Collider Simulation Studies
Progress in 6D Muon Cooling

D. J. Summers
Univ. of Mississippi - Oxford

MUTAC Review
Fermilab Commitium
16-17 March 2006

Collider Needs 10^6 in Cooling

- **Study 2 Linear Channel Cools by 15.**
- **RFOFO Ring → 50x 6D Cooling**

R. Palmer et al., PRSTA 8 (2005) 061003

- **Guggenheim RFOFO Helix Simulations**

No Kickers! β can Decrease as μ's Cool.

- **Tabletop Sector Cyclotron with RF**

Designed to Test 6D Cooling.

- **Tabletop Sector Cyclotron without RF**

Radial Injection. Axial Ejection.
Muons Spiral to the Center. $p \to 0$, $\Delta p \to 0$.

- **Muons Inc. Helical Dipole Cooling Channel**

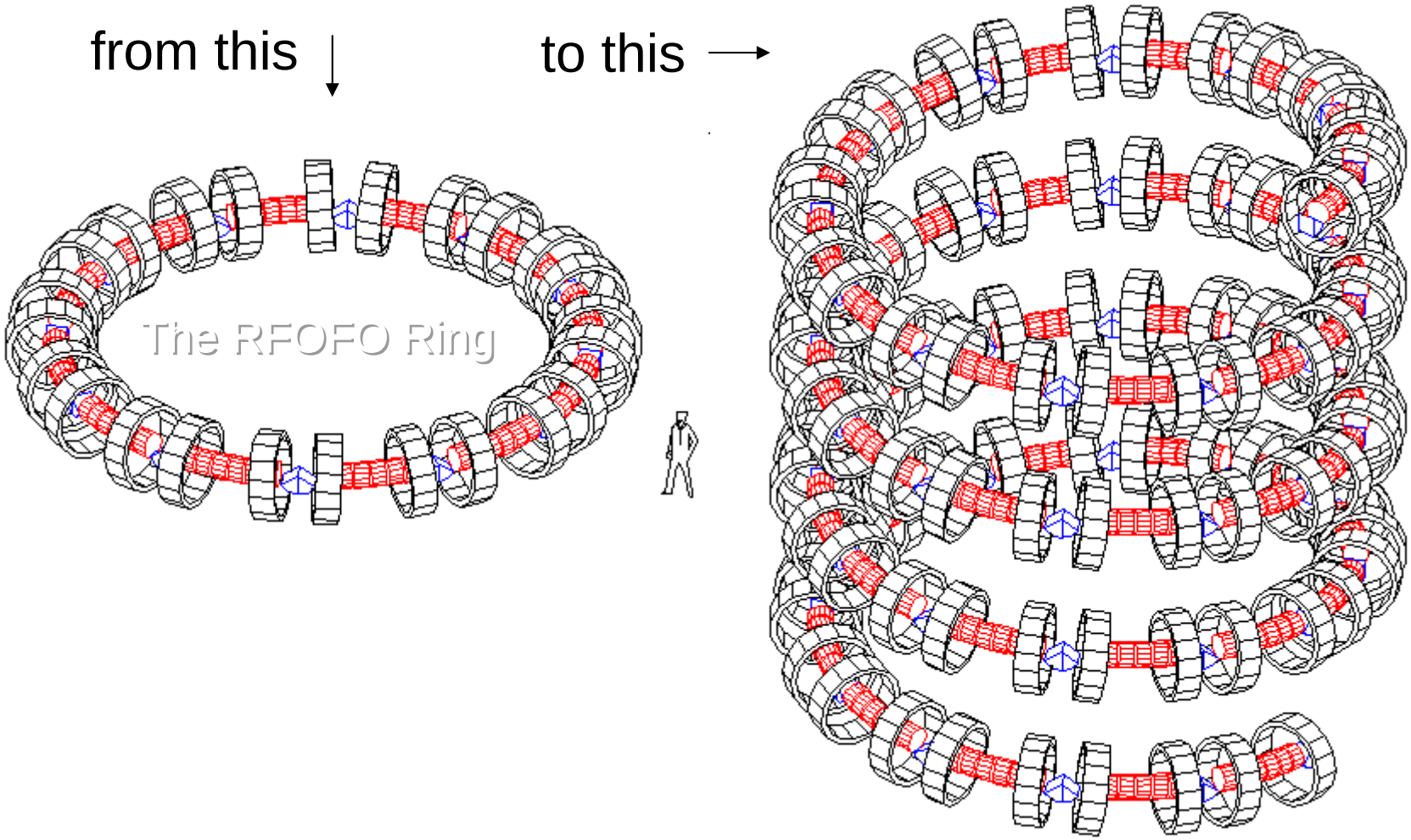
Parametric Resonance Cooling

- **60T BSSCO Solenoids for Final Cooling**

