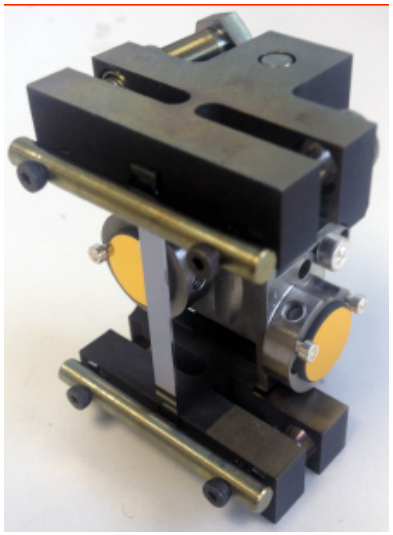


Sezioni d'urto di interesse astrofisico con i fasci estratti a LHC, prospettive sperimentali

Gianluca Cavoto (INFN Roma)

What Next Bologna 9th Nov 2015

Outline

- **Extracted LHC beam**
  - how feasible is **crystal** extraction for **fixed target** experiment (FT) ?
    - Goal of **CRYSBEAM:** efficient **crystal extraction** of a multi-TeV hadron beam for *fixed target experiments*

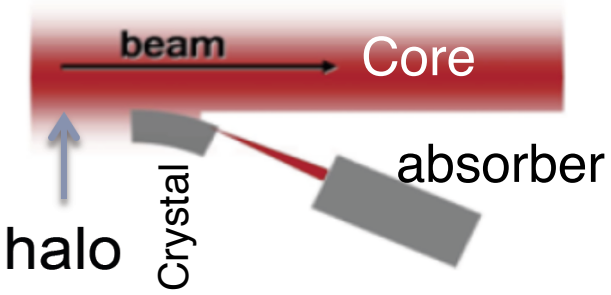
- ***Discuss some ideas:***
  - *Measure hadronic shower in FT p-N collisions (LHC beam dump)*
  - *Measure anti-p production in FT p-p and pHe (LHCb with **SMOG**)*
  - *Measure charged meson from pp LHC int.points (**SAS**)*

*(*) CRYSBEAM is funded with a **ERC Consolidator Grant GA 615089** (FP7 IDEAS action) with a **2M euro** budget for the period May **2014**- May **2019.***
***INFN** is the Host Institution*

Beam manipulations with crystals

CRYSBEAM basic idea

***PARASITIC** EXTRACTION of BEAM HALO with*
a bent crystal** in **channeling orientation
Low background, continuous extraction of the beam halo
10^8 particle per second might be possible

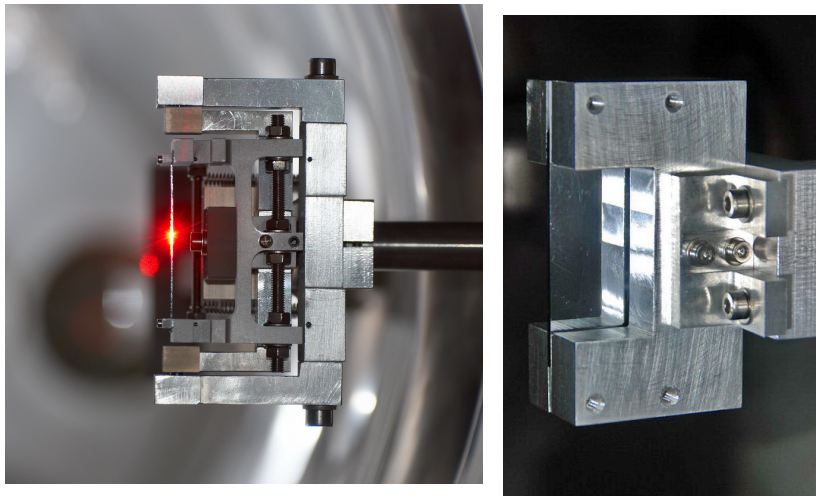


Critical angle for channeling

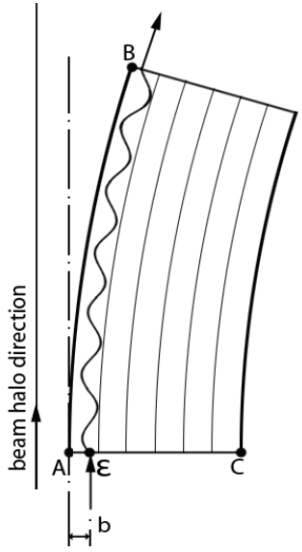
$$\theta_C = \sqrt{\frac{2U_0}{E}}$$

Potential well depth ***~Z***
[*22.7* eV for (110) Si]

Particle energy

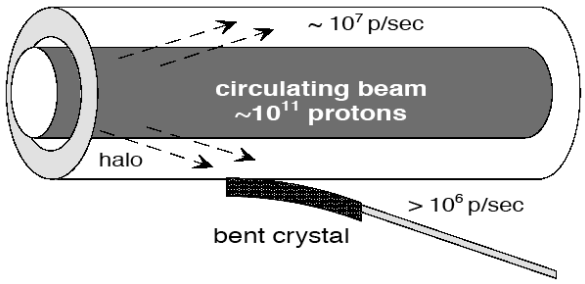


UA9 crystals

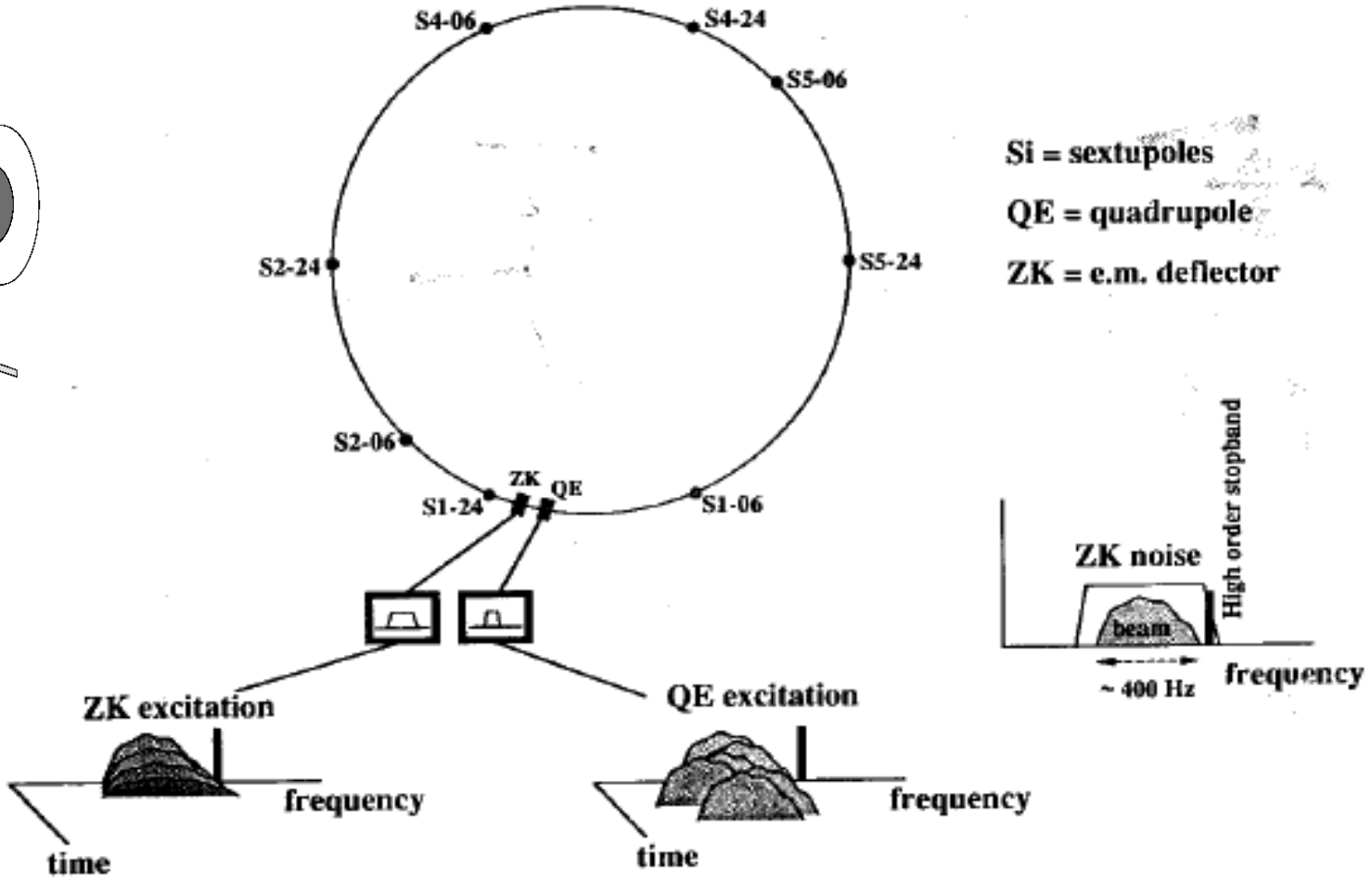


Bent crystal

Conceptual non-resonant extraction



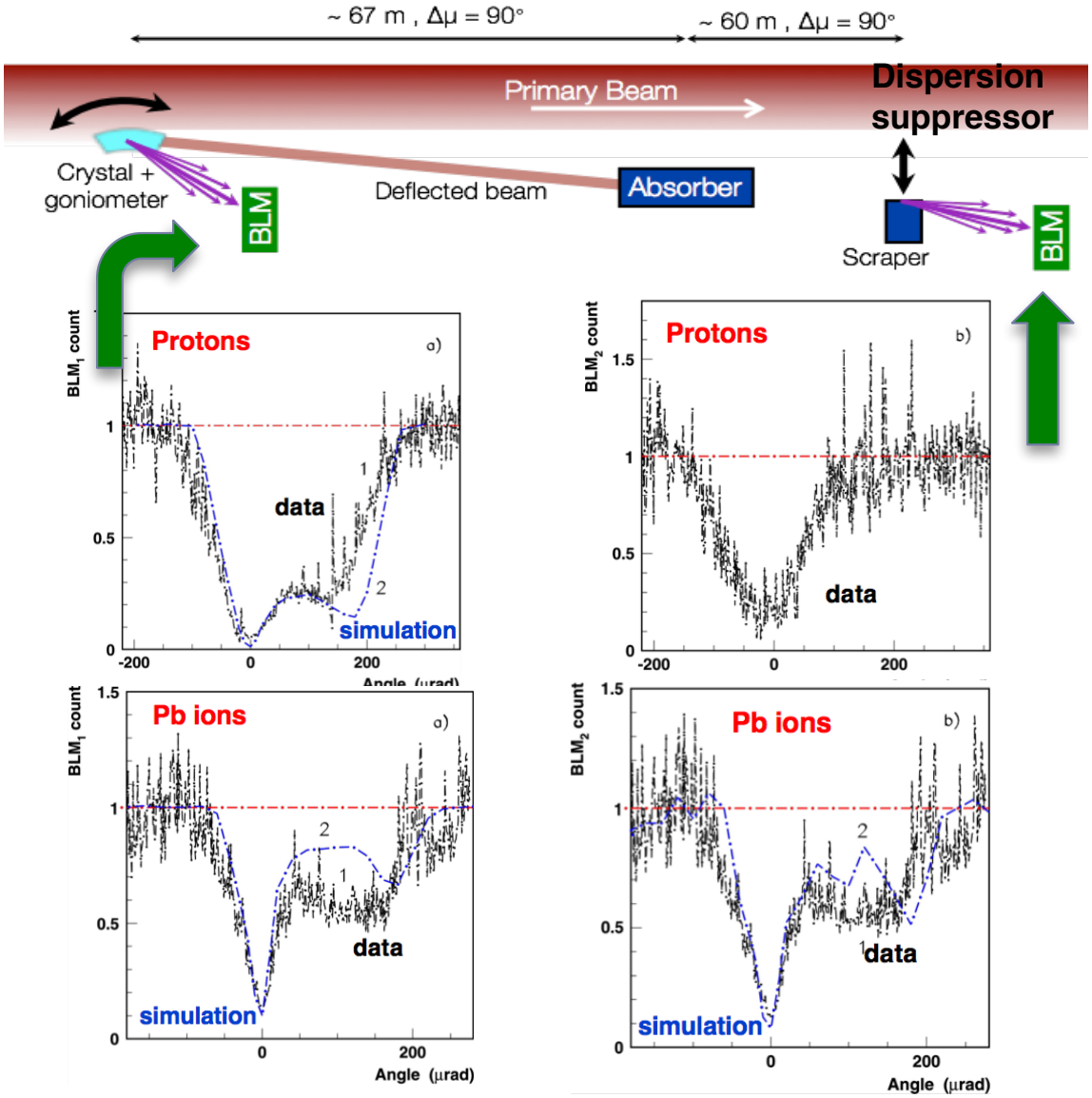
- Induce random deflection with e.m. device
- Increase trasverse diffusion speed and halo population
- **Extract** with a **crystal**



