WP4 – Muon Production and Cooling

International
MUON Collider
Collaboration

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MuCol

Muon Production and Cooling

- Production of the muon beam is critical to muon collider
  - Highly novel technologies
    - Ionisation cooling
    - Target with solenoid capture
  - Determines luminosity
- Produce muon beams by
  - Protons → target
  - Pions produced
  - Pions decay to muons
  - Muons cooled to low emittance before acceleration
- Work Package 4 seeks to develop
  - Understanding of the target
  - Cooling lattice
  - Simulation tools

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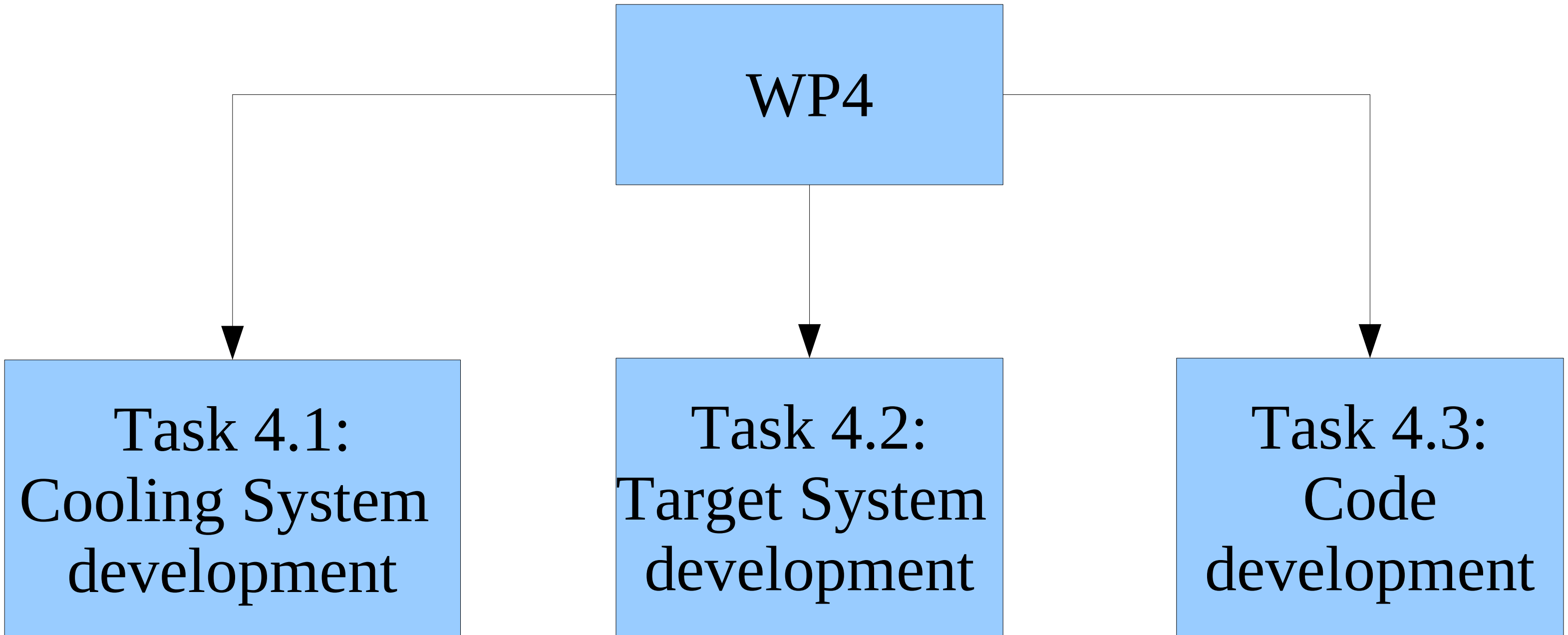
WBS



