Demonstrator for Cooling Design Considerations

Science & Technology Facilities Council
ISIS Neutron and Muon Source

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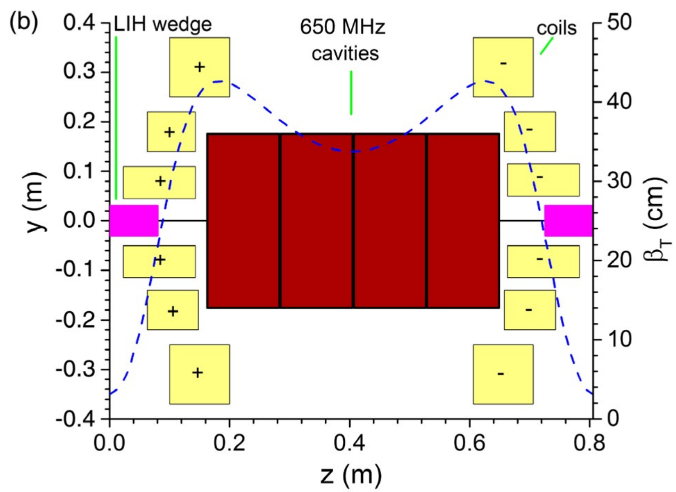
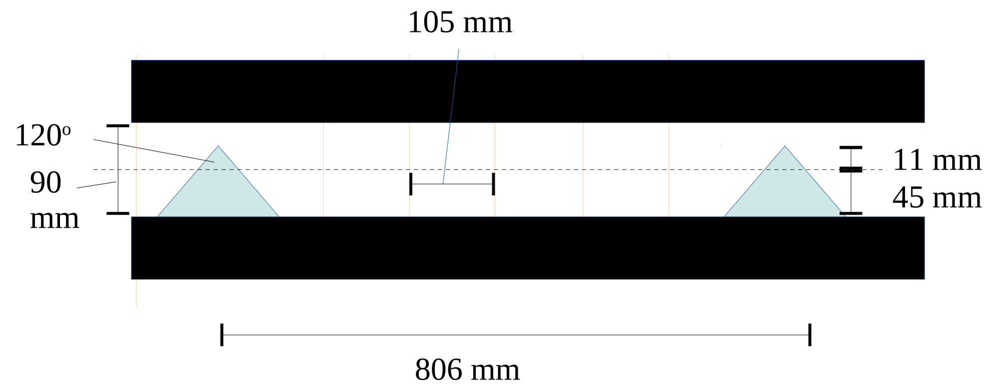
What should the facility demonstrate?

- Headlines
  - 6D cooling
  - Reacceleration
  - Cooling at low emittance (longitudinal and transverse)
- What do we need to do for CDR
  - Engineering integration
  - High-gradient RF cavity in magnetic field
  - Optics
  - High field magnets
  - Absorber infrastructure
  - Vacuum
  - Matching between different cooling cells
  - Diagnostics
  - Alignment and correction

Rectilinear B8 Lattice – as simulated





Wedge absorbers are modelled using a Lithium Hydride trapezium. Opening angle is 120° and height is 56 mm

RF windows thickness is between 20 micron. Adjacent cavities share the same window.

D. Stratakis et al, Rectilinear Six-Dimensional Ionization Cooling Channel for a Muon Collider: A theoretical and numerical study, PR ST AB 18 (2015)

Rectilinear B8 - Hardware

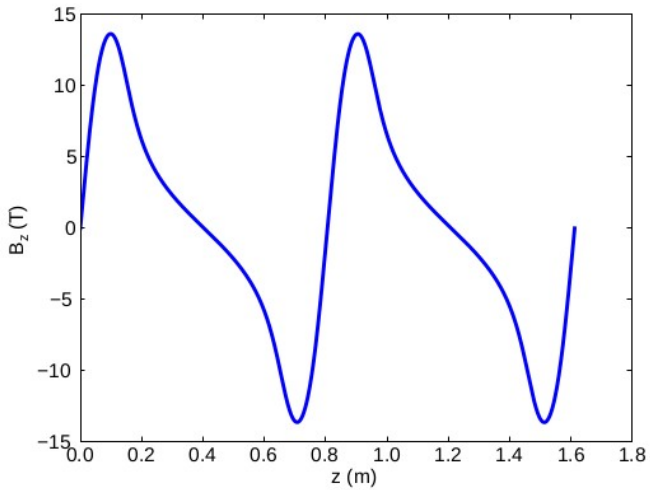


Figure 2: Stage 8: on-axis field.

