Super beams update

A. Longhin
IRFU-CEA Saclay

EURONU

EUROnu WP2 meeting
12-05-2010

Recent work on:

Super Beams with HP-PS2 (50 GeV) to LAGUNA sites + a 100 kton LAr with GEANT4

Cross-checks of the new GEANT4 simulation

1) GEANT4 pion yields and HARP differential cross sections @ 5 GeV – to validate the possibility of using it also for simulation of p-target interactions (FLUKA traditionally)

2) check of branching ratios implementation

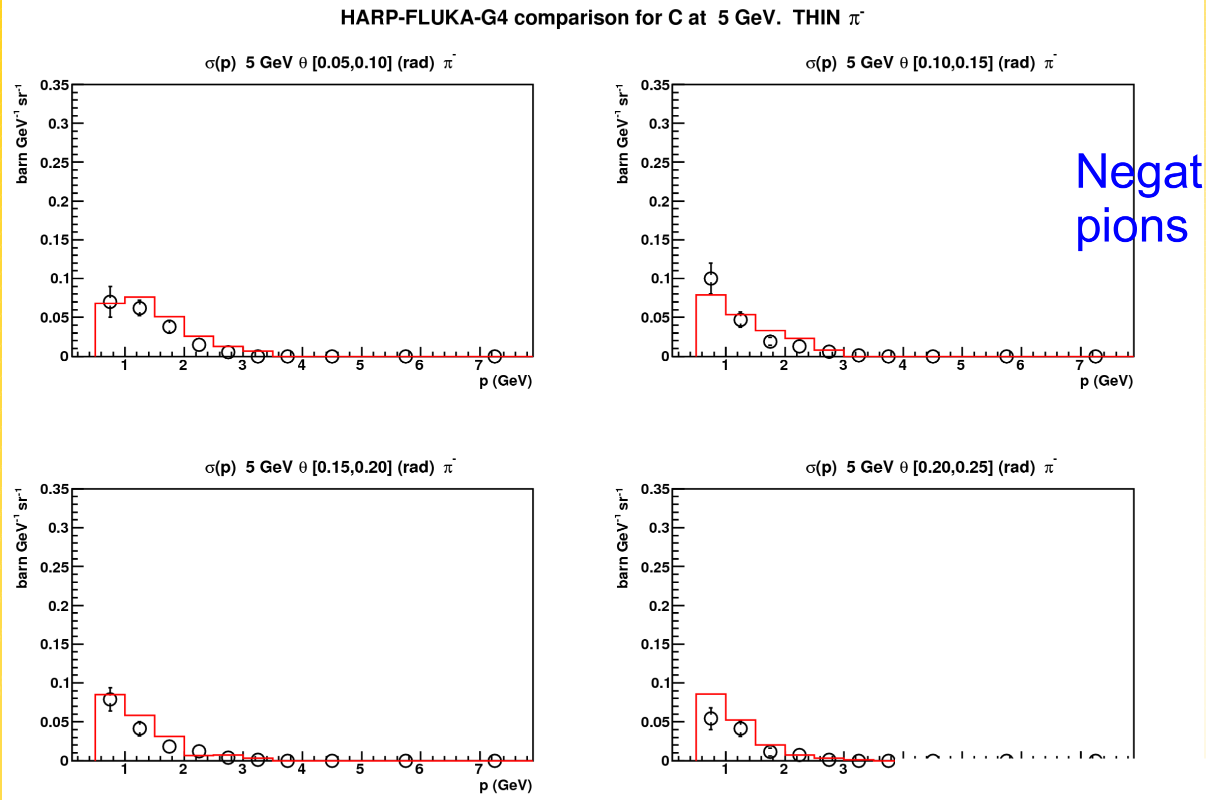
3) Comparison with previous GEANT3 simulation (Cazes, Campagne)

4) Comparison with NoVA fluxes

5) direct “nu-counting”

HARP-GEANT4

Negative pions

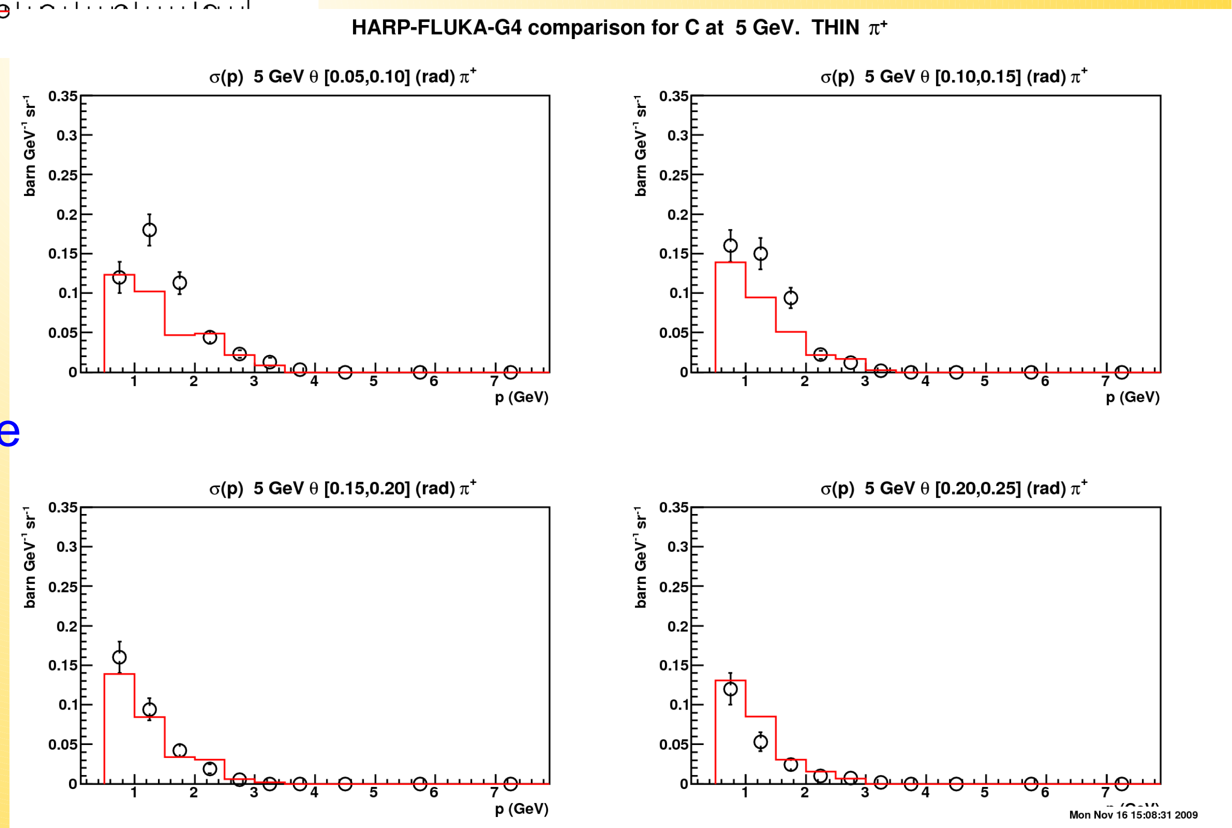


Forward angle data.
THIN graphite target.
5 GeV protons

σ(p) in four angular bins

HARP (bullets)
GEANT4 (histo)

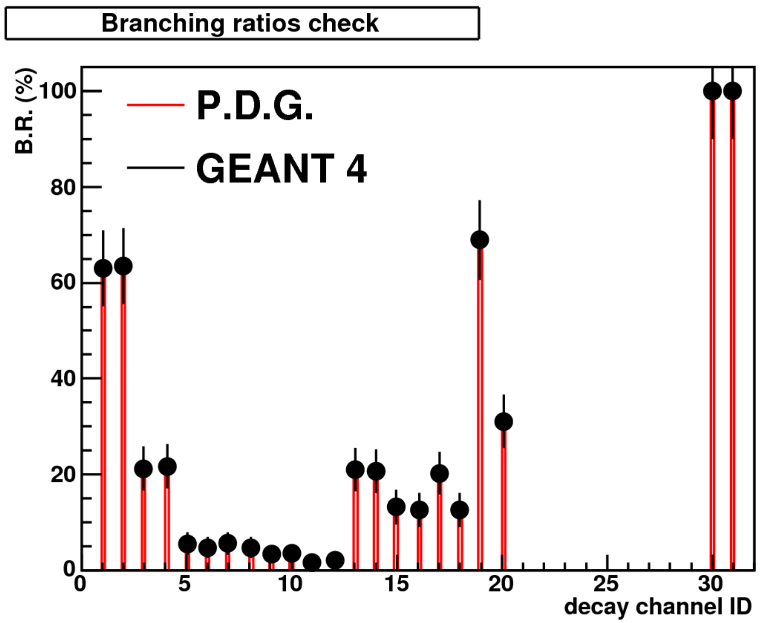
Positive pions

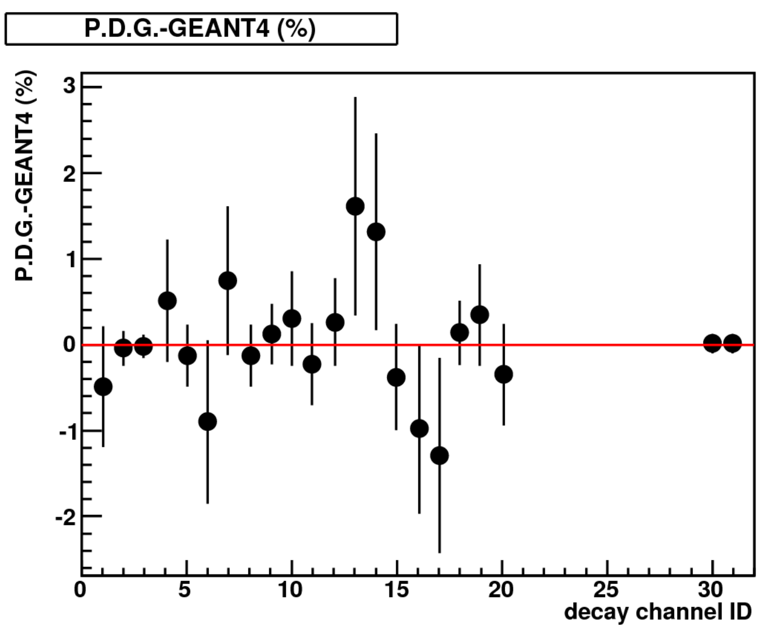


Not too bad!

A. Longhin

GEANT4 branching ratios cross check





1) $K^+ \to \mu^+\nu_\mu$
2) $K^- \to \mu^-\bar{\nu}_\mu$
3) $K^+ \to \pi^+\pi^0$
4) $K^- \to \pi^-\pi^0$
5) $K^+ \to \pi^+\pi^+\pi^-$
6) $K^- \to \pi^-\pi^-\pi^+$
7) $K^+ \to e^+\nu_e\pi^0$
8) $K^- \to e^-\bar{\nu}_e\pi^0$
9) $K^+ \to \mu^+\nu_\mu\pi^0$
10) $K^- \to \mu^-\bar{\nu}_\mu\pi^0$
11) $K^+ \to \pi^+\pi^0\pi^0$
12) $K^- \to \pi^-\pi^0\pi^0$

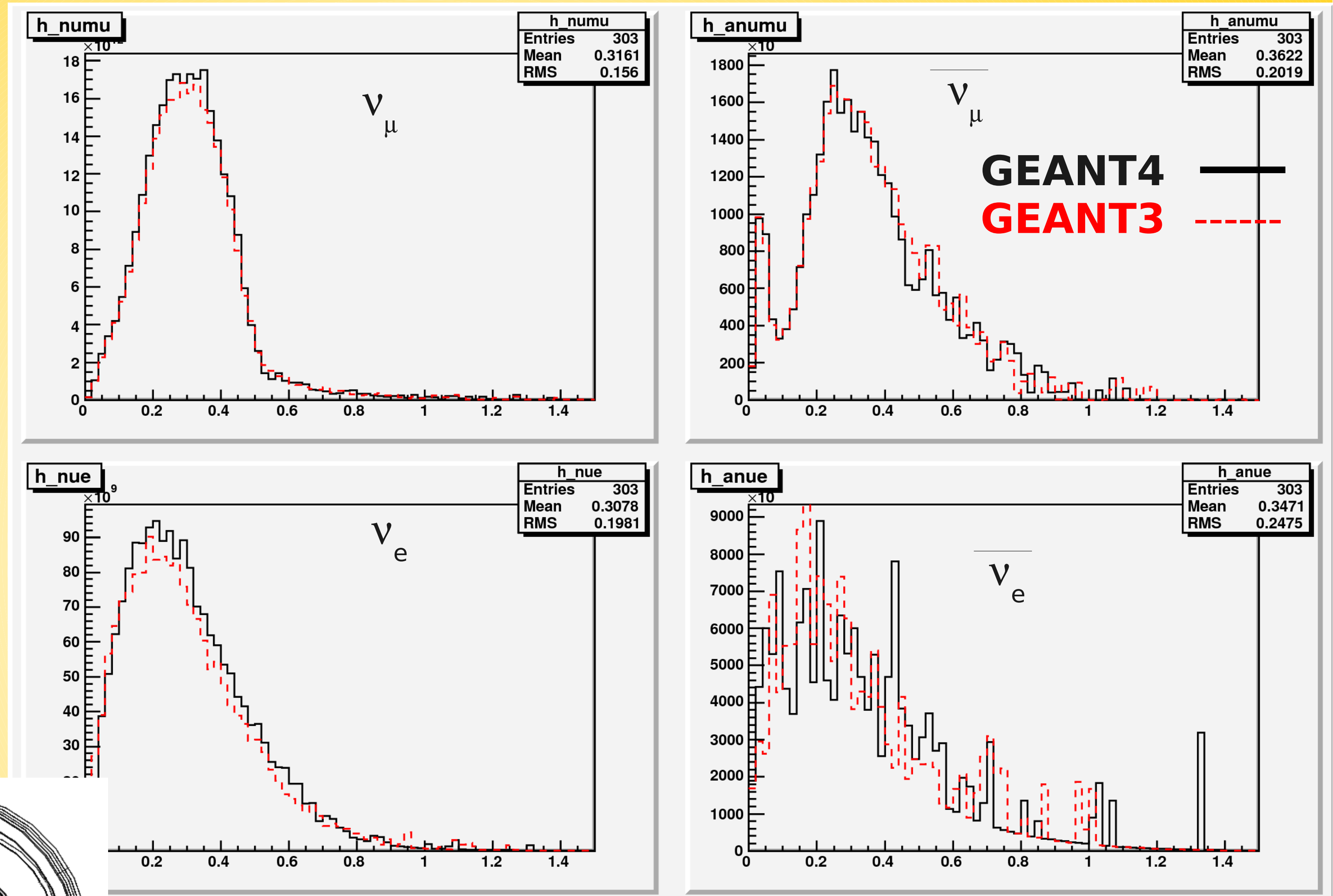
13) $K^0_L \to e^+\nu_e\pi^-$
14) $K^0_L \to$ #$e^-\bar{\nu}_e\pi^+$
15) $K^0_L \to \mu^+\nu_\mu\pi^-$
16) $K^0_L \to \mu^-\bar{\nu}_\mu\pi^+$
17) $K^0_L \to \pi^0\pi^0\pi^0$
18) $K^0_L \to \pi^+\pi^-\pi^0$
19) $K^0_S \to \pi^+\pi^-$
20) $K^0_S \to \pi^-\pi^0$
30) $\pi^+ \to \mu^+\nu_\mu$
31) $\pi^- \to \mu^-\bar{\nu}_\mu$

