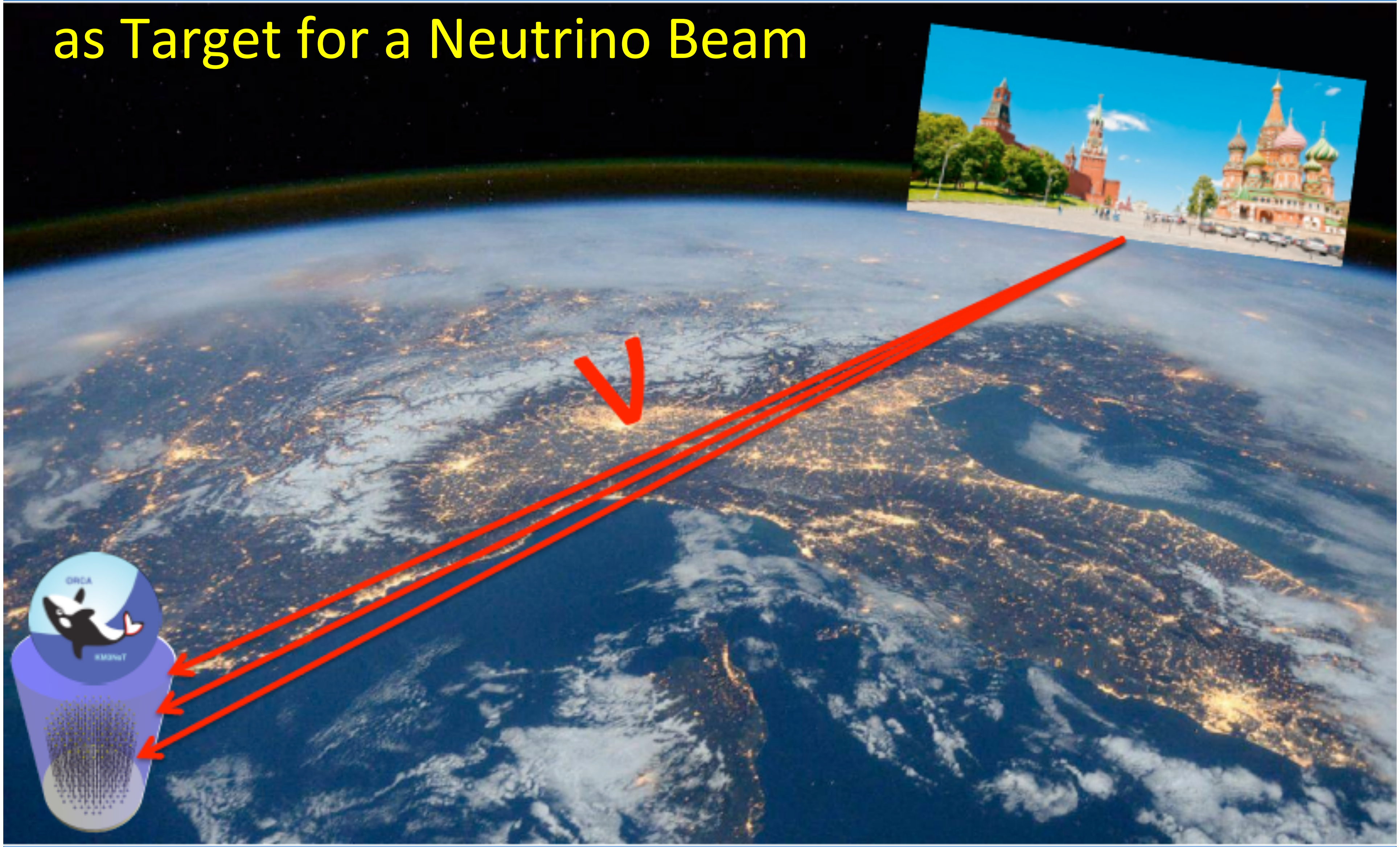
A Neutrino Detector in the Mediterranean Sea

