UA9 project and LAL contribution

L. Burmistrov
LAL Orsay (CNRS-IN2P3)

Outline

Introduction (UA9 project)

Introduction (LUA9 project)

Geant4 simulation

Measurements

Conclusions

Functions of collimation

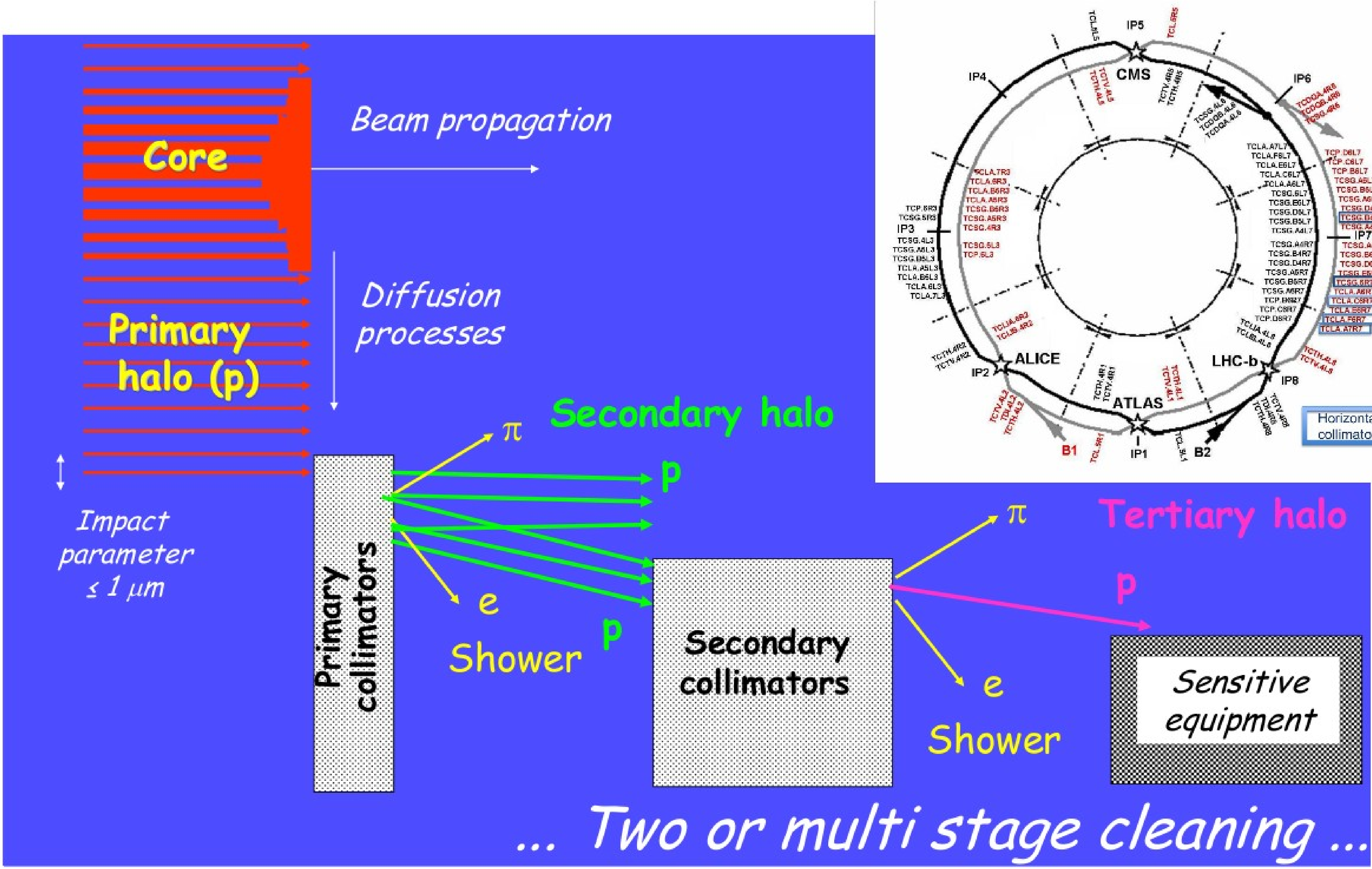
• Radioprotection:
intercept lost hadrons at well defined locations, (no or minimal losses and activation at other locations!)

• SC magnet integrity
prevent beam loss-induced quenches of super-conducting Magnets.

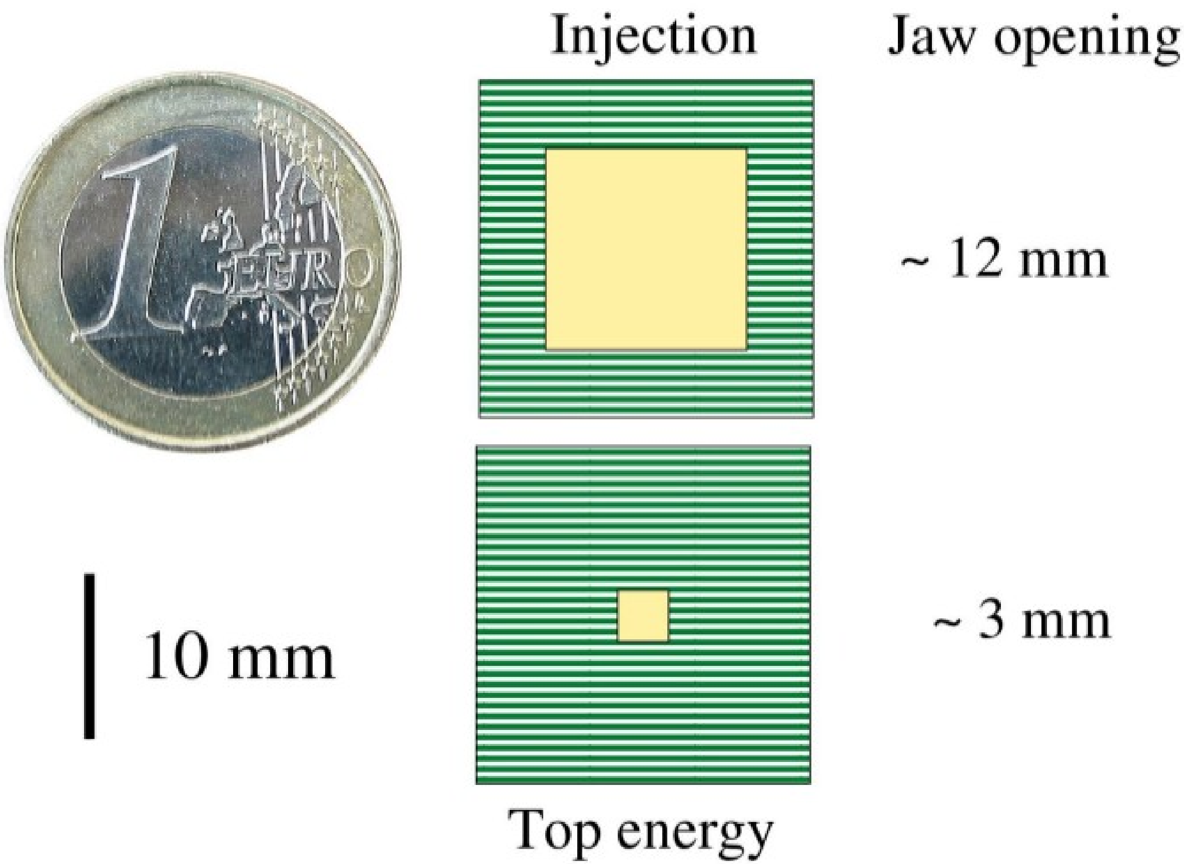
• Physics reach (maximum signal/background)
control background from beam halo in experiments

• Hardware integrity
set passive machine protection (beam lost first at collimators)

Principle of Beam Collimation



Collimating with small gaps



LHC beam will be physically quite close to collimator material and collimators are long (up to 1.2 m)!

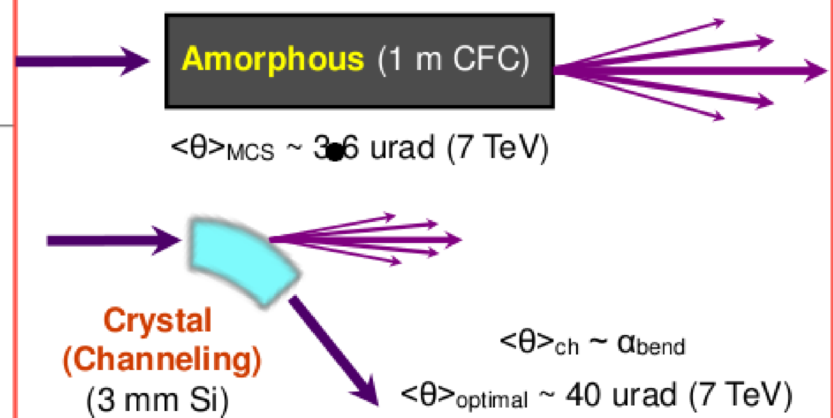
- ***Precision positioning***
- ***Risk of damage to collimators!***
- ***Beam electro-magnetic fields interact with the collimator material!***

⇓

Machine impedance increases while closing collimators.
*LHC will operate at the **impedance limit** with collimators closed!*

Crystal collimation concept

UA9 MISSION: investigate bent crystals as primary collimators in hadron colliders.



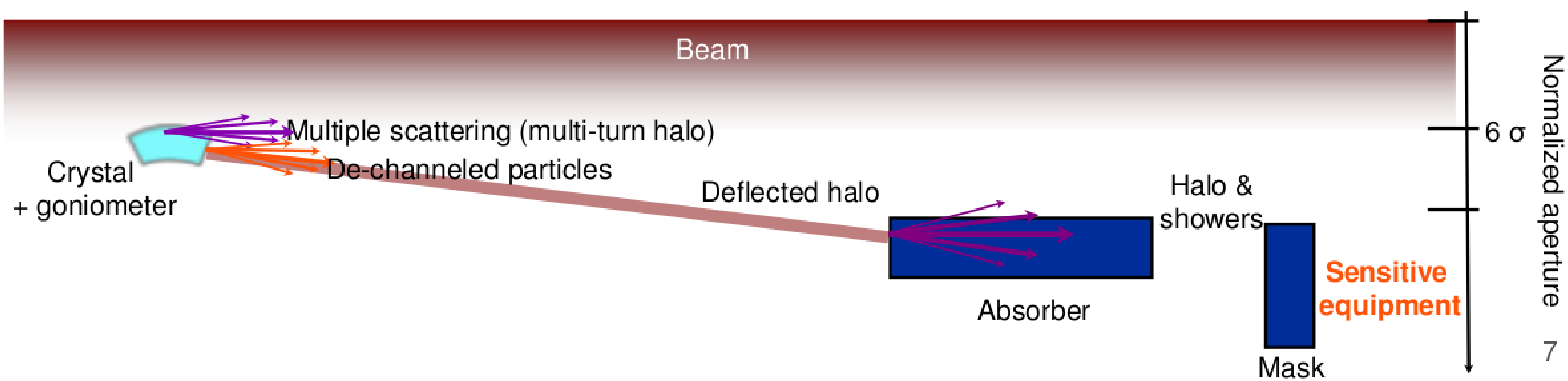
R.W. Assmann, S. Redaelli, W. Scandale, "Optics studies for a possible crystal-based collimation system for the LHC", EPAC 2006

- Mechanically bent crystal instead of amorphous primary deflector.
- Particles are subjected to a coherent interaction (channeling):
  - reduced loss rate close to the crystal
  - reduced probability of diffractive events and ion fragmentation/dissociation

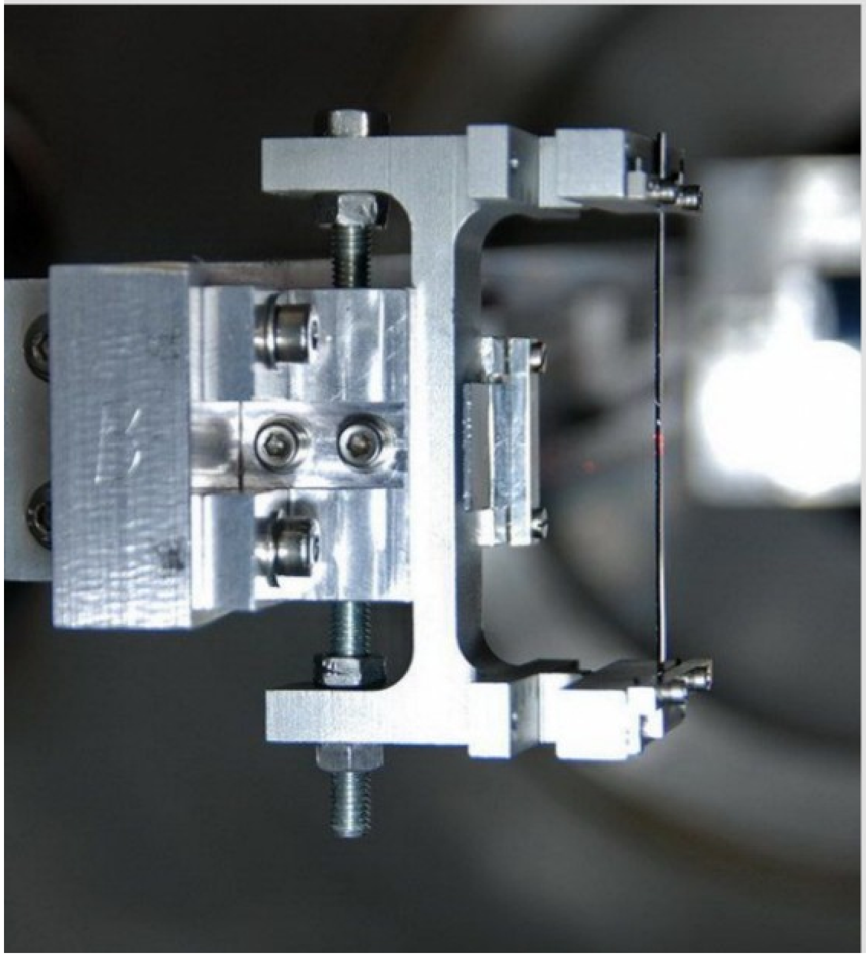
  BUT
  - small angular acceptance $2 \times \theta_c$ depending on the beam energy
  - localization of the losses on a single absorber, thanks to large deflection angle

