CRYSBEAM - crystal extraction for the LHC

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Introduction

- The initial goal of ***CRYSBEAM*** was to demonstrate that

✦a bent crystal can be used to **parasitically extract** the **LHC** beam up to the highest energy (the **crystal kicker**)

✦the **flux** of the crystal deflected beam can be **measured** (the **Cherenkov screen**)

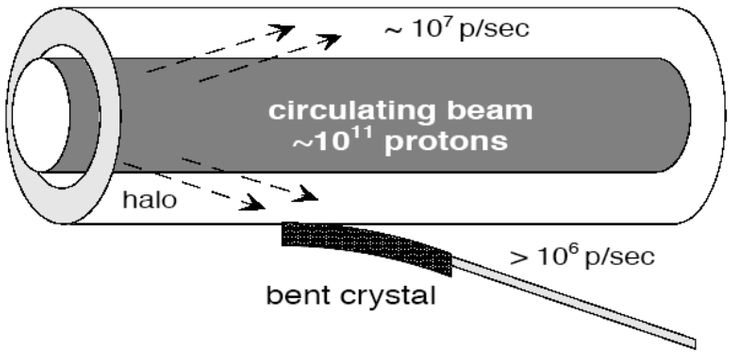
✦the deflected beam can be used to measure **hadronic cross sections** relevant for the Ultra High energy cosmic ray shower interpretations (the **smart absorber**)

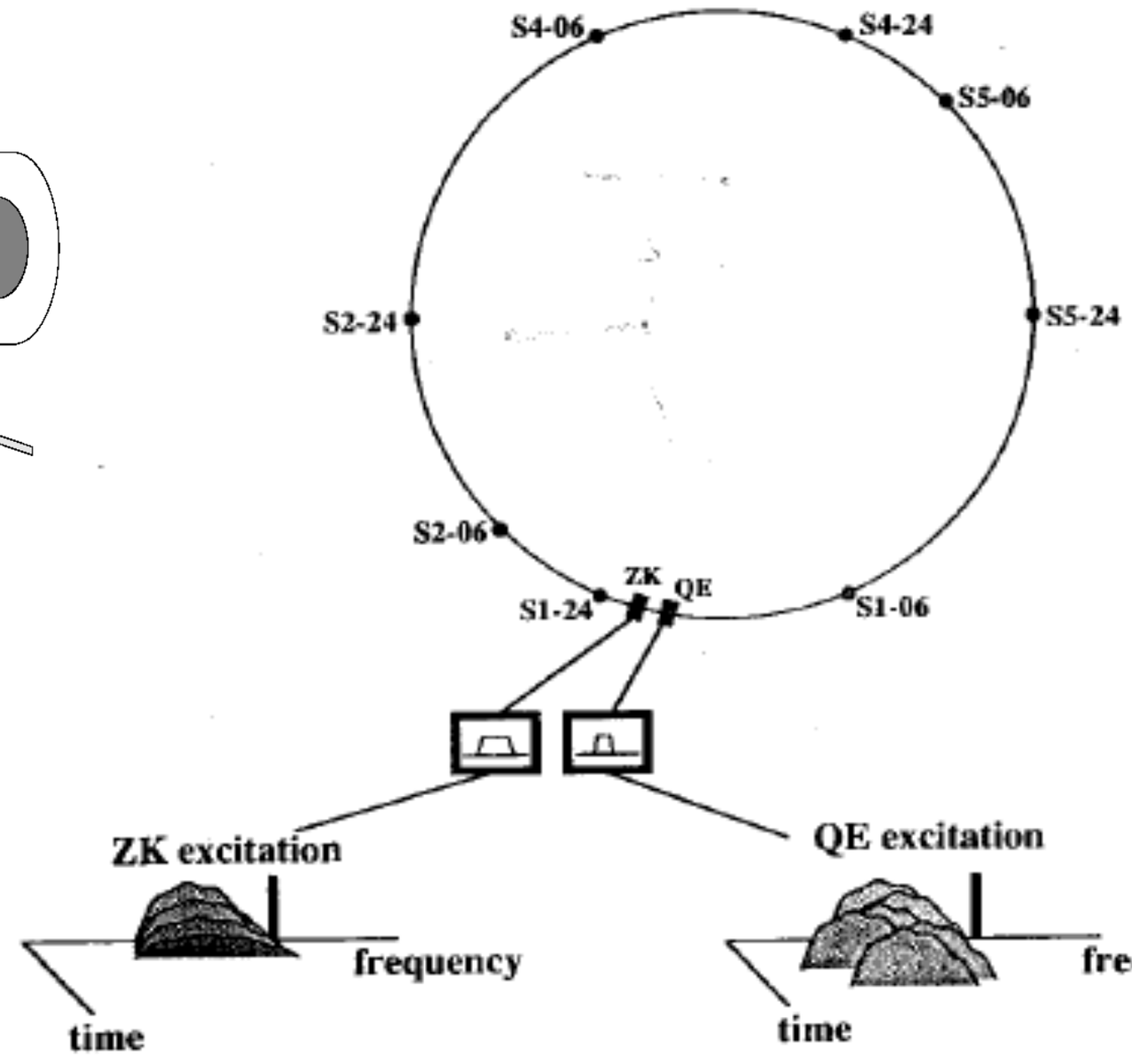
- ***CRYSBEAM*** was financed with an ERC-CoG 2013 (started 2014, ending Apr 2019)

http://crysbeam.roma1.infn.it/

- In the last years most of the INFN R&D activities on crystals were funded by this grant (personnel, equipments, consumables)

A non-resonant extraction scheme

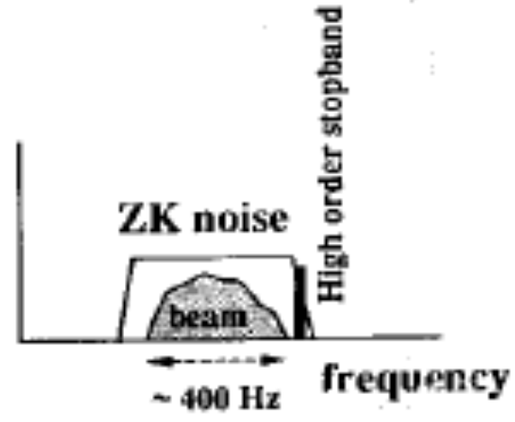




Si = sextupoles

QE = quadrupole

ZK = e.m. deflector



- Induce random deflection with e.m. device
- Increase trasverse diffusion speed and halo population
- Extract with a crystal

A solution for a reduced aperture machine (LHC)

