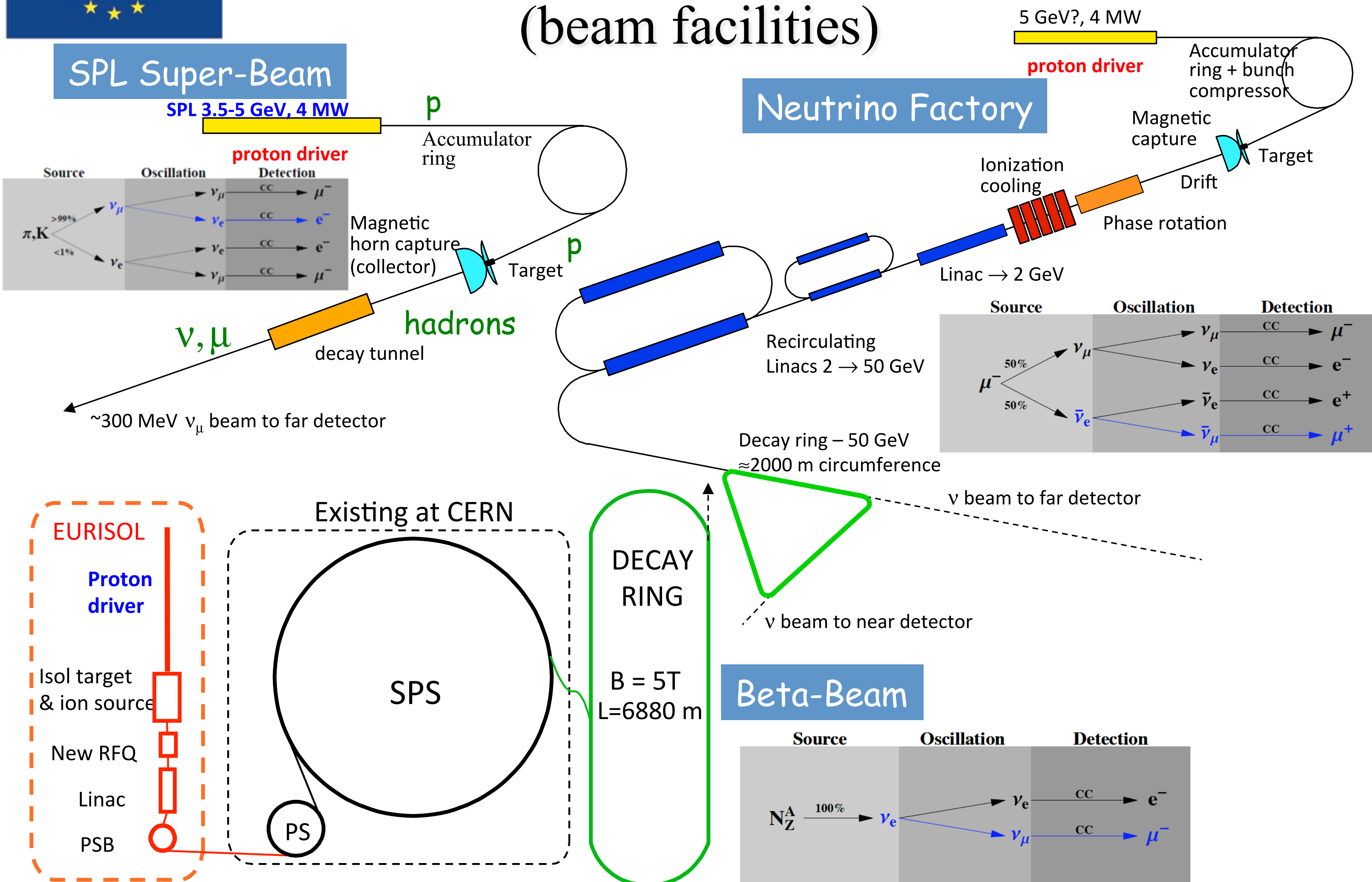
ESS based neutrino Super Beam for CP Violation discovery

Marcos DRACOS
IPHC-IN2P3/CNRS Strasbourg

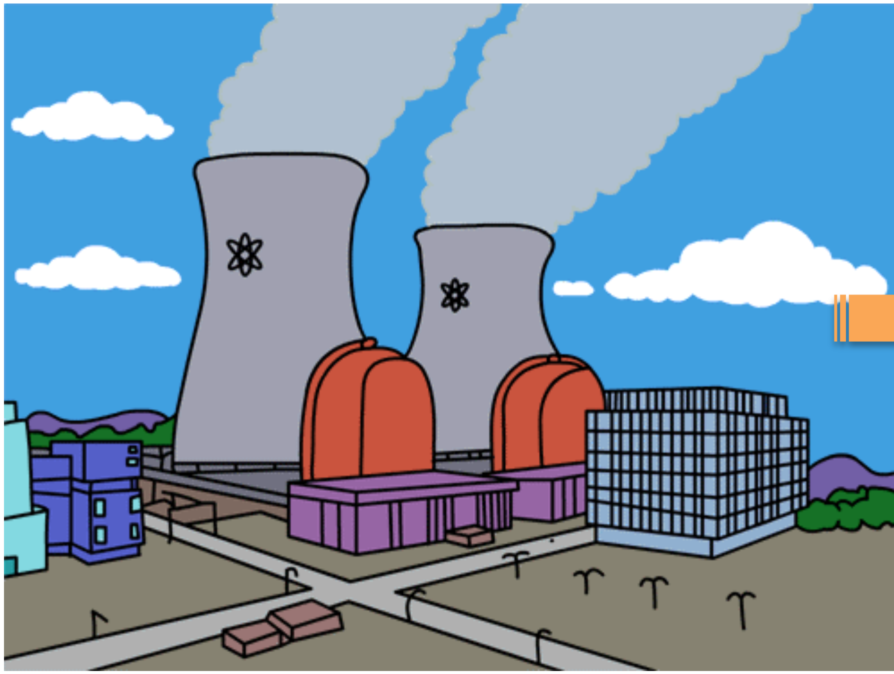
EUROnu Projects
(beam facilities)



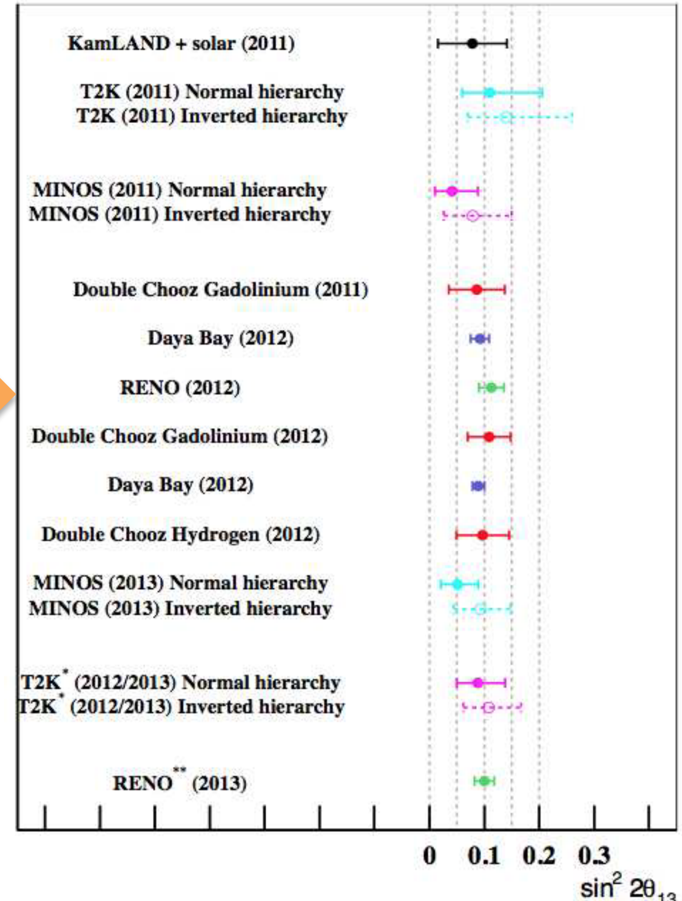
^{6}He for ν_e and ^{18}Ne for $\bar{\nu}_e$

θ_{13} is large!!!

reactor experiments discovered the 1→3 oscillation



measurements



year

proposed facilities have to be readjusted…
now, the name of the game is CPV

CP Violating Observables (and MH)

$$P_{\nu_\mu\to\nu_e(\bar\nu_\mu\to\bar\nu_e)} = s_{23}^2\sin^2 2\theta_{13}\left(\frac{\Delta_{13}}{\tilde B_\mp}\right)^2\sin^2\left(\frac{\tilde B_\mp L}{2}\right)$$ atmospheric

$$+c_{23}^2\sin^2 2\theta_{12}\left(\frac{\Delta_{12}}{A}\right)^2\sin^2\left(\frac{AL}{2}\right)$$ solar

Non-CP terms

$$+\tilde J\,\frac{\Delta_{12}}{A}\frac{\Delta_{13}}{\tilde B_\mp}\sin\left(\frac{AL}{2}\right)\sin\left(\frac{\tilde B_\mp L}{2}\right)\cos\left(\pm\delta_{CP}-\frac{\Delta_{13}L}{2}\right)$$ interference

CP violating

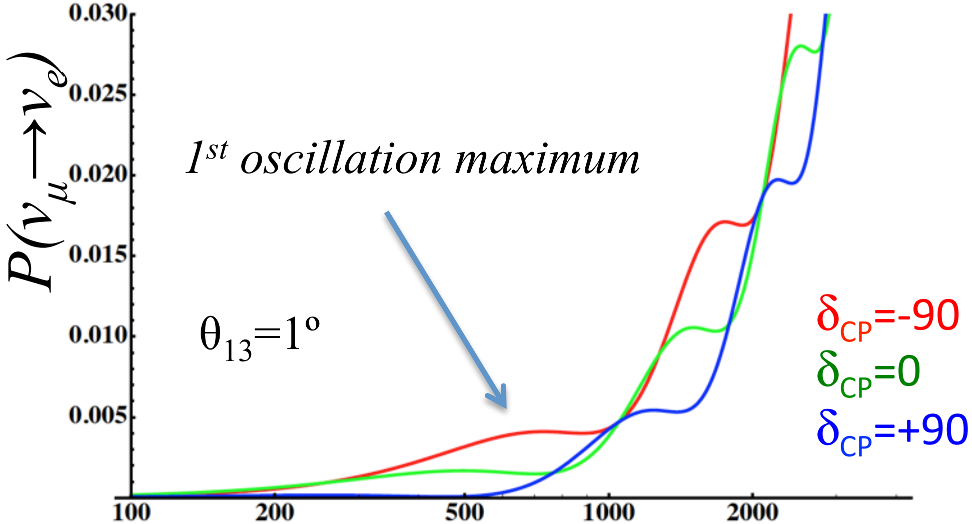
$$\tilde J \equiv c_{13}\sin 2\theta_{12}\sin 2\theta_{23}\sin 2\theta_{13},\ \Delta_{ij}\equiv\frac{\Delta m_{ij}^2}{2E_\nu},\ \tilde B_\mp \equiv \left|A\mp\Delta_{13}\right|,\ A=\sqrt{2}G_F N_e$$

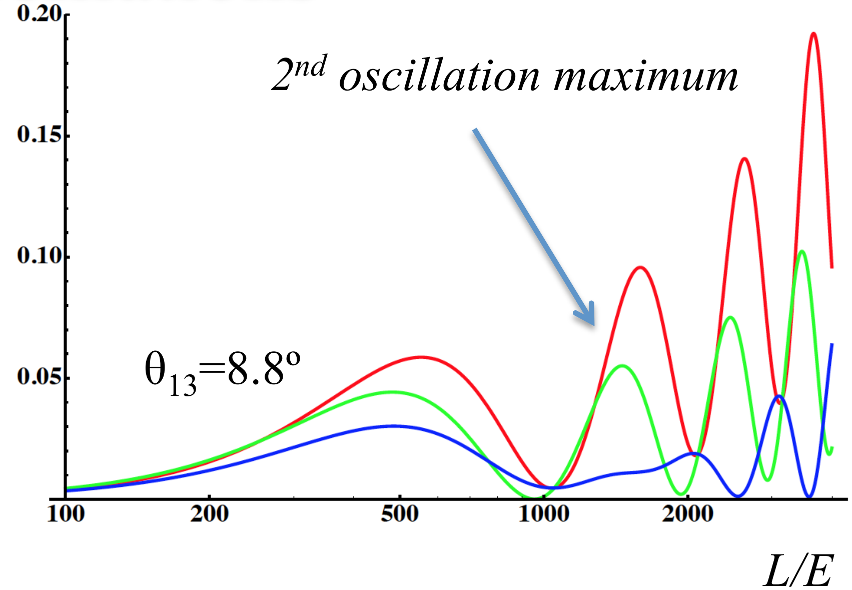
matter effect ⇒ accessibility to mass hierarchy ⇒ long baseline

$$\mathcal{A} = \frac{P_{\nu_\mu\to\nu_e} - P_{\bar\nu_\mu\to\bar\nu_e}}{P_{\nu_\mu\to\nu_e} + P_{\bar\nu_\mu\to\bar\nu_e}}$$

