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nuSTORM accelerator modelling

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28/06/2021, nuSTORM general meeting

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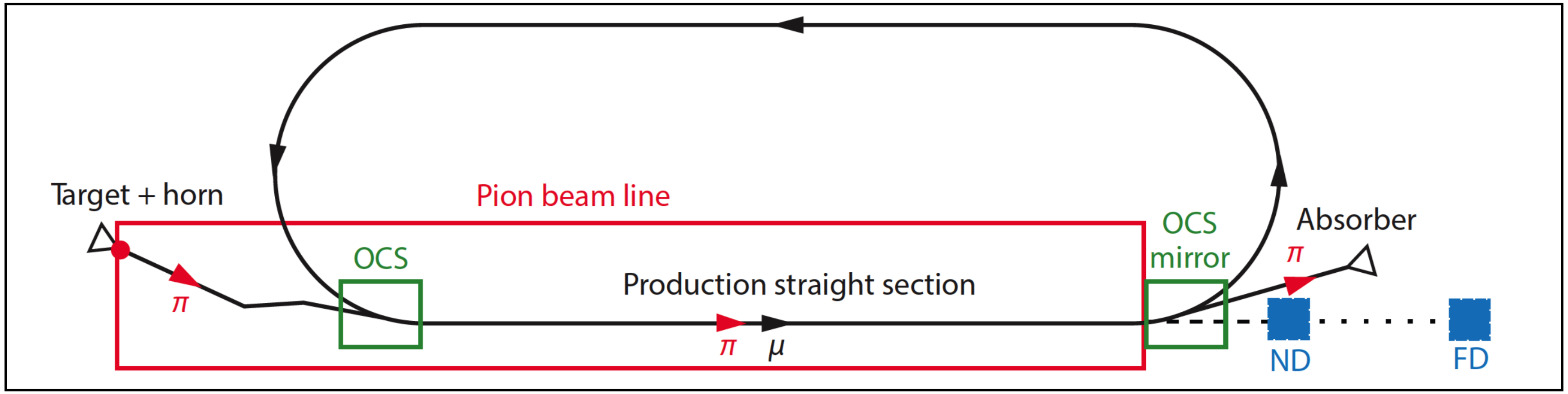
Outline

- Introduction
- Target
- Horn
- Injection line
- Storage ring
- Conclusions and future plans

nuSTORM - Origin - Idea

- nuSTORM (`NeUtrinos from STORed Muons') is a facility based on a low-energy muon decay ring.
- Can use existing proton driver (like SPS at CERN)
- Conventional pion production and capture (horn)
  - Quadrupole pion-transport channel to decay ring
  - Direct injection of pions into the decay ring to form circulating muon beam subsequently used as a source of neutrinos w/o a kicker



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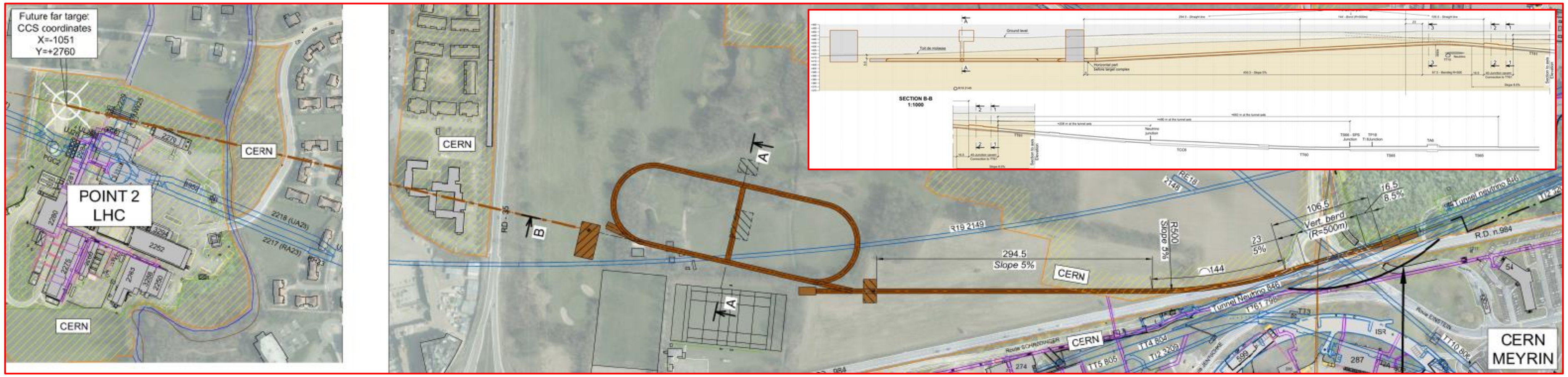
nuSTORM - Motivation

- Neutrino interaction physics – nuSTORM can measure neutrino cross sections precisely
  - Significantly reduce the main source of systematic errors for long base-line oscillation experiments
- Short baseline neutrino oscillation physics – search for sterile neutrinos
- Accelerator and Detector Technology Test Bed
  - Proof of principle for the Neutrino Factory concept
  - Muon Collider R&D platform

nuSTORM siting at CERN



- Extraction from SPS through existing tunnel
- Siting of storage ring:
  - Allows measurements to be made ‘on or off axis’
  - Preserves sterile-neutrino search option