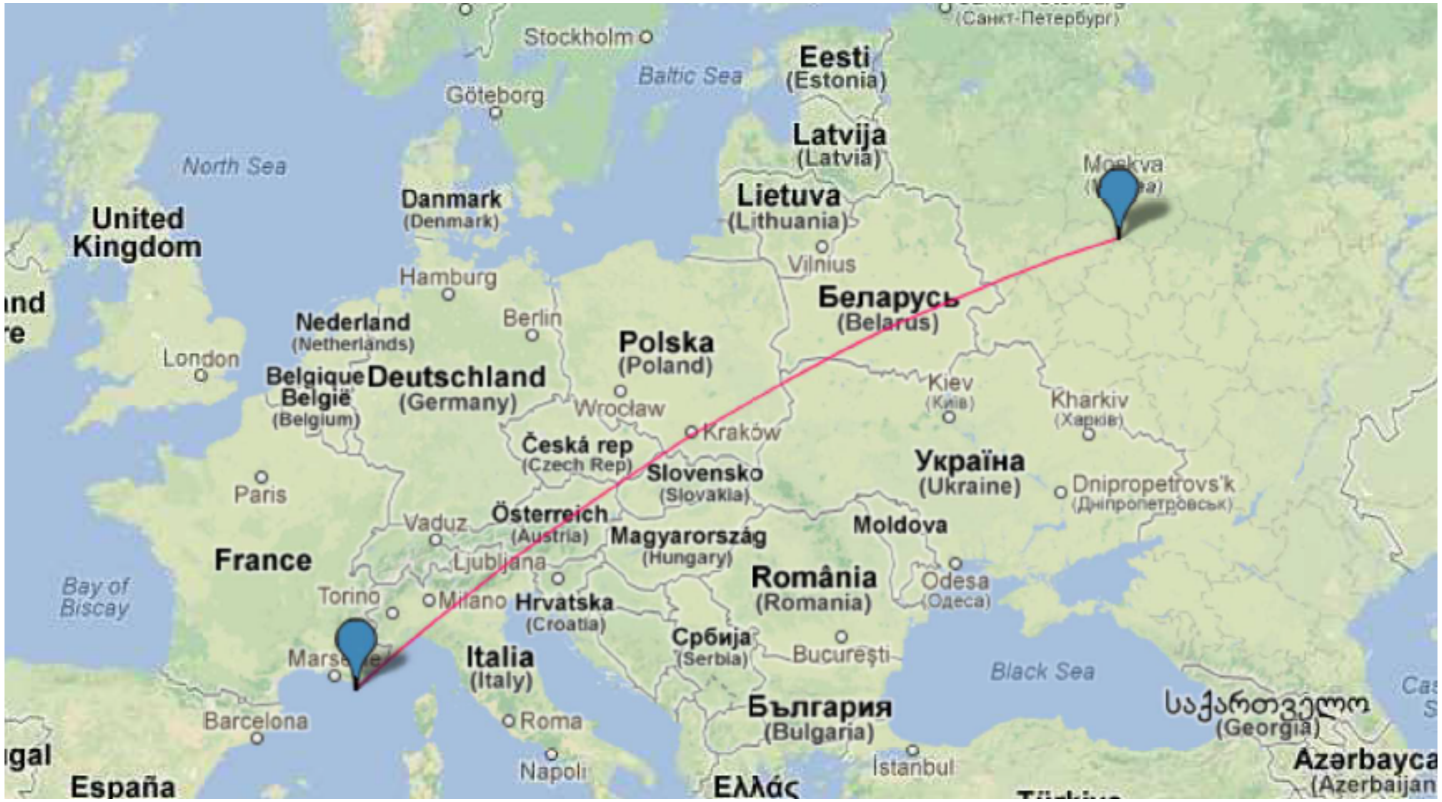
as Target for a Neutrino Beam



J. Brunner VLVnT 03/10/2018

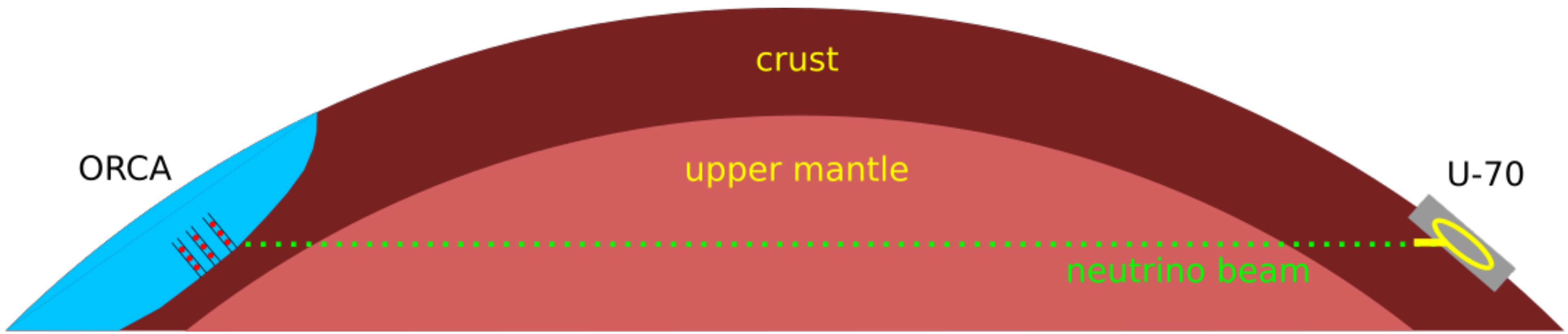
Protvino to ORCA – key numbers

- Baseline 2590 km
- First oscillation maximum 5.1 GeV
- Matter resonance maximum 3.8 GeV



