Physics Layout of the Demonstrator

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On behalf of the **international Muon Collider Collaboration**

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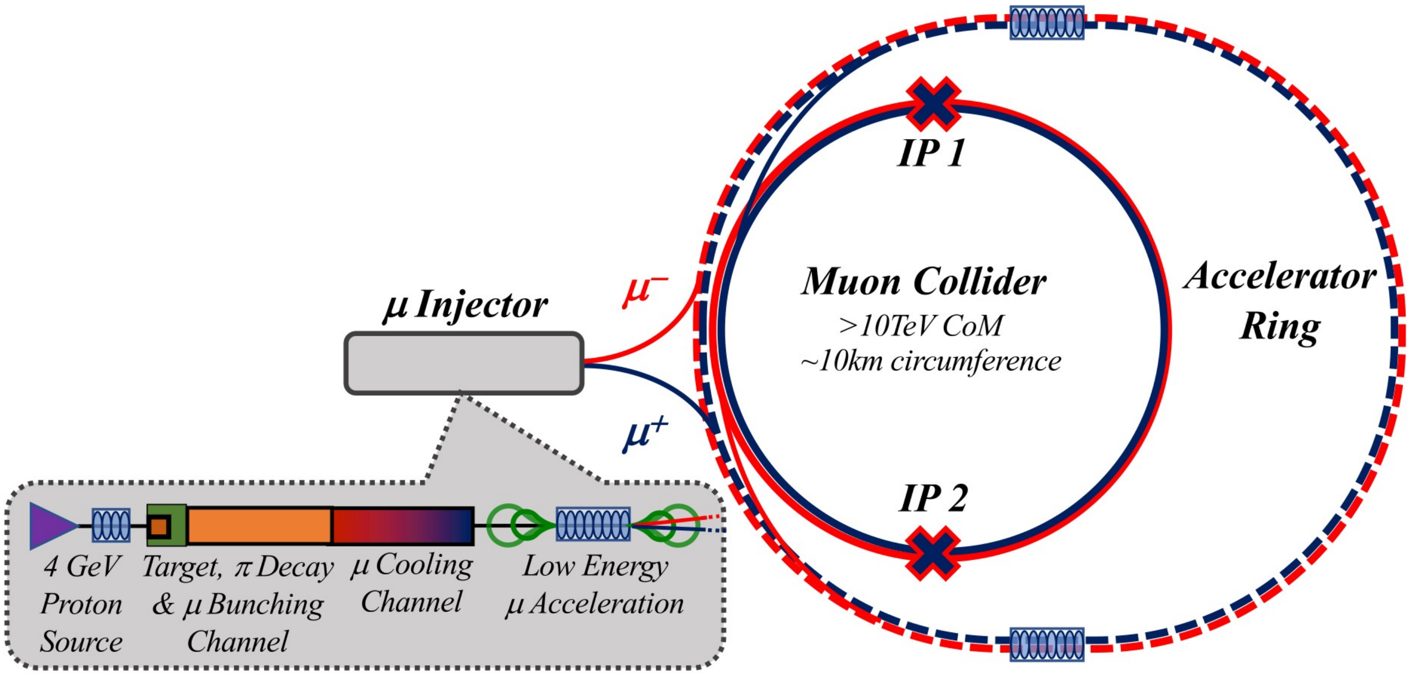
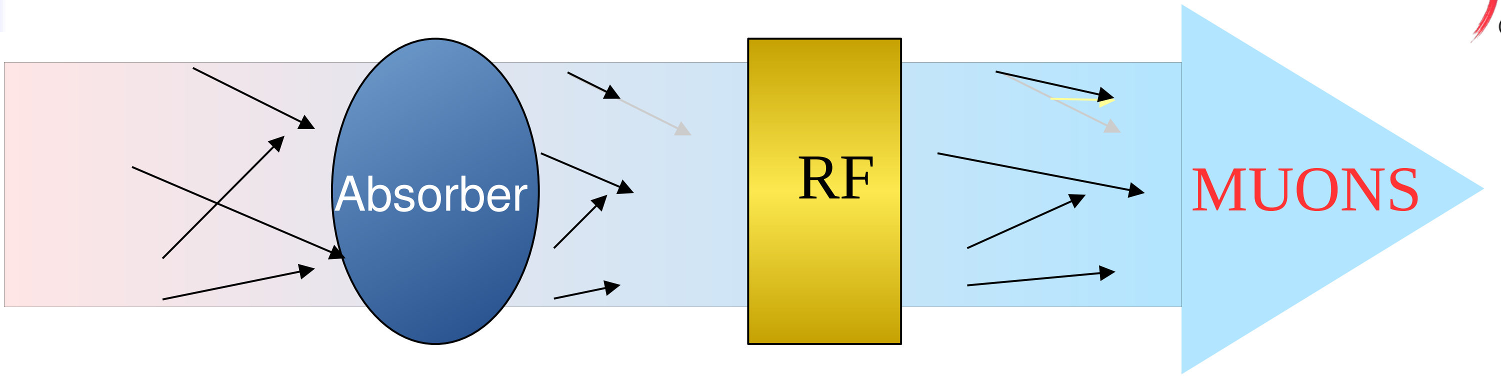
Ionisation cooling