Implementation is correct

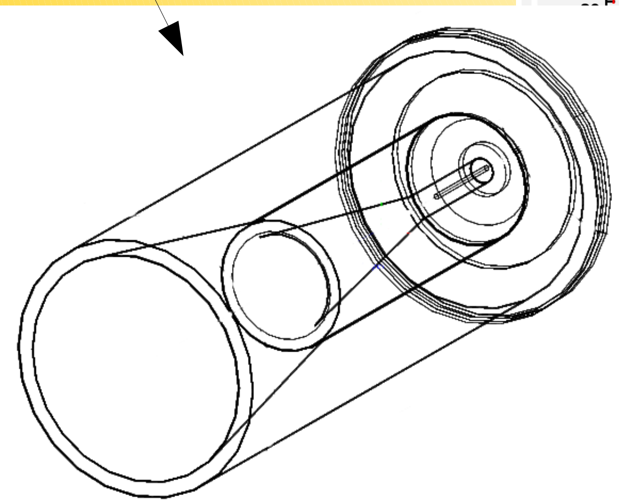
GEANT3-4 comparison with SPL standard horn

The original GEANT3 software (A. Cazes) rewritten in GEANT4

Fluxes comparison with the original horn geometry



standard horn geometry (GEANT4)



Good agreement found between the two simulation programs

GEANT4: benchmarking with NOvA fluxes

NOVA setup reproduced in the new GEANT4 framework

E= 120 GeV, L=810 Km, 10.8 Km OFF-AXIS

GEANT4 used also for the primary proton interactions (in place of FLUKA)

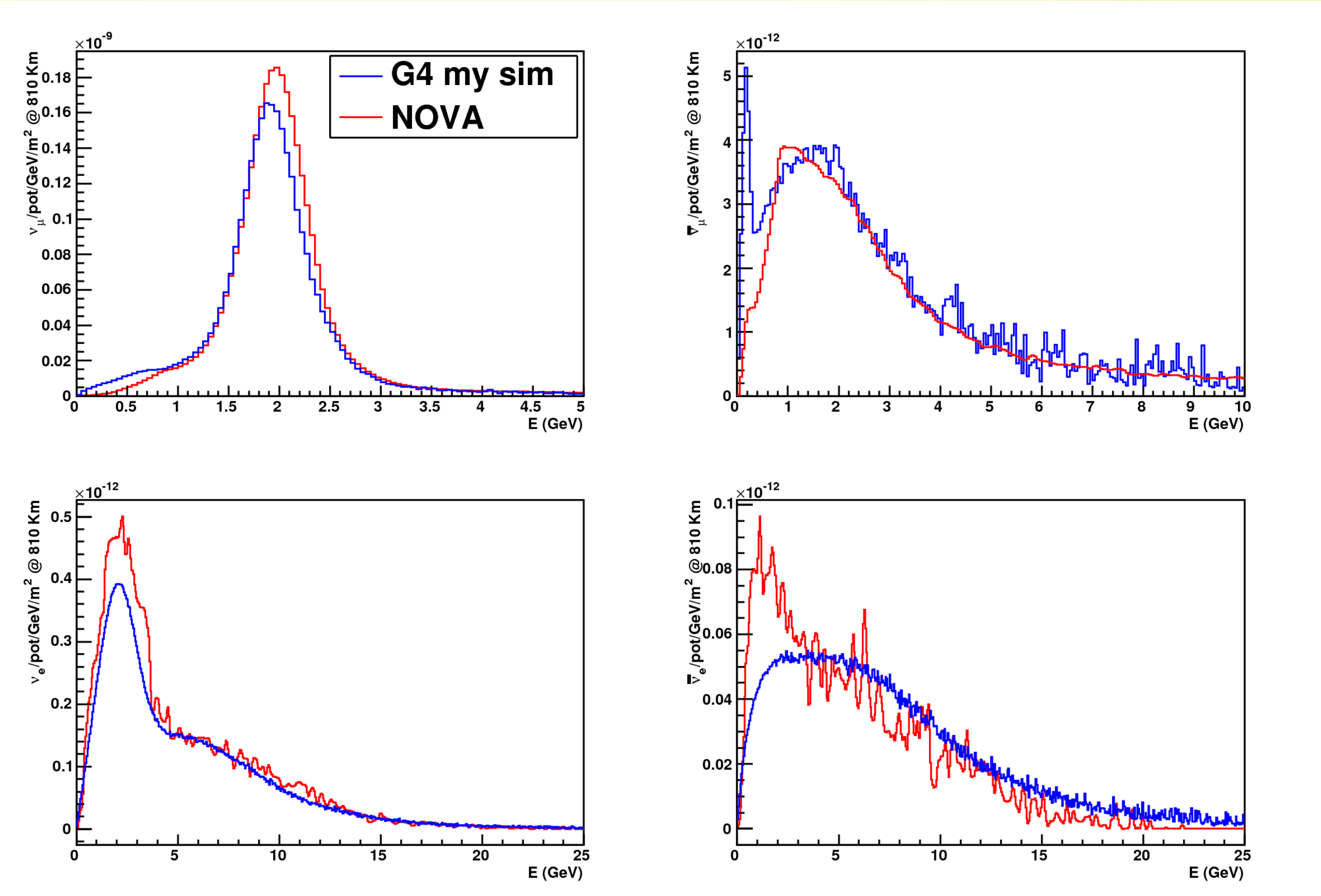
Reference fluxes from NoVA public web pages

http://enrico1.physics.indiana.edu/messier/off-axis/spectra/

Comparison in normalization and shape

Reasonable agreement - also considering that geometry is reproduced with approximations.

Simulations are completely independent



Cross-check: nu counting

To validate: 1) probability approach 2) off-axis treatment

Select neutrinos generated by GEANT4 decays in narrow cones around the forward direction and off axis direction

Easier with high energy beam. Done for the NOvA configuration.

Use numu spectrum to understand the maximal cone aperture cone which allows to have a realistic spectrum shape (at sufficient statistics)

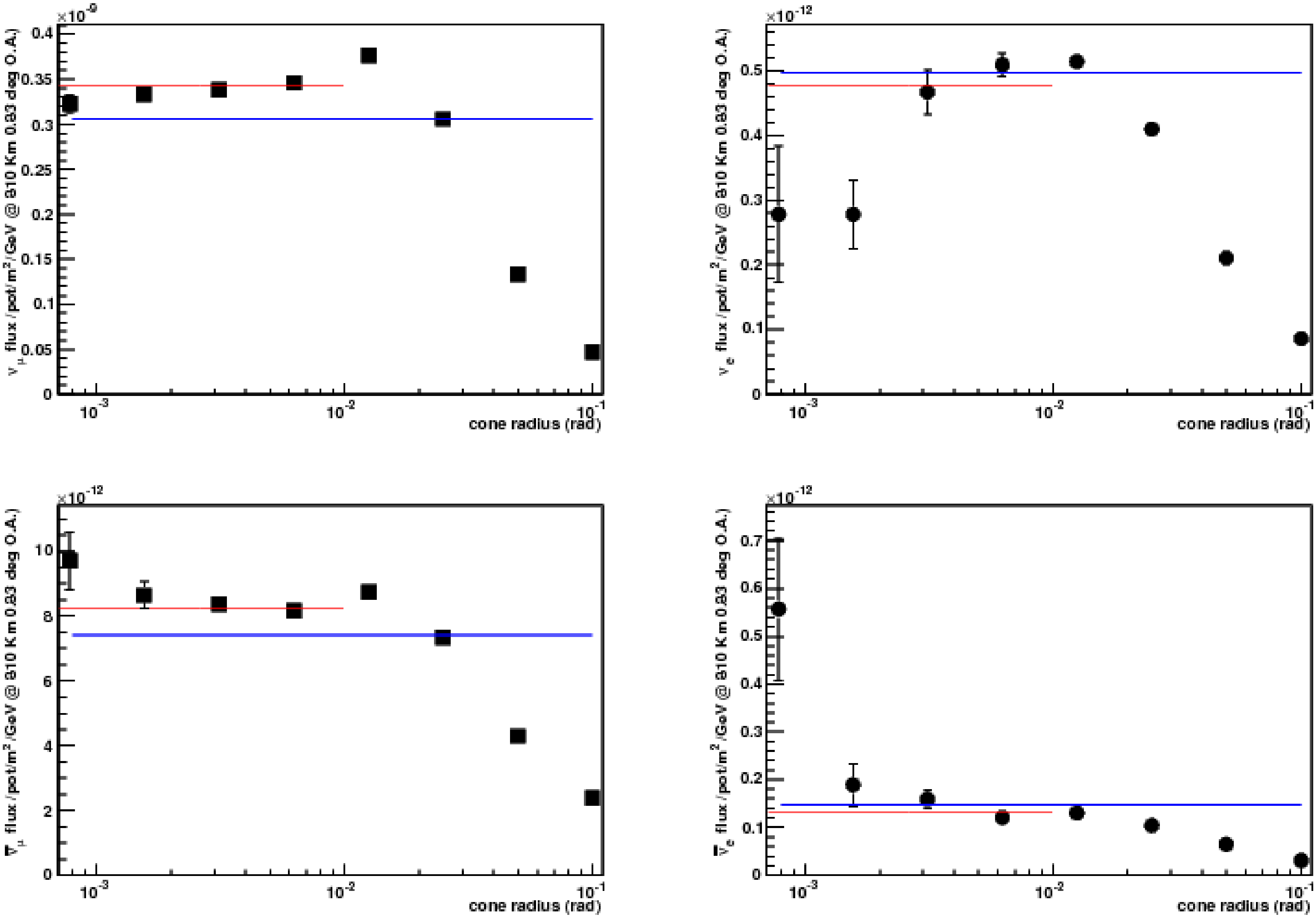
$\Omega = 1 / (4\pi L^2)$ (1 m^2 at 810 Km) ~ 1.5 prad

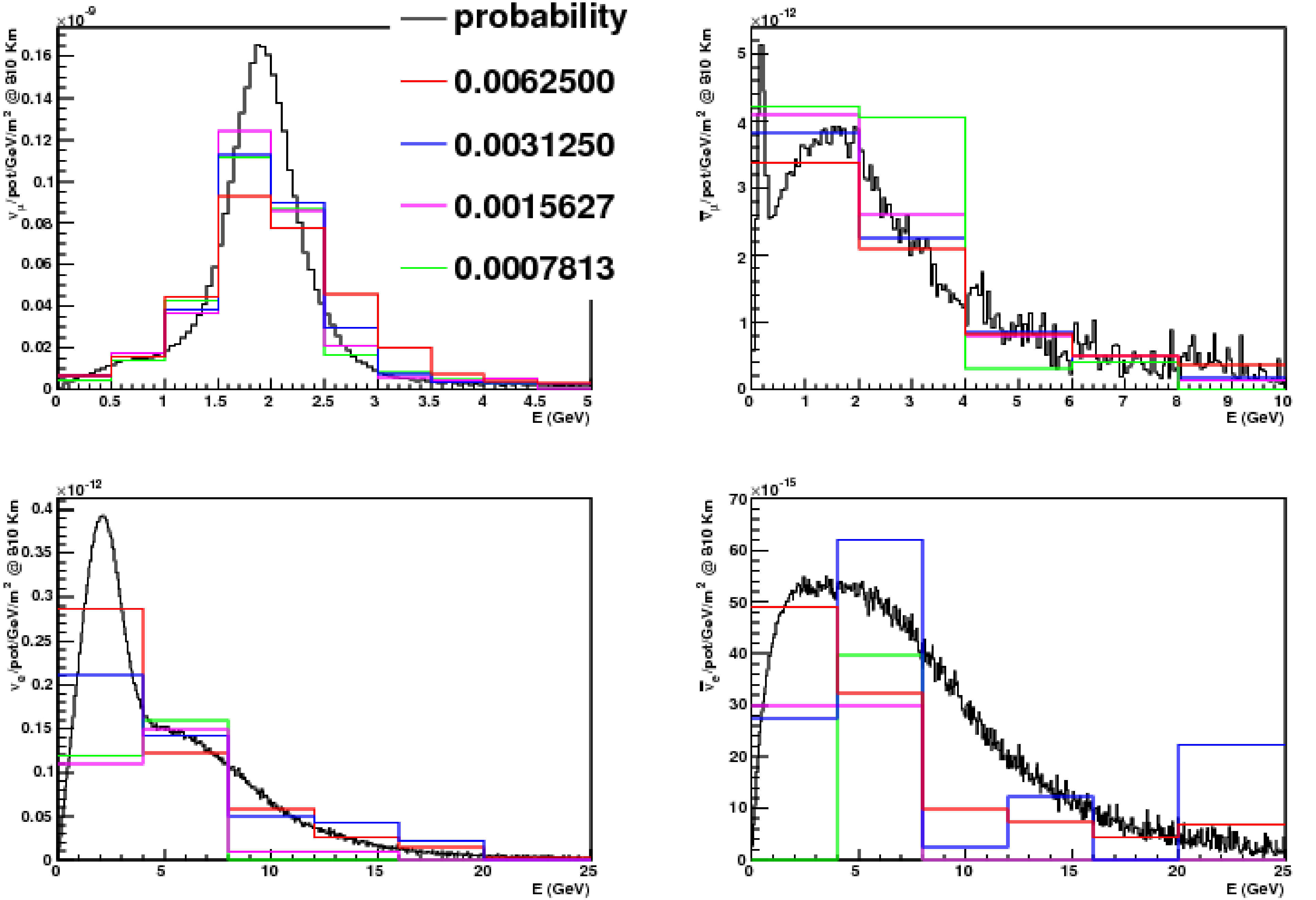
considered 7 cones of semi-aperture:
α =0.1 - 0.05 - 0.025 - 0.0125 - 0.00625 - 0.003125 - 0.0015625

solid angles Ω' (prad): 3.1e10 - 7.8e9 - 2.0e9 - 4.9e8 - 1.2e8 - 3.1e7 - 7.7e6
$\Omega' = 2\pi (1 - \cos\alpha)$

last cone ~ a detector ~ 2.2 Km x 2.2 Km

scale fluxes obtained with counting neutrinos in the cone by Ω/Ω'

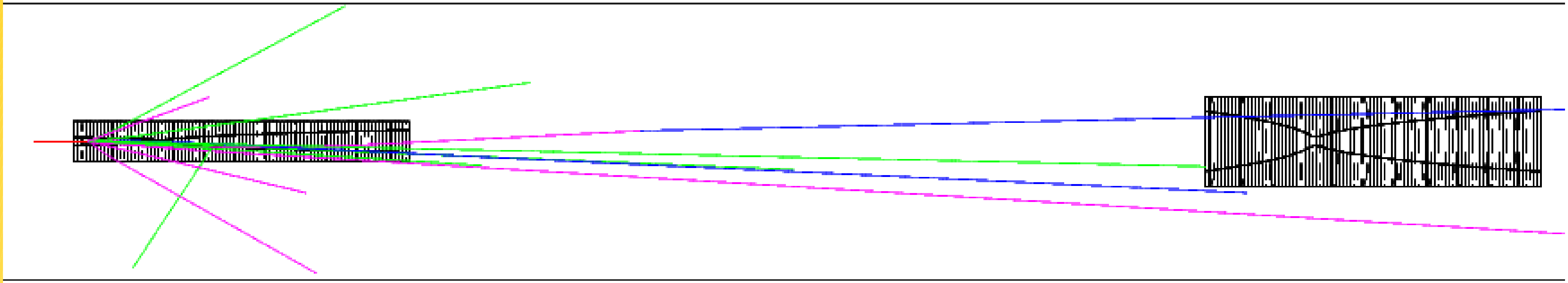

×10⁻⁹
ν_μ flux / pot/ m² / GeV @ 810 Km 0.83 deg O.A.)
cone radius (rad)
×10⁻¹²
ν_e flux / pot/ m² / GeV @ 810 Km 0.83 deg O.A.)
cone radius (rad)
×10⁻¹²
ν̄_μ flux / pot/m² /GeV @ 810 Km 0.83 deg O.A.)
cone radius (rad)
×10⁻¹²
ν̄_e flux / pot/m² /GeV @ 810 Km 0.83 deg O.A.)
cone radius (rad)



probability
0.0062500
0.0031250
0.0015627
0.0007813
ν_μ/pot/GeV/m^2 @ 810 Km
$\bar{\nu}_\mu$/pot/GeV/m^2 @ 810 Km
ν_e/pot/GeV/m^2 @ 810 Km
$\bar{\nu}_e$/pot/GeV/m^2 @ 810 Km
$\times 10^{-9}$
$\times 10^{-12}$
$\times 10^{-12}$
$\times 10^{-15}$
E (GeV)
E (GeV)
E (GeV)
E (GeV)