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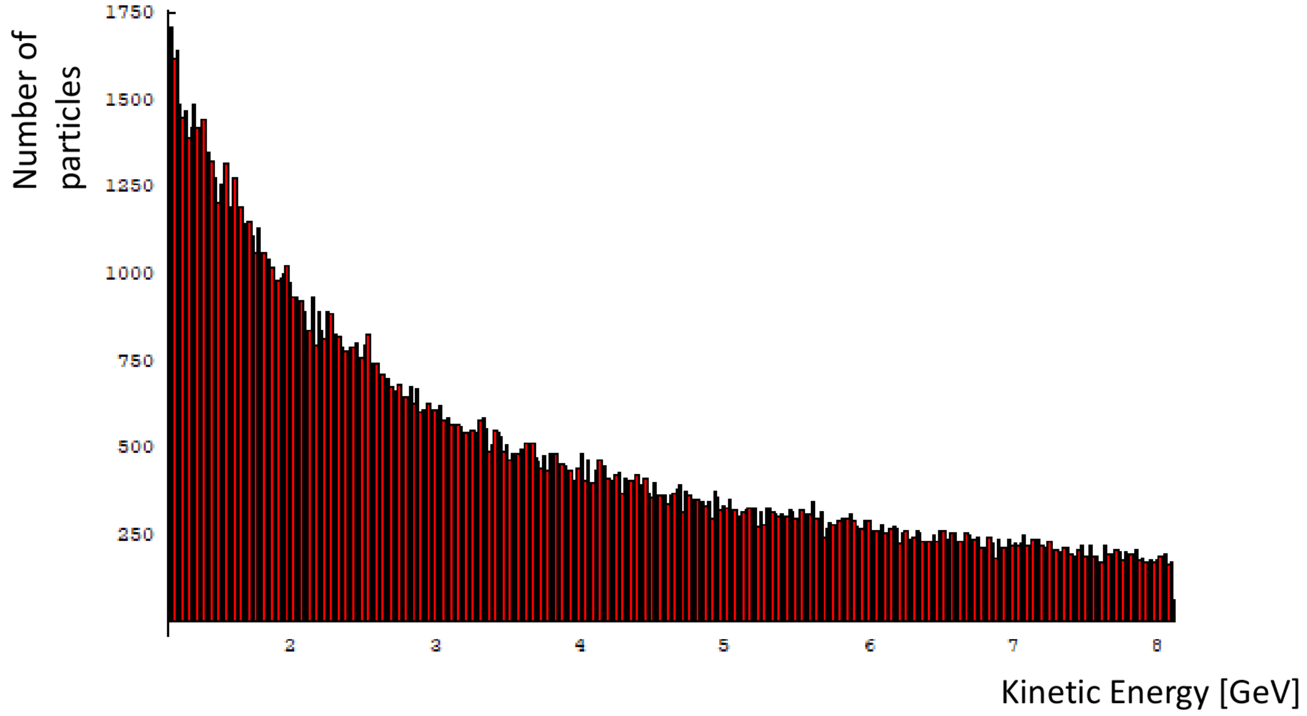
Target modelling in MARS code

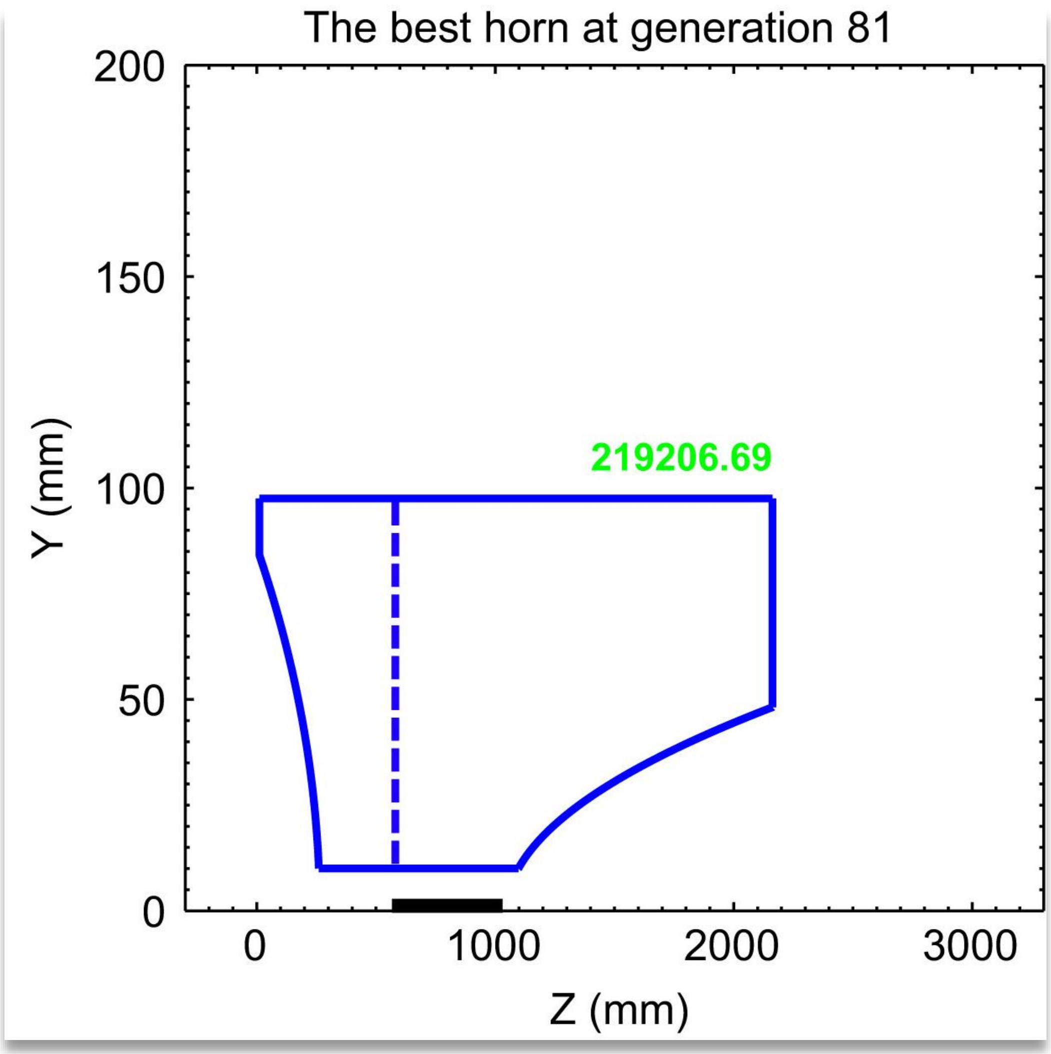
- Beam and target parameters used in MARS simulation (courtesy of S. Striganov):
  - Beam size: $\sigma_x = \sigma_y = 0.267$ cm
  - Proton beam energy: 100 GeV
  - Target material: inconel
  - Target size: radius=0.63cm, length=46cm