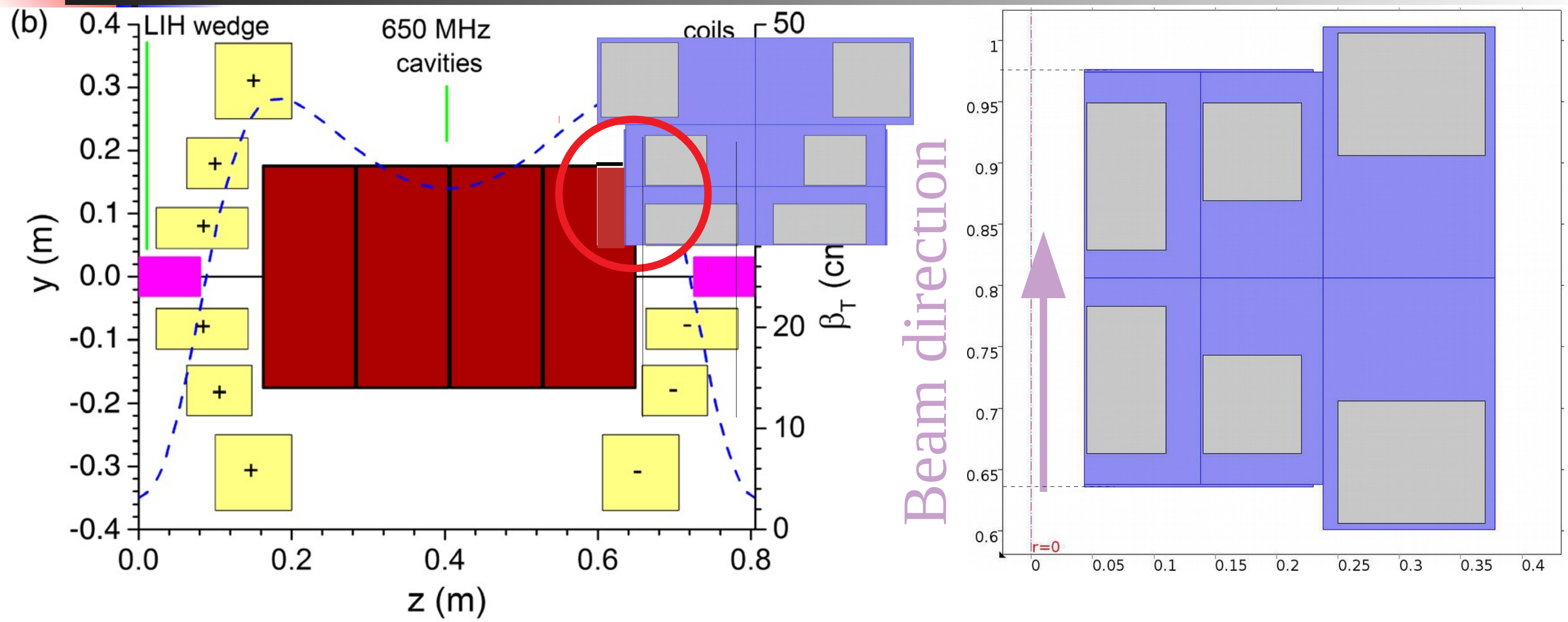
Table 1: Coil Dimensions

z1 (m)	dz (m)	r1 (m)	dr (m)	J (A/mm^2)
0.023	0.12	0.045	0.065	220
0.063	0.08	0.14	0.08	135
0.1	0.10	0.25	0.12	153
0.606	0.10	0.25	0.12	-153
0.663	0.08	0.14	0.08	-135
0.663	0.12	0.045	0.065	-220

