The University of Manchester

nuSTORM
Neutrinos from STORed Muons

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2 March 2020

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The Cockcroft Institute of Accelerator Science and Technology

Science & Technology Facilities Council

Overview

- Muon storage ring (μ^- or μ^+)
- Long straight sections for decays
- Produce ν_e, ν_μ, $\bar{\nu}_e$ and $\bar{\nu}_\mu$ beams
- Well known spectrum and flux
- Candidate site at CERN

$$\mu^- \longrightarrow e^- + \bar{\nu}_e + \nu_\mu$$

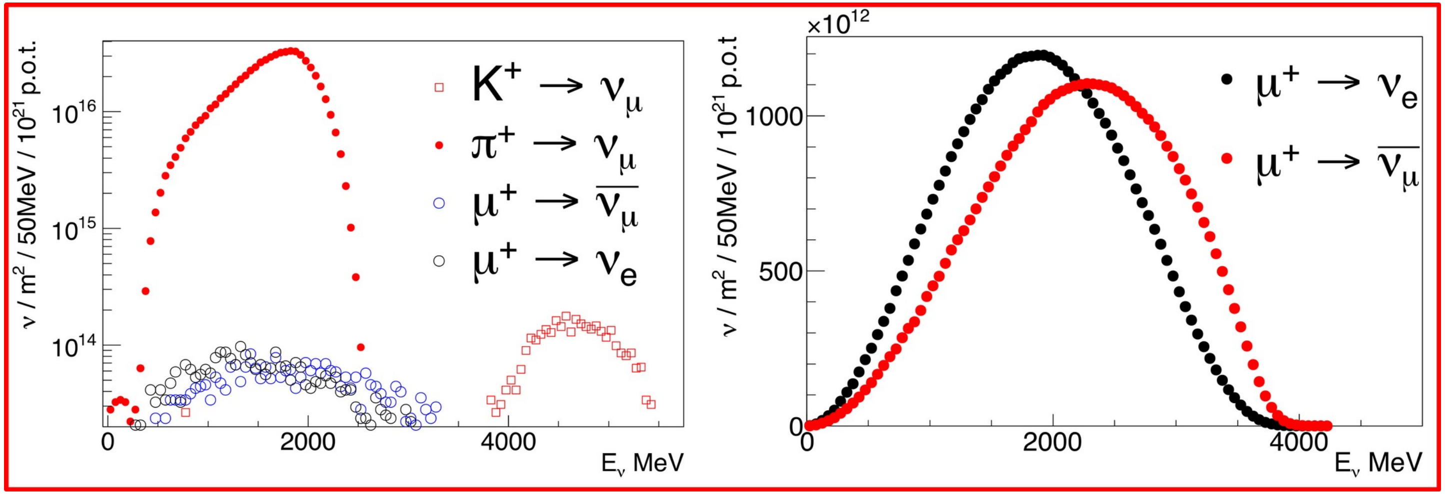
$$\mu^+ \longrightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

$$\pi^- \longrightarrow \mu^- + \bar{\nu}_\mu$$

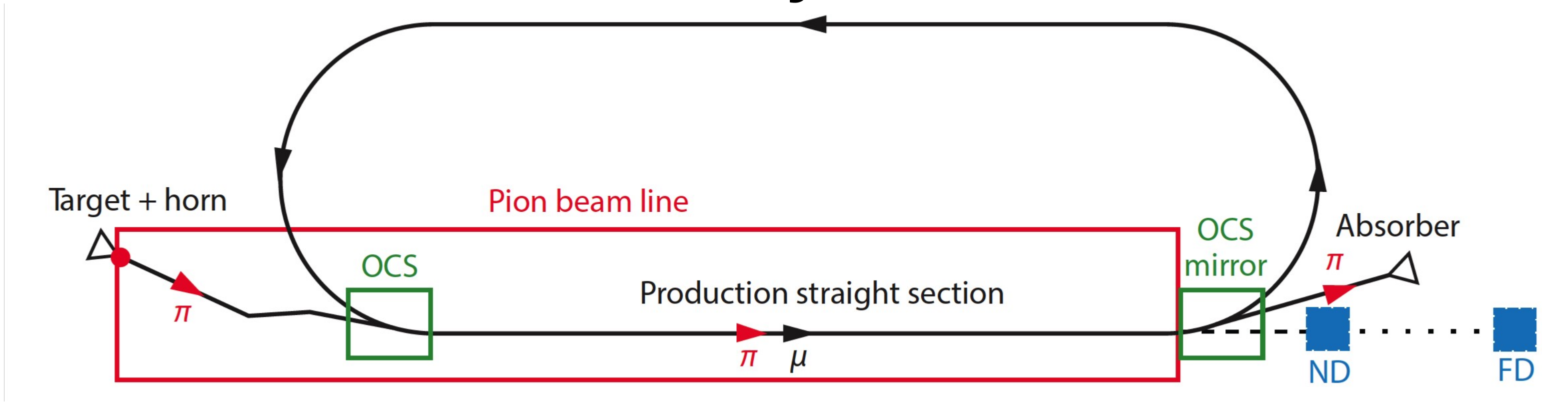
$$\pi^+ \longrightarrow \mu^+ + \nu_\mu$$

Physics case

- < 1% flux error give unique precision
- measure neutrino-nucleon cross sections
  - ν_e, ν_μ, $\bar{\nu}_e$ and $\bar{\nu}_\mu$
  - First precision ν_e and $\bar{\nu}_e$ cross sections in 1-4 GeV range
- Sterile neutrinos search
- R&D synergy with Neutrino Factory, Muon accelerators and colliders