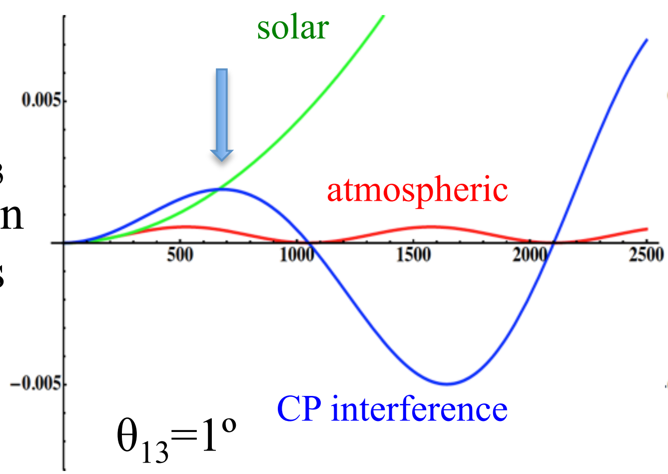
≠0 ⇒ CP Violation
be careful, matter effects also create asymmetry

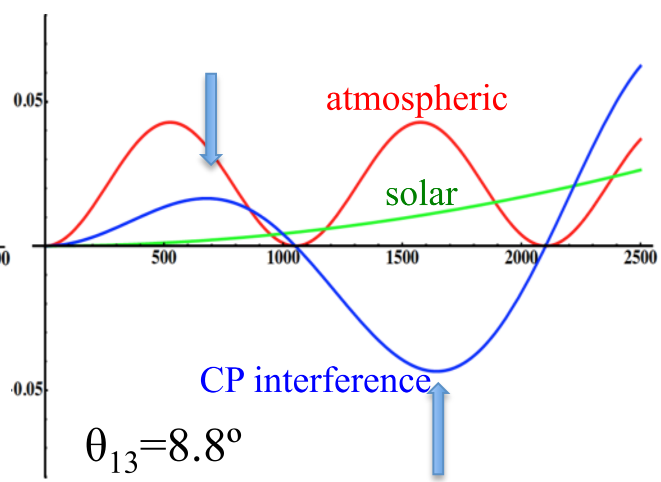
Neutrino Oscillations





for small θ_{13} 1^{st} oscillation maximum is better





for "large" θ_{13} 1^{st} oscillation maximum is dominated by atmospheric term, 2^{nd} oscillation maximum is better

(arXiv:1110.4583)

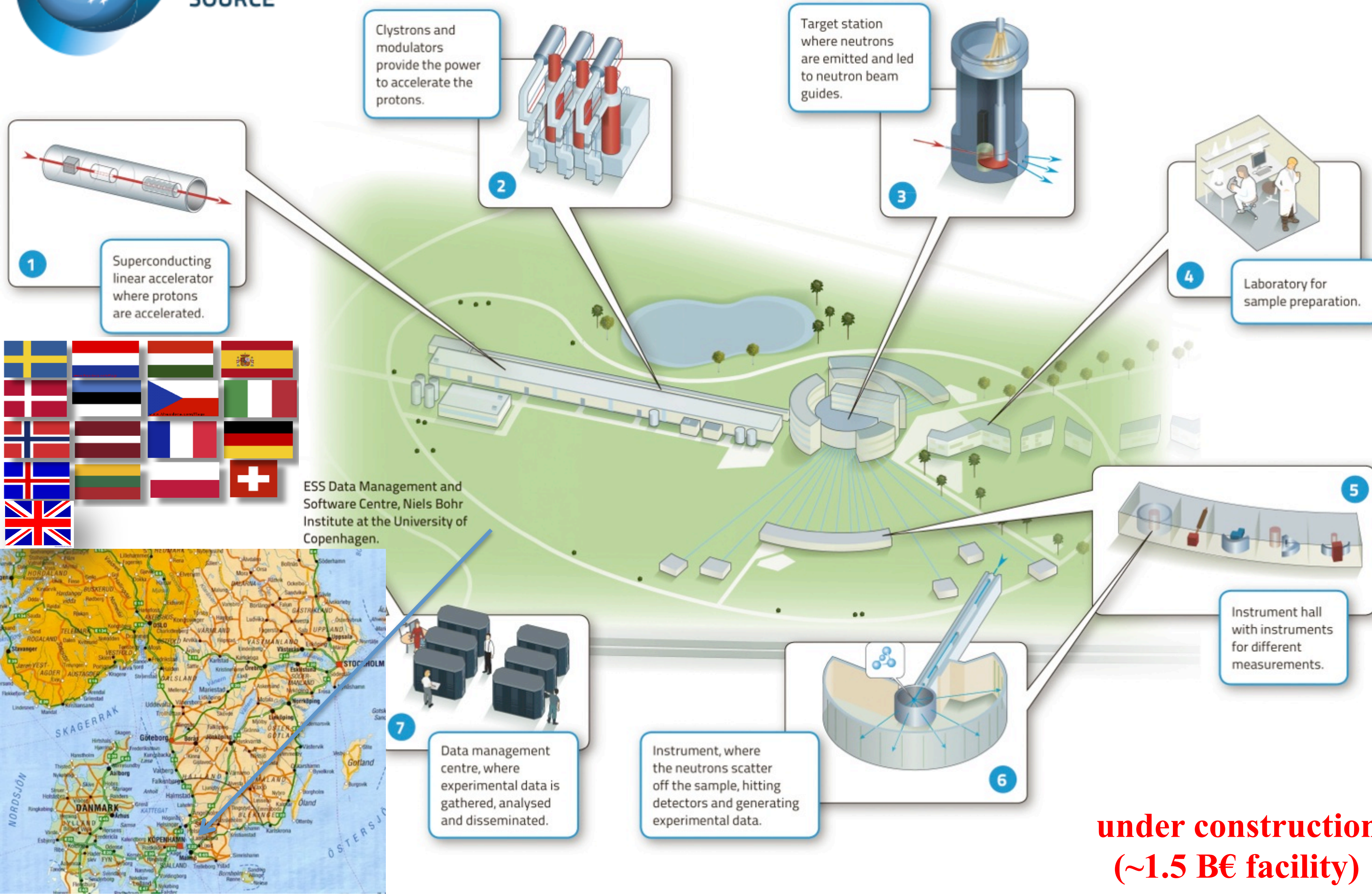
SPL not any more part of LHC upgrades

Any other intense proton source in Europe?

(in the context of European Strategy for Particle Physics)

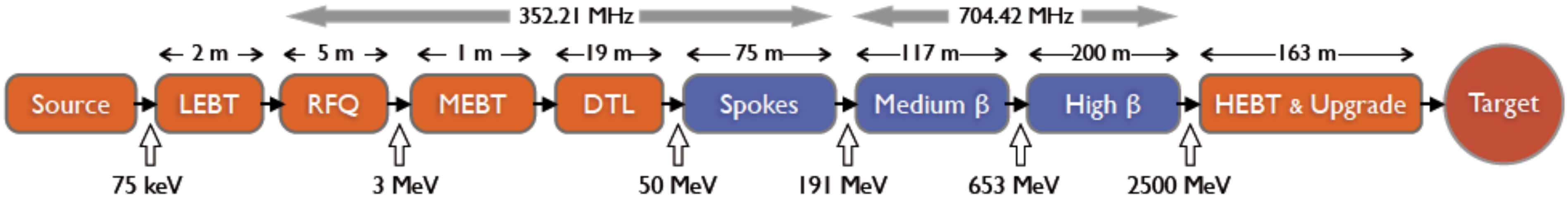
f) Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector. CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading neutrino projects in the US and Japan.

European Spallation Source

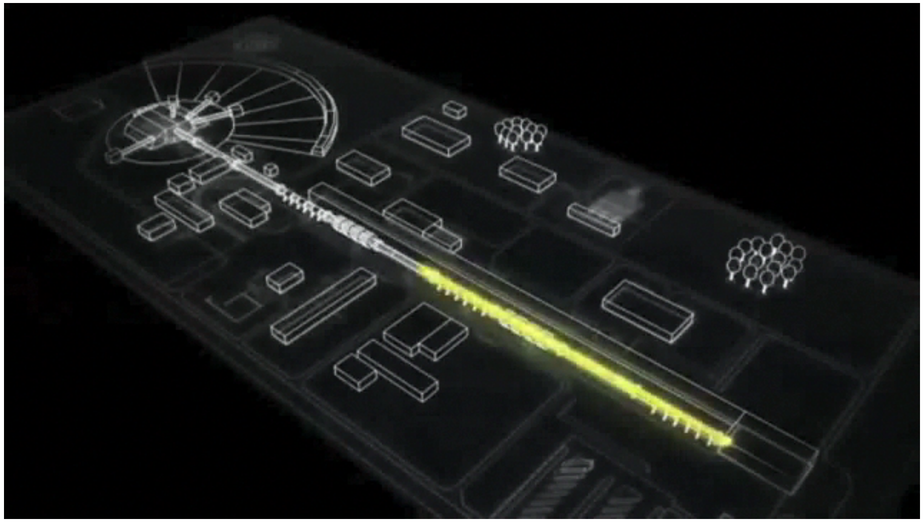


under construction
(~1.5 B€ facility)

ESS proton linac



- The ESS will be a copious source of spallation neutrons
- 5 MW average beam power
- 125 MW peak power
- 14 Hz repetition rate (2.86 ms pulse duration, 10^{15} protons)
- 2.5 GeV protons (up to 3.0 GeV with linac upgrades)
- **>2x10^{23} p.o.t/year**



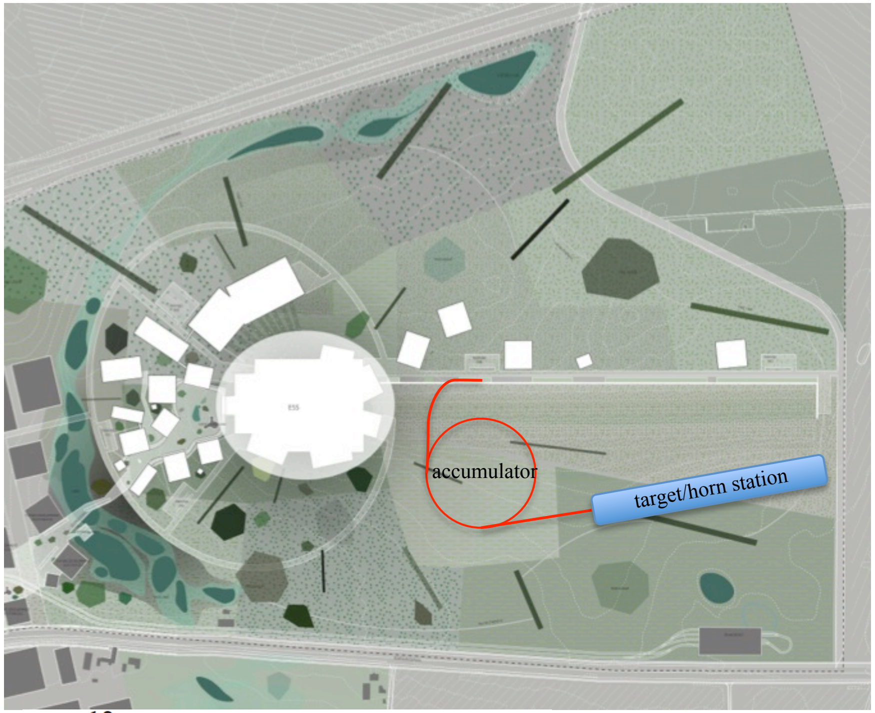
ESS Schedule

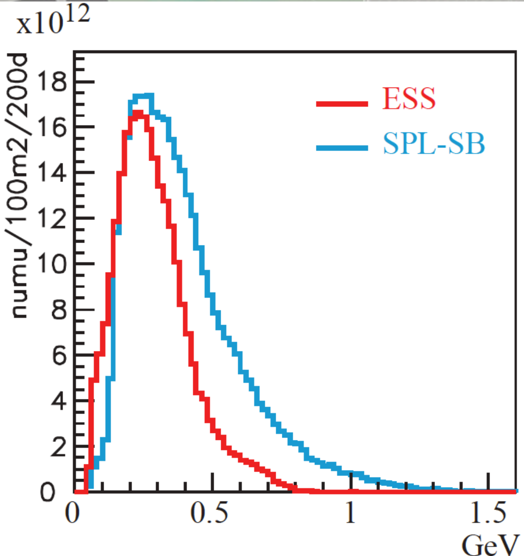
2010 -	**ESS Company set up**
2010 - 2012	**Technical Design Review**
2010 - 2012	**Pre-Construction & Site Planning**
2009 - 2012	**Licensing and Planning**
2010 - 2012	**Finalisation of international negotiations**
2013 - 2019	**Construction Phase - 7 instruments**
2019 - 2025	**Completion Phase - all 22-33 instruments in place**
2026 - 2066	**Operations Phase**
2066 – 2071	**Decommissioning Phase**

- 1st beam before the end of the decade
- 5 MW by 2023

How to add a neutrino facility?

