

VCI 2010

The Development of a high-resolution Scintillating Fiber Tracker with Silicon Photomultiplier Readout

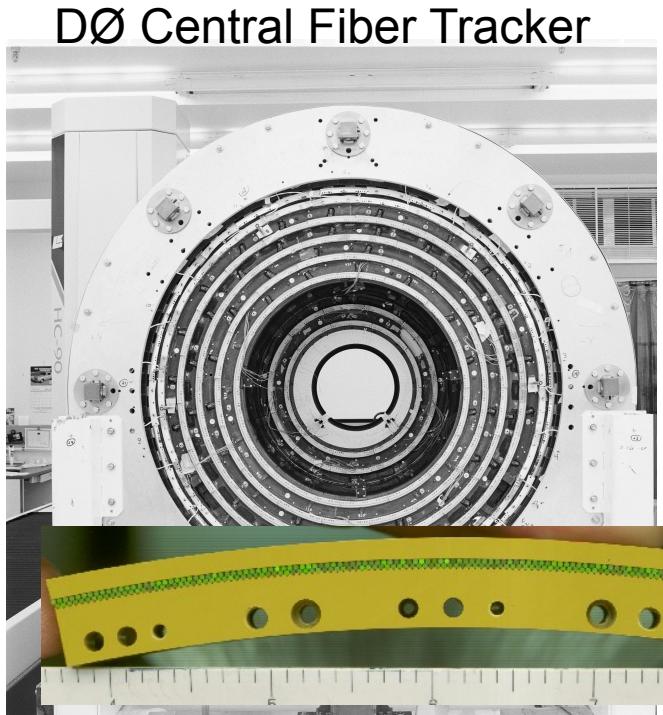
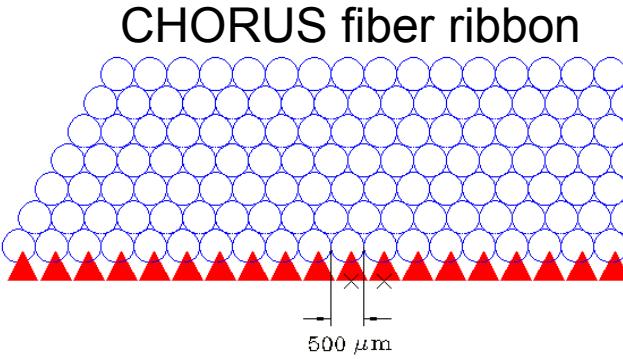
Gregorio Roper Yearwood

presented on th Vienna Conference on Instrumentation

February 18, 2010

- Design
- Prototypes
- Perspectives

Scintillating Fiber Trackers

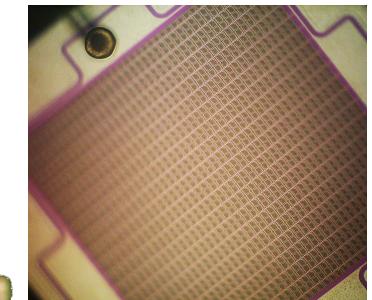
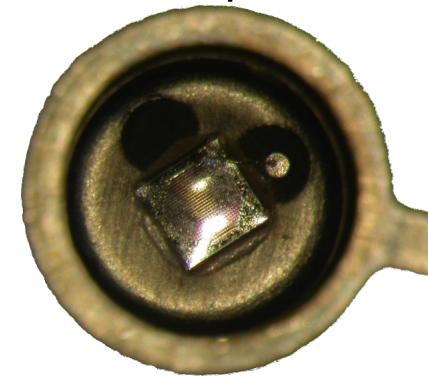


- Some previous Scintillating Fiber Trackers
 - CHORUS, UA2
 - $\varnothing=500\mu\text{m}$ fibers, 7 layers, image intensifiers, CCD camera
 - $\sim 150\mu\text{m}$ spatial resolution
 - requires $\sim 10\text{kV HV}$
 - E835, DØ
 - $\varnothing=835\mu\text{m}$ fibers, 2 layers, VLPCs
 - $\sim 100\mu\text{m}$ spatial resolution
 - VLPCs operated at cryogenic temperatures

Along came Silicon Photomultipliers

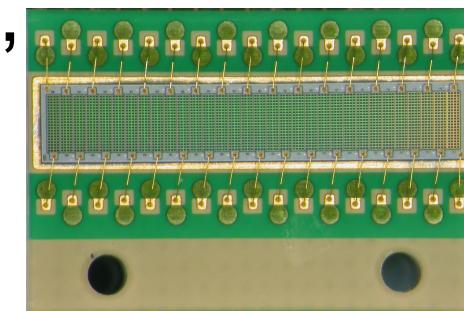
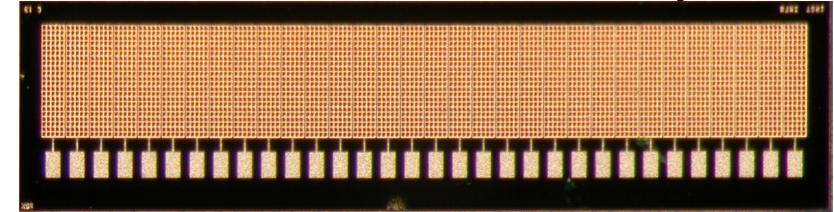
- operated at room temperature
- gain: $\sim 10^6$
- photon efficiency: $\sim 50\%$
- operating voltage: 20V..70V
- less overhead than VLPCs, II/CCD configurations
- more compact than PMTs

Photonique 2005



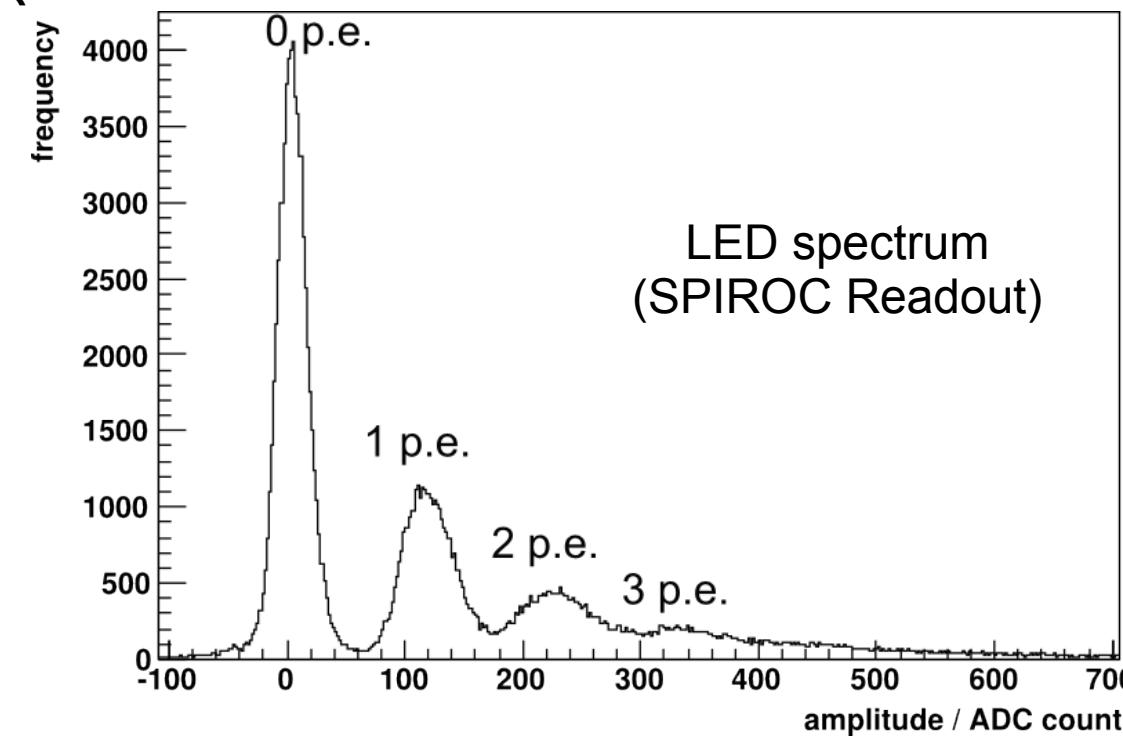
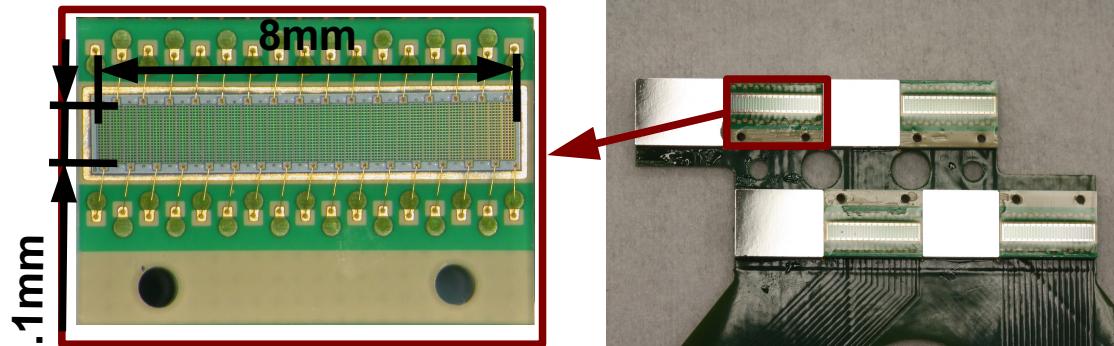
Hamamatsu 2006

FBK-irst 32 channel array 2007



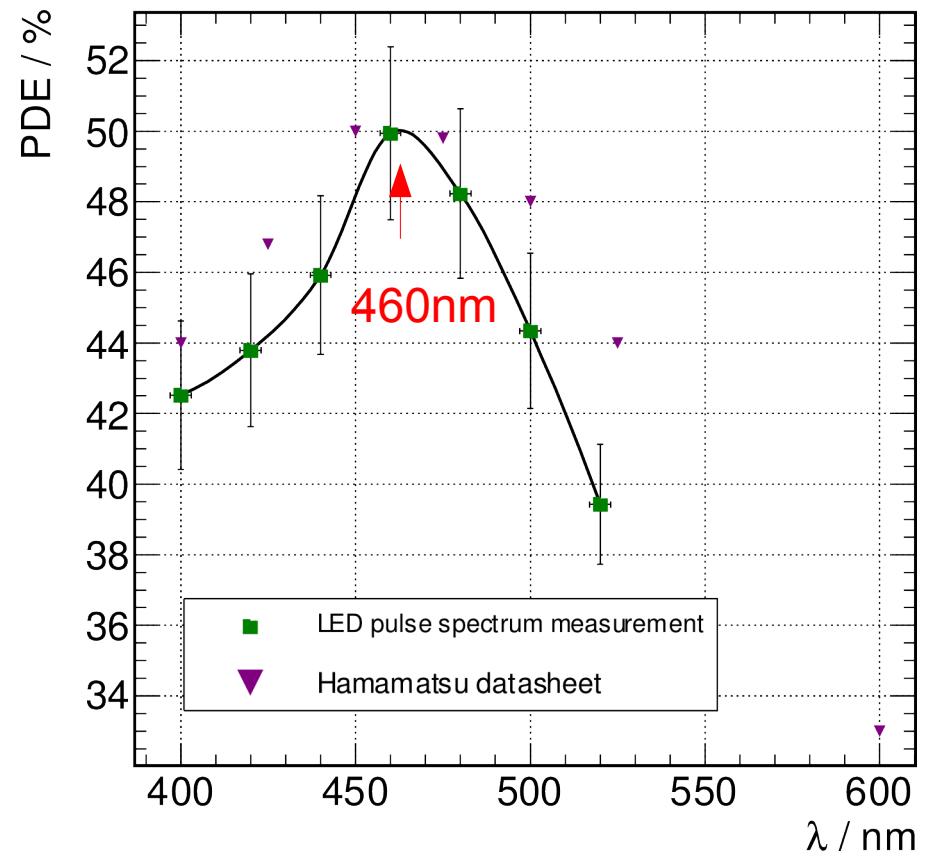
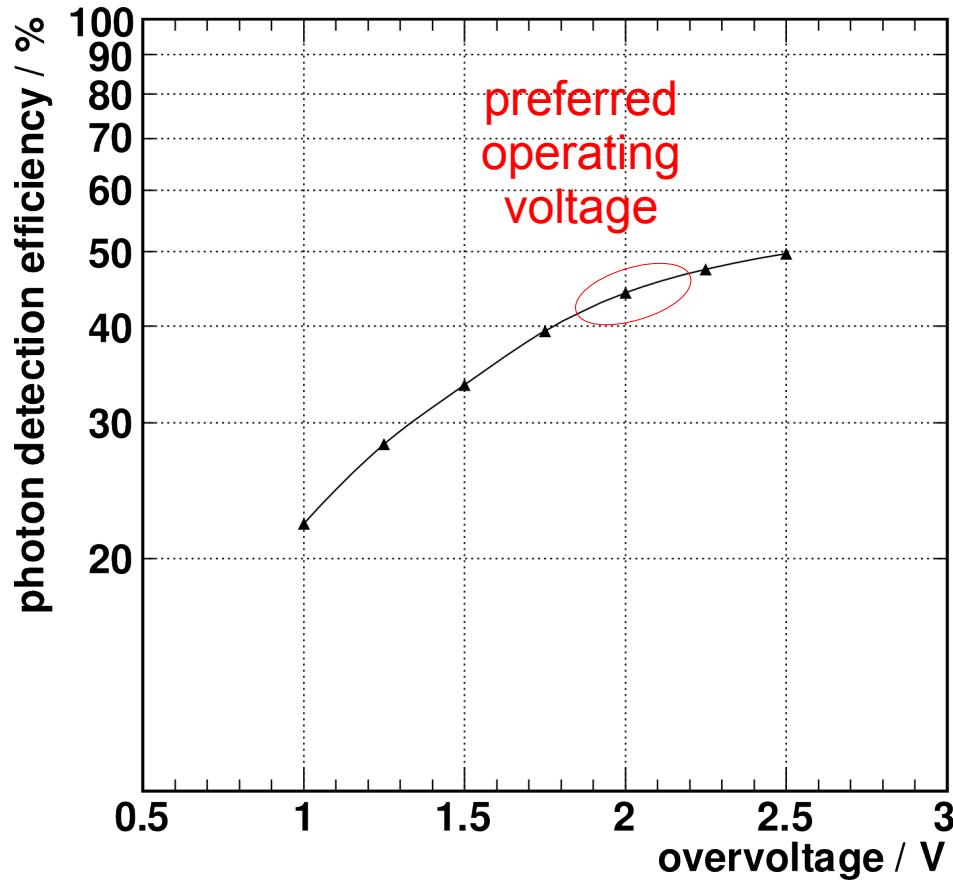
Hamamatsu
MPPC 5883
2008

