Simulating and Analyzing Crystal Channeling in the Large Hadron Collider

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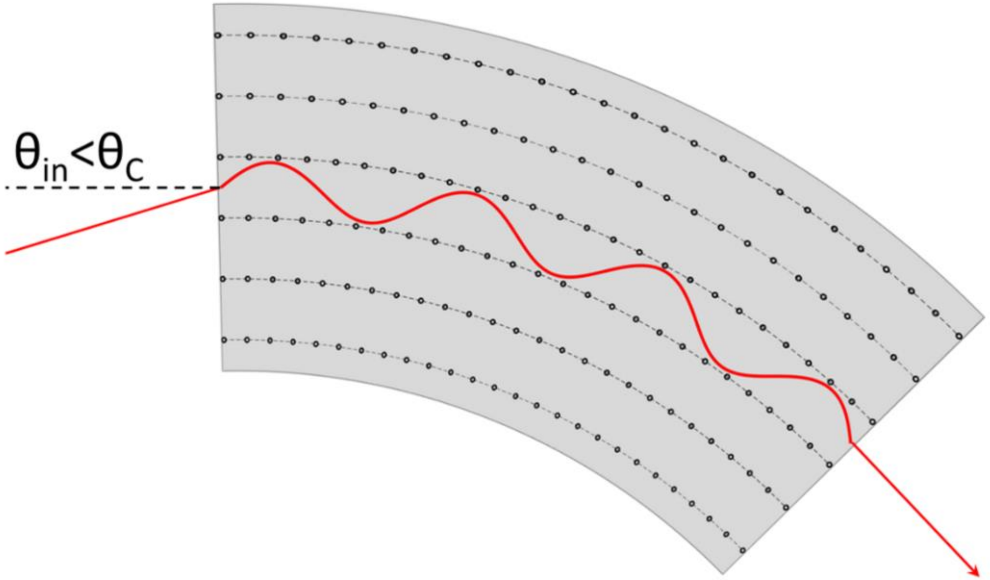
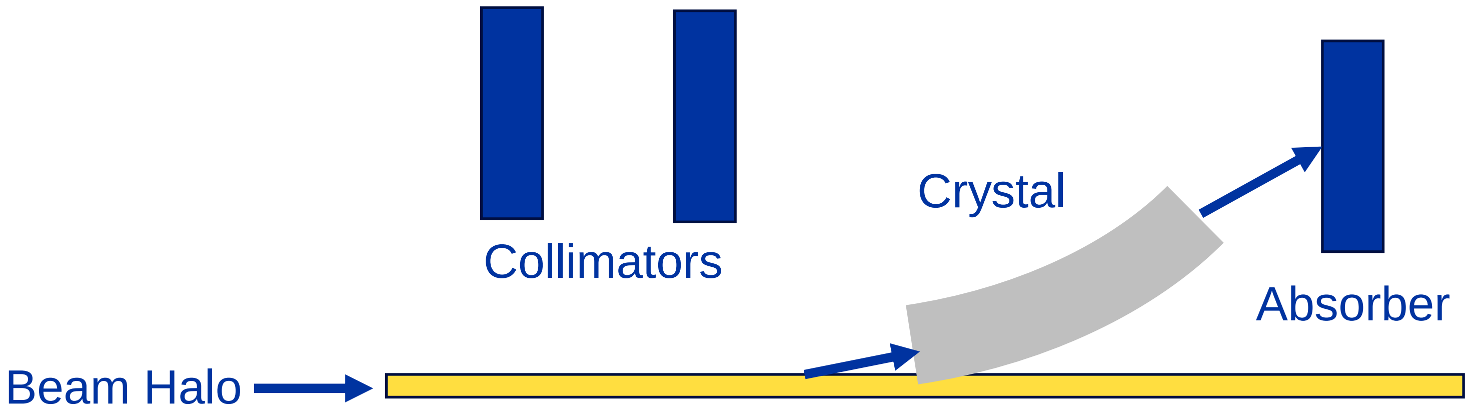
What is crystal channeling?

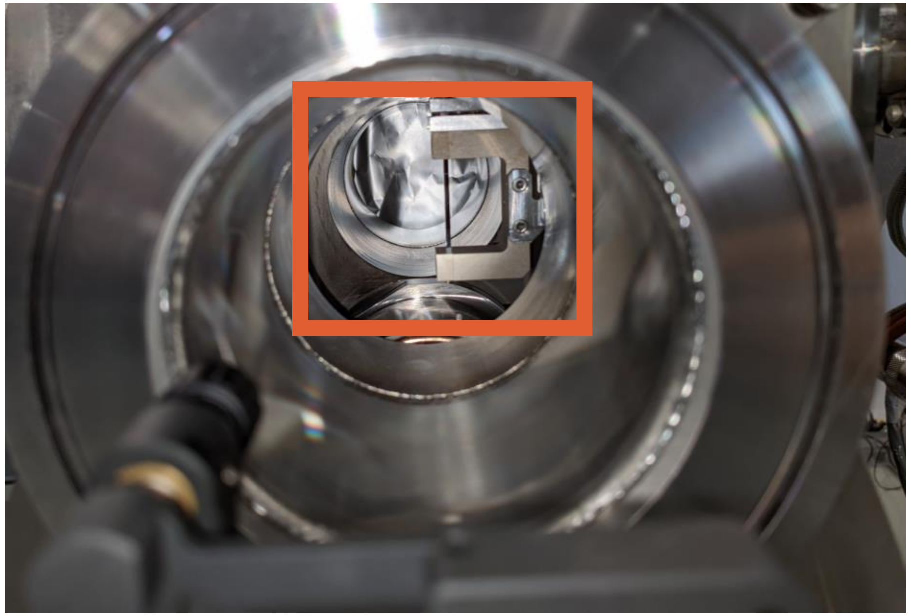
- Lattice structure
- **Channeling**: when particles are confined between crystalline planes
  - Incident Angle (θ_{in}) < Critical Angle (for channeling) (θ_c)
- Bent crystals used to control/redirect particles