H. Witte et al, Magnet design for a Six-Dimensional Rectilinear Cooling Channel – Feasibility Study, Proc. IPAC2014

- RF cavity
  - 650 MHz, 28 MV/m, 105 mm long
  - TM010 cylindrical pillbox – field is a Bessel function
- Magnet model
  - Modelled using 3 cylindrical current blocks and a polarity flip
  - In the model, slight tilt provides dipole field
    - May prefer trim coils

Engineering Integration

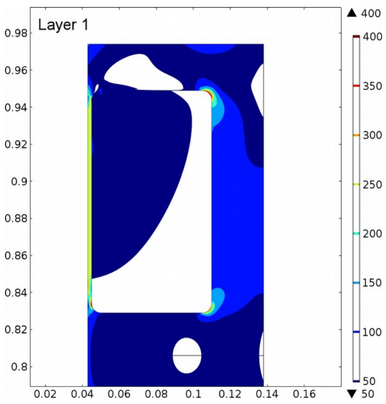


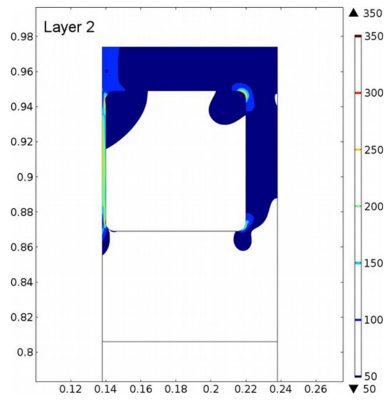
- Engineering integration
  - Note clash between the RF and the magnet
  - Cryogenic analysis was not done (but forces were)
  - Note also conflict between simulated bore and coil support
  - I guess insulating vacuum flask need to go around this?
- Challenge to bring services – vacuum, RF
- Operate RF at lN_2 temperature?
  - Make the RF → magnet interface easier?

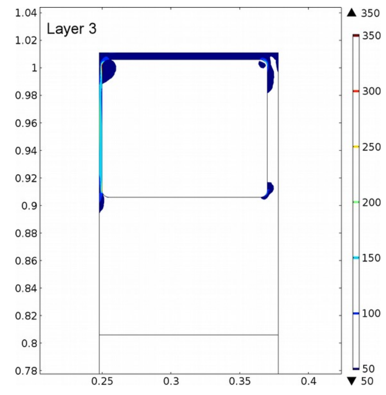
High Gradient RF

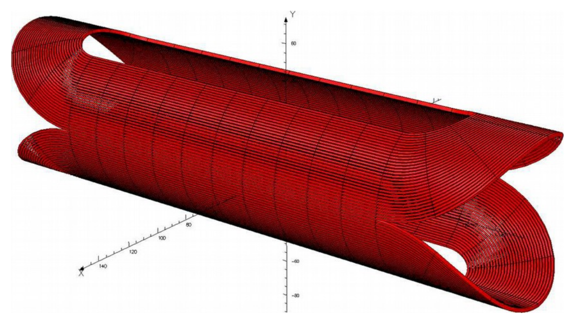
- RF systems
  - Challenge to operate RF in high field magnet
  - Breakdown → electrons stripped from surface
- Proof-of-principle operation using Beryllium-coated windows
  - Largely seems to suppress breakdown
- Experimental results for high pressure gas filled RF encouraging
  - Practical in an accelerator?
- New concept to pulse the RF power before spark has time to build (Sergey Arsenyev)
- Significant engineering overhead to do high pressure gas cell
  - Is it something we want to invest in?
  - Note pressure window dilutes cooling effect for short lattice
    - Instrumentation in the gas volume?
- RF windows – how thick do they need to be? Radial profiling?

