Calorimetry/Muon Summary

Andy White
University of Texas at Arlington

LCWS 2015, Whistler

Calorimetry/Muon
topics covered at this meeting

- **Electromagnetic calorimetry**
    - Silicon/tungsten ECal
    - Scintillator strip Ecal/HCal
    - Scintillator strip Calorimeter in PFA

- **Hadronic calorimetry**
    - Analog HCal/SiPMs
    - W-AHCAL Shower development
    - SiPM Gain studies
    - Semi-digital Hcal
    - SDHCAL/Arbor PFA

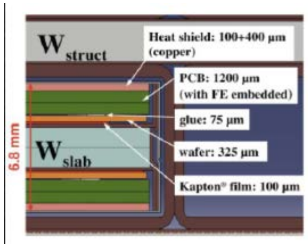
- **Beam/Luminosity calorimetry**
    - Radiation damage studies
    - LumiCal beam tests
    - Ultra compact LumiCal

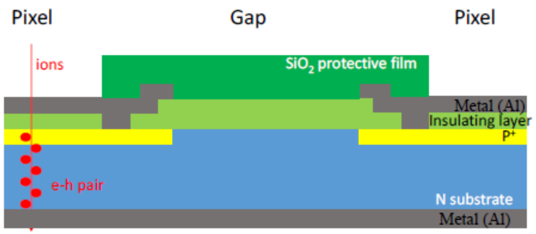
- **Dual readout calorimetry** ADRIANO
- ADRIANO Performance

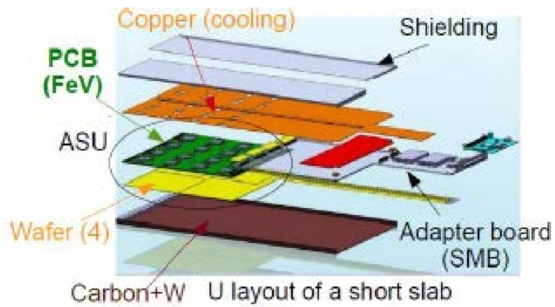
- Scintillator-based **muon** system

SiW ECal (CALICE)

T. Suehara







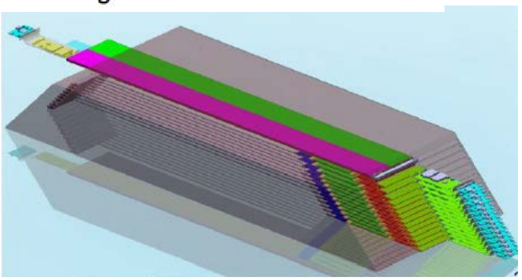
- One board / four wafers, 16 ASICS
- Long slab tested on 4 FEB daisy-chained
- Fixed the problem on afterpulsing
- Fully compatible with power-pulsing

Four FEB11 slabs + babies

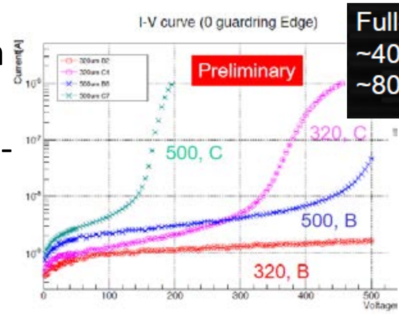
New Front end board – 4 FEB to be tested now at SPS

Next: 2016+
“Final” prototype test

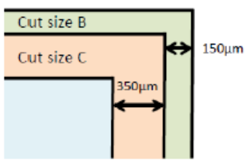
Tower of 18×18 cm² (2×2 wafers)
14 Short SLABs
1 Long SLAB



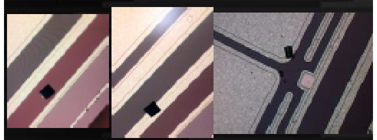
500μm sensor tested -



Full-dep. voltage
~40V in 320 μm
~80V in 500 μm

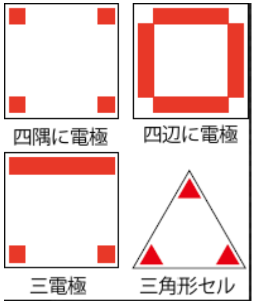


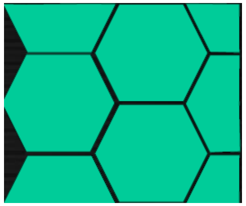
Guard-rings & cut sizes



0GR, 1GR & split 2GR
1GR has ring event
→ trying 0GR
Currently no critical disadvantages found

New idea – position sensitive detector





Square -> hexagonal pixels

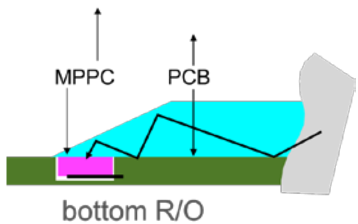
For “precision shower start finder” to be used in inner layers of ECAL

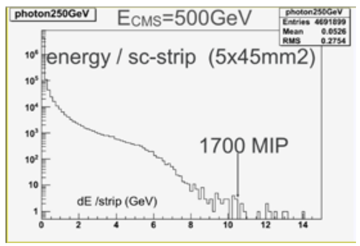
28.8% more area per wafer → 22.4% less wafers needed

Strip Scintillator ECal and HCal

T. Takeshita

ECal strip

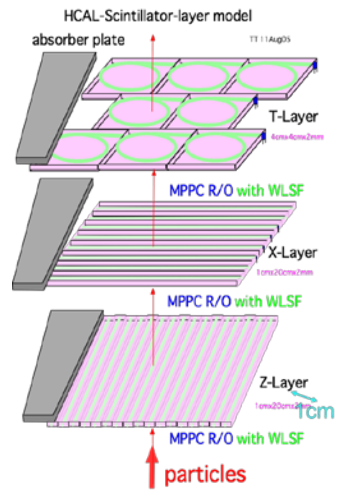




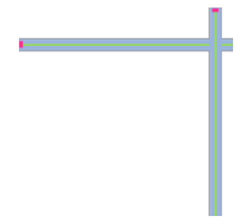
number of pixels in a MPPC should be 10k, when 7p.e./MIP

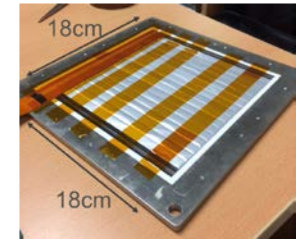
10K pixel MPPC exists!

