Neutrino Factory
Physics and R&D Status

Muon Collaboration

1. Motivation: Neutrino Oscillations
2. Physics Reach
3. R&D

Steve Geer

BNL April 2004

Neutrino Oscillations are Exciting

Stunning experimental results have established that neutrinos have nonzero masses and mixings

The Standard Model cannot accommodate neutrino mass terms, which require either the existence of right-handed neutrinos → Dirac mass terms, or a violation of lepton number conservation → Majorana mass terms.

Hence the Standard Model is broken, but we don’t know how it is broken.

We know that neutrino masses and mass splittings are tiny compared to the masses of any of the other fundamental fermions. This suggests radically new physics, which perhaps originates at the GUT or Planck Scale, or indicates the existence of new spatial dimensions.

Whatever the origin of the observed neutrino masses & mixings is, it will certainly require a profound extension to our picture of the physical world.

Neutrino Mixing - 1

Within the framework of 3-flavor mixing, the 3 known flavor eigenstates (ν_e, ν_μ, ν_τ) are related to 3 neutrino mass eigenstates (ν_1, ν_2, ν_3) :

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \left(3\times 3\right)\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

We know that U_{MNS} is very different from the CKM Matrix

$$\begin{pmatrix}\text{large} & \text{large} & \text{small/tiny ?}\\ \text{large} & \text{large} & \text{large}\\ \text{large} & \text{large} & \text{large}\end{pmatrix} \qquad \begin{pmatrix}\sim 1 & \text{small} & \text{tiny}\\ \text{small} & \sim 1 & \text{tiny}\\ \text{tiny} & \text{tiny} & \sim 1\end{pmatrix}$$

Neutrino Mixing - 2

In analogy with the CKM matrix, U_{MNS} can be parameterized using 3 mixing angles (θ_{12} , θ_{23} , θ_{13}) and one complex phase (δ) :

$$\begin{pmatrix} C_{12}C_{23} & S_{12}C_{13} & S_{13}\,e^{-i\delta} \\ \begin{matrix} -S_{12}C_{23} \\ -C_{12}S_{23}\,S_{13}\,e^{i\delta} \end{matrix} & \begin{matrix} C_{12}C_{23} \\ -S_{12}C_{23}\,S_{13}\,e^{i\delta} \end{matrix} & S_{23}C_{13} \\ \begin{matrix} S_{12}S_{23} \\ -C_{12}C_{23}\,S_{13}\,e^{i\delta} \end{matrix} & \begin{matrix} -C_{12}S_{23} \\ -S_{12}C_{23}\,S_{13}\,e^{i\delta} \end{matrix} & C_{23}C_{13} \end{pmatrix}$$

Neutrino Physics: First Round of Questions

Are there only three neutrino flavors, or do light sterile neutrinos exist? Are there any other deviations from three-flavor mixing?

There is one unmeasured angle (θ_{13}) in the mixing matrix. Is θ_{13} non-zero?

We don't know the mass-ordering of the neutrino mass eigenstates. There are two possibilities, the so-called "normal" hierarchy or the "inverted" hierarchy. Which mass hierarchy applies?

There is one complex phase (δ) in the mixing matrix accessible to ν oscillation measurements. If θ_{13} & $\sin\delta$ are non-zero there will be CP Violation in the ν-sector. Is there CP Violation in the Neutrino Sector ?

What precisely are the values of the neutrino masses? Are ν masses generated by Majorana mass terms, Dirac mass terms, or both?

The Importance of Neutrino Oscillations

The answers to these questions will guide our understanding of what lies beyond the Standard Model, and whether the new physics provides:

1. An explanation for the baryon asymmetry of the Universe (via leptogenesis)

2. Deep insight into the connection between quark and lepton properties (via Grand Unified Theories)

3. An understanding of one of the most profound questions in physics: Why are there three generations of quarks and leptons?

In addition, the answers may well further challenge our picture of the physical world, and will certainly have important implications for our understanding of cosmology and the evolution of the early Universe.

Neutrino Factory R&D

1. To address the first round of neutrino oscillation questions we certainly need high-intensity conventional neutrino beams (superbeams) and very massive detectors.

2. Superbeams may not be enough … but they will open the way to a new tool that can offer tremendous statistical and systematic precision and flexibility if needed … the Neutrino Factory.

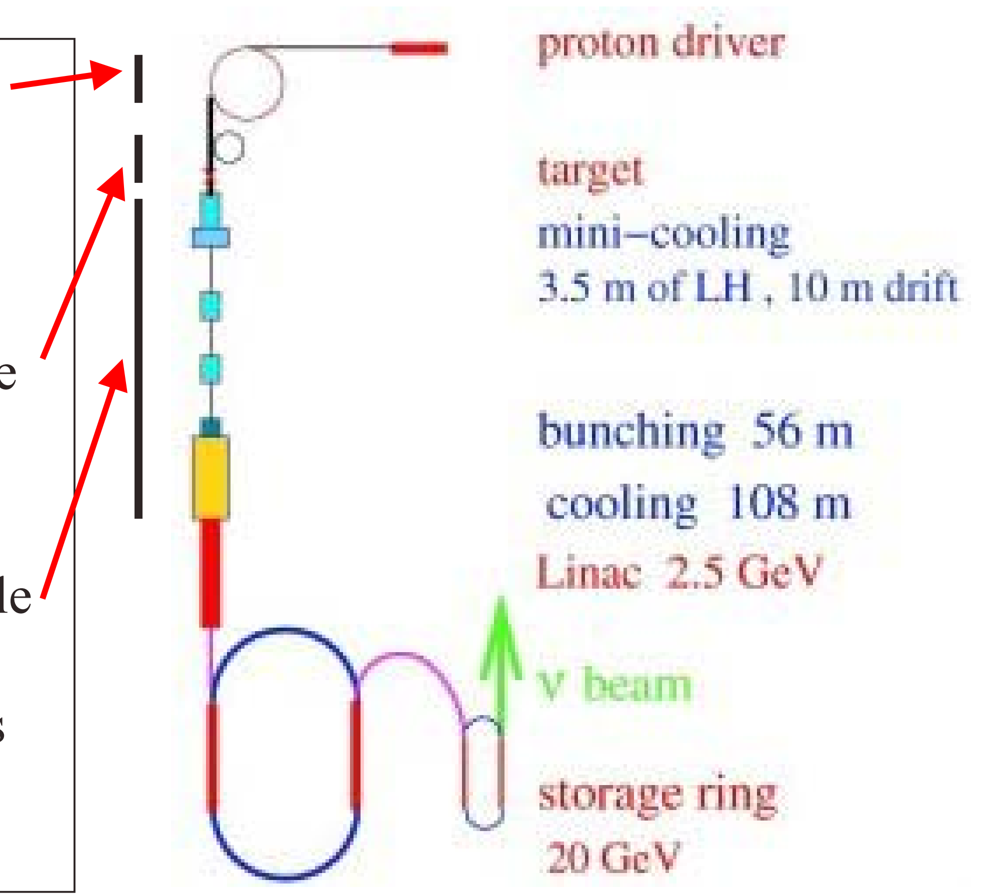
3. For this reason Neutrino Factory R&D is being pursued in the US, Europe, and Japan, and is a part of the current global neutrino program.

Neutrino Factory Concept

1. Make as many charged pions as possible
   → INTENSE PROTON SOURCE
   (In practice this seems to mean one with a beam power of one or a few MW)

2. Capture as many charged pions as possible
   → Low energy pions
   → Good pion capture scheme

3. Capture as many daughter muons as possible within an accelerator
   → Reduce phase-space occupied by the μs
   → Muon cooling – needs to be fast otherwise the muons decay



Beam Properties at a Neutrino Factory

$$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu \rightarrow 50\%\ \nu_e\ ,\ 50\%\ \bar{\nu}_\mu$$

$$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu \rightarrow 50\%\ \bar{\nu}_e\ ,\ 50\%\ \nu_\mu$$

Decay kinematics well known → minimal systematic uncertainties in:

1. Spectrum
2. Flux
3. Comparison of neutrino with antineutrino results

… but, most important, there are ν_e as well as ν_μ in the initial beam.

Electron Neutrinos & Wrong-Sign Muons

The primary motivation for interest in neutrino factories is that they provide electron neutrinos (antineutrinos) in addition to muon anti-neutrinos (neutrinos). This enables a sensitive search for $\nu_e \rightarrow \nu_\mu$ oscillations.

$$\begin{tikzcd}
\mu^+ \arrow[r] & e^+ & \nu_e \arrow[d] & \bar{\nu}_\mu \arrow[r, Rightarrow, "CC"] & \mu^+ \\
 & & \nu_\mu \arrow[r, Rightarrow, "CC"'] & \mu^- &
\end{tikzcd}$$

$\nu_e \rightarrow \nu_\mu$ oscillations at a neutrino factory result in the appearance of a "wrong-sign" muon … one with opposite charge to those stored in the ring:

Backgrounds to the detection of a wrong-sign muon are expected to be at the 10^{-4} level ⇒ background-free $\nu_e \rightarrow \nu_\mu$ oscillations with amplitudes as small as $O(10^{-4})$ can be measured !

Signal and Background

Note: backgrounds for $\nu_e \rightarrow \nu_\mu$ measurements (wrong-sign muon appearance) are much easier to suppress than backgrounds to $\nu_\mu \rightarrow \nu_e$ measurements (electron appearance).

