Muon Front End Status

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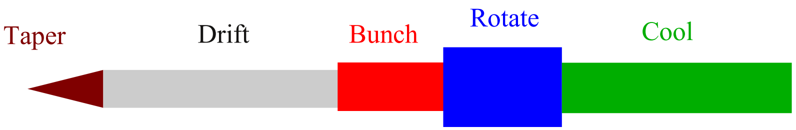
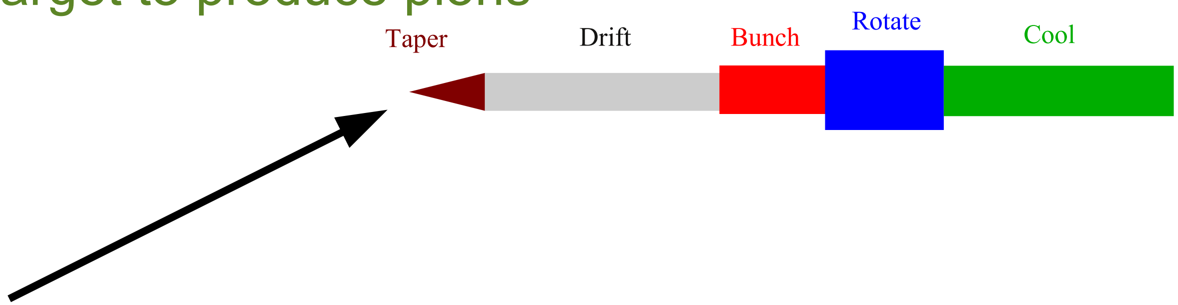
Proton beam strikes target

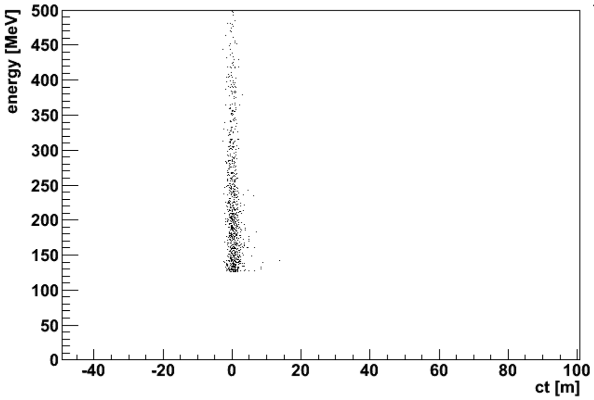
- Muon Front End baseline description
  - Longitudinal drift
  - Buncher
  - Phase-Energy Rotation
  - Ionisation Cooling
  - Hardware design
  - Performance
- Risks and mitigations
  - RF break down in magnetic fields
  - Transmission losses and secondary particles
- Future Plans



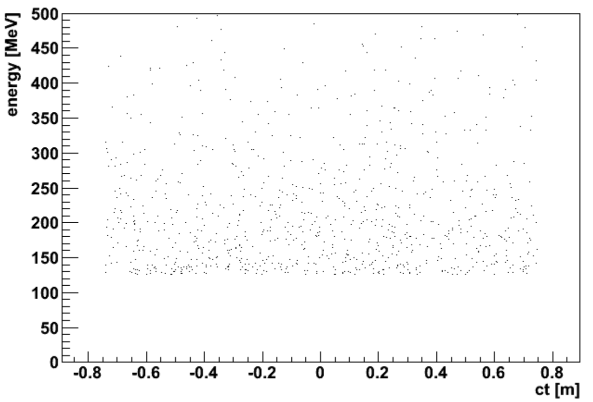
Proton beam strikes target

- Proton beam strikes target to produce pions





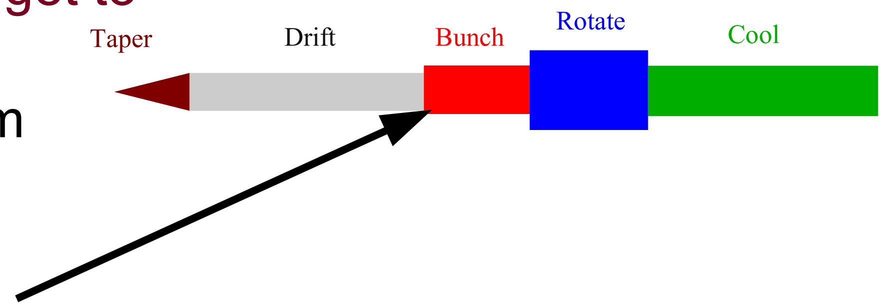
Macro bunch structure

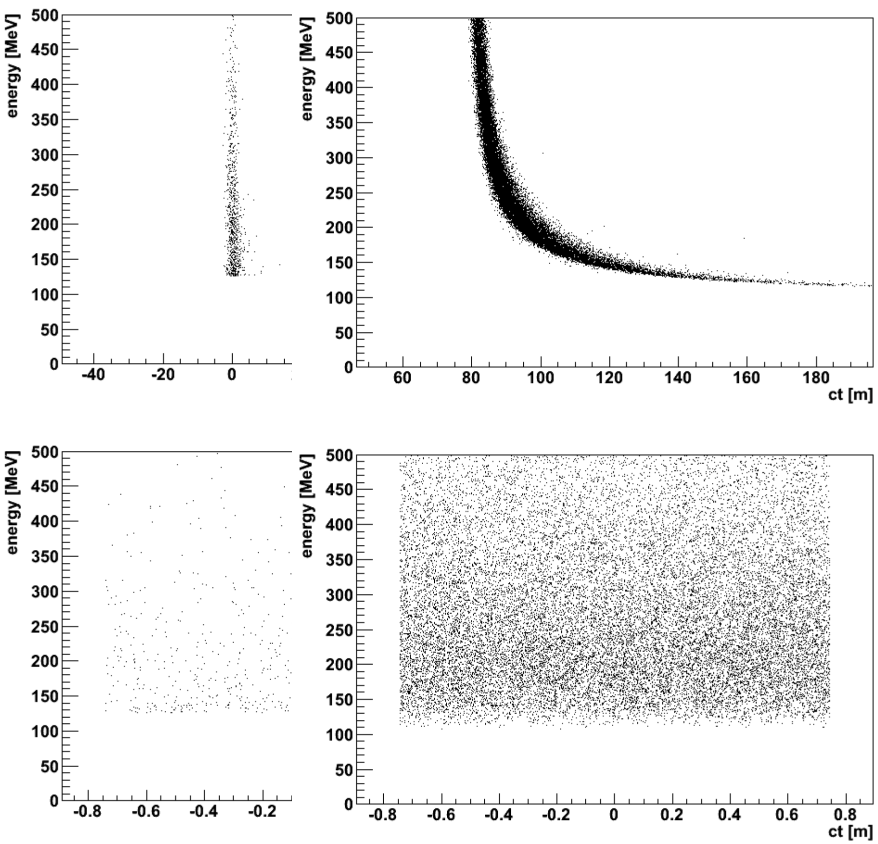


Micro bunch structure (single rf bucket)

