The Cherenkov Detector for Proton Flux Measurement (CpFM) in the UA9 Experiment

Status & new developments for double-beam splitting

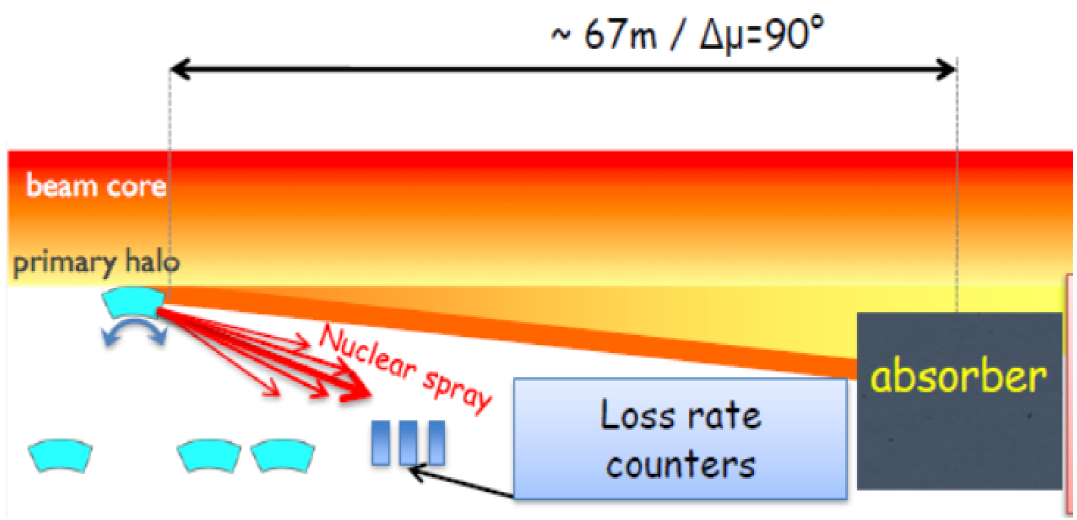
5th French-Ukrainian Workshop on Instrumentation, LAL Orsay – France, November 6, 2017

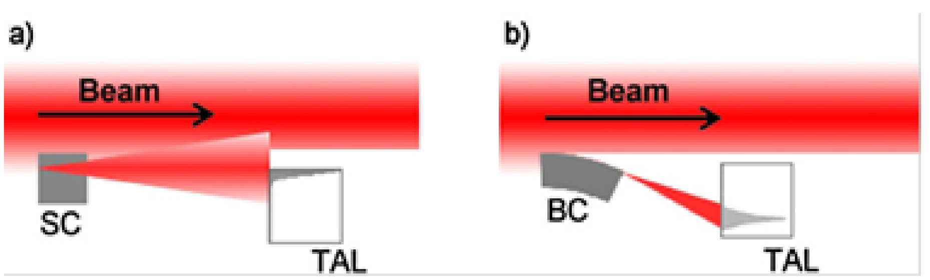
L. Burmistrov[1], D. Breton[1], S. Dubos[1], J. Maalmi[1], V. Puill[1], V. Chaumat[1], A. Stocchi[1], W. Scandale[1,3], F. Addesa[2], G. Cavoto[2], F. Iacoangeli[2], M. Garattini[3], S. Montesano[3], A. Natochii[4], T. Povar[4], V. Yeroshenko[4]

[1] Laboratoire de l'Accélérateur Linéaire – CNRS/IN2P3, Orsay, France
[2] INFN – Sezione di Roma I, Rome, Italy
[3] CERN, Geneva, Switzerland
[4] Taras Shevchenko National University of Kyiv, Kiev, Ukraine

R&D for the upgrade of the LHC collimation system

Crystals collimation which aims are to **improve the cleaning and reduce the impedance** is one of the R&D projects approved for the LHC collimation





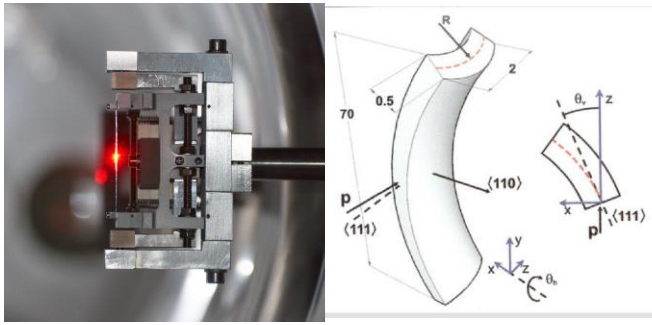
(a) Collimation scheme using a solid state primary collimator scatterer (SC).

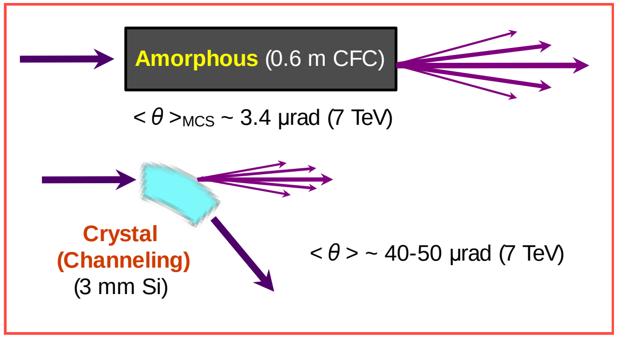
(b) Collimation scheme with a bent crystal (BC) as a primary collimator. **Halo particles are deflected and directed onto the absorber far from its edge**

The UA9 experiment

Investigate bent crystals as primary collimators in hadron colliders

- Bent crystals work as a “smart deflectors” on primary halo particles

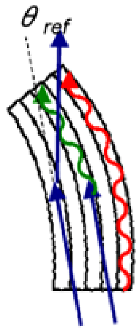




- If crystalline planes are correctly oriented, particles are subjected to a coherent interaction (channeling):

  ✓ large angle deflection also at high energy
  ✓ reduced interaction probability (e.g. diffractive events, ion fragmentation/dissociation)
  ✓ reduced impedance (less secondary collimators, larger gaps)

  ✗ small angular acceptance
  ✗ concentration of the losses on a single absorber

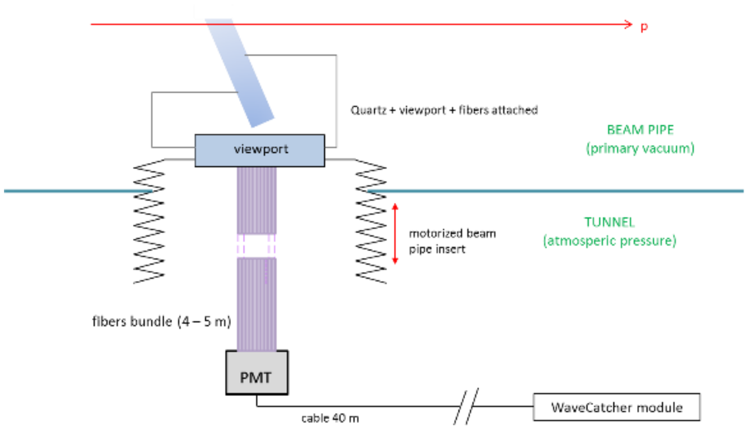


The UA9 Collaboration is investigating how to use bent crystals as primary collimators/deflectors:

- operational and machine protection concerns are considered in cooperation with the Collimation Team
- 3 installations (since 2014): SPS North Area (H8), SPS, LHC

The CpFM

- **<u>C</u>herenkov detector for <u>p</u>roton <u>F</u>lux <u>M</u>easurement**
- **Main contribution of LAL to UA9 Experiment**
- **Aim of the CpFM: count the number of deflected protons with a precision of about 5% in the LHC environment (<u>mean value over several bunches</u>, with expected values between 1 and 200 p/bunch)**

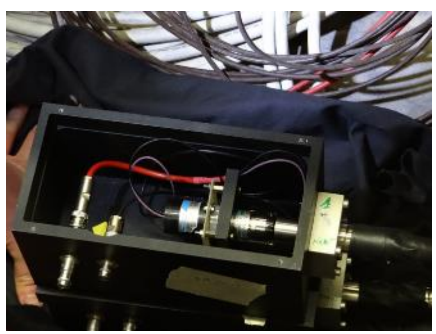


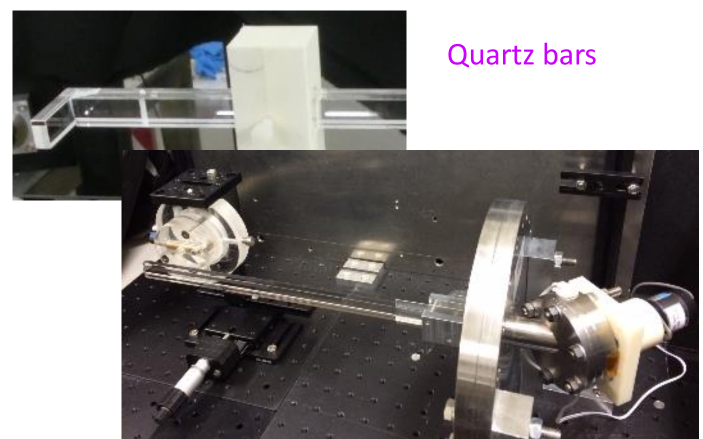
In vacuum, radiation hard detector:

- interception of the channeled beam by a quartz radiator (retractable finger)
- emission of Cherenkov light readout by a PMT placed 1 m from the beam pipe (light brought by silica fibers)
- PMT amplified signal readout by the WaveCatcher module (3,2 GHz digitizer)
- 2 channels (one to measure the background)

