Comparison of Different Detectors with same Beam

- Background about the Background
- Beam Description
- Description of Detectors
- Baseline Optimization
- A Word about Matter...
- Conclusions

Deborah Harris
Fermilab

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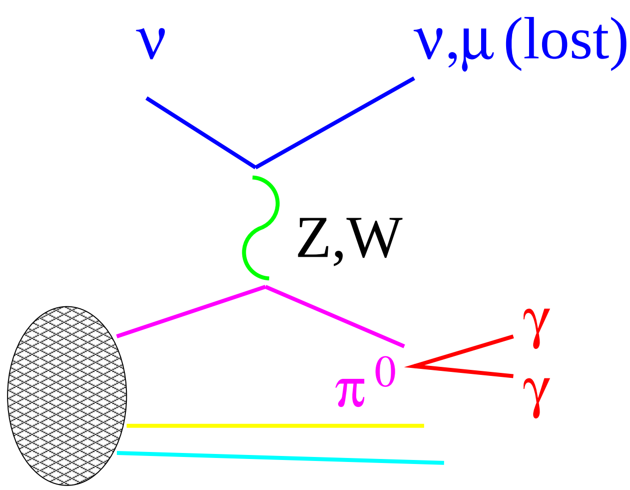
Large Detectors for ...
Low Energy Neutrinos from
High Intensity Sources

Backgrounds in Conventional Beams

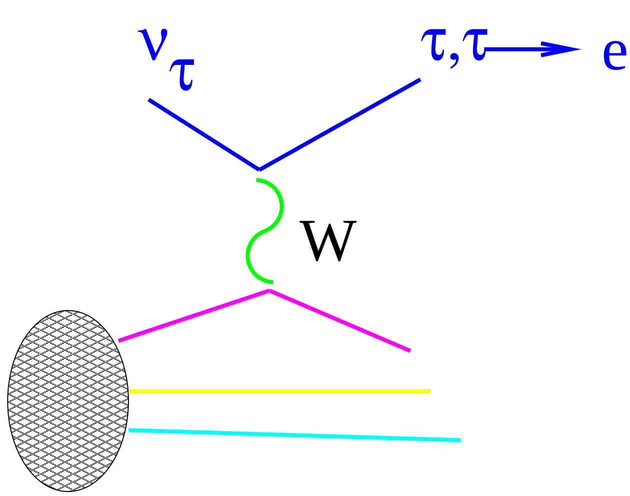
If signal is $\nu_\mu \to \nu_e$ or $\bar{\nu}_\mu \to \bar{\nu}_e$:

Intrinsic ν_e Contamination

$$K^\pm \to \pi^0 e^\pm \nu_e(\bar{\nu}_e)$$
$$\mu^\pm \to e^\pm \bar{\nu}_\mu(\nu_\mu)\nu_e(\bar{\nu}_e)$$
$$K_L \to \pi^\pm e^\mp \nu_e(\bar{\nu}_e)$$
$$\text{Charm} \to X e^\pm \nu_e(\bar{\nu}_e)$$

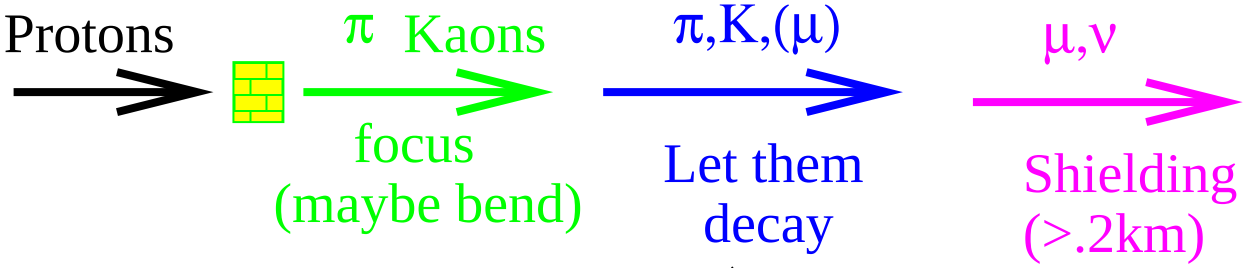


π^0 production in NC and CC (high y) events

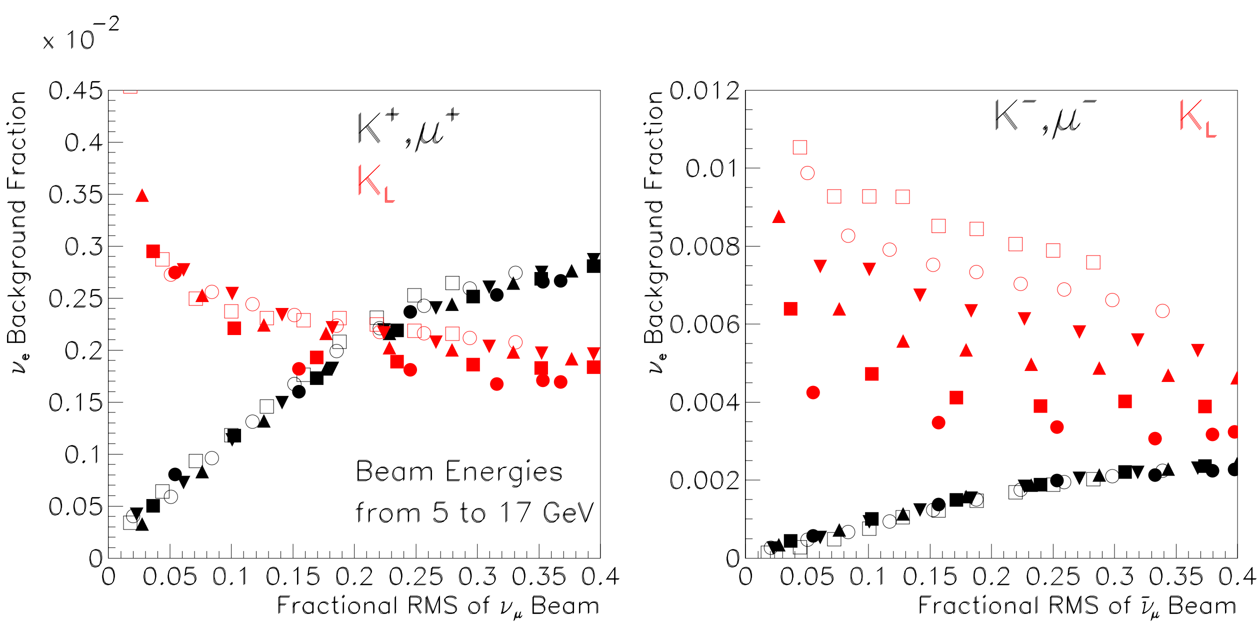


ν_τ Charged Current Events
Important for $E_\nu > 7GeV$

Intrinsic ν_e Background



Beamline	Peak ν_μ Energy (GeV)	ν_e/ν_μ event ratio	p Energy GeV
K2K	1.4	0.7%	12
MINOS LE	3.5	1.2%	120
MINOS ME	7	0.9%	120
MINOS HE	15	0.6%	120
CNGS	17	0.8%	400
JHF wide	1	0.7%	50
JHF HE	5	0.9%	50
MiniBoone	0.5	0.2%	8
ORLaND	0.0528	0.05?%	1.3



