Recent Advances in Muon Accelerator R&D

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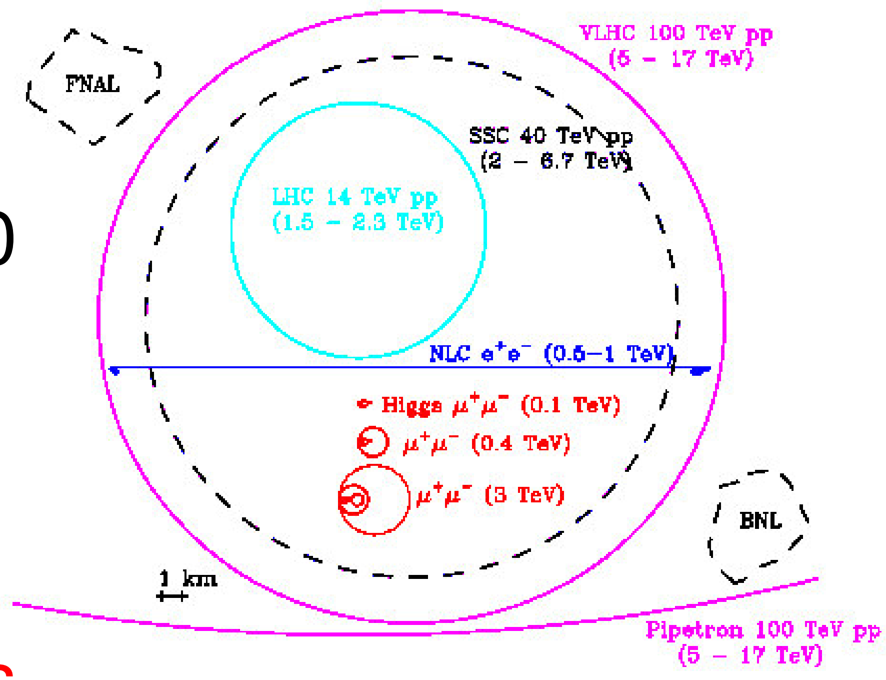
Outline

- Motivation: Why accelerate muons?
  - Muon Collider
  - Neutrino Factory
- Physics potential
- Challenges
- Possible solutions and current R&D activity

Why accelerate muons?

- **Muon Collider**
  - Muons are as fundamental as electrons, but 200 times as heavy
  - Compact ring, even for the TeV energy scale
  - BUT lifetime - 2μs



Physics at a muon collider

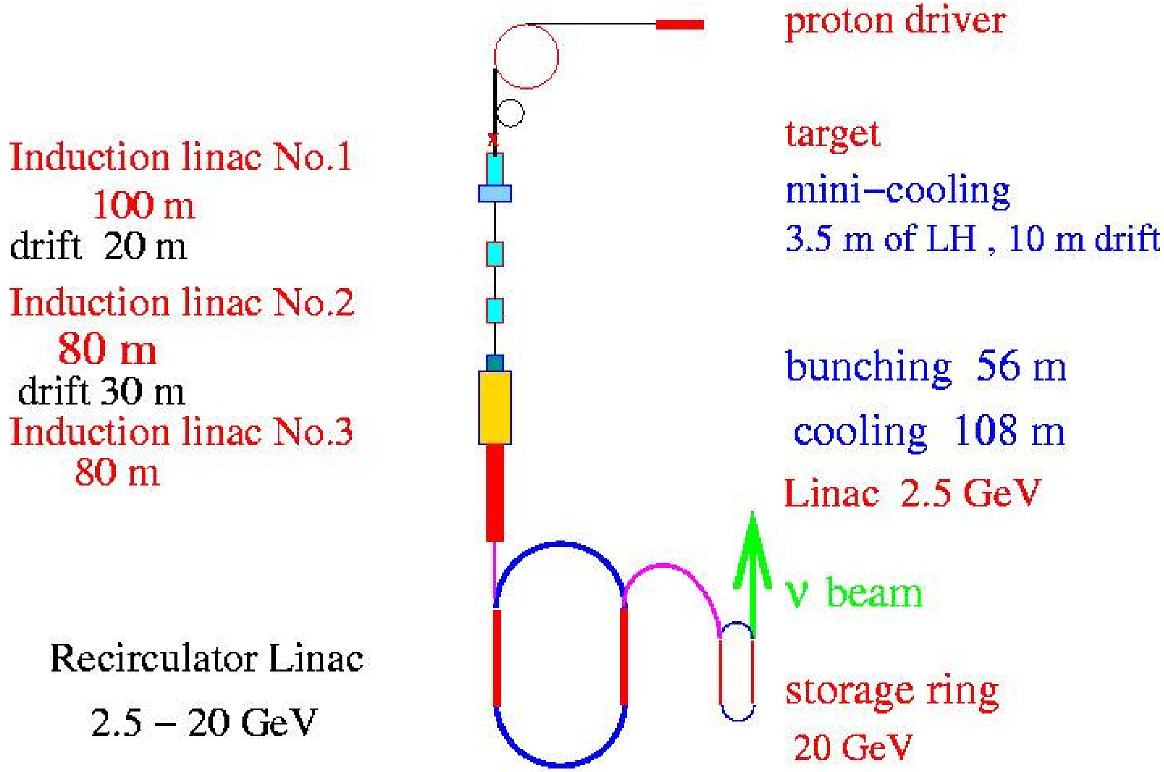
- S-channel production of Higgs bosons in a Higgs Factory (~100 GeV)
  - Precision measurements of the Higgs
  - Polarized muons can probe CP properties
- For SUSY Higgs – possible separation of H^0 and A^0 (TeV scale)
- See what the LHC tells us and hope for the best…