A test setup @ 50 GeV

Meant as a starting point, not optimized



Parameters of the focusing system

E_protons = 50 GeV
primary interactions : GEANT4
Horns
NOVA (= MINOS) shapes
currents = 200 kA
Aluminum thickness = 3 mm
horn-refl separation = 10 m
Target
graphite (ρ =1.85 g/cm^3)
L = 1 m
r = 2 mm
z = -35 cm
Tunnel
L = 300 m
r = 1.225 m
ON AXIS

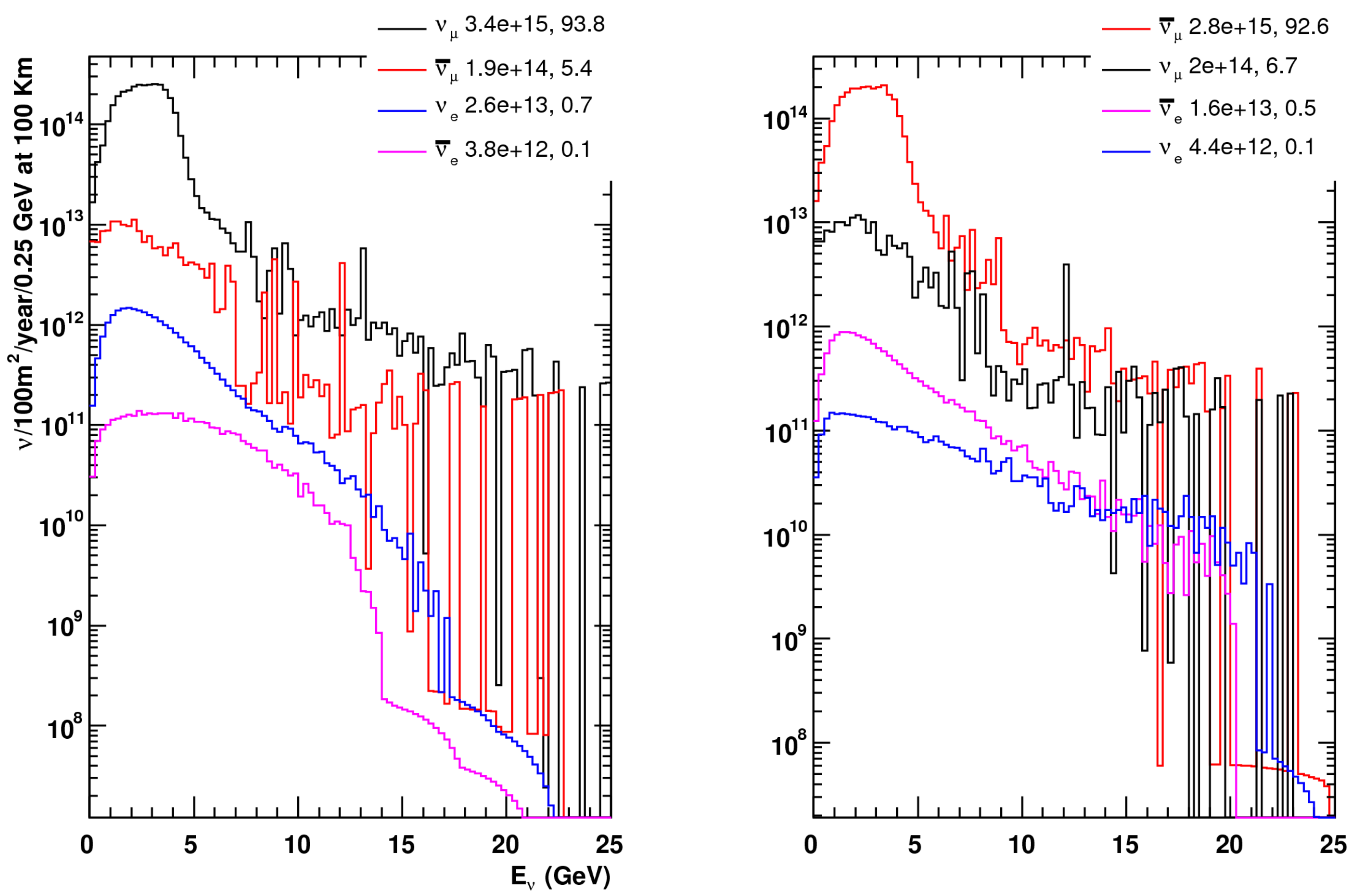
Ingredients for GloBES limit calculation:

* $3 \cdot 10^{21}$ pot/y
("PS2++" see A. Rubbia pres. at WIN09)
* 5 % sys err.
* 100 kton LAr
simplified description, refinement being worked upon (L.S.Esposito)
* 8y anti-nu + 2y nu running
* CERN-LAGUNA baselines

Thanks to A. Meregaglia
for the GloBES AEDL file

50 GeV test setup: fluxes

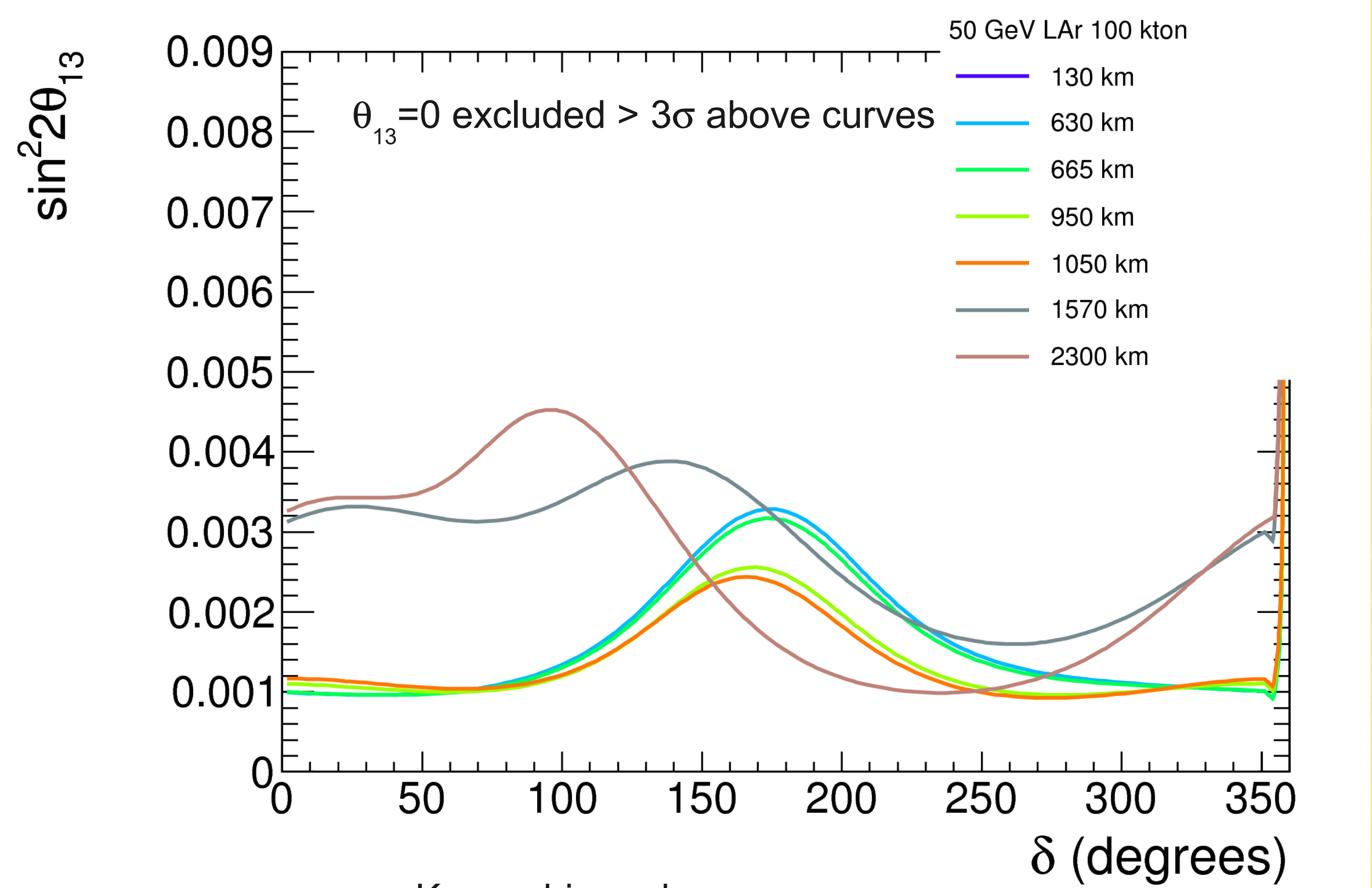
<E> ~ 2.8 GeV



50 GeV test setup: sensitivity on $\sin^2 2\theta_{13}$ vs L

Flux setup 0

<E> ~ 2.8 GeV

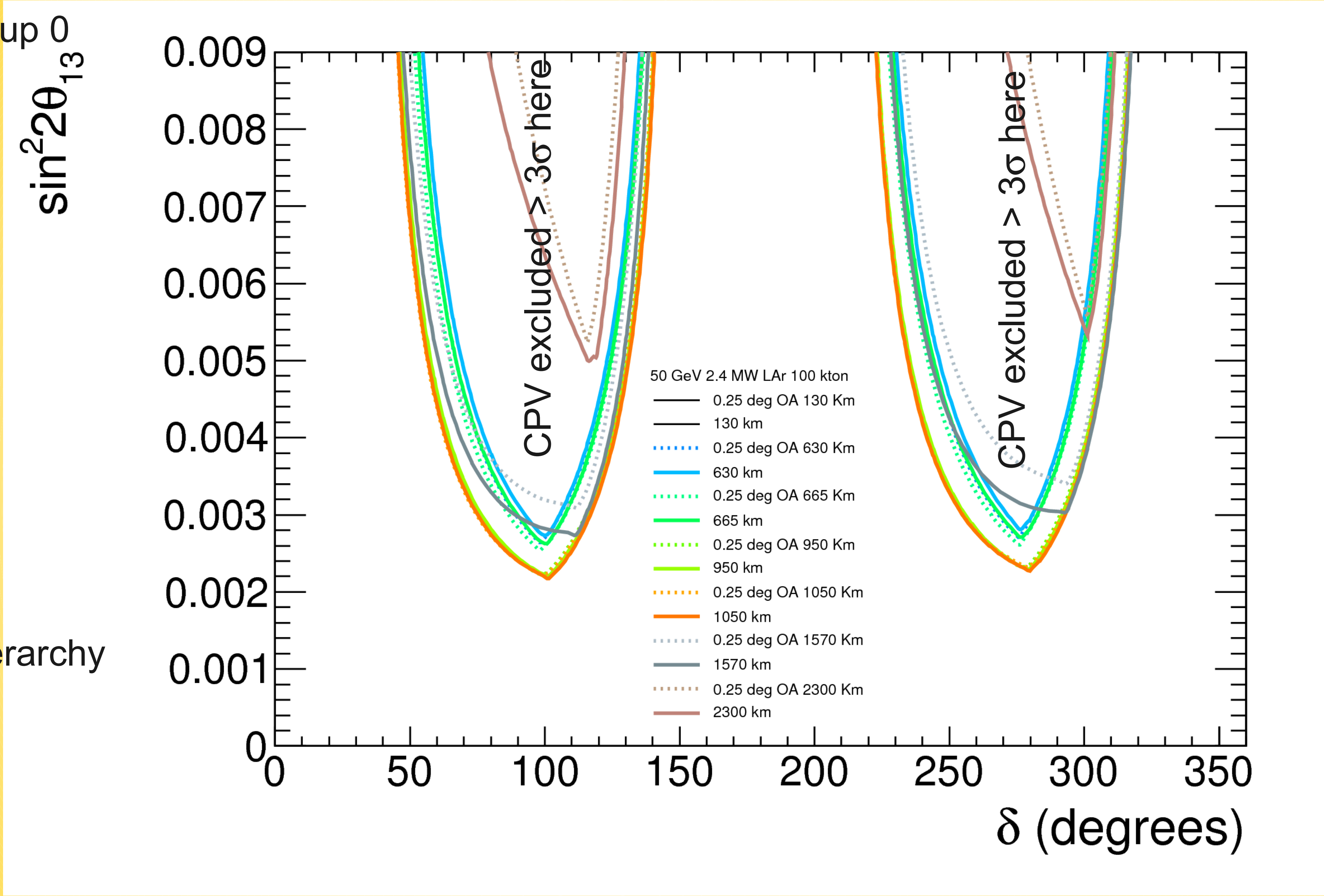


Known hierarchy

With this test setup best sensitivity at ~ 1000 Km
Energy spectrum fits first oscillation maximum for this L

50 GeV: CP violation @ 3σ vs L

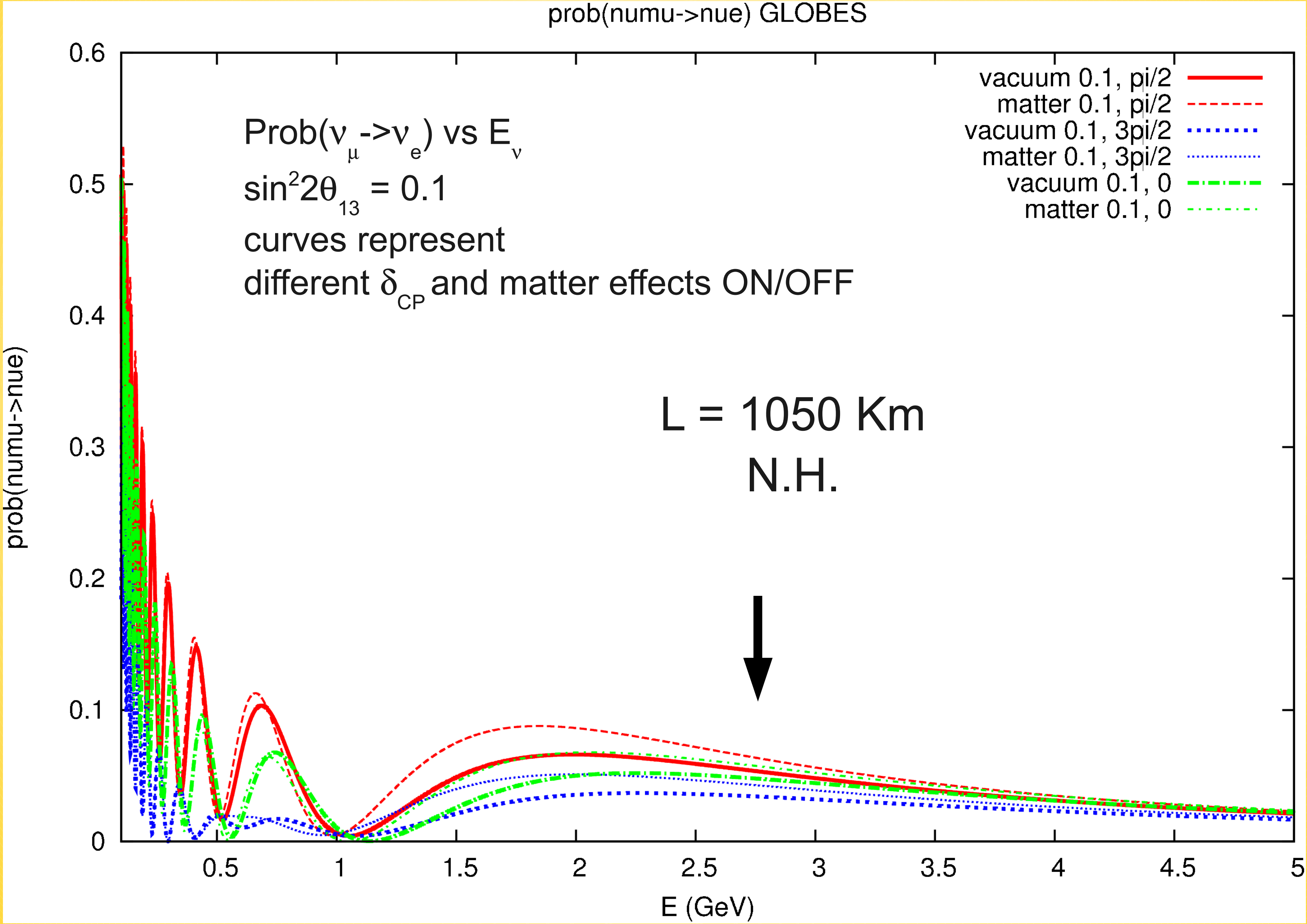
Flux setup 0



Known hierarchy

In the queue: add in the comparison the sensitivity to mass hierarchy (will prefer longer baselines)