A scenario for the LHC beam extraction

W. Scandale, Proc. LHC Workshop, eds G. Jarlskog and D. Rein, Aachen, 1990, vol. III p. 760.

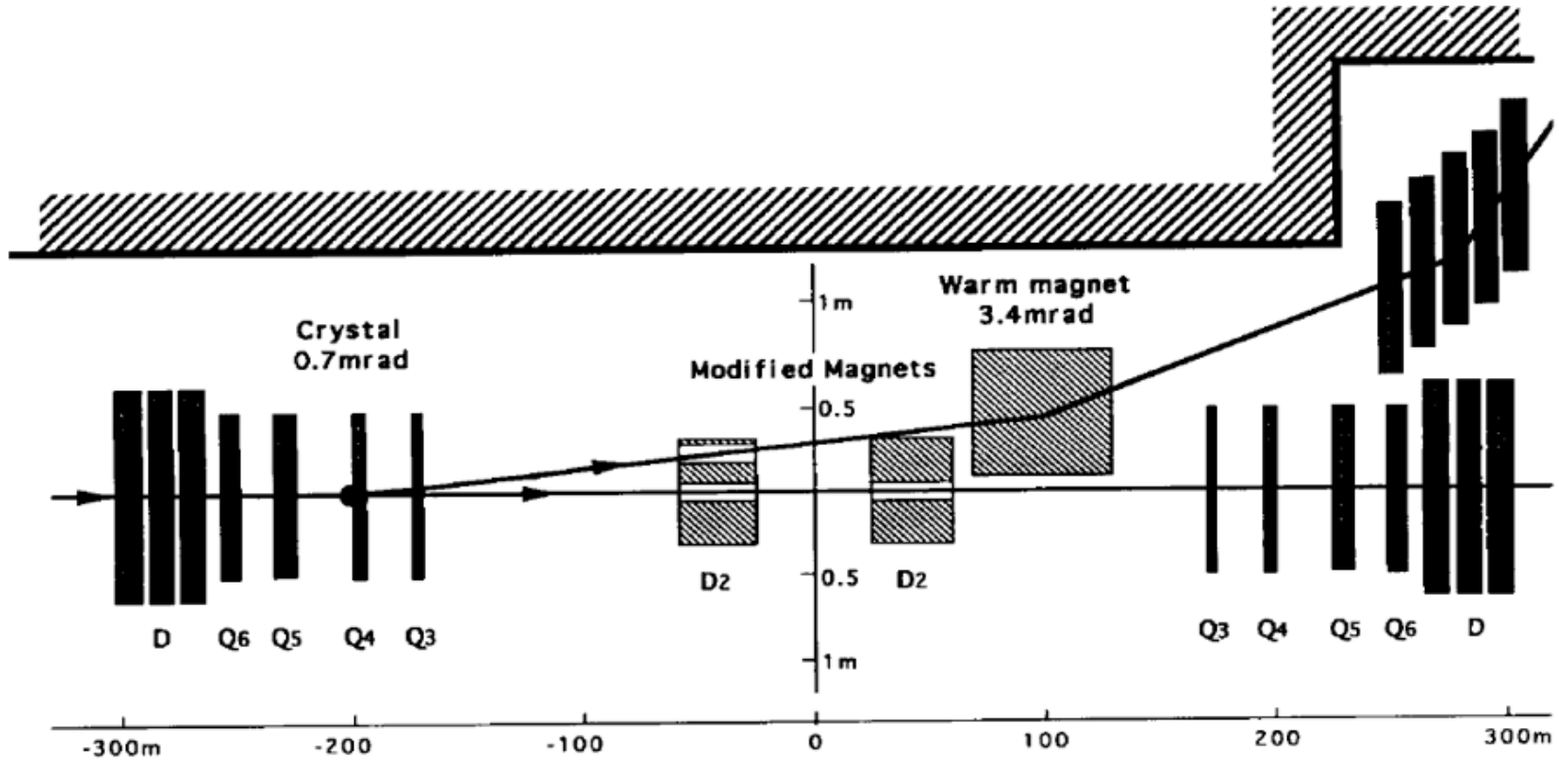
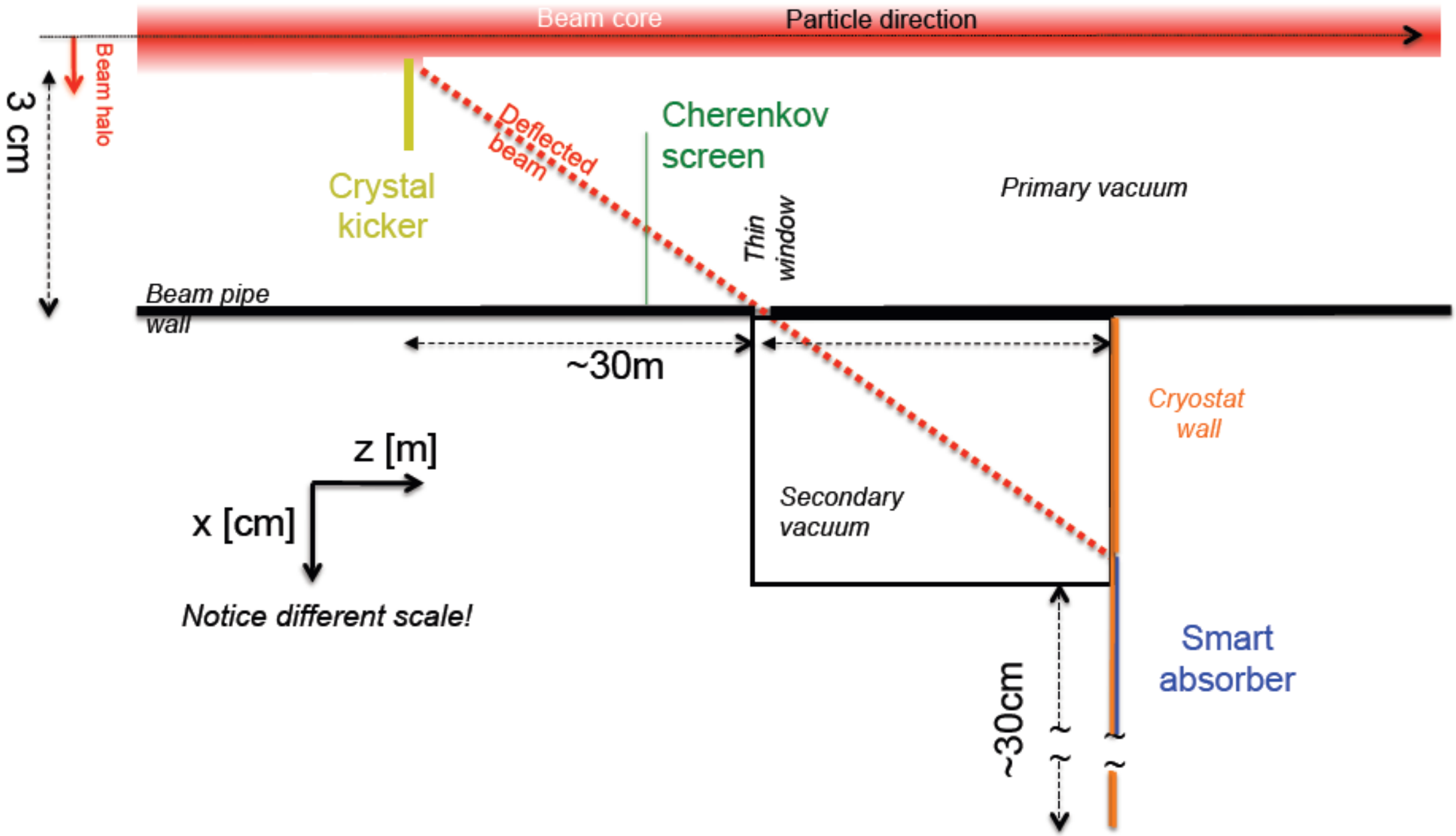


Fig. 2. Schematic layout of vertical halo extraction using channeling in a bent silicon crystal. After the warm septum magnet the extracted beam is bent by a string of five superconducting dipoles of the LHC type [14].

- Requiring a **1 mrad deflection angle,** with high efficiency

The CRYSBEAM layout



Critical radius for channeling

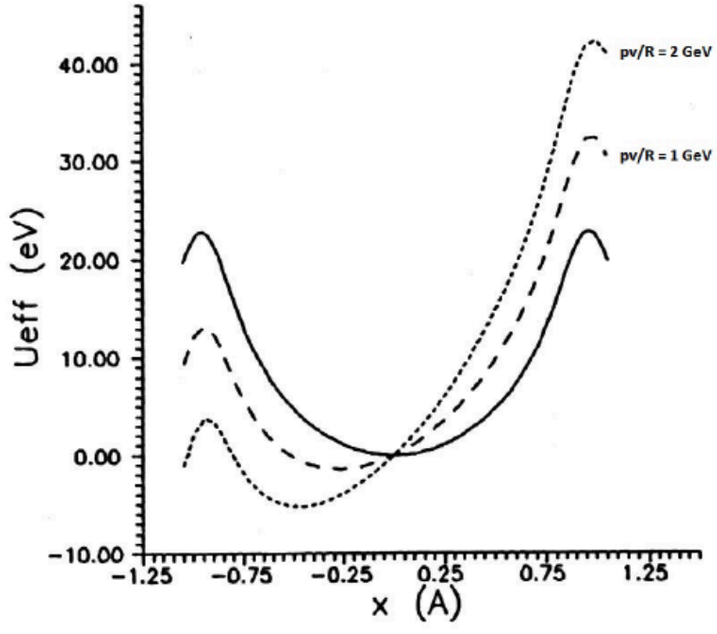
- Given a deflection angle Φ **[~1 mrad]**

$$\Phi = L/R$$

where R is crystal curvature radius and

L is the crystal length

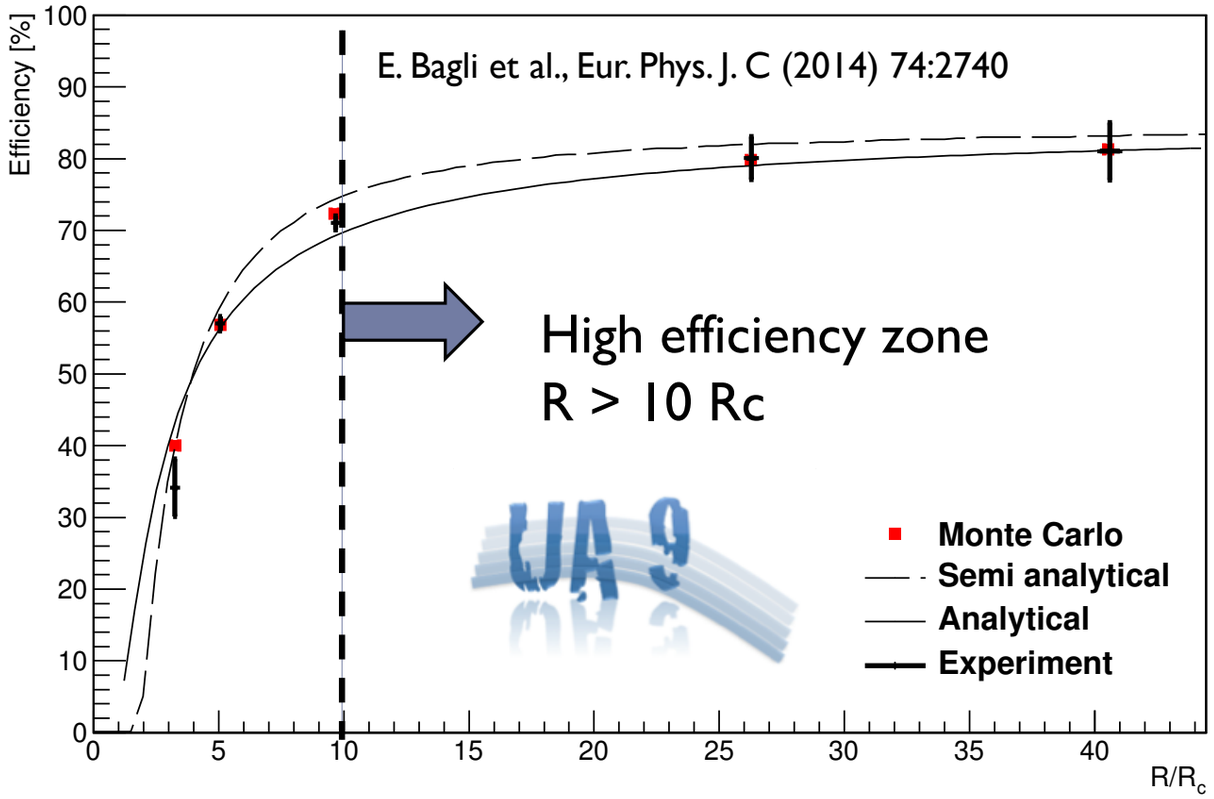
Effective potential in presence of centrifugal force (bending)



Critical radius to have an efficient channeling

$$R_c \approx \frac{\frac{p}{Z_i}\beta}{\pi Z e^2 N d}$$

Channeling efficiency versus R



- Experiment (H8 and SPS):
  - Si bent crystal (**L = 0.2cm**)
  - (1 1 0) plane
  - 400 GeV/c protons