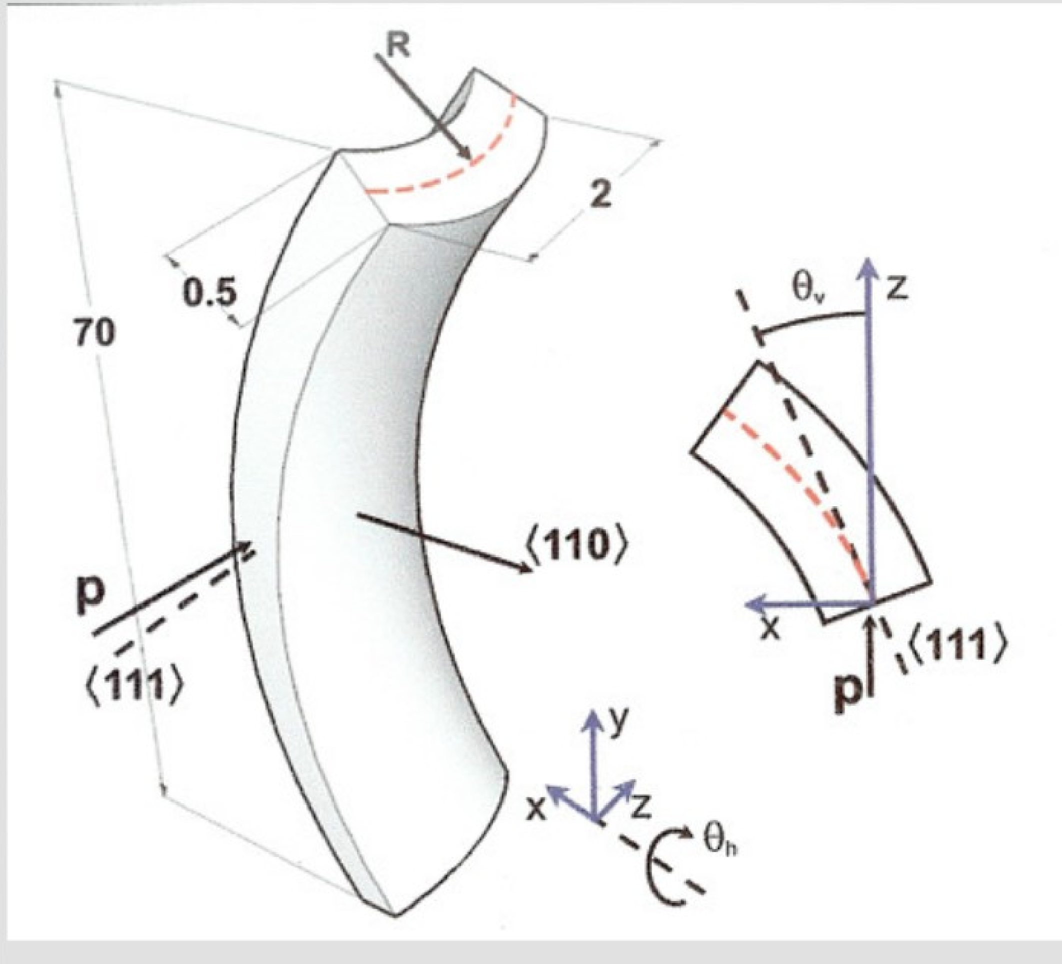
$$\theta_c = \sqrt{\frac{2U_{max}}{E}}$$

Energy	θ_c [μrad]
120 GeV	18.26
270 GeV	7.30
450 GeV	9.42
3.5 TeV	3.38
7 TeV	2.39



Bend crystal



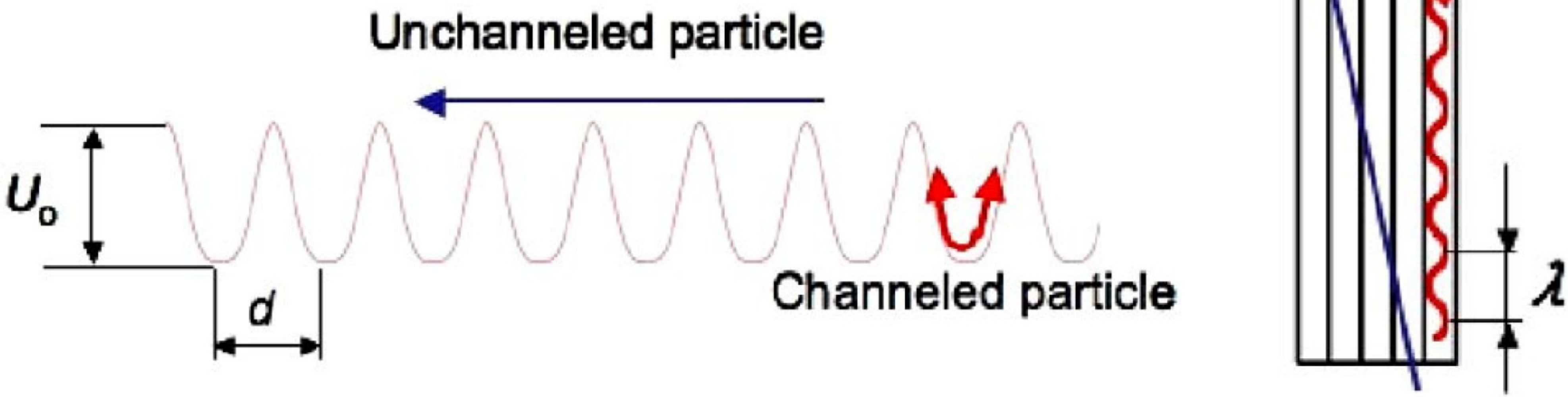


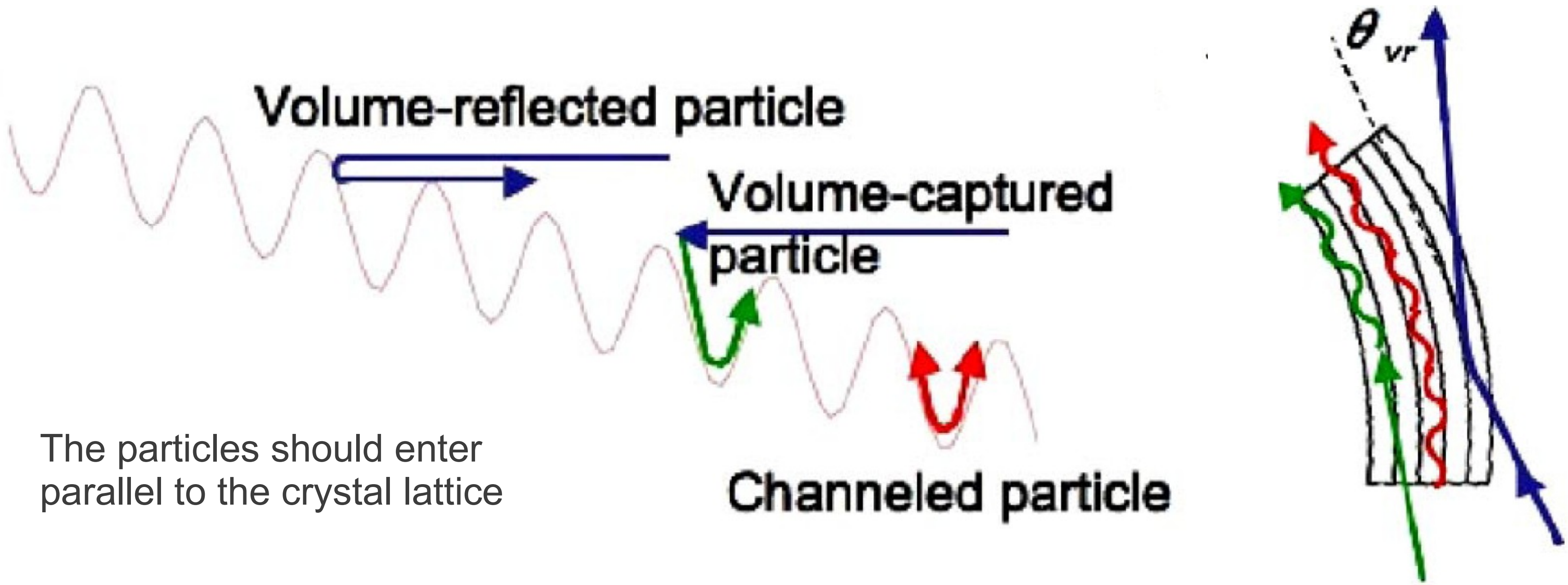
- Mechanically bend
- Use secondary curvature to tunnel the particles

Crystal vs bend crystal

W. Scandale 10.1103/PhysRevSTAB.11.063501

U_0 = 22.7 eV
d = 0.192 nm

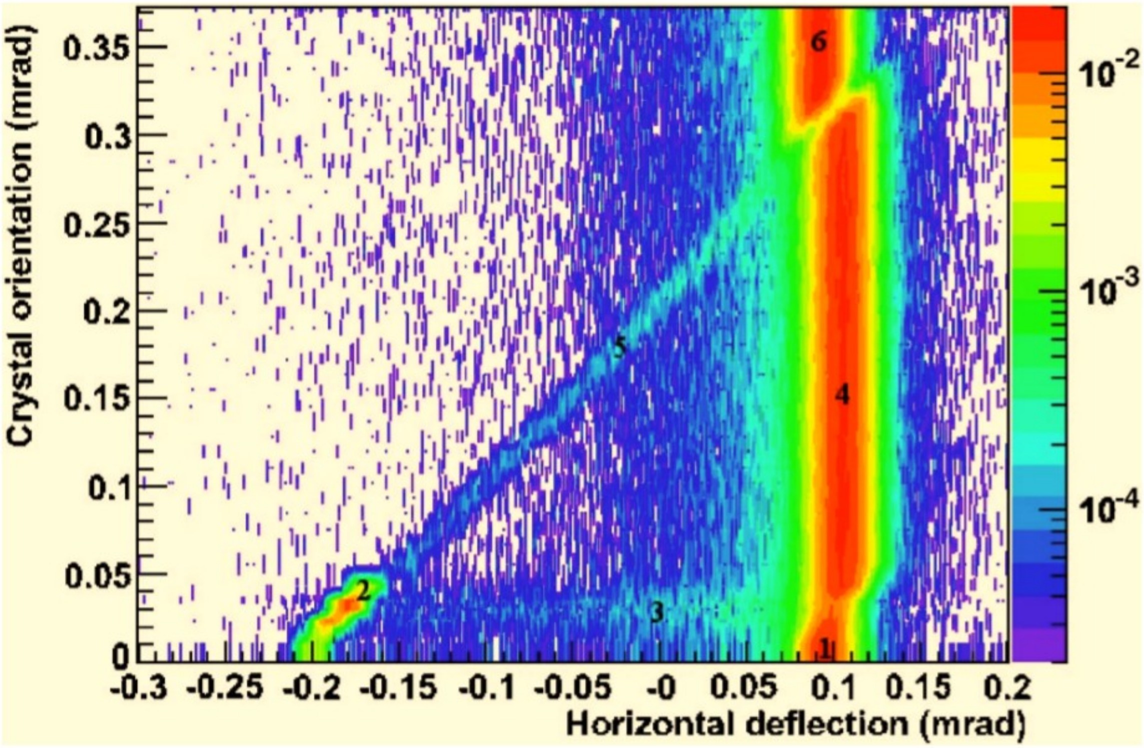




The particles should enter parallel to the crystal lattice

Bent crystal orientation

Citation: Rev. Sci. Instrum. 79, 023303 (2008); doi: 10.1063/1.2832638
View online: http://dx.doi.org/10.1063/1.2832638



Region 1 pertains the beam traversing the crystal in a nonaligned orientation: no deflection is observed.

Region 2 The channeling peak is separated from the unperturbed beam by 278.2 mrad, which corresponds to the crystal bending angle measured with optical technique.

Region 3 A small fraction of the initially channeled particles
exits the channel due to an increase of the transverse energy dechanneled particles.

Region 4 The volume reflection extends over a wide angular area along the vertical axis: almost the whole beam is displaced by 10.4 +/- 0.5 mrad

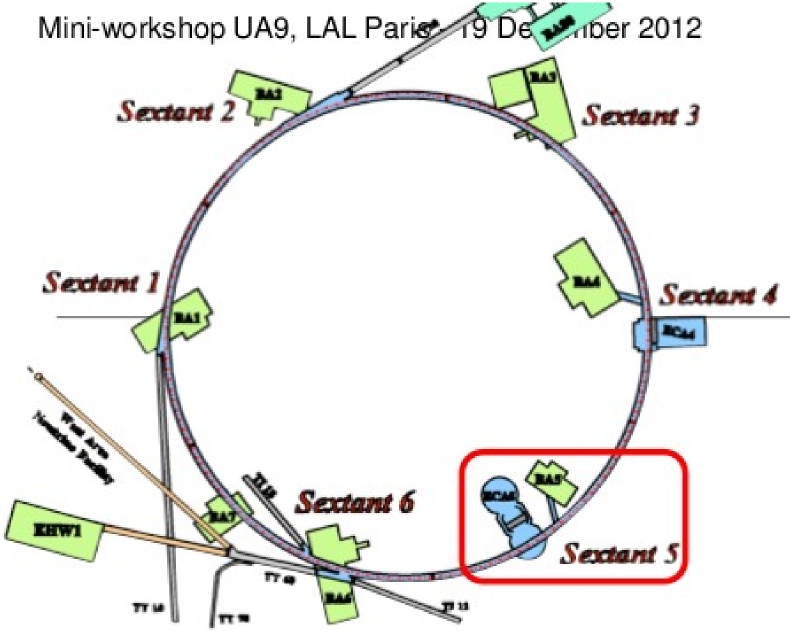
Region 5 The particle may lose a fraction of its transverse energy and be trapped in the potential well

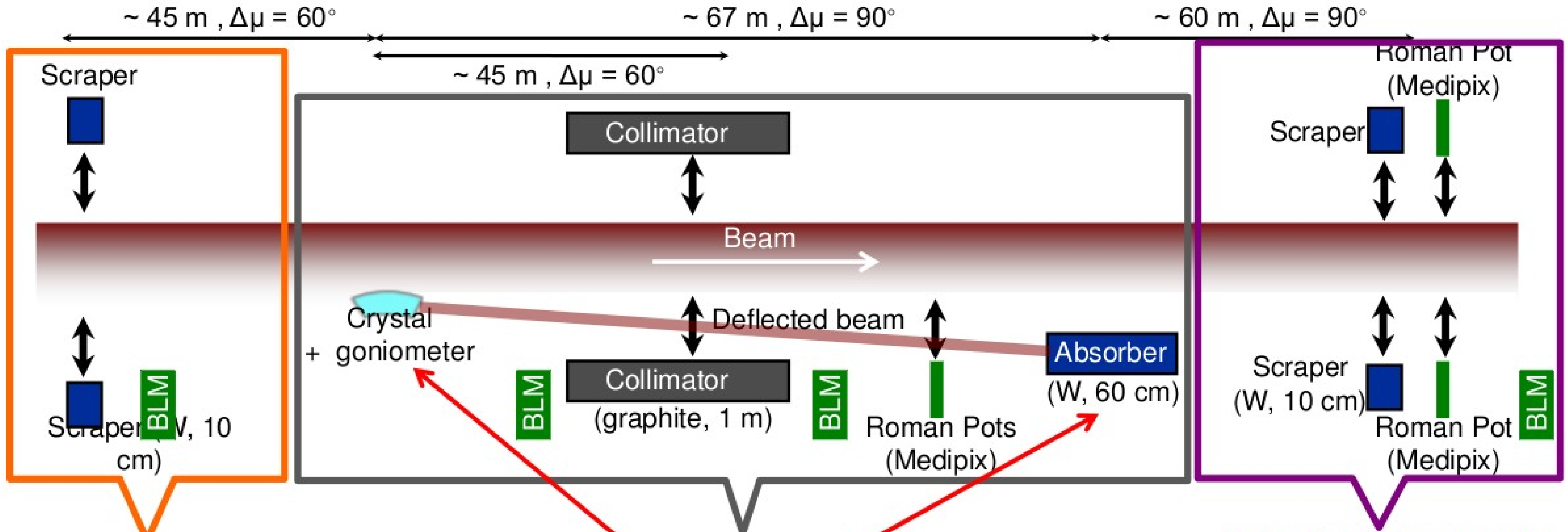
Region 6 volume reflection is no longer possible and the crystal is traversed by the incoming particles in a nonoriented condition, similar to region 1.