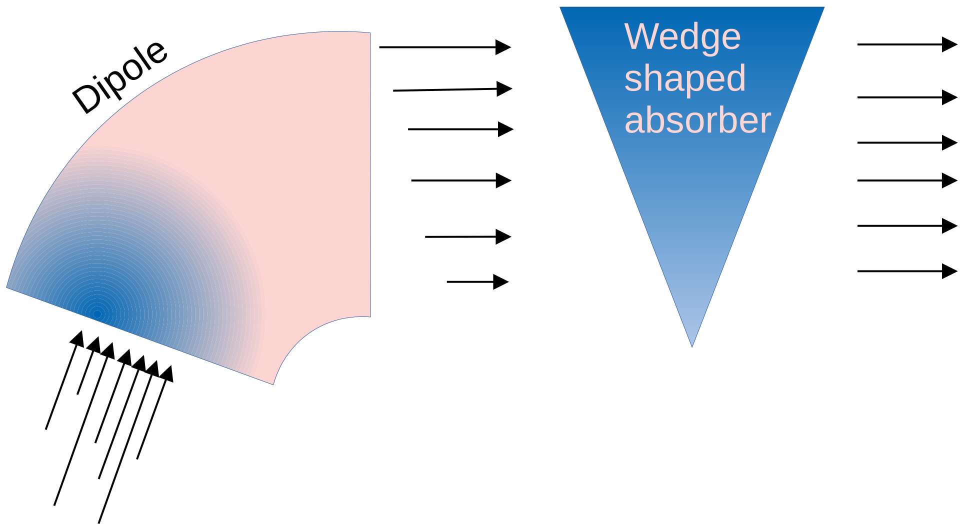
- Muons created at the target have a huge emittance
  - Need to cool the muon beam to get sufficient luminosity
- Conventional cooling techniques are too slow
  - Use ionisation cooling – fast
  - Novel technology demonstrated by Muon Ionisation Cooling Experiment

Ionisation Cooling



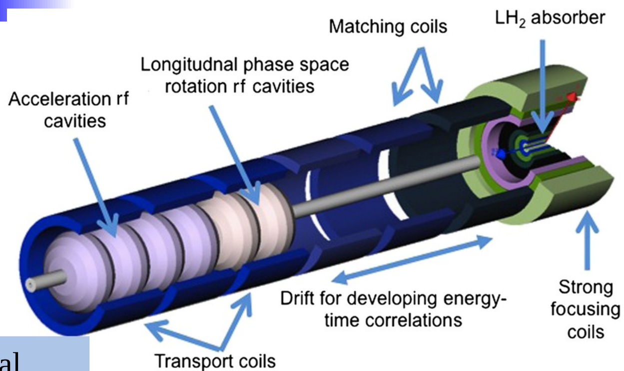
- Beam loses energy in absorbing material
  - Absorber removes momentum in all directions
  - RF cavity replaces momentum only in longitudinal direction
  - End up with beam that is more parallel
- Multiple Coulomb scattering from nucleus ruins the effect
  - Mitigate with tight focussing → low β
  -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

6D Ionisation Cooling

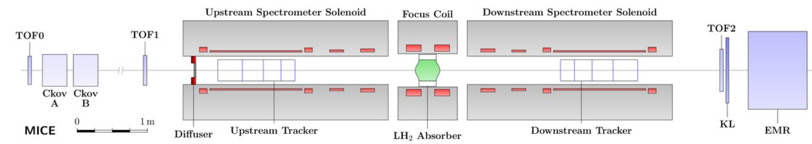


- Initial beam is narrow with some momentum spread
  - Low transverse emittance and high longitudinal emittance
- Beam follows curved trajectory in dipole
  - Higher momentum particles have higher radius trajectory
  - Beam leaves dipole wider with energy-position correlation
- Beam goes through wedge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

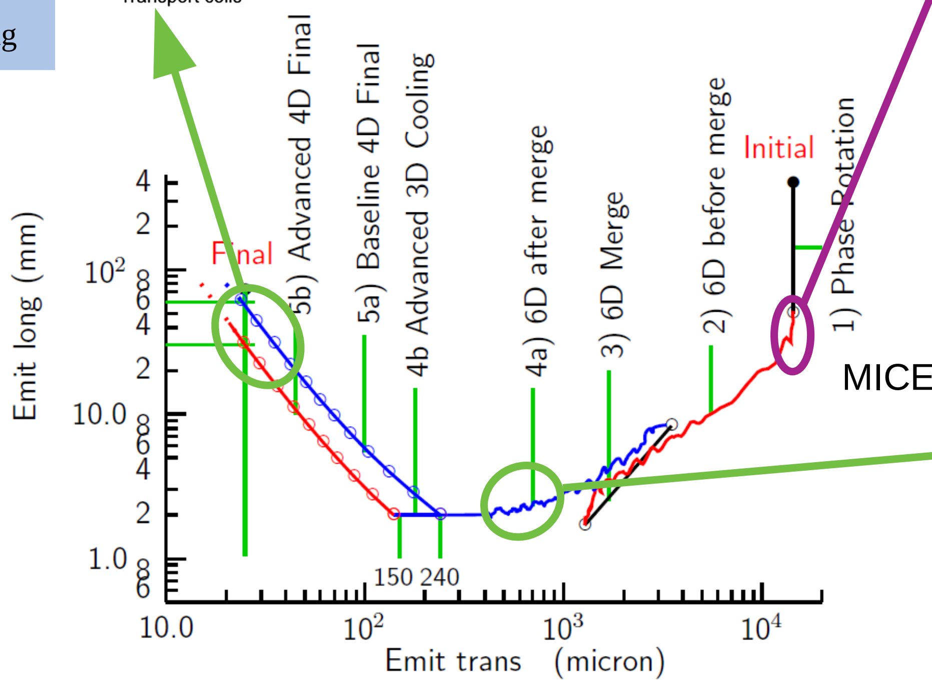
Cooling for a Muon Collider (MAP)



