ADRIANO:

A Dual ***R***eadout ***I***ntegrally ***A***ctive ***N***on-segmented ***O***ption for Future Colliders

Corrado Gatto

On behalf of:

T1015 Collaboration

Outline

- Dual-readout calorimetry and techniques
- ADRIANO simulation studies
- Prototype R&D
- Future prospects
- Conclusions

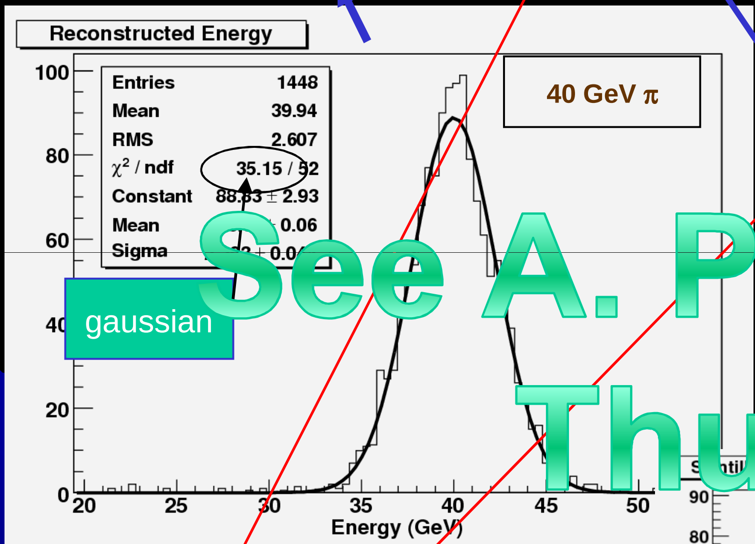
T1015 Collaboration at FNAL (28 scientists)

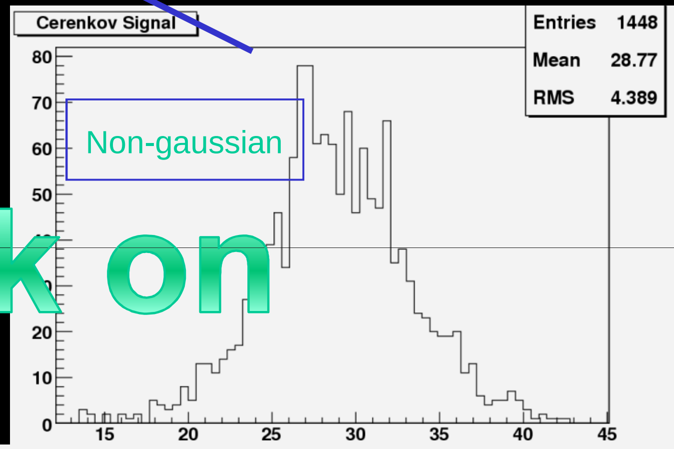
Institution	Collaborator
INFN Trieste/Udine and University of Udine	Diego Cauz
	Anna Driutti
	Giovanni Pauletta
	Lorenzo Santi
	Walter Bonvicini
	Aldo Penzo
Fermilab	Erik Ramberg
	Paul Rubinov
	Hans Wenzel
	Gene Fisk
	Aria Soha Anna Mazzacane Benedetto Di Ruzza
INFN Lecce	Corrado Gatto
	Vito di Benedetto Antonio Licciulli Massimo Di Giulio Daniela Manno Antonio Serra
INFN and University Roma I	Maurizio Iori
University of Salerno	Michele Guida
	NEITZERT Heinrich Christoph
	SCAGLIONE Antonio
	CHIADINI Francesco
University of Modena	Cristina Siligardi
	Monia Montorsi
	Consuelo Mugoni
	Luca Pasquali
	Giulia Broglia

Dual Readout Calorimetry

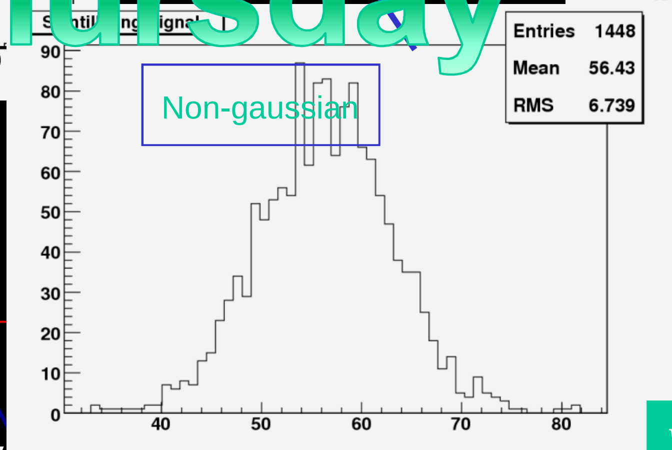
Total calorimeter energy: use two measured signals and two, energy-independent, calibration constants

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





See A. Para talk on Thursday



$$\eta_c = \left(\frac{e}{h}\right)_C \qquad \eta_S = \left(\frac{e}{h}\right)_S$$

From calibration

@ 1 Energy only

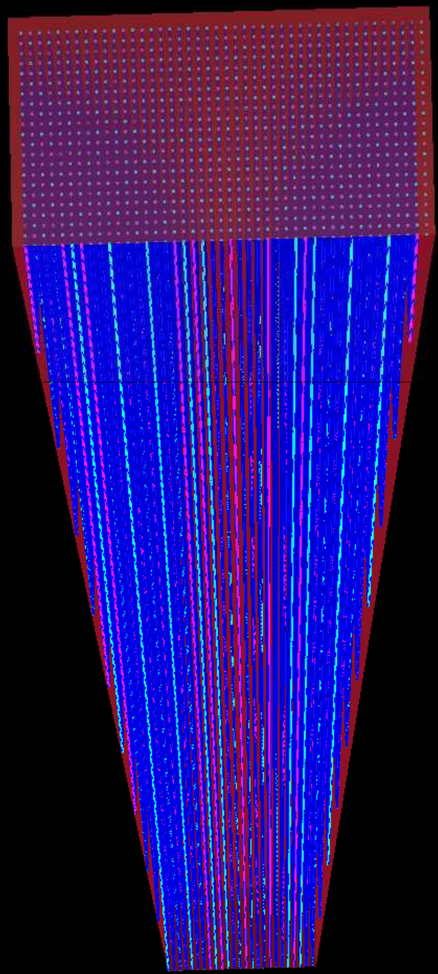
*We are measuring **fem event-by-event***

THE ORIGINAL APPROACH

Sampling *Dual-readout* (DREAM and 4th Concept)

After several years of simulations and studies with ILCroot we have learnt that Sampling Dual-readout (i.e. *Dual-readout* with PASSIVE absorber) has:

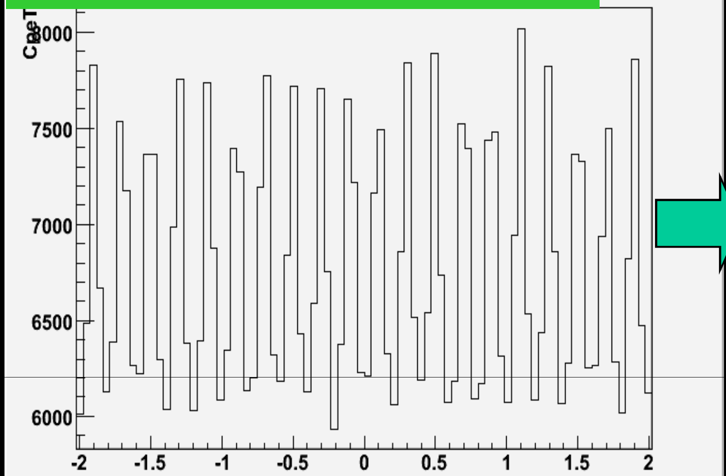
- Pros
  - First working example of dual-readout calorimeter
  - Scintillation and Cerenkov light are produced in distinct and optically separated volumes
  - Simulations confirm test beam data (more or less) and improvement in energy resolution
  - Cheap to build (brass and plastic fibers)
- Cons
  - Sampling is far too coarse shower generated by EM particles
  - Cerenkov light in fibers is very dim (~7.5 pe/Gev)
  - Large unbalance between Scintillation signal (~200 pe/Gev) vs Cerenkov (~7.5 pe/GeV)
  - Too many fibers to be routed to FEE for a 4π calorimeters



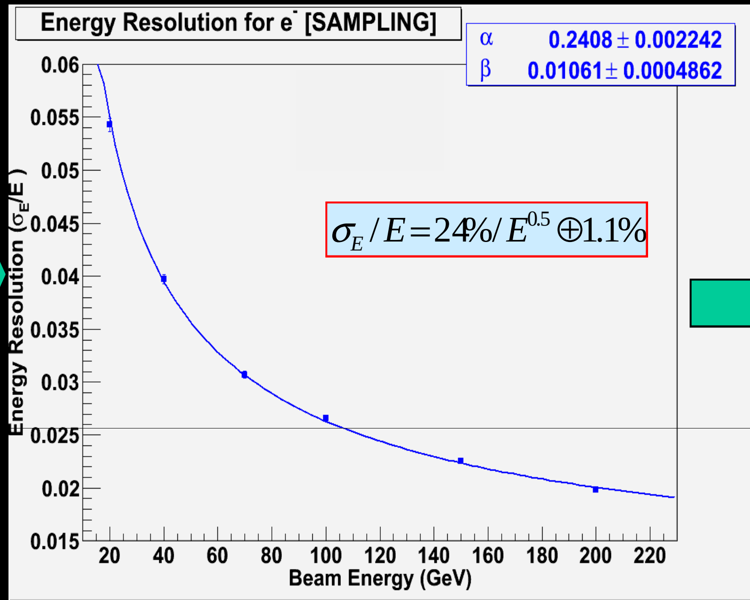
Sampling vs Integrally Active

Sampling frequency to be compared to absorption length of bulk of the particles in the shower (not X_o nor λ_I): **i.e 1 mm for e^-** (1 MeV e^- in typical *EM* showers)

Sampling Calorimeter (1mm fiber pitch)

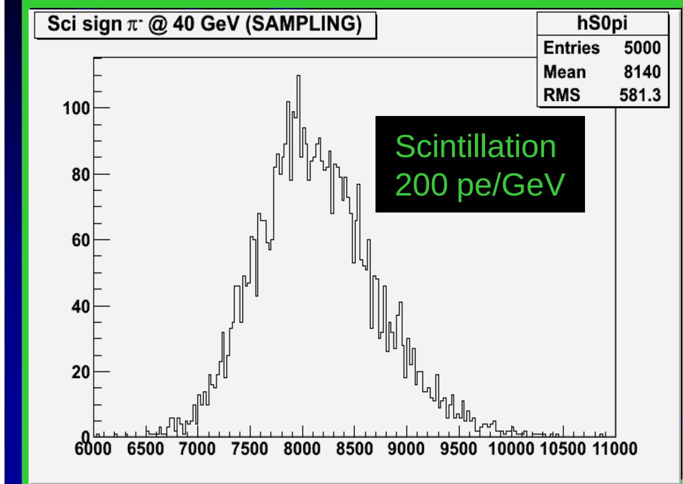


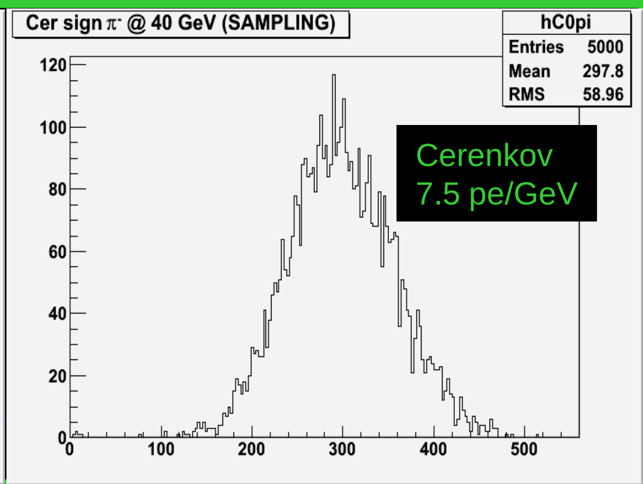
Č signal from e^-@45 GeV vs impact point [cm]



Consequences:

Need a front EM section





Consequences:

large unbalance between scintillation and Cerenkov signals

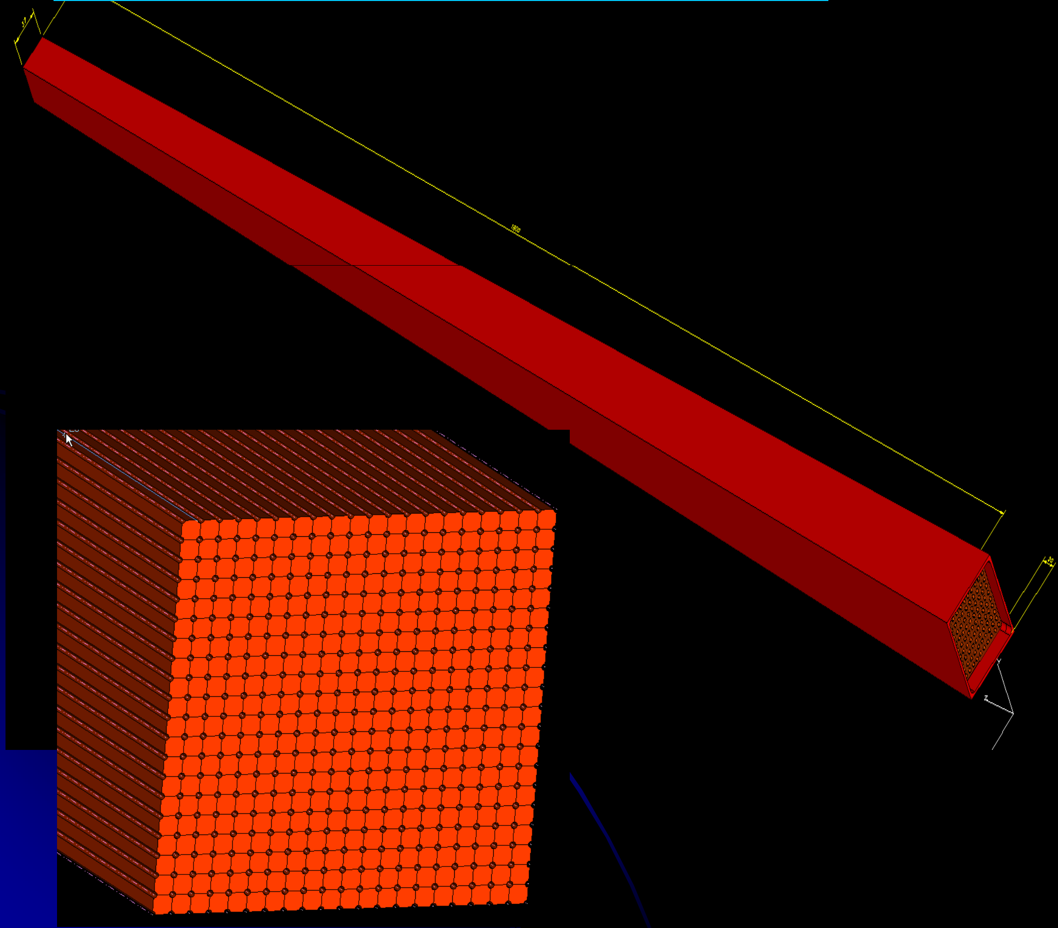
Combine the advantages of sampling and total active techniques

ADRIANO **technique: i.e. embedd scintillating fibers into heavy glass**

- Active Cerenkov component: Optical Heavy Glass
  - It functions as an **active absorber**
  - No scintillation light
  - Lots of Cerenkov photons thanks to n_l=1.95 (for λ ~ 510 nm)
- Scintillating component: scintillating fibers
  - **Optically separated** from Cerenkov absorber
  - Control the scintillation/Cerenkov signal with appropriate pitch between fibers
  - $\Gamma_{ADRIANO}$ = 8% (fraction of fiber volume)

ADRIANO Layout

- Fully modular structure
- 2-D with longitudinal shower COG via Light division techniques



- Cells dimensions: 4x4x180 cm^3

  Absorber and Cerenkov radiator: SF57HHT (for now)

  $\lambda_I \sim 7.5$ (with SF57HHT)

  Cerenkov light collection: 8 BCF92 fiber/cell

  Scintillation region: SCSF81J fibers, dia. 1mm, pitch 4mm (total 100/cell) inside 100μm thin steel capillary (opt.)