Layout

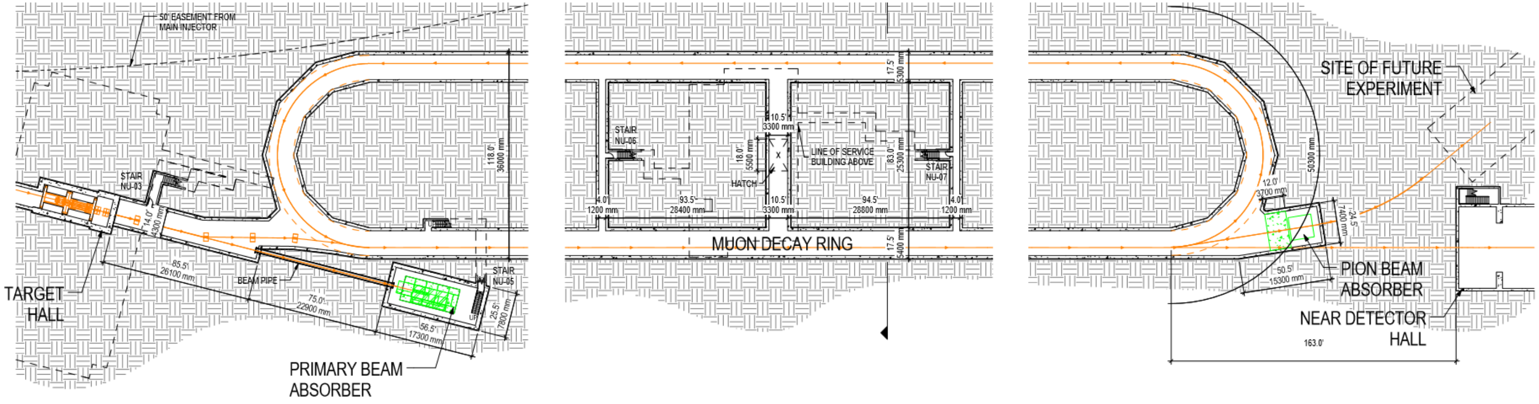


- Proton target with magnetic horn produces pion beam
- Chicane for charge selection
- Stochastic injection into main ring
- Long decay straights - ~150m
- Return arcs – total ring ~500m

- No kickers
- no acceleration
- no ramping

Fermilab

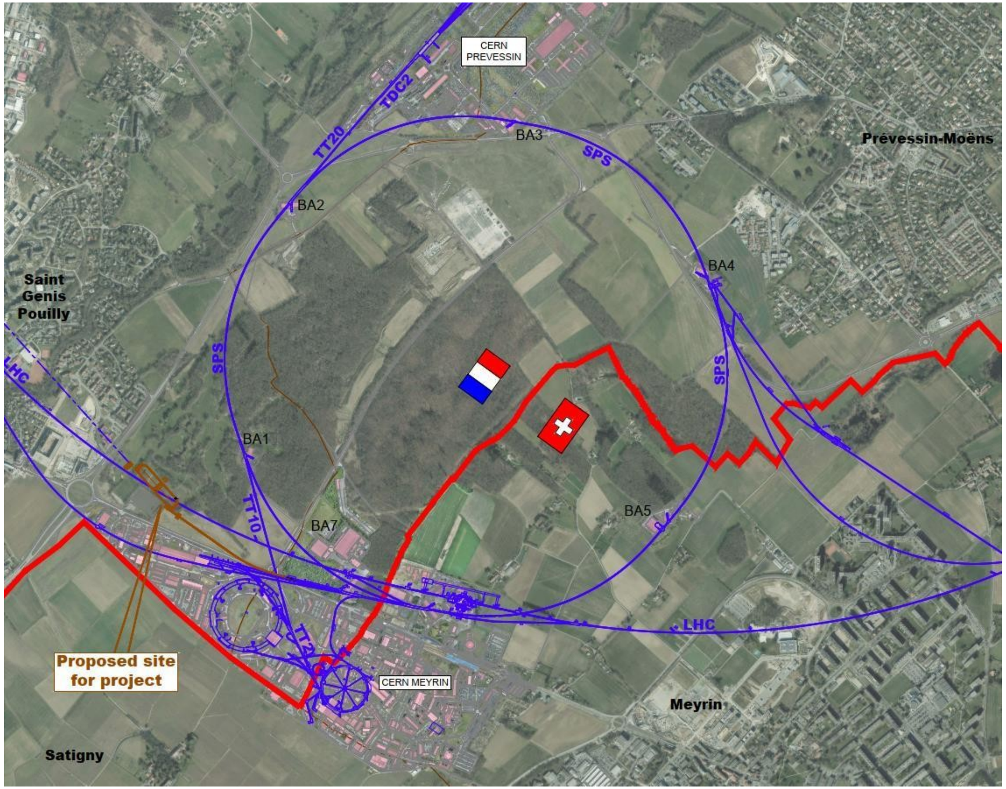
- Project definition report stage
- 120 GeV from the Main Injector
- 10^{21} POT
- 5±1 GeV/c pions injected
- 3.8±10% GeV/c muon stored
- 50m, 2000m detectors



FLOOR PLAN ELEV. 708.00'
SCALE: 1" = 30'-0"