5mmx45mm strips direct MPPC readout



HCal strip

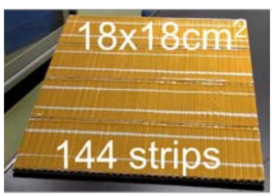


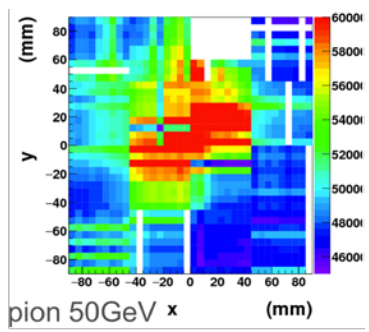


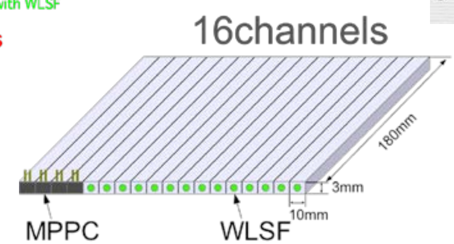
18 cm long strip with WLSF read out

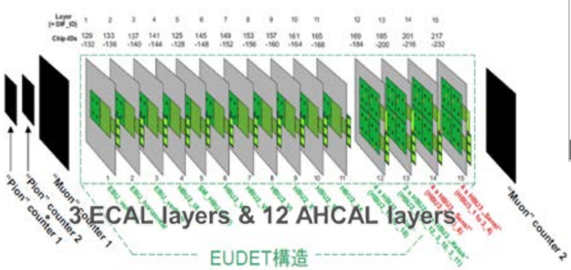
- **photon yield ~30p.e.**
- **18 cm long strip with**
- **WLSF read out**
- **good uniformity**

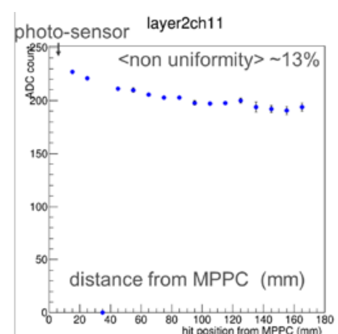
ScECal status

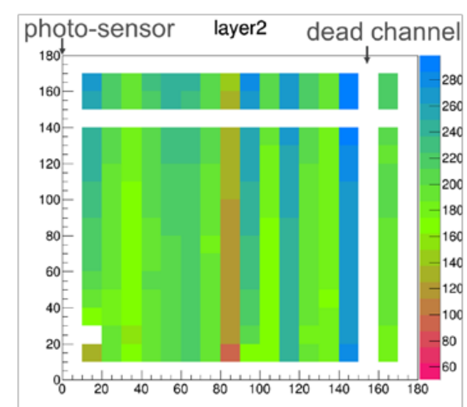












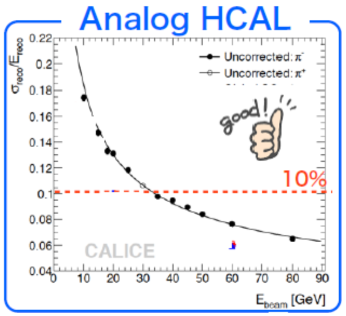
Tested at CERN ・ 2015 at SPS H2/6 with tungsten

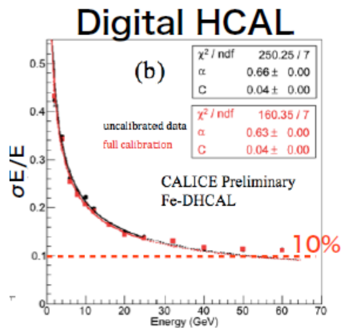
Strip Scintillator CAL in PFA

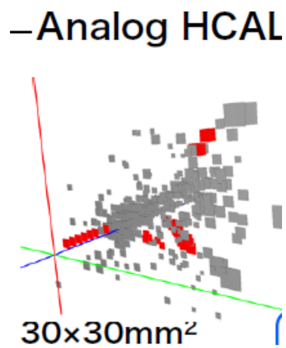
K. Kotera

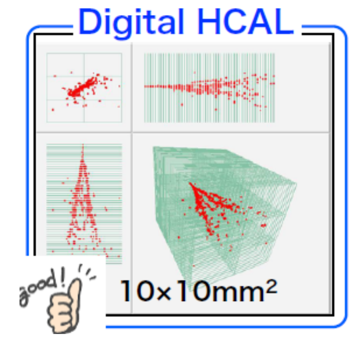
AHCAL takes more advantage of energy info.

D,SDHCAL take more advantage of fine granularity.

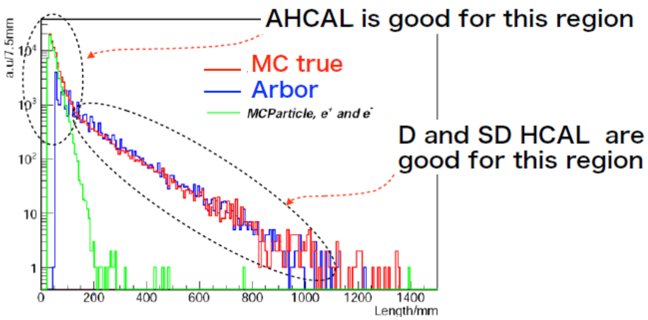


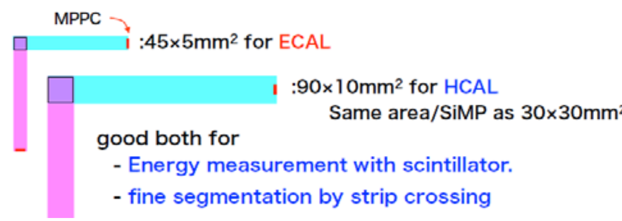




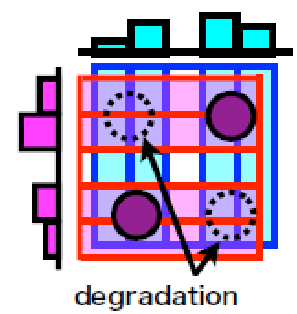


If we have - $10\times10mm^2$ AHCAL and
- algorithm which can show merit of $10\times10mm^2$,
we can take advantage of both cases→Strip CAL

