Muon Cooling Demonstrator Front End

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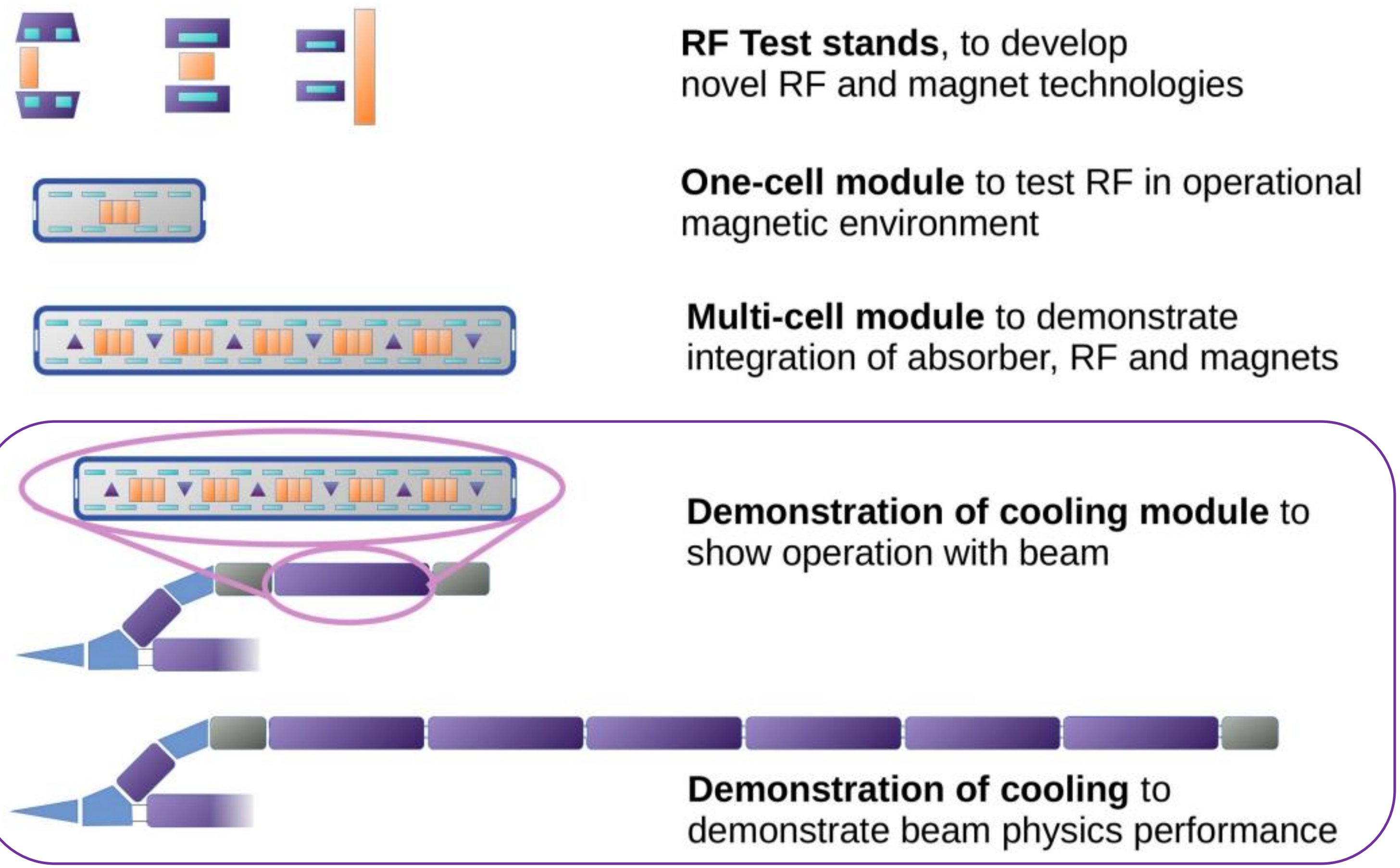
6D cooling R&D Plan



