# *Neutrino Factory and Muon Collider Collaboration*

# *($\nu F \mu CC$)*

# *R&D Plans*

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**Fermilab Feasibility Study Meeting**
**February 16, 2000**

# Outline

- Introduction
- Targetry goals and priorities
- MUCOOL goals and priorities
- Simulation goals and priorities
- Other R&D issues
- What I've learned here
- Summary

# Introduction

- Purpose of talk is to summarize R&D planning being done now by $\nu F\mu CC$ Technical Board
  - — also to summarize new items arising from Feasibility Study
- I will indicate present view of where we are and where we're heading
  - — details given here due mainly to leaders of the major R&D activities
    - o targetry (Kirk McDonald); cooling (Steve Geer); simulations (Jonathan Wurtele); RF (John Corlett/Al Moretti)
- Approach: define collective vision of where we want to be 3–5 years from now in all R&D areas
  - — then work backwards to see what's needed to get there (money and effort)
- Scenario should be "aggressive" but not crazy
  - — slow-downs in the plan should be due to inadequate support from DOE and/or Lab management, not our own inertia

# Introduction

- At the end of 3 years
  - — know what we want to build (including decision on polarization)
  - — all optics designs completed and self-consistent
  - — error assessments completed, with acceptable results
- At the end of 5 years
  - — validation experiments completed or well along
  - — know how to build the "hard parts"
    - o prototypes completed or at least designed
  - — ready to begin designing and costing most components

    ⇒ ready to begin CDR in earnest
- If aim for a CDR at the end of our work, it should take ≈2 years
  - — implies "prying loose" significant engineering support early

# Targetry Goals and Priorities

- Goals (5-year)
  - — demonstrate performance of 1-MW target in high-field solenoid
  - — measure pion and neutron yields to benchmark code
  - — demonstrate lifetime of target
  - — demonstrate solenoid survivability in high radiation field
  - — engineering (paper) design of 20-T solenoid
- Priorities and schedule for targetry experiment E951 (approved 10/1/99) are reasonable
  - — Tech Board recommends more study of solid-target performance
    - o mainly a fatigue issue (⇒ many cycles)
- Strategy from Tech Board: first create target test facility at BNL
  - — get initial results from some target (e.g., measure power deposition)

# MUCOOL Goals and Priorities

- Goals (5-year)
  - — define experiment, then complete realistic simulation
    - o assume initial portion of channel (⇒ 201 MHz cavities, big solenoid)
  - — create muon test beam facility at FNAL (requires MUTAC/MCOG buy-in and also Lab support)
  - — demonstrate high-gradient RF cavity in solenoid field and, if possible, in high radiation environment
  - — engineer and demonstrate survivability of absorber
  - — build component prototypes and bench test complete cooling cell
  - — carry out phased experiment demonstrating significant cooling
    - o test one cooling cell (first without, then with RF)
    - o perform proof-of-principle cooling experiment (aim for roughly factor of two emittance reduction)

# MUCOOL Goals and Priorities

- Component development
  - 805 MHz RF
    - high-power pillbox cavity (multipactor; Be performance) [FY00]
    - test solenoid [FY00]
    - high-power open cell cavity (high gradient performance) [FY00]
  - 201 MHz RF
    - high-power cavity suitable for cooling experiment [FY01]
      - three choices: 2-cell $\pi/2$ with Be windows; 2- or 3-cell gridded; 1-cell $\pi$ open cell
      - Be window and gridded cavity need engineering to validate; these are R&D drivers so launch them first [choose June '00]
    - solenoid ($\approx$4 T) [test June '01]
    - high-power tetrode or other power source [Jan '01]

# MUCOOL Goals and Priorities

- prototype absorber
  - $LH_2$ is more advanced
  - LiH alternative design should be studied
- instrumentation (fast timing, TPC, diagnostics,...)
  - specify [FY00]
  - design [FY01]
  - build and test [December '01]
- data analysis
  - simulation and analysis of sample data set, with errors [FY01]
    - need results for initial experiments for MUTAC next summer

# Simulation Goals and Priorities

- Goals (5-year)
  - — have validated simulation tools for all aspects of initial facility
- Front-end
  - — complete solution with/without initial phase rotation [May '00]
    - o optimize in terms of minimum length and/or cell count
    - o estimate degree of polarization in each case
  - — study front-end error sensitivities [December '00]
    - o use analytic tools where applicable
    - o determine realistically delivered phase space
    - o define parameters needing careful monitoring
    - o develop strategy to eliminate particles not surviving the channel
  - — have emittance exchange workshop (fall-back for $\nu F$?) [Summer '00]

# Simulation Goals and Priorities

- Acceleration chain [FY01]
  - — extend "tracking" (ICOOL?) through specified acceleration system
    - o learn to handle large energy spread
    - o determine effects of errors
    - o identify parameters that must be monitored and well controlled
- Storage ring [FY01]
  - — complete design
  - — verify adequate beam dynamics (transverse and longitudinal)
    - o determine effects of errors
    - o identify parameters that must be monitored and well controlled
- Proton driver
  - — study effects that might limit reaching high-intensity [FY00]

# Other R&D Issues

- Front-end
  - — build prototype induction linac + solenoid module [FY01]
- Acceleration [FY01]
  - — design and test low-frequency superconducting RF cavities [FY02]
- Storage ring
  - — identify components needing R&D and/or prototyping, e.g., superconducting magnets [FY02]
- Proton driver
  - — plan for high intensity test(s) [FY02]

# What I've Learned Here

- Below is a summary of what I've learned here (along with a few unsolicited opinions)

  ...is this what you really said?