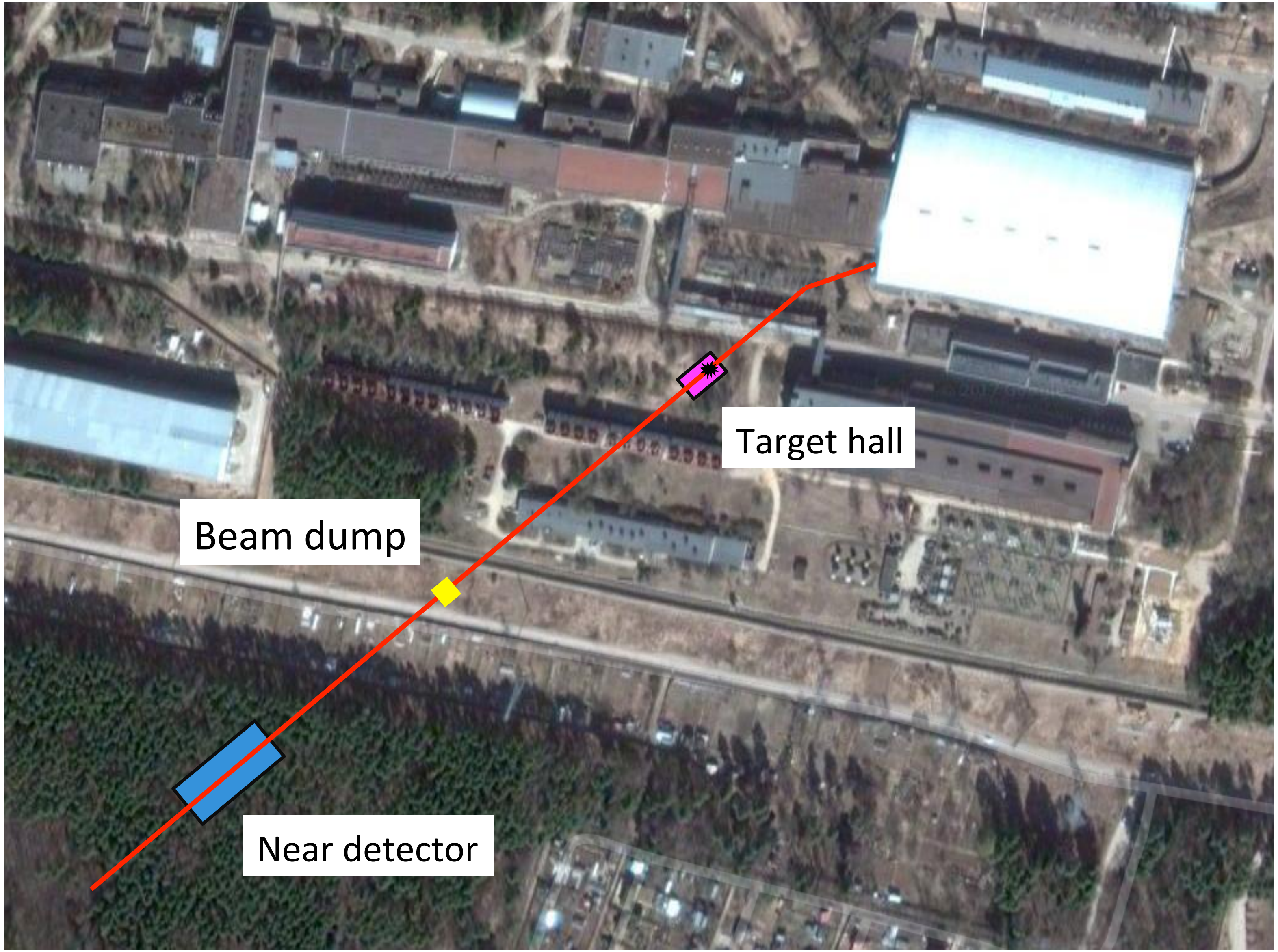
Beam profile through Earth

- beam inclination : 11.7˚ (cosθ = 0.2)
- Deepest point at 134 km
- Beam passes mostly through upper mantle
- Density 3.4 g/cm^3 , Z/A = 0.4956

