"All the Nu's that's fit to print"

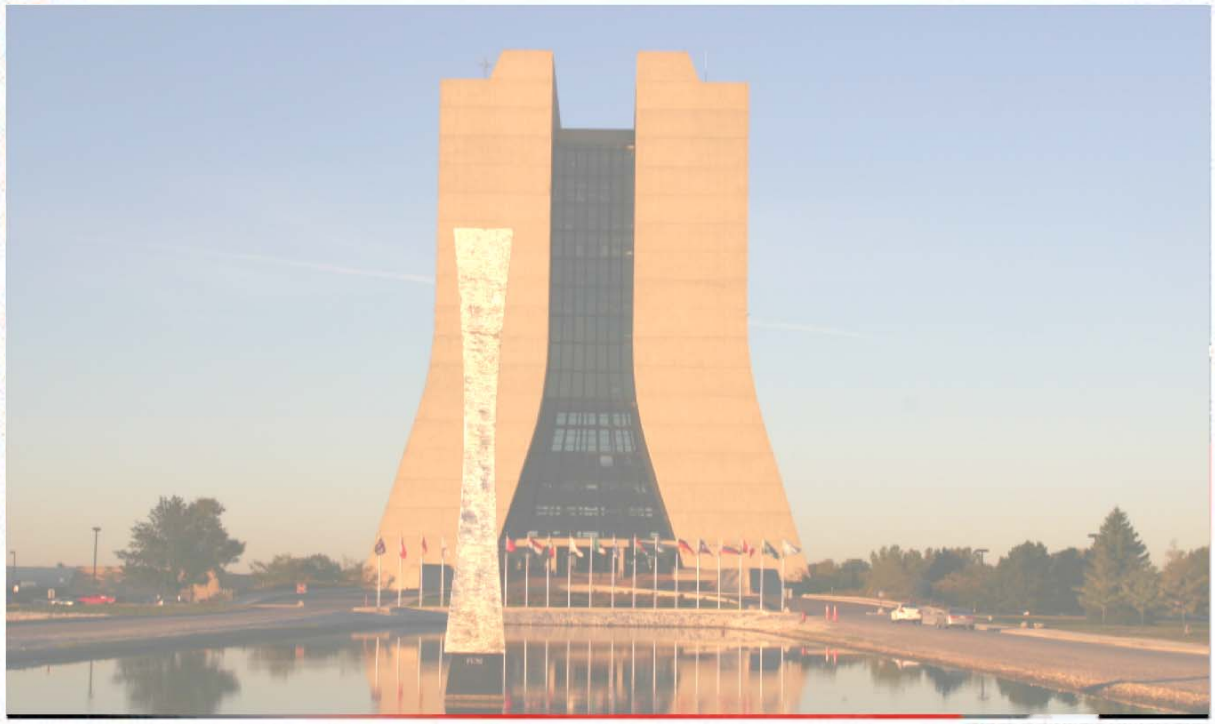
The Neutrino Nu's

Late Edition

Today, mostly sunny, light winds, high 69. **Tonight,** increasing clouds, spotty showers late, low 56. **Tomorrow,** clouds, a little sun, milder, high 73. Weather map is on Page B14.

VOL. CLVIII . . No. 54,457 © 2008 The New York Times NEW YORK, WEDNESDAY, OCTOBER 8, 2008 $1.50

Neutrinos Exhibit Quantum-Mechanical Oscillations



Fermilab: Home to Physics Beyond the Standard Model? Director Pier Oddone Charts New Course

Japan and Europe Catching up with their own facilities

By ADAM NAGOURNEY

Senators John McCain and Barack Obama debated for 90 minutes on Tuesday night before a nation in economic crisis, each

Mr. Obama placed the blame for the financial crisis on deregulation and the lack of fiscal discipline under President Bush,

Experiment still pushing for CP Violation in Neutrinos

By ERIC SCHMITT

WASHINGTON — An investigation by the military has concluded that American airstrikes on Aug. 22 in a village in western

the raid, and the American military, under Gen. David D. McKiernan, the top American military commander in Afghani-

FNAL MINOS EXPERIMENT POSTS NEW RESULTS ON NEUTRINO OSCILLATIONS

Mixing like quarks, implications beyond Standard Model

By EDMUND L. ANDREWS and MICHAEL M. GRYNBAUM

WASHINGTON — The promise of lower interest rates and new federal efforts to stem the financial crisis failed to dispel the fear gripping Wall Street on Tuesday.

Stocks rose at the session's opening but soon began to fall, and the selling intensified during the afternoon, even after Ben S. Bernanke, the chairman of the Federal Reserve, all but pledged to cut interest rates by the end of the month. The Dow Jones industrial average plunged 508 points, or 5.1 percent, extending a slide of months that has erased a third of its value in a year. In the last five trading days alone, the Dow has lost 1,400 points.

With the flow of credit still tight, investors have fixated on the threat of a serious recession despite the increasingly urgent attempts by policy makers to buttress the markets. Deepening problems in the European banking industry have compounded fears of a worldwide downturn.

"The Fed is just plugging holes in the dam and the water keeps rushing over," said Michael T. Darda, chief economist at the research firm MKM Partners.

In a somber speech, Mr. Ber-

strongest indication to date that the Fed will cut rates.

Fed policy makers are scheduled to meet on Oct. 28 and 29, and investors had already been betting that the central bank would reduce the overnight federal funds rate by as much as one-half of a percent, to 1.5 percent. But many analysts predict the Fed may act before the next meeting, given the sprawling nature of the credit crisis.

In its latest tactic, the Fed announced on Tuesday morning a new program to buy up parts of the short-term financing market to unlock the flow of credit to businesses. The program, which is expected to begin soon, was the latest and potentially biggest in a series of unprecedented ef-

Continued on Page A23

Dow Industrials

Neutrinos Don't Decay or Decohere

And don't forget the "LSND Effect," C. Athanassopoulos et al., Phys. Rev. Lett. 75, 2650 (1995)

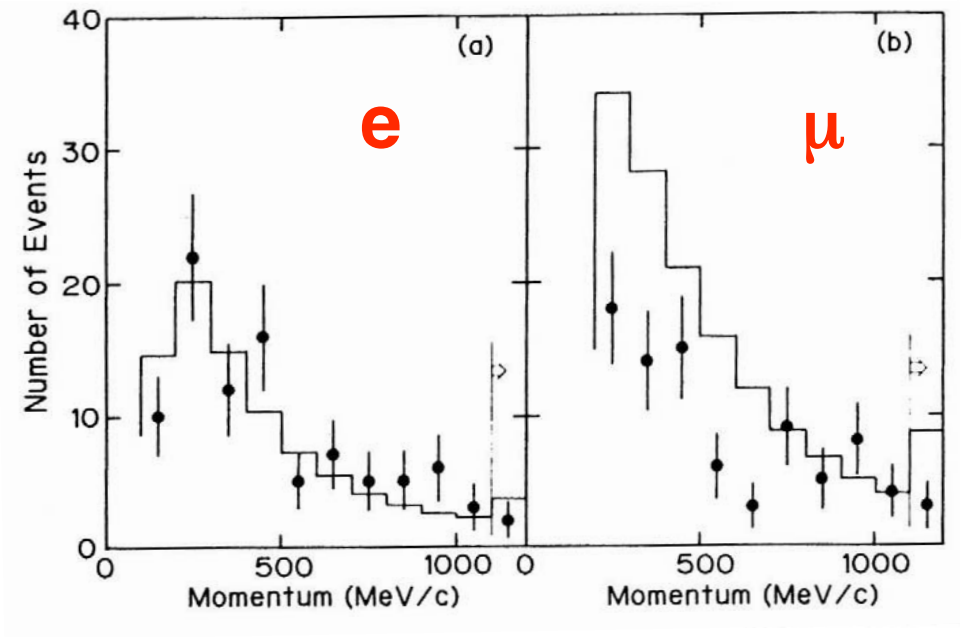
NEUTRINO CHRONICLE

chron.com THURSDAY, MAY 28, **1989** ★★★ VOL. 108 • NO. 227 • $1.00

ATMOSPHERIC NU "ANOMALY"

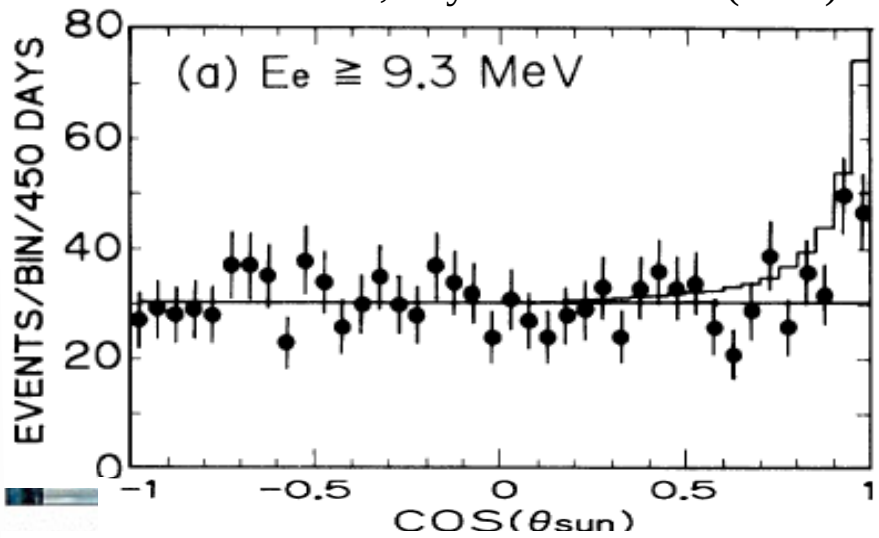
EXPERIMENTAL STUDY OF THE ATMOSPHERIC NEUTRINO FLUX.
KAMIOKANDE-II Collaboration (K.S. Hirata *et al.*), Phys.Lett.B205:416,1988

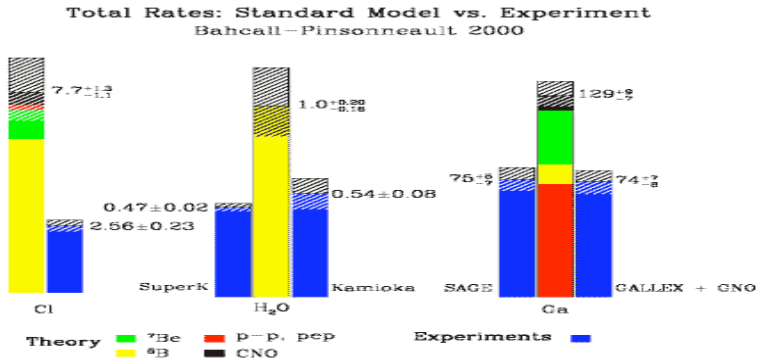
"At present this is highly speculative – there is no experimental evidence for neutrino oscillations…"
– D.J. Griffiths (1995), *Introduction to Quantum Mechanics*



Solar Neutrino "Problem"

K.S.Hirata et al., Phys. Rev. Lett. 63(1989) 16





ALL THE NEWS WITHOUT FEAR OR FAVOR

The Japan Times

113TH YEAR NO. 39,536 | ISSN 0289-1956 ©THE JAPAN TIMES, LTD., 2009 | Wednesday, May 27, 2009 | 4TH EDITION ¥180 | Consumption tax included (¥8 in ¥172)

水

TODAY

■ NATIONAL

Greenhouse goal

Environment Minister Tetsuo Saito suggests that Japan might adopt 15 percent as its target for greenhouse gas cuts for 2020.

Page 2

■ WORLD

Hispanic appeal

U.S. President Barack Obama taps U.S. Circuit Judge Sonia Sotomayor for the Supreme Court, officials say, making her the first Hispanic in history picked to wear the robes of a justice.

Page 5

■ BUSINESS

Future looks bright

Showa Shell aims to grow its share of the global solar panel market to 10 percent by 2014, up from less than 1 percent now.

Page 7

■ MARKET DATA

EQUITY INDEXES

Tuesday, Close

Topix	883.77	0.77
Nikkei 225	9,310.81	36.19
Dow*	8,277.33	UNCH
Nasdaq*	1,882.01	UNCH

TOKYO FOREIGN EXCHANGE

Tuesday, 5 p.m.

¥/$	94.65-67	.34

Super Kamiokande Exp't Observes Zenith Angle-Dependent Loss of ν_μ, not ν_e

Seoul
Test for Obama: Page 5

North Korea reportedly tested two more short-range missiles Tuesday, thumbing its nose at global powers just hours after the U.N. Security Council condemned the regime's provocative nuclear test.

Pyongyang also warned ships to stay away from waters off its western coast this week, a sign the country may be gearing up for more missile tests, South Korea's coast guard said.

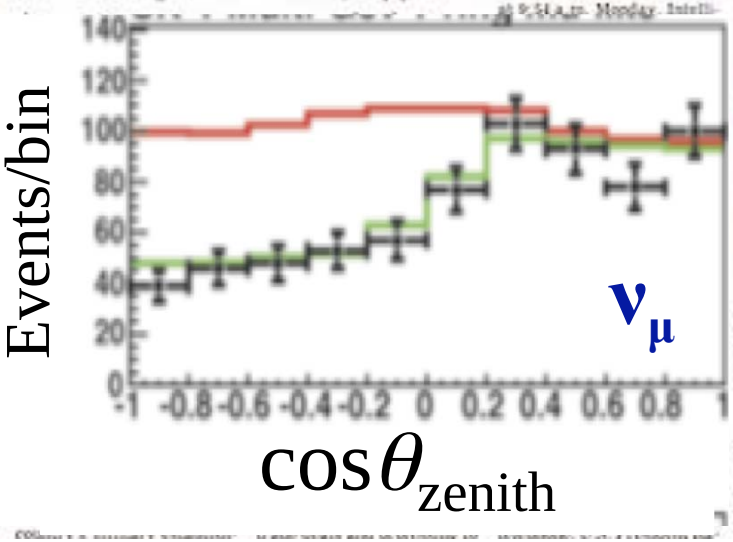
North Korea appeared to be displaying its might a day after conducting an atomic test in the northeast that the U.N. Security Council condemned as a "clear violation" of a 2006 resolution banning the regime from developing its nuclear program.

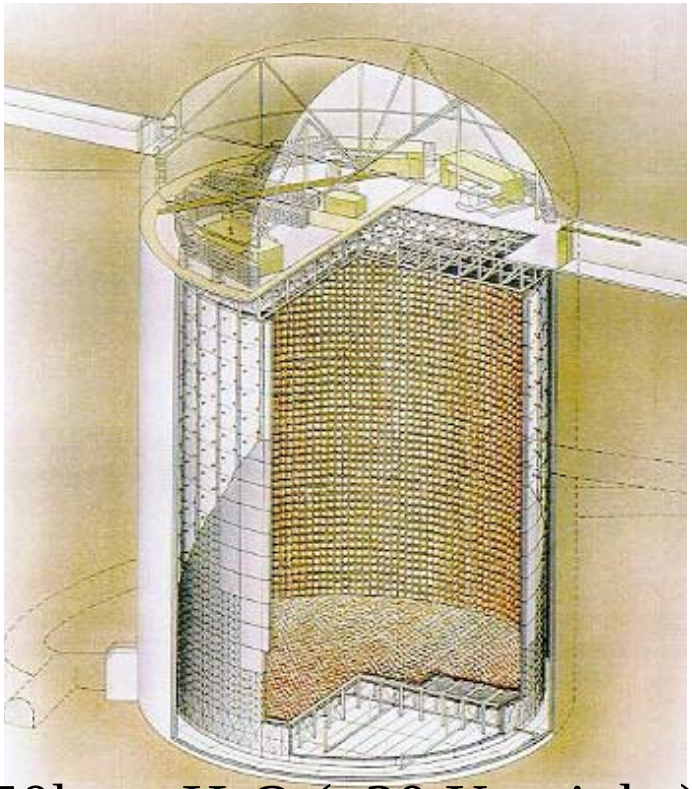
France called for new sanctions, while the U.S. and Japan pushed for strong action against North Korea for testing a bomb that Russian officials said was comparable in power to those that obliterated Hiroshima and Nagasaki during World War II.

However, many questioned whether new punishment would have any effect on a nation already penalized by numerous sanctions and clearly dismissive of the Security Council's jurisdiction.

Monday's nuclear test appeared to catch the world by surprise, but South Korea's spy chief told lawmakers Beijing and Washington knew Pyongyang was planning a test some 20 to 25 minutes before it was carried out, said Choi Kyu Ha, an aide to lawmaker Park Young Sun.

Russia said the test went off





50kton H_2O (x30 Kamioka)
SK-I – ('96-'00) and SK-III ('03 –) 11100 PMTs,
SK-II (2000-2003), 5200 PMTs

Hiroshima

A digital counter on the "peace clock" monument at Hiroshima Peace Memorial Museum

In the 12th reset since the clock was established by a peace group in August 2005, the digital counter was changed to one from 960 — the number of days since the last nuclear test

tests since the clock debuted.

The monument was produced and donated to the museum on the 50th anniversary of the Hiroshima bombing.

The 3.1-meter-tall monu-

First expt showing dynamic loss of ν's

Masami Ito and Jun Hongo
STAFF WRITERS

The government Tuesday welcomed the U.N. Security Council's quick opposition to North Korea's nuclear test but continued to scramble for a fresh response to Pyongyang's latest provocation.

Prime Minister Taro Aso and U.S. President Barack Obama agreed during a phone conference in the morning that Pyongyang's nuclear test was "a serious threat to the peace and stability of Northeast Asia and the international community," and that a swift adoption of a U.N. resolution against the reclusive state is necessary.

They also confirmed that Japan, the U.S. and South Korea will cooperate more closely over North Korea and stressed the importance of coordinating with China and Russia.

Chief Cabinet Secretary Takeo Kawamura said the government plans to hold phone conferences with the Chinese and Russian leaders.

He said he had not received word of whether Japan would draft a U.N. resolution but refused to rule out the possibility.

"I have not received a clear report on whether Japan will draft the resolution or not," Kawamura said. "But considering that we asked for a Security Council (meeting), I believe that Japan is fully capable of playing a central role in the discussions."

The government's top

ν Mixing in the Precision Era

- PMNS: a 3×3 unitary transformation to mass states:

$\sin\theta_{solar} < 0.62$ (*Smirnov, hep/0309299*)

Is this *non-zero???* Large enough to measure CP in $\nu_\mu \rightarrow \nu_e$

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

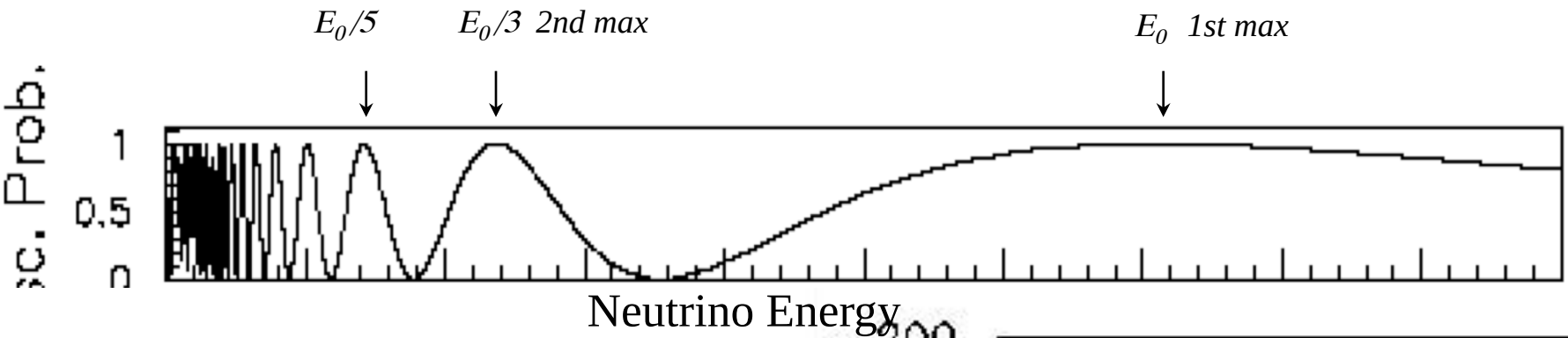
$c_{ij} \equiv \cos\theta_{ij}$ $s_{ij} \equiv \sin\theta_{ij}$

Is the mixing angle truly *maximal???*

- In the quarks, matrix has phase $\delta \neq 0$ responsible for C⁄P.

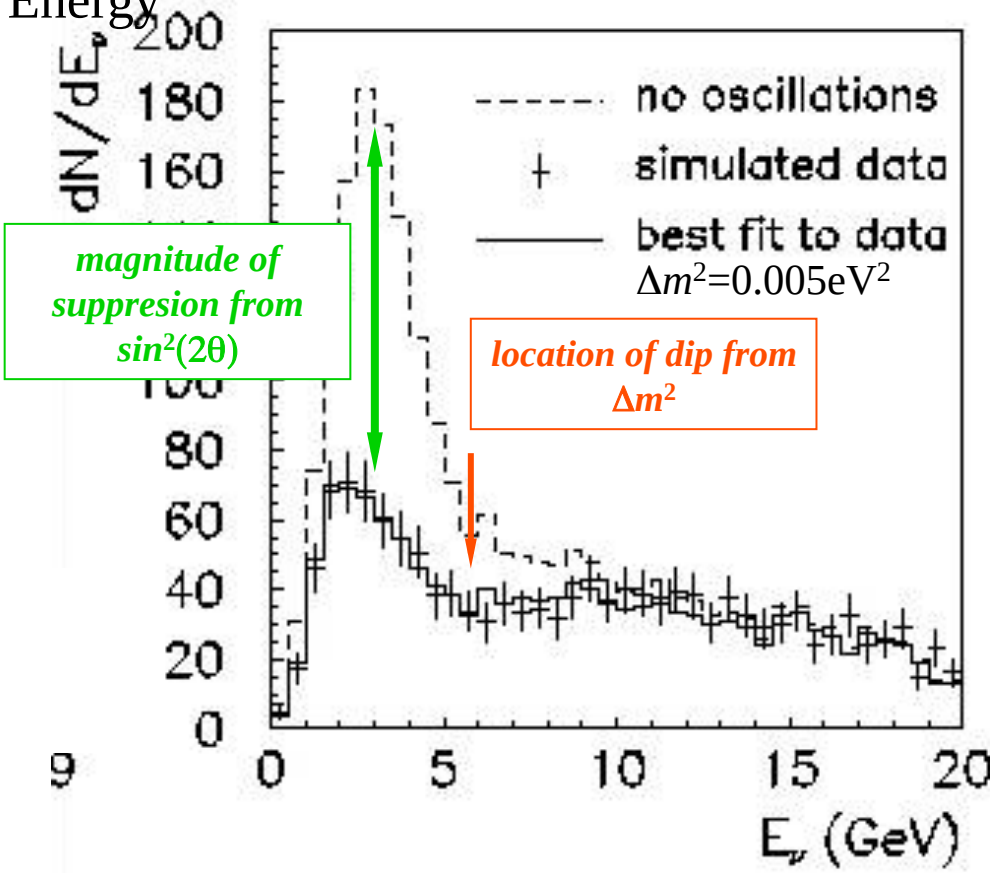
$$P(\nu_\mu \rightarrow \nu_\tau) = \sin^2 2\theta \sin^2\left(1.27 \frac{\Delta m^2 L}{E_\nu}\right)$$

Interpretation of Oscillation Results



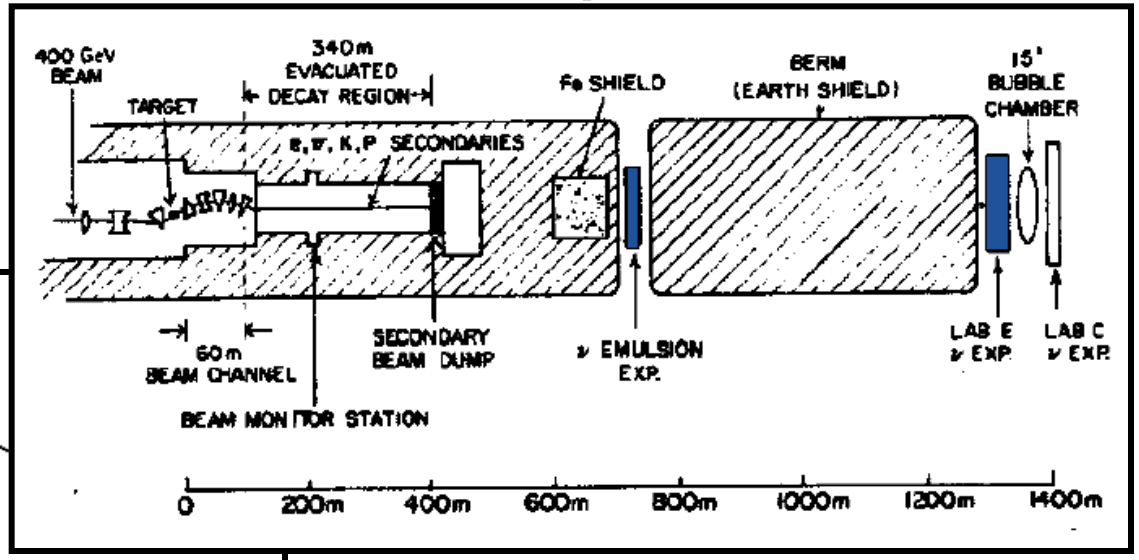
$$P(\nu_\mu \rightarrow \nu_\tau) = \sin^2 2\theta \sin^2\left(1.27\frac{\Delta m^2 L}{E_\nu}\right)$$

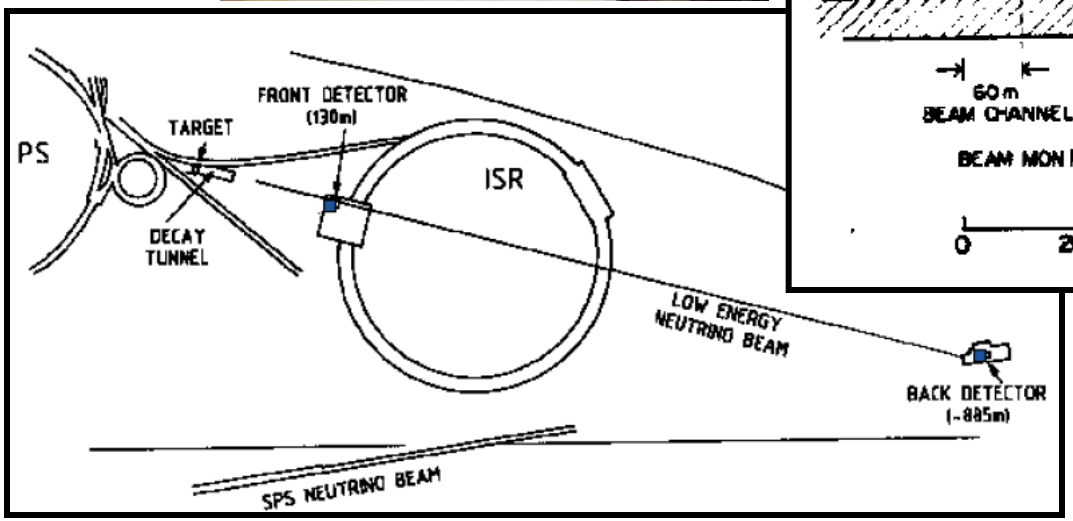
- Oscillations into unknown flavor causes dip in obvserved spectrum.