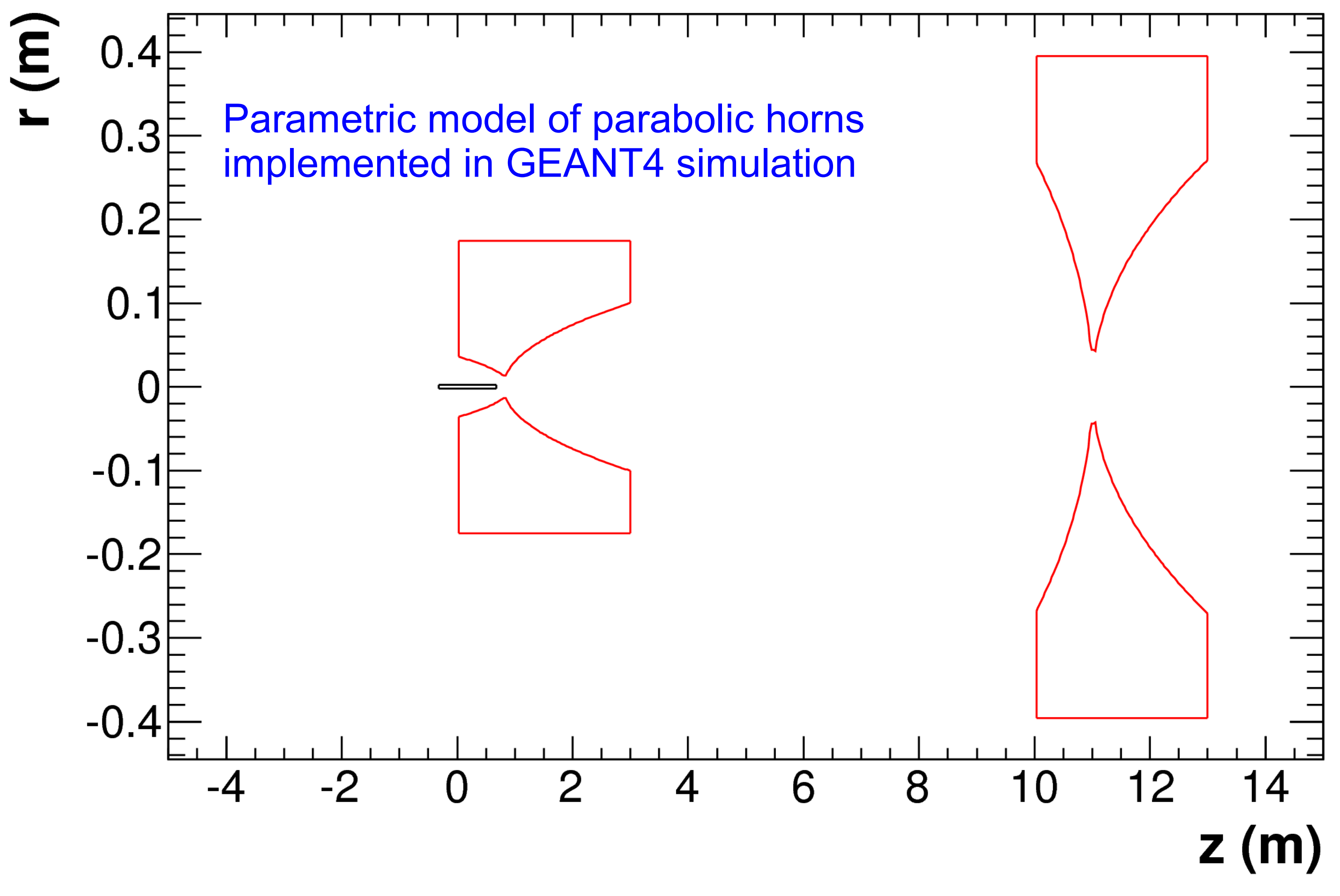
With this test setup best sensitivity at ~ 1000 Km
Energy spectrum fits first oscillation maximum for this L



Optimization for different baselines

$$- \; z \in [0, z_1] : f(z) = \sqrt{\frac{a-z}{b}} - c$$
$$- \; z \in [z_1, z_2] : f(z) = d$$
$$- \; z \in [z_2, z_3] : f(z) = \sqrt{\frac{z-a'}{b'}} - c'$$

Location	L_{CERN} [km]	$E_{1stO.M.}$ [GeV]
Fréjus (F)	130	0.26
Canfranc (ES)	630	1.27
Umbria(IT)	665	1.34
Sierozsowice(PL)	950	1.92
Boulby (UK)	1050	2.12
Slanic(RO)	1570	3.18
Pyhäsalmi (FI)	2300	4.65



Parameters' space

- $z \in [0, z_1] : f(z) = \sqrt{\frac{a-z}{b}} - c$
- $z \in [z_1, z_2] : f(z) = d$
- $z \in [z_2, z_3] : f(z) = \sqrt{\frac{z-a'}{b'}} - c'$

Parameter	horn	refl.	variation
a	85.7091	100	50%
b	7.0483	0.1351	50%
c	0.2	0.3	50%
a'	82.2123	100.	50%
b'	2.1850	0.2723	50%
c'	0.2	0.3	50%
d	0.9	3.9	50%
r	15	40	50%
z_1	80	97.617	50%
z_2	83.982	104.803	50%
z_3	300	300	50%
L_{tun}	[200,1000] m		
r_{tun}	[0.8,2] m		
z_{tar}	[-0.5,-1.5] m		
L_{tar}	1 m		
r_{tar}	2 mm		
Δ_{HR}	[4,50] m		
$i_H = i_R$	200 kA		
s	3 mm		

Configurations' sampling

2 configurations selected

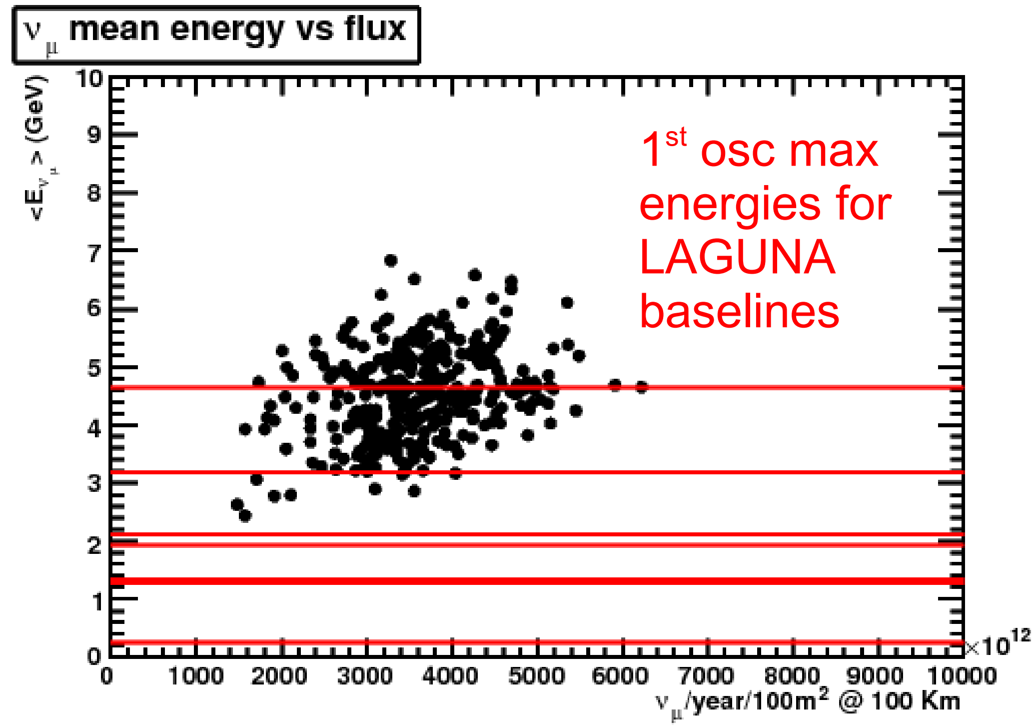
requiring

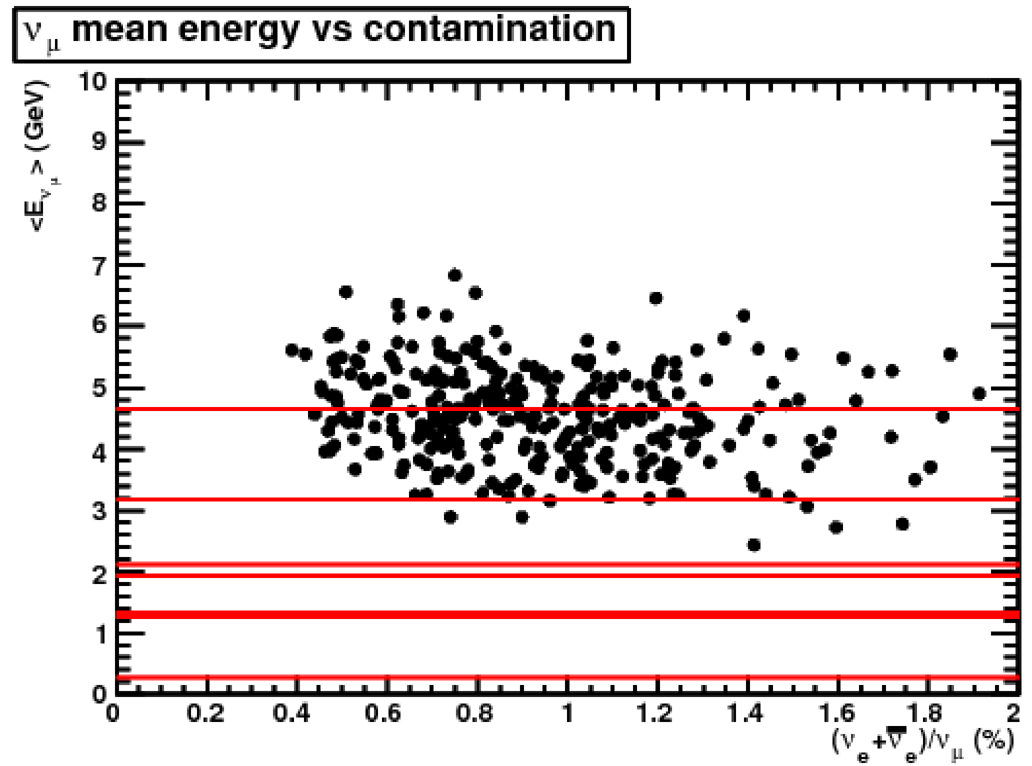
High-E:
contamination < 0.6 %
<E> > 5 GeV
+ highest numu flux

Low-E
contamination < 0.8 %
<E> < 3 GeV
+highes numu flux

NB:

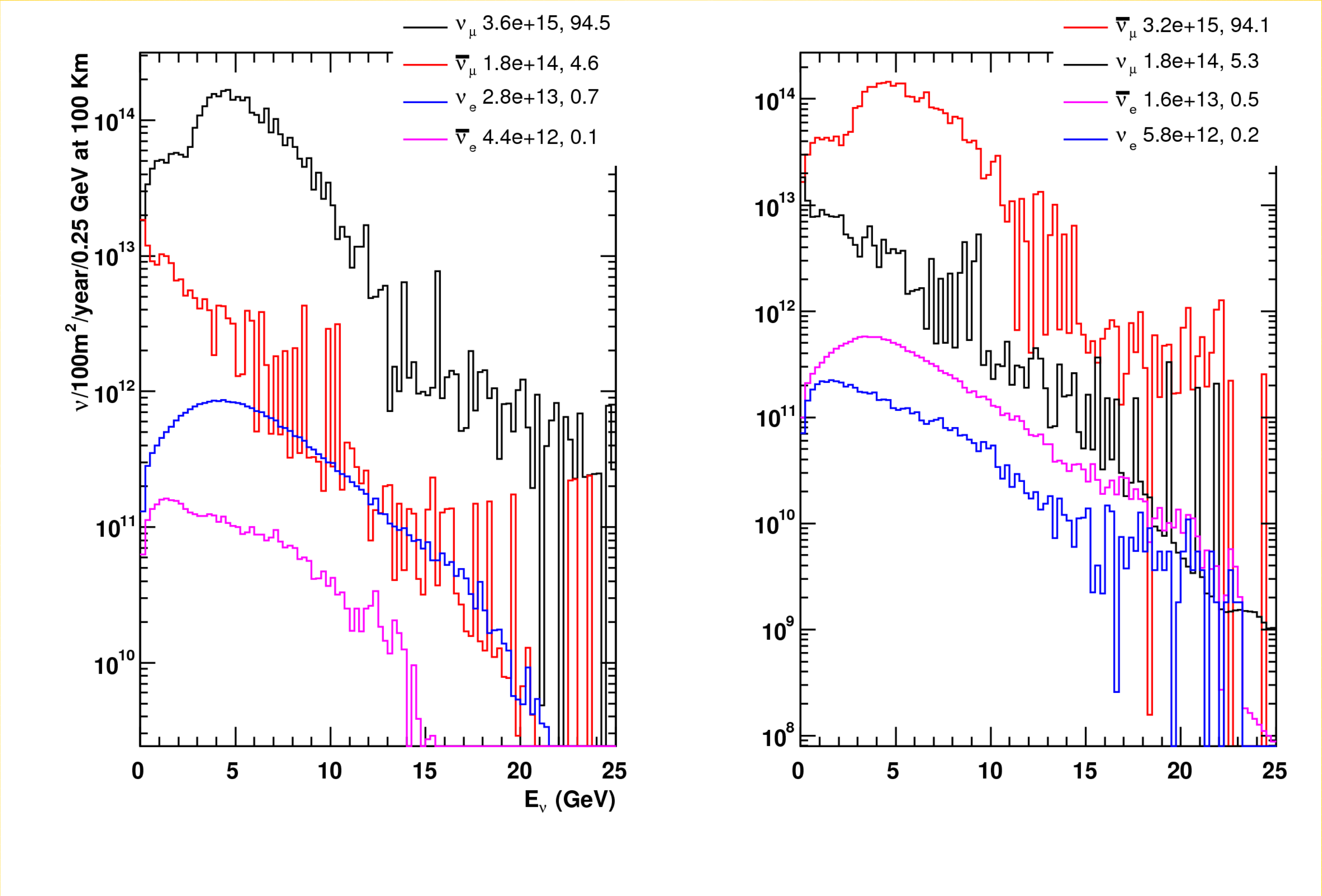
Limited sampling (~3*10^2)
Limited pot statistics (10^4)



