Beam tests at BTF (14-18 October 2013) of the CpFM prototypes

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Outline

1. Reminder

- **C**herenkov detector for **p**roton **F**lux **M**easurements (**CpFM**) for SPS and LUA9
- Geant4 simulation of the CpFM

2. CpFM prototype

- CpFM prototype
- PMT characterization

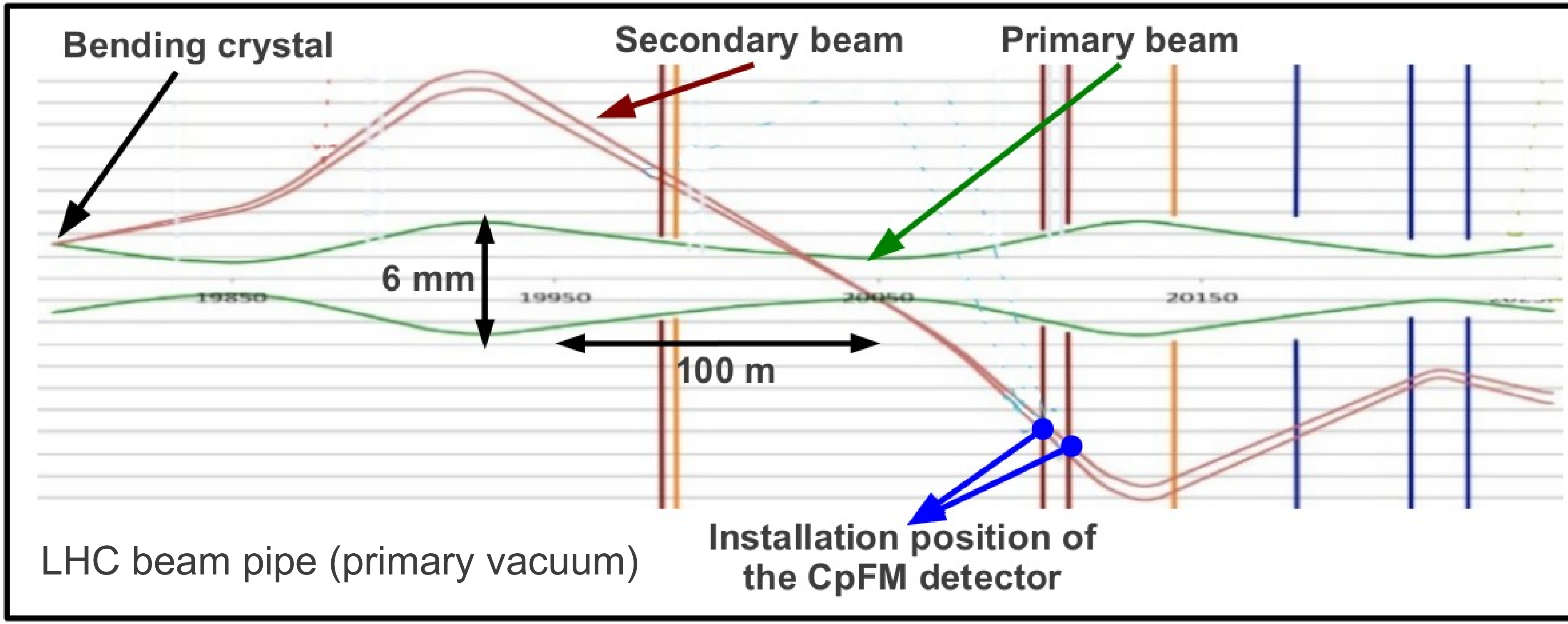
3. Beam test

- Beam test facility (BTF) at Frascati
- Analysis of the data and comparison with simulation

4. Conclusion

LUA9 project

Use bent crystal at LHC as a primary collimator.



To monitor the secondary beam - Cherenkov detector based on quartz radiator can be used. Initial idea belongs to the PNPI group with a prototype tested in SPS.

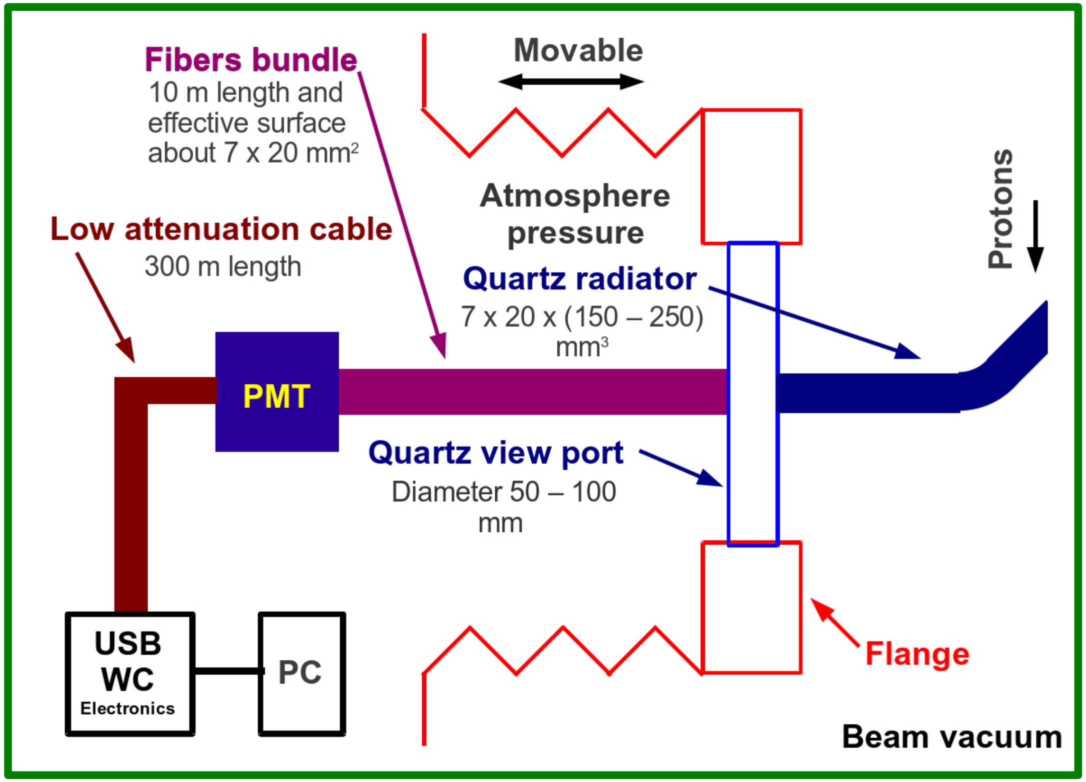
Aim: **count the number of protons** with a precision of about 5% (in case of 100 incoming protons) in the LHC environment.

Main constrains for such device:

- No degassing materials (inside the primary vacuum).
- Radiation hardness of the detection chain (very hostile radioactive environment).
- Compact radiator inside the beam pipe (small place available)
- Readout electronics at 300 m

Cherenkov detector for **p**roton **F**lux **M**easurements (**CpFM**)

CpFM detection chain components

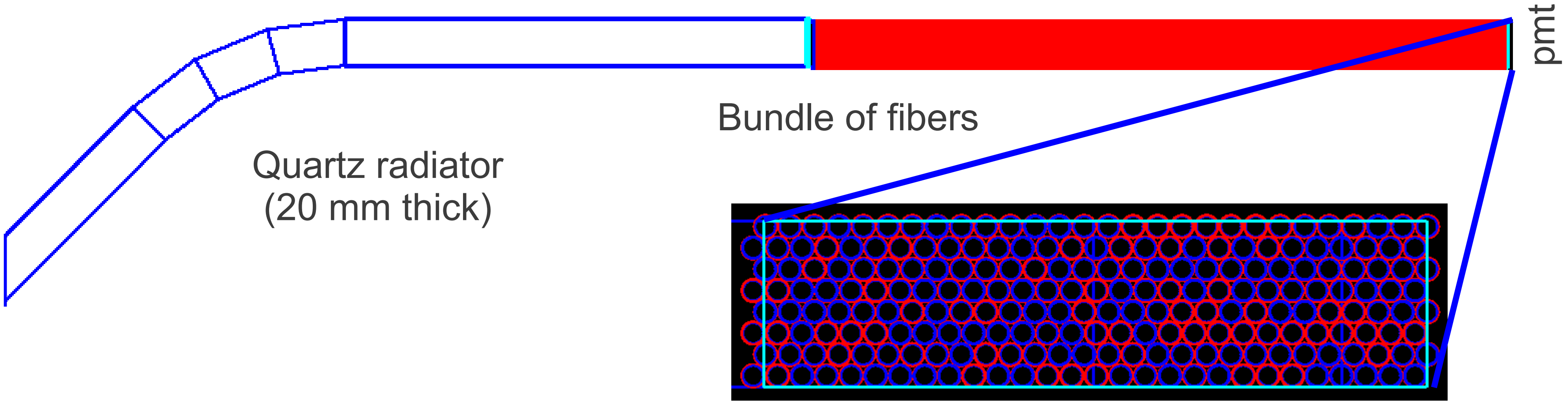


- Radiation hard quartz radiator
- The flange with view port attached to the movable bellow.
- The light will propagate inside the radiator and will then be transmitted to the PMT via a bundle of optical fibers.
- Quartz/quartz (core/cladding) radiation hard fibers.
- 300 m cable
- USB-WC electronics. For more details see :

  USING ULTRA FAST ANALOG MEMORIES FOR FAST PHOTO-DETECTOR READOUT,
  (D. Breton et al. PhotoDet 2012, LAL Orsay)

Geant4 simulation of the CpFM

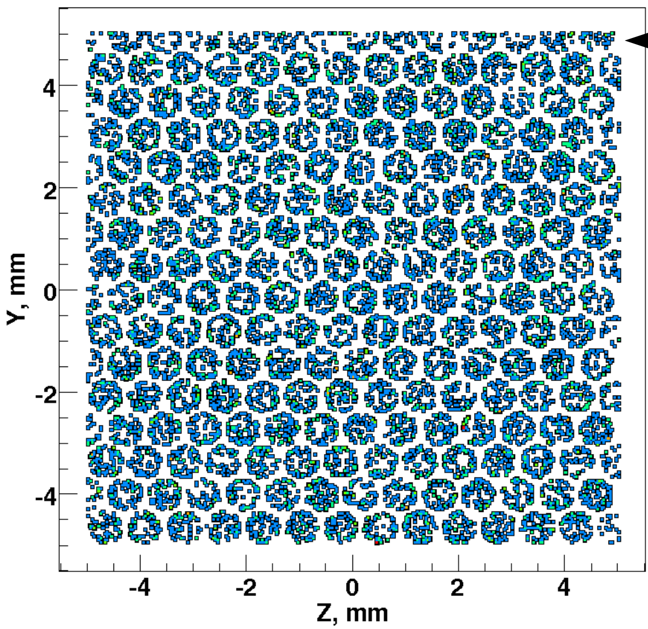
→ A lot of shapes of the quartz radiator has been simulated. We present one of them:



PMT:
- Bialkali photocathod (24 % @ 400 nm)
- Collection efficiency 80 %

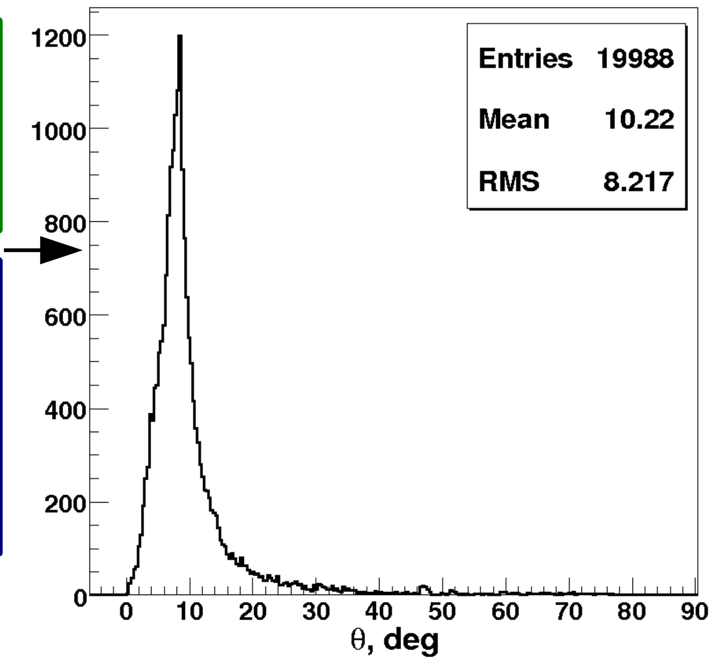
Fiber:
- Numerical aperture: 0.22
- Corr diameter: 0.6 mm
- Cladding diameter: 0.66 mm
- Buffer diameter: 0.7 mm

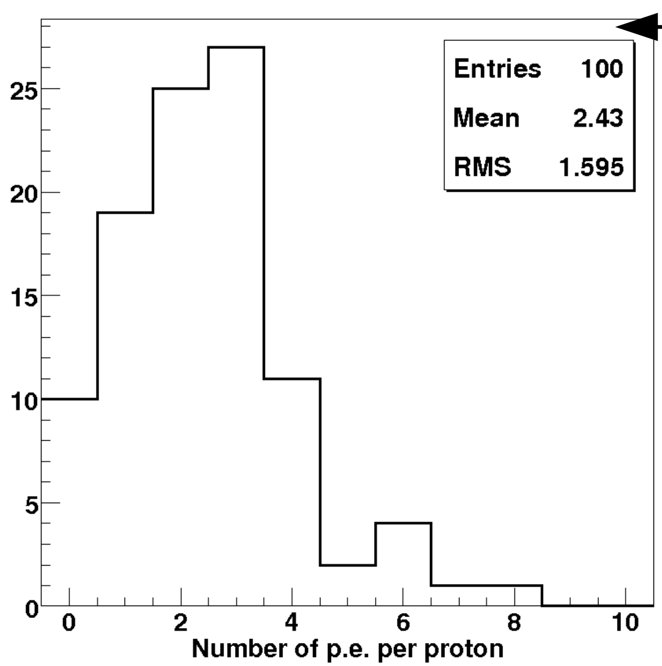
Results of the simulation



Position distribution of the photons on the PMT surface.

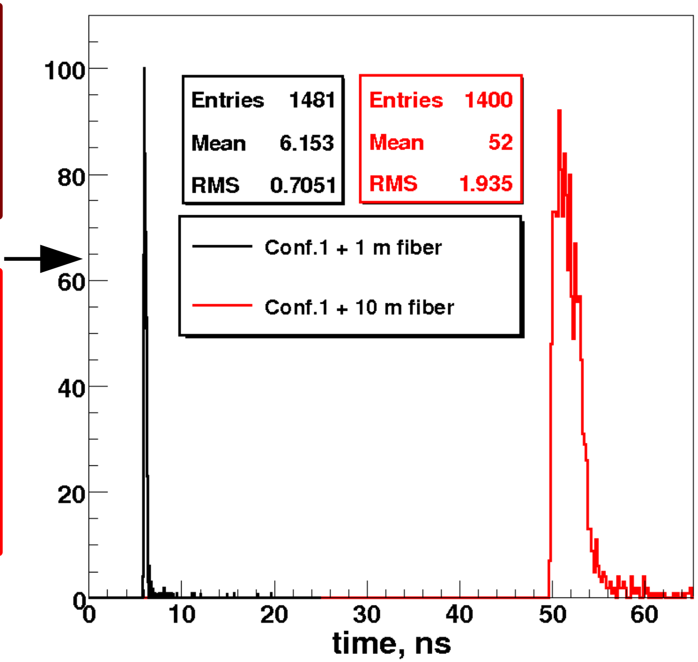
Theta distribution of the photons at the PMT entrance. Cut around 10° shows numerical aperture of the optical fiber.



