Dual Readout Calorimetry with Heavy Glasses in the T1015 Collaboration

Corrado Gatto

On behalf of:

T1015 Collaboration

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Outline

- Dual-readout calorimetry
  - rationale and techniques
- ADRIANO techniques:
  - baseline configuration
  - simulation studies
- Prototype R&D
  - construction methodologies
  - preliminary test beam results
- Future prospects

Status of Detector Technologies in HEP

- LHC detectors represent a major breaktrough in size (aka volume and #channels) but are based on older technologies

- Detectors for future colliders have far more demanding requirements:
    1) Unprecedented resolution (next slide)
    2) *O* (10^8-10^9) Channels
    3) Low material budget in tracking devices (lepton colliders only)

Performance Requirements at Future Colliders

- Jet energy resolution (W/Z invariant mass reconstruction from jets)

$$\sigma(E_j)/E_j = 30\%/\sqrt{E_j}\ (\mathrm{GeV})$$

➔ 1/2 w.r.t. LHC

- Impact parameter resolution for flavor tag (c/b-tagging in background rejection/signal selection)

$$\sigma_{IP} = 5 \oplus 10 / p\beta \sin^{3/2}\theta\ (\mu\mathrm{m})$$

➔ 1/2 resolution term, 1/7 M.S. term w.r.t. LHC

- Transverse momentum resolution for charged particles (e.g. Z mass reconstruction from charged leptons)

$$\sigma(p_t)/p_t^2 = 5\times10^{-5}\ (\mathrm{GeV/c})^{-1}$$

➔ 1/10 momentum resolution w.r.t. LHC

- Hermeticity (for missing energy signatures e.g. SUSY)

$$\theta_{\min} = 5\ \mathrm{mrad}$$

- Sufficient timing resolution to separating events from different bunch-crossings or from beam background

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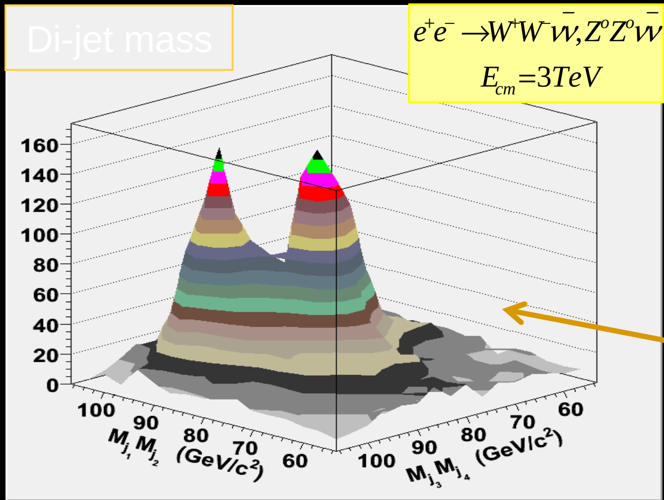
A. Mazzacane

Required Jet Energy Resolution at Future Lepton Colliders



- W-Z separation is necessary at TeV energies to tag different physics channels. Ex:

$$e^+e^- \to \chi_1^+\chi_1^- \to \chi_1^o\chi_1^o\ W^+W^-$$
$$e^+e^- \to \chi_2^o\chi_2^o \to \chi_1^o\chi_1^o\ Z^oZ^o$$

- Required jet energy resolution at future colliders:

$$\sigma(E_j)/E_j = 30\%/\sqrt{E_j\ (\mathrm{GeV})}$$

Largest factor limiting σ_E(jet):
fluctuations between the EM and non-EM component of a shower

Two possible solutions:

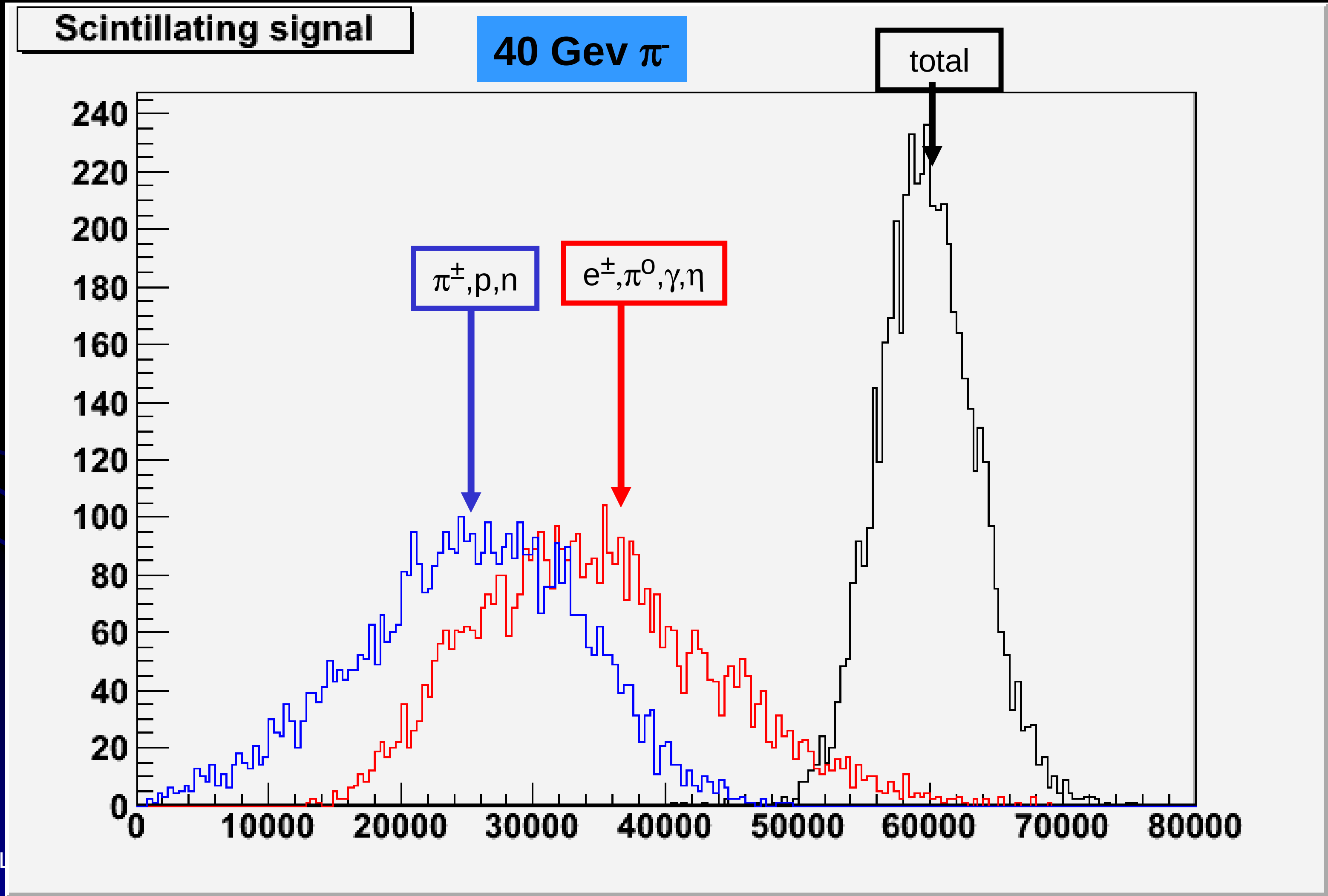
Compensating calorimetry
(unsuitable for experimants at colliders)

Ex.: SPACAL

Dual-readout calorimetry

Ex.: DREAM, T1004, T1015

The major source of fluctuations: *fem*



Dual Readout Calorimetry

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

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

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Dual Readout Calorimetry

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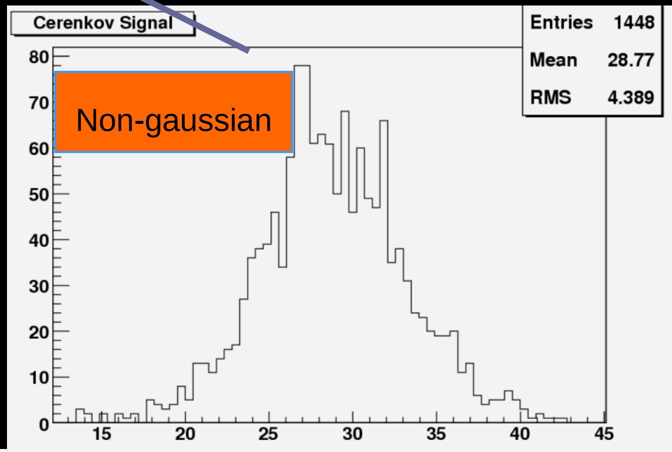

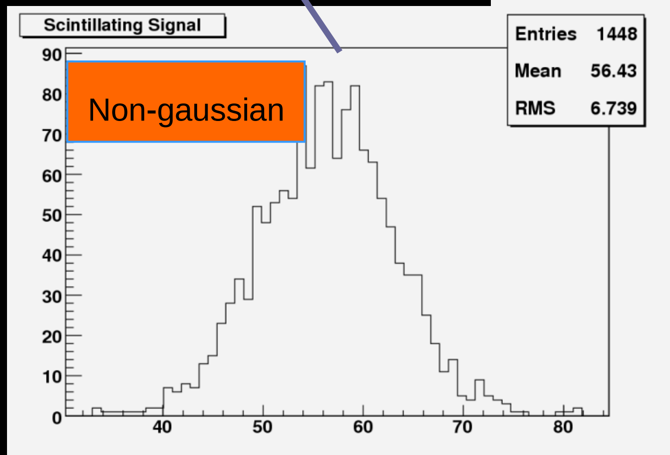

ILCroot simulations

Dual Readout Calorimetry

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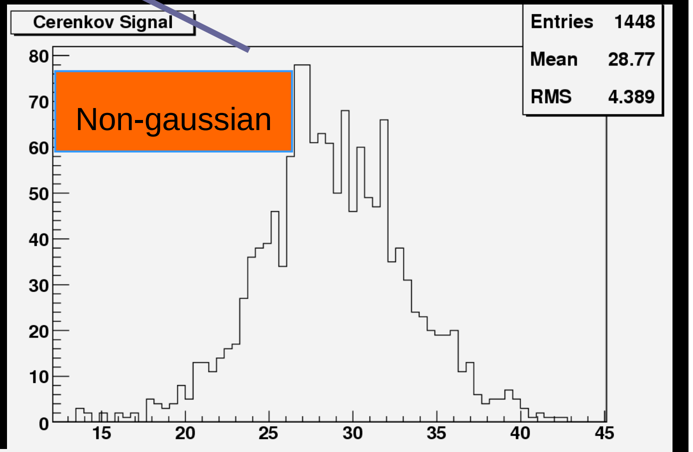
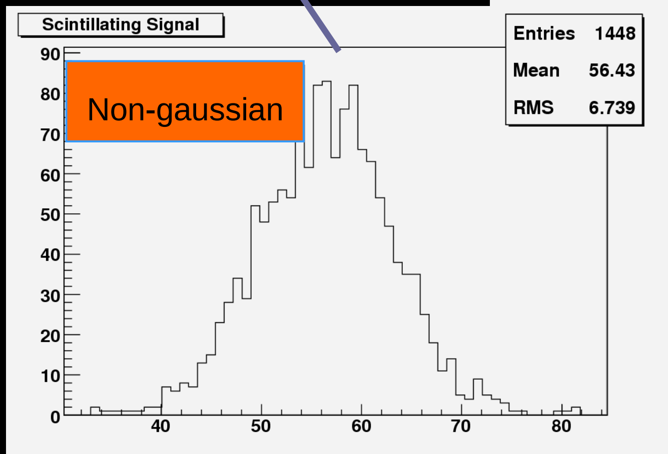




$$\eta_c = \left(\frac{e}{h}\right)_C \quad \eta_S = \left(\frac{e}{h}\right)_S$$

From calibration

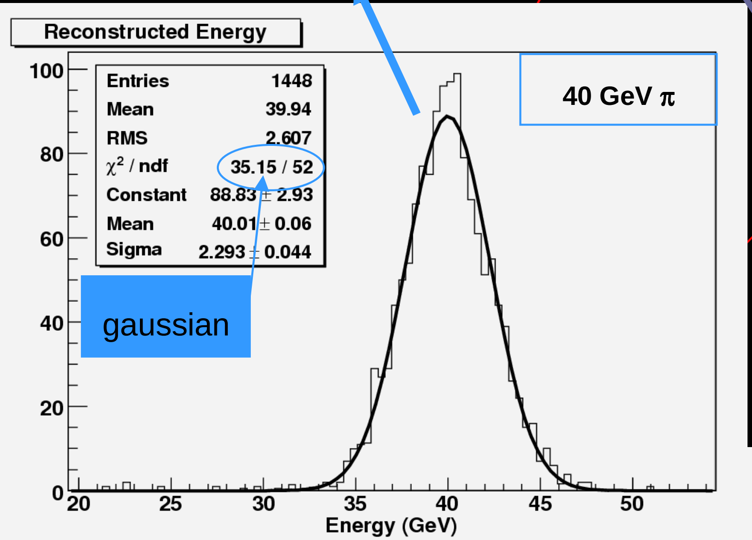
@ 1 Energy only

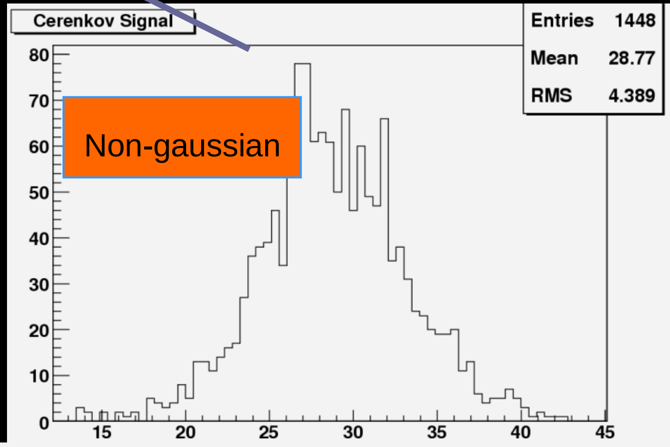
ILCroot simulations

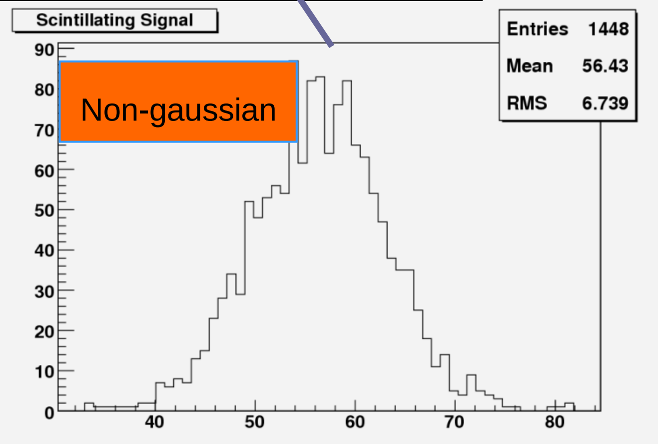
Dual Readout Calorimetry

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

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







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

From calibration @ 1 Energy only

Dual Readout calorimetry is two distinct calorimeters sharing the same absorber

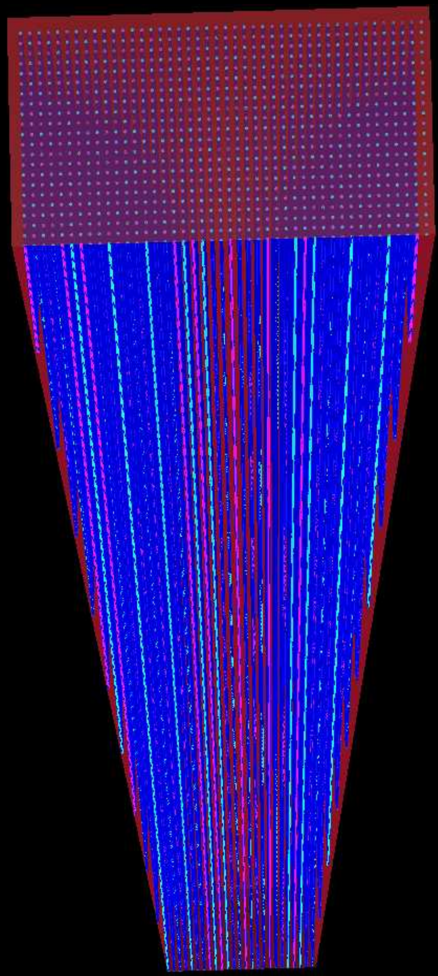
Measured Energy is gaussian because of compensation event by event

THE ORIGINAL APPROACH

Sampling Dual-readout (DREAM and 4th Concept)

After 4 years of simulations and studies with ILCroot we have learnt that Sampling Dual-readout (i.e. 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 for 4th)
  - Large unbalance between Scintillation signal (200 pe/Gev) vs Cerenkov (7.5 pe/GeV for 4th)
  - Too many fibers to be routed to FEE for a 4π calorimeters



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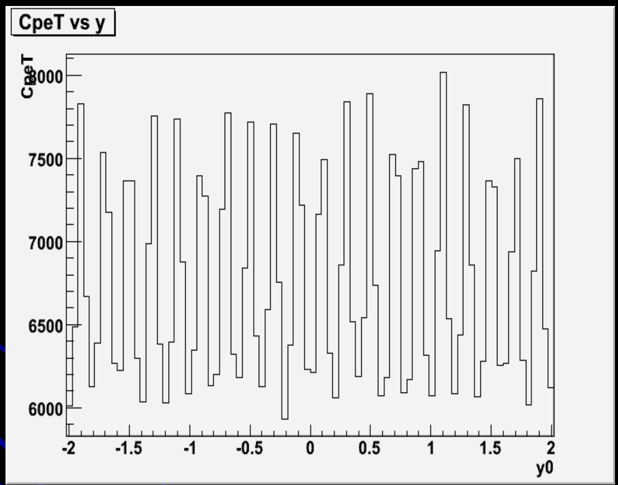
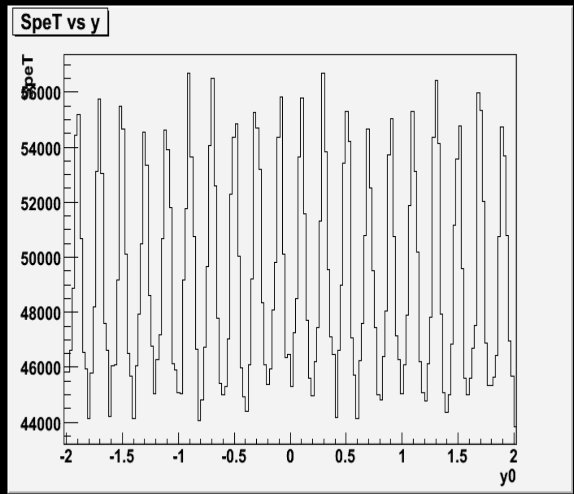
Cons N. 1: Sampling is far coarse for shower generated by *EM* particles

- Calorimeter sampling frequency must be compared to absorption length of bulk of the particles composing the shower (not X_o nor λ_I): **<u>i.e 1 mm for e^-</u>** (typical shower particle in em showers is a 1 MeV electron)

See R. Wigmans book

<u>Consequences: large signal fluctuations depending on impact point of impinging electron</u>





40 Gev electrons Simulated in ILCroot

- Cerenkov and Scintillating signal produced by e^- @ 45 GeV beam in 4th Calorimeter (1mm pitch between fibers) as function of e^- impact point

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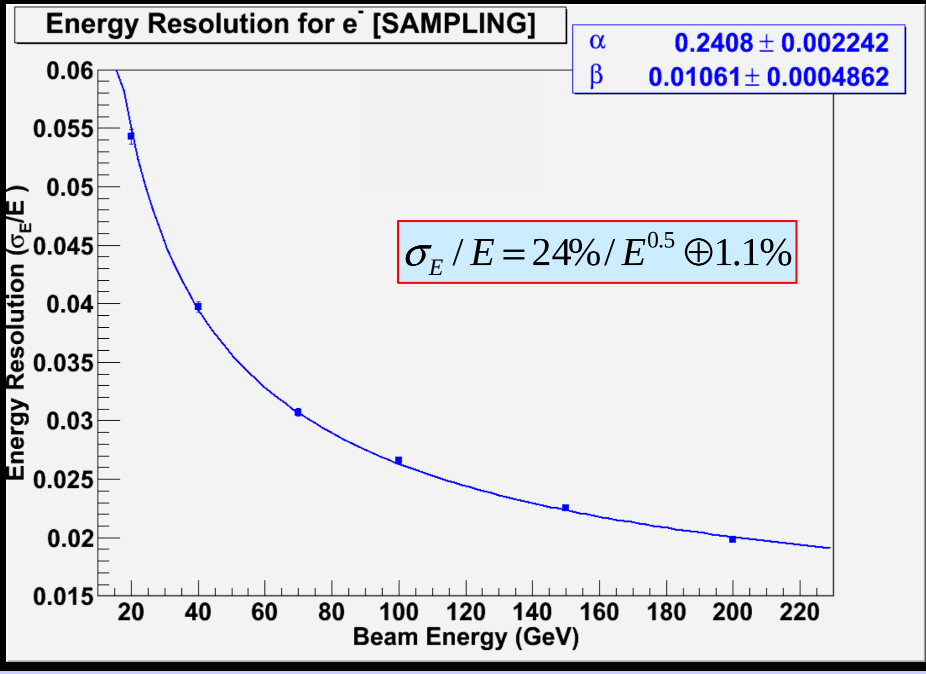
Cons N. 1 (cont'd)

Effects on energy resolution:

- energy resolution curve for electrons in **4th Concept** the hadronic calorimeter



No instrumental effects Included in this simulation

- **Very poor EM energy resolution. Hadronic sampling calorimeters require a front, EM section**

In real life this is a bad idea as:

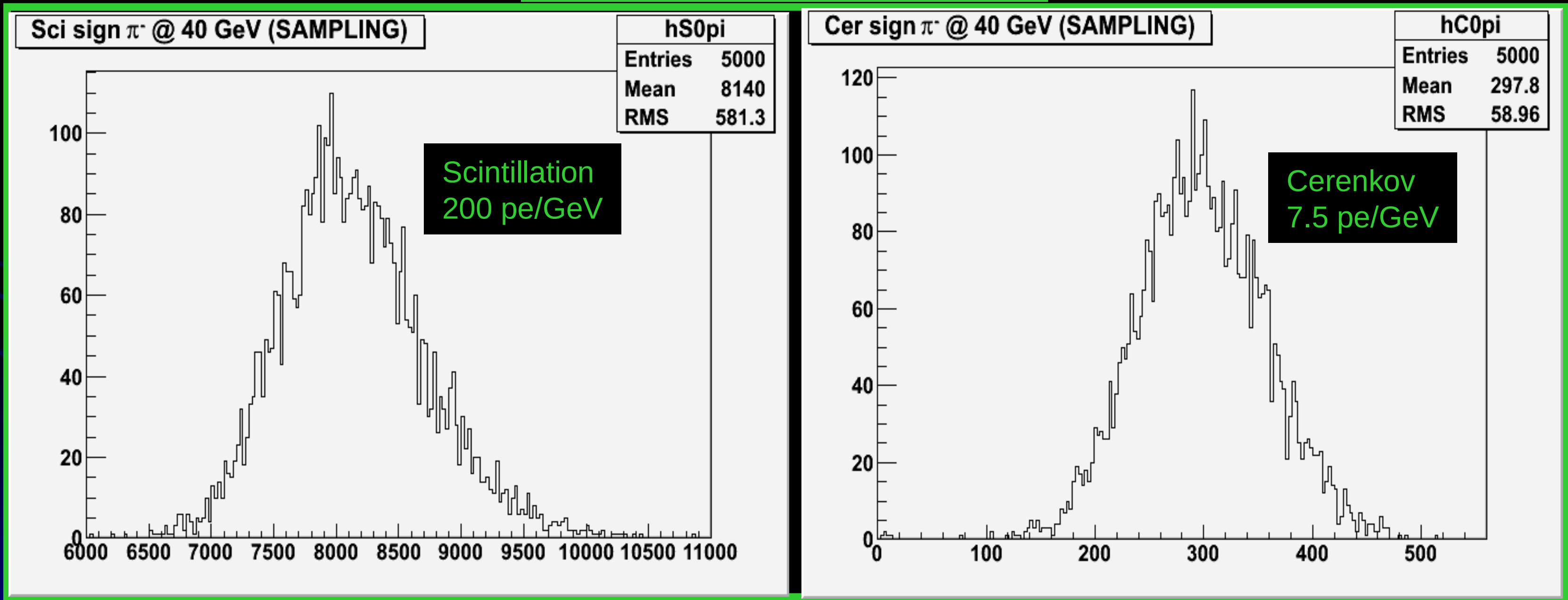
1. More complex calibration
2. Introduce extra fluctuations with hadronic showers

Cons N. 2: Cerenkov light in fibers is very dim

Consequences: large unbalance between scintillation and Cerenkov signals

4th Concept Calorimeter

40 Gev pions



- Cerenkov and Scintillating signal produced by π^- @ 40 GeV beam in 4th Calorimeter (1mm pitch between fibers) including FEE effects

Cons N.3: 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%.

Very large

- This issue is honestly recognized by DREAM Collaboration:

"…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…."