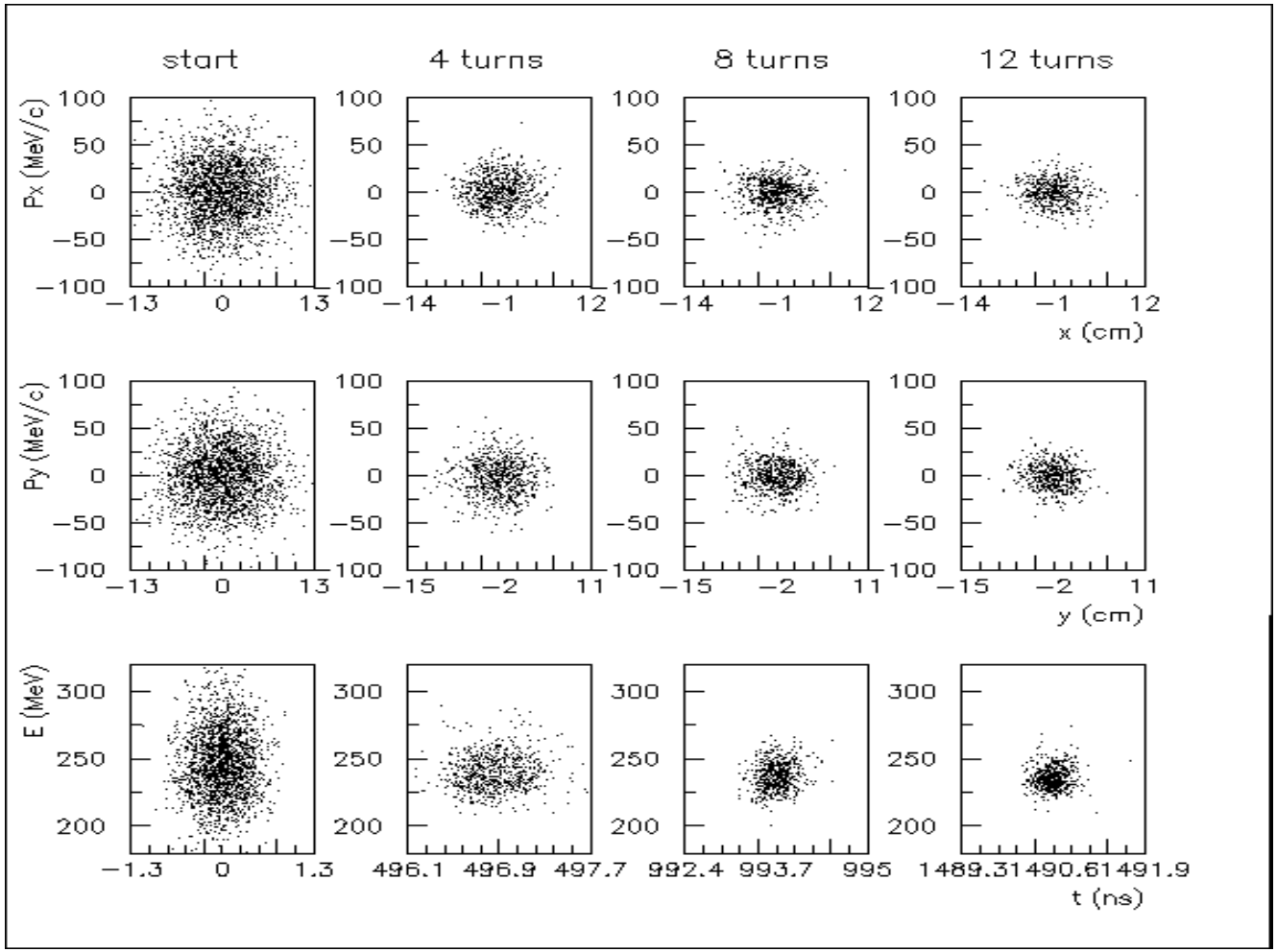
Competitor for Liquid Lithium Lenses

The idea: change the geometry

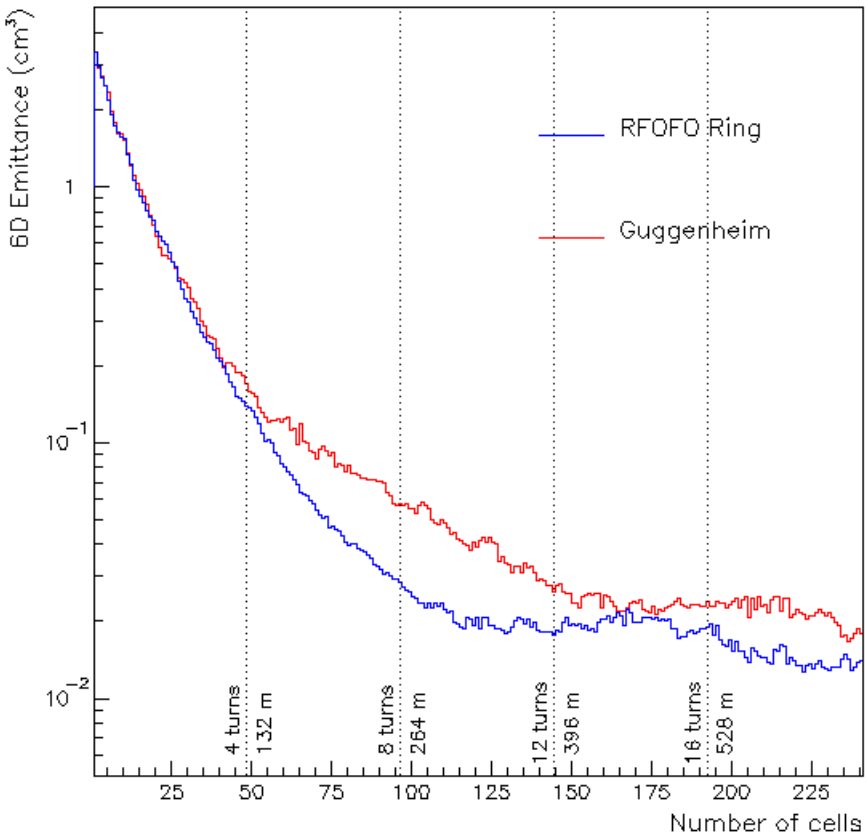
from this ↓ to this →

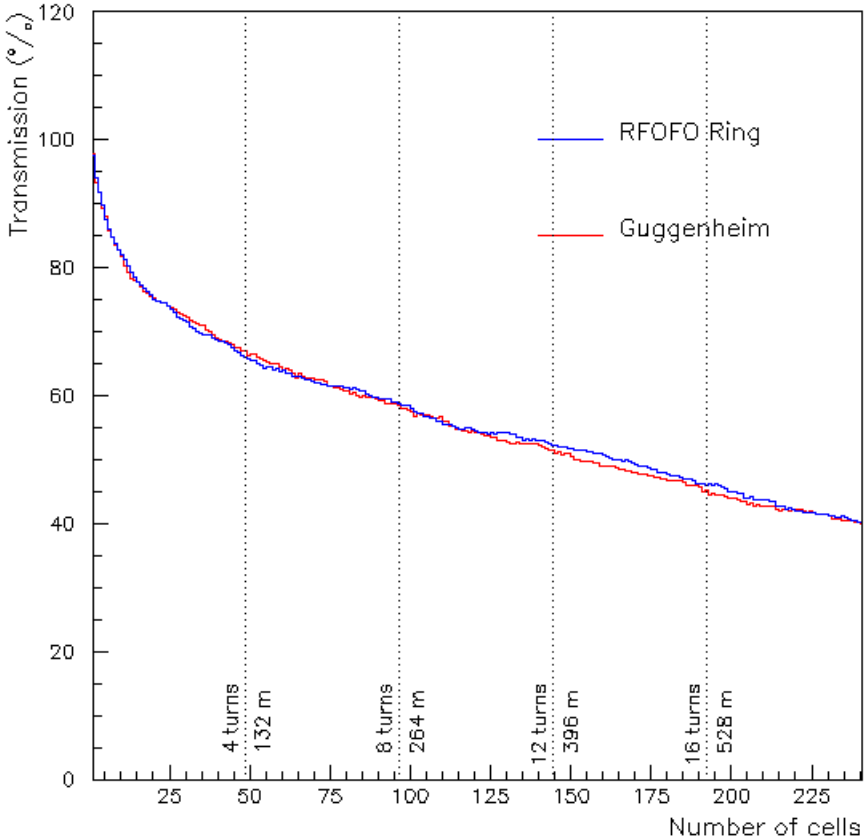


Cooling... seems to work

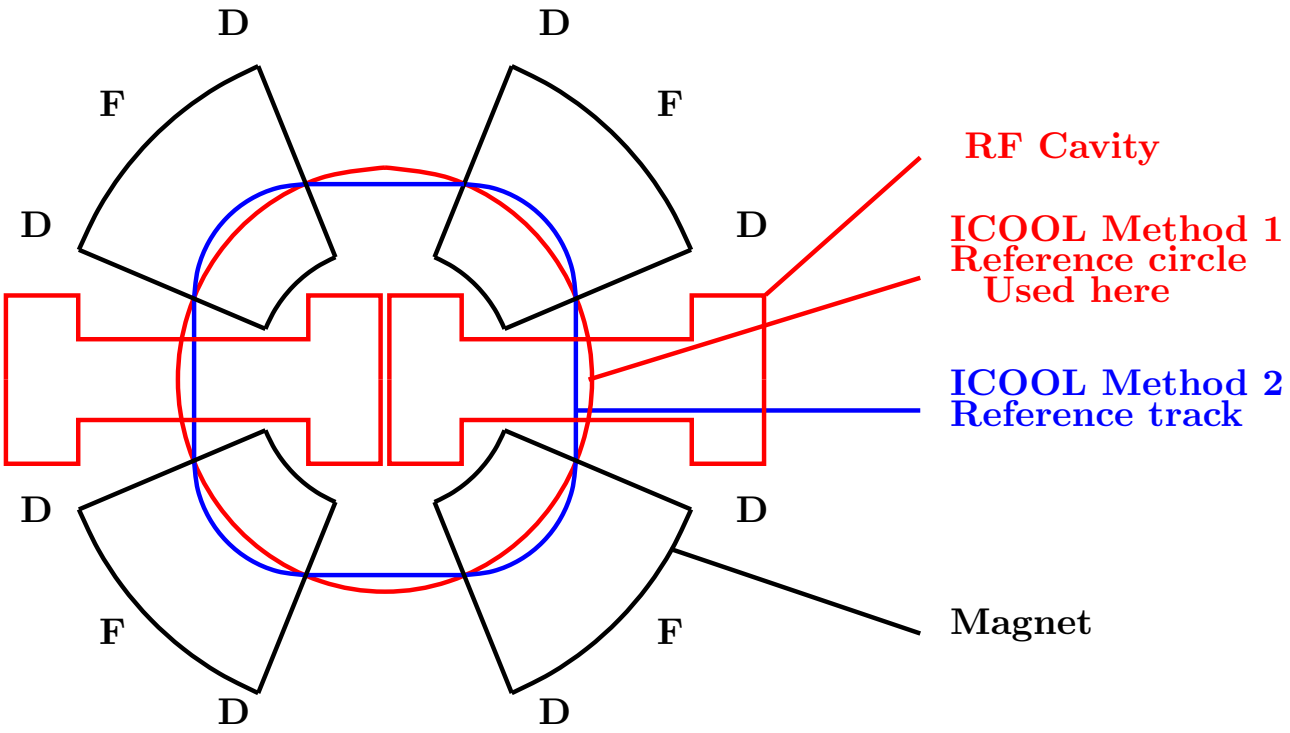


Comparing results





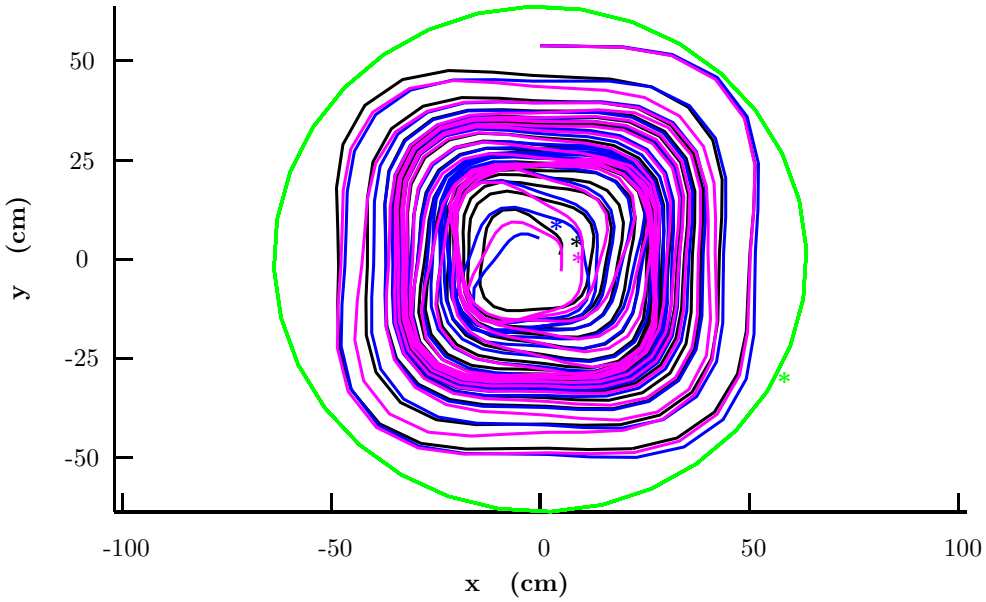
