Simulation Program

R.C. Fernow
BNL

MUTAC Review
BNL

18 April 2007

Outline

- overview of simulation activities in NFMCC
- present machine results from ISS neutrino factory studies
- discuss our near-term simulation plans

NFMCC simulation activities (1)

(1) perform design simulations for future muon-based facilities
- neutrino factory
- muon collider

major facility design areas
- proton driver
- target
- front-end
- acceleration
- storage or collider ring

NFMCC simulation activities (2)

(2) related simulation efforts inside the NFMCC collaboration
- MICE experiment (ionization cooling)
- MERIT experiment (liquid targetry)
- EMMA experiment (non-scaling FFAG)
- RF breakdown
- solid target shock
- small ring coolers

(3) active collaboration with outside-directed muon collider efforts
- Muons Inc
- Fermilab Muon Collider Task Force

Recent simulation highlights

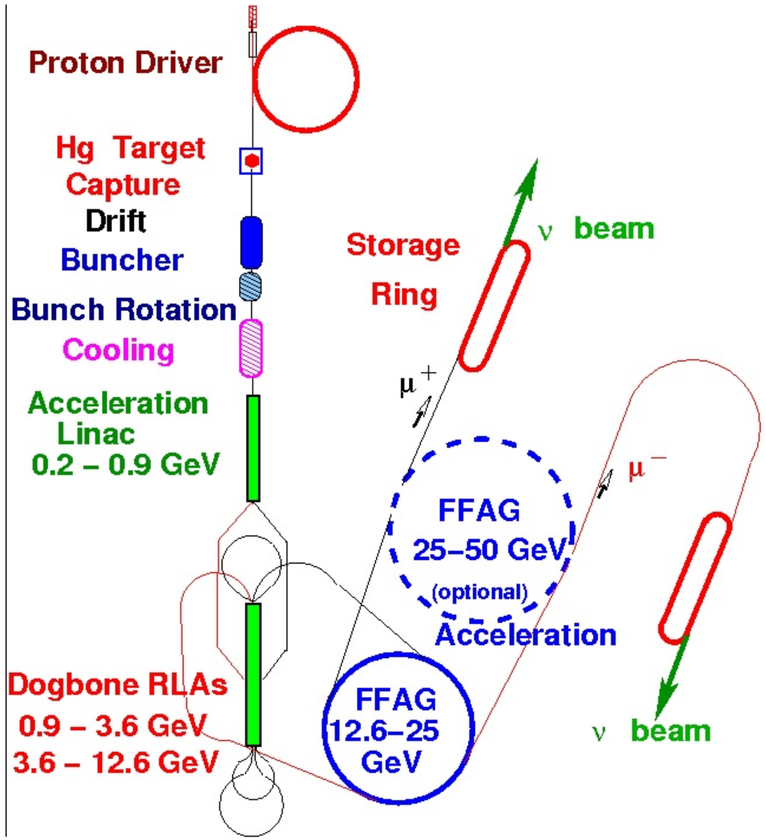
- completed International Scoping Study
  - aim to focus and consolidate neutrino factory machine options
  - workshops
    - RAL in April 2006
    - Princeton in July 2006
    - Irvine in August 2006

- increased effort on muon collider studies
  - successful LEMC workshop February 2007
  - began participation in new Muon Collider Task Force at FNAL
  - studying feasibility of two collider schemes

Neutrino factory overview

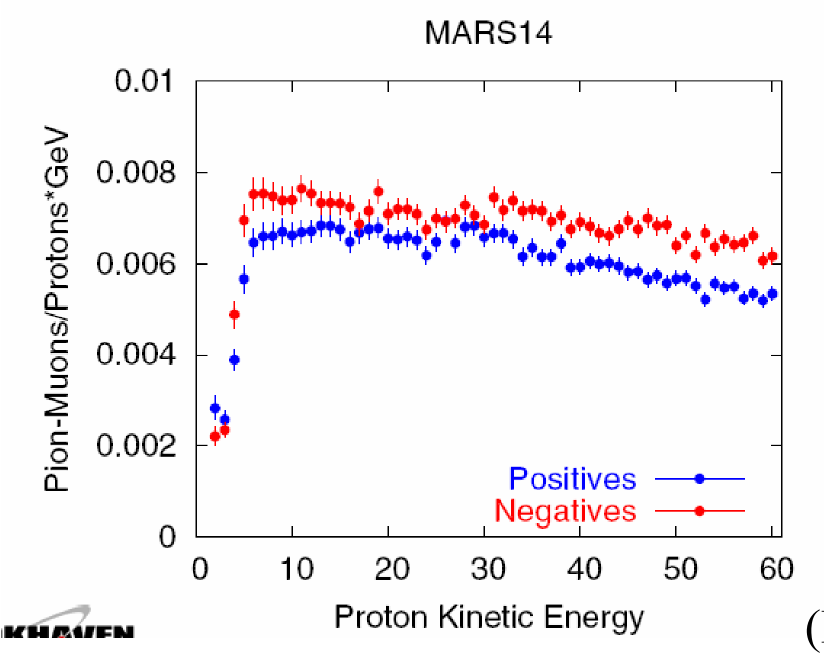
- goal: 10^{21} useful muon decays per year
- for θ_{13}: baseline ~7500 km removes degeneracies
- for CPV: optimum baseline ~3500 km
- facility ideally supplies two detectors