$\nu + N \rightarrow \ell + X$, but 3 different ways

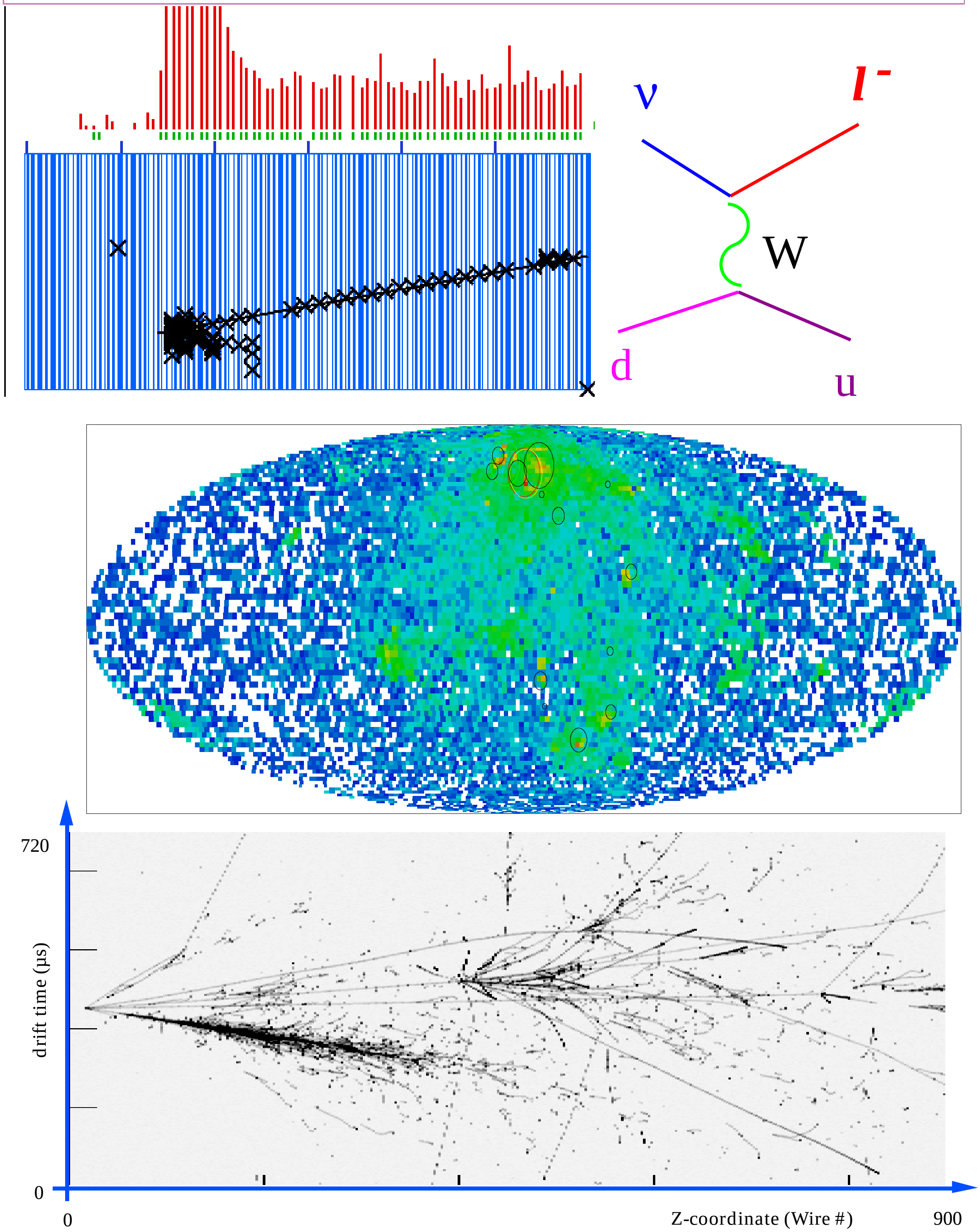
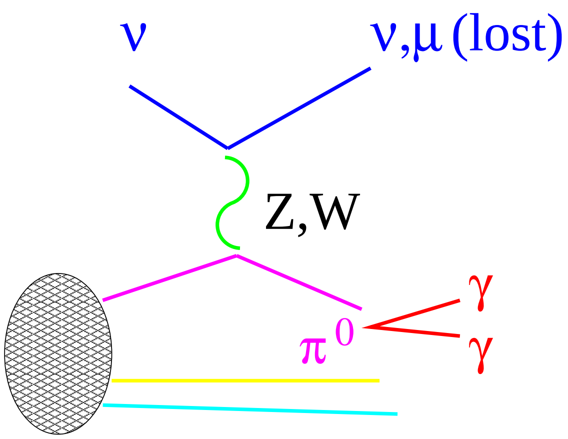
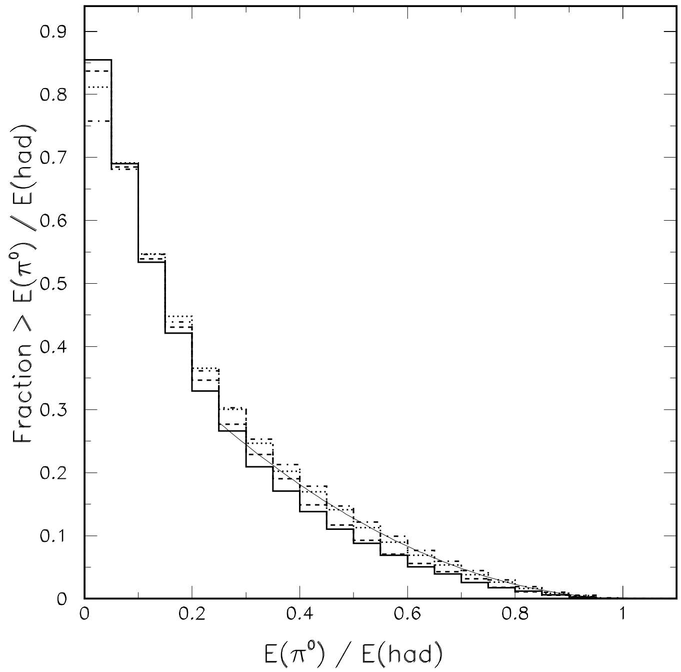


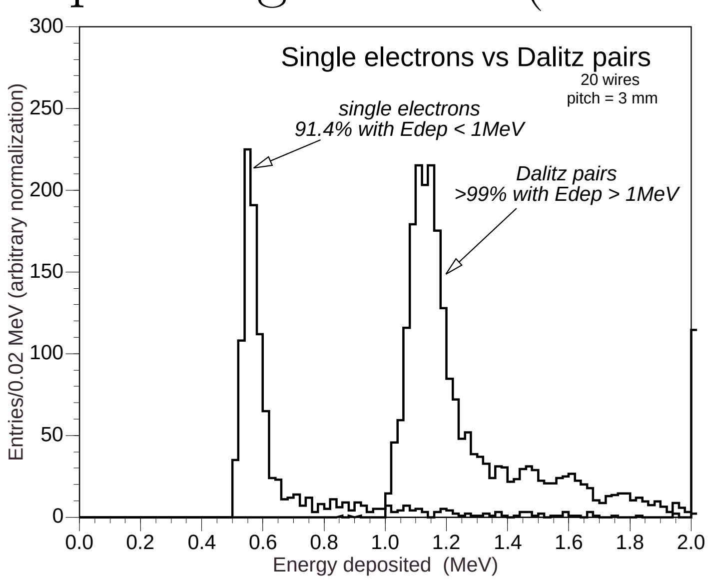
Figure 1

Neutral Current Background





- Liquid Argon TPC (ICARUS) (1/1000)