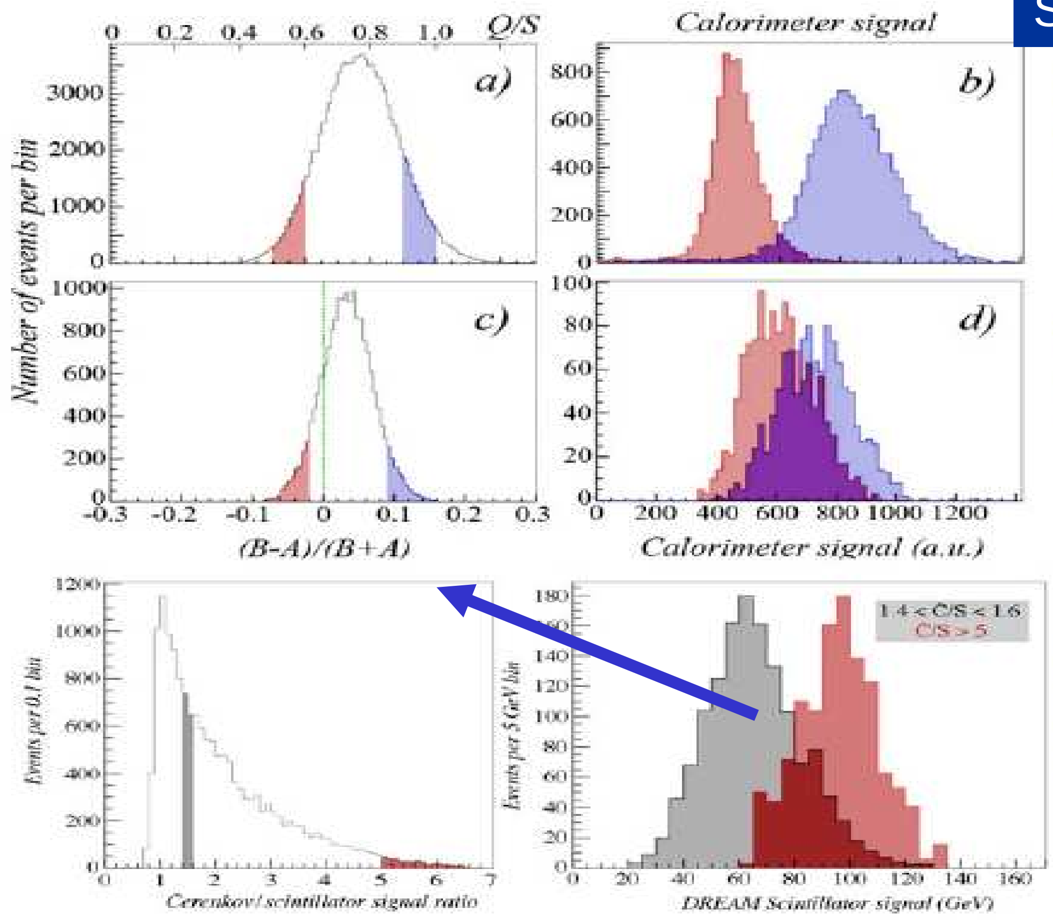
- **Goal is Γ < 10%**

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

Difficulties of Total Active Homogeneous Dual Readout

- Report form DREAM Collaboration studies

Separation Efficiency between S & C components



DREAM stand-alone (2 separate media)

$PbWO_4$ matrix (directionality)

BGO_{UV} (1 crystal)

(time structure + spectrum)

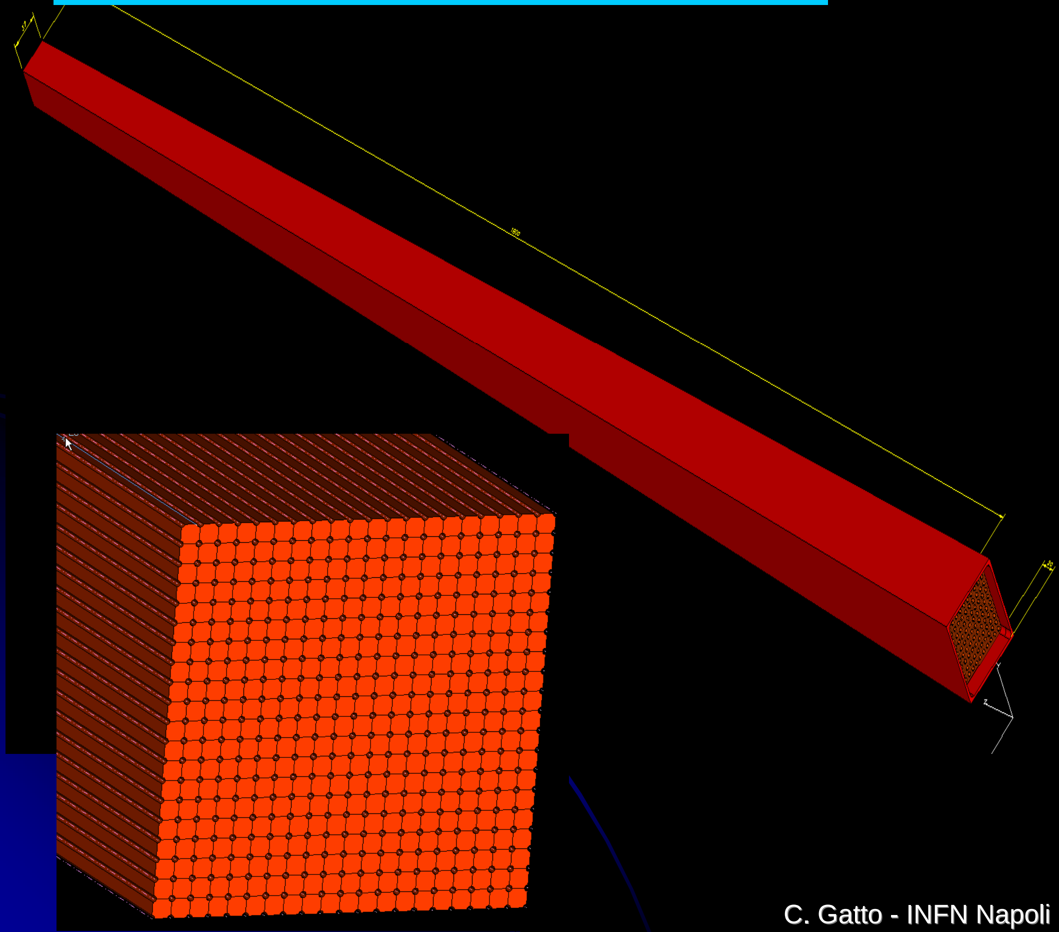
Combine the advantages of sampling and total active techniques

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_i=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%

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

- 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)

  Cerenkov light collection: 8 WLS fiber/cell

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

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

  Readout: front and back SiPM

  COG z-measurement: light division applied to SCSF81J fibers

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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

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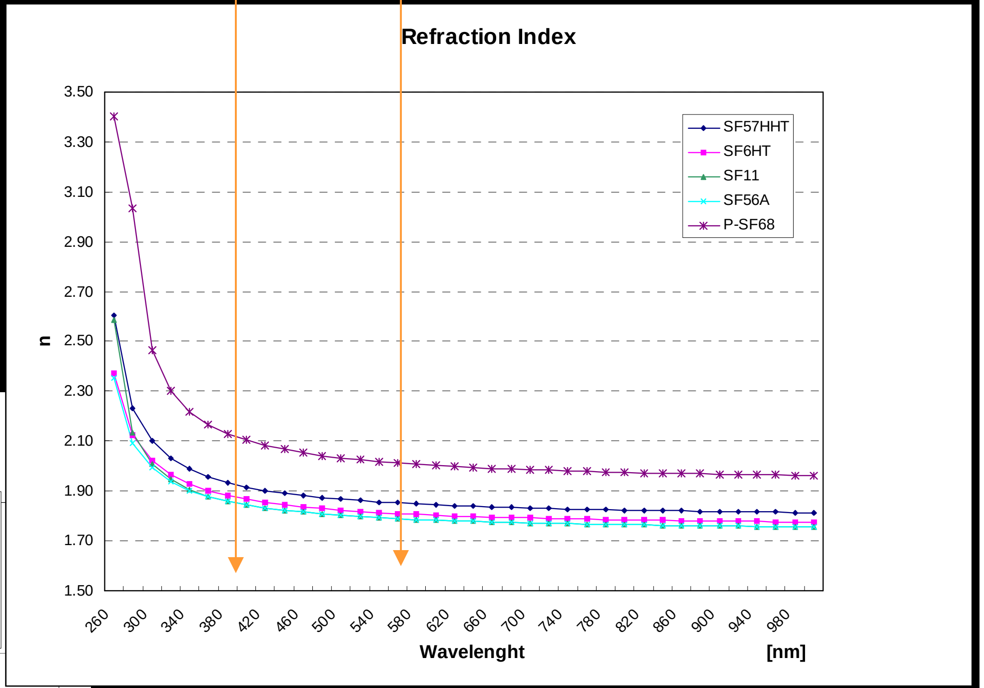
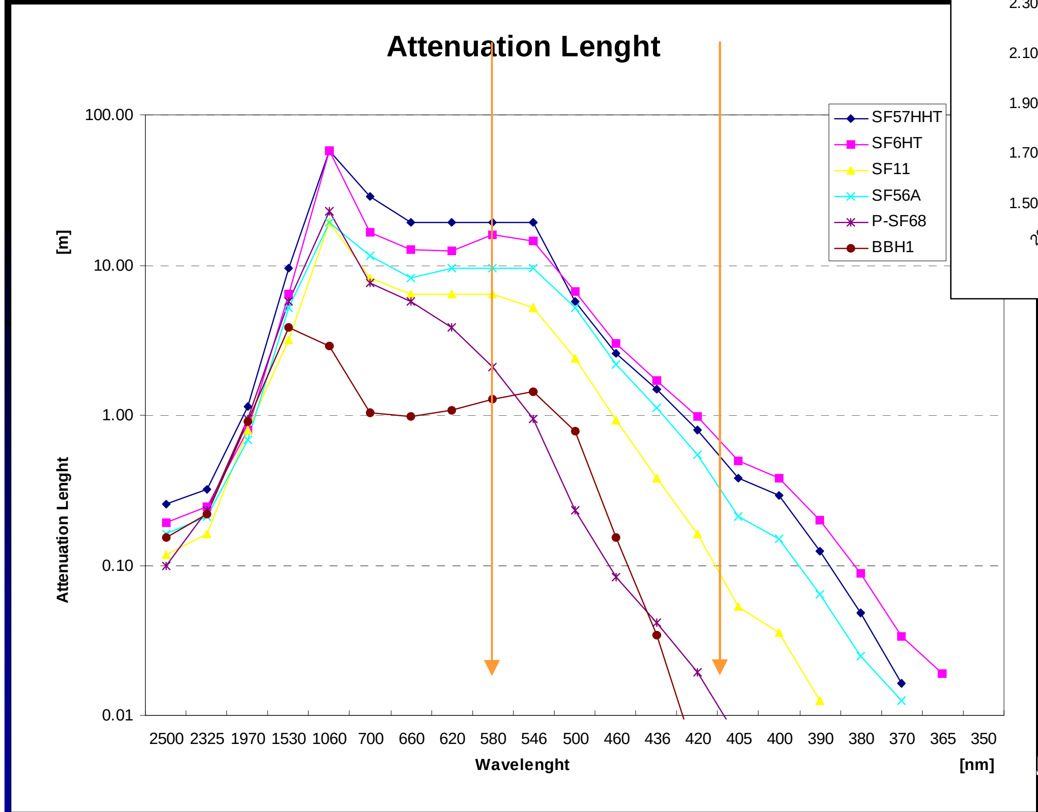
Comparing Optical Heavy Glasses

Arrows indicate
absorption window of most WLS fibers





Three candidate selected:
Schott SF57HHT
Ohara P-SF68 and L-BBH1

Simulation Studies with ILCroot on *ADRIANO* techniques

V. Di Benedetto

C. Gatto

A. Mazzacane

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***

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ADRIANO simulations in ILCroot

- *ADRIANO* is a melting pot of well established 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

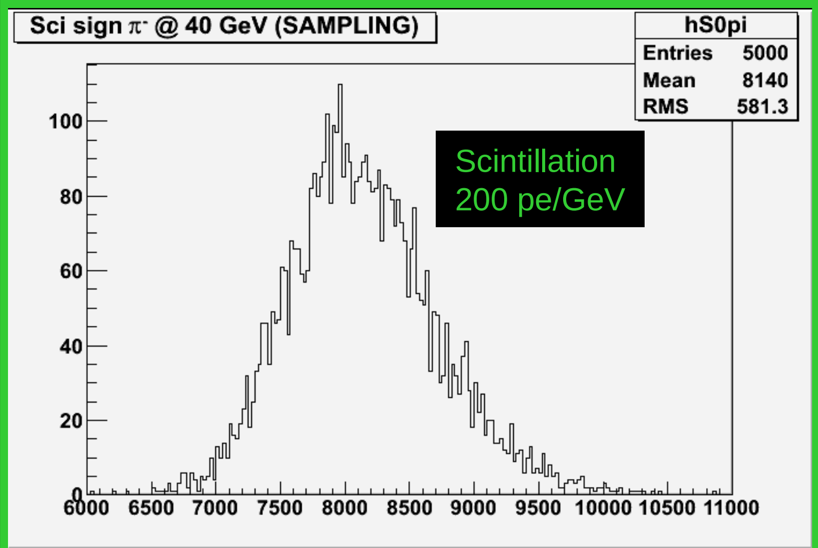
ILCRoot simulation

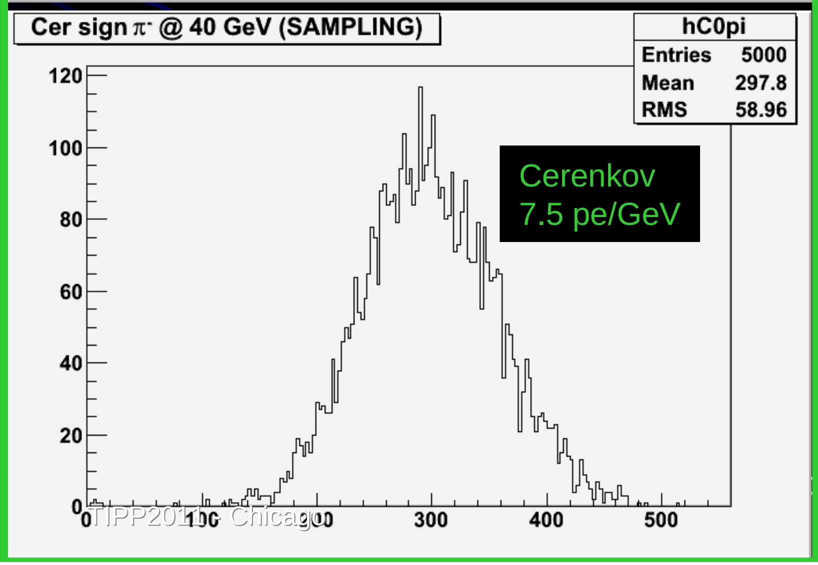
40 Gev pions

Photon yield:

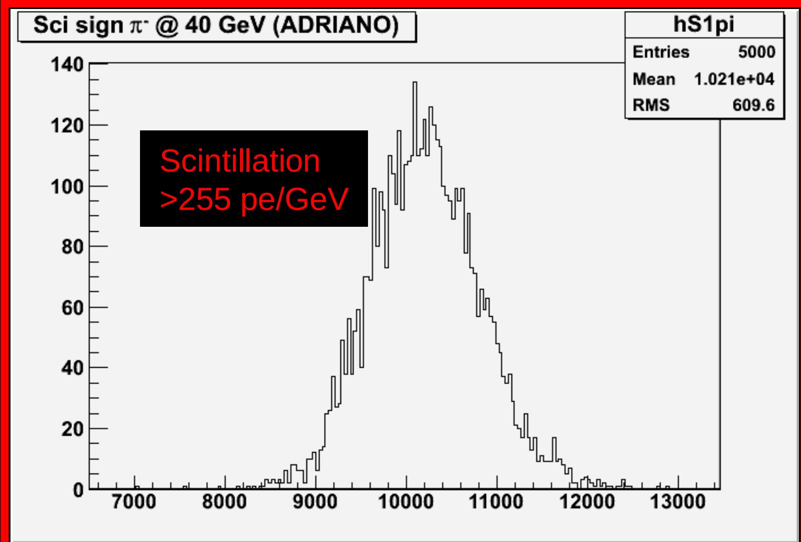
Sampling vs Integrally active

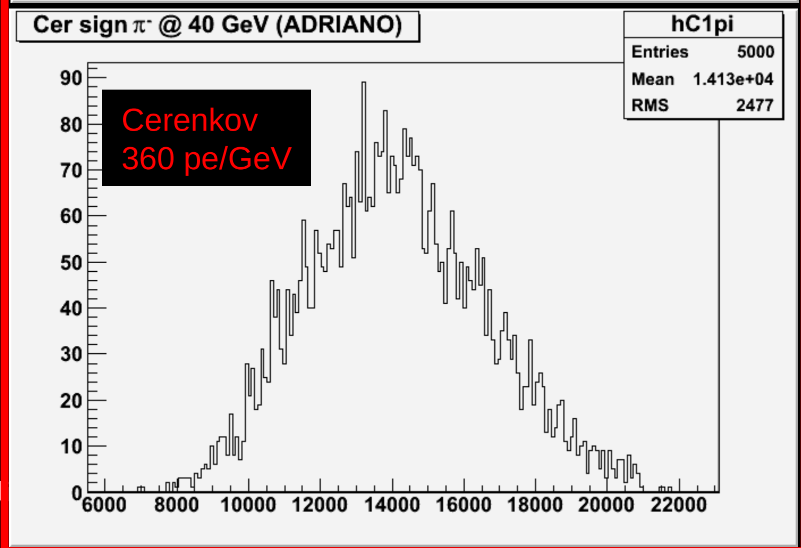
4th Concept Calorimeter





ADRIANO Calorimeter





ILCRoot simulation

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Photon yield:

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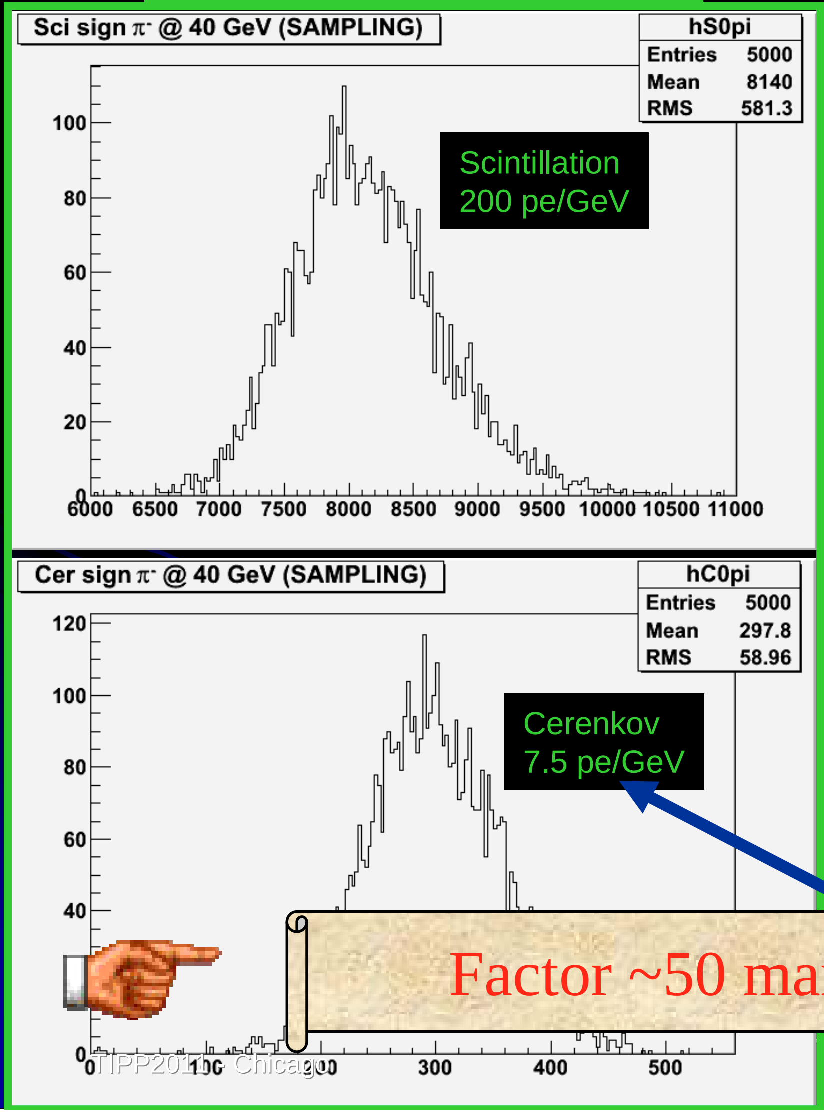
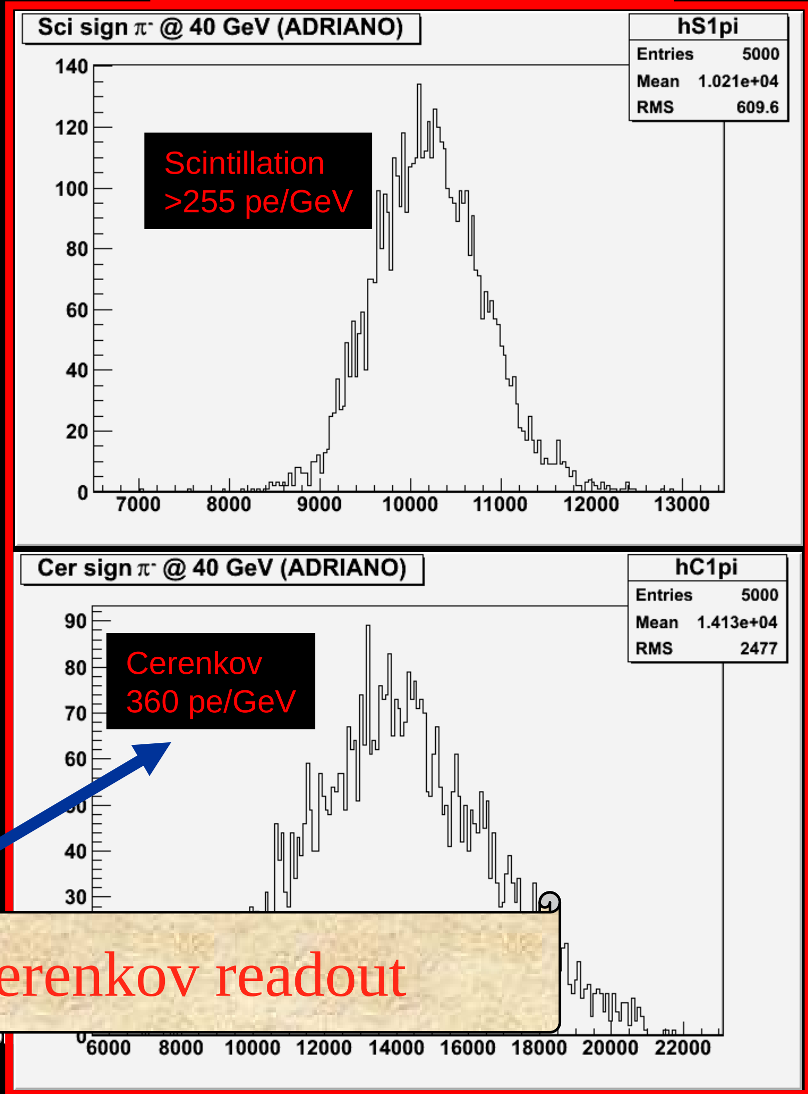


ADRIANO Calorimeter



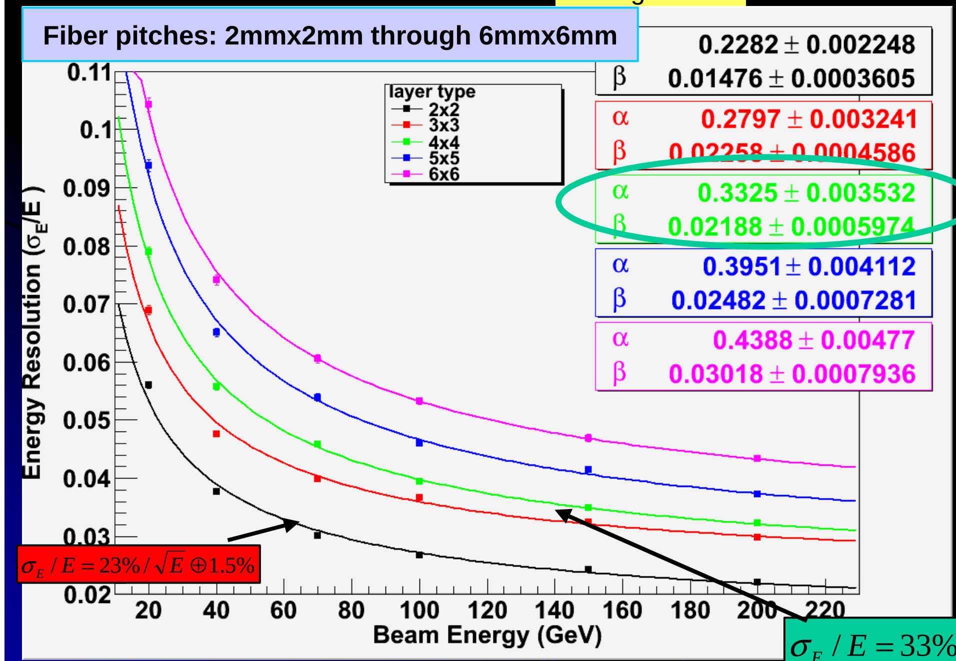
Factor ~50 margin in Cerenkov readout

ADRIANO Light Yield and E resolution

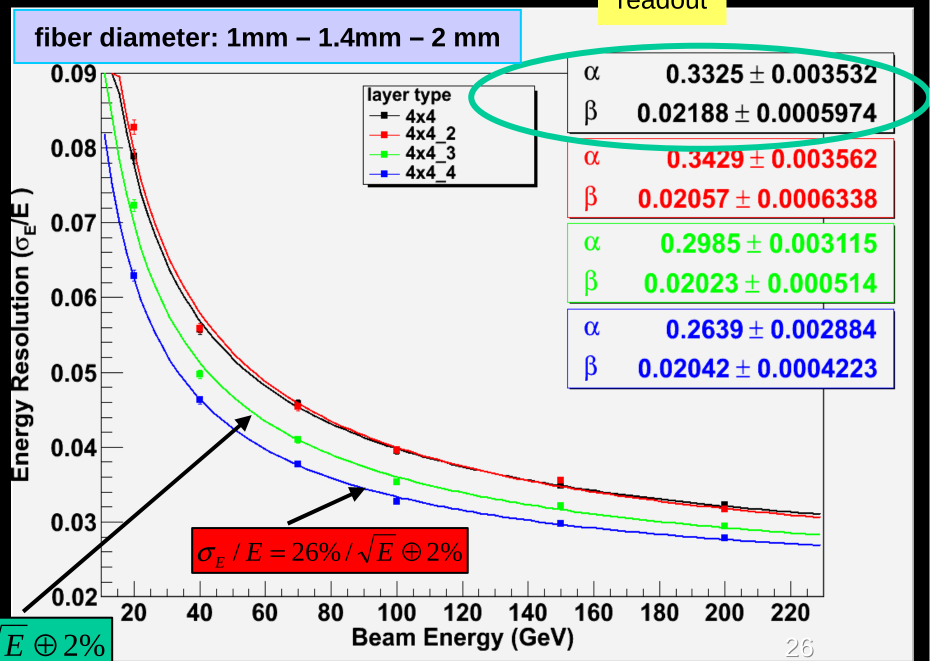
	Integrally Active with Double side readout (*ADRIANO*)								Sampling
Pitch [mm^2]	**2x2**	**3x3**	**4x4**	**5x5**	**6x6**	**4x4**	**4x4**	**4x4**	**Sampling**
Diameter	**1mm**	**1mm**	**1mm**	**1mm**	**1mm**	**1.4mm**	**2mm**	**Thick capillary**	
$\langle pe_S/GeV \rangle$	1053	430	254	163	124	500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