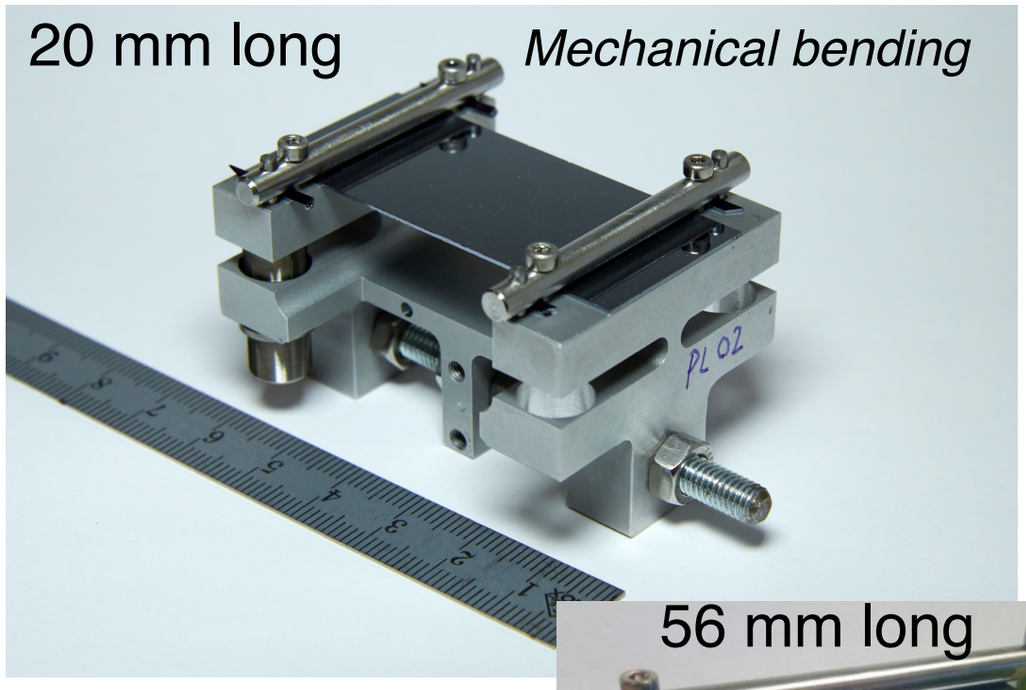
Si (110):
R_c = 12m at $p\beta$ = 7 TeV
Ge (110):
R_c = 7m at $p\beta$ = 7 TeV

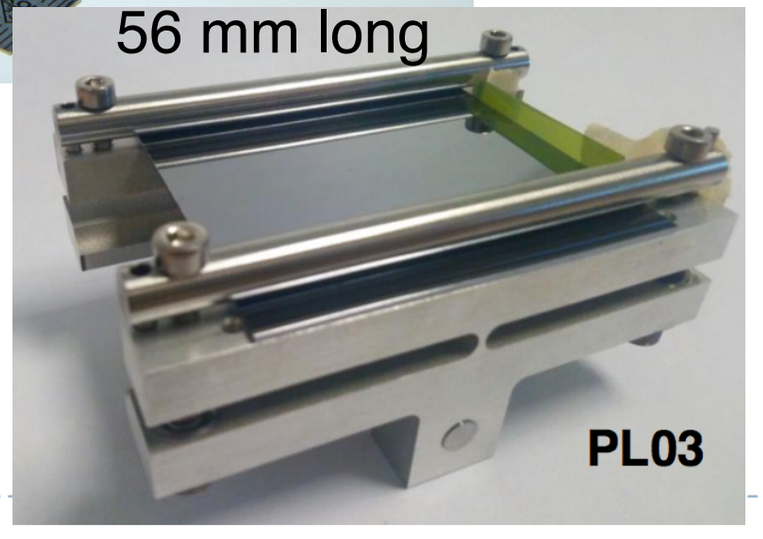
- ~1 mrad deflection requires ~12cm long Si crystal (or 7 cm long Ge crystal)

- Therefore an **efficient** (i.e. large fraction of deflected particles) and **large** bending **angle** crystals is required to be "**long**"

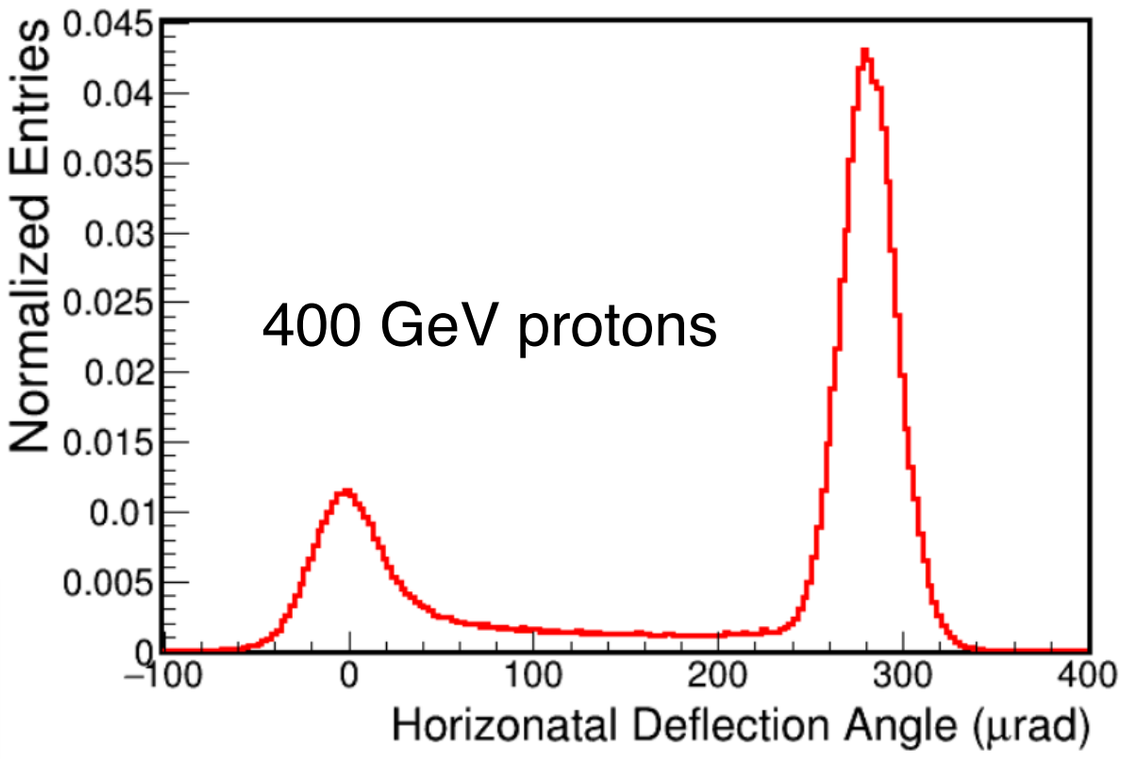
Long Crystals for the LHC

- **Few cm long crystals**





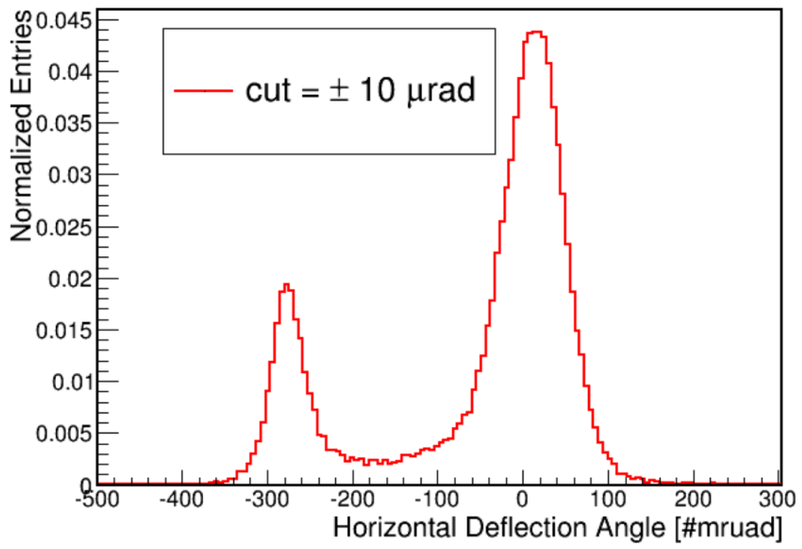
Compatible with required critical radius



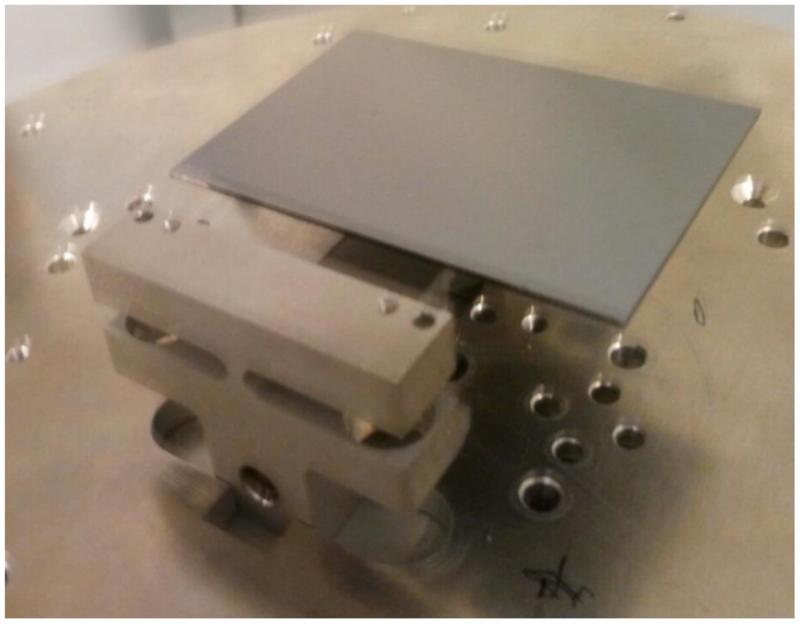
Advanced bending techniques

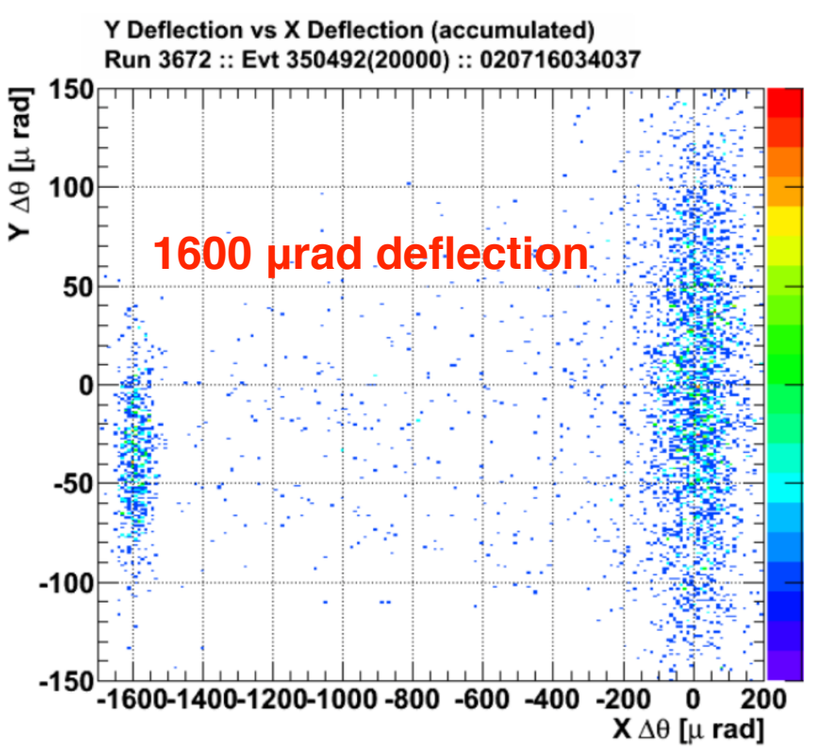
Self standing crystals: no holder needed!!!

