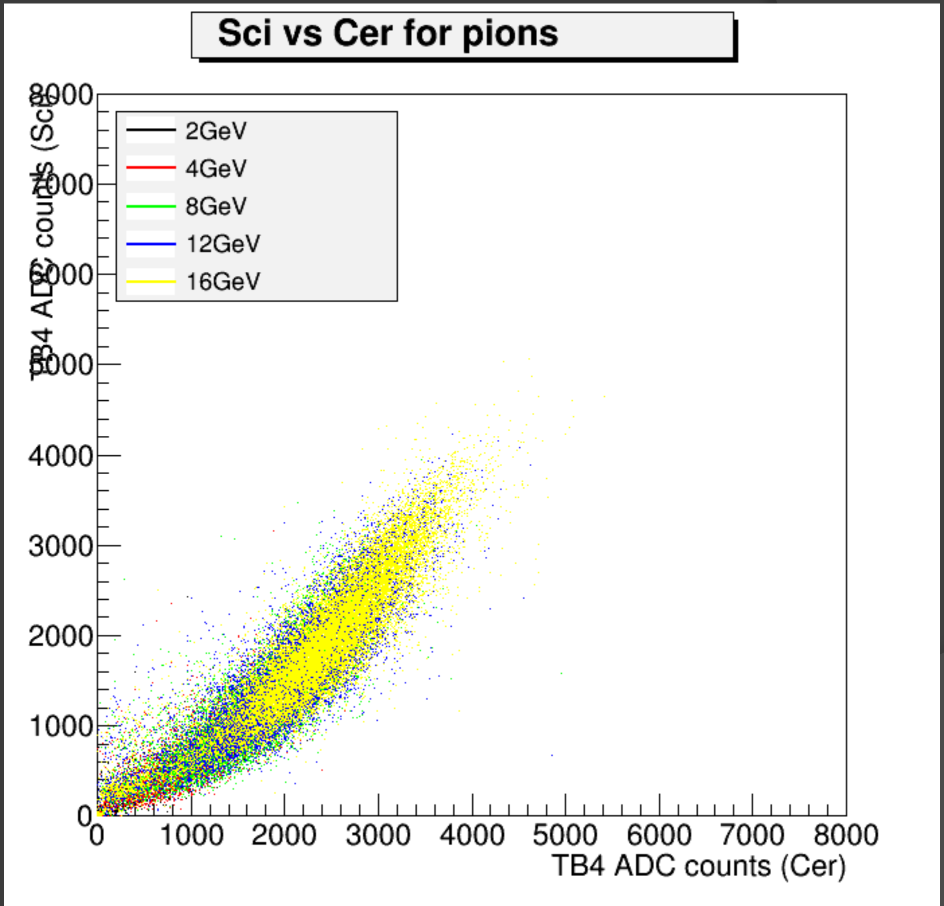


Hadrons scatter plots showers: ADRIANO 2014A and 2014B

ADRIANO 2014A

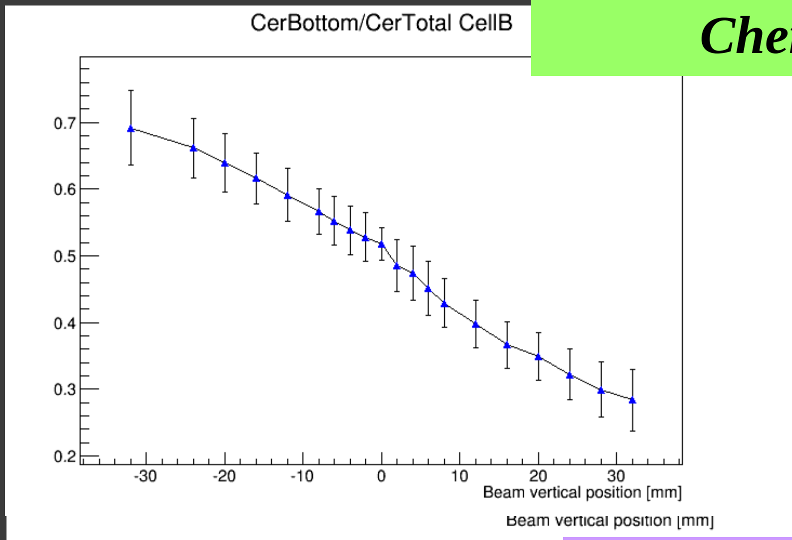


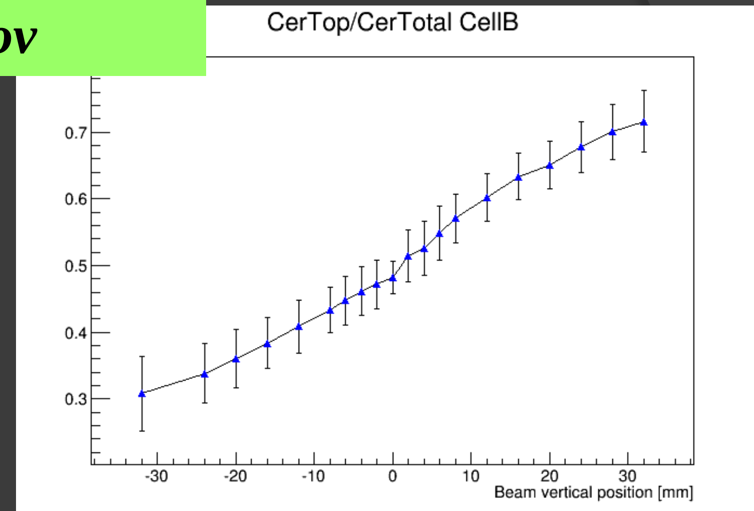
ADRIANO 2014B



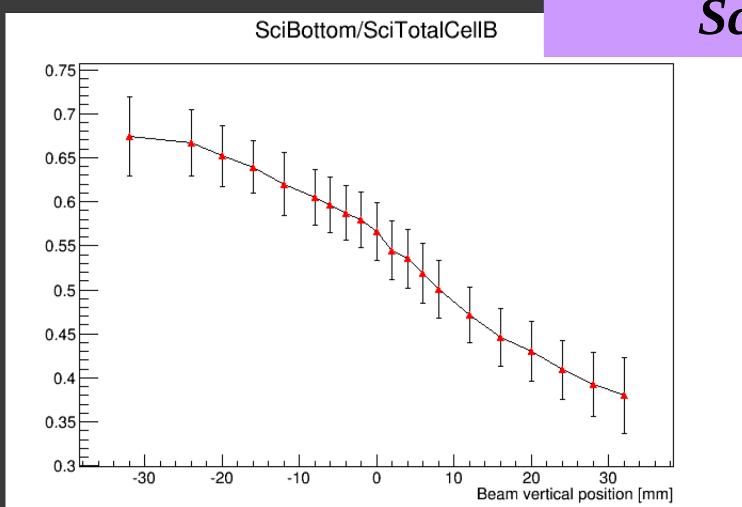
Vertical Scan with Protons: ADRIANO 2014B top half vs bottom half