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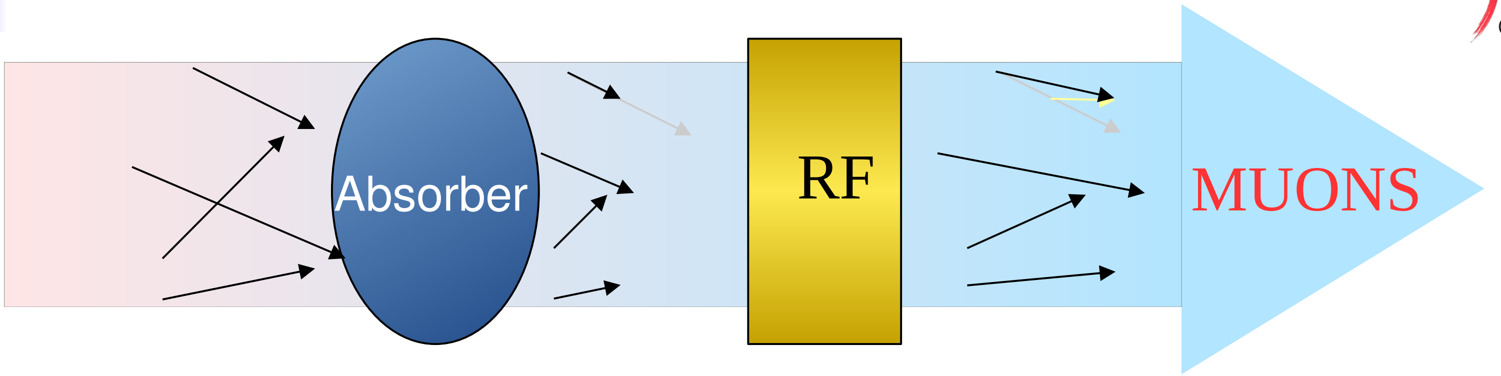
Ionisation Cooling



- Beam loses energy in absorbing material
  - Absorber removes momentum in all directions
  - RF cavity replaces momentum only in longitudinal direction
  - End up with beam that is more parallel
- Multiple Coulomb scattering from nucleus ruins the effect
  - Mitigate with tight focussing → low β
  - Mitigate with low-Z materials
  - Equilibrium emittance where MCS cancels the cooling
- Verified by the Muon Ionisation Cooling Experiment (MICE)

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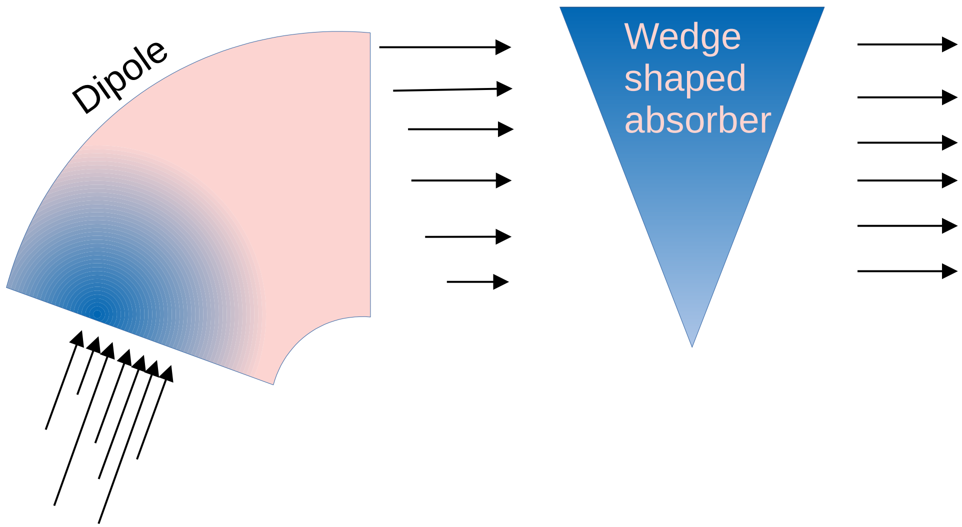
6D Ionisation Cooling



