Pre-showring Techniques

Apollo Go
National Central University, Taiwan
Erice 2003

Outline

- Classifying Pre-showering Techniques
  - By purpose
  - By Technique
  - By Technology

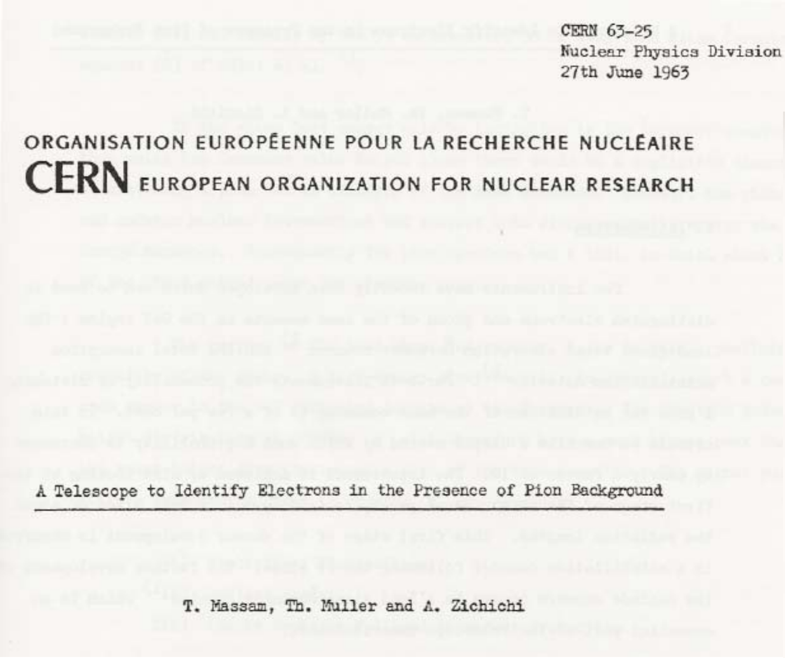
- Present generation of Pre-showering detectors
  - LHCb
  - ATLAS
  - CMS

- Pre-showering technique for SLHC
  - Case study: CMS Preshower

Pre-showering Techniques

Preshower detectors are of many types and purposes: the only unifying thing is pre (before) showering (Calorimeter)!

- One of the preshower was by Zichichi on e/$\pi^{\pm}$ separation looking at the early shower development.



CERN 63-25
Nuclear Physics Division
27th June 1963

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

A Telescope to Identify Electrons in the Presence of Pion Background

T. Massam, Th. Muller and A. Zichichi

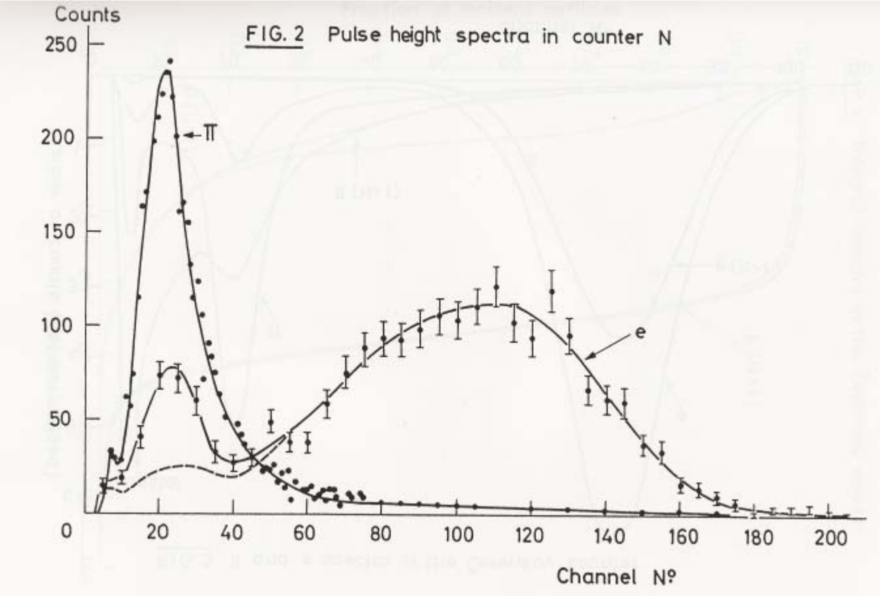


FIG. 2 Pulse height spectra in counter N

Preshower Classifications

By Purposes:

- e/π separation
- e/γ separation
- γ/π^0 separation
- Calorimeter energy correction.

By Technique:

- Shower foot determination (shower position)
- Early shower determination (longitudinal development)
- Early shower energy determination

By Technology:

- Lead/scintillators/fiber
- Lead/silicon
- Liquid Argon

$e^{\pm}/\pi^{\pm}$ separation

- The detector consists of lead and scintillator. It samples the early part of the shower (1-3 radiation lengths in Pb), where the electron shower have begun to develop; but the pion shower is so shallow that only a small fraction of the charged pions have interacted.

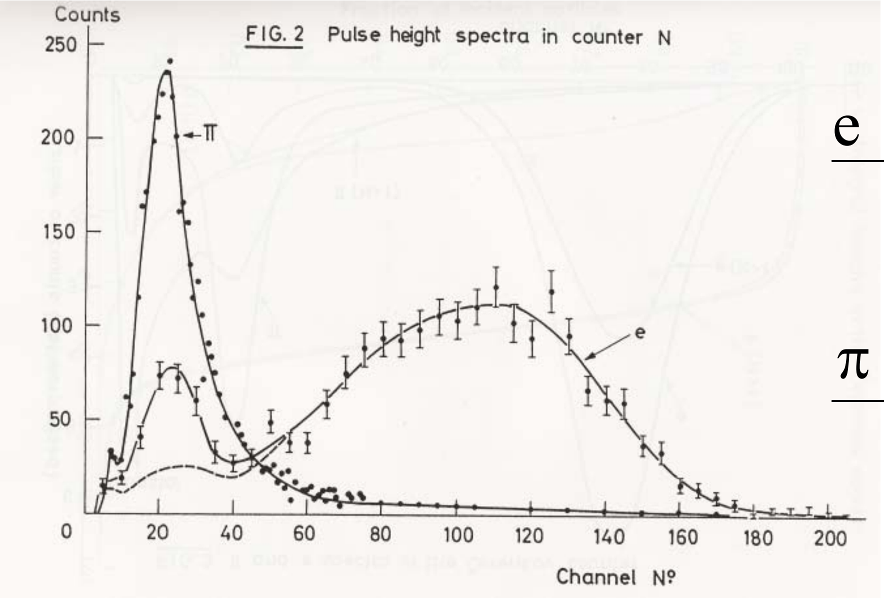
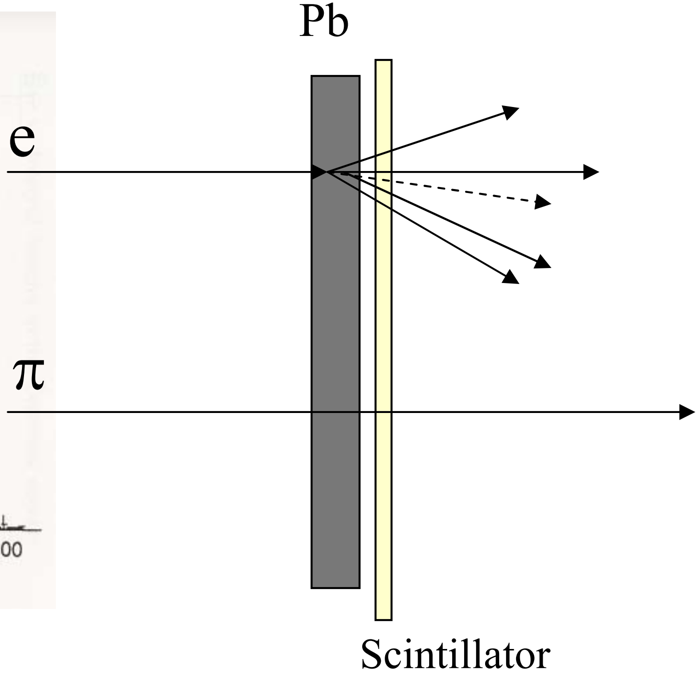
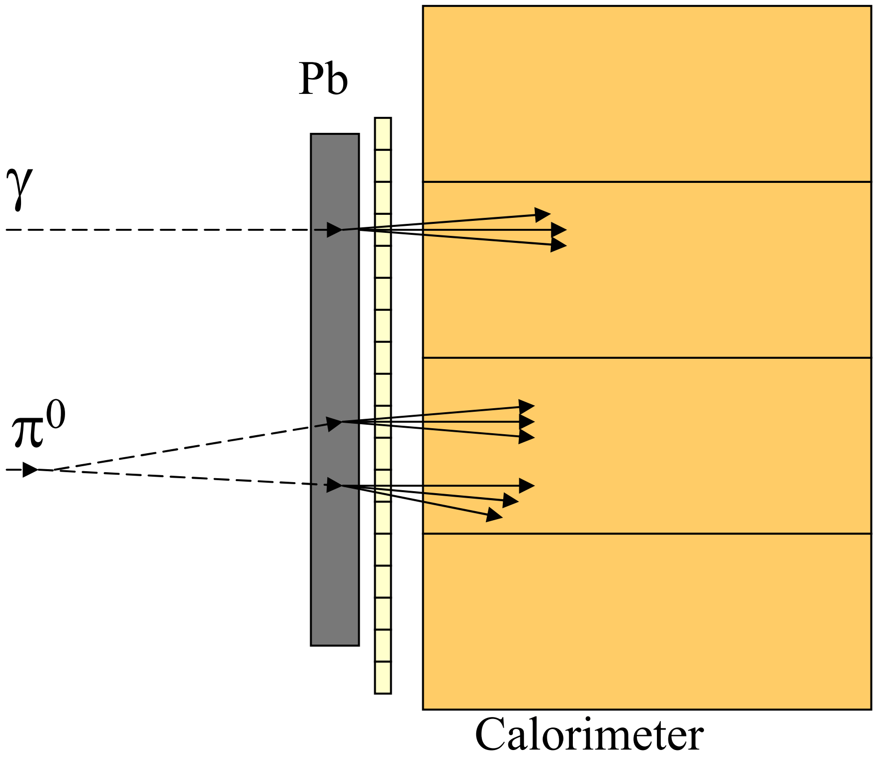


FIG. 2 Pulse height spectra in counter N



π^0/γ separation

- High energy π^0 that decays into two photons can often be confused with single photon (of double energy) because both photons go into the same calorimeter channel.
- A preshower detector with fine granularity is able to distinguish one or two photons, therefore reject π^0.



Essential for LHC's Higgs search: for $M_H<140\text{GeV}$, the main decay mode is $H\rightarrow\gamma\gamma$.

Important to reject $\pi^0\rightarrow\gamma\gamma$.

Other Purposes

e/γ separation

- A piece of plastic scintillator can do the job!
- As it is fast; can be used in the early triggers to do electron or photon rejection.

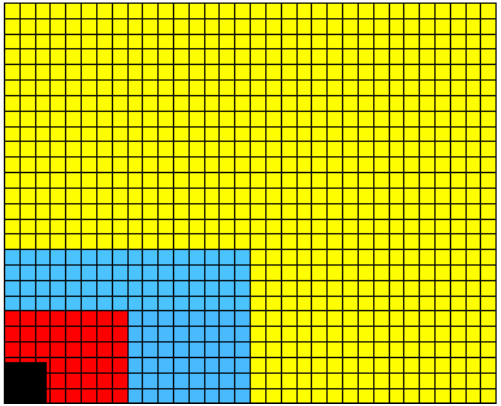
Energy Correction

- When there is considerable amount of dead material, it is necessary to has a separate energy measurement before the calorimeter in order to correct for this energy loss.
- It acts as an extra sampling layer.

LHCb: SPD & PS

LHCb has two detectors before the ECAL: SPD (scintillator pad) and PS (preshower).