  Particle ID: 4 BCF92 fiber/cell (black painted except for foremost 20 cm)

  Readout: front and back SiPM

  COG z-measurement: light division applied to SCSF81J fibers

Heavy glasses vs crystals for Dual-readout calorimetry

	Glass	Crystals
Light production mechanism	Only Cerenkov (minor fluorescence with some SF glasses)	Cerenkov + scintillation
Stability vs ambiental (Temp, humidity, etc)	Excellent	Poor
Stability vs purity	Very good if optical transmittance is OK	Very poor
Longitudinal Size	Up to 2m	20-30 cm max
Cost	0.8 EUR/cm^3	10-100 EUR/ cm^3
Density	6.6 gr/cm^3 (commercially available)	Up to 8-9 gr/cm^3
Radiation hardness	Medium (recoverable via UV annealing for Pb-glass) or unknown (for Bi-glass)	varies

Simulation Studies with ILCroot on *ADRIANO* techniques

V. Di Benedetto

C. Gatto

A. Mazzacane

ADRIANO simulations in ILCroot

- *ADRIANO* is a melting pot of <u>well established</u> experimental methodologies
- All algorithms are implemented parametrically
- Use known experimental setups to normalize the overall results:
  - DREAM for scintillating light production (fiber calorimeter is OK, BGO+fibers not quite there)
  - CHORUS for instrumental effects with sci-fibers
  - R. Dollan Work for WLS light collection with SF57

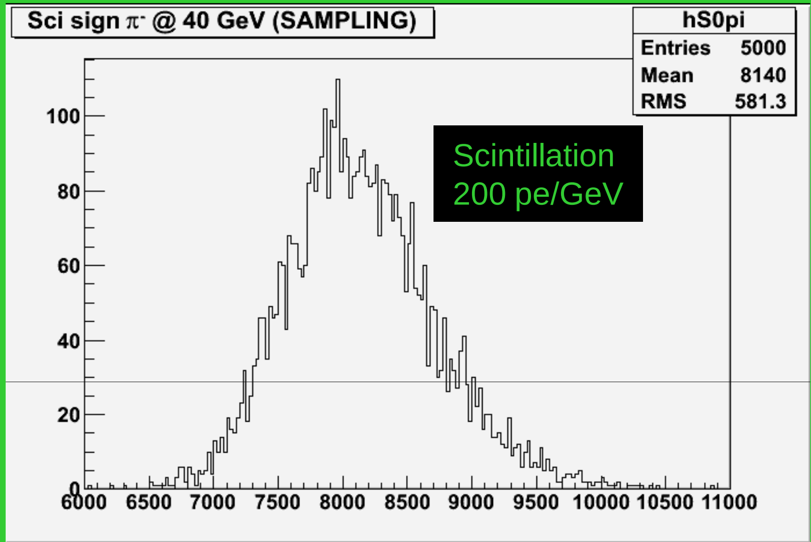
ILCRoot simulation

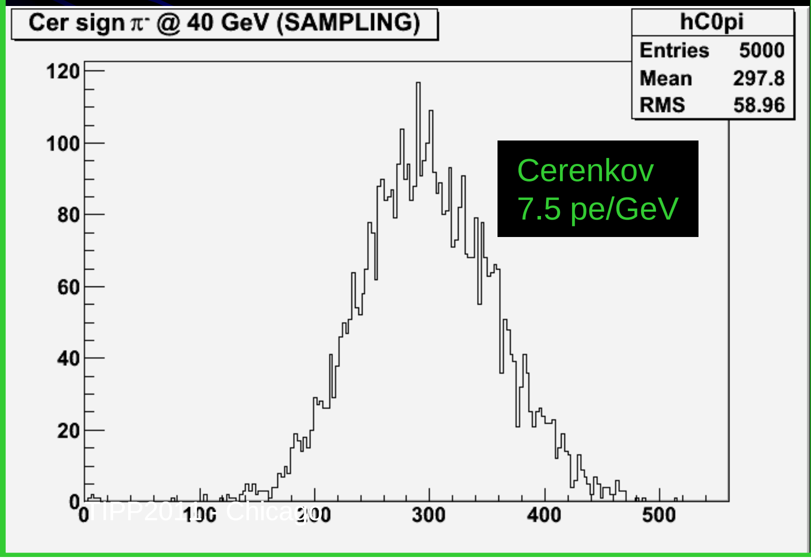
40 Gev pions

Photon yield:

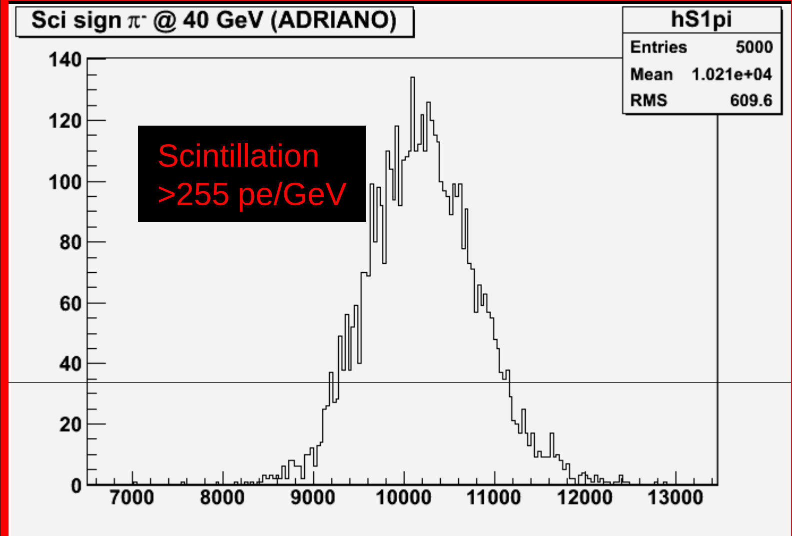
Sampling vs integrally active

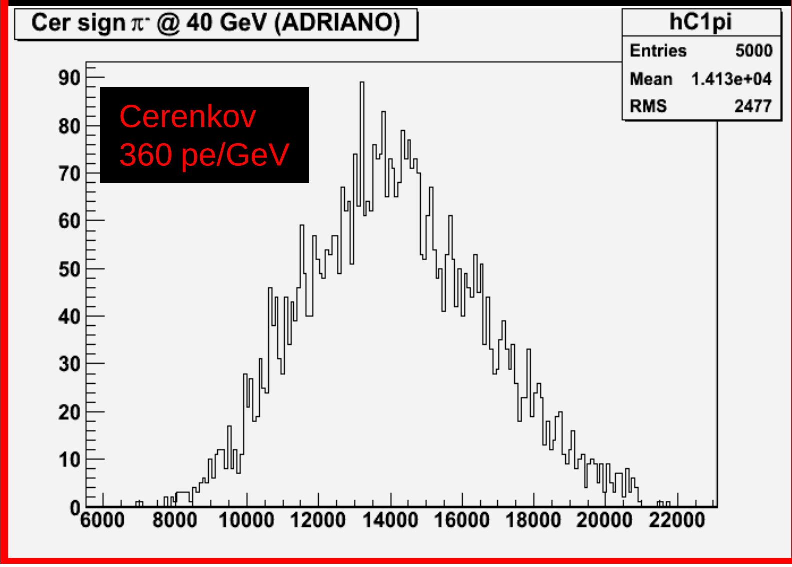
Sampling Calorimeter





ADRIANO Calorimeter



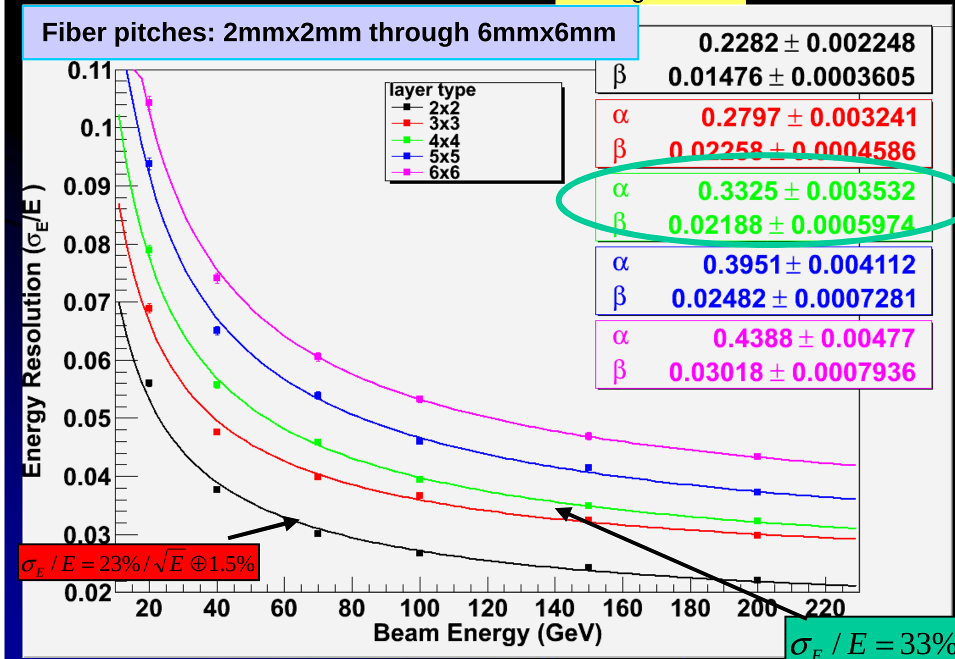


ADRIANO Light Yield and E resolution

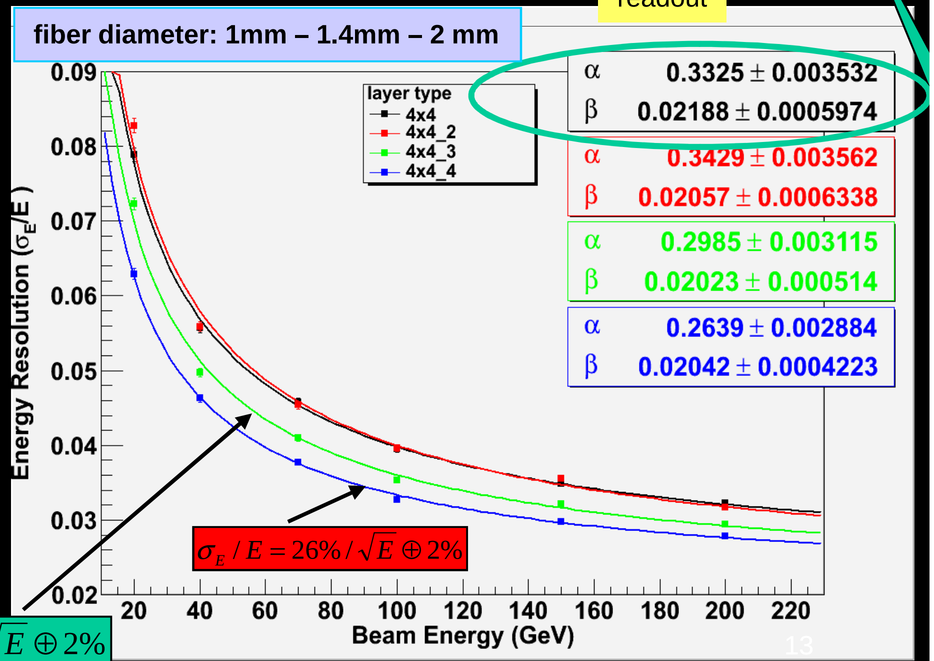
	Integrally Active with Double side readout (*ADRIANO*)								Sampling
Pitch [mm[2]]	**2x2**	**3x3**	**4x4**	**5x5**	**6x6**	**4x4**	**4x4**	**4x4**	**Sampling**
Diameter	**1mm**	**1mm**	**1mm**	**1mm**	**1mm**	**1.4mm**	**2mm**	**Thick capillary**	
$<pe_S/GeV>$	1053	430	254	163	124	500	110	250	200
$<pe_C/GeV>$	340	360	360	355	355	355	350	350	7.5

Baseline configuration

1-side readout



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



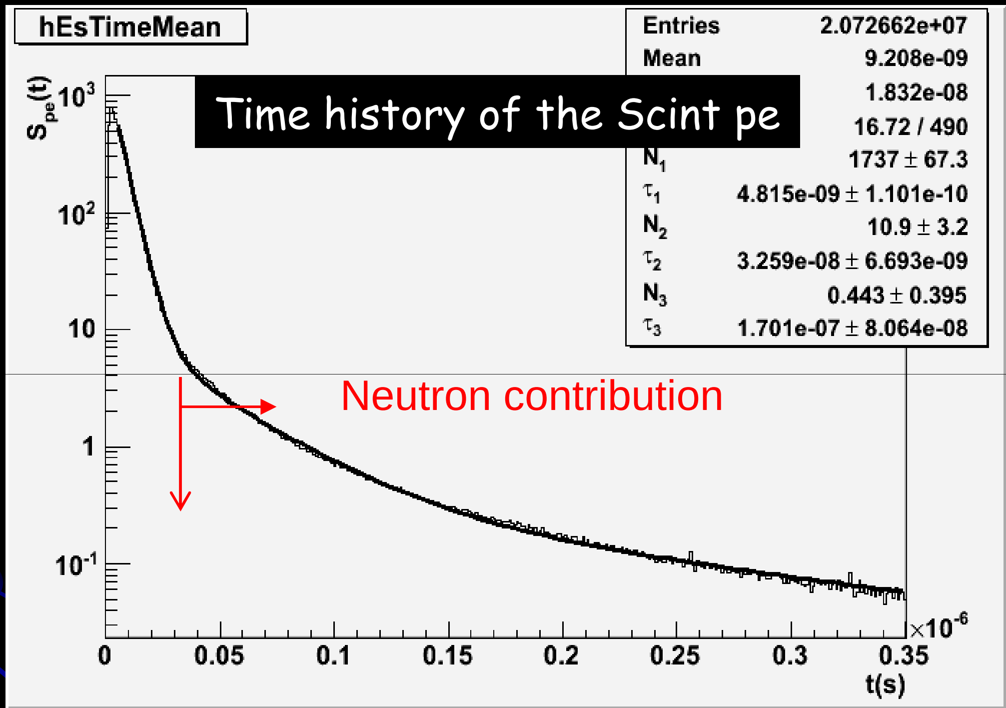
ILCRoot simulation

All numbers include the effect of photodetector QE

From Dual to Triple Readout

40 Gev pions

Disentangling the effect of neutrons from waveform



Time history of the scintillation signal in an ADRIANO module for π⁻@40 GeV.

