CpFM for UA9

Cherenkov detector for proton Flux Measurements

Véronique Puill

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LAL proposal: Cherenkov proton counting detector

Initial idea belongs to the PNPI group and it had been already tested in SPS

Aim: count the number of protons with a precision of about **5%** in the LHC environment (mean value over several bunches)

Constraints at the LHC:

- inside the primary vacuum (10^{-9} mbar) → no degassing materials
- very hostile radioactive environment → radiation hardness of the detection chain
  → readout electronics at 300 m
- small place available → compact radiator inside the beam pipe
  → small footprint of the photodetector + cables + …. Inside the tunnel

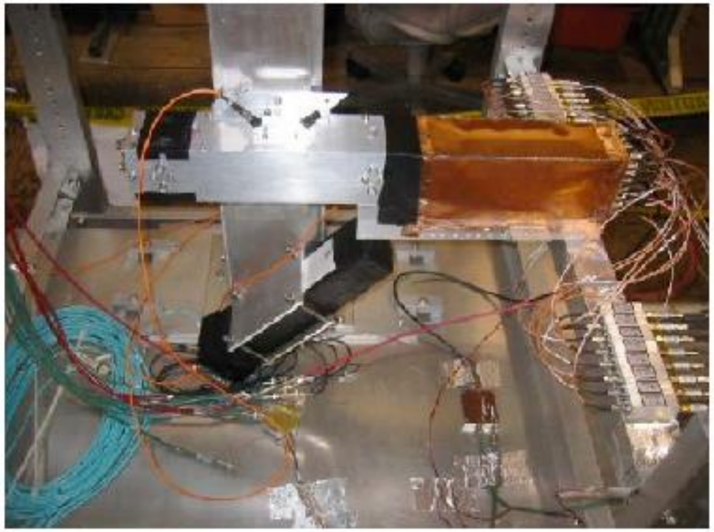
Our proposal:

- Radiator: **quartz**
- Photodetector: **PMT or SiPM**
- Readout electronics: **WaveCatcher**

CpFM
Cherenkov detector for proton flux measurements

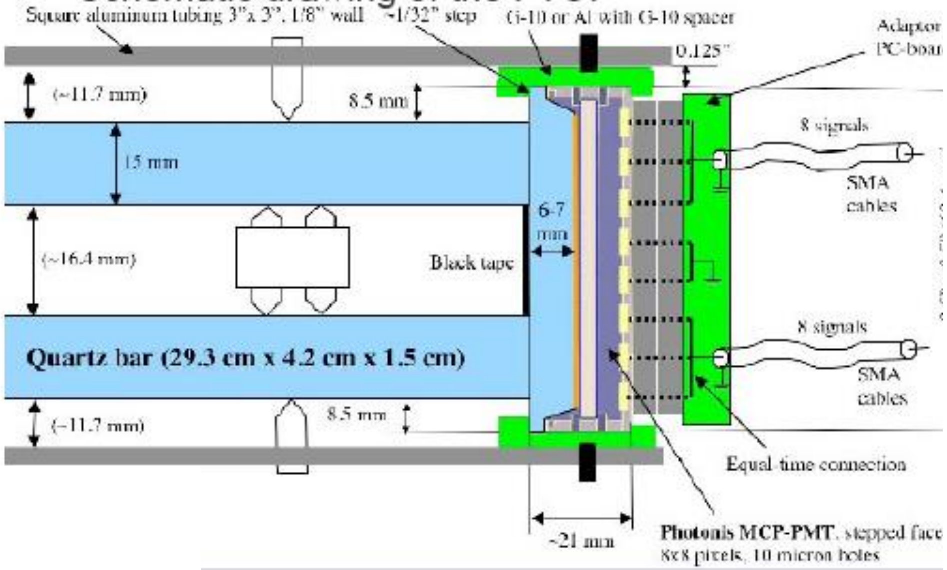
The LAL expertise in Quartz Cherenkov Detector

Prototype of the DIRC-like TOF detector

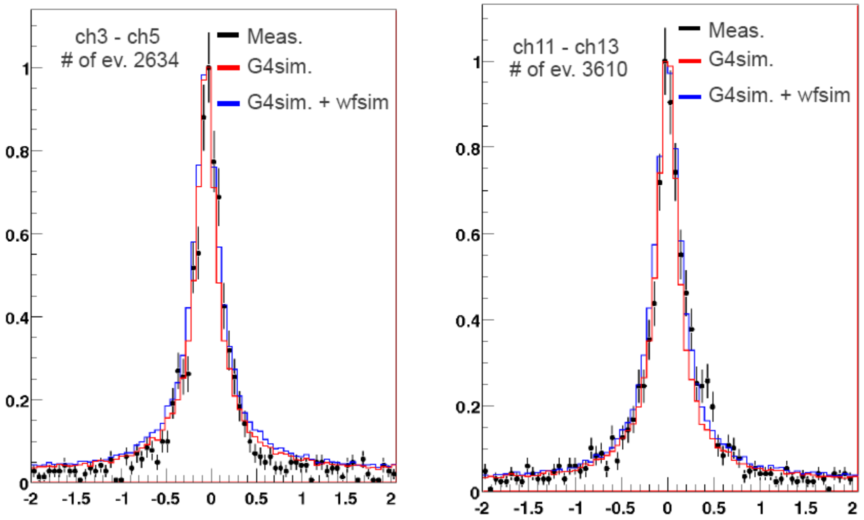


- Two quartz bars connected to one Photonis MCP-PMT (8x8 channels, stepped face, 10 micron holes).
- Tube operate at -2.7kV (gain ~ 7.0x10^5).
- 16 channels connected to the USBWC electronics developed by LAL and CEA/IRFU electronics team.
- Amplifiers (40dB).
- Filters (600MHz bandwidth).
- Installed at SLAC CRT in Fall 2010.

Schematic drawing of the FTOF



Time difference between not neighbor channels connected to same quartz bar. (type L3)

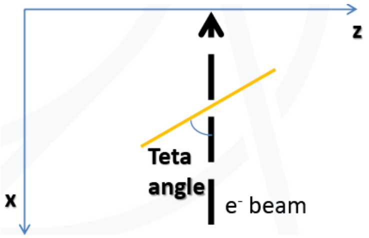


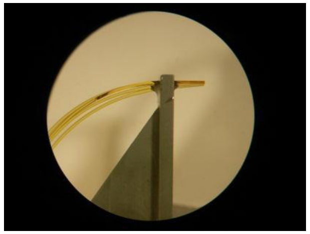
Average time resolution calculated using this type of time differences is ~110ps = **80ps/channel.**

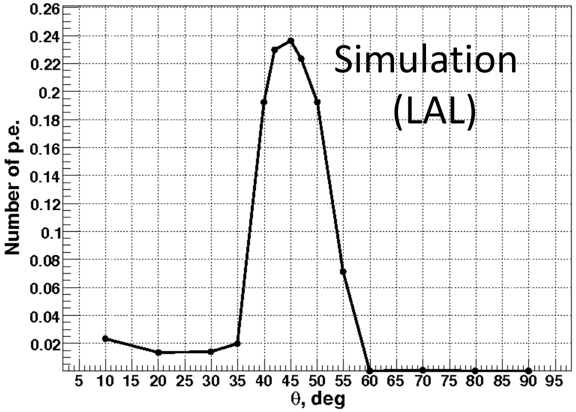
The LAL expertise in Quartz Cherenkov Detector

Study of Quartz fiber at BTF:

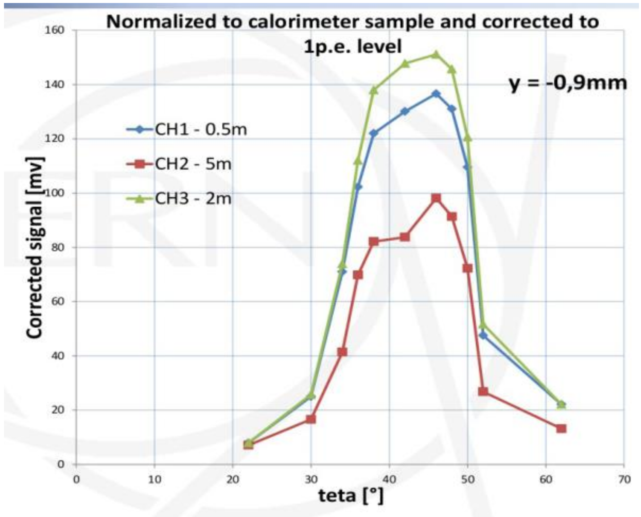
Simulation performed at LAL (L. Burmistrov)
Tests performed by the INFN team







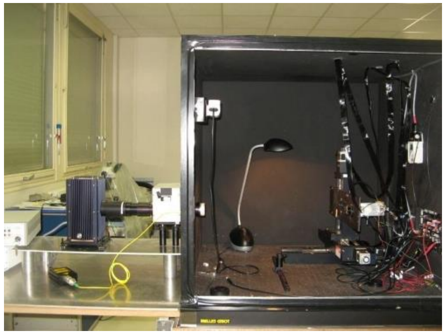
Simulation (LAL)

