Proton-Based muon collider and Cooling LoIs

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ISIS Neutron and Muon Source

C. T. Rogers
ISIS
Rutherford Appleton Laboratory

Snowmass

- Snowmass process aims to
  - define the most important questions for particle physics
  - identify the most promising opportunities to address these questions in a global context
- Two phases
  - Letters of Interest (Deadline August 31 2020)
    - See what proposals to expect
    - Encourage the community to begin studying them
  - Contributed Papers (Deadline July 31 2021)
    - White papers i.e. technical summary of the field and consideration of our approach/philosophy
    - New results on relevant physics topics
    - Expression of physics priority
- Important part of US prioritisation and funding process
- Important for coordinating related activities

LoIs

- Two Letters of Interest proposed
- A Proton-Based Muon Source for a Collider at CERN
  - Summary of the baseline proton muon source
  - Muon collider collaboration's plans for the next few years
  - Designed to inform the community of our collaboration's existence and plans
    - I think especially relevant in light of MAP history
- Issues and Mitigations for Advanced Muon Ionization Cooling
  - Summary of main technical issues for ionization cooling
  - Outline of approach that we will take in looking at cooling tests
  - Designed to inform the community of our collaboration's plans for hardware tests
- Nb: I have not put references in these slides – please see the LoIs for full list of references
  - The work is mostly not my own!

A Proton-Based muon source for a collider at CERN

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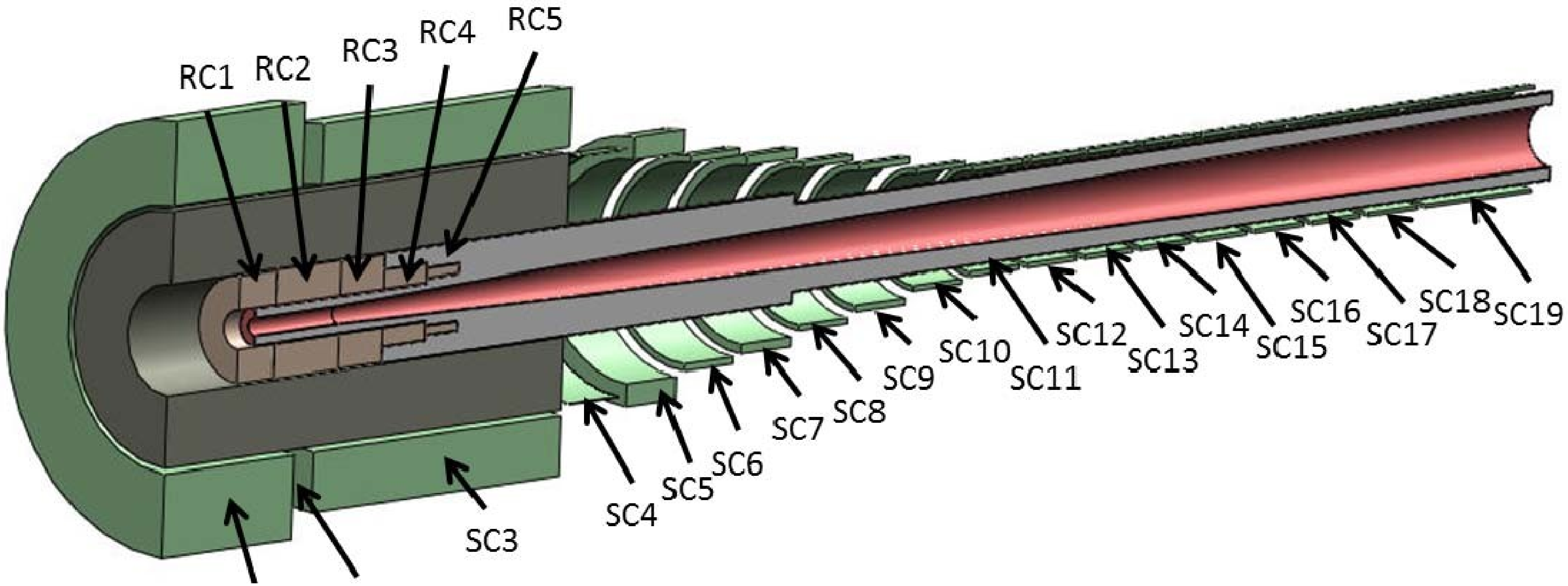
Introduction