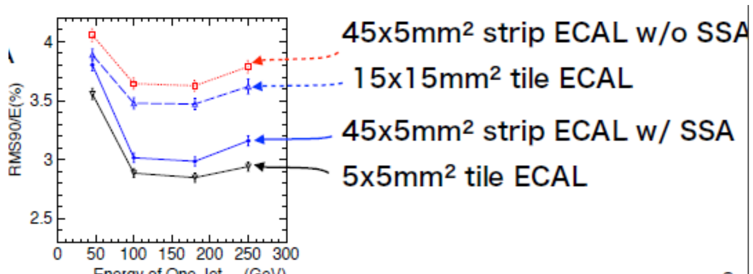




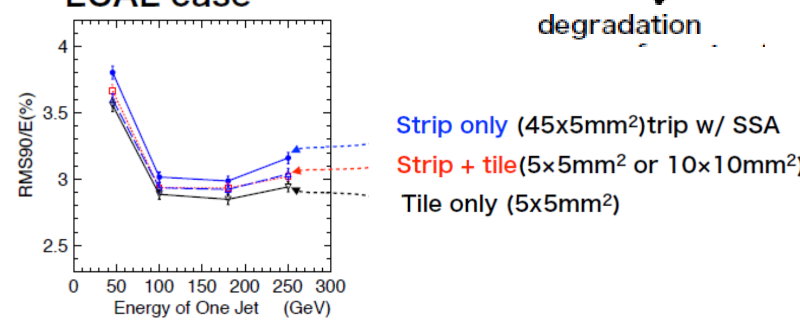
Issue with twofold ambiguities



Strip energy Splitting Algorithm



ECAL case

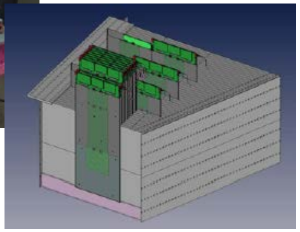


AHCAL – Technical Prototype

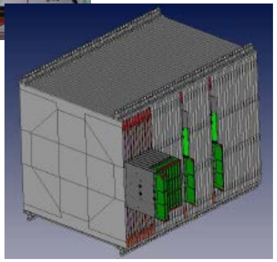
K. Kruger

AHCAL Testbeams at SPS in 2015

- first SPS test beam with 2nd generation electronics and DAQ
- extensive preparation
  - testbeams at PS in October and November 2014
  - testbeams at DESY in February, April and June 2015
  - tested long term stability of complete setup without beam at DESY
- system test: scalable DAQ, power distribution and cooling
- gain experience with variety of tiles and SiPMs
- new physics possibilities due to timing capabilities of new electronics



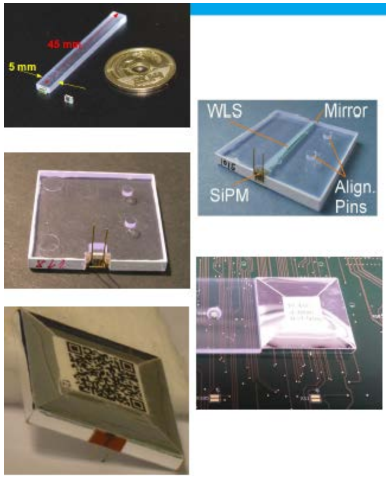
Steel prototype

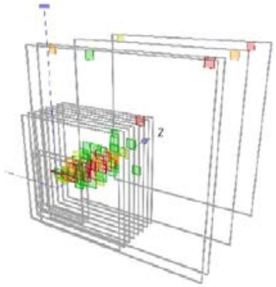


Tungsten prototype

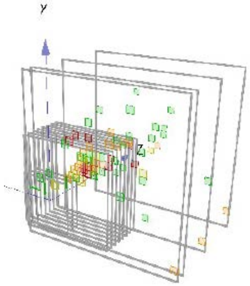
Two beam periods July, August 2015 At CERN

Variety of tiles/SiPMs tested

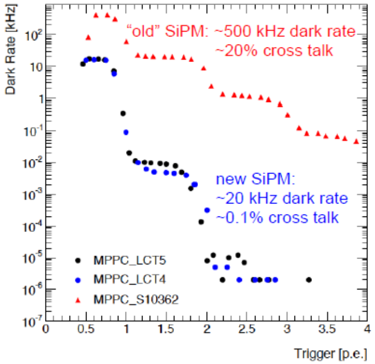




Electron

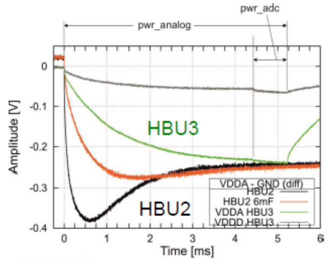


Pion/tungsten



for comparison: SiPMs in physics prototype
2 MHz dark rate, 30% cross talk

New SiPMs

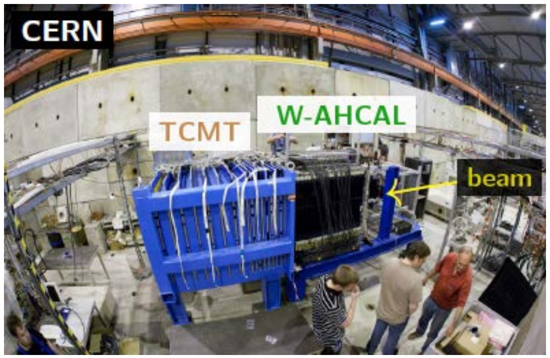


Power pulsing – new version of HBU -> HBU3

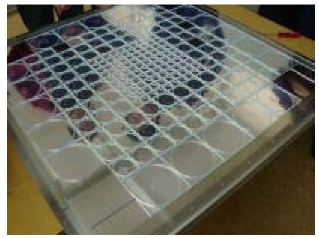
- 2016: test of a 15 layer e.m. stack with high quality photo-sensors at DESY and possibly SLAC: test power pulsing!
- 2017: construction of a big hadronic prototype
- 2018: test with hadrons at CERN

Shower development: CALICE W-AHCAL

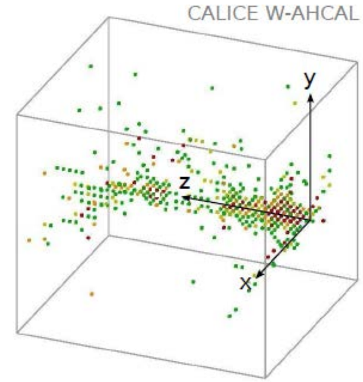
F. Sefkow,
E. Sicking



Test beam experiments at CERN SPS in 2011

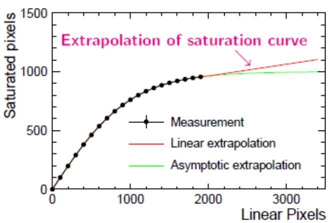


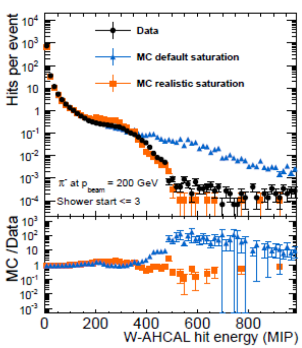
- W-AHCAL (38 layers $\hat{=}$ 5 λ_I) (+ TCMT $\hat{=}$ 5 λ_I)
- $10 \leq p_{beam} \leq 300$ GeV
- $e^{\pm}$ beam/ mixed beam $\mu^{\pm}$, $\pi^{\pm}$, $K^{\pm}$, p
- Focus of study: Comparison between data and Geant4 9.6.p02 for tungsten HCAL



