LCWS04, Paris

Scintillator Tile Hadronic Calorimeter Prototype

(analog or semidigital)

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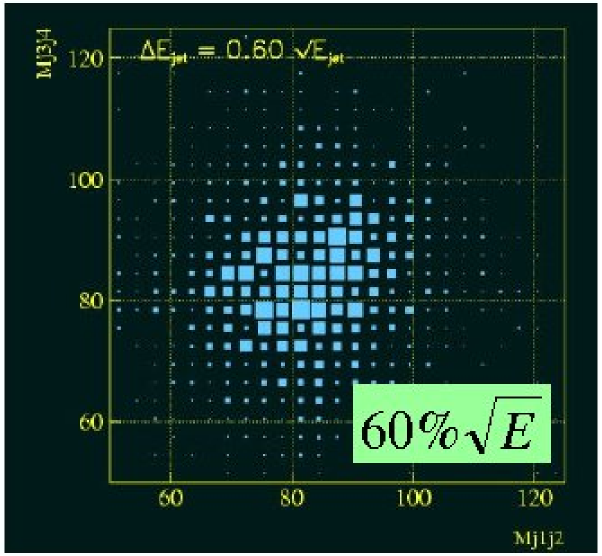
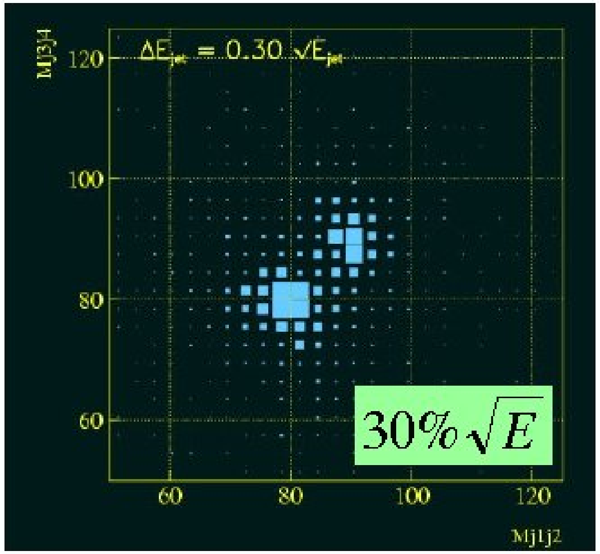
CALICE Collaboration

Outline

- Granularity required for Particle Flow Method
- Silicon Photomultiplier (SiPM)
- Optimization of Tile Fiber System
- Experience with MINICAL production (108 channels)
- Preparation of Physics Prototype
- Conclusions

LC Physics goals require $\Delta E_J/\sqrt{E_J} \sim 30\%$





This can be achieved with Particle Flow Method (PFM):

⇨ **Use calorimeter only for measurement of K,n, and γ**

Substitute charged track showers with measurements in tracker

LC detector architecture is based on PFM,
which is tested mainly with MC

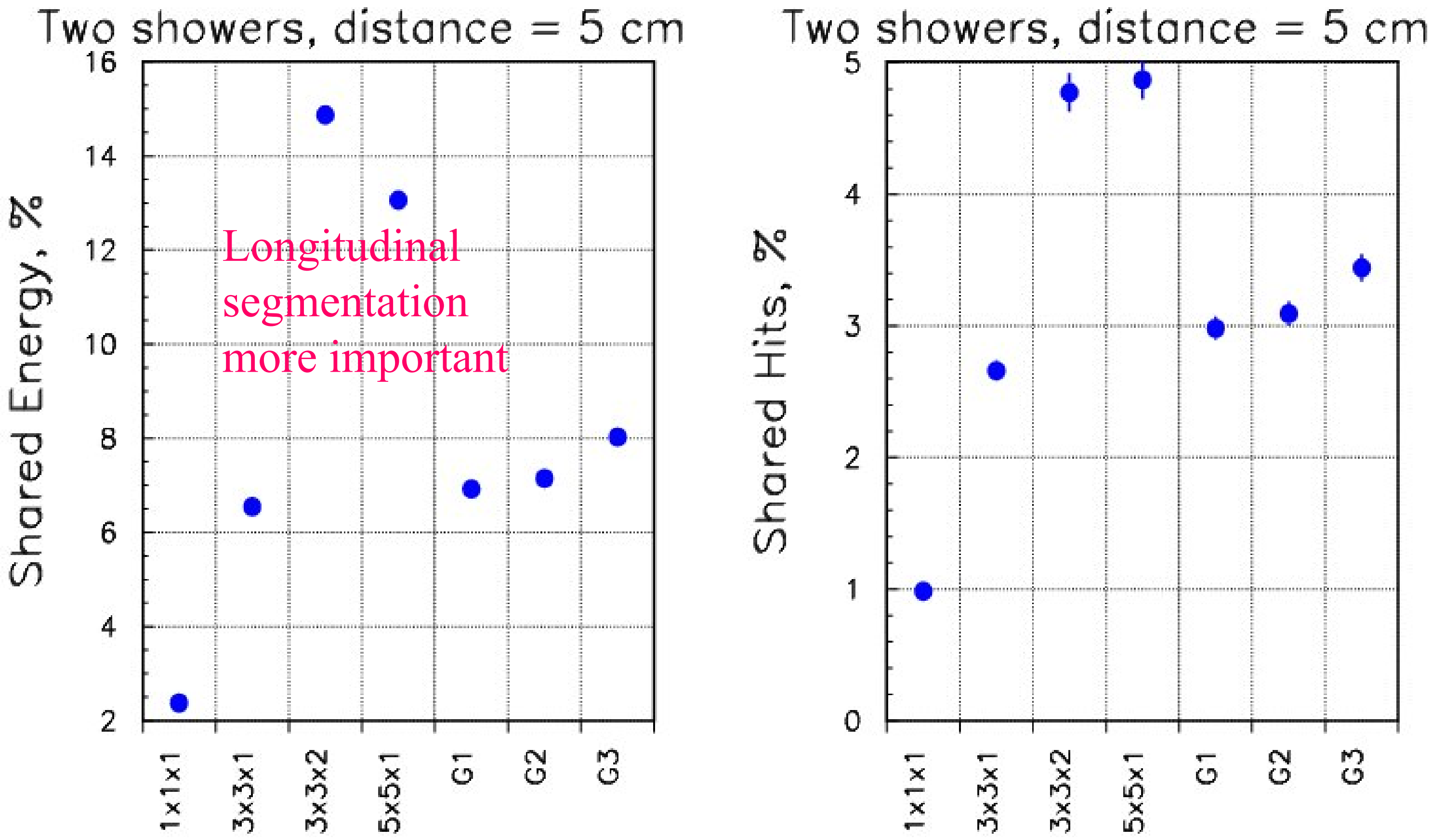
⇩

Experimental tests of PFM are extremely important

We are building now a prototype of scintillator tile calorimeter to test PFM

Tile Size Optimization

Separability of showers as main criteria for optimization



Longitudinal
segmentation
more important

⇑

Intrinsic property of PPT independent from clustering algorithm

Shower Reconstruction/Separation

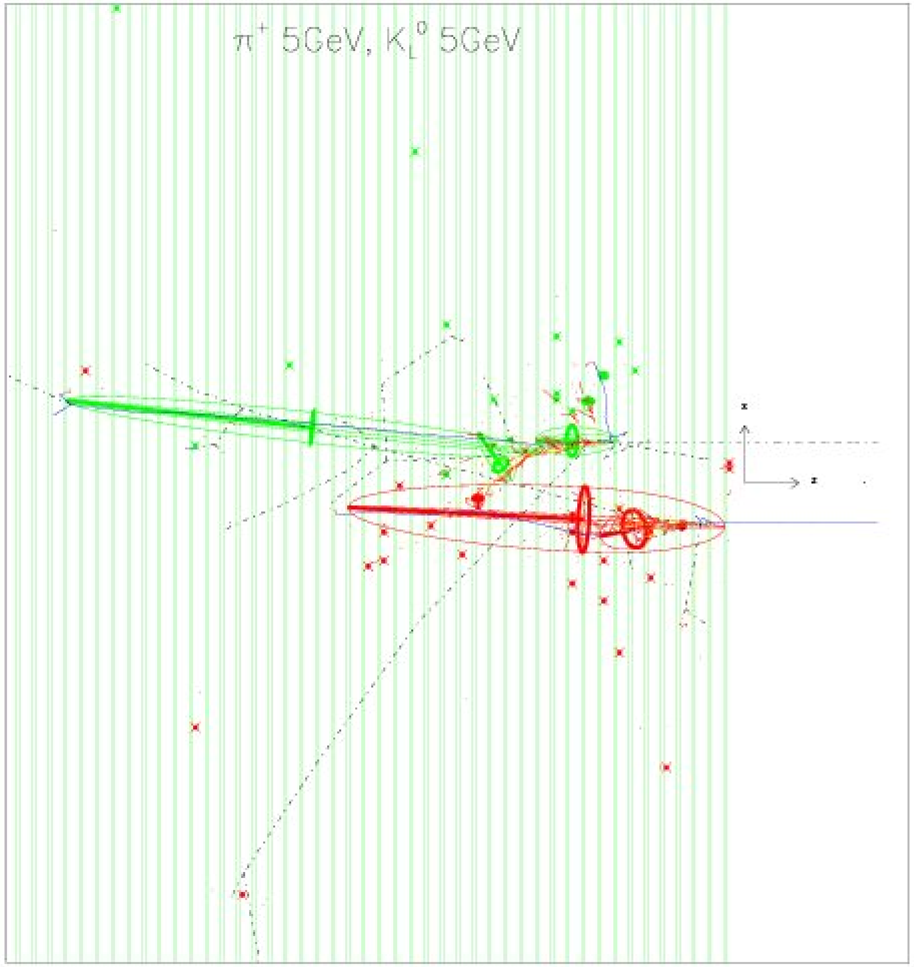
(A.Raspereza)

- Shower reconstruction based on clustering algorithm from Vassily Morgunov (Clustering makes no use of TPC-information)
- Idea : associate clusters into showers by topological reconstruction of shower tree
- First look : situation of two showers initiated by π^+ and K_L^0 is simulated (no ECAL)
- Partial use of tracker information : cluster with the starting point closest to the π^+ track intersection with HCAL front face is used as seed for charged shower
- Algorithm is tested for three options of tile size and readout scheme :