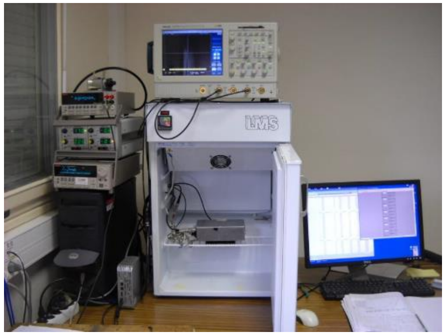


Measurements @ BTF (INFN)

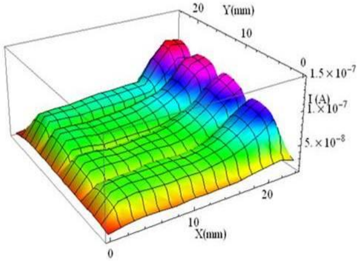
Detector testing devices at LAL

Optical Test benches for absolute calibration of photodetectors

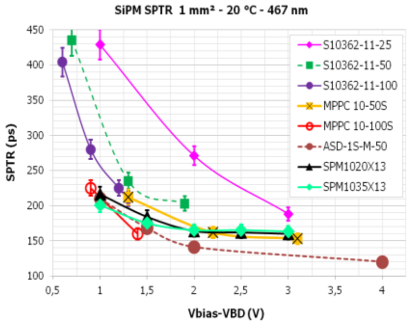




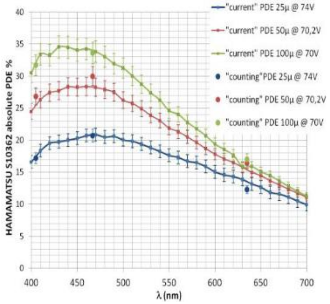
Mapping MCP-PMT signal 4 channels



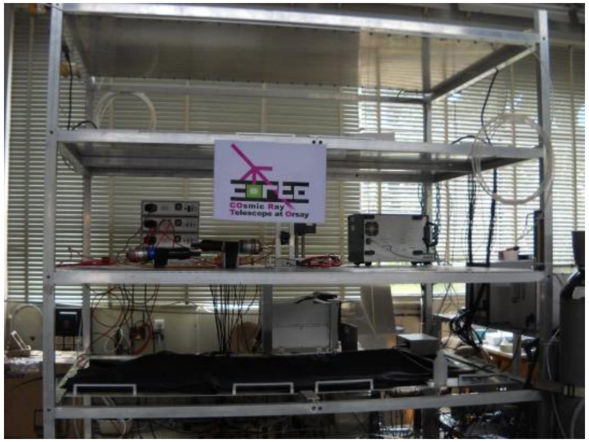
SiPM timing resolution



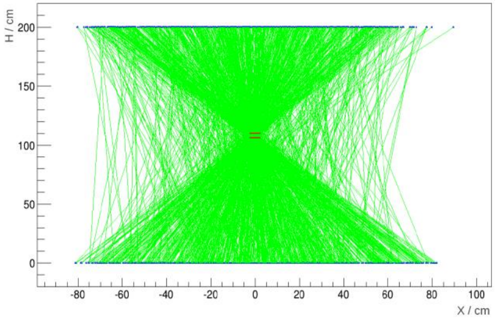
PDE SiPM



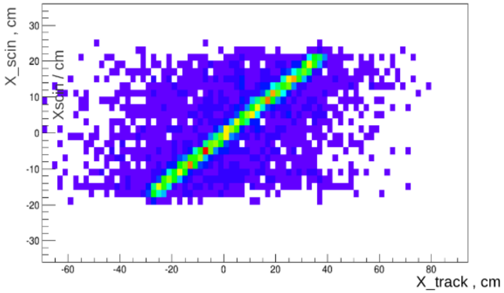
CORTO for the cosmic ray tests of detectors



Muons tracks passing through a detector

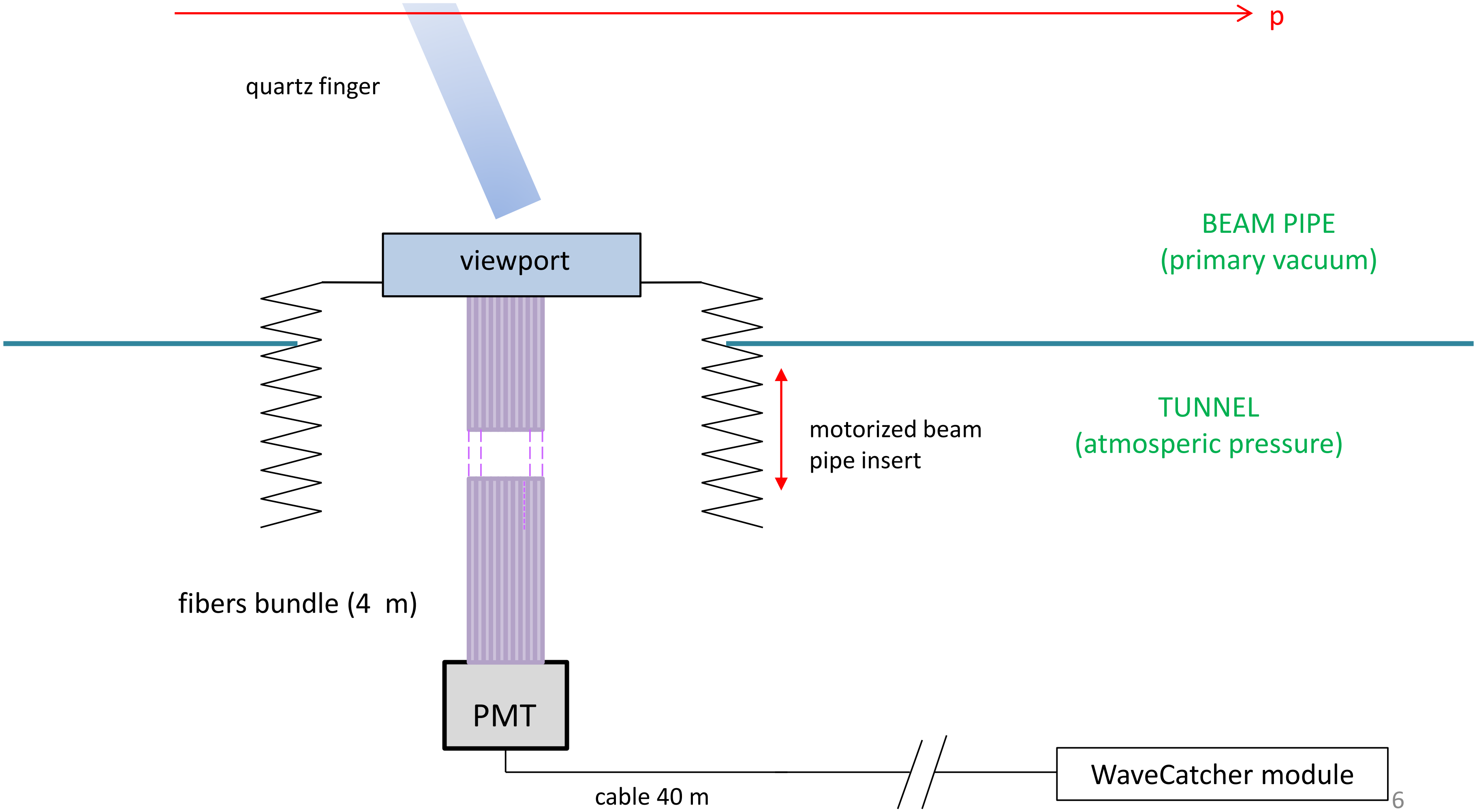


Scintillator image reconstruction



The CpFM concept for the SPS

1. interception of the channeled beam by a quartz radiator (retractable finger)
2. emission of Cherenkov light readout by a PMT placed 1 m from the beam pipe (light brought by silica fibers 4 m long)
3. PMT signal readout by the WaveCatcher module 40 m from this position



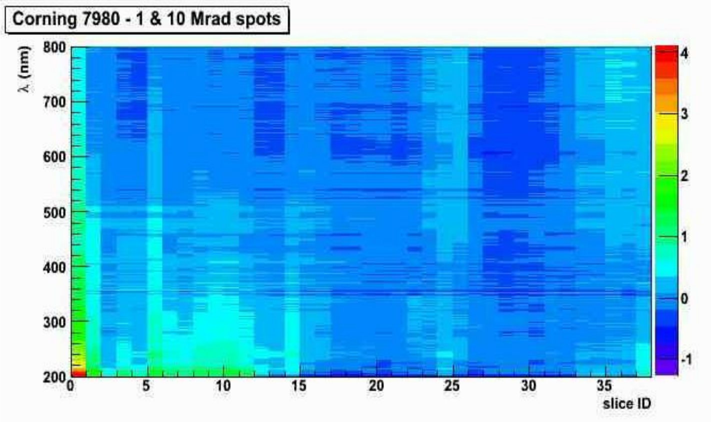
Radiation hardness of the CpFM components