- Introductory material
  - Reminder of European Strategy Update
  - Reminder of LEMMA – in passing
  - Our plan to adopt MAP scheme for the proton-based muon source

Target



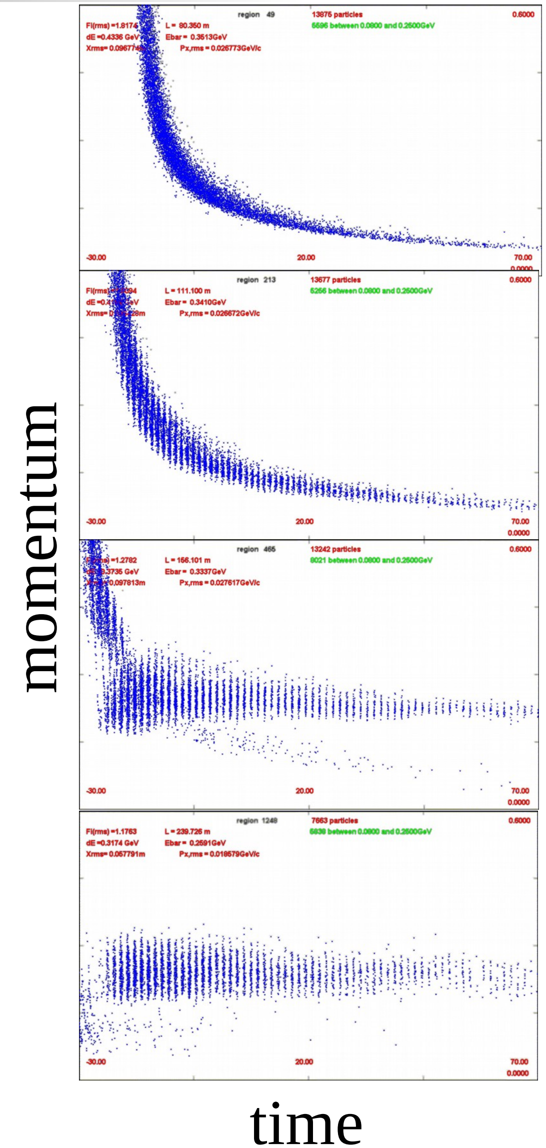
- 15 m long high field solenoid
  - 20 T pion capture region tapering to 2 T
- Graphite target is the baseline
  - May be possible with 1 MW proton beam
  - Higher beam power? Tight focussing? Instantaneous beam power?

Particle selection

- Significant particle leakage from proton target
  - Radiation hazard for the entire facility
- High acceptance chicane
  - “Bent solenoid” scheme needed to maintain high acceptance
  - Yields vertical dispersion – collimate all high momentum particles
- Proton absorber
  - Removes low momentum protons
- Low momentum electrons and muons remain
  - “Low momentum” → p less than about 500 MeV/c

Buncher/Phase Rotator

- Drift to develop energy-time relation
- Buncher - adiabatically ramp RF voltages
- Phase rotator - dephase RF
  - High energy bunches decelerated
  - Low energy bunches accelerated
- Many RF frequencies required
  - Bunch separation changes along the length of the front end
- Nb: plots to right were made without chicane
  - This would remove the high p muons
- Uniform solenoid field
  - Transport very high emittance muon beam



