Neutrino Factory and Beta Beam

Experiments and Development

Design Group Summary

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Neutrino Factory and Beta Beam Working Group Meeting–ANL
March 4, 2004

Outline

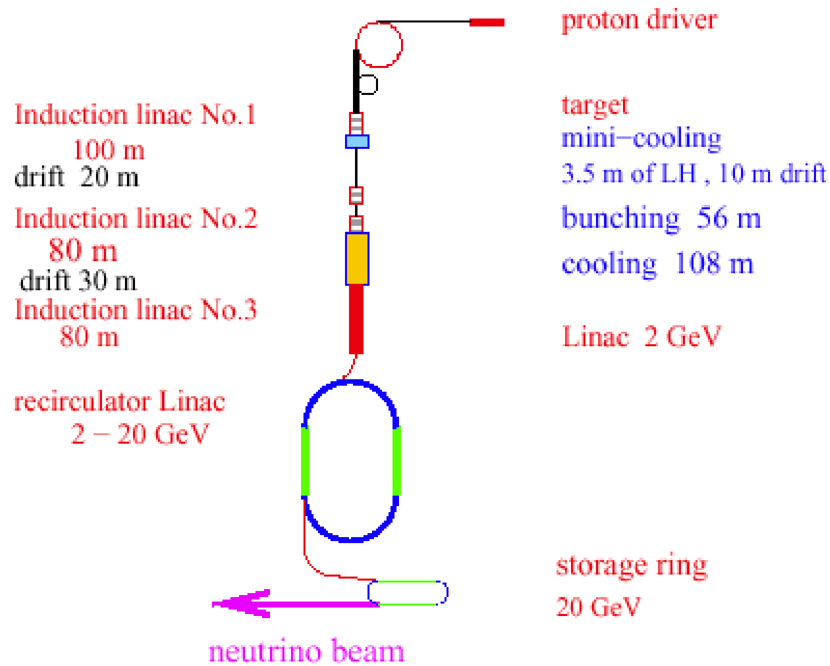
- Introduction
- Neutrino Factory ingredients
- Beta beam ingredients
- Progress and plans: Neutrino Factory
- Progress and plans: Beta Beams
- Possibilities for next meeting
- Summary

Introduction

- For Neutrino Factory design and R&D, strong and active groups already exist
  - Neutrino Factory and Muon Collider Collaboration (U.S.)
  - European Neutrino Group (EU)
  - Japanese Neutrino Group (Japan)
- Our goal is to build on that work and document it for the broader U.S. neutrino-science community
  - progress toward a more cost-effective implementation is particularly important
- Work on beta beams centered at CERN
  - they are happy to work with us to provide information on what has been done and what remains to be done
- Our goals are to understand the CERN work, to evaluate the R&D program required to realize a beta beam facility, and to consider a possible U.S. implementation of such a machine

Neutrino Factory Ingredients

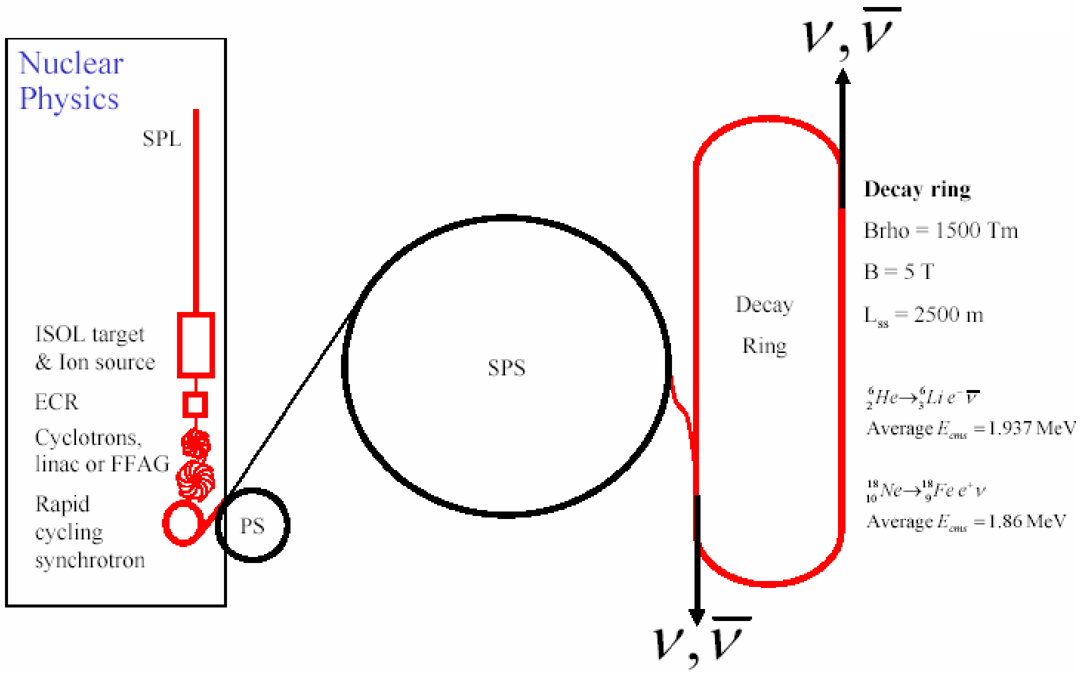
- Neutrino Factory comprises these sections
  - Proton Driver
    (primary beam on production target)
  - Target and Capture
    (create π's; capture into decay channel)
  - Phase Rotation
    (reduce ΔE of bunch)
  - Cooling
    (reduce transverse emittance of beam)
    ⇒Muon Ionization Cooling Experiment
  - Acceleration
    (130 MeV → 20–50 GeV with RLAs)
  - Storage Ring
    (store muon beam for ≈500 turns; optimize yield with long straight section aimed in desired direction)