Schematic view



Proton driver

- most site-specific subsystem (local topography, other physics interests)
- PD studies done at BNL, CERN, FNAL, JPARC, RAL
- pulse structure has to satisfy many constraints from downstream systems

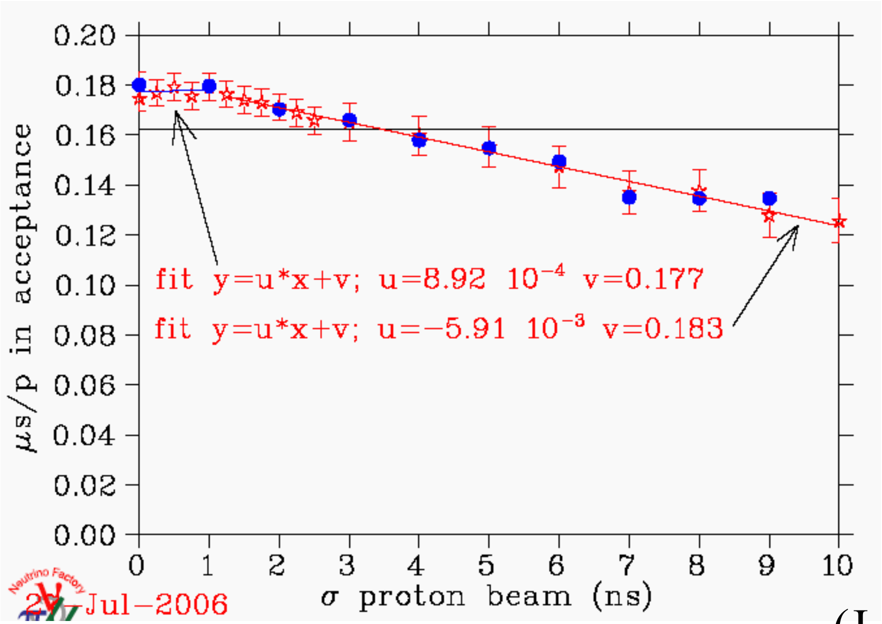


- looked at accepted μ after cooling
- maximum yield for high-Z targets
- best efficiency for E ~ 10 GeV
- yield slightly higher for μ^-

(H. Kirk)

Proton driver

- neutrino factory puts significant constraint on final proton driver pulse length

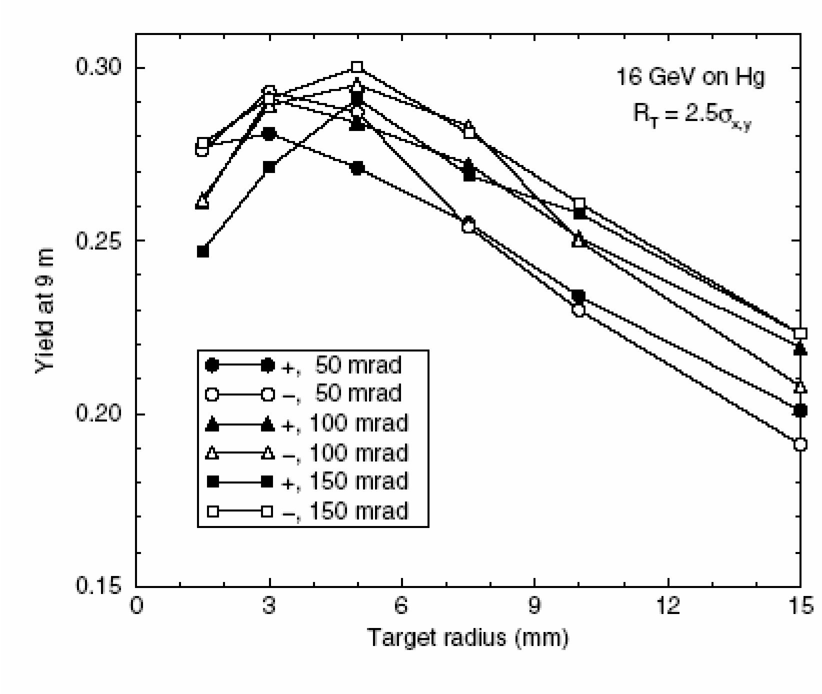


(J. Gallardo)