Large Admittance Sector Cyclotron



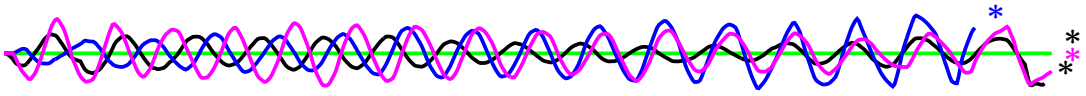
- **COOL 05: A. Garren, H. Kirk, S. Kahn, "6D Cooling of a Circulating Muon Beam."**

Single Turn Energy Loss Injection

- **Four Magnet (1.8T) Sector Cyclotron.**
  Soft edged fields, ICOOL simulation.
  Multiple scattering and straggling on.
  Radial LiH wedges surrouded by hydrogen.
  Matter decreases adiabatically with radius.
  3 identical 172 MeV/c muons are injected.



- **± 5 cm vertical motion along the 70 m spiral**



- **Injection scaling relation:** $\Delta p = .3\, B\, \Delta r$.

LEAR→PSI: NIM A394 (1997) 287

- **A New Method to Produce Negative Muon Beam of keV energies**
- **Foil: 3 nm of nickel (3 μg/cm^2) on Formvar 30 min. of sputtering – Franz Kottmann**

