Review of U.S. Neutrino Factory Studies

Michael S. Zisman†
Center for Beam Physics
Lawrence Berkeley National Laboratory

†in consultation with S. Geer and R. Palmer

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Introduction

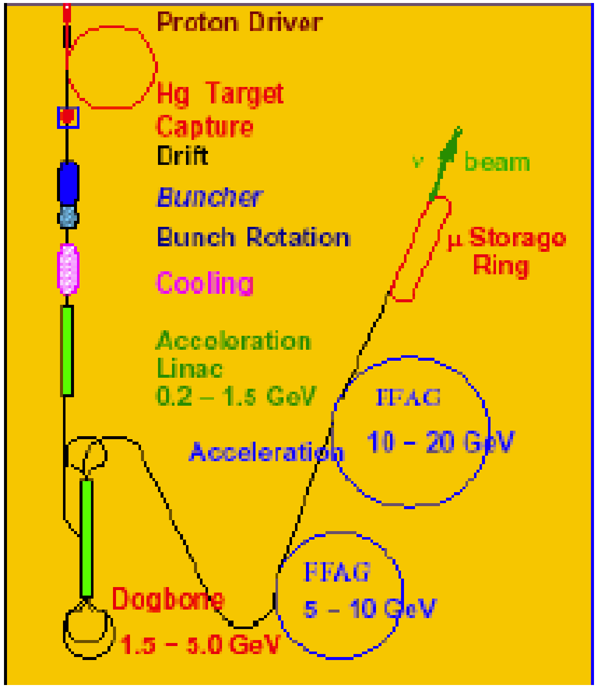
- Neutrino Factory design still evolving worldwide
  - Neutrino Factory and Muon Collider Collaboration (U.S.)
  - Beams for European Neutrino Experiments (Europe)
    - ASTeC/UKNF studies of cooling and acceleration
  - Japanese Neutrino Group (Japan)

- Comments here based on experience from U.S. design studies
  - representative of what might be needed
  - should be taken only as an example

- Scoping Study expected to pin down ingredients and issues more precisely
  - as prelude to subsequent World Design Study

Neutrino Factory Ingredients

- Neutrino Factory comprises these sections
  - Proton Driver
    - primary beam on production target
  - Target, Capture, and Decay
    - create π; decay into μ
  - Bunching and Phase Rotation
    - reduce ΔE of bunch
  - Cooling
    - reduce transverse emittance
  - Acceleration
    - 130 MeV $\rightarrow$ 20–50 GeV
  - Storage Ring
    - store for 500 turns; long straight



Very schematic

Neutrino Factory Study I

- Study I (1999—2000) instigated by Fermilab
  - http://www.fnal.gov/projects/muon_collider/nu/study/report/machine_report/
- Focus on feasibility
  - first attempt to specify NF from end to end
  - approach: base design on (reasonably) well-understood technologies
  - no attempt to optimize either cost or overall performance
- Proper approach at the time, as feasibility was most at issue
- Led to predictable result: feasibility established, performance poor, costs relatively high

Neutrino Factory Study II

- Study II (2000—2001) collaboration of MC, BNL
  - http://www.cap.bnl.gov/mumu/studyii/final_draft/The-Report.pdf
- Goal: maintain convincing feasibility, improve performance substantially
  - optimizing cost again given lower priority
- Result: performance 5x Study I
  - 1.2×10^{20} vs. 2.5×10^{19} ν_e per year (10^7 s) per MW
- Cost about 75% of Study I
  - due to choice of 20 GeV rather than 50 GeV

Lessons Learned

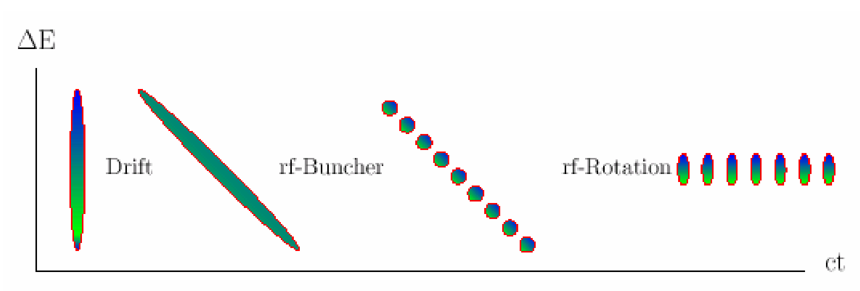
- Do "local" optimizations first
- Work as partners with engineers to converge on buildable design
  - scoping study does need some engineers as "consultants"
- Simulate entire concept before starting detailed engineering (develop self-consistent solution)
  - complete this step by the end of scoping study
- Facility is costly, $\mathcal{O}$(€2B)
  - but, costed in $, so getting cheaper over time!