High-field magnets



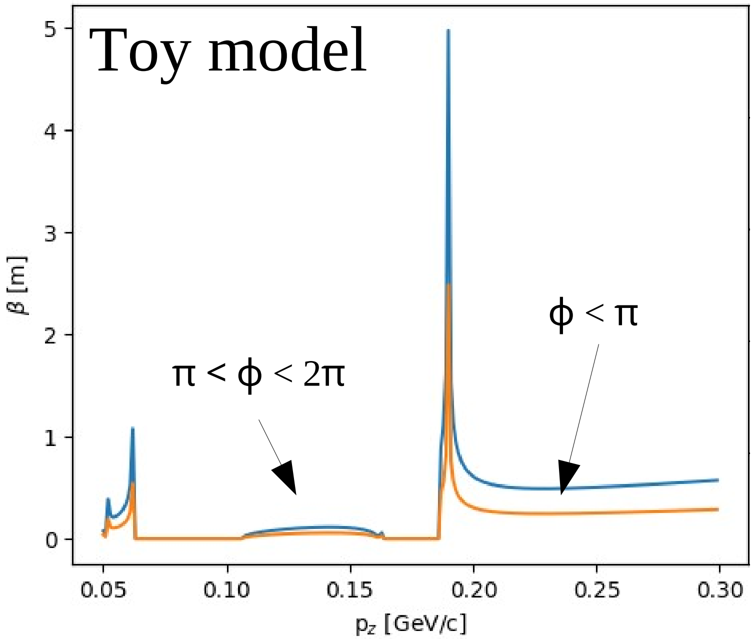


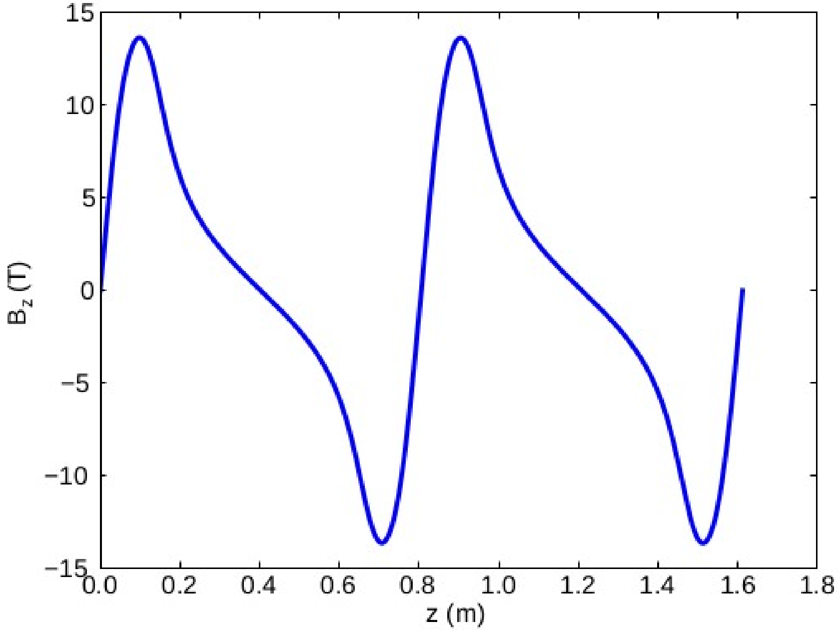




- High-field magnets
  - Can we manage the forces (also during unbalanced quenches/etc)?
  - Can we deal with the cryogenics?
- Quench protection
  - Neighbouring magnets strongly coupled
  - If one magnet quenches do we quench the entire line? What about in muon collider (where “line” is ~3 km of magnets)
- (Radiation load)
  - MC will have a high radiation load – needs care

