Ministero dell'Università e della Ricerca

INFN Istituto Nazionale di Fisica Nucleare

ICHEP 2024

CREMA Collaboration

Investigating crystal channeling for beam extraction at medical synchrotrons

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On behalf of the CREMA collaboration
CNAO, INFN, Università di Milano, Imperial College

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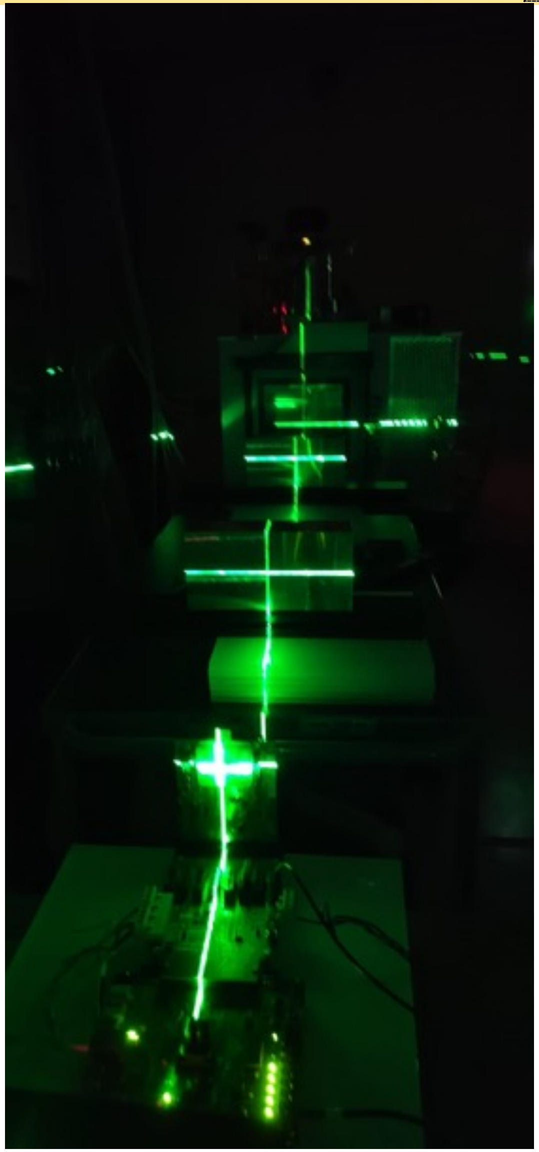

Istituto Nazionale di Fisica Nucleare

Introduction

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Crystal channeling has been demonstrated to be capable to extract or collimate the halo in high energy beam at the SpS and was proposed as an extracting or collimating method at LHC

It was also demonstrated to be efficiently used as a collimator to reduce the halo in a high energy Pb beam at LHC

Channeling for low energy ions extensively studied for ion implantation in semiconductors

Intermediate energies (100 – 500 MeV/u) of heavy ions not explored yet. ⇒ CREMA project

Aim: to produce a low emittance hadron beam for precise hadrotherapy, improving over electrostatic separation, allowing for an even more reproducible extraction intensity for a precise irradiation treatment.

Using the accelerator at C.N.A.O. Centro Nazionale di Adroterapia Oncologica (Pavia, Italy)

CNAO accelerator

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25 m diameter synchrotron

^{12}C ions up to 400 MeV/u

p to 250 MeV

Primary purpose: deliver hadron beam to patients.

Present beam extraction methods:

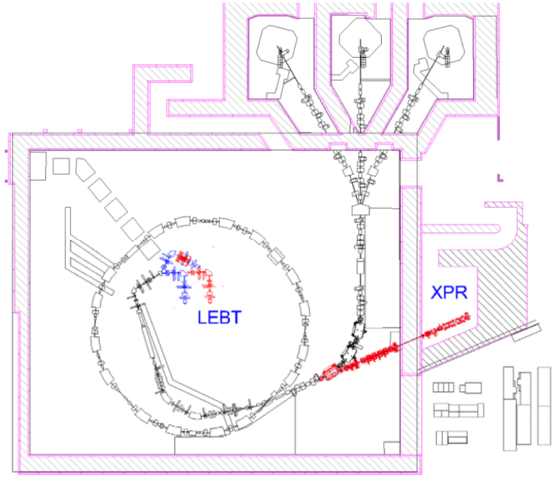
a) Betatron core pushing the de-bunched ^{12}C beam to energy resonance, via chromaticity
b) radio frequency knock out (RF-KO) this allows re-use of remaining beam for next energy step

Clinical intensities of extracted beam:

- 4×10^8 to 4×10^9 protons
- 8×10^6 to 8×10^7 ion/s

over a spill duration of 3 s

Patient treatment
Limited time available for experiments
Extremely strict radioprotection rules