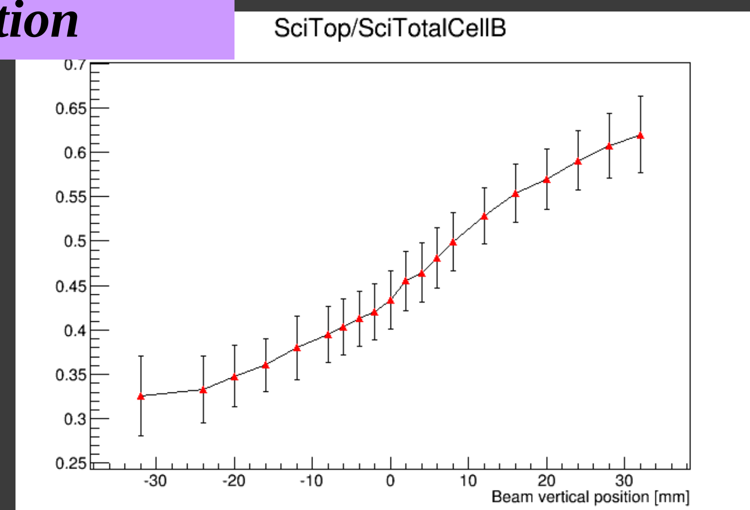
Cherenkov





Scintillation





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/cm³	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 gr/cm^3

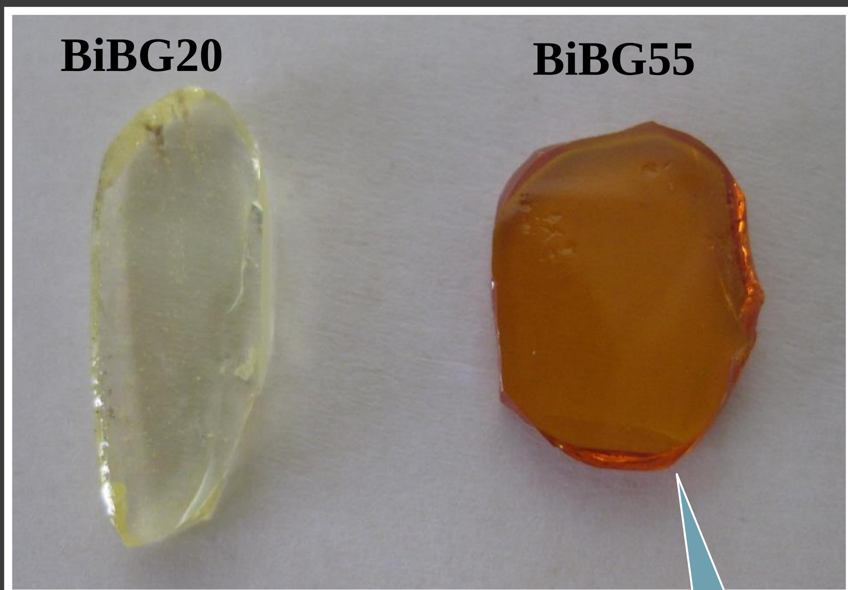
- Rare earths doped scintillating heavy glasses:
  - Ba-Bi-B matrix to accomodate Ce_2O_3 :
  - Density achieved up to now: 7.5 gr/cm^3 (see next slide)
  - Several rare earth oxides tested: Dy_2O_3 promising
  - Lithium content for neutron sensitivity

Consuelo Mugoni

Bismuth Borate Glasses BiB-G

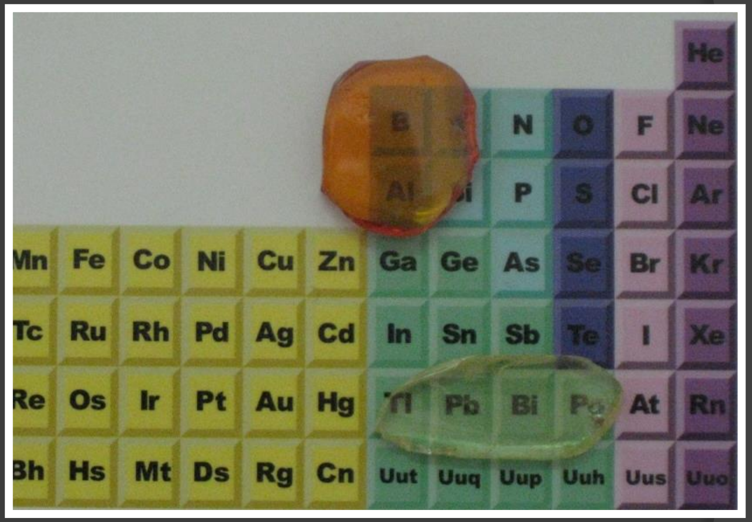
Goal *High density glasses by melt quench method*

