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ADRIANO Calorimeter Performance Simulations

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LCWS2015

3 Novembre 2015

Dual-Readout Technique

- The Dual-Readout is a calorimetric technique based on the simultaneous measurement of two different signals from the same shower and reflecting two different physics mechanisms.

- This technique has been proposed to eliminate the factors that limit the performance of hadron calorimeters such as electromagnetic fraction fluctuations in the shower development.

- By comparing signals generated by the Cerenkov and the scintillation lights, it is possible to determine the electromagnetic shower fraction on an event-by-event base.

- Initially proposed by DREAM Collaboration, this technique has been successfully dimonstrated to improve the hadronic energy resolution of a fiber Dual-Readout calorimeter.

- Realistic layout of a fiber Dual-Readout calorimeter has been proposed by the 4th Concept Collaboration at ILC and an intensive simulation program has culminated with the submission of the LoI on March 31, 2009.

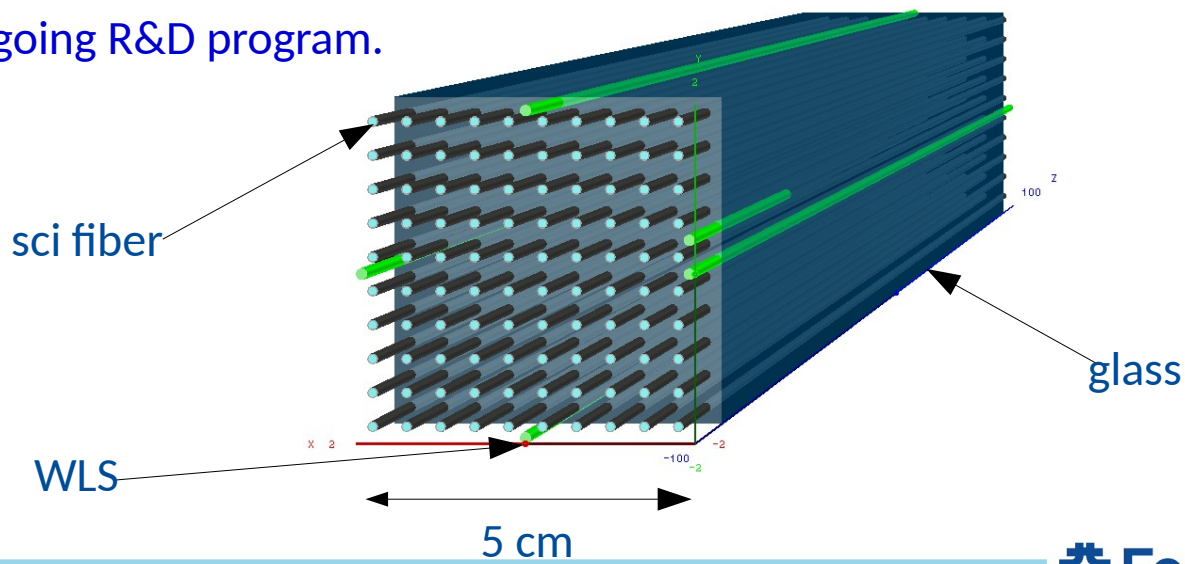
ADRIANO: A Dual-Readout Integrally Active Non-segmented Option

- ADRIANO is an implementation of the Dual-Readout technique making use of signals from high transmittance optical glasses (for the Čerenkov light collected by WLS) and plastic fibers (for the scintillating component).

- It' s integrally active, there is no passive absorber (glass+ plastics).

- It has been proposed to overcome the low photo-electron statistics in the Čerenkov signal and sampling fluctuations of sampling Dual-Readout calorimeters.

- There is an intense ongoing R&D program.
  See C. Gatto's talk.



ADRIANO: Baseline Configuration

- Goal is to keep **the number of fibers to a manageable level** for a 4π calorimeter without loosing too much light.
- Define Γ = total photodetectors area/total calorimeter area.
- Γ takes into account:
  - The needed photodetector area to read circular fibers with an optimum packing
  - *The crowdiness of your FEE*

Quite large

- ***Example:*** Γ_{DREAM} ***= ~24%;*** $\Gamma_{4th\ Concept}$ ***= ~ 21%;*** Γ_{Spacal} ***= ~ 21%***
- **In its baseline configuration** $\Gamma_{ADRIANO}$ **= 8%**
- **Several ADRIANO layouts have been simulated**

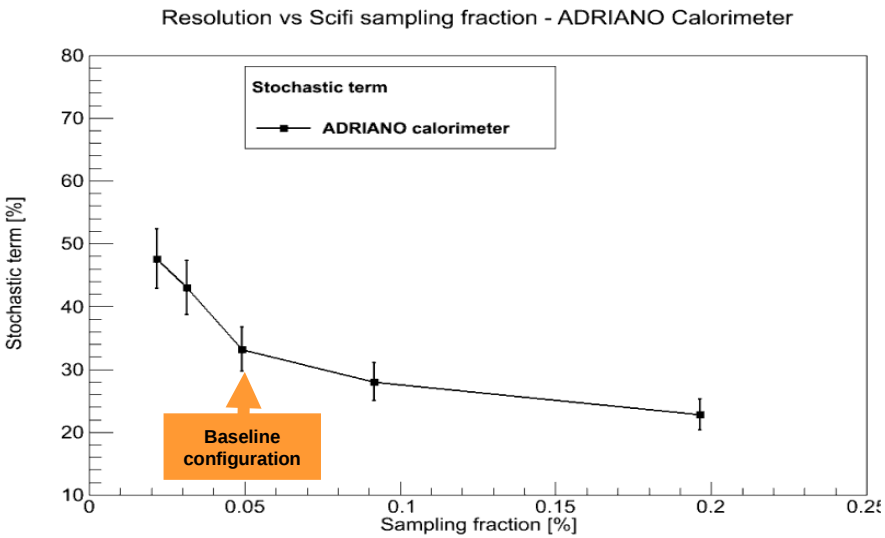
ADRIANO: Summary of performance studies

ILCroot Simulation

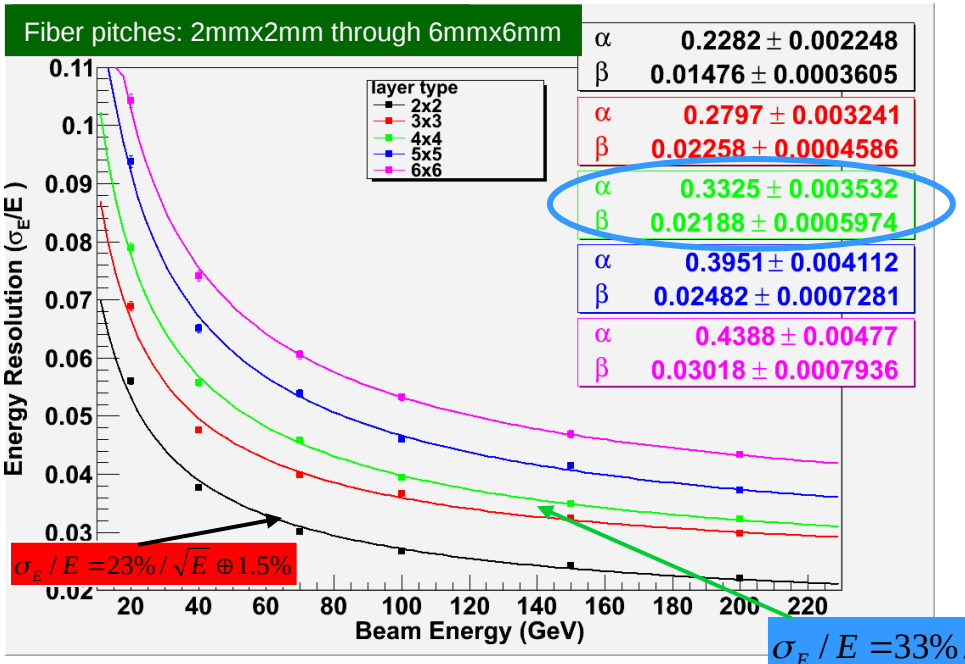
Integrally Active with Double side readout (*ADRIANO*)

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	1100	250
$\langle pe_C/GeV \rangle$	340	360	**360**	355	355	355	350	350

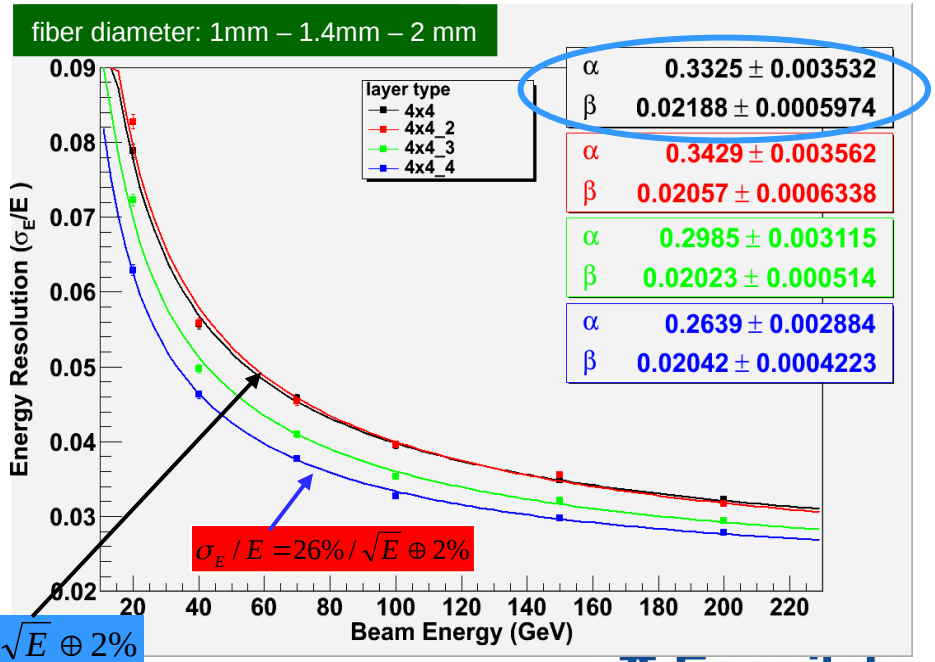
Baseline configuration
total photosensors area/total detector surface = 8%