- looked at accepted μ after cooling
- varied time spread of initial production
- want short proton driver pulse on target
- problem when $\varepsilon_{L0} > A_L$ of PR & cooler

Target system

- believe liquid metal jet is favored solution for 4 MW proton beam
- Hg may also provide suitable beam dump

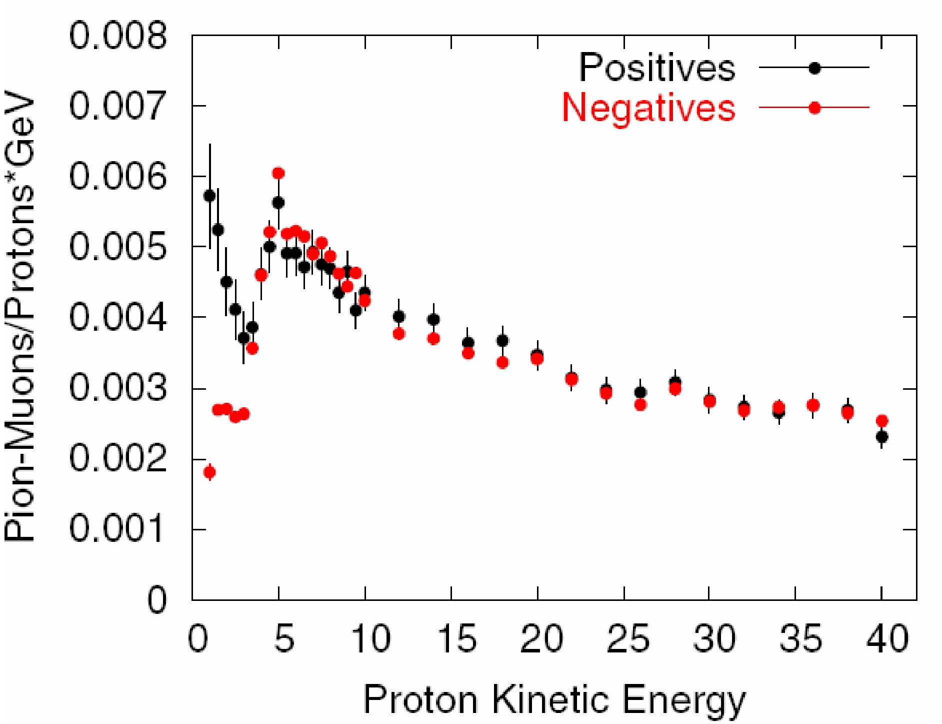


Hg jet radius ~5 mm is optimum

(H. Kirk)

Target system

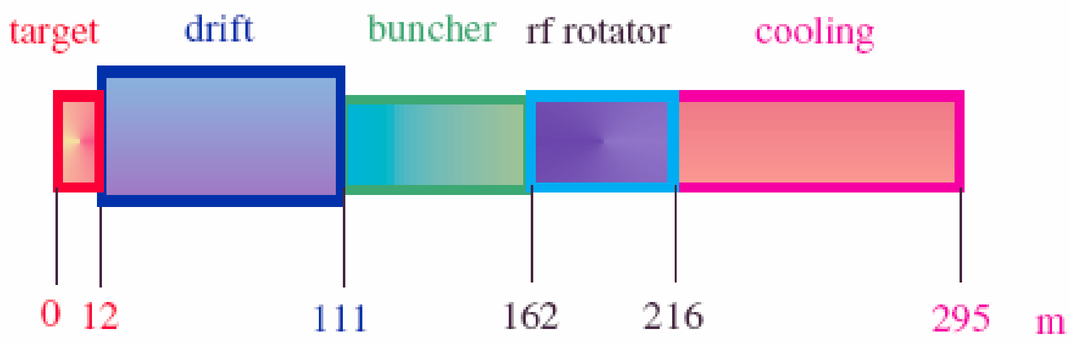
- C target at 5 GeV may be suitable for a 1 MW-class neutrino factory



(H. Kirk)

Front end

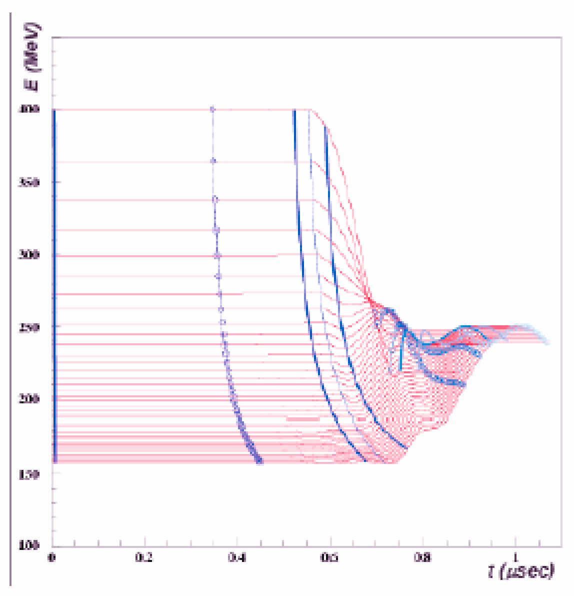
- ISS front end based on Study 2a
- uses Neuffer's scheme for bunching and phase rotation
- small amount of transverse ionization cooling
  - simplified solenoid lattice
  - LiH absorbers on RF windows



