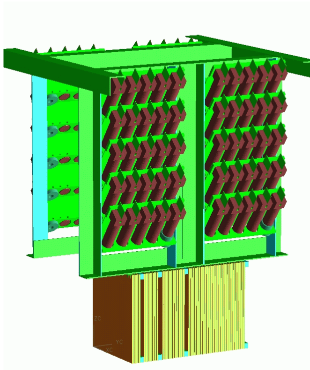
A scintillator- Si hybrid EMcal for the Linear Collider



- Prototype description
- Test beam results
- Conclusions and plans

LCCAL: Official INFN R&D project, official DESY R&D project PRC R&D 00/02

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11th International Conference on Calorimetry in HEP

Perugia, 29th March – 2nd April, 2004

Design principles :

From the LC Physics requirements:

- high granularity,(Energy Flow)
- σ_E O$(10\%/\sqrt{E}\ +1\%)$
- longitudinal segment. (e/π) separation
- working in magnetic field
- high density (25-30 X_0 in $\sim$ 50 cm)

Tesla TDR solutions:

- **Si W**
- **Shashlik (thanks to CALEIDO)**

The LCCAL Proposed solution:

- ❑ **Keep Si-W advantages (flat geometry, high granularity)**
- ❑ **Erec not from Si but from Scintillator-WLS fibers**
- ❑ **Reduce (factor >10) the number of channels**

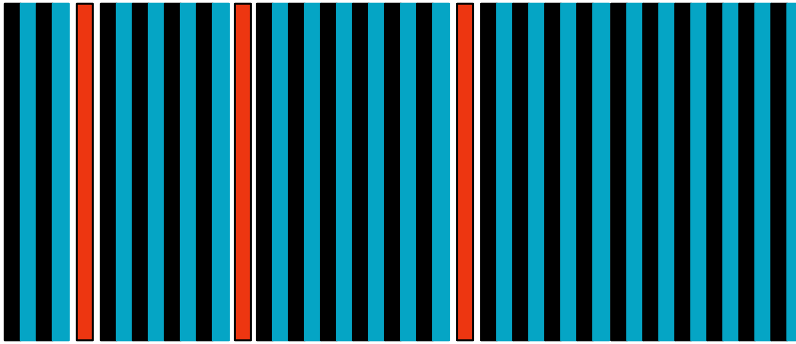
LCCAL: an hybrid em calorimeter

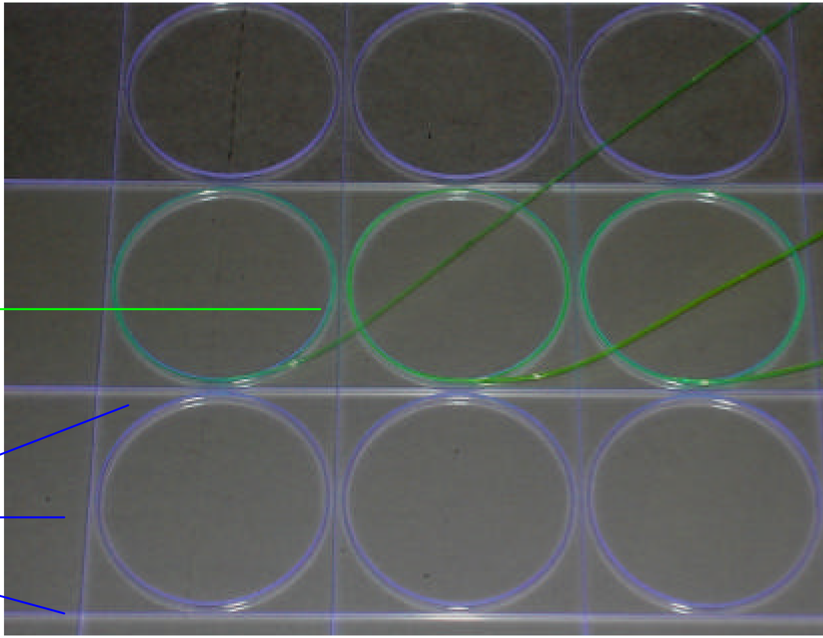
- **50 layers** ® **45 layers** (budget!!)
- **25 × 25 × 0.3 cm³ Pb**
- **25 × 25 × 0.3 cm³ Scint.:**

  25 cells 5 × 5 cm²
- **3 Silicon planes (at 2, 6, 12 X_0)**
- **625 ® 252 Silicon Pads** (budget..)

  0.9 × 0.9 cm² Si Pads

Pb/Sc + Si





Scintillation light transported with
WLS s tail fibers:

Coupled with clear fibers (to PM)

Cell separation with grooves in Sc.
plates with Tyvec strips inside

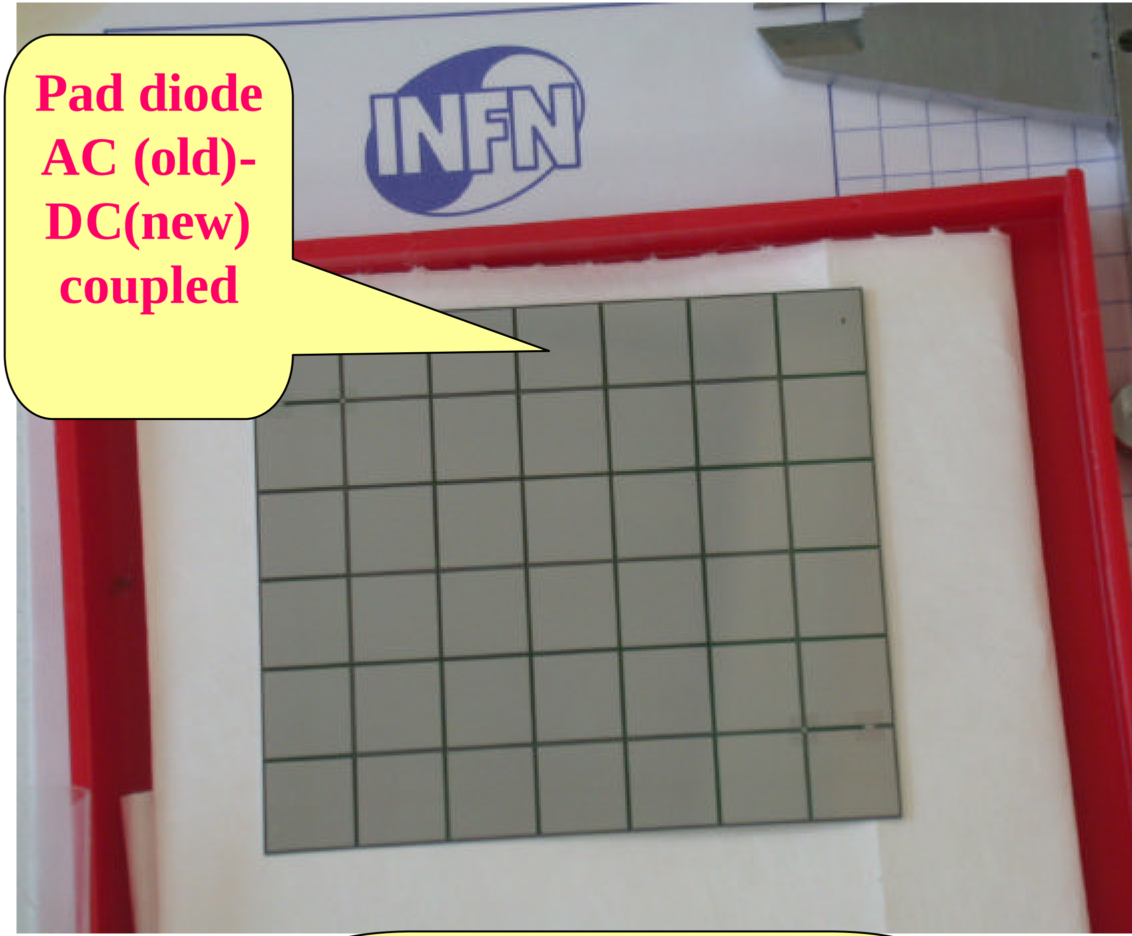
Prototype : 3 planes of Si Pads

Goals: shower-shower separation, position measurement, e/h ID

- **Pad dimension < shower dimension:** **0.9 x 0.9 cm^2**
- **Longitudinal sampling:** **3 planes**
- **Analogic ReadOut :** **VA hdr9c from IDEas**

Actual design:

- **Each sensor: 6x7 pads**
- **Plane: 3x2 detectors**



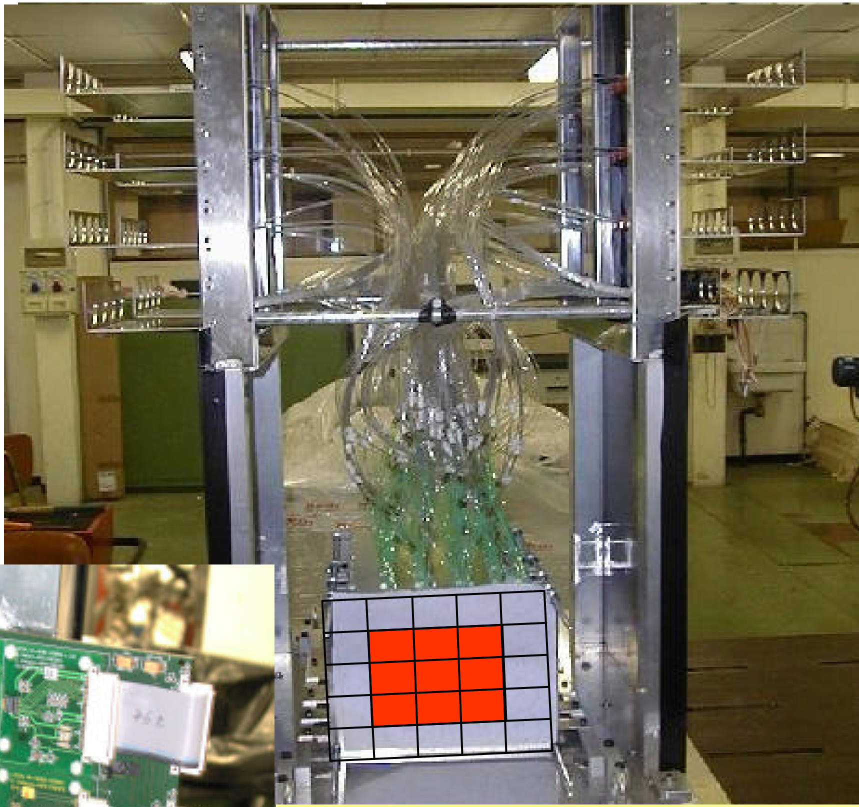
Pad diode AC (old)-DC(new) coupled

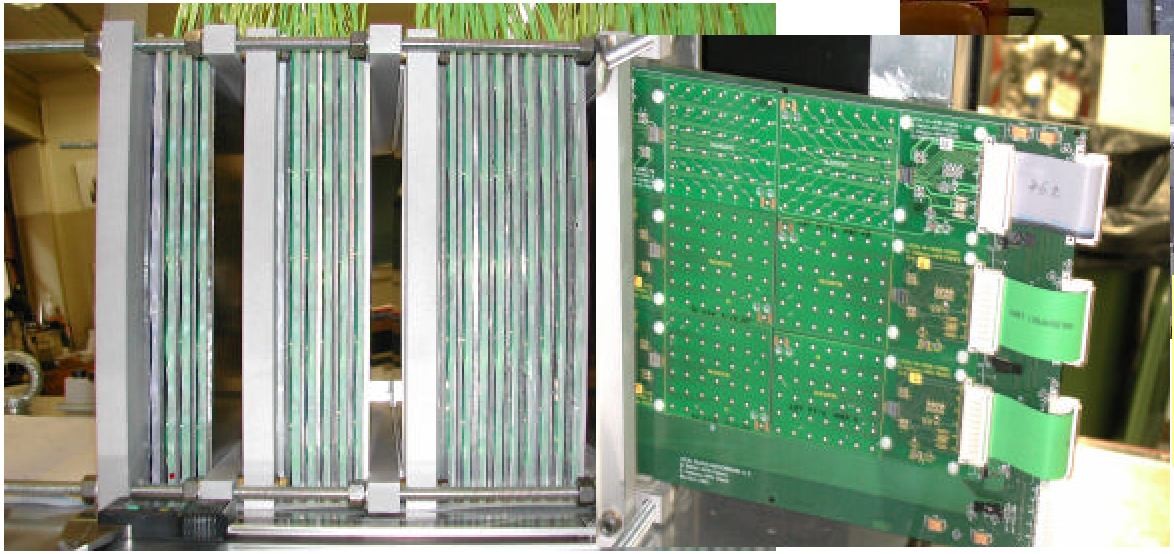
PCB contact with conductive glue

LCCAL: an hybrid em calorimeter

- **45 Lead-Sci Layers prototype completely built in 2002:**
  Fibres grouped into 25x4 bundles making a 4-fold longitudinal segmentation.

- **Slots for the insertion of the 3 Si pad planes (Motherboard)**





Only 3x3 central cells readout by a PM for each long. segmentation

History of Silicon sensors production

Institute of Electron Technology
ITE

3 technological runs

First batch of
11 sensors
(spring ’02)

Soft
Breakdown

Second batch of
9 sensors
(summer ’02)

“Leaky”
pads

Third batch of
9 sensors
(summer ’03)

GOOD!

