Muon Collaboration Status

124 Scientists & Engineers from 33 Institutions

Co-spokespeople: Steve Geer & Bob Palmer
Project Manager: Mike Zisman

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124 Scientists & Engineers from 33 Institutions

6 US Labs

ANL
BNL
FNAL
LBNL
Oak Ridge Nat. Lab.
Thomas Jefferson Lab.

16 US Universities

Columbia Univ.
Cornell Univ.
IIT
Indiana Univ.
Michigan State Univ.
NIU
Northwestern Univ.
Princeton Univ.
UC-Berkeley
UC-Davis
UCLA
Univ. Chicago
U. Illinois, Urbana-Champaign
Univ. of Iowa
Univ. Mississippi
Univ. Wisconsin

11 Foreign Institutes

CERN
DESY
JINR, Dubna
Karlsruhe
KEK
Kernfysisch Versneller Instit.
Osaka Univ.
Oxford Univ.
Pohang Univ.
RAL
Tel Aviv Univ.

Collaboration Goals

The collaboration is governed by a charter which defines its goals and organization. The goals are defined :-

"To study and develop the theoretical tools and the software simulation tools, and to carry out R&D on the unique hardware, required for the design of Neutrino Factories and Muon Colliders."

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HEPAP Subpanel Recommendation

Accelerator R&D

"We give such high priority to accelerator R&D because it is absolutely critical to the future of our field. ... As particle physics becomes increasingly international, it is imperative that the United States participates broadly in the global R&D program."

Neutrino Factory & Muon Collider R&D

"We support the decision to concentrate on intense neutrino sources, and recommend continued R&D near the present level of 8M$ per year. This level of support is well below what is required to make an aggressive attack on all of the technological problems on the path to a neutrino factory."

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Physics Evolution

1. At the time of the HEPAP sub-panel presentations the scenario yielding the weakest case for a Neutrino Factory was the one in which only the atmospheric ν deficit was due to flavor transitions → simple 2-flavor oscillations. The recent SNO results have have removed this scenario (since solar ν deficit is also due to flavor transitions) .

2. It is believed that the strongest case for a Neutrino Factory can be made for those scenarios in which the LMA solution describes the solar neutrino deficit → chance to observe CP violation in the lepton sector. The LMA solution is currently favored.

3. Preference for the LMA solution has focused attention on theoretical (GUT) models that can tolerate LMA. There are now a handful of these models that make explicit predictions for the oscillation parameters, & illustrate the importance of measuring $\sin^2 2\theta_{13}$, δ_{CP}, $\mathrm{sgn}[\Delta m_{32}^2]$ … just the parameters that a Neutrino Factory can probe.

Impact of correlations and degeneracies - 1

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If the LMA solution is confirmed, and the $\nu_\mu \rightarrow \nu_e$ oscillation amplitude parameter θ_{13} is large enough for a high-performance Superbeam to see a signal, then the dependence of $P(\nu_\mu \rightarrow \nu_e)$ on the ν mixing parameters is complicated.

$$
\begin{aligned}
P(\nu_e \to \nu_\mu) \approx\ & \sin^2 2\theta_{13} \sin^2 \theta_{23} \frac{\sin^2((1-\hat{A})\Delta)}{(1-\hat{A})^2} \\
& \pm \sin \delta_{CP}\ \alpha \sin 2\theta_{12} \cos \theta_{13} \sin 2\theta_{13} \sin 2\theta_{23} \sin(\Delta) \frac{\sin(\hat{A}\Delta) \sin((1-\hat{A})\Delta)}{\hat{A}(1-\hat{A})} \\
& + \cos \delta_{CP}\, \alpha \sin 2\theta_{12} \cos \theta_{13} \sin 2\theta_{13} \sin 2\theta_{23} \cos(\Delta) \frac{\sin(\hat{A}\Delta) \sin((1-\hat{A})\Delta)}{\hat{A}(1-\hat{A})} \\
& + \alpha^2 \sin^2 2\theta_{12} \cos^2 \theta_{23} \frac{\sin^2(\hat{A}\Delta)}{\hat{A}^2}
\end{aligned}
$$

Fits prone to correlations between the parameters & to degenerate (false) solutions

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Impact of correlations and degeneracies - 2

Several groups have now made detailed studies. Conclusions are sensitive to Δm_{21}^2 … and will need to be revisited when we have KamLAND results.