Fibres bundle

PMTs socket and housing





Quartz bars

CpFM Beam-tests at BTF and H8

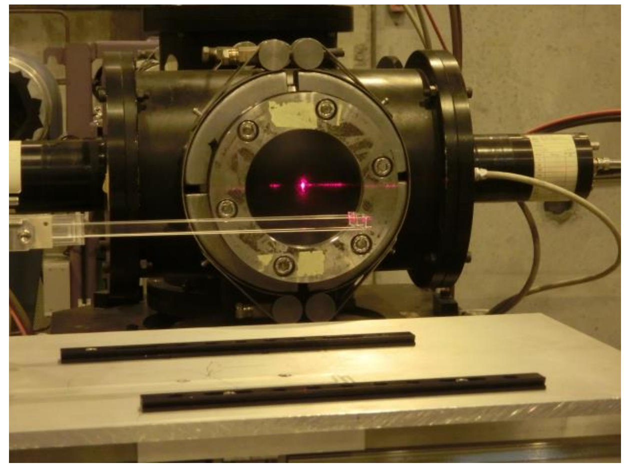
400 GeV/c p , 180 GeV/c π^+

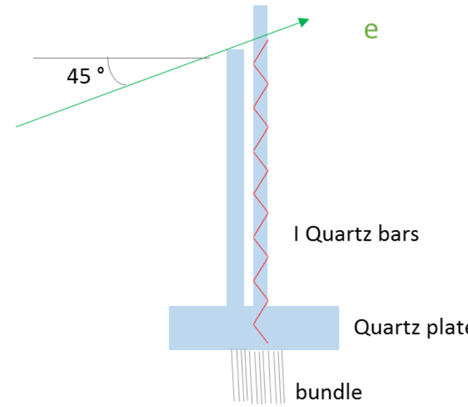
bundle

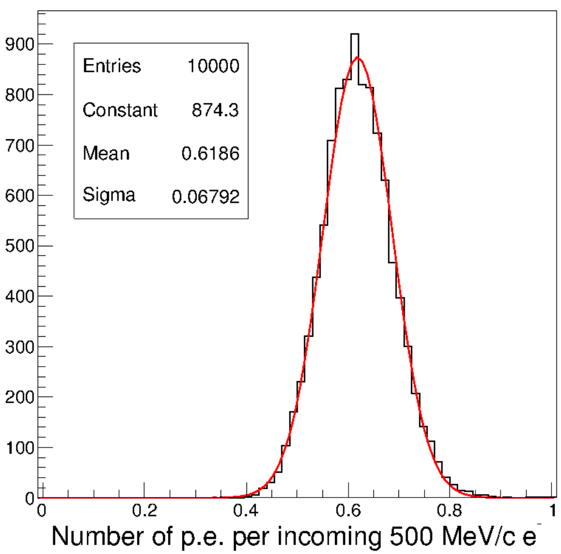
40 m cables

PMTs

‘I” bars + quartz viewport + bundle
-> Need calibration





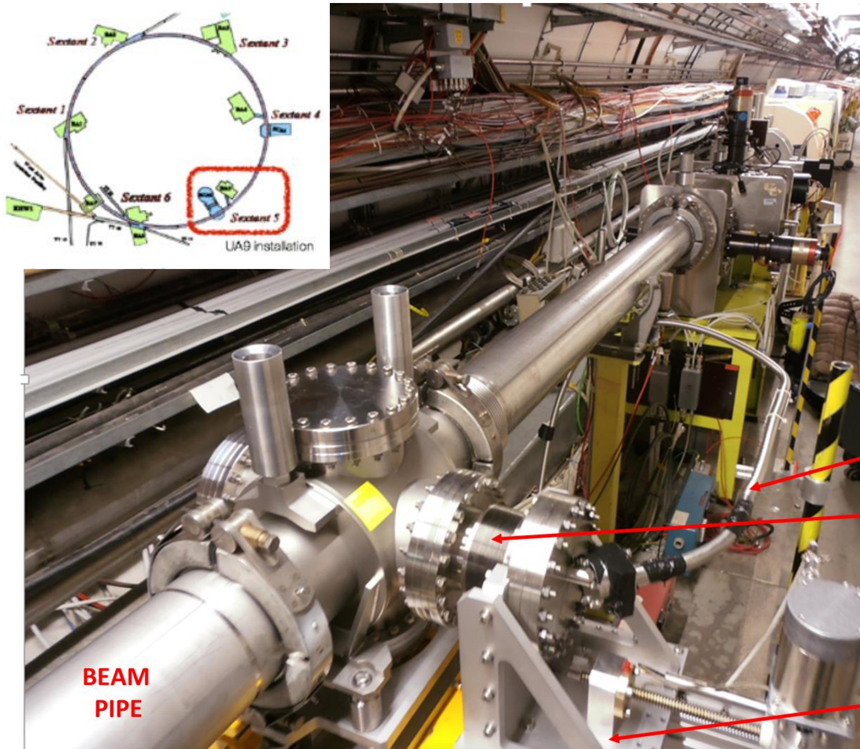


- Quartz window decreases the signal by a factor 2
- **0.62 p.e. per incoming electron for the final configuration :**
I bar + window + 4 m fibers bundle + PMT + 30 m cable + WaveCatcher

resolution = 15 % for 100 incoming electrons

CpFM installation on SPS

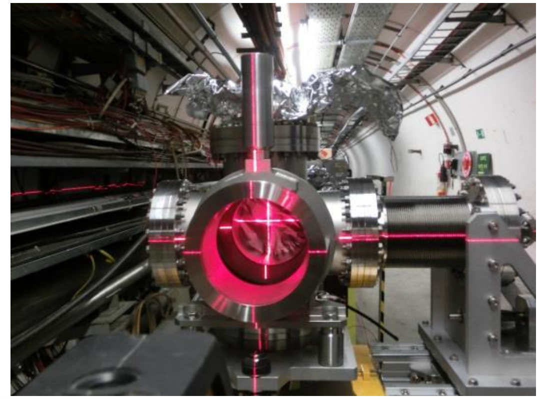
The CpFM was successfully installed on the SPS, 58 m downstream the crystal

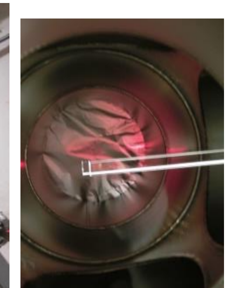


Fibers bundle

Inserting bellow

Motorized support of the quartz bars

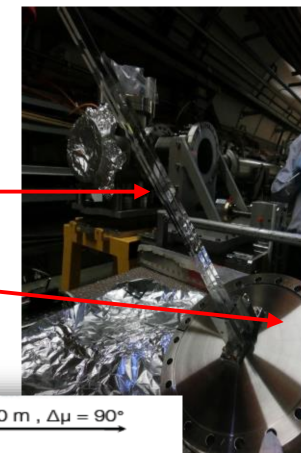


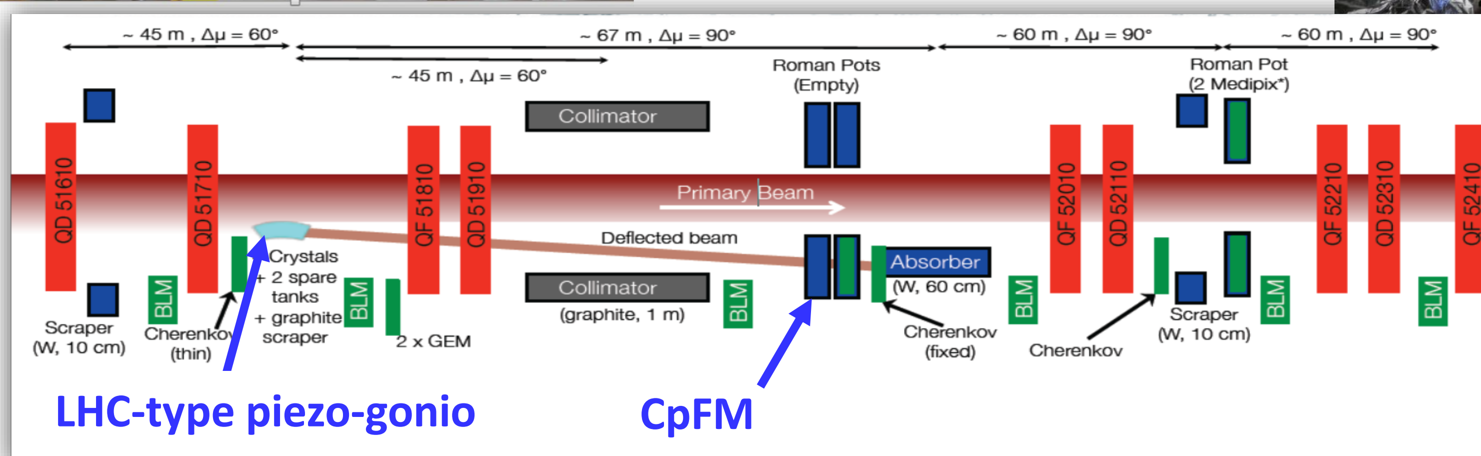


alignment of the quartz bars

Quartz bars

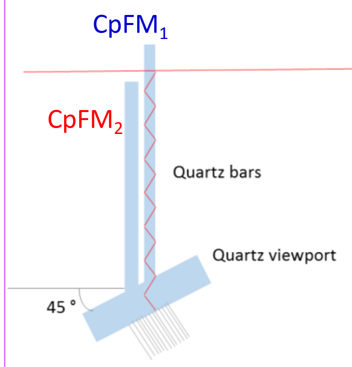
flange

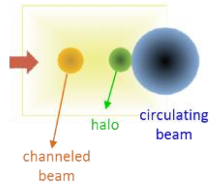


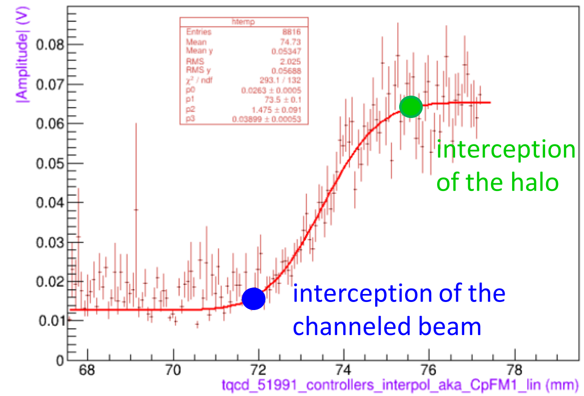


CpFM in operation

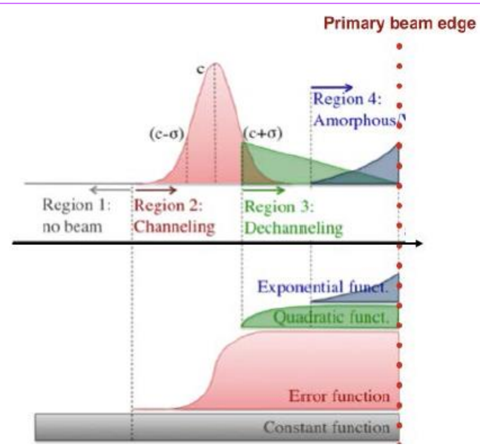
Linear scan: insertion of the bars in the beam pipe

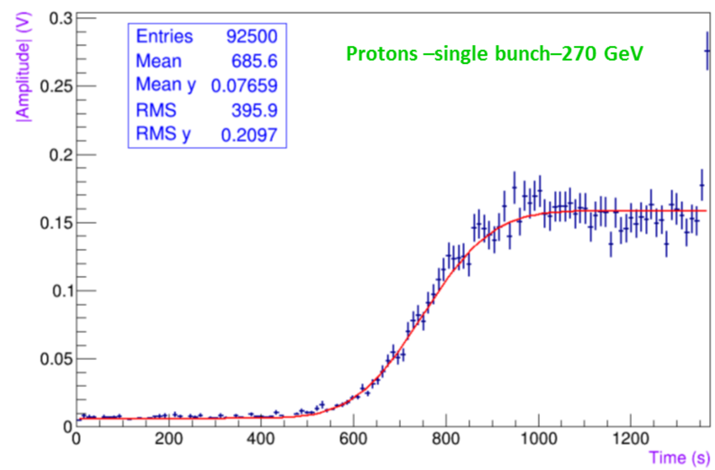






CpFM amplitude distribution in the channeling region in **good agreement with the expectations**





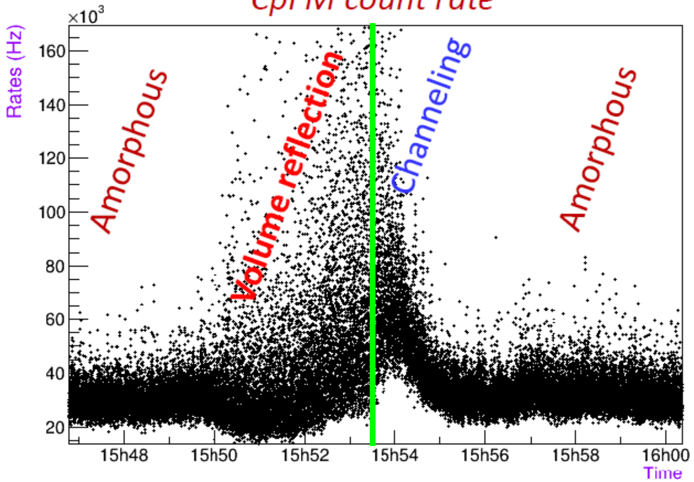
Fit of the amplitude distribution in the channeling region with an error function → its derivative corresponds to the Gaussian profile of the channeled beam.