Phase rotation optimization

- wrap MINUIT around ICOOL+ENDOF9+ECALC9
- chose 5 parameters to vary
- minimized energy spread after rotation
- found Study 2a parameters were close to optimum
- may be able to make small improvements in performance

Energy



Time

(M. Appolonio)

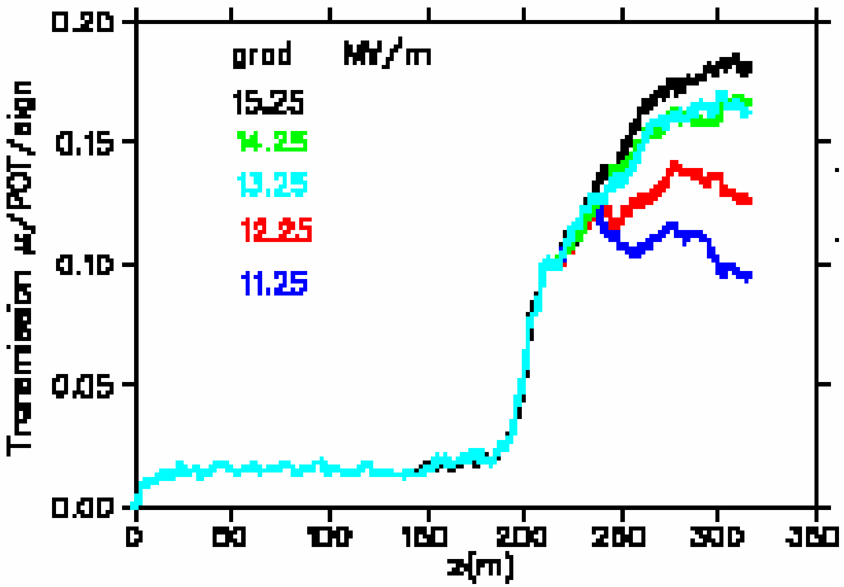
Effect of reduced rf gradient

- what if we can't achieve 15 MV/m in a magnetic field?
- operation with 2/3 gradient reduces performance by 20%

  compensated by adjusting amount of absorber and rf phase
- another study assumed construction gives distribution of gradients

  best to put highest gradients at start of channel

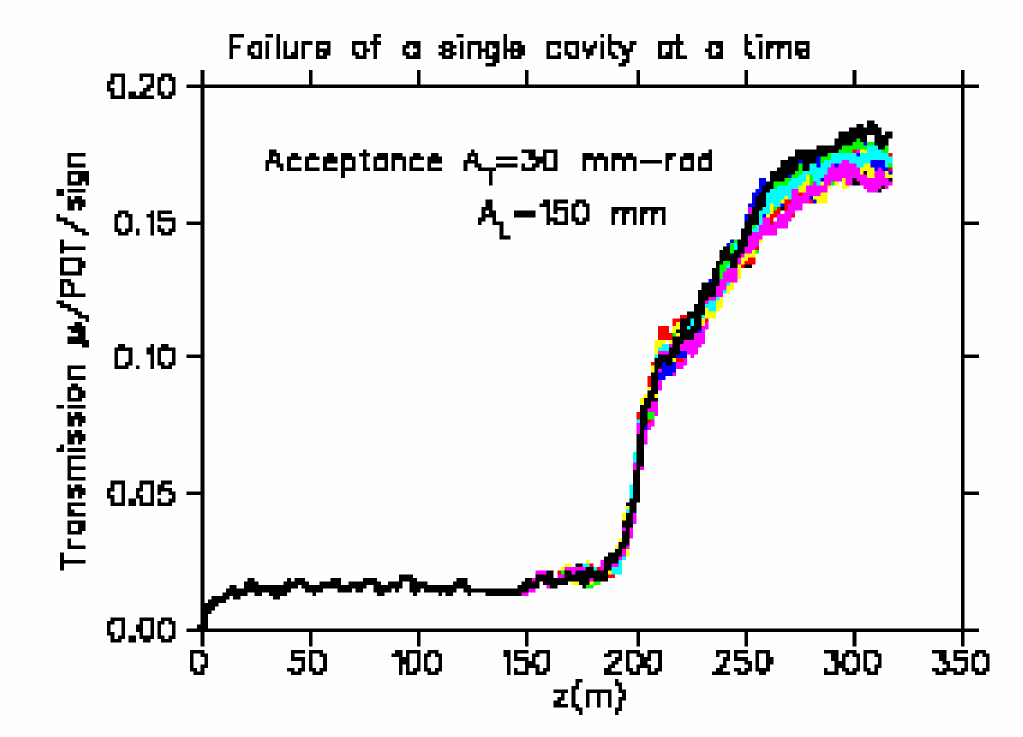
  12 full gradient cavities restored performance loss



