



Performance Of Shashlik Calorimeters Read Out By Silicon Photomultipliers

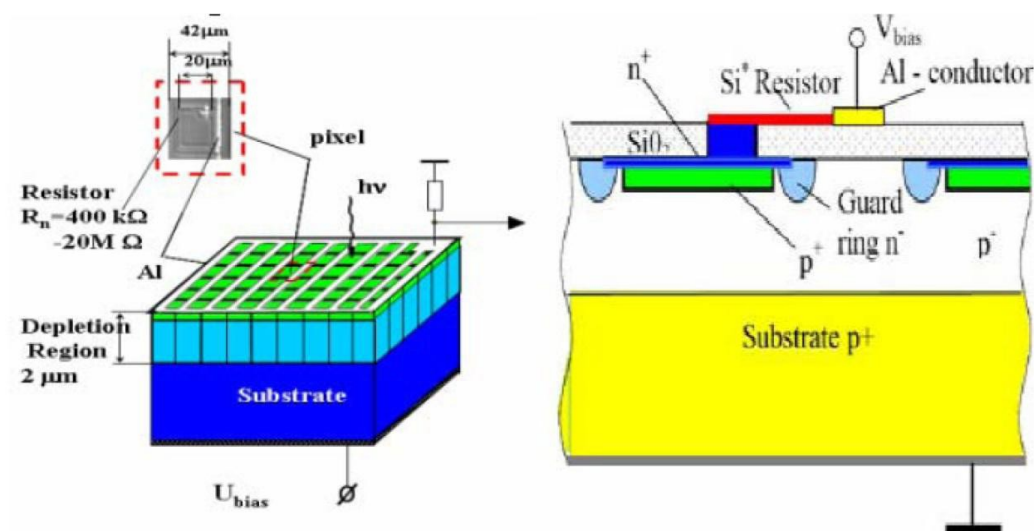
***Erik Vallazza
INFN Trieste***

Outline

- ***Silicon Photomultipliers: principles of operation***
- ***The FACTOR project***
- ***The FBK-IRST SiPM***
- ***The Shashlik Calorimeters***
- ***The Geant4 Simulation***
- ***Experimental results at CERN PS and SPS***
- ***Conclusions and Outlook***

Silicon Photomultipliers: principles of operation

- Silicon devices composed by a matrix of pixels connected to a common output
- Each pixel can be considered as a diode working above the breakdown voltage
- When a photon hits the pixel, a Geiger-mode discharge is formed; each pixel can then be considered as a binary counter
- The analog response (for low fluxes) is obtained considering the number of pixels fired



Silicon Photomultipliers: Comparison with PMT

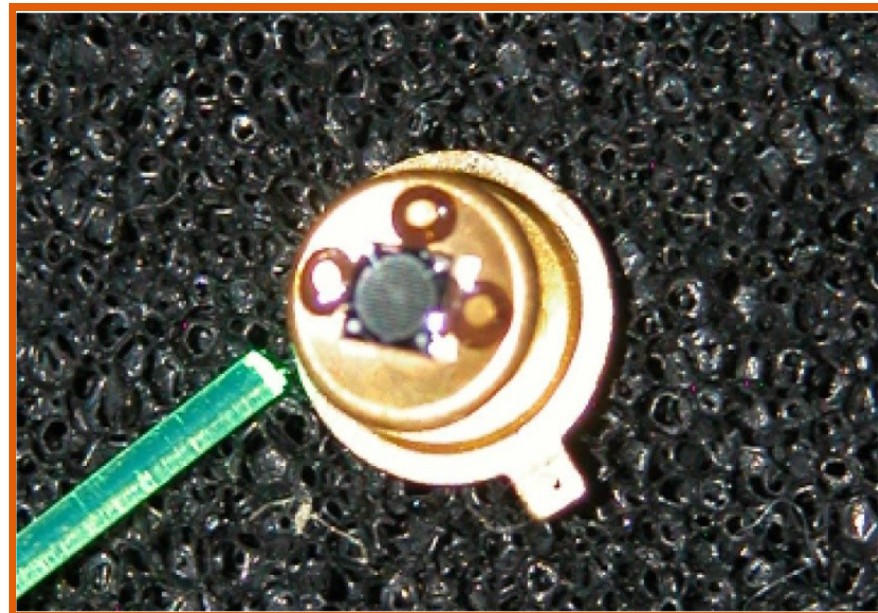
- **Main advantages**
 - Low bias voltage ($\sim 50\text{V}$)
 - Small dimensions ($\sim \text{mm}^2$)
 - Insensitivity to magnetic fields
 - Simple readout
- **Drawbacks**
 - Performance degradation after radiation damage
 - High temperature-dependent dark noise

The FACTOR project

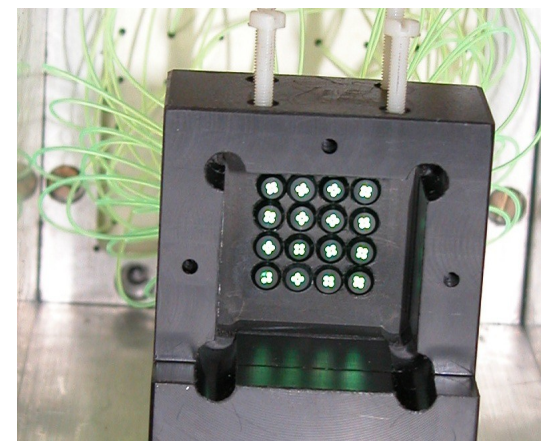
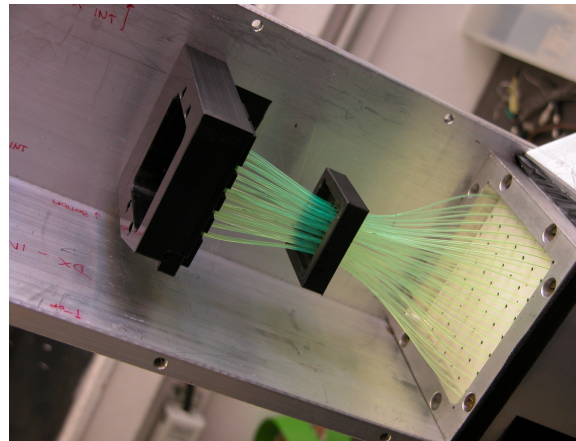
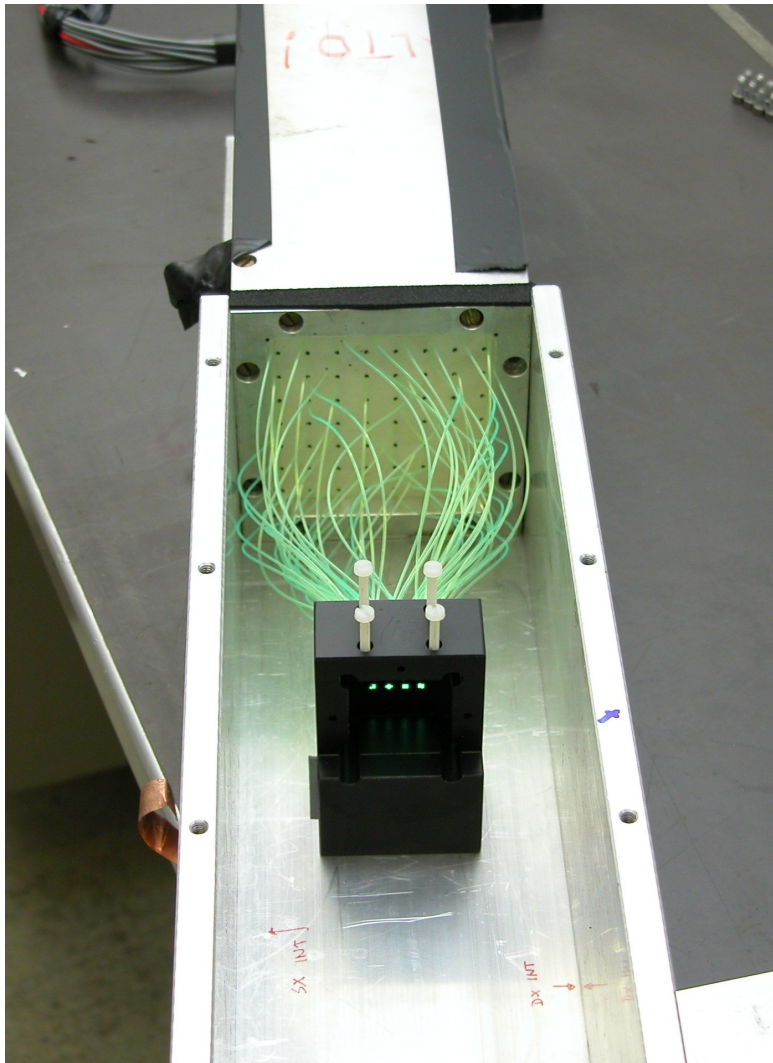
- Proposal submitted to INFN Group V in Sept. 2006
- Participants: INFN Sections of Trieste, Udine Roma 1 and Messina, ~ 7 FTE
- Collaboration with Insubria University, Como and INFN-MiB
- Duration: 3 yrs (2007- 2009) + extension 2010
- Collaboration with FBK-IRST (Trento, Italy)
- Strong interest both for the development of the device and for future (close) applications to (but not only) ***read-out of fiber calorimeters in HEP and to future space experiments for UHECR detection.***

The FBK-IRST SiPM

- Breakdown voltage: $\sim 31\text{V}$
- Overvoltage range: $\sim 5\text{V}$
- Number of pixels: 688
- Quantum Efficiency $> 90\%$ (380-530 nm)
- Photon Detection Efficiency $\sim 40\%$
- 1 mm diameter
- Pixel area: $40 \times 40 \mu\text{m}^2$
- Fill factor 44%
- Gain: $\sim 10^6$
- Most important: no amplification used for the signal output!