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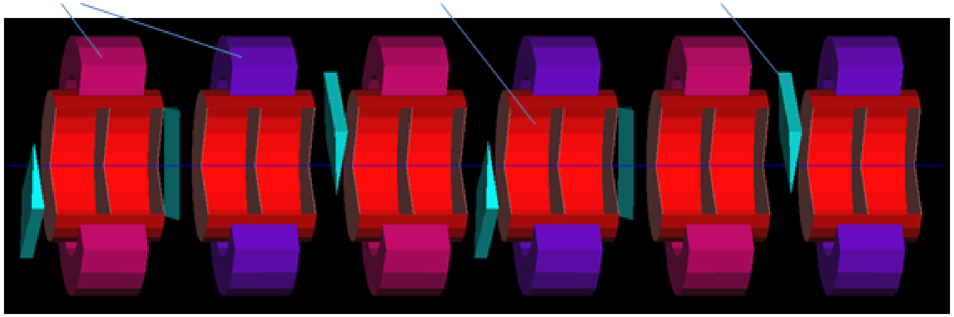
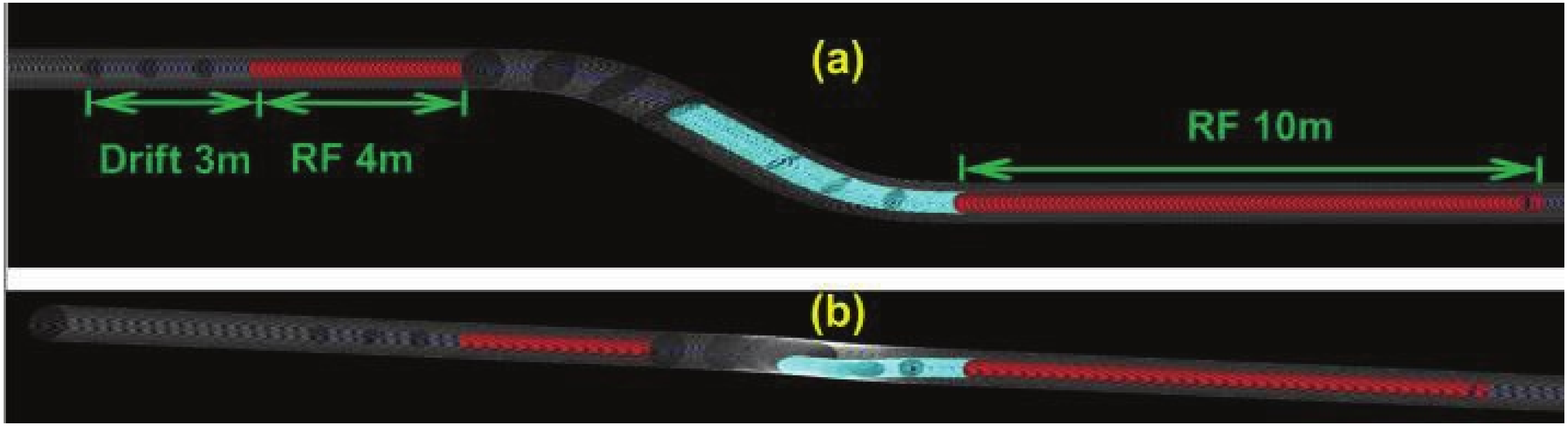
Initial Cooling (HFoFo)



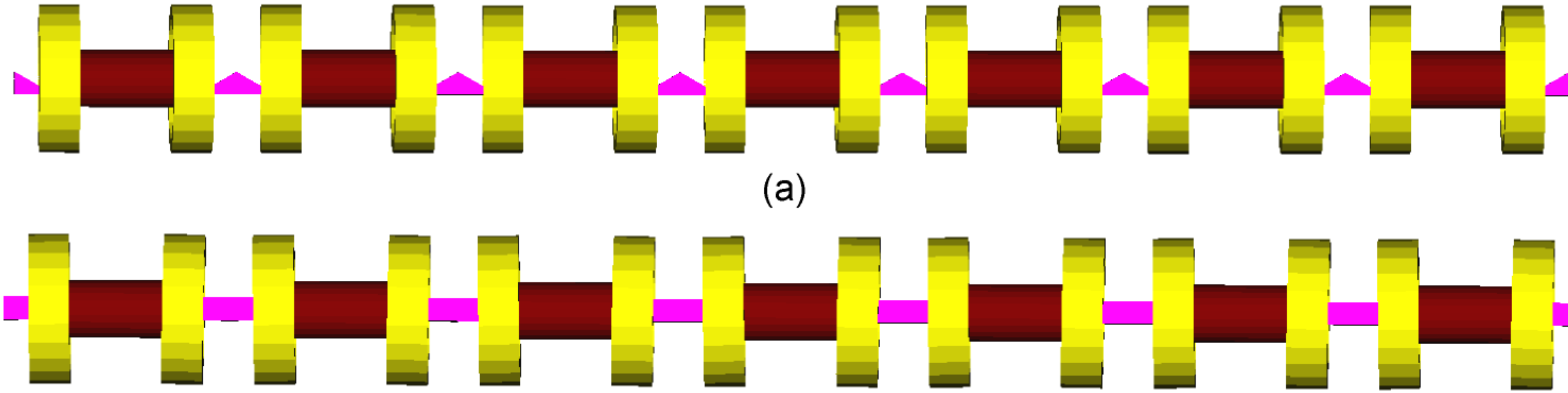
- Initial cooling to get muon beam to “manageable” emittance
- Simultaneously cool mu- and mu+ in the same lattice
  - Initially too high emittance to split charges
  - This is quite a challenge
- Baseline is to fill the channel with high pressure gas
  - Potentially suppresses breakdown
  - May choose vacuum option…

