NUMI Off-Axis Beam (OAB) Possibilities→ Road to CP violations

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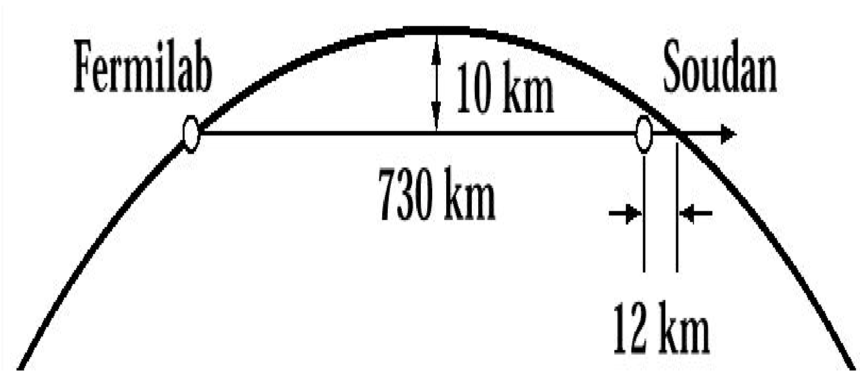
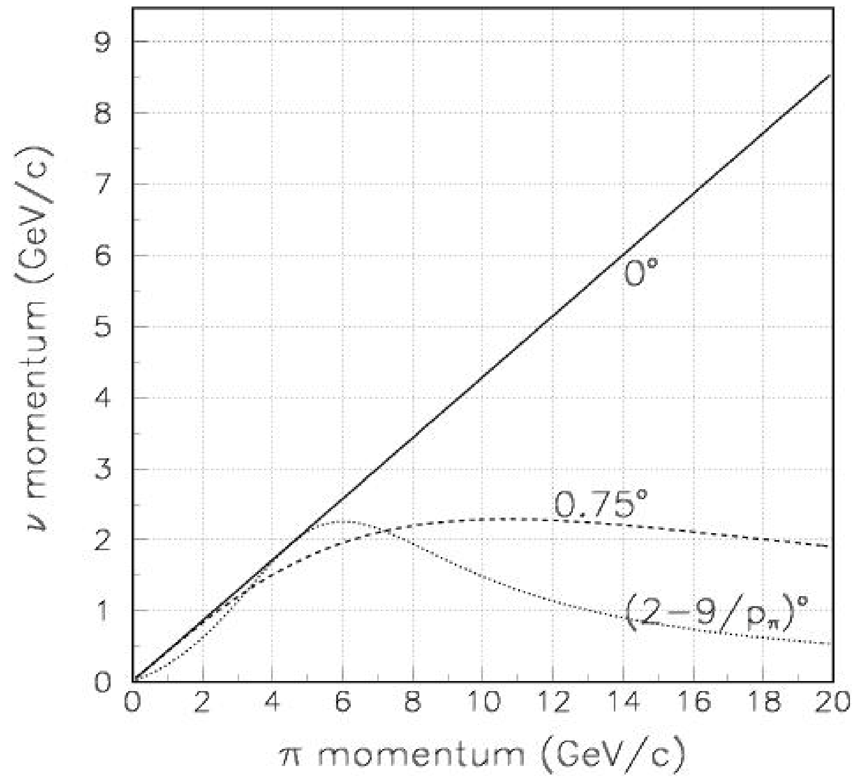
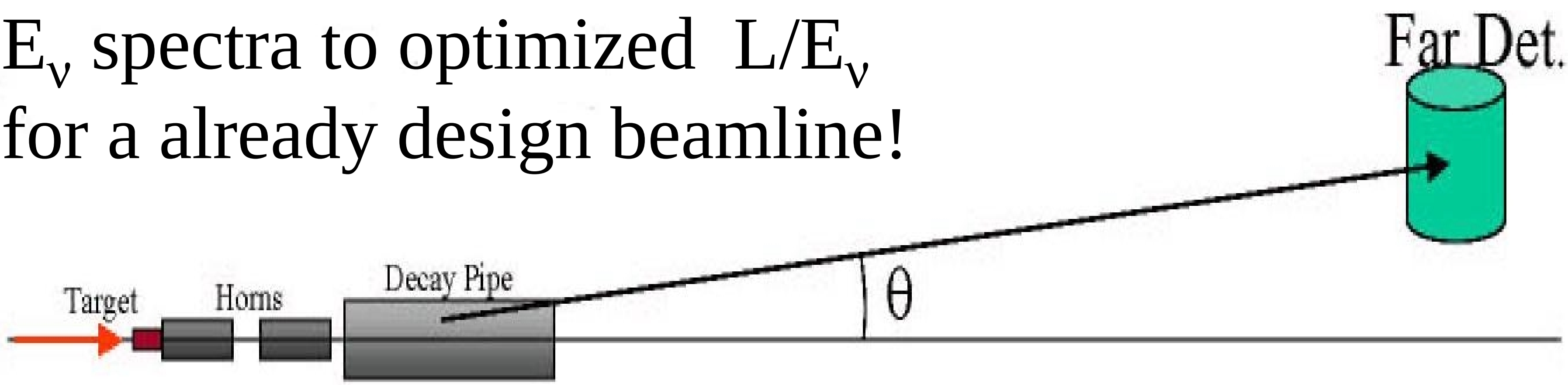
- OAB with NUMI as IS…
  - Measure |Ue3|^2
- OAB with NUMI upgrade it with a stronger proton source …Proton Upgrades (PU)…
  - Measure Matter effects and CP-phase δ

OAB– Detector placed at angle from beam axis

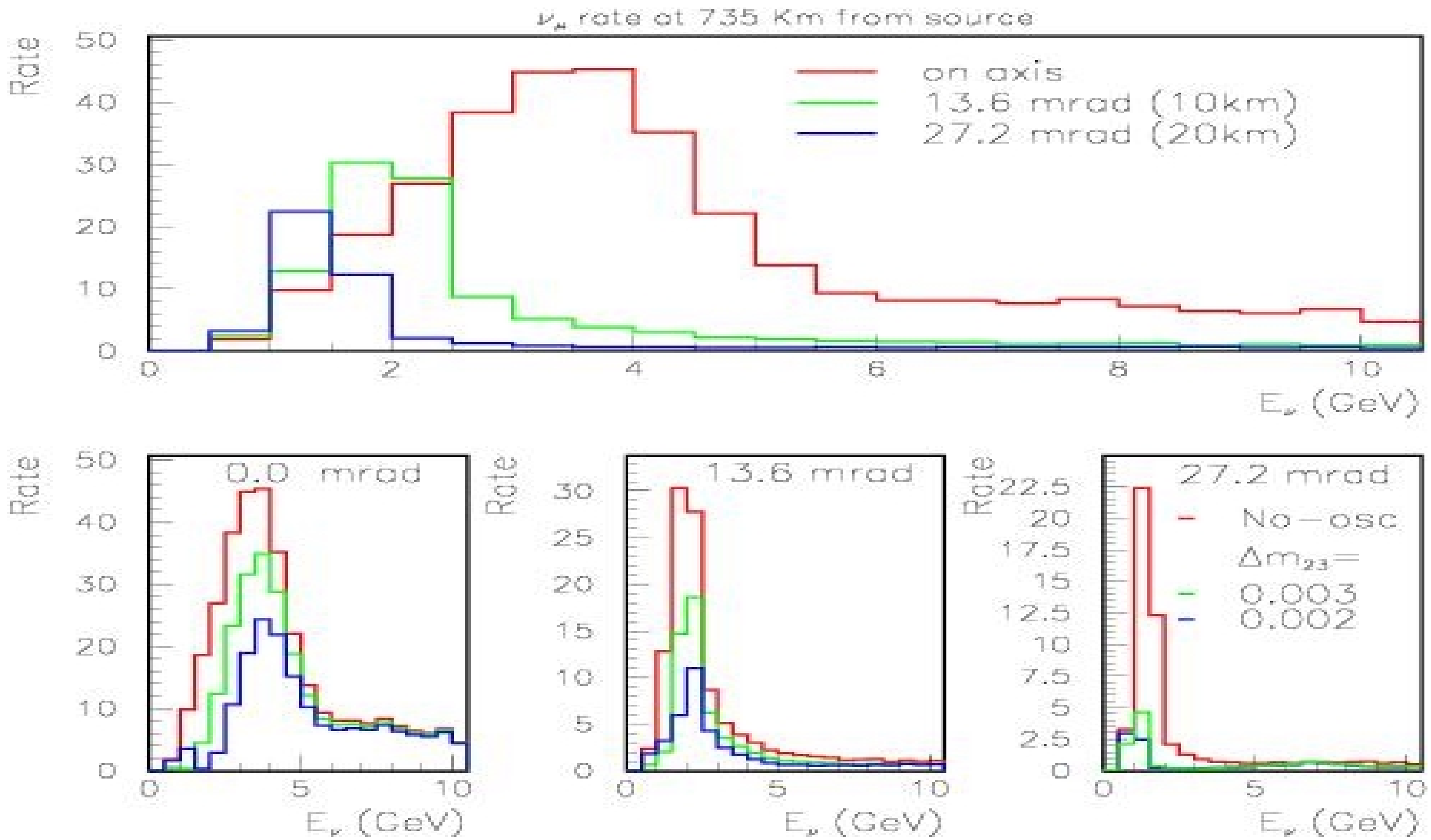




Off Axis allows us to change E_ν spectra to optimized L/E_ν for a already design beamline!



OAB with and without oscillations @ NUMI low energy configuration



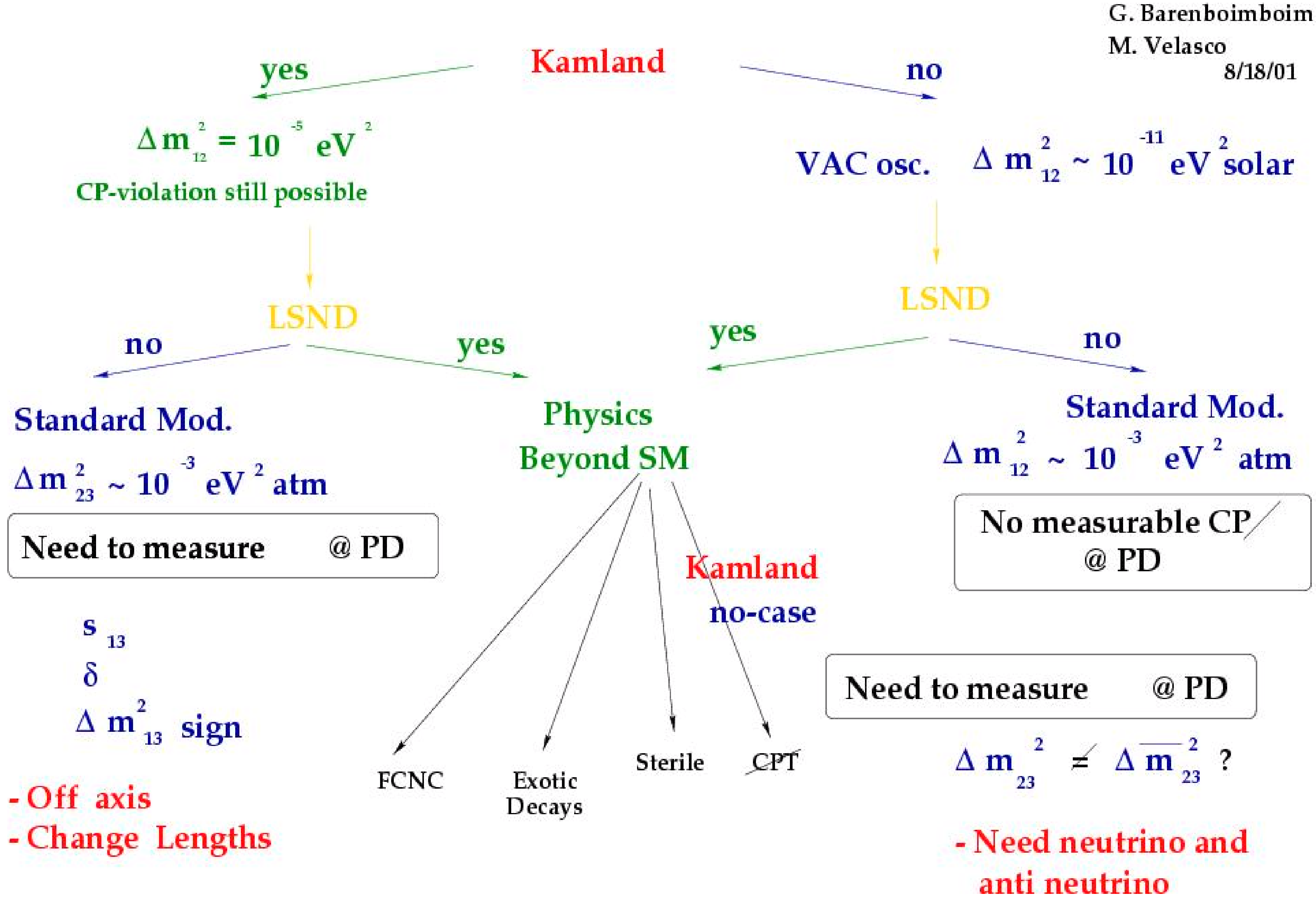
Why we like OAB?