A solution for a reduced aperture machine (LHC)

~1000 μrad deflection crystals needed

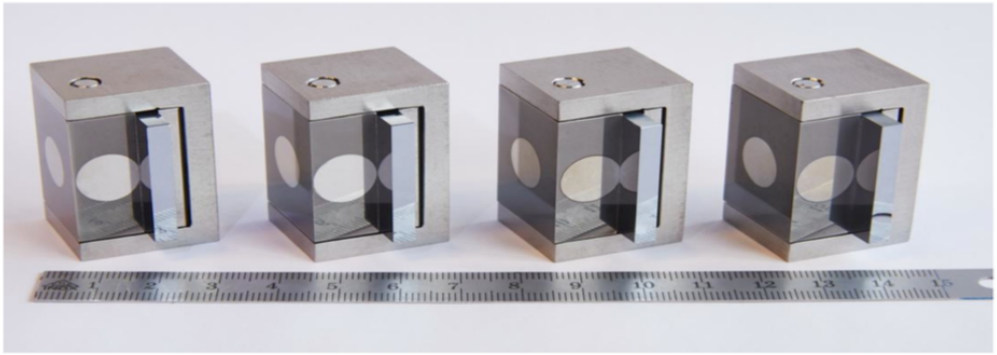
Silicon crystal collimation at SPS



- Extensive tests with 120-270 GeV protons and Pb ions
  - **150 μrad deflection**
  - θ_c ~ **20-13 μrad**
  - Single bunch and multi-bunch dedicated beams
- Fast and reproducible crystal alignment
- Clear loss ***reduction with respect to an amorphous orientation***
  - ***Up to x20 reduction***

LHC type Si crystals

10 QM Crystals (PNPI-Gatchina)



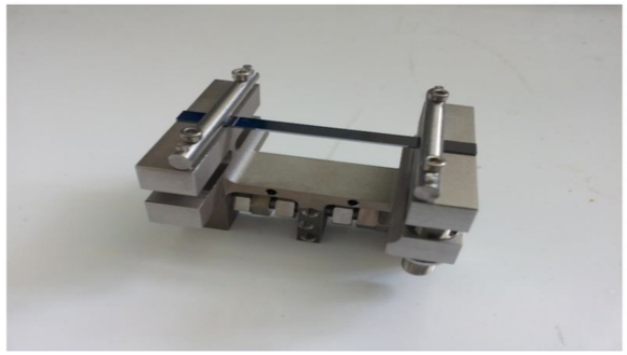
50 µrad deflection

Crystal	run	Beam divergence ±5 urad		
		Deflection angle	Efficiency	Angular cuts
		urad	%	urad
QMP46	2737	**51.3**	69.8	(-6 ..+4)
QMP46	2791	**51.4**	67.4	(-9..+1)
QMP46	2798	**52.1**	70.5	(-12..-2)
QMP46-bo	3078	**50.2**	71.2	(-14 ..-4)
QMP52	2655	**54.0**	67.5	(-12..-2)
QMP52-bo	3063	**53.5**	69.4	(-9 ..+1)
QMP53	2664	**54.9**	71.1	(-1 ..+9)
QMP53-bo	3043	**54.5**	71.4	(-6 ..+4)
QMP54	2805	**58.2**	69.8	(-10..+0)
QMP54-bo	3101	**54.8**	69.5	(-5 ..+5)

2 STF Crystals (INFN-Fe)

Tests with a new titanium holder shows encouraging results about the Crystal deformations problems

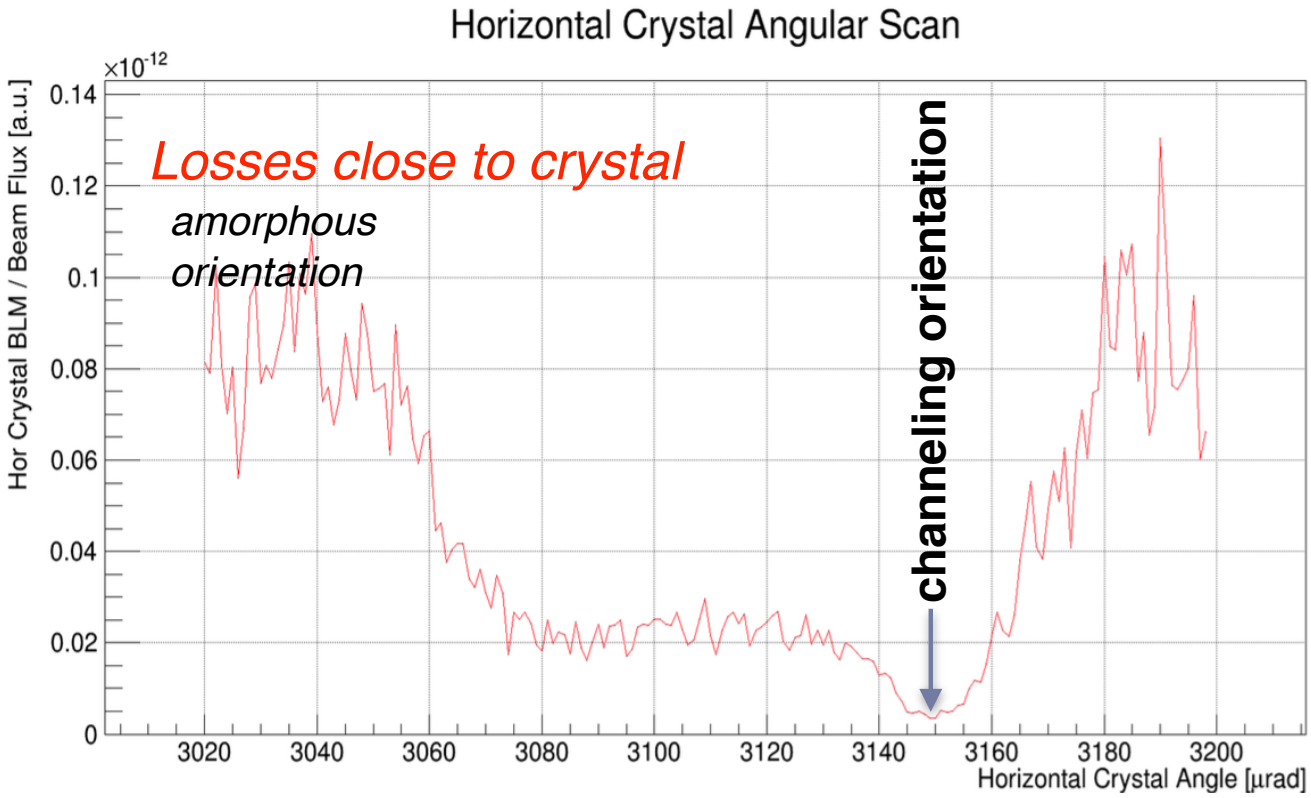
	Bending angle [µrad]		Channeling efficiency		Torsion	
	±2.5 µrad	±5 µrad	±2.5 µrad	±5 µrad	p0 (offset)	p1 (torsion)
STF105	49.64	49.48	0.778	0.739	-0.6161± 0.4271	1.457± 0.5125
STF106	40.95	40.64	0.773	0.739	-0.03649± 0.3675	0.279± 0.4523



Thoroughly tested at CERN H8 beam line with proton, pion and Ar ion beam

First LHC collimation test

- Aug 30th, only 2h to find channeling orientation!



Angular scan for horizontal crystal performed with the LHC primary collimators (TCPs) out of 1 mm, and all the TCSGs upstream the crystal out.

The losses reduction factor (between CH and amorphous orientation) can be estimated around 20