Baseline configuration (4x4, 1mm)

1-side readout (Sampling)



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



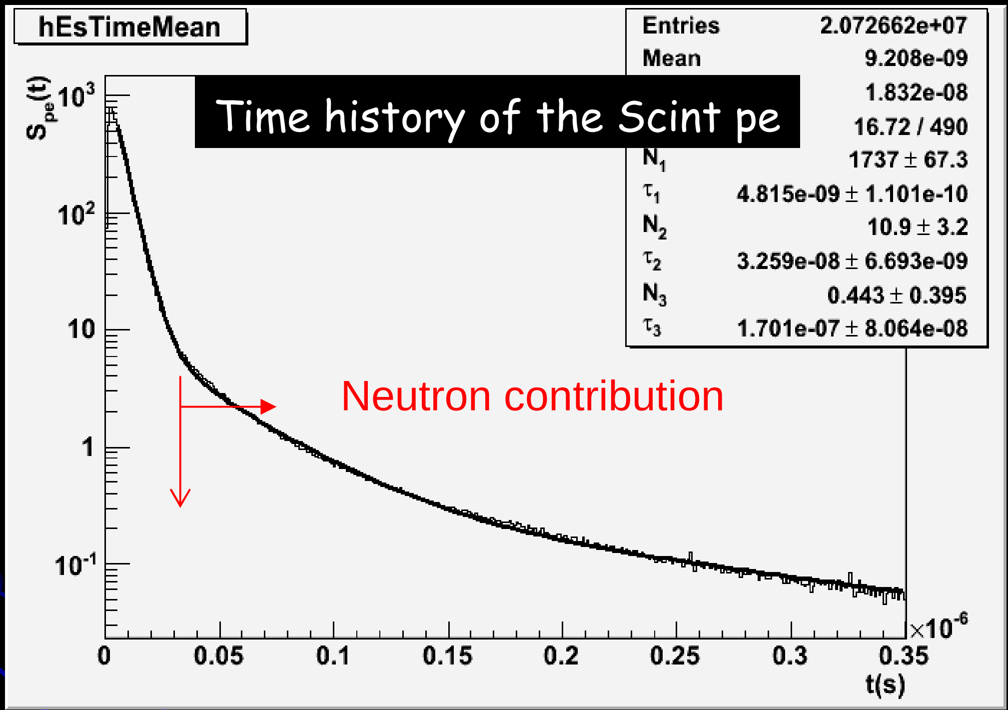
ILCRoot simulation

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

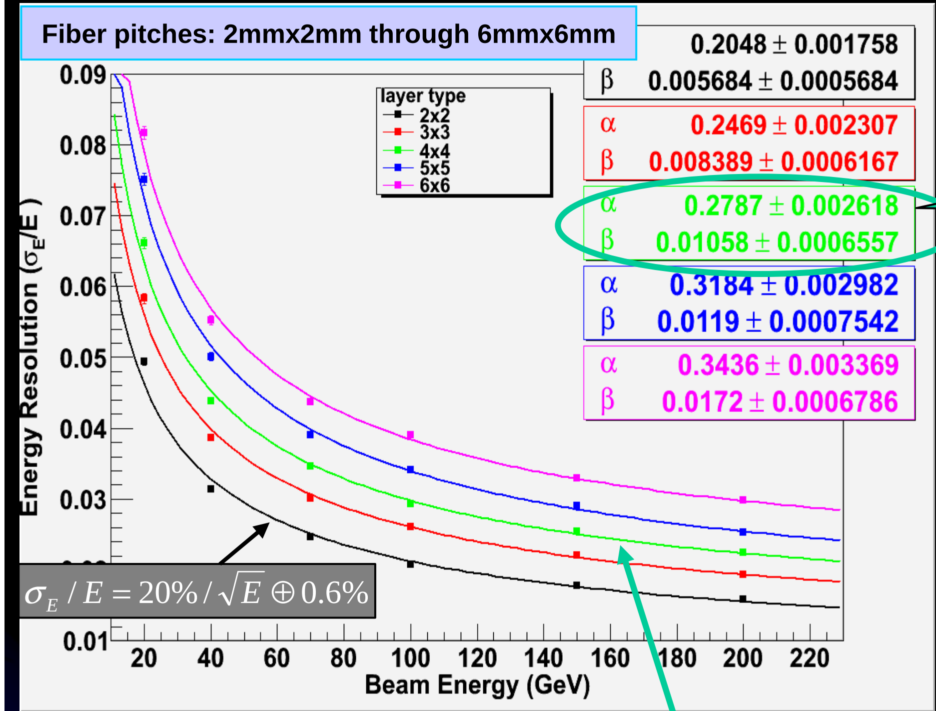
$$E_{HCAL} = \frac{\eta_S \cdot E_S \cdot (\eta_C - 1) - \eta_C \cdot E_C \cdot (\eta_S - 1)}{\eta_C - \eta_S} + \eta_n \cdot E_{neutrons}$$

Triple readout aka Dual Readout with time history readout

ILCRoot simulation

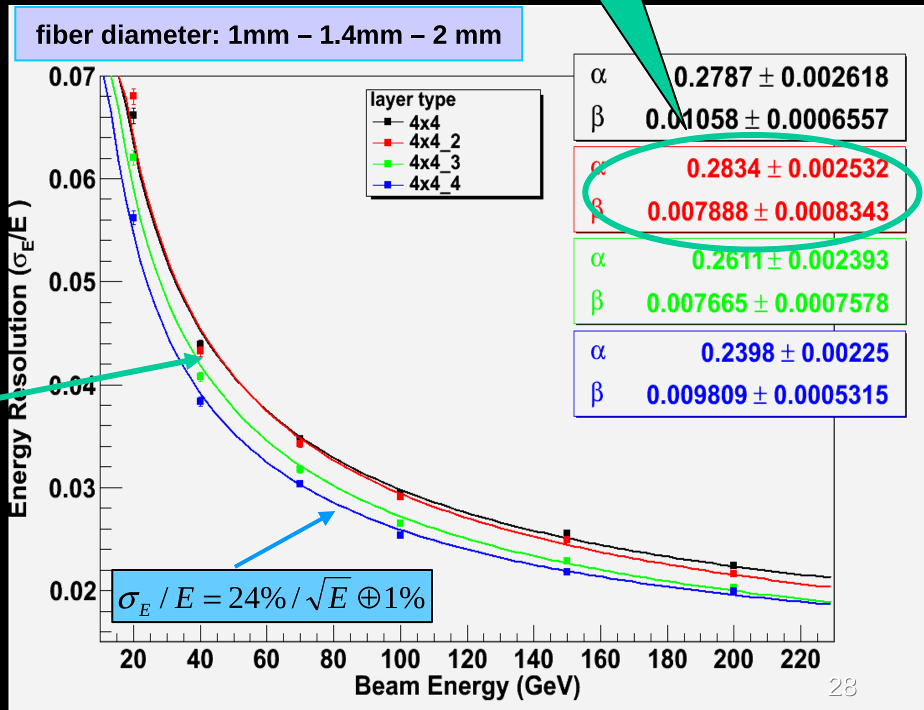
Pion beams

ADRIANO in Triple readout configuration



Baseline configuration

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



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

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100 Gev pions

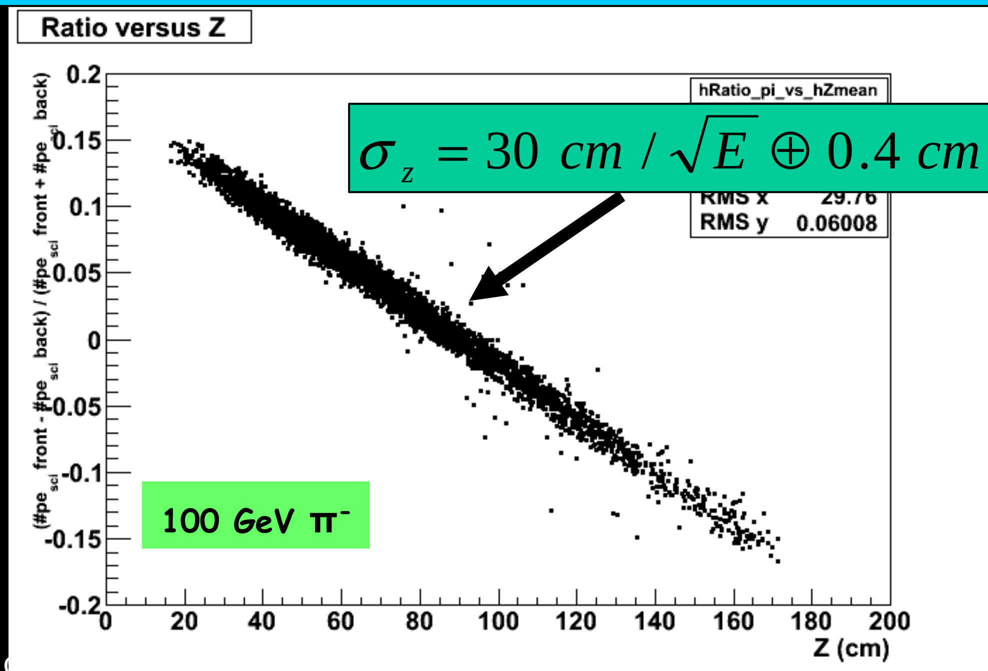
Adding the 3rd Dimension info with light division methods

- 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



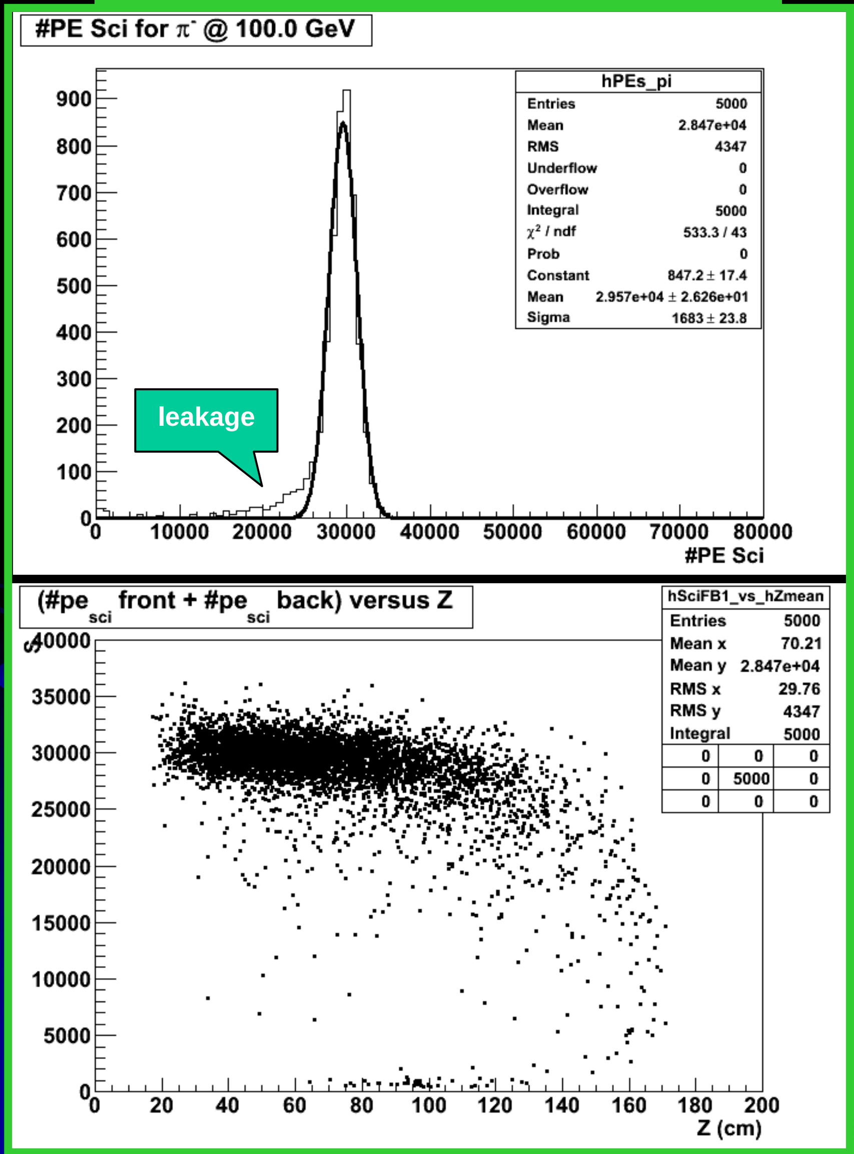
ILCRoot simulation

ILCRoot simulation

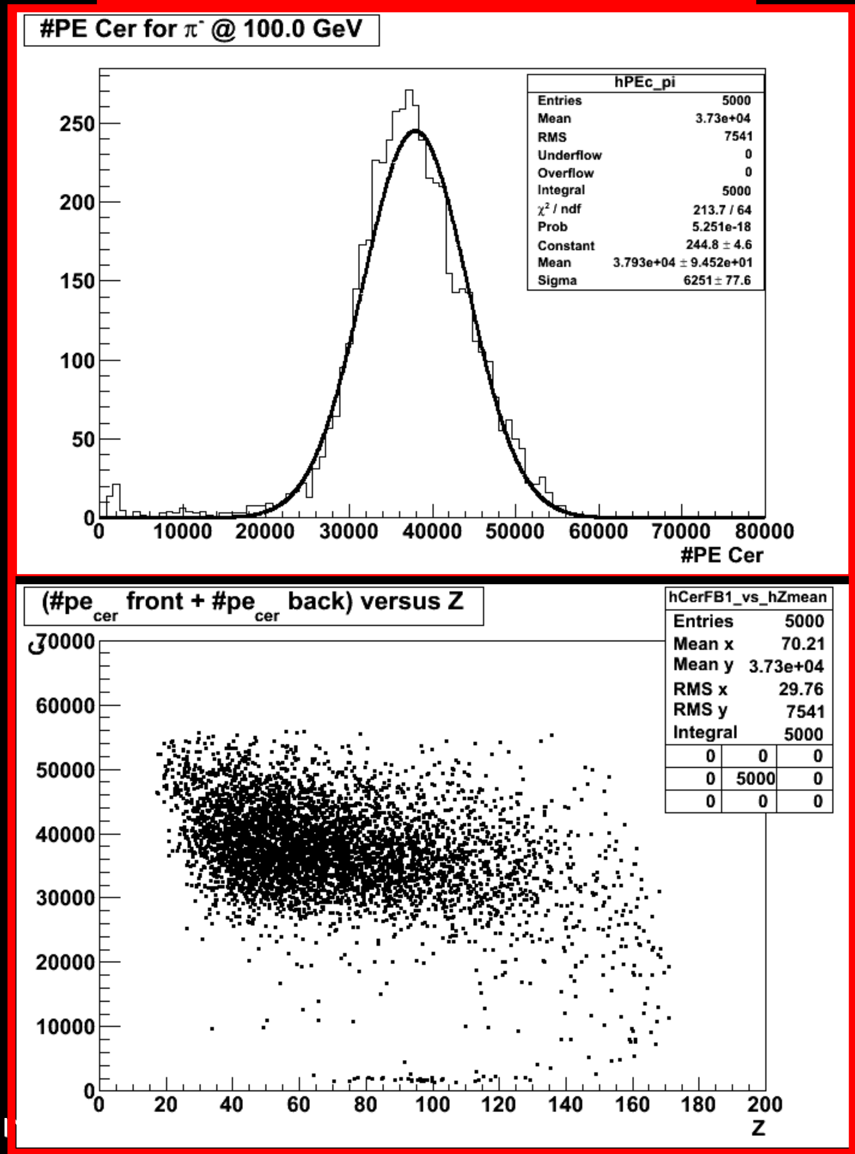
100 Gev pions

Leakage in 180 cm long *ADRIANO* module

Uncorrected scintillating signal



Uncorrected Cerenkov signal

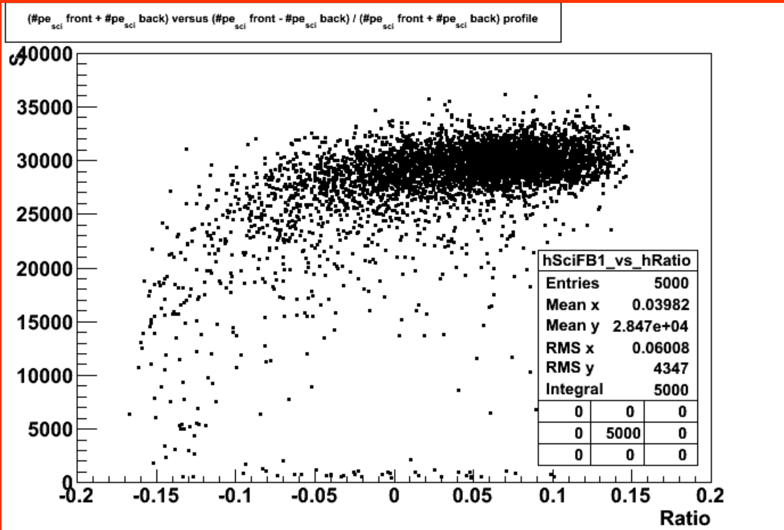


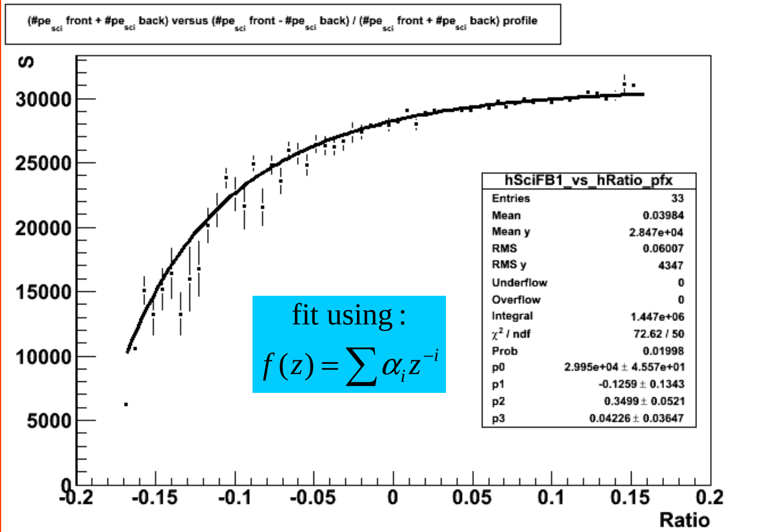
ILCRoot simulation

100 Gev pions

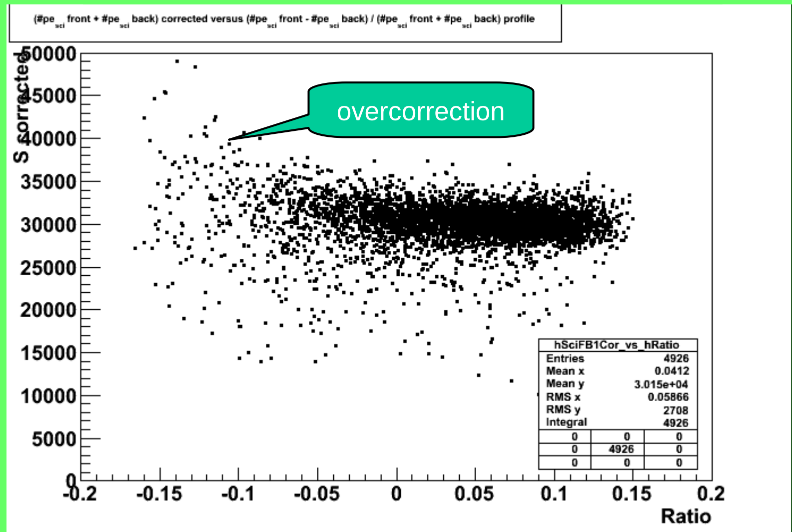
Applying leakage corrections from CoG measured with a light division

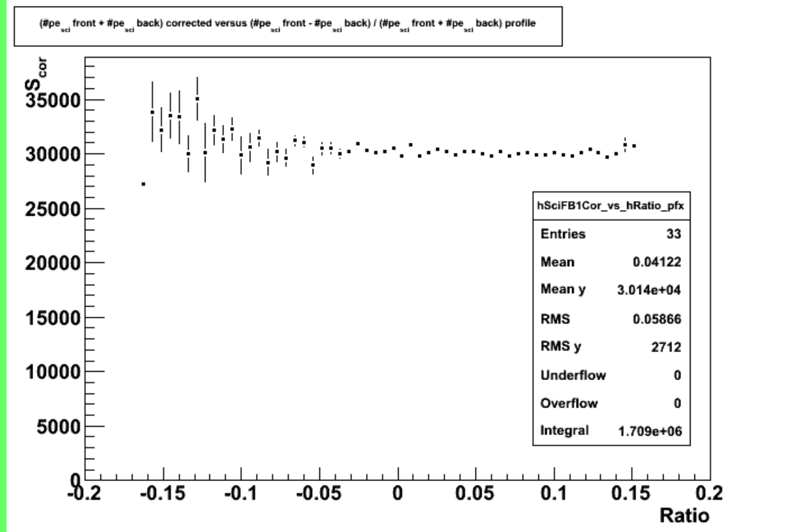
Uncorrected scintillating signal





Corrected scintillating signal

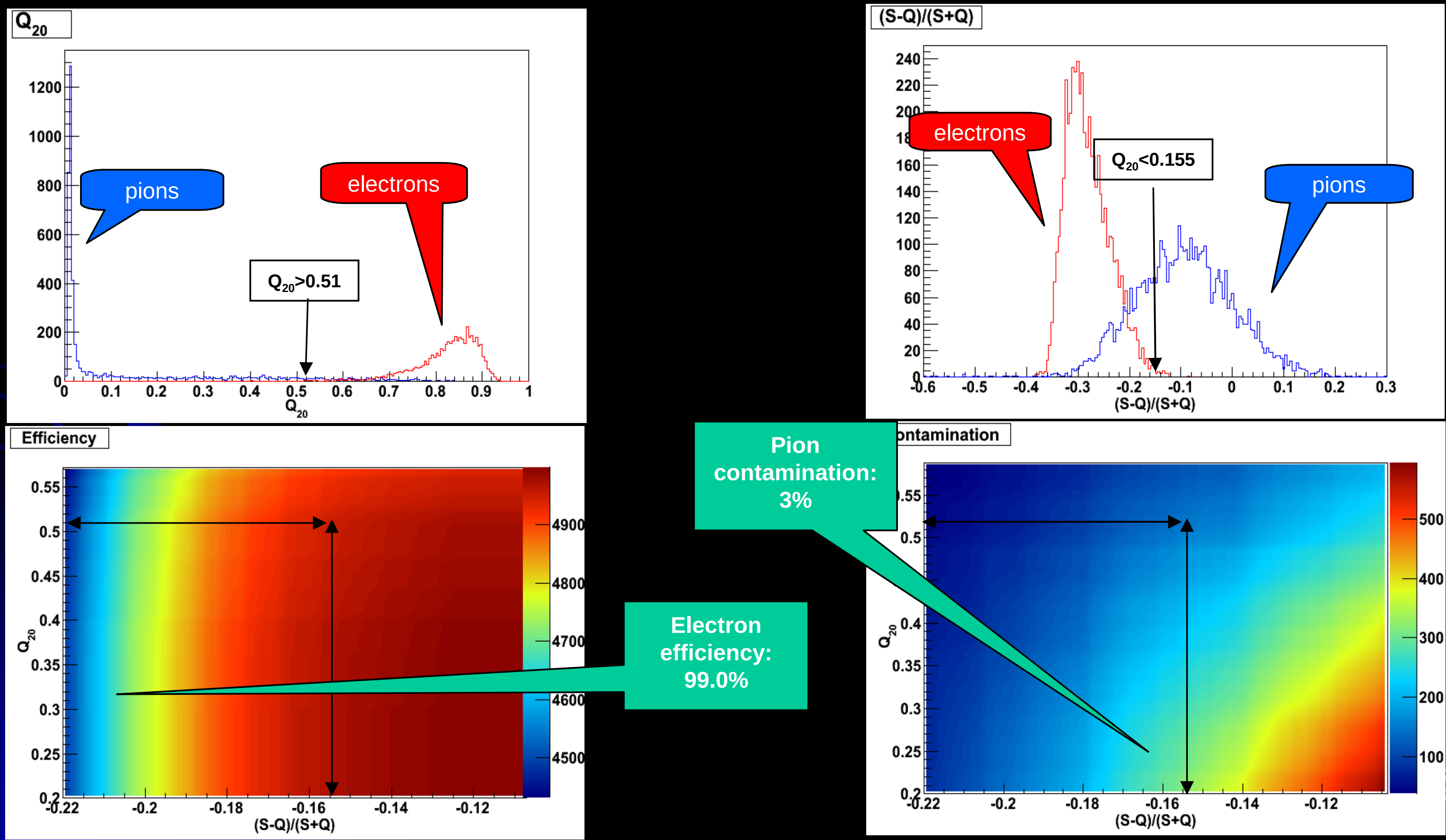




ILCRoot simulation

Identifying EM Showers in ADRIANO

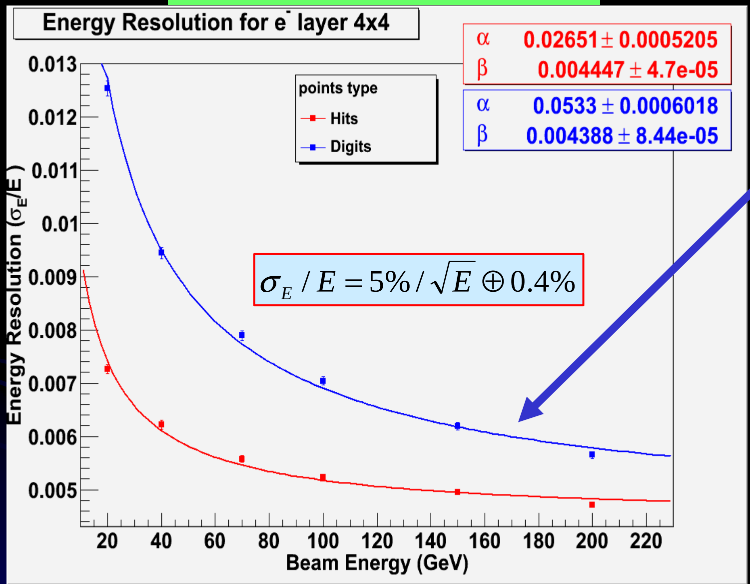
- Use Q_{20} fibers and (S-Q)/(S+Q) to disentangle EM particles from hadrons
- Use $E_{Cerenkov}$ from heavy glass **ONLY** for EM showers