Patterned tensile layer of 100 nm SiN film



Plasticization of a surface

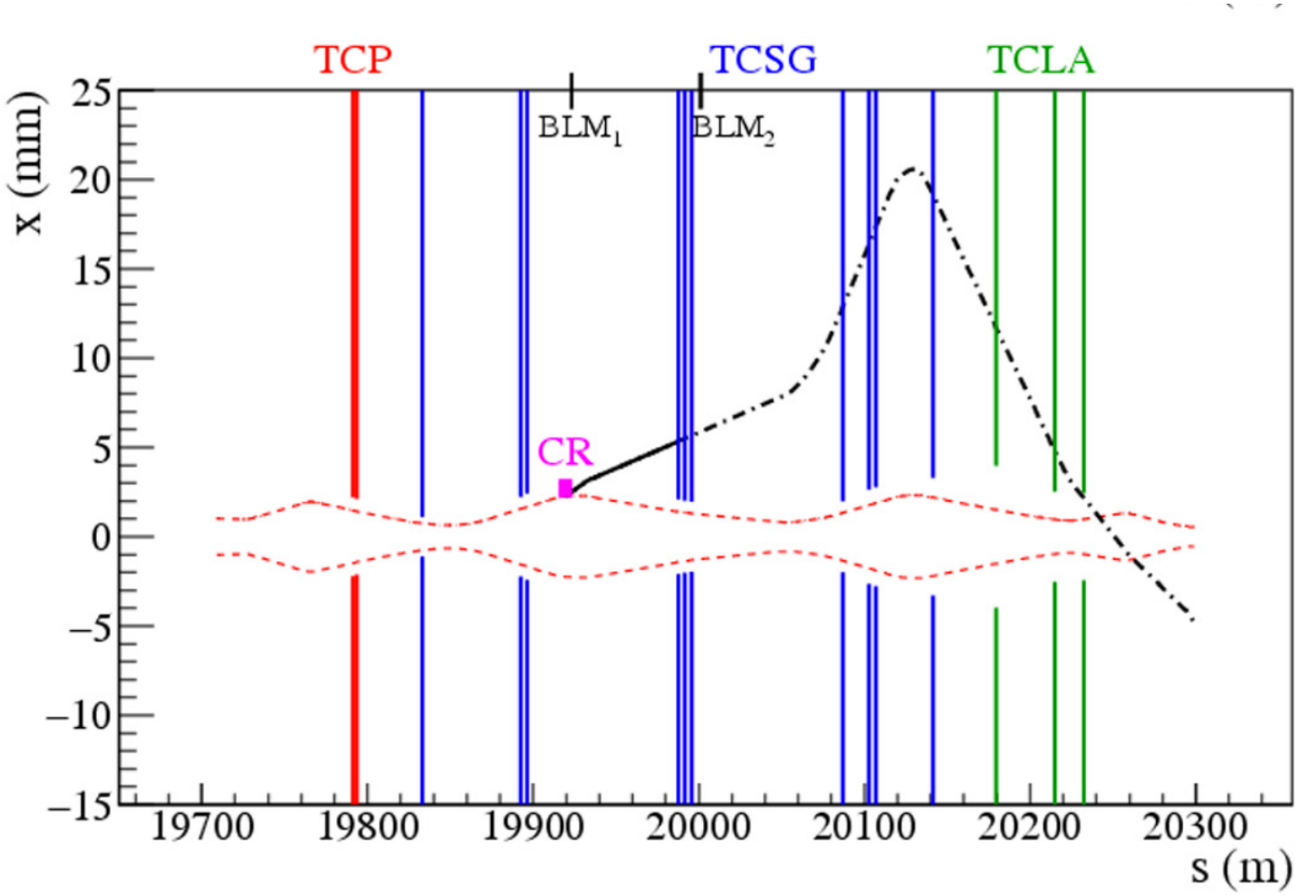




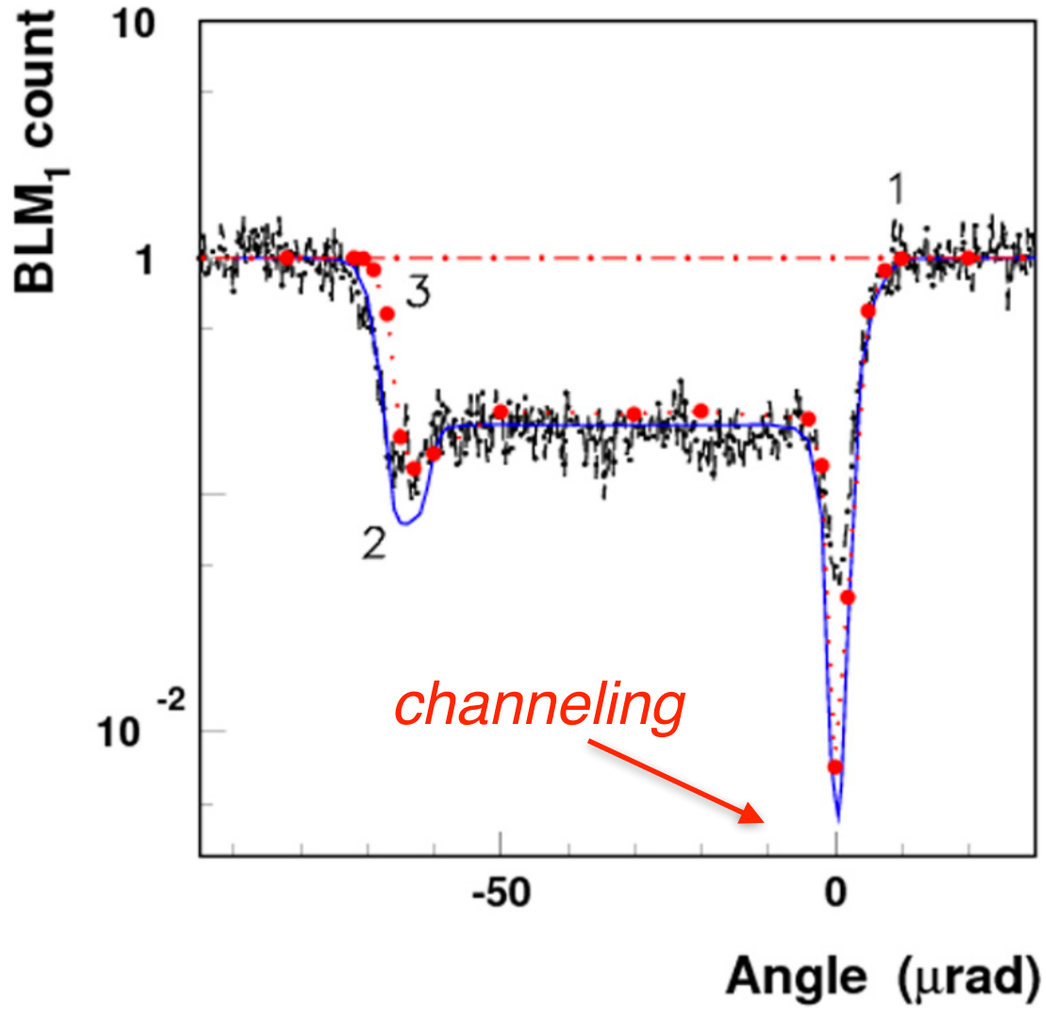
Phys.Lett. B758 (2016) 129-133

LHC crystal channeling

- Successful test with **6.5 TeV protons in** Nov 2015



Beam trajectory in LHC
~50 µrad deflection



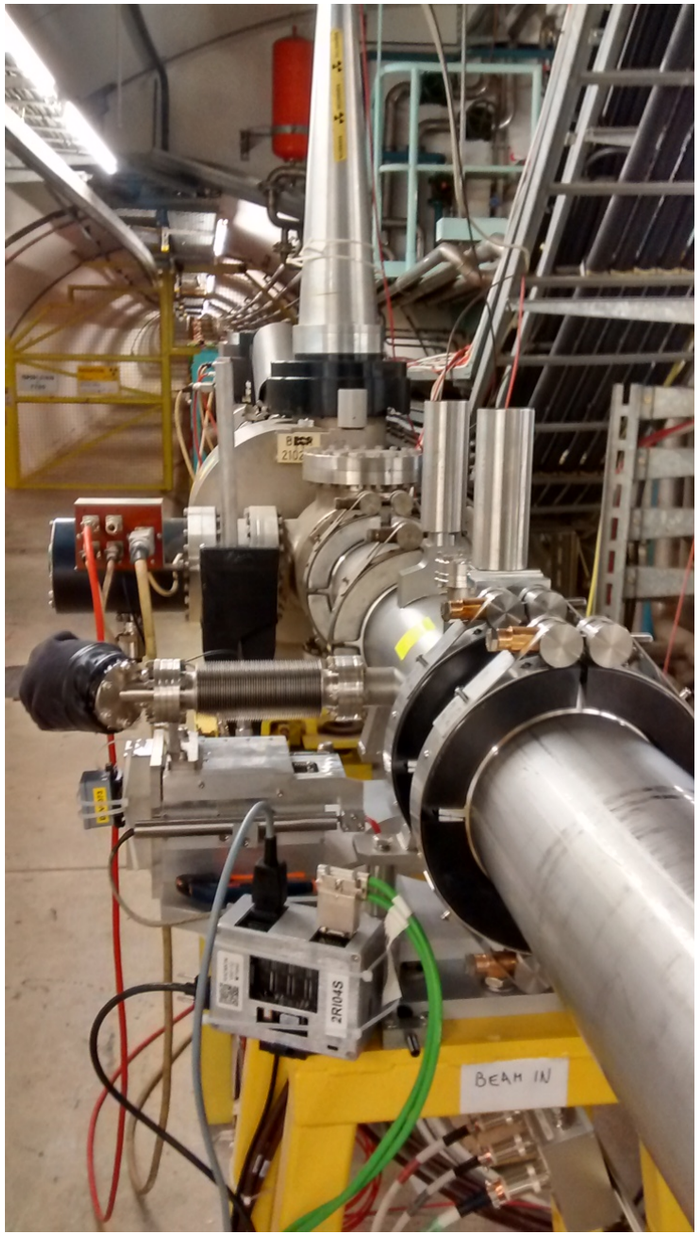
Piezo-goniometer (CERN/EN-STI)

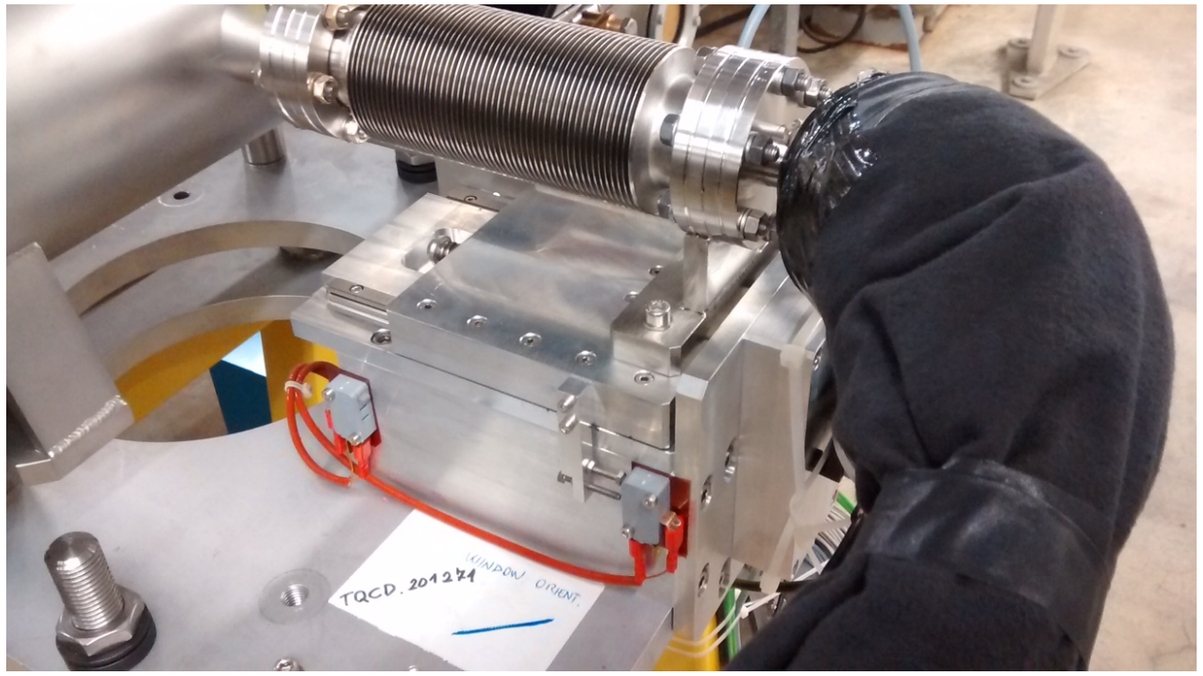
Strip crystal (INFN)

