Neutrino Factory and Beta Beam

Experiments and Development

Michael S. Zisman
CENTER FOR BEAM PHYSICS

Muon Collaboration Meeting–Riverside
January 31, 2003

Outline

- Introduction
- Previous Neutrino Factory studies
- Beta beams
- Goals for this Study
- Organizational meeting
  - Neutrino Factory discussion
  - Beta beams
- Summary

Introduction

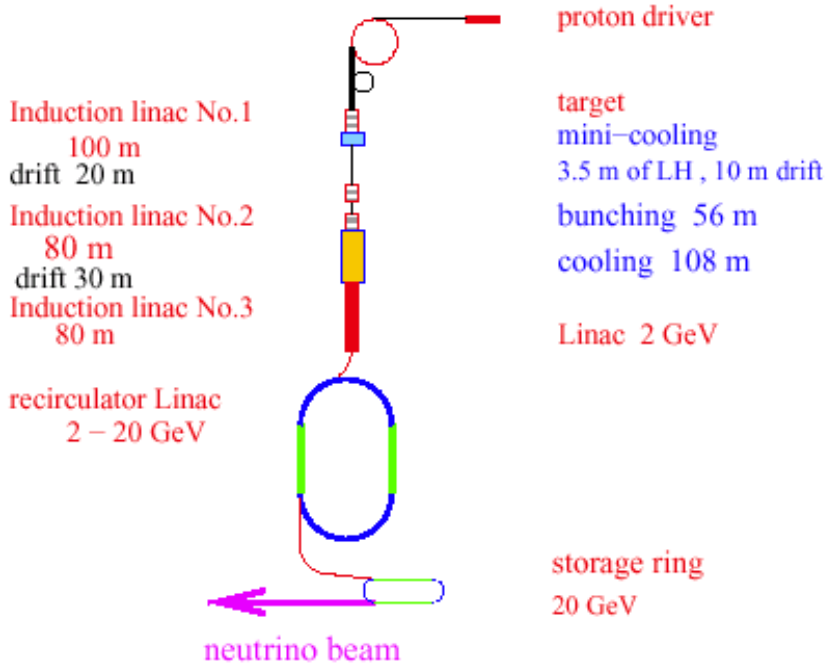
- Invitation to become Working Group Co-leader was very recent
  - ideas are in the very early stages of formation
- For Neutrino Factory design and R&D, strong and active groups already exist
  - Neutrino Factory and Muon Collider Collaboration (U.S.)
  - European Neutrino Group (EU)
  - Japanese Neutrino Group (Japan)
- Work on beta beams is happening mainly at CERN
  - necessarily kept at a low level due to CERN priorities

Introduction

- MC has been involved in two end-to-end Feasibility Studies of a Neutrino Factory complex
  - we have some experience in organizing such endeavors
- Possibility of doing "World" Neutrino Factory Feasibility Study is currently under discussion
  - this would involve U.S., EU, and Japan
    - driving force at present is mainly UK scientists
    - funding being sought from Brussels for this work
- "Feasibility Study model" is what we have in mind for this Working Group

Introduction

- 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)
    $\Rightarrow$Muon Ionization Cooling Experiment
  - **Acceleration**
    (130 MeV $\rightarrow$ 20–50 GeV with RLAs)
  - **Storage Ring**
    (store muon beam for ≈500 turns; optimize yield with long straight section aimed in desired direction)



- Not an easy project, but no fundamental problems found

Previous Neutrino Factory Studies

- Study I (1999–2000) instigated by the Fermilab Director
  - MC invited to participate
  - basic organization and decision-making done by Fermilab editors (Holtkamp and Finley)
- Focus on feasibility
  - first attempt to specify a Neutrino Factory from end to end
  - approach: base design on (reasonably) well-understood technologies
  - no attempt made to optimize either costs or overall performance
- Proper approach at that time, as feasibility itself was most at issue
- Led to predictable result: feasibility established, performance poor, and costs relatively high
- In large measure results were generic; not dominated by site-specific parameters

Previous Neutrino Factory Studies

- Study II (2000–2001) done as collaboration between MC and BNL as sponsoring laboratory
  - co-led by S. Ozaki (BNL), R. Palmer (BNL–MC), M. Zisman (MC)
- Goal: maintain convincing feasibility, improve performance substantially
  - minimizing costs was again given lower priority
- Results:
  - performance 6x that of Study I
    - 1.2×10^{20} vs. 2×10^{19} ν_e per year (10^7 s) per MW
  - cost about 75% of Study I
    - mainly due to using 20 GeV rather than 50 GeV, saving one RLA
  - performance scalable with proton power, if target does not limit this parameter
    - should be able to operate at 4 MW