- We must not affect the neutron program and if possible be synergetic
- Linac modifications: double the rate (14 Hz → 28 Hz)
- Accumulator (ø 143 m) needed to compress to few μs the 2.86 ms proton pulses, affordable by the magnetic horn (350 kA, power consumption, Joule effect)
  - H^- source (instead of protons)
  - space charge problems to be solved
- Target station (studied in EUROnu)
- Underground detector (studied in LAGUNA)
- ~300 MeV neutrinos
- Linac and accumulator could be the first step towards the Neutrino Factory

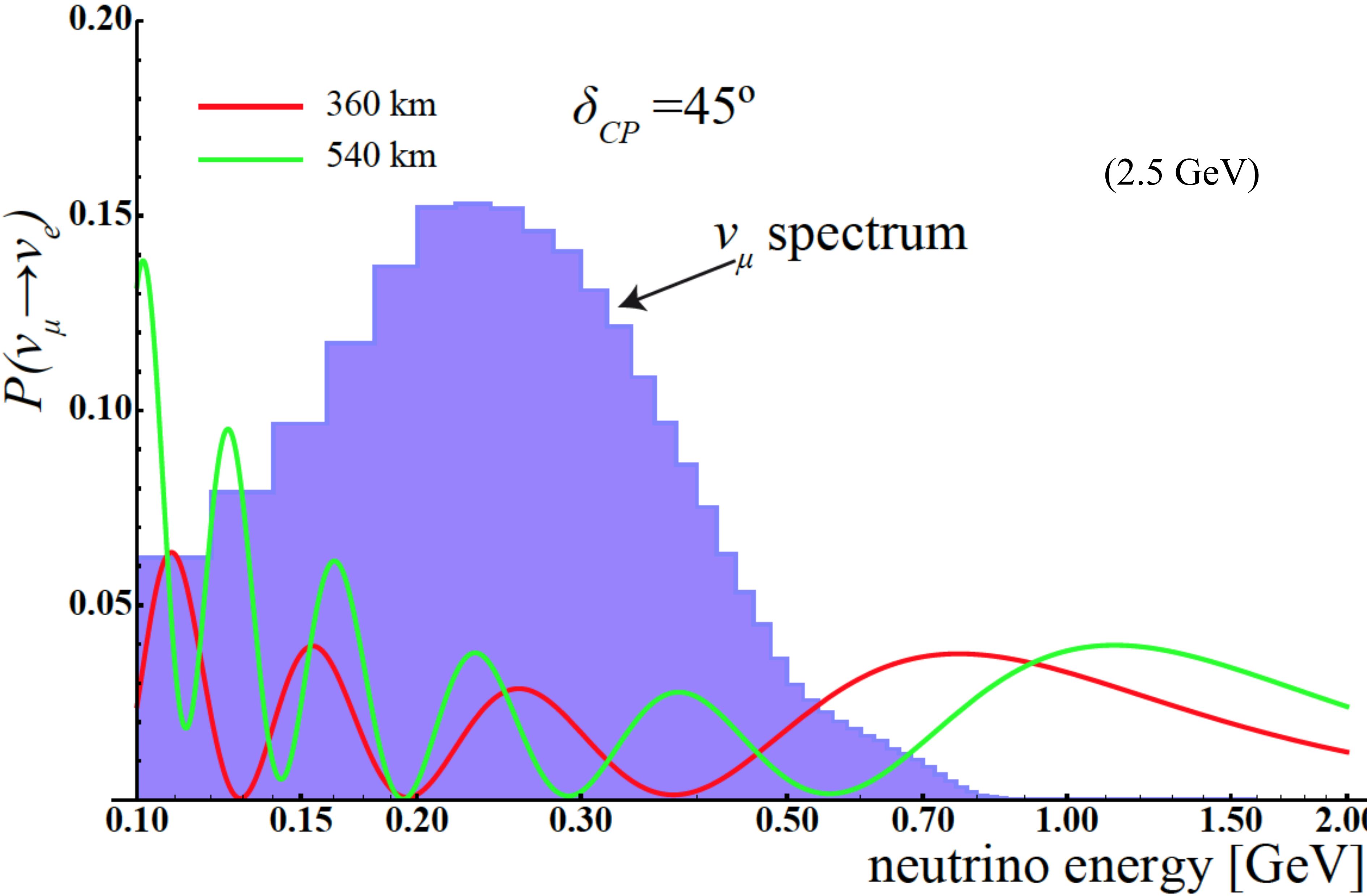




flux at 100 km

(http://lanl.arxiv.org/abs/1212.5048)

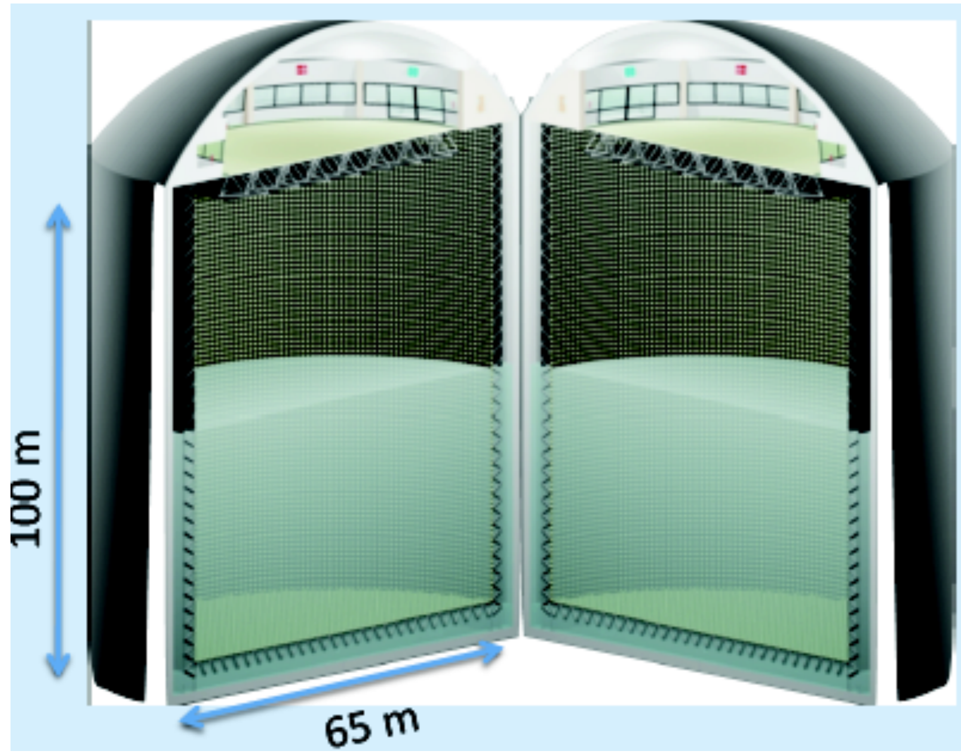
Neutrino Oscillations



The MEMPHYS Detector (Water Cherenkov) (LAGUNA)

Mainly to study:

- **Proton Decay (GUT)**
  - up to ~10^{35} years lifetime
- **Neutrino properties and Astrophysics**
  - Supernovae (burst + "relics")
  - Solar neutrinos
  - Atmospheric neutrinos
  - Geoneutrinos
  - neutrinos from accelerators (Super Beam, Beta Beam)

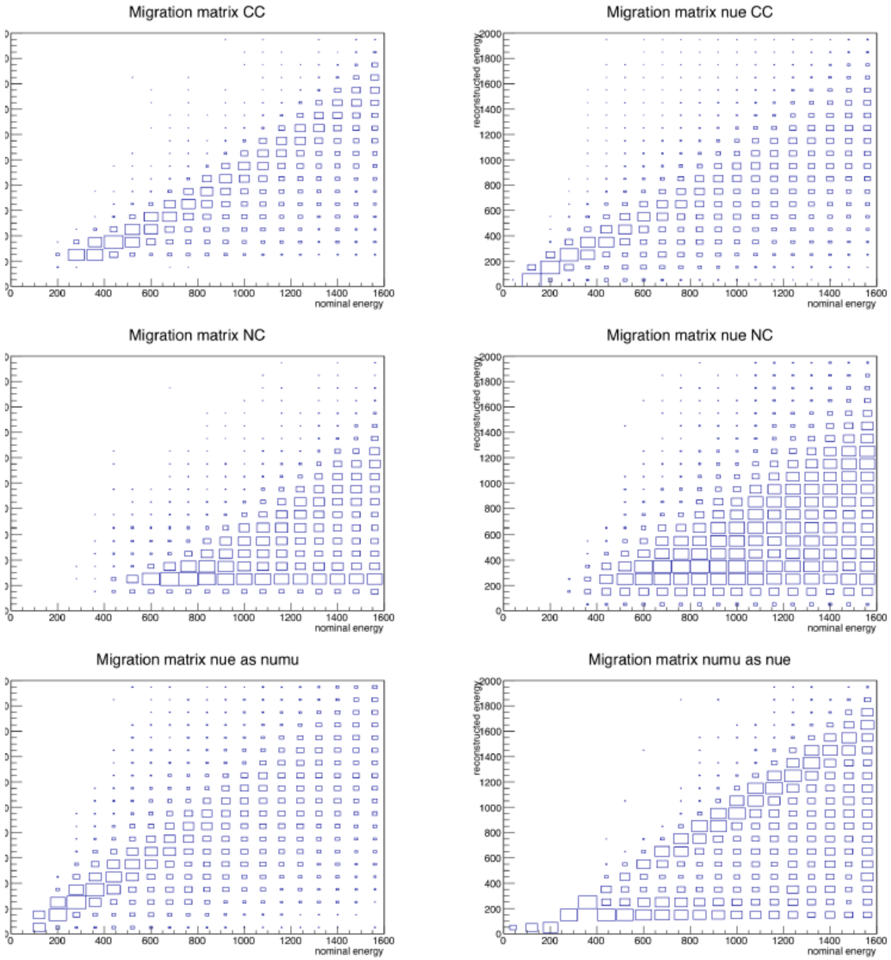


Water Cerenkov Detector with total fiducial mass: 500 kt:
- 2 Cylindrical modules 100x65 m
- Readout: 22.2k 8" PMTs, 30% geom. cover.