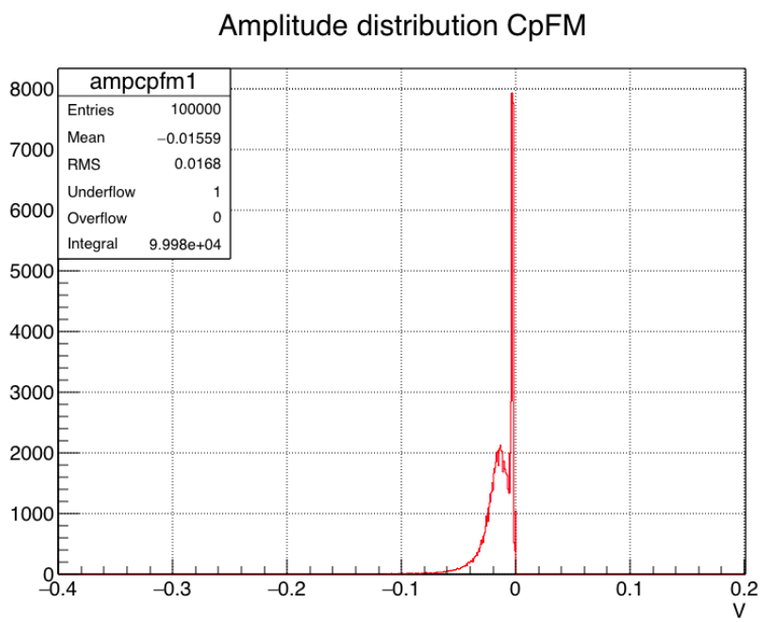
https://cds.cern.ch/journal/CERNBulletin/2015/49/News%20Articles/2105080?ln=en
http://home.infn.it/newsletter-eu/pdf/NEWSLETTER_INFN_17_italiano_pag3.pdf

In collaboration with **LHC Collimation** group

The Cherenkov screen



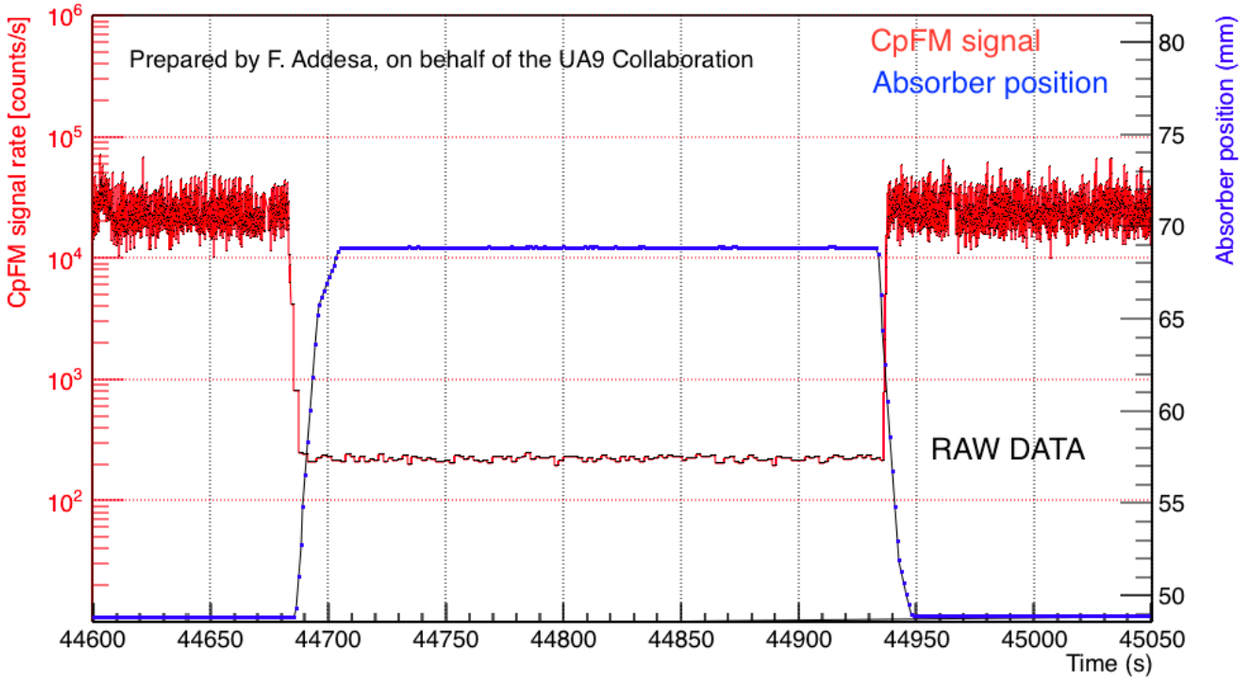


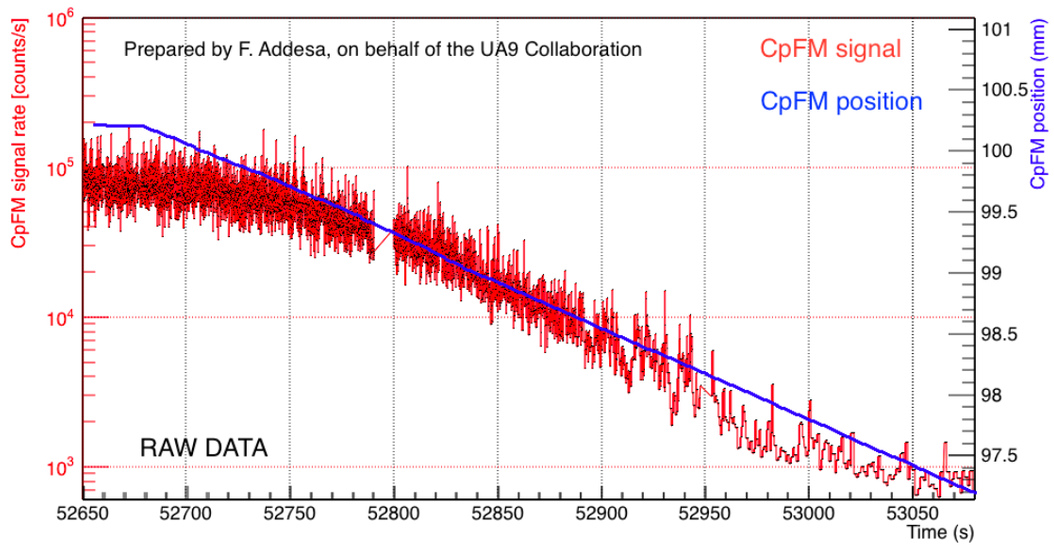


First test shows integrity of the hardware (Jun 2016)

Crystal kicked particles in TT20!

