Backward Endcap Calorimeter

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Outline

- Introduction
- Design of the backward endcap EMC
- Cost Estimate and manpower
- Expected TOF performance
- Measurements of similar calorimeters
- Construction of a prototype
- R&D results in Bergen

Introduction

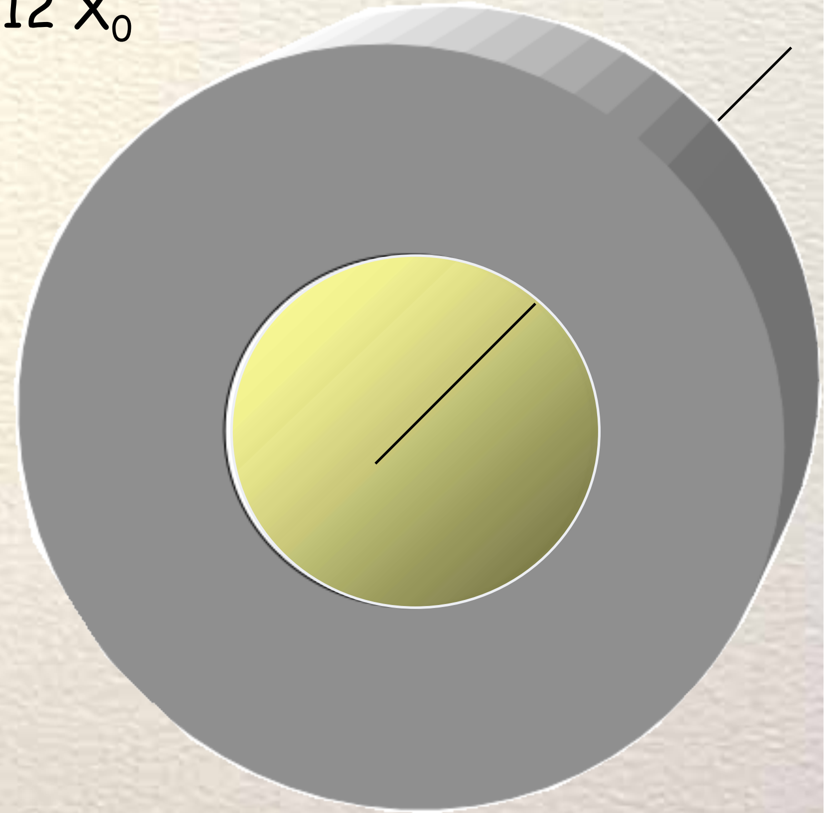
- Since in SuperB the asymmetry of beam energies is reduced to 4 GeV×7 GeV from 3.1 GeV×9 GeV, the rear region of the detector gains more importance than in BABAR
  ➔ need a more hermetic 4π detector than BABAR

- In addition, one important physics goal in SuperB is to exploit the recoil of fully reconstructed B decays
  - Analyses like $B\to\tau\nu$, $B\to K^{(*)}\nu\nu$ and $B\to X_s\ell\ell$ profit significantly from a hermetic detector, since E_{miss} is improved
  - For final states with a K^0_L, backgrounds are reduced
  - For inclusive $B\to X_s\gamma$ the π^0 veto is improved
  - Due to high angular resolution, π^0 reconstruction may be possible

- Since we do not have background measurements at 10^{36} $cm^{-2}s^{-1}$ a backward endcap EMC is an important element to determine E_{miss}

- Plan to build a sampling calorimeter that has an energy resolution 18%/$\sqrt{E}$ or better

Present Backward EC Calorimeter Design



- The backward endcap calorimeter is a 12 X_0 Pb-scintillator sampling calorimeter, arranged in 24 layers of 0.3 mm thick scintillator strips and 0.28 mm thick Pb plates

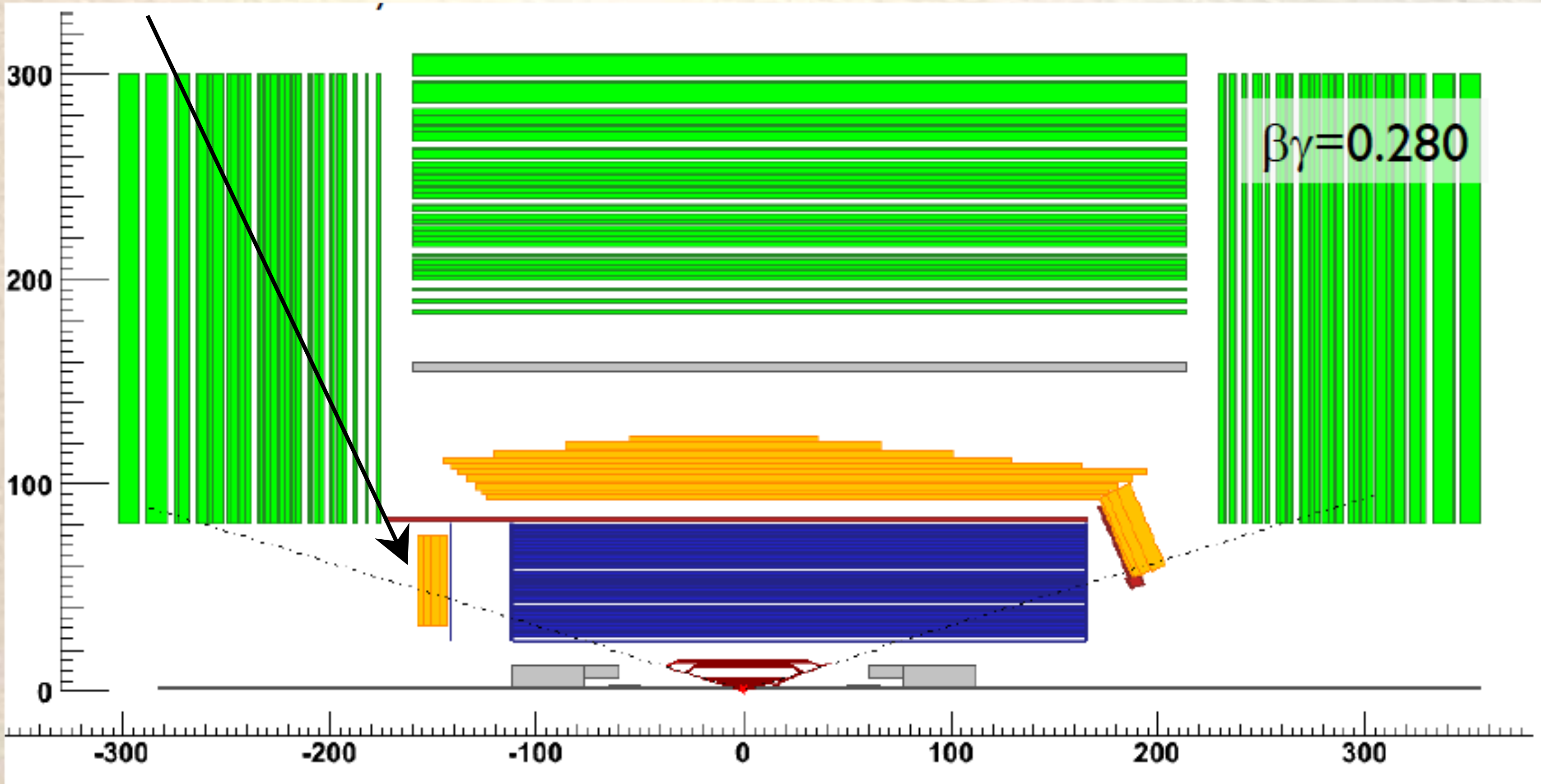
- It is located behind the DCH at z=-132 cm and is 18 cm deep
  ➔ It has been moved back by 22 cm to leave more space for DCH electronics

- Inner and outer radii: r_i=31 cm, r_o=75 cm ➔ r_i was chosen by 300 mrad at -110 cm (I would like to move in)

- The CALICE analog hadron calorimeter (steel-scintillator) served as guidance for the design which has taken data in test beam for the last 5 years (C. Adloff et al., JINST 5, P05007 (2010))

SuperB Design

Rear endcap:

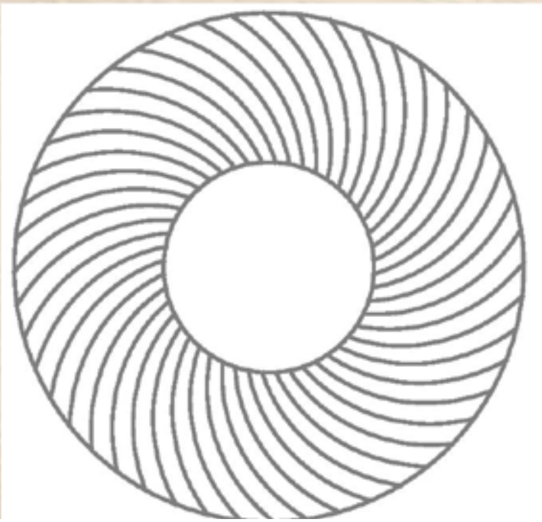


Position: r_i=31 cm, r_o=75 cm, z_i=132 cm, z_o=150 cm

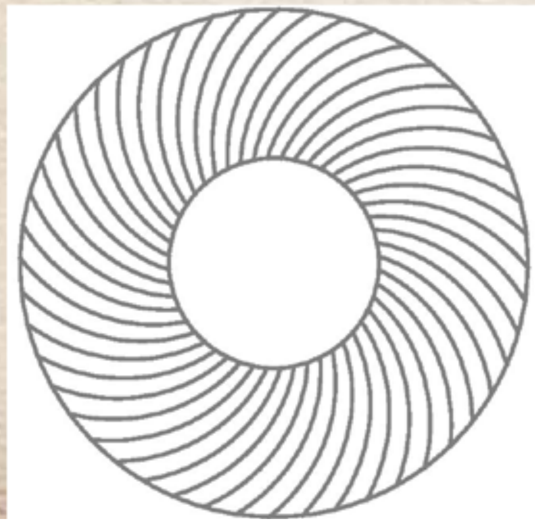
Backward EC Calorimeter Design

- On average only 1-2 particles are expected in the backward EC EMC,
  ➔ pixel design is not required, strips are fine ➔ less RO channels
- Dave Hitlin suggested to use spiral-shaped strips as in Mark II
  advantage ➔ all strips of a given type are the same
  ➔ all fibers go from inner to outer edge, where they are read out
  ➔ there is a natural ambiguity resolution, region defined by intersection is smaller at small radii where occupancy is higher
- Thus, we use 3 different shapes of strips:

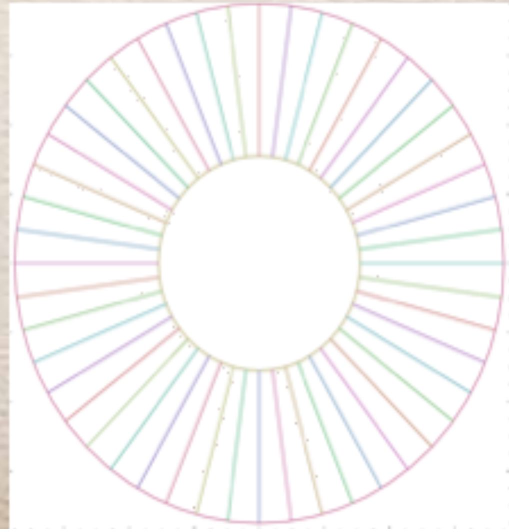
Left-handed spiral



Right-handed spiral

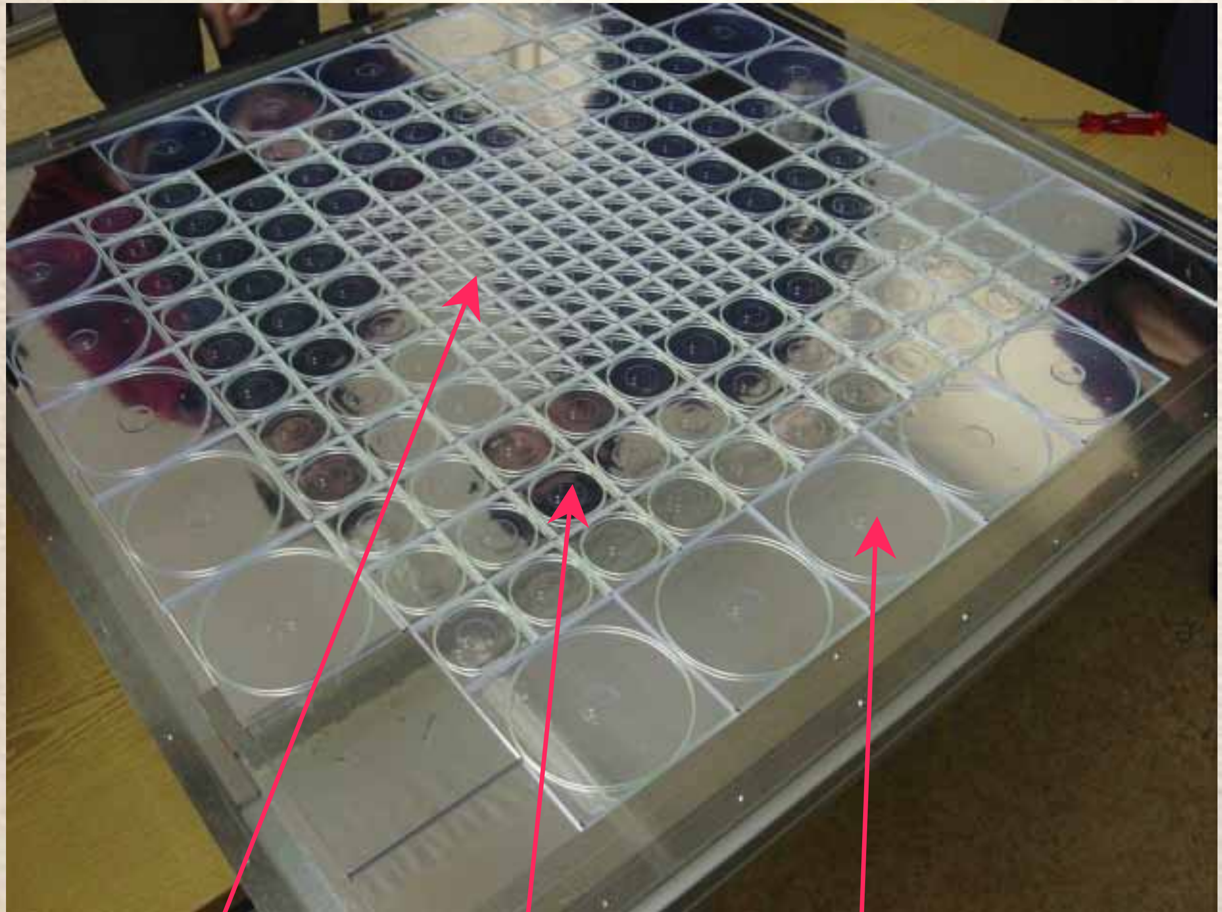


Sectors



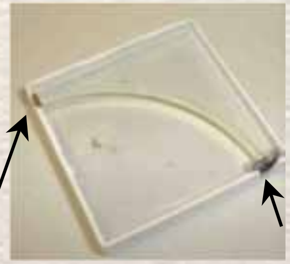
Readout in the Analog Hadron Calorimeter

- Example of a scintillator layer for an analog hadron calorimeter



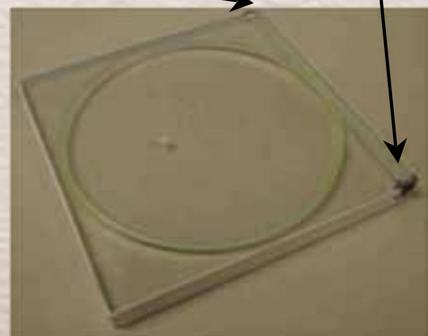
3×3 cm^2 6×6 cm^2 12×12 cm^2

- Propose same types of tile-fiber-SiPM couplings



SiPM

3M reflector



Backward EC Calorimeter Design

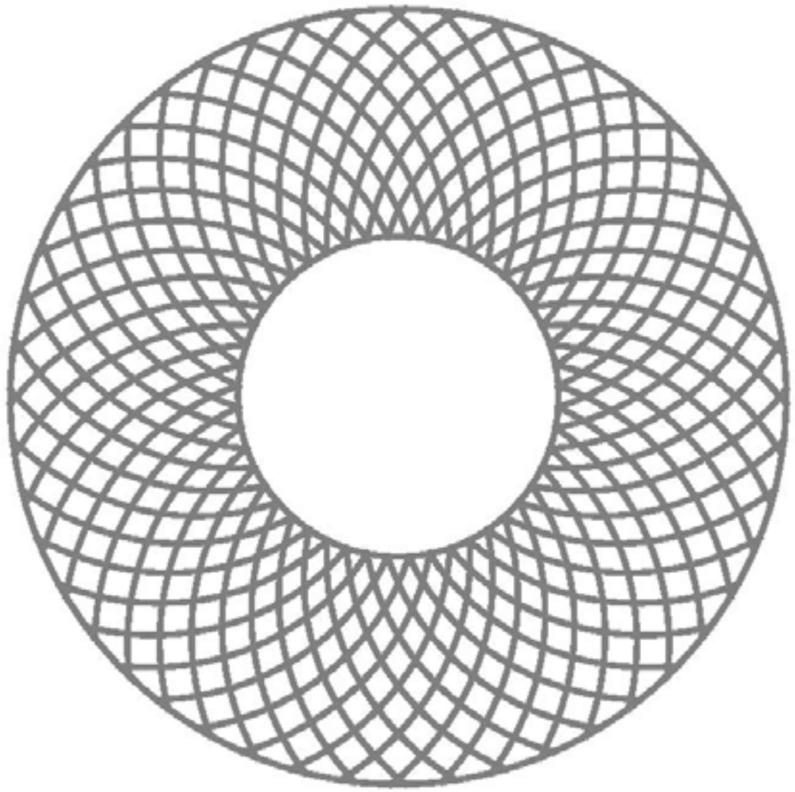
- In the 24 layers, the 3 strip shapes will alternate 8 times
- There are 48 strips per layer yielding 1152 strips in total
- The strip size varies from 4.1 cm at r_i to 9.8 cm at r_o
- The Molière radius $r_M \cong 3.8$ cm (r_M (Pb)=1.5 cm, r_M(scint)=6.0 cm)
- Optimal design is to assemble each layer completely
  ➔ this requires that the EMC EC needs to slide back on the beam pipe (assembly of two separate halves is possible ➔ impact: 10 spiral strips in each layer are cut into two separate segments ➔ 160 extra channels)
- Pb plates are produced in two half rings
- The scintillator strips are read out with WLS fibers (Y11) coupled to an MPPC
- A groove is milled in the center of the strip housing the Y11 fiber

Position Determination from Spiral Planes

- The left-handed logarithmic spirals are defined by

  x(t) = r Exp[b * t] Cos[t] – r

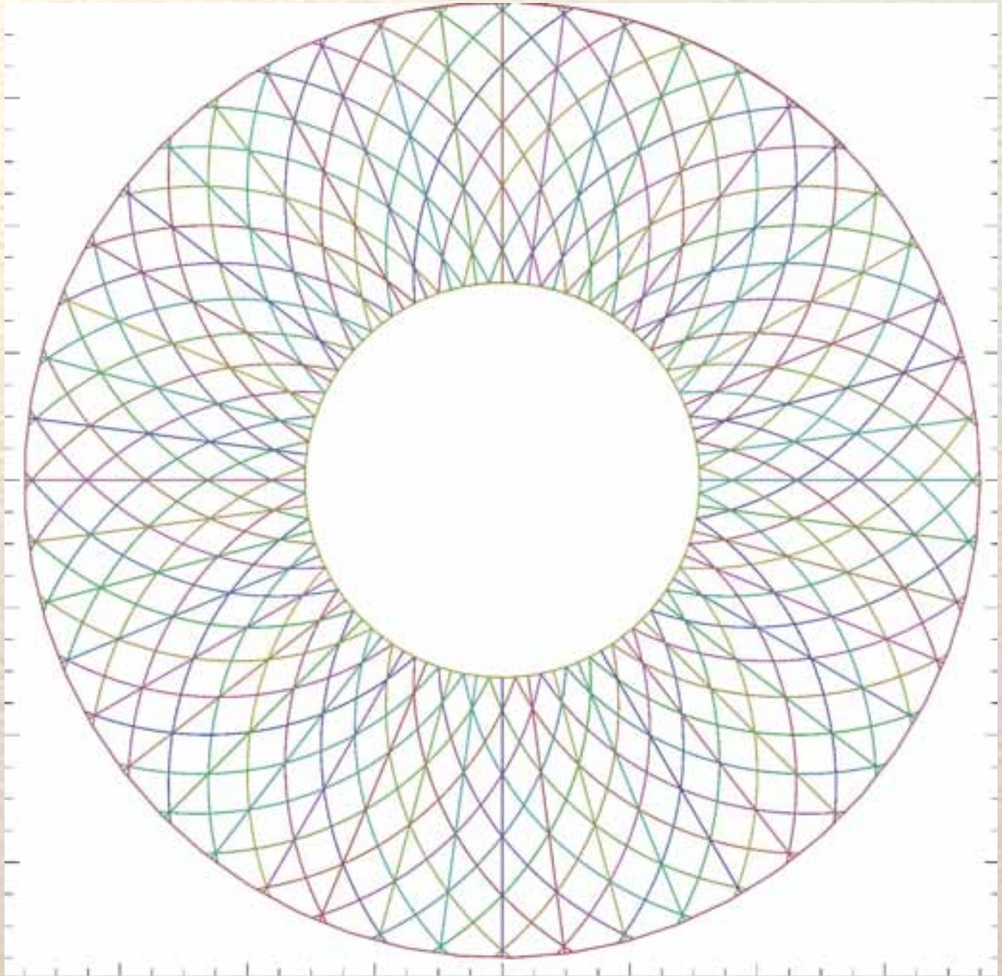
  y(t) = r Exp[b * t] Sin[t]



- For $r=r_o/2=37.5$ cm, b=0.2 get 8 complete "tiles" and 2 fractions of a tile
- The overlay of left-handed and right-handed spirals project out a tile structure,
  ➔ in radial direction we get 5 tiles
  ➔ $\Delta r\sim$ 10 cm for 4 tiles
  & $\Delta r\sim$ 4 cm for outermost tile
- In the worst case the resolution is $\sigma_r\sim\sigma_\varphi\sim2.9$ cm (outer region)
- In the best case the resolution is $\sigma_\varphi\sim1.2$cm (inner region)
- This can be improved at the cost of more channels

Position Determination from all 3 Planes

- Adding sector strips improves σ_φ by factor of 2 around sector boundaries
- For separating two tracks only σ_φ is relevant
- Since sector strips can be cut out from a smaller rectangular sheet than spiral strips, save scintillator material



Scintillator Strip Readout

- Originally, we wanted to use larger sheets separating strips by slots leaving 1-2% connections between strips ➔ cross talk position depend.
- The 3 mm thick scintillator strips are cut individually
  - best would be a spiral mould (usable for both left-handed and right-handed spirals), probably too expensive
  - need sufficiently big plates to cut out 12 spiral strips
  - for radial strips, 75 cm $\times$ 75 cm plates are sufficient
- Presently, St Gobain BC 404 scintillator is our choice (due to TOF use)
- At the inner edge the strips are 3.8 cm wide, increasing to 9.8 cm at the outer edge
- The sides are painted with a white diffuse reflector
- Front and back faces are covered with reflectors sheets (3M, Tyvec)
- To restore uniformity, implement a pattern of black dots onto to the reflector sheets

Properties of BC Scintillators

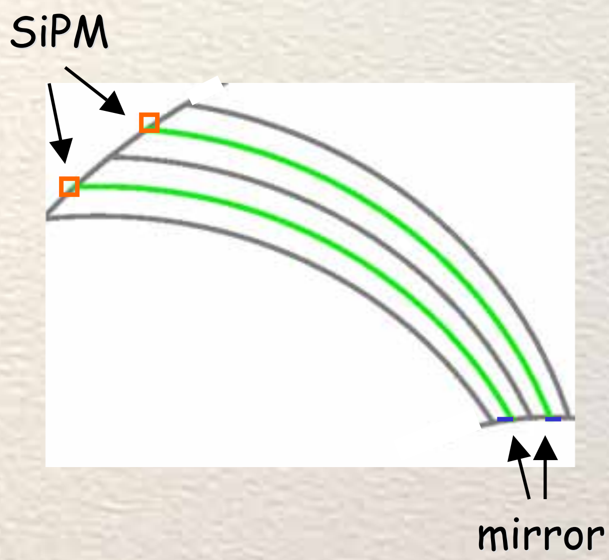
- We purchased 25 plates (75 cm× 75 cm) of cast scintillator from St Gobain (Bicron) BC-404, since it is faster (TOF application) for the prototype

- BC-408 would be better matched to the Y11 fiber

	BC-400	BC-404	BC-408	BC-412	BC-416
Light Output, % Anthracene	65	68	64	60	38
Rise Time, ns	0.9	0.7	0.9	1	-
Decay Time, ns	2.4	1.8	2.1	3.3	4
Pulse Width, FWHM, ns	2.7	2.2	~2.5	4.2	5.3
Light Attenuation Length, cm*	160	140	210	210	210
Wavelength of Max. Emission, nm	423	408	425	434	434
No. of H Atoms per cm^3, ($x10^{22}$)	5.23	5.21	5.23	5.23	5.25
No. of C Atoms per cm^3, ($x10^{22}$)	4.74	4.74	4.74	4.74	4.73
Ratio H:C Atoms	1.103	1.1	1.104	1.104	1.11
No. of Electrons per cm^3, ($x10^{23}$)	3.37	3.37	3.37	3.37	3.37
Principal uses/applications	General purpose	Fast counting	TOF counters, large area	Large area	Large area, economy

Scintillator Strip Readout

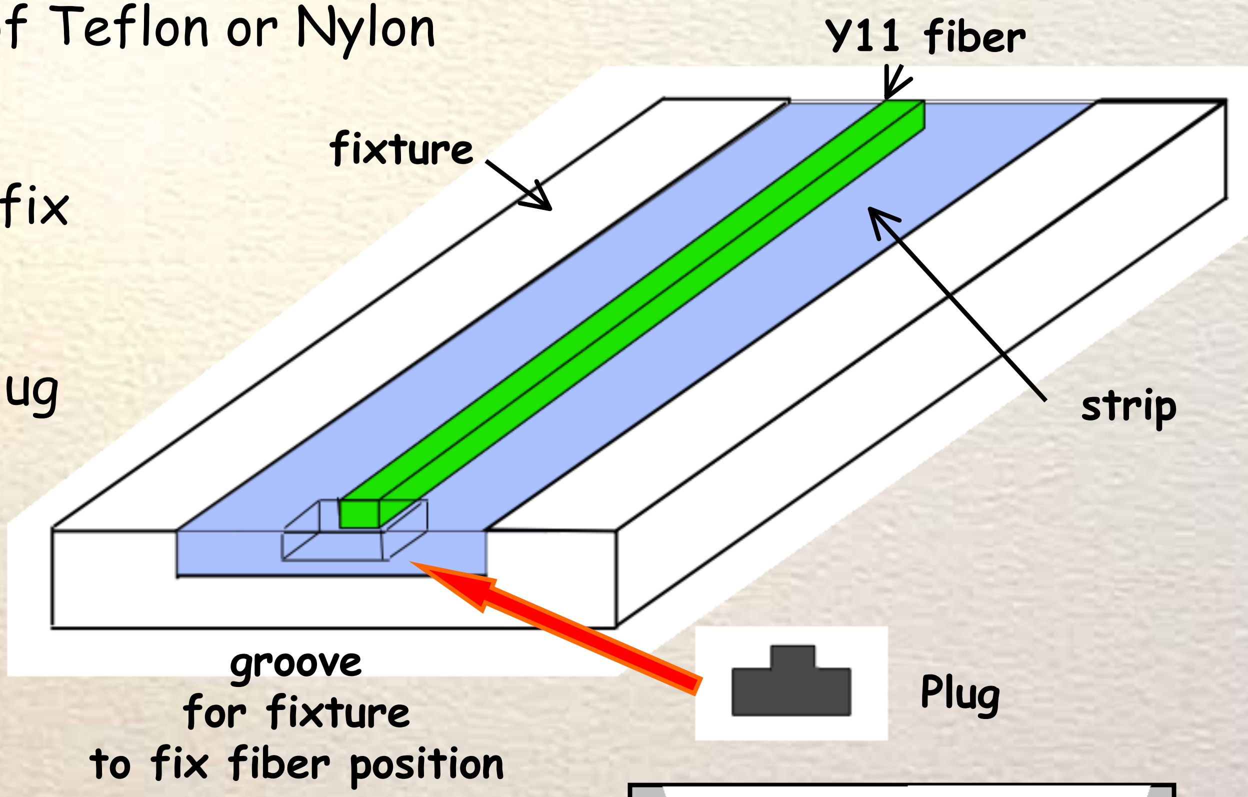
- In the center a 1mm deep spiral-shaped groove is milled into which the 1 mm thick Y11 WLS fiber is inserted
- A SiPM (MPPC) is mounted at the outer edge into a precisely cut small groove
- A mirror is positioned at the inner edge of the fiber into a small groove
- Use 2 mm thick coax cables to couple the MPPCs to the ASIC

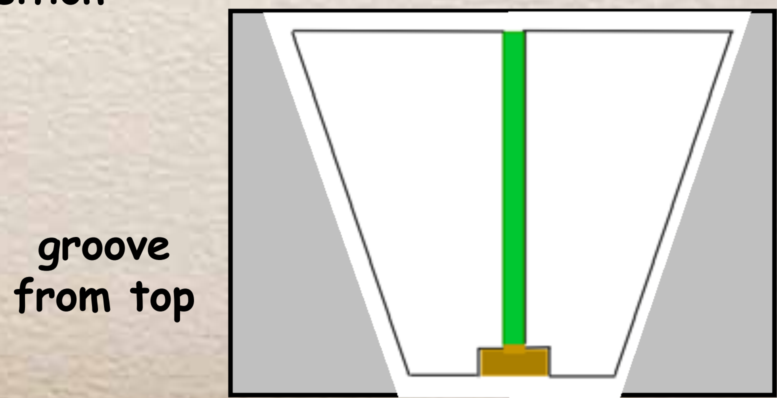


- We insert a clear fiber into each strip at the outer ring transporting light from a UV LED providing gain calibration and monitoring
- Each cell (strip+Y11 fiber+MPPC) will be tested before insertion into the detector with a ^{106}Ru or ^{90}Sr source

Mounting MPPCs to Y11 Fiber

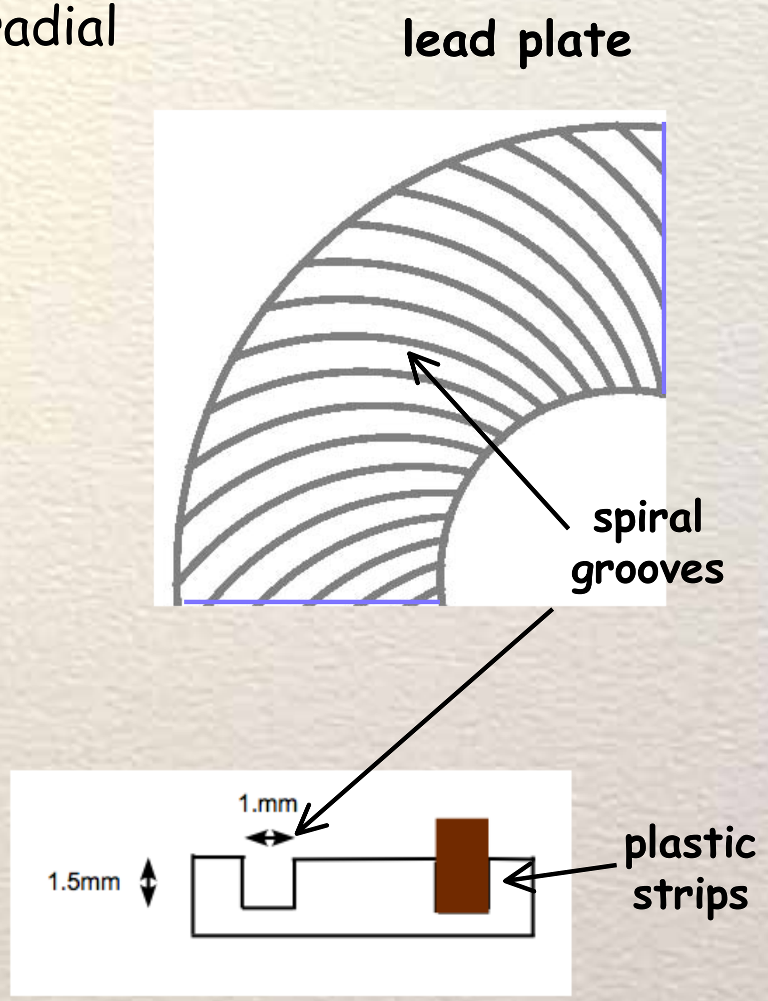
- Build a fixtures out of Teflon or Nylon that holds a strip
- Insert Y11 fiber and fix it by inserting a plug
- Press fiber against plug and hold by a drop of glue
- Remove plug, insert MPPC and glue it to Y11 fiber
- On the other end a mirror is glued to fiber
- We pick up tolerances in length of the fiber at the mirror end