Taper, Decay and Drift

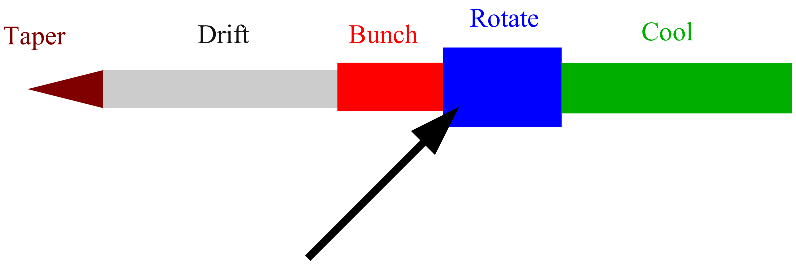
- Adiabatic B-field taper from Hg target to longitudinal drift and pion decay
- Longitudinal drift in ~1.5 T, ~100 m solenoid
  - Allow bunch to lengthen for RF

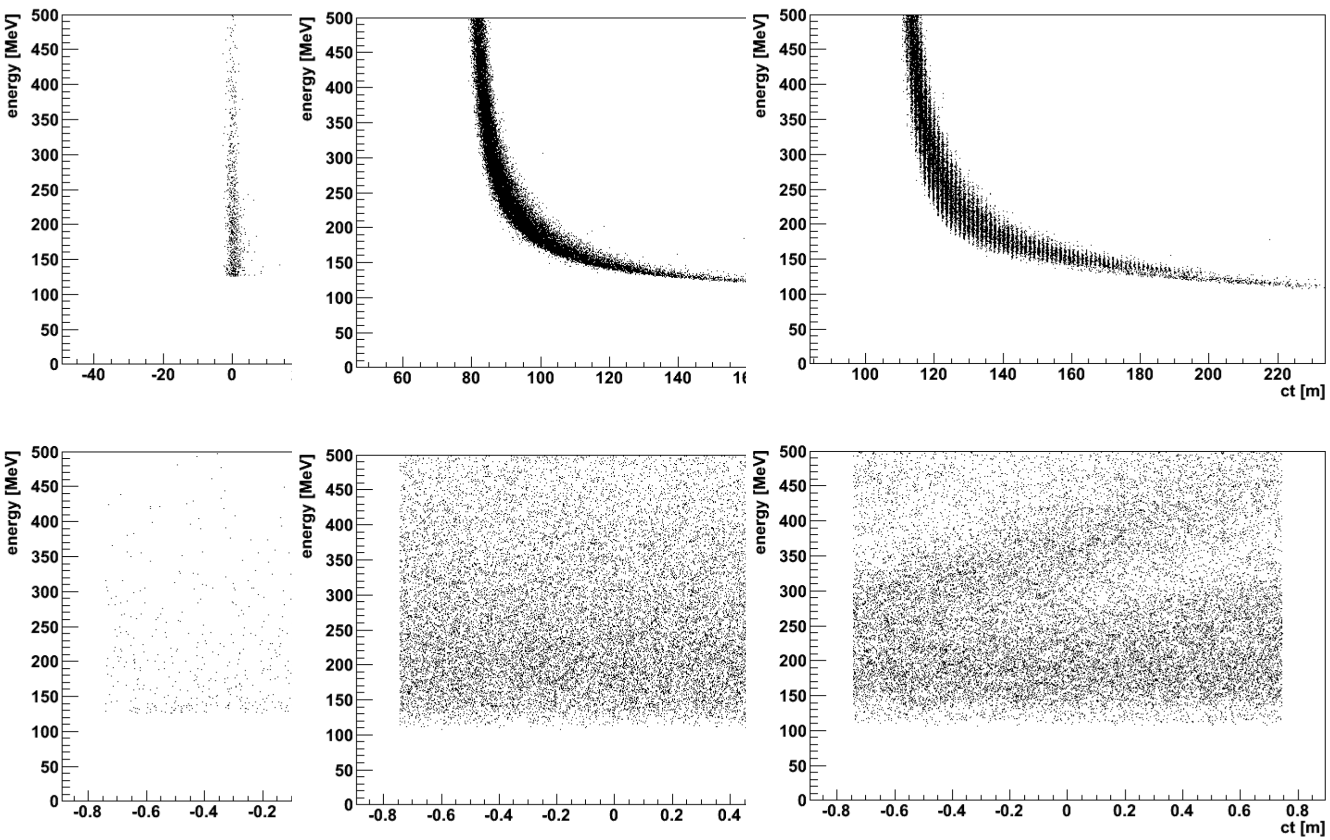




Adiabatic Buncher

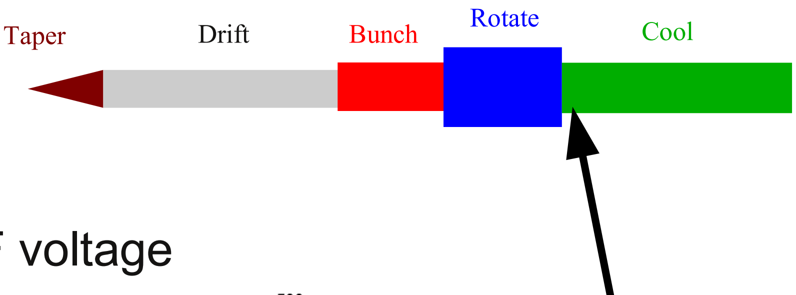
- Adiabatically bring on RF voltage
  - Introduce “micro bunches”