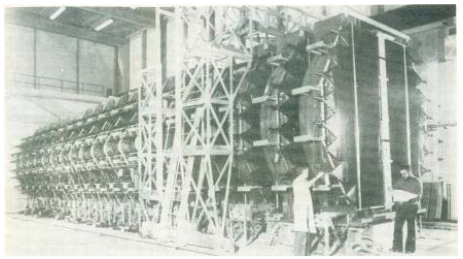


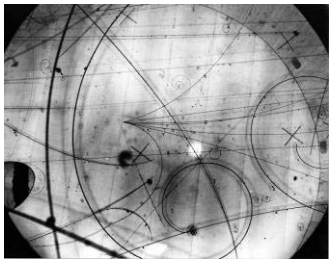
Two Detector ν Experiments

FNAL CCFR experiment, 1982-83









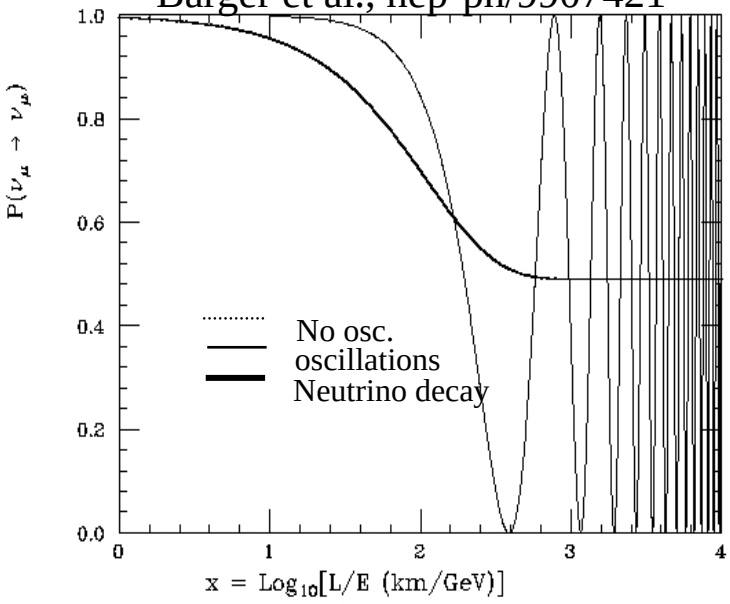
CERN CHARM/CDHS experiments, 1982-83

- Near detector predicts ν energy spectrum and rate at far detector (asssuming an absence of oscillations)
- Greatly reduces systematic uncertainties due to calculating beam flux.

Alternatives for ν_μ Disappearance?

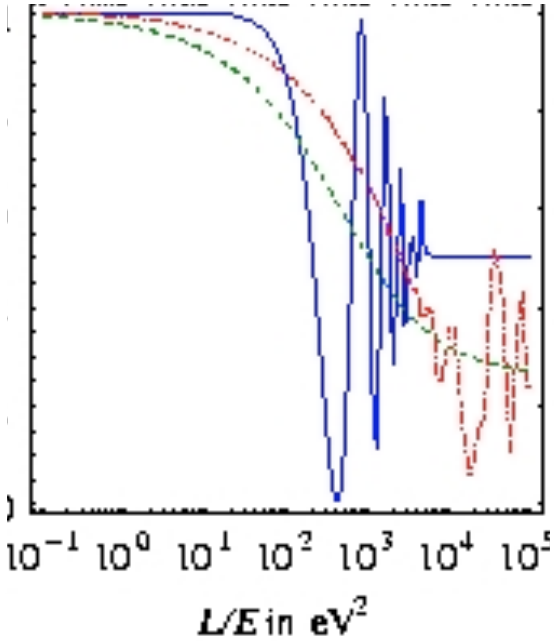
"Neutrinos actually decay to lighter states"

Barger et al., hep-ph/9907421



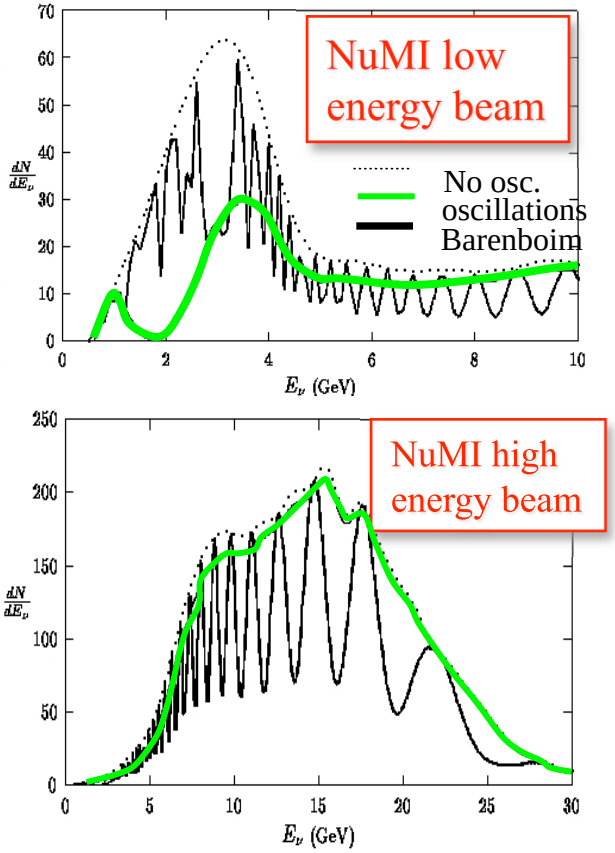
"Neutrinos propagating in Extra Dimensions"

Barbieri et al., hep-ph/9907421



"SuperK effect is combination of Δm^2(solar) and Δm^2(LSND)"

Barenboim et al., hep-ph/0009247



- All of these models modify expected L/E_ν shape.
- Other models will surely come along in coming years?
- Reasonable to consider hybrid osc+NP scenarios?

Long Baseline Times

latimes.com

COLUMN ONE

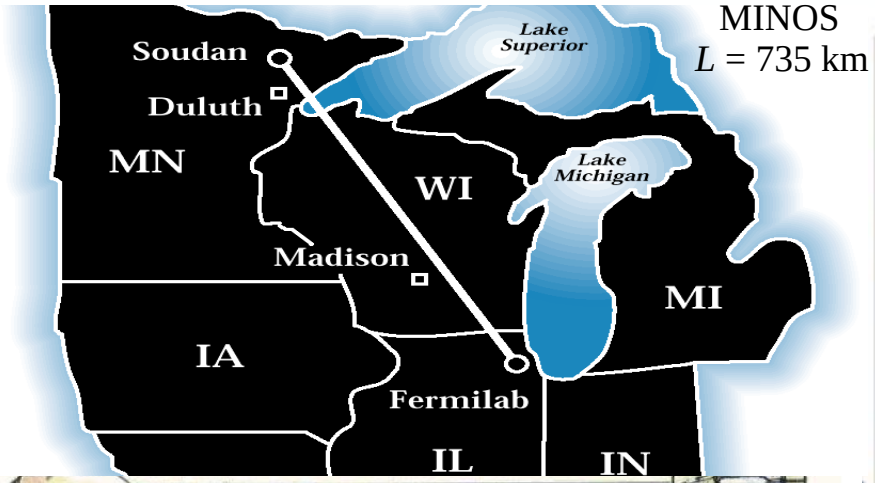
Exp'ts in U.S. Japan, Europe

MINOS:
200 scientists,
23 universities
& laboratories

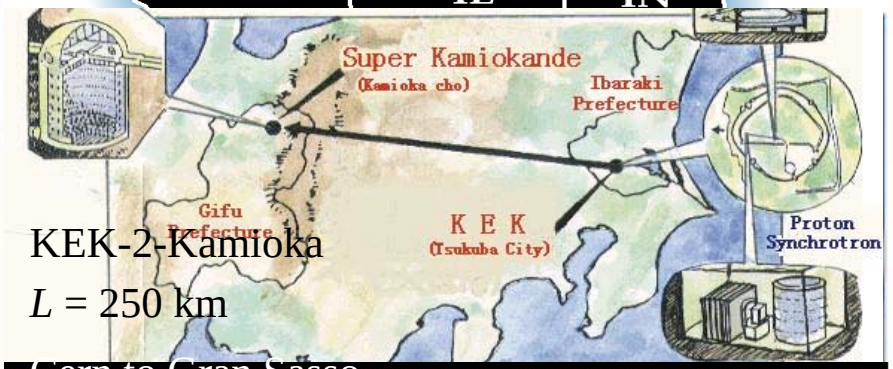
Hiba Qassir dreams of making movies. She's ambitious and precocious enough. At 18, she's taught herself how to edit video and sound on a computer, and has her sights set on directing gripping social and psychological dramas.

But if the movie business doesn't work out, that's OK. She has other dreams: perhaps to become a cop or a pilot. Or maybe a suicide bomber.

"Martyrdom is the shortest way to heaven, and the history



MINOS
L = 735 km



KEK-2-Kamioka
L = 250 km

Cern to Gran Sasso
L = 750 km

Reproduce Atmospheric Effect With Controlled Accelerator Beam

"Thank Goodness Earth is Round" – A. Zichichi

Fire chiefs in tinder-dry Southern California, faced with lean budgets while more people squeeze into the region, are starting to rethink long-standing policies on ordering mass evacuations in a wildfire, debating whether it may be wiser in some situations to let residents stay and defend their homes.

"We don't have enough resources to put an engine at every house in harm's way," said Ventura County Fire Chief Bob Roper. "We figure, if people are going to stay, maybe they can become part of the solution."

Borrowing from tactics used in Australia for nearly two decades, top officials from fire

Freeman, chairman of Firescope.

Roper acknowledges that building consensus for the program will be difficult and could take several years. But he hopes that eventually the entire state will follow stay-and-defend guidelines.

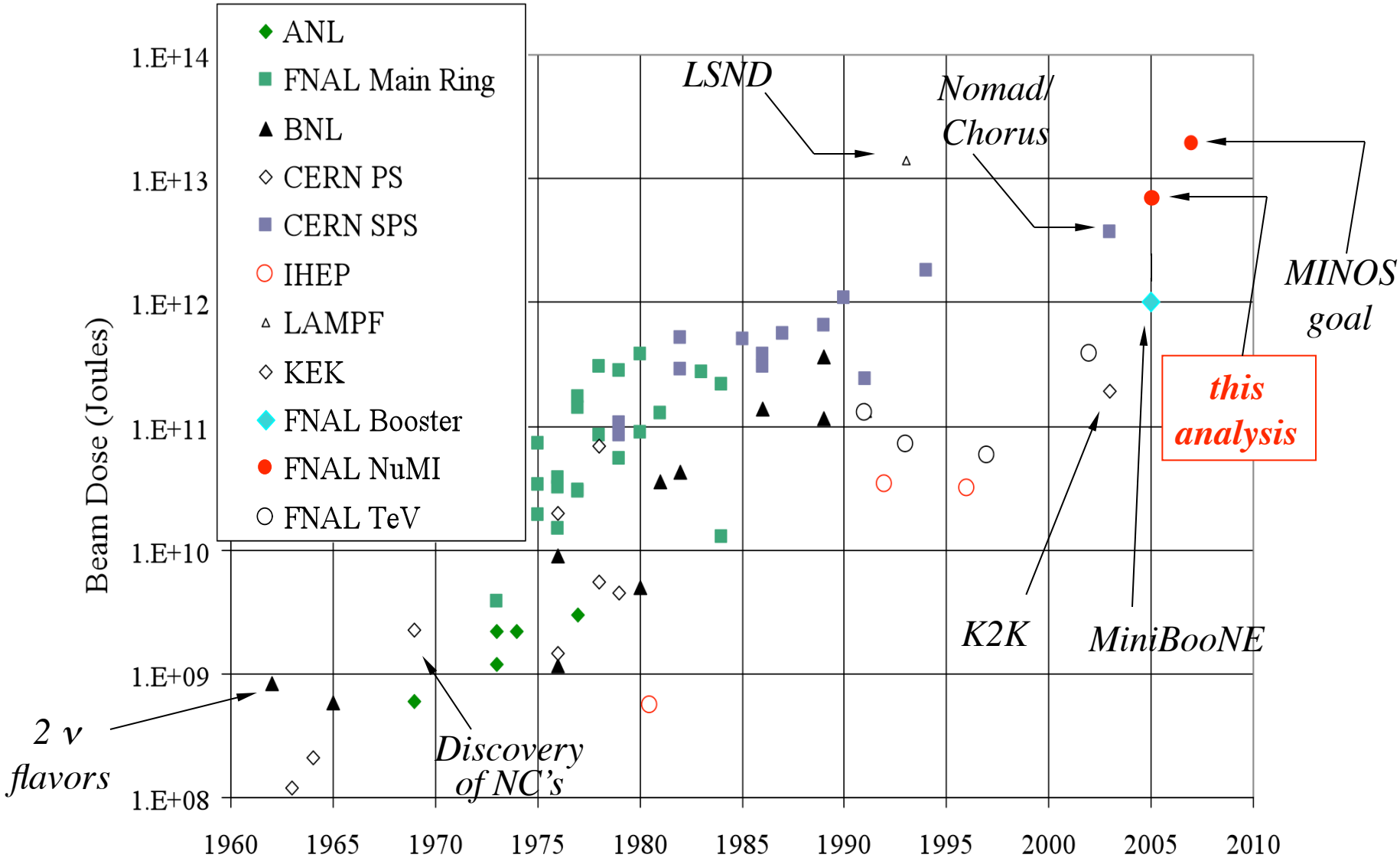
"This is a paradigm shift," he said. "We can't do it overnight."

Roper has been holding

[See Wildfires, Page A13]

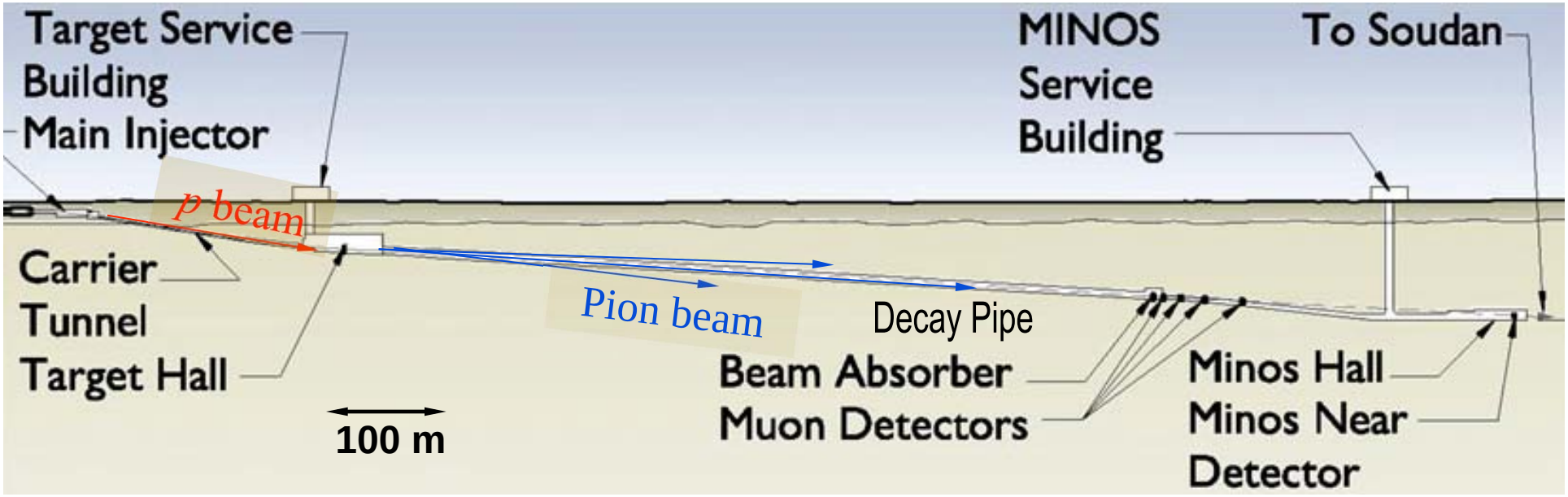
Near Detector
980 tons
Far Detector
5400 tons
L ~ 734 km

Moore's Law for Neutrinos?



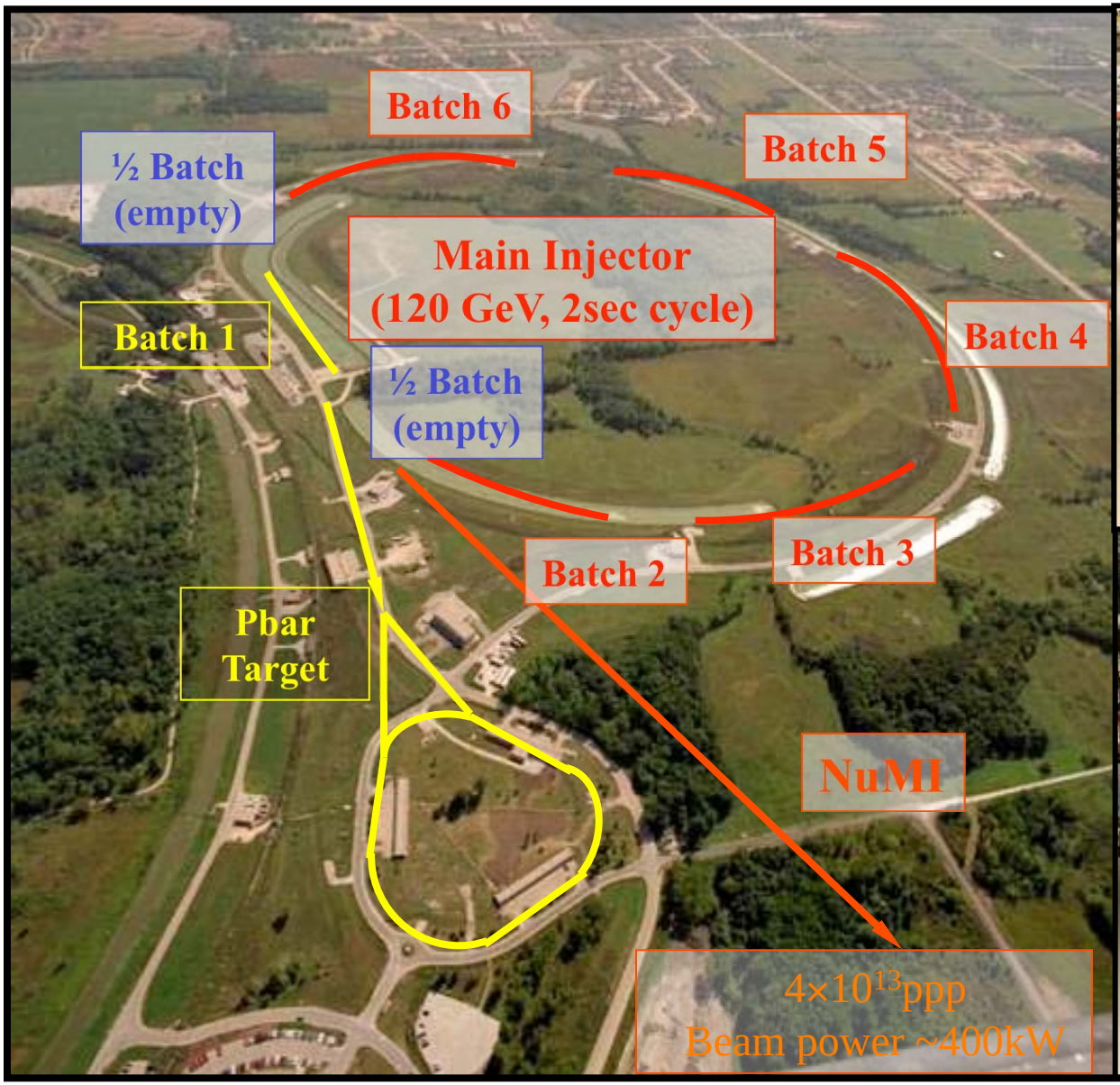
S. Kopp, "Accelerator Neutrino Beams,"
Phys.Rept. **439**: 101-159 (2007)

NuMI: "Neutrinos *at the* Main Injector"



- Neutrinos produced from $\pi^+, K^+ \rightarrow \mu^+\nu_\mu$ (*or* $\pi^-, K^- \rightarrow \mu^-\bar{\nu}_\mu$)
- NuMI beam aimed at Soudan Underground Lab. (Minn, USA).

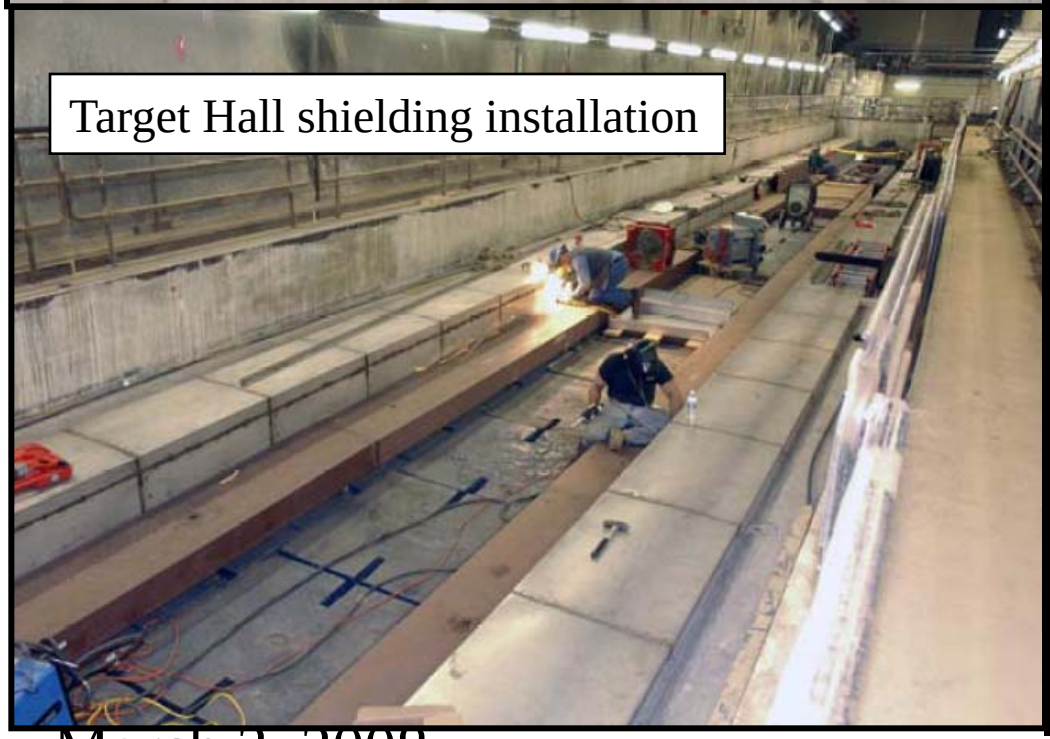
NuMI: "Neutrinos *at the* Main Injector"




Angling down
Final Bend Toward Soudan
Extracted Proton Beam Line
Final Focus to NuMI Target Hall
Shielding Wall to Target Hall
Toroid
Final BPM's+ SEM's

Target Hall


Target Hall after Contractor completion
Decay pipe

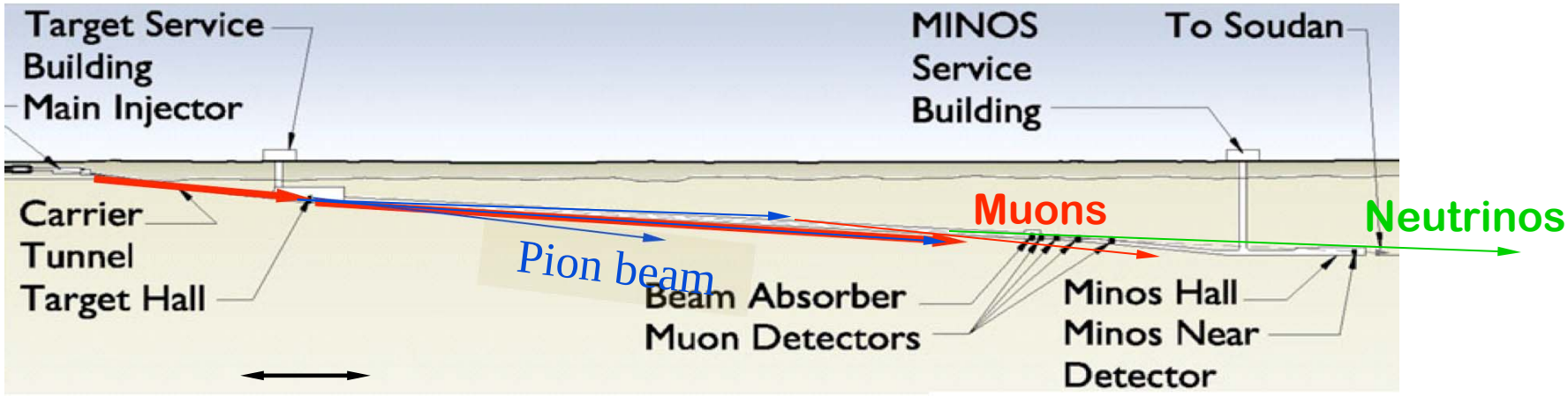

Target Hall shielding installation

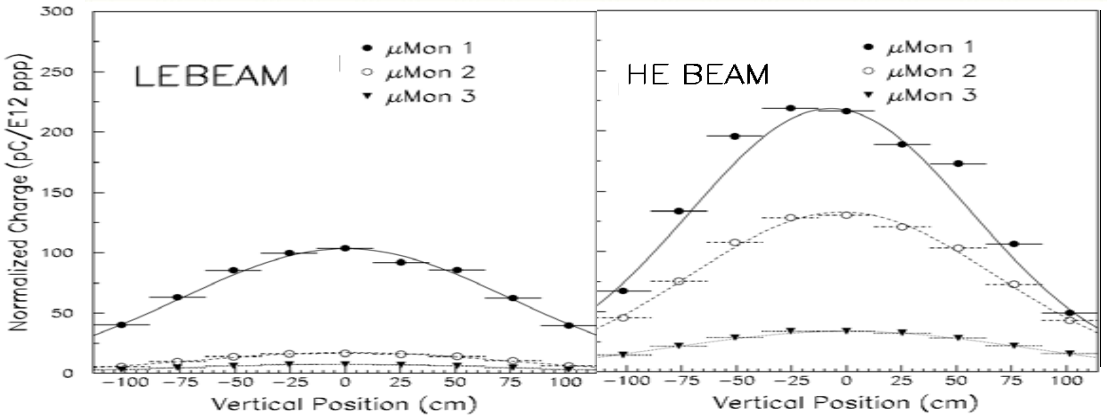

Horn 2 suspended from shielding module being lowered into shielding pit

Beam Commissioning Runs

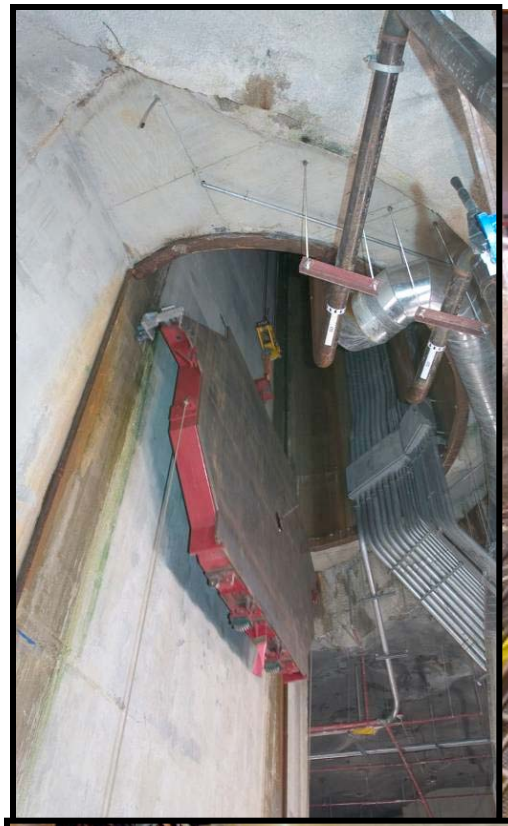
Dec., 2004 -- Mar., 2005

- Sequenced commissioning of primary (proton), secondary (meson), and tertiary (muon+neutrino) beams.