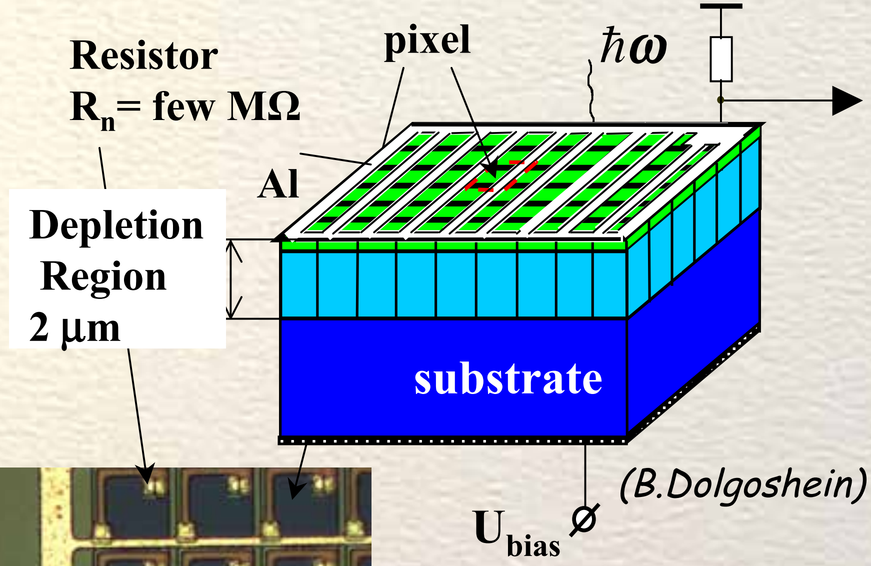
Procedure to Hold Strips

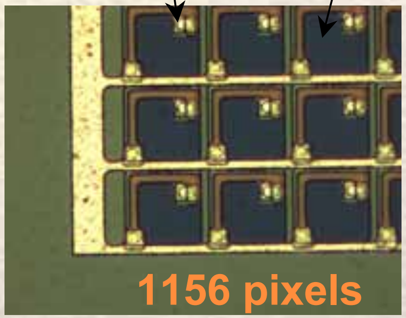
- In order to hold strips we cut spiral or radial grooves into the lead segments
- Grooves are 1.5 mm deep and 1 mm wide
- A 3 mm thick, 1 mm wide and 55 cm long plastic strip is inserted into the groove and is glued
- This structure is strong enough to hold the scintillator strips in place
- This has the advantage that the calorimeter can be rotated by 90^0 to use cosmic muons for MIP calibration

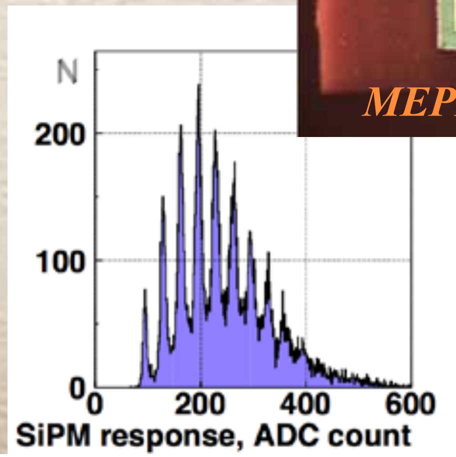


Properties of SiPMs & MPPCs

- Multipixel Geiger Mode APD
  - Gain 10^6
  - Bias U~50 V
  - Active area 1 mm^2
  - 1156 pixels, $20\mu m \times 20\mu m$
  - Efficiency 10-15%
  - Insensitive to B field
  - Each pixel has few $M\Omega$ quenching resistor
  - Recovery time < 100 ns
- SiPM detectors are auto-calibrating
- SiPM response is non linear
- Dynamic range is limited by #pixels
- We have chosen Hamamatsu MPPCs with 1600 pixels and a gain of few 10^5







Properties of New MPPC's

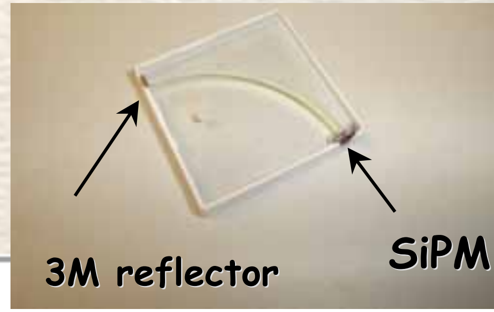
- Hamamatsu has produced two new photo sensors with 2500 pixels and 4489 pixels
- These have larger dymanic range but smaller gain

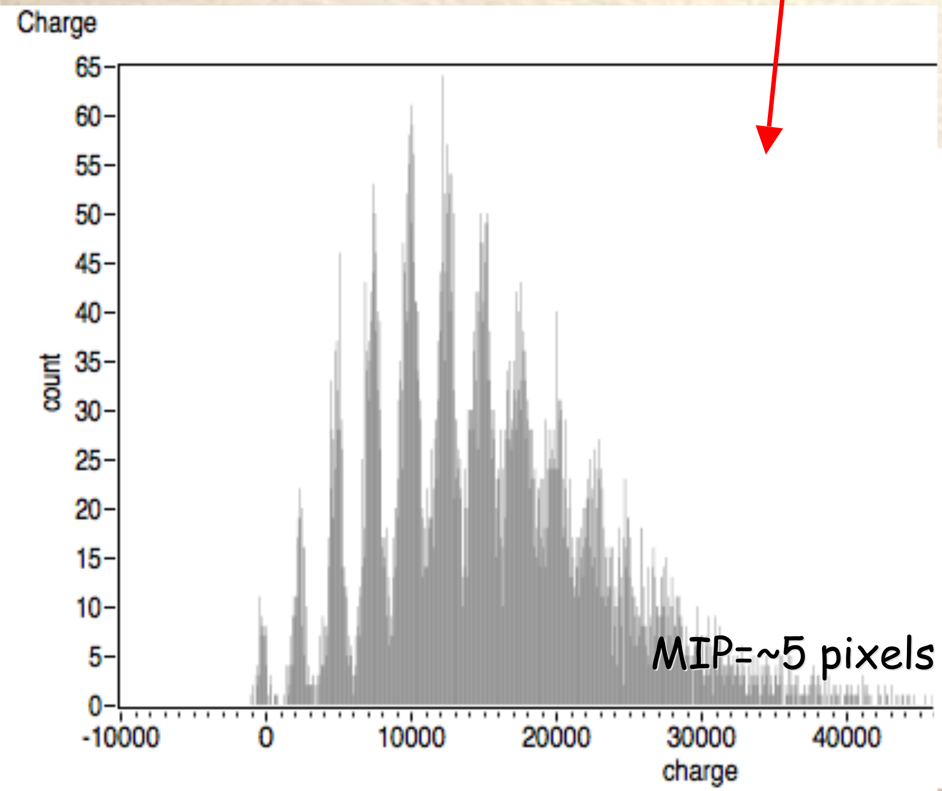
MPPC type	# cells 1/mm^2	C, pF	R_{cell}, kOhm	C_{cell}, fF	$\tau = R_c x C_c$, ns	VB, V T=23 C	V_{op}, V T=23 C	Gain(at V_{op}), X10^5
15 µm pitch	4489	30	1690	6.75	11.4	72.75	76.4	2.0
20 µm pitch	2500	31	305	12.4	3.8	73.05	75.0	2.0
25 µm pitch	1600	32	301	20	6.0	72.95	74.75	2.75
50 µm pitch	400	36	141	90	12.7	69.6	70.75	7.5

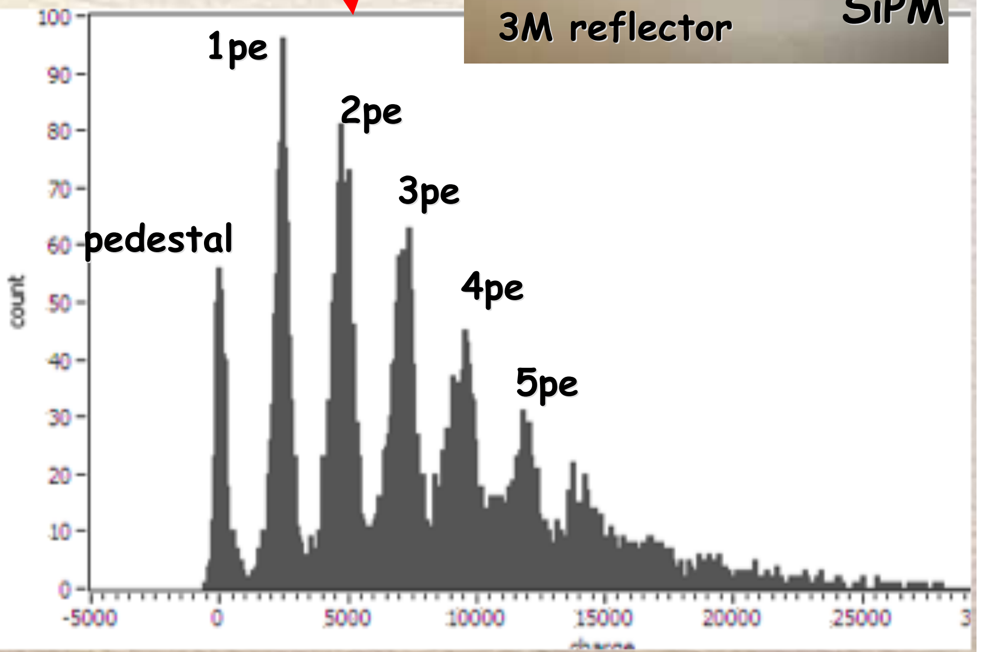
Scintillator Spectra

- Operate SiPM with $gain_{SiPM}$~4×10^5
- Measure spectrum with ^{90}Sr source and light pulser

1156 pixels

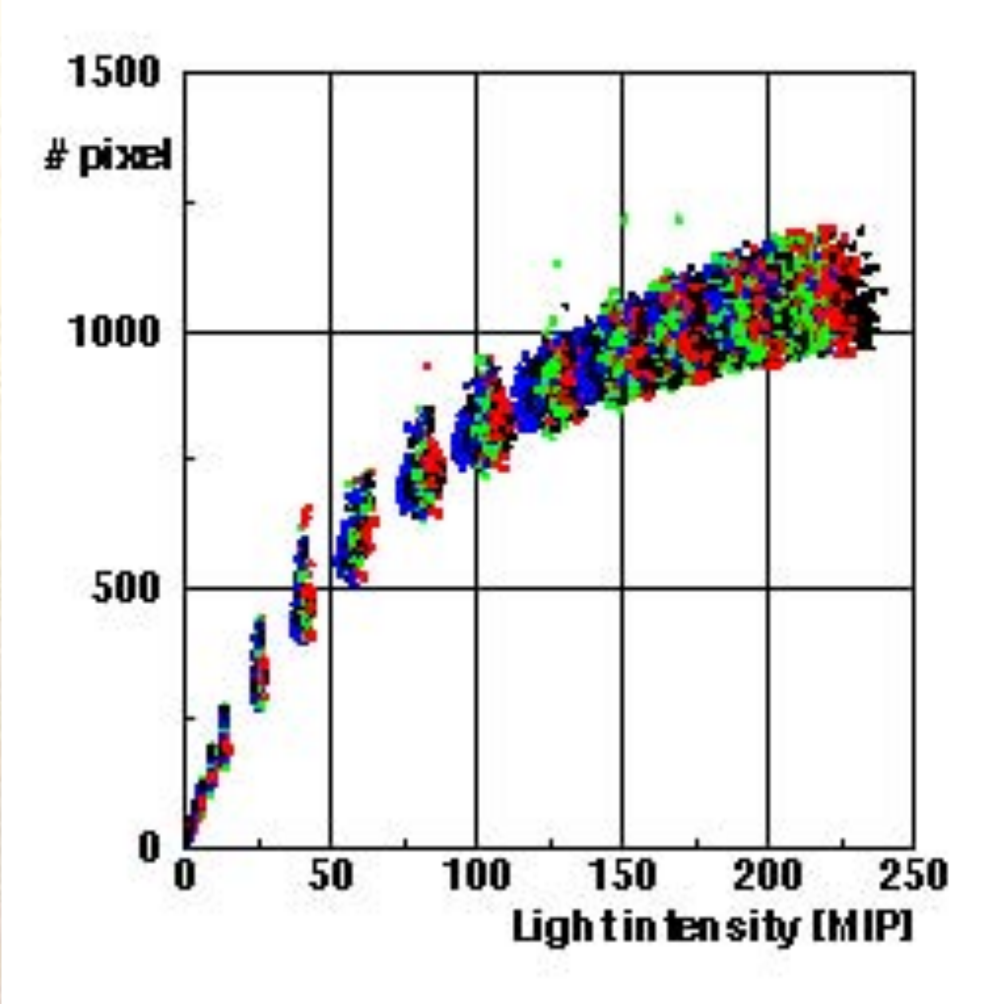






SiPM Response Function

- The SiPM response is non-linear and needs to be measured for each detector
- The shapes are very similar and agree within 15%
- A monitoring system may be necessary to measure the SiPM response function when required

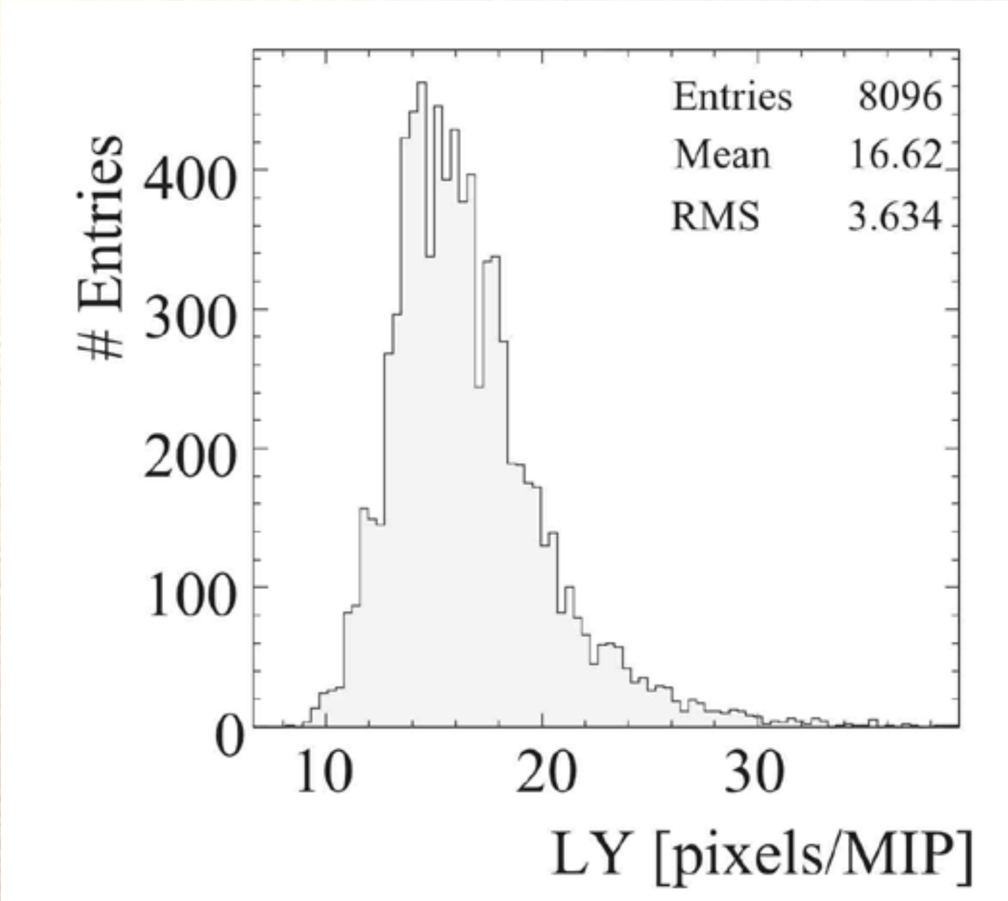


10000 SiPMs in the analog hadron calorimeter

Measured Light Yield of MIP

- We have measured the light yield of the tile-fiber-SiPM configuration for the cells installed in the AHCAL prototype plus spares

- The MIP is at 16.6 pixels the spread is 3.6 pixels
  ➔ this gives a dynamic range of 70 MIPs per cell

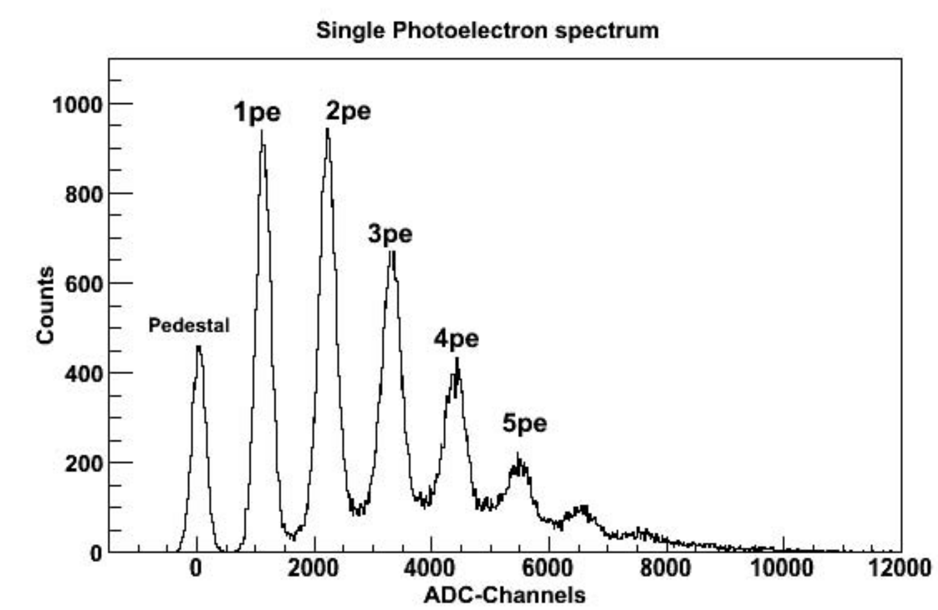


- For the backward EC we aim for a MIP of ~10 pixels

➔ this gives a dynamic range of 160 MIPs/cell for Hamamatsu MPPCs
➔ if necessary we could reduce pixel size to 20 μm or 15 μm increasing the dynamic range to 250 MIPs/cell or 450 MIPs/cell

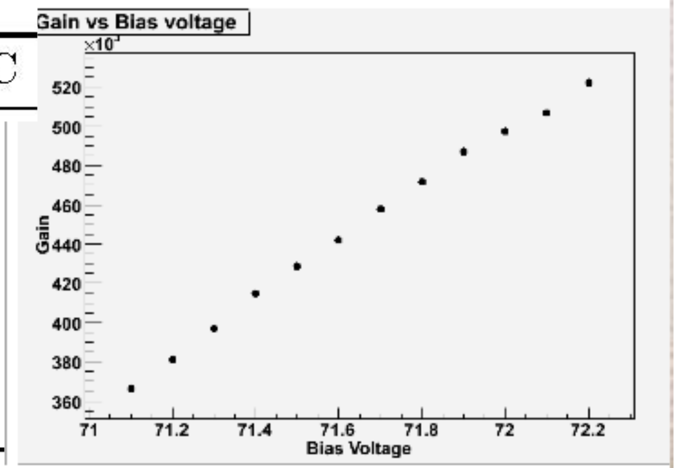
Some Properties of MPPCs

- Breakdown voltage for 1x1 mm^2 MPPCs is ~70V
- Capacitance of 1x1 mm^2 MPPCs is ~ 22-26 pF
- Temperature and voltage dependence for 1x1 mm^2 MPPCs is ~4.5%/0.1V and -2.2%/^{0}C



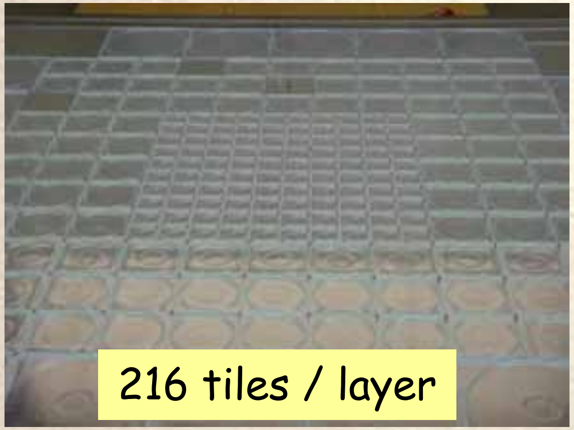
- Use stable power supplies, need to monitor temperature and gain

Photodetector	C_{pixel}[fF]	$V_{breakdown}$	%G/0.1V	%G/1°C
S10362-11-025C				
Sample738	22.29±0.15	68.31±0.65	4.35	
Sample739	23.97±0.15	69.13±0.60	4.47	
Sample740	21.73±0.30	68.28±1.34	4.24	
Sample741	26.09±0.19	68.58±0.71	4.68	-2.19
Sample742	21.63±0.19	69.00±0.86	4.27	-2.21

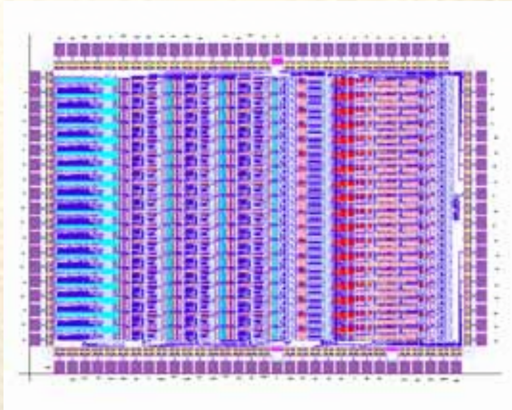


HCAL Readout Architecture

- The VFE electronics from the AHCAL prototype can be used for the rear endcap

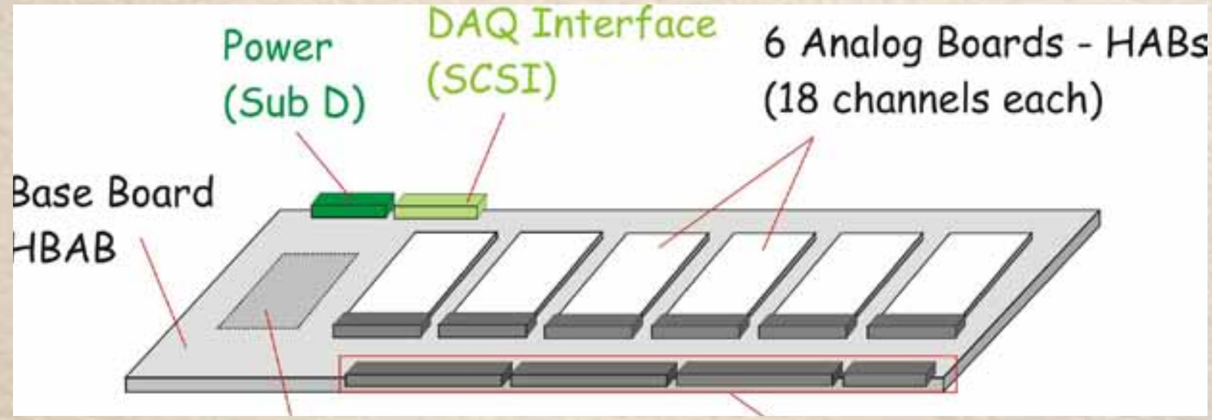


216 tiles / layer

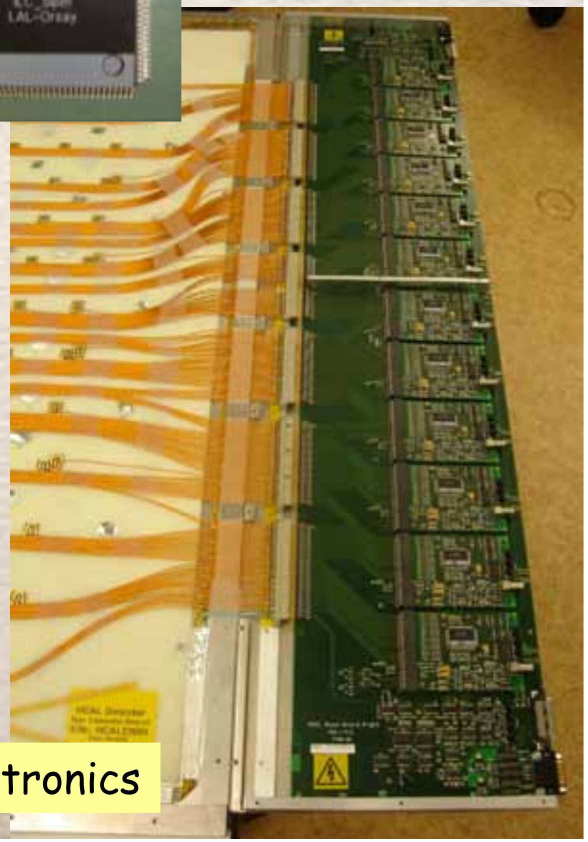


18 analog channels / chip

ILC_SiPM chip



2 base boards (12 piggy backs) / layer



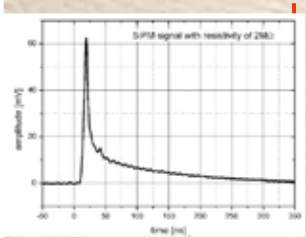
very front-end electronics

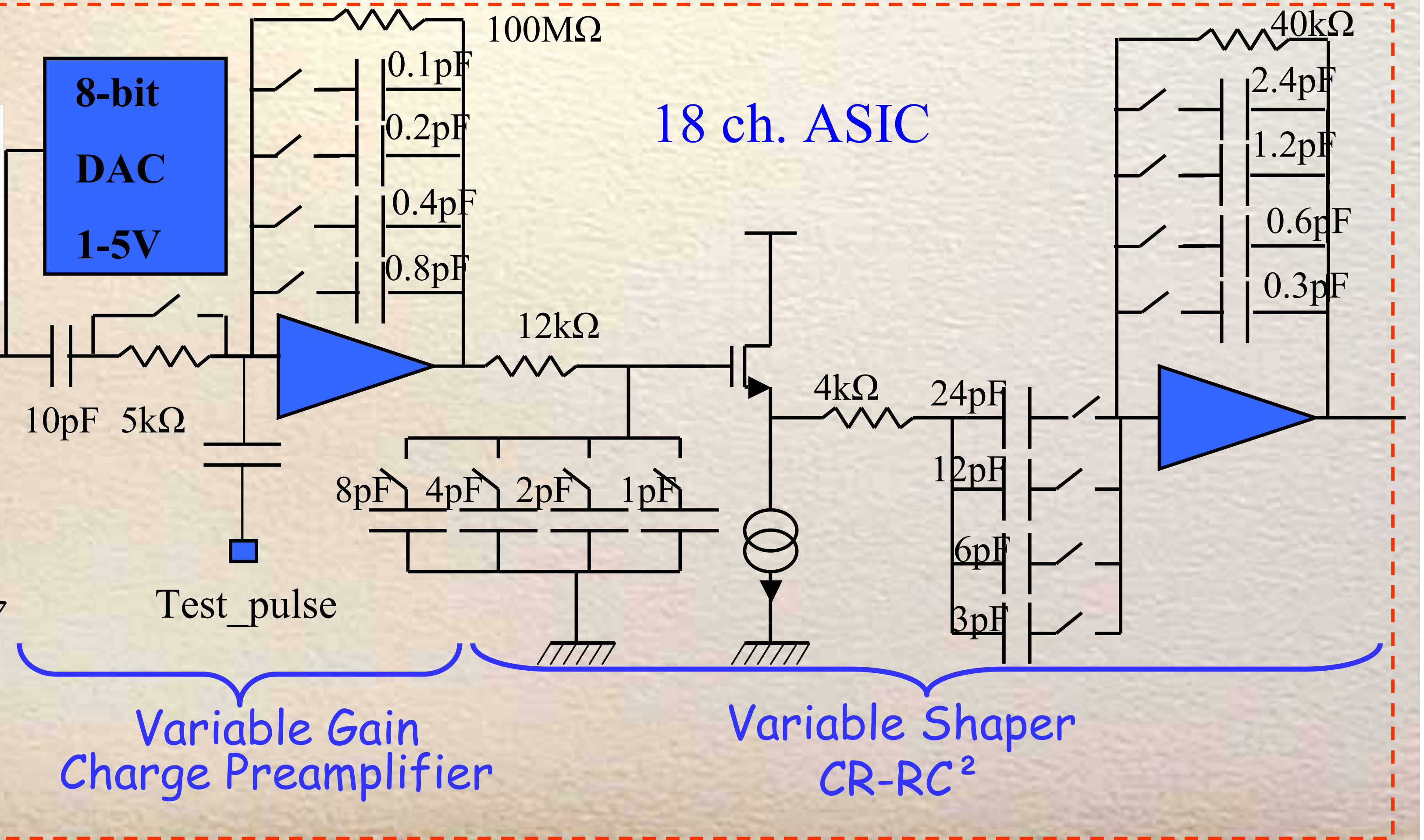
Frontend SiPM Chip

- SiPM bias voltage adjustment (1-5 V)
- Global gain settings and shaping
- Track & hold, multiplexing

- Based on ECAL Si-W ASIC

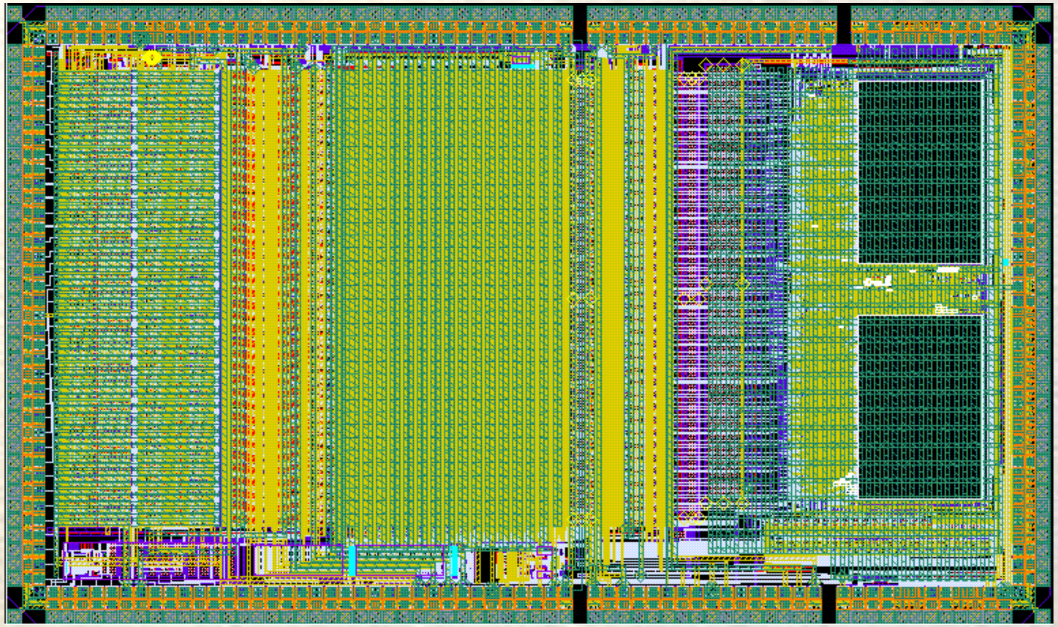
From L.Raux (LAL)





SPIROC Chip

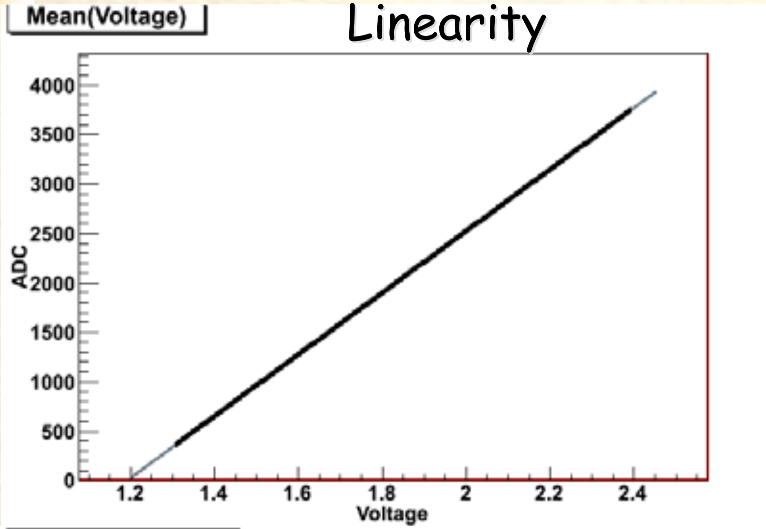
- SPIROC: dedicated very front-end electronics for an ILC prototype hadronic calorimeter w SiPM readout
- Designed to provide
  - large dynamic range
  - low noise
  - low consumption
  - high precision
  - large # RO channels



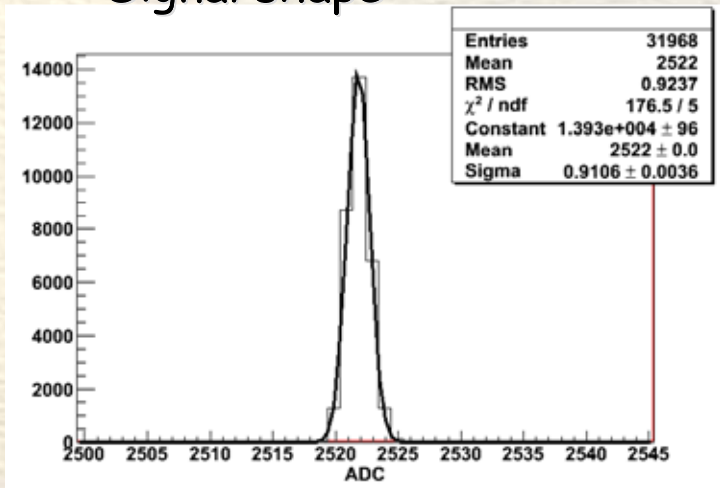
- SPIROC is an auto-triggered, bi-gain, 36-channel ASIC
  ➔ allows to measure the charge Q from one p.e to 2000 p.e. (on each channel)
  ➔ allows to measure the time t with a 100ps accurate TDC
- Analogue memory array (depth of 16 for each) stores t and Q measurements
- 12-bit Wilkinson ADC is embedded to digitize analogue memory contents (t & Q on 2 gains) ➔ data are stored in a 4kB RAM
- High-level state machine is integrated to manage all these tasks automatically and control the data transfer to the DAQ