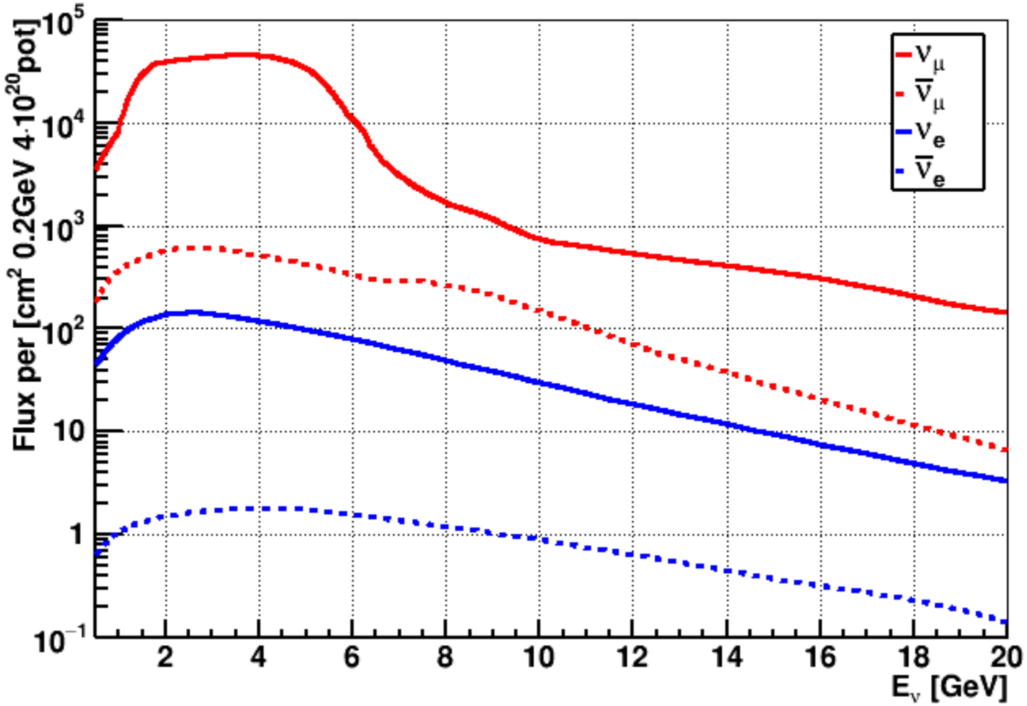


Graphic : D. Zaborov

Possible location of the near beam detector



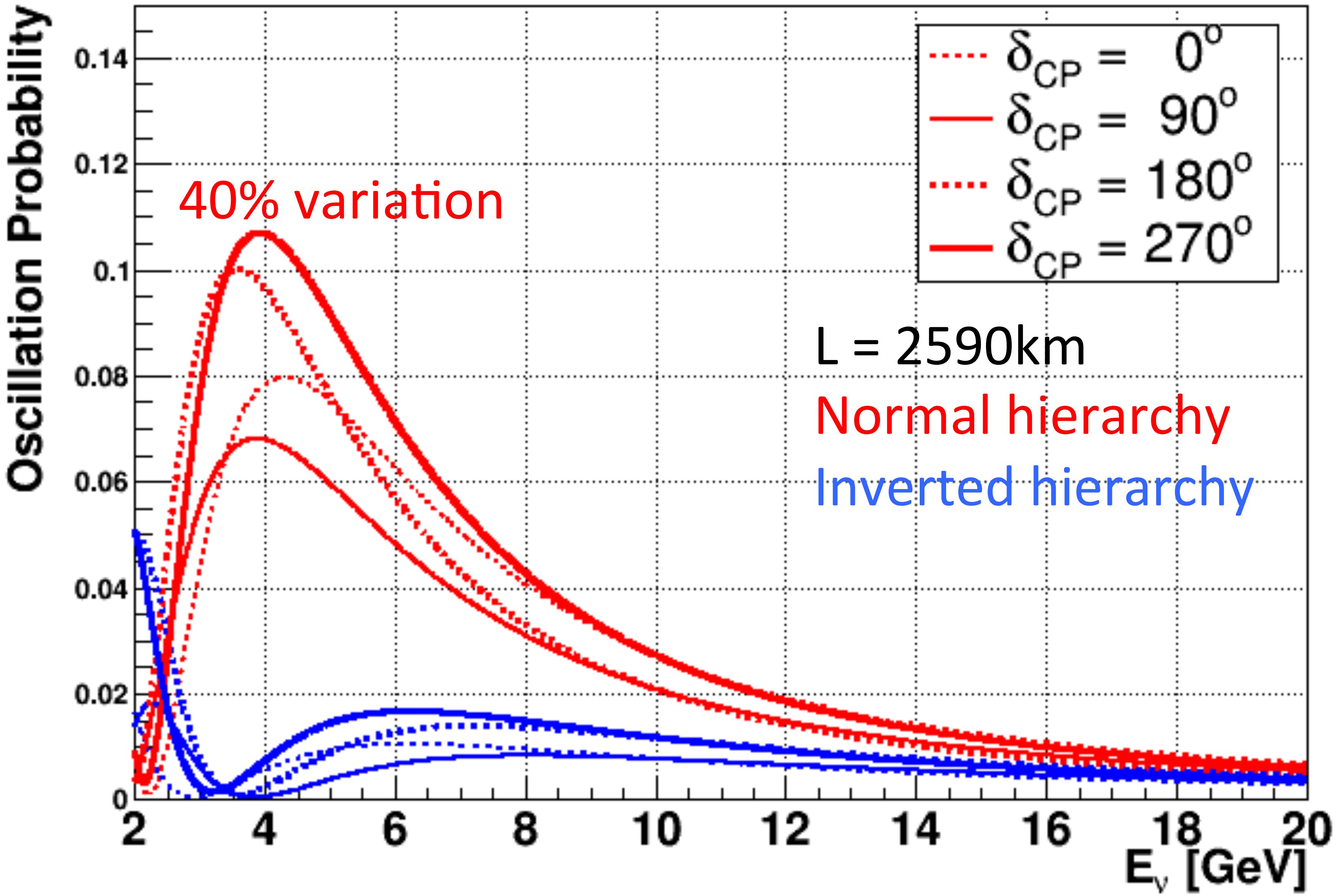
Neutrino Flux



Focus π^+ (Neutrino beam)