Charge Separation



- Further cooling (and the collider) requires separation of mu+ and mu-
  - Basic concept is to use a bent solenoid to introduce vertical dispersion
    - Challenge to maintain bunch structure
  - Quite early-stage simulation was done

Rectilinear cooling channel

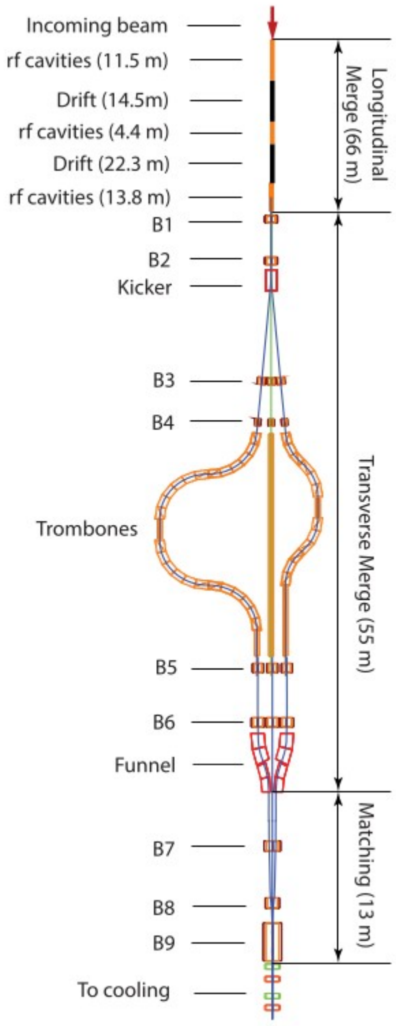


(a) (b)

- “Tilted solenoids” to induce dispersion
  - Solenoids with added dipole coils might be more tunable
- Wedge-shaped absorbers
- Magnetic Fields up to ~ 14 T
- RF gradients up to 30 MV/m at 650 MHz

Bunch merge

- Remember, the buncher/phase rotator made a bunch train of 21 bunches (or so)
- Combined longitudinal and transverse merge
  - RF cavities do phase rotation on 21 bunch train to make 7 bunches
  - Kick each bunch into 7 separate “trombone” arc
    - Only 3 are shown
  - Funnel bunches together transversely to make a single bunch
- Followed by further rectilinear cooling channel