Feasibility Study II version

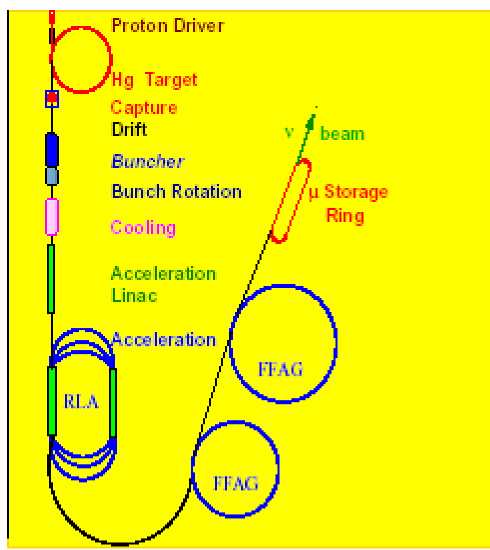
Beta Beam Ingredients

- CERN scheme
  - one extra step compared with Neutrino Factory: ionization of beta unstable isotopes
    - also one step less: no cooling of beam
  - premium on rapid acceleration, but less so than for muon beams

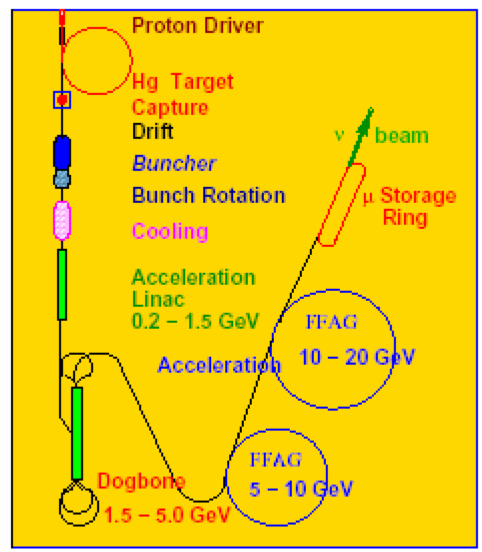


Progress and Plans: Neutrino Factory

- Starting place for Neutrino Factory design is Palmer's updated version of "Study-II" design (Gallardo talk)
  - uses RF sections for both bunching and phase rotation
  - uses new cost-optimized cooling channel
  - uses acceleration scheme based on FFAGs



Racetrack RLA



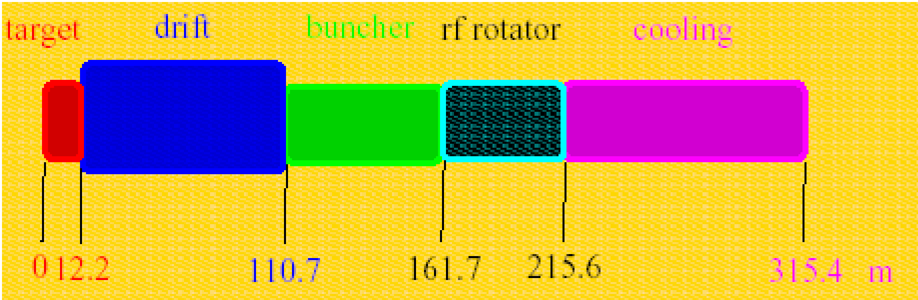
Dogbone RLA

Progress and Plans: Neutrino Factory

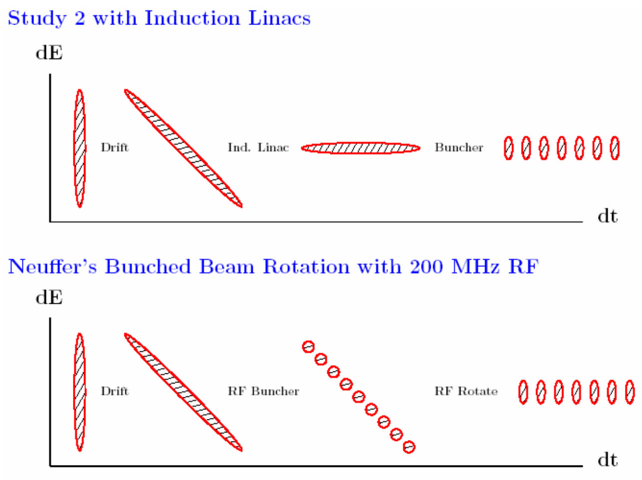
- These changes should markedly reduce cost of the facility
  - RF bunching and phase rotation section shorter than induction linac version, and uses less expensive components
    - original scheme took 25% of total cost
    - new scheme can keep both μ^- and μ^+ simultaneously
  - RLA was major cost in Study II Neutrino Factory design (23%)
    - large aperture FFAG magnets accommodate the large energy change per turn without requiring separate arcs
      - avoids large aperture splitter-recombiner magnets
  - increased acceptance downstream allows reduction in required cooling (20% of facility cost)