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

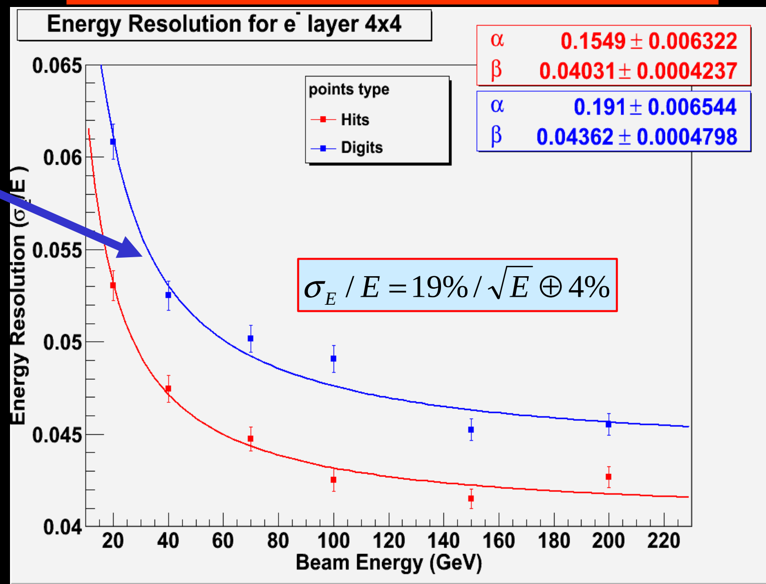
Use only Cerenkov light



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)

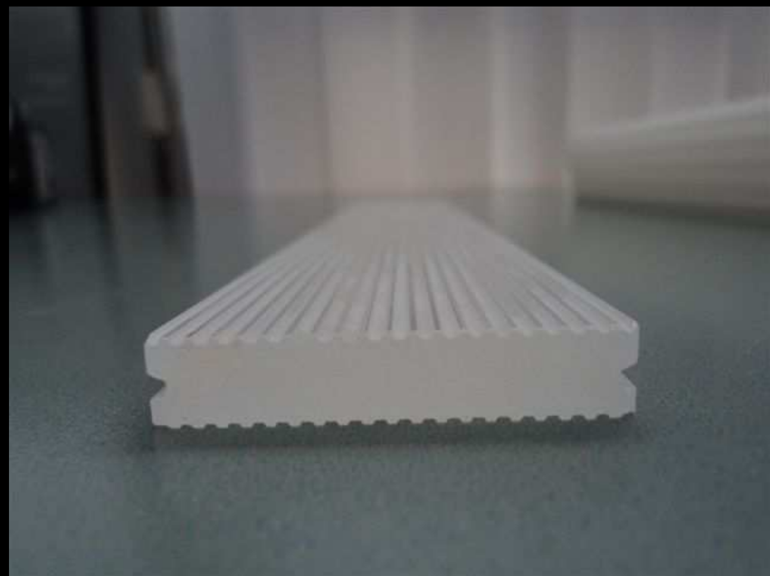
ADRIANO does not need a front EM section

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



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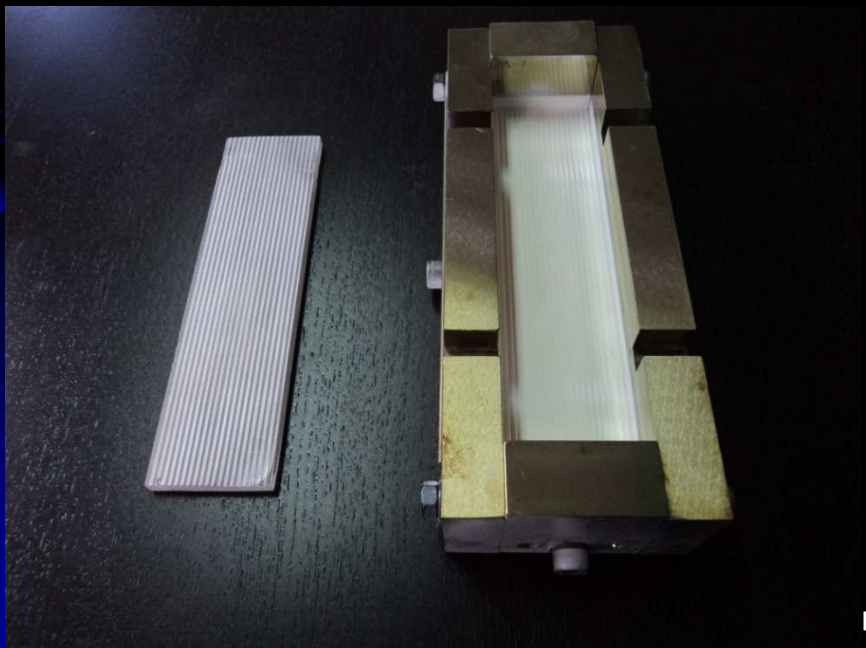
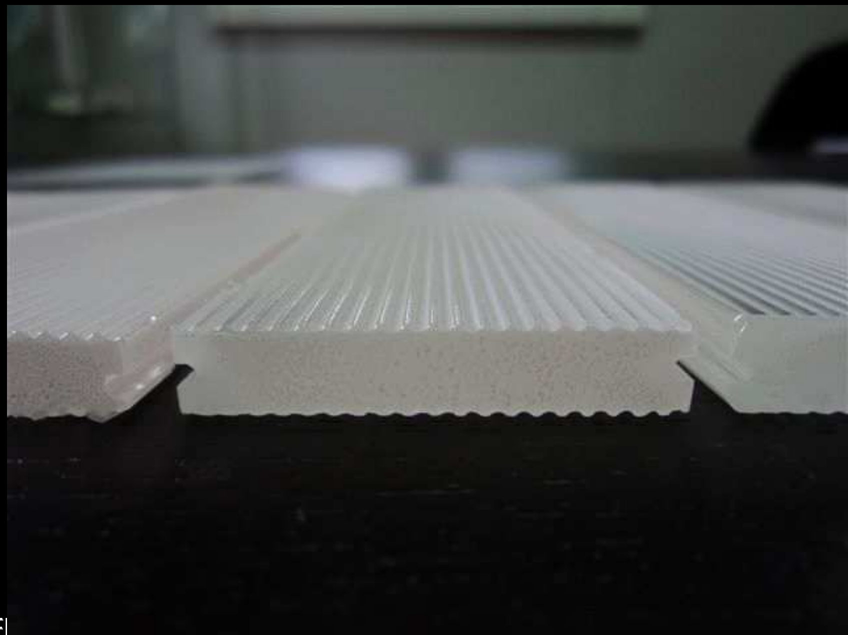
Fabrication Technology #2: Precision molding

- 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

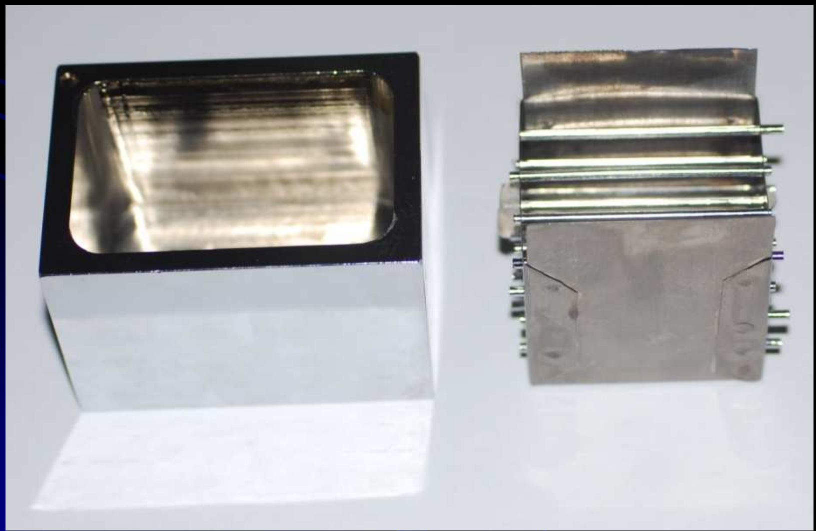




Fabrication Technology #3: Glass melting

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

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



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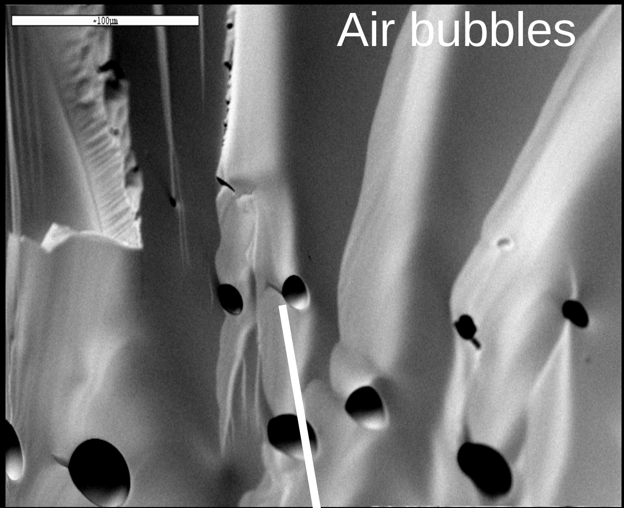
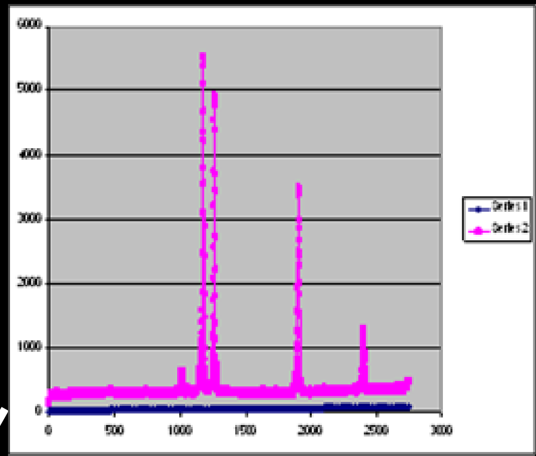
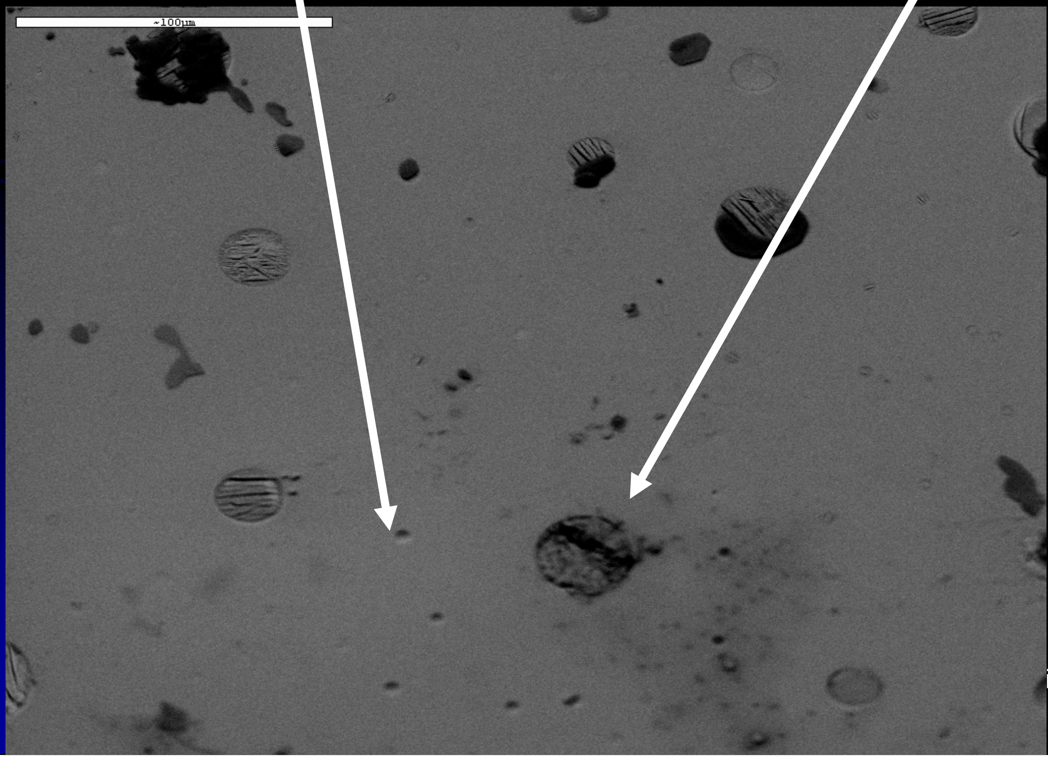
SEM/XRD analysis of glass samples

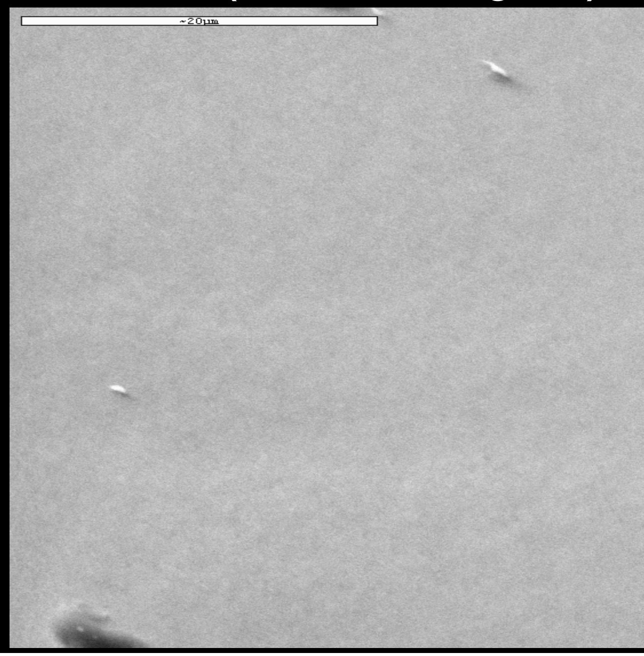




XRD spectrum



Perfect sample
(same as original)

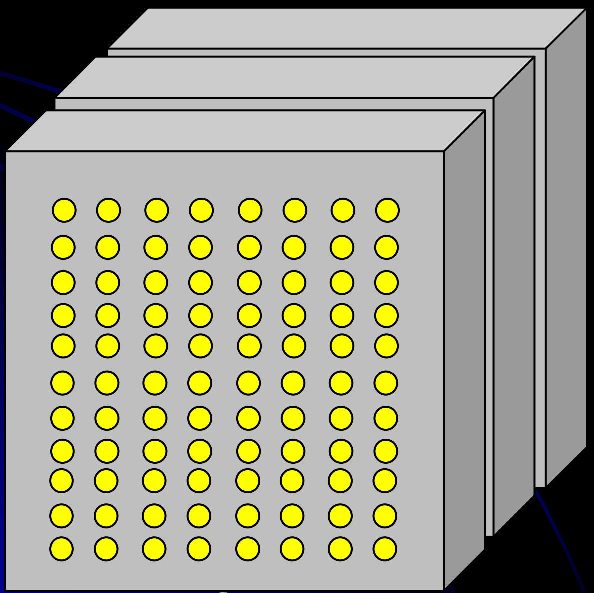


SALENTEC advanced technologies

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



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T1015 Test Beam Program

- Three test beam at FTBF by the end of 2011: total 8 cells with different configurations
- ADRIANO cells from INFN Lecce
- SiPM by BKF and INFN Trieste
- Tail catcher and DAQ by Fermilab
- Construction: 50% Fermilab (E. Hahn)+ 50% INFN
- Lab spectroscopy: Fermilab (A. Pla) + INFN-Le & Ms
- Several parameters to optimize (layout, fab. tech., polishing, optical coupling, SiPM, etc.)

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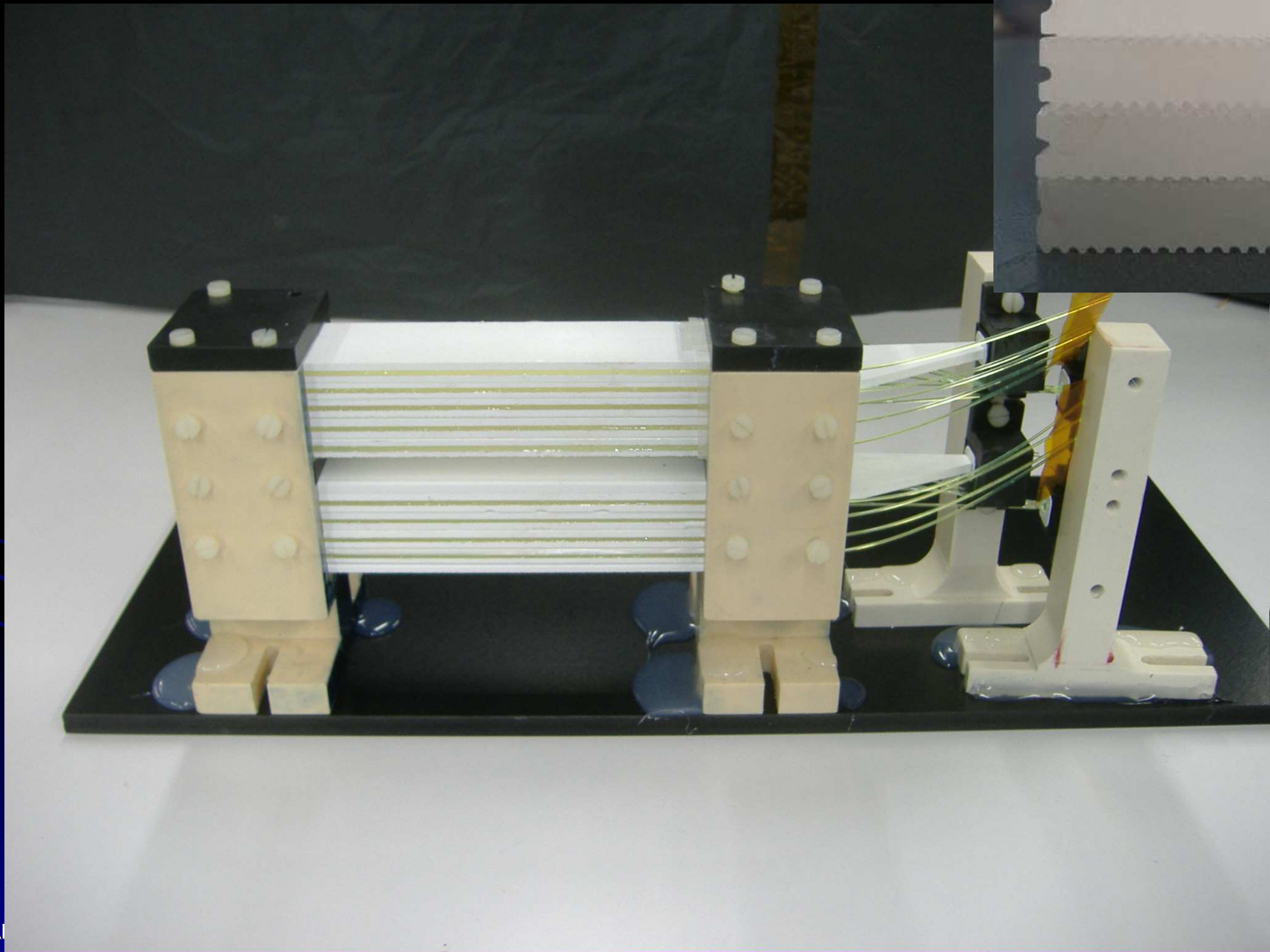
July 2011 Test Beam
(Cerenkov only)