The studies suggest Superbeams & Neutrino Factories are complementary. Both are needed.

i) If $\sin^2 2\theta_{13}$ close to the current limit ν Superbeams might yield a few σ signal for maximal CP violation (CPV), but will not be able to precisely measure δ_{CP}. A Neutrino Factory would be needed to confirm CPV, precisely measure all of the parameters, & hence discriminate between contending theoretical (GUT ?) models.

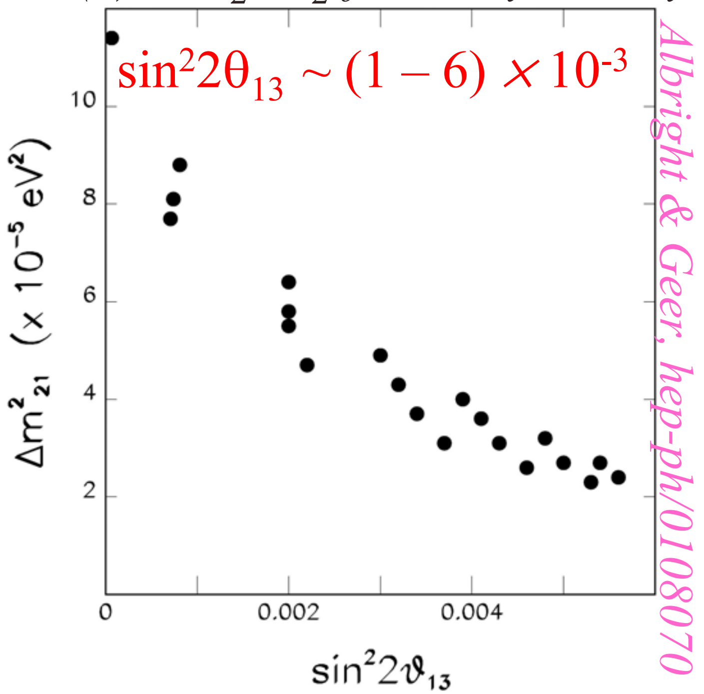
ii) If $\sin^2 2\theta_{13}$ is large enough to see a $\nu_\mu \rightarrow \nu_e$ signal at a Superbeam, but too small to search for CPV, a Neutrino Factory will be sensitive to maximal CPV over the full parameter space, and precisely measure all the parameters ($\sin^2 2\theta_{13}$, δ_{CP}, sgn[Δm^2]).

iii) If no $\nu_\mu \rightarrow \nu_e$ signal seen at a Superbeam, a Neutrino Factory would improve the $\sin^2 2\theta_{13}$ sensitivity by $\times$ O(100), & for a significant region of parameter space be able to observe CPV and measure all of the parameters ($\sin^2 2\theta_{13}$, δ_{CP}, sgn[Δm_{32}^2]).

GUT predictions … an aside:

GUT predictions are all over the map → measurements/constraints can reject models !
If Superbeam experiments tell us that $\sin^2 2\theta_{13} < 10^{-2}$-$10^{-3}$ we should keep on searching !

Model 4: *SO(10) with*
$U(1) \times Z_2 \times Z_2$ flavor symmetry



Model 1 : *Naturalness* $\sin^2 2\theta_{13} > m_2 / m_3 \sim 0.01$

Model 2: *Phenomenological Model for charged lepton mass matrix; Bi & Dai, hep-ph/0204317*
$\sin^2 2\theta_{13} \sim 10^{-4}$

Model 3: *L_e-L_μ-L_τ symmetry broken by Planck-scale effects; Babu & Mohapatra, hep-ph/0201176*
$\sin^2 2\theta_{13} \sim 10^{-3}$

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Technical Progress

Since our presentations to the HEPAP sub-panel last year we have had our annual external technical review by the Muon Technical Advisory Committee (MUTAC).

The MUTAC report (Spring 02) was very positive. The MUTAC report received a strong letter of transmittal from our oversight group (MCOG = representatives from BNL, LBNL & FNAL Directorates):