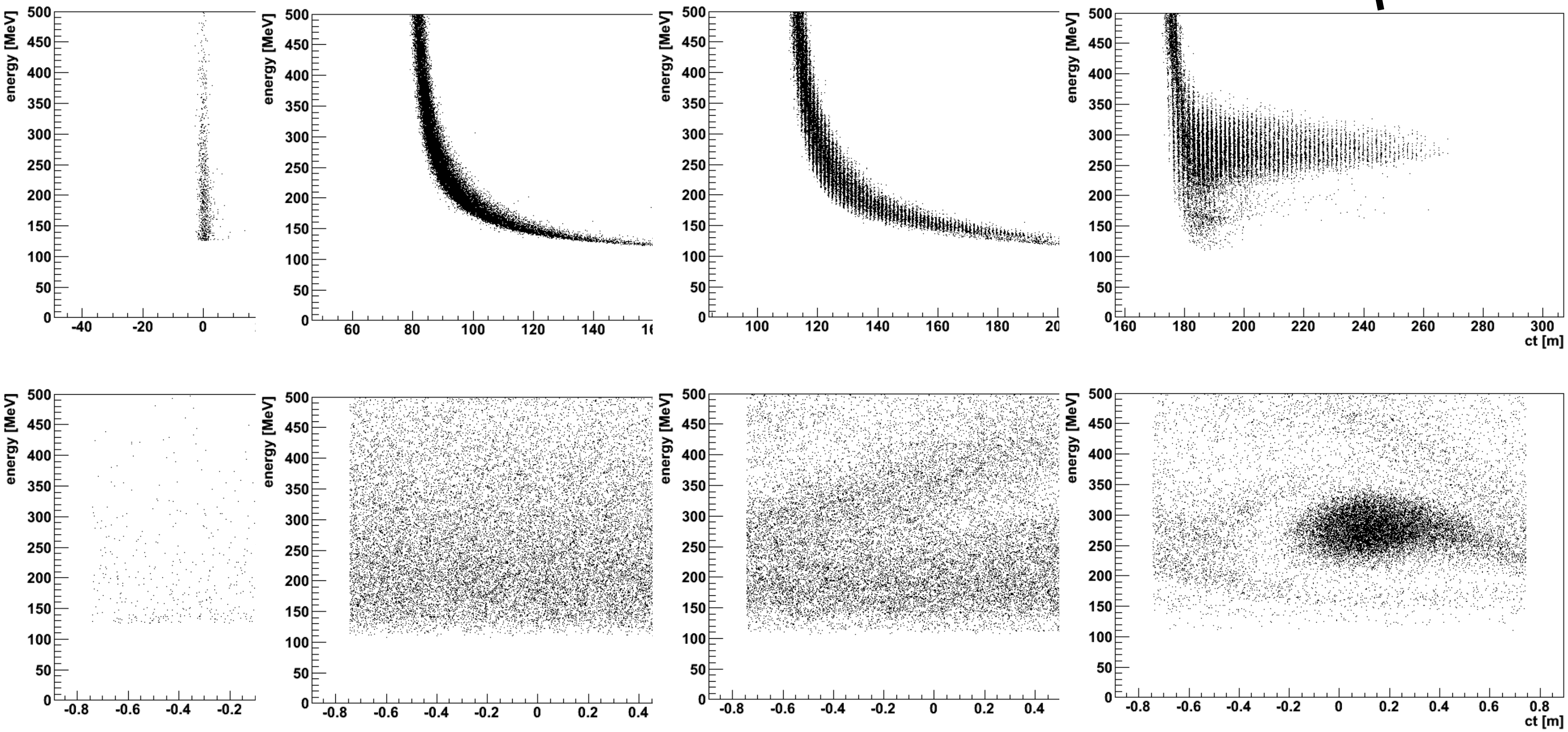




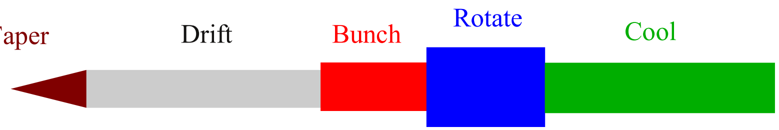
Phase-energy rotation

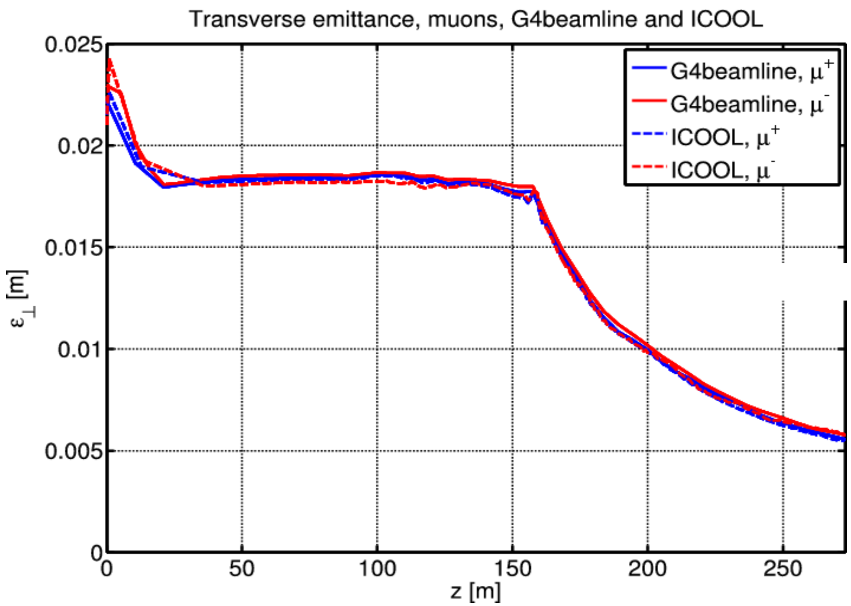
- Phase-energy rotation
  - RF out of phase with bunches
  - Higher energy head receives negative RF voltage
  - Lower energy tail receives positive RF voltage





Ionisation Cooling

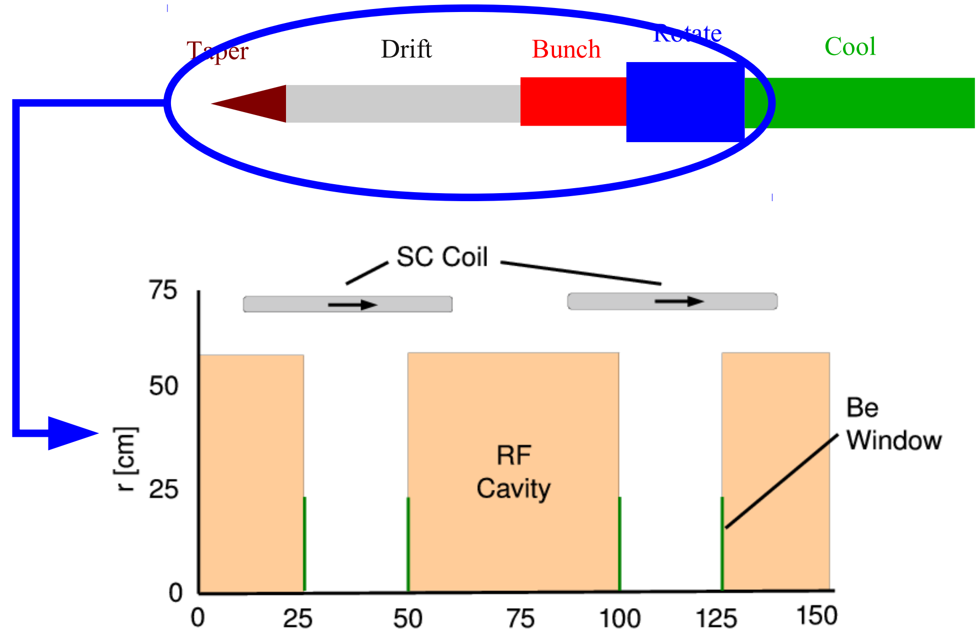




- Ionisation Cooling
  - Reduce transverse beam size
  - Place material in the beam line to reduce energy
  - Replace energy using RF cavities only in longitudinal direction
  - Reduces transverse beam size (emittance)