Silicon detectors: Signal to Noise ratio

Theory:

Front-End

$$\mathrm{ENC} = A + \frac{B}{pF} \approx 1000\, e^- +$$

I Leakage

$$\mathrm{ENC} = \frac{e}{q}\sqrt{\frac{q I_l T_p}{4}} \approx 30\, e^- +$$

Bias Resistance

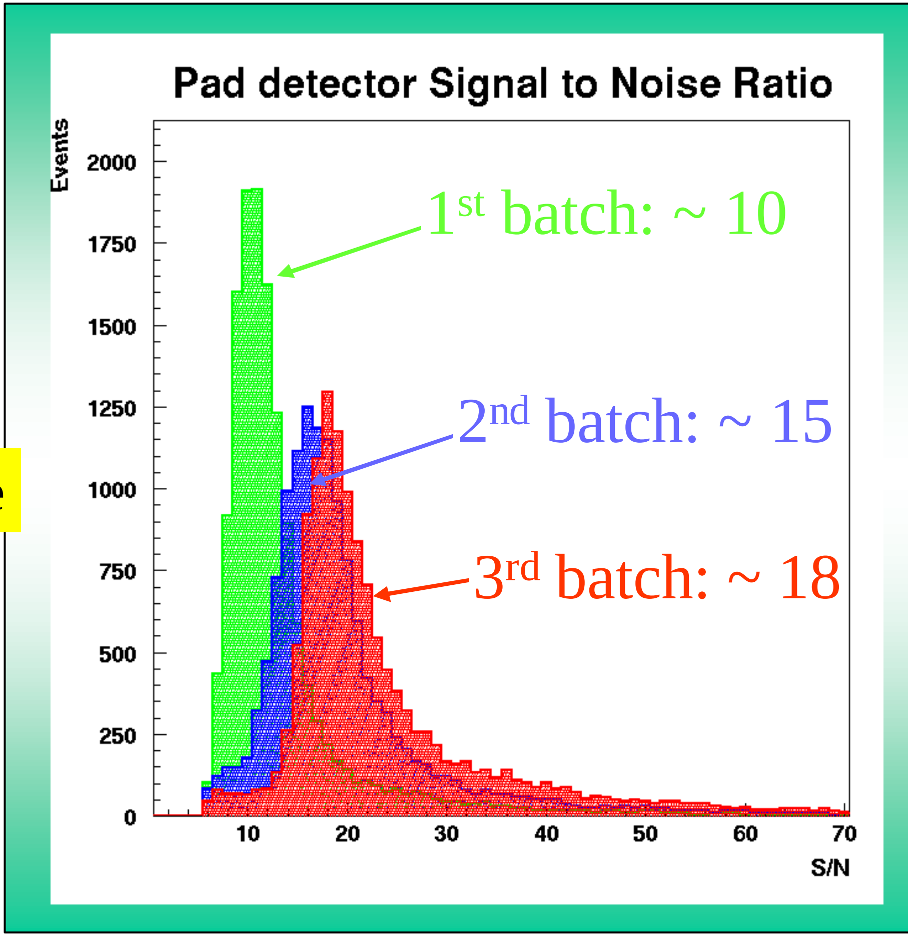
$$\mathrm{ENC} = \frac{e}{q}\sqrt{\frac{T_p k_B T}{2R}} \approx 230\, e^- =$$

$$1026\ e^-$$

MIPS = (80 e-/ μm) x 300 μm

» **24000 e-**

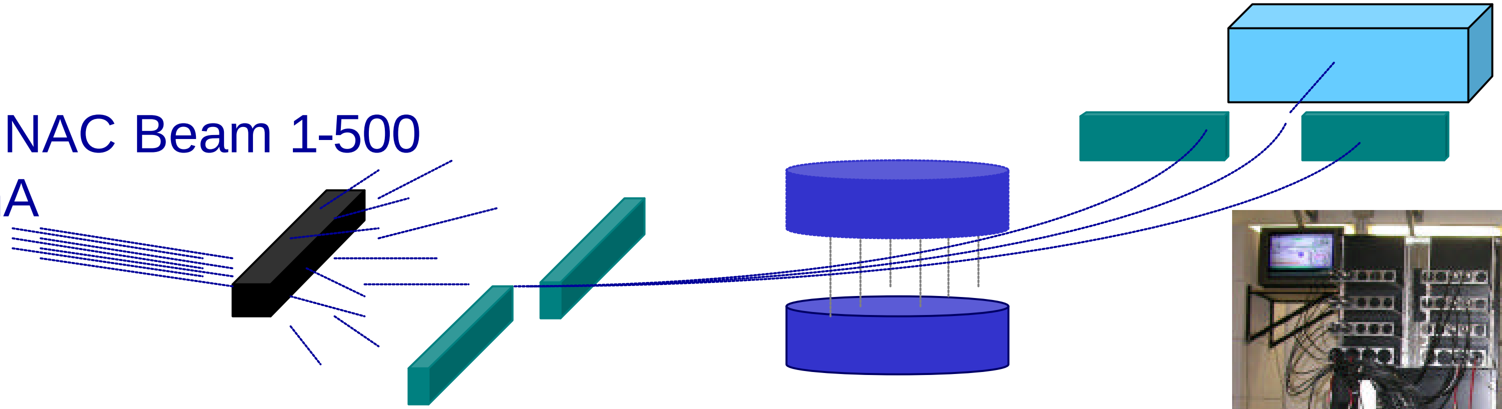
Theoretical*
SNR ~ 23

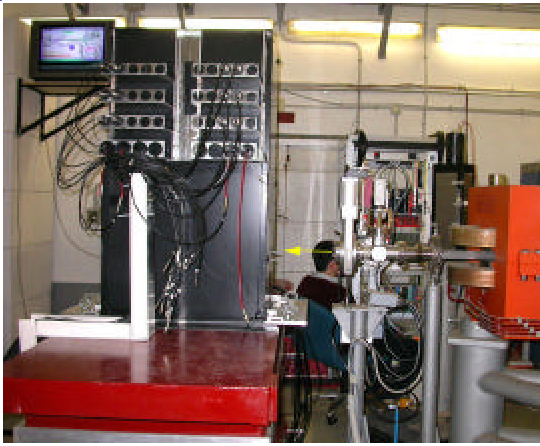


Very close to what achieved for detector of the 3rd batch

Test Beam activities

- **after a 2002 pre test with the 1st layer only (2.1 X_0) at CERN**
- **two runs at Frascati Beam Test Facility (50 – 750 MeV)**



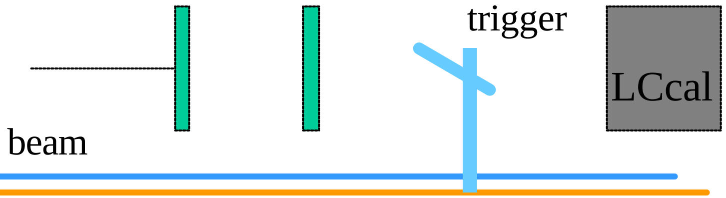


Multiplicity can be tuned .....

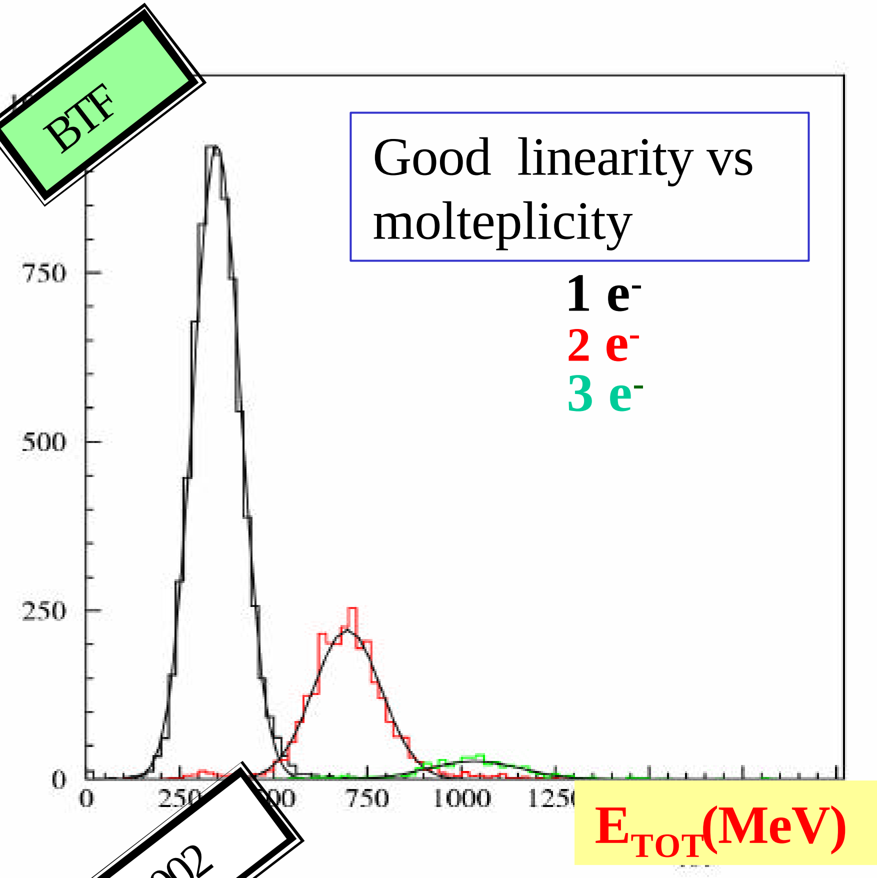
- **run at CERN SPS H6 beam line (e/p 5 – 150 GeV)**

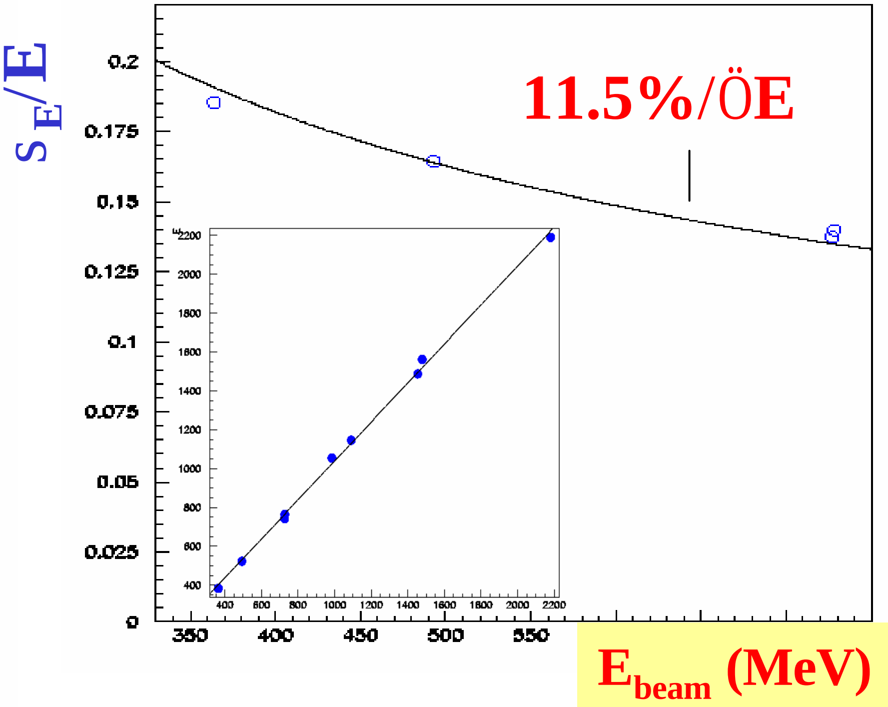
All tests: two beam position monitors (telescope) in front of the calorimeter covering the central area of the prototype (9.5×9.5 cm^2):

Each detector consisting of 400×400 x–y Si strips with a pitch of 240 μm



Linearity and Energy Resolution (BTF)