SPS tests

First use of the collimator in circulations ring

UA9 layout in 2012





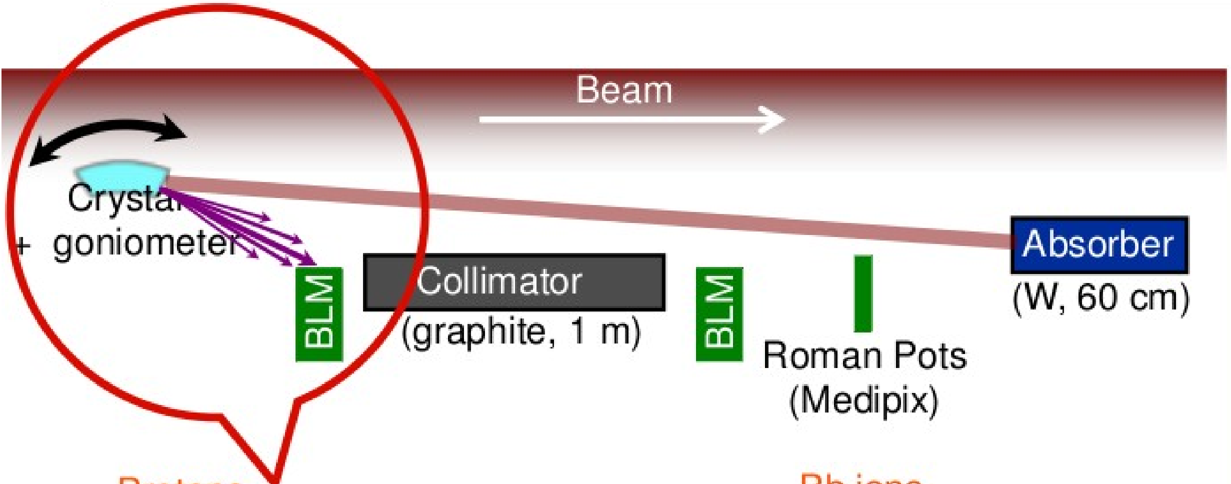
Non-dispersive area for measurements “far” from the collimation system

Crystal collimation system (in two stages)

With instrumentation for loss rate and efficiency measurement

High-dispersion area for measurements on off-momentum halo

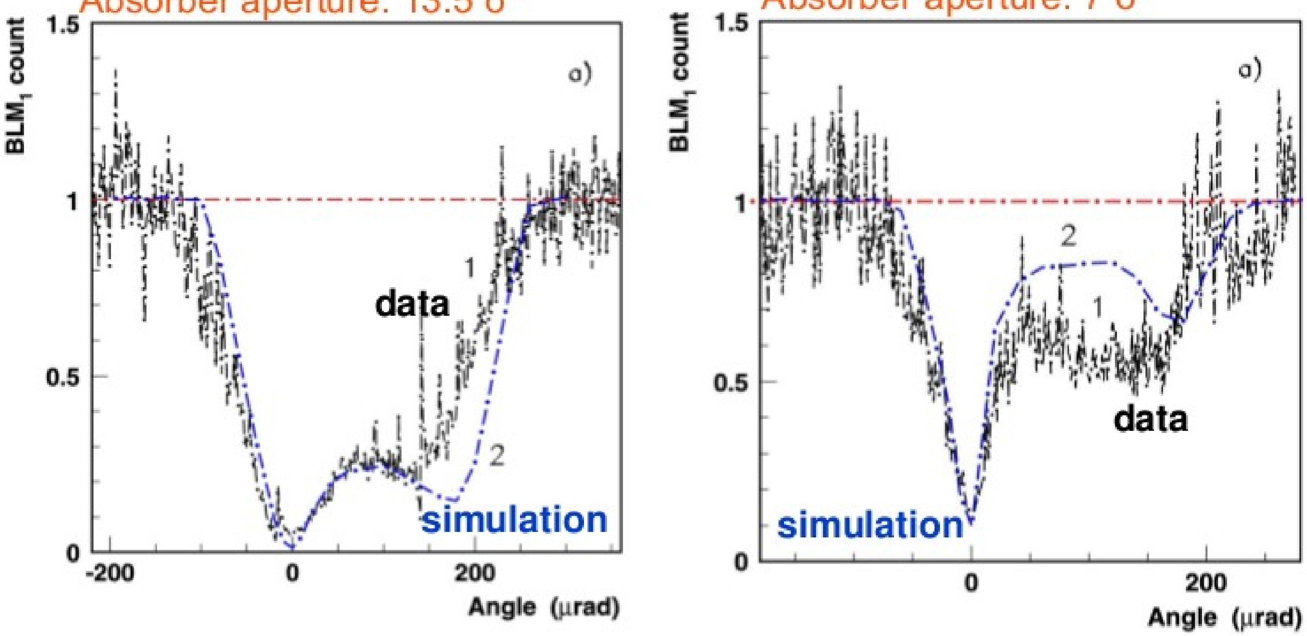
Loss rate reduction in the crystal area

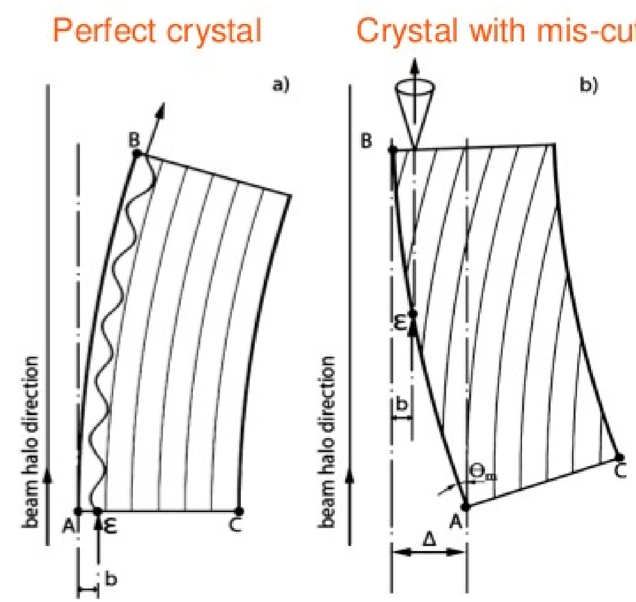


- Large loss reduction factor from “amorphous” to “channeling” orientation
  - 5÷20x reduction for protons
    3÷7x reduction for Pb ions
  - Best performance using a 1 mm long crystal
- Small discrepancy data/simulation
  - Mis-cut crystal modeled in simulation

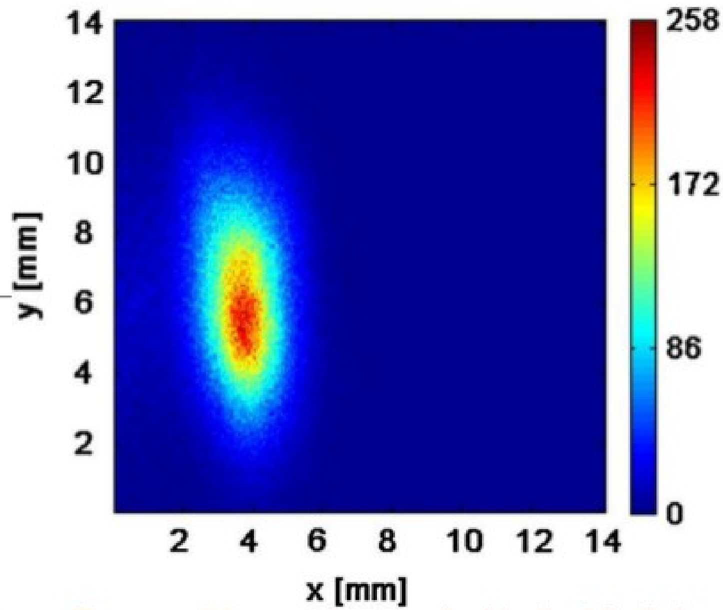
Protons
Crystal aperture: 9 σ
Absorber aperture: 13.5 σ

Pb ions
Crystal aperture: 3.5 σ
Absorber aperture: 7 σ

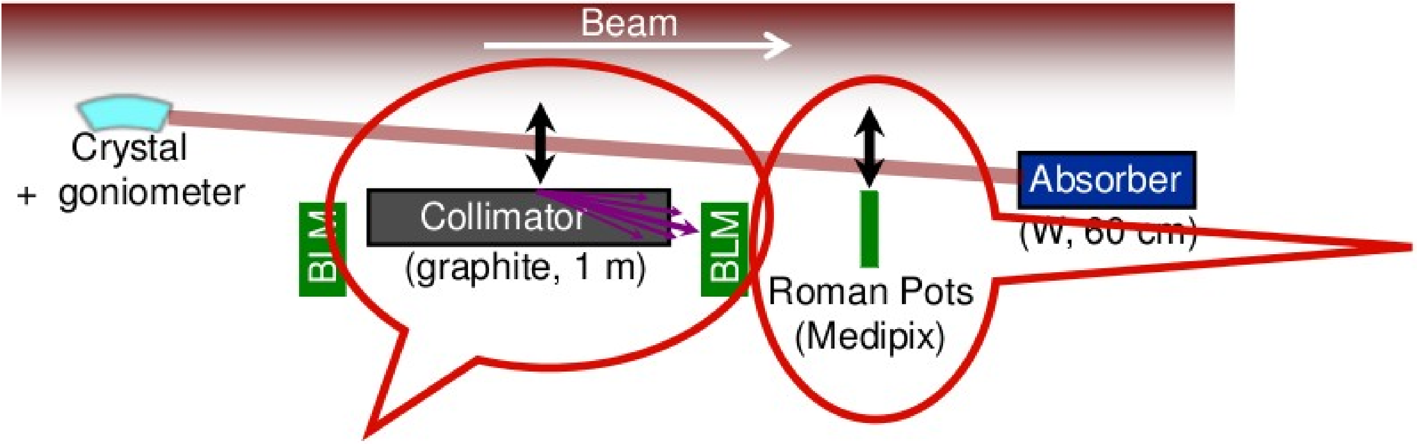


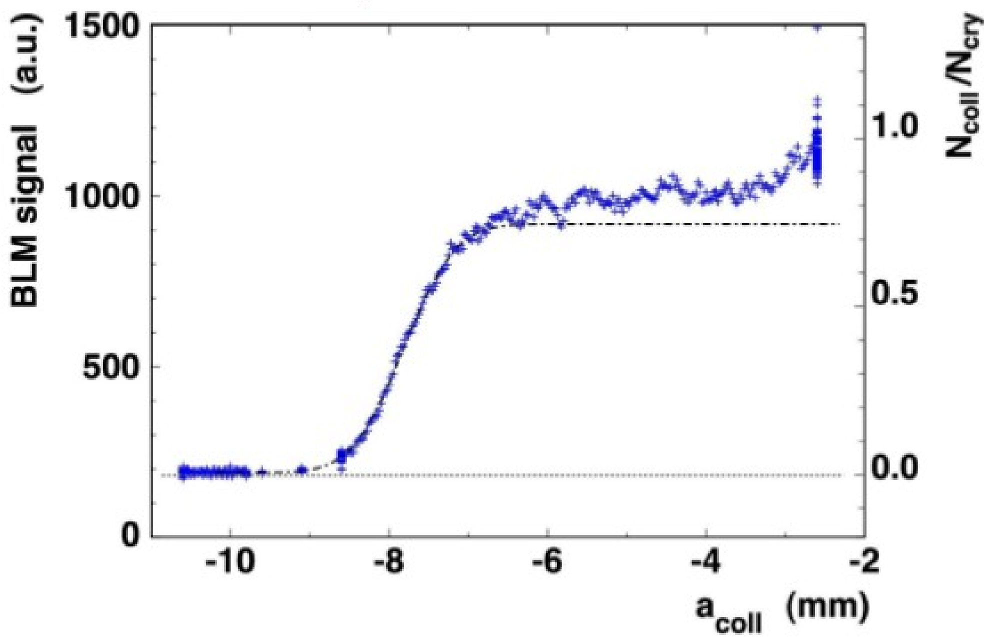


Extraction efficiency



Extracted beam observed with the Medipix





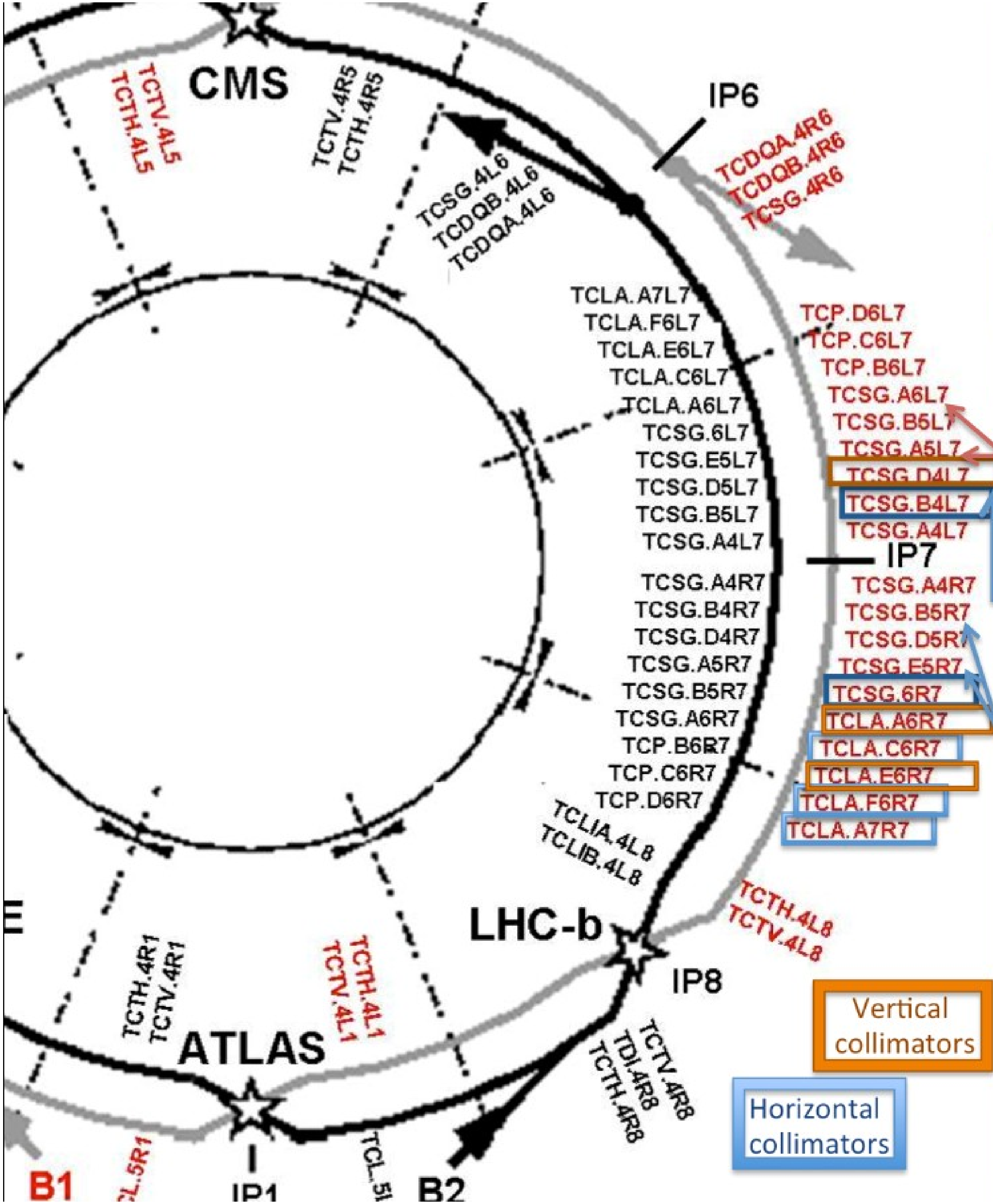
- Efficiency = $N_{deflected}$ / $N_{crystal}$
- Assumptions:
  - the number of particles intercepted by a moving object is proportional to the loss rate downstream the object
    - $N_{deflected}$ is proportional to the losses when intercepting the whole deflected beam
    - $N_{crystal}$ is proportional to the losses when the collimator is the primary aperture
- efficiency for protons: 70÷80%
- efficiency for Pb ions: 50÷70%

LUA9

Successful tests on SPS makes possible use of bent crystals collimation system in LHC

SPS → LHC

UA9 → LUA9



Layout

Installation in beam-line B1
Several positions for Crystals (see D.Mirarchi)
But only:

2 horizontal secondary collimators
1 vertical secondary collimator

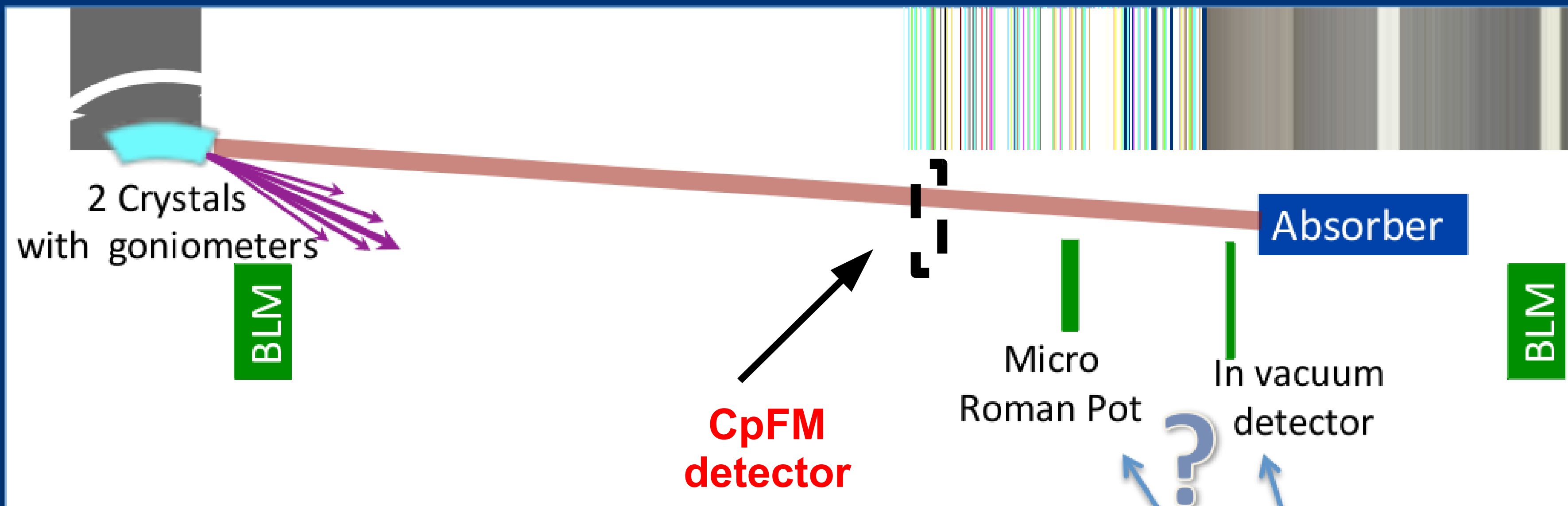
Little choice for placing the detector upstream the corresponding absorber.

2 alternative positions for a vertical detector upstream the vertical absorber

1 horizontal detector to capture channeled particles before they are absorbed by the first horizontal collimator.

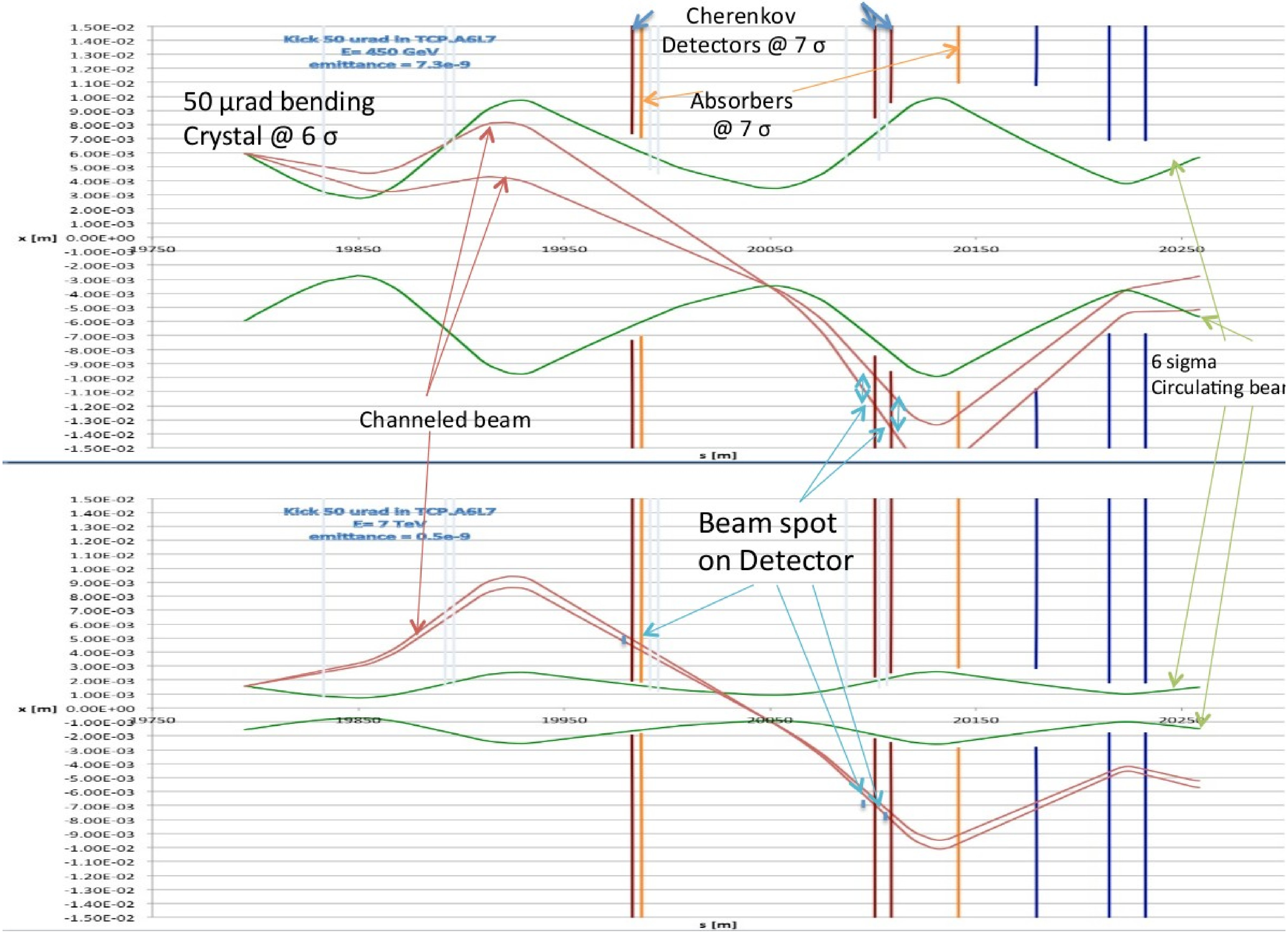
2 alternative horizontal detector position upstream the second horizontal collimator

LUA9 Layout

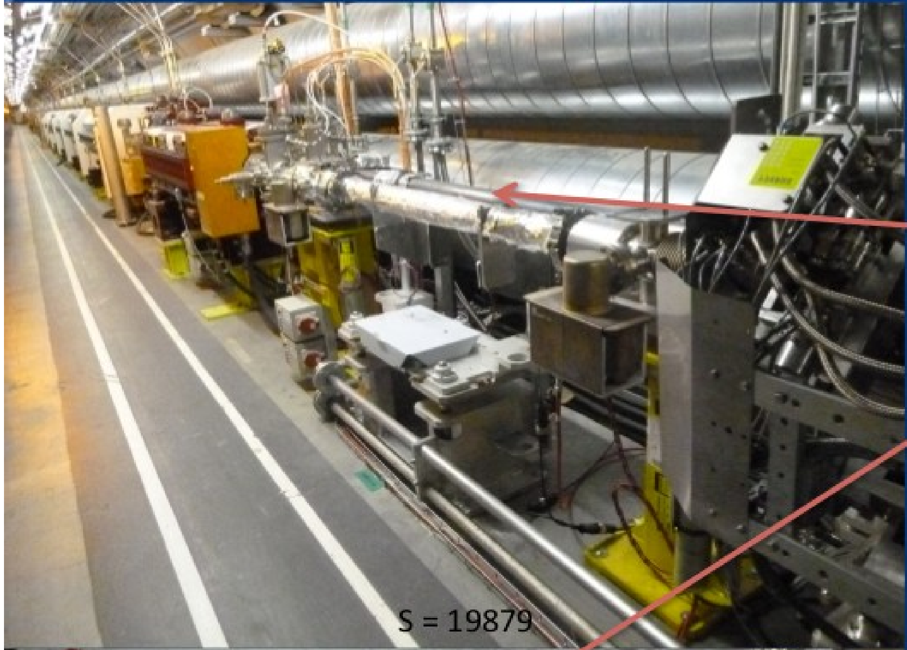


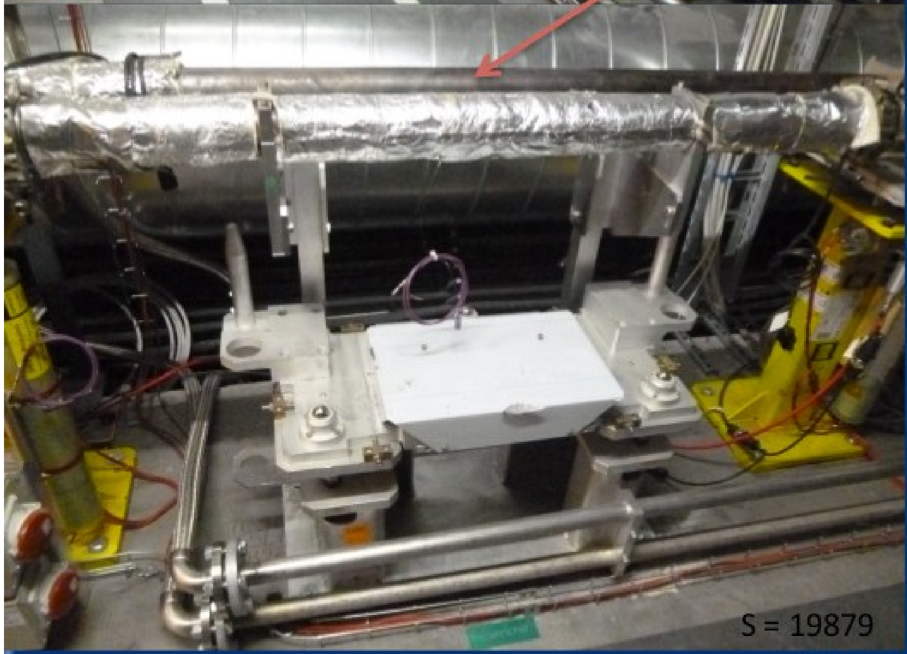
- 1 horizontal crystal + 1 vertical crystal
- Detectors
  - Rely on LHC standard BLM system
  - + 2 dedicated detectors, one per each plane (kind tbd)