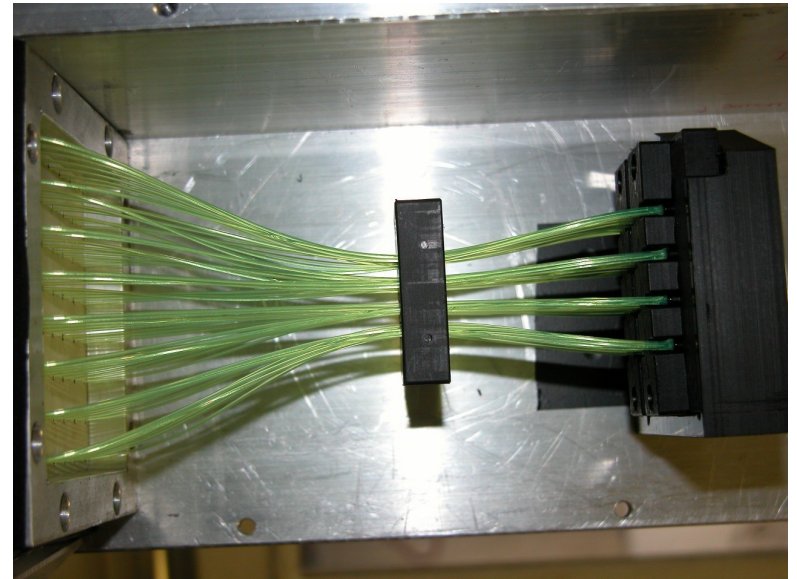
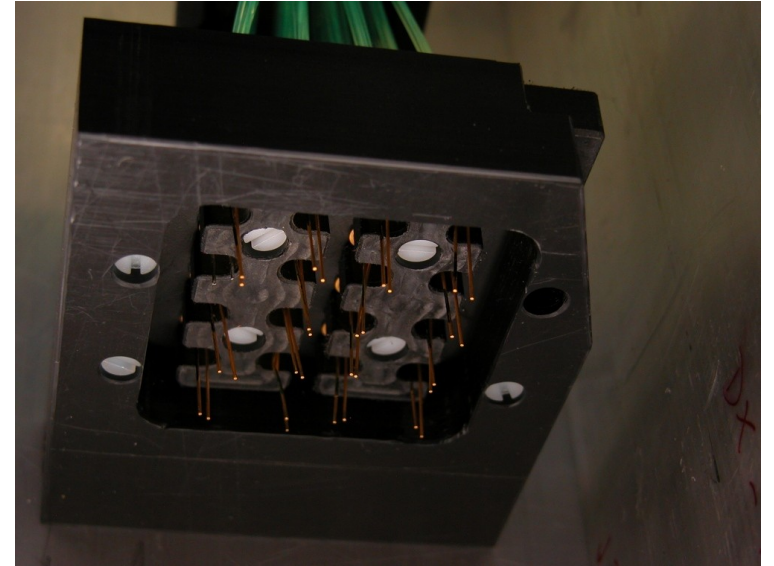
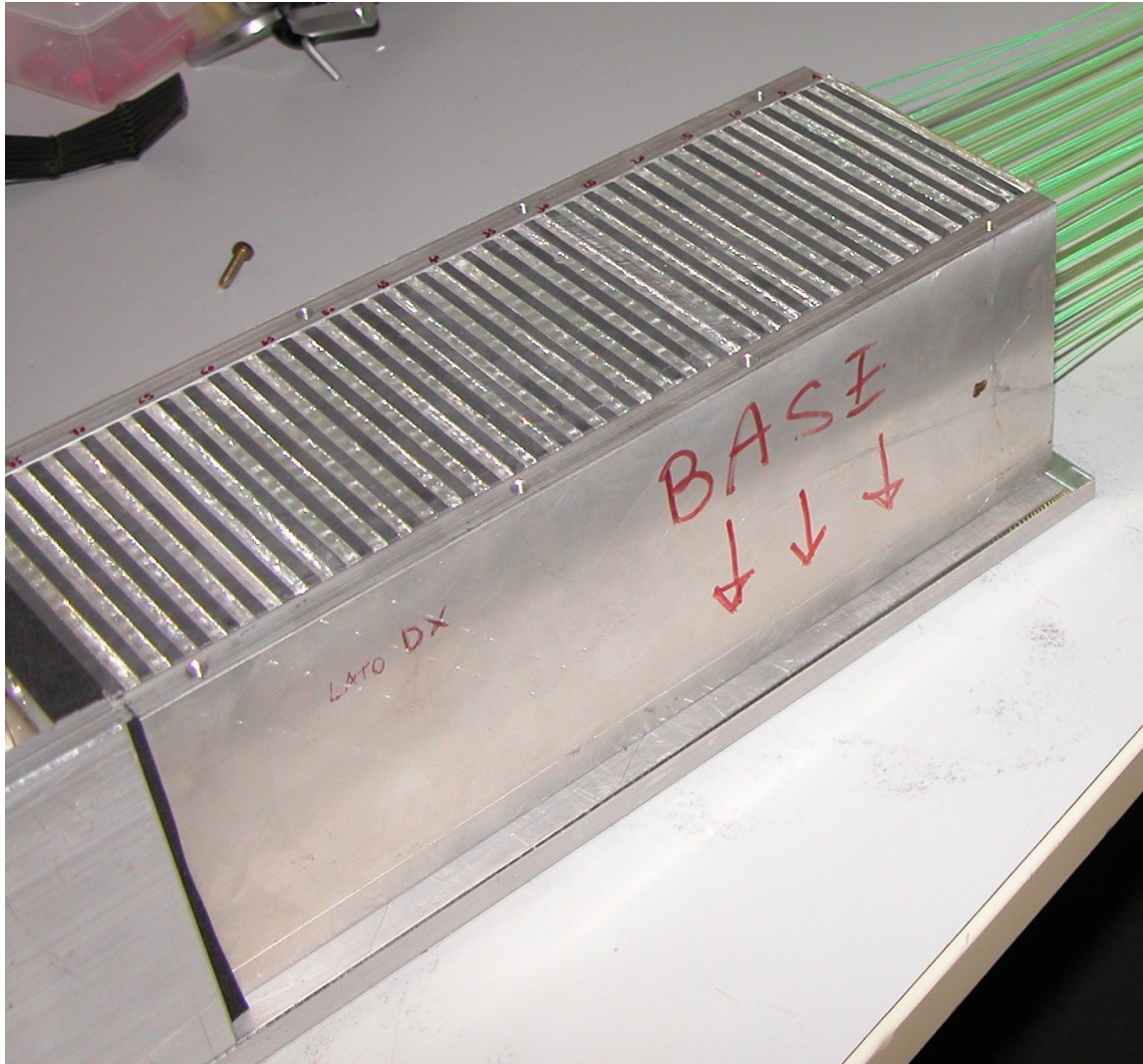


The Shashlik Calorimeter - 1

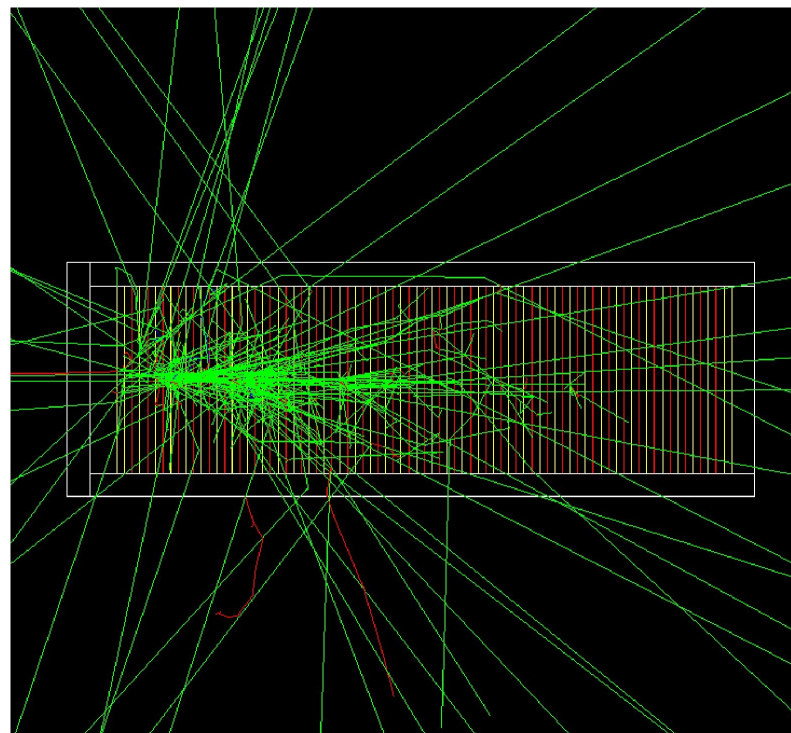
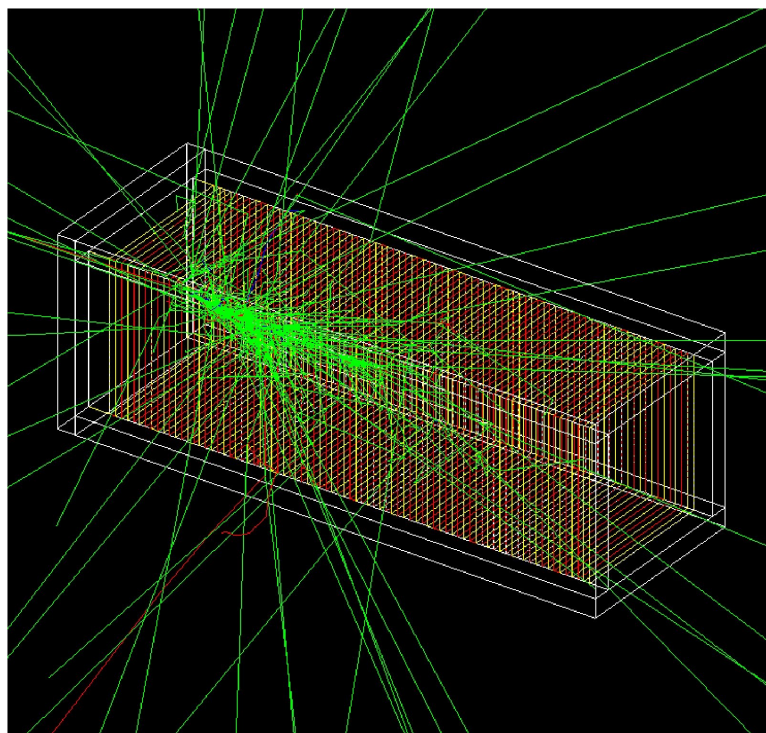


- **Manufactured by INFN Trieste**
- **41 tiles of scintillator $8 \times 8 \text{ cm}^2$ and 40 tiles of lead (both 3.27 mm thick) for a total of $24 X_0$**
- **64 0.8mm WLS fibers (Kuraray Y-11) for the readout collected in groups of 4**
- **3 different types of readout:**
 - ★ **Multi-anode PMT (Hamamatsu H8711)**
 - ★ **1 mm^2 SiPMs**
 - ★ **9 mm^2 SiPMs**
- **Tests with electrons, muons, pions, photons**