→ σ → angular spread of the channeled beam: **12.8 μrad, in good agreement with the critical angle for 270 GeV proton (12,2 μrad)**

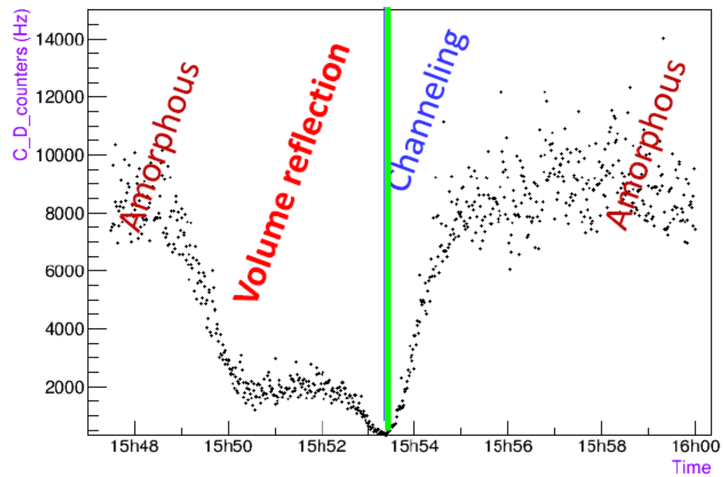
CpFM in operation

Angular scan: counting of the deflected proton when changing the angular orientation of the crystal (from 1800 to 900 μrad)

CpFM count rate



Losses measured by scintillators near the crystal



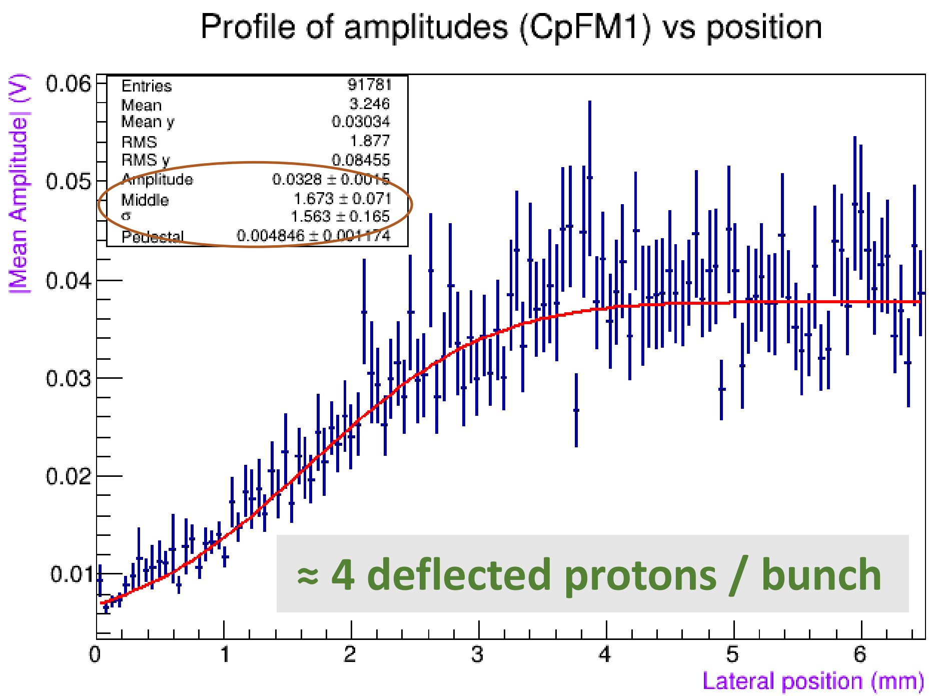
max signal on CpFM ⟷ min losses on the scintillator

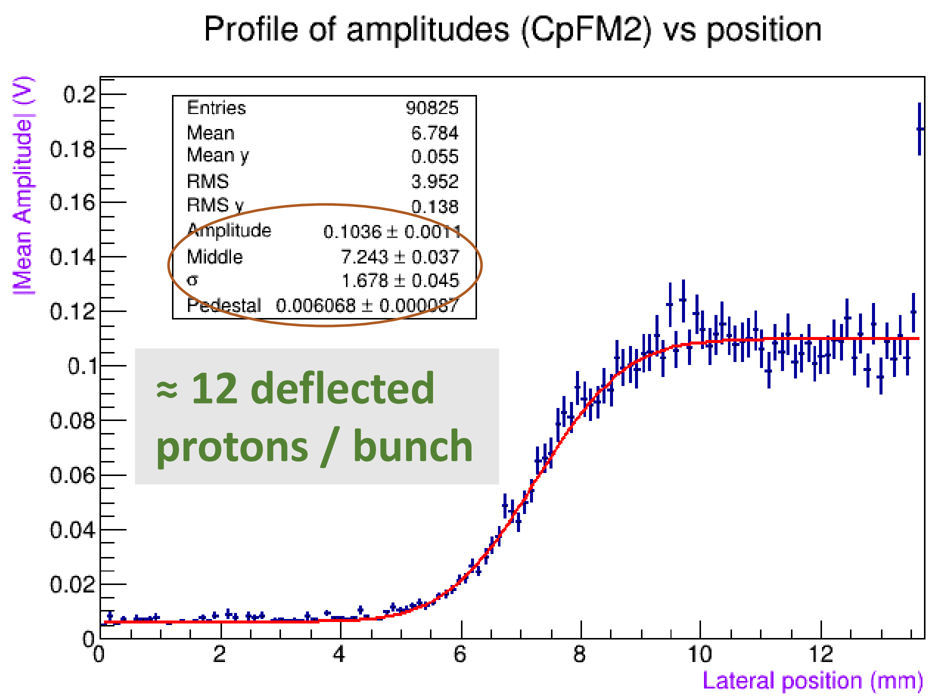
Channeling angle found at 1432 μrad

→ good agreement bewteen the CpFM and the scintillator BLM

CpFM in operation

Uncertainties about the number of deflected protons!



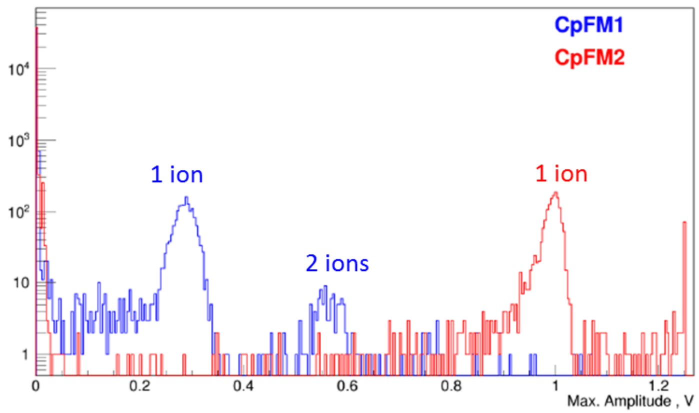


CpFM1:		CpFM2:
Amplitude: 32.8 mV ± 1.5 mV	$G_{CpFM2} > G_{CpFM1}$?	Amplitude: 103.6 mV ± 1.1 mV
Pedestal: 4.8 mV ± 1.1 mV		Pedestal: 6.1 mV ± 0.1 mV
Center: 1.67 mm ± 0.07 mm	Distance: 5.57 mm	Center: 7.24 mm ± 0.04 mm
σ = 1.56 mm ± 0.17 mm	≈	σ = 1.68 mm ± 0.05 mm

-> We should have the same number of deflected protons measured in the channeled beam!

In situ calibration

With Pb ion beam



CpFM1 $_{750\ V}$ = 271 mV
CpFM2 $_{750\ V}$ = 995 mV

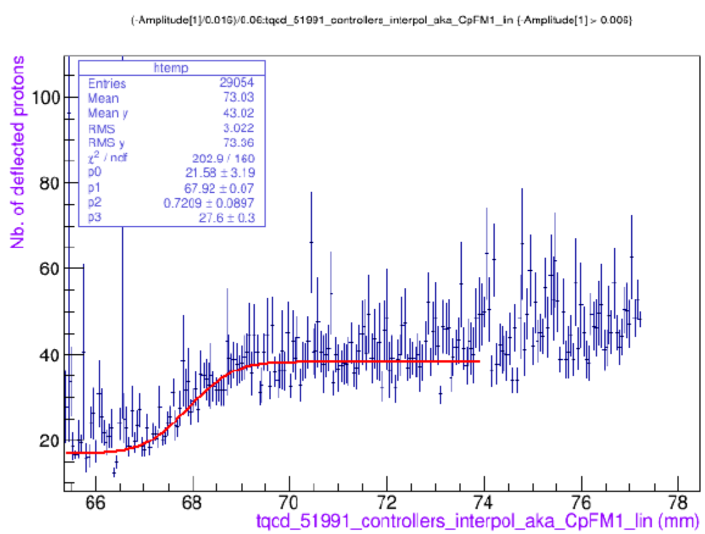
Pb ions generates 6724 times more Cherenkov light than protons (Z^2)

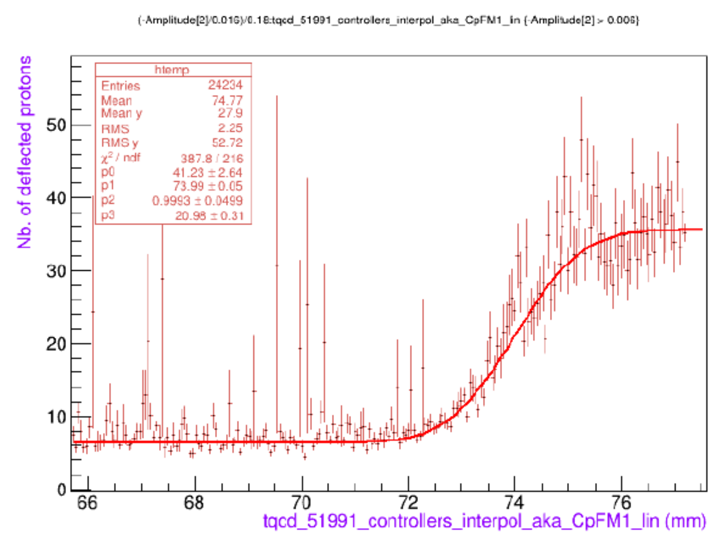
<u>Calibration coefficients:</u>

$CpFM_1$: 0.06 pe/part. 10 times less than expected
$CpFM_2$: 0.18 pe/part. 3,3 times less than expected