Progress and Plans: Neutrino Factory

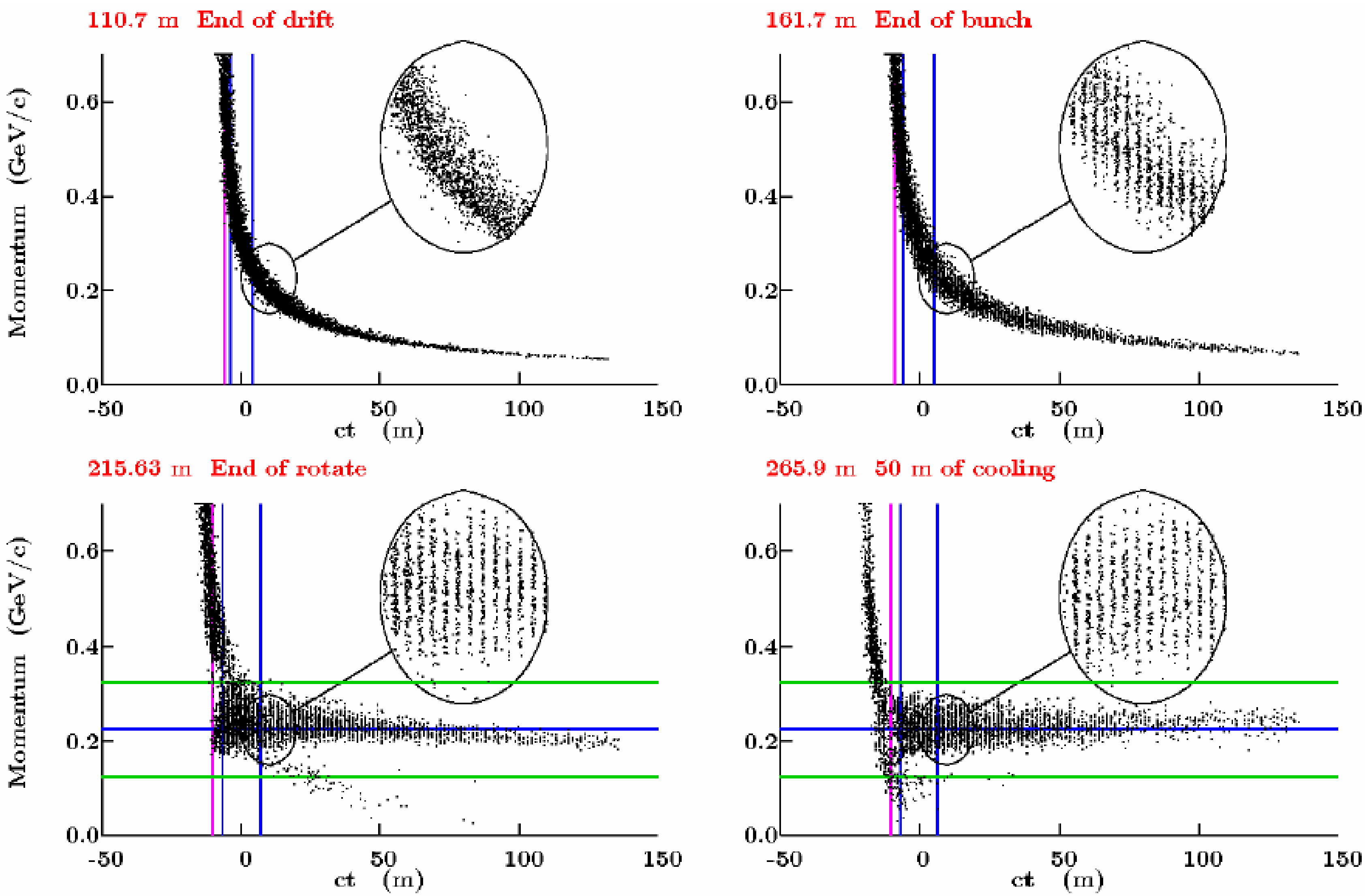
- Buncher and rotator concept due to Neuffer
- Overall layout more compact than Study II version