SPIROC Properties

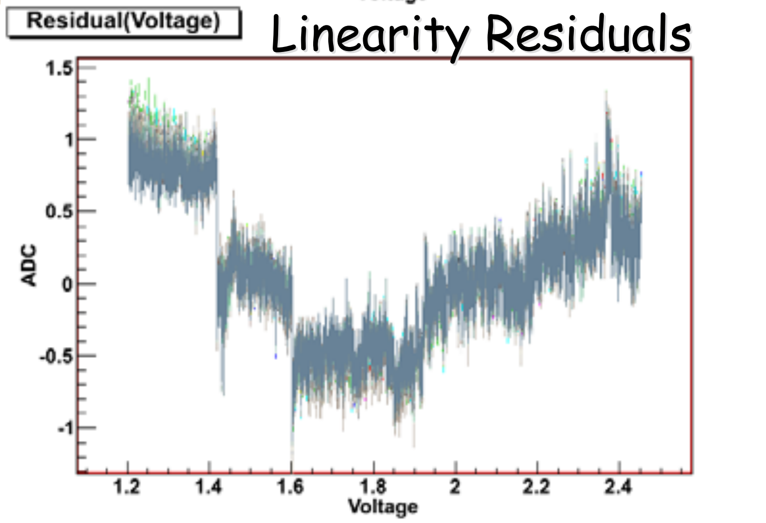
Linearity



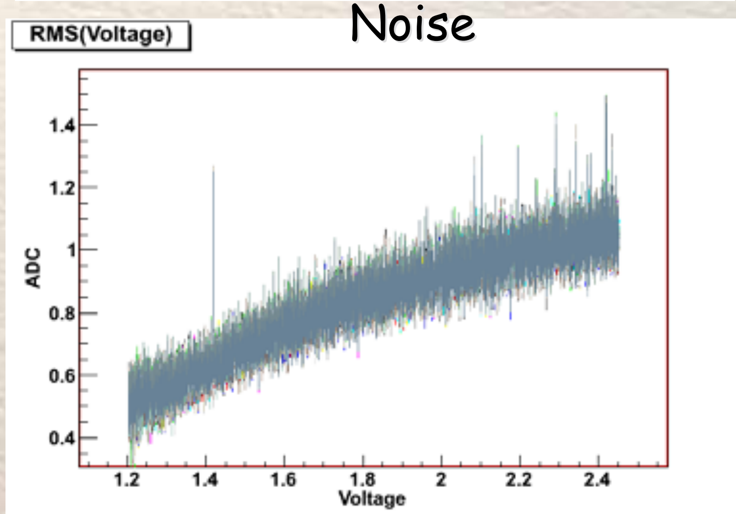
Signal shape



Linearity Residuals



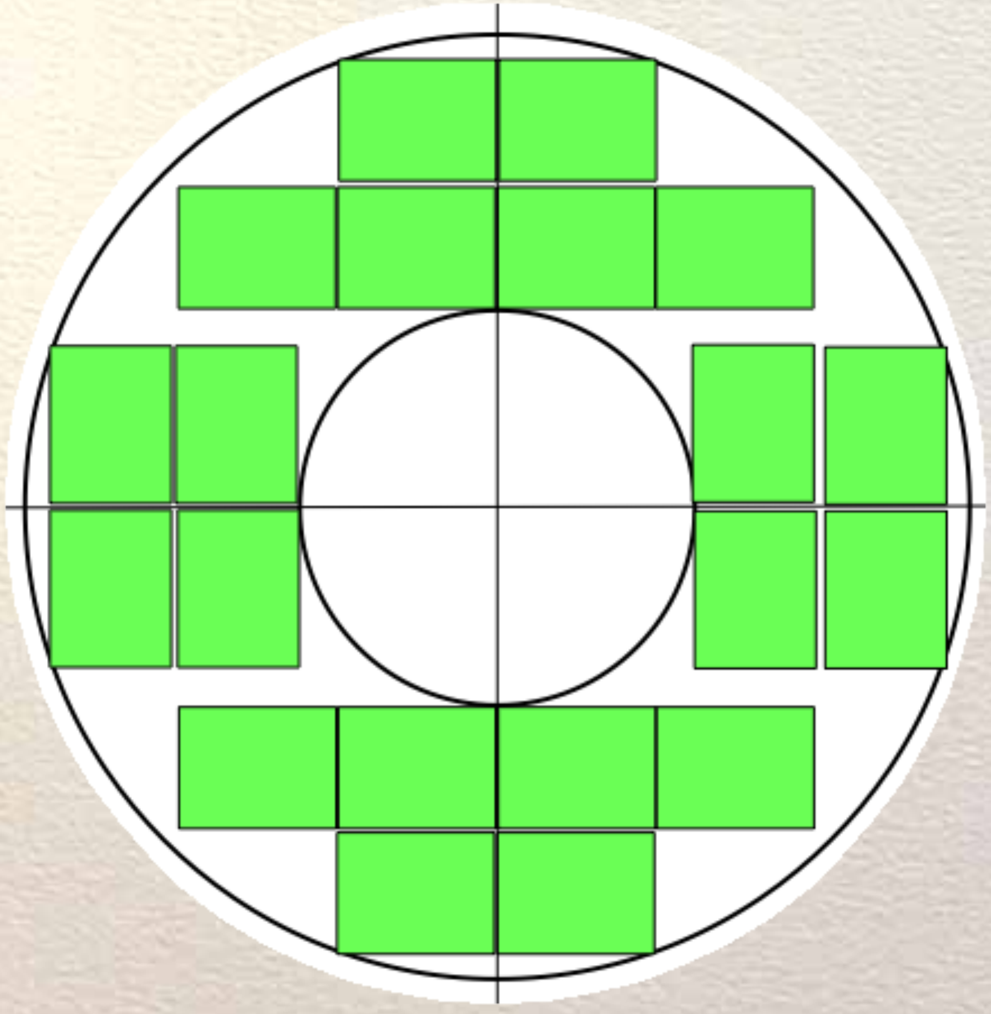
Noise



- SPIROC gives Gaussian signals with no tails, shows excellent linearity and low noise

ASIC Board Arrangement

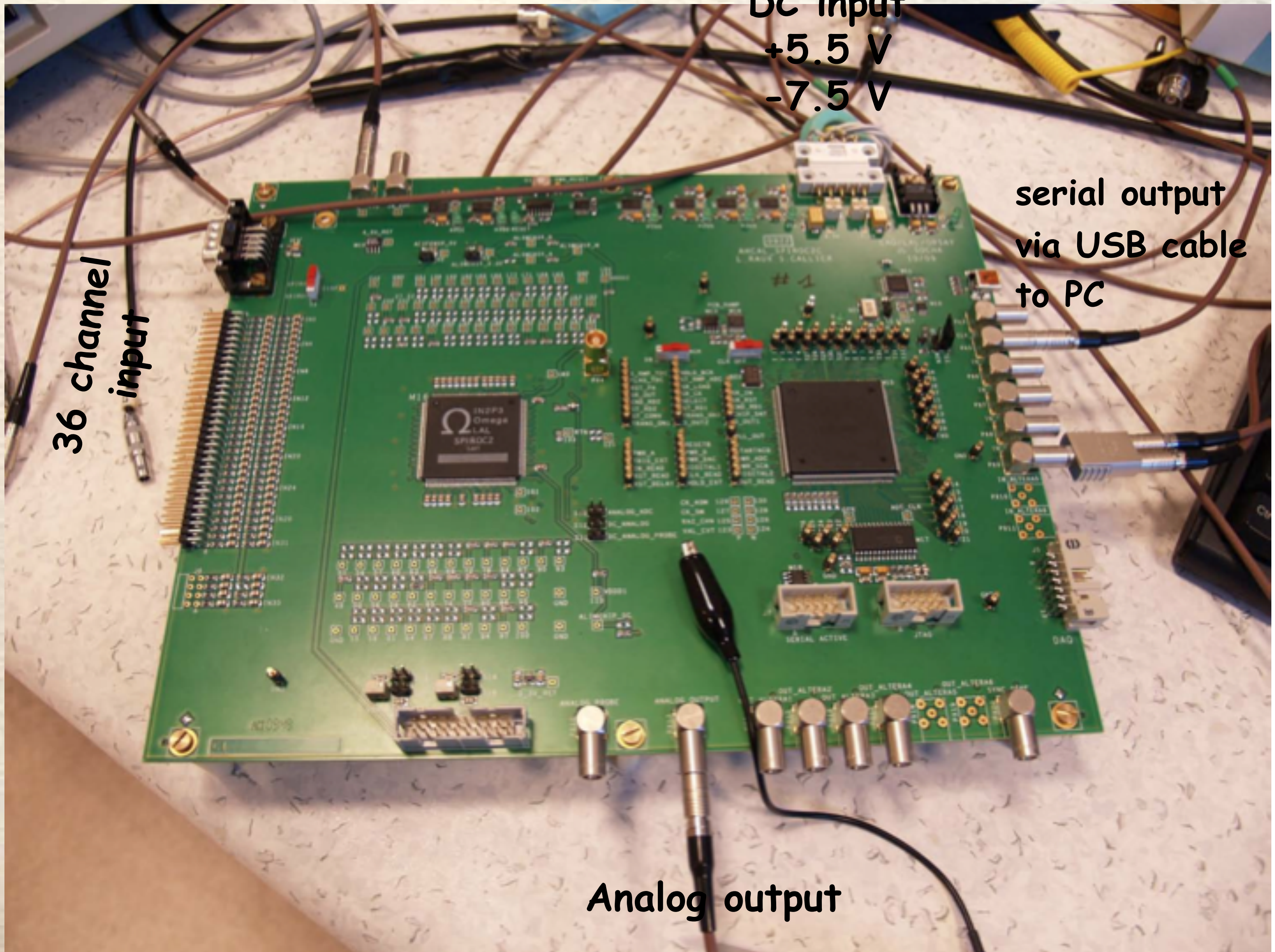
- 32 ASIC readout boards are fixed in 2 layers behind the calorimeter (first layer with 20 boards, second layer with 12 boards)
- 36 MPPCs connect to one board with a ribbon cable
- They are designed for ILC at $L=10^{34}\ cm^{-2}s^{-1}$ (radiation hard for $10^{36}cm^{-2}s^{-1}$?)



First layer with 20 boards

SPIROC Setup in Bergen

- SPIROC chip has 36 input channels



SPIROC Setup in Bergen

- SPIROC runs under Labview
- The ASIC board is connected to a PC with a USB cable
- SPIROC is optimized for gain of 10^6, it works with MPPC (Gain few 10^5)

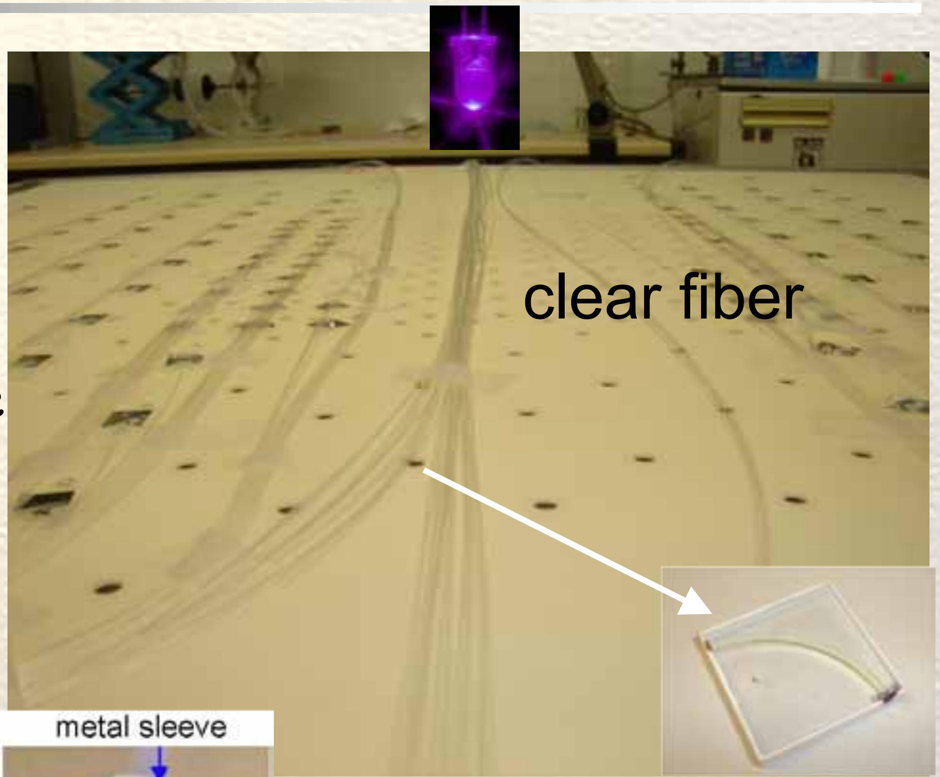
Calibration-Monitoring System

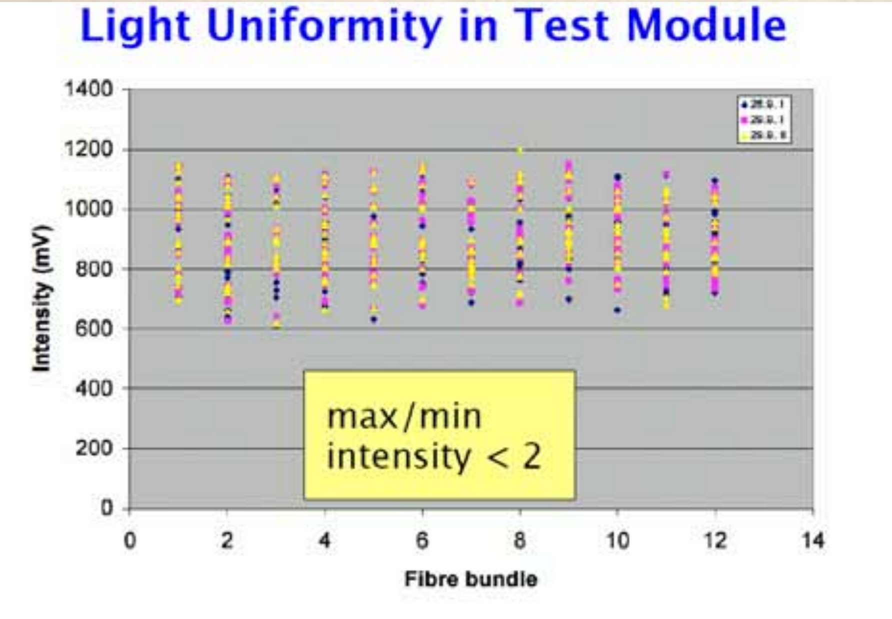
- Monitor stability of strip-fiber-MPPC system between MIP calibrations with fixed LED intensities
- Perform gain calibration
- Measure SiPM response function
- Determine intercalibration constants
- Temperature and voltage dependence of SiPM
  - dG/dT ~ -1.7% / K
  - dG/dV ~ 2.5% / 0.1V
- Temperature and voltage dependence of light yield at fixed light intensity
  - dQ/dT ~ -4.5% / K
  - dQ/dV ~ 7% / 0.1V

➔ stability of LED system after PIN diode correction <1%

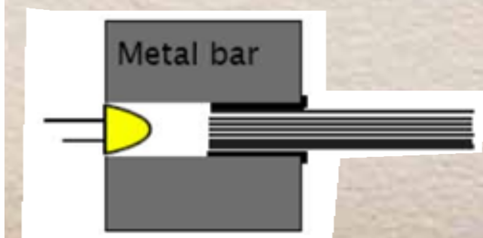
Calibration-Monitoring System

- Use system similar to that of AHCAL
- Provide UV light to each tile via clear fiber
- Monitor each LED with PIN diode
- Record temperature & voltage with slow control system





bundle of 19 fibers
18 → tiles, 1 → PIN diode



LED fiber coupling

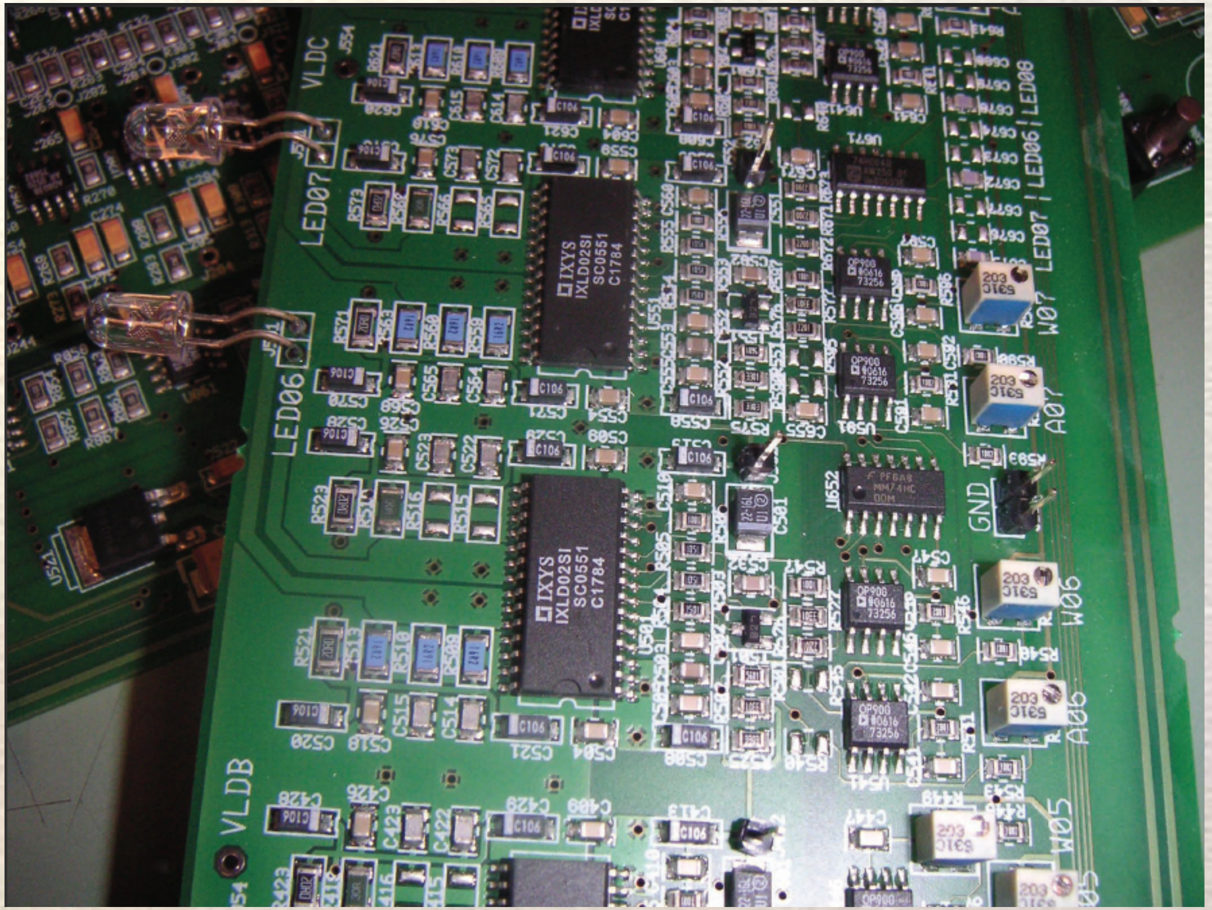
Calibration and Monitoring

- Use calibration and monitoring board of the AHCAL prototype

- It has 12 LEDs that could be coupled to 19 clear fibers

- Since we have 144 channels just need 12+1 per LED

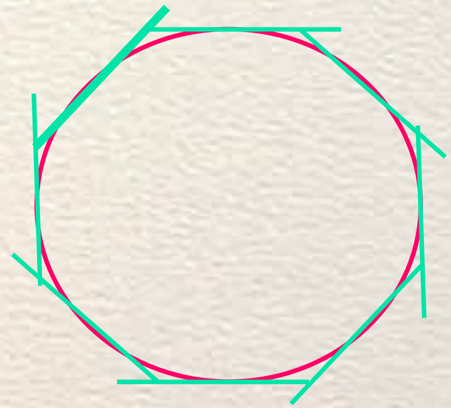
- Advantage: Use spare board

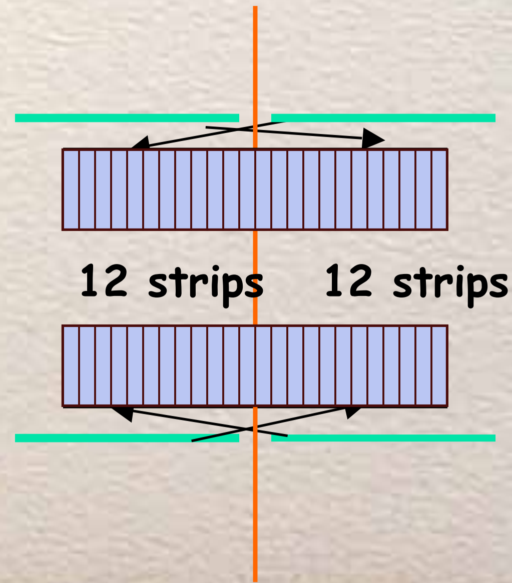


- Disadvantage: Need to deal with 158 clear fibers

Layout of Calibration Boards

- Since the CMB boards are too big need to re-layout the boards, but the basic concept can be used
- Place 6 LEDs on one board,each LED feed 13 clear fibers
- Place 8 boards in a ring around the EC
- With two rings get 1152 channels
- Left LED supplies 12 right channels via fibers, while right LED supplies 12 left channels
- There are 2×48 LED's and 96 PIN diodes



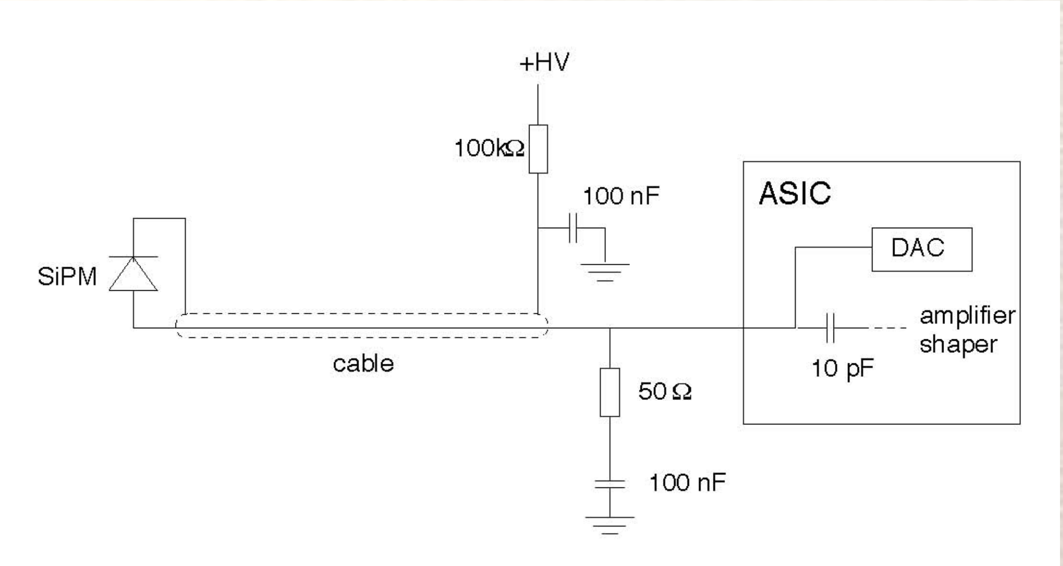


Cables Tray

- Each SPIROC board has → 36*6 cables
  - one multiplexed output (USB) to DAQ
  - a low voltage input for +5.5 V and -7.5V
  - a high voltage input 70V
  - an electronic calibration input
  - an analog output
- Each calibration board has → 16*8 cables
  - low voltage for LED 7V
  - operating voltage
  - 6 PIN diode output
- 4 thermocouples per layer → 24*4 cables
- Total number of cables 108+128+96=332 cables → area: ~100*0.3 cm^2

HV Coupling for the SiPM in the AHCAL

- In the AHCAL the HV for the SiPM is supplied through the ASIC
- This feature was implemented into the SPIROC chip
- With DAC individual HV (±5 V) can be supplied to each MPPC



Mechanical Support Structure

- The entire calorimeter just weighs about 1300 Kg
- An Al frame with a strong back will hold the EMC backward EC layers
- If the EC is built as a single unit, it needs to slide back on the beam pipe supported on the tunnel walls
- So it needs to be fixed at the tunnel and is rolled in
- Since the inner radius is 31 cm, there should be sufficient clearance for pumps and other beam elements ➔ need detailed drawing
- I need to talk to Dominique Breton

Mechanical Support Structure

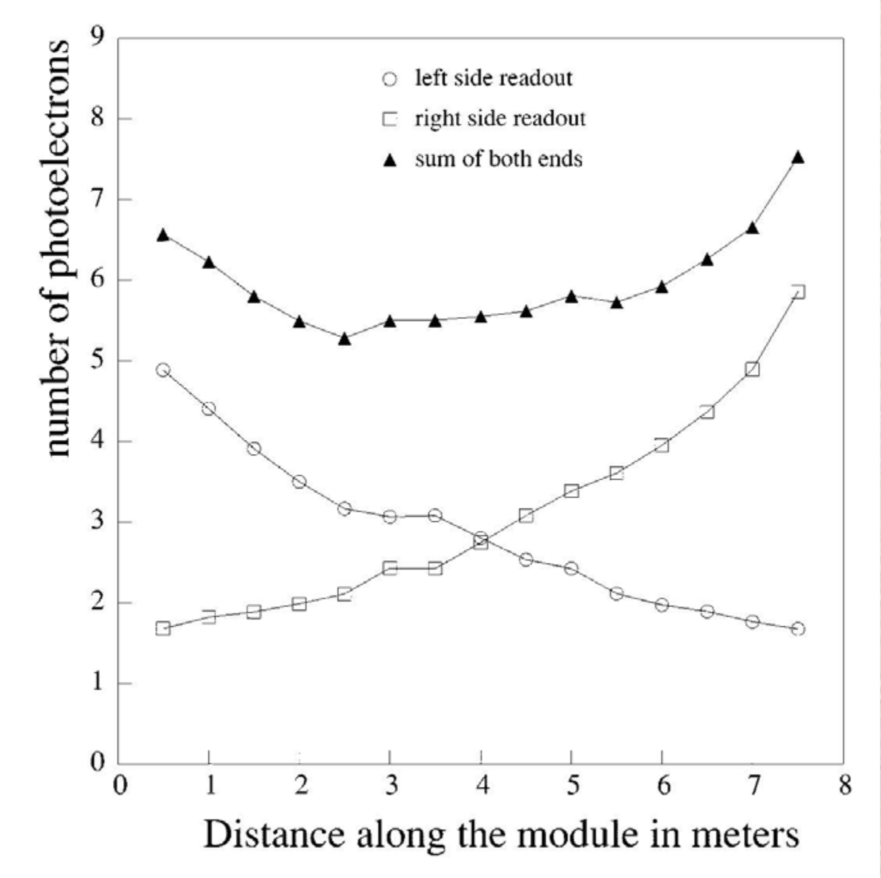
- It is possible to built the EMC backward EC in two halves (vertical split), ➔ impact:
  - 10 strips per layer will be cut into two segments
    ➔ the inner segments need to be read out at the inner radius
  - Increase number of channels by 240
    ➔ need 240 additional MPPCs
    ➔ need 7 additional SPIROC boards (arrange in a second plane)
    ➔ need 20 additional LEDs (4 boards) ➔need to feed fiber in at inner edge (routing is not trivial here)
  - Need extra thermocouples (2 per layer ➔48)
- Though this is possible the performance will deteriorate near the boundary (need study to determine by how much)
- There will be 122 additional cables, increase by 37%
- This add extra costs

Attenuation Length of Y11 Fiber

- In the EMC backward EC the Y11 fibers have a length of l=55.39 cm

- This is longer than in other calorimeter prototypes

- Minos measured the attenuation length of a 1.2 mm thick Y11 fiber to be of > 7 m



Calibration and Physics Mode Operation

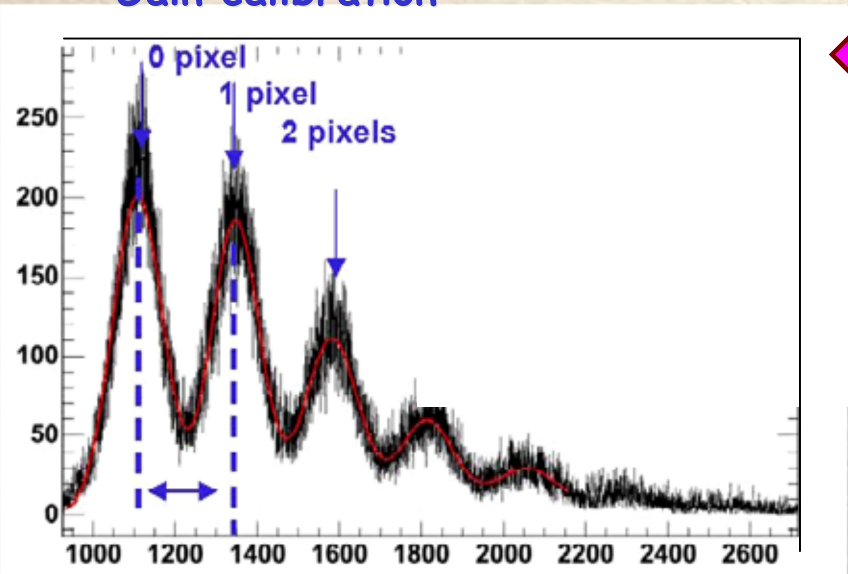
- Need to calibrate MPPC gain and MIP position, since energy is

$$E_{total}\,[GeV] = \frac{\sum_i E_i\left[MIP\right]}{w\left[MIP/GeV\right]} \quad \text{where} \quad E_i\,[MIP] = \frac{\tilde{E}_i\left[ADC\right]}{C_i^{MIP}} f_{sat}\left(\frac{\tilde{E}_i\left[ADC\right]}{C_i^{pix}}\right)$$

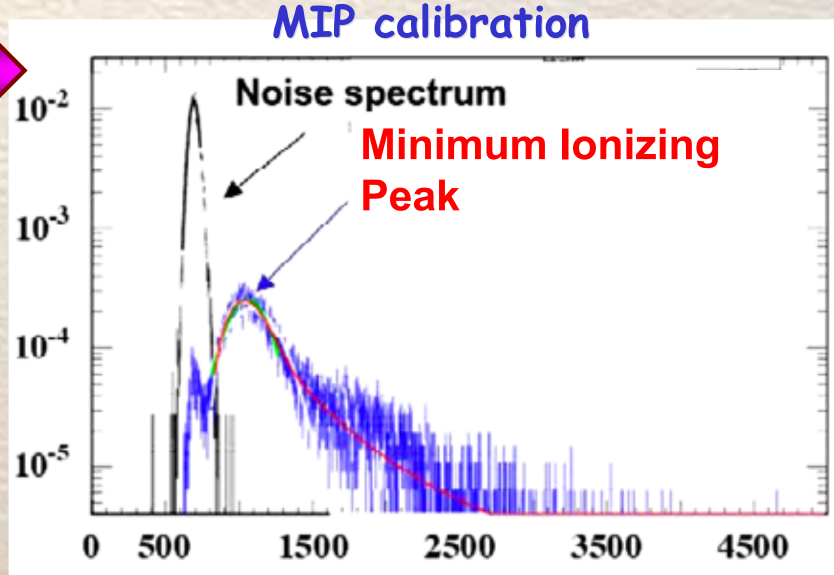
- Use high gain & fast shaping for calibration
- Use low gain & long shaping for beam mode

Intercalibration

Gain calibration



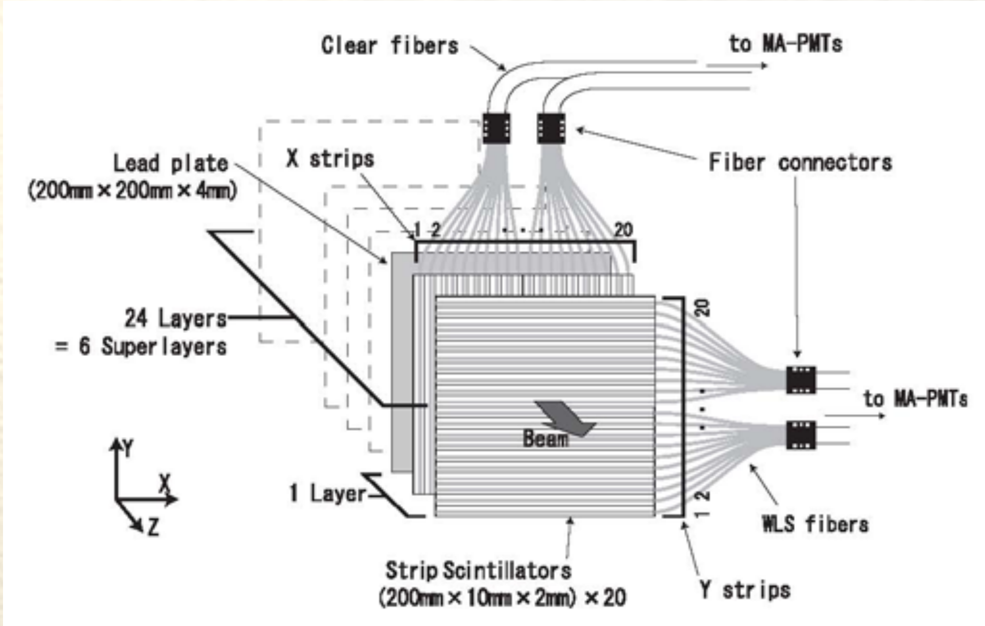
MIP calibration

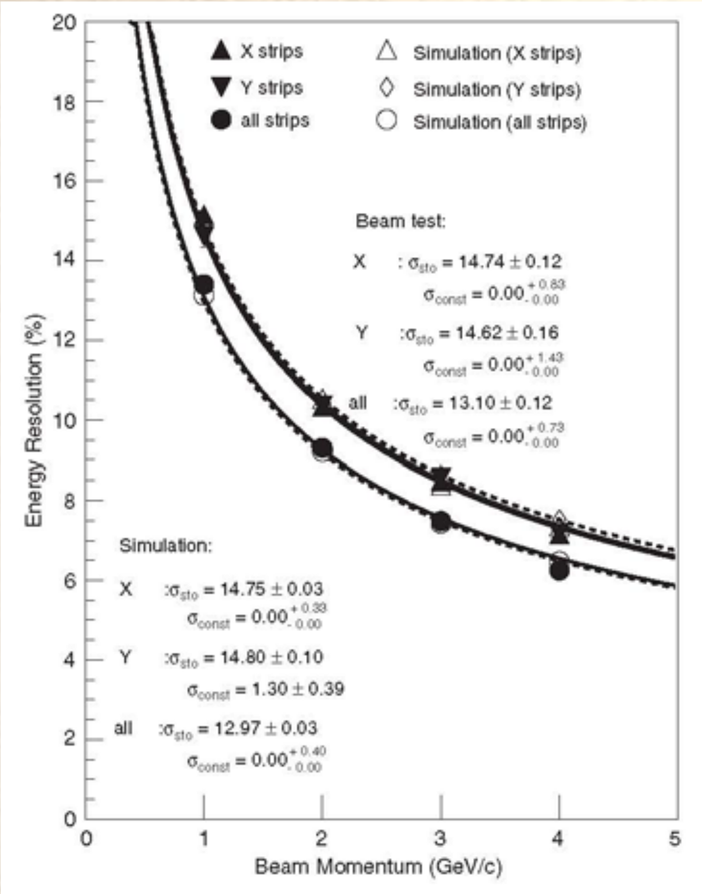


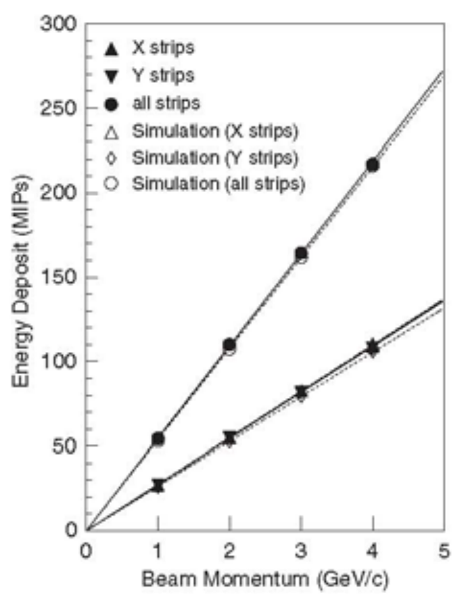
- Set MIP peak at ~10 pixels ➔ dynamic range of 160 MIPs/cell