- Single bunch (43 KHz rev. frequency)
- Channeled beam stopped by absorber
- If absorbed removed, beam detected in TT20
  - with CpFM (INFN-LAL)

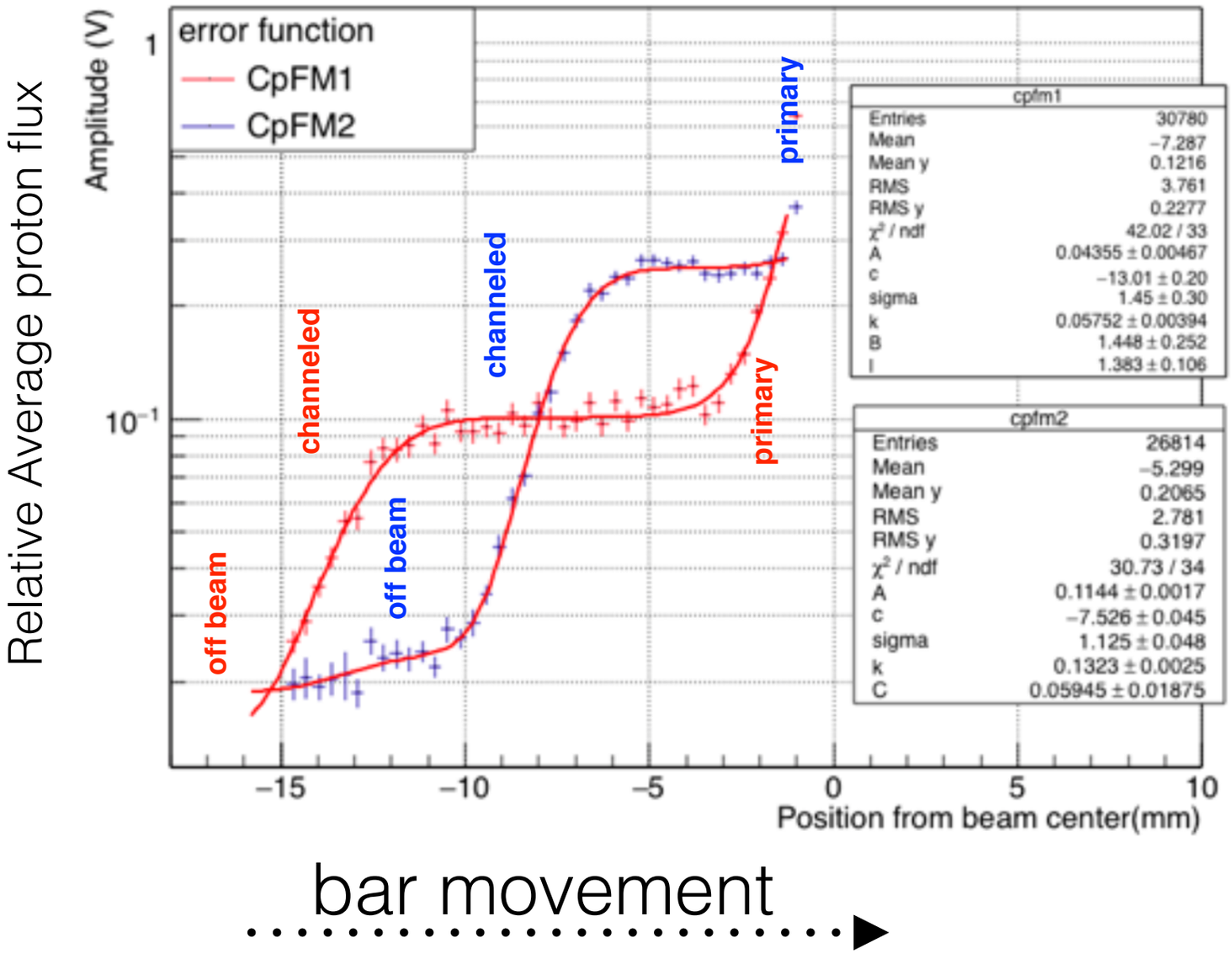


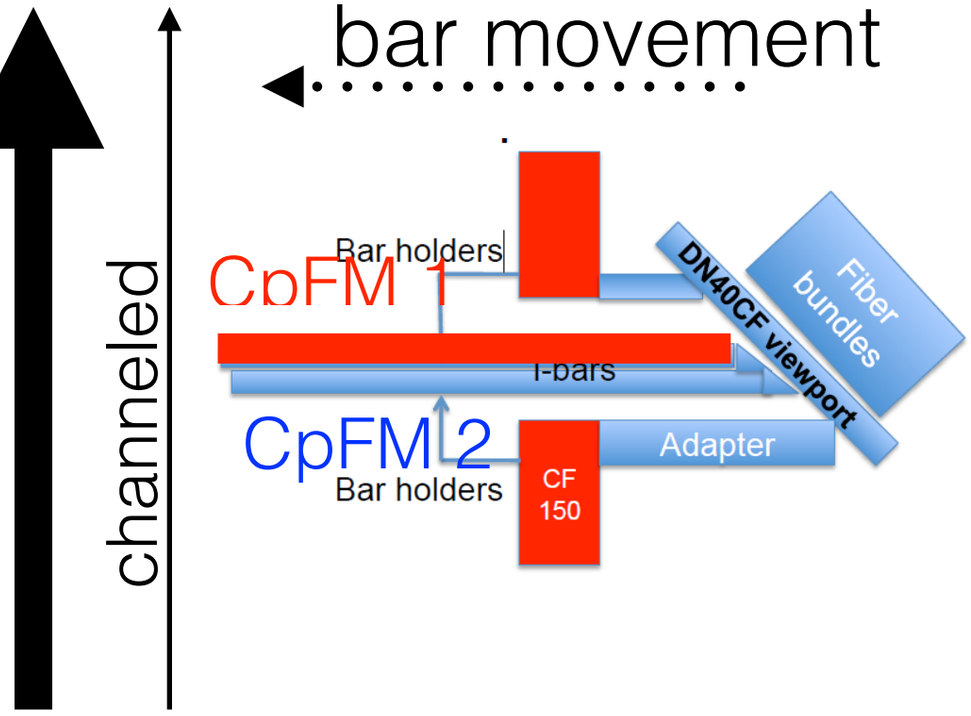


B.Goddard about **SPS beam dump** at PBC Workshop https://indico.cern.ch/event/608491/timetable/#20170301.detailed

Another Cherenkov screen

- Lateral scan of SPS beam (two staggered bars)

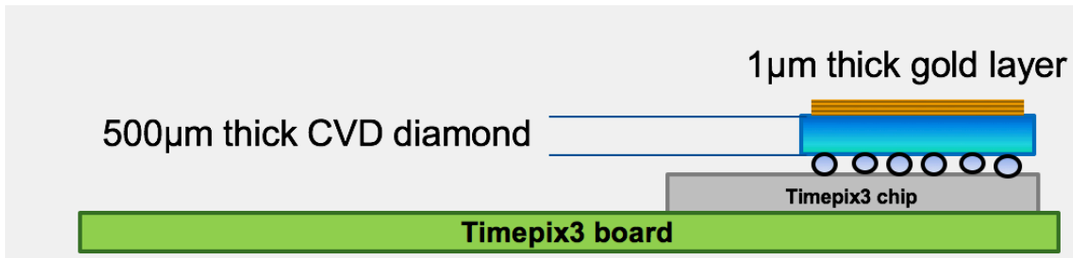


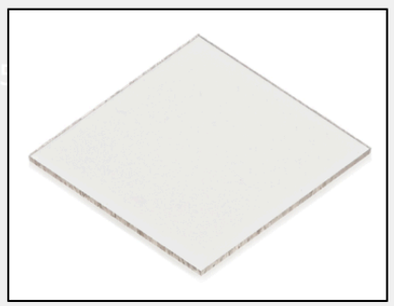


Very good agreement with expected beam position

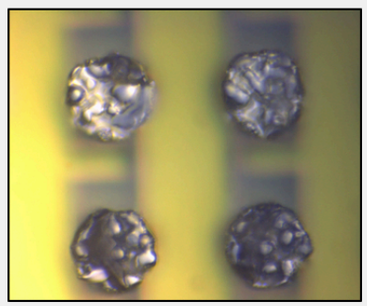
A pixelated diamond BLM

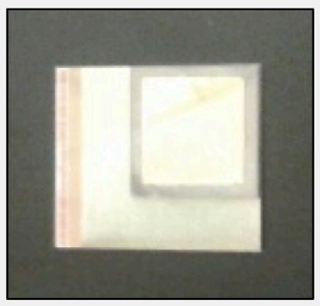
- Diamond coupled to a Timepix3 chip
- Can be used as beam loss monitor
  (high spatial resolution close to the crystal)



