

Prospects for Conventional Long-Baseline
Oscillation Experiments
and
Comparison with a
Neutrino Factory

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Fermilab

Neutrinos and Implications for
Physics Beyond the Standard Model
Stony Brook, New York
October 13, 2002

- Overview: challenges
- Why this is hard
- Coping Strategies
- Example: NUMI Off-Axis Proposal

First Step—MORE MORE MORE

All the proposals listed on the previous page, will see ν_e candidate events even w/o oscillations! → Gains in Sensitivity come in square roots

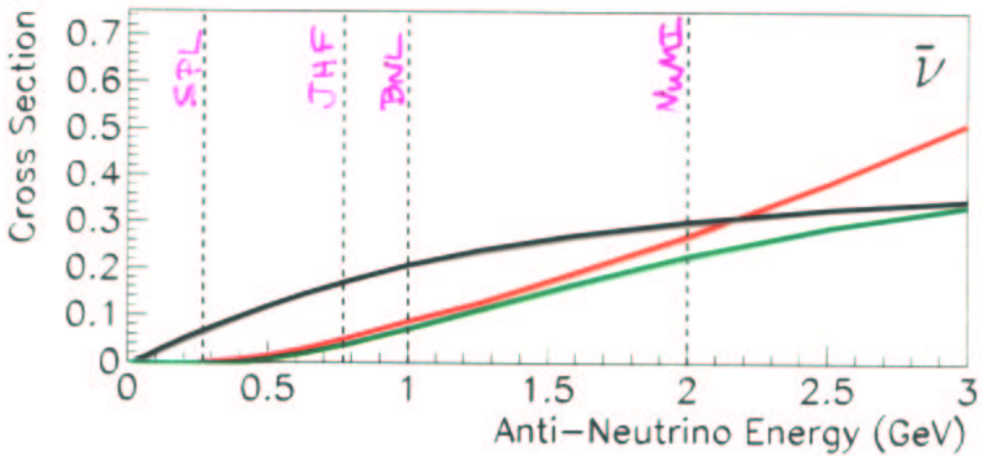
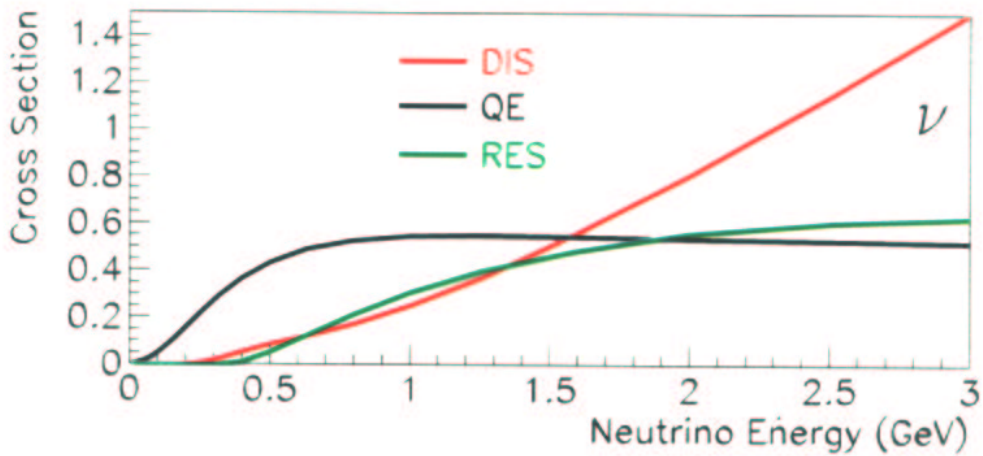
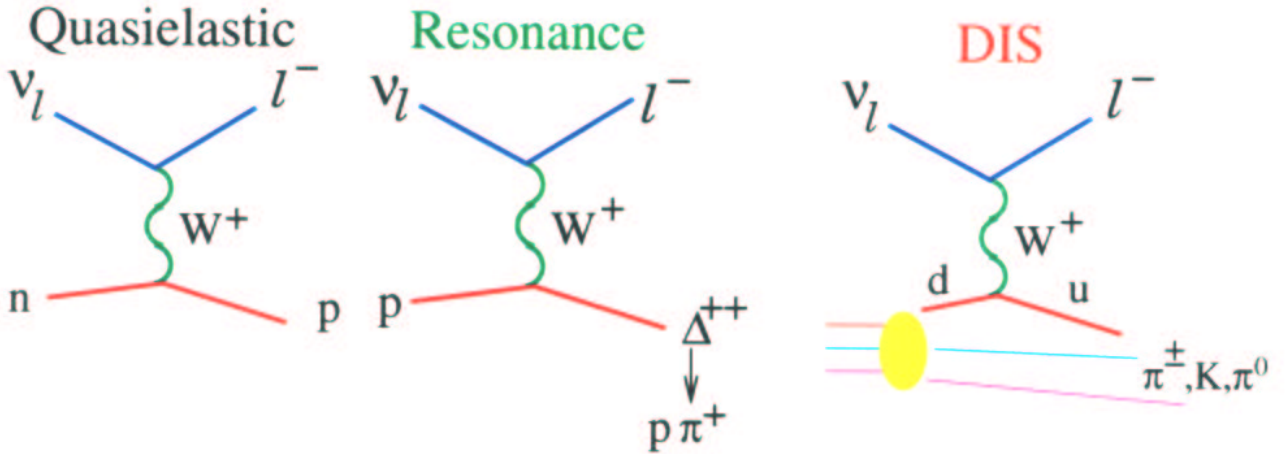
- More Detector Mass than ever Before
 - Water Cerenkov Devices figure prominently: instrument surface only!
 - “Industrialization” of Detector Construction a must
 - typical estimates: factors of 4 to 20 above current largest detector of any given technology
- More Beam Power
 - New Proton Drivers
 - New Super Rad-hard beamlines

Beam Optimization—Pick One!

- Narrow Band Beams (JHF2K, NUMI-OA)
 - Good News: Backgrounds have broad energy spectrum
 - Bad News: Beam width is much narrower than oscillation width
- Very Low Energy (CERN SPL)
 - Good News: Good Signal Acceptance & bkgd rejection
 - Bad News: Cross Section is very small, esp. $\bar{\nu}$'s
- Very Long Distance (BNL2NUSL)
 - Good News: matter effects amplify signal
 - Good News: CP violating part increases with L
 - Bad News: pion production spectrum steeply falling
 - possible good news: $\sigma_{tot}^{\nu} \propto E_{\nu}$

