Plans for running MiniBooNE in FY06

1. The case of a signal **in neutrino mode**
2. The long-term plan **if no signal is observed** in neutrino mode
3. The physics we can do in FY06

The ground rules we were given:

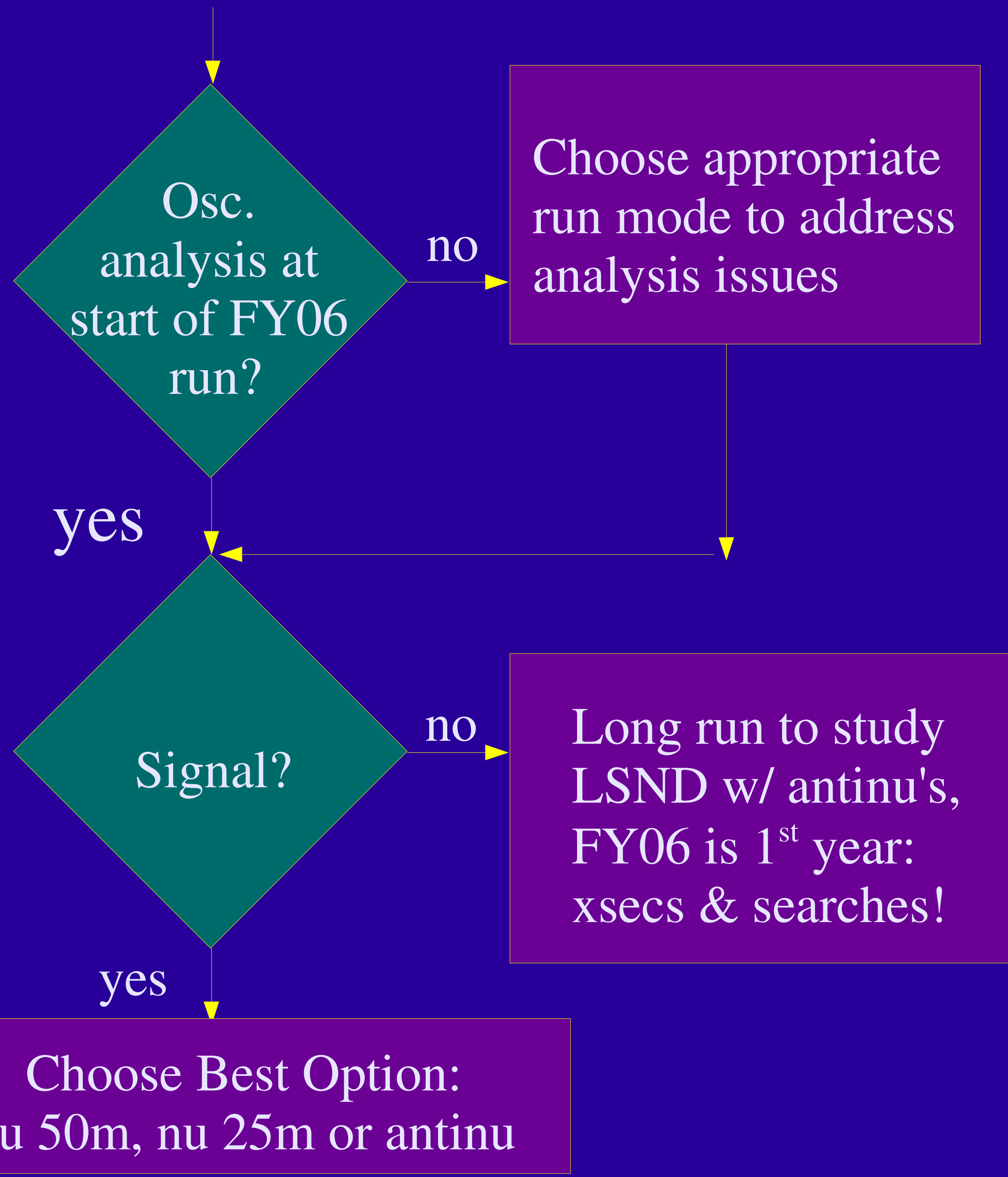
1. FY05 running is settled
   (Please wish us good beam!)

2. FY06 is expected to be part of a long-term plan,
   which will be considered next year.

3. FY06 is what it to be addressed in this meeting,
   presented within the context of the FNAL Proton Plan

An overview of the plan...

Our Goal!!!



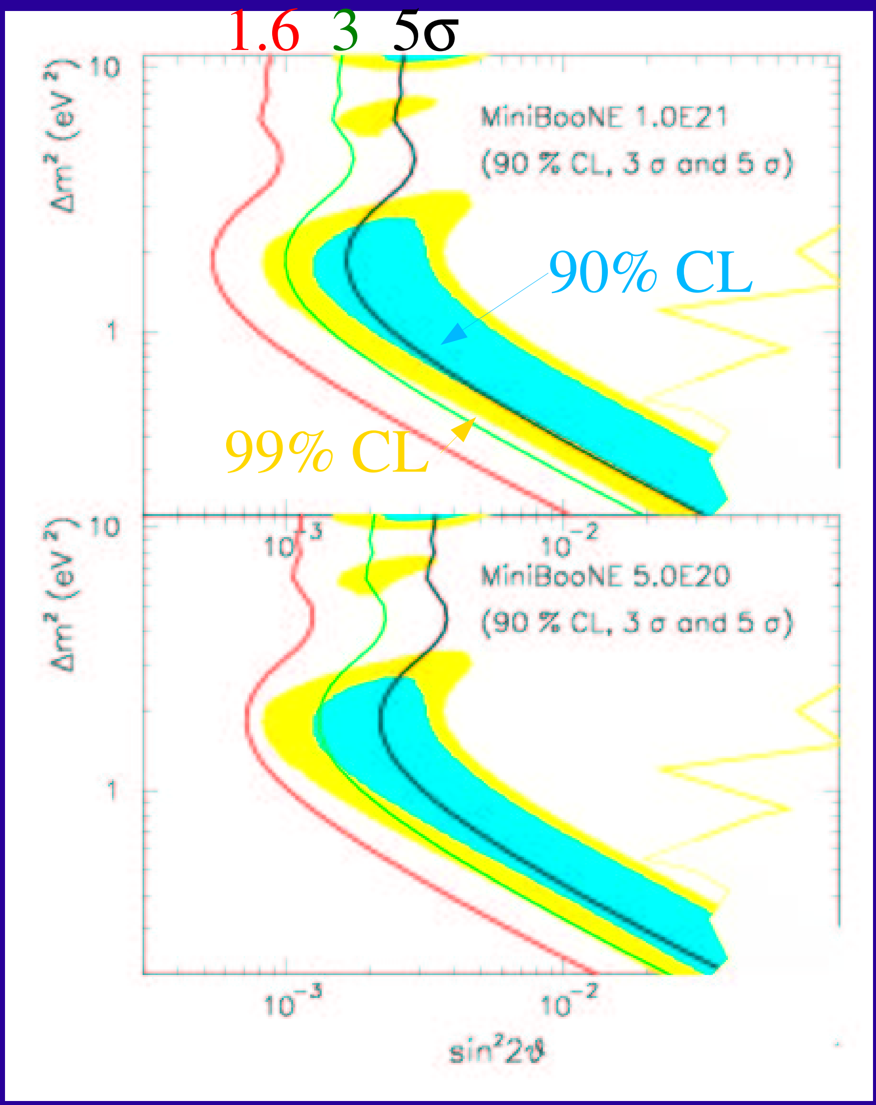
The Case of a Signal

Note:
LSND
is 4σ

(Energy fit)

We expect to accumulate,
a total between...