- fine-grained calorimeter (THESEUS) longitudinal shower development (1/40)
- Water Cerenkov (K2K) (10^{-2} below 1GeV)

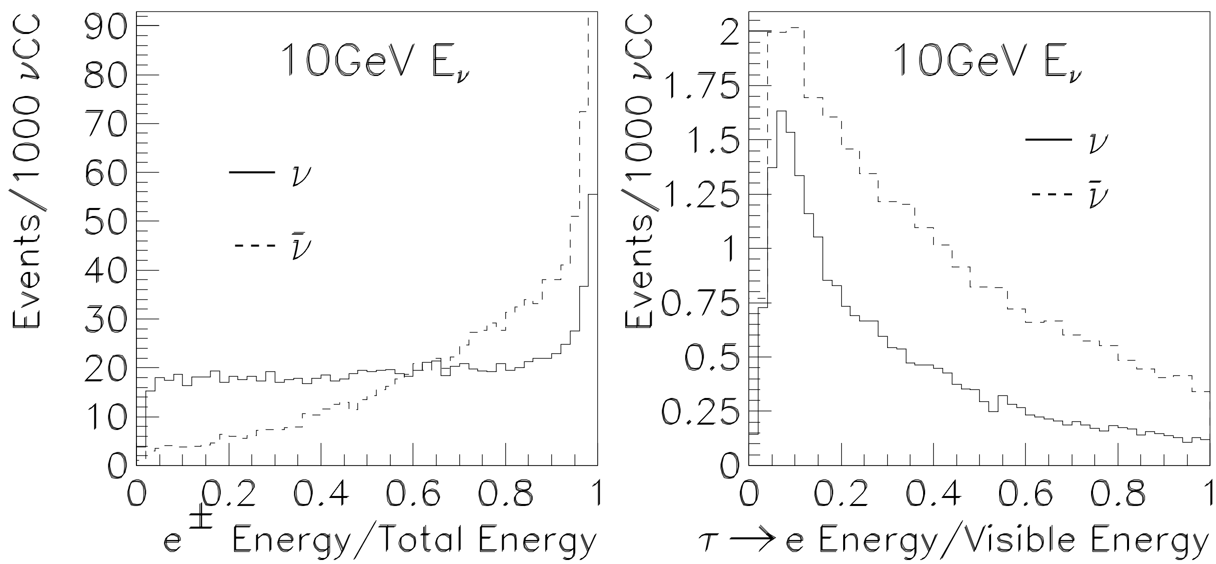
$\nu_\mu \rightarrow \nu_\tau, \tau \rightarrow e$

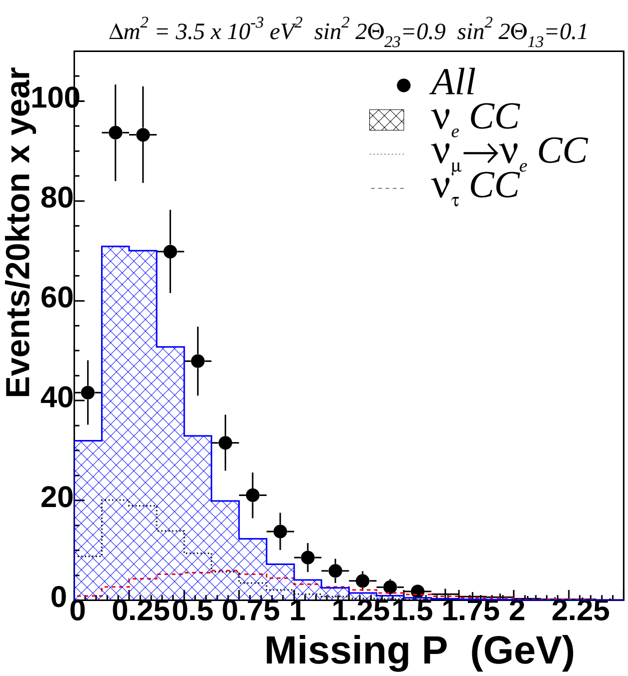
Today's discovery is tomorrow's background...

$BR(\tau \rightarrow e(\gamma)\nu_\tau\bar{\nu}_e) = 0.20,\ BR(\tau \rightarrow n\pi^0 X\nu_\tau) = 0.37,$

ν_τ flux is $\propto \sin^2 2\theta_{23} \sin^2(\delta m_{23} L/E)$ i.e. $\mathcal{O}(1)$...

Kinematic Handle on $\tau \rightarrow e$: electron energy





Other Kinematic Handles: p_T

ICANOE proposal

$\delta m^2_{23} = 3.5 \times 10{-}3$

$\sin^2 2\theta_{13} = 0.1$

Backgrounds in Conventional Beams
Executive Summary

Background	Baseline	Dependence on Detector	Beamline	Rate
NC/CC π^0 production	$1/L^2$	a lot	some	$10^{-1} \longrightarrow 10^{-3}$
$\nu_\mu \longrightarrow \nu_\tau$ $\tau \longrightarrow e$	flat	some	some	$10^{-1} \longrightarrow 0$
Intrinsic ν_e	$1/L^2$	barely	all	$10^{-2} \longrightarrow 10^{-3}$

Rules of the game...(for this talk)

First Caveat:
I will only talk about measuring ν_μ to ν_e, without considering a measurement of CP violation or of matter effects.

Question: How can we remove these backgrounds?

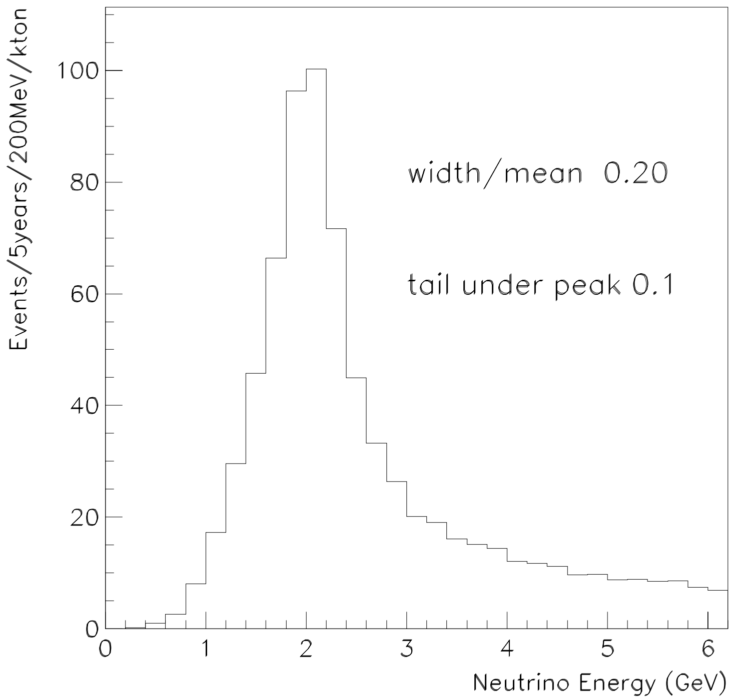
- intrinsic ν_e contamination
- Neutral Current Contamination (π^0 mis-identification)

How well you remove backgrounds depends on your detector...