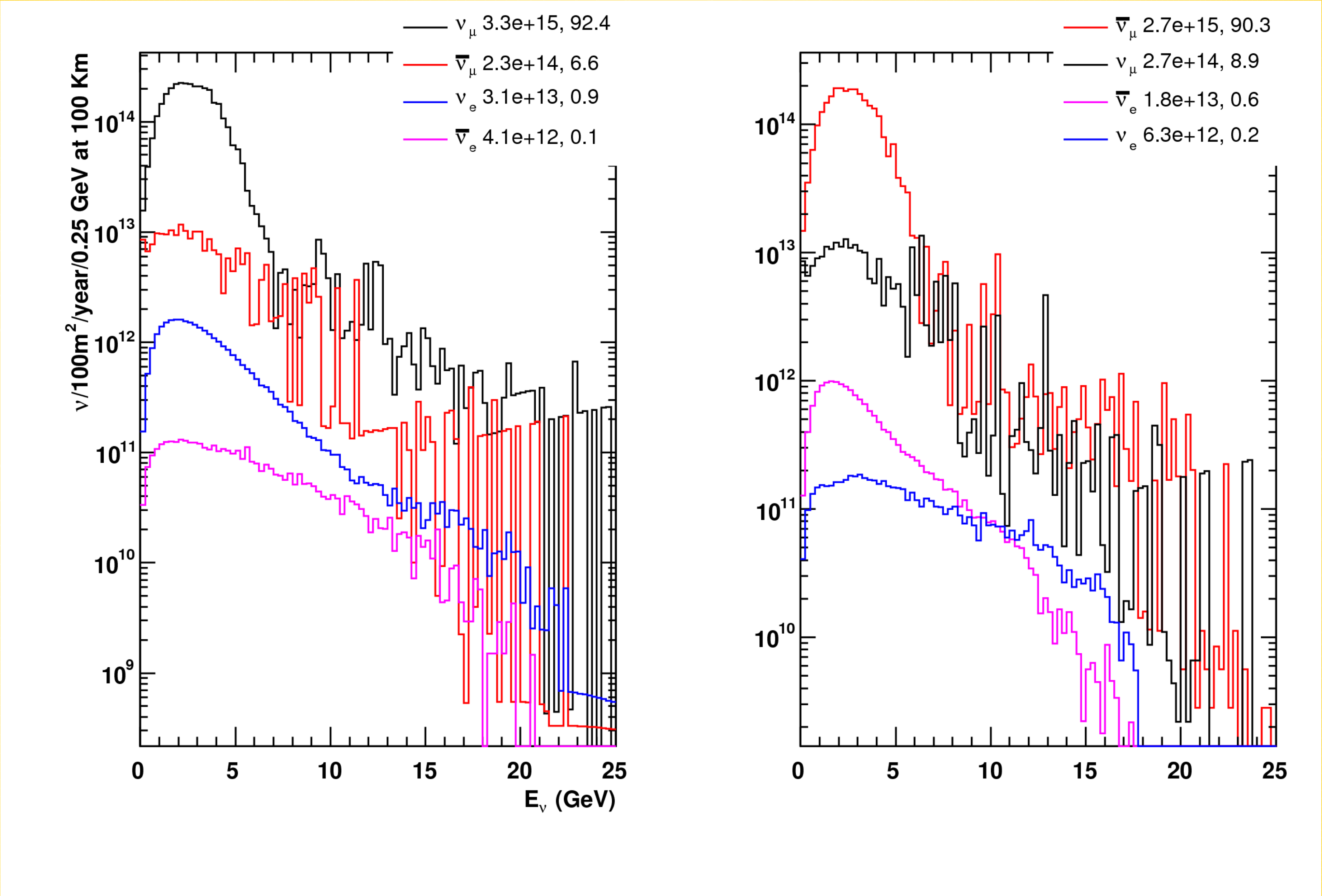


A. Longhin

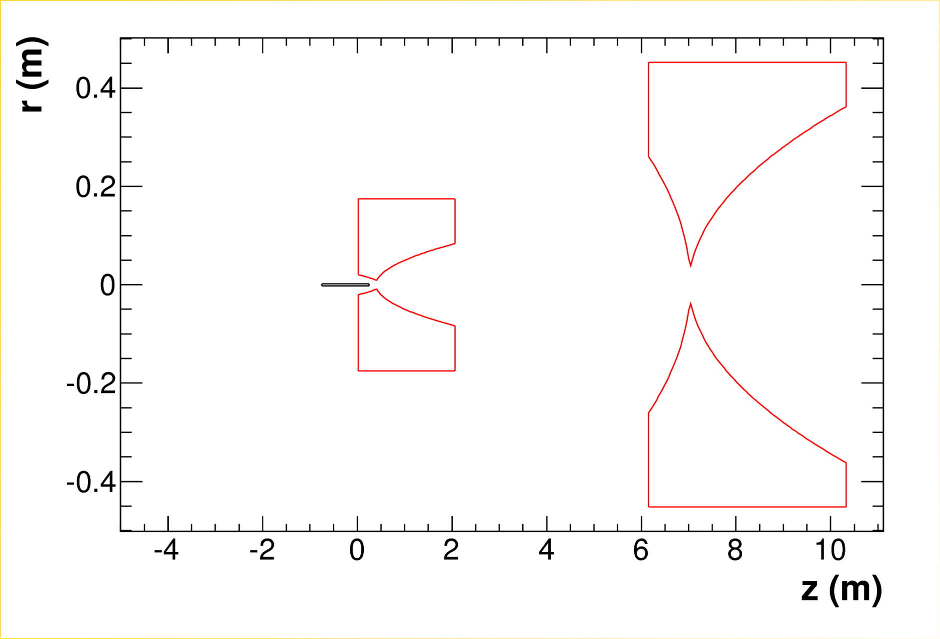
High-E_ν configuration fluxes

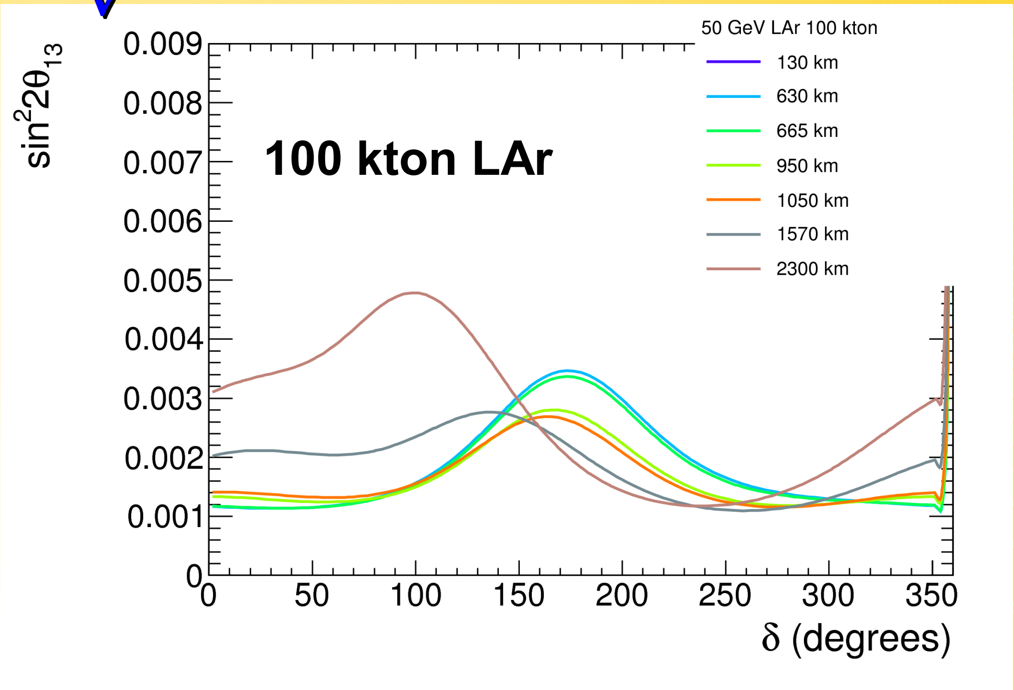


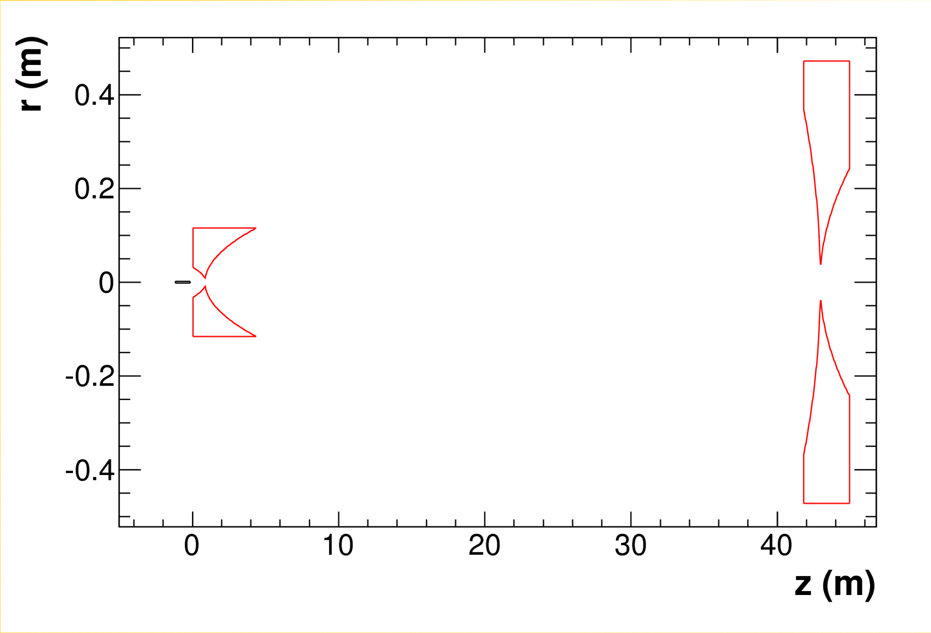
Low-E_ν configuration fluxes

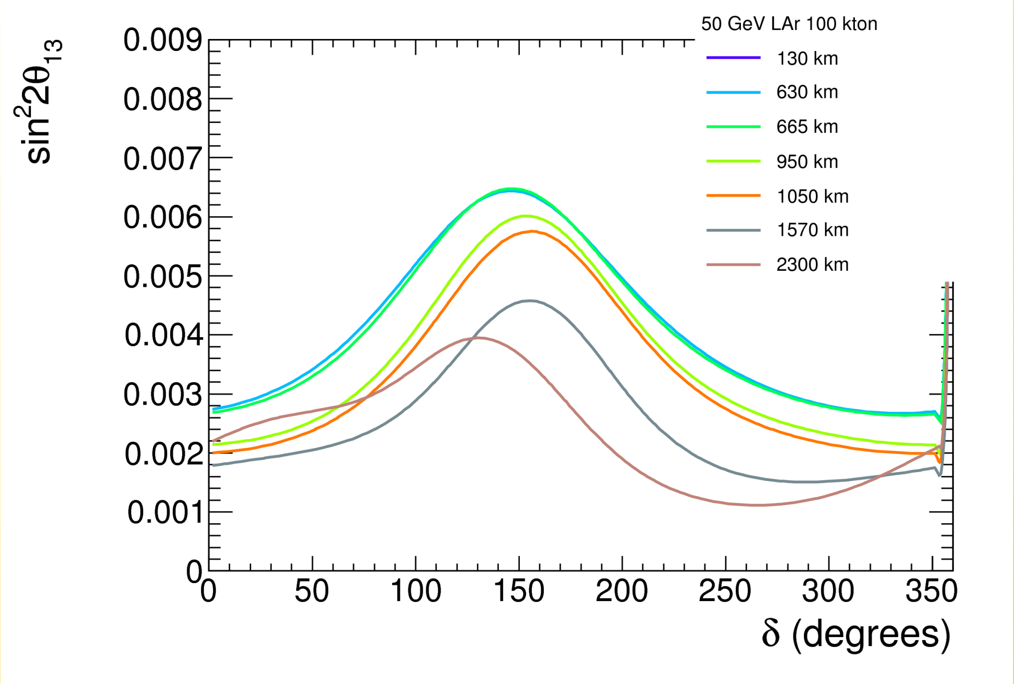


High-E_ν <~~> Low-E_ν configurations

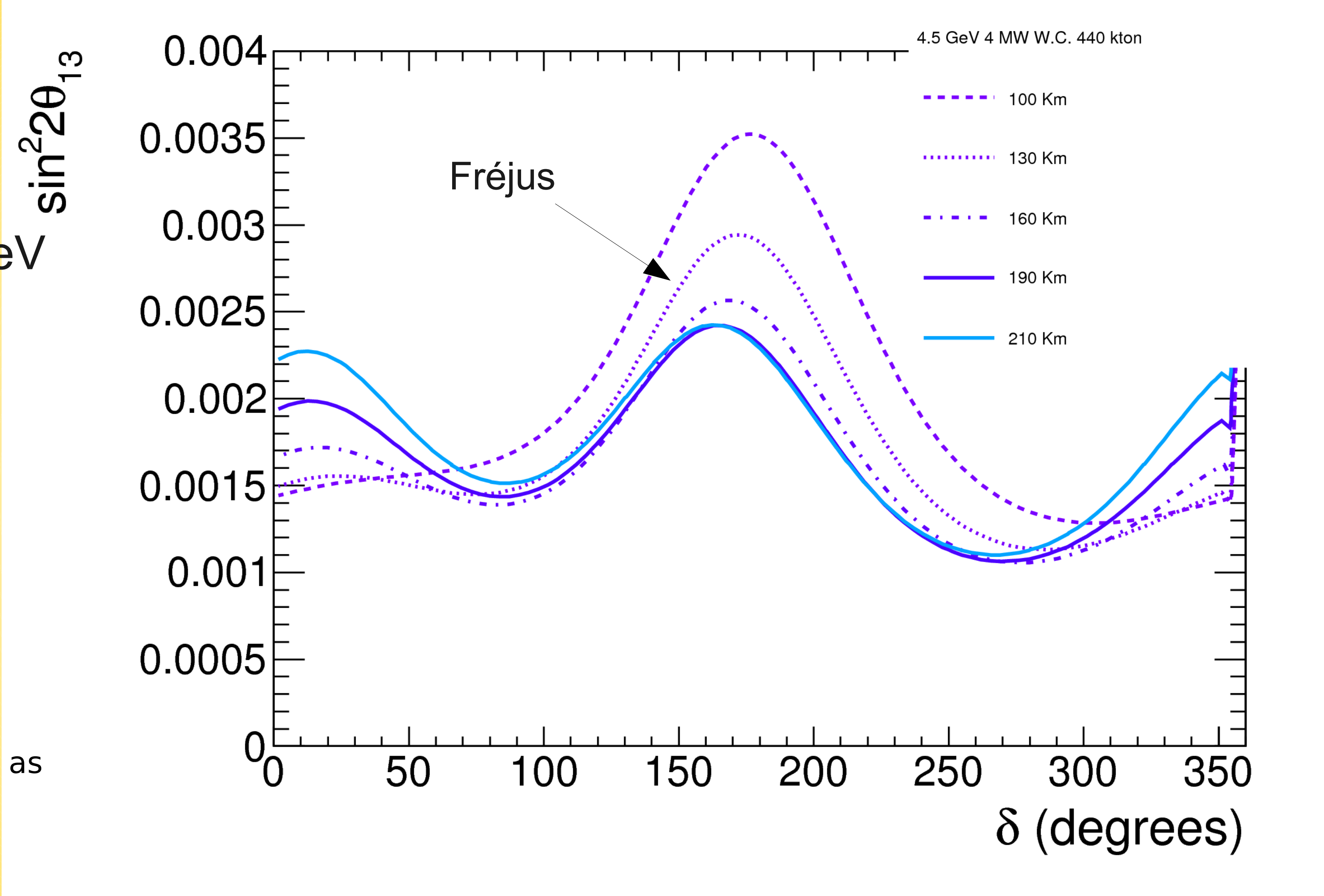








An exercise: SPL->W.C. at L≠130 km ?