Many groups have calculated signal & background rates. Recent example
Hubner, Lindner & Winter; hep-ph/0204352

JPARC-SK: Beam = 0.75 MW, $M_{fid} = 22.5$ kt, $T = 5$ yrs
JPARC-HK: Beam = 4 MW, $M_{fid} = 1000$ kt, $T = 8$ yrs
NUFACT: Beam = 2.6×10^{20} decays/yr, $M_{fid} = 100$ kt, $T = 8$ yrs

$\Delta m_{32}^2 = 0.003\ \mathrm{eV}^2$, $\Delta m_{21}^2 = 3.7\times10^{-5}\ \mathrm{eV}^2$, $\sin^2 2\theta_{23} = 1$, $\sin^2 2\theta_{13} = 0.1$, $\sin^2 2\theta_{12} = 0.8$, $\delta = 0$

	Superbeams		Neutrino Factory
	JPARC-SK	JPARC-HK	
Signal	140	13000	65000
Background	23	2200	180
S/B	6		360

Correlations & Ambiguities

LMA solar solution is confirmed. Extracting precise & unambiguous values for all of the three-flavor oscillation parameters (Δm_{32}^2, Δm_{21}^2, $\sin^2 2\theta_{23}$, $\sin^2 2\theta_{13}$, $\sin^2 2\theta_{12}$, $\delta = 0$) will be challenging :

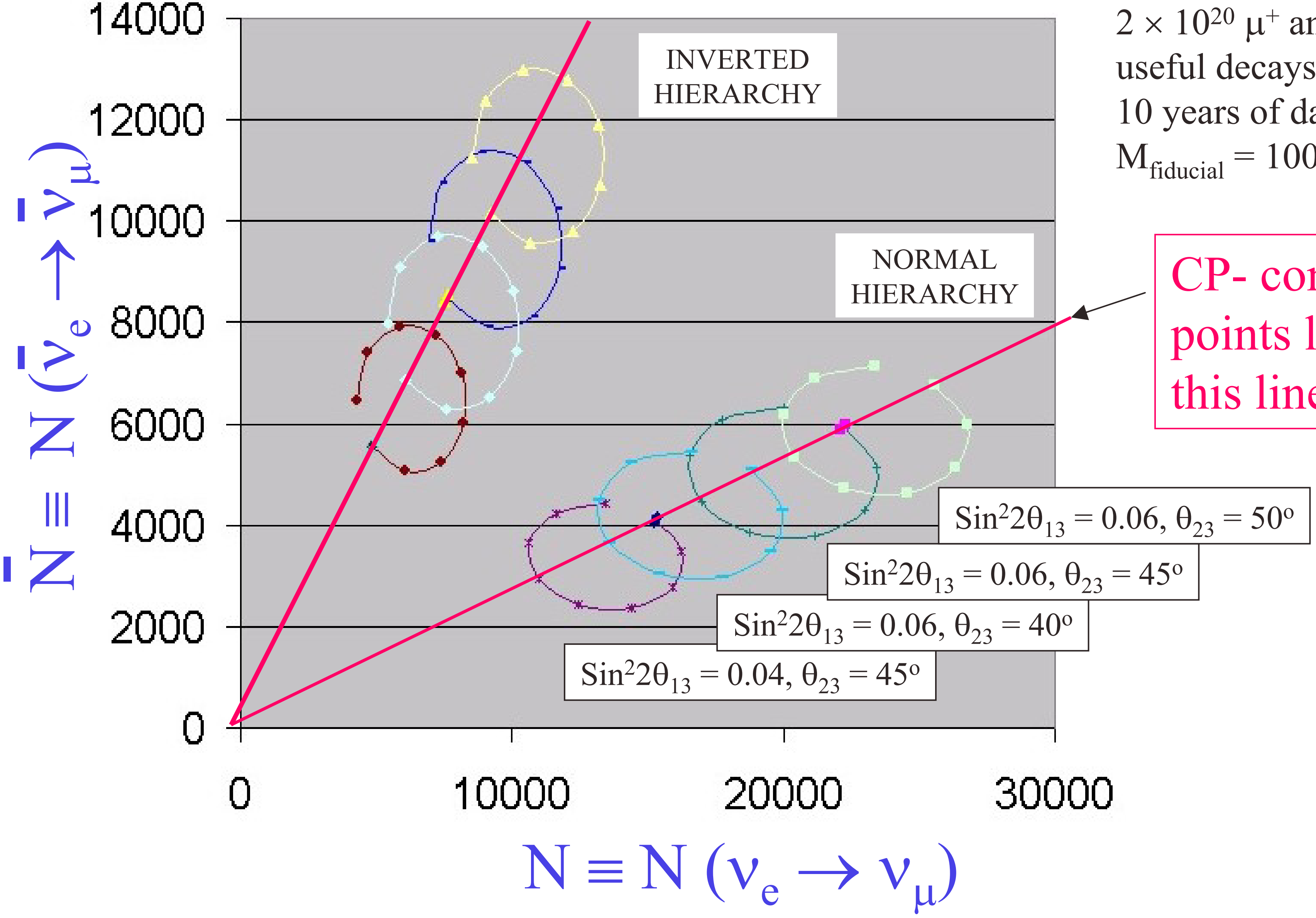
Expansion in powers of $\alpha = \Delta m^2_{21}/\Delta m^2_{31}$ & sinq13; $\Delta = \Delta m^2_{31} L/4E$

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

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

Dependence on θ_{13}, θ_{23}, δ_{CP} and $\mathrm{sgn}(\Delta m^2)$

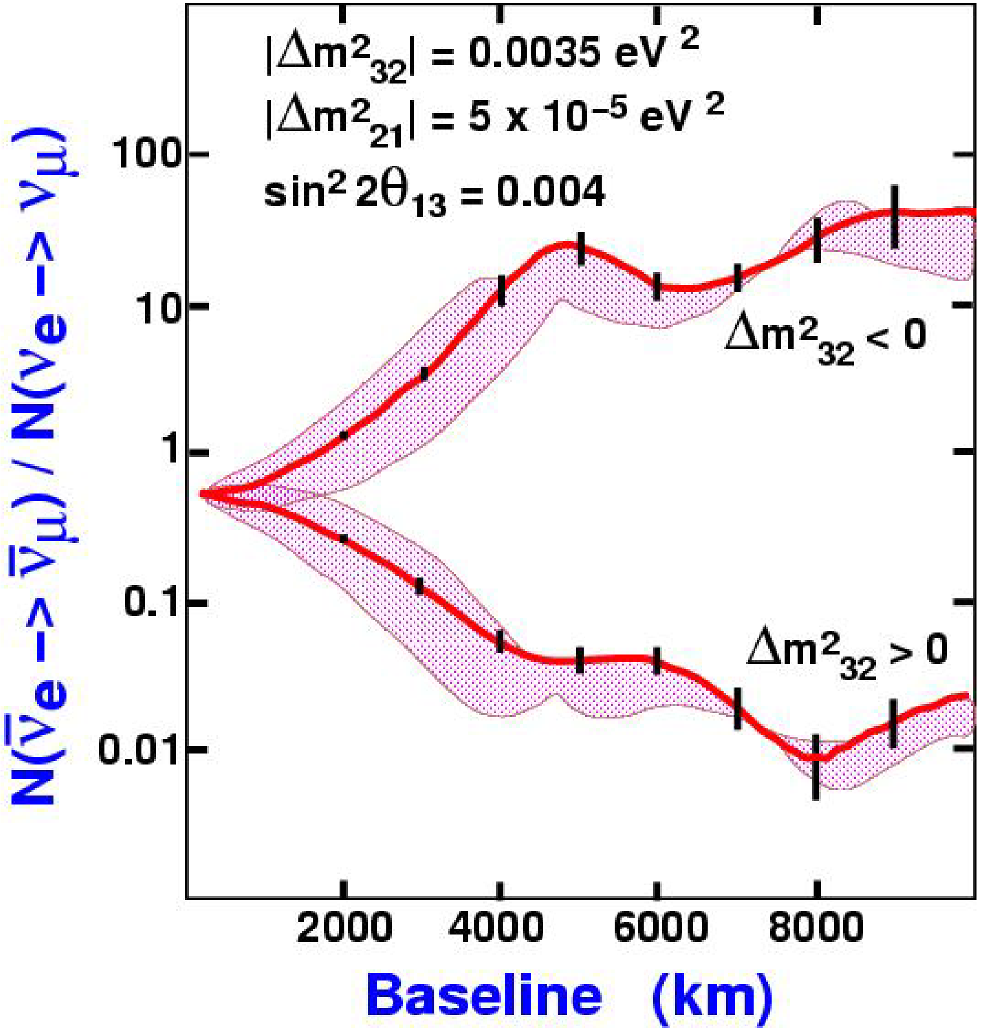
$E = 16$ GeV, $L = 2000$ km
2×10^{20} μ^+ and 2×10^{20} μ^-
useful decays / year
10 years of data taking
$M_{fiducial} = 100$ kt



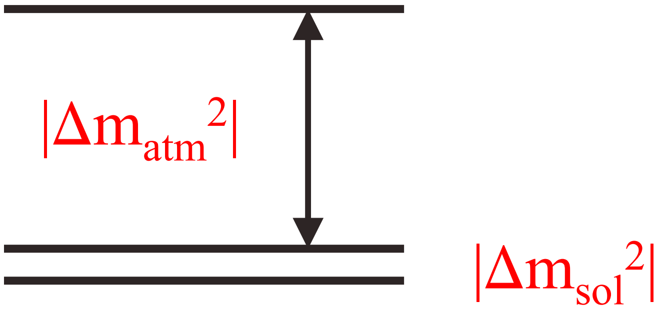
CP- conserving points lie on this line

CP-Violation & the pattern on neutrino masses

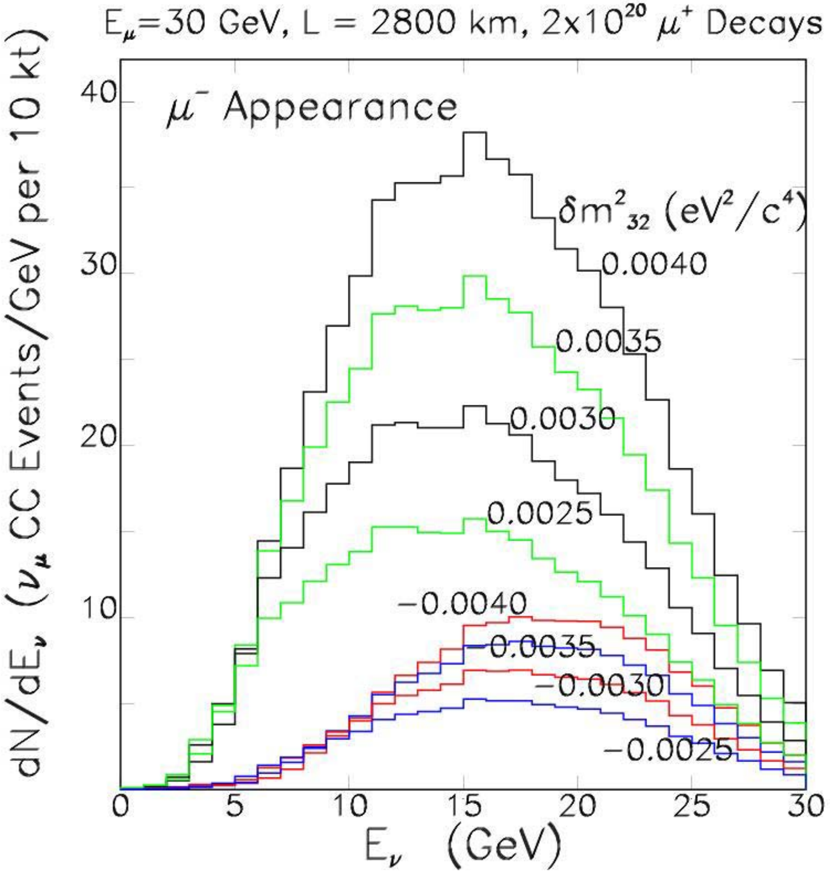
Barger, Geer, Raja, Whisnant, PRD 62, 073002
S. Geer, hep-ph/0008155