- SPD is before the lead converter and PS after the lead converter.
- SPD does e/γ separation and to reduce high E_t π^0 tail
- SP is for charged π rejection
- Used in the level 0 trigger as electron trigger
- Same granularity as the ECAL



Outer section :

121.2 mm cells

2688 channels

Middle section :

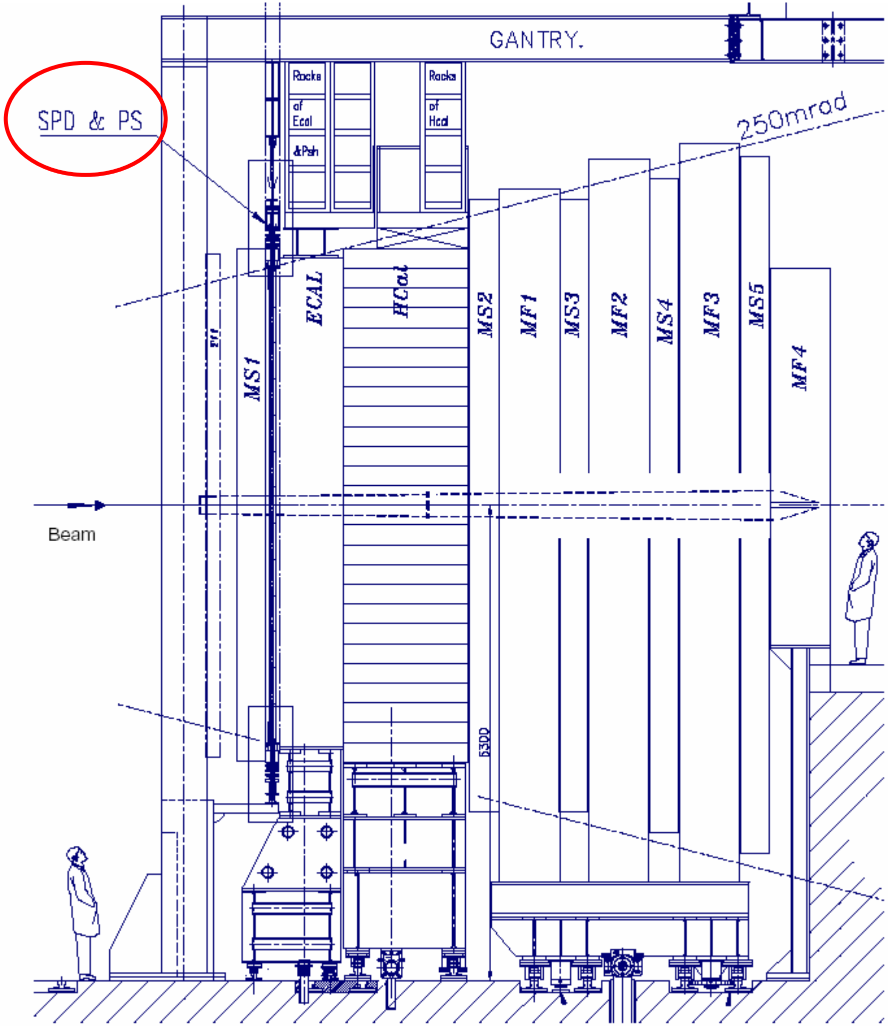
60.6 mm cells

1792 channels

Inner section :

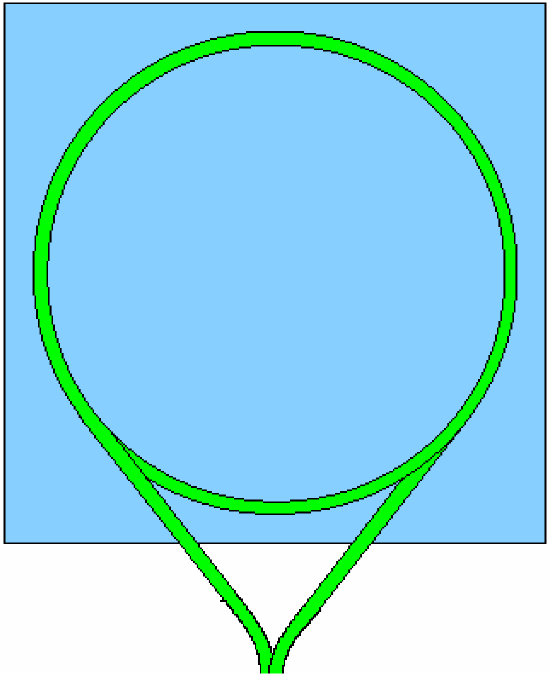
40.4 mm cells

1472 channels



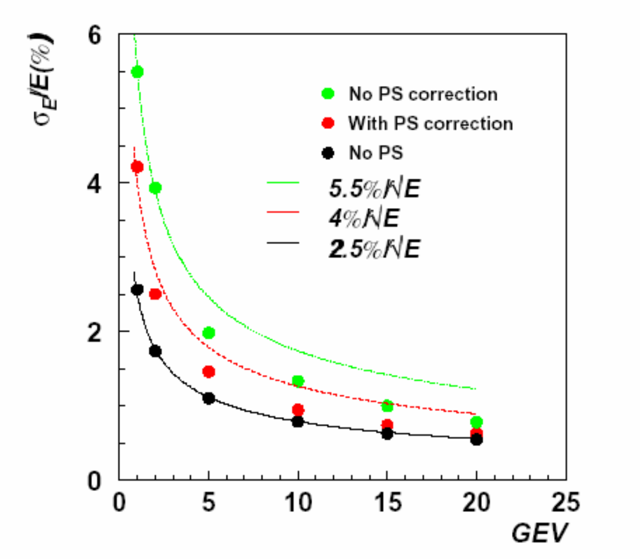
LHCb: SPD and PS

- Both are 15mm thick scintillator pad with WLS fiber in the groove and clear fibers to bring out of detector.
- read out by 8x8 multi-anode PMTs (20-30 p.e./MIP).
- SPD acts as veto counter (1bit), used simple discriminator set at ½ MIP.
- PS has a dynamic range of 0-100MIP and is digitized by 10 bit ADC.
- Optimize lead converter thickness to have electron showering but not the charged π (MIP)
- $2X_0$ lead (12mm) was chosen not to worsen the $10\%/\sqrt{E}$ energy resolution.

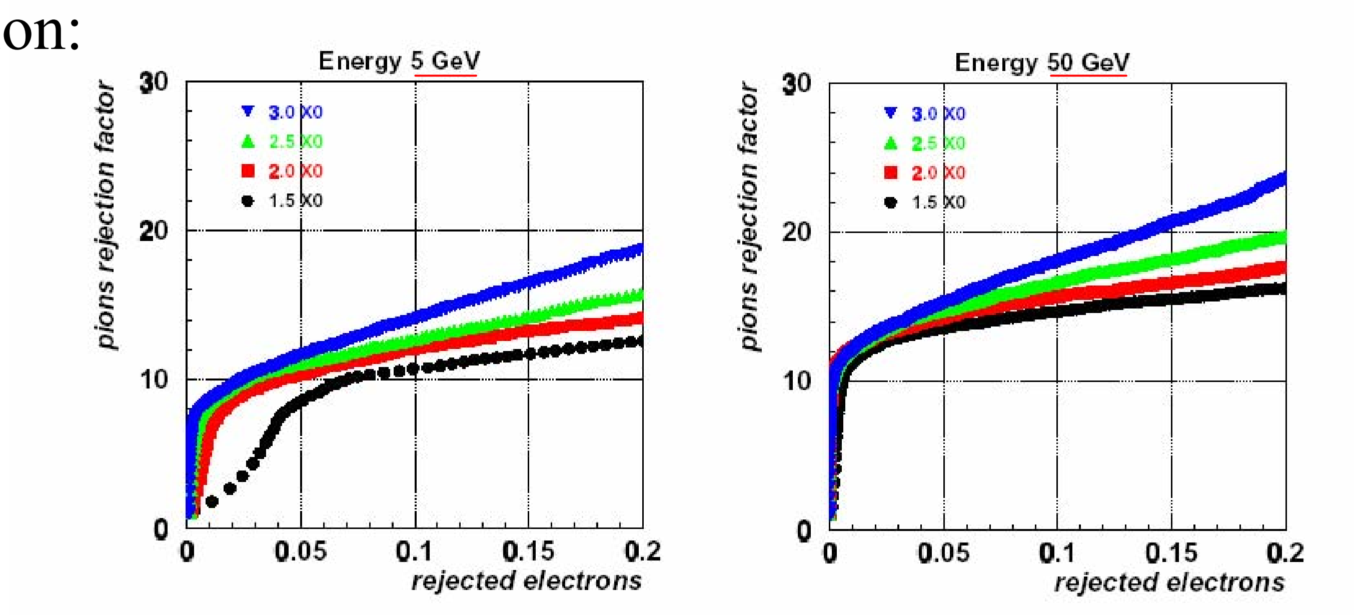


LHCb PS Performance

Adding extra sampling layer degrades the energy resolution:

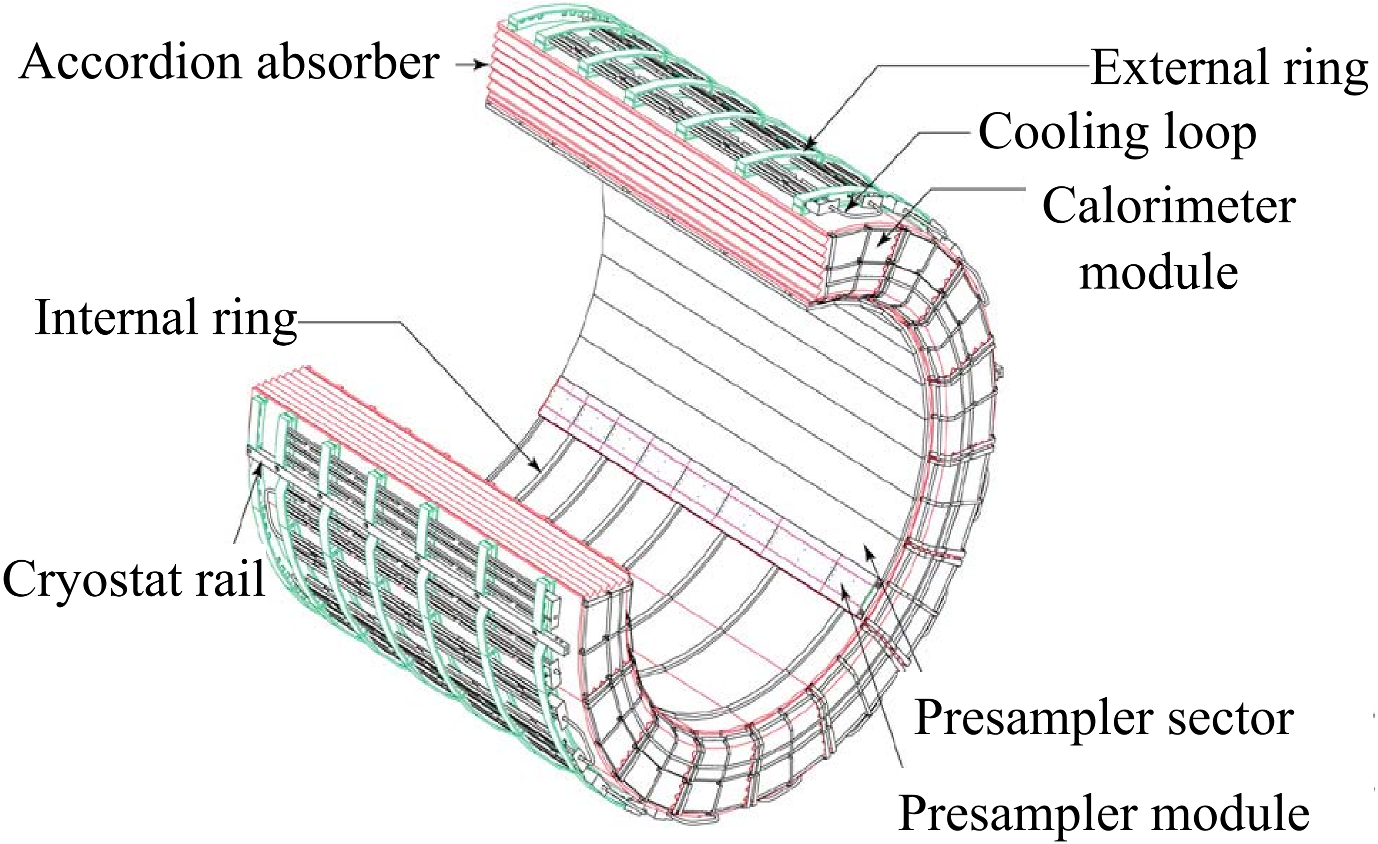


Pion rejection:



ATLAS EM Calorimeter

Liquid Argon “accordion” calorimeter.

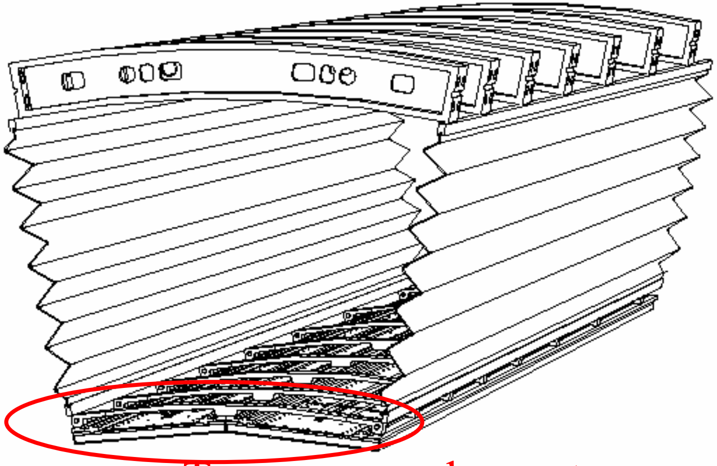


ATLAS Presampler

Purpose:

In order to reach a sufficient energy resolution, one has to correct for the energy loss upstream of the electromagnetic calorimeter (inner detector, solenoid, cryostat wall: $1.8X_0$ at $\eta=0$ to $4.4X_0$ at $\eta=1.5$). For this purpose, a separate presampler detector will be used. It acts as a thin (11 mm) active layer of liquid argon, which provides a first sampling of the showers in front of the electromagnetic calorimeter.