- *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



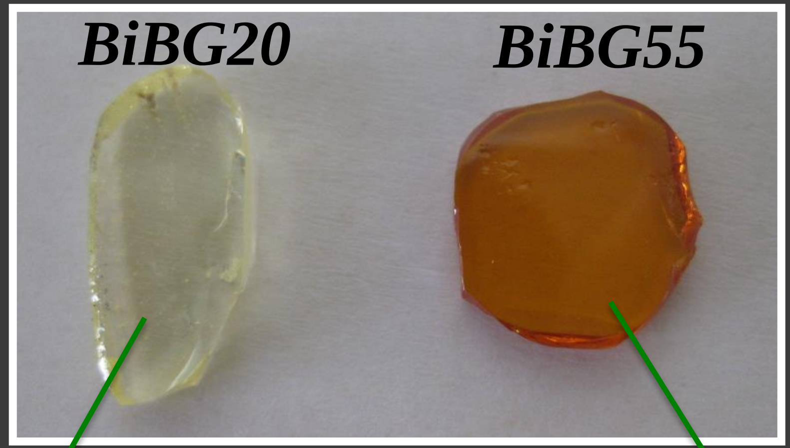
DENSITY

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

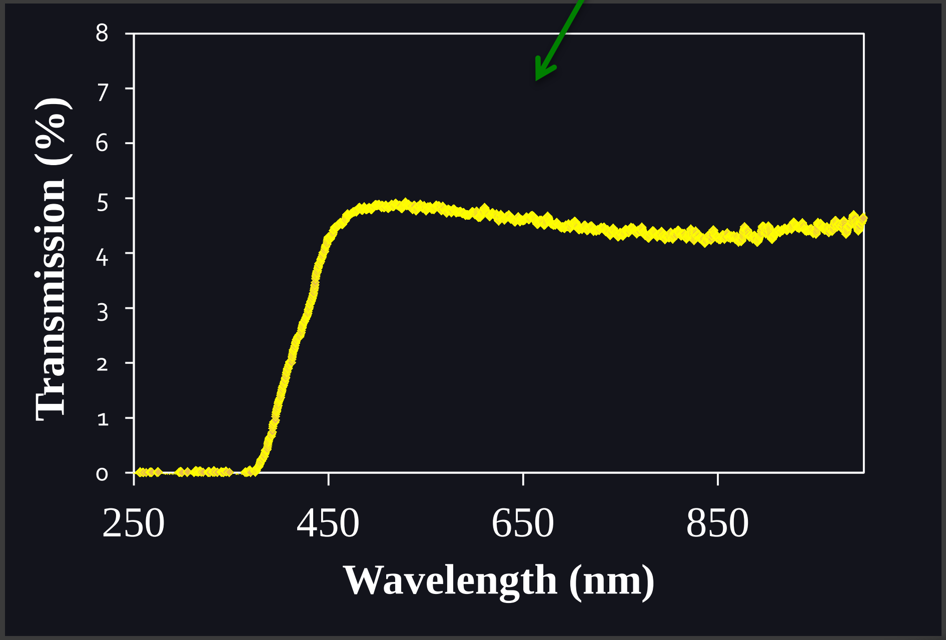
exp.error ± 0.01

Consuelo Mugoni

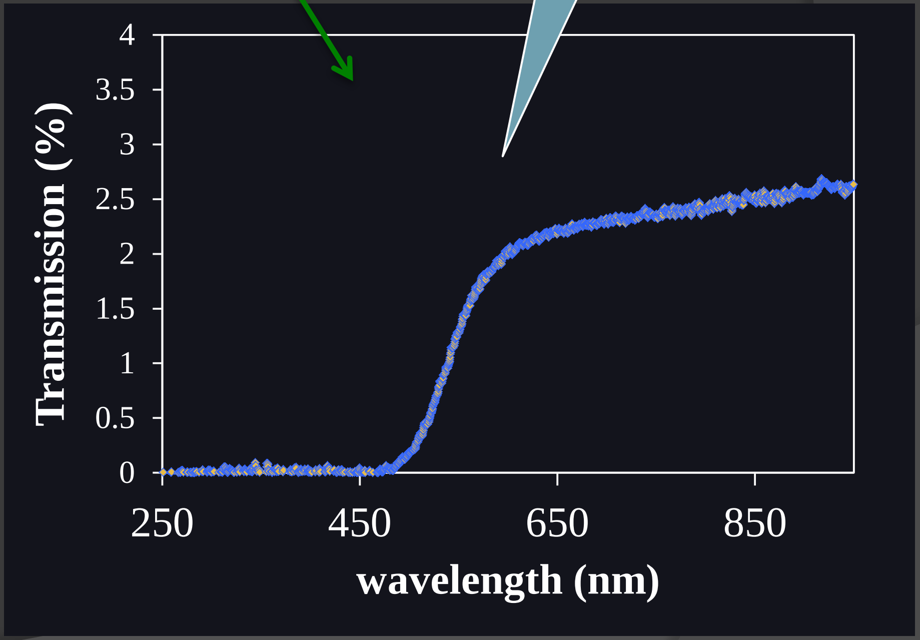
Transmission Spectra



No absorption bands



thickness c.a 0.3 cm

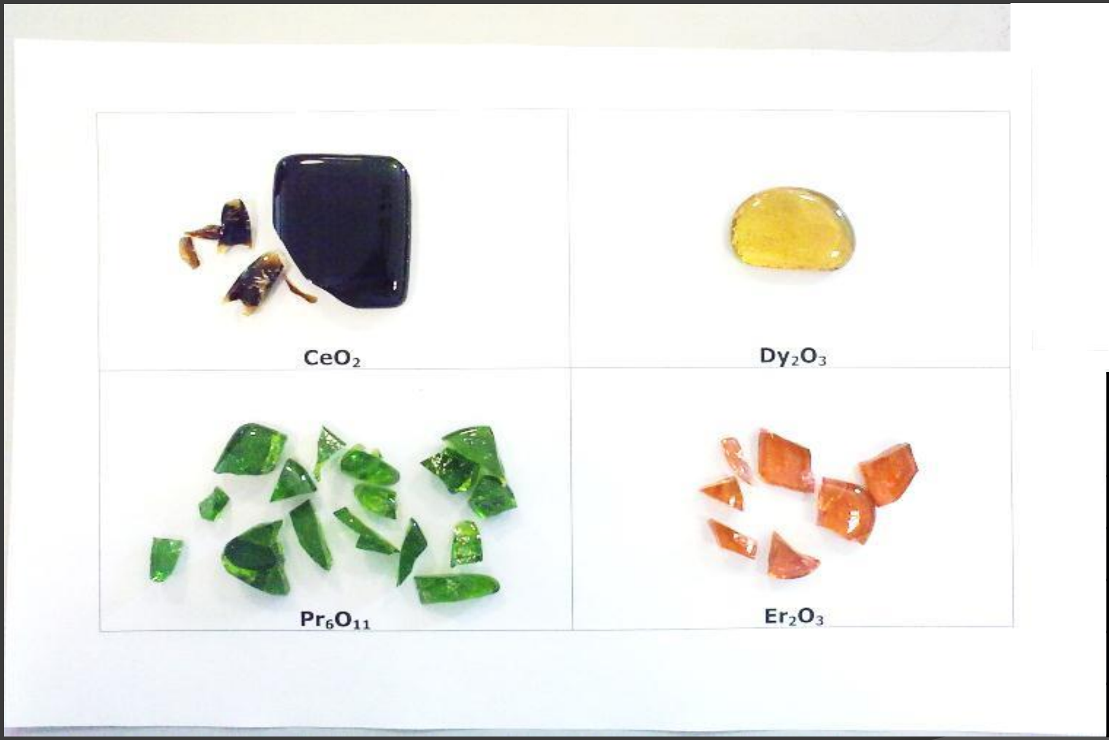


thickness c.a 0.3 cm

Consuelo Mugoni

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 succesfully 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 ligth 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 cm^2