1×10^{21} POT:
Good coverage:
90% LSND allowed at > 4σ



5×10^{20} POT:
90% CL LSND @ ~3σ
Only just covers at LSND 99% CL
at <1.6σ

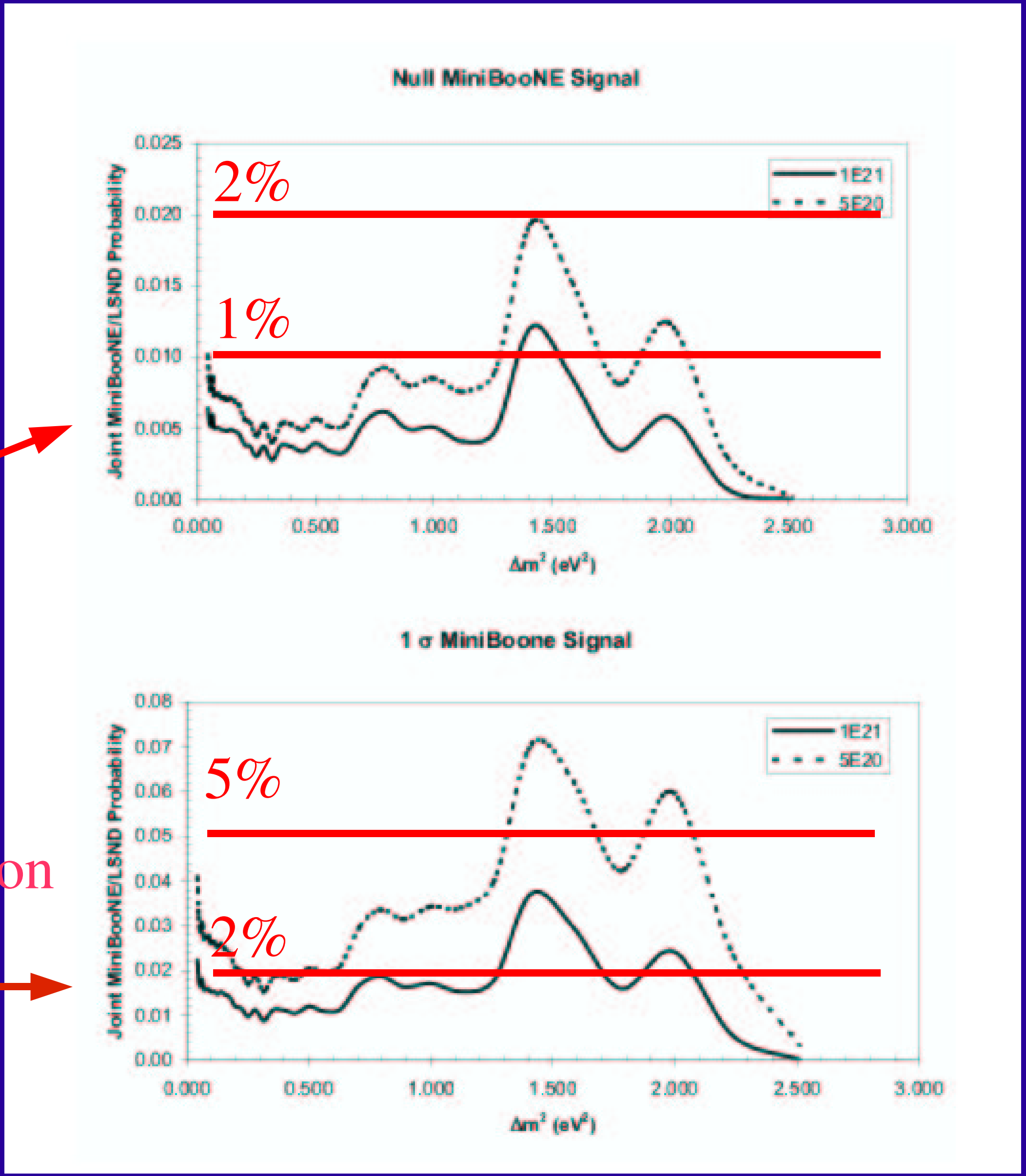
Which means the result may or may not be decisive.

Do a joint analysis...
Form a χ^2 for the agreement of Posc to find joint probability

⇒ Depends upon assumed Δm^2, since L/E is not the same!

Top: MiniBooNE null signal

Bottom: 1σ background fluctuation (16% probability for upward fluctuation)



Depending on the result there are several options:

1. Continue present running conditions
   → if we are confident of systematics and the issue is only statistics
   (note from run plan: stat err= sys err at 2E21)

2. Run with the 25 m absorber installed
   → if we want to check systematics

3. Switch to antineutrino running
   → an interesting alternative if we are satisfied the signal is solid

If we see an indication of a signal,
there is a solid case for continued running
at least through FY06

We will choose the best option when the time comes...

The Case of No Signal in Neutrino Mode

Long Term Plan:

MiniBooNE in $\bar{\nu}$ mode

If no signal is observed in neutrino mode

LSND needs to be checked in antineutrino mode because underlying physics might lead to a difference in the oscillation probabilities....

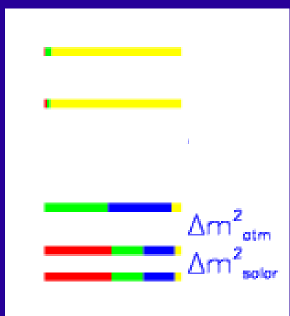
One example:

(because it is new since the Run Plan)

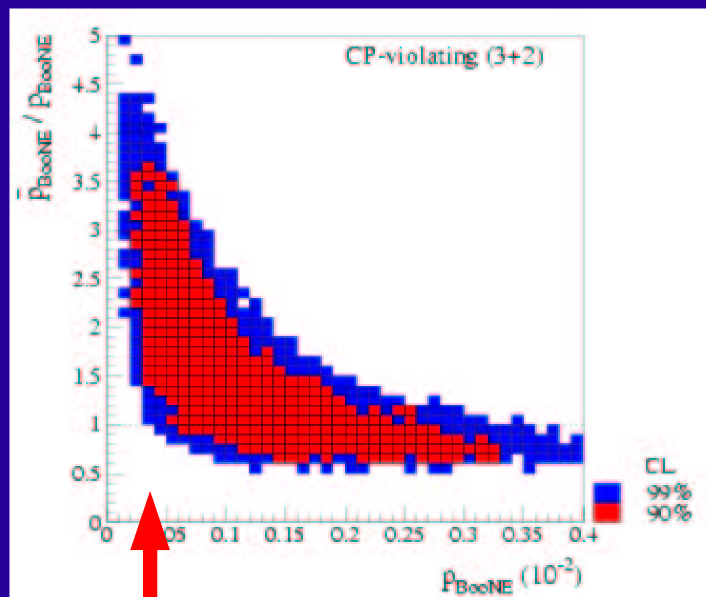
CP Violation

CP Violation:

$$\mathbf{P_{osc}}(\nu_\alpha \rightarrow \nu_\beta) \neq \mathbf{P_{osc}}(\bar{\nu}_\alpha \rightarrow \bar{\nu}_\beta)$$