- RF buncher and rotator

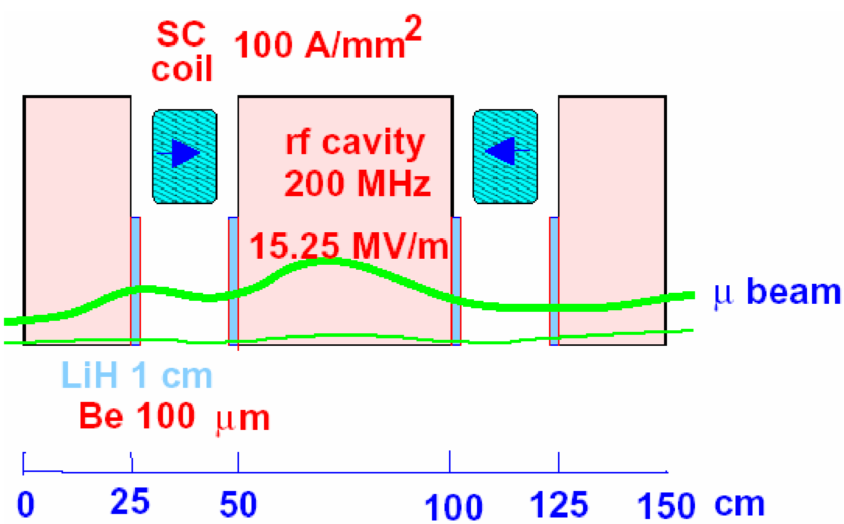


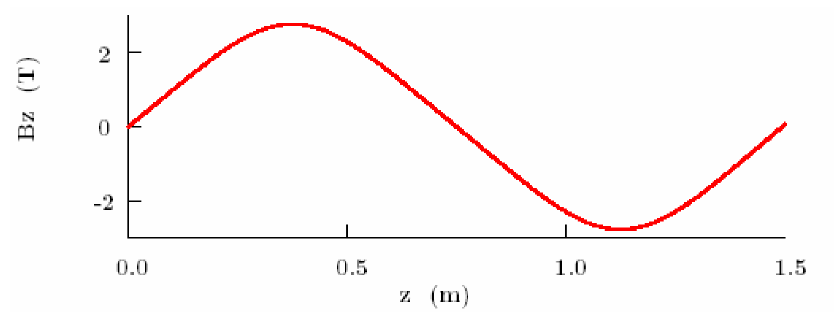
Progress and Plans: Neutrino Factory



Progress and Plans: Neutrino Factory

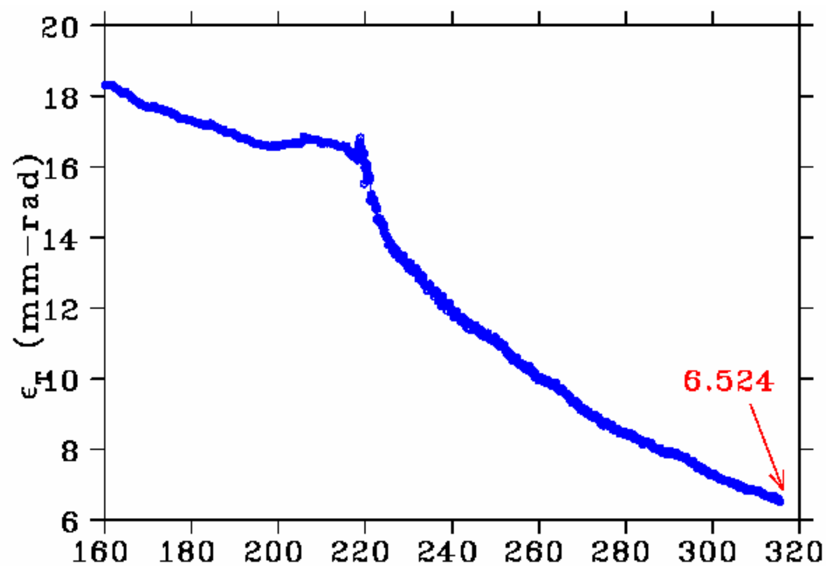
- New design (Palmer) uses less cooling than Study II version
  - 50 m vs. 108 m
  - weaker focusing, $\beta_{\perp}$ = 70 cm vs. 40 cm
  - fewer solenoids
  - solid (Li or LiH) vs. liquid-hydrogen absorbers
    - no performance difference in a short channel

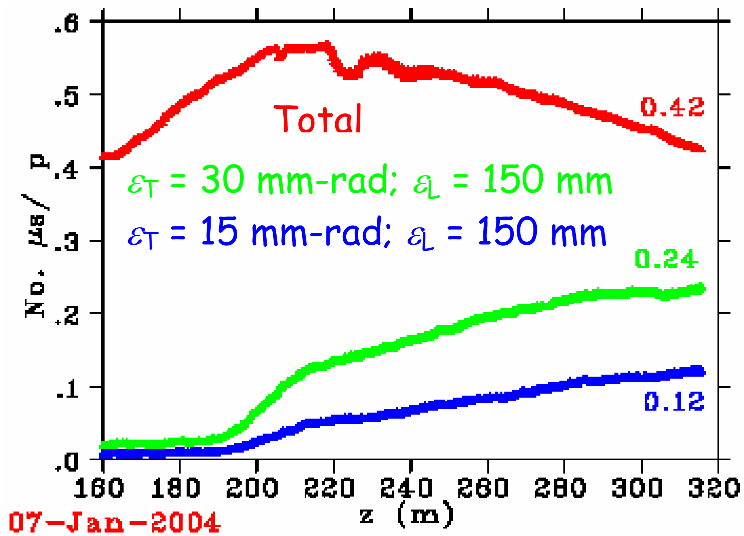




Progress and Plans: Neutrino Factory

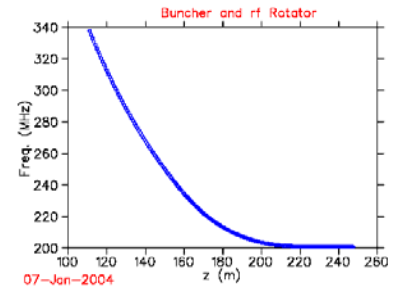
- performance is acceptable (yield better than Study II if larger downstream acceptance is realized)
  - **must verify this** when more realism is added to simulation model





Progress and Plans: Neutrino Factory

- But, much work to be done to make initial simulations more realistic (Fernow talk)
  - must produce lattice for entire front end
    - replace constant buncher and rotator fields with periodic solenoids
    - join all separately-calculated regions into one continuous lattice
    - carry out proper matching between regions



  - add beam-pipe constraints in capture section
  - add realistic RF windows in all cavities
  - implement discrete RF frequencies for buncher and rotator
  - use MARS to make sure radiation levels in capture and decay region are acceptable
  - do GEANT simulation of final configuration

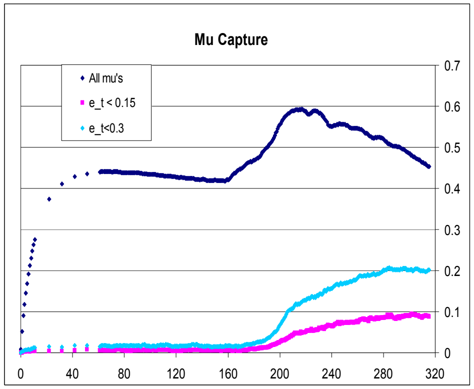
Progress and Plans: Neutrino Factory

- Other studies undertaken to see how well optimized the design is with regard to cost-performance trade-offs
  - optimize magnetic channel for capture and decay region
  - compare alternative window and absorber materials
  - attempt to shorten phase rotator section
  - evaluate dependence of performance on RF gradient
- Present assignments (abridged)*
  - Gallardo: periodic transport solenoids, buncher windows
  - Fernow: design capture solenoids, match into cooling section
  - Kirk: develop MARS radiation map and new particle distribution
  - Paul: optimize field profile for capture and decay section
  - Neuffer: study material effects and optimize rotator length
  - Fukui: study performance effect of reduced gradients