What's next:

- LDRD proposal in praparation 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 λ_{81J} = 3.5 m
- Similar to charge division methods in drift chambers with resistive wires
- A technique already adopted by UA1 and ZEUSS

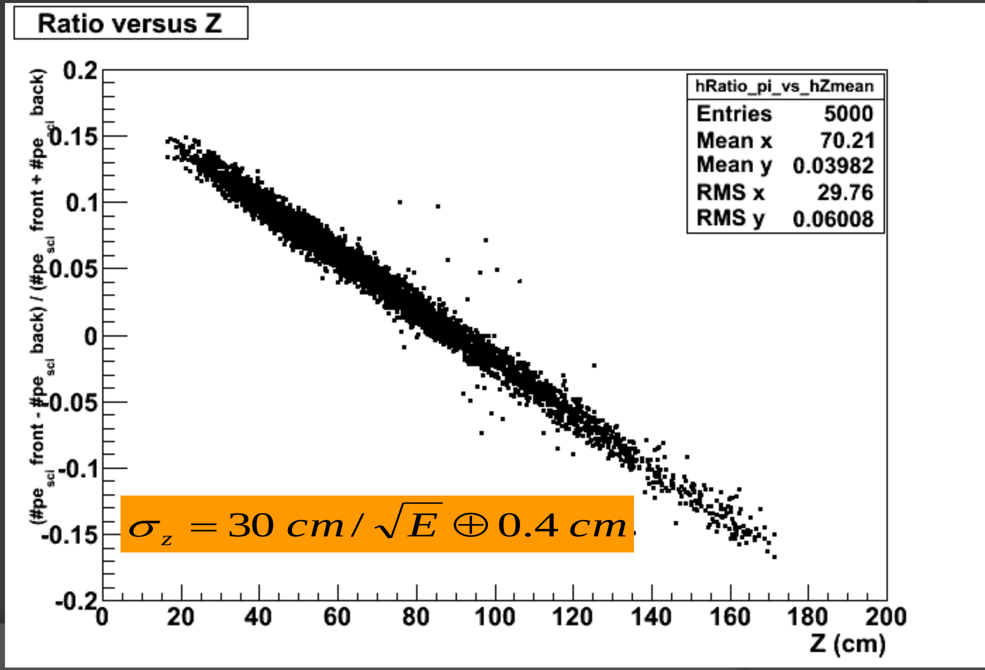
Instrumental effects included in ILCroot :

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

ILCroot simulations

100 Gev pions

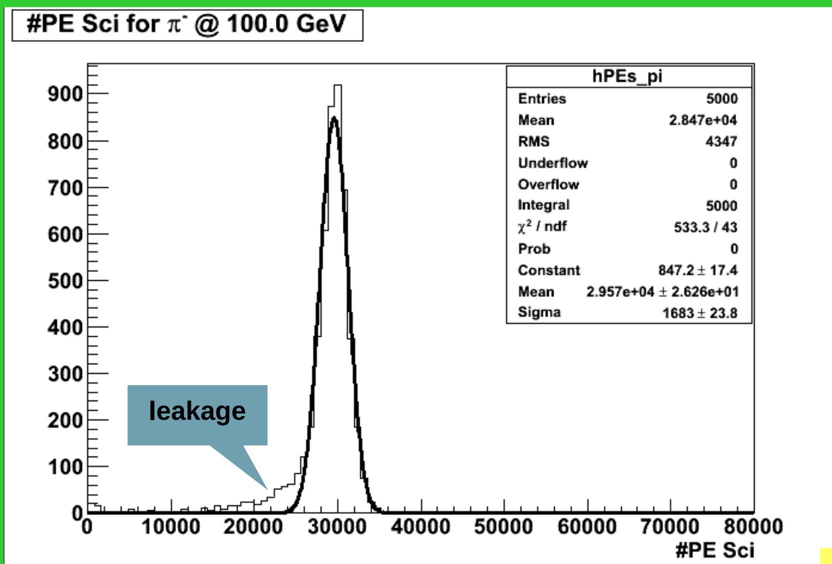
Front vs back Scintillation light vs true shower CoG