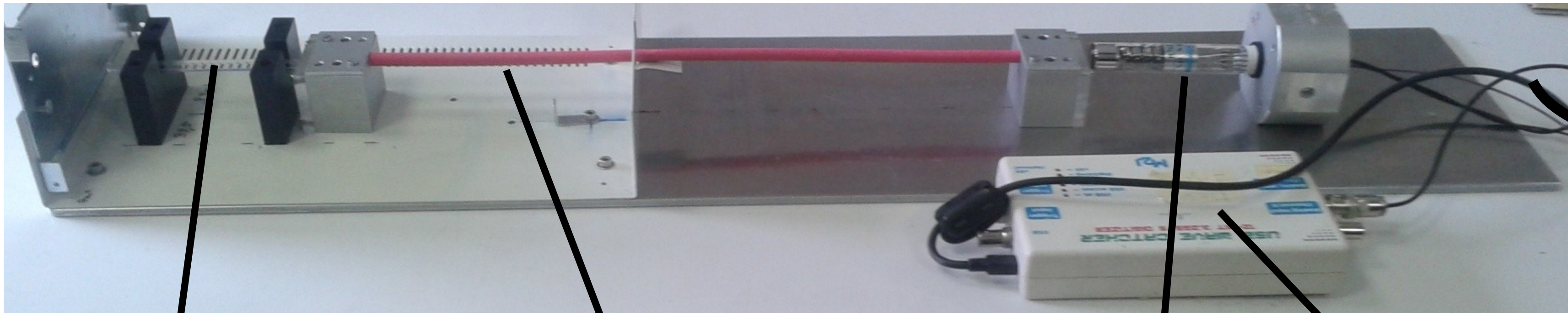


Per proton we are going to detect 2.4 photo-electrons.

The timing length of the photon signal increases with length of the fiber (10 m).

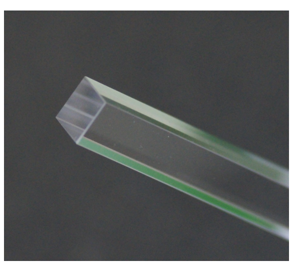


Simplified CpFM prototypes



Remotely driven PC

Quartz finger
100 x 10 x 10 mm^3

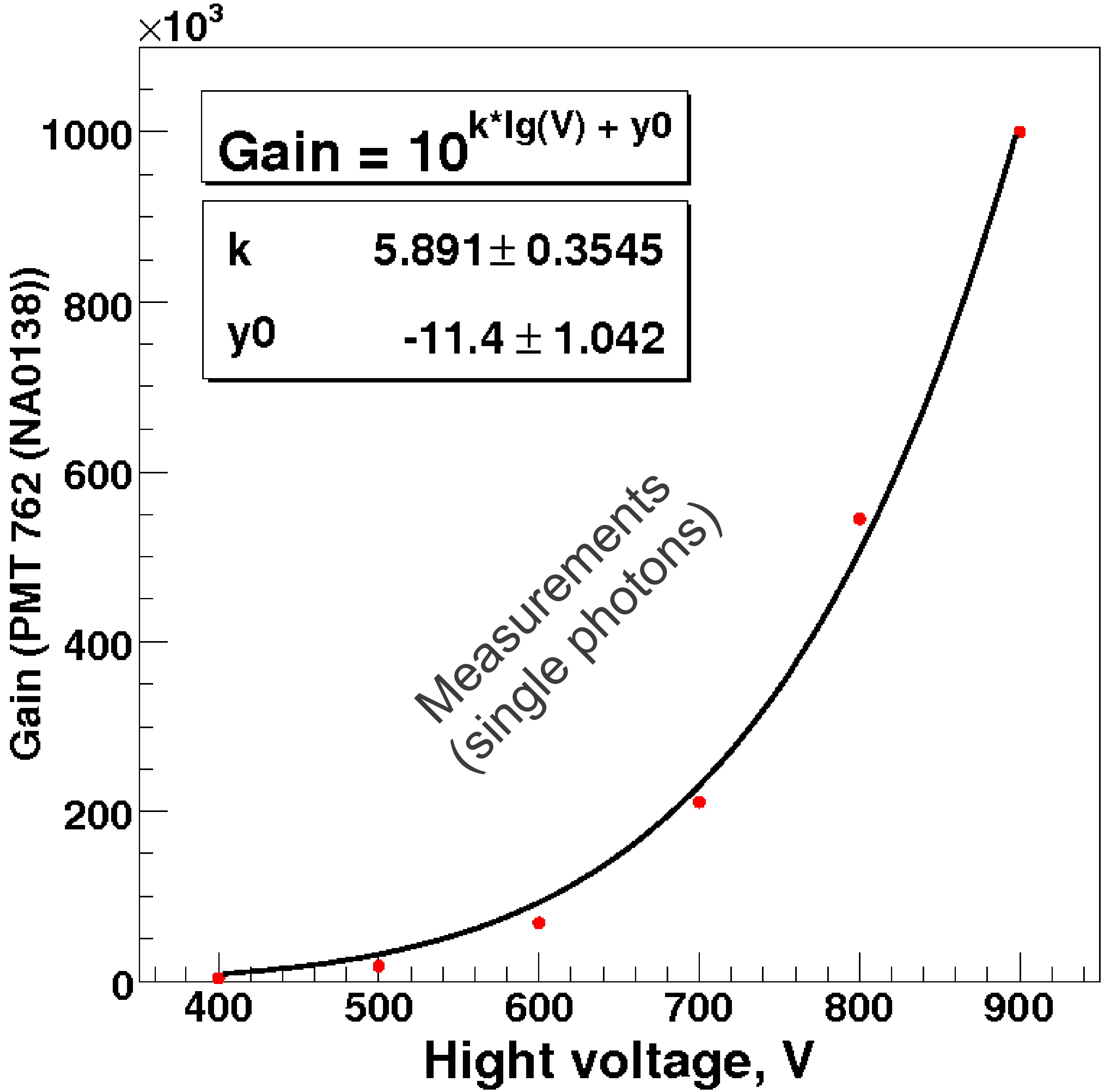


Home made bundle Quartz/quartz
(core/cladding) of fiber
400 x 2.8 x 5 mm^3

PMT R762
(15 mm effective diameter)

(2 or 8) channels
USB - Wavecatcher
electronics

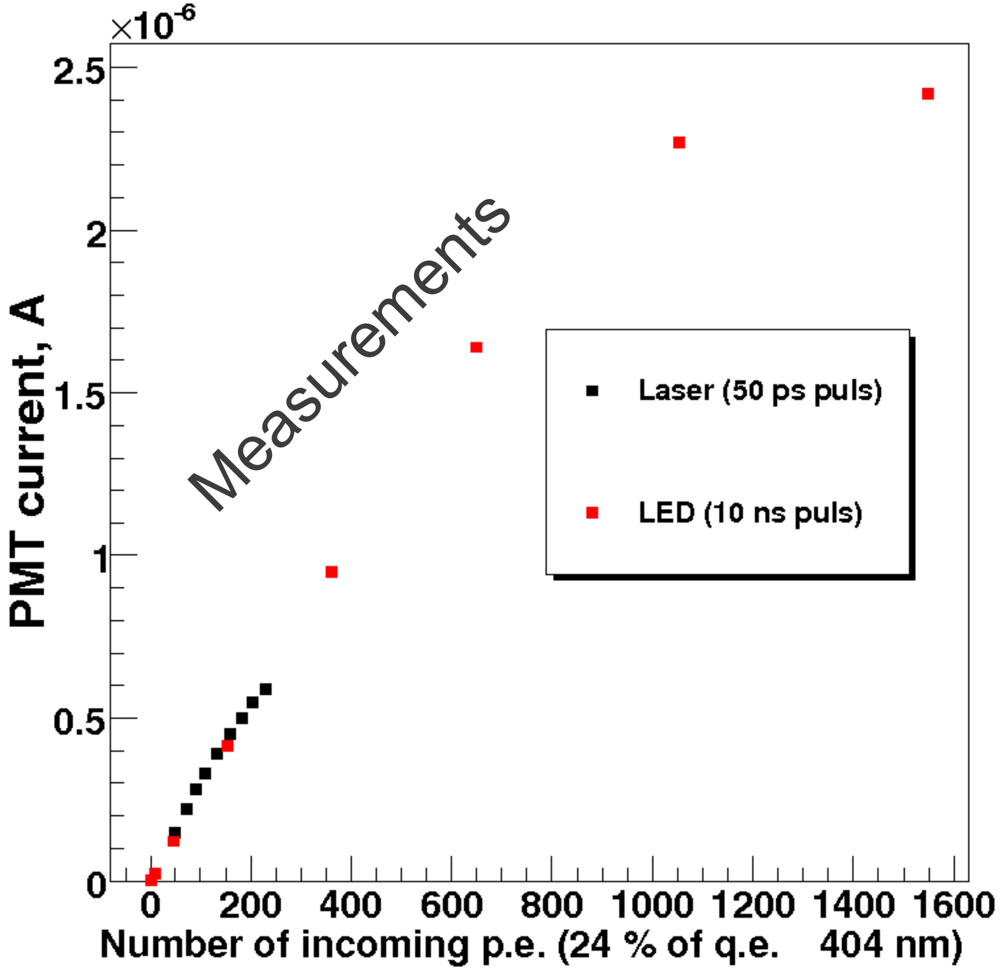
Calibration of the PMT with single photon (laser 404 nm)



H.V.		PMT gain
1200	→	$5.5 \cdot 10^6$
1100	→	$3.3 \cdot 10^6$
1000	→	$1.9 \cdot 10^6$
900	→	$1.0 \cdot 10^6$
800	→	$5.0 \cdot 10^5$
700	→	$2.3 \cdot 10^5$
600	→	$9.2 \cdot 10^4$

Measurements done by:
V. Chaumat
S. Conforti Di Lorenzo

Preliminary study of the PMT response as a function of photon flux



Measurements done by:
V. Chaumat
S. Conforti Di Lorenzo

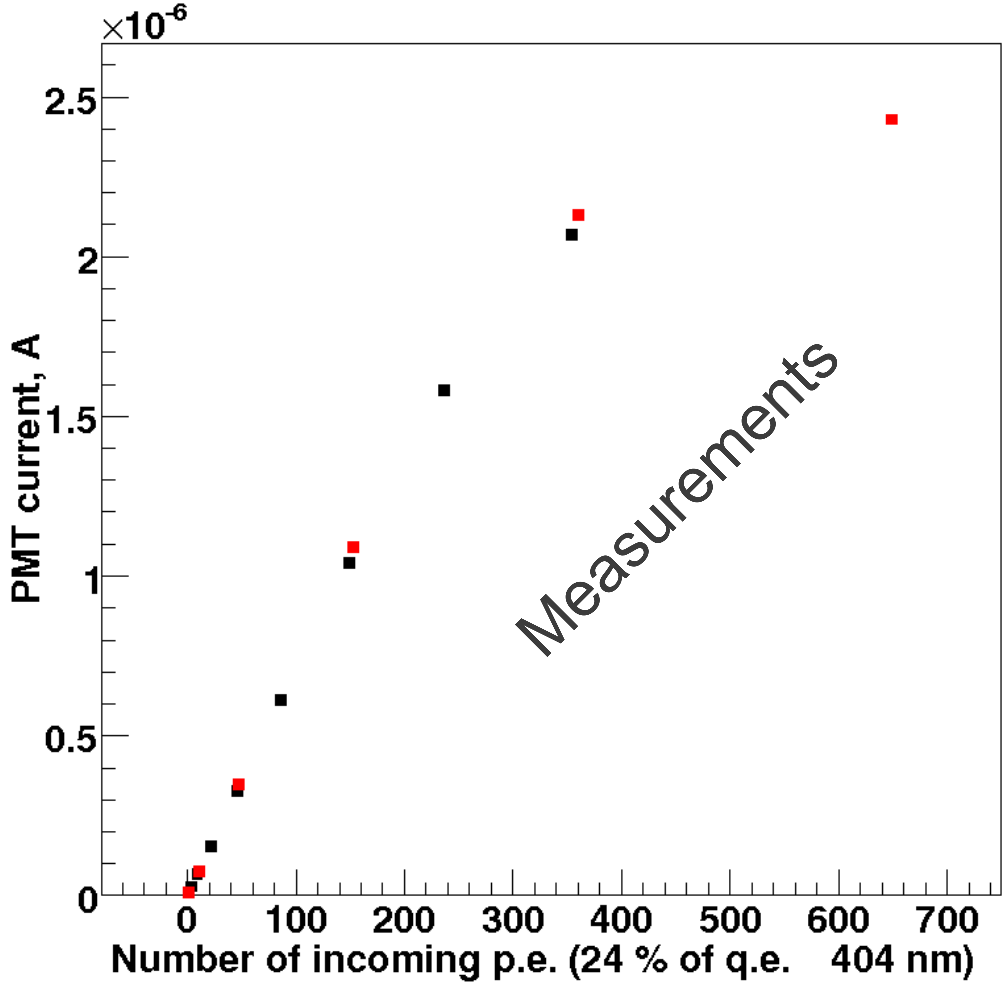
H.V. = 1000 V

Saturation of the PMT observed in both measurements (with LED and Laser)

At 600 incoming p.e. One can see the ~10% saturation effect

The PMT doest not react on increasing of photon flux after 1500 p.e.

Preliminary study of the PMT response as a function of photon flux



H.V. = 1150 V

Measurements done by:
V. Chaumat
S. Conforti Di Lorenzo

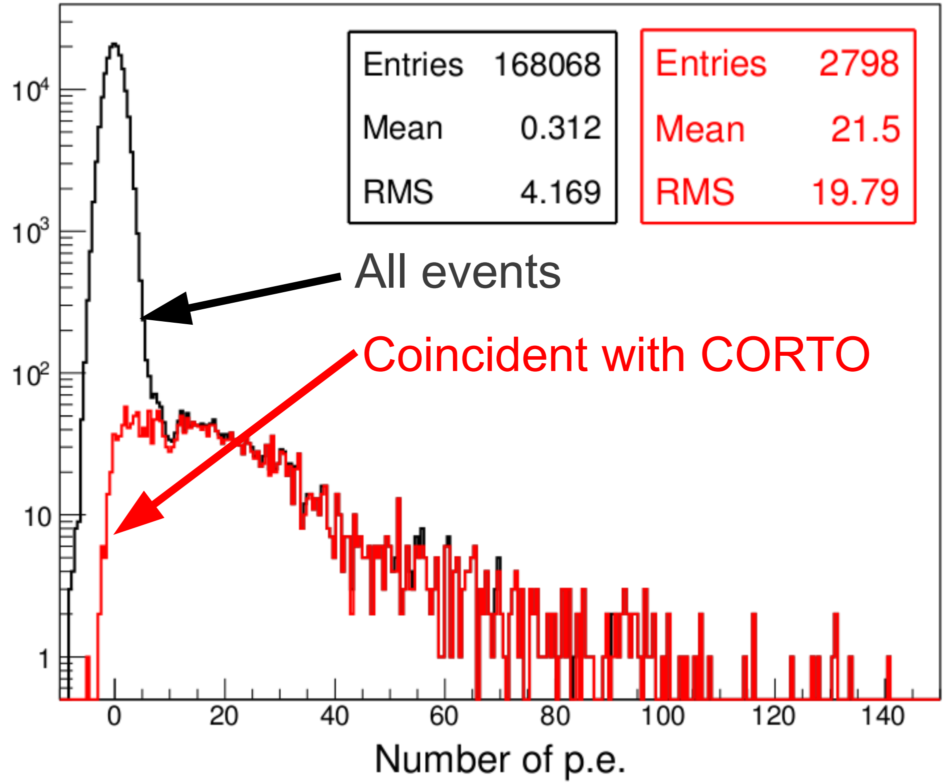
At 600 incoming p.e. One can see the ~20% saturation effect

The PMT doest not react on increasing of photon flux after 1000 p.e.