Crystal collimation

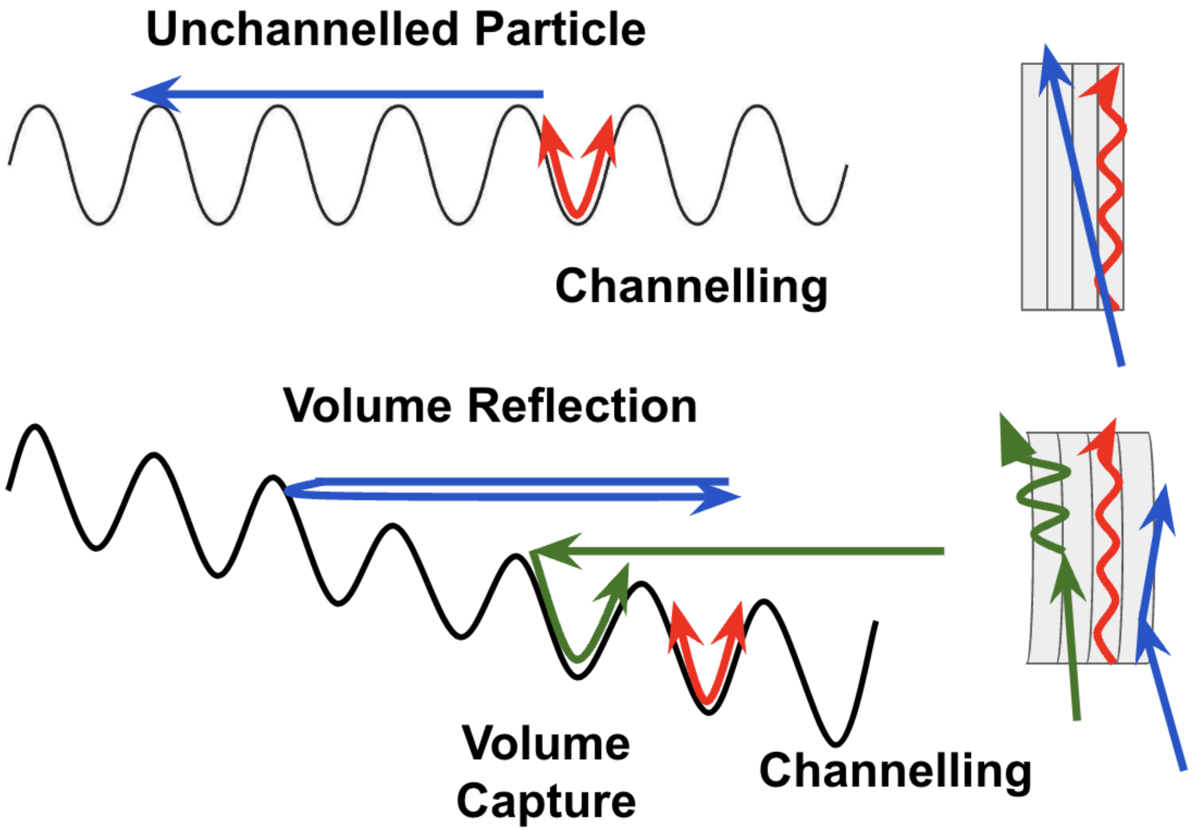


- B2H Crystal
- 4 mm length
- Bending Angle: 45 μrad



- Conventional collimation relies on random scattering
- Crystal collimation is deterministic
- Effect is equivalent to a magnetic field of 100s of Tesla