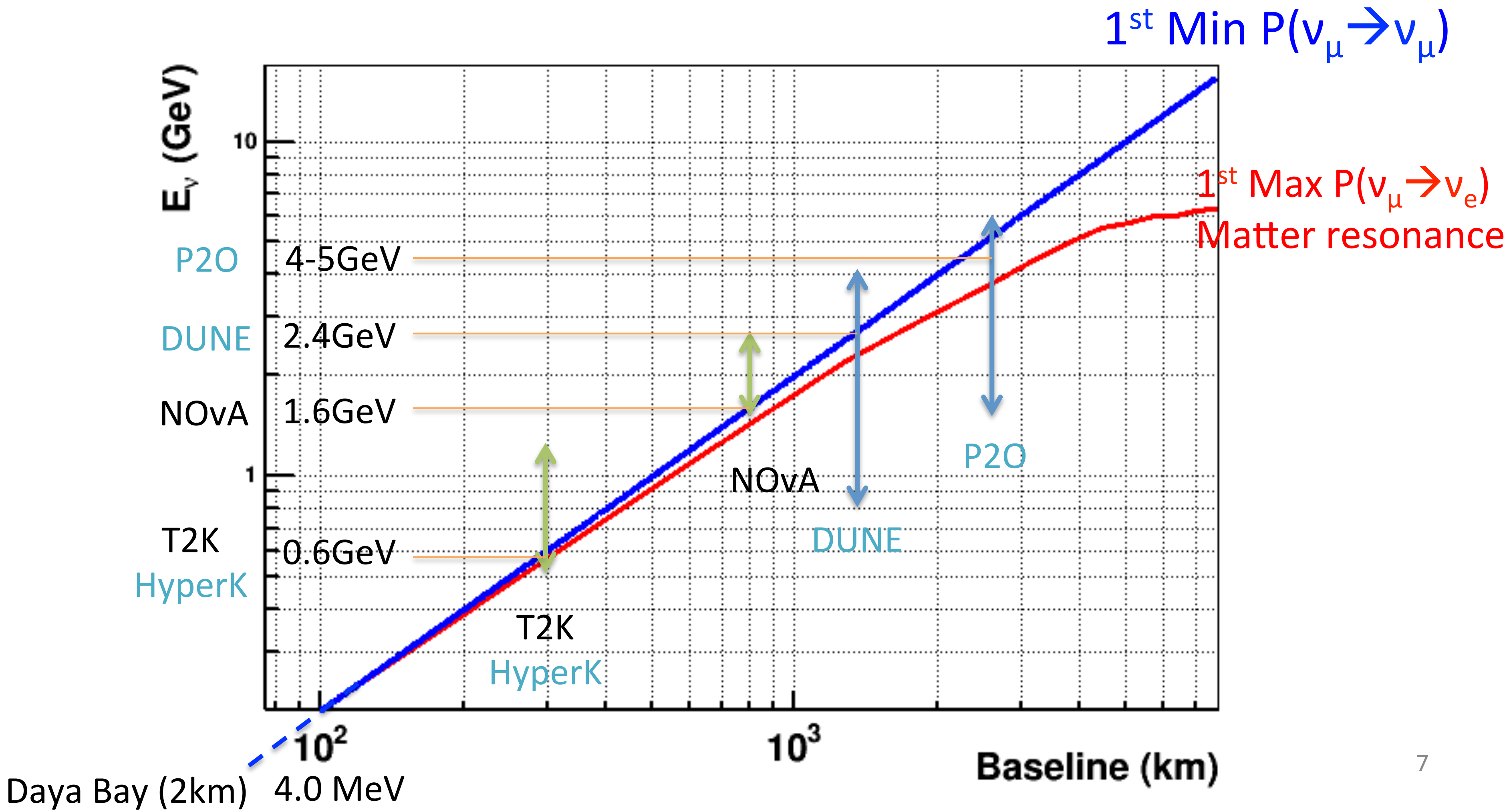
- Used for current study : IHEP Protvino internal note 2015-5
- Designed for Beam to Gran Sasso (2200km)
- Beam pipe 250m long on-axis → high yield
- Most neutrinos 1-6 GeV → matches oscillation maximum
- 1% anti-neutrino contamination
- ν_e on sub-percent level