Factor 3 between the 2 channels

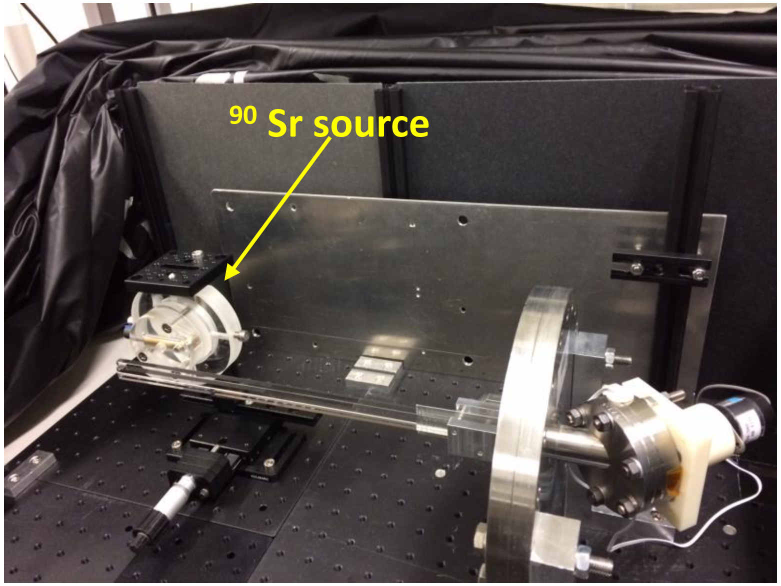
Corrected number of deflected protons as a function of the position

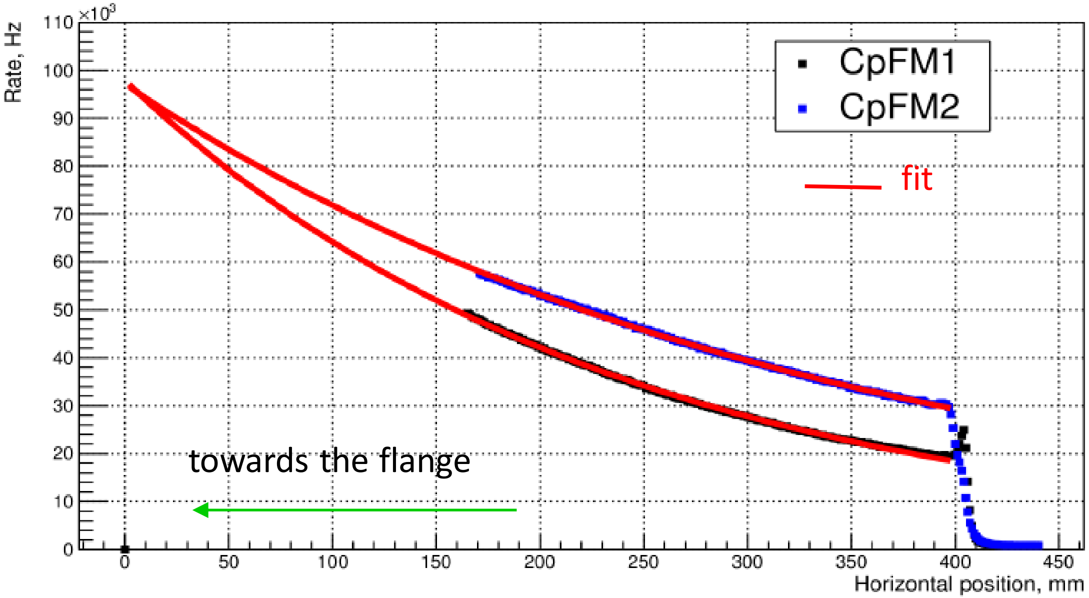




Research of the dysfunction causes of the CpFM

Tests of the quartz (TS Feb 2017)





Measurements performed with a β source shows that the **polishing quality of both quartz bars is not as good as expected and not the same**

→ factor 1.5 between them

UA9 evolution for double crystal experiment

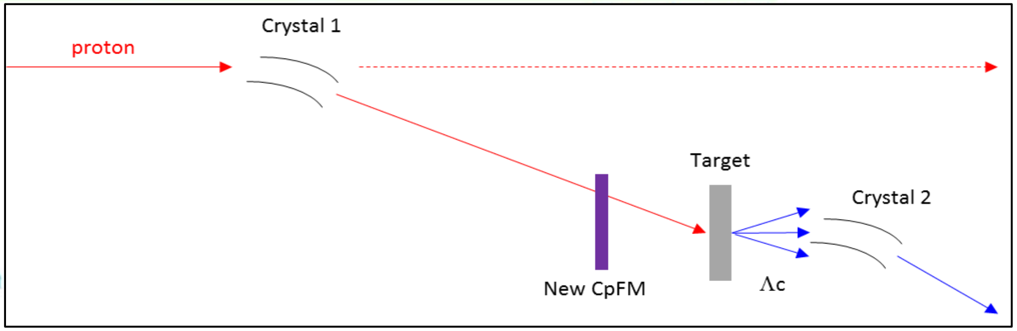
- Measurement of the magnetic moment of the charmed charged hadrons starting from Λc
- To be installed in LHC, but tested in SPS (evolution of UA9 -> double crystal experiment)

UA9: double crystal experiment - layout

- Schematic view of double crystal experiment:
  - deflect protons from LHC beam halo and send it to an internal target
  - bend particles produced in a target and send them into an experiment
- Setups under consideration:
  - Test the experimental scenario at the SPS
  - Export it into LHC in an existing detector for parasitic mode FT operation

Double crystal setup should allow magnetic and electric moment measurement

D.Mirarchi[1], S. Redaelli[1], **W. Scandale**[1,2], A. Stocchi[2],
[1]CERN, [2]LAL.
"Physics Beyond Colliders Kickoff Workshop",
Geneva, September 6th and 7th 2016

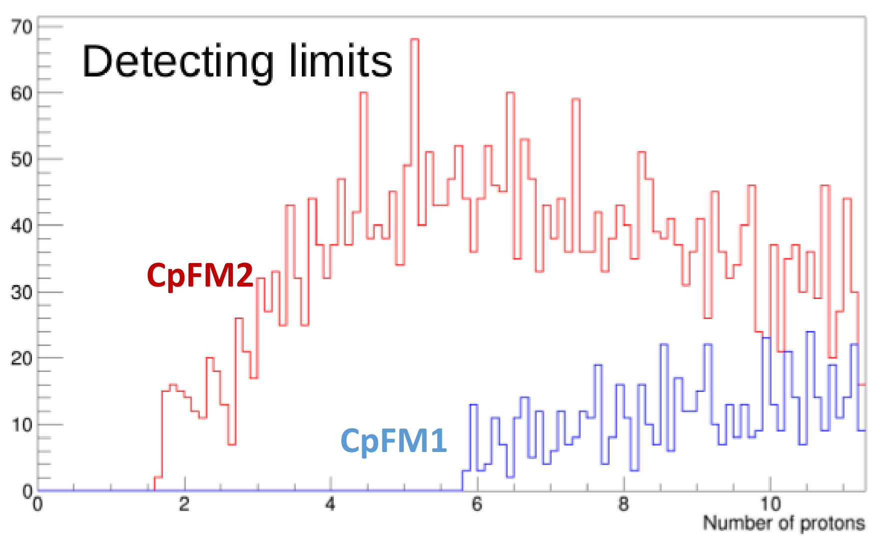


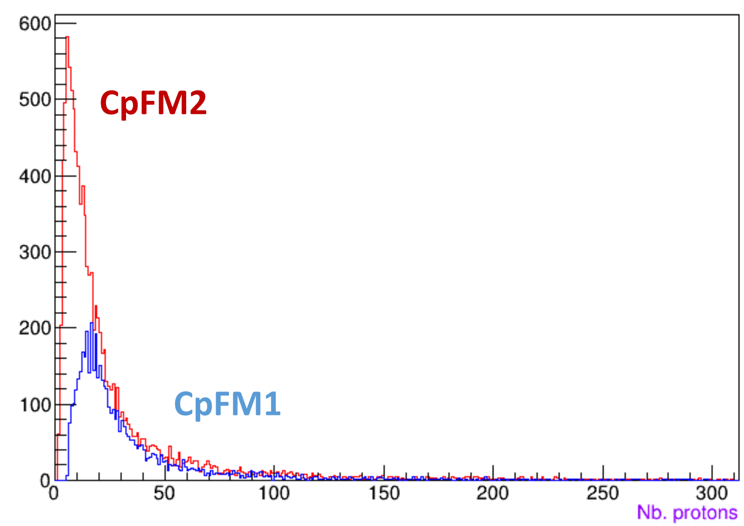
From Walter's presentation

CpFM – Feedback & new specifications

- ✓ We could use direct coupling (PMT just disposed behind the viewport), no bundle
- ✓ "Simple" geometry for quartz radiators used (and low thickness) -> light production could be optimized with more complex geometries and better polishing quality. We need to have enough light to see a single proton for a range of 1-100 protons/bunch (detection threshold should be minimized)
- ✓ In old CpFM, one bunch every 23us (43 kHz), measure of 1/1000 by the WC (43 Hz) -> we loose the "history" of the extraction
- ✓ For the new CpFM: minimum 1 bunch every 23 us (measure at 43 kHz), maximum of 4 trains of 72 bunches (each spaced by 25 ns) every 23 us -> We should work at 40 MHz to measure each bunch

-> Development of a new electronics with charge extracted at 40 MHz with no dead-time (started at LAL – work in progress)
-> New crystals with improved quality & geometries for the Cherenkov radiator