- Initial beam is narrow with some momentum spread
  - Low transverse emittance and high longitudinal emittance
- Beam follows curved trajectory in dipole
  - Higher momentum particles have higher radius trajectory
  - Beam leaves dipole wider with energy-position correlation
- Beam goes through wedge shaped absorber
  - Beam leaves wider without energy-position correlation
  - High transverse emittance and low longitudinal emittance
- Tests done at Fermilab

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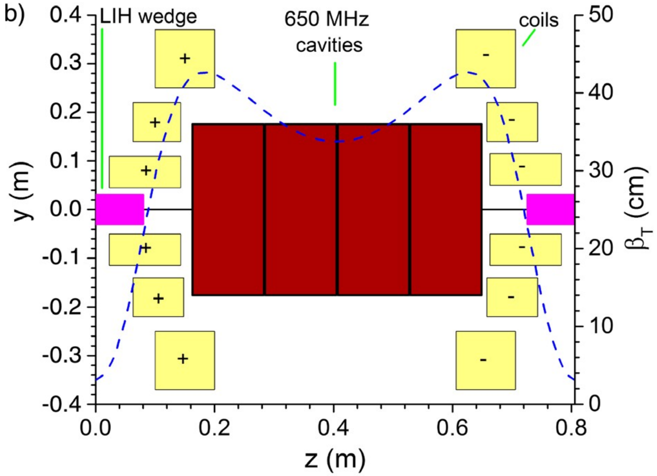
Rectilinear Lattice



D. Stratakis et al, Rectilinear six-dimensional ionization cooling channel for a muon collider: A theoretical and numerical study, PRAB 18, 2015

- Beam passes through wedge
- Focused by solenoids
- Re-accelerated by RF cavity
- Challenging integration – RF and solenoid very close
- More gradient available – should improve performance

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Task 4.1

- Exploit RF cavity demonstrated performance
  - Increase RF gradient to 50 MV/m – how does the performance improve?
- Improved realism – space for
  - Physics support of magnets
  - Thermal shielding between components
  - Diagnostics
  - Alignment equipment
  - Etc
- Assessment of integration into cooling test

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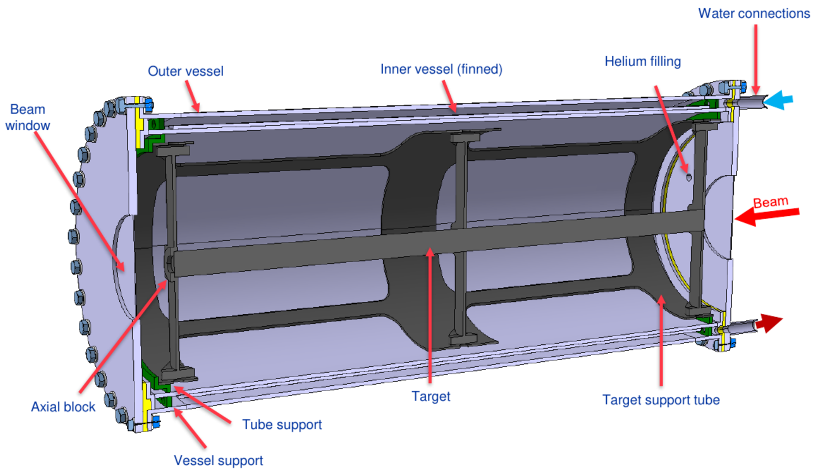
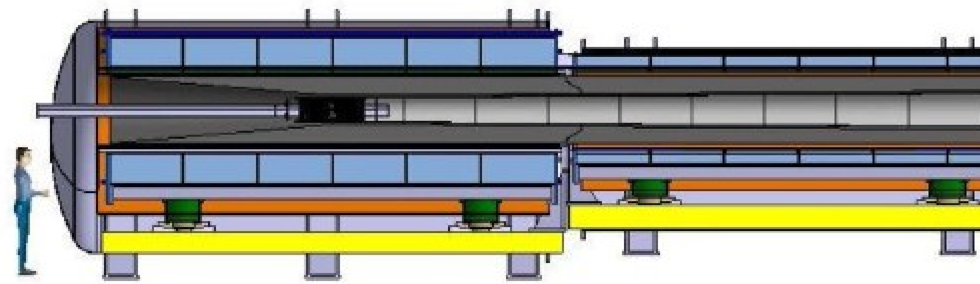
Target Baseline