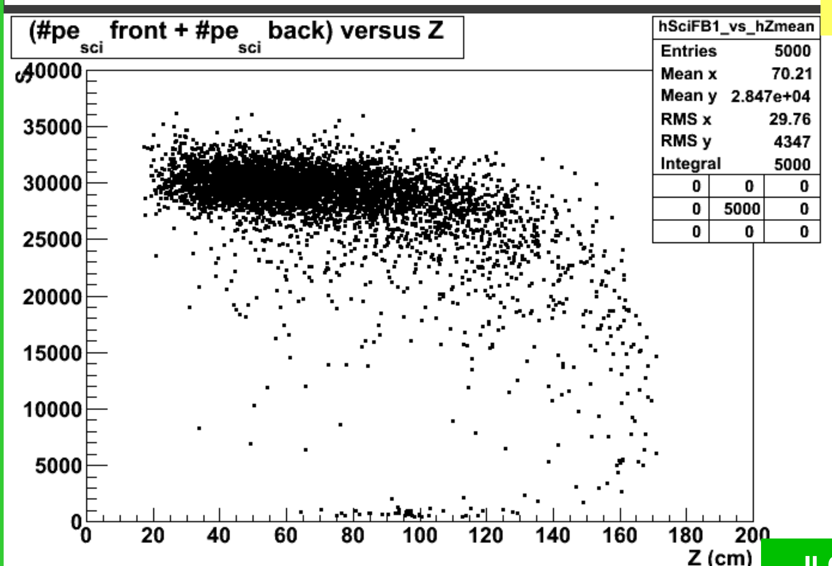


$$\sigma_z = 30\,cm/\sqrt{E} \oplus 0.4\,cm$$

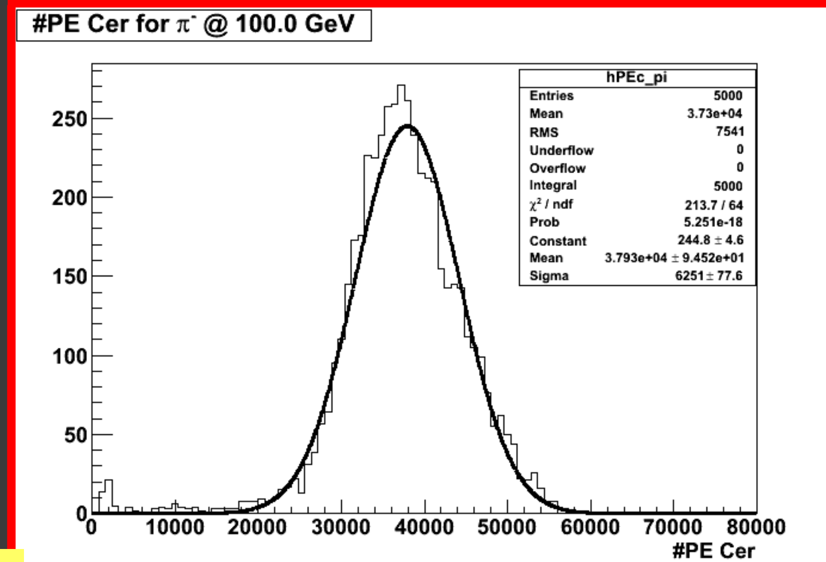
Leakage in 180 cm long *ADRIANO* module

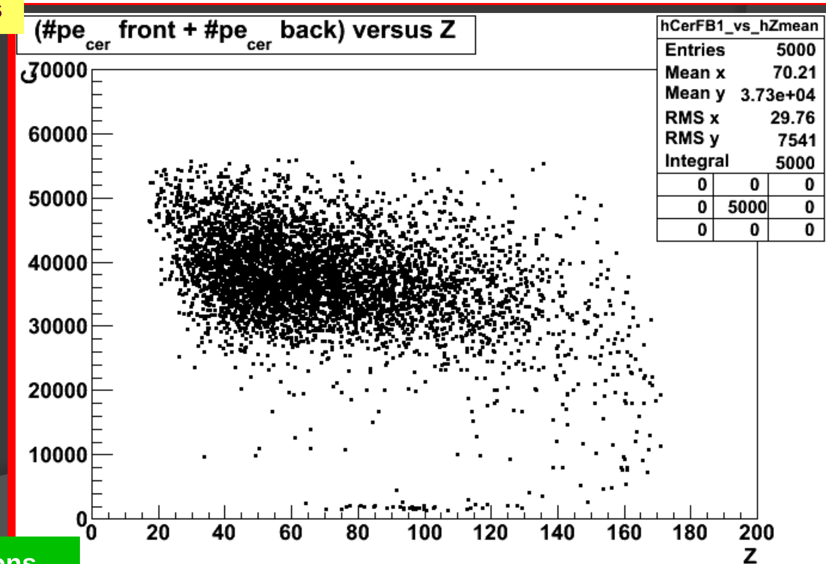
Uncorrected scintillating signal





Uncorrected Cerenkov signal



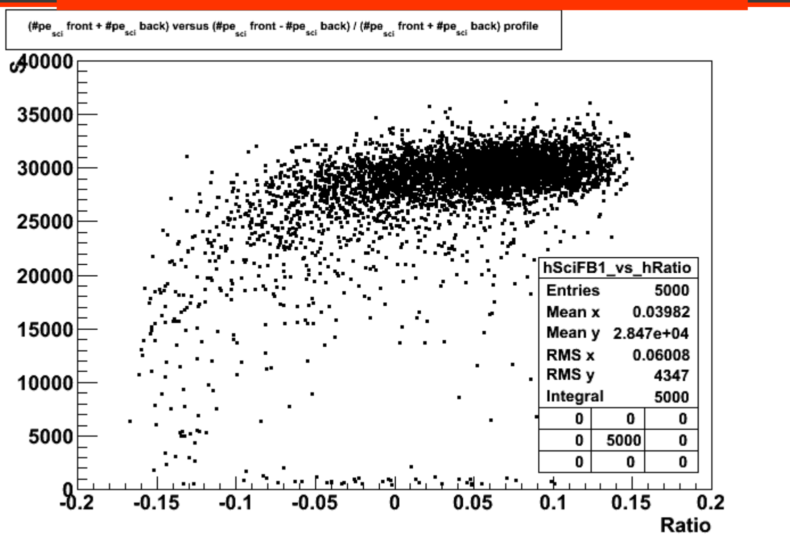


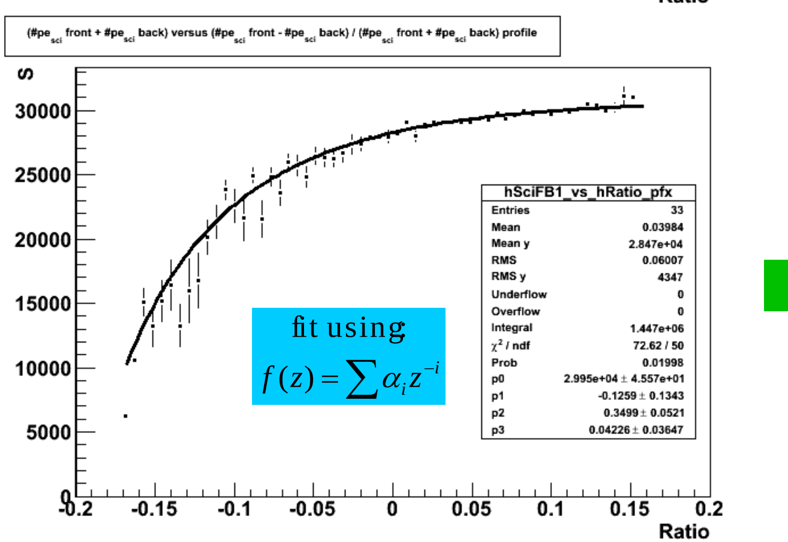
100 Gev pions

ILCroot simulations

Applying leakage corrections from CoG measured with a light division