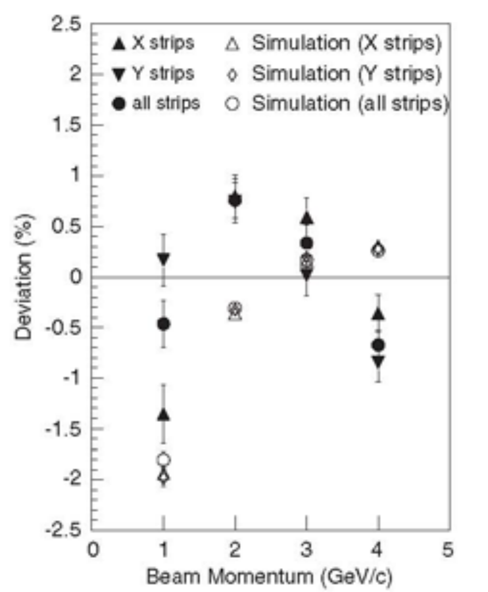
Performance of Scintillator Strip ECAL

- Pb-scintillator sandwich with fiber and PM readout





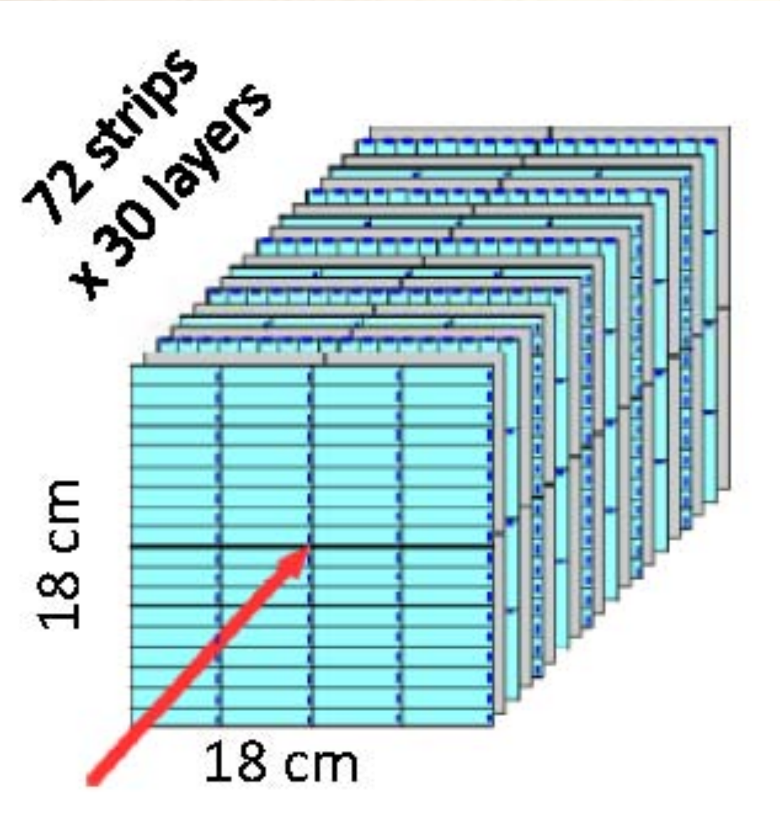


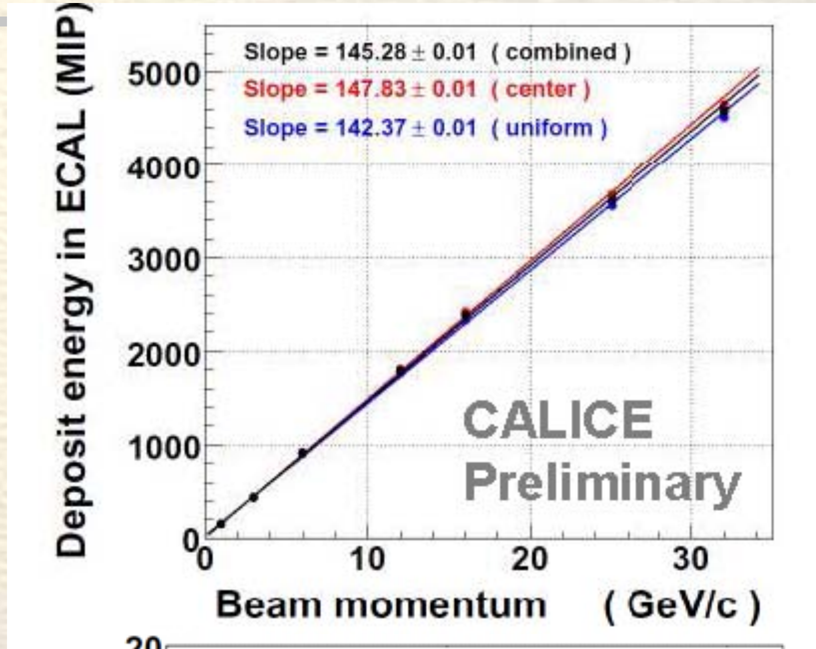


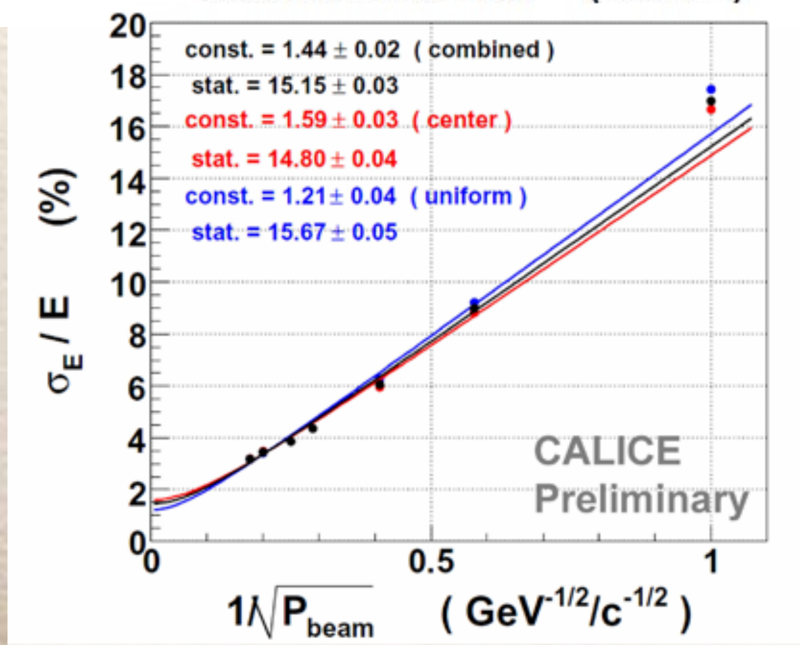
A. Nagono et al NIM A557:460-478,2006

Performance of Scintillator Strip ECAL

- W-scintillator sandwich with Y11 fiber and MPPC



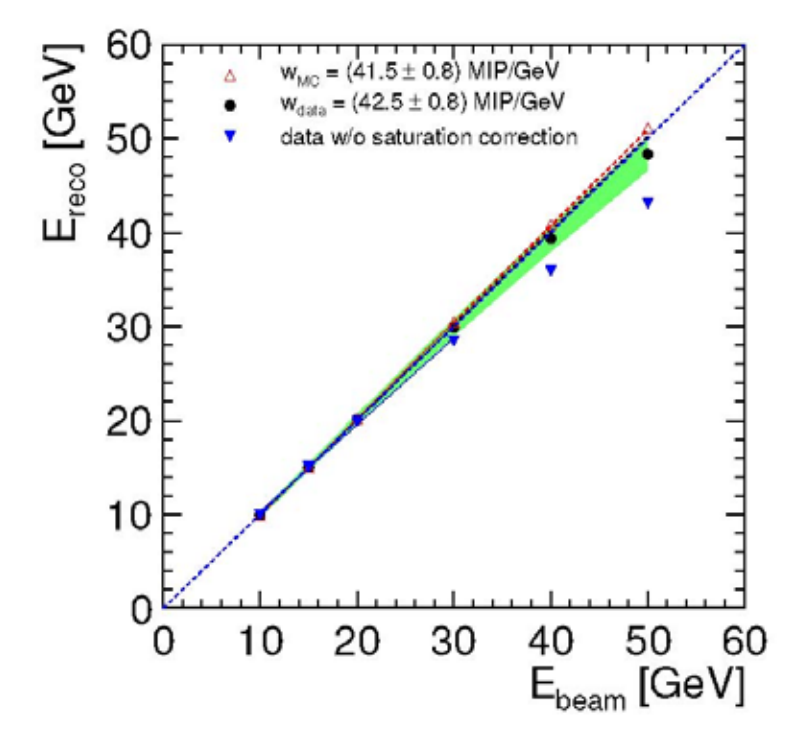


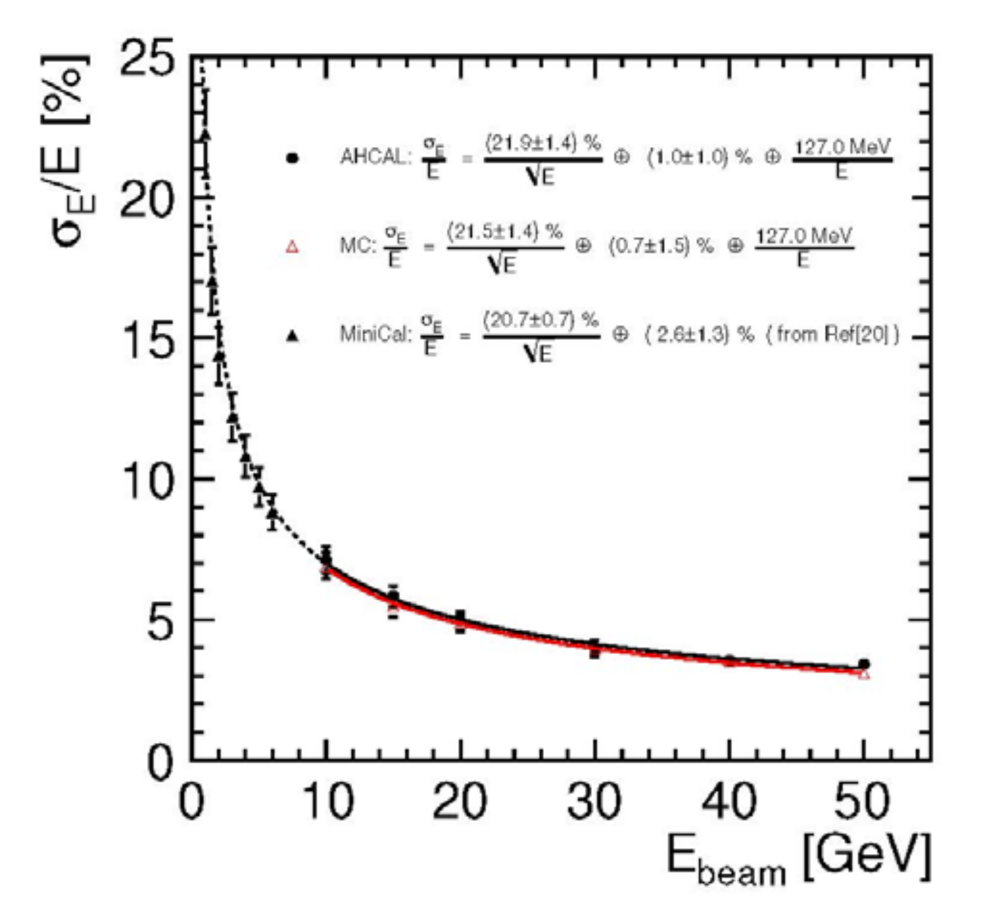


A. Nagono et al NIM A557:460-478,2006

Performance of AHCAL to Electrons

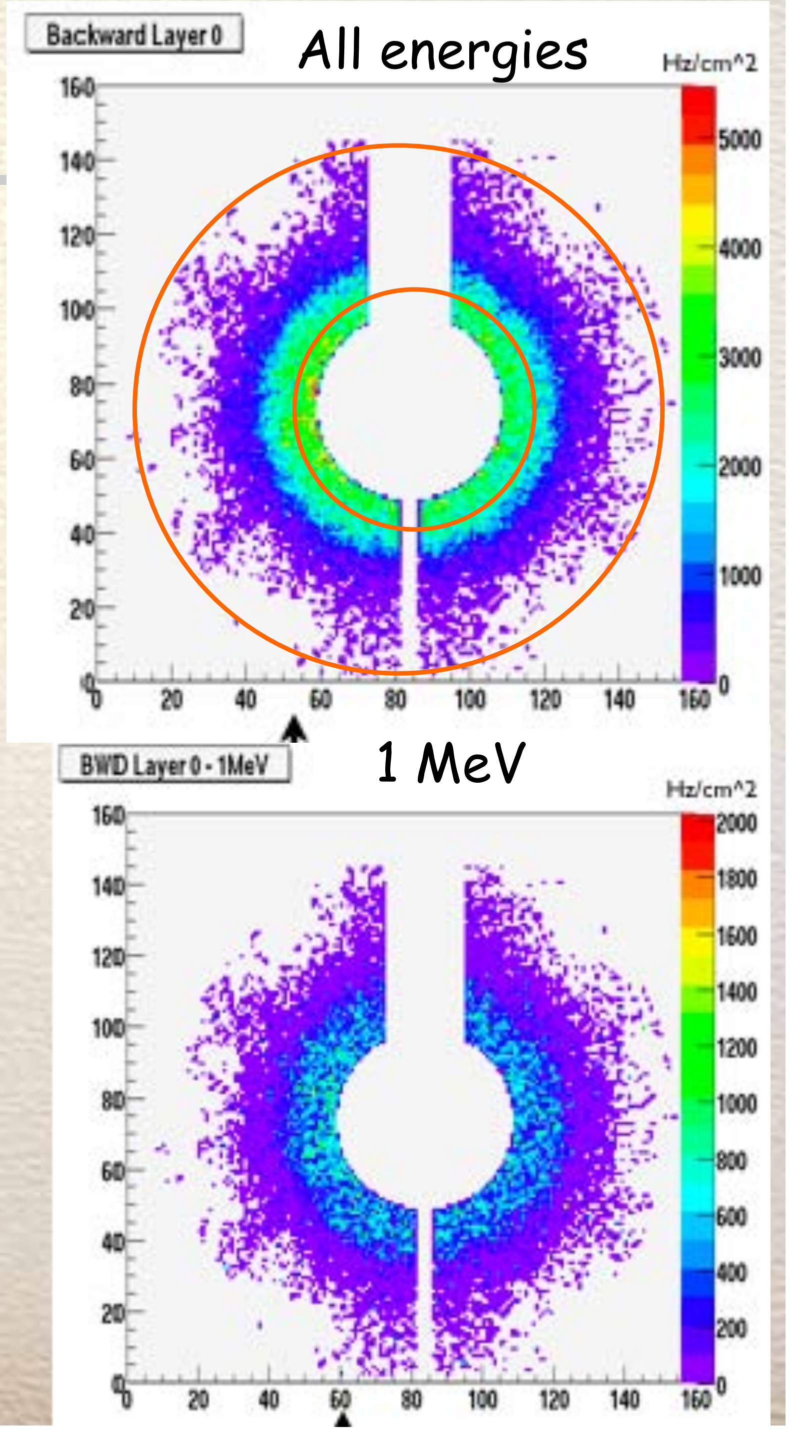
- Read out of 3×3 cm^2 tiles with Y11 fiber coupled to SiPM
- 38 layers of 20 mm steel and 5 mm scintillator





Expected n Flux

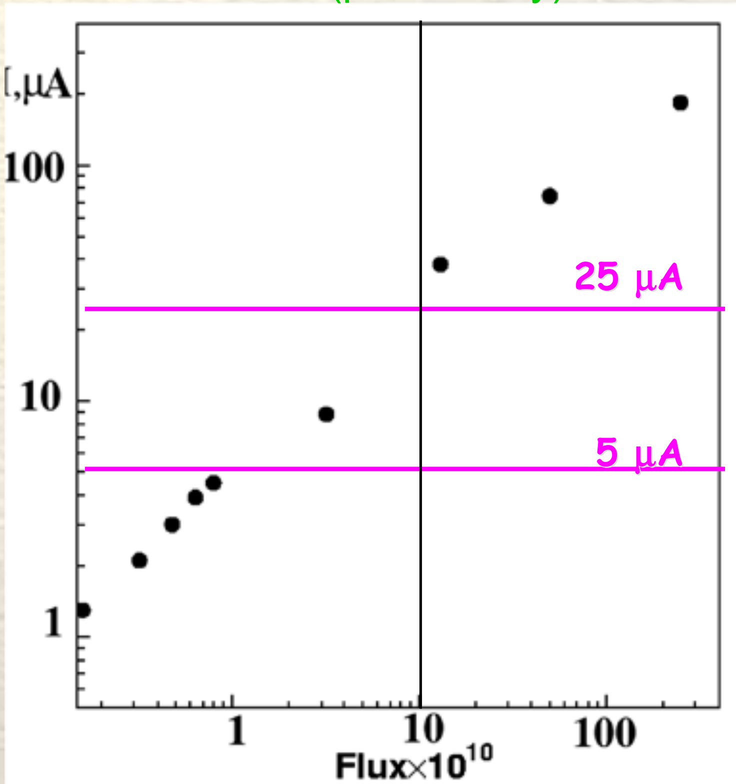
- Take values from Eugeneo's values from Annecy talk
- In layer 0 of backward IFR EC, worst rate is 3500 Hz/cm^2
  ➔ rate a z=-128 cm should be be lower
- In ten years (200 days running) estimate $6.1*10^{11}$ n/cm^2 or $6.1*10^{9}$ n/mm^2
- This high flux is only in the inner region (r=31-41 cm)
- The rate drops by significantly towards outer edge
- If n's come from IP, MPPC is perpendicular to flight path



Radiation Damage Measurements

- Dark current increases linearly with flux Φ as in other Si devices: $\Delta I = \alpha \Phi$ Veff Gain, with $\alpha = 6\times10^{-17}$ A/cmVeff ~ 0.004mm^3 determined from observed ΔI looks a bit too high since it includes SiPM efficiency, but is not completely unreasonable
- Initial SiPM resolution of ~0.15 p.e. is much better than that in other Si detectors ➔ it suffers sooner: after Φ ~10^{10}/cm^2 individual p.e. signals are smeared out
- However MIP signal are seen even after Φ ~10^{11}/cm^2

ITEP Synchrotron Protons
E=200MeV (preliminary)



M. Danilov

Neutron Irradiation of MPPCs

✳ **Prospective damage**

Increasing lattice defect in silicon bulk

Flux

3.1×10^{8} neutron/cm^2
3.1×10^{9} neutron/cm^2
3.1×10^{10} neutron/cm^2
3.1×10^{11} neutron/cm^2

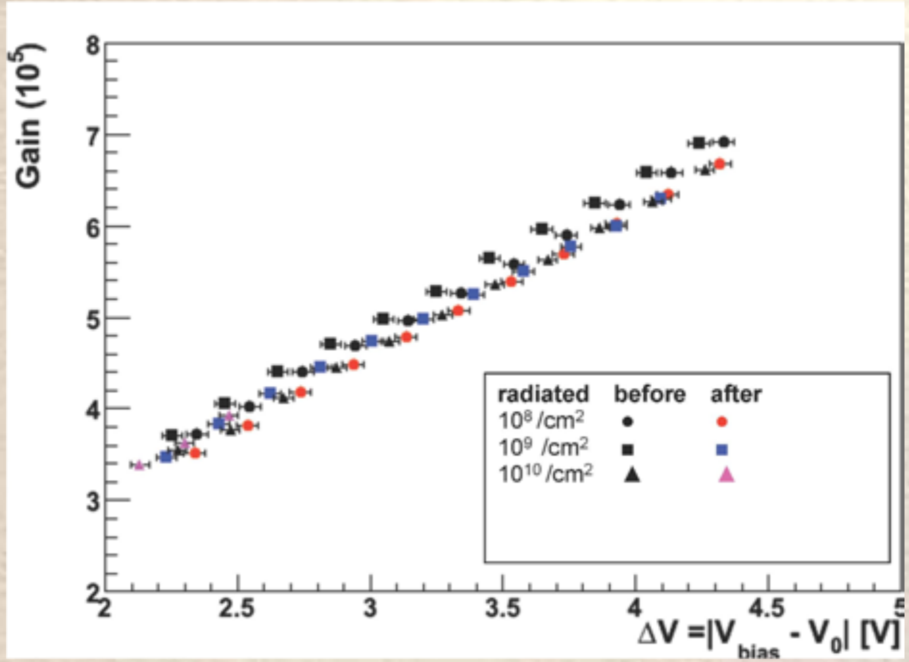
Radiation test location

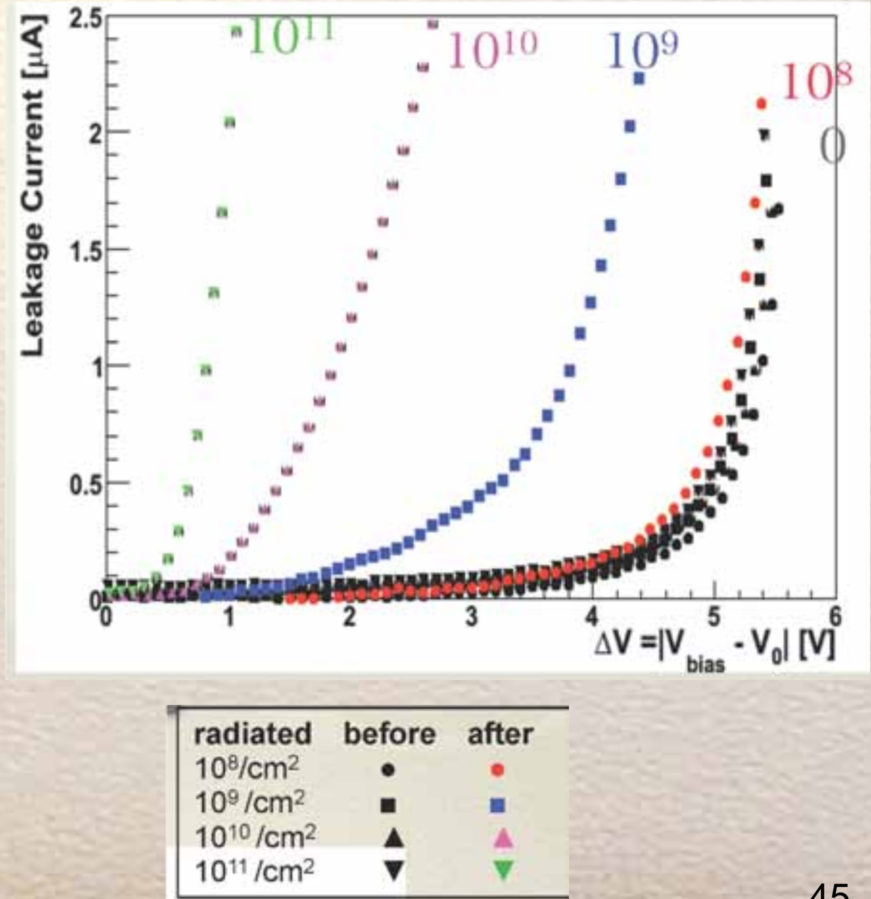
The reactor YAYOI
(Fast neutron source reactor of the University of Tokyo)

From talk by T. Takeshita
CALICE meeting Sep 17, 2009

Gain and Leakage Current

- No significant changes on the gain due to neutron irradiation
- Huge increase in leakage current for neutron flux > $3 \times 10^9/cm^2$

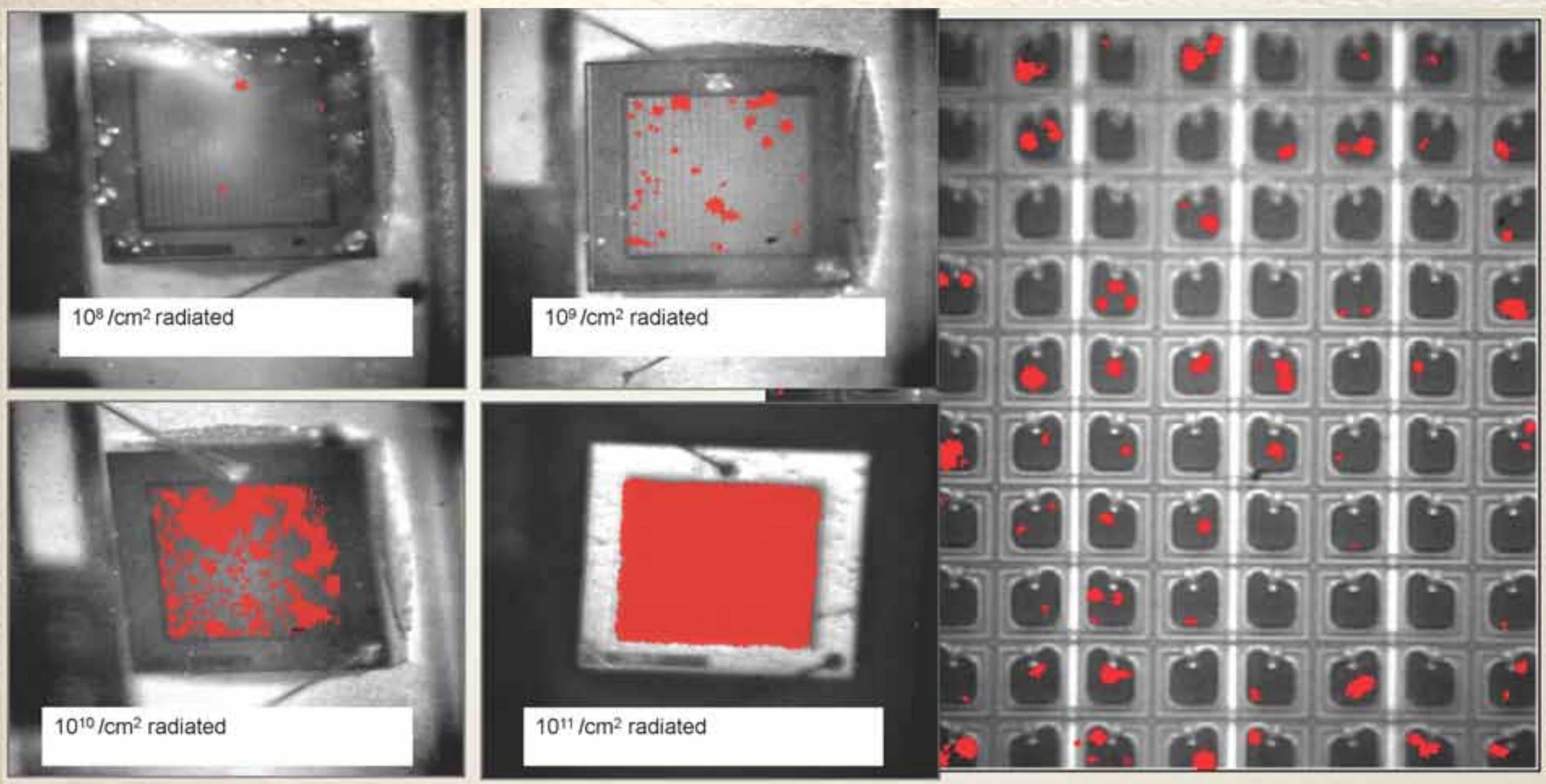




Measured with 25 μm pixel MPPC

Hot Spot Pictures

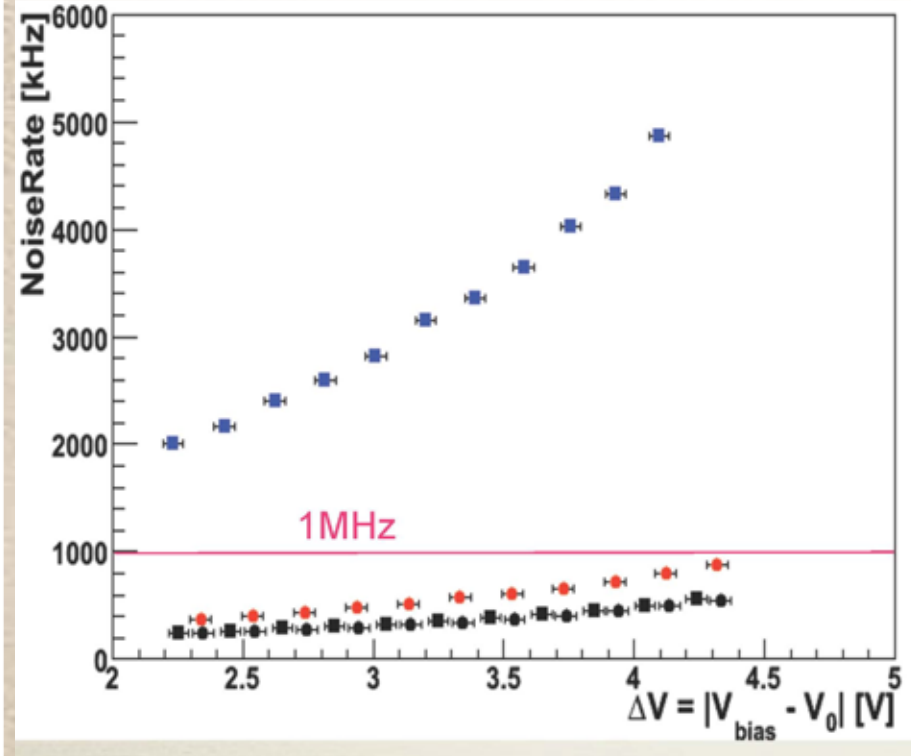
- Observe increased number of hot spots after irradiation of $3x10^9$ n/cm^2

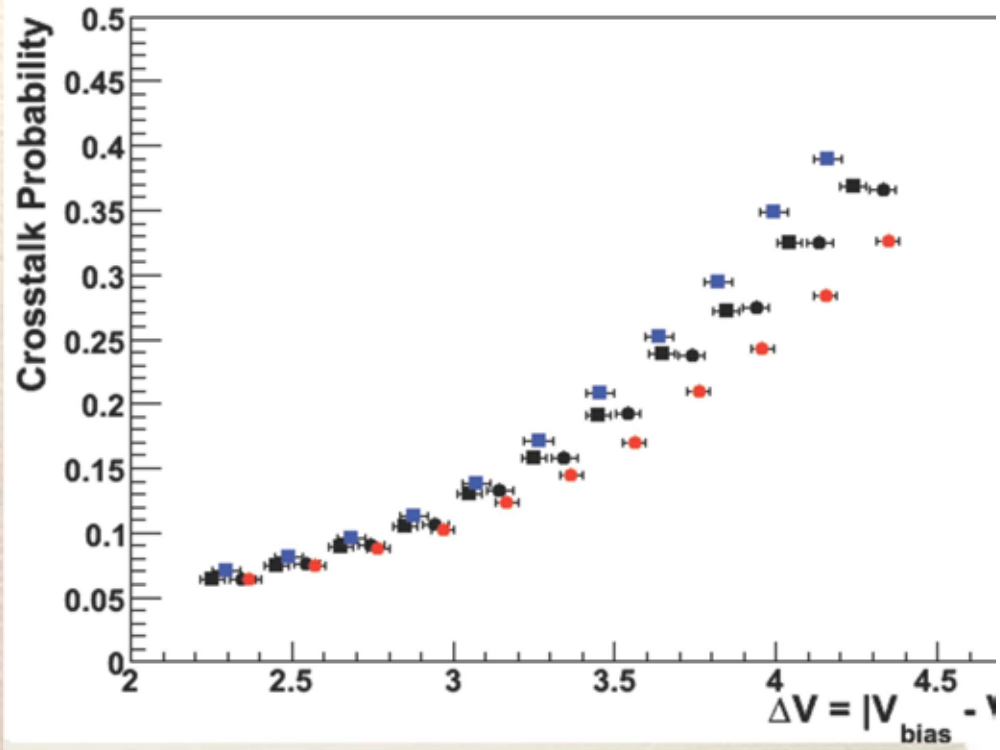


Noise Rate and Cross Talk

- Significant changes on noise rate already for $3x10^9/cm^2$
- No significant changes on the cross talk probability

radiated	before	after
$10^8/cm^2$	●	● (red)
$10^9/cm^2$	■	■ (blue)