Previous Neutrino Factory Studies

- Lessons learned from the two Studies
  - necessary to optimize the "front end" (decay, bunching, phase rotation, cooling) as one system to get high performance
  - necessary to simulate entire concept before starting detailed engineering (self-consistent solution)
  - necessary to work as partners with engineers to converge on buildable design
  - facility as conceived was costly, $\mathcal{O}$($2B)
  - increasing proton driver power is cost-effective way to get higher performance
    - it also tends to mesh well with other programs, e.g. Superbeams

Previous Neutrino Factory Studies

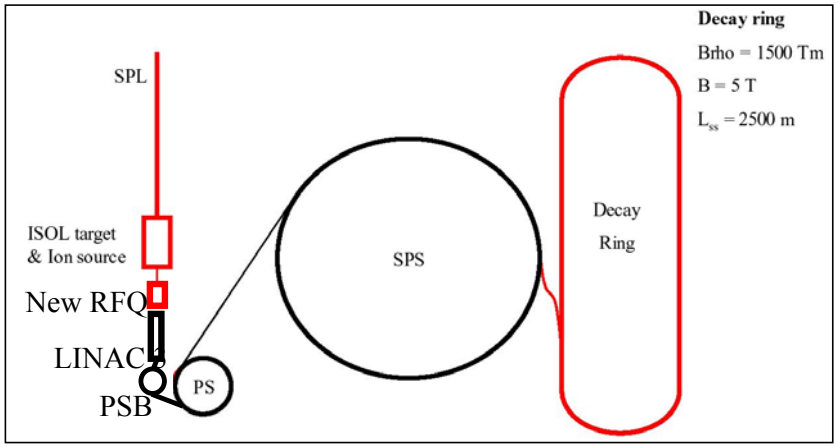
- For Neutrino Factory, we have already studied those portions of "design space" representing
  - low performance, high cost
  - high performance, high cost
- What's left?
  - high performance, optimized cost
    - note that I resisted temptation to say "low" cost
- Based on previous work, we have some ideas where to begin:
  - replace induction linacs with RF bunching and phase rotation scheme
  - replace RLA with FFAG ring or very fast cycling synchrotron
  - examine trade-off between amount of cooling and acceleration system/storage ring acceptance
    - and between beam intensity and detector size

Previous Neutrino Factory Studies

- These changes could 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
      - if we can take advantage of this feature
  - RLAs also represent a major cost in the present 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 may allow reduction in required cooling (20% of facility cost)
- Note that "replacements" will not be free, however

Beta Beams

- Beta beam work presently centered in Europe (CERN)
  - information here abstracted from talk by J. Bouchez at NuFact03
  - 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 $\gamma \approx 100$), decay ring with long straight section pointed toward detector



Beta Beams

- There are many technical challenges of beta beams that would benefit from further study
  - production target and ion source to give required intensity
    - multiple targets required for ^{18}Ne intensity of 1.3×10^{13}
    - pulsed ECR source to give bunch train of fully stripped ions
  - space-charge blowup and radiation losses in various rings
  - stacking multiple turns in decay ring without cooling the beam
- Generalizing the scenario beyond CERN-specific design would also be of interest

Goals for This Study

- For Neutrino Factory: examine approaches to reduce overall cost without sacrificing performance
  - then carry out simulations of updated front end and demonstrate acceptable performance
    - carry simulations through remainder of Study II channel if time permits
  - explore possibility of staged approach, beginning with Superbeam
- If successful, this would provide a good strawman design for a subsequent World Design Study

Goals for This Study

- For beta beams, seems prudent to aspire to more modest goals
  - assess progress of CERN design
    - perhaps attend design meetings in Europe
  - identify and understand outstanding technical issues and time scale for dealing with them
- Experts from nuclear physics facilities or projects, e.g. RIA, have the right expertise
  - if we can get a few volunteers we can learn something here

Organizational Meeting

- Machine discussion was attended by:

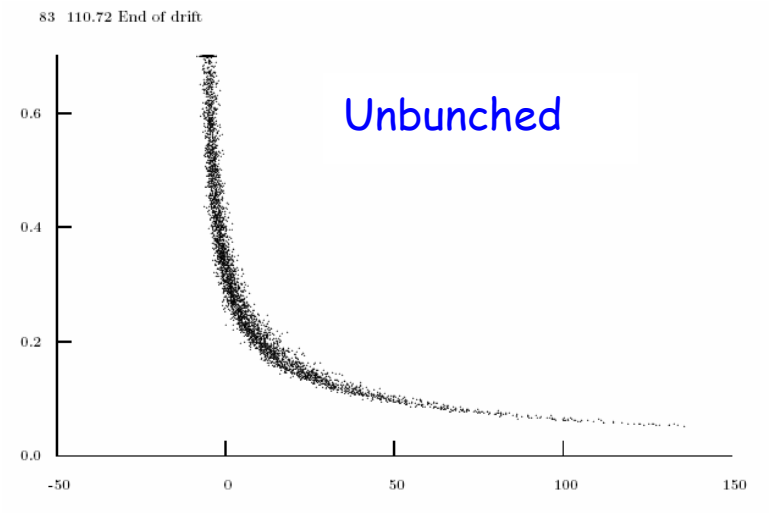
Daniel Galehouse (U. Akron)
David Finley (Fermilab)
Steve Geer (Fermilab)
Jim Norem (ANL)
Bob Palmer (BNL)
Petros Rapidis (Fermilab)
Yağmur Torun (IIT)
Mike Zisman (LBNL)