Patient treatment areas

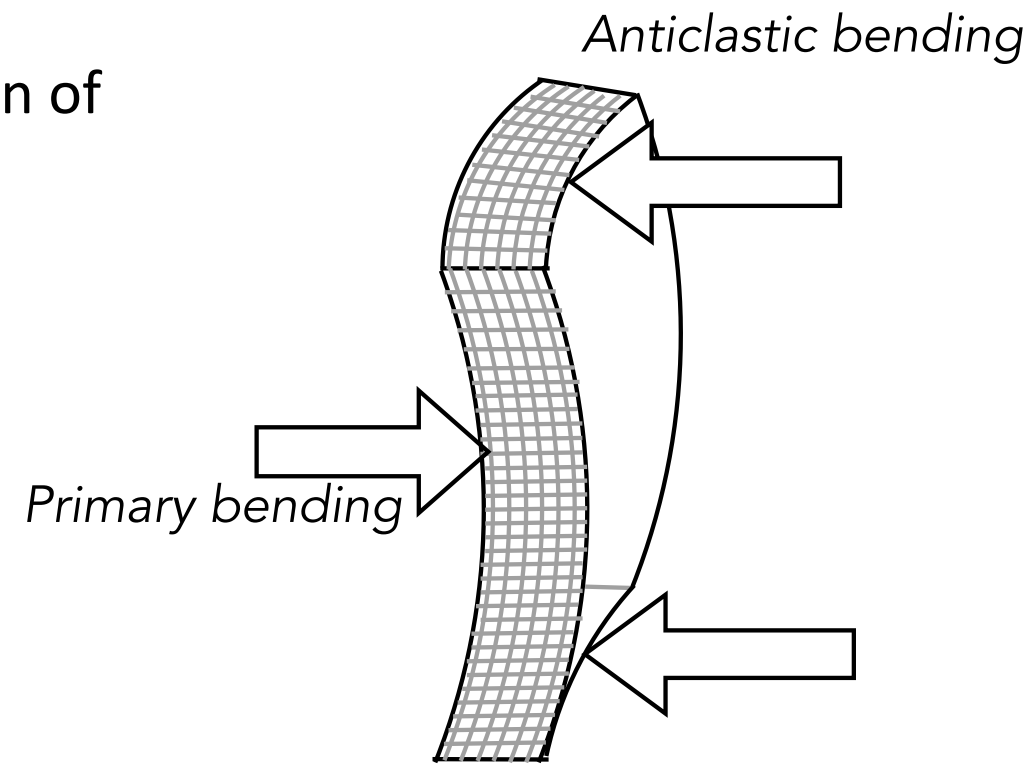
Physics experimental hall

Figure 1: Layout of CNAO. The present Low Energy Beam Transfer line (LEBT) and the path of the experimental beamline are visible in blue; in red the new layout being implemented.

Plans for this study

Research plan

- Study emittance of collimated and uncollimated Carbon ion extracted beam at the CNAO accelerator complex (Pavia, Italy) using Silicon pixel detectors (hybrid or monolithic)
- Estimate crystal channeling efficiency as a function of
  - beam incidence angle,
  - crystal bending angle (primary or anticlastic)
  - Ion kinetic energy
- Re-measure in vacuum
- Optimize crystal proposal for circulating beam



Monte Carlo simulations

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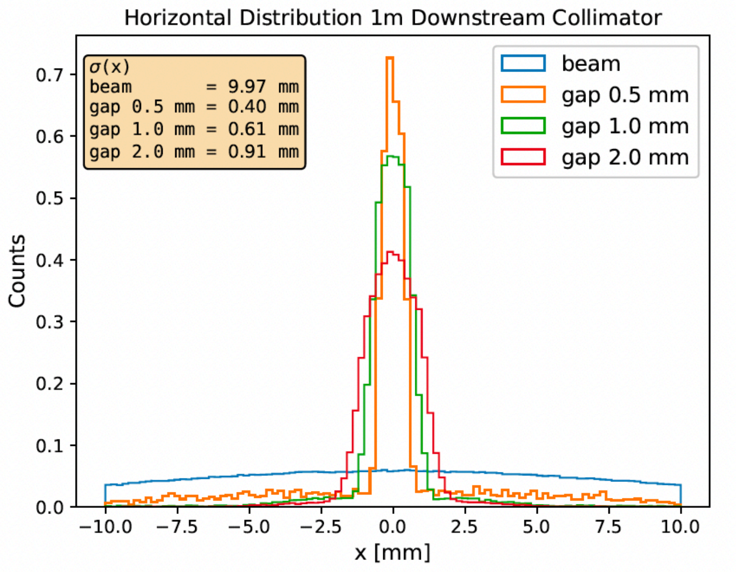
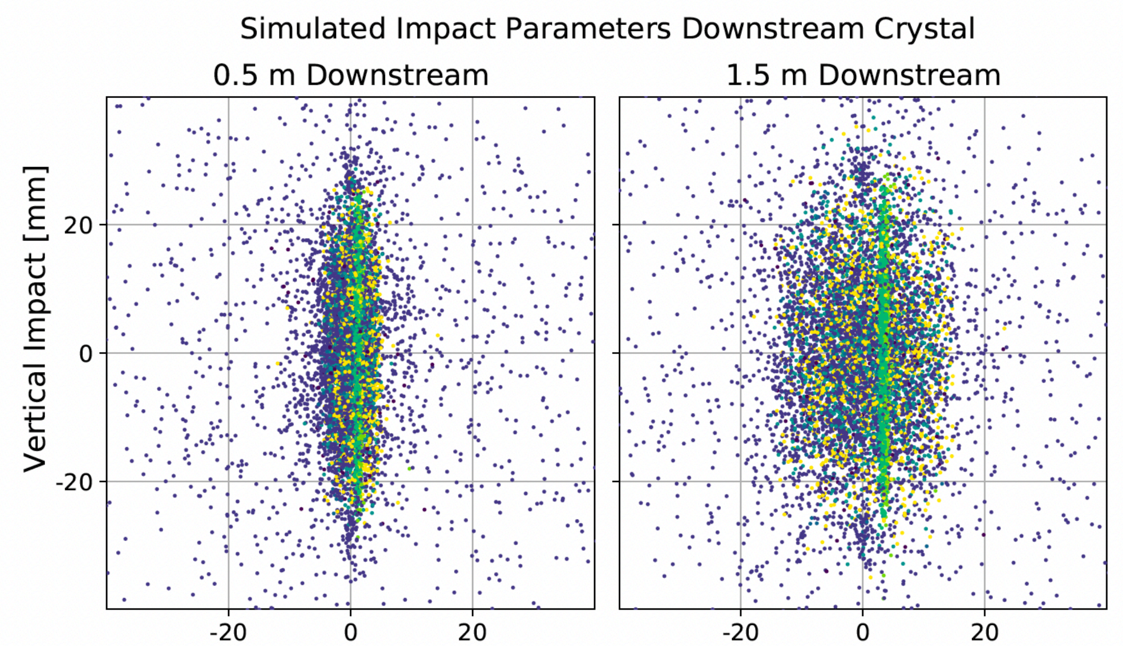
Fluka Monte Carlo simulation of $^{12}C^{6+}$ 400 MeV/u
Low energy beam: large critical angle →
Channeling efficiency expected 18% in vacuum
Efficiency: ions channeled / ion hitting the crystal
Depends strongly on beam size and divergence

Beam Species	Energy	Critical Angle
$^{12}C^{6+}$	400 MeV/u	223 µrad
$^{12}C^{6+}$	150 MeV/u	365 µrad
p	227 MeV	419 µrad

Beam collimation with slits



Green: channelling, volume capture
Blue dechannelling, amorphous scattering,
Yellow: volume reflection