Oscillation Probabilities $P(\nu_\mu \rightarrow \nu_e)$



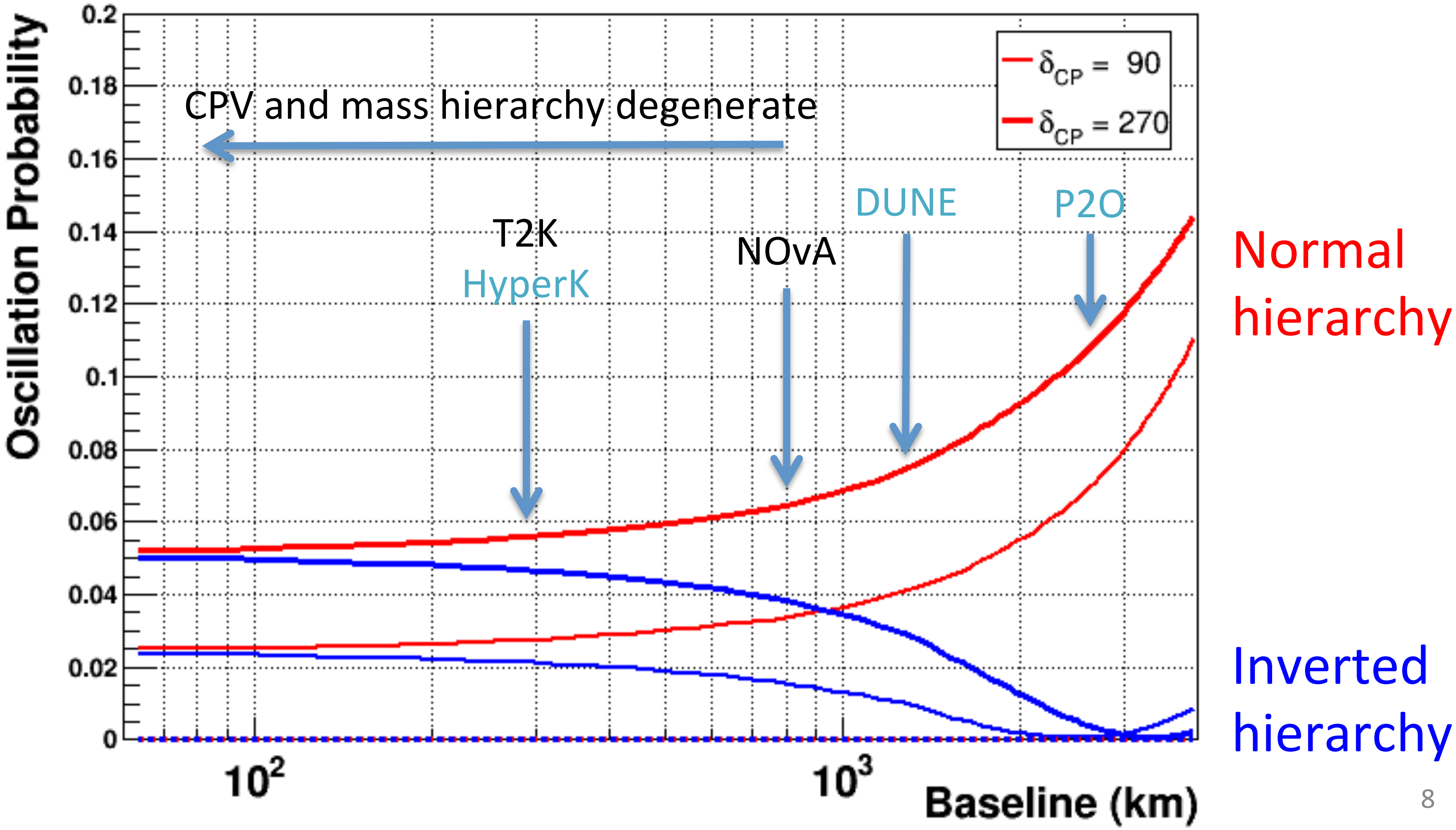
Comparison of LBL Projects

- Energy versus baseline