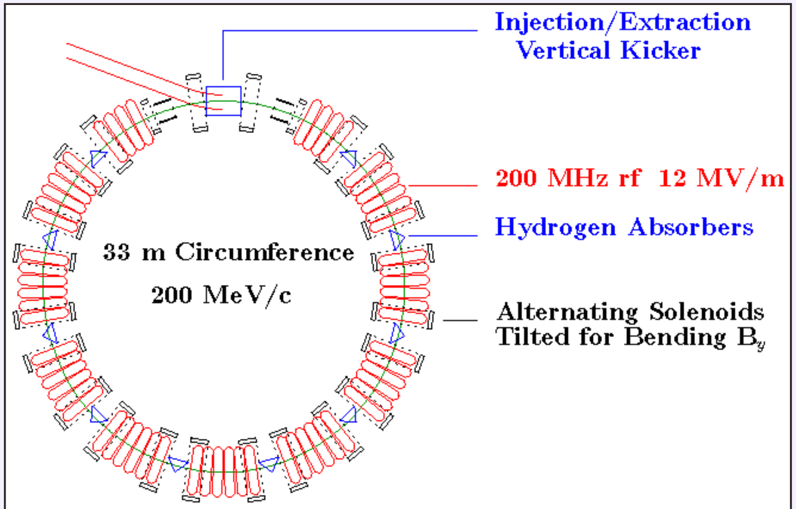
> " *The impressive record of progress is epitomized by the summary judgment of the report, namely, that*
> *The committee finds the progress since last year excellent.* "

Technical Progress – Design - 1

Recent simulation has activity focused on reducing Neutrino Factory cost

At the time of the sub-panel presentations the cost estimate was dominated by three sub-systems: (i) Phase Rotation, (ii) Cooling Channel, (iii) Acceleration.

Cooling Channel Progress:



Linear transverse cooling system → Cooling Ring (cools both Transverse & Longitudinal Emittances)

Reduces 6D Emitt. ~160 c.f. 15 for linear channel.

Hardware similar to linear channel, but many hardware questions to be addressed.

Circumference 33 m (c.f. 108 m linear channel)
→ cost could be cheaper by a factor of two ?

Technical Progress – Design - 2

Progress with Phase Rotation:

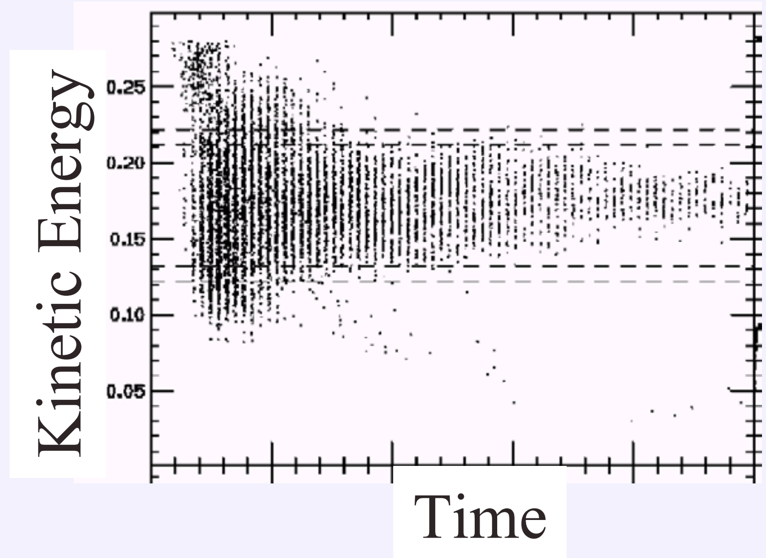
Induction Linac replaced with RF system

-- Performance Similar to Induction Linac

-- Total Length 168 m (c.f. 260 m)

-- 68 m of 200 MHz RF
(c.f. 260 m 1MV/m Induction Linac)

-- Cost Guesstimate < 1/2



Progress with Acceleration:

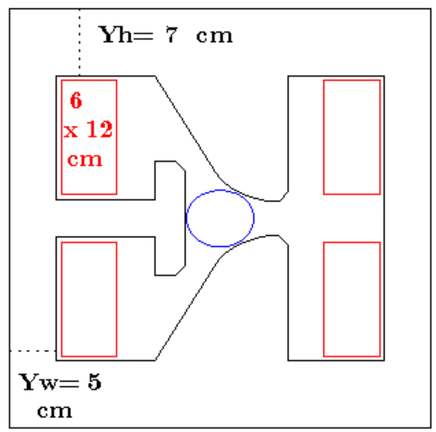
Replace RLA

Two possibly cheaper options

FFAG

-- Single Arcs (vs. 4 in RLA)
-- Less RF
-- 3 design concepts under study
-- Workshop this & last week