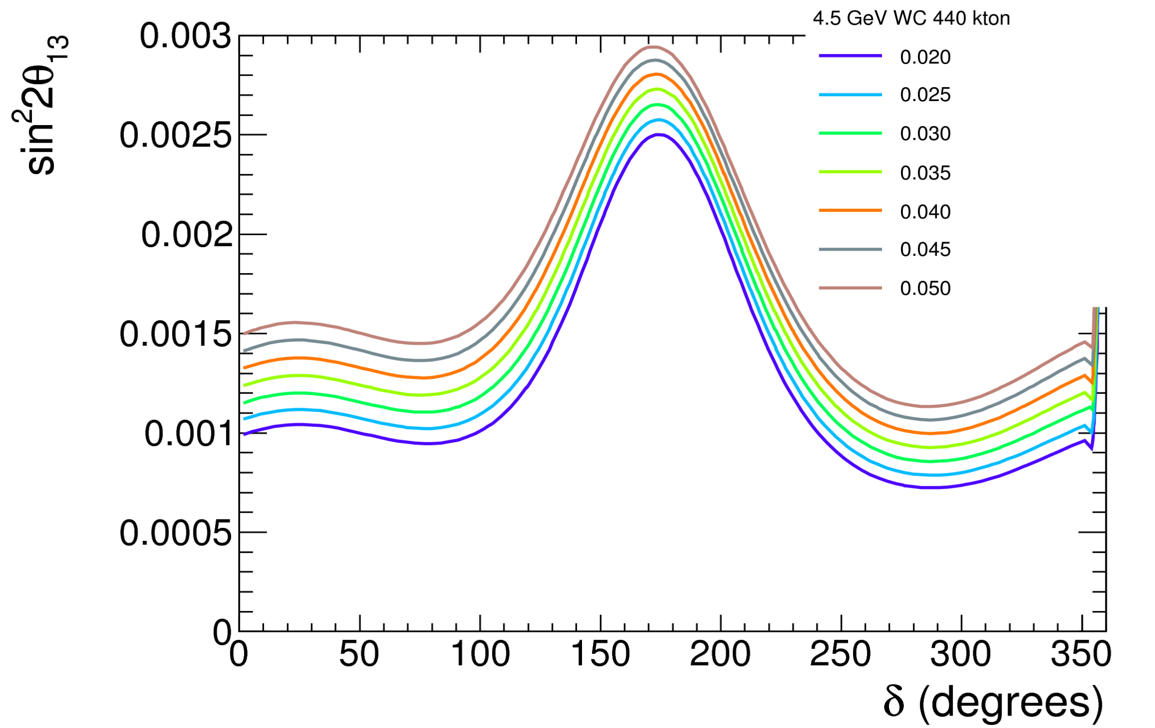
* HP-SPL 4.5 GeV
* $5.6 \cdot 10^{22}$ pot/y
* 5 % sys err.
* 440 kton WC
* 8+2 years
* 3σ C.L.
* GEANT4 for primary pions

Standard MEMPHYS description in GLoBES as for J. Phys. G29 (2003),1781-1784

The new focusing produces spectra with higher mean energy so that longer baselines ~ 160-200 Km become favored

Effect of systematics on fluxes

SPL

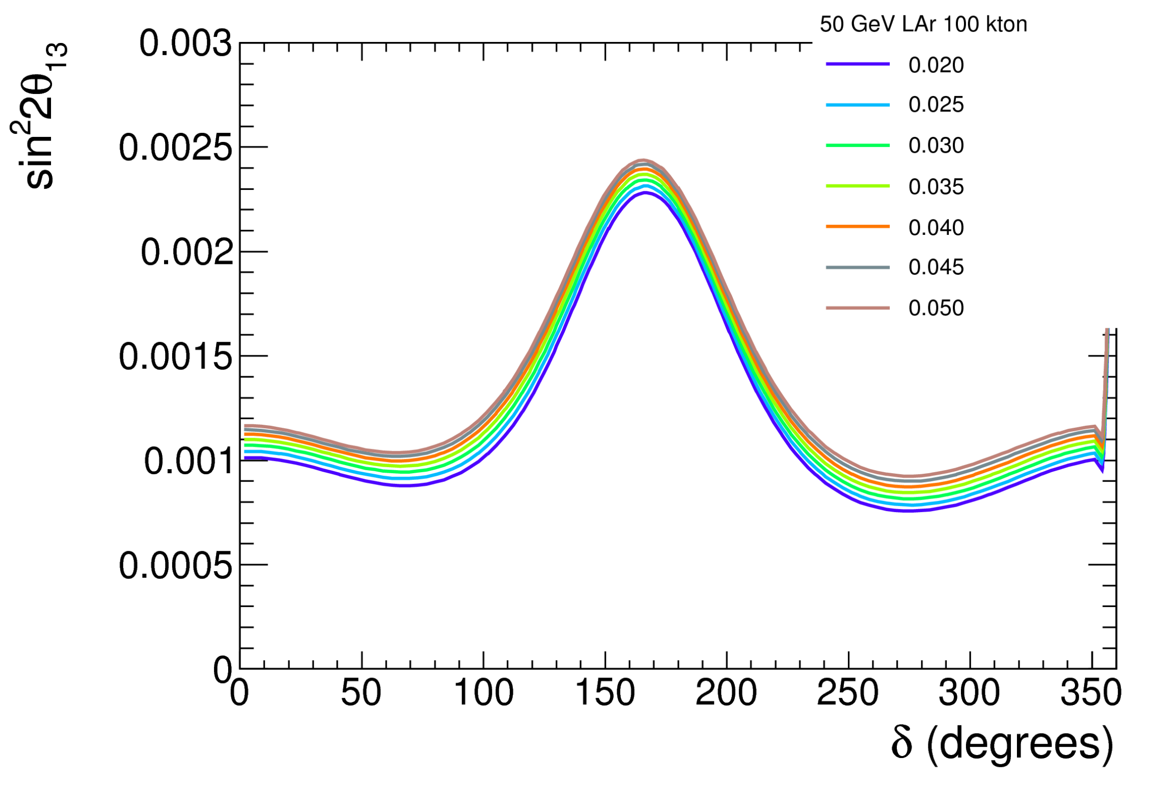


GloBES

less important for LAr

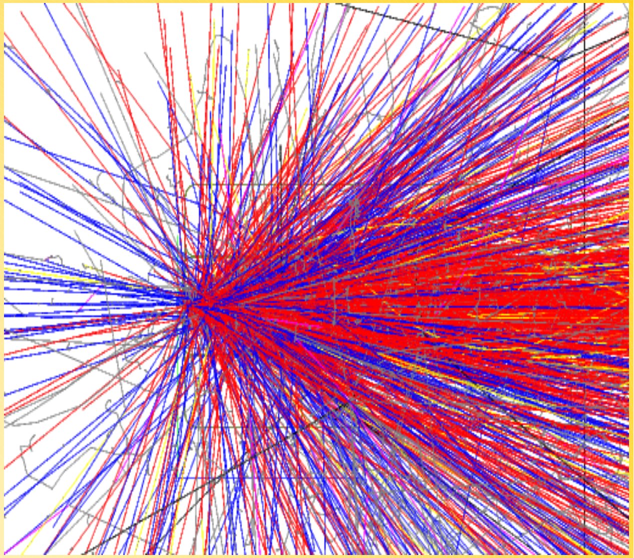
caveat: description of LAr detector in GloBES at a more basic level wrto to water Cherenkov

PS2



A. Longhin

Conclusions II



PS2 SuperBeam -> LAGUNA baselines (50 GeV)

Flexible GEANT4 ν-fluxes simulation developed and cross checked

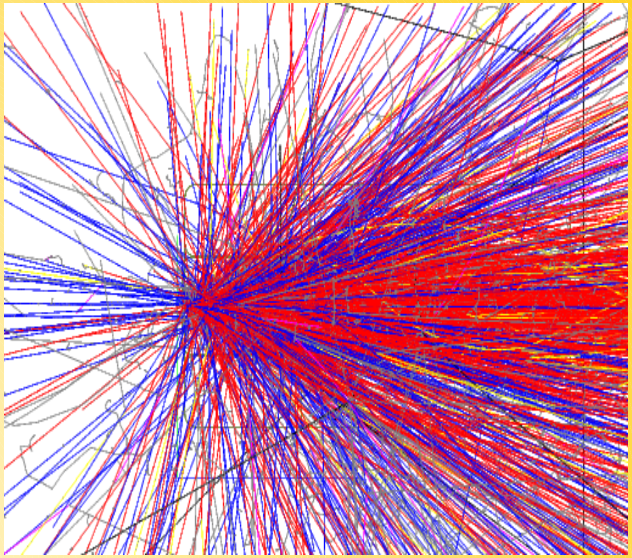
An interesting tool to study different options on an equal footing with "homogeneous" tools

Optimization tool written

Pair of preliminary configurations tuned for different baselines

Back-up slides

Conclusions I



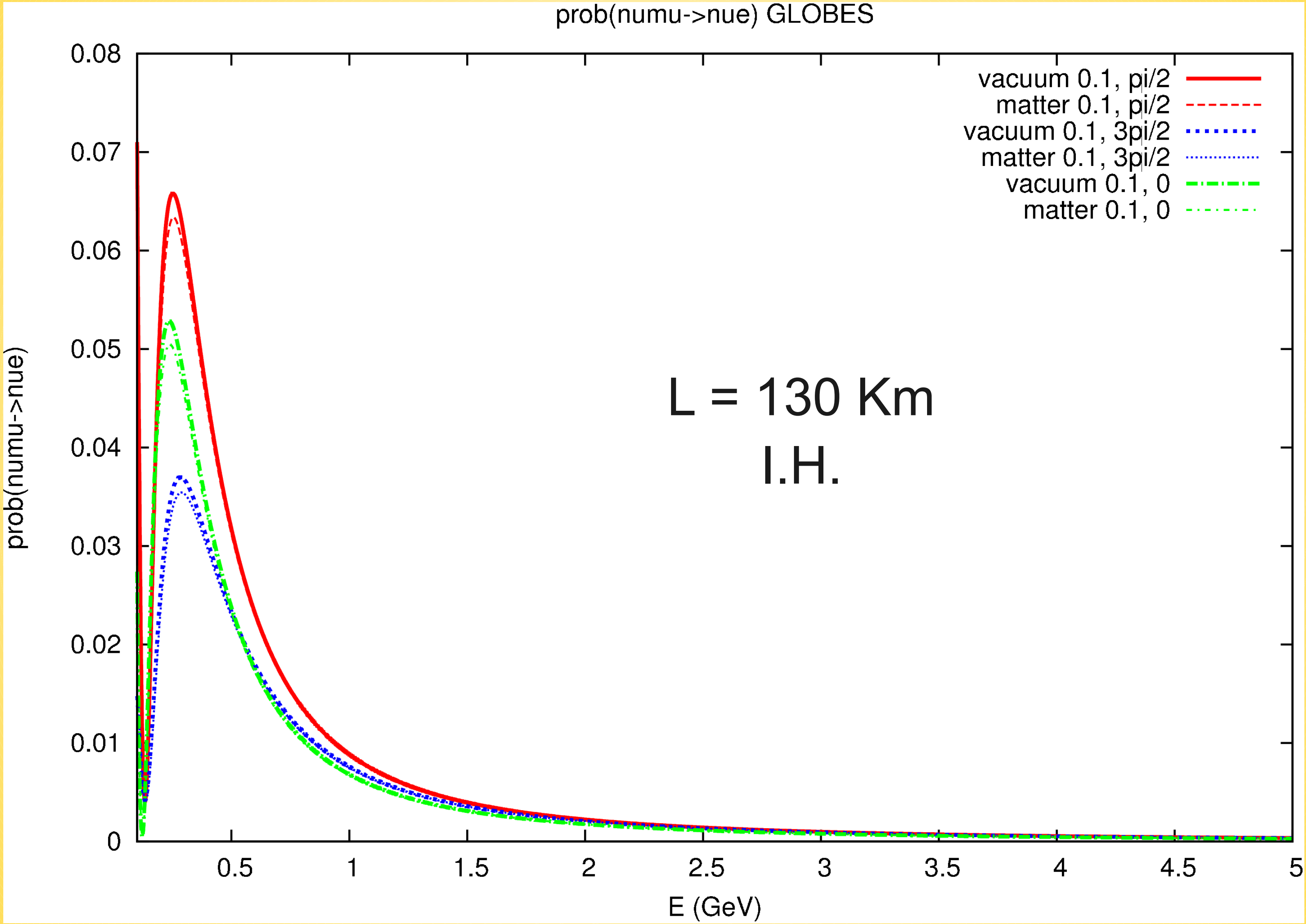
SPL-Fréjus Super Beam (4.5 GeV)