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

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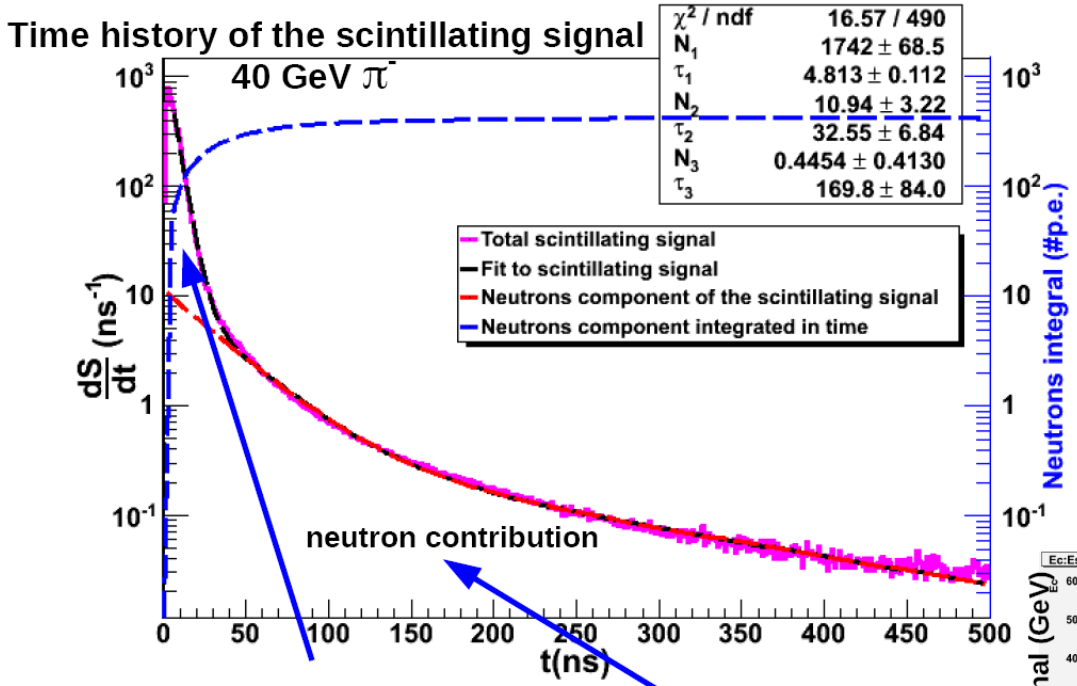
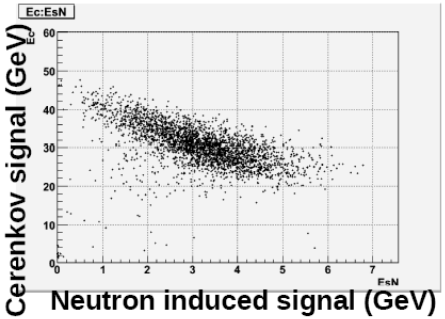
ADRIANO: From dual to triple readout

Disentangling neutron component from waveform

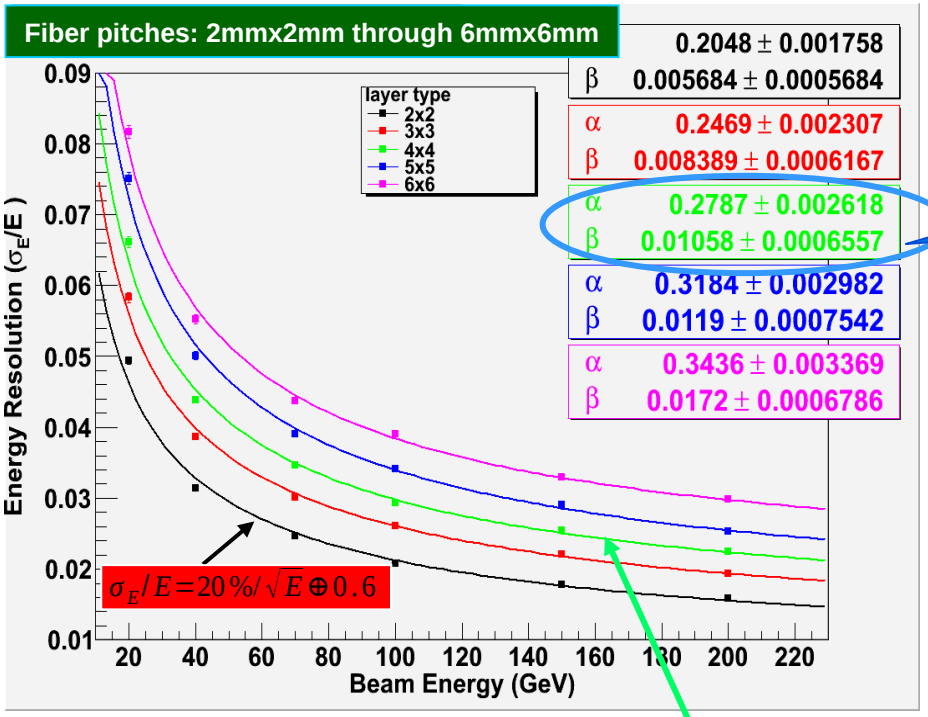


After 50ns only neutrons contribute to the signal

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

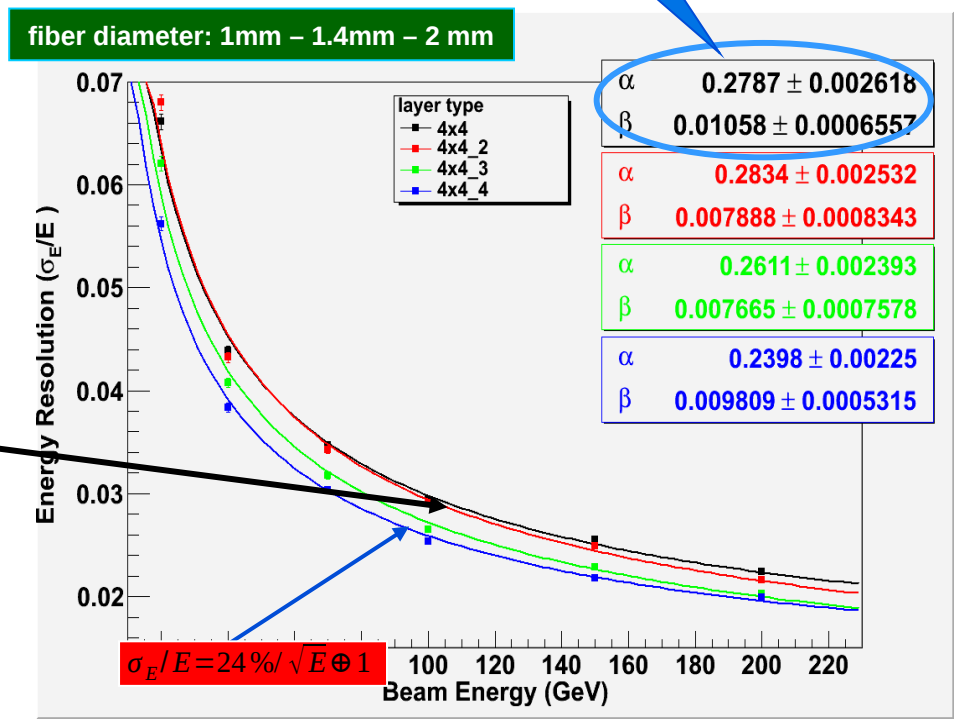


ADRIANO in Triple Readout Configuration



ILCroot Simulation

Baseline configuration
Total photosensors area/total detector surface = 8%



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

Compare to ADRIANO in Double Readout configuration

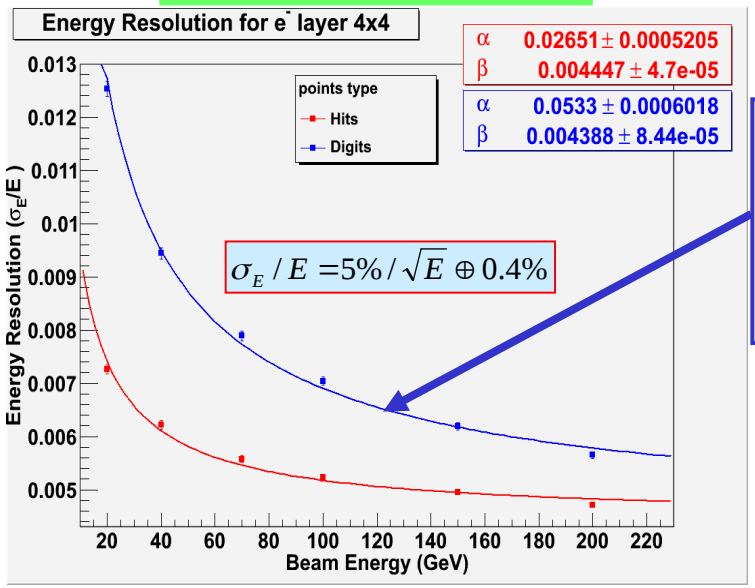
$$\sigma_E/E = 33\%/\sqrt{E} \oplus 2$$

ADRIANO EM Resolution (with and without instrumental effects)

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

ILCroot Simulation

Use only Cerenkov light

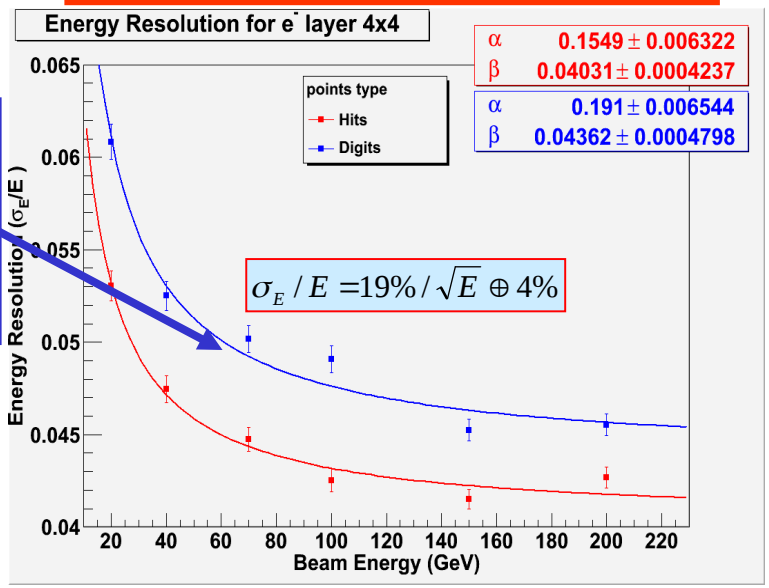


Blue curve includes:

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

ILCroot simulations

Dual-readout (scintillating+Cerenkov)



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

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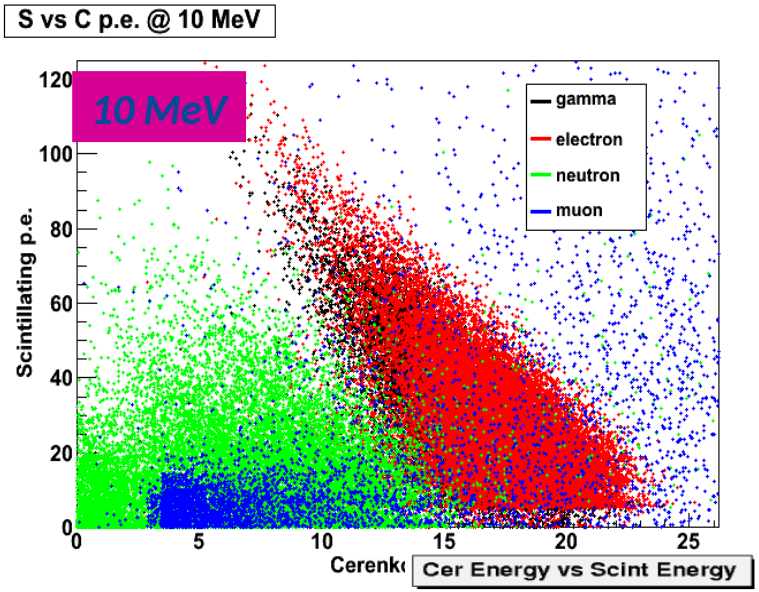
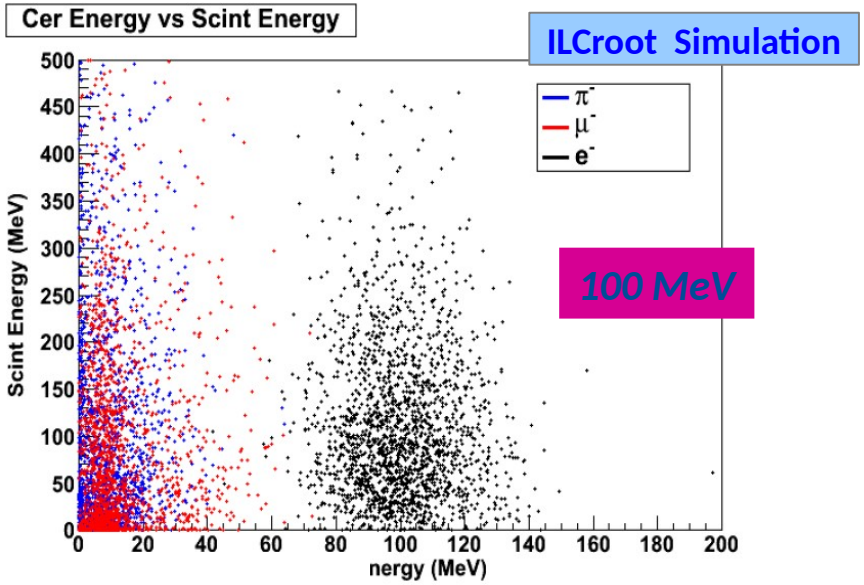
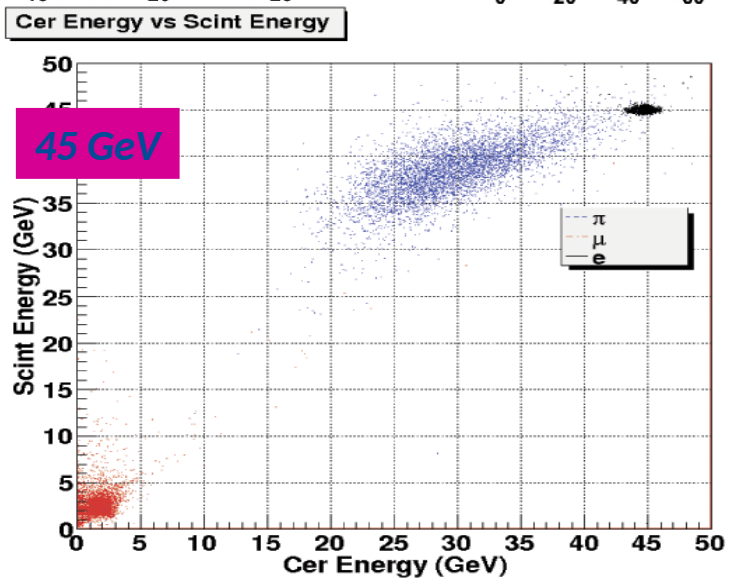
Particle ID with ADRIANO







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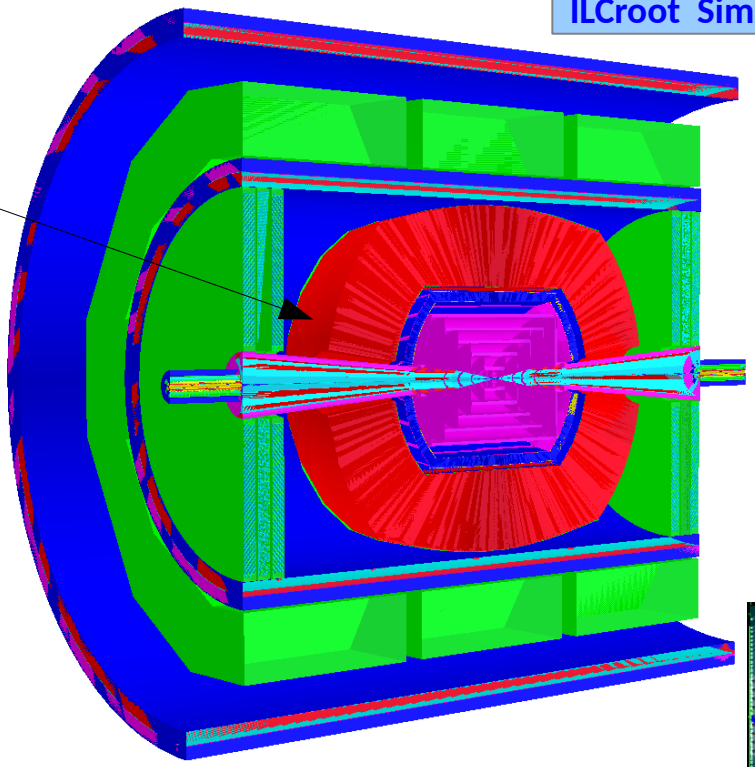
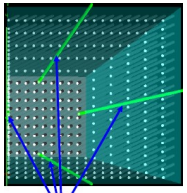
ADRIANO Calorimeter for MuC

ADRIANO

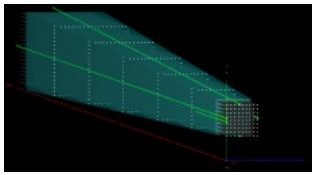
- Lead glass + scintillating fibers
- ~1.4° tower aperture angle
- Split into two separate sections
- Front section 20 cm depth
- Rear section 160 cm depth
- ~ 7.5 λ_{int} depth
- > 100 X_0 depth
- Fully projective geometry
- Azimuth coverage down to ~8.4°
- Barrel: 16384 towers
- Endcaps: 7222 towers

ILCroot Simulation





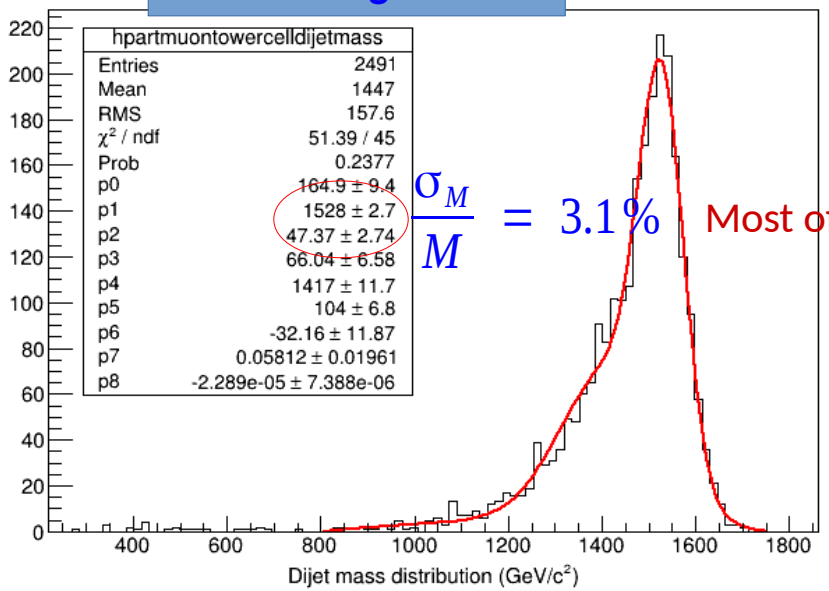
WLS



- All simulation parameters corresponds to ADRIANO prototype #9 tested by Fermilab T1015 Collaboration in Aug 2012 @ FTBF (see also T1015 Gatto's talk at Calor2012)
- Several more prototypes tested @ FTBF (Fermilab)
- New test beam in November @ Fermilab.