RF Test stands, to develop novel RF and magnet technologies

One-cell module to test RF in operational magnetic environment

Multi-cell module to demonstrate integration of absorber, RF and magnets

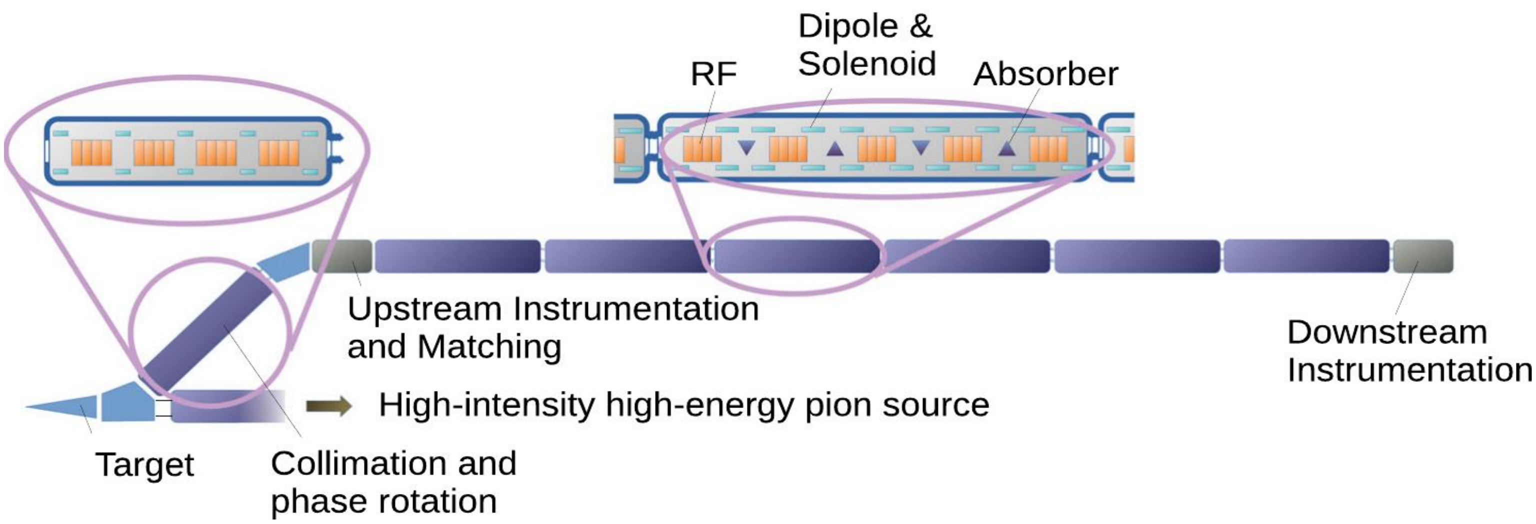
Requires beam

Demonstration of cooling module to show operation with beam

Demonstration of cooling to demonstrate beam physics performance

C. Rogers

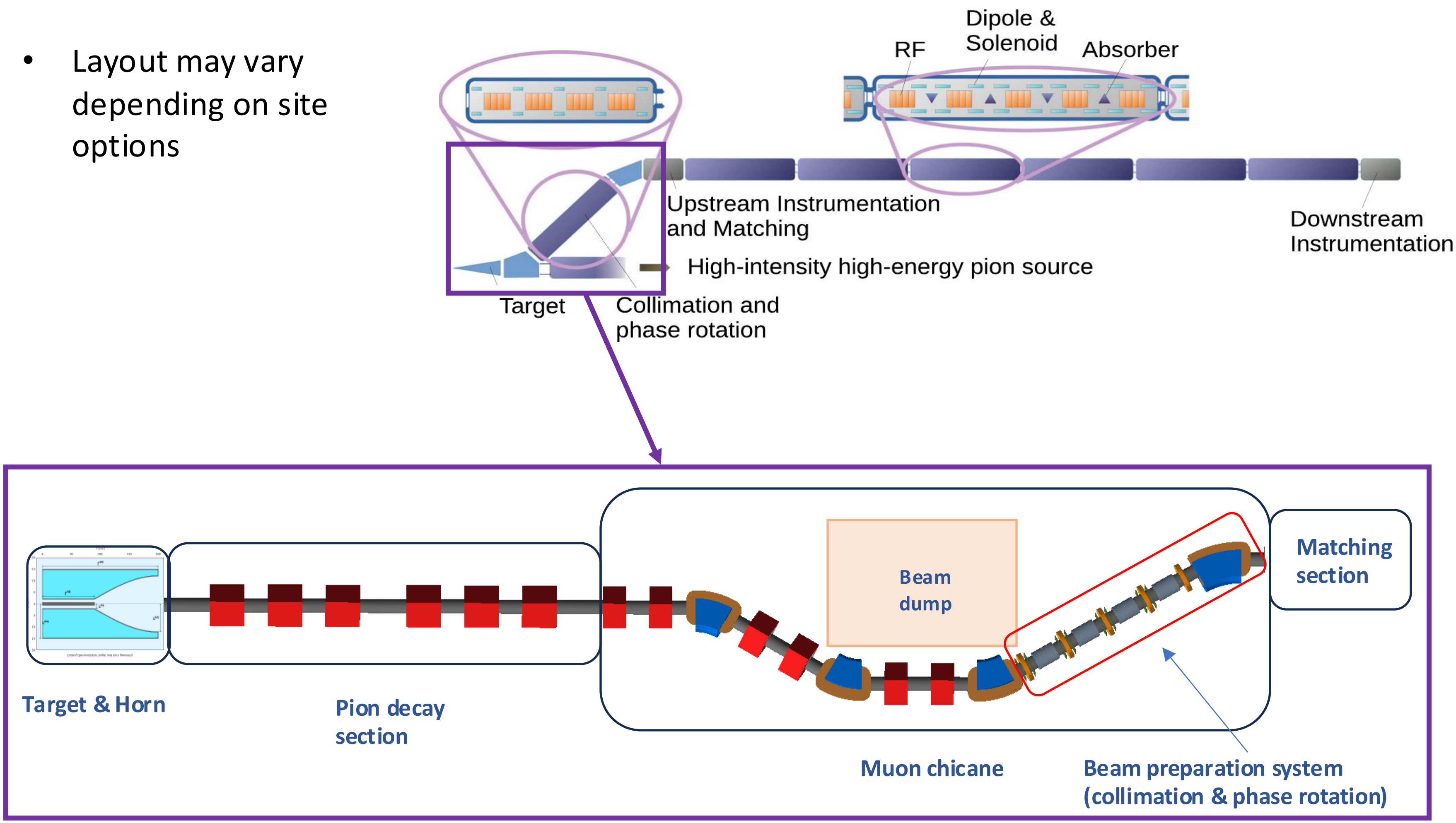
Muon Cooling Demonstrator



- Initial design efforts focussed on the cooling cell
- Aim to produce an integrated design of the facility