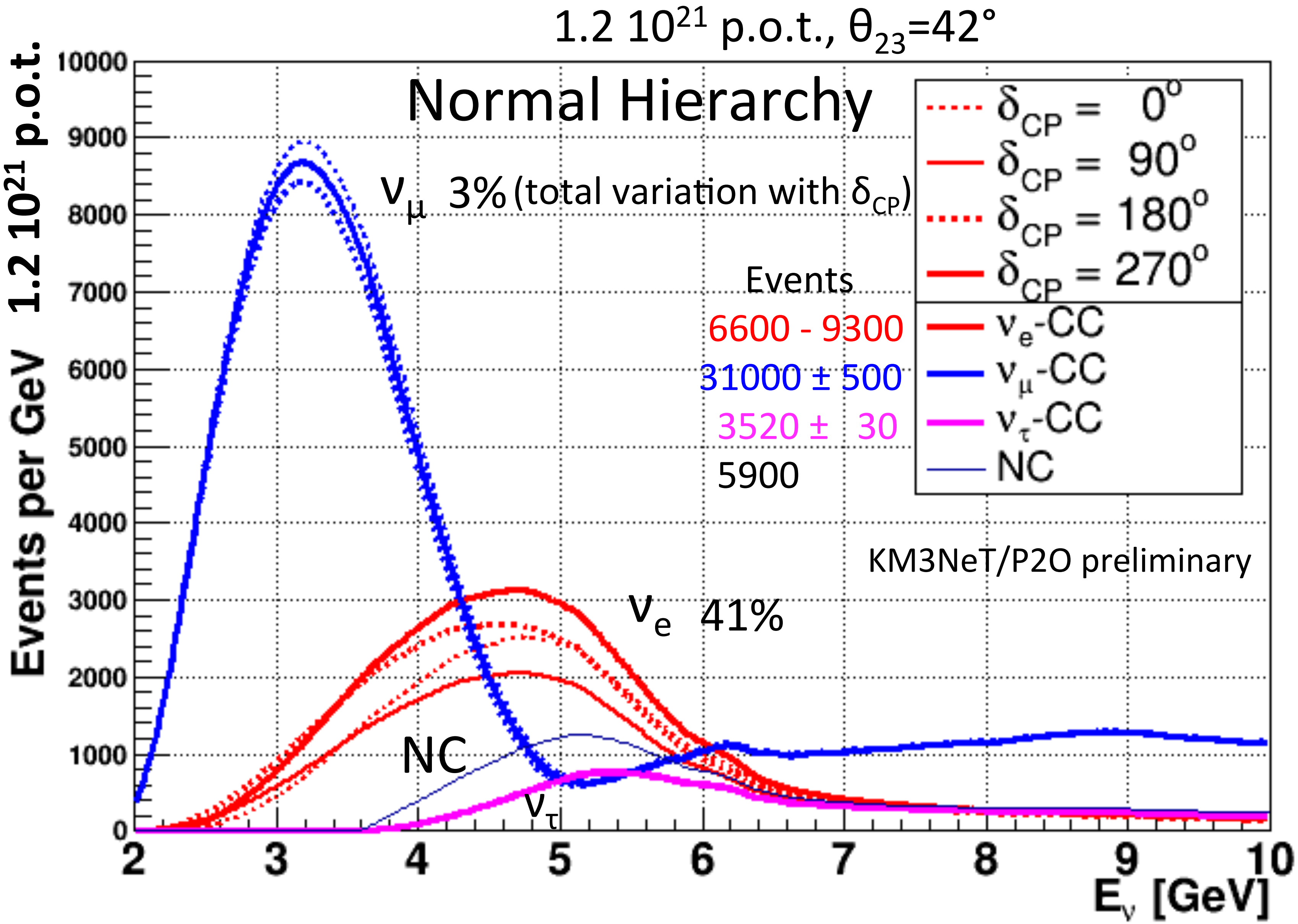


Comparison of LBL Projects

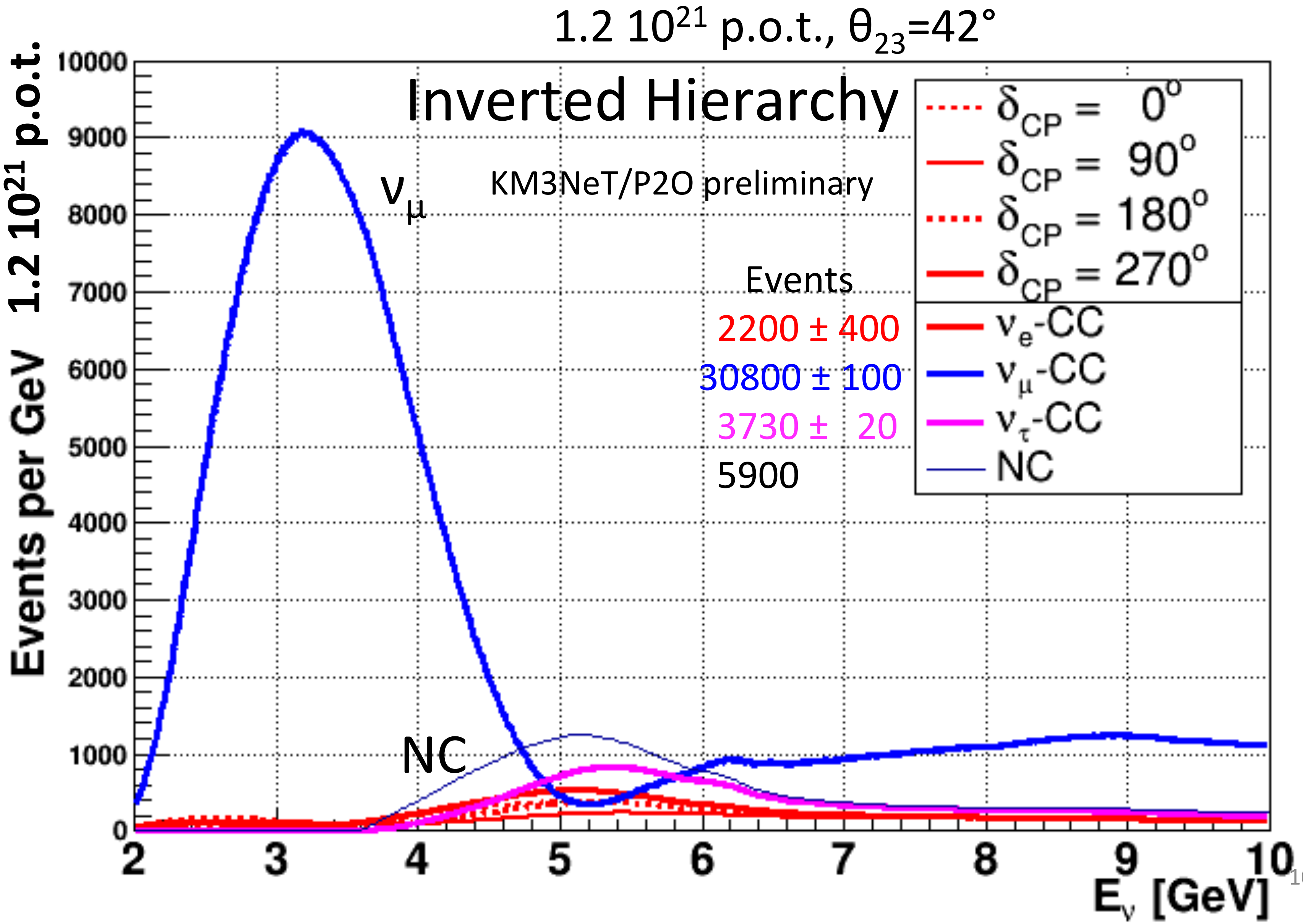
- Main Signal : Appearance of ν_e : $P(\nu_\mu \rightarrow \nu_e)$