  o 3×3 cm^2 $\times$ 1 layer

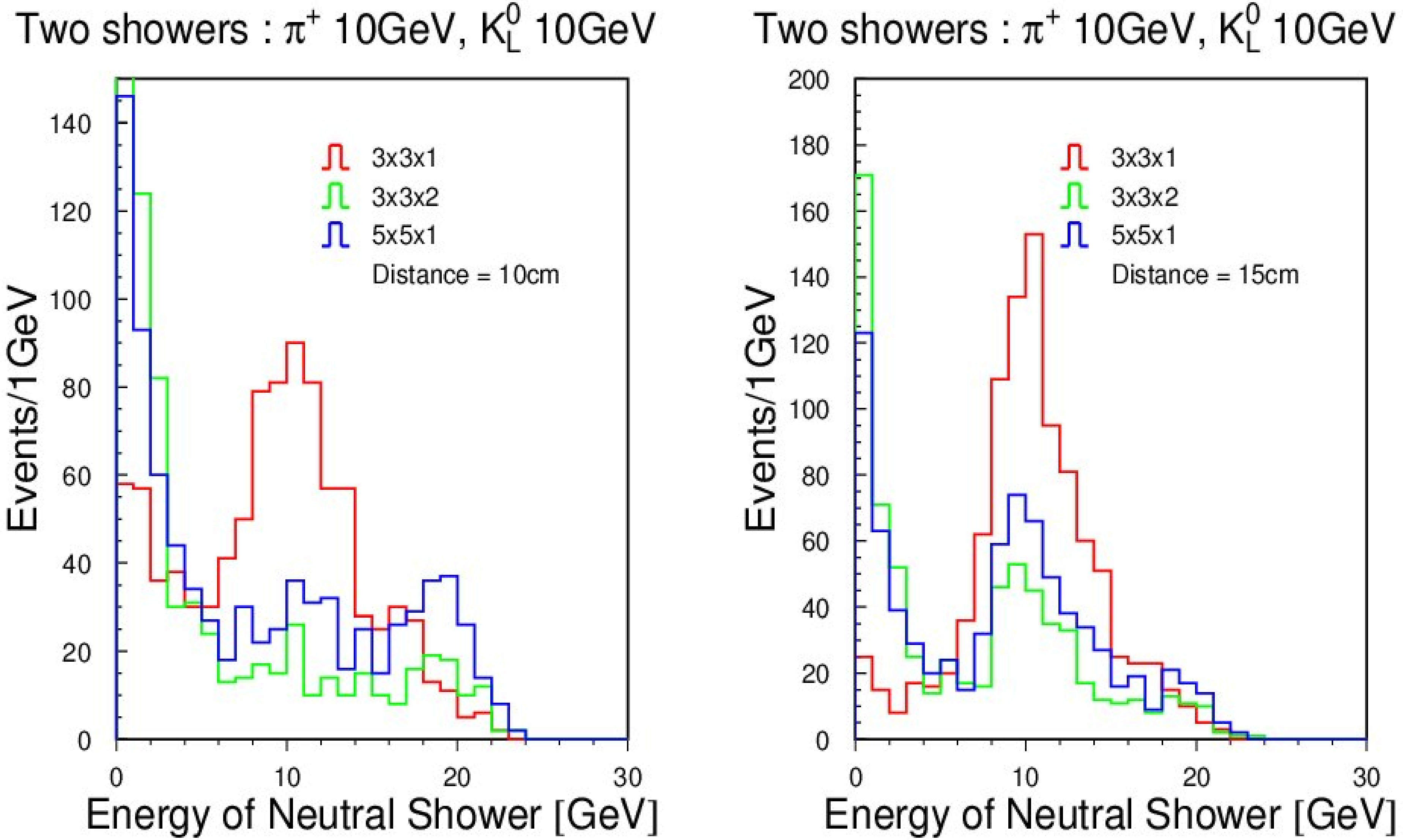
  o 5×5 cm^2 $\times$ 1 layer

  o 3×3 cm^2 $\times$ 2 layer



- **Algorithm is optimized separately for each of these options**

Shower Reconstruction/Separation


Two showers : π^+ 10GeV, K_L^0 10GeV

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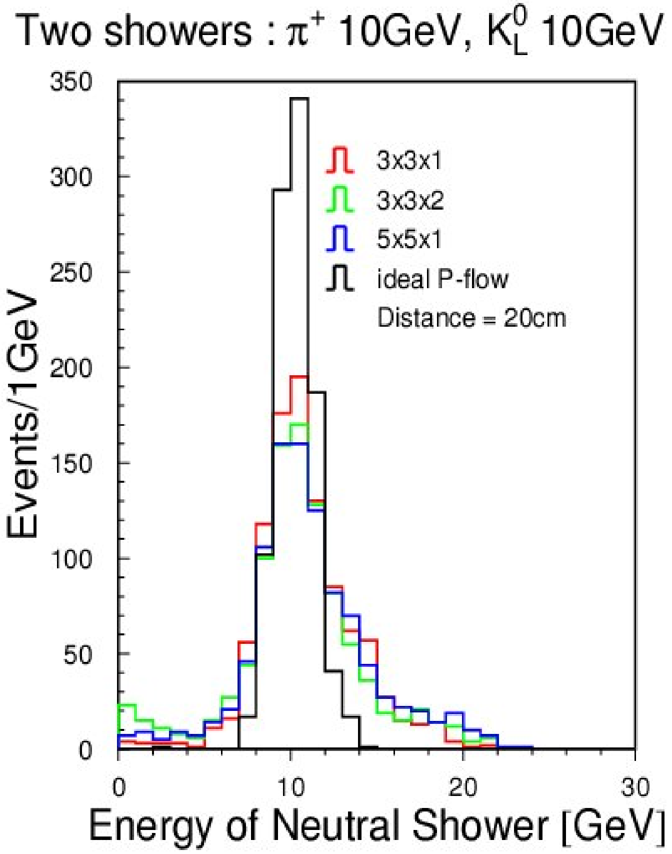
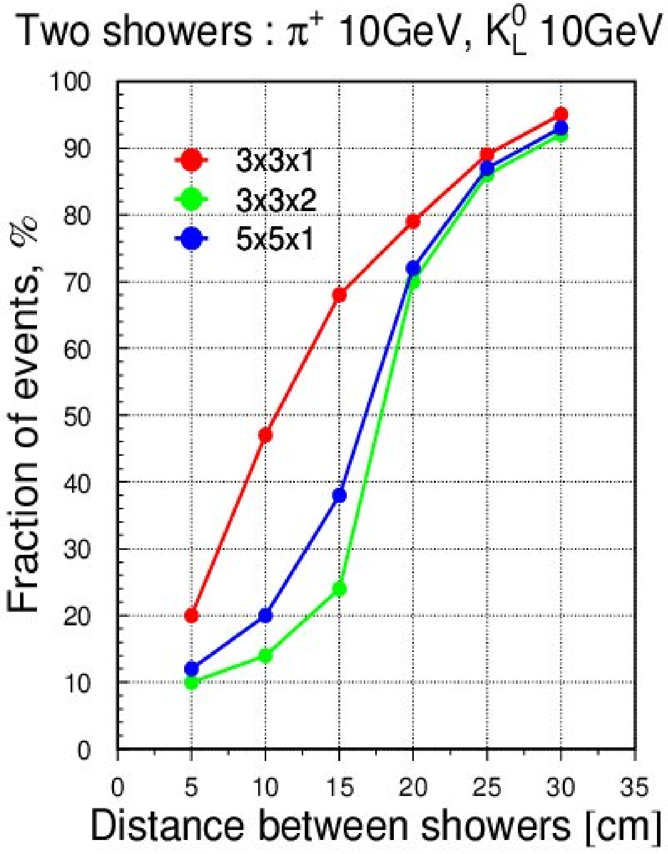
Shower Reconstruction/Separation


Two showers : π^+ 10GeV, K_L^0 10GeV

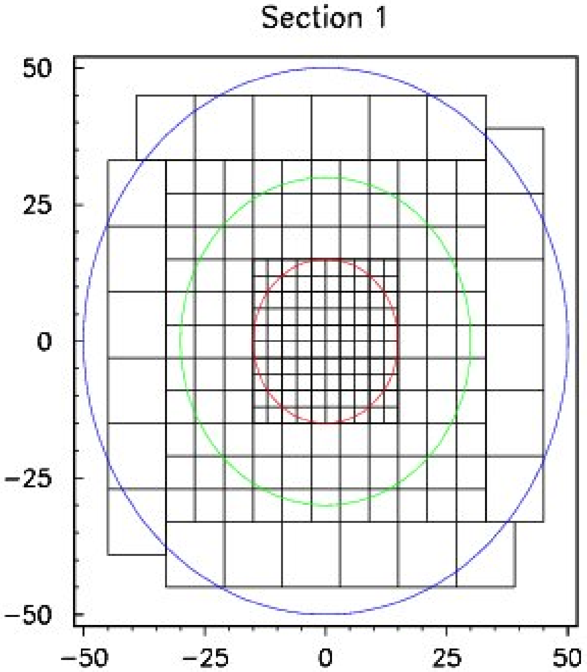

Two showers : π^+ 10GeV, K_L^0 10GeV

Shower separation quality is defined as fraction of events in which the energy of neutral shower is consistent with the nominal energy within 3σ of reconstructed neutral shower energy distribution in the absence of accompanying showers

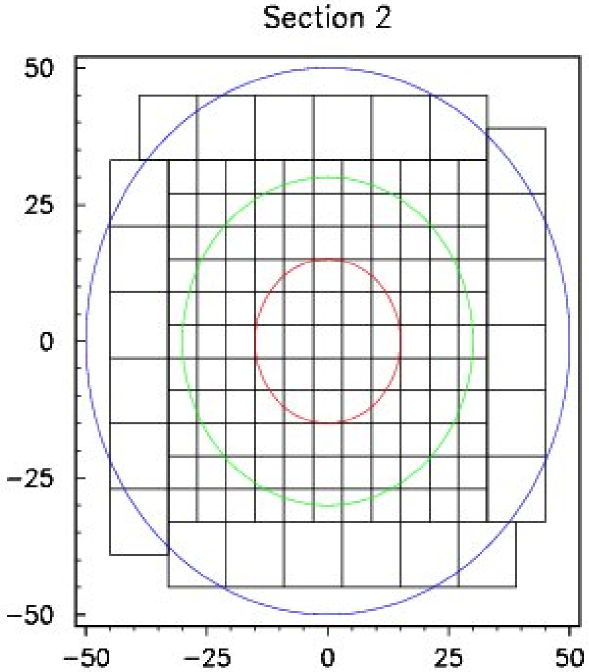
Separation can be further improved by optimization of algorithm

Prototype geometries

3,6,12 cm tiles for flexibility


Section 1

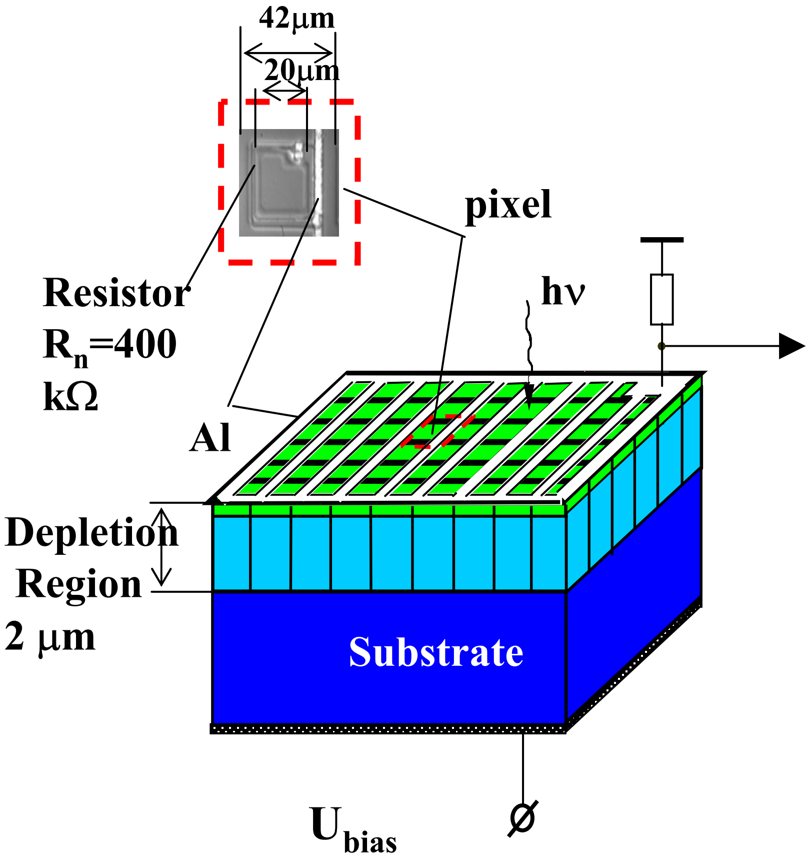
100 - 3x3 cm, 96 - 6x6 cm, 24 - 12x12 cm