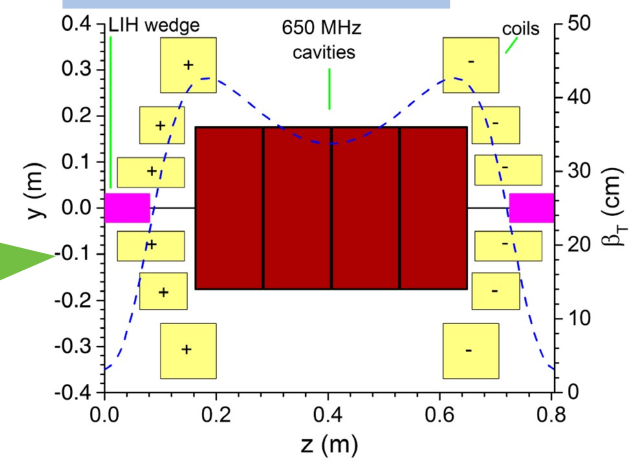
Final cooling



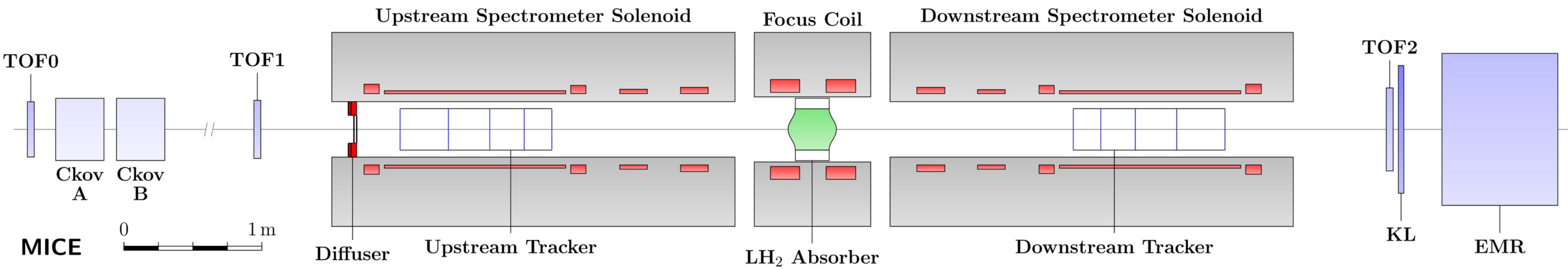
"MICE-like"



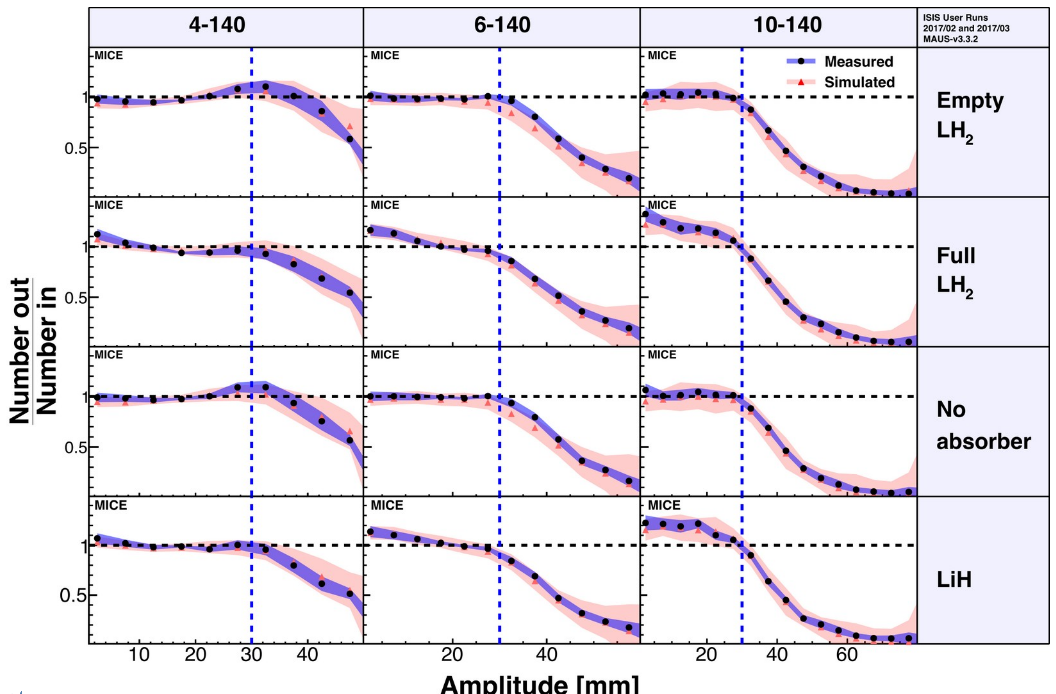
Rectilinear B (Stage B8)



MICE



- MICE
  - Demonstrated transverse cooling only
  - Very nice result
    - Clear signal
    - Good agreement with simulation
  - Single absorber – no RF
  - Single particle experiment



Plots from the MICE collaboration
Demonstration of Cooling by the Muon Ionization Cooling Experiment
Nature 578, 2020