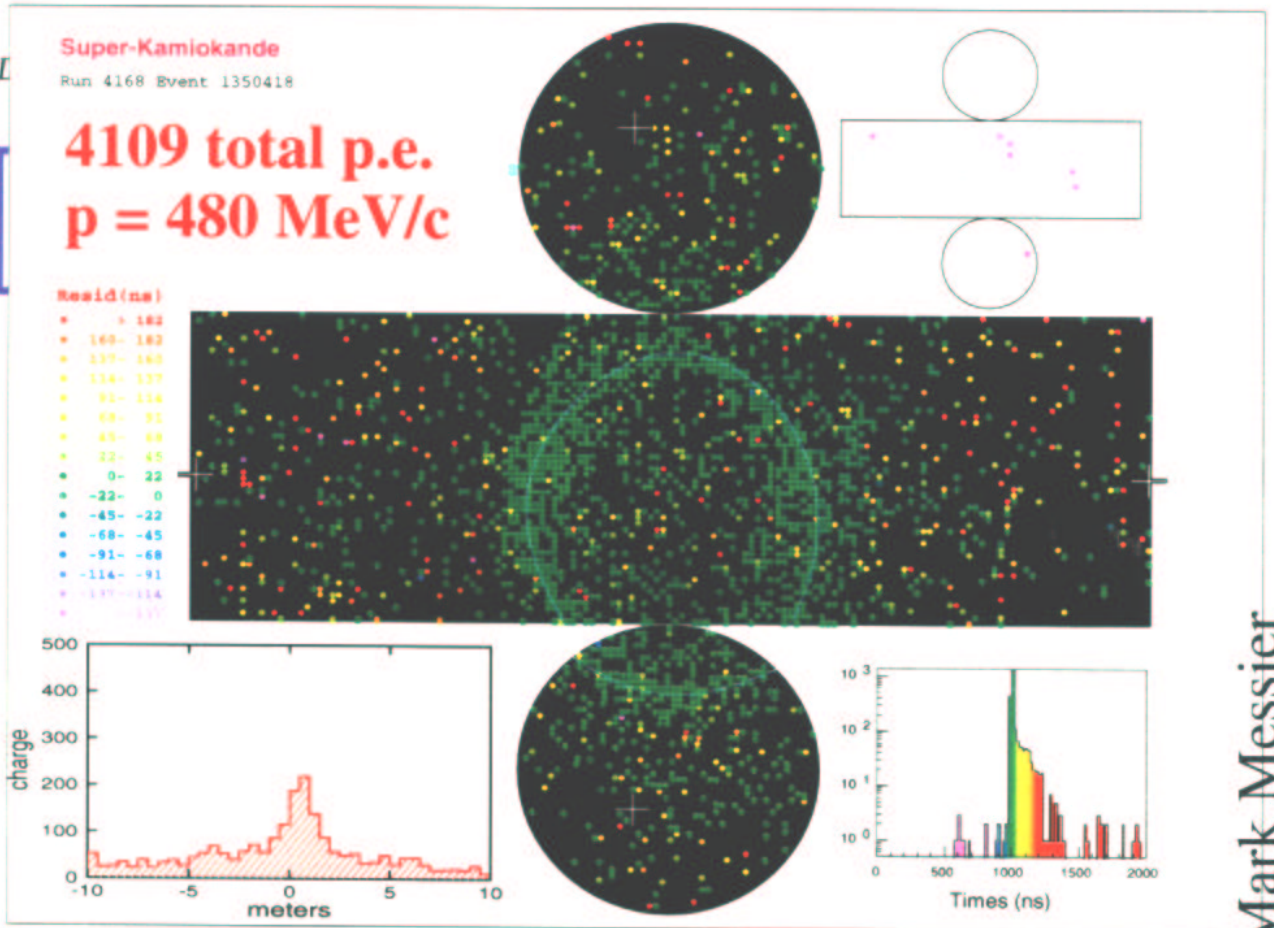
Detector Optimization

But first, a reminder about neutrino interactions

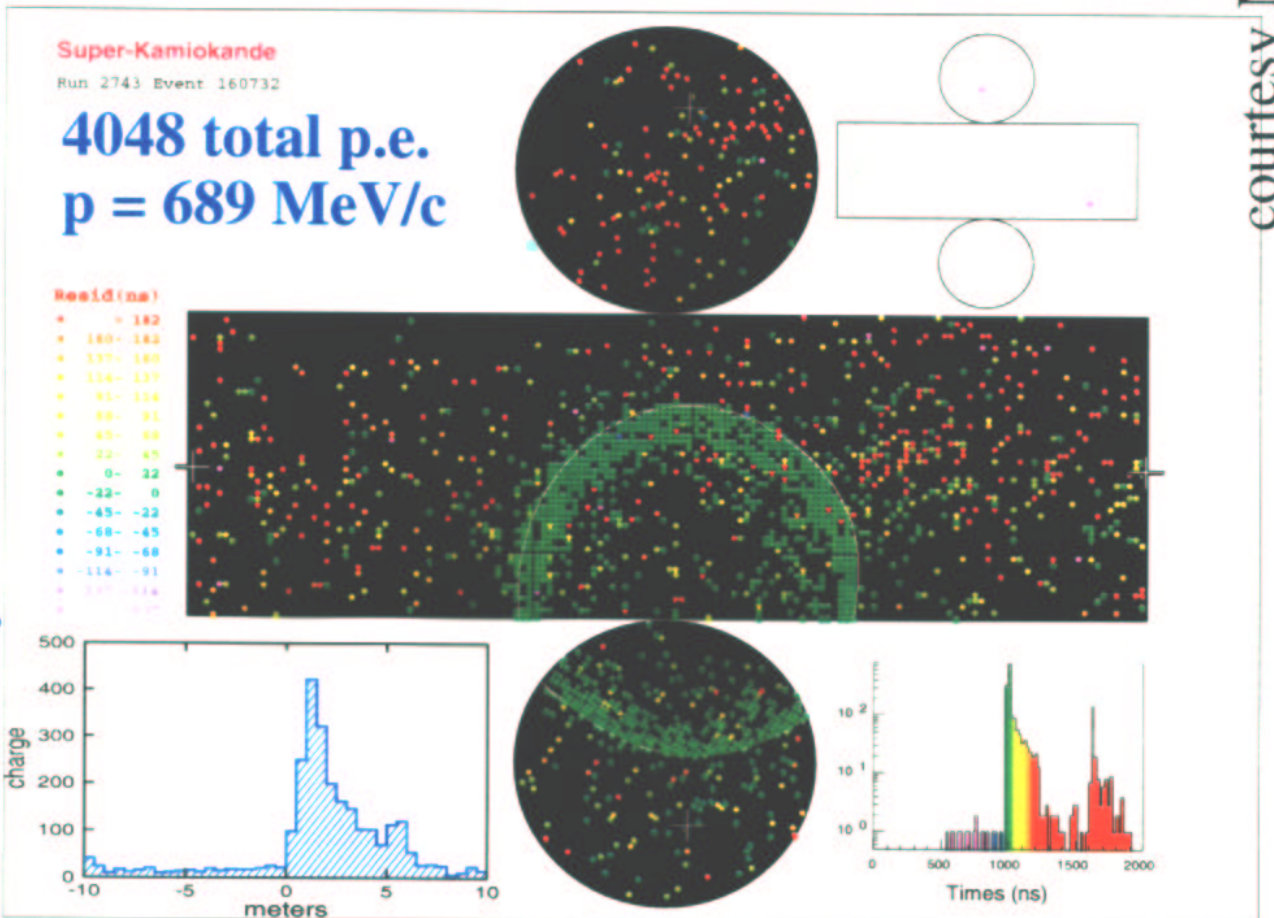


Ref: FLUKA, no nuclear corrections

e-like



μ -like

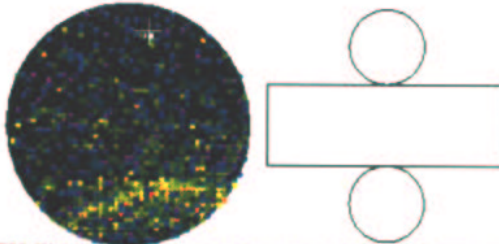


courtesy Mark Messier

Particle ID in Water Cerenkov-2GeV

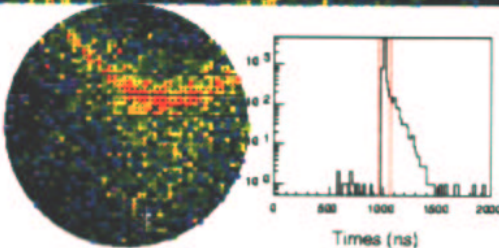
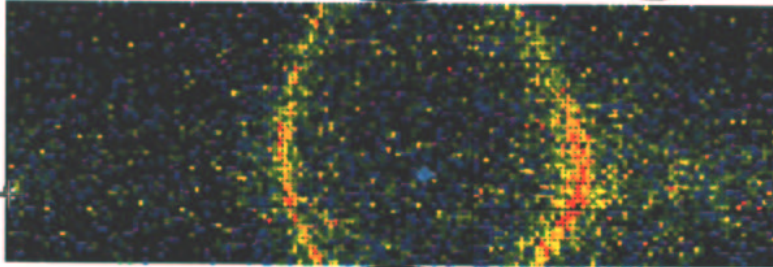
Super-Kamiokande

Run: 999999 Sub: 1 Ev: 262
 99-10-24:00:29:35
 Data: 6018 hits, 16715 pE
 Outer: 4 hits, 2 pE (1A-01ms)
 Trigger ID: 8x83
 D wall: 378.1 cm
 FC @ 110s, p = 2218.5 MeV/c



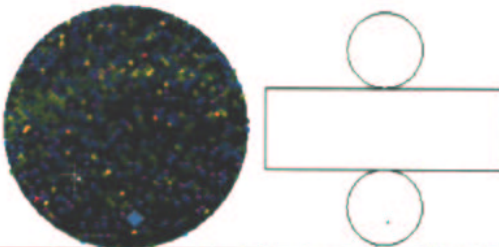
Charge (pe)

- * >15.0
- * 13.1-15.0
- * 11.4-13.1
- * 9.8-11.4
- * 8.2-9.8
- * 6.5-8.2
- * 4.9-6.5
- * 3.3-4.9
- * 1.7-3.3
- * 0.0-1.7
- * -1.7-0.0
- * -3.3-1.7
- * -4.9-3.3
- * -6.5-4.9
- * -8.2-6.5
- * -9.8-8.2
- * -11.4-9.8
- * -13.1-11.4
- * -15.0-13.1
- * <-15.0



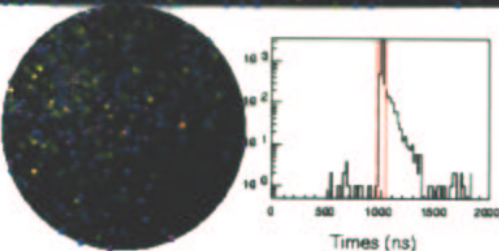
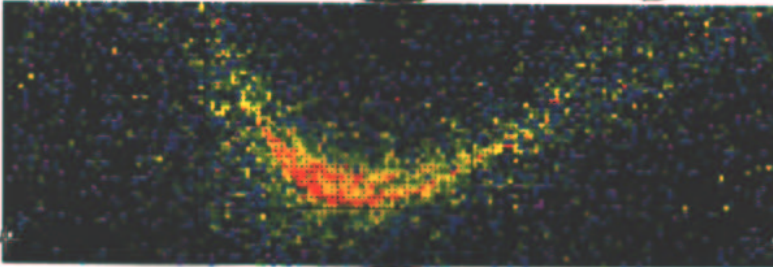
Super-Kamiokande

Run: 999999 Sub: 1 Ev: 195
 99-10-24:00:22:04
 Data: 5081 hits, 12483 pE
 Outer: 5 hits, 2 pE (1A-01ms)
 Trigger ID: 8x83
 D wall: 318.5 cm
 FC @ 110s, p = 1477.3 MeV/c



Charge (pe)