Hamamatsu MPPC 5883

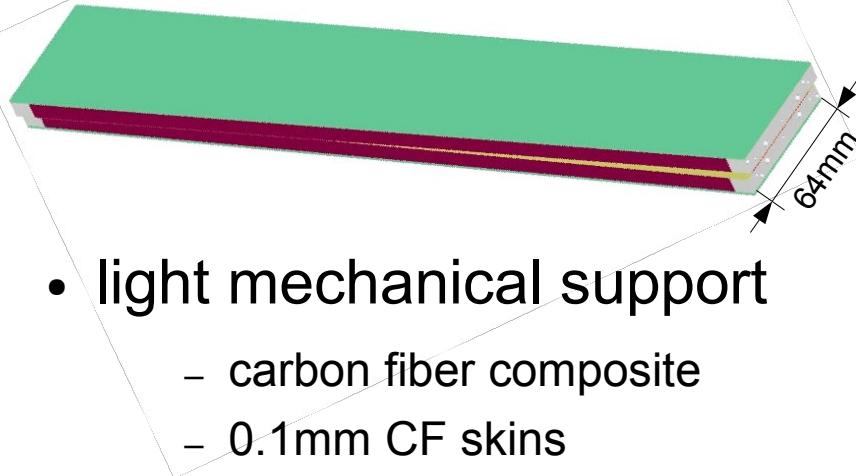


- $U_{bias} \sim 70V$
 - uniform for whole array
- 32 channel array
 - 0.25mm pitch
 - 4×20 pixels / channel
- pixel crosstalk ~ 30%

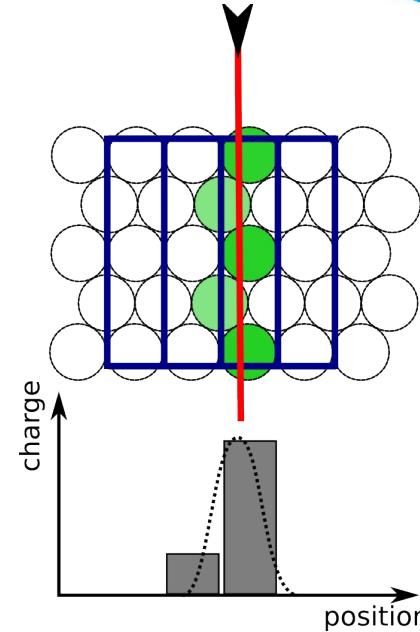
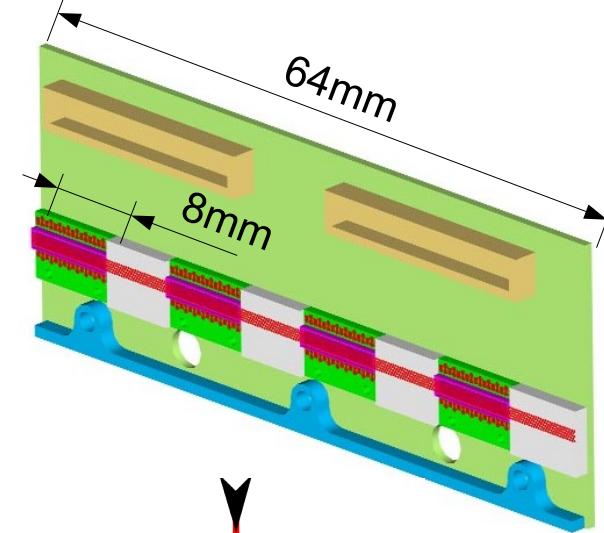
MPPC 5883 Efficiency



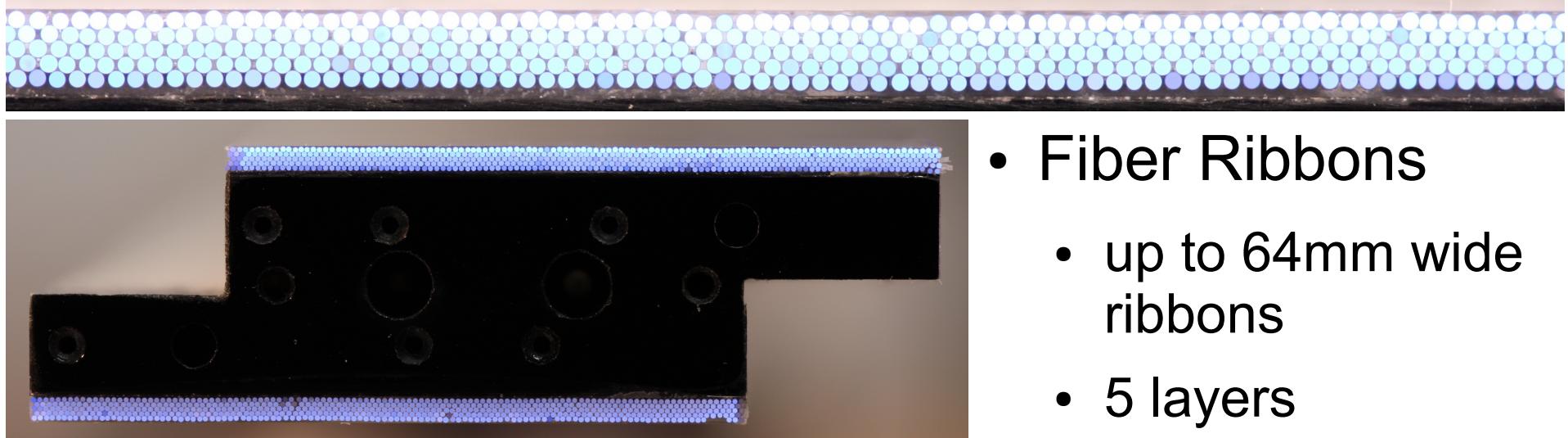
A Modular Scintillating Fiber Tracker



- light mechanical support
 - carbon fiber composite
 - 0.1mm CF skins
 - 16mm Rohacell (50kg/m^3)
- 2 × fiber ribbons
 - top and bottom ribbon with stereo angle
 - 0.7% X_0 for double layer + mechanical support
- SiPM Array coupled to fibers
 - direct coupling
 - no fiber sorting



Fiber Ribbons produced in Aachen



- Kuraray SCSF-78MJ
 - $\varnothing=0.250\text{mm}$
 - thickness varies by 0.006mm (RMS)
 - emission at $\lambda=450\text{nm}$
- Fiber Ribbons
 - up to 64mm wide ribbons
 - 5 layers
 - light yield
 - 0.275mm fiber pitch
 - epoxy matrix
 - EPOTEK 301

Fiber Ribbon Quality Control

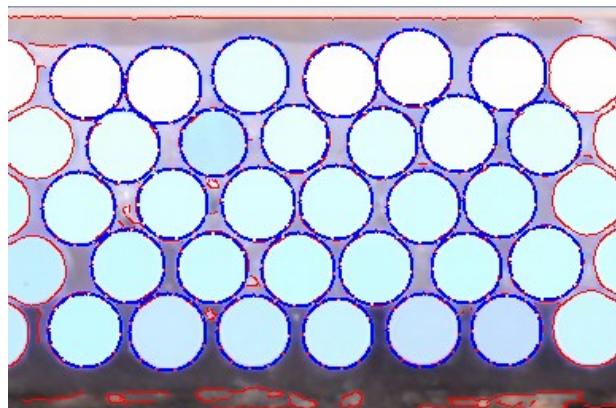
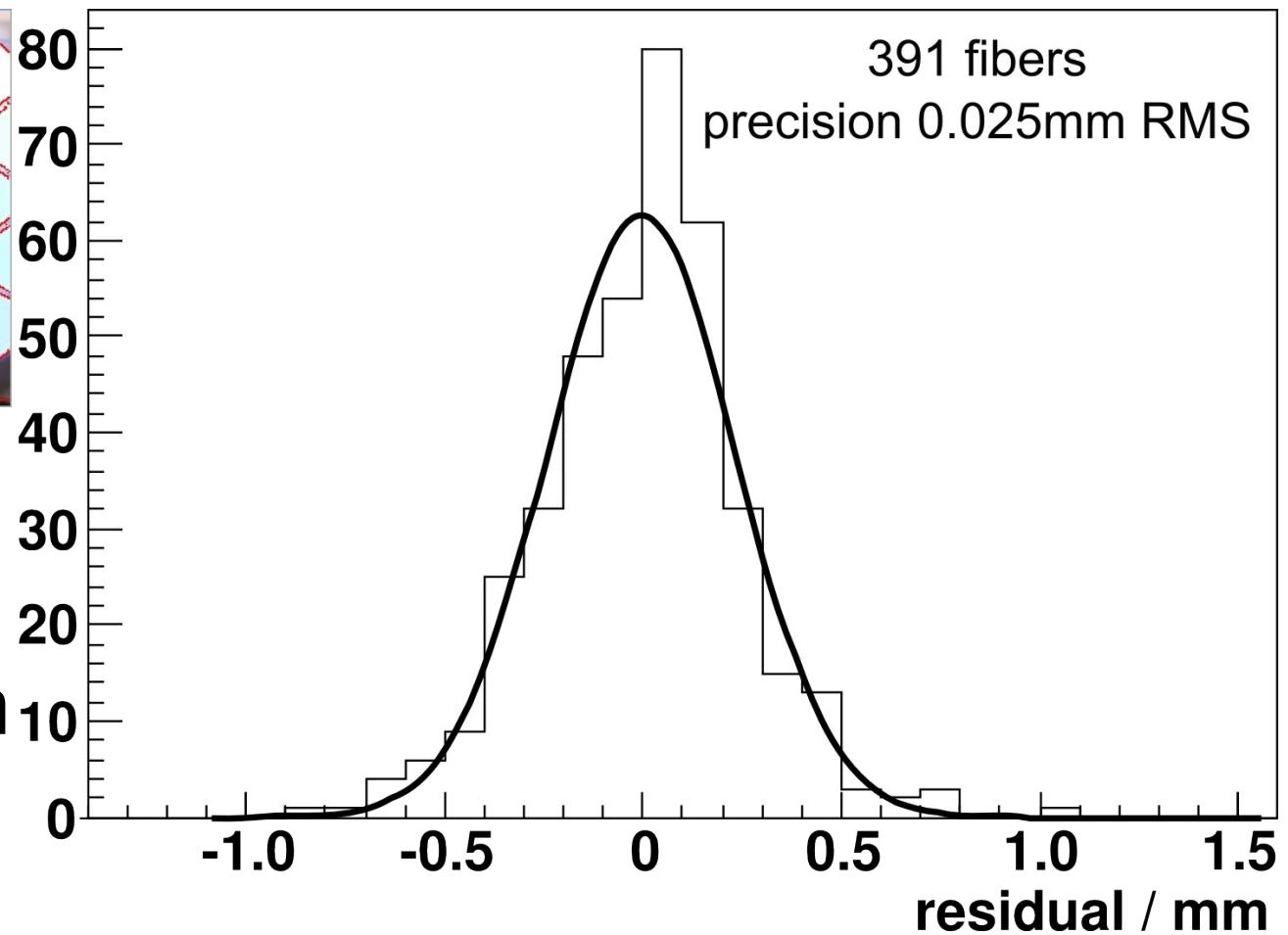