Muon decay can be useful too

- $\mu^+ \rightarrow \bar{\nu}_\mu e^+ \nu_e$ – **Neutrino Factory**

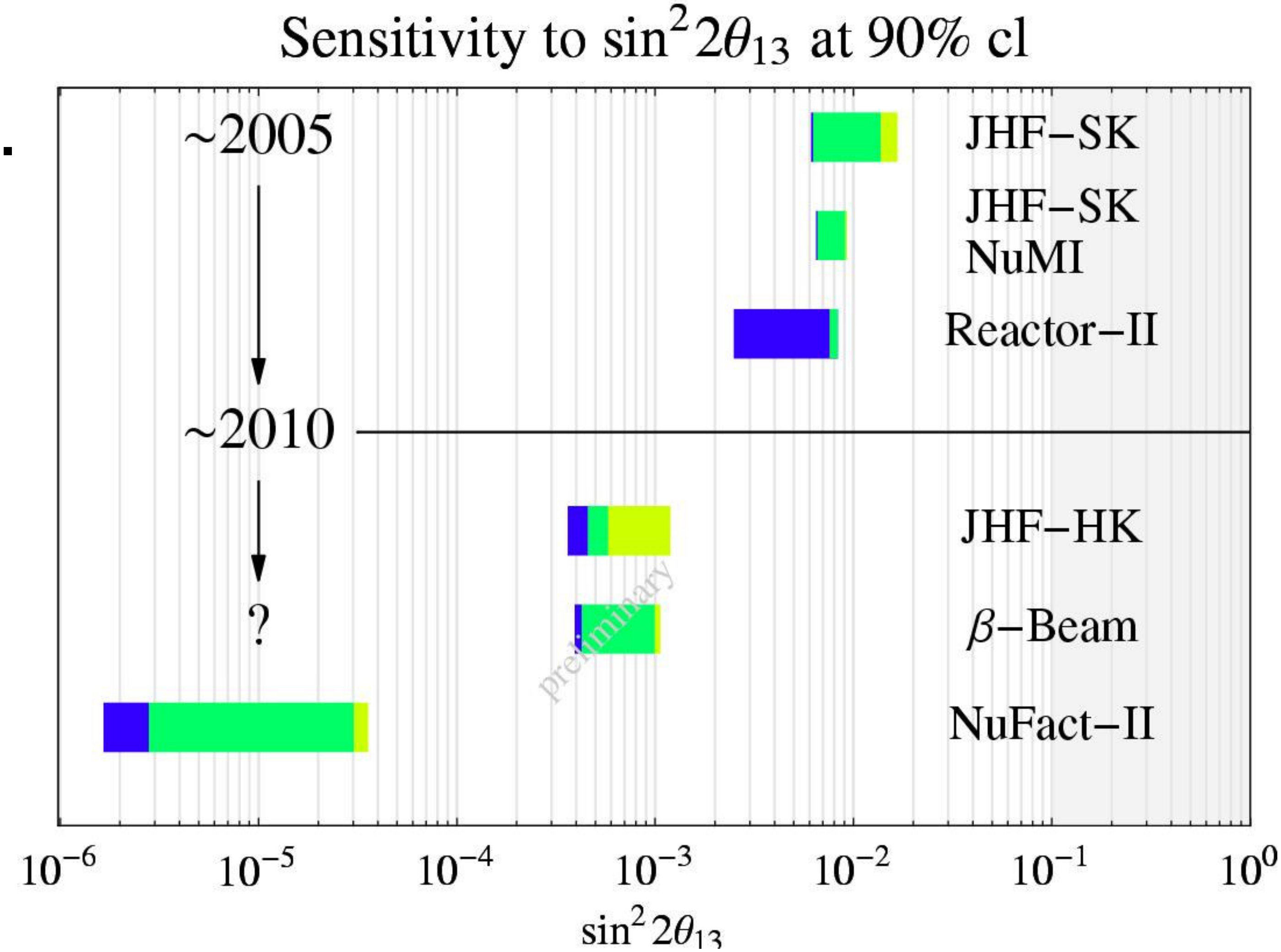
Study 2

(BNL, 2001)



Physics at a ν factory

e.g.



M. Lindner
NuFact04
July 2004

Challenges

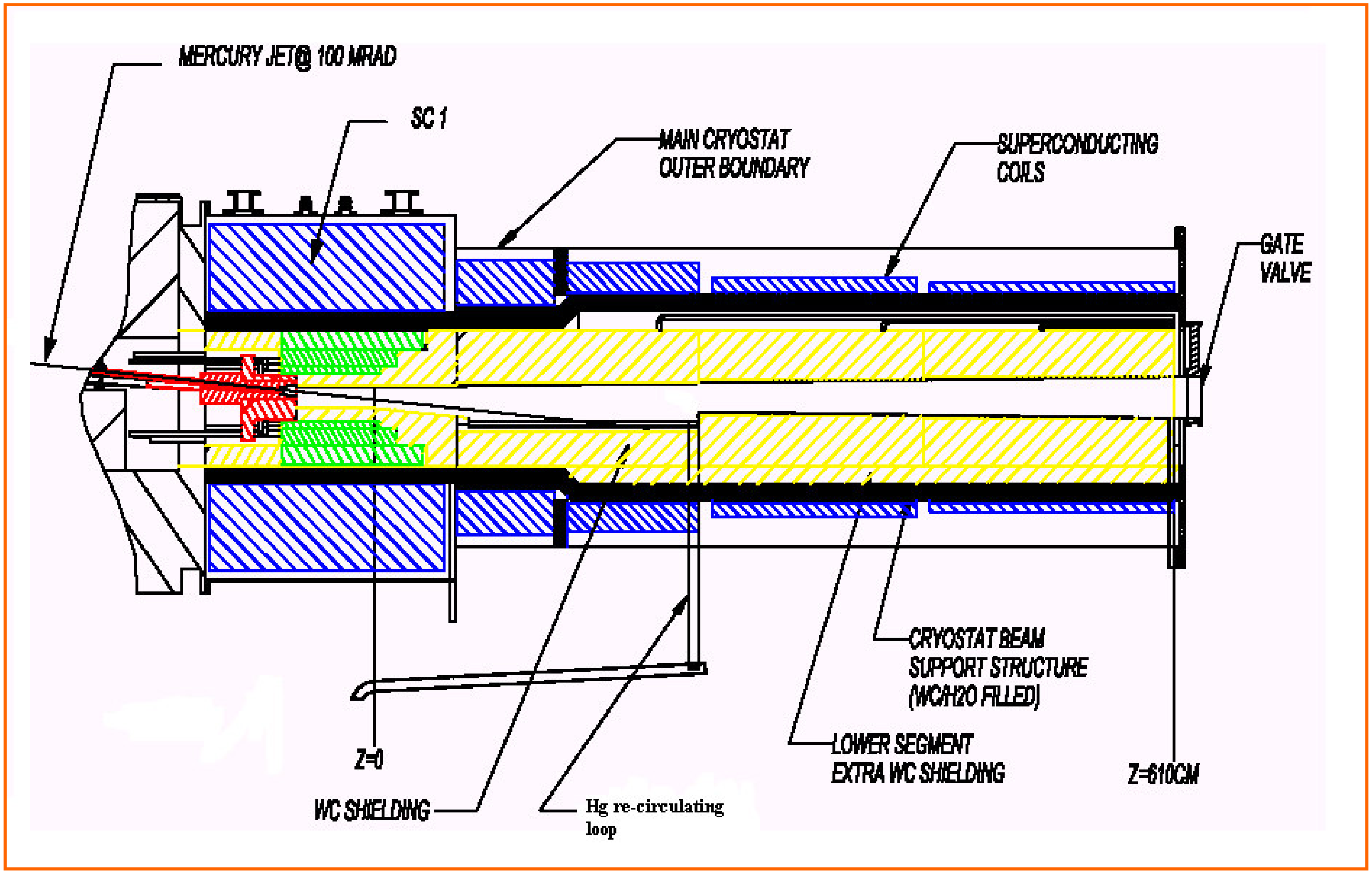
- Intense muon beams require intense proton beams (up to 4MW) hitting a target$\rightarrow\pi^{\pm}\rightarrow\mu^{\pm}\nu_{\mu}$
- Fast cooling of the muon beam
  - ν Factory: transverse $\varepsilon_{final}/\varepsilon_{initial} \sim 10^{-1}$
  - μ Collider: 6D $\varepsilon_{final}/\varepsilon_{initial} \sim 10^{-6}$!