- Make a really narrow energy neutrino beam –cut on energy
- Make a very clean beam, no "high energy tails"

Name This Beam

- Narrow Band ν_μ Beam at 2GeV

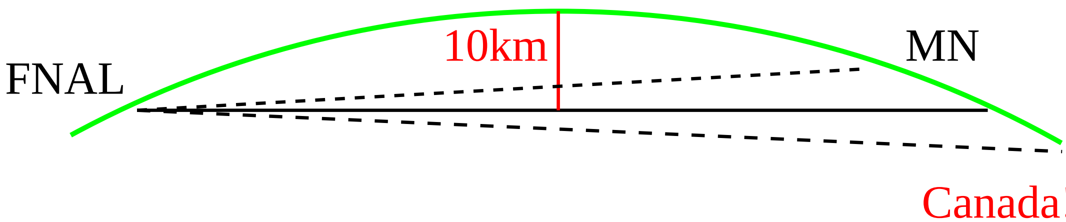


A.Para, M.Szleper, `hep-ex/0110032`

- Low intrinsic ν_e contamination
  - 0.5% under the peak
- 0.4MW proton source, 10^{-5} duty cycle
- Beamline Design is Complete
- Target, Decay Pipe Region Fully Excavated
- Prototype horn has been pulsed over 2M times
- Will start running by the end of 2004

$\Rightarrow$ MINOS Off-Axis Beam (1.5mrad)

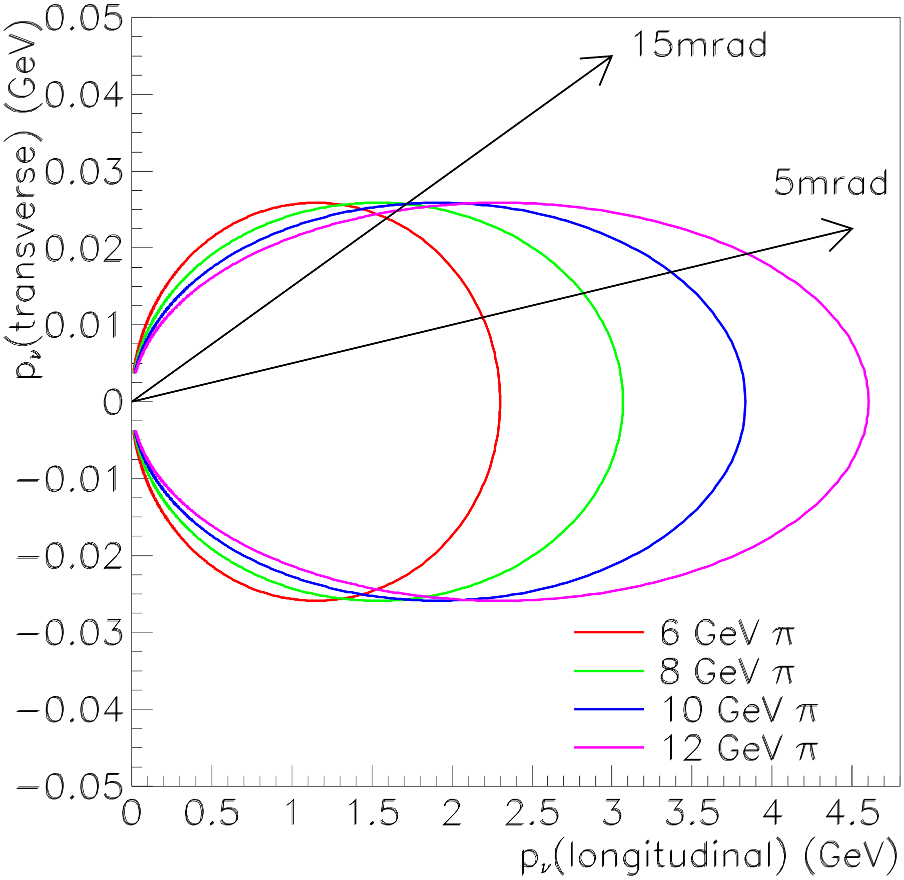
Where is the MINOS off-axis beam?

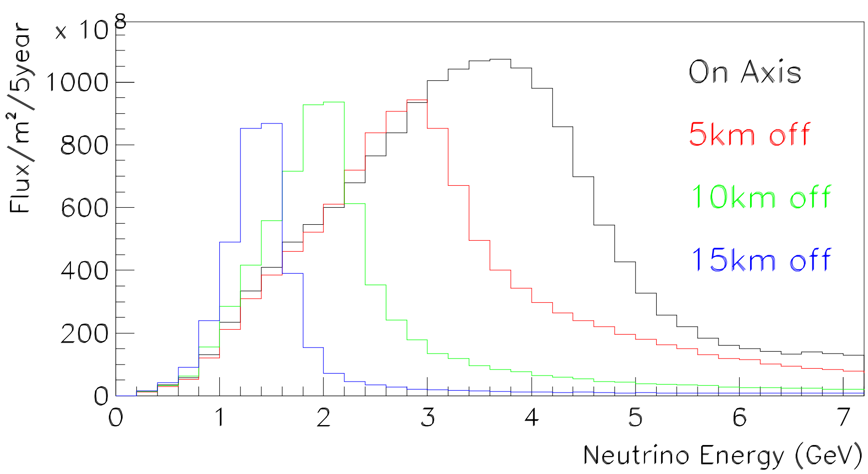


For 10km off, could be as far as 911m away!

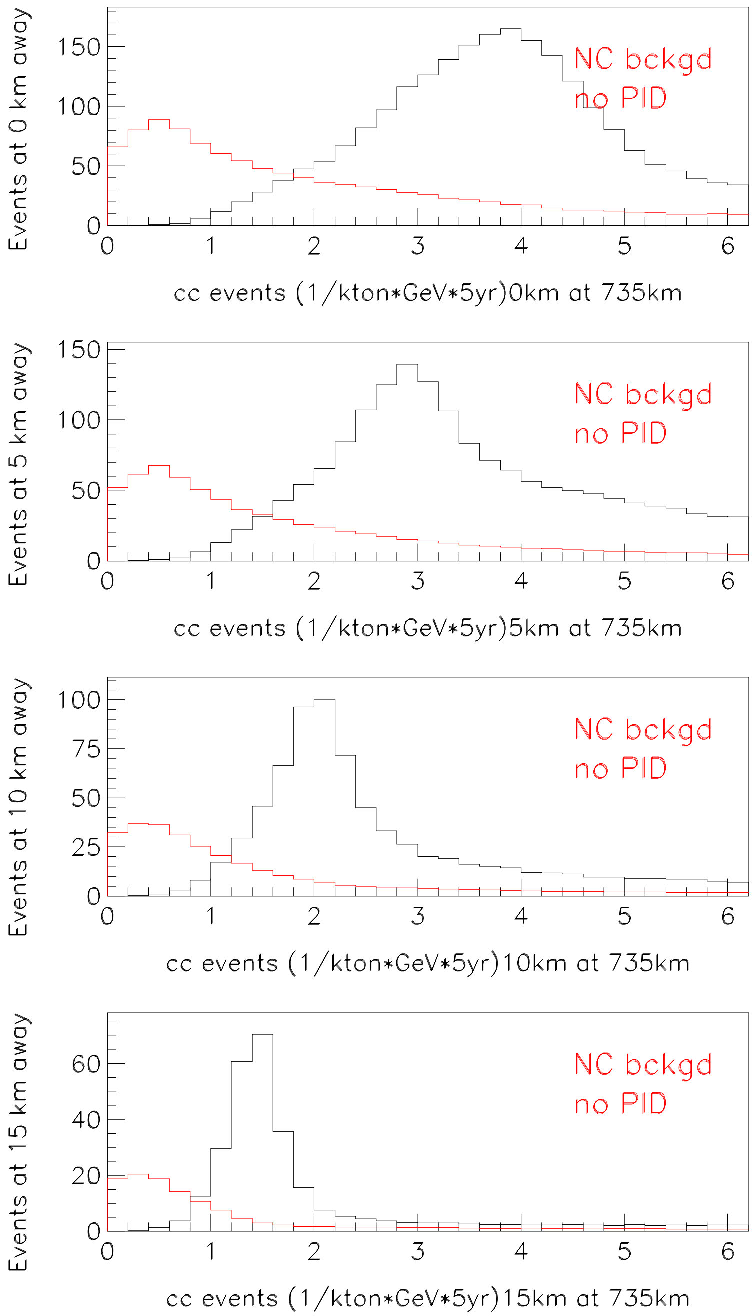
And that one isn't even the only one!