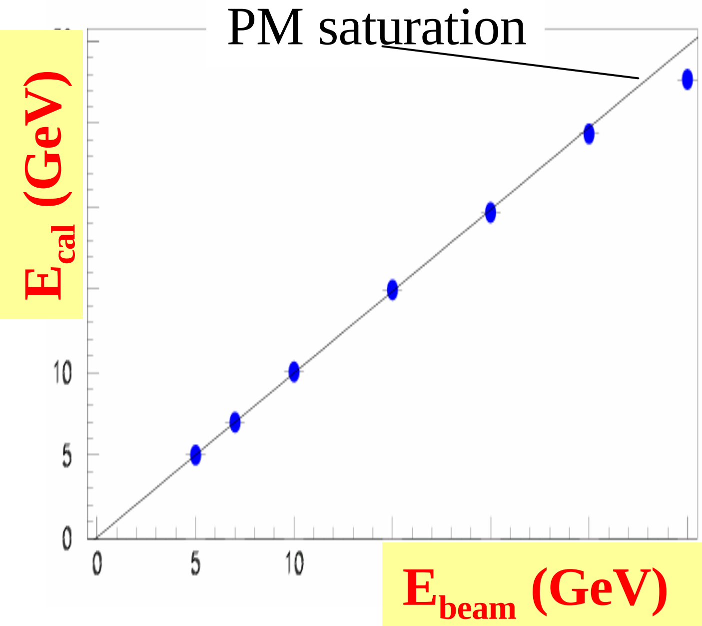


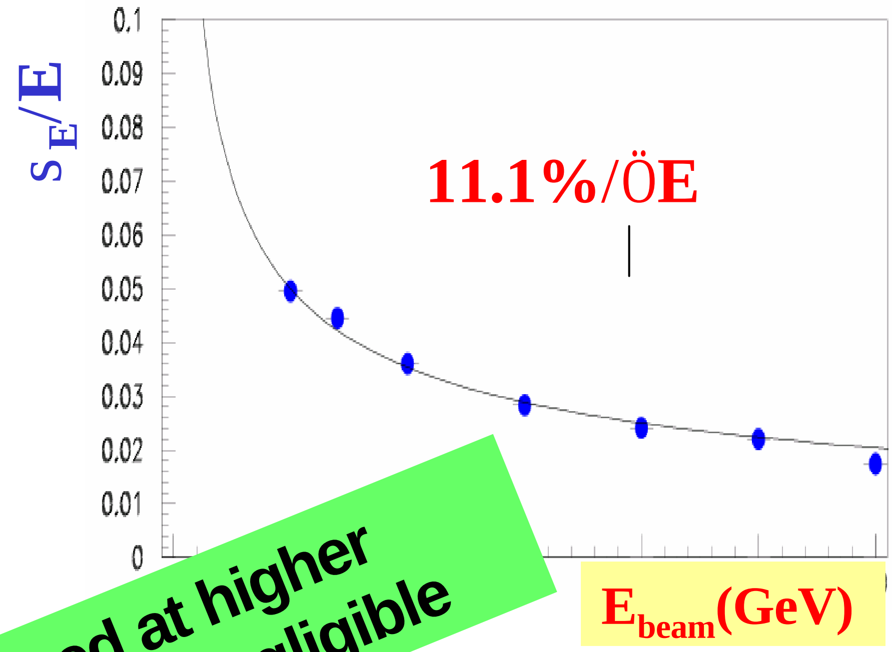


N_{phe}>5.1 /layer ? **Cal(45 layers)**
250 MeV/Mip ~ 800Npe/GeV
OK also @ BTF (E ~500 MeV)

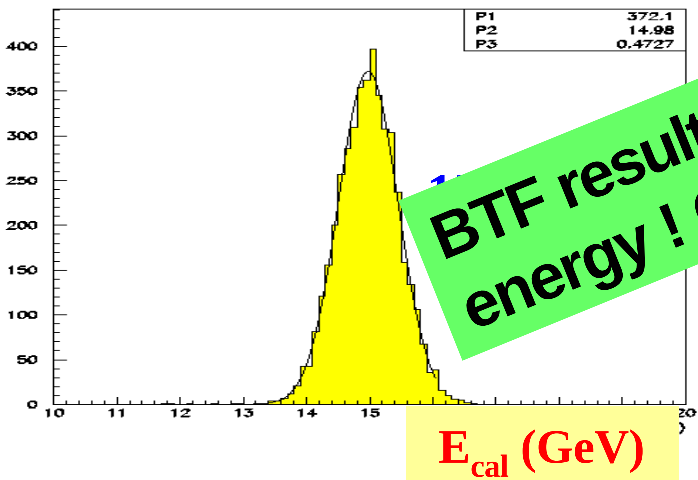
1. Photoelectron statistics **negligible**
2. Stocastic Term **11.5% as in MC**
3. Light disuniformity **<<10%**.. better measurement at **SPS** together with effects on resolution in **Aug03**

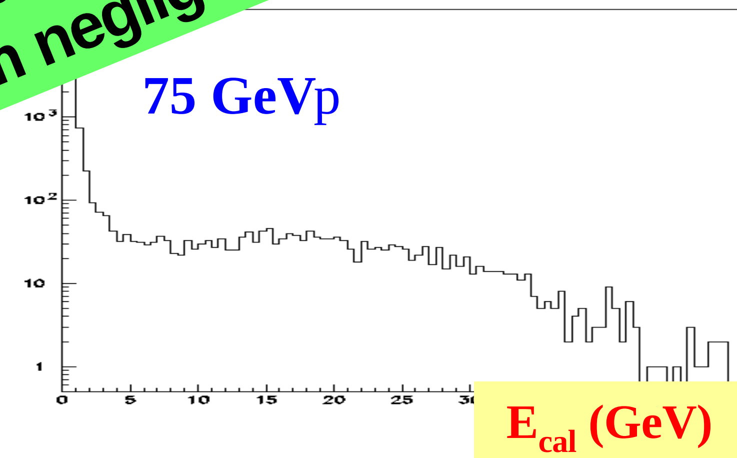
Linearity and Energy Resolution (Cern 03)





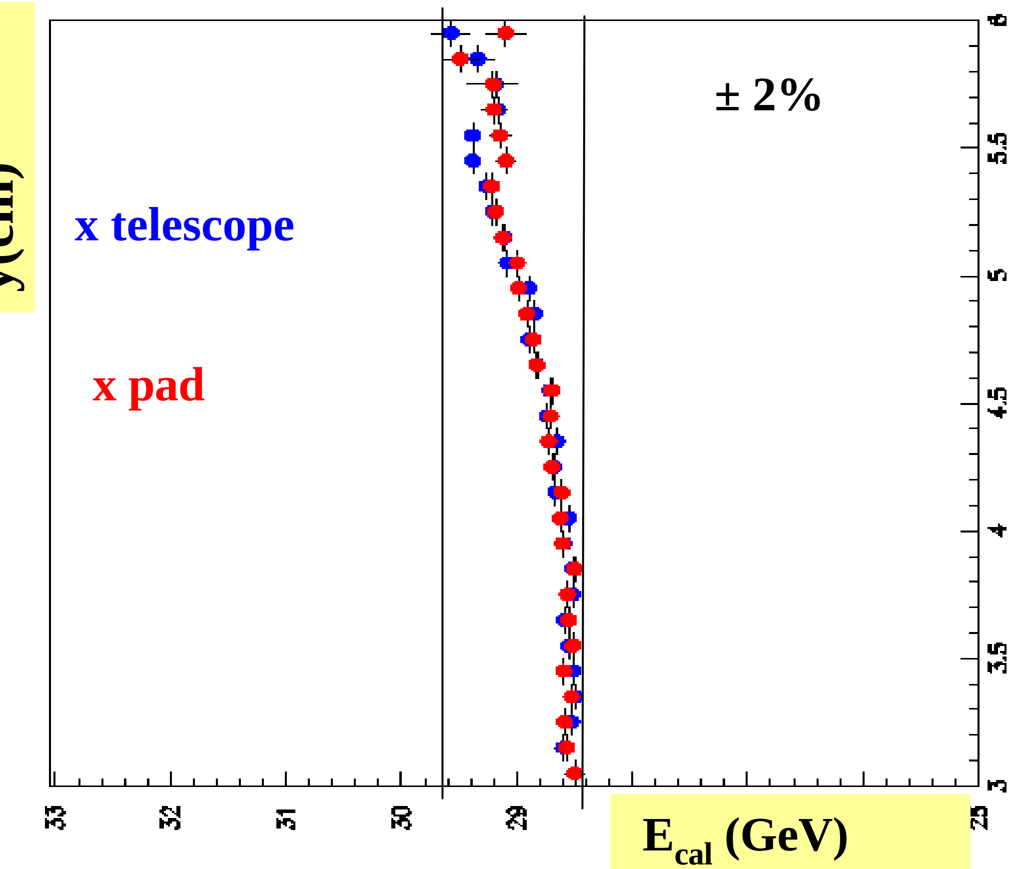
BTF results confirmed at higher energy ! Constant term negligible



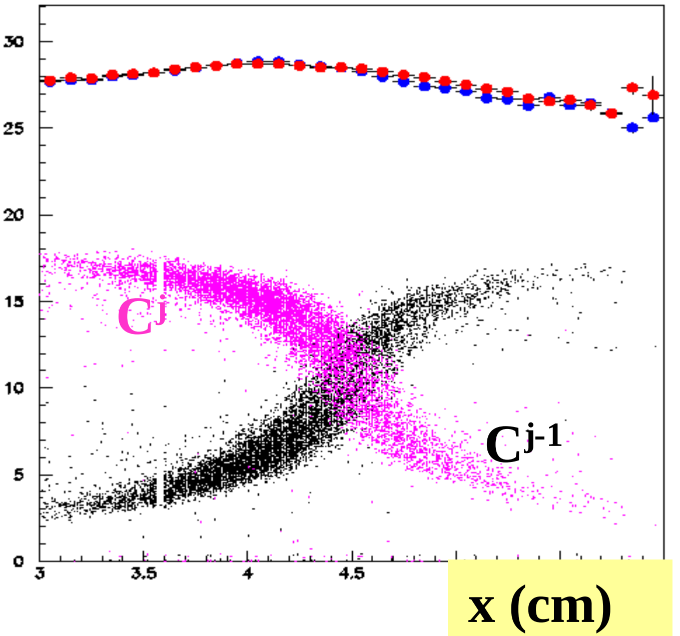


Uniformity in (light) Energy response: Cern 03

- **disuniformity < 2% consistent with negligible constant term on energy resol.**
- **correction on energy response from pad reconstruction can be applied!**



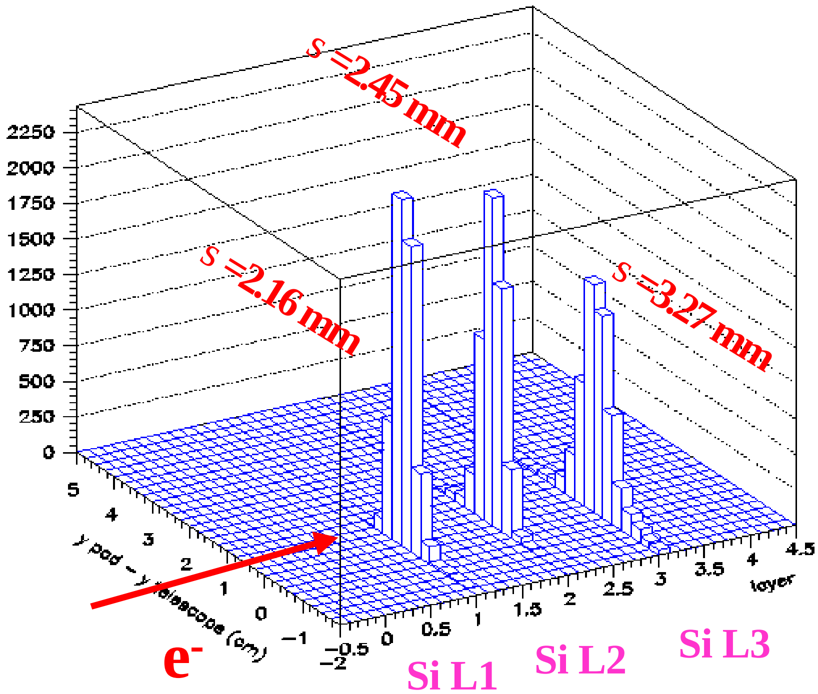
PRELIMINARY: cell border effects dominated by residual miscalibration