  The only way we know – **Ionization Cooling**
- Fast muon acceleration
  - ν Factory: ~20 GeV
  - μ Collider: ~ TeV

R&D Effort toward ν Factory

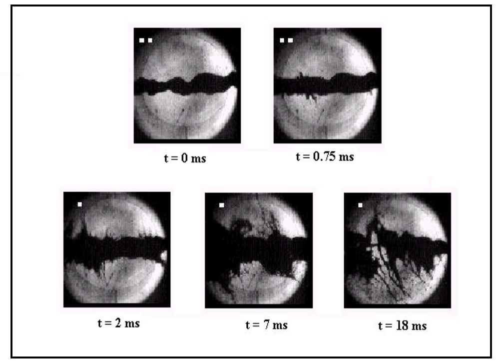
- Target
  - Hg jet, solid target
- Cooling
  - MICE (M. Ellis)
  - MuCool activity (M.A. Cummings, Y. Torun)
- Acceleration
  - FFAG (D. Summers)
- New feasibility study

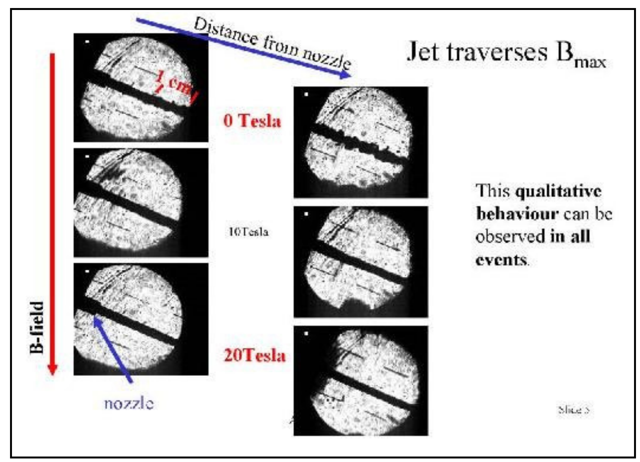
Muon production: Hg jet target



Liquid Target R&D

- Ongoing international R&D effort:
  - Hit Hg jet with proton beam – done
  - Hg jet in strong (20T) magnetic field – done
  - Combination – not done