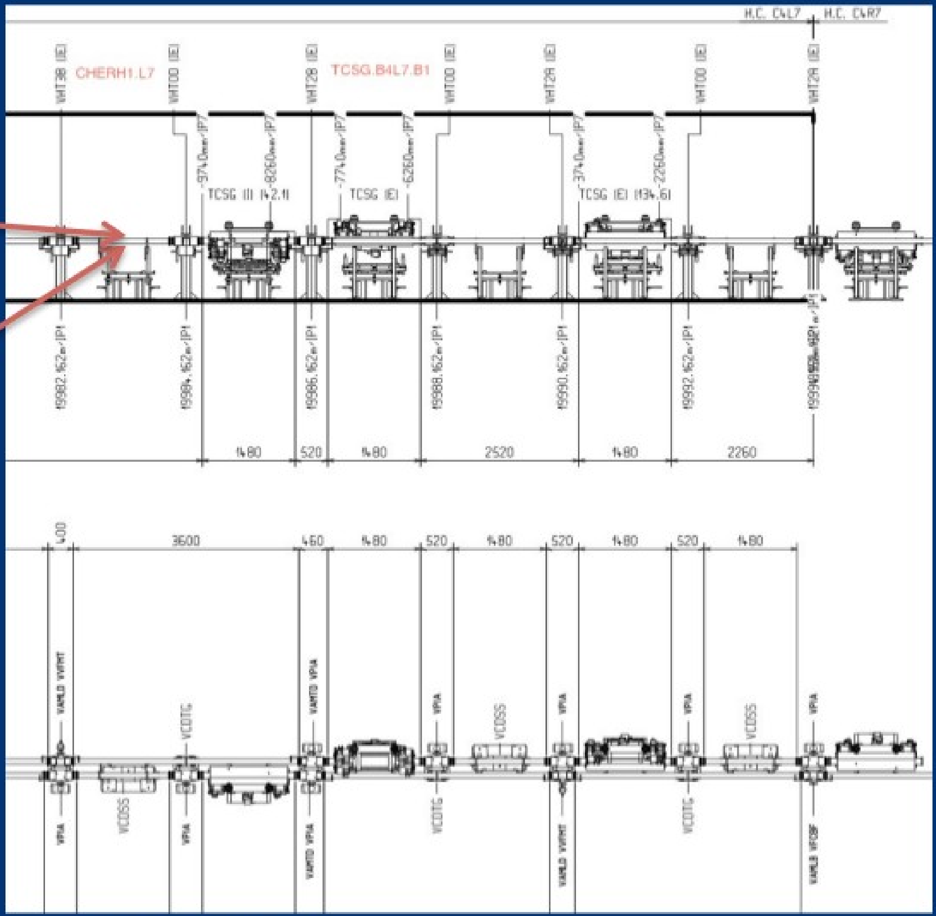
Secondary beam



Detector position for Horizontal Absorber 1





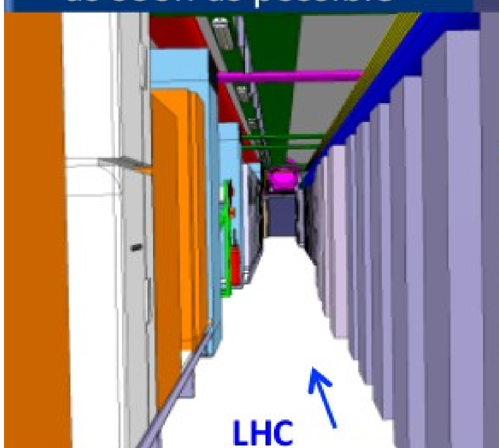


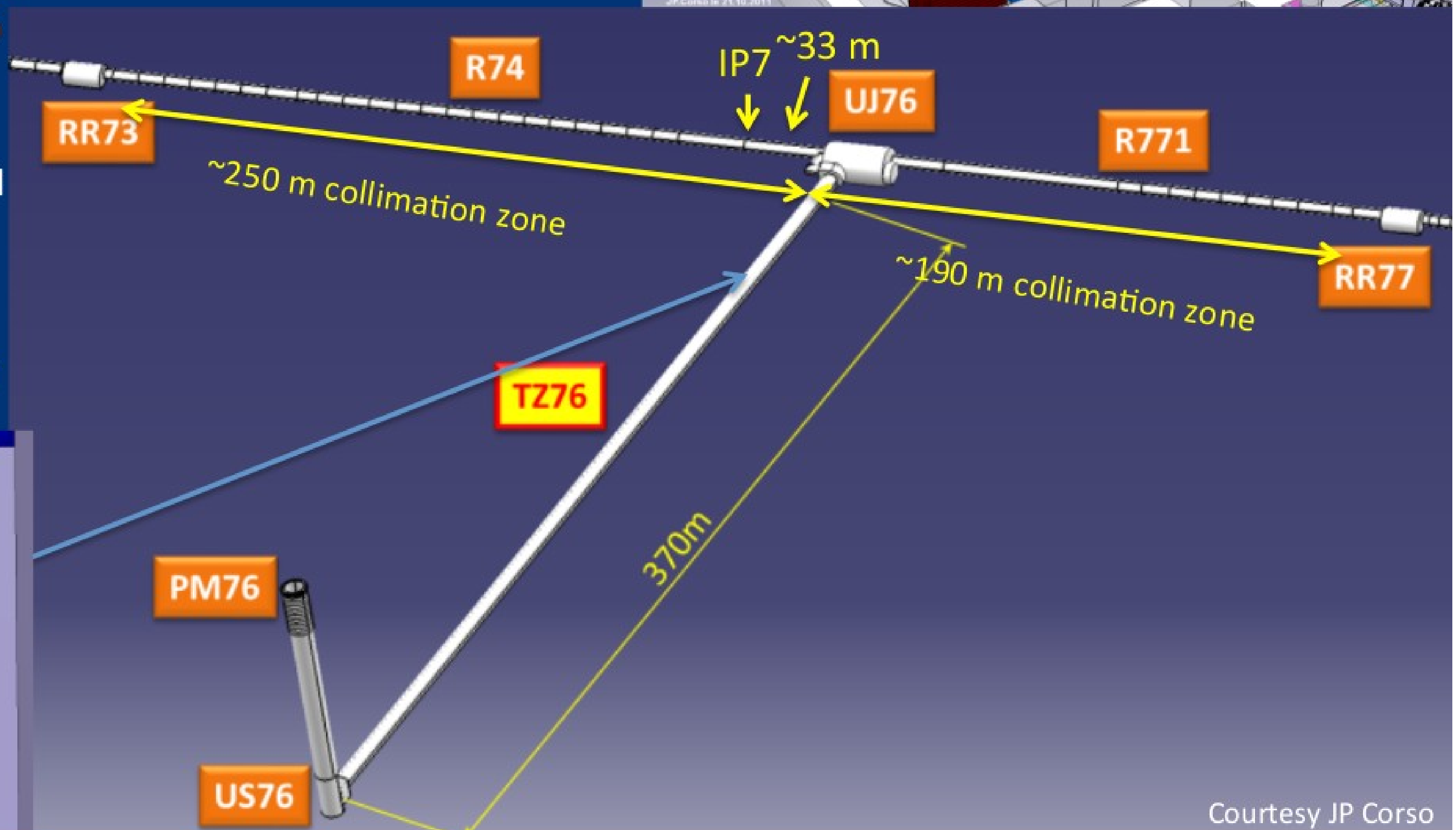
Absorber TCSG.B4L7.B1

- 1 suitable position for H1 Cherenkov detector
- Standard length of 1480 mm available
- Ready beam pipe
- Support for a collimator of phase 2 on beam-line 2

TZ76: Electronics rack tunnel

- 2/3 of the tunnel filled with electronics racks.
- First empty rack at 220 m from UJ76
- Some free and NOT INSTALLED racks (depth 40 cm) reserved for collimation at ~35 m from UJ76: we might be allowed to use them, but we must order installation as soon as possible



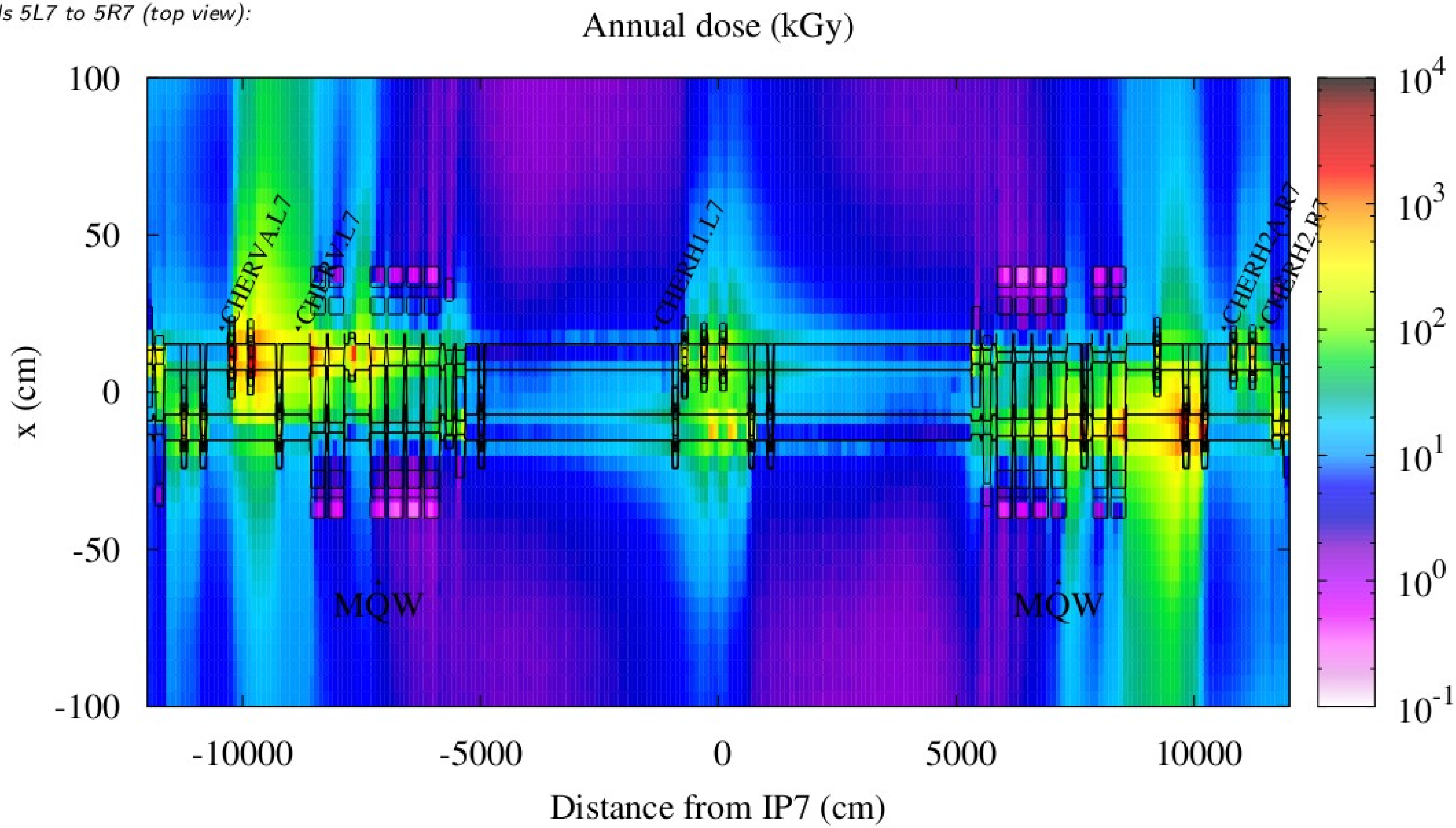


Courtesy JP Corso

Radiation doses

Dose at potential detector locations

IR7 cells 5L7 to 5R7 (top view):



Note:

- Dose values are averaged vertically over ±5 cm.
- The beam 1 and 2 collimator layout is not symmetric around ±10 m from IP7: hence, due to the simple beam 1/beam2 mapping, dose artifacts occur for beam 2 (less for beam 1) in the central region.

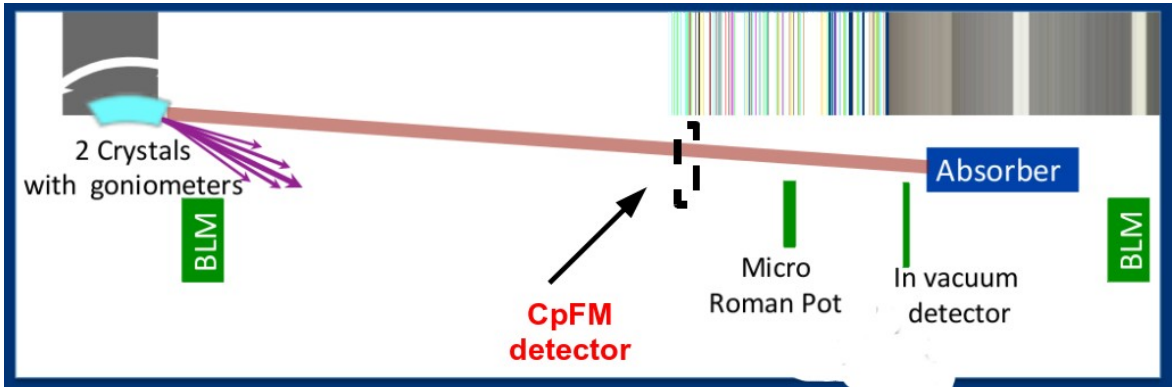
- Compared to previous slide, annual dose values are generally lower at potential detector locations
- See next slides for more details (lateral dose profiles at individual locations)

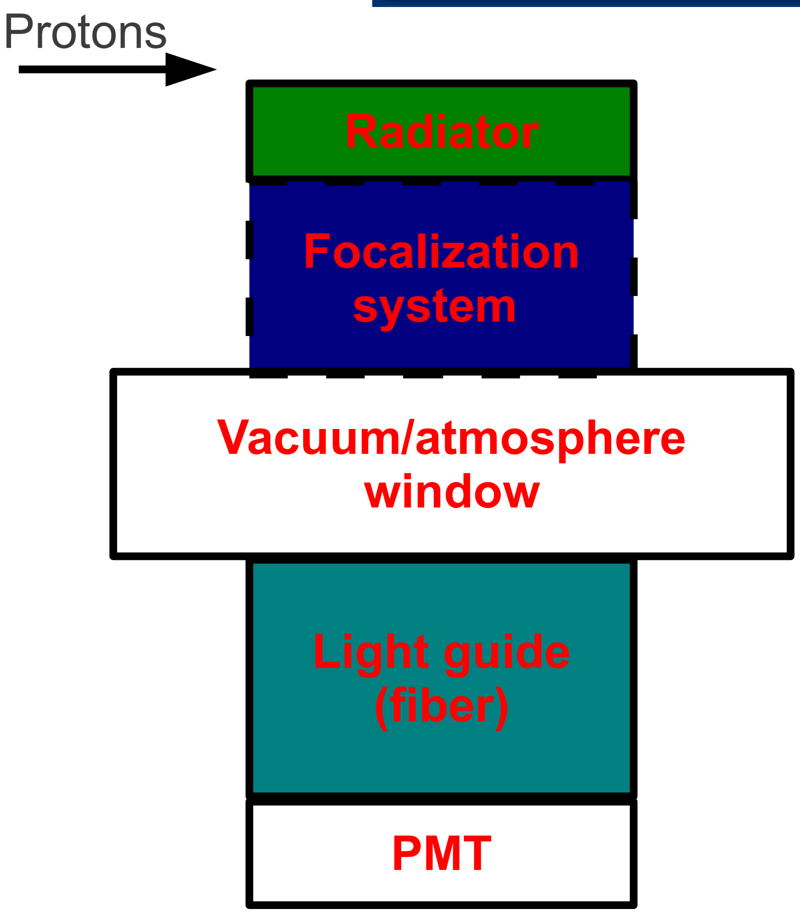
LAL contribution

LAL contribution

- Development, construction of the detectors
  - Cherenkov detector for proton Flux Measurements (CpFM) for LHC and SPS
  - Detector which will detect Lead ions and provide a trigger to the DAQ system (H8 test in 2015 at CERN)
- Acceleration physics
  - Calculation of the Beam impedances (which is changes due to installation of the related systems)
- Data analysis for SPS, LHC and H8 test.

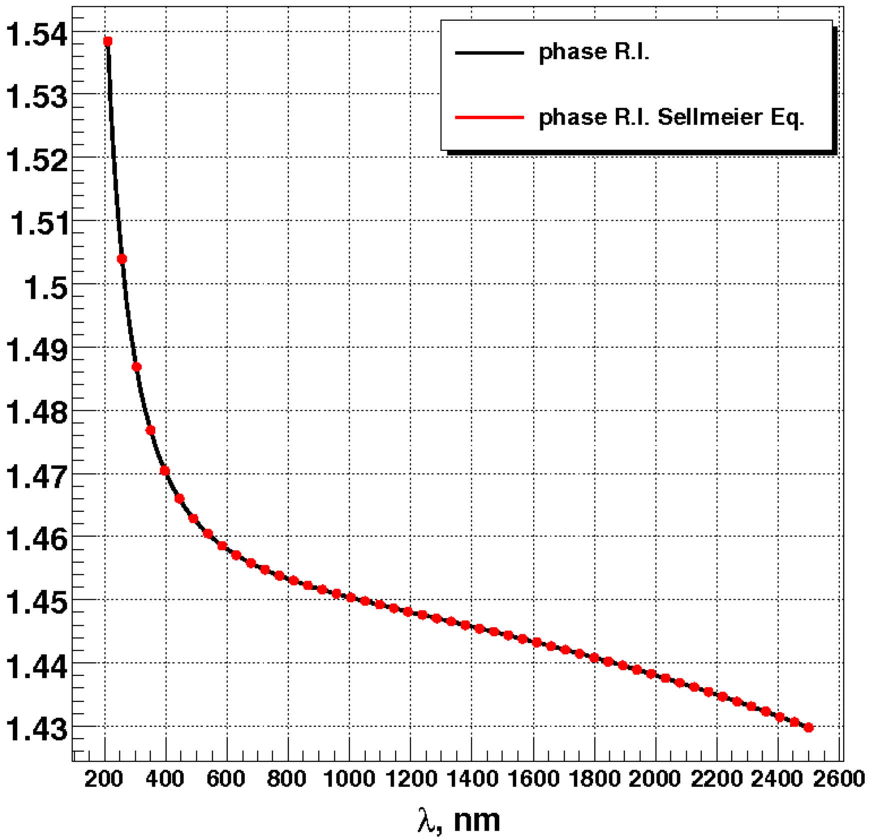
CpFM detector

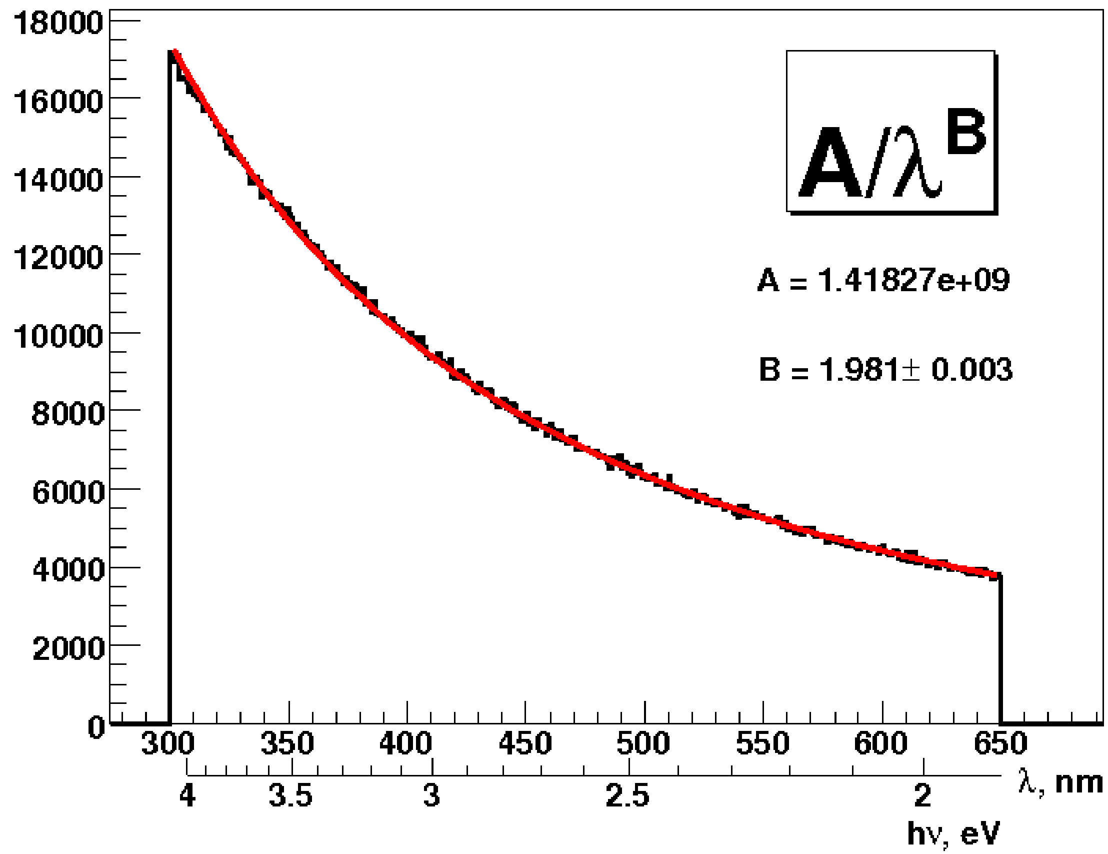




- Needs for monitoring of the secondary beam
- 5 % resolution of 100 protons
- Radiation resistant and robust
- Monitor the background