The contribution after 35 ns is from neutrons only. The distribution has been fitted with a triple exponential function

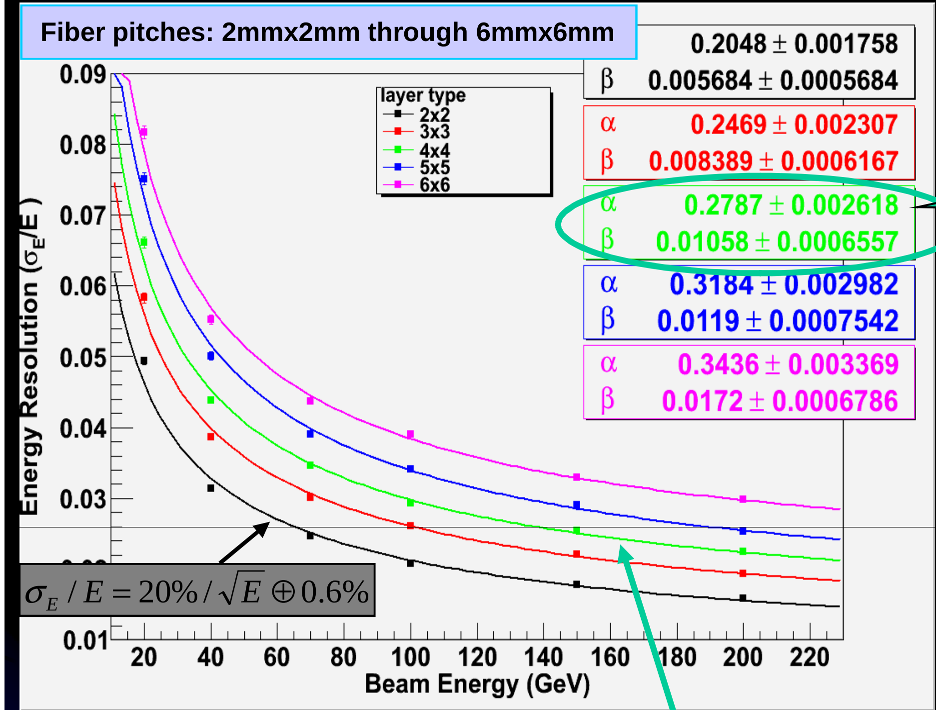
Triple readout aka Dual Readout with time history readout

ILCRoot simulation

Pion beams

ADRIANO in Triple readout configuration

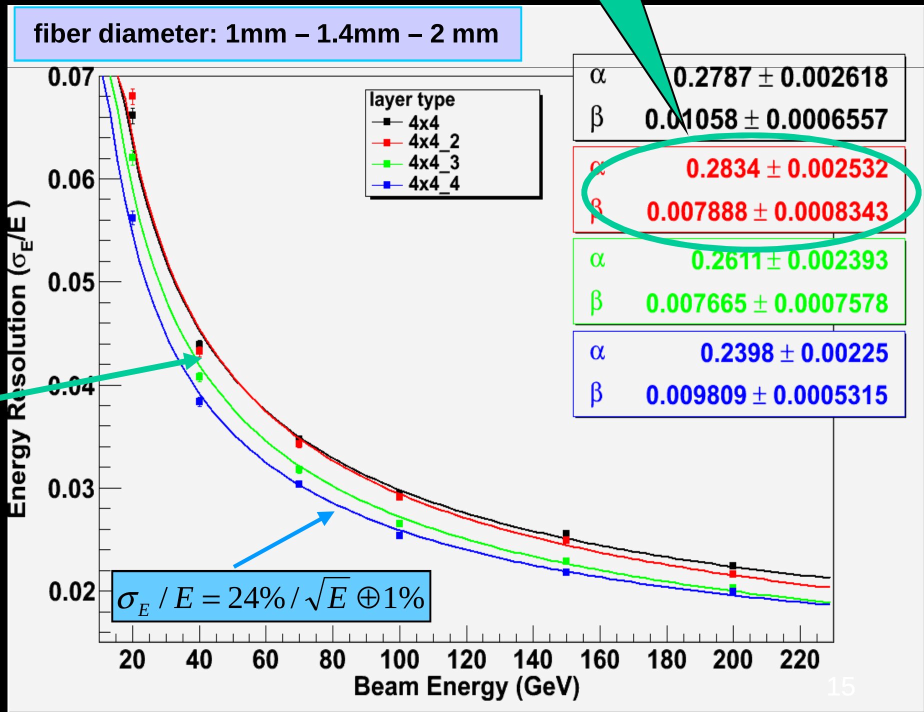
Fiber pitches: 2mmx2mm through 6mmx6mm



Baseline configuration

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

fiber diameter: 1mm – 1.4mm – 2 mm



ILCRoot simulation

Overcoming the Limitations of a 2-D Calorimeter

- ***ADRIANO*** **is a 2-D calorimeter**
  - Easier to build and to calibrate
  - Fewer number of channels
  - No cracks nor unhomogeneities due to longitudinal segmentation
  - However, in principle, it misses the ability to determine the longitudinal shower profile

100 Gev pions

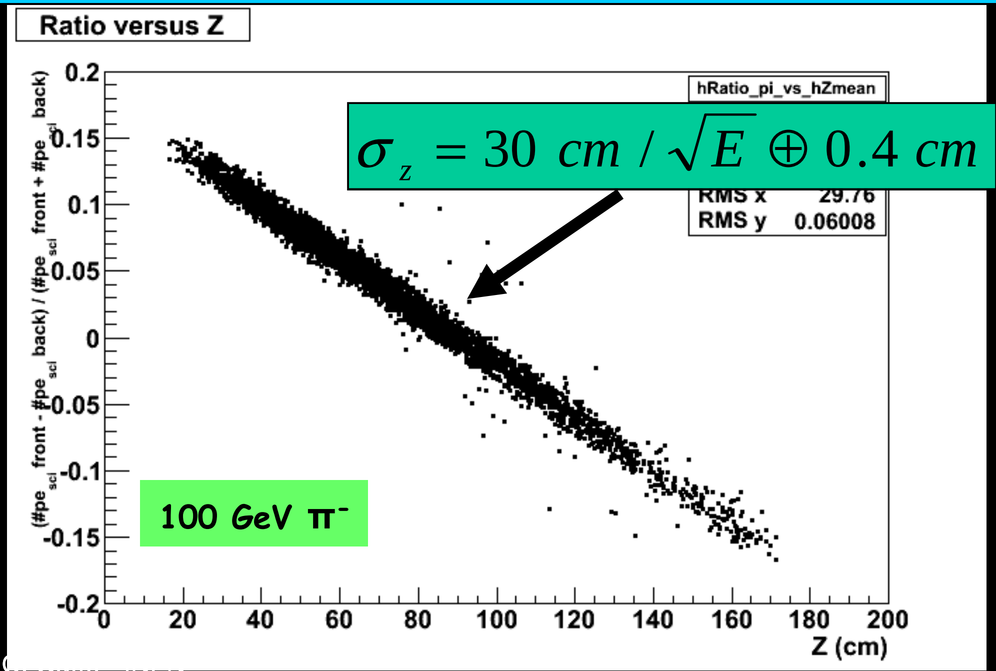
Adding the 3rd Dimension info with light division methods

- Determine Center of Gravity of showers by ratio of front vs back scintillation light
- It works because $\lambda_{81J} = 3.5$ 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.