The Shashlik Calorimeter - 2

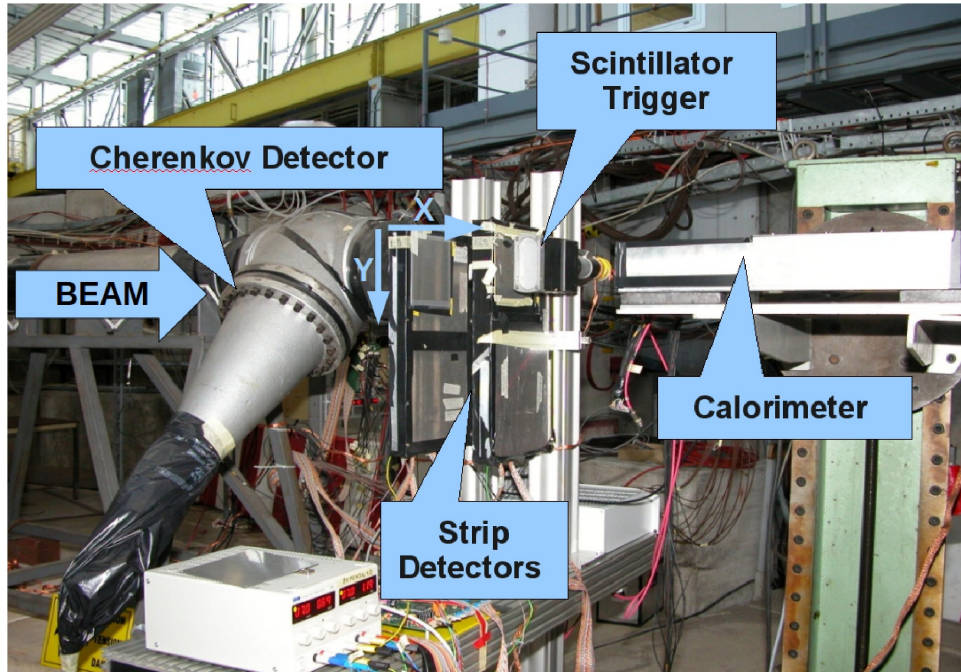


GEANT4 Simulation



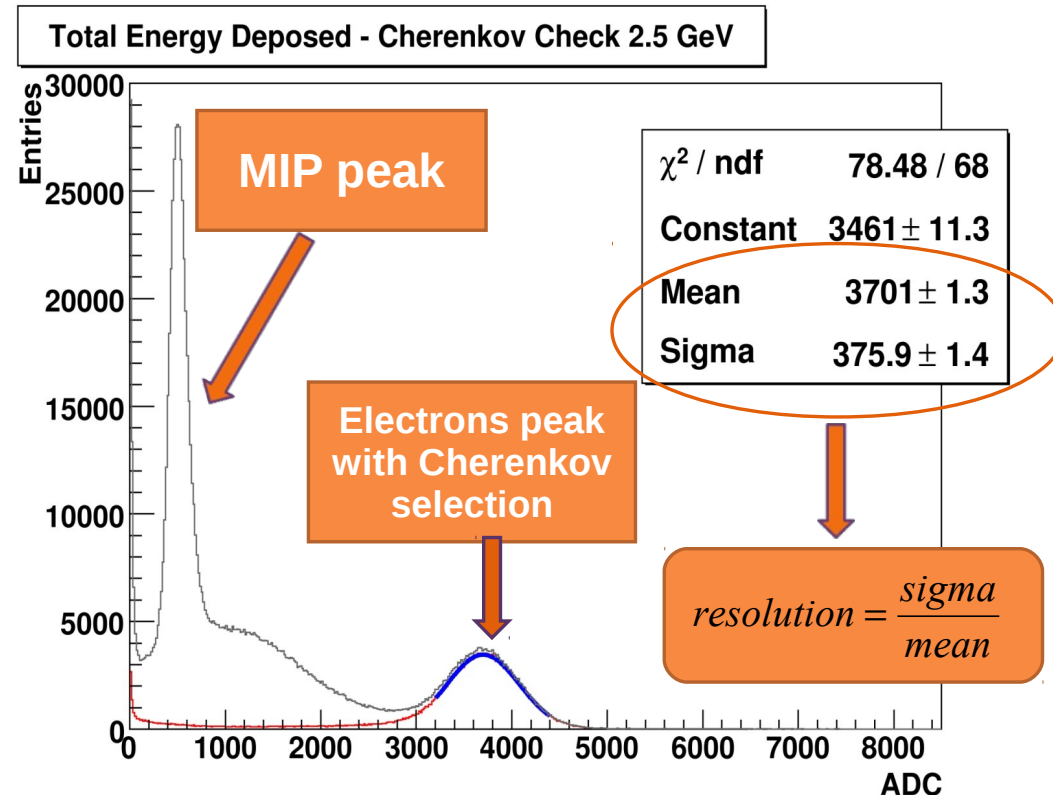
- *Electromagnetic and hadronic process*
- *Attribution of the energy loss in scintillator without taking into account the light spread and WLS process (just the spatial distribution)*
- *Good linearity and **expected resolution of 11.7%/√E** which sets the best expected performance*
- *Work going on to implement the full treatment of the light in the scintillator and the WLS fibers up to the SiPM (A. Berra, PhD student)*

T10 Beamline setup



- Secondary beam at the CERN PS East Hall
- Beam momentum up to 7 GeV/c
- Fraction of electrons from 60-80% at 1 GeV/c to <10% at 5 GeV/c

- Cherenkov counter to tag the electrons
- Beam Chambers (30 μm resolution) to track the particles
- Calorimeter under test



Experimental results at CERN

PS T10: Procedure

- ***Gain equalization with MIPs***
- ***Perform calibration with energy scan***
- ***For the position resolution:***
 - ***Group the 4 “towers” in x-y***
 - ***Apply the algorithms by Awes and al, NIM A 311, 130***
- ***Compare the extrapolated position with the expected one***

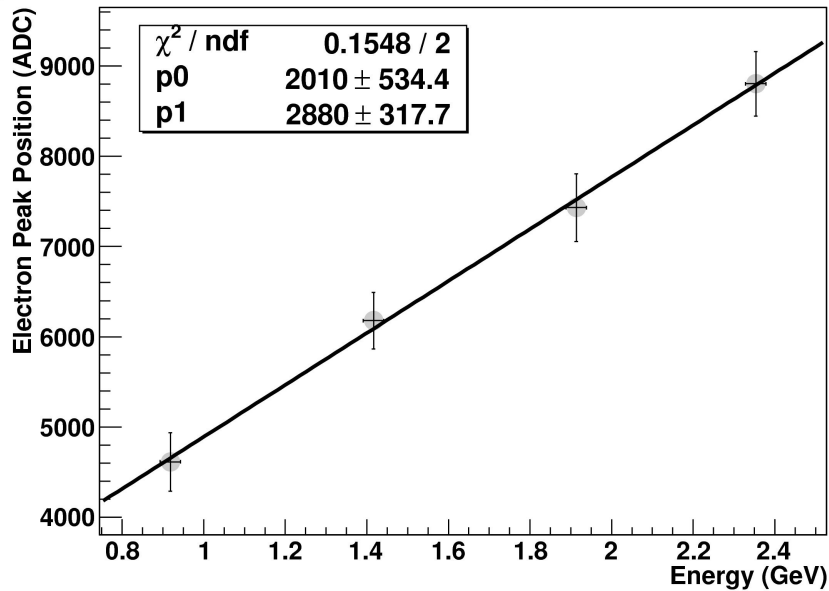
	1X	2X	3X	4X
1Y	1	2	3	4
2Y	5	6	7	8
3Y	9	10	11	12
4Y	13	14	15	16

$$X_{calc} = \frac{\sum w_i x_i}{\sum w_i}$$

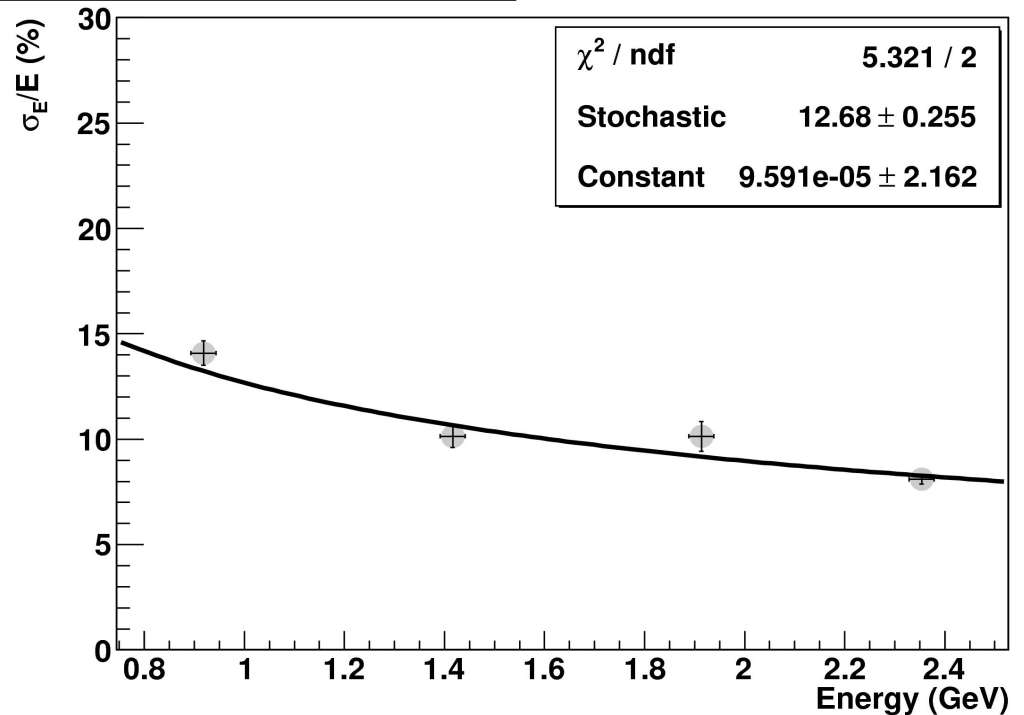
$$w_i = \text{Max}\left(0, \left[w_0 + \ln \frac{E_i}{E_{tot}} \right] \right)$$