Radiation levels close to the pipe: γ dose = 10 Mrad/year

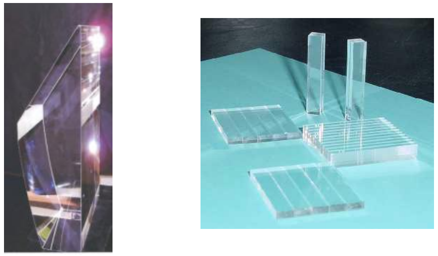
thermal neutrons fluence = 10^{14} n/cm²/year

protons fluence = 10^{13} p/cm²/year

Quartz radiation hardness



M. Hoek, RICH 2007



3 fused silica types (Corning 7980, Schott Lithosil Q0, Heraeus Suprasil 1) irradiated with 150MeV **proton** beam with dose levels: 100krad, 1Mrad and 10Mrad

→ **No significant radiation damage observed in any fused silica sample**

γ **Irradiation** (^{60}Co) with a dose of 11 MGy (1100 Mrad) : **stability of the samples** Heraeus Suprasil Standard & Infrasil, Spectrosil A and B (Saint-Gobain) and Corning 7940

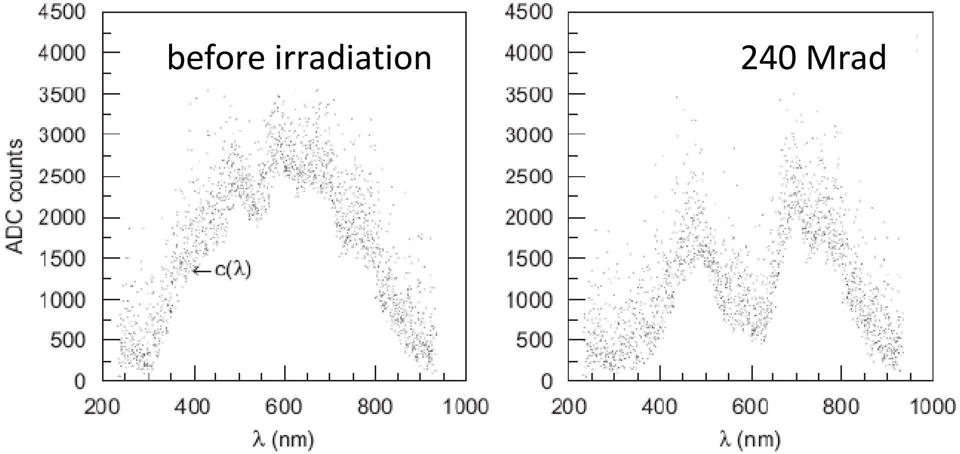
Our choice: Corning 7980 & Heraeus Suprasil

Backup choice: Sapphire

Radiation hardness of optical fibers

Studies of radiation hardness of fibers (WLS, pure quartz, …): upgrade of ATLAS HCAL, ATLAS LUCID, upgrade of CMS Hadronic Endcap

Irradiation with protons

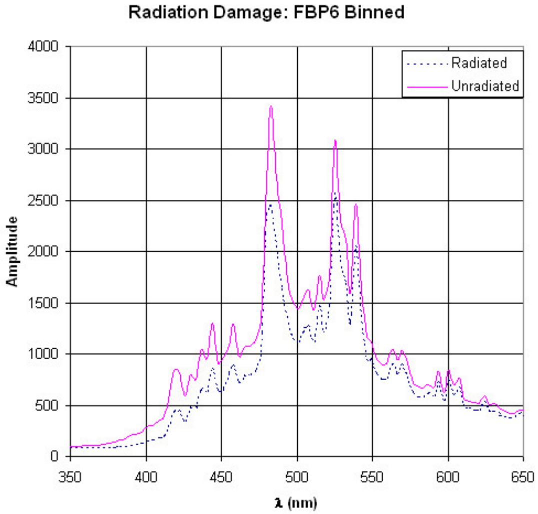


transmitted light spectra from a 1.25m of qq fiber

U. Akgun, CALOR 2008

➡ « Best » results with fiber with quartz core and quartz clad

Irradiation with γ and neutrons

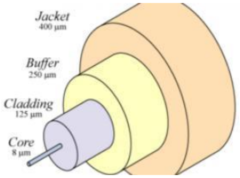


P. Bruecken

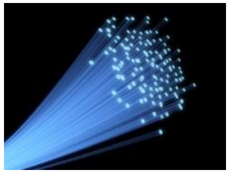
FBP 600-660-710 spectra before and after irradiation : 17.6 MRad of n and 73.5 MRad of γ

⚠ Measurement after irradiation performed 10 weeks after it ….

Good candidate: LEONI all silica fiber:



core 600 µm
attenuation @350nm <=0,06dB/m
operational in 200-1200 nm range
18 rad/s (0.3 rad/s LHC worst)

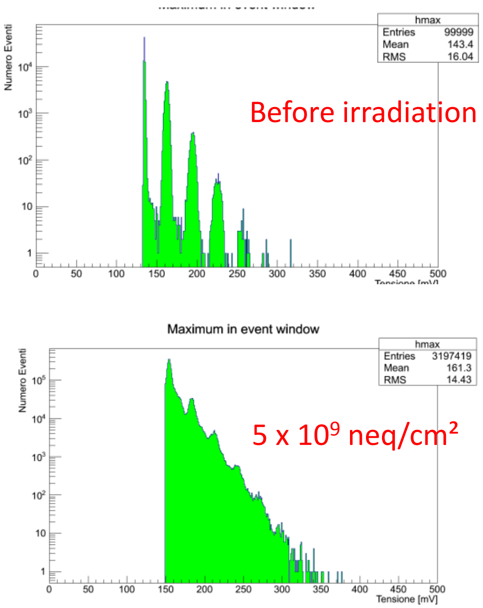


Why not SiPM as the photosensor ?

protons / neutrons
bulk damages caused by lattice defects

γ-rays, X-rays
creation of trapped charges near the Si-insulator interface

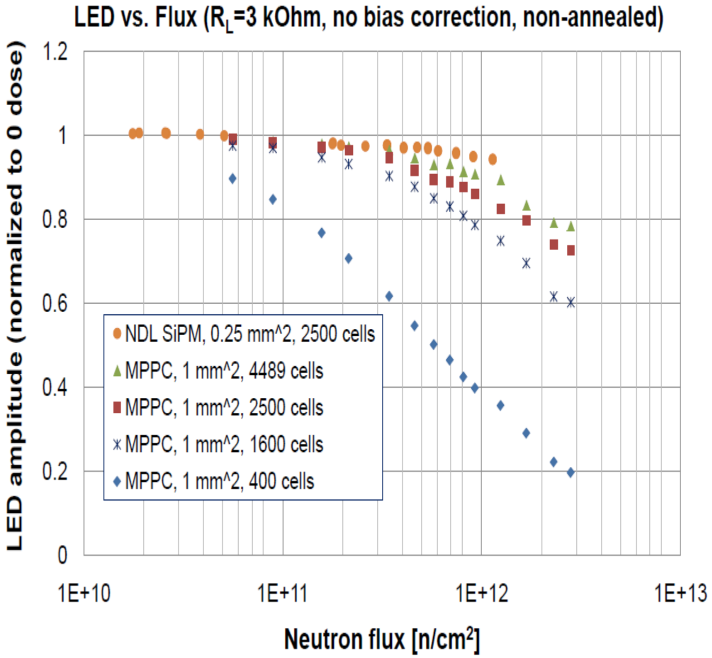
- increase of the dark current and the DCR
- change of the breakdown voltage
- change of the gain and PDE dependence as a function of bias voltage



Before irradiation

5 x 10^9 neq/cm²

W. Baldini, TIPP 2014



J. Anderson CALOR 2012

HAMAMATSU, KETEK and FBK SiPMs **survive 10^{12} n/cm² 1 MeV equivalent neutron flux** (it was 10^8 n/cm² 3 years ago) → **not enough for UA9**