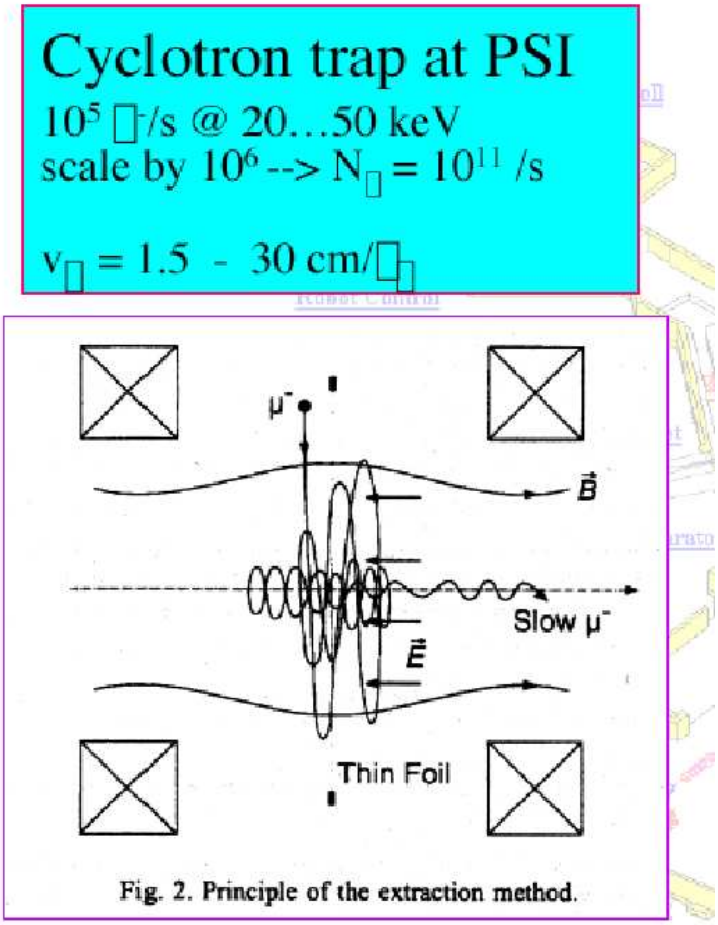


Fig. 2. Principle of the extraction method.

Emittance Reduction Goals

- **A muon collider needs 10^6 cooling.**
- $\epsilon = (\Delta p_x \, \Delta x) \, (\Delta p_y \, \Delta y) \, (\Delta p_z \, \Delta z)$
- Δp_x**: 30 MeV/c → 0.3 MeV/c**
- Δp_y**: 30 MeV/c → 0.3 MeV/c**
- Δp_z**: 30 MeV/c → 0.3 MeV/c**
- Δx**: 70 mm → 50 mm**
- Δy**: 70 mm → 50 mm**
- Δz**: 10000 mm → 50 mm**
- **In: 10× transverse cooler, physics/0411123.**
- **Out: "Frictional μ cooling," H. Abramowicz, A. Caldwell, R. Galea, and S. Schlenstedt, NIM A546 (2005) 356.**

Summary

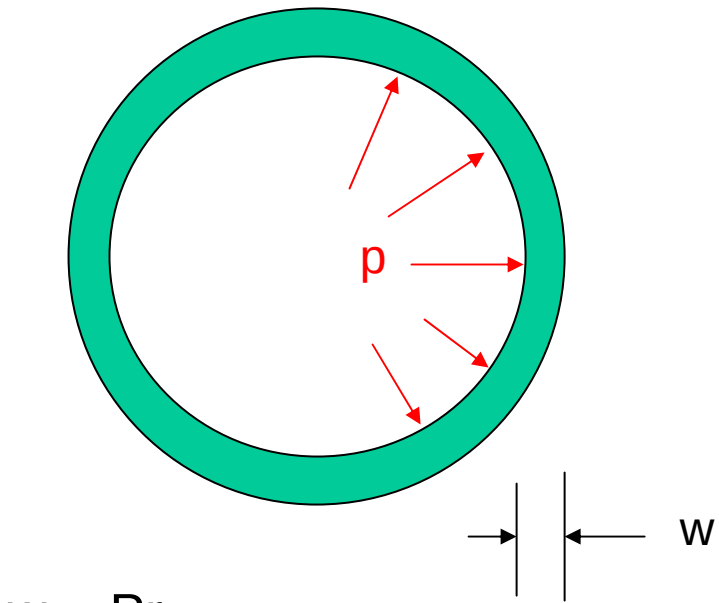
- **Large admittance sector cyclotron.**
- **Tangential energy loss injection.**
- **Absorber ρ decreases smoothly with r.**
- **LiH wedges in low pressure gas.**
- **Muons ferried in well to center as $\Delta L \to 0$.**
- **As $p \to 0$, $\Delta p \to 0$.**
- **Helium gas inhibits $\mu^+ e^-$ formation.**
- **Deuterium gas frees μ^- via fusion.**
- **Central magnetic bottle holds muon swarm.**
- **A bunch train is coalesced.**
- **Axial ejection with an electric kicker.**

A Proposal for a High Field Solenoid Magnet R&D

- The availability of commercial high temperature superconductor tape (HTS) should allow significantly higher field that can produce smaller emittance muon beams.
- HTS tape can carry significant current in the presence of high fields where Nb_3Sn or NbTi conductors cannot.
- We would like to see what we can design with this commercially available HTS tape. Consequently we have chosen what is called *First Generation* HTS.
  - Specifications for *Second Generation* HTS seem to imply that its main advantage is cost reduction not higher field. It has similar current capabilities.