- Baseline is solid graphite target
  - Protons → π → μ
- ~15-20 T solenoid field to capture pions
- High radiation environment
  - Challenges with target damage
  - Challenge to shield the solenoid

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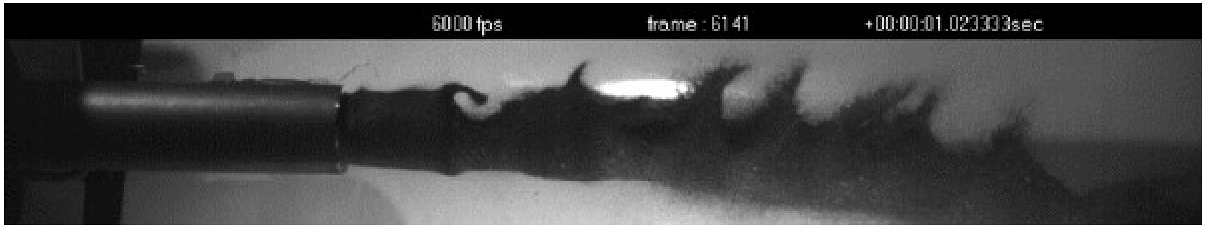
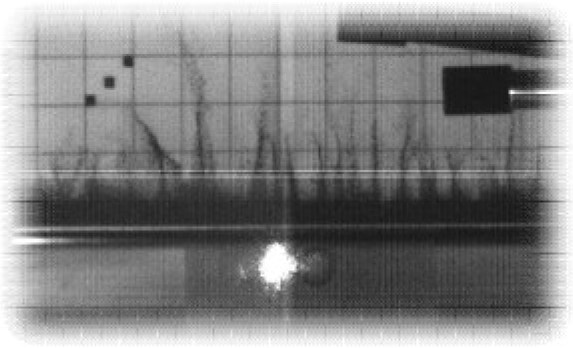
Fluidised Tungsten Target





- Fluidised granular tungsten target mitigates risk that solid target cannot withstand beam power
  - Either because the solid target is not robust
  - Or because higher beam power is required than expected
- Study how such a target can be realised

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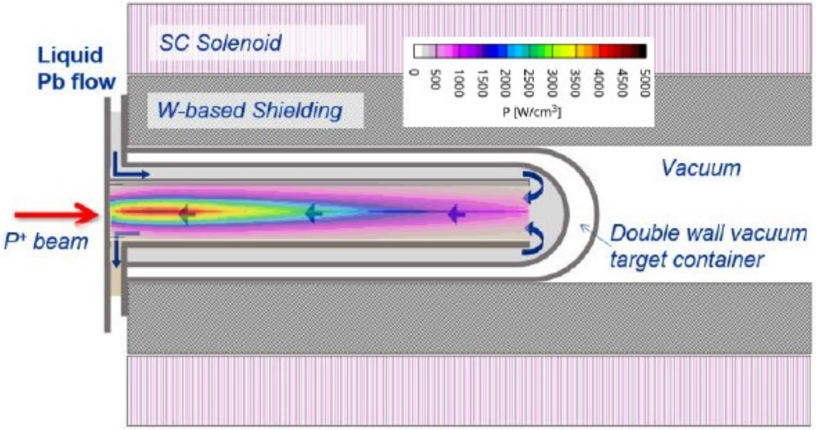
Liquid Metal Target