Pion spectrum from MARS simulation



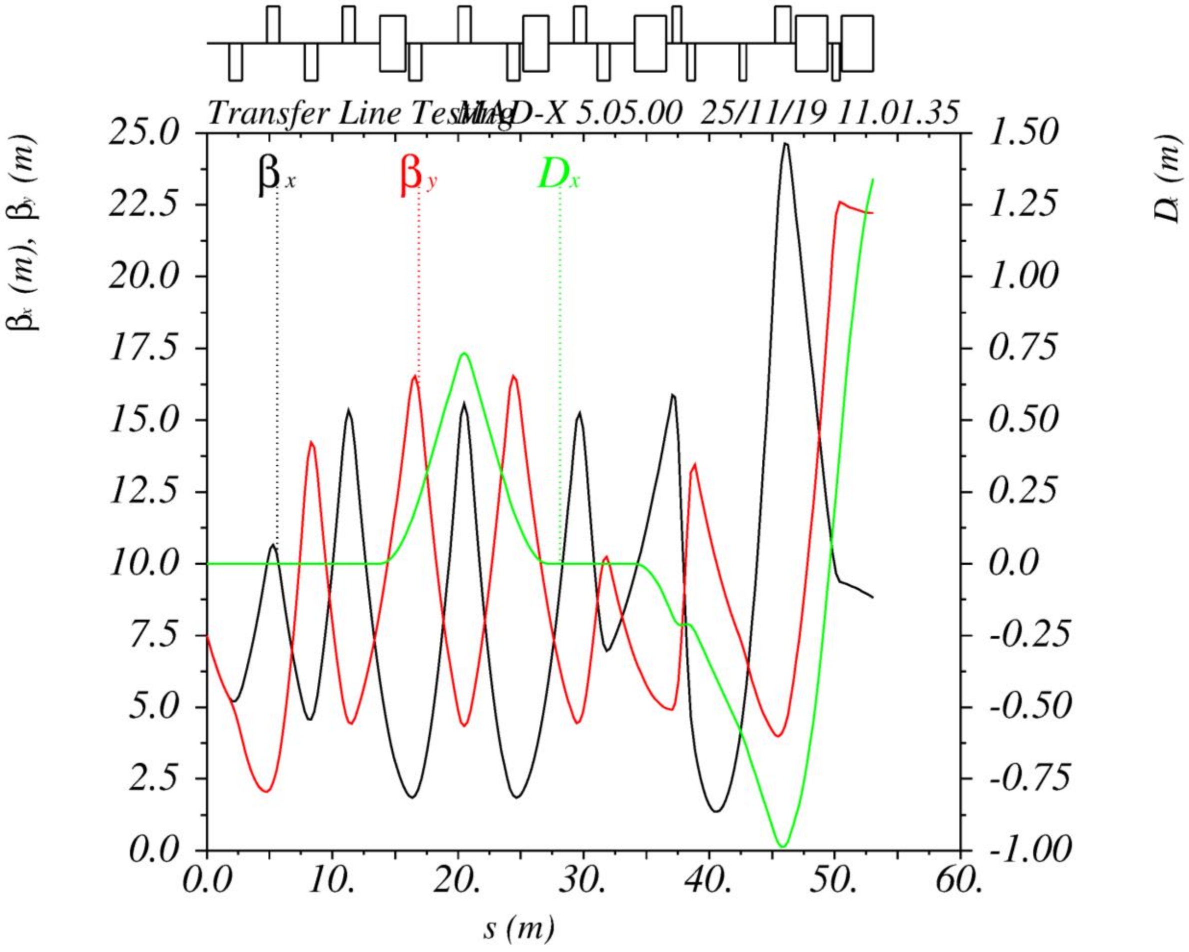
Horn modelling

- Fermilab design by A. Liu was used
- Only forward part was modelled
- Magnetic field was modelled, but scattering in the conductor still needs to be incorporated
- Current was scaled for different energies