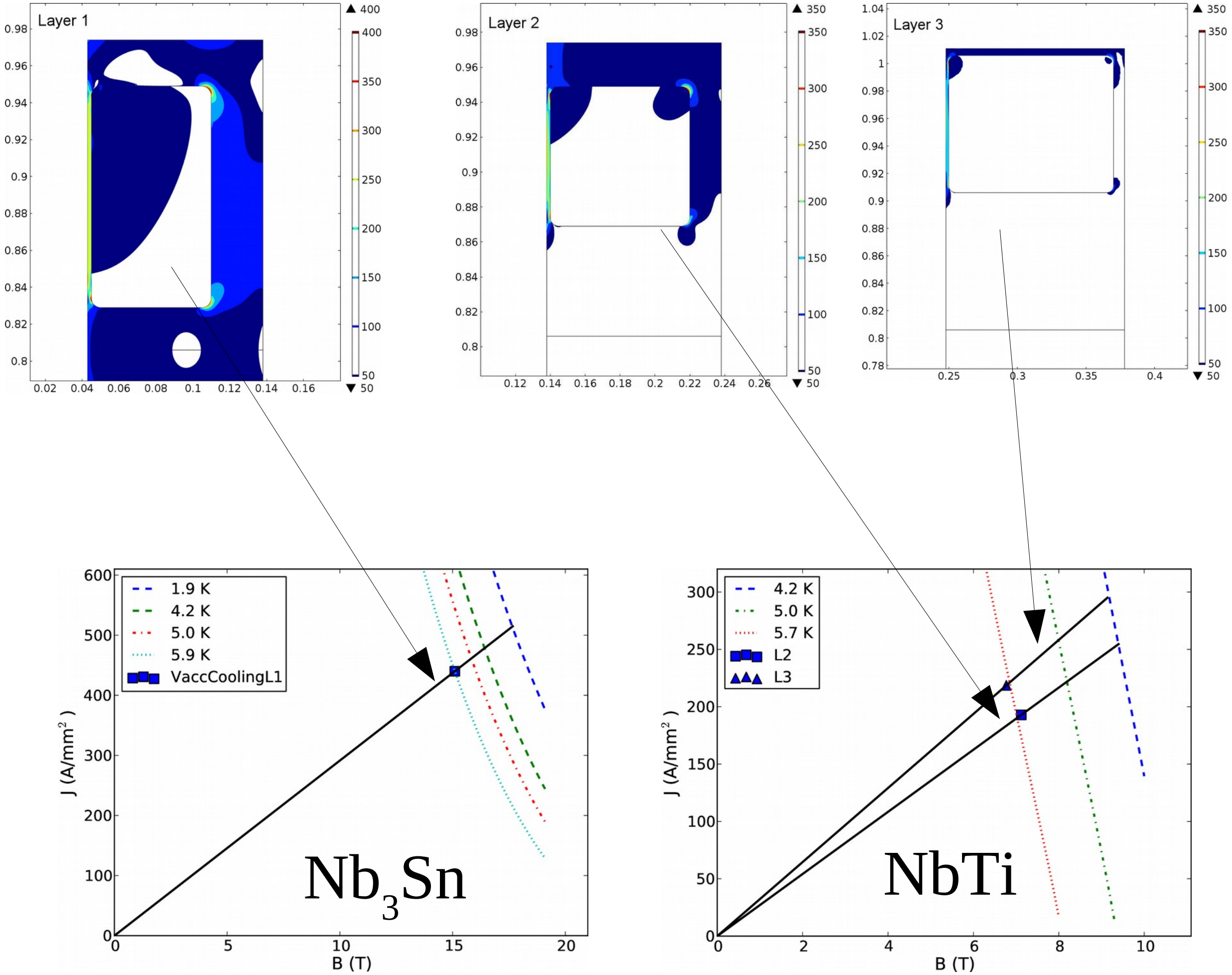
Optics questions

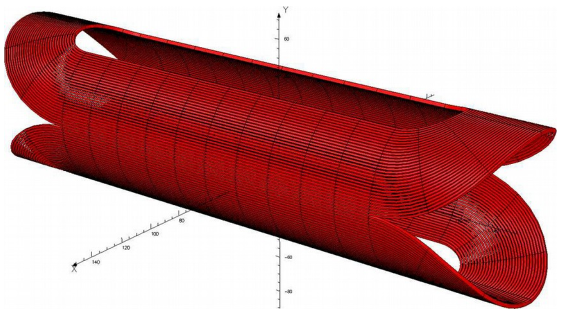




- How tunable is the optics
  - Can we test in both stability regions?
  - Can we tune dispersion and β? How much?
  - Can we tune wedge opening angle? How much?
  - Can we use a dual sign lattice (like HFoFo)?