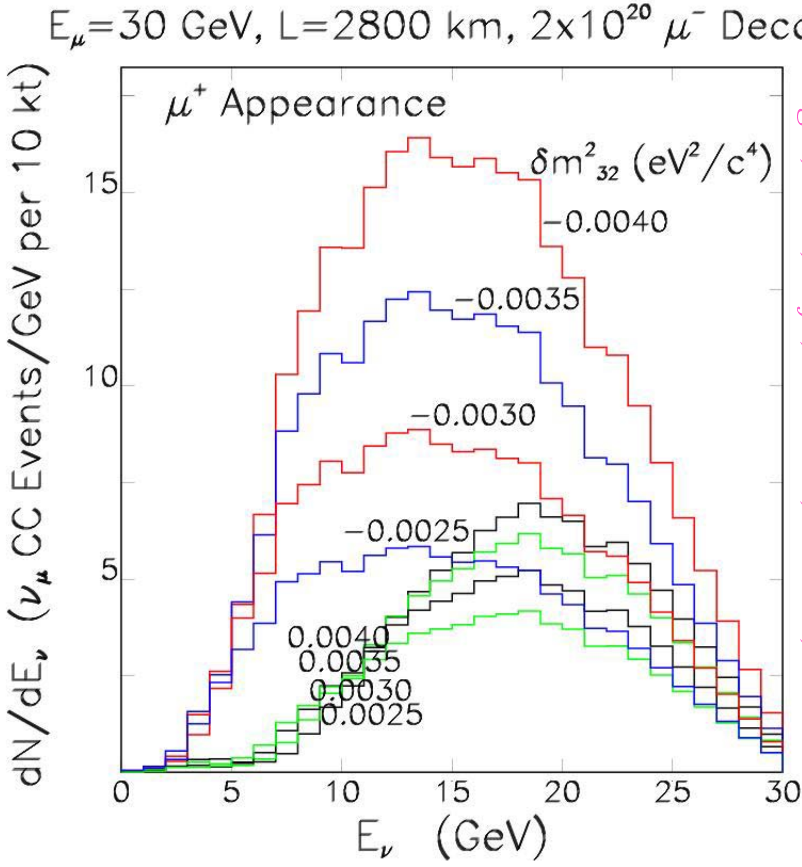


Error bars → 2×10^{20} decays / yr for 5 years



Additional Information in the Spectra





Barger, Geer, Raja, Whisnant, PRD 62, 013004

μ^- Appearance

+tve Δm_{32}^2 gives larger rate & softer spectrum than –tve Δm_{32}^2

μ^+ Appearance

+tve Δm_{32}^2 gives smaller rate & harder spectrum than –tve Δm_{32}^2

Oscillation Measurements at a Neutrino Factory

There is a wealth of information that can be used at a neutrino factory. Oscillation parameters can be extracted using events tagged by:

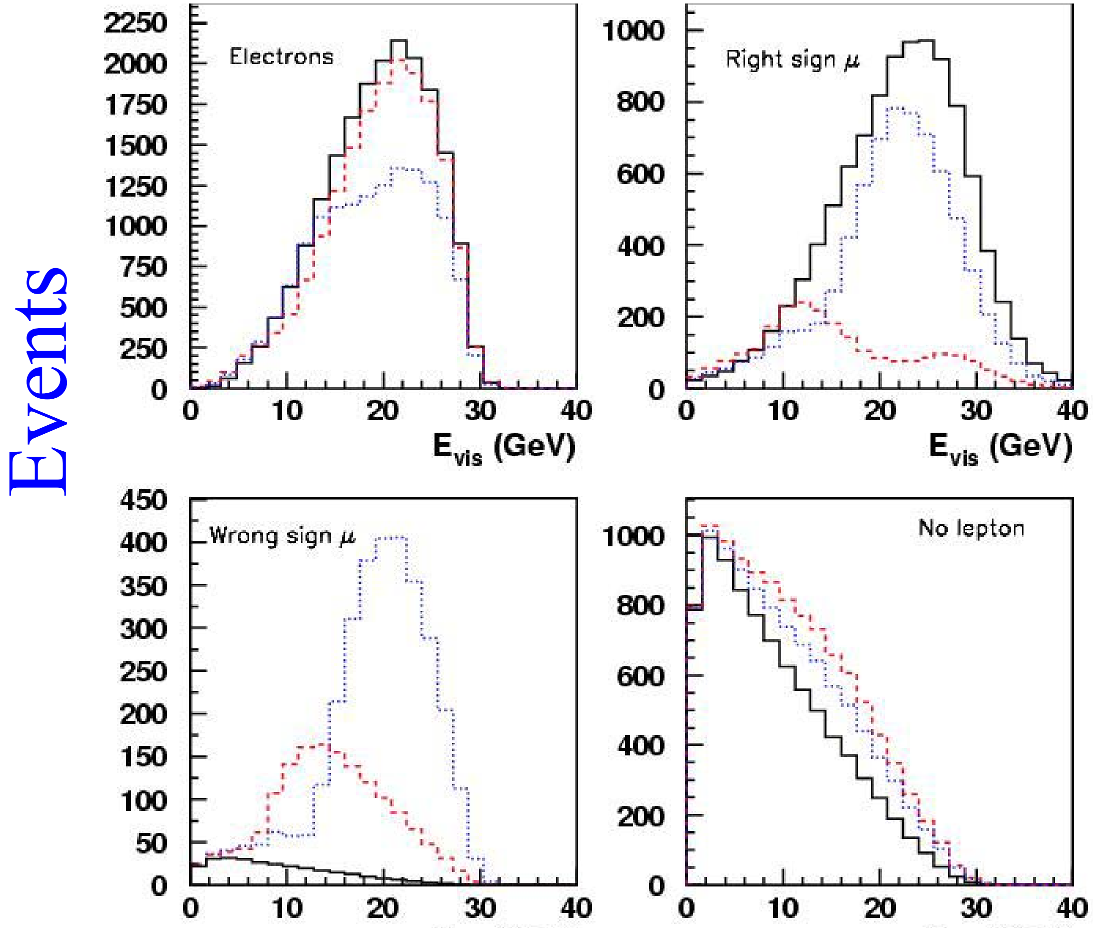
- a) right-sign muons
- b) wrong-sign muons
- c) electrons/positrons
- d) positive τ-leptons
- e) negative τ -leptons
- f) no leptons

×2 (μ^+ stored and μ^- stored)

The distributions are sensitive to the oscillation parameters

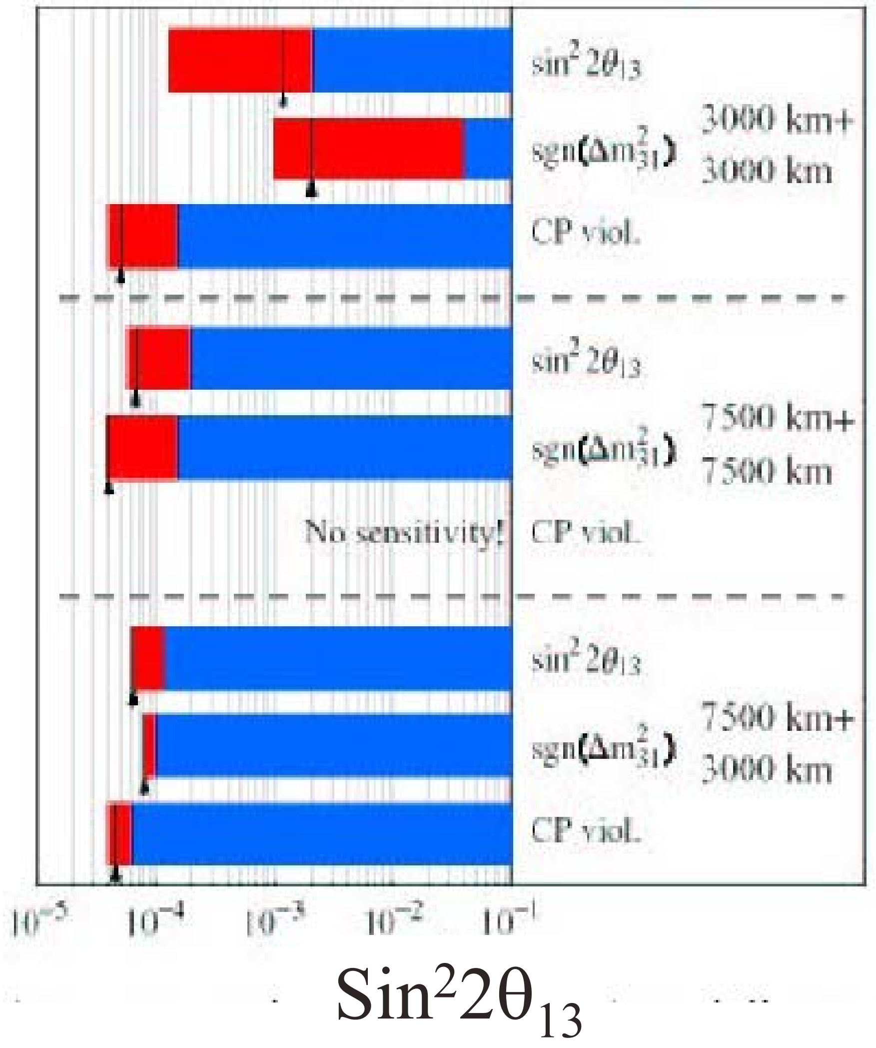
Bueno, Campanelli, Rubbia; hep-ph/00050007

Simulated distributions for a 10kt LAr detector at L = 7400 km from a 30 GeV nu-factory with 10^{21} μ^+ decays.