Monte Carlo simulations

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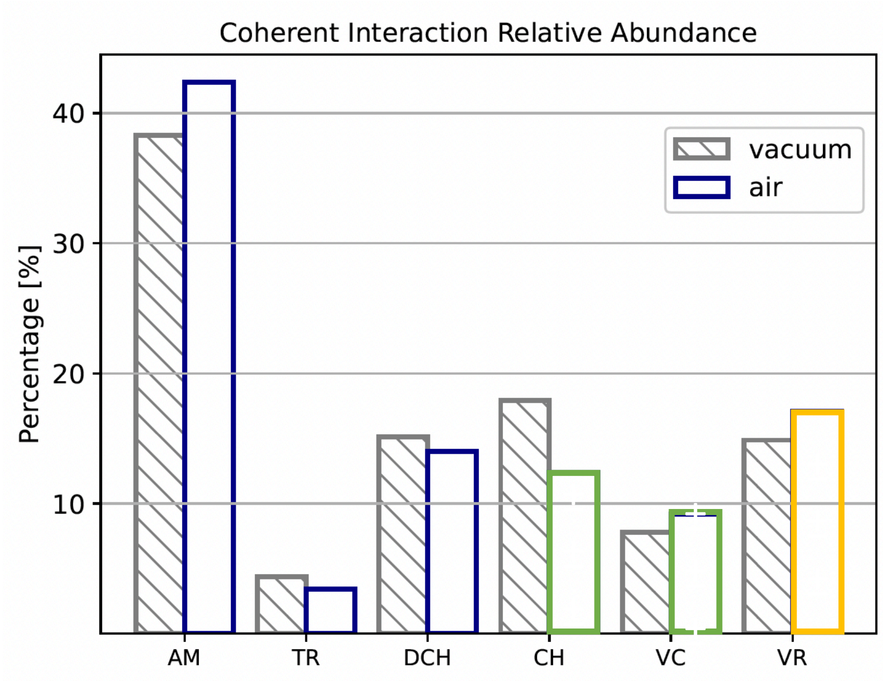
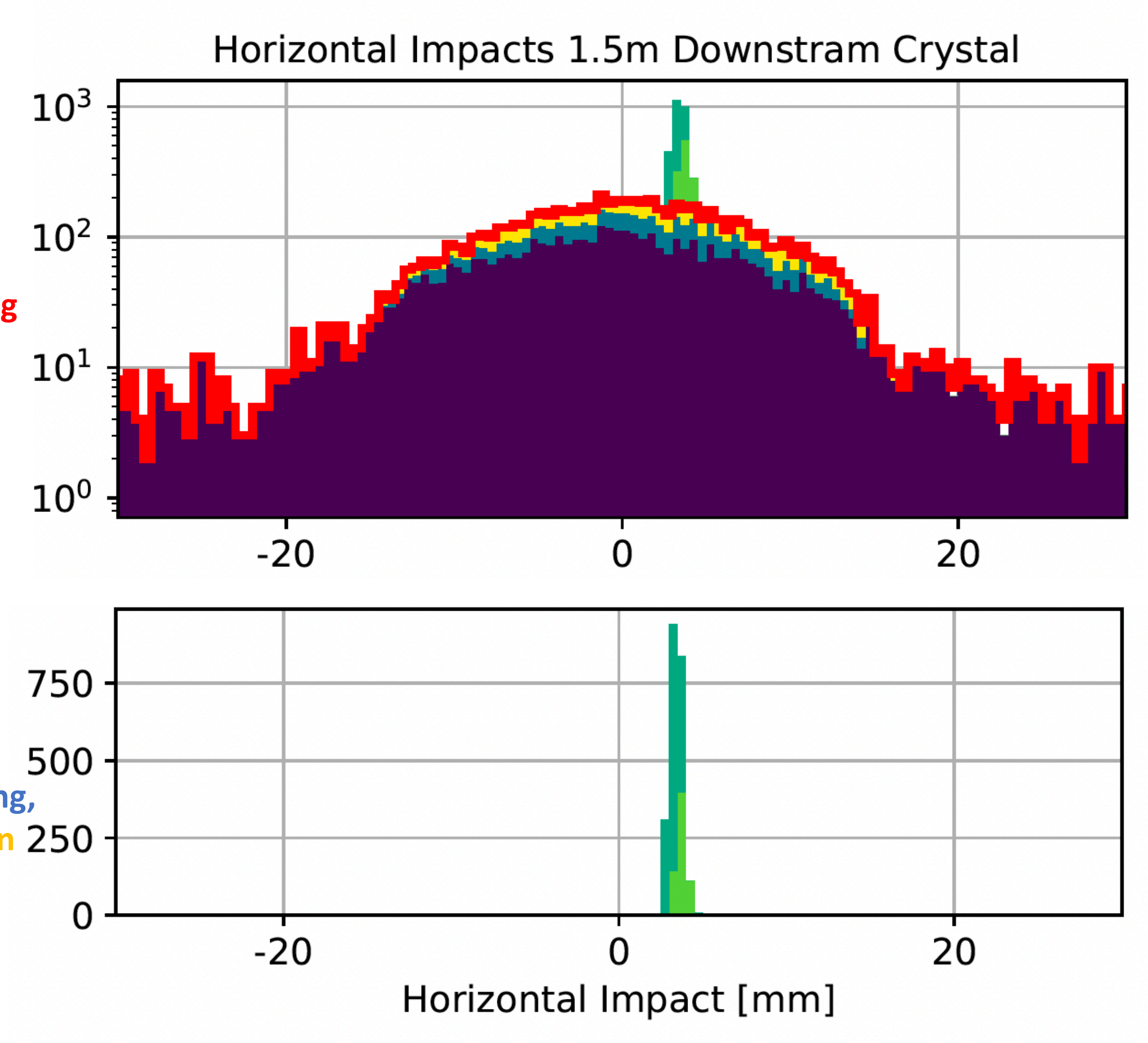


Red: no channeling

Green: channelling, volume capture
Blue dechannelling, amorphous scattering,
Yellow: volume reflection