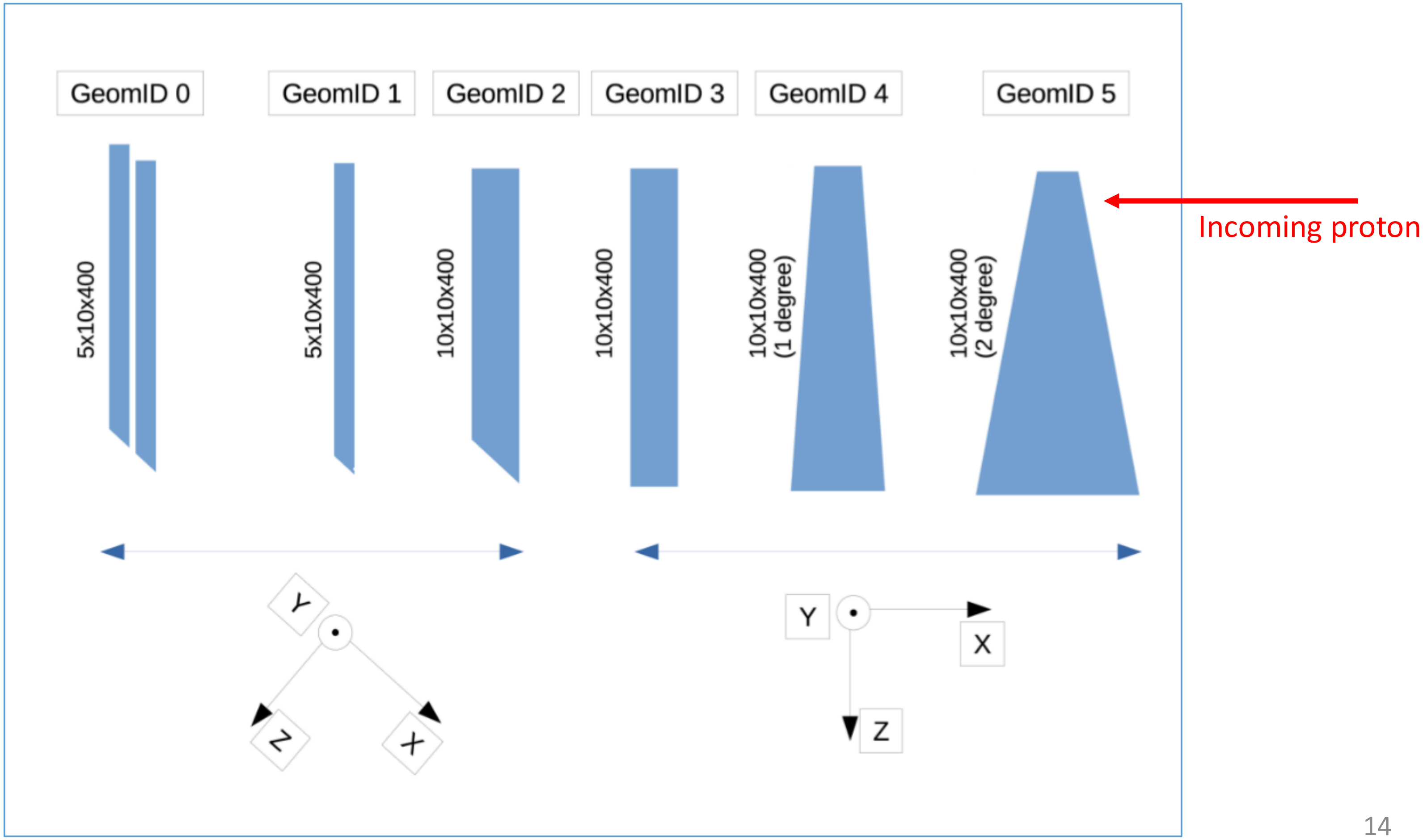




Study of new geometries for quartz radiator

Andrii Natochii (LAL)

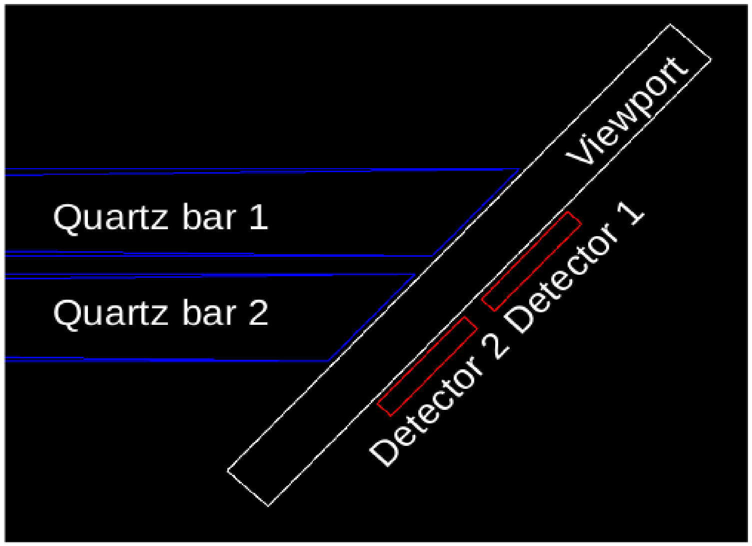
- ✓ Simulation of different quartz geometries (various thicknesses, 47° degrees cut or not, “I” or “pyramid” shape)
- ✓ Actual geometry: configuration #0 or #1 (length of 400 mm, kept for this simulation)
- ✓ With GEANT4: response to a flux of incoming protons impinging the extremity of the bars (close to the circulating beam)

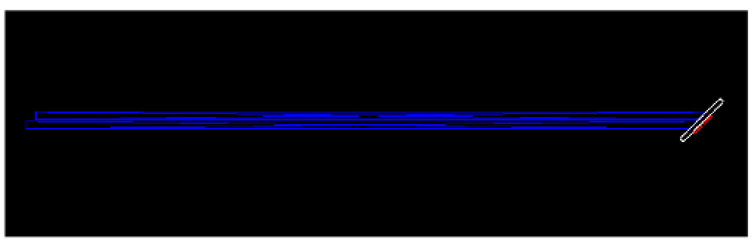


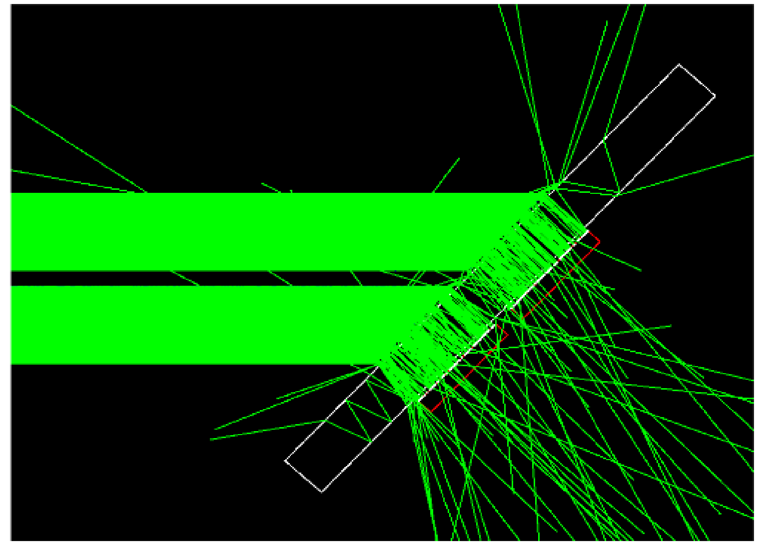
Study of new geometries for quartz radiator

Andrii Natochii (LAL)

- Simulation of different quartz geometries (various thicknesses, 47° degrees cut or not, "I" or "pyramid" shape)
- Actual geometry: configuration #0 or #1 (length of 400 mm, kept for this simulation)
- With GEANT4: response to a flux of incoming protons impinging the extremity of the bars (close to the circulating beam)



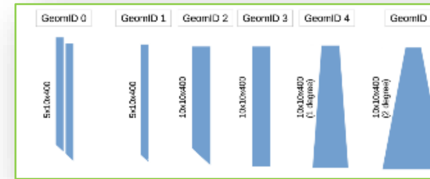


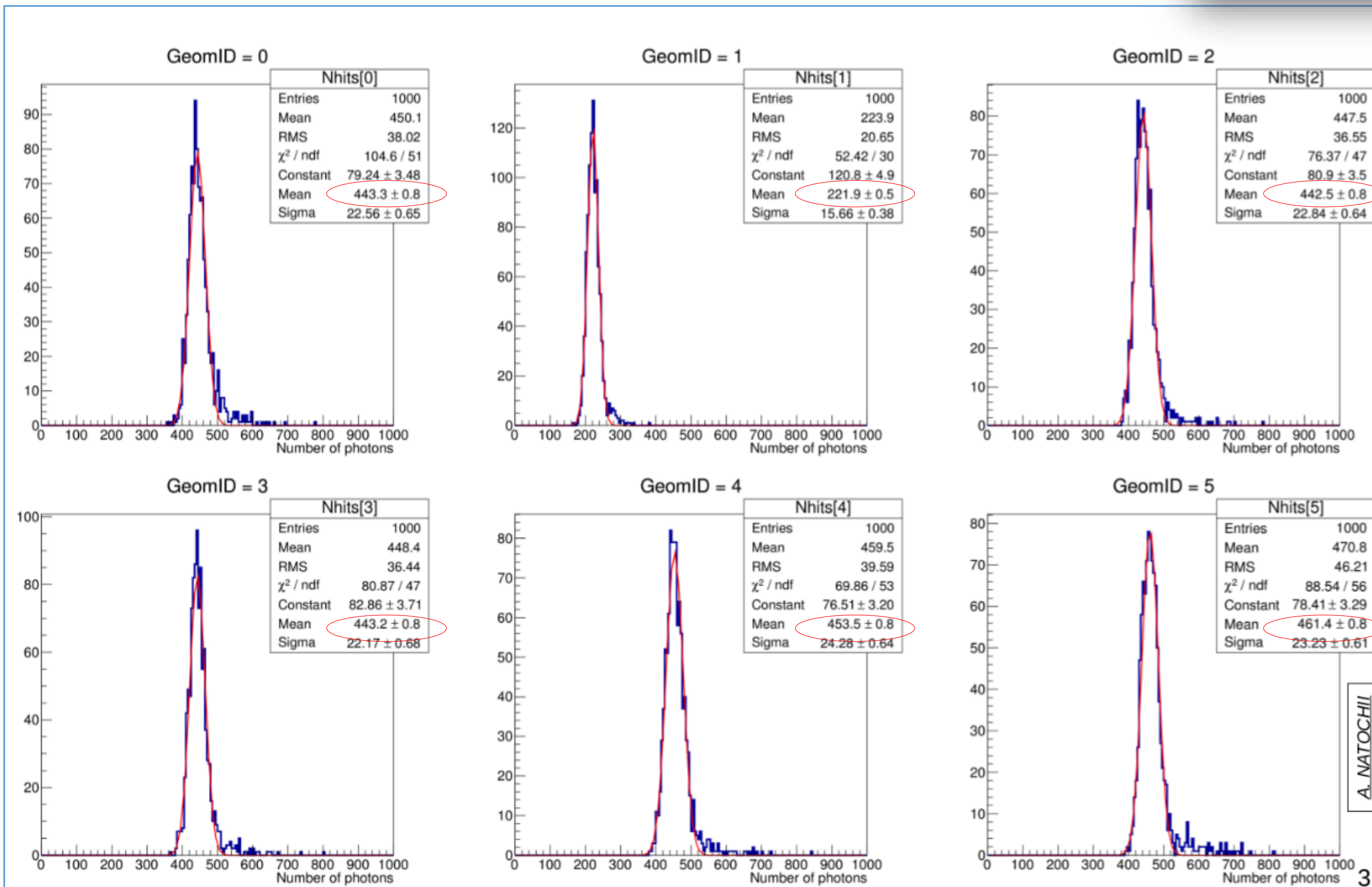


-> For each proton, tracking of all Cherenkov photons generated.
-> Transportation (reflections, absorption, diffraction) & detection (or not) by a photodetector

Study of new geometries for quartz radiator

- ✓ **Distribution of the number of photons hitting the detection surface:**
- ✓ **… between 443 and 461 photons / proton**
- ✓ **Nb. of reflections?**