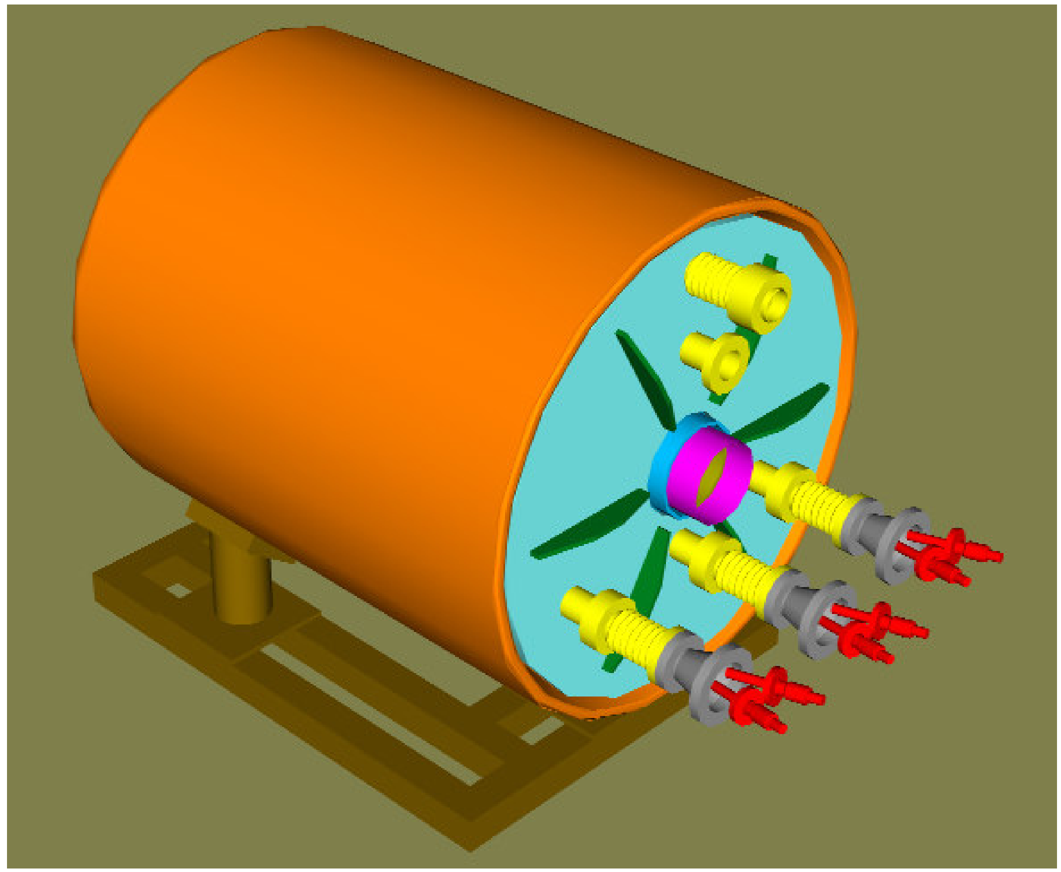


Target experiment proposed

Pulsed magnetic solenoid:

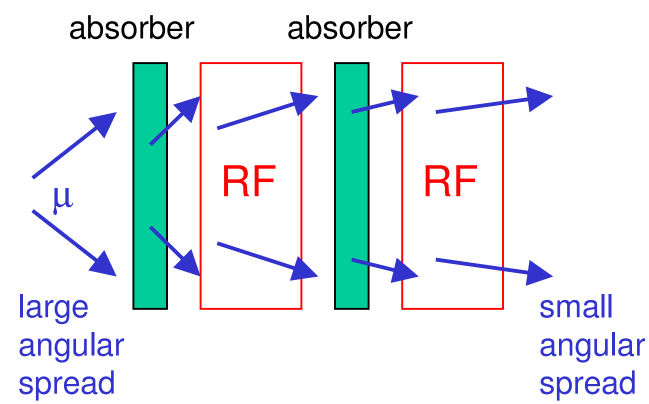
- 69^{o} K Operation
- 15 T with 4.5 MVA Pulsed Power
- 15 cm warm bore
- 1 m long beam pipe

Scheduled delivery Nov. 2004



Ionization Cooling

- The idea is quite simple (transverse cooling)



- Heating due to multiple scattering
  – Use low-Z material (best – liquid hydrogen)
- There is an equilibrium emittance

  goes up with Z and β (beam focusing)

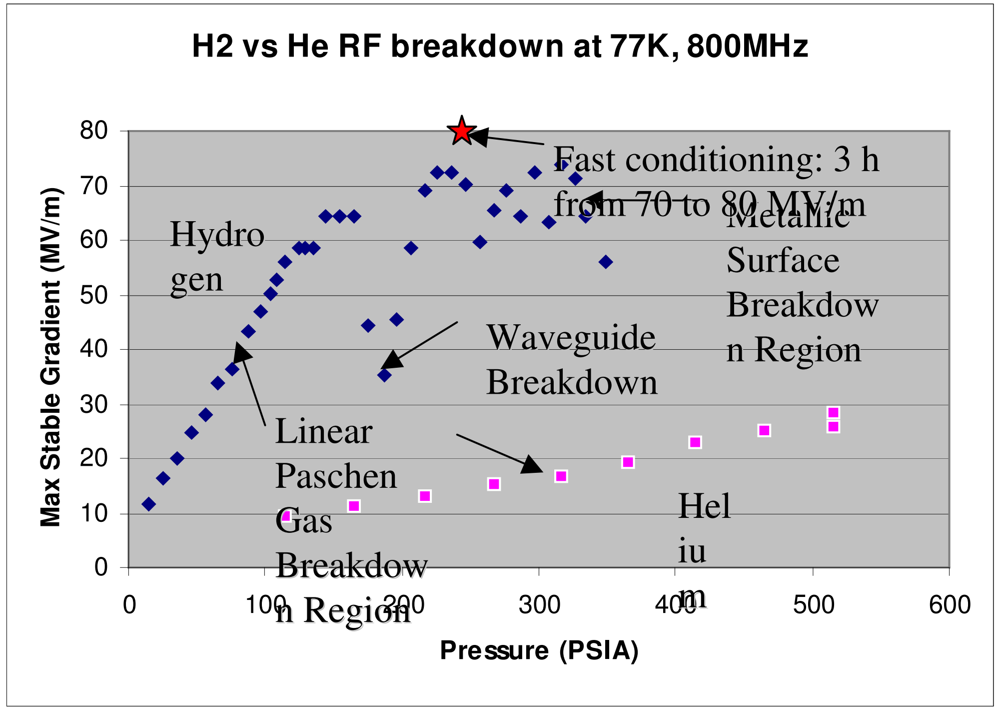
Ionization Cooling R&D

- Muon Ionization Cooling Experiment (MICE) approved, to be built at RAL
  (M. Ellis)
- Absorber R&D at Fermilab (MTA)
  (M.A. Cummings)
- NC RF cavities R&D at Fermilab
  (Y. Torun)
- High-pressure hydrogen gas in RF cavity
- 6D cooling (later in this talk)

Gas absorber R&D

- Fill RF cavity with pressurized H_2 gas

  Muons Inc. (work done at Fermilab)



  – Proposed experiment: MANX (“gas-filled MICE”)

Accelerating muon beams

- Rapid acceleration means using either
  - RLA (“old” technology) or
  - Fixed Field Alternating Gradient ring - FFAG (D. Summers)

New ν factory feasibility study

- Old feasibility studies:
  - Study 1 (FNAL 2000): technical problems
  - Study 2 (BNL 2001): In principle, Neutrino Factory is achievable, but costly (~$2B)
- Next feasibility study goals:
  - Reduce cost
  - Maintain (at least) Study 2 performance
  - World-wide effort