ADRIANO Performance in ILCroot

NO Background



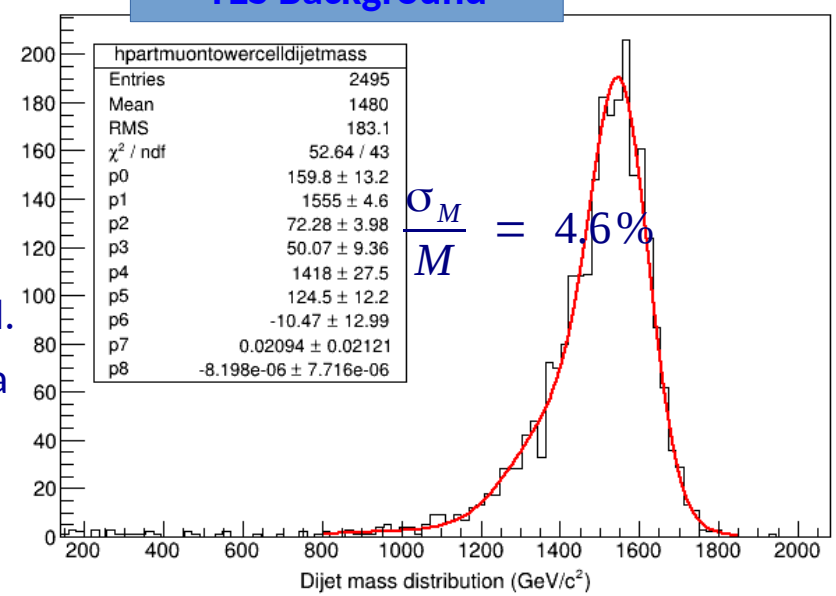
$$\frac{\sigma_M}{M} = 3.1\%$$

Fully simulated H/A → bb and beam background

Applied time and energy cut theta dependent to reject the beam background.

Most of the background are low momenta photons and neutrons.

YES Background



$$\frac{\sigma_M}{M} = 4.6\%$$

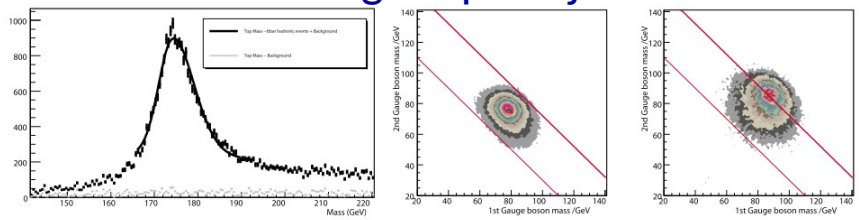
Heavy Neutral Higgses (H/A) and charged Higgses ($H^{\pm}$) are possible New Physics beyond the Standard Model. H and A can be produced as s-channel resonances at a Muon Collider. (Eichten and Martin arXiv:1306.2609).

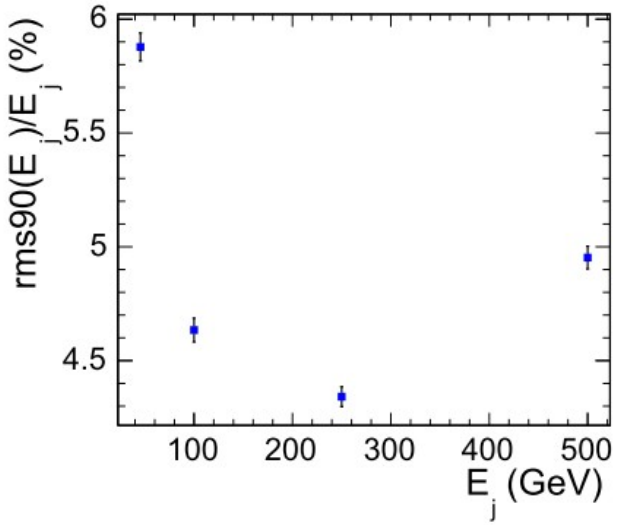
A. Mazzacane – Snowmass 2013

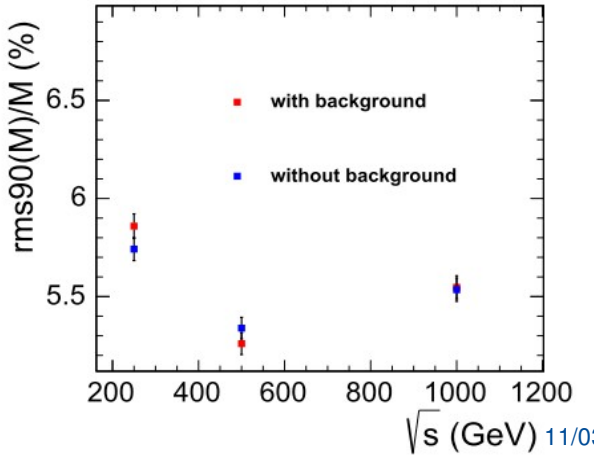
ADRIANO performance in slic/lcsim

Plans:

- Implement ADRIANO in SiD detector.
- Repeat some of physics & performance studies presented in the SiD Detailed Baseline Design – Final Draft to study energy and mass resolution through the simulation of:
  - Z' boson of different masses decay at rest into two pair light quark jets.
  - ZZ at different beam energies, decay into neutrinos and two light quark jets.
  - Chargino and neutralino four jets events.







ADRIANO performance in slic/lcsim

Goals:

- Compare ADRIANO performance with those of the SiD baseline calorimeter.
- Study the effect on the energy resolution of ADRIANO with a shorter interaction length to fit between SiD central tracker and solenoid.
- Explore eventual differences between ilcroot and slic/lcsim.

Key issues with dual-readout calorimetry and PFA in Sid:

- Shower leakage is an important factor in the performance.
- Measurements are spoiled no matter if PFA or compensating calorimeters are used.
  - Study on a leakage correction algorithm for standard ADRIANO and a sampling version with Pb absorbing layers are ongoing.

Status of the simulations

- **Simulation of ADRIANO in LCDD description is complete:**
  - PFA hadronic and electromagnetic calorimeters have been removed.
  - ADRIANO has been inserted between the tracker and the solenoid.
  - All other subdetectors are unchanged.

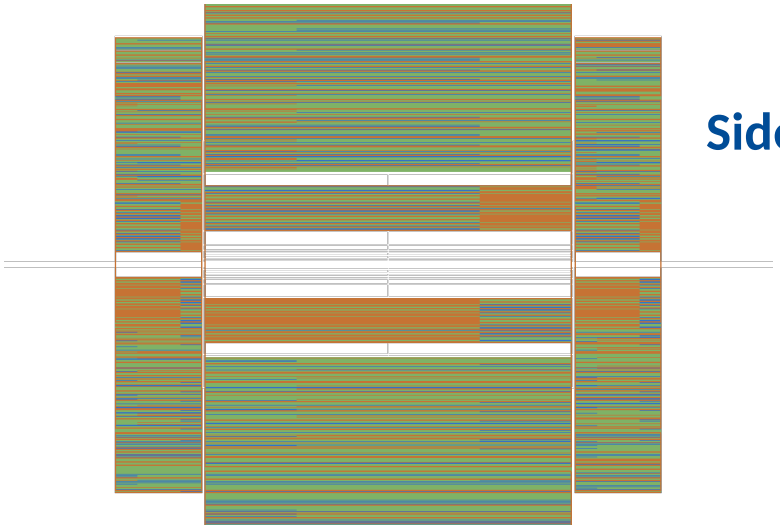
- **ADRIANO layout:**
  - 24 layers, 5 x 5 cm cells log style (to save extra space).
  - Each cell is composed of 8 slices of 6.26 mm pb glass alternate with 0.5mm Sci ribbon.
  - Compare with 4th concept with projective towers (but 180 cm available)

- **Slic simulation is using dual-readout hit processor implemented by H. Wenzel for the MuC.**

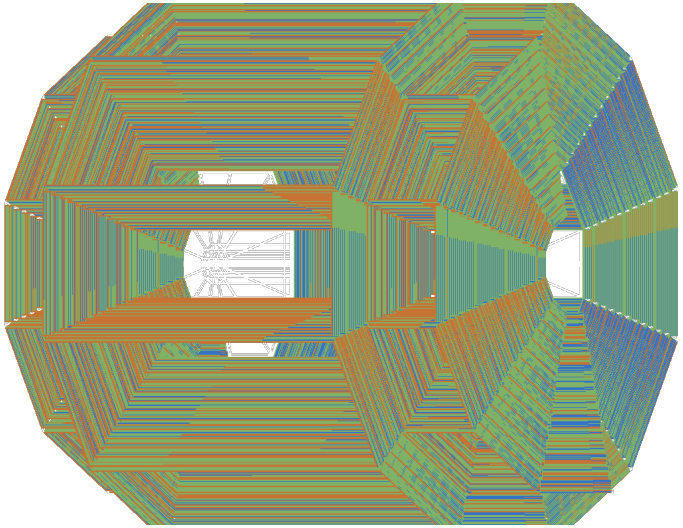
- **Digitization and reconstruction is fully implemented in LCsim.**
  - Added Birks effect in the Sci fibers.
  - Added light attenuation in glass and sci fibers.
  - New geometry for the endcap (PolyhedraLogsCalorimeter2)

- All physics events are simulated as planned. Unfortunately an issue in ADRIANO endcap simulation requires a reprocessing of the events.