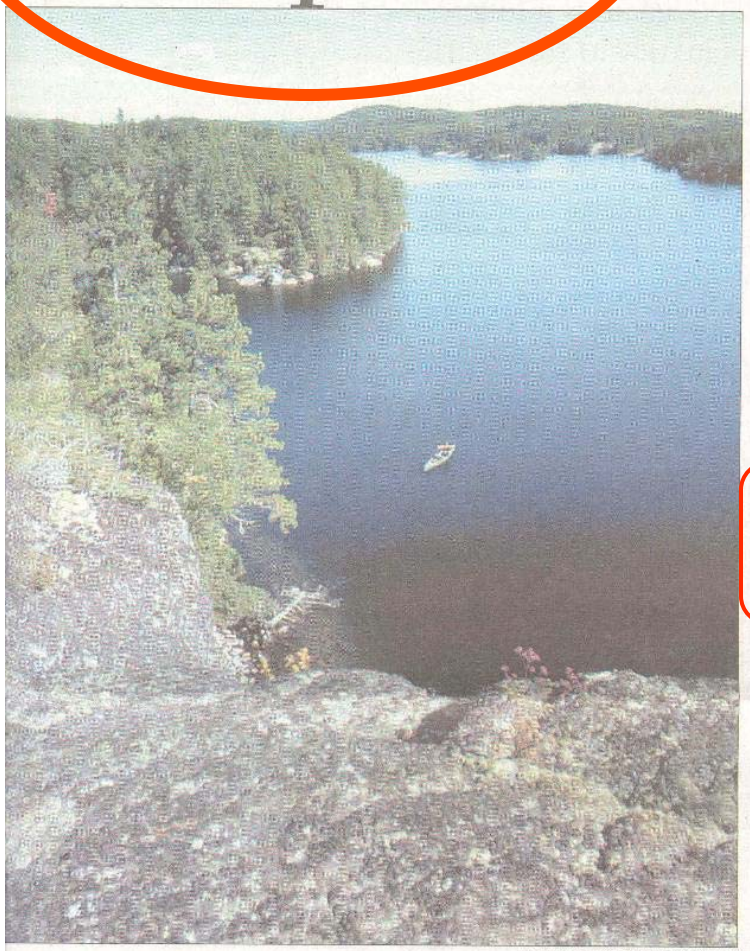
MINOS Near Detector




MINOS Far Detector
magnetized Fe-scintillator calorimeter
segmented scint for X, Y tracking
485 planes, 8m diam, 5400 tons
25TON
485

Bound to impress

Canoes glide through Minnesota's vast unspoiled trove of lakes and wilderness



You can canoe all day without seeing another person in the Boundary Waters Canoe Area Wilderness, which has more than 1,500 miles of water trails. The area is the largest wilderness preserve east of the Rocky Mountains.

ELY, MINN. CHAMBER OF COMMERCE PHOTOS

By Beth Gauper
SAINT PAUL PIONEER PRESS

Along Minnesota's northern border with Canada, more than 200,000 people a year find an increasingly rare commodity — absolute wilderness.

The million-acre Boundary Waters Canoe Area Wilderness is barely changed since voyageurs used its chain of lakes and rivers to push deep into the continent's interior. Today, the foot trails over which they carried canoes and 180-pound packs are used by vacationers, who wind their way from lake to lake in search of the perfect combination of woods, water and solitude.

As they paddle along the glassy waters of more than 1,000 lakes, they may see moose, lynx, otters and beaver, who have rebounded from near-extinction at the hands of trappers. In the evening, at nearly 2,200 campsites, they listen for the trill of loons and the howl of wolves, whose numbers also have rebounded.

To people who consider the Midwest flyover land, the BWCA Wilderness puts Minnesota on the map. National Geographic Traveler listed it as one of 50 Places of a Lifetime/The World's Greatest Destinations, along with the Grand Canyon and Big Sur. In the book "1,000 Places to See Before You Die," it's the only Minnesota entry.

Whenever I travel outside the Midwest, people I meet always scan their brains for whatever they know about Minnesota, then ask, "Have you been to the Boundary Waters?"

Last August, I finally took a week and went. And I was surprised. The

See **CANOE**, back page

Rangers, outfitters help you dip your toe in the waters

The easiest way for a beginner to go to the Boundary Waters is with a group or a friend who has good gear to share — lightweight tent, stove and water filter, in addition to the [illegible]. Therma-

Austin *American-Statesman* Newspaper,
Sunday, April 18, 2004

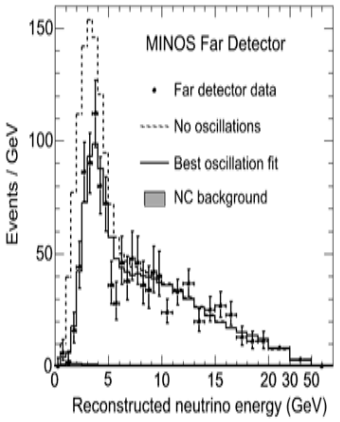
Raison d'Être for a Northern Minnesota Experiment!

To people who consider the Midwest flyover land, the BWCA Wilderness puts Minnesota on the map. National Geographic Traveler listed it as one of 50 Places of a Lifetime/The World's Greatest Destinations, along with the Grand Canyon and Big Sur. In the book "1,000 Places to See Before You Die," it's the only Minnesota entry.

Chicago Tribune
Wednesday
June 15, 2008
50¢ CITY & SUBURBS • $1.00 ELSEWHERE
For breaking news and more, go to chicagotribune.com
CHICAGO

MINOS Experiment: Neutrinos *do* Oscillate

Other theoretical neutrino models disfavored at 4sigma



Tribune photo by Alex Garcia

"We all thought we were going to be rich," Fernando Chavarin says of the agave craze.

Energy-dependent deficit of neutrinos observed

"Where did they go?" – *Pier Oddone*

By Phil Rosenthal
Tribune media columnist

In the parlance of the Cold War era that spawned the federally mandated Emergency Alert System, launch codes were issued throughout Illinois on Tuesday morning, automatically pre-empting dozens of radio and television stations as if the region faced nuclear annihilation.

Rather than President Bush reassuring citizens after an atomic blast or some other calamity, the audience of many Chicago outlets was treated to the sound of dead air followed by the voice of WGN-AM 720 morning man Spike O'Dell struggling to figure out what had happened.

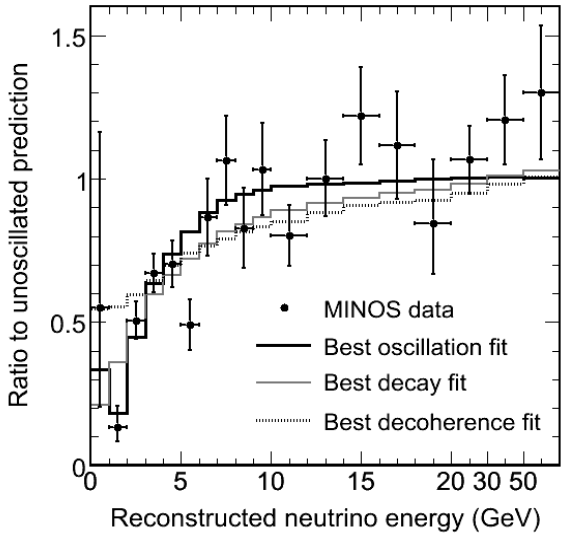
It turns out O'Dell's pair of brief surprise appearances between 7:30 a.m. and 8 a.m. on everything from local public broadcasting to music stations—an "unintentional disruption," a Federal Emergency Management Agency spokeswoman called it—stemmed from a FEMA contractor's installation of the state's Emergency Alert System satellite receiver in Springfield as part of a nationwide upgrade.

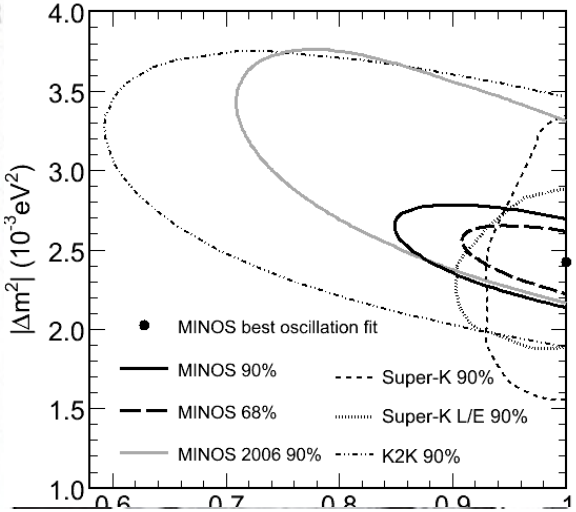
The FEMA spokeswoman said the new Illinois receiver inadvertently picked up a closed-circuit test between receivers in Richmond, Va., and Cleveland.

While the interrupted morning drive-time broadcasts proved the Illinois system worked, the fact that what's known as an Emergency Action Notification, or EAN—the highest level of EAS alert, indicating an emergency message is coming from the White House—could be relayed mistakenly to override stations was a bit of a jolt, sending engineers scrambling at the affected outlets throughout Illinois and in adjacent media markets such as St. Louis.

Compounding the error, an actual presidential code, minus any audio explanation, was sent rather than a lesser alert or a notification of a systems test of

PLEASE SEE EMERGENCY, PAGE 18





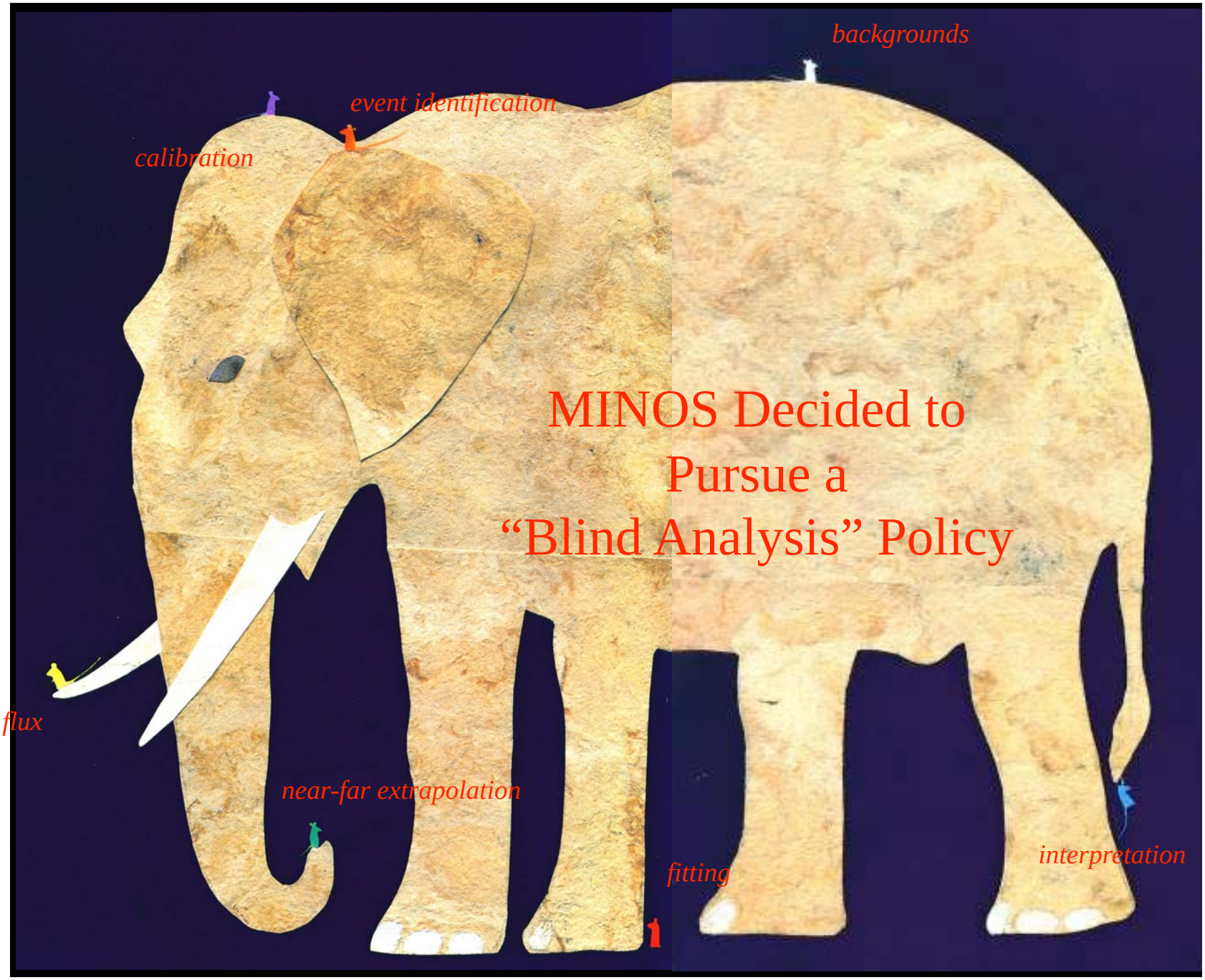
World's most precise oscillation parameters

Neutrino Physics transitions from discovery to precision measurements.

By Tom Hundley

"We all thought we were going to be rich," Fernando Chavarin says of the agave craze.

AHUALULCO, Mexico — Tequila could be the ruin of Fer-

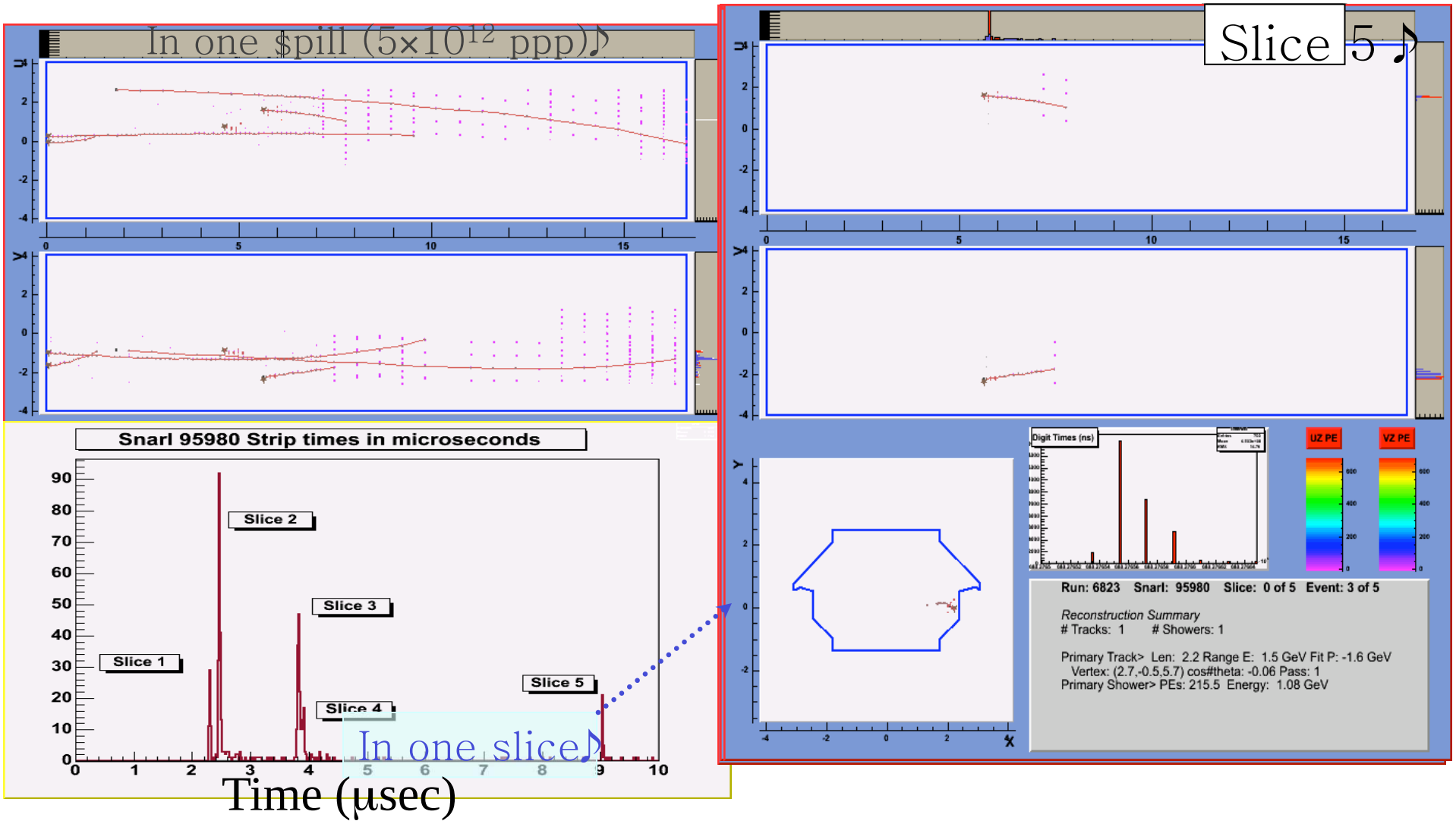

backgrounds
event identification
calibration
MINOS Decided to
Pursue a
“Blind Analysis” Policy
beam flux
near-far extrapolation
fitting
interpretation

Step 1: Look at ND Data

- Hope no gross disagreements with beam MC
- See if neutrino identification is OK

Coping with High Intensity

- 10-20 events/spill in the ND (*cf* 10^{-4}/spill in the FD!)



ND Compared to Beam MC

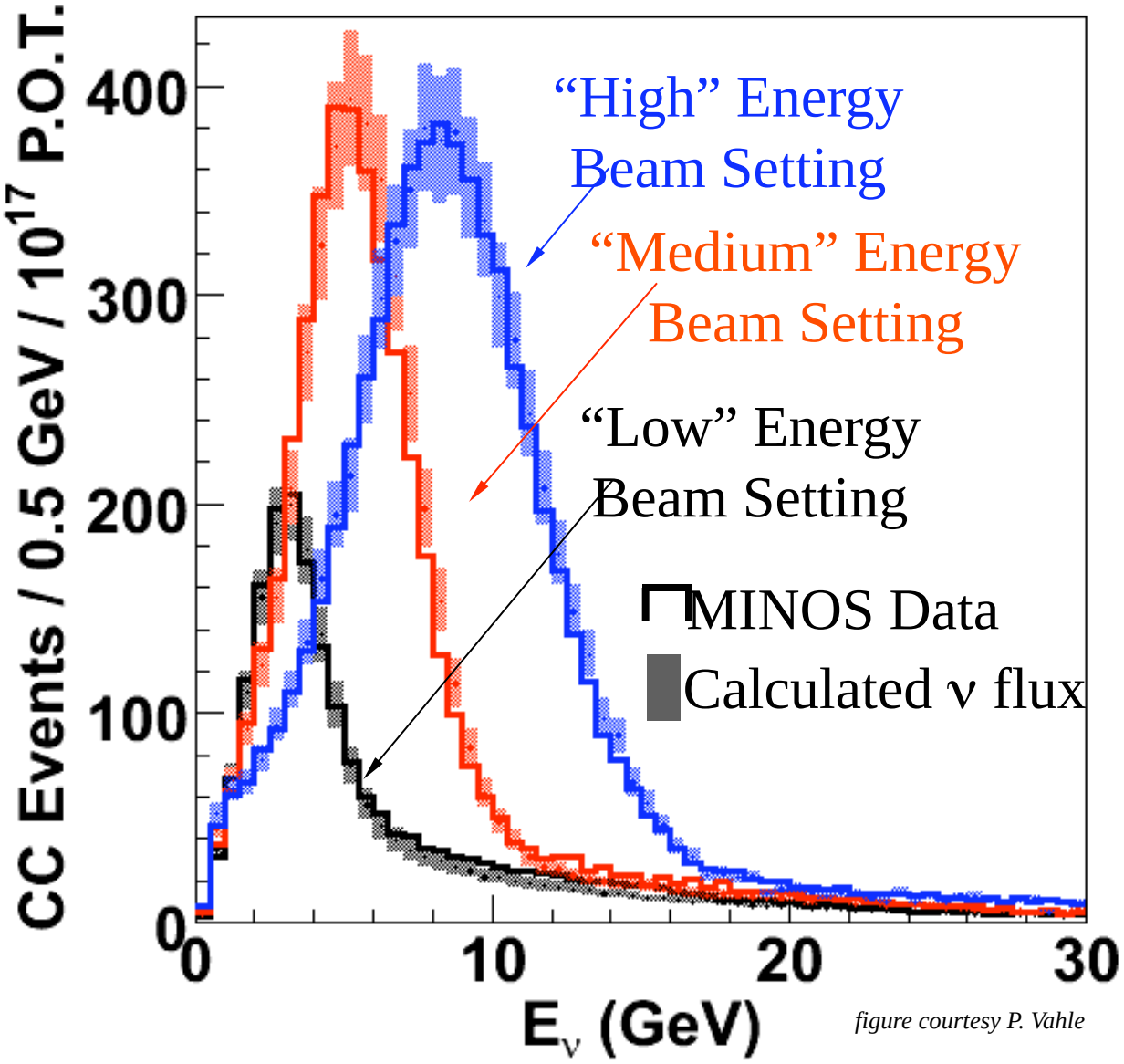


figure courtesy P. Vahle

- These plots show the beam spectrum as "dead reckoned" by Fluka2005 + our tracking MC through the beam line.
- Errors bars from the beam systematics (dominated by π/K production in the target).
- Some real apparent contradictions? MC is low in the LE beam, but high in the ME beam.