- Well defined E_ν
- Lower High E_ν tails
- Higher luminosity at E_ν-peak

θ(mrad)	E_ν (GeV)
13.6	2.2 - 3.6
20.0	1.5 - 2.5
27.0	1.1 – 1.85

E_ν= (30-50 MeV)/θ:

How is this good for the physics to come?



Two Paths

- ***Path KAMLAND yes:***

(1) requires clean beamline with low high energy tails to be able to measure $P(\nu_\mu \rightarrow \nu_e)$ … better done at off-axis.

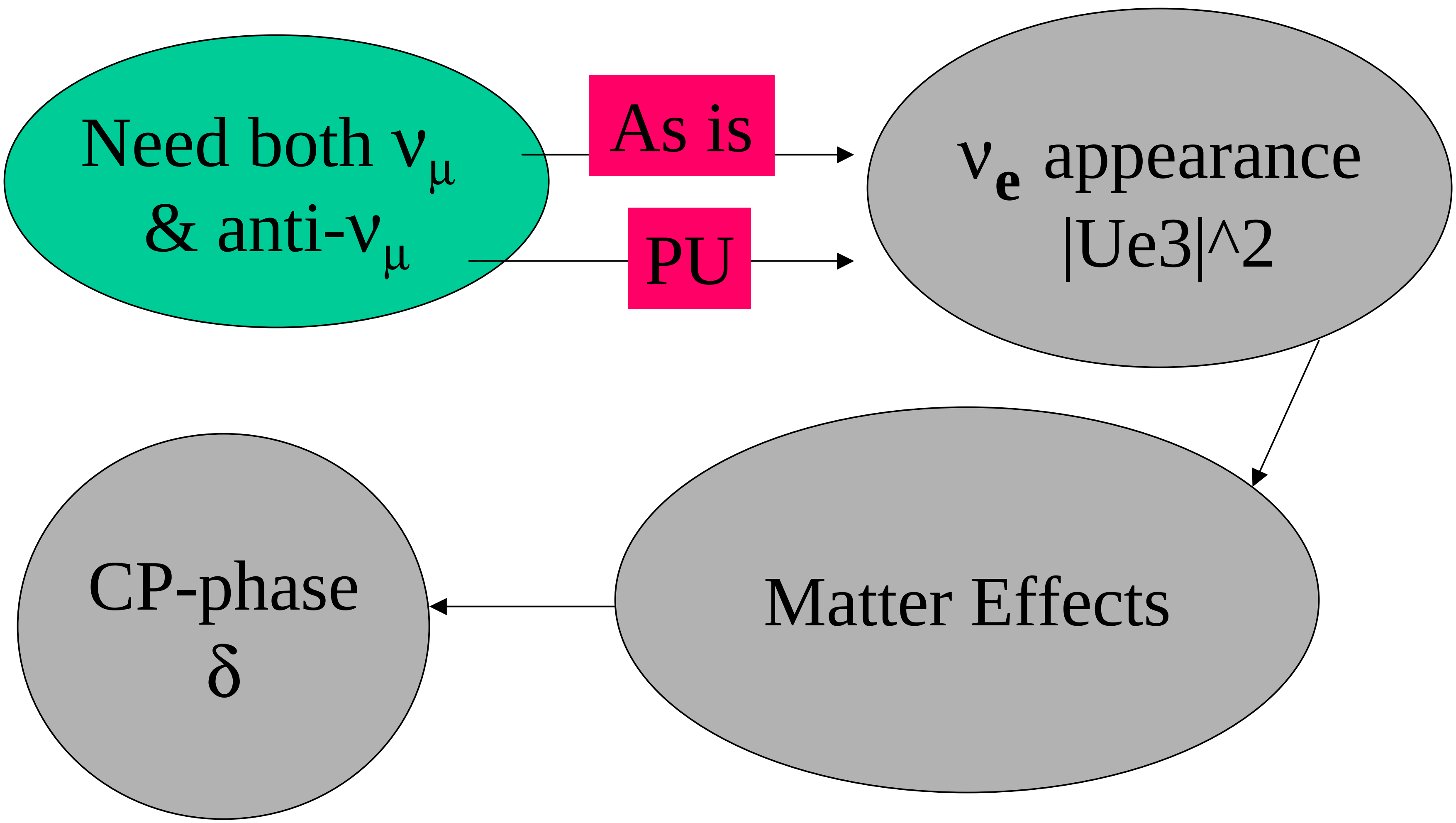
(2) Matter Effects and δ from comparisons with $P(\text{anti-}\nu_\mu \rightarrow \text{anti-}\nu_e)$ … possible with PU

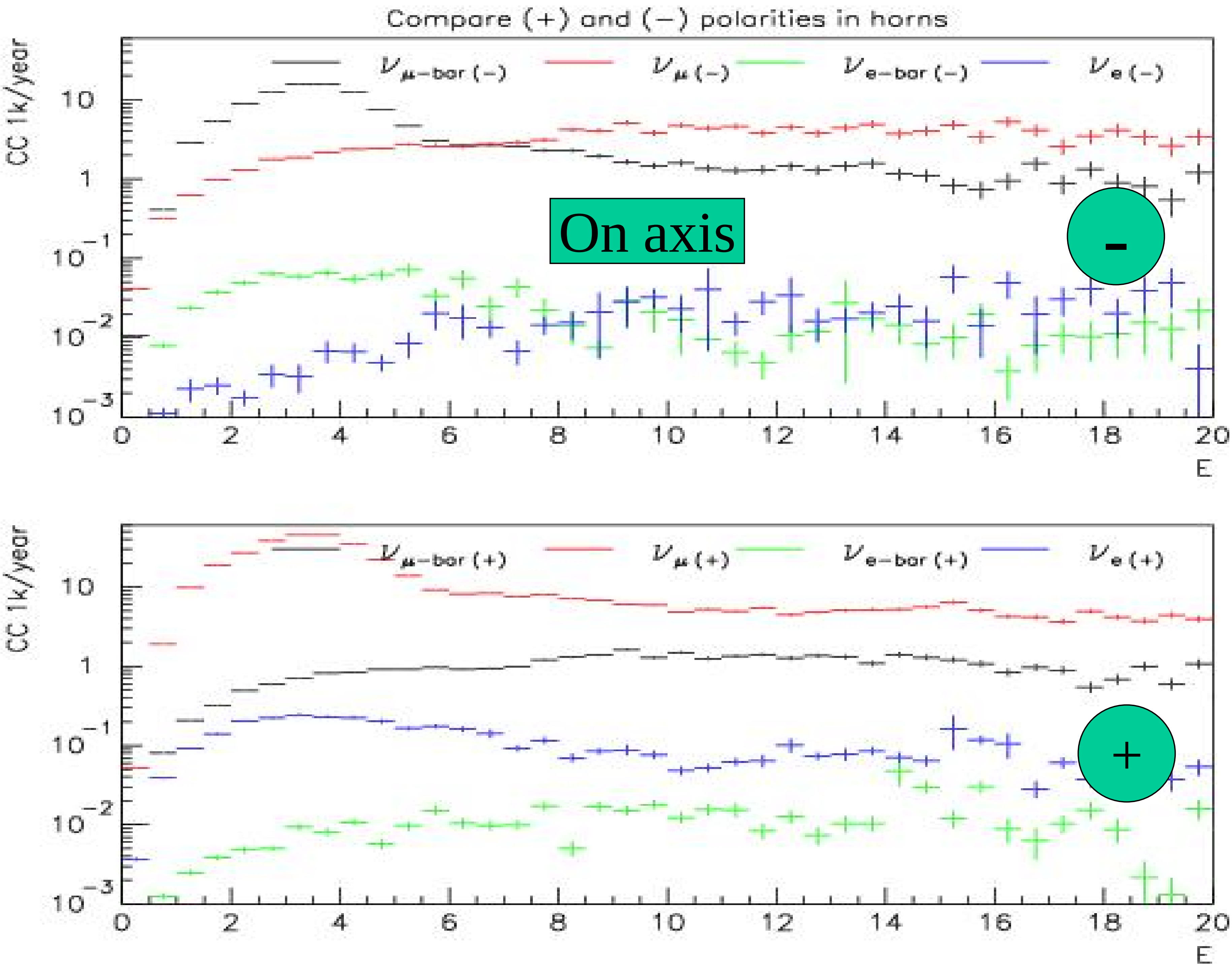
- ***Path KAMLAND no:***

(1) Focus on comparing $P(\nu_\mu \rightarrow \nu_\mu)$ and $P(\text{anti-}\nu_\mu \rightarrow \text{anti-}\nu_\mu)$ … better done at off-axis

(2) Matter Effects … better done with PU

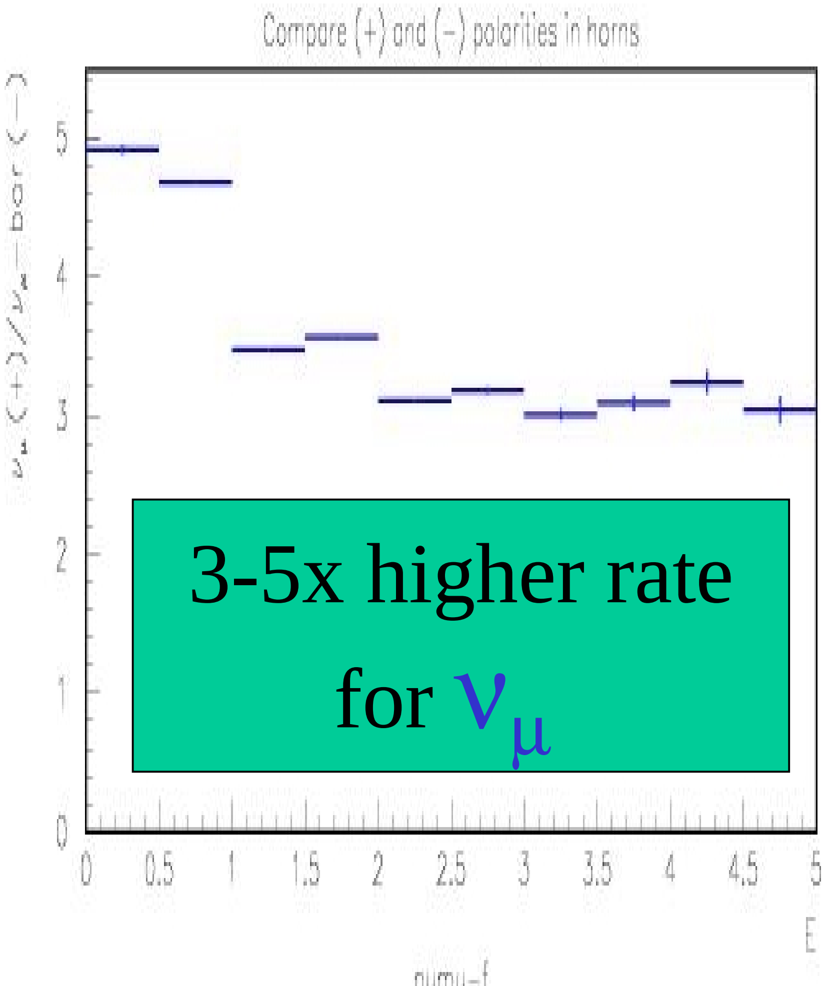
OAB NUMI Future→CP violation in neutrino