- * >15.0
- * 13.1-15.0
- * 11.4-13.1
- * 9.8-11.4
- * 8.2-9.8
- * 6.5-8.2
- * 4.9-6.5
- * 3.3-4.9
- * 1.7-3.3
- * 0.0-1.7
- * -1.7-0.0
- * -3.3-1.7
- * -4.9-3.3
- * -6.5-4.9
- * -8.2-6.5
- * -9.8-8.2
- * -11.4-9.8
- * -13.1-11.4
- * -15.0-13.1
- * <-15.0

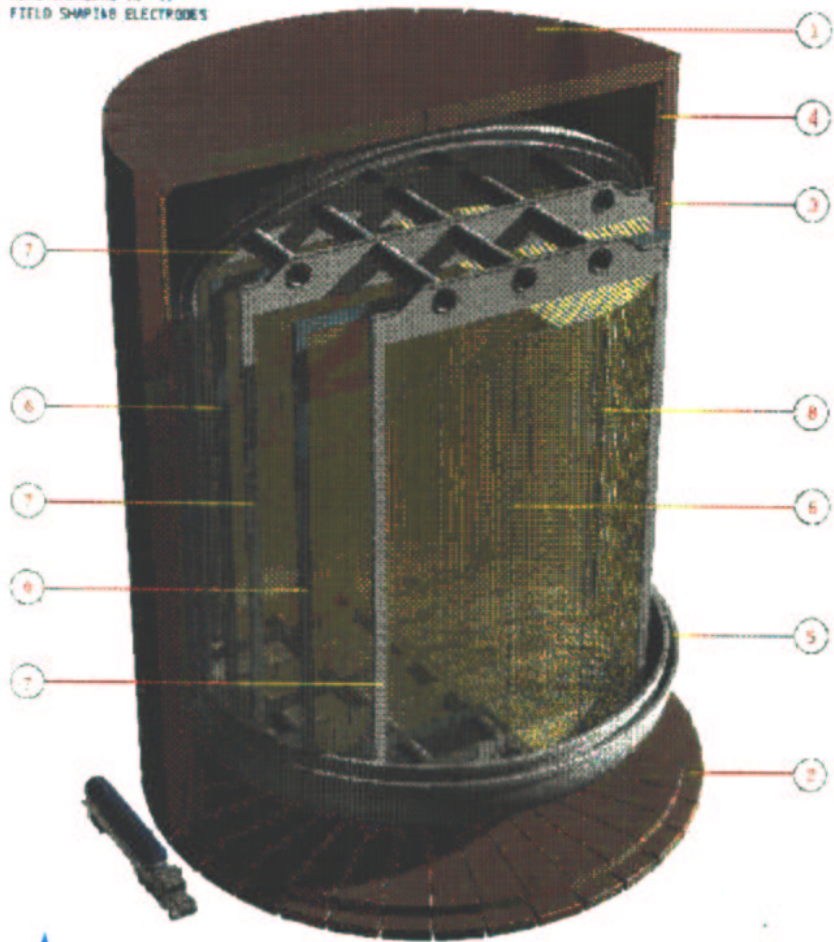


Which is
 ν_e CC,
 which
 is
 ν_{NC} ?

courtesy Mark Messier

Liquid Argon TPC

- 5- CRYOSTAT
- 6- CATHODES (N° 5)
- 7- WIRE CHANGERS (N° 4)
- 8- FIELD SHAPING ELECTRODES



① Electronic
 ② Bubble
 ③ Chamber
 ④ 3mm wire
 pitch
 ⑤ 3m wire plane
 spacing
 ⑥ Cline et al,
 astro-
 ph/0206124

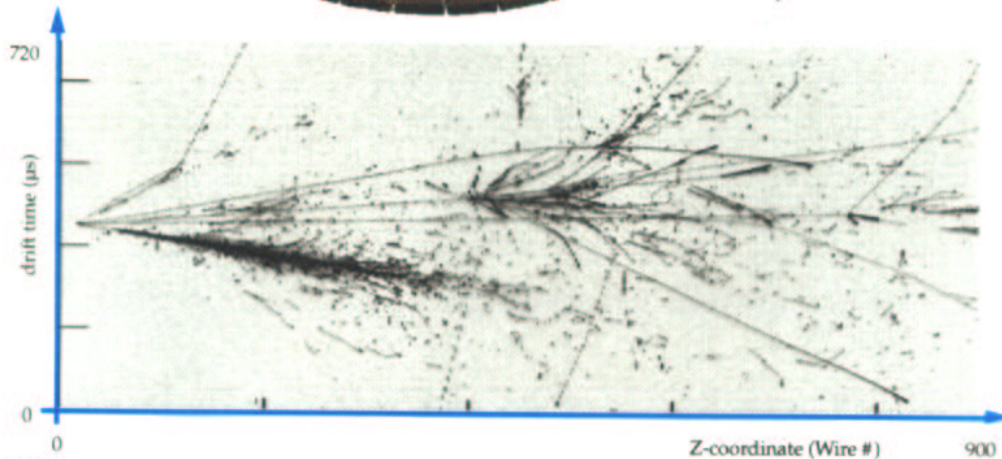
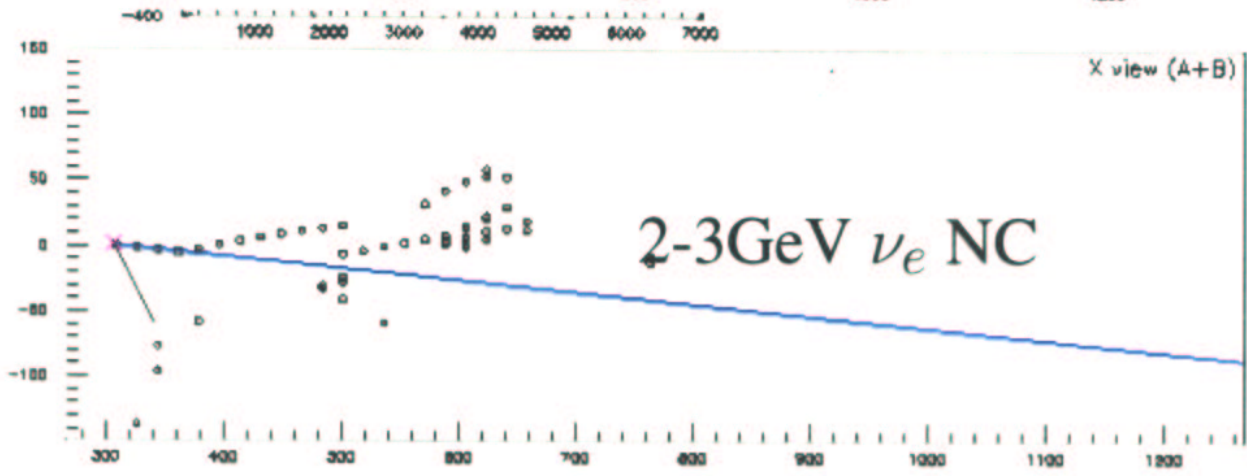
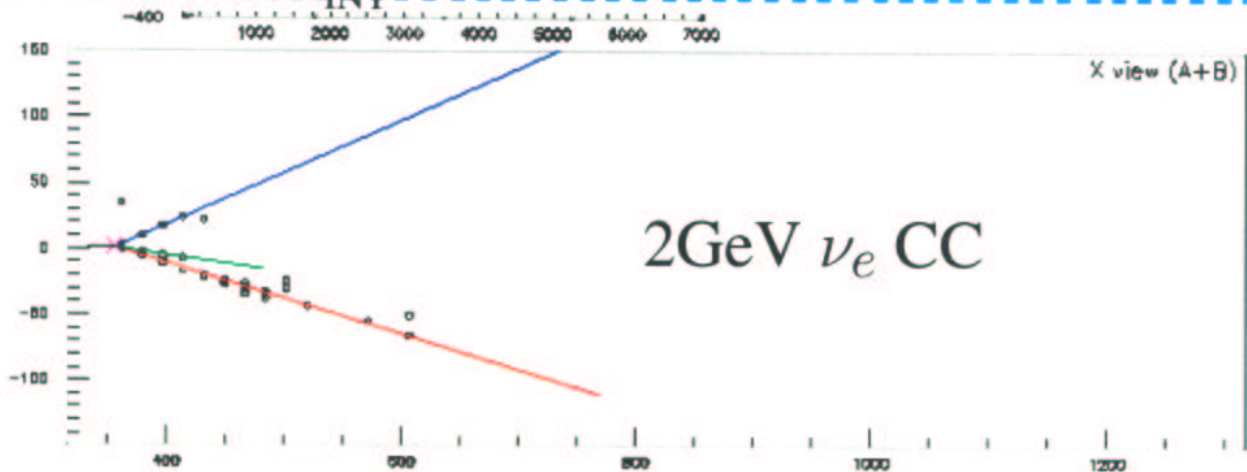
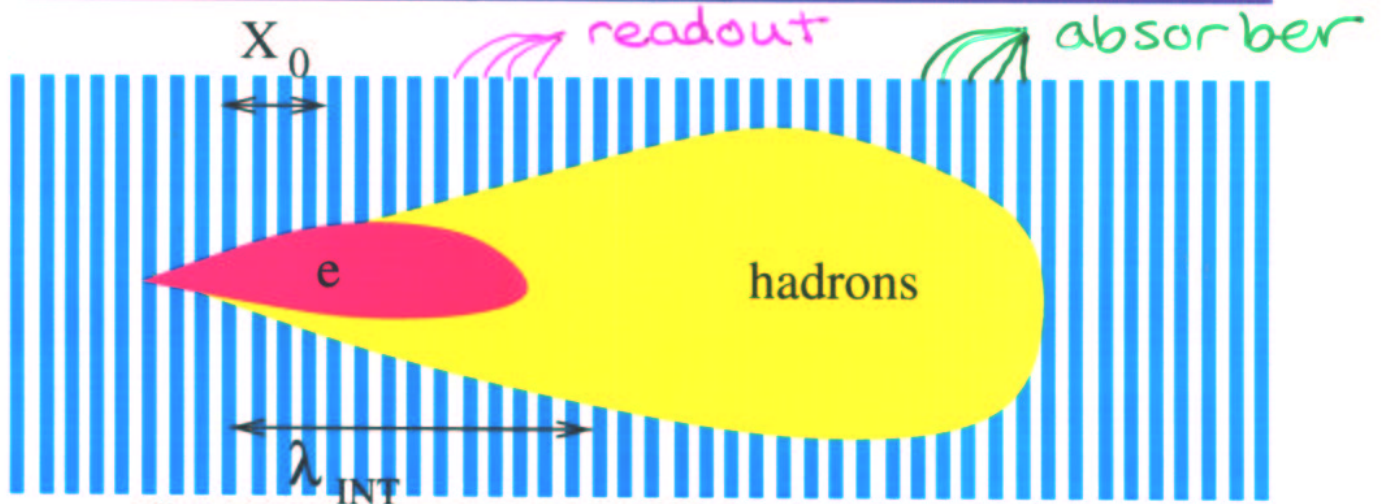