Geant 4 simulation of the CpFM (quartz properties)

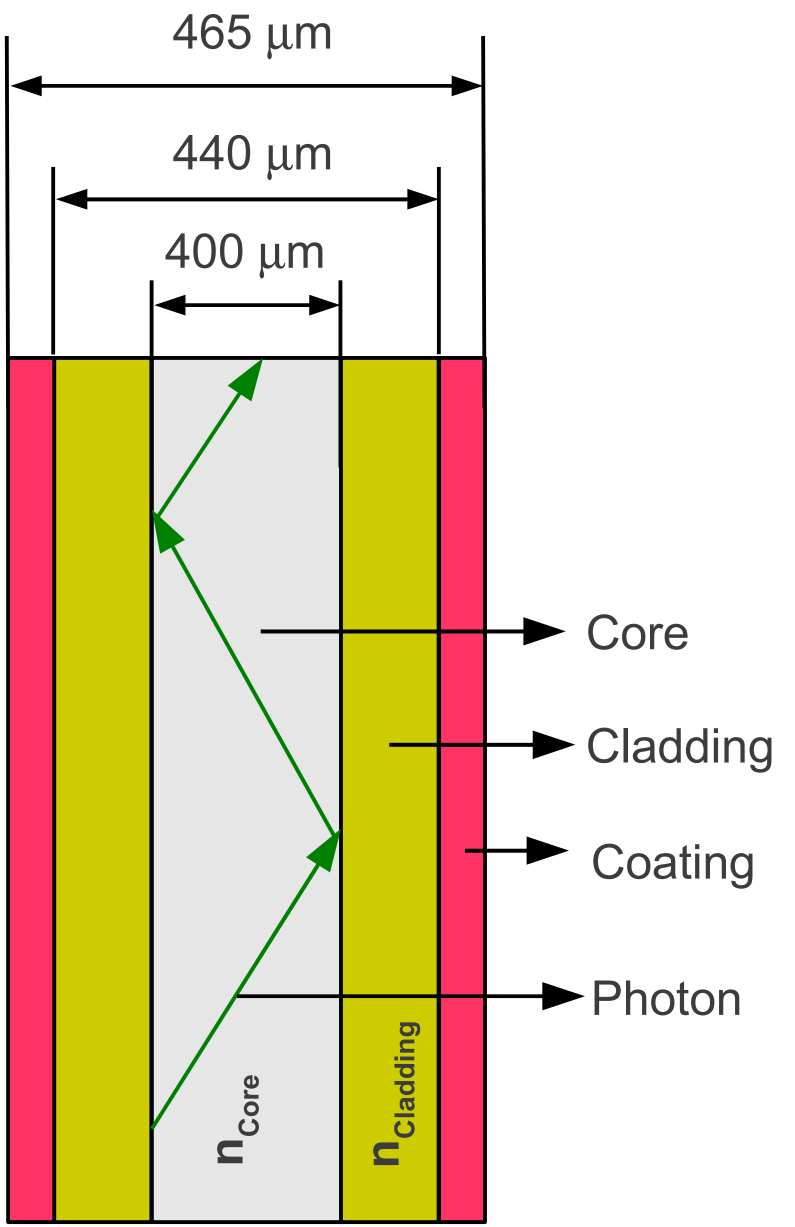




$$n^2(\lambda) = 1 + \frac{B_1\lambda^2}{\lambda^2 - C_1} + \frac{B_2\lambda^2}{\lambda^2 - C_2} + \frac{B_3\lambda^2}{\lambda^2 - C_3}$$

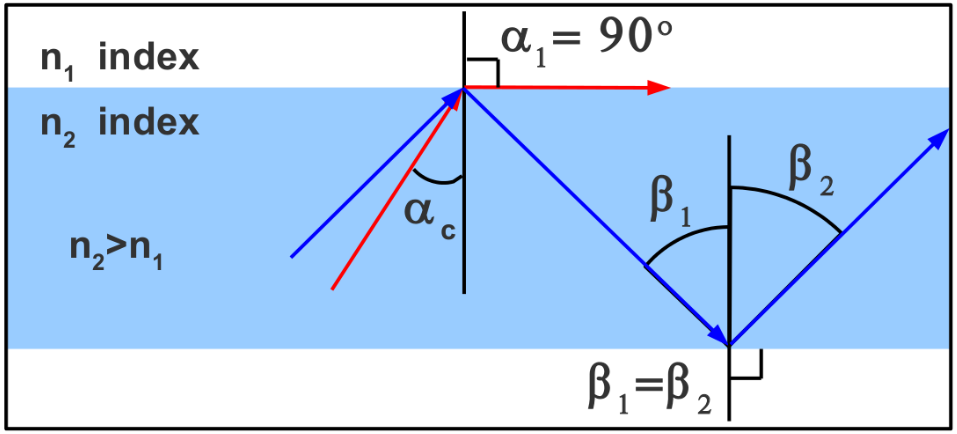
B_1	0.6961663
B_2	0.4079426
B_3	0.8974794
C_1	4.67914826×10^{-3}
C_2	1.35120631×10^{-2}
C_3	97.9340025

Simulation of the Quartz fiber



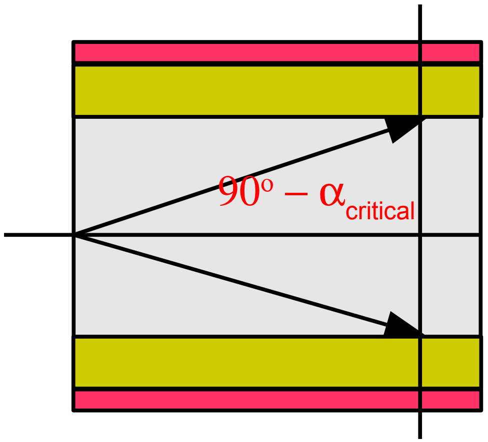
Numerical aperture = 0.22 = sqrt($n_{Core}^2 - n_{Cladding}^2$)

$n_{Core}^2 > n_{Cladding}^2$

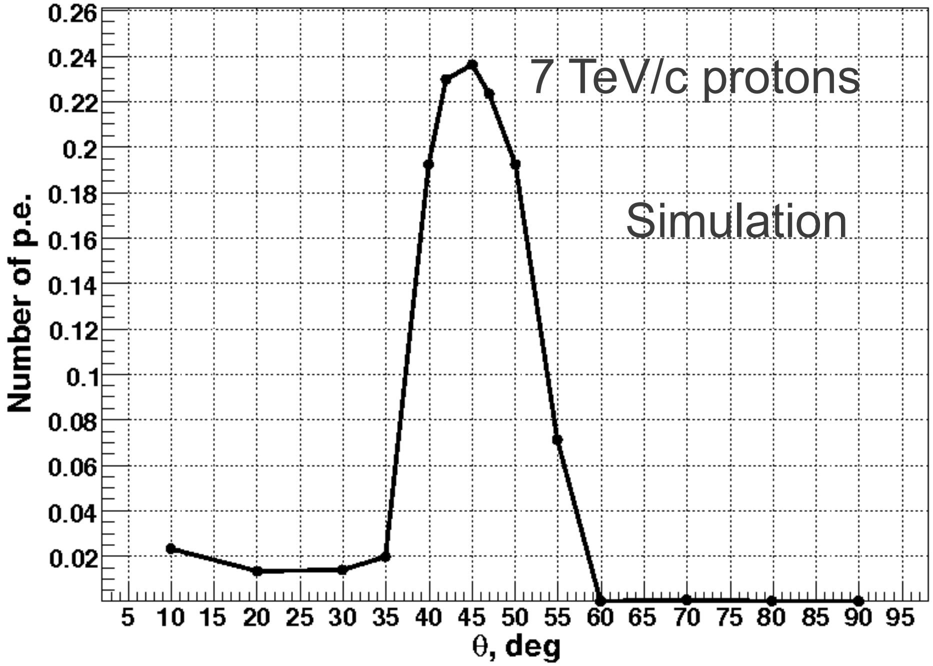


$90^o - \alpha_{critical}$ = ATan(Numerical aperture) = 12°

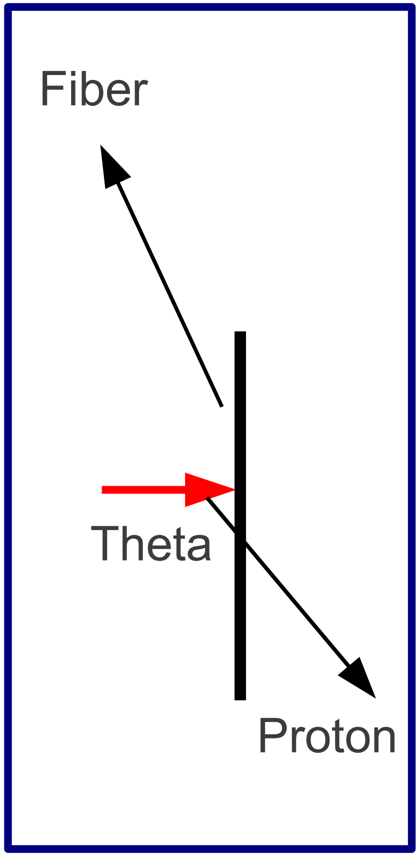
Total angle of acceptance is 24°

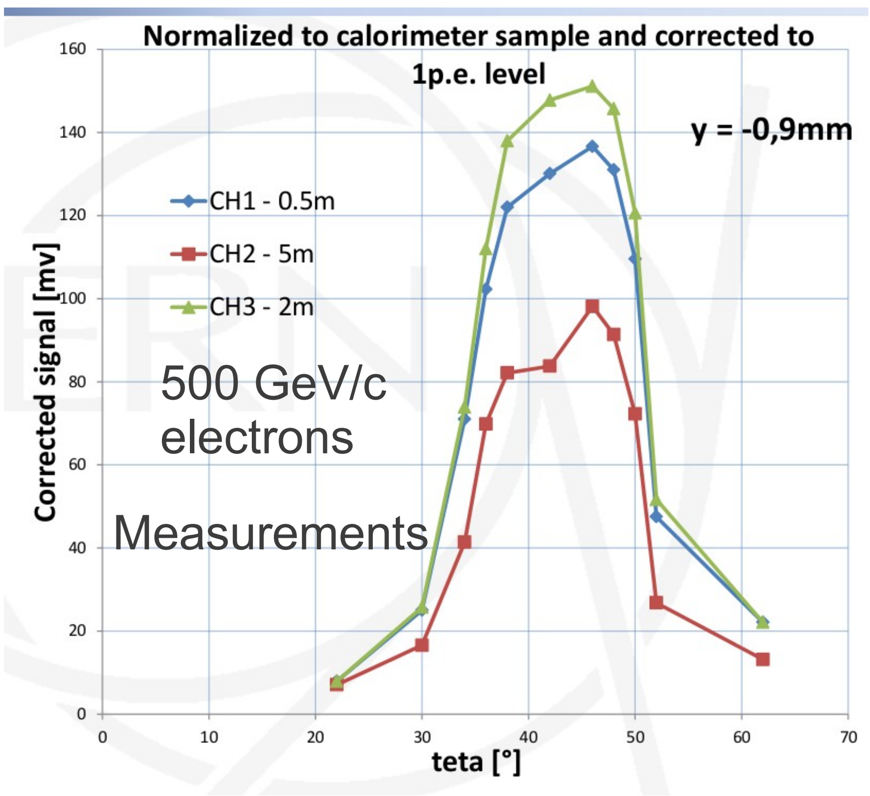


Number of p.e. as a function proton angle in the fiber



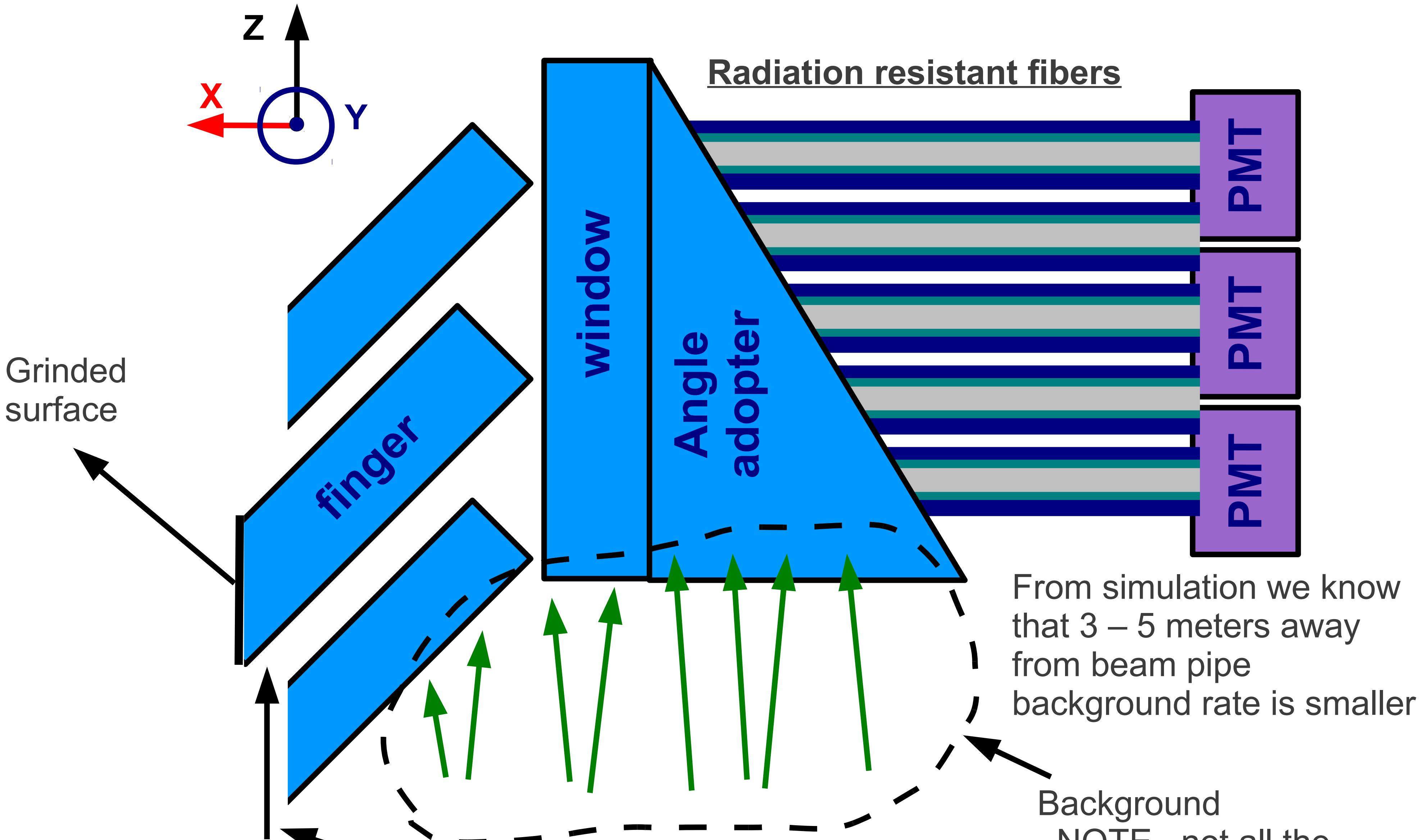
Photon detection efficiency (PDE) = 10 %