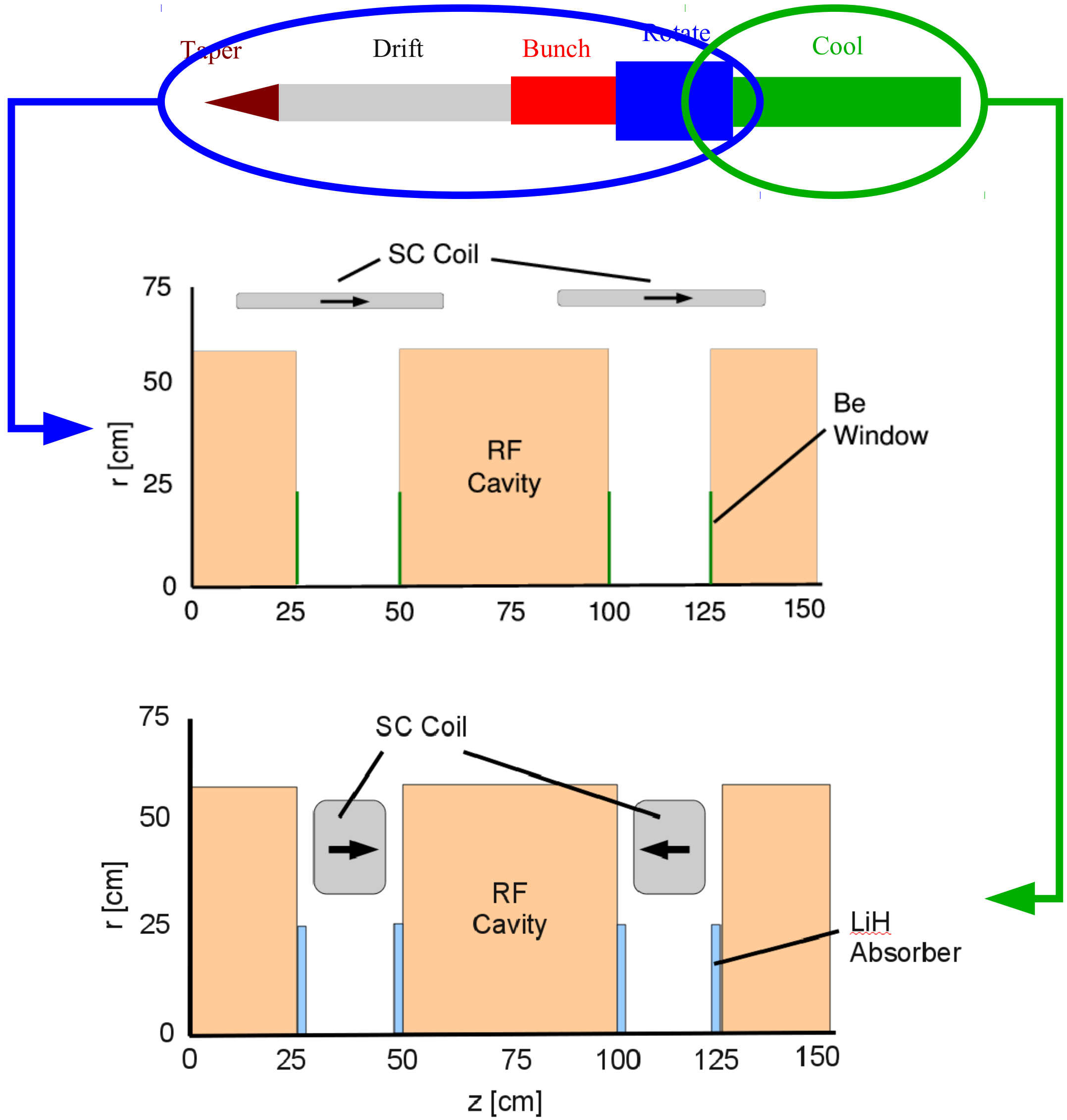
Drift/Bunch/Rotator Hardware

- Drift/Buncher/Rotator shares 1.5 T solenoidal field
  - Plan for large aperture superconducting coils
  - May revise to normal conducting (see comments on losses)
- Normal conducting RF
  - Range 200-320 MHz
  - Up to 12 MV/m
  - Accommodates lengthening macro-bunch
  - Sealed by Be windows



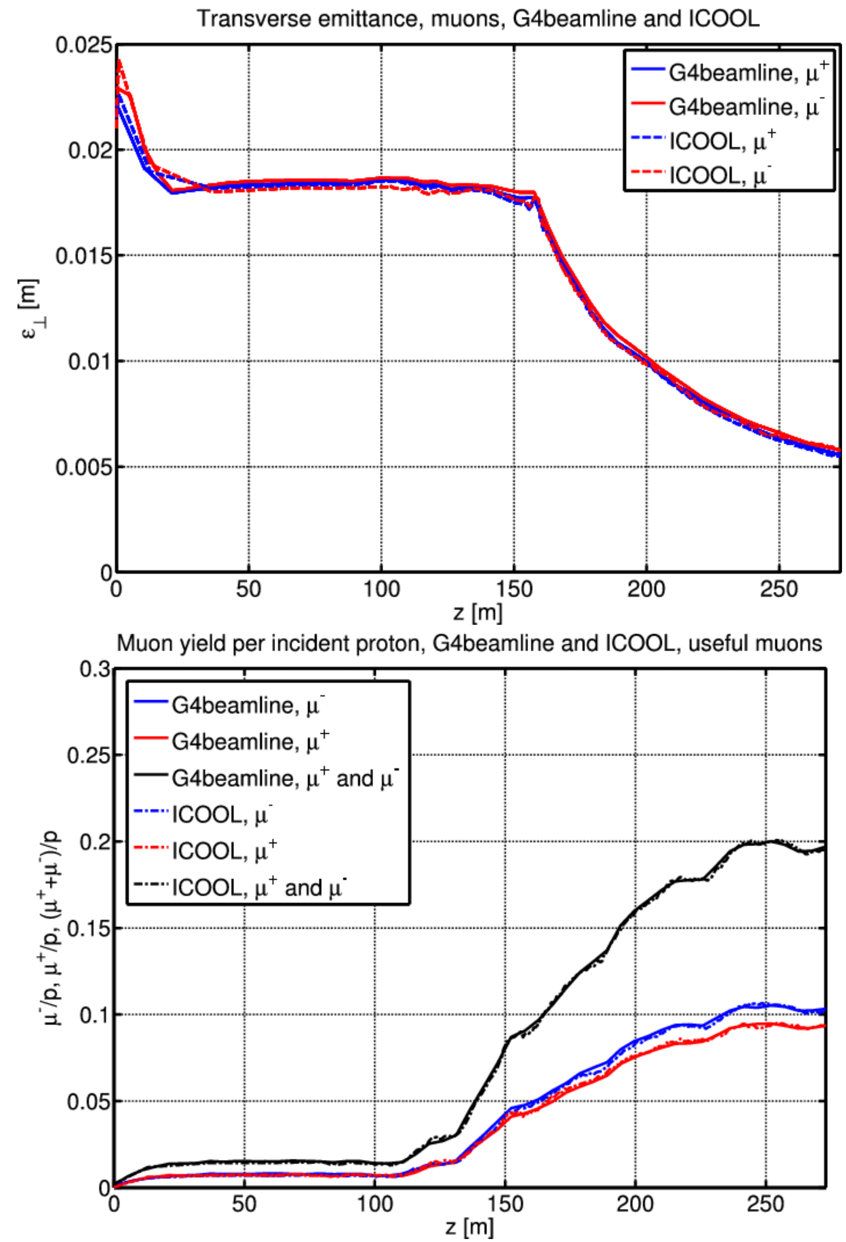
Cooling Hardware

- Superconducting coils for transverse focussing
  - Alternating field +/- 2.8 T on adjacent coils
- Normal conducting RF for re-acceleration
  - 201.25 MHz
  - 15 MV/m
  - LiH provides ionisation cooling
  - Be coating on LiH provides electromagnetic seal for RF