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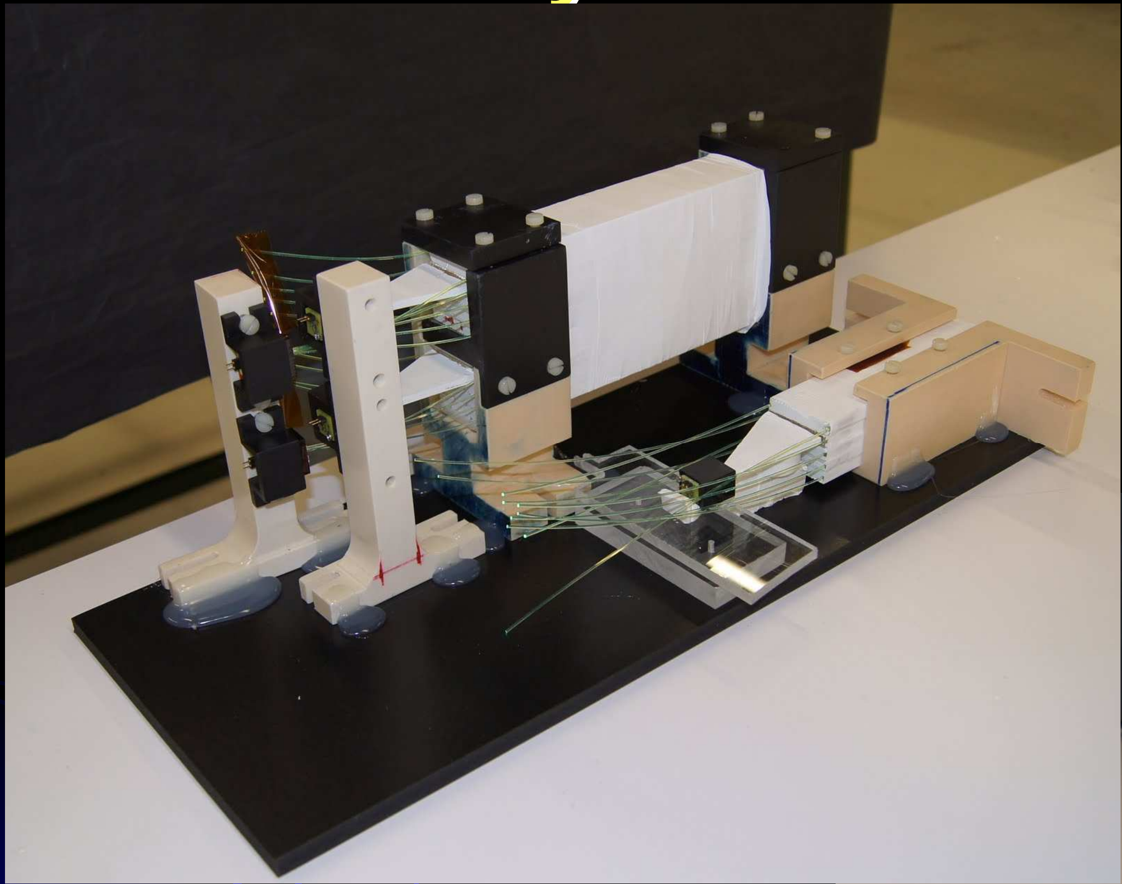
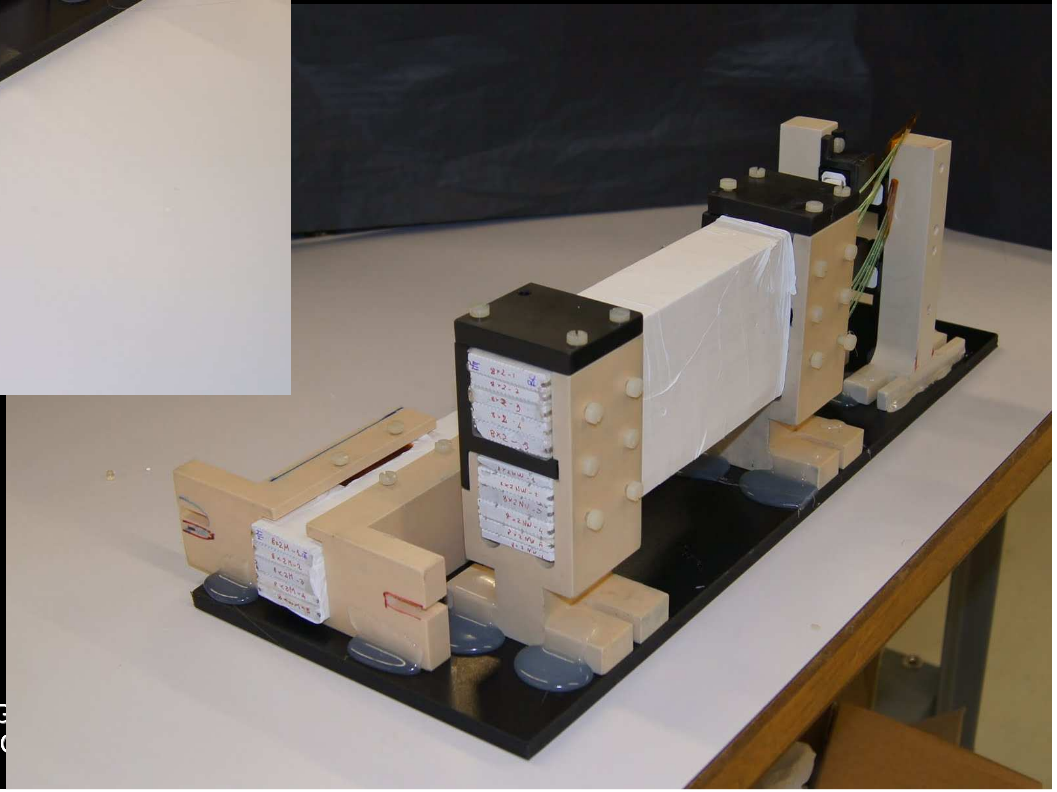
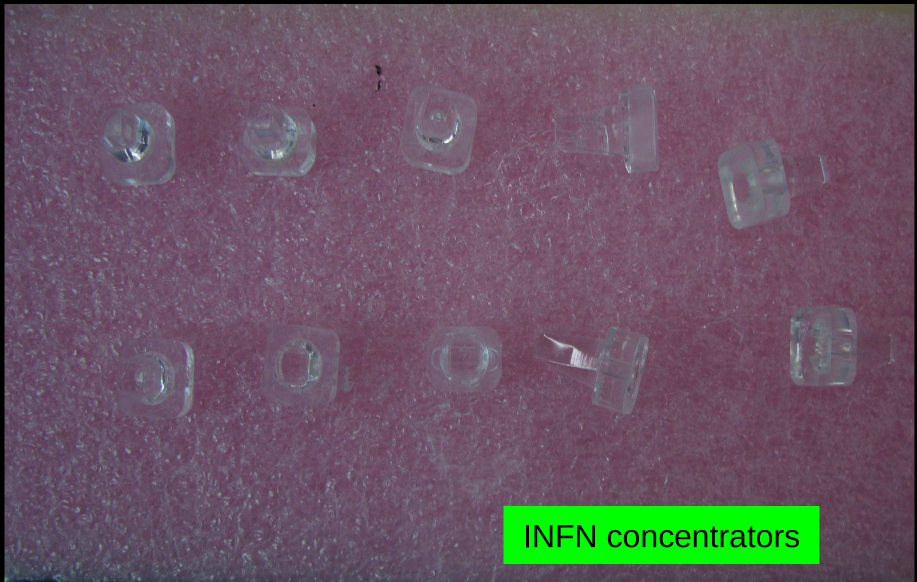
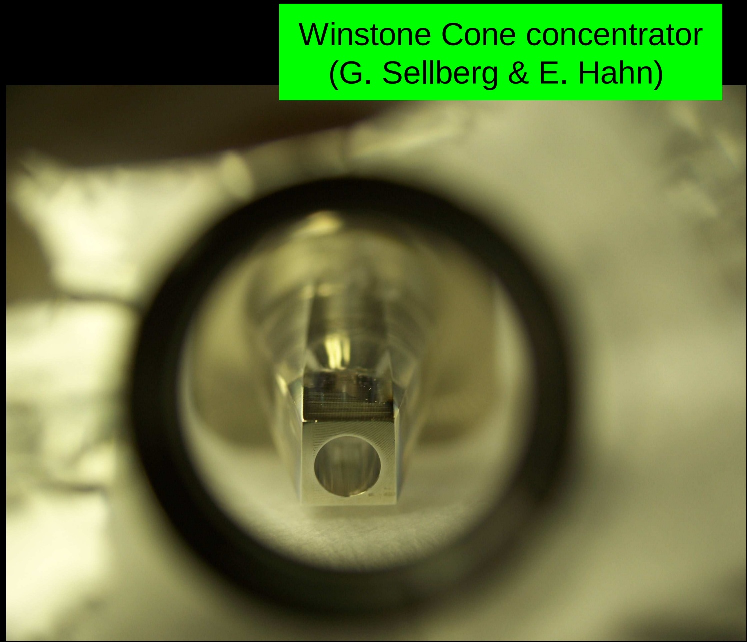
July 2011 Test Beam

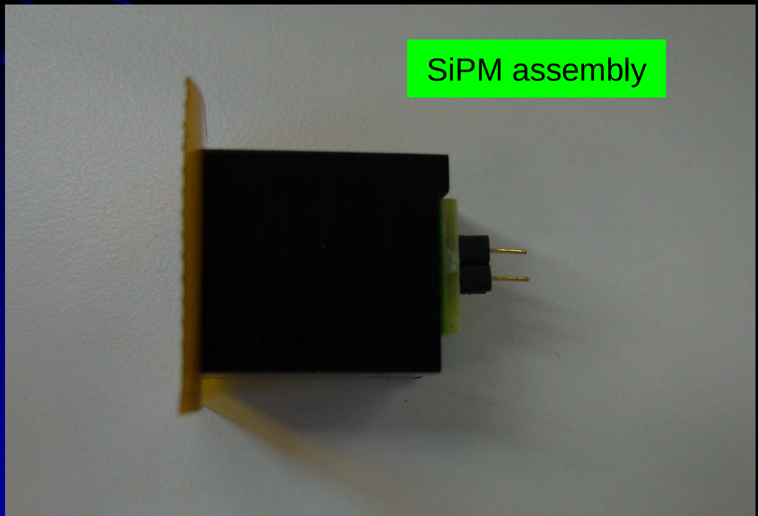


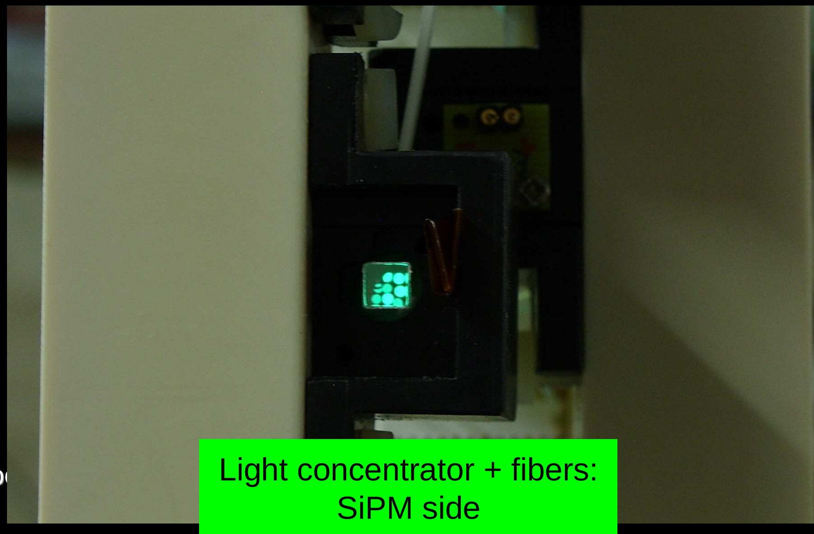


July 2011 Test Beam

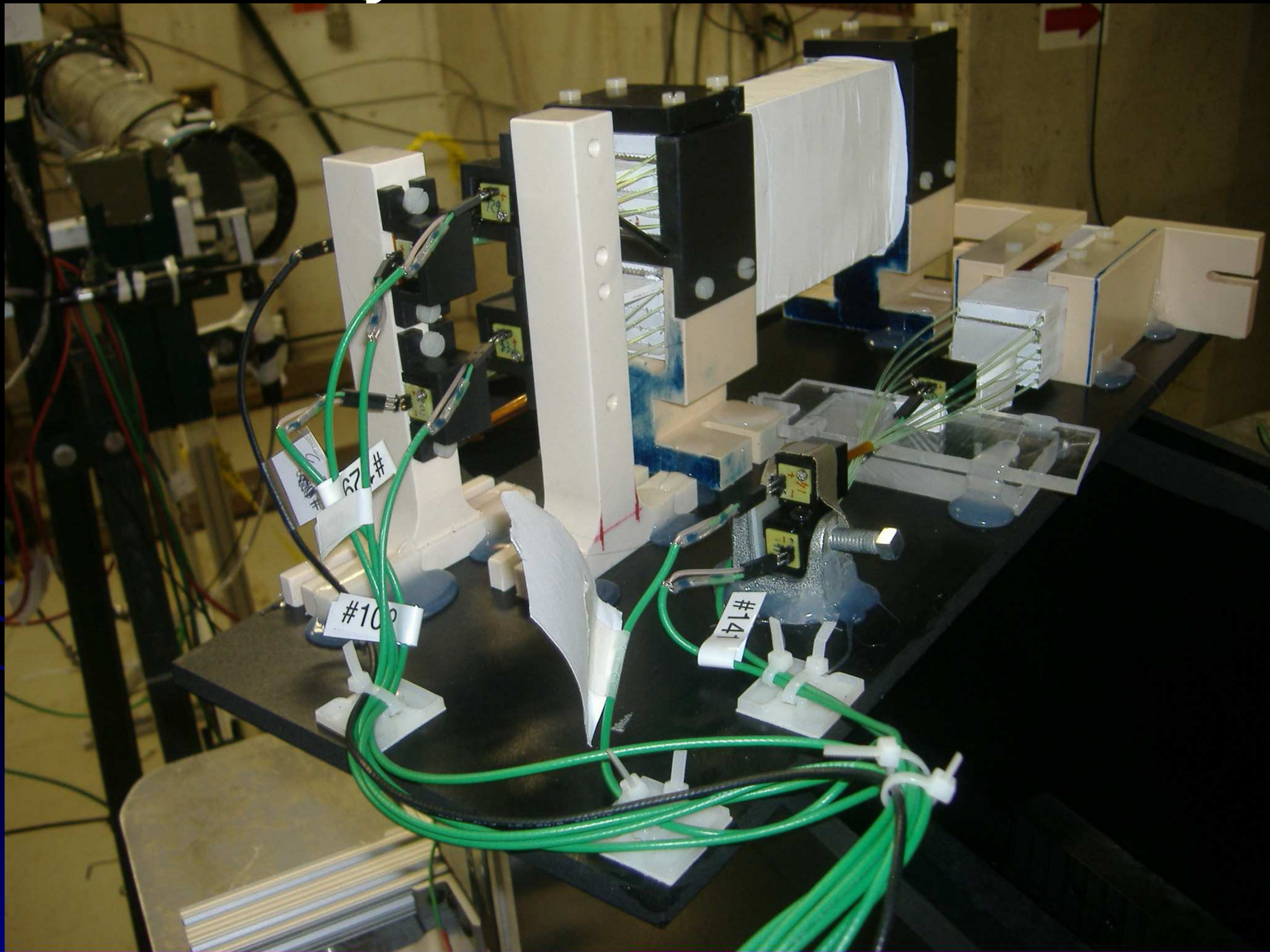








July 2011 Test Beam

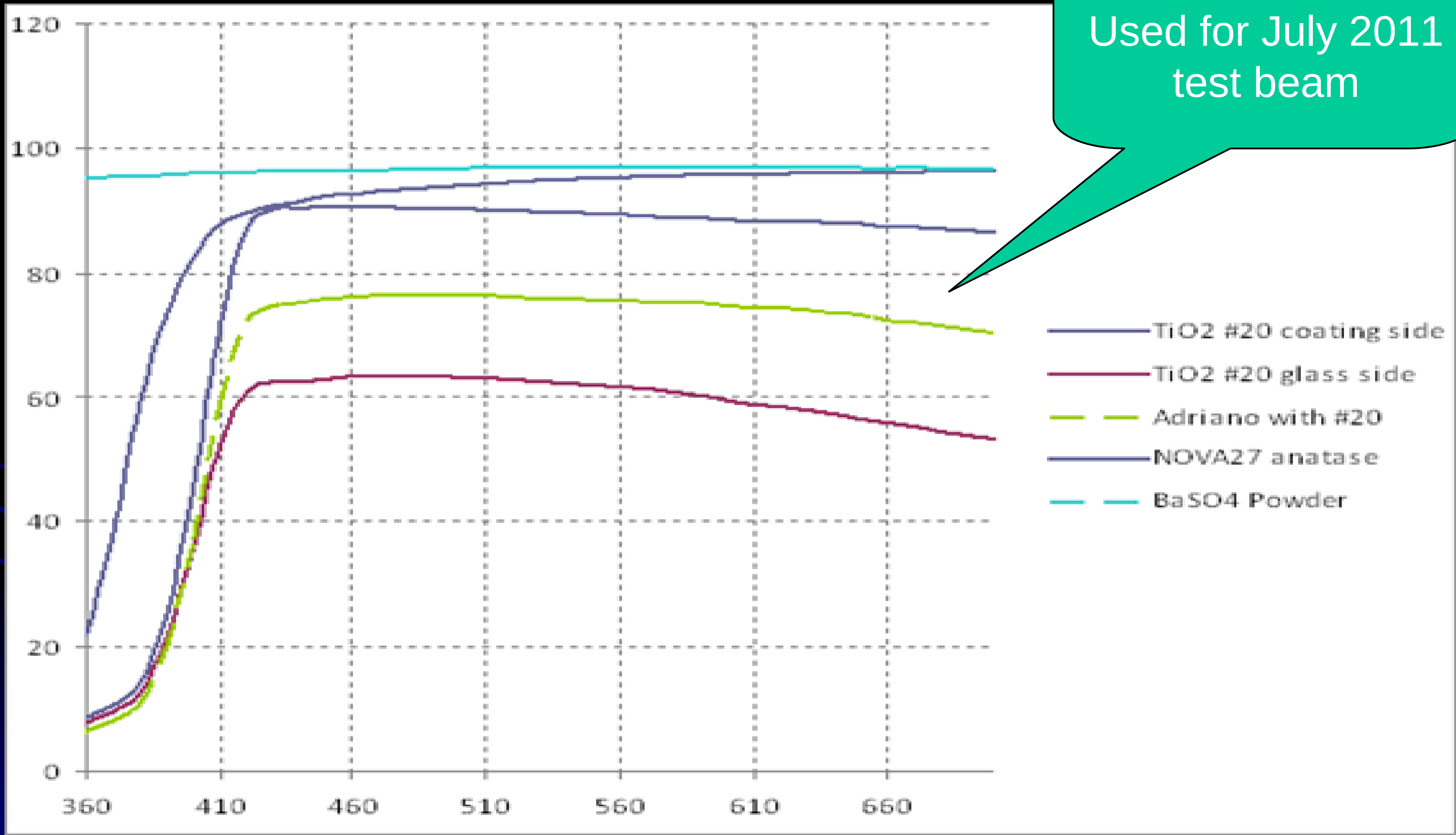


July 2011 Test Beam

A. Pla

Spectroscopy Measurements

Spectral reflectivity of various coatings

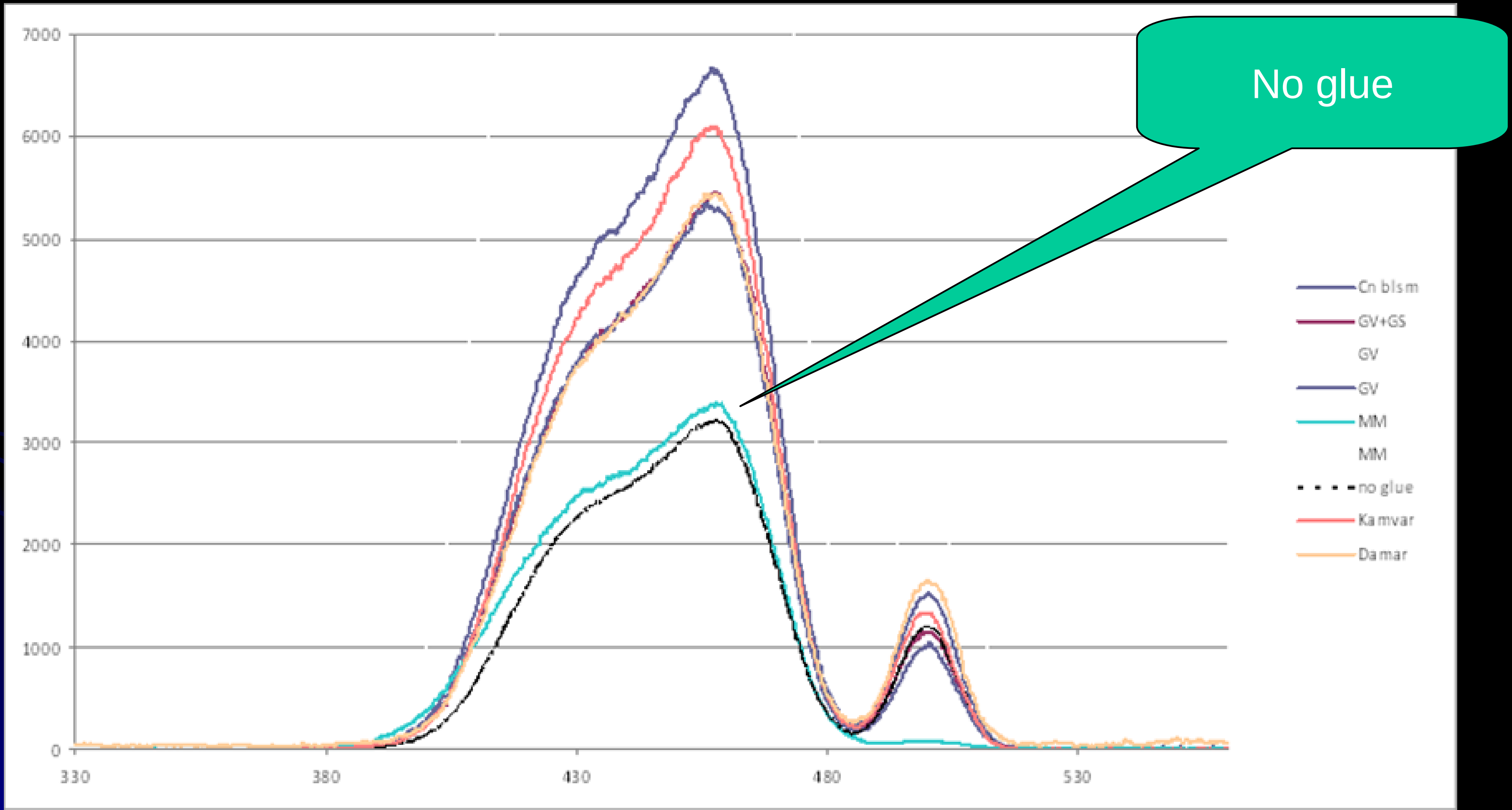


Used for July 2011 test beam

A. Pla

Spectroscopy Measurements

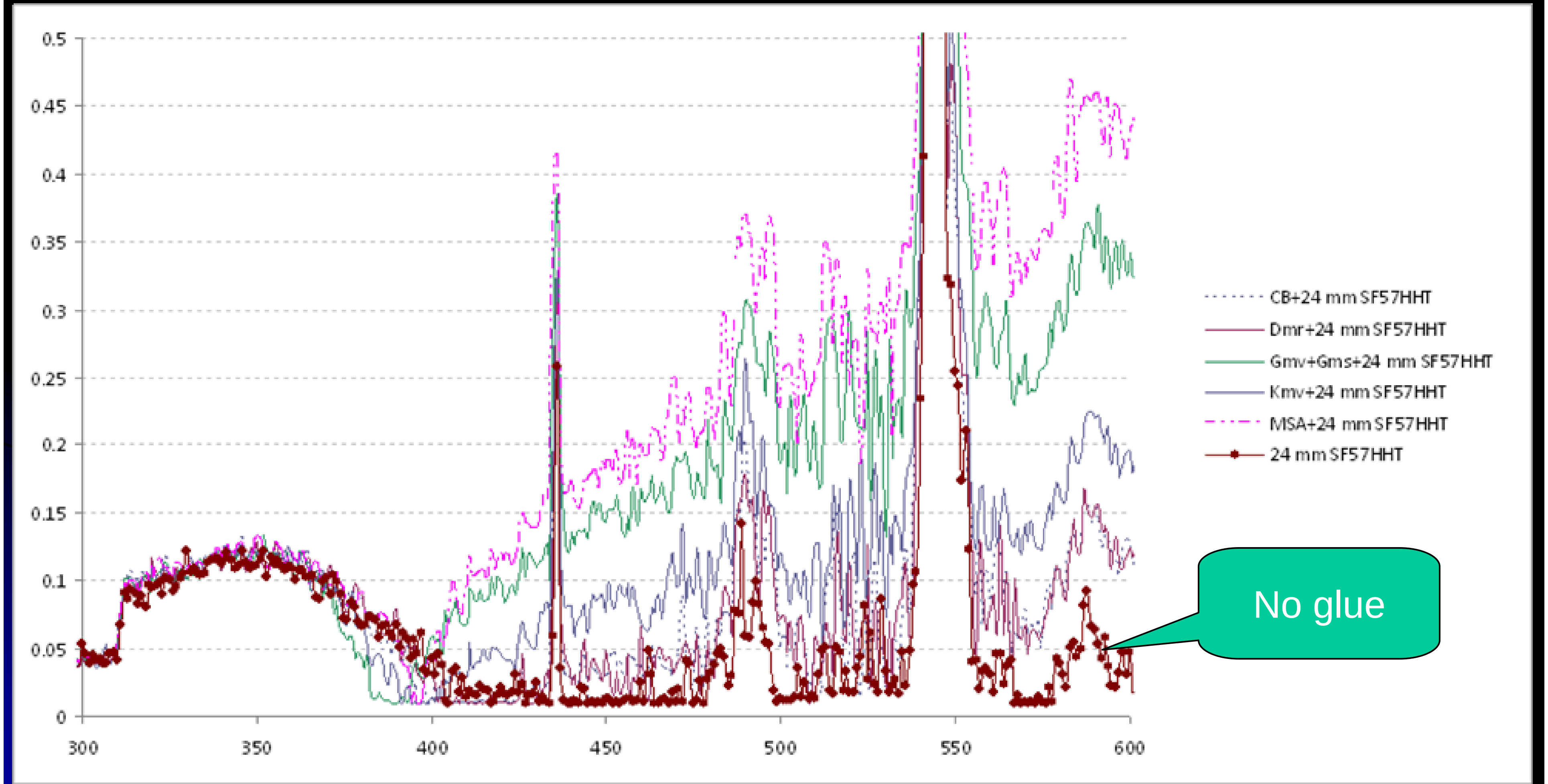
Spectral excitation curves of various optical glues



E. Piacentino

Spectroscopy Measurements

Spectral transmission curves of various optical glues+glass

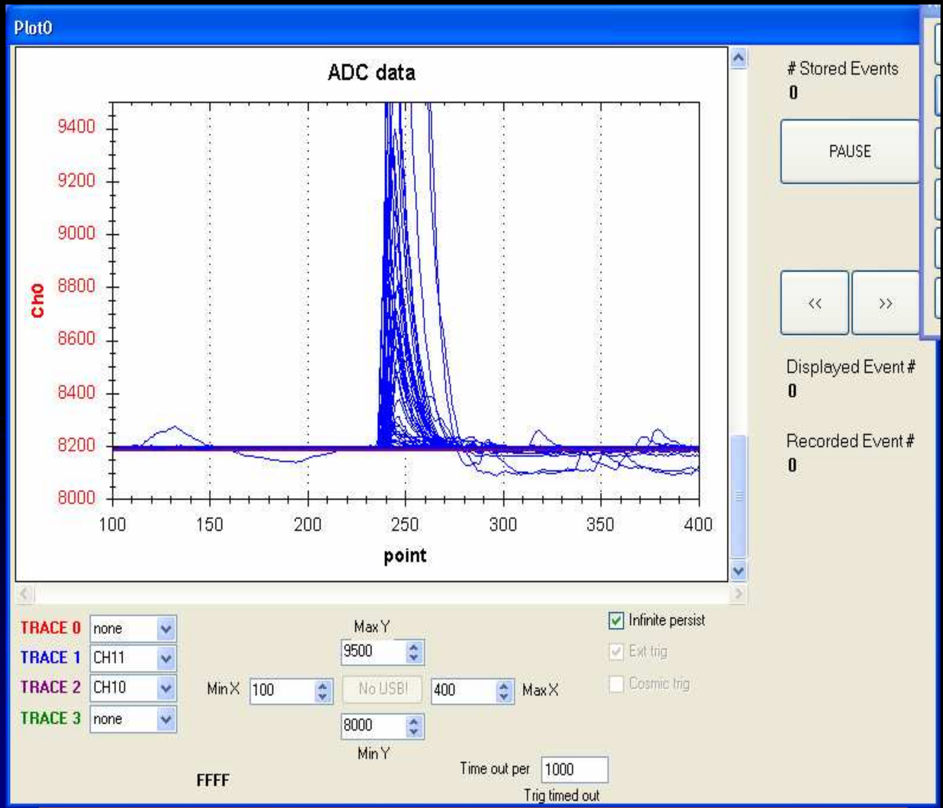


Configuration for Summer Tests

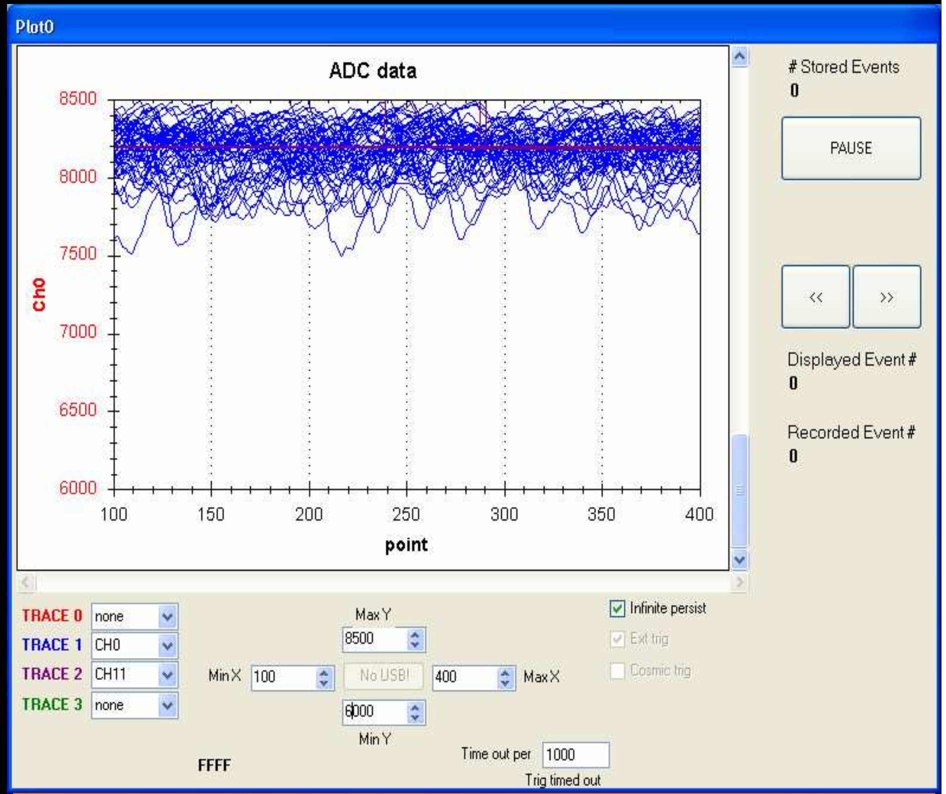
- 1 glass type: SF57HHT by Schott
- 2 slices fabrication techniques: cold machining and high temp. molding
- 3 WLS fibers: Y11 (1.2mm) & BCF92 (1.0, 1.2 mm)
- Several glues (mostly homemade)
- 3 photodetectors: 2 SiPM (2.8 round and 4.3x4.3 square) 1 PMT (P30CW5 with