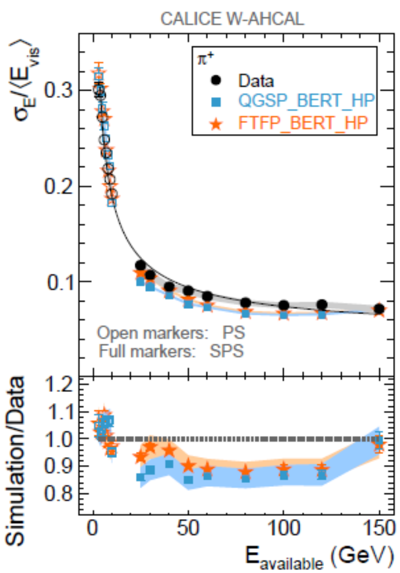
π^+ event at 80 GeV

- Higher energy density in W than in Fe

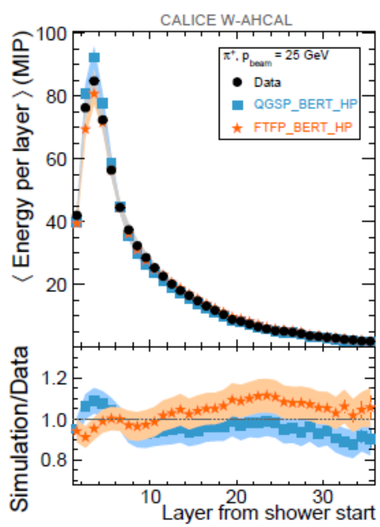


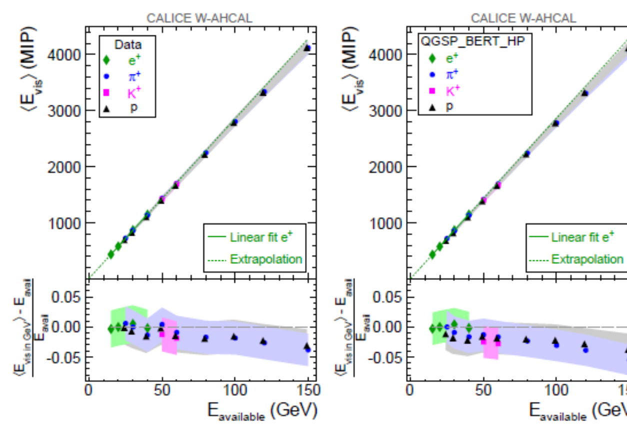


Pion resolution



Pion shower profiles





High Precision (HP) neutron tracking needed for tungsten simulation

- FTFP_BERT_HP better than QGSP_BERT_HP for all observables except E_{vis}

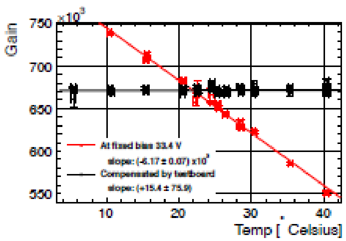
SiPM Gain Studies

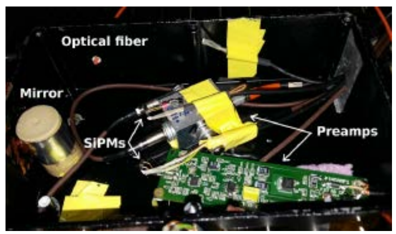
G. Eigen

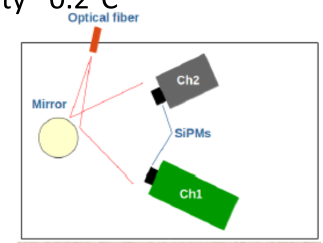
- The gain of SiPMs increases with V_{bias} and decreases with T
- For stable operation, the gain needs to be kept constant, especially in large detectors such as an ILC/CLIC analog hadron calorimeter with 10^6 channels

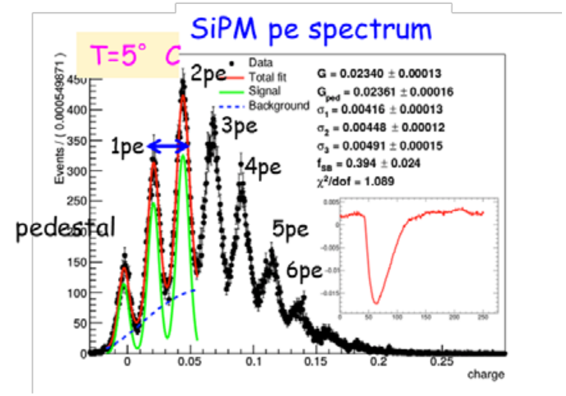
The method is to adjust V_{bias} when T changes
➔ this requires knowledge of dV/dT that can be determined from measurements of dG/dV & dG/dT

Worked in climate chamber at CERN, temp stability ~0.2°C

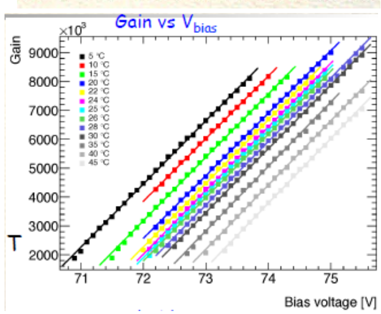




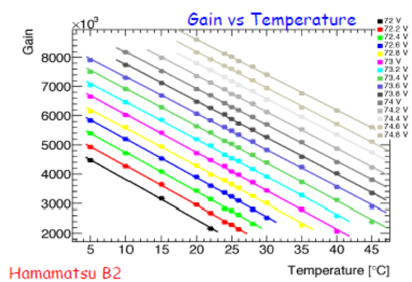


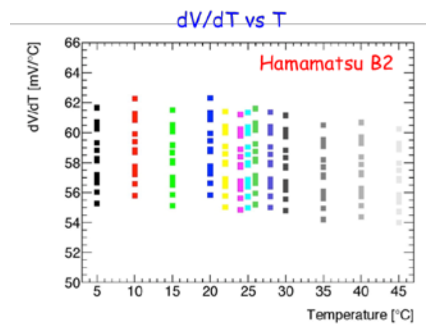


dG/dV Measurements



dG/dT Measurements

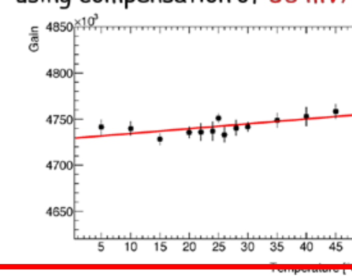




dV/dT=(58.15±0.10$_{stat}$±0.51$_{sys}$) mV/°C

Test of Gain Stabilization

- Adjust V_{bias} with regulator board using compensation of 58 mV/° C



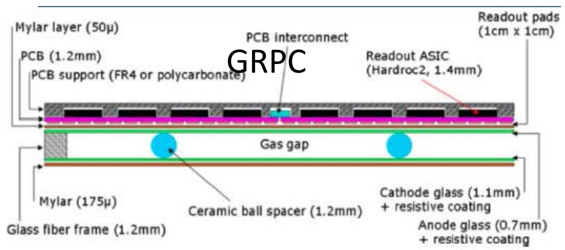
- Gain is uniform in 5° C-45° C T range
➔non-uniformity is ⊕0.1%

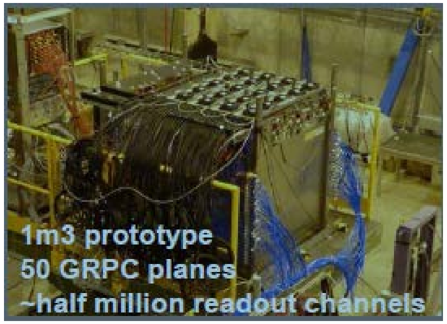
Studies also carried out for:
- Hamamatsu LCT4 (with trenches to suppress xtalk)
- KETEK SiPM W12