Effects of radiation on PMTs

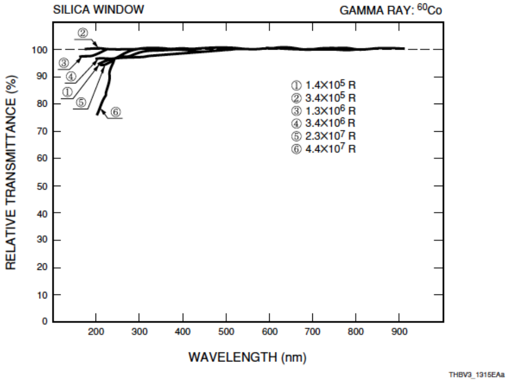
protons / neutrons /γ-rays

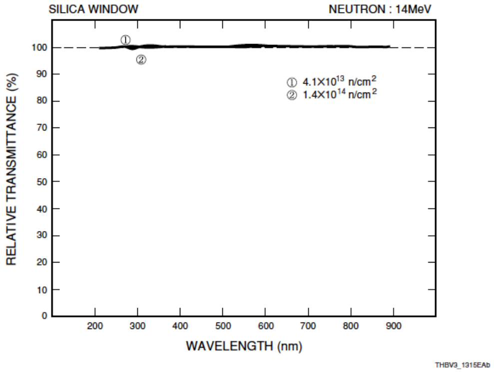
coloring of the glass

glass scintillation

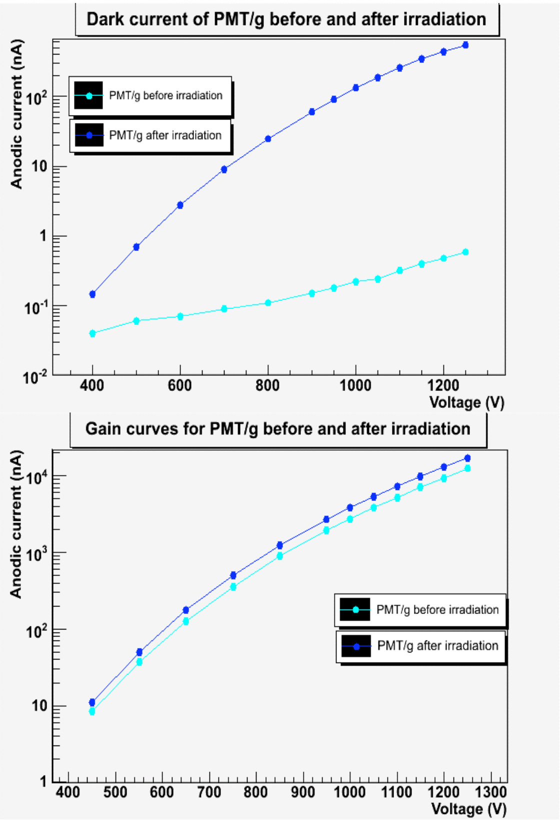
- ➢deterioration of the borosilicate window transmittance but not for a fused silica window
- ➢increase of the dark current
- ➢no important change of the gain and quantum efficiency

No variation of the transmittance of quartz window





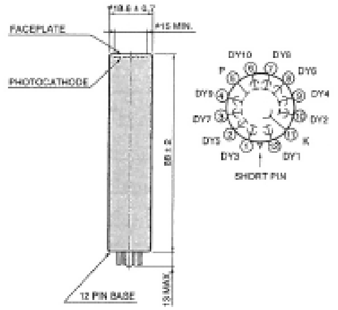
HAMAMATSU R762

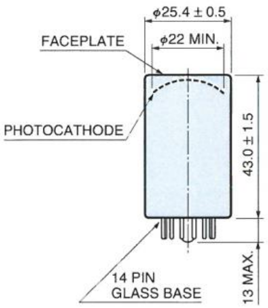


γ: 60Co, E = 1.22 MeV Dose = 20±1 Mrad

A. Sbrizzi LUCID in ATLAS

Our choices: Hamamatsu R762 & R7378A





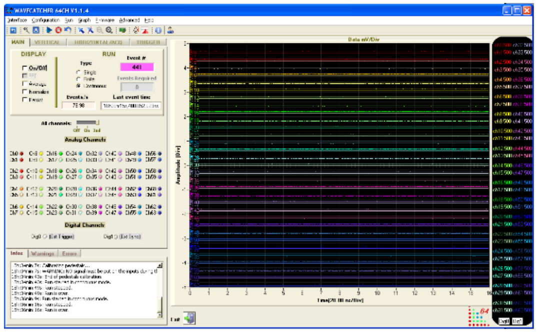
The CpFM readout

The WaveCatcher boards and modules:
2 to 64-channel 12-bit 3.2GS/s oscilloscope-like digitizers, close to the picosecond level in timing precision

- **Based on the SAMLONG Analog Memory ASIC**
- **Sampling rate ranging between 400 MS/s and 3.2GS/s.**
- **1024 samples/channel**
- **12 bits of dynamic range**
- **Small signal bandwidth > 500MHz**
- **Sampling time precision better than 5 ps rms at the system level**
- **Up to 64+8-channel synchronous system**
- **Advanced Oscilloscope-Like Software (Plug and Play)**
- **Embedded feature extraction: Baseline, Peak, Charge, CFD (TDC-like mode) …**
- **Real-time channel hit rate measurement**
- **Data storage in ASCII and binary formats**

The 8-channel desktop module

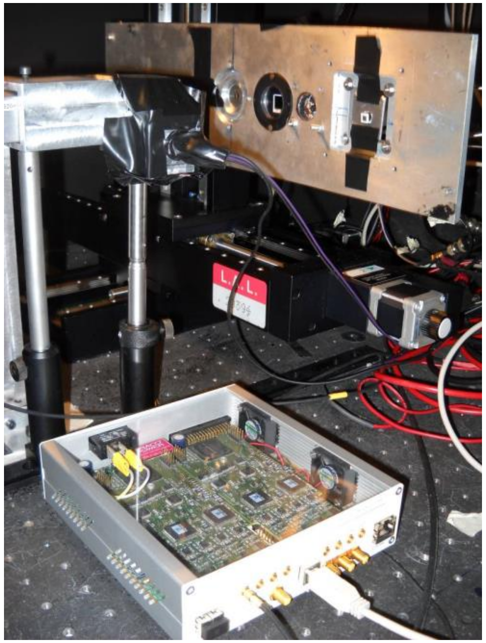
The 64-channel mini-crate



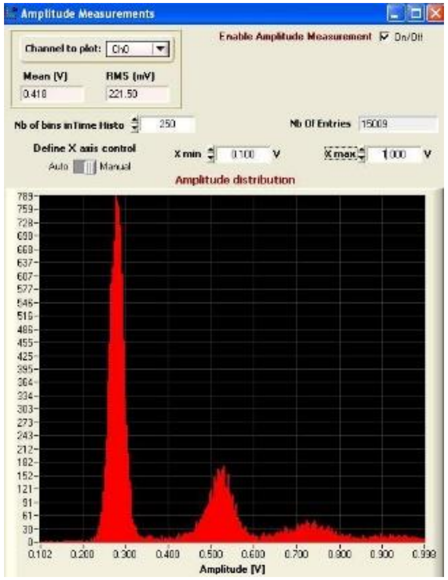
The oscilloscope-like acquisition software

The CpFM readout

Characterization test bench for SiPMs @ LAL with the 8-channel WaveCatcher



Amplitude distribution performed by firmware measurement (< 30s).



Channel to plot: Ch0

Enable Amplitude Measurement ☑ On/Off

Mean [V] 0.418

RMS [mV] 221.50

Nb of bins in Time Histo 250

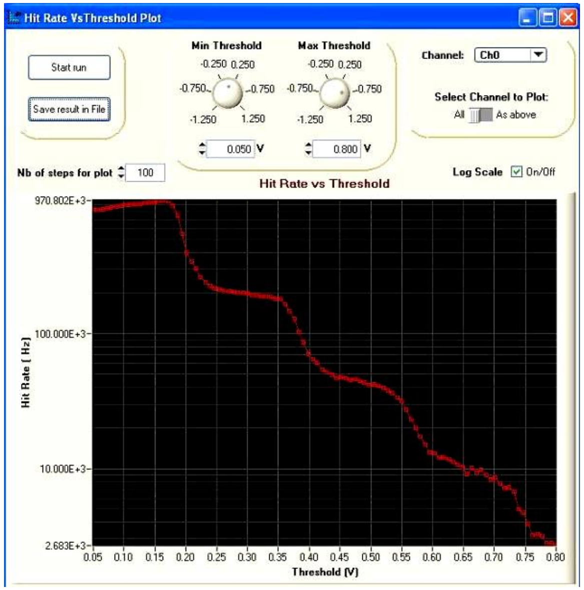
Nb Of Entries 15009

Define X axis control Auto / Manual

X min 0.100 V

X max 1.000 V

Result of a hit rate vs amplitude plot. This type of measurement is automatically performed by the software.