Neutrino Factory Sensitivity if θ_{13} is Small

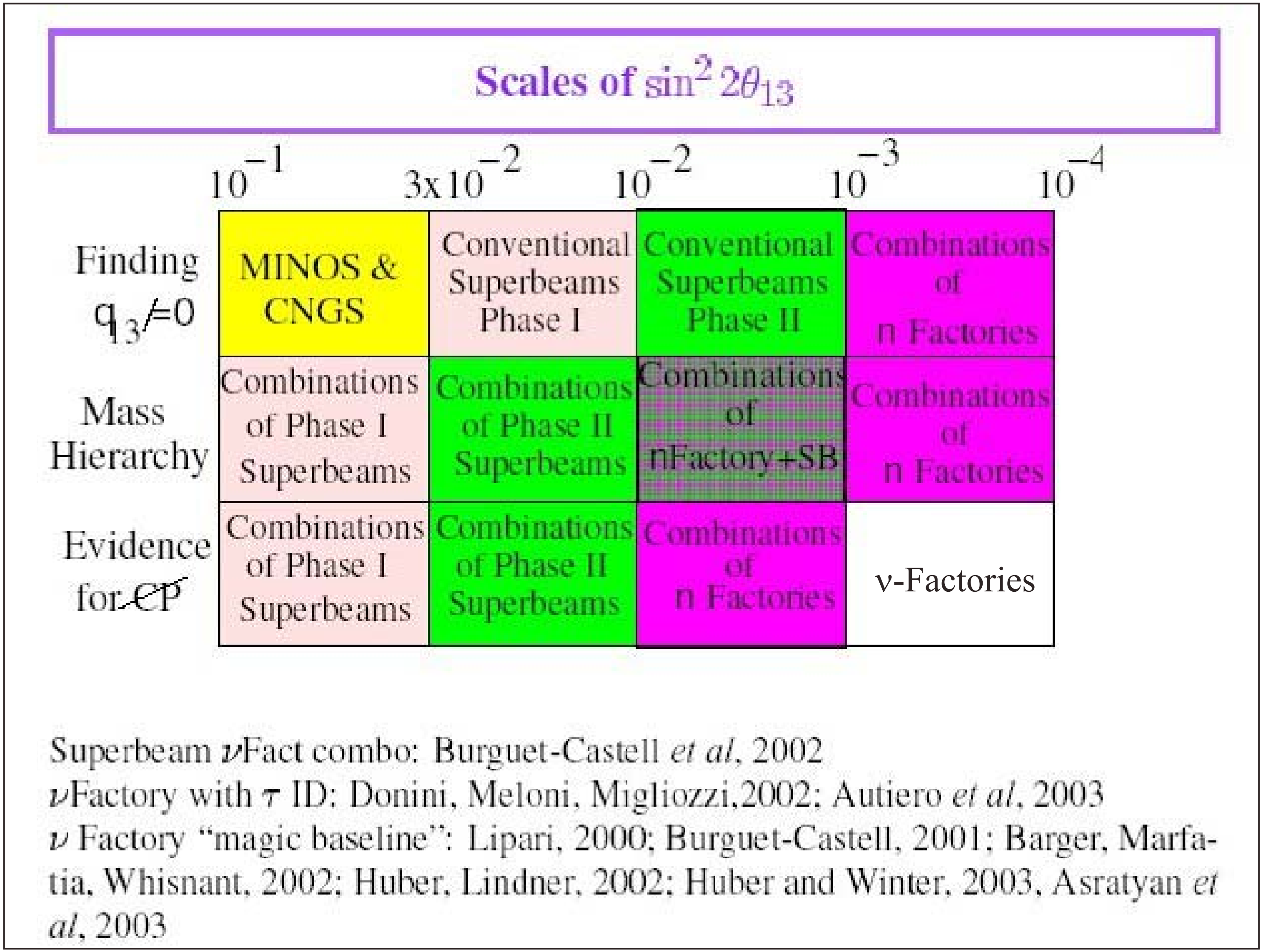
Huber, Winter; Phys. Rev. D68, 2003



The full physics program (Establishing the magnitude of θ_{13}, Determining the mass hierarchy, & searching for CP Violation) can be accomplished provided $\mathrm{Sin}^2 2\theta_{13} > O(10^{-4})$!

Summary of Physics Reaches

D. Harris, ANL Workshop, 3-4 March, 2004



Scales of $\sin^2 2\theta_{13}$

10^{-1} 3×10^{-2} 10^{-2} 10^{-3} 10^{-4}

Finding $q_{13}\neq 0$	MINOS & CNGS	Conventional Superbeams Phase I	Conventional Superbeams Phase II	Combinations of n Factories
Mass Hierarchy	Combinations of Phase I Superbeams	Combinations of Phase II Superbeams	Combinations of nFactory+SB	Combinations of n Factories
Evidence for $\not{CP}$	Combinations of Phase I Superbeams	Combinations of Phase II Superbeams	Combinations of n Factories	ν-Factories

Superbeam νFact combo: Burguet-Castell *et al*, 2002
νFactory with τ ID: Donini, Meloni, Migliozzi,2002; Autiero *et al*, 2003
ν Factory "magic baseline": Lipari, 2000; Burguet-Castell, 2001; Barger, Marfatia, Whisnant, 2002; Huber, Lindner, 2002; Huber and Winter, 2003, Asratyan *et al*, 2003

Selected $SO(10)$ Models and θ_{13} Predictions

Model	(Level) Flavor Sym.	Texture	$\tan\beta$	$\sin^2 2\theta_{13}$
AB	(4) $U(1)\times Z_2\times Z_2$	Lopsided	~ 5	0.0008-0.003
ABMSV	(1) Min. eff. ops.	Sym (II)	?	0.10
BO	(1) Min. eff. ops.	Sym	?	0.004-0.008
BKOT	(1) Min. eff. ops.	Sym	?	0.0004-0.01
BPW	(3) $U(1)$ eff. ops.	Sym (II)	low	?
CM	(4) $U(2)\times(Z_2)^3$	Sym	10	0.09
FKO	(1) Min. eff. ops.	Sym	45	0.16
GMN	(1) Min. eff. ops.	Sym(II)	10	0.10
KM	(2) $SU(3)\times U(1)$	Lopsided	small	~ 0.19
KRV-S	(4) $SU(3)\times Z_2\times U(1)_A$	Sym/Asym	?	0.02
M	(2) $U(1)_A\times Z_2$	Lopsided	5	~ 0.19

AB	Albright, Barr	$\sin^2 2\theta_{atm}\simeq 0.99$
ABMSV	Aulakh, Bajc, Melfo, Senjanovic, Vissani	not spelled out
BO	Bando, Obara	
BKOT	Bando, Kaneko, Obaro, Tanimoto	
BPW	Babu, Pati, Wilczek	
CM	Chen, Mahanthappa	$\sin 2\beta = 0.74$, $\delta_{CKM}\sim 35°$
FKO	Fukuyama, Kikuchi, Okada	$\Delta m^2_{sol}/\Delta m^2_{atm} = 0.188$
GMN	Goh, Mohapatra, Ng	$\sin^2 2\theta_{atm}\le 0.92$, $\sin^2 2\theta_{12}\ge 0.9$
KM	Kitano, Mimura	satisfies LMA mixing?
KRV-S	King, Ross, Velasco-Sevilla	
M	Maekawa	satisfies LMA mixing?

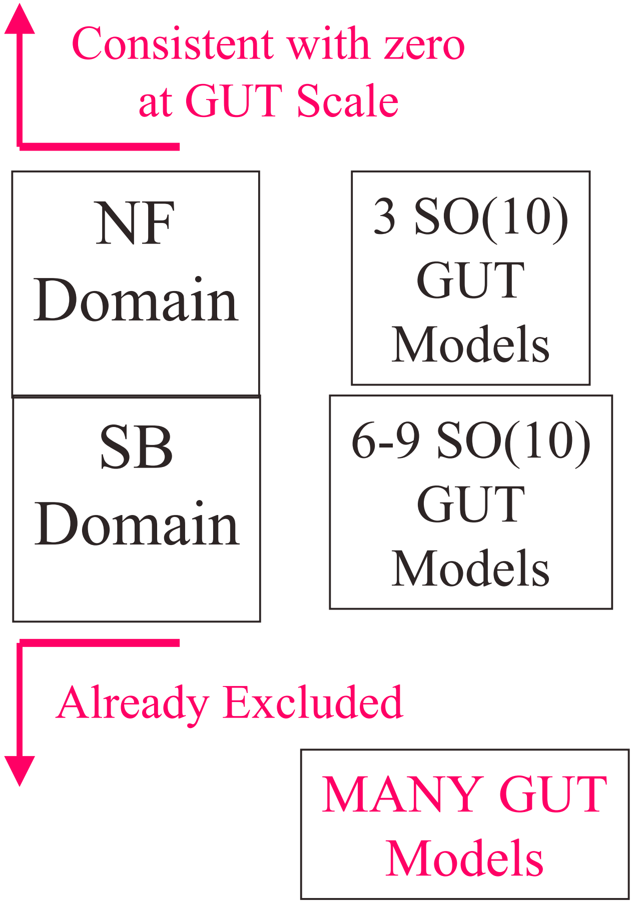
GUT Model Expectations for θ_{13} - Carl Albright

θ_{13} "predictions" all over the map … with a fair fraction of them in the NF sphere of interest.