Section 2

121 - 6x6 cm, 24 - 12x12 cm

Geometry ID	Layers		Number of tiles
	Section 1	Section 2	
G1	1 - 30	31 - 39	7905
G2	1 - 26	27 - 39	7605
G3	1 - 20	21 - 39	7155

SiPM main characteristics



➢Pixel size ~20-30µm

➢

Electrical inter-pixel cross-talk minimized by:
- decoupling quenching resistor for each pixel
- boundaries between pixels to decouple them
  ➔ reduction of sensitive area and geometrical efficiency

• Optical inter-pixel cross -talk:
-due to photons from Geiger discharge initiated by one electron and collected on adjacent pixel

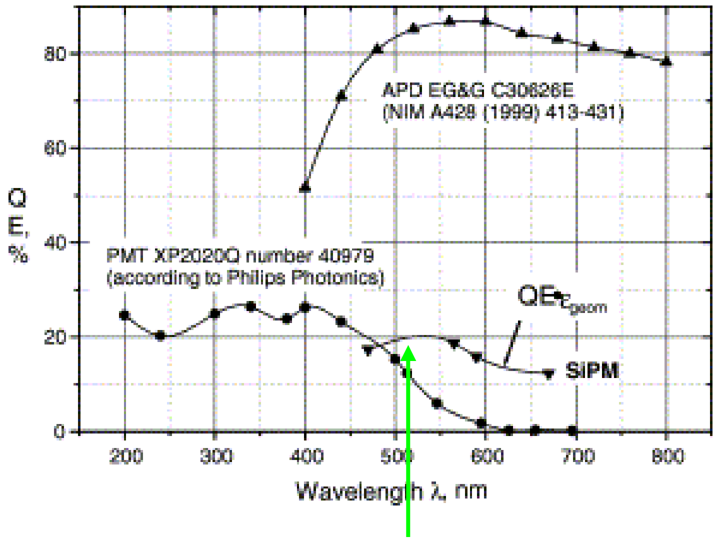
➢Working point: $V_{Bias} = V_{breakdown} + \Delta V \sim 50\text{-}60$ V
$\Delta V \sim 3$V above breakdown voltage

Each pixel behaves as a Geiger counter with
$Q_{pixel} = \Delta V \, C_{pixel}$
with C_{pixel}~50fmF ➔ Q_{pixel}~150fmC=10^6e

Dynamic range ~ number of pixels (1024)
➔ saturation

SiPM Spectral Efficiency

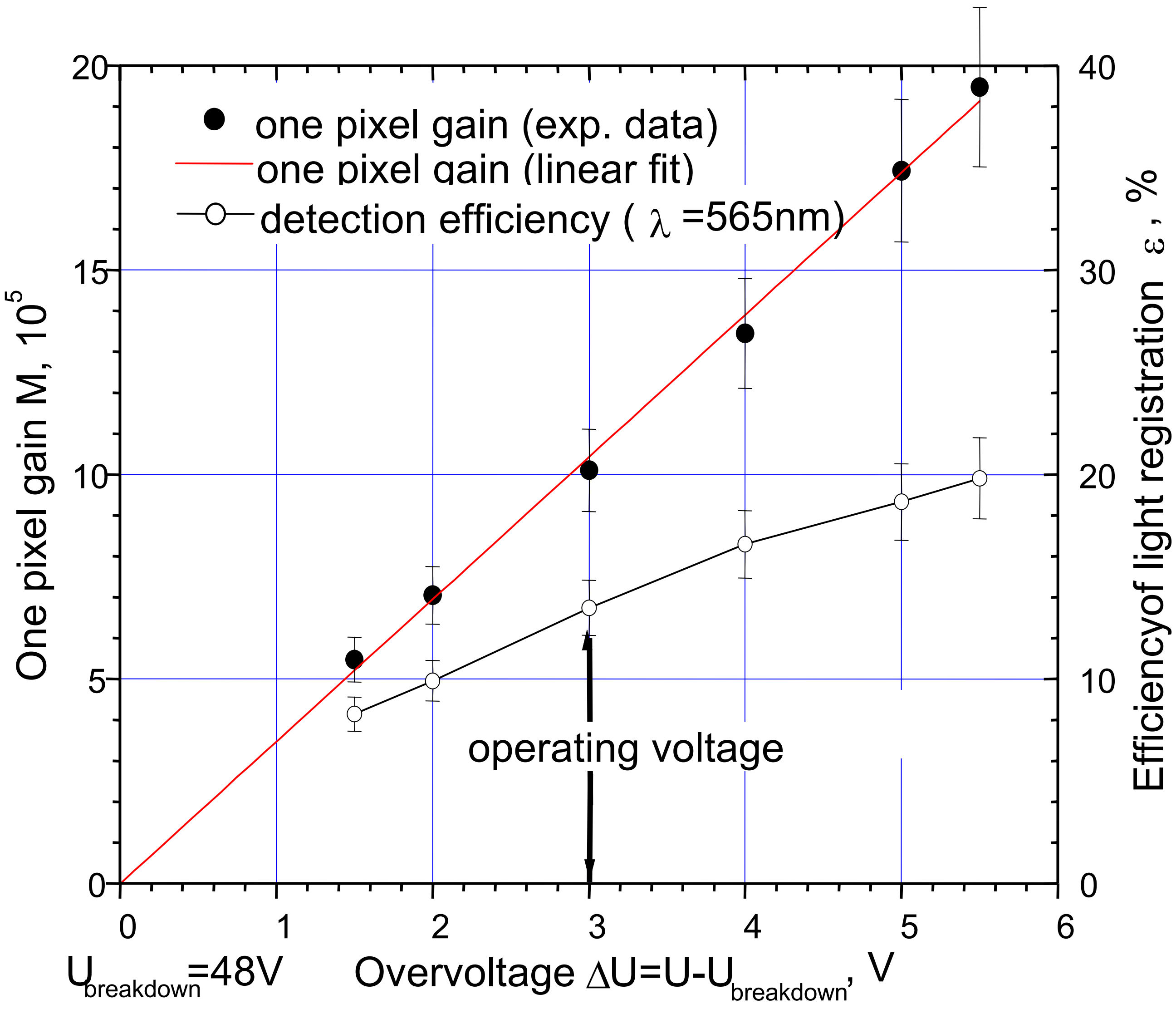
Depletion region is very small ~ 2μm
➔strong electric field (2-3) 10^5 V/cm
➔carrier drift velocity ~ 10^7 cm/s
➔very short Geiger discharge development < 500 ps
➔pixel recovery time = (C_{pixel} R_{pixel}) ~ 20 ns



WLS fiber emission

Photon detection efficiency (PDE):
- for SiPM the QE (~90%) is multiplied by Geiger efficiency (~60%) and by geometrical efficiency (sensitive/total area ~30%)
- highest efficiency for green light
  ➔ important when using with WLS fibers

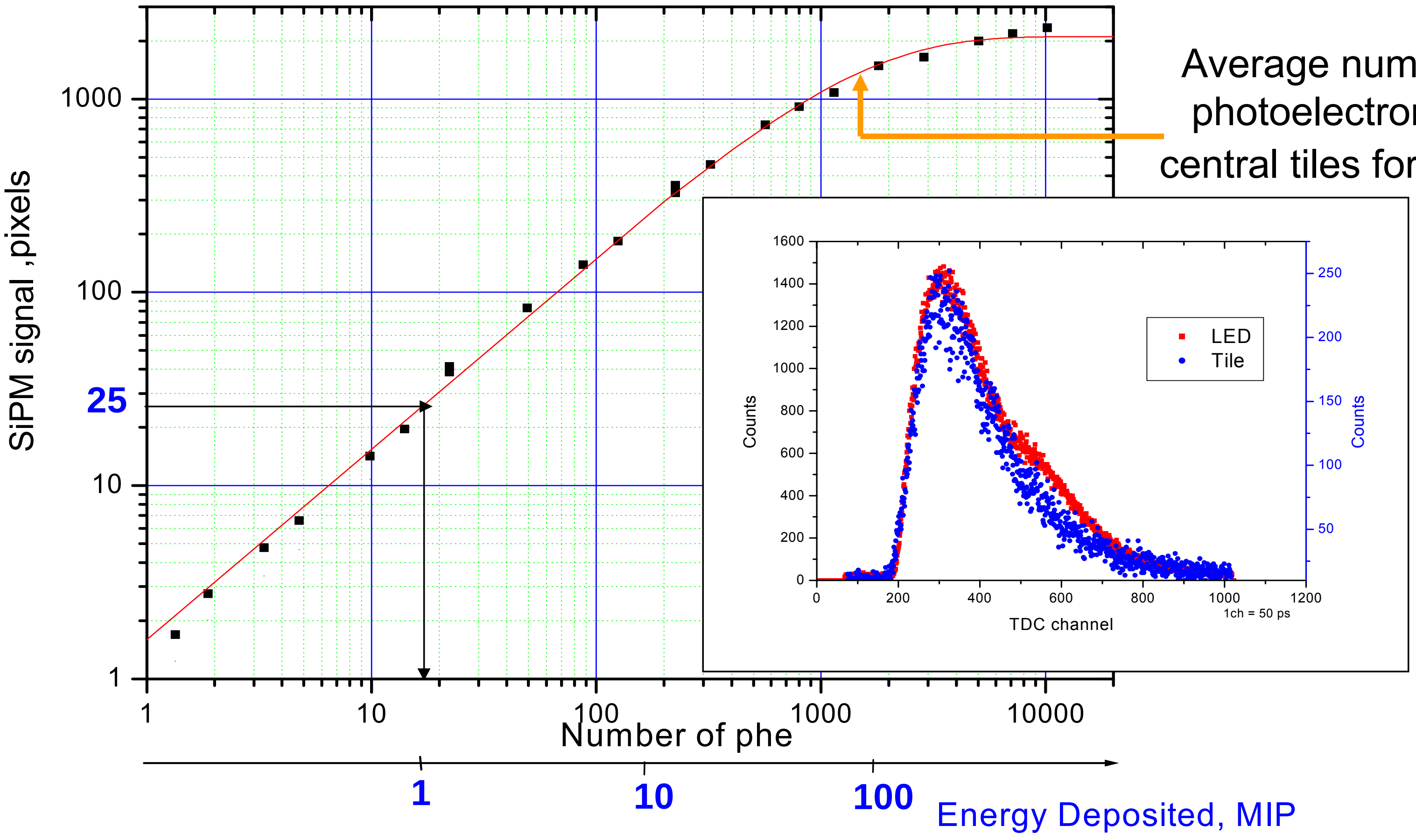
Temperature and voltage dependence:
-1 °C ➔ +3% in Gain * PDE
+0.15 V ➔ +3% in Gain * PDE



Photon detection efficiency $\varepsilon = QE \cdot \varepsilon_{geom}$

SiPM signal saturation due to finite number of SiPM pixels

calibration curve:SiPM signal vs energy deposited:

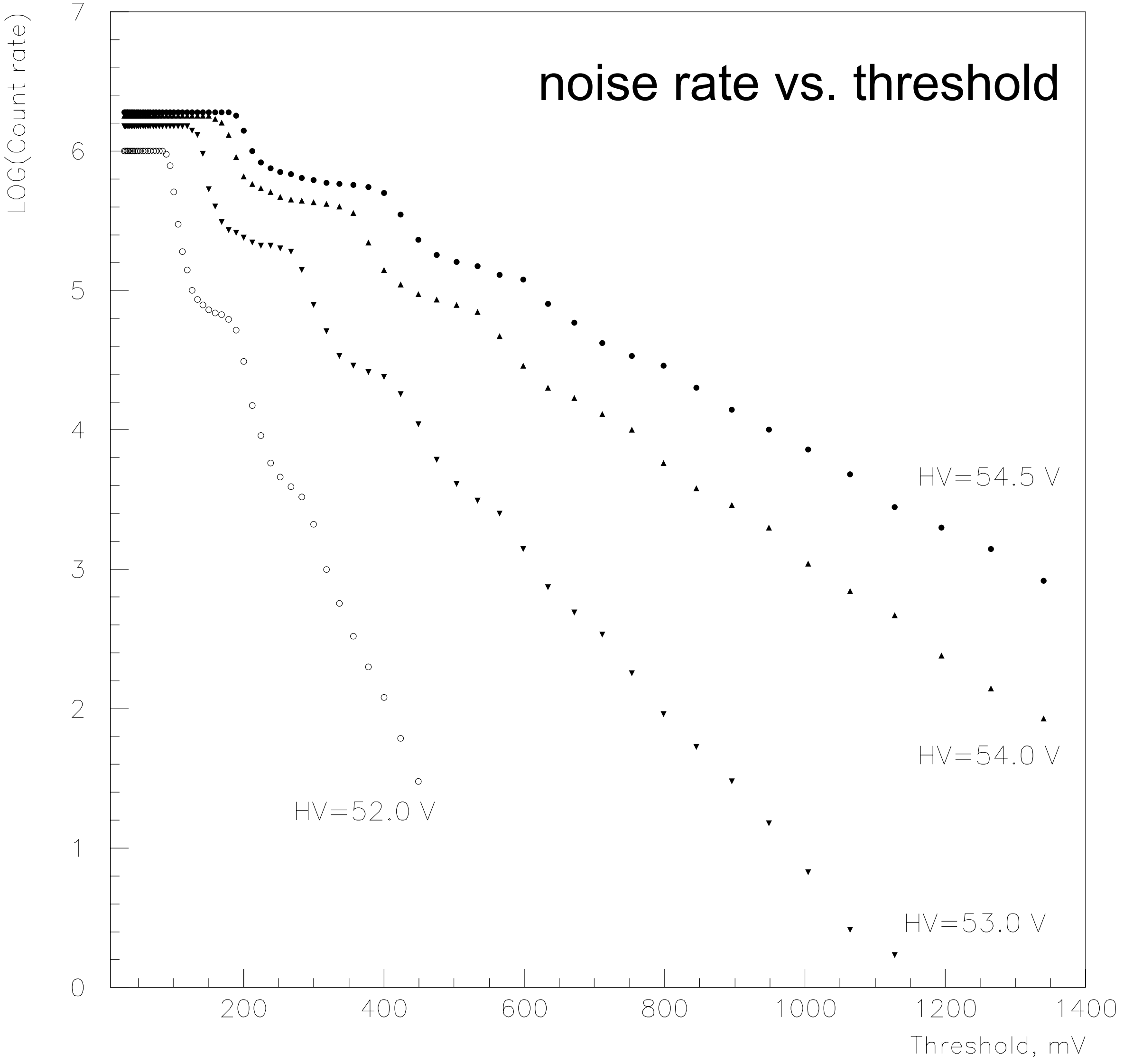


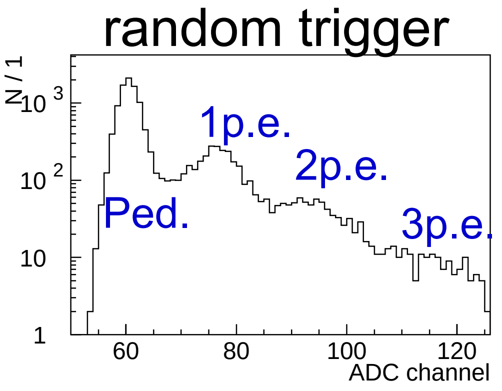
Average number of photoelectrons for central tiles for 6 GeV

Very fast pixel recovery time ~ 20ns

For large signals each pixel fires about 2 times during pulse from tile

SiPM Noise





1p.e. noise rate ~2MHz.
threshold 3.5p.e. ~10kHz
threshold 6p.e. ~1kHz

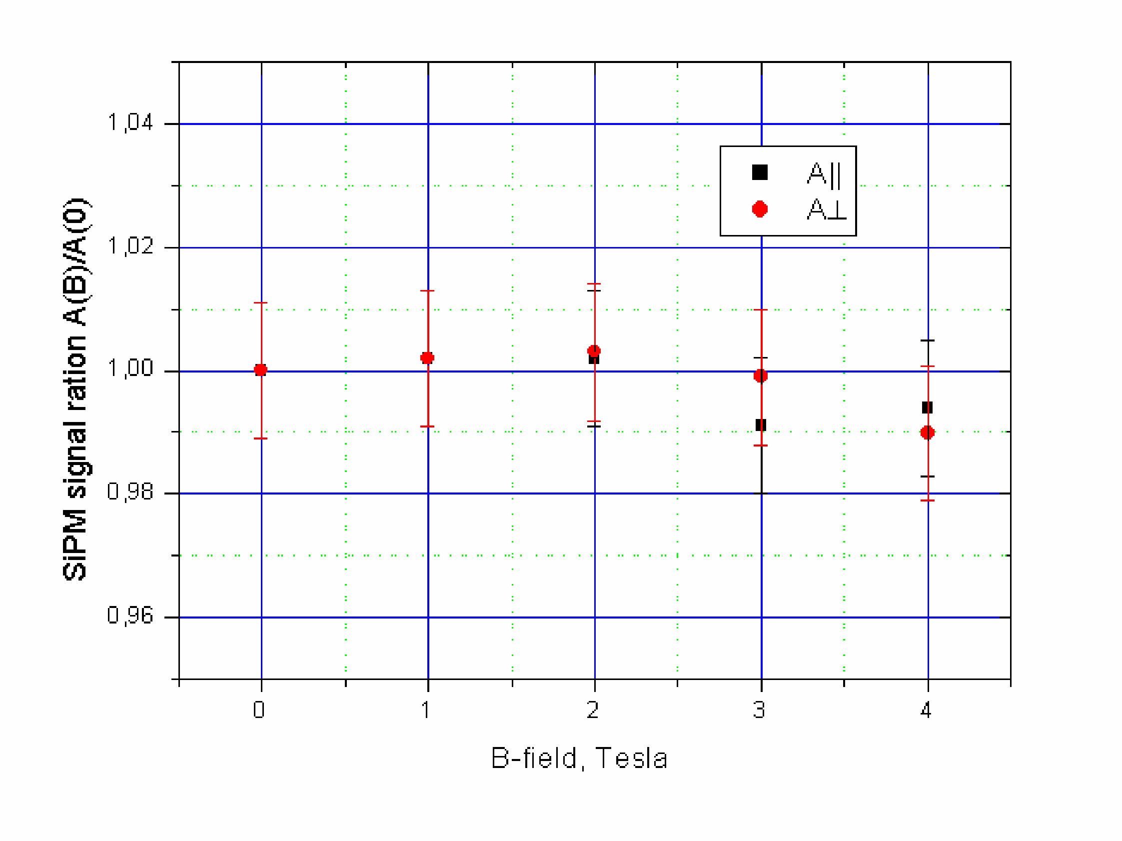
Optimization of operating voltage is subject of R&D at the moment.

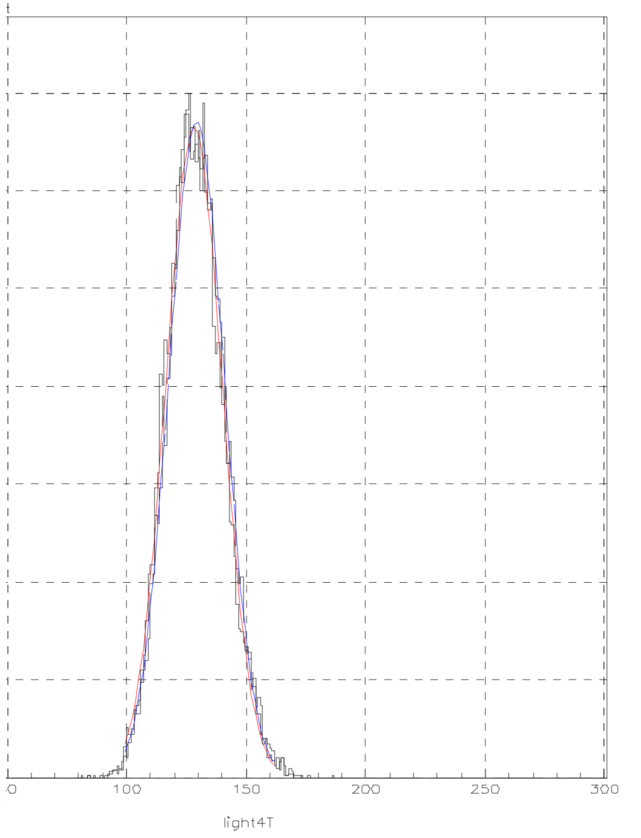
Comparison of the SiPM characteristics in magnetic field of B=0Tand B=4T

(very prelimenary, DESY March 2004)

LED signal ~150 pixels

A=f(G, ε, x)





No Magnetic Field dependence at 1% level

(Experimental data accuracy)

Long term stability of SiPM

20 SiPMs worked during 1500 hours

Parameters under control:

- One pixel gain
- Efficiency of light registration
- Cross-talk
- Dark rate
- Dark current
- Saturation curve
- Breakdown voltage

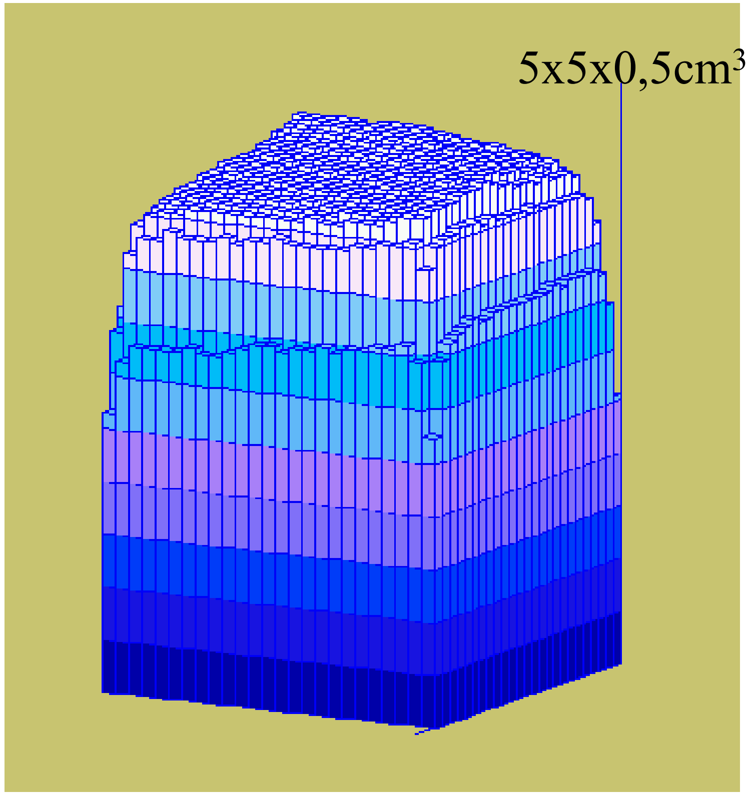
No changes within experimental errors

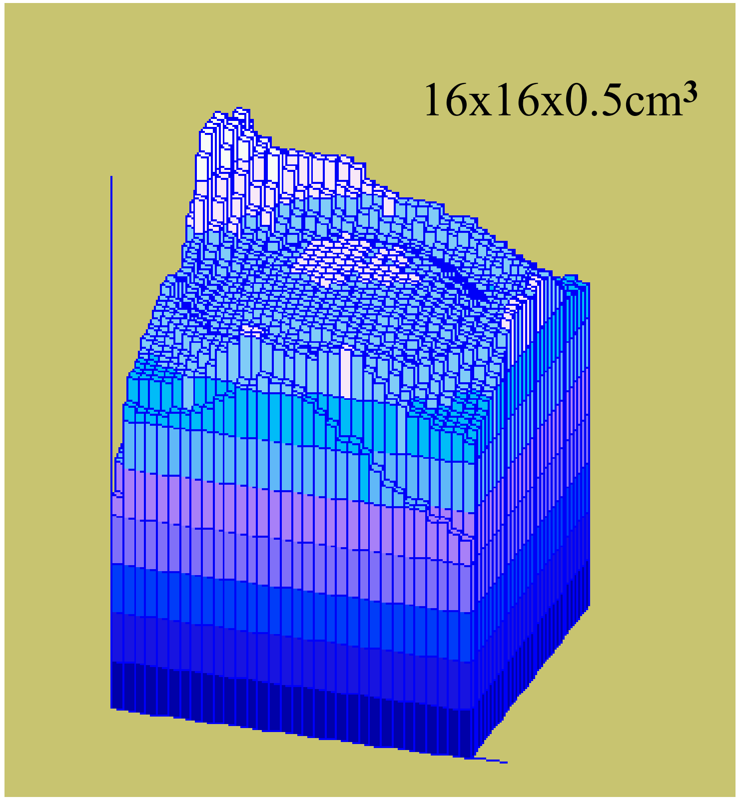
5 SiPM were tested 24 hours at increased temperatures of 30, 40, 50, 60, 70, 80, and 90 degrees