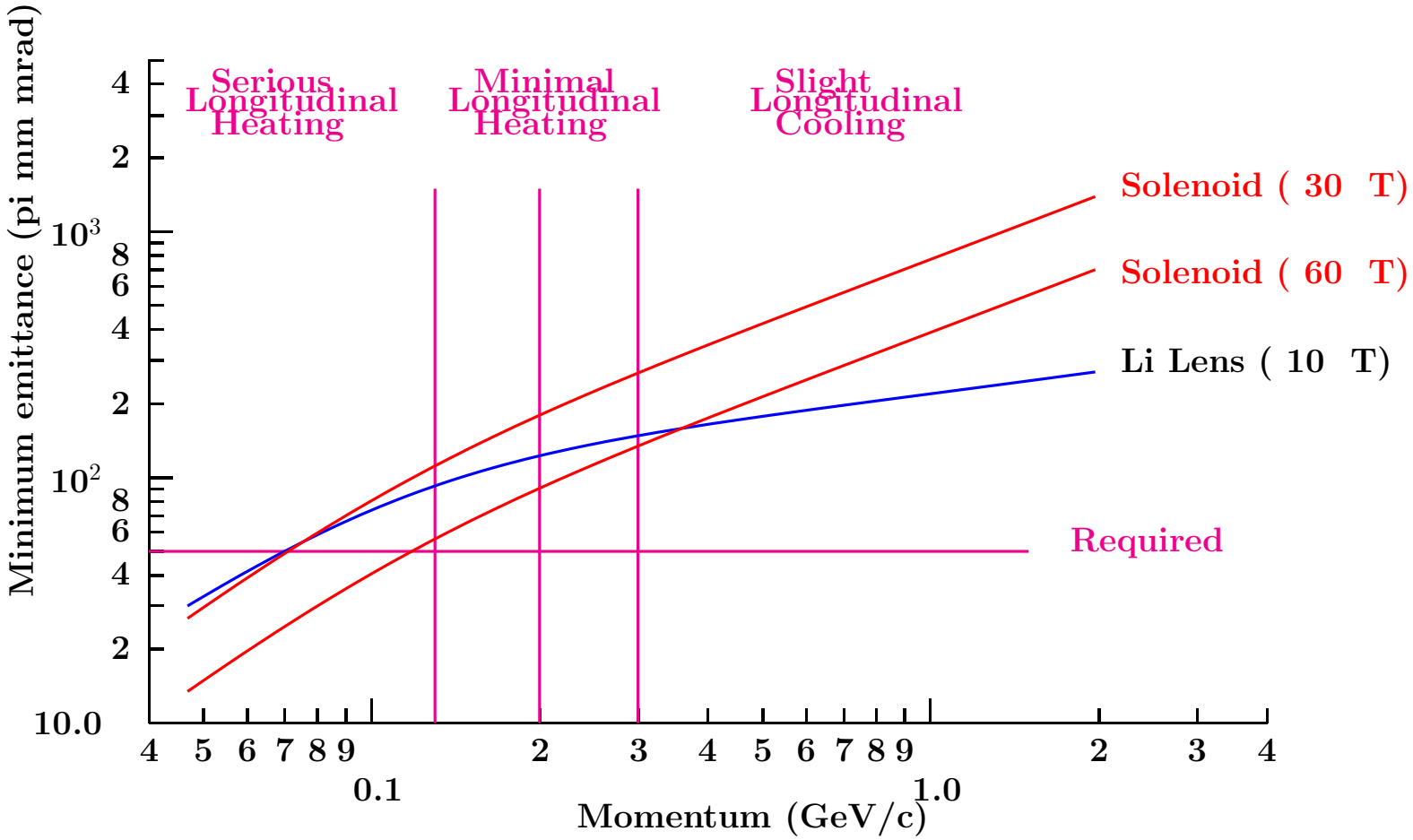
How Do We Constrain the Radial Force?

- Suppose we try to constrain the radial force with a stainless steel shell.
  - Stainless Steel 316 Tensile Strength: σ=460-860 MPa.
    - Choose σ=700 MPa.
  - Radial stress from superconductor: P =84 MPa
  - Superconductor outer radius: 88 mm.
  - The constraining shell needs to be at least 10.6 mm thick.
  - This is possible!