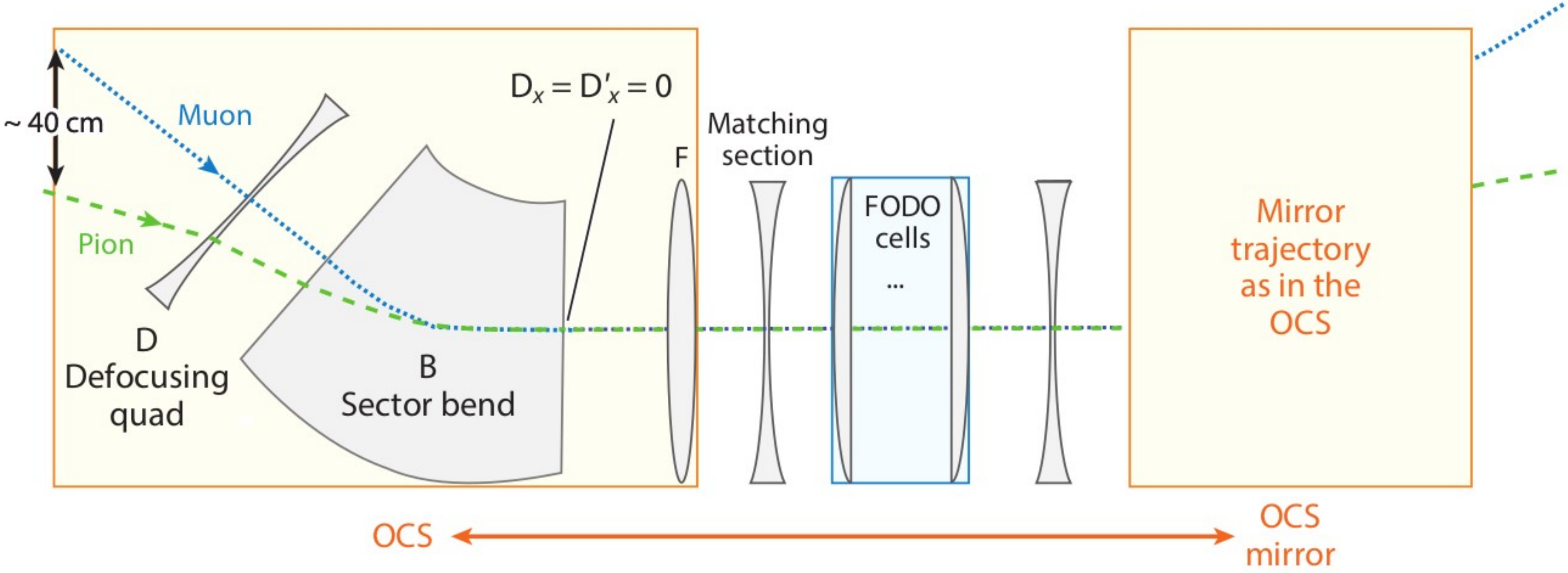
CERN

- Investigated as part of Physics Beyond Colliders
- 100 GeV protons from SPS
- Muons up to 6.5 GeV/c
- Far detector at LHC point 2 (1.75 km) + near detector
- Feasibility studies done for integration, civil eng and radiation protection

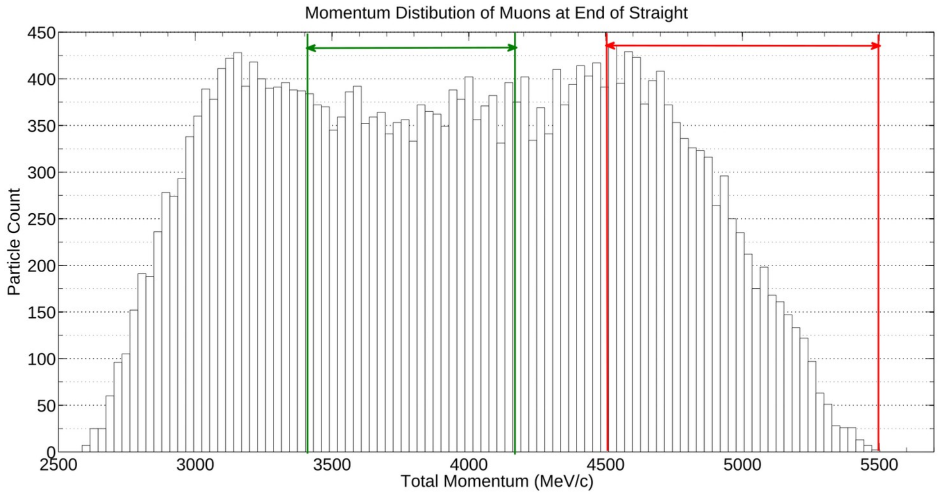


Stochastic injection

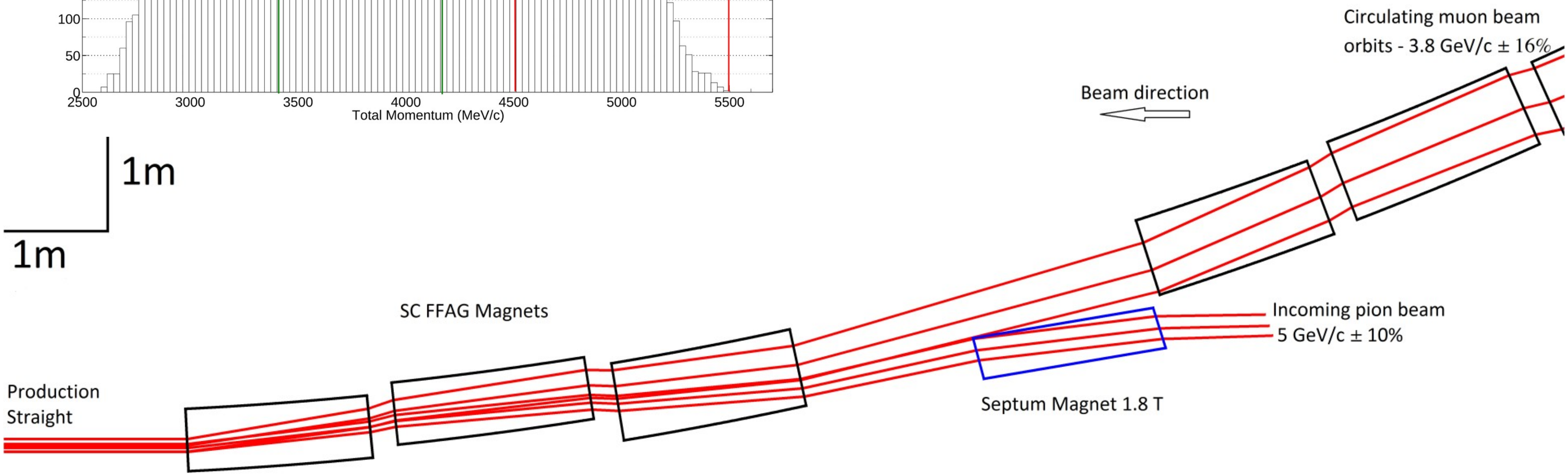
- Novel stochastic injection – purely optical
- Injection channel for Pion momentum
- Pions decay to muon in 1st straight
- Muons within momentum acceptance captured