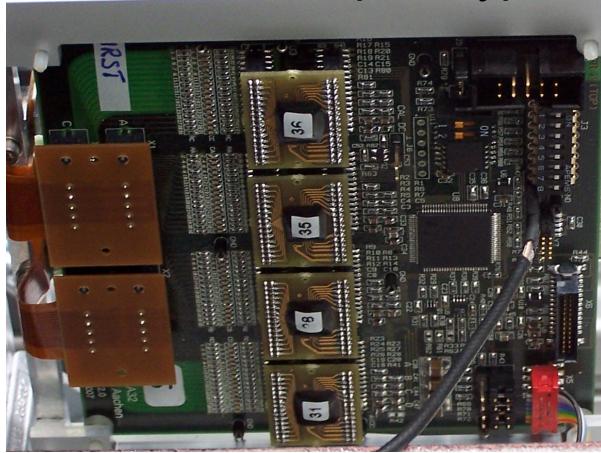
image recognition
software

- fibers placed with 0.025mm precision

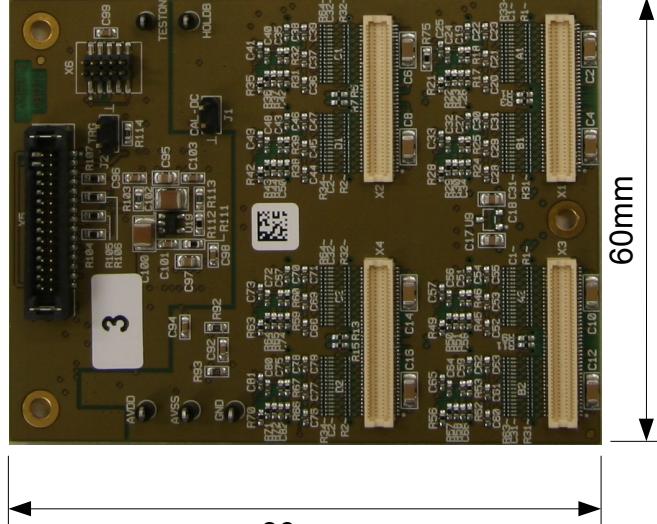


Frontend Electronics

HPE-VA128 prototype

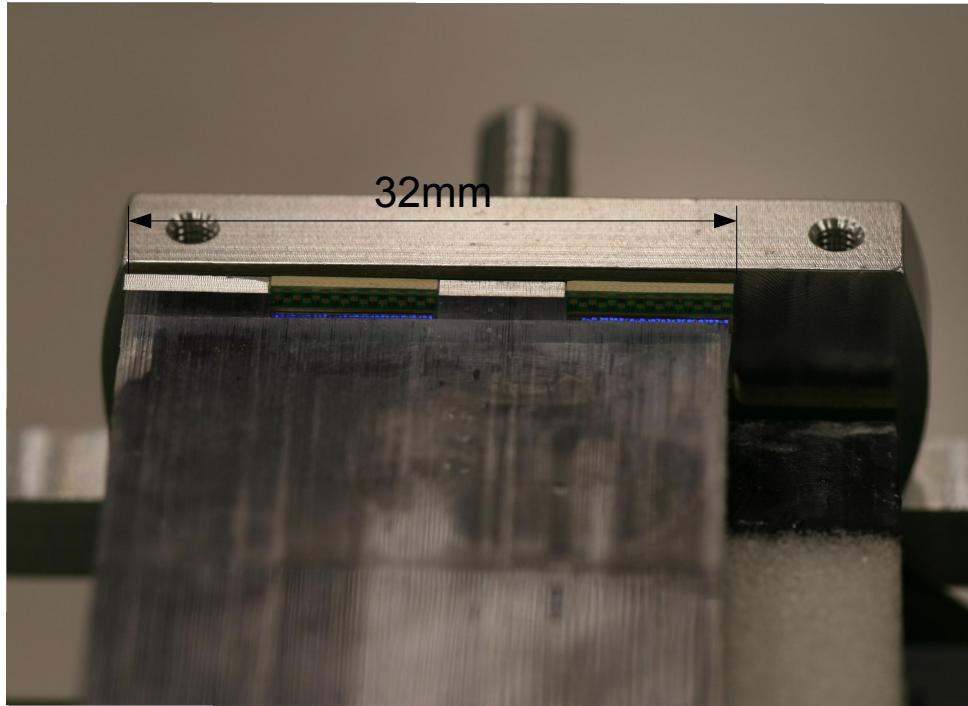


HPE-VA256rev1.0



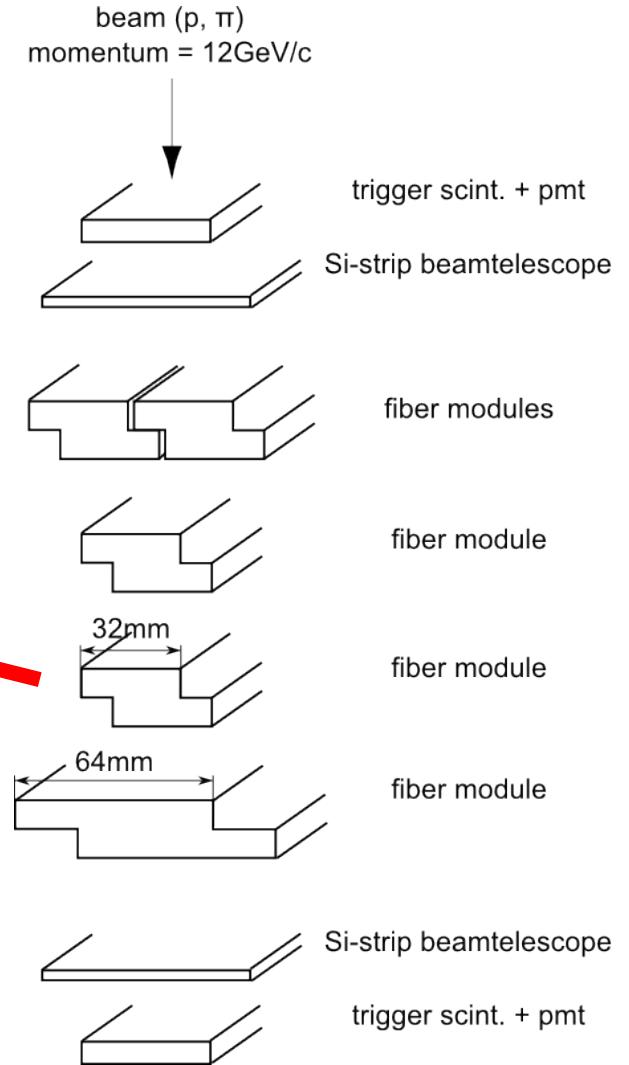
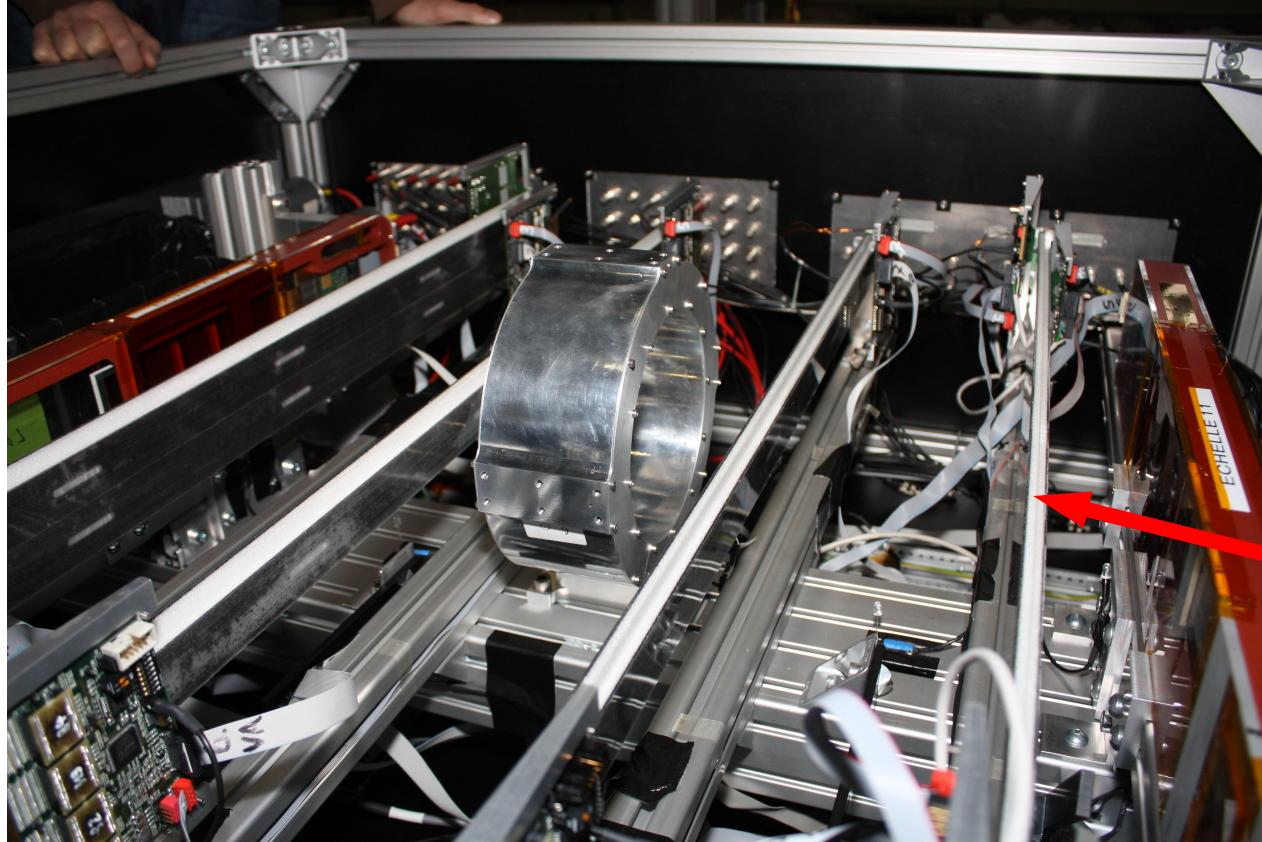
- frontend readout boards
 - IDEAS VA32/75
 - 36fC dynamic range = 0.2 p.e.
 - resistor network to attenuate the SiPM signal
 - 2.4mW/channel
 - IN2P3/LAL Orsay, SPIROC2
 - specifically for SiPM readout
 - adjustable gain
 - 2mW/channel
 - DACs to adjust bias voltage per array

Prototypes, Autumn 2009

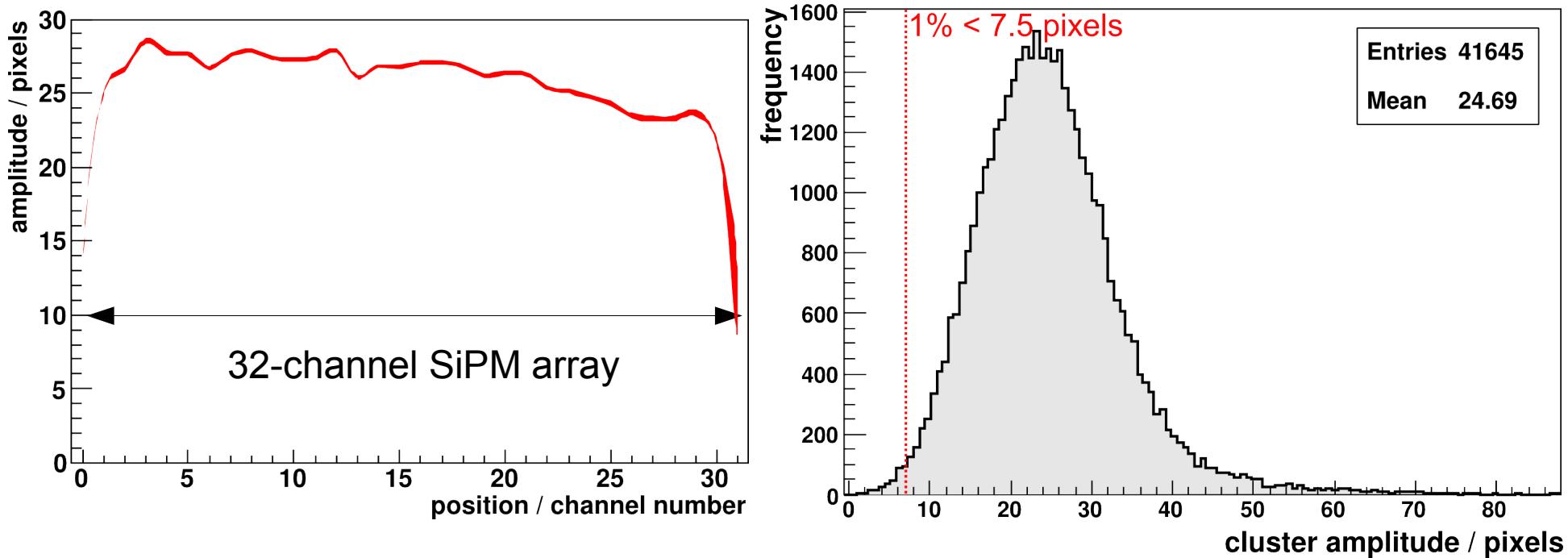


- 5 modules
 - different fiber types
 - Kuraray SCSF-78MJ
 - Kuraray SCSF-81M
 - readout ASICs
 - VA32/75
 - SPIROC1
 - optical grease
 - OC-459
 - OCK-451