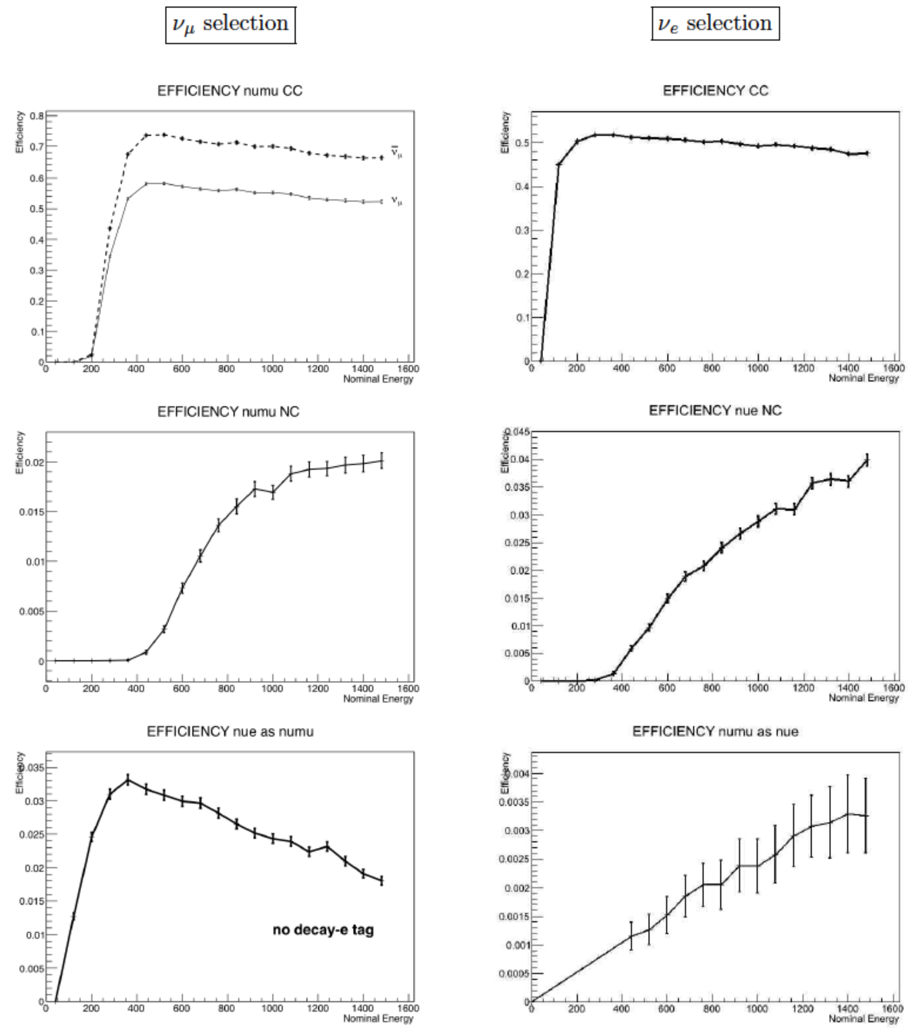
(arXiv: hep-ex/0607026)

MEMPHYS Parameters

migration matrices



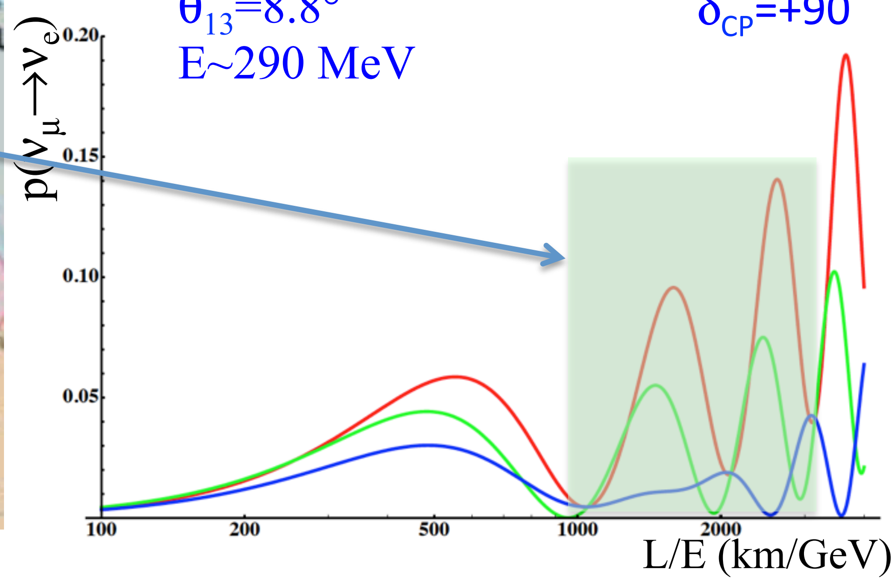
detection efficiency



Possible Detector Locations

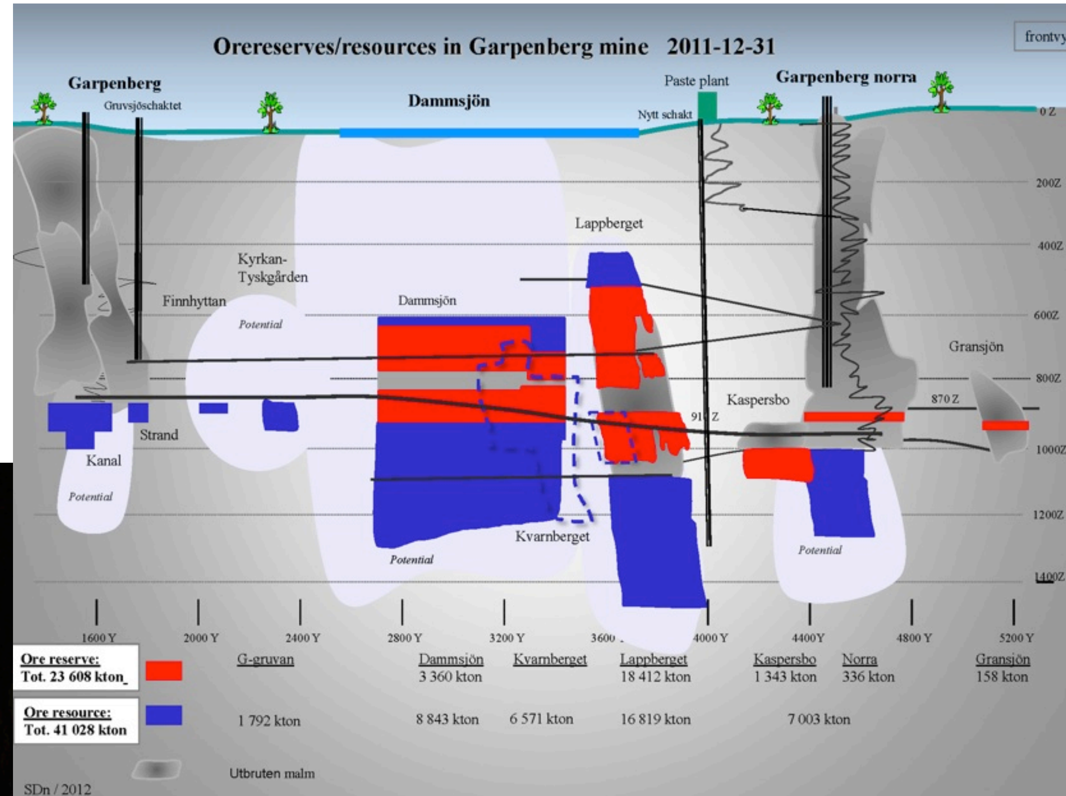
- Many mines (active or not) are available in Sweden
- What is the optimal position for CPV?
- How this project could help for MH?

$\Delta m^2_{sun}=7.5\text{x}10^{-5}\ eV^2$
$\Delta m^2_{atm}=2.4\text{x}10^{-3}\ eV^2$
$\theta_{23}=41.4°$
$\theta_{12}=33.6°$
$\theta_{13}=8.8°$
E~290 MeV



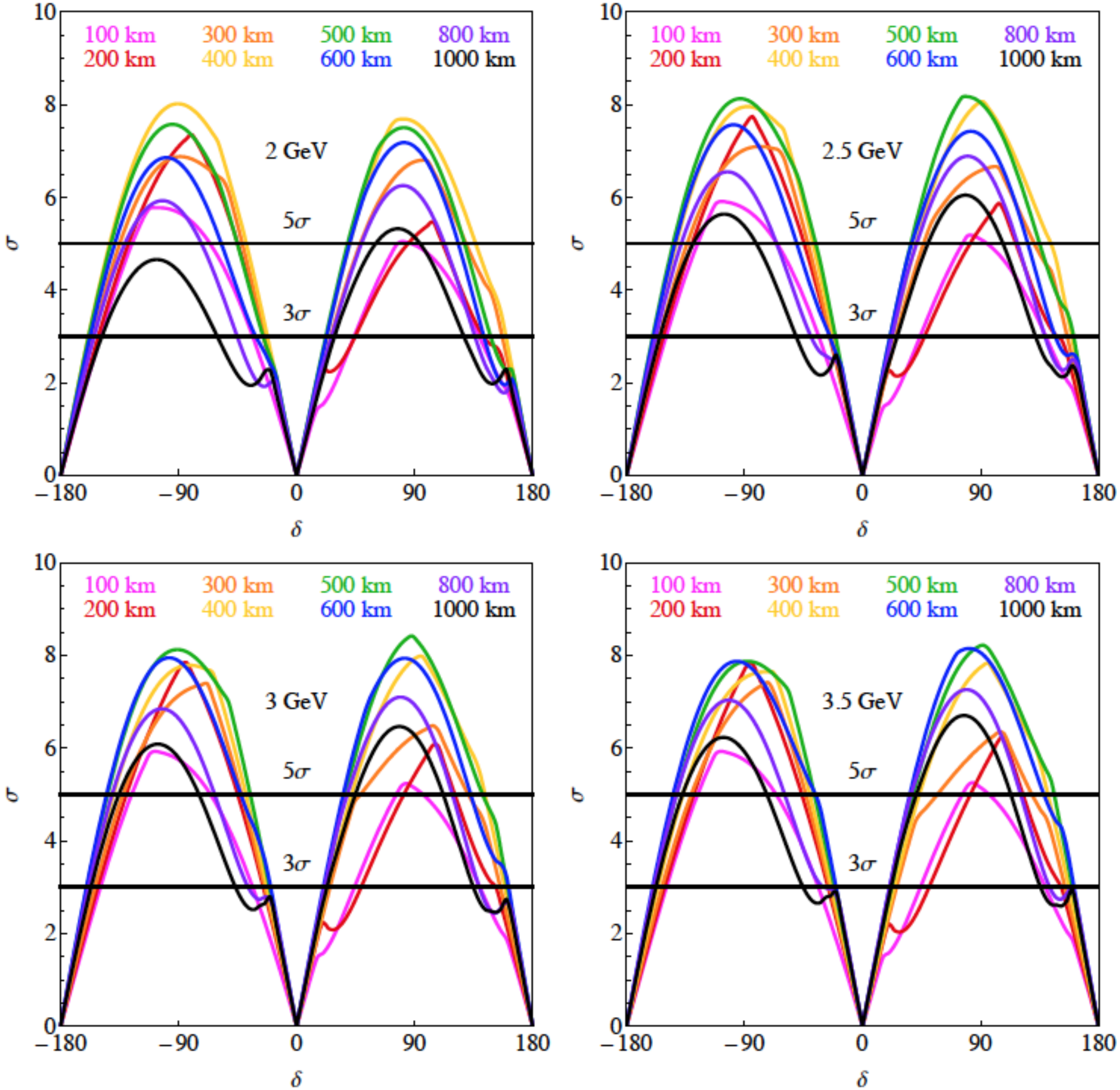
Garpenberg Mine (Boliden)

- Distance from ESS: 540 km
- Depth: 1232 m
- Truck access tunnels
- Two ore hoist shafts



A new ore hoist shaft is planned to be ready in 3 years, leaving the two existing shafts free for other uses

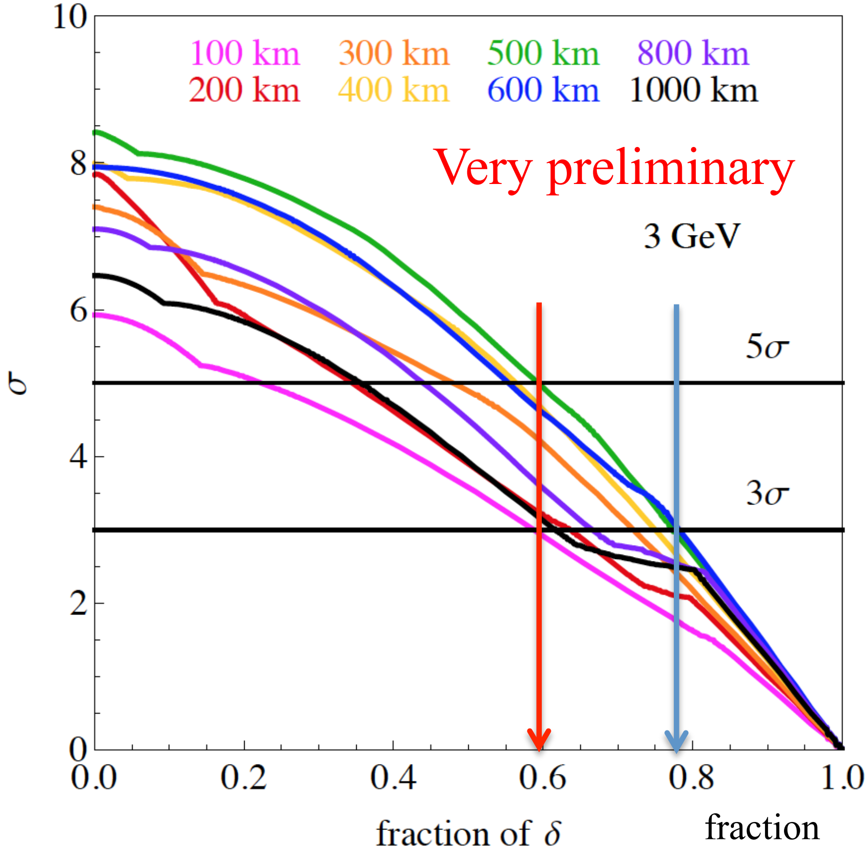
Which baseline?