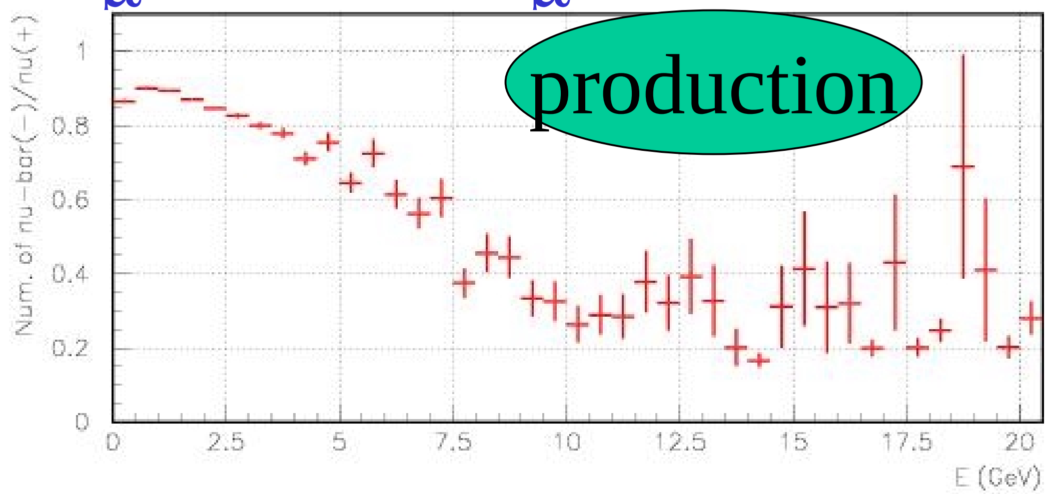


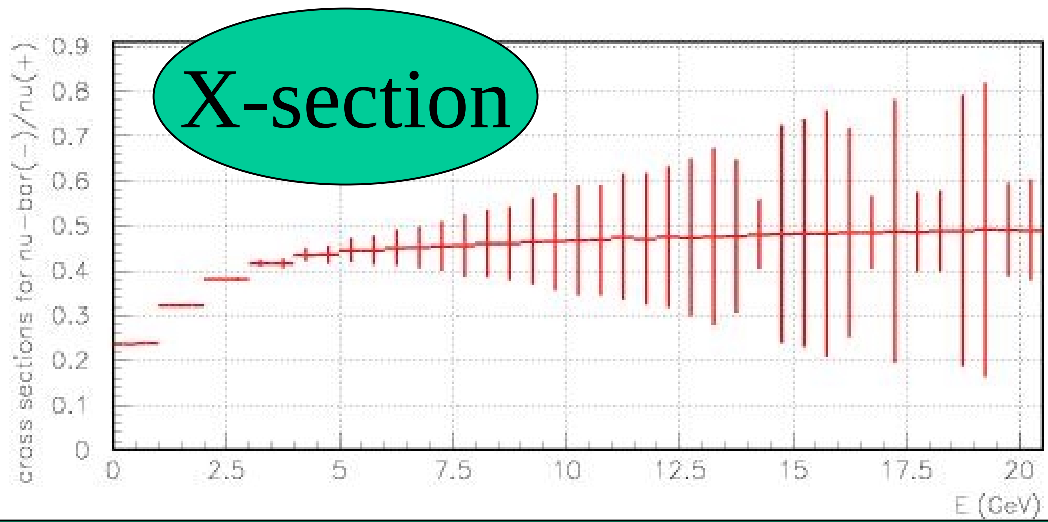


Compare (+) and (−) polarities in horns
$\nu_{\mu\text{-bar}}$ (−)
ν_{μ} (−)
$\nu_{e\text{-bar}}$ (−)
ν_{e} (−)
CC 1k/year
On axis
-
E
$\nu_{\mu\text{-bar}}$ (+)
ν_{μ} (+)
$\nu_{e\text{-bar}}$ (+)
ν_{e} (+)
CC 1k/year
+
E

By changing Horn Polarity run for either ν_μ & anti-ν_μ beam

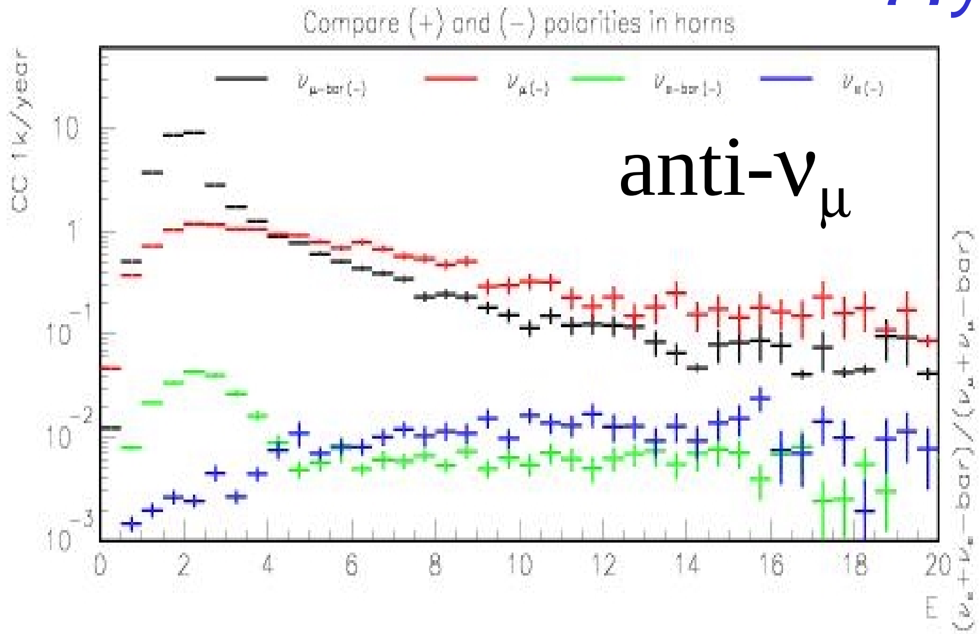


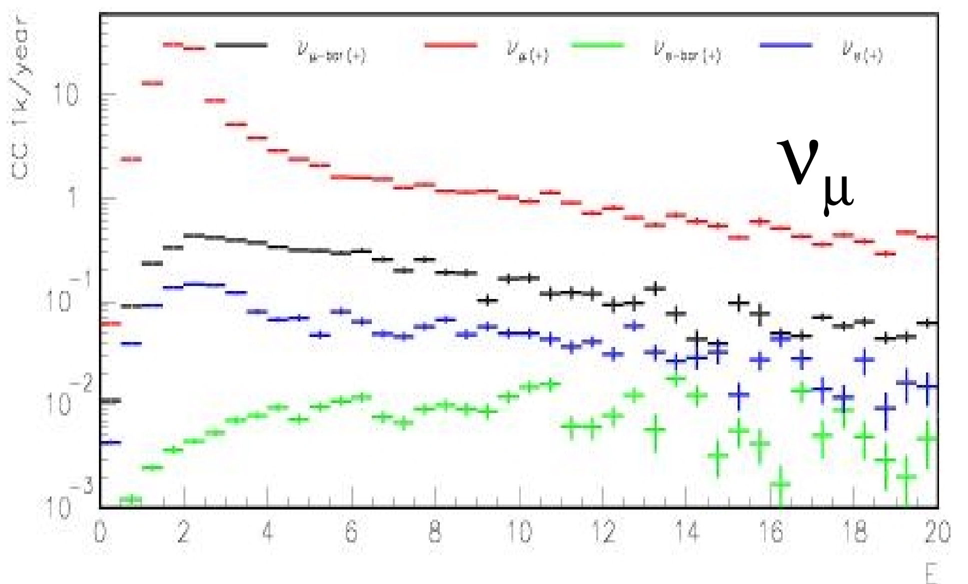


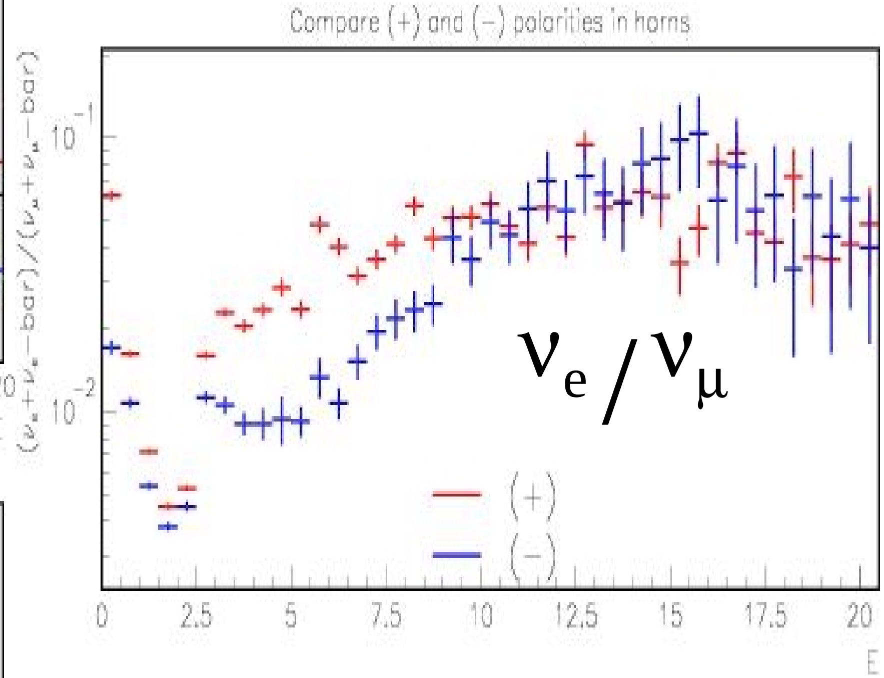


Want more Protons when running for anti-ν_μ beam

NUMI Low Energy (735km,10km)