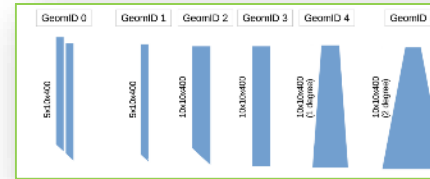


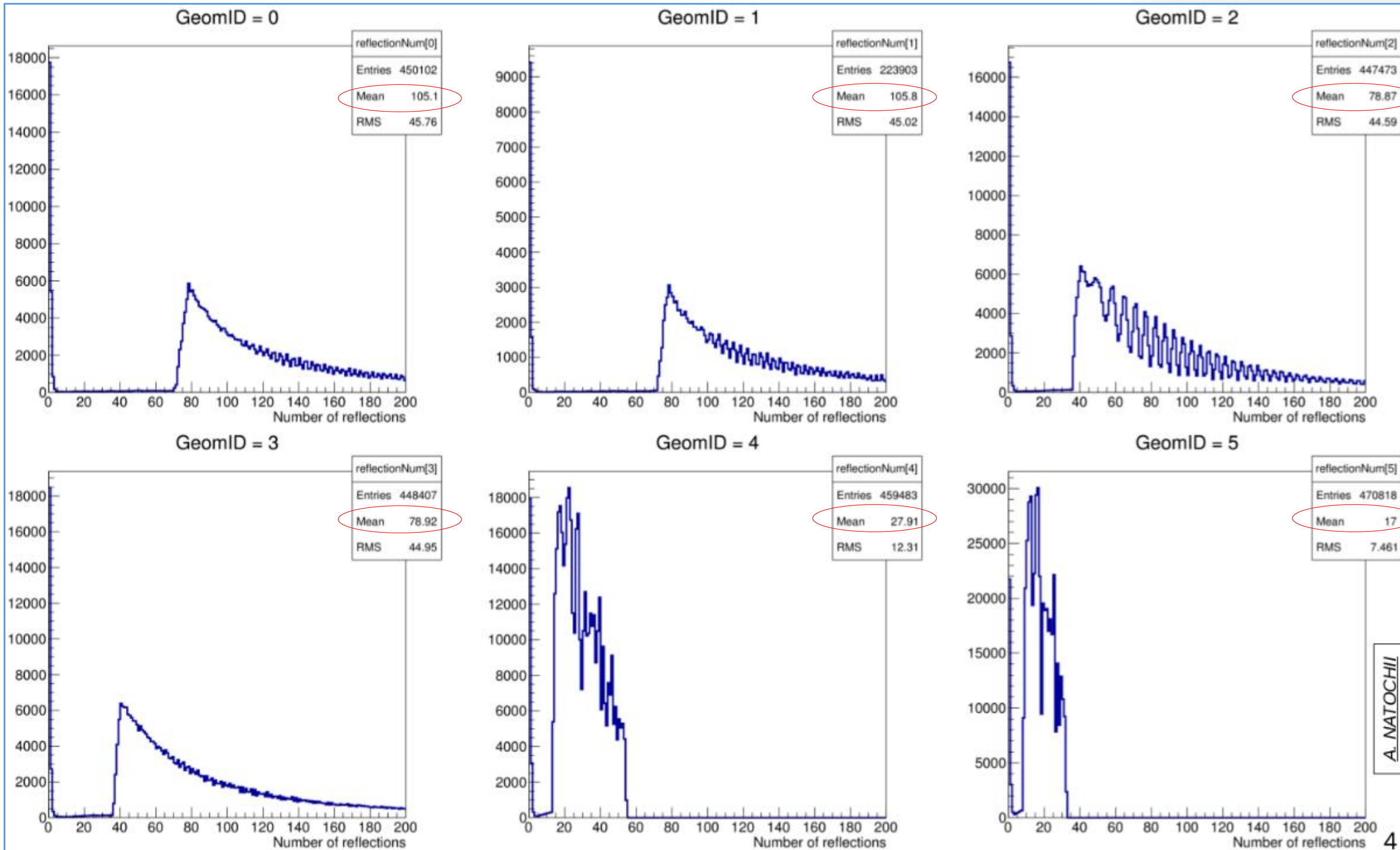


Andrii Natochii (LAL)

Study of new geometries for quartz radiator

- ✓ **Distribution of the number of reflections for each Cherenkov photon:**

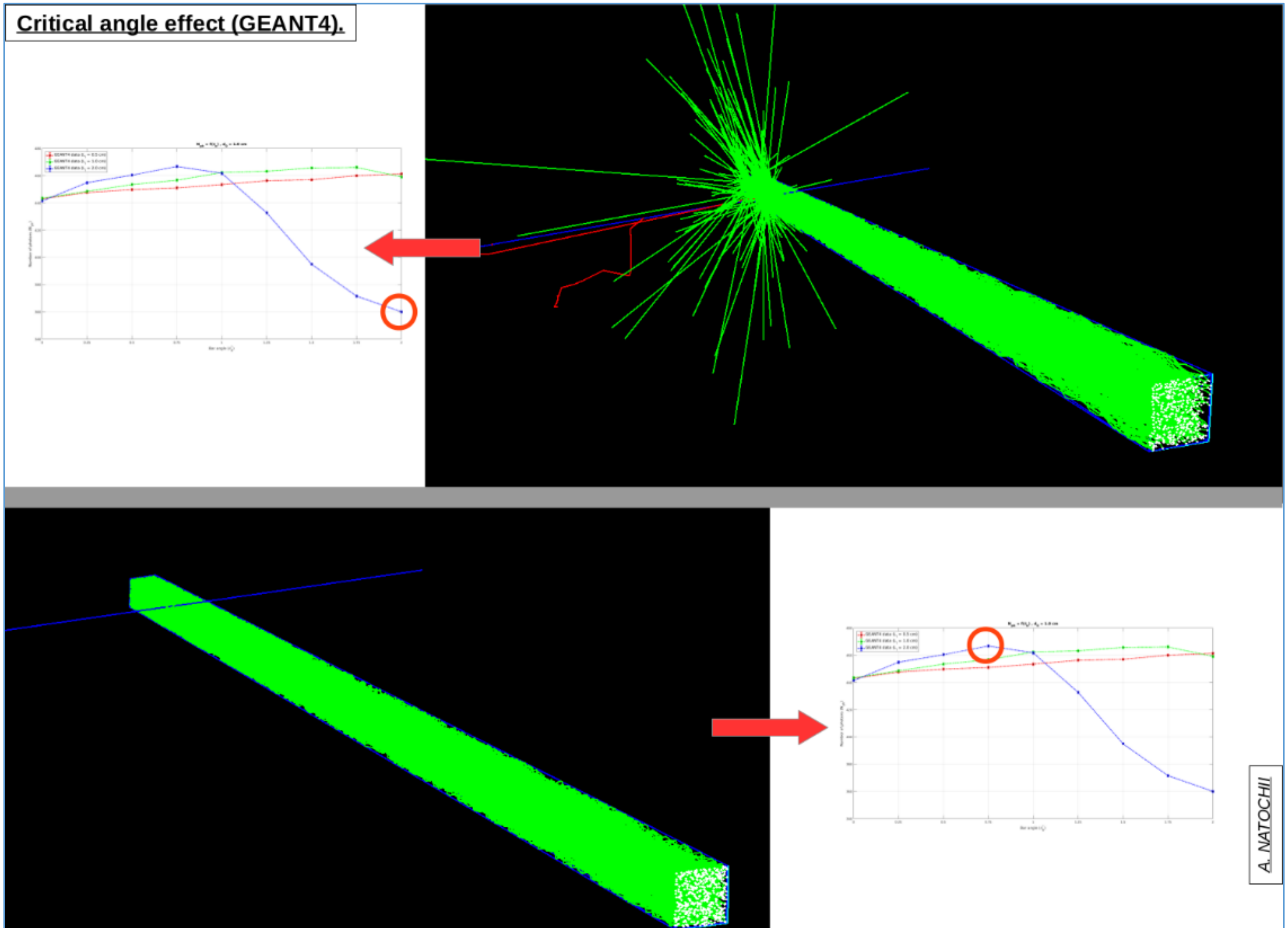




Andrii Natochii (LAL)

Study of new geometries for quartz radiator

- ✓ **Example of critical angle effect: L_i = 2.0 cm & θ_b = 0.75° or 2° -> refracted ray escaping from the detector volume**

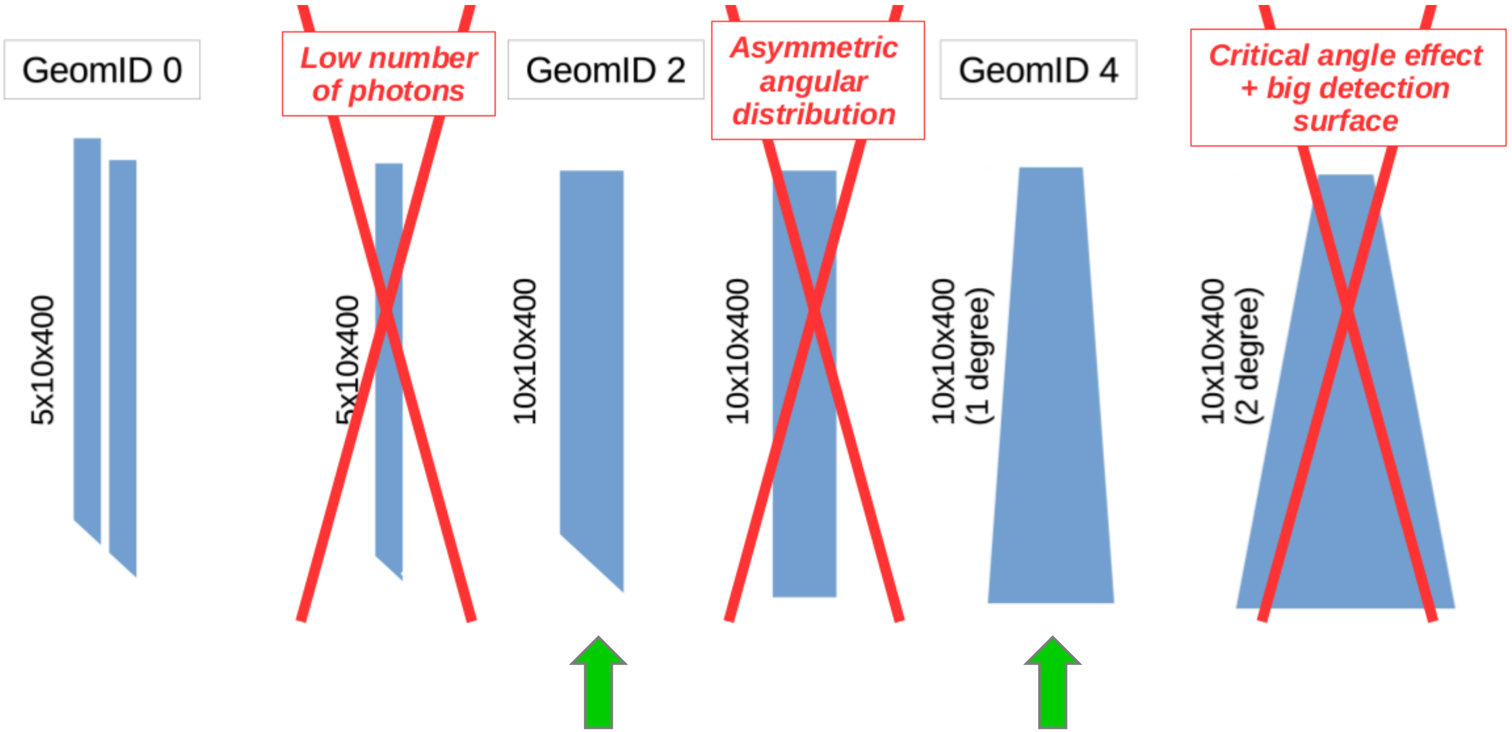


Andrii Natochii (LAL)