Uncorrected scintillating signal

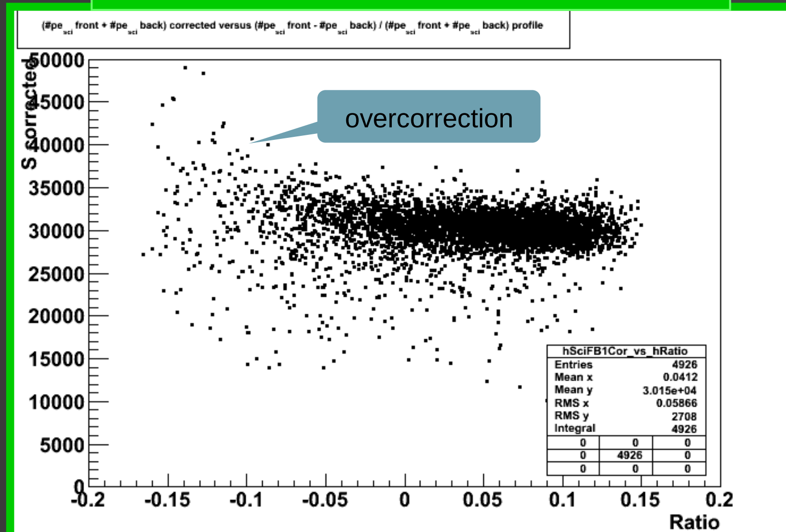


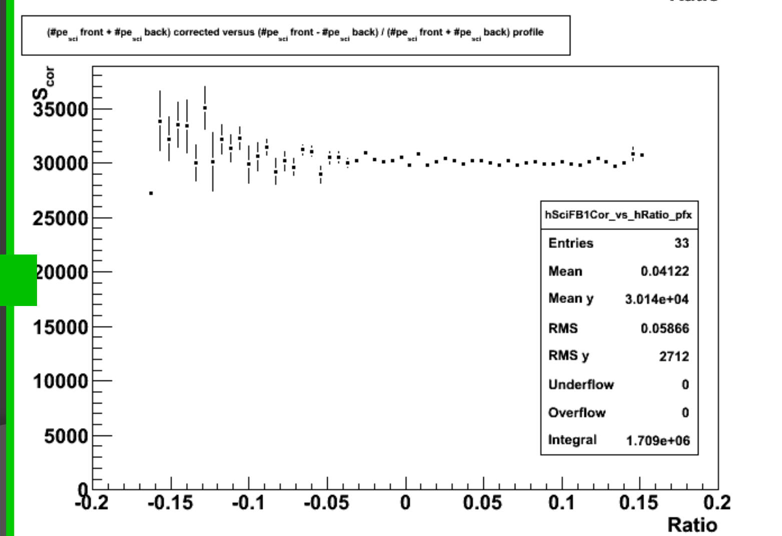


100 Gev pions

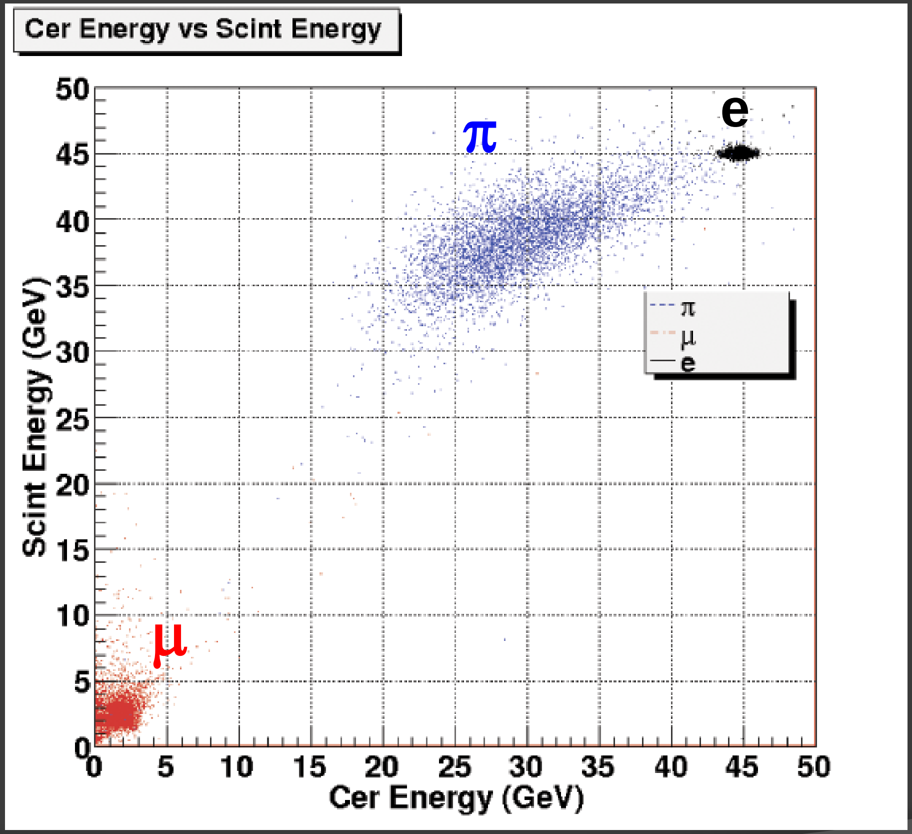
ILCroot simulations

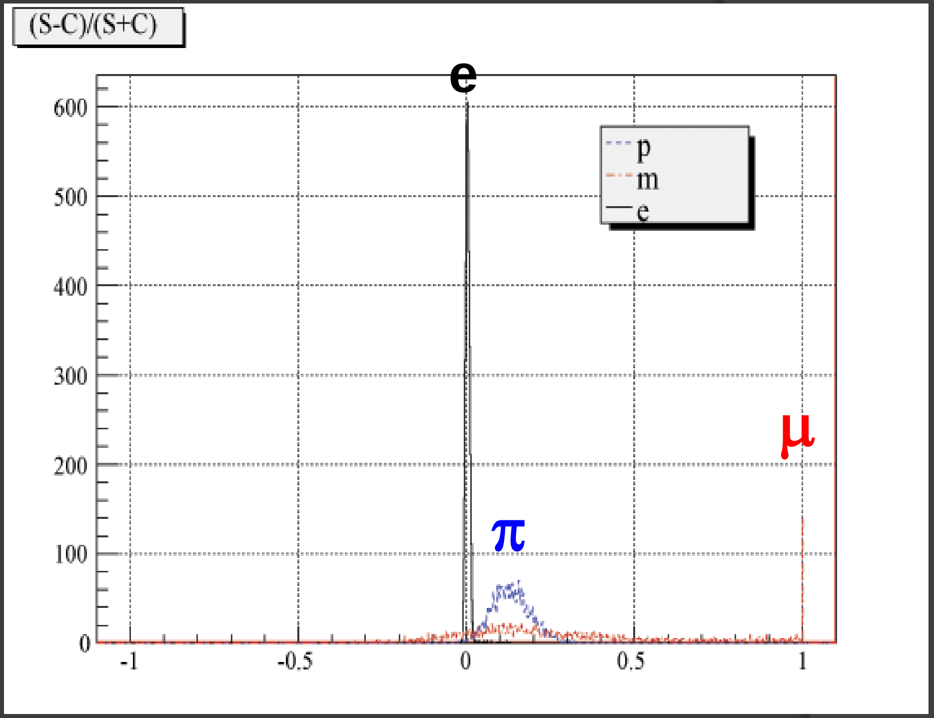
Corrected scintillating signal





Particle Identification in Dual Readout calorimeters



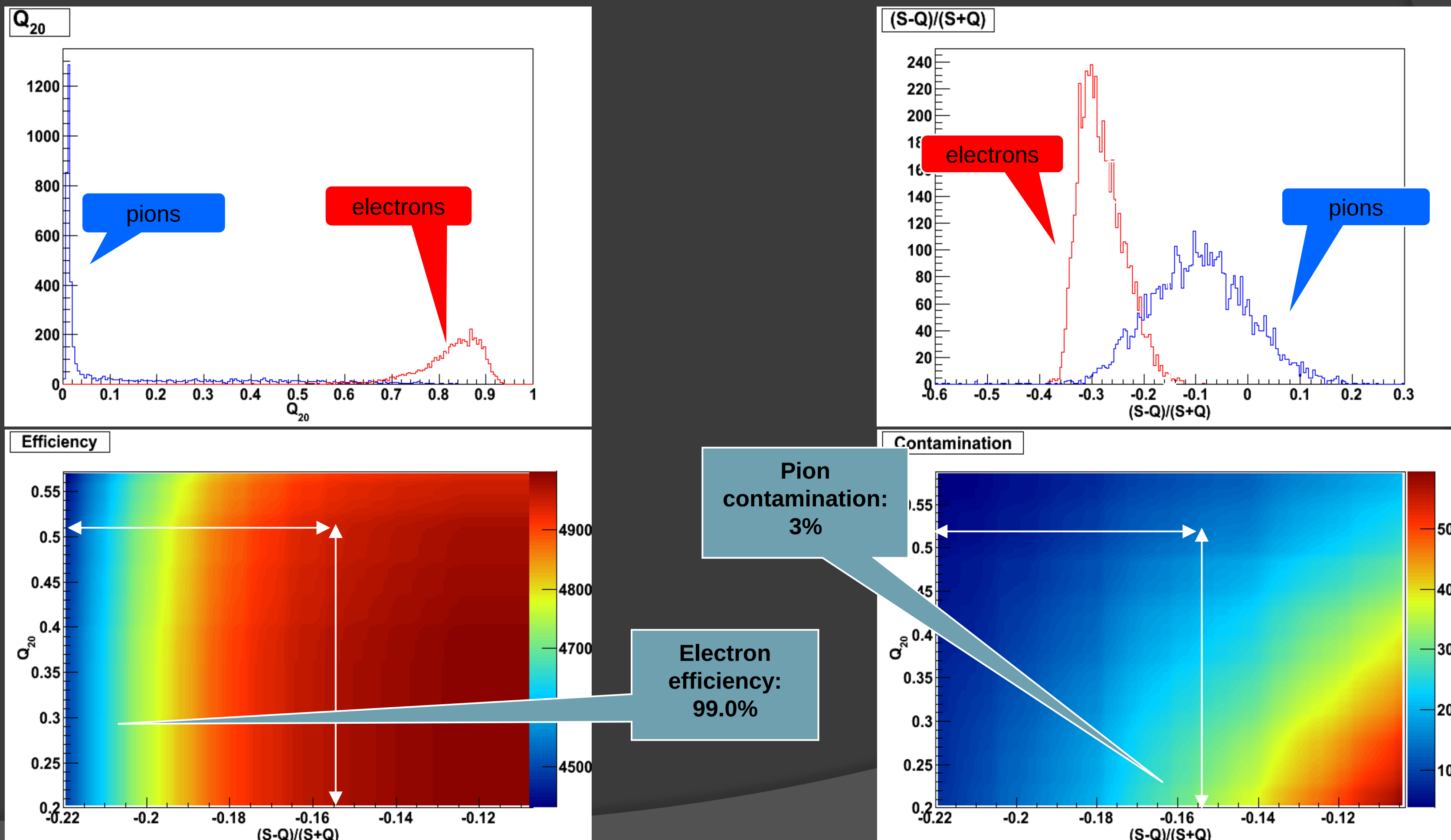


- 45 GeV particles

ILCroot simulations

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



ILCRoot simulation