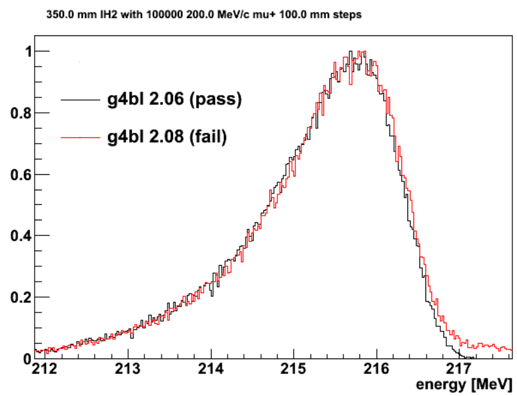
Baseline performance

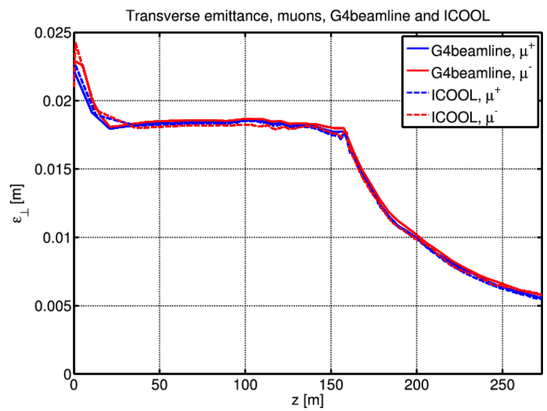
- Good baseline performance
  - Count number of muons in 30 mm transverse and 150 mm longitudinal acceptances
    - Motivated by accelerator acceptance
  - Capture 0.2 muons per 8 GeV proton
  - Small transverse emittance
- Transverse capture robust
- Some longitudinal leakage

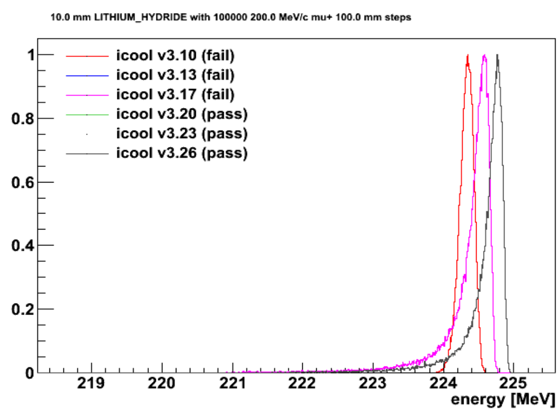


Code and Lattice Validation

- Mostly automated monitoring of physics process model
  - Compare different versions of ICOOL and G4Beamline
  - Shows some significant variation over time
- Verification of lattice performance shows good consistency
  - Using, for example, g4beamline 2.06 and ICOOL 3.20







Hardware tests

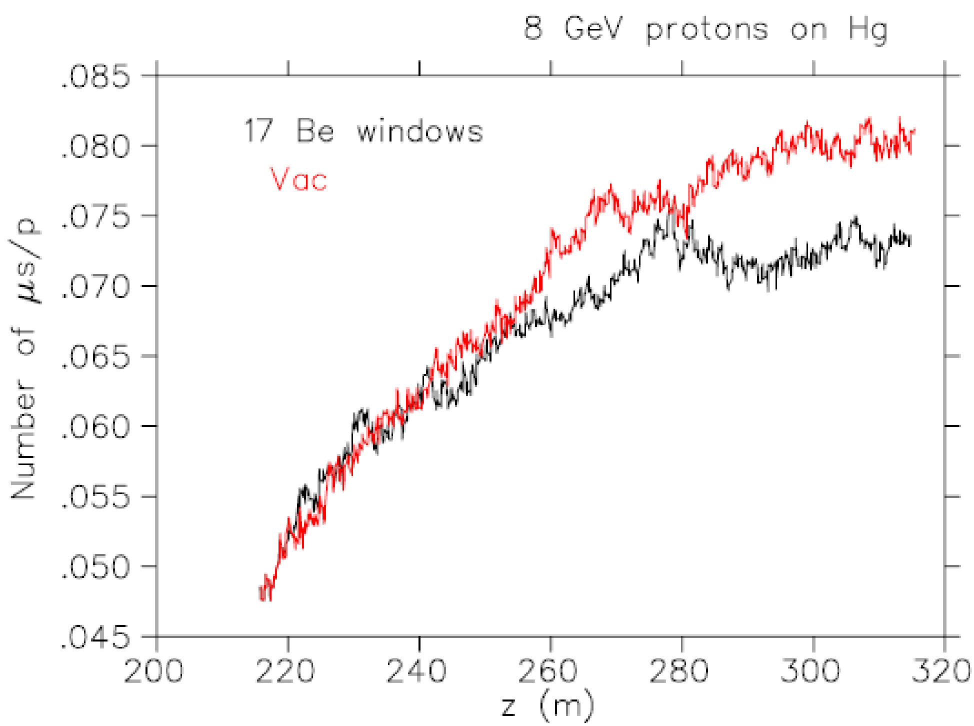
- Integration testing of hardware at Fermilab MUCOOL Test Area
  - Tests of RF cavities at 805 and 201 MHz
  - Tests of cavities in magnetic fields
  - Effects of surface treatments on cavities
  - Enhancements to basic RF technology
    - Pressurised RF cavities
    - Magnetically insulated cavities
  - Hydrogen absorber technology testing
- System testing of hardware in Muon Ionisation Cooling Experiment
  - Under construction at Rutherford Appleton Laboratory
  - Test physics model
  - Test integration of RF, superconducting magnets and liquid Hydrogen and Lithium Hydride absorbers
  - Test ease of engineering