Test with cosmics

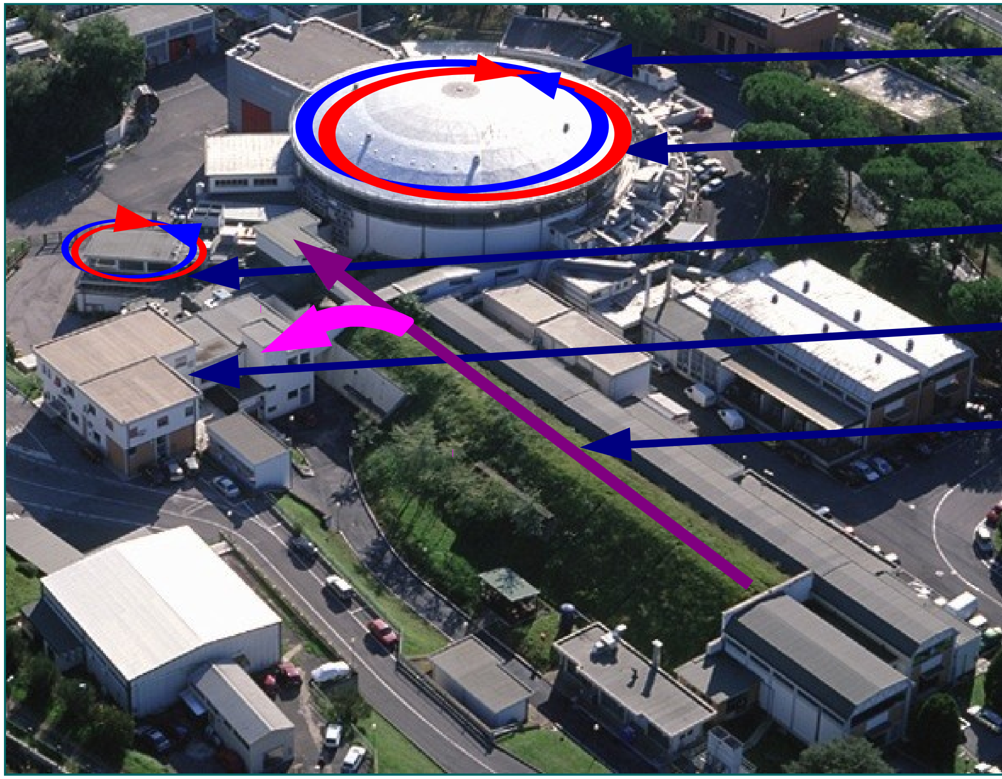
- Before beam tests of the prototype we performed measurements with cosmic muons reconstructed with CORTO (Cosmic Ray Telescope at Orsay)

Results

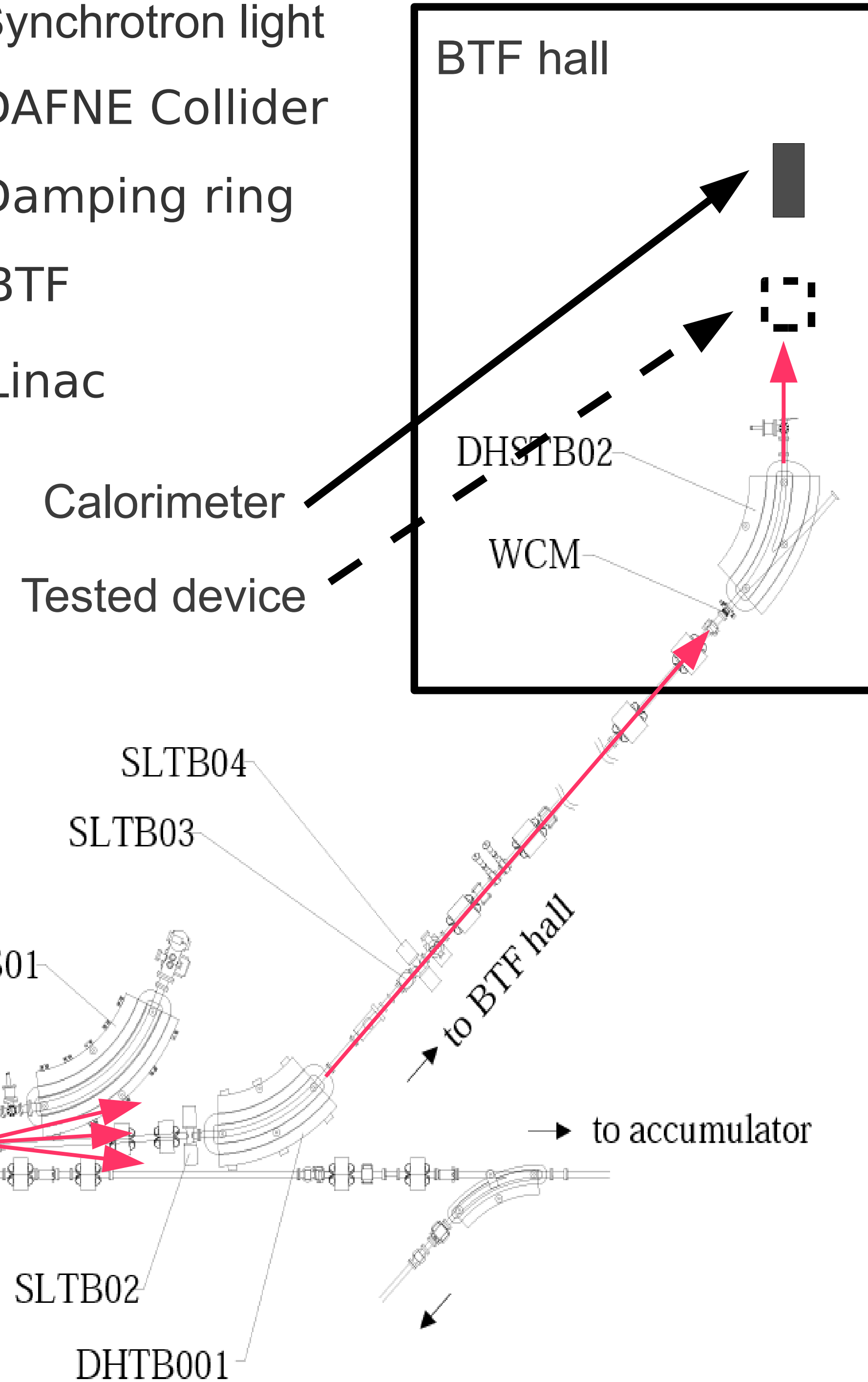


- In average for all incoming muons we detected 21 p.e.

BTF – (Beam Test Facility) at Frascati



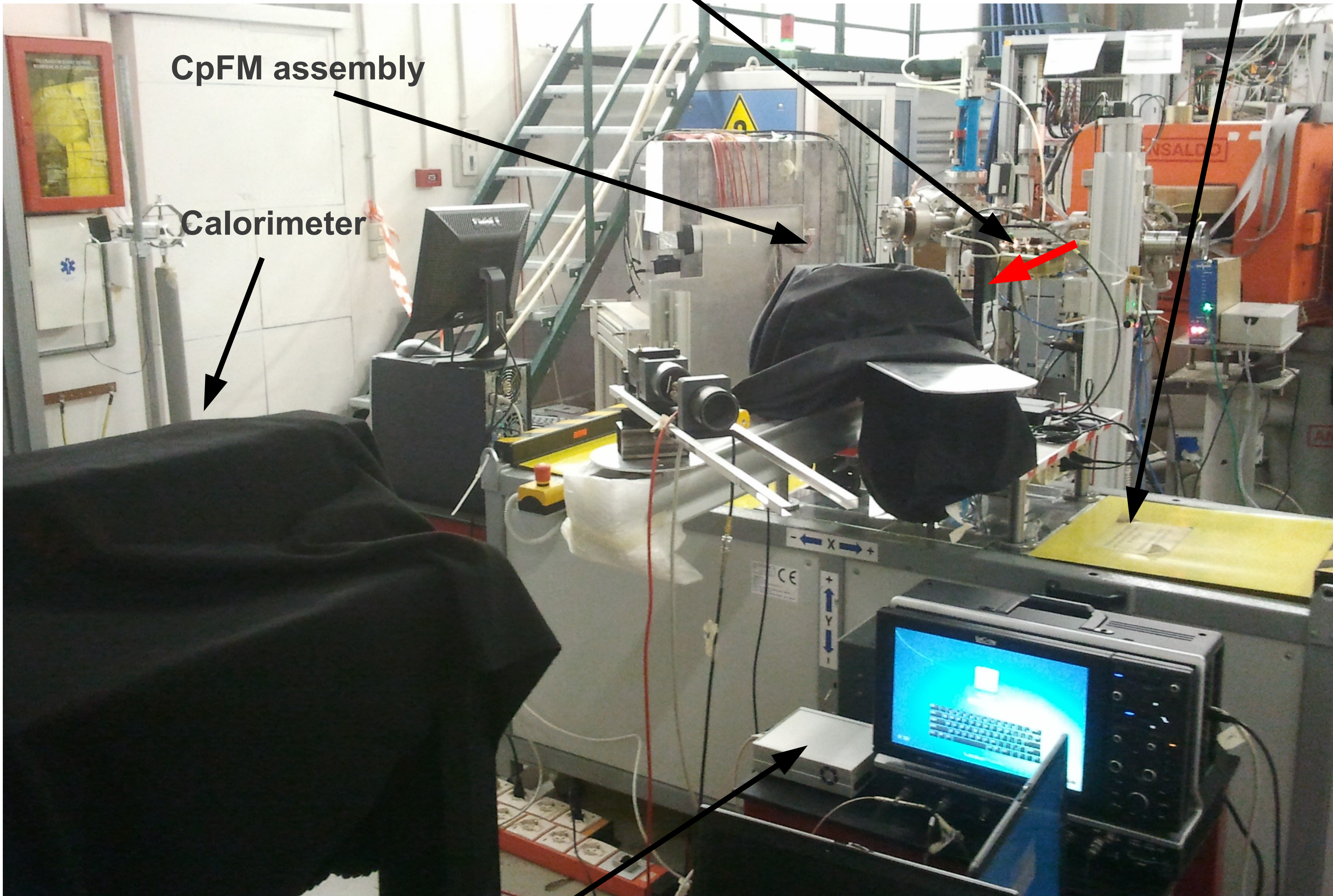
Characteristics of the e^- beam @ BTF	
Particles number:	1 - 10^5 e^-/pulse
Energy:	25 – 500 MeV
Frequency:	20 Hz
Pulse duration:	10 ns



Beam tests at BTF (14-18 October 2013)

Electron beam with energy around 446 MeV

Translation stage



8-channel USB-WaveCatcher

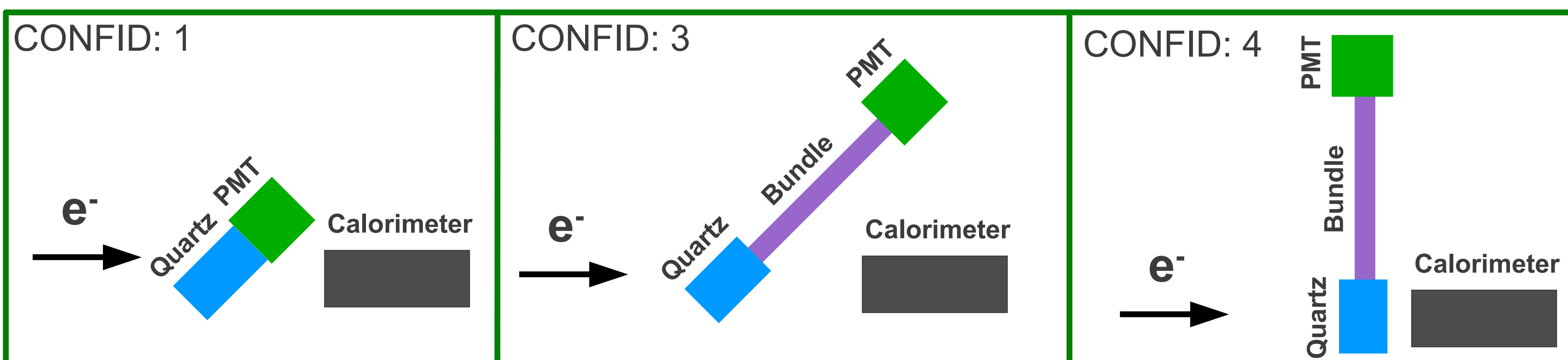
Run descriptions

CONFID	description:	READOUT electronics config.*
0	quartz 45 deg + + + PMT(762 NA0138) + detectors in front + CALO + big beam	-1
-2	quartz 45 deg + + + PMT(762 NA0138) + NO DIAMOND + CALO + big beam	1
-1	quartz 45 deg + + 30M cable + PMT(762 NA0138) + NO DIAMOND + CALO + big beam	1
1	quartz 45 deg + + + PMT(762 NA0138) + + CALO + small beam	1
2	quartz 45 deg + bundel of fibers + + PMT(762 NA0138) + detectors in front + CALO + big beam	1
3	quartz 45 deg + bundel of fibers + + PMT(762 NA0138) + + CALO + small beam	1
4	quartz 90 deg + bundel of fibers + + PMT(762 NA0138) + + CALO + small beam	1
5	50 cm quartz rod + + 2 HAMAMATSU PMT + + CALO + small beam	2

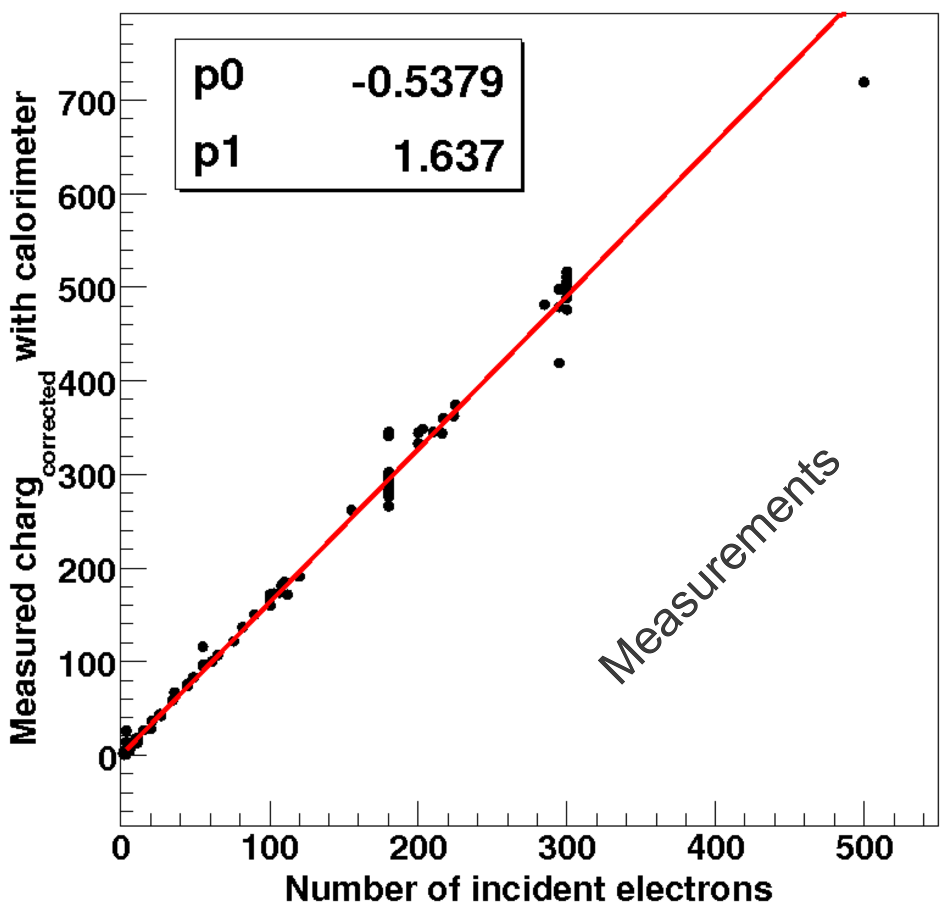
*READOUT electronics configuration
We use 8 channels USBWC electronics