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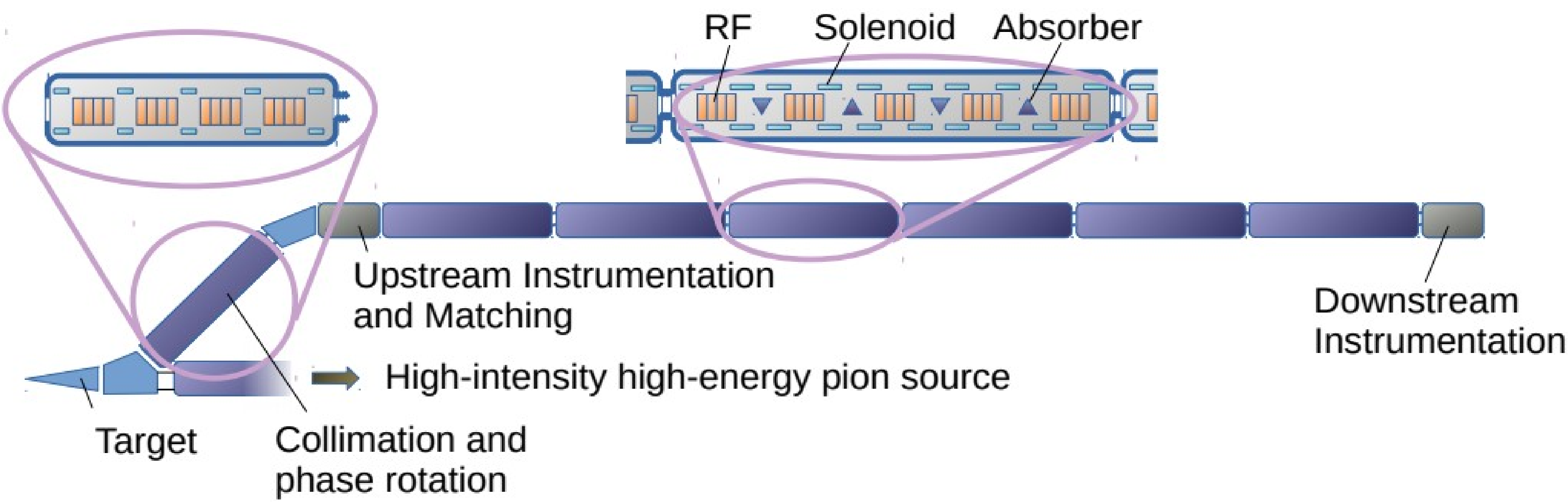
International MUON Collider Collaboration

What needs to be done?

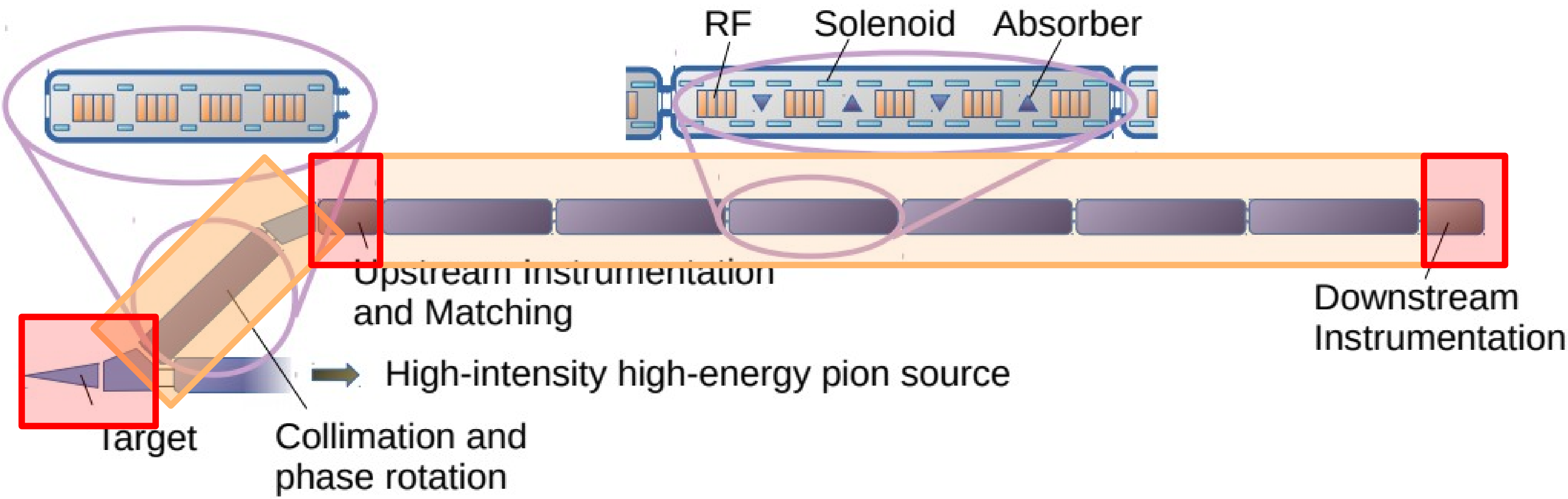
- Demonstrator
  - Larger emittance change
  - Longitudinal and transverse cooling
  - Multiple absorbers & chaining cooling cells
  - Reacceleration including RF
    - RF breakdown in magnetic fields
  - Commissioning and operation with bunched beam
    - Instrumentation requirements
- Intensity effects out of scope
  - Consider proton demonstrator