No changes within experimental accuracy

Light Yield from Tiles with Circular WLS Fibers

(Y11 MC 1mm fiber, Vladimir Scintillator, mated sides, 3M foil on top and bottom)
Reduction near tile edges is due to finite size of a β source



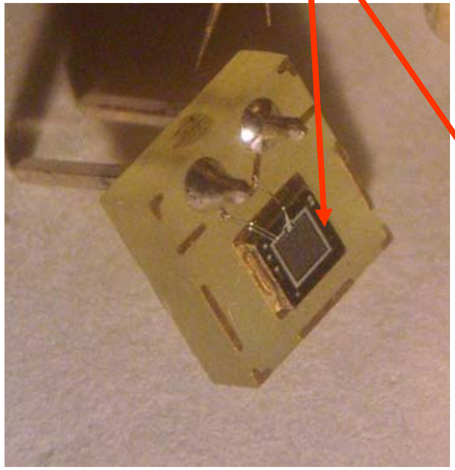


Sufficient uniformity for a hadron calorimeter even for large tiles
Can be further improved if required
Sufficient light yield of 17, 28, 21 pixels/mip for 12x12, 6x6,
and 3x3 cm^2 tiles (quarter of a circle fiber in case of 3x3 cm^2 tile)

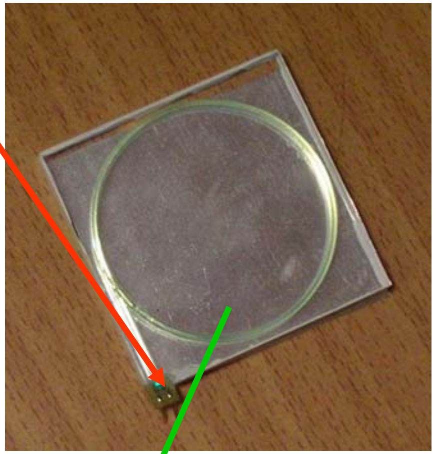
Experience with a small (108ch) prototype (MINICAL)

Moscow → Hamburg

SiPM

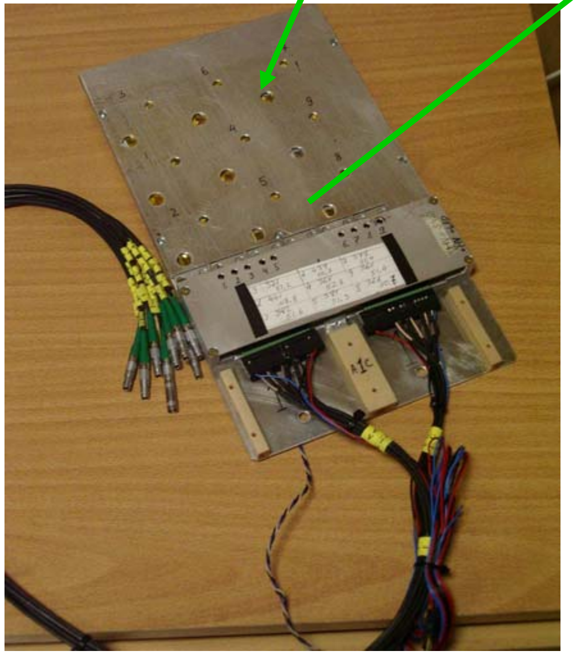


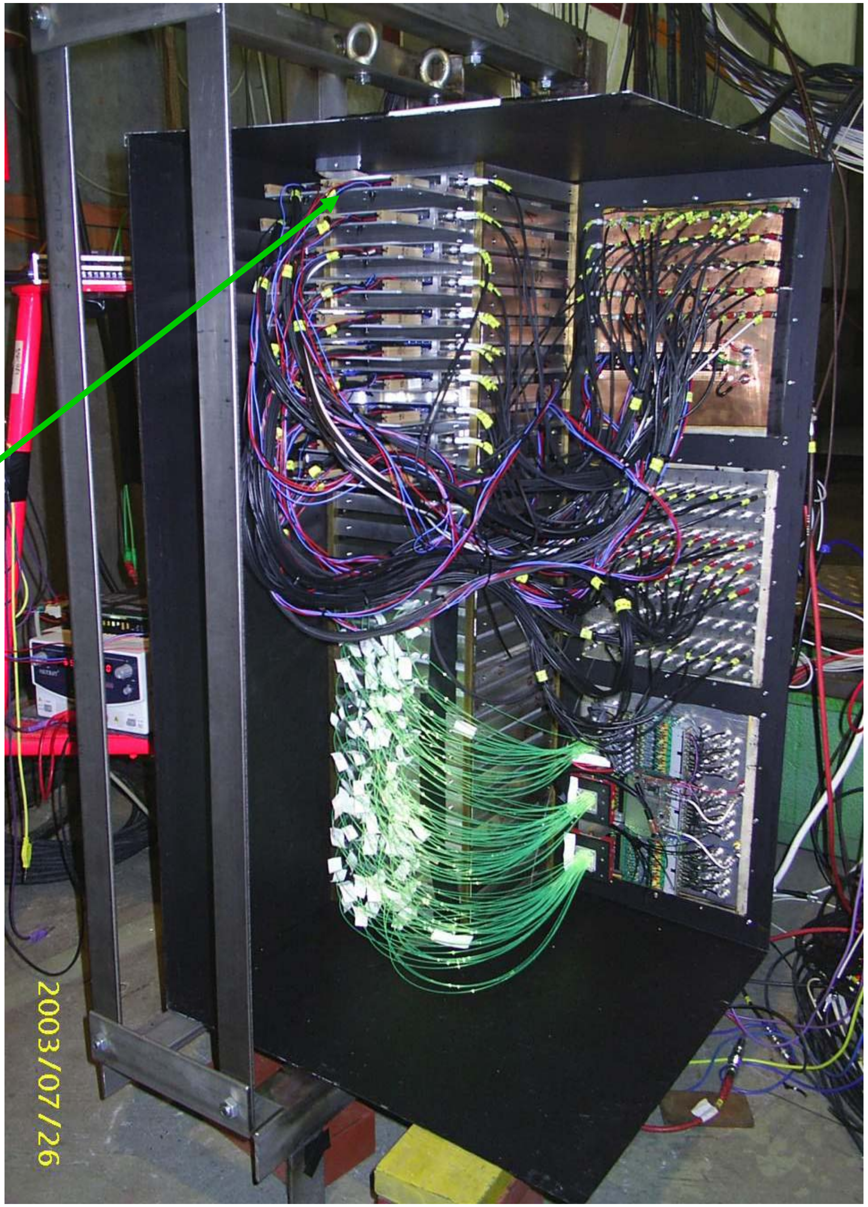
Tile with SiPM



cassette

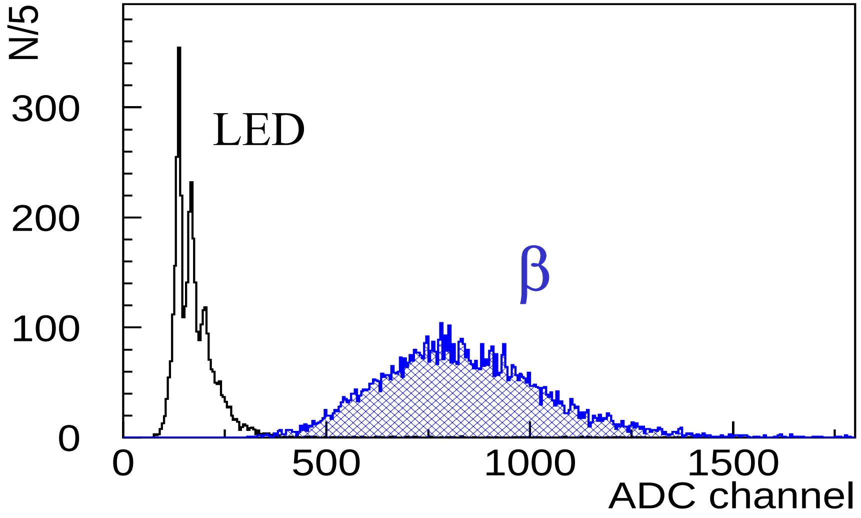
3x3 tiles

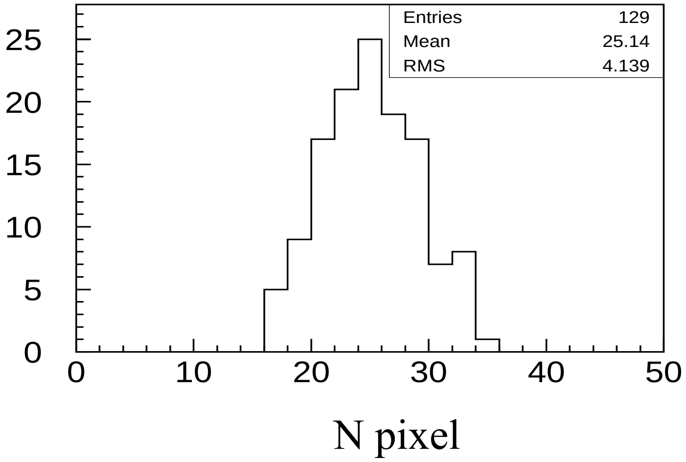




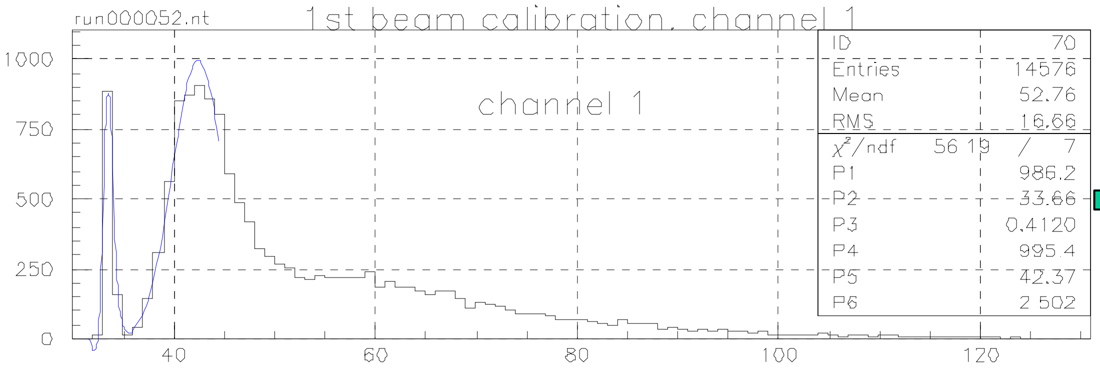
Light Yield from Minical tiles (5x5x0.5cm³)