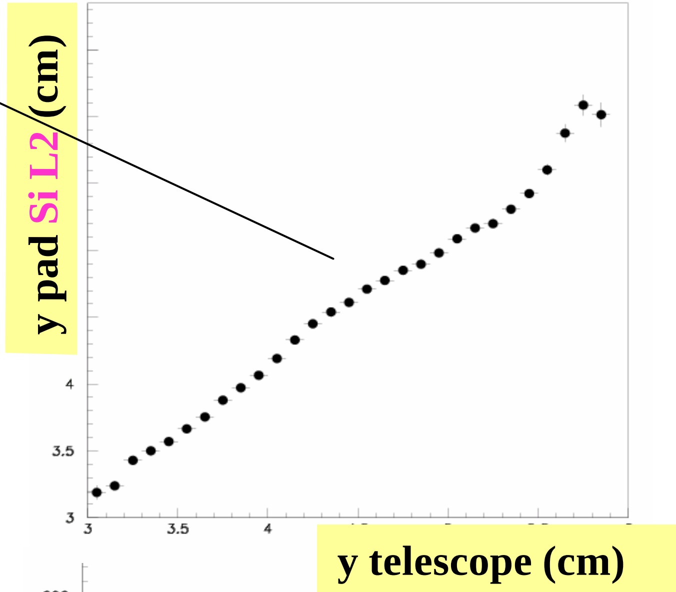


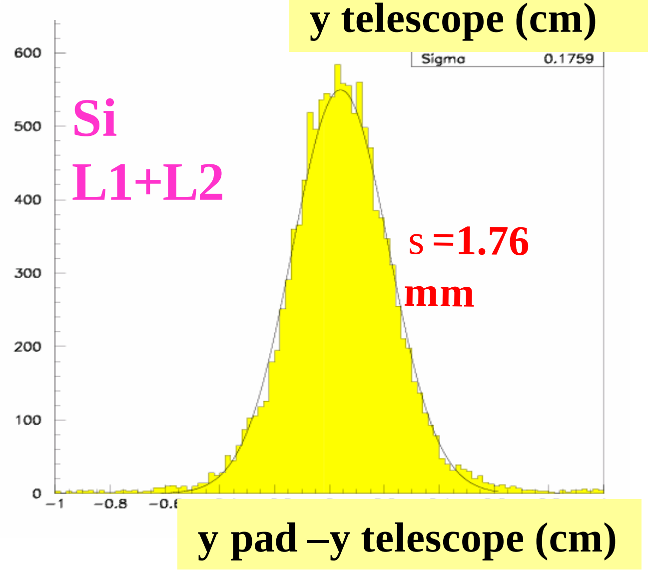
Si Pads (Position measurement) Cern 03

30 GeV electrons

Pad size effect!
more sophisticated
"centroid" algorithm
can be applied



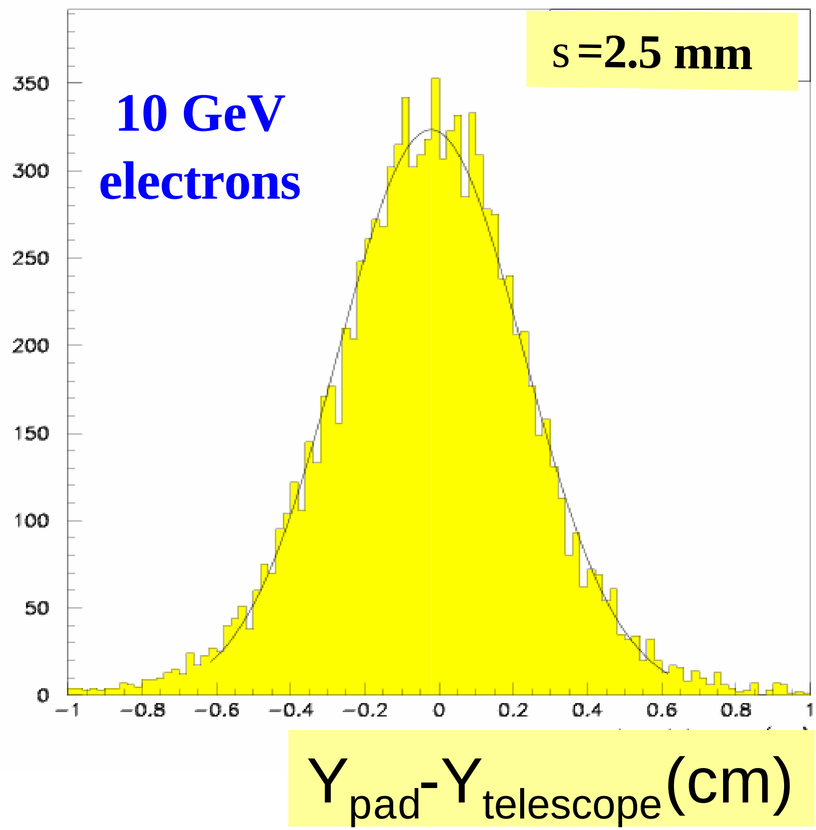


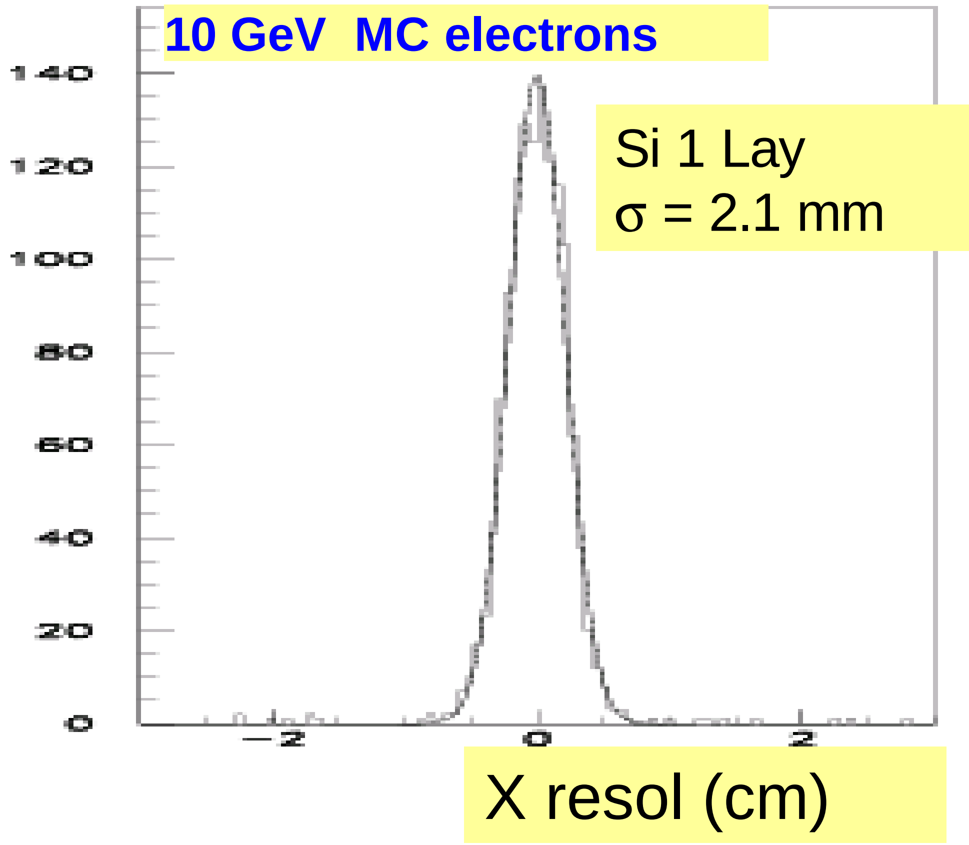


Si pad detector (Position resolution)

PRELIMINARY analysis: pad noise subtraction not optimised

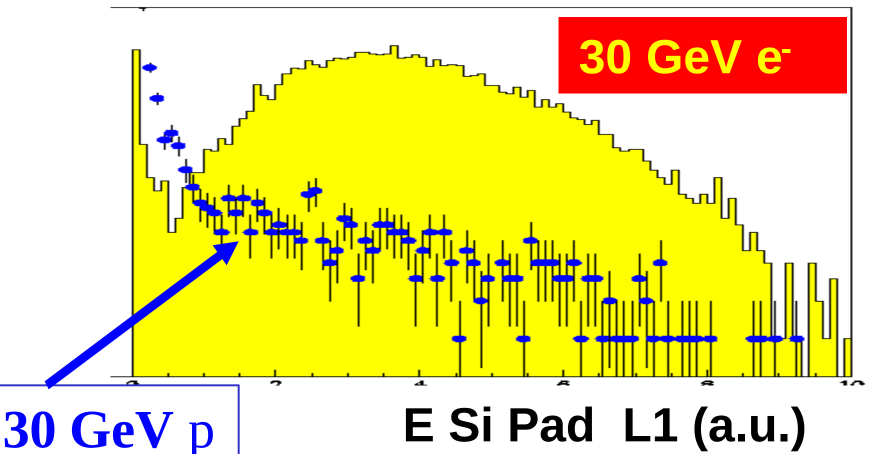
- **Position resolution ~ 2.5 mm, not far from Monte Carlo**
- **beam multeplicity under investigation**

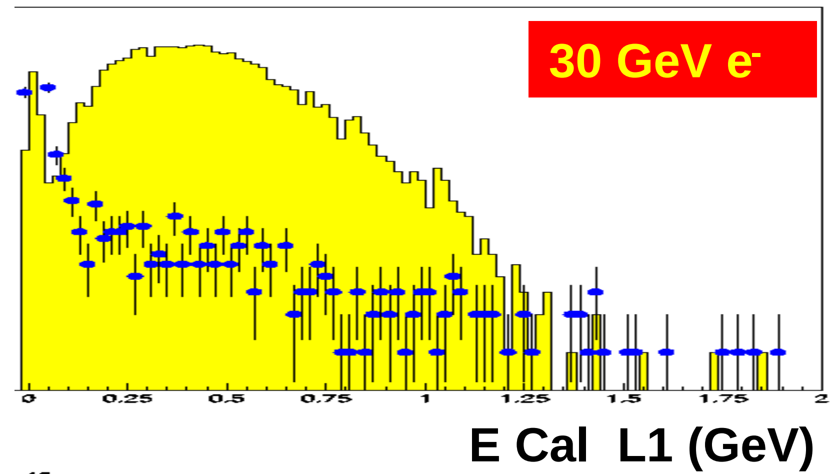


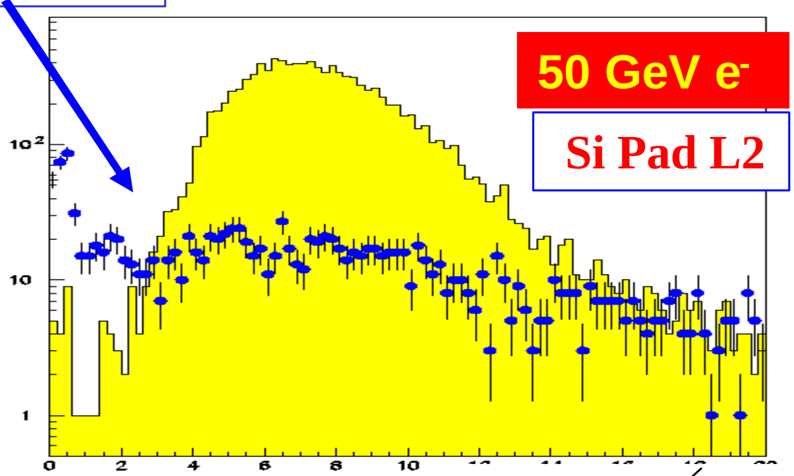


e/π rejection: Cern 03

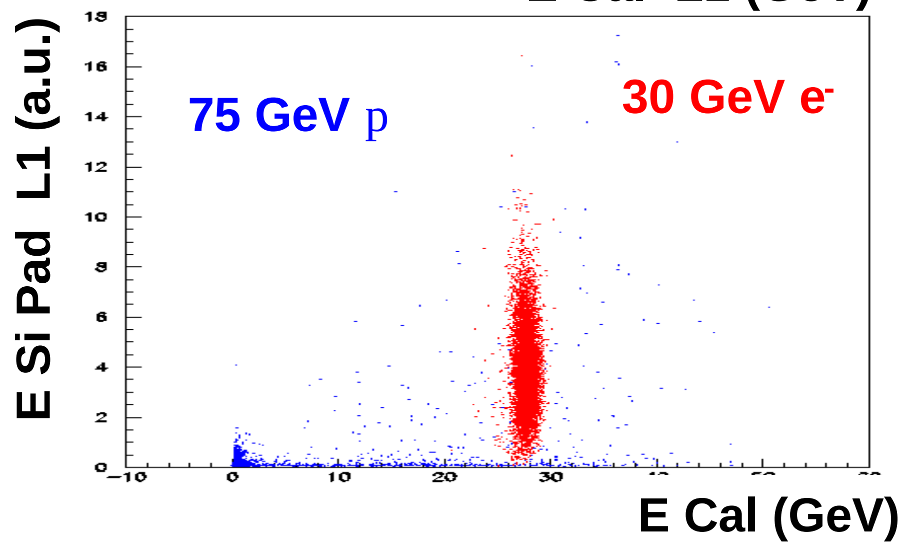
Redundancy of the information on longitudinal lateral shower development helps the rejection; difficult to quantify below 10^{-3} due to beam contamination







shower variance: $\sum_i r_i^2 E_i \Big/ \sum_i E_i$



Si Pads: two pads separation

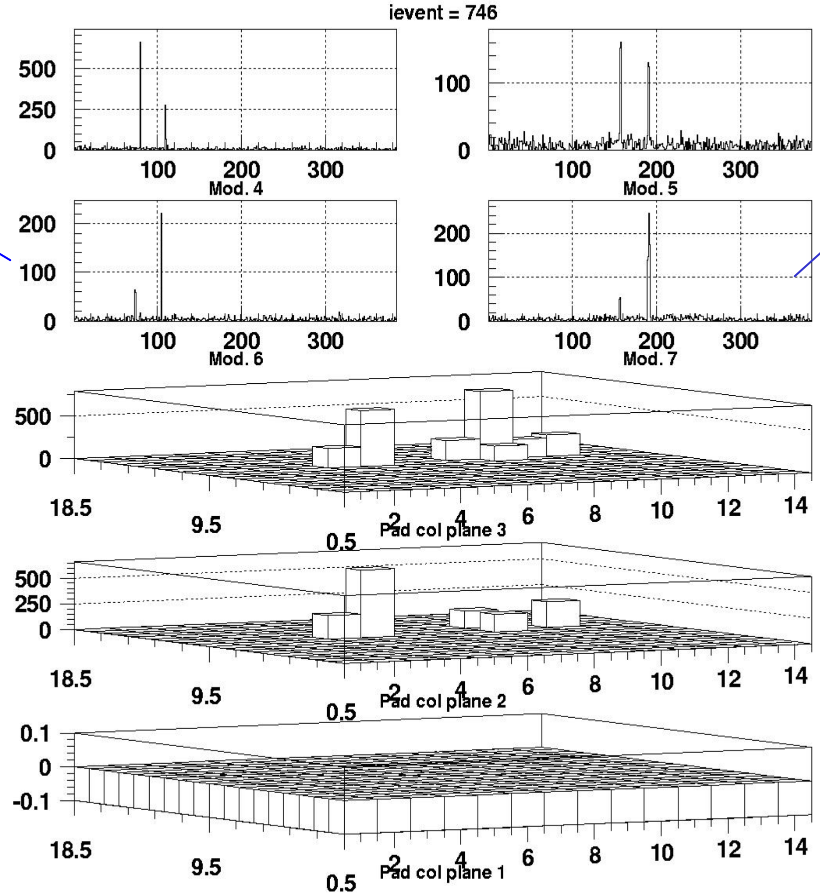
exhaustive analysis not fully accomplished