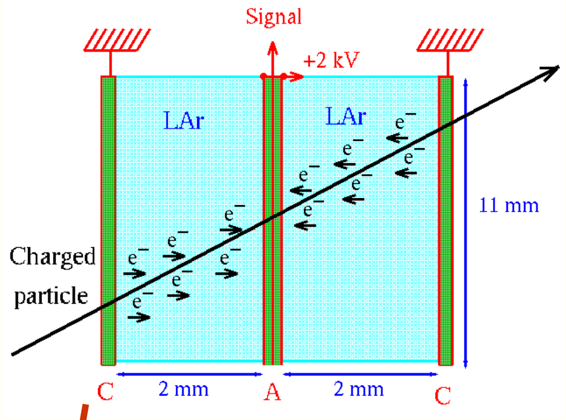
It is used only for energy measurement, so has coarser granularity than the calorimeter: $\Delta\eta \times \Delta\phi = 0.025 \times 0.1$

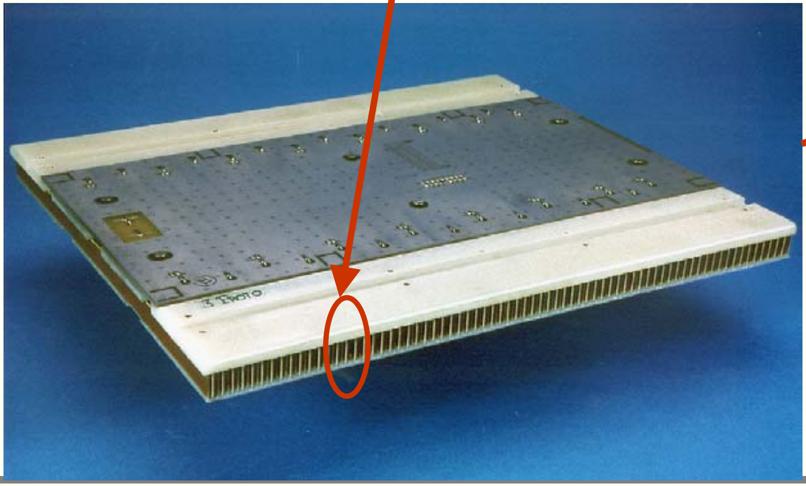


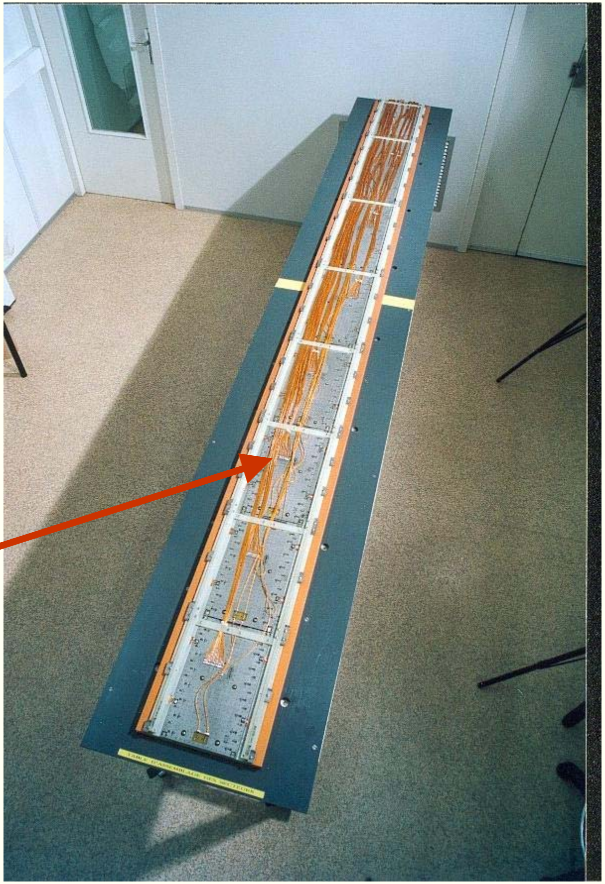
Two presampler sectors

ATLAS Presampler

- 64 sectors (3100×280 ×35); 512 modules of 8 types
- ~(50000 anodes + 50000 cathodes)
- Granularity: $\Delta\eta\times\Delta\phi=0.025\times0.1$; (# of channels: 7808)



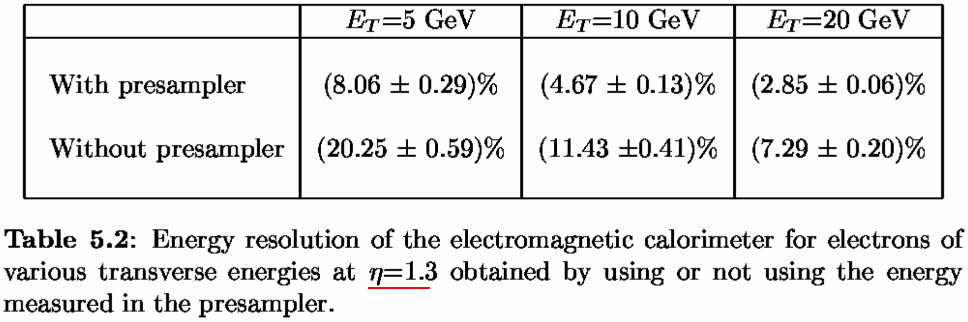




ATLAS Presampler Performance

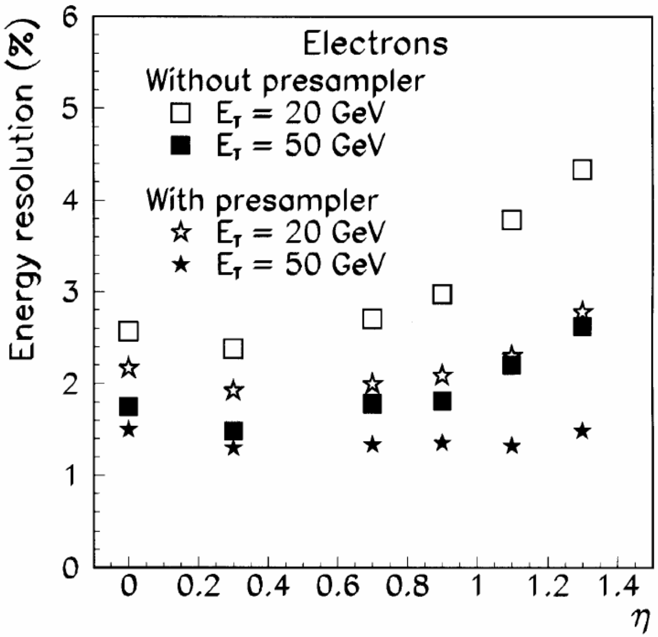
The presampler does the job well in correcting for energy loss upstream:

Amount of upstream material	0.7 X_0	1.7 X_0	2.7 X_0
Energy resolution without presampler	1.03 ± 0.02%	1.43 ± 0.04%	2.02 ± 0.05%
Energy resolution with the presampler	1.01 ± 0.02%	1.10 ± 0.04%	1.33 ± 0.03%



	E_T=5 GeV	E_T=10 GeV	E_T=20 GeV
With presampler	(8.06 ± 0.29)%	(4.67 ± 0.13)%	(2.85 ± 0.06)%
Without presampler	(20.25 ± 0.59)%	(11.43 ±0.41)%	(7.29 ± 0.20)%

Table 5.2: Energy resolution of the electromagnetic calorimeter for electrons of various transverse energies at η=1.3 obtained by using or not using the energy measured in the presampler.



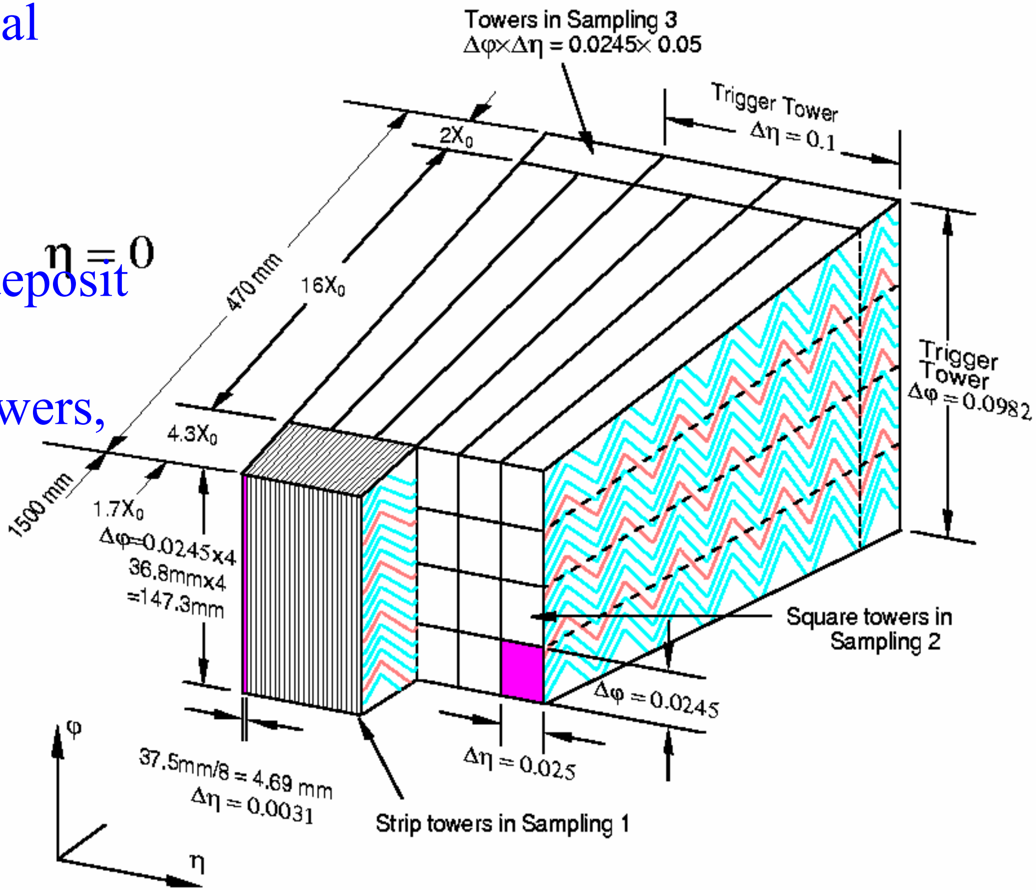
ATLAS EM Calorimeter

"Accordion" geometry, Liquid Argon Calorimeter with 3 radial compartments:

> S1 (Strips) : γ/π^0 separation
  ($\Delta\varphi\times\Delta\eta=0.1\times0.0031$)

> S2 (Middle) : main energy deposit
  ($\Delta\varphi\times\Delta\eta=0.0245\times0.025$)

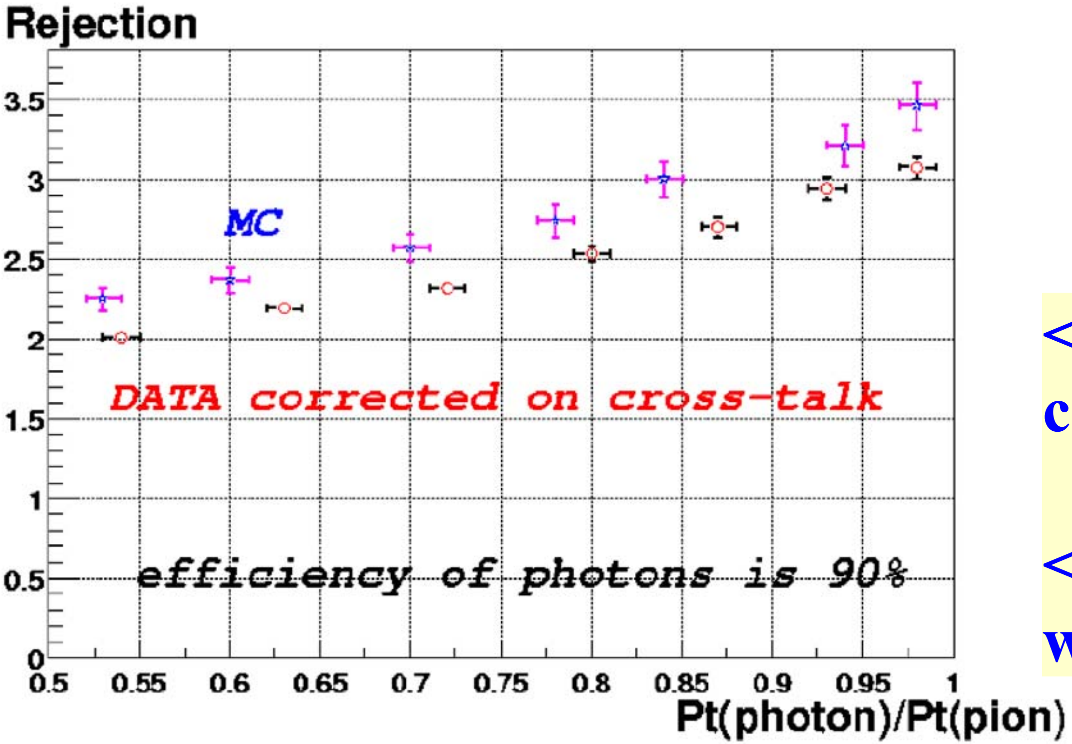
> S3 (Back) : high energy showers, hadr/em separation
  ($\Delta\varphi\times\Delta\eta=0.0245\times0.05$)



Actually, the S1 compartment can also be considered "preshower" as it is before main energy deposition, has fine granularity and does the job of γ/π^0 separation!