Pixel detector

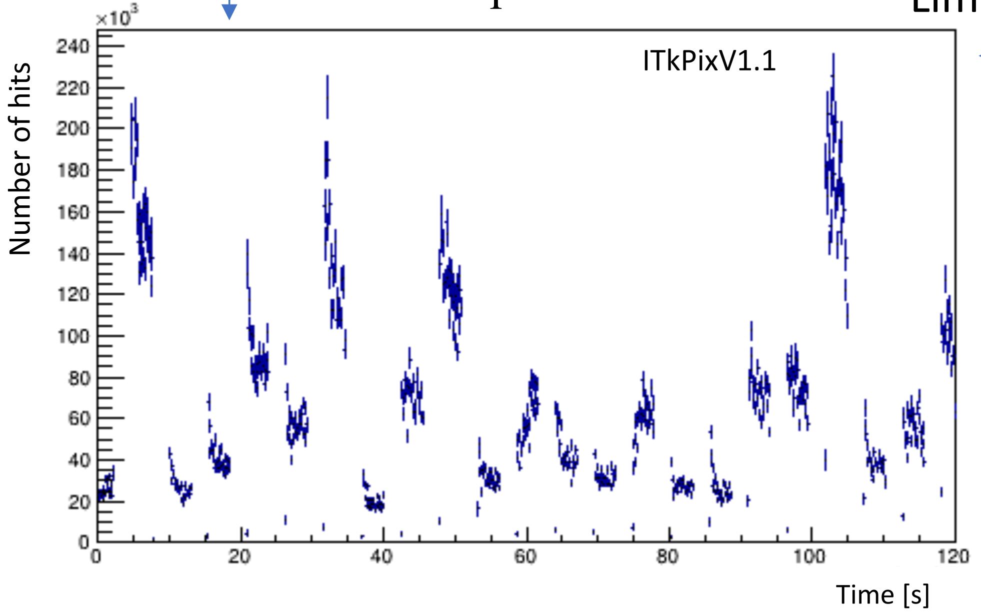
We have used
- ITkPixV1.1 hybrid pixel detector for high intensity beam 50 x 50 µm pitch, 3D silicon sensors, single-chip ~20 x 20 mm^2
- ATLASPIX3 single-chip monolithic detector for low intensity beam 50x150 um pitch (see talk by R. Zanzottera) ~20 x 20 mm^2

Both are digital readout chip, threshold $1000\ e$, ToT only available for AtlasPix3;

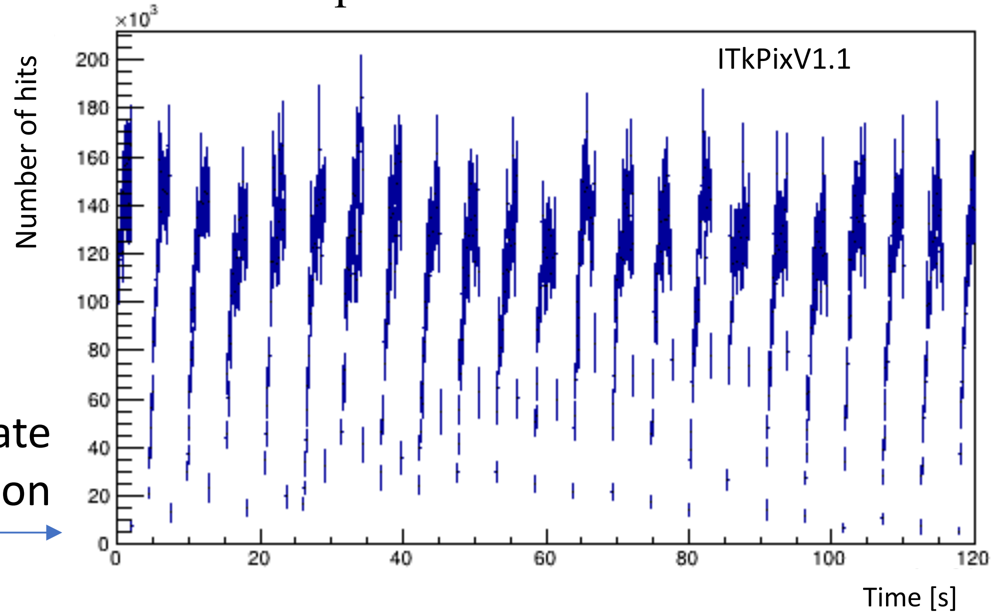
External random trigger; max trigger rate depending on event occupancy, limited by DAQ (FPGA board and Readout)