Other phenomena



Project overview

Develop a data analysis script

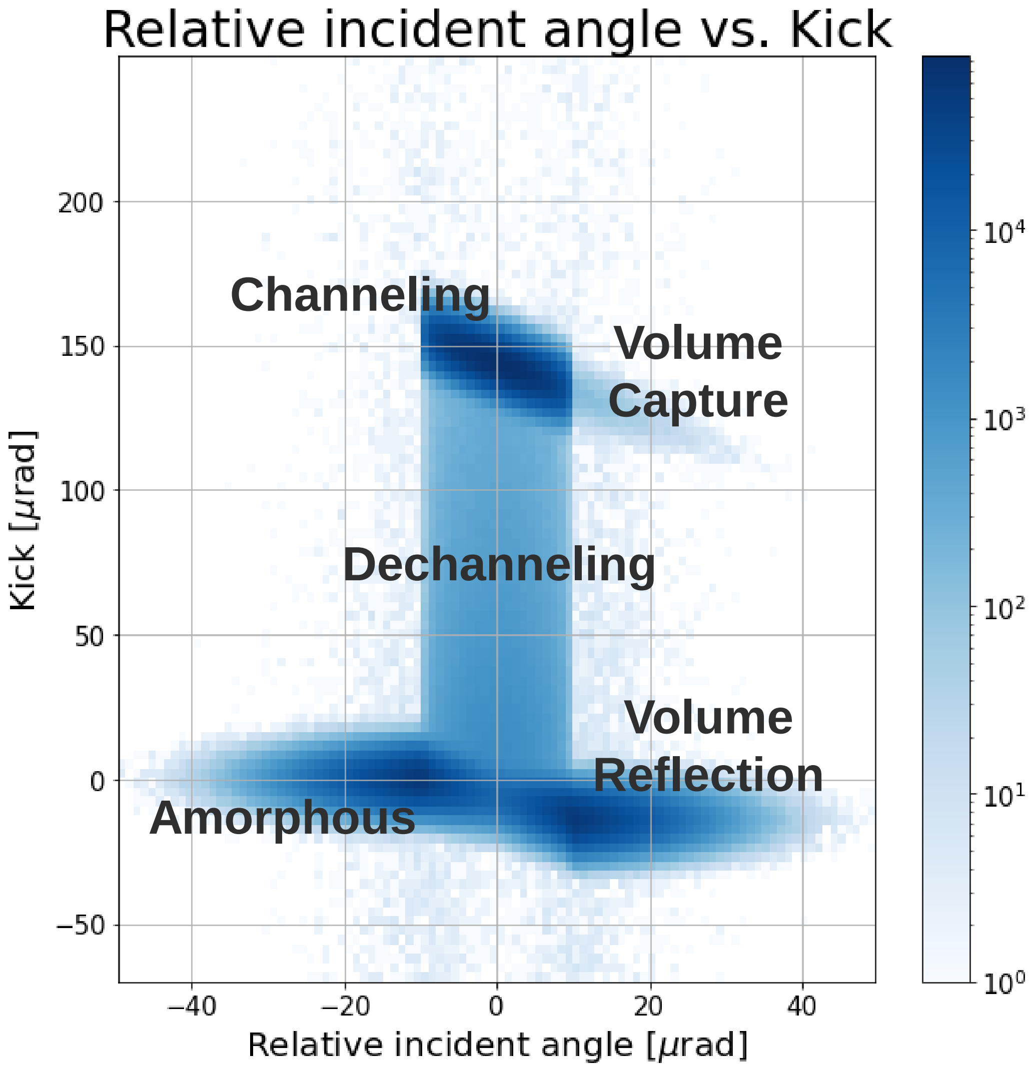
Run SixTrack simulations

Make updates to the NDC Section Webpage

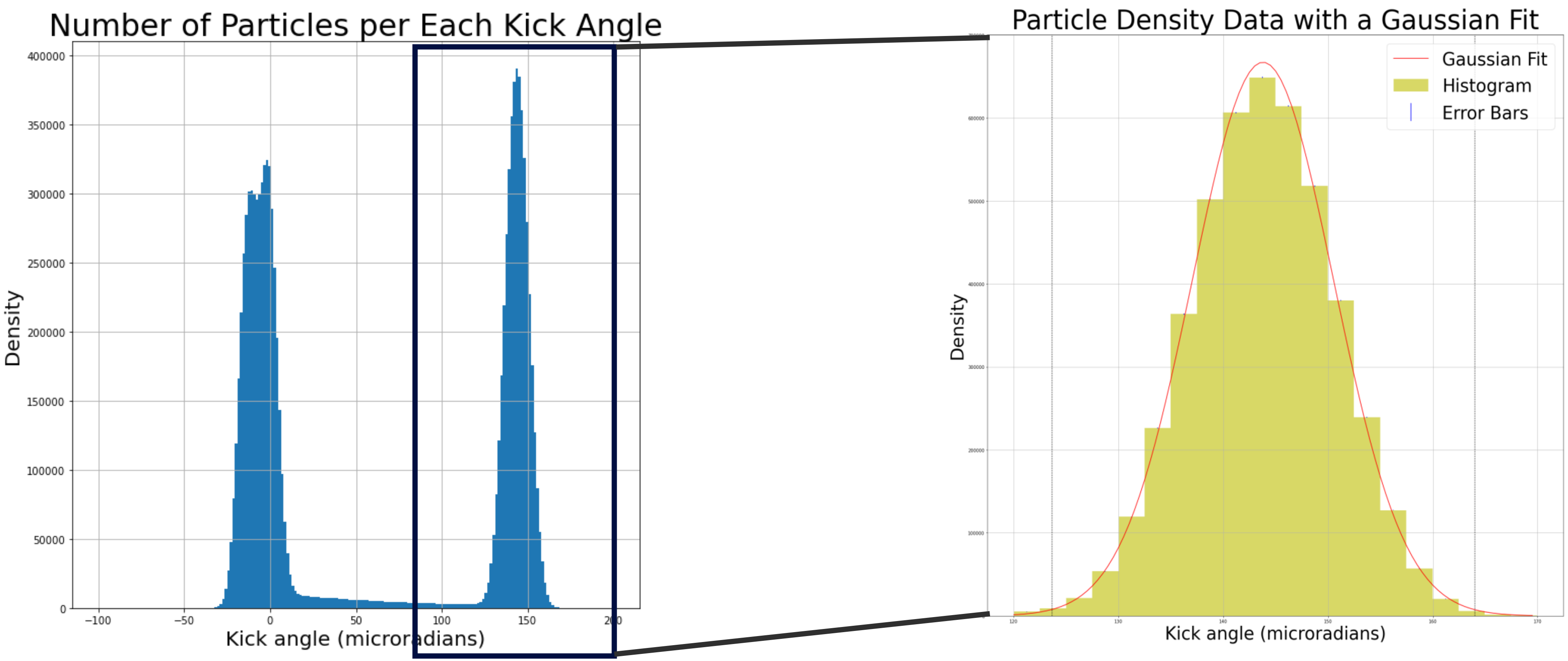
Building the analysis script

Main Goals

- ❑ Learn how to differentiate and recognize different channeling phenomena
- ❑ Isolate channeled particles from simulated data
- ❑ Calculate channeling efficiency
- ❑ Compare results to previous papers