Calibration à la DREAM

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

Step 1

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

for electrons

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

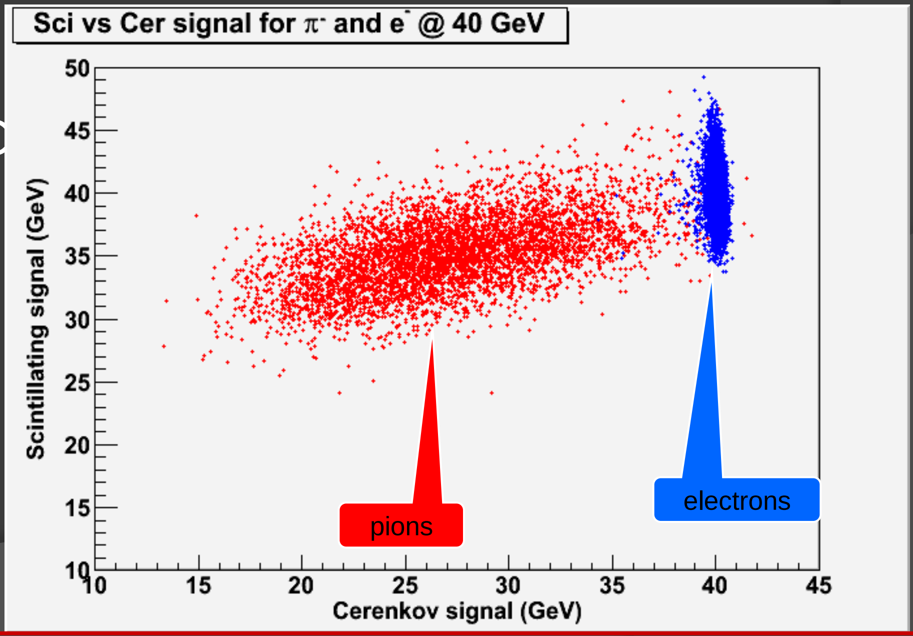
- Final calibration with pio

minimize

Step 2

$\chi^2(E_{HCAL}-E_{beam})$

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



ILCRoot simulation

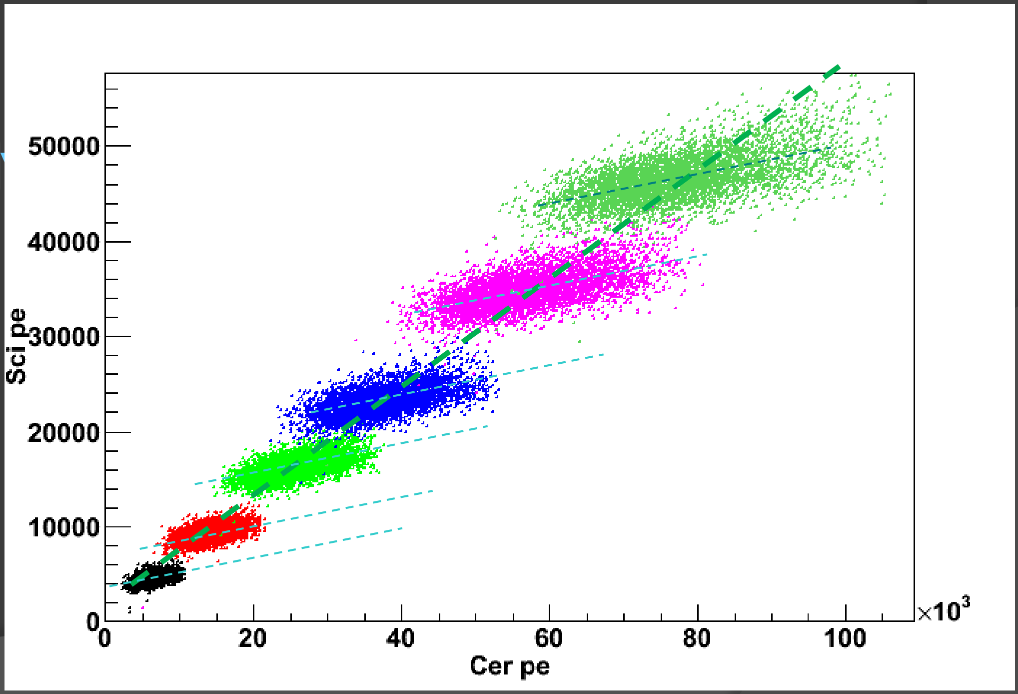
Calibration à la TWICE