10^8 protons/s

Limited by beam intensity

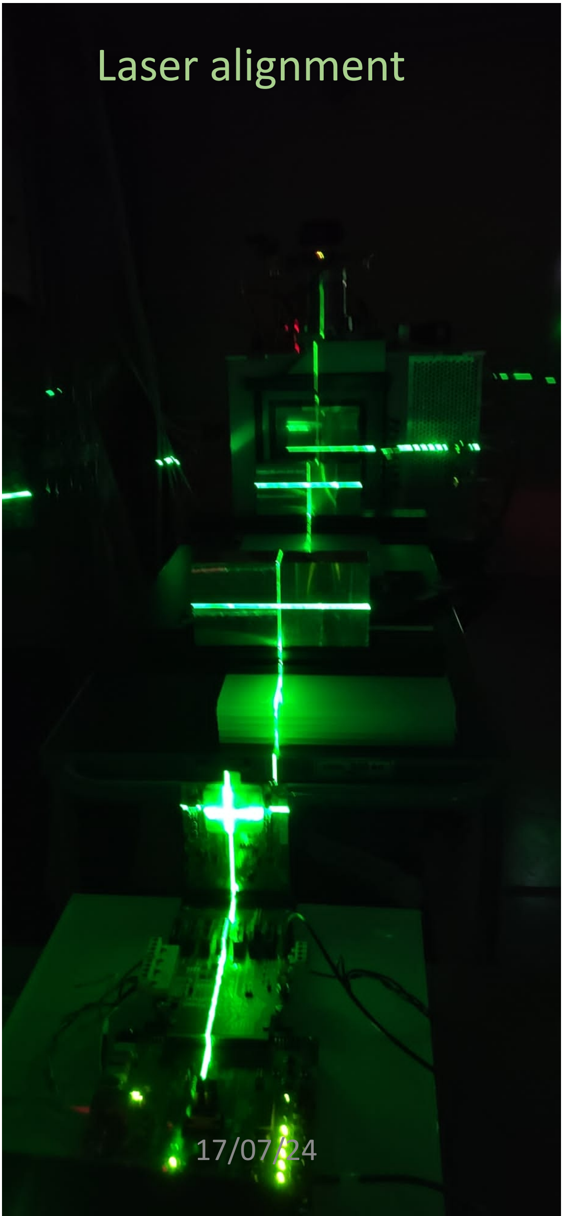


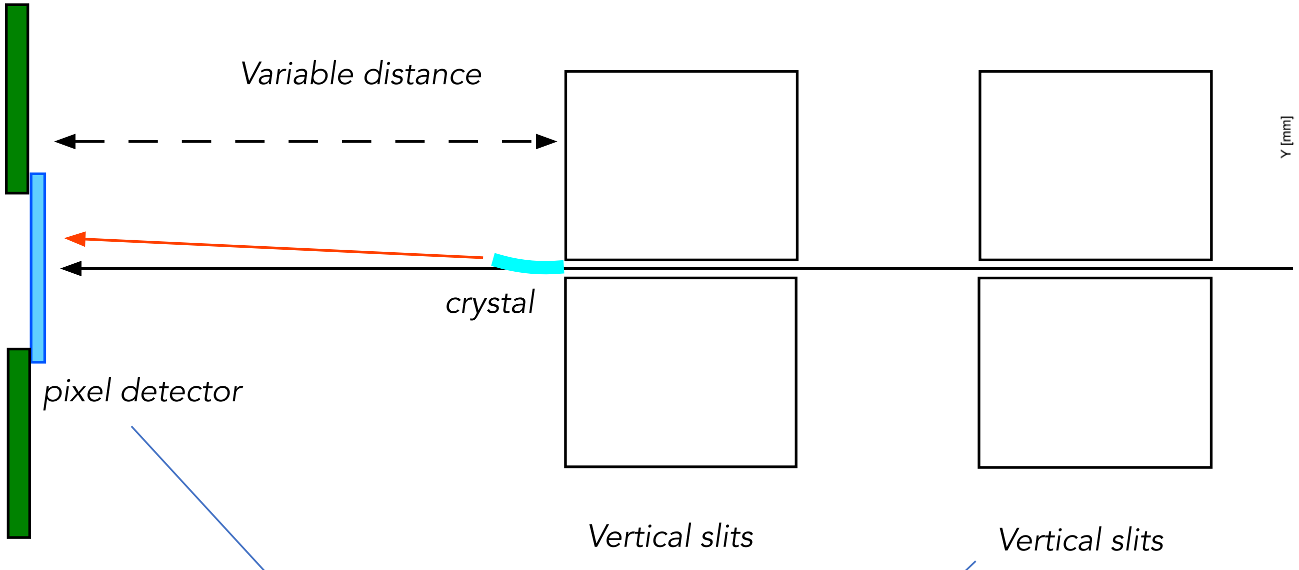
2×10^9 protons/s



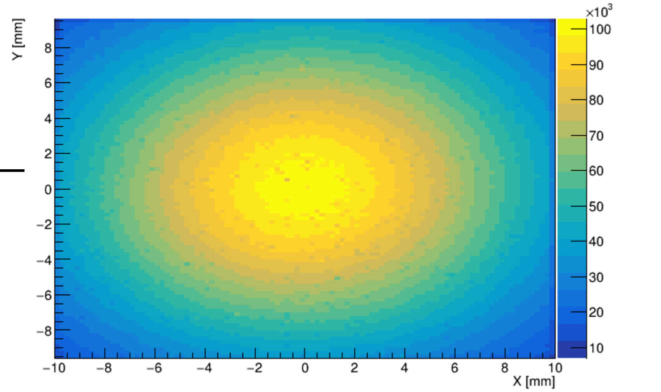
Limited by trigger rate
Less spill to spill variation