High-field magnets



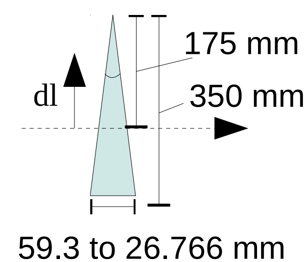


- Challenging!

Absorber Integration

Lattice	Material	Height [mm]	Opening angle [o]	Vertex to beam axis [mm]	Base length [mm]	Length on axis [mm]	Energy Loss on axis [MeV]	dE/dl [MeV/mm]
HFoFo	LiH	350	9.68	175	59.3	29.7	4.7	1.90E-002
HFoFo	LiH	350	4.38	175	26.8	13.4	2.1	1.22E-002
Rectilinear B8	LiH	56	120	11	193.98	38.1	6.1	5.52E-001
HFoFo	LH2	350	9.68	175	59.3	29.7	0.9	3.47E-003
HFoFo	LH2	350	4.38	175	26.8	13.4	0.4	2.22E-003
Rectilinear B8	LH2	56	120	11	193.98	38.1	1.1	1.01E-001
HFoFo	LH2	350	36	248	227.4	161.2	4.7	1.89E-002
HFoFo	LH2	350	23.5	175	145.6	72.8	2.1	1.21E-002
Rectilinear B8	LH2	56	168	11	1065.6	209.3	6.1	5.53E-001
All subject to Rogers reading lattice files – need to cross check with tracking								

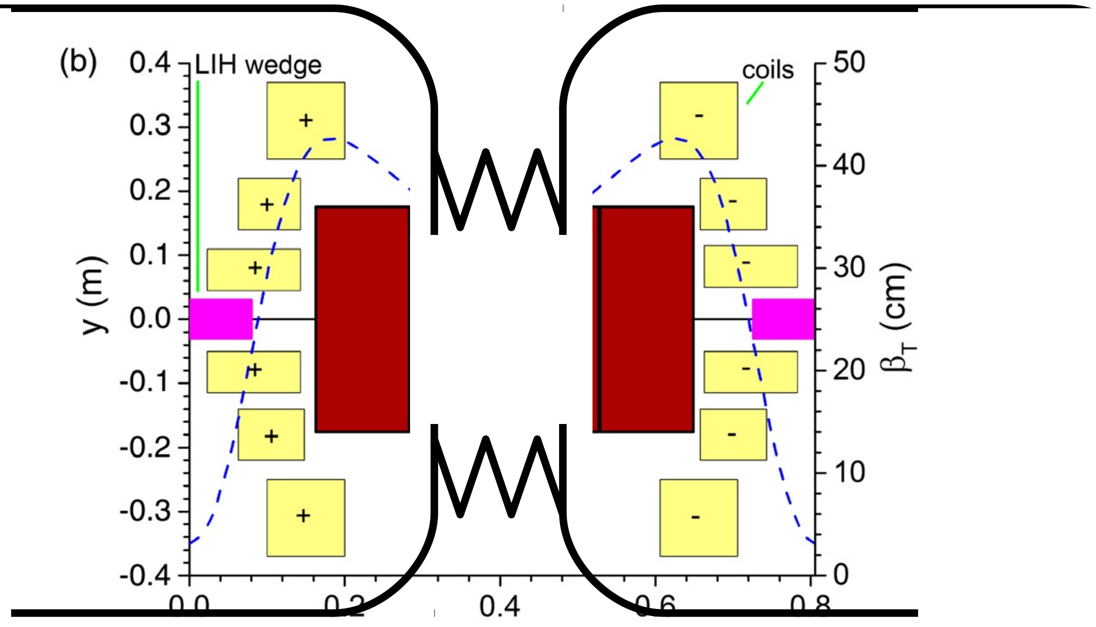
- LiH absorber baseline for Rectilinear B8 and HFoFo
  - Relatively straight forward
  - Test active cooling?
- Would be interesting to test LH2 absorber
  - For rectilinear require large (non-physical) opening angle
    - We care about dE/dl i.e. energy loss vs transverse position
    - Reoptimise optics?
  - For rectilinear pipe work conflicts with RF cavities
  - Interesting option for HFoFo
- Windows - Mylar? Al? What thickness?