ATLAS LAr Calo: γ/π^0 separation

- Simulation of the $\pi^0 \to \gamma\gamma$ decay ($P_t(\pi^0)$=50 GeV)
- Replacement of simulated photons by real ones with the correct kinematics



- π^0 rejection for $H \to \gamma\gamma$ signal extraction

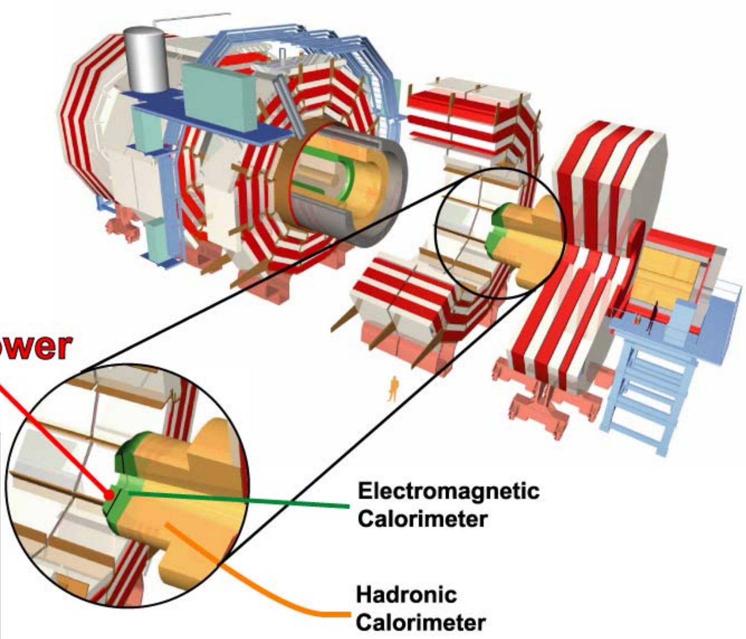
- Main use of fine η strips $\Delta\eta$=0.025/8 ~5mm

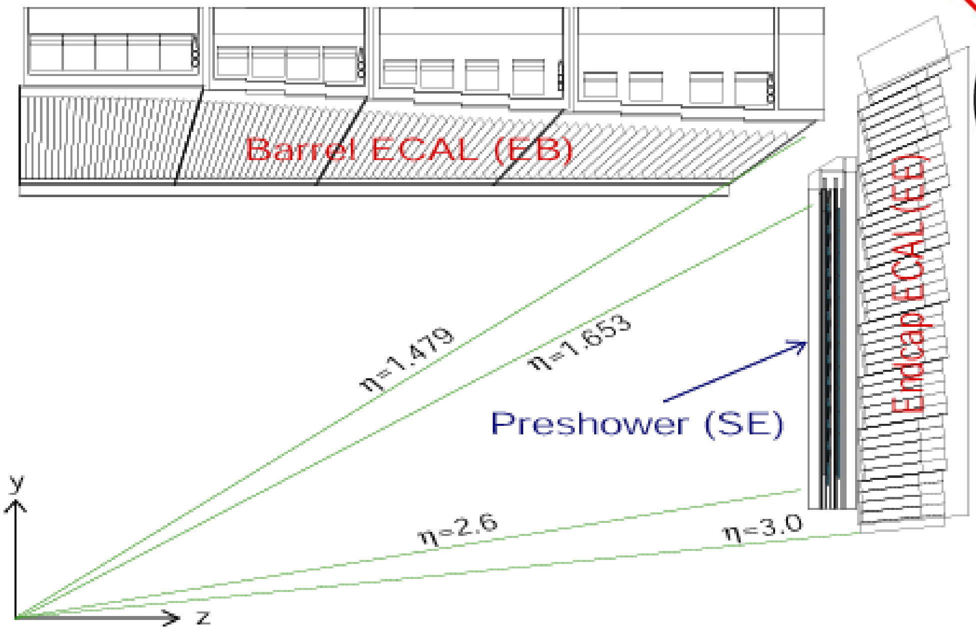
<R>=2.6 ± 0,05 for data crosstalk corrected

<R>=2.82± 0.1 for MC with electronic noise

CMS Preshower

Only in the end-cap region of CMS in front of ECAL

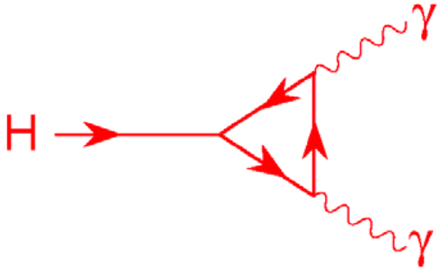




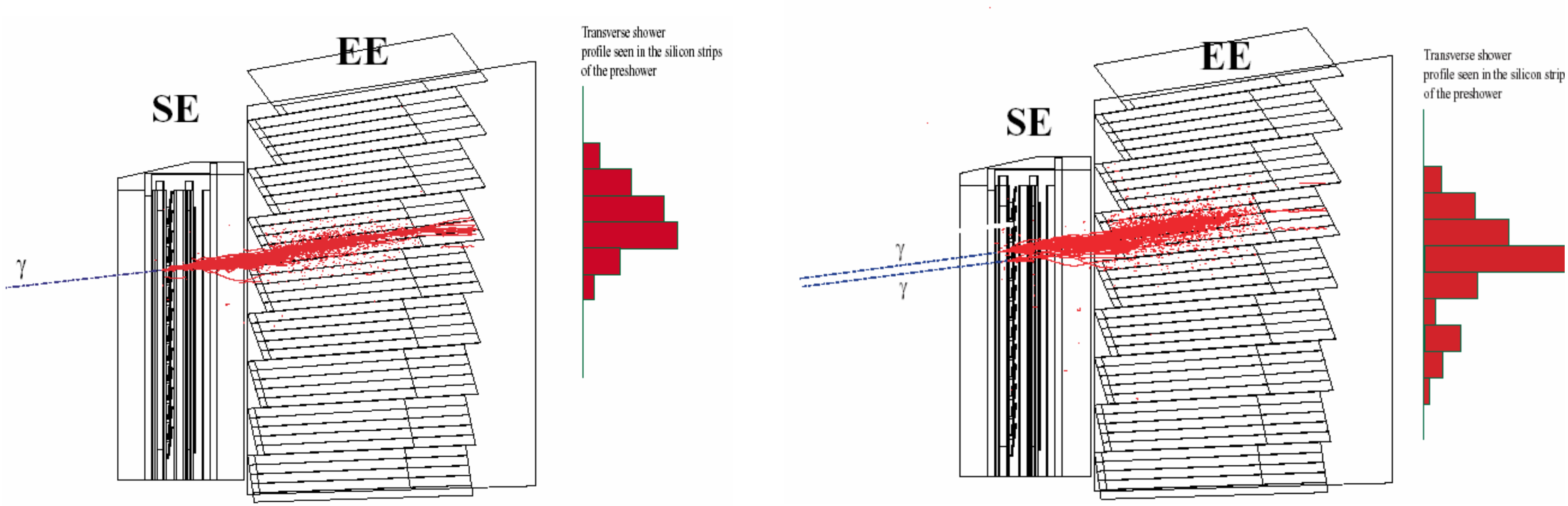
Fiducial coverage of preshower is $1.653<|\eta|<2.6$,
~ corresponding to trigger towers 20 - 26

Physics Motivation: Higgs Search

Main Purpose: to do π^0/γ separation for Higgs search in $H \rightarrow \gamma\gamma$ mode.



- For a Higgs mass <140GeV, $H \rightarrow \gamma\gamma$ is the main decay mode
- Important to be able to reject $\pi^0 \rightarrow \gamma\gamma$



The endcaps have higher particle density => ECAL towers are not fine enough => need a fine grain Preshower

CMS Preshower Requirements

Lead Converter:

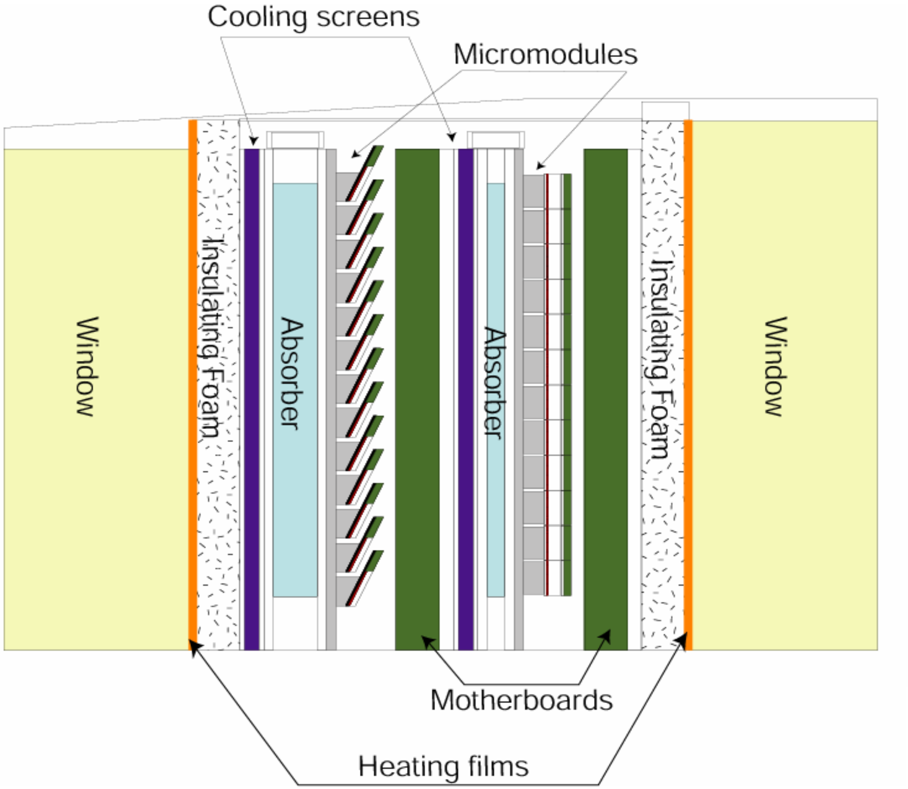
- Convert photons in a dense media. Measure early transverse shower shape in sensitive medium.
- $3X_0$ was chosen as a good compromise between conversion probability and ECAL energy resolution deterioration.

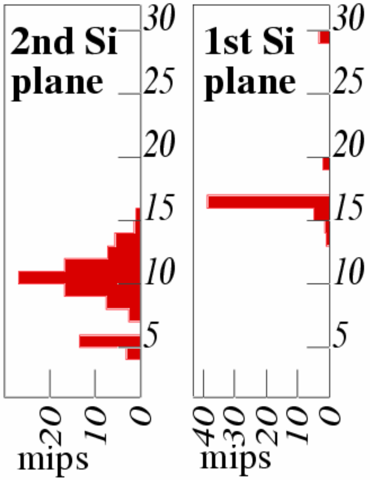
Silicon Sensor:

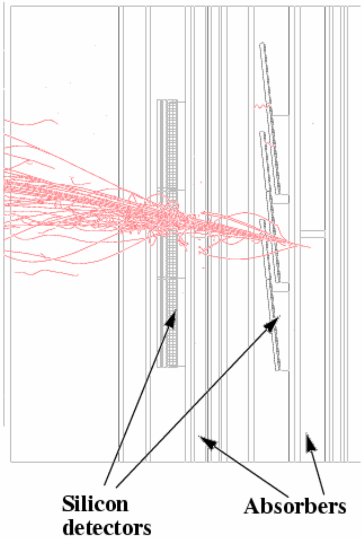
- Good granularity, fast response, good linearity, rad hard.
- Required granularity: 2mm (π^0 photons separation)
- Size: 63mm x 63mm (max for 4' wafer technology)
  32 strips of 1.9mm pitch
  Limit occupancy and inter-strip capacitance
- Single side sensor (cost) → need two sensor planes
- Minimize absorber-sensor distance (due to B field) → two absorbers planes.