If $\theta_{13} = 0$ at GUT scale, radiative corrections on $\sin^2 2\,\theta_{13}$ expected to be $< O(10^{-4})$!
(Aguilar-Saavedra, Branco, Jouquin).

θ_{13} Conversion Table

Θ_{13}	$\sin\theta_{13}$	$\sin^2\theta_{13}$	$\sin^2 2\theta_{13}$
0.2	0.0035	0.000012	0.000049
0.5	0.0087	0.00076	0.00030
1	0.017	0.00030	0.0012
2	0.035	0.0012	0.0049
5	0.087	0.0076	0.030
10	0.17	0.030	0.12



Consistent with zero
at GUT Scale

NF
Domain

3 SO(10)
GUT
Models

SB
Domain

6-9 SO(10)
GUT
Models

Already Excluded

MANY GUT
Models

What Happens if $\sin^2 2\,\theta_{13} > 0.01$?

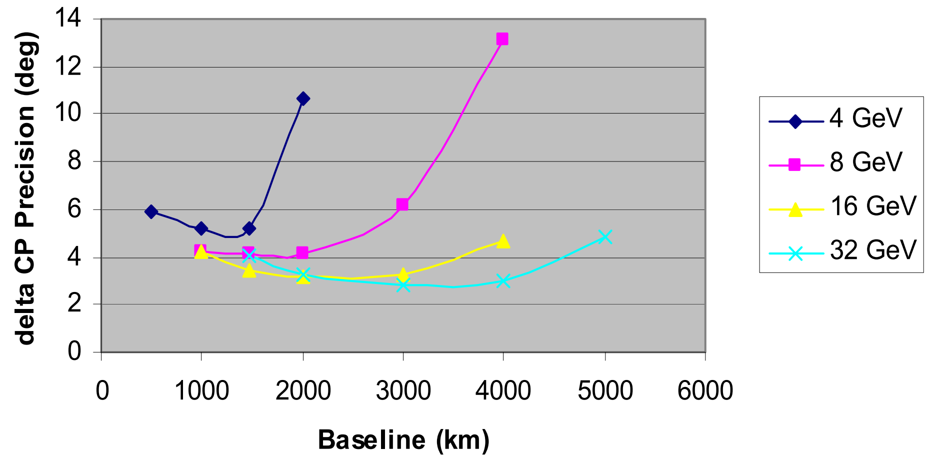
Much harder to answer since it depends on:

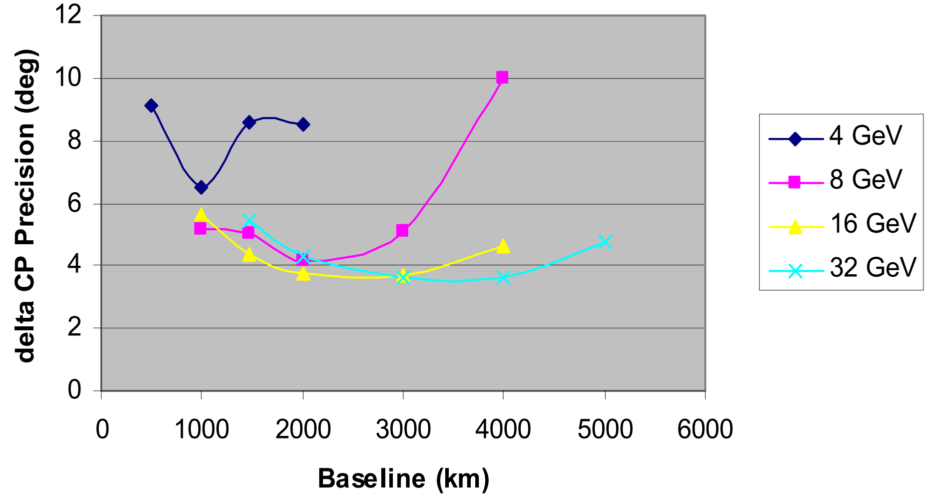
1. Will there be any surprises along the way ?
2. Will improved sensitivity to δ be important ?
3. We have not yet had the first generation of ν_e appearance searches yet. How well will superbeam experiments really do ?
4. Beyond the first generation of questions, what new set of basic questions will emerge ?

