Short baseline $\nu_\mu \rightarrow \nu_\tau$ oscillation search

Consider using the NuMI medium energy beam to search for $\nu_\mu \rightarrow \nu_\tau$

Andrew Bazarko
Princeton University

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Sam Zeller
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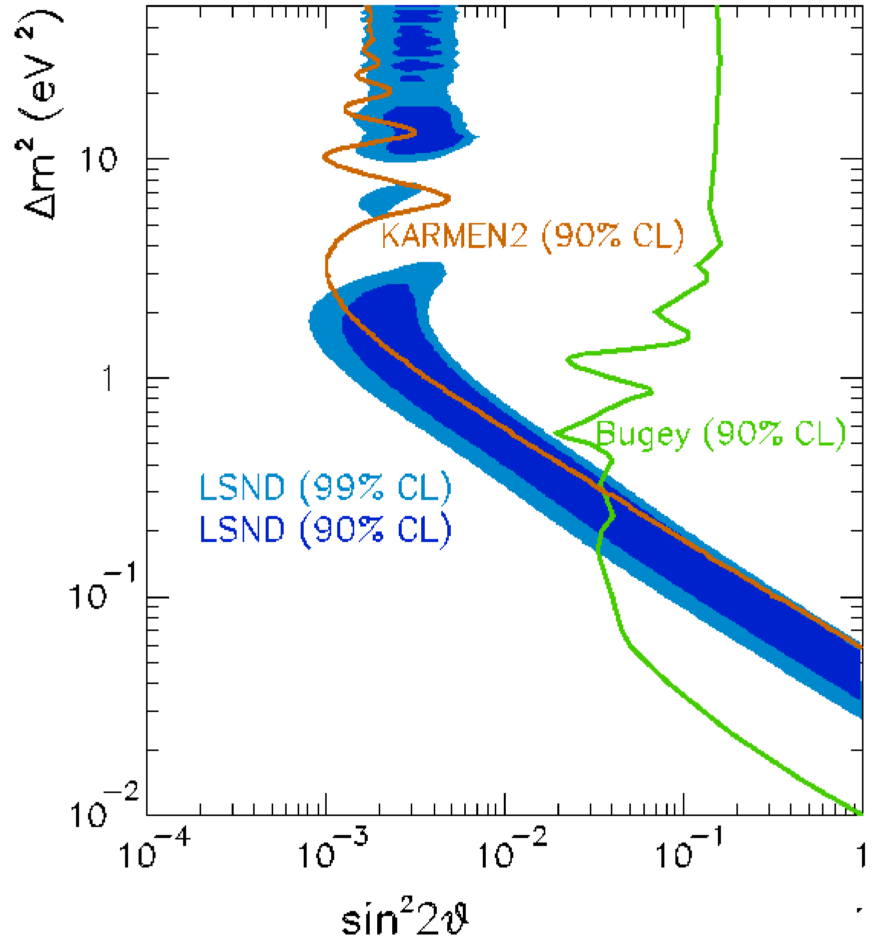
Bonnie Fleming

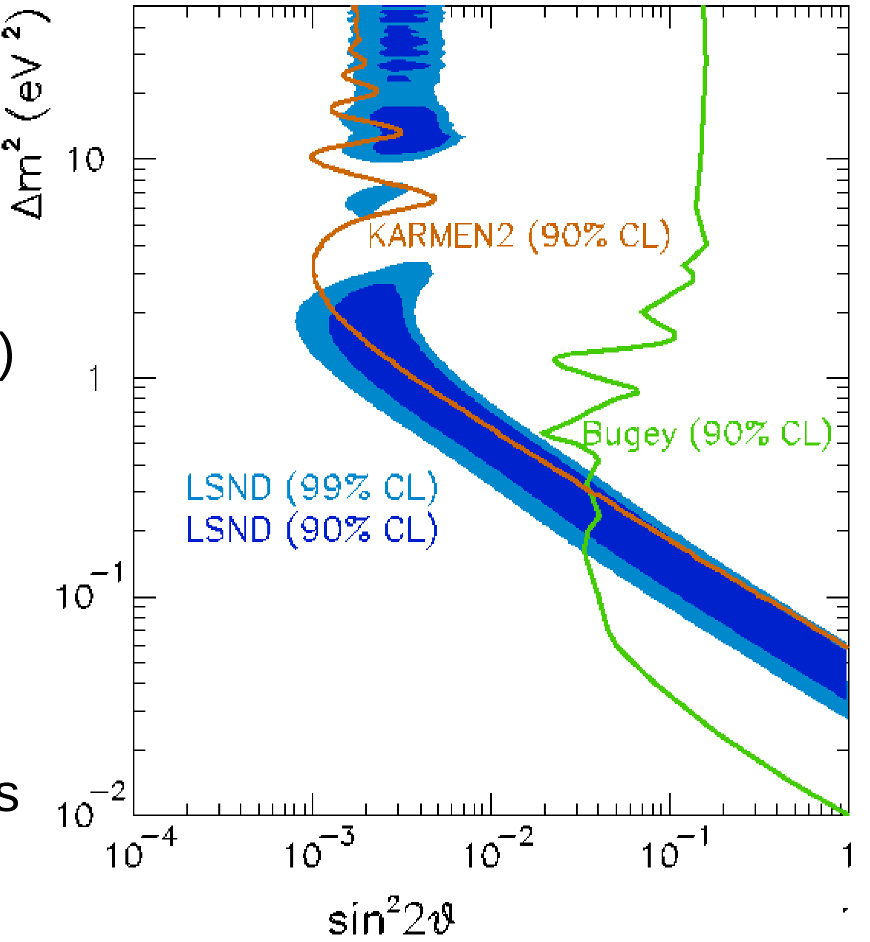


Short baseline $\nu_\mu \rightarrow \nu_\tau$ oscillation search

If MiniBooNE confirms LSND

→ another mass scale (or mass scales) involved in oscillations

$\Delta m^2 > 0.2 \text{ eV}^2$



Goal: explore this mass scale

Understand contributions from sterile ν's

exploit all channels: ν_μ disappearance

$\nu_\mu \rightarrow \nu_e$

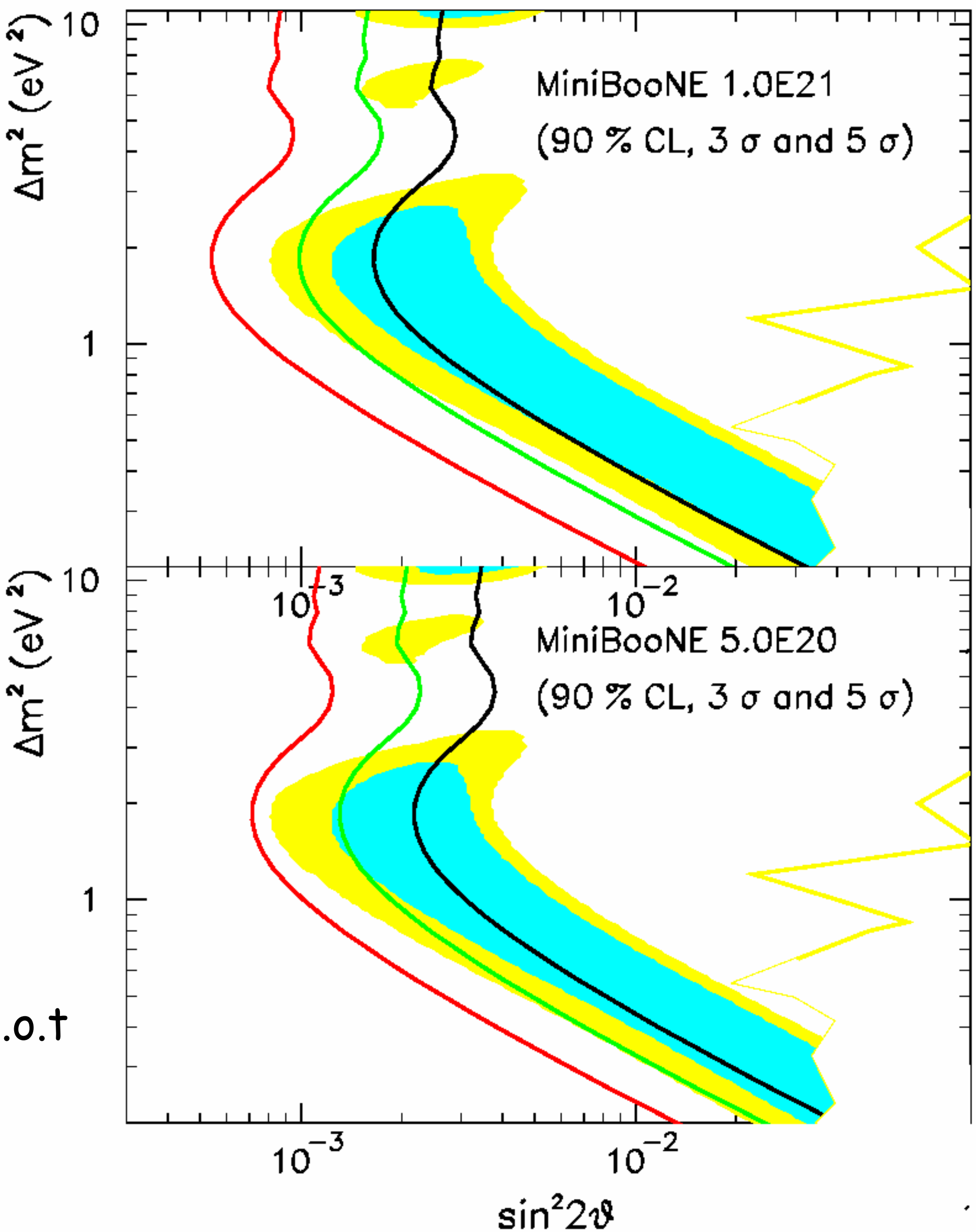
$\nu_\mu \rightarrow \nu_\tau$

MiniBooNE sensitivity

Expected for 1 x 10^{21} p.o.t

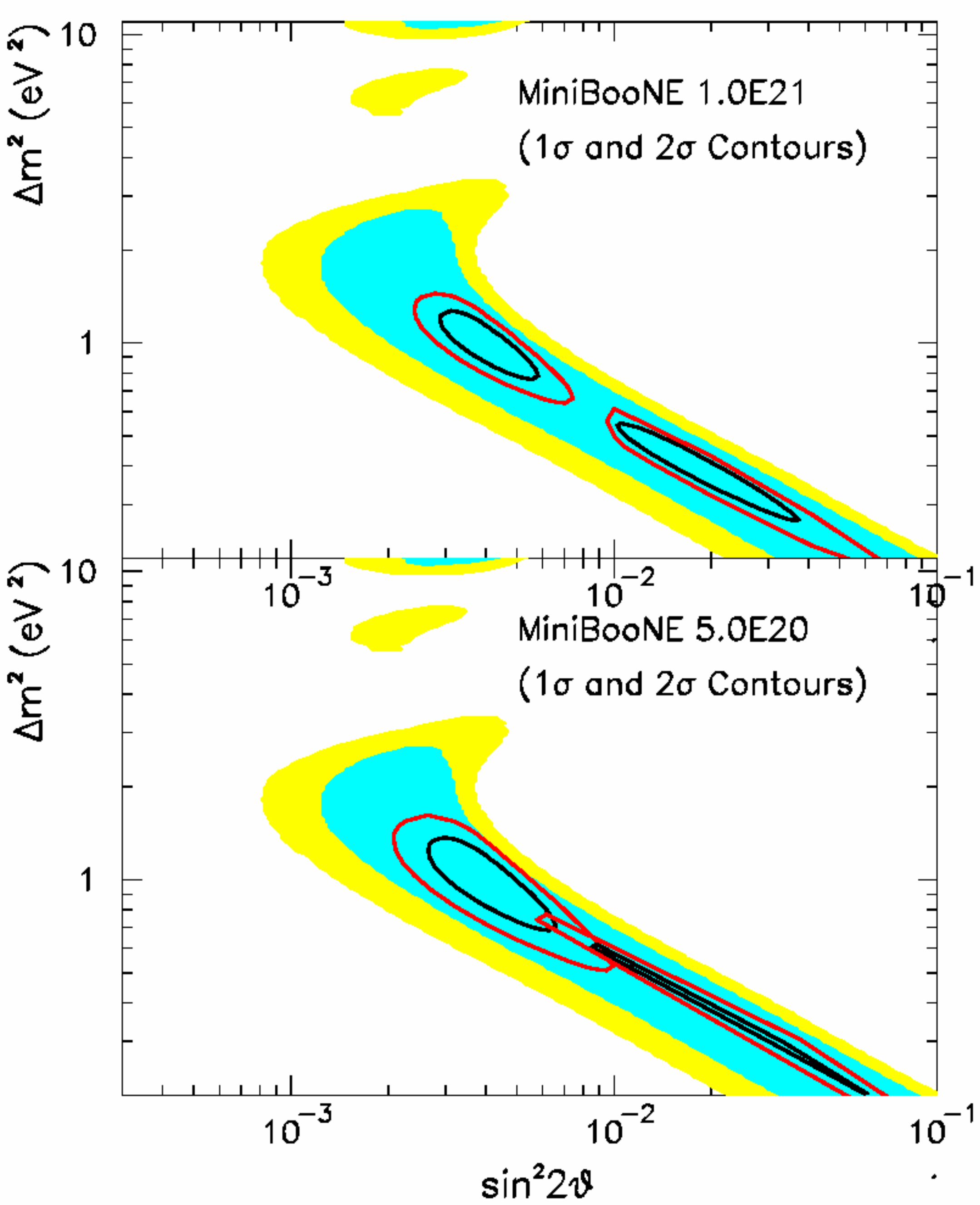
and for 5 x 10^{20} p.o.t.

current status: 3.5 x 10^{20} p.o.t



MiniBooNE parameter measurement capability

expected contours for signals at $\Delta m^2 = 1.0$ and 0.4 eV^2 at the center of LSND's allowed region

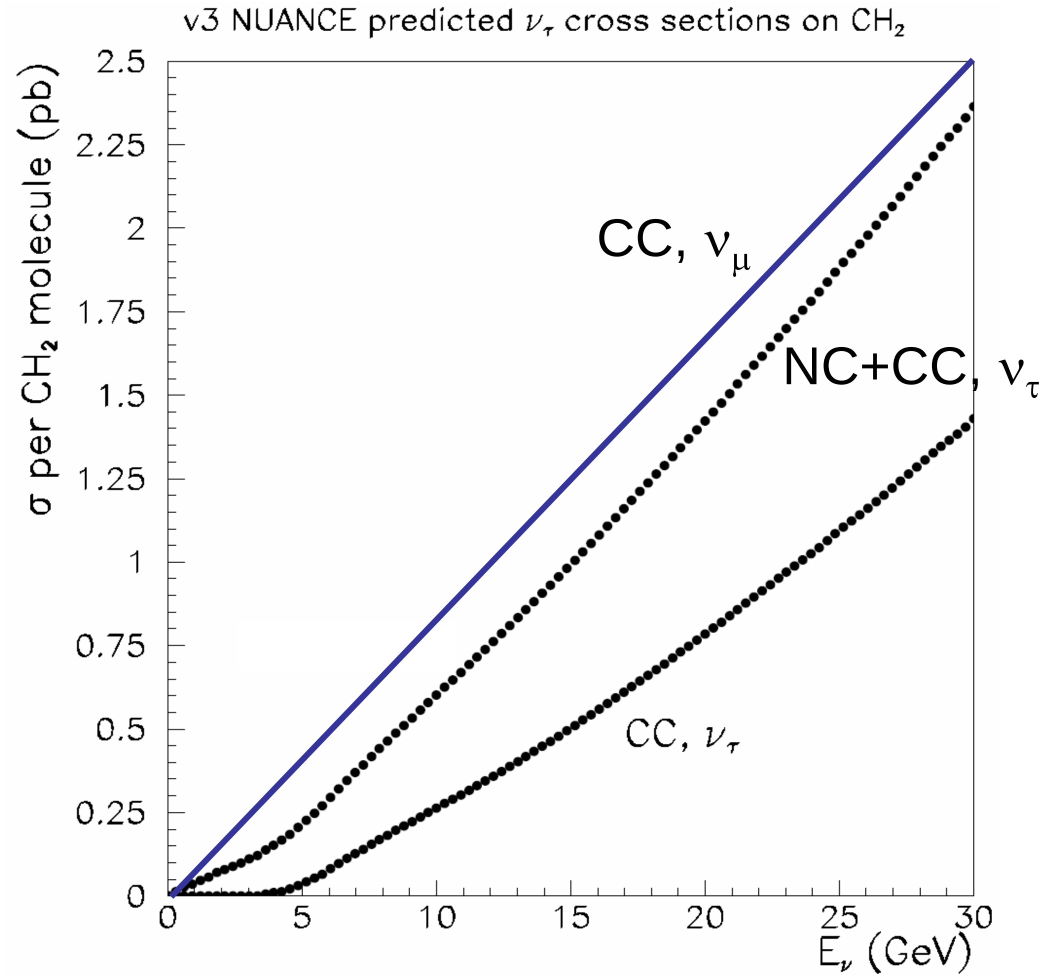


Requirements:

beam energy above
τ production threshold
(3.5 GeV)

detect $\nu_\tau \rightarrow \tau$

emulsion	OPERA	kiloton (!) detectors
LAr	ICARUS	

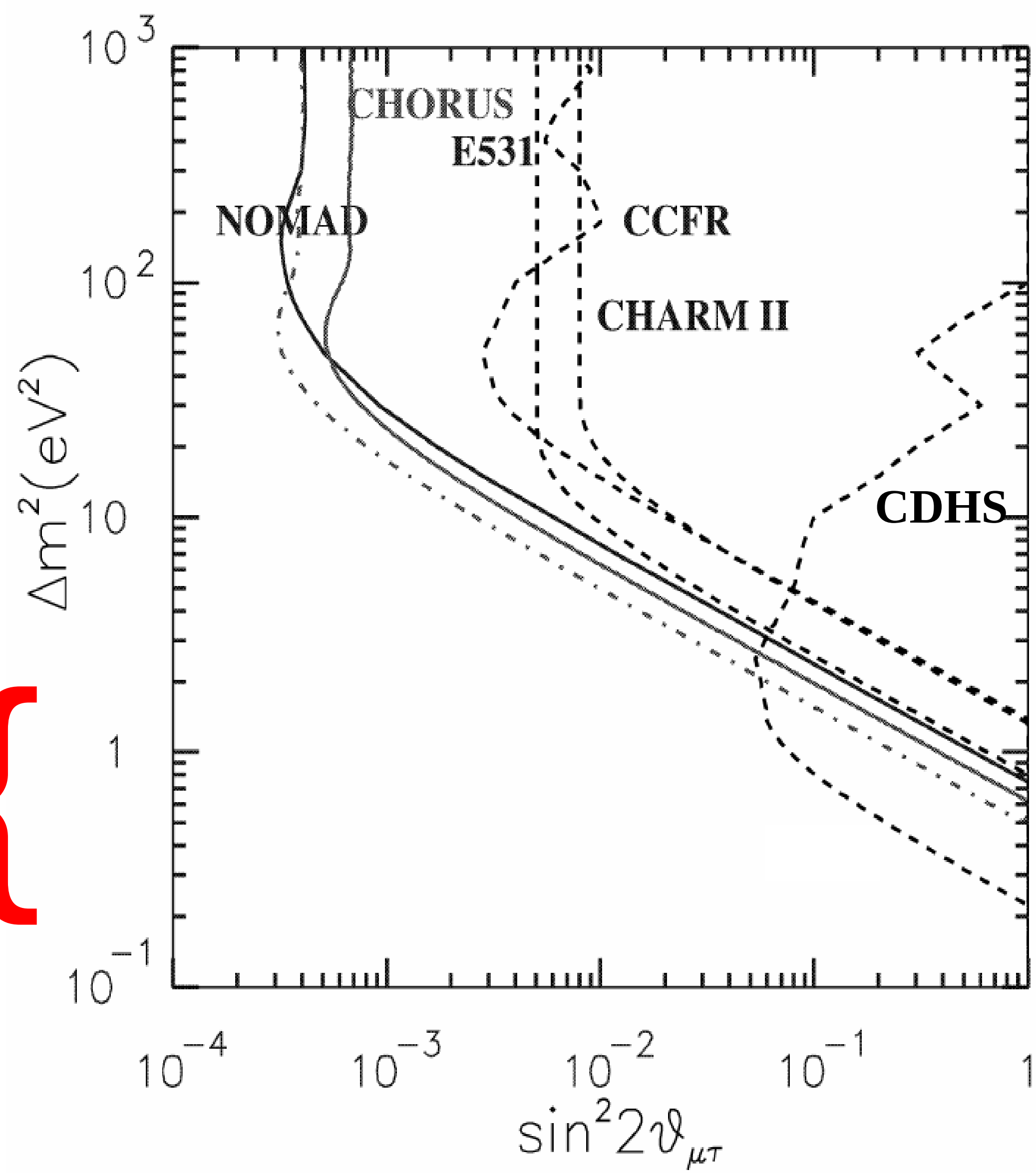


note ν_τ CC cross section penalty

Current $\nu_\mu \rightarrow \nu_\tau$ limits

direct limits

region of interest



Current $\nu_\mu \rightarrow \nu_\tau$ limits

Adding sterile neutrinos to the mix

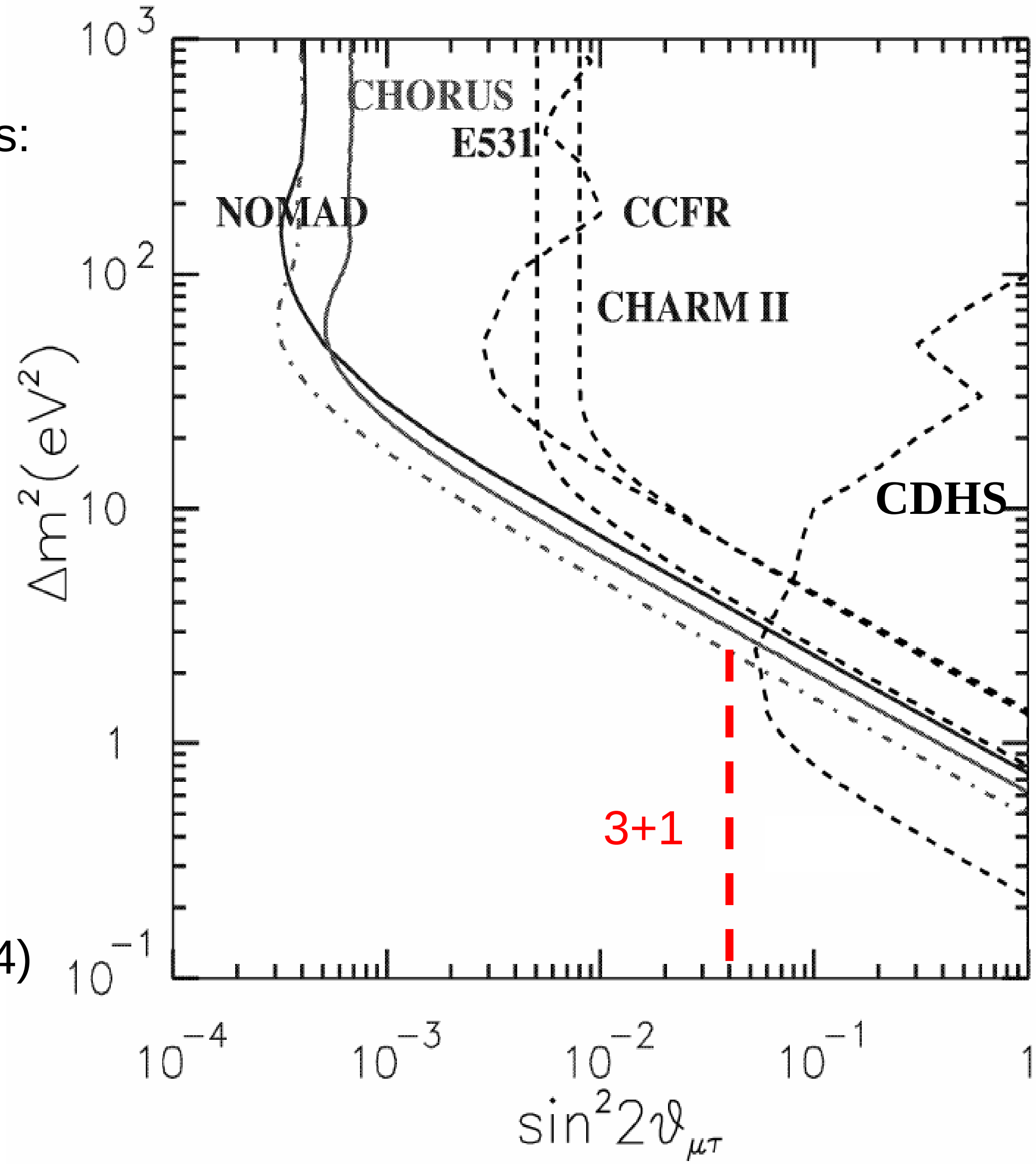
reconcile three distinct Δm^2's
by adding additional sterile ν's:

3+1
3+2
3+3 …

including direct limits from reactor and atmospheric data in (3+1) model:

Using results from Maltoni et al.
global analysis in (3+1)
hep-ph/0405172 v3 (Sept 04)

find $\sin 2\theta_{\mu\tau} < 0.04$

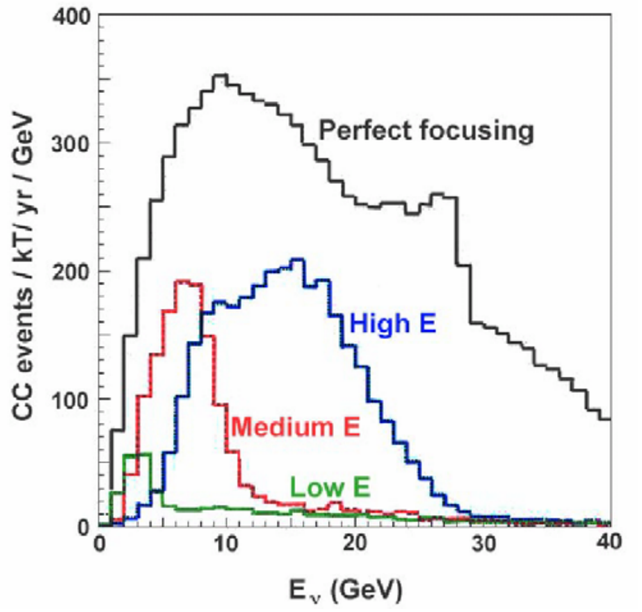


Consider searching for $\nu_\mu \rightarrow \nu_\tau$ in the NuMI beam

The NuMI beam points down at 3.3 degrees

Near detector hall at L=1040 m
360 ft below ground

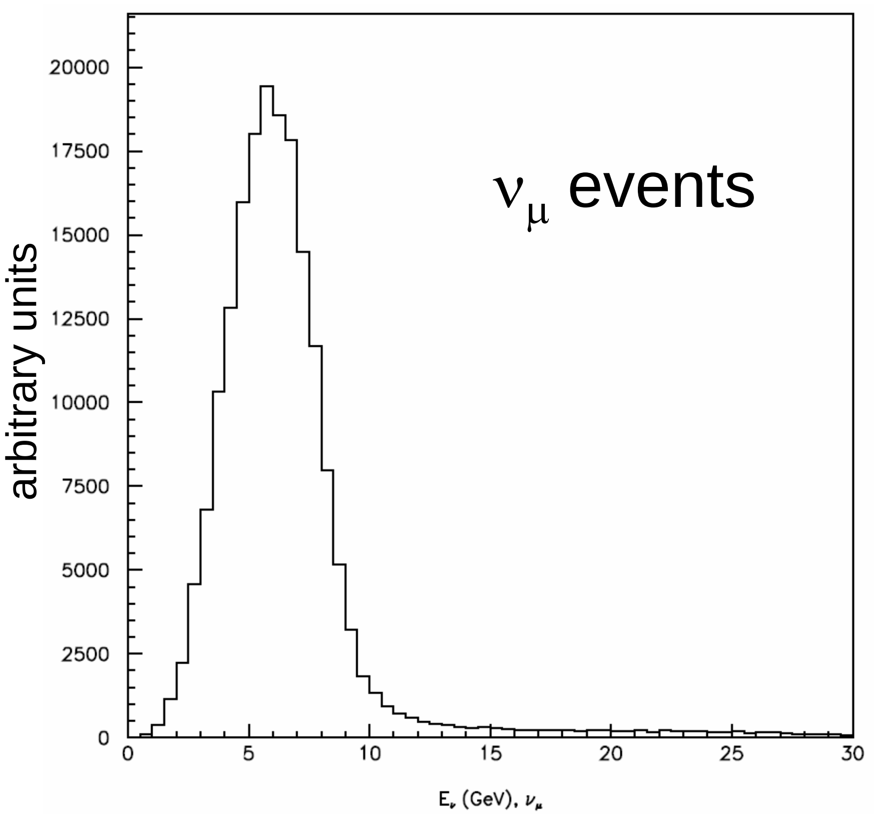
The longer the baseline, the deeper you have to dig.

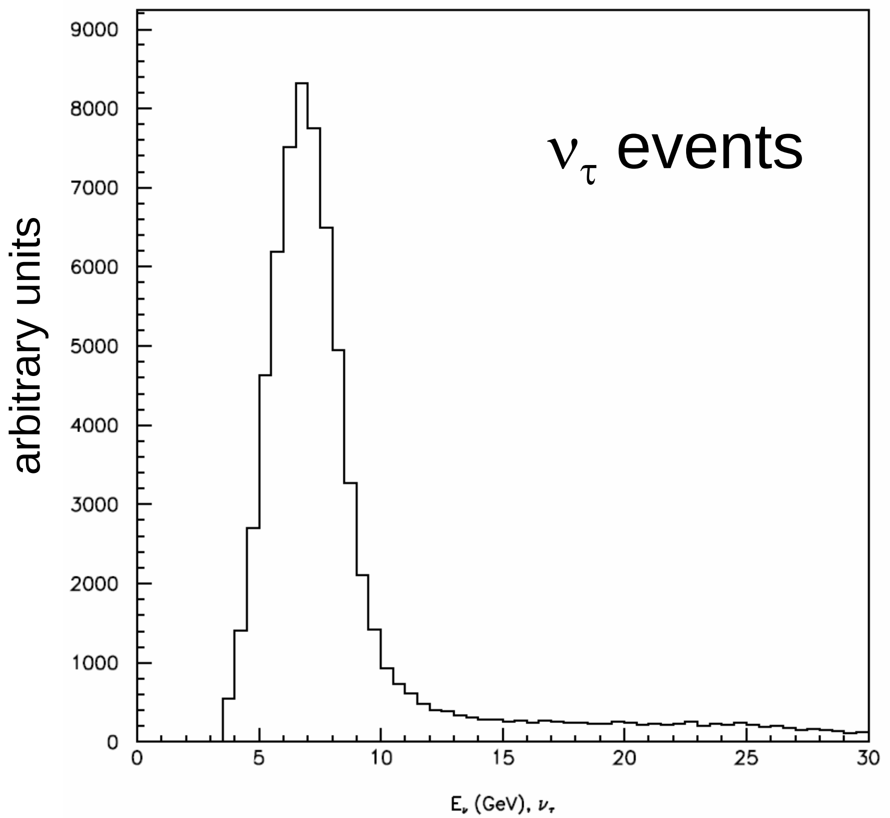


The medium energy beam peaks at about 7 GeV.

for $\Delta m^2 = 0.4\ \mathrm{eV}^2$ osc maximum at 22 km
for $\Delta m^2 = 1.0\ \mathrm{eV}^2$ osc maximum at 9 km

NuMI medium energy beam event spectra

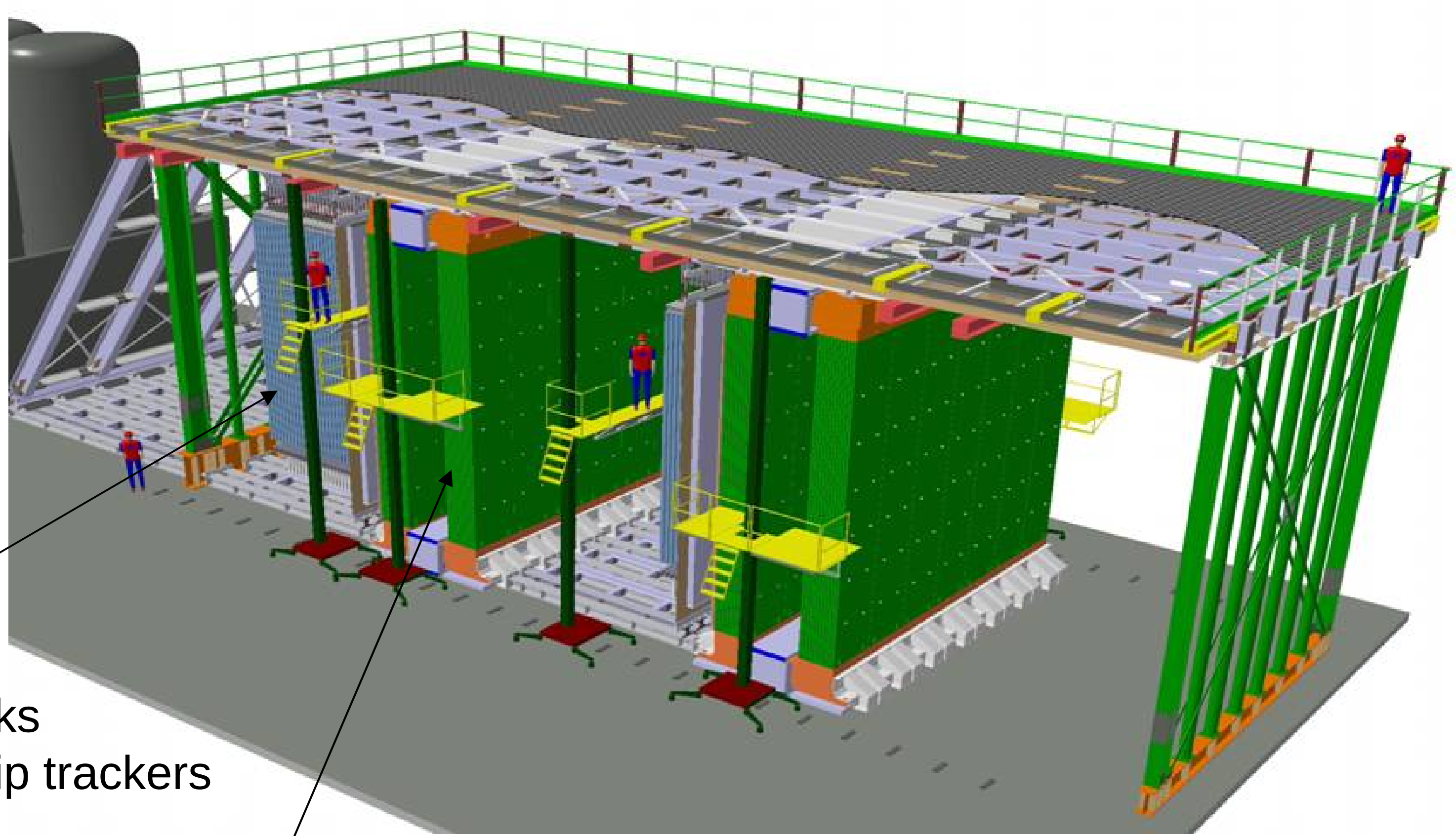




Tau detection with a large detector

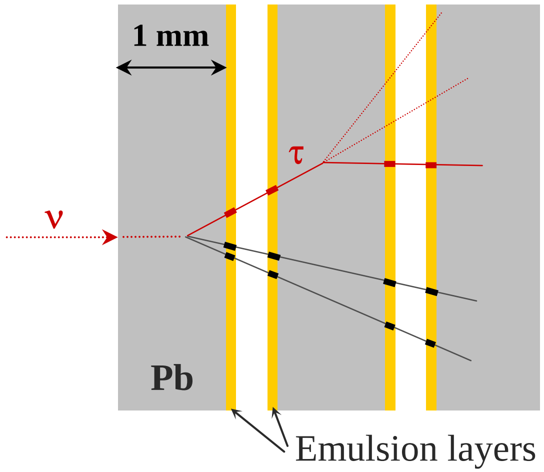
OPERA: kiloton emulsion detector

ν



Target:
Emulsion bricks
Scintillator strip trackers

Magnetic spectrometer:
RPCs and drift tubes



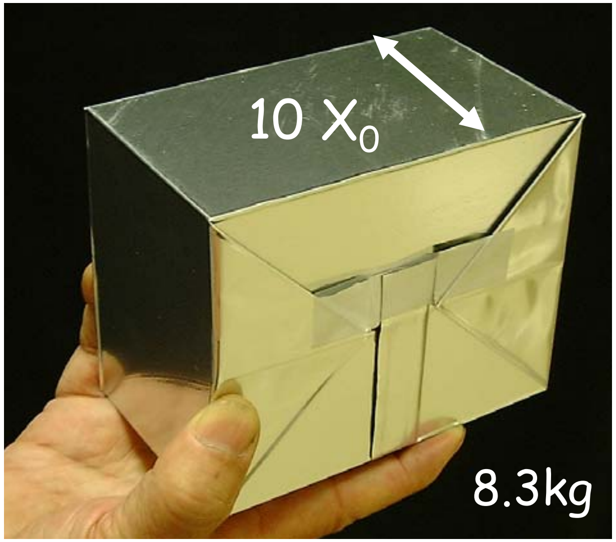
The basic unit is the emulsion-Pb brick

56 Pb sheets (1 mm) and
emulsion sheets (Fuji, industrial production)

ECC – emulsion cloud chamber

each brick is a stand-alone detector:

neutrino vertex and kink topology
dE/dx p/m separation at low energy
electron identification
hadron momentum via multiple scattering

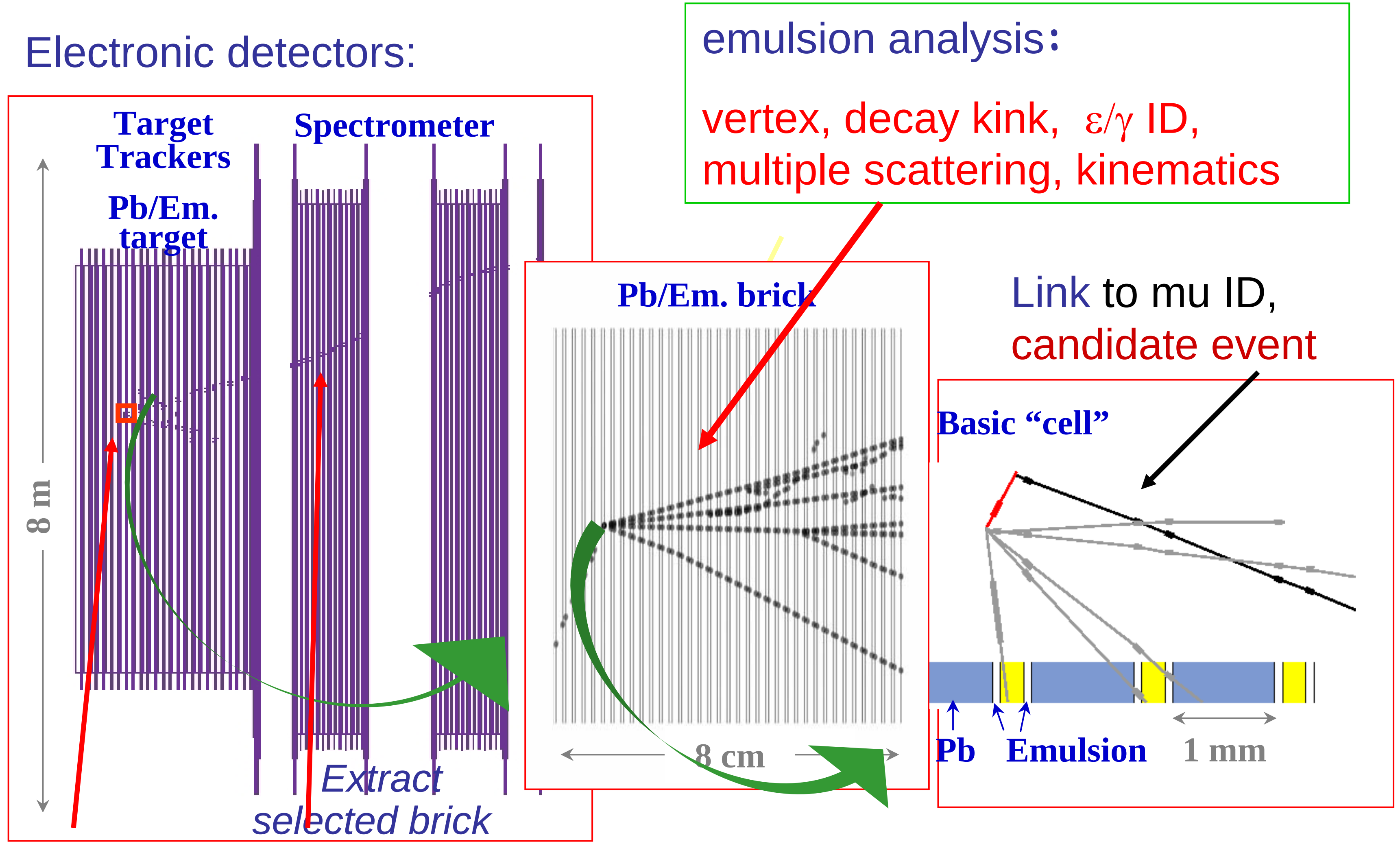


10.2 x 12.7 x 7.5 cm

In total: ~206k bricks
and 1.76 ktons

Electronic detectors:

- **trigger** and **localization** of neutrino interactions
- **muon** identification and momentum/charge measurement

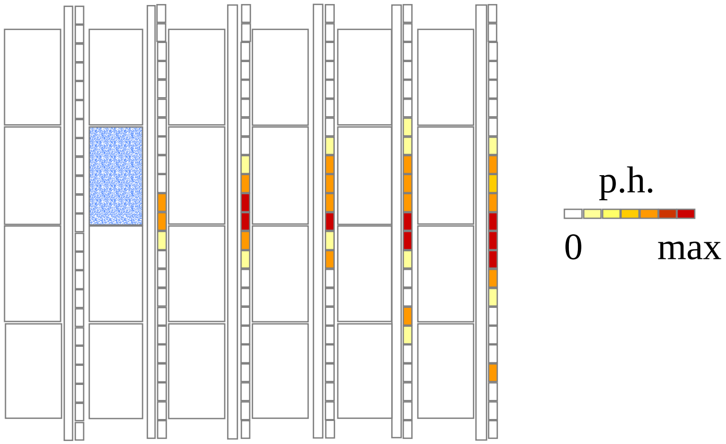


Brick finding, muon ID, charge and *p*

Remove the brick where the neutrino interacted

OPERA expects to remove ~30 bricks/day

Scanning proceeds throughout the run. All emulsion data digitized.



Tau detection efficiencies

$\tau \rightarrow e$

$\tau \rightarrow \mu$

$\tau \rightarrow h$

including branching ratios

9.1%

backgrounds

charm

large angle muon scattering

hadronic

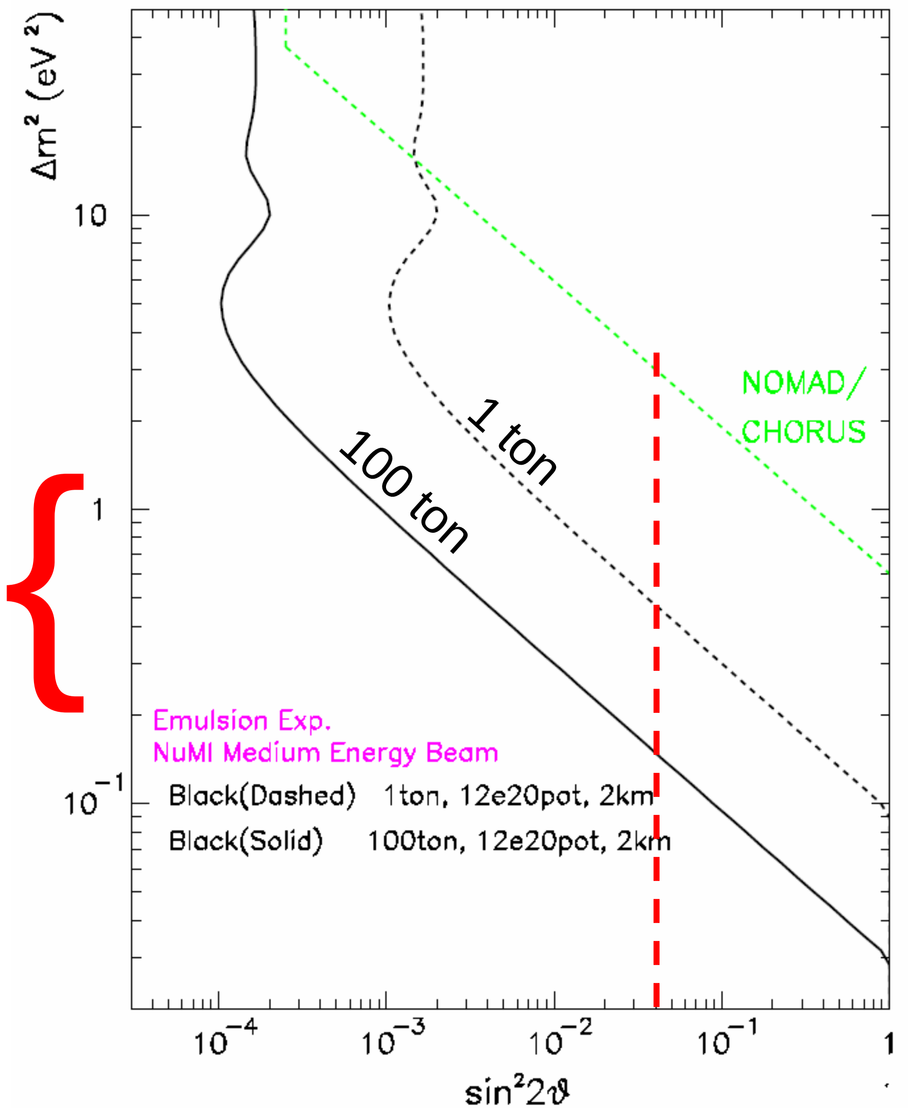
3×10^{-5} per ν_μ event

NuMI med energy
12e20 p.o.t.

L = 2 km

small $\Delta m^2 \rightarrow$
(detector mass)$^{1/4}$

high $\Delta m^2 \rightarrow$
(detector mass)$^{1/2}$



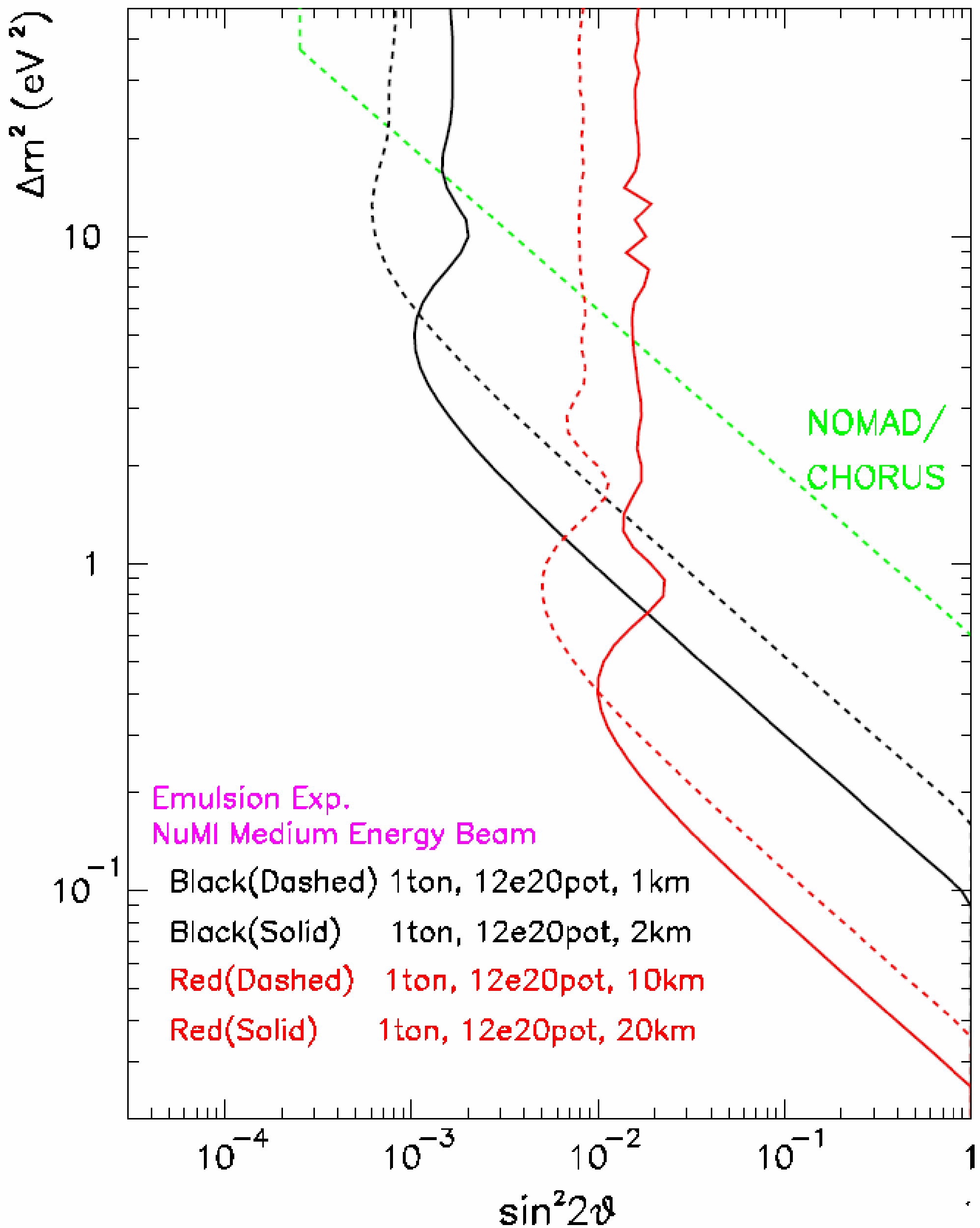
12e20 p.o.t. 1 ton @ 2km N_τ = 9857 N_μ=795k N_{bkgd}=23.8

L = 1, 2, 10, 20 km

1 ton detector

12e20 p.o.t.

small $\Delta m^2 \rightarrow L$

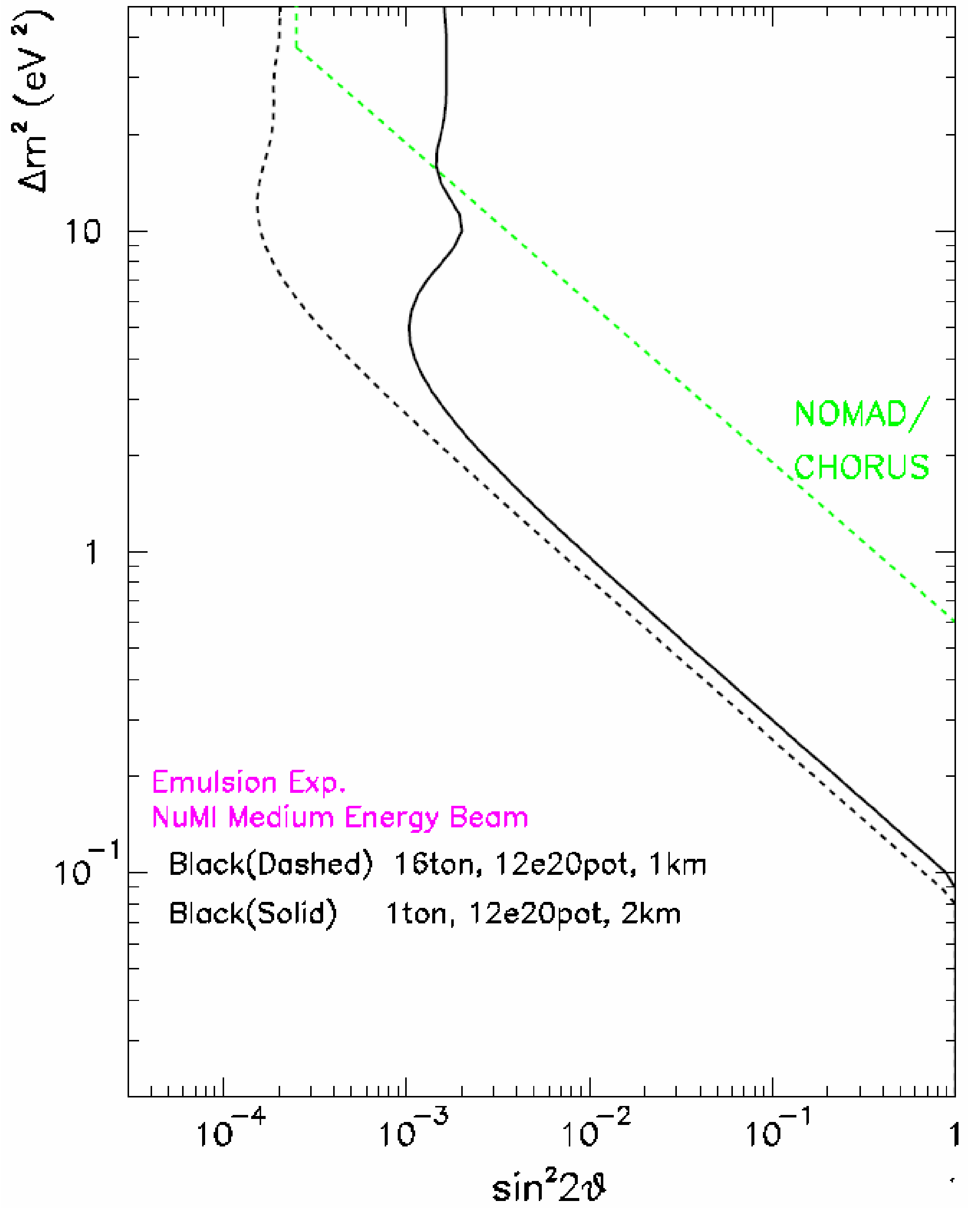


small angle
scaling rules
indicate that

1 ton at L = 2 km

is the same as

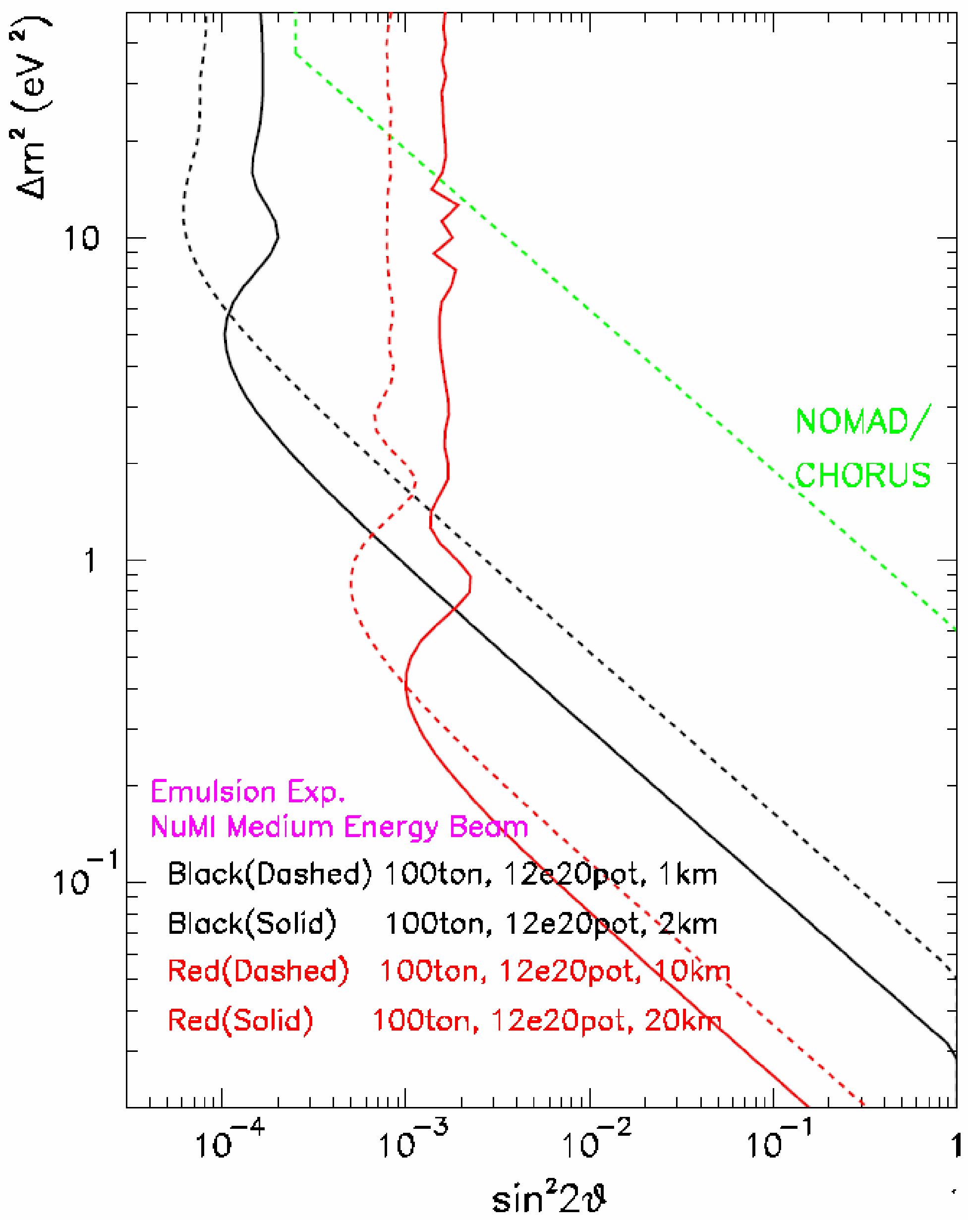
16 ton at L = 1 km



L = 1, 2, 10, 20 km

100 ton detector

12e20 p.o.t.

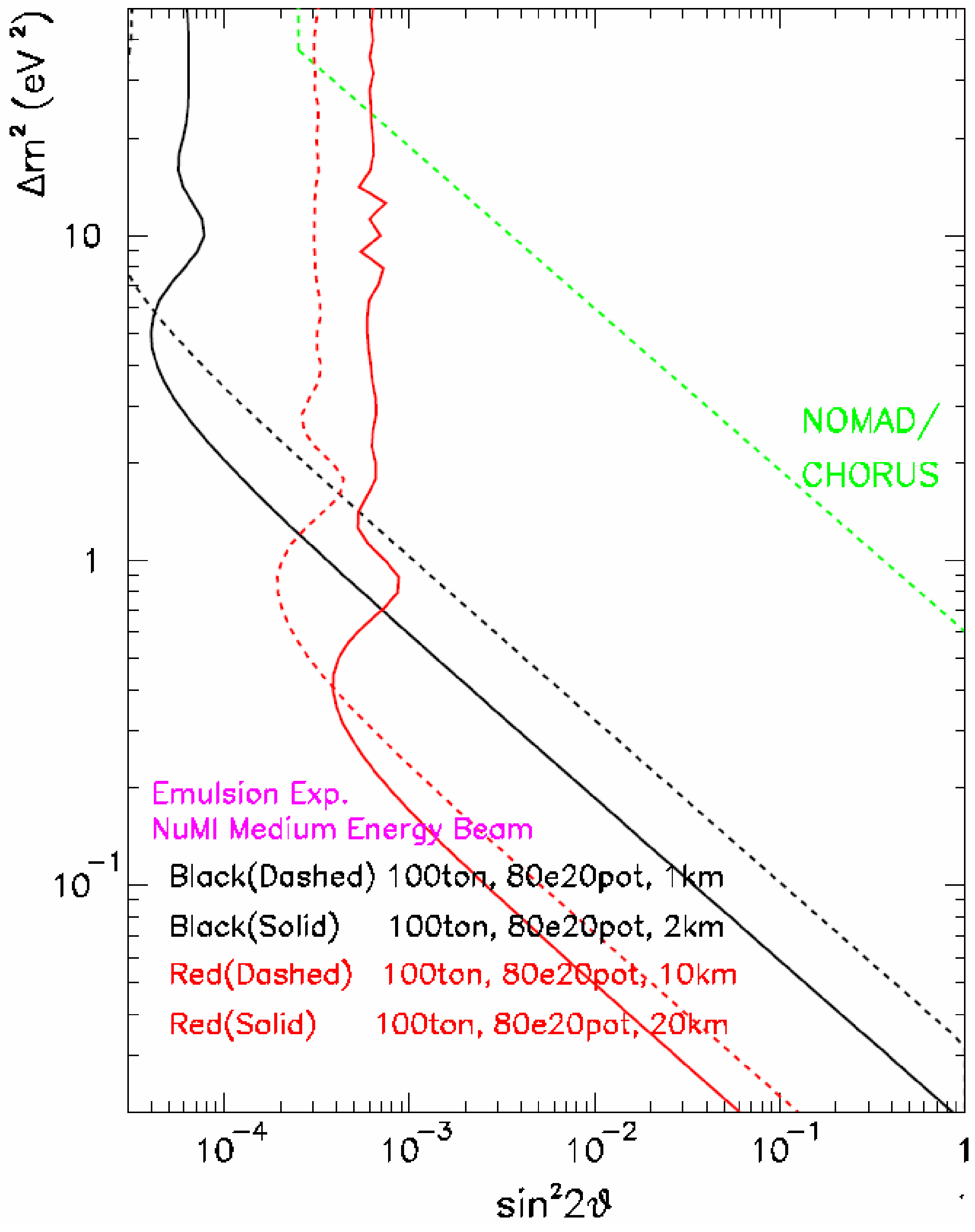


Proton Driver:

L = 1, 2, 10, 20 km

100 ton detector

80e20 p.o.t.

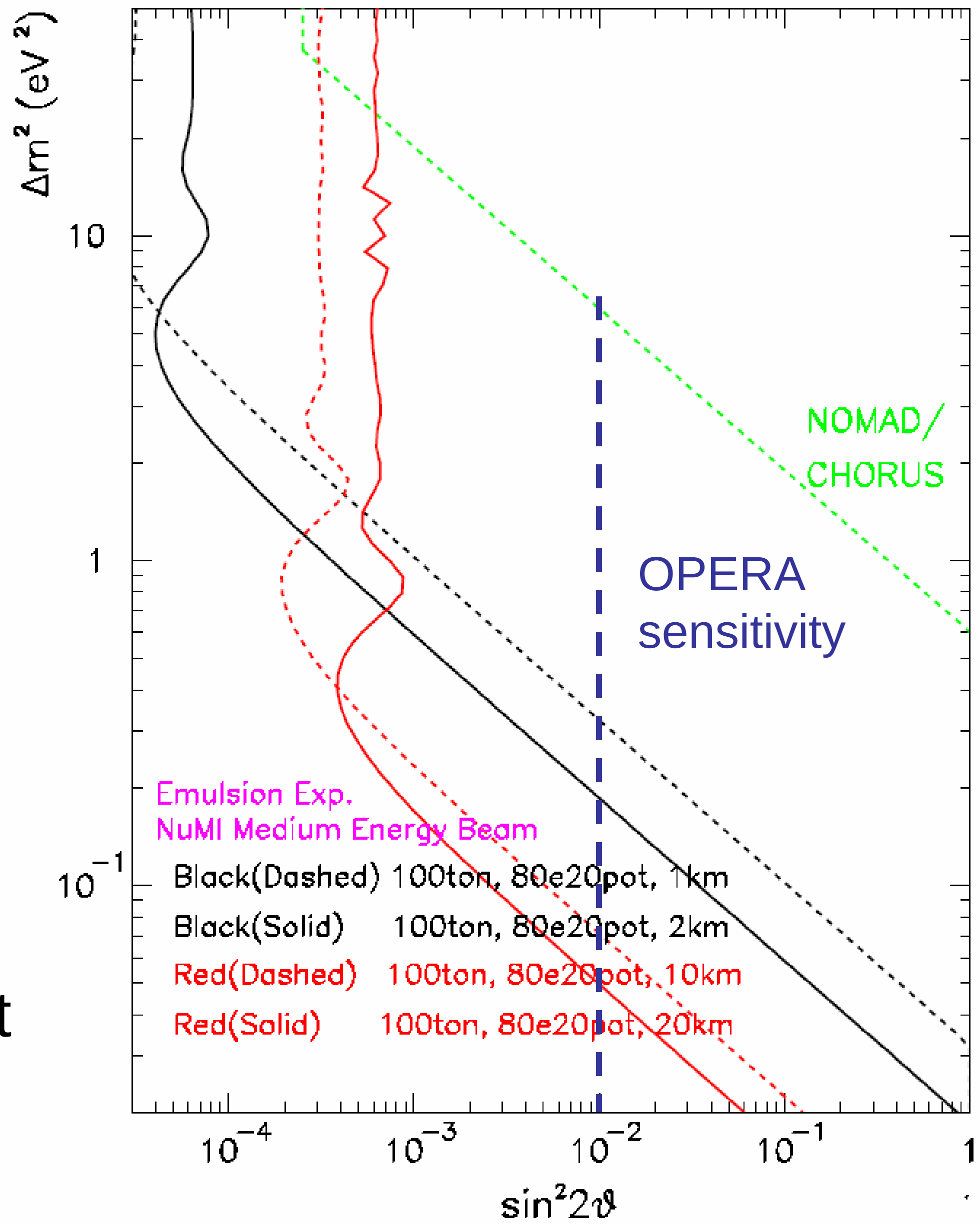


note:

OPERA will find
$\nu_\mu \rightarrow \nu_\tau$ oscillations
at $\Delta m^2_{atmospheric}$

Any additional high Δm^2
oscillations will be
a “background” at OPERA

A short baseline experiment
is needed to resolve
$\nu_\mu \rightarrow \nu_\tau$ at high Δm^2



Conclusions

We may find that neutrino mixing goes beyond 3 x 3

Anticipate the study of sub-leading effects

observing small mixings requires high statistics

small mixings involving steriles?

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \\ \nu_s \\ \nu_{s'} \\ \vdots \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} & U_{e5} & \cdots \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} & U_{\mu 5} & \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} & U_{\tau 5} & \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} & U_{s5} & \\ U_{s'1} & U_{s'2} & U_{s'3} & U_{s'4} & U_{s'5} & \\ & & \cdots & & & \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \\ \nu_4 \\ \nu_5 \\ \vdots \end{pmatrix}$$

Future experimental directions will be determined by what we discover.