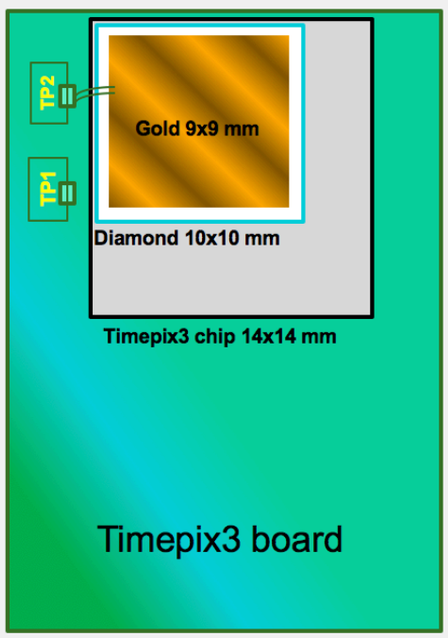


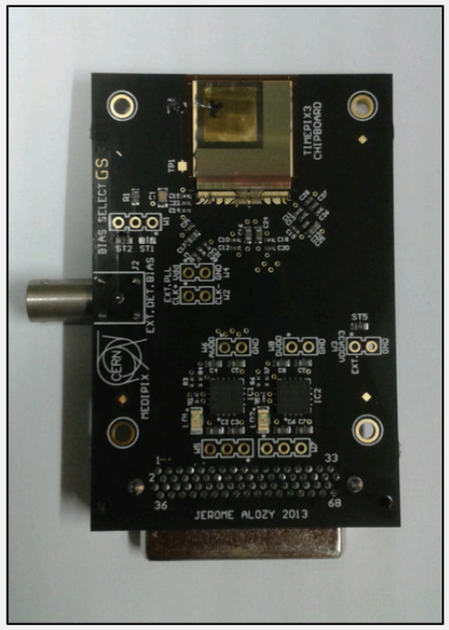
CVD polycrystalline DIAMOND (elementsix™, USA)





Diamond bump-bonding assembling (Fraunhofer IZM, Germany)

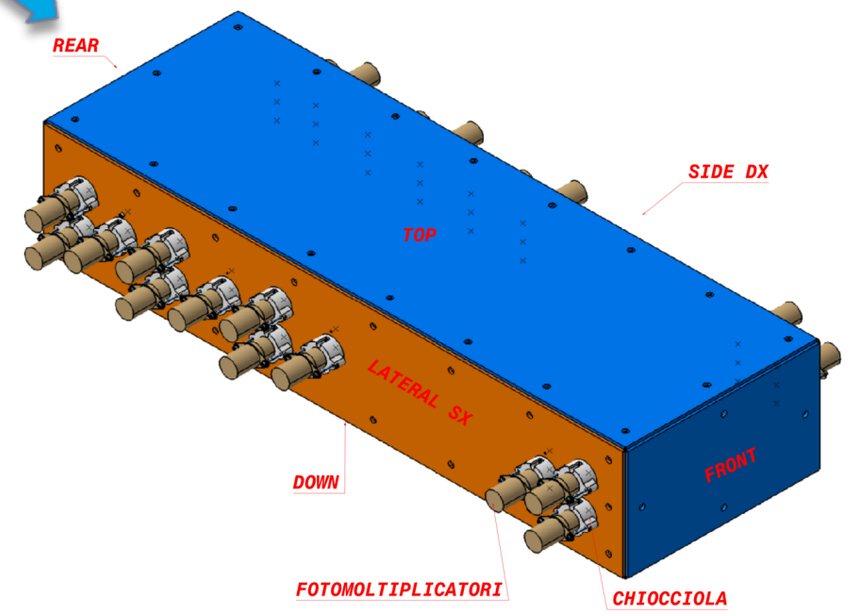


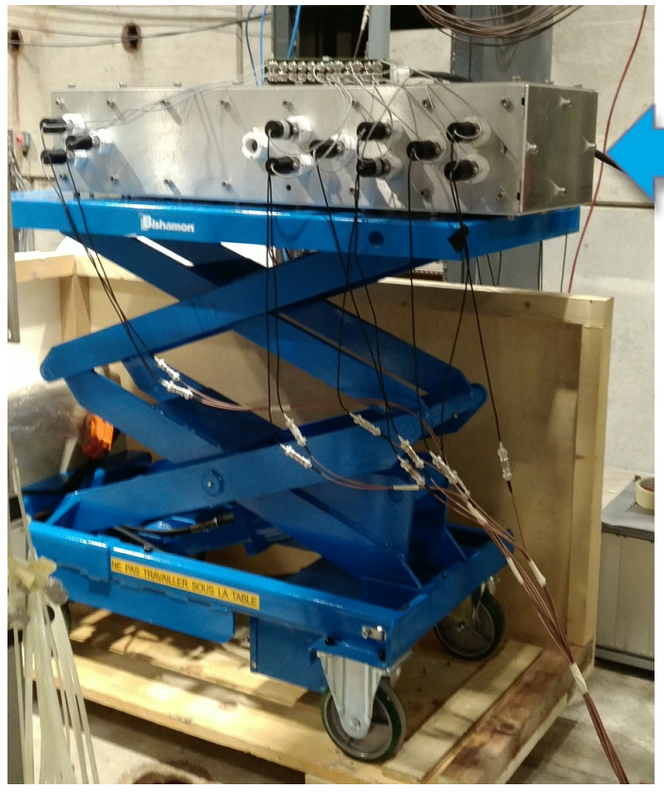


The smart absorber

The smart absorber has been designed and built with alternating layers of tungsten and fused silica Cherenkov radiators.

incoming beam direction





- Absorber dimensions 30 cm x 7,5 cm x 80 cm
- Cherenkov Radiators and tungsten layers

- Used during the LEMMA test-beam as a muon filter (against electrons)

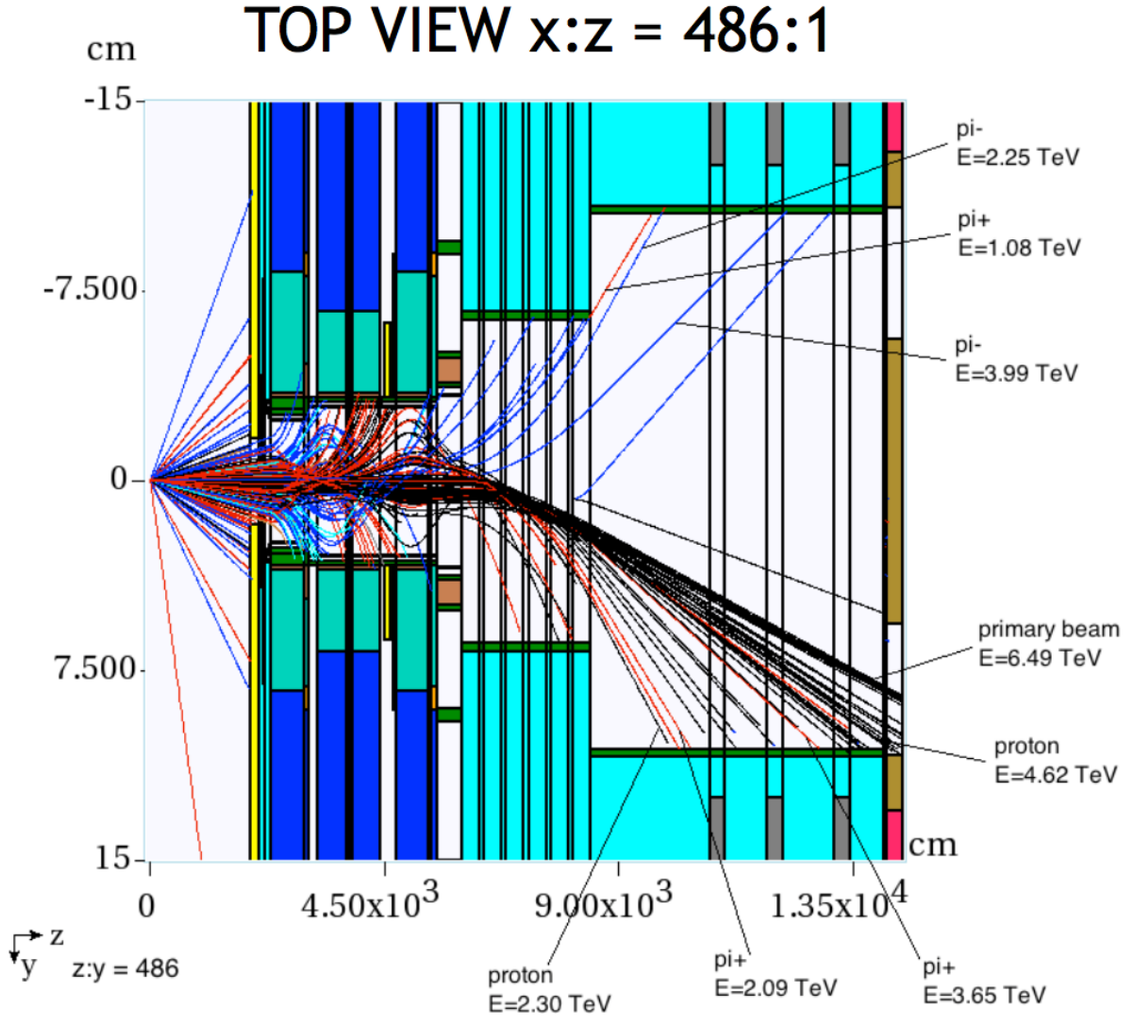
Conclusion and outlook

- **CRYSBEAM's** goal of building high quality crystal prototypes for the 7 TeV LHC extraction beam has been reached.
  - Some characterisation done at **H8** (pions)
  - Next round in July devoted entirely to CRYSBEAM crystals
  - Papers submitted and in preparation.
- A LHC extraction beam line is being considered within the Physics Beyond collider workshop (the **AFTER** proposal)
  - Study of the integration of a crystal in the LHC layout is critical
- **CRYSBEAM spurred the research of novel or revisited bending techniques coupled to the high quality of crystals manufacturing at INFN Ferrara.**

Forward physics and cosmic rays

- Secondary particle production from IP at very small angle: calibration of MC for cosmic rays.