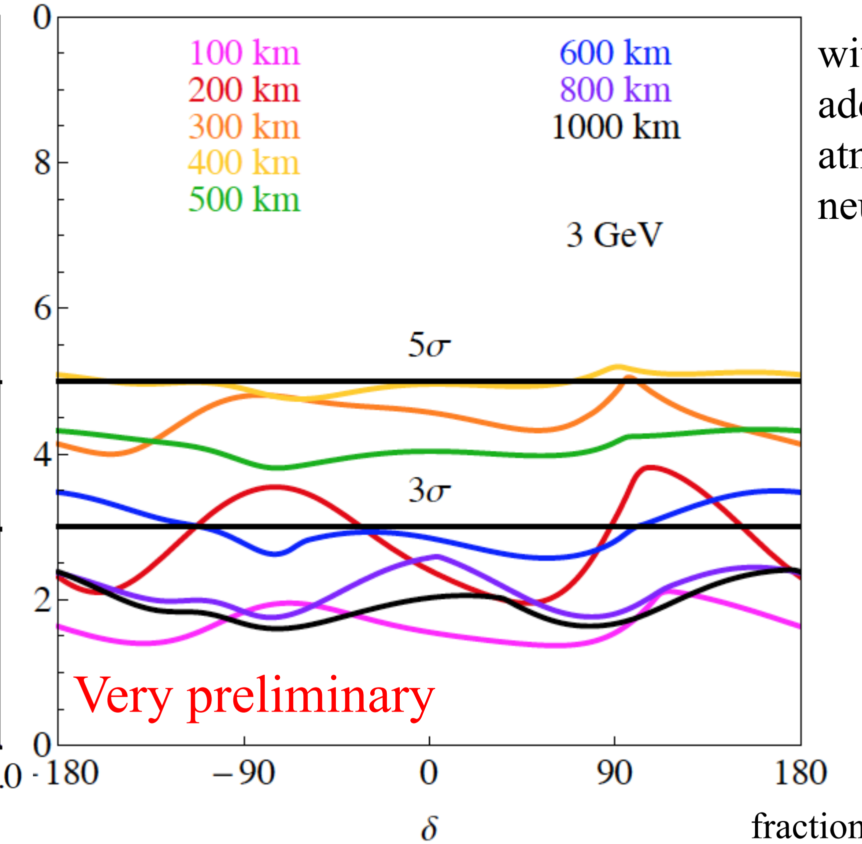
Physics Performance

(Enrique Fernantez)

CPV



MH



without adding yet atmospheric neutrinos

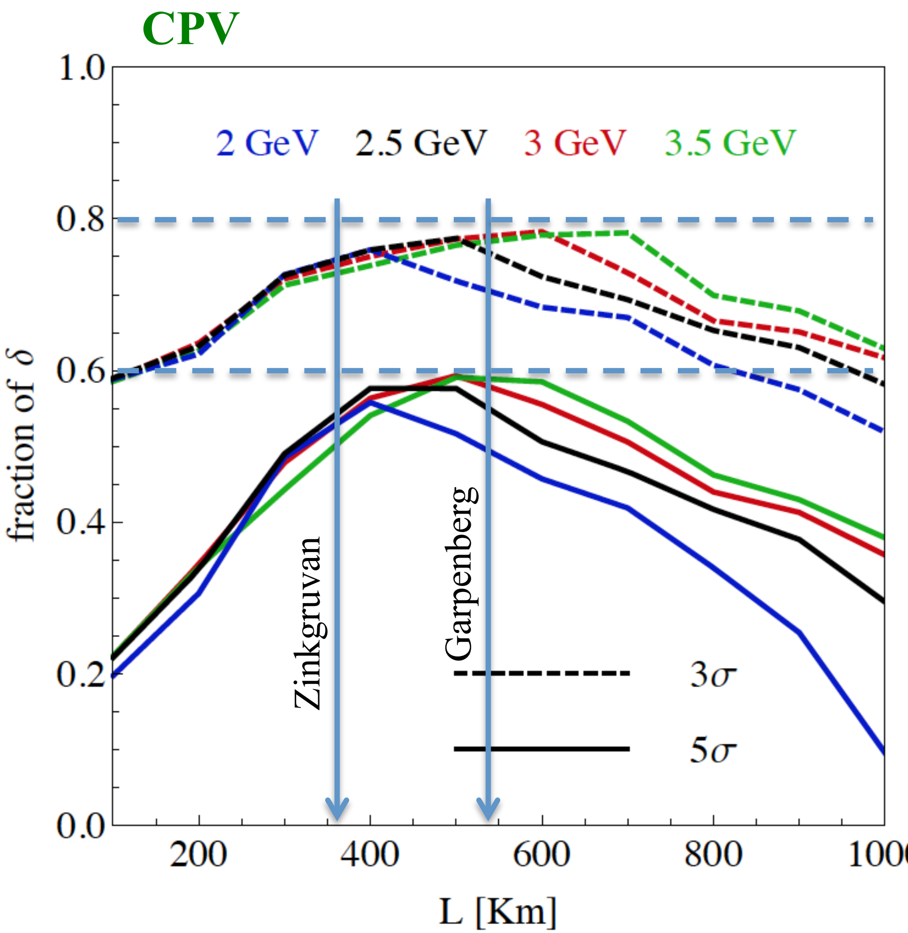
EUROν parameters without particular optimization

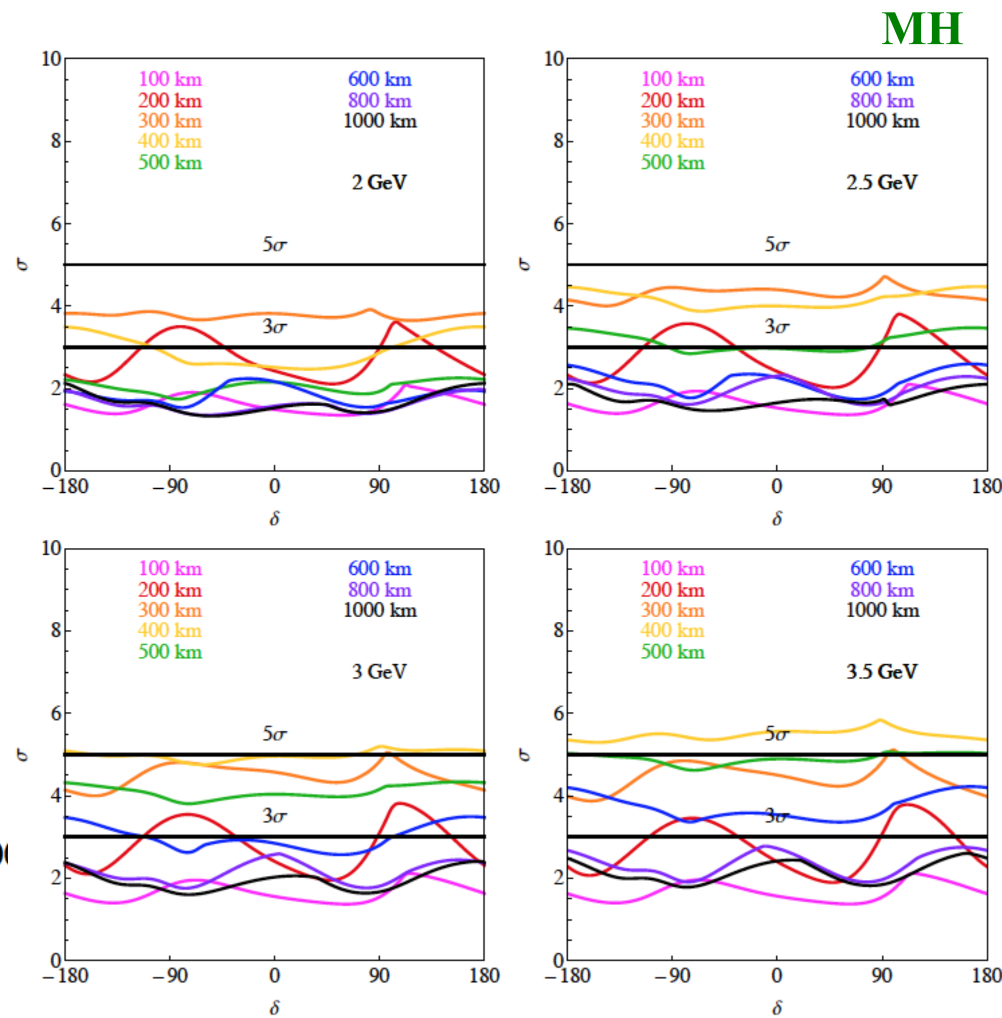
- 1 Mton WC detector (440 kton fiducial), 5%/10% syst.
- 3.0 GeV protons
- 5 MW proton beam
- 10 years (200 days/year)

- Solar sector $\begin{cases} \Delta m^2_{21} = 7.62^{+0.19}_{-0.19} \cdot 10^{-5} \text{eV}^2 \\ \sin^2\theta_{12} = 0.320^{+0.015}_{-0.017} \end{cases}$
- Atm. sector $\begin{cases} \Delta m^2_{31} = 2.53^{+0.08}_{-0.10} \cdot 10^{-3} / -2.40^{+0.10}_{-0.07} \cdot 10^{-3} \text{ eV}^2 \\ \sin^2\theta_{23} = 0.49^{+0.08}_{-0.05} / 0.53^{+0.05}_{-0.07} \end{cases}$

$$\sin^2\theta_{13} = 0.026^{+0.003}_{-0.004} / 0.027^{+0.003}_{-0.004}$$

Which baseline?



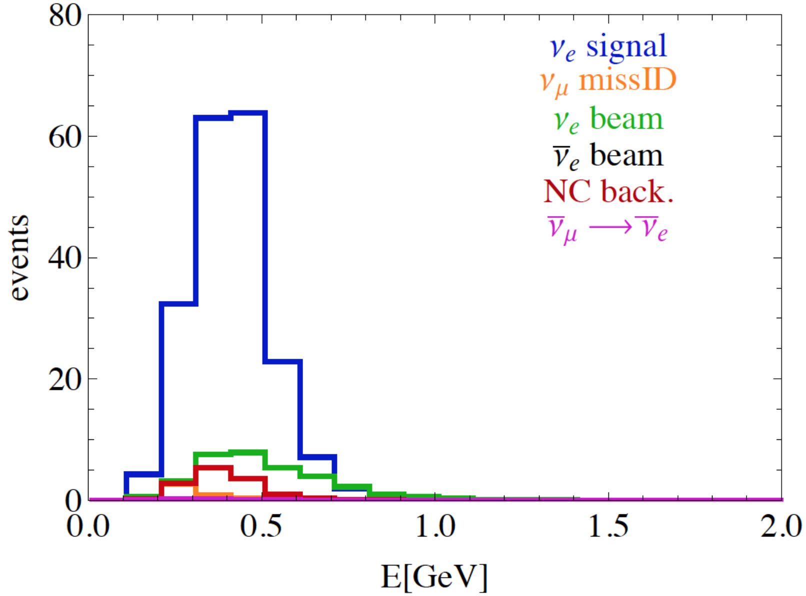


- Zinkgruvan is better for 2 GeV
- Garpenberg is better for > 2.5 GeV

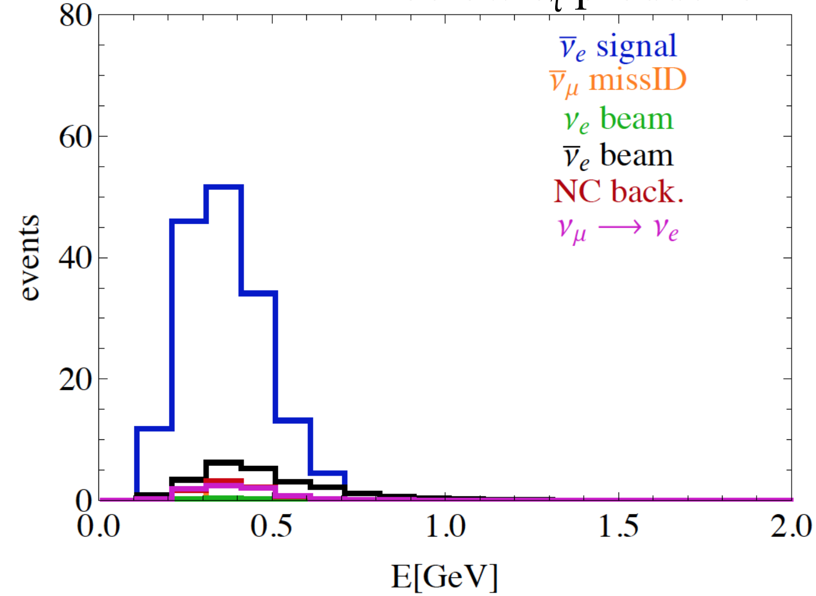
- Zinkgruvan is better
- **atmospheric neutrinos are needed (at least at low energy)**