Stochastic injection

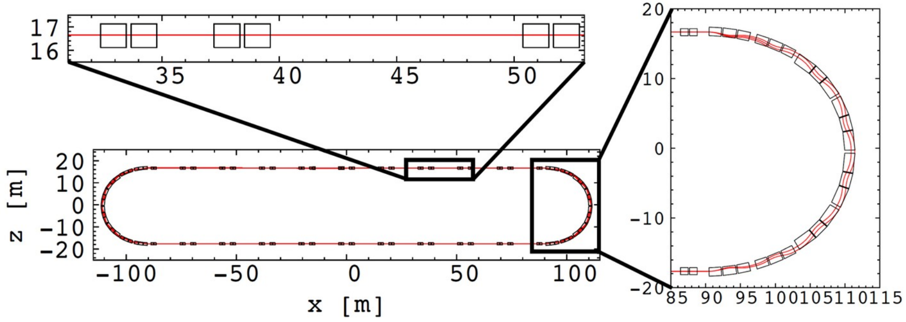


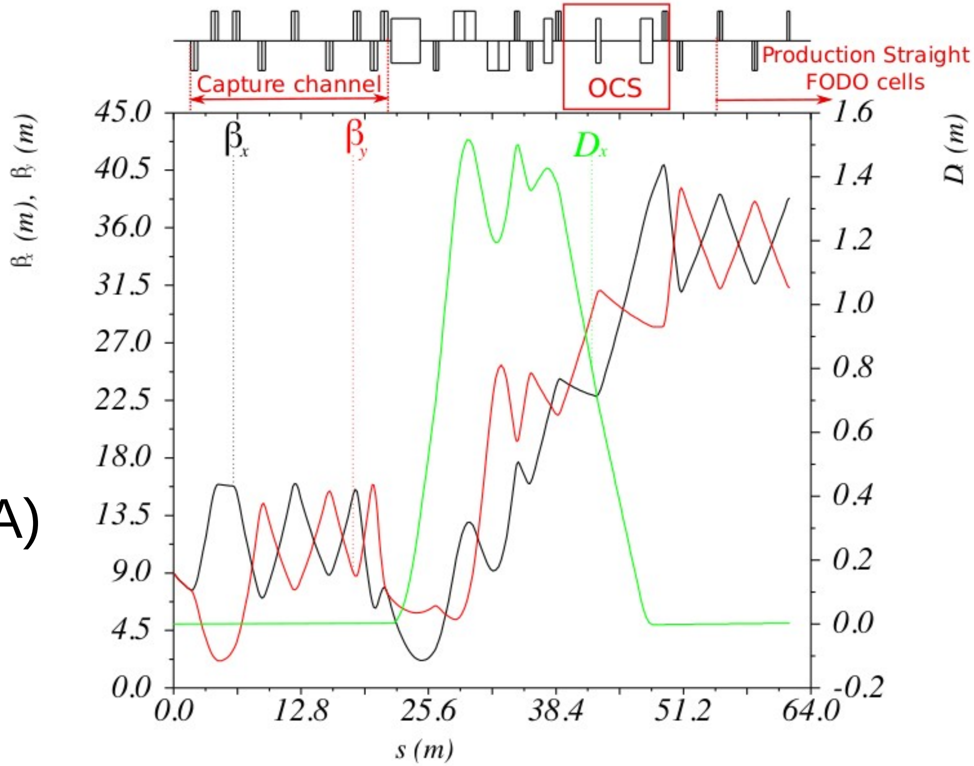
- No kicker required
- Remaining pions extracted by mirror and end of straight



Lattice options

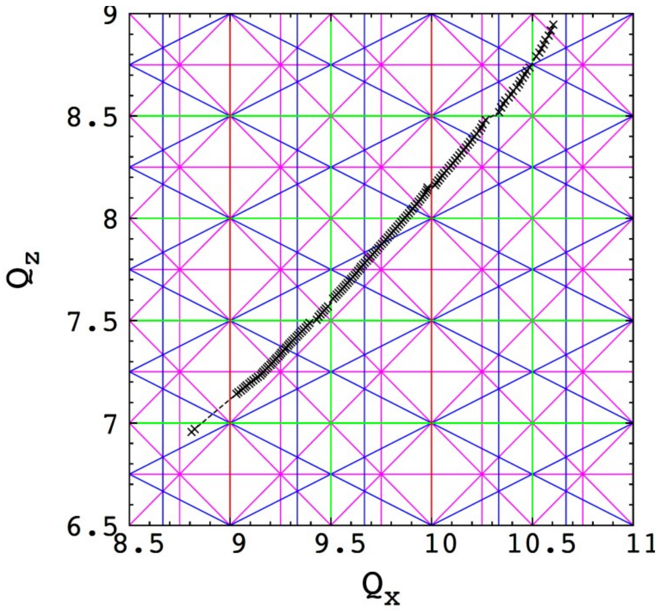
- Requirements
  - Large dynamic aperture
  - Small angles in straights
- 3 lattice options
  - FODO – traditional FODO lattice
  - Fixed-Field Alternating-Gradient (FFA)
  - Hybrid (FODO on injection straight)