Step 2: Decide How to Extrapolate ND → FD

- FD Spectrum = (F/N ratio) × ND Spectrum

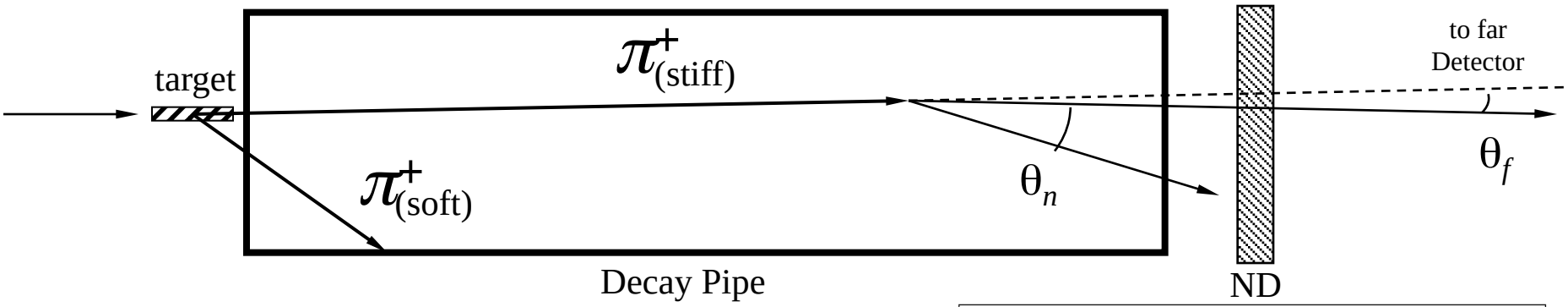
$$N^{i}_{E_\nu,FD} = \Re^{i}_{FN} \times N^{i}_{E_\nu,ND}$$

N_{E_ν} = Number of events at given energy of neutrino in ND or FD

i = particular energy bin

- Tests on “mock data” to ensure no biases, understand systematics

Neutrino Beams from Meson Decay



- ND and FD spectra similar, but not identical

$$E_\nu = \frac{0.43 E_\pi}{1+\gamma^2\theta^2}$$

$$Flux \propto \frac{1}{L^2}\left(\frac{1}{1+\gamma^2\theta^2}\right)^2$$

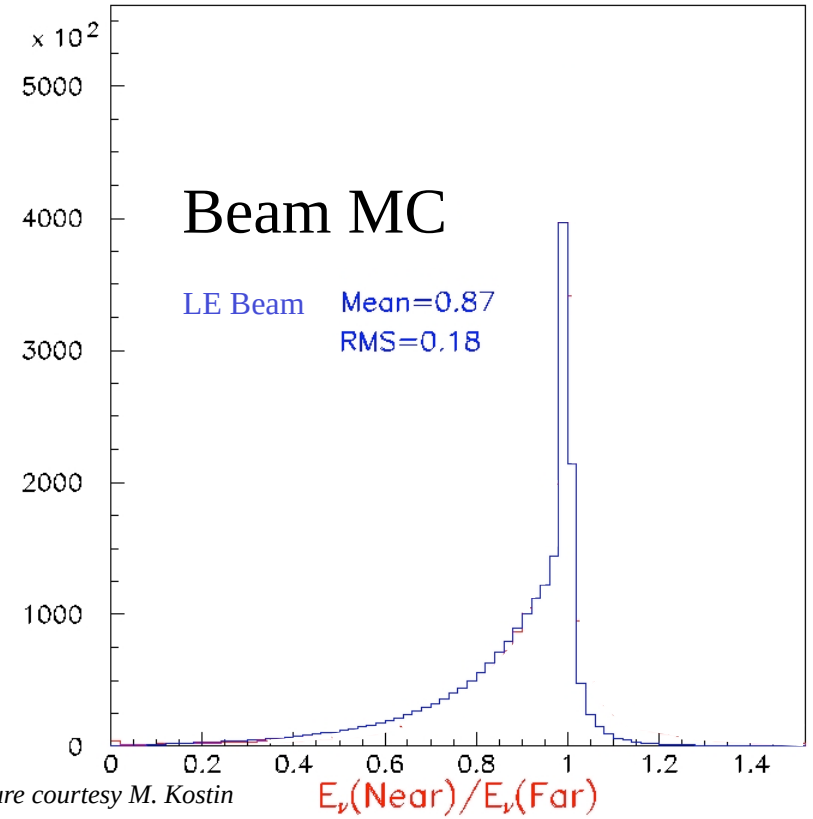
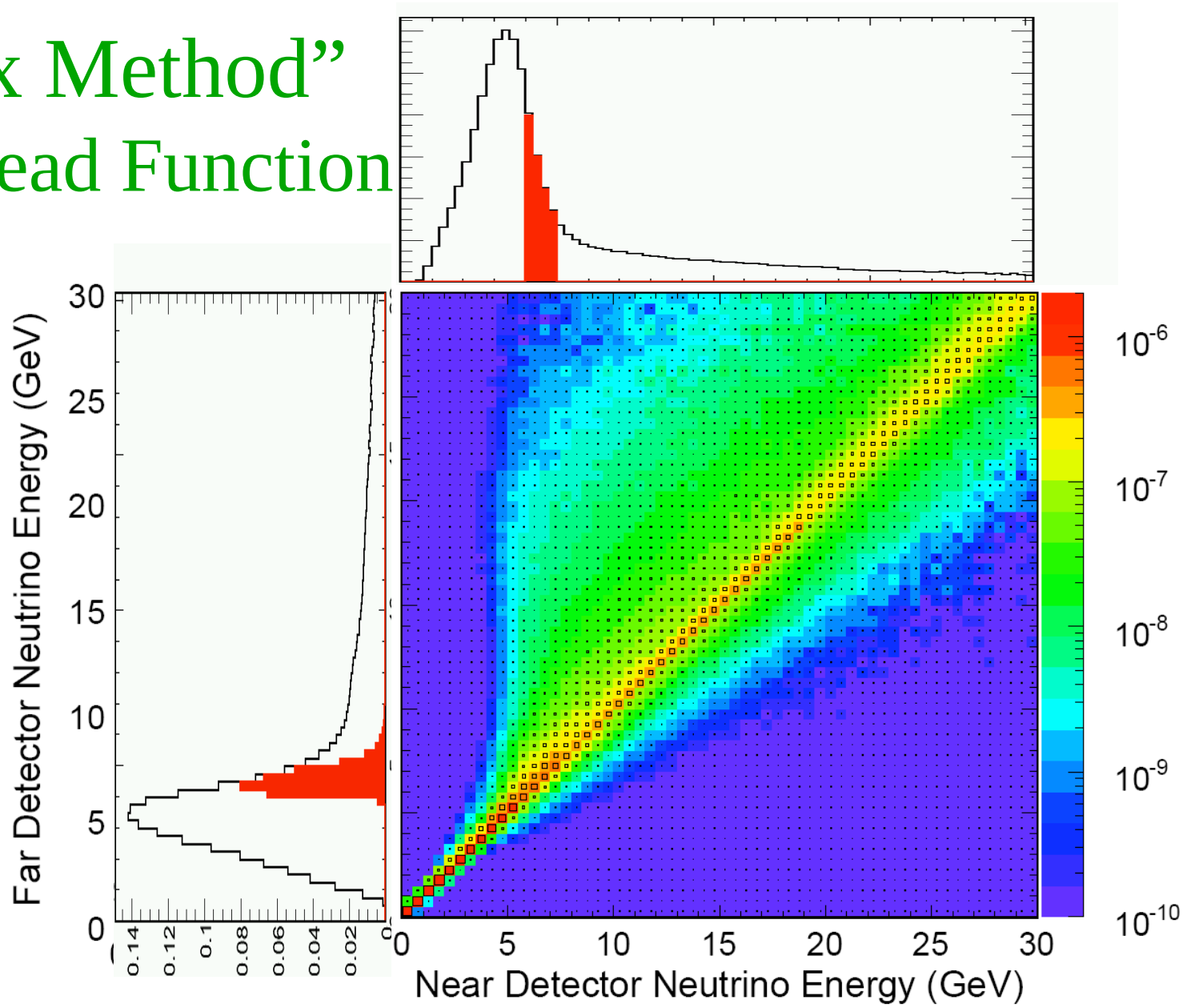


figure courtesy M. Kostin

“Matrix Method” Point Spread Function

A. Para & M. Szleper, arXiv:hep-ex/0110032



Step 3: Peek *at the* Far Detector Data (“Box is still closed”)

- In 2006 analysis, question was “Do ν’s disappear?”
  - unknown “blinding function” to hide most of the data
  - Collaborators given free access to “open” data set
  - Only got to see full data set once “box was open”
- In 2007-2008 analysis, wanted unbiased Δm^2, $\sin^2(2\theta)$ measurement
  - Access to all the data, but complete blinding of all rates
  - Did not look at energy spectrum, so couldn’t bias Δm^2

Calibration

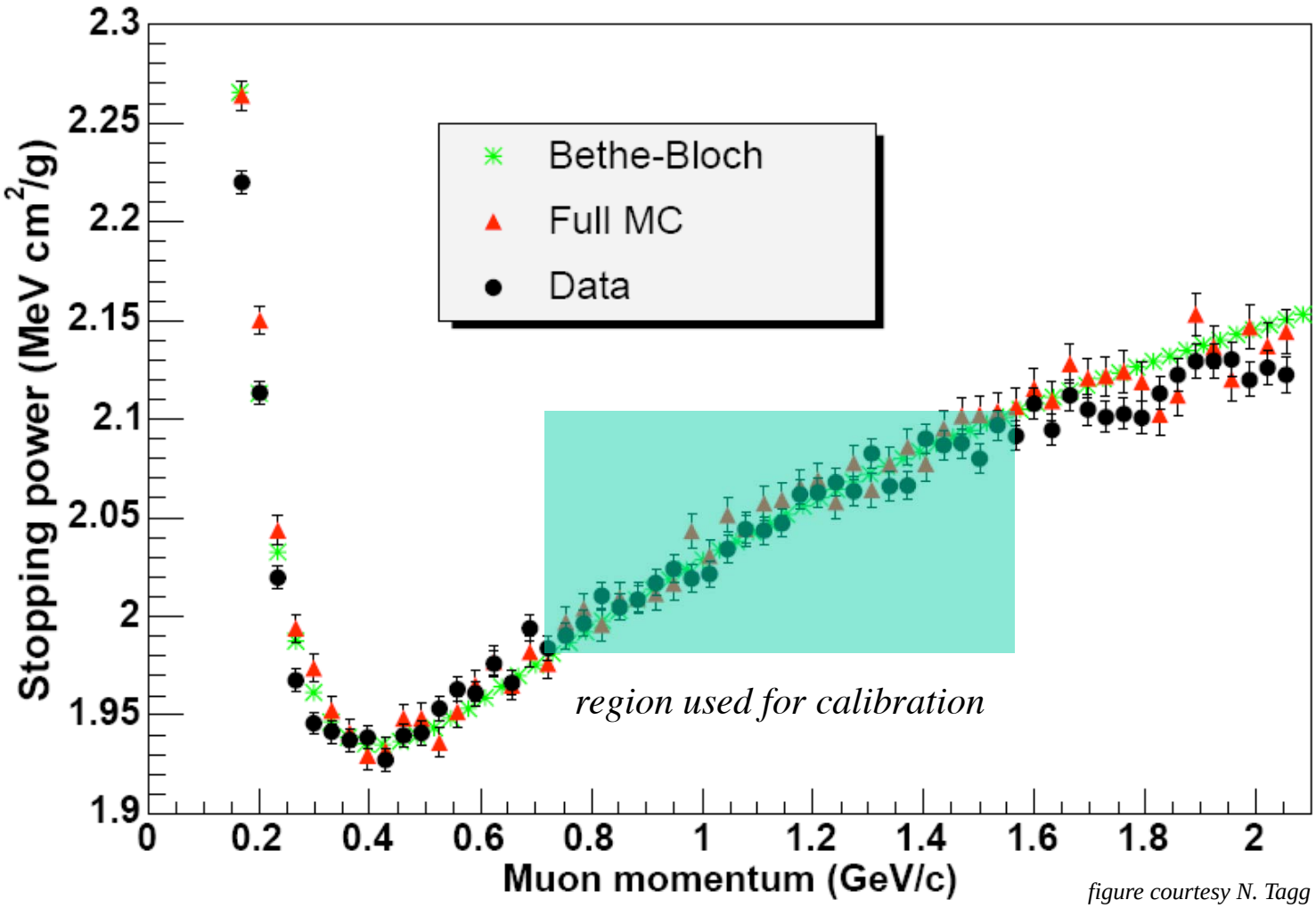
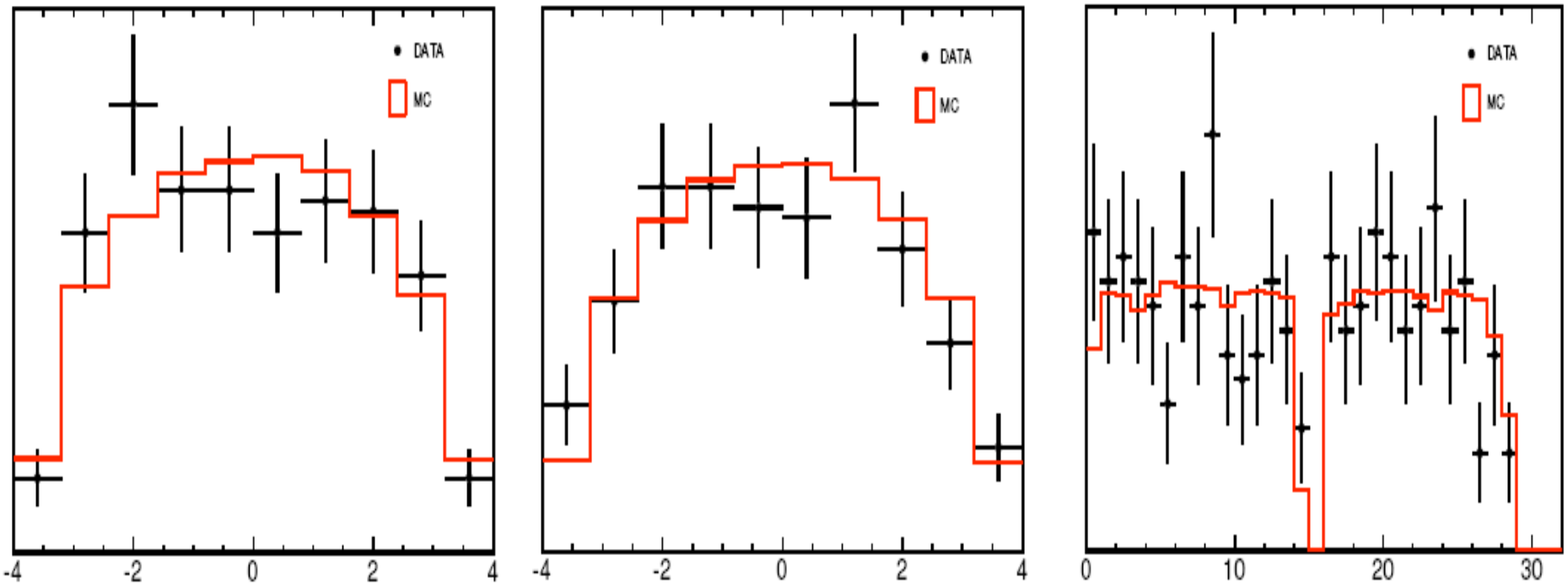


figure courtesy N. Tagg

- Calibratrions based on stopping cosmic ray μ's.
- Study ionization for 20-plane window upstream of stopping μ location.

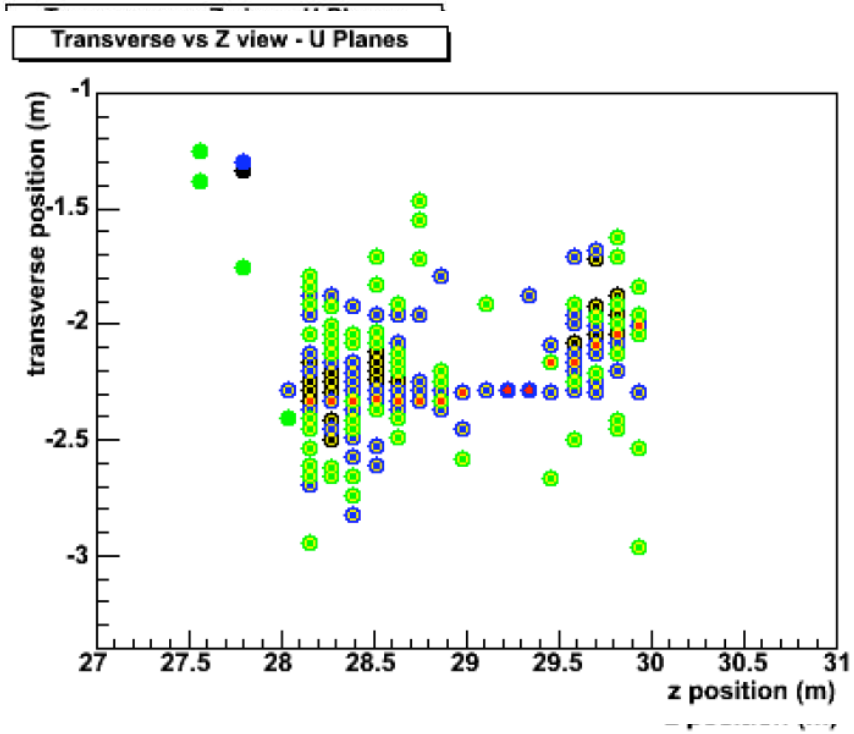
Checks on the FD Data

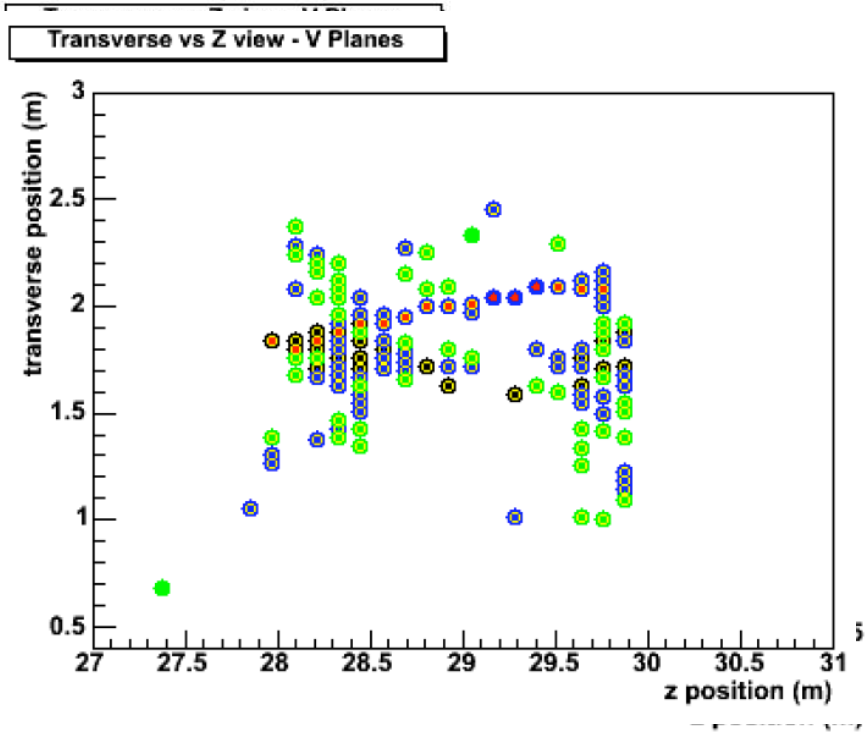


Track Vertex in *X* (m) **Track Vertex in *Y* (m)** **Track Vertex in *Z* (m)**

- These are all CC neutrino events
- Rates blinded – we don't know the normalization
- MC has been scaled to agree with data

Example Events



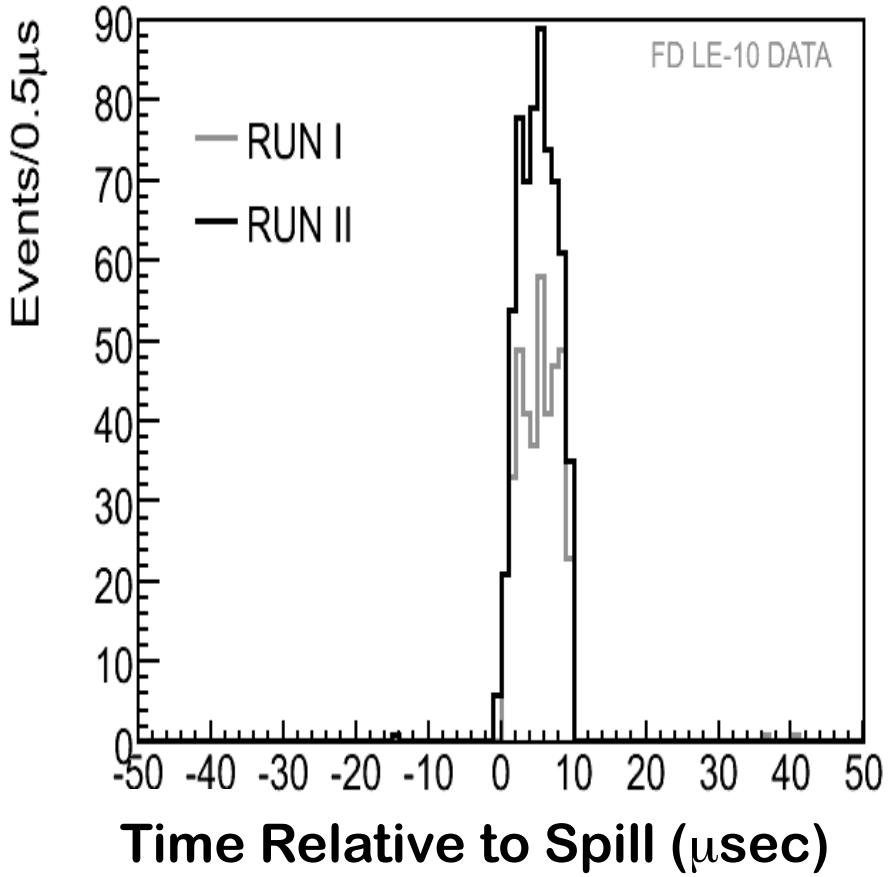


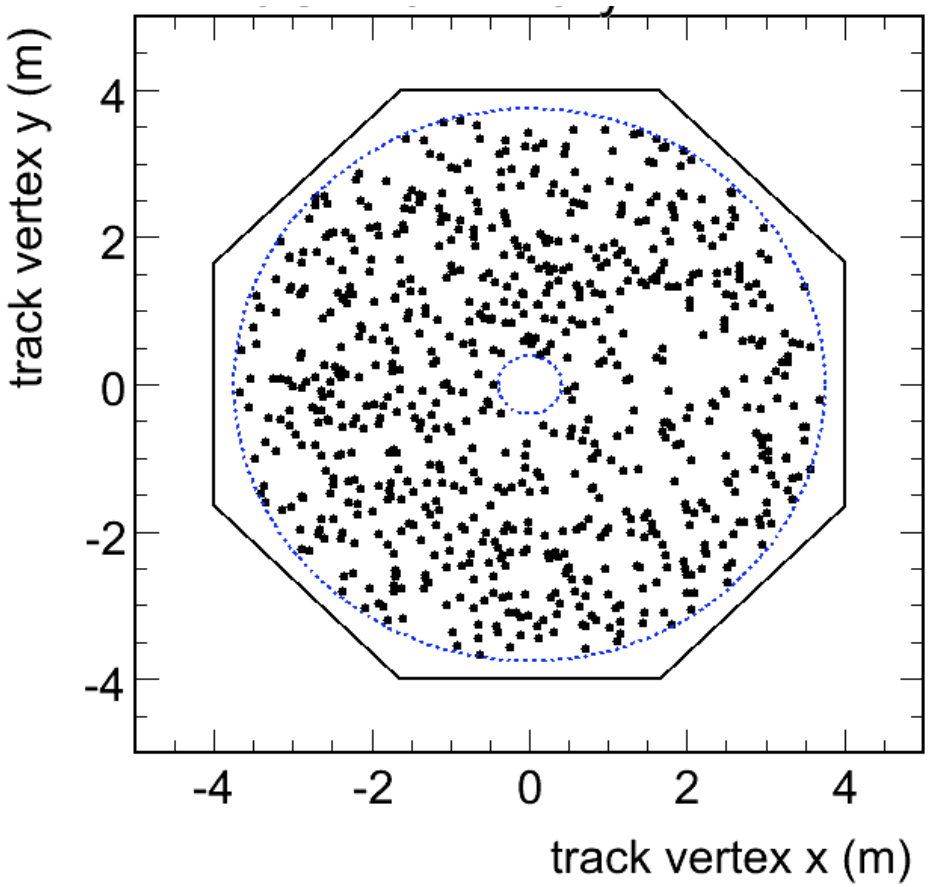
- These events taken from the “open” data sample in the FD (which we are permitted to look at in detail).
- E_ν = 38.6 GeV
- y = 0.4 (‘quasi-elastic’?)