Two electrons with energy 750 MeV

X silicon chambers

Y silicon chambers

BTF test



First layer

Second layer

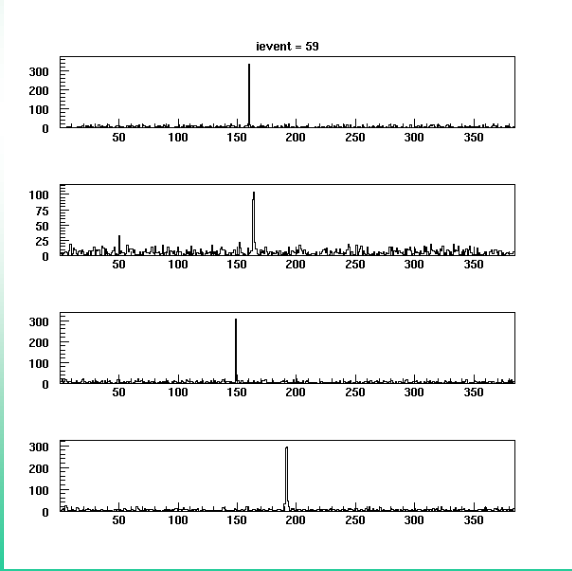
Third layer

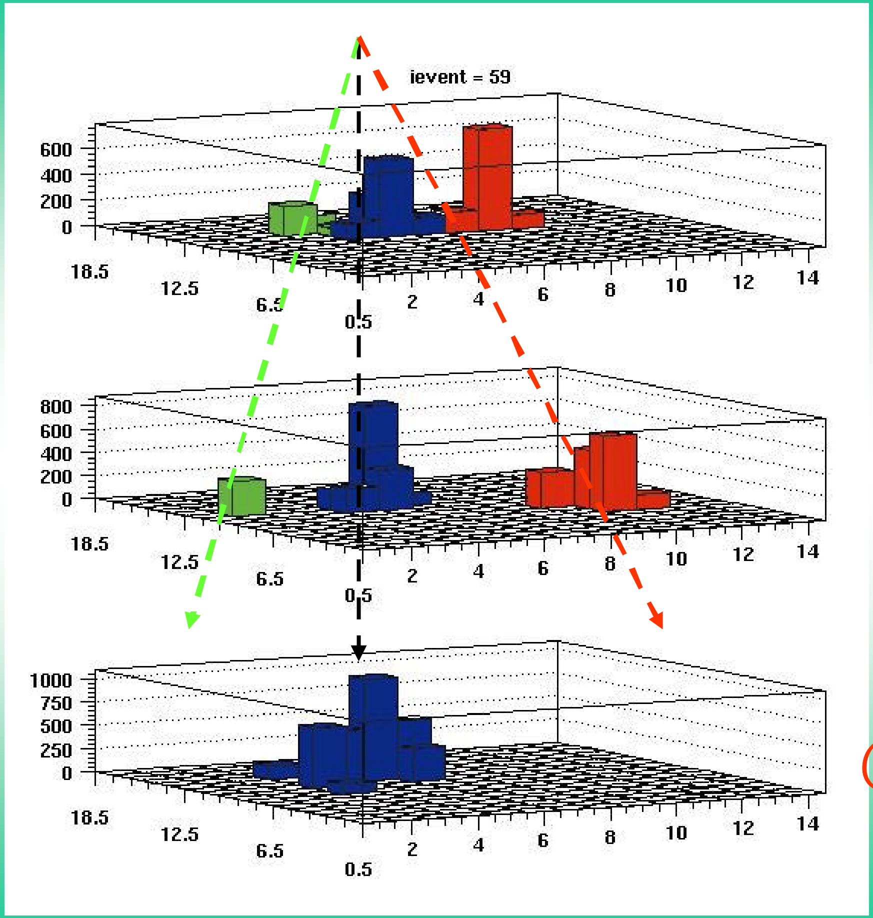
NB: not fully equipped+ problematic channels

Shower reconstruction Cern 03

20 GeV e^-

Forward tracker





@ $2X_0$

@ $6X_0$

@ $12X_0$

Conclusion and future plans

A calorimeter prototype with the proposed technique has been built and fully tested. **All results are preliminary.**

Energy and position resolution as expected:

$\sigma_E/E \sim 11.-11.5\% /\sqrt{E}$, $\sigma_{pos} \sim 2$ mm (@ 30 GeV)

Light uniformity better than 2% !!

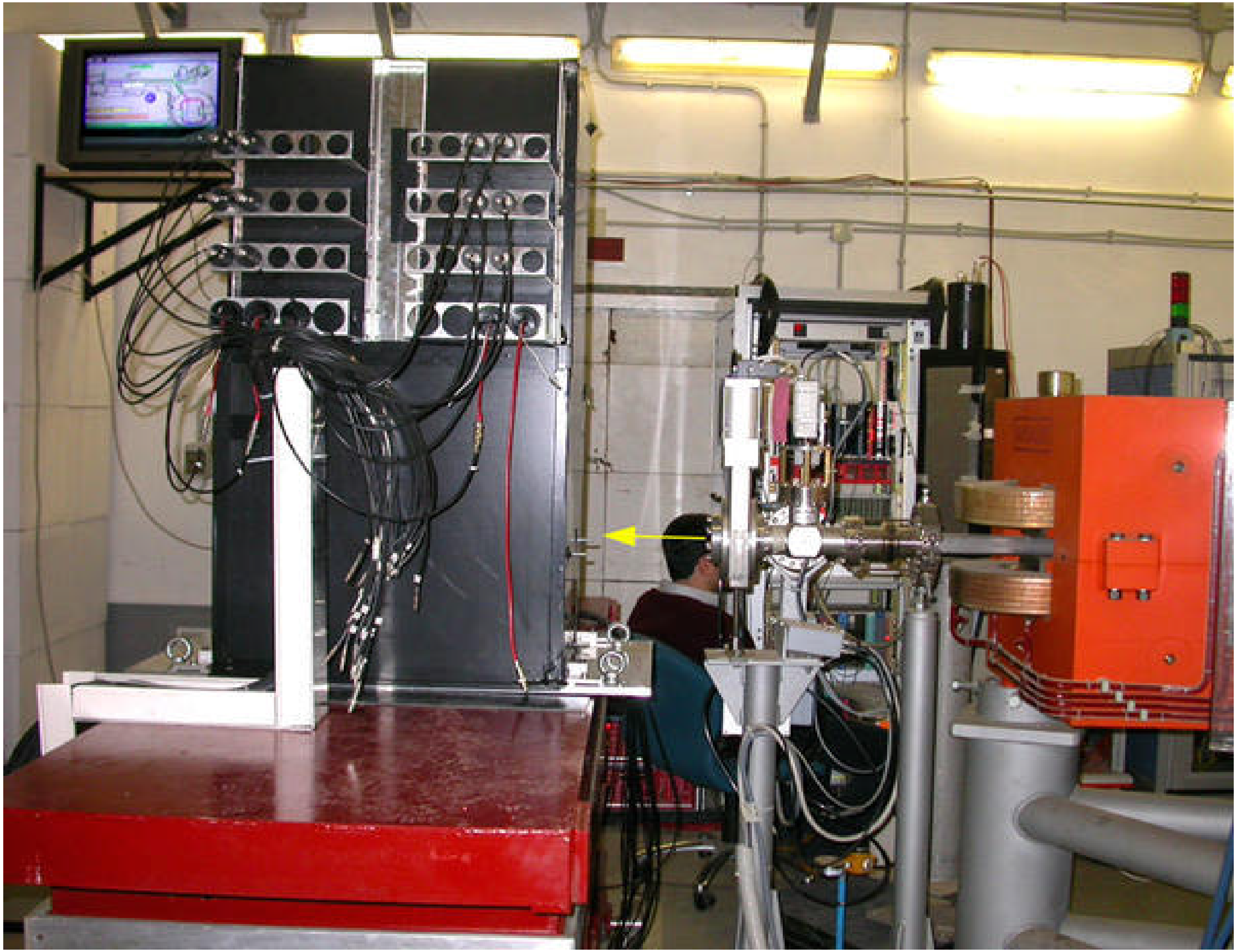
Negligible constant term observed in energy resolution.

e/π rejection very good ($< 10^{-3}$).

Two particles separation results coming soon.

Complete simulation of the prototype geometry in progress to compare shower shapes and particles separation power.

BACKUP SLIDES

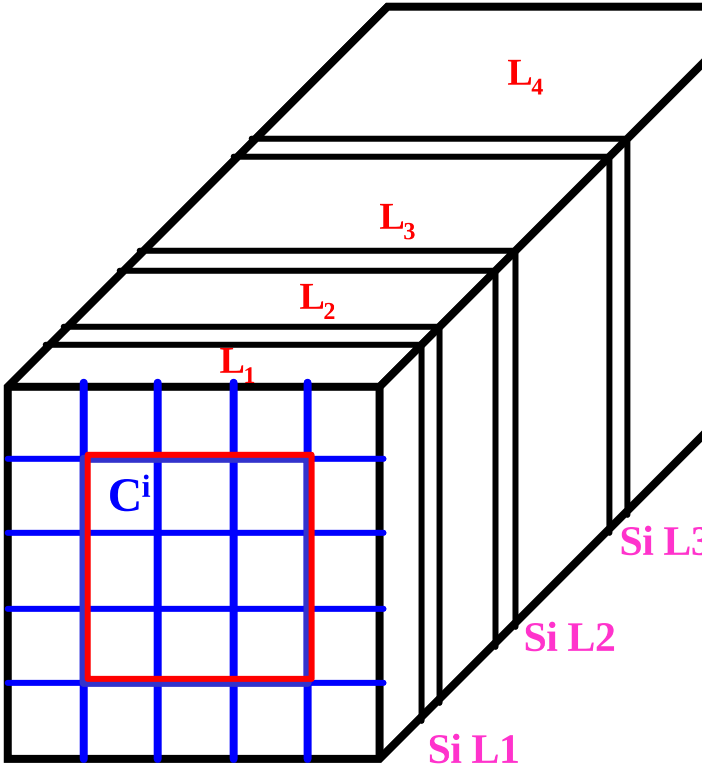


Test Beam: detector calibration

define the 'cell-energy' as the calibrated sum of the four longitudinal layers on the same lateral position:

$$C^i = b^i \; S^4{}_{j=1} \, (a_j \, L^i{}_j)$$

(4-1+9-1+16 parameters)

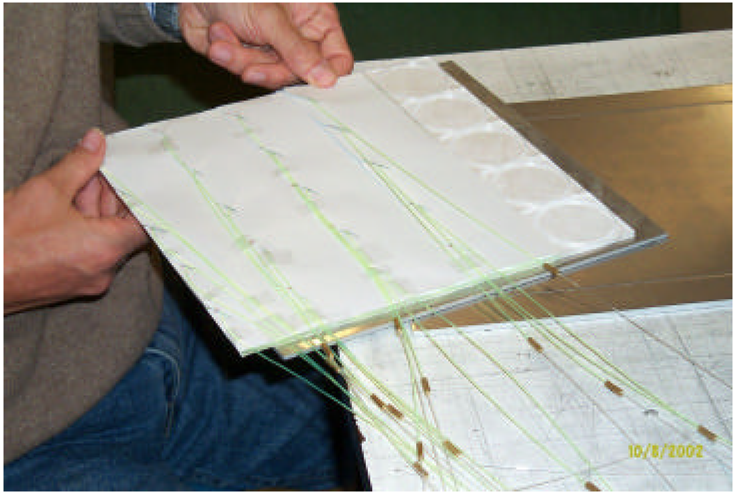


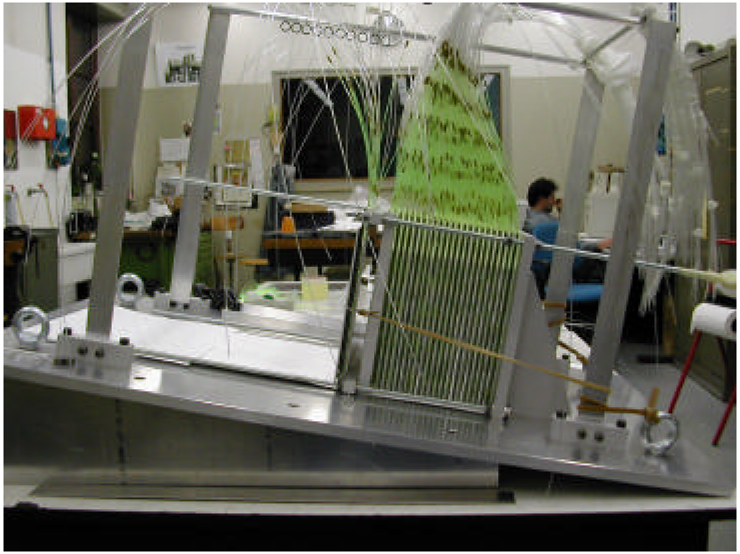
Calibration procedure in two steps:

- ❑ equalise the layer response to the same incoming energy $L^i{}_j = b^k/b^i \; L^k{}_j$
- ❑ minimise the Energy spread on the sum of 9 cells **(iterative procedure)**

$$a_j \mid \text{min. width } E_{cal} = S_{n=1,9} C^n$$

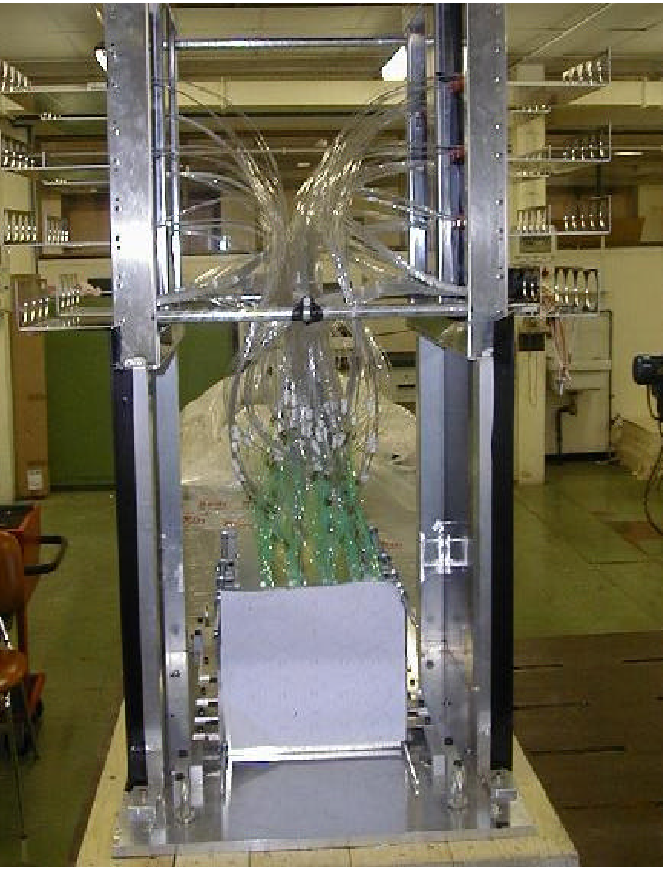
Detector Assembling:



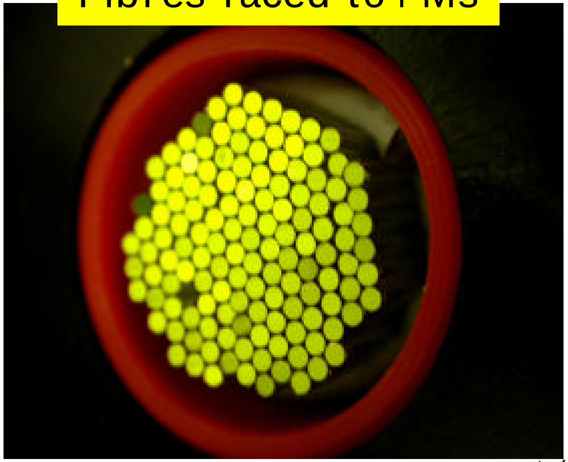


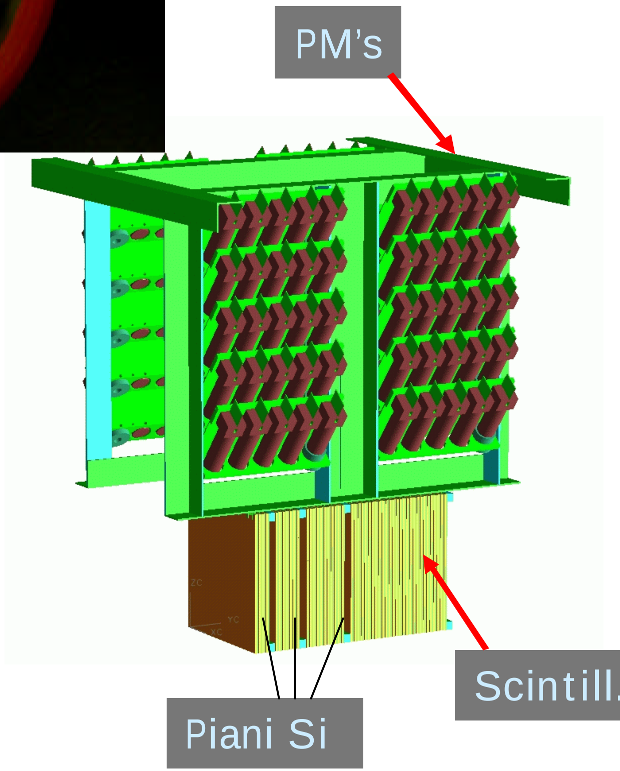
More pictures

Fibres with PM support structure



Fibres faced to PMs

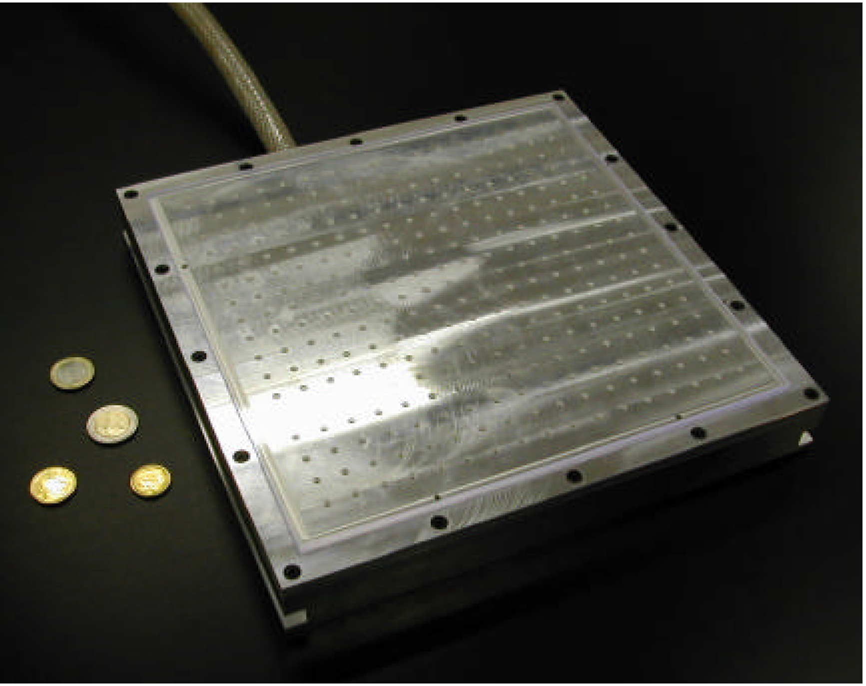


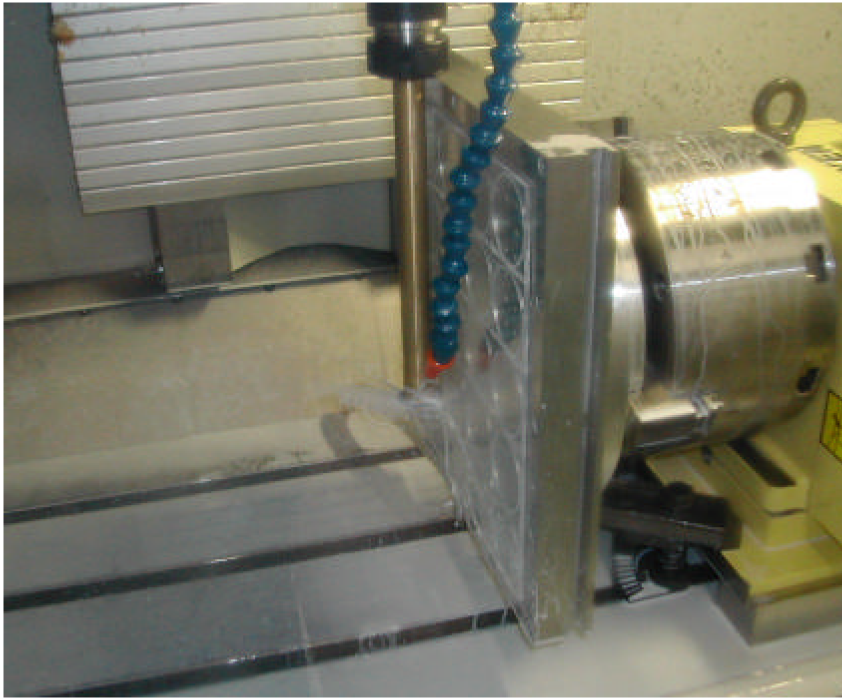


Construction details: Scintillator

- 3 mm Kuraray SCSN-61 (25x25 cm^2)
- 3 mm Bicron BC-408 (25x25 cm^2)

Machined with vacuum plate as holder

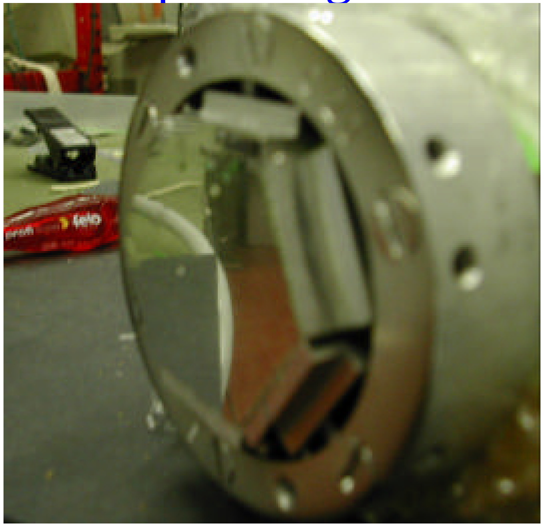




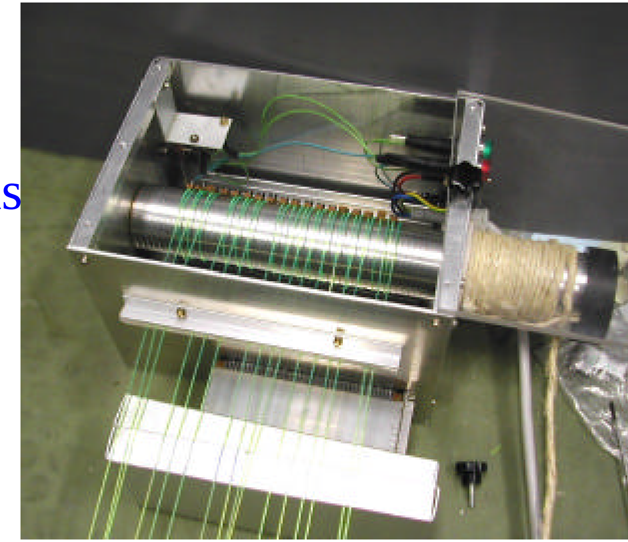
Whole Production (>50 tiles) done in september 2002

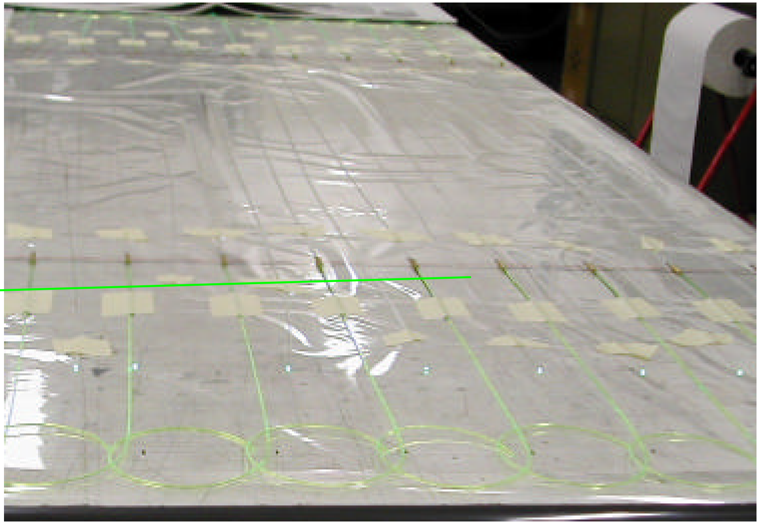
Fibers: Kuraray 1mm d. Y11 300 ppm multicladding

Face polished and aluminized by
sputtering



To get the 2.4 cm radius curvature : middle temperature (50^0-70^0) oven used





plicing with optical glue nd a supporting tube : stable in >30 day time

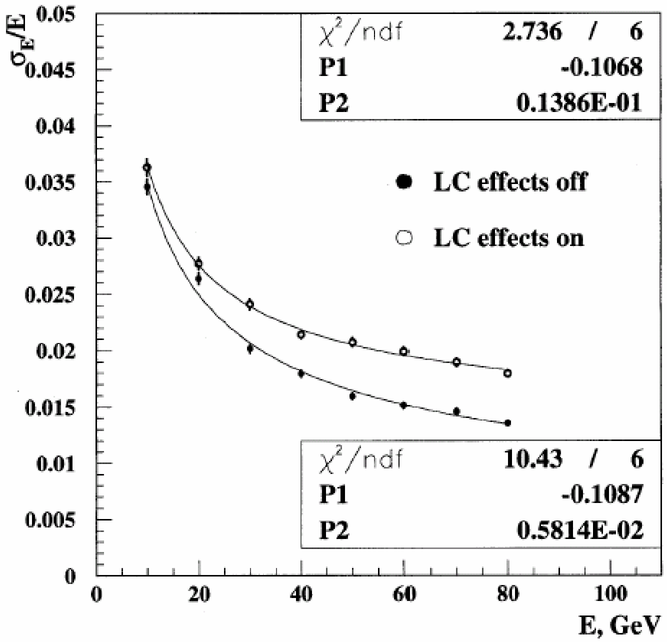
Test beam results: First calorimeter sector $(2.1\ X_0)$