Study of new geometries for quartz radiator

✓ **Conclusions for the design of a new detector:**

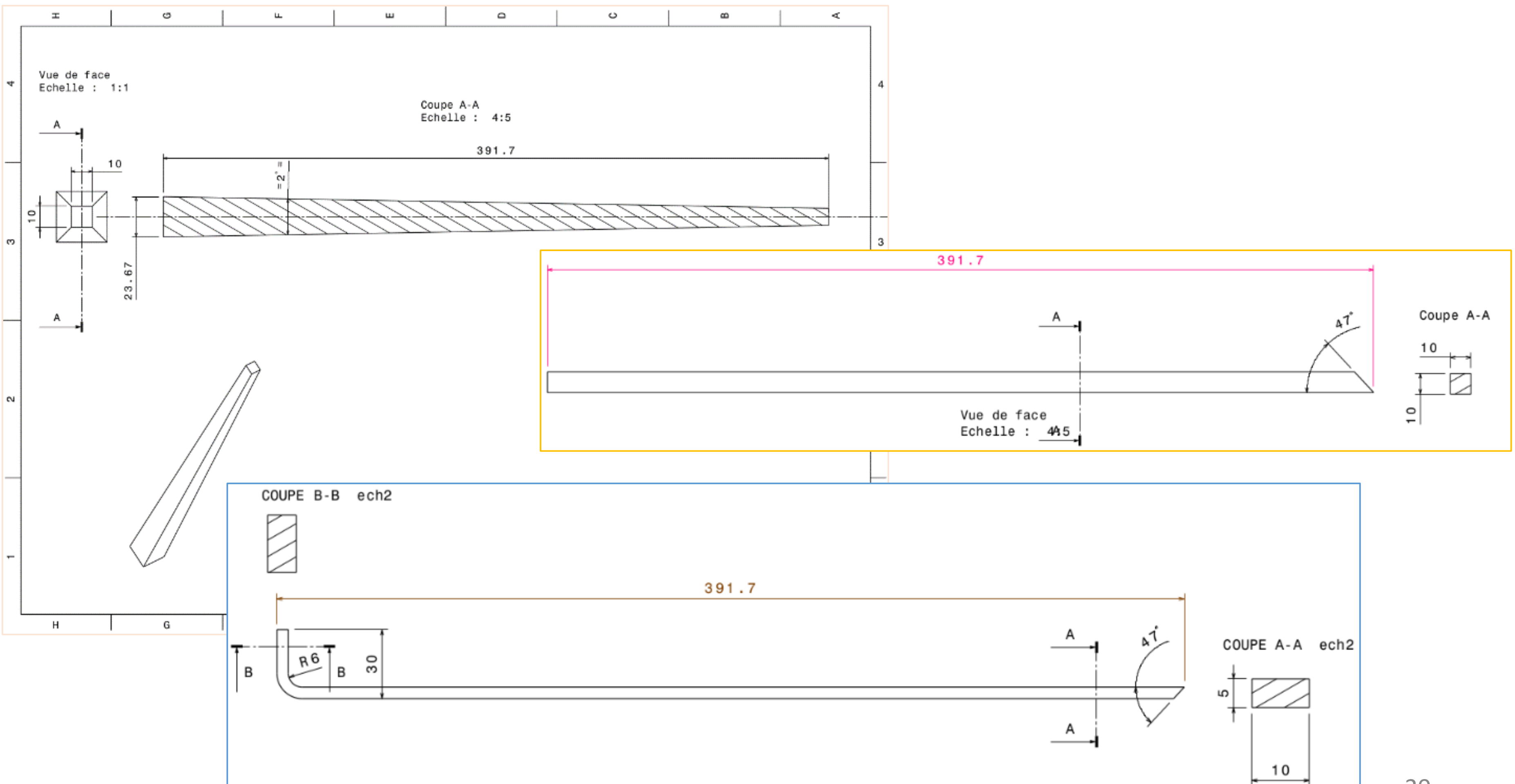
- **Geometry #0: installed**
- **Geometry #2: more Cherenkov photons generated (compared to #1) and less reflections (compared to #0), adapted to the using of a fibers bundle**
- **Geometry #4: high number of Cherenkov photons produced, low number of reflections, photons focussed on a “small” surface (2.4 * 2.4 cm^2). Also, suitable for direct coupling.**



Study of new geometries for quartz radiator

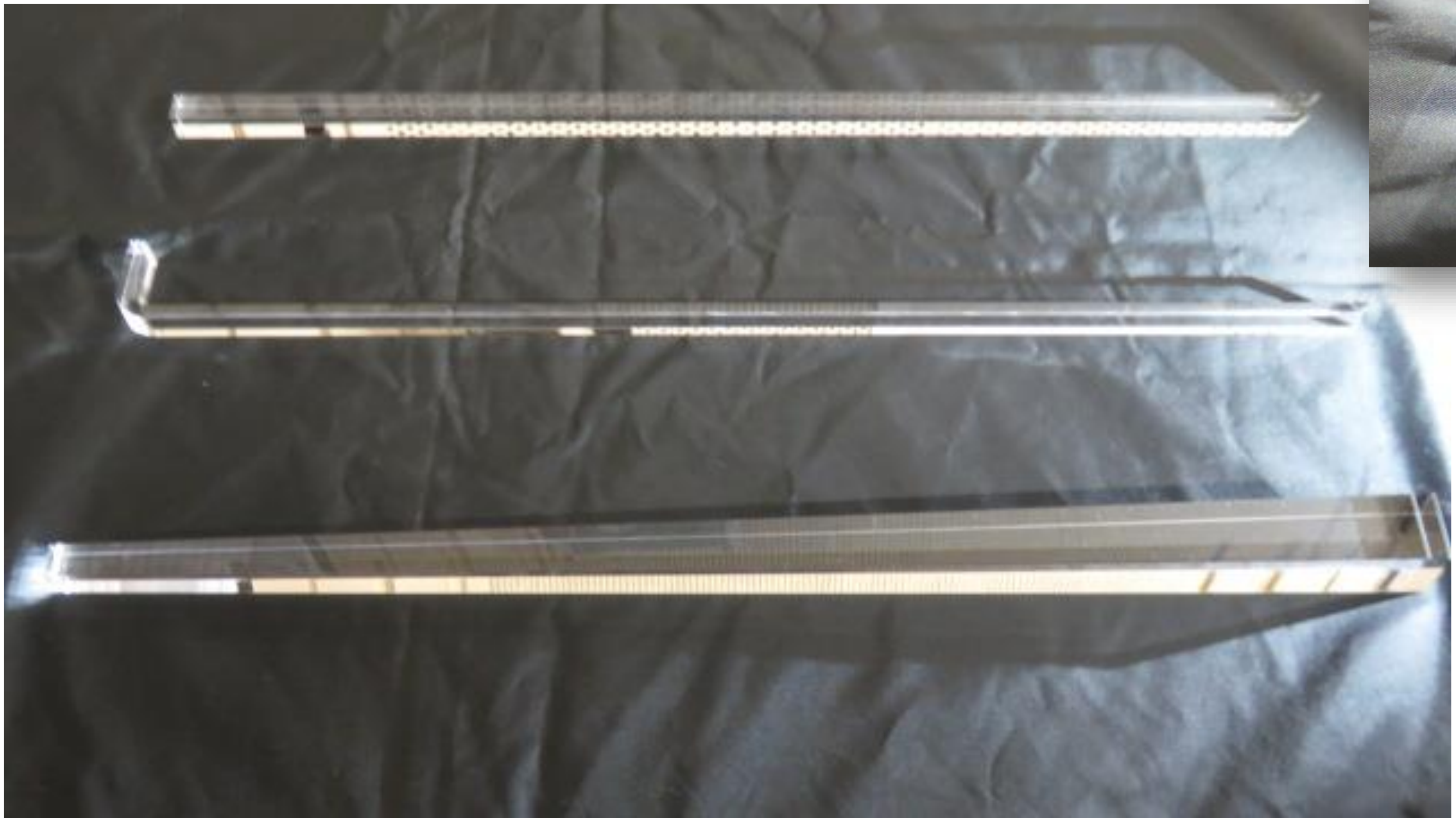
✓ **For the new CpFM, we decided to order:**

- One “pyramid”-shape bar (geometry #4), to be used without bundle (direct coupling)
- One “I”-shape bar of 10*10 mm² (geometry #2), as a backup or an update for the “old” CpFM
- One additional “banana”-shape bar (nose of 3 cm, thickness of 0.5 cm), as a backup or an update for the “old” CpFM



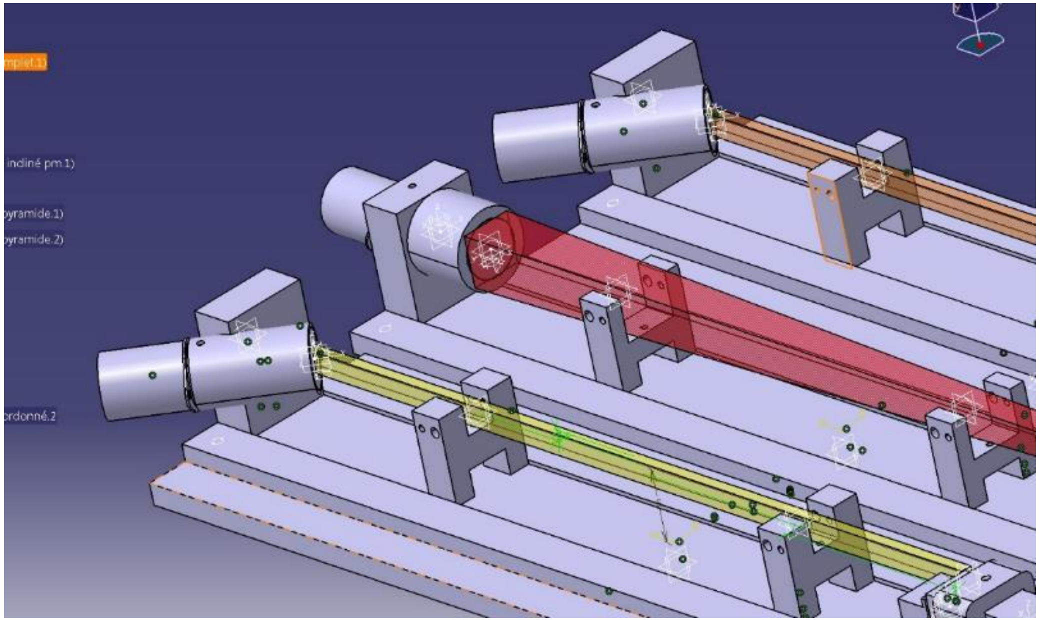
Study of new geometries for quartz radiator