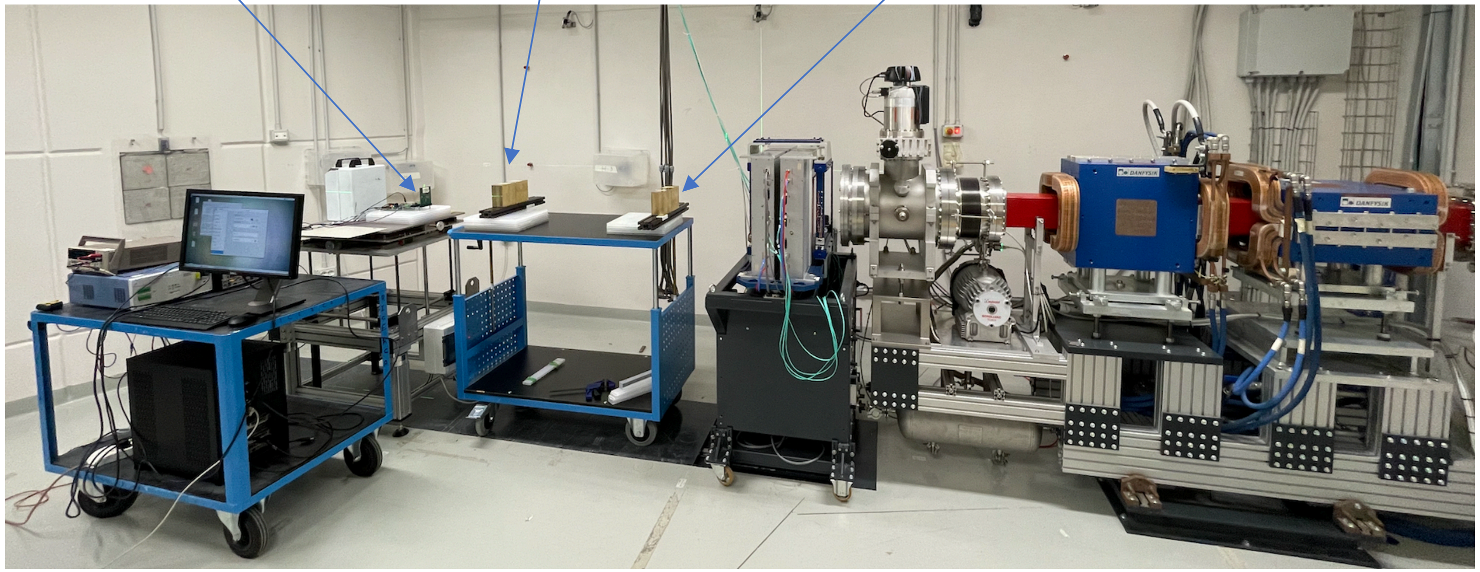
Experimental setup





Beam profile (p) non collimated

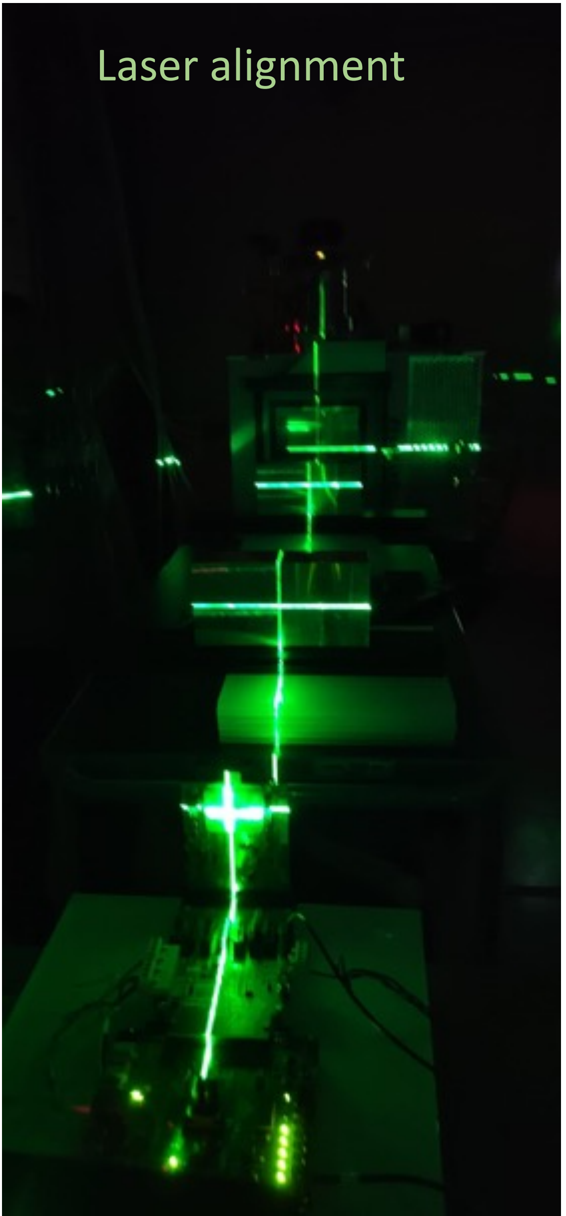


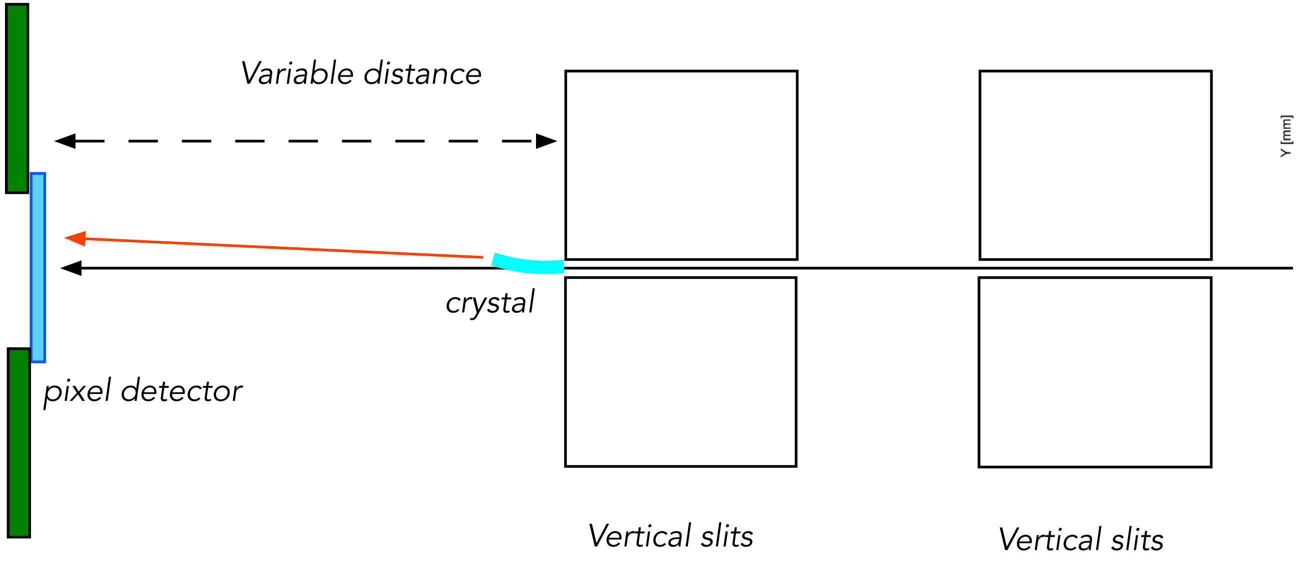


Very preliminary
Test setup

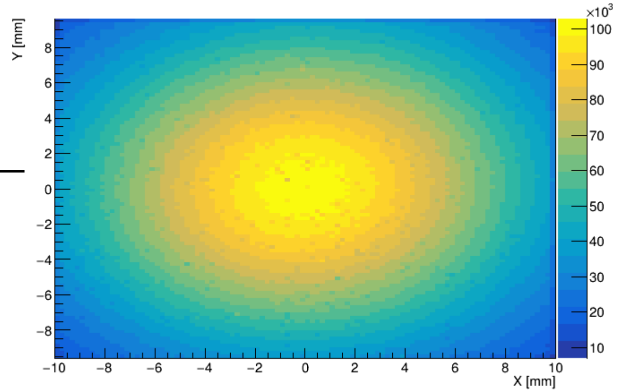
Bending crystal
not present yet

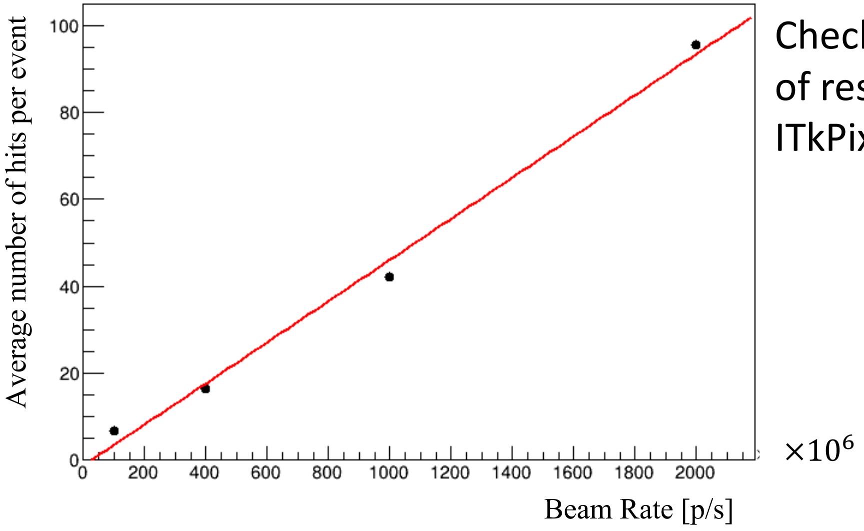
Experimental setup





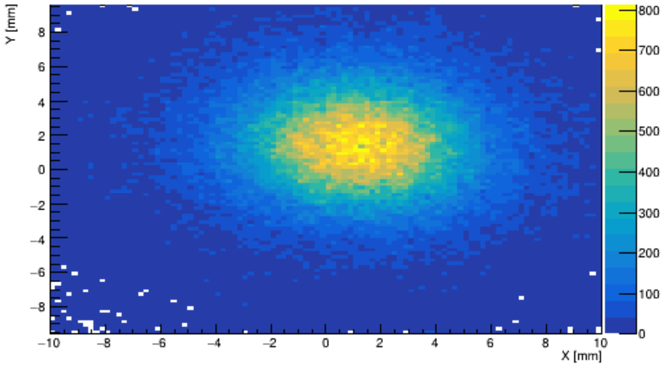
Beam profile (p) non collimated





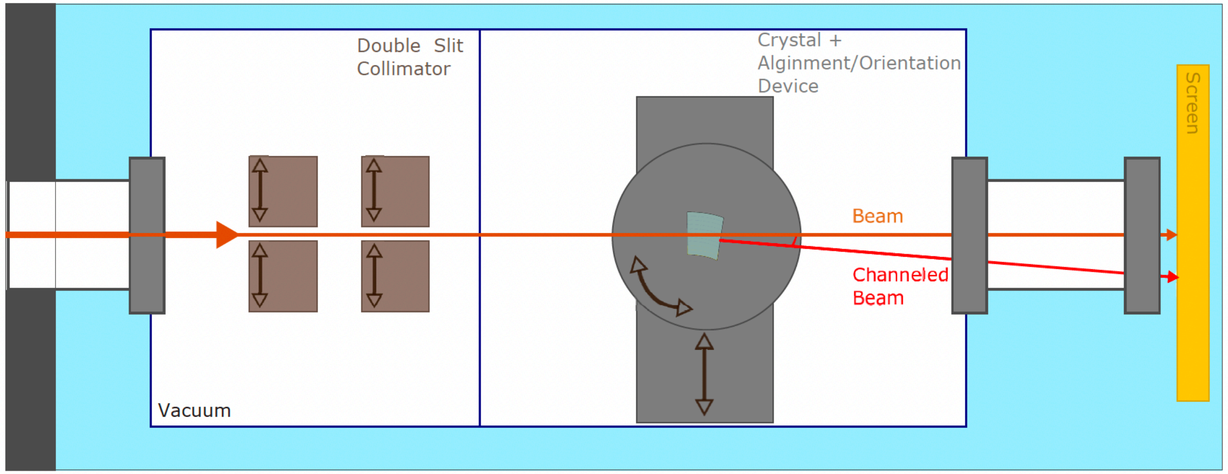
Check linearity of response ITkPix V1.1

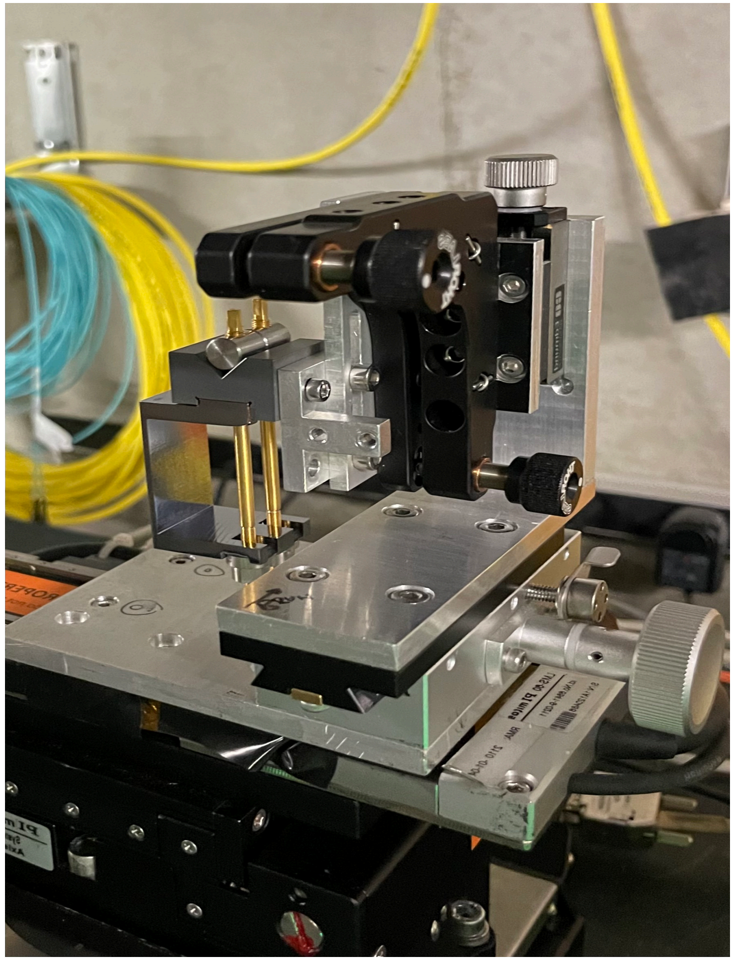
Beam profile C^{6+} non collimated



Next steps

- Channeling efficiency measurements will be based on beam intensity measurement provided by XPR at CNAO cross-checked with measured rate on downstream pixel detector
- Plan to install polished (110) Silicon crystal on precise rotary stage (goniometer)
  - 3 crystals available different thickness and quality
- Bending strategy: primary or anticlastic different bending tools
- Perform measurement in air
- Include slits and goniometer and possibly pixel detector in vacuum chamber