Experimental results at CERN PS T10: PMT Linearity and resolution

Energy Response Linearity - PMT

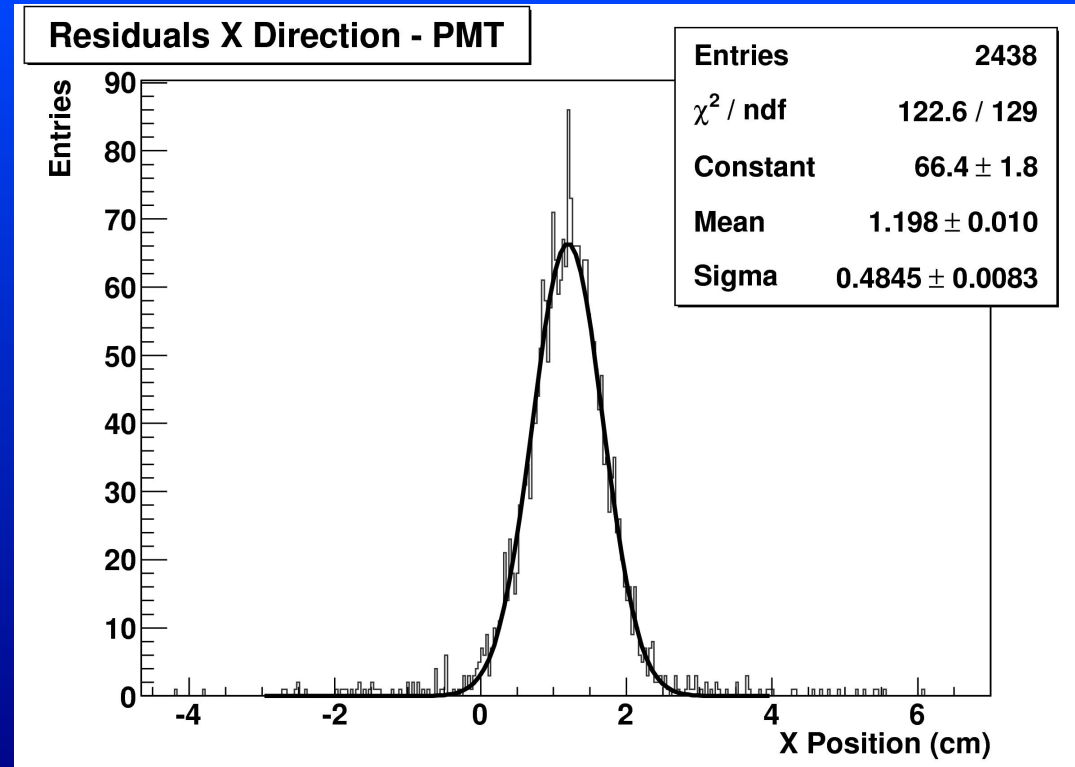
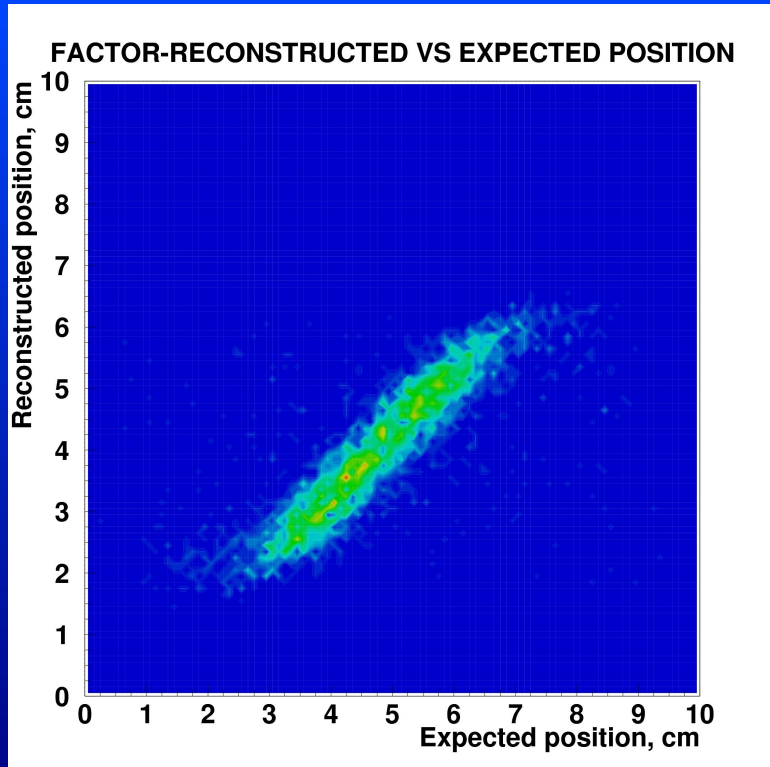


Energy Resolution - PMT



$$\text{resolution} = \frac{P0}{\sqrt{E}} + P1 \simeq \frac{12.7}{\sqrt{E}}$$

Experimental results at CERN PS T10: PMT position resolution (1.5 GeV e-)



X resolution

0.48 cm

Y Resolution

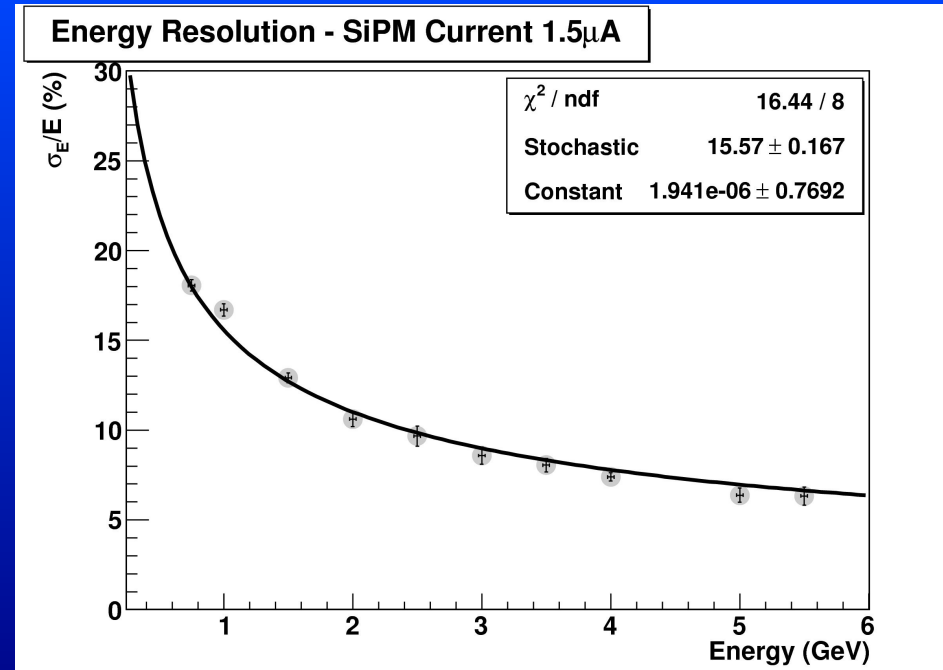
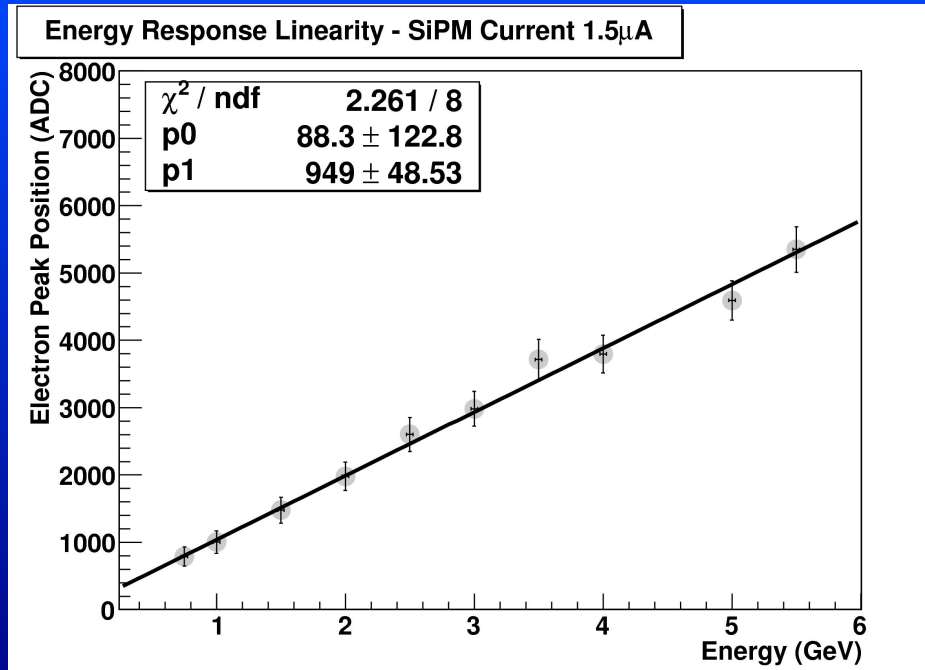
0.45 cm