  - Muon beam production/front end studies
    - Target & Pion capture
    - Pion transport & decay
    - Muon transport, collimation & phase rotation
    - Matching to cooling channel

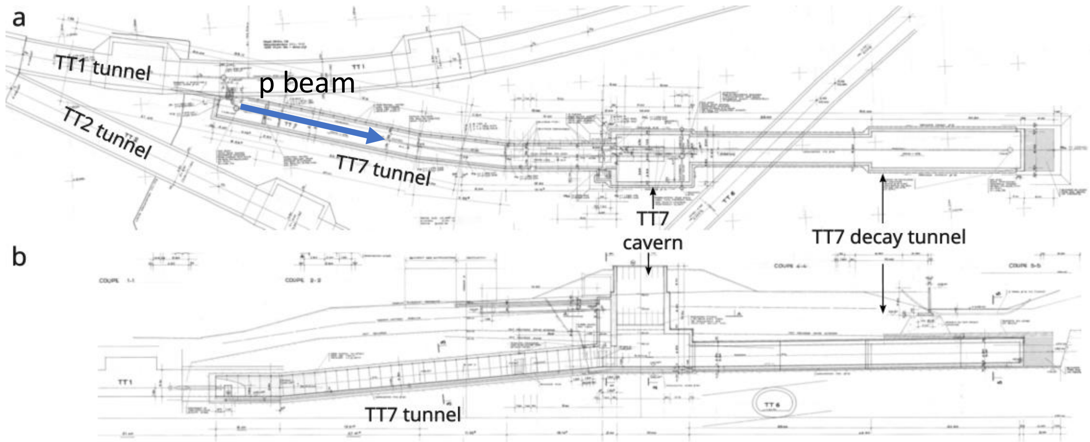
Front End

- Layout may vary depending on site options

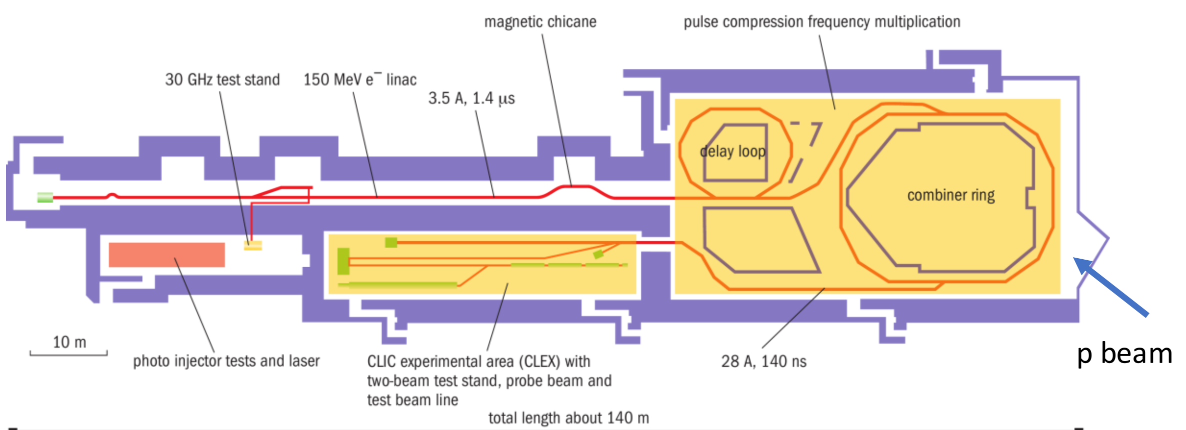


CERN Site Options (low beam power)

- **TT7 tunnel**
  - Proton beam extracted from the Proton Synchrotron (PS)
  - Underground, close to surface level
  - Limited to < 10 kW average beam power