- We have recruited more participants at this meeting

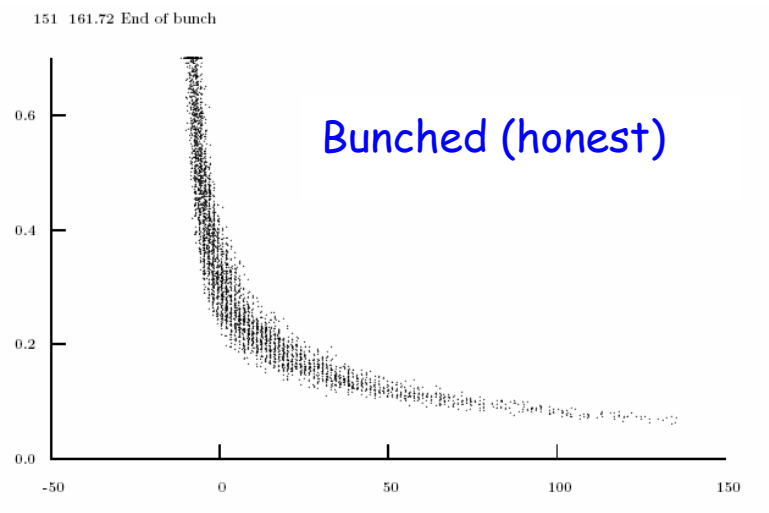
Neutrino Factory Discussion

- Palmer is already hard at work to improve on Study II
  - cost drivers (each ≈25%) are known to be
    - bunching and phase rotation
    - cooling
    - acceleration
- Palmer has begun to look at the first two, with encouraging results
  - phase rotation and bunching
    - applied Neuffer scheme with RF bunching and phase rotation
    - RF ranges from 330 MHz to 201 MHz along channel
      - presently unrealistic smooth variation of RF; need to go to "stepped" scheme with, say 10 steps