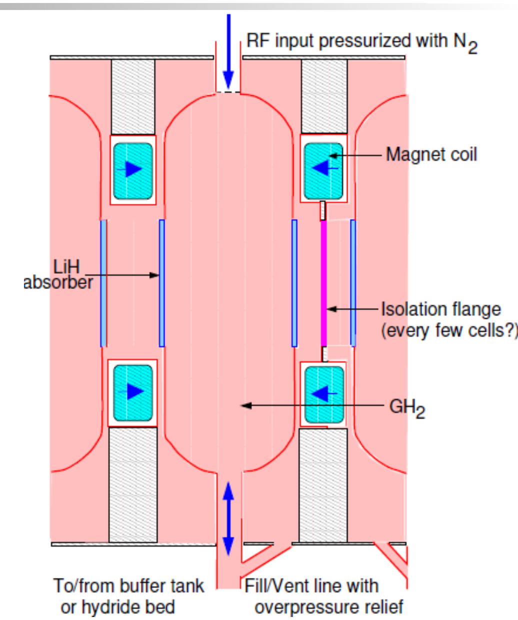
RF Problem

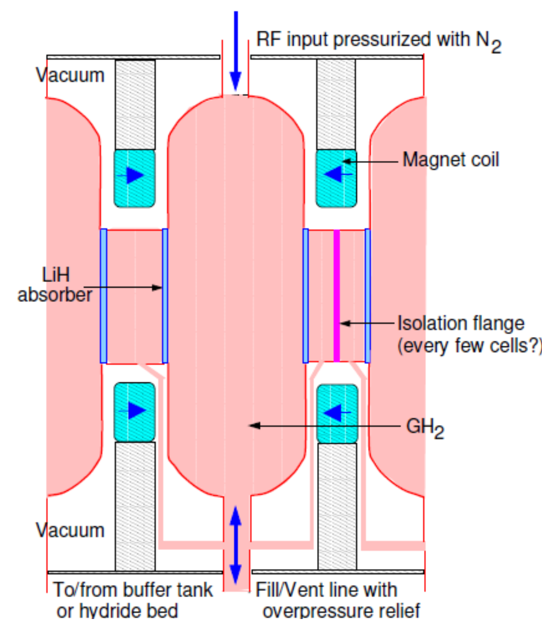
- We need lots of RF in the front end
  - We have significant longitudinal manipulations to perform
  - Ionisation cooling needs strong acceleration
- We need lots of solenoidal focussing in the front end
  - Try to contain large transverse emittance beam
  - Ionisation cooling needs tight focussing to reduce multiple scattering effects
- Leads us to overlapping solenoidal focussing with RF cavities
  - RF cavities sit in ~1-2 T fields
- Some empirical evidence that RF cavities and magnetic fields don't co-exist well
  - Somehow the B-field induces breakdown in the RF cavity
  - Possibly limits peak field to ~ 1/2 expected limit in > 1 Tesla fields
  - Not well understood, many caveats
- Choose highest performing lattice
- Prepare risk mitigating options

HP RF lattice

- High Pressure RF lattice
  - Use high pressure Hydrogen to suppress breakdown
  - Provides some cooling medium
    - Supplement with LiH
  - Add Be safety windows to segment large pressurised H_2 volume

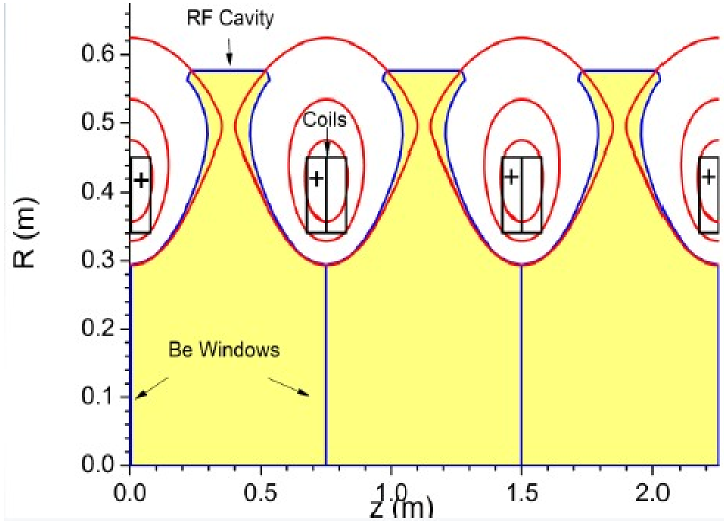


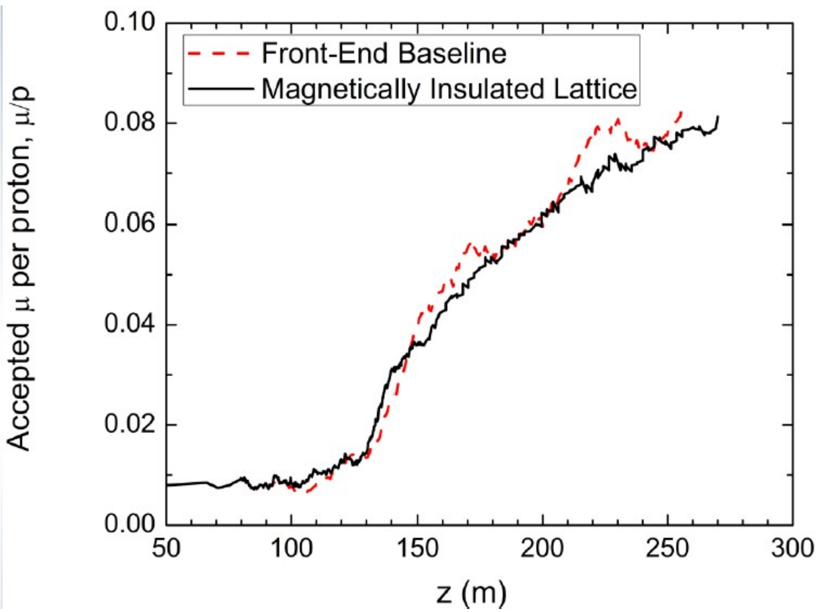


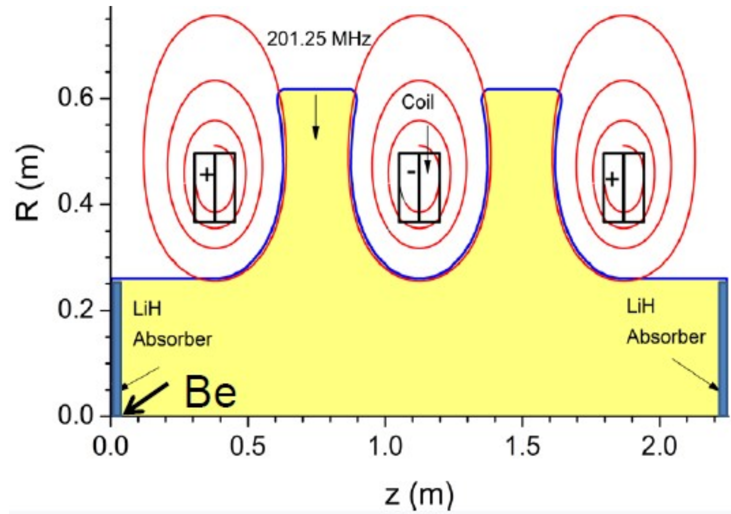


Insulated lattice

- Magnetically insulated lattice
  - B-field perpendicular to E-field
  - Suppress break down on RF cavities
- Similar performance to old FS2A lattice
  - Requires more RF power
  - Coupling between cavities may be a problem