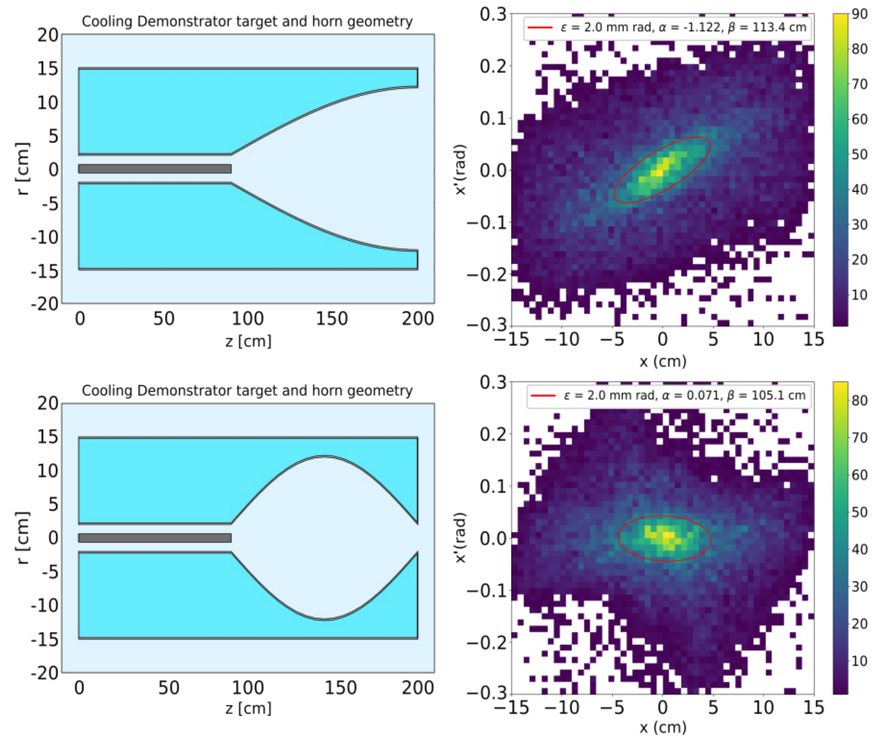


- **CTF3 area**
  - Proton beam extracted from the PS
  - Surface level
  - Beam power TBD, expect similar to TT7



Target & Horn

- First-pass design optimized for using **14 GeV** proton beam to produce ~ **300 MeV/c** pions
    - **Note**: does not incorporate engineering constraints, no assessment of stresses
- **Graphite** target (90 cm), **horn**-based pion capture **(I = 220 kA)**
- **Parabolic** and **ellipsoidal** inner conductor profiles considered
- Pion yield (in 210-330 MeV/c range and 2 mm rad transverse acceptance)
    - **7.9 x 10^{-4} π^+/POT** (max yield, parabolic profile)

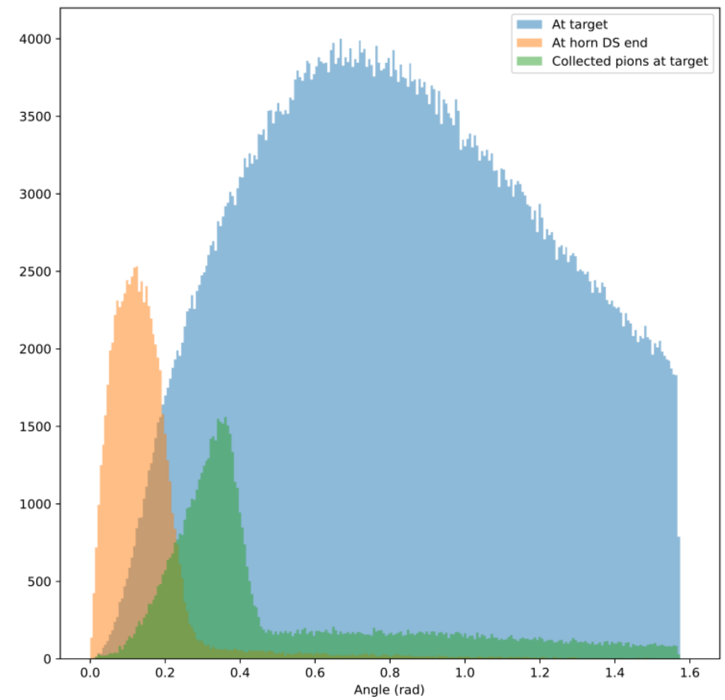


[Initial target thermal analysis (S. Candido, R. Ximenes)]