Step 4: Look at All Events

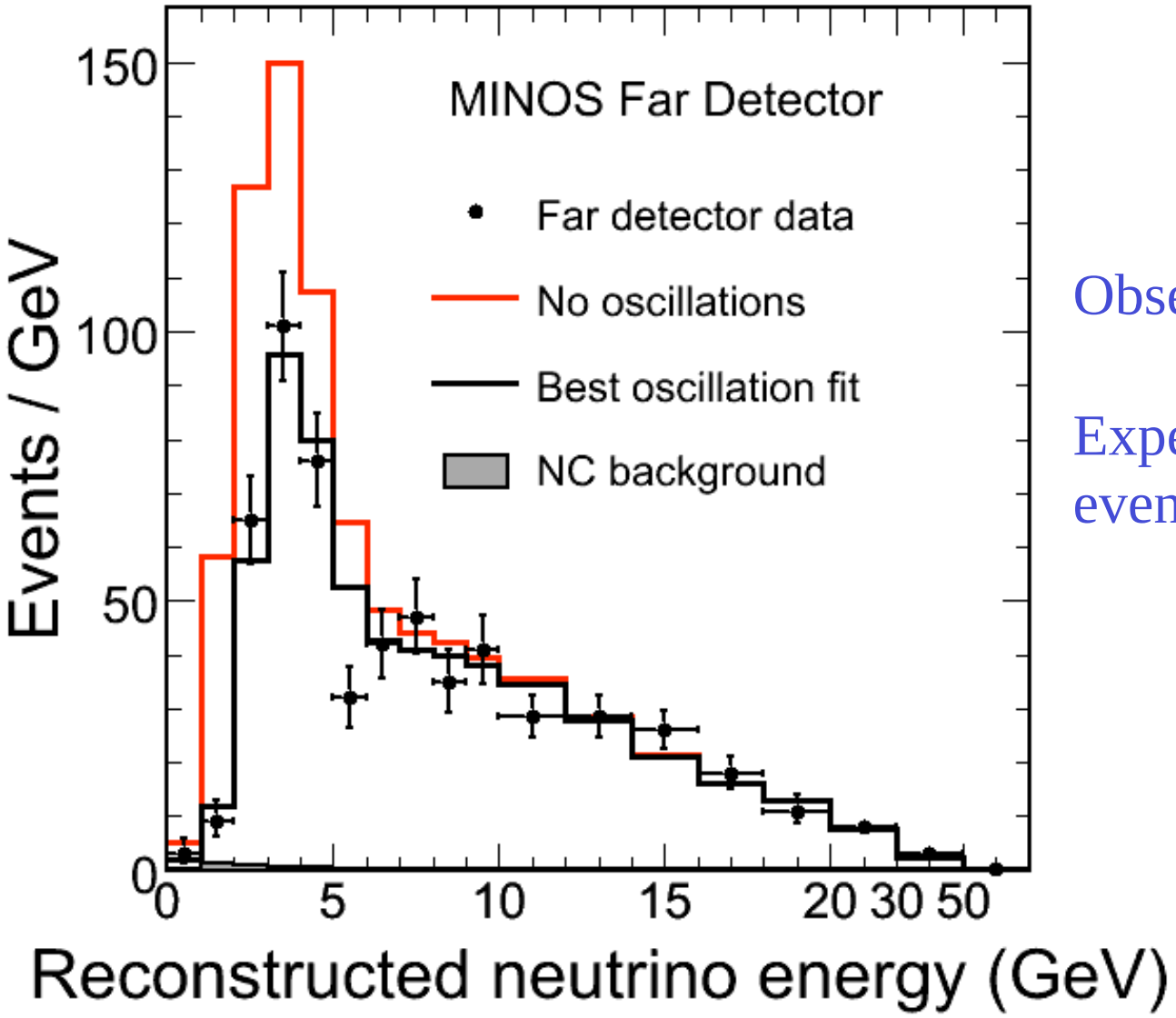
“Open the Box”

FD Events are “In time” and Uniform



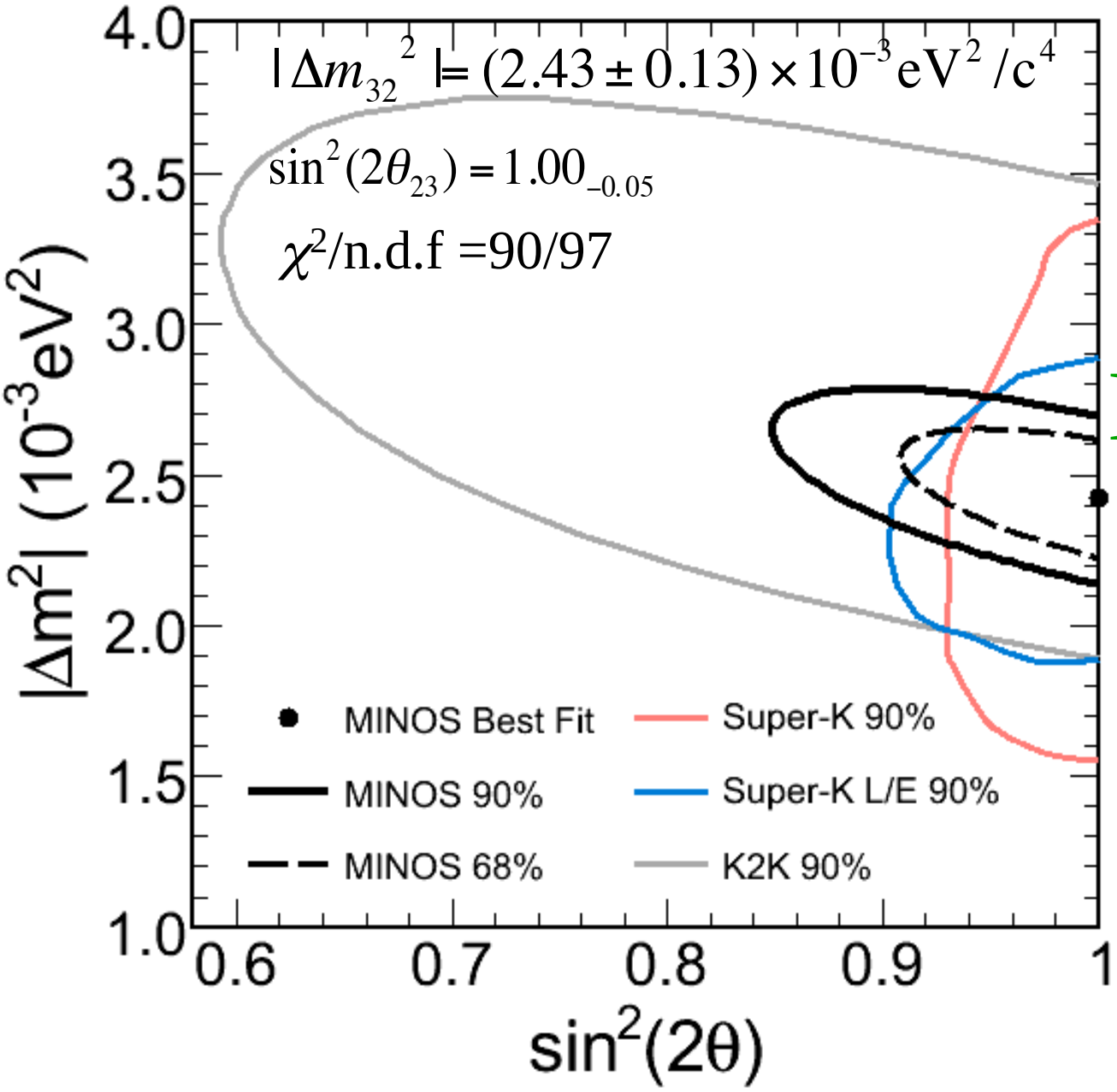


Measurement of ν_μ Disappearance



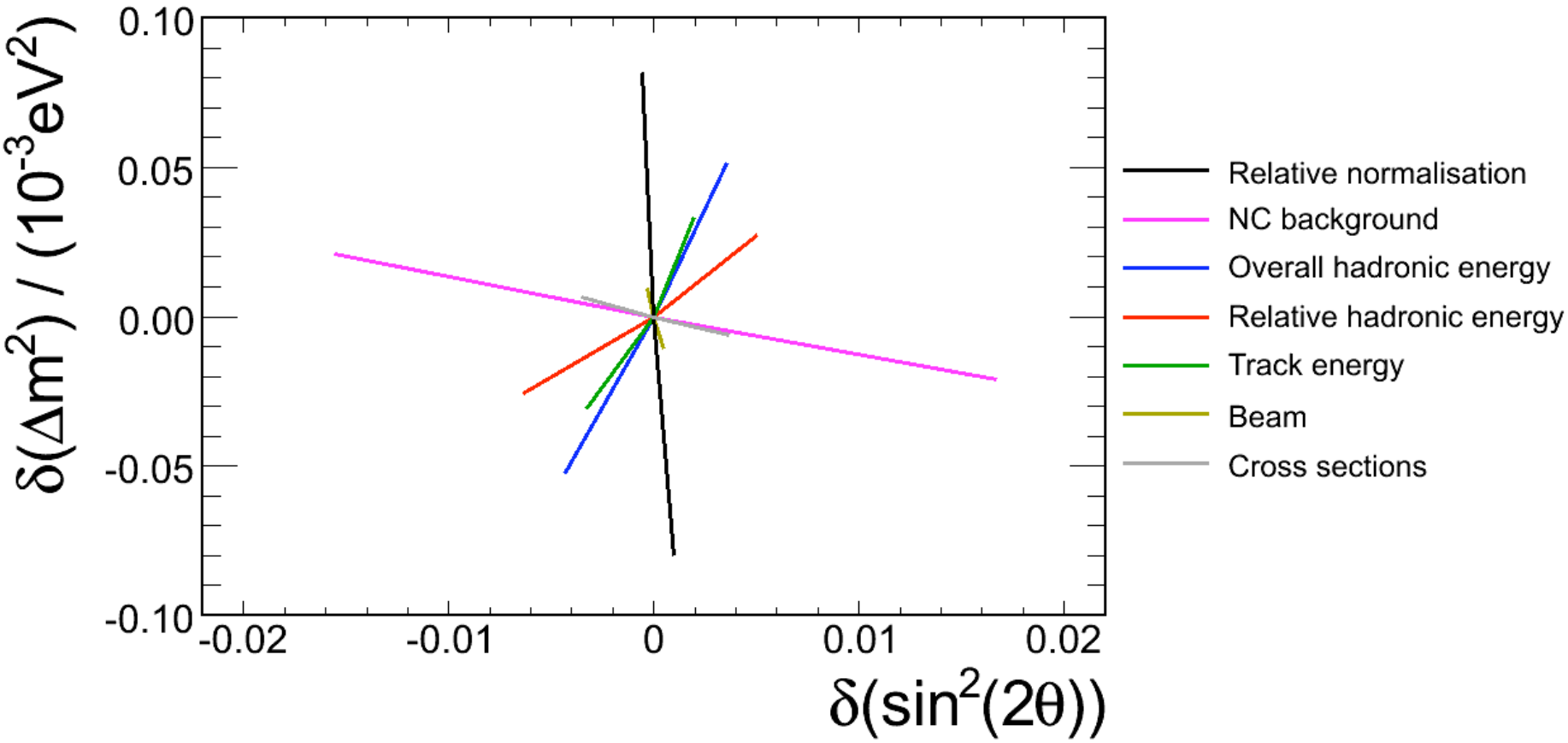
Observed 848 events

Expect 1060 ± 60 events if no oscillations

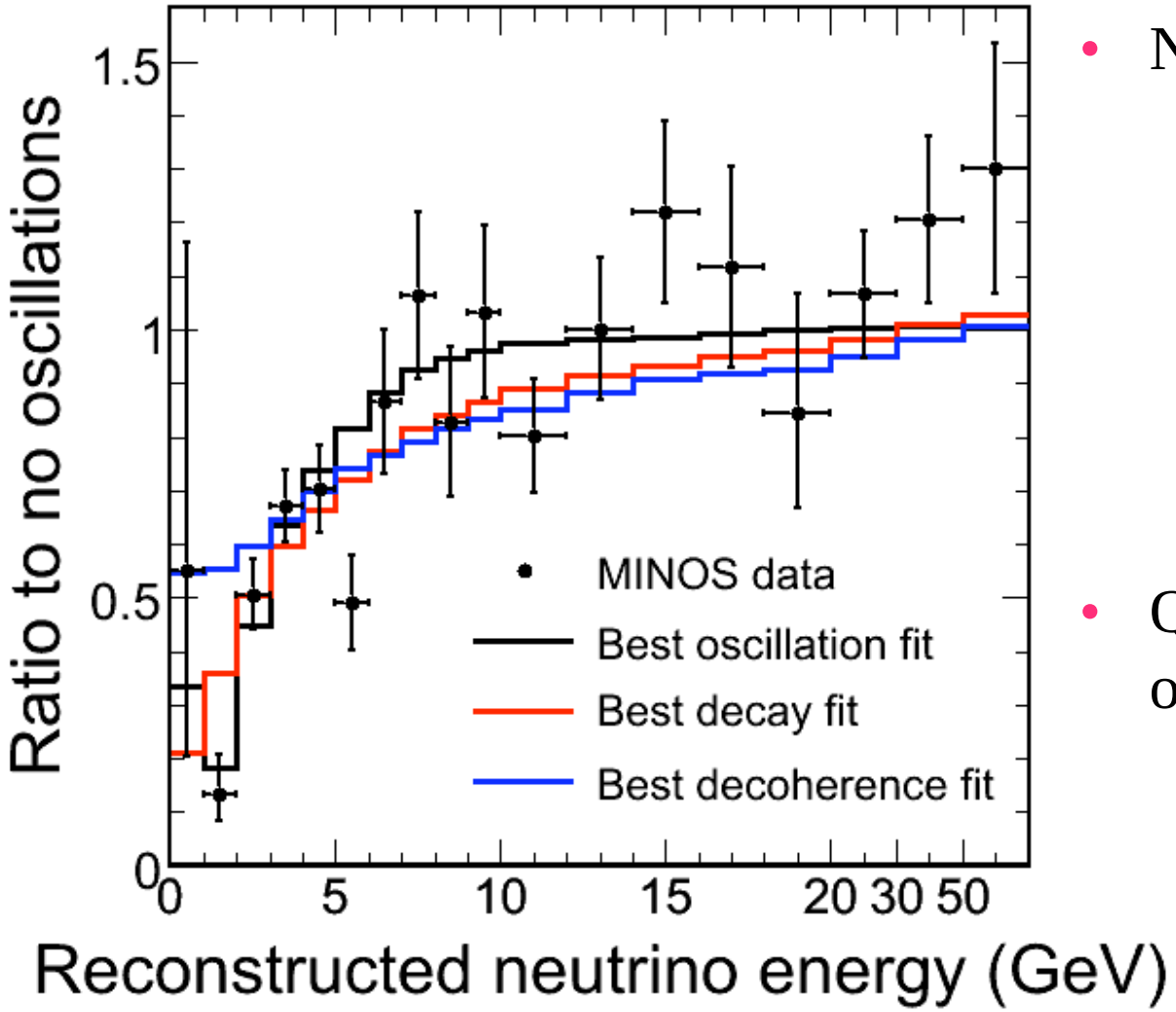


Oscillation Hypothesis Fit

Systematic Uncertainties



Consistency with Other Models?



- Neutrino decay
  - V. Barger et al., Phys. Rev. Lett. 82 2640, 1999
  - Disfavored at 3.7σ
  - When NC events included in the fit, this model is further disfavored at 5.4σ
- Quantum decoherence of neutrino wave packets
  - G. L. Fogli et al., Phys. Rev. D67 093006, 2003
  - Disfavored at 5.7σ.

“Accident & Substance: Two possible explanations for the bulk of reality”

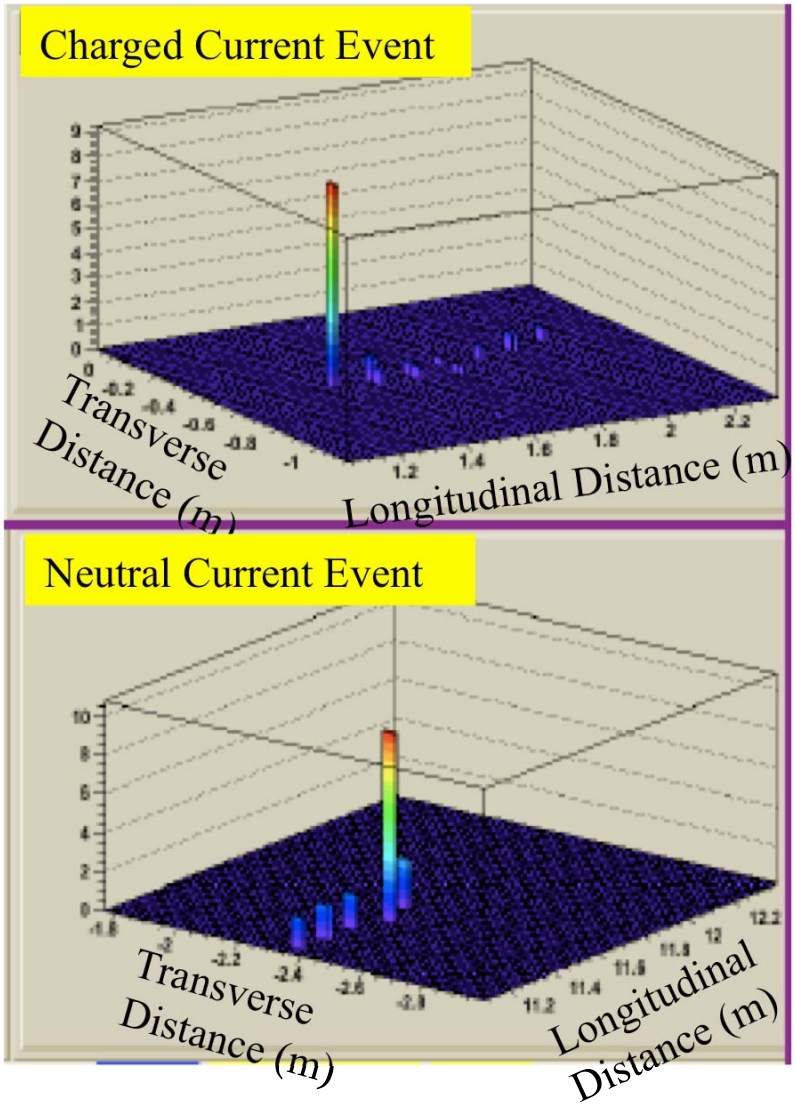
April 6, 2006 Inside article:

“*One possible explanation for dark matter is a group of subatomic particles called neutrinos. … Last week, researchers working on the MINOS experiment at Fermilab, near Chicago, confirmed these results. …*”

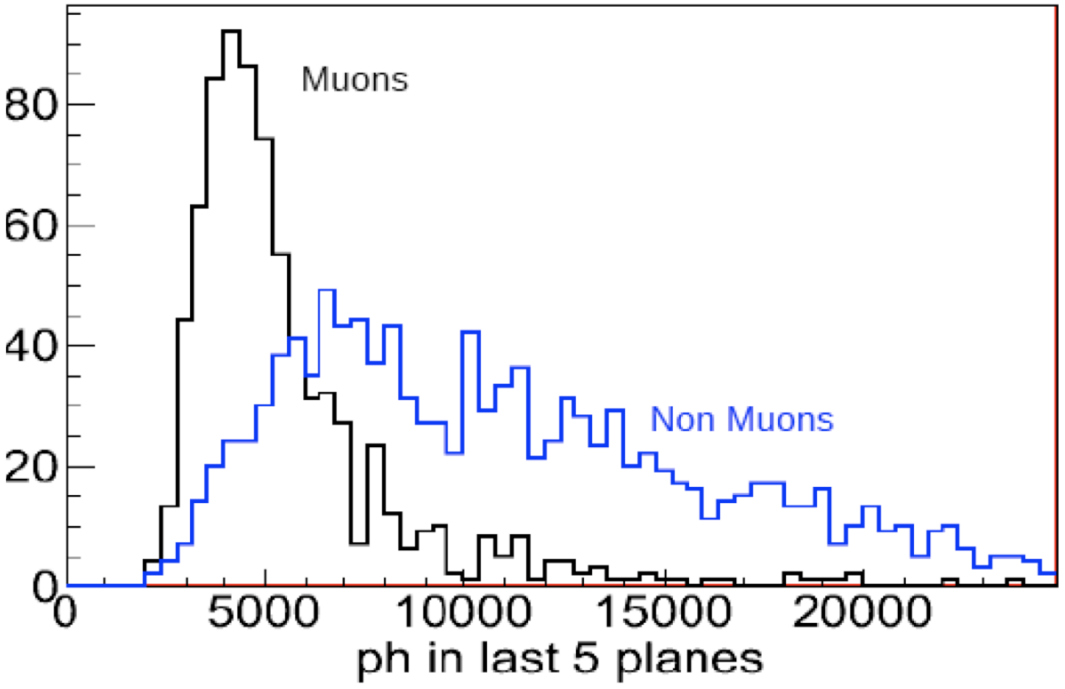
“*The researchers created a beam of muon neutrinos … The neutrinos then travelled 750km (450 miles) through the Earth to a detector in a former iron mine in Soudan, Minnesota.*”

“*By comparing how many muon neutrinos arrived there with the number generated, Fermilab's researchers were able to confirm that a significant number of muon neutrinos had disappeared—that is, they had changed flavour. Thus the neutrino does, indeed, have mass and a more accurate number can be put on it.*”

Future: Lower Energy Threshold



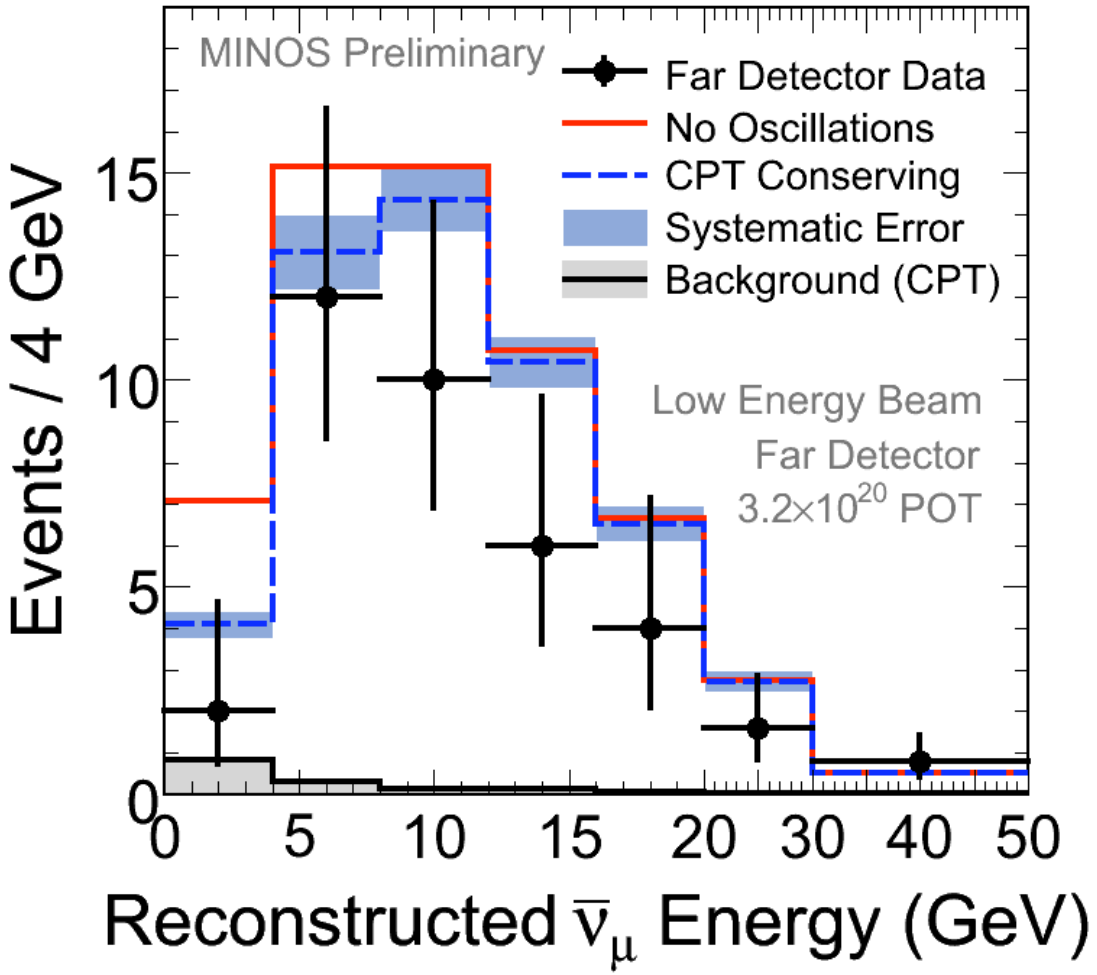
- Events with E<2 GeV show rise below oscillation max
- Difficult to separate muon track from pion track – nuclear scatter?



CPT Violation in Oscillations?

- Observe **42 events** in the Far detector (First direct observation of $\bar{\nu}_\mu$ in an accelerator long-baseline experiment)

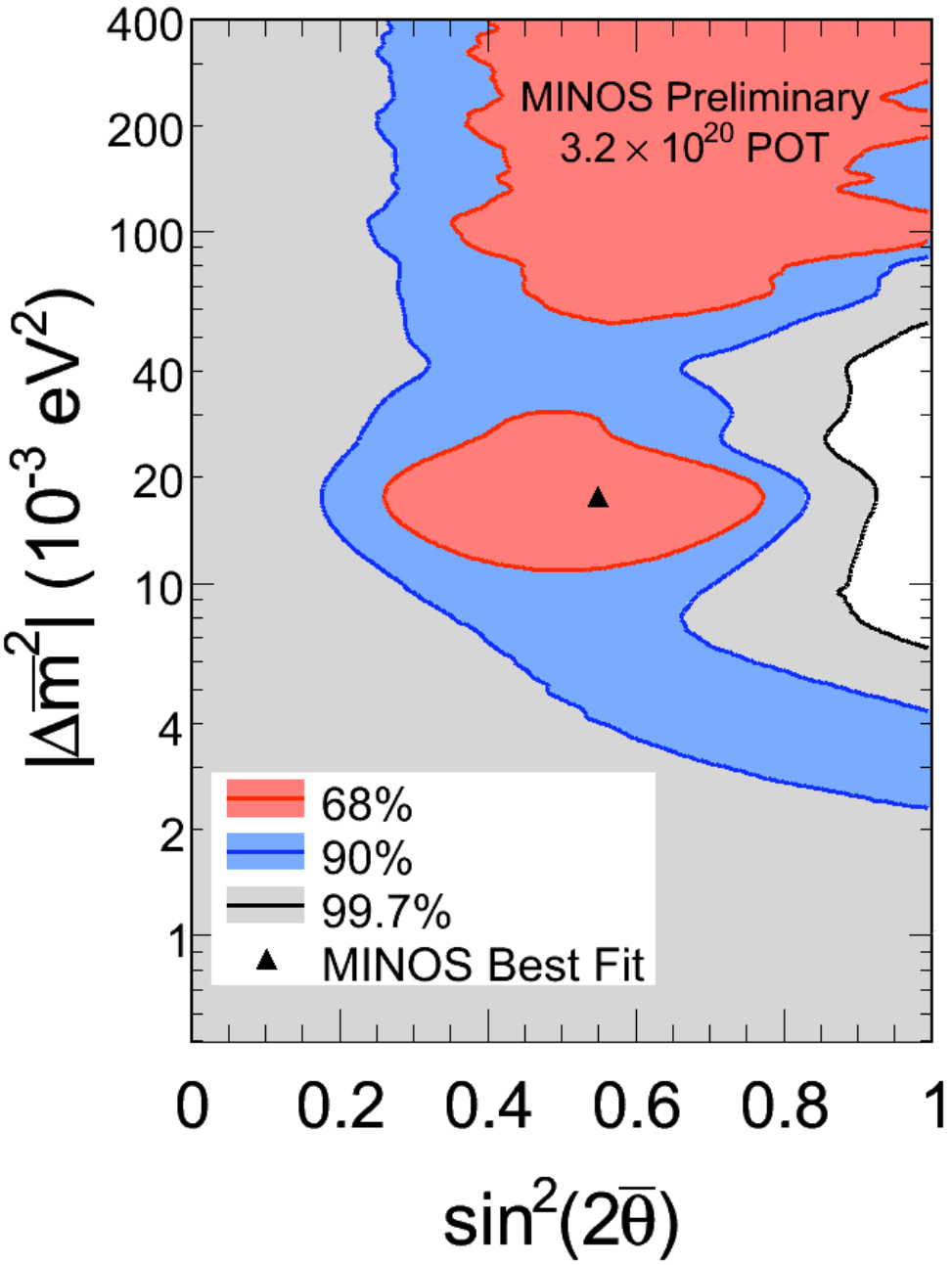
- Predicted events with CPT conserving oscillations:
  - 58.3 ± 7.6 (stat.) ± 3.6 (syst.)
- Predicted events with null oscillations:
  - 64.6 ± 8.0 (stat.) ± 3.9 (syst.)