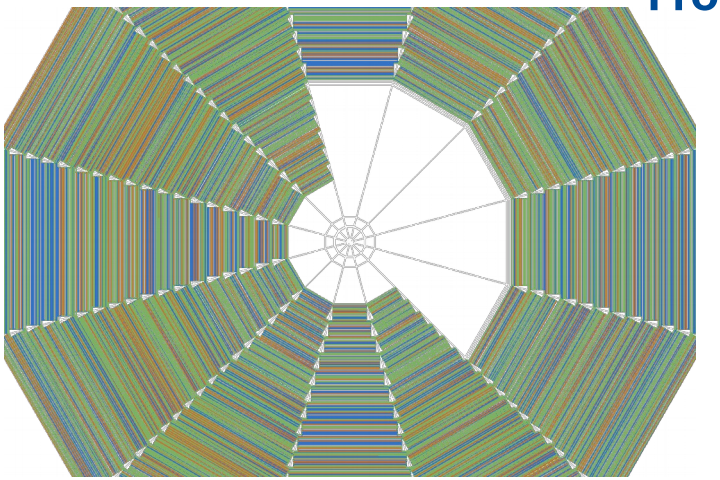
ADRIANO for SiD in SLIC/LCsim

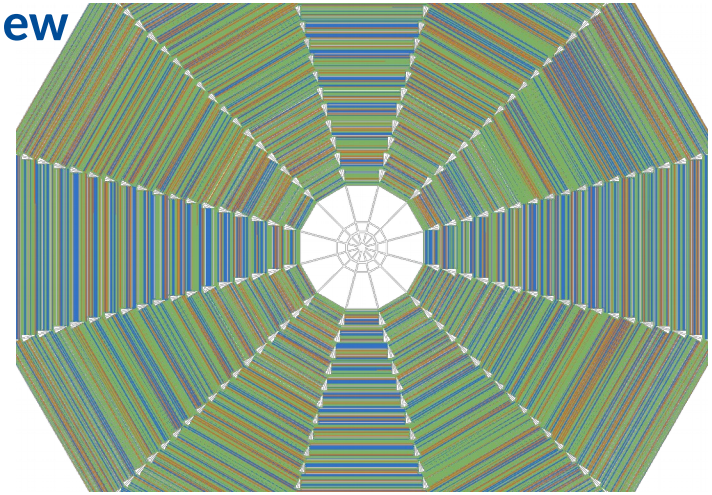


Side view



Front view

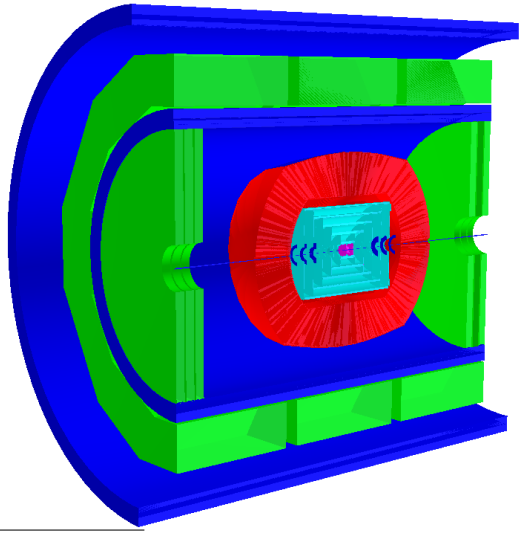




ADRIANO for SiD in ILCroot Detector Simulation

ILCroot Simulation

- It's just a temporary study to understand what to expect from SLIC+LCsim (physics does not changed with the software framework).
- **Modified ADRIANO size** in ILCroot framework to fit in the SiD detector.
- Quick study using already tested infrastructures.



Overall dimensions given in cm.

BARREL	Technology	Inner radius	Outer radius	Z max
Vertex	Silicon pixels	3	12.9	6.25
Tracker	Silicon pixels	19.5	126.5	163
ADRIANO Calorimeter	Dual Readout	**151**	**274**	336.5
Solenoid	**5 Tesla**	350 – 600	400 – 650	600 – 720
Muon	Drift tube	400	565	600

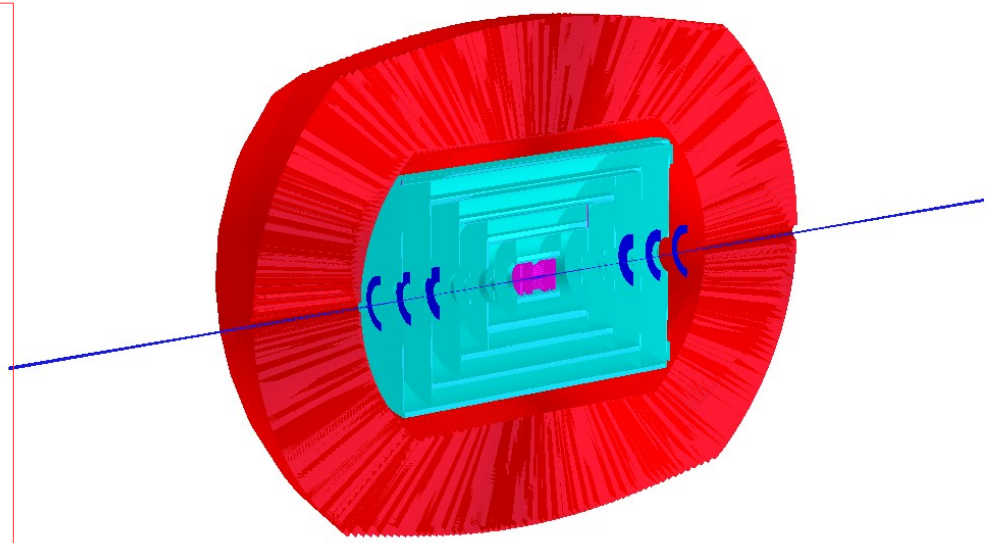
ENDCAP	Technology	Inner z	Outer z	Outer radius
Vertex	Silicon pixels	7.4	21.7	18.7
Tracker	Silicon pixels	28.1	169.7	129.4
ADRIANO Calorimeter	Dual Readout	**151**	**336**	238

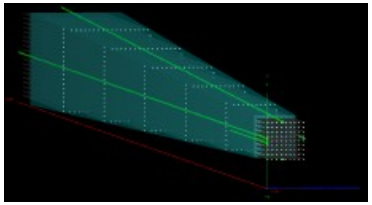
ADRIANO for Sid Details (ilcroot simulation)

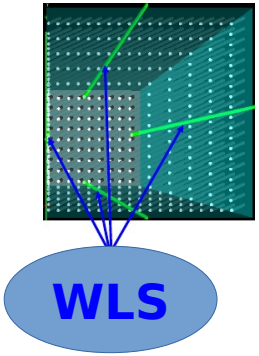
ADRIANO

- Lead glass + scintillating fibers
- ~1.4° tower aperture angle
- ~ 123 cm depth
- ~ 5.5 λ_{int} depth
- >70 X_0 depth
- Fully projective geometry
- Azimuth coverage down to ~2.8°
- Barrel: 16384 towers
- Endcaps: 7450 towers

ILCroot Simulation







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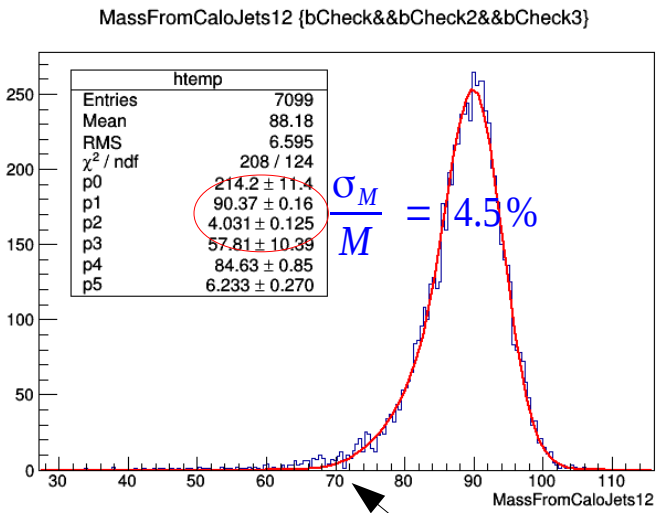
- Several more prototypes tested @ FTBF.
- New test beam in November @ Fermilab.

ZPole Studies – no correction for leakage

- Full simulation and reconstruction of Zpole events: $Z^0 \rightarrow q\,\bar{q}$

ILCroot Simulation

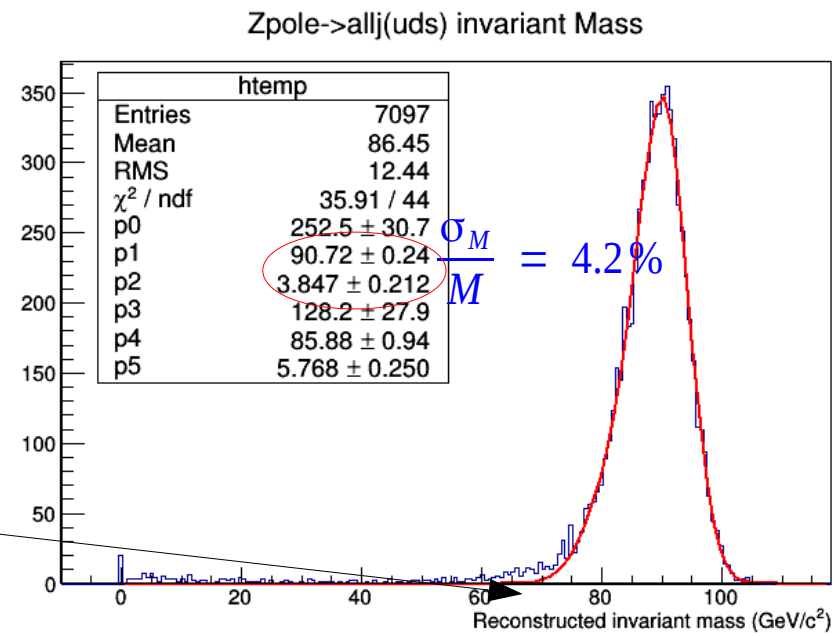
- Jet reconstruction using information from tracking and calorimeter systems.



$\frac{\sigma_M}{M} = 4.5\%$

'Calo jets"

"Calo-track jets"