- No showstoppers
- Preliminary He forced convection cooling system explored

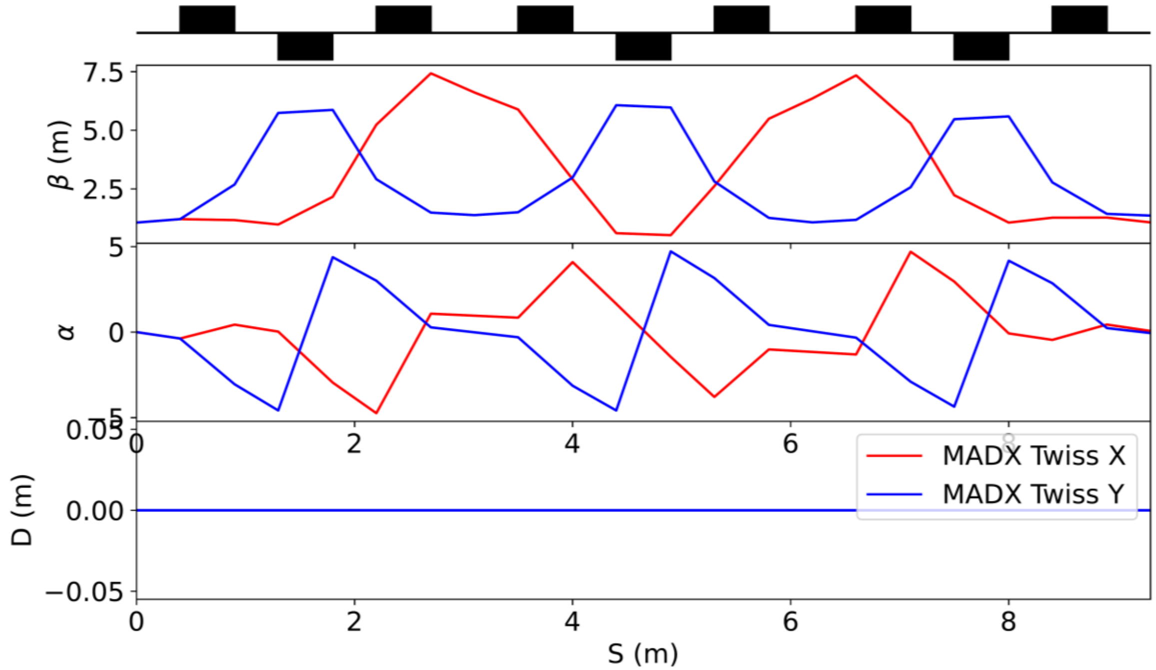
Target & Horn

- Horn capture **challenge**
  - 300 MeV/c pions have a broad angle distribution spanning all the way up to 90 degrees
    - From a long rod source
- Work on optimization **ongoing**
  - Exploring different geometries, horn currents up to 400 kA, and higher-Z target materials (e.g. tungsten)
  - Setting up a parallelised **Bayesian Optimization** framework on the Imperial computing cluster (**R. Kamath**)



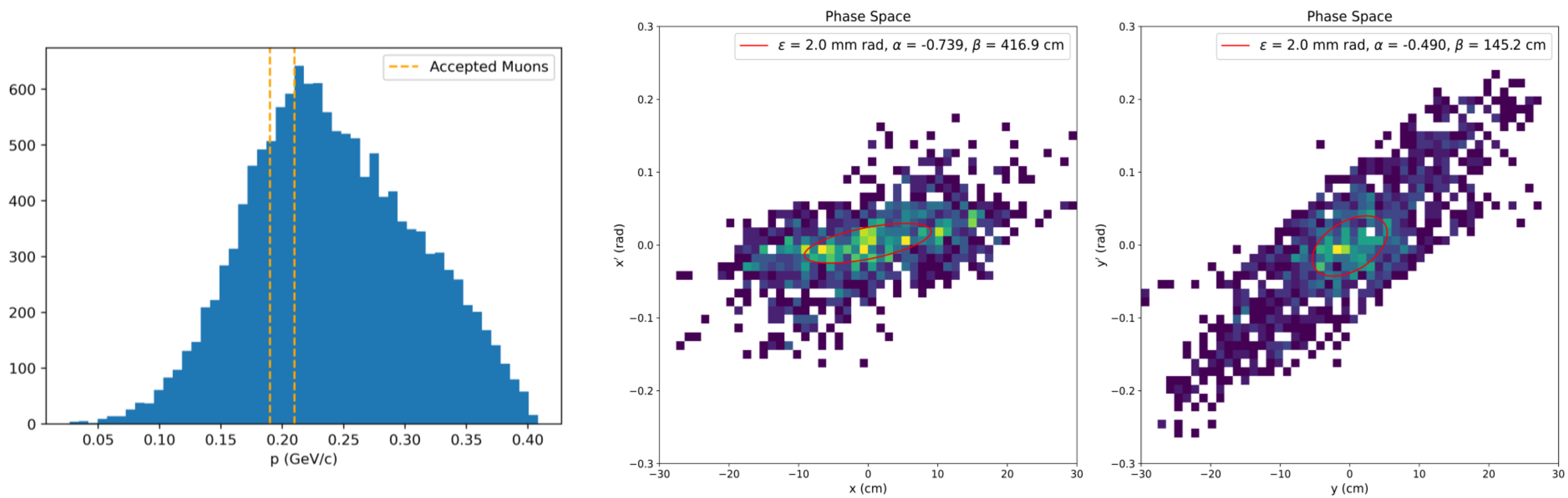
Pion decay channel - Optics

- Based on three **quadrupole triplets** (J. Pasternak)
  - Same solution currently considered for **TT7** and **CTF3**
  - 9.5 m lattice, ~ **40%** pions decay at 300 MeV/c
- Large pion momentum acceptance: ~ ± 50%
- Low pion beta function to reduce losses