*additional volunteers welcome

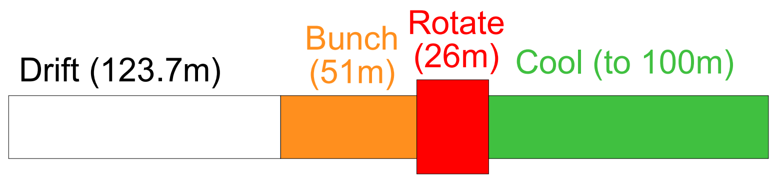
Progress and Plans: Neutrino Factory

- Studying variants permits understanding of cost-performance trade-offs (Neuffer talk)
  - things to examine: energy of cooling channel, buncher and phase rotator parameters, absorber materials
- Looked at replacing LiH absorbers with Be absorbers
  - we have Be foils anyway for terminating the RF cavity fields
  - find cooling somewhat worse $\varepsilon_{\perp}$ = 9.3 mm (vs. 7.3 mm for LiH)
    - get μ/p = 0.21 at 80 m (vs. 0.25 at 100 m for LiH)
- Need to look at H_2 gas-filled cavity performance also



Progress and Plans: Neutrino Factory

- Looking at performance of shorter bunch rotator

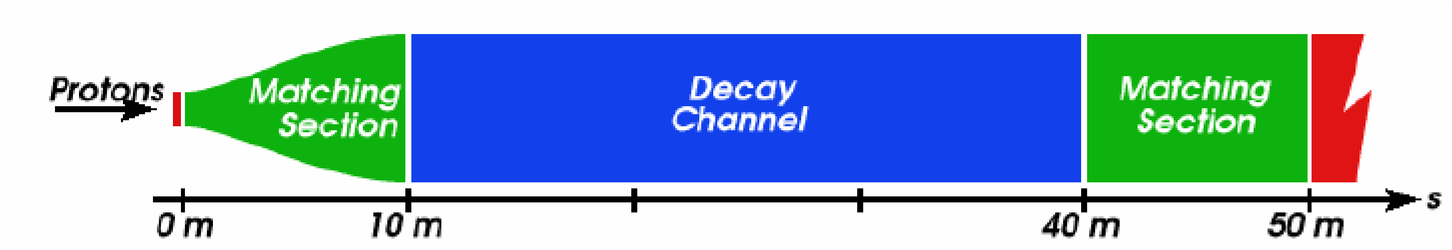


Palmer scheme | Short rotator

  - gives μ/p = 0.22 (vs. 0.24 for Palmer scheme)
- Need to assess how many discrete frequencies are needed for adequate implementation of buncher
  - previous work showed that 10–20 frequencies will suffice
  - tried buncher with 11 frequencies, rotator with 6 frequencies
  - results in μ/p = 0.2 (vs. 0.22 for continuous frequency scheme)
- While these simulations done without fully realistic windows and magnetic fields, results expected to scale to fully realistic case

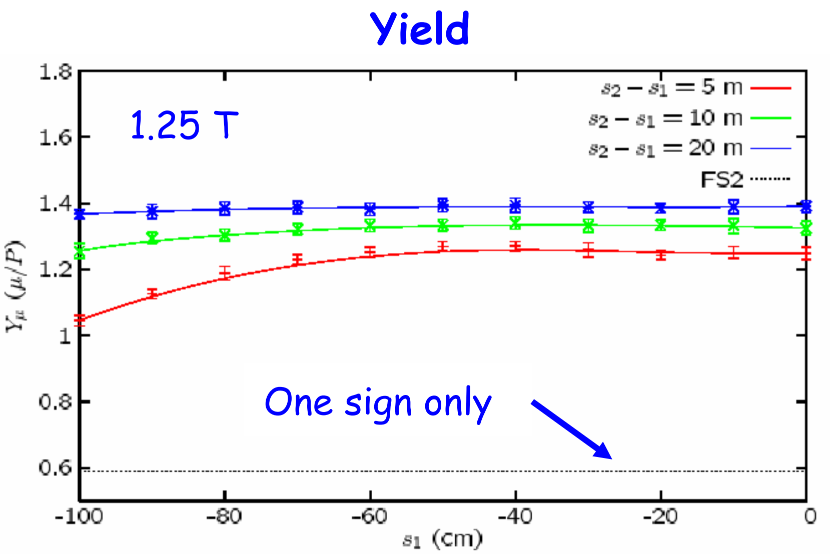
Progress and Plans: Neutrino Factory

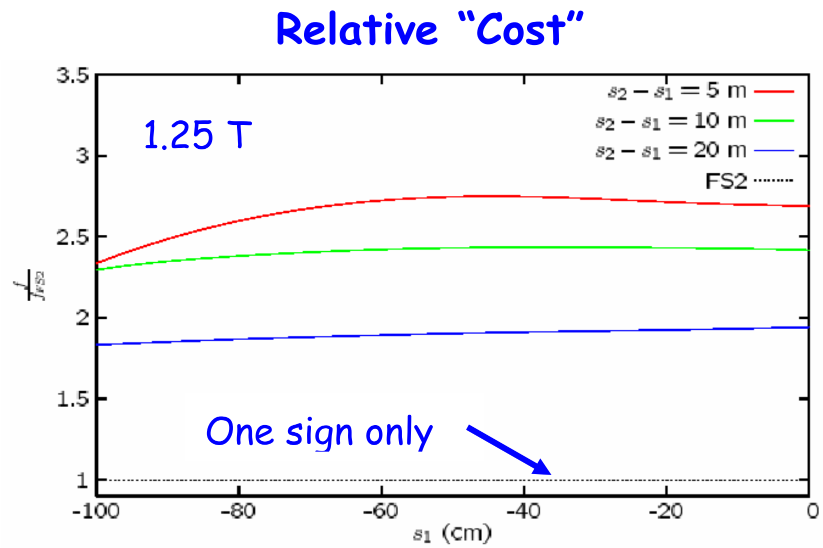
- Optimization of capture and decay region (Paul's talk)
  - goals: maximize muon yield, evaluate cost-optimization
  - start from Study II configuration
    - 24 GeV p incident at 67 mrad from solenoid axis
    - Hg jet, 1-cm diameter, at 100 mrad from solenoid axis
    - tapered solenoidal matching section (≈20 T at target to ≈1 T in decay channel)
    - uniform solenoidal decay channel