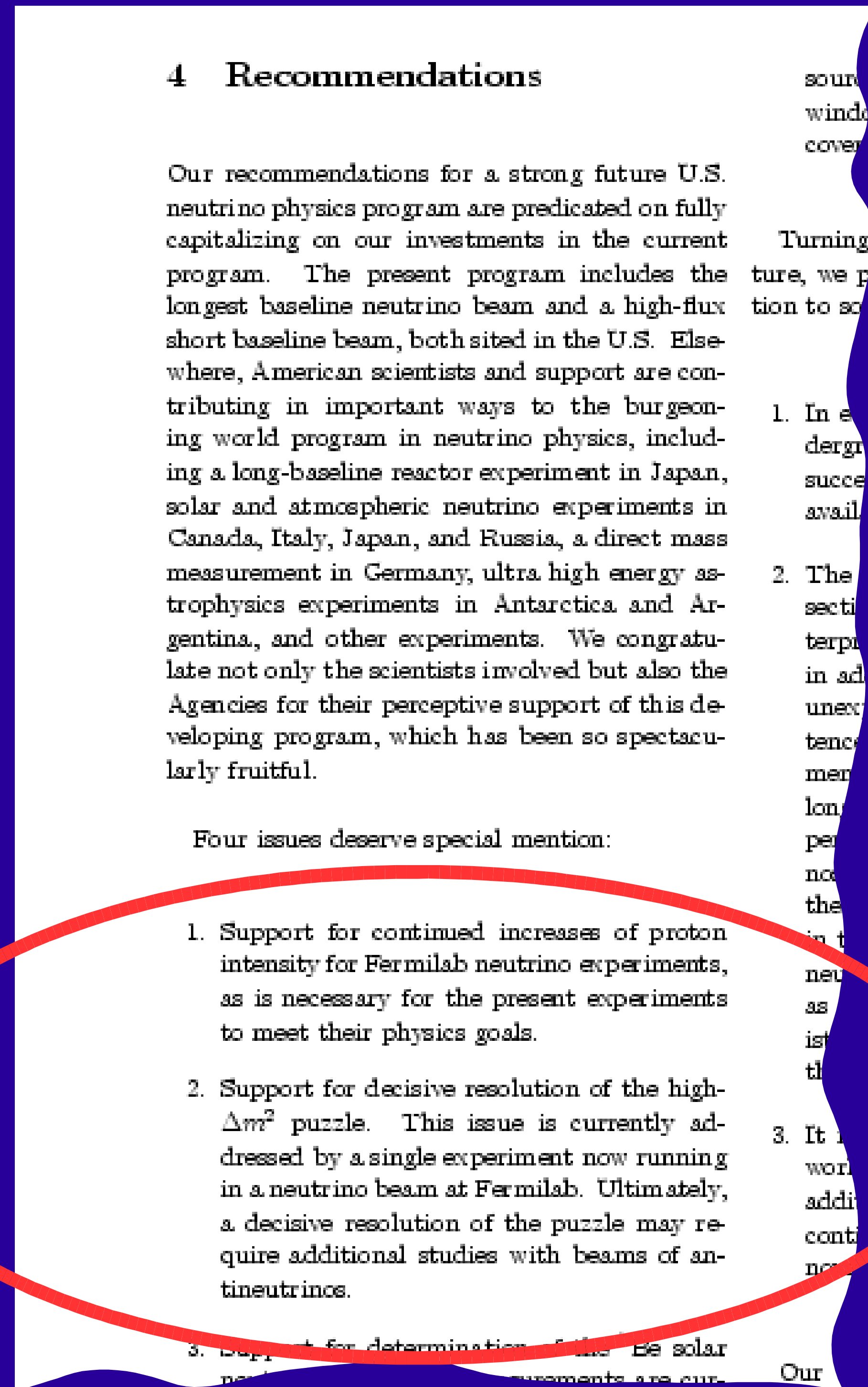
The same mechanism as for 3-generation CP violation



Aguilar-Arevalo, Barger, Sorel and Whisnant, preliminary

MiniBooNE can have
a small signal in neutrino-mode
(which could easily fluctuate to a null signal!)
& a ×3 larger signal in antinneutrino mode

Report of the APS Multidisciplinary Study on the future of Neutrino Physics



4 Recommendations

Our recommendations for a strong future U.S. neutrino physics program are predicated on fully capitalizing on our investments in the current program. The present program includes the longest baseline neutrino beam and a high-flux short baseline beam, both sited in the U.S. Elsewhere, American scientists and support are contributing in important ways to the burgeoning world program in neutrino physics, including a long-baseline reactor experiment in Japan, solar and atmospheric neutrino experiments in Canada, Italy, Japan, and Russia, a direct mass measurement in Germany, ultra high energy astrophysics experiments in Antarctica and Argentina, and other experiments. We congratulate not only the scientists involved but also the Agencies for their perceptive support of this developing program, which has been so spectacularly fruitful.

Four issues deserve special mention:

1. Support for continued increases of proton intensity for Fermilab neutrino experiments, as is necessary for the present experiments to meet their physics goals.
2. Support for decisive resolution of the high-Δm^2 puzzle. This issue is currently addressed by a single experiment now running in a neutrino beam at Fermilab. Ultimately, a decisive resolution of the puzzle may require additional studies with beams of antineutrinos.
3. Support for determination of the ^{7}Be solar ...

A.3 Executive Summary of the Superbeams Working Group

participants: *C. Albright, D. Ayres, A. Bazarko, F. Bertrand, G. Bock, D. Boehnlein, S. Brice, B. Brown, L. Buckley-Geer, J. Conrad, J. Cooper, S. Feldman, D. Ferenc, B. Gouvea, D. Harris, M. H R. Kephart, T. Kirk, G. Littenberg, W. Louis, J. G. McGregor, C. McGre Mishra, H. Montgomery, Pope, E. Prebys, D. Rah K. Scholberg, M. Shaevitz J. Thron, J. Urheim, R. Wojcicki, Q. Wu, C. Yar*

II. Short-term Recommendations:

- **Significant design studies for a new proton driver facility have been completed over the last few years. We urge a rapid decision on this facility.**

  We expect that it will take roughly 8 years from now before a new proton driver could be completed, if the decision to proceed and selection of the site is done soon. Moving now to decide on this machine will permit the U.S. to have the leading program of neutrino measurements in the following decade.