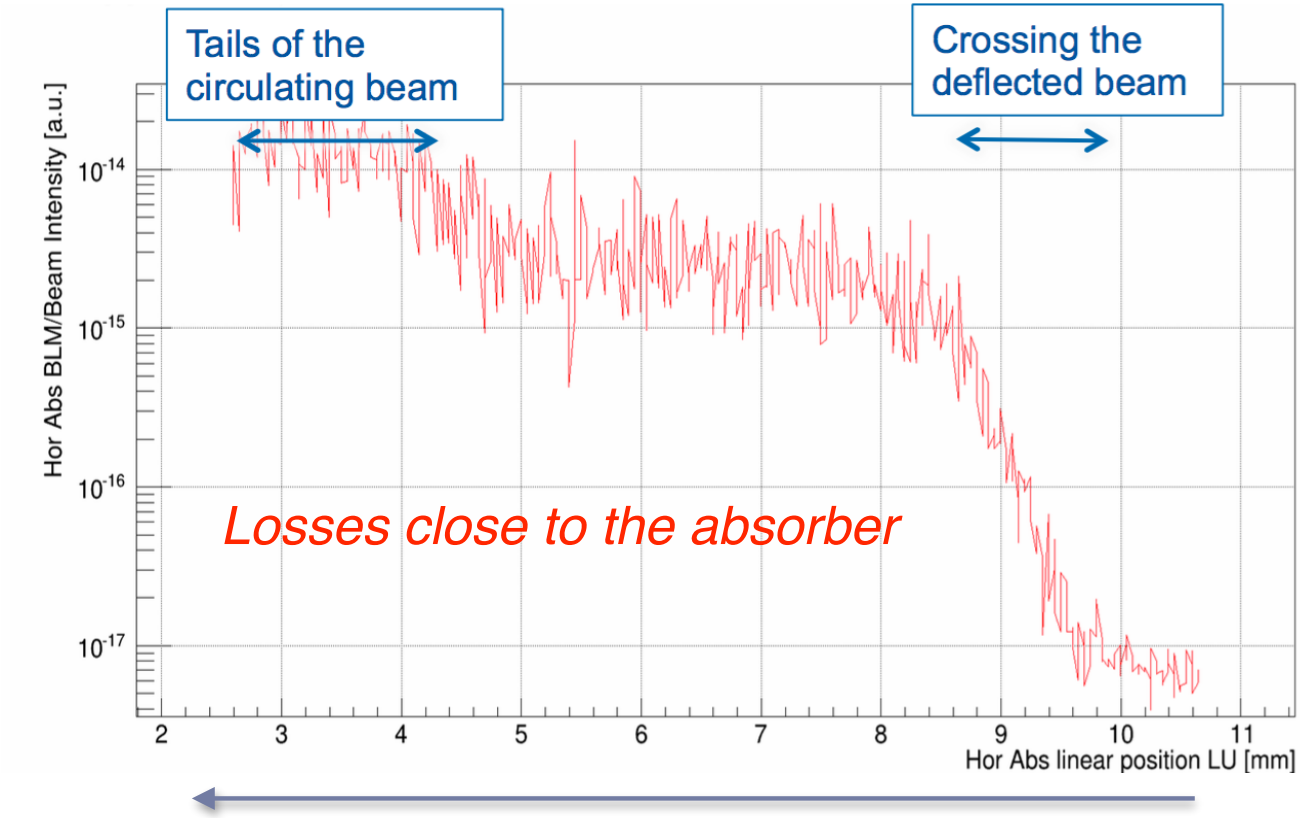
Beam energy: 450 GeV

Both crystals successfully tested

Latest news: last Nov 6th our crystal was successfully tested at 6.5 TeV!!!

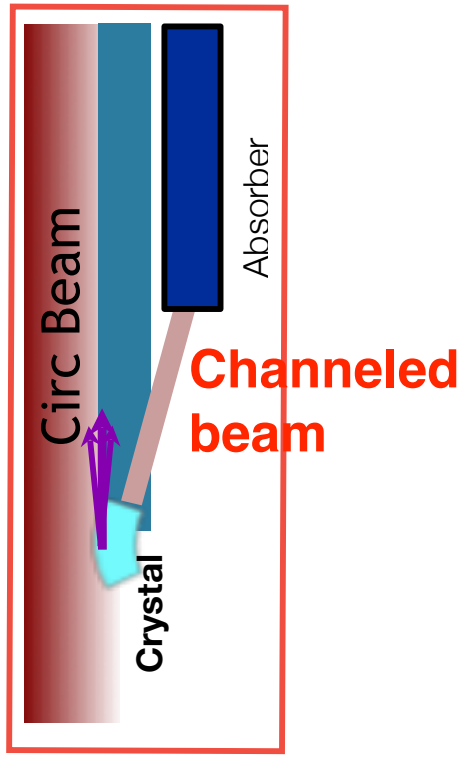
Finding the channeled beam

Horizontal absorber scan with the same reduced collimator layout and crystal fixed in CH.



Moving absorber
towards to the circulating beam

Moving absorber
up to the circulating beam



Challenges for an LHC crystal extracted beam:
large bending angle (~**1000 µrad**)
small critical angle (**2.4 µrad)**

Critical Radius for channeling

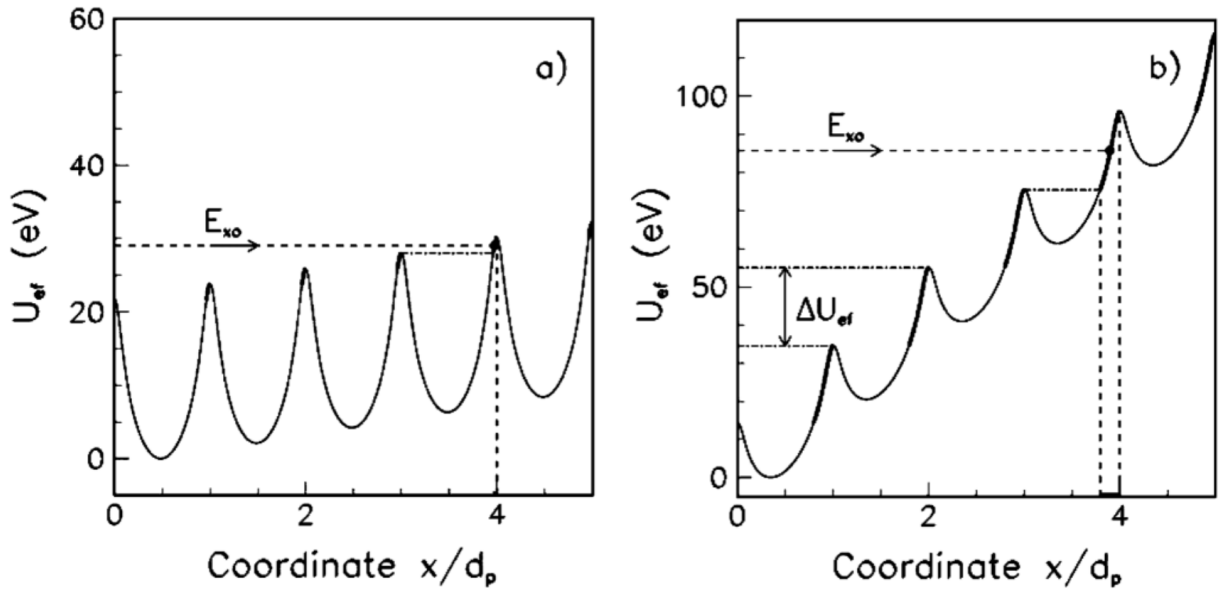
- Given a deflection angle Φ

  $\Phi = L/R$

  where R is **crystal curvature radius** and

  L is the crystal **length**

Effective potential in presence of centrifugal force (bending)

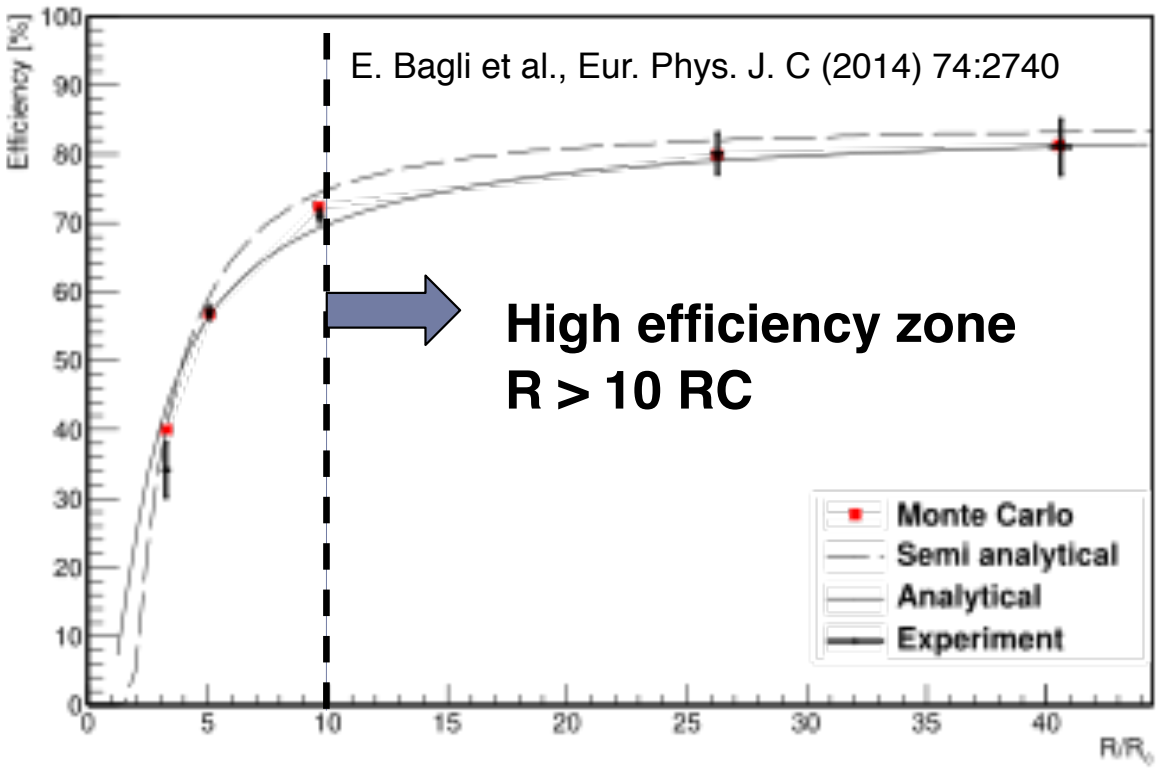


$\Delta U_{el} = (pv/R)d$

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 Rc



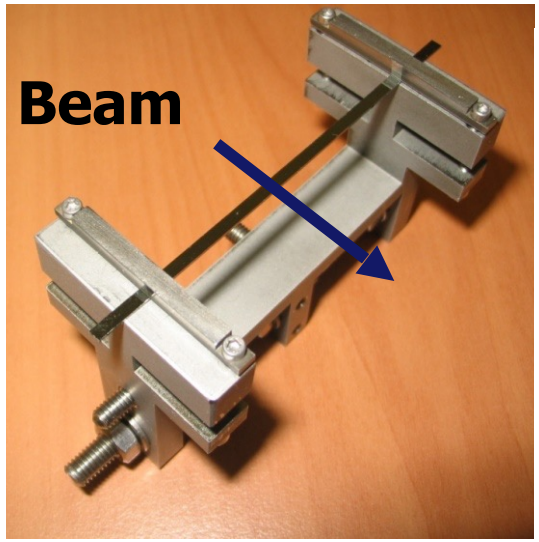
- Experiment (H8 and SPS):
  - Si bent crystal (**L = 0.2cm**)
  - (110) plane
  - 400 GeV/c protons

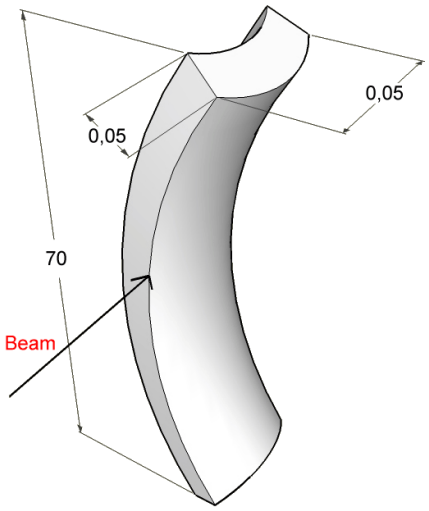
Si (110):
R_c = 12m at $p\beta$ = 7 TeV
Ge (110):
R_c = 7m at $p\beta$ = 7 TeV

- Fully efficient ~1 mrad deflection requires **~12cm long Si crystal** (or 7 cm long Ge crystal)
- Much longer than what UA9 tested and used so far