Yoke: 45 x 44 cm



Pulsed Synchrotron

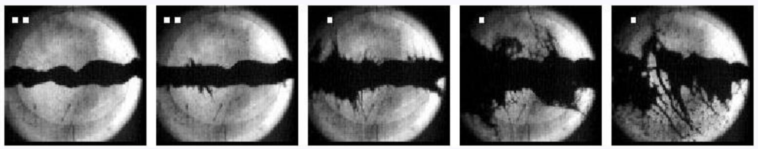
-- Single Arcs (vs. 4 in RLA)
-- Alternating Gradient Design
-- Small Magnet
-- 1/3 RF because more turns

Technical Progress - Hardware

Targetry

Need target that can handle 4MW proton beam

Carbon-rod & Hg-jet targets studied at BNL →
-- Hg jet preferred because:
x 2 pion yield
May survive 4 MW proton beam



t = 0 0.75 ms 2 ms 7 ms 18 ms

-- Jet (2 m/s) remains intact for beam spill
-- Fragments have small velocities

BUT WE NEED TO:

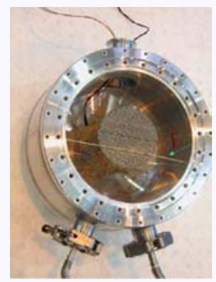
-- develop & test 20m/s jet
-- test in higher intensity (x 4) AGS beam
(needs AGS running in FY04)
-- test in high-field solenoid + beam.

Ionization Cooling

Cooling channel components are demanding:
-- Liq. H2 absorbers with thin windows
-- 16 MV/m 200 MHz RF in multi-Tesla field

PROGRESS:

-- Absorber designed
-- Thin windows tested
-- 5T solenoid for RF test built
-- Two 805 MHz cavities built
-- 34 MV/m achieved at 805 MHz
-- RF tests in magnetic field →
large dark currents&breakdown



BUT WE NEED

-- Test area (back from bid)
-- Absorber tests
-- 200 MHz cavity (designed)
-- magnet for 200 MHz test

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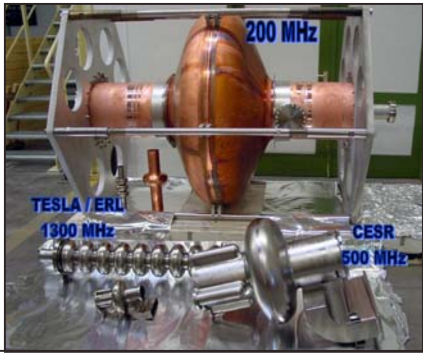
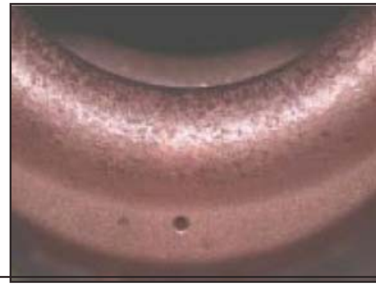
Hardware Activities



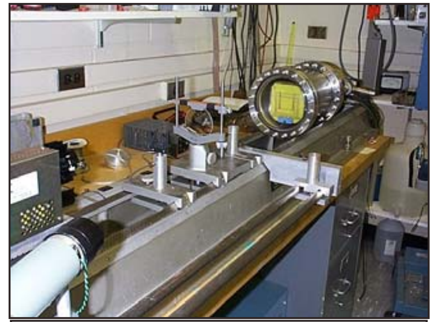
200 MHz SCRF Cavity for Acceleration – Cornell

High-Gradient RF Tests in High Magnetic Field – FNAL



Studied Iris damage in 805 MHz cavity within multi-Tesla magnet

5T Cooling Channel Solenoid – LBNL & Open Cell NCRF Cavityoperated at Lab G – FNAL