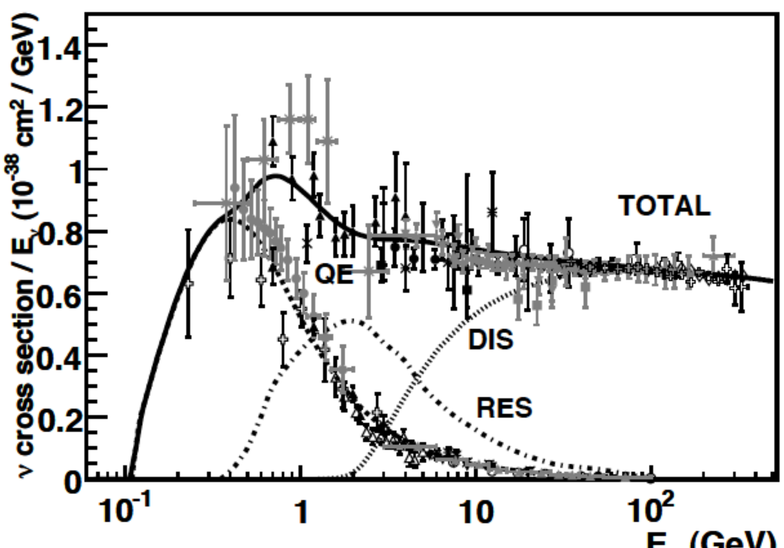
Neutrino spectra

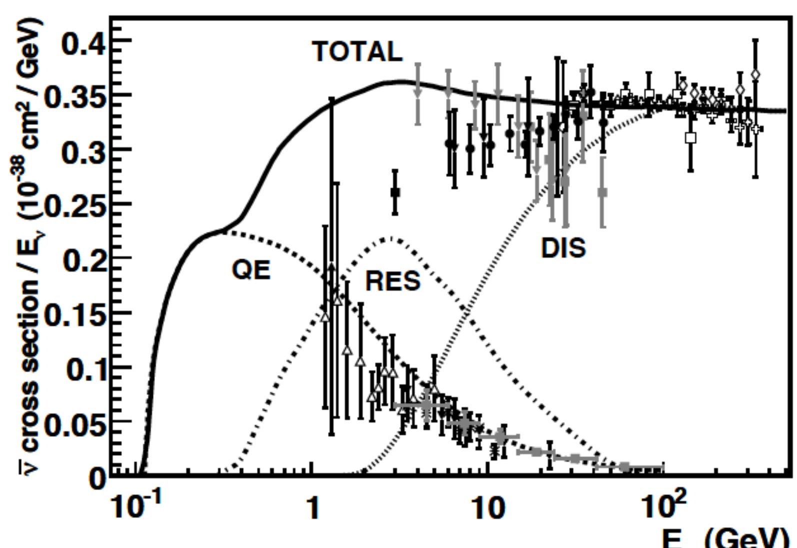
540 km (2 GeV)



below ν_τ production







Neutrino spectra

neutrinos

	$\nu_\mu \to \nu_e$	ν_μ (miss-ID)	ν_e (beam)	$\bar{\nu}_e$ (beam)	ν_{NC}	$\bar{\nu}_\mu \to \bar{\nu}_e$
T2HK	3560	35	880		649	46
ESS 540 km	196.7	4.6	33.3	0.04	13.7	0.9
ESS 360 km	303.3	10.7	70.8	0.08	29.2	1.4

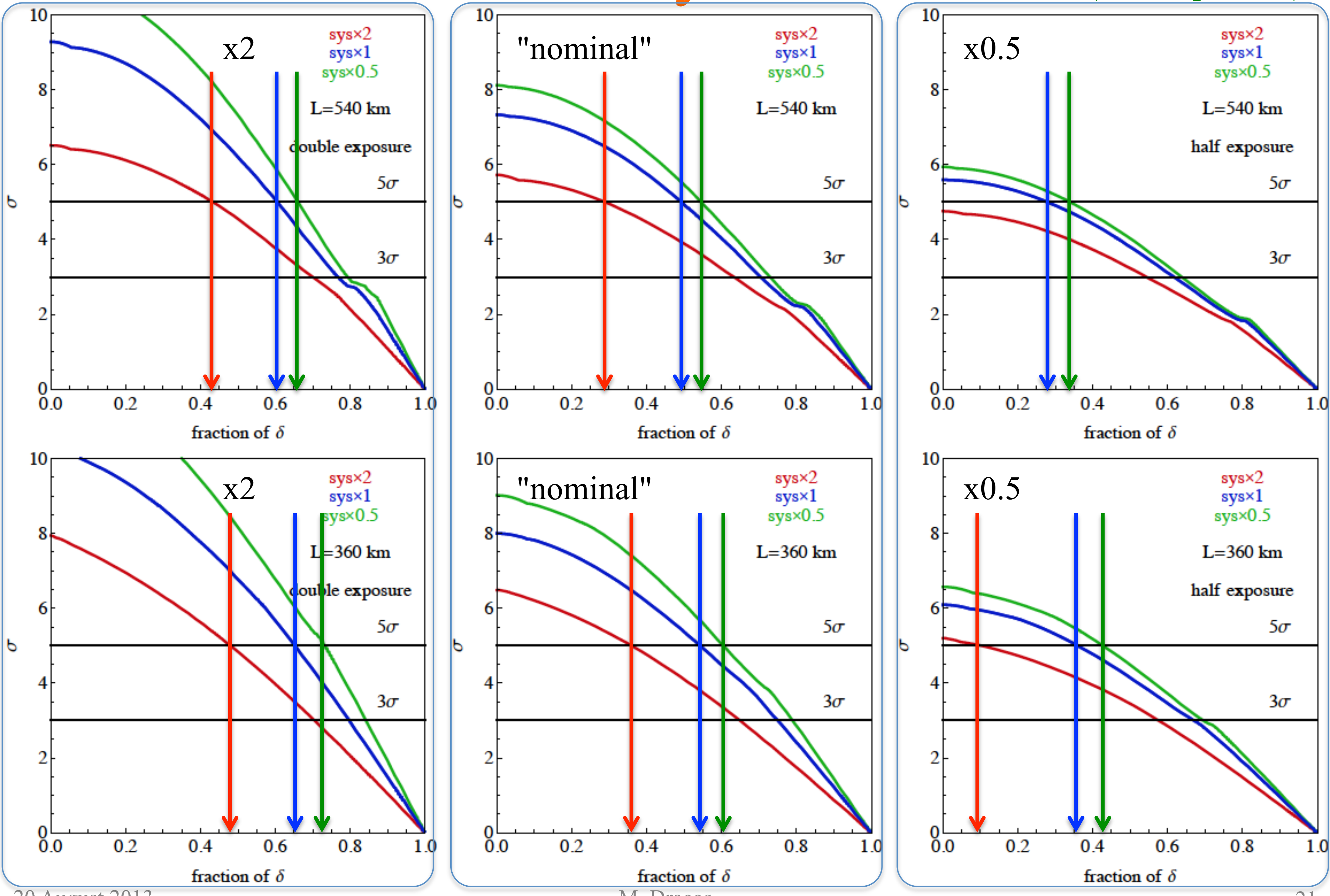
anti-neutrinos

	$\bar{\nu}_\mu \to \bar{\nu}_e$	$\bar{\nu}_\mu$ (miss-ID)	ν_e (beam)	$\bar{\nu}_e$ (beam)	ν_{NC}	$\nu_\mu \to \nu_e$
T2HK	1959	23		878	678	380
ESS 540 km	162.9	2.8	1.1	23.5	8.2	7.8
ESS 360 km	246.1	6.1	2.4	50.6	17.4	13.3

ESS: 2 years neutrinos, 8 years anti-neutrinos, 200 days/year (almost no kaon contamination)
T2HK: neutrinos: 2.25 MW x 10^7 s, anti-neutrinos: 5.25 MW x 10^7 s

Statistics/Systematics

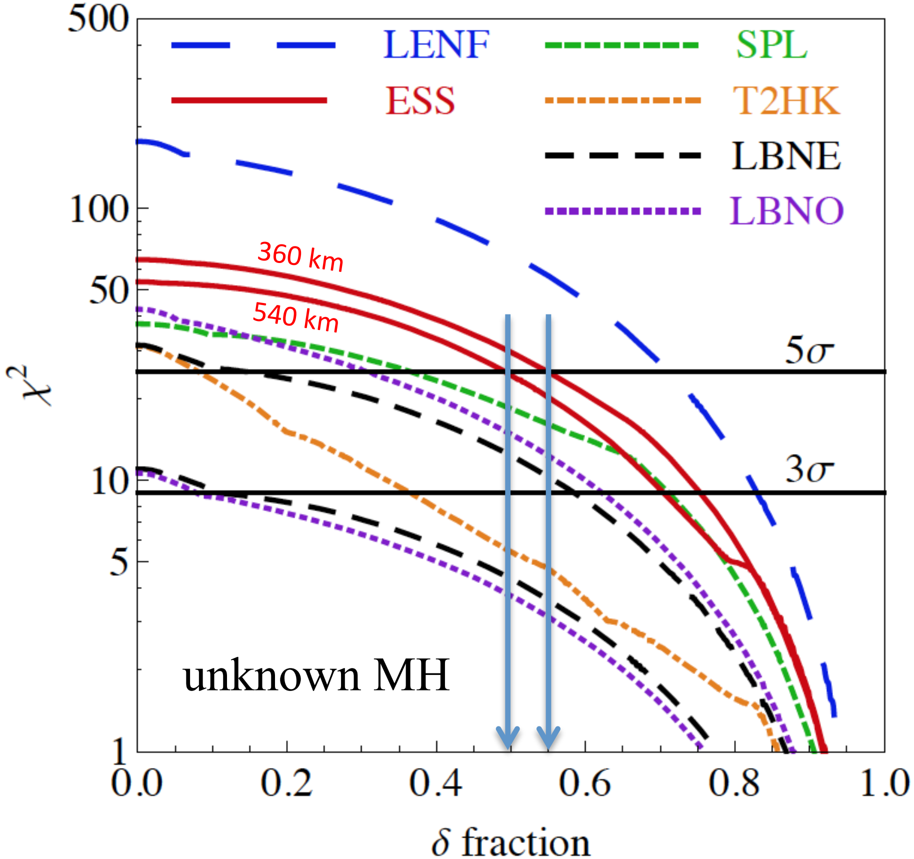
CPV (2 GeV protons)