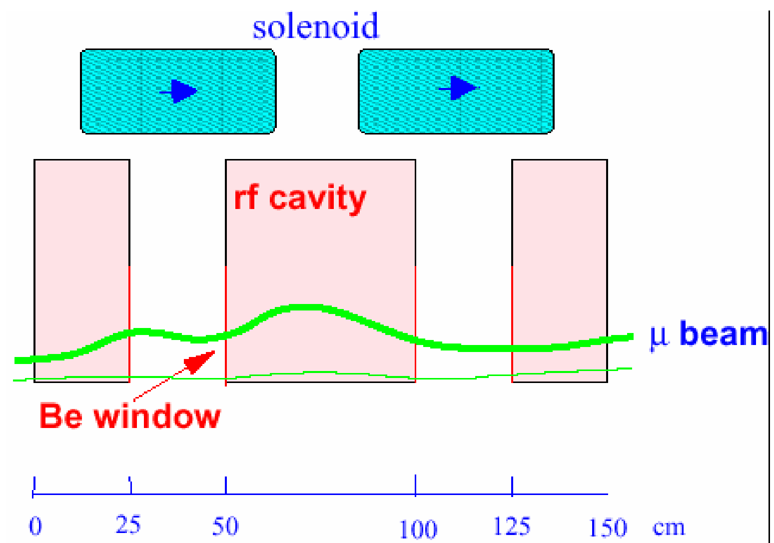
Neutrino Factory Study IIa

- Already studied portions of NF design space representing
  - low performance, high cost
  - high performance, high cost
- Need to study high performance, "optimized" cost
- Previous work gave good idea what to change
  - replace induction linacs with RF bunching and phase rotation
  - replace RLA with FFAG rings
  - examine trade-offs between amount of cooling and downstream acceptance
- Results available at
  - http://www.aps.org/neutrino/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=58766

Buncher and Phase Rotation

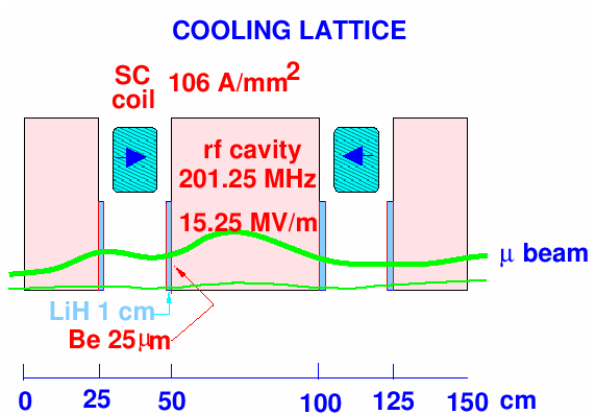
- FS2: induction linacs to phase rotate, rf to bunch
  - worked well, but relatively expensive
    - keeps only one sign muon
- FS2a: rf to bunch, then rf to phase rotate
  - performance less good, but much less expensive
    - keeps both μ^+ and μ^-