Pion decay channel – Muons

- Muons from decays of pions with **270 ± 50% MeV/c** momentum and maxiumum **2 mm rad** single particle emittance
- Muons with **190-210 MeV/c** momentum
  - diffuse beam – **red** ellipse indicates **2 mm rad** single particle emittance

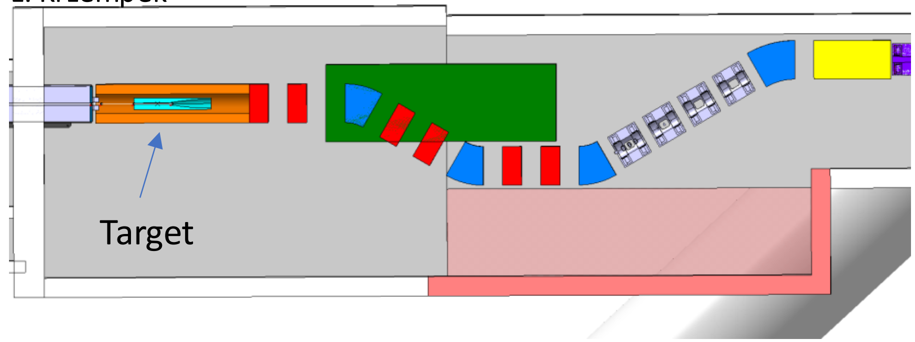


Chicane

- Muon momentum selection (**190 – 200 MeV/c**), proton beam dump & muon beam preparation
- Significant space constraint in TT7
    - Requires tunnel expansion
- More flexibility in CTF3 assuming the target can be situated closer to PS extraction
- **NOTE**: Figures only show a placeholder lattice