Figure 1

*V_e CC,
 Monte Carlo*

*Courtesy
 Mario
 Campanelli*

Fine-Grained Calorimetry



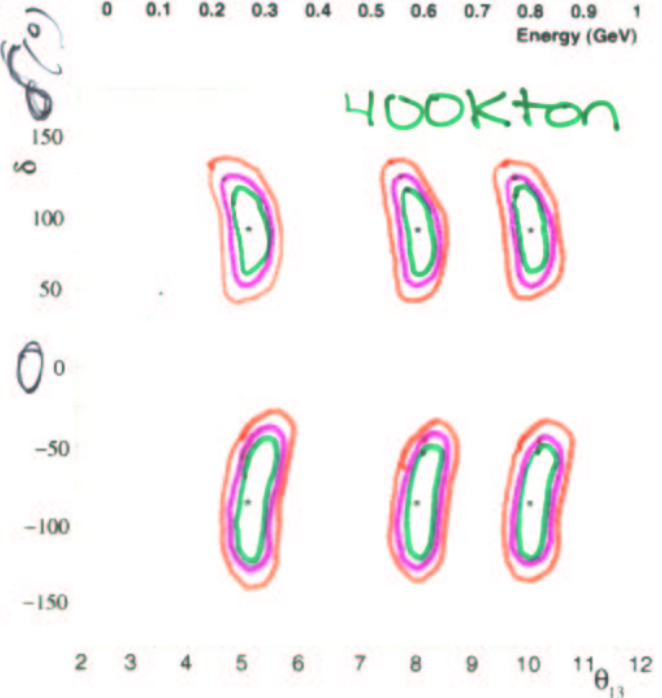
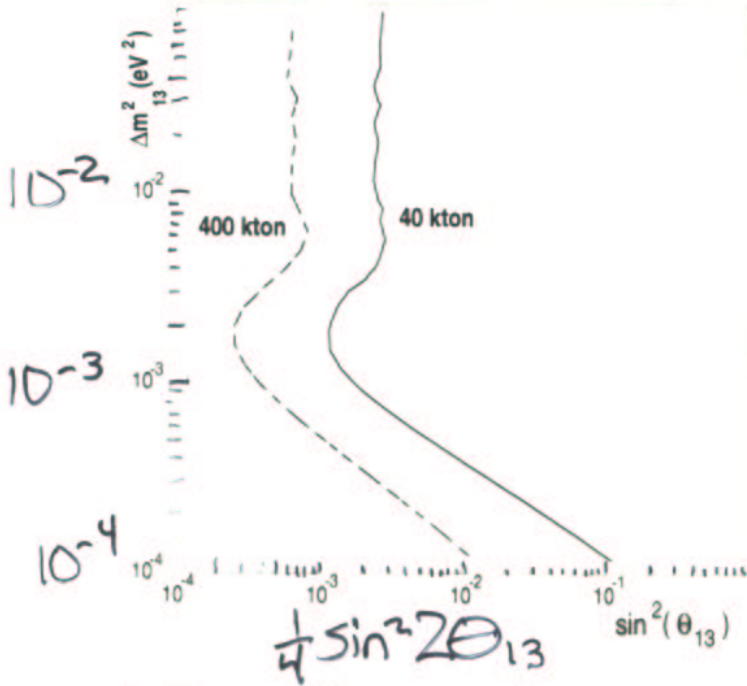
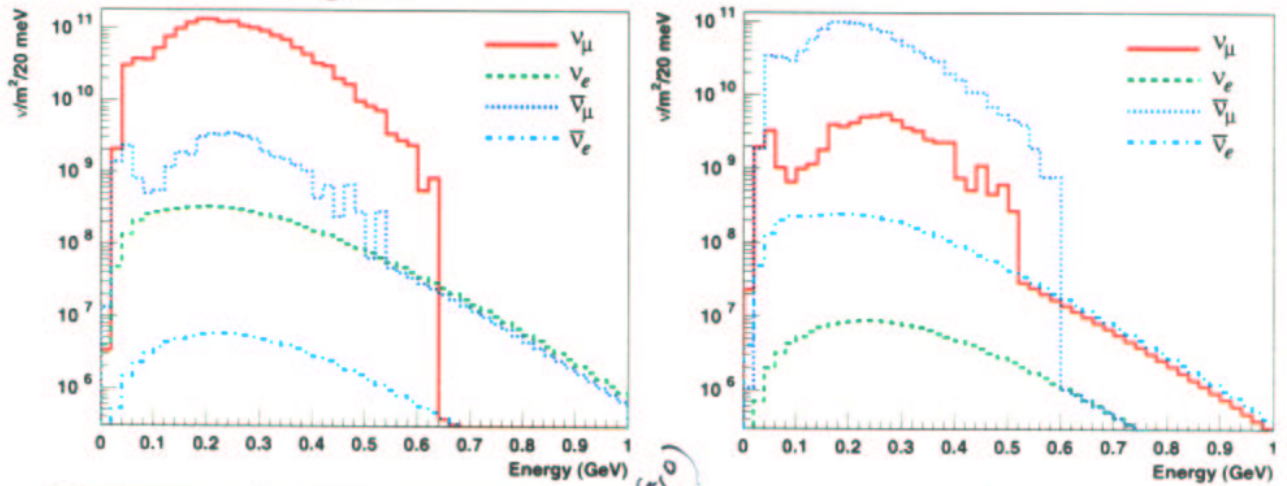
hep-ex/0210005

Readout Ideas: RPC, Scintillator, Streamer Tubes

Absorber Ideas: Plastic, Water, Particle Board
Steel (?)

How Low Can you Go?

CERN SPL: use 2.2 GeV protons to make a neutrino source, with LEP cavities, and UNO detector at Frejus