Allowed Region

- Contours obtained using Feldman-Cousins technique, including systematics
- Null oscillation hypothesis excluded at 99%
- CPT conserving point from the MINOS neutrino analysis is within 90% contour
- $\bar{\nu}_\mu$ best fit is at high value, due to deficit at high energy

- MINOS plans to undertake a dedicated $\bar{\nu}_\mu$ run next year



8 great books for the hammock
VARIETY

Vintage car shows revving up B3

H62° L53°
Stuck in clouds most of the day. More, B8

SterileTribune

Wednesday • 50¢

MAY 27, 2009 • MINNEAPOLIS • ST. PAUL • "WHAT EXERCISE IS TO THE BODY, EMPLOYMENT IS TO THE MIND AND MORALS." THOREAU

N. KOREA TESTS MORE MISSILES

North Korea lashed out at the United States and reportedly launched three more short-range missiles. A3

Did LSND result at $\Delta m^2 \sim 1$ eV^2 imply a 4th mass state?

NEW ν STATES IN OSC EXPTS?

the supreme court nomination

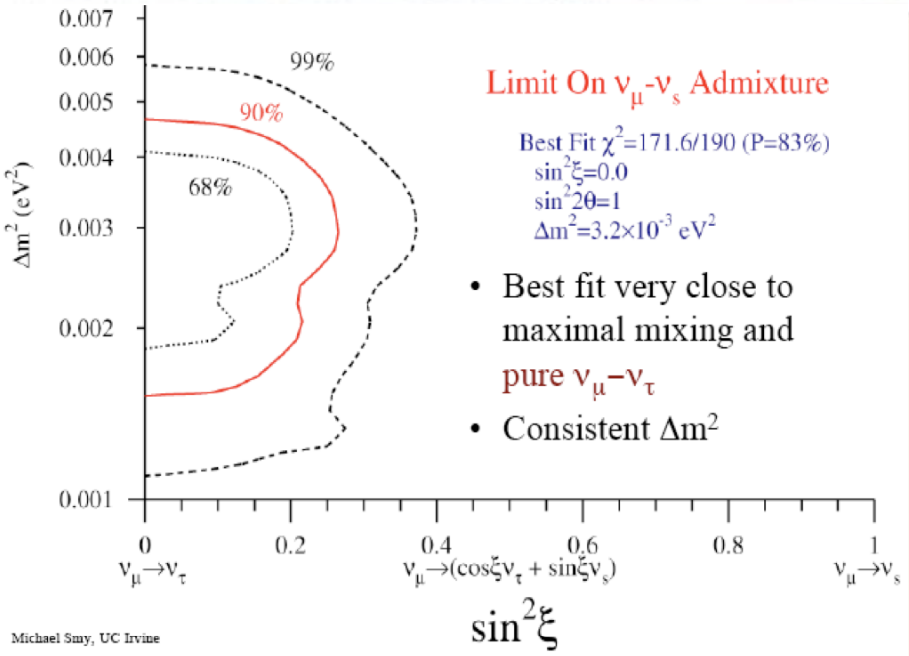
• With the cancer growing and chemo to resume today, the teen was allowed to go home, despite county objections.

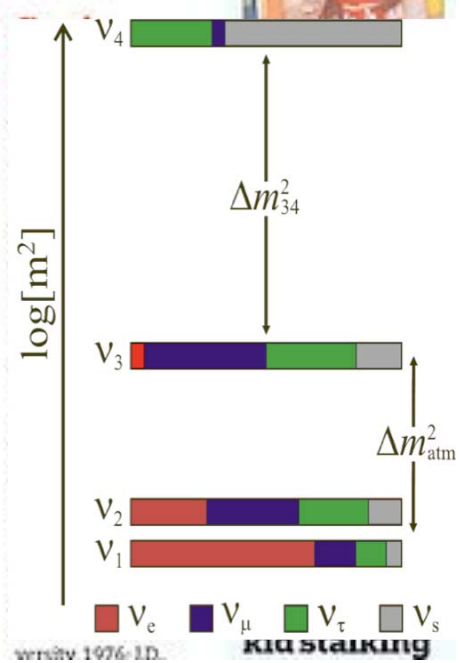
By JENNA ROSS and JACKIE CROSBY
Star Tribune staff writers

NEW ULM, MINN. – Inside a Brown County courtroom Tuesday, Judge John Rodenberg looked directly at the parents of cancer-stricken Daniel Hauser and asked them both a blunt question.

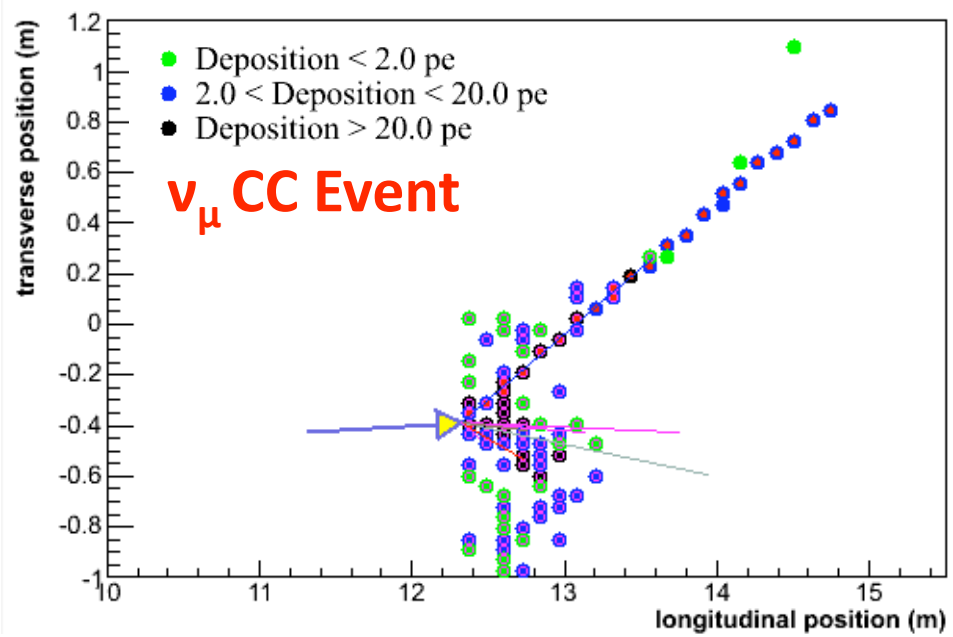
"Do you believe that chemotherapy is necessary to save Daniel's life?"

Colleen Hauser, the 13-year-old boy's mother, grabbed some tissues. "Yes, I do," she said. So did Anthony Hauser, Daniel's father.

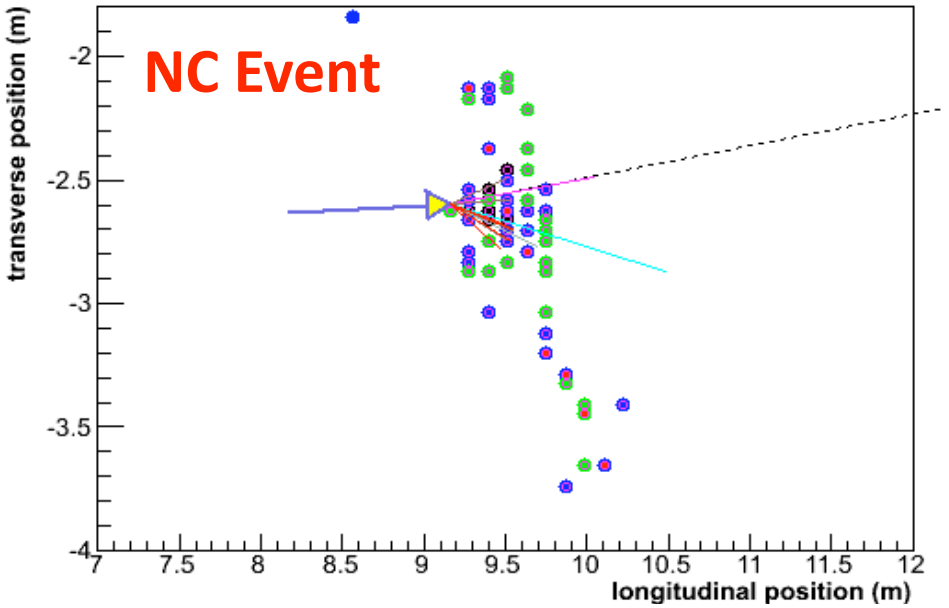




Neutral Current $\nu_x N \rightarrow \nu_x X$ Events



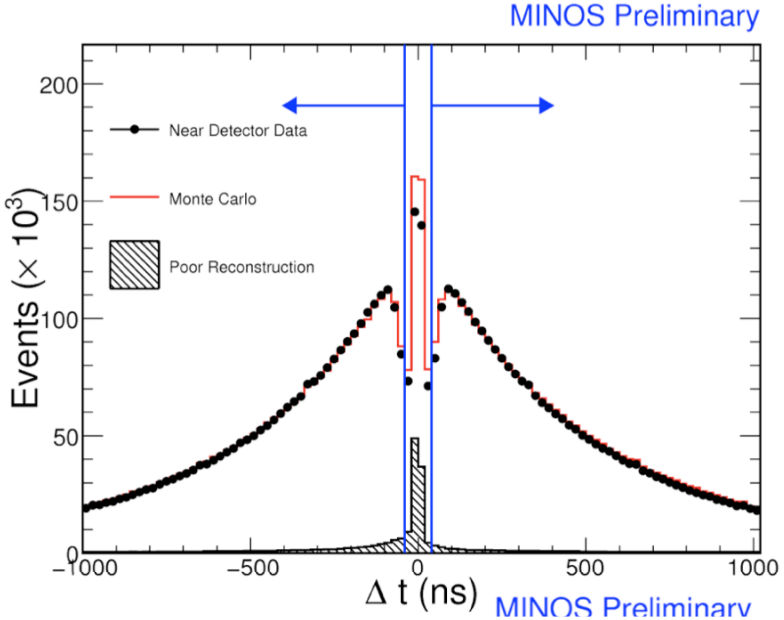
- Charged lepton track
- Hadronic shower

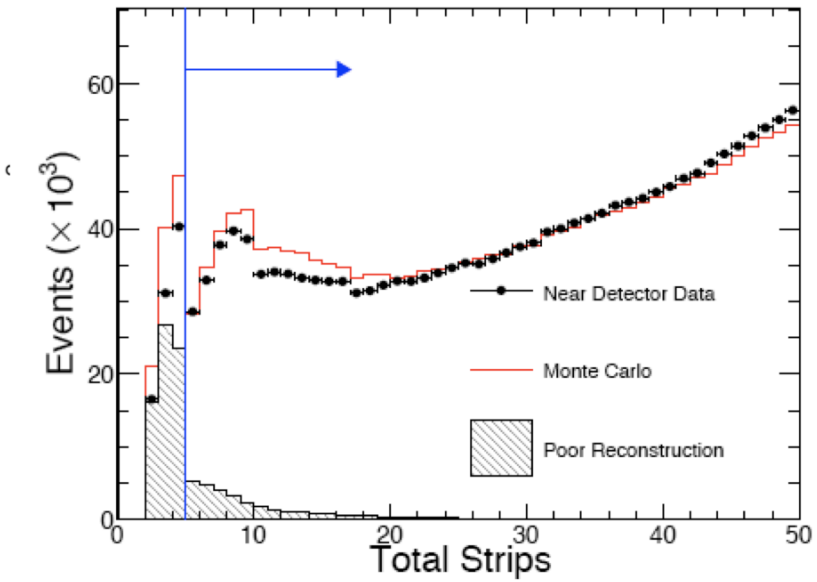


- No track
- Unobserved neutrino
- Hadronic shower

Images courtesy Christopher Backhouse, Fermilab Annual Users Meeting June 2009

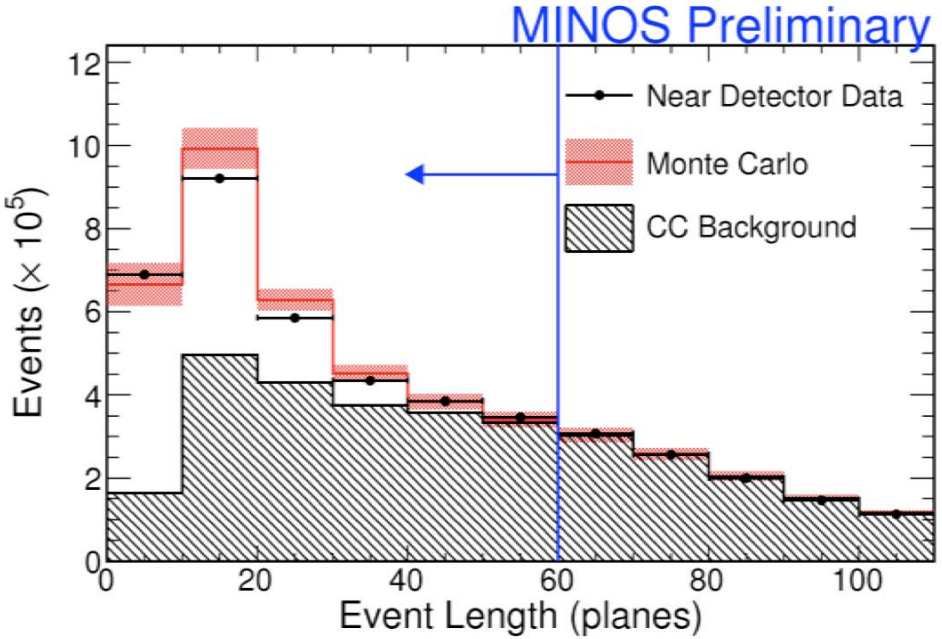
ND Pre-Selection Cuts

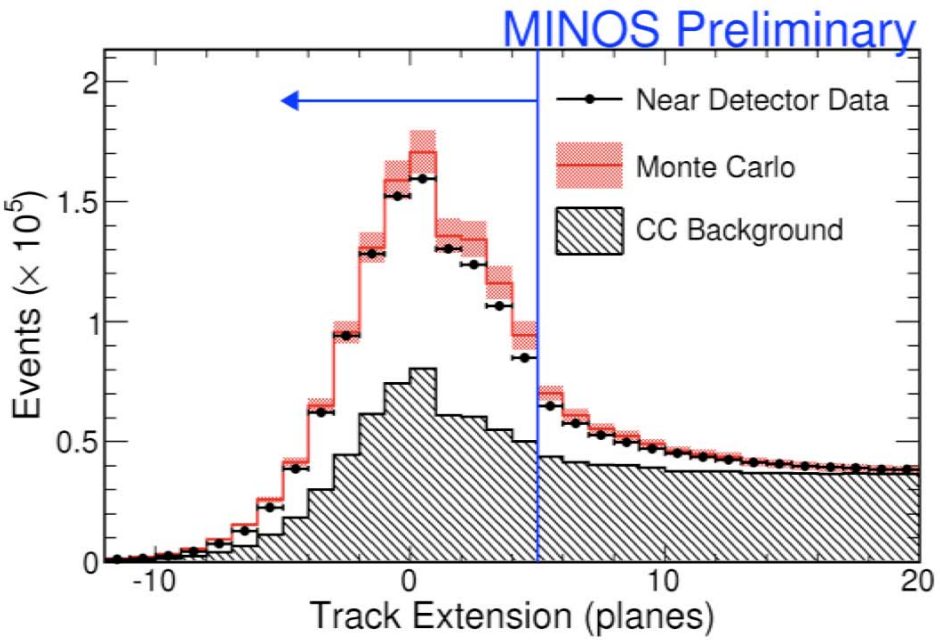




- High event rate in ND can cause poor event reconstruction
  - Split events
  - Incorrect vertex
- Apply a series of cuts
  - Time and spatial separation
  - Total number of hit strips
  - Event steepness
  - Activity in edge region
- Reduce poorly reconstructed background <1GeV from 34% to 8%

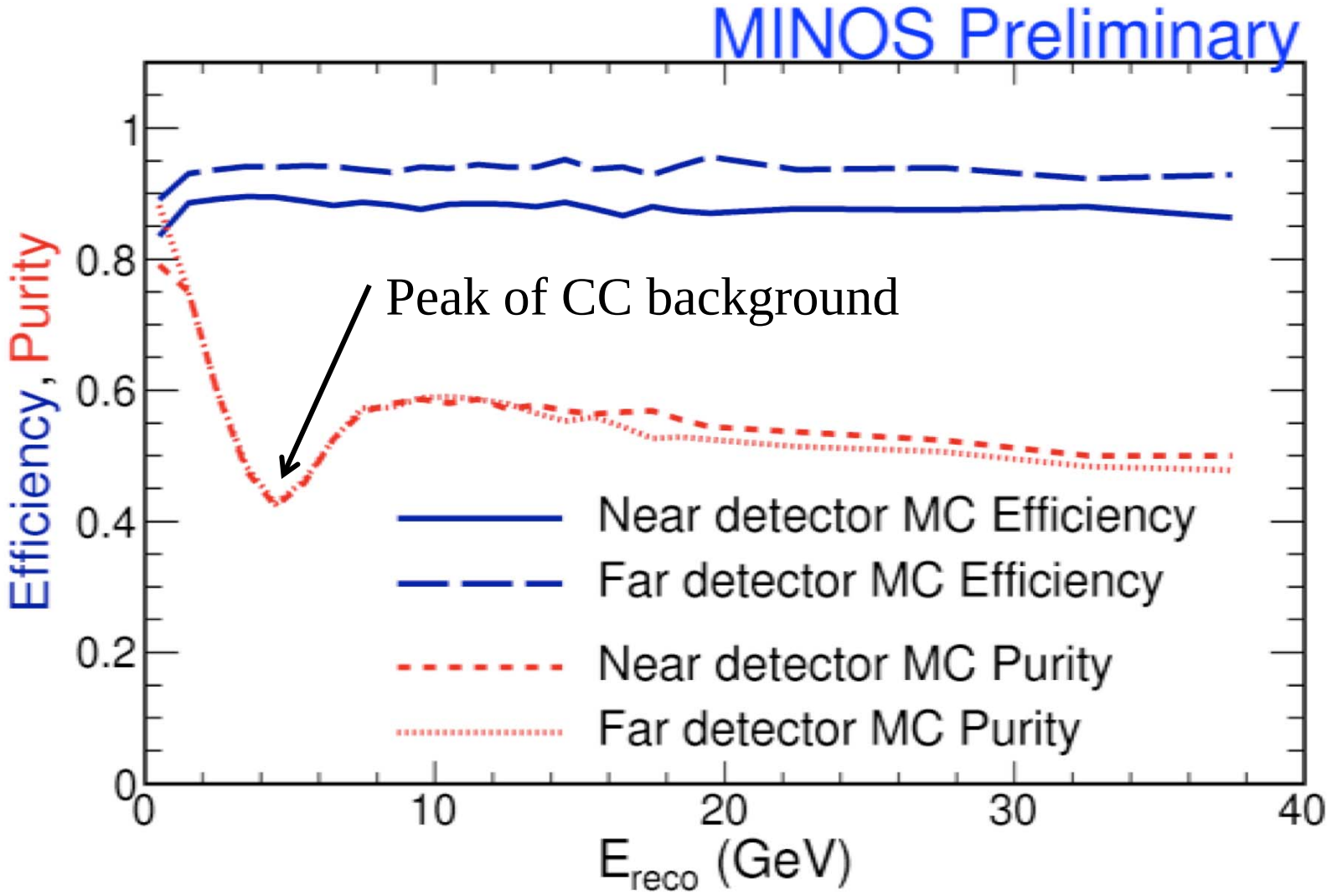
NC Event Selection





- Discard events >60 planes
- Discard events with a track >5 planes longer than the shower
  - Same selection applied at FD
  - Variable distributions similar

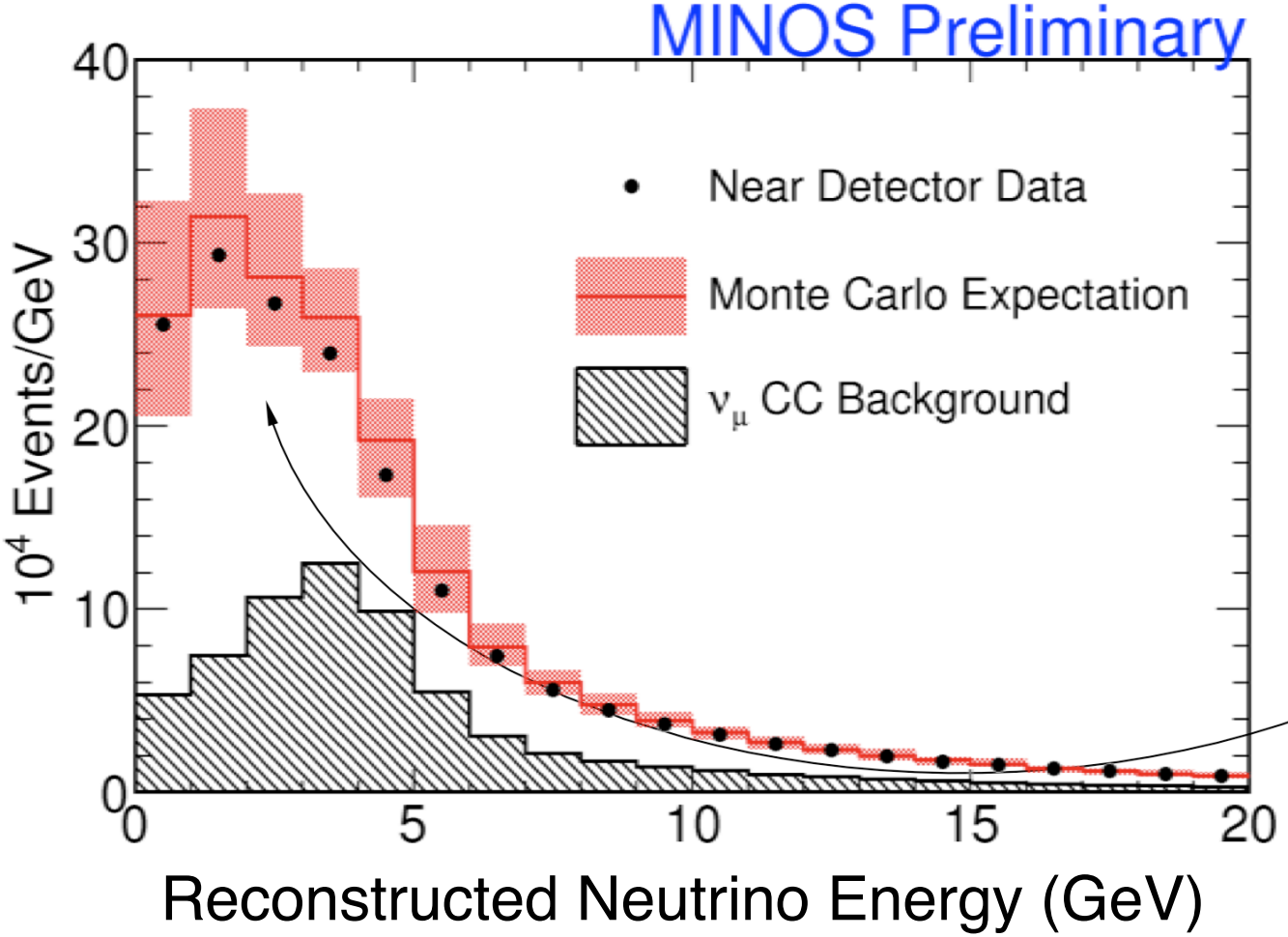
Neutral Current Selection



- NC events selected with ~ 90% efficiency and ~60% purity

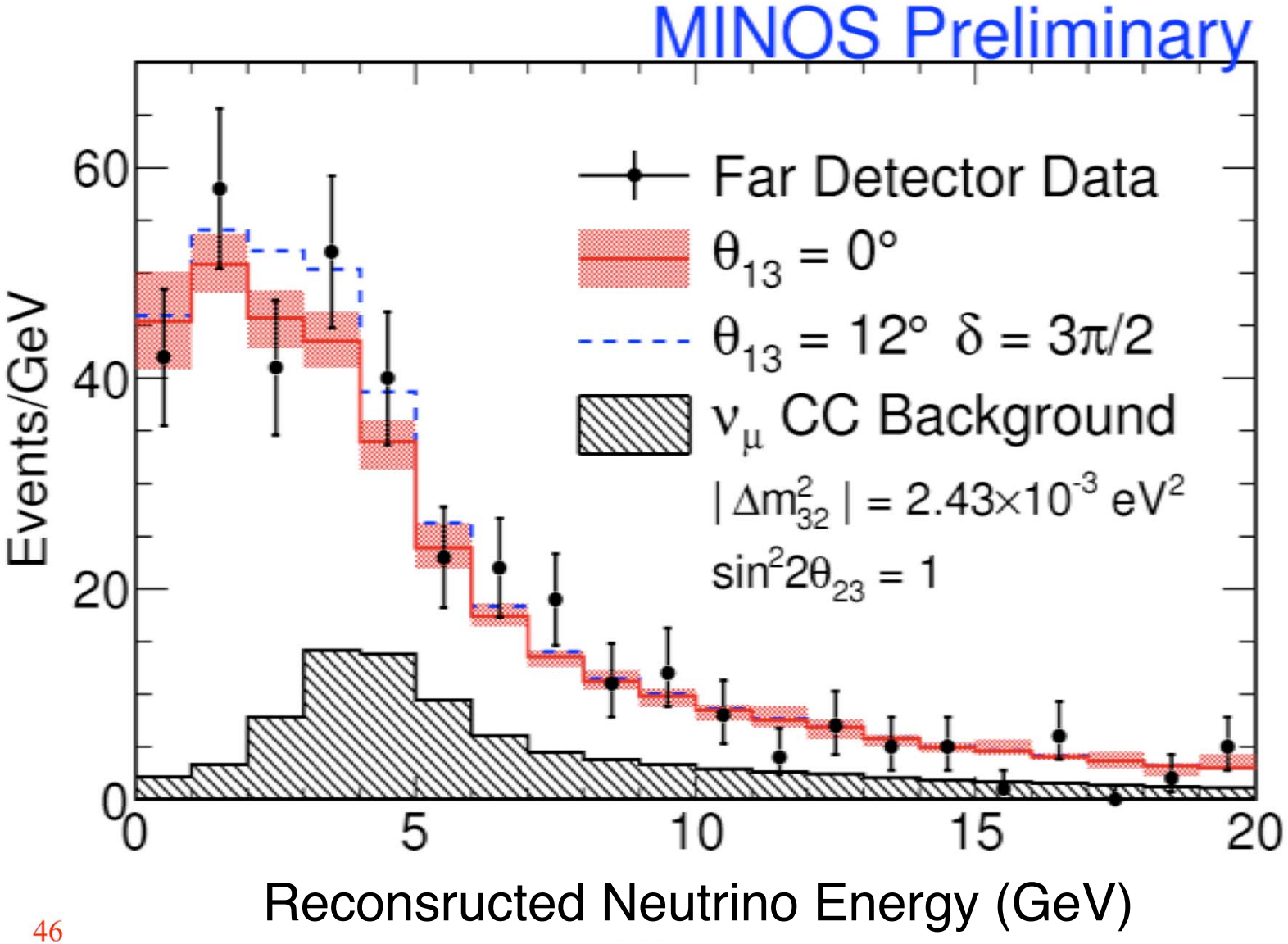
Energy Spectrum at the Near Detector

- Charged current – identifies flavor of interacting ν_μ
- Neutral current – inclusive, all "active" ν flavors interact