$\frac{\sigma_M}{M} = 4.2\%$

Tails from leakage

Leakage effects are evident: add lead absorber + COG corrections

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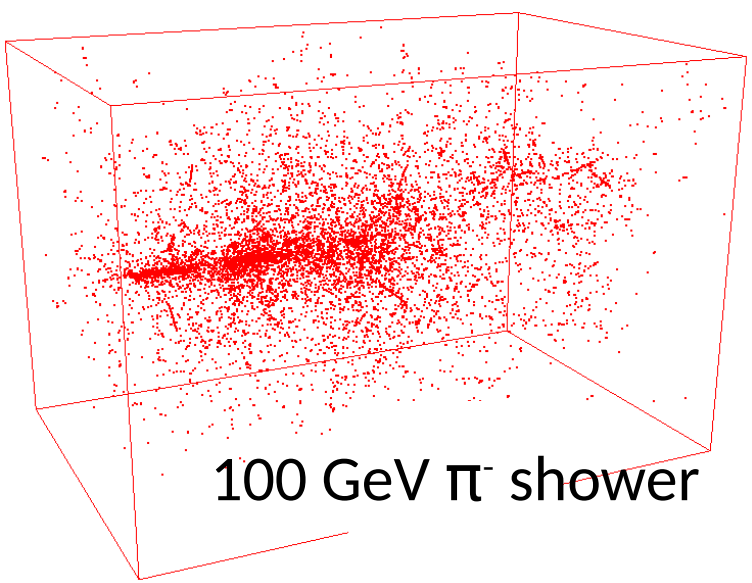
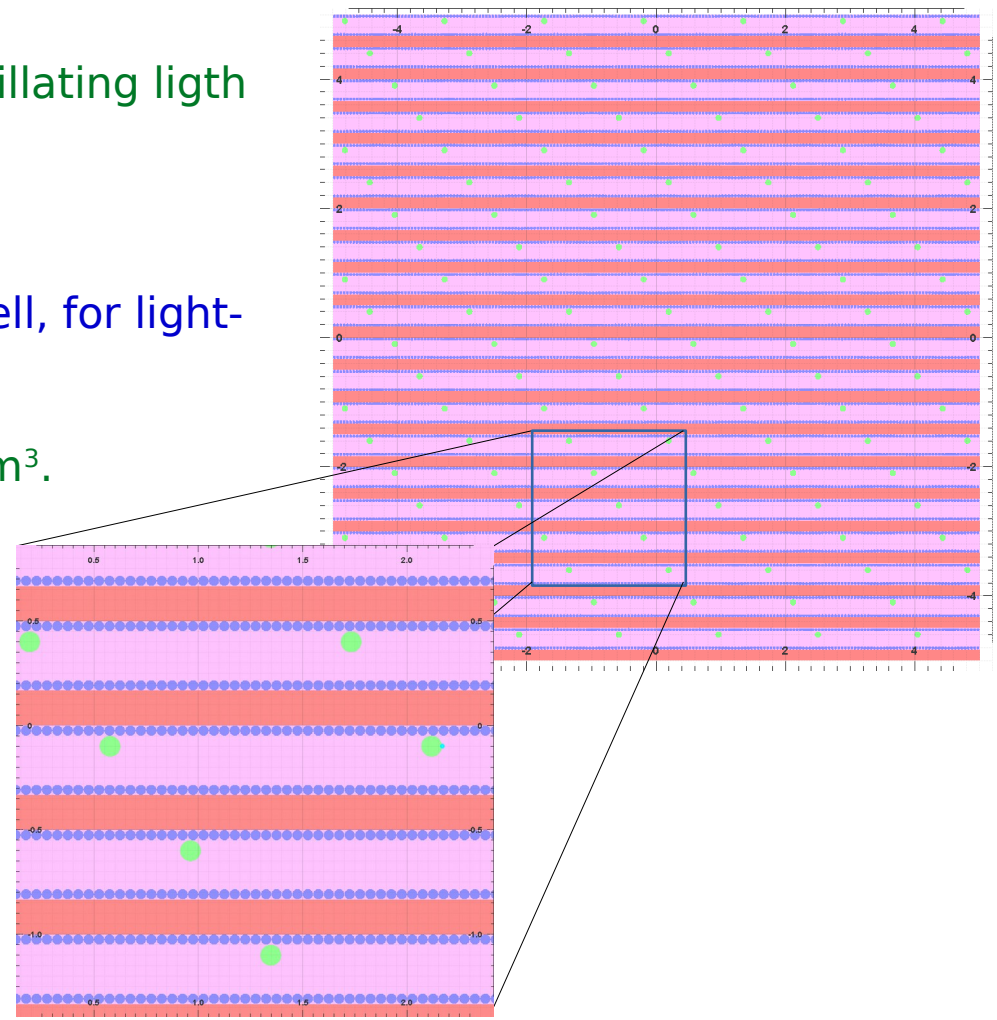
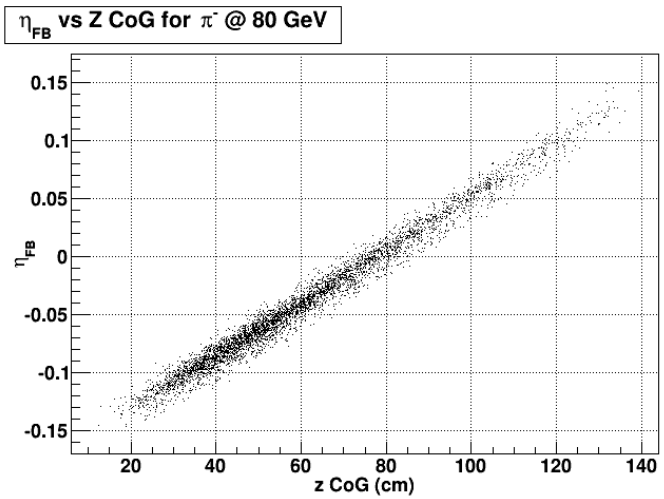
ADRIANO for Sid - Pb Absorber and Sci Ribbon

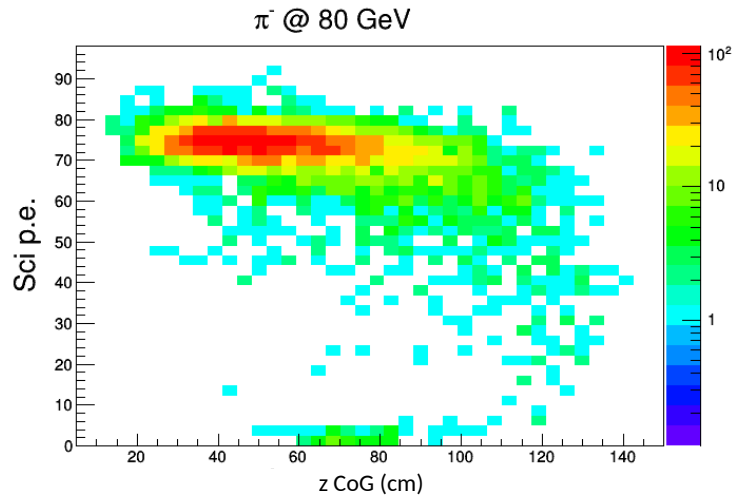
- Add absorbing Pb layers to reduce λ_{int}.
- Thin ribbon to produce and collect scintillating ligth
- LeadGlass to produce Cerenkov signal.
- WLS to collect Cerenkov photons.
- Sci signal collected both ends of the cell, for light-division measurement.
- Simulated module size 100x100x150 cm^3.
- Cell size 10x10x150cm^3.





ADRIANO for Sid – Shower Center of Gravity





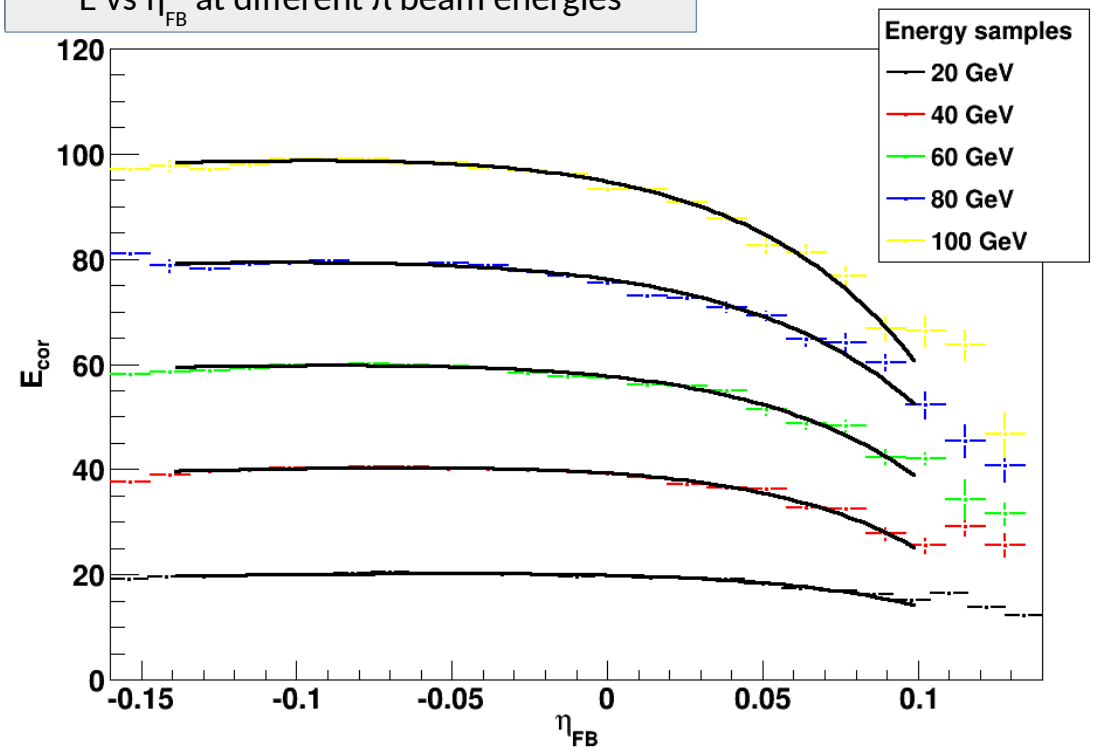
$$\eta_{FB} = (SciBack - SciFront)/(SciBack + SciFront)$$

η_{FB} is the ratio back-front of the scintillating signal.

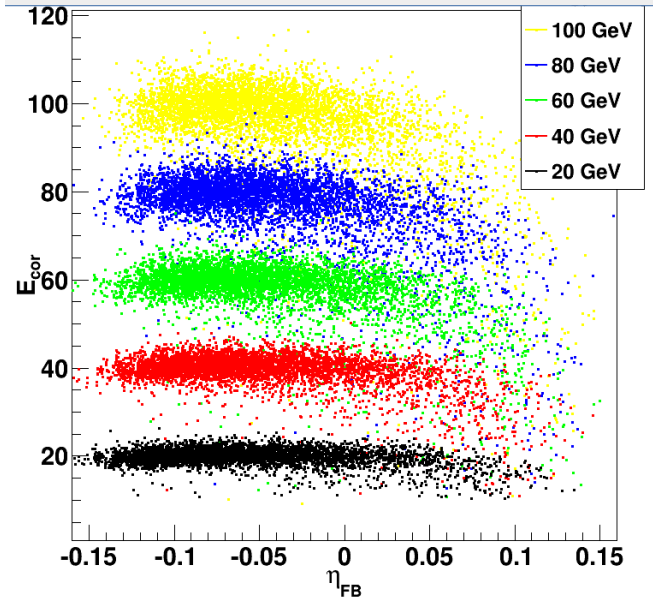
- This ratio is strongly correlated with the z CoG (Center of Gravity) of the shower.
- Showers with high z CoG are affected by the leakage (the number of Sci p.e. is lower at high z CoG).