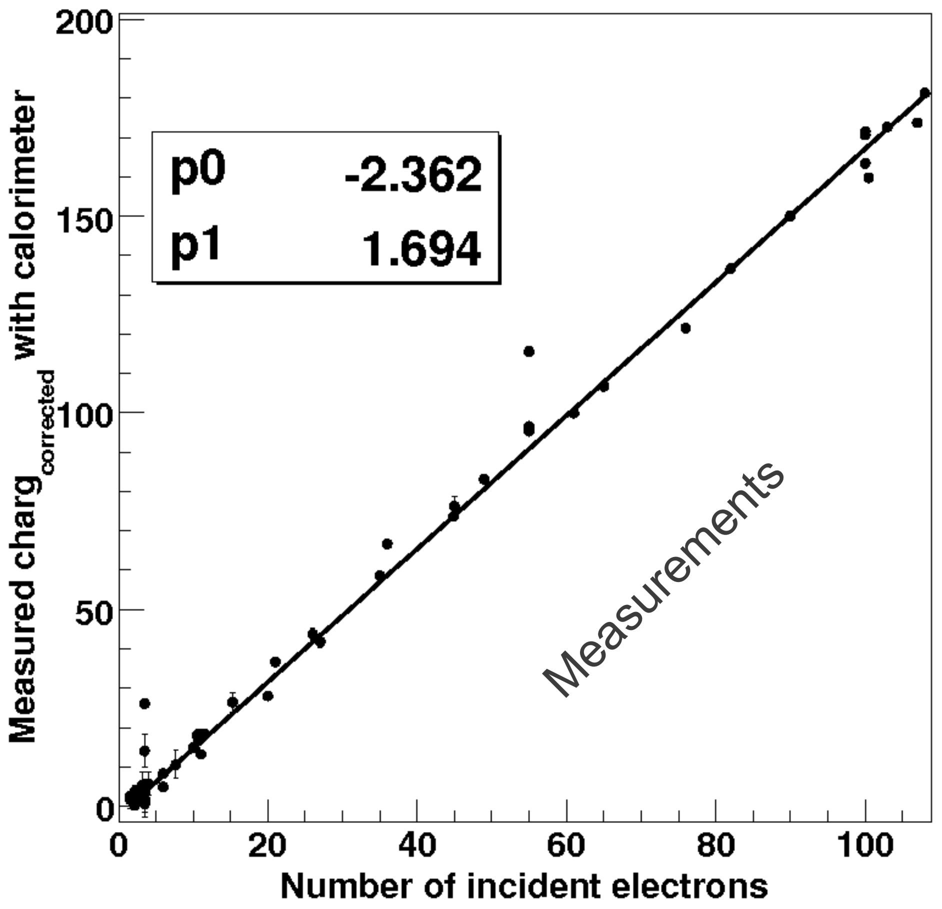
ID	ch0	ch1	ch2	ch3	ch4	ch5	ch6	ch7	software version	remarc
-1	CALORIMETER	CpFM							2.1.5	500 per file
0	CALORIMETER	CpFM							2.1.5	all ev. in file
1	CALORIMETER	CpFM	INFN OSCILO. TRIGGER	INFN CHER.					2.1.5	all ev. in file
2	CALORIMETER	PMT1	PMT2						2.1.5	all ev. in file

In total we perform 137 runs



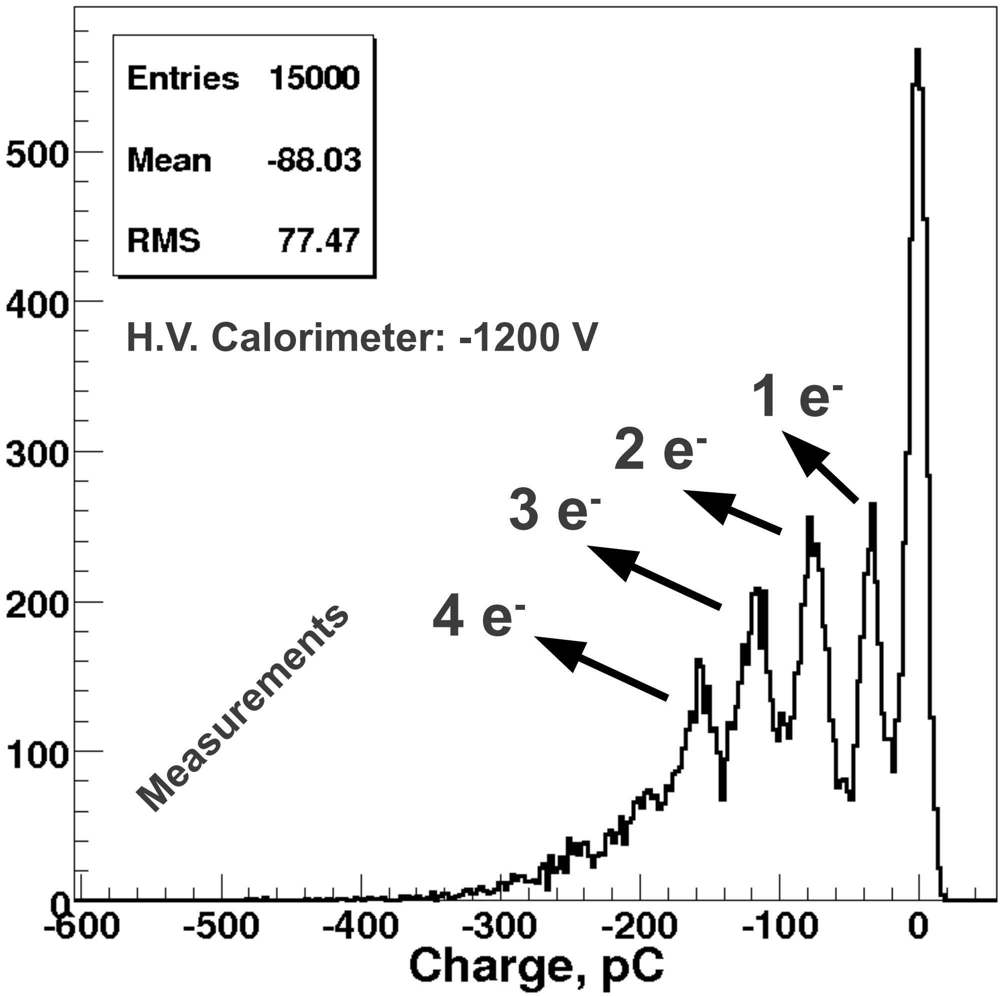
Check of the calorimeter linearity



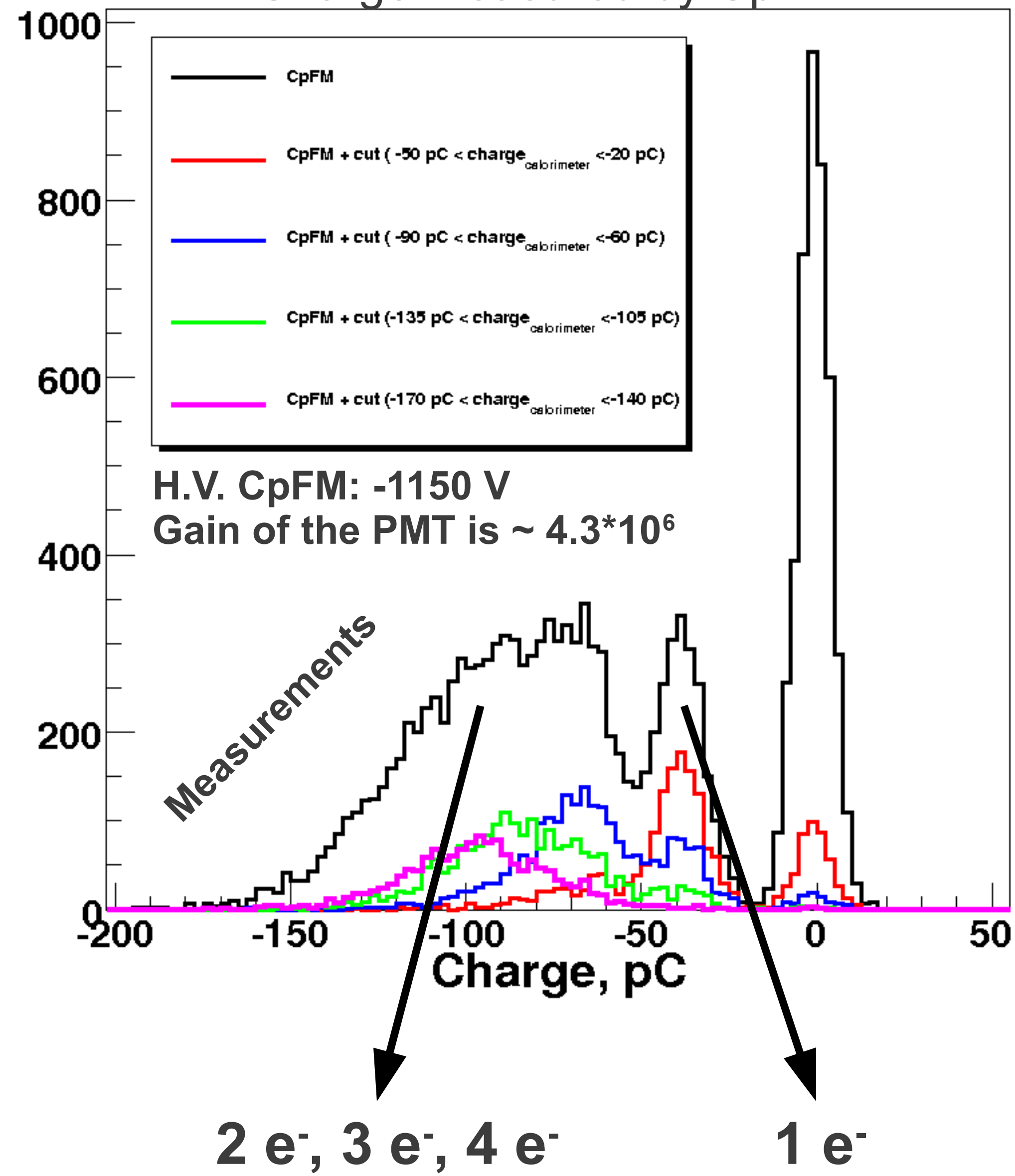


CpFM detector response on low flux of electrons

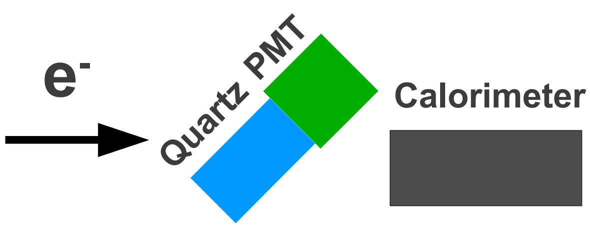
Charge measured by calorimeter



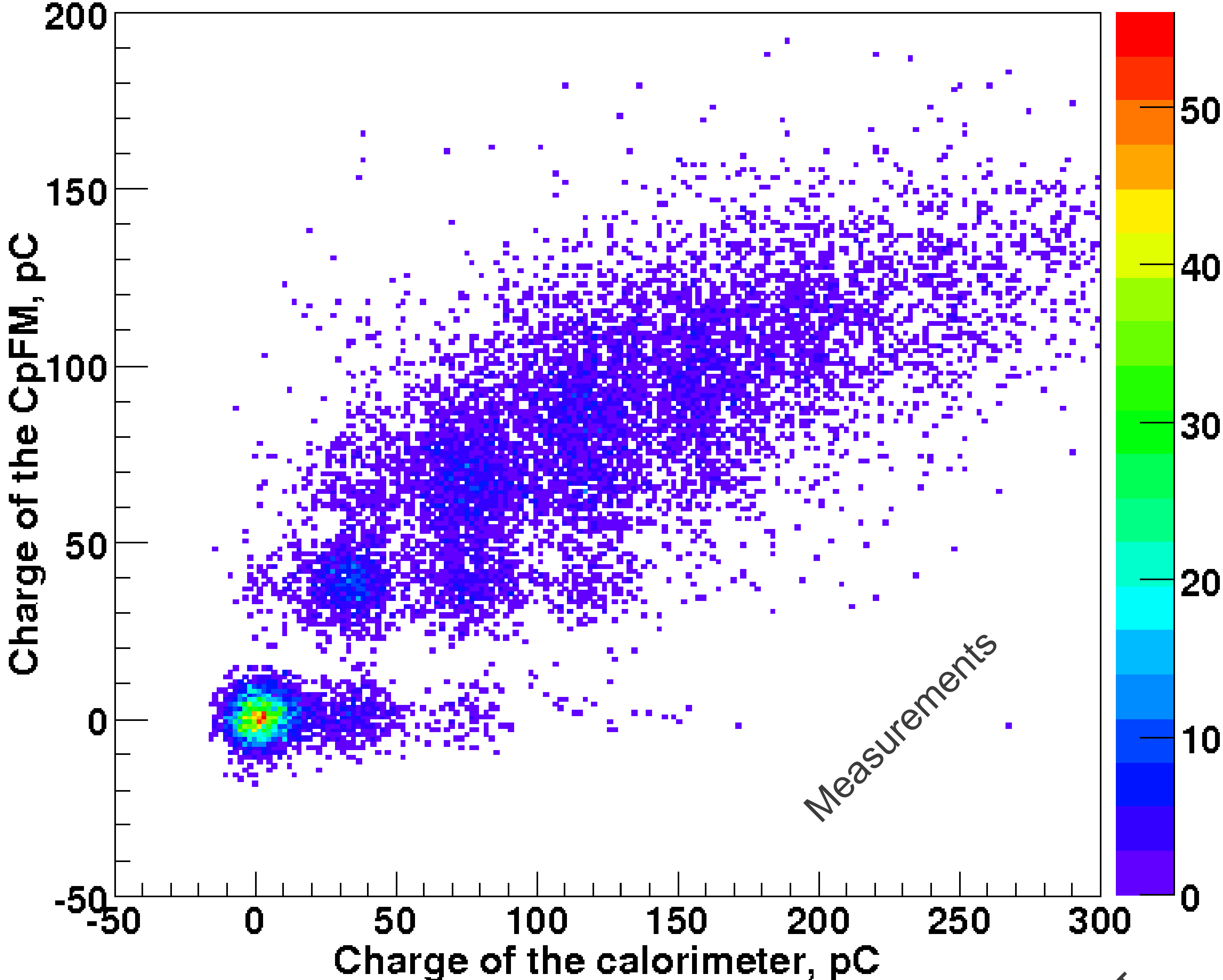
Charge measured by CpFM

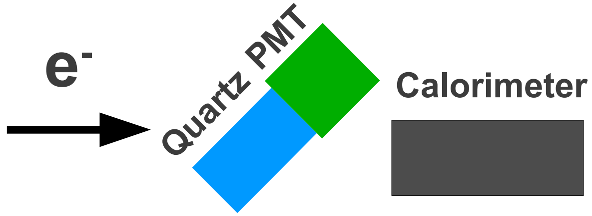


Saturation of the PMT



Charge measured with CpFM vs calorimeter



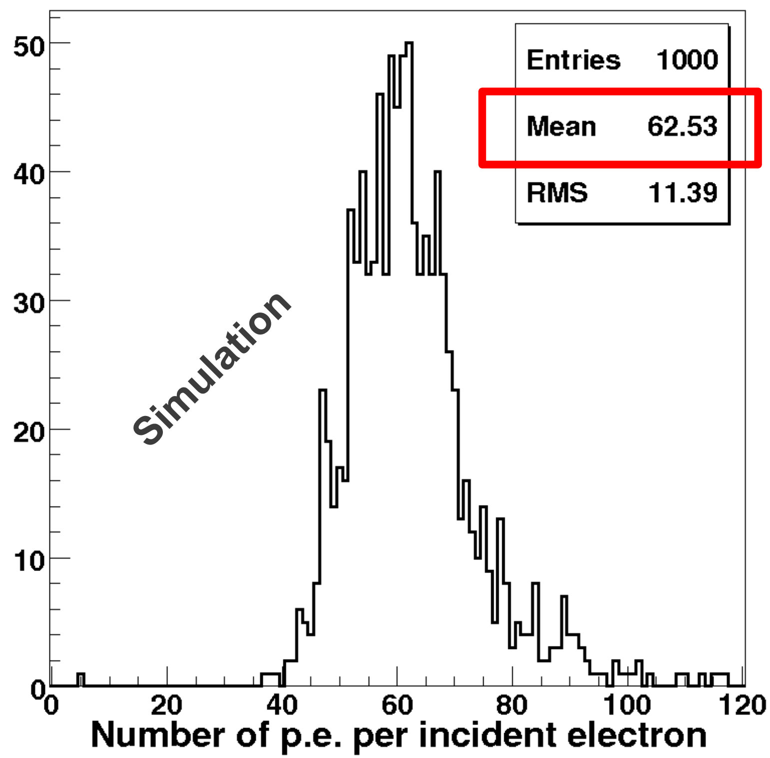


Quartz + PMT (comparison with simulation)