Layout



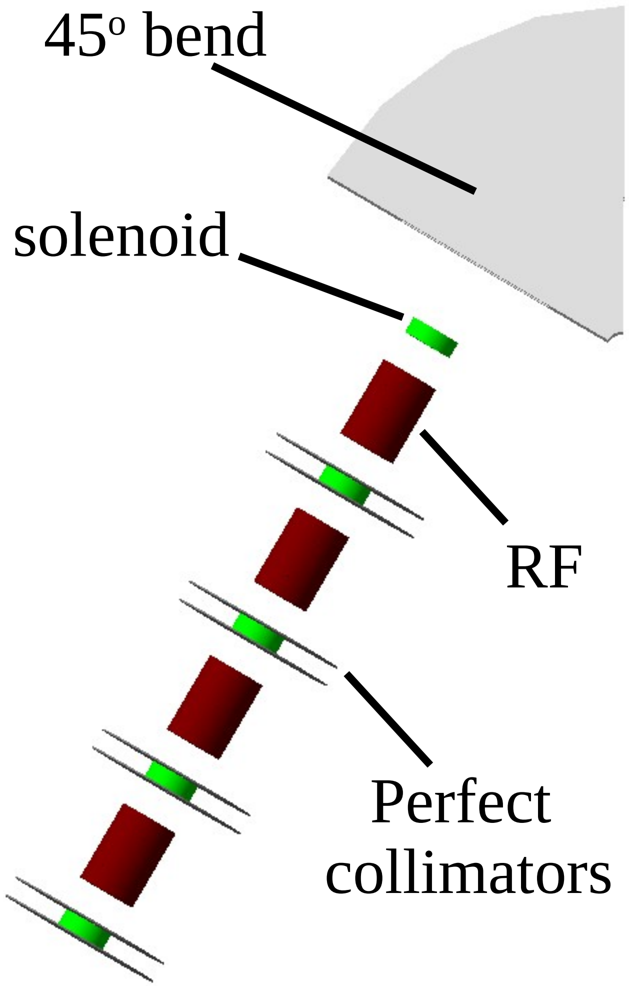
- Cooling system test Demonstrator
  - Produce pions on a target
  - Collimate +capture longitudinally
  - Characterise the incoming muons
  - Cool the muons
  - Characterise the outgoing muons

Layout



- Status
  - Preliminary physics design exists
  - No design exists

Beam Preparation System

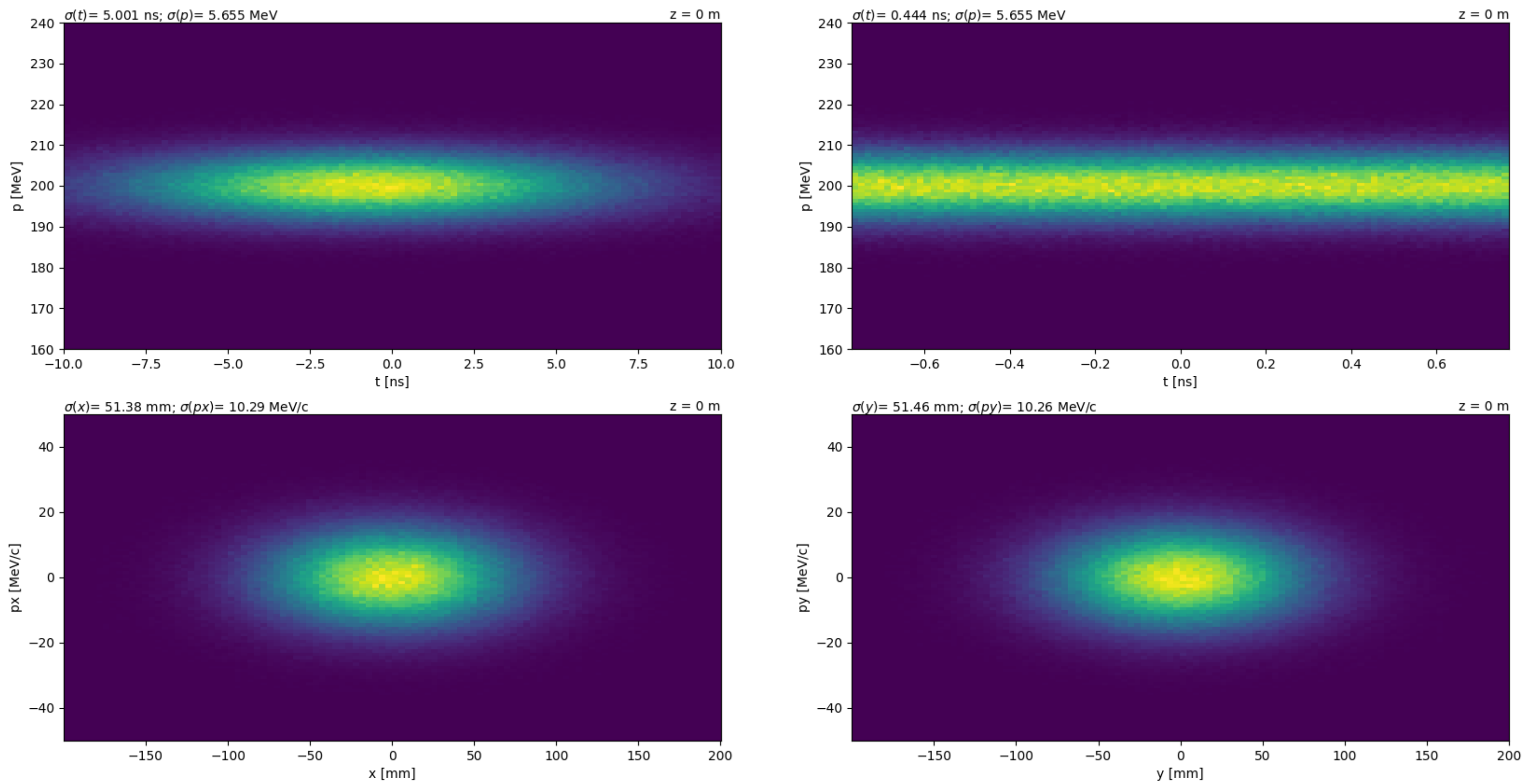


Beam Preparation System

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

- Simulated in G4Beamline
  - First pass simulation
  - Perfect collimators
  - No pion/electron contamination
- Can we make a bunched beam?
  - (Also transverse collimation)