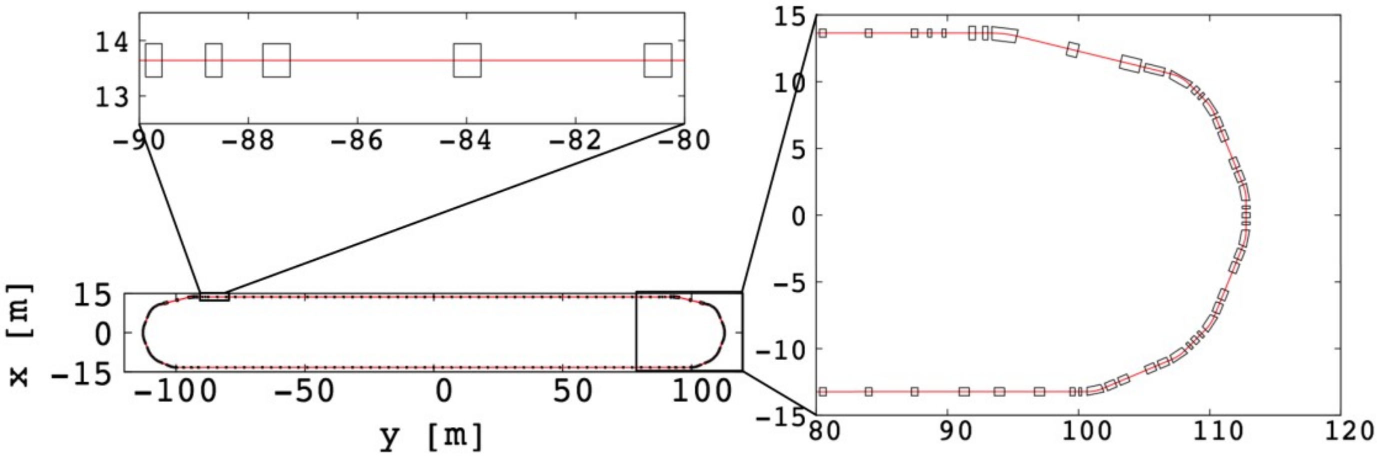


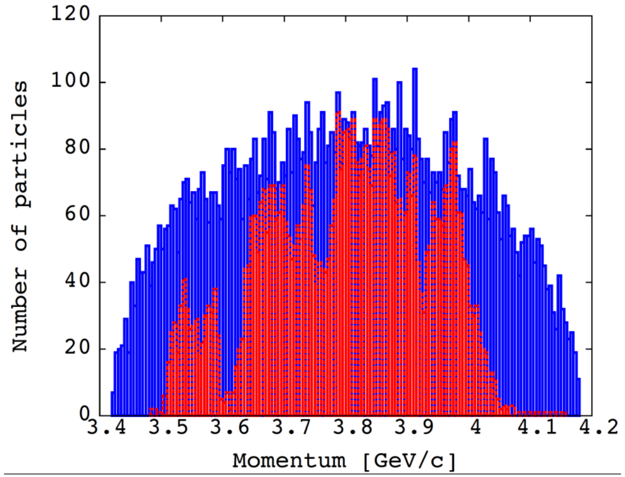


FODO lattice

- Race-track synchrotron
- Zero dispersion straights
- Tune crosses integers
- Significant resonant losses

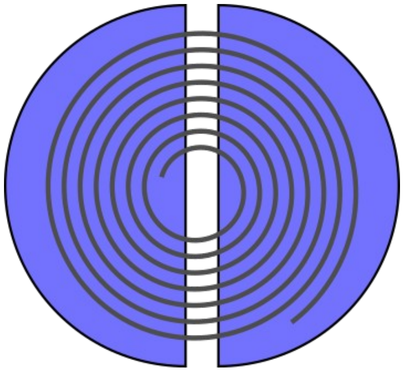


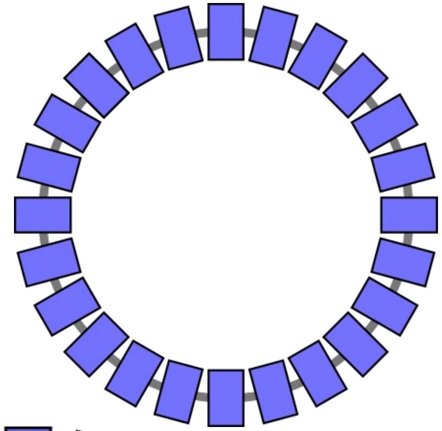


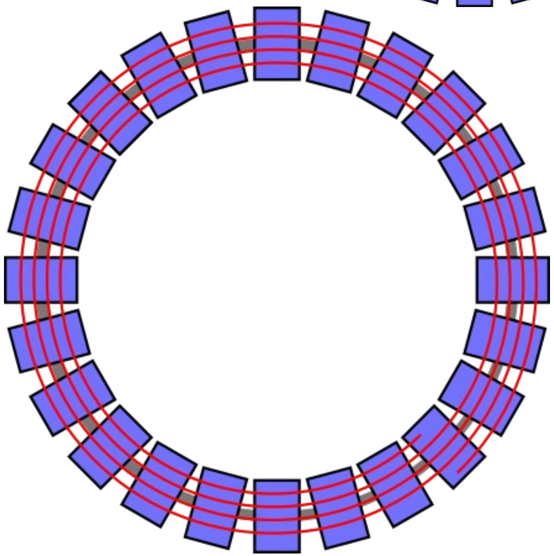


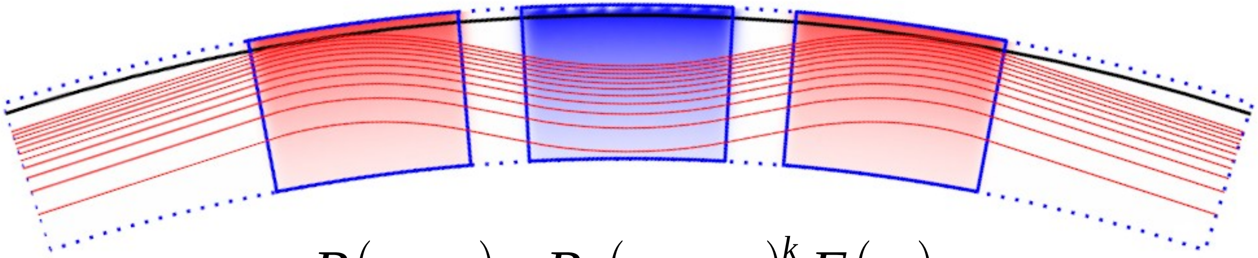
Fixed-field Alternating-Gradient

- Magnets fixed in time
  - Like a cyclotron
- Alternating Gradient
  - Like a Synchrotron
- Field increases with radius
- Higher momentum particles move outwards
- In scaling FFA optics same for all momentum