Conclusions

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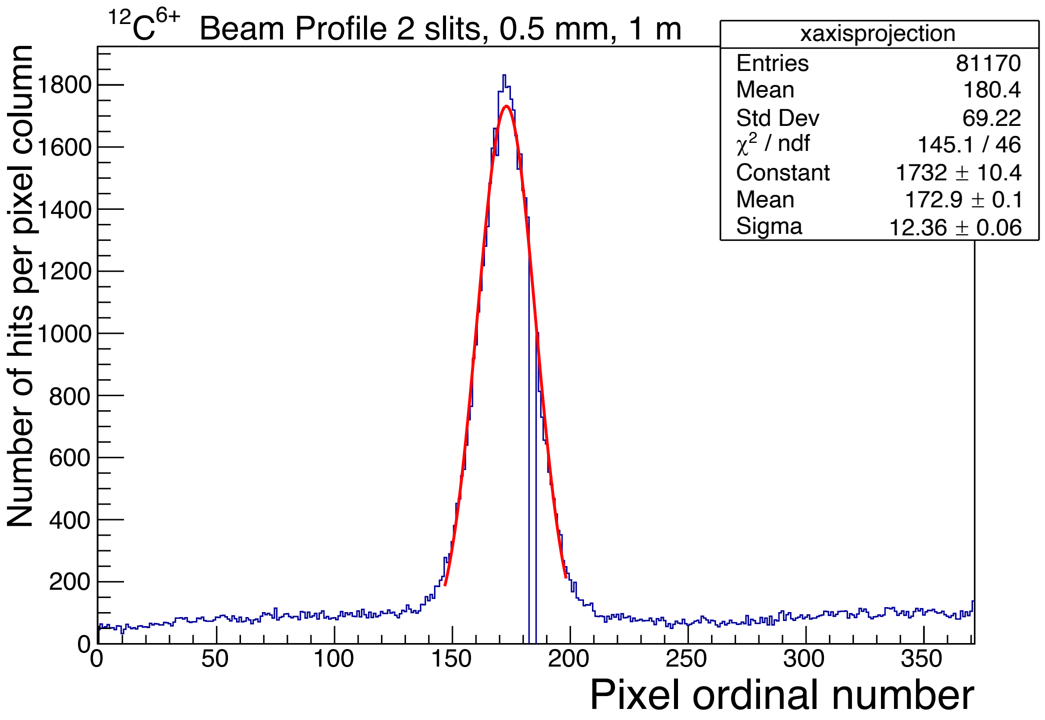
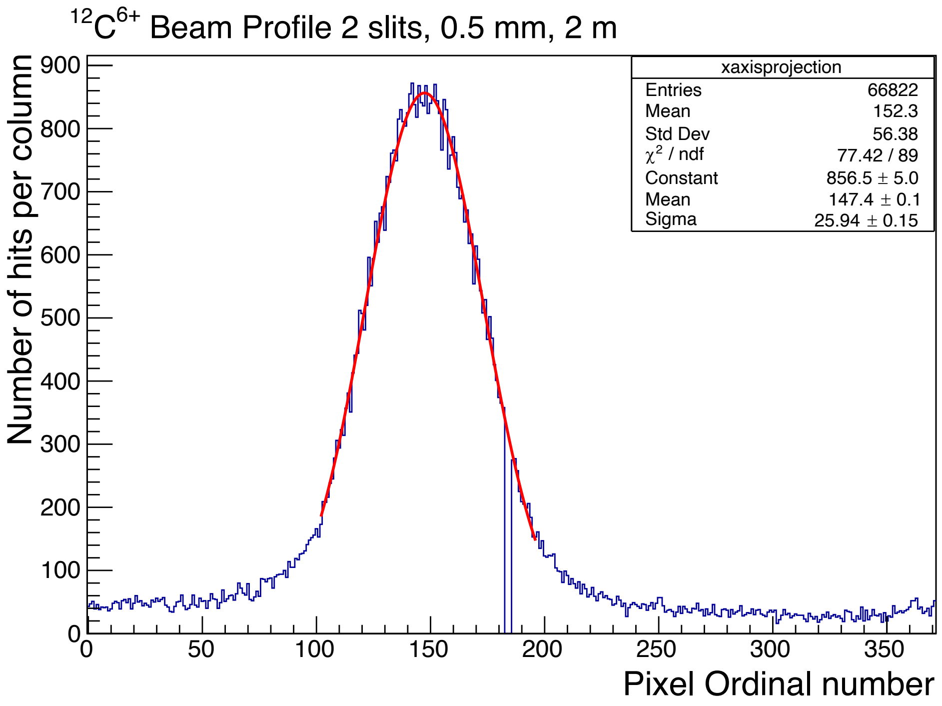
- Monte Carlo studies performed with FLUKA confirm that channeling is a promising solution to extract ion beams at hadrotherapy accelerators
- Expect 18% efficiency when operated in vacuum (no multi-turn effect included)
- Preliminary measurements have been performed to calibrate the pixel detector readout and measure beam profile and divergence.
- Measurement plan on going, adding crystal on a rotating stage

Thank you for your attention

and your questions

Beam Monitoring Results





Beam divergence after collimation ≈0.7 mrad

Also collected data with unpolished Silicon Si (1.5 x 11 x 44) (110) no rotating stage for multiple scattering test

Abstract:
The CREMA project investigates channeling of low energy carbon ions by bent crystals in the hundreds MeV/u energy range. The project aims at designing a crystal-assisted extraction scheme for medical synchrotrons, to complement or even replace the electrostatic septum usually deployed in such machines for beam extraction.
Channeling efficiency will be assessed with a dedicated experimental set up in the experimental area (XPR) of the CNAO accelerator complex in Pavia (Italy). This contribution presents the layout and calibration measurements for the data taking, as well as simulation results that confirm the feasibility of the channeling tests.