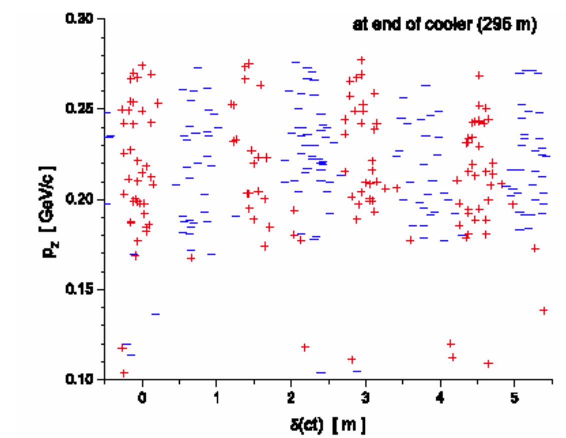


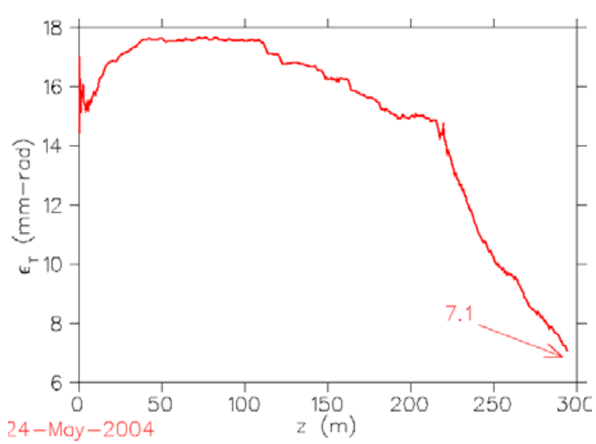


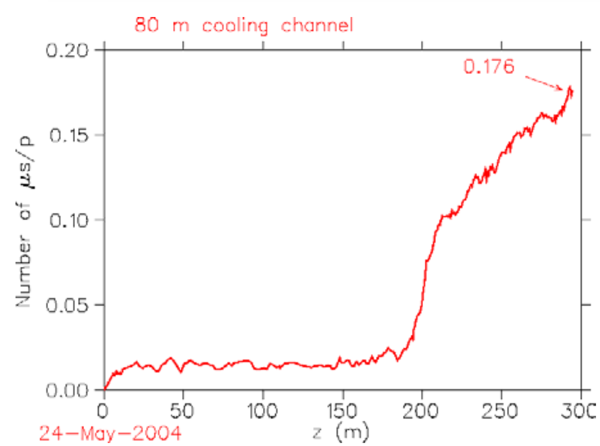
Cooling

- Cooling channel simplified considerably cf. FS2
  - shorter, fewer magnets, fewer rf cavities, simpler absorbers
    - no LH_2; replace with LiH
  - performs as effectively as FS2 channel…for both signs