Waveforms from TB4 DAQ: SiPM with light concentrator vs PMT

Muons beam



Direct coupling of WLS to PMT window

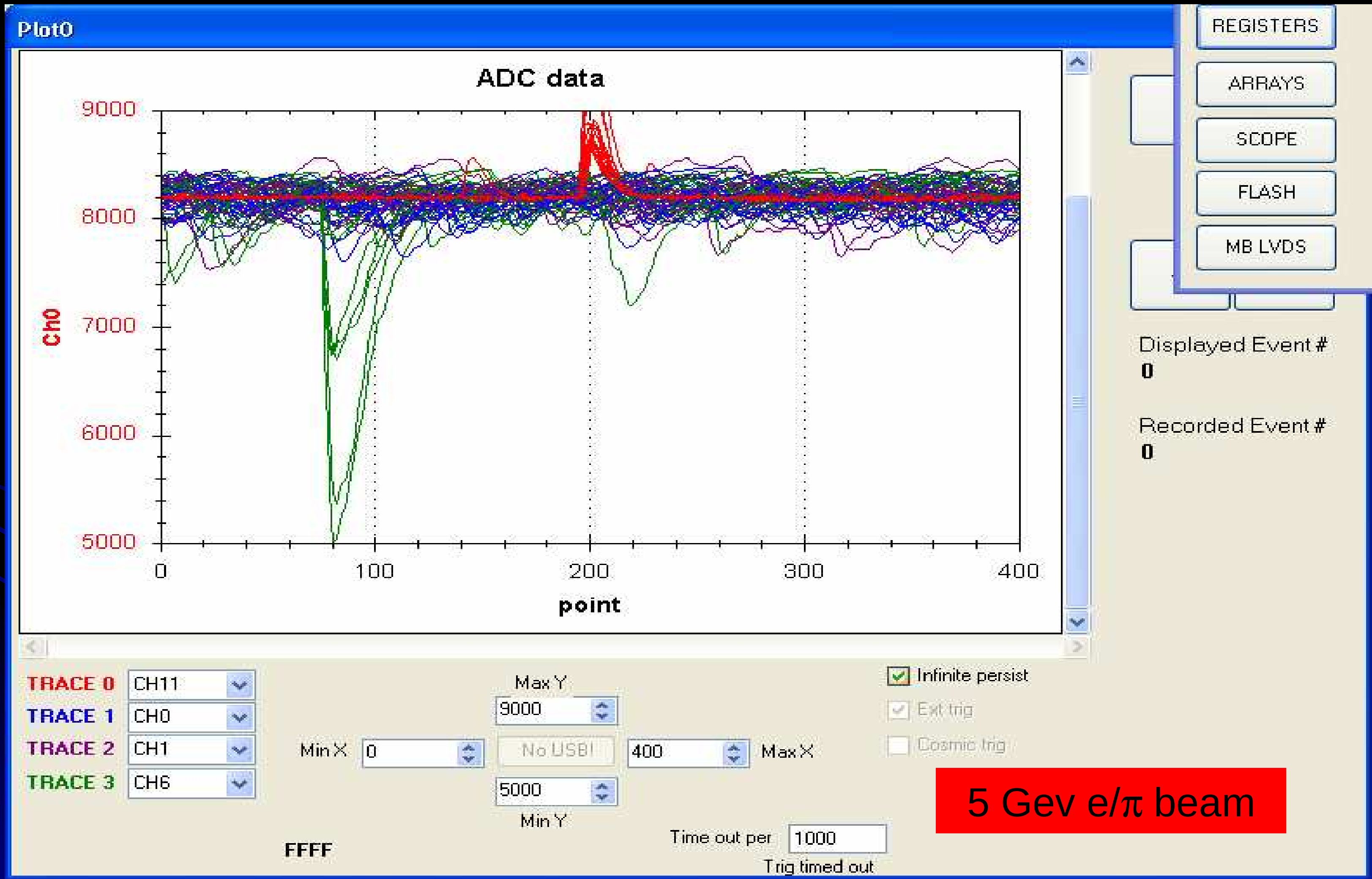


WLS to SiPM through a light concentrator

Waveforms from TB4 DAQ:

SiPM with INFN light concentrator (blue)

vs direct fiber readout (green)

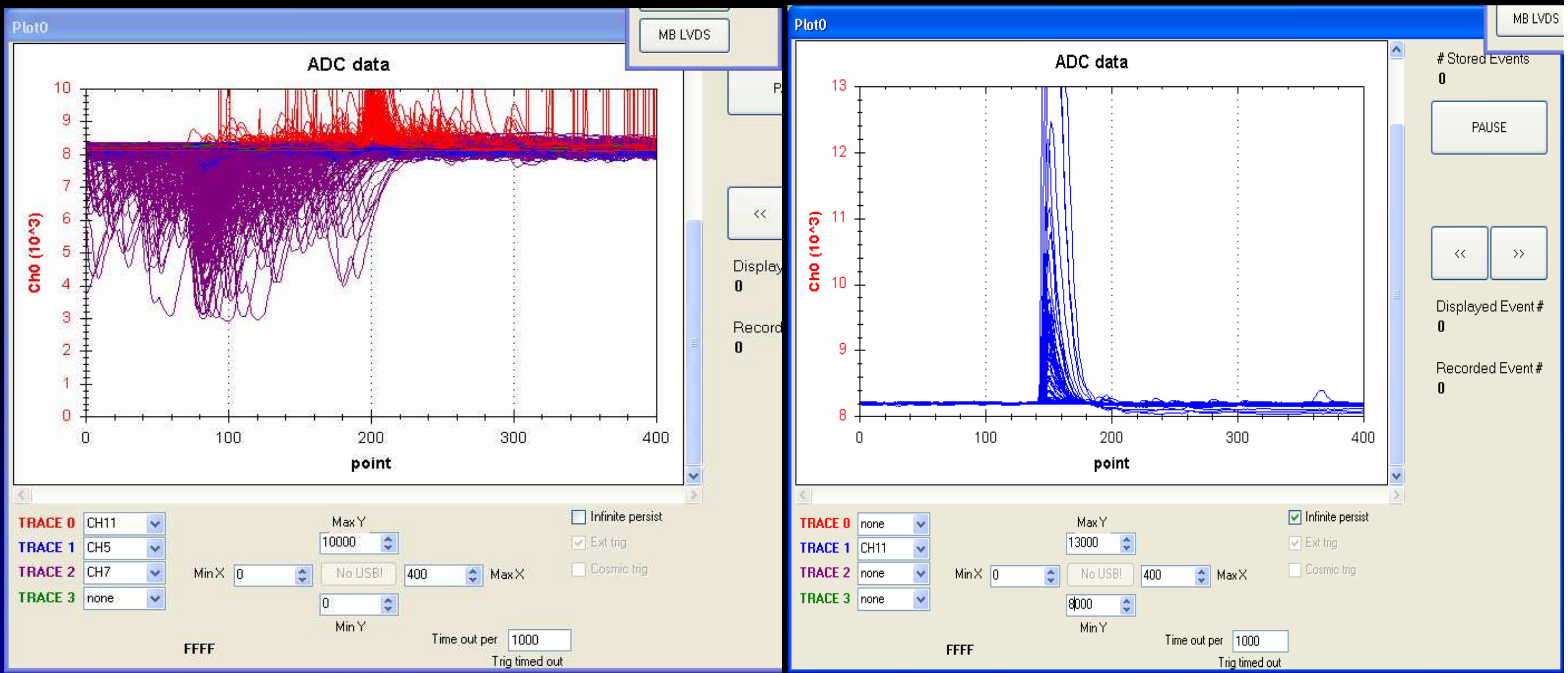


5 Gev e/π beam

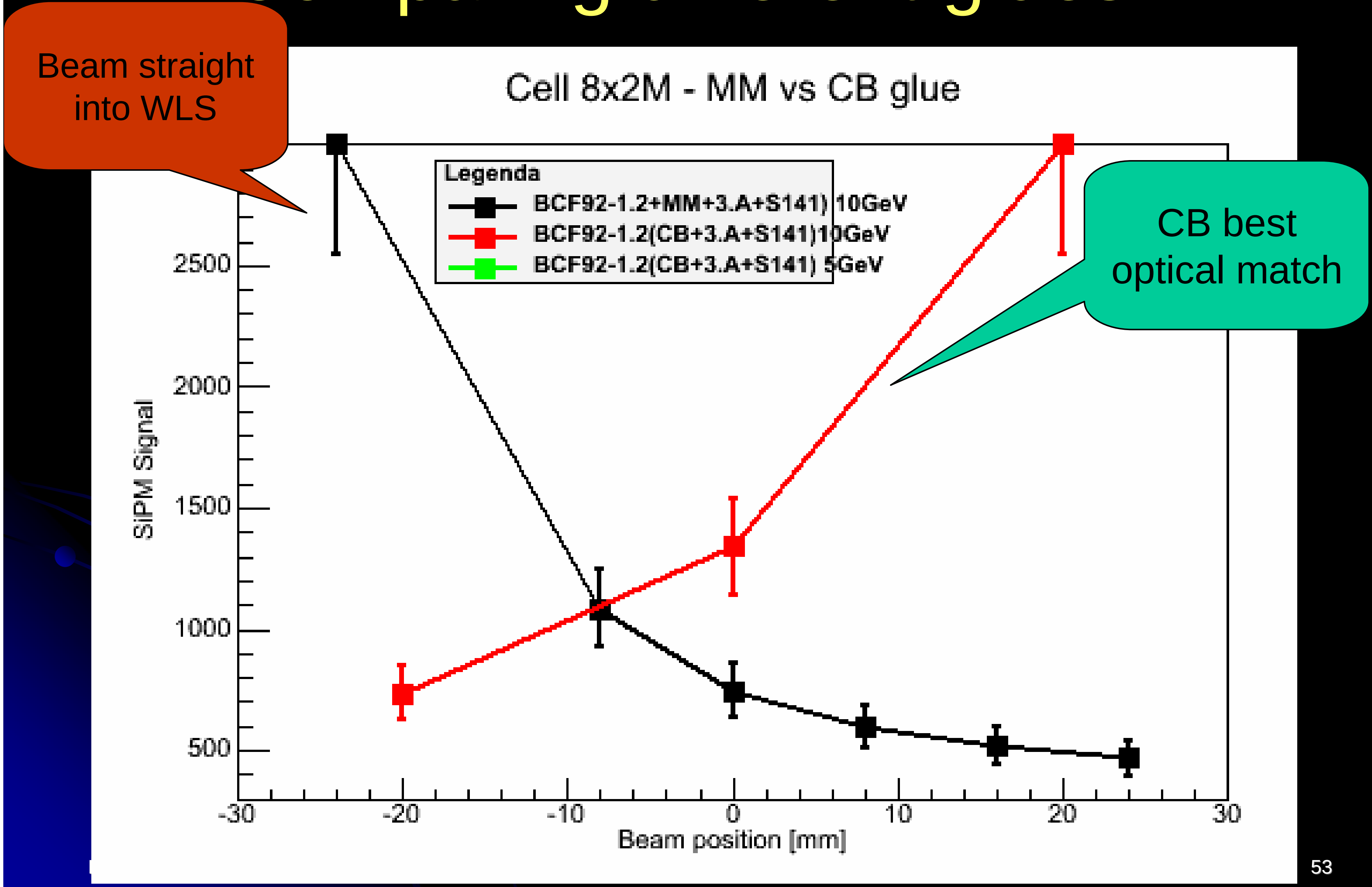
Waveforms from TB4 DAQ:

SiPM with W.C. light concentrator (by G. Sellberg) vs PMT

5 Gev e/π beam



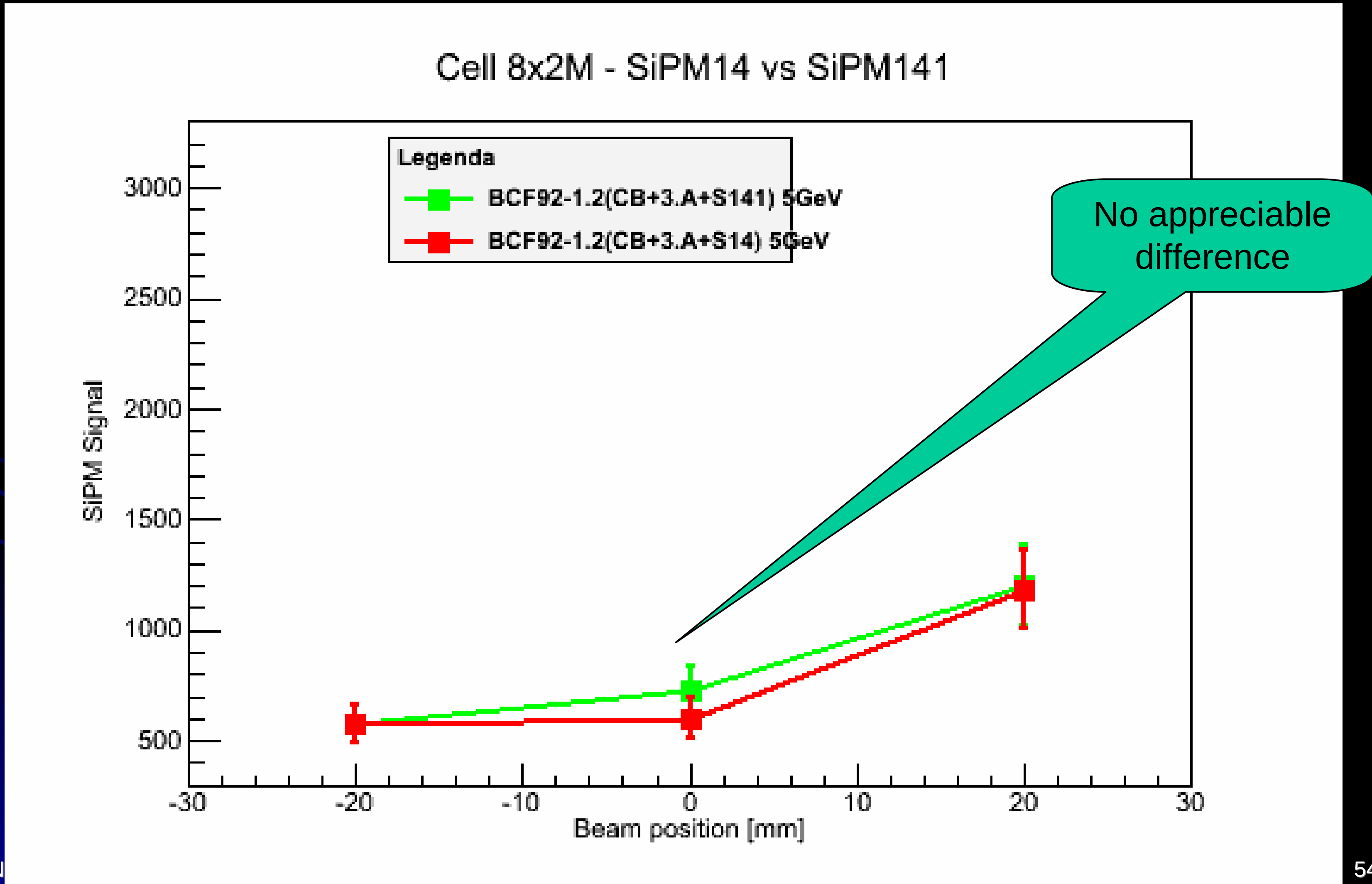
Comparing different glues



Preliminary results

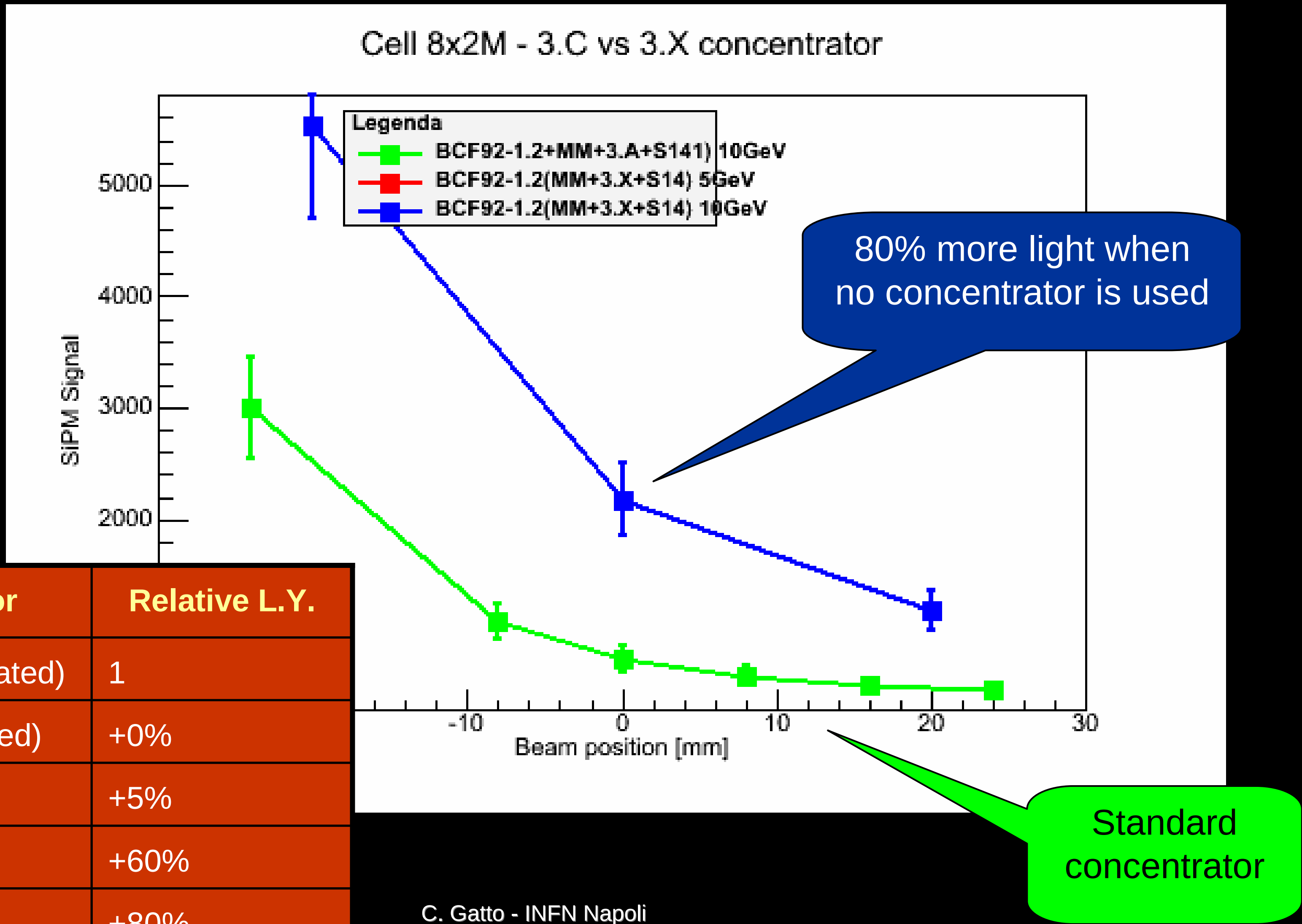
Comparing different SiPM

2.8 mm round vs 4x4mm^2 square



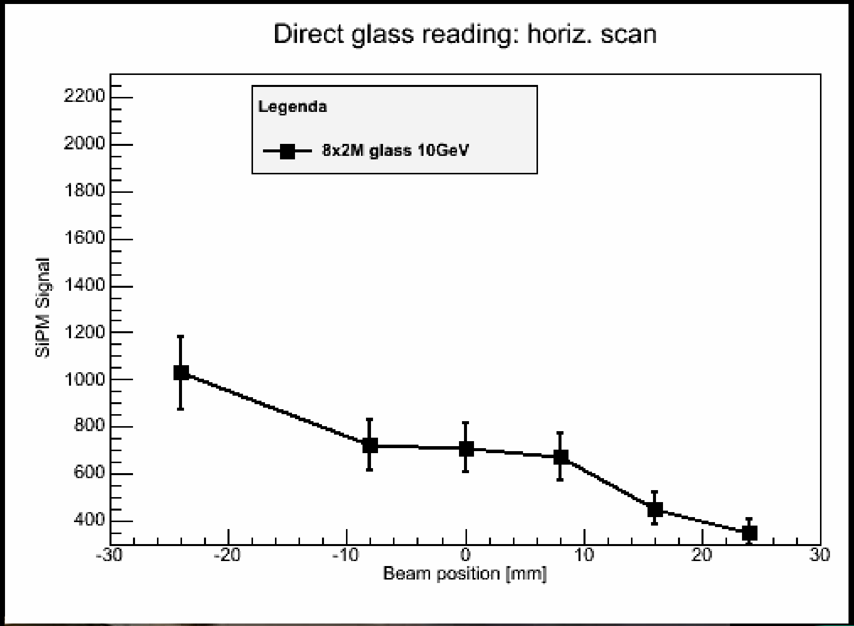
Preliminary results

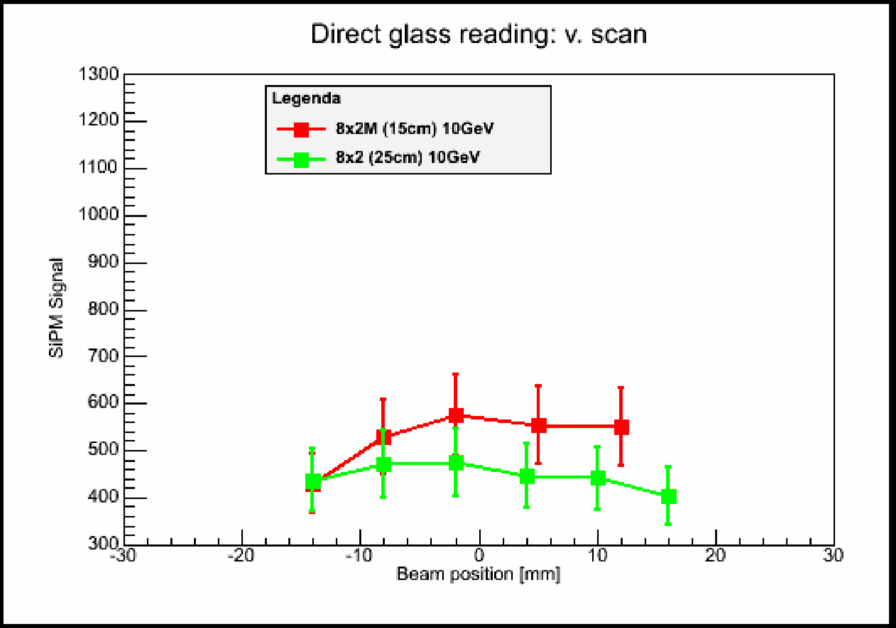
Comparing different Light Concentrators

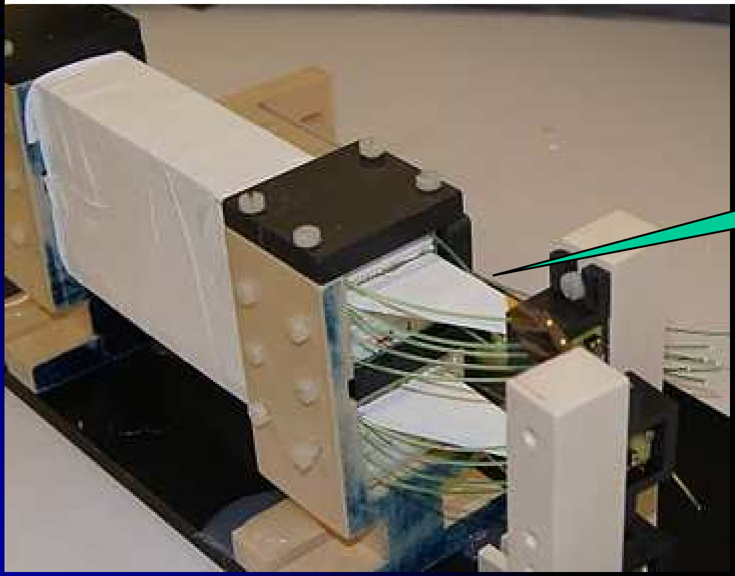


Concentrator	Relative L.Y.
Original (TiO_2 coated)	1
Original (Ag coated)	+0%
super polished	+5%
Winstone cone	+60%
none	+80%