Input beam



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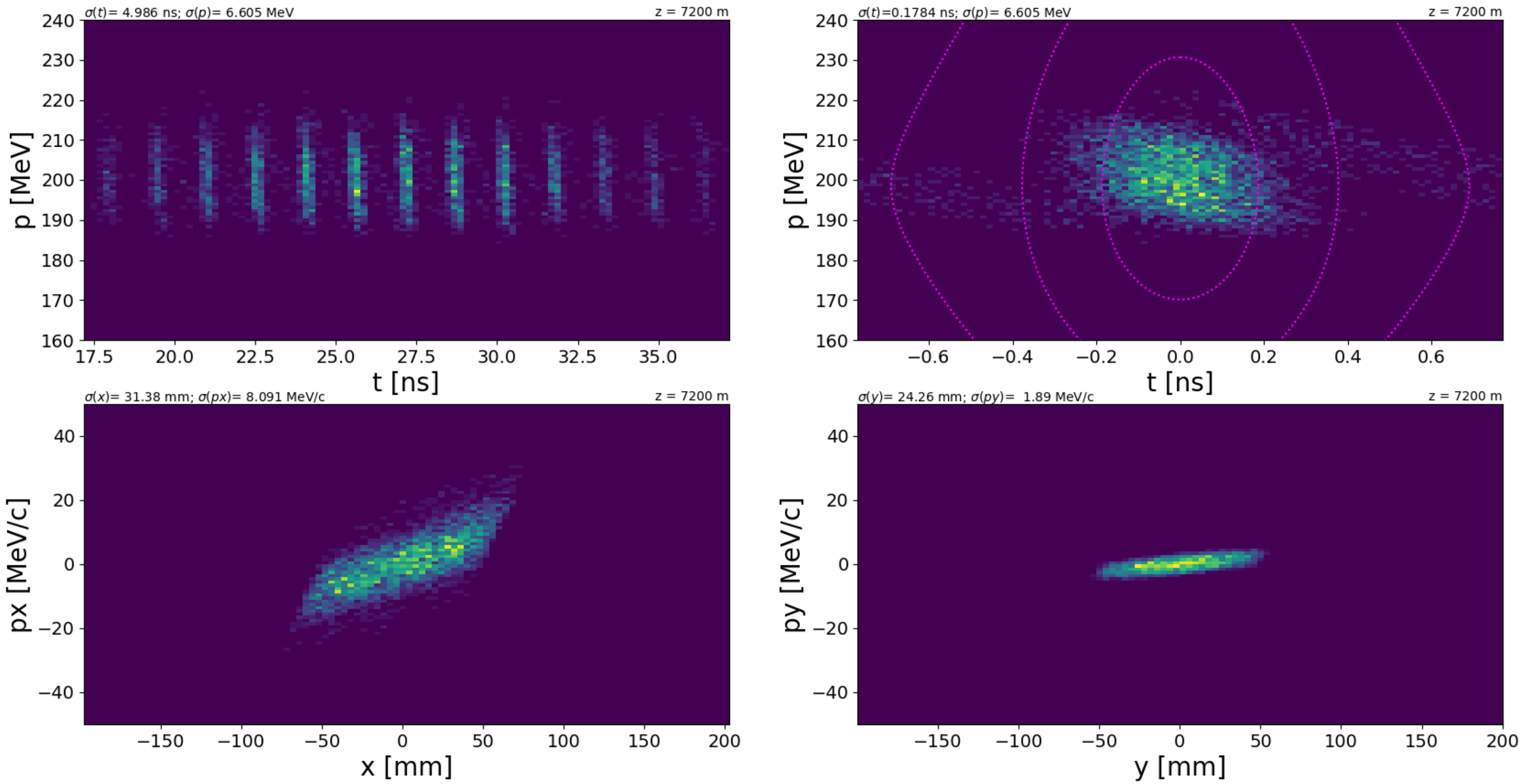
Beam Preparation System