How to impart a large curvature

Usual mechanical bending

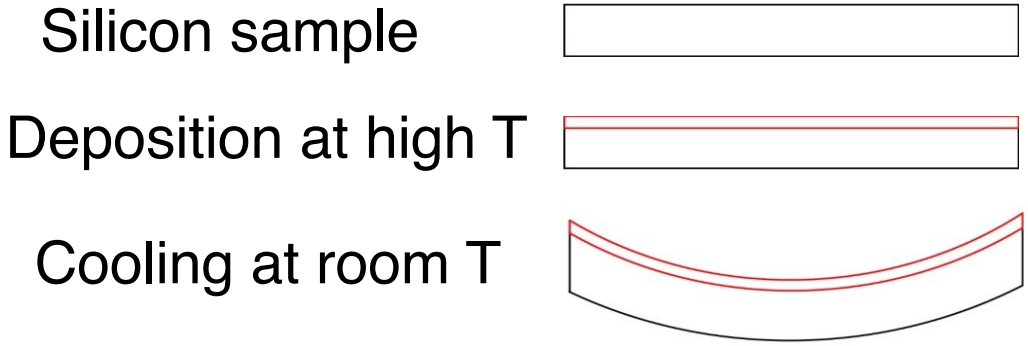




- A primary curvature is imparted by mechanical external forces, which result in a secondary (anticlastic) curvature

JAP 107(2010) 113534

Assistance from a tensile layer



NIM B **234** (2005) 40

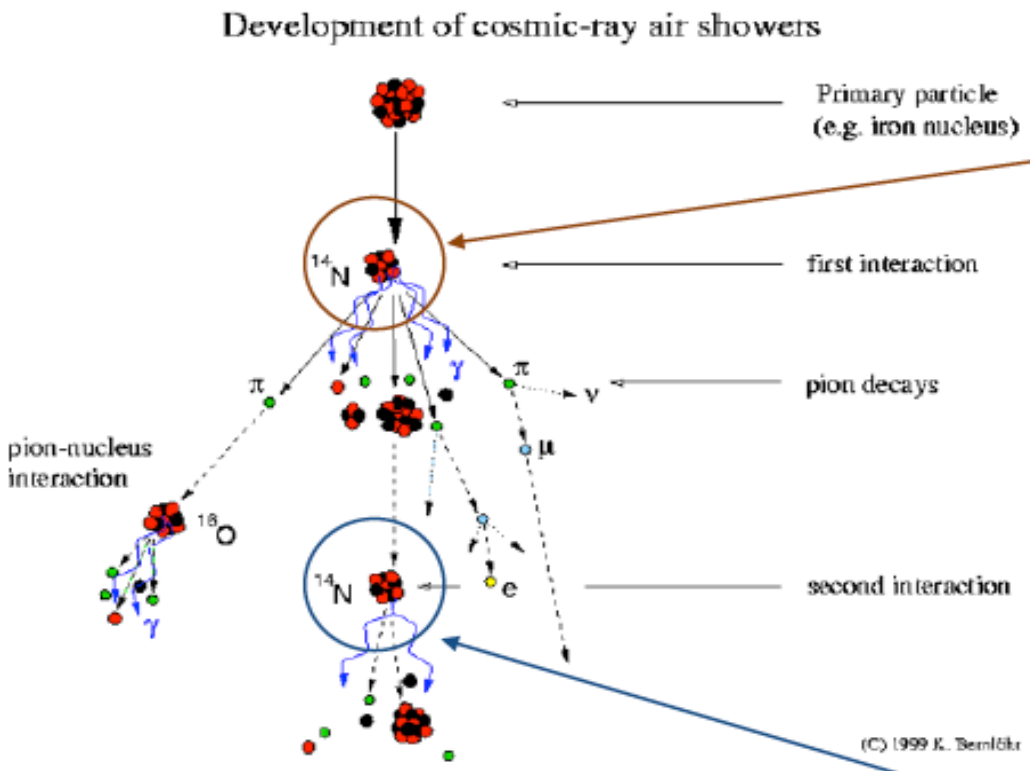
INFN (Ferrara labs) actively working on a long crystal for a 1000 µrad bending

Possible Measurements with a LHC ext. beam

Hadronic interaction in air showers

Ultra High Energy Cosmic Rays

G.Mitsuka (LHCf coll)



Largest systematic uncertainty of indirect measurement is in first interaction.

E~TeV

1. Inelastic cross section
   large → rapid development
   small → deep penetrating
2. Inelasticity $k = 1 - p_{lead}/p_{beam}$
   large → rapid development
   small → deep penetrating
3. Forward energy spectrum
   softer → rapid development
   harder → deep penetrating
4. Nuclear effects
5. Extrapolation to high energy
   precise measurements at available energies are crucial

E~GeV

1. Charge ratio
2. Multiplicity
   number of muons in air shower sensitive to mass composition

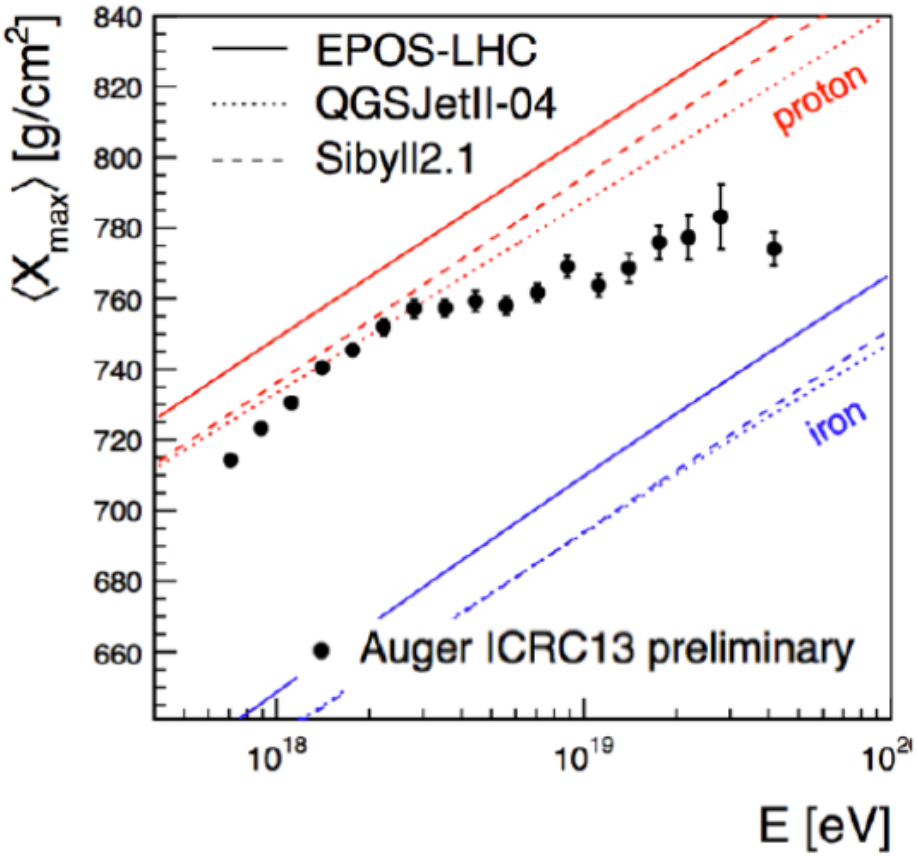
- Accelerator based experiments to unravel this (**LHC-f**, **NA61** at CERN,…)

CR Mass composition

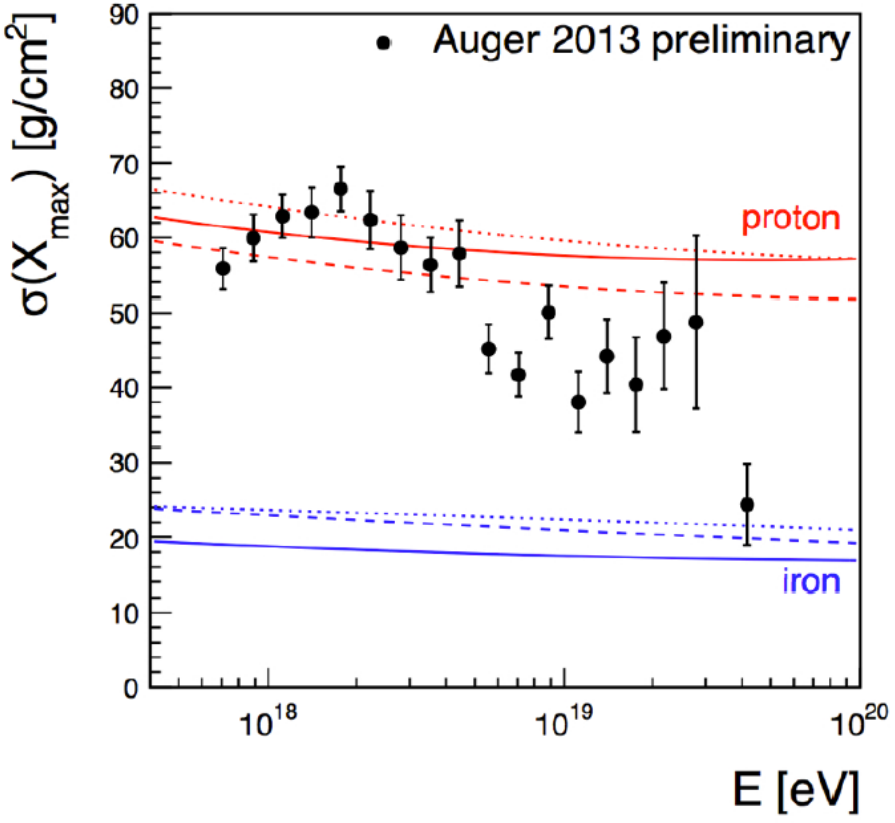
UHECR

Pierre Auger Observatory

Shower maximum position



Cross section

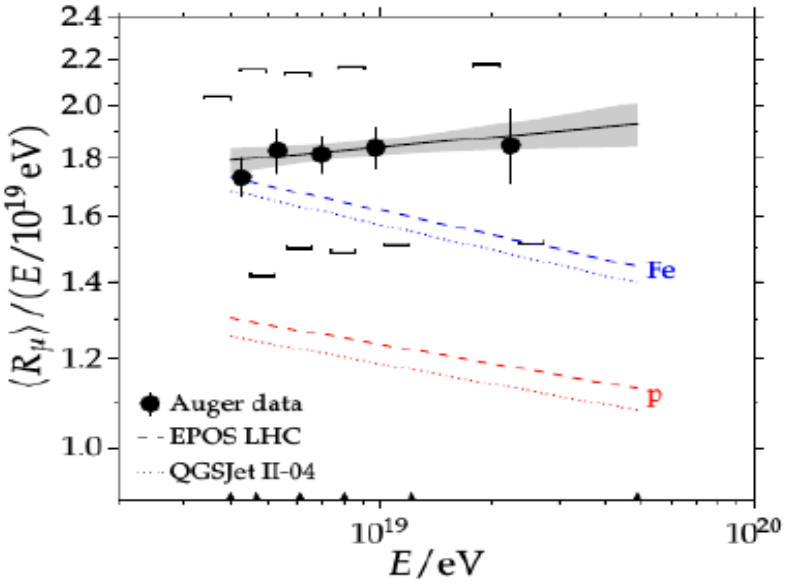


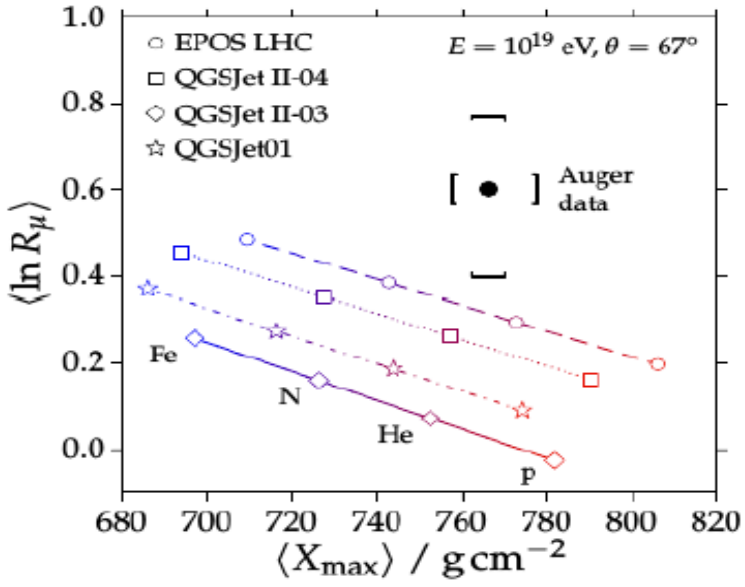
Data interpretation depends on MC used to described the shower