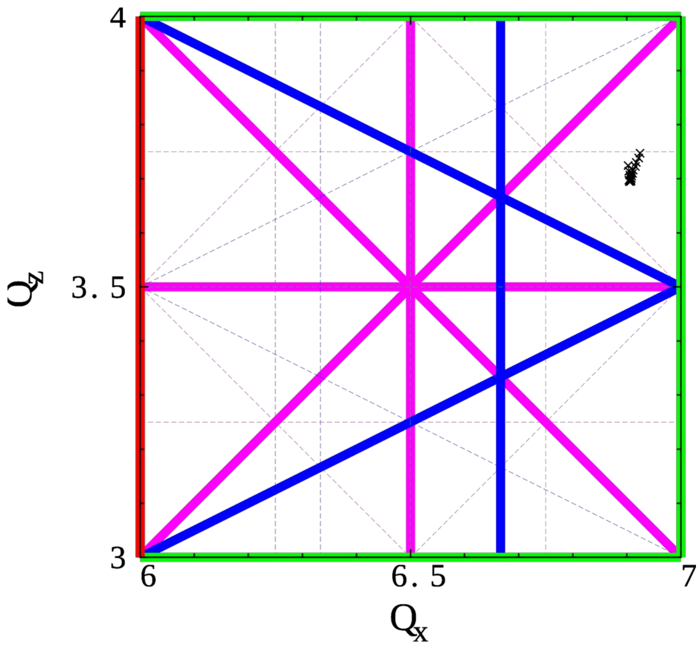
$$B(x, y) = B_0 (x - x_0)^k F(y)$$

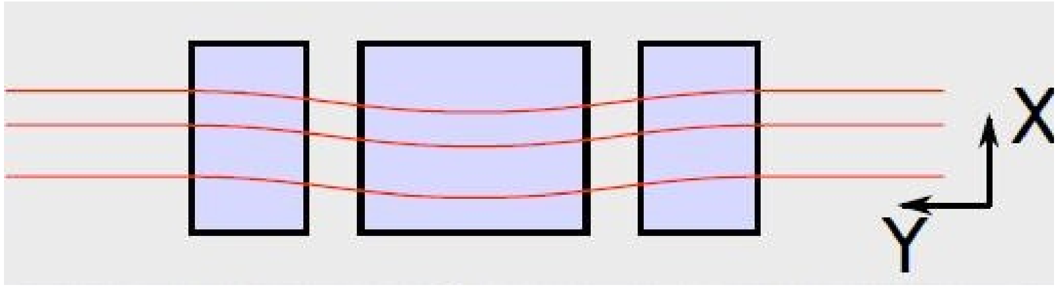
FFA lattice

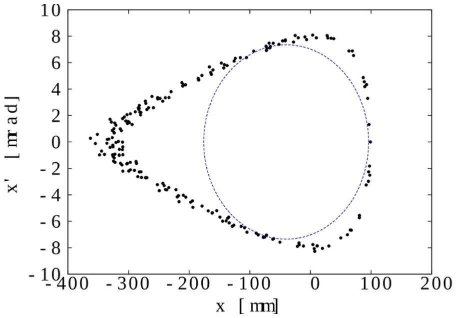
- Straight FFA section
- Magnets have field