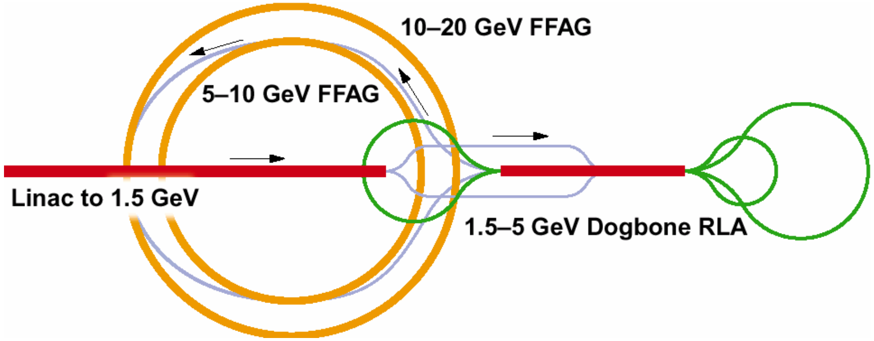


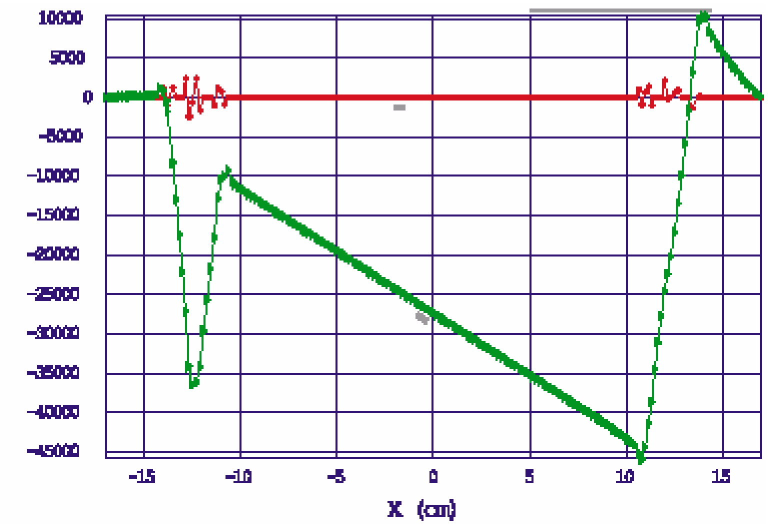


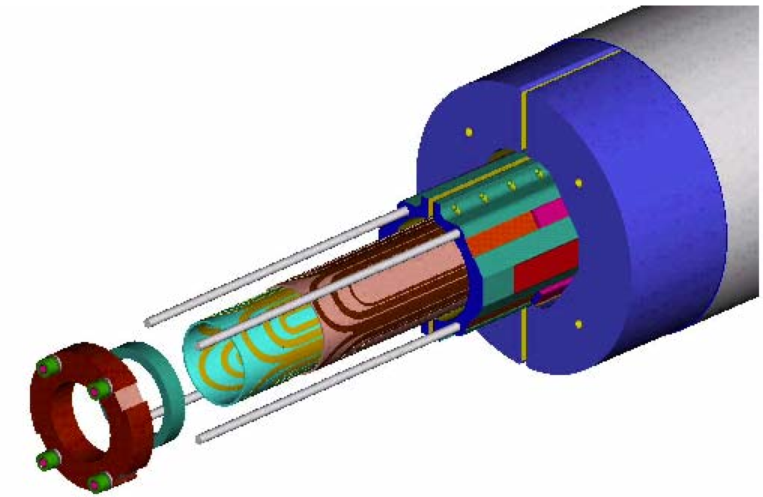


Acceleration

- FFAGs are cost-effective for accelerating muons
  - use eclectic mix of machines to accelerate to 20 GeV
    - linac, dogbone RLA, 2 FFAGs…something for everybody!
  - SC combined-function magnet appears suitable







Study IIa Cost Improvement

- **Compared with Study II, predicted cost reduction in Study IIa was substantial**
  - **we're on the right track!**

	All ($M)	No PD ($M)	No PD & Tgt. ($M)
FS2	1832	1641	1538
FS2a-scaled (%)	67	63	60

Issues to Study (1)

- Development of baseline specifications
  - required proton energy and intensity
    - beam power, pulse structure, repetition rate, beam energy
  - detector parameters
    - size, distance from source, technology(?)
    - trade-offs between neutrino intensity and detector size
  - need for both signs simultaneously
  - final energy of muon beam (cost issue)
  - trade-offs between cooling and downstream acceptance
- Relative costs of proton driver for selected energies (say 4, 20, and 50 GeV)
  - consider both 1 and 4 MW versions
  - practical intensity limit for 1-3 ns bunches at each energy

Issues to Study (2)

- Practical accelerating gradient and cost per GeV at several frequencies (say, 5, 88, 201 MHz)
  - include power sources as well as cavities
- Performance and cost comparison of alternative acceleration systems (linacs, FFAGs, RLAs,…)
  - for several values of acceptance
  - consider both scaling and non-scaling FFAGs
- Commonalities and differences between Superbeam and Neutrino Factory proton driver, target, and capture sections
  - how do we migrate from one to the other?
  - compare capture efficiency of horn and solenoid into fixed downstream acceptance
  - can solenoid (with later sign selection) solution work for both?

Issues to Study (3)

- Storage ring issues have not been looked at carefully in previous U.S. studies
  - do we need multiple baselines simultaneously?
    - triangular ring
  - can multiple signs be alternated between detectors?
    - change magnet polarities periodically
  - or, do we need two storage rings?
    - both beams circulate in same direction but shifted in time relative to each other

- Optical matching to production straight section parameters is non-trivial
  - matching region should be shielded from detector's view

- Instrumentation needs for facility largely ignored to date

Comments on Issues to Study

- Many of the suggested topics require ("top-down") cost evaluation
  - even the initial scoping study will require engineering resources knowledgeable in accelerator and detector design
    - somebody will need to pay for these
- Implications of keeping both signs must be evaluated
  - beam transport, thermal issues, detector issues
- We need to develop tools for end-to-end simulations of alternative facility concepts
  - correlations in the beam and details of the distributions can have significant effect on transmission at the interfaces
    - muons have "memory"

More Comments

- Must ensure common understanding of, and buy-in for, the results
  - best if trade-off studies include those from all regions
- Goal is to examine possibilities to choose the best ones
  - not easily done if each group "defends its own choices"
- Study leadership needs to foster this "mixing"

Summary

- Challenge is to try to reach consensus on a single optimized Neutrino Factory scheme
  - if we can do this ourselves, without requiring an uninvolved panel of "wise persons" to do it for us, we have truly accomplished a lot as an international community
- Even if we don't quite succeed in selecting a single design, whatever convergence we attain will improve the probability of having a future international facility
- Developing optimal design requires an adequately-funded accelerator R&D program
  - we need to articulate this need and define the ingredients of the program