Is it useful to reproduce in lab such showers at (much) lower energy

Muon in cosmic air-showers

UHECR





More muons in air-shower data than expected Auger, arXiv-1408.1421 [atro-ph]

- Can be a problem in interaction physics in air-shower model ?
- A muon counting experiment after a beam dump can be interesting to help unravel this.
- It might be relevant for **high energy neutrinos too.**

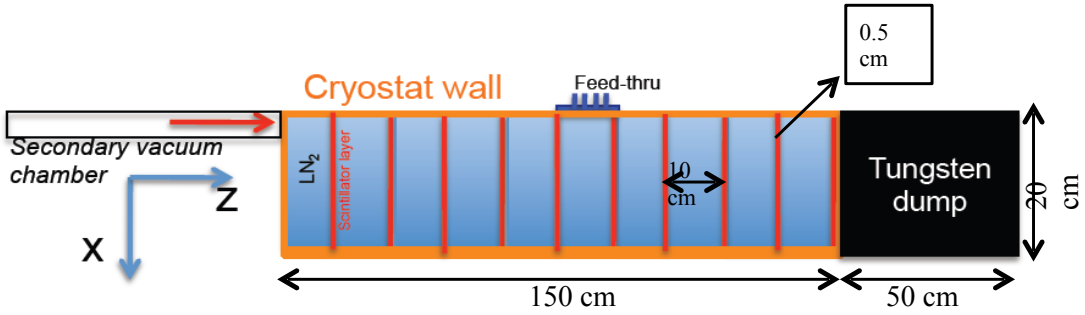
- Do we need to study **charm** content of a shower ?

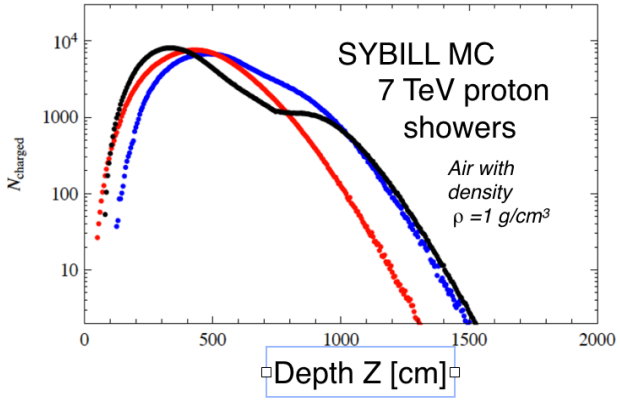
Access to parton with momentum fraction x→1 in the target ("intrinsic charm")

- Study production of charm from light nuclei directly.

A smart absorber experiment

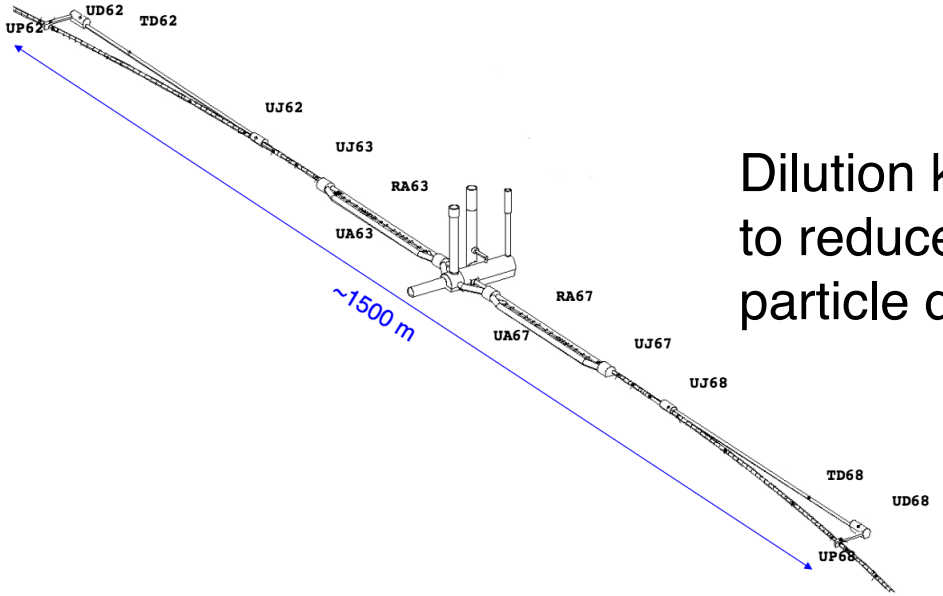
- Dump the extracted beam onto a light element absorber.
  - Possibly change the absorber material
  - Count the number of particles crossing thin active layers
    Measure shower max, RMS(max), etc.



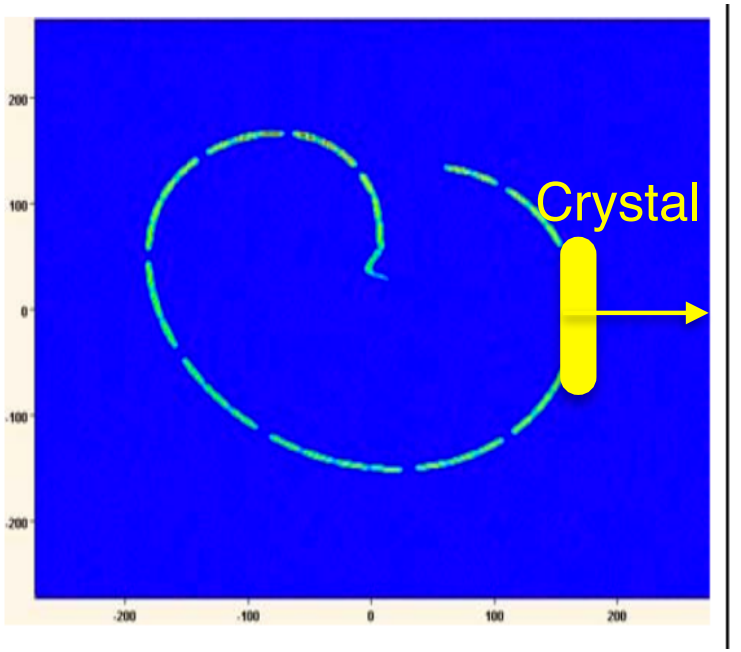


A possible location might be the **LHC beam dump tunnel.**
Deflect with a crystal a small portion of the full LHC beam onto the absorber.
Compare measurements with **standard MC code** for CR shower or hadronic shower code (FLUKA).
Another possibility: **count muons after the carbon target in beam dump itself.**

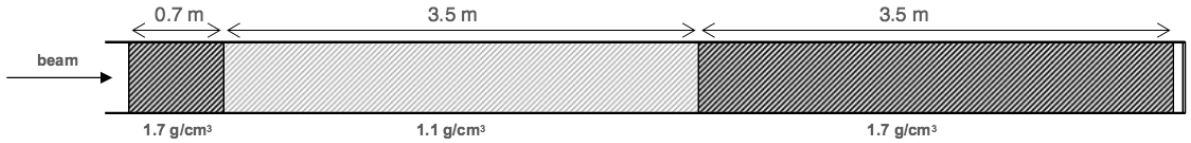
LHC beam dump system



Dilution kicker to reduce particle density



Beam dump block (graded density graphite)



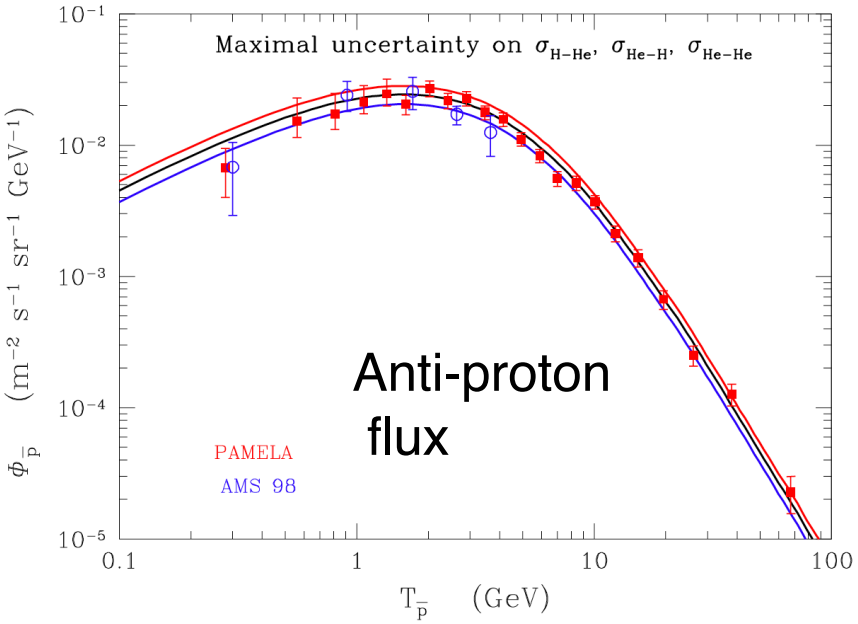
Muons after the block?

Simulations studies going on

Propagation of Cosmic Rays in Galaxy

- Evidence of anti-matter excess in **galactic cosmic** rays (PAMELA, AMS-02, etc.)
  - Is this a sign of ***Dark Matter annihilating*** in our Galaxy?