Testbeam at PS, CERN

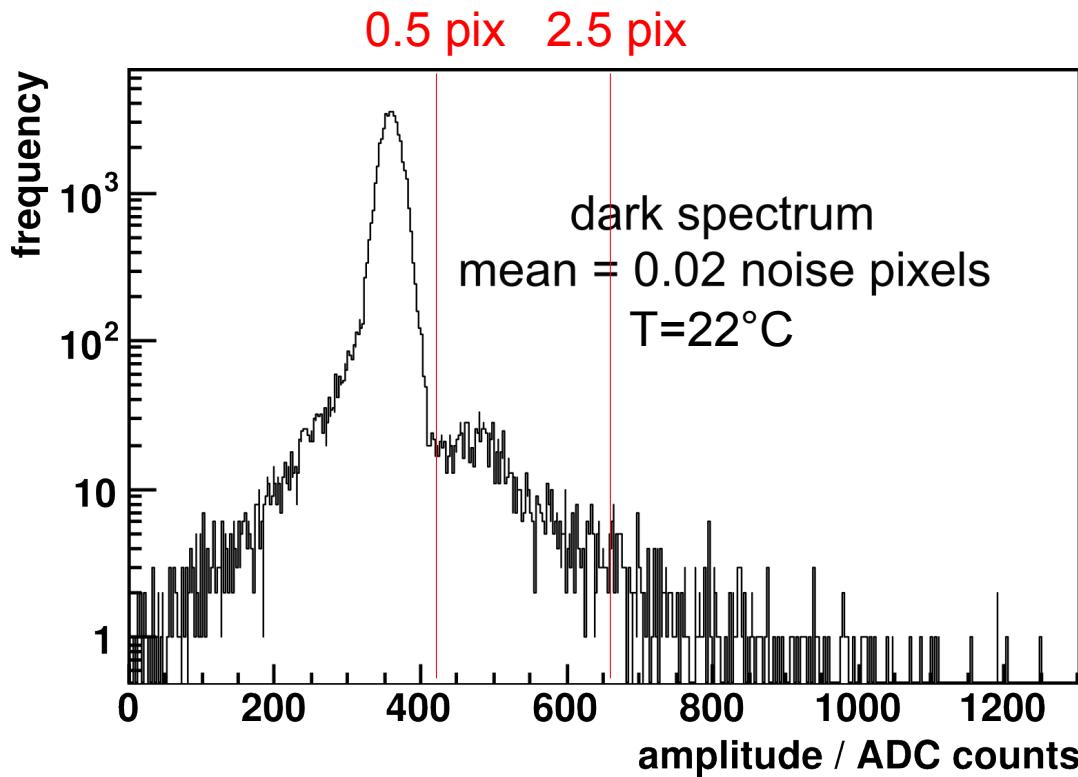


Measured Light Yield



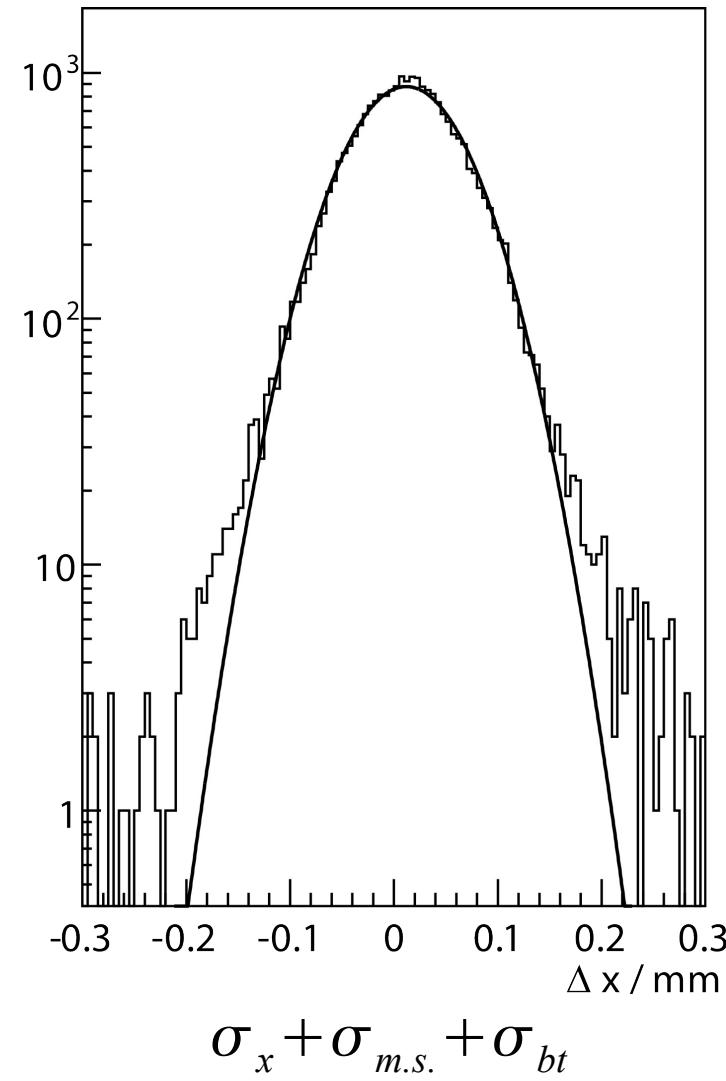
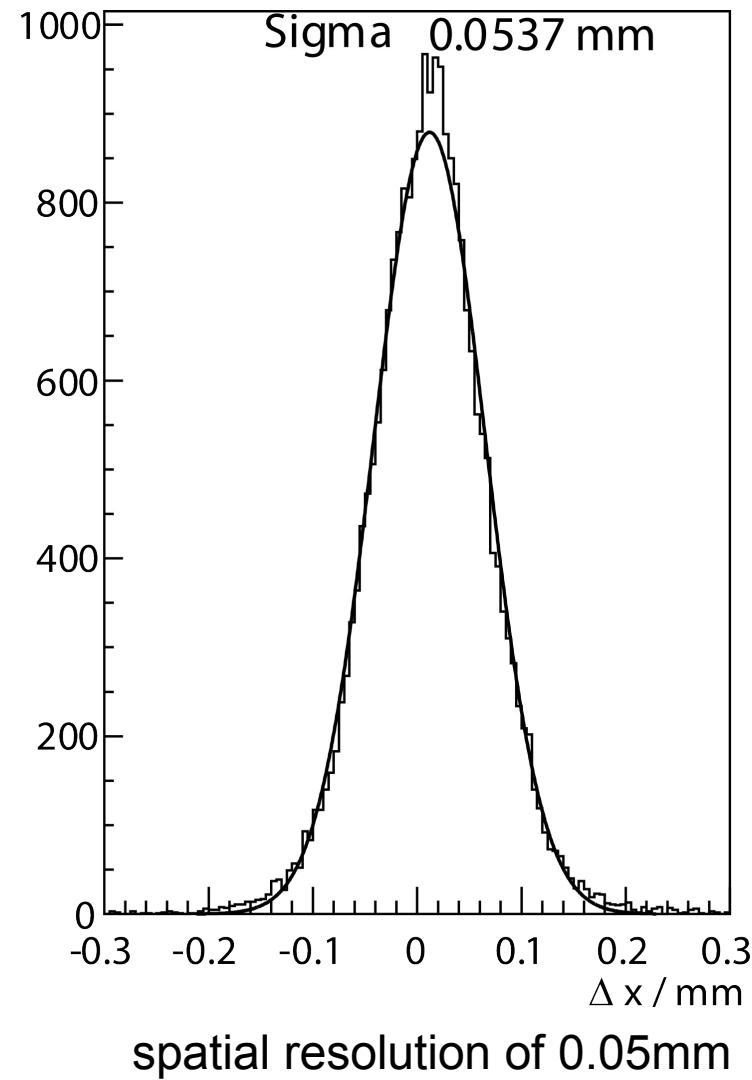
- ~25 pixels fire for every MIP
- = 18 primary photons + 7 crosstalk

MPPC5883 Noise Characteristics

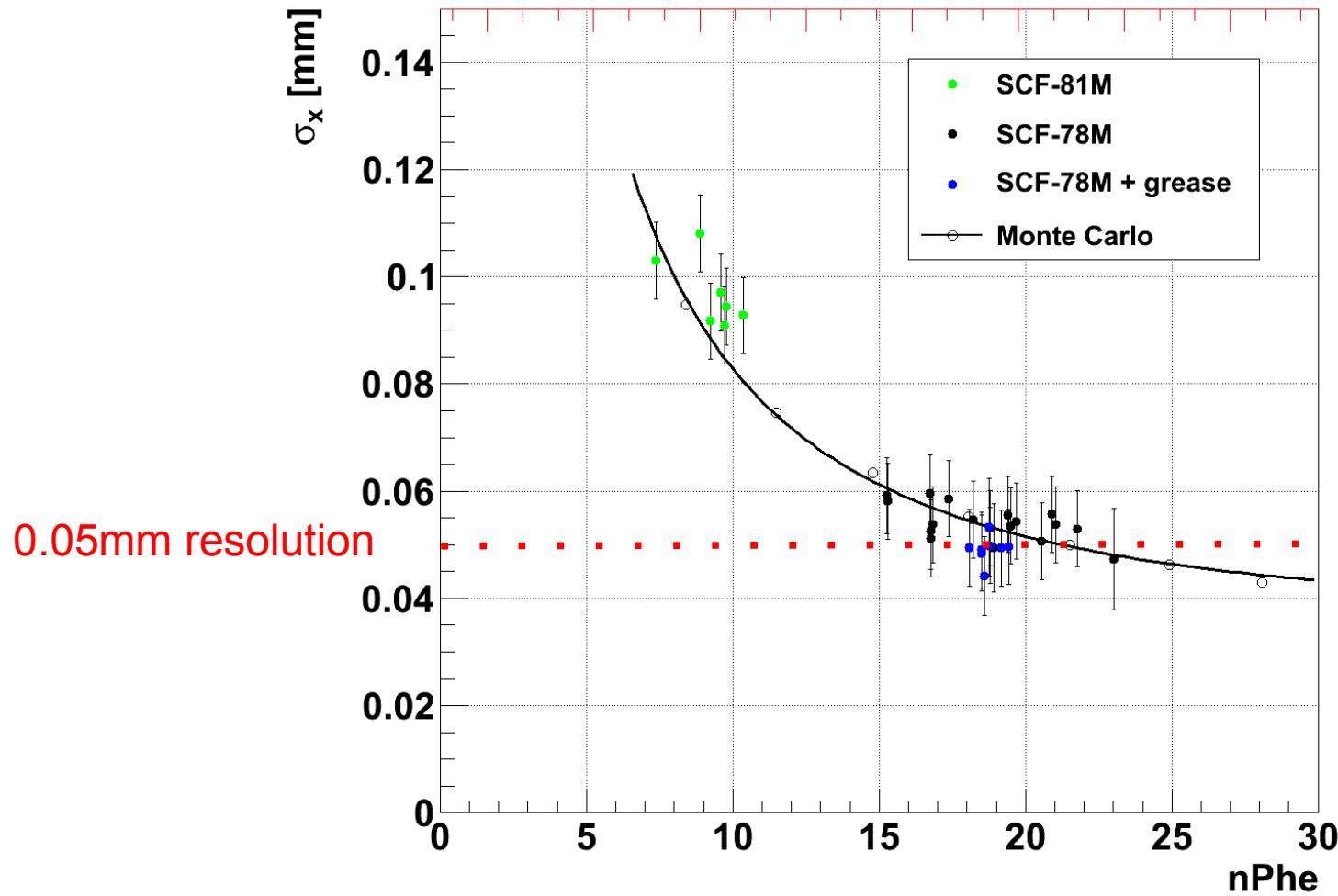


- noise occupancy
 - 10^{-2} for 0.5 pixel cut and room temperature
 - $\times 10^{-1}$ by cooling to 0°C
 - $\times 10^{-1}$ by cutting 2.5 pixels

Measured Residuals

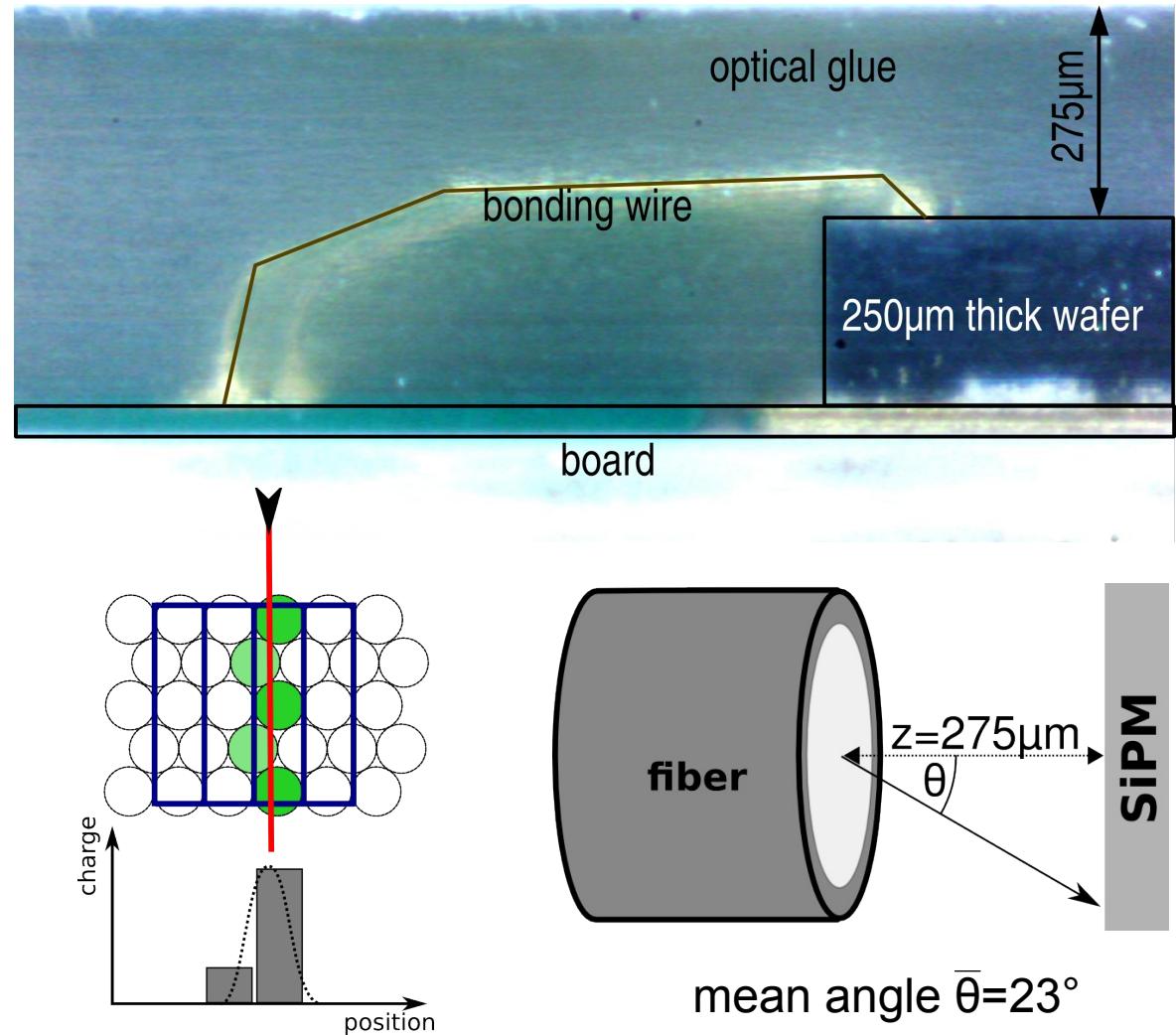


Measured Spatial Resolution



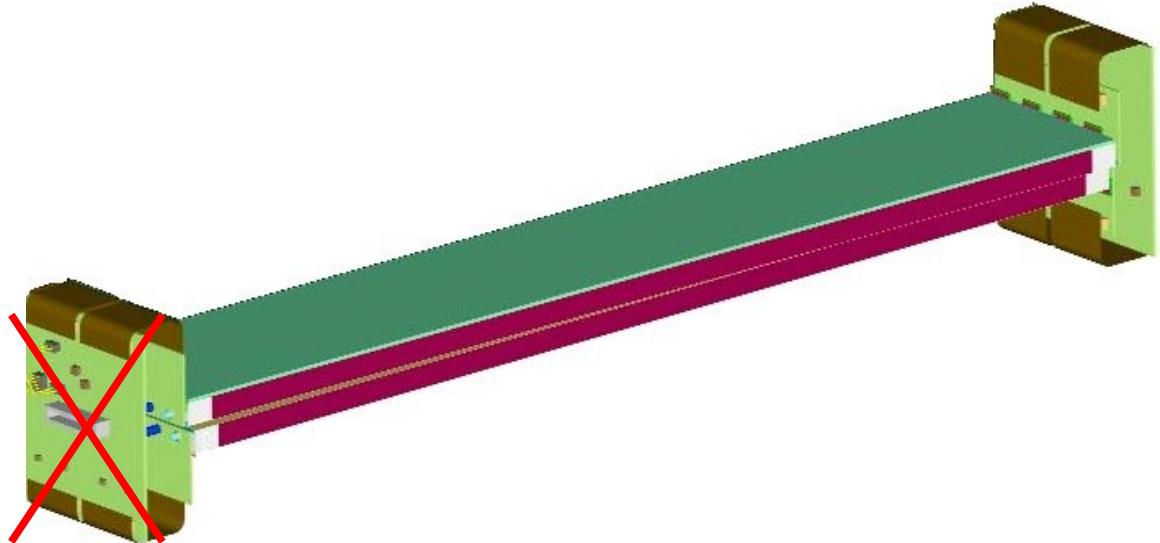
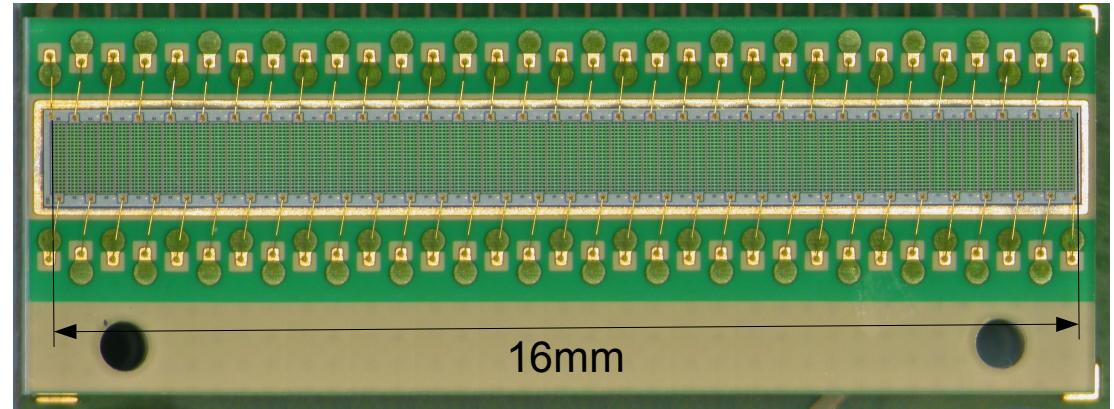
Improve Coupling to Fibers

- reduce gap between SiPM and fiber to $100\mu\text{m}$
 - Hamamatsu already delivered new arrays
- expect improved resolution of $\sim 0.04\text{mm}$

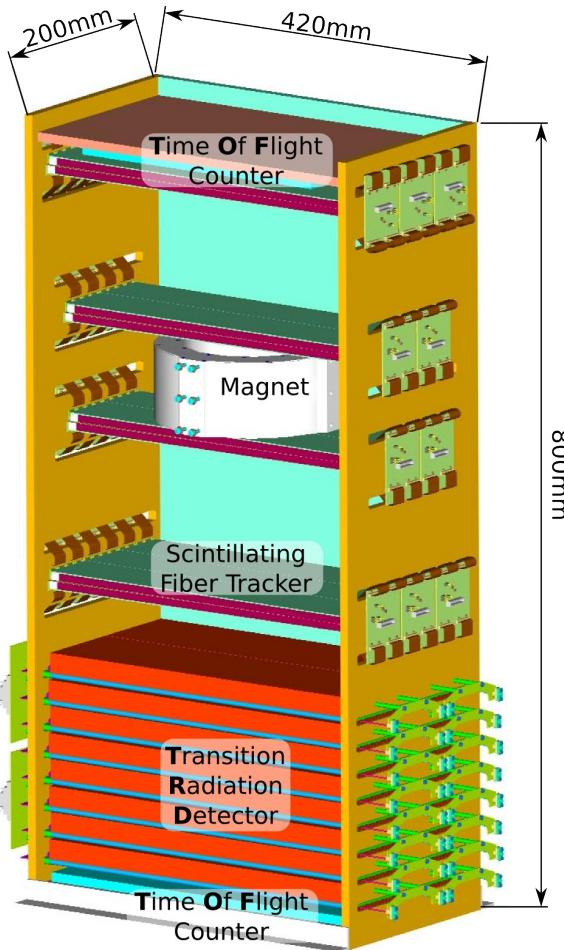


Improved SiPM Arrays

- simplify fiber readout
 - larger arrays
 - 64 channels
 - $1.2 \times 16 \text{ mm}^2$
 - multiple arrays in single ceramic package
 - $<0.25\text{mm}$ dead area between arrays
 - active readout can be put on just one module end

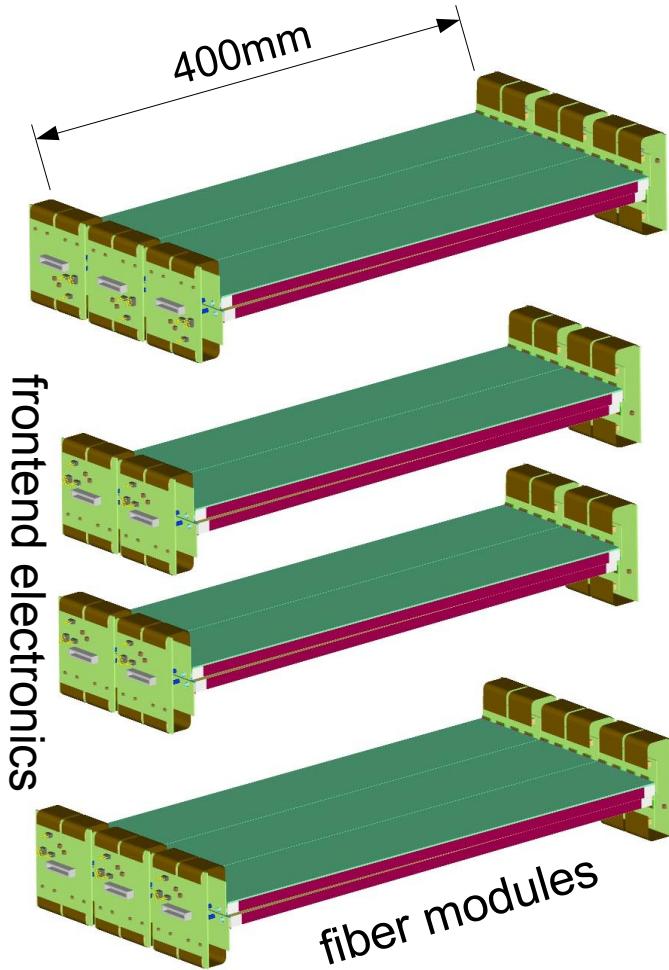


A Fiber Tracker For PERDaix



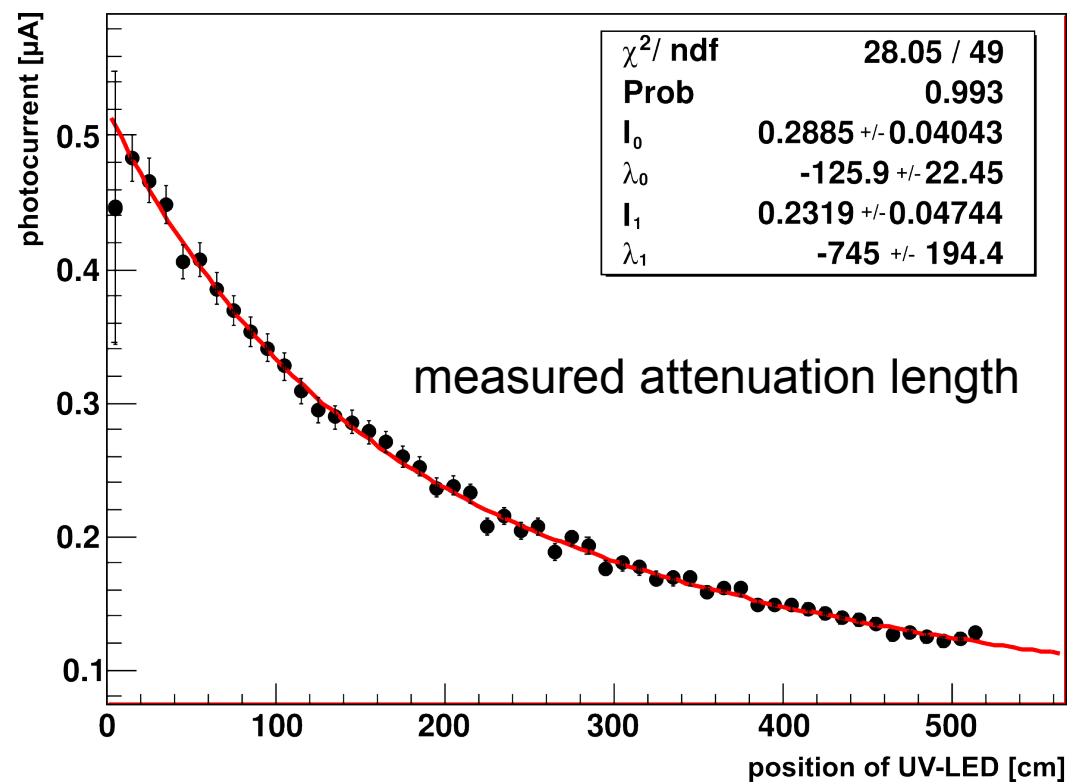
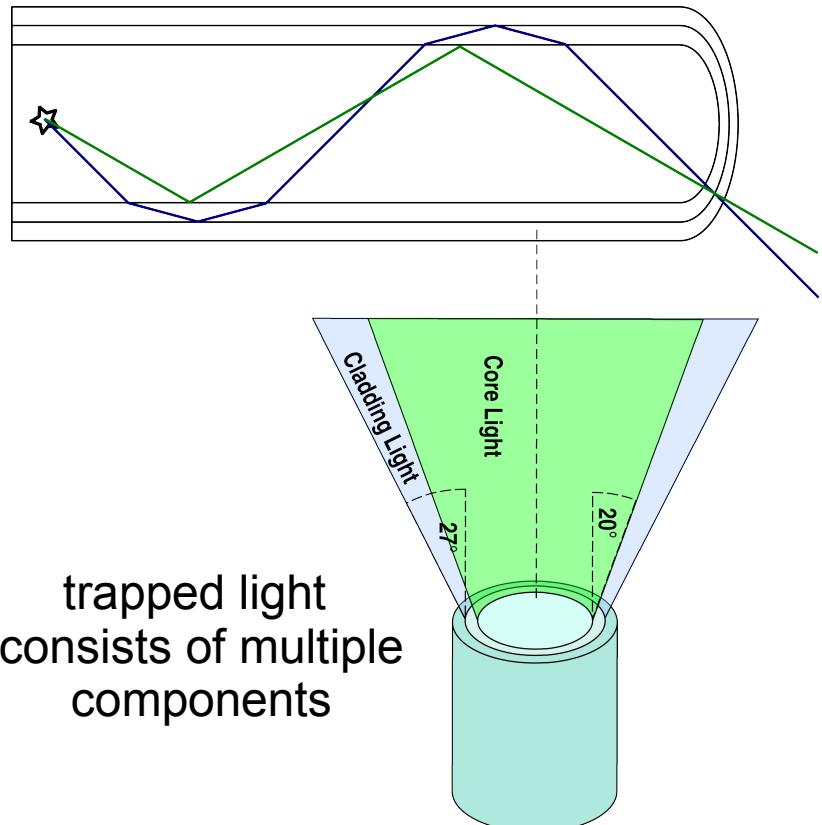
- Proton Electron Radiation Detector Aix-La-Chapelle
- balloon-borne spectrometer
- measurement of cosmic rays up to 5 GeV
- Launch in autumn 2010
 - balloon experiments for university students
 - programme by DLR / SSC

PERDaix Fiber Tracker



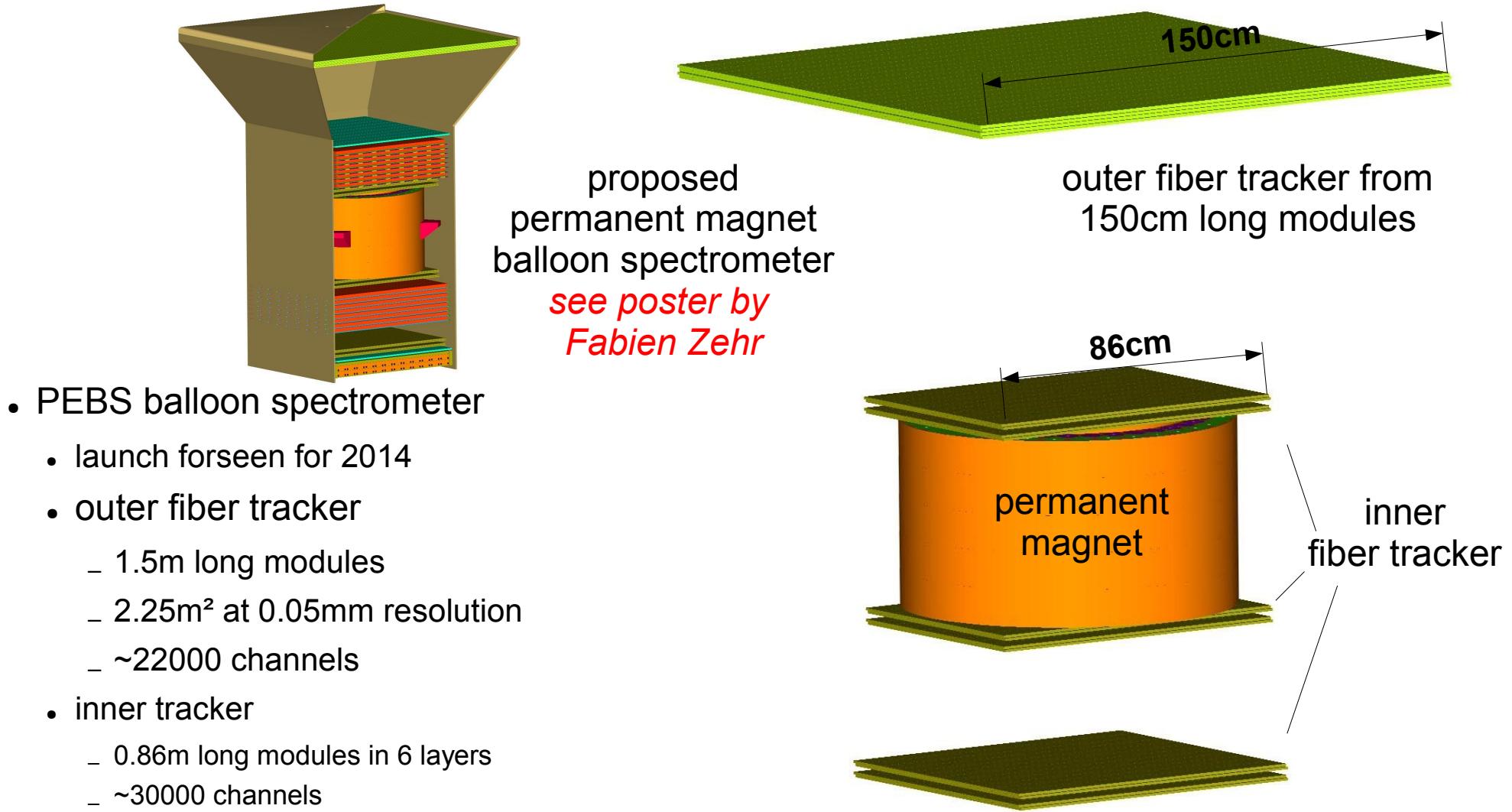
- 4 layers of stereo modules
 - 400mm long
 - 64mm wide
 - +/-1 degree stereo angle
 - <0.05mm spatial resolution
 - new SiPM arrays with reduced passivation layer
- VA32/75 based readout
 - 5000 channels
 - 25W total power

Fiber Attenuation Length

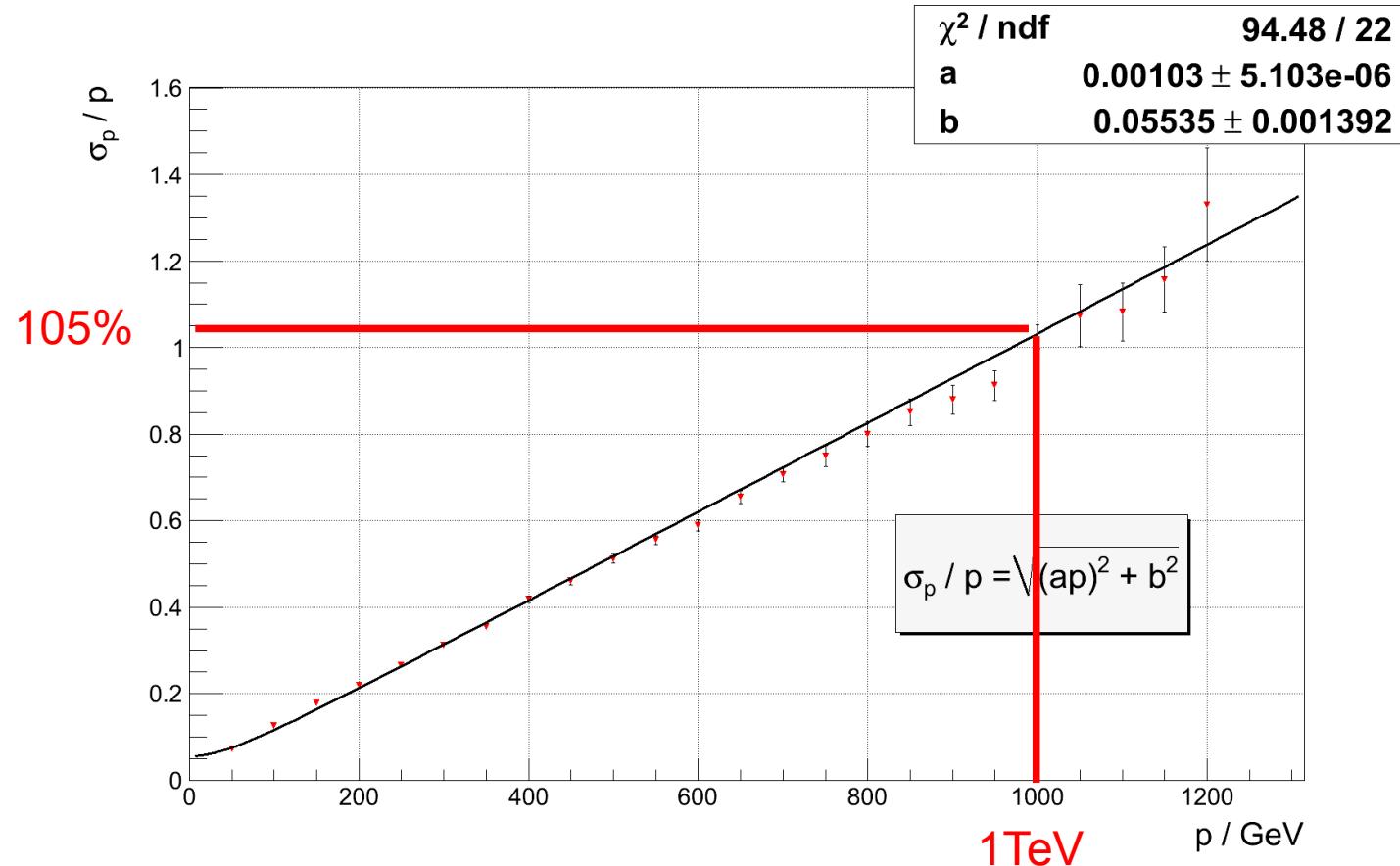


- long attenuation length allows for long modules
 - short range component (~50%): $\lambda=1\text{m}$
 - long range component (~50%): $\lambda=7\text{m}$

Large Fiber Trackers



PEBS momentum resolution



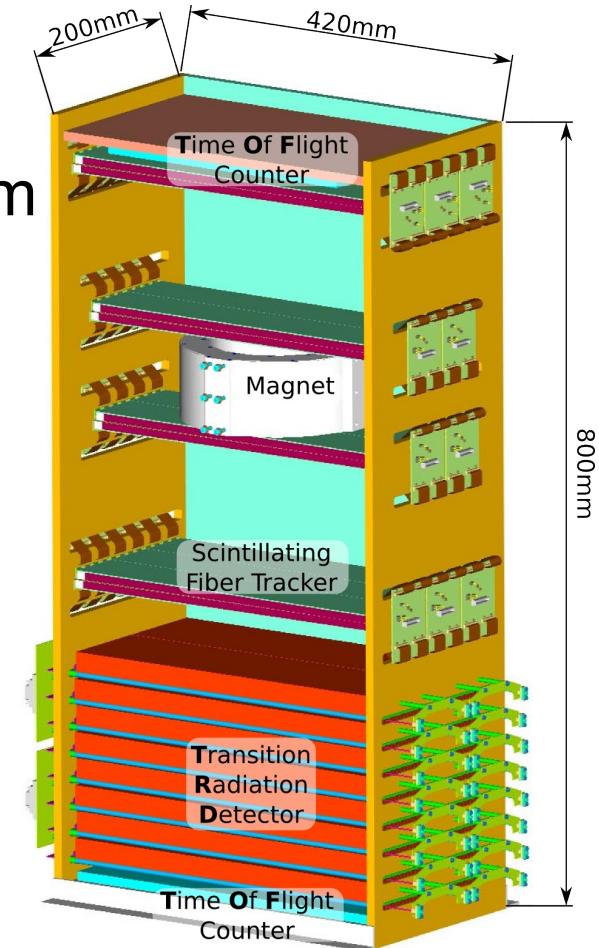
- excellent momentum resolution (MDR $\sim 1\text{TeV}$) due to large lever arm of outer fiber tracker

Pros & Cons

- fibers are cheap
 - $\sim 0.2\text{€}/\text{m} = \sim 5\text{k€}/\text{m}^2$
- long modules
 - few readout channels per area
- low overhead
 - no gas, no HV, no cooling (of fibers)
- robust
 - magnetic fields, temperature
- SiPMs are not that cheap (yet)
 - $\sim 10\text{€}/\text{channel}$
- long modules
 - low readout granularity
 - bad for high occupancy
- radiation hard ???
 - after 10^{10} n/cm^2 SiPM noise will significantly increase ($\times 10^2..10^3$)

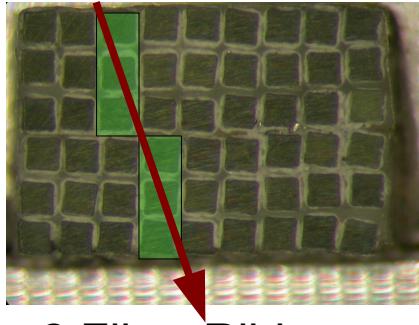
Conclusion & Outlook

- single point resolution 0.05mm
 - optimized SiPM/fiber coupling → ~0.04mm
 - increase SiPM readout granularity → ~0.03mm
- module size up to 64mm × 860mm
 - → ~200mm × ~2000mm
- development for future detectors
 - LHCb upgrade
 - PEBS balloon spectrometer

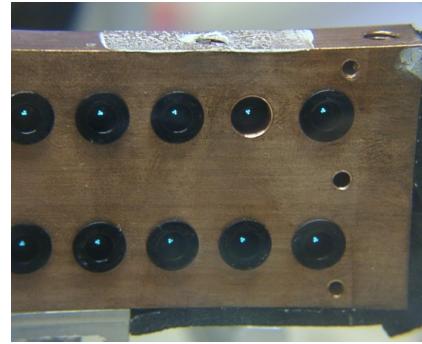


The PERDaix experiment using our scintillating fiber tracker launches in autumn 2010

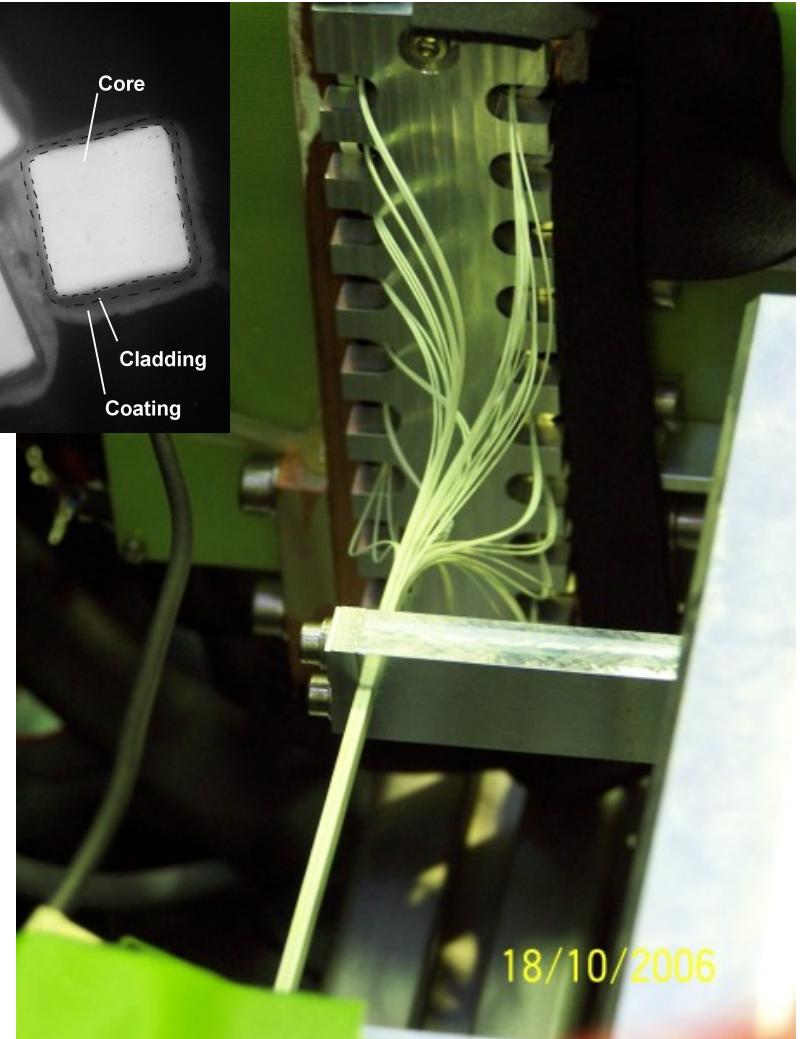
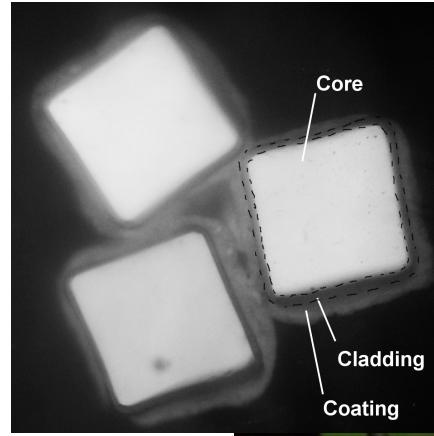
2006



2 Fiber Ribbons

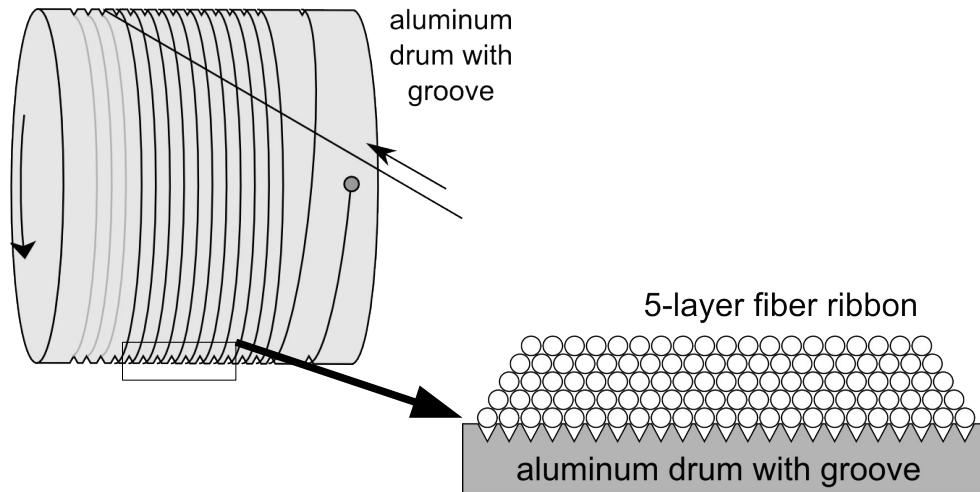


SiPM connectors

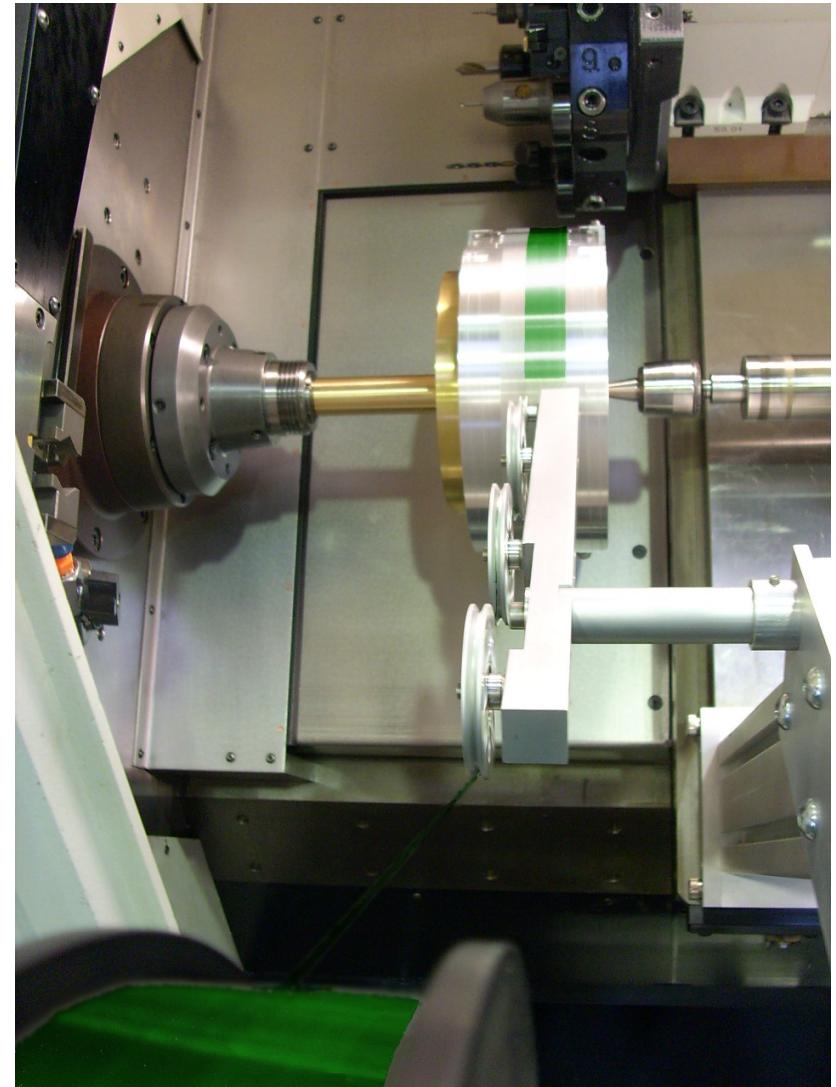


First prototype

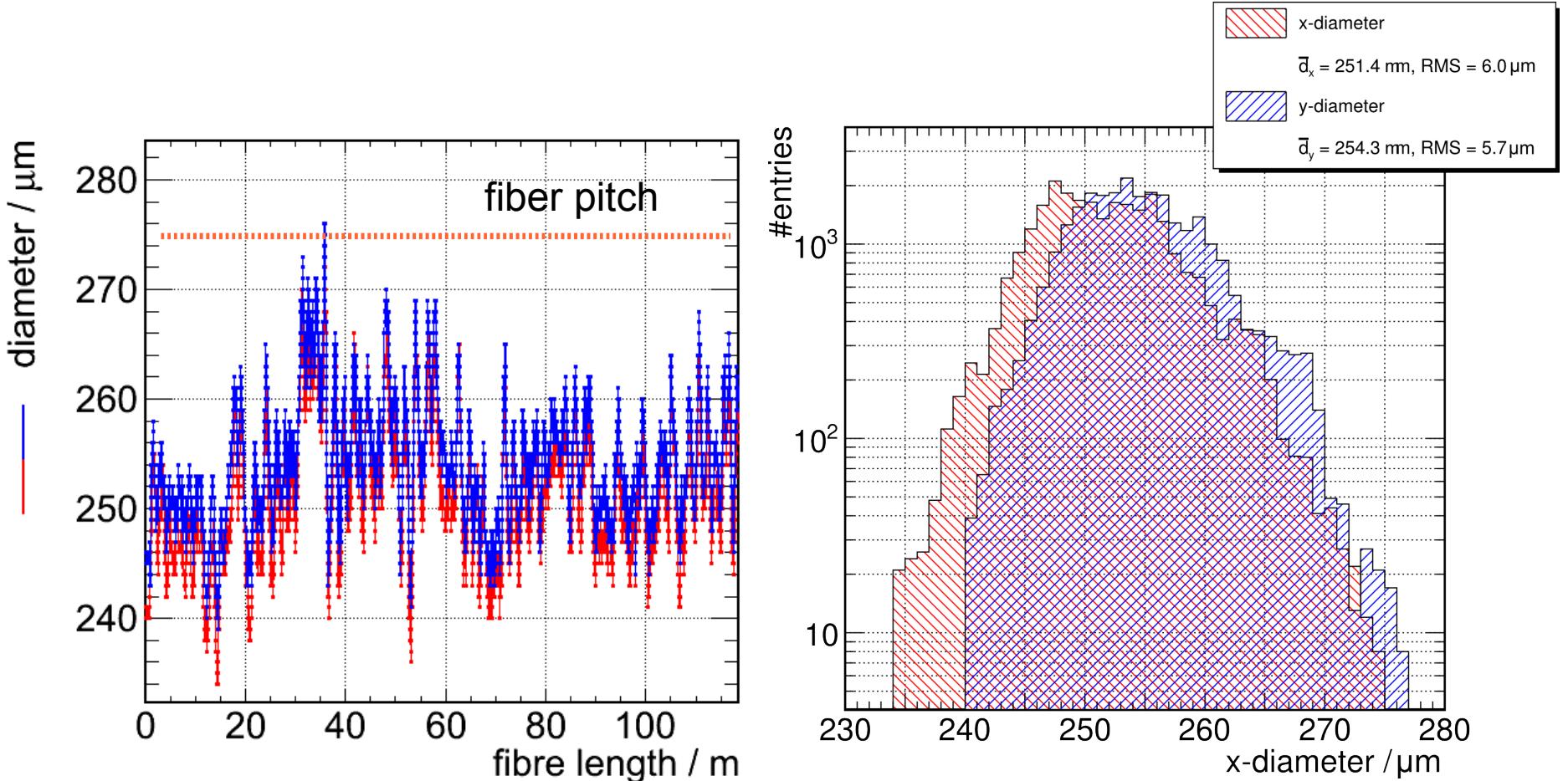
Fiber Ribbon Production



- fiber ribbon quality depends on:
 - fiber tension
 - fiber diameter
 - homogeneous distribution & curing of glue

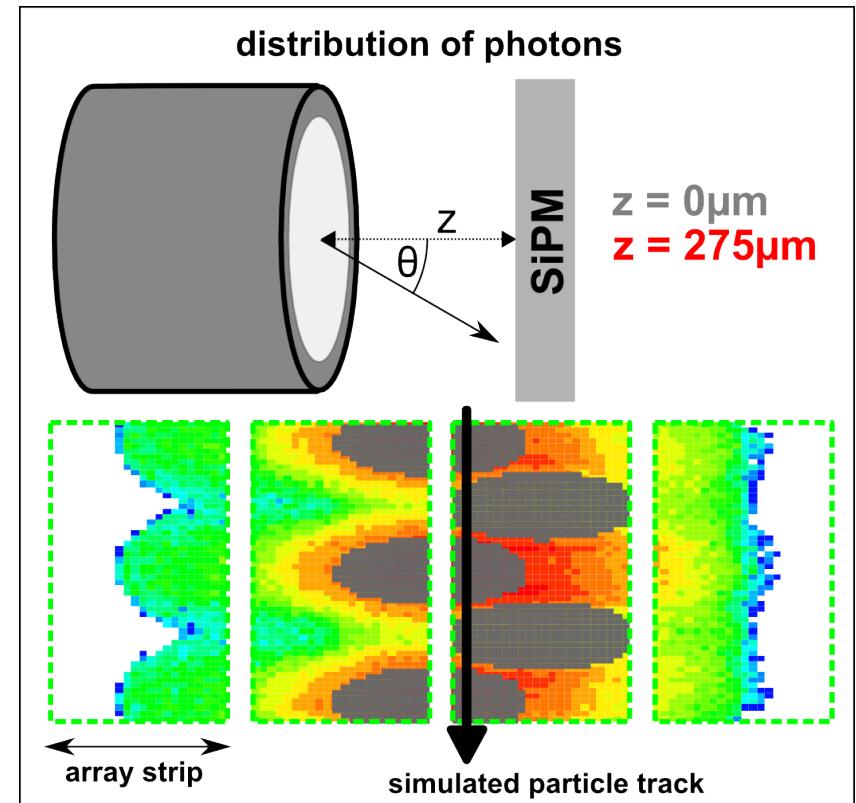
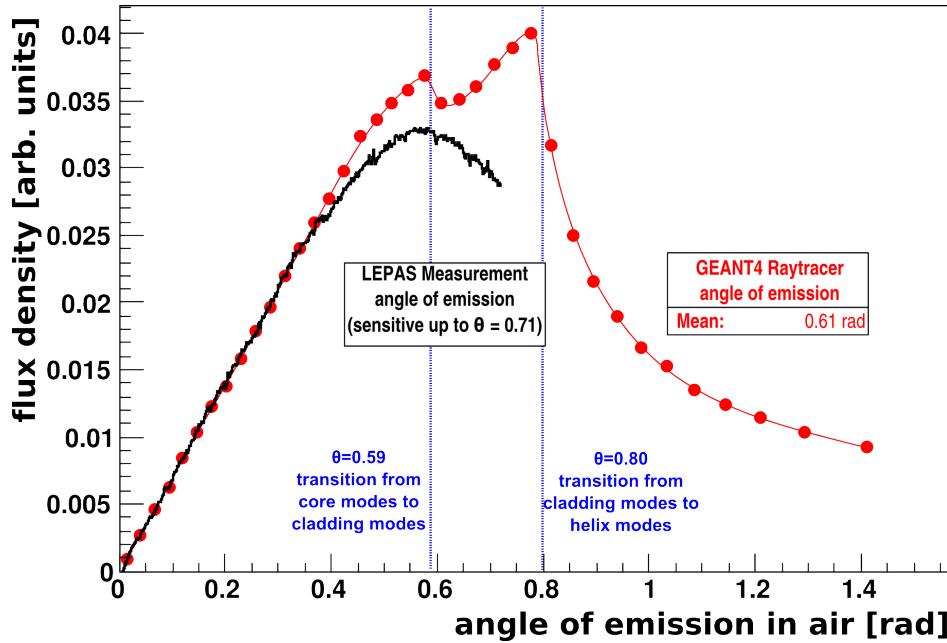


Variations in Fiber Diameter

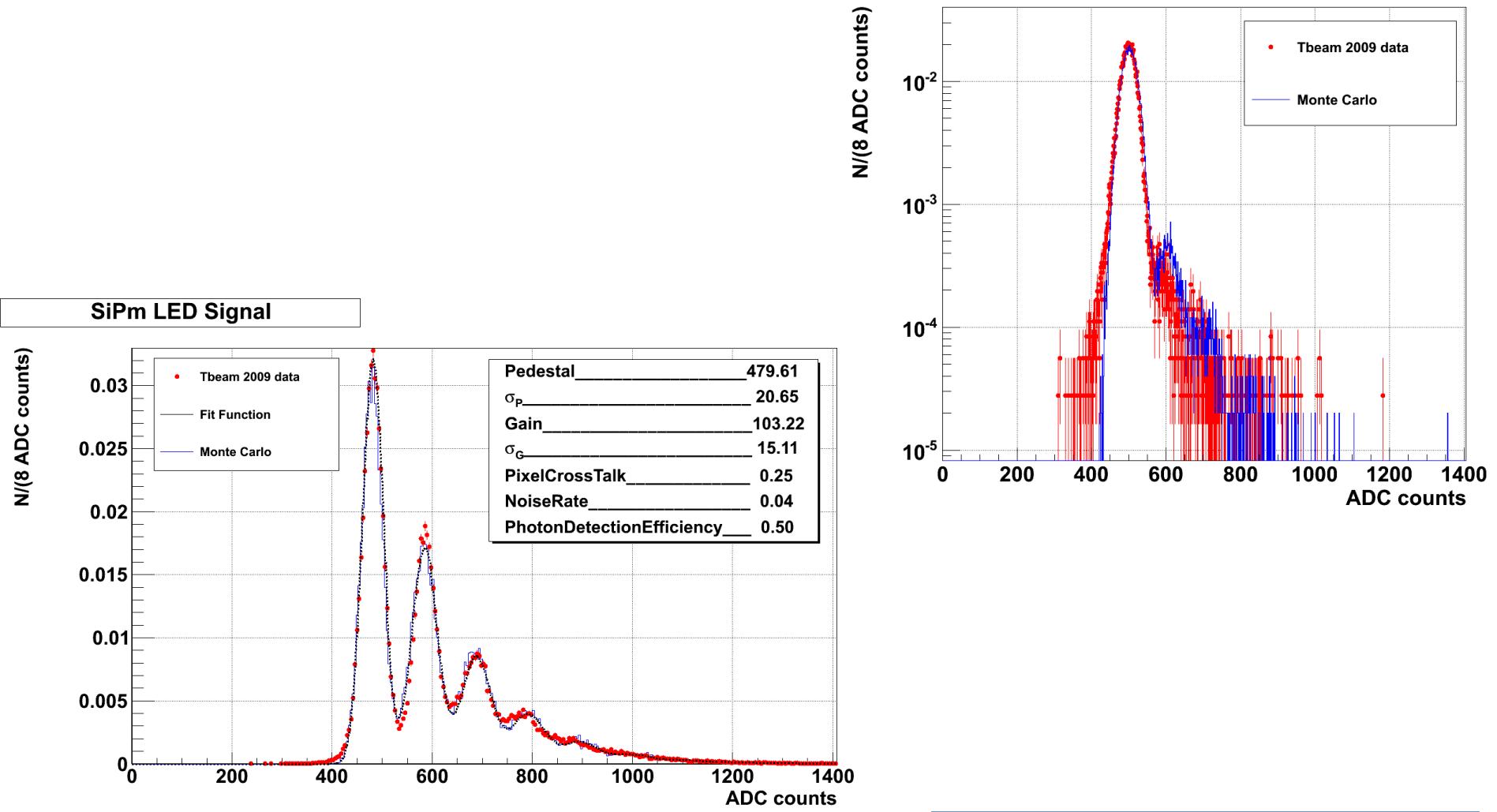


- cause defects in fiber ribbon
- reduce light trapping efficiency

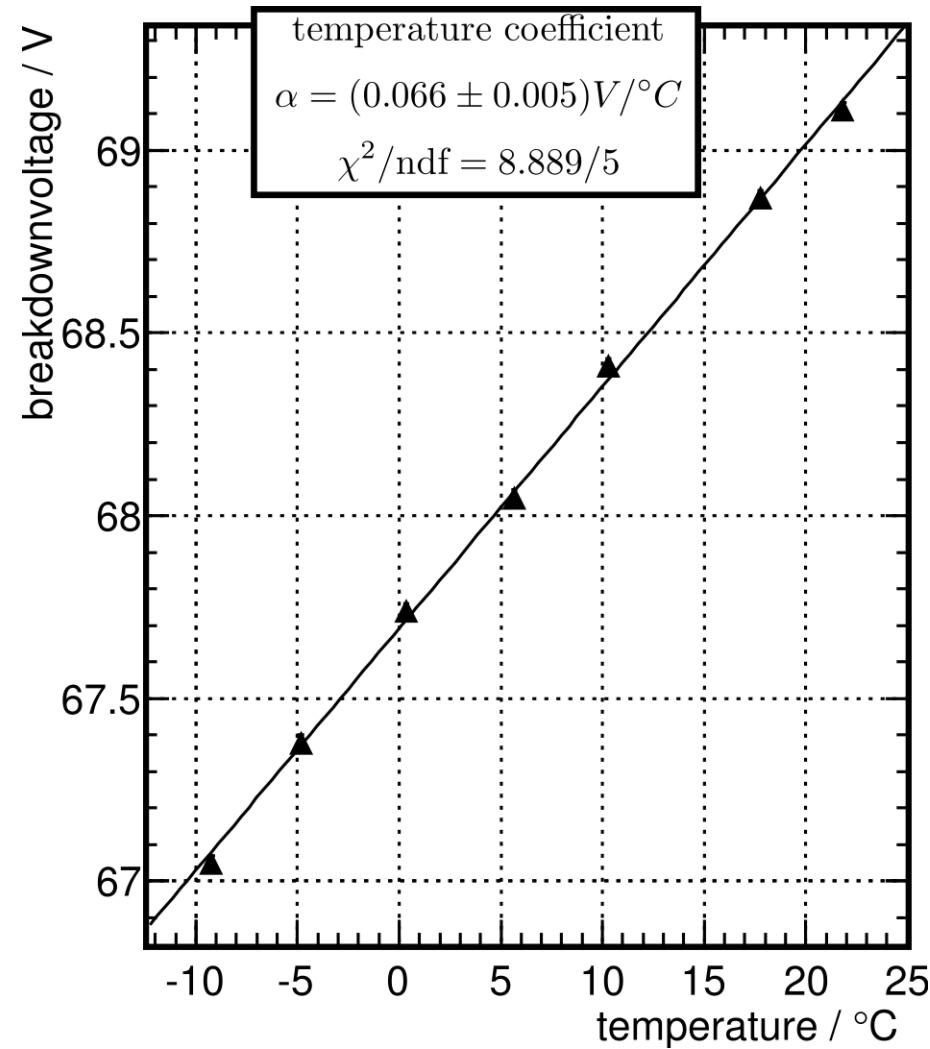
SiPM Coupling



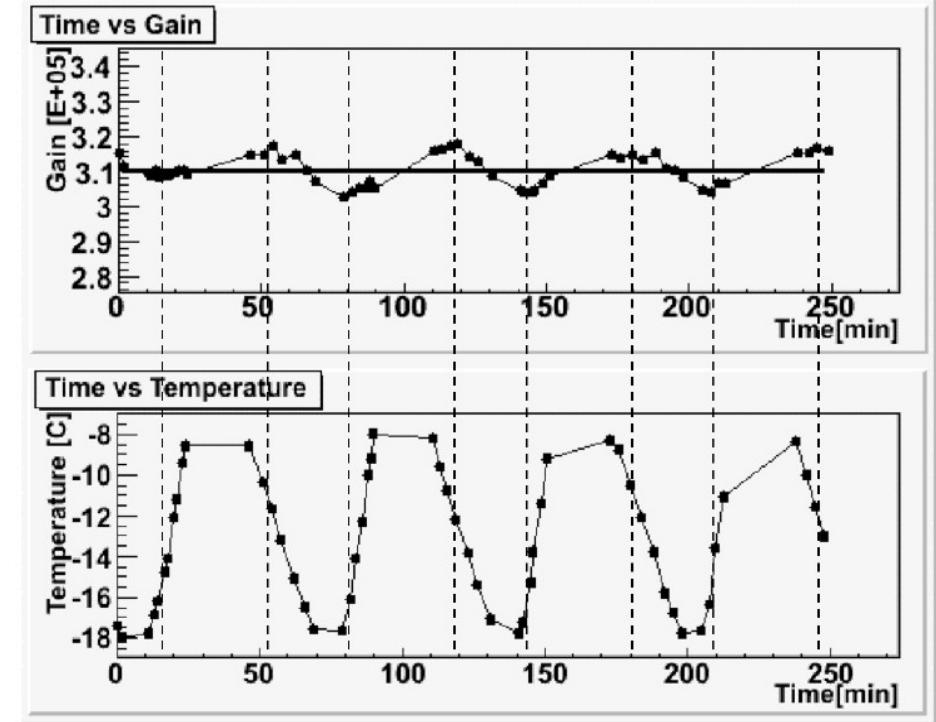
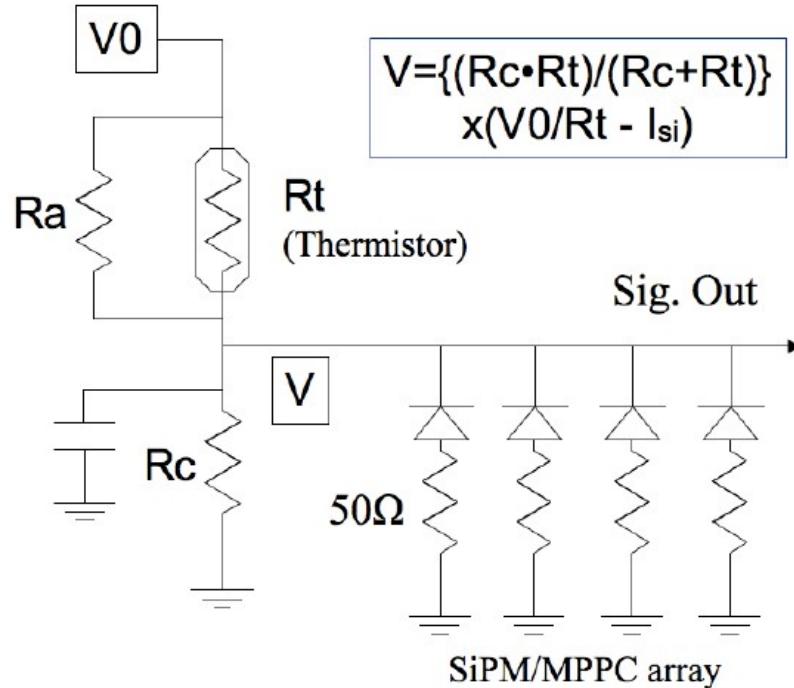
SiPM Array Calibration



Temperature Coefficient MPPC5883



Temperature Stability



- Miyamoto et al. (*PROCEEDINGS OF THE 31st ICRC, ŁODZ 2009*)
- <10% gain variation for $\Delta T=10K$

Perspectives

- development of tracker for LHC upgrade
 - LHCb outer tracker
- build large fiber modules
 - increase max. length to ~2m
 - increase max. width to ~500mm
- increase SiPM readout granularity
 - push single point resolution to ~0.03mm