Beam Instrumentation

- Muon rate is likely to be low ~ 10^6-10^7 or so
- Potential non-muon backgrounds
  - Muon decay electrons
  - Beam impurities
  - Dark currents (electrons from RF cavity surfaces)?
  - Knock on electrons (electrons knocked out of absorber/windows)?
- Beam Instrumentation:
  - Conventional BPM?
  - Scintillator screen
    - Can be non-destructive for muons
  - Phosphorescent coating on e.g. RF windows
  - Wire scanner
  - Decay electron monitoring
  - Something else?

Alignment

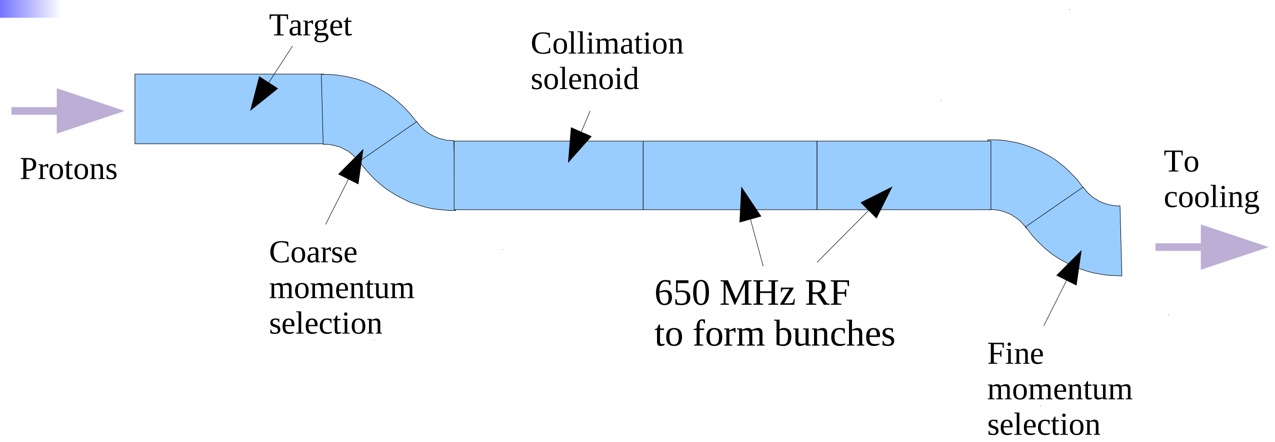


- Alignment Scheme proposes lumping several cooling cells together (approx 5 m chunks)
  - HFoFo has a natural “supercell” of 4.25 m length
  - Rectilinear more arbitrary
  - Remove RF and use the space for bellows
  - Shorten absorber appropriately
- How do we stand off forces between magnets?
  - First order cancellation if we ramp the line at the same time… but quench?

Correction for misalignment

- Solenoid lattice → dispersion in vertical and horizontal
- Use trim coils inside magnet to control dispersion
- How sensitive is the lattice to alignment?
- Do we need horizontal and vertical steering coils?
  - E.g. Horizontal generates dispersion in the absorber
  - Vertical corrects for misalignments
  - What about trim solenoid?
- What sort of instrumentation do we need to check?
  - How sensitive?

Collimation



- Powerpoint level of study
  - Chicane to do a first momentum selection
  - Collimation solenoid 1-2 metres - no need for high field?
  - Section of RF to do time selection
    - Need about 20-30 MeV → guess about 50 MV here
  - Pions are decaying as we go – how much of a mess does this make?
    - (Nb: pion lifetime is about 8 metres at 200-300 MeV)
  - What about electron impurities?
- How clean do we need the beam to be?

Resource requirement

- Breakdown
  - **Engineering integration**
  - High-gradient RF cavity in magnetic field – share with RF group
  - Optics studies – share with cooling group
  - High field magnets – share with magnets group
  - **Absorber infrastructure**
  - **Vacuum**
  - Matching between different cooling cells – share with cooling group
  - **Diagnostics**
  - **Alignment and correction**
  - **Collimation/beam selection**