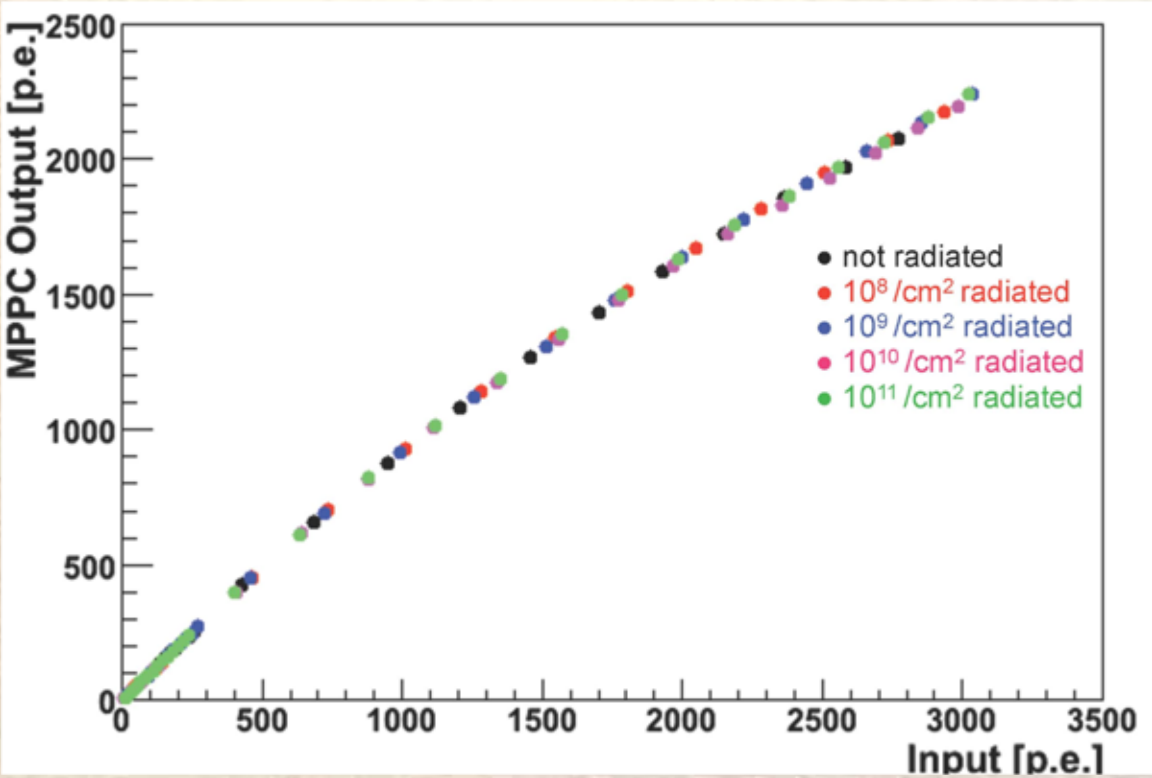




Measured with 25 μm pixel MPPC

Saturation Curve

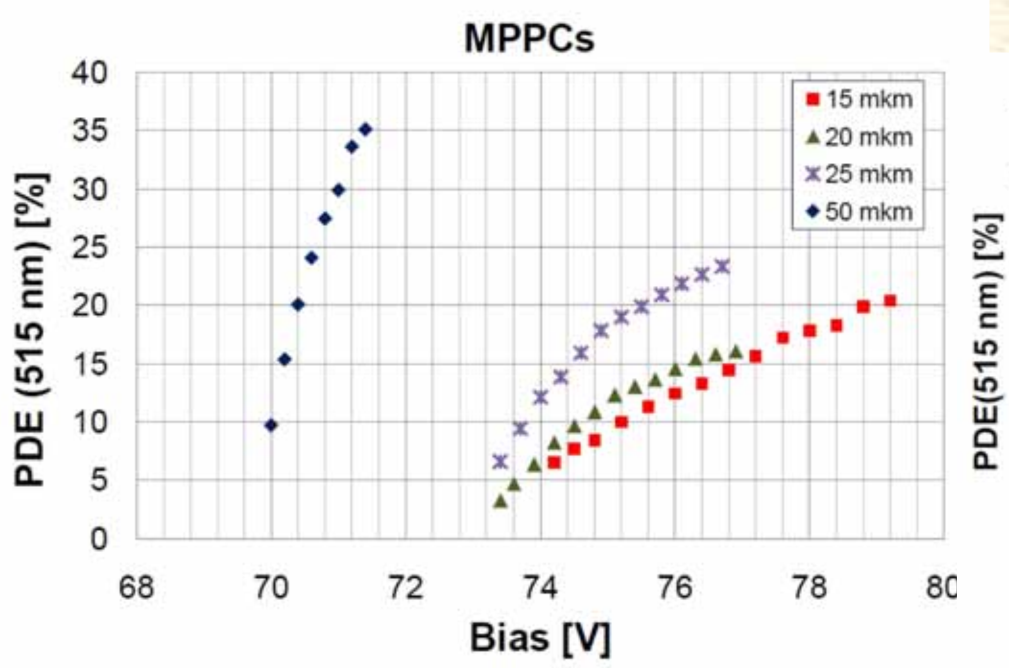
- Observe no significant change on the saturation curve

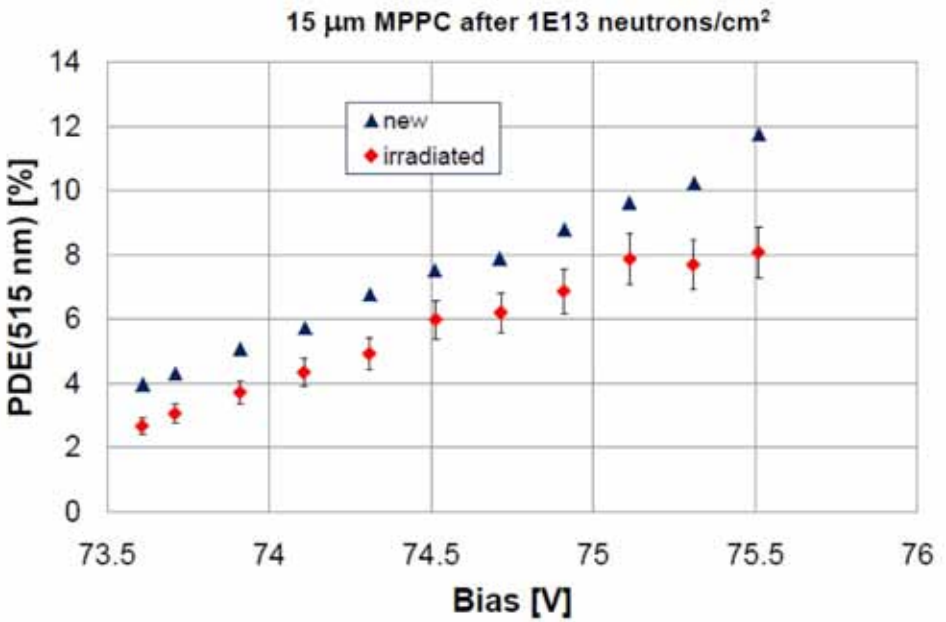


- Results look consistent with ITEP measurements
- Main change after high n dose is increase in noise

Performance of 15 μm MPPC after 10^{13} n/cm^2

- The new MPPCs have lower efficiency (more boundaries) and need higher bias voltage to compensate for loss

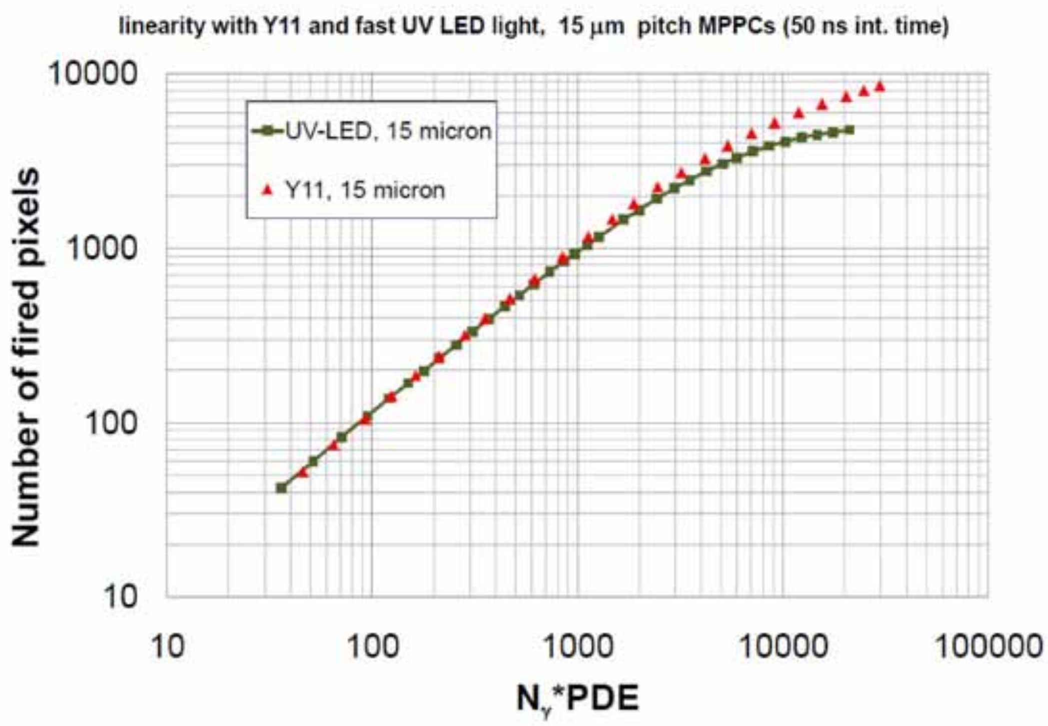




Y. Musienko, A. Heering

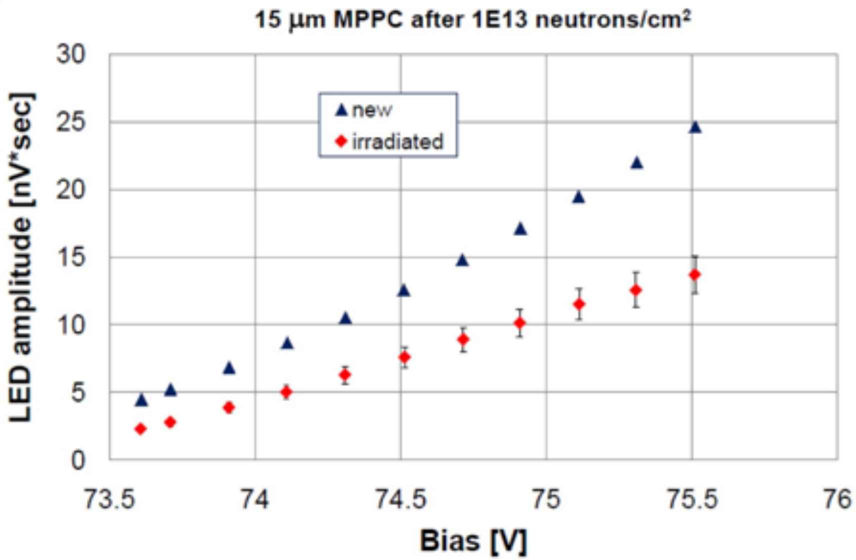
- There is also a new SiPM from China (NDL) that looks good too

Performance of 15 μm MPPC after 10^{13} n/cm^2

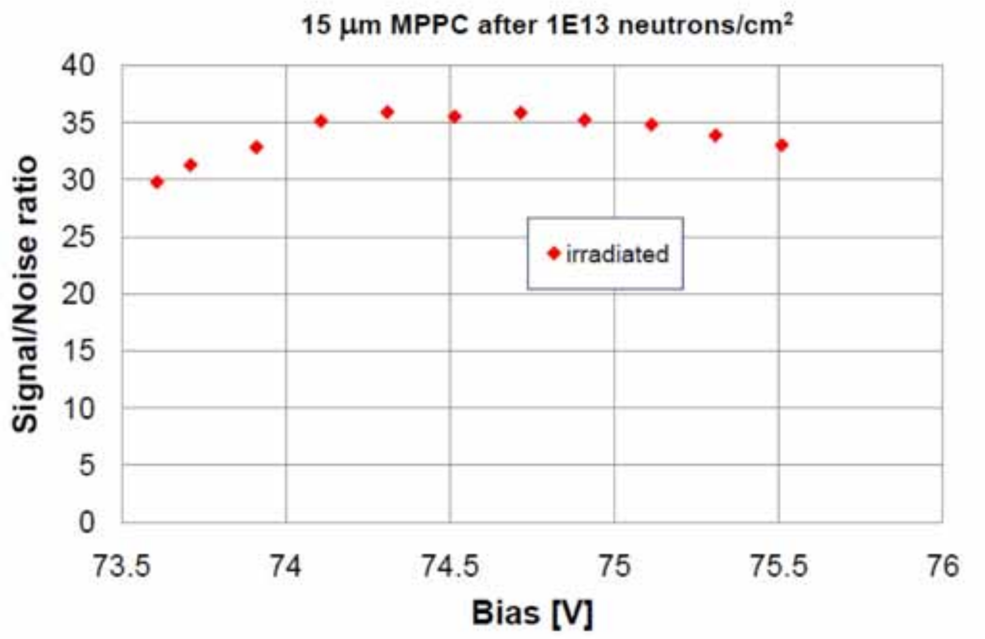


- 15 μm MPPCs still work fine after 10^{13} n/cm^2 irradiation
- Saturation curve is not effected
- Response decreases by 40%

Y. Musienko, A. Heering

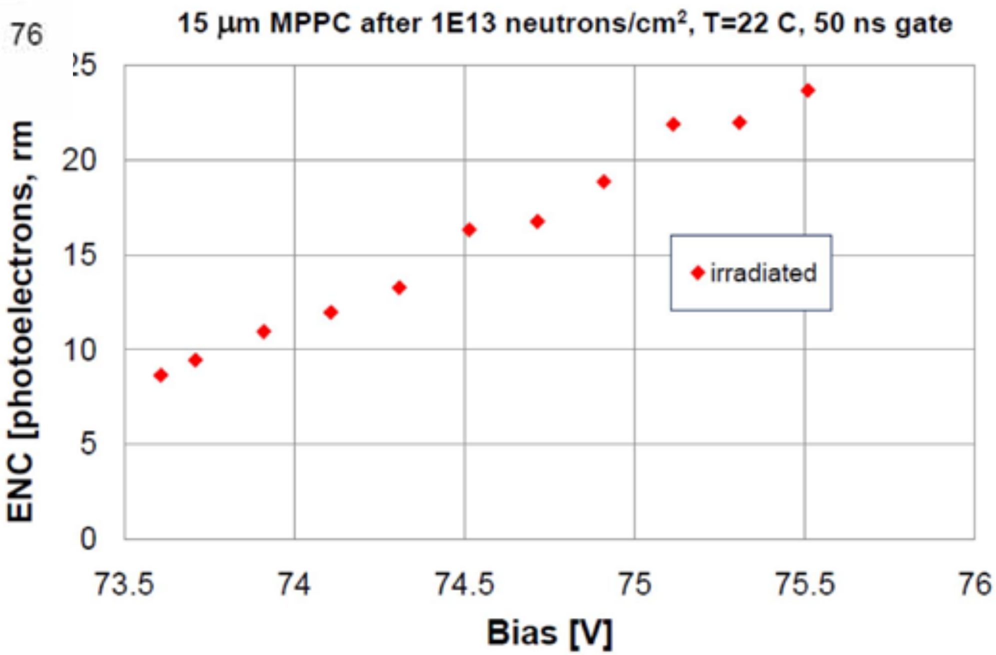


Performance of 15 μm MPPC after 10^{13} n/cm^2



- S/N and equivalent noise charge after irradiation looks ok
- According to Eugenio's study backward endcap EMC will see 10^9 n/mm^2 after 10 years

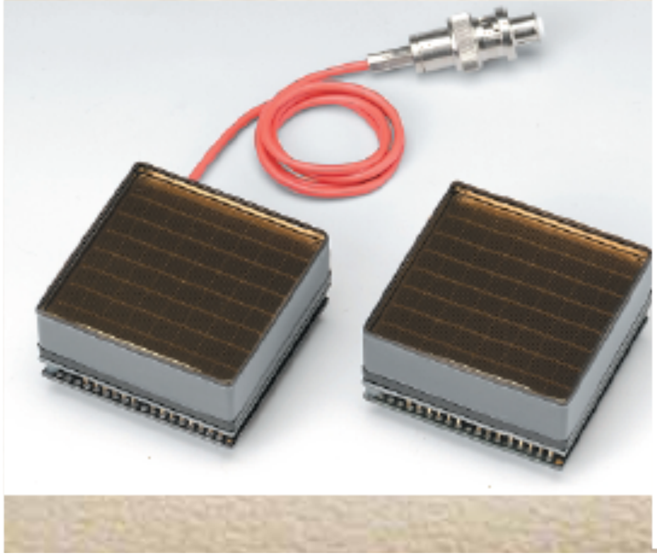
Y. Musienko, A. Heering



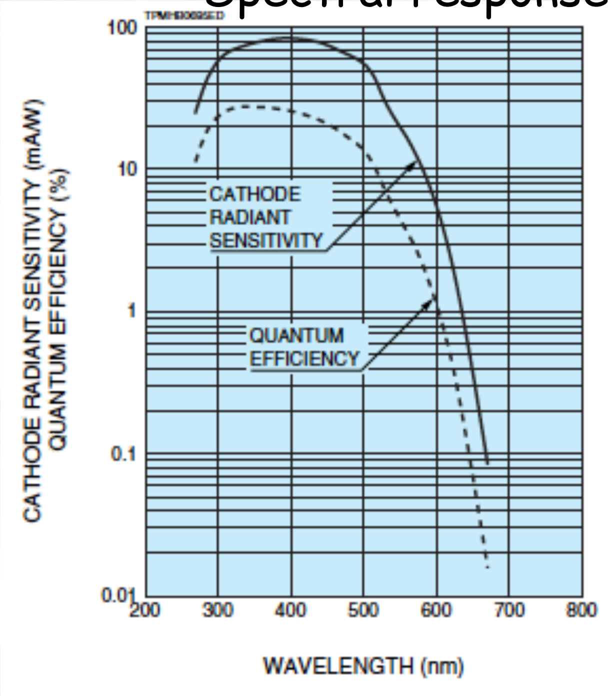
- So if the 25 μm pixel MPPC show a problem we switch to 20 μm pixel or 15 μm pixel MPPCs
  → here we have a safety margin of at least 20 in a small region of the inner edge

Alternative Readout Solution

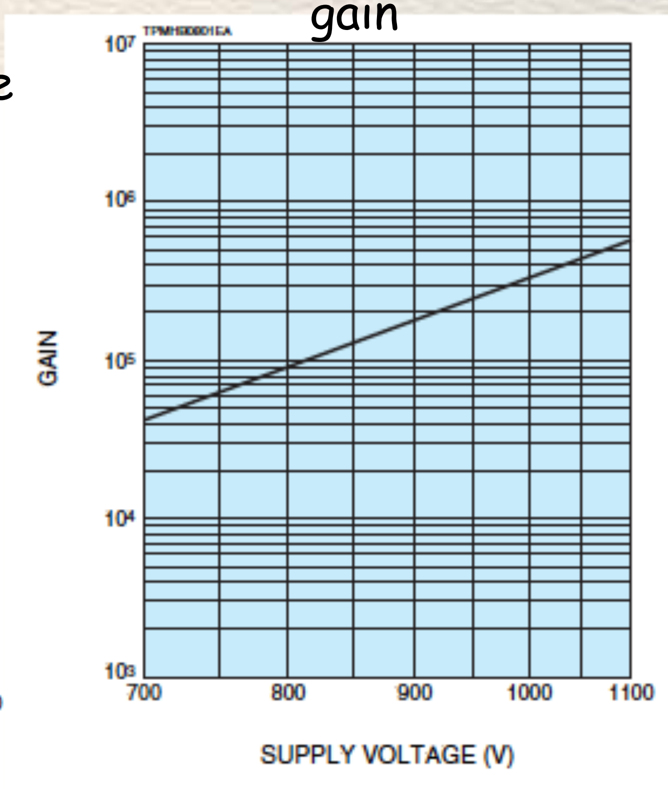
- One ongoing issue is the neuron flux in the detector
- The MPPC's can be operated in stable mode for n flux < 3×10^9 n/cm^2
- If simulations confirm that the n flux is too high for stable MPPC operation, we could modify the calorimeter using smaller-size APDs or new pixelated PMs coupled to clear fibers
- New PMs have 64 pixels



Spectral response



gain



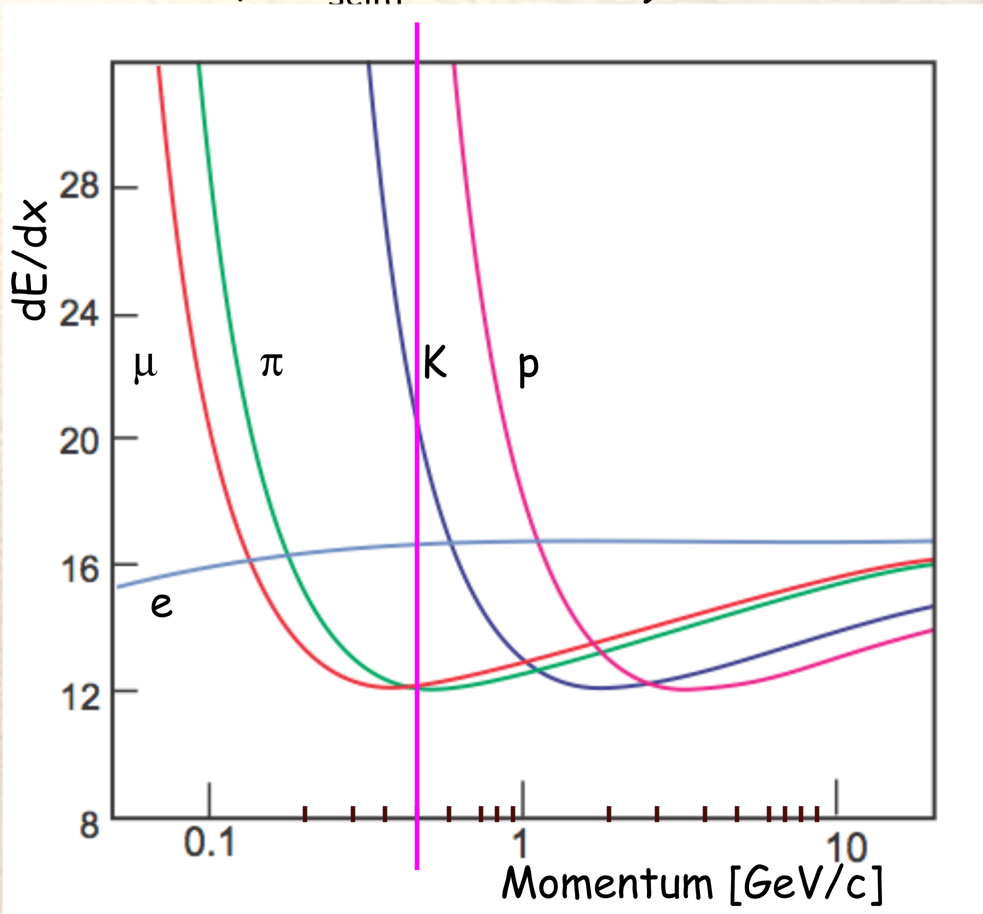
Particle Identification: dE/dx

- Do dE/dx pattern recognition for hadrons ➔ for MIP-like particles energy losses are (dE_{Pb}=4.3 MeV, dE_{scint}=0.6 MeV)

- A 0.5 GeV π is at the minimum while a 0.5 GeV K is below the minimum

- For MIPs, ΔE= 100 MeV in 24 layers

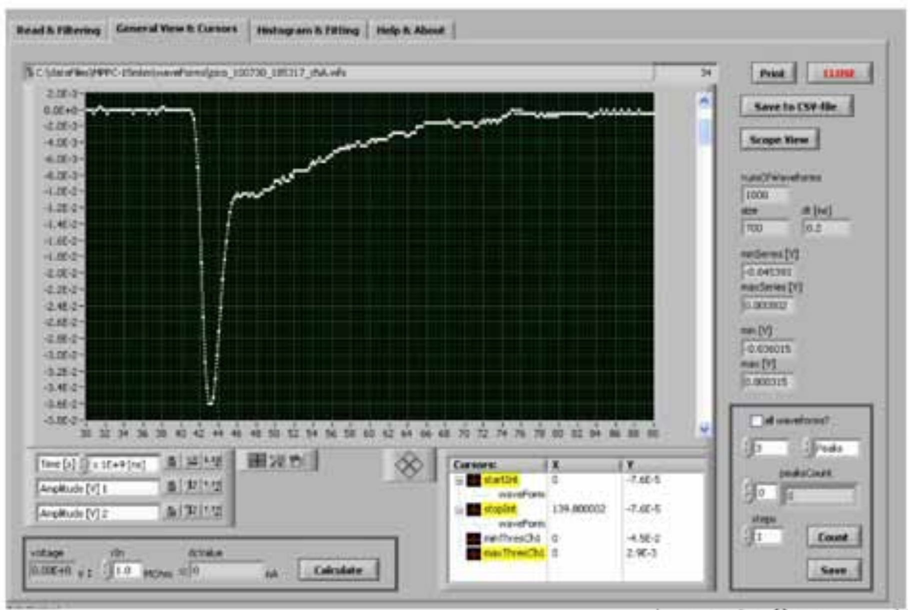
- For particles below minimum dE/dx increases with depth ($1/\beta^2$)

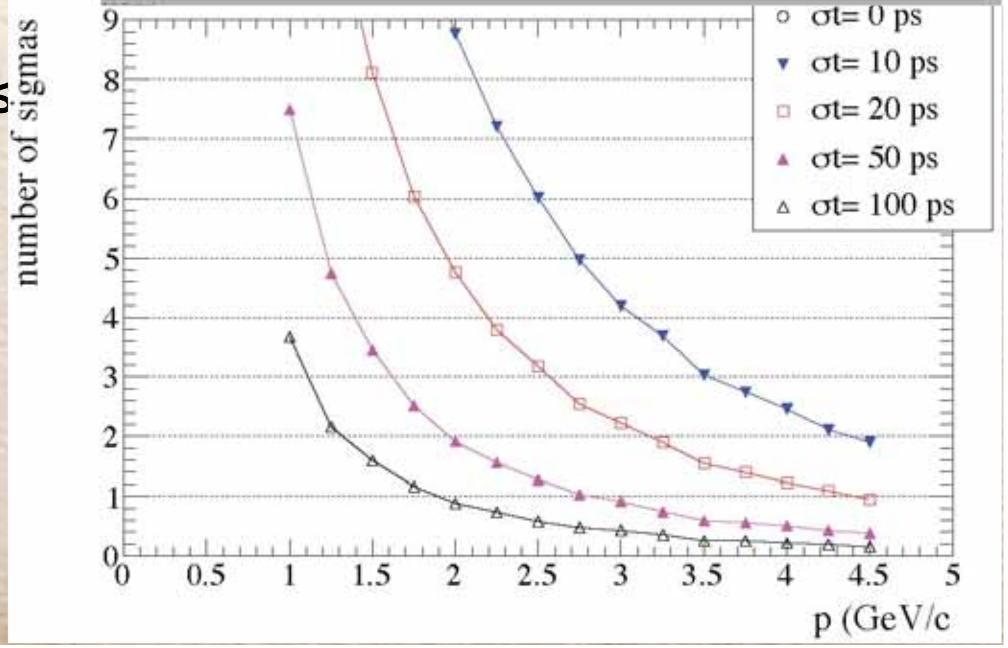


➔ look at dE/dx pattern and combine it dE/dx information from SVT and DCH ➔ improve K/π separation (3σ) up to 0.6-0.7 GeV

Particle Identification: ToF

- ToF application ➔4 time constants
  - Scintillator τ_{sc}=2.2 ns
  - Y11 fiber τ_{fiber}=2.3 ns
  - MPPC rise time resolution σ_{MPPC}~0.1 ns
  - transition time in fiber t_{fiber} =2 ns (56 cm)
- MPPC signal is trigger by arrival of first photon
- We have up to 24 measurements
- Need a measurement for spiral strip
- With TOF measurements K/π separation (3σ) may be improved to >1.2 GeV





Cost Estimate

- Scintillator material: 10^5 cm^3 (89 Kg), St Gobain BC 408 sheets: 75 cm x75 cm $876 ea ➔ 140k$
- Labor: 1152 h for cutting sides and grooves ➔ 60k$
- Pb sheet: 10^5 cm^3, (1120 Kg), 20$/Kg ➔ 48 half-ring shapes (cut to rght size) ➔ 16k$
- MPPCs: 1152 detectors, 30 € (w/o tax) ➔ 50k$
- Fiber: 1 mm Y11 fiber, 800 m ➔ 4k$
- Support structure, Al ➔ 30k$
- Thermocouples, cables, reflector, paint ➔ 5k$
- Power supplies ➔ 20k$
- Frontend electronics: LAL SPIROC chip? 1 LED/strip plus driver 100$/channel ➔ 115k$
- DAQ ➔ 10k$
- Total ➔ ~450k$

Manpower Issues

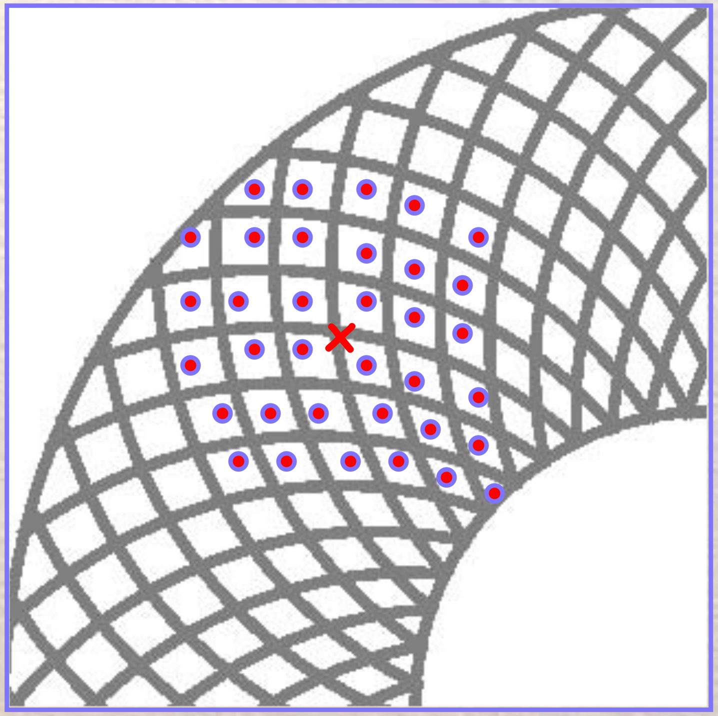
- Cutting 1152 strips takes 1152 h (30 d), cutting grooves into Pb takes 96 h ➔ need efficient machine shop with computerized milling machine
- Preparing mechanical support structure takes 3-4 days
- Mounting 1152 cells (strip+y11 fiber +MppC) and testing them with ^{106}Ru source takes about 2300 h (60 d)
- Stacking a layer (2 persons) takes about 8 h-> 192 h for EC (24 d)
- Connection to ASIC and DAQ -> 40h
- Miscellaneous tasks -> 5 d
- Total assembly time 15 weeks
- Simulations studies 1 year

Manpower Issues

- I will get a postdoc through AIDA (3 y) and a technical student (3y) who can work 50% on this fro middle of 2011
- It is also possible to attract master students
- If a German group gets involved and is interested in calorimetry I can get support from DESY
- I also applied for a grant to pay master students to help building the prototype
- The postdoc, the technical student and one of my master students will be involved with building and testing a backward EMC prototype

Prototype Design

- Since the Molière radius is 3.8 cm, most particles hit one strip
 ➔ shower is contained in the 6 strip arrangement
- Use 75 cm × 75 cm scintillator plates to cut out 6 strips/layer, left-handed spiral, right-handed spiral and radial sectors with circular boundaries for (24 layers) ➔ cut groove for fiber, MPPC and mirror
- Use 75 cm × 75 cm Pb plates (24 layers) cut to the right ring-shaped geometry
- MPPC is read out from Y11 fiber at outer edge and mirror is placed at inner edge
- Insert UV light via clear fiber at outer edge
- Place temperature sensor near MPPC



➔ In this setup, scintillator & PB plates may be reused for full detector

Status of Prototype Preparations

- We have the scintillator sheets (75 cm x 75 cm x 0.3 cm) in Bergen 25 BC 404 sheets from St Gobain