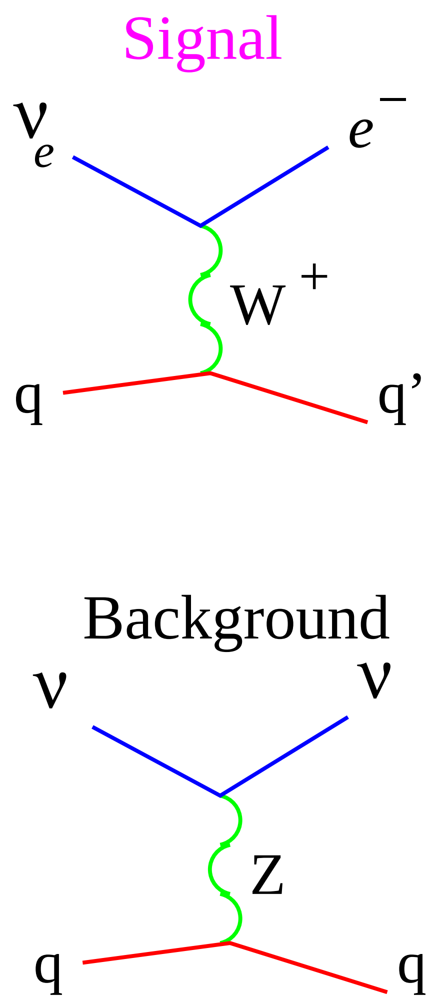
Following example from BNL-889 and JHF-SK (D. Beavis et al., BNL No. 52459, April 1995):





Neutral Currents On and Off Axis



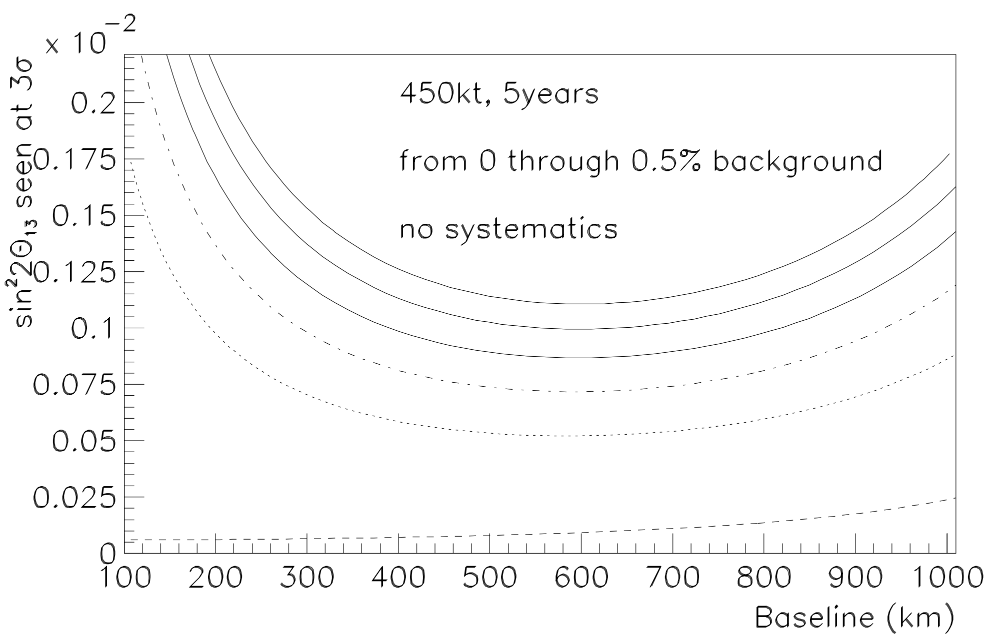


Optimize, Optimize, Optimize

Problem: Given a beam flux, the basline where you are the most sensitive depends on:

- Mass of Detector
- f_s Signal efficiency
- f_b Background efficiency
- ϵ_b Systematic uncertainty on f_b
- Δm^2 (maybe even the sign)

How is a person to chose?
Argument we've all heard (made?) before:
$\Phi \sim 1/L^2, \sin^2(\Delta m^2 L/E) \sim L^2$ –not so fast!



Detectors to Consider

Requirements: Electron Appearance!

- Good Longitudinal and transverse segmentation
- Good Energy Resolution to remove NC and ν_e events
- Particle ID at the 10^{-2} level at least!

Vital Statistics of Detectors:
(as defined for this study)

- NC Background "Efficiency"

$$f_{NC} = \frac{\text{NC Events accepted after all cuts}}{\nu_\mu \text{ events in energy peak}}$$

- Detector Signal Efficiency

$$\epsilon_s = \frac{\text{NC Events accepted after all cuts}}{CC\nu_\mu \text{events in energy peak}}$$

- Mass

Target	Readout	Segment	ρ	ϵ_s	f_{NC}
MINOS[a]	Scint	$1.4X_0$	~ 4	40%	0.7 %
Steel[b]	Scint	$0.25X_0$	~ 4	28%	0.15%
Plastic[c] Pellets	Glass RPC	$0.5X_0$	0.75	35 %	0.1%
ICARUS[d]	TPC	a lot	1.4	90%	0.01%
H_2O Č[e]	PMT's	n/a	1	24.0%	1.%

References:

[a] M.Diwan, M.Messier, B.Viren, L.Wai, NUMI-L-714

[b] M. Szleper, M.Velasco

[c] A. Para

[d] M. Campanelli, and ICANOE Proposal

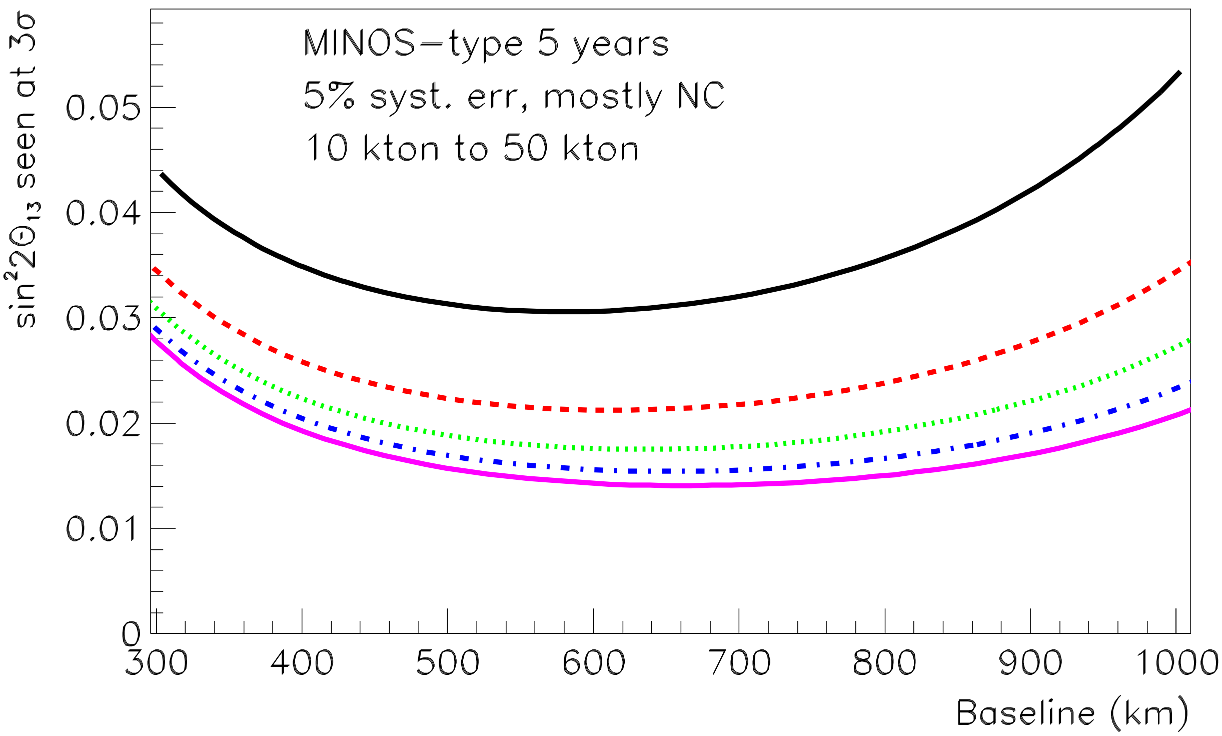
[e] D. Casper

Caveats:

All of above numbers come from geant-based monte carlos studies, but Water Cerenkov monte carlo has many more backgrounds included, also noise, detector inefficiencies, etc, and has been **TUNED WITH REAL DATA!!!**

MINOS-type Detector

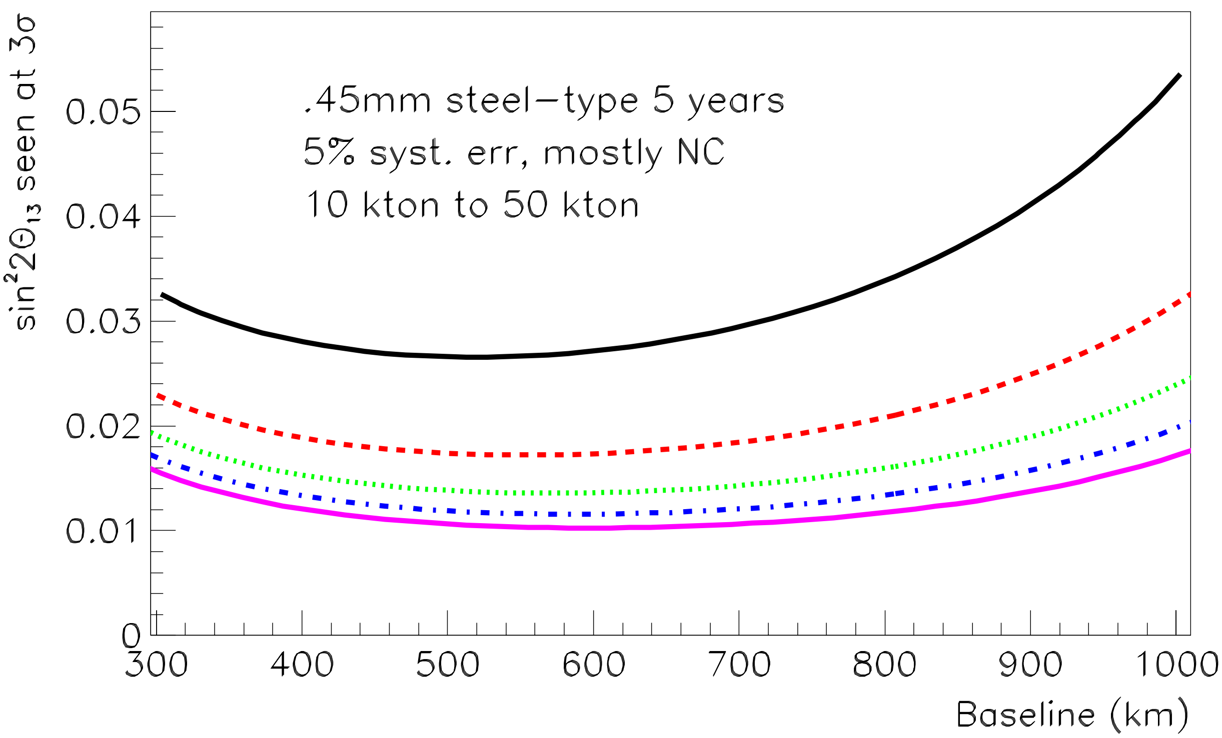
NC Background: 0.68%
Beam Background*acceptance= 0.2%
Acceptance 40%



Ref: M.Diwan, M.Messier, B.Viren, L.Wai, NUMI-L-714

4.5mm Steel Detector

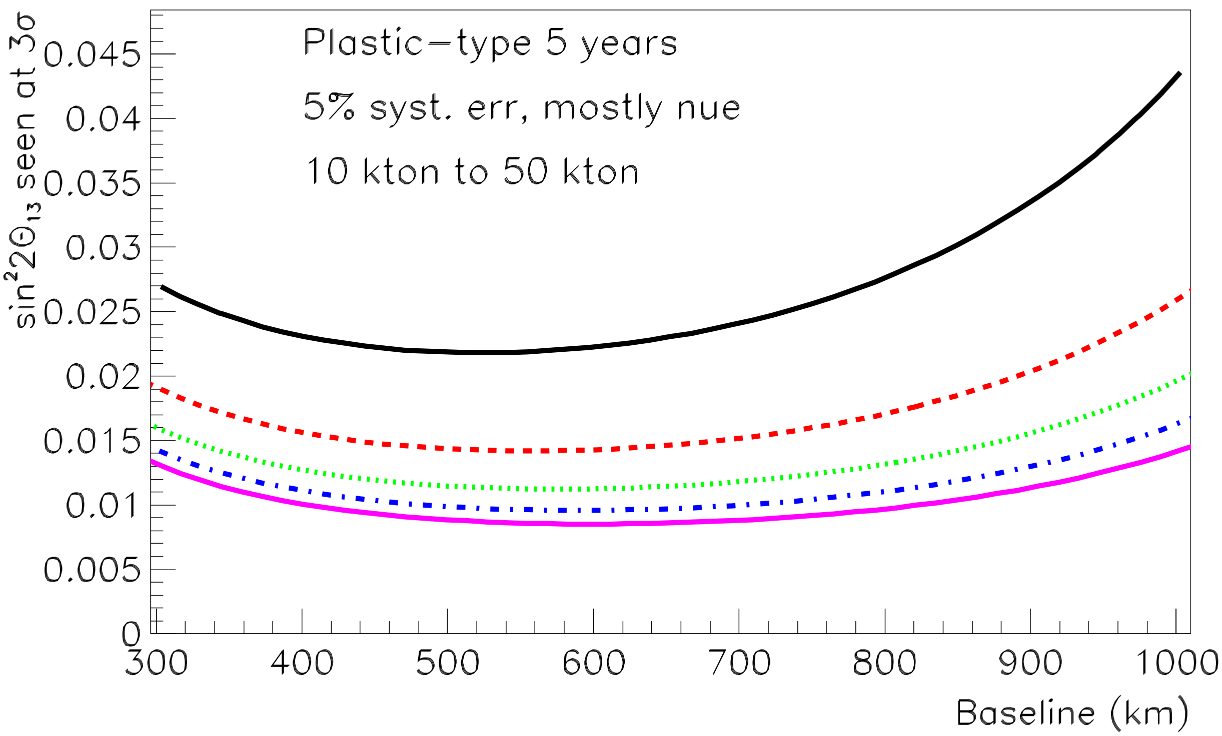
NC Background: 0.15%
Beam Background*acceptance= 0.12%
Acceptance 28%