ADRIANO for SiD – Leakage Correction

E vs η_{FB} at different π^- beam energies



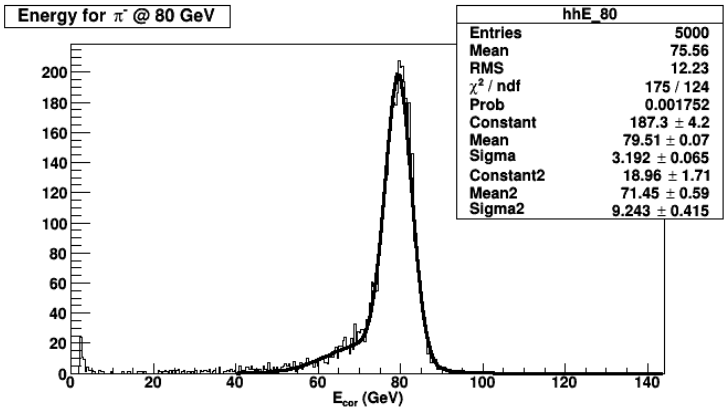
E vs η_{FB} at different π^- beam energies

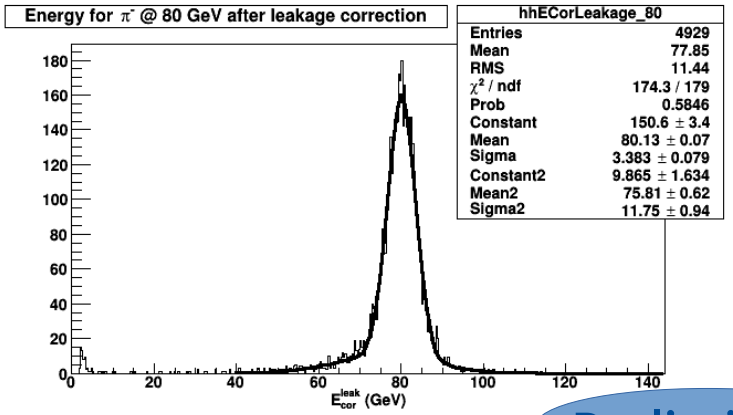


- Energy profile vs η_{FB} is fitted with $f_{fit}(p_0(E_{beam}), p_1, p_2)$.

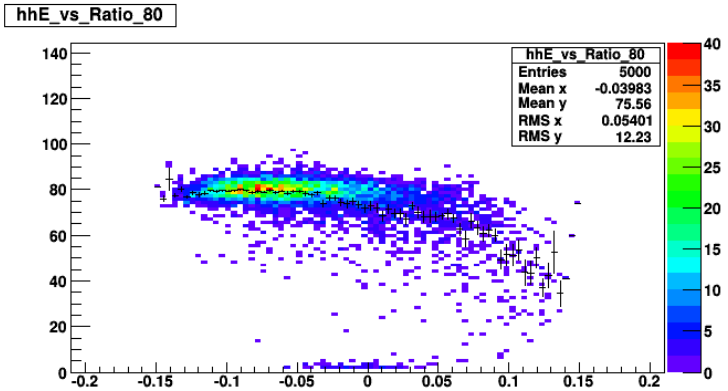
Work in Progress

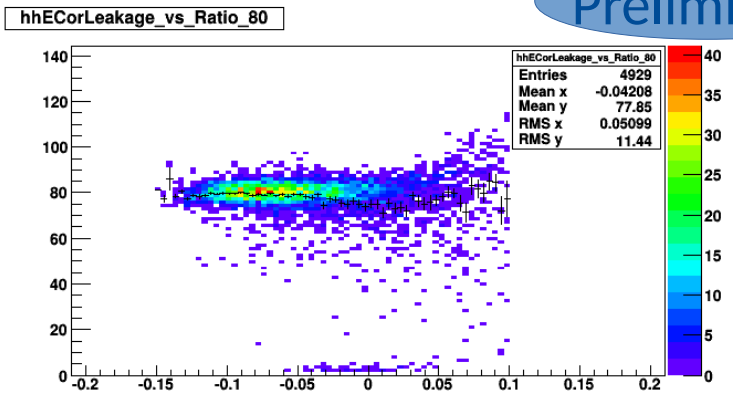
ADRIANO for SiD - Leakage Correction (Cont'd)





Preliminary



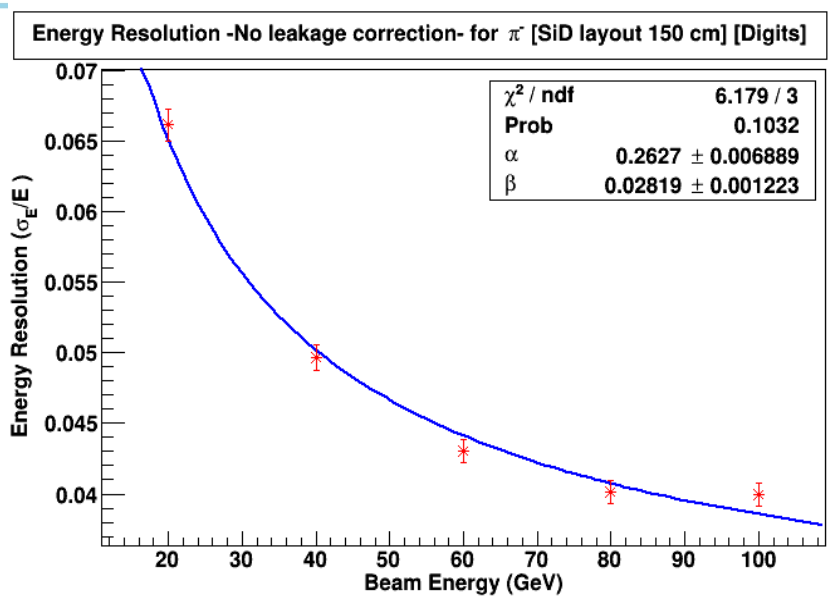


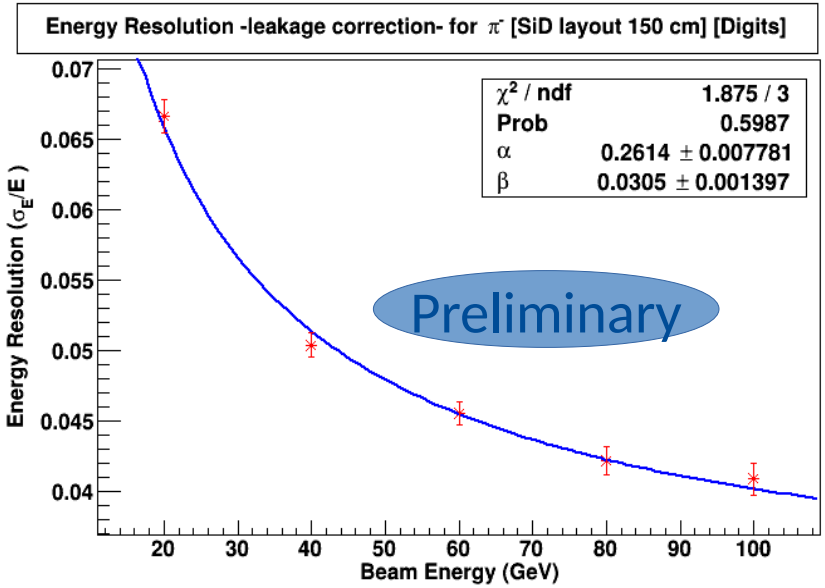
Before Correction

After Correction

- The leakage tail is partially absorbed, its contribute after correction is halved.

ADRIANO for SiD – Energy Resolution with and without leakage correction





ADRIANO configuration:

Absorber Pb thickness (mm)	LeadGlass thickness (mm)	WLS diameter (mm)	WLS step (mm)	Cer L.Y. p.e./GeV	Sci ribbon thickness (mm)	Sci L.Y. p.e./GeV
1.7	3.3	1.0	15.4	170	2x0.5	3045
Energy resolution: $\sigma(E)/E = 26\%/\sqrt{E} \oplus 3\%$						

- This ADRIANO configuration has a good energy resolution.
- The leakage correction results in a more accurate fit.

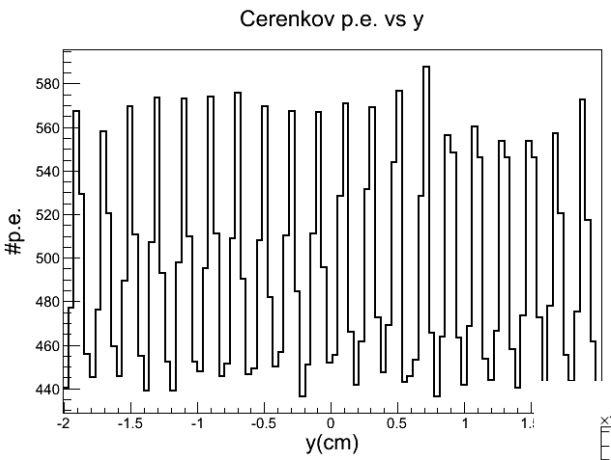
Summary

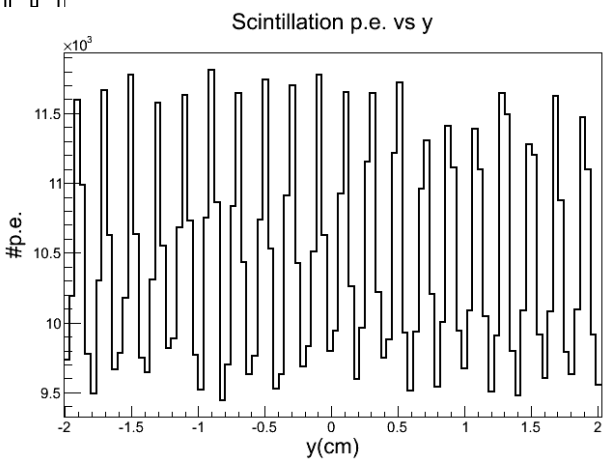
- Dual-readout is quickly becoming a valid alternative to PFA technique.
- ADRIANO technique has been proposed to overcome the low Čerenkov photo-electron statistics experienced by sampling Dual-Readout calorimeters (DREAM-4th Concept).
- R&D and simulations are going step-by-step to improve the performance of the detector.
- Simulations of ADRIANO for SiD are in progress to compare its performance with the baseline PFA-based calorimter.
- Slic/lcsim machinery is in place: stay tuned for results at next meeting.