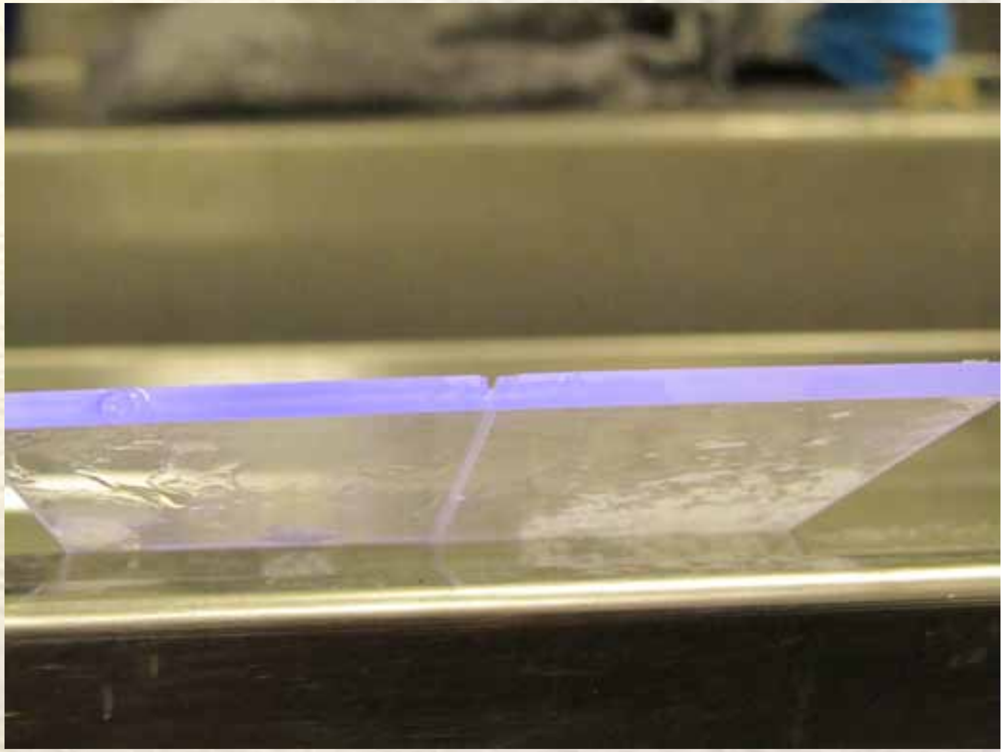
- The first radial strip is cut with the old machine
- The 24 hardened Pb plates from JL Goslar machined to the correctsegment shapes are at CERN
- We have 160 MPPCs in Bergen, 16 more than we need for the prototype
- We have our own PC with Labview which needs to be interfaced to the SPIROC chip and the CALICE CMB
- Gigi Cibinetto promised to send me 80 m of Kuraray Y11 fiber, once they finished cutting fibers for their prototype, but I have not heard back from him after the summer
- I have two SPIROC boards in Bergen (need another 2)
- I will get 1 calibration board from Prague with 12 LEDs & clear fibers

Prototype Preparations Continued

- Ludovic Raux and Stephane Callier from LAL came to Bergen for a day first week of April to set up SPIROC chips readout in Bergen
  ➔ we have SPIROC I (no digitization) and SPIROC II with digitization
- An electronics engineer from Prague will come to Bergen in the spring to set up the calibration board
- All the major components have been purchased except high precision power supplies
  (I spent 25K$ of personal money I inherited on the prototype plus another 10k$ from the instrumentation budget)
- I need to order temperature sensors and diffuse reflectors (different reflectors were tested but I have not seen results)
- Yesterday, Gigi told me that he has 50 m Y11 fiber he will send me
- 2 weeks ago, I applied for a University grant (35k$) to buy power supplies, hire a student for stacking prototype and travel for testbeam

First Strip

- First radial strip milled with old machine
- The groove for the MPPC is visible

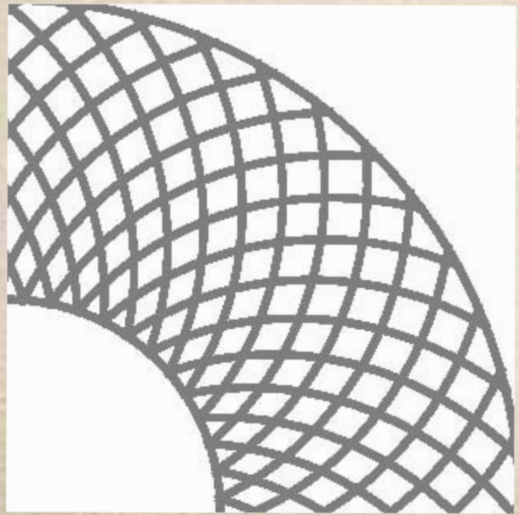


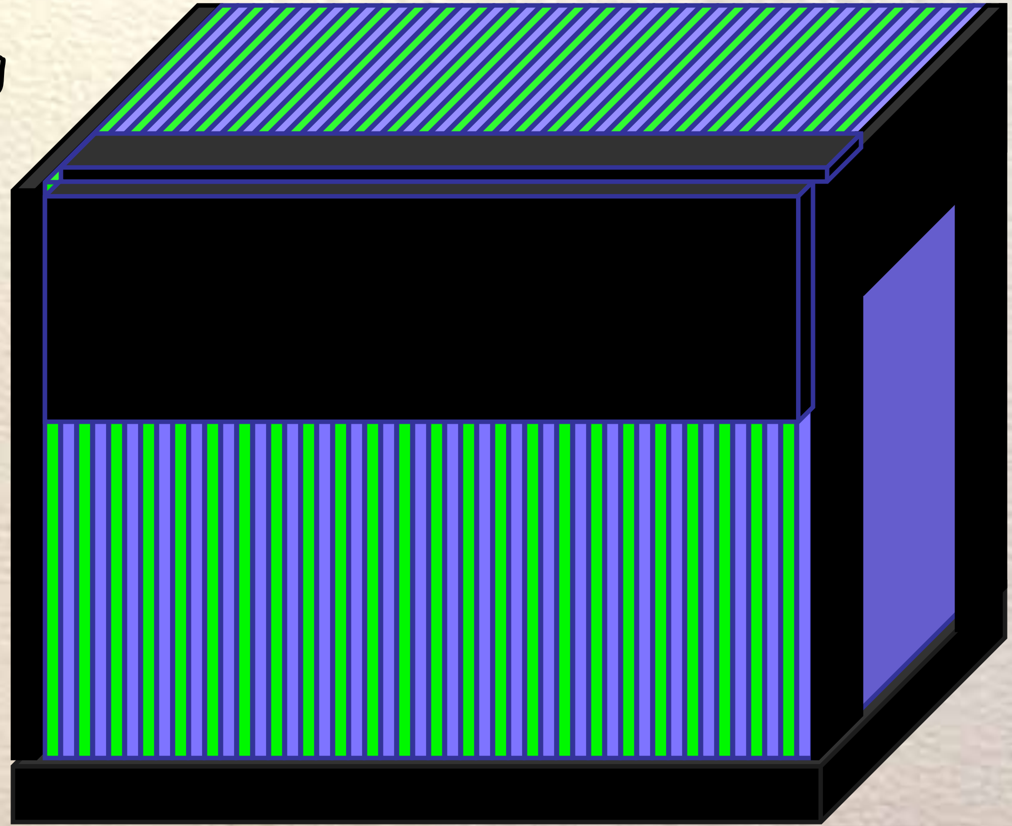
Status of Prototype Preparations

- The machine shop in Bergen has a computer-controlled milling machine
- Dominik Fehlker, our electronics engineer has programmed 48 left-handed spirals and 48 right-handed spirals in Pro Engineer
- Dominik is transferring one spiral from Pro Engineer to the milling machine

PrototypeMechanical Support Structure

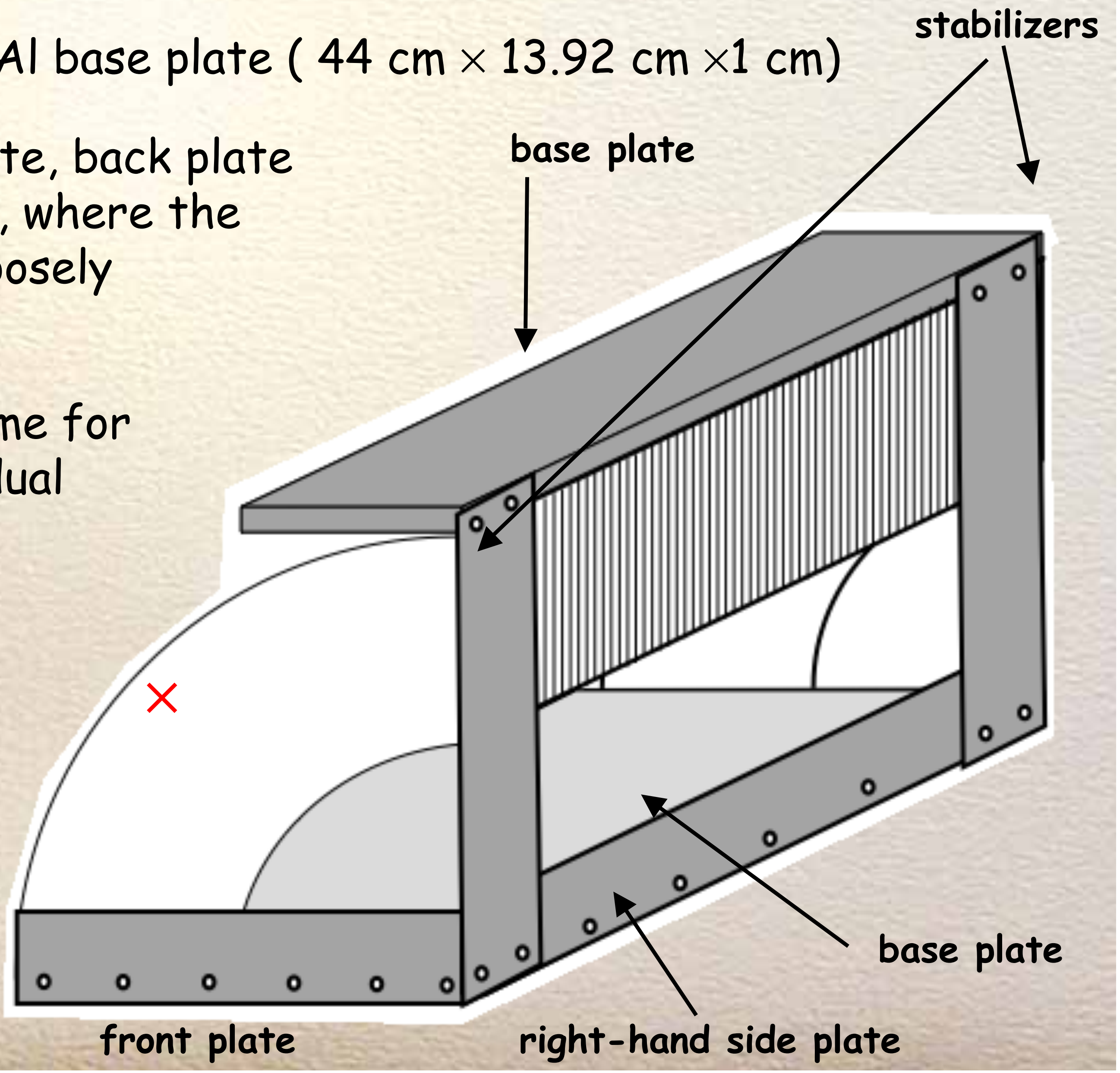
- Build Al frame to hold layers ➔ leaves holes to get to MPPCs, RO
  - Bottom: solid base plate with full coverage
  - Back: solid back plate with full coverage
  - Front: 2 side and top bars
  - Top: bar near left
  - Left: plate covering top part
  - Right: bar near bottom





Mechanical Support Structure

- We first place the Al base plate (44 cm × 13.92 cm ×1 cm)
- We bold a front plate, back plate and two side plates, where the back plate is only loosely attached
- This provides a frame for stacking the individual lead plates and scintillator strip layers
- After stacking back plate is fixed and additional stabilizers are added

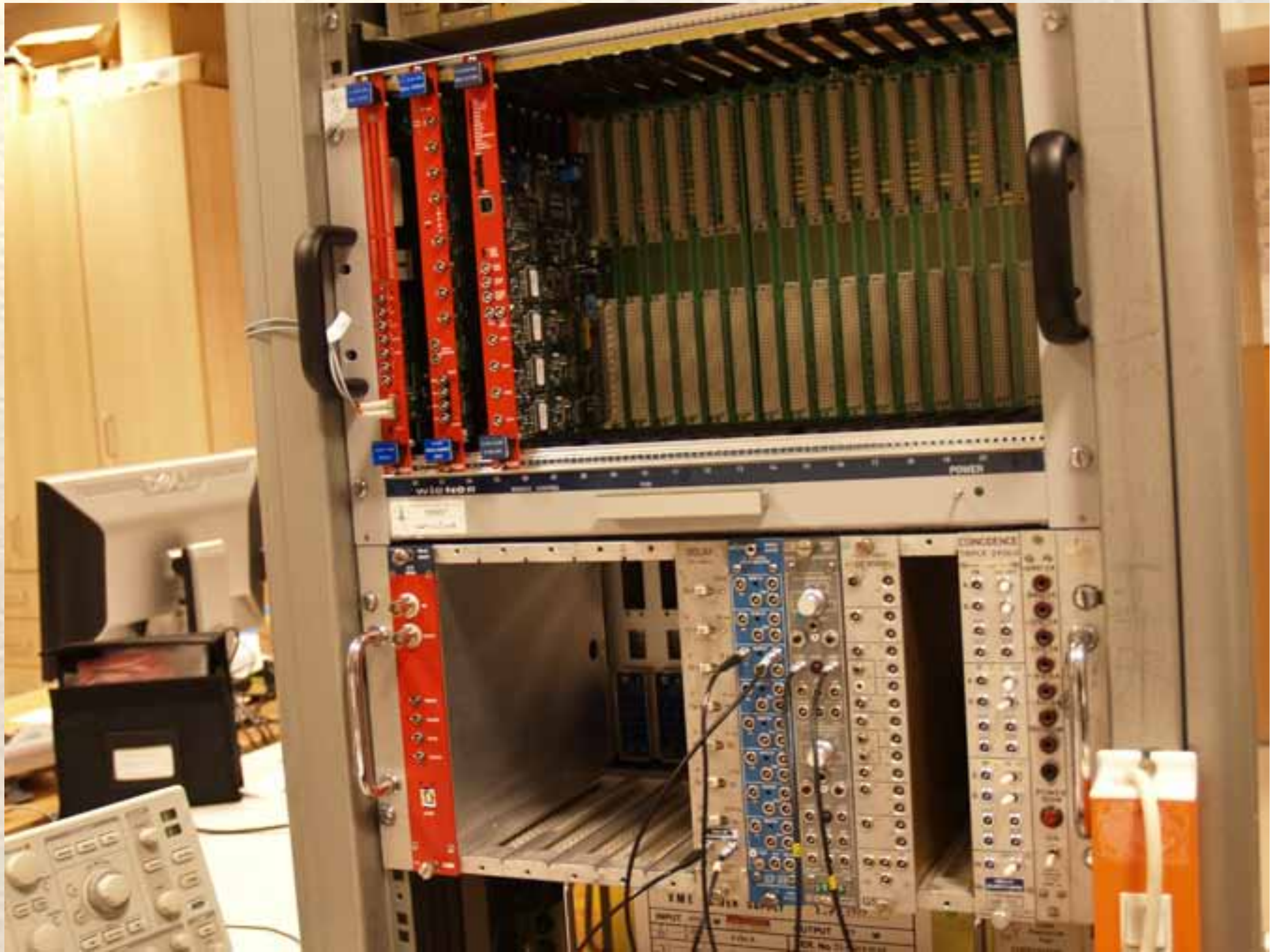


R&D in Bergen

- We have built a black box, and made fixtures for tile measurements

R&D in Bergen

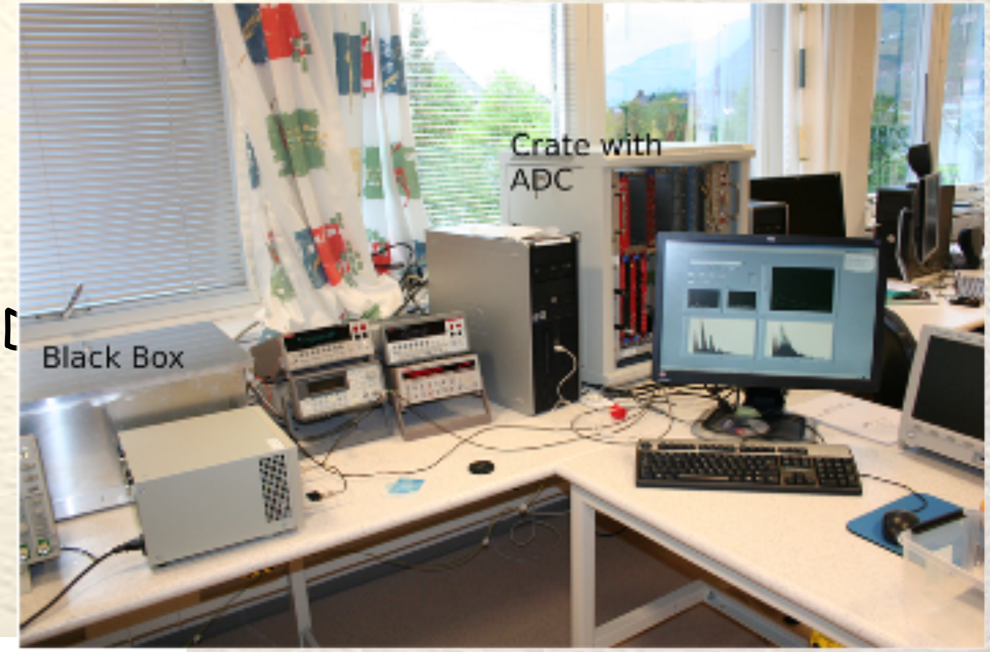
- We have a VME system to read out detectors
- We bought a 14 bit ADC from Caen
- We have set up LabView
- I have an engineer and had one master student

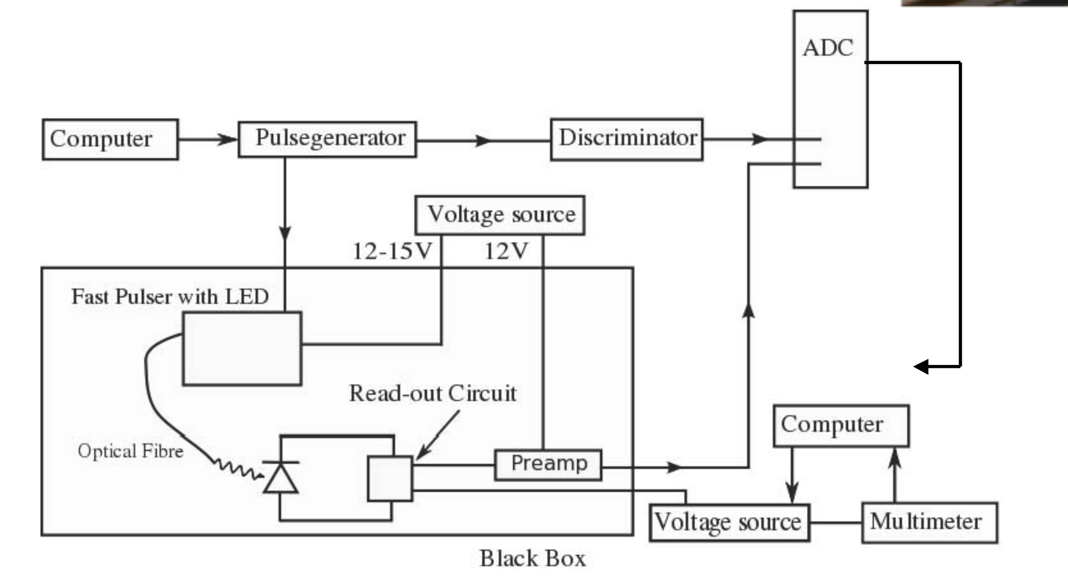


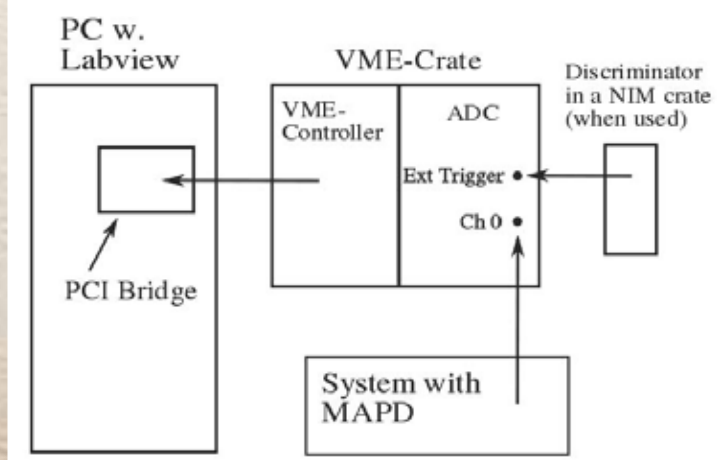
R&D in Bergen

- We have started to measure properties of SiPMs, MPPCs and MAPDs in our laboratory

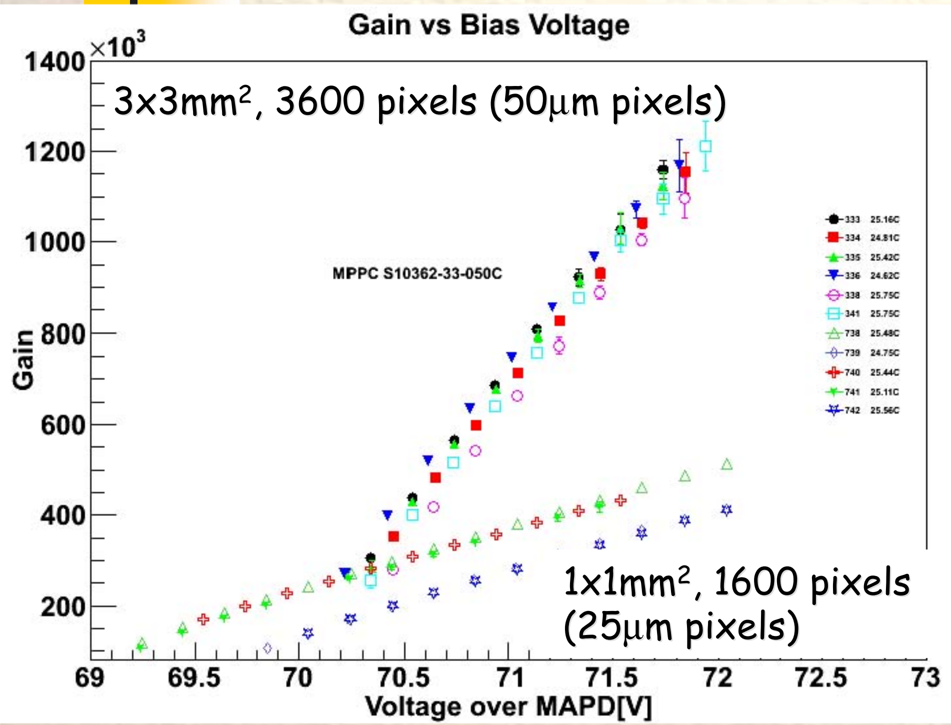
- We have started to measure LED and source spectra from scintillator tiles







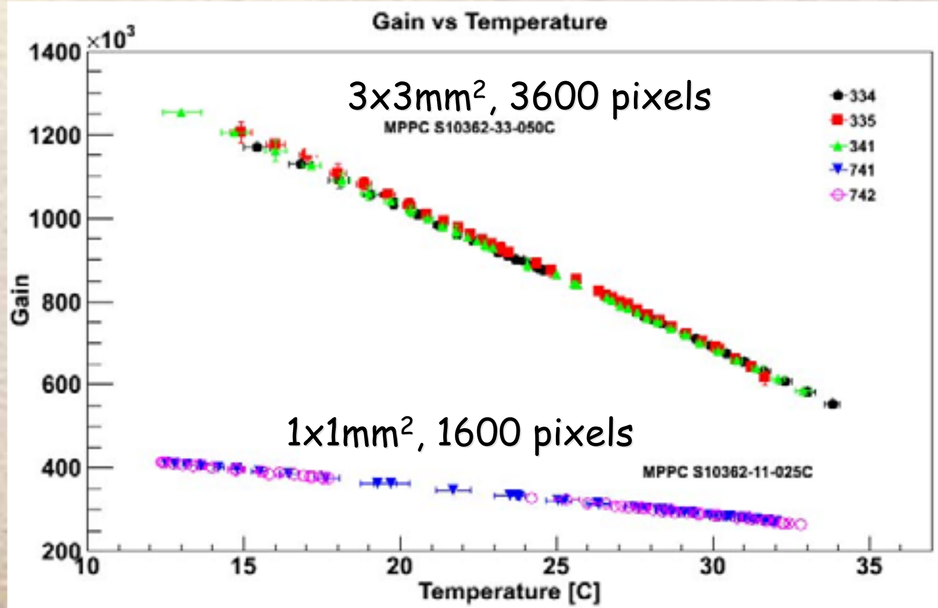
MPPC Gain vs Voltage and Temperature



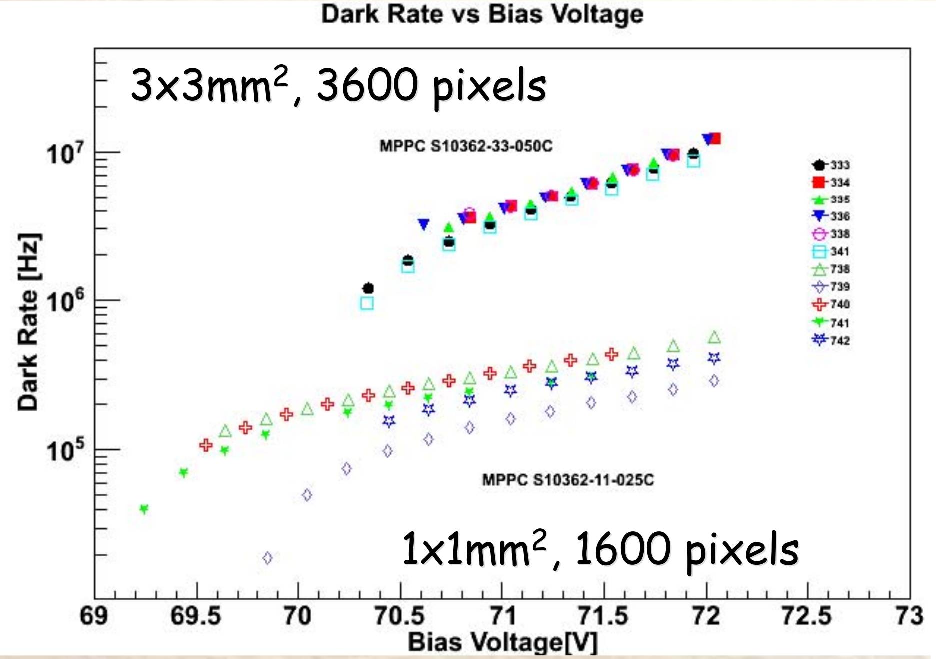
- MPPC gain depends linearly on voltage, it is lower than SiPM gain

$$G = \frac{Peak_{1pe} - Pedestal}{G_{preamp}\varepsilon}$$

- MPPC gain drops linearly with temperature
  - $1/G*dG/dT=-3.81\%/1^oC$
  - $1/G*dG/dT=-2.2\%/1^oC$

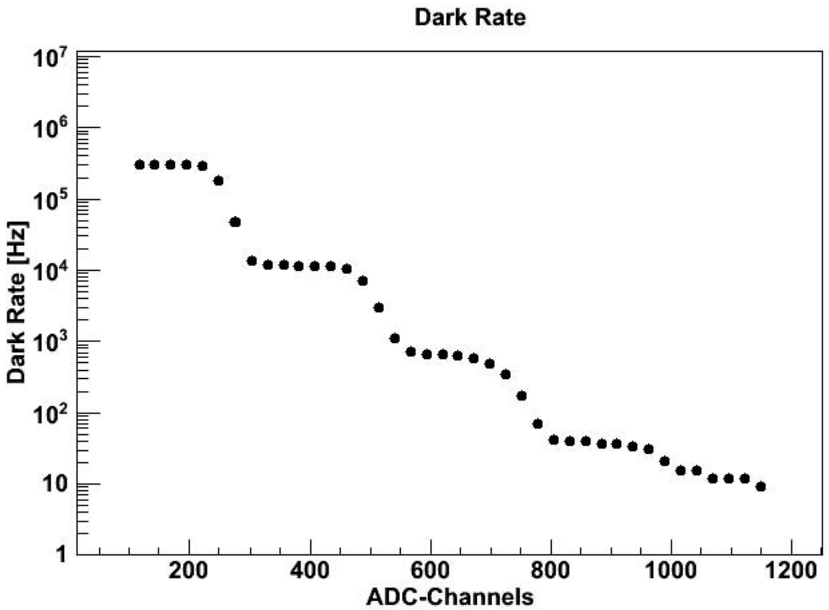


Dark Rate



- Dark rate increases with bias voltage, for 1x1 mm^2 detectors the slope is much flatter than that for 3x3 mm^2 detectors

- Dark rate drops with increasing threshold, typically cut at 0.5 MIPs for data taking, no cut for gain calibration



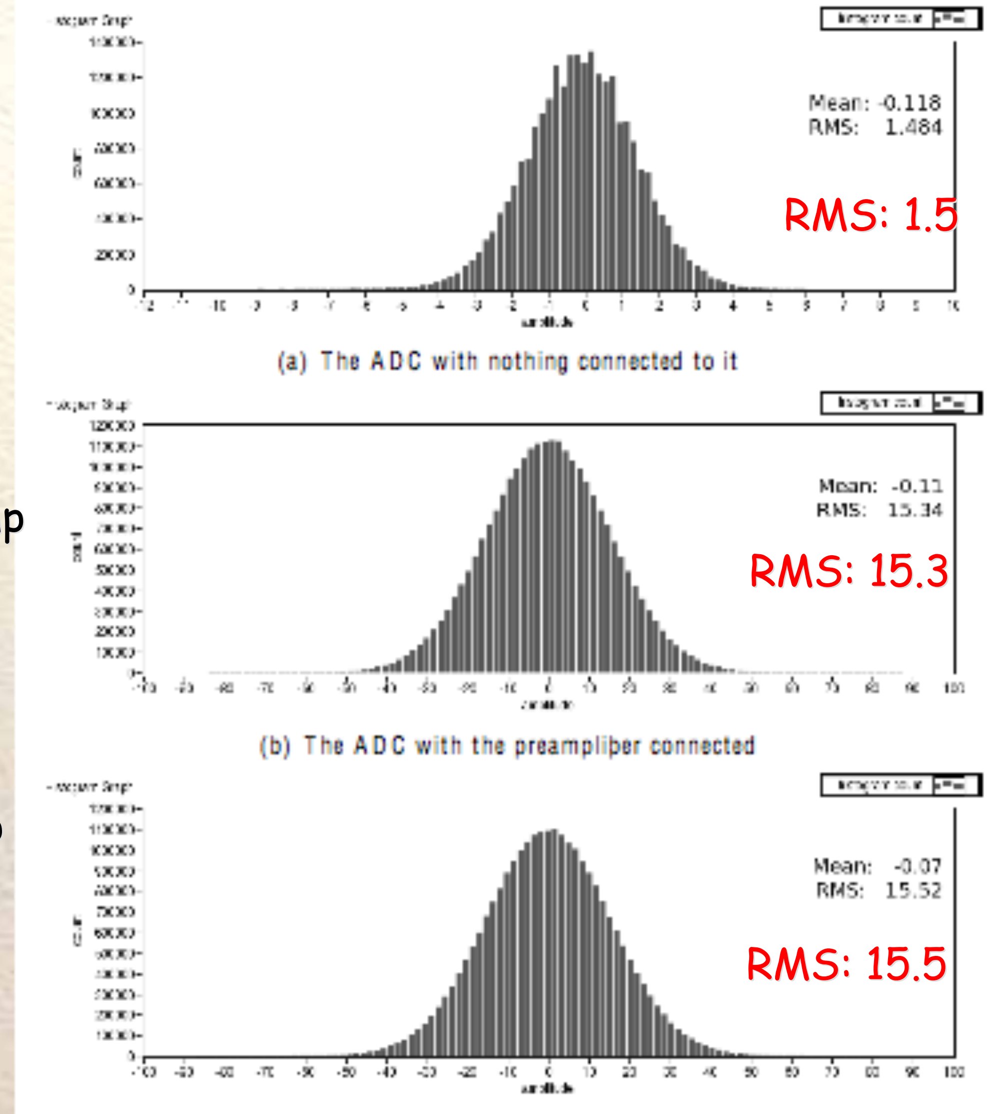
Noise Studies of Setup

- For recommended operating voltage noise of 1x1 mm^2 MPPC is 4 ADC bins

ADC

ADC +preamp

ADC +preamp +MPPC



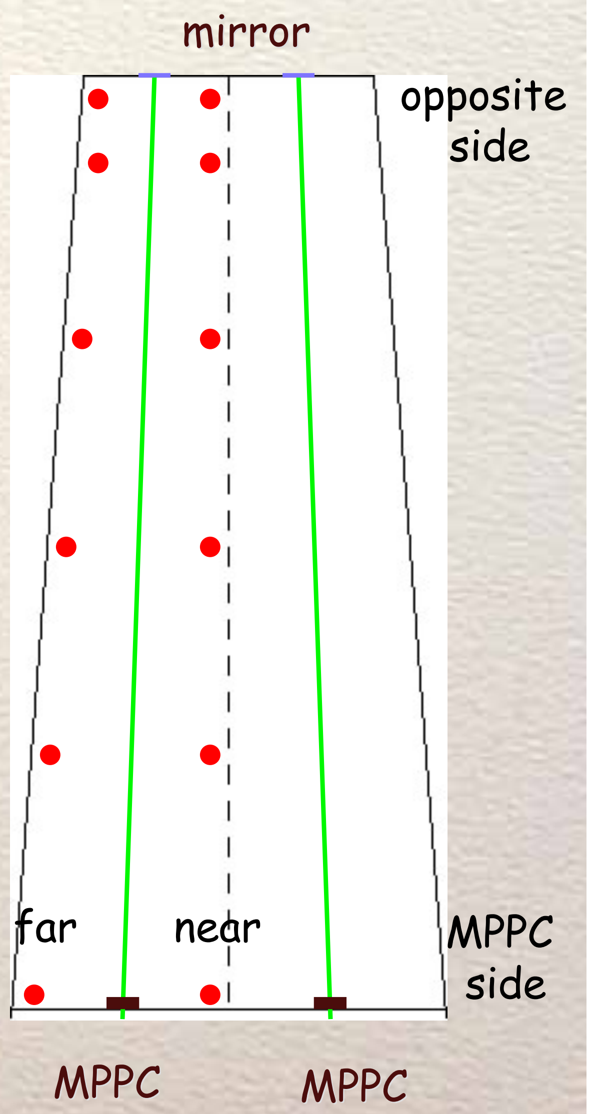
(a) The ADC with nothing connected to it