M.Szleper, M.Velasco, Northwestern University

Recycled Plastic Pellet Detector

NC Background: 0.11%
Beam Background*acceptance= 0.16%
Acceptance 35%



A. Para, Fermilab

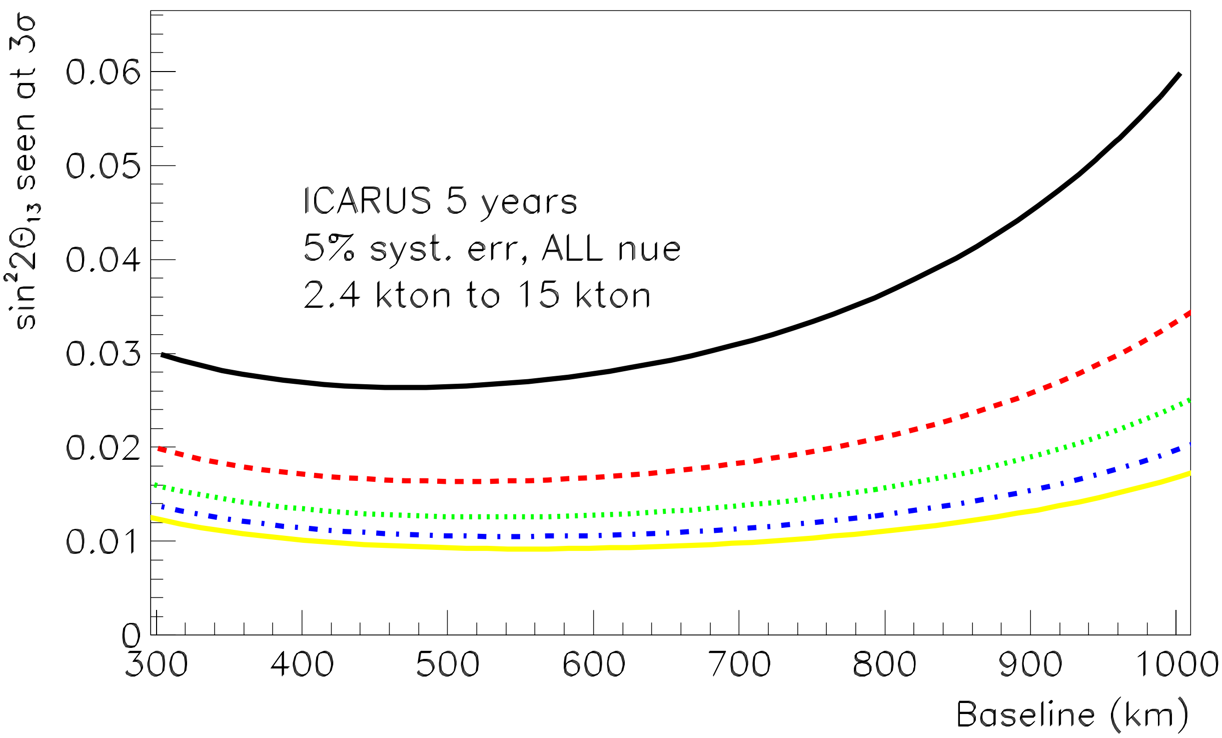
ICARUS Detector

NC Background: 0.05%

Beam Background*acceptance= 0.4%

Acceptance 90%

Note lower mass!