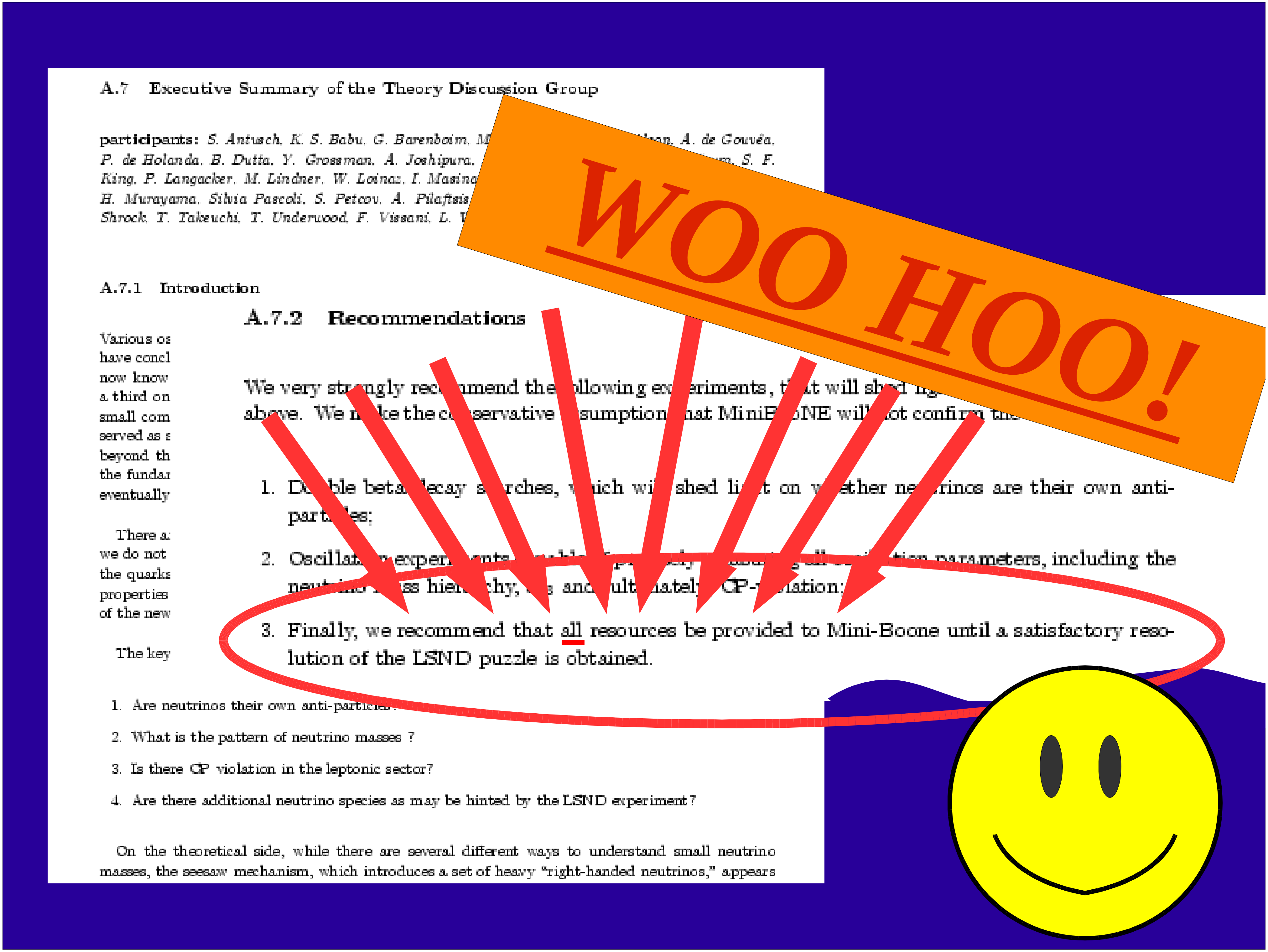
- **Increase proton intensity at Fermilab, roughly by about a factor of 2 in both the Booster and Main Injector neutrino beamlines over the next few years.**

  Both the MINOS and Mini-BooNE experiments offer exciting discovery and measurement potential in the next few years but their capabilities depend critically on proton intensity. Roughly, we encourage investment with a goal of delivering about 4×10^{20} protons per year at both 8 GeV and 120 GeV.

- **We recommend the LSND result be tested with both neutrinos and anti-neutrinos.**

  Mini-BooNE is currently using neutrinos to test the LSND result (which is $\bar{\nu}_e$ appearance in an initial beam of $\bar{\nu}_\mu$). It is essential that this test be conclusive. Should Mini-BooNE not confirm LSND with neutrinos, testing the result with anti-neutrinos will be important. Improvements in proton intensity as discussed in the preceding recommendation would permit Mini-BooNE to also test LSND with anti-neutrinos.

- We ... the ... of a long-baseline ν_e appearance experi...



A.7 Executive Summary of the Theory Discussion Group

participants: *S. Antusch, K. S. Babu, G. Barenboim, M... A. de Gouvêa, P. de Holanda, B. Dutta, Y. Grossman, A. Joshipura, ... S. F. King, P. Langacker, M. Lindner, W. Loinaz, I. Masina ... H. Murayama, Silvia Pascoli, S. Petcov, A. Pilaftsis ... Shrock, T. Takeuchi, T. Underwood, F. Vissani, L. W...*

A.7.1 Introduction

Various os... have concl... now know... a third on... small com... served as ... beyond th... the fundar... eventually...

There a... we do not... the quarks... properties... of the new...

The key...

A.7.2 Recommendations

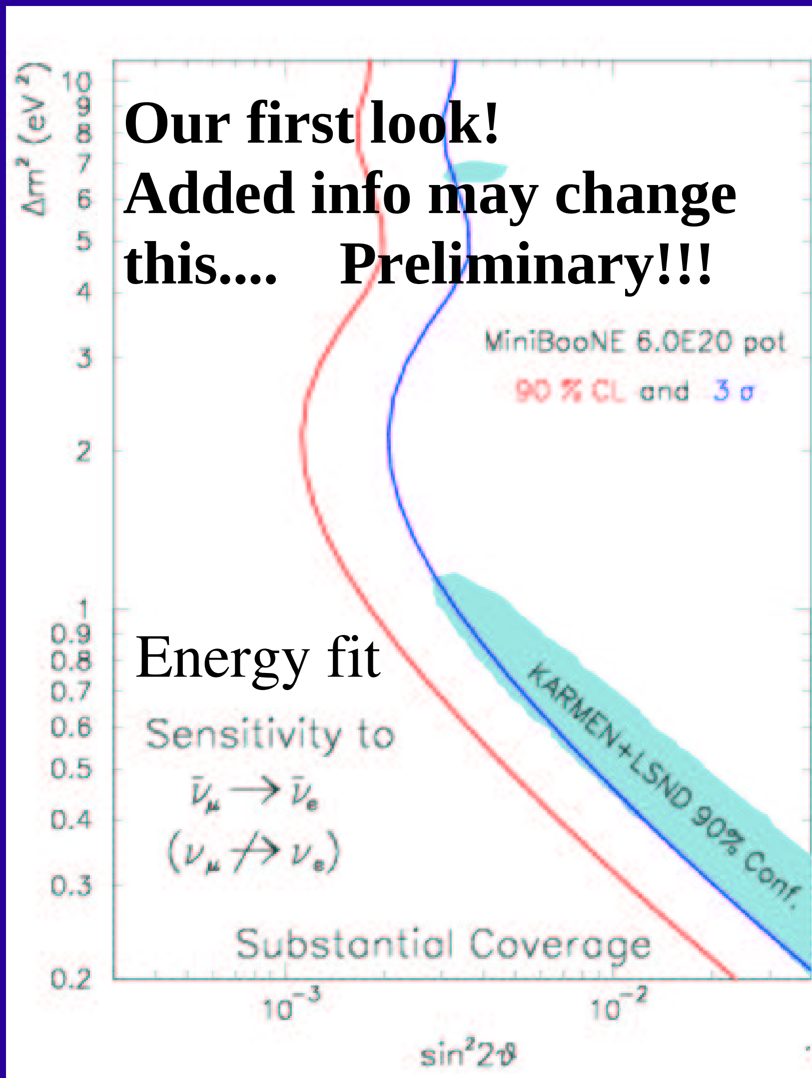
We very strongly recommend the following experiments, that will shed light ... above. We make the conservative assumption that MiniBooNE will not confirm the ...

1. Double beta decay searches, which will shed light on whether neutrinos are their own anti-particles;
2. Oscillation experiments capable of precisely measuring all oscillation parameters, including the neutrino mass hierarchy, ... and ultimately CP-violation;
3. Finally, we recommend that all resources be provided to Mini-Boone until a satisfactory resolution of the LSND puzzle is obtained.