Fiber Readout vs Direct Glass Readout







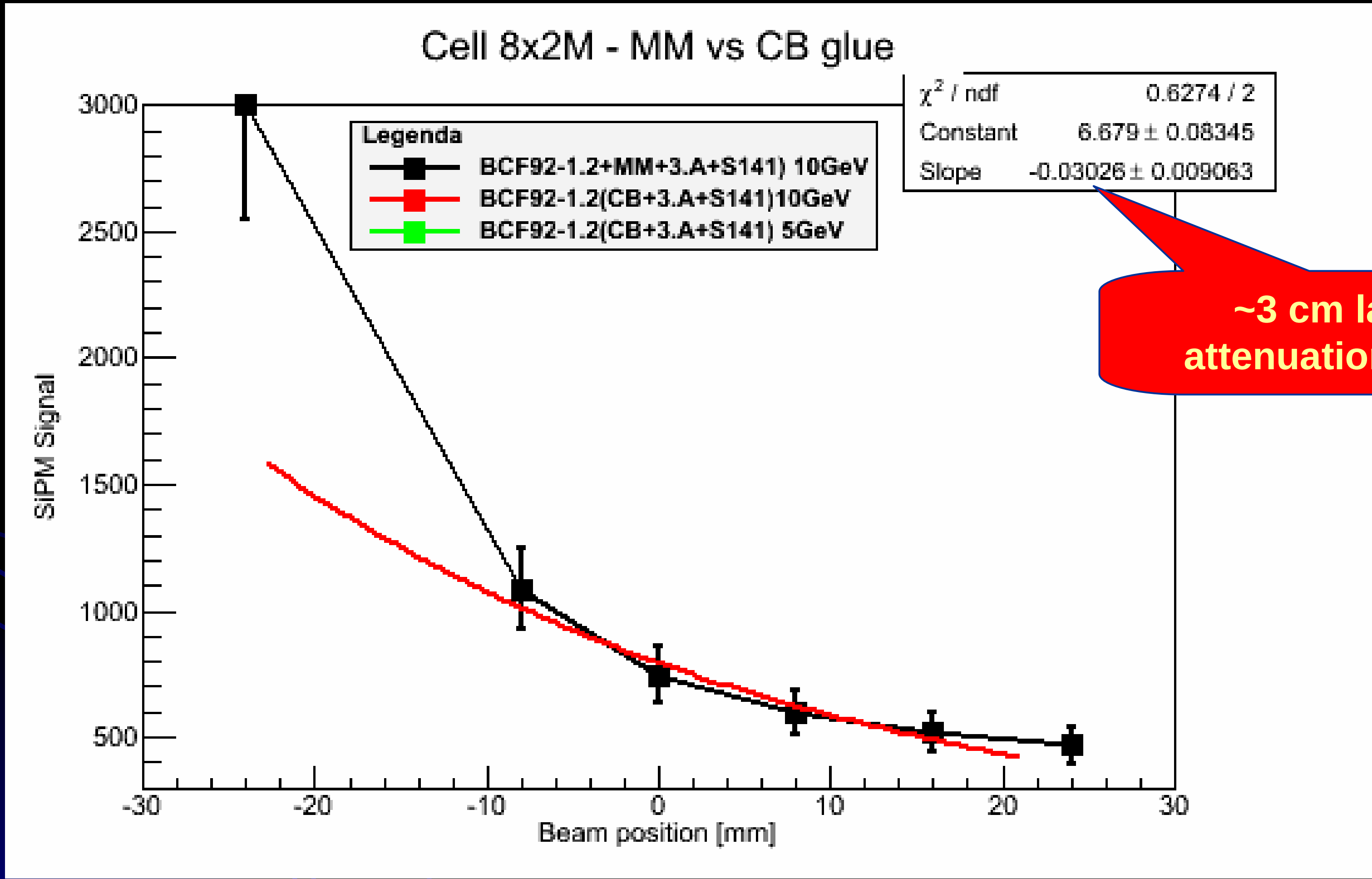
Only ~16% of Cerenkov light is collected

~73% more light collected by directly reading the glass

~2 cm longitudinal attenuation length

Preliminary results

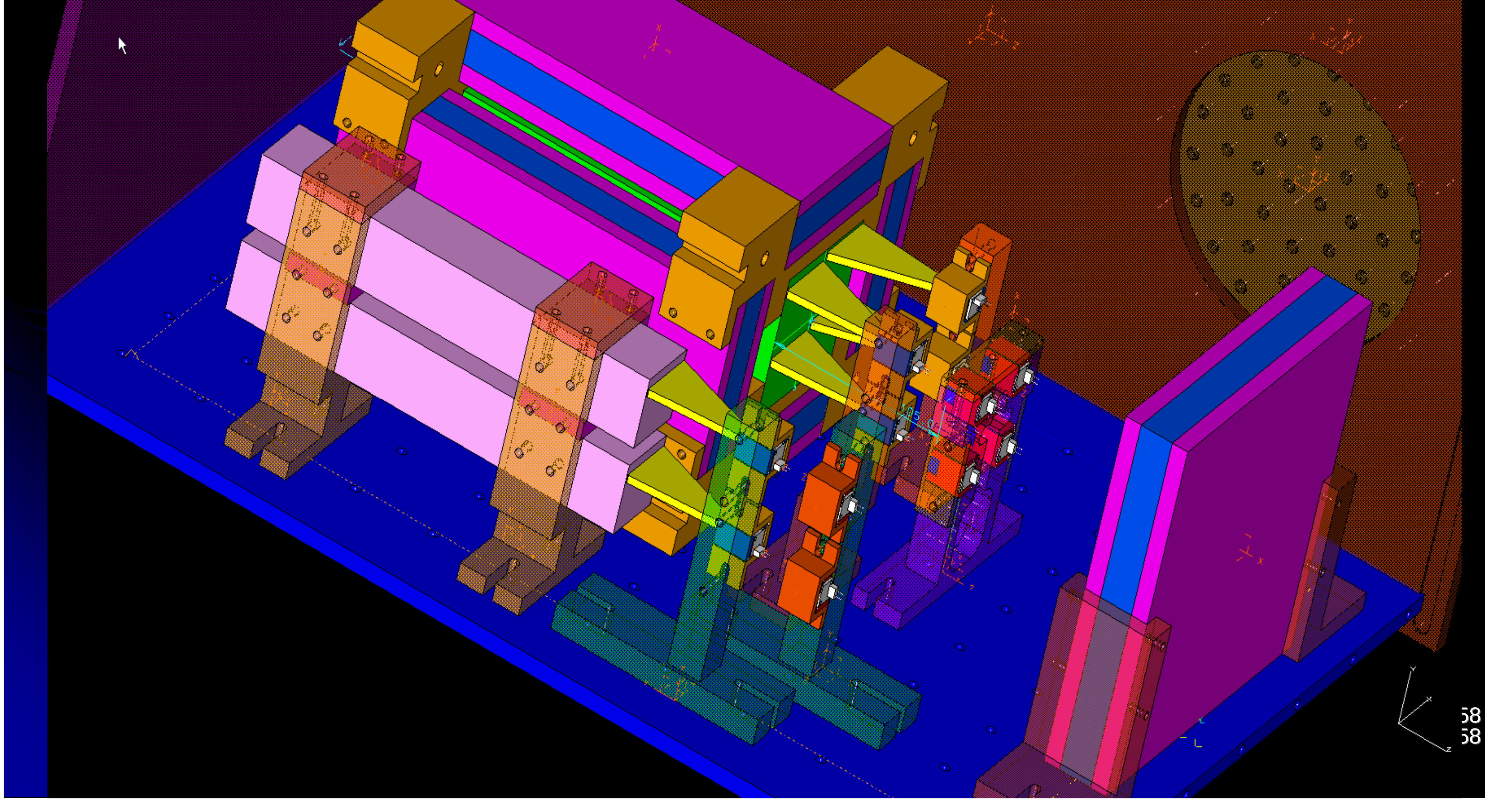
Horizontal Beam Scan



~3 cm lateral attenuation length

FTBF December 2011 Test Beam

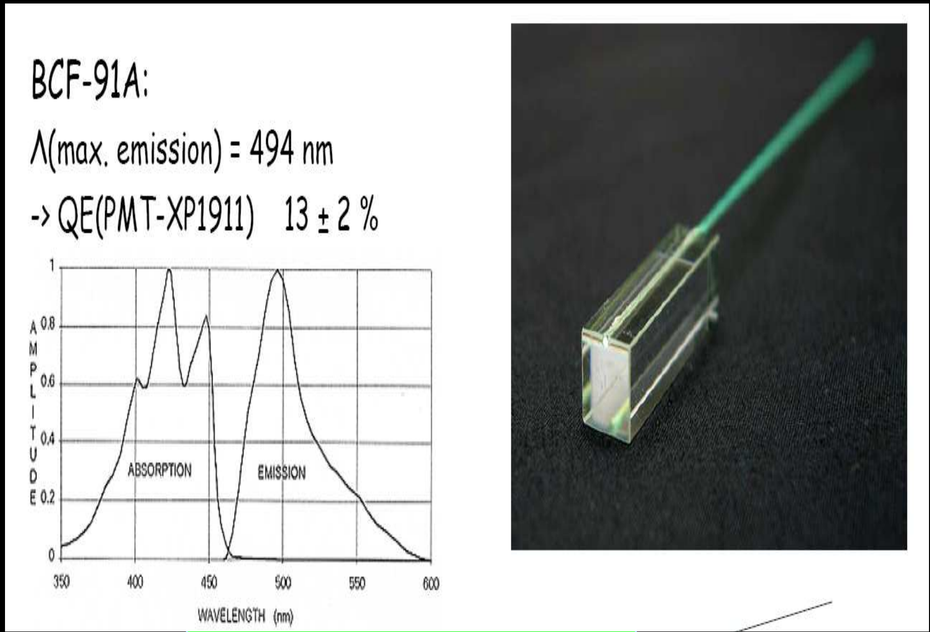
- Five complete cells (Cerenkov + Scintillation) + half cell L-BBH1 by Ohara
- Two layers of scintillator based tail catcher around the cells (FNAL)
- New SiPM with large dynamic range (IRST)



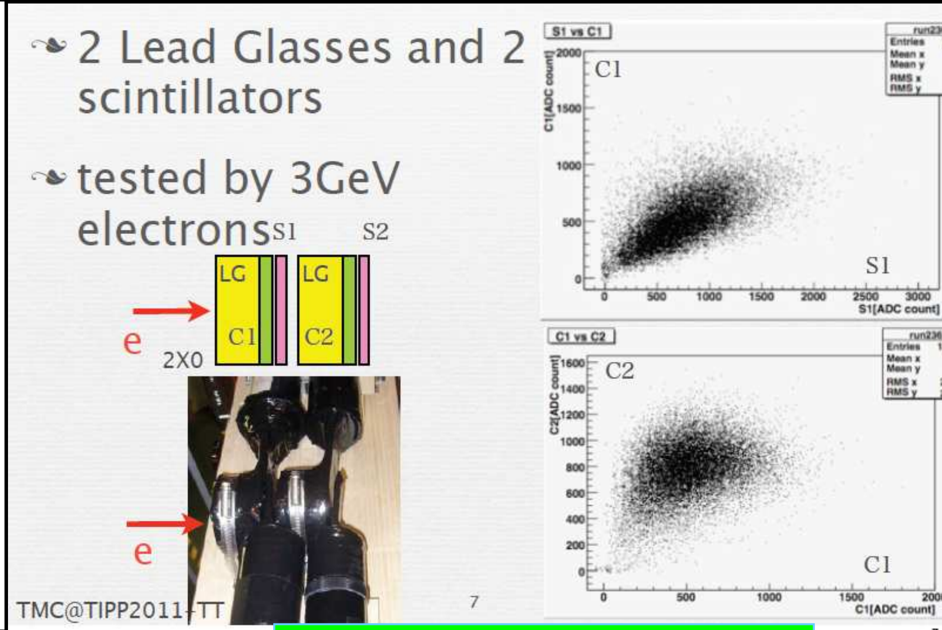
Summary of Preliminary Analysis of July 2011 Test Beam Data

- 8x2 WLS fiber layout with Y11 yield ~33 pe/GeV or 4.4 times 4^{th} Concept detector (expected 200-300 pe/GeV with 1.2 mm fibers)
- Lateral attenuation length 2-3 cm rather than expected 20 cm -> TiO2 coating has only ~75% reflectance and glass is not polished. Need a better solution (we are working on that)
- Coupling of fibers to SiPM is critical: air gap between light concentrator and SiPM more than halves the light yield
- Y11 fibers produce about 45% more light tha BCF92
- Different glues produce up to a factor of 2 in light yield
- Cold vs hot construction methods make no appreciable difference
- Direct reading from glass yield ~70% more light than reading fibers
- SiPM and PMT produce comparable signals. However, large noise from present version ofSiPm make them hard to use in low energy applications

Compare with Similar Works

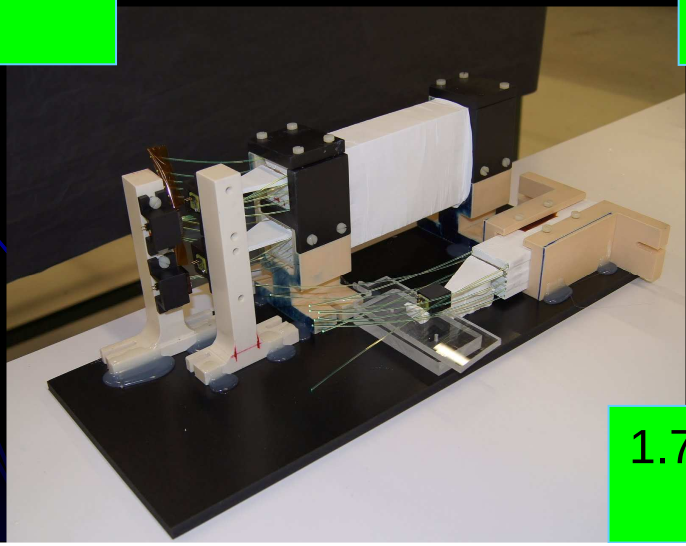


2.4 pe detected/cm
Desy (D)



0.2 pe detected/cm
Shinshu University (JP)

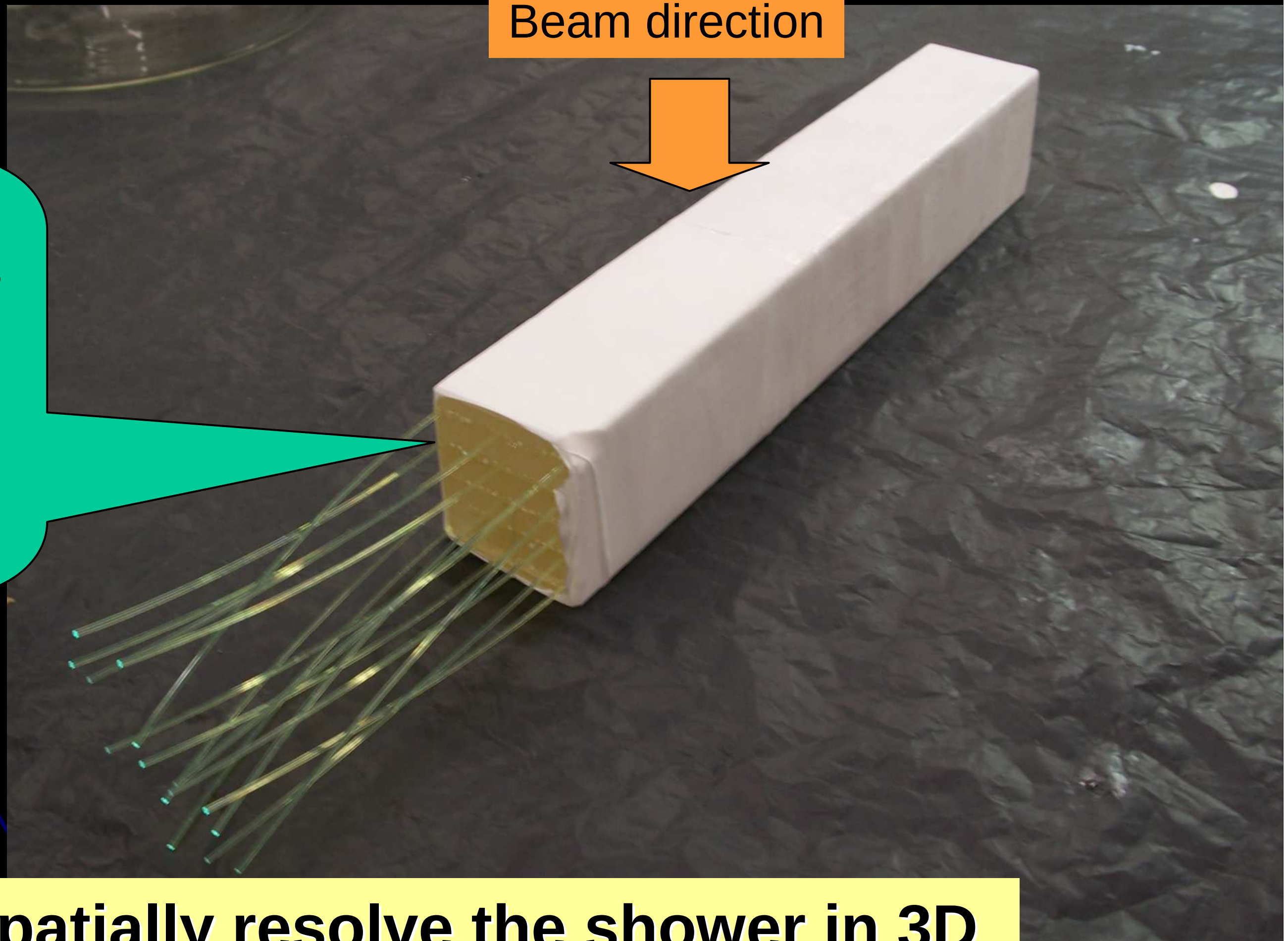
Cosmic ray measurements



1.7 pe detected/cm
ADRIANO

FTBF August 2011 Test Beam

- July 2011 prototype with PMT (no SiPM)
- ADRIANO for imaging calorimetry
- New layout with no TiO2 coating and aluminized scifi



WLS fibers interspersed with glass (1 coordinate only)

3 planes of fibers, 8mm apart

Goal is to spatially resolve the shower in 3D

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 glass
- 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)
- Current status:
  - Several rare earth oxides tested: Dy_2O_3 promising (next slide)
  - BiO glass OK (6.6 gr/cm^3), WO unsuccesful (need a very high temp furnace)

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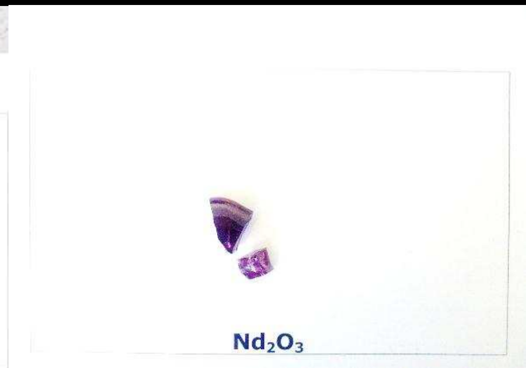
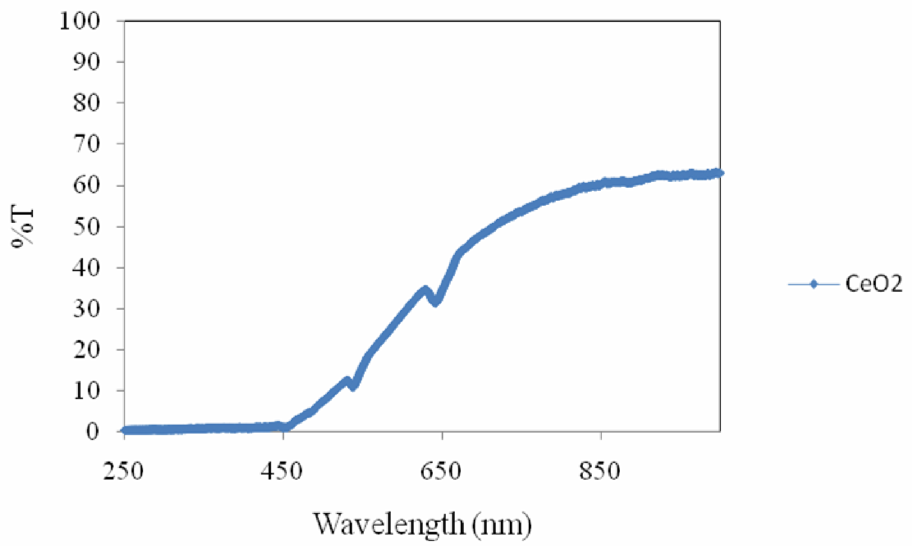
Rare Earth Heavy Glasses

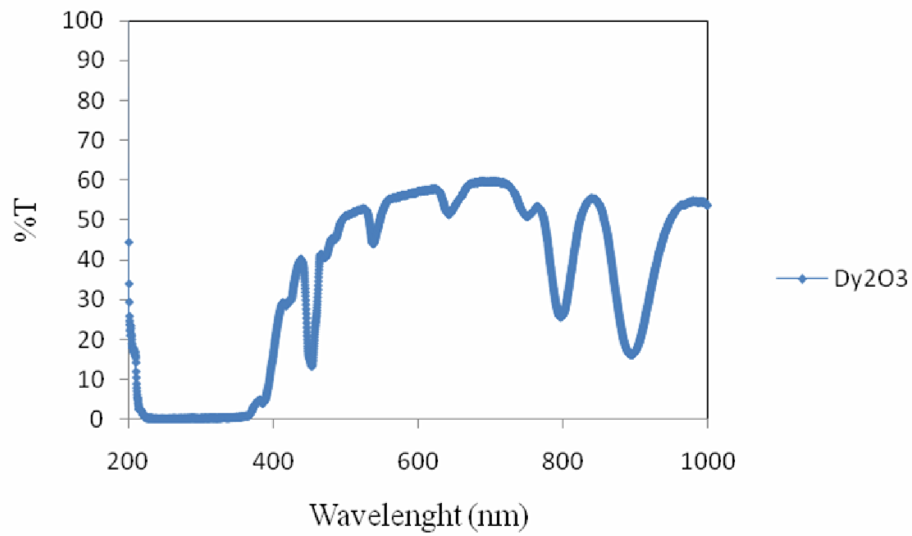
- Rare earths oxides + Ho_2O_3 + ZnO + P_2O_5+B_2O_3+SiO_2
- R.e. considered: CeO_2, Dy_2O_3, Nd_2O_3, Pr_6O_{11}, Er_2O_3

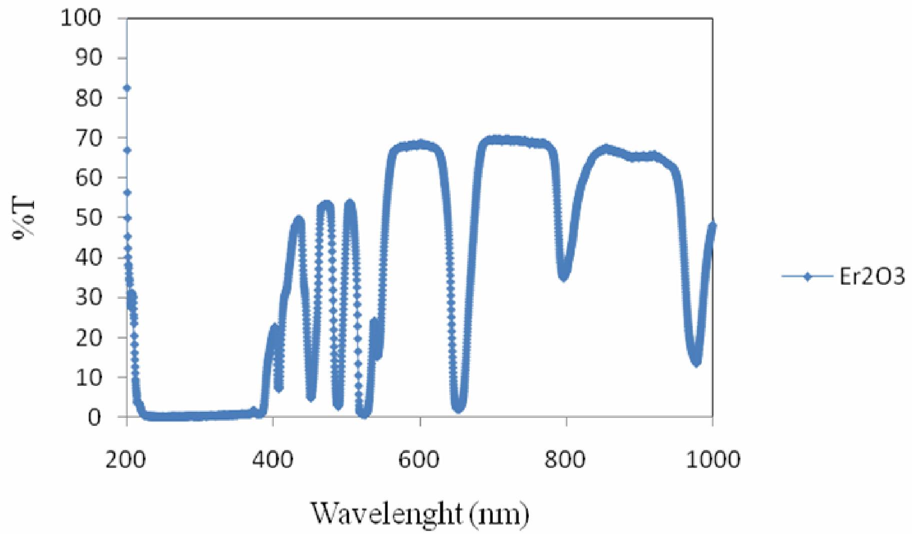


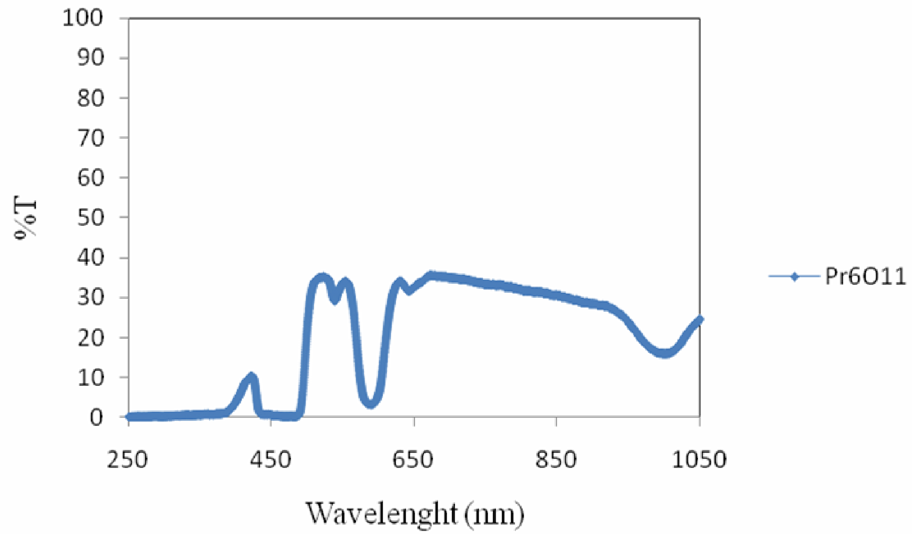
Composition	Density (g/cm^3)
CeO_2	3,3776
Pr_6O_{11}	3,7445
Dy_2O_3	3,8851
Er_2O_3	4,0690
Nd_2O_3	4,2441