Front-Back Scintillation light vs true shower CoG



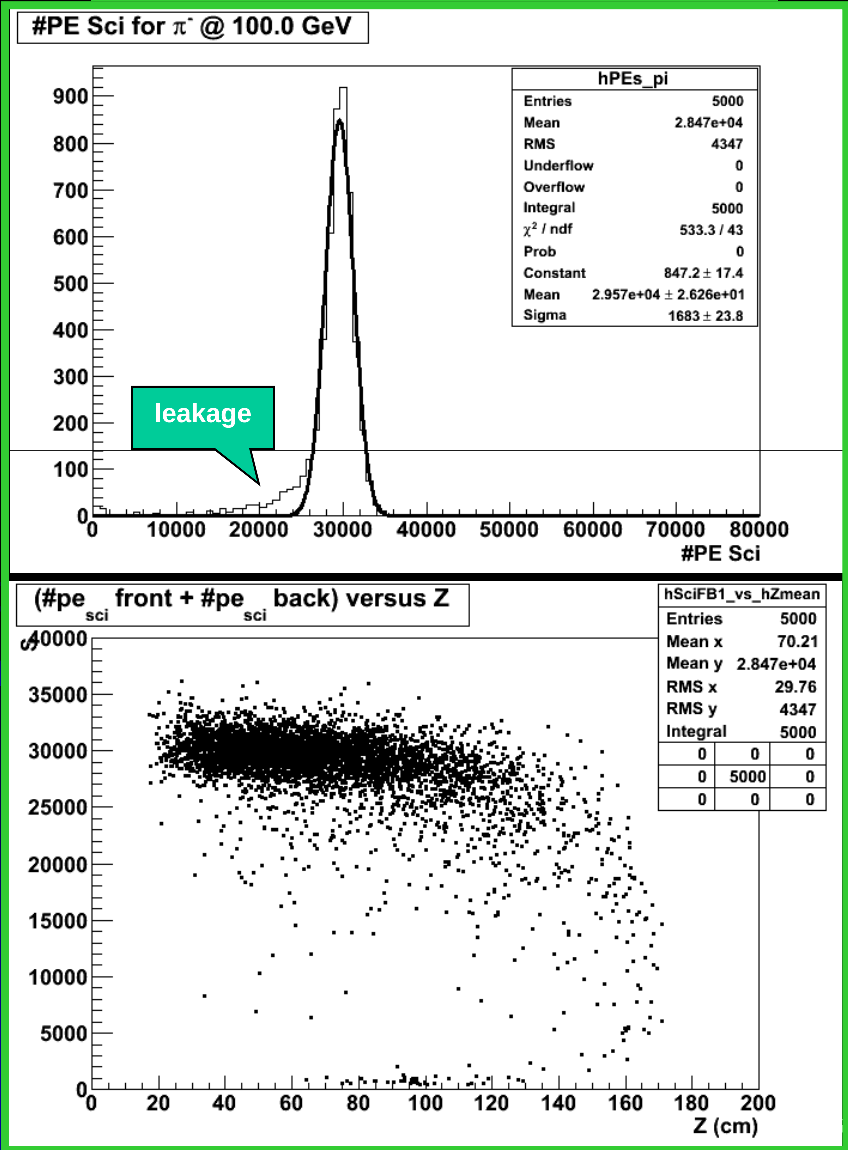
ILCRoot simulation

ILCRoot simulation

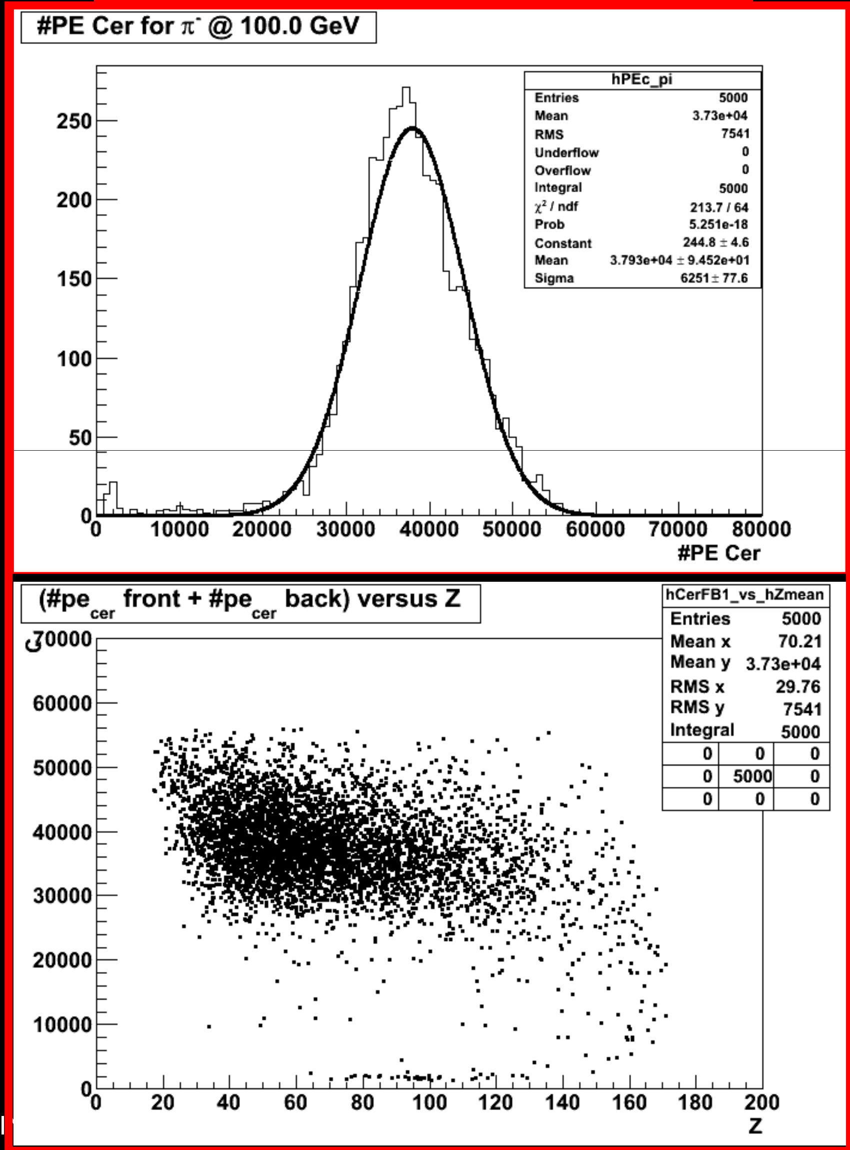
100 Gev pions

Leakage in 180 cm long *ADRIANO* module

Uncorrected scintillating signal



Uncorrected Cerenkov signal

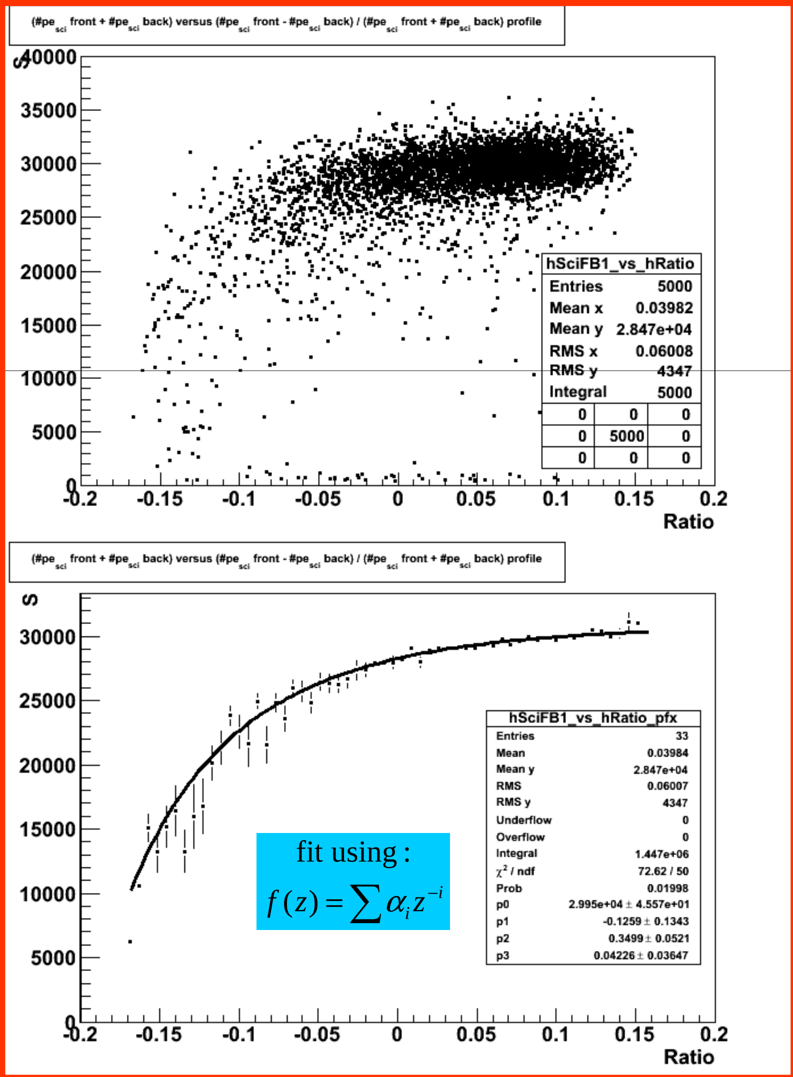


ILCRoot simulation

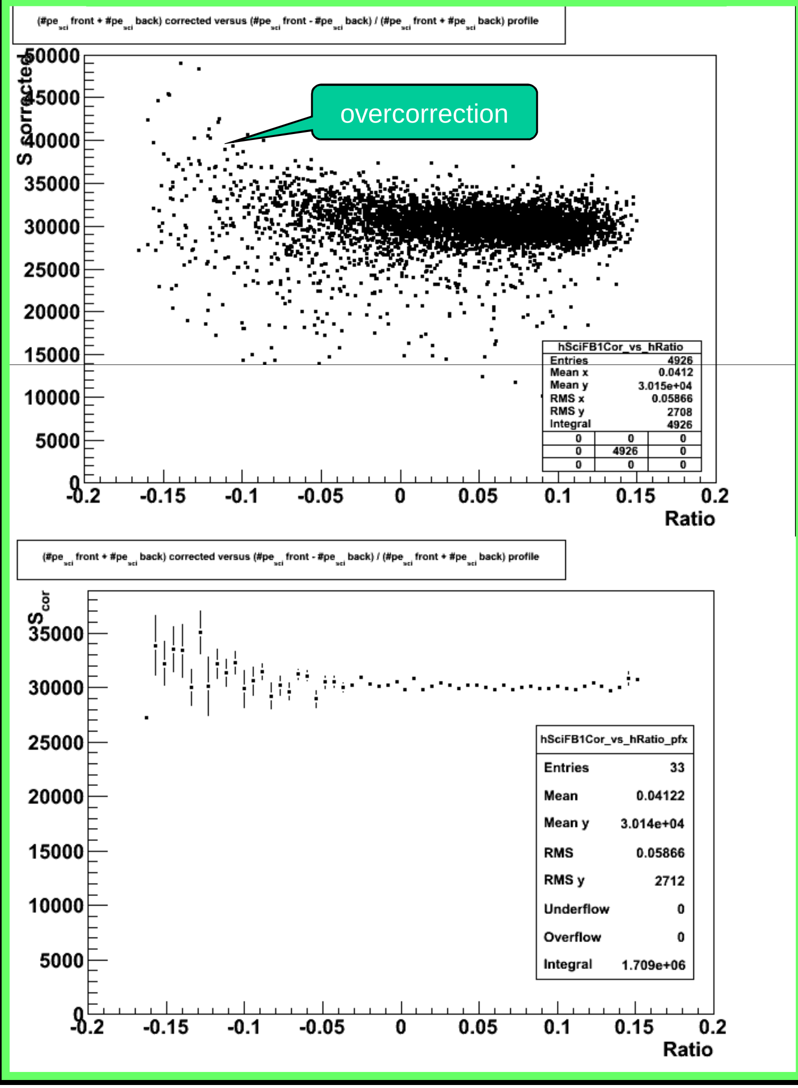
100 Gev pions

Applying leakage corrections from CoG measured with a light division

Uncorrected scintillating signal

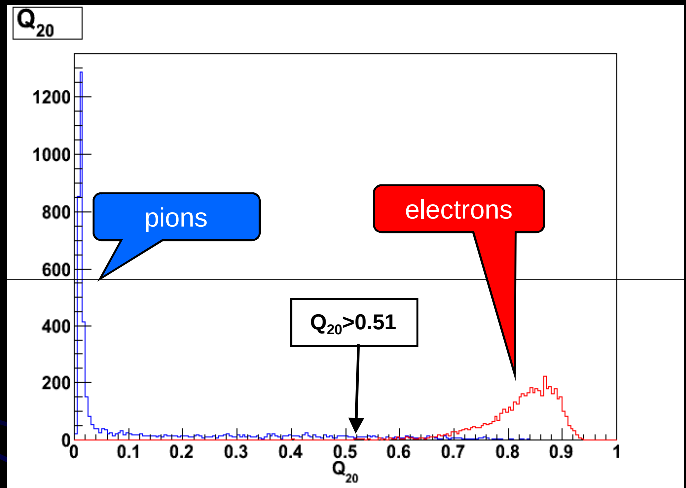


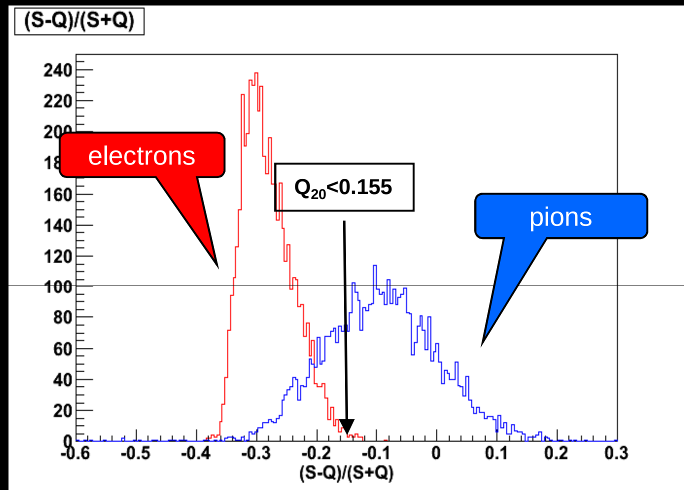
Corrected scintillating signal

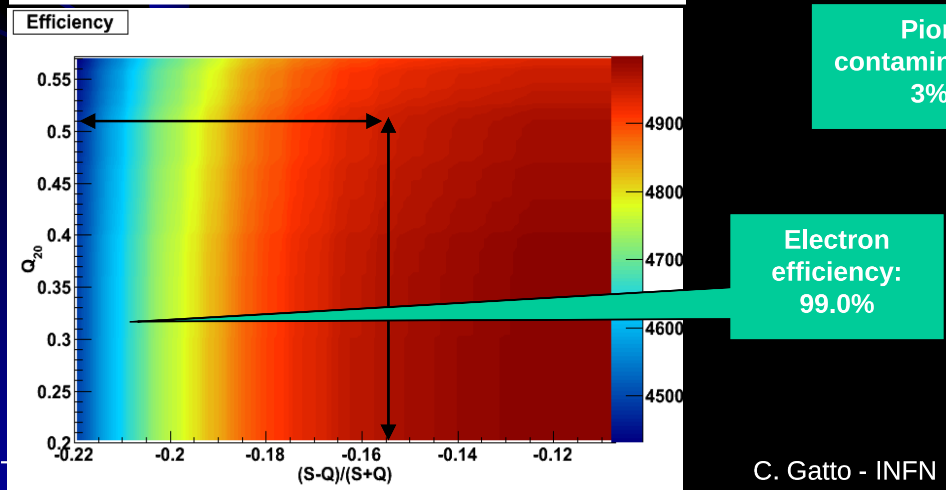


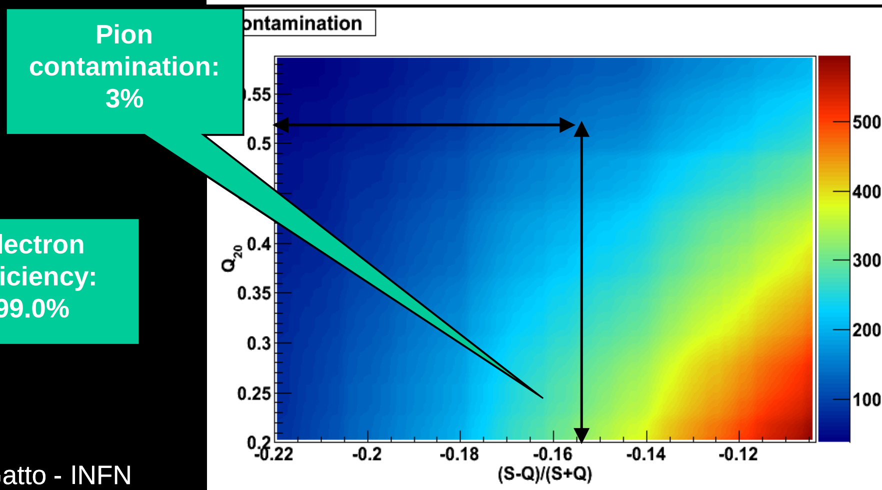
Identifying EM Showers in ADRIANO

- **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**





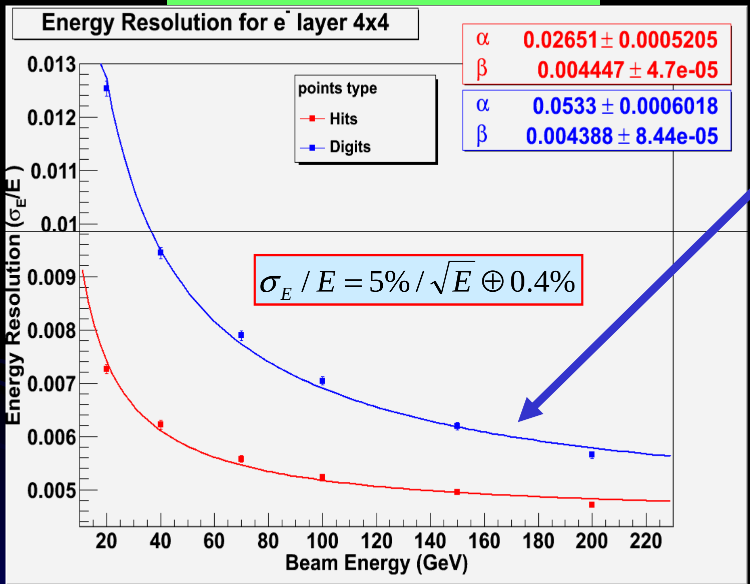




ADRIANO EM Resolution (with and without instrumental effects)

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

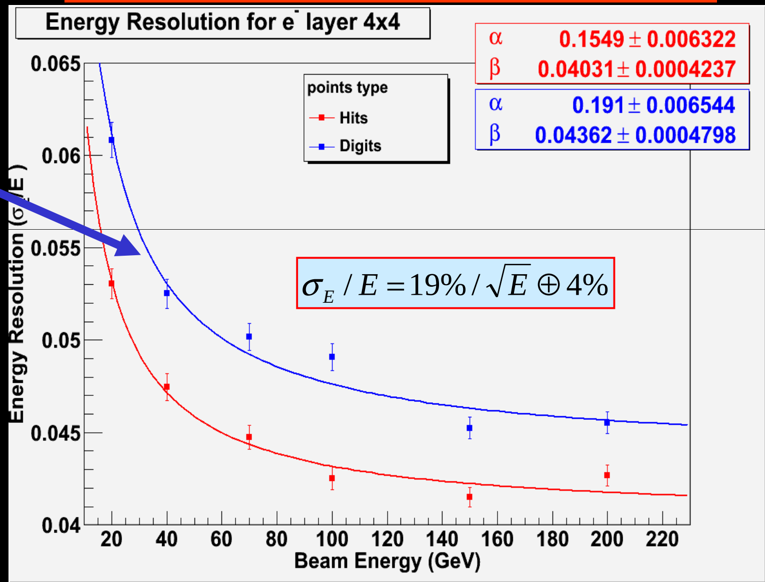
Use only Cerenkov light



Blue curve includes

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

Dual-readout (scintillating+Cerenkov)



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

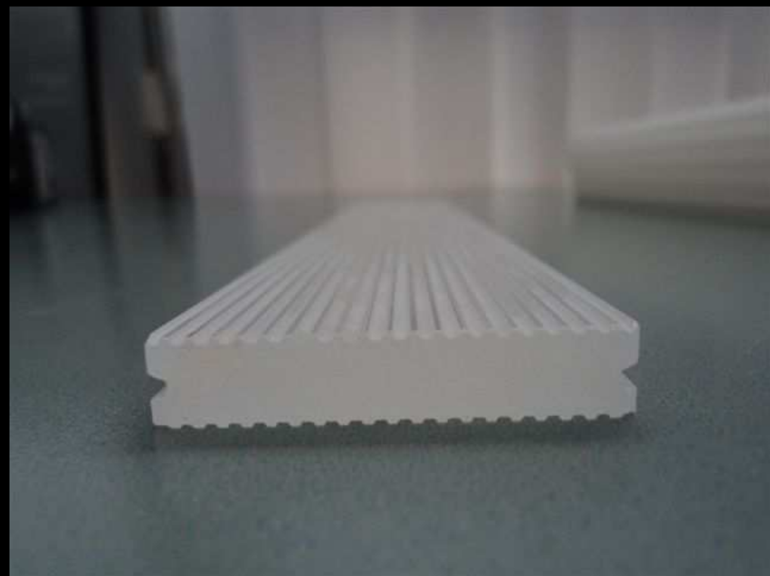
ADRIANO does not need a front EM section

ILCRoot simulation

Fabrication Technology #1: Diamond tools machining

- Pro
  - Minimal R&D required
  - Room temp (min effect on n_D)
  - It allows construction of longer cells

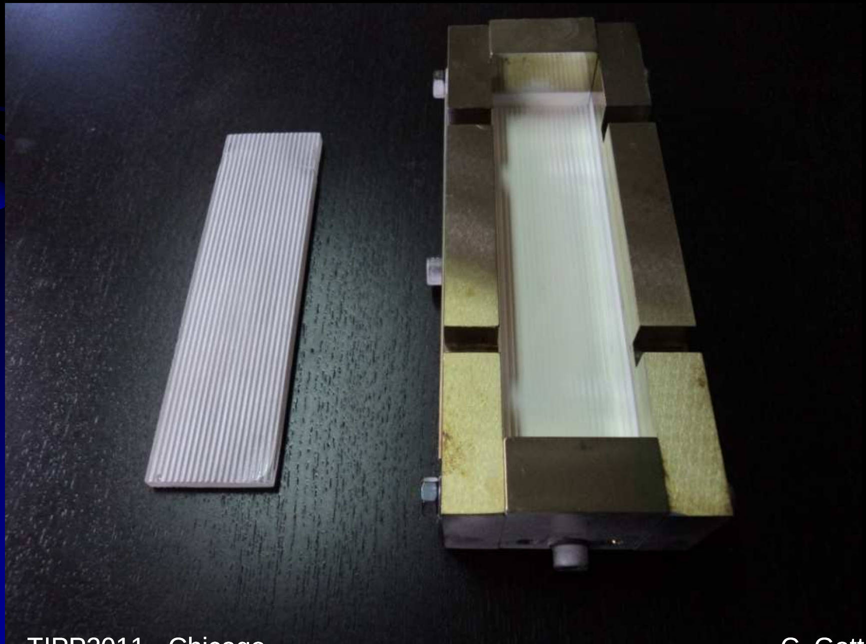
- Cons
  - Longer fabrication process
  - Large waste
  - Lower light output

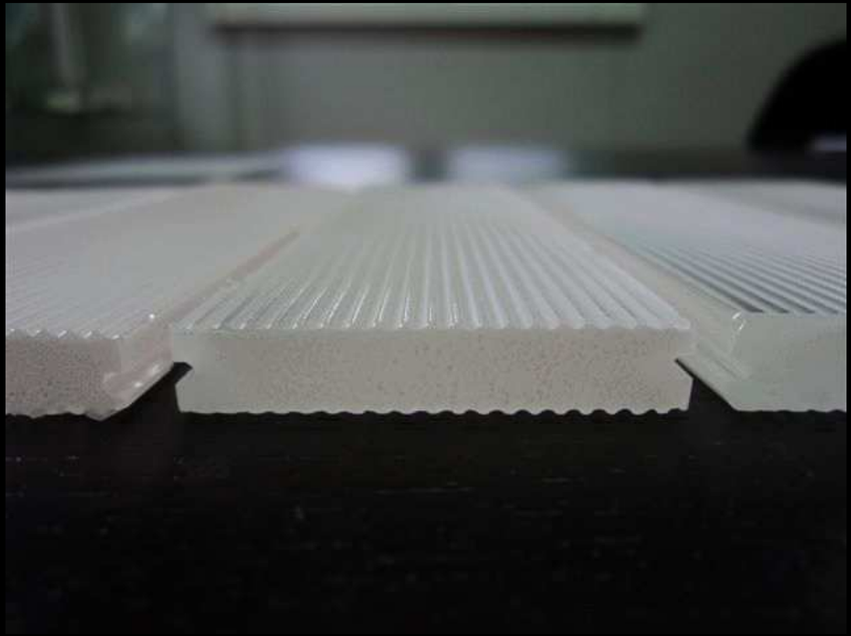


Fabrication Technology #2: Precision molding

- Pro
  - Cheapest and fastest (15 min)
  - Optical finishing with no extra steps
  - Low temp cycle (min effect on n_D)

- Cons
  - Molds are expensives
  - Lots of R&D
  - Lower light output

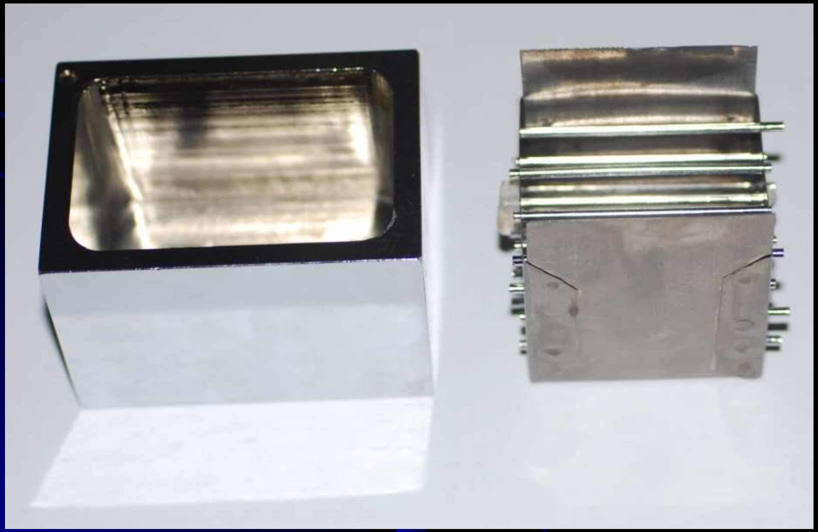




Fabrication Technology #3: Glass melting

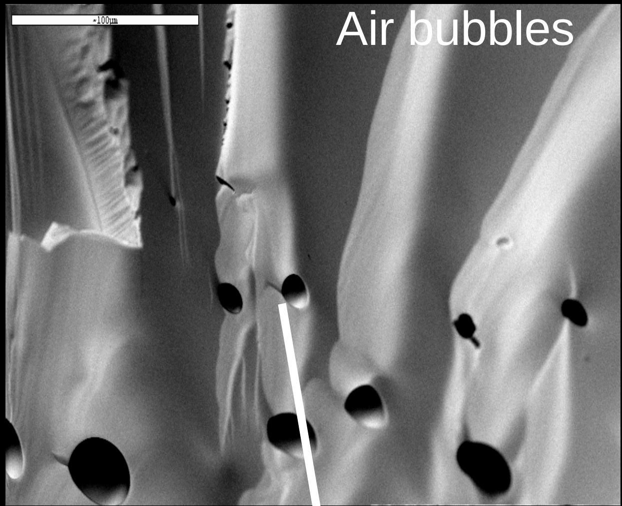
- Pro
  - Build entire cell in one step
  - Very robust mechanical structure