- To incorporate these ideas into the R&D plan requires additional info

  — schedules/milestones; estimated costs (effort + M&S)

- Most important

  — identify key issues

    - required for feasibility demonstration (credibility)
    - associated with "cost drivers"
      - demonstrate or improve technology

# What I've Learned Here

- Physics study
  - — Firm up strategy for "staging" physics goals
    - o $10^{19} \Rightarrow 2 \times 10^{20}$ decays per year
  - — simple start-up seems good if there's a clear and convincing upgrade path
- Proton driver
  - — improve ability to generate high intensity proton bunches
    - o study microwave instability below transition
    - o space-charge compensation (inductive inserts)
  - — develop high-gradient, low frequency RF system for synchrotron
  - — high-gradient low frequency RF for phase rotation less compelling
    - o maybe needed for polarization; otherwise, I'd maintain focus on induction linac

# What I've Learned Here

- Solid target
  - R&D seems worthwhile and necessary
    - hard issues are radiation damage and fatigue (many cycles)
  - graphite target
    - should be part of Targetry effort
    - model shock and fatigue effects
    - explore geometry and cooling options: NUMI-like; band targets
    - do high intensity single-pulse tests an BNL
    - do failure tests at LANL or elsewhere for a *selected* design

# What I've Learned Here

- MARS code
  - reality check important for credibility of design (Q/C)
    - especially concerning radiation dose to target solenoid
    - and yields
      - ◊ I like figure of merit taken downstream of target
- support facility
  - need complete strawman design to identify lurking R&D issues
  - time interval between target changes needs better definition (weeks or months?)
  - complete target thermal and radiation analyses, including supports and shield
  - identify dangerous failure modes
    - –mitigate with component R&D on selected designs (beam window, Bitter coil,...)

# What I've Learned Here

- target solenoid
  - study radiation hardness
  - study Bitter coil lifetime
  - revisit reliability budget (is it too loose?; does it include power supply?)

- Precooling channel design
  - verify design calculations with (Collaboration) standard code
    - need to incorporate into integrated front-end simulation
    - need others to be able to modify design
  - finalize induction linac parameters as part of integrated front-end simulation

# What I've Learned Here

- Induction linac engineering
  - complete design
  - test Finemet core
  - test SCR switch
  - test single cell, complete with solenoid
  - test prototype pulser system
- Buncher
  - optimize buncher-to-cooling channel transition (should not be "explosion bonded"!)
  - investigate effects of improved $\Delta E$ from induction linac
  - develop emittance exchange techniques; later incorporate into design if practical and beneficial
    - evaluate as part of full 6D front-end simulation

# What I've Learned Here

- Front-end simulations
  - — improve performance of integrated front-end simulation
    - o iterate on coil design to reduce field on coil
      - – verify with magnet designers
    - o adopt 201 Mhz RF for coil dimensions
    - o improve matching between bunching and cooling sections (yes, again)
    - o iterate on absorber window parameters with absorber group
    - o compare Be foil and gridded cavities
  - — examine error sensitivity

# What I've Learned Here

- Absorbers
  - complete thermal design
  - decide on containment windows
    - need to validate AlBeMet option
  - fabricate and test system with beam
- RF power
  - evaluate options (klystron, multi-beam klystron, inductive output tube, tetrode) at 201 MHz
  - design, procure, test most promising option(s) with eye toward mass production
  - evaluate efficacy of water temperature tuning
    - is it fast enough?
    - do we need to control individual RF cells?

# What I've Learned Here

- RF cavity
  - — check effect of grids on scattering
  - — verify fabrication methods with high-power test cavity
  - — optimize bore size
- Front-end solenoids
  - — check stresses of realistic designs, considering the large coil radius

# What I've Learned Here

- Acceleration
  - — study radiation effects on hardware (RF, magnets, diagnostics)
  - — verify number of passes in RLA2
  - — study/refine spreader/combiner concept, including magnet designs
  - — do multi-particle studies (do we need HOM dampers?)
  - — are sextupoles needed?
  - — finalize a lattice for each RLA
  - — determine proper RF frequencies for each stage

# What I've Learned Here

- Superconducting RF
  - demonstrate 200 MHz SCRF at 15 MV/m
    - high-power couplers need study
  - study microphonics and detuning issues with pulsed RF
  - learn how to build and process big cavities
    - long lead time, and costly also
  - decide on optimum filling strategy

# What I've Learned Here

- Lattices and rings
  - still look complicated and inflexible (can this be improved?)
  - need definition of diagnostics (harsh environment)
    - is there any room in lattice for "utility straights"
    - things *do* get added later
  - RLA splitter magnets look complicated; can this be done more simply
  - verify pulsed magnet designs; they're always harder than they look
    - reliability is an issue
  - curved dipole should be demonstrated, with adequate field quality
  - do we need to worry about worst-case point beam loss in ring?

# Summary

- Collaboration now revising R&D plans for updated initial goal of $\nu F$
  - — reorientation results in modified priorities
    - still includes R&D activities aimed at a Muon Collider
  - — important to coordinate with other interested groups (CERN, Japan) to avoid duplication
- We must get long lead time items under way
  - — target test facility at BNL is proceeding now
  - — muon beam test facility at FNAL is presently stalled
    - need MUTAC approval soon
  - — new high-power RF sources will also be a pacing item in getting ready for MUCOOL experiment and the CDR stage that follows it
- Need aggressive program of component development
- Design verification: simulate <u>all</u> pieces linked and all errors included