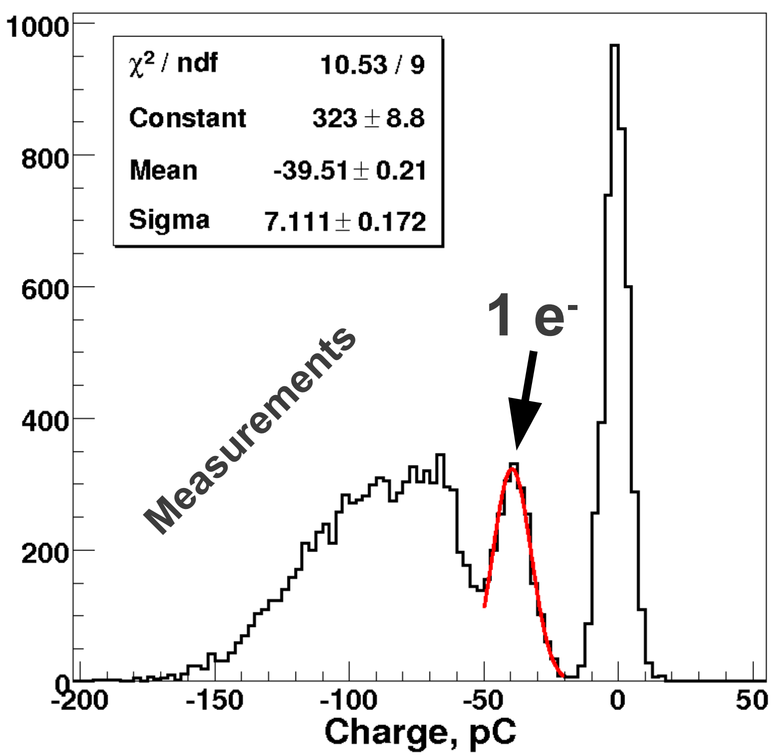
Simulation

446 MeV e^- with 45° incident angle

Bialkali photocathode with
100% collection efficiency



Measurements



Gain of the PMT is ~ 4.3×10^6
for H.V. = -1150 V

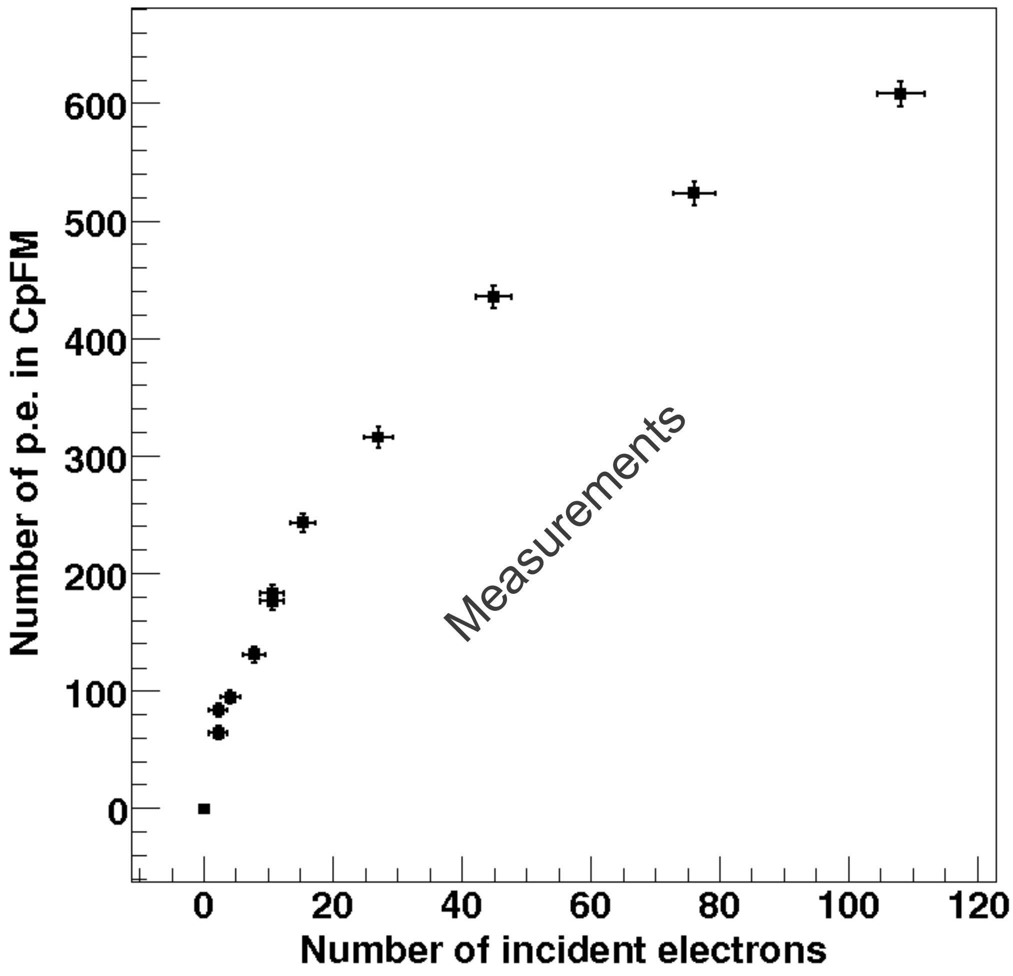
39.5 pC per incident electron

57.4 p.e. per incident electron

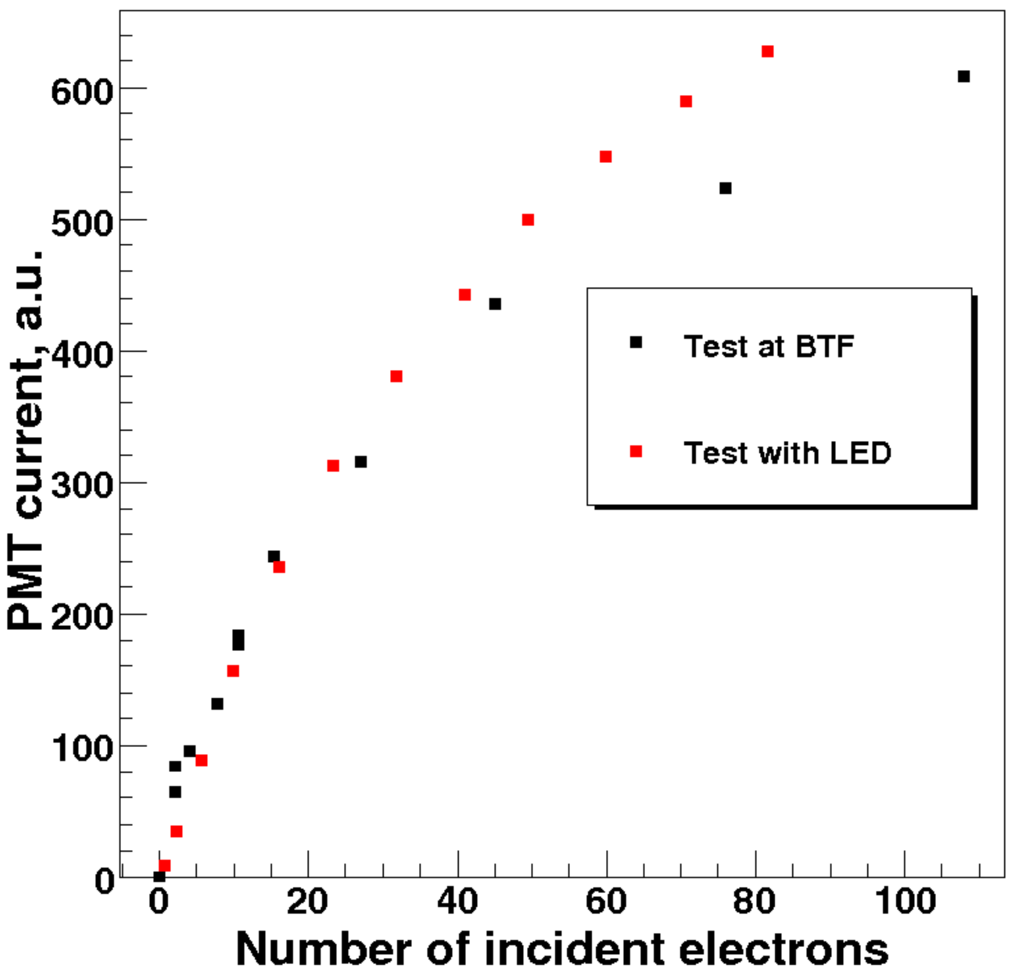
Good agreement !!!

CpFM detector response on “high” flux of electrons

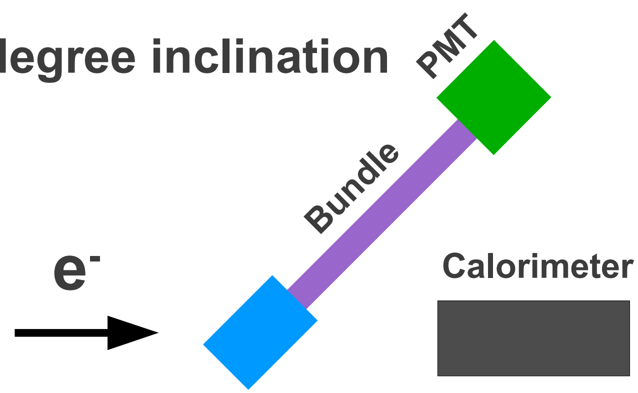
Nonlinear behavior of the PMT

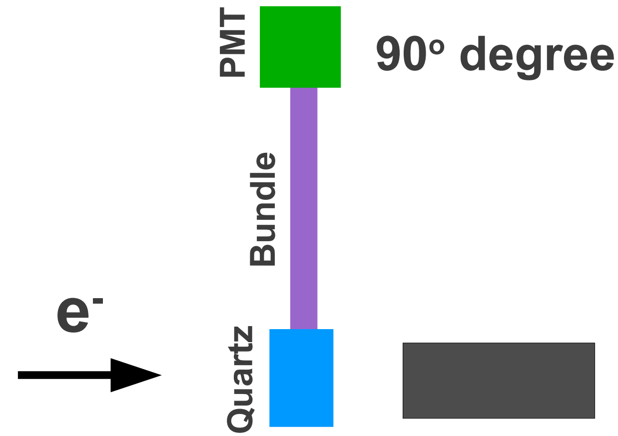


Nonlinear behavior of the PMT crosscheck at optical test bunch



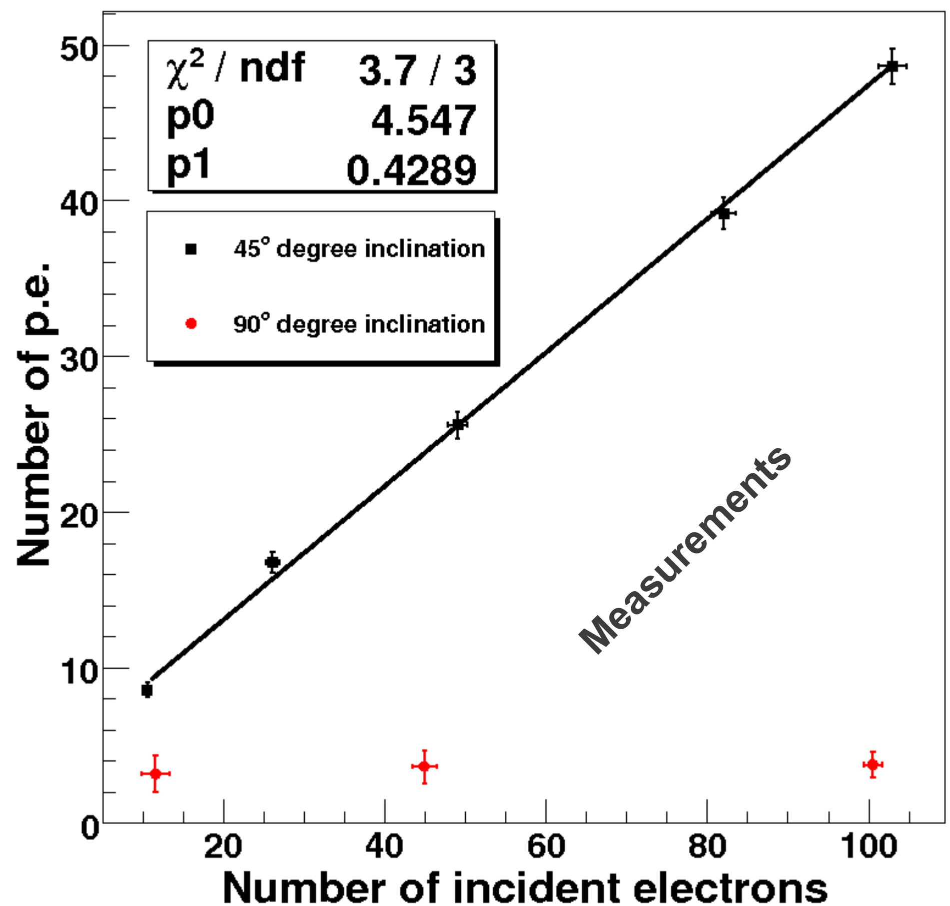
Quartz + bundle of fibers + PMT



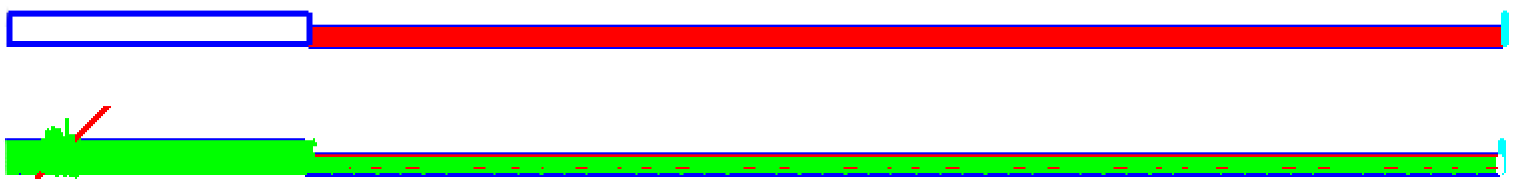


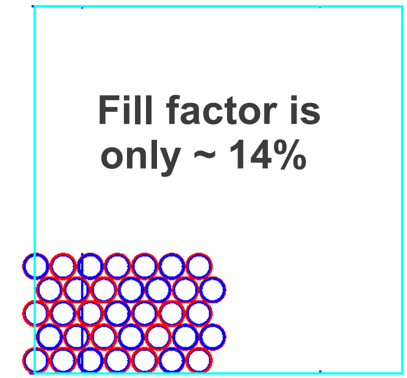
We detect 0.43 p.e. per incident electron