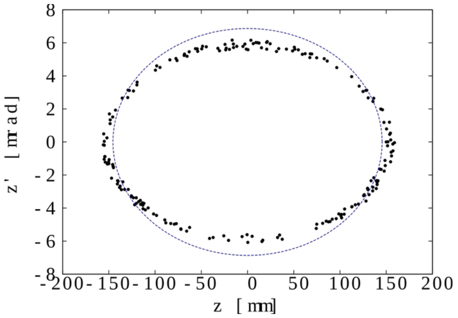
$$B(x,y)=B_0 e^{m(x-x_0)} F(y)$$

- Zero chromaticity
- Large acceptance
- Triplet and quadruplet options



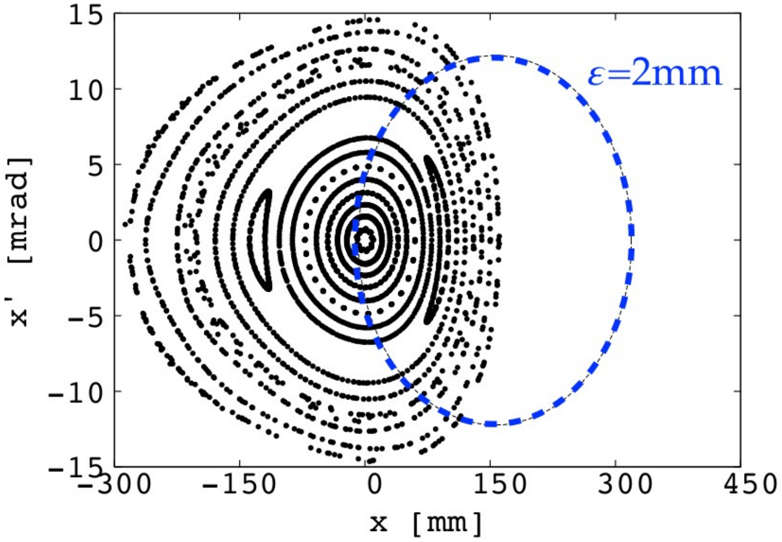


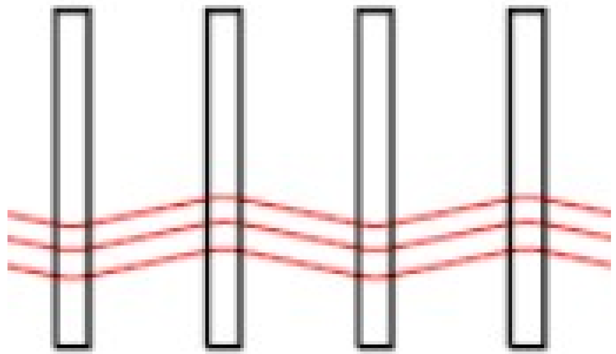




FFA issues

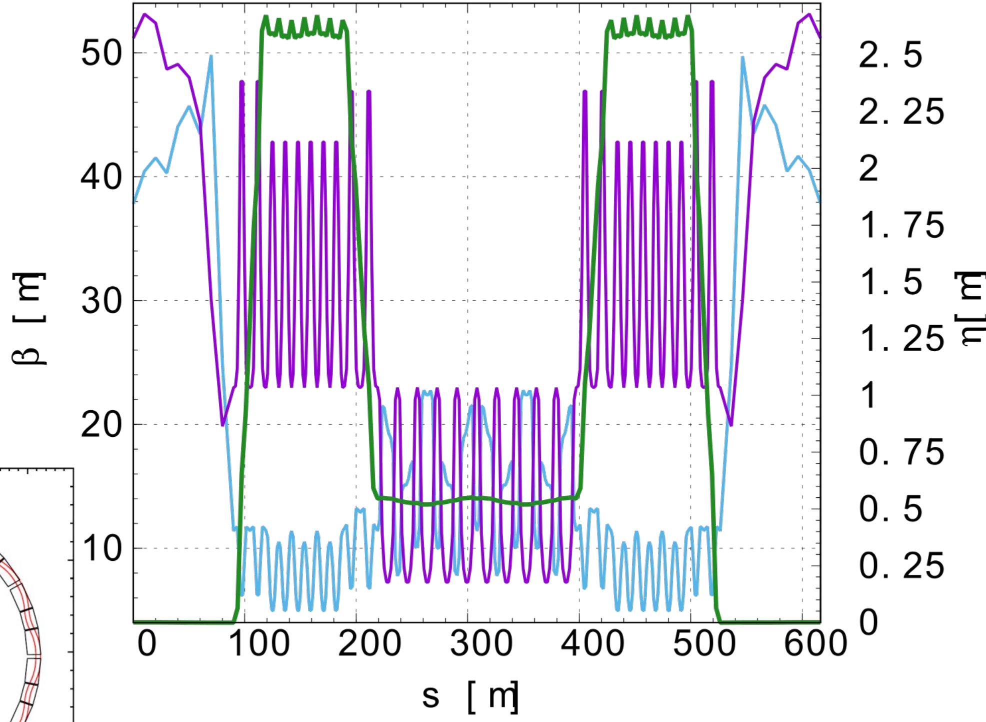
- FFA inherently has dispersion
  - Closed orbit for incoming pions is offset from captured muons
  - Reduces capture efficency
- Scallop angle
  - Closed orbits not straight
  - Greater spread in ν beam