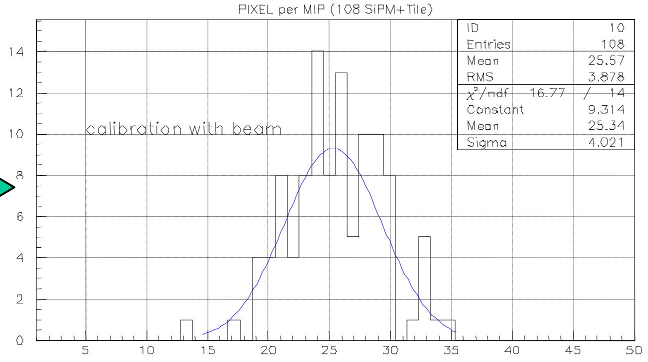
Using triggered Sr source and LED at ITEP





Using electron beam at DESY (SiPM signals without amplification)

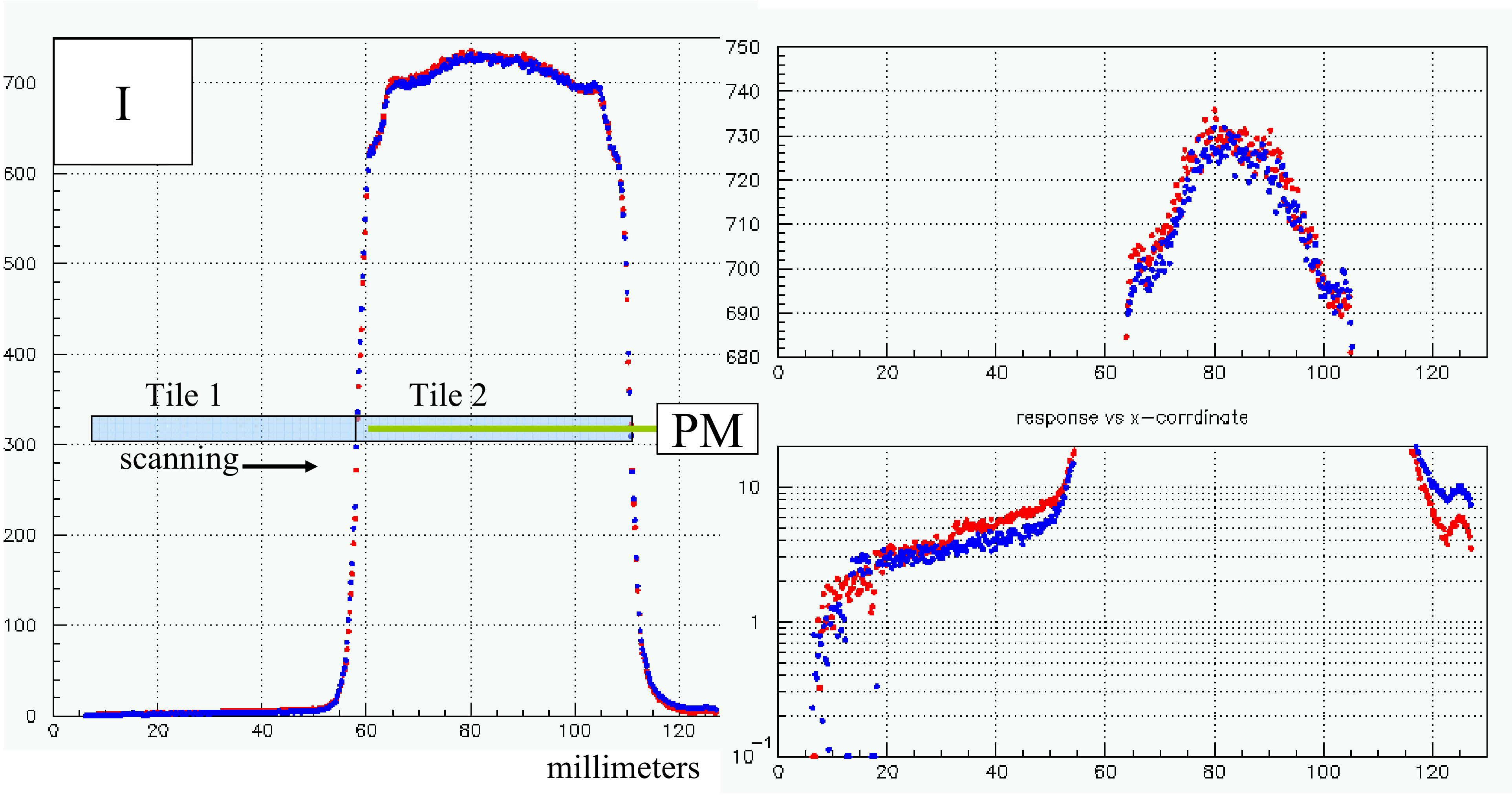




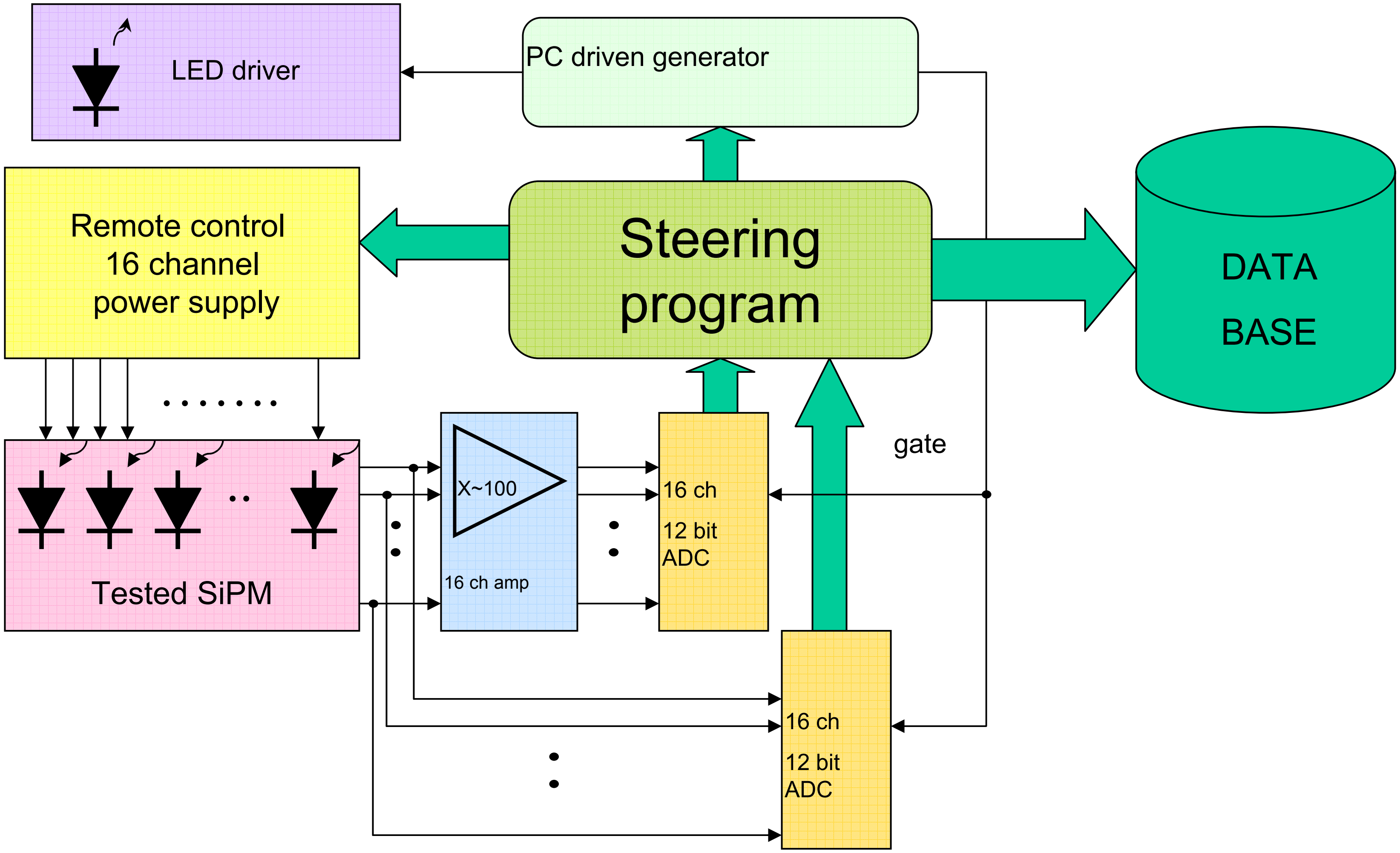
Good reproducibility after transportation from Moscow to Hamburg

Cross-talk measurement

- Conditions: 50 mm tiles with mated edges, β - source, 2mm collimator.
- Red points: 3M film on top and bottom of both tiles;
  blue points: black paper instead of 3M for tile 1.
- Right picture: details of top and bottom of the left one.
- Conclusion: Cross talk <1%



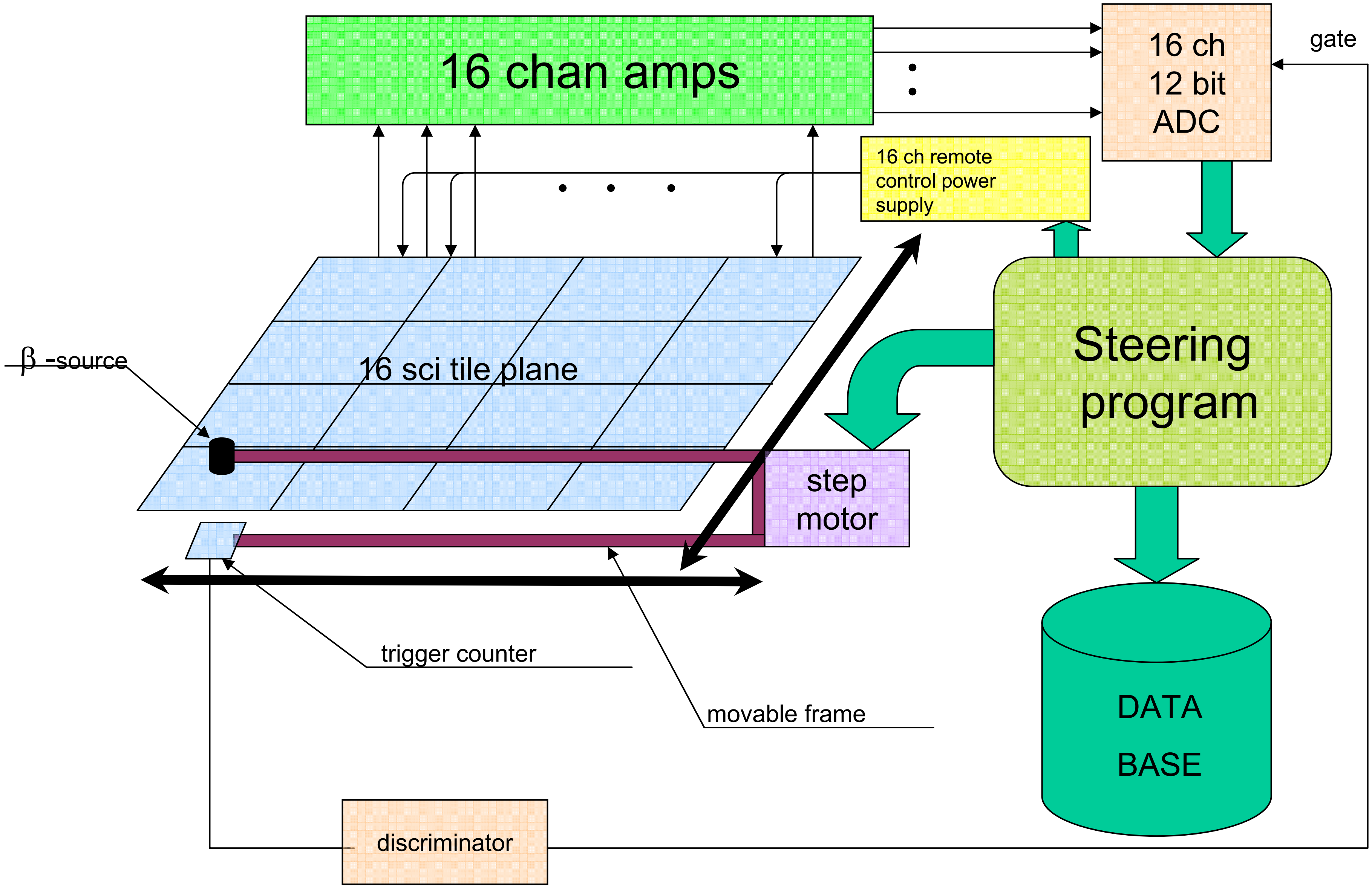
SiPMs will be tested and calibrated with LED before installation into tiles (noise, amplification, efficiency, response curve, x-talk)