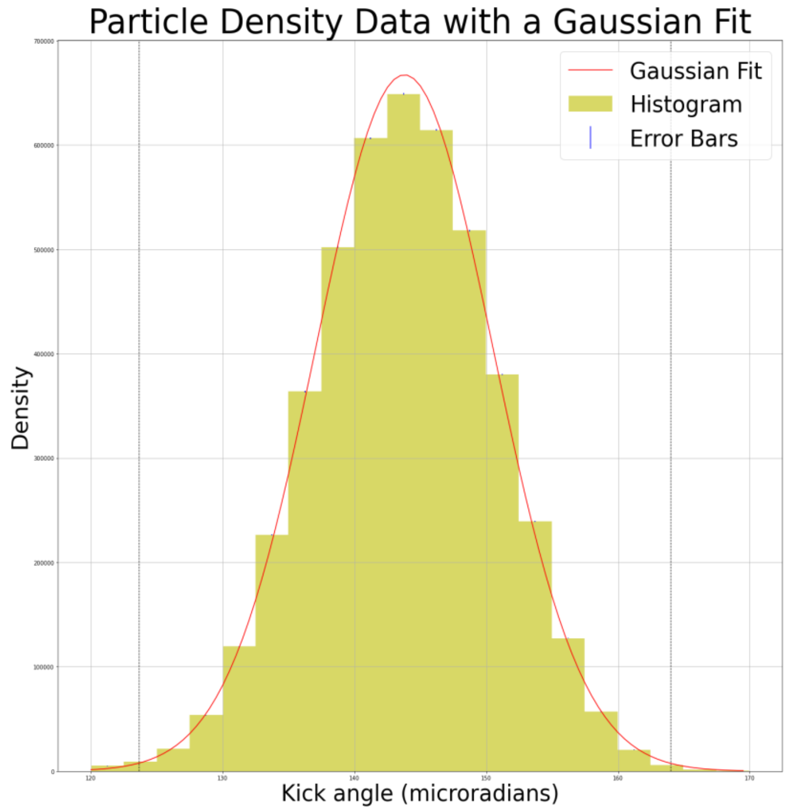
Building the analysis script



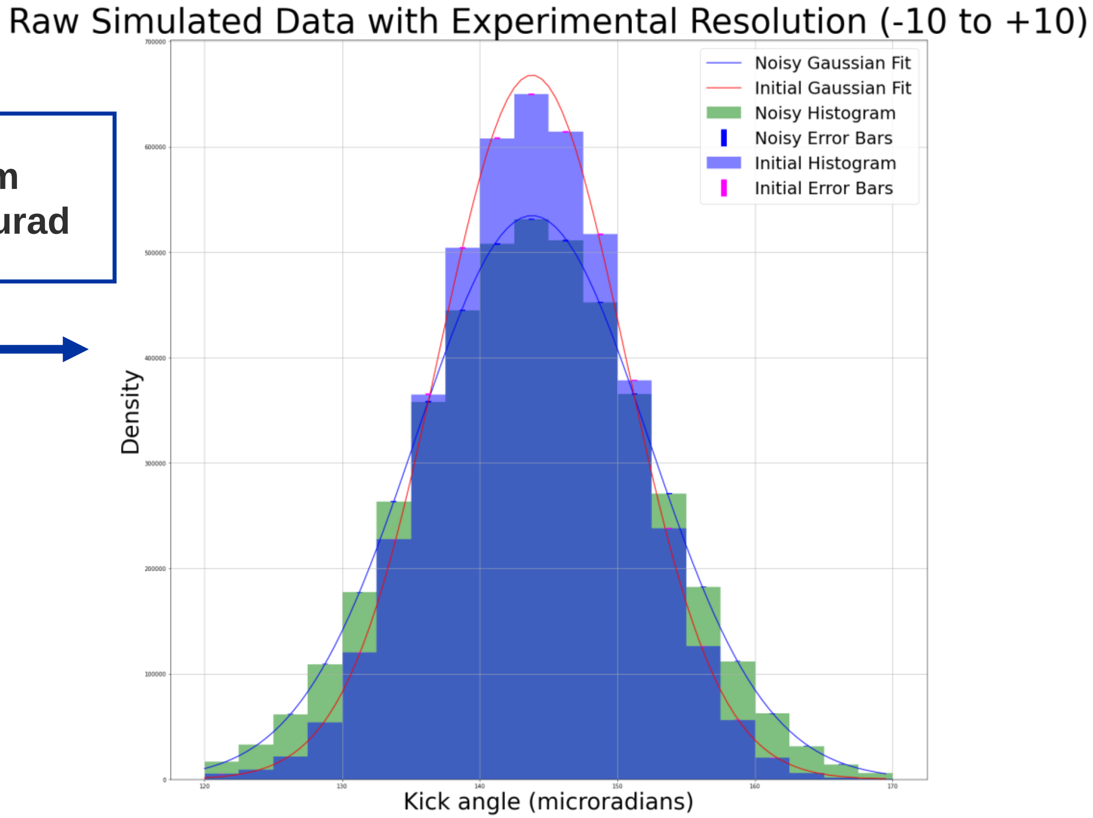
Total number of particles in the critical angle: 6.8 x 10^6