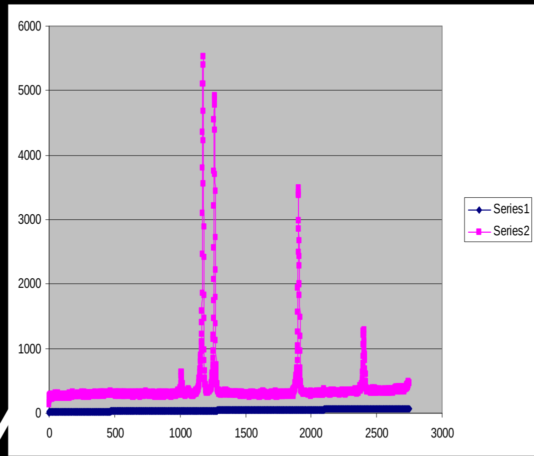
- Cons
  - High temperature cycle
  - Extra passive material
  - Easy to get glass defects



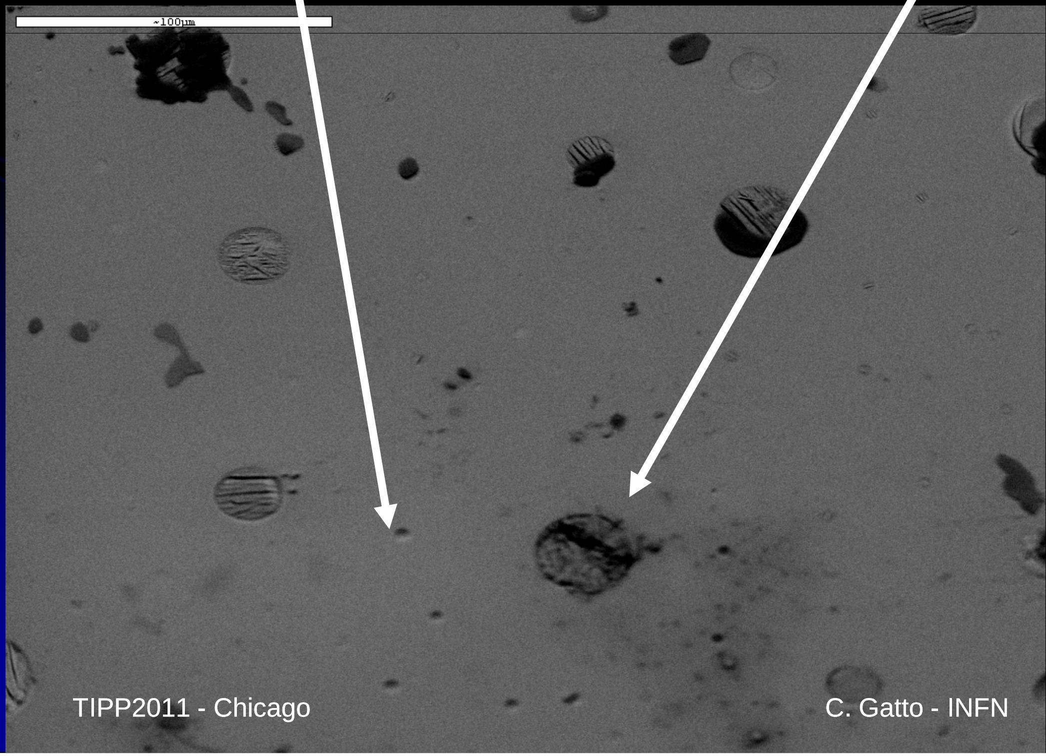
SEM/XRD analysis of glass samples

Air bubbles

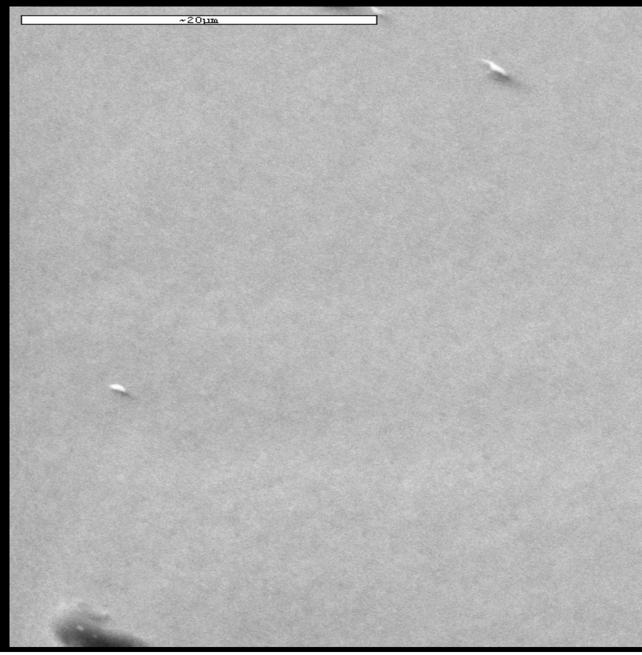




XRD spectrum



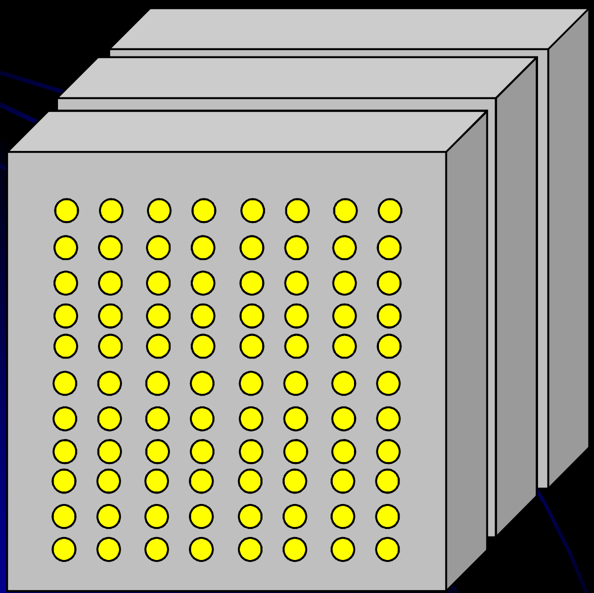
Perfect sample
(same as original)



Fabrication Technology #4: Laser + diamond drilling

- Pro
  - Orthogonal layout
  - Potentially highest light output
  - Fine longitudinal segmentation

- Cons
  - Early stages of R&D
  - Glass easily cracks

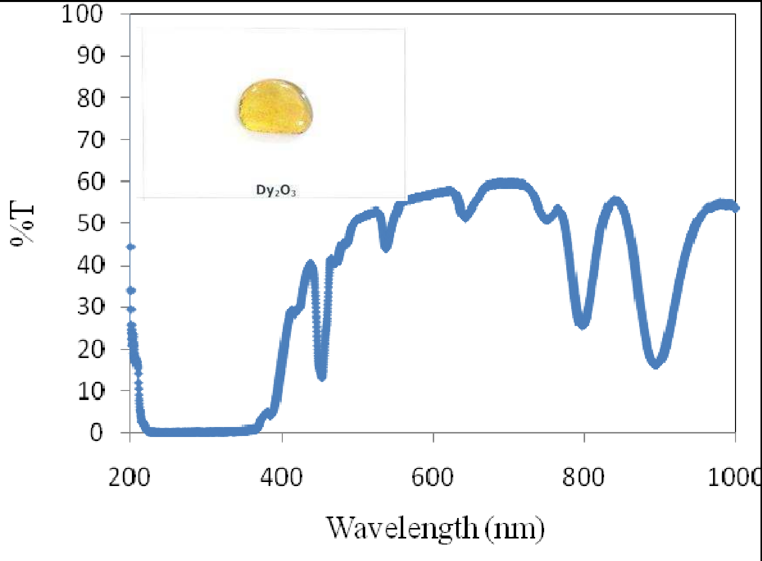


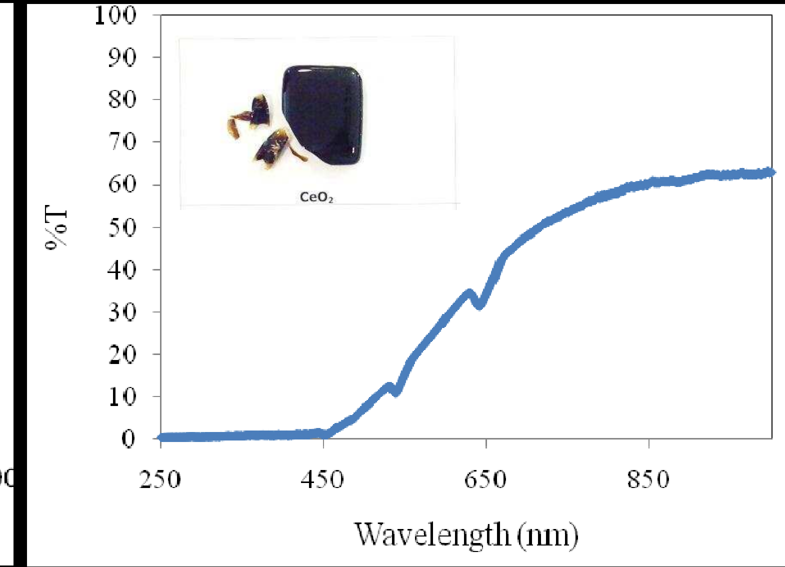
Scintillating Glass

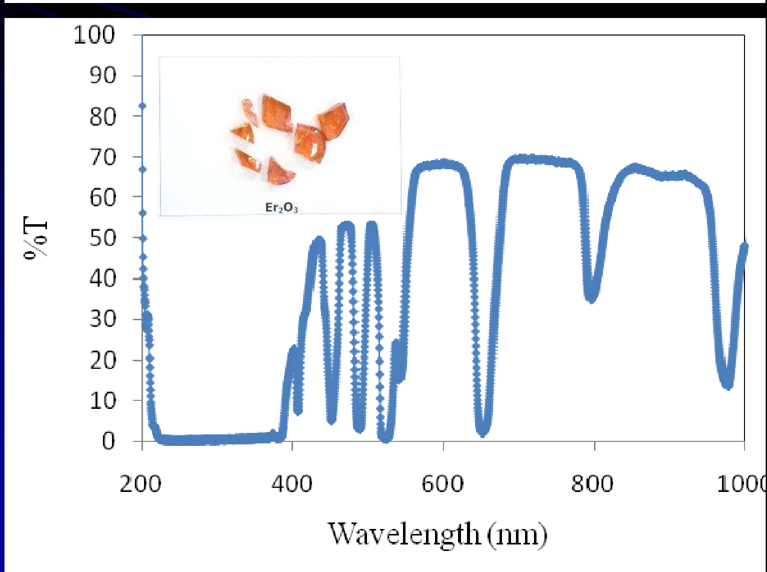
- Scintillation and Cerenkov at the same time in a totally homogeneous active absorber
- Major issues:
  - absorption lines in rare earths induce Č->S shift
  - Need high density
- Separate the two problems:
  - Fix the optical problem by finding the correct ratio of oxides
  - Increase the density with proper vetrous matrix (BiO and WO under consideration)

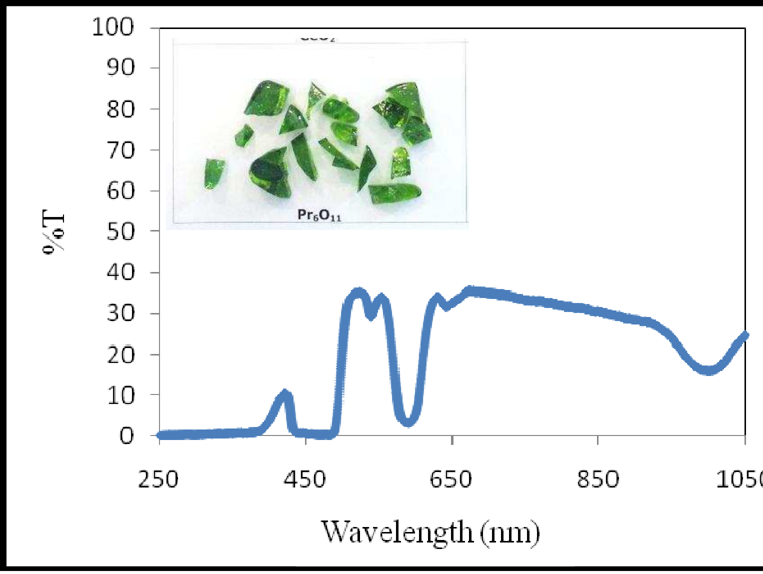
Rare Earth Based Heavy Glasses

- Rare earths oxides + Ho_2O_3 + ZnO + P_2O_5+B_2O_3+SiO_2









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

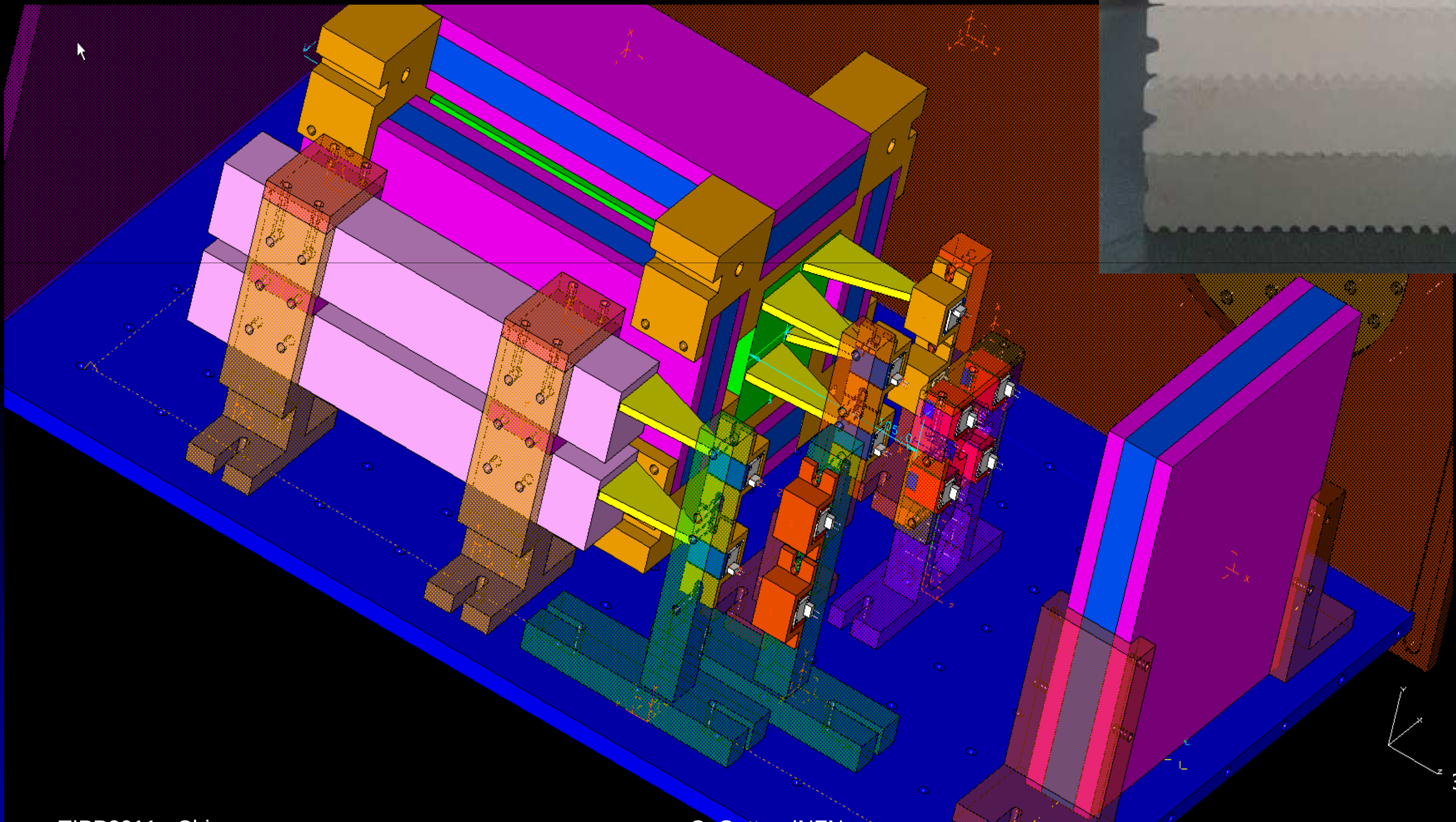
*samples have different thickness

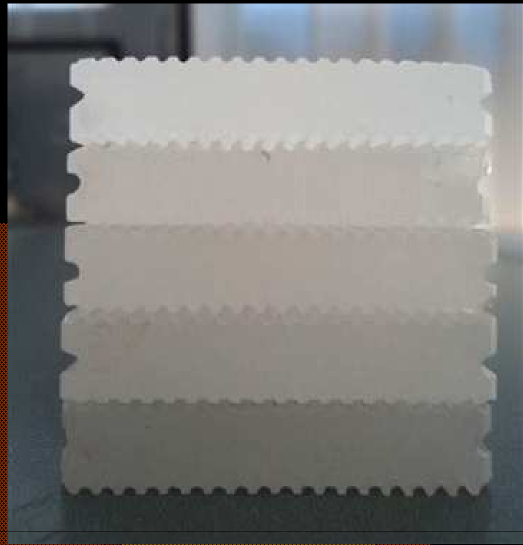
Department of Materials and Environmental Engineering