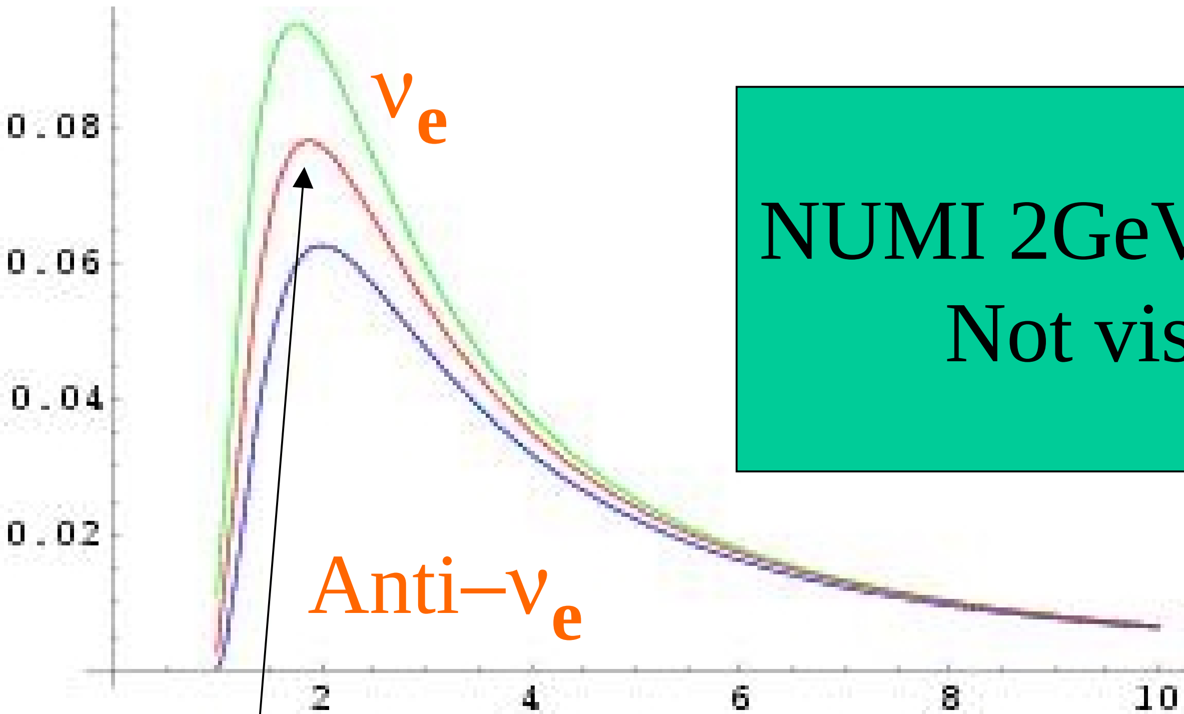


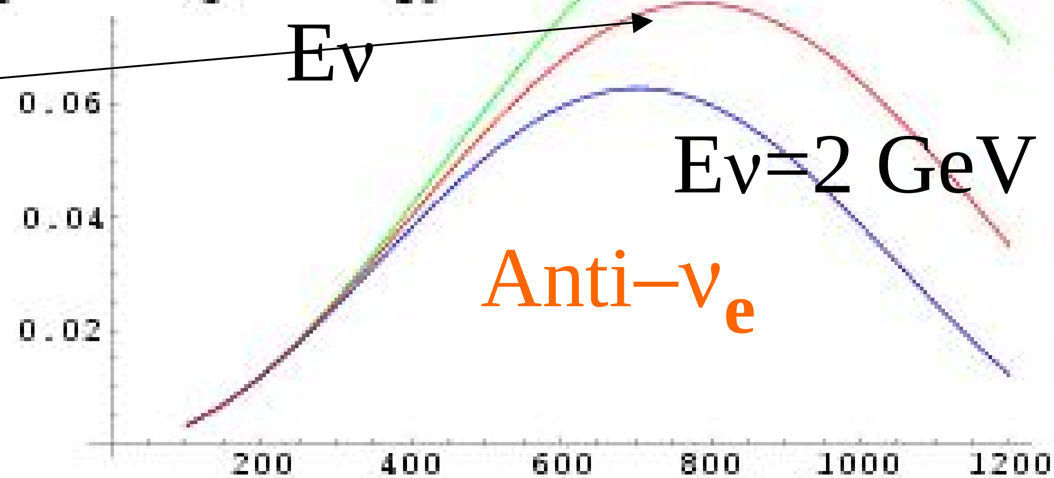
Off Axis (13.6 mrad)

Matter Effects(MaEf)

Barenboim, De Gouvea, Velasco

NUMI 2GeV --- Large MaEf
Not visible at JHF

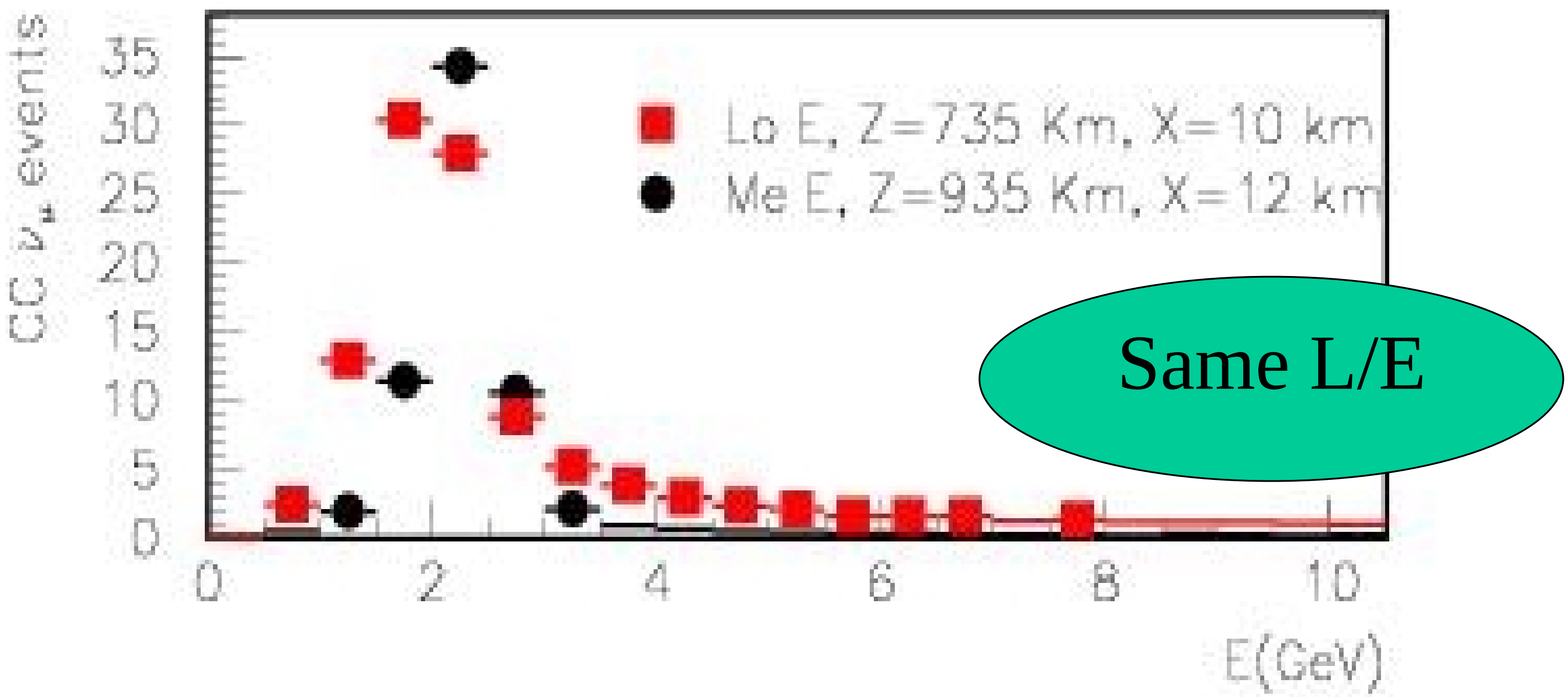




Transition probabilities
Δm_{12}=10^-4 eV^2

Optimize MaEf by letting
L = 935 km & r =12 km (12.8mrad)

Compensate for drop in Intensity by running in @ ME



Better of OAB experimental conditions can be obtained by:

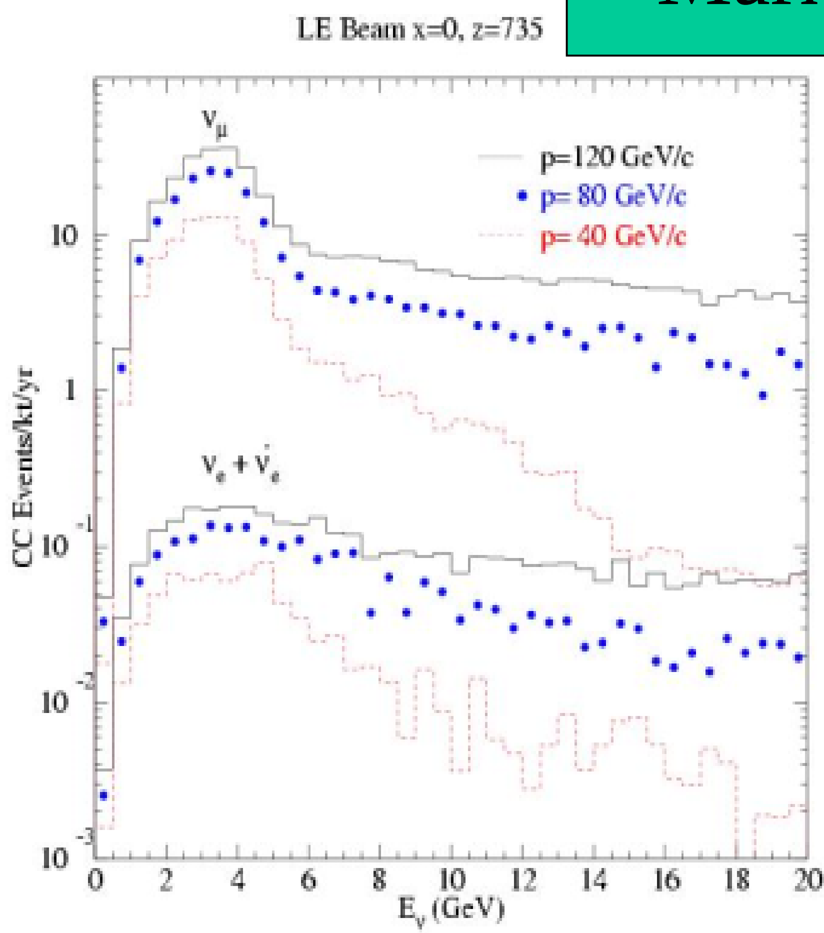
- Adjust L
- Adjust Radius from Axis
- Adjust beam Energy

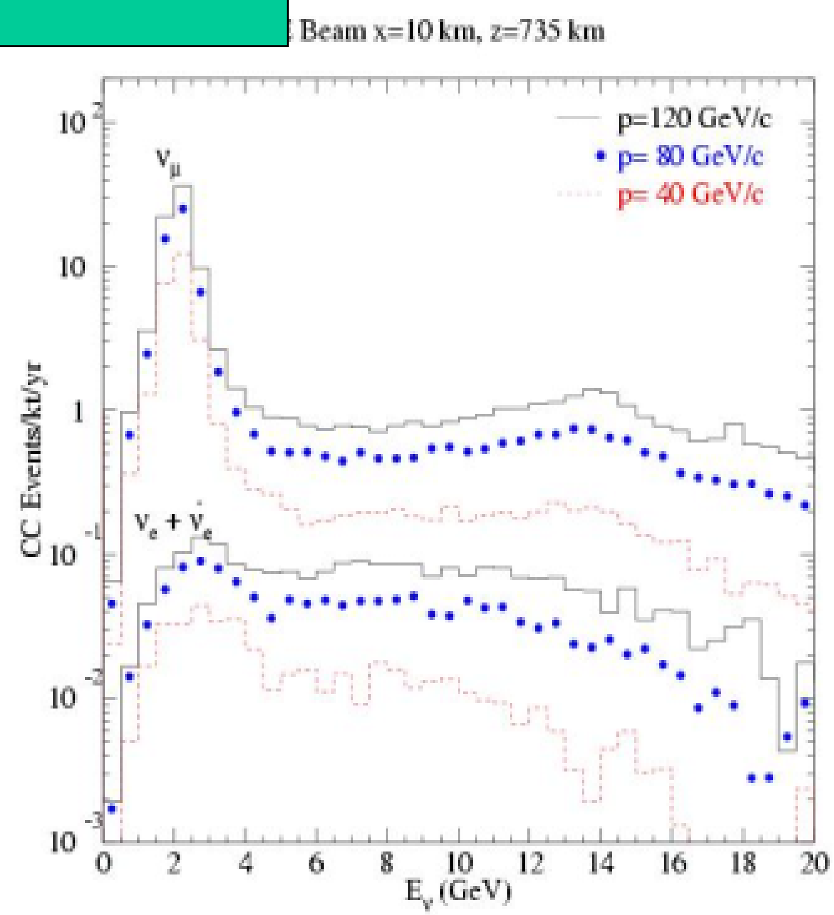
OAB experimental conditions will Not improve by:

- Lowering proton beam energy, while keeping the same beam intensity
- Adding Hadronic hose and not reducing pipe length

Lowering Proton beam Energy will reduce the overall beam intensity

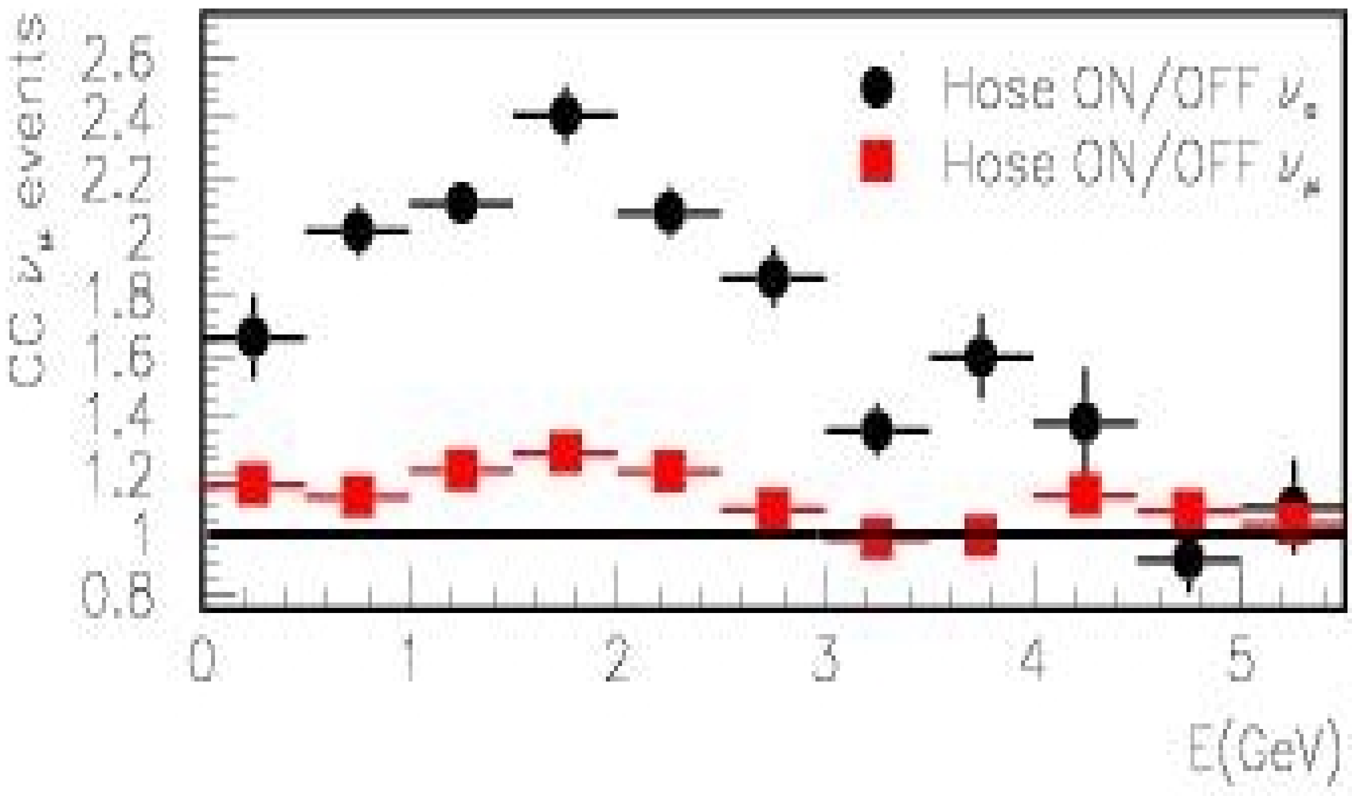
Mark Messier



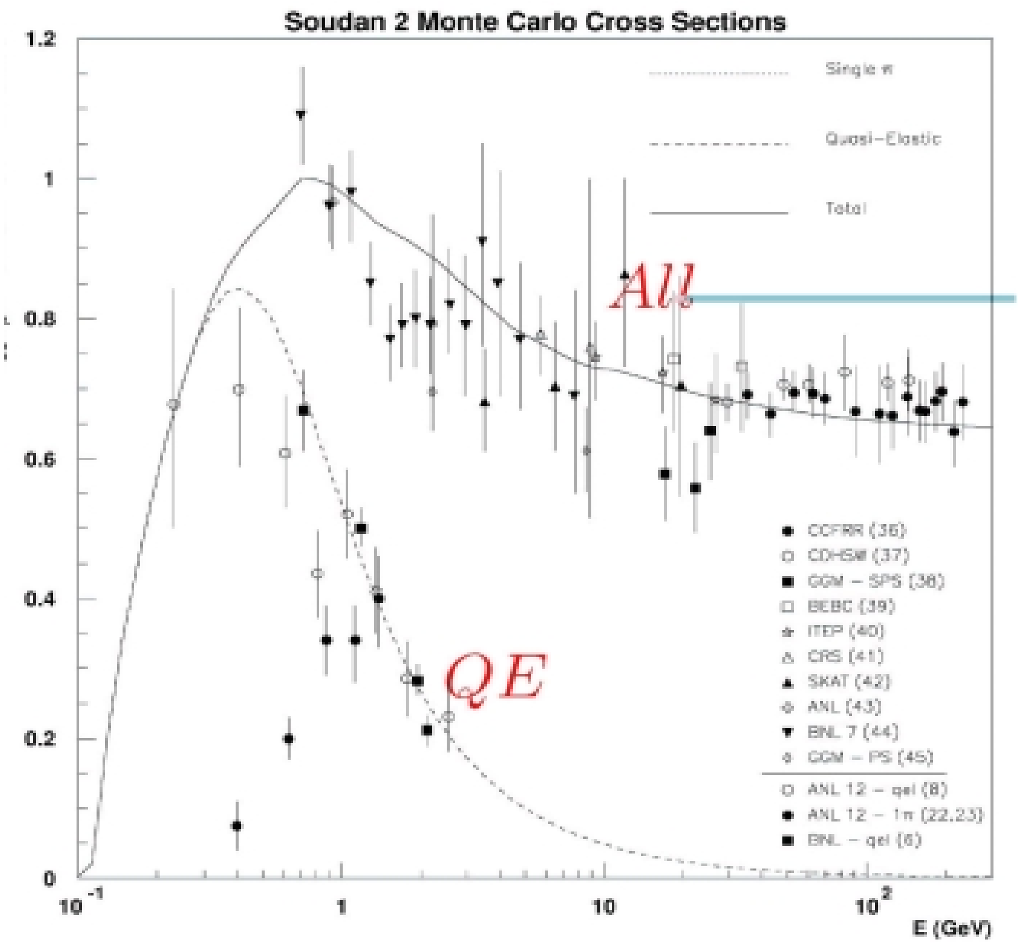


Hadronic-Hose will not be of great help unless decay pipe is made shorter to reduce ν_e from μ-decays

See S. Kopp for details



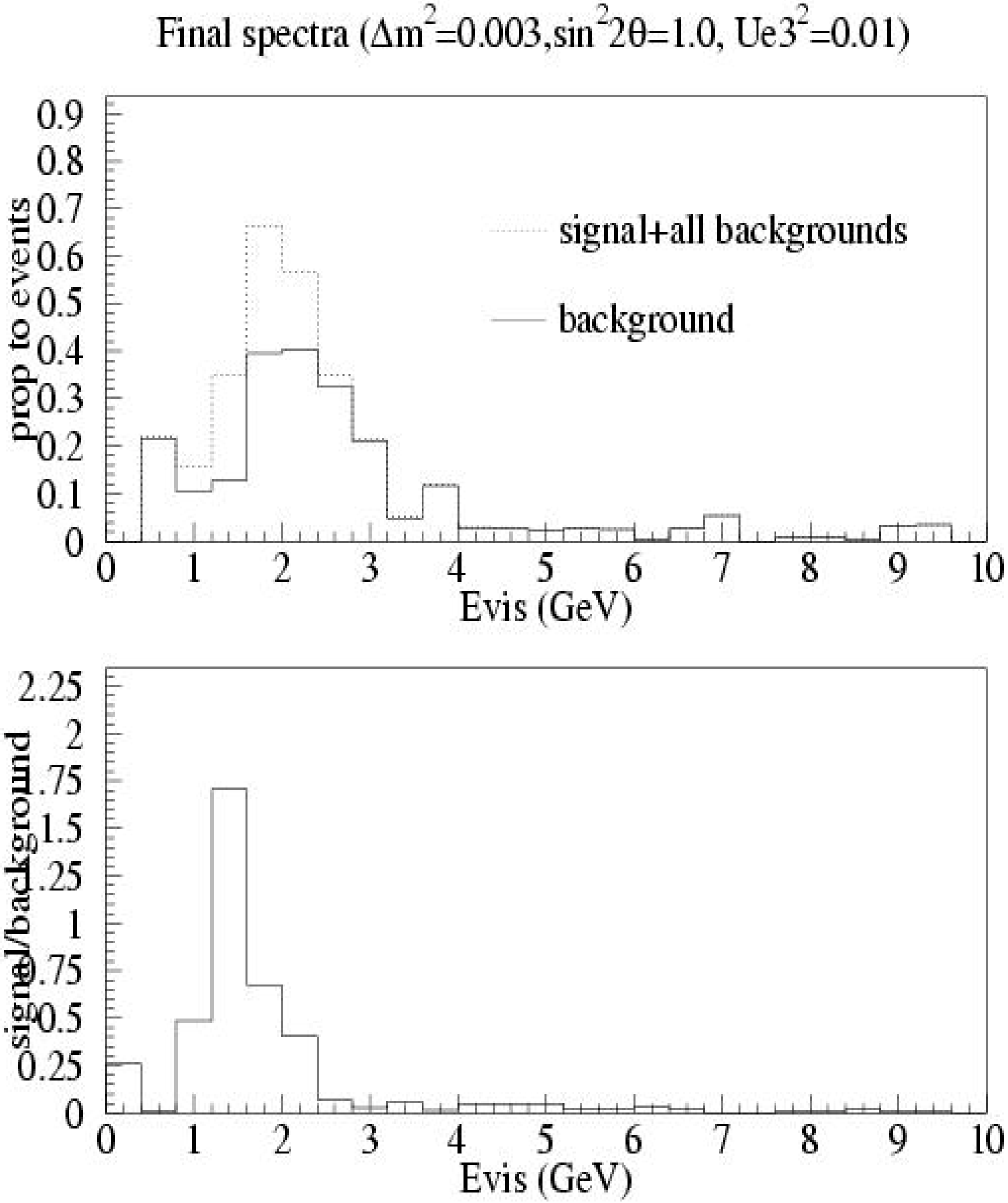
Better beam, what about detectors?



- Invest in detector for Quasi-Elastic ev.
- E_ν < 2.5GeV
- 10 Km (13.7 mrad)
- Nominal NUMI
  - 4 X 10^13 p
  - 10^7 s/year
  - 2 sec. rep.rate

Detector to be consider for θ_{13} measurements at 13.6 mrad

	Water Cherenkov	MINOS	Segmented OFF MINOS
Signal CC nu_e	0.2 – 0.3	0.28	0.25
Background:			
NC	0.02	0.015	<0.001
Muon CC	0.005	0.001	<0.001



Water Cherenkov Results at 13.6 mrad (Mark Messier)

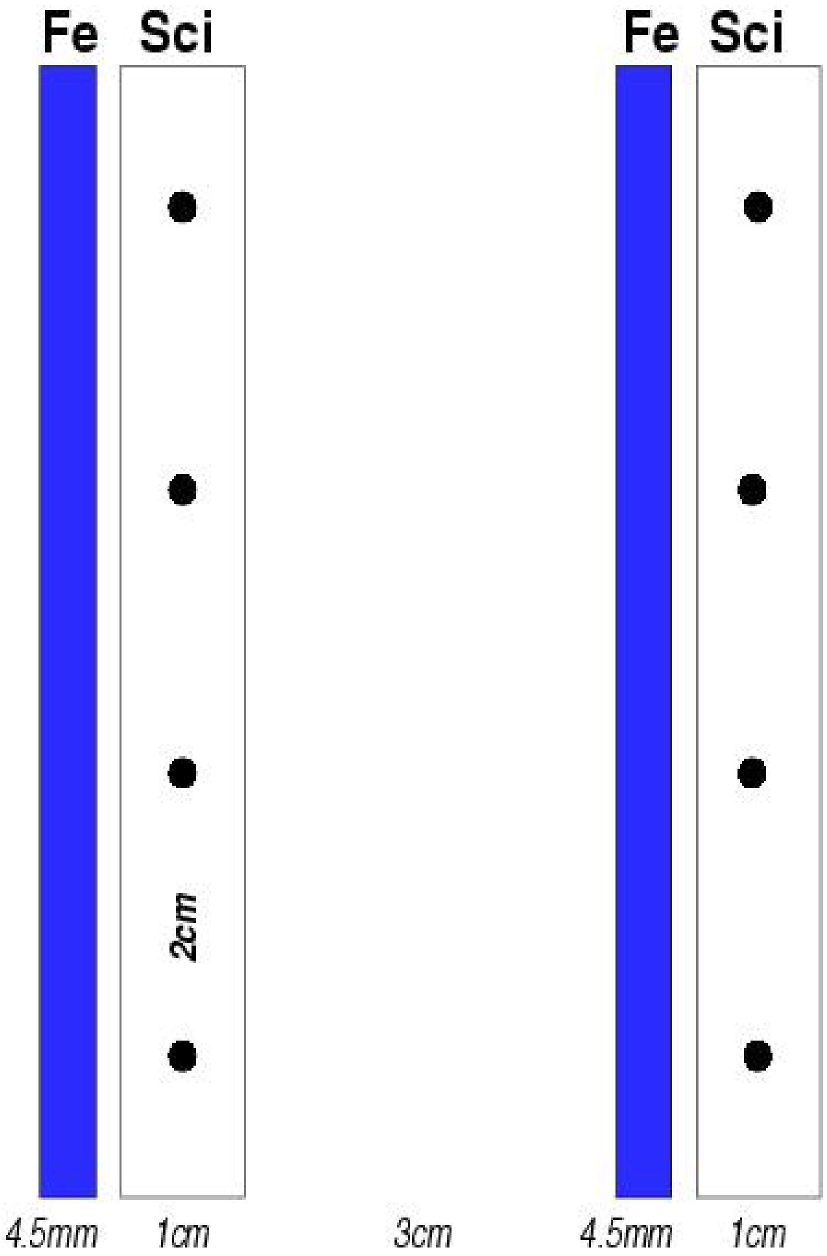
Highly Segment Iron-Scintillator detector (SOMINOS)

- MINOS Has shown that large detectors of this kind can be built (1 plane/day)
- Scaling price and size (J. Nelson)

  MINOS: 5kt, 8m dia., 500 planes $25M

  SOMINOS: 5kt, 12m dia.,875 planes $77M

  *** Reduction in fiber and electronics possible…also some think that we can save in price of plastic.



MINOS:

2.54 cm steel & 4 cm cells

SOMINOS:

0.45cm steel & 2 cm cells

Tracking and
Full simulation
for SOMINOS

Szleper & Velasco

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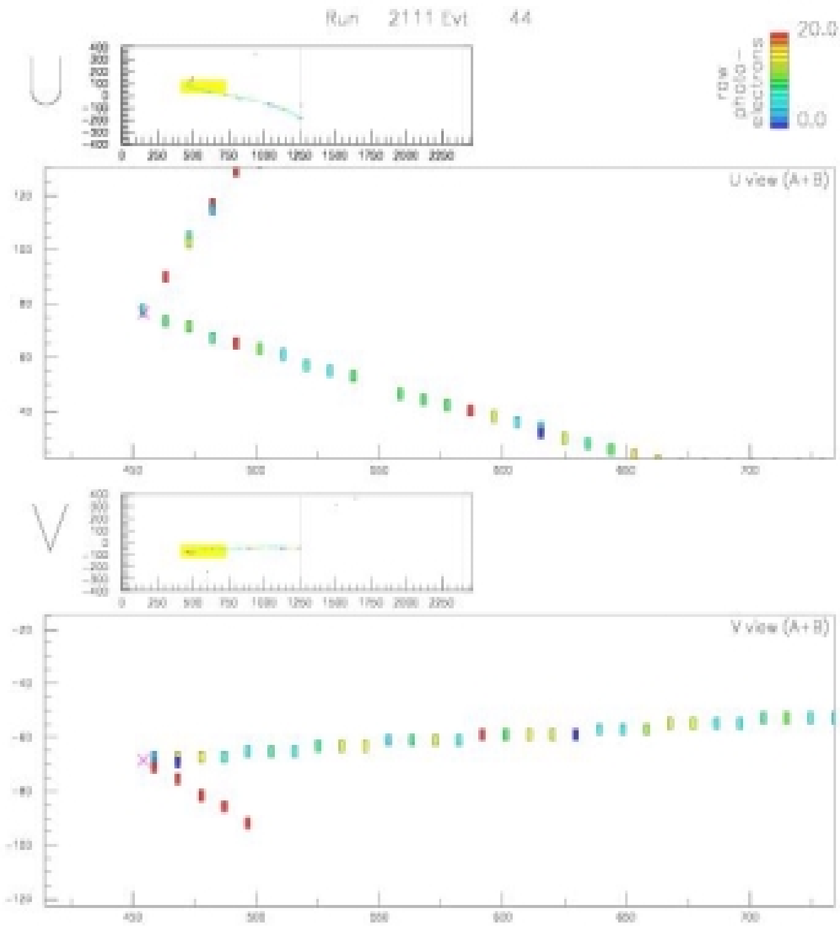
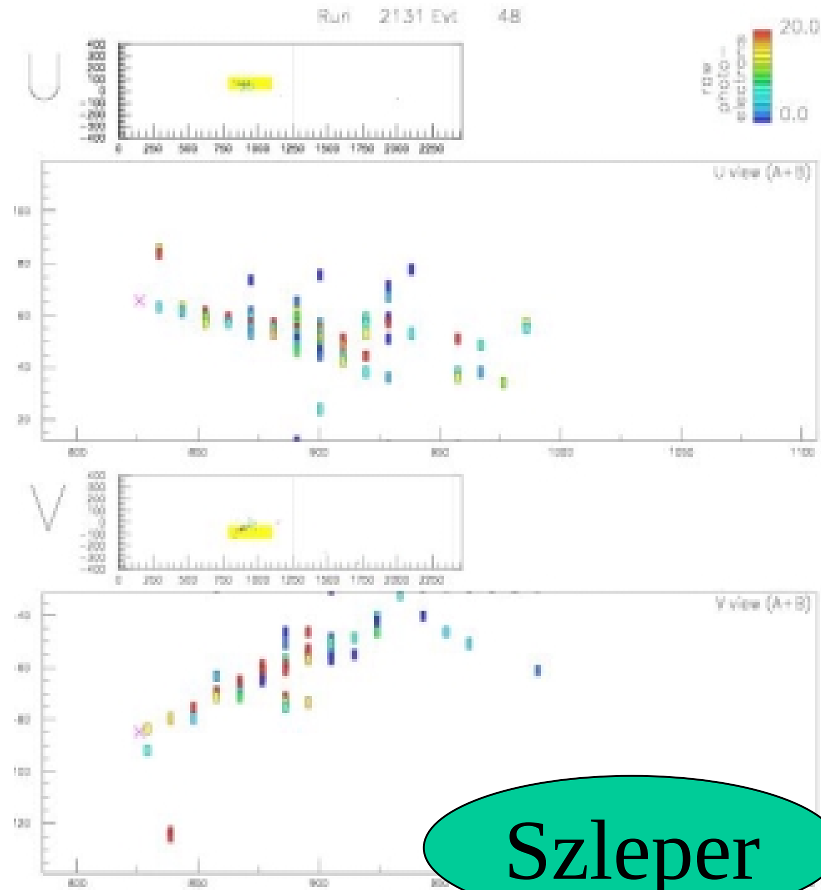
Highly Segment Iron-Scintillator Detector



CC νμ 2 GeV



Szleper

CC νe 2 GeV

SO-MINOS and MINOS for $\Delta m_{23}^2=0.003\ eV^2$ and $|U_{e3}|^2=0.01$

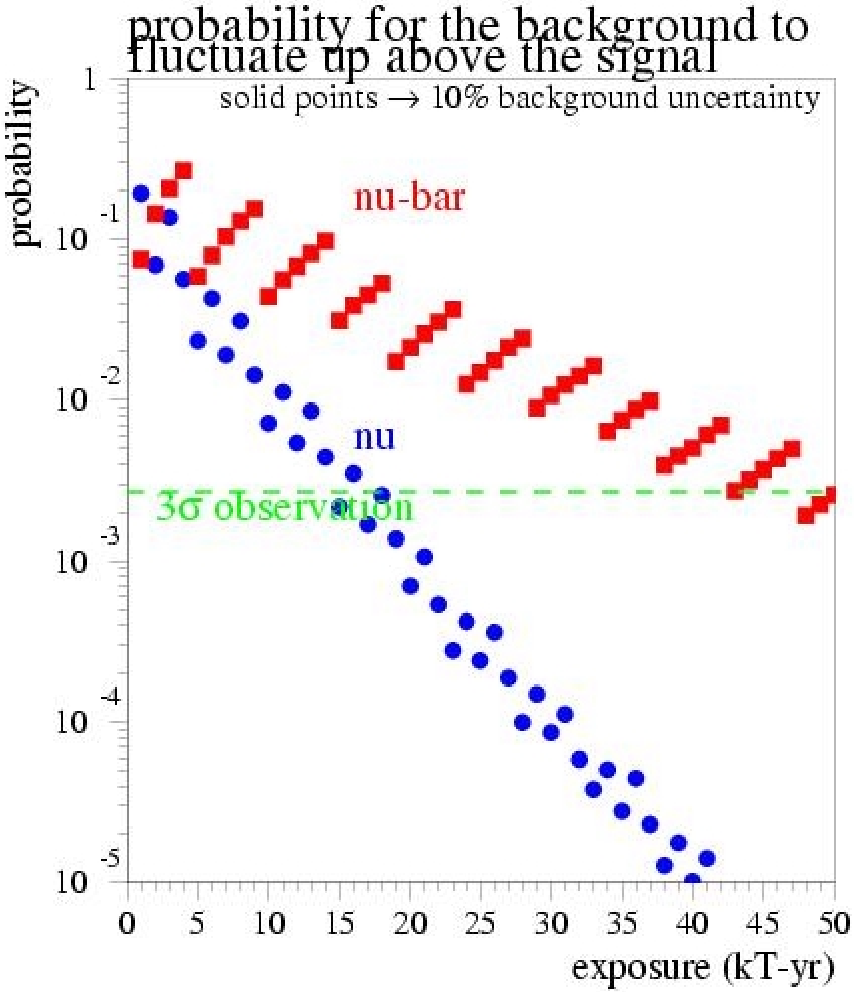
Assume 1Kton*year FOM=S/Sqrt(BG)

Exp.	Signal	ν_e CC	ν_μ CC	ν_τ CC	NC	Tot. BG
MINOS	0.85	0.56	0.39	0.3	2.73	3.97
SO MINOS	0.40	0.14	0.04	0.0	0.04	0.22

$FMO_{SOMINOS}=0.9$

$FMO_{MINOS}=0.44$

Observation Probability for this case with ν and anti-ν



SOMINOS = 5Ktons

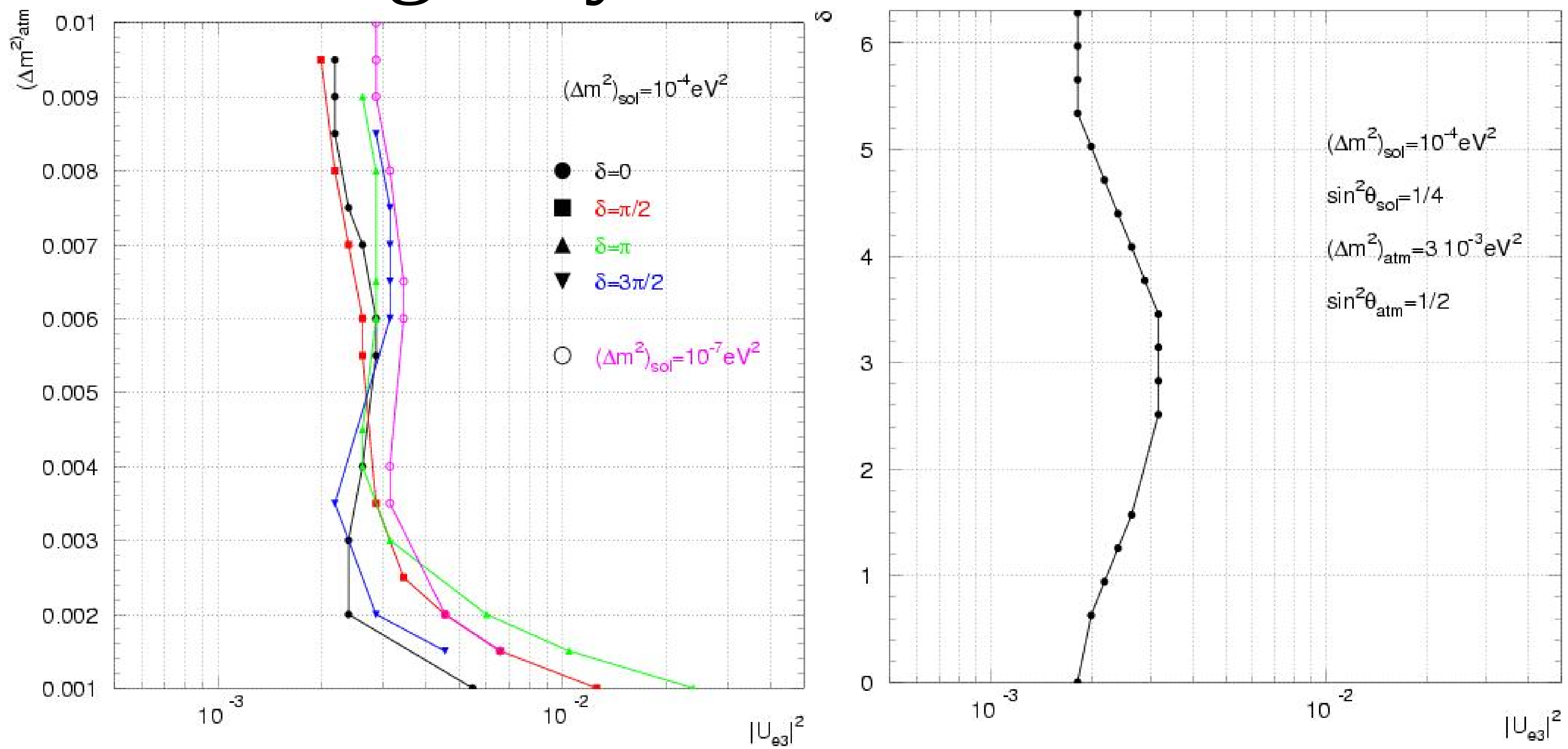
In presence of a PU could have 4 times more luminosity to compensate for lower rates with anti-ν

Scenarios studied in detailed(old reconstruction)

- Solar Δm^2 at 10^-4 CP visible … if Ue3 is measurable → (TYPE I)
- Solar Δm^2 at 1-2 10^-4 CP visible … if Ue3 is measurable, but tricky due to large uncertainties in Δm_{12} → (TYPE II)
- Solar Δm^2 at 10^-7 Can't see CP, focus on MaEf & CPT → (TYPE III)

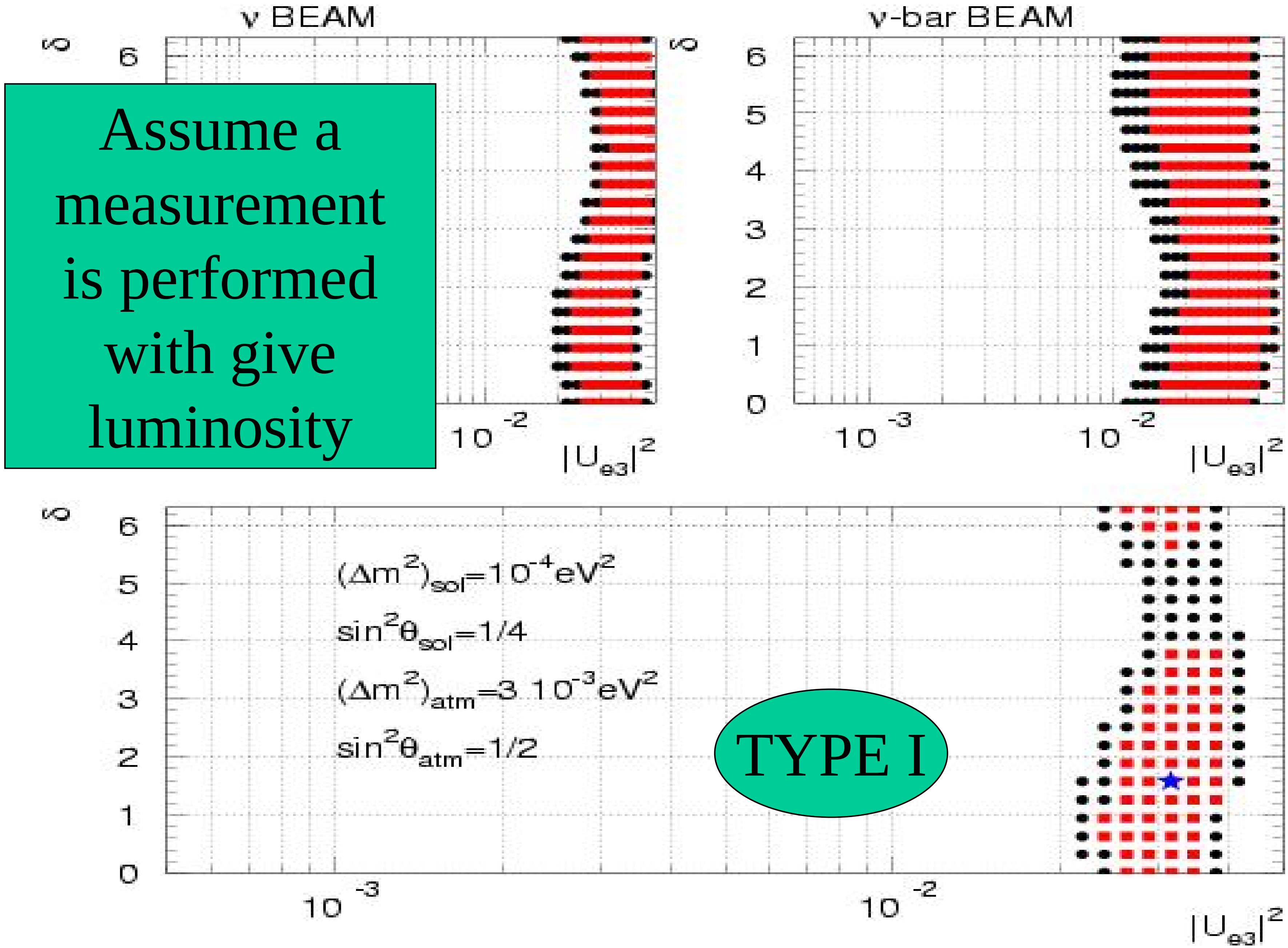
Assume 40 kt-year with ν_μ
80 kt-year with anti-ν_μ
& Highly segment Iron-Scintillator detector

Setting only a limit for TYPE I

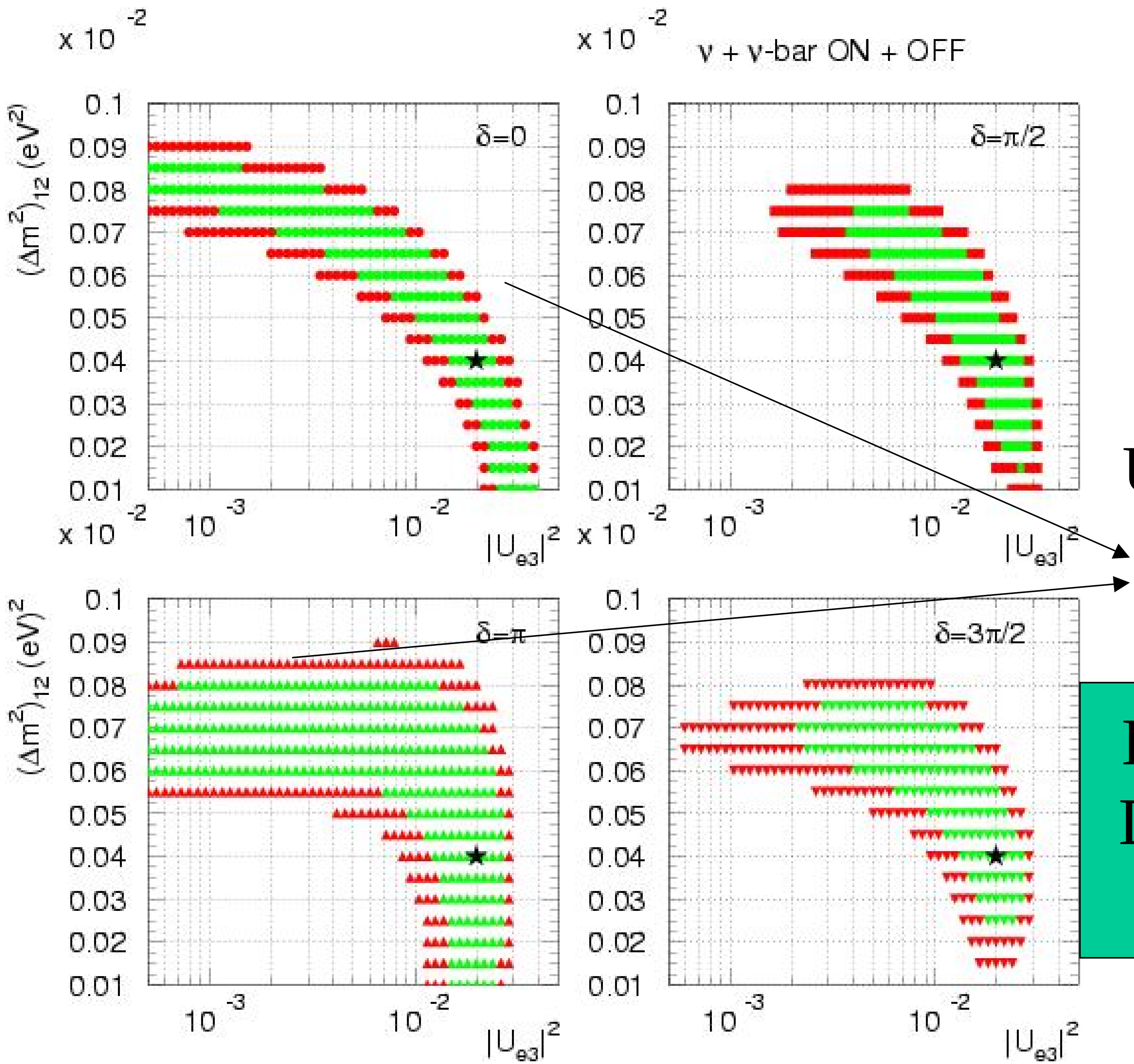


Barenboim, De Gouvea, Velasco

Assume a measurement is performed with give luminosity



TYPE I



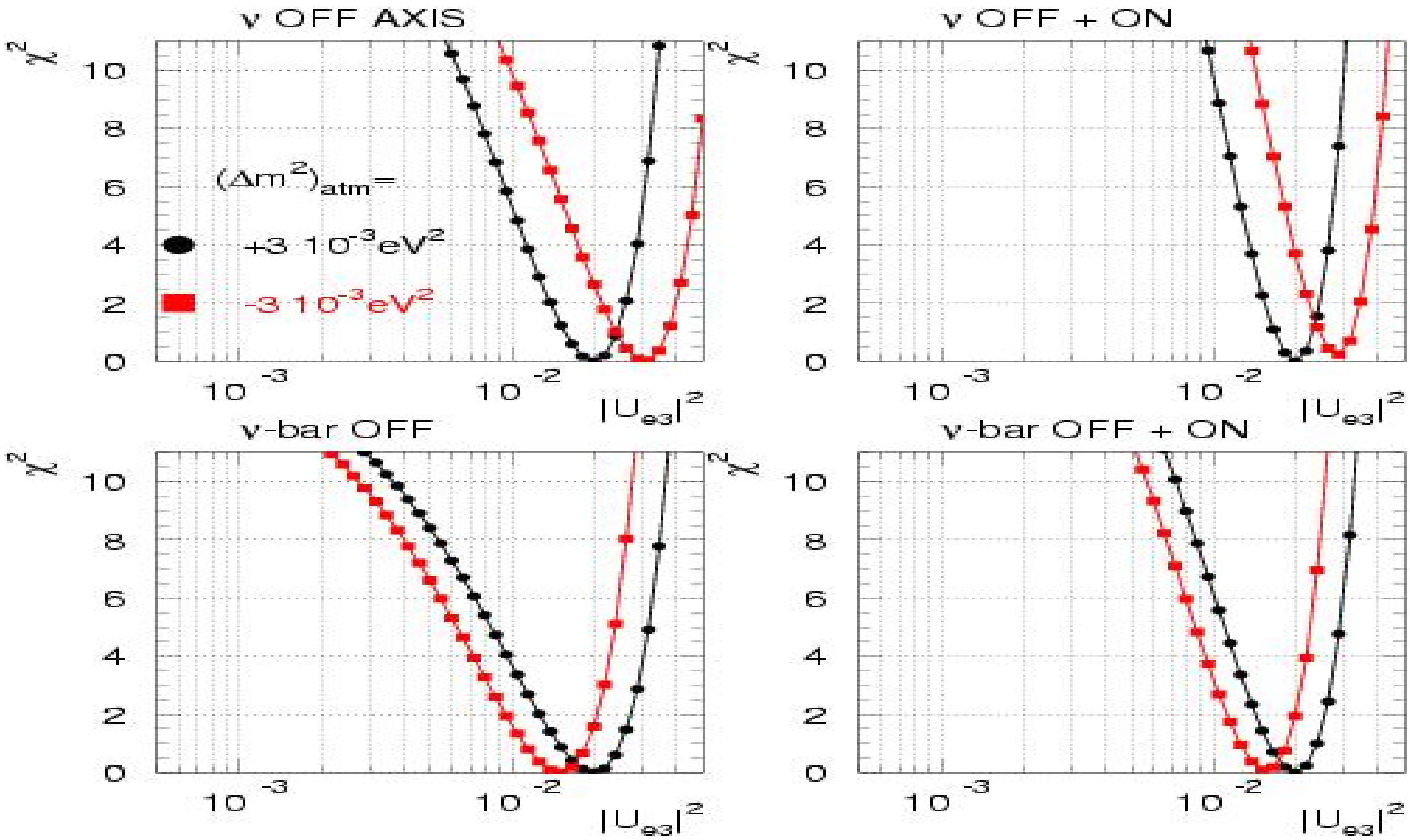
TYPE II

Uncertainty

in Δm_{12}

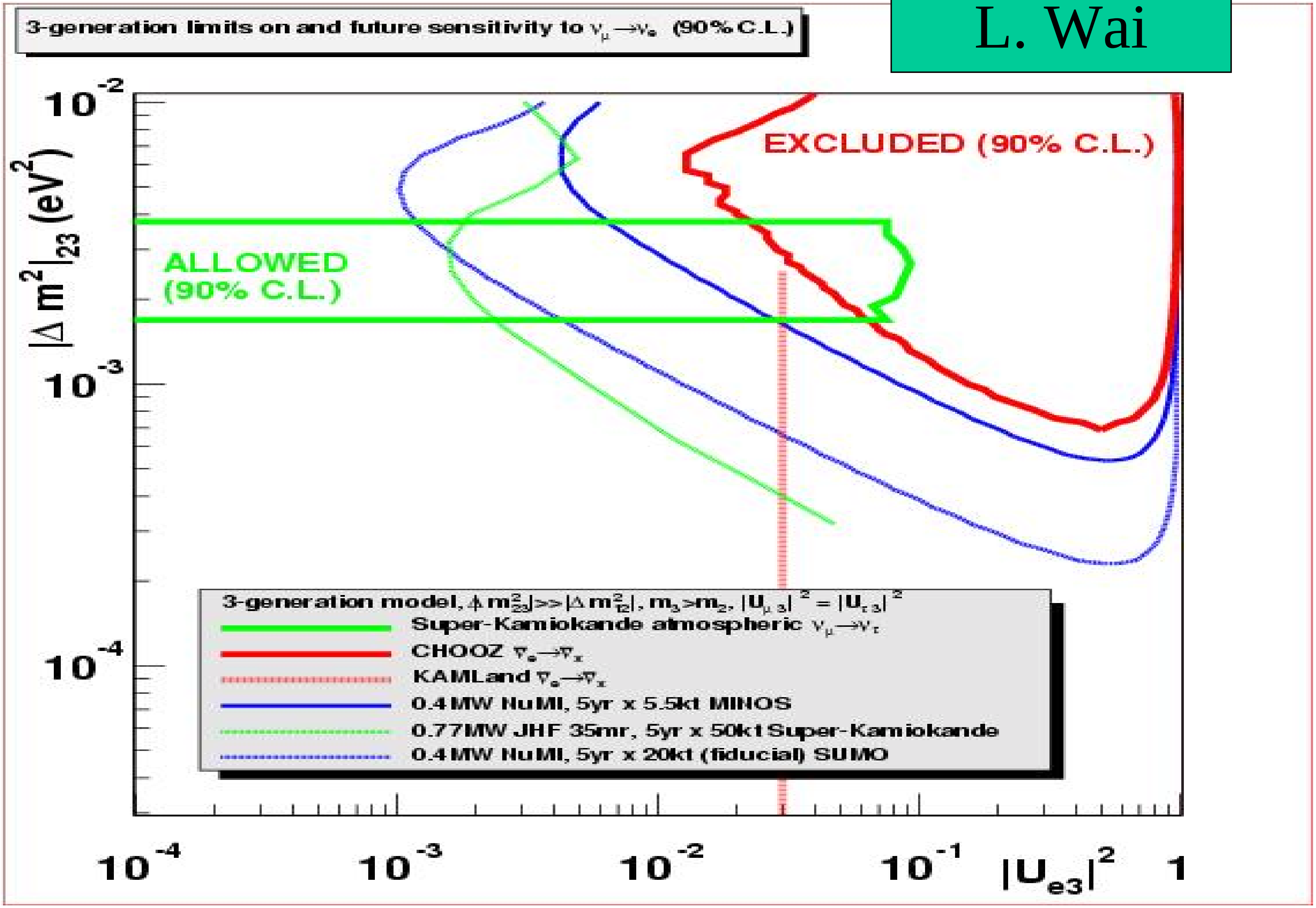
Barenboim, De Gouvea, Velasco

TYPE III- Hierarchy Studies

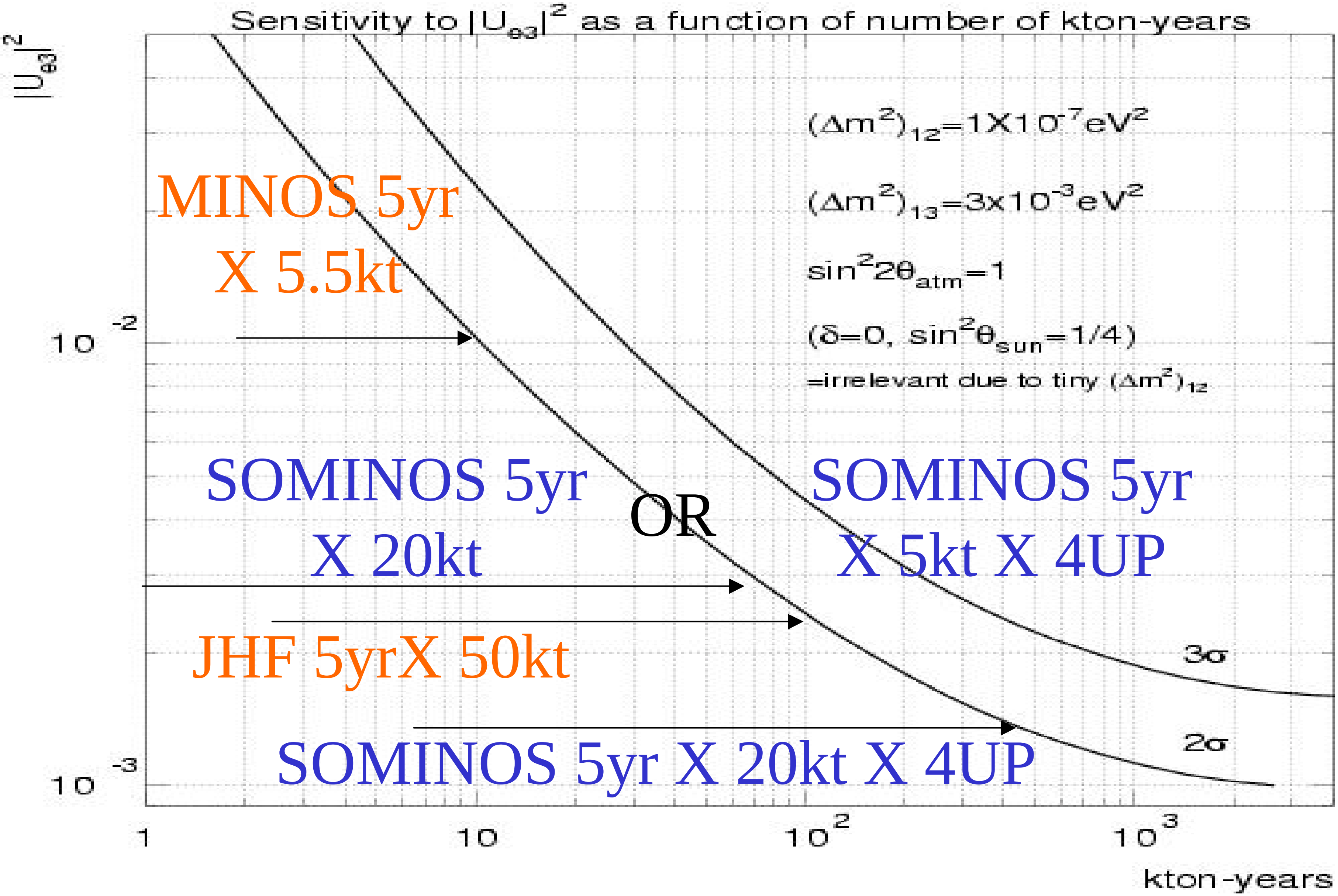


Barenboim, De Gouvea, Velasco

L. Wai


3-generation limits on and future sensitivity to $\nu_\mu \to \nu_e$ (90% C.L.)
$|\Delta m^2|_{23}$ (eV^2)
EXCLUDED (90% C.L.)
ALLOWED (90% C.L.)
3-generation model, $|\Delta m^2_{23}| >> |\Delta m^2_{12}|$, $m_3 > m_2$, $|U_{\mu 3}|^2 = |U_{\tau 3}|^2$
Super-Kamiokande atmospheric $\nu_\mu \to \nu_\tau$
CHOOZ $\bar{\nu}_e \to \bar{\nu}_x$
KAMLand $\bar{\nu}_e \to \bar{\nu}_x$
0.4 MW NuMI, 5yr x 5.5kt MINOS
0.77MW JHF 35mr, 5yr x 50kt Super-Kamiokande
0.4 MW NuMI, 5yr x 20kt (fiducial) SUMO
10^{-4}
10^{-3}
10^{-2}
10^{-1}
$|U_{e3}|^2$
1

SOMINOS Type Detector



What is Next?

- Repeat all the above with L=935 km.
- Use results from improve reconstruction in the analysis of TYPE I, II, III scenarios
- All discussion in this workshop on new target, horn, radiation, etc… are extremely important for any upgrade needed at NUMI in the presence of a PU.

Conclusion

- OAB with the current design of NUMI could provide a good reach in $|U_{e3}|^2$ if we invest in the *proper* detector.
- OAB+PU could expand significantly the reach while continuing to use the same detector… and give access to CP violation in the lepton sector and/or MaEf… Better than JHF if a 20kT detector is used.