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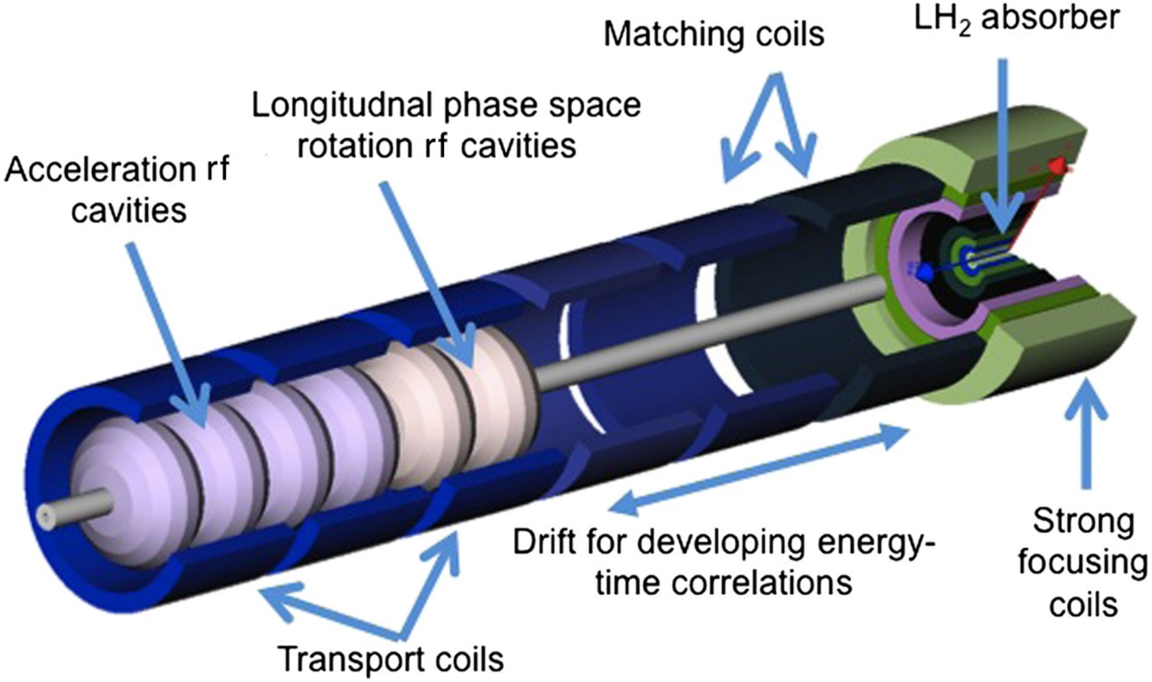
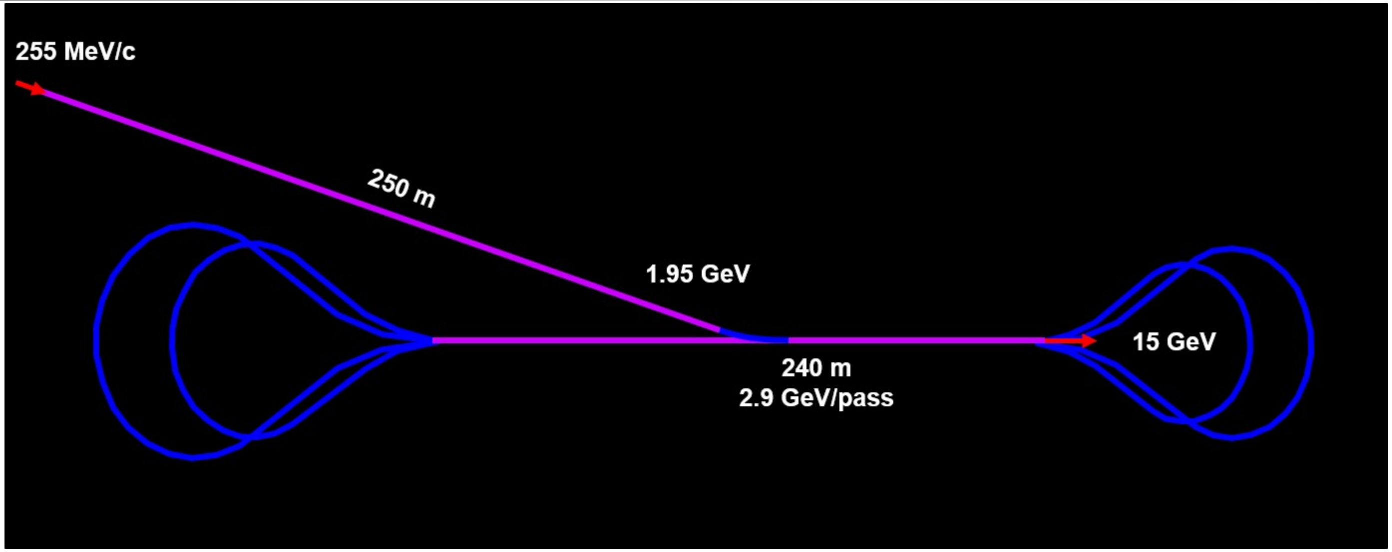
Final cooling