T1015 Test Beam Program

- Three test beam at FTBF by March 2012
- SiPM by BKF and INFN Trieste
- Several parameters to optimize (layout, fab. tech., polishing, optical coupling, SiPM, etc.)
- Extended simulation support
- 29 people involved

Spring 2011 Test Beam: 3 cells





ADRIANO calorimetry in T1015 Collaboration

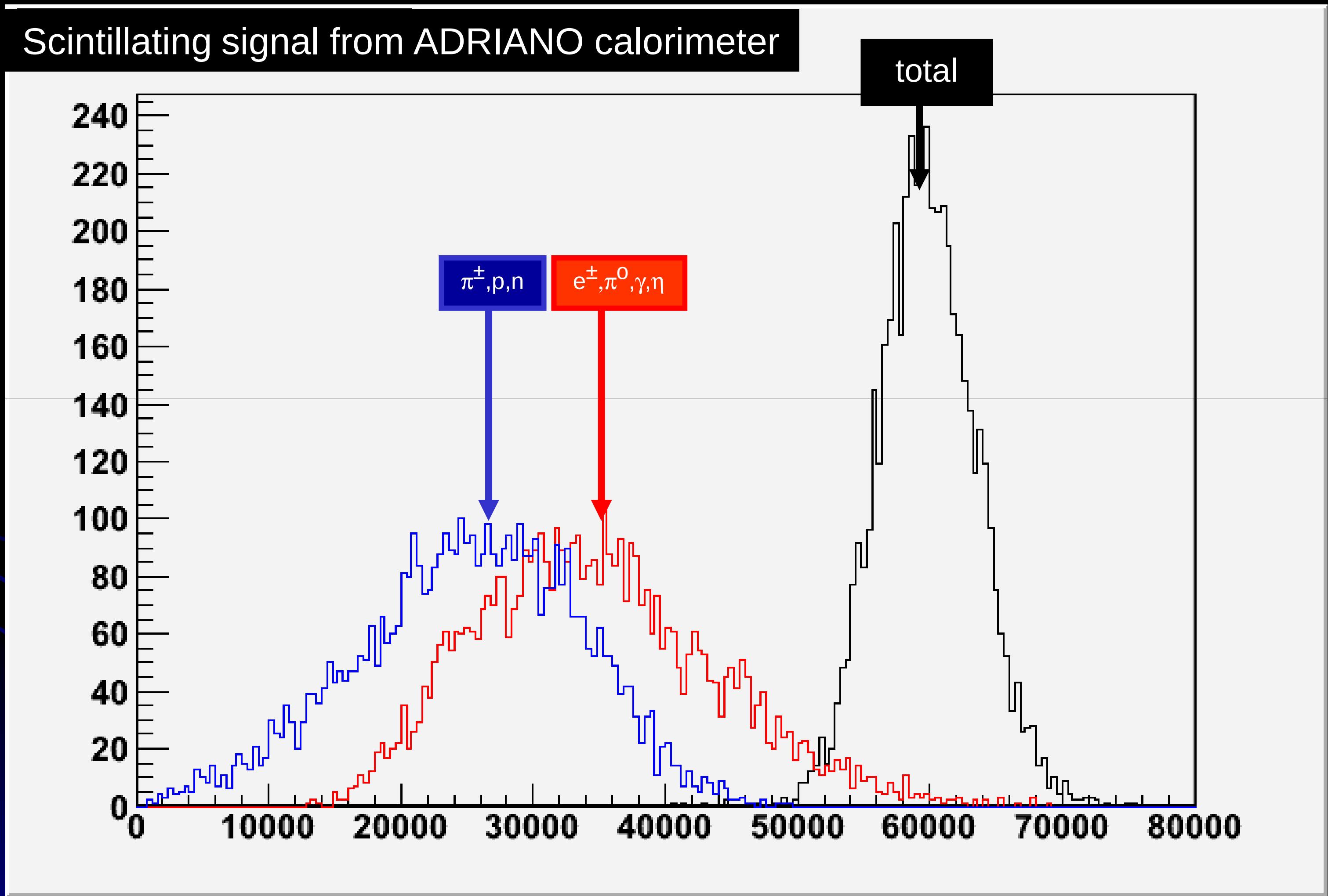
- Fermilab based T1015 collaboration is finalizing its MOU
- It exploit new techniques based on heavy glass (no sampling calorimetry nor crystals)
- It gathers 5 INFN institutions + Fermilab
- First year R&D on fabrication techniques already producing clear directions
- Precision molding technique (ADRIANO) and Dy-doping (scintillating heavy glass) most promising
- Starting in year 2012 will exploit:
  - A laser-based technique coupled with diamond milling
  - High-tech, finely polished , Pt-Ir coated (Ra ~ 5-10 nm) molds
  - Dedicated, high speed (< 30 min) molding machine (if funds allow)
- Talks in progress with Ohara for sponsorship/partership for bismuth optical glass (6.6 gr/cm3)
- At present is looking for International Collaborators

Conclusions

- The novel *ADRIANO* dual-readout technique has been presented
- Full simulations and studies are well advanced
- Results from current studies are very encouraging
- Prototype R&D is in full progress within T1015 collaboration
- Correctly matching calorimetric techniques with SiPM and FFE is crucial for the success
- The newly formed T1015 Collaboration will address these issues and exploit new techniques based on heavy glass
- Next two-three years are of paramount importance to master the technology and validate the simulations
- We are currently looking for collaboration with other groups and institutions

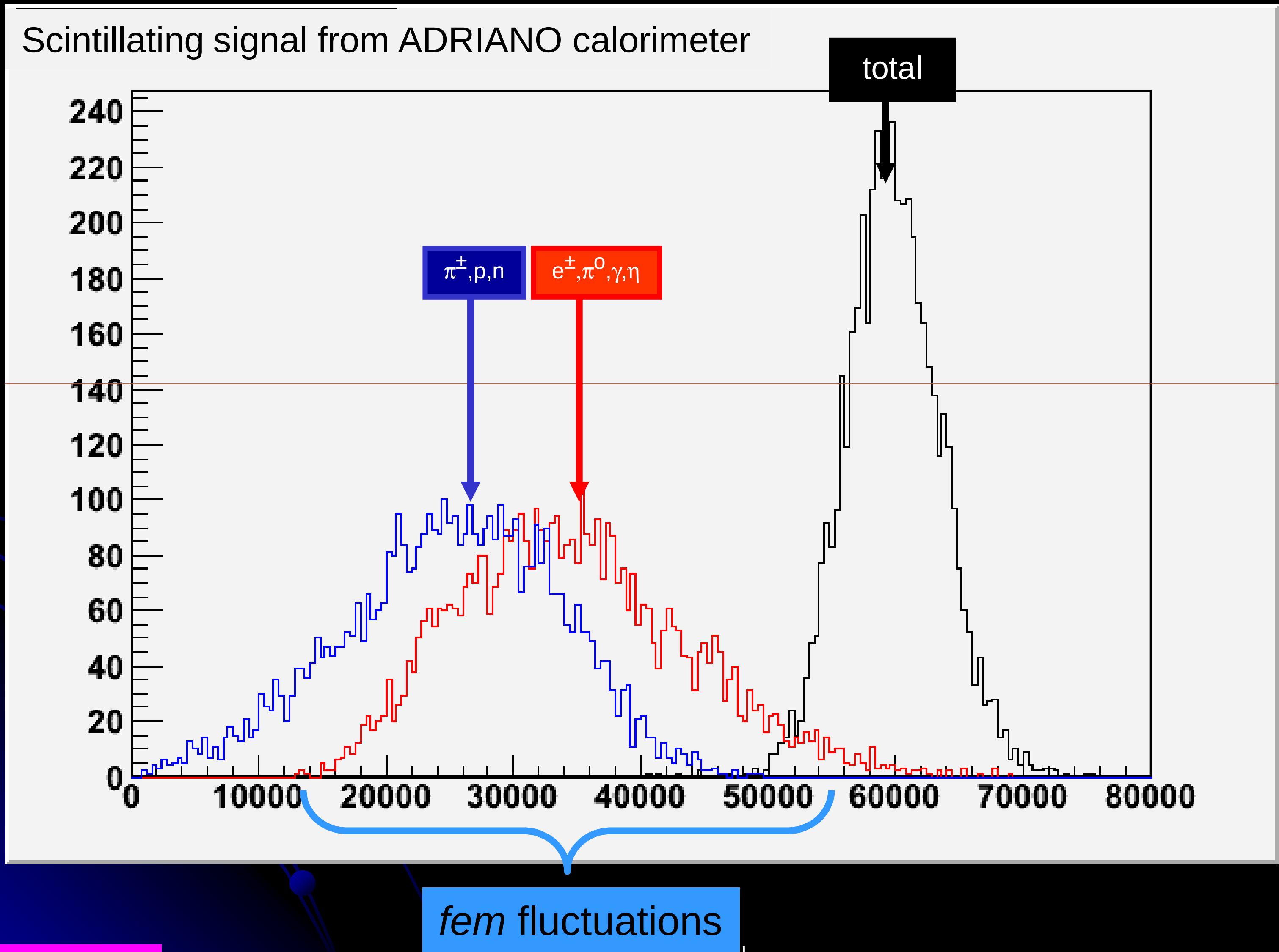
Backup Slides

The major source of fluctuations: *fem*



ILCRoot simulation

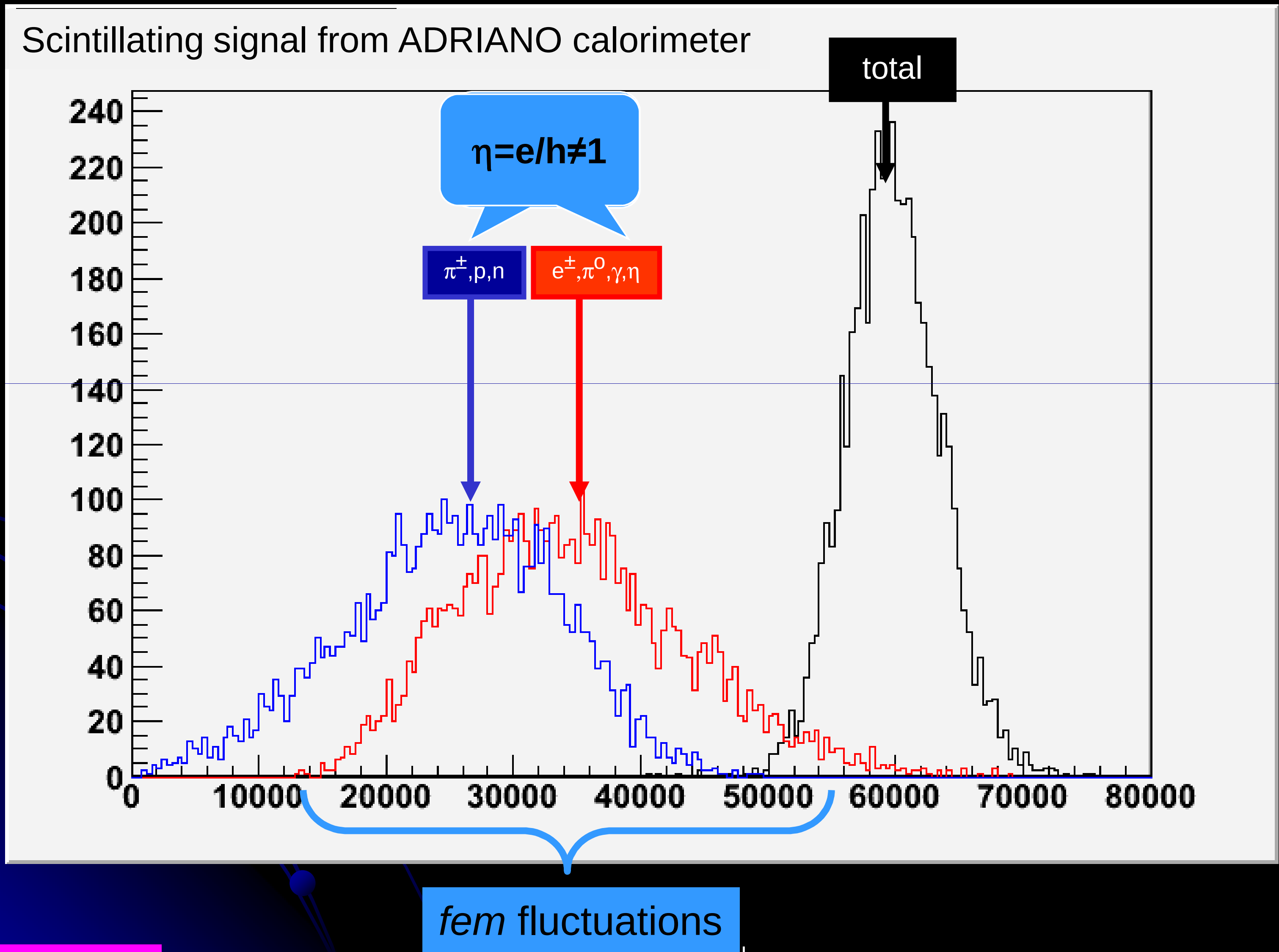
The major source of fluctuations: *fem*



ILCRoot simulation

40 Gev pions

The major source of fluctuations: *fem*

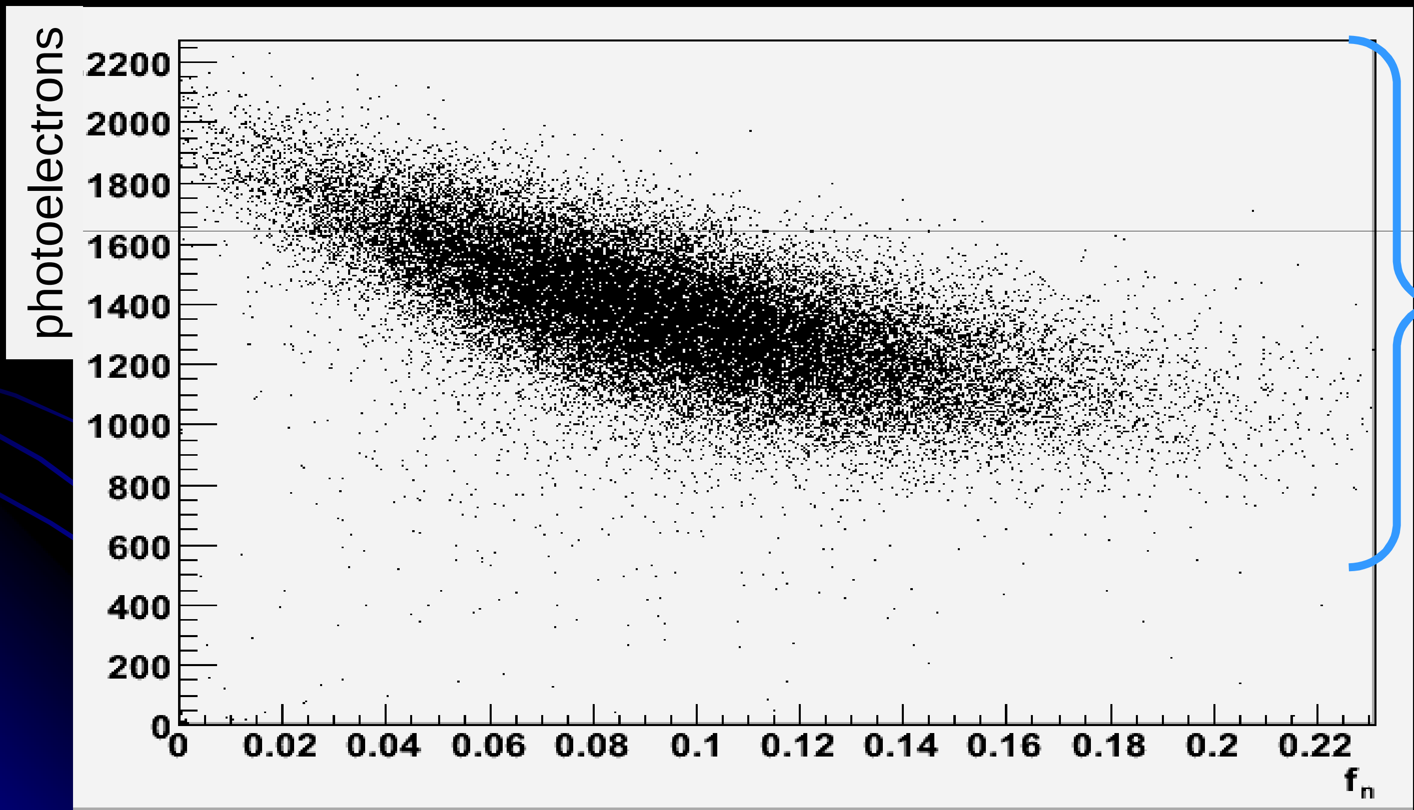


ILCRoot simulation

Neutron fluctuations

45 GeV π^-

Cerenkov signal vs Neutron fraction in 4th Concept calorimeter



neutron fluctuations

ILCRoot simulation

Dual Readout Calorimetry

i.e.: two distinct calorimeters sharing the same absorber

fem is:

1) Energy dependent -> the calorimeter is non linear
2) Fluctuating event-by-event -> the energy resolution is non gaussian if $\eta_s \sqrt{\neq} \eta_c$

If $\eta_s \sqrt{\neq} \eta_c$ then the system can be solved for E_{HCAL}

We are measuring fem event-by-event

Calibration à la DREAM

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

Step 1

for electrons

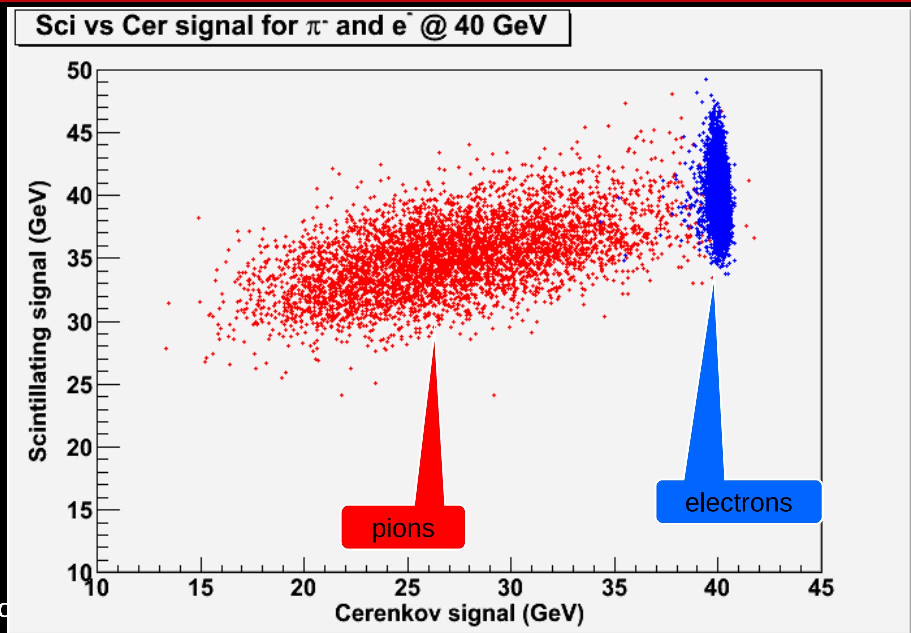
- Final calibration with pions:

  minimize

Step 2

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

$E_{HCAL} = \eta_S E_S$



Calibration à la TWICE

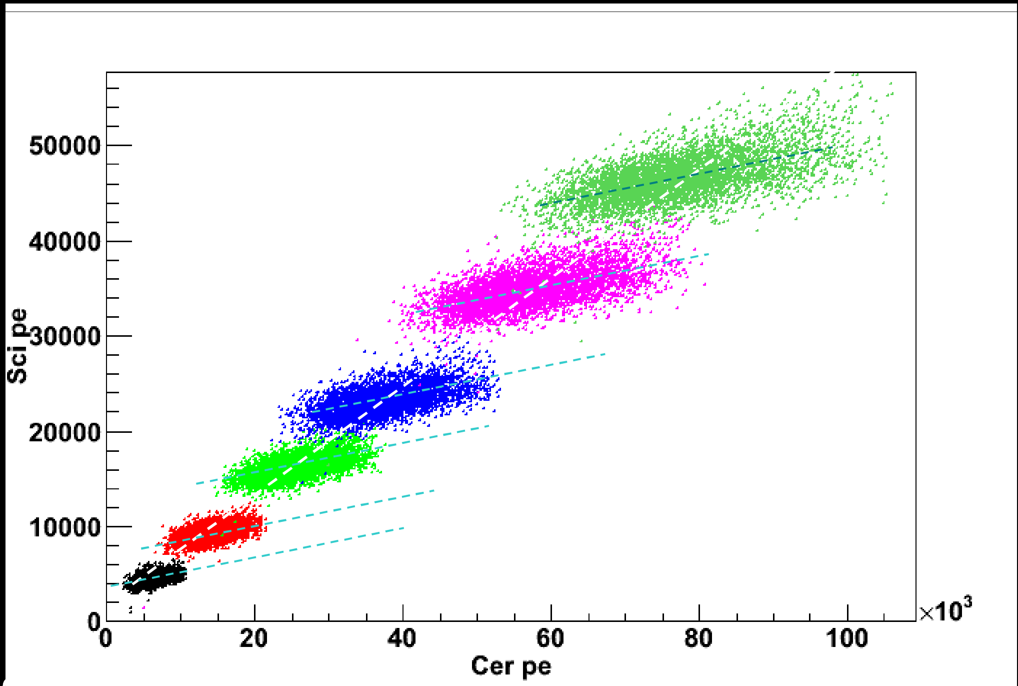
- Take advantage of the fact that η_S and η_C are energy independent
- Use a sample of *n* pions of **ANY** known energy
- For the *i-th* pion rewrite the dual readout equation as:

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

- Then, from LR analysis

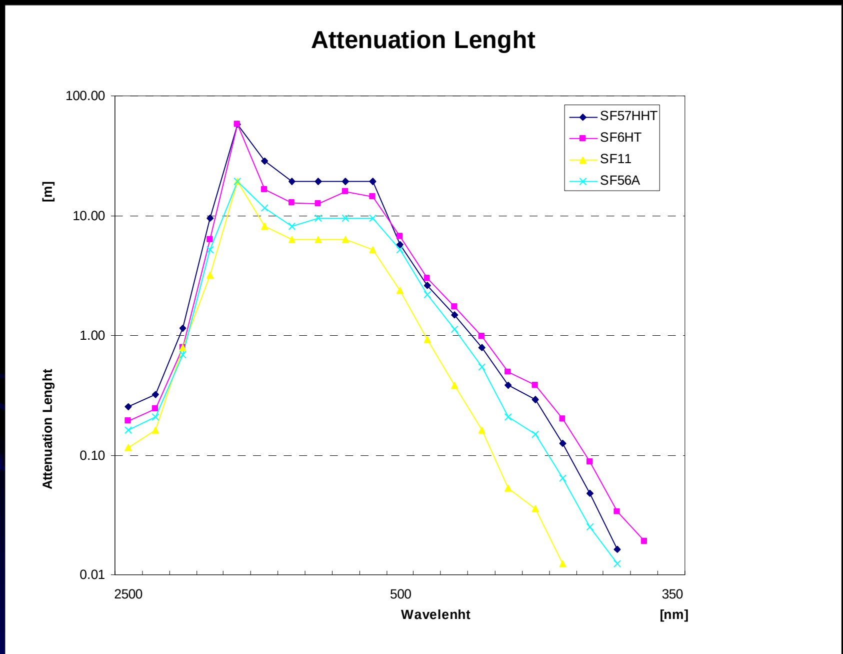
$$\beta = \frac{\sum_1^n (\hat{Q}_i/E_i)(\hat{S}_i/E_i) - 1/n \sum_1^n (\hat{Q}_i/E_i) \sum_1^n (\hat{S}_i/E_i)}{\sum_1^n (\hat{Q}_i/E_i)^2 - 1/n (\sum_1^n \hat{Q}_i/E_i)^2}$$

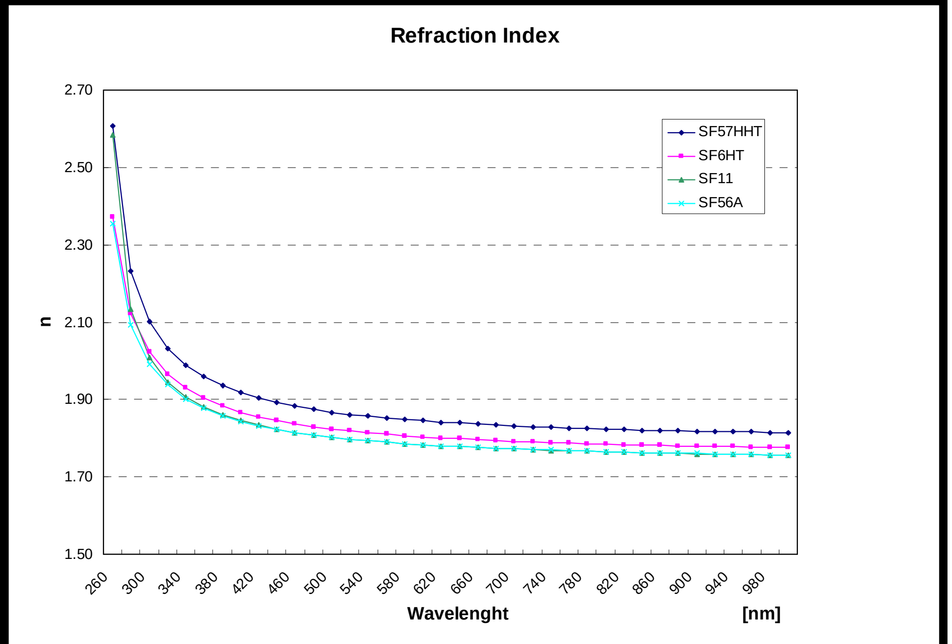
$$\alpha = 1/n \sum_1^n (\hat{S}_i/E_i) - \beta/n \sum_1^n (\hat{Q}_i/E_i)$$



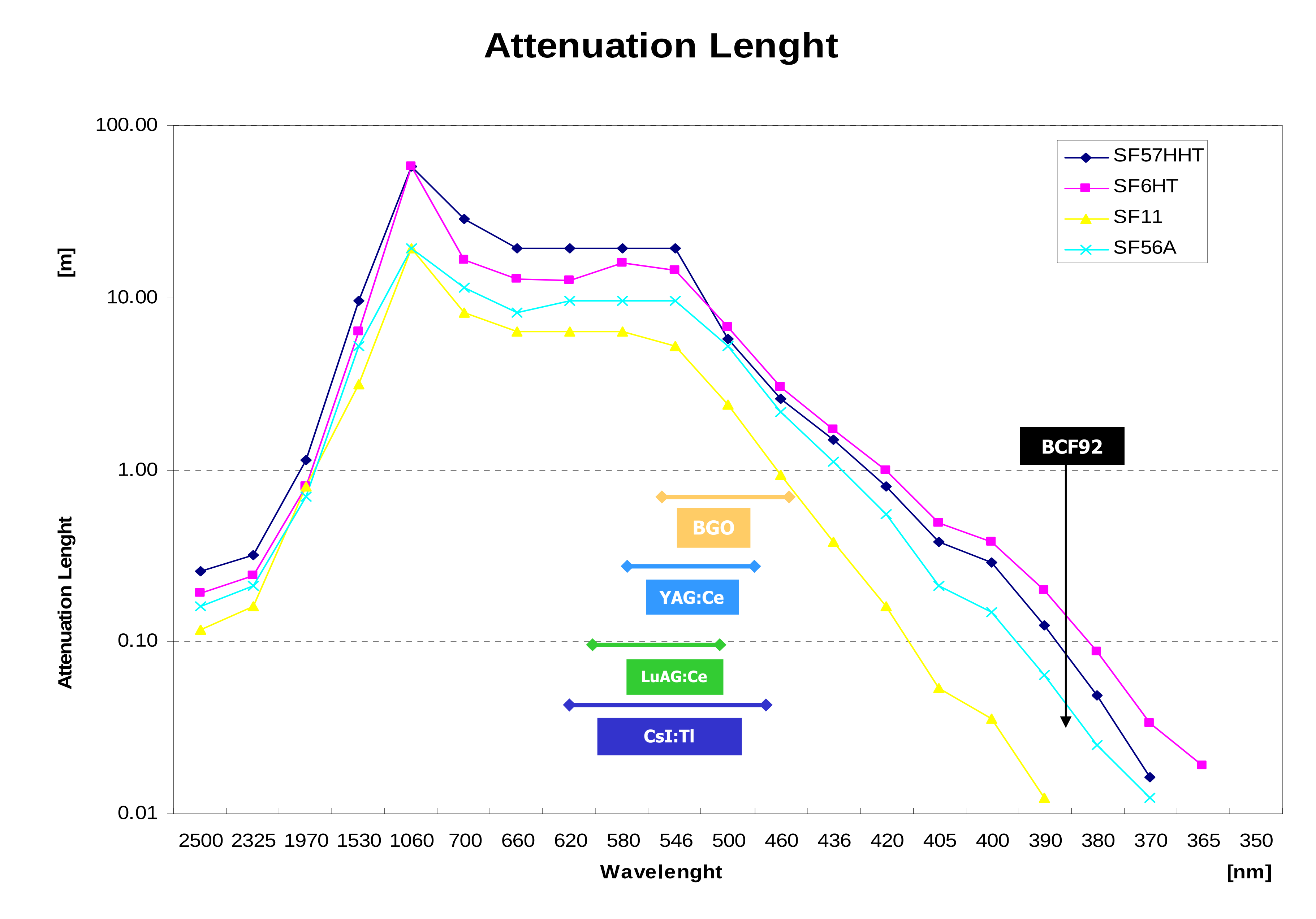
ILCRoot simulation

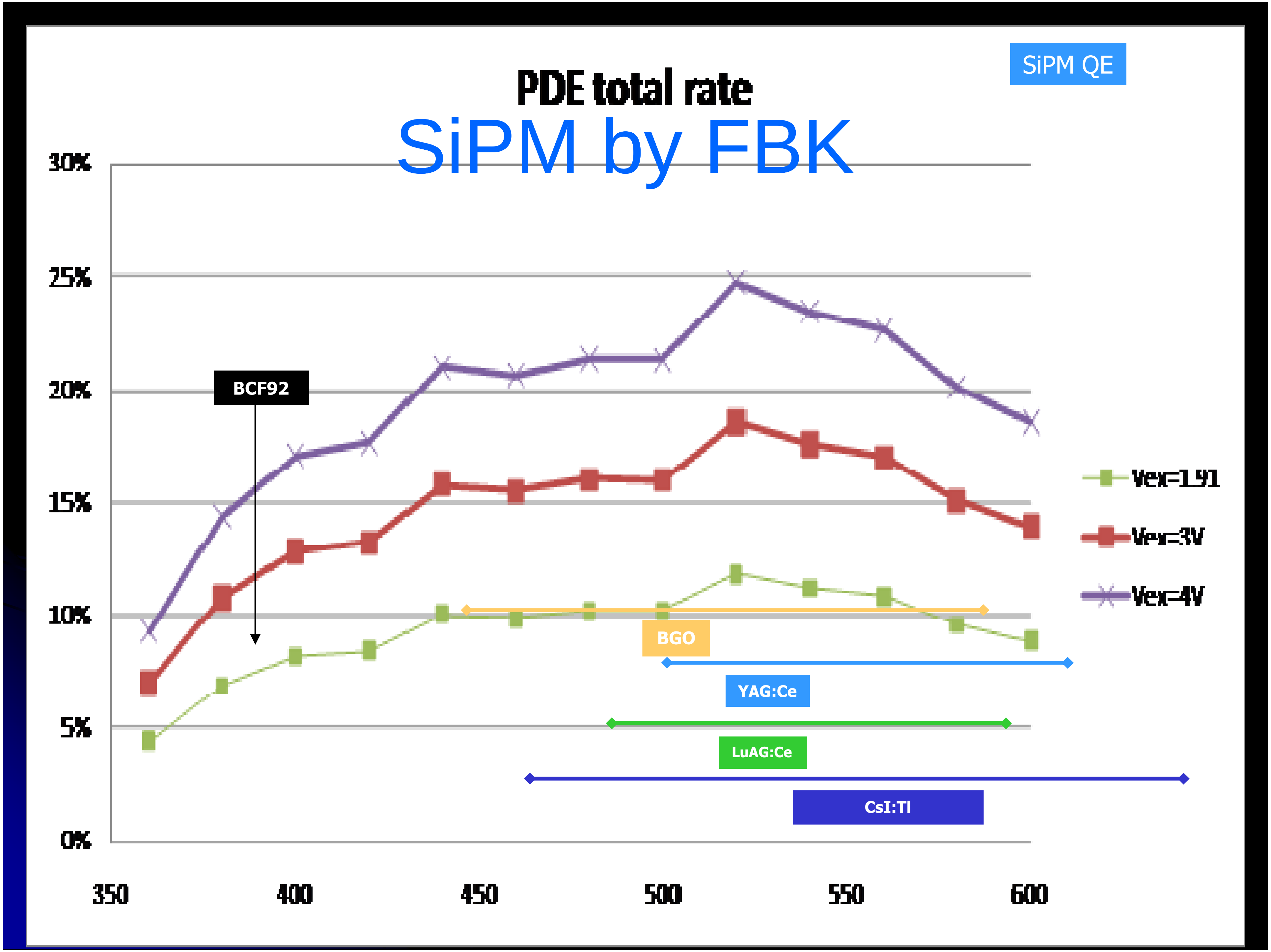
SF57HHT


Attenuation Lenght
100.00
10.00
1.00
0.10
0.01
[m]
Attenuation Lenght
SF57HHT
SF6HT
SF11
SF56A
2500
500
350
Wavelenht
[nm]