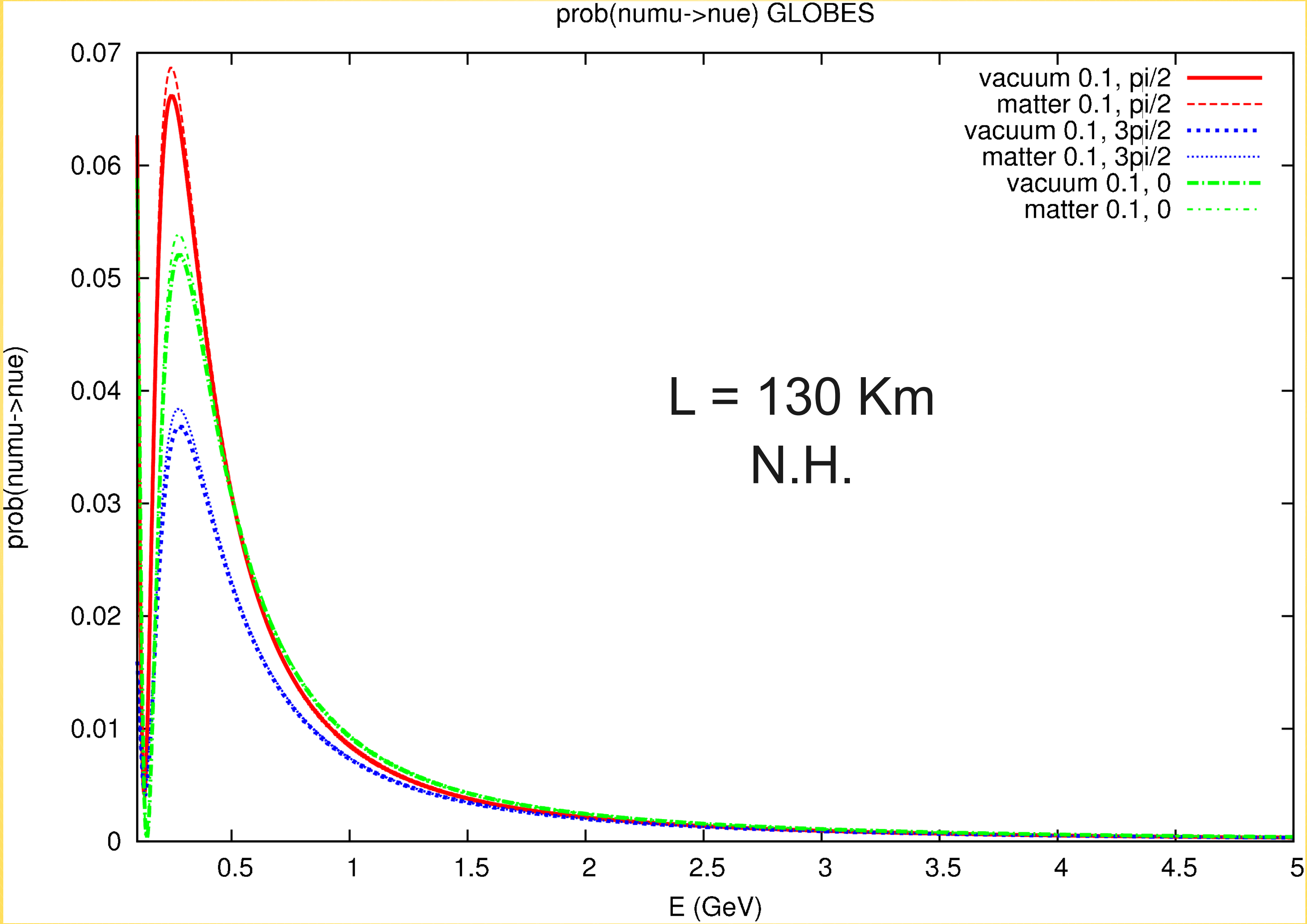
Activity revived within EUROnu WP2

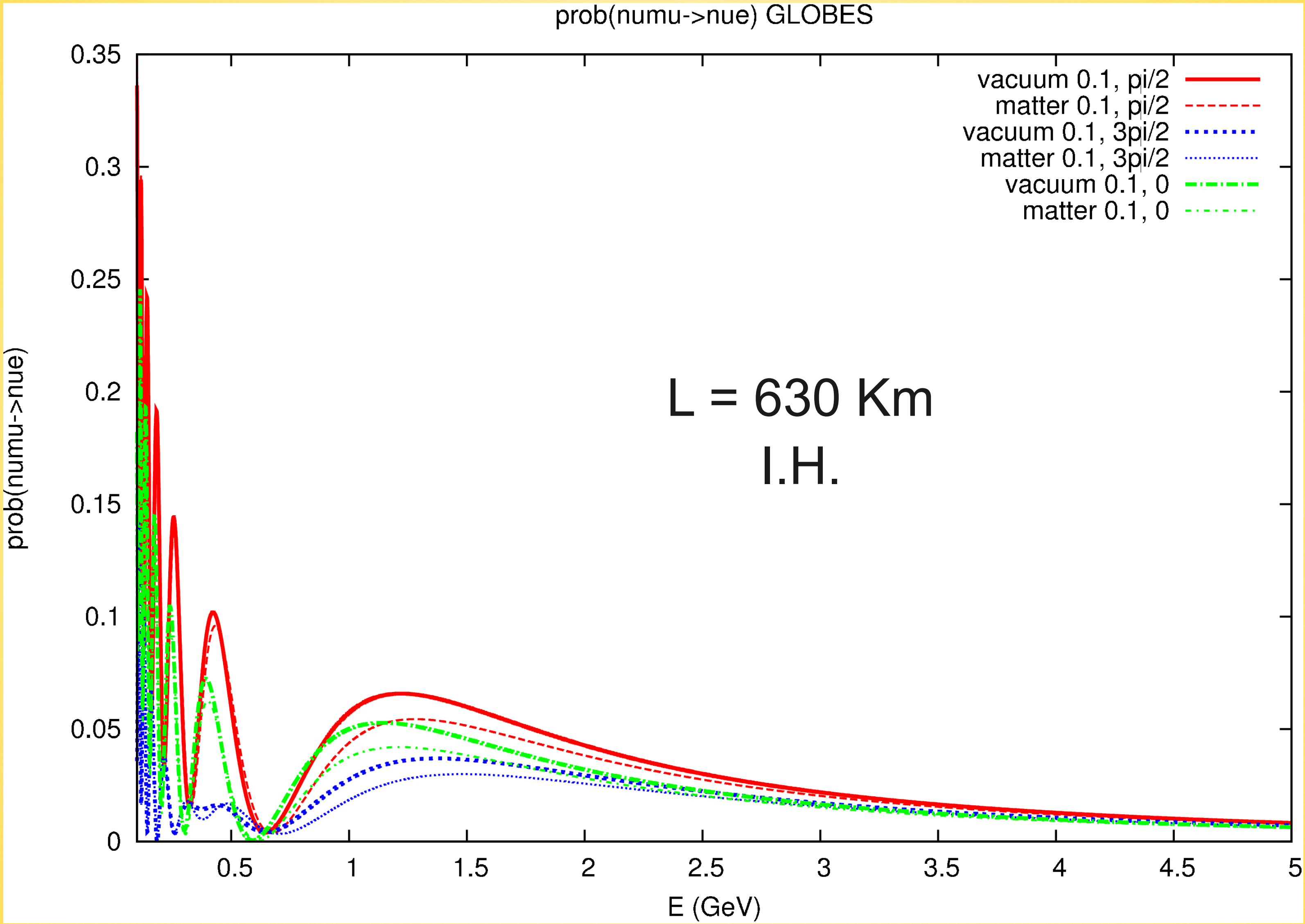
Simulation tools working and being updated
-GEANT-FLUKA-GLoBES-

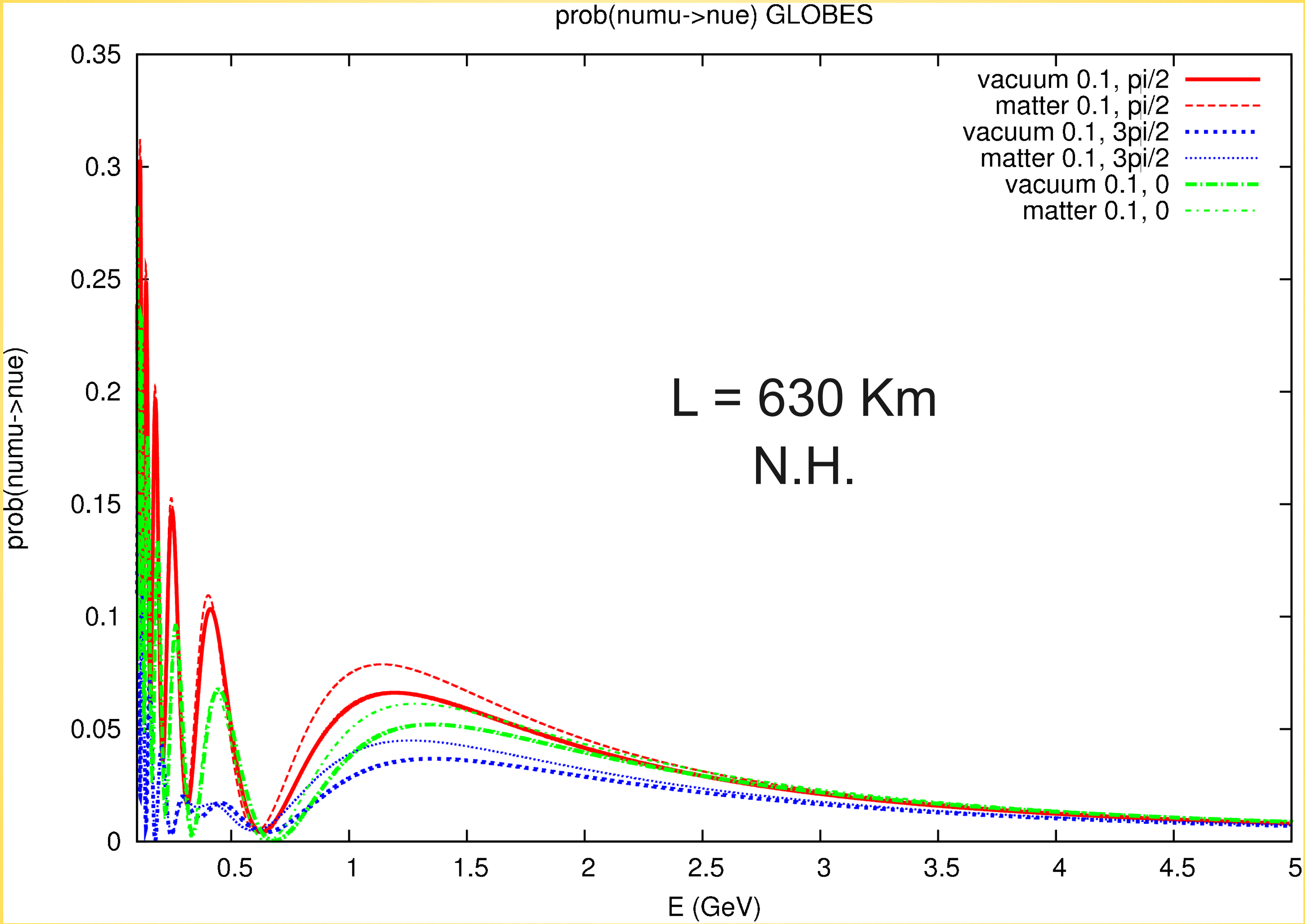
Solid target + multiple horns is now the new baseline

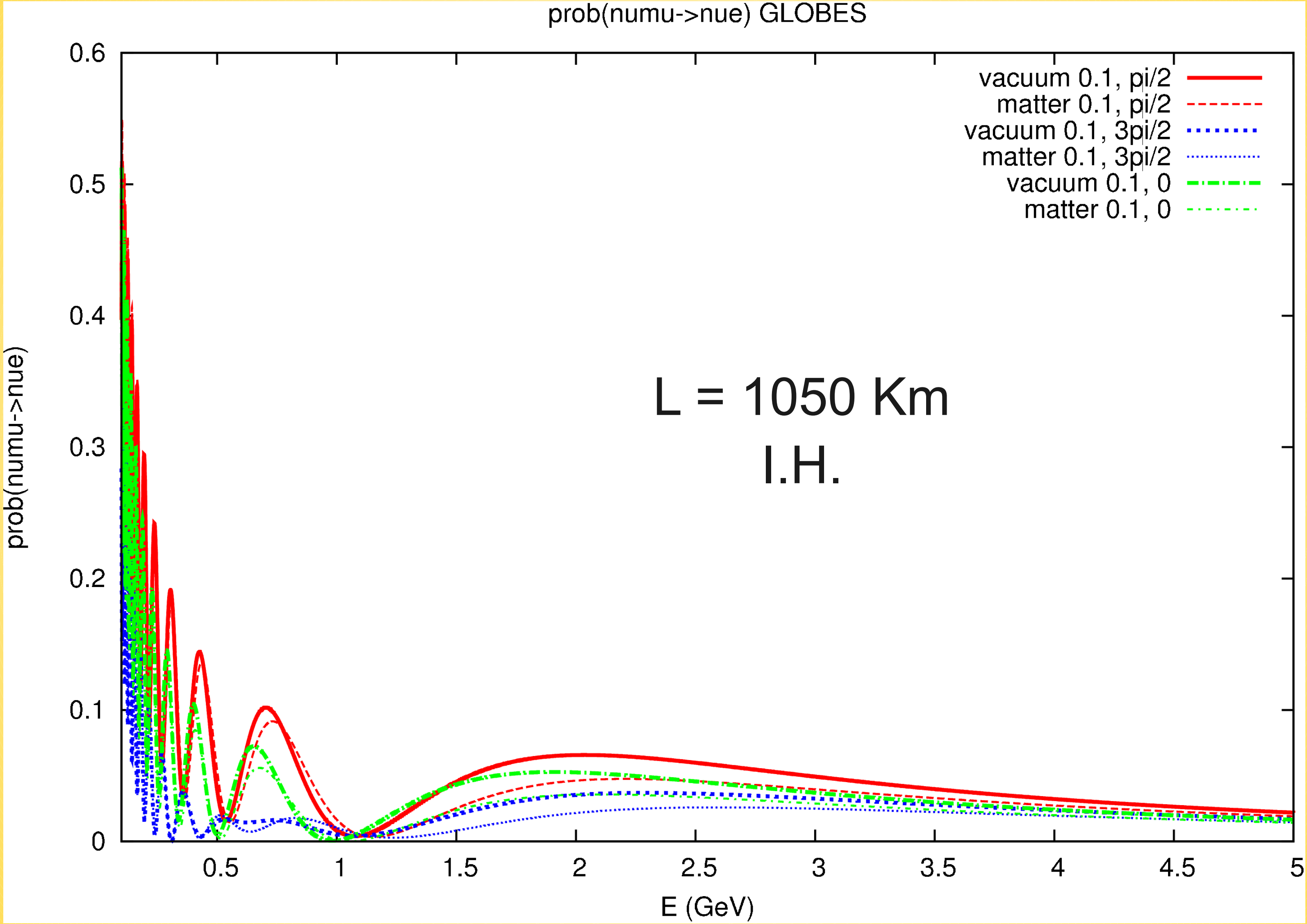
More realistic with better/similar physics reach!

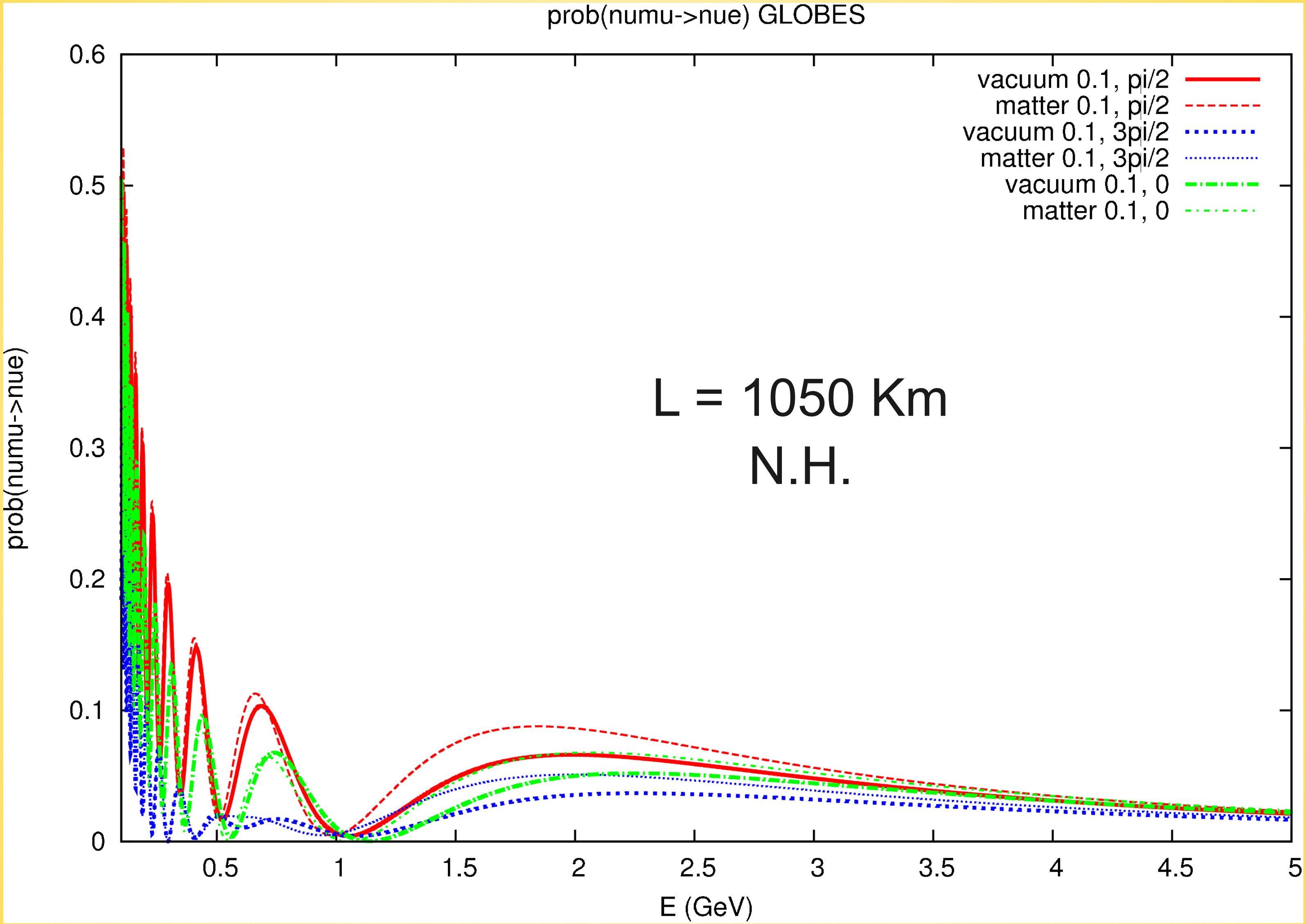

prob(numu->nue) GLOBES
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
E (GeV)
prob(numu->nue)
vacuum 0.1, pi/2
matter 0.1, pi/2
vacuum 0.1, 3pi/2
matter 0.1, 3pi/2
vacuum 0.1, 0
matter 0.1, 0
L = 130 Km
I.H.