(b) The ADC with the preampliþer connected

(c) The entire system is connected, here sample 341 is used as an example

Cross & Homogeneity Talk Measurements

- Read out 2 tapered strips simultaneously that are separated by cuts
- Shine LED light via a clear fiber on 12 fixed positions located on both sides of Y11 fiber
- Define cross talk fraction as ratio of MIP peaks of far tile to that of near tile
- Start with ~50% cuts (bridges) and measure cross talk, average several measurements
- Remove bridges down to 2% in steps to establish a relation of cross talk vs size of bridges ➔consider points: 50%, 25%, 10%, 5%, 2%

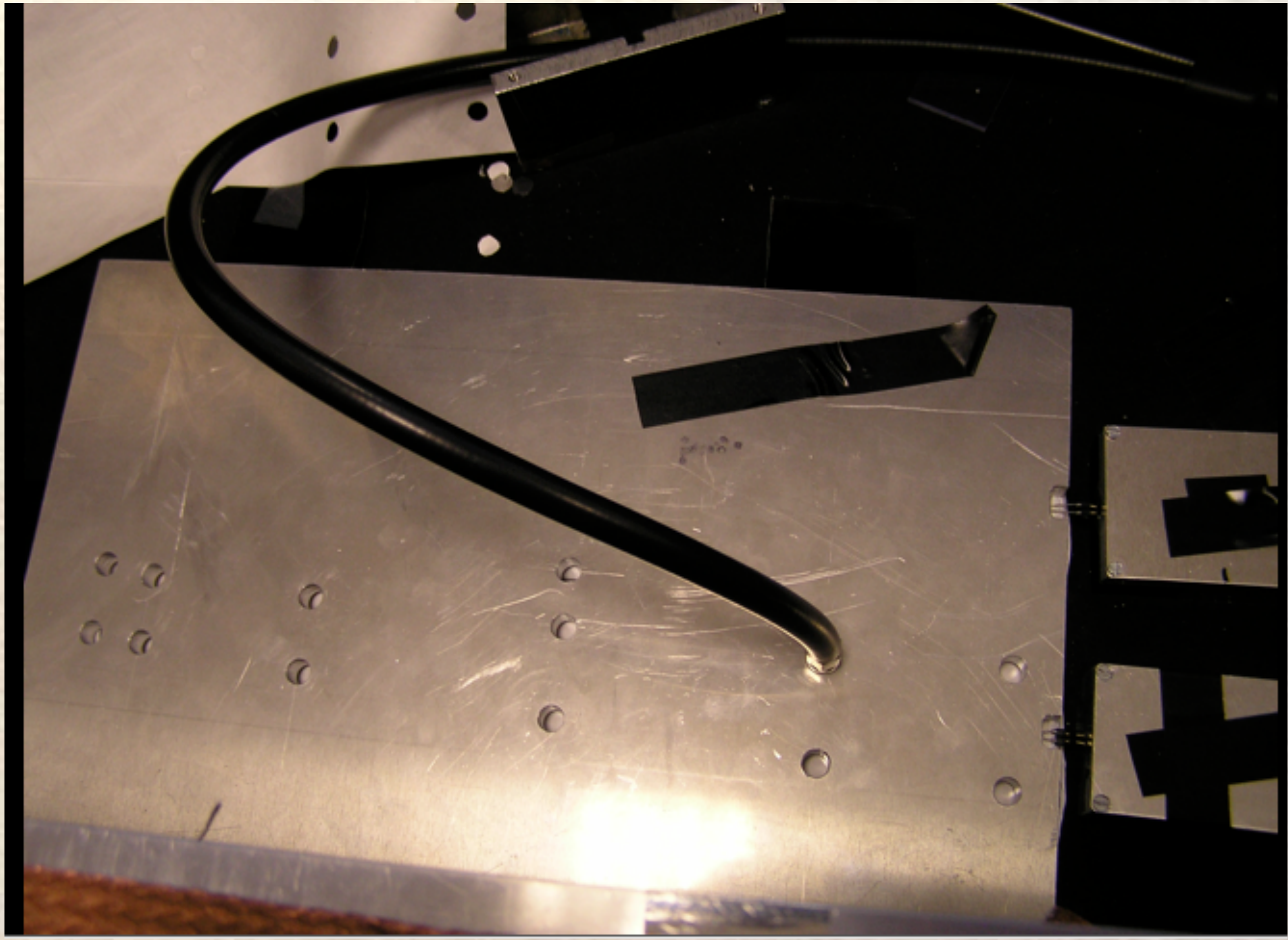


Setup for Cross Talk Measurements

- Using 2 independent readout chains simplifies measurement considerably

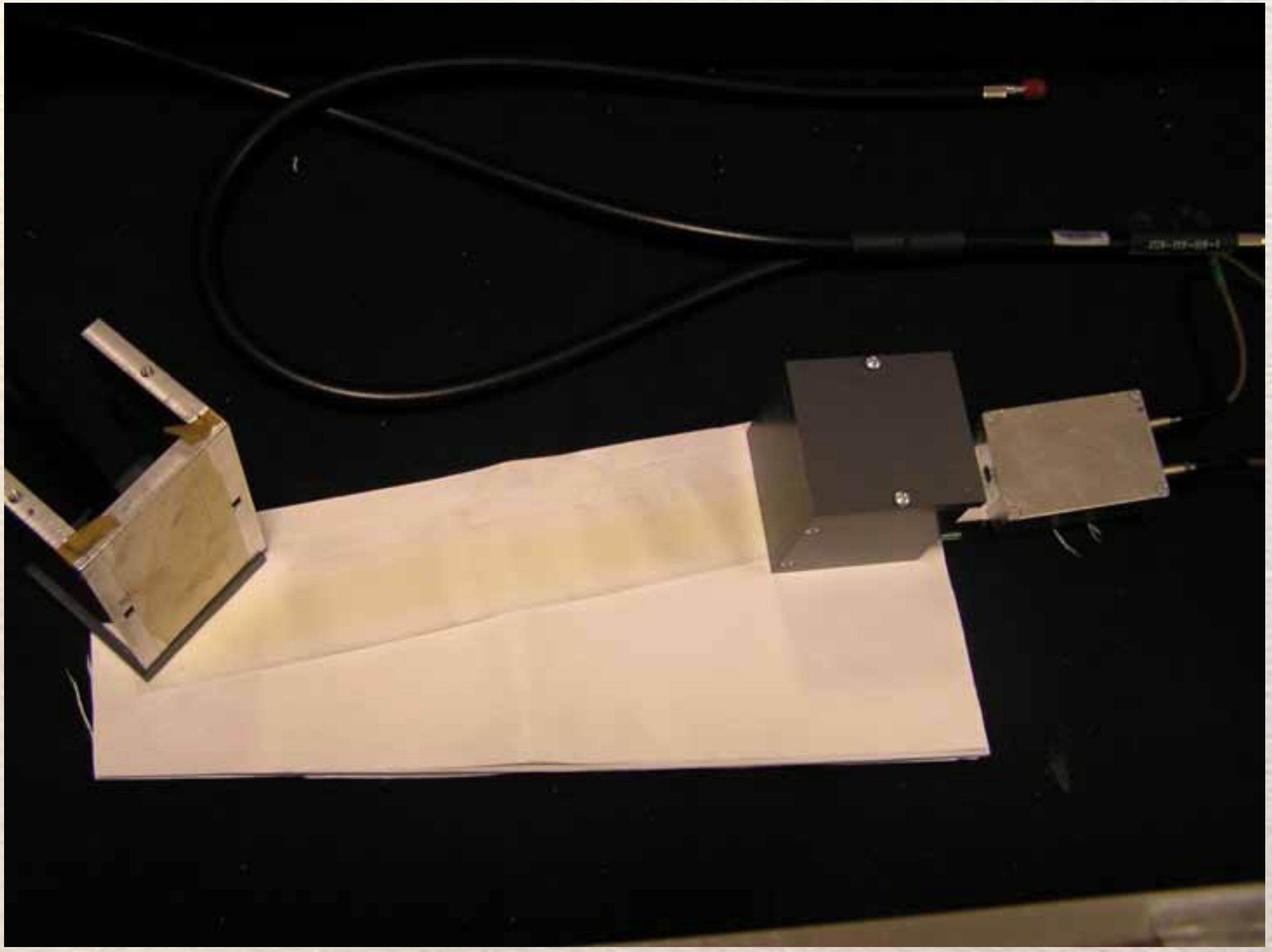
→ Reduces systematics

- Before each set of 12 measurements MPPCs are recalibrated



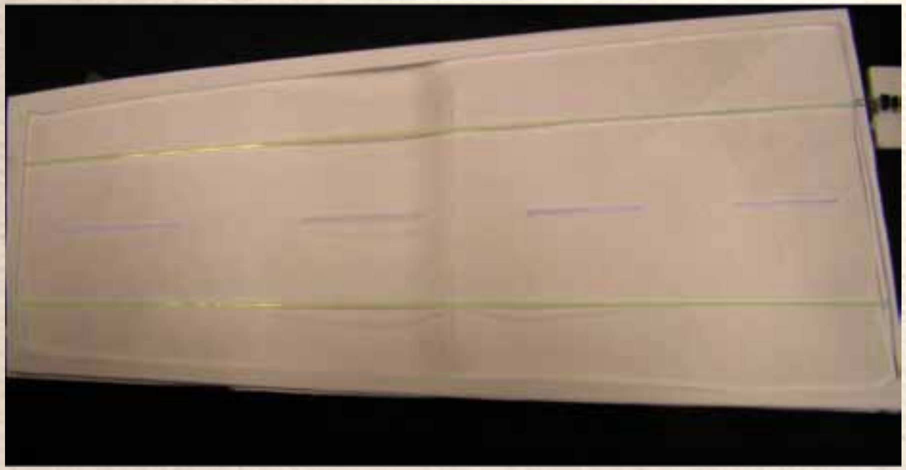
Setup for Cross Talk Measurements

- Use UV LED
- Fiber is held by Al fixture
- Since we have only 1 preamp we presently use the same MPPC for both strips
  ➔ introduces systematics fiber-MPPC matching
- Try to get another preamp

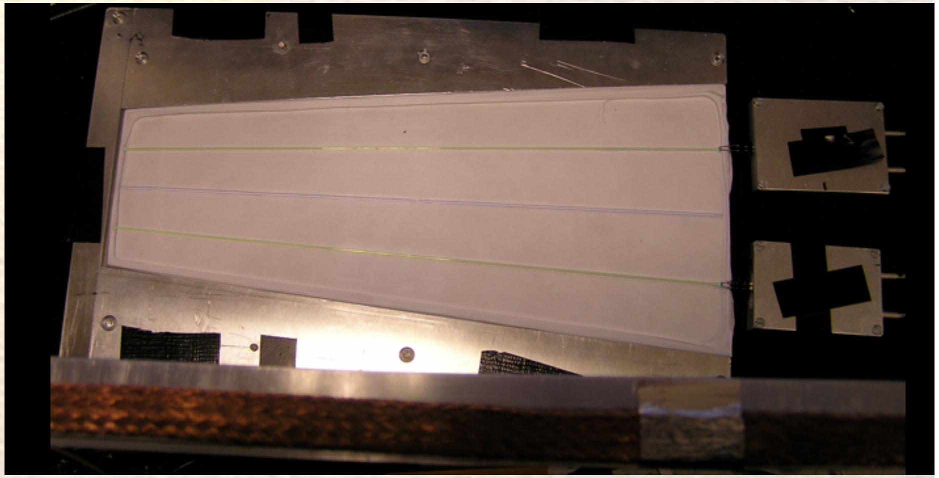


Setup for Cross Talk Measurements

- Layout for 50%



Layout for 2%

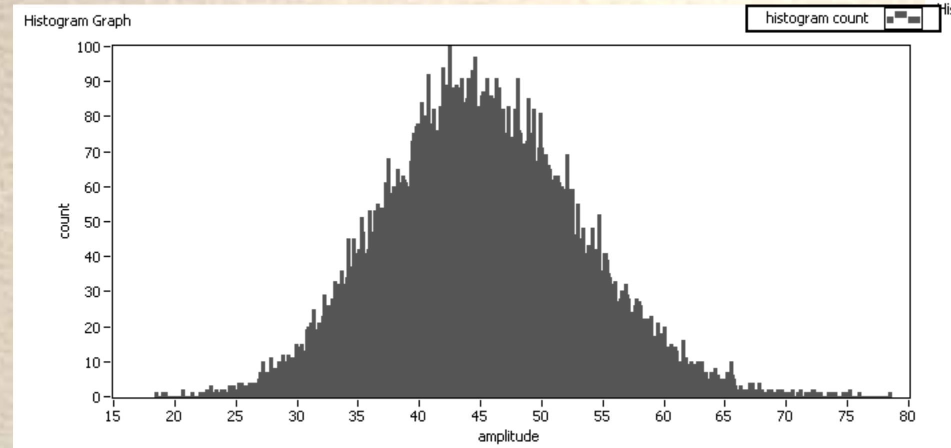


- 2 connected scintillator strips
- Bridges are clearly visible
- Strips are covered with Tyvec sheets edges are wrapped withTeflon

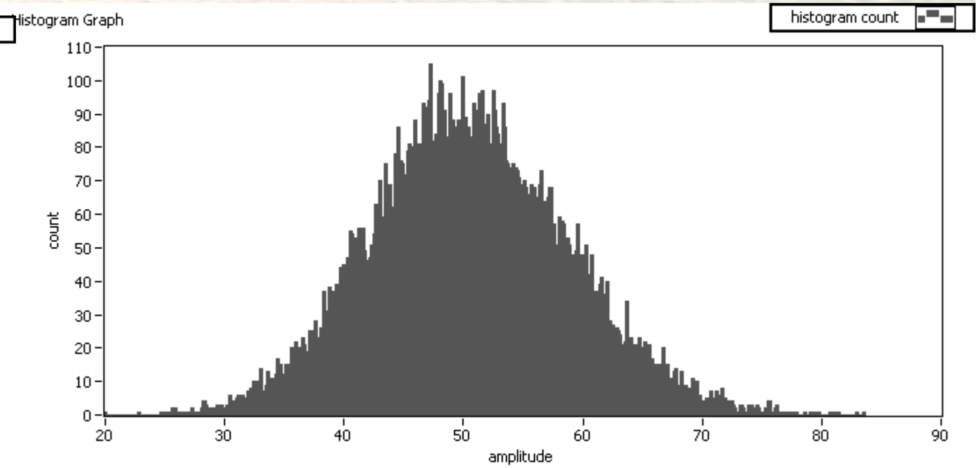
LY Distributions

- Light yield distributions look fine

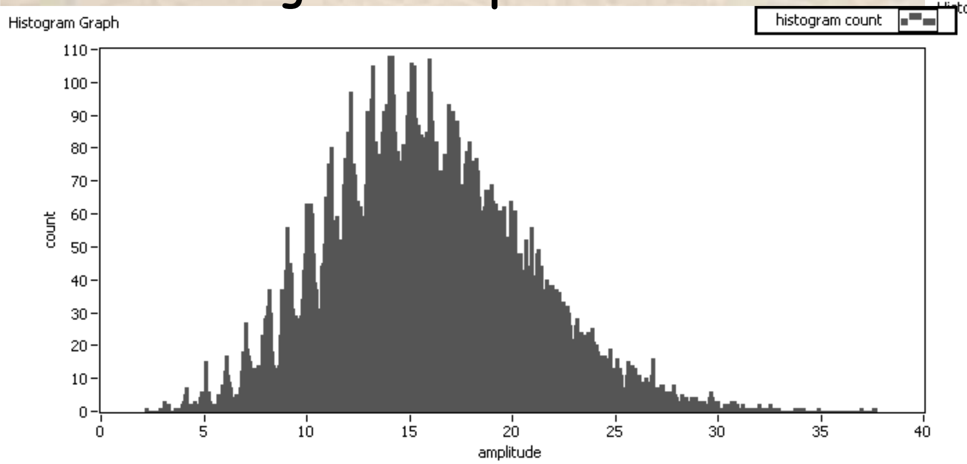
Reference near side



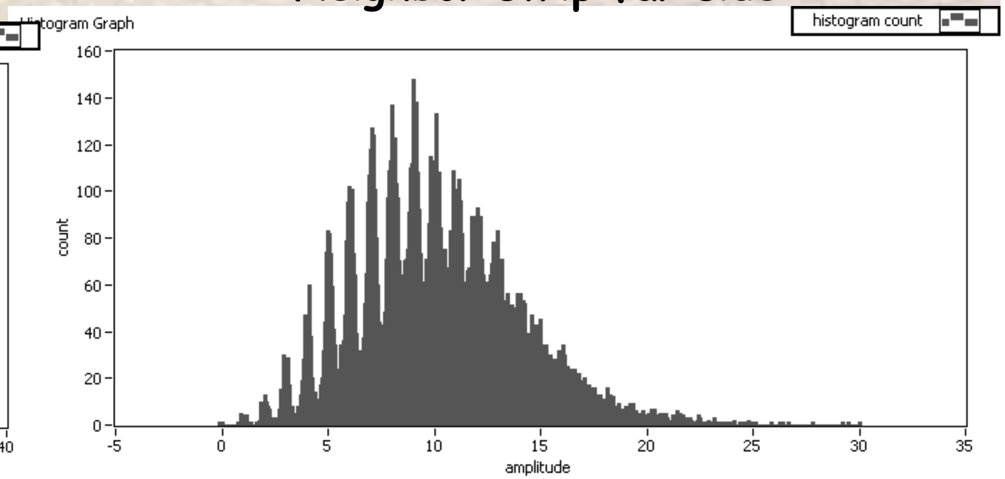
Reference far side



Neighbor strip near side



Neighbor strip far side

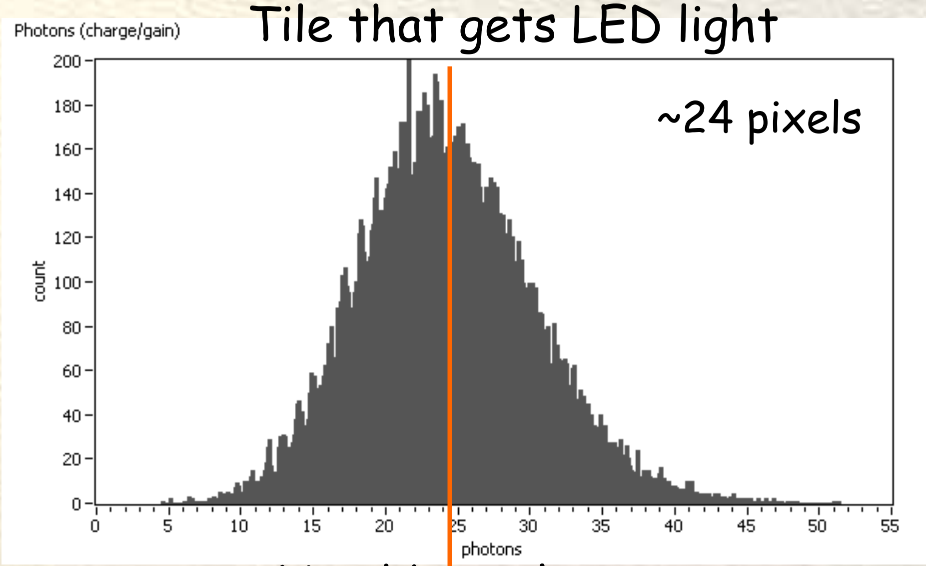


Cross Talk Measurements

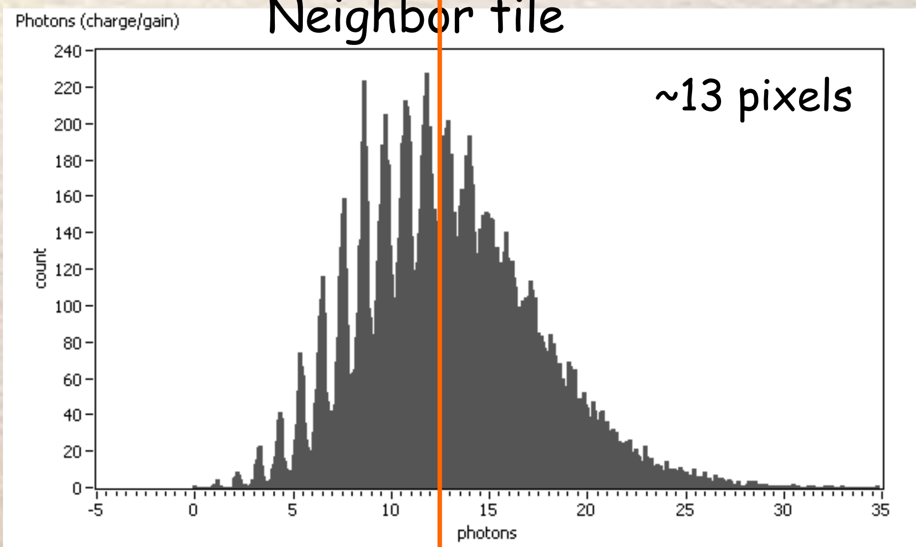
- The 2 tiles are connected by bridges that cover 50% of the total length
- Total length is 12 inch (Eljen scintillator)
- We shine light from an LED via a clear fiber onto tile at the outer broad side
- We measure with the same detector first light from tile that is illuminated and then neighbor tile
- We have repeated these measurements a few times

➔ systematic effect, groove for MPPC is too large to reproduce optimal MPPC-fiber matching

Tile that gets LED light

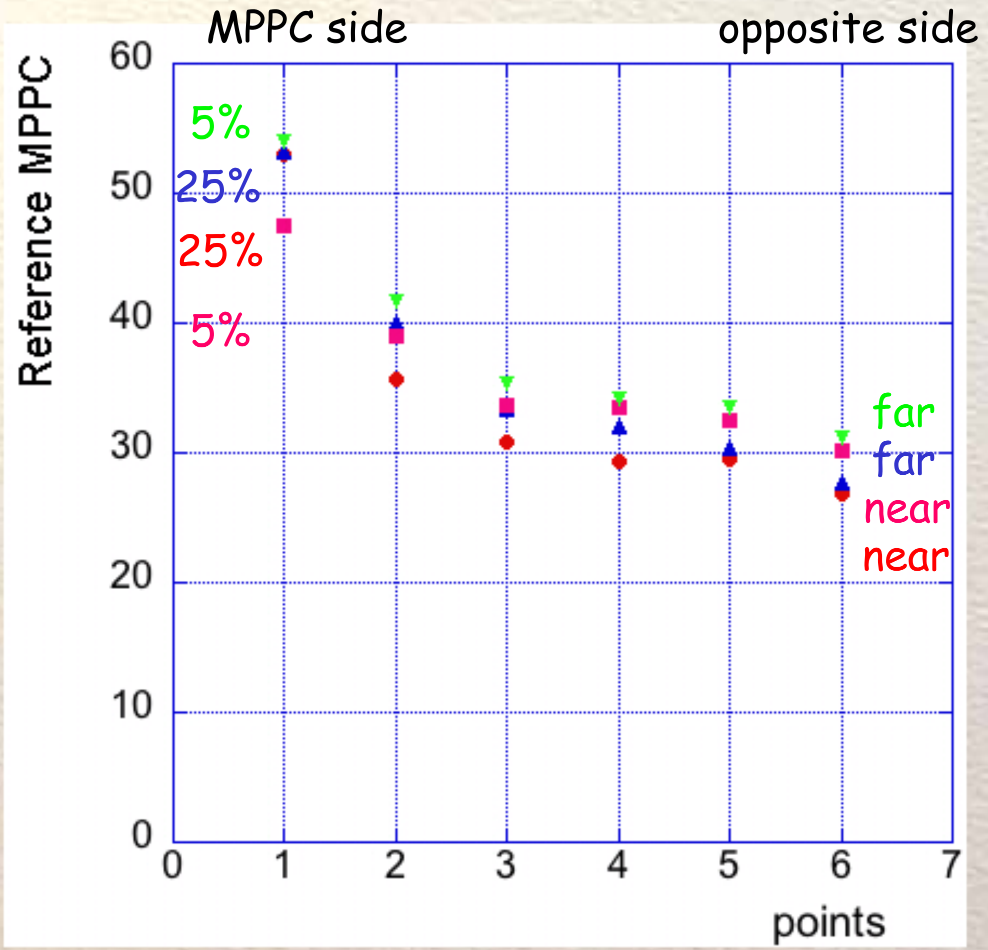


Neighbor tile



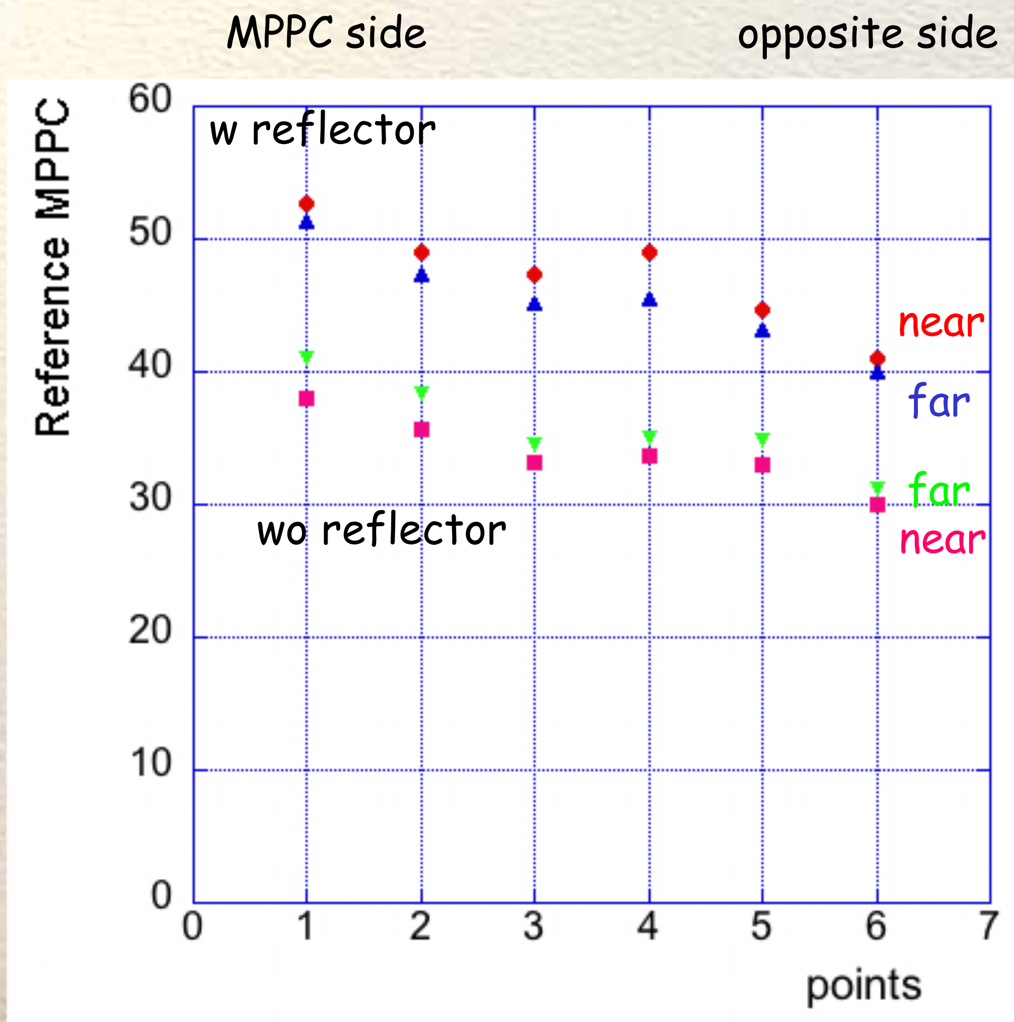
Homogeneity Measurements

- Use pulse heights in reference MPPC to look at homogeneity
- Due to tapered shape would expect non homogeneity
  ➔ higher light yield near large face (MPPC side)
- We need to study this with strip dimensions used in prototype
- We need to look at homogeneity of spiral strips
- Develop method to produce homogeneous light output



Homogeneity Measurements

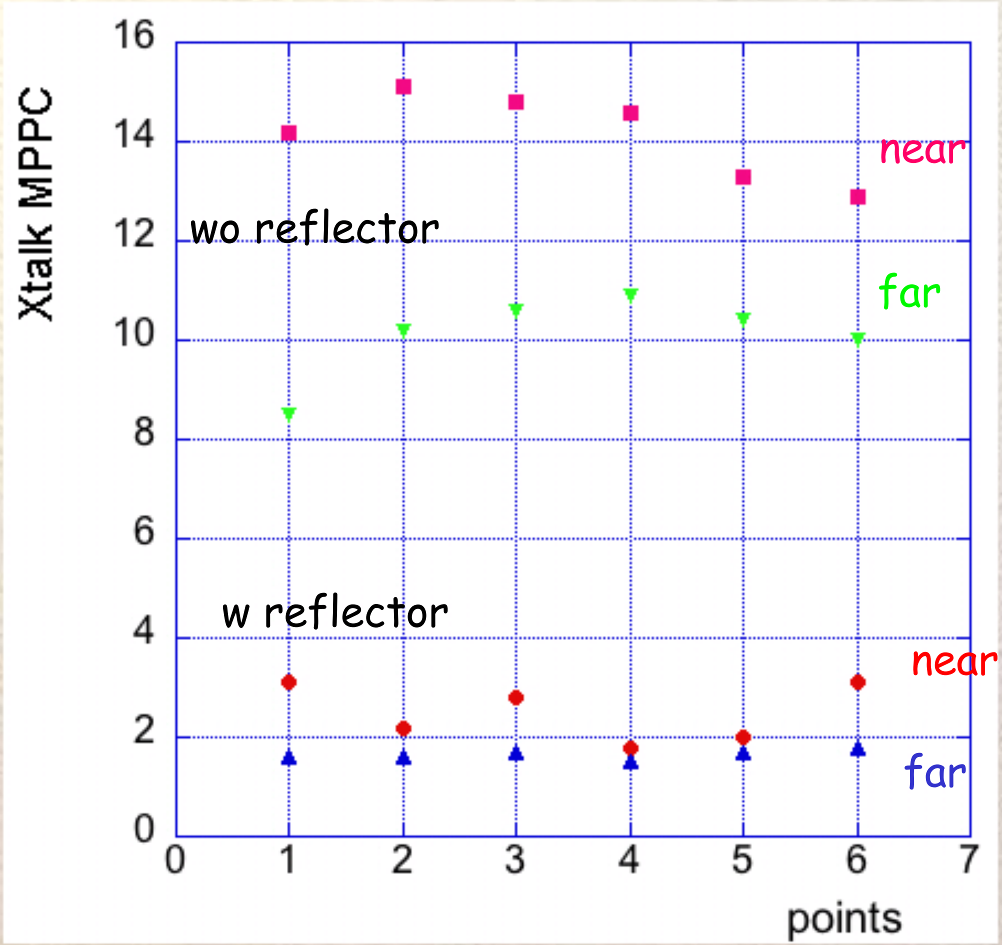
- Use pulse heights in reference MPPC to look at homogeneity
- Due to tapered shape would expect non homogeneity
  ➔ higher light yield near MPPC side (larger face)
- With a reflector between strips light yield increases
- Light yield increases from ~40 at opposite side to 50 at MPPC side
- Develop method to produce homogeneous light output
- We need to look at homogeneity of spiral strips



Homogeneity Measurements

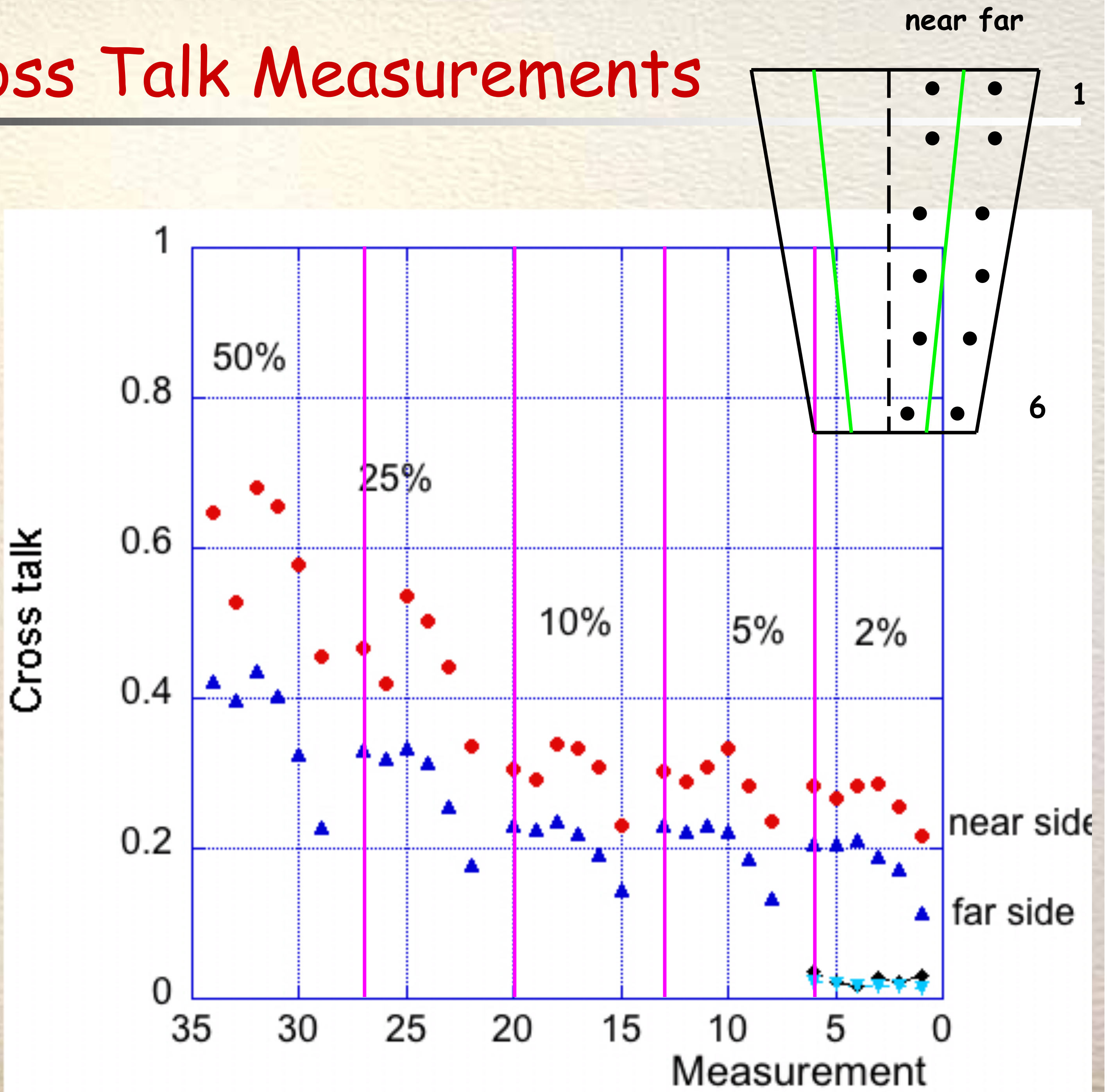
- Look at light yield of the strip that is not directly illuminated
- Compare performance with Tyvec reflector between strips and without
- With reflector we see a small amount of Xtalk (O(2%)) as expected
- Xtalk is slightly higher for near side wrt far side
- Cross talk is independent of light production point