Experimental results at CERN

PS T10: SiPM

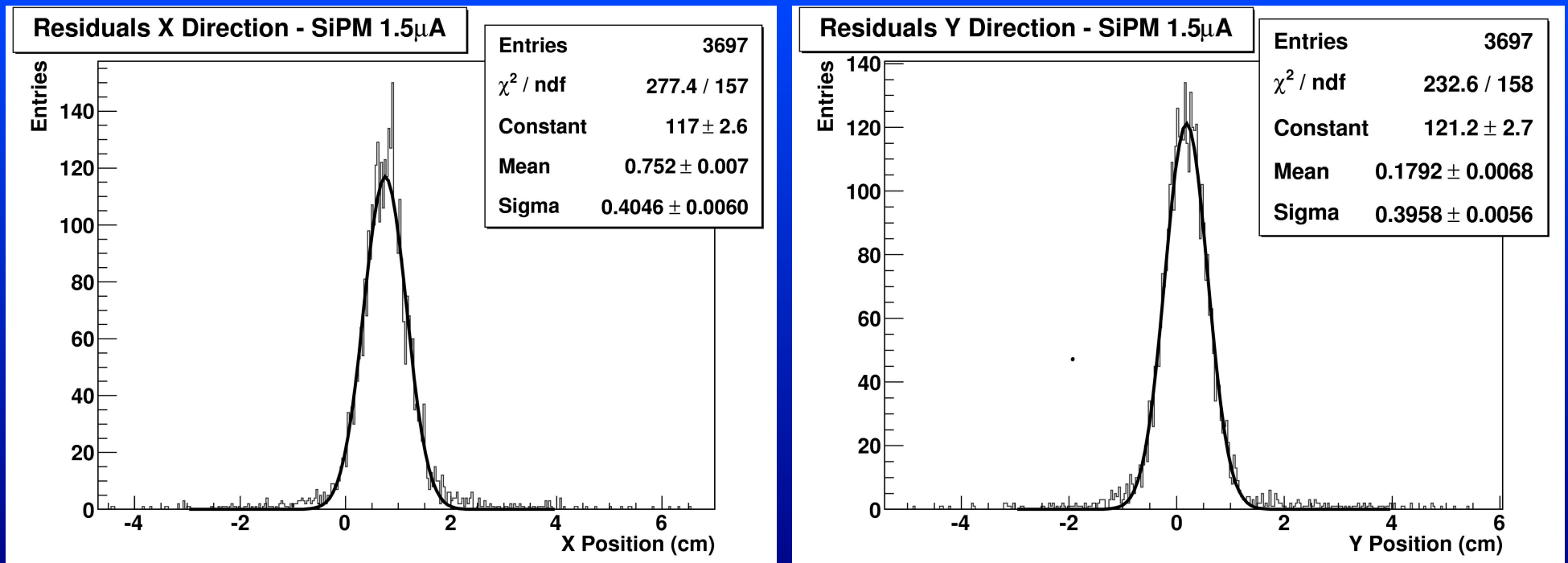
- **SiPMs runs:**
 - **1 mm² SiPMs manufactured by FBK-IRST**
 - **Biased in groups of 4 (with 4 different power supplies) with different voltages in order to equalize the current consumption**
 - **3 different runs with currents $\sim 2\mu\text{A}$, $\sim 1.5\mu\text{A}$ and $\sim 1\mu\text{A}$**
 - **Only 15 channels working**

Experimental results at CERN PS T10: SiPM resolution and linearity



	Simulation	PMT	SiPM, 1uA	SiPM, 1.5uA	SiPM, 2uA
Resolution, Stochastic	11.7	12.7	16.4	15.6	14.6

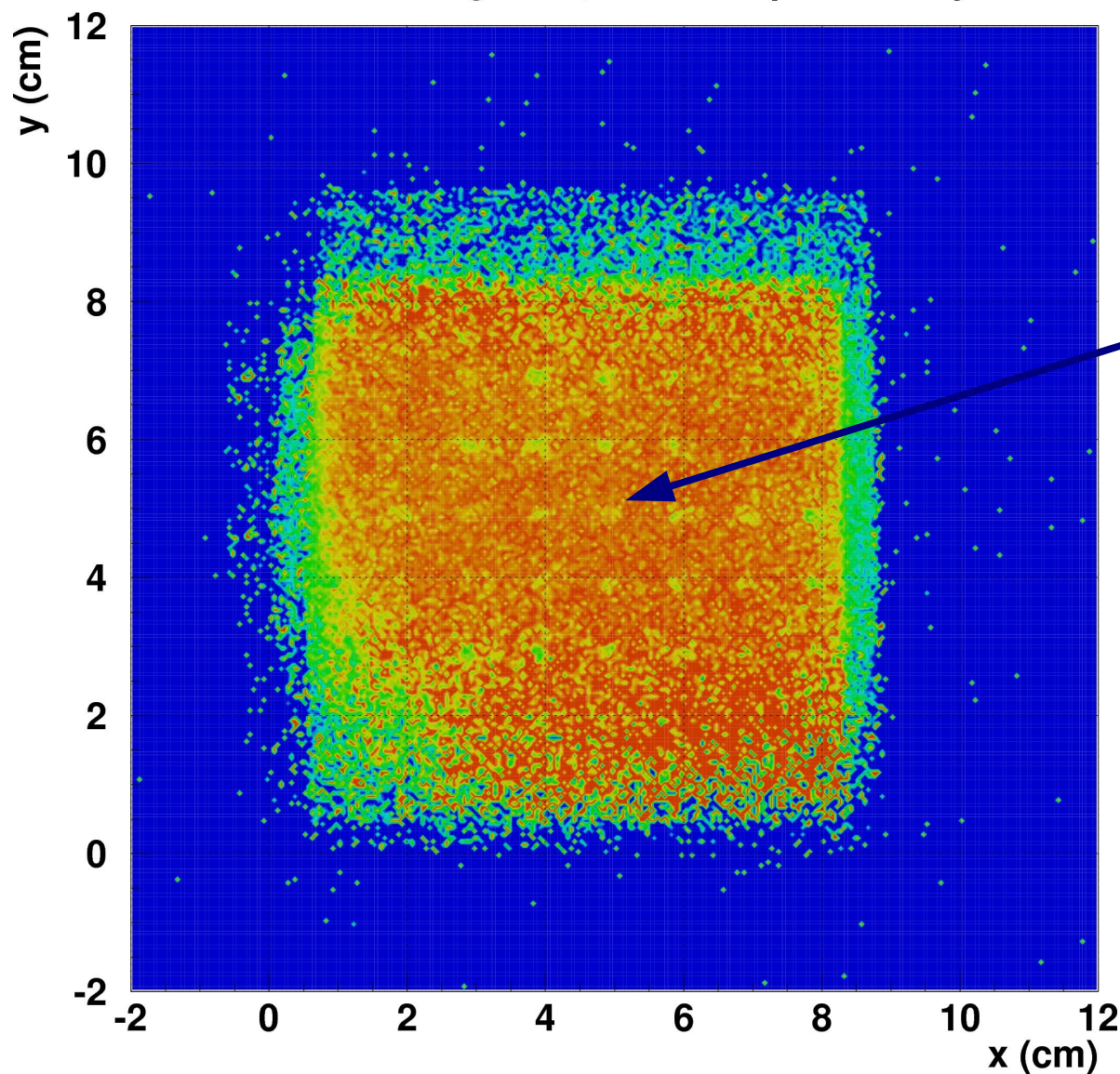
Experimental results at CERN PS T10: SiPM position resolution (1.5 GeV e-)



	1 uA	1.5 uA
X resolution	0.5 cm	0.4 cm
Y resolution	0.5 cm	0.4 cm

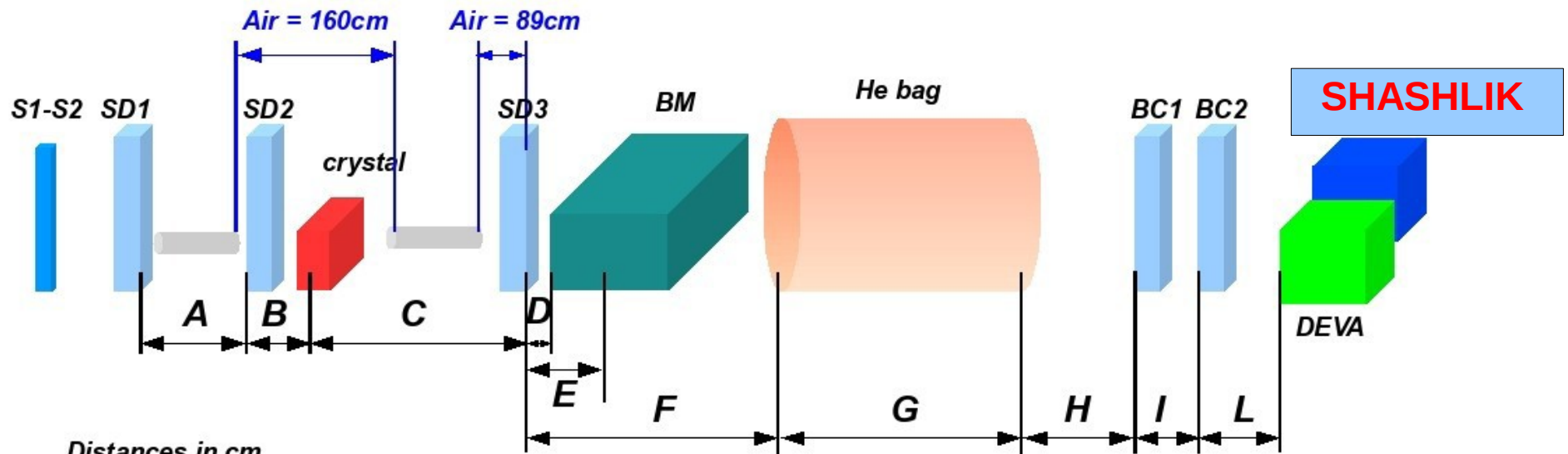
Experimental results at CERN PS T10: SIPM