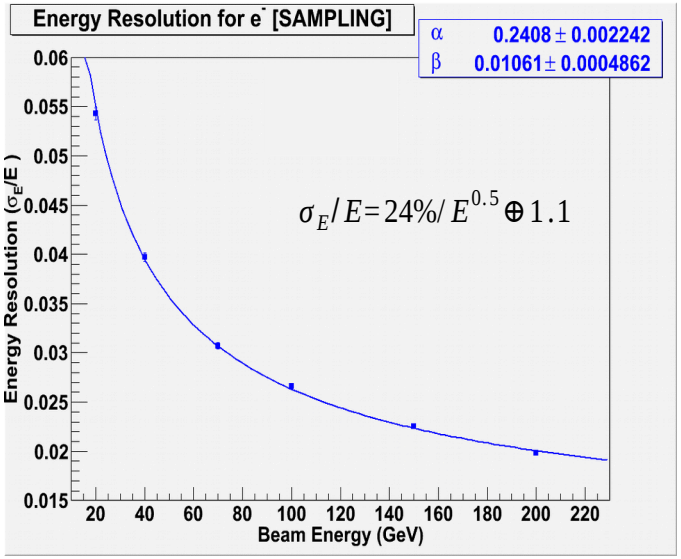
Backup Slides

Sampling Fluctuations

ILCroot Simulation





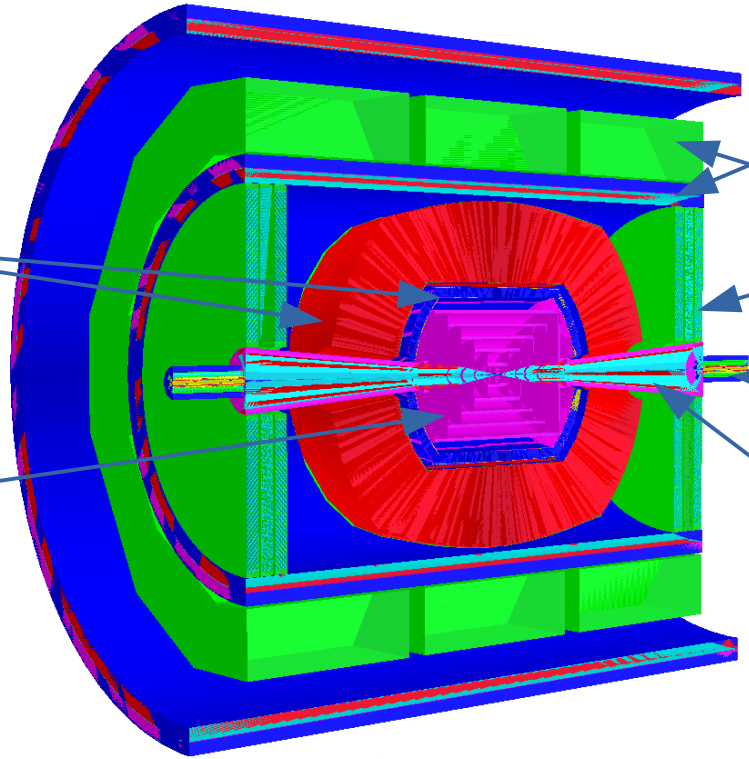


C and S from horizontal beam scan in a sampling calorimeter

Cerenkov and Scintillating signal produced by e^- @ 45 GeV beam in sampling dual readout calorimeter with 1mm pitch between fibers as function of e^- impact point.

ADRIANO Simulation in a MuC Detector

ILCroot Simulation



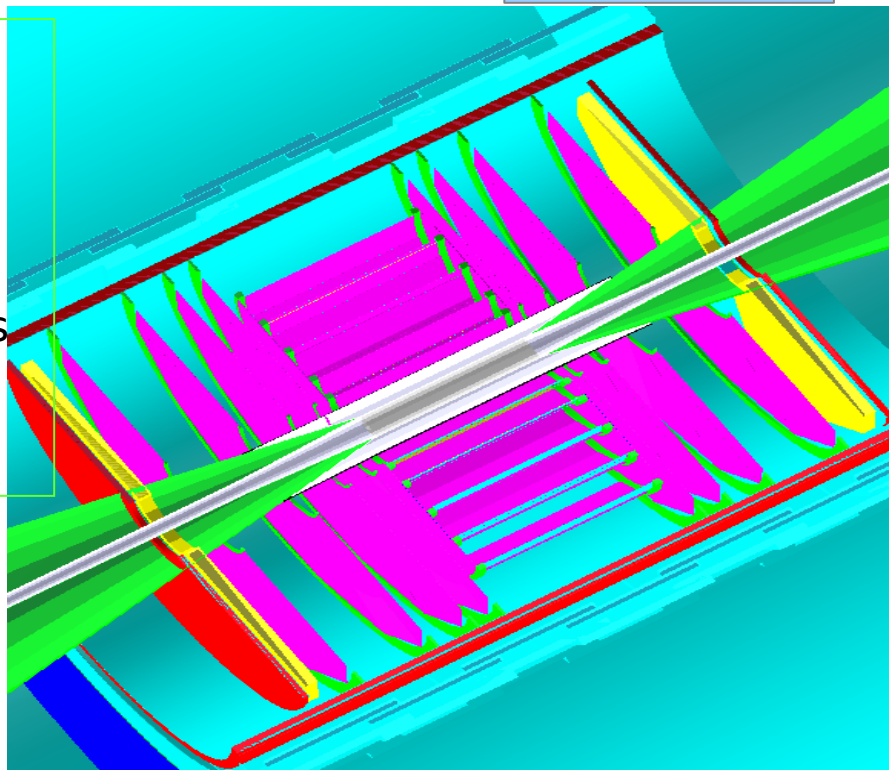
- Detailed geometry (dead materials, pixels, fibers ...)
- Detailed magnetic field (including the magnetic field of the last MDI quad.
- Full simulation: hits-sdigits-digits. Includes noise effect, electronic threshold and saturation, pile up...
- Tracking Reconstruction with parallel Kalman Filter.
- Light propagation and collection for photon detectors.
- Jet reconstruction using tracking and calorimeter information.

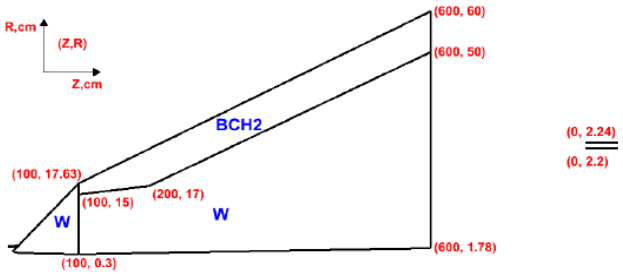
Vertex Detector (VXD) and Beam Pipe

VXD

- 75 μm thick Si layers in the barrel
- 100 μm thick Si layers in the endcappixel
- 20 μm x 20 μm Si pixel Si pixel
- Barrel : 5 layers subdivided in 12-30 ladders
- R_{min}~3 cm R_{max}~13 cm L~13 cm
- Endcap : 4 + 4 disks subdivided in 12 ladders
- Total length 42 cm
- Single/double layer version available.

ILCroot Simulation





NOZZLE

- W - Tungsten
- BCH2 – Borated Polyethylene
- Starting at ±6 cm from IP with R = 1 cm at this z

PIPE

- Be – Berylium 400 μm thick
- 12 cm between the nozzles

Fermilab

Silicon Tracker (SiT) and Forward Tracker Detector (FTD)

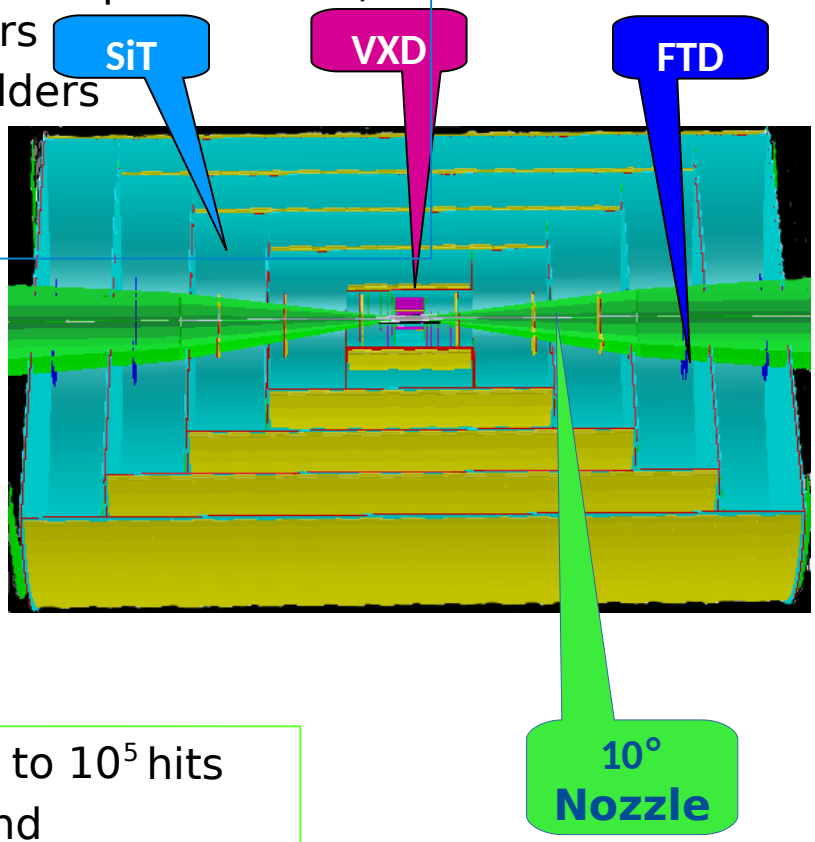
SiT

- 200 μm thick Si layers
- 50 μm x 50 μm Si pixel (or Si strips or double Si strips available)
- Barrel : 5 layers subdivided in staggered ladders
- Endcap : (4+3) + (4+3) disks subdivided in ladders
- R_{min}~20 cm R_{max}~126 cm L~340 cm
- Single/double layer version available.

FTD

- 200 μm thick Si layers
- 50 μm x 50 μm Si pixel
- Endcap : 3 + 3 disks
- Distance of last disk from IP = 190 cm

ILCroot Simulation



- Silicon pixel for precision tracking amid up to 10^5 hits
- Tungsten nozzle to suppress the background