M.Campanelli, and ICANOE proposal

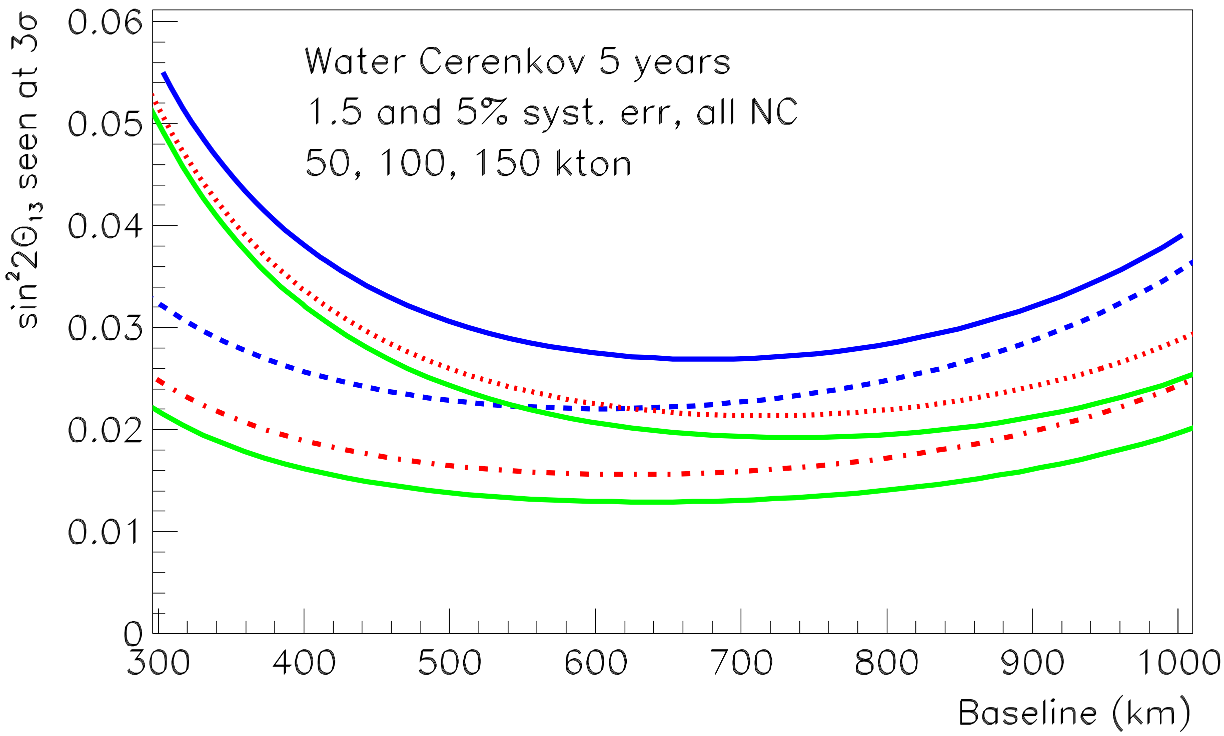
Water Cerenkov Detector

NC Background: 5.6%

Beam Background*acceptance= 0.4%

Acceptance 90%

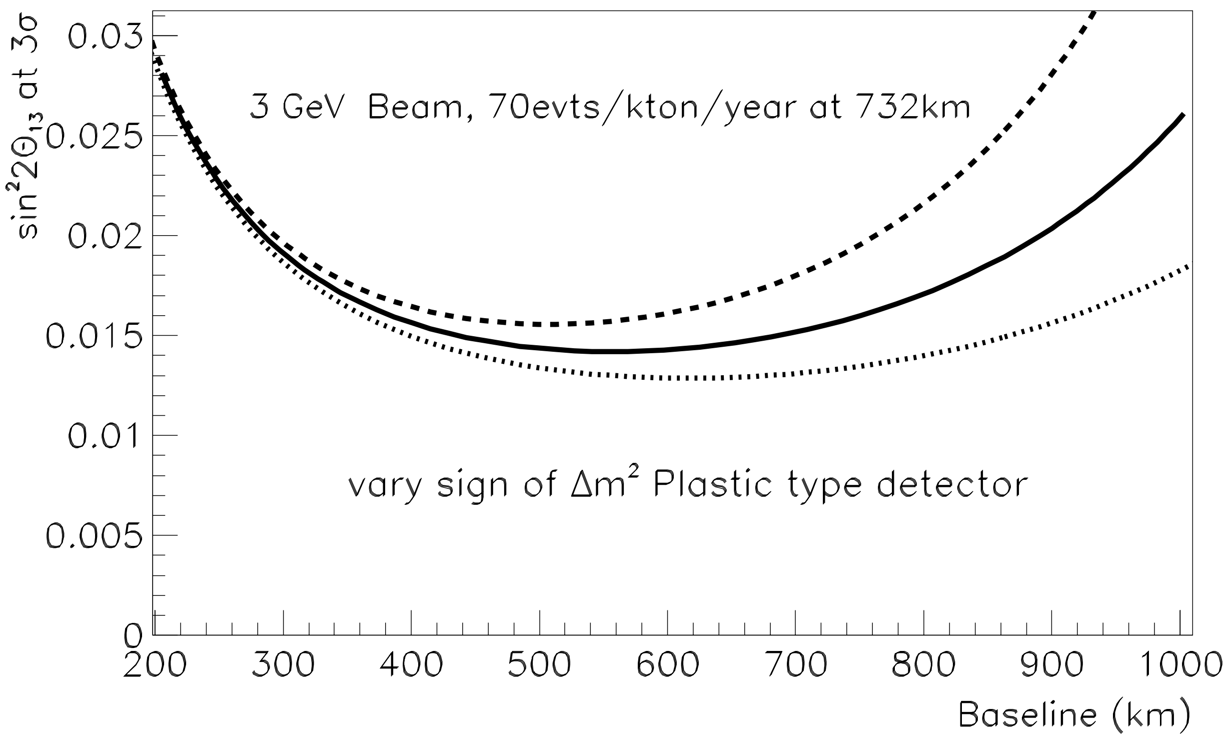
Note high mass



Two plots: 1.5% and 5% Systematic Errors assumed

Analysis by D.Casper, UC Irvine

How does this change with matter effects put in?



2-generation matter effects , constant density

If mass hierarchy is in the "charged fermion" direction, this will tend to enhance the appearance probability.

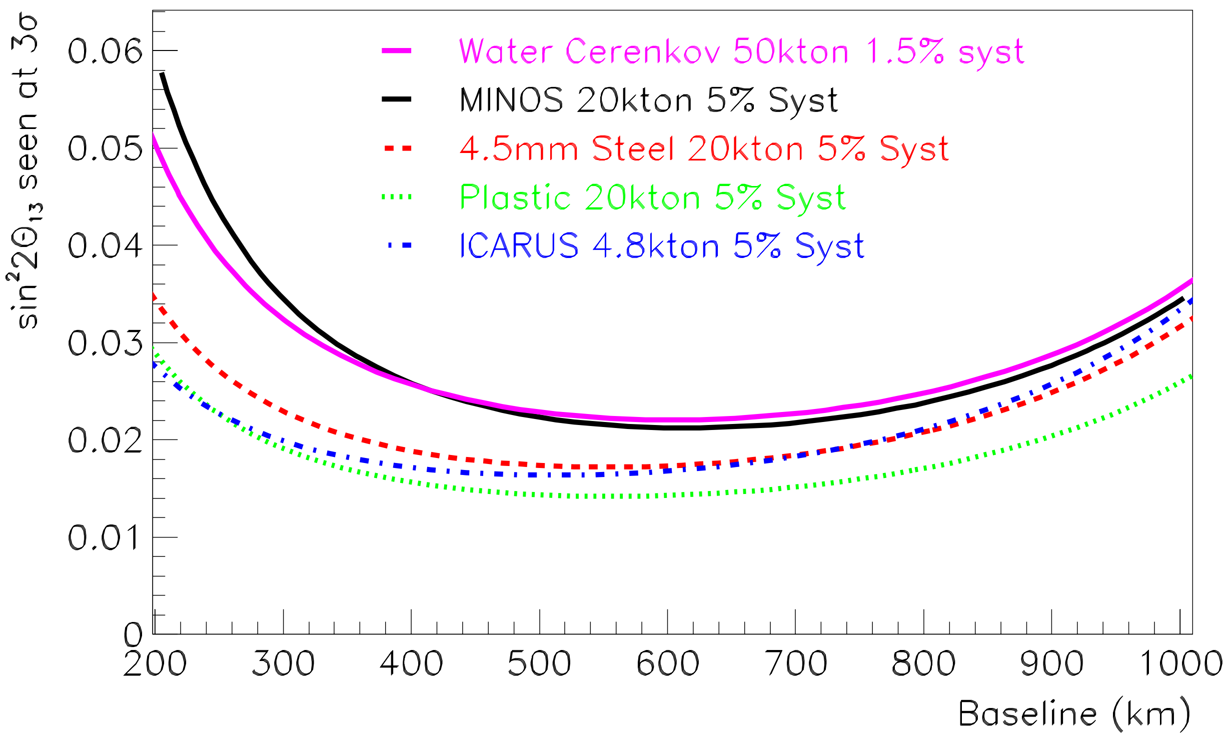
$\sin^2 2\theta_{13}$ one can see at 3σ will get lower.

Also, as L increases, the enhancement factor increases almost enough to account for the $1/L^2$

But: if the mass hierarchy goes the other way, then you're in this position for antineutrino running.

Unfortunately $\sigma^{\bar{\nu}}/\sigma^{\nu}$ still around 0.5...

Detector Summary



Detectors considered can see $\sin^2\theta_{13}$ at about 2 to 3%, which is a factor of 4 better than CHOOZ. But for the following assumptions:

- "Standards": 20kton, 5% bkgd uncertainty
- $\Delta m^2_{23} = 3.0 \times 10^{-3} eV^2$, $\theta_{23} = 45°$
- Liquid Argon needs 1/8th the "standard mass"
- Water Cerenkov needs 2.5 times the mass, 1/3 the syst. err

- Otherwise, can measure $\sin^2 2\theta_{13}$ at 3σ if it's a factor of 5 or so past the CHOOZ limit
- What if we get more proton power?
- Systematics must go below 5% –there will be MINOS on-axis near detector, preliminary studies promising (Michal Szleper, Adam Para, `hep-ex/0110001`)
- Have to reduce ν_e's–maybe through using a lower proton energy, but a faster rep rate...stay tuned...

But at any rate, taking advantage of this beam is important–
matter effects are big enough that if a next generation experiment measured things at the 5 or 6 σ level, then comparisons with shorter baselines may determine the sign...