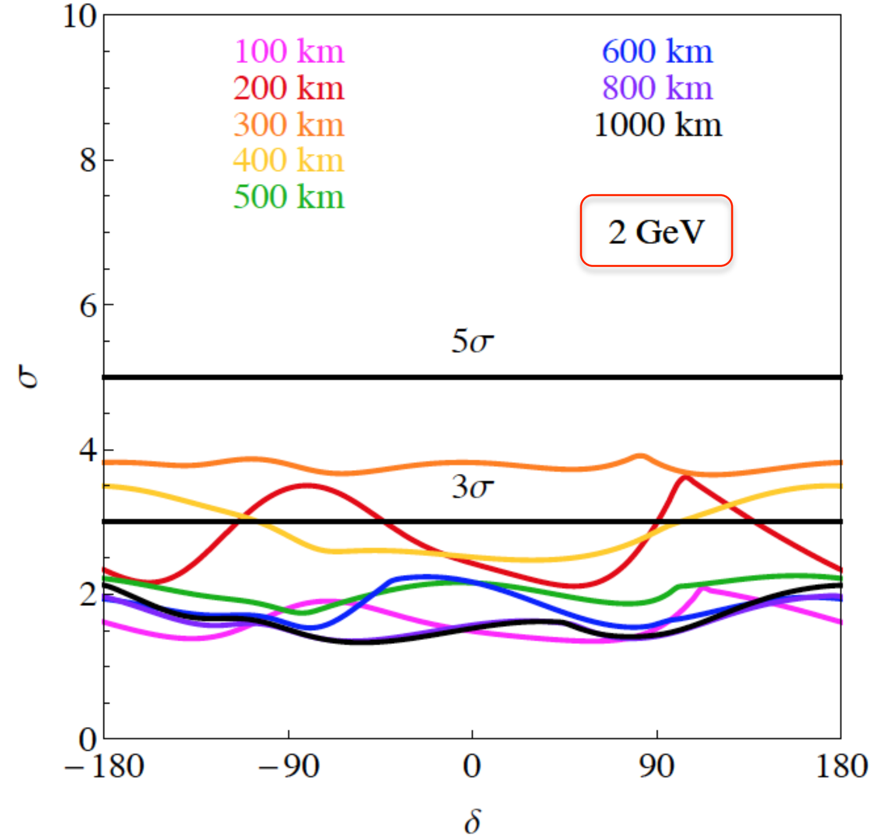
Physics Performance for Future SB projects

(Enrique Fernantez)

CPV



MH (unknown)



- LBNE: 5+5 years, 0.7 MW, 10/35 kt LAr
- T2HK: 3+7 years, 0.75 MW, 500 kt WC (5%/10% syst. errors)
- SPL: 2+8 years, 4 MW, 500 kt WC (130 km, 5%/10% syst. errors)
- ESS: 2+8 years, 5 MW, 500 kt WC (2 GeV, 360/540 km, 5%/10% syst. errors)
- C2Py: 20/100 kt LAr, 0.8 MW, 2300 km

Physics Performance for Future SB projects

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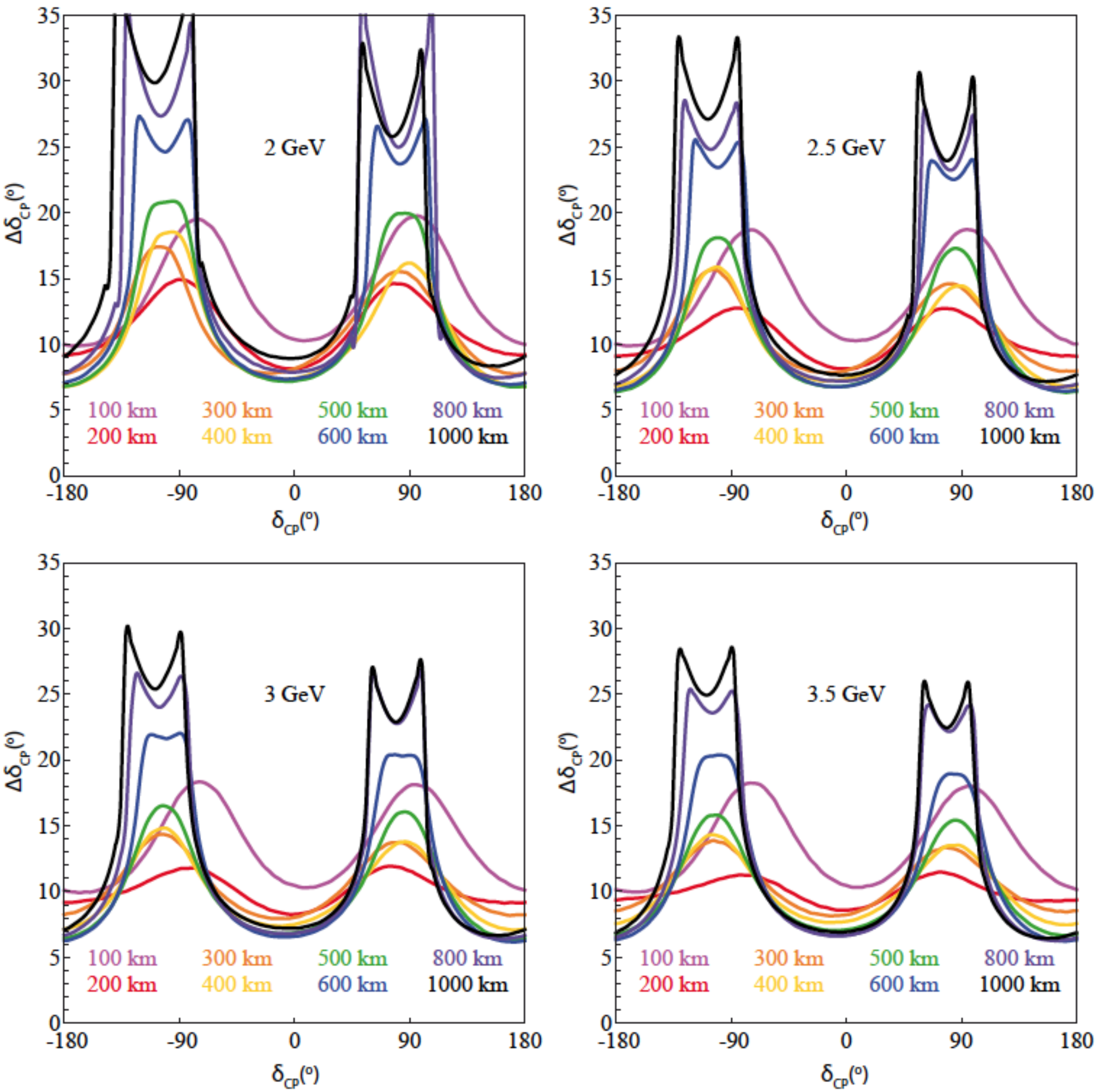
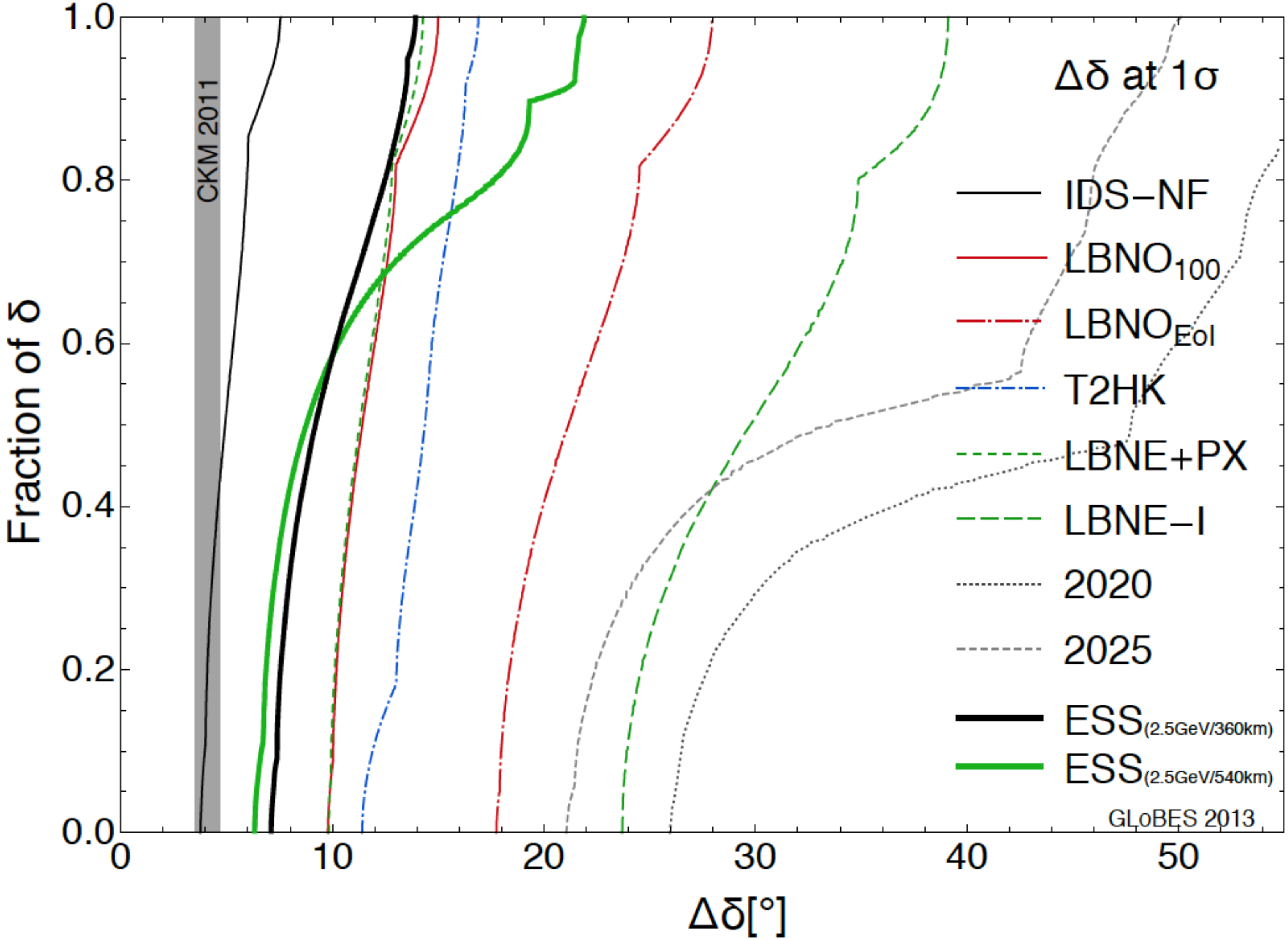


- for 2 GeV
  - optimum 300-400 km
- for 3.5 GeV
  - optimum 500-600 km
- but the variation is small

δCP accuracy performance

(snowmass)



Conclusions

- ESS is under construction
  - very intense source of protons, 5 MW, 2-3 GeV
  - more than 2×10^{23} protons/year
  - well defined schedule
- Modifications are needed to transform ESS to neutrino facility
  - Double the rate
  - Add an accumulator
  - Add a target station
  - Underground detector (MEMPHYS), mines available

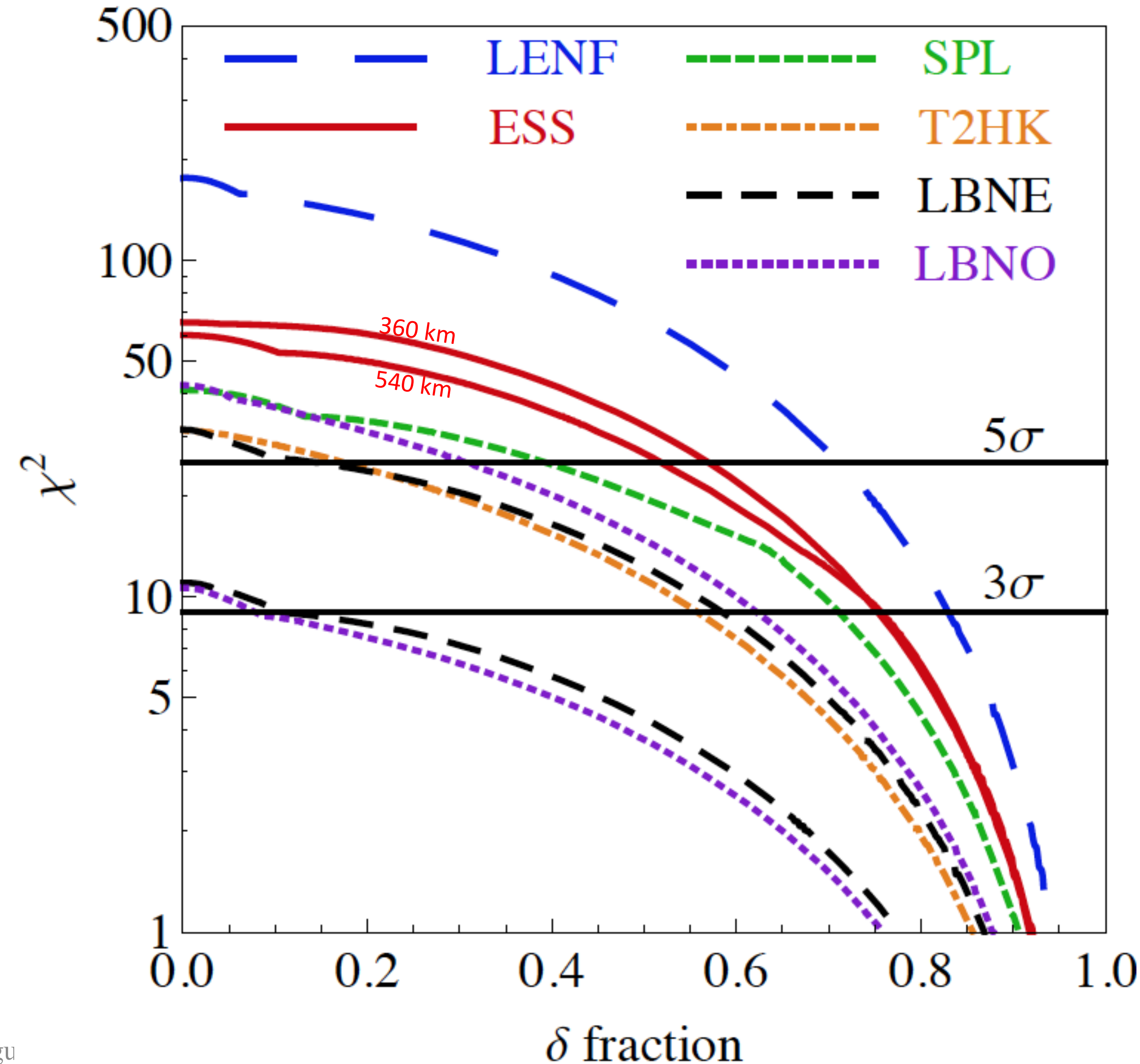
  } could be the first step towards the Neutrino Factory
- Very promising physics performance using EUROnu optimizations:
  - CPV: coverage up to 60%
  - MH: could reach 5 σ combining atmospheric neutrinos
- First ESS beam 2019, full power/energy by 2023.