A $\nu_\mu \rightarrow \nu_{\text{sterile}}$ oscillation would result in a deficit of NC events at the Far Detector

Energy Spectrum at the Far Detector



Simple Statistic for NC Disappearance

- No ν disappearance for R=1

$$R = \frac{N_{data} - \sum B_{CC}}{S_{NC}}$$

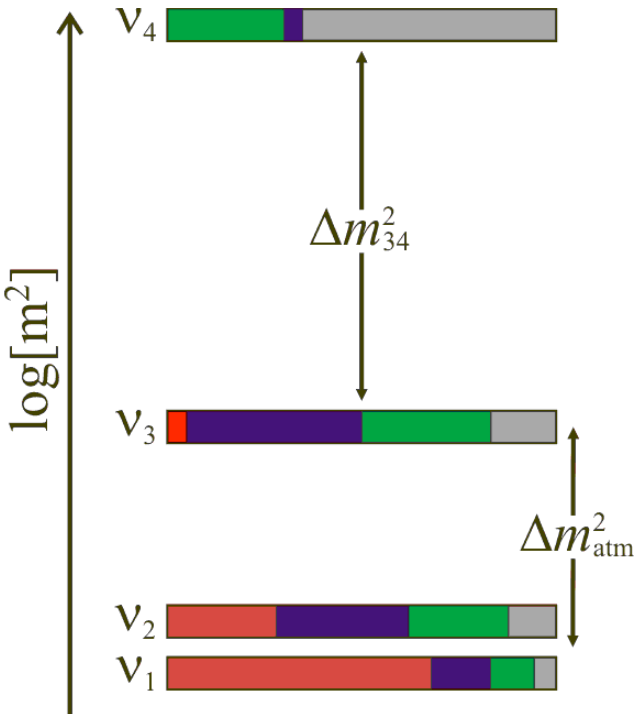
$E_{\rm reco}$ (GeV)	$N_{\rm Data}$	$S_{\rm NC}$	$B^{\nu_\mu}_{\rm CC}$	$B^{\nu_\tau}_{\rm CC}$	$B^{\nu_e}_{\rm CCn}$
$0-3$	141	125.1	13.3	1.4	2.3 (12.4)
$3-120$	247	130.4	84.0	4.9	16.0 (32.8)
$0-3$	$R = 0.99 \pm 0.09 \pm 0.07 - 0.08(\nu_e)$				
$3-120$	$R = 1.09 \pm 0.12 \pm 0.10 - 0.13(\nu_e)$				
$0-120$	$R = 1.04 \pm 0.08 \pm 0.07 - 0.10(\nu_e)$				

10

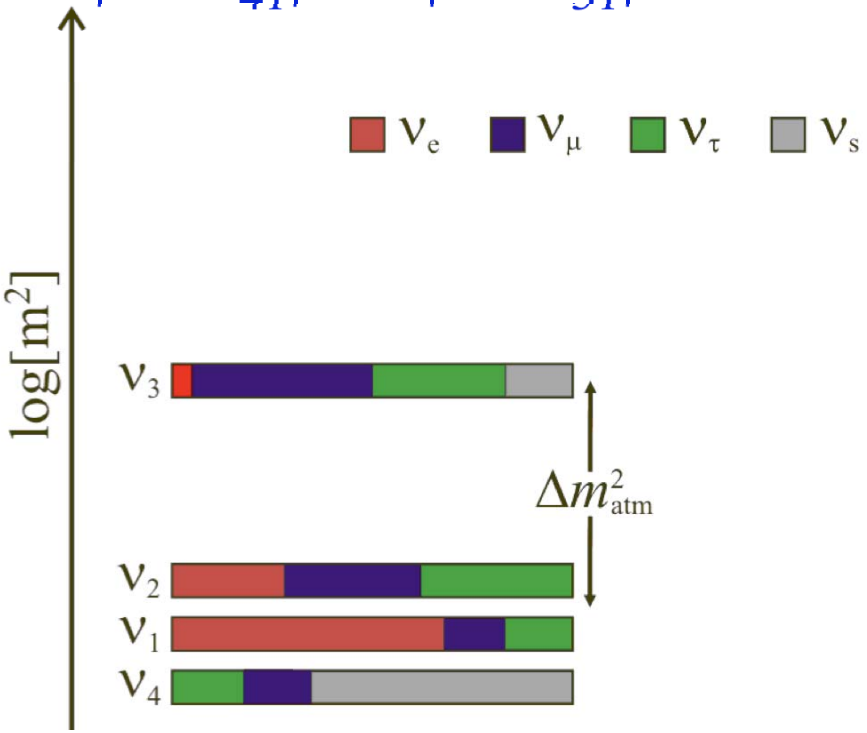
4-Flavour Analysis

- Assume additional sterile ν and an additional Δm^2
- Extend mixing matrix with extra angles & phases
- Consider two mass scales (simplify osc formulae)

❖ $|\Delta m^2_{41}| >> |\Delta m^2_{31}|$



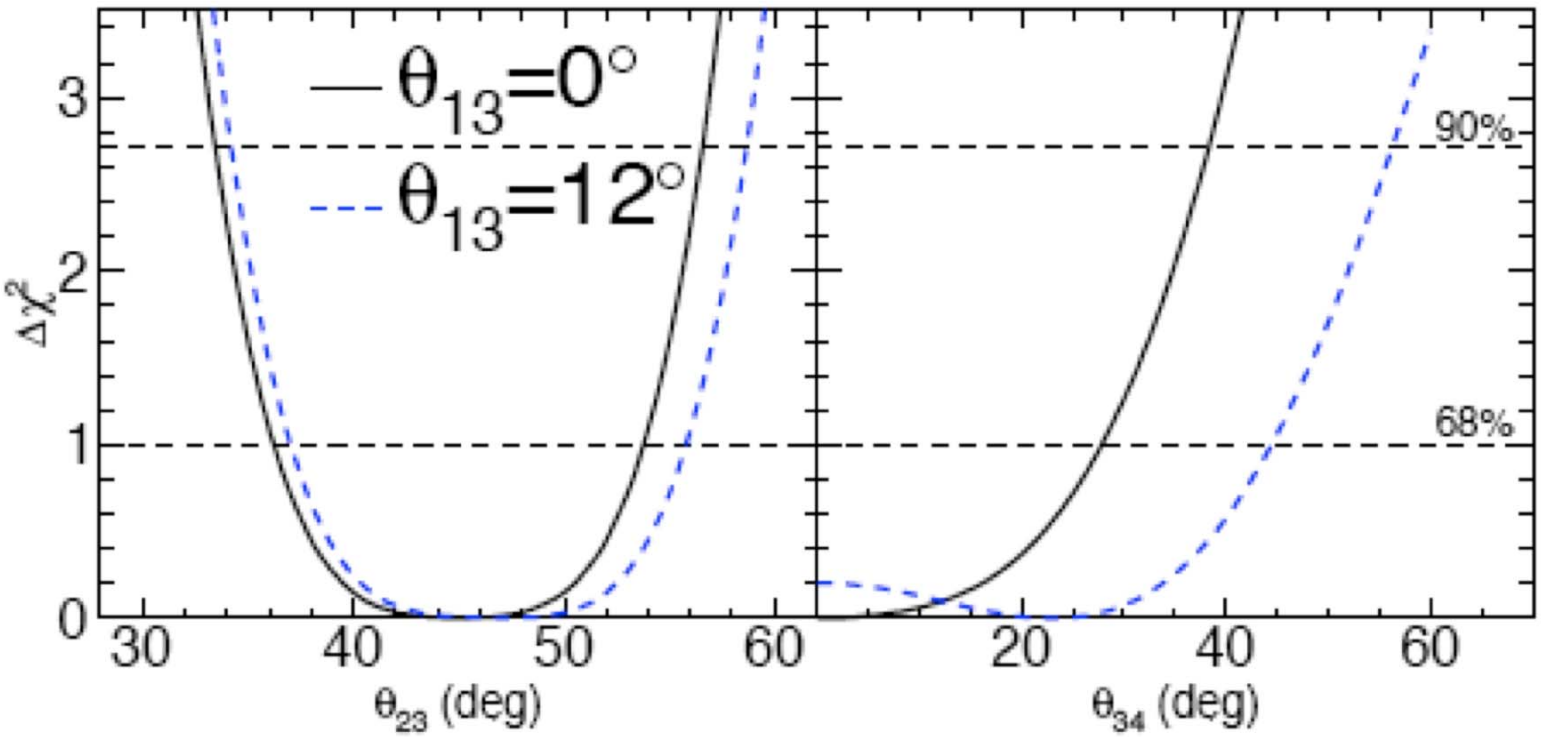
❖ $|\Delta m^2_{41}| << |\Delta m^2_{31}|$



4-Flavour Analysis: $m_4=m_1$

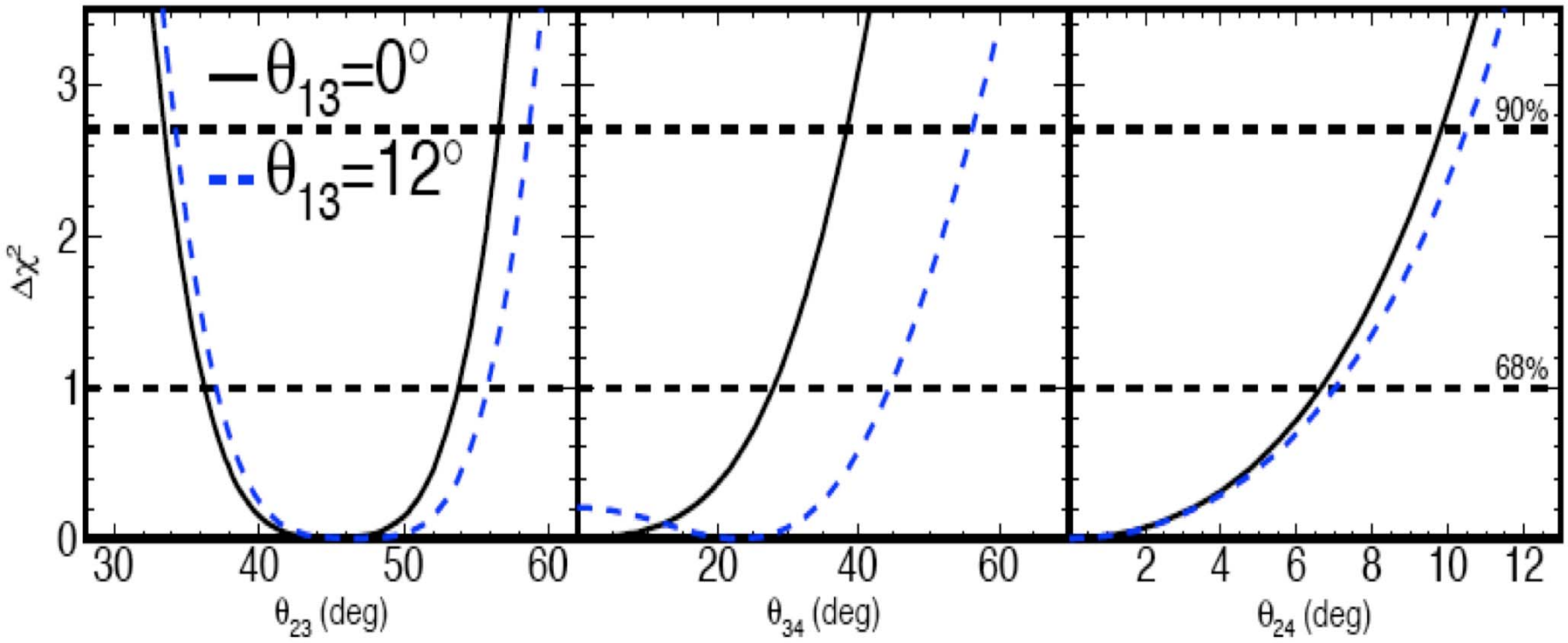
- Effectively $\theta_{14}=\theta_{24}=0°$ in this case, and

$$P_{\nu_\mu\to\nu_\mu} = 1 - 4|U_{\mu 3}|^2\left(1-|U_{\mu 3}|^2\right)\sin^2\Delta_{31}$$



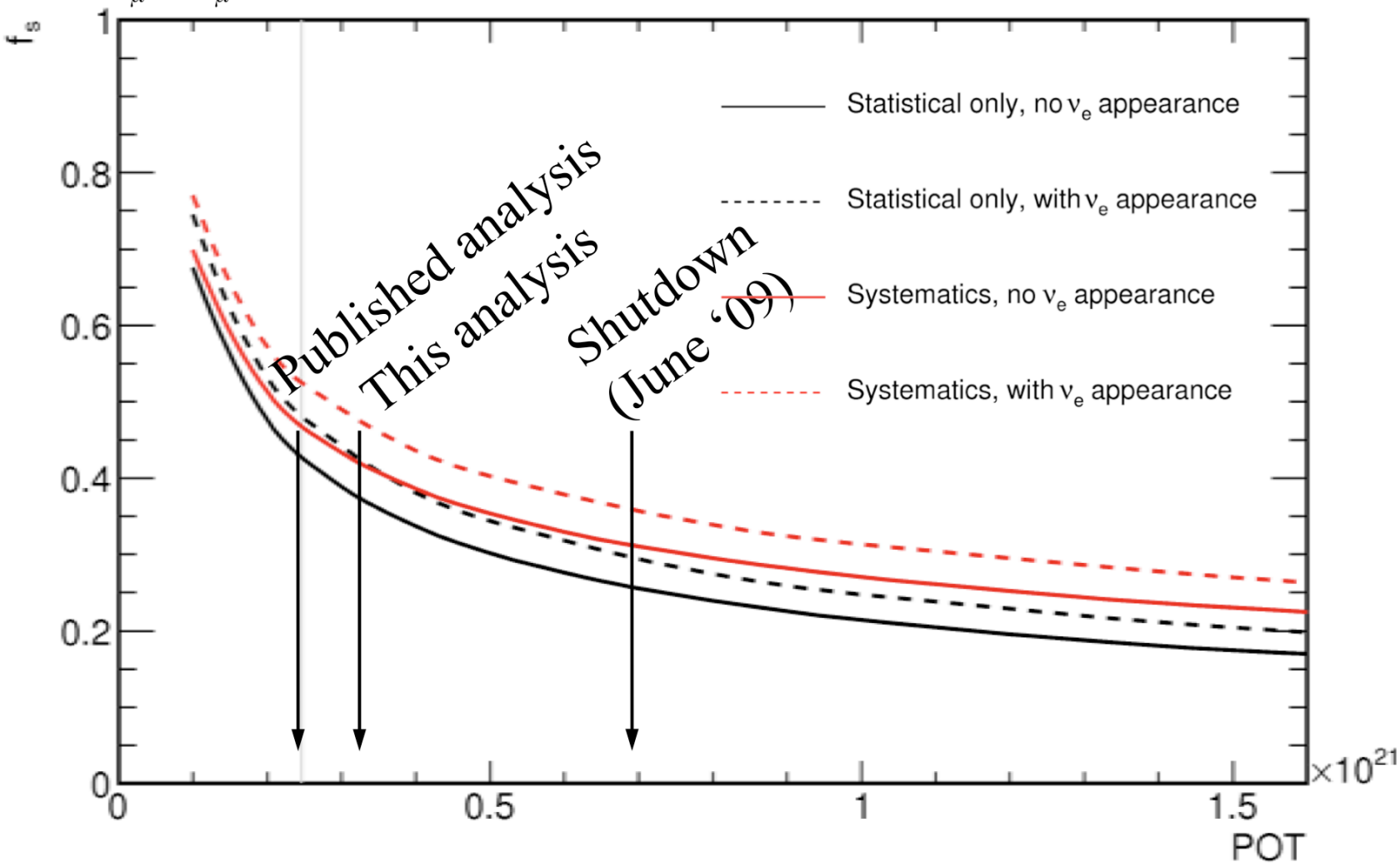
4-Flavour Analysis: $m_4 >> m_3$

$$P_{\nu_\mu \to \nu_\mu} = 1 - 4\left\{ |U_{\mu 3}|^2 \left(1 - |U_{\mu 3}|^2 - |U_{\mu 4}|^2 \right) \sin^2 \Delta_{31} + \frac{|U_{\mu 4}|^2}{2} (1 - |U_{\mu 4}|^2) \right\},$$



$$f_s = \frac{P_{\nu_\mu \to \nu_s}}{1 - P_{\nu_\mu \to \nu_\mu}}$$

Future Sensitivity



The CP-Violating Globe

WEDNESDAY, MAY 27, 2009

news

be unions
cuts in pay and
g The New York
r to the savings
to continue
aper. **B5.**

painful but
over the abuse
e care of Roman
rs orders, Presi-
leese said in a
A5.

te officials are
e legality of a
transporting
chool students
osts. **B1.**

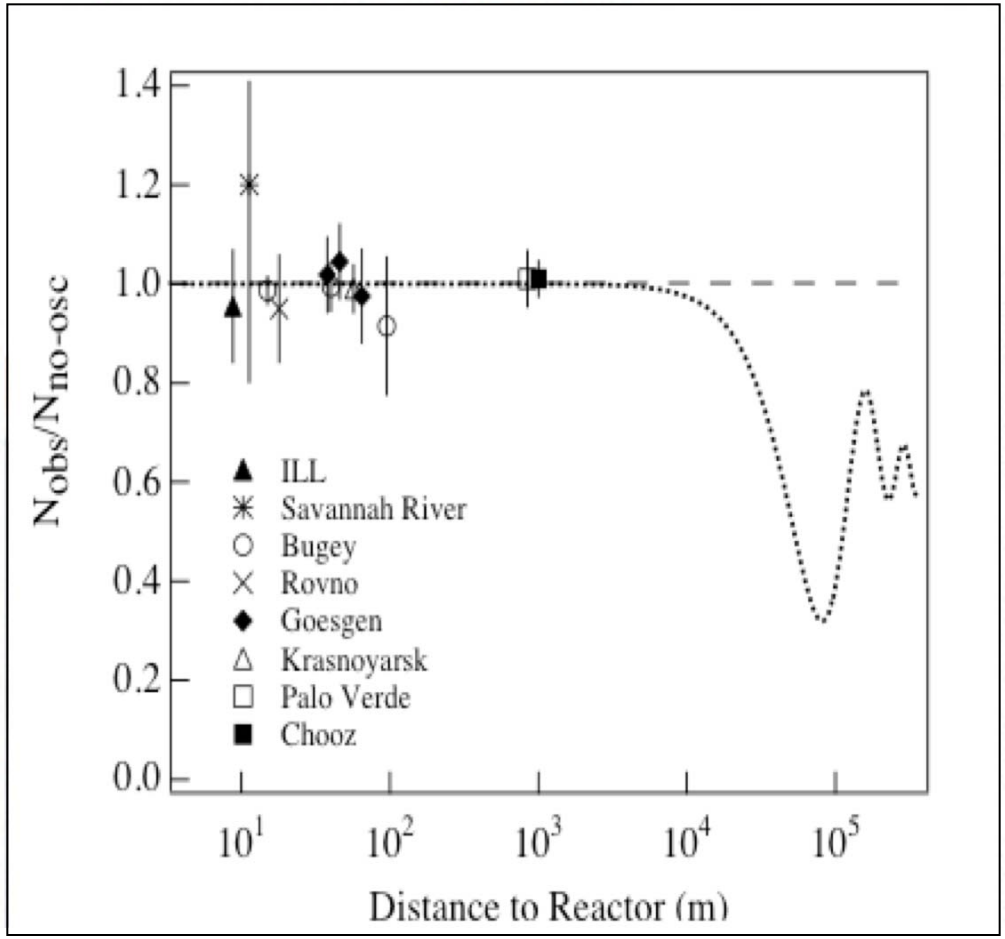
Men's Wear-
s will bid for
ene's Basement
p the brand
official said. **B5.**

ureate Aung
stified in her
at she did not
s of her house
temporary
ntruder. **A4.**

ourt over-
ruling that
estioning with-
sent. Justice
ns, who wrote
ion, was one of
yesterday. **A6.**

No hint of rarest transition $\nu_\mu \rightarrow \nu_e$

Must find $\theta_{13}>0$ to study CP Violation



Search for θ_{13} via reactors (disappearance) or accelerators (appearance)

WASHINGTON — Introducing Sonia Sotomayor yesterday as his first Supreme Court nominee, President Obama relished telling her up-from-poverty life story and highlighting her history-making ethnic roots. But he stressed that he picked her because of her intellect, judicial experience, and her determination "to approach decisions without any particular ideology or agenda."

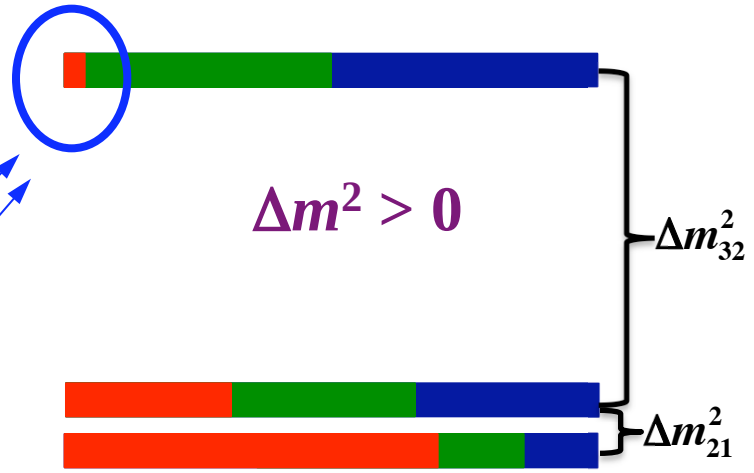
Obama, however, was quickly challenged by critics who contended she was picked more for her personal story — and her gender and ethnicity — than her legal credentials. They buttressed their contention by noting that she recently joined a three-judge panel that ruled unanimously against white firefighters in a

preme Court yesterday, selecting a woman who is a product of both New York City public housing and Ivy League universities, and who would become the first Hispanic and third female to serve on the high court.

Calling the 54-year-old Sotomayor "an inspiring woman," Obama praised her three-decade career as a corporate litigator, prosecutor, and federal appellate judge. But in his first chance to shape the closely divided high court, Obama also said her real-life experience filled his desire for a justice who has "a sense of compassion, an understanding of how the world works and how ordinary people live."