$$\sqrt{s} = 13 \text{ TeV } (E_p = 10^{15} \text{ eV})$$



Small **A**ngle **S**pectrometer

https://indico.cern.ch/event/435373/

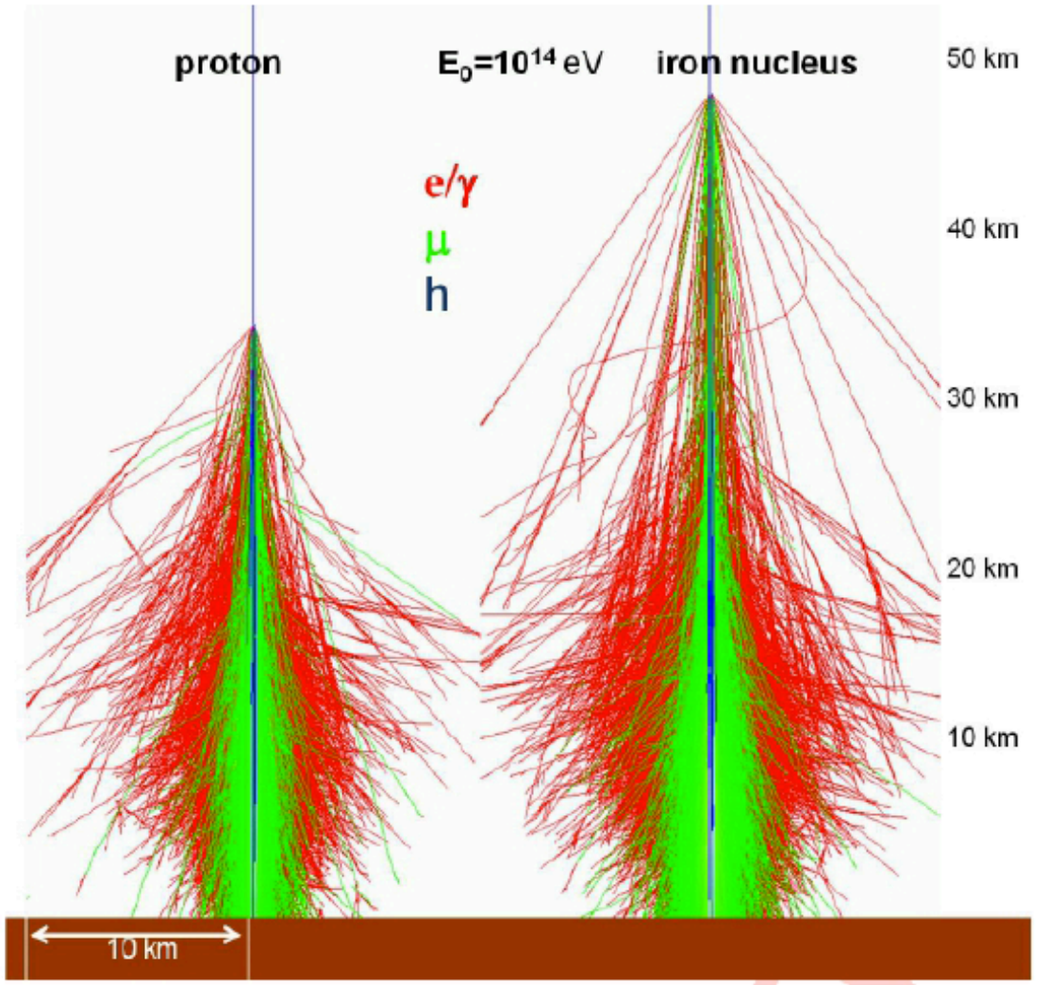
200 inelastic collisions at Point 5
(13 TeV, β* = 0.55 m)

LHC magnets close to IP deflect secondaries toward to the pipe

Modified pipe to extract secondaries

Install device in air to measure angle, energy and mass (TRD)

Ultra high energy Cosmic rays



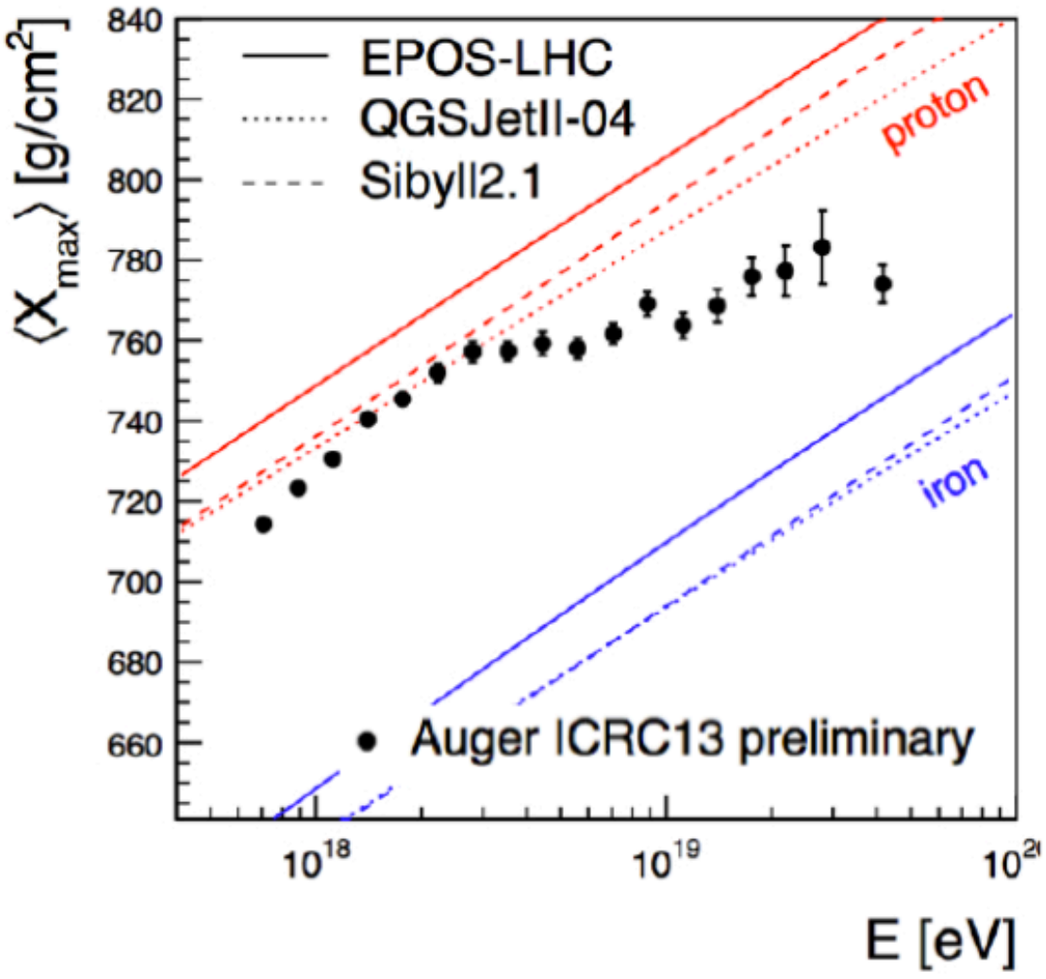
-When UHECR enters the Earth's atmosphere it produces a extensive cosmic ray showers.
It is possible by analyzing these showers to discover many of the traits of the original CR.

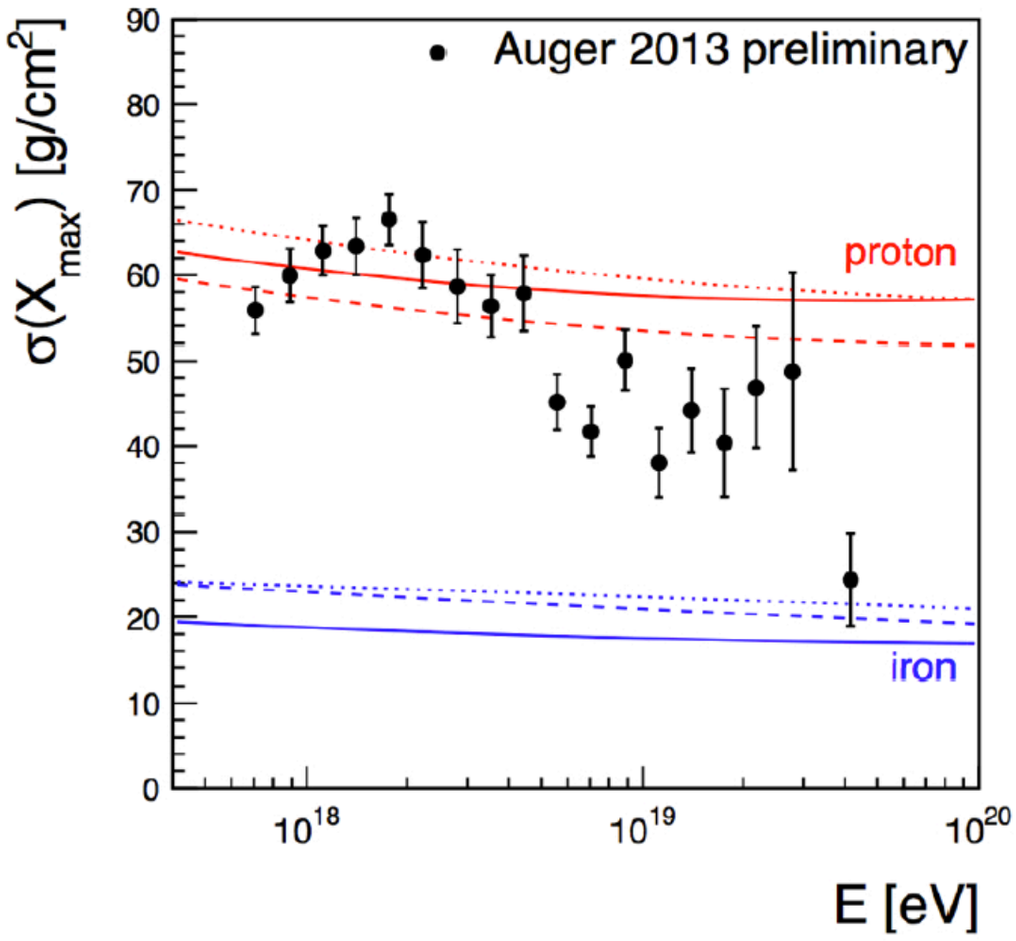
→Observations of Comsic Ray at ground level (i.e. Pierre Auger Observatory , HiRes..

Cosmic ray experiment observation depends on detailed **MonteCarlo code** to disentangle primary ray

Nature of cosmic rays

Pierre Auger Observatory





Data interpretation depends on MC used to described the shower

Cosmic rays in a lab

- Sub-showers of UHECR air-shower can be reproduced in lab: compare with MC (*CORSIKA*)
  - Following shower evolution as in air-shower experiment!