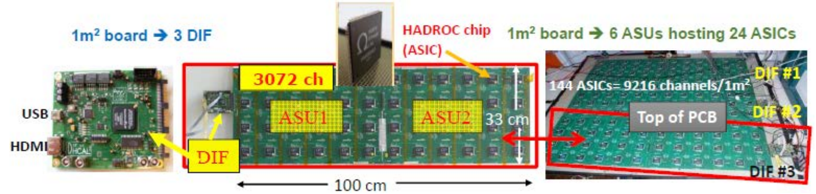
Semi Digital HCal

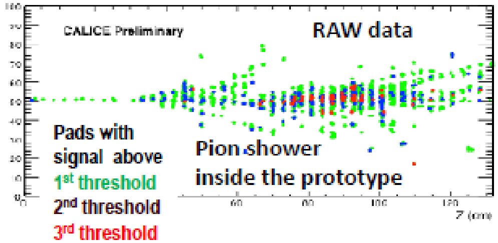
M.C Fouz

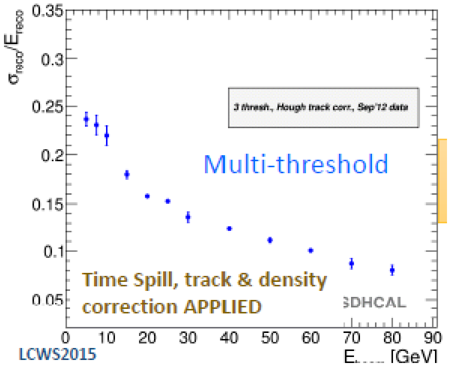
Readout 1m2 GRPC prototypes (Electronics embedded in the detector)

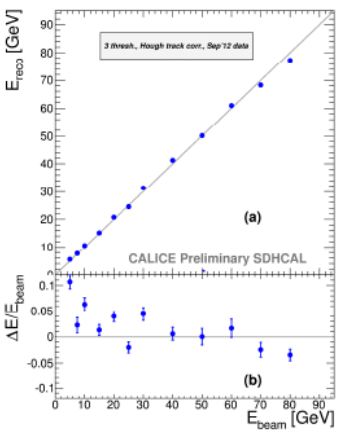


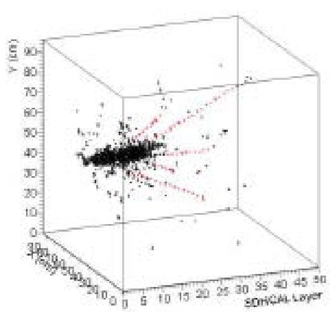




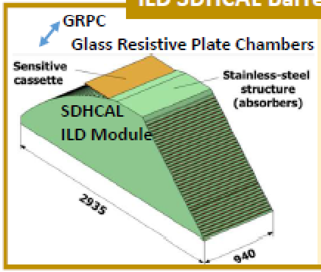






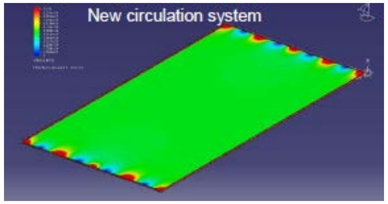


ILD SDHCAL Barrel Module Design



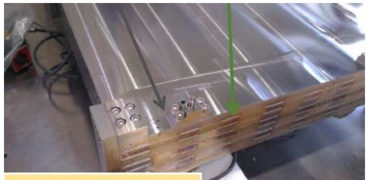
Stainless still plates
up to ~3x1m2
15mm thick,
<1 mm planarity

Assembled together with lateral **spacers** by **welding**



Main Differences

1m3 prototype	New Prototype
~1x1m2 plates 51 plates ***Bolts***	~3x1m2 plates 4 plates ***Welding***



Prototype after welding

Use of electron beam welding

A **new prototype** with **less planes but bigger chambers** will be build.
The prototype should be **closer to the ILD final design**

Arbor PFA - SDHCAL

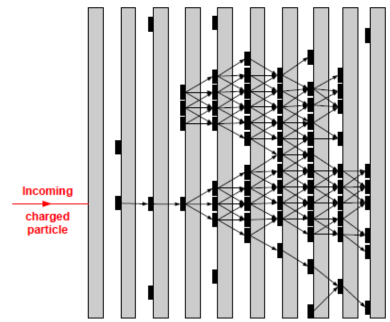
E. Remi

Provides a dedicated API for Arbor algorithms built on top of PandoraSDK APIs.

Match the PandoraPFA package structure :

- PandoraSDK : toolkit for generic PFA development
- PandoraMonitoring (optionnal) : ROOT Eve event display designed for PFA
- **ArborContent** : the algorithm contents (connector seeding, cleaning, tree associations ...)
- **MarlinArbor** : Marlin processor implementation for ArborContent

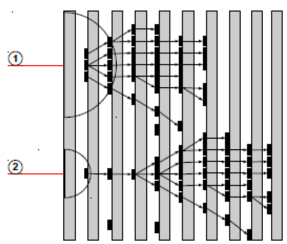
Particle Flow Algorithm based on hadronic shower **tree-like topology**.

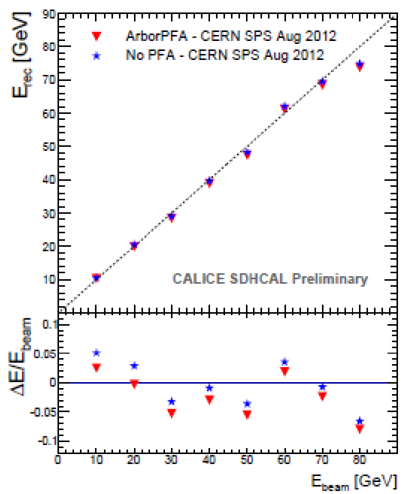


⑥ Track-to-tree association

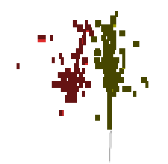
■ Association between tracks and trees performed with simple criteria :

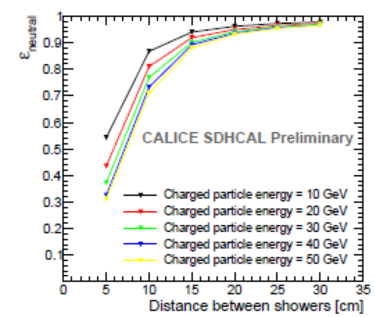
- Distance between a tree seed and track extrapolation to the calorimeter front face.
- Track momentum - tree energy comparison
- Handling of special cases as early interactions