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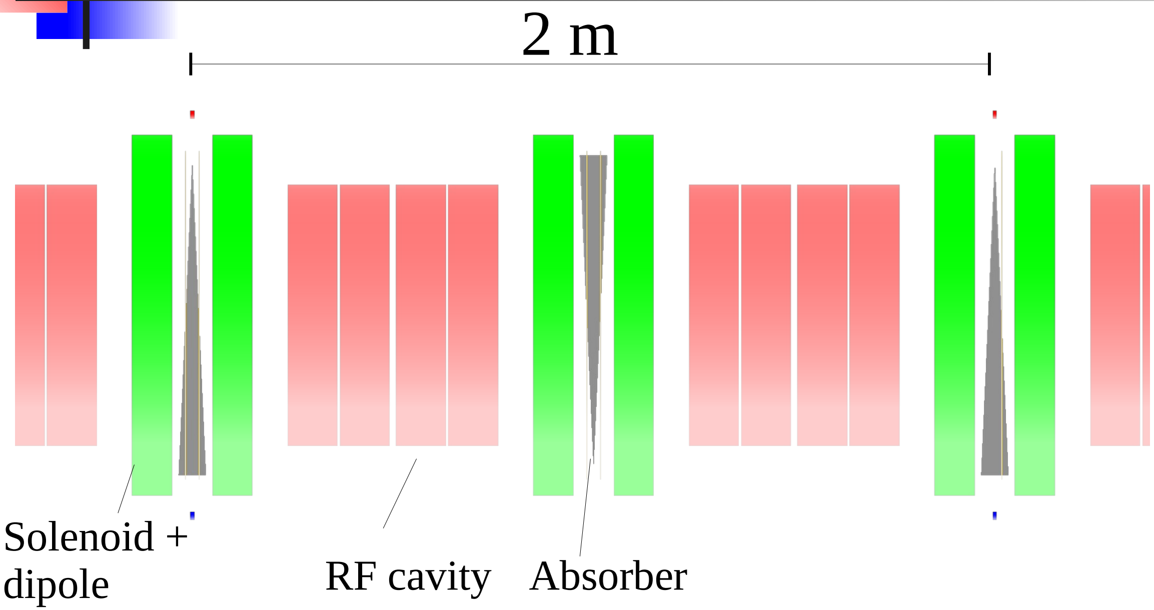
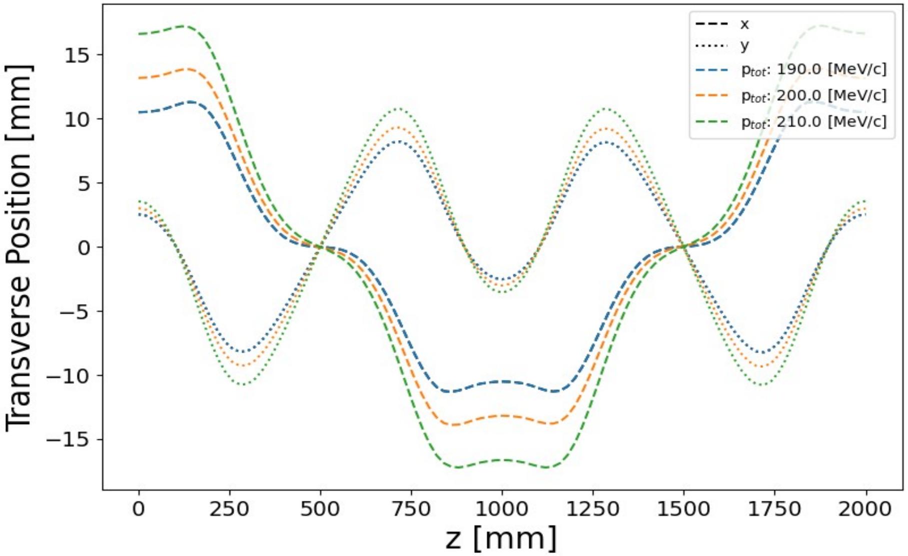
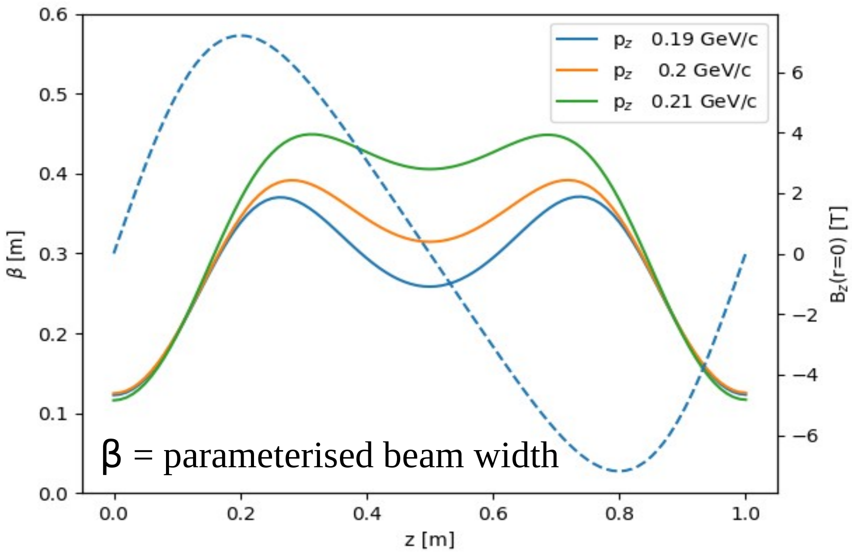
Preliminary Cooling Cell Concept

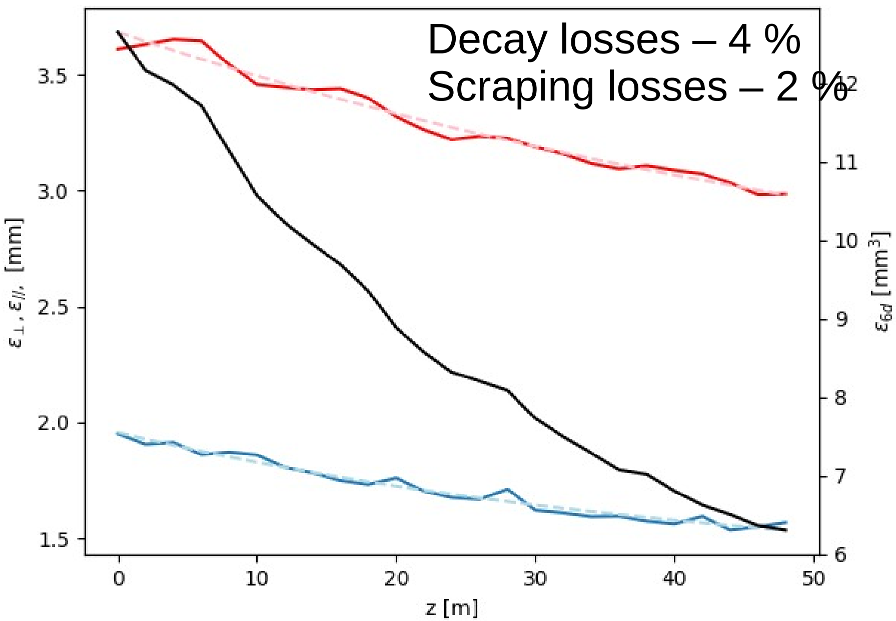


Cooling System	
Cell length	2 m
Peak solenoid field on-axis	7.2 T
Dipole field	0.2 T
Dipole length	0.1 m
RF real estate gradient	22 MV/m
RF nominal phase	20°
RF frequency	704 MHz
Wedge thickness on-axis	0.0342 m
Wedge apex angle	5°
Wedge material	LiH