Collaborators are welcome…

(just email tord.ekelof@physics.uu.se, marcos.dracos@in2p3.fr)

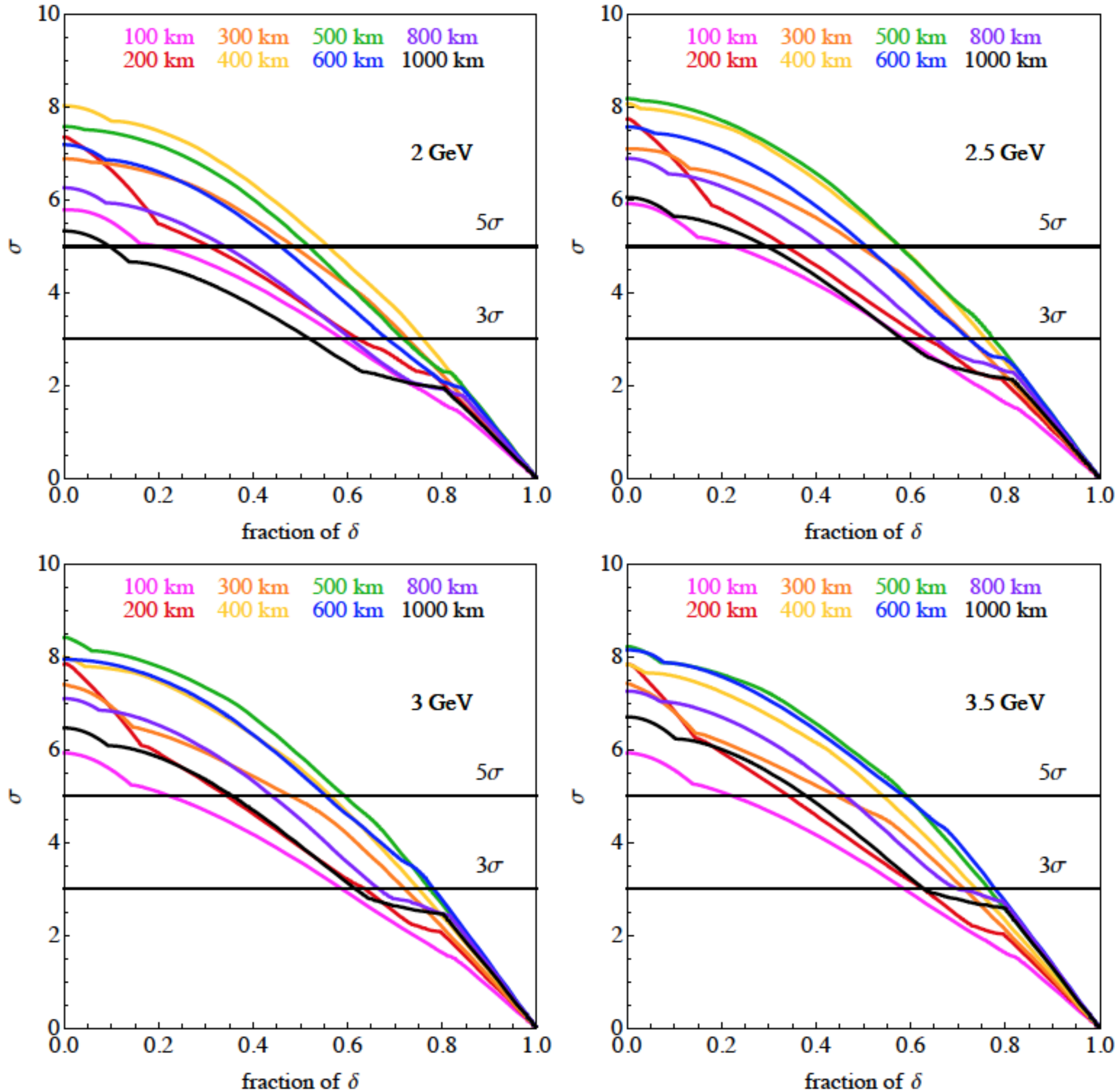
Backup

Which baseline?



known MH

Which baseline?



Physics Performance for Future SB projects

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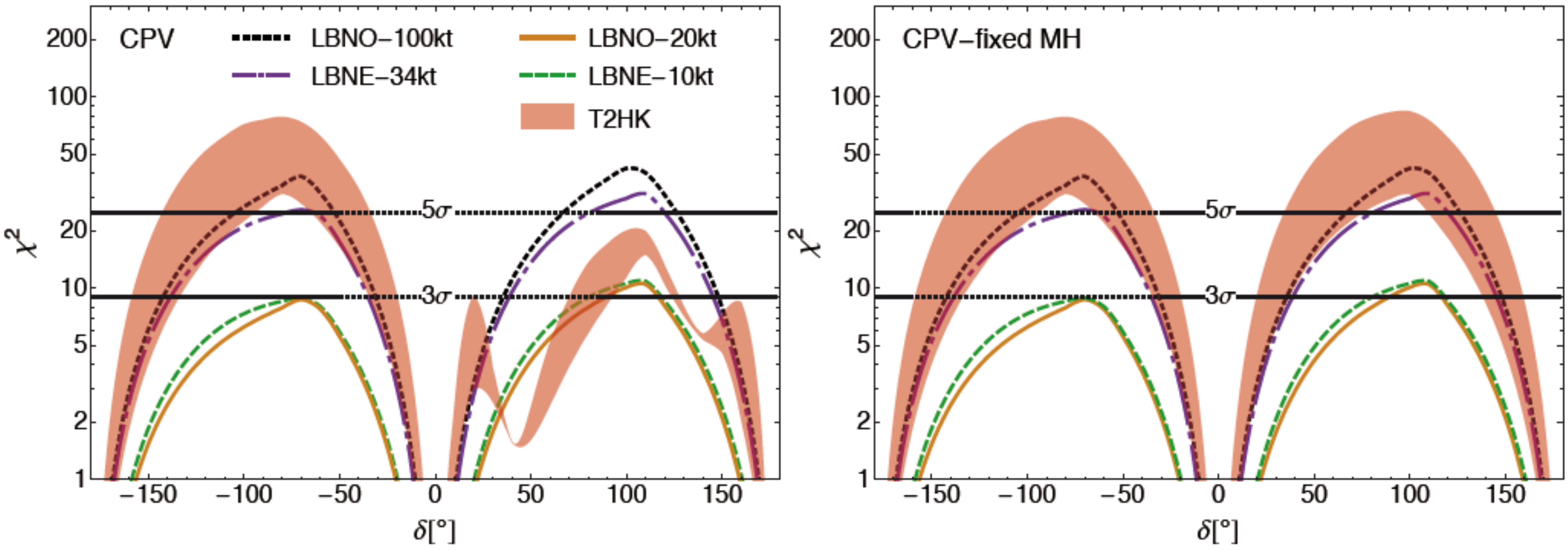
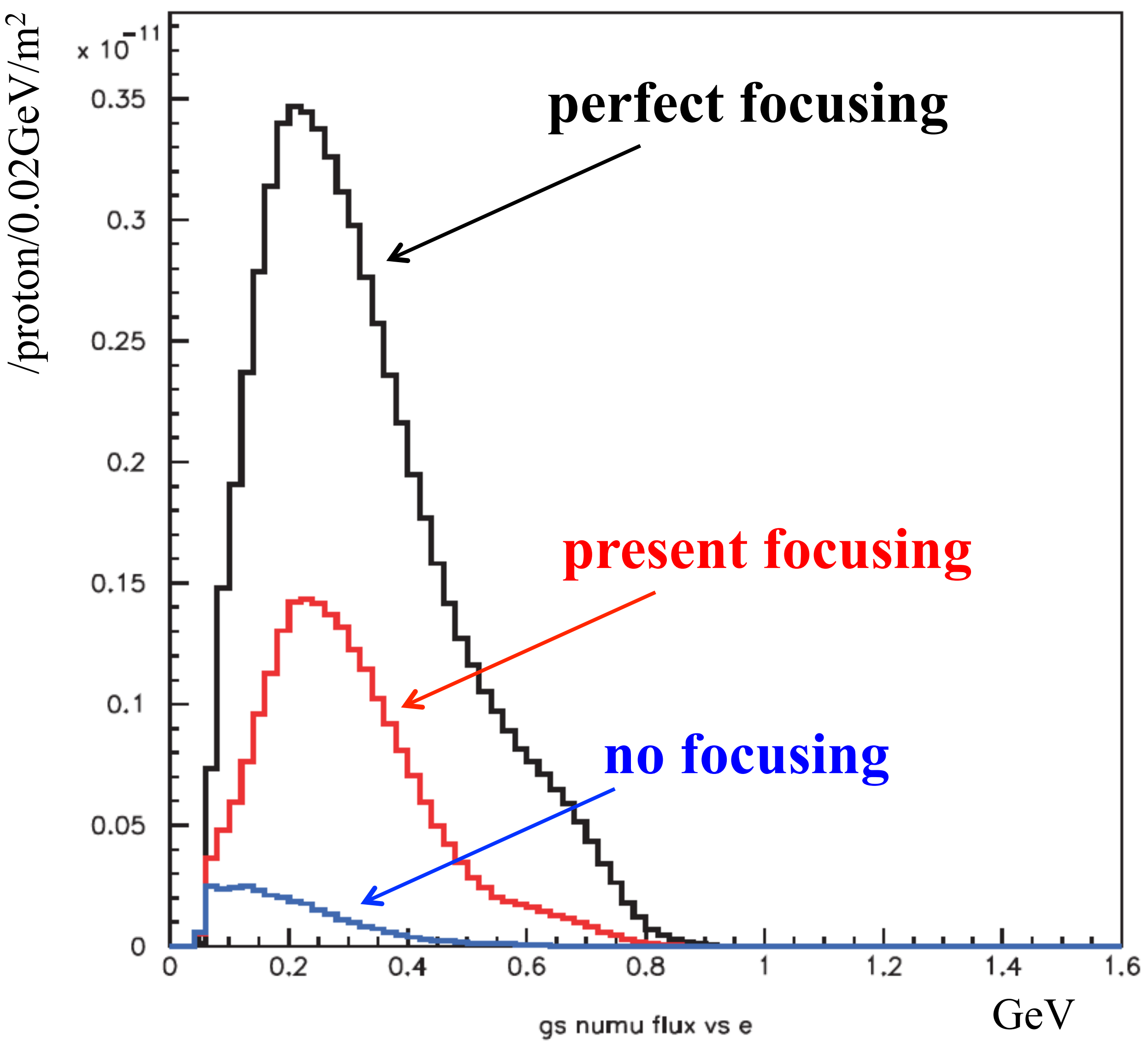


Horn Optimization



for 2.5 GeV

Physics Performance for Future SB projects

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