Injection line (1)

- CERN design by C. Hunt was simulated in G4BeamLine
- Large momentum acceptance was confirmed
- Problems were encountered in modelling the exact geometry from the injection septum downstream
  - Potential problems with sector bends in G4BeamLine
    - It could be mitigated using rectangular bends and/or field maps
- We aim to perform simulations using BDSIM



Optics in the injection line (MAD-X)

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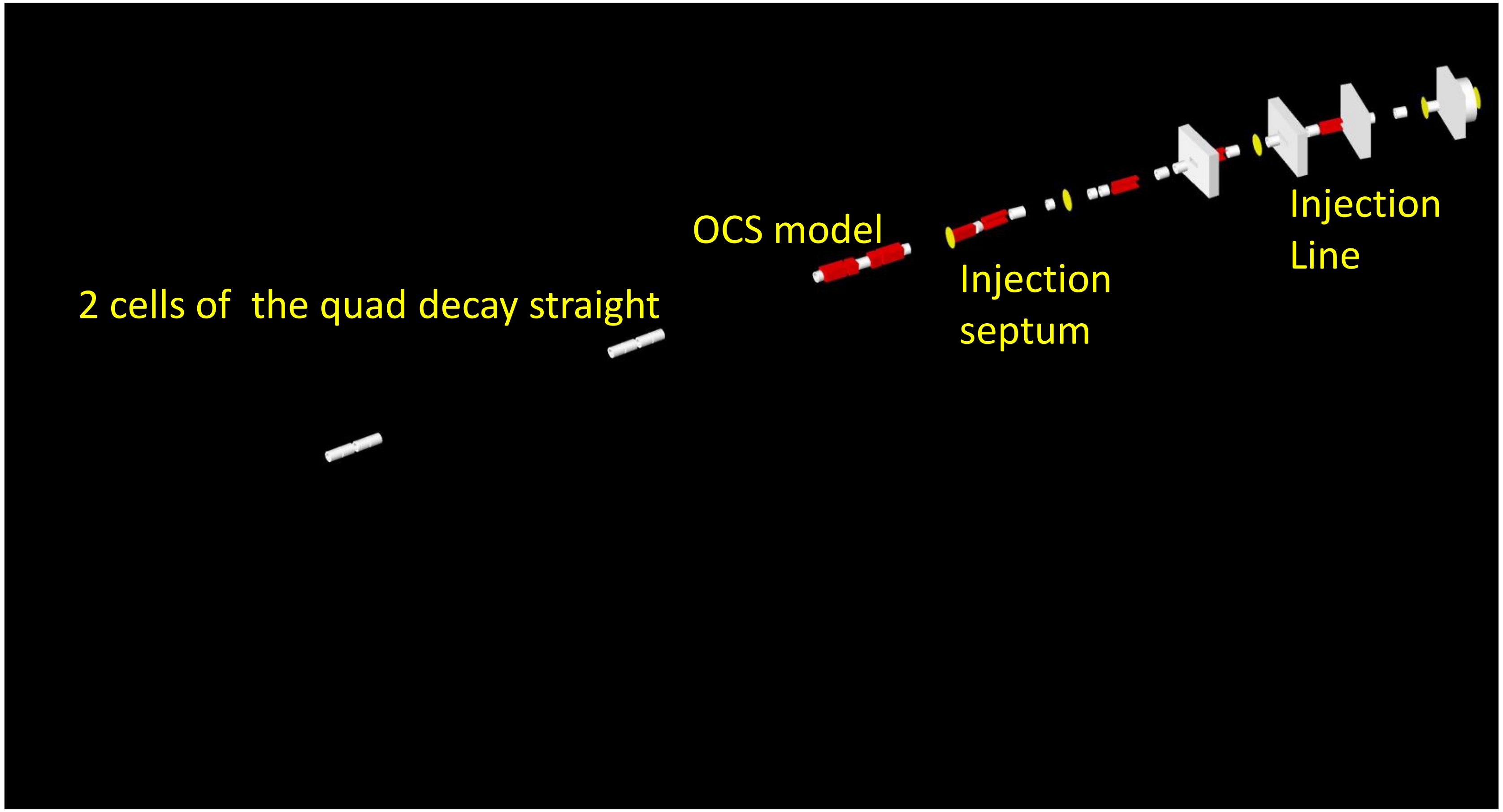
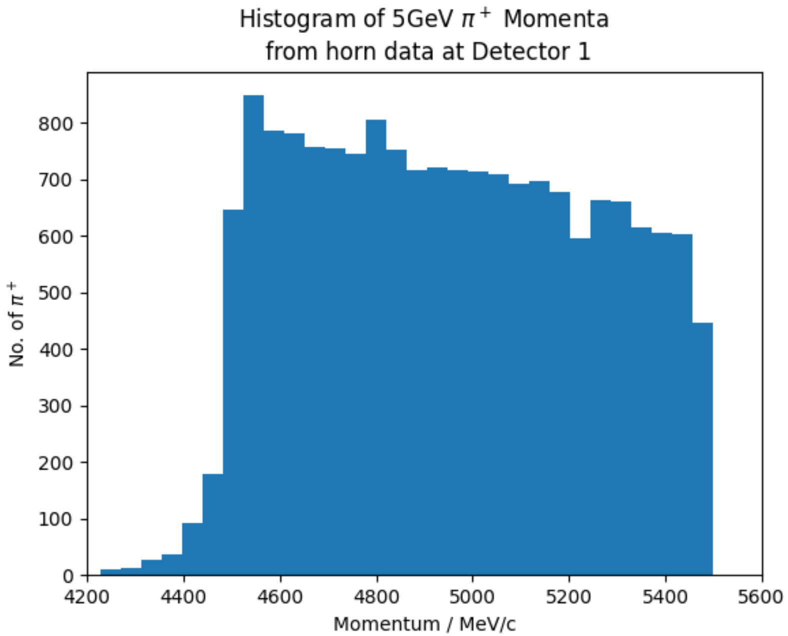
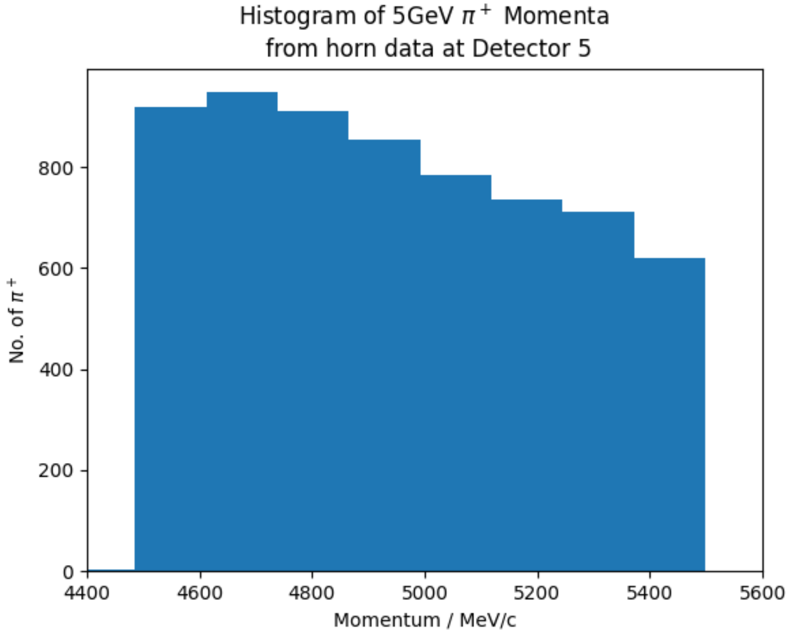
Injection line (2)