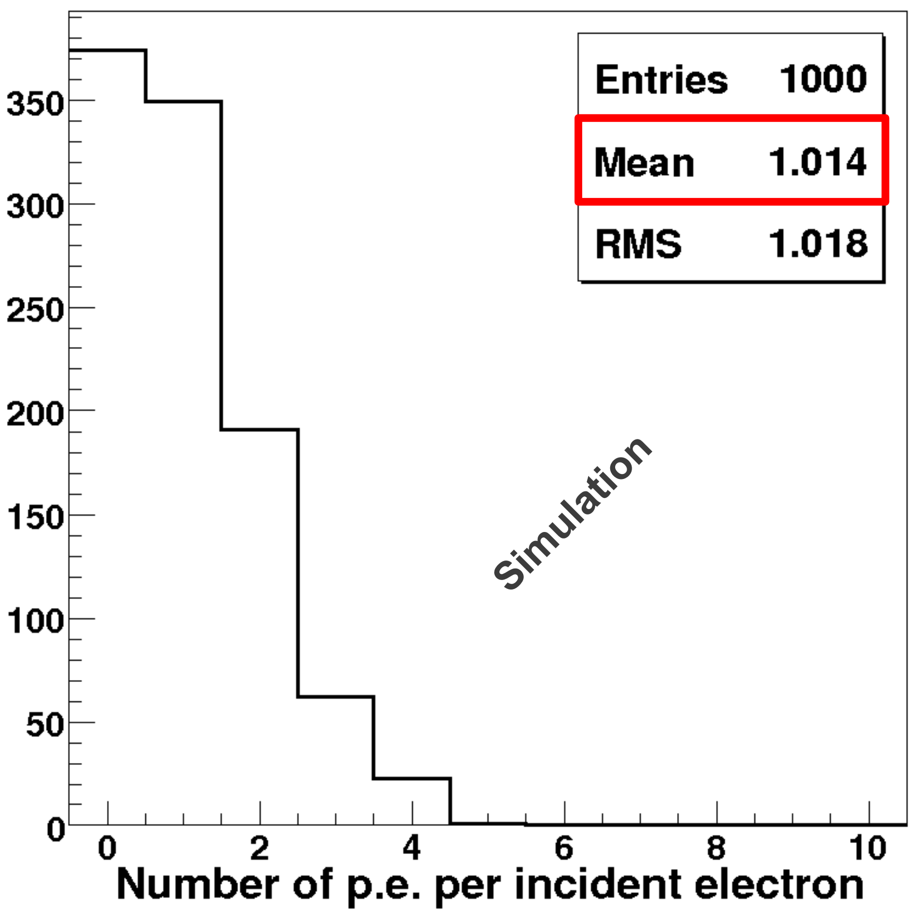
Due to small angular acceptance of the fibers (numerical aperture 0.22) geometry with 90° degree inclination does not detect any light.



Quartz + bundle of fibers + PMT (comparison with simulation)





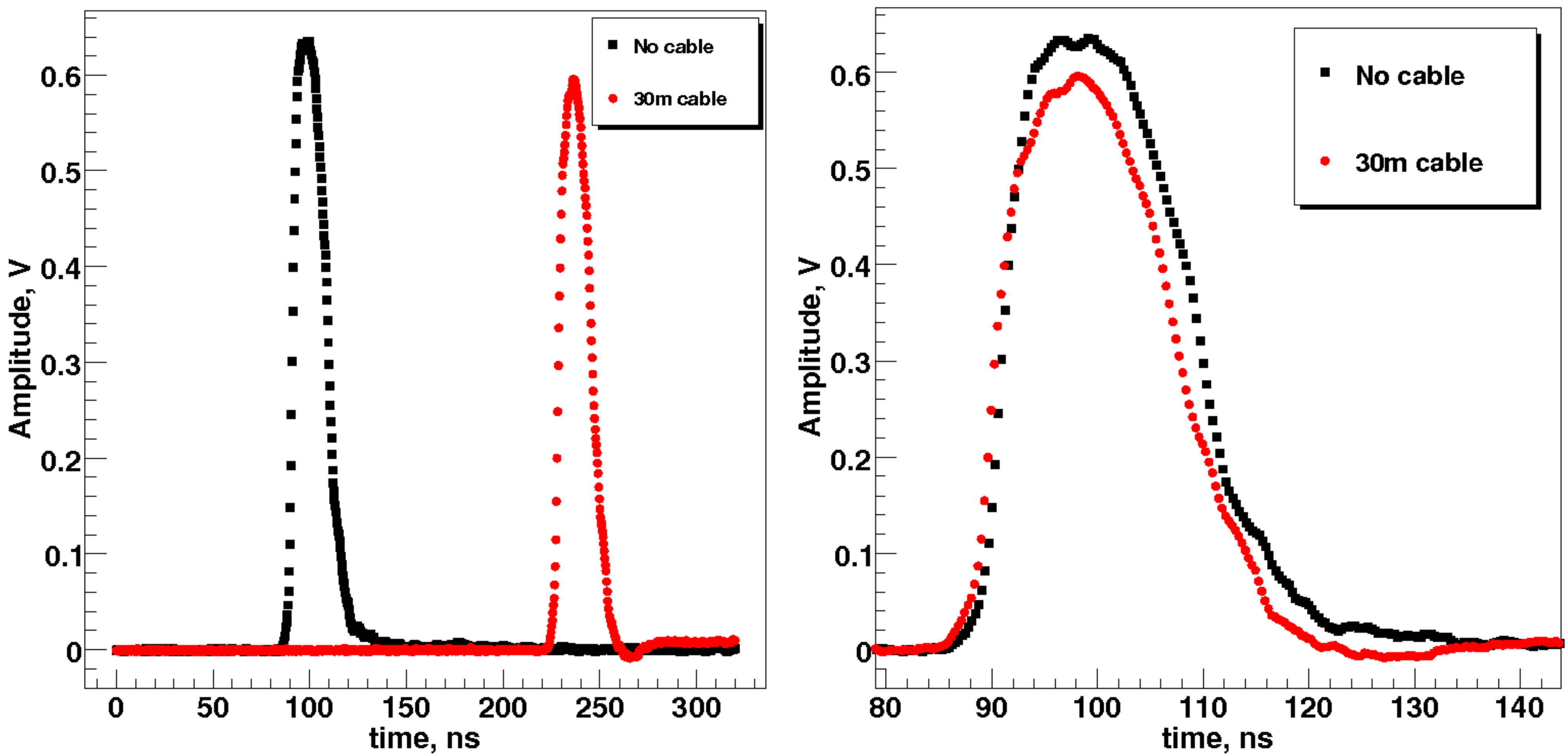


The difference between measurements and simulation is roughly factor of two. It is probably coming from the poor quality of the home made bundle.

The interfaces efficiency:

quartz finger vs bundle
bundle vs finger
can be estimated: ~70 %

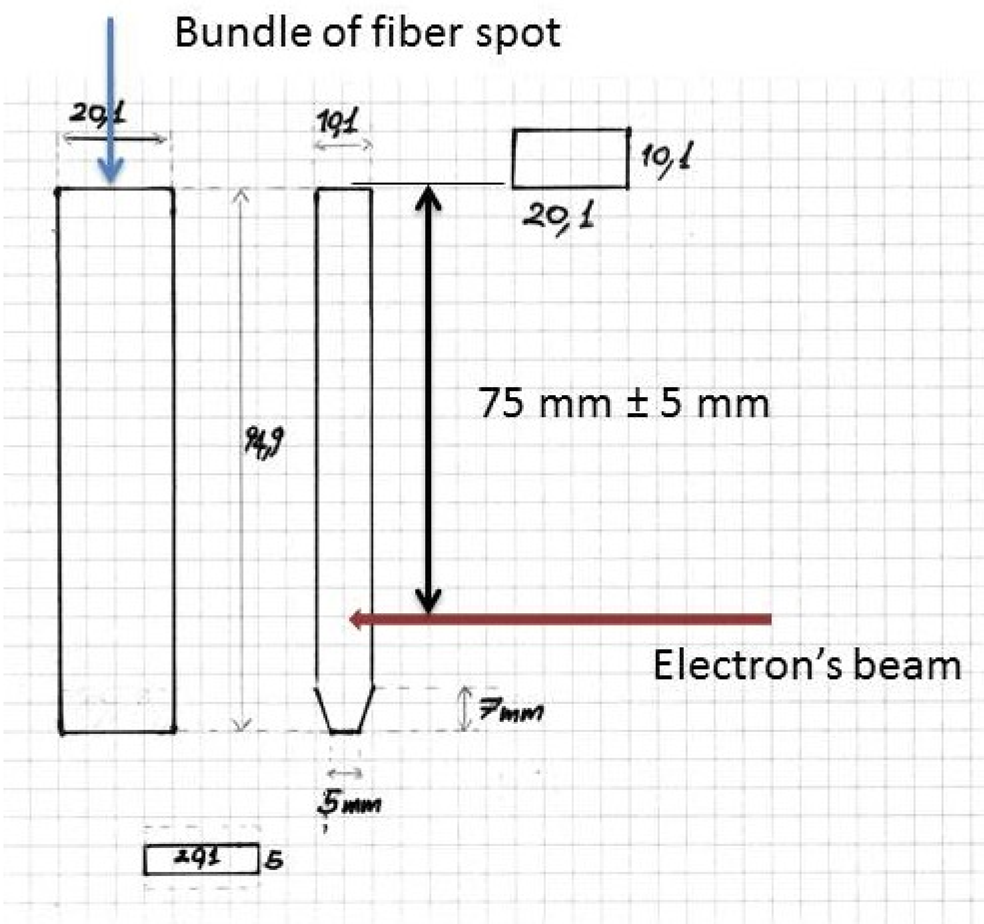
Cable attenuation



Less the 10 % effect

Shape does not change a lot

Test with 300 m cable is needed



We used 2 bundle of fiber: the first is around 13cm , made up of 25 fiber (but only 24 work rightly) placed into a round area with diameter 6mm; The second is around **45 cm** (but I need to verify), and made up of **25 fiber** (only 24 well-functioning), placed **into a round with area 5mm** Both the bundles were placed in the center of rectangular side of quartz bar (see the sketch)

The fibers are the same used in the past:

Fibers: Fibertech

Type AS600/660 UVST

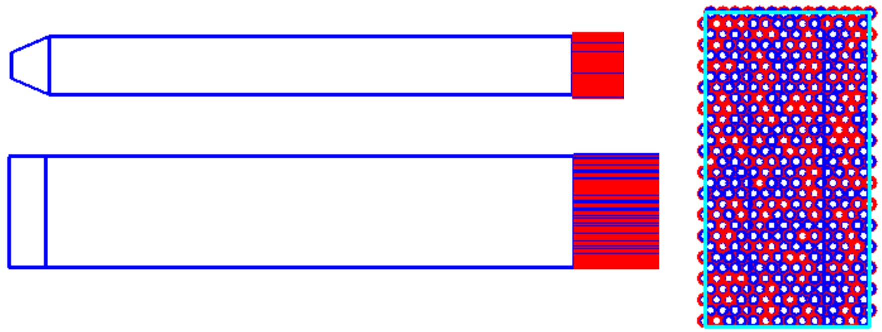
Coating 780 μm Silicone

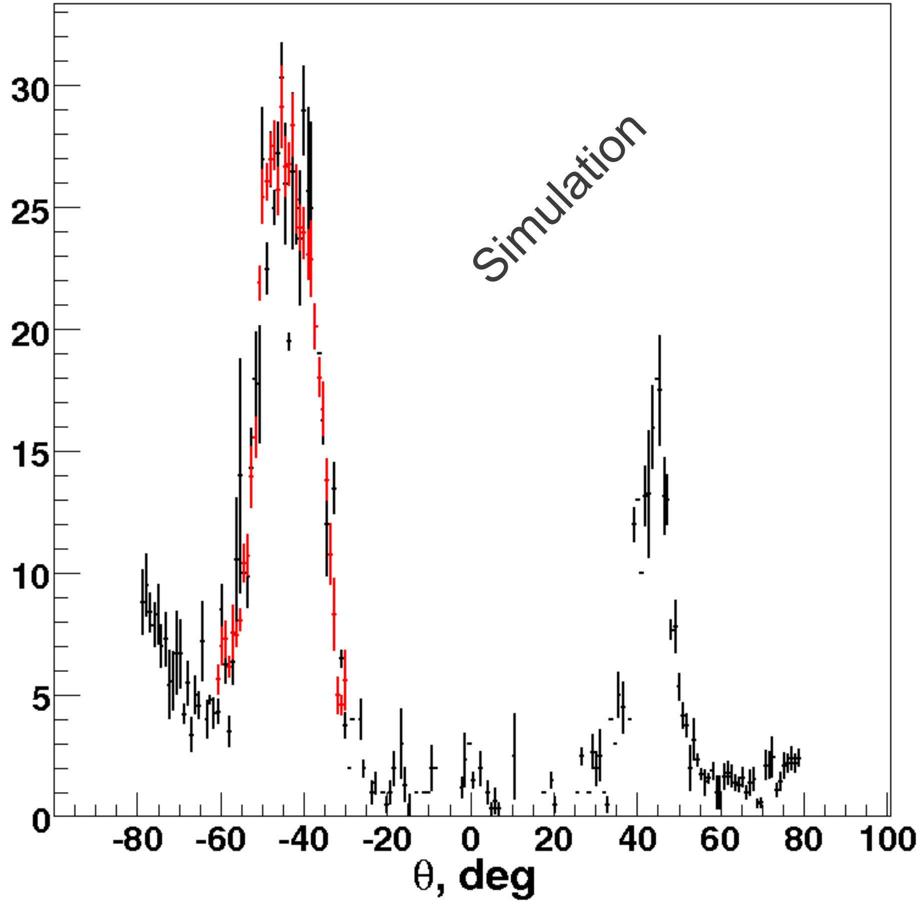
Jacket 940 μm Tefzel

0.6 dB/m at 350 nm

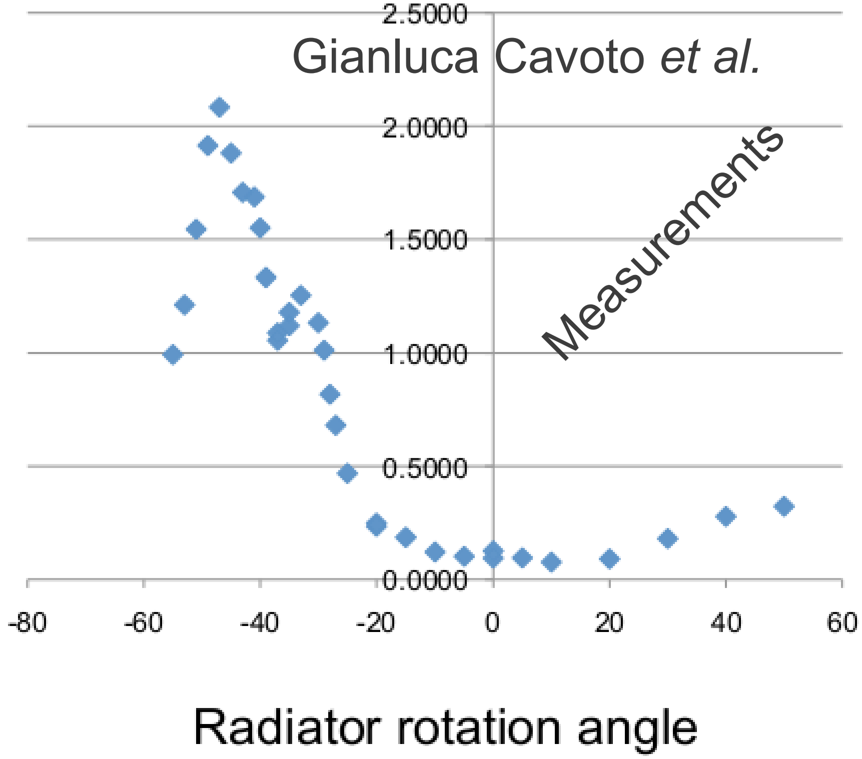
FROM email: 02.11.2013 Francesco Iacoangeli