Progress and Plans: Neutrino Factory

- Present results favor long taper (20 m); 1.25 T and 2 T decay channels similar
  - crude cost optimization (based on yield per unit of stored energy in magnets relative to that in Study II) favors 1.25 T field





  - looks like 10 m drift is a sensible compromise
  - need to evaluate with same energy cuts as downstream channel (100–300 MeV/c)

Progress and Plans: Neutrino Factory

- High-power proton drivers are a key ingredient for a Neutrino Factory, a Beta Beam facility, a Superbeam
  - also important for neutron spallation, kaon or muon beam facilities
- There are many proposals for proton drivers (Kirk talk)

SNS at 1.2 MW	→	2.0 MW			
JPARC 0.7 MW	→	4.0 MW			
FNAL 0.4 MW	→	1.2 MW	→	2.0 MW	
BNL 0.14 MW	→	1.0 MW	→	4.0 MW	
CERN(PS) 0.1 MW	→			SPL	4.0 MW

  - we need to compare the needs of the various users to assess how well the proposed projects fulfill them
- Fermilab proposing Proton Driver project (CD-0 by end of year) to
  - replace 400 MeV linac
  - develop new 8 GeV proton driver (0.5 MW)
  - upgrade MI to 2 MW

Progress and Plans: Neutrino Factory

- Acceleration goal is to replace Study II RLAs with (hopefully) less expensive system based on FFAG rings (Berg talk)
  - limited FFAG energy swing (2:1) means that linac and RLA probably cannot be avoided
- Plan is as follows
  - base FFAGs on cost-optimized parameter sets (5–10 GeV and 10–20 GeV) [Berg]
  - develop rough magnet design to get end fields [Kahn]
  - track beam with ICOOL [Palmer] (start with 5–10 GeV; hardest)
    - validate with another code [Berg]
  - design linac and RLA for low energy acceleration [Bogacz]
  - specify kicker specifications [Palmer]
  - produce realistic FFAG magnet design for costing [BNL/LBNL] (start with 10–20 GeV; most expensive)

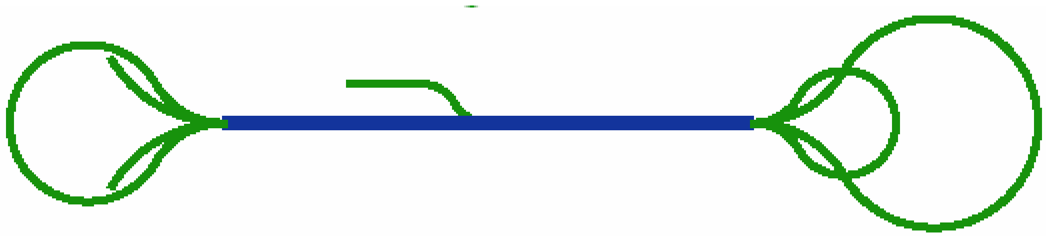
Progress and Plans: Neutrino Factory

- Tentative FFAG parameters

E_{min} (GeV)	5		10	
E_{max} (GeV)	10		20	
$V/\omega\Delta T\Delta E$	1/8		1/12	
$A_{\perp n}$ (mm)	30			
L_0 (m)	2			
L_Q (m)	0.5			
V per cell (MV)	7.5			
Empty cells	8			
ν_x, ν_y at E_{min}	0.35			
n	90		105	
C (m)	606.918		767.953	
V total (MV)	675.0		787.5	
	QD	QF	QD	QF
L (m)	1.612338	1.065600	1.762347	1.275747
ρ (m)	15.2740	-59.6174	18.4002	-70.9958
x_0 (mm)	-1.573	7.667	1.148	8.745
r (cm)	14.0916	15.2628	10.3756	12.6256
B_0 (T)	1.63774	-0.41959	2.71917	-0.70474
B_1 (T/m)	-9.1883	8.1768	-15.4948	12.5874

Progress and Plans: Neutrino Factory

- Low energy system will start with linac to 1.5 GeV, followed by "dogbone" or racetrack RLA



Dogbone

Racetrack

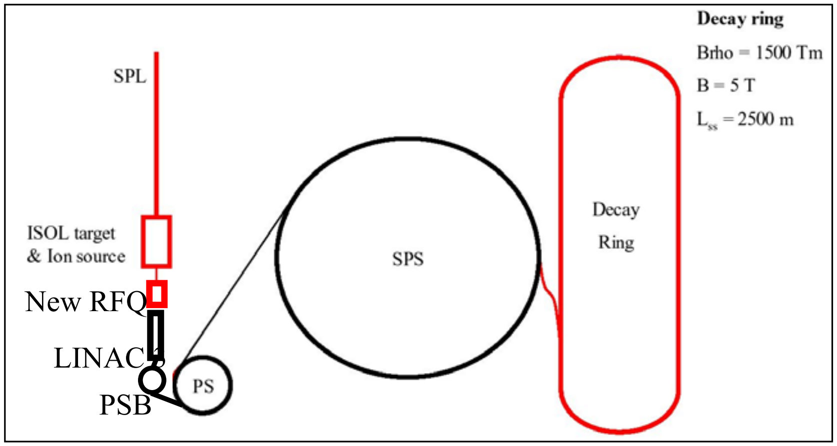
- Hope to provide sufficient detail for a crude cost estimate
- Will track the favored design