T10 PS - Aug 2009, FACTOR preliminary



***Effect of particles passing
through fiber holes clearly
seen***

Tagged Photon Beam at CERN SPS H4 Line

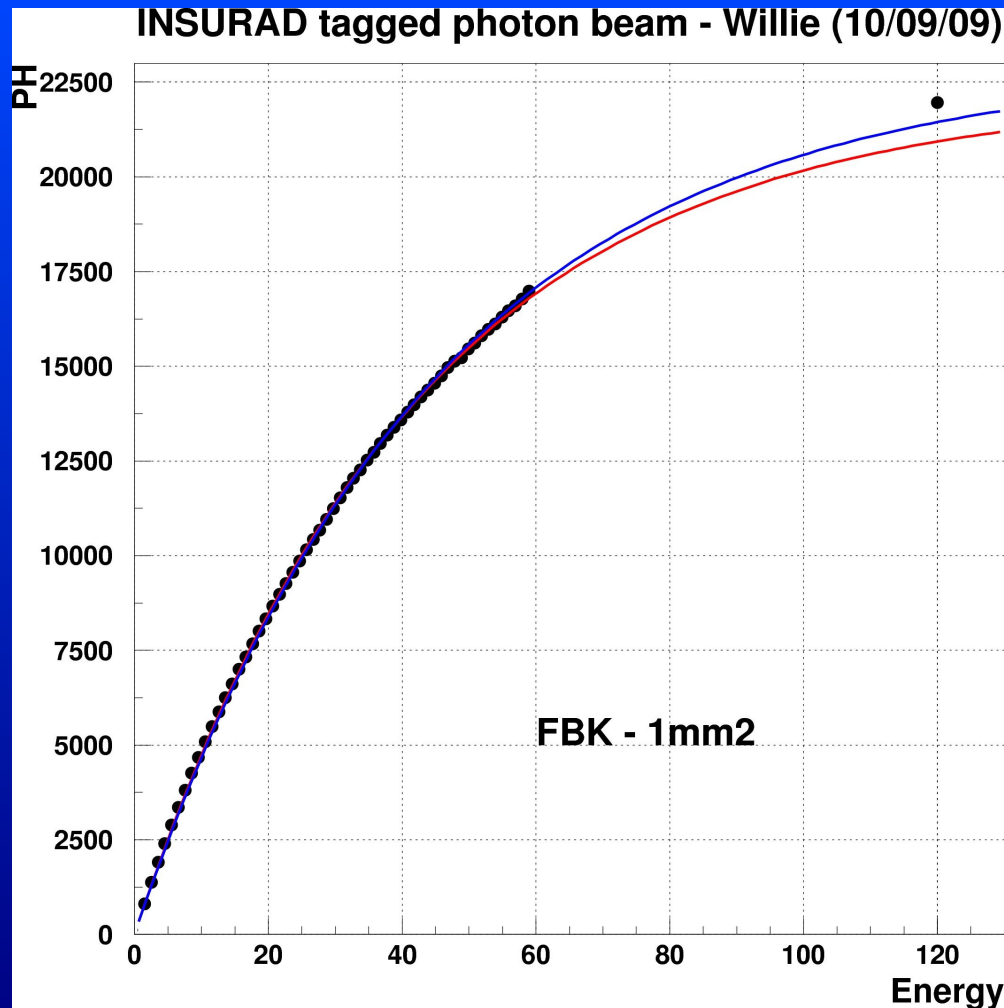


- A = 746
- B = 40.8
- C = 691
- D = 51
- E = 150
- F = 345
- G = 960
- H = 327
- I = 17.7
- L = 38.7

**INSURAD: Radiation from
channeling in bent crystals**
<http://insulab.dfm.uninsubria.it>



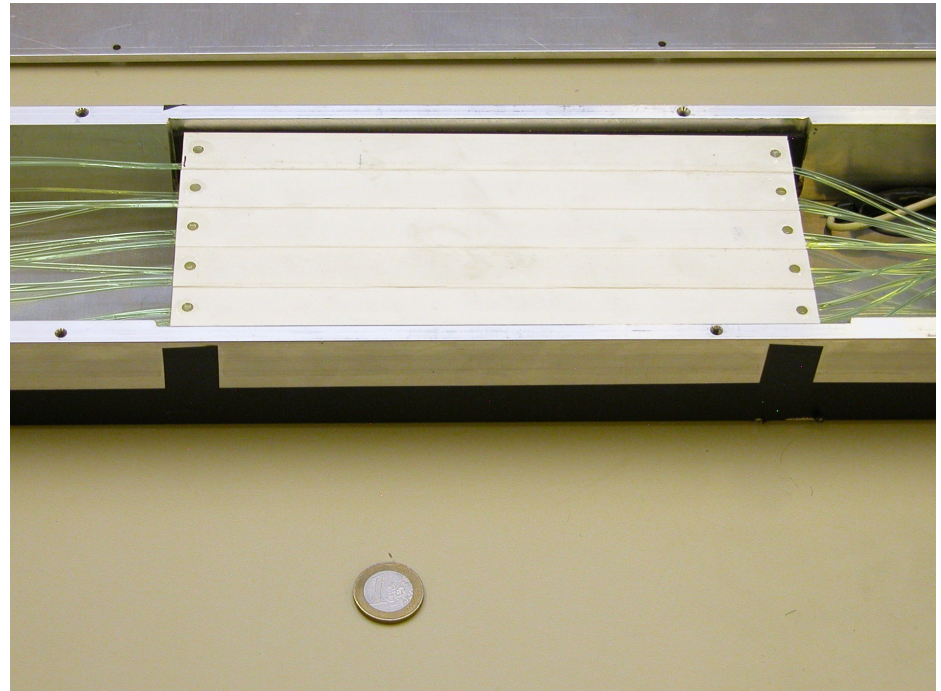
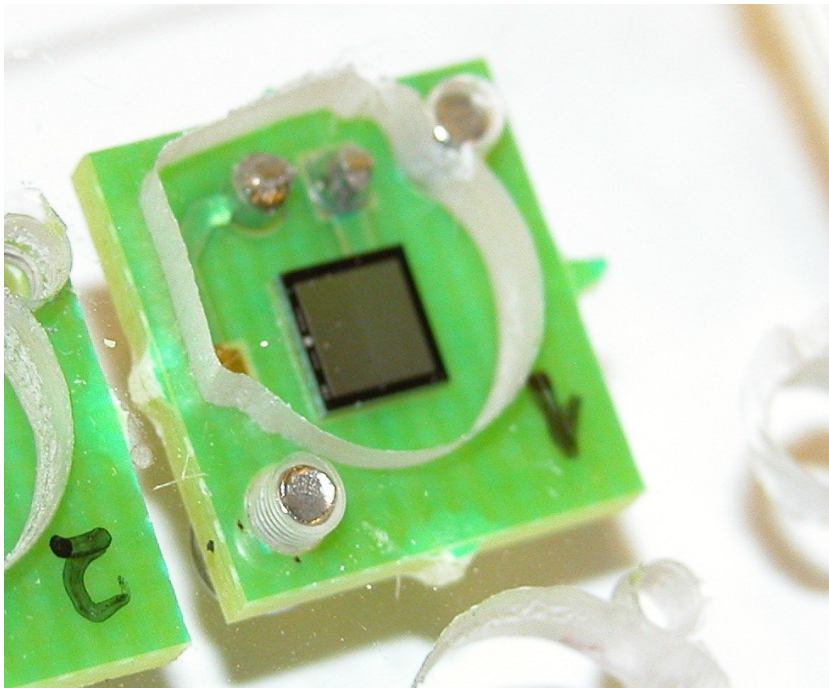
Experimental results at CERN SPS: Calorimeter + 1mm² SiPM



- ***Clear saturation***
- ***Acceptable linearity up to 10 GeV***
- ***Resolution up to 10 GeV comparable with the one measured at PS (taking into account the spectrometer resolution)***
- ***Expected from the low number of cells***

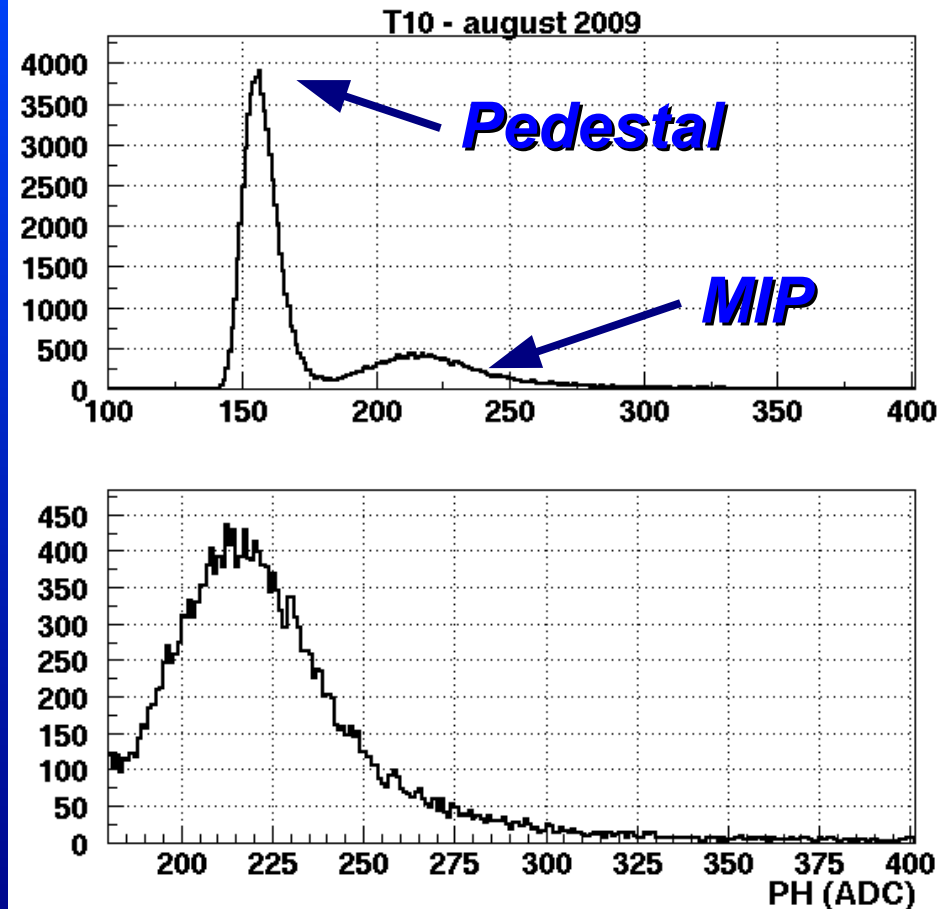
3x3 mm² FBK-irst SiPM – Scintillator bar

- ***Number of cells of SiPM: 3600***
- ***Cell size 50x50 μm^2 , fill factor 50%***
- ***Detector: 1 scintillating bar (1.5x1.9x20 cm³) readout by 3 1.2 mm WLS fibers (Bicron BCF-92)***
- ***No amplification of the signal, $I=10\mu\text{A}$***