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Storage ring designs

- FODO design (example: A. Liu's design)
  - Separate-function magnets
  - Relative momentum acceptance ~±9%
  - Large, natural chromaticity, some losses induced by resonances
  - Zero dispersion in the injection/production straight
    - Good efficiency of muon storage and neutrino production
- Full FFA (Fixed Field Alternating gradient) design
  - Combined function magnets
  - Relative momentum acceptance ~±16% or more
  - Zero chromaticity, no resonance crossing
  - Small dispersion and scalope angle in the the injection/production straight
    - Reduced efficiency of muon storage and some effects on the neutrino spectrum
- Hybrid design
  - Combined function magnets in the arcs and in the return straight, quads in the injection/production straight
  - Relative momentum acceptance ~±16%
  - Relatively small chromaticity originating from the injection/production straight
    - Tune spread between integer and half integer lines
    - Some extra correction possible
  - Zero dispersion in the injection/production straight
    - Good efficiency of muon storage and neutrino production

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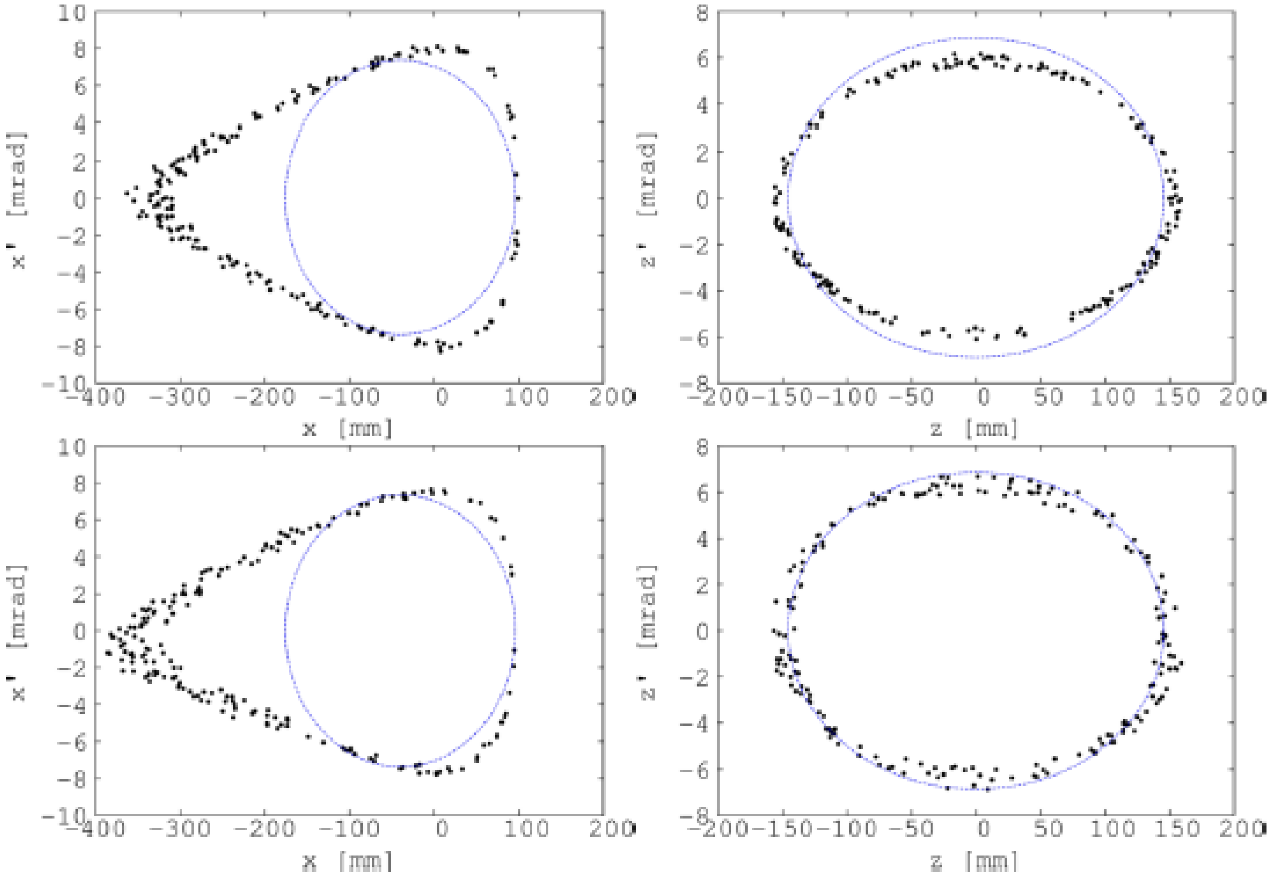
PyZgoubi vs FixField (JB's code) comparison for the full FFA triplet lattice

JB

PyZgoubi



*Triplet lattice

S. Tygier,
First discussion of nuSTORM in the context of the Physics Beyond Colliders workshop, IC, 16/02/17

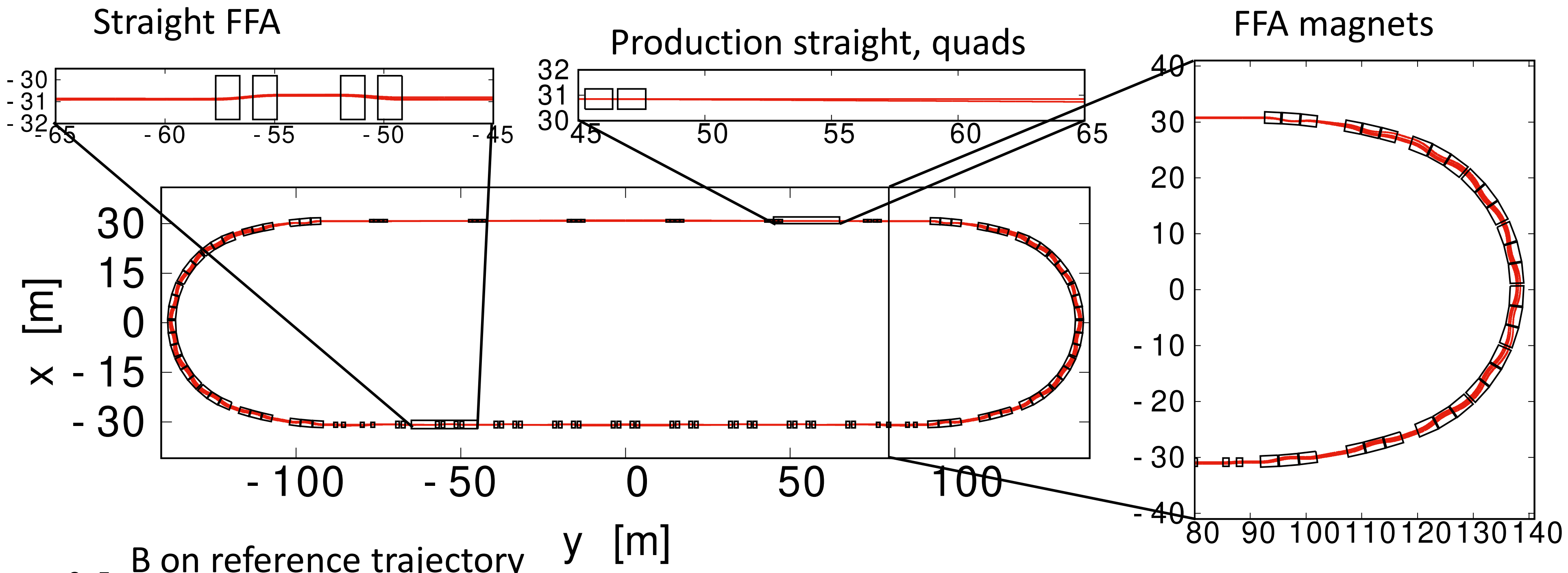
Very good agreement!