Min Threshold 0.050 V

Max Threshold 0.800 V

Channel: Ch0

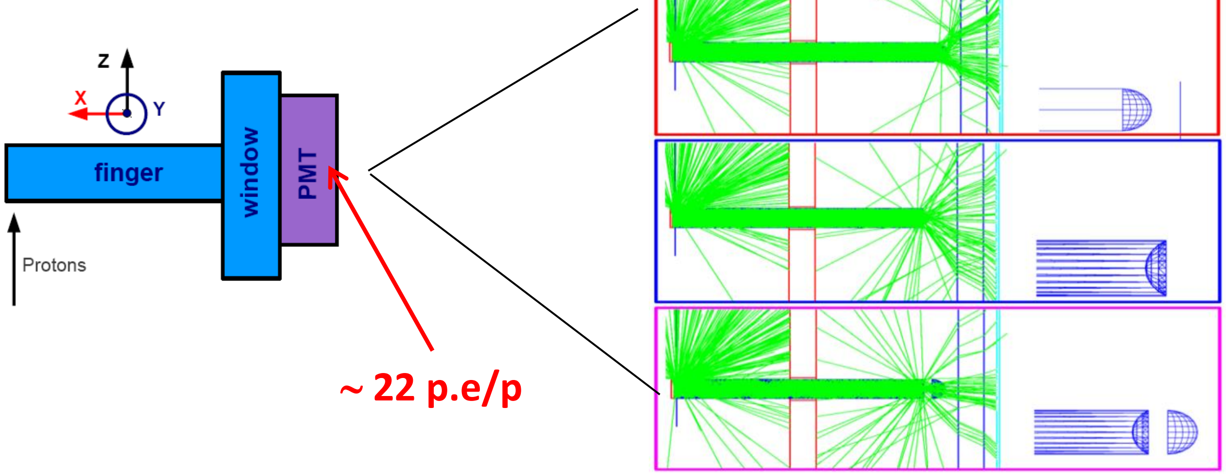
Select Channel to Plot: All / As above

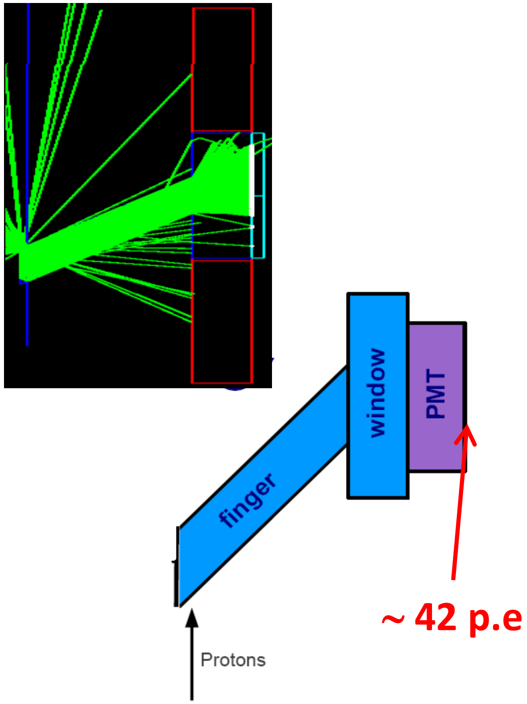
Nb of steps for plot 100

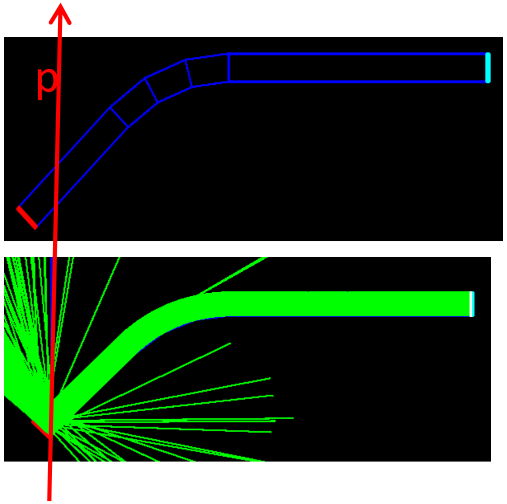
Log Scale ☑ On/Off

Quartz radiator geometries simulations

More than 10 geometries tested (Geant 4 simulations @ LAL)







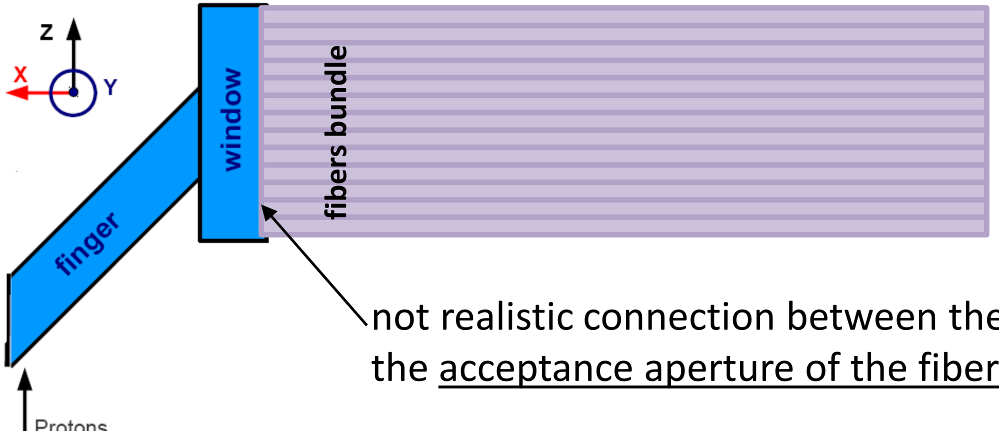
Best result with an angle of 47 ° between the beam direction and the quartz radiator

⇩

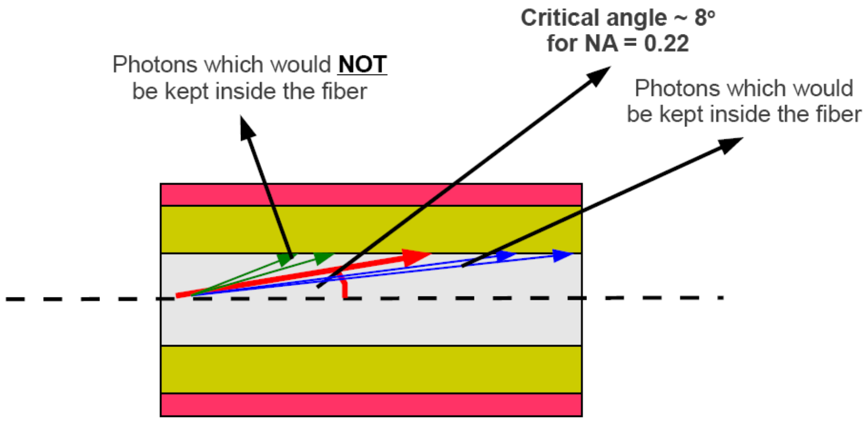
Which interface between the quartz radiator and the PMT ?

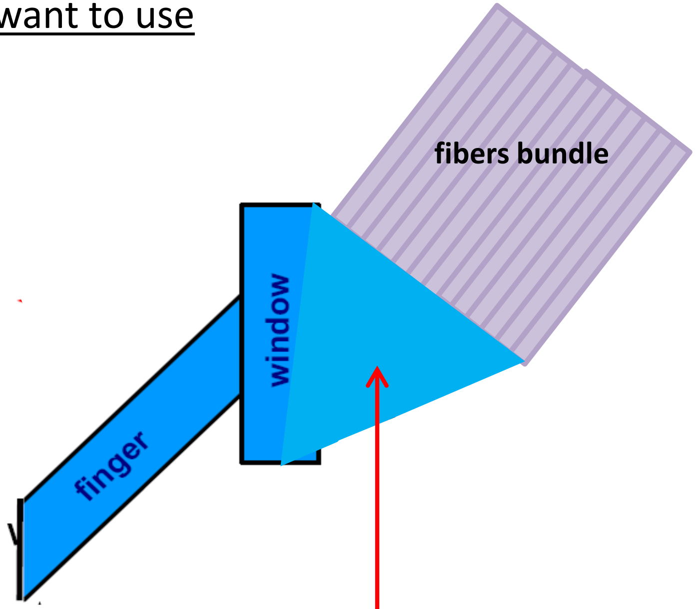
⚠ to the light transportation → simulation

Too much radiation to place the PMT close to the beam pipe → need of a (long) fibers bundle



not realistic connection between the viewport and the fiber bundle because of the acceptance aperture of the fiber we want to use