Scheme of test bench for SiPM selection at ITEP

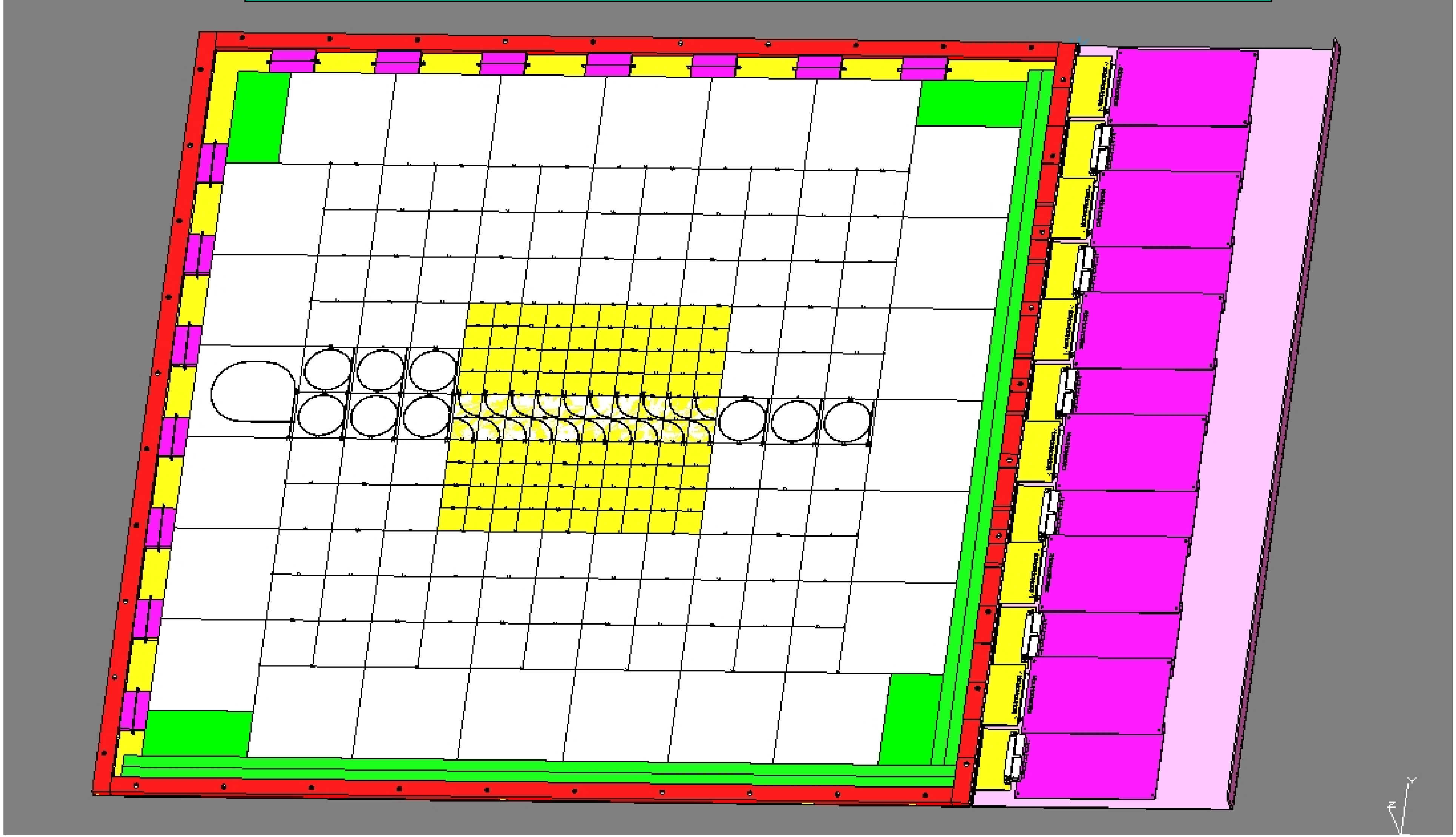
Tiles will be tested with a triggered β source and LED before installation into cassette

Test bench for tile tests at ITEP

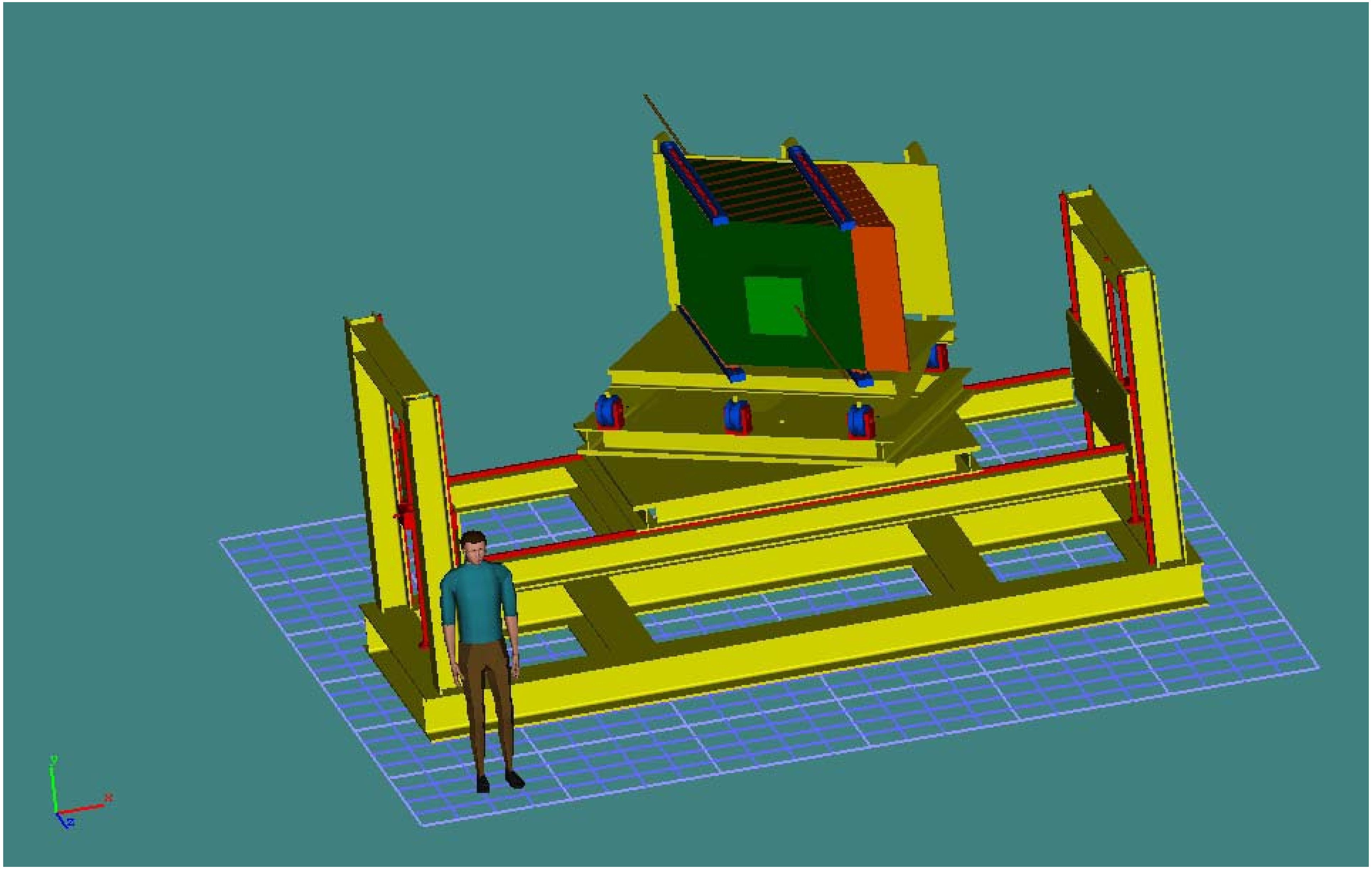


All tiles in the cassette will be tested before transportation to DESY
Final tests and commissioning with FE electronics and DAQ will be done at DESY

Cassette with Tiles and Electronic Cards



Absorber and Support Structure



CONCLUSIONS

Particle Flow Method requires high granularity especially longitudinally

Scintillator tiles with WLS fiber light collection and SiPM mounted directly on tiles can be used to build highly segmented hadronic calorimeter, which can be used in analog or semidigital mode

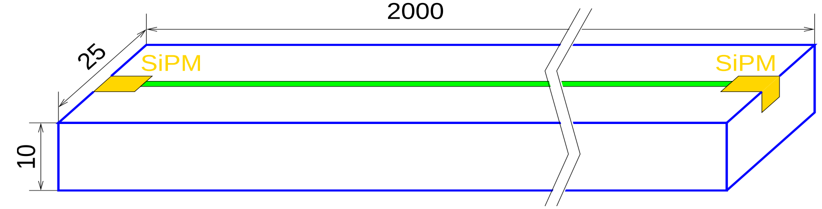
Tests of 108 channel prototype (MINICAL) demonstrated effectiveness and robustness of this technique

Seven thousand channel calorimeter prototype with tiles in the core as small as 3x3 cm^2 is being constructed now. It will be ready for tests next year.