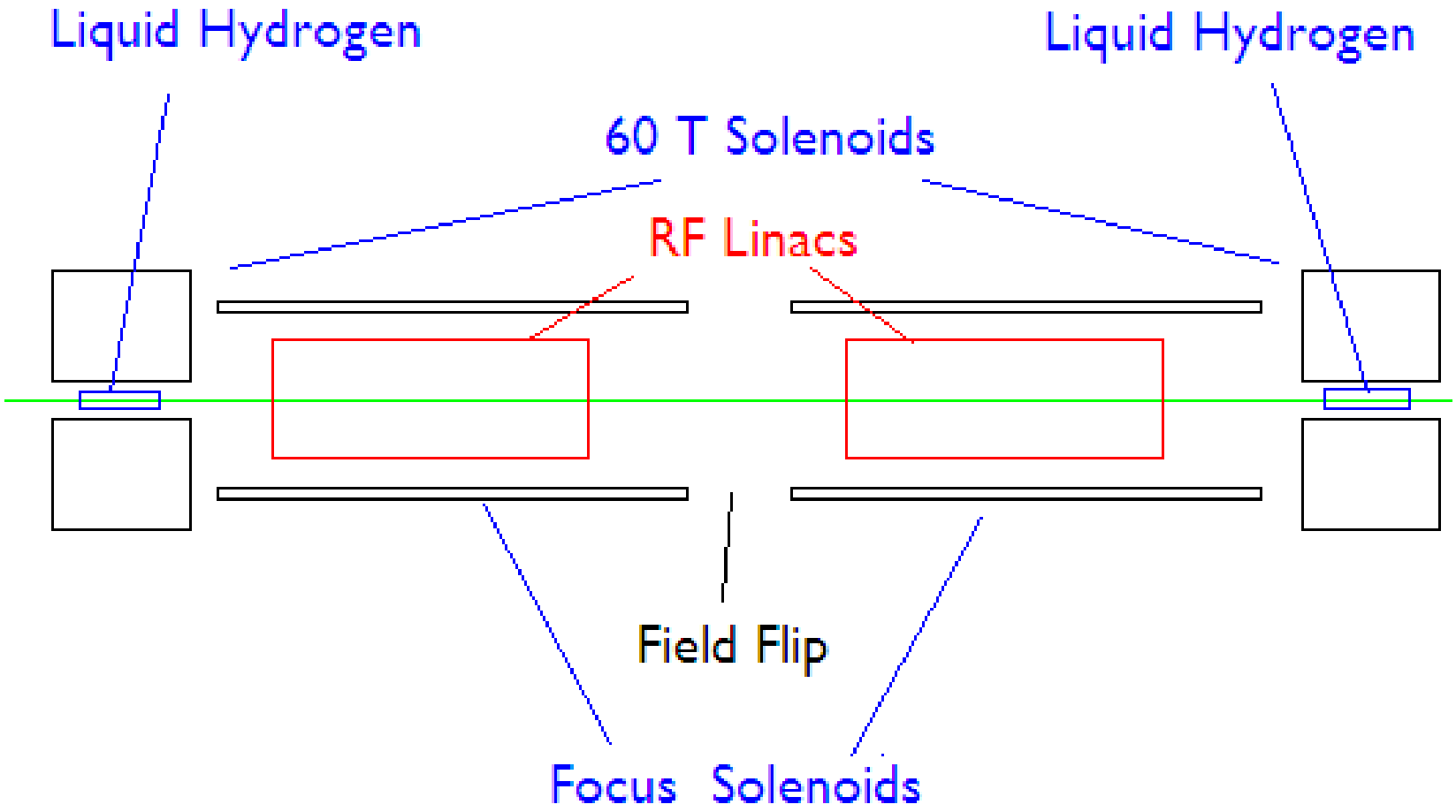
$w\sigma = Pr$

Calculated Minimum Emittance vs. Momentum



- To reach 50 pi mm, the momentum must be very low and the length of each section must be relatively short
- 30 T Solenoid appears roughly equivalent to 10T Li Lens

Concept of Final cooling Stages



Full System & Li Lens comparison