Bolometer detectors for Window Beam profile Measurements – U. Chicago

Thin absorber windows Tested – new technique – ICAR Universities

Tested Be-Windows for RF Cavities – LBNL

Liq.H Absorber – KEK To be tested at FNAL

International Cooling Experiment

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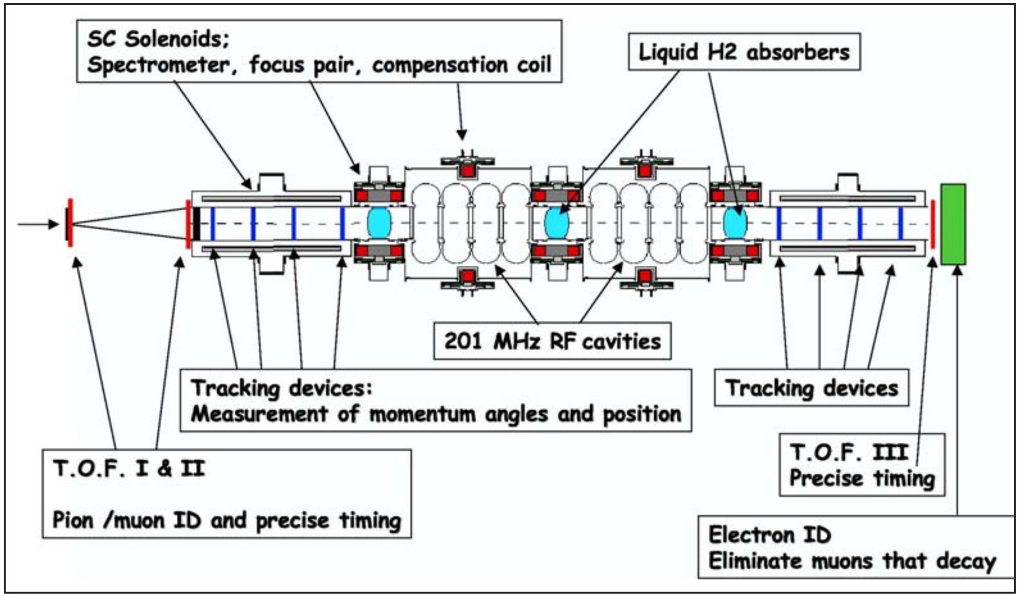
Our external technical review committee said that: *"The cooling demonstration is the key systems test for a Neutrino Factory "*



Strong international collaboration has been assembled to propose a muon cooling experiment.

LoI submitted to RAL early 2002 had a favorable review, & we have been invited to (and will) submit a full proposal by the end of the year.

RAL has assembled a project team to help.

We have a strong international team, a good experimental design, & a laboratory interested in hosting the experiment. Now is the time to move ahead.

We have submitted a proposal to NSF for support for the cooling experiment
→ future HEPAP presentation ?

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Funding History

The Collaboration is supported by direct DOE & NSF funds & by support through the BNL, FNAL, & LBNL base programs.

Since the HEPAP sub-panel presentations the direct DOE support has been cut by a factor of 3.4. The total annual DOE support has been reduced from 8 M$ to 3.5 M$

Also support from NSF at ~ 1M$/ year for 3 years (we are in year 2).

The present level of funding is insufficient to sustain the minimum basic hardware activity needed to keep the design & simulation efforts in contact with reality.

Year	DOE-base ($M)	DOE-MC ($M)	TOTAL ($M)
FY99	2.8	2.2	5.0
FY00	3.3	4.7	8.0
FY01	3.0	3.2	6.2
FY02	3.0	2.8	5.8
FY03[a]	2.1	1.4	3.5

Appeal to HEPAP

1. The sub-panel noted in their report that it is possible there will be no onshore linear collider. In this case, as an example of a viable scenario for the U.S., the panel suggest *"A major new neutrino facility in the US with significant international participation."* **(i.e. there needs to be Plan B, & a Neutrino Factory might be its cornerstone).**
2. MC is a grass-roots collaboration funded directly from DOE & NSF→ New model for accelerator R&D involving accelerator & particle, Laboratory & University physicists.
3. However, because the MC R&D is a broad-based grass roots activity, & not based predominantly at a single Lab, no Lab director is fighting for a neutrino factory, & we do not get significant exposure in any DOE program review.
4. The sub-panel recommended a funding level that, although less than we wanted, would keep Neutrino Factory & Muon Collider R&D healthy, enabling design studies & sufficient hardware activity to keep the design work in touch with reality.
5. Our funding has been severely cut in FY02 and in FY03, & is now far below that envisioned by the sub-panel. The minimum hardware activity needed to inform our design & simulation work is at risk.

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Summary

1. The MC is a grass-roots collaboration funded directly from the DOE & NSF.

2. This model for doing accelerator R&D is succeeding.

3. Since the sub-panel presentations we have:
   (i) Had an excellent external technical review
   (ii) Built a strong international collaboration for a cooling experiment
   (iii) Made substantial design progress that may lead to significantly reduced Neutrino Factory cost.

4. Recent developments in neutrino oscillation physics
   -- SNO results
   -- Detailed studies of the impact of correlations & degeneracies
   -- Explicit GUT model predictions that can accommodate LMA

   add to our enthusiasm.