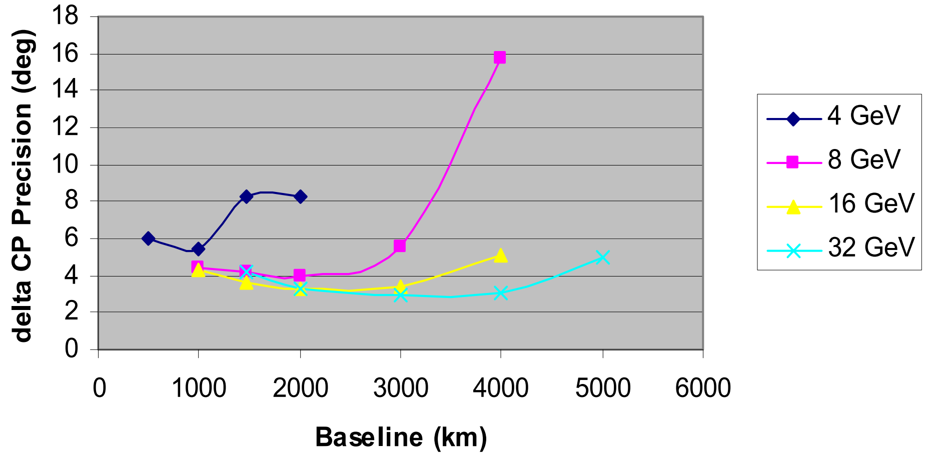
Nevertheless …

Large θ_{13} at a Neutrino Factory

Statistical Precision (1σ) for determining δ_{CP} if δ_{CP} near 0 or π

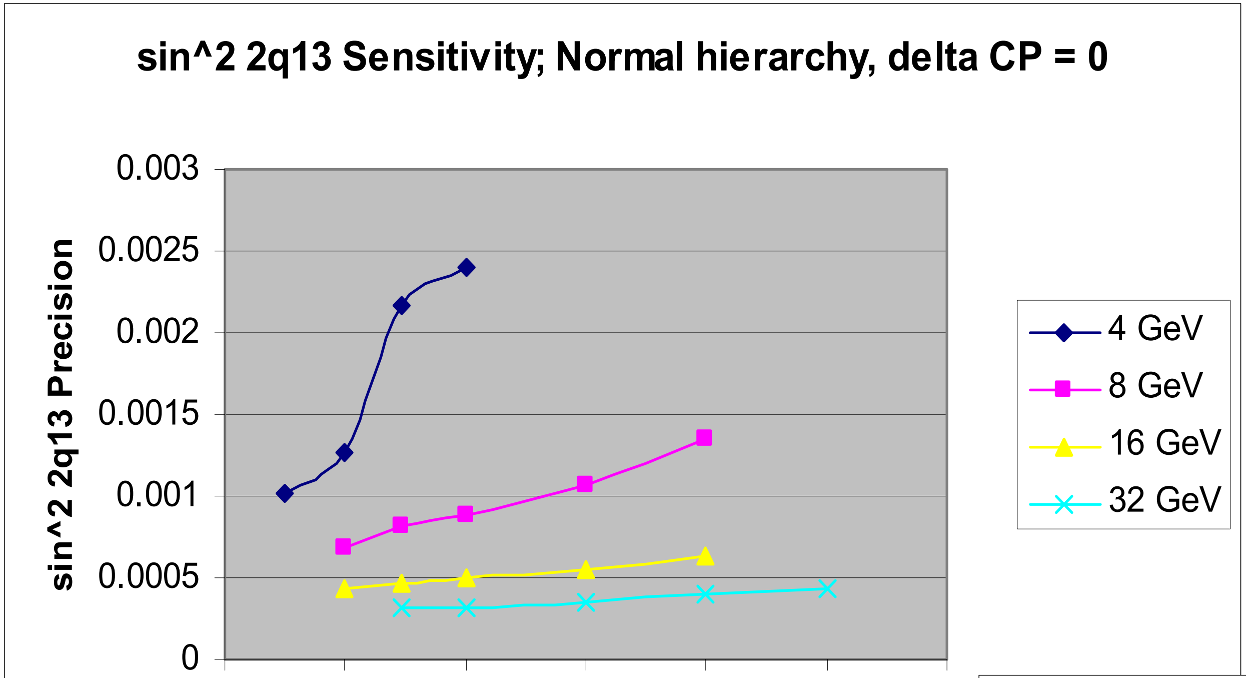

delta CP Sensitivity; Inverted hierarchy, s^22q13 = 0.04

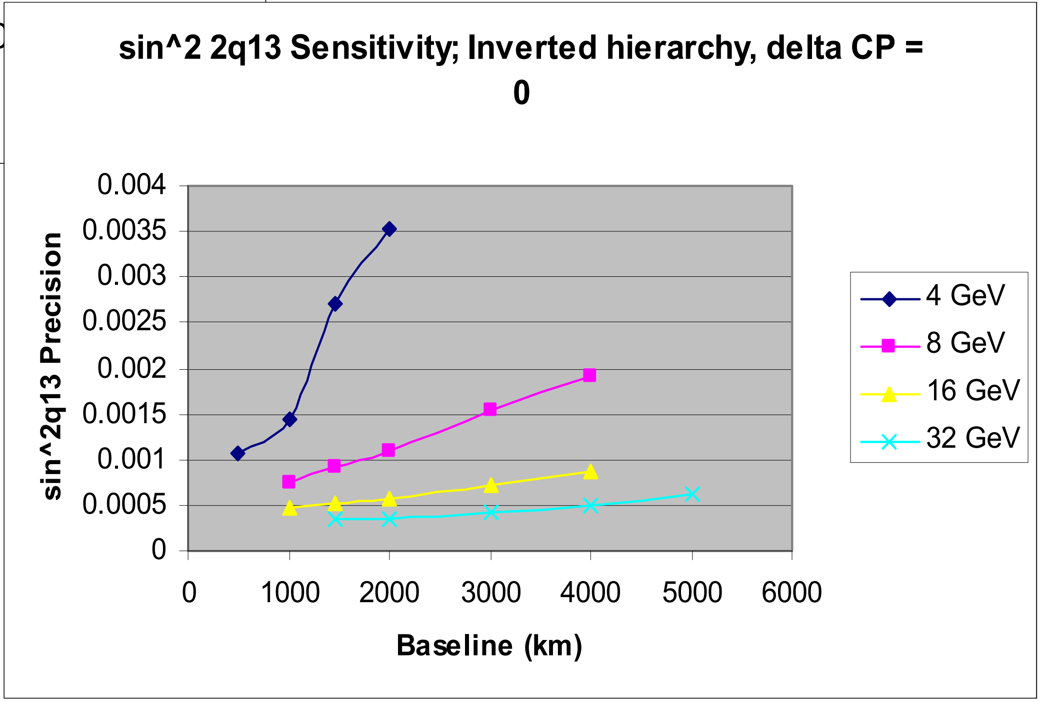

delta CP Sensitivity; Normal hierarchy, s^22q13 = 0.06


delta CP Sensitivity; Inverted hierarchy, s^22q13 = 0.06

Large θ_{13} at a Neutrino Factory

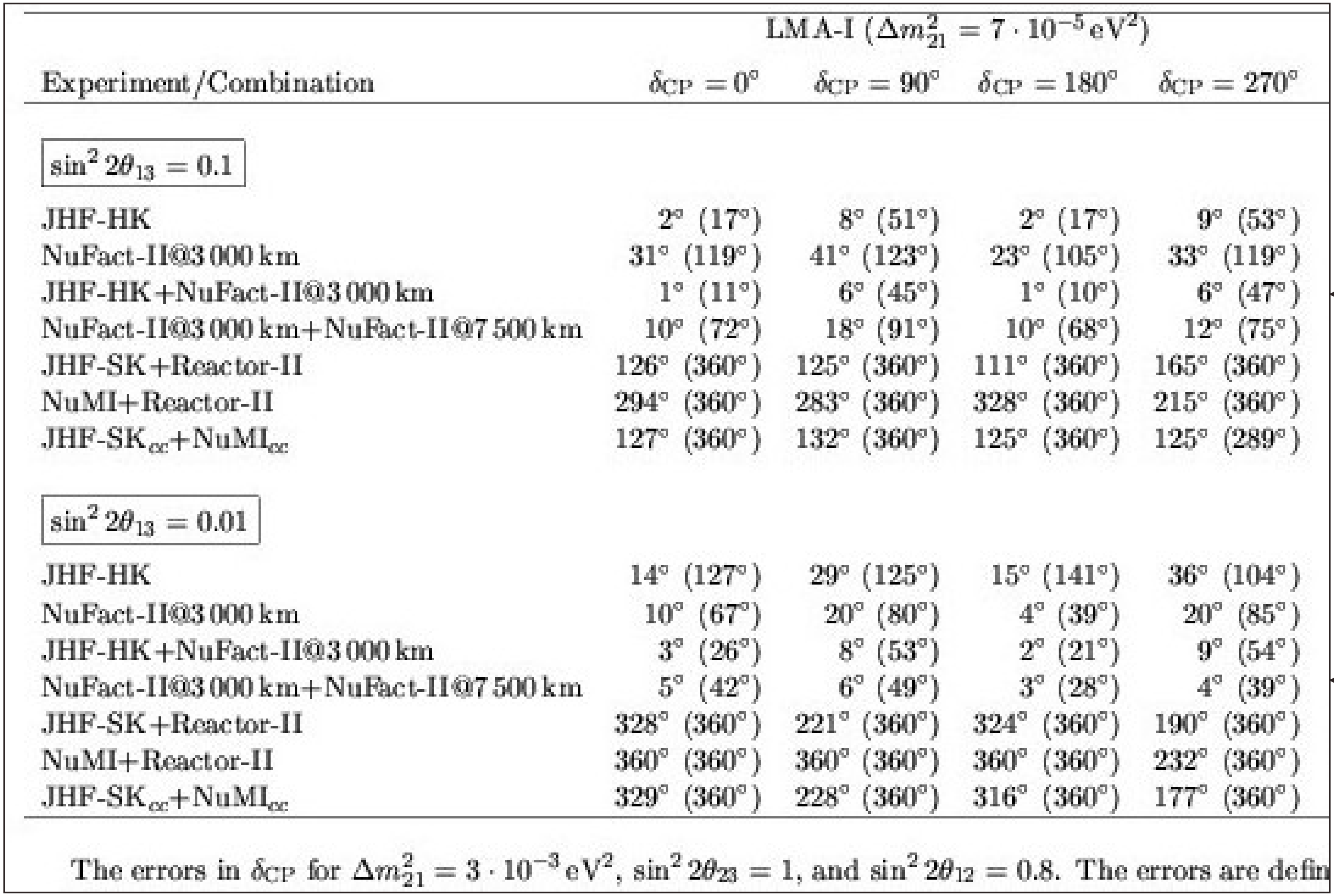
Statistical Precision (1σ) for determining θ_{13} if δ_{CP} near 0 or π





Large θ_{13} Neutrino Factory Study

How close can δ_{CP} be to 0 or π and CP Violation still be observed at a Neutrino Factory ? Numbers from Huber, Lindner & Winter:



	LMA-I ($\Delta m^2_{21} = 7 \cdot 10^{-5}\,\mathrm{eV}^2$)			
Experiment/Combination	$\delta_{CP} = 0°$	$\delta_{CP} = 90°$	$\delta_{CP} = 180°$	$\delta_{CP} = 270°$
$\sin^2 2\theta_{13} = 0.1$				
JHF-HK	2° (17°)	8° (51°)	2° (17°)	9° (53°)
NuFact-II@3 000 km	31° (119°)	41° (123°)	23° (105°)	33° (119°)
JHF-HK+NuFact-II@3 000 km	1° (11°)	6° (45°)	1° (10°)	6° (47°)
NuFact-II@3 000 km+NuFact-II@7 500 km	10° (72°)	18° (91°)	10° (68°)	12° (75°)
JHF-SK+Reactor-II	126° (360°)	125° (360°)	111° (360°)	165° (360°)
NuMI+Reactor-II	294° (360°)	283° (360°)	328° (360°)	215° (360°)
JHF-SK$_{ac}$+NuMI$_{ac}$	127° (360°)	132° (360°)	125° (360°)	125° (289°)
$\sin^2 2\theta_{13} = 0.01$				
JHF-HK	14° (127°)	29° (125°)	15° (141°)	36° (104°)
NuFact-II@3 000 km	10° (67°)	20° (80°)	4° (39°)	20° (85°)
JHF-HK+NuFact-II@3 000 km	3° (26°)	8° (53°)	2° (21°)	9° (54°)
NuFact-II@3 000 km+NuFact-II@7 500 km	5° (42°)	6° (49°)	3° (28°)	4° (39°)
JHF-SK+Reactor-II	328° (360°)	221° (360°)	324° (360°)	190° (360°)
NuMI+Reactor-II	360° (360°)	360° (360°)	360° (360°)	232° (360°)
JHF-SK$_{ac}$+NuMI$_{ac}$	329° (360°)	228° (360°)	316° (360°)	177° (360°)

The errors in δ_{CP} for $\Delta m^2_{21} = 3 \cdot 10^{-3}\,\mathrm{eV}^2$, $\sin^2 2\theta_{23} = 1$, and $\sin^2 2\theta_{12} = 0.8$. The errors are defin

NF brings modest improvement (factor of 2 ?) in δ_{CP} 1σ sensitivity

NF brings significant improvement (factor of 5 ?) in δ_{CP} 1σ sensitivity

Large θ_{13} and Neutrino Factories

If θ_{13} is “large” Neutrino Factories would deliver exquisite statistical and systematic precision for parameter determination, and provide new tests of the oscillation framework ($\nu_e \rightarrow \nu_\tau$ for example).

How important will this be ?

Possibly crucial if we get a surprise that requires a Neutrino Factory to sort out the physics and/or the next generation of fundamental questions might require the statistical+systematic precision provided by a NeutrinoFactory and/or the additional factor of few improvement in δ_{CP} precision is critical and of course θ_{13} might be small !

We would like to have a Neutrino Factory option that can become part of the Global neutrino physics program in about 10 years if required

Neutrino Factory R&D

In the US Neutrino Factory R&D is being pursued by the Muon Collaboration – 130 members – accelerator & particle physicists from Labs and Universities. The mission of the Collaboration is:

> *"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."*

The R&D is also becoming increasingly international with initiatives from Europe, and healthy participation from Japan.

R&D Program

Design: Two serious engineering studies have established feasibility and performance, and identified the required R&D program. Biggest outstanding design issue is cost optimization.

Hardware: Two areas needing substantial R&D are Targetry and Ionization Cooling. New acceleration ideas should also be explored when resources permit.

Targetry: Successful initial program has shown liquid Hg jet is likely to work. Preparing for a convincing test in a couple of years.

Ionization Cooling: Component development (MUCOOL) advanced, and international Muon Ionization Cooling Experiment (MICE) has Scientific Approval at RAL.

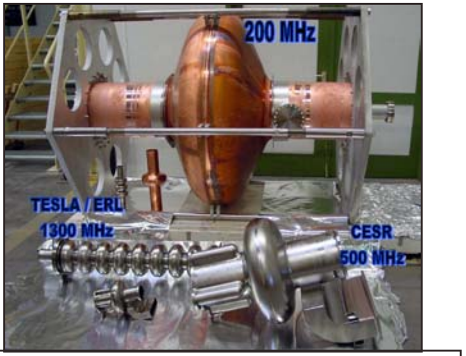
Neutrino Factory Design

1. The Neutrino Factory Study 2 cost estimate was dominated by three roughly equally expensive sub-systems: (i) Phase Rotation, (ii) Cooling Channel, (iii) Acceleration. These accounted for ~3/4 of the total cost.

2. In the last couple of years we have focused on, and are making good progress in developing, potentially cheaper solutions for all three sub-systems. Factors of two in cost reduction for each of these sub-systems may be possible.