F. Donato et al. ApJ 2001, PRL 2009

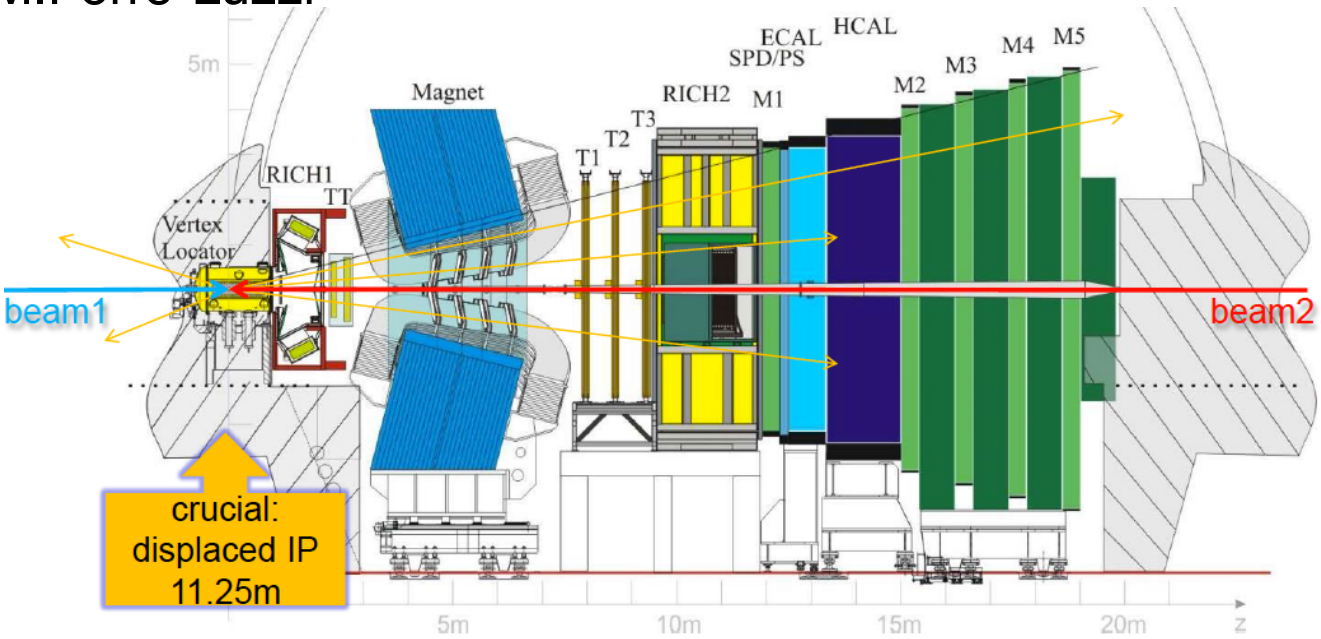


- It might only be due to cosmic rays interaction in interstellar medium
  - ***Improve propagation models*** with more precise cross section measurement
    - (B/C spallation, anti-proton production from He target,…)
- **Measure p-p and p-He cross sections in the Ep ~1 GeV – few TeV range**

$$T_{anti\text{-}p} \sim 0.1\, E_p$$

Internal gas target at LHC-b (SMOG)

M.Ferro-Luzzi



Beam-gas interaction used for luminosity meas. (**SMOG**)

They injected ~10^{-7} mbar Ne in LHC beam pipe (!!!)

Other gases are possible

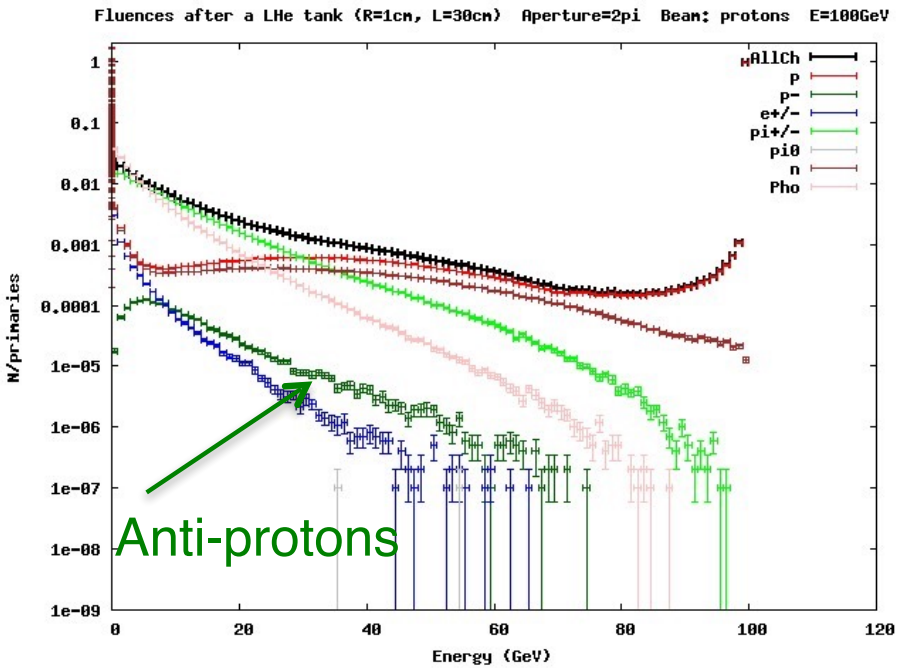
LHC-b is a naturally forward detector

Given its very good tracking and PID capability could easily measure particle spectra! (but limited rapidity coverage)

If problem with He in beam pipe a crystal can be used to split the beam!

https://indico.cern.ch/event/325836/session/0/contribution/3/material/slides/1.pdf

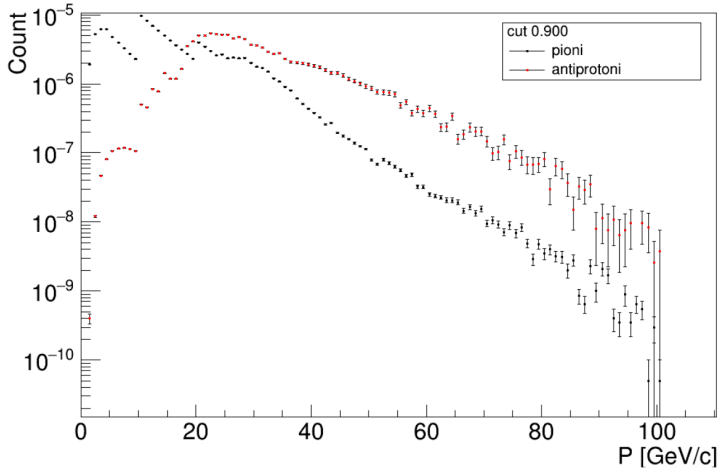
Antiproton production from He (FLUKA)



A crystal can redirect the halo beam on He liquid target.

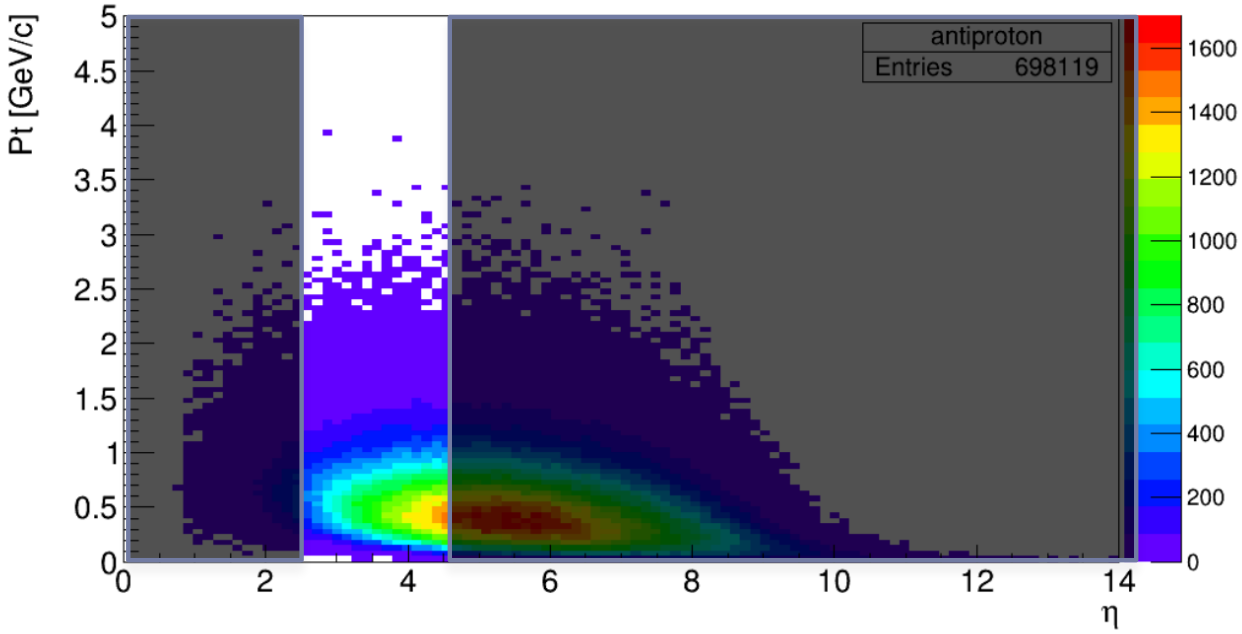
Parasitic measurement, possibility to **change** the target

LHCb PID efficiency for anti-proton (and pion contamination)



Limited acceptance

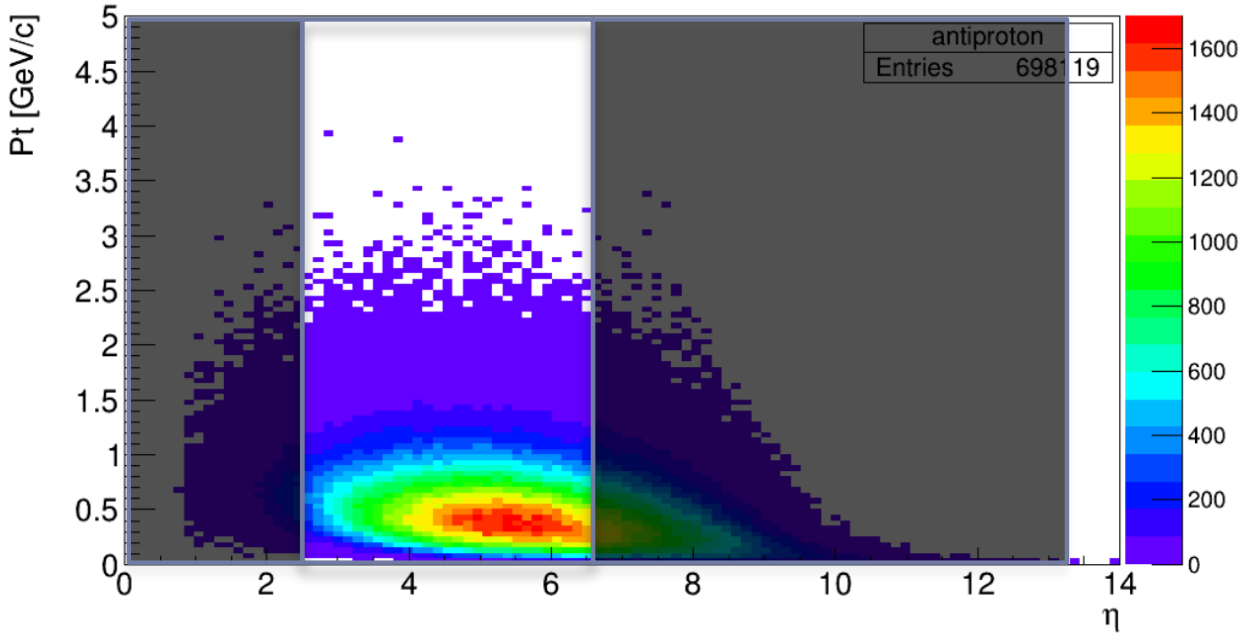
- If target is located at IP8 (LHCb int. point), reduced acceptance