<http://muonstoragerings.cern.ch>

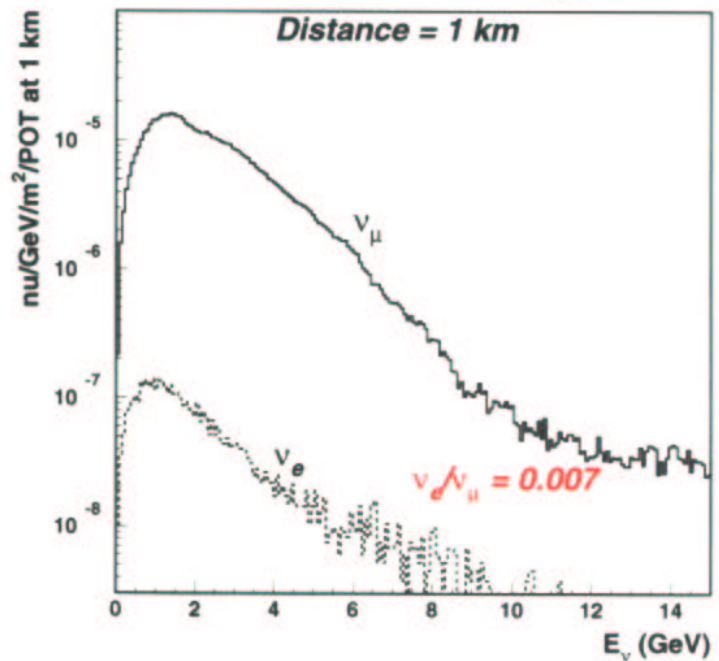
ECFA study, ν osc. study group

$\theta_{13} (^\circ)$

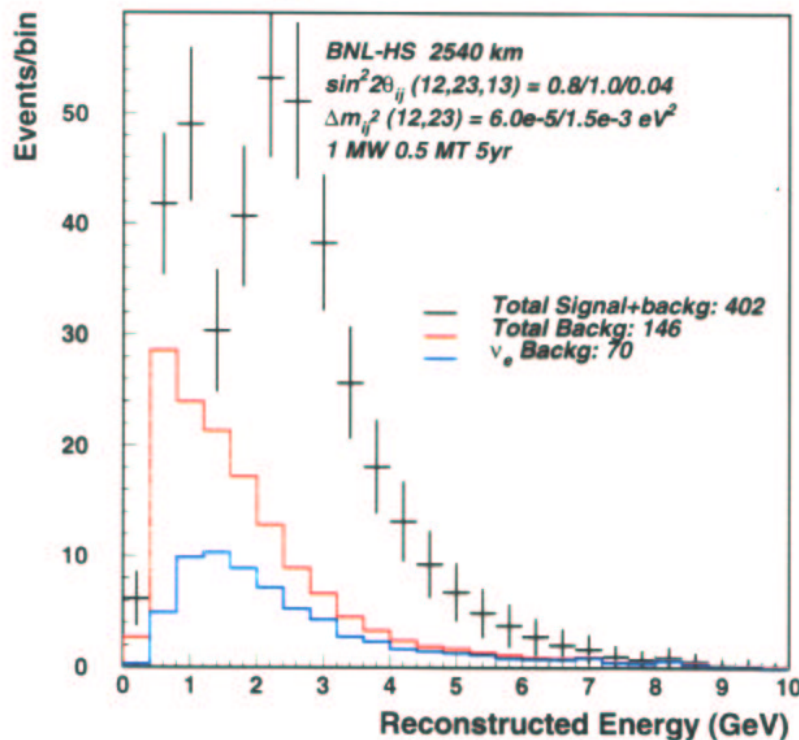
How Far Can you Go?

Brookhaven LOI:
see
Milind Diwan's
talk,
coming up next

BNL Wide Band. Proton Energy = 28 GeV



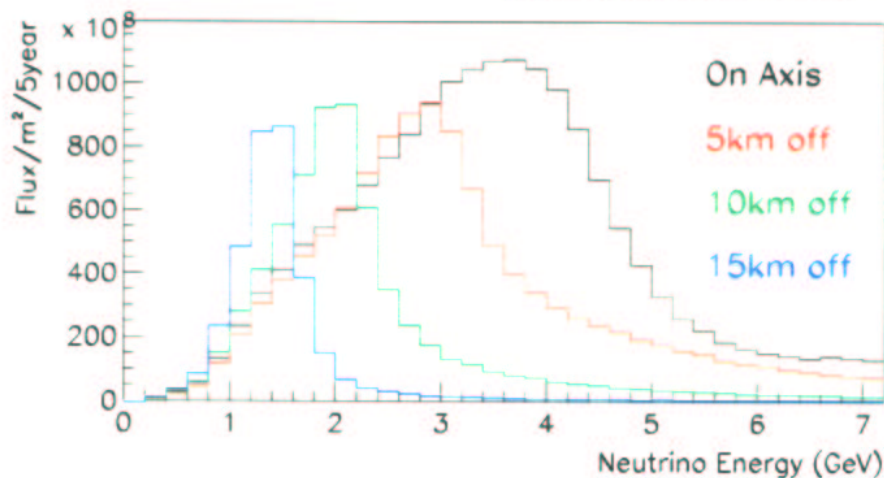
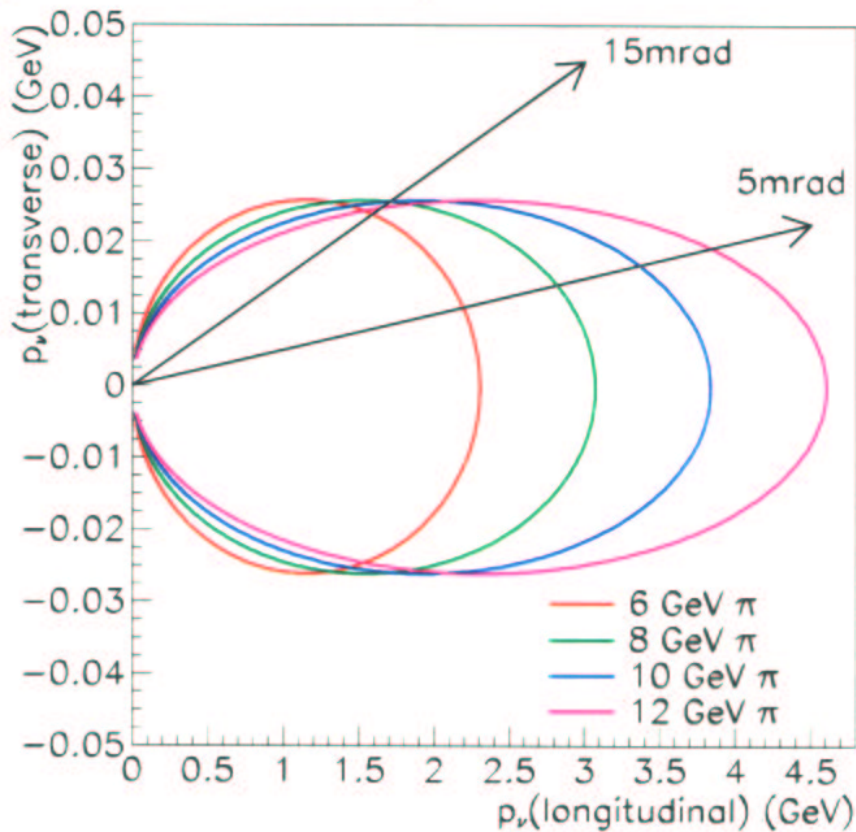
ν_e APPEARANCE



Goal is to see
two
oscillation
maxima
evidence for δ
 ν running only

How Narrow Can you Go? (NUMI-OA)

Following example from BNL-889 and JHF-SK
(D. Beavis et al., BNL No. 52459, April 1995):



What Baselines Are Available?

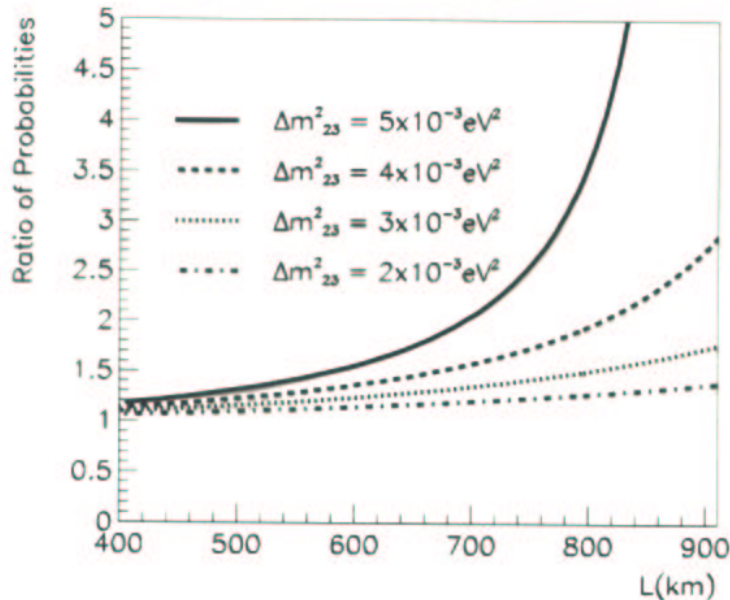


Canada!

Duty Cycle:

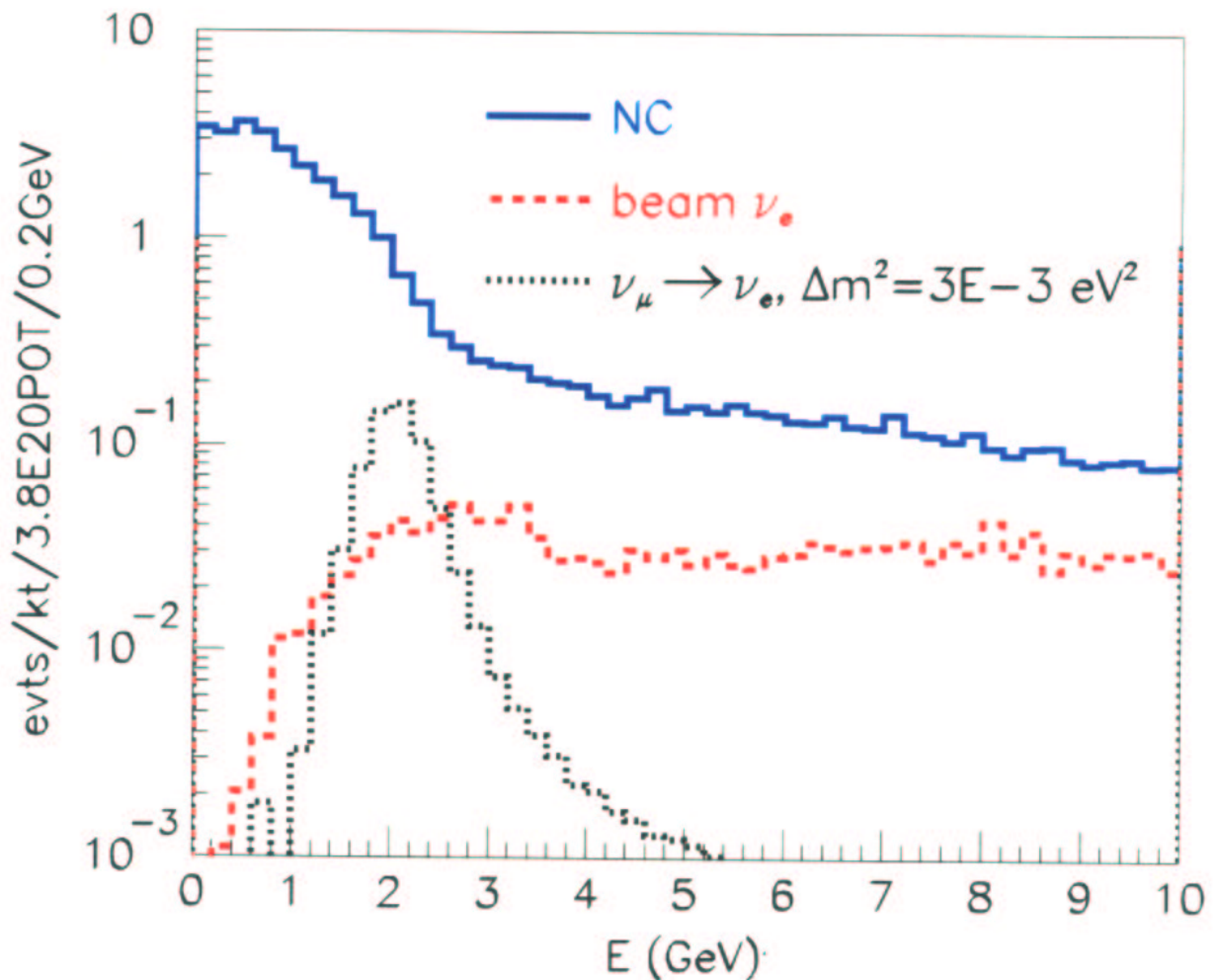
$$\frac{10\text{ms}}{2\text{sec}} = 5 \times 10^{-6}$$

Surface Detector possible



Ratio of $\bar{\nu}$ to ν probabilities, no δ effects, $\Delta m^2_{12} = 0$, 2GeV beam

What Are the Backgrounds Like?



- **0.5% ν_e ! (peak) of NUMI-OA**
 - 14mrad off angle beam, ν_μ width: 20%
 - plot shows $\sin^2 2\theta_{13} = 0.04$, 735km
 - No Neutral Current Rejection Assumed here

Background Comparison

For NUMI-Off Axis Beam, several monte carlo studies have been done

Detector Type	ν Energy (GeV)	CC ν_e acc.	NC acc. $\times 10^{-2}$
H_2O Черенков ^m	2	0.24	2
MINOS ^{dmvw}	2	0.40	1.5
Fine Grained ^p Low Z	2	0.30	.17
Fine Grained ^{nw} High Z	2	0.40	.2
Liquid Ar ^{ic}	2	0.90	.1

CAVEAT: ~~Some~~ ^{most} numbers are preliminary!

References:

^{dmvw} M.Diwan, M.Messier, B.Viren, L.Wai,

NUMI-L-714

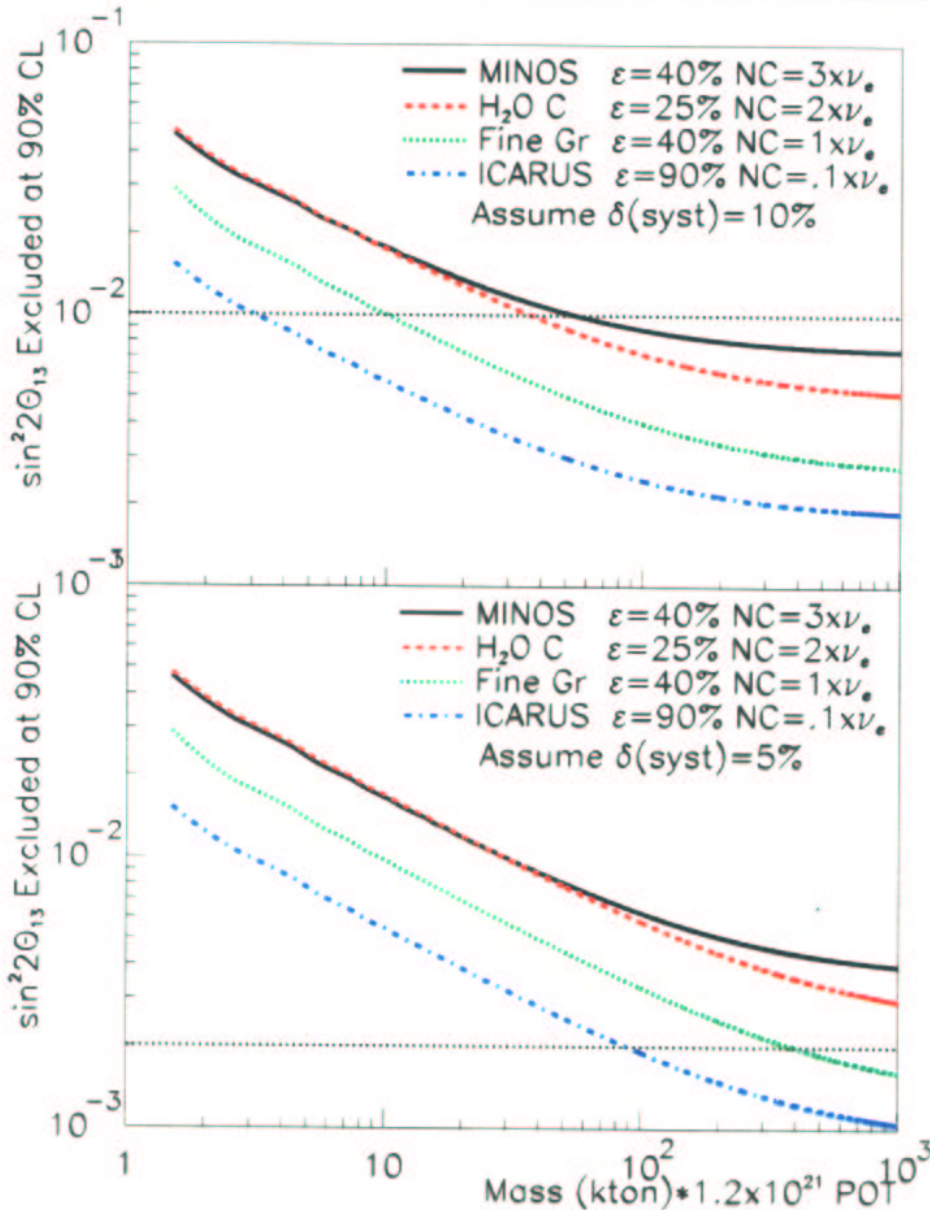
^{nw} M.Velasco, *et al* hep-ph/0204208

^p A. Para, LOI hep-ex/0210005

^{ic} M. Campanelli, and ICANOE Proposal

^m Mark Messier, Dave Casper

NUMI-OA Sensitivity vs Detector Technology



10% syst. uncertainty assumed

5% syst. uncertainty (proton source upgrade)

Different rejection factors and signal efficiencies mean different detector mass requirements for same physics reach!

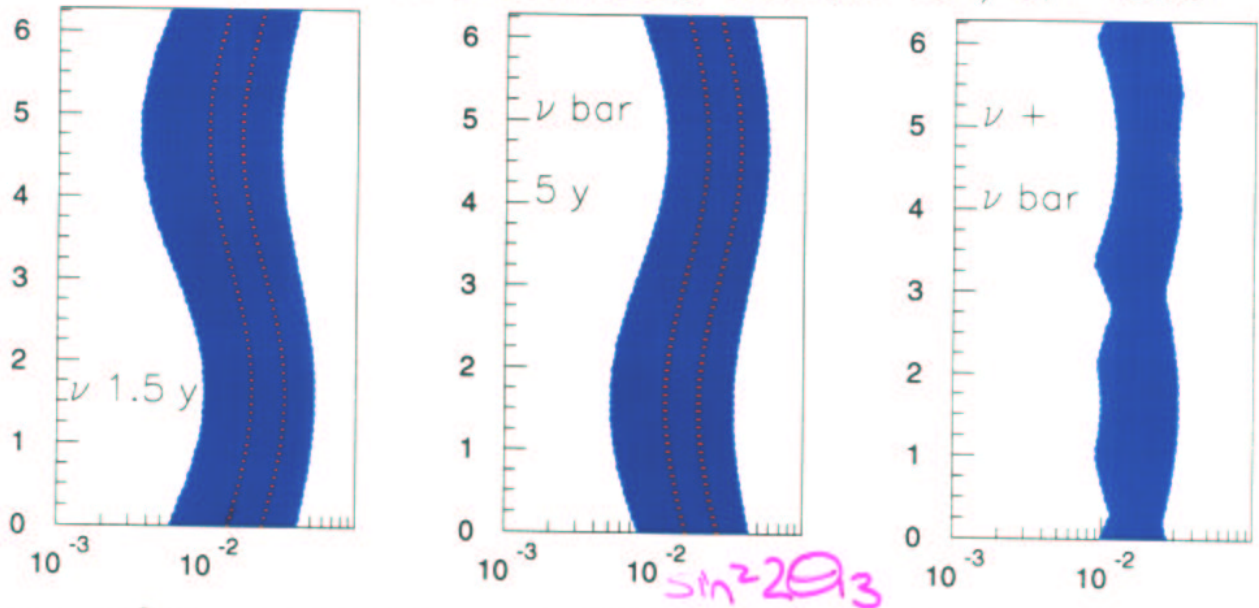
no degeneracies or correlations

NUMI Off-Axis $\nu\bar{\nu}$ Running

$\delta - \sin^2 2\vartheta_{13}$ correlation, $\sin^2 2\vartheta_{13} = 0.02$, $\delta = 3\pi/2$, Phase I