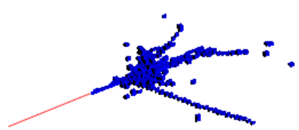
Overlaid showers





Reconstruction inputs

- Data : CERN SPS 2012 - August-September
- Particles : $h^{\pm}$
- Energies : [10 ; 80] GeV by steps of 10 GeV
- "Fake" track generated :
  - $\vec{p} = (0, 0, E_{beam})$
  - Entry point $\vec{e}$: barycentre (b_x, b_y) of hits in the 5 first layers $\rightarrow \vec{e} = (b_x, b_y, z_{front})$
- No magnetic field ($\vec{B} = \vec{0}$ T)



Conclusion

- Particle flow algorithm development based hadronic shower tree topology for the SDHCAL prototype
- Performance extraction for single particle - OK
- Performance extraction for two overlaid particles - OK till 5 cm

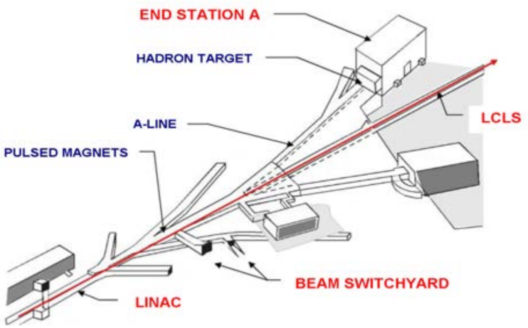
BeamCal – radiation damage

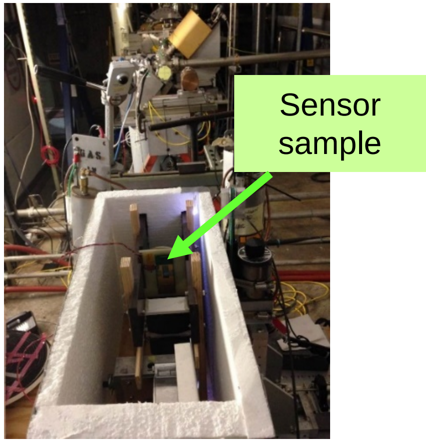
B. Schumm

Motivation

BeamCal maximum dose ~100 MRad/yr
BeamCal is sizable: ~2 m^2 of sensors.
A number of ongoing studies with novel sensors: GaAs, Sapphire, SiC
➔ Are these radiation tolerant?
➔ Might mainstream Si sensors in fact be adequate?

Results from the SLAC ESTB T-506 Irradiation Study





Embed sample sensors in tungsten:

"Pre-radiator" (followed by ~50 cm air gap) spreads shower a bit before photonic component is generated

"Post-radiator" brings shower to maximum just before sensor

"Backstop" absorbs remaining power immediately downstream of sensor

➔ Realistic EM and hadronic doses in sensor, calibrated to EM dose

Dose of 90 Mrad

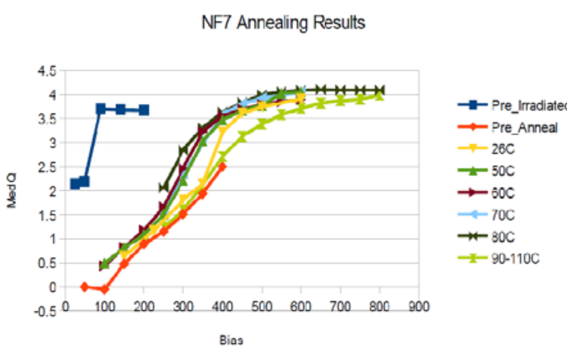
GaAs

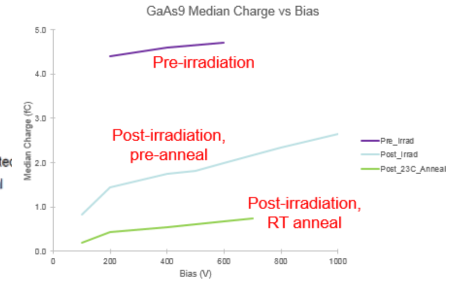
Have irradiated and several Si sensors to as much as 300 Mrad, and GaAs to 20 Mrad.

Si sensors show fair charge collection after ~3 years irradiation; of order 0.05W/cm^2 to bias

GaAs charge loss significant at 6 Mrad and substantial at 21 Mrad. Significant loss from mild annealing. Explore further annealing…

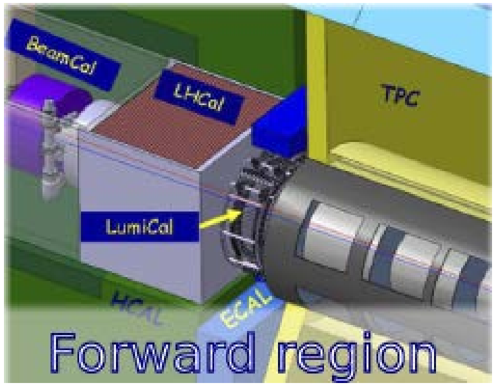
SiC sensor irradiated to 100 Mrad; awaiting I-V and CCE study

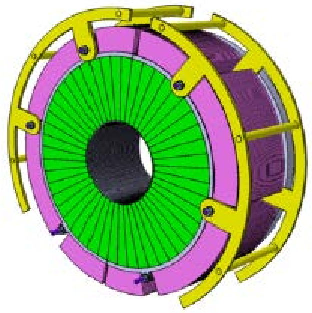


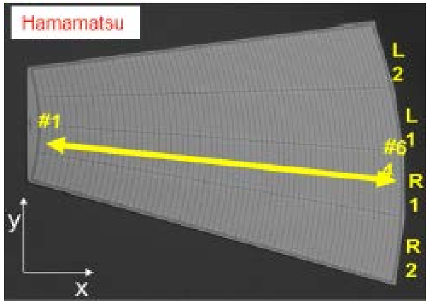


LumiCal – beam tests

A. Levy





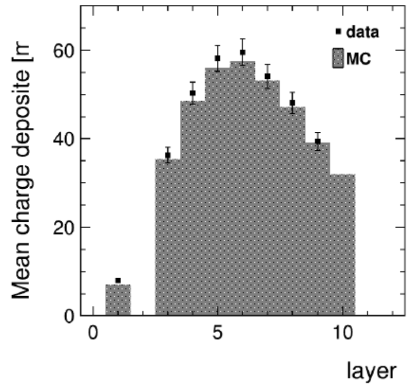


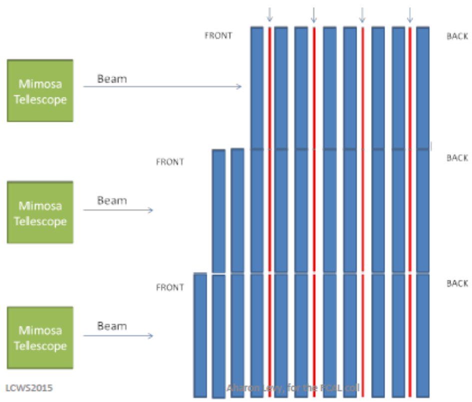
Optimisation of the design of the very forward region of LC detector

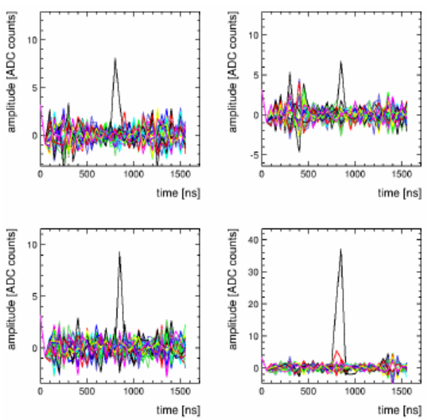
- Precision luminosity measurement
- Fast feedback and beam tuning
- Detector hermeticity

Test and demonstration, for the first time, a multi-plane operation of the prototype forward detector system.