The president cited Sotomayor's humble upbringing, including her father's death when she was 9 years old, and the dia-

Are there $\nu_\mu \rightarrow \nu_e$ Oscillations?



$$P(\nu_\mu \rightarrow \nu_e) \approx \sin^2(2\theta_{13})\sin^2(\theta_{23})\sin^2\left(1.27\Delta m^2_{31}\frac{L}{E}\right) \quad \} \text{ atm } \Delta m^2$$

$$+ \sin^2(2\theta_{12})\cos^2(\theta_{23})\sin^2\left(1.27\Delta m^2_{21}\frac{L}{E}\right) \quad \} \text{ solar} \Delta m^2$$

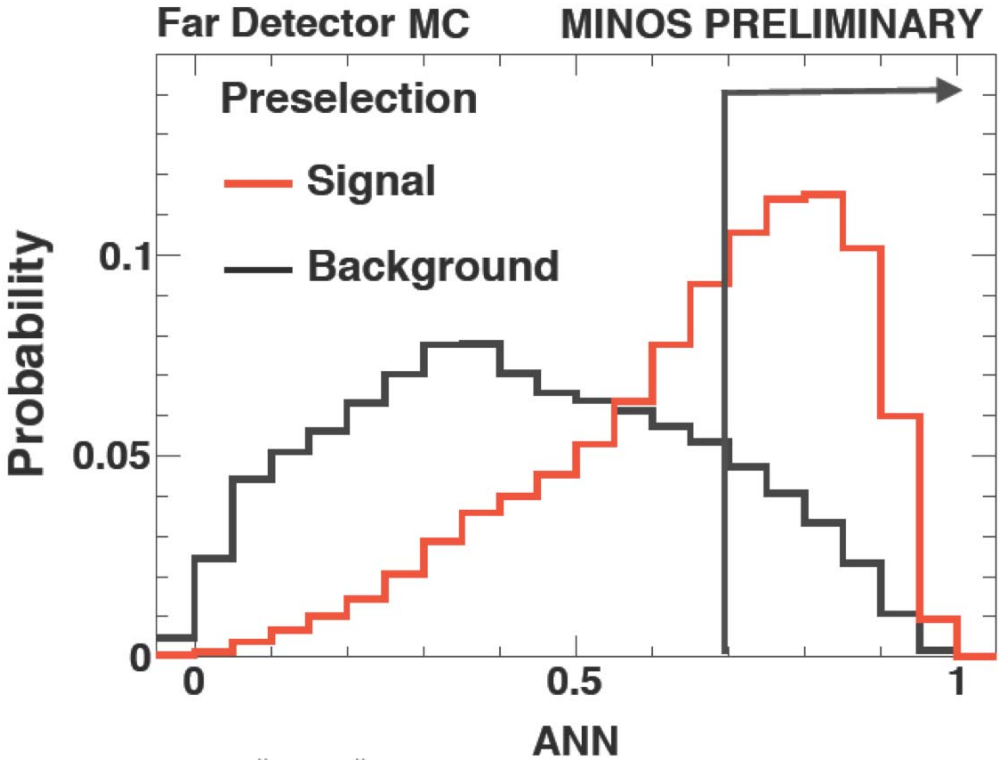
$$+ \sin(2\theta_{13})\sin(2\theta_{23})\sin(2\theta_{12}) \times$$

$$\sin\left(1.27\Delta m^2_{31}\frac{L}{E}\right)\sin\left(1.27\Delta m^2_{21}\frac{L}{E}\right)\cos\left(1.27\Delta m^2_{32}\frac{L}{E} \pm \delta_{CP}\right) \quad \} \text{ atm } \Delta m^2$$

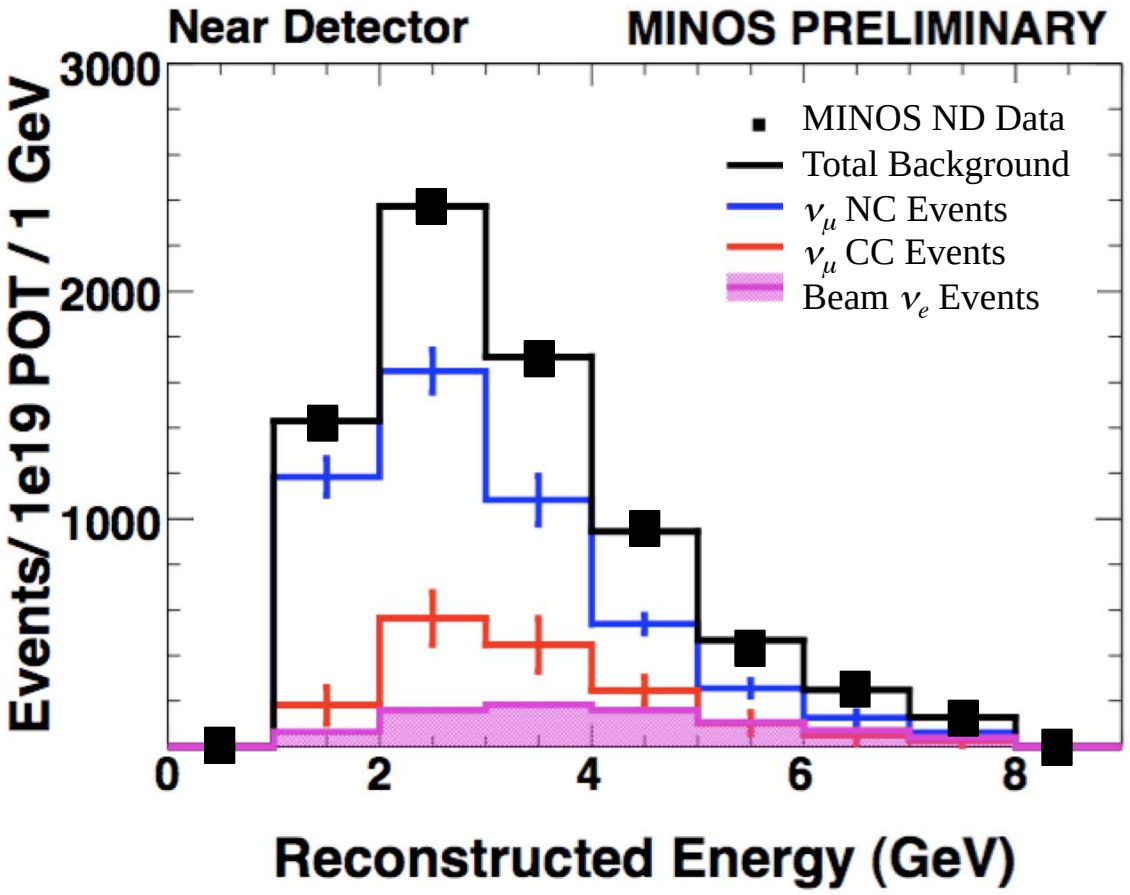
formula in vacuum

Selecting ν_e Events in MINOS

- Neural network developed using 11 variables, *eg*:
  - ❖fraction of shower near core
  - ❖lateral shower size
  - ❖fall-off of shower
- ANN achieves
  - ❖CC rejection 99.4%
  - ❖NC rejection 92.3%
  - ❖ν_e effic ~ 41%
  - ❖signal/noise ~ 1:4

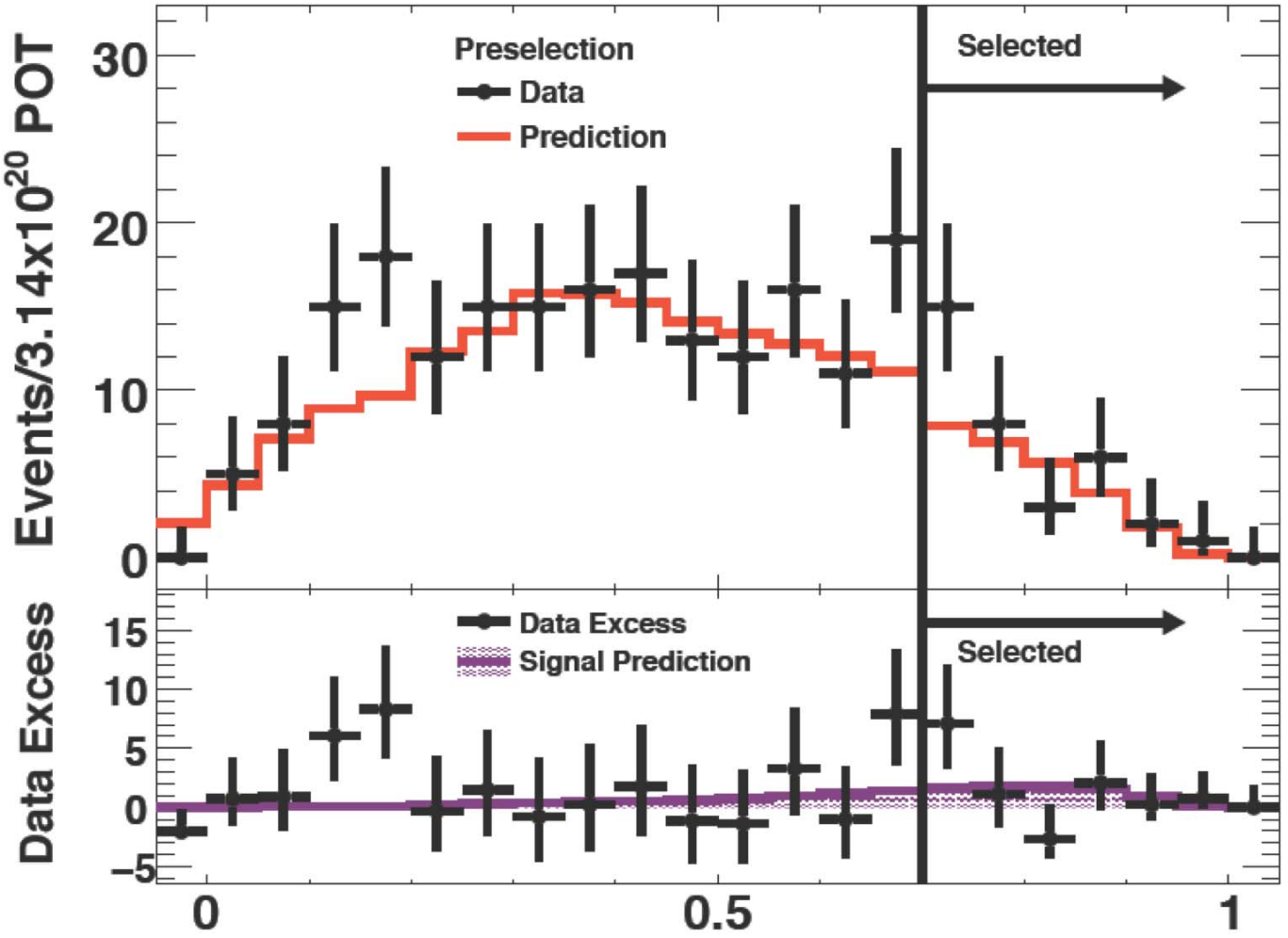


Near Detector Measures Backgrounds



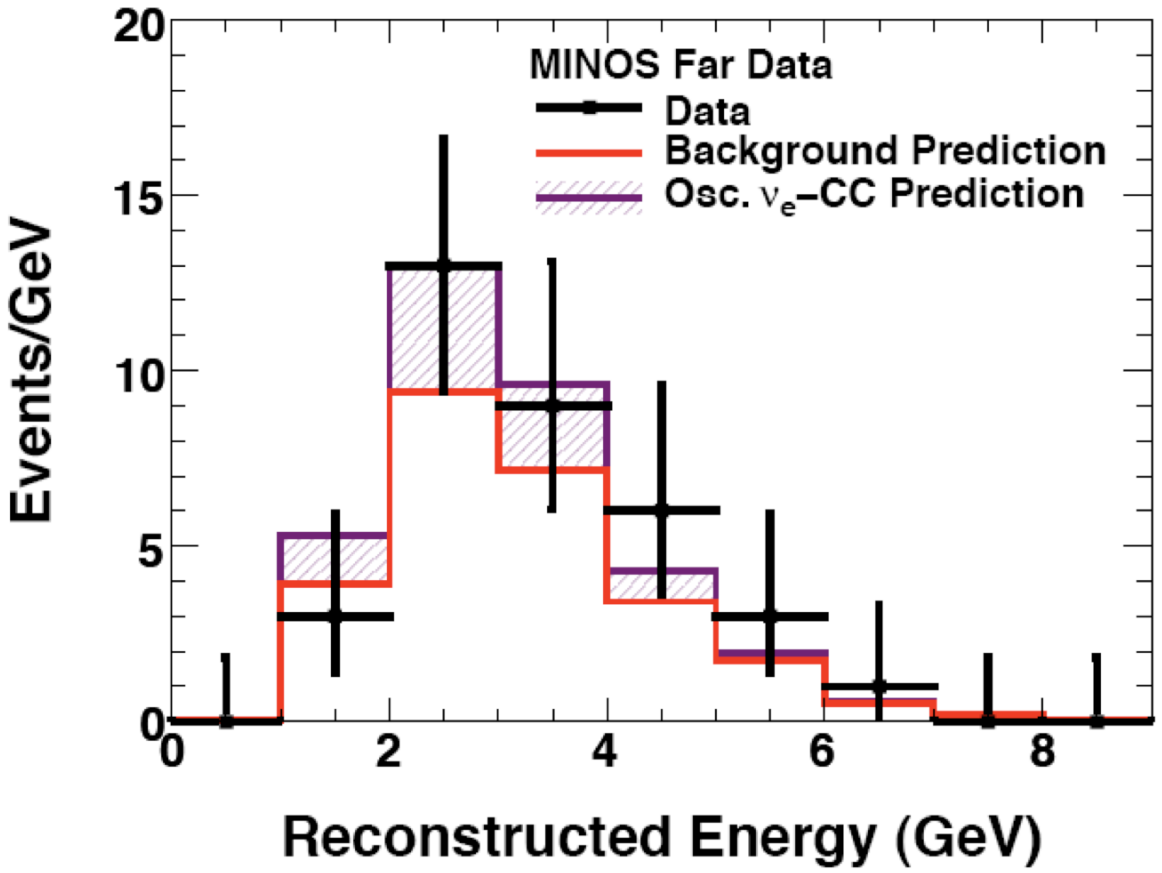
- Our beam is 94% ν_μ, 5% $\overline{\nu}_\mu$, and ~1% ν_e.
  - $\pi \rightarrow \mu \nu_\mu \rightarrow e \nu_\mu \nu_\mu \nu_e$
  - $K \rightarrow \pi e \nu_e$
- Can measure level of individual NC and CC backgrounds via horn-on and horn-off running

Observation in Far Detector



- Oscillations $\nu_\mu \rightarrow \nu_e$ would be excess ν_e rate over beam and instrumental backgrounds.

ν_e Signal in Far Detector

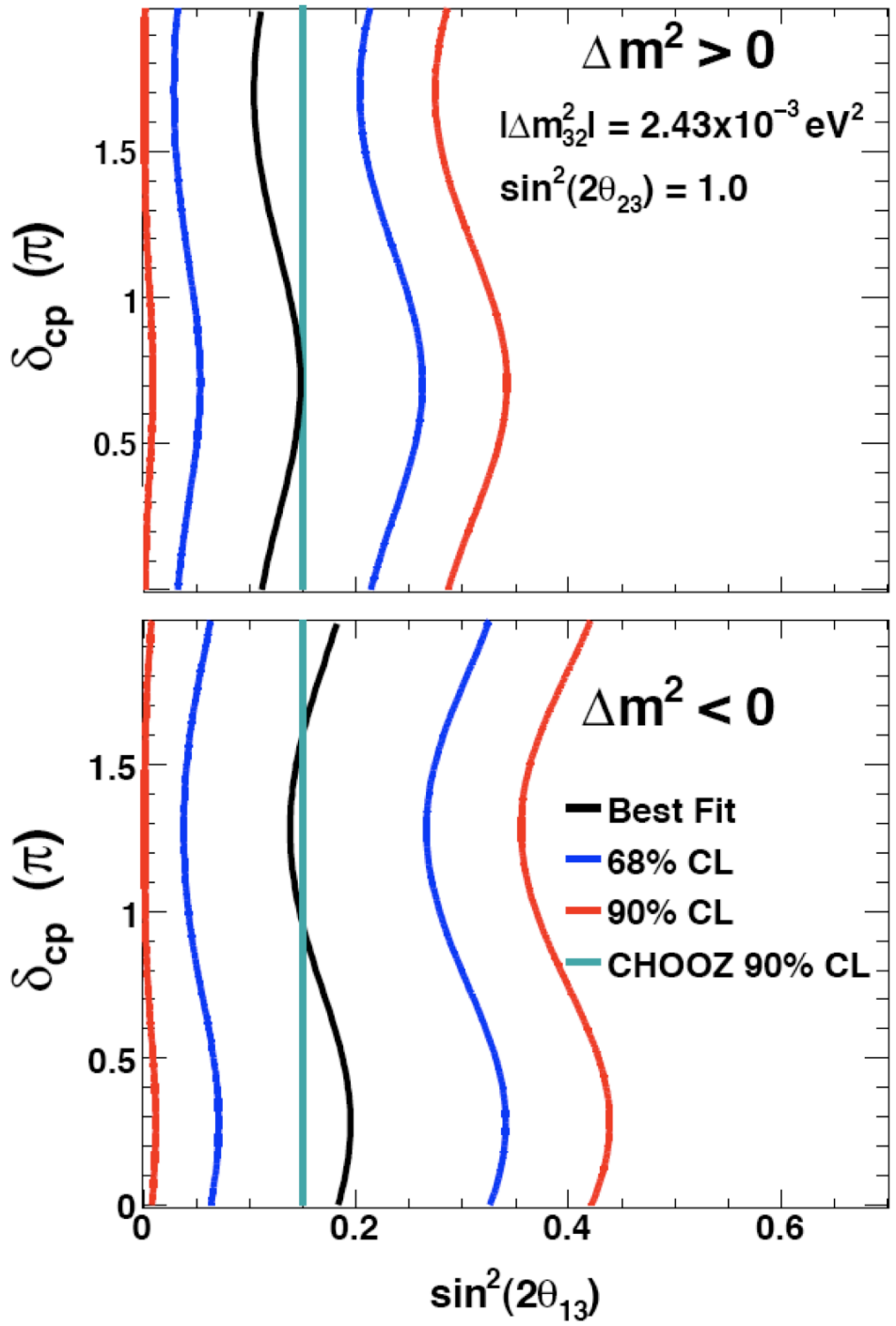


- Expected background 27±5(stat) ±2(syst) (mis-reconstructed showers, beam ν_e)
- Observed:

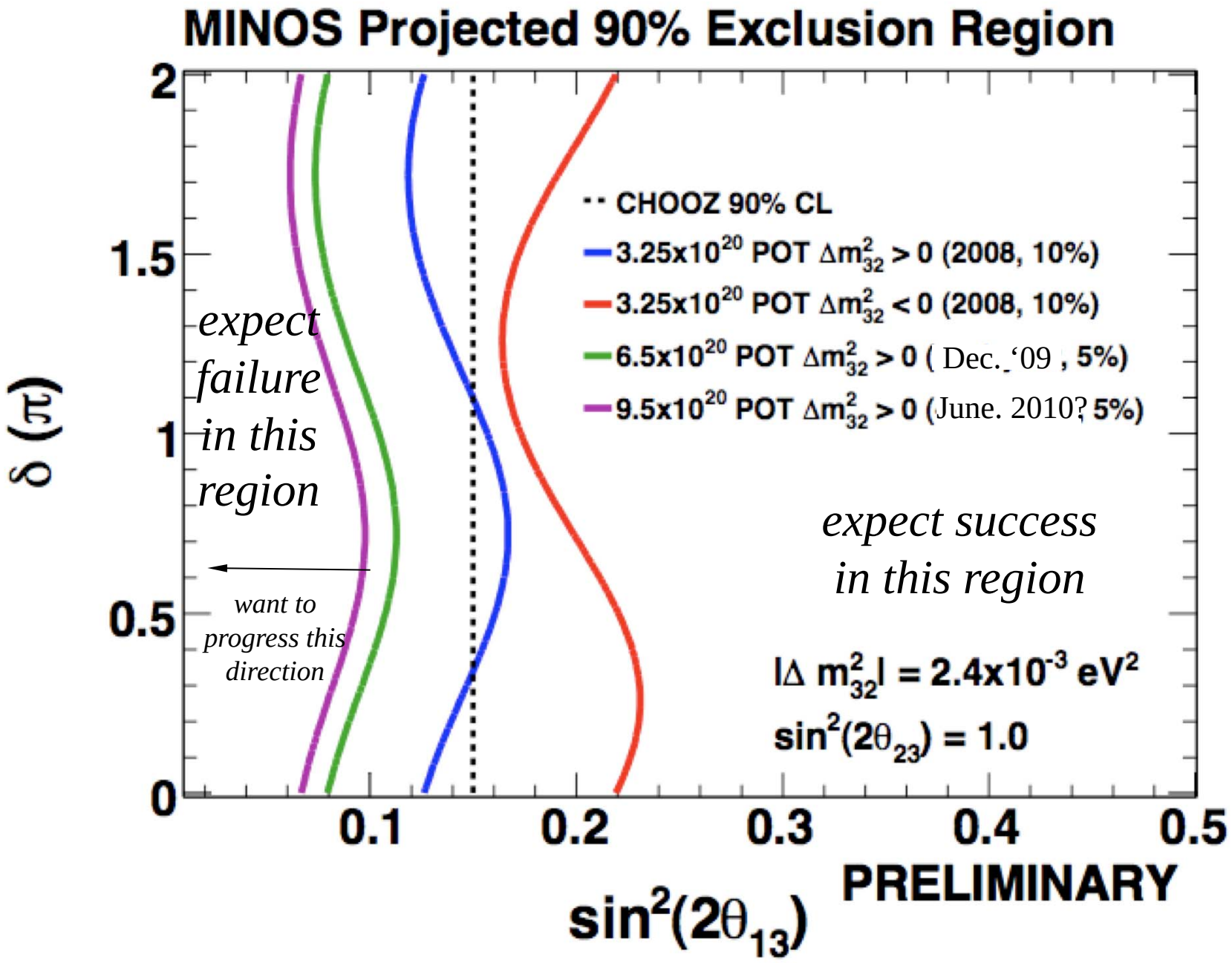
35 events

- Observed is 1.5σ over bckgd. expectation

We integrated ~7 x 10^{20} POT as of June 15!



MINOS ν_e Appearance Contours


MINOS Projected 90% Exclusion Region
CHOOZ 90% CL
3.25x10^20 POT Δm²32 > 0 (2008, 10%)
3.25x10^20 POT Δm²32 < 0 (2008, 10%)
6.5x10^20 POT Δm²32 > 0 (Dec. '09 , 5%)
9.5x10^20 POT Δm²32 > 0 (June. 2010? 5%)
expect failure in this region
want to progress this direction
expect success in this region
|Δ m²32| = 2.4x10^-3 eV²
sin²(2θ23) = 1.0
δ (π)
sin²(2θ13)
PRELIMINARY
0
0.5
1
1.5
2
0.1
0.2
0.3
0.4
0.5

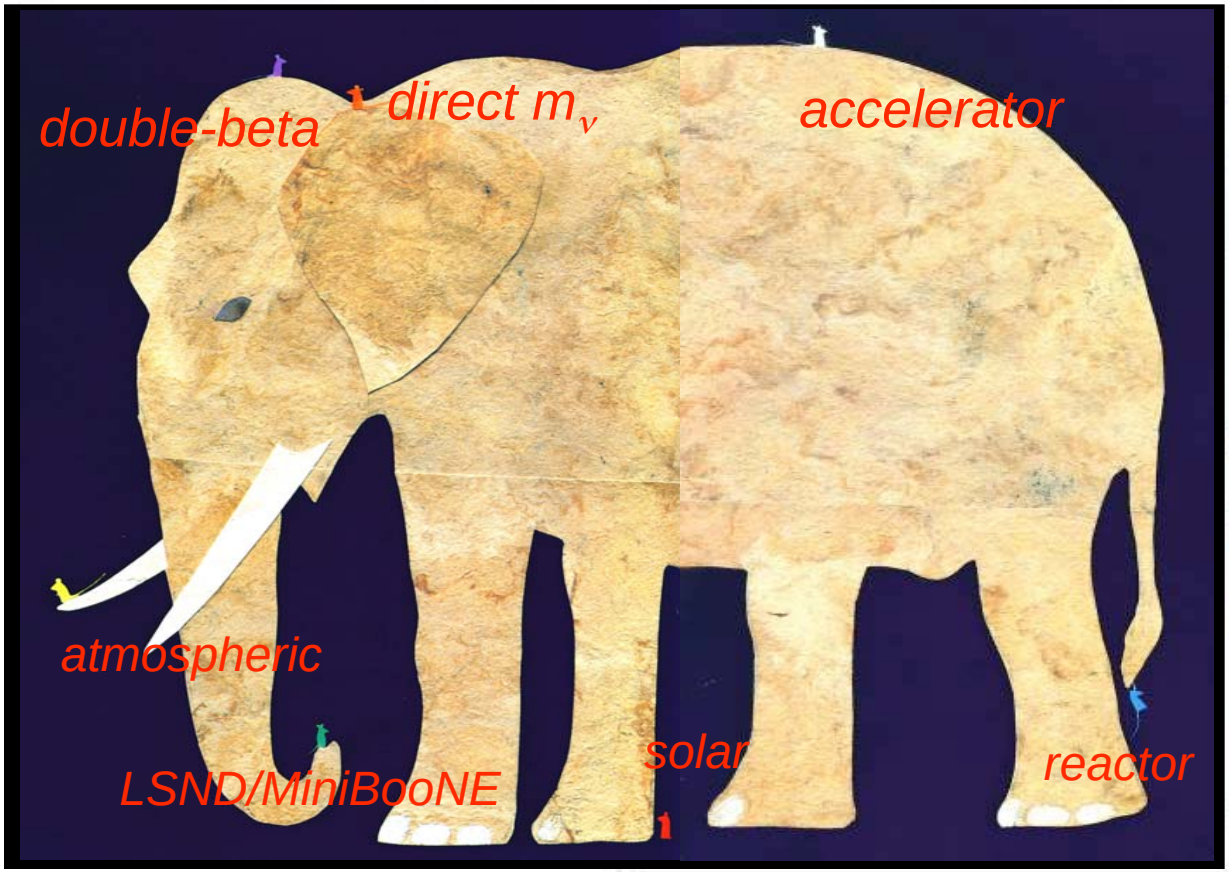
"All the Nu's that's fit to print"

The Neutrino Nu's

Late Edition

Today, mostly sunny, light winds, high 69. Tonight, increasing clouds, spotty showers late, low 56. Tomorrow, clouds, a little sun, milder, high 73. Weather map is on Page B14.

VOL. CLVIII . . No. 54,457 © 2008 The New York Times NEW YORK, WEDNESDAY, OCTOBER 8, 2008 $1.50



MINOS PRODUCING MANY RESULTS IN NU OSCILLATIONS

Most Precise Measurement of Atmospheric Mass Splitting

By EDMUND L. ANDREWS and MICHAEL M. GRYNBAUM

WASHINGTON — The promise of lower interest rates and new federal efforts to stem the financial crisis failed to dispel the fear gripping Wall Street on Tuesday.

Stocks rose at the session's opening but soon began to fall, and the selling intensified during the afternoon, even after Ben S. Bernanke, the chairman of the Federal Reserve, all but pledged to cut interest rates by the end of the month. The Dow Jones industrial average plunged 508 points, or 5.1 percent, extending a slide of months that has erased a third of its value in a year. In the last five trading days alone, the Dow has lost 1,400 points.

With the flow of credit still tight, investors have fixated on the threat of a serious recession despite the increasingly urgent attempts by policy makers to buttress the markets. Deepening problems in the European banking industry have compounded fears of a worldwide downturn.

"The Fed is just plugging holes in the dam and the water keeps rushing over," said Michael T. Darda, chief economist at the research firm MKM Partners.

In a somber speech Mr. Ber- strongest indication to date that the Fed will cut rates.

Fed policy makers are scheduled to meet on Oct. 28 and 29, and investors had already been betting that the central bank would reduce the overnight federal funds rate by as much as one-half of a percent, to 1.5 percent. But many analysts predict the Fed may act before the next meeting, given the sprawling nature of the credit crisis.

In its latest tactic, the Fed announced on Tuesday morning a new program to buy up parts of the short-term financing market to unlock the flow of credit to businesses. The program, which is expected to begin soon, was the latest and potentially biggest in a series of unprecedented ef-

Continued on Page A23

World-Wide Effort to Interpret Nu Disappearance, Mass

By ADAM NAGOURNEY

Senators John McCain and Barack Obama debated for 90 minutes on Tuesday night before a nation in economic crisis, each

Mr. Obama placed the blame for the financial crisis on deregulation and the lack of fiscal discipline under President Bush,

Experiments still pushing for CP Violation in Neutrinos

By ERIC SCHMITT

WASHINGTON — An investigation by the military has concluded that American airstrikes on Aug. 22 in a village in western

the raid, and the American military, under Gen. David D. McKiernan, the top American military commander in Afghani-

Ongoing Searches for Non-Standard Oscillations