(J. Gallardo)

Failure of an rf cavity in Study 2a

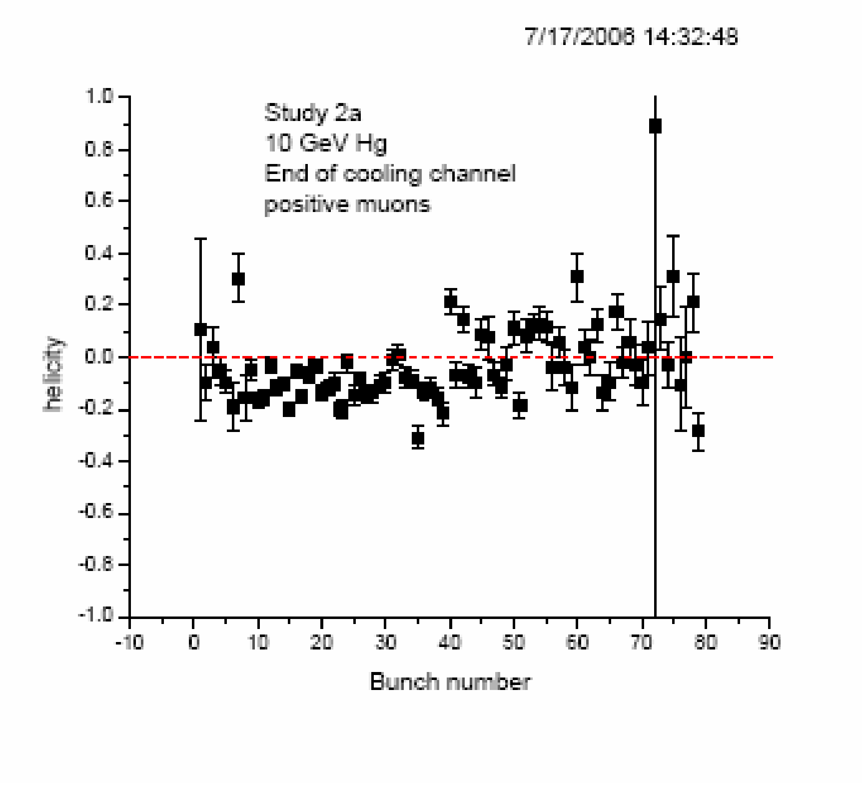
- looked at failure of single cavities in rotator or cooling channel
- find ~3% loss in μ_A/p



(J. Gallardo)

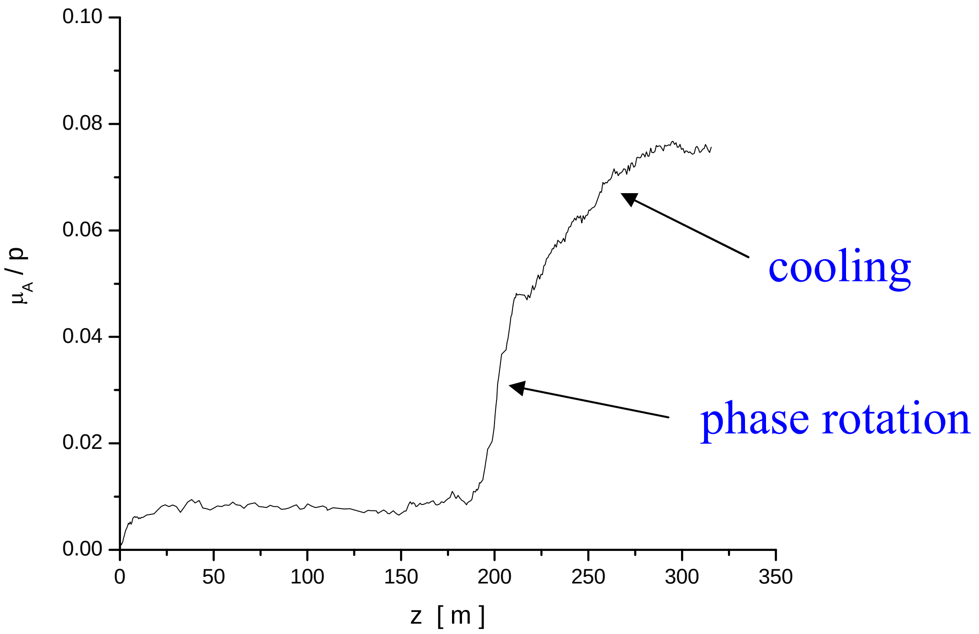
Muon helicity

- NF produces train of muon bunches
- average polarization is small ~8% for both signs
- correlation of helicity with bunch number is small
- peak helicity is ±15% for end bunches