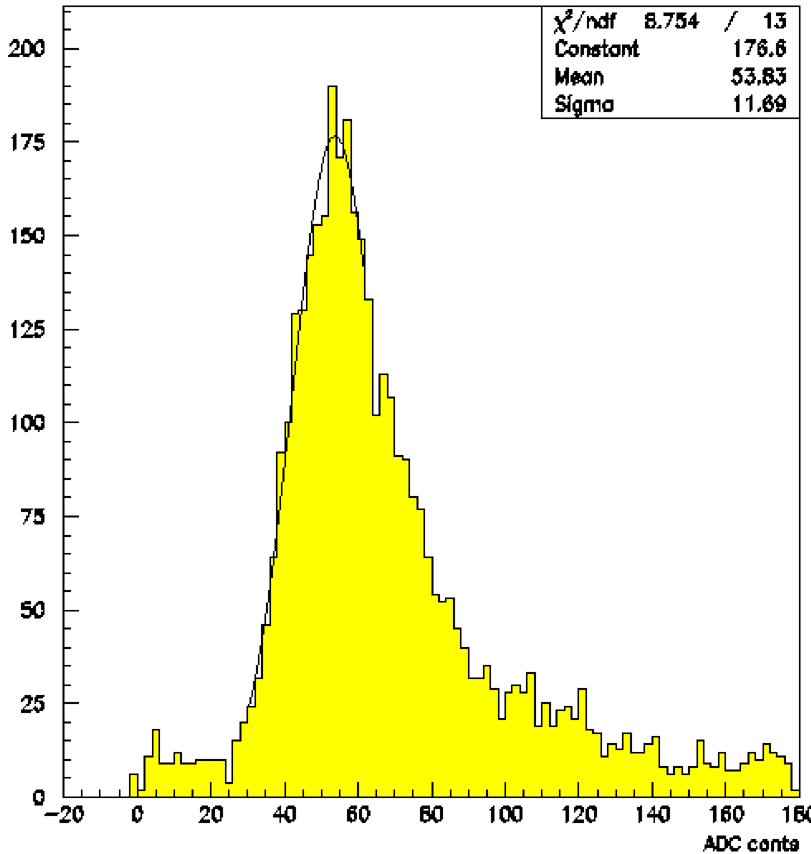
- 4 layers only
- m.i.p. ? check light output and uniformity in Light collection:
- Ratio signal/sigma ? lower limit for photoelectrons

❑ N_{phe}>5.1 /layer

❑ cal(45 layers): > 220 phe/m.i.p.

Simulated Light collection disuniformity(20%)

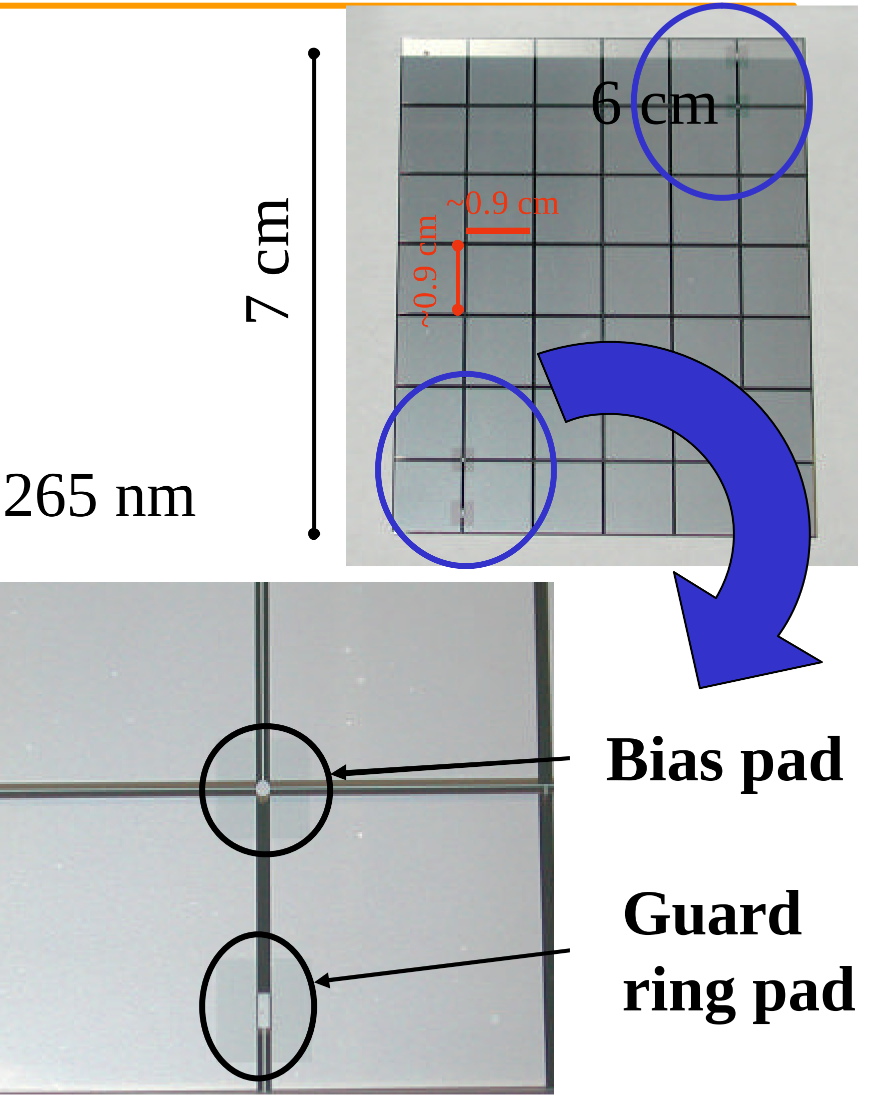




Sensor details

Main characteristics:

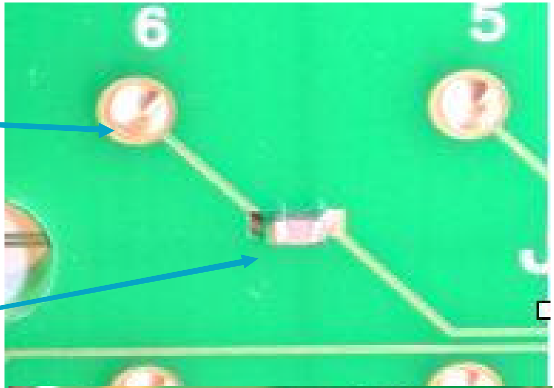
- Sensor thickness: 300μm
- Resistivity: 4-6kΩ
- AC coupling (2 ways)
  - Silicon dioxide thickness: 265 nm
  - SMD capacitors
- Bias grid and guard ring
  - 3MΩ poly-Si bias resistors
  - Symmetric structure

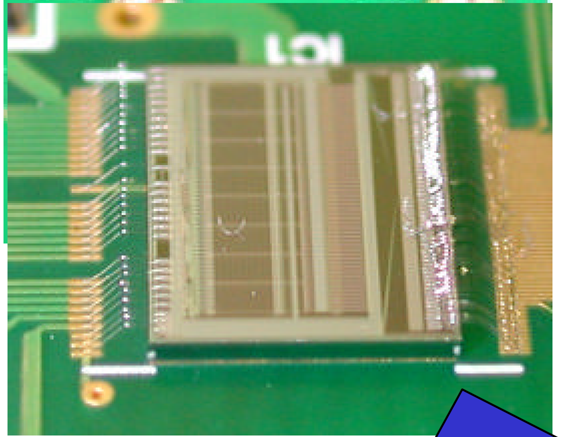


Hybridisation details

- Hybridisation through conductive glue
- Analogue Readout Chip:
  VA-HDR9c (IdeAs)
  - VA → Viking family
  - HDR → High dynamic range
  - 9c → Four selectable gains