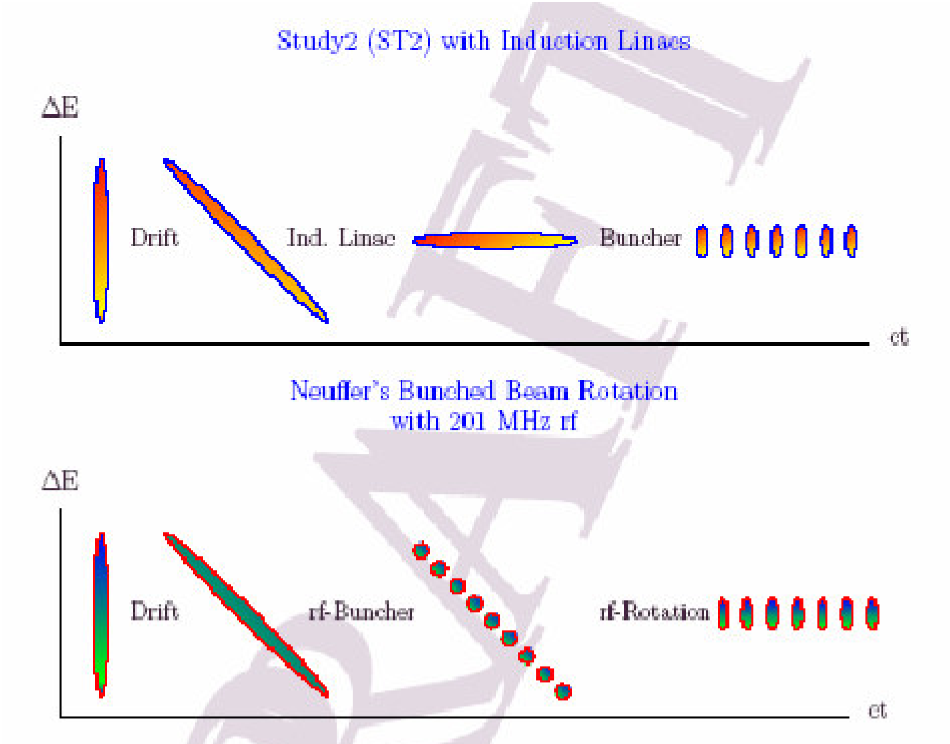
The first step: Study 2a

- Changes w.r.t. Study 2:
  - Improved pion/muon collection increases μ/p ratio by 10% (K. Paul, U.Illinois)
  - Bunching before phase rotation (to achieve small ΔE beam) instead of long induction linacs reduces the cost significantly
  - New cooling ideas: solid absorbers cost less
  - Acceleration: new RLA design, FFAG

Study 2a front end

- Old scheme: use induction linac for phase rotation

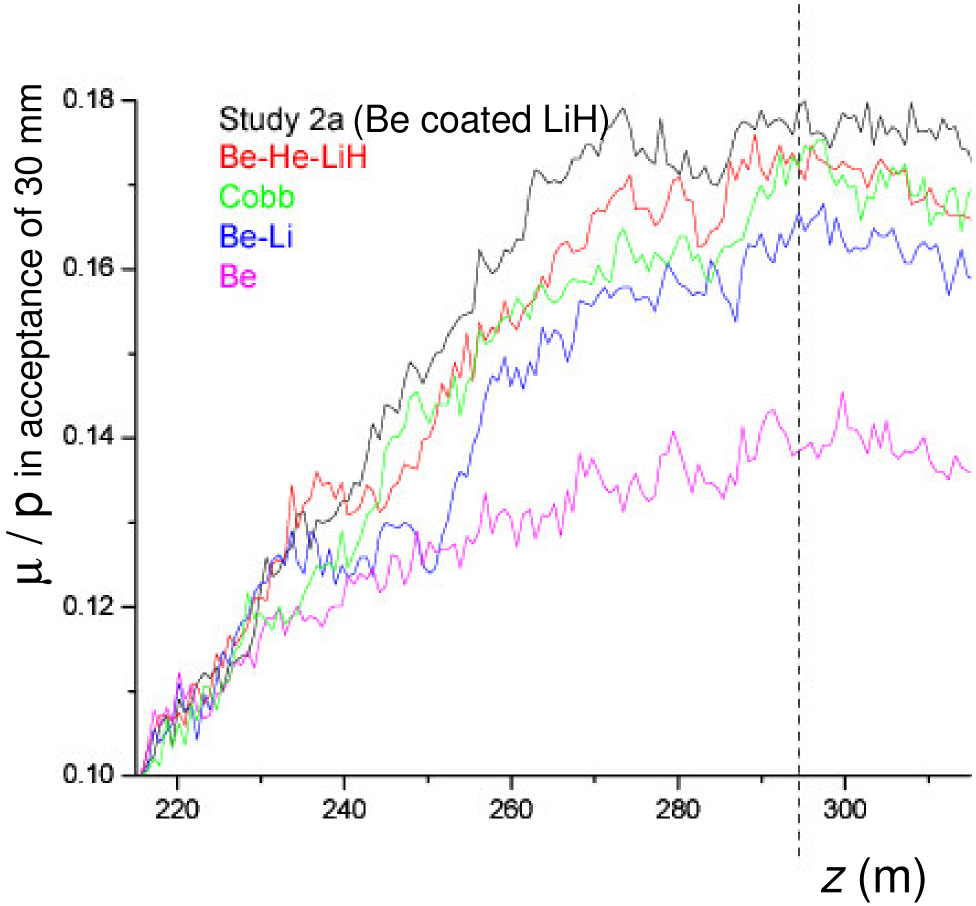
- New scheme (D. Neuffer, FNAL): bunching with varying RF frequency