Progress and Plans: Neutrino Factory

- Discussion issues
  - use of μ^+ and μ^- beams simultaneously needs to be worked out, including detector implications
  - we presently are designing for 1 MW proton driver
    - should we be optimizing for 2 MW instead?
      - has implications for cooling and/or acceleration design and costs
      - if Superbeams use 2 MW, shouldn't we?
    - related question: is 1×10^{20} ν_e per year enough?
  - is there agreement that 20 GeV beam energy will suffice?
    - we still hear mention of 50 GeV sometimes
  - all our work to date assumes proton driver energy of 8–24 GeV
    - we should acknowledge possibility of 120 GeV beam from MI

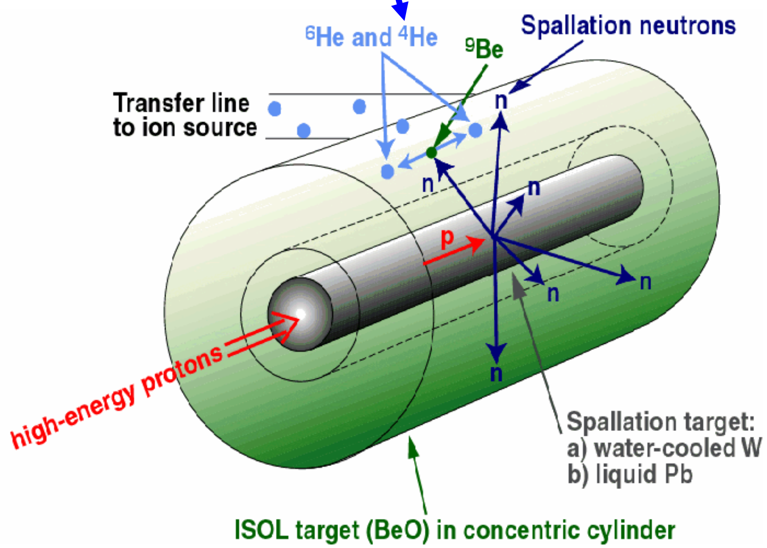
Progress and Plans: Beta Beams

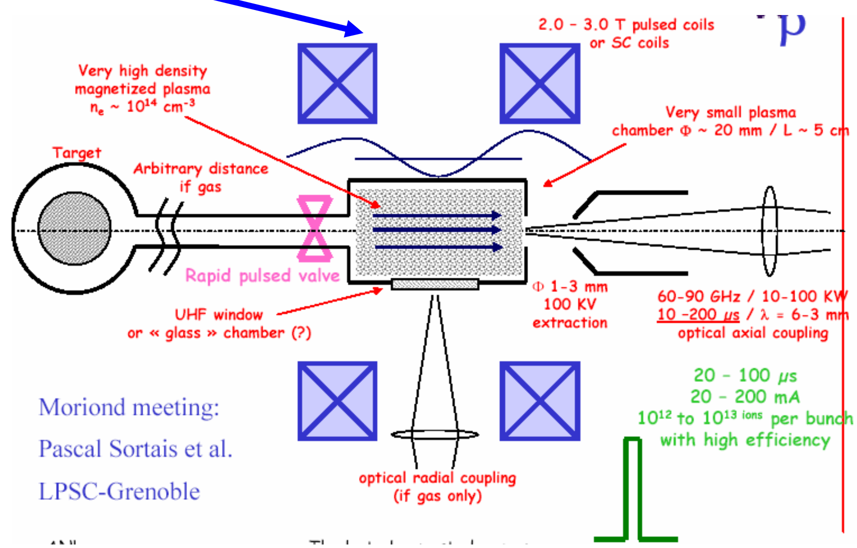
- Beta beam work presently centered at CERN (Blondel talk)
  - based on acceleration and storage of light beta-unstable isotopes
    - use ^{6}He for β^- ($t_{1/2}$ = 0.8 s)
    - use ^{18}Ne for β^+ ($t_{1/2}$ = 1.7 s)
- Current scheme involves SPL, ISOL target, pulsed ECR source, 50 MeV linac, pulsed synchrotron (300 MeV/u), PS (to γ = 9.2), SPS (to γ ≈ 100), decay ring with long straight section pointed toward detector



Progress and Plans: Beta Beams

- There are **many technical challenges** of beta beams
  - **production target and ion source** to give required intensity