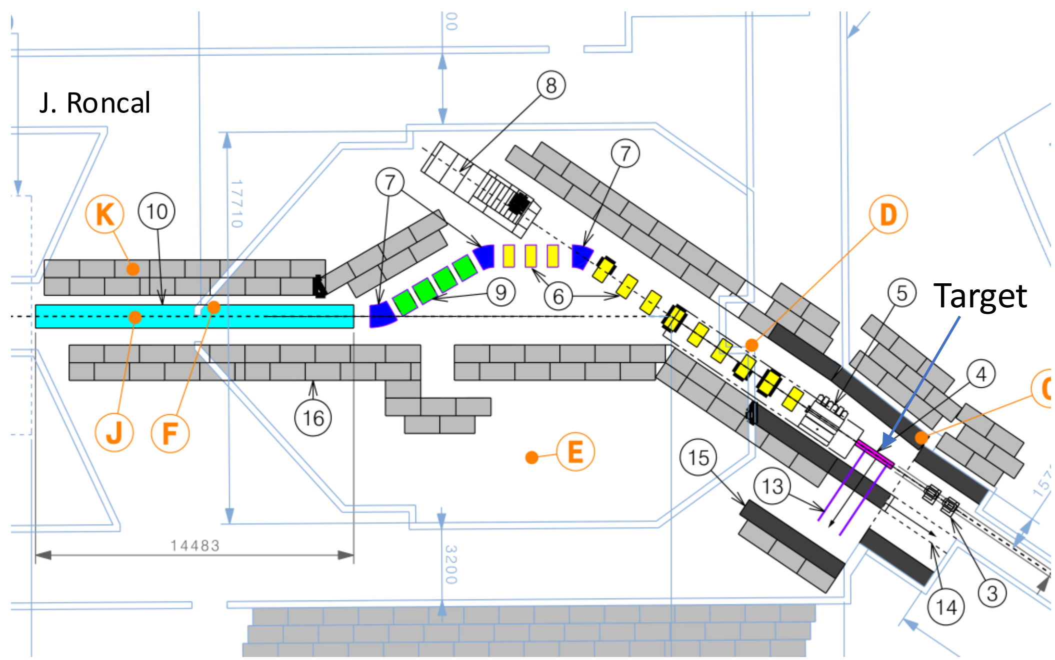
L. Krzempek

TT7



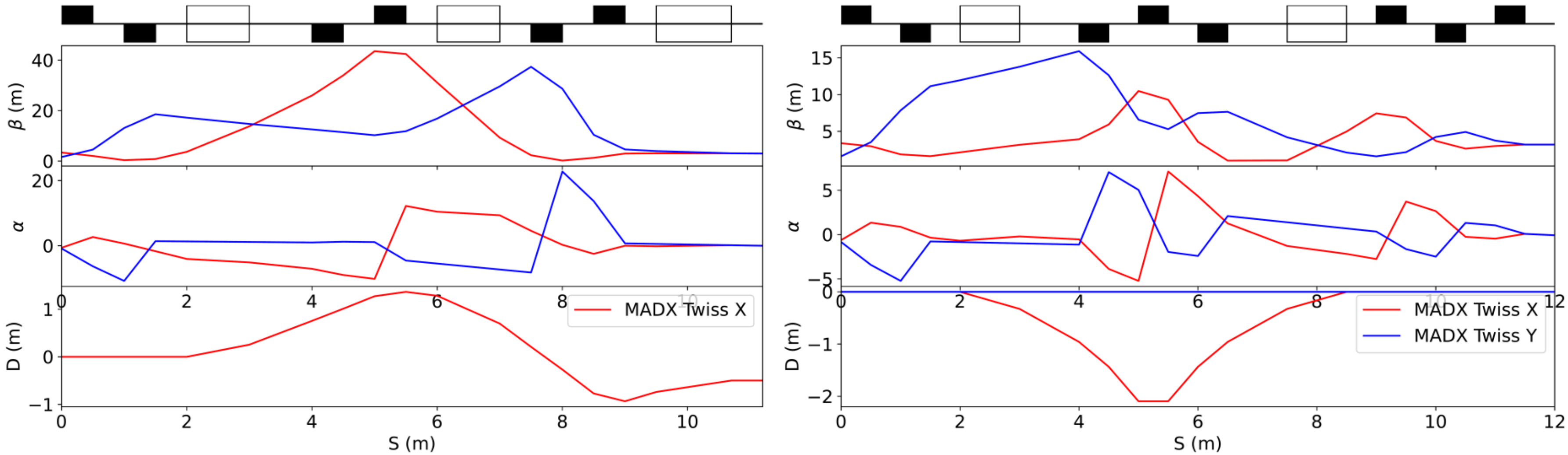
J. Roncal

CTF3



Chicane – Optics Matching

- Performed exploratory chicane lattice design to verify if the muon beam can be matched into the Beam Preparation System (BPS)
- Optic plots shown here assume a beam with $\beta_{x,y}$ = 3 m and $\alpha_{x,y}$ = 0 required at BPS



TT7

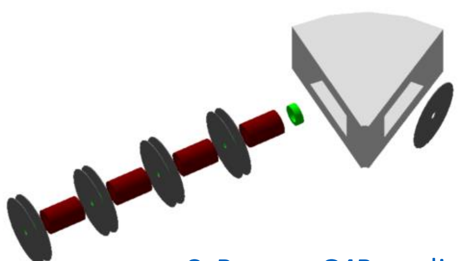
- 3-bend configuration
- Dispersion (X) not fully suppressed (~ -0.4 m)
- Challenging to maintain a low beta to avoid losses in the magnet apertures

CTF3

- 2-bend configuration
- Zero dispersion
- Beta < 15 m can be achieved

Beam Preparation System (BPS)

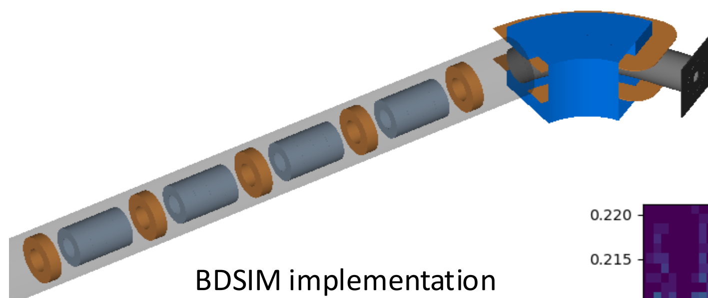
- Proton-driven muon beams have an intrinsically large transverse emittance
- Muon bunch length dependent on proton bunch length: expect 5-10 ns
- **Require**: ~ **1-2 mm** transverse emittance and ~ **100 ps** bunch length
  - Achieved through transverse collimation and longitudinal phase rotation
- **BPS**: sequence of RF cavities, solenoids, collimators and a dipole (momentum collimation)



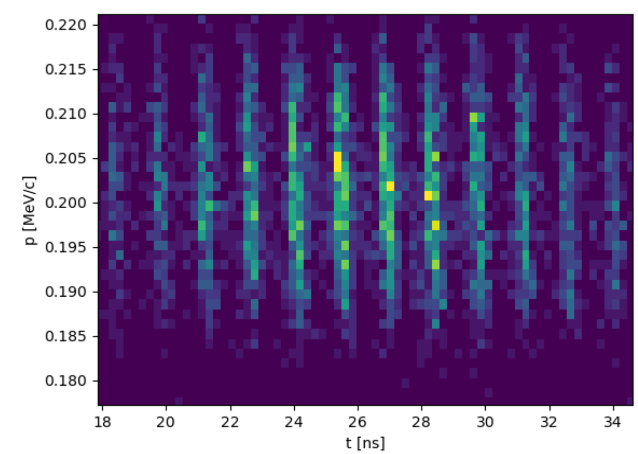
C. Rogers, G4Beamline

Beam Preparation System

Parameter	Value
Cell length	1 m
Peak solenoid field on-axis	0.5 T
Collimator radius	0.05 m
Dipole field	0.67 T
Dipole length	1.04 m
RF real estate gradient	7.5 MV/m
RF nominal phase	0° (Bunching)
RF frequency	704 MHz