Front end performance

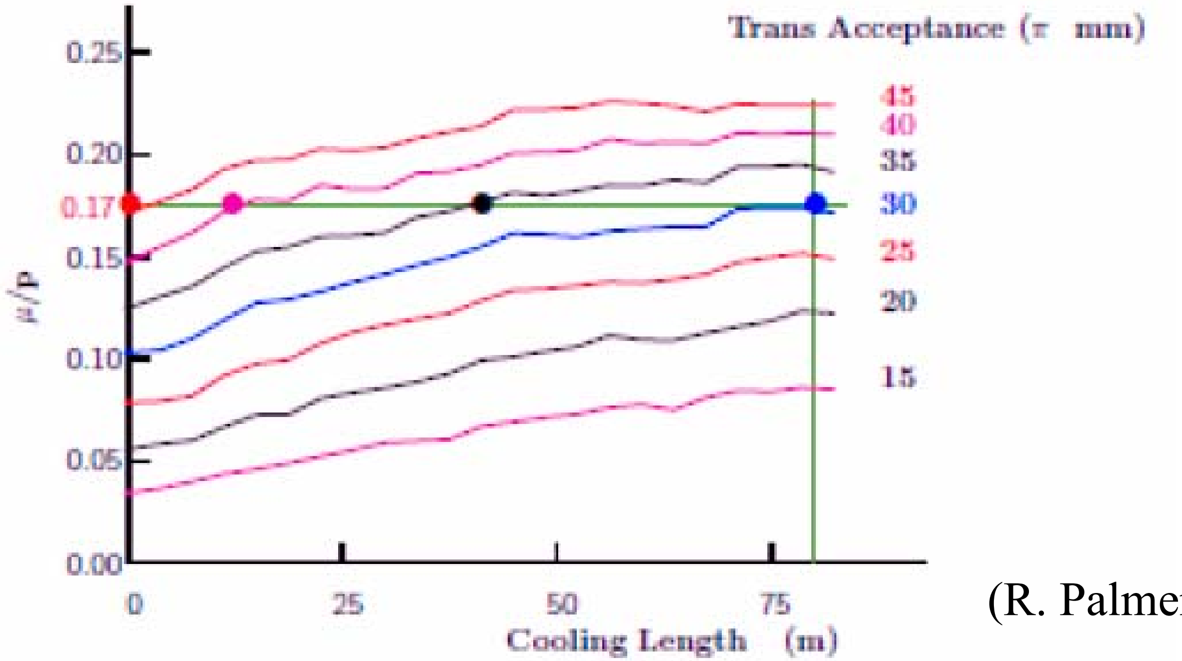
- performance with 10 GeV beam is similar to Study 2a (at 24 GeV)
- μ_A/p GeV= 0.0073 for positives
- μ_A/p GeV= 0.0088 for negatives



Cooling versus acceptance

- there is a trade-off between cooling and accelerator acceptance
- this is an important concept for cost optimization
- not clear now that large FFAG transverse acceptances are possible
- some cooling is probably necessary for neutrino factory

Study 2a simulation



(R. Palmer)

Acceleration scenario

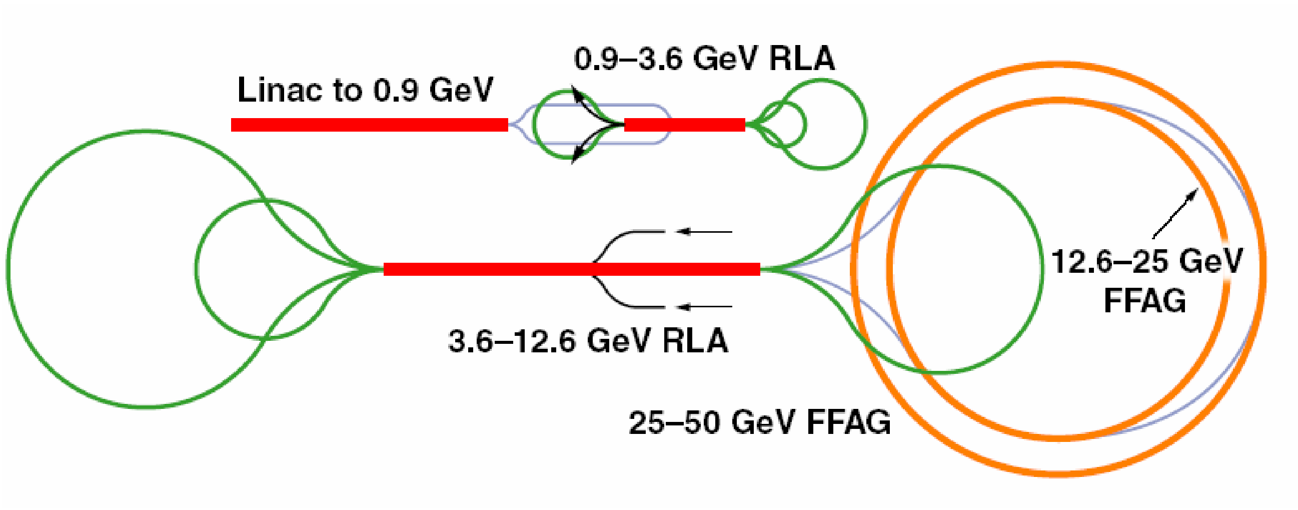
• lot of work to optimized cost / performance