Number of particles within ±3σ: 4.5 x 10^6
Channeling Efficiency: 66.1%

Adding experimental resolution



Add random noise: [-5,+5] urad

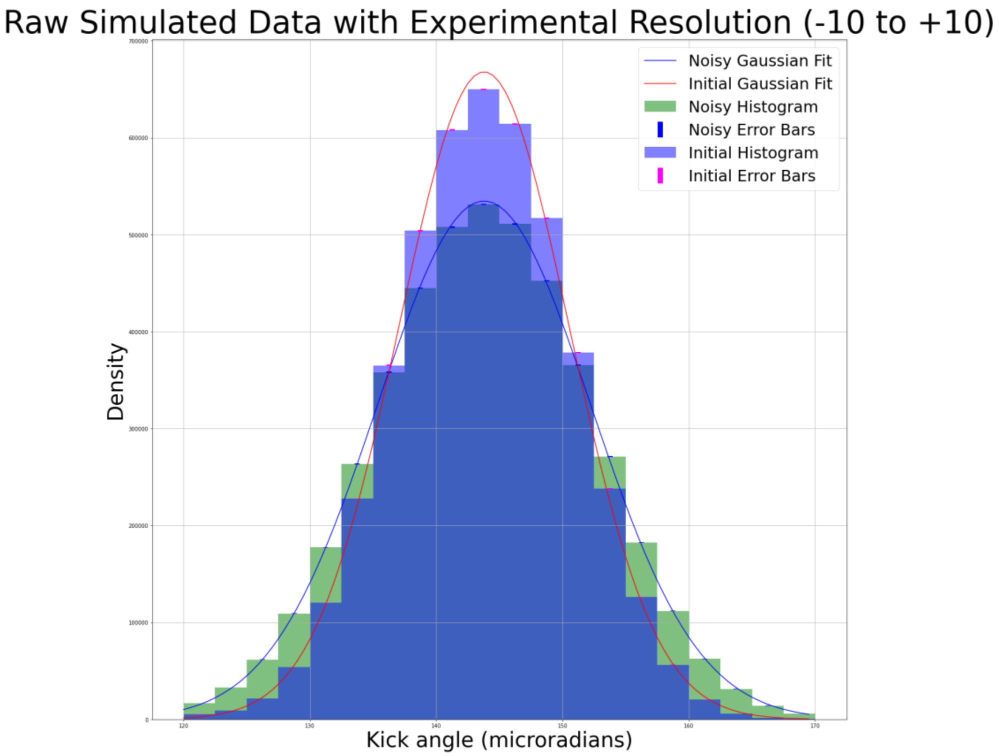


Total number of particles in the cut: 6.8 x 10^6
Number of particles within ±3σ: 4.5 x 10^6
Channeling Efficiency: 66.1%

Total number of particles in the cut: 6.8 x 10^6
Number of particles within ±3σ: 4.5 x 10^6
Channeling Efficiency: 66.2%

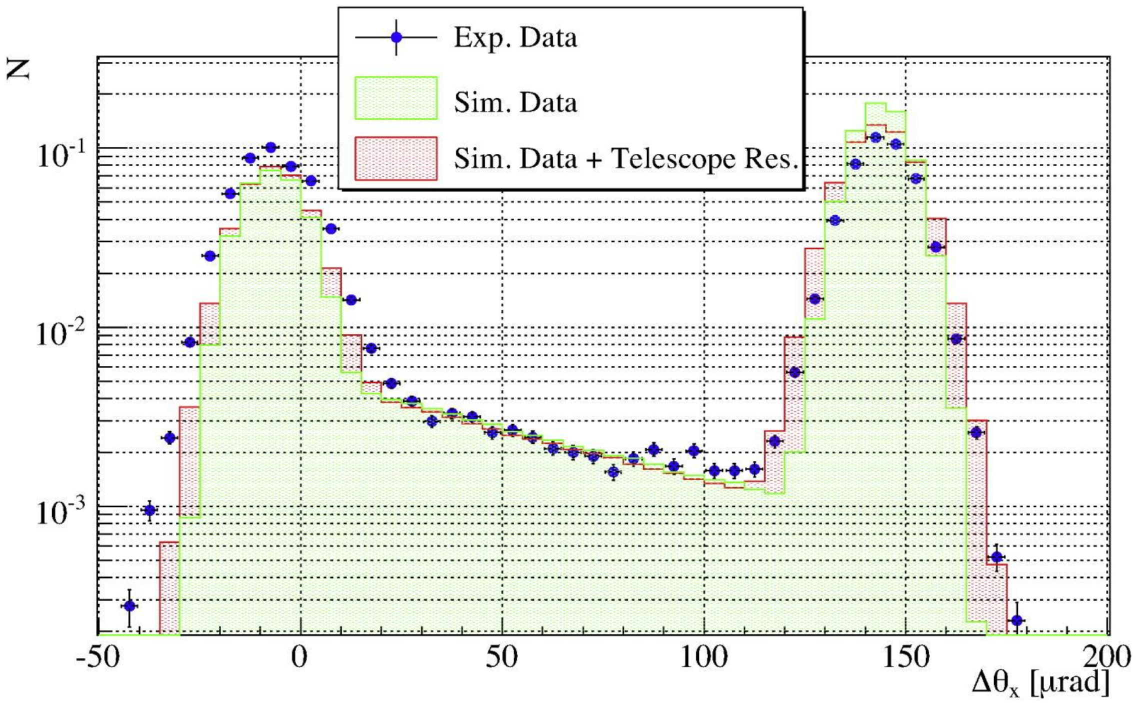
Comparing Results

My analysis script:



Raw Channeling Efficiency: 66.1%
Resolution Channeling Efficiency: 66.2%

Previous Paper [1]:

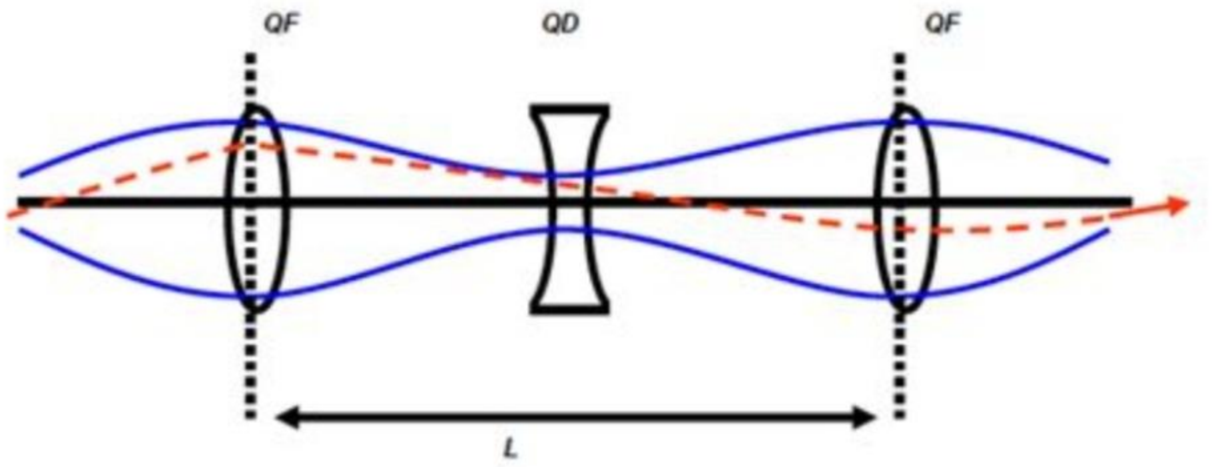


Raw Channeling Efficiency: 60.8%
Resolution Channeling Efficiency: 63.9%

Running SixTrack simulations

Main Goals:

- ❑ Learn how to use SixTrack
- ❑ Use SixTrack to simulate results of a recent Machine Development (MD)
- ❑ Compare results to recent paper



What is SixTrack?

- A simulation tool
- Tracks position and momentum of particles
- Records interactions of particles with elements of the accelerator