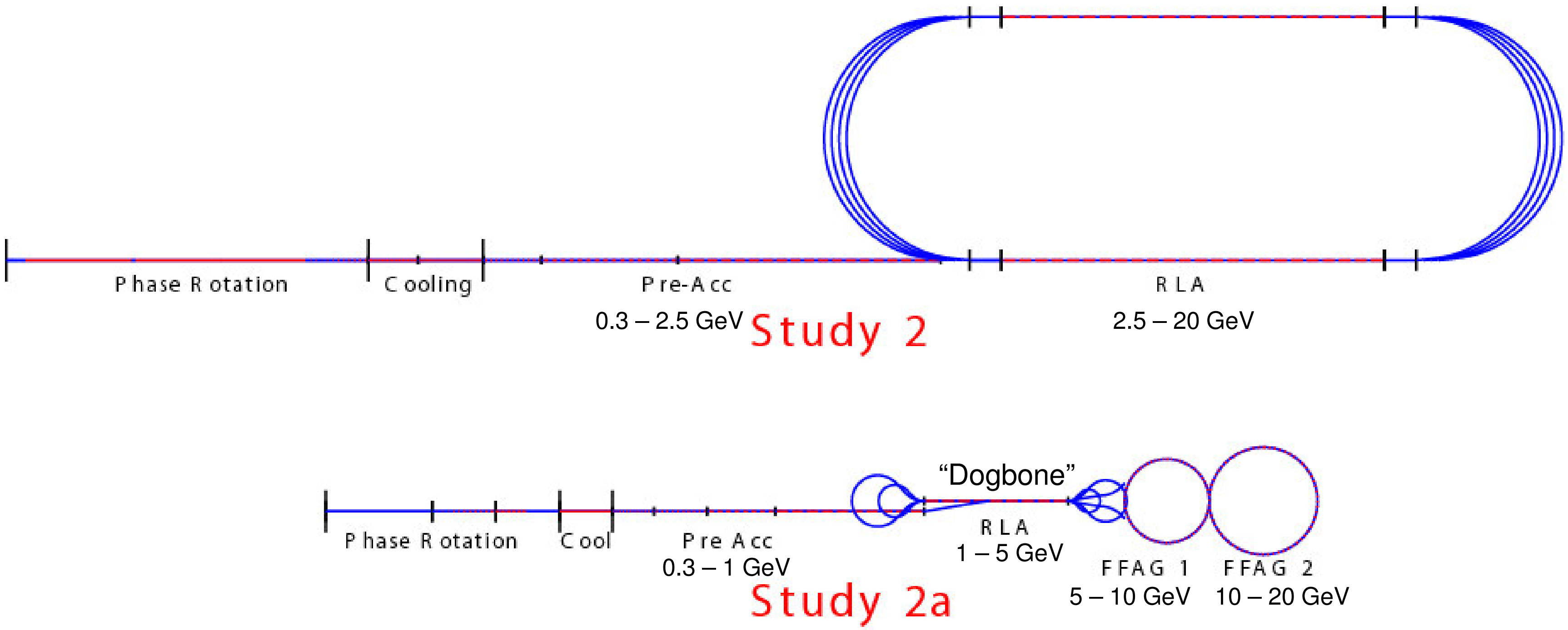
Can do both signs: $\mu^{\pm}$

Study 2a cooling

- Solid absorber material is easier to use and probably safer than liquid hydrogen



Study 2a acceleration



Study 2a system is significantly smaller than Study 2

Cost reduction

- Cost estimate for acceleration system (J.S. Berg, R.B. Palmer, BNL):

  Study 2a acceleration system costs about 1/3 less than that of Study 2.

  (could save a few $100M)

  For all the components, the study has to be finalized to estimate actual cost

Muon Collider R&D

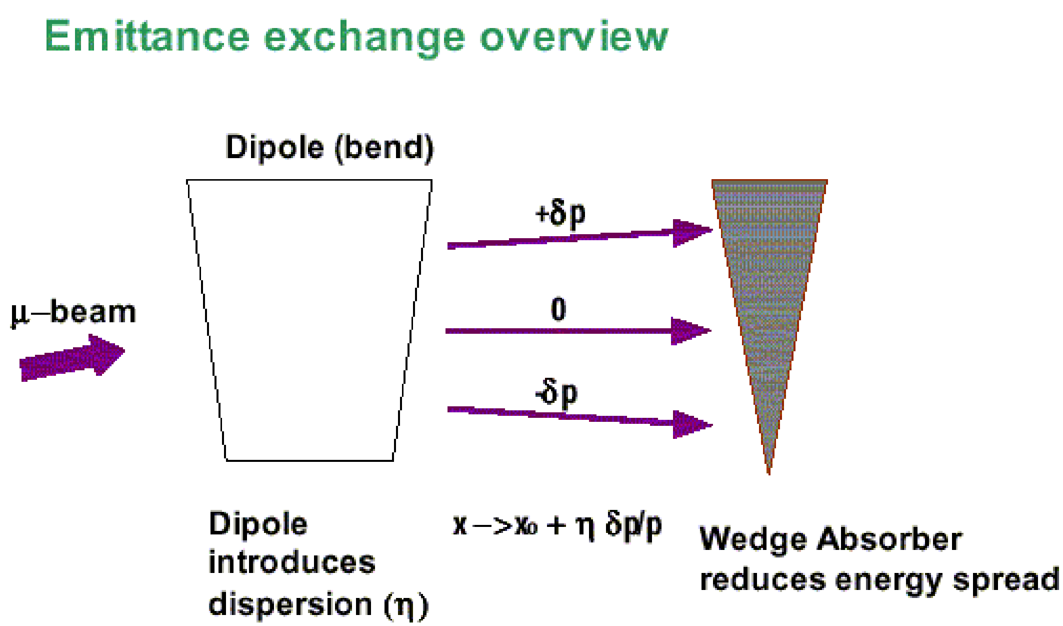
- 6D cooling – emittance exchange / rings (D.J. Summers, and also in this talk)
- Further transverse cooling – Lithium Lenses (Y. Fukui)