Preshower Cross Sectional View

- First lead converter ($2X_0$) followed by silicon strip sensors in x direction.
- Second lead converter ($1X_0$) followed by silicon strip sensors in y direction.



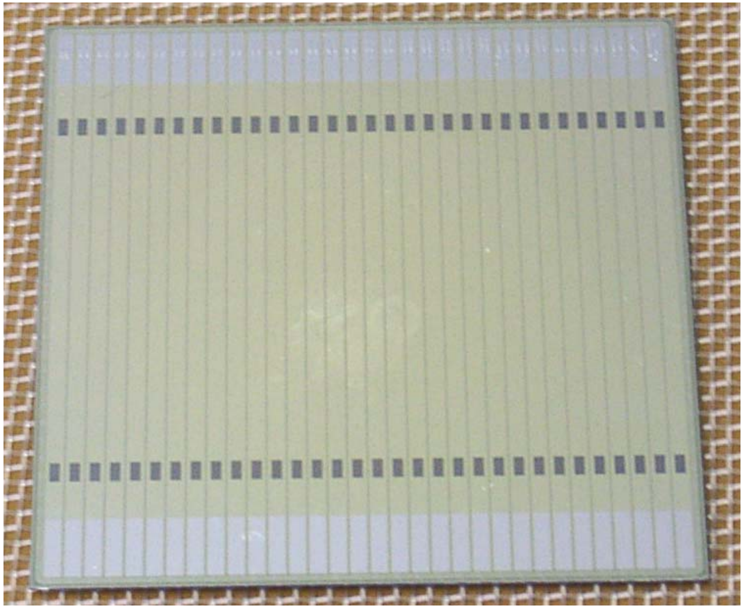




Preshower Silicon

- 63x63mm^2 , 320µm thick, 32 strips, DC coupled
- Large strip: 1.9mmx6cm (1cm^2 surface)
- Large capacitance: 50pf
- High breakdown voltage (>500V due to high operating voltage after irradiation)
- Dynamic range: 400MIPs

need ~5000 silicons (one of the largest silicon-based calorimeter!)



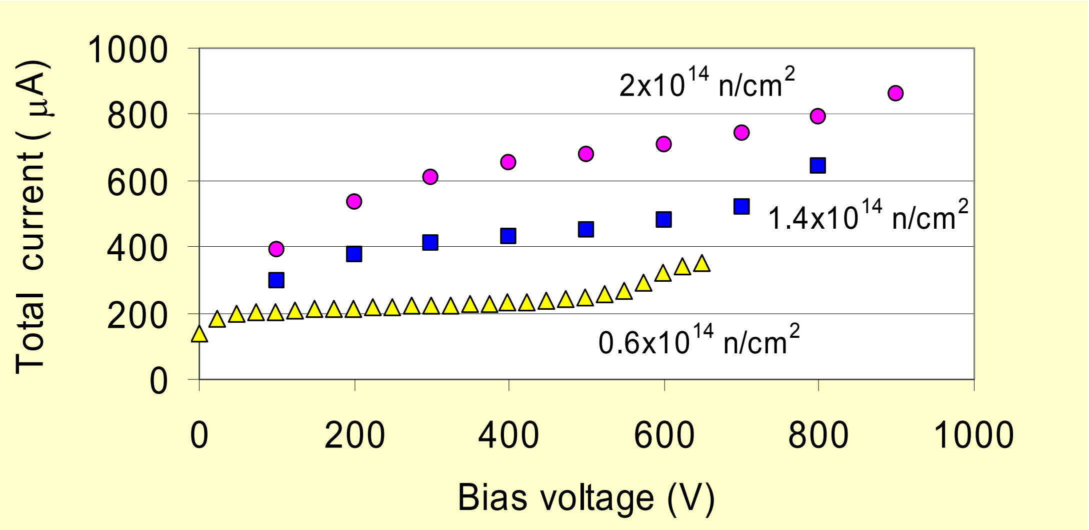
Produced at:

1. NCU/ERSO, Taiwan
2. Dubna/ELMA, Russia
3. BARC/BEL, India
4. Hammamatsu, Japan

Radiation Resistance: Leakage Current

Requirement: $2*10^{14}$ n/cm^2 after 10 years of running (at the center, 10% of sensors).

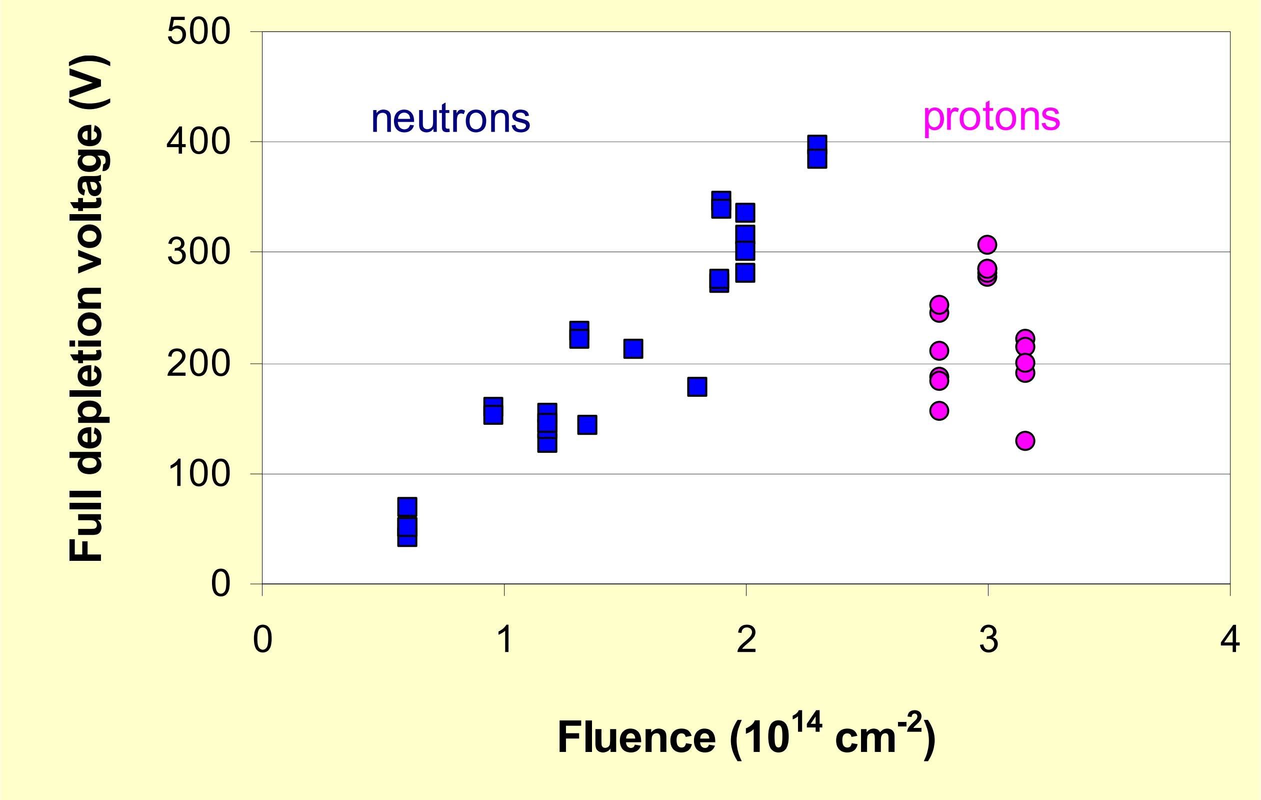
Leakage current



- Low operational temperature: -5^{0}C
- Expected leakage current at center of Preshower (10 years): 20uA/strip.

Radiation Hardness: Breakdown Voltage

Full depletion voltage increases with radiation damage (after type inversion) → high breakdown voltage.