- Challenge is to get very tight focussing
- Go to higher fields and lower momenta
  - Causes longitudinal emittance growth
  - Chromatic aberrations introduce challenges
    - Elaborate phase rotation required to keep energy spread small
    - Move to low RF frequency to manage time spread

Acceleration



- Dogbone RLAs followed by RCS is the baseline
- Not quite sure where the "Proton-based" muon source ends and we are just describing the muon collider facility
- Acceleration for LEMMA may be a bit different due to lower beam emittance and current
- Thought it was worth mentioning

Plans

- Summary of (long term) plans of muon collider collaboration
- Modification to CERN complex to make a proton driver
- Consideration of the target – derisking
- Cooling R&D, especially final cooling where design improvements may improve luminosity and derisk
- Acceleration scheme and collider ring
  - VFFA
  - Neutrino Radiation
- Demonstrator for muon beam technologies

Issues and Mitigations for Advanced Muon Ionization Cooling

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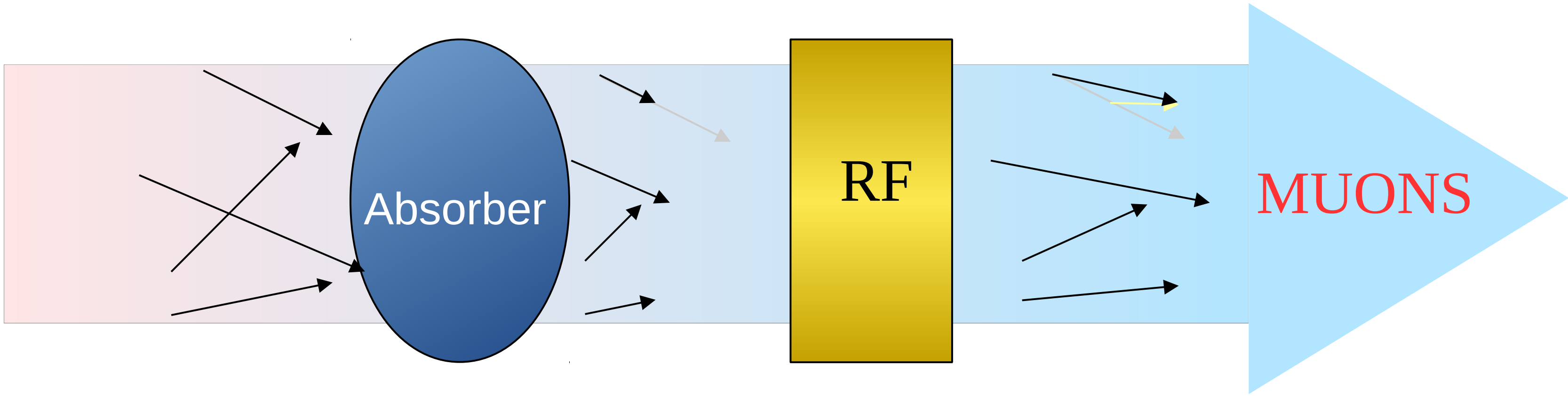
Introduction

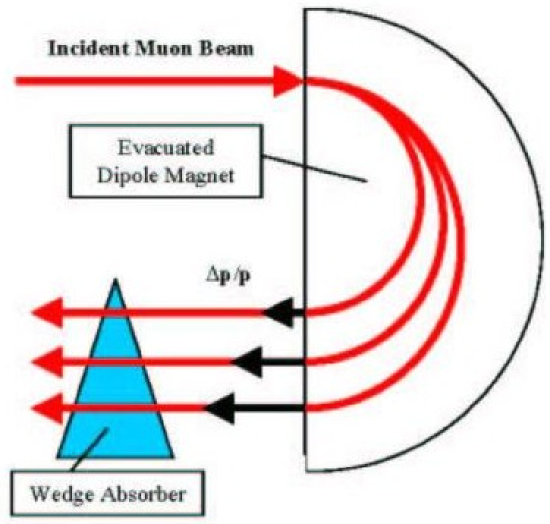
- Introductory material
  - Reminder of MICE successful demonstration of ionization cooling
  - Reminder of European Strategy Update
  - Reminder of need for cooling
    - Why muon beams have high emittance