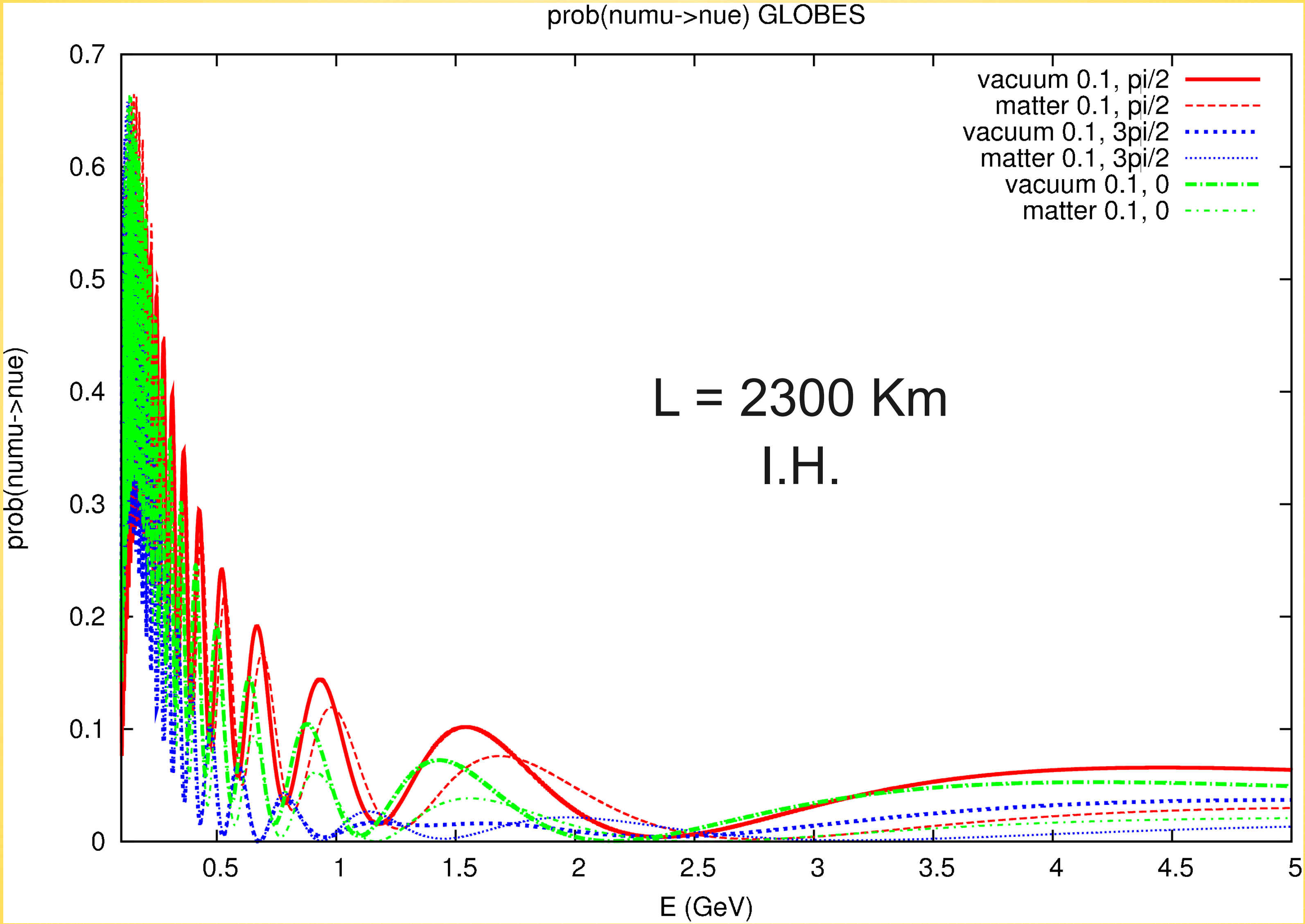

prob(numu->nue) GLOBES
vacuum 0.1, pi/2
matter 0.1, pi/2
vacuum 0.1, 3pi/2
matter 0.1, 3pi/2
vacuum 0.1, 0
matter 0.1, 0
L = 130 Km
N.H.
prob(numu->nue)
E (GeV)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

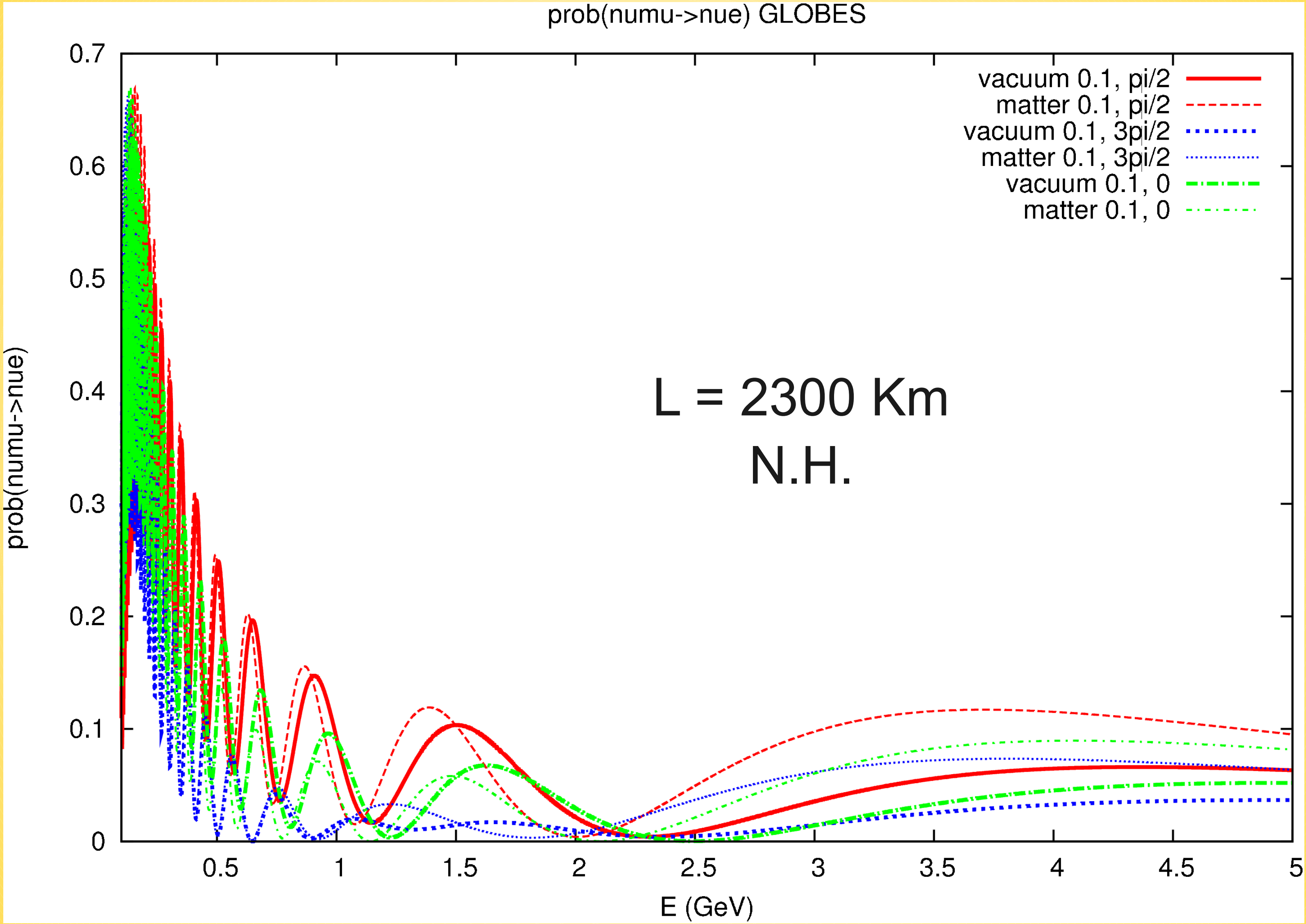

prob(numu->nue) GLOBES
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
prob(numu->nue)
vacuum 0.1, pi/2
matter 0.1, pi/2
vacuum 0.1, 3pi/2
matter 0.1, 3pi/2
vacuum 0.1, 0
matter 0.1, 0
L = 630 Km
I.H.
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
E (GeV)

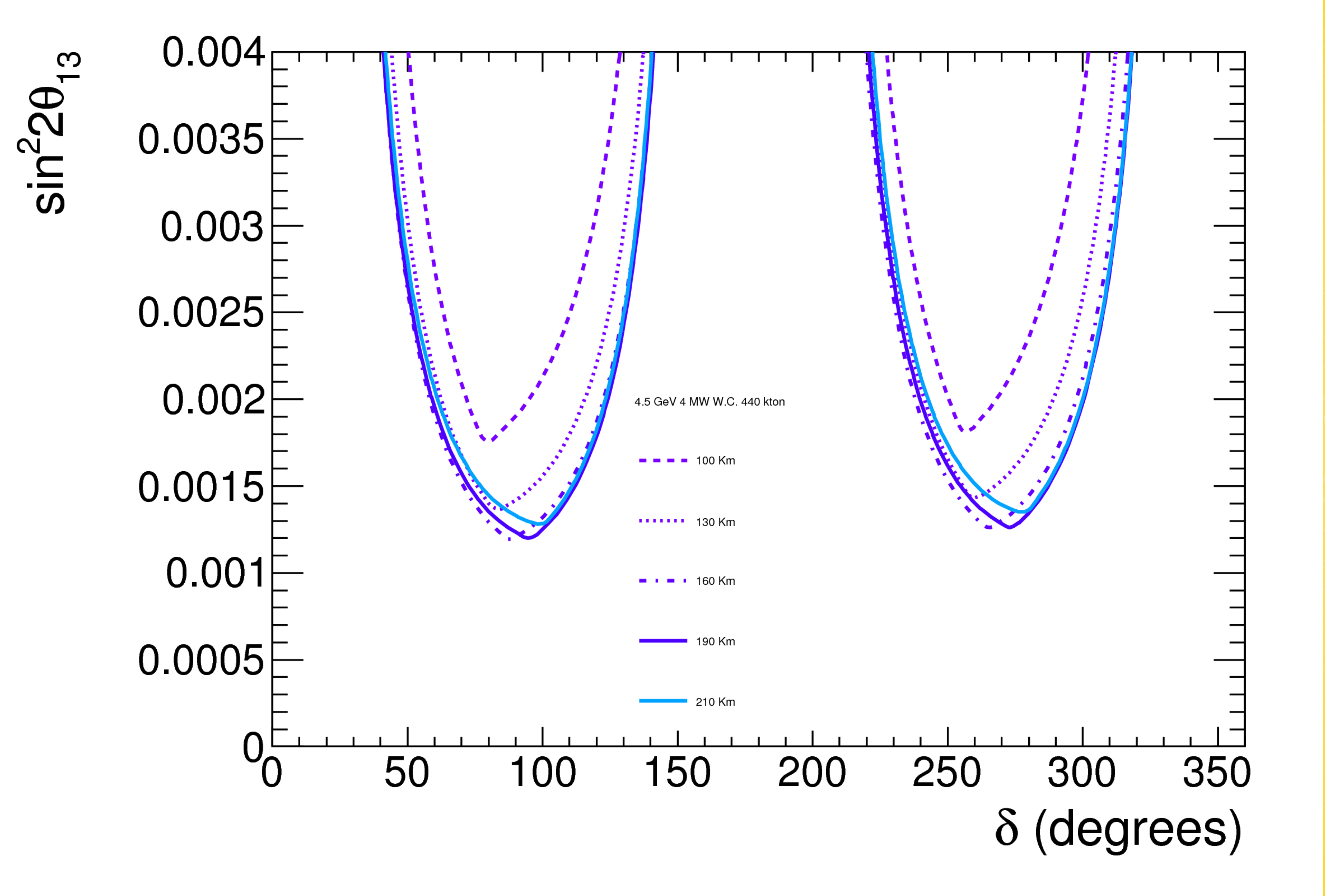

prob(numu->nue) GLOBES
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
prob(numu->nue)
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
E (GeV)
vacuum 0.1, pi/2
matter 0.1, pi/2
vacuum 0.1, 3pi/2
matter 0.1, 3pi/2
vacuum 0.1, 0
matter 0.1, 0
L = 630 Km
N.H.


prob(numu->nue) GLOBES
vacuum 0.1, pi/2
matter 0.1, pi/2
vacuum 0.1, 3pi/2
matter 0.1, 3pi/2
vacuum 0.1, 0
matter 0.1, 0
L = 1050 Km
I.H.
prob(numu->nue)
E (GeV)
0.6
0.5
0.4
0.3
0.2
0.1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


prob(numu->nue) GLOBES
0.6
0.5
0.4
0.3
0.2
0.1
0
prob(numu->nue)
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
E (GeV)
vacuum 0.1, pi/2
matter 0.1, pi/2
vacuum 0.1, 3pi/2
matter 0.1, 3pi/2
vacuum 0.1, 0
matter 0.1, 0
L = 1050 Km
N.H.


prob(numu->nue) GLOBES
vacuum 0.1, pi/2
matter 0.1, pi/2
vacuum 0.1, 3pi/2
matter 0.1, 3pi/2
vacuum 0.1, 0
matter 0.1, 0
L = 2300 Km
I.H.
prob(numu->nue)
E (GeV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


prob(numu->nue) GLOBES
vacuum 0.1, pi/2
matter 0.1, pi/2
vacuum 0.1, 3pi/2
matter 0.1, 3pi/2
vacuum 0.1, 0
matter 0.1, 0
L = 2300 Km
N.H.
prob(numu->nue)
E (GeV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5



$\sin^2 2\theta_{13}$
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
0
50
100
150
200
250
300
350
δ (degrees)
4.5 GeV 4 MW W.C. 440 kton
100 Km
130 Km
160 Km
190 Km
210 Km