linac to 0.9 GeV

two RLAs to 12.6 GeV

one or two FFAGs to ~25-50 GeV (physics & detector dependent)

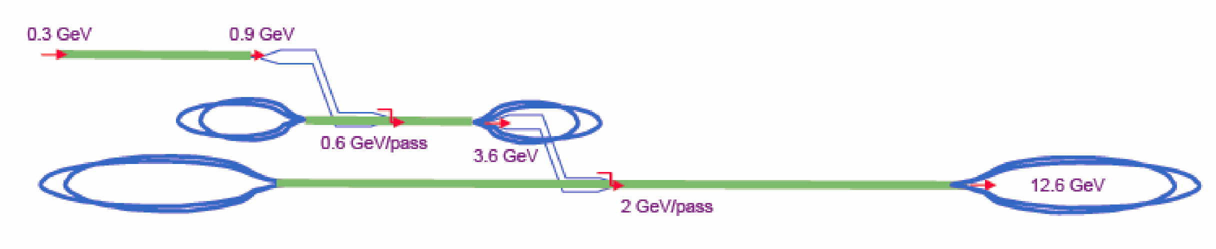
A_{TN} = 30 mm, A_{LN} = 150 mm



Preliminary acceleration layout

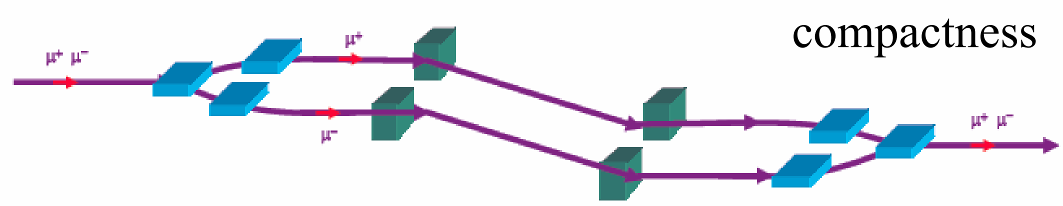
RLA

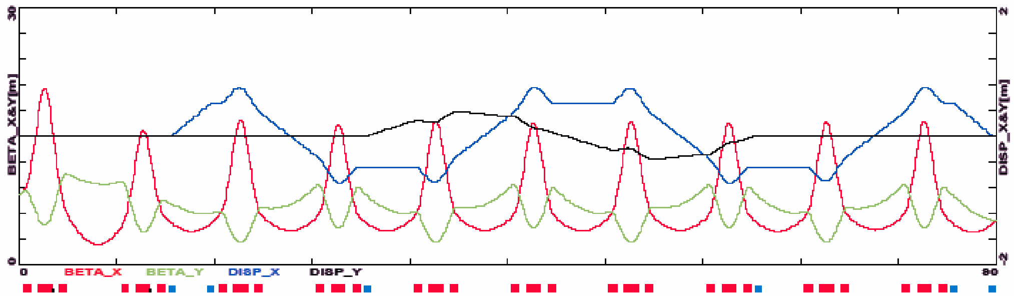
- dogbone gives better orbit separation for higher passes
  & symmetric acceleration for μ^+ and μ^-
- FODO focusing in RLA linacs



Injection scheme

Vertical stacking for compactness





Injection double chicane optics

(A. Bogacz)