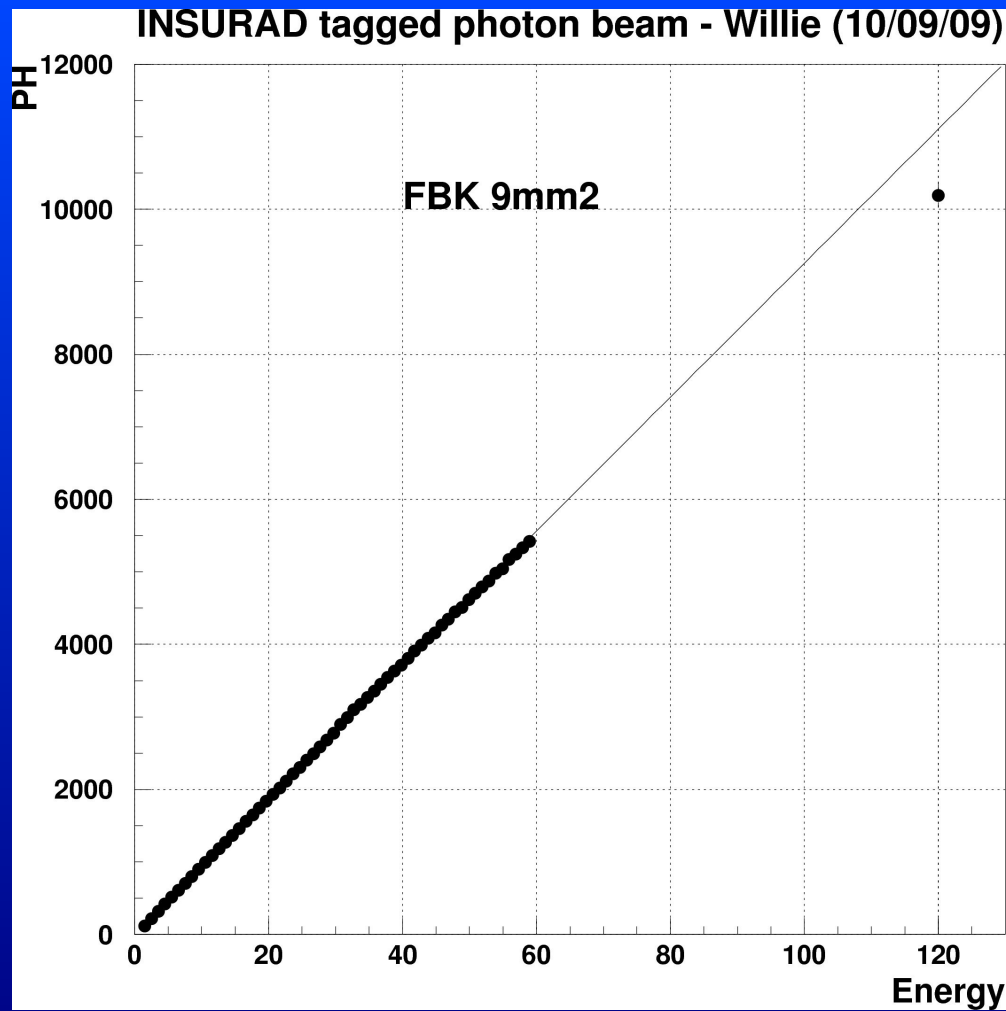
3x3 mm² SiPM – Scintillator bar

- ***No signal amplification***
- ***Good S/N ratio with MIP (8.5)***



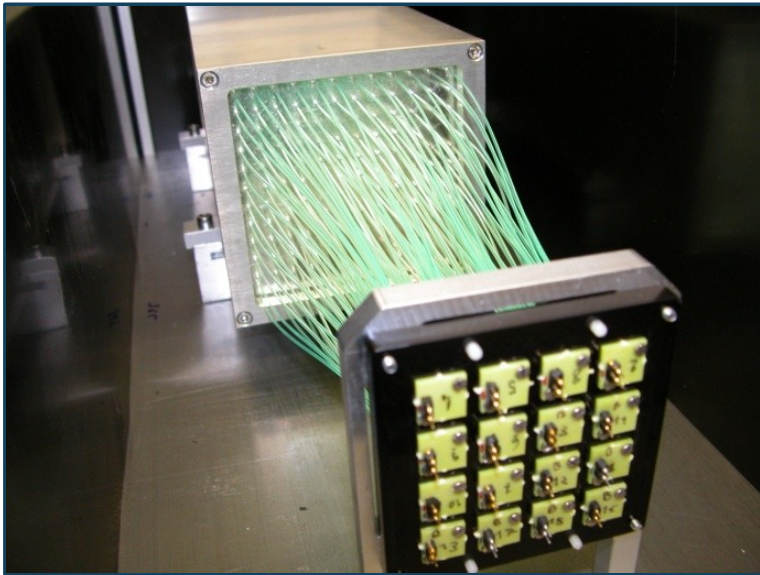
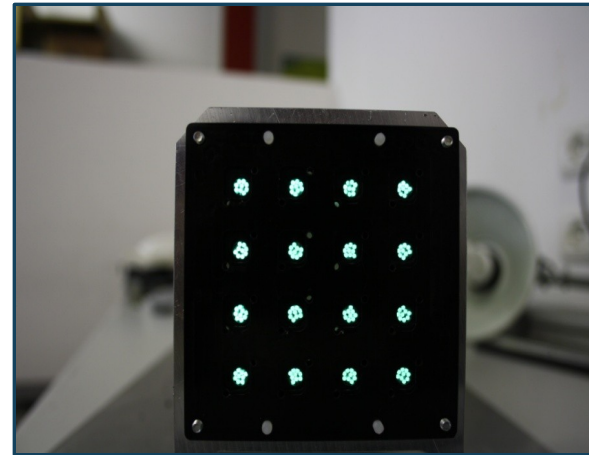
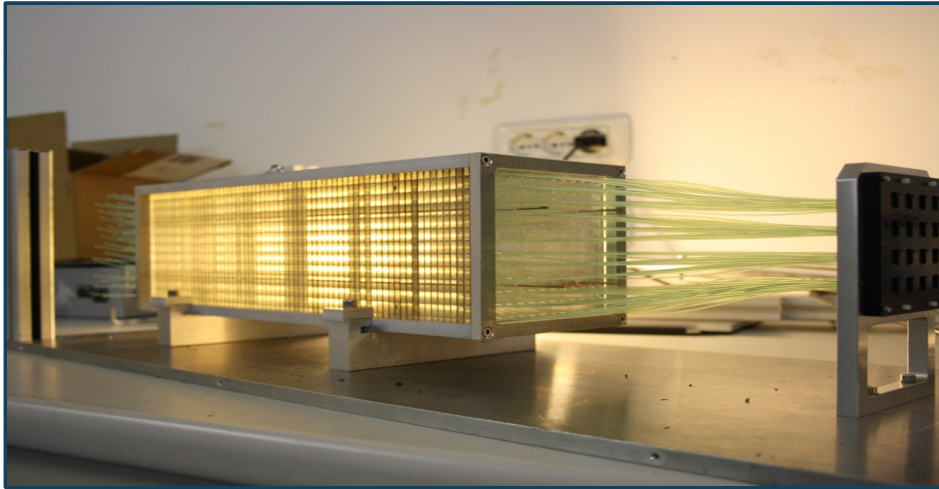
Experimental results at CERN

SPS: Calorimeter + 9mm² SiPM



- ***Some saturation at 120 GeV***
- ***Very good linearity up to 60 GeV***
- ***Resolution: stochastic term 30% so more tests needed***

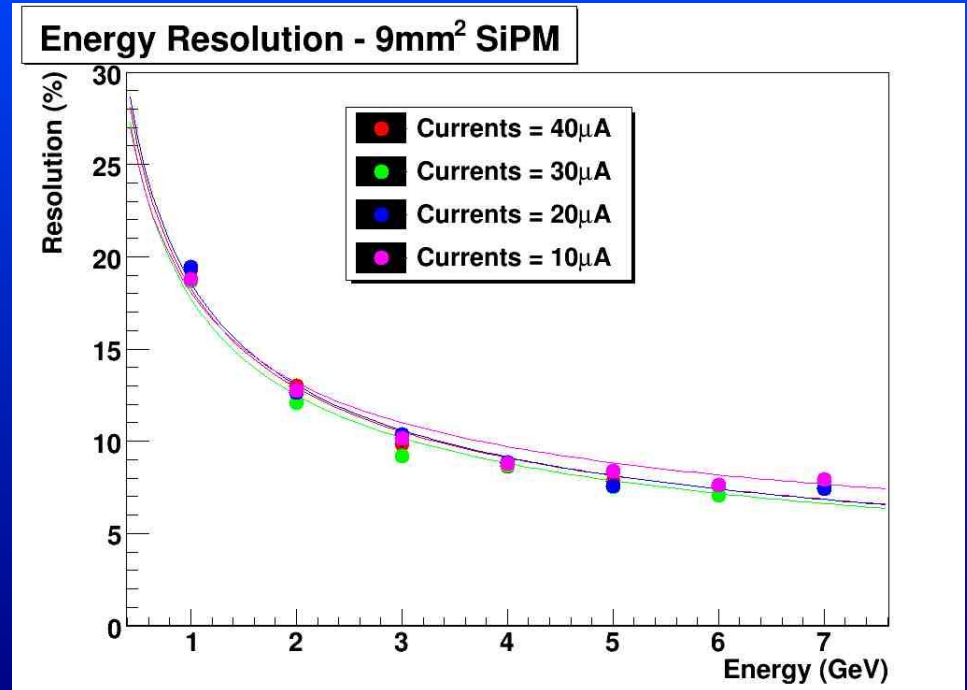
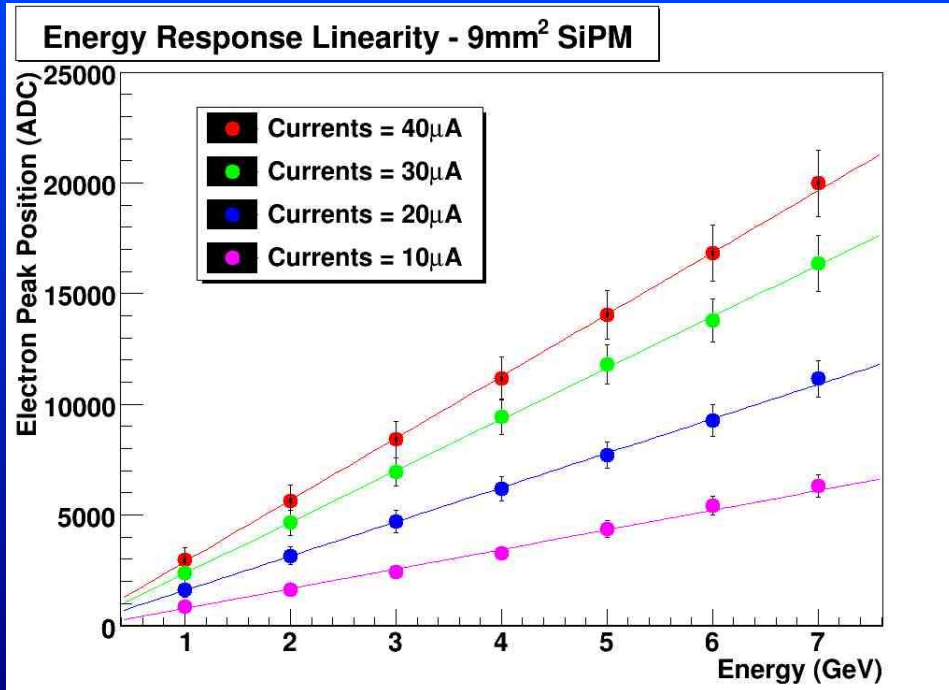
The Shashlik Calorimeter II