1. Are neutrinos their own anti-particles?
2. What is the pattern of neutrino masses ?
3. Is there CP violation in the leptonic sector?
4. Are there additional neutrino species as may be hinted by the LSND experiment?

On the theoretical side, while there are several different ways to understand small neutrino masses, the seesaw mechanism, which introduces a set of heavy "right-handed neutrinos," appears

And so, our long-term plan is to run in antineutrino mode:



As an example....

For 3 years of running at 2E20, Coverage is... ← Substantial

MiniBooNE
Coverage Scale:
Complete
Substantial
Moderate
Marginal
Bronx Cheer

(This is worst case:
no neutrino oscillation
only antinu oscillation)

We will present our long-term goals in light of the neutrino running data at a PAC meeting next year

The Physics of FY06

in the case of a signal:
Pursue it!

in the case of no observed
signal in neutrino mode:

What can we accomplish in the
1^{st} year of antineutrino running?

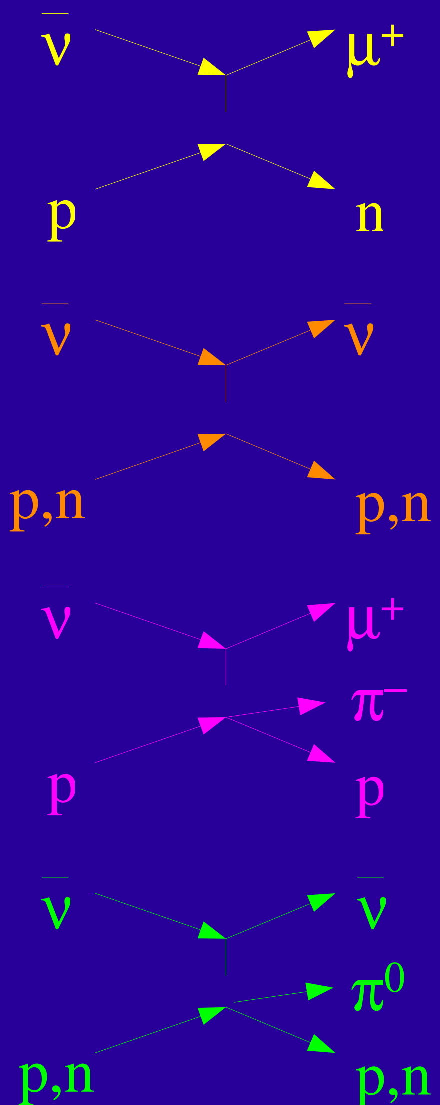
Truth in Advertising Slide...

Things we know well...
a) Response of our detector (all discussion is based on
well-tuned hit-level MC with
full reconstruction)
b) "Design Properties" of the beam (proton beam size & divergence,
response of the horn, etc.)

Things we do not know so well...
a) Secondary production of π^- (we are analyzing HARP data now)
b) Cross sections for events (that's the point,
we are going to measure them!)

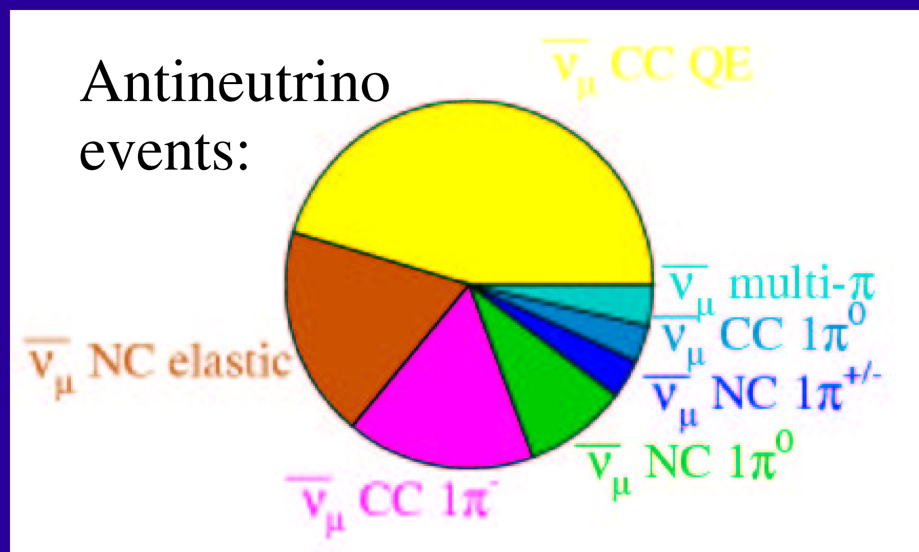
So in 2 years, don't expect exactly the number of events I show.

Event Rates for 1st year:



CCQE	32,500
NC elastic	13,300
CC π^-	11,900
NC π^0	6,500

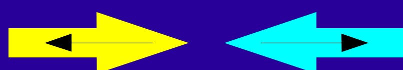
(2E20 pot)



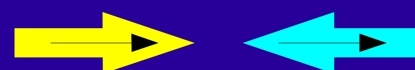
For those who have not thought about antineutrinos in a while...

1. The antineutrino beam, produced by π^-, has **lower intensity** and is **softer** ($\langle E_{\bar{\nu}}\rangle$=650 MeV compared to $\langle E_{\nu}\rangle$=750 MeV)

2. **Spin suppresses the cross section** for $\bar{\nu}$ interactions (RH) because at our energies we only hit valence quarks (LH)
   Compare:

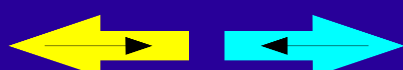


LH neutrino + LH quark
Jz=0



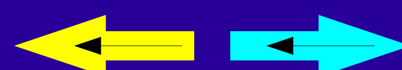
RH antinu + LH quark
Jz=1

easily scatters into:



Jz=0

cannot scatter into:



Jz =−1

Overall Result: About 4 times less antineutrino than neutrino events...

All anti-neutrino beams suffer from
neutrino (aka "wrong-sign") background

Why?
Because the leading
+ charged particle
is hard to defocus

At MiniBooNE:	$\bar{\nu}$	ν
CCQE	32,500	11,200
NC elastic	13,300	4,700
CC π^-	11,900	0
CC π^+	0	770
NC π^0	6,500	2,200

(rates before nuclear effects are applied)

Compare to ~2% WS
contamination in neutrino mode

Link, Tanaka, Wascko and Zeller
have developed a method to reduce WS error on xsec to 2%
THIS IS CRUCIAL TO OUR PHYSICS GOALS

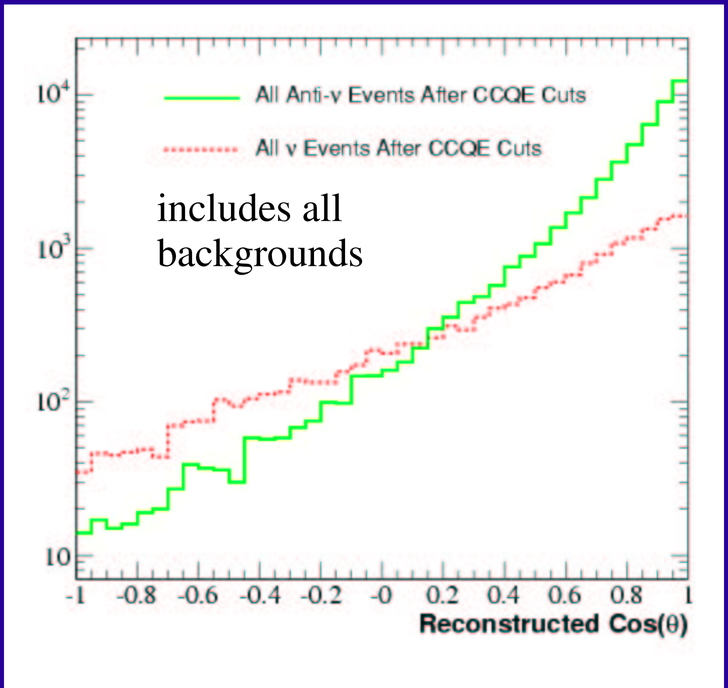
Anyone with a
1 GeV beam and
a large Cerenkov
detector.