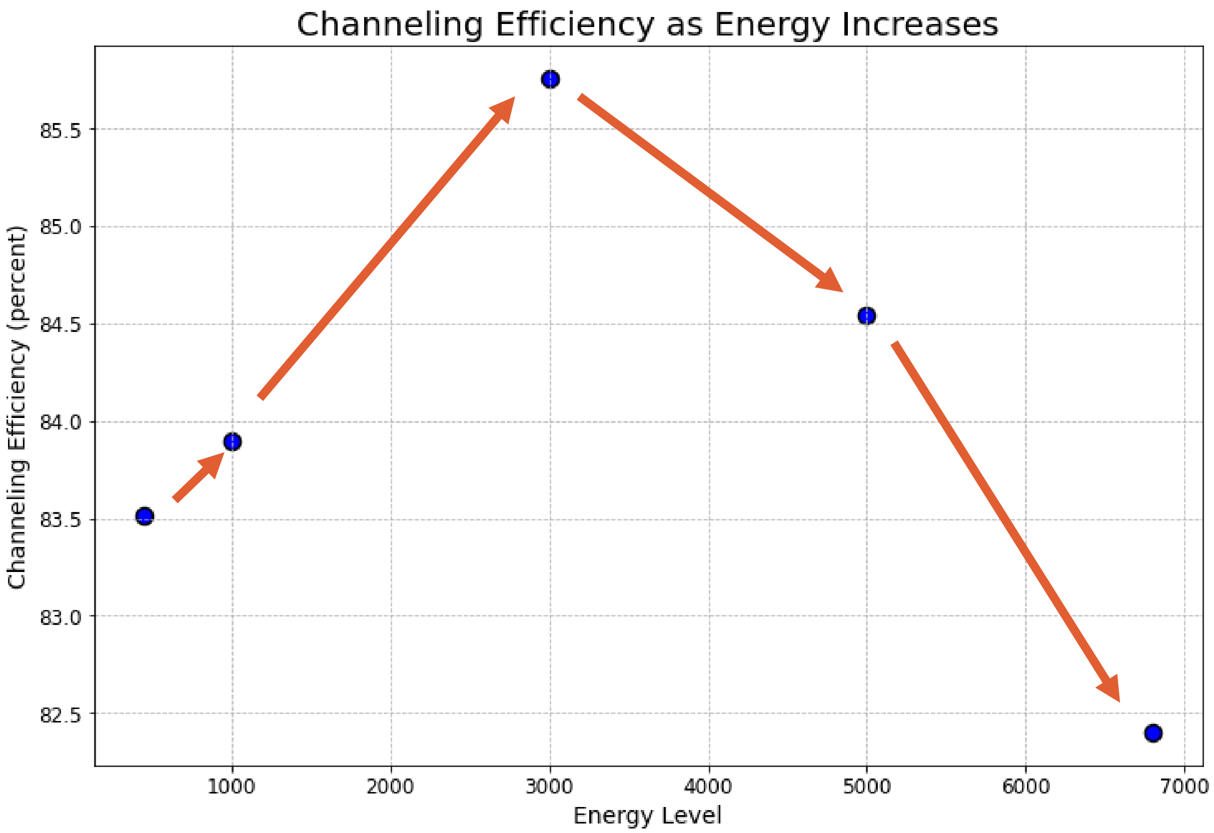
Creating and editing input files

- Aim: simulate multi-turn efficiency & compare to measurement
- Find collimator/crystal settings
  - Use various logging systems to find settings
- Edit settings -> Input file
- Run MAD-X
- Run SixTrack
- Repeat for all energy levels

Energy Level	
450 GeV	← Injection
1000 GeV	Intermediate energies
3000 GeV	
5000 GeV	
6800 GeV	← Top-Energy

Results of the simulation

Energy Level	Total Particles [10^6]	Channeled Particles [10^6]	Channeling Efficiency
450 GeV	8.96	7.48	83.51%
1000 GeV	9.52	7.99	83.90%
3000 GeV	9.81	8.41	85.76%
5000 GeV	9.78	8.27	84.54%
6800 GeV	9.78	8.06	82.40%



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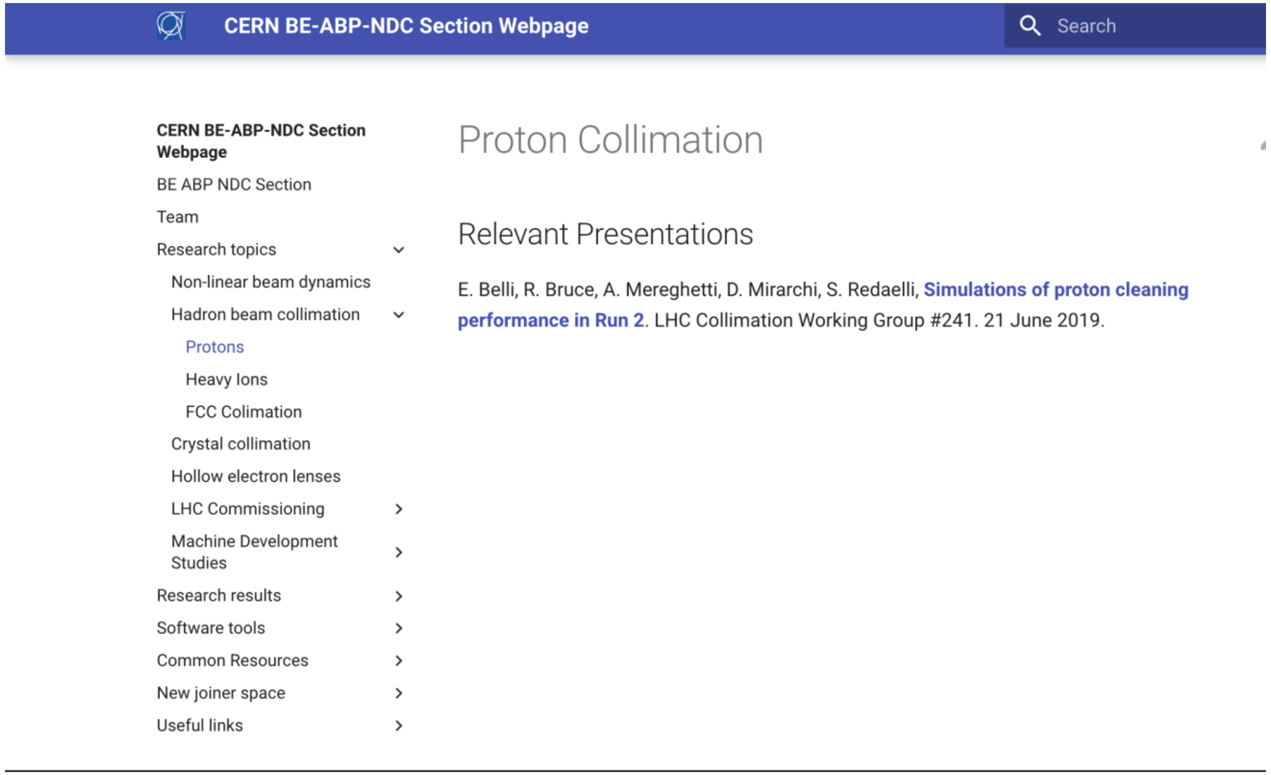
[2]:

Cleaning plane	450 GeV		6.8 TeV	
	Bending angle [μ rad]	Channeling efficiency	Bending angle [μ rad]	Channeling efficiency
B1H	47.5 ± 2.5	$82 \pm 15\%$	n.a.	n.a.
B1V	45.2 ± 2.3	$75 \pm 26\%$	47.4 ± 2.4	$68 \pm 17\%$
B2H	47.1 ± 2.4	$86 \pm 18\%$	45.4 ± 2.3	$70 \pm 11\%$
B2V	52.1 ± 2.5	$87 \pm 19\%$	49.1 ± 2.5	$73 \pm 21\%$

Updates to the webpage

Main Goals:

- ❑ Correct any typos and update out of data information
- ❑ Add new topics and members to the website
- ❑ Edit sections to ensure they are not too complicated for a section webpage
- ❑ Learn how to use a git repository



Updates to the webpage: example

FCC Collimation

The Future Circular Collider (FCC) study includes two accelerators, a high-energy lepton collider (FCC-ee) and an energy-frontier hadron collider (FCC-hh). Both machines share the same tunnel infrastructure. The NDC section hosts the coordination of the FCC-hh design studies. FCC-hh design meetings.