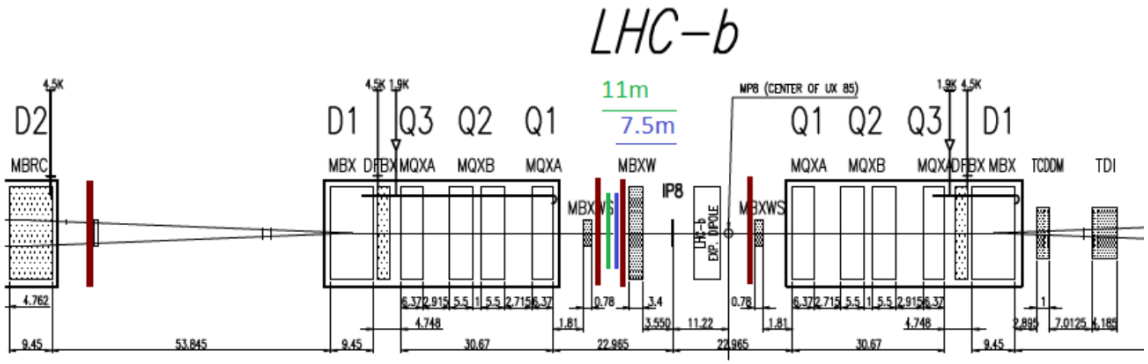
anti-proton from p-He collisions

First test with He in SMOG already going on

Extended acceptance



- A second target 7.5 m upstream can widen the coverage



A bent crystal can help to redirect the beam within LHC-b acceptance

Small Angle Spectrometer

- Key idea: detect secondary high energy forward charged particle from p-p collision at $\sqrt{s}$ =13 TeV (E_p =10^{15} eV)

LHC-f detected photons, neutrons and neutral pions

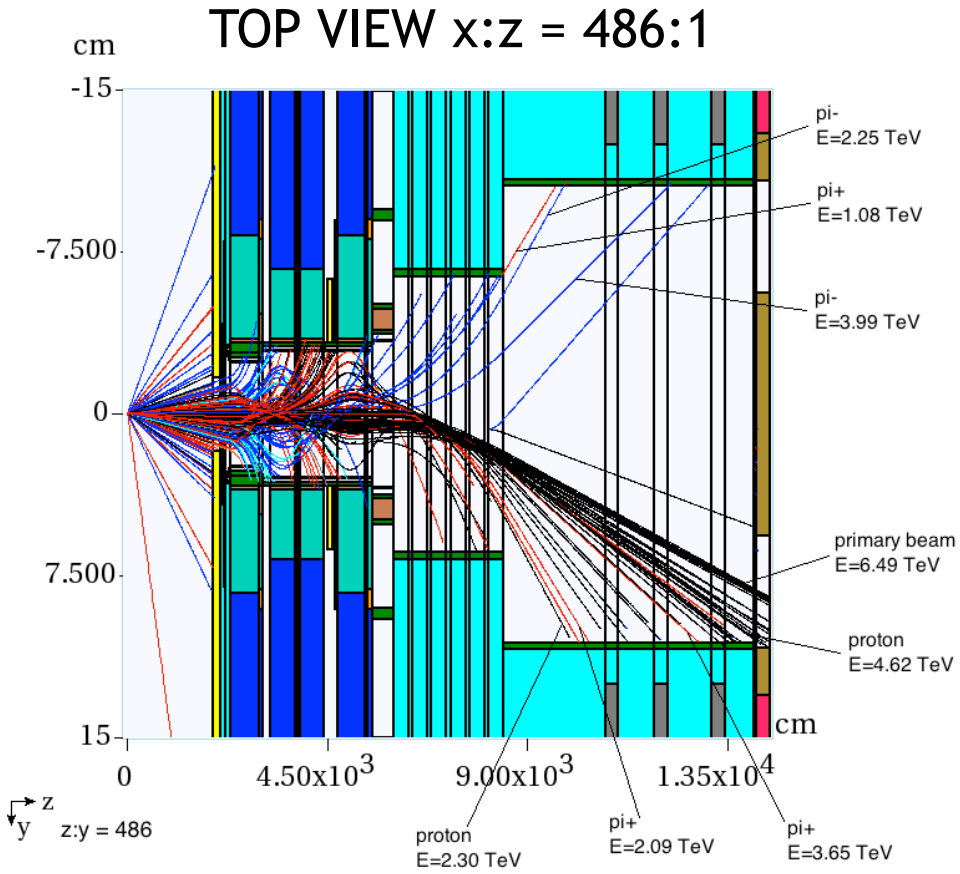
200 inelastic collisions at Point 5
(13 TeV, β* = 0.55 m)

LHC magnets close to IP deflect secondaries toward to the pipe

Modified pipe to extract secondaries

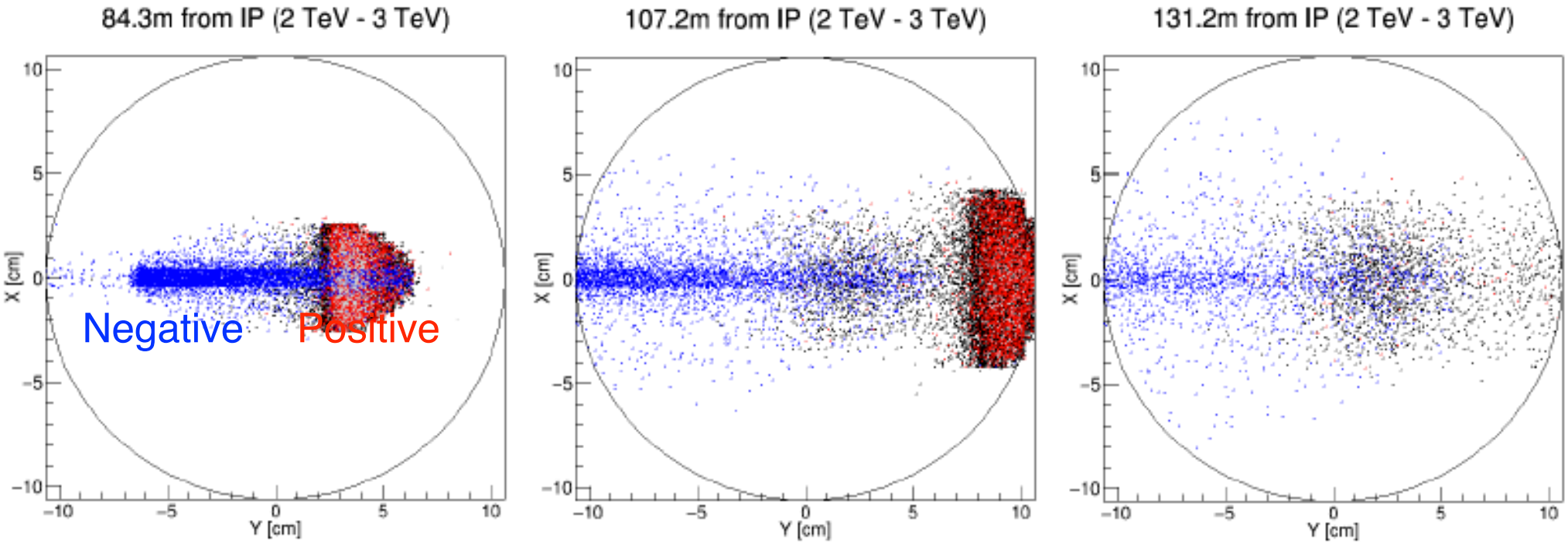
Install device in air to measure angle, energy and mass (TRD)

Workshop SAS at CERN
https://indico.cern.ch/event/435373/



Albrow, Mokhov (FNAL)

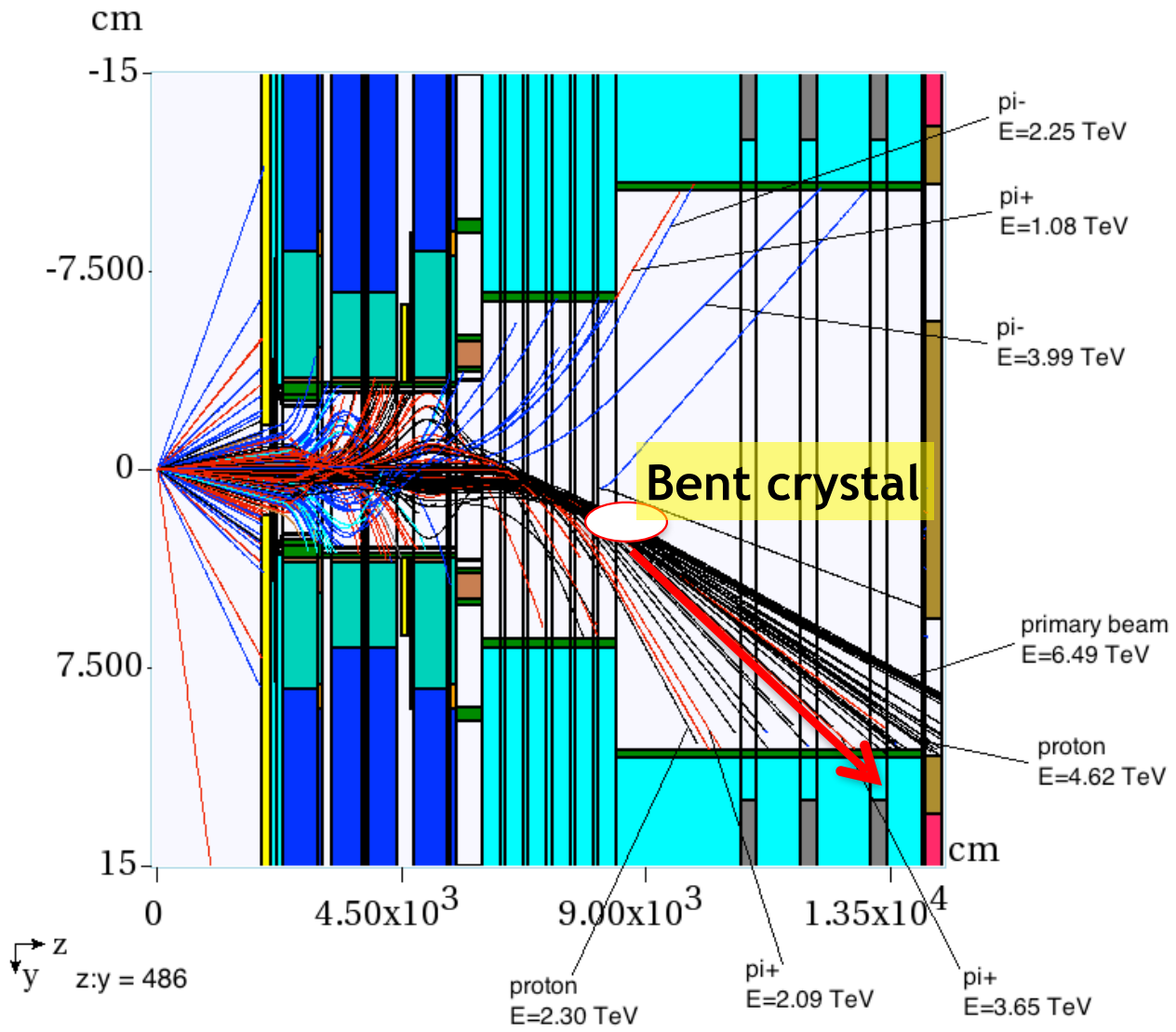
Deflection of TeV particles



Rectangular shapes are due to the F/D quad field for given energy slice.