Runs/ events	e- & μ-	Hadron
Configuration 1	75 / 30k	4/20k
Configuration 2	60/36k	1/2k
Configuration 3	55/45k	8/38k







to do:

- Molière radius…
- Compare hadron, muon and electron runs.
- Apply clustering and reconstruct showers for spatial and angular resolution.
- ……….

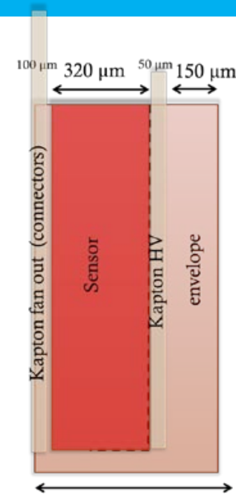
Ultra compact LumiCal

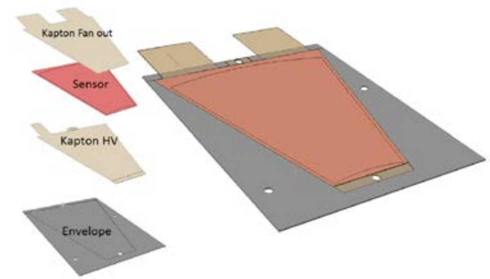
Y. Benhammou

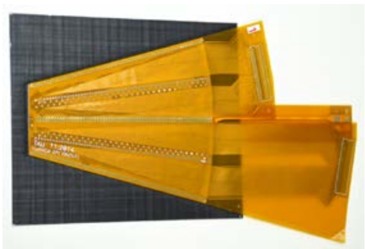
Current LumiCal modules are based on 3.5 mm thick PCB : compactness is an essential requirement to provide small Molière radius/accurate shower position reconstruction.

In current LumiCal conceptual design the space between absorbers is 1 mm!

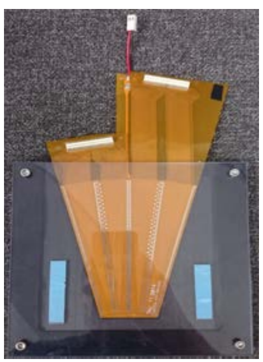
Easy to mount on tungsten planes







Carbon fiber chosen for mechanical support

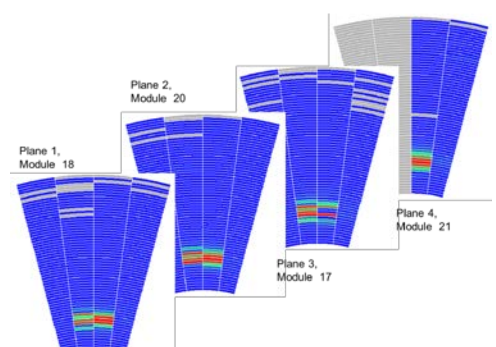


Module 18 tests @ CERN

Readout whole sensor (256 pads) with APV

DESY Test Beam

4 planes with thin sensor scotched on tungsten
FEB : APV chip based
DAQ : SRS system, designed by RD51 collaboration.
Silicon telescope : 6 planes with MIMOSA chip



Test beam analysis started

Dual Readout Calorimetry (ADRIANO)

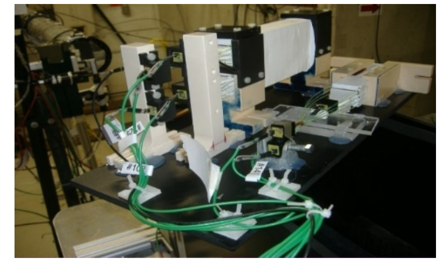
C. Gatto

Scintillating and Čerenkov light in *OPTICALLY SEPARATED MEDIA:* ->non-homogeneous detector

- Use the absorber as Čerenkov component of dual-readout
- Use scintillating fibers for the second component
- Control the scintillation/Čerenkov with appropriate pitch between fibers

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

2011 – Series of prototypes tested at FTBF



Use glass for Cerenkov component – WLS fiber readout

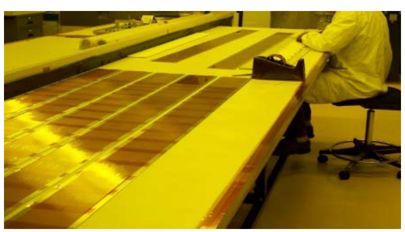
2014 – example of 23 groove prototype

	ADRIANO 2014A	ADRIANO 2014B
Scintillation L.Y.	523 pe/GeV	256 pe/GeV
Čerenkov L.Y.	354 pe/GeV	338 pe/GeV

more than adequate for 25-30%/sqrt(E) calorimetry

Nov. 2015 test Beam at Fermilab

2015 Program: ADRIANO for ILC (SiD)



Scifi ribbon built on 100% cotton paper (no acid)

Grooved lead glass slices

T1015 2016-2017 program

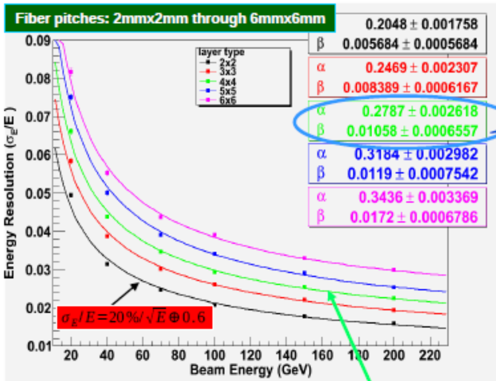
- Čerenkov light yield already exceeded requirements for ILC and for High Intensity experiments
- Next big challenge is to find a faster construction technique to reduce the construction costs
- Rolled glass appears to be the most promising
- Once the technique is in place, two new detectors will be built

ADRIANO – Performance simulations

A. Mazzacane

ADRIANO EM Resolution

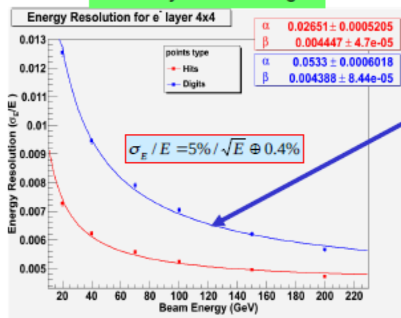
Energy resolution with triple readout



$\sigma_E/E = 20\%/\sqrt{E} \oplus 0.6$

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

Use only Cerenkov light



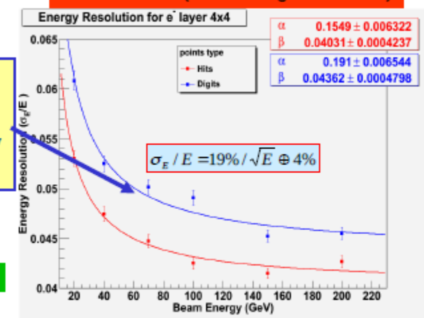
$\sigma_E/E = 5\%/\sqrt{E} \oplus 0.4\%$