Simulation of the radiator connected to the bundle



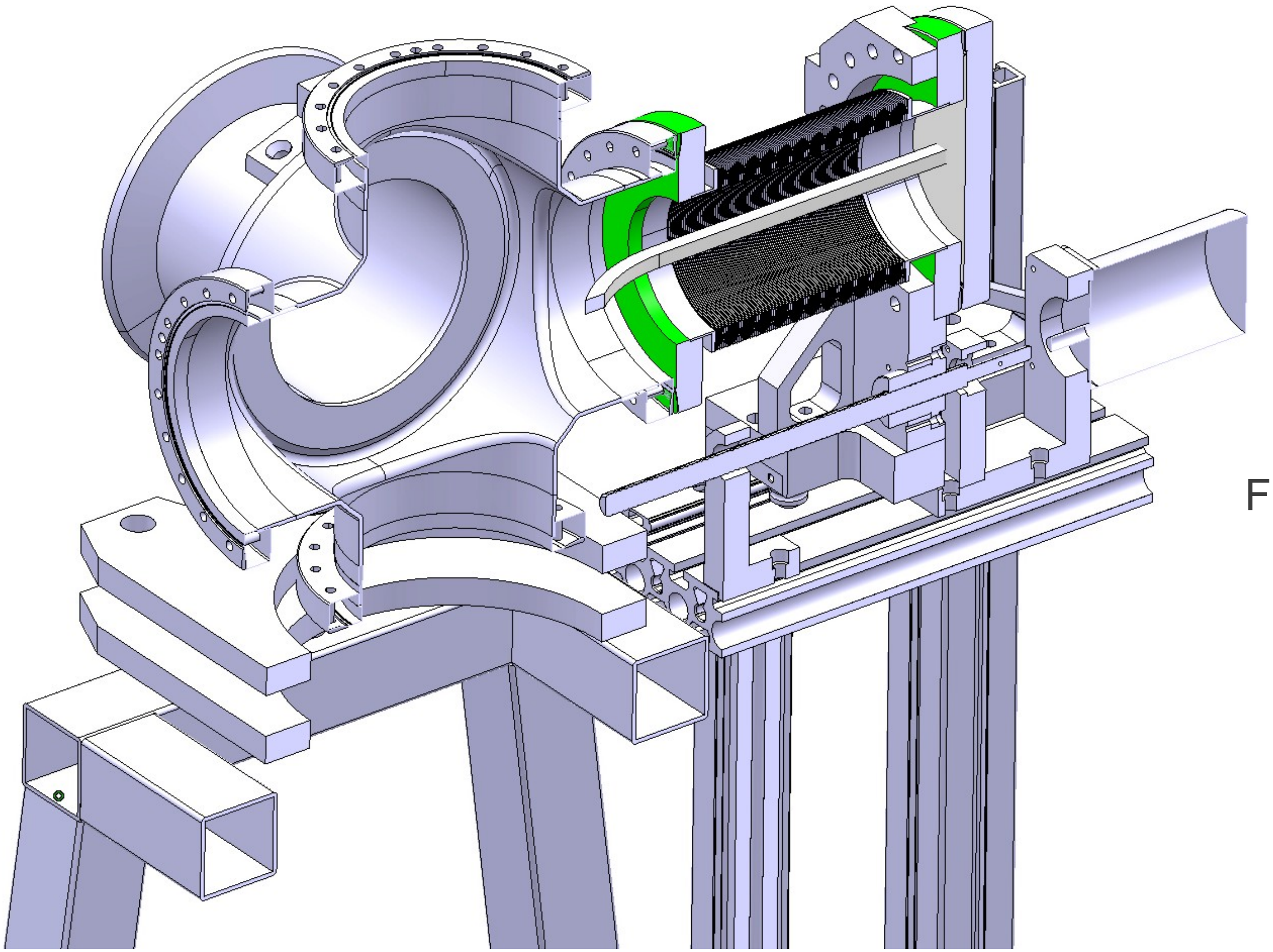


Charge signal normalized
to number of incident electron
and electron pathlength in the radiator



First version of tank design is done !!!

- CF150 flange.
- bellow with external size 132 mm.
- distance between the axis of the flange and the axis of the radiator of 20 mm.
- curvature radius of 100 mm (on the axis) for the radiator.



Frederic Loprete

Conclusions

- BTF tests prove the feasibility of the CpFM detector. However additional tests are needed before construction and calibration of the final version of CpFM.
- Quality of the optical fiber bundle need to be improved. It will be produced by a specialized company.
- Mechanical support design on going at CERN.
- The CpFM prototype will be tested under irradiation (protons and gammas).
- The CpFM will be calibrated at BTF and then installed.

    1. inside the SPS beam pipe in June 2014.
    2. inside the LHC beam pipe at the beginning of 2015.

Backup

Radiation hardness of the CpFM components

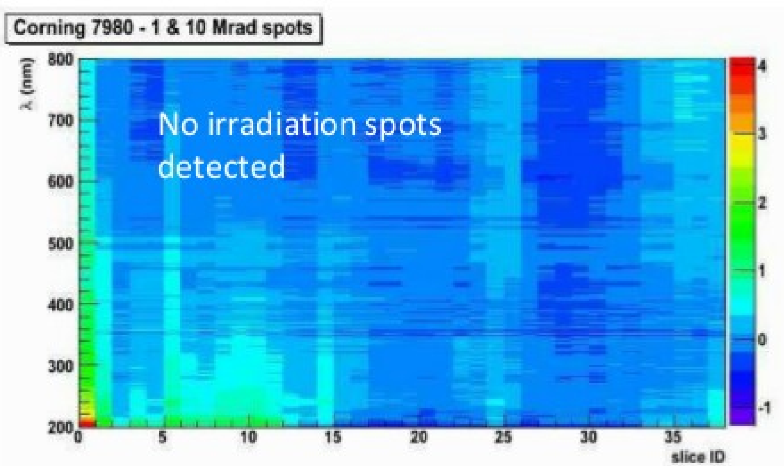
Annuel Radiation levels close to the pipe: γ dose = 10 Mrad

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

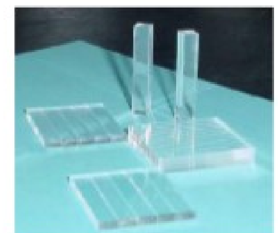
protons fluence = 10^{13} p/cm²

(1 Gy = 100 rad)

Quartz radiation hardness



M. Hoek, RICH 2007



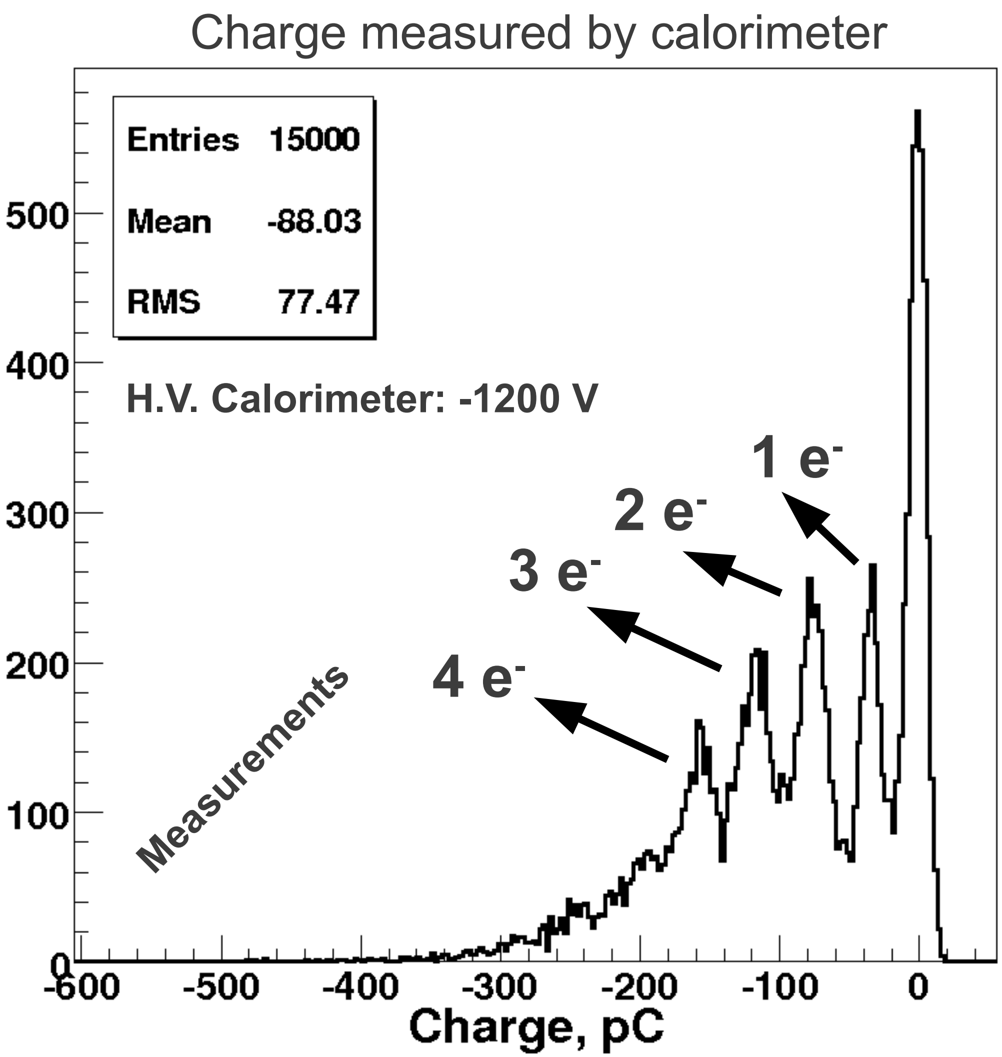
3 fused silica types (Corning 7980, Schott Lithosil Q0, Heraeus Suprasil 1) irradiated with 150 MeV **proton** beam with dose levels: 100krad, 1Mrad and 10Mrad

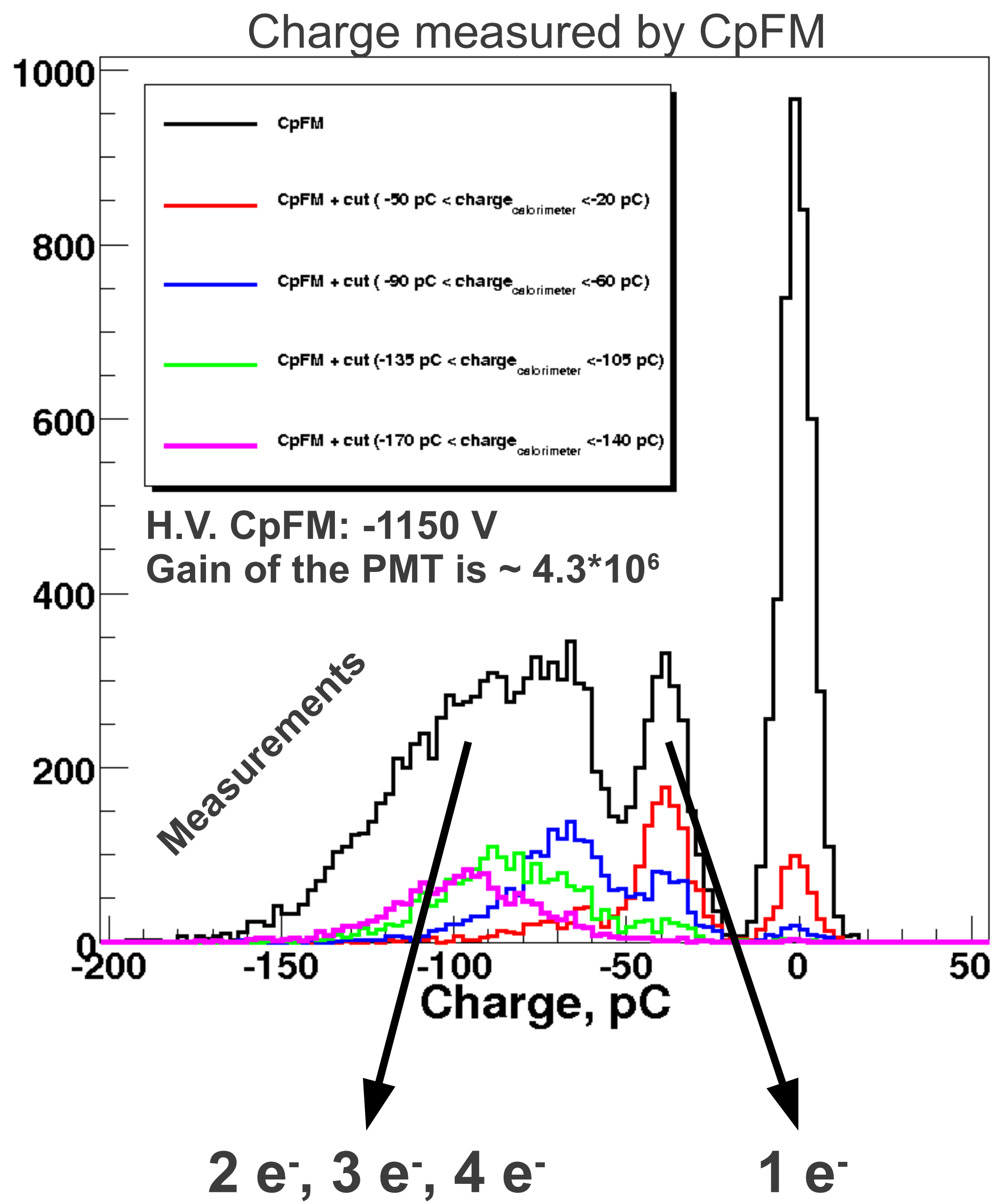
→ **No significant radiation damage observed in any fused silica sample**

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

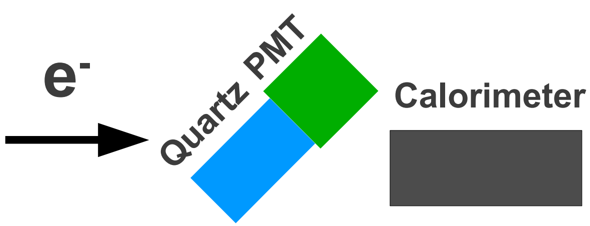
⇨ Our choice: Corning 7980 & Heraeus Suprasil