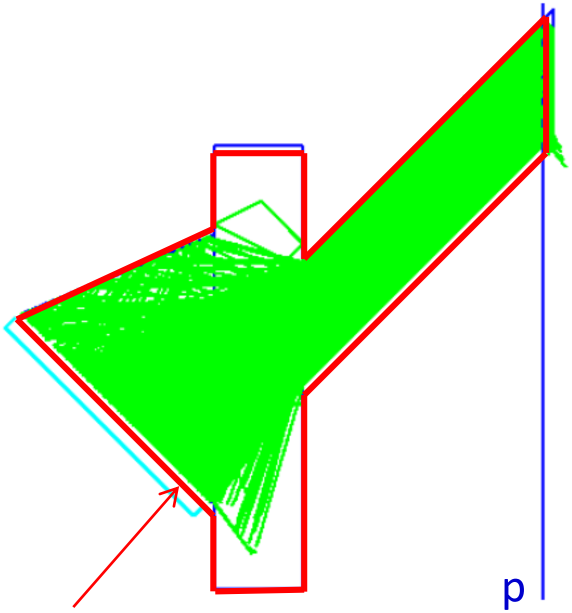




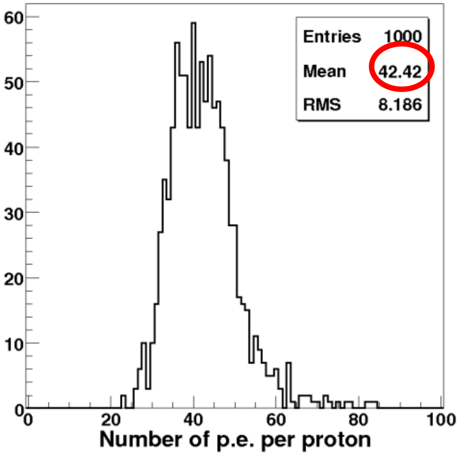
➡ need of a quartz adapter

The “best” geometry

Quartz radiator + viewport + fiber adapter = single piece

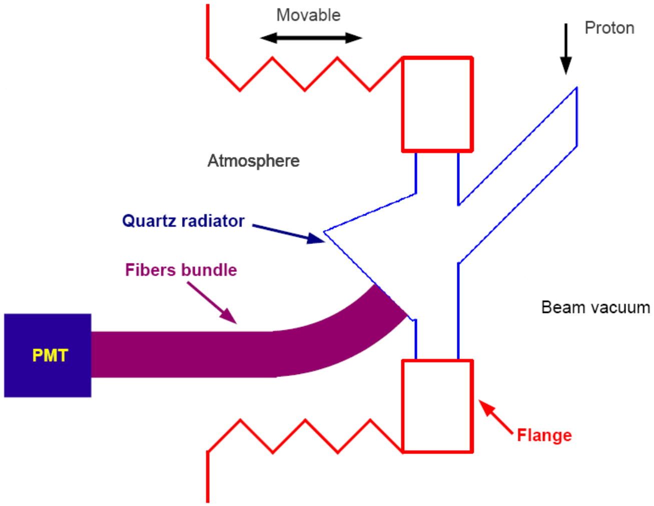


Fiber adapter to optimize the entrance of the photons inside the fibers



taking into account a PMT with Bialkali PC + CE

≈ 42 p.e/proton

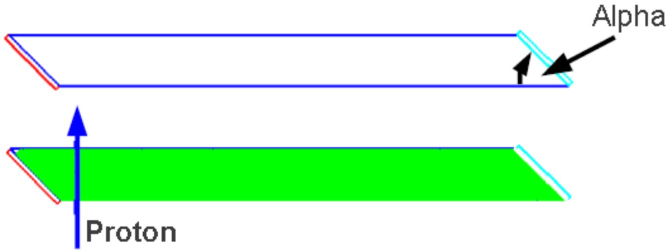


The quart piece <u>is</u> the interface between the vacuum inside the beam pipe and the atmosphere inside the tunnel

BUT the manufacturing + polishing of such a complicate piece is impossible (even by the specialized producers) → need of a simpler but efficient geometry

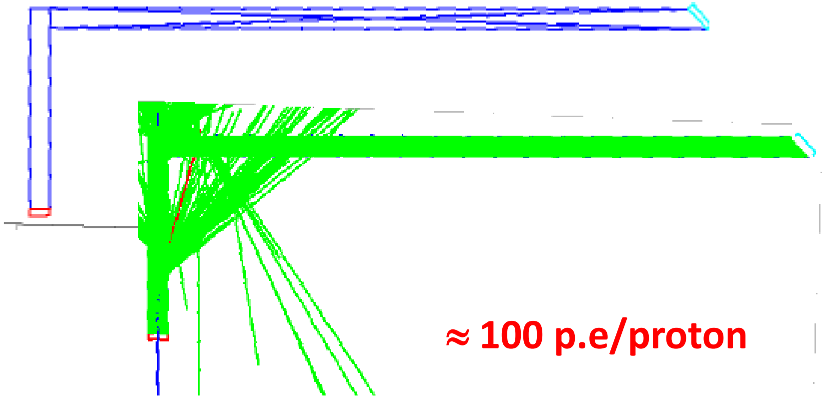
→ New geometries

I bar

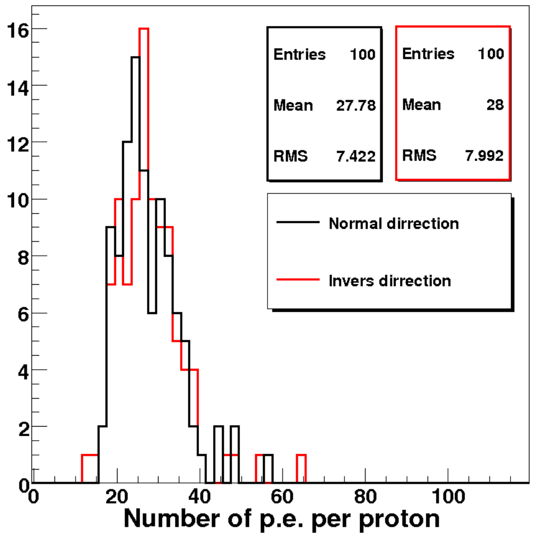


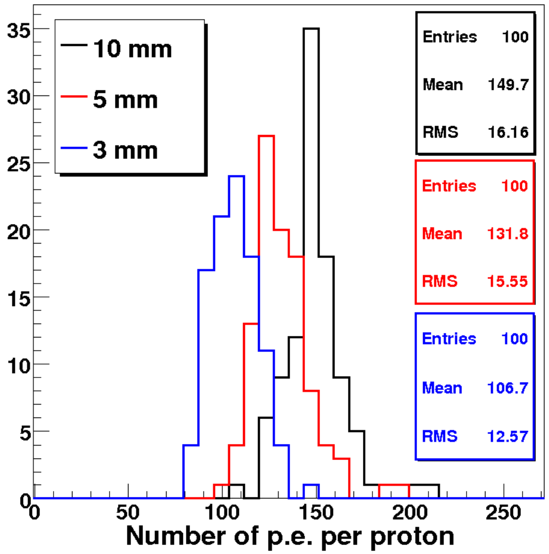
≈ 28 p.e/proton

L bar



≈ 100 p.e/proton



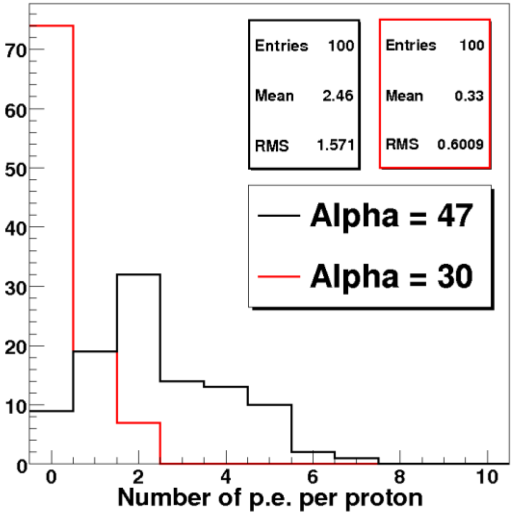


- ✓ Less complicated to manufacture
- ✓ End of the radiator (toward the fibre bundle) **cut at an angle of 47 °**

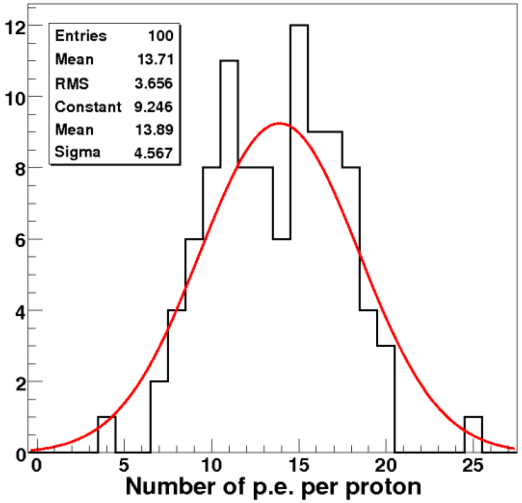
Loss factors

- ✓ Loss of light at the optical couplings (bars/window – window/bundle – bundle/PMT)
- ✓ Loss of the light in the fibers bundle (dead space between the fibers)
- ✓ Attenuation of the signal inside the coaxial cable