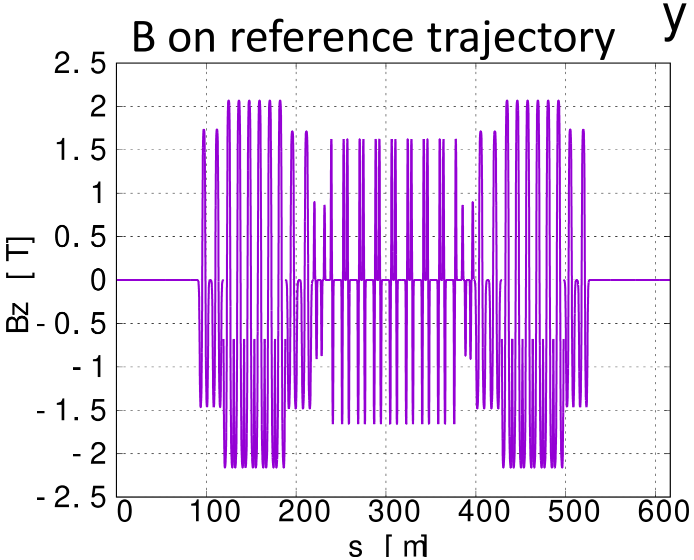
Hybrid design assumptions

- Long straight sections kept at 180m (as in FNAL designs)
- Arc modified to accommodate higher momentum (up to 6.5 GeV/c orbit)
- Dispersion in the arcs is kept smaller to reduce the magnet aperture
- FFA parts (both arcs and straight FFA) were made with a fully transparent optics (both phase advances modulo π).
- For the quad production the solution made of regular cells is selected
- Extra matching sections added in the straight FFA part

Hybrid design

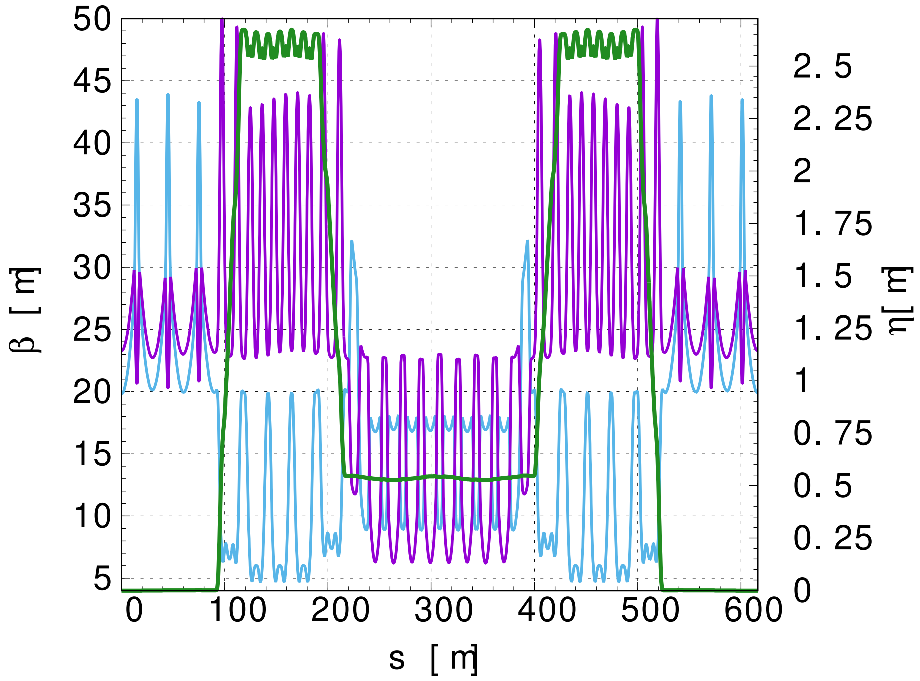
Arc with two matching sections, FFA magnets