20KT
0.4MW

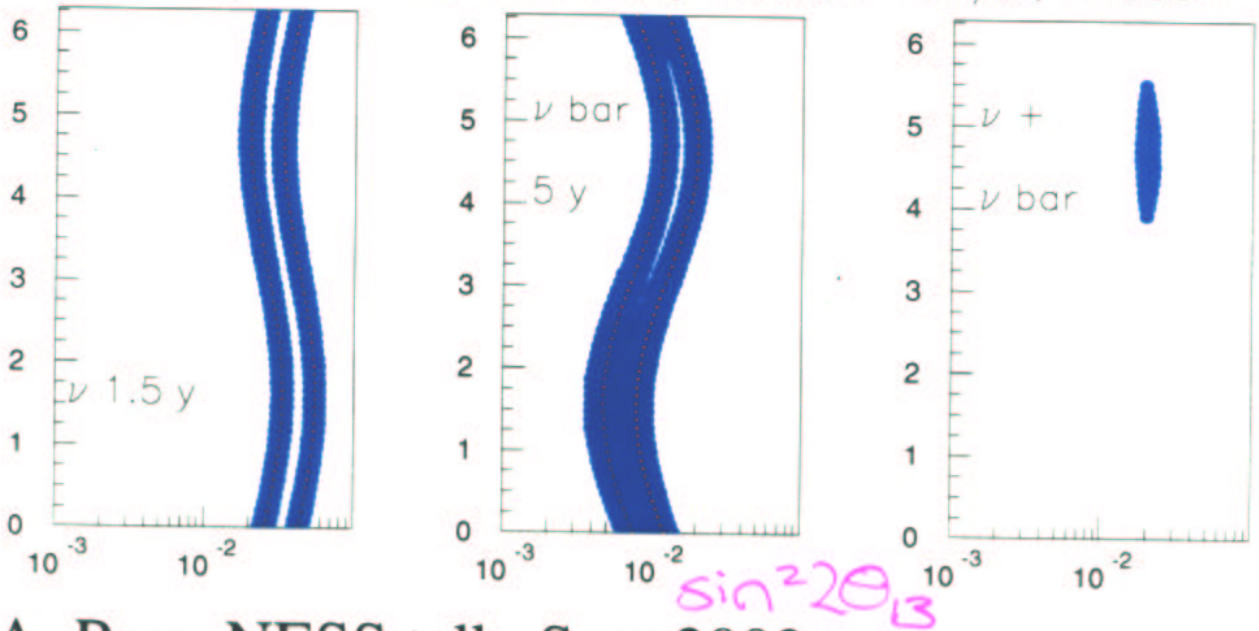
δ (radians)



$\delta - \sin^2 2\vartheta_{13}$ correlation, $\sin^2 2\vartheta_{13} = 0.02$, $\delta = 3\pi/2$, Phase II

= 25X
Phase
I

δ (radians)

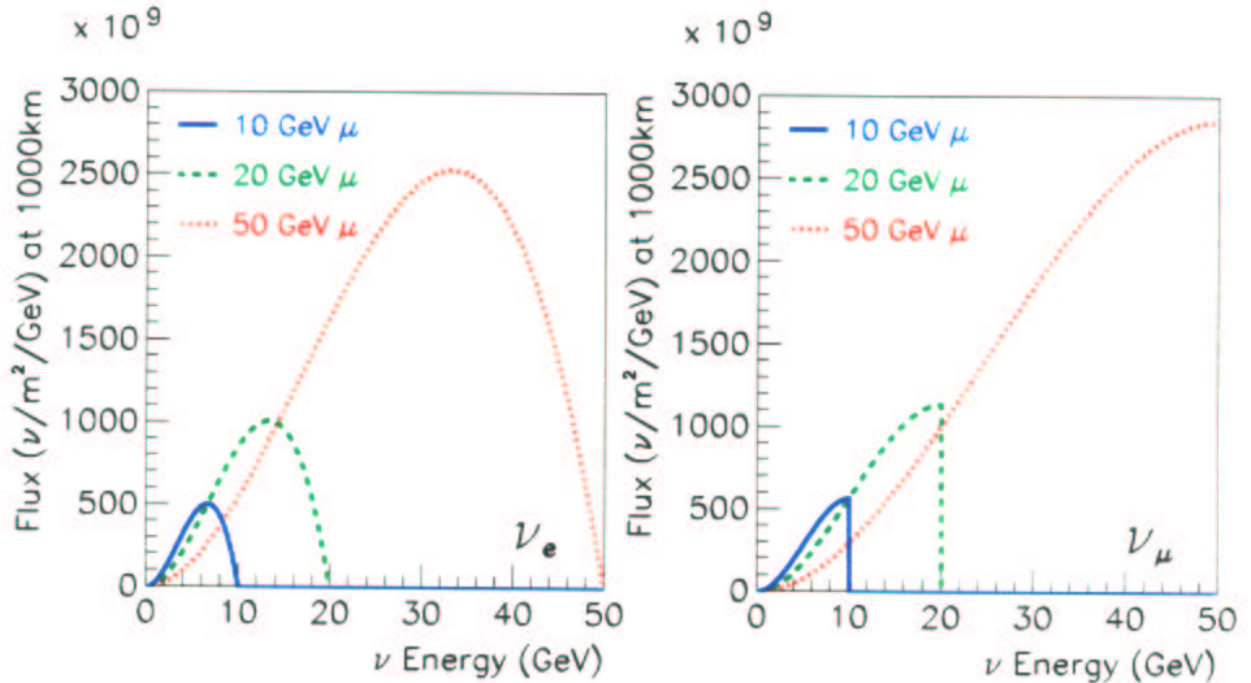


A. Para, NESS talk, Sept. 2002

1σ contours shown, both mass hierarchies

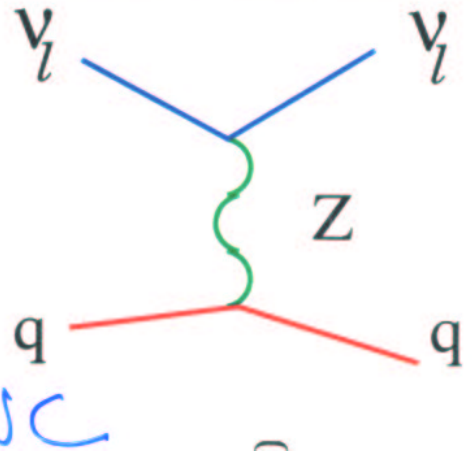
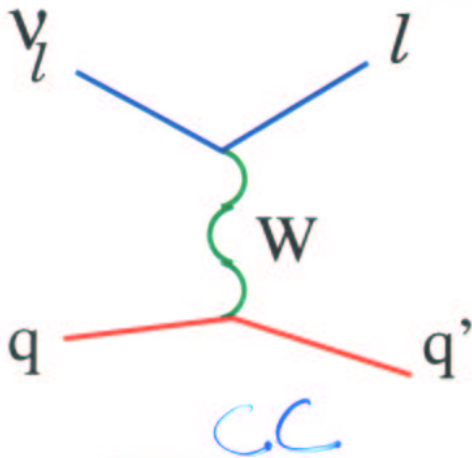
→ perfect measurement, both Δm^2

Neutrino Factory Beams

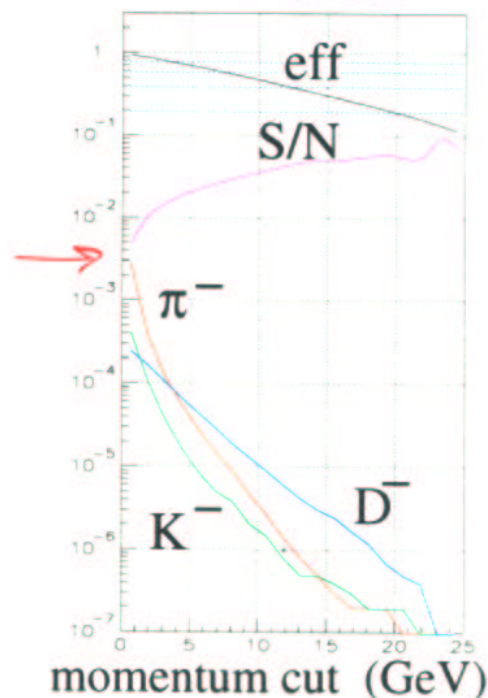
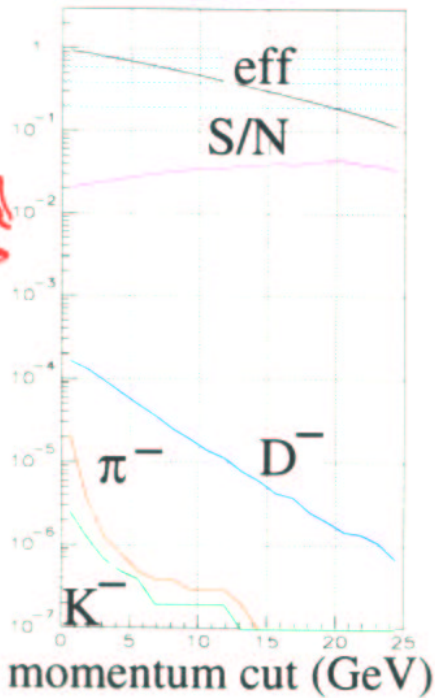