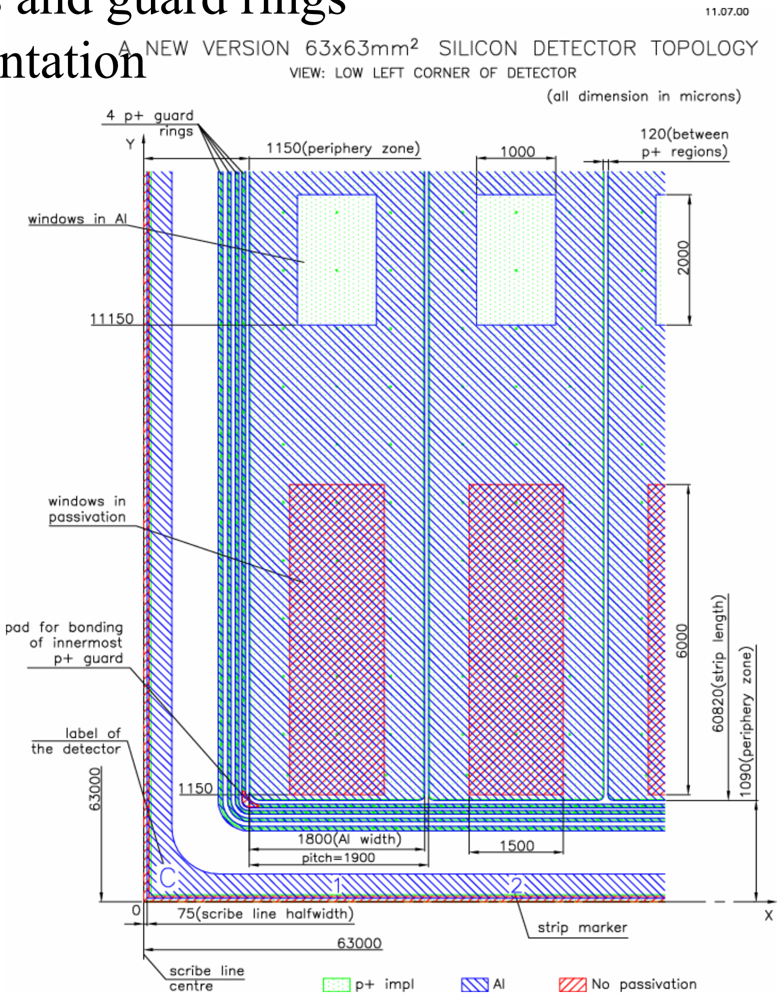


- Require breakdown voltage > 500V

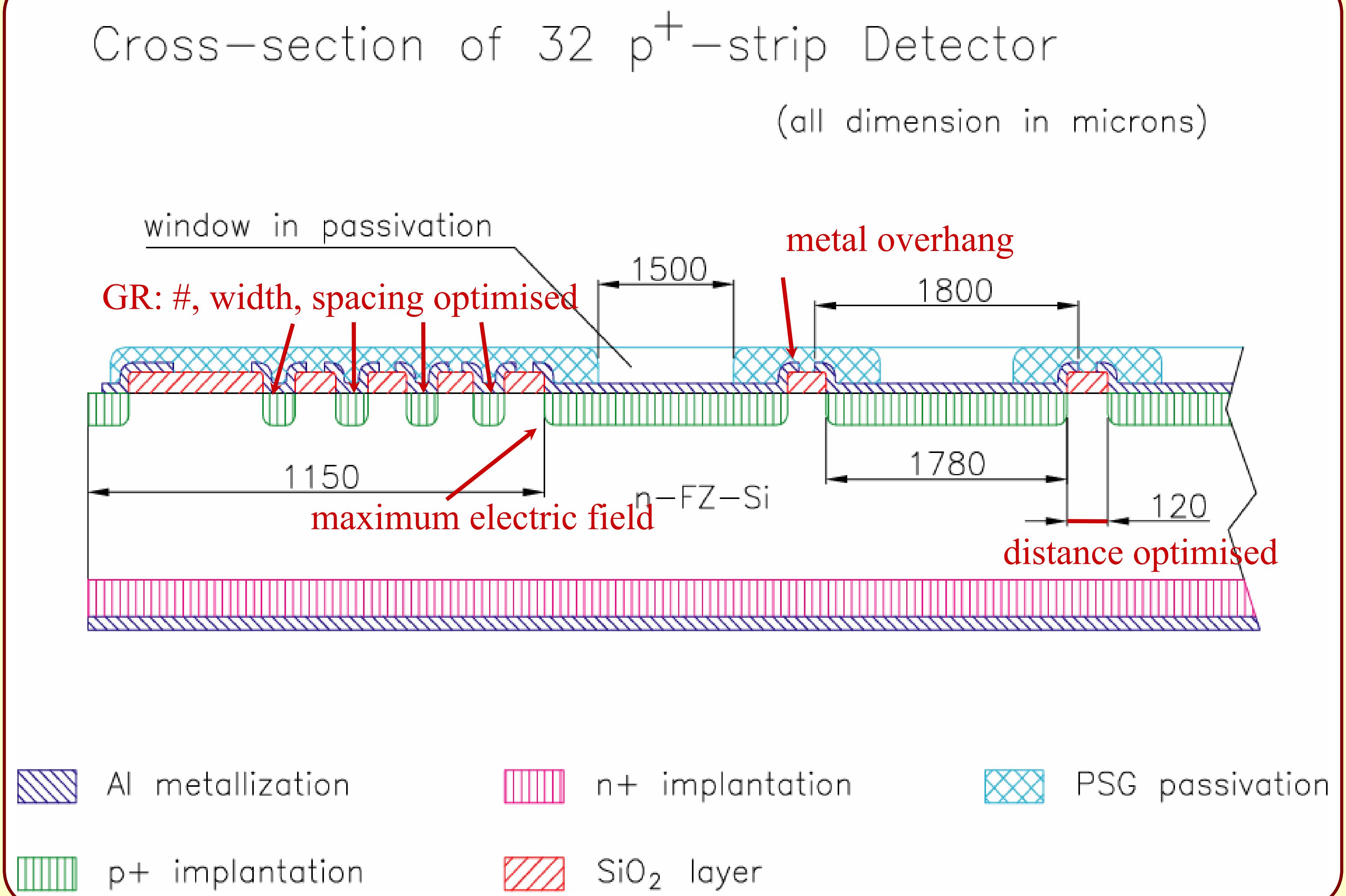
Radiation Hardness: Breakdown Voltage

High breakdown voltage design rules:

- Guard rings: number, width and spacing were simulated
- Rounded corners of all strips and guard rings
- Metal lines wider than implantation



Radiation Hardness: Breakdown Voltage



GR: #, width, spacing optimised

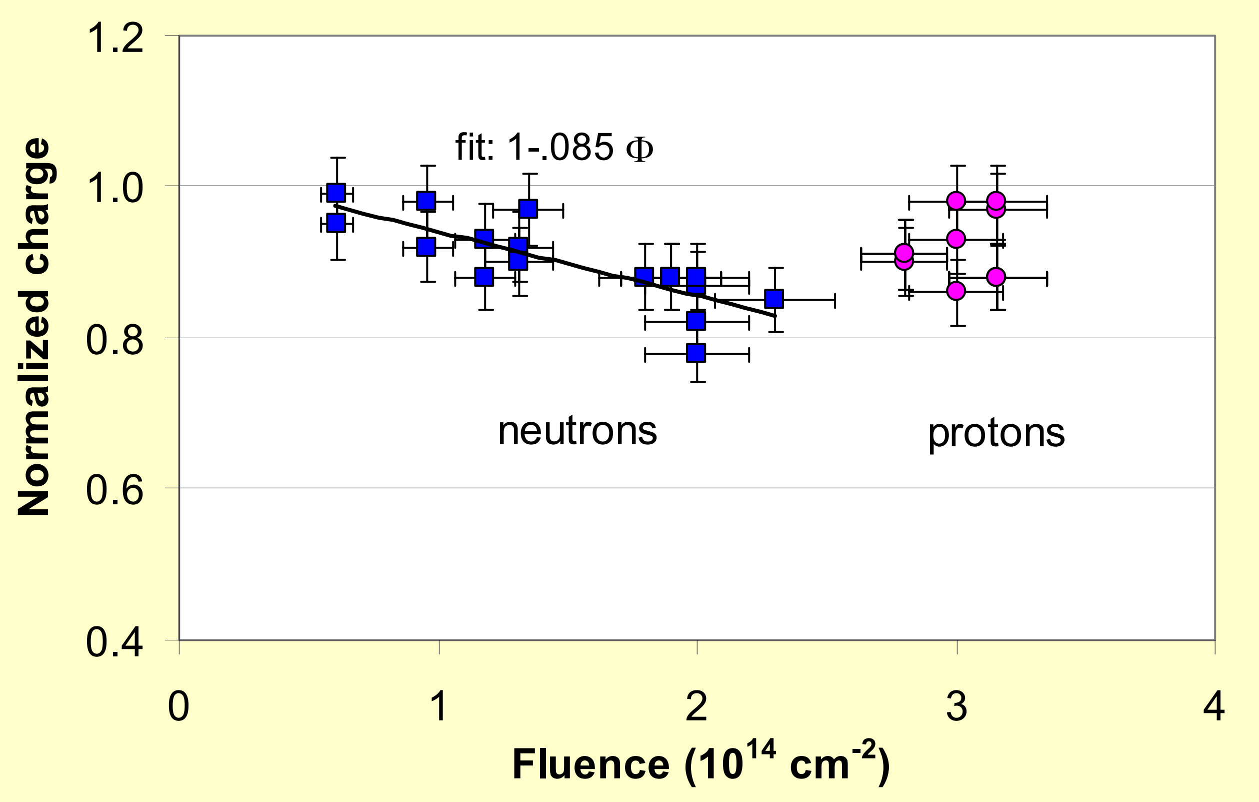
metal overhang

maximum electric field

distance optimised

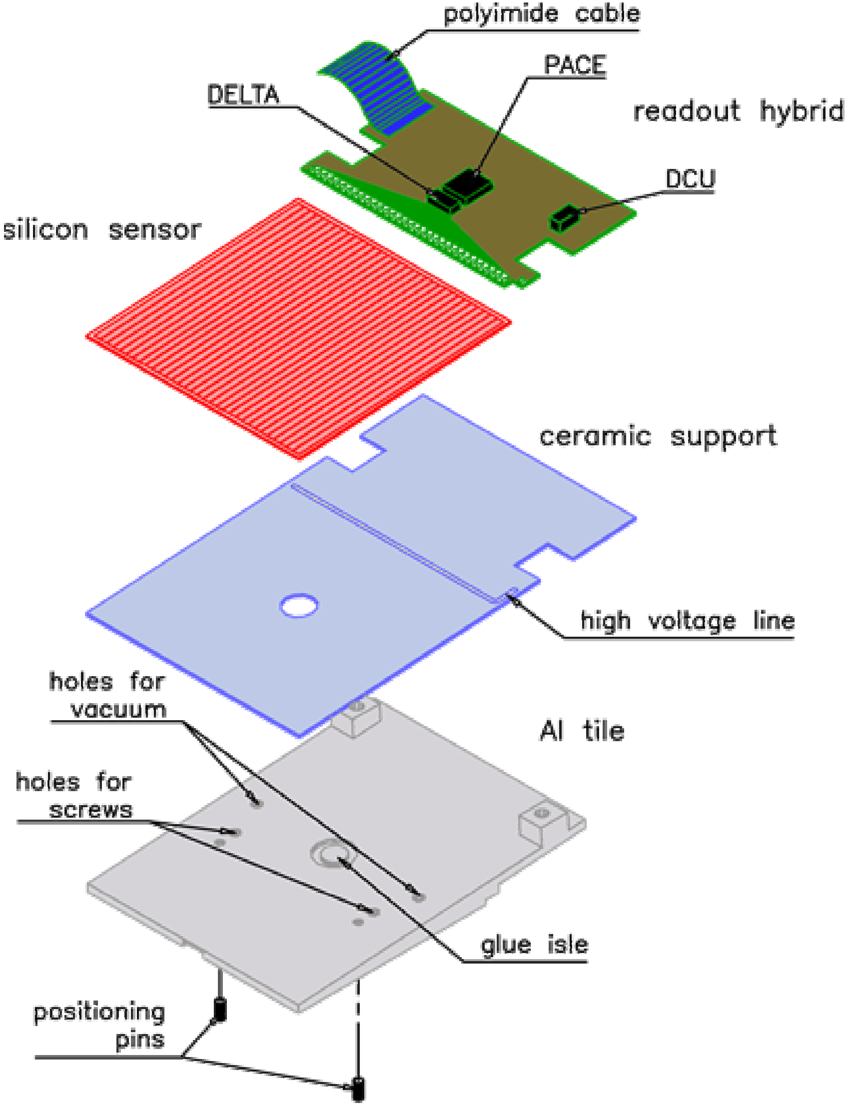
Radiation Hardness: CCE

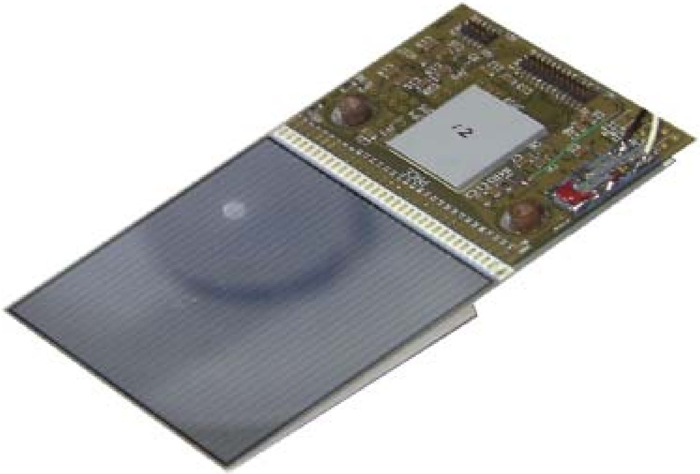
Radiation damage also introduce loss of charge collection efficiency:

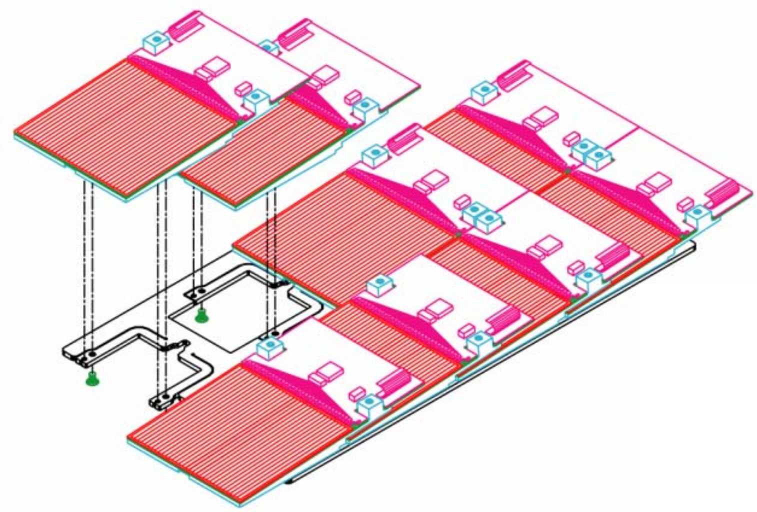


Still 83% CCE after 10 years ($2*10^{14}$ n/cm^2)

Preshower Front-end Micromodule







Preshower FE electronics

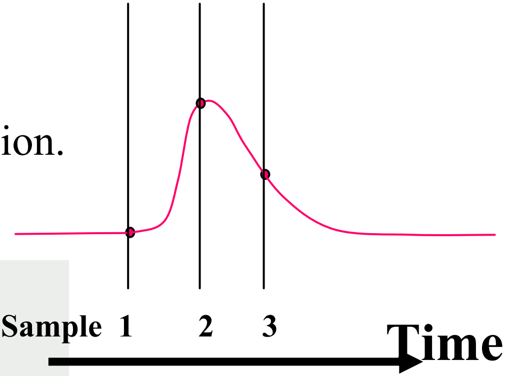
PACE is the combination of 2 chips in .25µm technology:

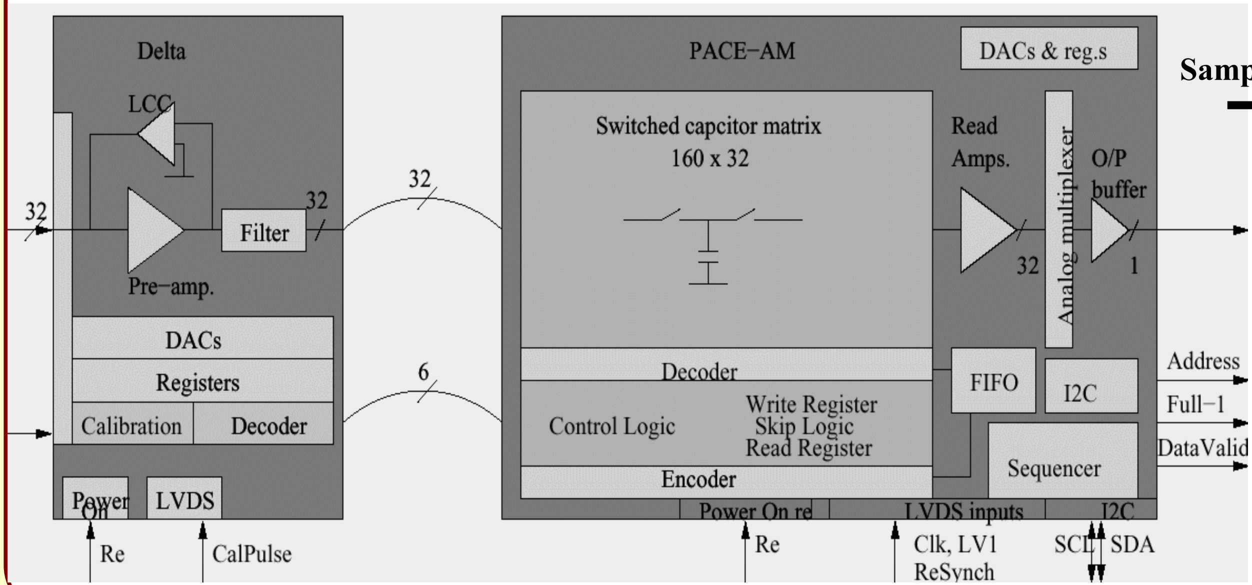
Delta

- Preamp with leakage current compensation.
- Switched gain shaper. Low gain (400 MIP) for physics, high gain (50 MIP) for single MIP calibration.
- Programmable biasing and calibration pulse via internal DACs.