- 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:

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

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

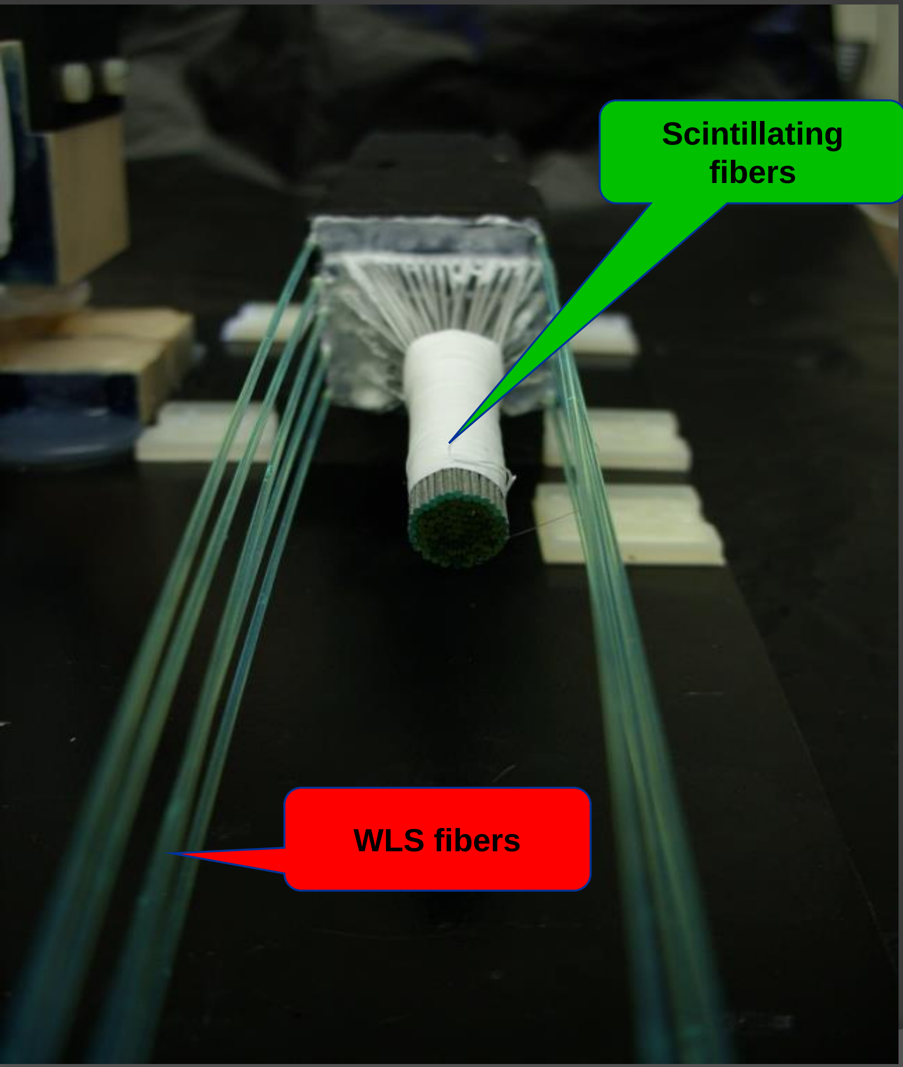
$$\alpha = 1/n \sum_1^n (\hat{S}_i/E_i) - \beta/n \sum_1^n (\hat{Q}_i/E_i)$$



Department of Materials and Environmental Engineering

ADRIANO Applications

Dual-readout Calorimetry
(compensate e/h fluactuations)



Imaging Calorimetry
(spatially resolve the shower in 3D)