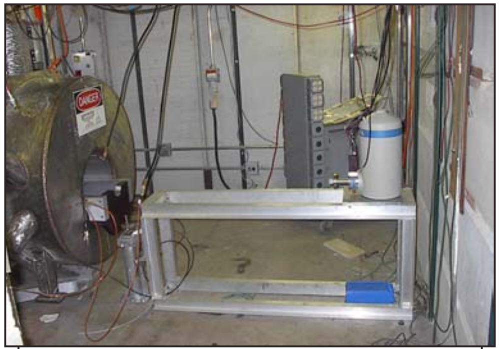
3. In 1-2 years time hope to launch a “Study 3” focused on a cost-optimized design.

Hardware Activities - 1

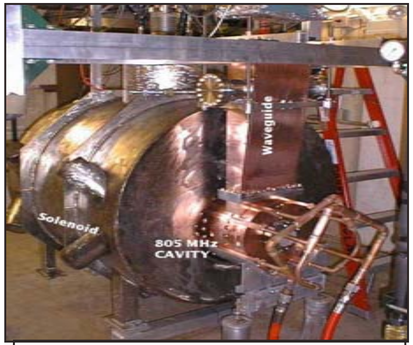


201 MHz SCRF Cavity for Acceleration – Cornell

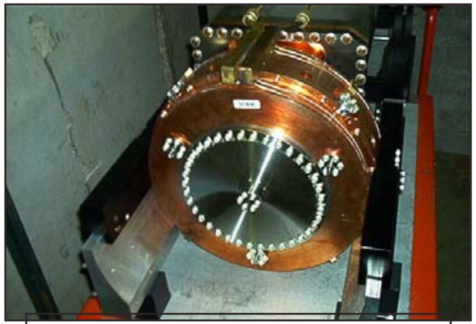
High-Gradient RF Tests in High Magnetic Field – FNAL



Studied dark current & X-rays from cavity with various detectors



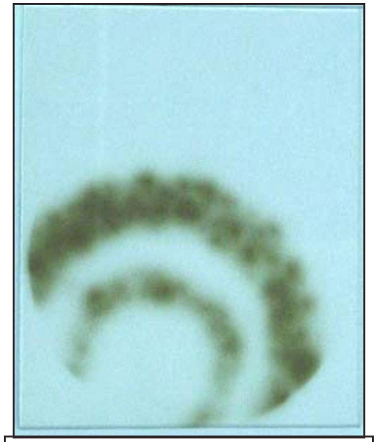
5T Cooling Channel Solenoid – LBNL & Open Cell NCRF Cavity operated at Lab G – FNAL



Single cell cavity with Be windows - LBNL

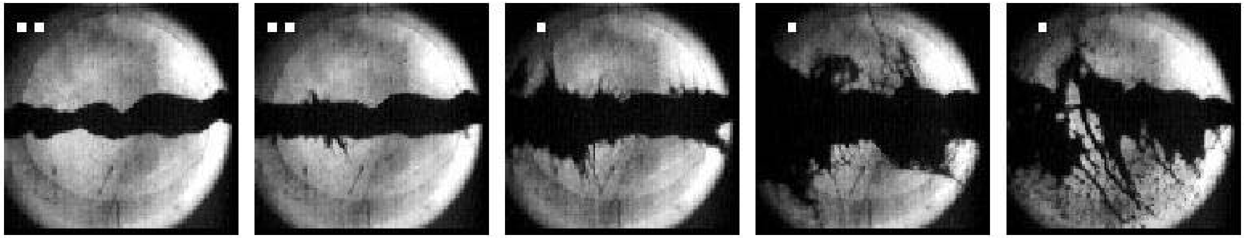
High pressure seal test for high-pressure RF studies – Muons Inc

Tested Be-Windows for RF Cavities – LBNL



Dark current ring measurements on glass plate – ANL/FNAL/IIT

Hardware Activities - 2

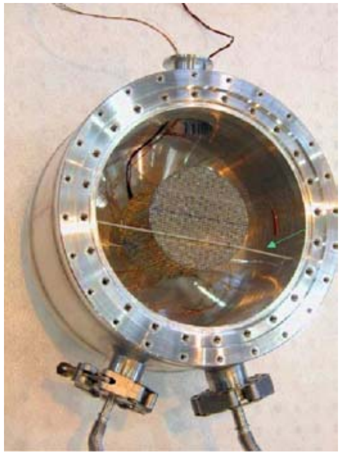


t = 0 0.75 ms 2 ms 7 ms 18 ms

Hg jet beam tests – Target experiment

Bolometer detectors for Window Beam profile – cryogenic setup– U. Chicago

Thin absorber windows Tested – new technique – ICAR Universities



Liq.H Absorber with central heater– KEK

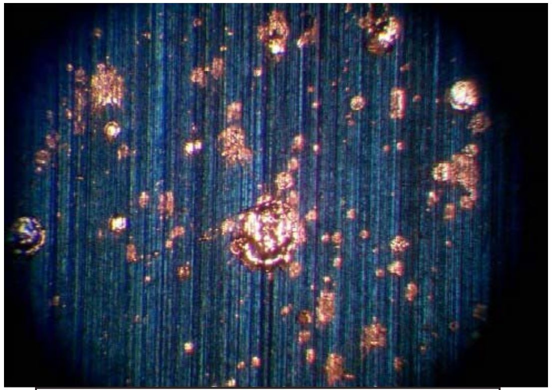
Liq.H Absorber – KEK To be tested at FNAL

Window burst tests – ICAR Universties

Hardware Activities - 3

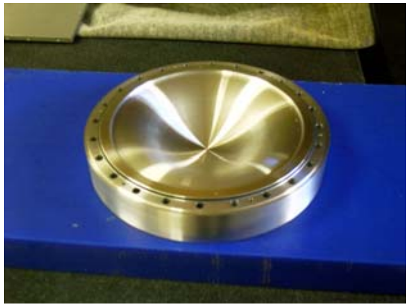
Calibration of LH2 Level Sensor – KEK

201 MHz half-shell ebeam welding of Stiffening – JLab



Be RF Window Tested – LBNL

500 MHz Cavity for sputtering studies – Cornell



New Double Bell Absorber Window – U. Mississippi

2000 Atmos H2 805 MHz Test Cell – Muons Inc

805 MHz SS Domed Window – LBNL

Hg Pump for high-speed Jet – Princeton

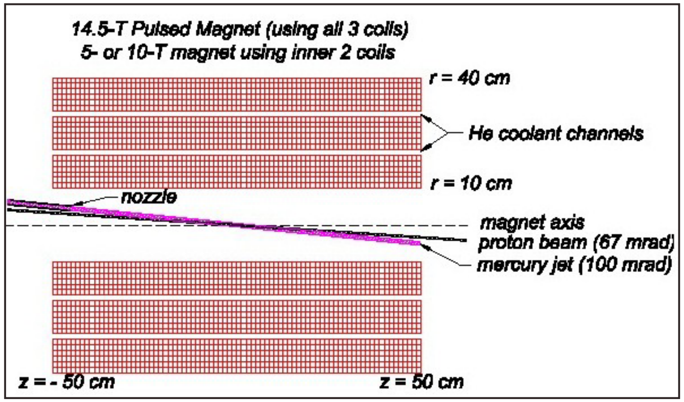
Hardware Activities - 4

LH2 Absorber Cryostat – KEK

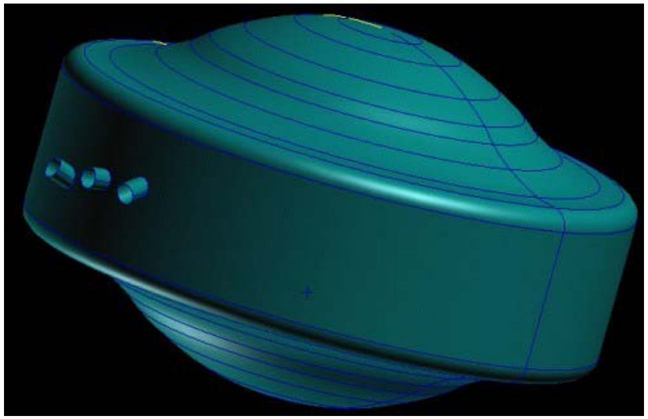
LH2 Absorber Cryostat installed in MTA FNAL/KEK

New MUCOOL Test Area Completed – FNAL

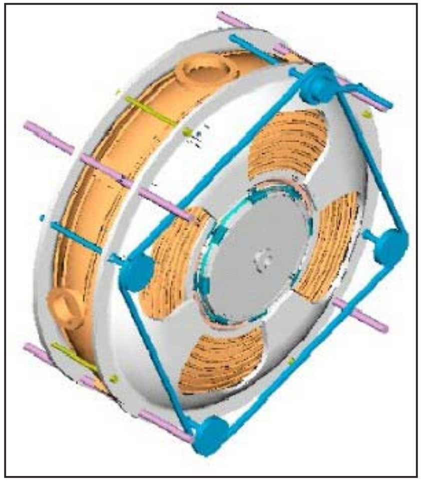
Design Activities - 1



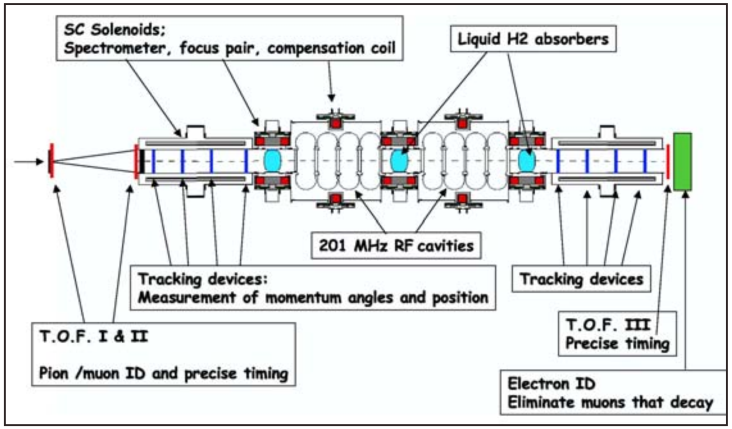
Design for pulsed target test magnet - BNL