PACE-AM

- 32 channels, 192 columns analog memory. 48x8 FIFO.
- Programmable biasing, latency, mux freq., modes of operation.
- I^{2}C inputs for parameter loading

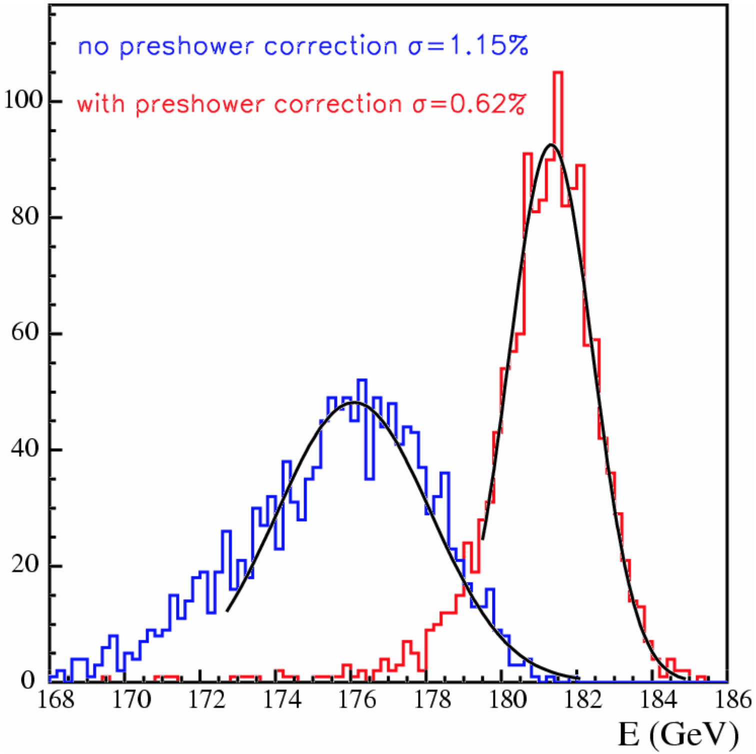


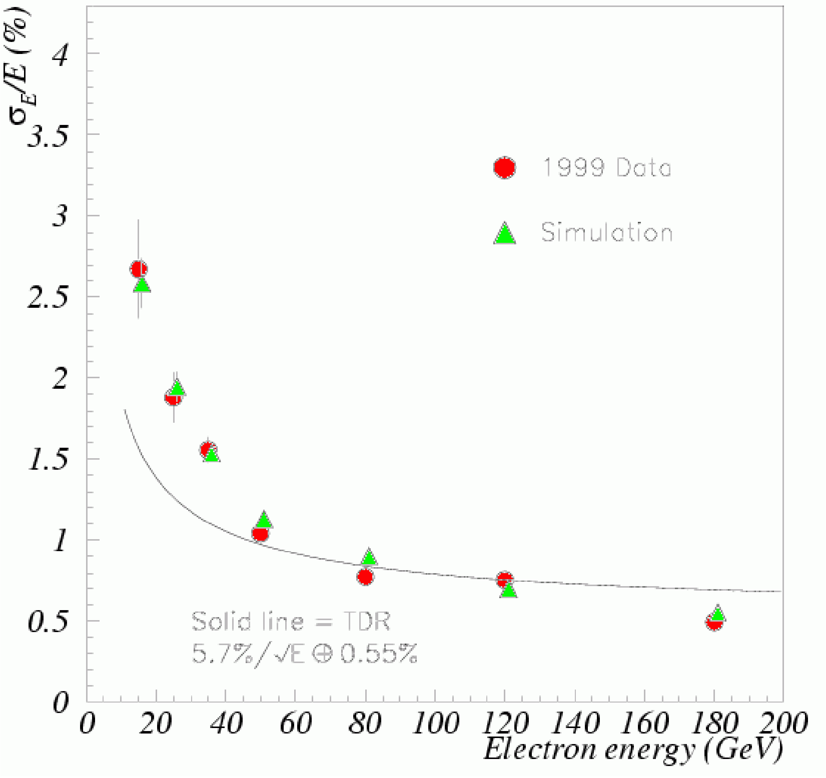


Noise:
1000e$^-$+35e$^-$/pf

Energy Resolution

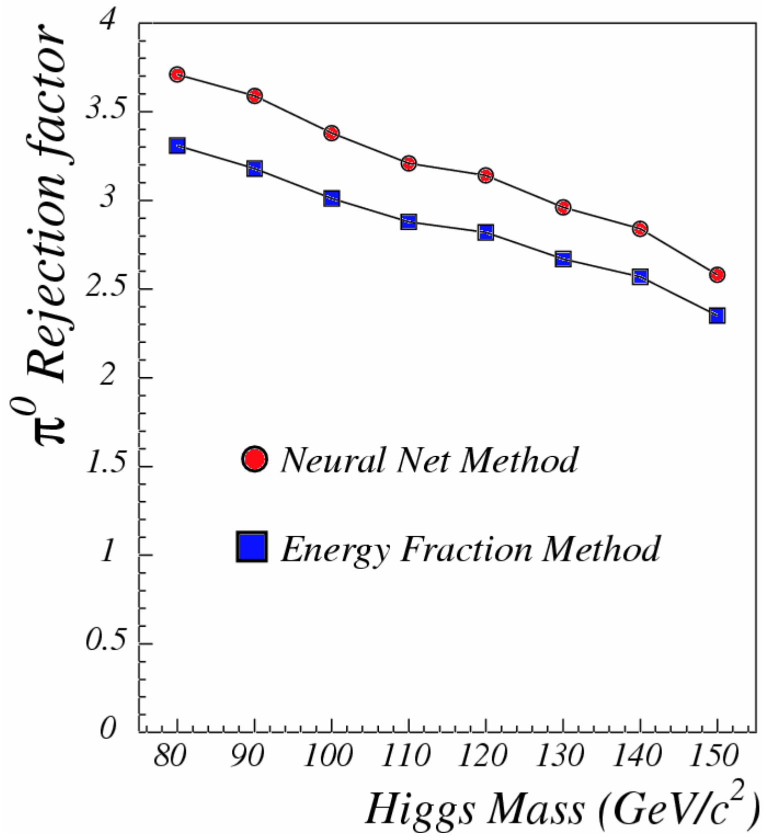
Adding an extra layer of sampling (Preshower) before the calorimeter deteriorates the energy resolution of the homogeneous calorimeter. But this can be mostly recovered:



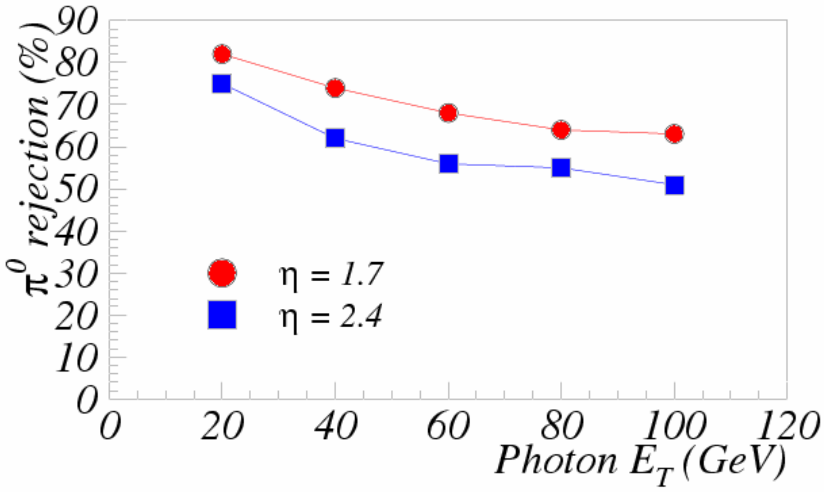


π^0 Rejection Performance

As function of Higgs mass:



As function of photon energy:



Future upgrade: SLHC

LHC luminosity upgrade (12.5ns, $L=10^{35}cm^{-2}\ s^{-1}$, $1x10^{15}n/cm^{-2}$) will pose serious challenge to CMS Preshower:

1. Radiation Damage
2. Ocuppancy

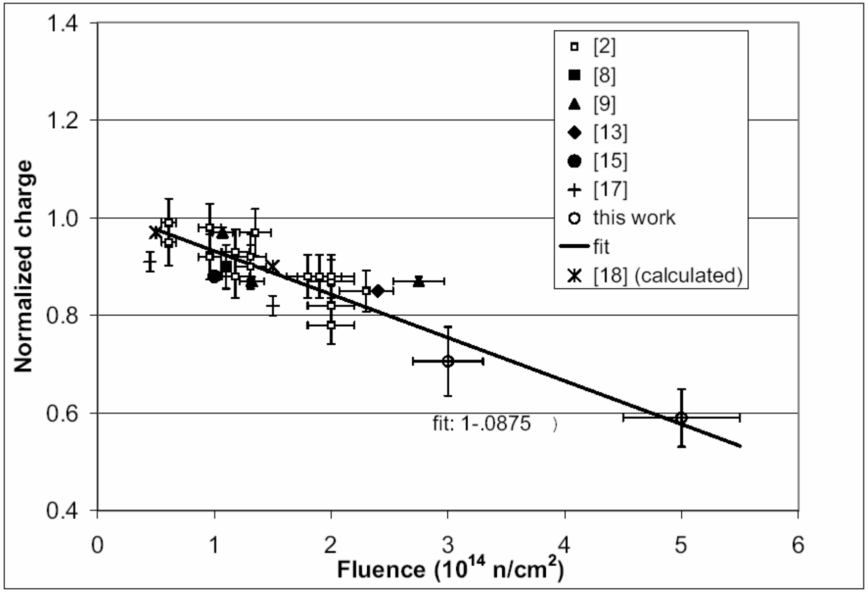
Specific to Silicon shower (as opposed to tracking):

1. Radiation damage mainly due to neutrons (backscatter from ECAL)
2. Large signal, not just MIP (shower measurement)
3. Not afraid of material before it (converter to produce shower)

These are different requirements from those of tracking devices. They could be both advantages and problems.