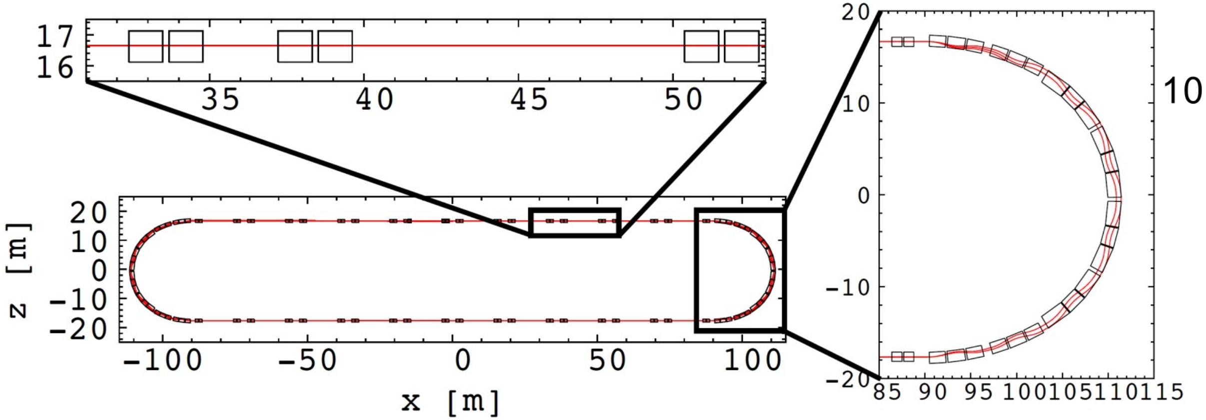




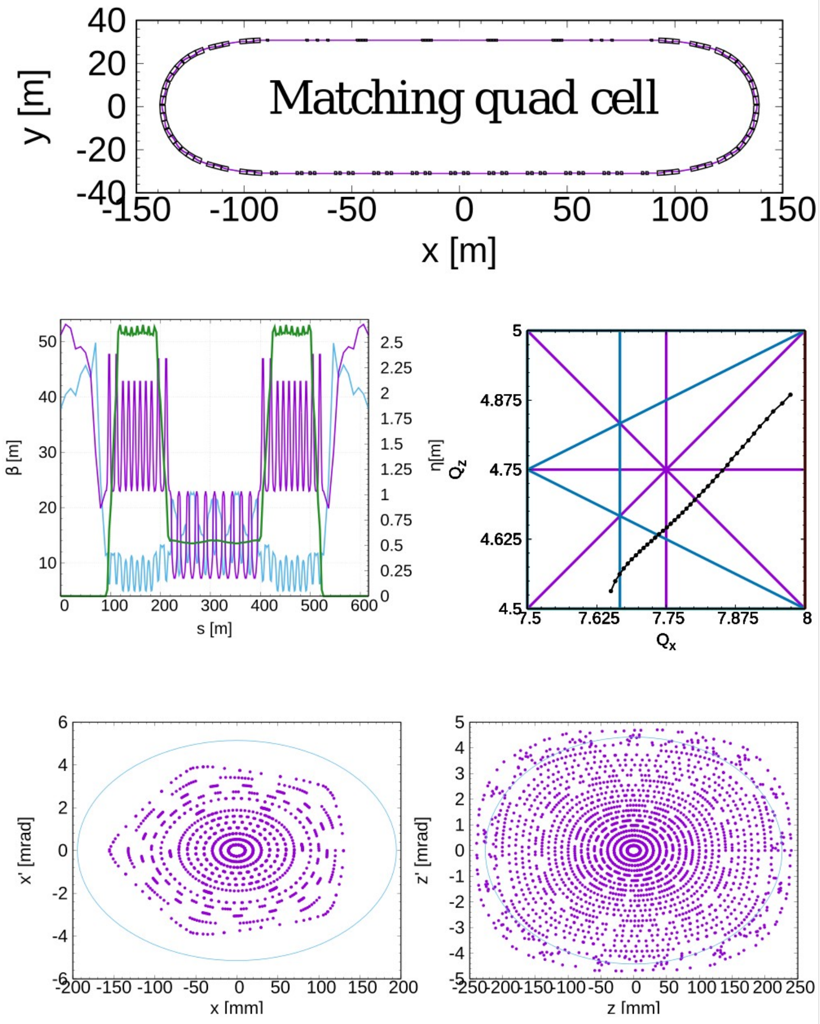
Hybrid lattice

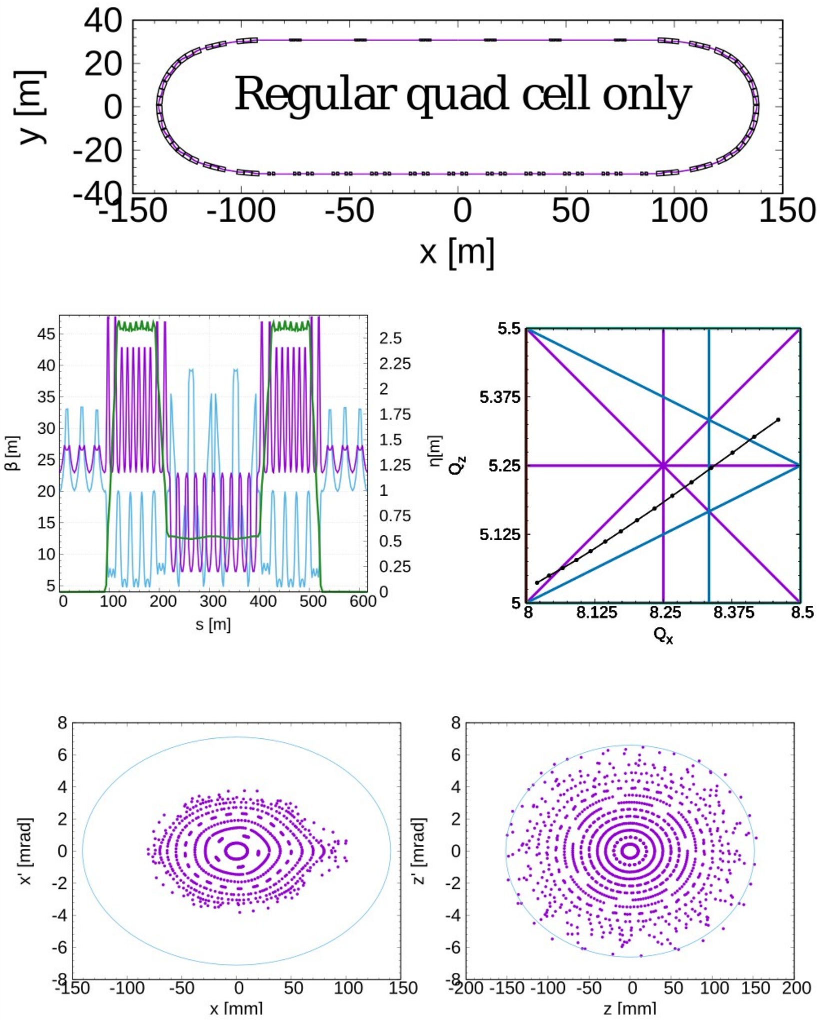
- FODO straight for capture/decay
  - Zero dispersion to maximised capture
  - No scallop angle
- FFA return straight to control tune
  - Low chromaticity
  - Higher acceptance



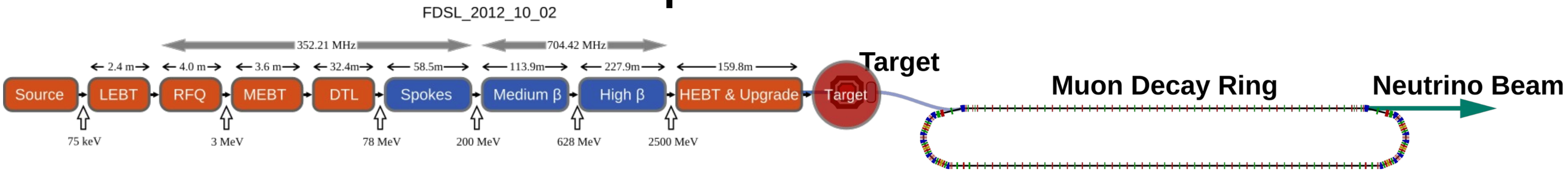


Hybrid optimisation





Prospects at ESS



- Protons at 2 GeV
  - Smaller arcs
  - New horn design
  - Lower pion momentum
  - Reduced pion lifetime
  - Compact pion transport

EUROPEAN SPALLATION SOURCE

- Early study on muon storage rings by Neuffer considered 8, 4.5 and 1.5 GeV muons (based on 80, 30 and 8 GeV protons)

Conclusion

- NuStorm low flux error gives unique access to ν cross sections which are a large source of systematic in long baseline experiments
- Contributes to searches for sterile ν
- Proof or principle for Neutrino Factory, step to Muon Collider
- Several lattice options being optimised and compared
- Feasibility study for CERN
- ESS source would be lower momentum than previously investigated
- Detailed studies needed