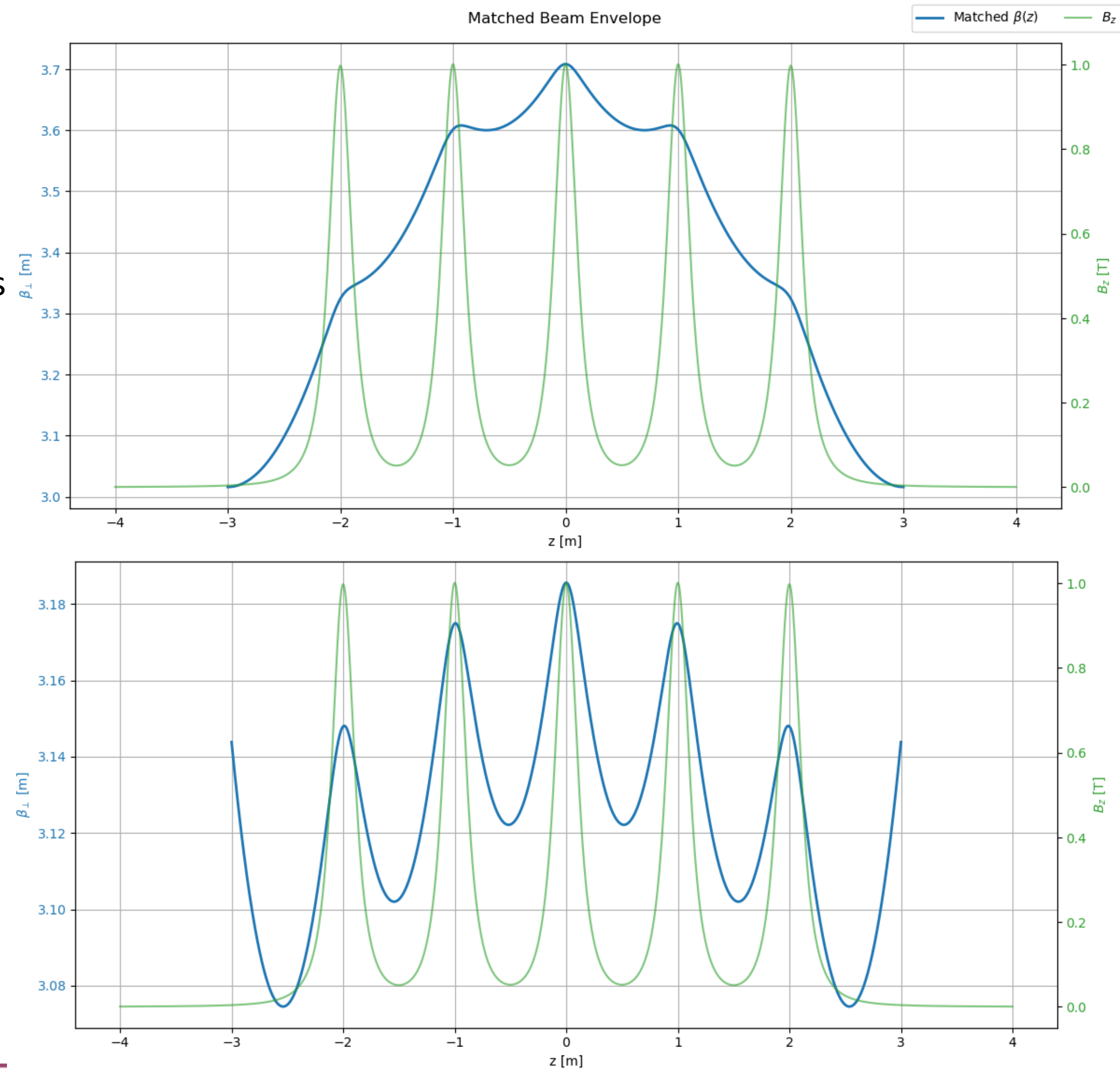


BDSIM implementation



BPS – Beam optics

- Current cooling cell design ~ **1 mm** equilibrium emittance
  - Need > 1 mm beam to pass through the BPS
    - Studying the field requirements to achieve this (normal vs. superconducting coils)
- Limiting aperture – RF cavity iris <= **81.6 mm** (at 704 MHz)
- Beta matching solutions shown here for a 5 x 1T solenoid configuration (24.3 A/mm^2)
  - **2 mm** beam with **β = 3 m** -> RMS beam size = **77.5 mm**



Summary

- Efforts to produce an integrated front end design for the Muon Cooling Demonstrator underway
- Two CERN sites considered: TT7 tunnel, CTF3 area
- Horn+target design optimization ongoing
  - Bayesian optimisation algorithm
    - Horn geometry refinement, explore different target materials
- Transport line
  - Preliminary pion decay channel
  - Chicane matching shows promising solutions, more challenging in TT7 due to space constraints
  - Beam preparation system
    - Exploring stronger focussing solutions
    - Longitudinal dynamics studies to follow
- Future work
  - Implement transport line model in FLUKA for radioprotection studies to inform beam power and shielding requirements
  - **Pre-cooling-channel matching section**; likely after a first complete solution of the whole front end

Thank you

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