Refraction Index
2.70
2.50
2.30
2.10
1.90
1.70
1.50
n
SF57HHT
SF6HT
SF11
SF56A
260
300
340
380
420
460
500
540
580
620
660
700
740
780
820
860
900
940
980
Wavelenght
[nm]

Integrally absorbing calorimetry with SF glass and crystals





SiPM QE
PDE total rate
SiPM by FBK
30%
25%
20%
15%
10%
5%
0%
350
400
450
500
550
600
BCF92
BGO
YAG:Ce
LuAG:Ce
CsI:Tl
Vex=1.91
Vex=3V
Vex=4V

ILCroot: root Infrastructure for Large Colliders

- **C++ Software architecture based on root, VMC & Aliroot**
  - G3, G4, Fluka + all ROOT tools (I/O, graphics, PROOF, data structure, etc)
  - **Single framework, from generation to reconstruction through simulation and analysis**

- **Main add-ons Aliroot:**
  1. Interface to external generator files in various format (MARS, STDHEP, txt, etc.)
  2. Standalone VTX track fitter
  3. Pattern recognition from VTX (for silicon central trackers)
  4. Parametric beam background (# integrated bunch crossing chosen at run time)

- Growing number of experiments have adopted it: Alice (LHC), Opera (LNGS), (Meg), CMB (GSI), Panda(GSI), 4th Concept, (SiLC ?) and **LHeC**
- ***It is Publicly available at FNAL on ILCSIM since 2006***

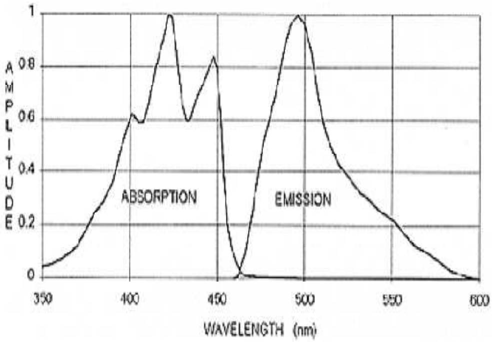
Reading Heavy Glass light using WLS Fibers: Desy technique

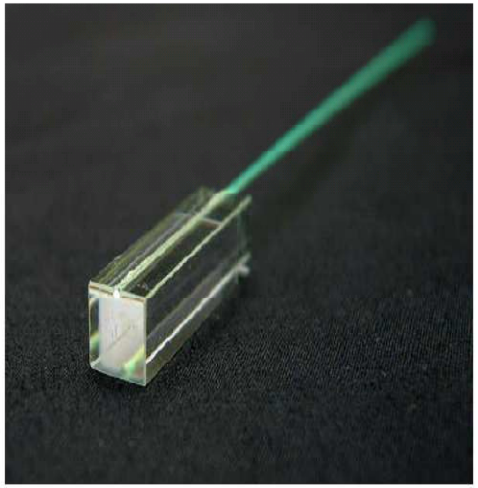
http://www-zeuthen.desy.de/lcdet/Feb_05_WS/talks/rd_lcdet_sim.pdf

BCF-91A:

Λ(max. emission) = 494 nm

-> QE(PMT-XP1911) 13 ± 2 %





From LHCB studies

Table 3.4: *The fiber decay time extracted from a fit to the pulse-shape measurements.*

Fiber type	Decay time	
BICRON BCF-92	2.4	± 0.4
BICRON BCF-99-29A	3.5	± 0.4
Pol.Hi.Tech. (S250)	7.3	± 1.1
KURARAY Y-11 (MS250)	7.2	± 1.1
KURARAY Y-11 (M200)	8.8	± 1.5
BICRON BCF-91A	10.8	± 2.3

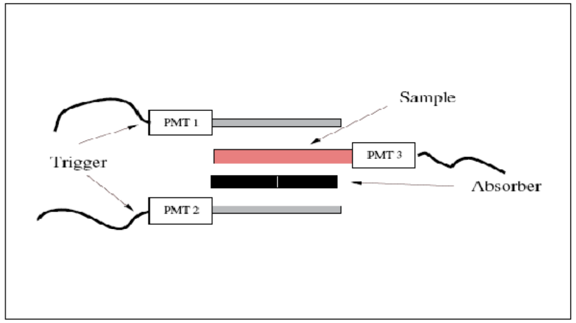
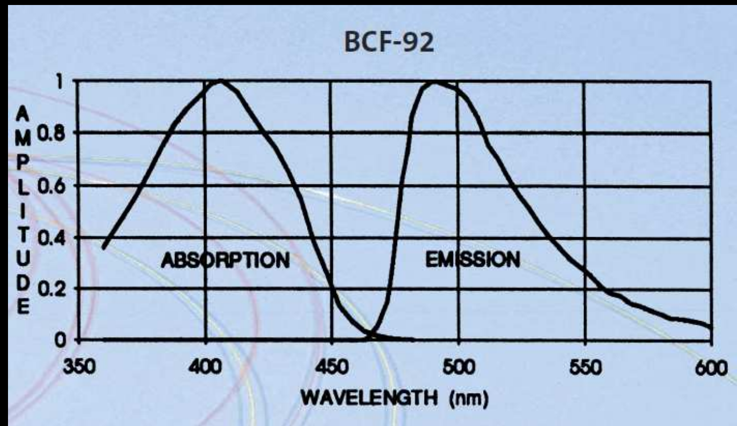


Figure 3.1: *Cosmic Telescope.*



R. Dollan

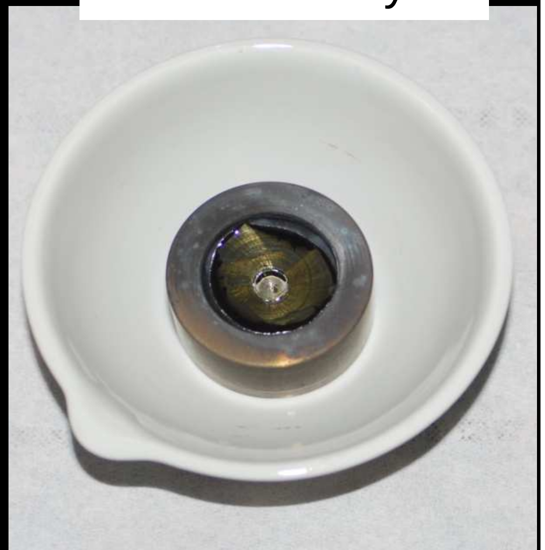
R&D on optical glass melting

All tests performed with F2 glass

Melting furnace in vacuum

Melting furnace in air

Before termal cycle



After termal cycle

Cons N.4: Too many fibers for a 4π calorimeter

- Define Γ =(total area of photodetector/total external calorimeter area).
- Γ takes into account:
  - The needed photodetector area to read circular fibers with optimum packing
  - Th crowdiness of your FEE
- At present:
  - Γ_{DREAM} = ~24%. $\Gamma_{4th\ Concept}$ = ~ 21%.
- This issue is honestly recognized by DREAM Collaboration:

Very large

"…The grouping of the
fibers was labor intensive and required the fibers to extend about 50 cm beyond the end of the calorimeter. While this worked very well in the beam tests, it probably would not scale well with the lateral size of the calorimeter…."

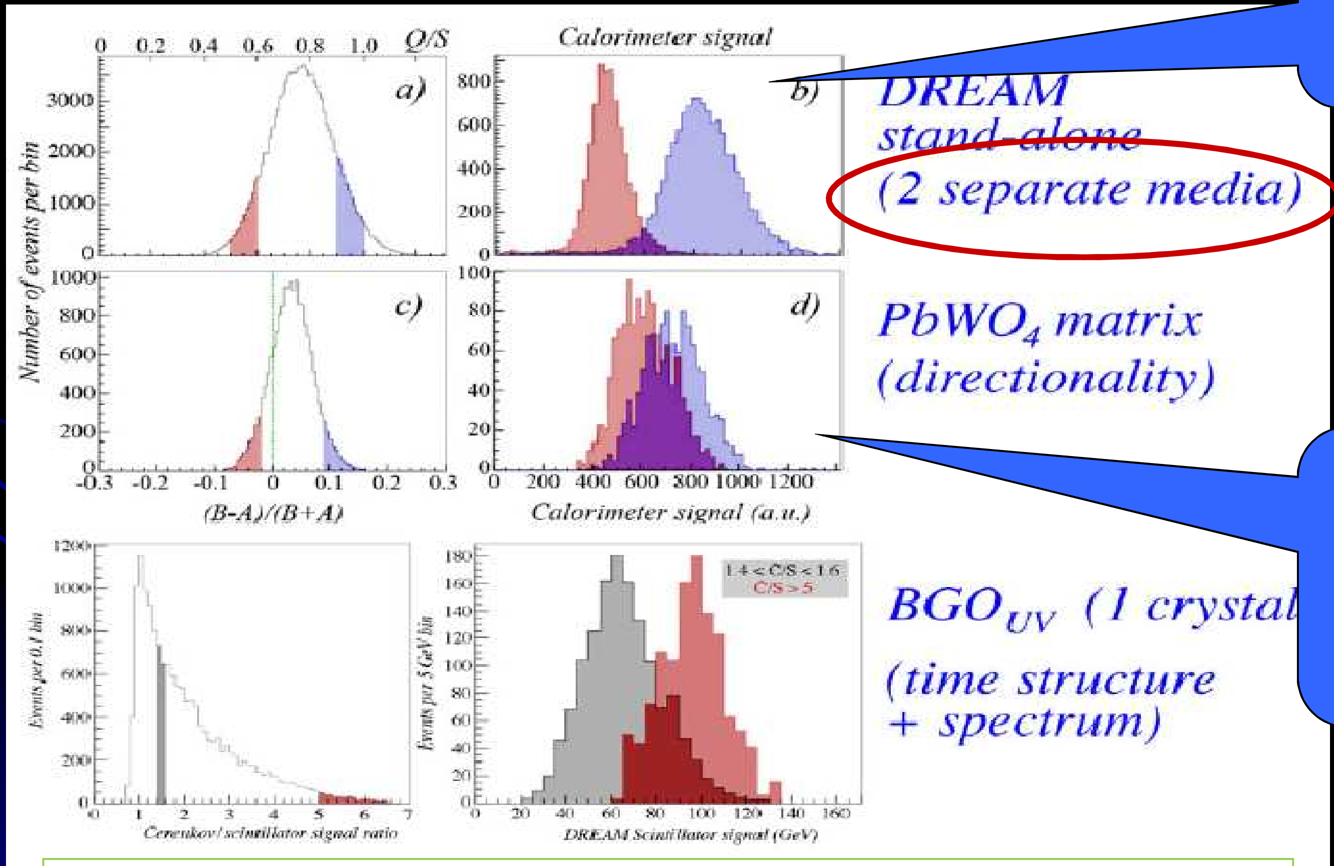
- **Goal is Γ < 10%**

Excerpt from:
R.Wigmans, et al., Dual-Readout Calorimetry for the ILC -
A University Program of Accelerator and Detector Research for the International Linear Collider (vol. III) FY 2005 - FY 2007
Available at: http://www.hep.uiuc.edu/LCRD/LCRD_UCLC_proposal_FY05/6_16_Wigmans_LCRD1.pdf

Largest advantage of sampling Dual-readout:

Distinct vs homogeneous active regions

- DREAM test beam: compare separation effeciency in 2 separate media vs 1 homogeneous crystal
- 2 metodologies of extracting *S* and *C* signals from a crystal



With sampling techniques

S & C signals very well separated

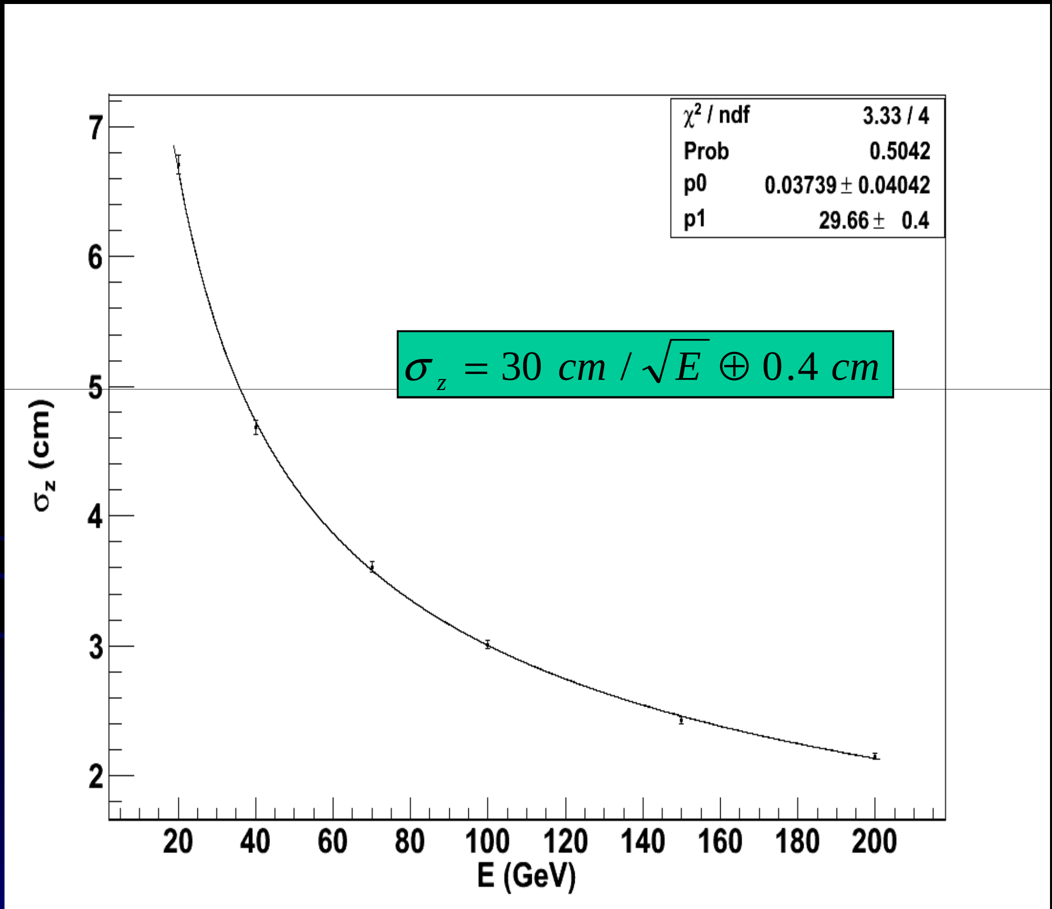
With homogeneous techniques

S & C signals marginally separated

From: http://www.pv.infn.it/~franchino/CAL_III_4_Franchino.pdf

Pion beams

CoG resolution for hadronic particles in ADRIANO module with Light Division Methods



- Module length: 180 cm
- Fiber type: Kuraray SCSF81J
- Fiber pitch:4mmx4mm
- Fiber Diameter: 1 mm

INCLUDES SIMULATION OF INSTRUMENTAL EFFECTS

ILCRoot simulation