- μ^- in the Storage Ring: $\nu_\mu + \bar{\nu}_e$
 - $\rightarrow \mu^-$ for $\nu_\mu \rightarrow \nu_\mu$
 - $\rightarrow \mu^+$ for $\bar{\nu}_e \rightarrow \bar{\nu}_\mu$
 - $\rightarrow \tau^\pm$ from $\nu_\mu \rightarrow \nu_\tau$ or $\bar{\nu}_e \rightarrow \bar{\nu}_\tau$
- μ^+ in the Storage Ring: $\bar{\nu}_\mu + \nu_e$
 - $\rightarrow \mu^+$ for $\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$
 - $\rightarrow \mu^-$ for $\nu_e \rightarrow \nu_\mu$
 - $\rightarrow \tau^\mp$ from $\bar{\nu}_\mu \rightarrow \bar{\nu}_\tau$ or $\nu_e \rightarrow \nu_\tau$
- Charge ID has parent Neutrino Flavor

Background Rejection at a ν factory



conventional beam levels →

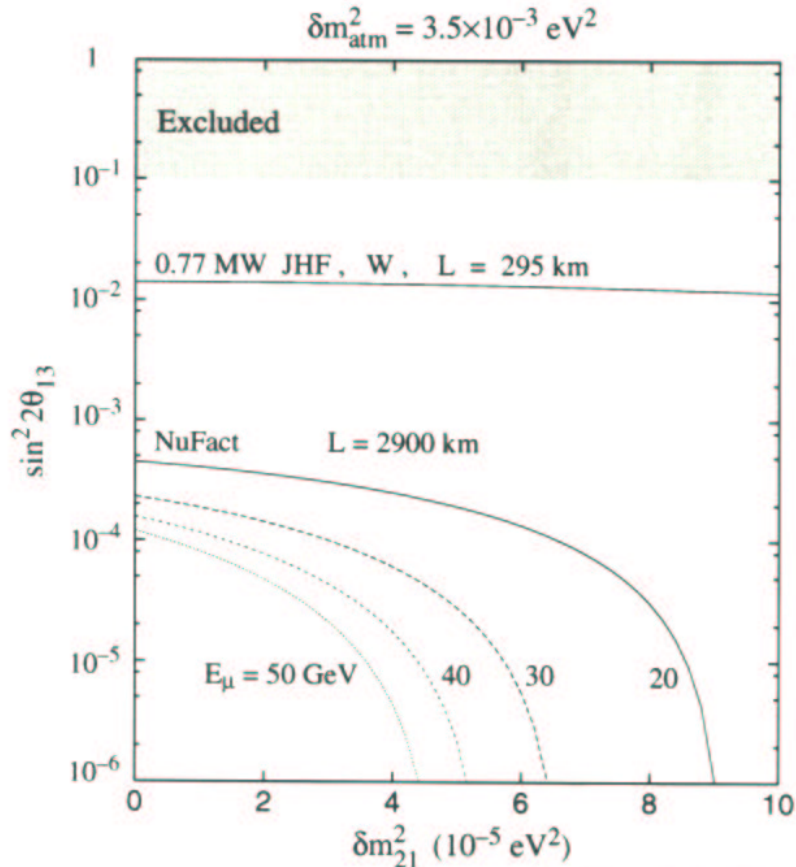


Cervera et al, Nucl. Phys. B579 2000

With a MINOS-type Detector

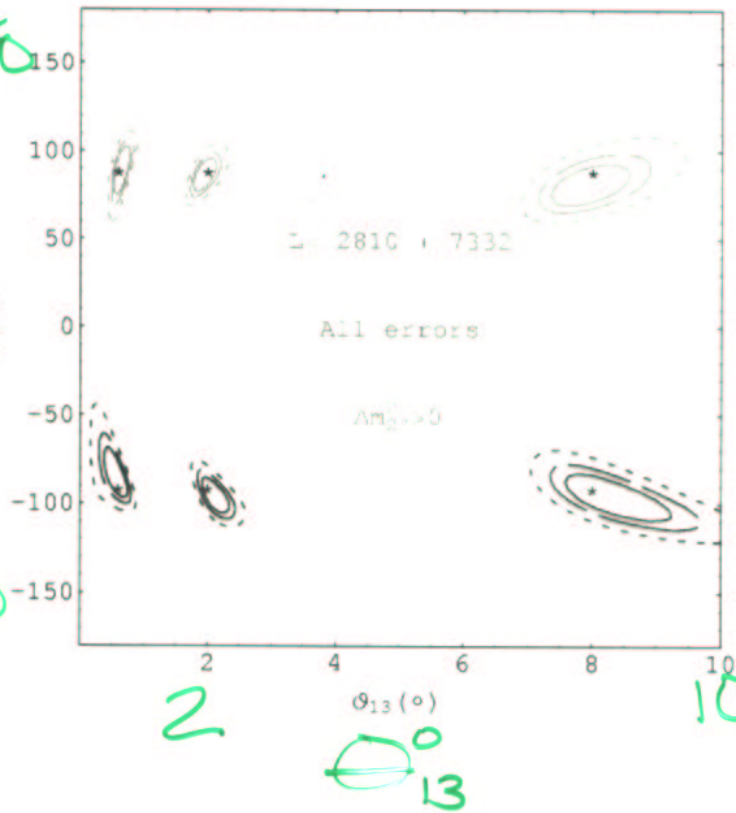
Ability to accelerate muons AND have very low backgrounds means sensitivities with 50kton detectors still beat conventional beams with 500kton detectors!

Physics Sensitivity at a ν Factory



Barger, Geer,
Raja, Whisnant
Phys. Rev. **D63**
(2001)

Burguet-Castell
et al,
Nucl. Phys. B
608 (2001)
two baselines



$\delta(\circ)$

$\Delta m_{32}^2 > 0$

-150

50kton MINOS

2

θ_{13}^0

10

Conclusions

Beam Name	Mass (kton)	Power (MW)	$\sin^2 2\theta_{13}$ sens. ^a	δ^b	Matter Effect
OPERA ^o	1.8	0.15	0.04	-	
ICARUS ^o	2.4	0.15	0.03	-	
MINOS ^m	5	0.4	0.05	-	
JHF2SK	22.5	0.8	0.006	-	-
NuMI-OA	20	0.4	0.005	-	\geq CP
SJHF2HK	450	4	$\sim 0.001^s$	$ \delta > 20^\circ$	$<$ CP
SNUMI-OA	100	2	$\sim 0.001^s$	135 ± 20	\geq CP
BNL2NUSL	500	1	0.004	45 ± 20 <i>✓ only</i>	$> \& <$ CP
CERN SPL	40	4	0.005	90 ± 60	\ll CP
CERN SPL	400	4	0.0016	90 ± 30	\ll CP
ν Factory	50	4	$< 10^{-4}$	90 ± 20	huge!

^a at $\Delta m_{32}^2 = 3 \times 10^{-3} eV^2$, at 90%CL

^b all evaluated at different regions of parameter space!

^o M. Komatsu, P. Migliozzi, F. Terranova hep-ph/0210043

^m M. Diwan, M. Messier, B. Viren, L. Wai, NUMI-L-714

^s Assume 5% systematic uncertainty!

No correlations, No degeneracies here....

Conclusions

Near Term, we have 2 great opportunities that could be complementary

	JHF \rightarrow SK	NUMIOA
Nominal Design	0.8 GeV, 295 km	2 GeV ⁷³⁰ 980 km
Range of Motion	0.5 \rightarrow 1 GeV	0.5 \rightarrow 3 GeV 500 \rightarrow 1100 km
Natural Resource	SK Detector zoom [*]	NUMI Beamline / COMB
Main Obstacles (besides \$)	(1) Finalize Beam Design (2) Build Beamline (3) Proton Driver 0 \rightarrow 0.8 MW	(1) Prove that FG is cheap (2) Works on Surface (3) Build It (4) Proton Driver 0.2 \rightarrow 0.4 MW

Both show X20 improvement / CHOOZ limit

From Discovery \rightarrow Precision
 need many measurements to get to
 θ_{12} + mass hierarchy

Many Ideas for Precision Step

Go Narrow \rightarrow JHF, sNUMIOA
 Go Long \rightarrow BNL LOI

Go Low \rightarrow CERN SPL
 Go Away \rightarrow Factory

Best Long term approach may be
 NONE of the ABOVE \rightarrow
 depends on what discovery phase sees!