Future upgrade: Rad Hard Sensors

Present silicon: ~10% charge collection efficiency left at $1\text{x}10^{15}\text{n/cm}^{-2}$



New sensor needed

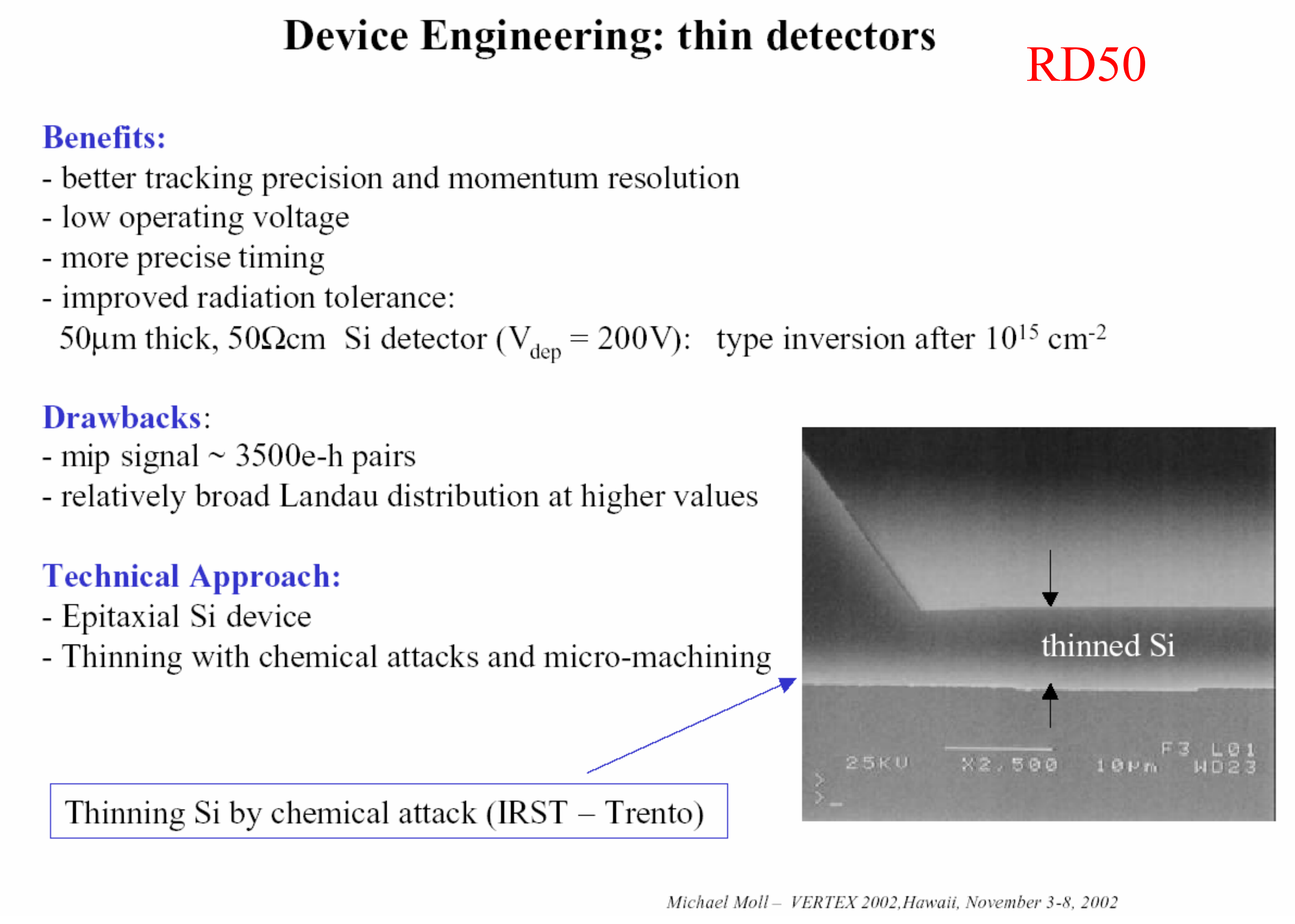
Four possibilities considers:

1. Thin detector
2. Cryogenic detector
3. Diamond detector
4. SiC

Also new rad-hard electronics:

- Smaller feature size (.13μm) uses less bias voltage(1.2-1.5v): large dynamic range (up to 400MIPs) might be a problem,
- Noise increases with 12.5ns shaping time ($60e^-$/pf).

Future upgrade: Thin Silicon



Device Engineering: thin detectors

RD50

Benefits:

- better tracking precision and momentum resolution
- low operating voltage
- more precise timing
- improved radiation tolerance:

50µm thick, 50Ωcm Si detector ($V_{dep} = 200V$): type inversion after 10^{15} cm^{-2}

Drawbacks:

- mip signal ~ 3500e-h pairs
- relatively broad Landau distribution at higher values

Technical Approach:

- Epitaxial Si device
- Thinning with chemical attacks and micro-machining

Thinning Si by chemical attack (IRST – Trento)

Michael Moll – VERTEX 2002,Hawaii, November 3-8, 2002

Thin Silicon

Advantages:

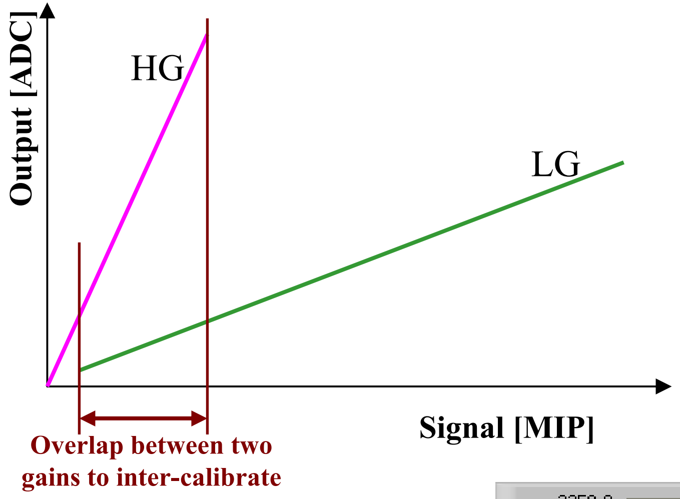
- It should be more affordable than diamond or SiC
- The small signal is not a problem for calorimetery
  - (50GeV e gives 60MIPs and 112MIPs on the two layers)

Challenges:

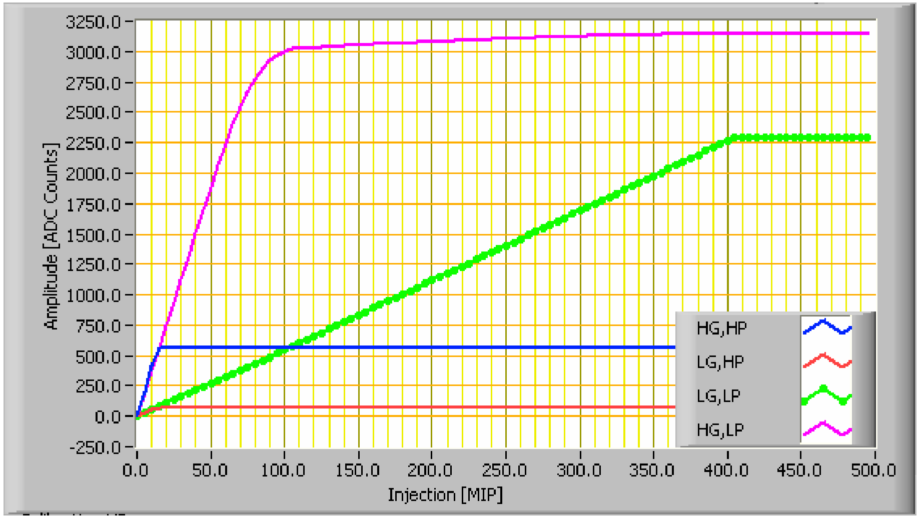
- Need to find another way of absolute calibration (use physical processes??)
- Thinner detector means increase on capacitance => increase noise
  - Solution: smaller strips
  - => increase channel count => cost
  - Combined 2/4 channels after shaper/preamp??

Silicon Sensor: MIP Calibration

Use high gain to measure Physics MIP and inter-calibrate to full dynamic range with low gain (LG).

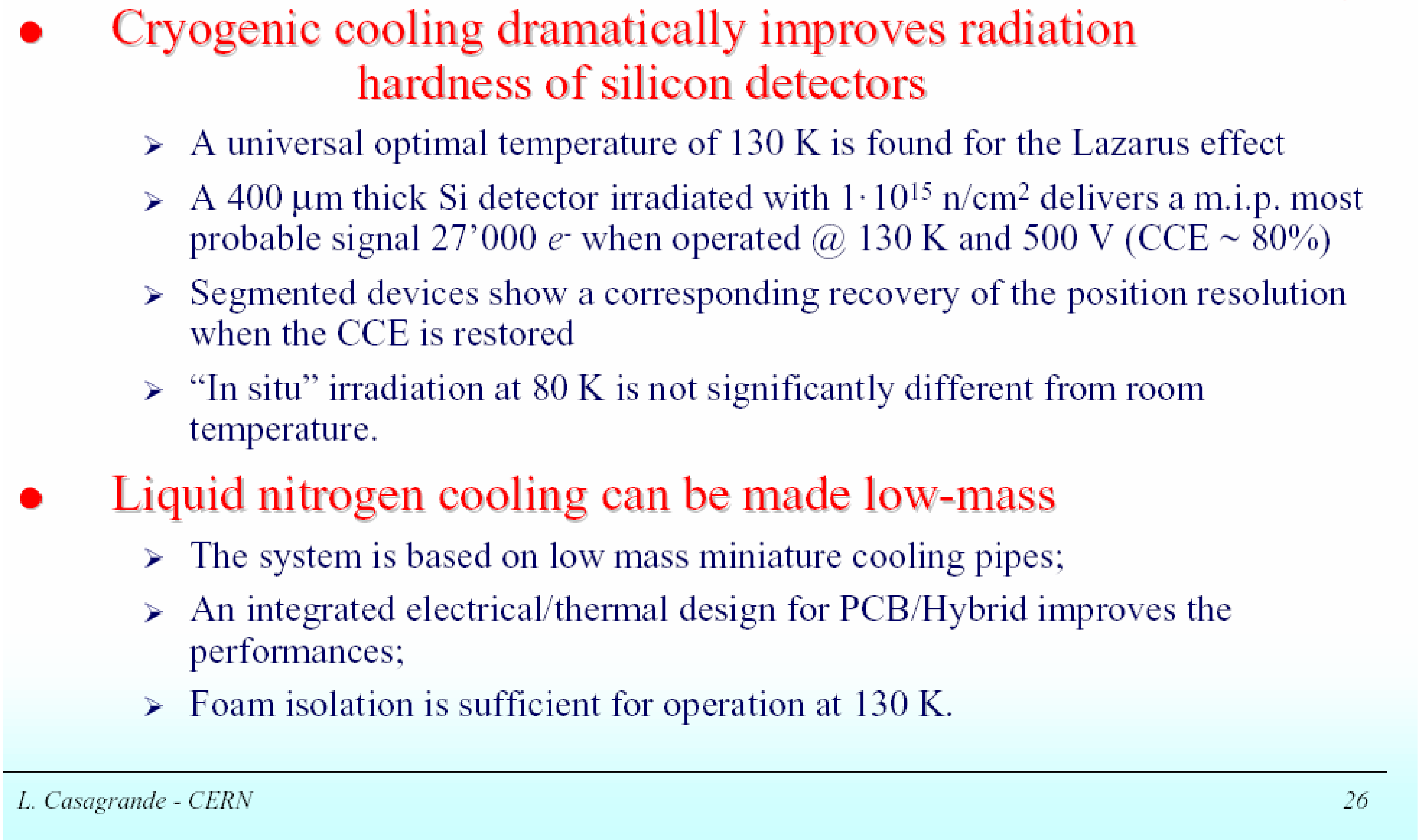


Use high precision (HP) injection pulse to map the MIP and low precision (LP) to extend to the full dynamic range.



Cryogenic Silicon

RD39



- **Cryogenic cooling dramatically improves radiation hardness of silicon detectors**
  - A universal optimal temperature of 130 K is found for the Lazarus effect
  - A 400 μm thick Si detector irradiated with $1 \cdot 10^{15}$ n/cm^2 delivers a m.i.p. most probable signal 27'000 e^- when operated @ 130 K and 500 V (CCE ~ 80%)
  - Segmented devices show a corresponding recovery of the position resolution when the CCE is restored
  - "In situ" irradiation at 80 K is not significantly different from room temperature.
- **Liquid nitrogen cooling can be made low-mass**
  - The system is based on low mass miniature cooling pipes;
  - An integrated electrical/thermal design for PCB/Hybrid improves the performances;
  - Foam isolation is sufficient for operation at 130 K.

L. Casagrande - CERN *26*

Cryogenic Silicon

Advantage:

- No need to replace Silicon
- Front Cryogenics wall could be used as “converter”, instead of the lead converter…

Challenges:

- Fit cryogenics in the limited space (20cm thick)
- Keep constant temperature for encap ECAL (±0.1^{0}C)
- Back cryogenics wall might be problem…destroy the excellent energy resolution of the homogenous ECAL crystals??

Other type of sensors

Oxigenated Silicon:

- (-) Little improvement with neutrons, cannot be used.

Diamond:

- (-) Price, size
- (OK) Smaller signal (13000) than silicon

SiC:

- (+) Very rad hard
- (-) Price ($9000 for 2’ wafer!)
- (-) Technology not yet prooven.

Conclusion

Pre-showing Technique is covers quite a wide range of purpose and technology:

1. LHCb PSD&Preshower: $\pi^{\pm}$ rejection, e/π separation, Scintillator/Fiber.
2. ATLAS Preampler: energy correction, LARG.
3. CMS Preshower: π^0/γ separation, Silicon.

SLHC is challenging in term of radiation hardness

Two promising technologies:

1. Thin silicon,
2. Cryogenics silicon.