- By measuring **x, y, θ_x and θ_y** for a particle exiting the pipe, given the machine **optics** we can reconstruct its p_T, p_z, ϕ at the **IP**

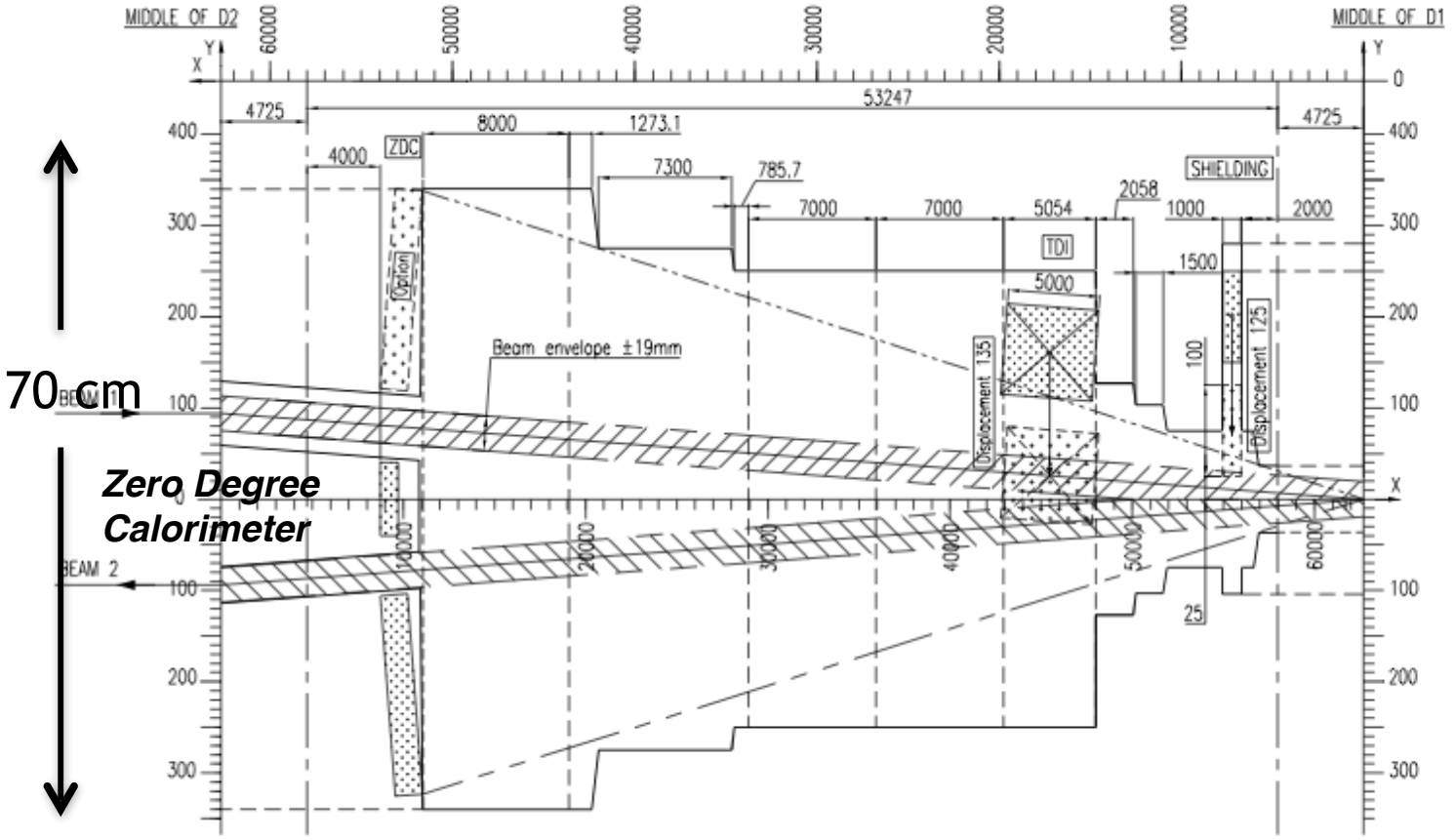
Extending acceptance with crystals



A crystal is critical to provide an extra-kick for the higher energy particles

Possible location

ALICE conical beam pipe



Muons	Calorimeter	----------TRD----------	Tracking	← particles
1m	2.5m	6 - 8m	2m	total = 12- 15m

LAYOUT

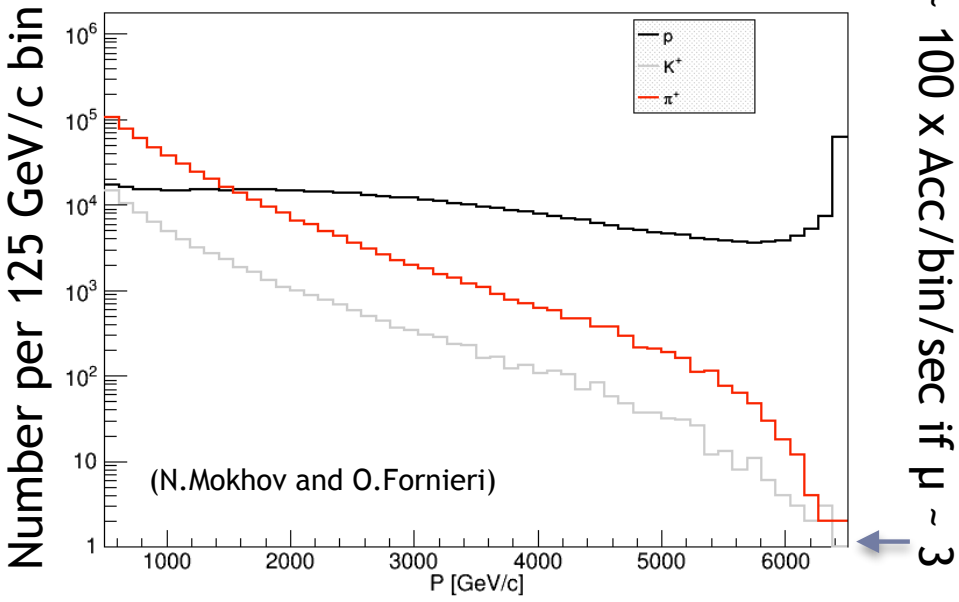
Detect charged pion and kaons

- **Transition Radiation det. likely the only technology**
  - Several ideas floating around (different radiator material, different configurations…)
  - Highly not trivial

DPMJET prediction at IP

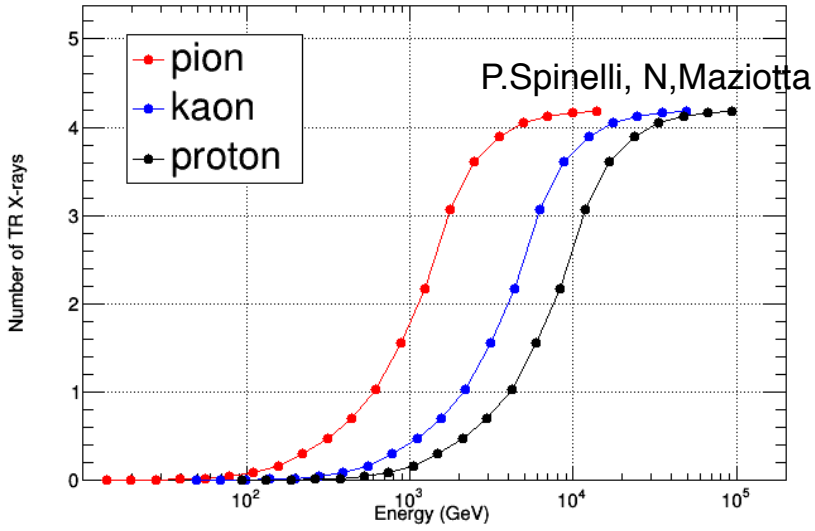
30 x 10^6 bunch crossings in 1 sec

Momentum distribution at the IP



TR Detectors

Pol/Air, 100 μm/ 2000 μm, Nf=100

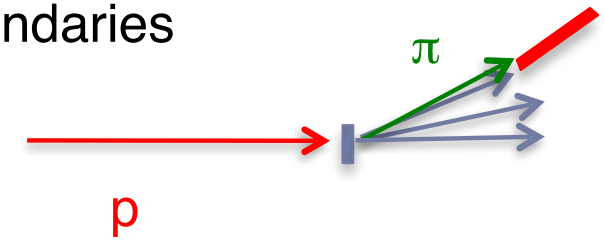


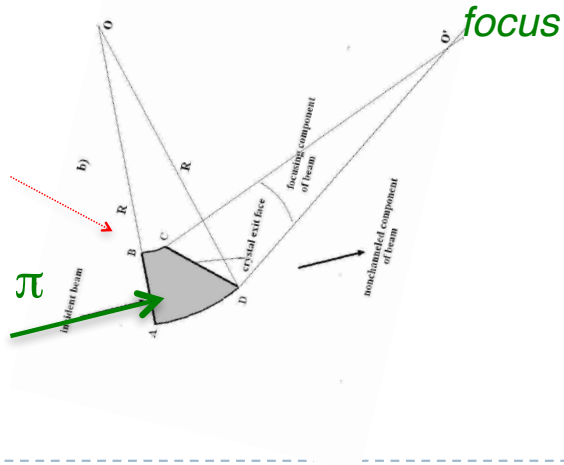
pion/proton separation possible,
difficulties with kaons

More on the list ?

- A 7 TeV beam can be used for direct calibration of detectors
  - Gamma-400 calorimeter, LHC-f (but also FCC det. prototypes)
- Sub-shower in air-shower are mainly due to pions
  - A special crystal can be used to focus secondaries from the interaction of primary 7TeV proton from a thin target

A ***focusing crystal*** can intercept a fraction of the secondaries





Summary & Outlook

- A parasitic LHC beam extraction is under study
  - ***Beam bending by crystals*** *has been* ***successfully*** *tested up to the 6.5 TeV in the* ***LHC***
  - *A full Fixed target physics program with a multi-TeV proton beam can be envisaged (AFTER@LHC)*
    - *Study* ***showers in a beam dump*** *can be useful for CR MC validation*
- ***Galactic cosmic ray*** *propogation requires knowledge of p-p &* ***p-He*** *cross section for* ***anti-matter*** *productions (****10-1000 GeV****)*
  - *LHC-b might already be on track for this*
  - *A crystal might* ***redirect the beam*** *and provide a* ***larger acceptance***
- ***Secondary*** *productions in* ***UHECR showers****, high energy* ***neutrinos*** *origin*
  - *Study of secondaries production at* ***sqrt(s) ~ 13 TeV:*** ***SAS at LHC aided*** *by secondaries (****crystal****) extraction*