- Liquid metal target also promising
  - Heat dissipation by metal flow
  - Radiation damage not an issue
- Can target withstand beam?
  - Instantaneous heating
  - Cavitation
  - Leverage SNS experience



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Task 4.2

- Impact of beam on target system
  - Target lifetime
  - Mitigation strategies
- Impact of beam on surrounding systems
  - Especially magnet
  - Shielding and magnet requirements
- Assessment of pion yield

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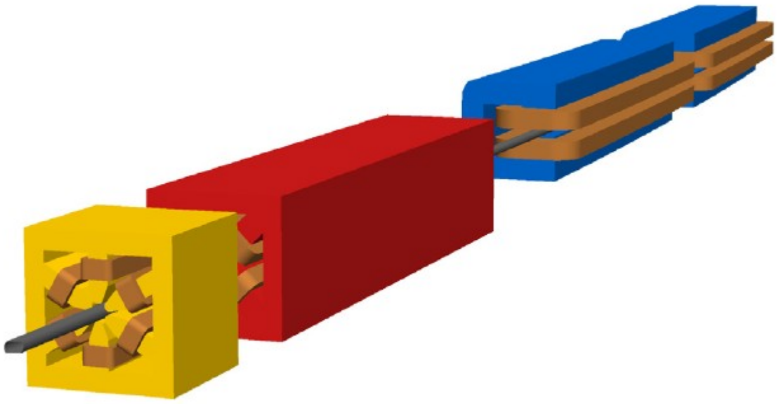
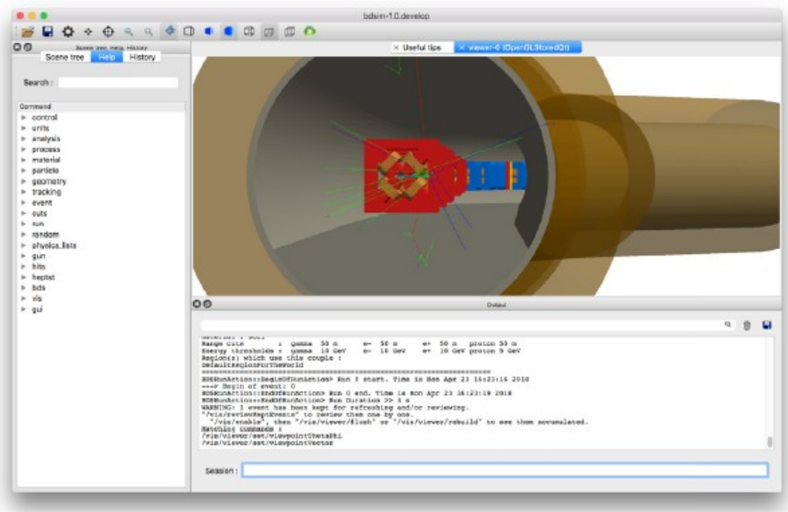
BDSIM

- BDSIM based on CLHEP/G4/ROOT stack
- Combined accelerator tracking and G4 physics processes
- Previously applied to MDI
- Now use for ionisation cooling
- Task 4.3 will implement
  - Compact solenoid geometries
  - Absorber materials and geometries
  - Appropriate RF cavity designs





L.J. Nevay, S.T. Boogert, J. Snuverink et al.
Computer Physics Communications 252 (2020) 107200

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Time line

- D4.1
  - Time: February 2025
  - Successful simulation of rectilinear cooling system using BDSIM
- D4.2
  - Time: November 2025
  - Preliminary report on key subsystems for ESPPU input
- D4.3
  - Time: December 2026
  - Consolidated report on key subsystems
- Deliverables should be available 3 months before final date for internal review

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Outlook

- The muon source is a key part of the muon collider facility
- In many parts, the system is entirely novel system
- WP4 → crucial to determine muon collider performance

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