Fibers are reasonable modeled with Geant4

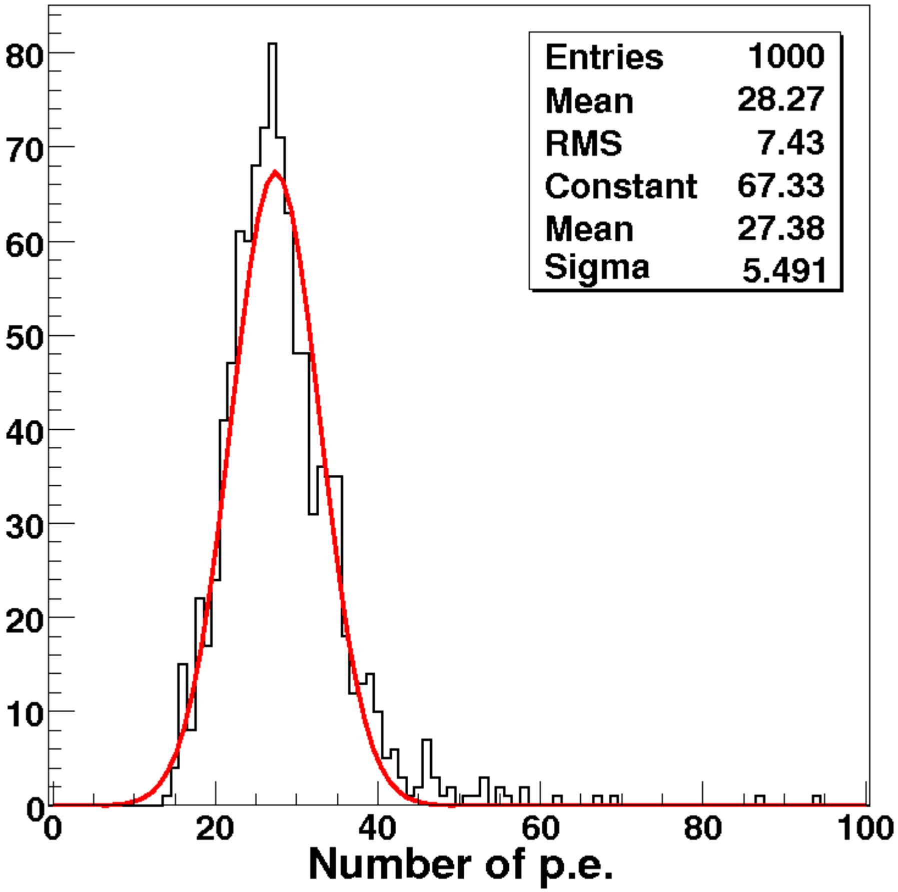
Separate pieces (finger + window) finger inclined by 45° + idea of Luca to use the more short fingers to measure the background + fibers to transport the light 2-4 meters away from beam pipe

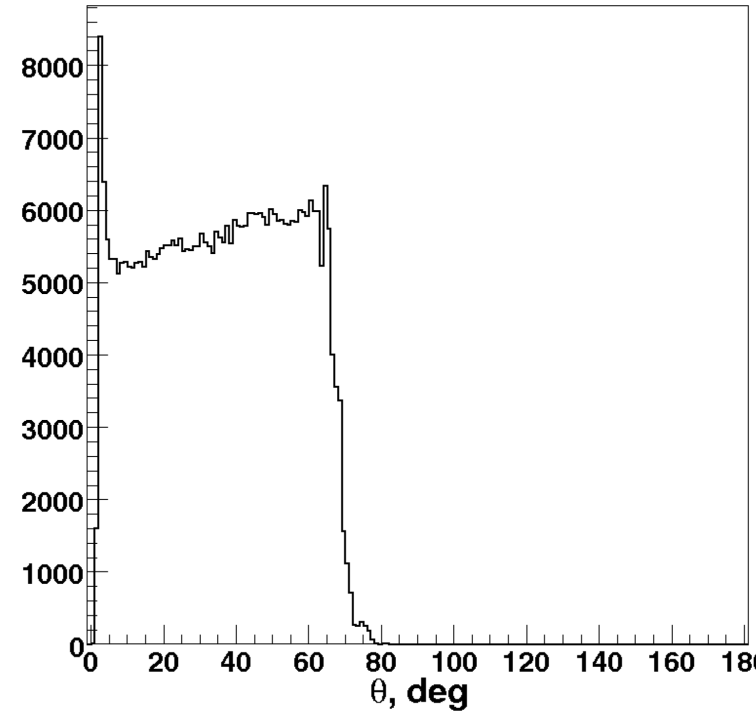


(Geom. e)

With 45° angle (Geom. b)

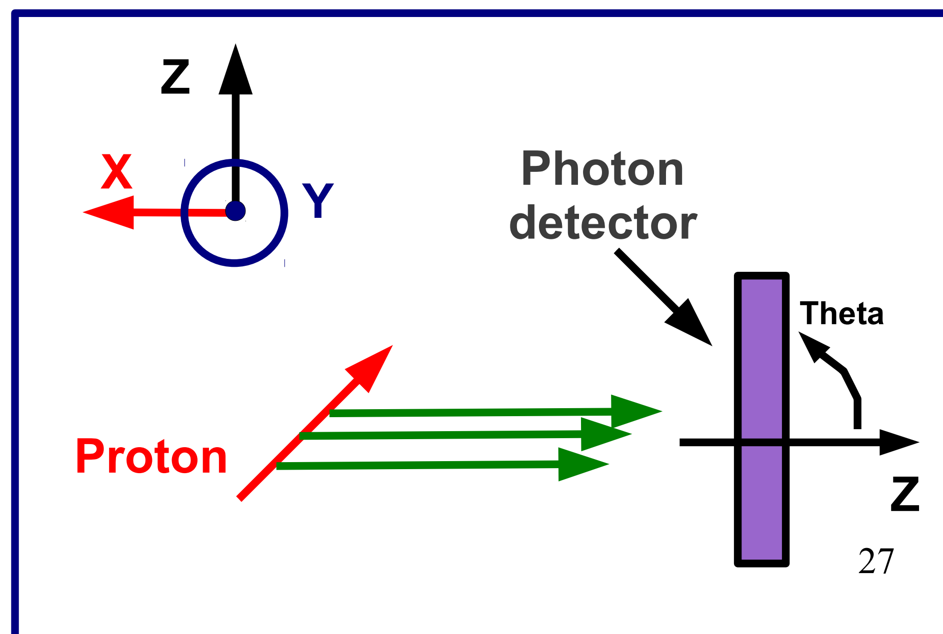
Number of the photoelectrons





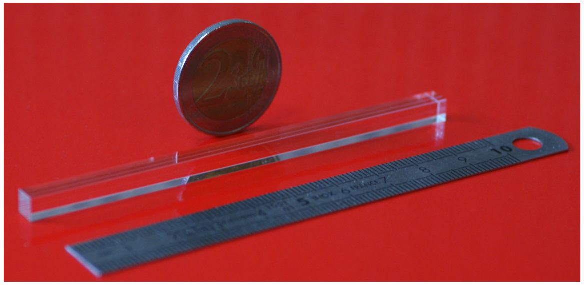
28.0 -> 10 p.e. factor of 3 loses due to the fiber angle acceptance

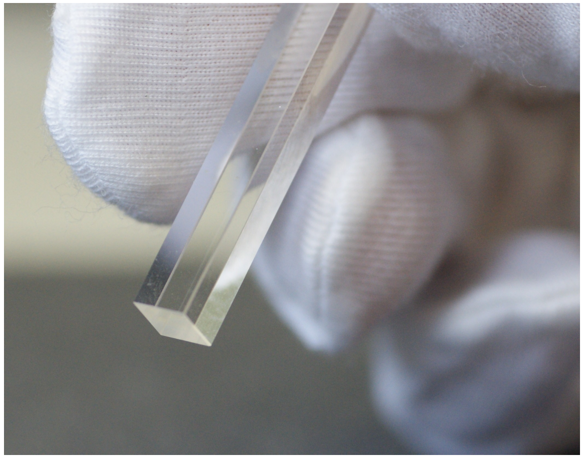
~3 % precision for proton counting (100 particles) can be achieved

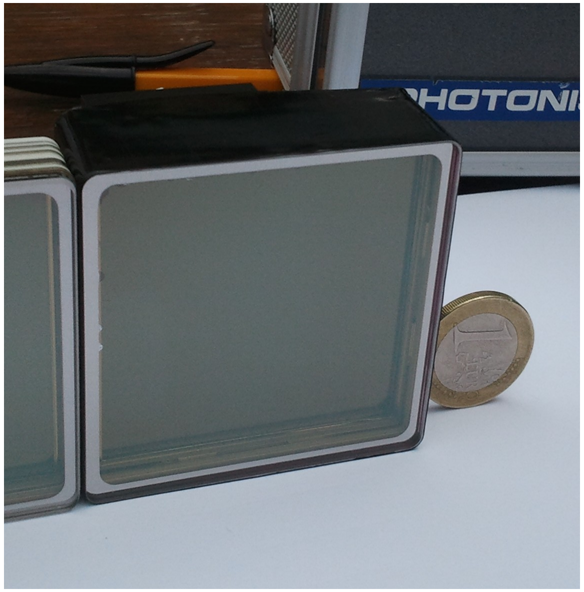


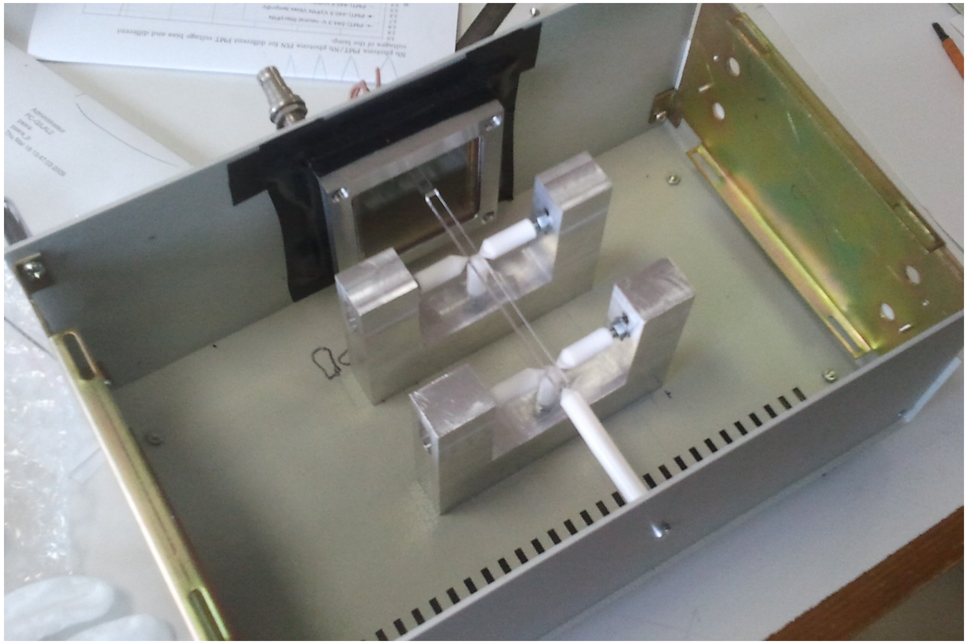
Very first measurements done at LAL

Geometry of the experiment (1)









5 x 5 x 100 mm^3 well polished quartz bar Connected to the Burle MCP-PMT (XP85012)

We use CARGILLE OPTICL GEL (CODE 0607) to improve the light contact between MCP-PMT and quartz finger.

The bar is fixed with 7 teflon rods with arrow-headed ends (to decrease the contact surface with quartz)

All this structure based inside the box

Geometry of the experiment (2)

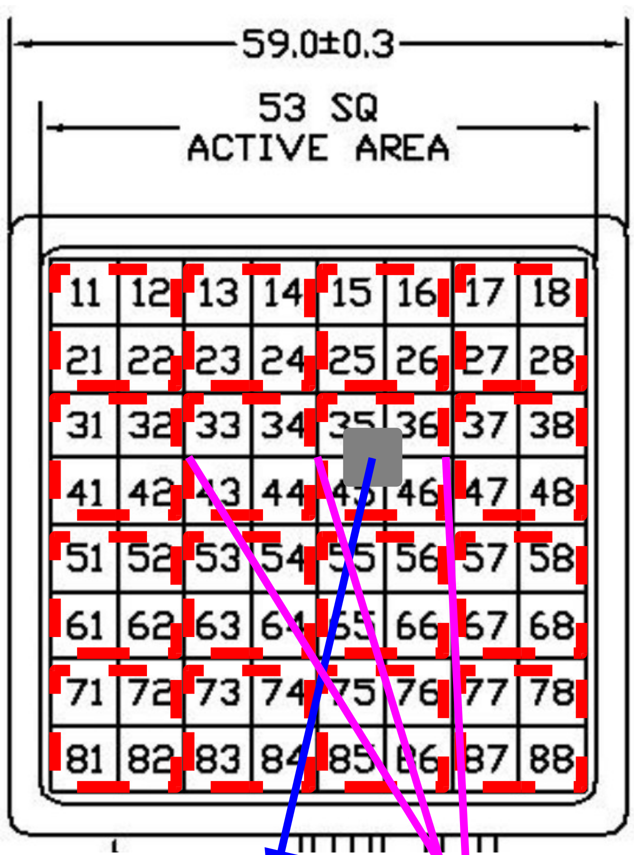
Planacon MCP-PMT photon detector (XP85012)

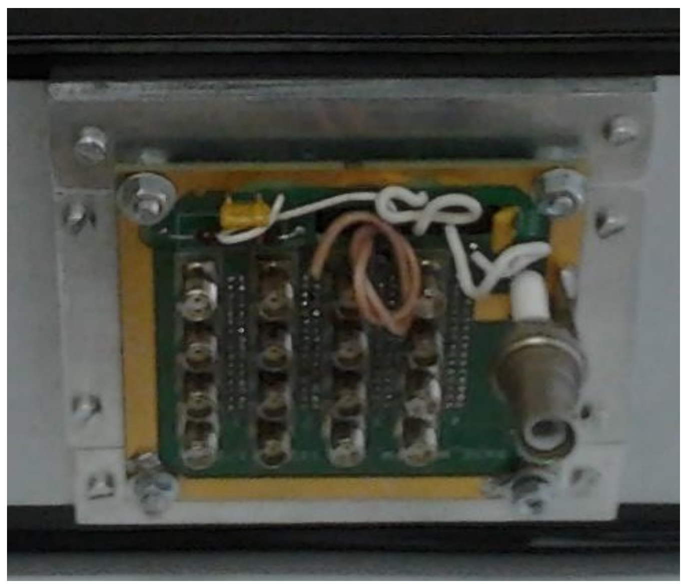
Model	XP85012
Window material	UV-Glass, Schott 8337B or equivalent
Photocathode	Bialkali
MCP pore diameter	25 μm
MCP pore length to diameter ration	40:1
Initial anode structure	8 $\times$ 8 array, 5.9/6.5 mm (size/pitch)
Active area	53 $\times$ 53 mm^2
Open-area-ratio	80 %
Collection efficiency	50 %

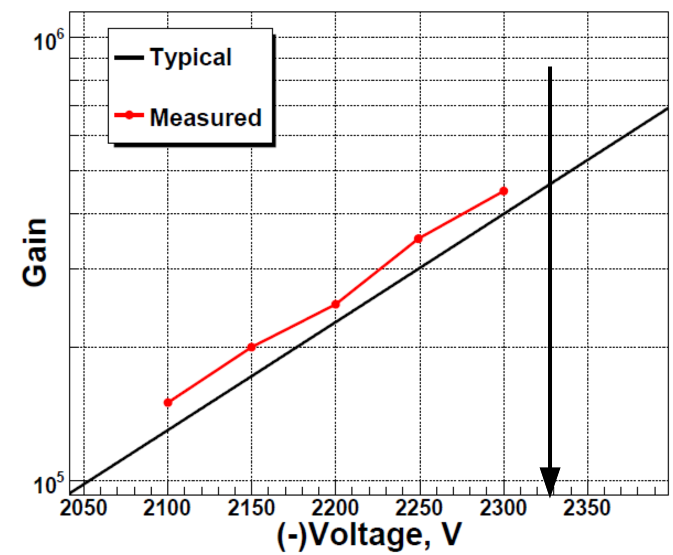
4 neighbor channels are grouped in to the one.