- Only simulations have been done so far

  But this can change…

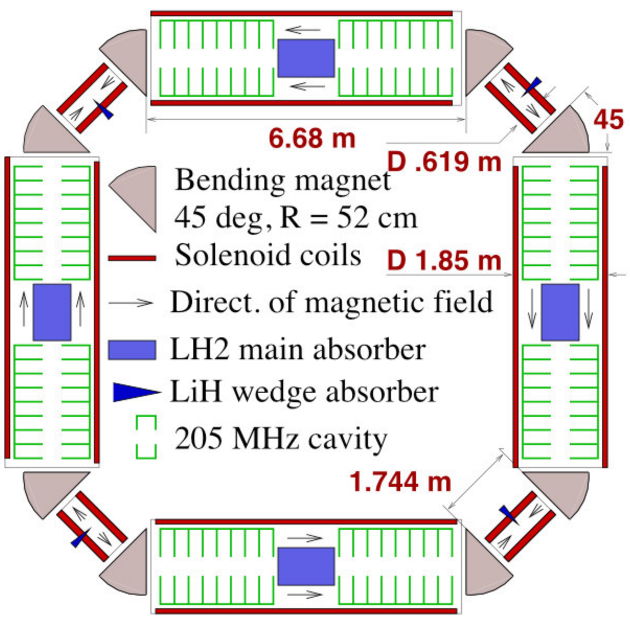
Emittance Exchange

- Transverse cooling becomes longitudinal using dispersion (dipole)



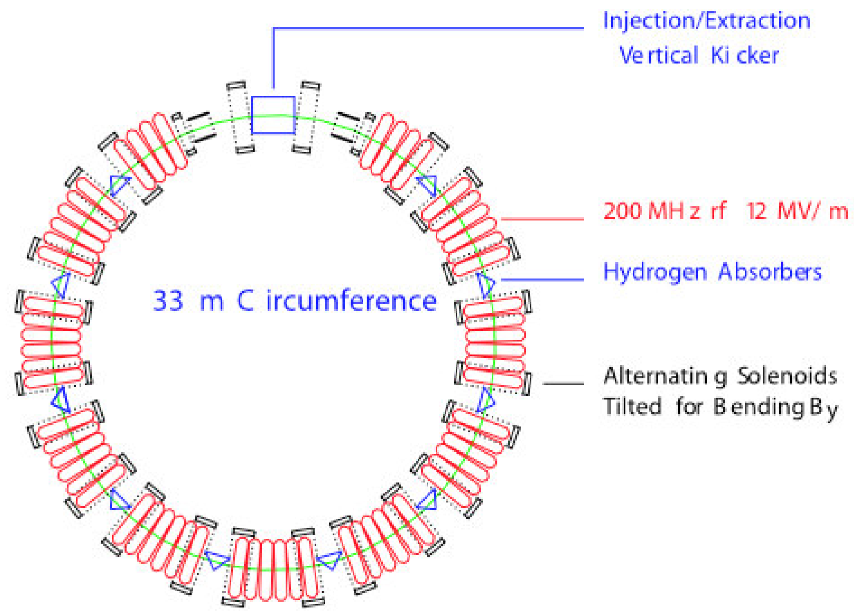
Ring Coolers

Tetra (V. Balbekov, FNAL)



(the first cooling ring to be simulated)

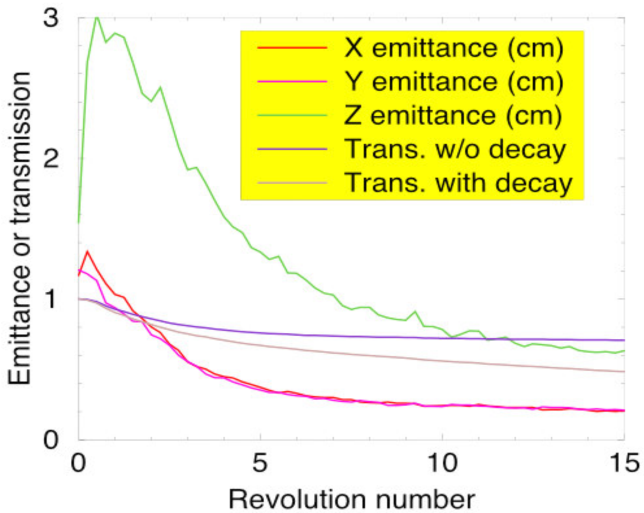
RFOFO (R.B. Palmer, BNL)



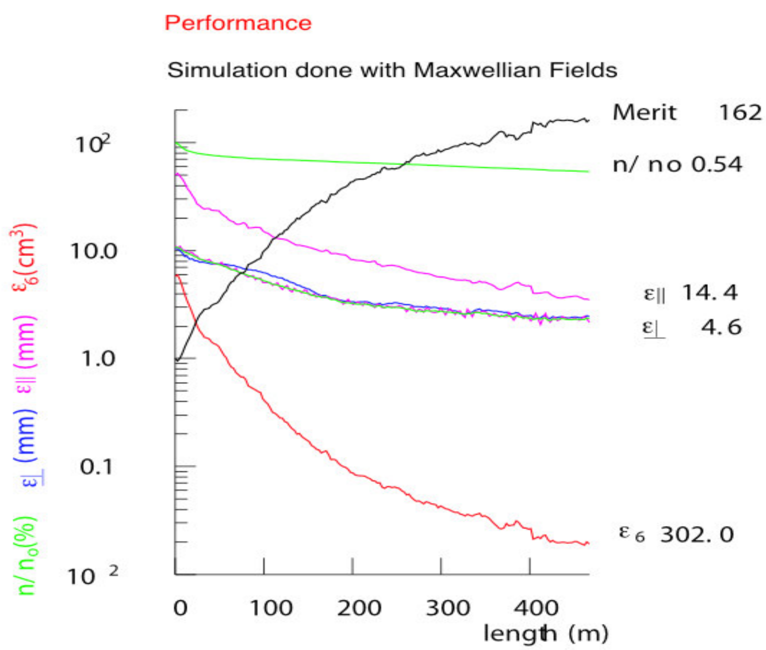
(the only one so far that is simulated with realistic magnetic fields)

Performance of cooling rings

Tetra:



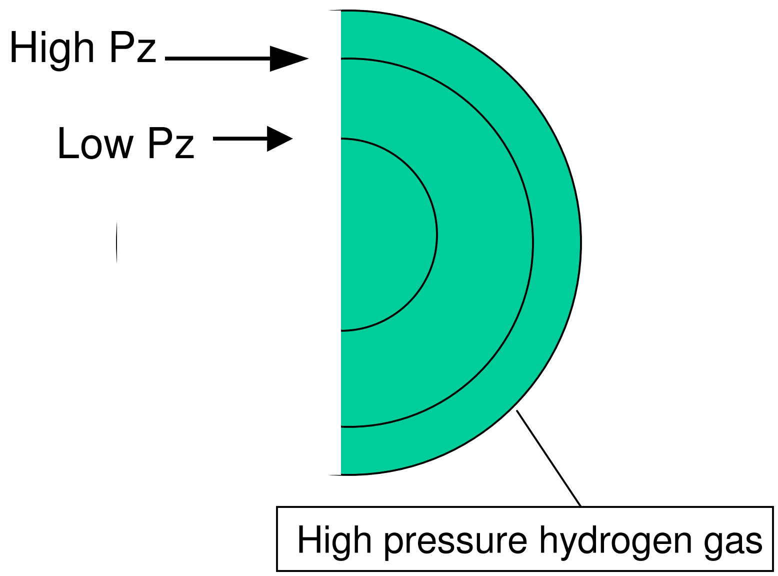
RFOFO:



Both rings were simulated with several simulation codes that agree well

Gas filled ring cooler

- The "wedge" is made of hydrogen gas
- High momentum particles "see" less material
- Acceleration done with pressurized RF cavities

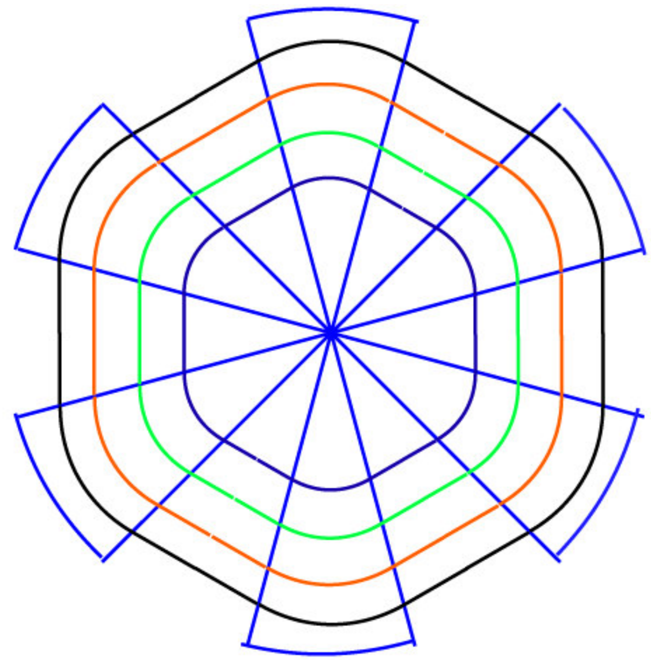


The gas-filled dipole ring

(A. Garren, UCLA, H. Kirk, BNL)

- Dipole edge focusing
- Fully scaling
  - Circumference depends on momentum and dipole field
- RF cavities in space between dipoles

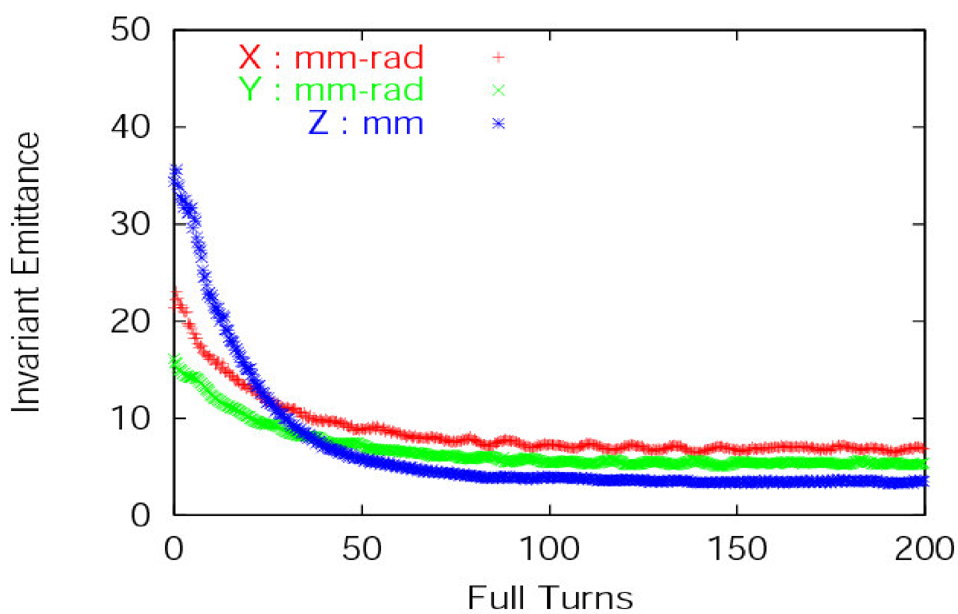
6-dipole ring



Gas ring cooler - performance

- For muon cooling (~200 MeV/c) the ring can be very compact (few m diameter)
- Performs very well!

(use skew quads to couple $\varepsilon_{\perp}$ and $\varepsilon_{||}$)



- Merit factor >200

A gas ring cooler experiment

- Being so compact, a “poor man’s” version of the gas dipole ring can be used to demonstrate 6D cooling.
- Performance doesn’t have to be optimized for this demonstration
  - merit factor of 10 is sufficient
- Low cost (the goal is ~$5M)
- Still very preliminary…

Conclusions

- Muon accelerator R&D is very active (8 of the talks in this session, 3-4 in other sessions at DPF2004)
  - Neutrino factory Hardware R&D is advancing (MICE, MuCool)
  - New feasibility study is on the way
  - Muon collider R&D is still in the simulation stage, but this can change soon!