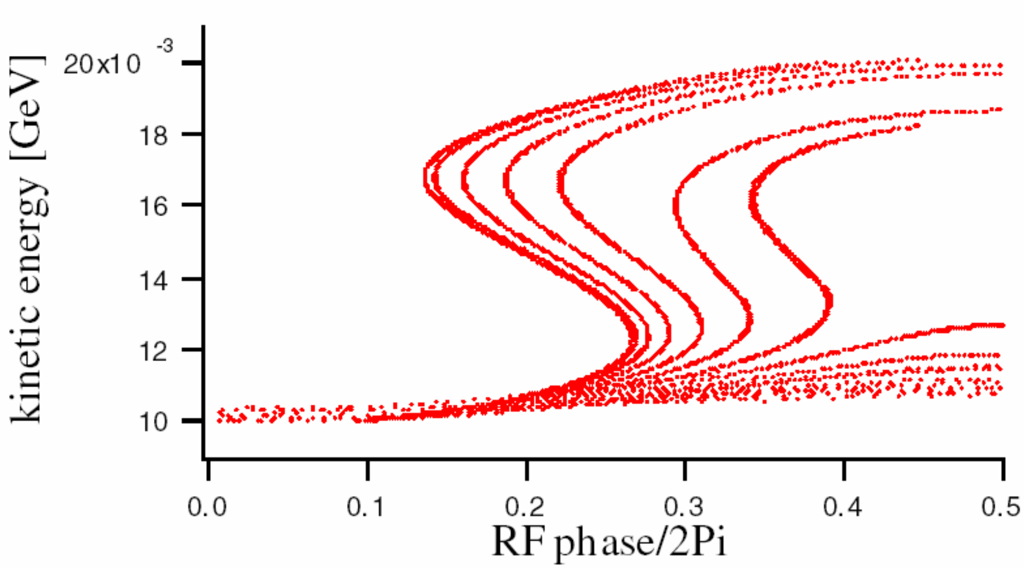
FFAG

- dependence of TOF on amplitude limits acceptance and ability to stage rings
- high transverse amplitude particles get out of synch with RF
- possible solutions under investigation:

  reduce tune range during acceleration

  increase energy gain per cell

  add higher RF harmonics



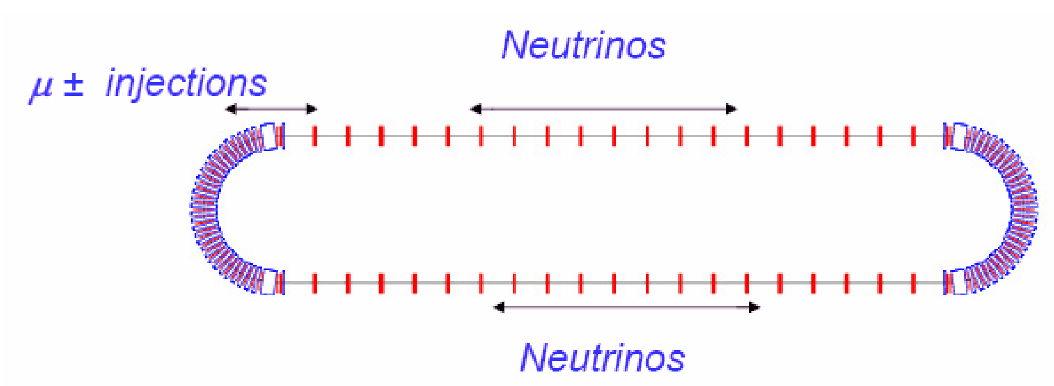
Low amplitude

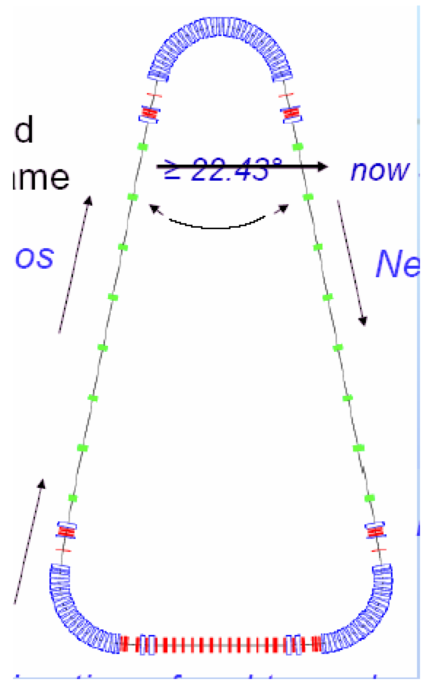
High amplitude

(S. Machida)

Decay ring

- goal: maximize muon decays in straight sections
- racetrack, triangle, and bowtie geometries have been examined
- 2 racetracks are currently favored (most flexibility)
- use long straight sections ~400 m
- vertical depth of ring (~200-400 m) is issue for long baselines





Near-term plans

- neutrino factory
  - begin collaboration on International Design Study
  - looking at backup phase rotation & cooling lattices with small B on RF or with B ~perpendicular to E
- muon collider
  - continue investigation of NF-compatible schemes
    - bunch coalescence at low energy
    - helical cooling channels and cooling rings
    - final cooling using 50 T solenoids
  - discussions with Muons Inc on their very low emittance approach
  - collaborate with Fermilab MCTF on new 1.5 TeV collider design

Summary

- have active program of simulation work
- for past 8 years our major emphasis has been on neutrino factory
  - Study 1→Study 2→Study 2a→ISS → IDS
- there's been recent renewed interest in a muon collider
- NF technology useful for collider
- have continued to make progress in all areas over last year