Applicable for: K2K cross section measurements
T2K CP violation search
SK Mass hierarchy measurements

Three Independent Methods of Understanding WS Background.

1. Angular distribution of the CCQE scatters:

   Fitting the angular distribution:
   7% measure of WS (2% error on xsec)



2. Muon Lifetime measurement:

   8% of μ^- capture but 0% of μ^+ capture
   Affecting the measured
   lifetime of stopped μ
   30% measure of WS (9% error on xsec)

3. CC π^+ analysis

   15% measure of WS
   (5% error on xsec)

Neutrino type	# before cuts	# after CC π^+ event selection
ν_μ (WS)	30,539	2,525
$\bar{\nu}_\mu$ (RS)	71,547	461
total	102,086	2,986

Three examples of physics measurements that can be completed in FY06:

- 2 Interesting Cross Section Measurements
- Antineutrino Disappearance

... other ideas are in development

Cross Sections

4 Recommendations

Our recommendations for a strong future U.S. neutrino physics program are predicated on fully capitalizing on our investments in the current program. The present program includes the longest baseline neutrino beam and a high-flux short baseline beam, both sited in the U.S. Elsewhere, American scientists and support are contributing in important ways to the burgeoning world program in neutrino physics, including a long-baseline reactor experiment in Japan, solar and atmospheric neutrino experiments in Canada, Italy, Japan, and Russia, a direct mass measurement in Germany, ultra high energy astrophysics experiments in Antarctica and Argentina, and other experiments. We congratulate not only the scientists involved but also the Agencies for their perceptive support of this developing program, which has been so spectacularly fruitful.

Four issues deserve special mention

1. S[illegible] increases of proton

sources. This capability would open a new window to astrophysics with significant discovery potential.

Turning to the recommendations for the future, we preface our remarks by drawing attention to some basic elements in common:

1. In every instance the need for suitable underground detector facilities emerges. A successful neutrino program depends on the availability of such underground space.
2. The precise determination of neutrino cross sections is an essential ingredient in the interpretation of neutrino experiments and is, in addition, capable of revealing exotic and unexpected phenomena, such as the existence of a neutrino magnetic dipole moment. Interpretation of atmospheric and long-baseline accelerator-based neutrino experiments, understanding the role of neutrinos in supernova explosions, and predicting the abundances of the elements produced in those explosions all require knowledge of neutrino cross sections.

Why MiniBooNE?

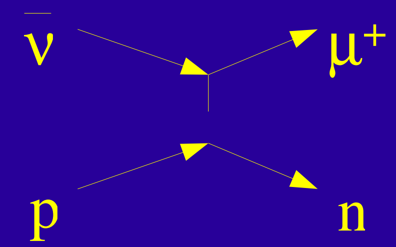
Opportunity:

- We can do these measurements now, without upgrades.
- No other experiment will have our event rates for many years!

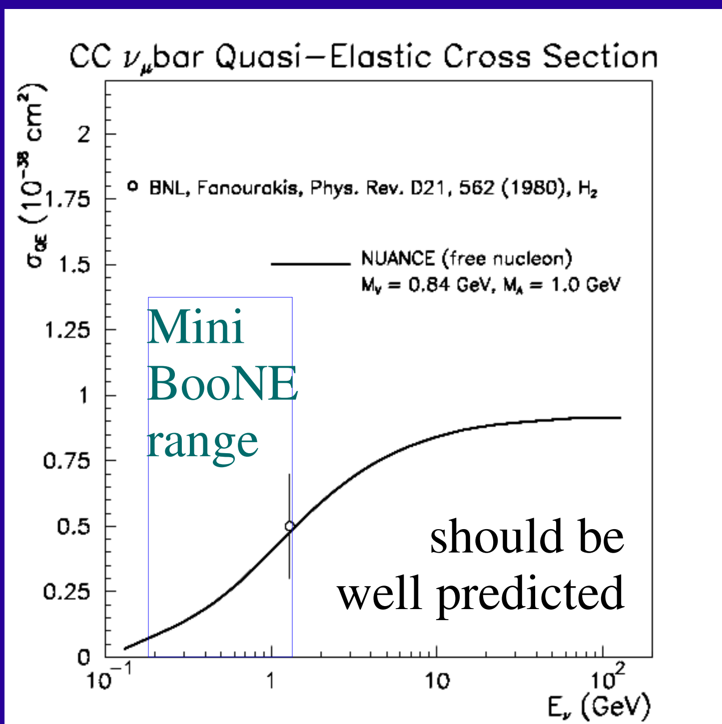
1. Our beam:
   a) The secondary production will be well-understood from HARP
   b) The design is simple and therefore systematics from design are low
      (e.g. only one horn, beamline is only 50 m, etc.)
   c) ~1 GeV is an important energy range for study.
   d) Because L=500m, there is no beam parallax

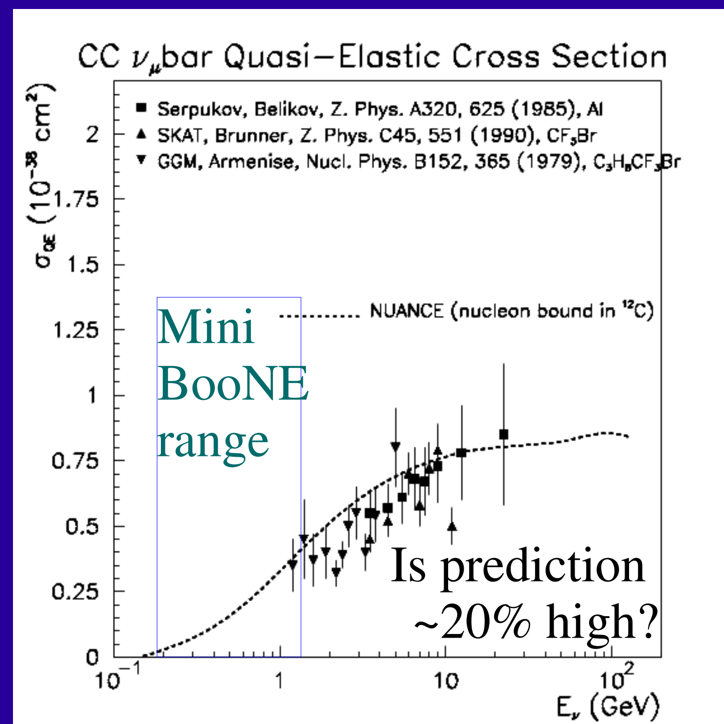
2. Our detector:
   a) Carbon-based measurements are valuable for any future experiment
      using scintillator or oil-base
   b) Cerenkov detectors are good at isolating CCQE and single π
      event types in the ~1 GeV range

Cross Sections: CCQE



Existing data set is <1000 events,
Scattering from free protons should be well understood,
Scattering from Carbon is <u>not.</u> This is *due to nuclear effects*





Planned CCQE Analysis:

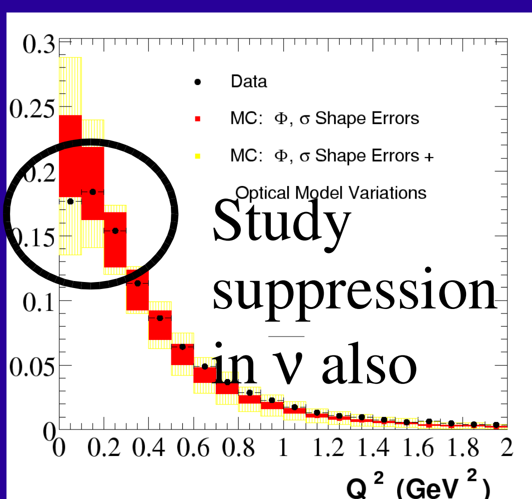
An order of magnitude more events

Start w/ 40k events ($\bar{\nu}+\nu$)
hit level MC
with all processes.
Apply the ν reconstruction...