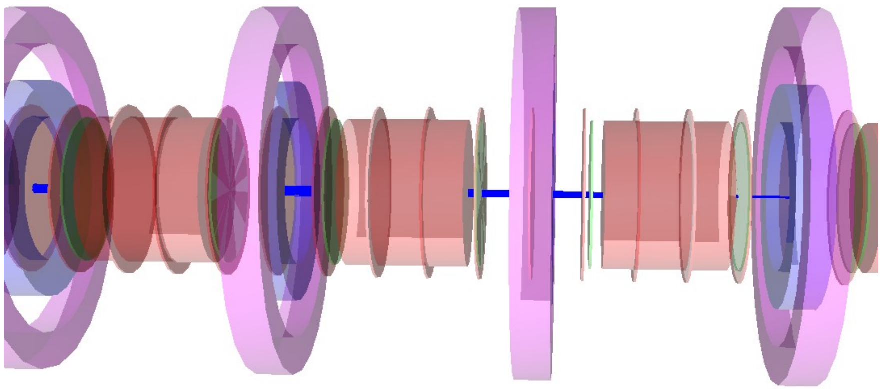


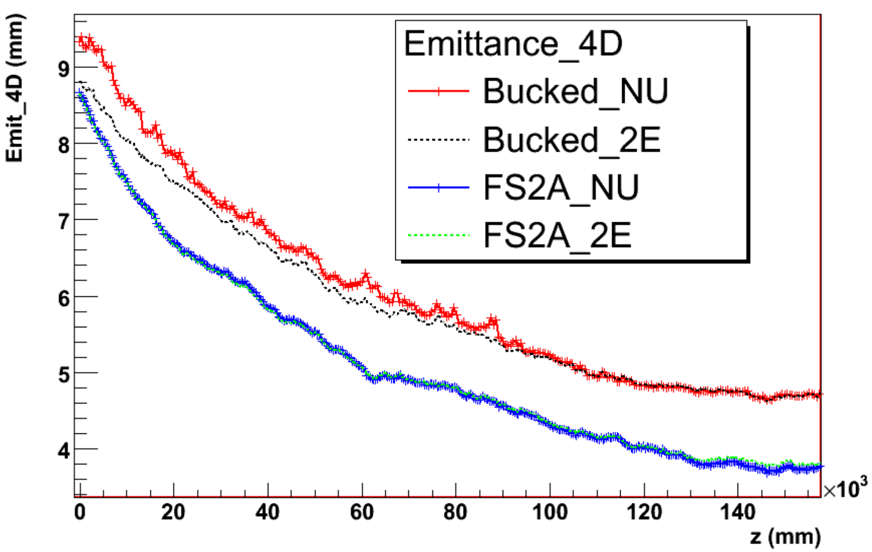




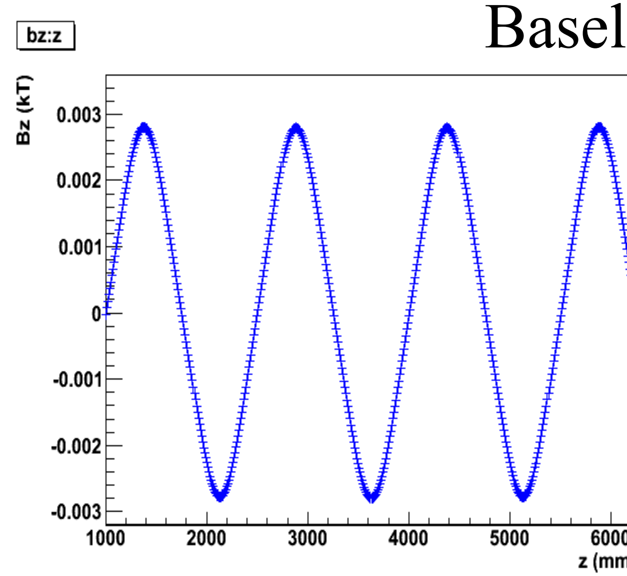
Bucked lattice

- Reduced magnetic field on RF cavities
  - May enable higher accelerating voltage
- Slightly higher equilibrium emittance