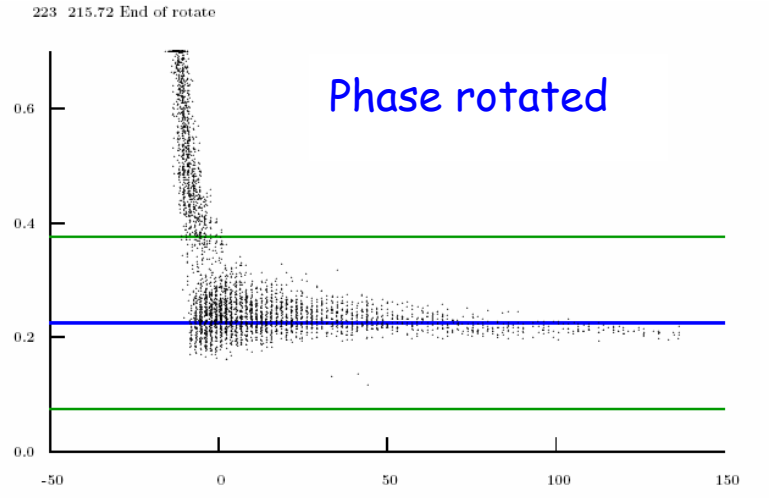
Neutrino Factory Discussion



Unbunched



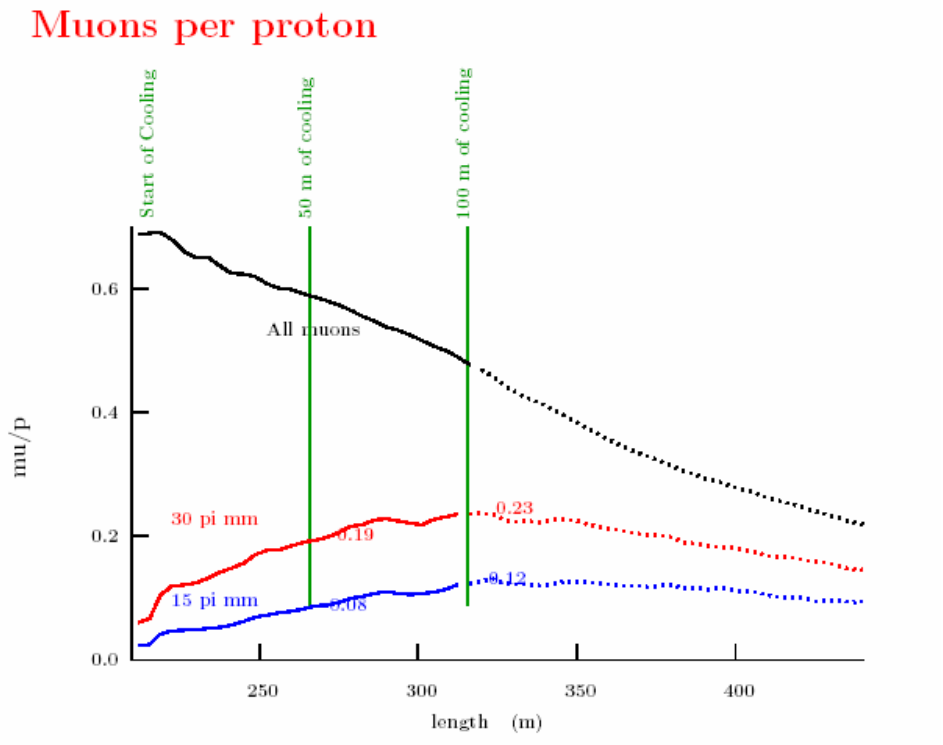
Bunched (honest)



Phase rotated

Neutrino Factory Discussion

- **Bottom line**
  - **can get better performance than Study II with same cooling channel or same performance with shorter channel**



Neutrino Factory Discussion

- Still lots of variables to adjust and optimize
  - need to add some realism to the simulation
    - window thicknesses and materials, etc.
  - need to decide how to handle both μ^- and μ^+
    - is it a blessing or a curse?
- We think it is prudent to focus mainly on "front-end" system, and cover acceleration only as time permits

Neutrino Factory Discussion

- The plan
  - since completion of Study II, MC has done a lot more work on optimizing pieces of a Neutrino Factory
  - we plan to put this all together and see if we are indeed on track for a more cost-optimized design
- In particular, we hope for
  - improvements in collector and decay channel
  - updated phase rotation and bunching system
  - more optimal cooling channel
- If possible, we would like to revisit the preacceleration section, between cooling channel and main accelerating system
  - we think we know how to make acceleration acceptance bigger
  - need to do the same here for it to matter

Neutrino Factory Discussion

- Proposed tasks from Fernow for NF Study 2A
  - baseline configuration
    - decay region
      - fix dB' at start
      - periodic B_s
    - adiabatic buncher
      - periodic B_s
      - discrete frequency implementation
      - RF windows (R=30 cm, G<12 MV/m)
    - phase rotation
      - periodic B_s
      - discrete frequency implementation
      - fix dB' at end
    - matching section
      - RF windows (R=30 cm, G=15.25 MV/m)
      - f = 201.25 MHz
      - coating for LiH?

Neutrino Factory Discussion

- precooler
  - RF windows (R=25 cm, G=15.25 MV/m)
  - f = 201.25 MHz
  - coating for LiH?

— studies of alternatives

- update MARS distribution from target (Nicholai, Harold?, Kevin?)
  - target geometry
  - field over target region
- get new pion collection field profile (Kevin)
- adjust Be window thickness in phase rotation
- design shorter phase rotator (Dave)
- replace LiH with Li, Be, ... in match and precooler
- lower RF gradients
- radius in precooler

— Geant confirmation

- final design only (Amit)

Beta Beams

- Try to assess technical challenges of beta beams
  - production target and ion source to give required intensity
  - space-charge blowup and radiation losses in various rings
  - stacking multiple turns in decay ring without cooling the beam
- Generalizing the scenario to a U.S.-based version would be of interest
  - there is some talk now about higher energy beams having better physics potential
- As noted, for beta beams, we will aspire to modest goals
  - assess progress of CERN design
  - identify and understand outstanding technical issues and time scale for dealing with them
- Recruit experts from nuclear physics facilities or projects, e.g. RIA
  - have a volunteer (Finley) to look into these matters

Summary

- Have a plan how to proceed on Neutrino Factory and Beta Beam study
- Anticipate having one or more "mid-course" in-person meetings
  - next WG meeting scheduled for March 3-4, 2004 at ANL
  - http://www.neutrinooscillation.org/studyaps/neutrinofactoryworkshop.html
  - we may also wish to meet in conjunction with Superbeams group
    - there are technology issues (as well as physics) in common
      - proton driver and target considerations
- We think it is important that the case for continued accelerator R&D in support of the physics program be part of the roadmap
- Succeeding in this endeavor will improve the odds of someday having a powerful neutrino beam...something we can use to do good science!
- For this study, we have a lot to do, and not much time to do it

...let the race begin!