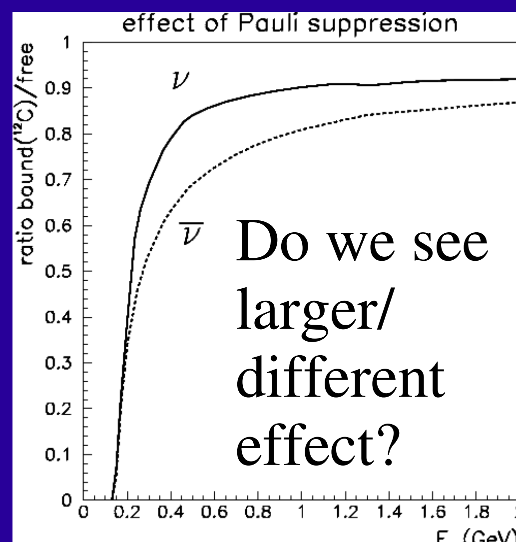
Event type	# events passing CC QE selection
CC QE $\bar{\nu}_\mu$ (RS)	10,893
CC QE ν_μ (WS)	3,332
1π $\bar{\nu}_\mu$ backgrounds	3,341
1π ν_μ backgrounds	1,032
QE $\bar{\nu}_\mu$ hyperon production	329
total	18,927

Goals:

1. Obtain the cross section vs. energy -- 20% measurement.
   needed for our oscillation analyses!
2. Study nuclear effects



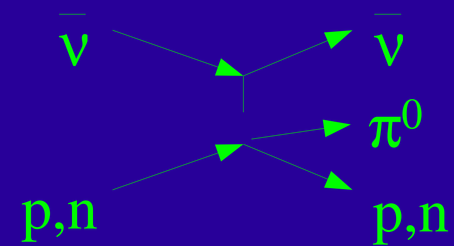
Study suppression in $\bar{\nu}$ also



Do we see larger/ different effect?

Joint analysis of
MiniBooNE ν
MiniBooNE $\bar{\nu}$
&
e- scattering data
(collaboration started by our xsec group)

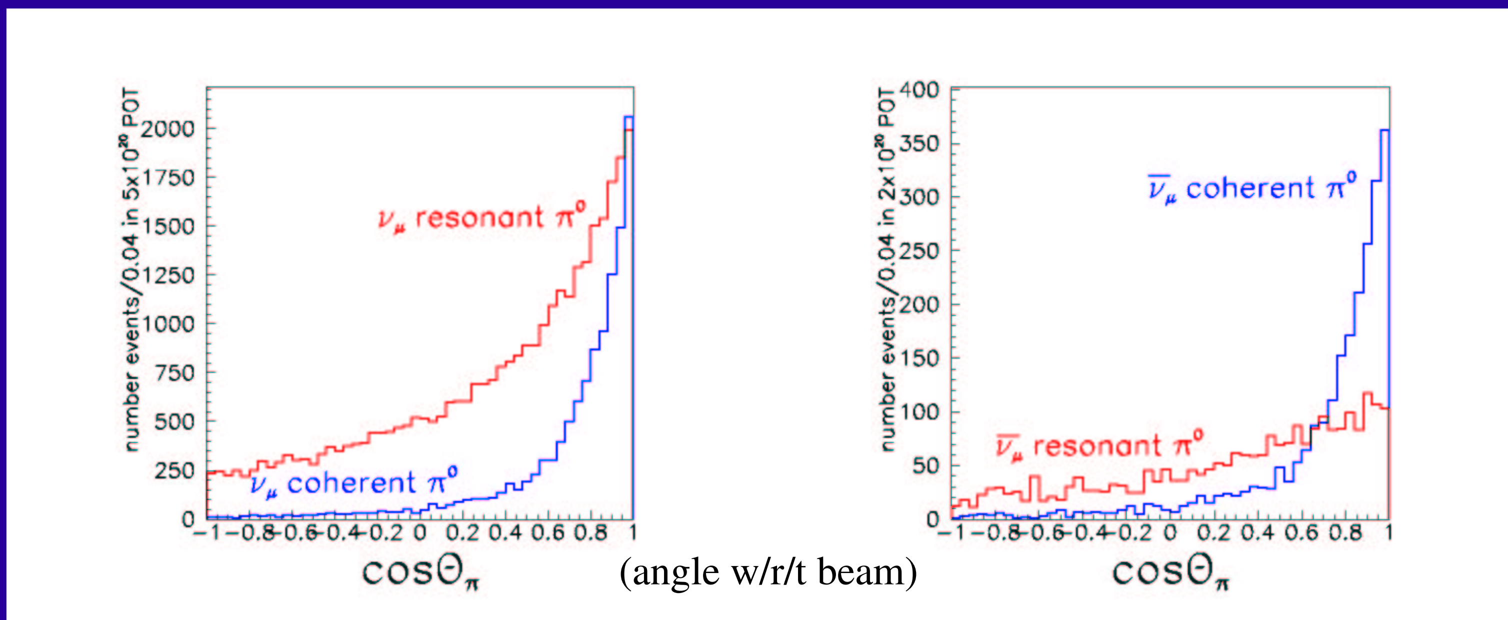
Cross Sections: NCπ^0



Existing data set:

There are **<u>NO</u>** published $\bar{\nu}$ measurements in our range
(one published measurement of a single data point at 2 GeV)

antineutrinos isolate the coherent contribution:



Range of ν-mode predictions
(compared to resonance):

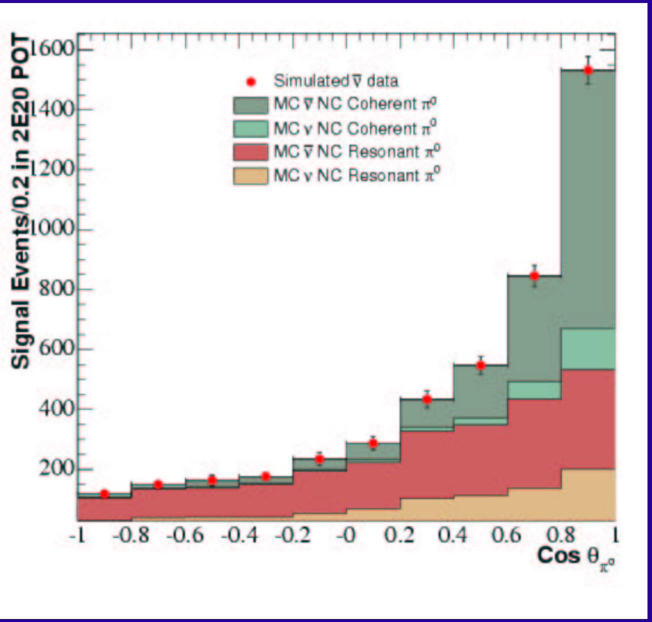
50% (shown) $\rightarrow$ 5%

Coherent is not hit by the
helicity suppression
(& lower E helps too)...