Transmission Spectra









Department of Materials and Environmental Engineering

ADRIANO calorimetry in T1015 Collaboration

- Fermilab based T1015 collaboration was born in 2011
- It exploit new techniques based on heavy glass (no sampling calorimetry nor crystals)
- It covers R&D on a broad range of aspects related to high performance hadronic and EM calorimetry :
  - Production and characterization of large area SiPM
  - Custom FEE
  - Construction and tests of calorimeter prototypes
  - Total active multiple-readout calorimetry
  - Scintillating heavy glass for dual-readout homogeneous calorimetry
  - *ADRIANO* calorimetry
- It gathers 5 INFN institutions + Fermilab
- Material science and Ceramic Engineering groups are also participating
- It has been approved in 2010 and funded by INFN for the next 3 years, including several test beams at FNAL
- One fully working cosmic ray test stand at Fermilab
- Two cosmic ray test in preparation (Roma and Salerno)

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
	Giulia Broglia

Future Prospects

- 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 we will exploit:
  - 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
- Ohara sponsorship/partership for bismuth optical glass (6.6 gr/cm3) in progress: two strips (total 1.4 Kg) are being sent at no

Conclusions

- The novel *ADRIANO* dual-readout technique has been presented along with preliminary results from first test beam at FTBF
- Full simulations and studies are well advanced
- Results from recent test beams prove that Cerenkov light readout from heavy glasses with WLS is feasible: **however, the devil is in the details**
- R&D of several ADRIANO prototypes 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

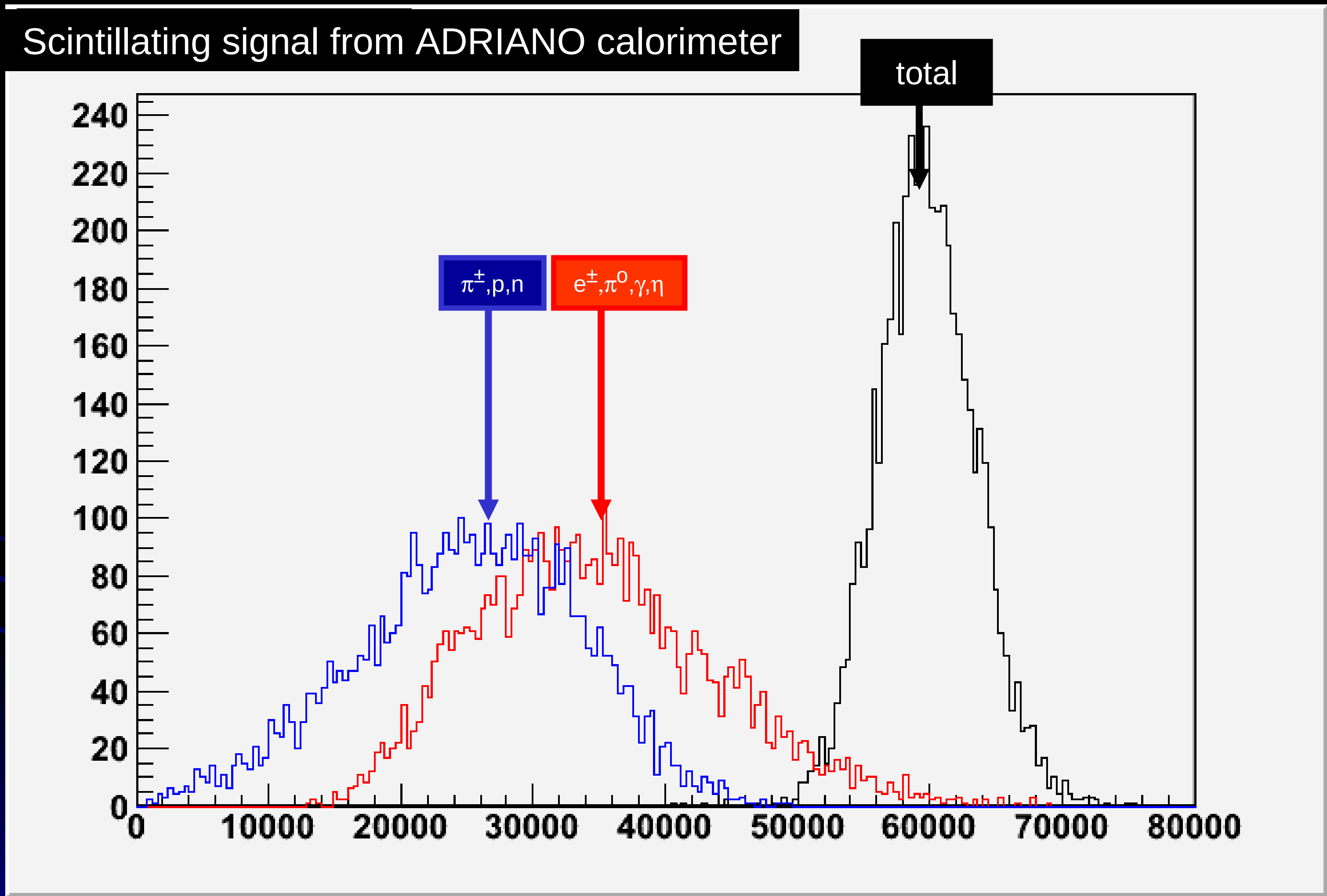
Special Thanks

... go to Eileen Hahn and Anna Pla for their fantastic contribution to the success of July and August test beams

Backup Slides

40 Gev pions

The major source of fluctuations: *fem*

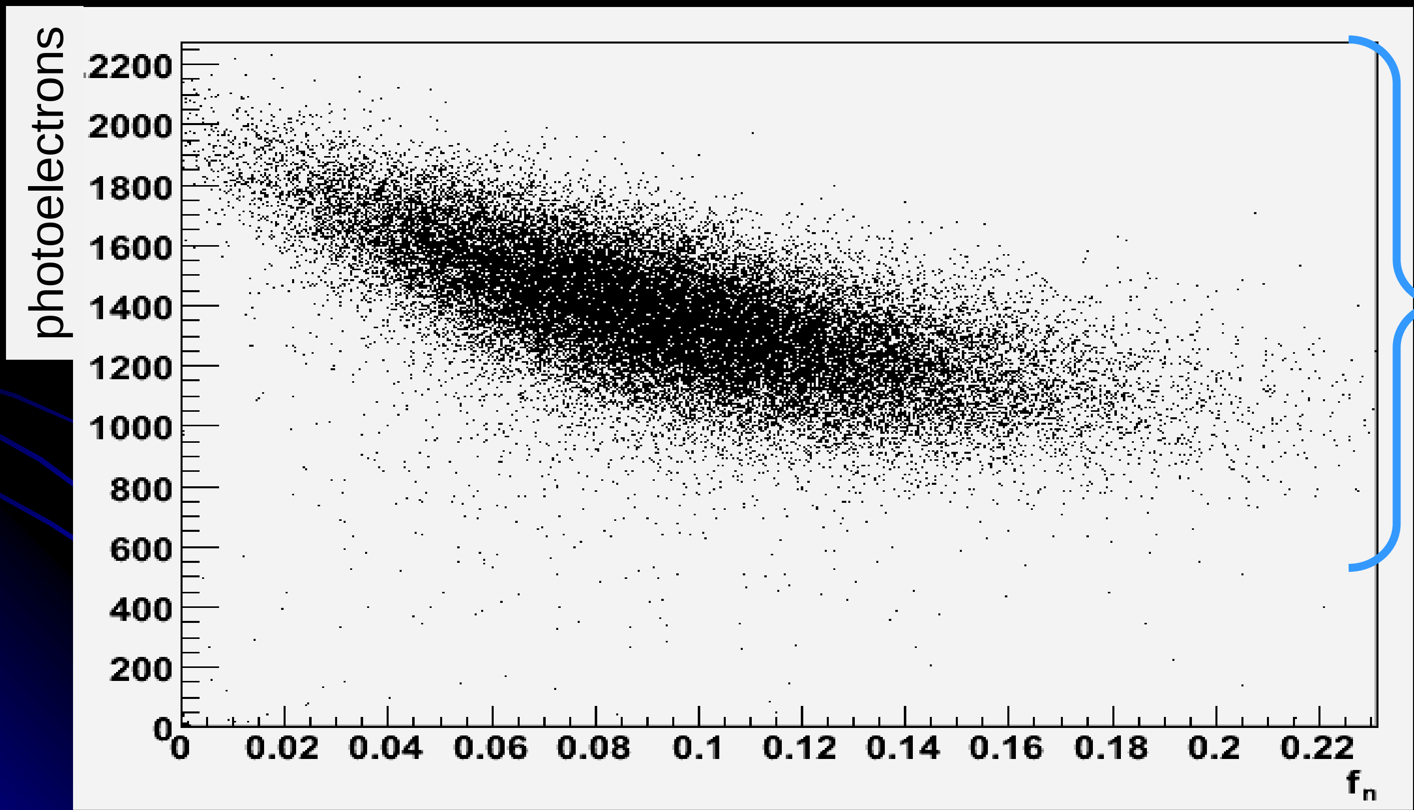


ILCRoot simulation

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

$$\begin{cases} E_S = \left[fem + \dfrac{(1 - fem)}{\eta_S} \right] \cdot E_{HCAL} \\ E_C = \left[fem + \dfrac{(1 - fem)}{\eta_C} \right] \cdot E_{HCAL} \end{cases} \qquad \left(\eta_S = \left(\frac{e}{h}\right)_s \quad ; \quad \eta_C = \left(\frac{e}{h}\right)_C \right)$$

fem is:

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

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

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

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

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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

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

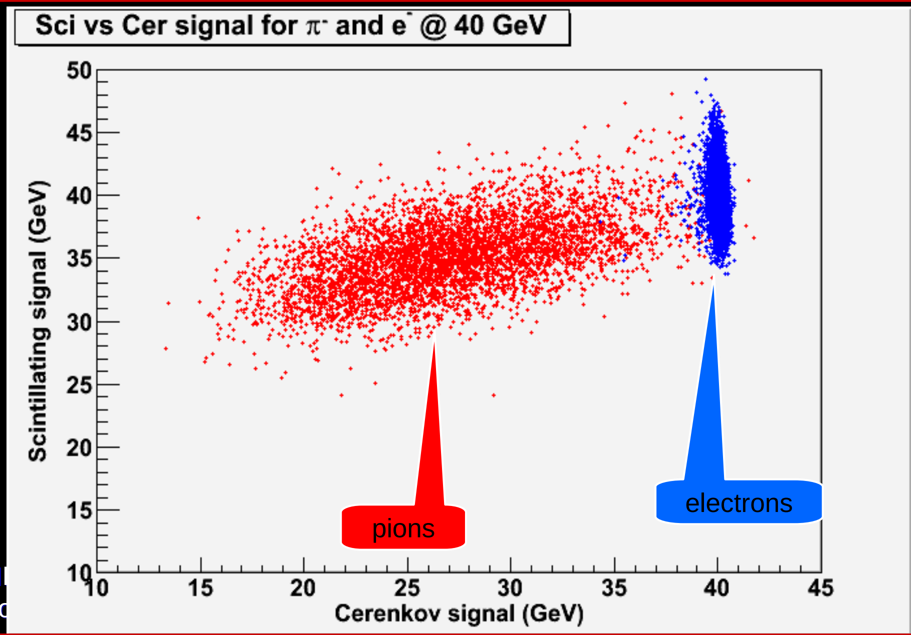
- Final calibration with pions:

  minimize

Step 2

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

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

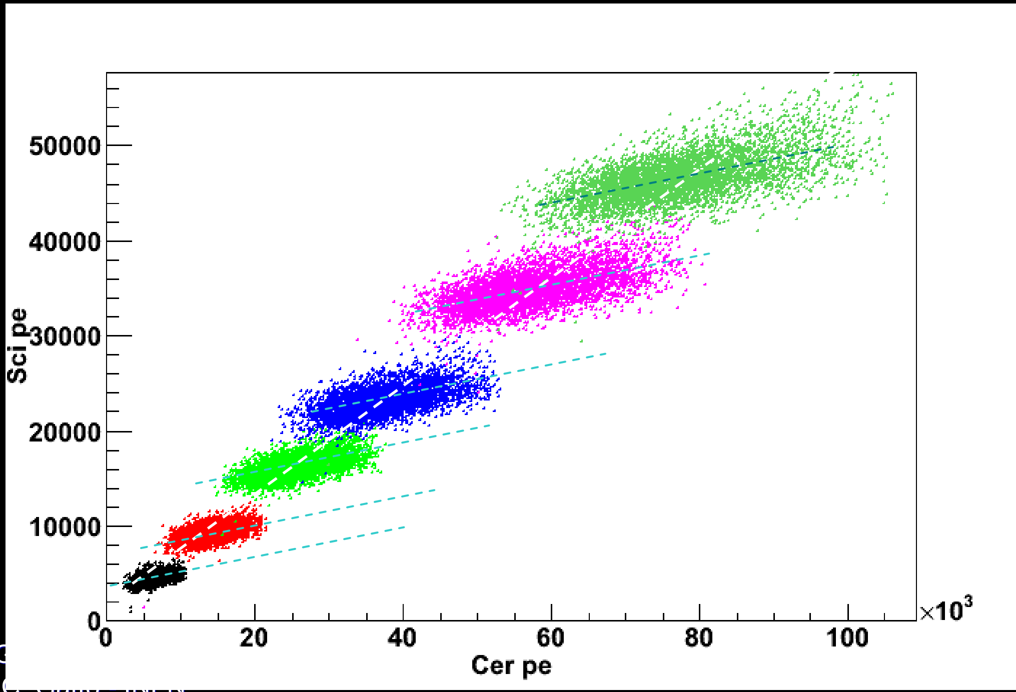


Calibration à la TWICE

- 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

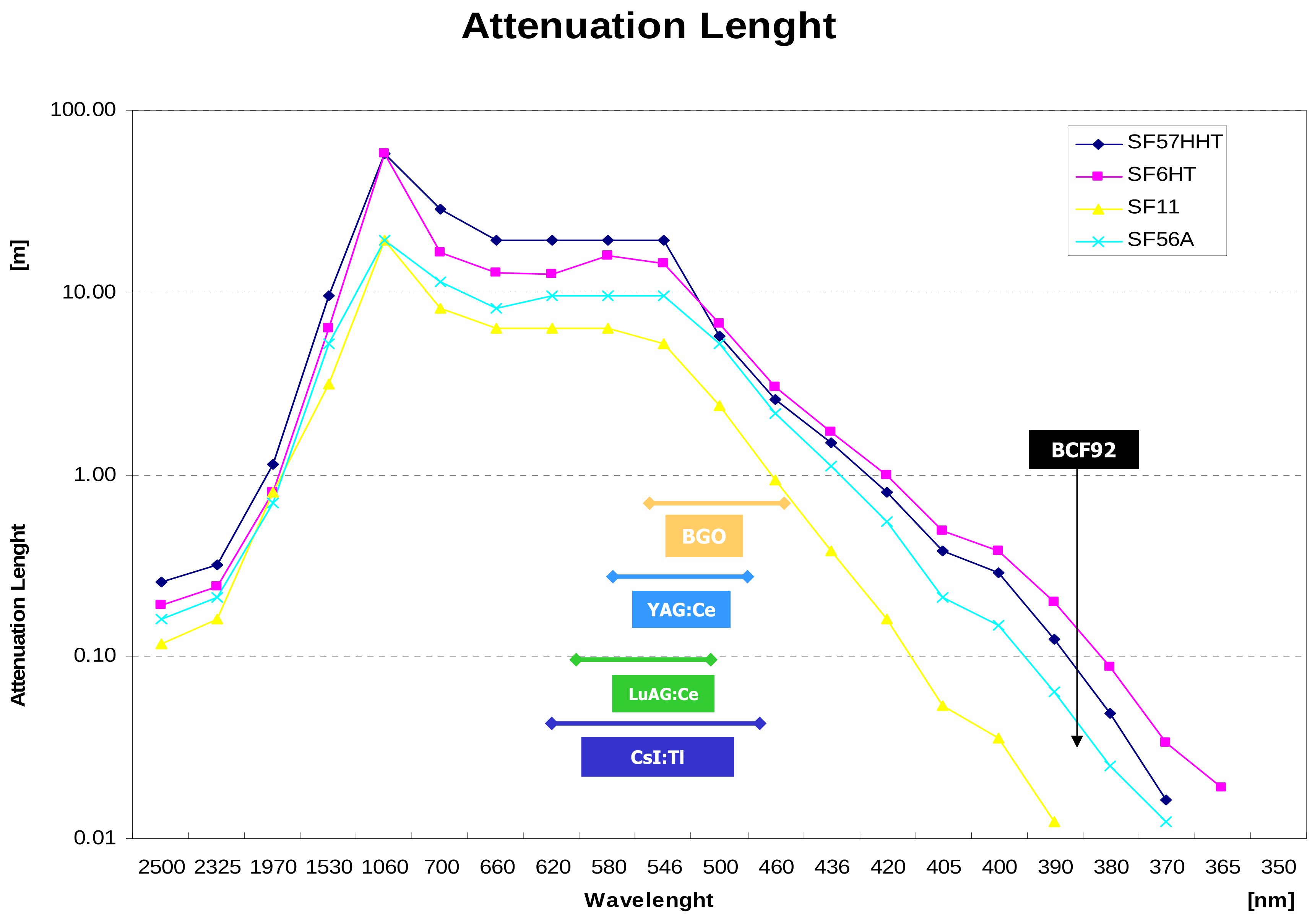


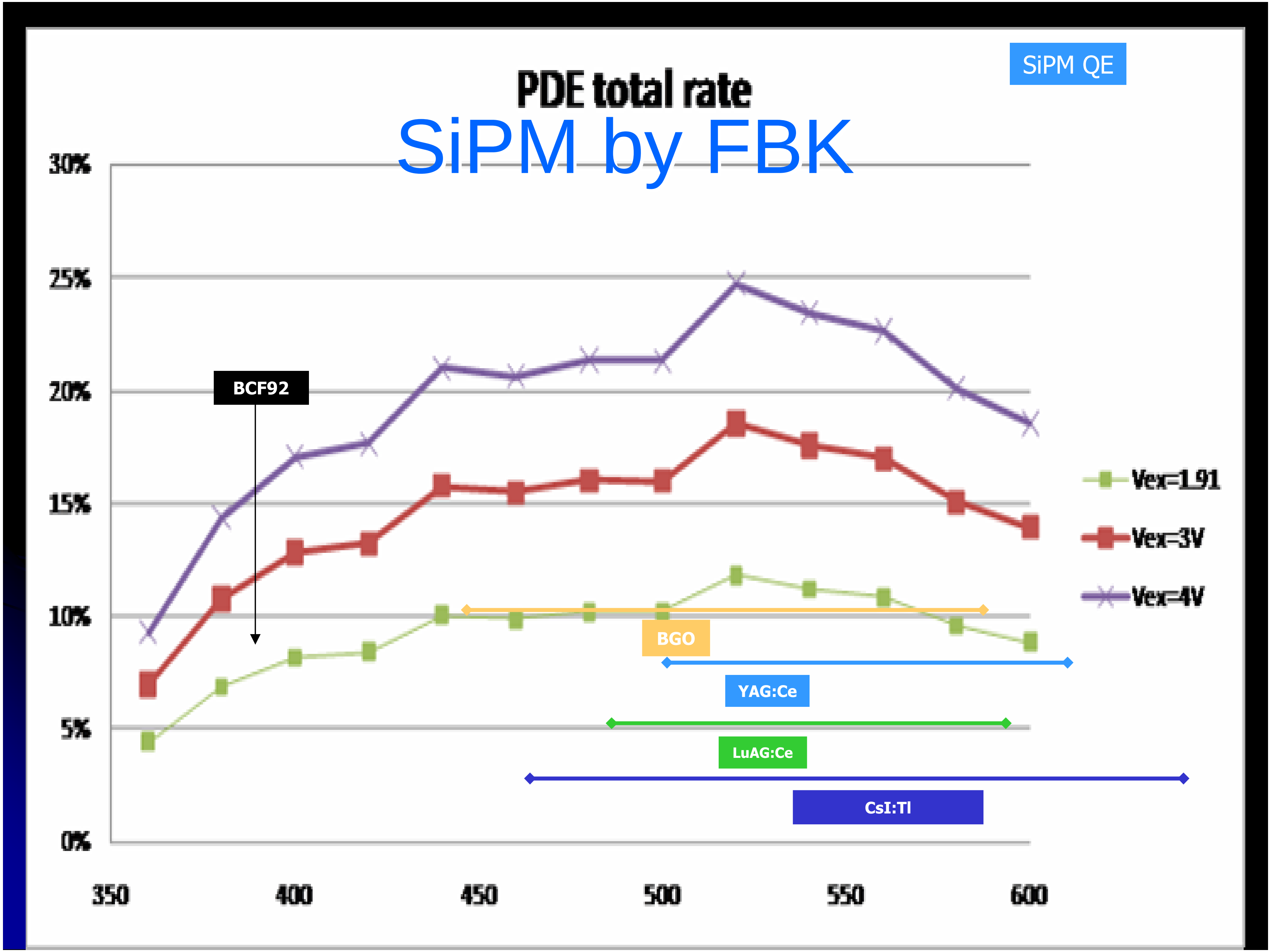
$$\beta = \frac{\sum_1^n (\hat{Q}_i/E_i)(\hat{S}_i/E_i) - 1/n \sum_1^n (\hat{Q}_i/E_i) \sum_1^n (\hat{S}_i/E_i)}{\sum_1^n (\hat{Q}_i/E_i)^2 - 1/n (\sum_1^n \hat{Q}_i/E_i)^2}$$

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

ILCRoot simulation

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

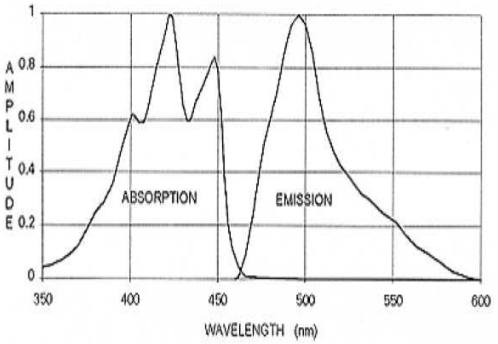
Reading Heavy Glass light using WLS Fibers: Desy technique

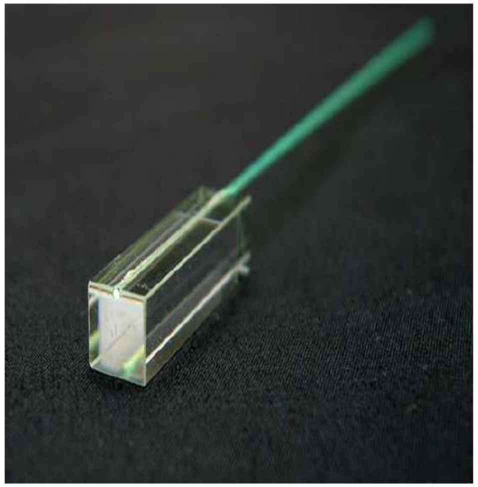
http://www-zeuthen.desy.de/lcdet/Feb_05_WS/talks/rd_lcdet_sim.pdf

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

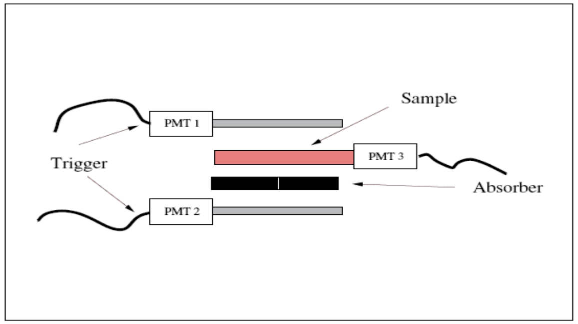
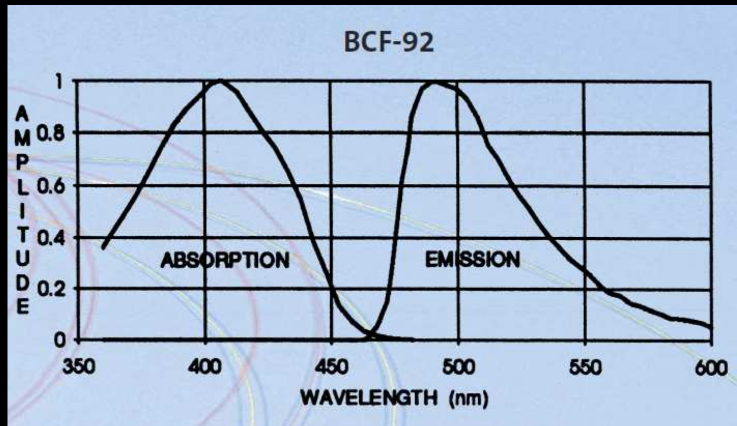


Figure 3.1: *Cosmic Telescope.*



R. Dollan