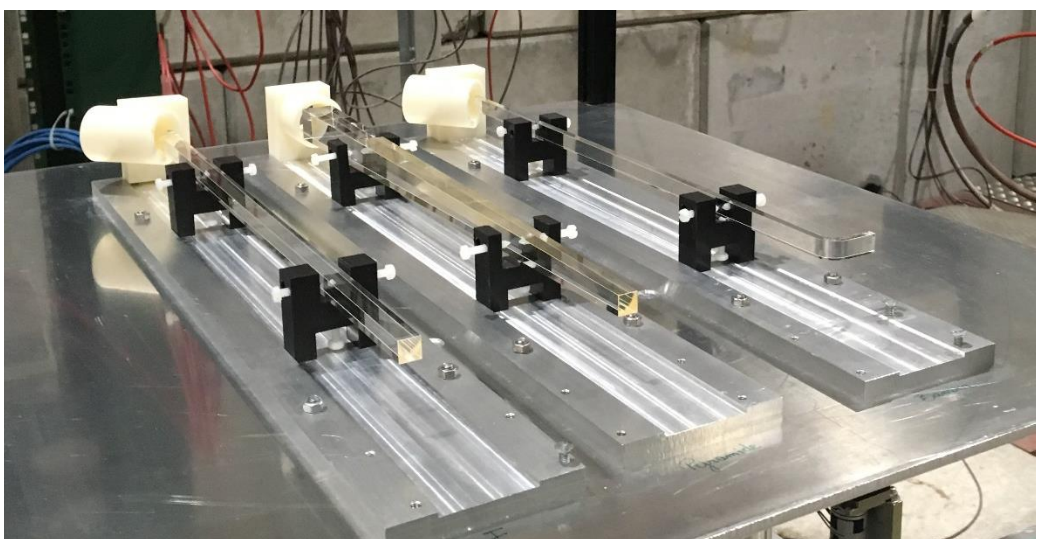
- ✓ **For the new CpFM, we decided to order:**
  - One "pyramid"-shape bar (geometry #4), to be used without bundle (direct coupling)
  - One "I"-shape bar of 10*10 mm² (geometry #2), as a backup or an update for the "old" CpFM
  - One additional "banana"-shape bar (nose of 3 cm, thickness of 0.5 cm), as a backup or an update for the "old" CpFM

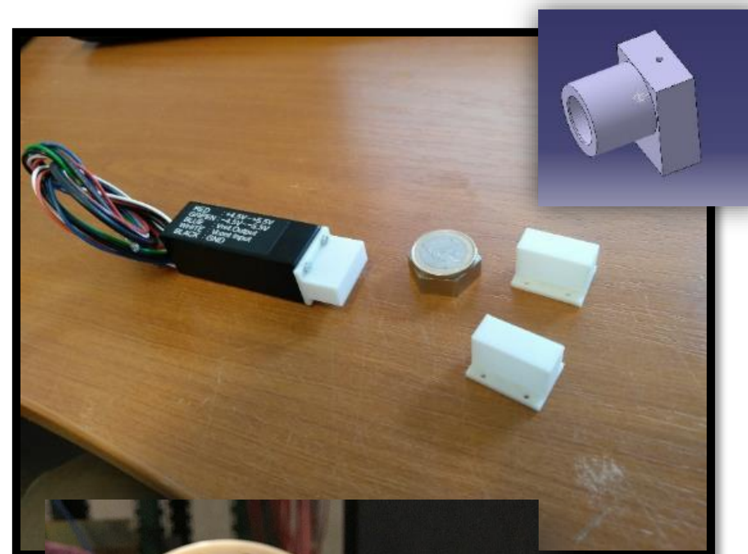


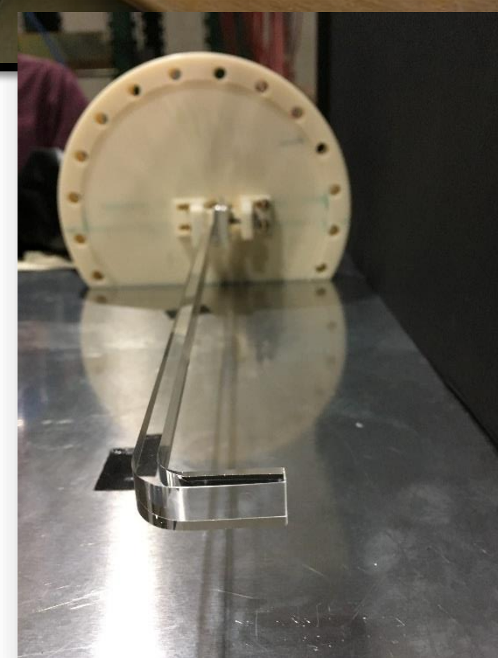
Test setup for H8 beam-tests

- ✓ **Mechanical pieces fabricated (holder, boards) or made with the LAL 3D printer (PMT holder, scintillator package)**



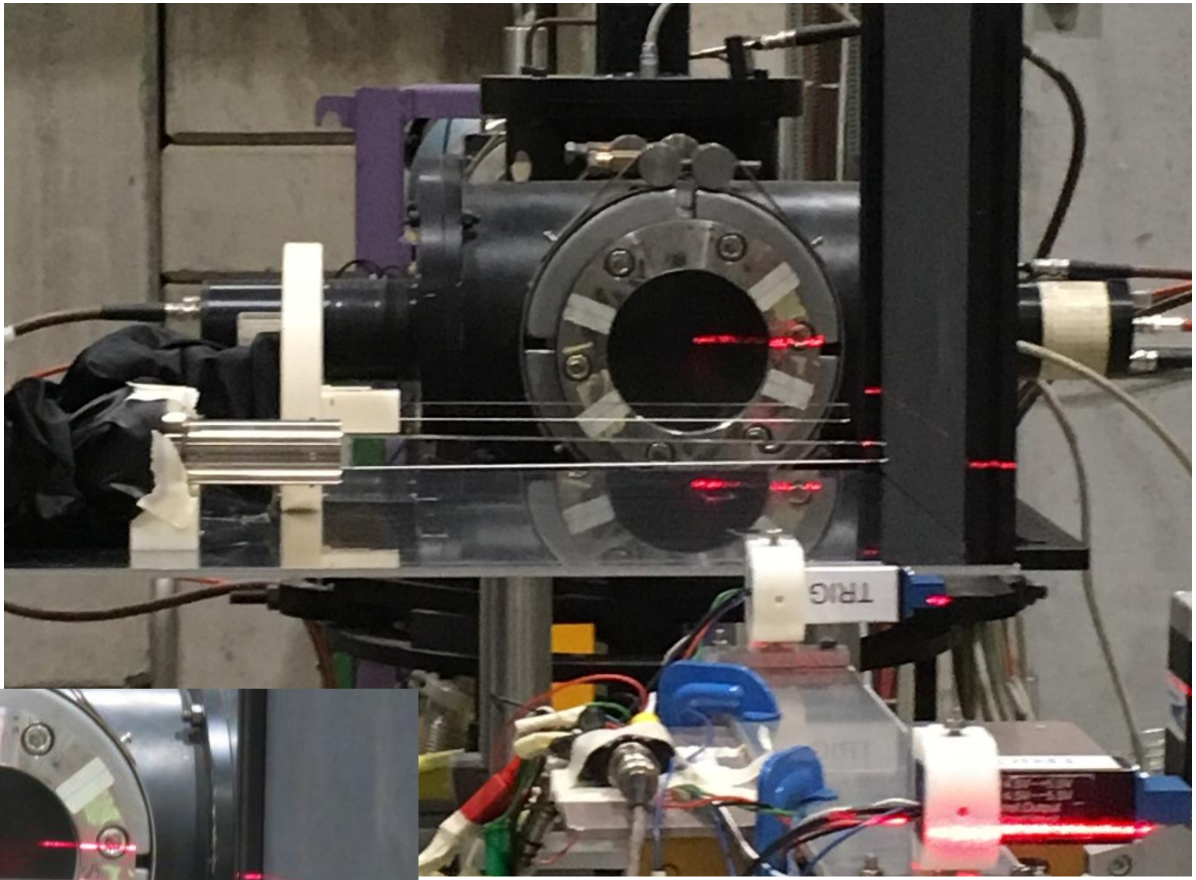


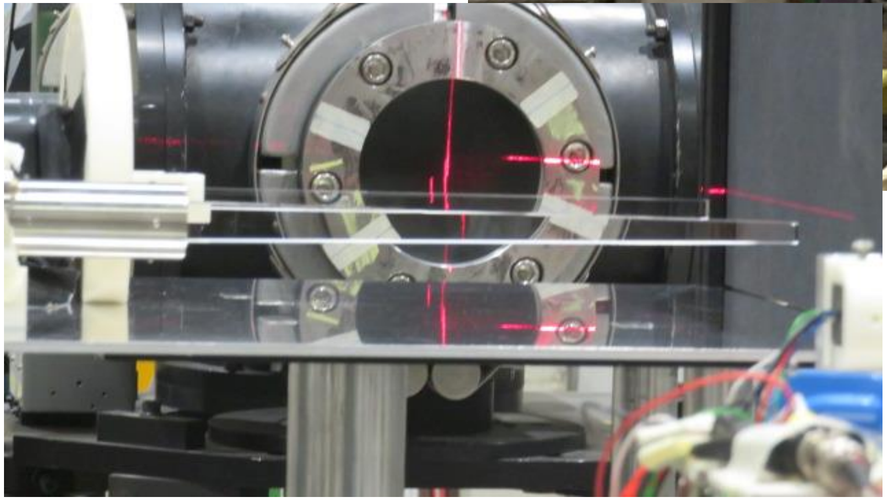




Test setup for H8 beam-tests

✓ **Not only characterization of quartz… But also complete calibration in the final configuration!**





Preliminary results & conclusion

- ✓ **HUGE signal observed for all configurations:**
  - ➢ **<u>900 mV / particle</u> (HT 1050V, maximum gain) for pyramid bar**
  - ➢ **125 mV / particle for ”I” bar**
  - ➢ **300 mV / particle for “banana” bar**
  - ➢ ***Reminder: before, from 1 to 4 mV / incoming particle at same PMT gain!***

- ✓ **Only 10% of light lost with the new setup (holder + flange) for the pyramid bar (before: 50%)**

- ✓ **Perfectly suitable for the new CpFM (low threshold and 1-100 particles range)**

- ✓ **Almost ready to be installed in SPS (waiting for a new tank from CERN and the new electronics from LAL)**

- ✓ **Now: We’ll take profit from this R&D to update the “old” CpFM with this new setup (-> To be done during the next winter technical stop)**