Planned NCπ^0 Analysis:

Points:

extracted number of signal π^0 events in each bin using our neutrino-mode analysis technique



Soild:

breakdown of the signal by type

Goals:

1. Distinguish between the mechanisms:
   In most forward bin,
   We expect between 100 and 1000 coherent events with Nuance compared to ~500 resonance events.
2. Make a measurement valuable to other oscillation experiments
   Backgrounds for $\bar{\nu}\mu \rightarrow \bar{\nu}e$ (MiniBooNE, *et al*)
   Signal for sterile vs. active studies (SK)

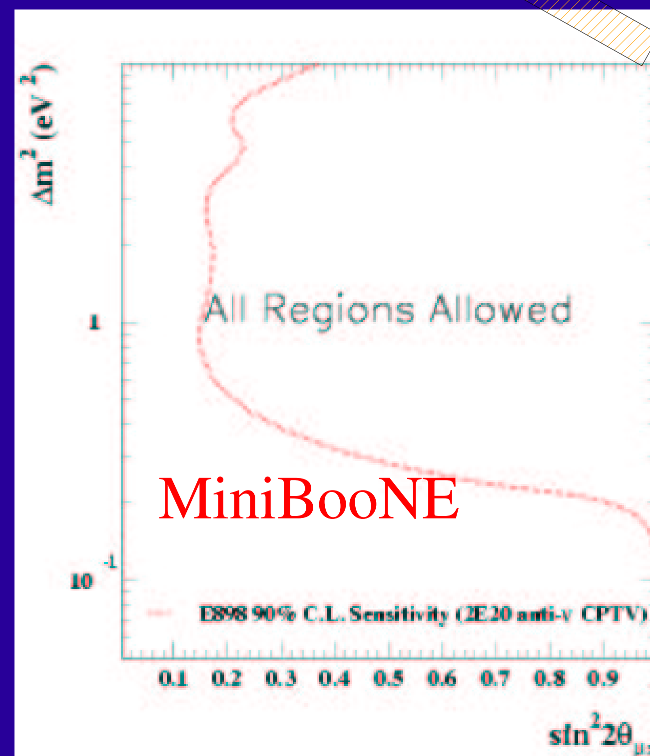
$\bar{\nu}_\mu$ Disappearance

CCFR antineutrino results are up here

Disappearance in antineutrino mode
has not been explored
in our range at all....

Systematics limited after 1 yr of running

If we don't see
a signal in neutrino mode
this is a search for CPT violation
(See, for example, for 3+1 models
Barger, et al, hep-ph/0308399)



Summary of analyses in FY06

If we see a signal in neutrino mode,

We will choose the best running mode to pursue it further.

FY06 running will be very important.

Should we confidently exclude LSND in neutrino mode

- We plan to embark on antineutrino running
- We have identified interesting analyses

  cross section measurements & new physics searches

  All of which can be done with 2E20 POT
- More ideas are under development
- We see this as the first step in a long term antineutrino run.

This plan is "ready to go" ...

The necessary power supply for running in antineutrino mode was purchased by LANL in 2002.
(Not yet tested, but we expect no problems since change in circuit is straightforward)

The absorber to allow 25 m running was installed when the beam was constructed.

The detector is running well.

State of The MiniBooNE Collaboration in FY06...

U. Alabama, Bucknell U., U. Cincinnati, U. Colorado,
Columbia U., Embry Riddle Aeronautical U., Fermilab,
Indiana U., Los Alamos, Lousiana State, U. Michigan,
Princeton, St Mary's of Minn., Westerm Il., Yale

8 full-time graduate students (2 graduating this spring)
3 new full-time graduate students expected next summer

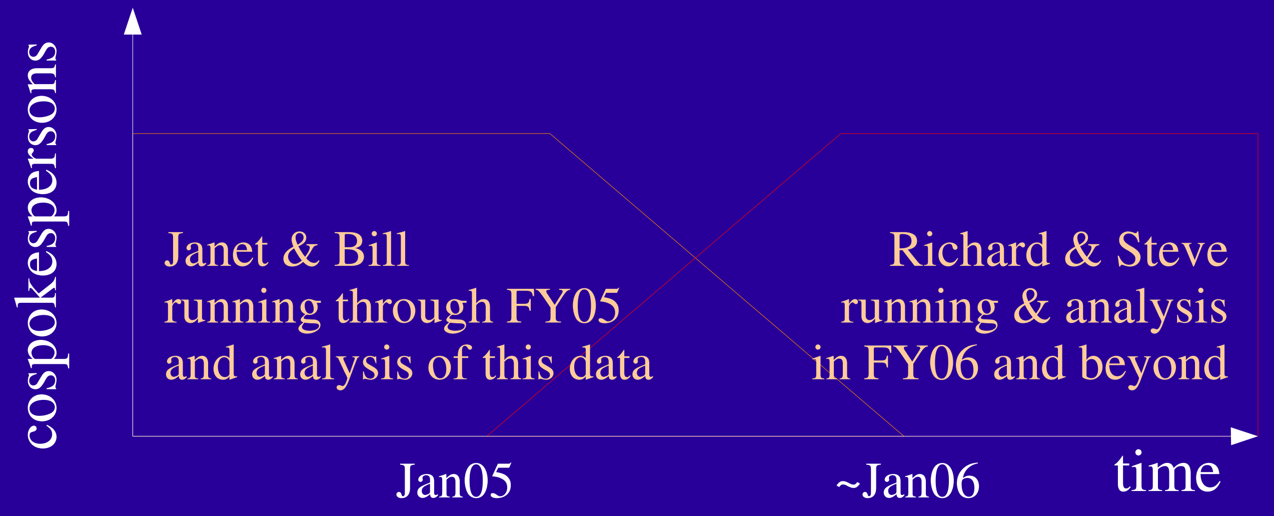
9 post docs presently
(3 found faculty/scientist-level positions last year,
3 are seeking this year)
3 new postdocs to arrive this winter

The collaborators are committed to FY06 running and beyond

The split between the initial neutrino running
and FY06 and beyond
is an optimal time to change cospokespersons...

Janet and Bill will look after all issues related
to the run through FY05 & analysis

starting in January,
Steve Brice and Richard Van de Water
will be responsible for all issues related
to the run starting FY06 and beyond



Our Request to the PAC

This extension to the MiniBooNE Run Plan is written in response to the Director's recent communication. In his letter, "Prospects for the Booster Neutrino Beam," dated August 6, 2004, the statement was made:

> *Collaborations proposing experiments to run in the Booster neutrino beam in FY2006 and beyond should plan their physics program on the basis of* $1 - 2 \times 10^{20}$ *POT per year. Proponents may want to discuss what additional physics could be done with somewhat more protons, but they should understand that is beyond our present expectations for the beam.*

On the basis of this letter and the compelling physics case presented in this document, we ask the PAC to endorse that:

- $1 - 2 \times 10^{20}$ POT be delivered in FY2006 to the Booster neutrino beam line; and
- higher proton intensity should continue to be vigorously pursued.

We ask the PAC to endorse our strong physics program for FY2006. As per the request of the Director, we have also outlined the beginning of a multi-year program which we plan to present in the future.