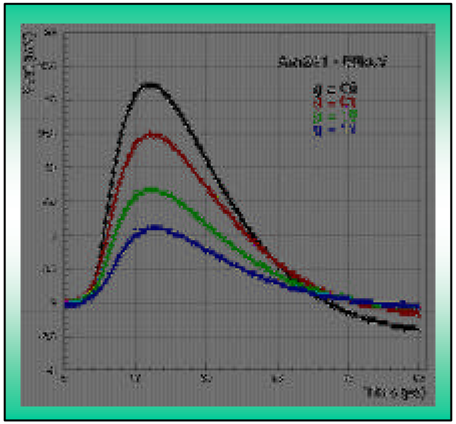
SMD caps

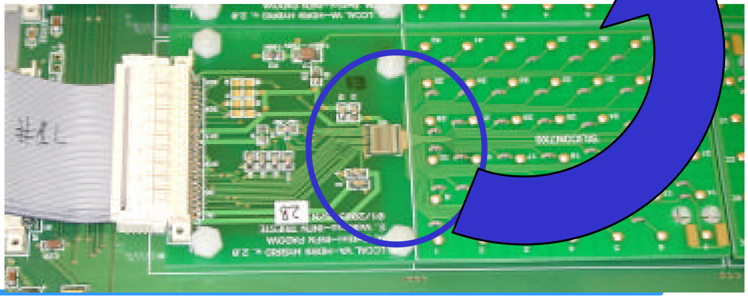




Gain* [mv/fC]	DR [mip]
3.3	± 100
2.5	± 140
1.7	± 200
1.2	± 300

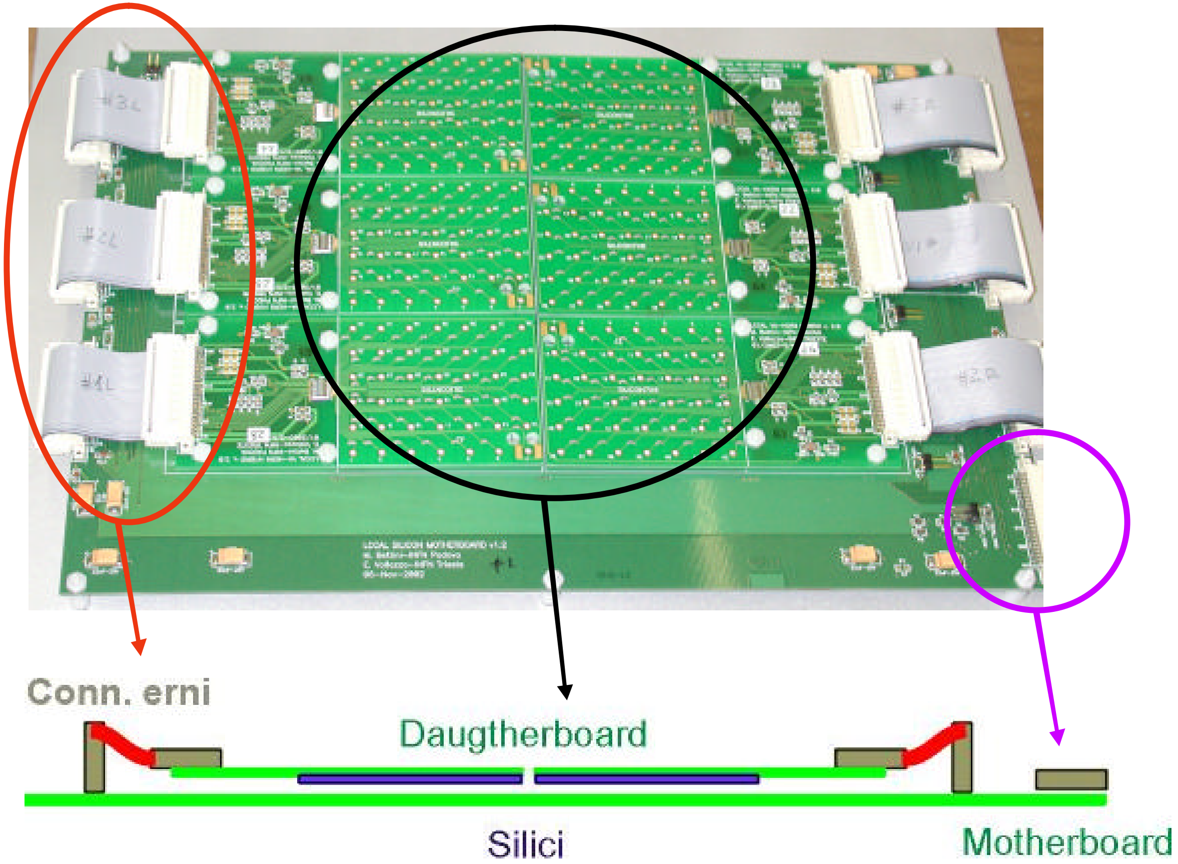
*Measured value





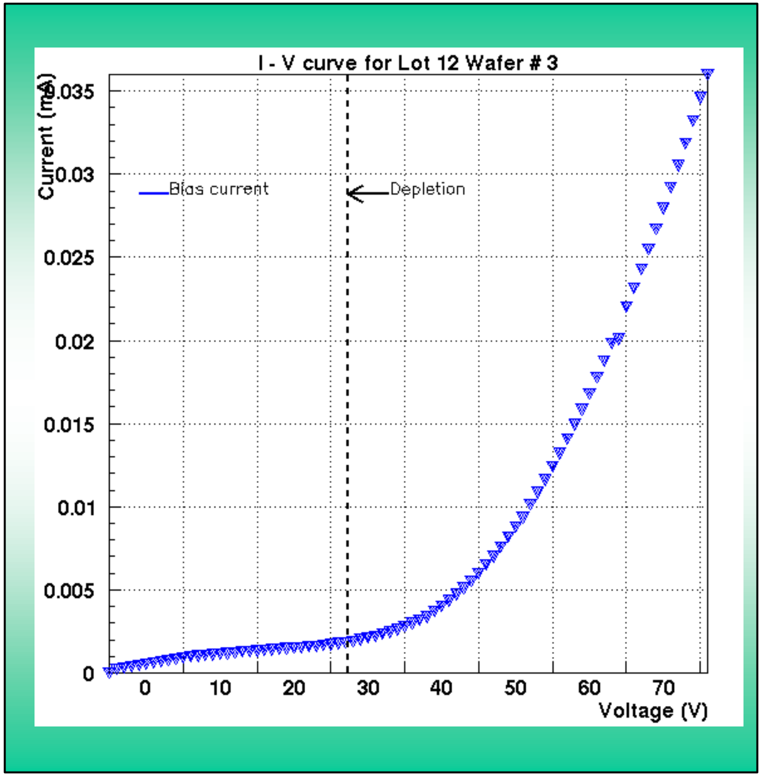
Motherboard design

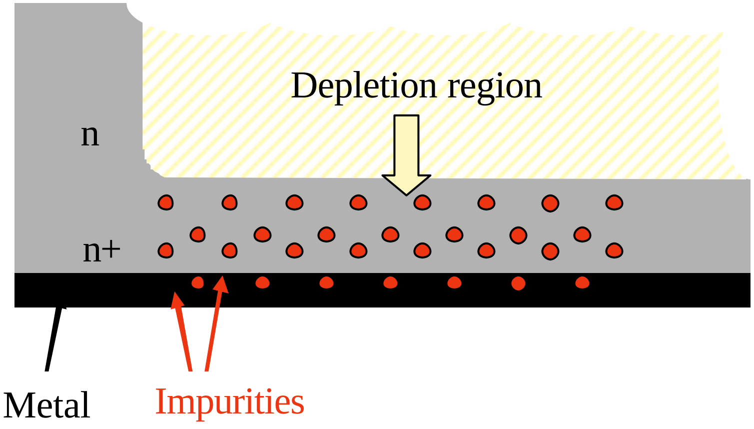
- 6 sensors per motherboard with serial readout.
- Signal routing through Erni connectors



Soft breakdown

- Bias current reasonable (few μA)
- Strange shape with a “soft” breakdown
- n+ or metal shallow impurities on the backplane



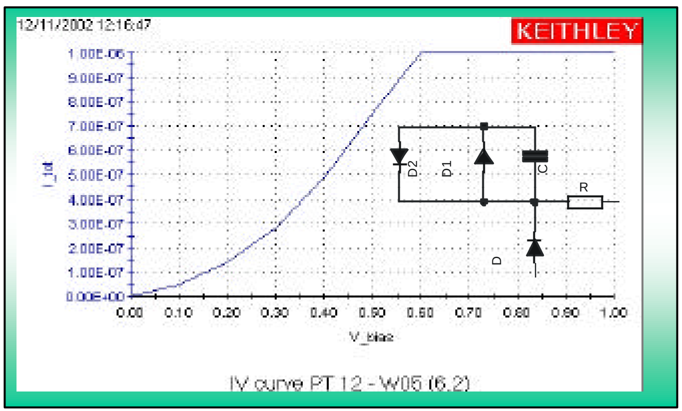


Solution 1: replace the implanted backside contact with a diffused one, but it does not work!

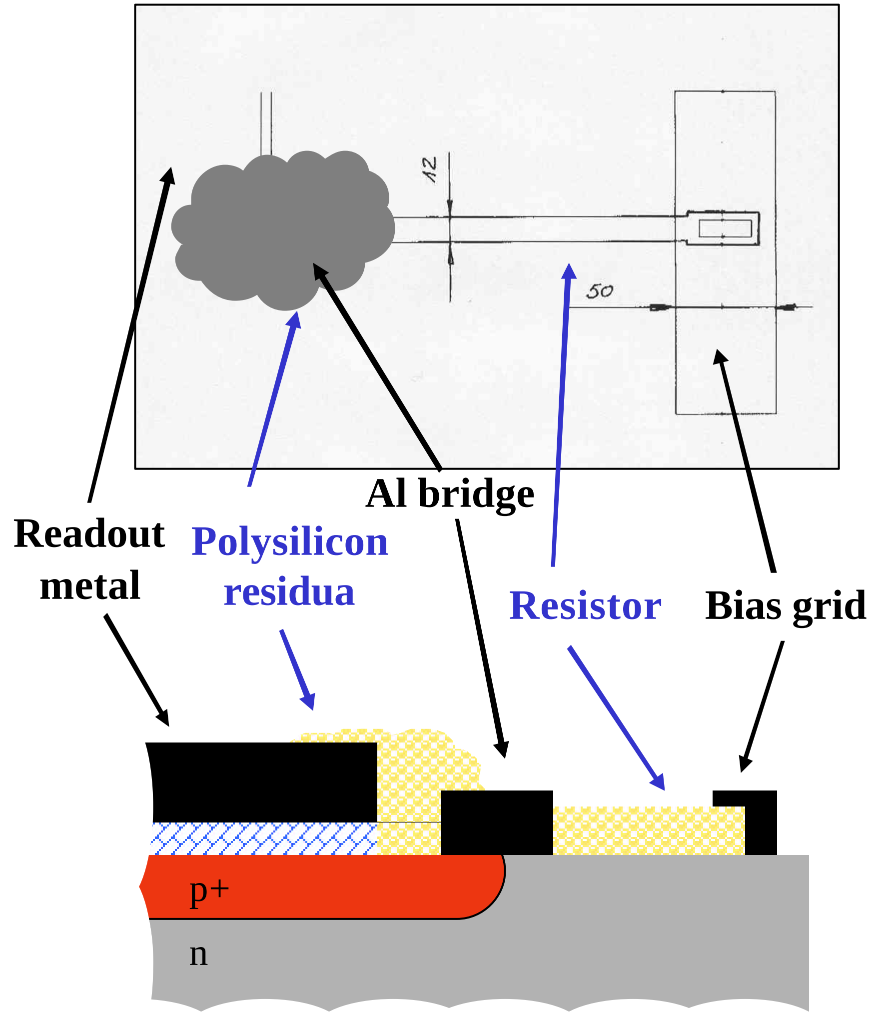
Solution 2: replace the mash backplane contact with a uniform one, it works

“Leaky” pads: a surface effect

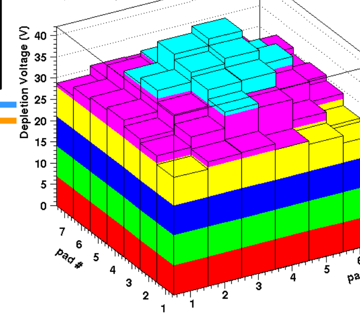
- No pin holes in SiO_2
- Surface leakage → residua of polysilicon after the etching of the polysilicon layer
- Equivalent circuit with two opposite diodes.

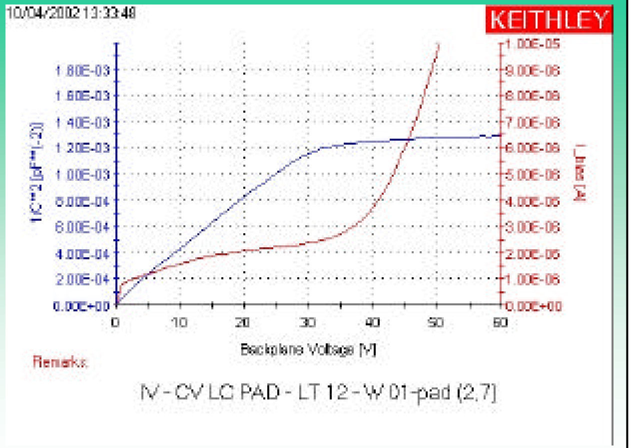


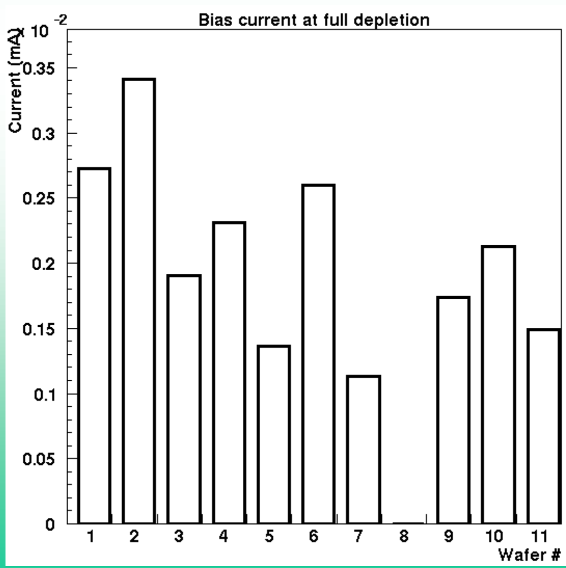
Solution: remove the integrated capacitors



Production yield and Bias







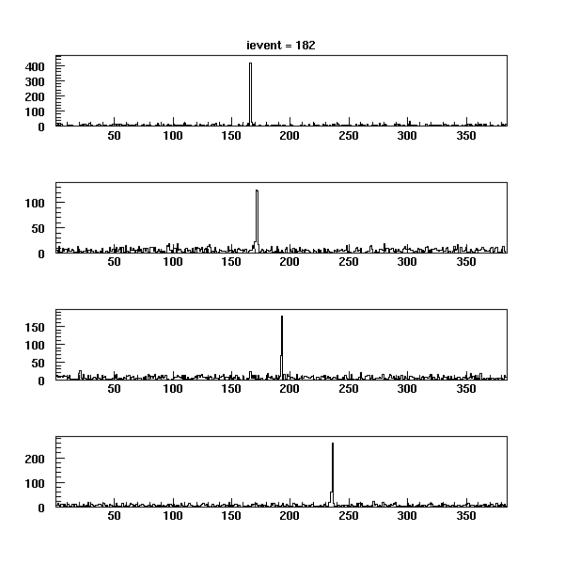
Quite uniform behaviour of the depletion voltage

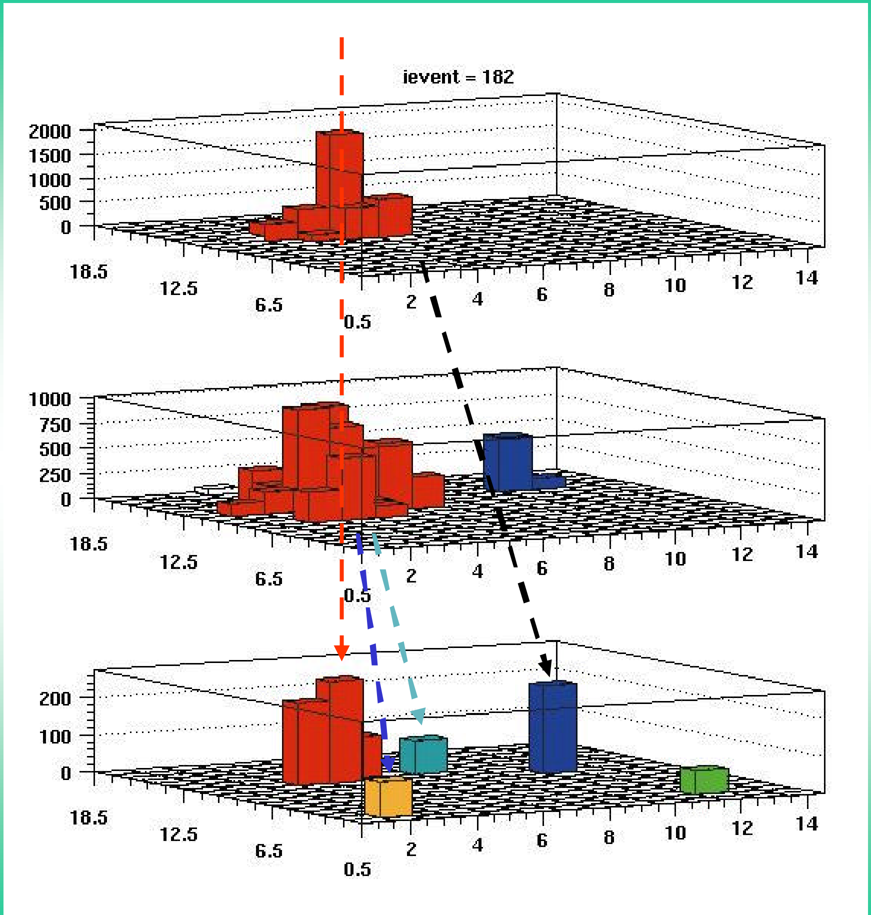
YIELD	1st Batch	2nd Batch	3rd Batch
Coupling	**AC**	**AC**	**DC**
Wafer Rejected	**1/11**	**2/9**	**0/9**
Depletion Voltage	**32V**	**27V**	**28 V**
Current @ depletion	**2.1 mA**	**0.8 mA**	**0.6 mA**
Not depleted pads	**0/420**	**8/249**	**0/378**

Test beam: shower reconstruction / 2

20 GeV e^-

Forward tracker





@ $2X_0$

@ $6X_0$

@ $12X_0$