Part of the detection chain	Factor of loss
Passage through the Quartz window	50 %
Fibers bundle	30 %
Optical couplings	30 %
40 m coaxial cable	20 %



l + bundle

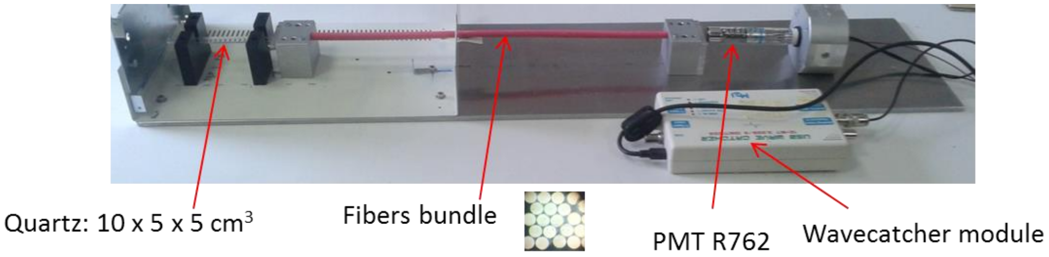


L + bundle

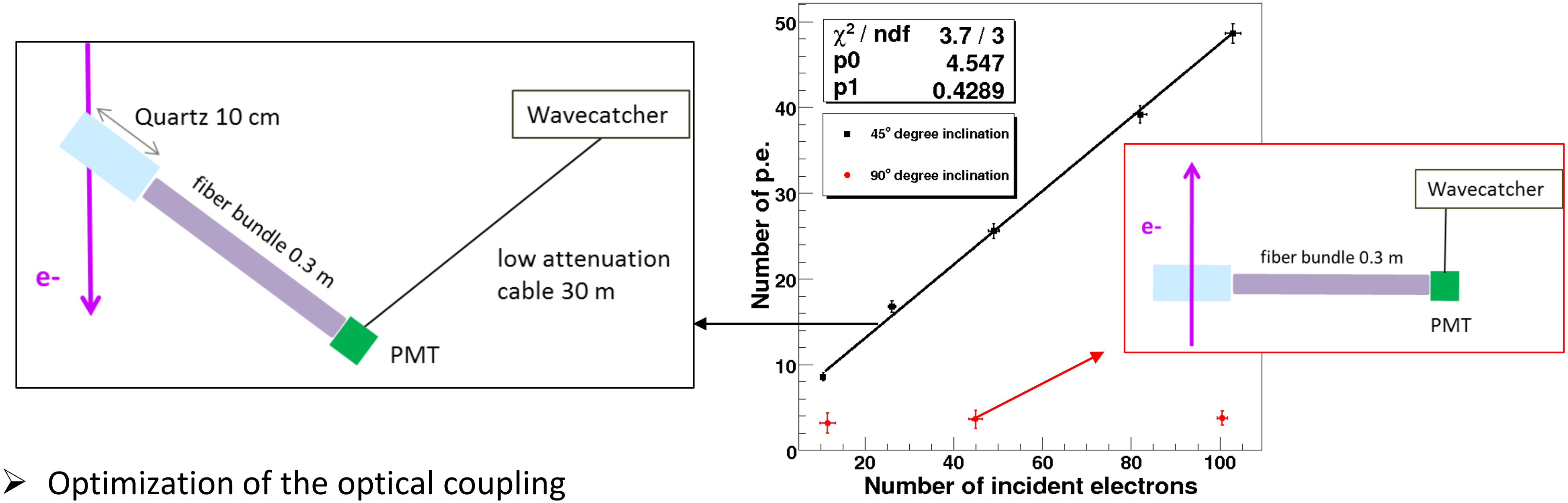
CpFM Beam tests at BTF (2013)

Objective 1: CpFM proof of principle

all the CpFM components chosen for the SPS



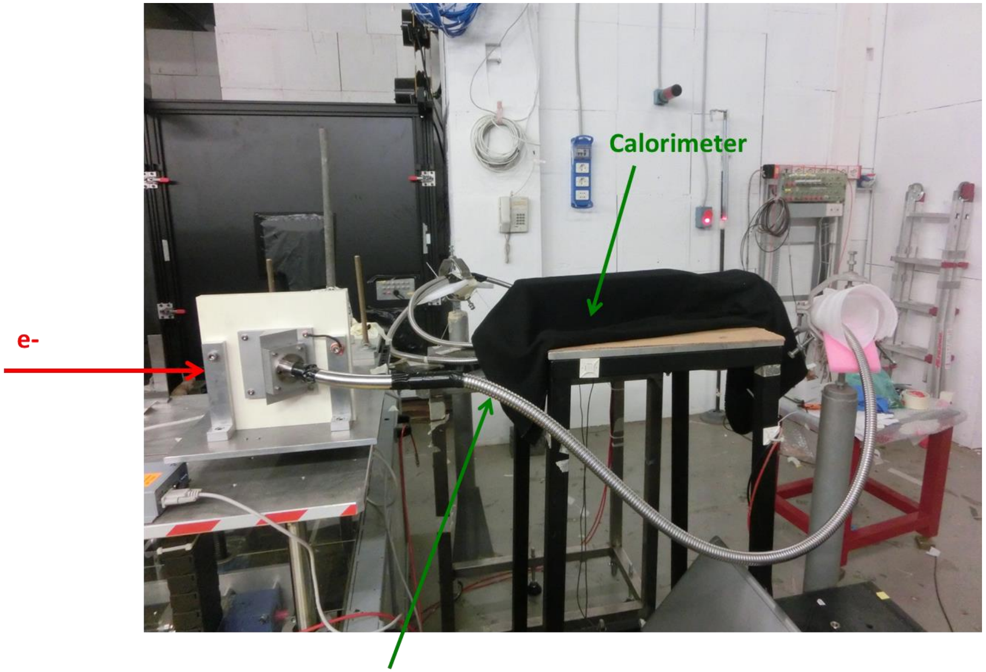
Quartz bar
Quartz fibers
PMTs (R762)
Coaxial cable (40 m)
Readout electronics

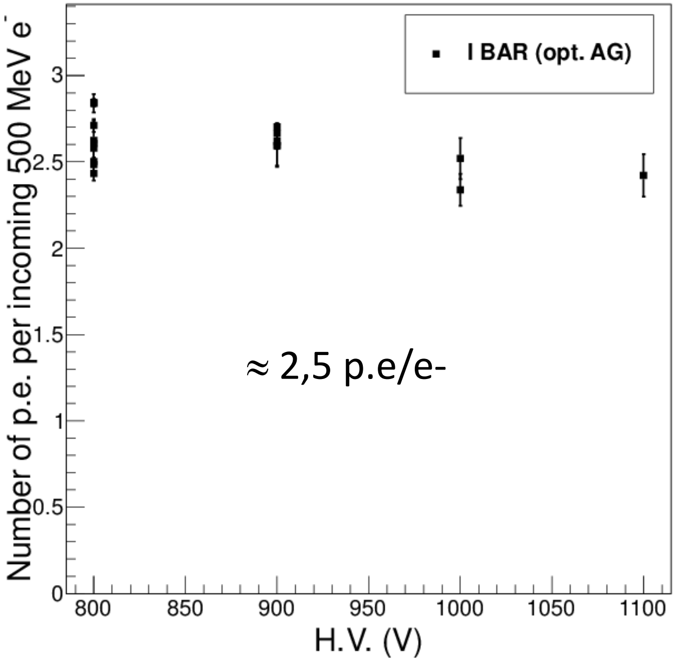


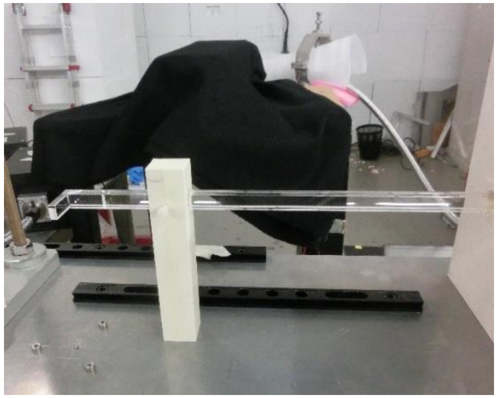
- Optimization of the optical coupling
- Measurement of the signal attenuation in the cable
- **Best results with 45 ° between the e- beam direction and the quartz bar**

CpFM Beam tests at BTF (2014)

Objective 2: validation of the CpFM final configuration







Tests performed with INFN & CERN teams

Simulation parameters: Qε = 25 %, CE=80 %

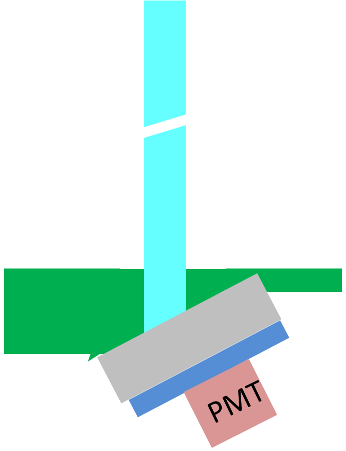
13,7 p.e/p (for 30 mm) → ≈ 2,3 p.e/p for 5 mm

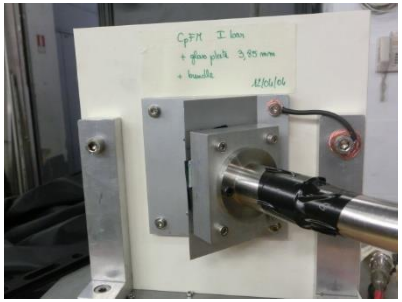
↓

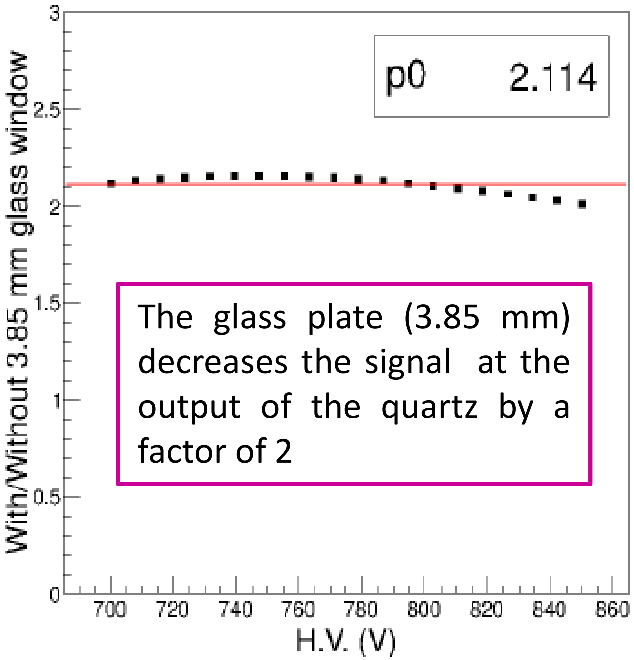
Simulation & measurements in agreement

CpFM tests at BTF (2015)