Quartz + PMT

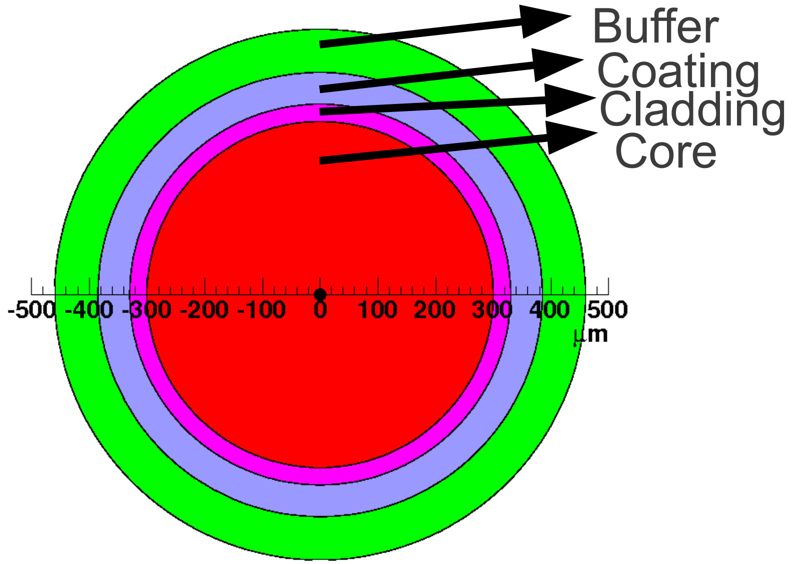




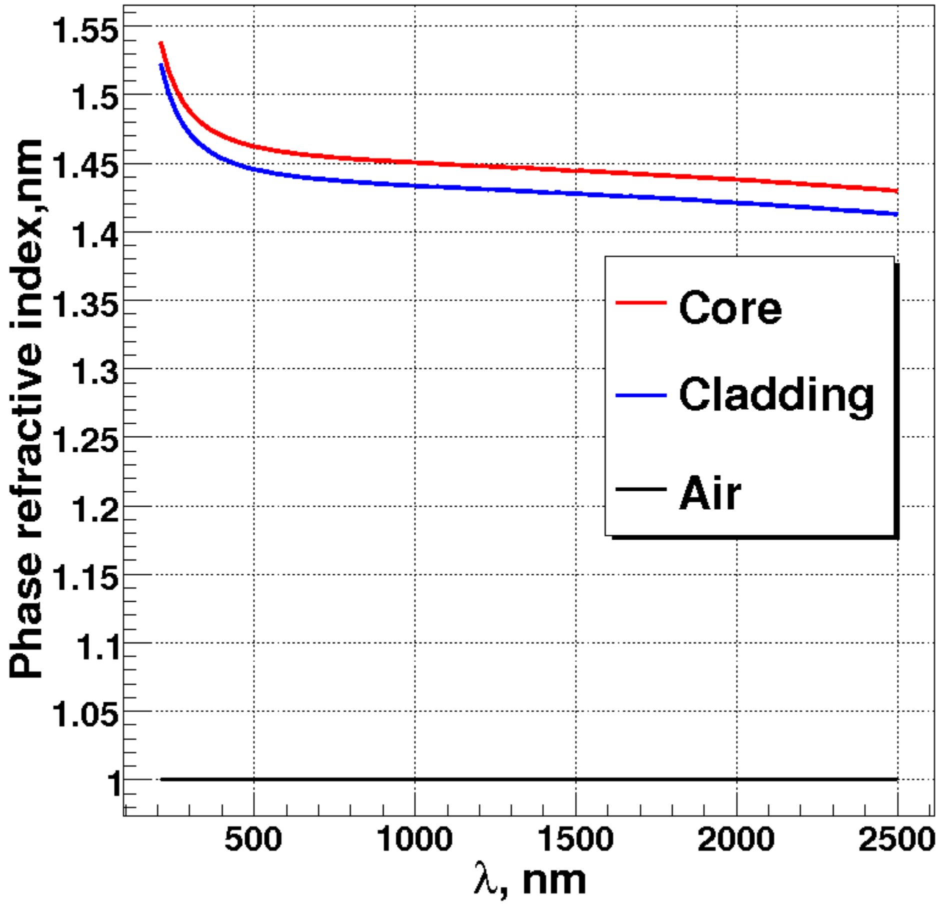
Saturation of the PMT ???

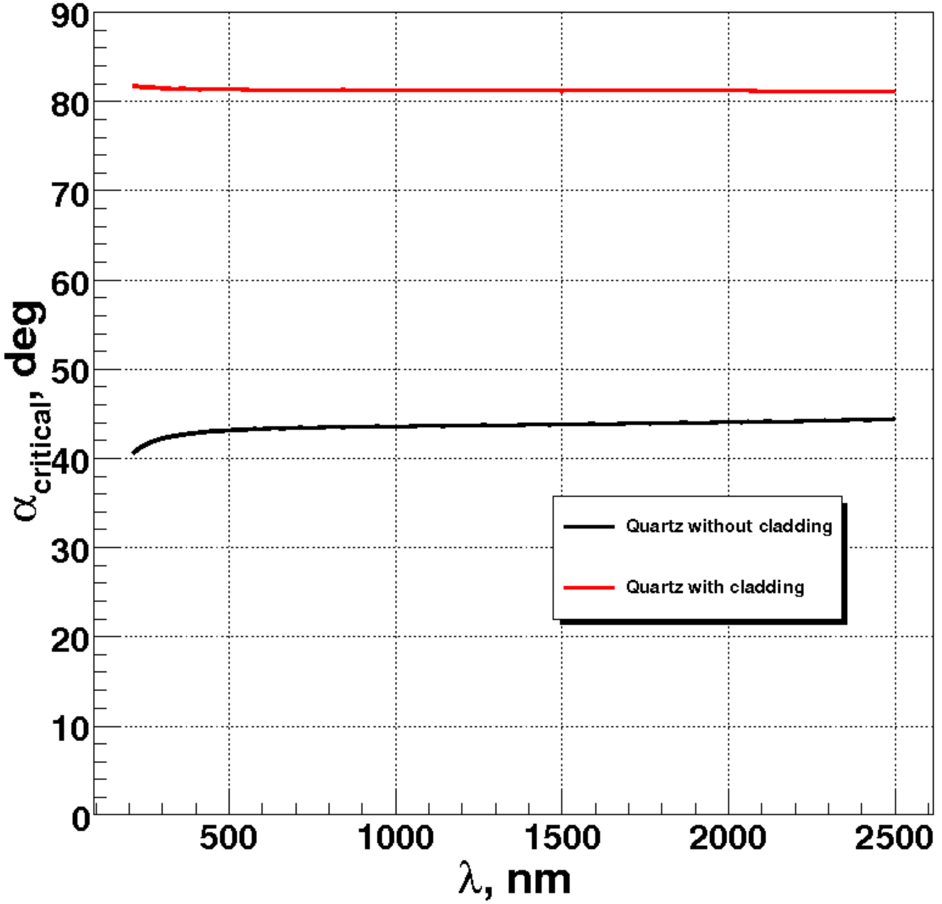


Optical fiber

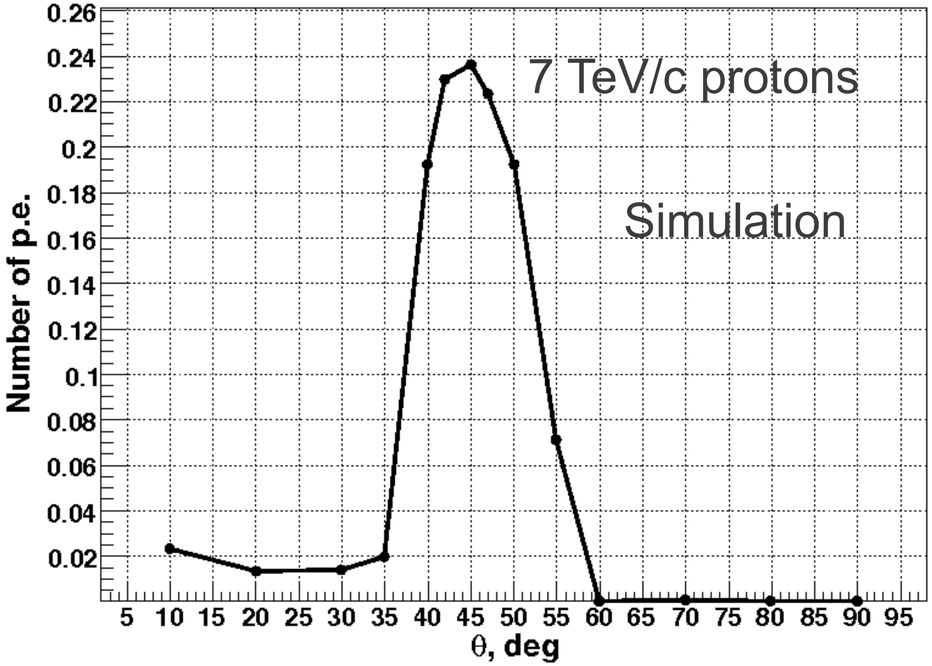


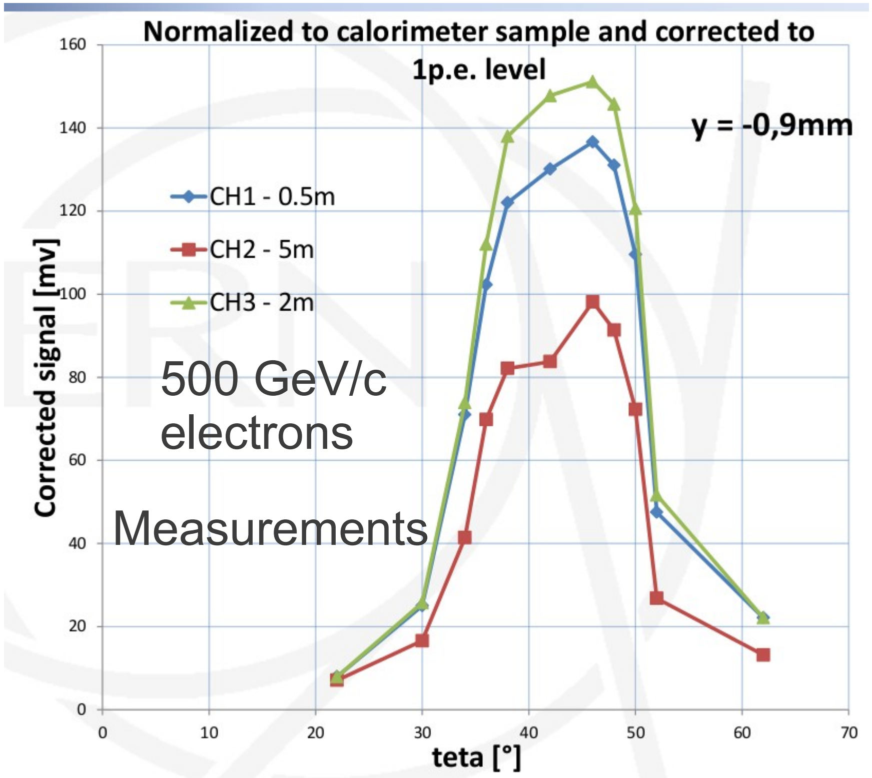
Numerical aperture => $0.22^2 = n_{Core}^{\ 2} - n_{Cladding}^{\ 2}$



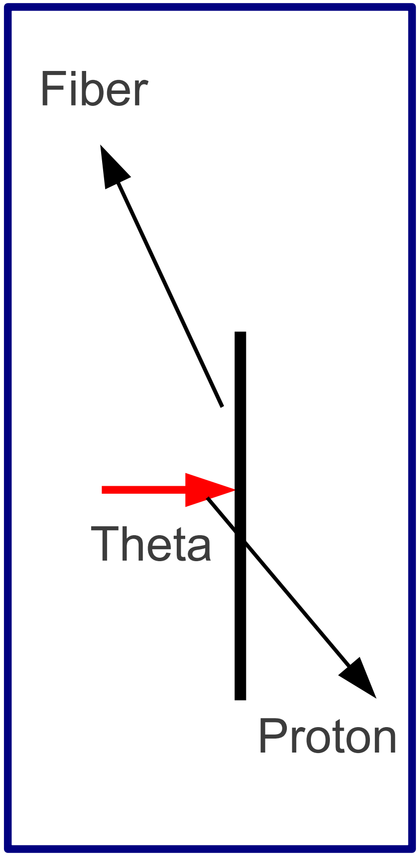


Number of p.e. as a function proton angle





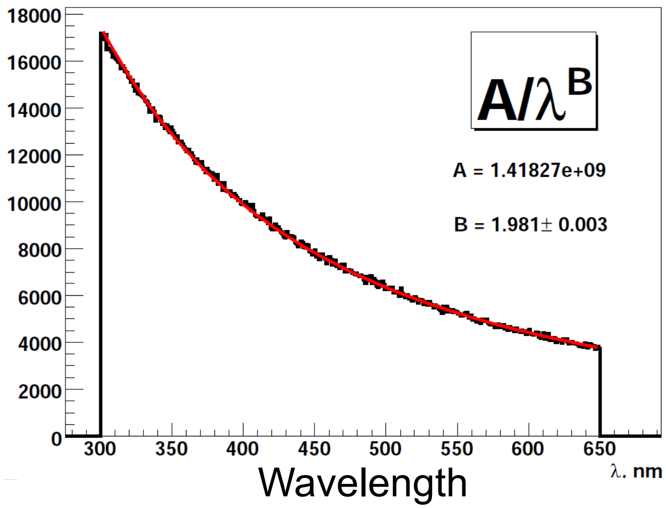
Photon detection efficiency (PDE) = 10 %

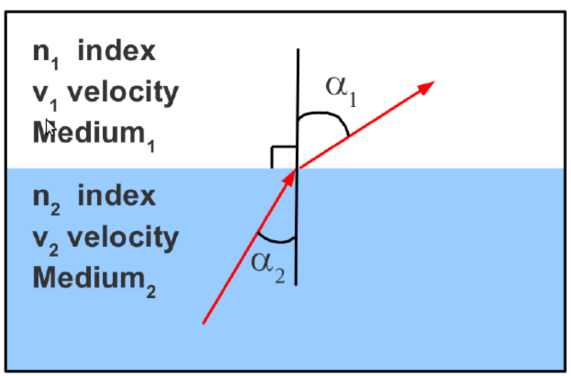


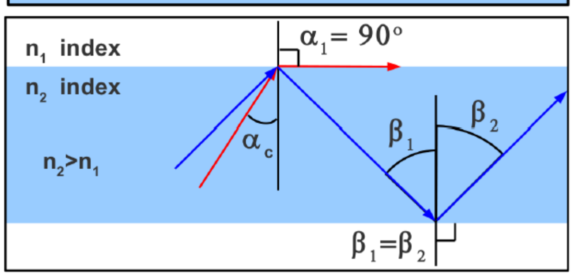
Geant4 simulation of the detector

Optical physics: Cherenkov effect and Snell's laws

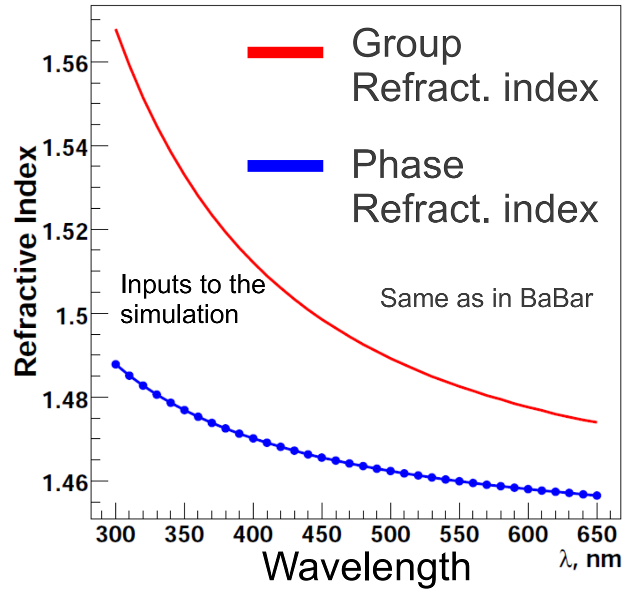
$$\cos\theta_c = \frac{1}{n\beta}$$

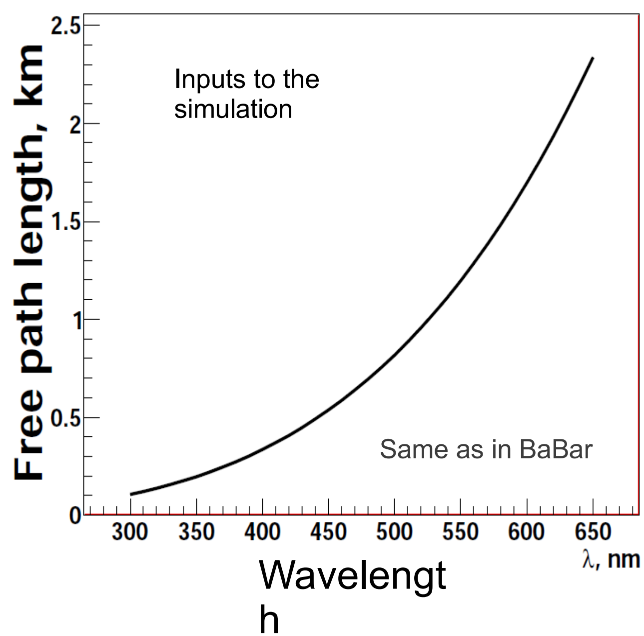






Optical properties of the quartz radiator:





Properties of the quartz and mirror surfaces: