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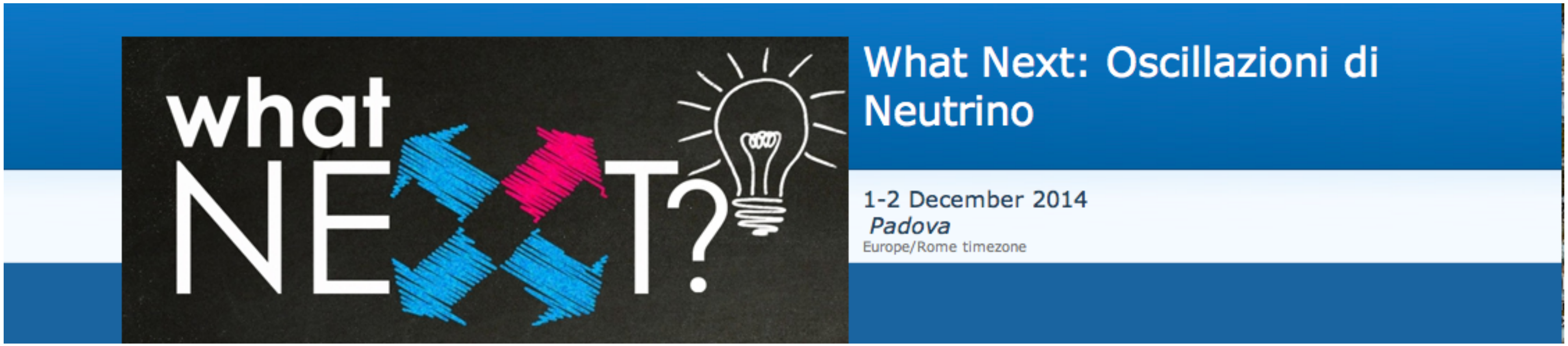
Il ruolo del (ν_μ) disappearance nello studio dei neutrini sterili

Perché è necessario un esperimento à –la-NESSiE

- Caveats and concerns
- The “sterile” issue at 1 eV mass scale
- The NESSiE Collaboration
- CERN and FNAL proposals
- Conclusions



CAVEATS and CONCERNS

- **Gli esperimenti dei neutrini sono intrinsecamente più difficili degli altri**
  (statistica, sistematiche, sezioni d'urto)
  Detto da uno che ha fatto fisica agli elettroni - positroni,
  elettroni - protoni, antiprotoni - protoni

- **E' un grande campo d'azione**
  (dove cercare BSM)

- **Dove si conosce meno il MS**

- Finora "grande" ha pagato, molto
  (il Liquid-Argon deve ancora dimostrarlo)

- **Comunità "statisticamente" debole**
  (neu-vel vale per tutte)

La statistica non e' una opinione…

Una scoperta si misura con 5 σ

Una esclusione si calcola con
- 2 σ (cioè al 95.45% C.L.) per rivelatori "controllati"
- 3 σ (cioè al 99.7% C.L.) per rivelatori "di nuova concezione" (leggi LAr)

Ma si continua a preferire il C.L. al 90%

E ci sono assurdità (pubblicate su per-review)

- nuStorm predice dei limiti a 10 σ (C.L. del 99.9999999999999999999)
- MINOS combina esclusioni in modo non-sense

@T.Dorigo

PHYSICAL REVIEW D **85,** 031101(R) (2012)

Search for Lorentz invariance and *CPT* violation with muon antineutrinos in the MINOS Near Detector

trino rates is undetected and consistent with zero. Since the measurement errors are also normally distributed and uncorrelated between the neutrino and antineutrino data sets we can combine the two limits as

$$1/(CL)^2 = 1/(CL)^2_{\nu} + 1/(CL)^2_{\bar{\nu}},$$

where (CL) is the combined 99.7% C.L. upper limit [17].

dove (!!!)

[17] K. Nakamura *et al.* (Particle Data Group), J. Phys. G **37**, 075021 (2010).

Notiamo la versione (arXiv:1201.2631) prima dei dubbi (fondatissimi) del referee, che però si è lasciato abbindolare

maining 27 SME coefficients, however, we can improve the limits by combining the results from [8] with those in Table III. Let $(CL)_\nu$ be the 99.7% C.L. upper limit on an SME coefficient determined in [8] and $(CL)_{\bar{\nu}}$ the 99.7% C.L. upper limit determined here. We combine the two limits as

$$1/(CL)^2 = 1/(CL)_\nu^2 + 1/(CL)_{\bar{\nu}}^2,$$

where (CL) is the combined 99.7% C.L. upper limit. The most sensitive upper limits we have determined with the MINOS neutrino and antineutrino data are given in Ta-

Discussione in:
http://www.science20.com/quantum_diaries_survivor/people_who_believe_upper_limits-86145

The "sterile" issue

From masses to flavours:

$$|\nu_e\rangle = U_{e1}|\nu_1\rangle + U_{e2}|\nu_2\rangle + U_{e3}|\nu_3\rangle$$
$$|\nu_\mu\rangle = U_{\mu 1}|\nu_1\rangle + U_{\mu 2}|\nu_2\rangle + U_{e\mu 3}|\nu_3\rangle$$
$$|\nu_\tau\rangle = U_{\tau 1}|\nu_1\rangle + U_{\tau 2}|\nu_2\rangle + U_{\tau 3}|\nu_3\rangle$$

U is the 3 × 3 Neutrino Mixing Matrix
mixing given by 3 angles, θ_{23}, θ_{12}, θ_{13}

transition amplitudes driven by
$\Delta m^2_{solar} = \Delta m^2_{21}$
$\Delta m^2_{atm} = |\Delta m^2_{31}| \approx |\Delta m^2_{32}|$

The **wonderful frame** pinpointed for the 3 standard neutrinos, **beautifully** adjusted by the θ_{13} measurement, left out some relevant questions:

- Leptonic CP violation
- Mass values
- Dark Matter
- Anomalies and discrepancies in several results

The "sterile" issue (cnt.)

The previous picture is working **wonderfully**.
So it should stay whenever extensions are allowed !

Exploit 3+1 or even 3+2 oscillating models, by adding one or more "**sterile**" neutrinos

$$\begin{bmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{bmatrix} \Rightarrow$$

$$P(\nu_\alpha \to \nu_\beta) = \sin^2 2\theta_{\alpha\beta} \sin^2\left(\frac{\Delta m_{41}^2 L}{4E}\right)$$

APPEARANCE

$$P(\nu_\alpha \to \nu_\alpha) = 1 - \sin^2 2\theta_{\alpha\alpha} \sin^2\left(\frac{\Delta m_{41}^2 L}{4E}\right)$$

DISAPPEARANCE

when $\Delta m_{21}^2 << \Delta m_{31}^2 << \Delta m_{41}^2$ and $|U_{s4}^2| \leq 1$

with

$$\sin^2 2\theta_{e\mu} = 4|U_{e4}|^2 |U_{\mu 4}|^2$$

for **APPEARANCE**

and

$$\sin^2 2\theta_{ee} = 4|U_{e4}|^2 \left(1 - |U_{e4}|^2\right)$$

$$\sin^2 2\theta_{\mu\mu} = 4|U_{\mu 4}|^2 \left(1 - |U_{\mu 4}|^2\right)$$

for **DISAPPEARANCE**

sterile: *not weakly interacting neutrinos* (B. Pontecorvo, JETP, 53, 1717, 1967)

The "sterile" issue (cnt.)

➔ Experimental hints for more than 3 standard neutrinos, at eV scale
➔ Strong tension with any formal extension of 3x3 mixing matrix

ν_e disappearance

Reactor anomaly ~2.5σ
Re-analisys of data on anti-neutrino flux from reactor short-baseline (L~10-100 m) shows a small deficit of
R=0.943 ±0.023
G.Mention et al, Phys.Rev.D83, 073006 (2011) , A.Mueller et al. Phys.Rev.C **83,** 054615 (2011).

Gallex/SAGE anomaly ~3σ
Deficit observed by Gallex in neutrinos coming from a ^{51}Cr and ^{37}Ar sources
***R* = 0.76+0.09 −0.08**
C. Giunti and M. Laveder, Phys.Rev. C83, 065504 (2011), arXiv:1006.3244

ν_e appearance

Accelerator anomaly ~3.8σ
Appearance of anti-ν_e in a anti-ν_μ beam (LSND). *A.Aguilar et al. LSND Collaboration Phys.Rev.D 64 112007 (2001).*

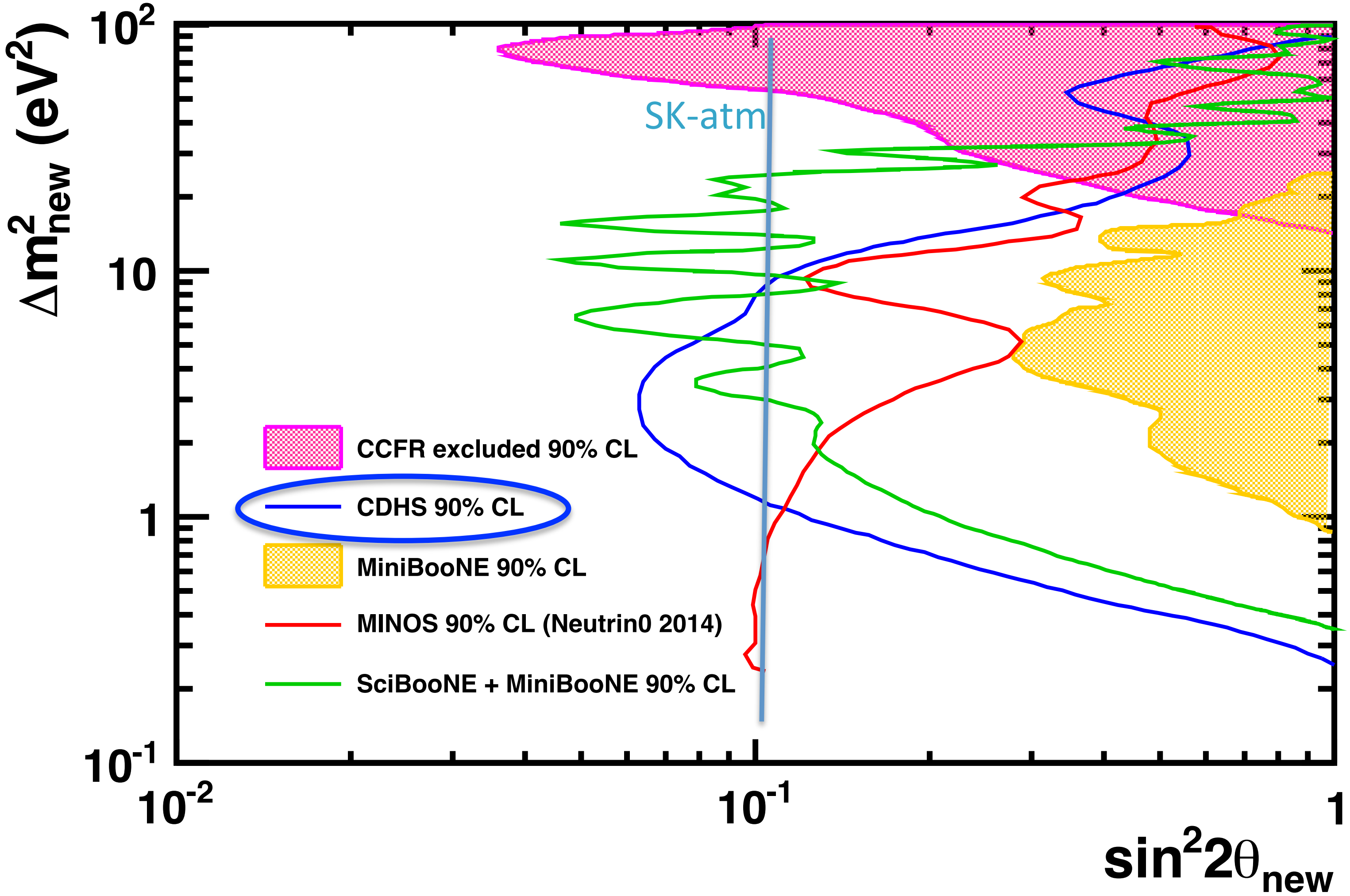
Confirmed (?) by miniBooNE (which also sees appearance of ν_e in a ν_μ beam) *A.Aguilar et al. (MiniBooNE Collaboration) Phys.Rev.Lett. 110 161801 (2013)*

?? Where is ν_μ disappearance ??

CMB/cosmology: N_ν>3 at 1 σ

Ecco I limiti attuali sul ν_μ disappearance

Tutte le esclusioni sono al 90% C.L.

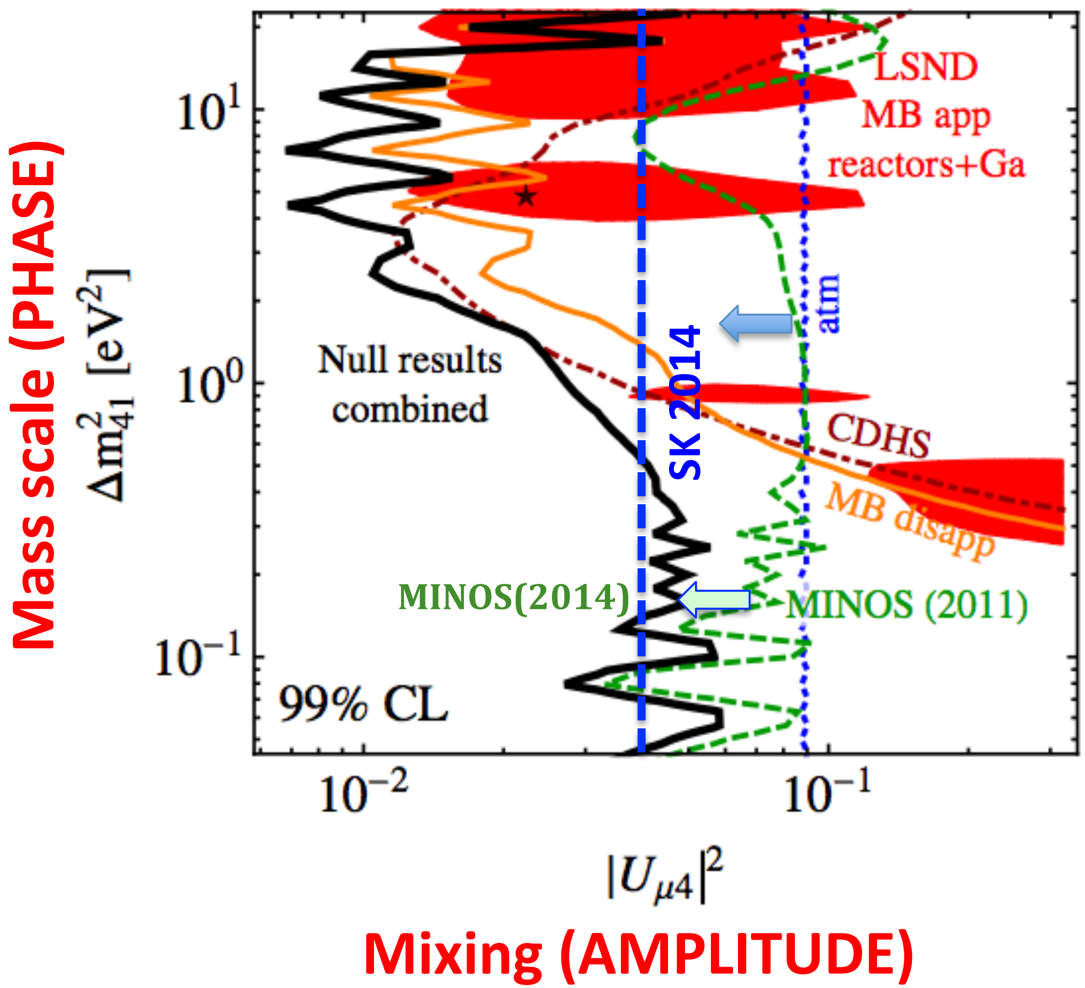


Best limit from CDHS (1984) : 3300 eventi, 135 m e 885 m, 1.5 m di ferro ma con 19.2 GeV p…

Possible explanation: mixing of the active flavours with a sterile neutrino Δm2 ~ 1 eV^2

But there are STRONG tensions between
ν_e (appearance and disappearance) and ν_μ disappearance

(by J. Kopp at Neutrino2014 and references therein)



What is the community undergoing ?

Many proposals and experiments to confirm the anomalies.

Why not directly going to measure the ν_μ disappearance ?

NESSIE

The NESSiE Collaboration

Neutrino Experiment with SpectrometerS in Europe

or

Neutrino Experiment with SpectrometerS in FERMILAB

Make a conclusive experiment to clarify the ν_μ disappearance behavior at 1 eV scale, by using spectrometers to allow muon charge and momentum measurement

Spectrometers at a neutrino beam. Extended studies:

- SPSC-P-343, arXiv:1111.2242
- SPSC-P347, arXiv:1203.3432
- ESPP, arXiv:1208.0862
- LOI CENF: https://edms.cern.ch/nav/P:CERN-0000096725:V0/P:CERN-0000096728:V0/TAB3
- L. Stanco et al., *AHEP 2013 (2013)* ID 948626, arXiv:1306.3455v2
- FNAL-P-1057, arXiv:1404.2521
- Nucl.Phys.B supplement: arXiv:1410.3980
- A.Anokhina et al, paper submitted to Phys.Rev. D

The NESSiE Collaboration

INFN and Physics Departments (Italy),
Lebedev Institue (Russia).
MSU (Russia),
Boskovic Institute (Croatia),
CERN.

All these groups have long experience in Neutrino Physics and Hardware (Chorus, Macro, Nomad, Opera, T2K …)

A. Anokhina[11], A. Bagulya[10], M. Benettoni[12], P. Bernardini[8,7], R. Brugnera[13,12], M. Calabrese[7], A. Cecchetti[6], S. Cecchini[3], M. Chernyavskiy[10], P. Creti[7], F. Dal Corso[12], O. Dalkarov[10], A. Del Prete[9], G. De Robertis[1], M. De Serio[2,1], L. Degli Esposti[3], D. Di Ferdinando[3], S. Dusini[12], T. Dzhatdoev[11], C. Fanin[12], R. A. Fini[1], G. Fiore[7], A. Garfagnini[13,12], S. Golovanov[10], M. Guerzoni[3], B. Klicek[15], U. Kose[5], K. Jakovcic[15], G. Laurenti[3], I. Lippi[12], F. Loddo[1], A. Longhin[6], M. Malenica[15], G. Mancarella[8,7], G. Mandrioli[3], A. Margiotta[4,3], G. Marsella[8,7], N. Mauri[6], E. Medinaceli[13,12], A. Mengucci[6], R. Mingazheva[10], O. Morgunova[11], M. T. Muciaccia[2,1], M. Nessi[5], D. Orecchini[6], A. Paoloni[6], G. Papadia[9], L. Paparella[2,1], L. Pasqualini[4,3], A. Pastore[1], L. Patrizii[3], N. Polukhina[10], M. Pozzato[4,3], M. Roda[13,12], T. Roganova[11], G. Rosa[14], Z. Sahnoun[3‡], S. Simone[2,1], C. Sirignano[13,12], G. Sirri[3], M. Spurio[4,3], L. Stanco[12,a], N. Starkov[10], M. Stipcevic[15], A. Surdo[7], M. Tenti[4,3], V. Togo[3], M. Ventura[6] and M. Vladymyrov[10].
(a) Spokesperson

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‡ Also at Centre de Recherche en Astronomie Astrophysique et Geophysique, Alger, Algeria

Prospects for the measurement of ν_μ disappearance at the FNAL-Booster

The NESSiE Collaboration

Submitted to FNAL-PAC:
FNAL-P-1057 and arXiv:1404.2521

6 mesi di lavoro seguendo le indicazioni dell'ESPG e del P5…

Key-points of the proposal:

1. The muon-neutrino disappearance is **mandatory**
   - either in case of null result on electron-neutrino
     (the sterile possibility might still be there due to interference modes and data mis-interpretation)
   - or in case of positive result **at SBL**
     (to address the correct interpretation of sterile, see current tension between appearance/disappearance)

2. **Standalone** measurement of muon-neutrinos
   (fully compatible with upstream LAr, or, in case, a small active scintillator target may be foreseen at Near-site for NC/CC and absolute rate control)

3. Interplay between **systematic** and statistical errors:
   optimized configuration for Near and Far site

4. **IDENTICAL** near and far detector
   (the same iron slab will be cut in two pieces to be put corresponding in the Near and the Far)

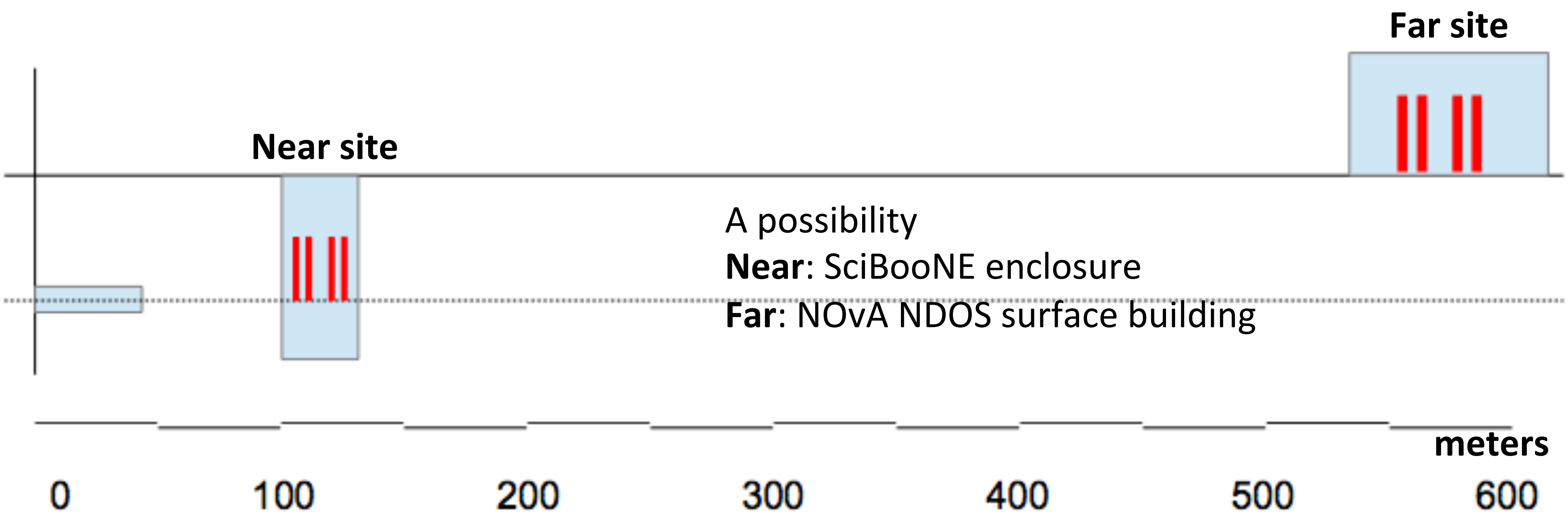
5. No R&D/refurbishing/upgrade: **robustness** of the program
   (80% of re-used well proven detectors, straightforward extension; 100 kWatt needed for each site)

Careful study of the FNAL-Booster neutrino beam, based on previous knowledge from MiniBooNE, SciBooNE and data obtained by HARP and E910.

- full simulation of the beam with GEANT4 and FLUKA
  (from proton to neutrinos)

- detailed systematic error source analysis
  (use of Sanford-Wang parametrization)

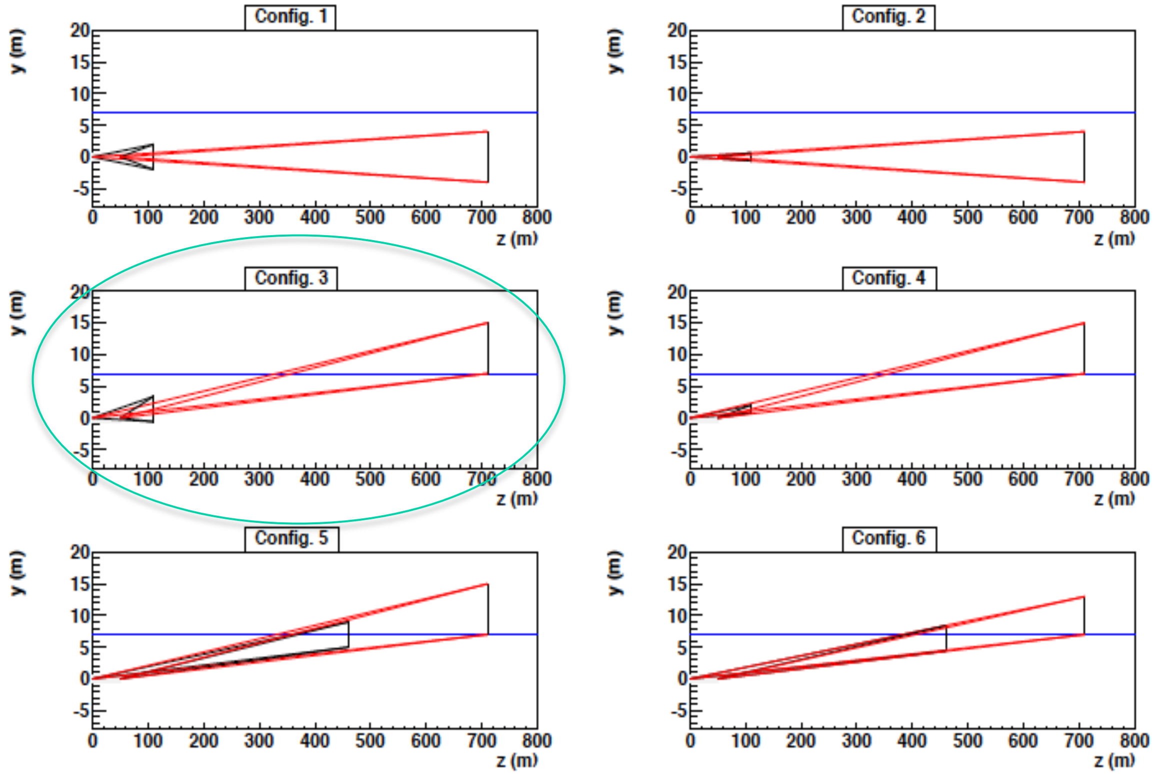
- Several configurations analyzed, on/off-axis including MicroBooNE site and different detector sizes



Near-site Far Near-off Far Near-size Far

configuration	L_N (m)	L_F (m)	y_N (m)	y_F (m)	s_N (m)	s_F (m)
1	110	710	0	0	4	8
2	110	710	0	0	1.25	8
3	110	710	1.4	11	4	8
4	110	710	1.4	11	1.25	8
5	460	710	7	11	4	8
6	460	710	6.5	10	4	6

Table 2: *Near-Far detectors configurations. $L_{N(F)}$ is the distance of the Near (Far) detector from the target. $y_{N(F)}$ is the vertical coordinate of the center of the Near (Far) detector with respect to the beam axis which lies at about -7 m from the ground surface. $s_{N(F)}$ is the dimension of the Near (Far) detector.*



Near almost on axis
Far on surface,
Full "NESSiE" configuration

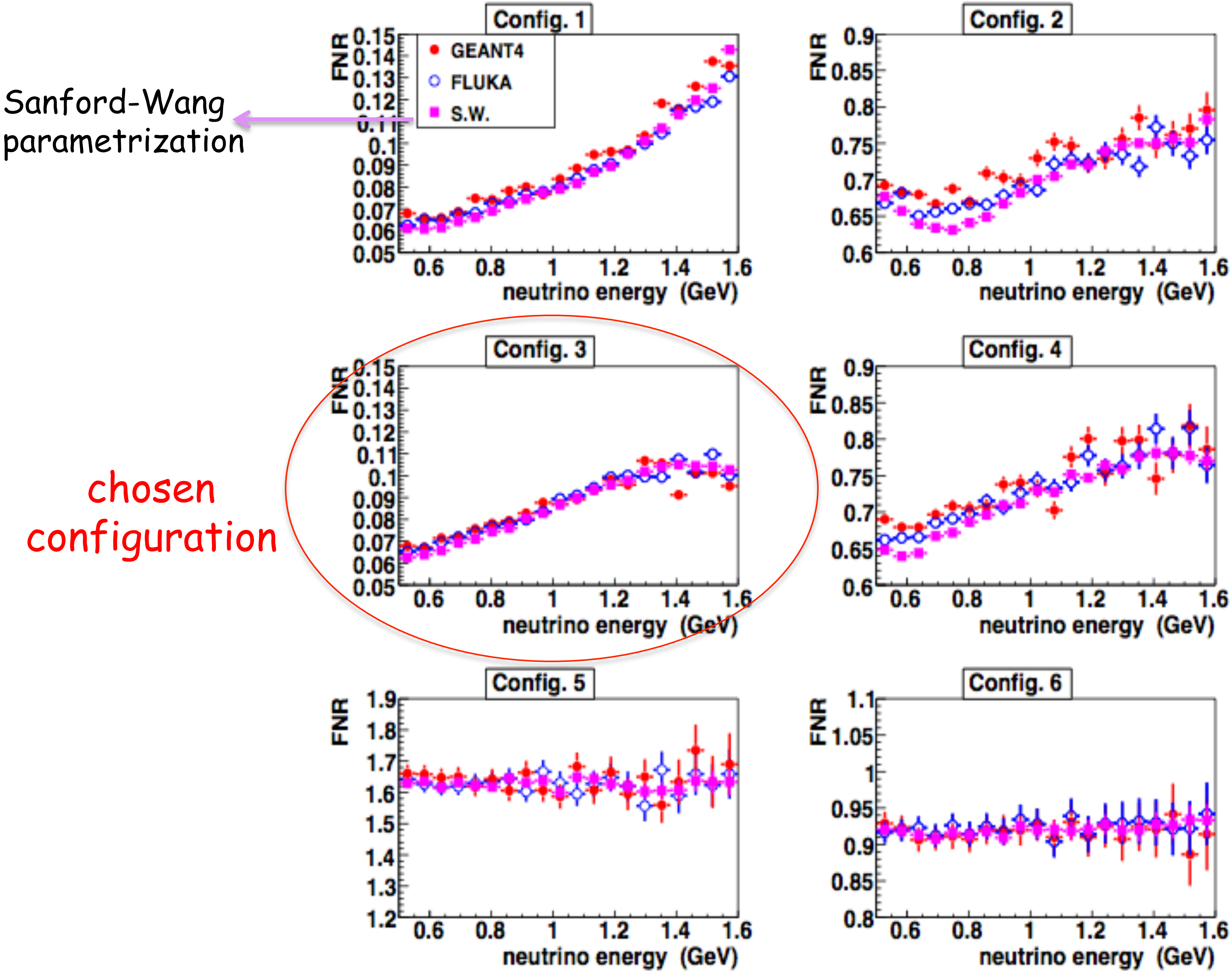
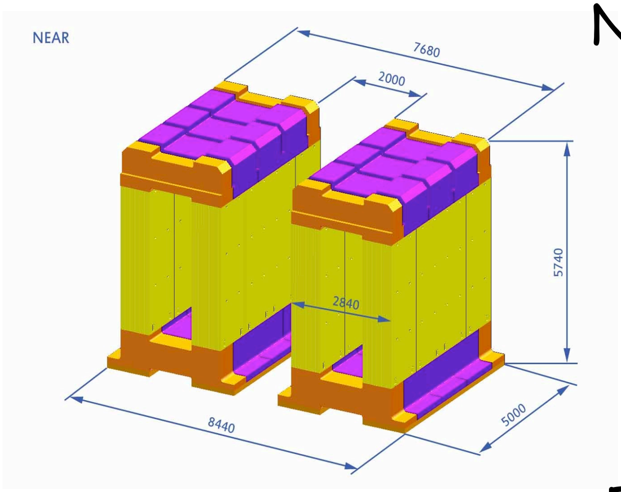
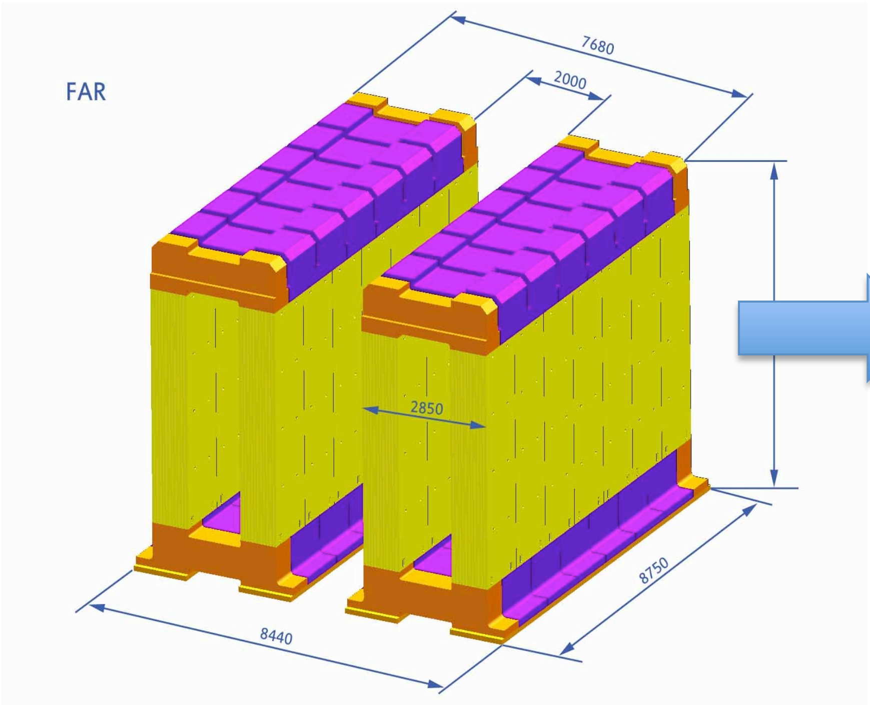


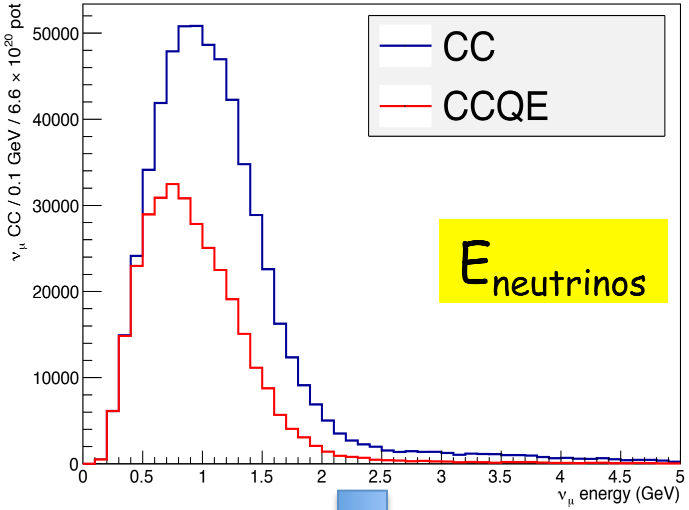
Figure 10: *Far-to-Near ratios for the six considered configurations. Comparison of FLUKA and GEANT4 for hadroproduction.*

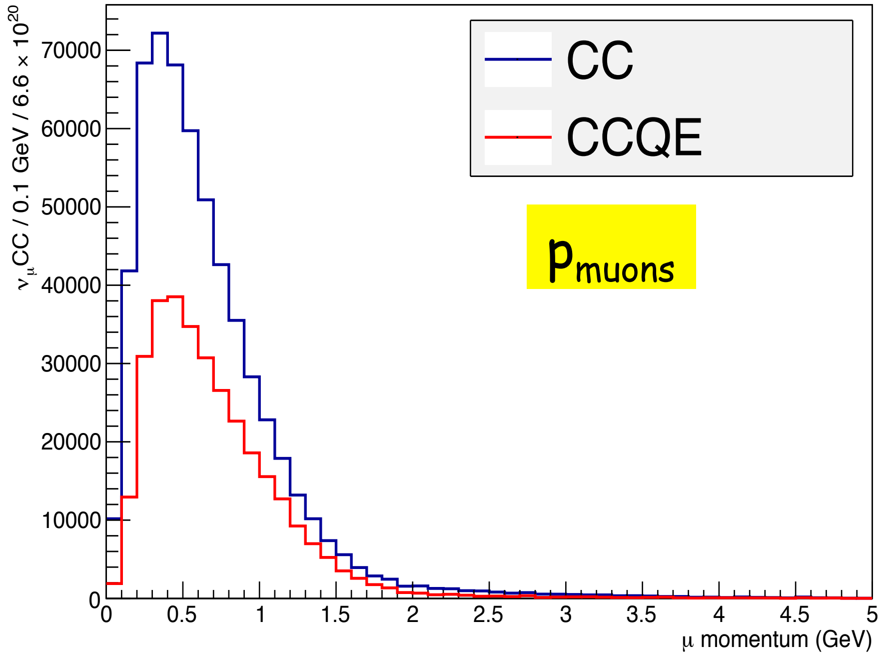
Near site



Far site







ABSOLUTE nb. interactions in the FAR fiducial volume, 3 years data taking

DATA COLLECTION

absolute number of ν_μ CC interactions, seen by the Near detector at 110 m, either in the E_ν or the p_μ variables, normalized to the expected luminosity in 3 years of data taking at FNAL–Booster, or 6.6 × 1020 p.o.t.
(full simulation including RPC digitalization)

	Number of events in 3 year (6.6 x 10^{20} pot)	
Trigger	NEAR	FAR
num. planes ≥ 2	5.1 x 10^6	2.8 x 10^5
num. planes ≥ 3	4.1 x 10^6	2.3 x 10^5
num. planes ≥ 5	2.7 x 10^6	1.5 x 10^5

Schedule and Costs

A bit aggressive, but reliable schedule based on successful OPERA experience

Year(portion)	Action
1^{rst} half 2015	Define tenders/contracts
2^{nd} half 2015	Site preparation Setting up Detectors Test-stands
1^{rst} half 2016	Mechanical Structure construction Start Magnet installation Start detectors installation
2^{nd} half 2016	End installation
1^{rst} half 2017	Commissioning and Starting Run
2^{nd} half 2019	End Data Taking

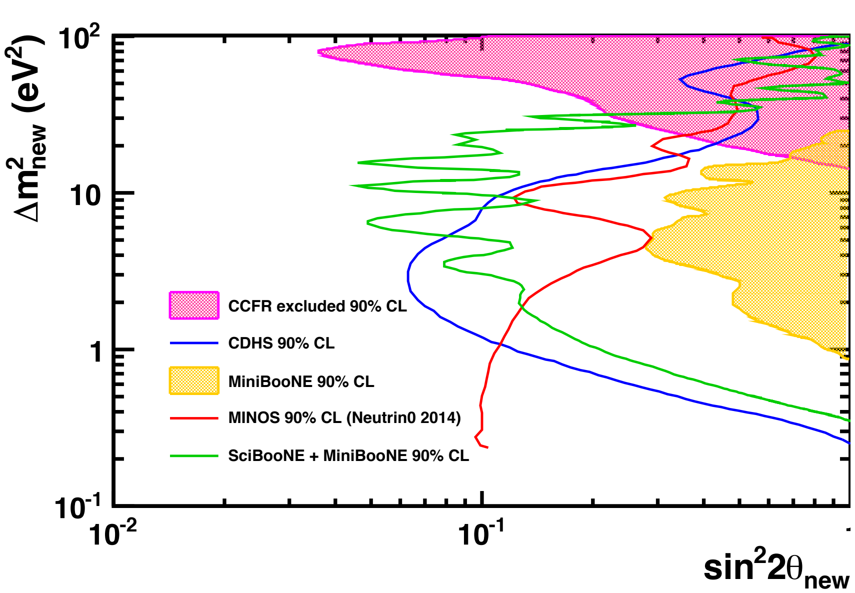
Both Near and Far

Item	Cost (in M €)
Far	
Magnet	2.5 (in–kind)
RPC detectors	0.8 (in–kind)
Strips	0.3 (in–kind)
New Electronics	0.2
Data Acquisition	0.1
Near	
Magnet	2.0 (in-kind)
Top/bottom yokes	1.0
Coils, Power Supplies	0.2
RPC detectors	0.6 (in–kind)
New detectors	0.2
Strips	0.2 (in–kind)
New Electronics	0.1
Data Acquisition	0.1
Transportation	0.6
Total	2.5 + 6.4 (in–kind)

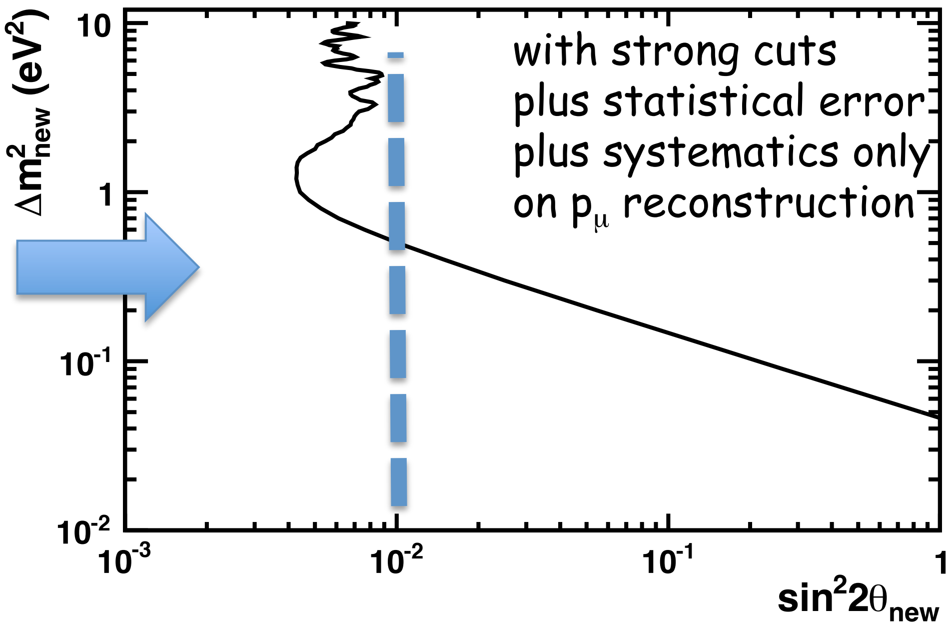
(new Electronics, new DAQ, 2 x coil number)

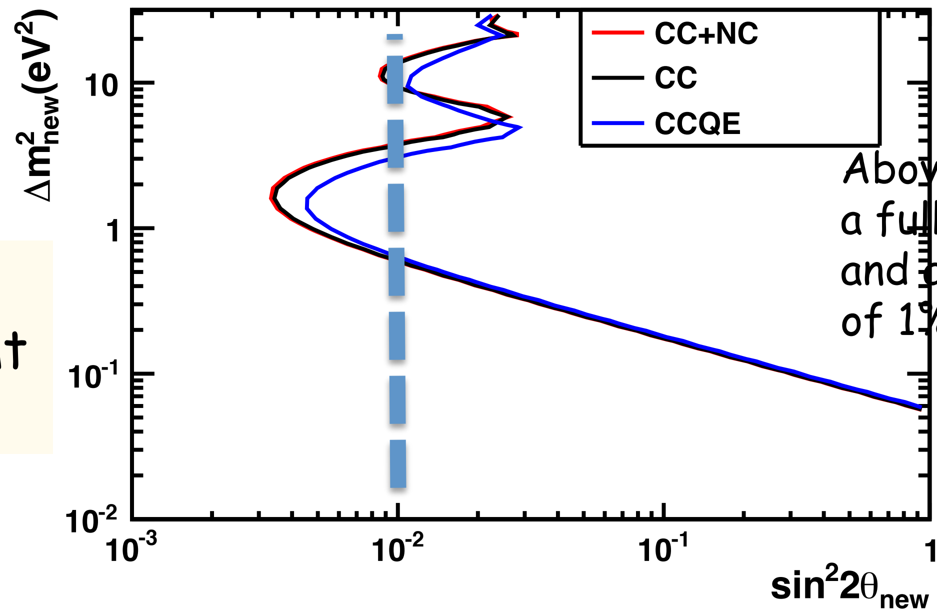
Sensitivity

from here (now)



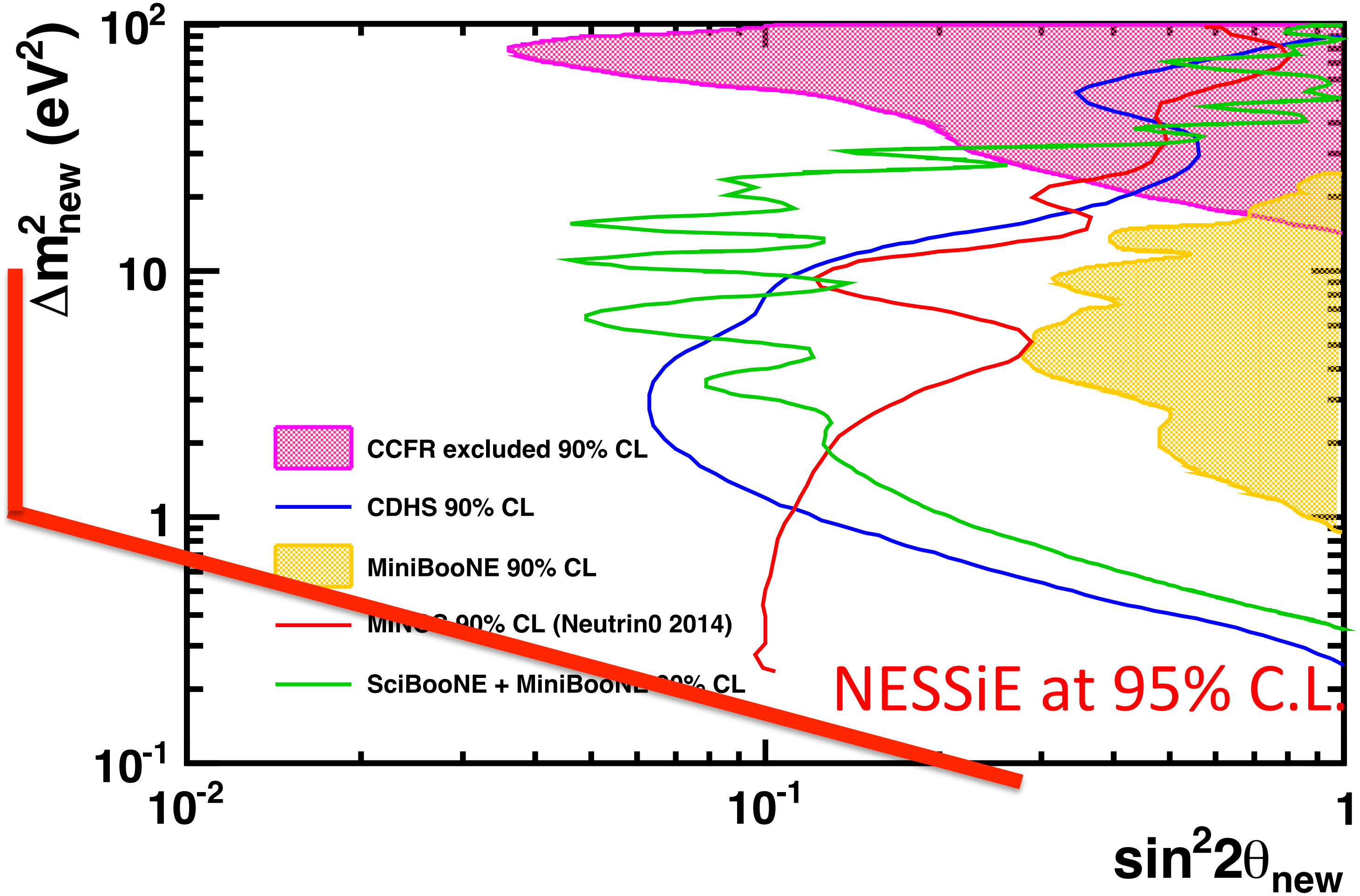
to here (NESSiE)





Above conditions plus
a full simulation
and a careful treatment
of 1% systematics error

Three independent analysis, with different statistical approaches



Δm^2_{new} (eV^2)
10^2
10
1
10^{-1}
10^{-2}
10^{-1}
1
$\sin^2 2\theta_{new}$
CCFR excluded 90% CL
CDHS 90% CL
MiniBooNE 90% CL
90% CL (Neutrin0 2014)
SciBooNE + MiniBoo
NESSiE at 95% C.L.

Conclusioni

1) Necessario fare (infine) un esperimento di SBL sul ν_μ disappearance

2) Che estenda di un ordine di grandezza il precedente risultato di CDHS

3) Utilizzando la “forza bruta”

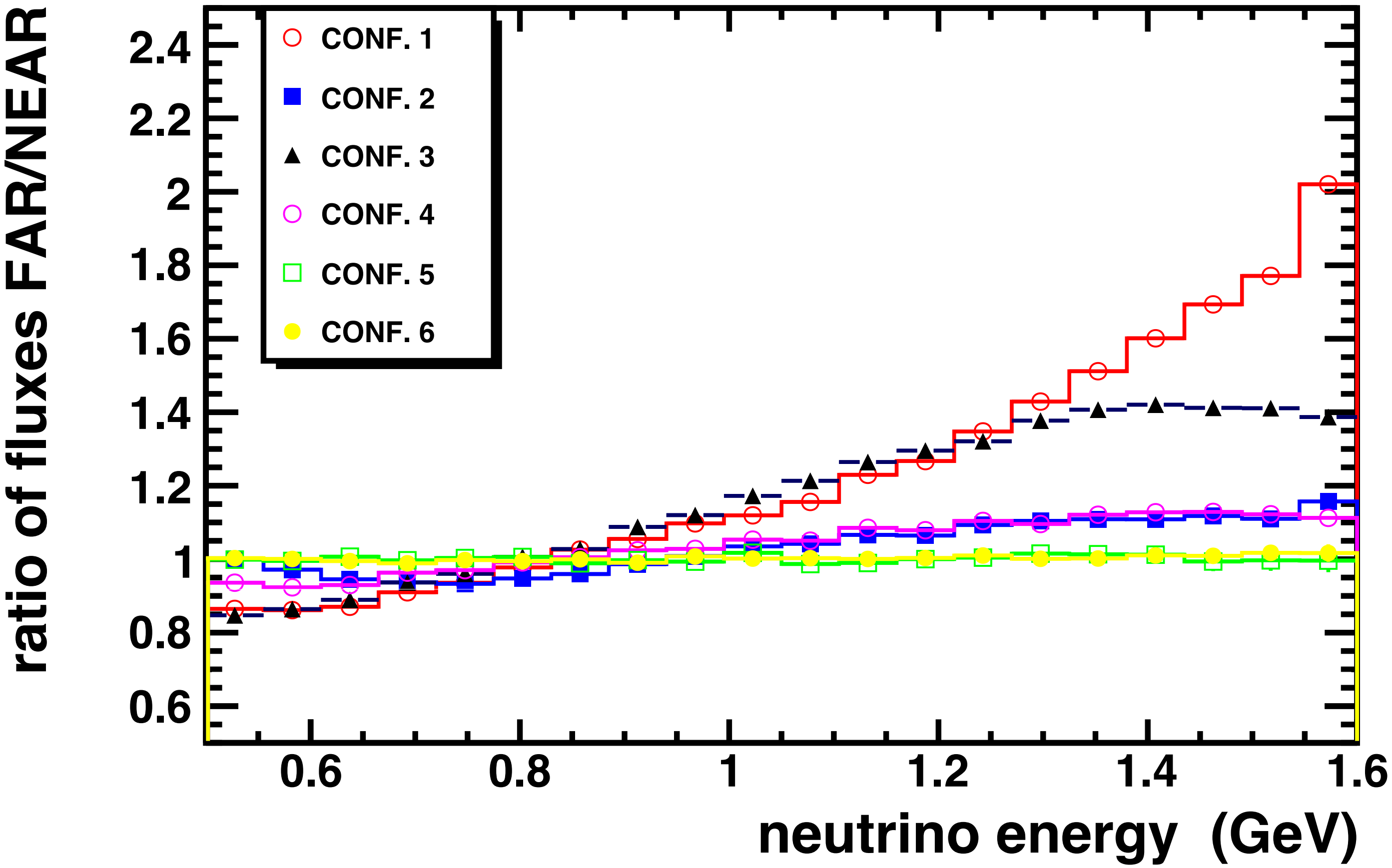
4) 1 kton di ferro in 2 siti (grandi masse e compatti)

5) NESSiE ha dimostrato che si può fare a FNAL (8 GeV di protoni)

Thank you !

NESSiE at FNAL

BACKUP



CONF. 1
CONF. 2
CONF. 3
CONF. 4
CONF. 5
CONF. 6
ratio of fluxes FAR/NEAR
neutrino energy (GeV)
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4

Iron slabs thinner than those available by OPERA NOT worth

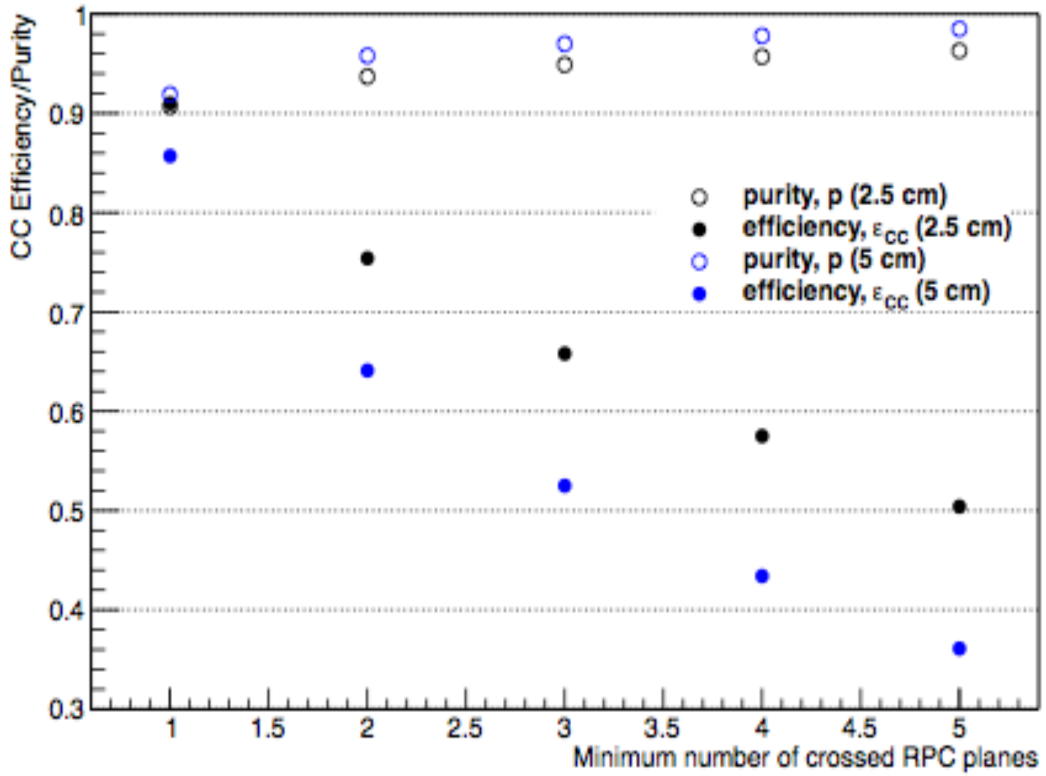
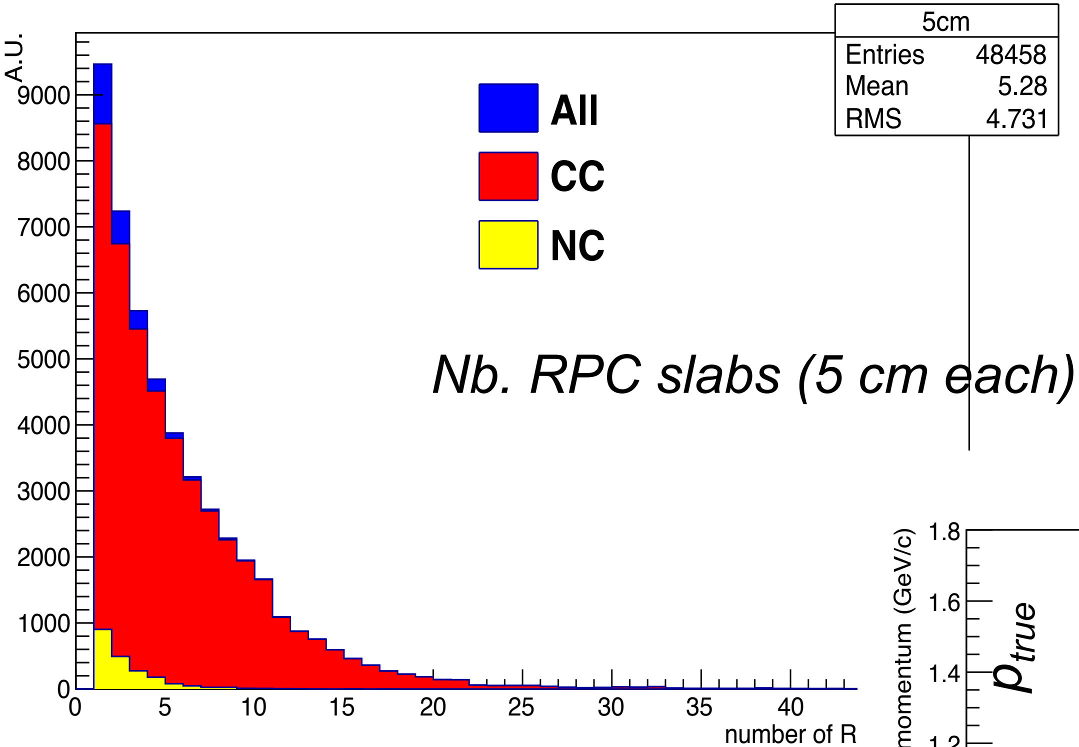
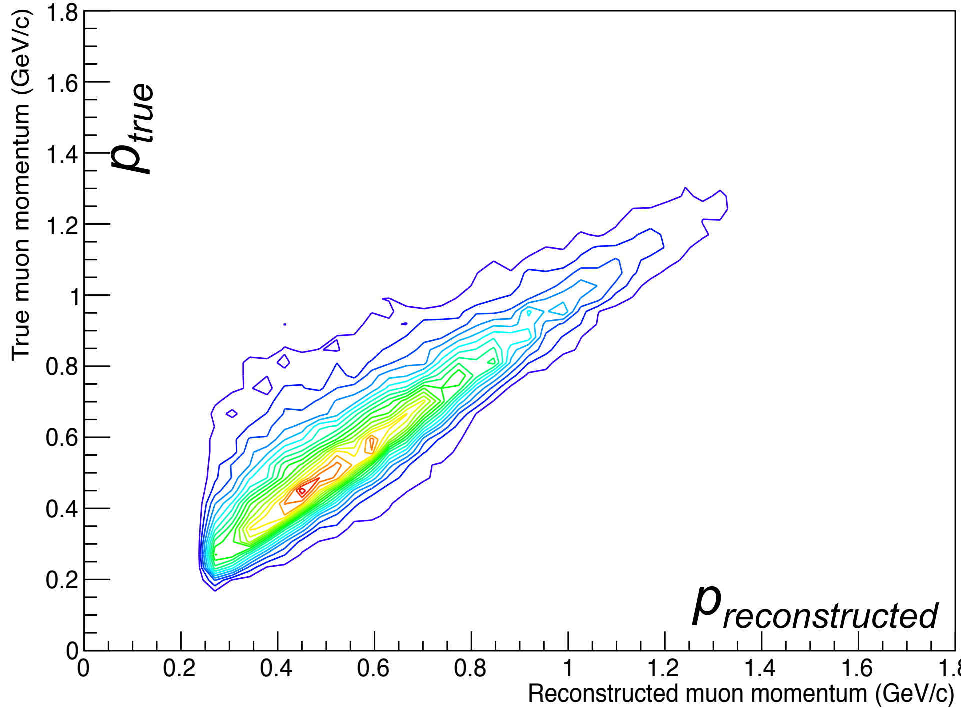


Figure 18: *CC efficiency (ε_{CC}, points) and purity (p, open circles) as a function of the minimum number of RPC planes for the two spectrometer geometries, 5 cm slabs (in blue) and 2.5 cm slabs (in black). For a given level of purity p the efficiencies for the two geometries are similar, therefore no advantage in statistics is taken requiring the same NC contamination suppression.*

The collected neutrino interactions:

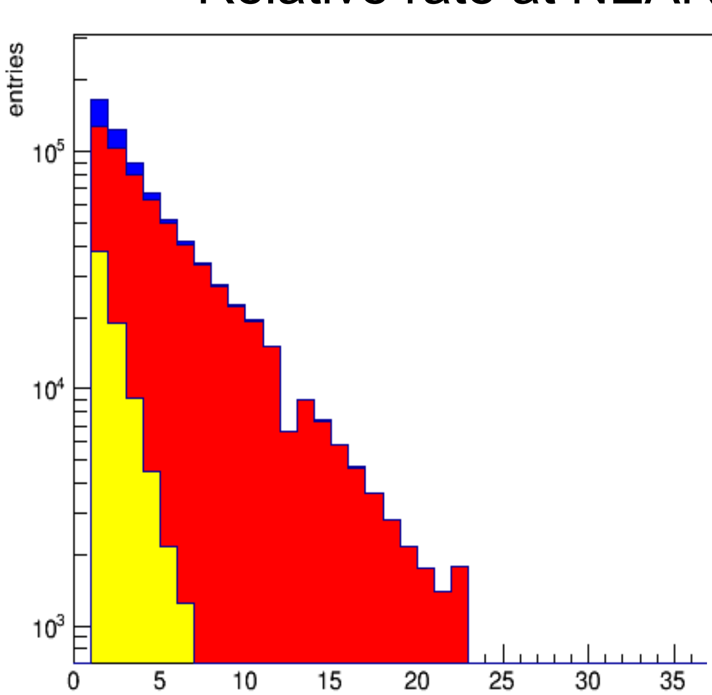


(about 400 MeV)



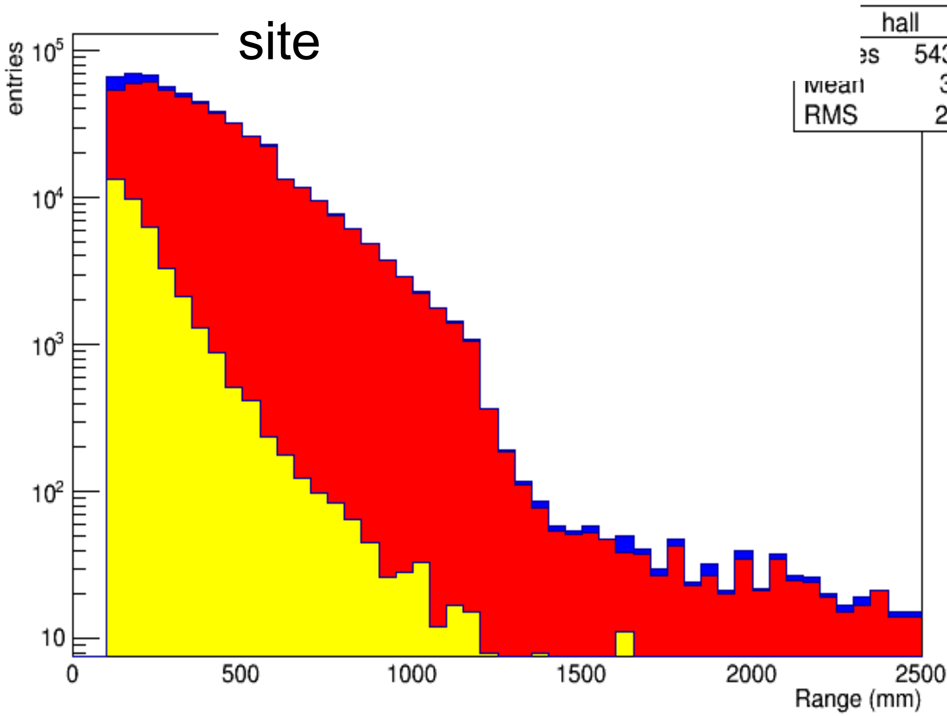
The collected neutrino interactions:

Relative rate at NEAR site



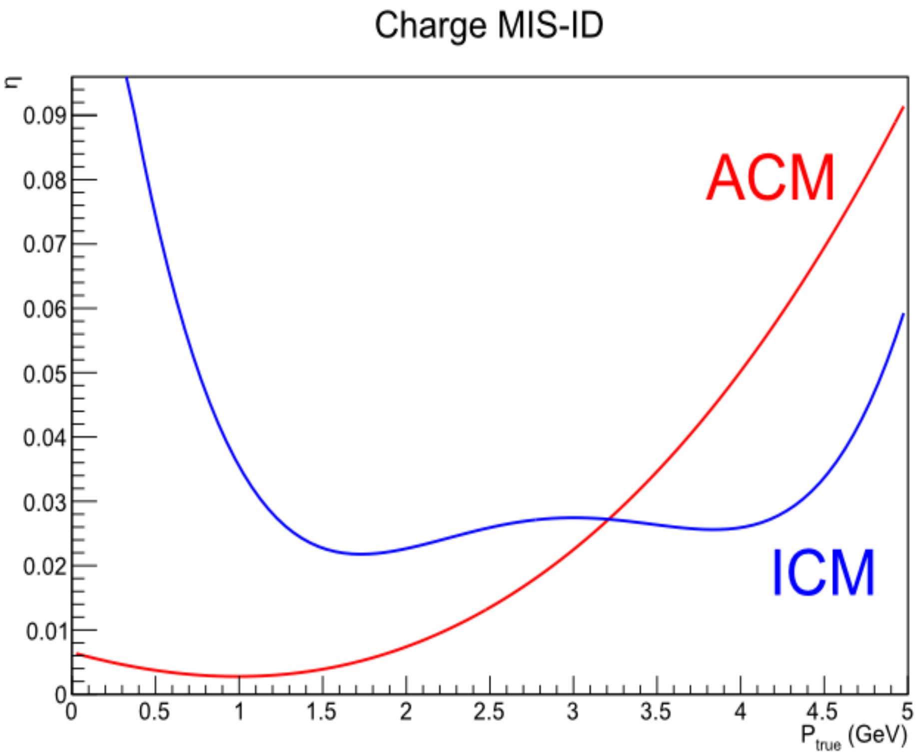
nb. of iron slabs

Relative rate at NEAR site

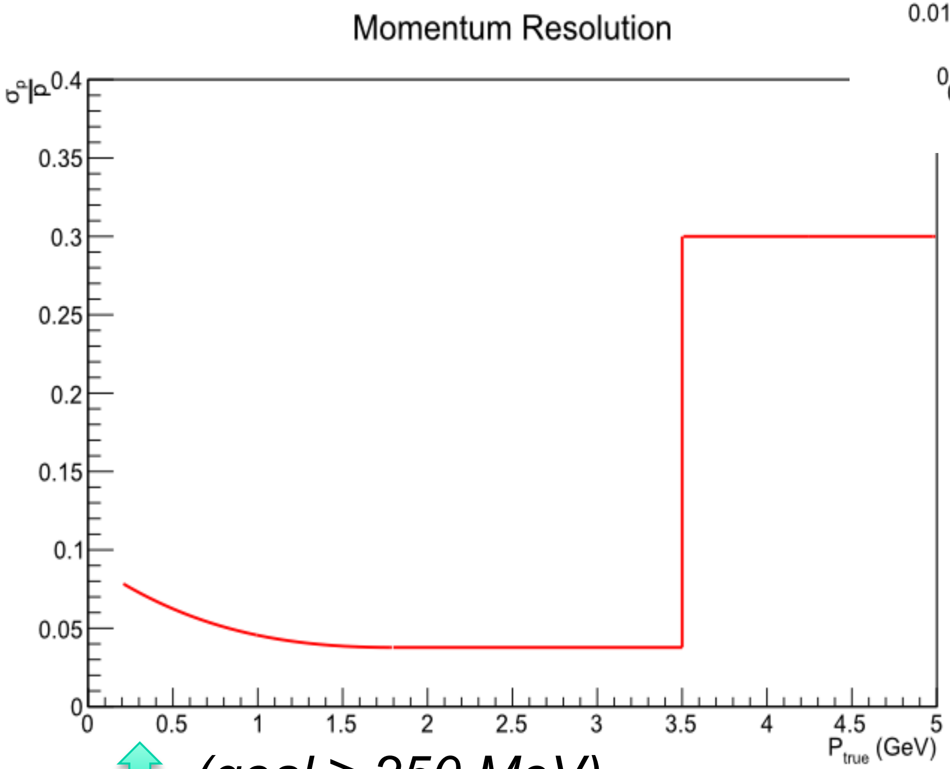


Resolutions:

Sensitivities from the actual NESSiE configurations
(full simulation, with neutrino beam)



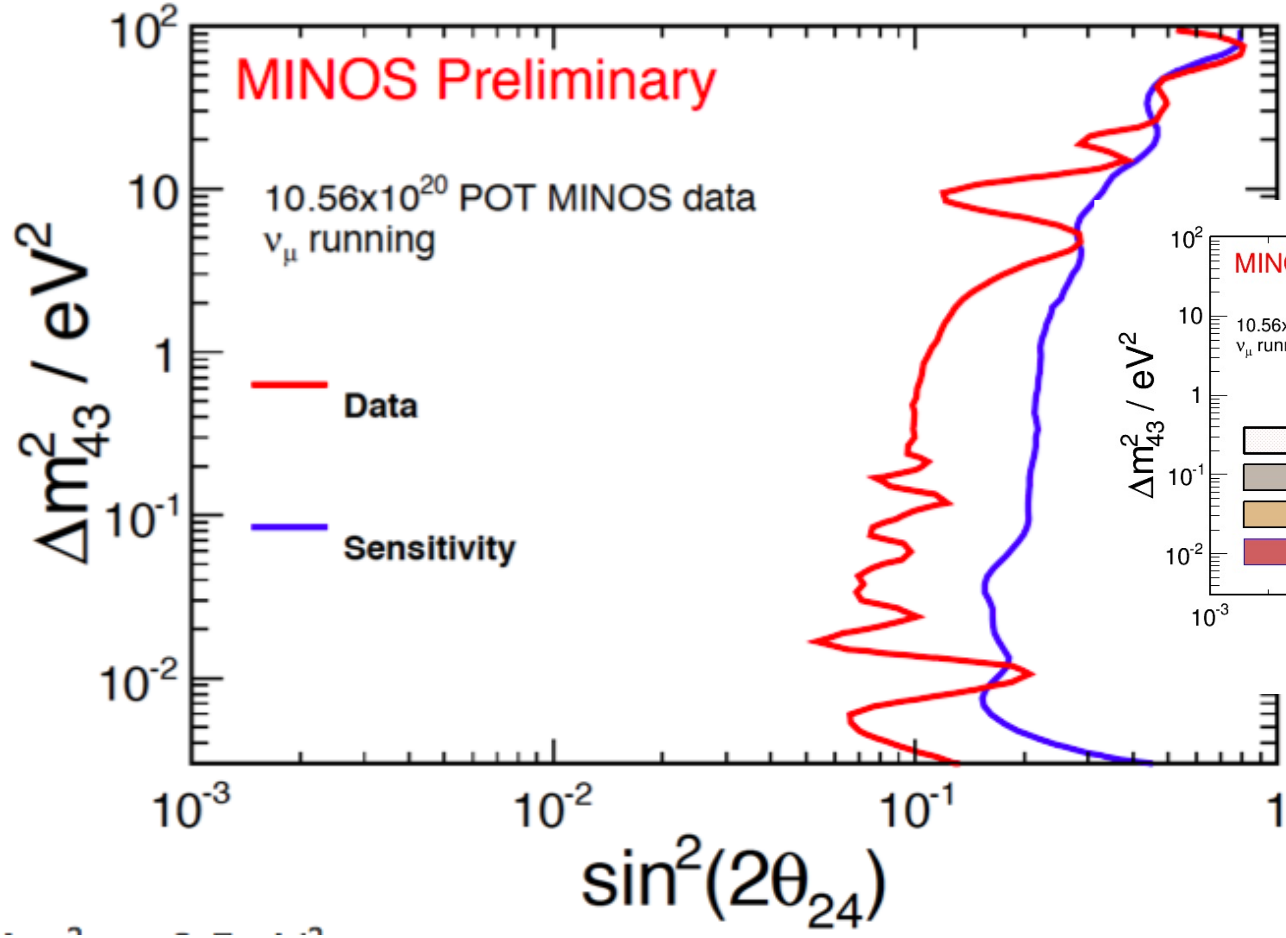
Charge-ID measured by iron slabs (ICM: blue line)

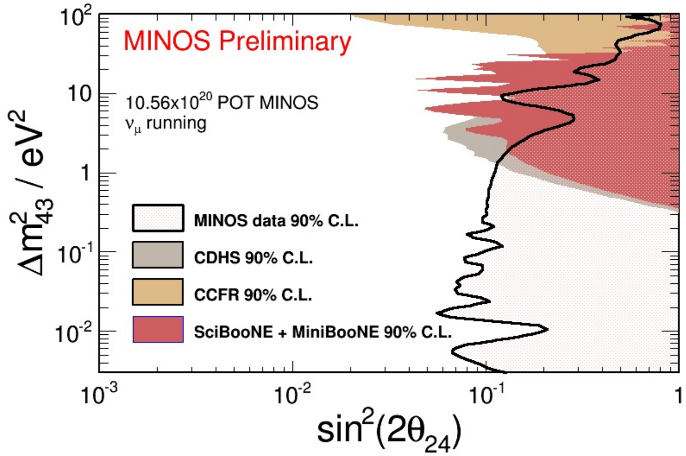


Momentum measured by range (ICM) up to 3.5 GeV, then ≈30% are provided

(goal ≥ 250 MeV)

Sterile Limit Data and Sensitivity





MINOS at NEUTRINO 2014 Conference, Boston, USA