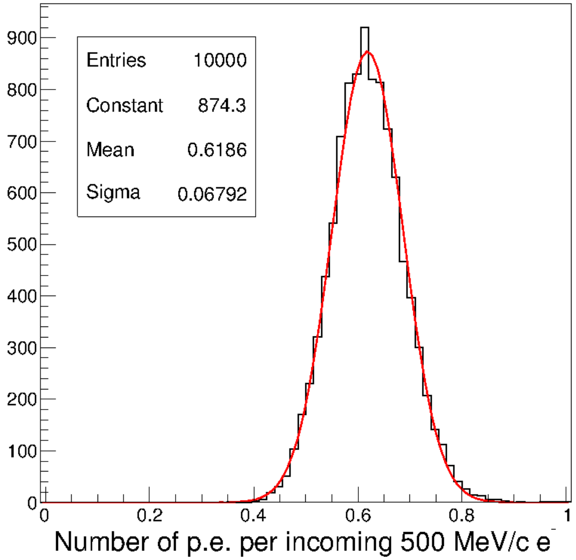
Simulation of a quartz window between the bar and the bundle







The glass plate (3.85 mm) decreases the signal at the output of the quartz by a factor of 2



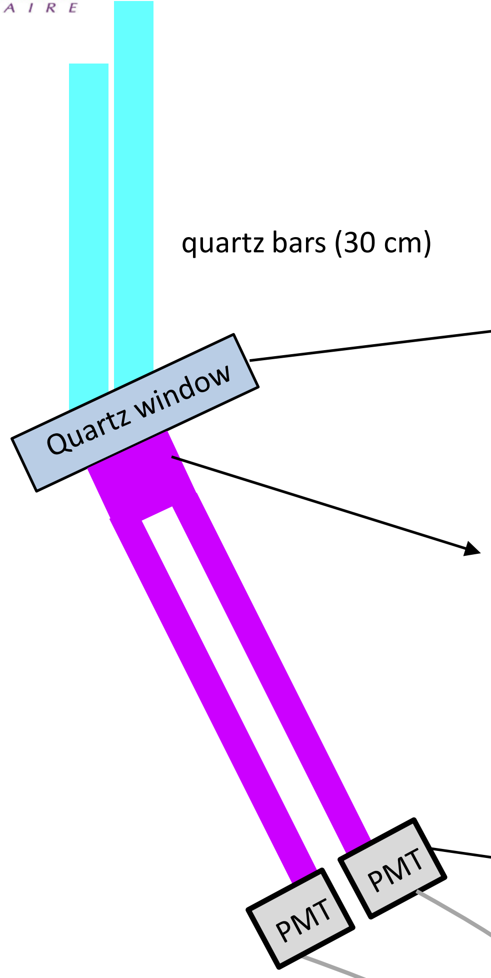
Conclusions:

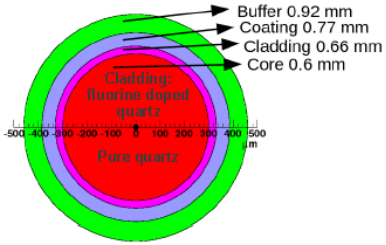
- L bars not enough polished → using of I bar
- Quartz window decreases the signal by a factor 2
- 0.62 p.e. per incoming electron

⬇

resolution =15 % for 100 incoming electrons

CpFM structure





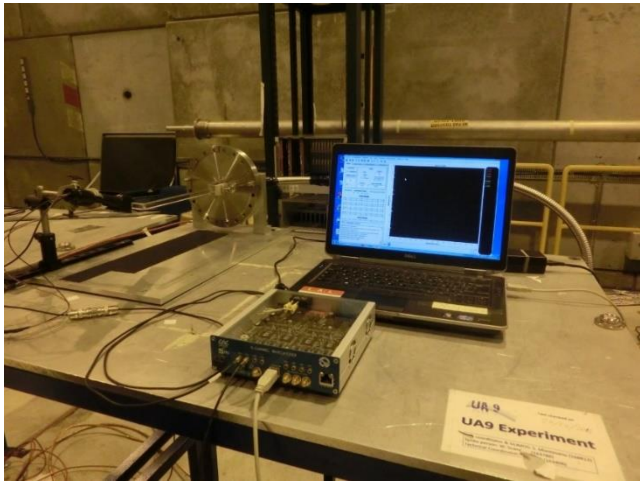
HAMAMATSU R7378A

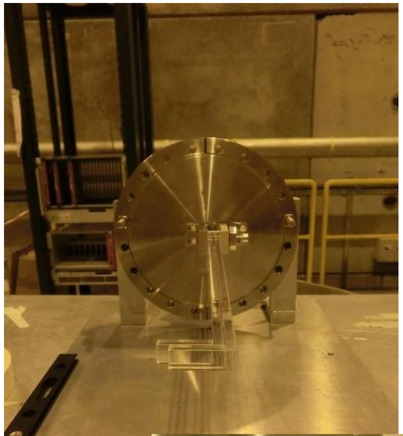
cable (40 m)

Module WaveCatcher

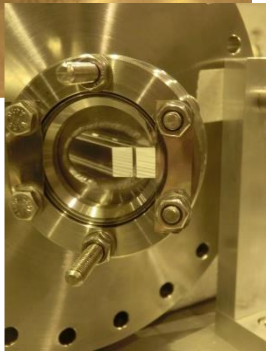
CpFM Beam Tests in H8 (2015)

180 GeV/c π^+

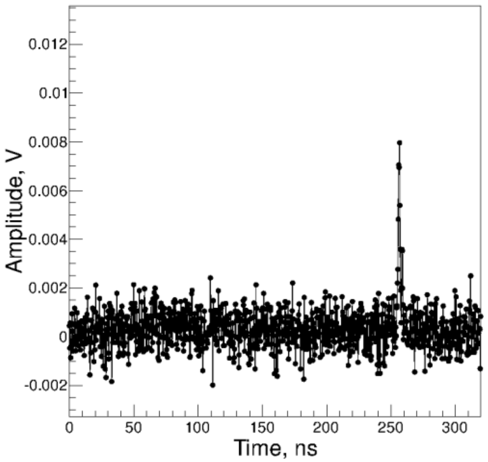


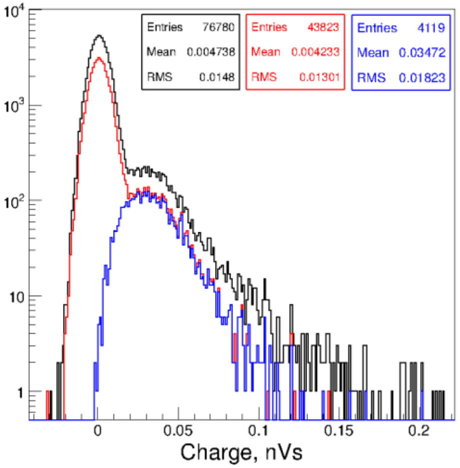


2 “I” bars



Tests performed with INFN & CERN teams

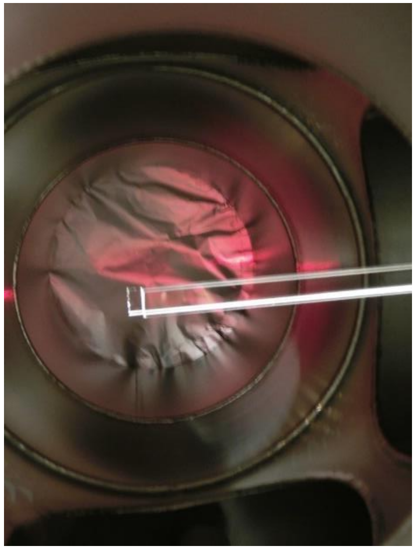




- ➢ 0.2 p.e. per incoming Pion

Need to performed other tests at BTF (where the beam can be controlled) to calibrate the chain → April 2015 with a copy of the CpFM

CpFM installation in SPS



Installation performed with INFN & CERN teams

- Tank and motorized support (INFN)
- 2 quartz bars inserted inside the SPS beam pipe
- Readout OK
- Waiting for beam !

Conclusion

- Cherenkov Detector in the primary vacuum = Challenging detector development
- Use of the LAL knowhow in the field of the Cherenkov detector simulation and readout electronics
- Installation of the CpFM in the SPS in January 2015
- Design of a new CpFM chain for UA9-SE