- *Manufactured by INFN Trieste*
- *70 tiles of scintillator $12 \times 12 \text{ cm}^2$ 4 mm thick*
- *69 tiles of lead (1.5 mm thick) for a total of $19 X_0$*
- *144 1.2 mm WLS fibers (Bicron BCF-92) for the readout collected in groups of 9*
- *Read out by 9 mm^2 SiPMs*
- *Tests with electrons, muons, pions*
- *Expected stochastic term from GEANT4 of about 6-7 %*

The Shashlik Calorimeter II

PRELIMINARY



- Tested at CERN T9 beamline
- Good linearity, currents from 10 to 40 μ A
- Stochastic term about 17-19%
- To be investigated

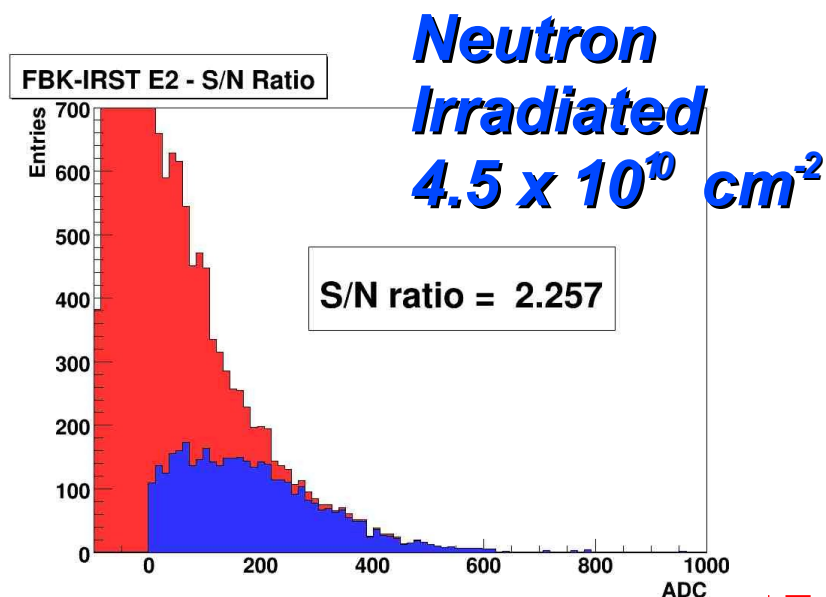
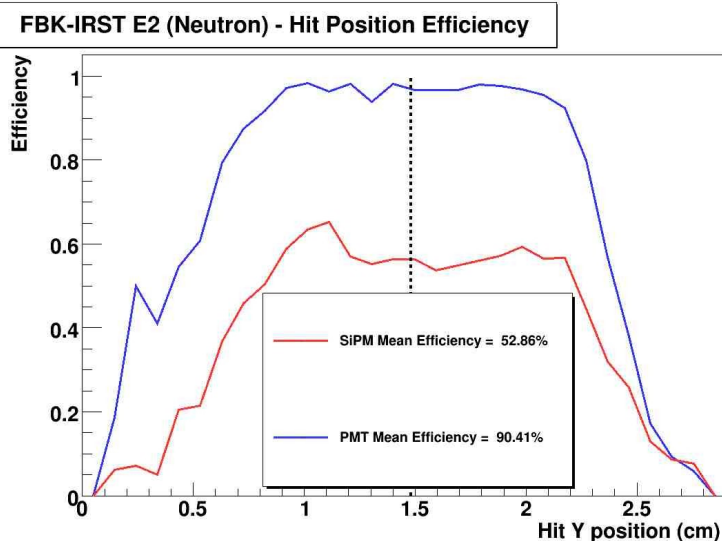
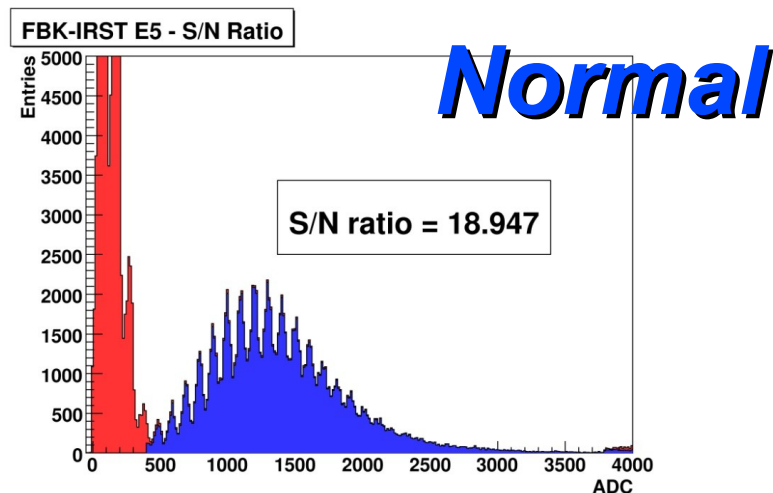
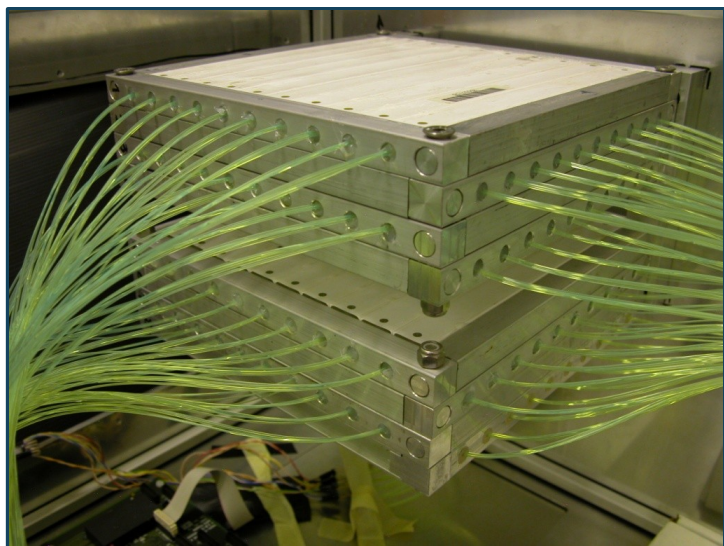
Conclusions and Outlook

- Very satisfactory run in **non-optimal** conditions
- Very good stability of SiPM (one month of run)
- **Need to understand the light loss with the 3x3 mm² SiPM**
- More tests with 4x4 mm² SiPM from FBK
- Readout with discrete amplifiers and with SPIROC ASICs under preparation

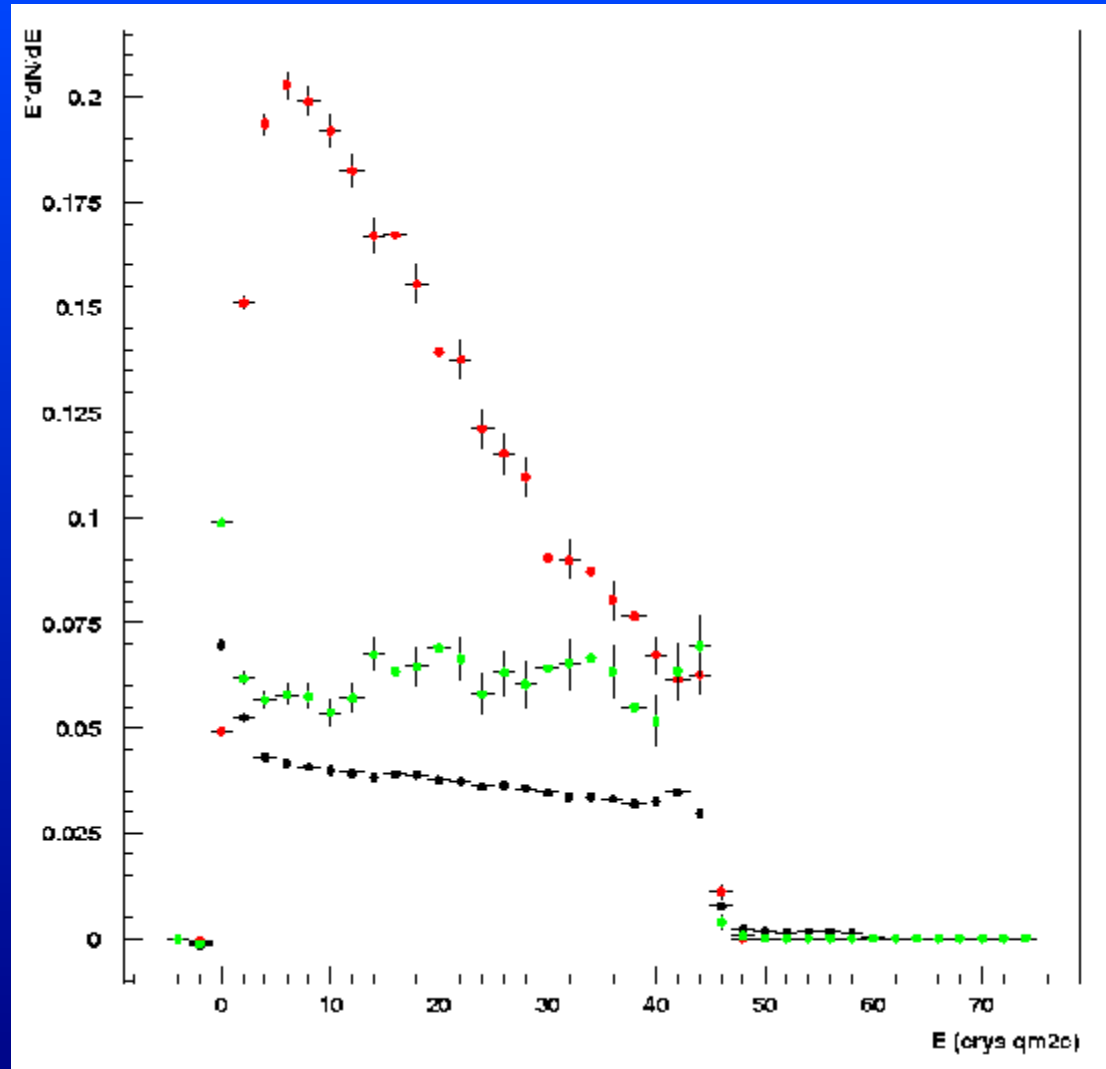
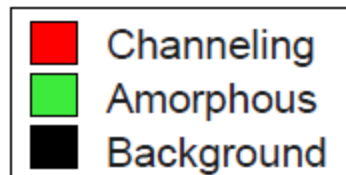
Thank you

BACKUP

Radiation Damage (from A.Berra et al, NIM A 611, 129)



Radiation emission in channeling/VR – INSURAD preliminary



Radiation emission in channeling/VR – INSURAD preliminary