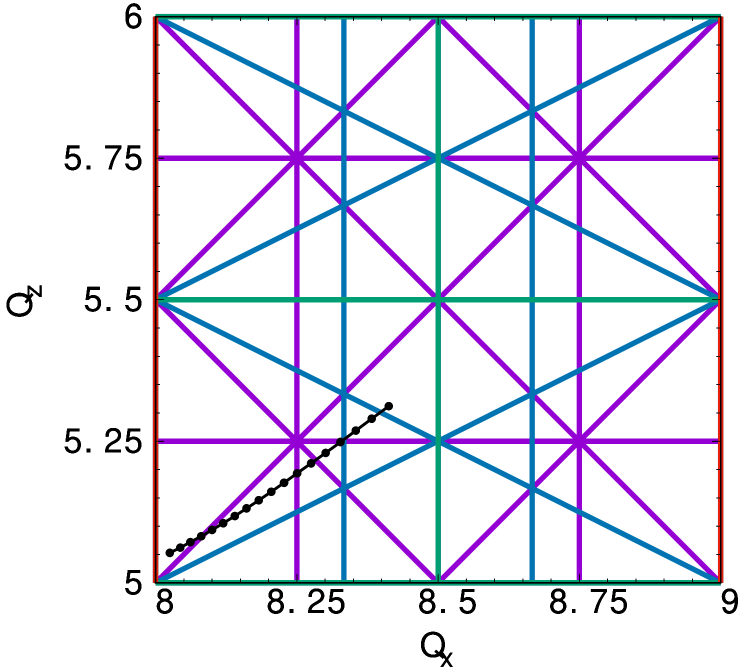




- SC magnets in the arcs
- NC magnets in the straights
- Several types of the lattice cells combined
- Injection in the dedicated straight at the end of the arc

Hybrid optics

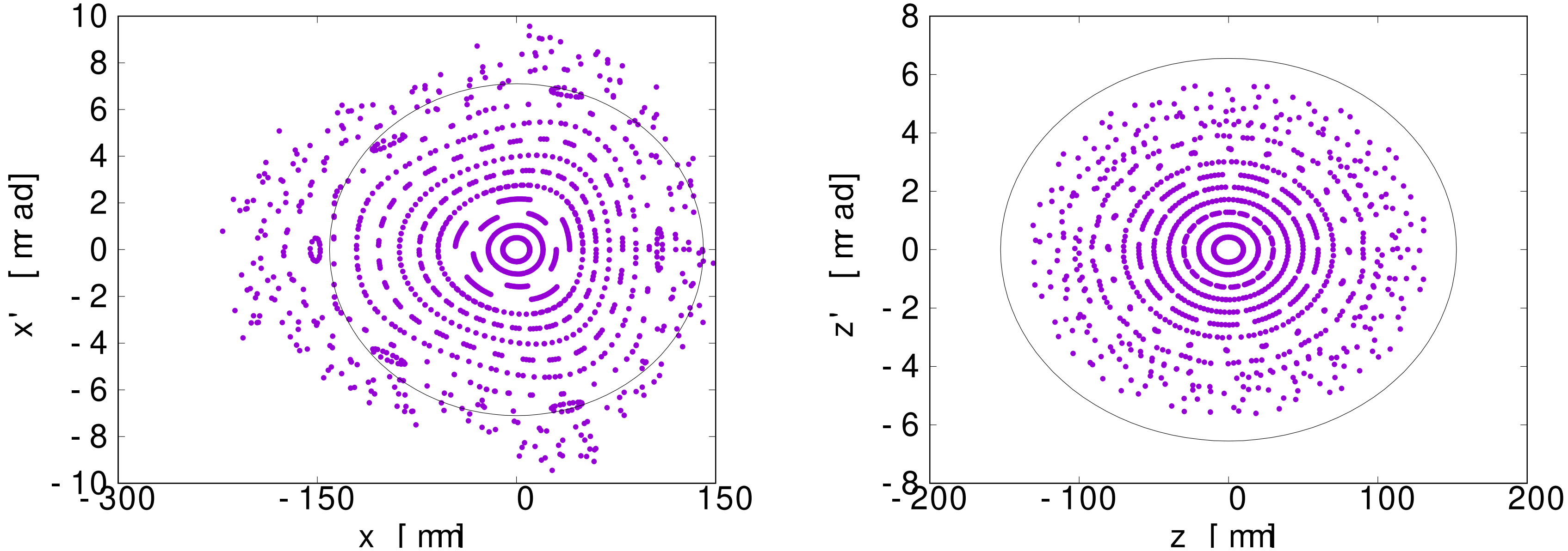




Tune shift for ±16% relative momentum spread

- Good dispersion matching to zero in the production straight
- Relatively large beta functions in the production straight for good neutrino production efficiency

Hybrid ring, tracking in FixField



- Good DA in both planes
- Cross check with PyZgoubi (work in progress)
- Tracking with the full beam distribution (next step)

Current focus and near future plans for Hybrid design

- Work on the Hybrid FFA design:
  - Cross check between codes
  - Possibly a modest chromaticity correction to reduce the tune spread to ~0.2
  - Further design work on injection
- Evaluation of the performance: momentum spread, DAs, transmission and the neutrino fluxes, and comparison with other lattices (FODO, full FFA).

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Conclusions

- nuSTORM is a serious candidate to serve both neutrino physics and R&D for a Muon Collider
- We aim to perform further studies on the injection line
  - Potential modifications of the injection section
  - Search for flexible front end to allow for fiding ENUBET, nuSTORM and Muon Collider test facility
  - Further tracking studies to inform normalisation PPT
- We will make further studies on the storage ring
- VFFA can be an ideal machine for muon acceleration in a Muon Collider and also serve for ISIS-II. We aim to seek a potential use in nuSTORM