MPPC side opposite side



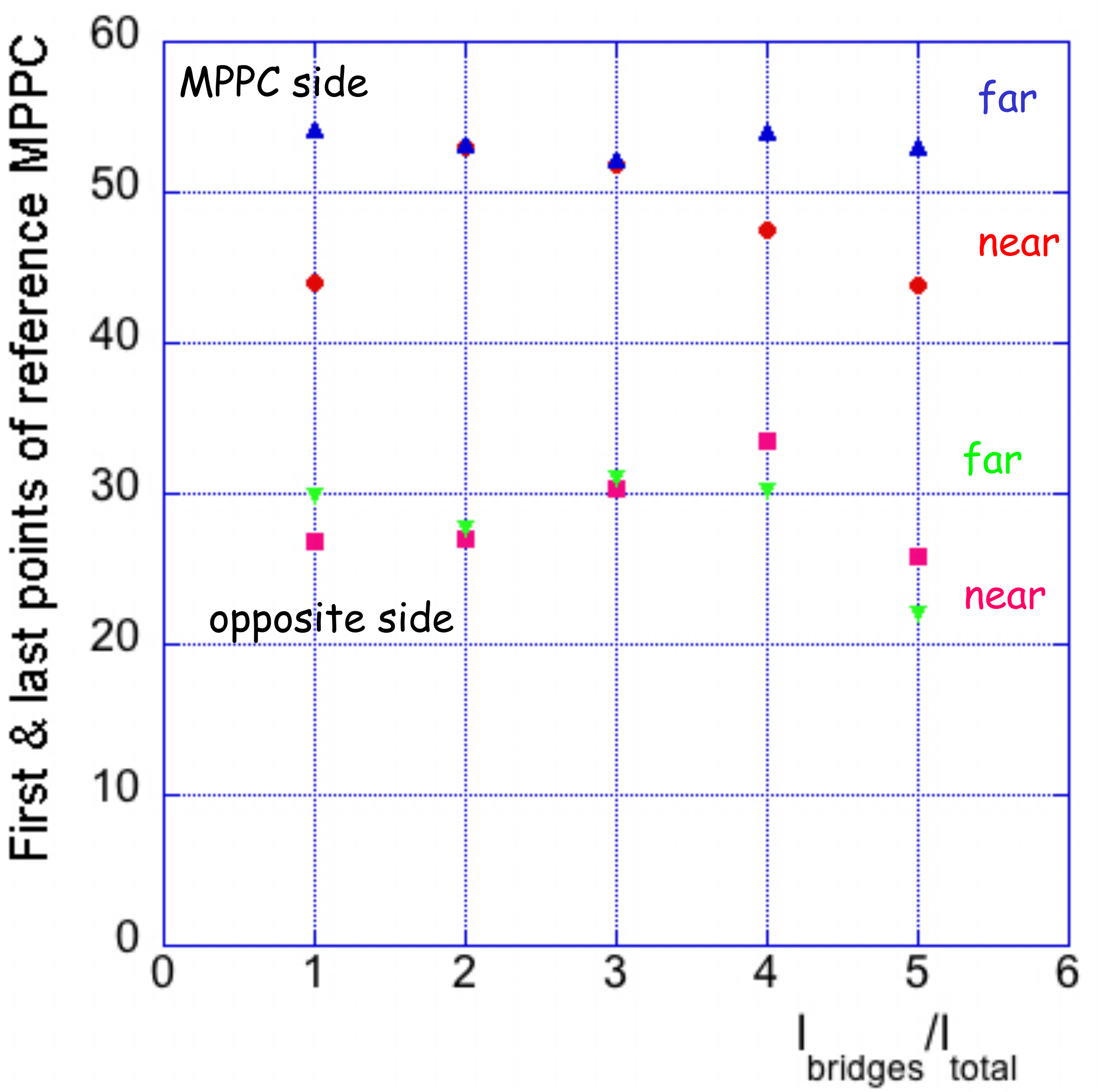
Cross Talk Measurements

- Cross talk for 2% connections is of the order of 2 % as expected.
- Cross talk at the near side is slightly larger than at the far side



Homogeneity Measurements

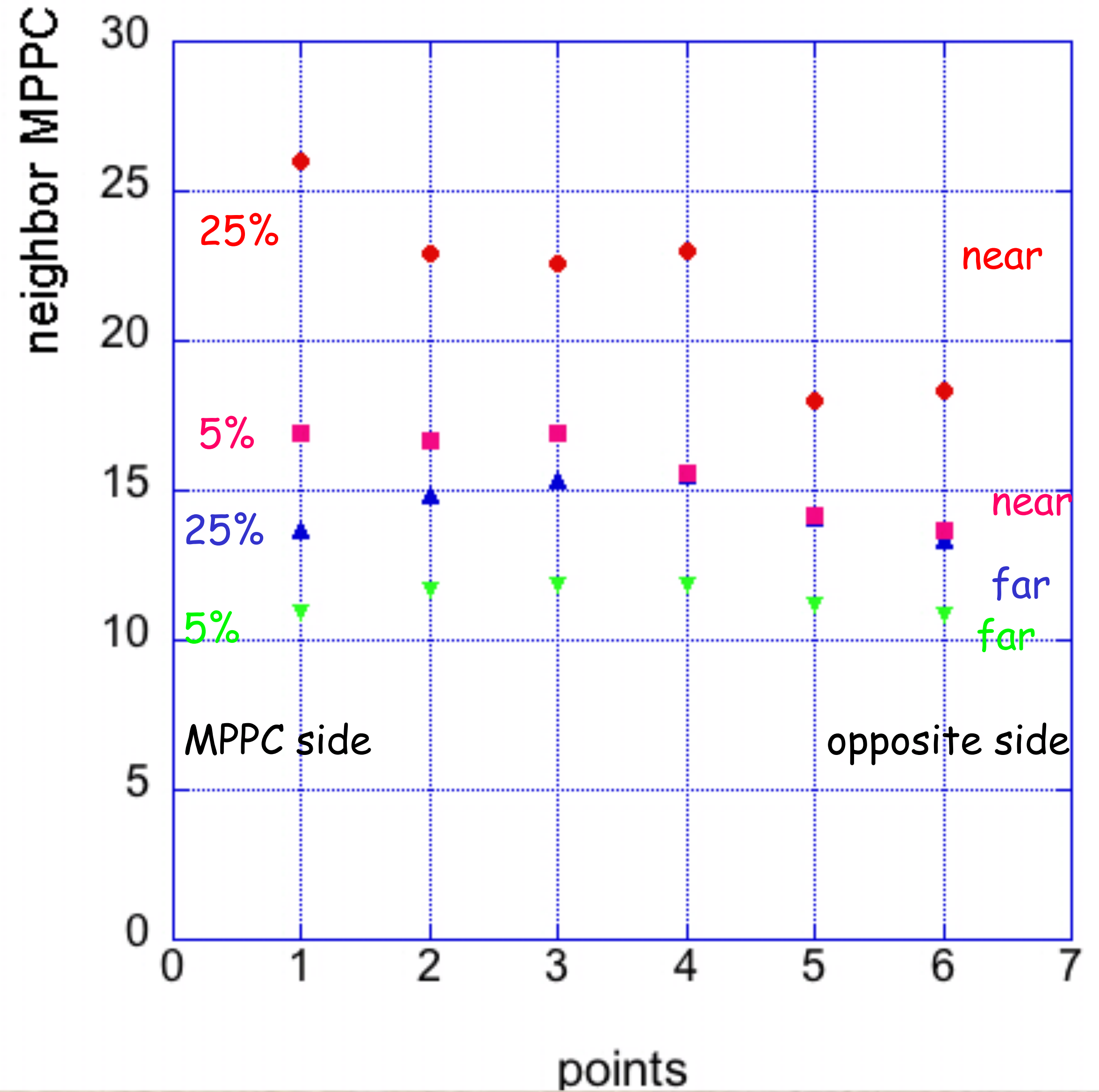
- Measurements in reference MPPC on far side and near side at both ends of strip
- Expect uniform distribution for each set of points, also for far and near side
- Fluctuations show systematic effects in reproducibility



50% 25% 10% 5% 2%

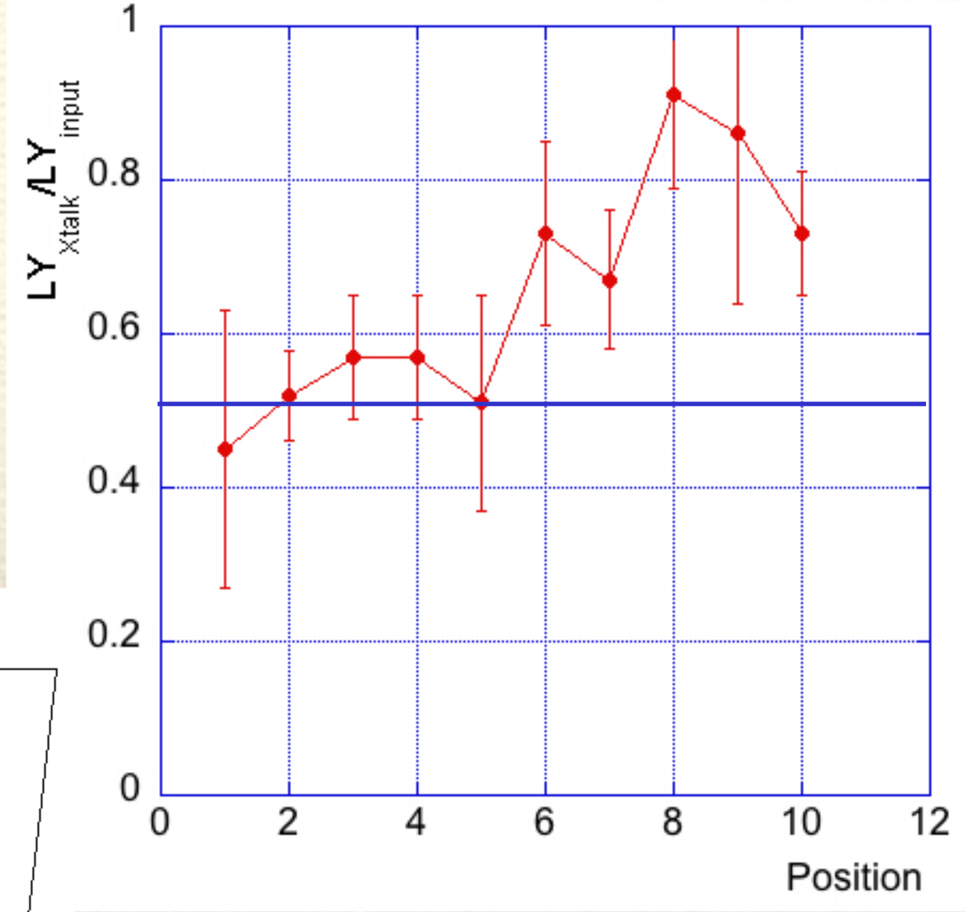
Homogeneity Measurements

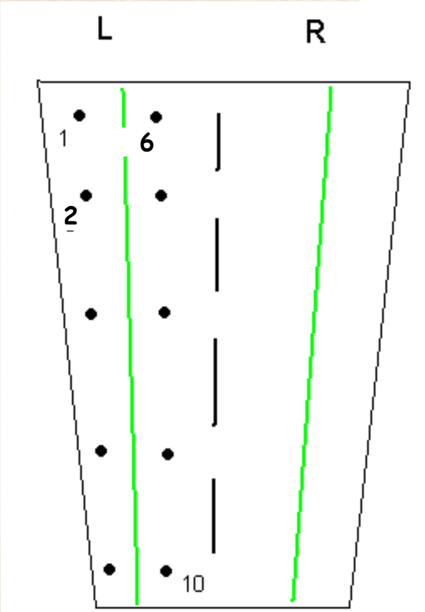
- Measurement of the neighbor MPPC
- Light yield shows only small position dependence
- Drop from 25% to 5% is less than expected
- Student forgot to add reflector in the gaps
- I ask him to repeat 2% points with Tyvec in gaps and with a source



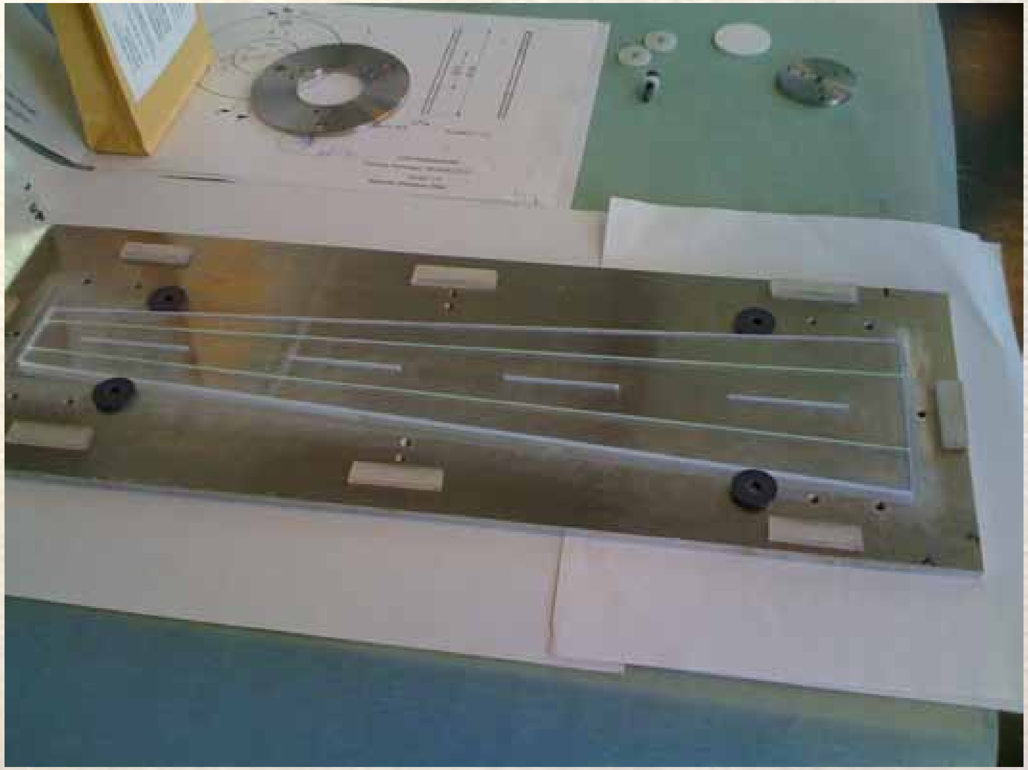
Cross Talk Measurements

- Plot cross talk for 10 measurements at 10 points
- For light far from neighbor we get results consistent with 50% expectation
- For light close to neighbor we get results consistent that are ~ 70% which are much higher than the expectation
- So maybe the bridges should be at the top and bottom





Setup for New Cross Talk Measurements



- We will repeat Xtalk measurements with full-size strips
- We got two full-size sector strips from machine shop
- Strips will be covered with Tyvec on top and Bottom and with Teflon on sides
- Start with 50% connections
- Gaps will be covered with Tyvec
- Place top plate with 12 holes in fixed position so the fiber is always inserted on the same positions

Conclusion

- The backward EC EMC is an important component for achieving a hermetic detector for rare decay analyses and for measuring (machine) backgrounds
- We have an affordable design providing reasonable energy resolution
- The spiral strip arrangement elegant for achieving good position info (particularly in φ), while minimizing the # readout channels
- The detector can be built in one piece or two halfes
- The detector can be used for particle identification, TOF, dE/dx
- If n flux is 3500 Hz/cm^2 in worst case, this should provide no problem for MPPC operation, ➔ have a safety margin of at least 20 and can switch from 25 μm pixels to 20 (15) μm pixels
- It would be useful to have collaborators to increase manpower, funding

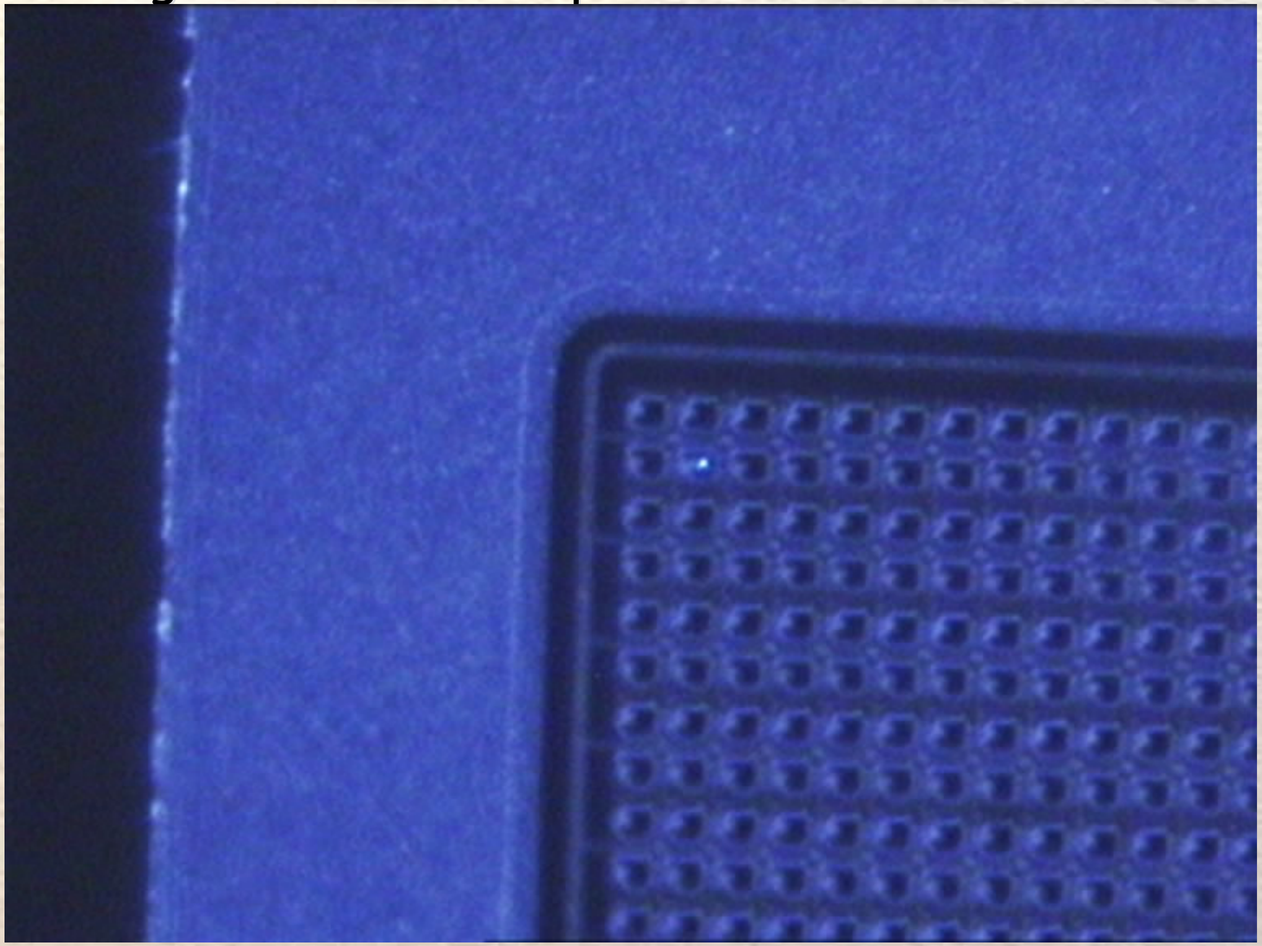
Next Steps

- The near-term goal is to build a 144 cell prototype with the full length
- Major components are in Bergen, get 50 m Y11 fiber from Gigi
- I am pushing our machine shop to get the remaining 143 strips produced
- Calibrate finished strips with ^{106}Ru source
- Aim for late spring/ early summer to calibrate it with cosmic muons
- Then move to test beam at DESY or CERN and Frascati to measure electrons and photons

Backup Slides

Studies of MPPC Properties

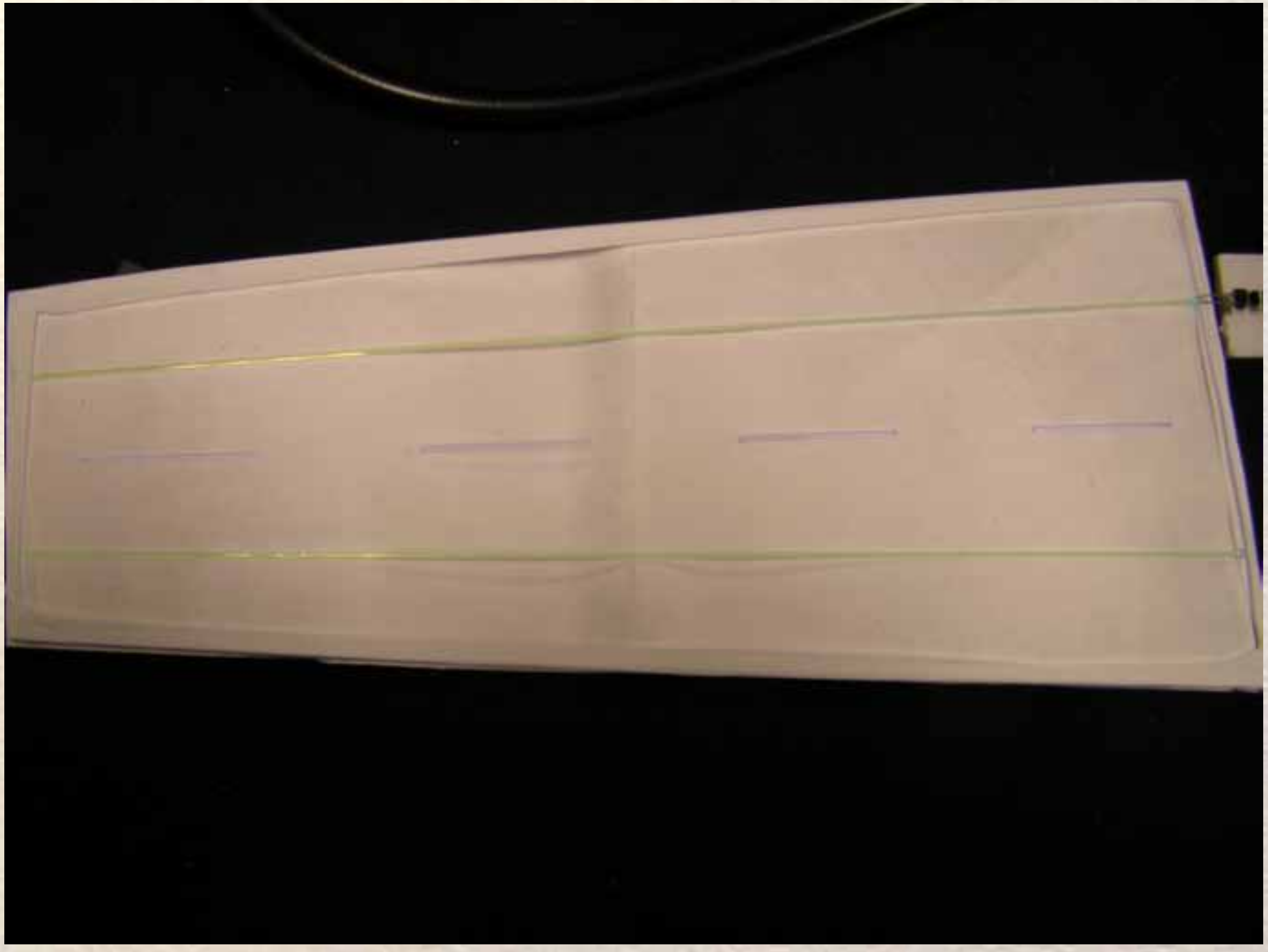
- We have a setup with a microscope and a precision x-y table that allows us to shine LED light on individual pixels



- We will study efficiencies, inter-pixel cross talk

Setup for Cross Talk Measurements

- 2 connected scintiilator strips
- Bridges are clearly visible
- Strips are covered with Tyvec sheets edges are wrapped with Teflon



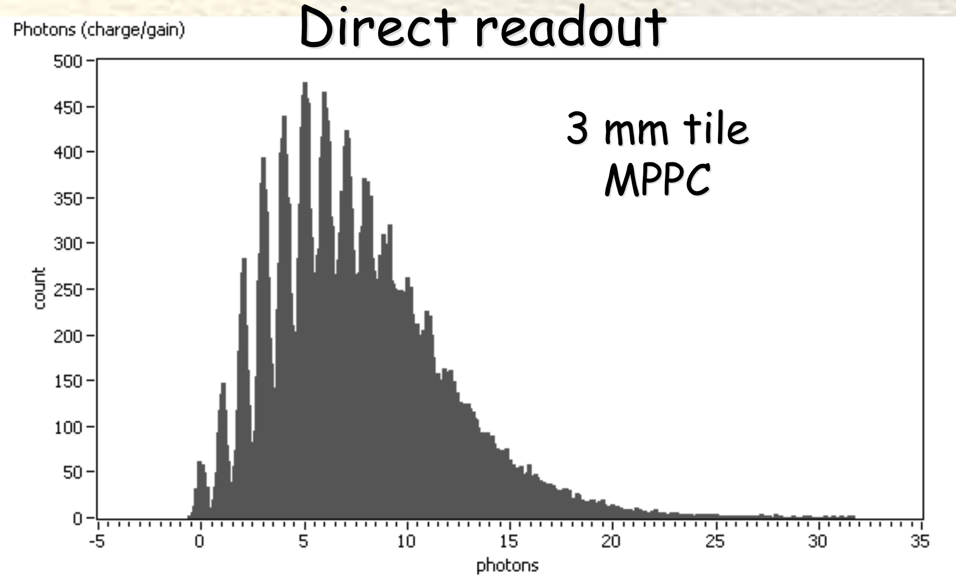
First Tests of 3mm Thick Tiles

- Test 3mm thick 3 cm x 3 cm tiles using Sr source
- Tiles are wrapped with 2 layers of Teflon tape, (reflector not optimal) ➔ AHCAL uses 3M super reflector
- Attach MPPC on one side of tile on fiber or directly on tile
- Place source in the center of the tile
- Trigger with second scintillator read out with PMT
- For SuperB readout via WLS fiber has advantages

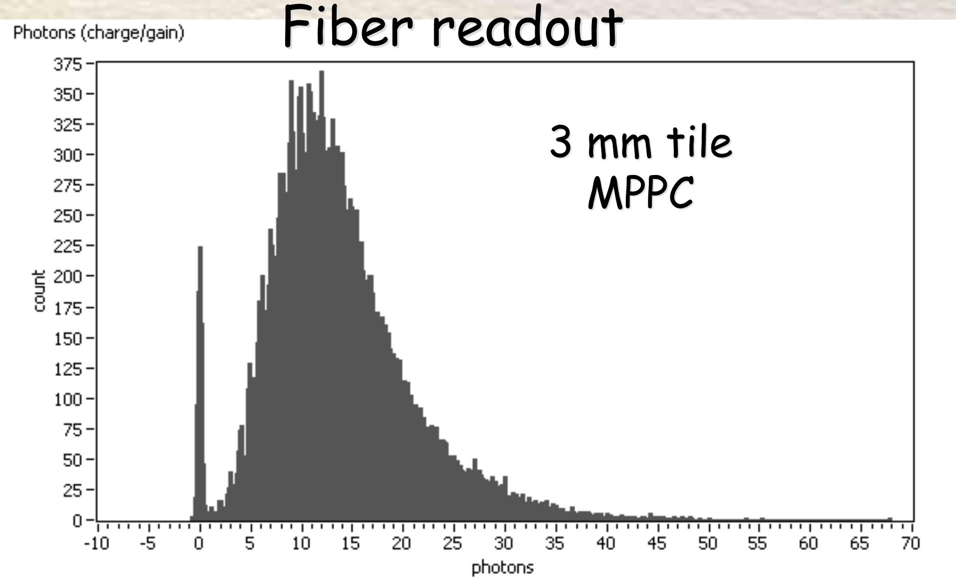
MPPC Readout of 3mm Thick Tiles

- Use ^{90}Sr source to measure MIP position in 3 cm × 3 cm tiles read out with Y11 fiber and MPPC
- Trigger on scintillator below tile read out with PM
- MIP peak is ~6 pixels for direct readout
- MIP peak is ~11 pixels for fiber RO
- Extrapolation from 5 mm tile yields 8-9 pixels

Direct readout

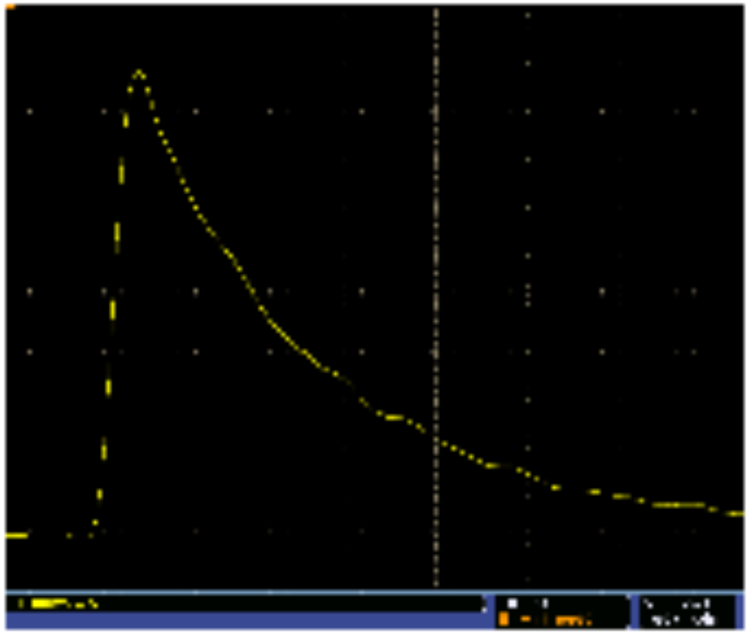


Fiber readout

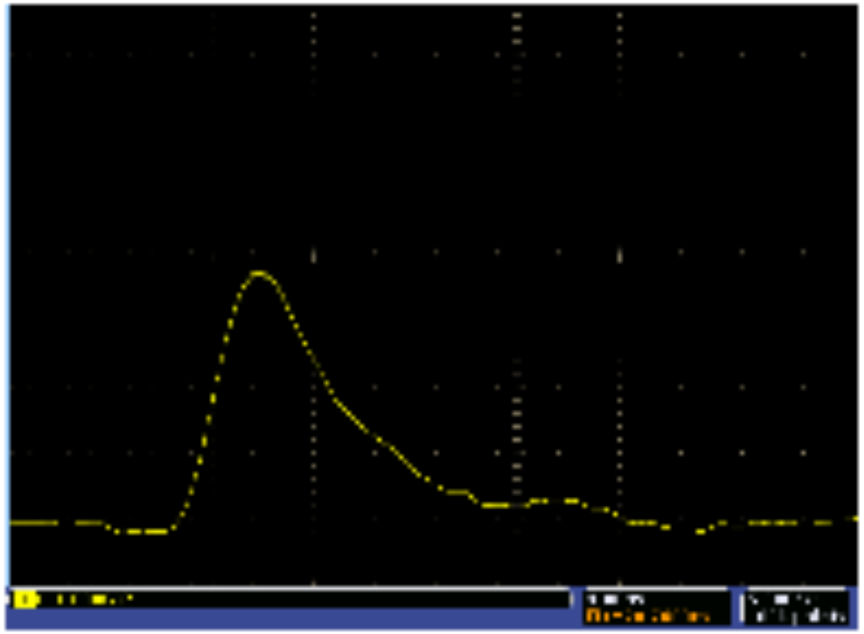


MPPC Signals

- We have detectors from 4 different manufacturers, tests were done on MPPCs (1x1 mm^2,3x3 mm^2), SiPMs , MAPDs,
- The 1x1 mm^2 MPPC has a faster response than the 3x3mm^2 MPPC (2 ns vs 2.7 ns)



(a) MPPC 10362-33-050C, sample 341. X-axis: 10 ns, Y-axis: 1 mV



(b) MPPC 10362-11-025C, sample 741. X-axis: 4 ns, Y-axis: 1 mV

Measured Properties of 10000 SiPMs

- In CALICE, we have measured various properties of SiPMs on the bench, such as the crosstalk among pixels, dark current and noise
- The arrows indicate our cut-off