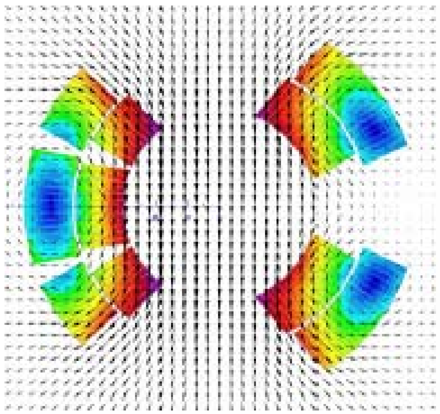




Progress and Plans: Beta Beams

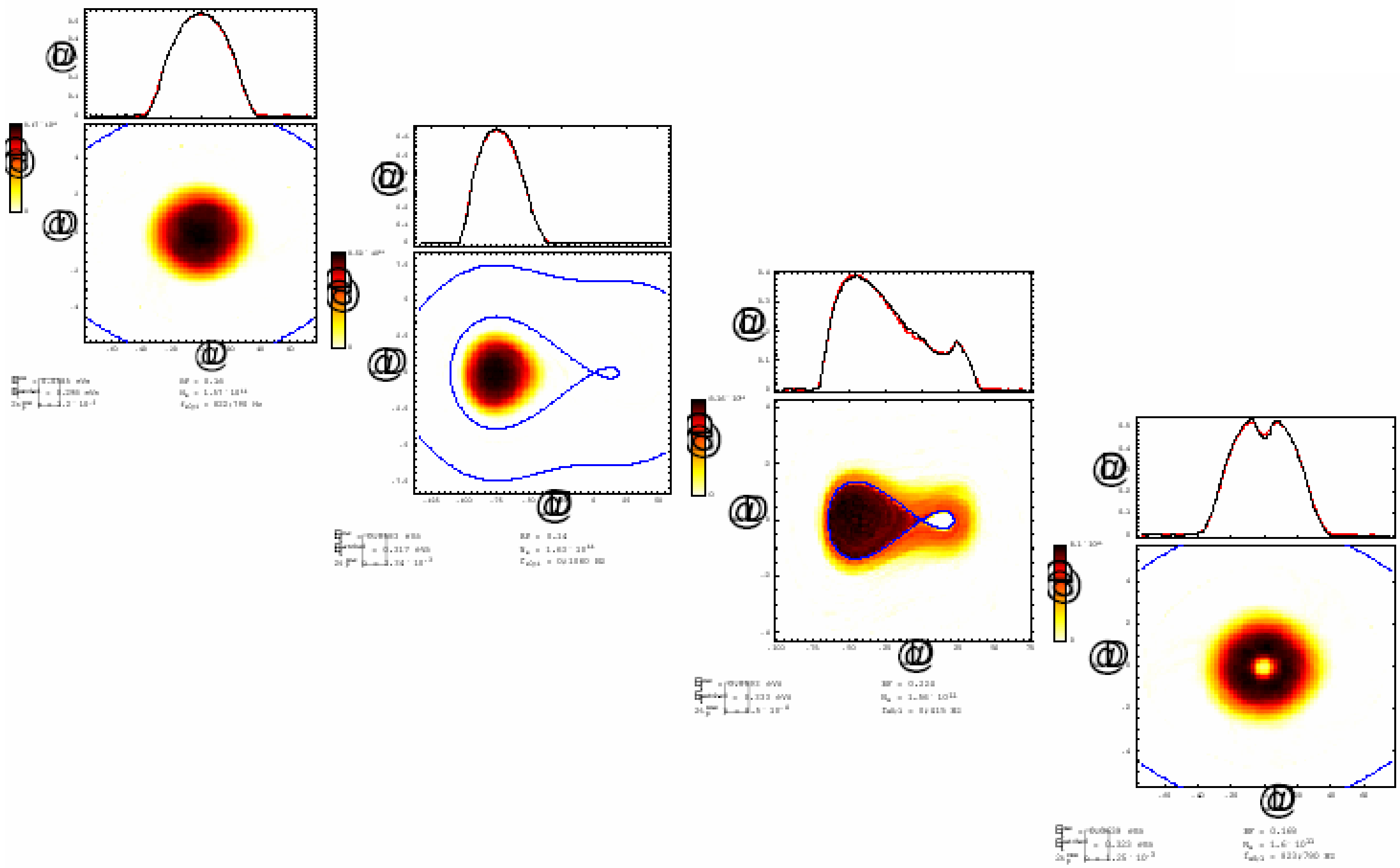
— radiation losses in various rings

- carrying out FLUKA calculations for all stages
- initial results
  - PS would be heavily activated (replacement needed?)
  - some issues regarding tritium and sodium
- decay ring dipole with no midplane coil has been proposed



Progress and Plans: Beta Beams

– stacking multiple turns in decay ring without cooling the beam



Progress and Plans: Beta Beams

- **Predicted intensity values:**

Stage	^{6}He	^{18}Ne (single target)
From ECR source:	2.0×10^{13} ions per second	0.8×10^{11} ions per second
Storage ring:	1.0×10^{12} ions per bunch	4.1×10^{10} ions per bunch
Fast cycling synch:	1.0×10^{12} ion per bunch	4.1×10^{10} ion per bunch
PS after acceleration:	1.0×10^{13} ions per batch	5.2×10^{11} ions per batch
SPS after acceleration:	0.9×10^{13} ions per batch	4.9×10^{11} ions per batch
Decay ring:	2.0×10^{14} ions in four 10 ns long bunch	9.1×10^{12} ions in four 10 ns long bunch

Only β-decay losses accounted for, add efficiency losses (50%)

Progress and Plans: Beta Beams

- R&D issues
  - isotope production (GEANT simulations)
  - target design (only 100 kW proton beam is present scenario)
  - pre-bunching of high-intensity ion beams (60 GHz ECR source)
  - design of superconducting dipoles
    - need ramped magnets for PS/SPS
    - need high-field, rad-hard dipoles for decay ring
- Scenarios for higher energy U.S. beta beam being explored (Jansson talk)

Possibilities for Next Meeting

- Organizers have a mid-course meeting on April 1–2, 2004
- Expect report to be completed in June-July
- It seems worthwhile to have at least one in-person meeting to present our conclusions and plan for the report writing
  - it may also be prudent to meet with the Superbeam group (since we failed badly this meeting)
- Possible dates (based on my schedule)
  - mid-April (12-26)
    - early in this period, Chicago is preferred venue
    - after April 22, BNL is the preferred venue
  - May (after 5/10)
    - we need to be writing report by then!
  - early June (depending on when report is due)

Summary

- Have a plan how to proceed on Neutrino Factory and Beta Beam study
- We still have a lot to do, and not much time to do it
- It is important that the case for continued accelerator R&D in support of the physics program be part of the roadmap
- It should be clear from the work summarized here that there's a lot we may be able to do to make a more cost-optimized facility
  - it will help to get a firm idea of what performance is good enough, since, in general,

"Good enough is best"