Blue curve includes:

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

ILCroot simulations

Dual-readout (scintillating+Cerenkov)

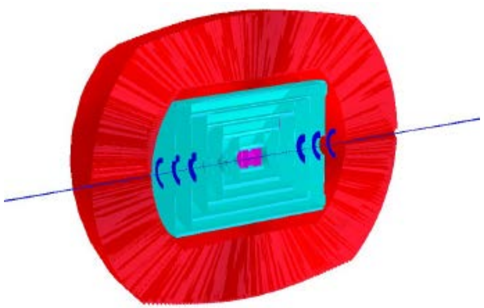


$\sigma_E/E = 19\%/\sqrt{E} \oplus 4\%$

ADRIANO does not need a front EM section

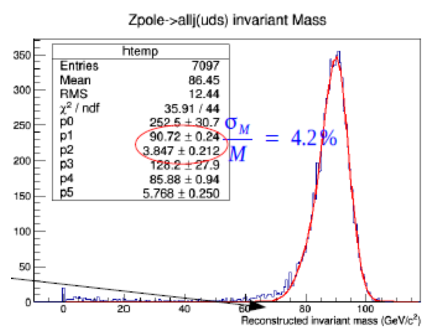
If Čerenkov ligth yield is large enough

ADRIANO for Sid Details (ilcroot simulation)

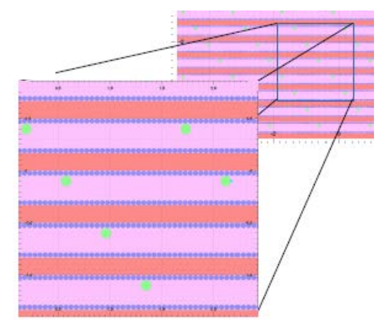


ADRIANO

- 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

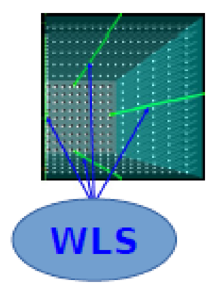


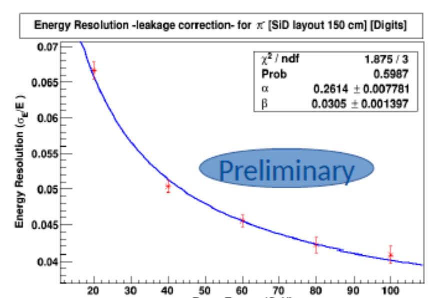
$\frac{\sigma_M}{M} = 4.2\%$



Add Pb layers to reduce λ_{int}

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



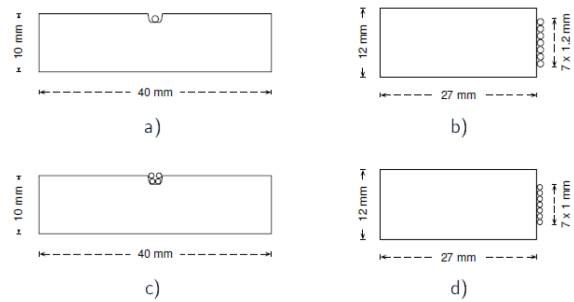


Muon system – position resolution

S. Lukic

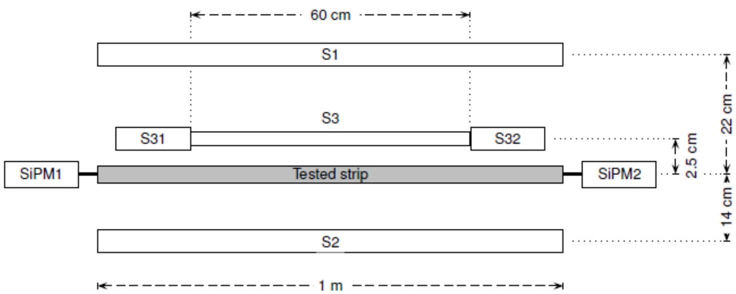
Motivation

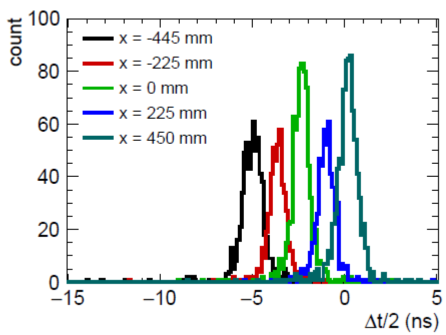
- Few tests so far of possible muon-system sensors for future colliders
- Instrumented area very large and difficult to reach for maintenance – a reliable and economical solution would be of great advantage
- Long scintillator strips (up to ∼3 m) with SiPM readout interesting for reliability, reasonable construction and operation costs and relatively low number of readout channels
- Measurement of hit position along the strip offers a possibility to resolve multiple hits and limit position uncertainty

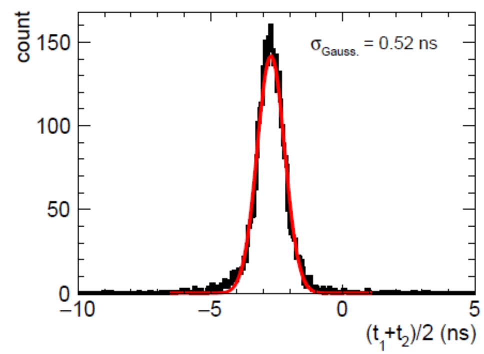


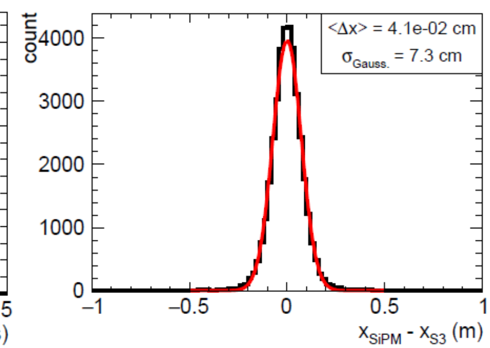
Configuration	Photon yield per muon (photoelectrons)
A	10
B	19
C	20
D	>30

Test setup with reference counter/PMTs









Conf.	side #	Yield per μ (photoel.)	σ_x (setup 1) (cm)	σ_x (setup 2) (cm)	σ_t (ns)	v^* (cm/ns)
C	1 2	21 20	14.8	14.8	0.91	18.1
D	1 2	31 36	7.7	7.3	0.52	17.2