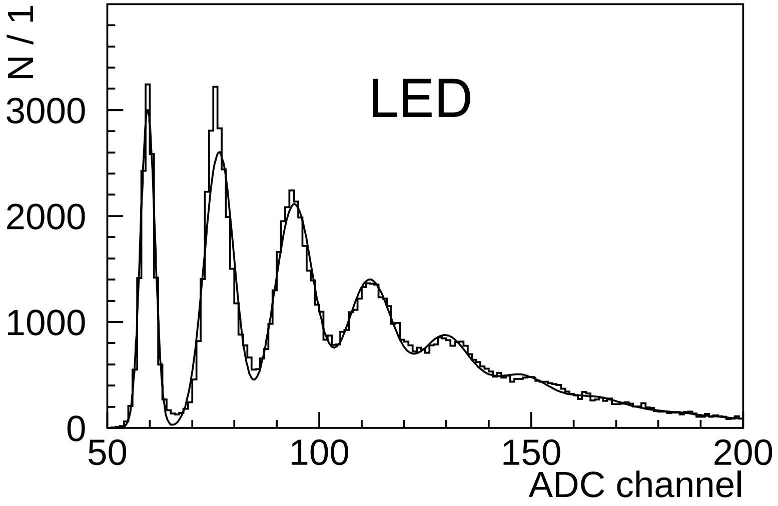
Hcal prototype together with Ecal prototype will allow to to test experimentally the Particle Flow Method

Scintillator strips with WLS fiber and SiPM readout can be used for muon system and shower position detectors in electromagnetic calorimeters

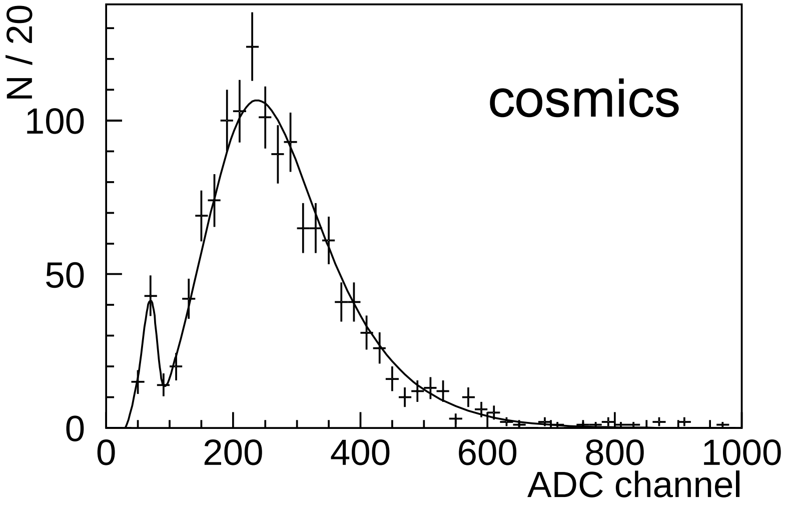
Scan of Strip Using Cosmics Setup at ITEP



groove depth 2.5mm



$\sum$ Poiss$\oplus$Xtalk$\cdot G(x_0+i\cdot\Delta x,\sigma_0+\sigma_1\cdot\sqrt{i})$

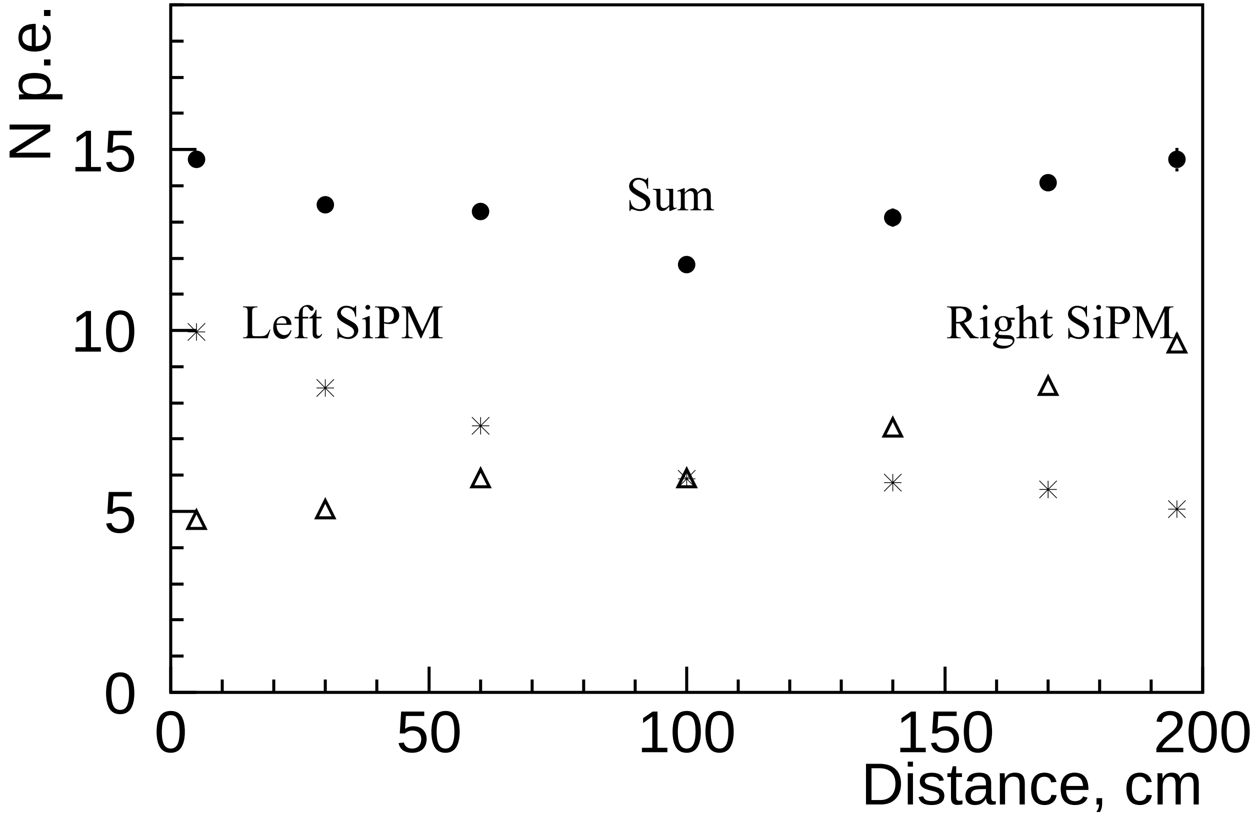


Center of strip, N pixels (peak) = 9.7 from each side

Scan of Strip Using Cosmics Setup at ITEP

Light yield was corrected for cosmics angular distribution and interpixel cross talk in SiPM

Poisson mean for MIP at normal incidence for a strip 200x2.5x1cm^3

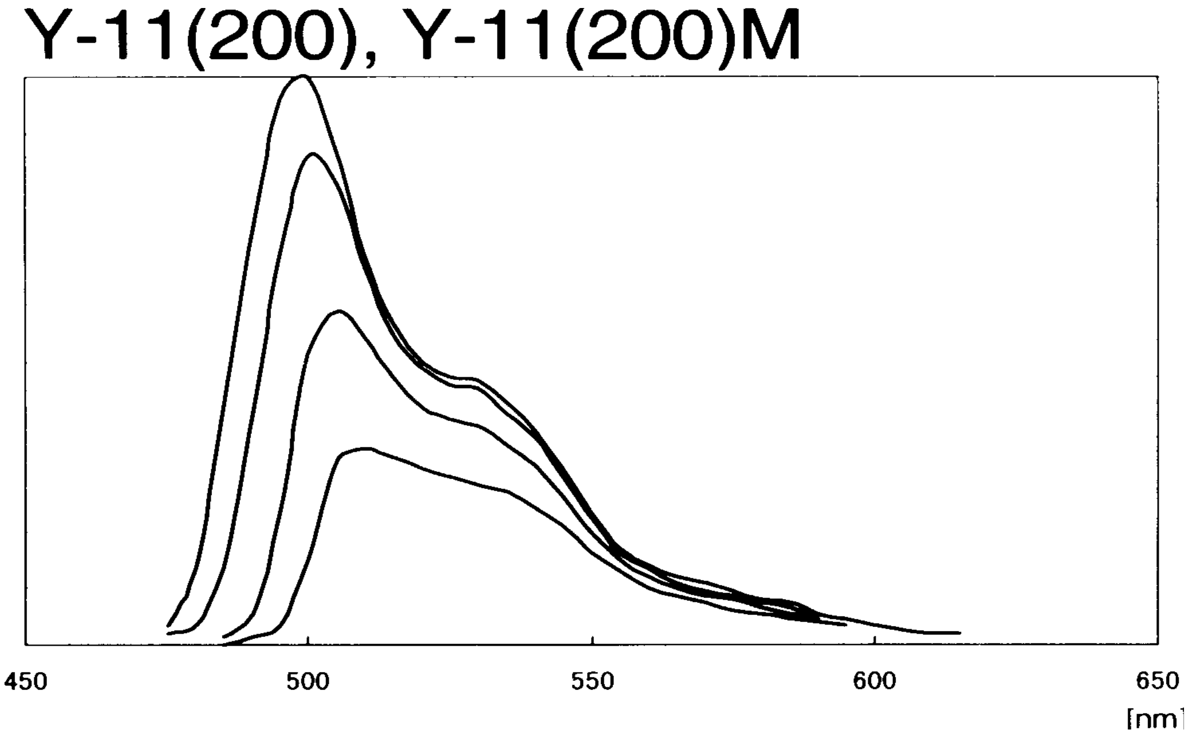


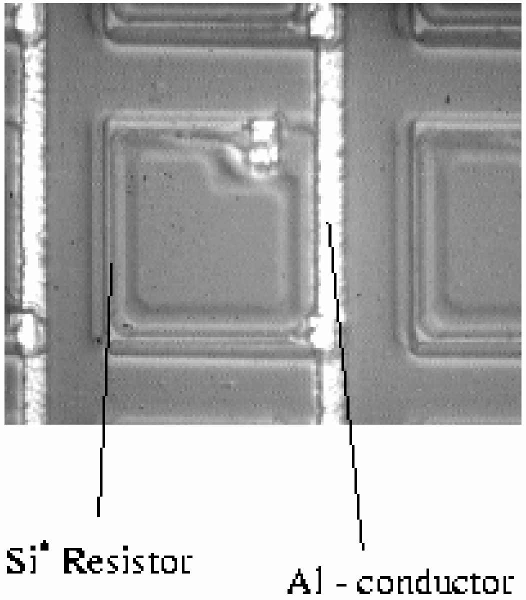
Large number of p.e. leads to high efficiency >99.9

Technique for a compact,efficient and simple in operation muon detector

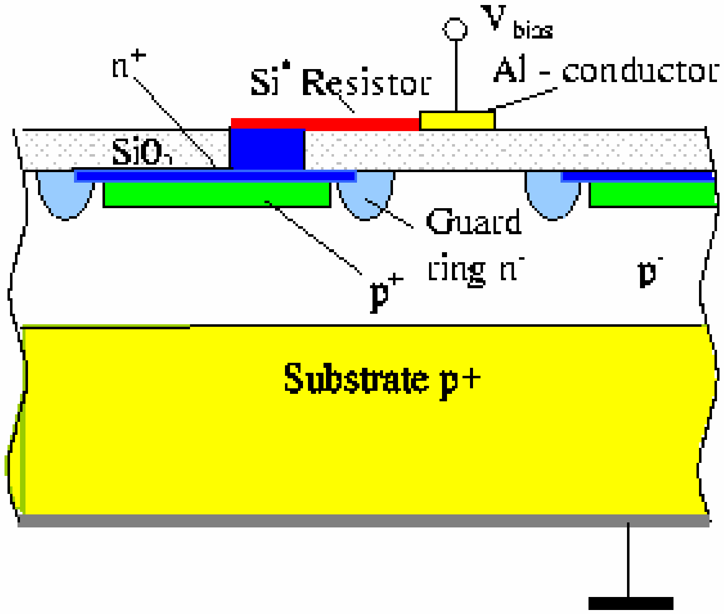
Emission Spectrum of Y11 WLS Fiber

Measured at distances 10cm, 30cm, 100cm and 300cm from source.




Si* Resistor
Al - conductor

a


V bias
n+
Si* Resistor
Al - conductor
SiO2
Guard
ring n-
p+
p-
Substrate p+

b

Amplitude Dependence on

SiPM k394. Регистрация света от LED L53SYC (λ=595nm, $t_и$=10нс, t_g=100нс, ус-ль - LeCroy 612AM, k_l=20).
Изменение сигнала от в зависимости от температуры при фиксированном напряжении. Напряжение выбиралось при 20^{0}C из условия: $k_{pixel}=10^6$. Затем температура понижалась до 10^{0}C и проводились измерения через каждые 5 градусов

T=+9.5^{o}C

T=+14.6^{o}C

T=+20.1^{o}C

T=+25.3^{o}C