4 x 4 = 16 channels MCP-PMT

Operation voltage of the MCP-PMT: -2.33 kV corresponds to 5.0 * 10^5 gain



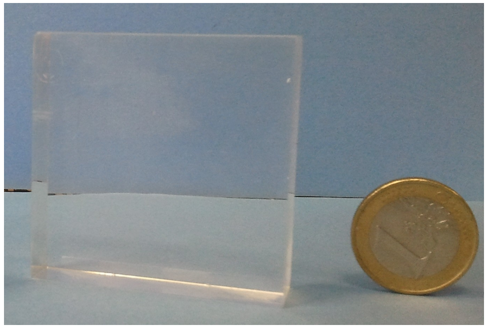


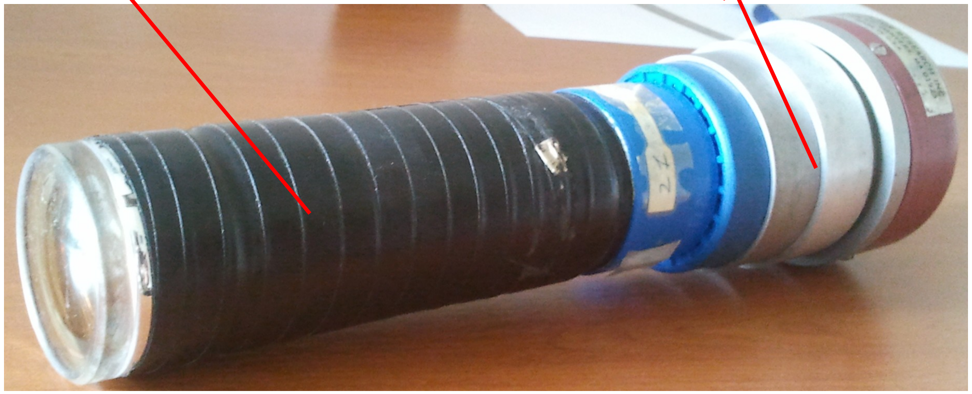


Quartz bar Readout channels with LeCroy 740 zi oscilloscope

Geometry of the experiment (3)

PMT 5 x 17 cm^3 H.V. Divider 5.8 x 9.5 cm^3





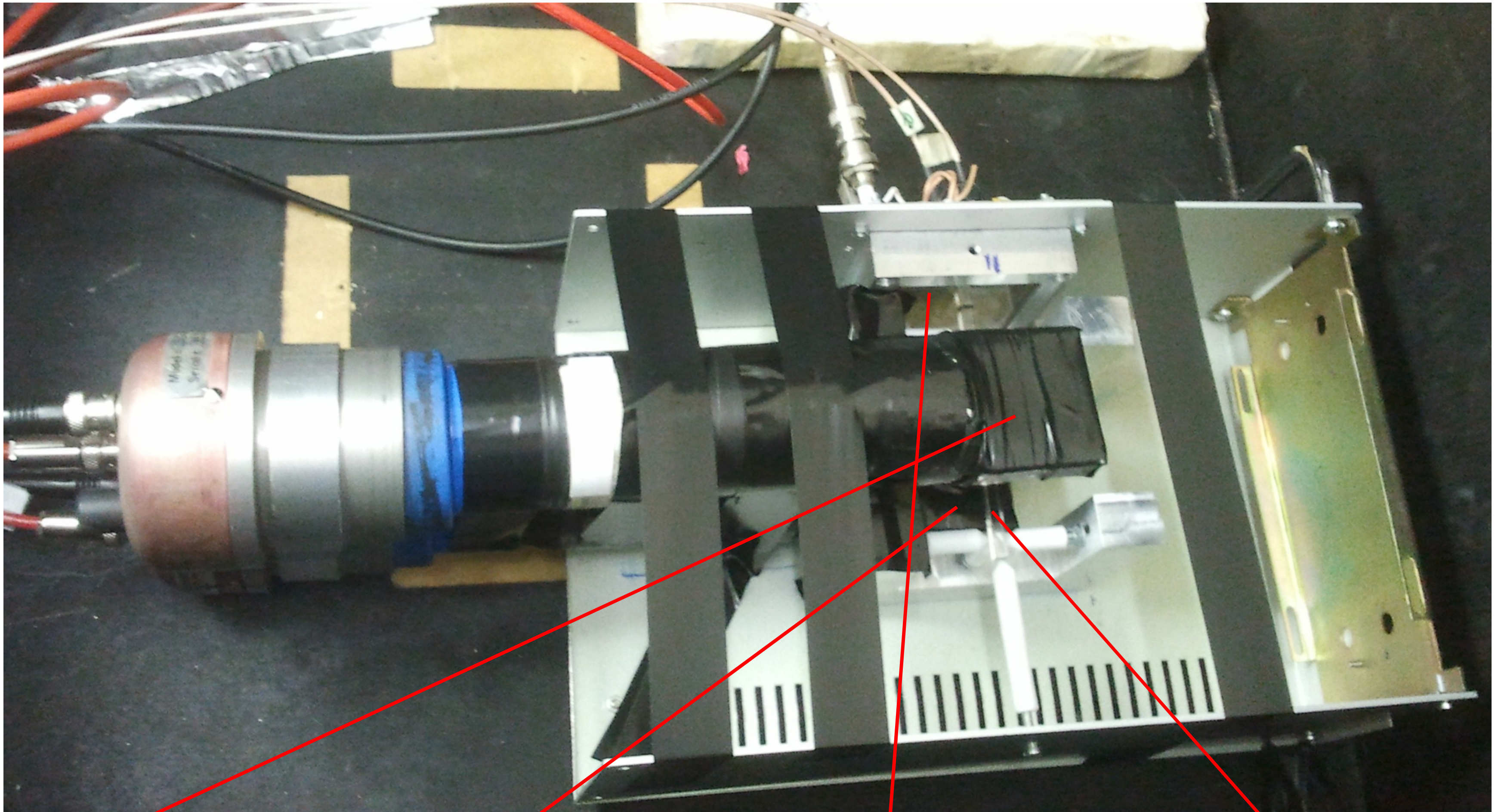
Two 50 x 50 x 15 mm^3 plastic scintillators

Wrapped in aluminum foil and then shielded from the light by the black tape

Attached to the 56 AVP 03 A PMT tube

Assemble two triggers: TOP and BOTTOM

Geometry of the experiment (4)



Trigger counter from the top

Operation voltage: -1600 V

Trigger counter from the bottom

Operation voltage: -1650 V

Planacon MCP-PMT

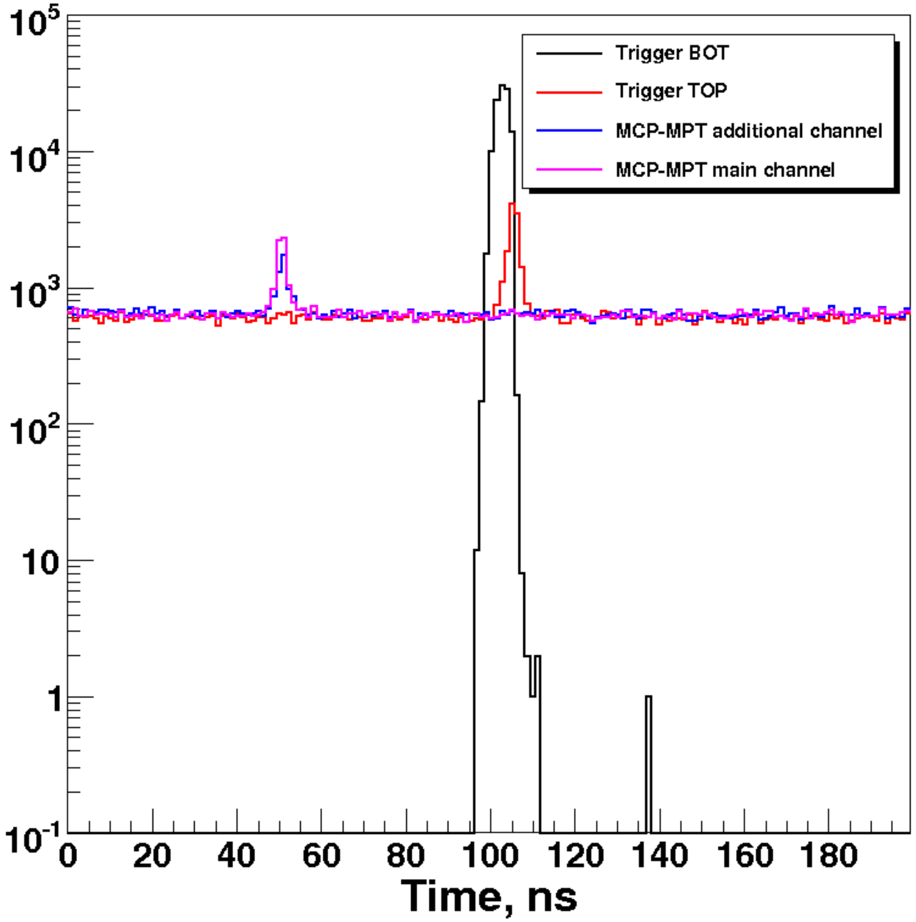
Operation voltage: -2330 V

Quartz bar

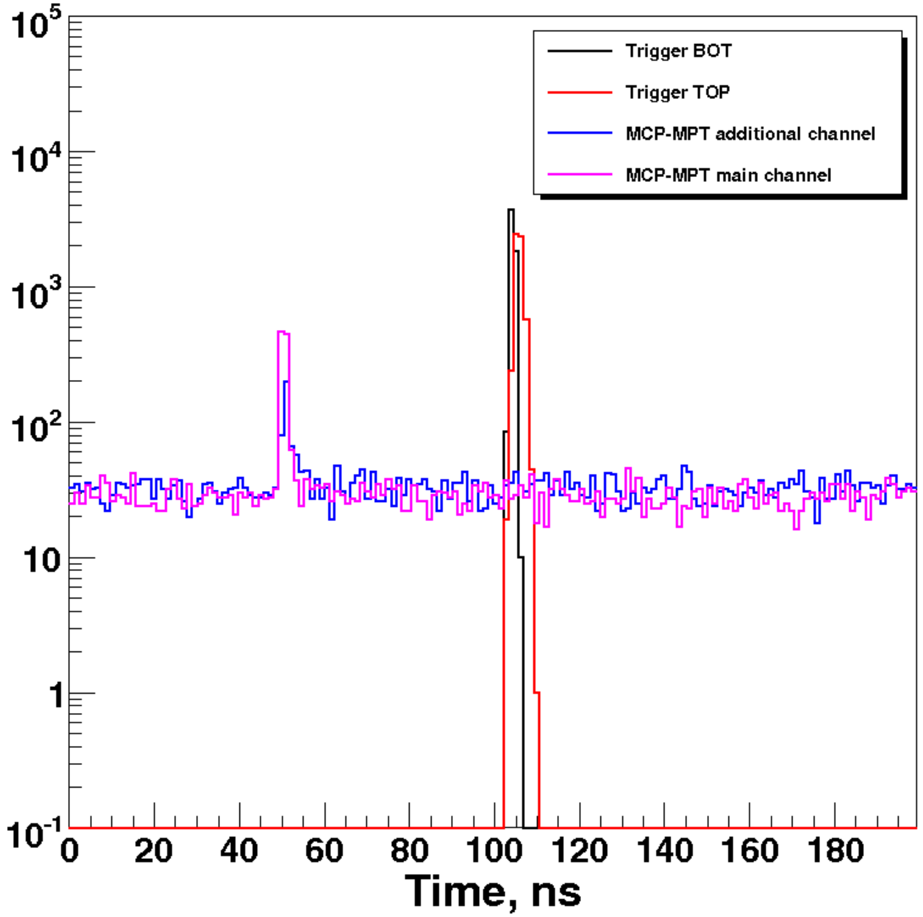
All the detectors has been installed in the light tight box

Measurements (1)

All events

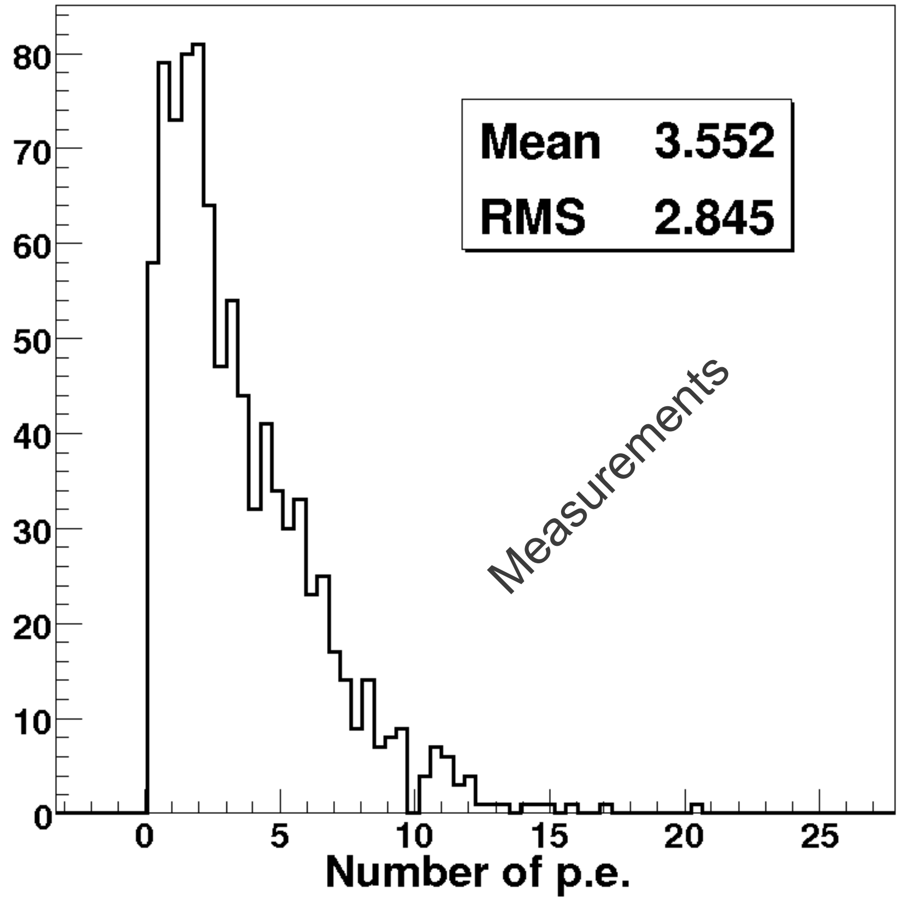


Coincidence between top and bottom triggers



Measurements (2)

Number of detected photo electrons



We measure **3.6 p.e.** per muon
(8.5 p.e. with simulation)

Conclusions

Collimation concept based on the bending crystal looks very promising option for the LHC.

CpFM detector is going to be used to control the deflected (channeled) beam and measure the number of protons

We started development of such a device.

First test at LAL of the quartz detector for the proton flux measurements at LHC halo has been started.