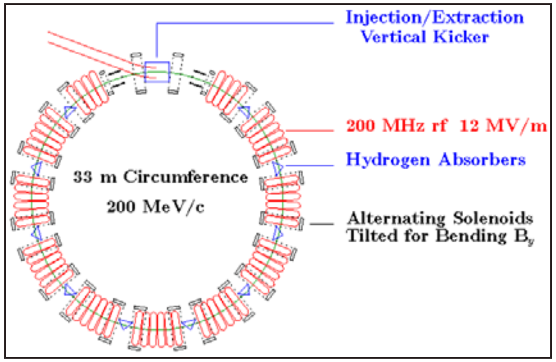
Improved absorber window design -- U. Oxford



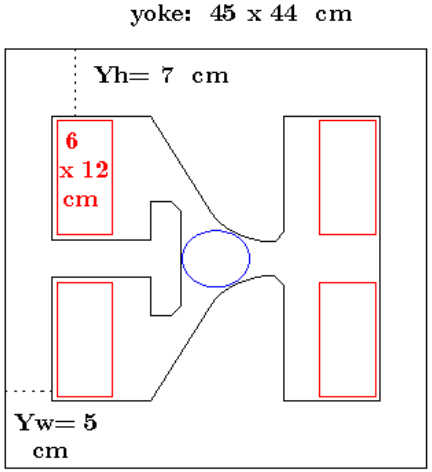
200 MHz NCRF Cavity design -- LBNL



Cooling experiment design (MICE)

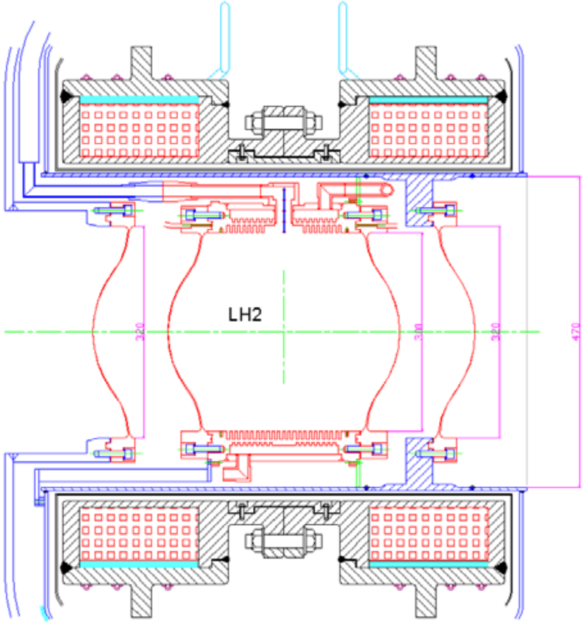


Ring cooler design work

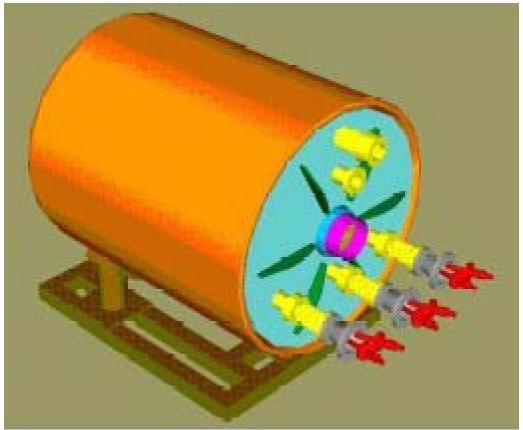


Rapid cycling magnet design – U. Mississippi

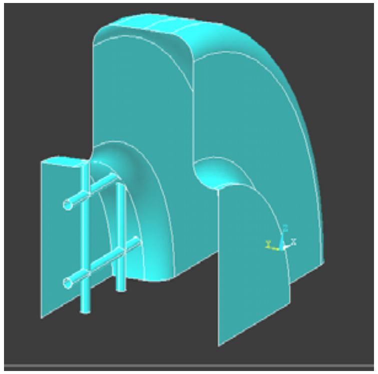
Design Activities - 2



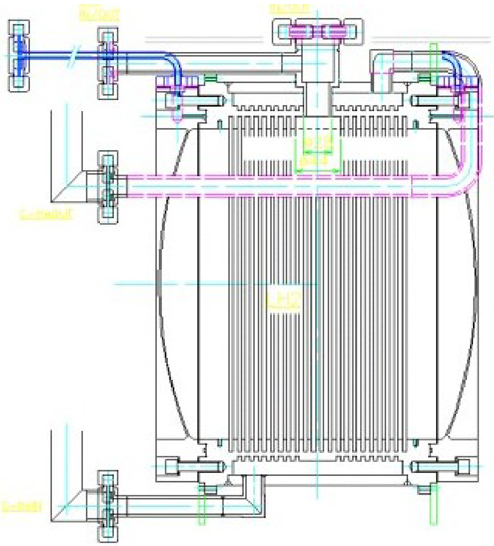
MICE Intergrated Absorber & Magnet Design – Oxford/IIT/LBNL/NIU



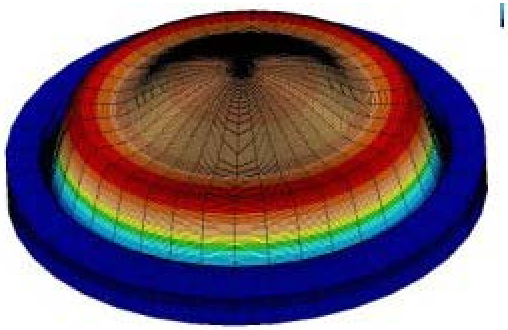
Target Solenoid – BNL



Gridded Tube RF Design – FNAL/IIT



MICE Absorber – Oxford/IIT/LBNL/NIU



New window design FEA studies – Oxford

MICE

130 Scientists from Europe, US, and Japan

CCLRC

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Our Ref: JVW/ csd/MICE2 2003-10-24

24-October-2003

Dear Alain,

The last few months have seen the international MICE project proposal peer reviewed at both a national and an international level. The scientific case, technical merits and timeliness of the proposal have been strongly endorsed in each case. CCLRC accepts the strong endorsement of the proposal by the Astbury panel and consequently considers the proposal to have full scientific approval.

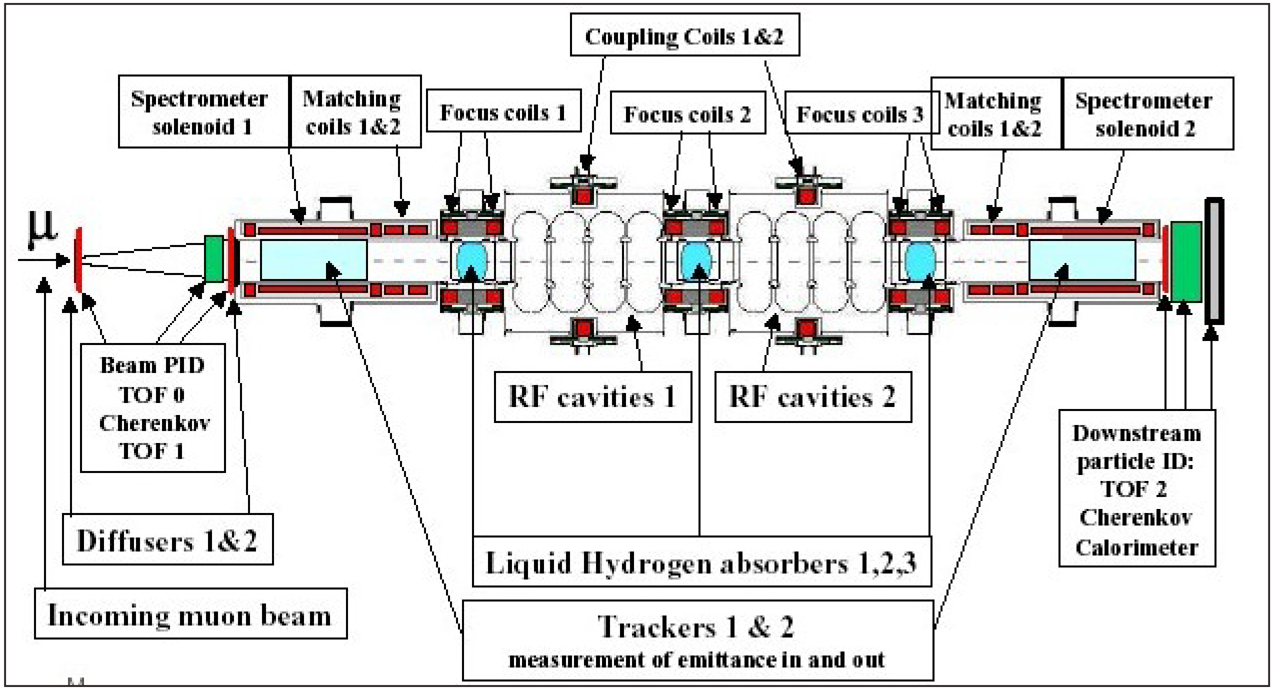
Progress of the project is now dependent on satisfactory funding arrangements being in place together with an appropriate project management structure. These arrangements will require scrutiny to ensure "best value" for UK and other investors. Within the UK this will be ensured by an independent review through the "Gateway" process that will be managed by the Joint MICE Project Board.

CCLRC therefore approves the project subject to a satisfactory progress through Gateway. The MICE proponents are now encouraged to actively seek funds to support MICE.

Yours sincerely

Professor J V Wood
Chief Executive

Cc Professor Ian Halliday, PPARC
Professor Ken Peach, CCLRC



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Concluding Remarks

Neutrino Oscillations provide us with exciting experimentally driven science. We might be in for big surprises.

Neutrino Factories offer a new type of neutrino beam with impressive statistical and systematic precision, and flexibility. If θ_{13} is smaller than O(0.01) they will offer a way forward … but only if we invest in the R&D so that the option exists when the time comes.

The Muon Collaboration plus its international partners are making good technical progress on Neutrino Factory R&D with limited resources. If supported at the level recommended by the HEPAP sub-panel it will take about 10 years to arrive at a cost-effective design with proven technology and a reliable cost basis.

A Neutrino Factory could become part of the global ν plan in about 10 years … and there could be great neutrino discoveries ahead of us !