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 straight
- Multiple Coulomb scattering from nucleus ruins the effect
  - Mitigate with tight focussing
  - Mitigate with low-Z materials
  - Equilibrium emittance where MCS completely cancels the cooling

Emittance exchange



- Reminder for emittance exchange
  - Dipole introduces correlation between momentum and position (dispersion)
  - Wedge shaped absorber removes the dispersion
  - These are shear transformations – move emittance from longitudinal to transverse phase space
- Reminder of the cooling lattices that are out there
  - References for more details

Issues – Interaction of beam with Material

- Describe potential issues with ionization cooling
  - Aim is to frame thoughts on risk mitigations/test stands
- Energy loss
  - Energy loss is understood at ~ 1 % level
  - This is probably good enough
  - Spread in energy loss is less well constrained
  - How good is good enough? Needs a study
- Multiple Coulomb scattering
  - MuScat experiment measured MCS distribution
  - Repeated by MICE – analysis ongoing
  - Probably good enough

Issues – Optics, Magnets and RF

- Optics
  - Single particle optics very well understood
  - Some work to get to very low emittances - simulation-based
- Magnets
  - High fields up to 30 T and sometimes large apertures
  - Likely need dedicated prototyping activity
  - Radiation issues from muon decay
  - Quench protection system may be challenging
    - Quench in a single coil → quench the entire line(!)
- RF
  - In a good position
  - Careful cavity surface preparation is useful
  - MTA Demonstrated two solutions that achieve required gradients
    - High pressure RF
    - Beryllium-sealed cavities

Issues – Bulk effects

- Space charge may be an issue at lowest longitudinal emittance
- Absorber heating may be an issue for solid absorbers
- Bulk ionization of material and interaction with beam may be a problem at lowest emittances
- Beam loading of RF cavities and plasma loading of RF Cavities may be an issue

Mitigations – Test stands

- In the light of these issues, what are the mitigations?
- Simulation
  - Relatively cheap
- Engineering test stands (i.e. no beam)
  - Enables more rapid prototyping
  - Enables testing of different ideas – MTA is a great example

Mitigations – Ring

- Test cooling ring
  - Protons or muons
  - Superconducting ring
    - Needs relatively large radius to inject muons
      - Relativistic, high emittance
      - Can't do charge exchange injection
  - Cheaper, normal conducting ring may be possible for protons
    - Won't get to the very low emittances
- Diagnostics can be easier
  - Multiple passes → more cooling

Mitigations – Beam Line

- Test cooling beam line
  - Protons
    - Higher beam currents available
      - Intensity-dependent effects may be observable
    - Different physics processes
      - Thinner absorbers
      - Hadronic interactions
  - Muons
    - Lower beam currents
      - Challenging to measure intensity-dependent effects
    - Correct physics processes
  - Hybrid solution?
    - Alternate particle species
- Diagnostics may be challenging
  - MICE style detectors? – but rate limited
  - Many cooling cells to get a measurable signal?

Conclusions

- First we understand where are the potential problems
- Then we design tests to de-risk

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Discussion

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1 Year Plan?

- Lots of the LoIs have a “1 year plan” or suggestion for what might be in a longer “Contributed Paper”
- I believe we are in such an early phase it is hard to really make a dedicated plan
- The aim is to give a feel for where we are as a collaboration and our basic plans
  - For the international community
  - For potential collaborators
  - For US funding agencies

Author List

- Given where we are in the formation of the collaboration, I have a fairly easy approach to authors
  - Mostly this is a summary of others' work anyway
  - Many need to get funding before committing to any serious work
  - Worth showing there is serious interest from the community

Contents

- Any comments on the contents in general?

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Submission

- Propose submission to
  - Energy Frontier and
  - Accelerator Frontier
- Other "frontiers":
  - Neutrino
  - Rare and Precision
  - Theory
  - Instrumentation
  - Computational
  - Underground Facilities
  - Community Engagement
- Propose submission early next week
  - Deadline for further comments - Friday