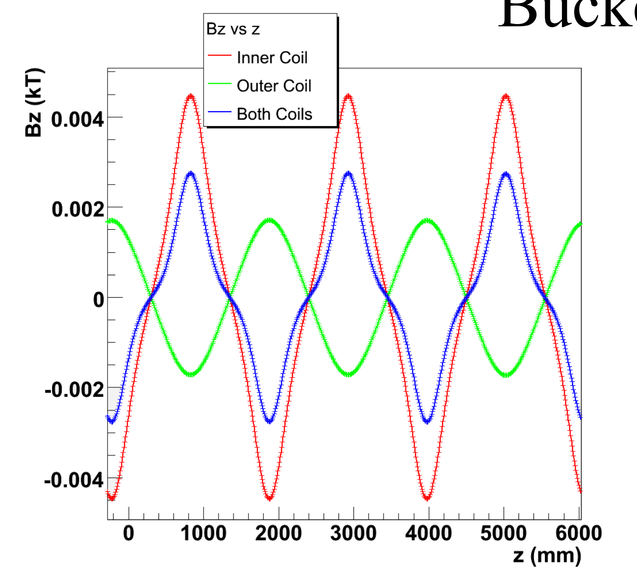




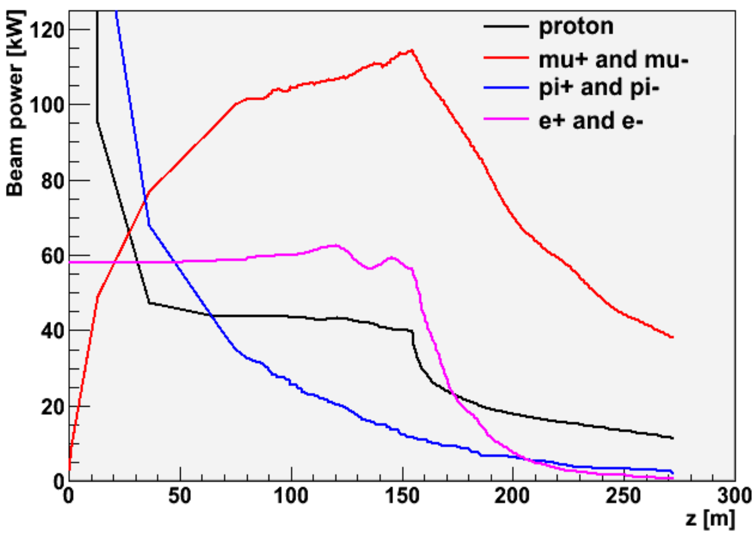
Baseline



Bucked

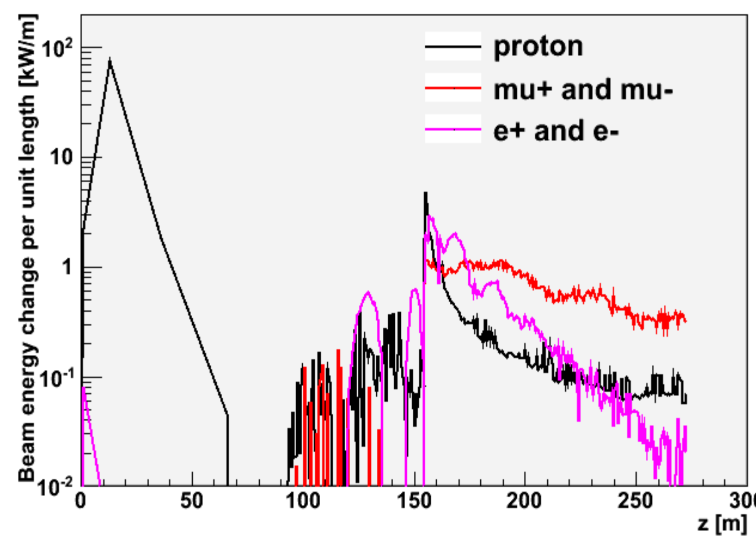


Beam power



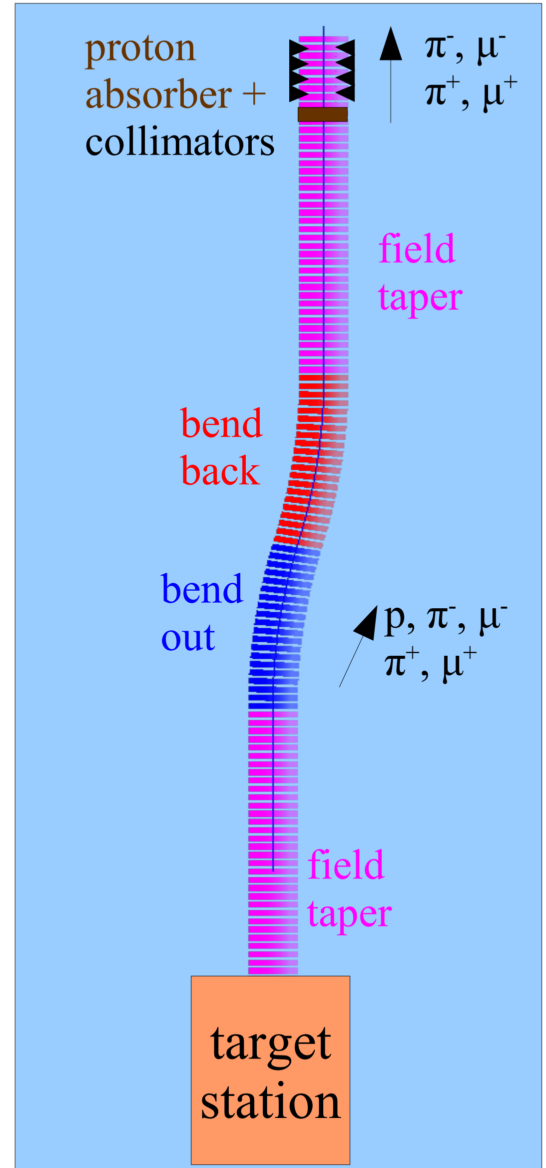
- Beam power normalised to 4 MW
  - Rather high
  - Obviously significant losses
- Beam power of secondaries is rather high

- Try to constrain hadronic losses
  - Prevent activation
  - Permit hands on maintenance
- Prevent heat deposition on superconducting equipment
  - Cost of cryogenic cooling
  - Quench limit



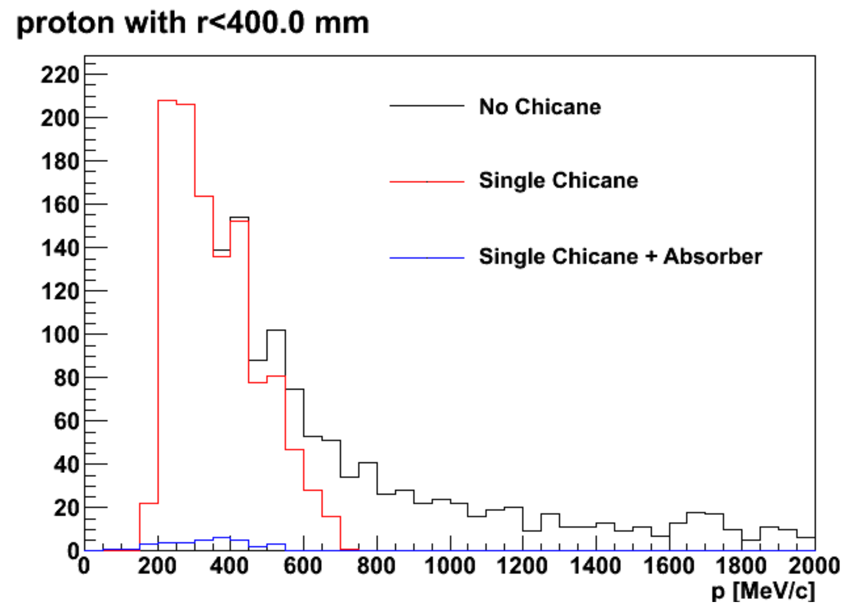
Mitigation Strategy - Preliminary

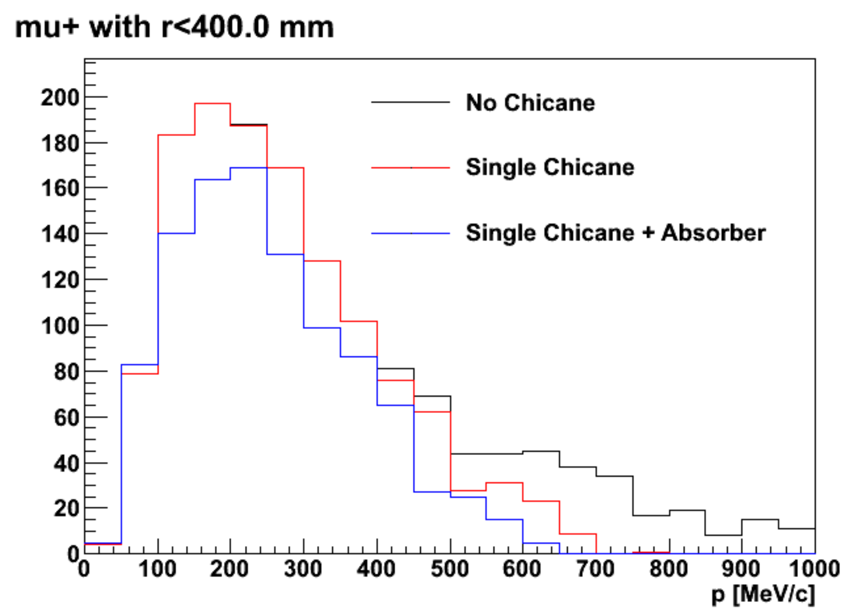
- Clearly heat deposition is significant
- Three issues:
  - Activation of the linac
  - Heat load on superconductors
  - Radiation damage (to e.g. superconductors)
- These losses are 2-3 orders of magnitude too high
- Try:
  - Proton absorber for low momentum protons
    - Protons stop quicker than pions/muons in material
  - Chicane for high momentum particles
  - Transverse collimation
    - Take out particles with large transverse amplitude at a convenient point away from sensitive hardware



Muon Chicane - Preliminary

- Bent solenoid chicane
  - One chicane for both signs
  - Optics still under optimisation
  - Removes protons with p > 600-700 MeV/c
- Proton absorber effectively removes low momentum protons
  - Some further optimisation possible
- Beam dumps need work
  - How does beam get out of solenoids?
- Optimisation continues





Future Plans

- Potential issue of RF in high magnetic field
  - Await results from Fermilab MUCOOL Test Area
  - Alternatives look promising
- Transmission losses can be controlled effectively
  - Further optimisation possible
- Further work required in several areas
  - Alignment and tolerance study
  - Instrumentation
  - Engineering design for more accurate costing

Conclusions

- Muon front end design is mature
- Good capture efficiency for muons
- New risks identified and mitigating options developed