Performance – sample lattice



Stage	ε_T^{sim} [mm]	ε_L^{sim} [mm]	P_z^{sim} [MeV/c]	T [%]
Begin	17.00	46.00	255	
A1	6.28	14.48	238	70.6
A2	3.40	4.64	229	87.5
A3	2.07	2.60	220	88.8
A4	1.48	2.35	215	94.6
Begin	5.10	10.04	209	
B1	3.76	7.76	210	89.7
B2	2.40	6.10	208	90.6
B3	1.55	4.28	207	89.2
B4	1.10	3.40	207	89.7
B5	0.68	2.97	204	87.5
B6	0.50	2.16	202	88.0
B7	0.38	1.93	200	89.6
B8	0.28	1.57	200	89.0
BR in	1.95	3.61	200	-
BR out	1.57	2.99	200	94 %

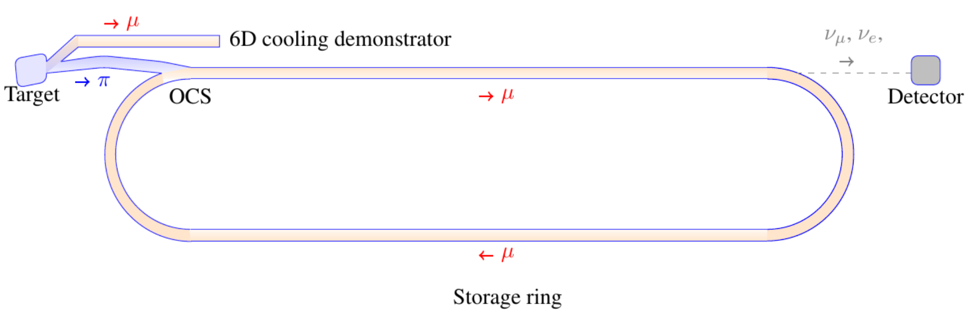
- Performance – okay compared to Stratakis lattices
  - Better transmission
  - Worse emittance reduction
- Optimisation continues (discussion on Wednesday)
  - Acceptance
  - lH2

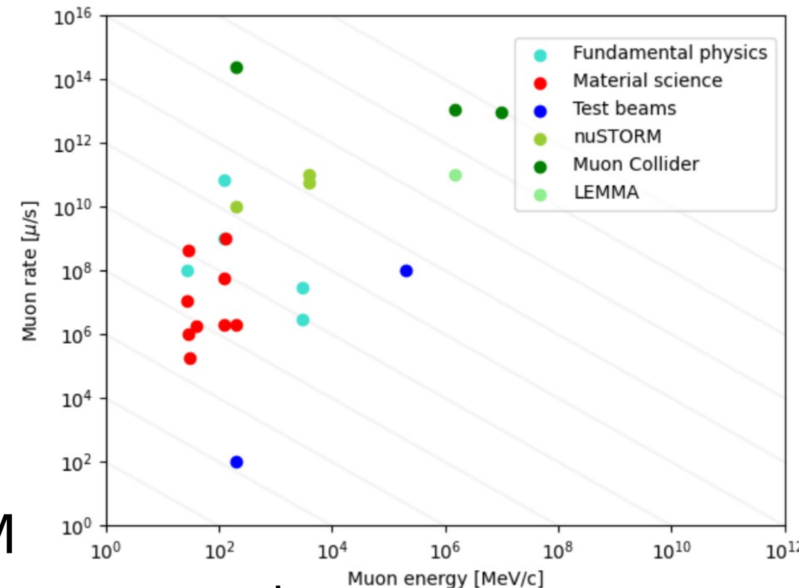
Table from Stratakis and Palmer,
Rectilinear six-dimensional ionization cooling channel for a muon collider: A theoretical and numerical study
Phys. Rev. ST Accel. Beams 18, 2015

Job List

- EU WP4 Baseline cooling cell – month 12
- EU WP8 Preliminary concept design deliverable – month 15
  - Input to the hardware studies
  - Cooling cell beam physics design
  - Detailed hardware considerations are out-of-scope
- Further cooling cell optimisation
  - See talk yesterday – Dynamic Aperture optimisation in progress
- Integrate target region
  - Switchyard design and preliminary radiation estimation
- Matching and upstream instrumentation
- Cooling cell hardware implementation
  - RF in magnetic fields
- Downstream instrumentation

nuSTORM





- New site compatible with nuSTORM
  - Measurement of neutrino scattering cross sections
  - Beyond Standard Model physics programme
  - Muon beam test area for Demonstrator
- Demonstration of highest-current high-energy muon beam facility
  - Pion beam handling
  - Target concepts can be tested
  - FFA storage ring → rapid acceleration concepts

Outlook

- Well placed to meet EU milestones/deliverables
  - Presented at NuFact – design document is prepared
- Consideration of implementation is ongoing
  - May be some juggling in the light of practical constraints e.g. available space at CERN
  - RF vs magnetic fields is probably critical path item – crucial to get working on this
- Planning for a “synergies” workshop Spring 2023
  - Consider physics opportunities that can be supported by a muon cooling demonstrator
    - e.g. nuSTORM
  - Consider physics/staging of a muon collider