The FCC integrated programme offers the most powerful post-LHC experimental infrastructure proposed to address key open questions in particle physics. It envisions an initial electron–positron collider phase, FCC-ee, which will be followed later by a proton–proton collider, both of which will be installed in the same 91 km circumference tunnel at CERN. Although the focus of the present phase of the FCC feasibility study is on the electron-positron collider, FCC-ee, full compatibility with the future hadron collider, FCC-hh, has been ensured. Throughout the design, synergies between FCC-ee and FCC-hh have been sought for maximum performance at minimum total cost.

FCC-hh considers two values for the main dipole field, namely 14T (to be realised with Nb3Sn magnets) and 20T (to be realised with high-temperature superconductor), which correspond to the centre-of-mass energies of 85TeV and 120.8TeV, respectively.

Current work for FCC-hh done in the section is the definition of the baseline design.A feasibility study including the design of the experimental insertions and technical insertions where different systems are located (Injection of each of the clockwise and anti-clockwise circulating beams, RF cavities, betatron collimation, momentum collimation and beam dump) is being conducted. We also adapt the global layout of the ring, following the results of placement studies for the tunnel and optimise the dipole filling factor to increase the centre of mass energy for experiments and maximise its scientific potential.

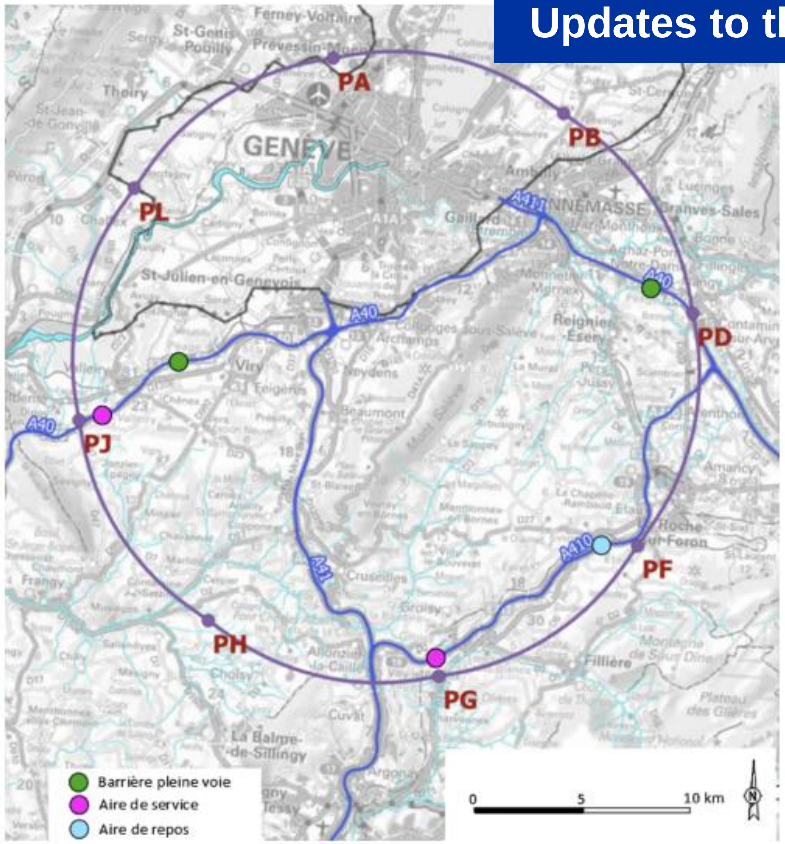


Fig. 1: Overlay of the FCC accelerator with locations of technical and experimental areas.

Relevant references

G. Perez-Segurana et. al, Study of the corrector systems for the new lattice of the CERN hadron-hadron Future Circular Collider. IPAC'24, Nashville, USA, 19-24 May 2024.

G. Perez-Segurana et. al, A new baseline layout for the FCC-hh ring. IPAC'24, Nashville, USA, 19-24 May 2024.

A. Abramov et. al, Collimation system for the updated FCC-hh design baseline. IPAC'23, Venice, Italy, 07-12 May, 2023.

M. Giovannozzi et. al, Recent updates of the layout of the lattice of the CERN hadron-hadron Future Circular Collider. IPAC'23, Venice, Italy, 07-12 May, 2023.

Thank you!

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Thank you to the University of Michigan, Dr. Steve Goldfarb, Dr. Junjie Zhu, and Dr. Myron Campbell.

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[1] D. Mirarchi et. Al, "A crystal routine for collimation studies in circular proton accelerators," 2015.
[2] M. D'Andrea et. al, "Characterization of bent crystals for beam collimation with 6.8 TeV proton beams at the LHC," 2024.

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