Event numbers – Neutrino Beam



Event numbers – Neutrino Beam



Modified Multi-Parameter fit

- Combined fit of nuisance and oscillation parameters
- Choice of nuisance parameters and priors inspired by LBNO study

Parameter	True value	Prior	Start value
θ_{12}	33.4°	fix	fix
Δm^2 [eV^2]	7.53 10^{-5}	fix	fix
θ_{13}	8.42°	0.15°	8.42°
θ_{23}	41.5°	1.3°	41.5°
ΔM^2 [eV^2]	2.44 10^{-3}	0.06	2.44 10^{-3}
δ_{CP}	many	no	many

Only used for CP fits, not for NMH

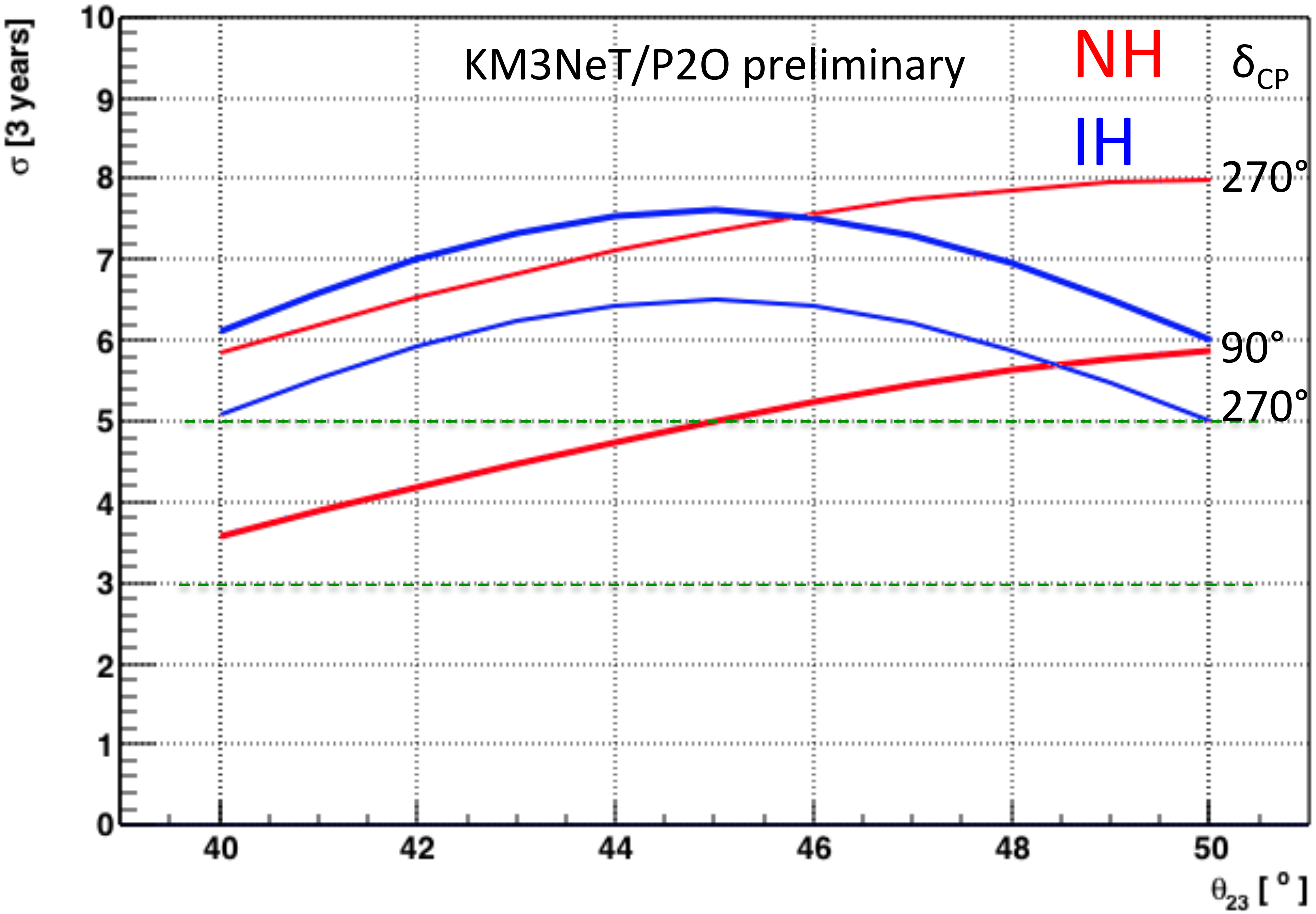
Parameter	True value	Prior	Start value
Norm ν_e CC	from ν_μ CC	fix	fix
Norm ν_μ CC	1	0.05	1
Norm ν_τ CC	1	0.10	1
Norm NC	1	0.05	1
PID	1	0.10	1

Phased approach – Phase 1

- ORCA : 1 building block
- 115 detection units, performance as in LoI
- Accelerator : moderate intensity upgrade
- 15 kW → 90kW
- 2 10^{13} protons per pulse
- Repetition cycle 5 sec
- 8 months per year operation
- 8 10^{19} protons on target per year

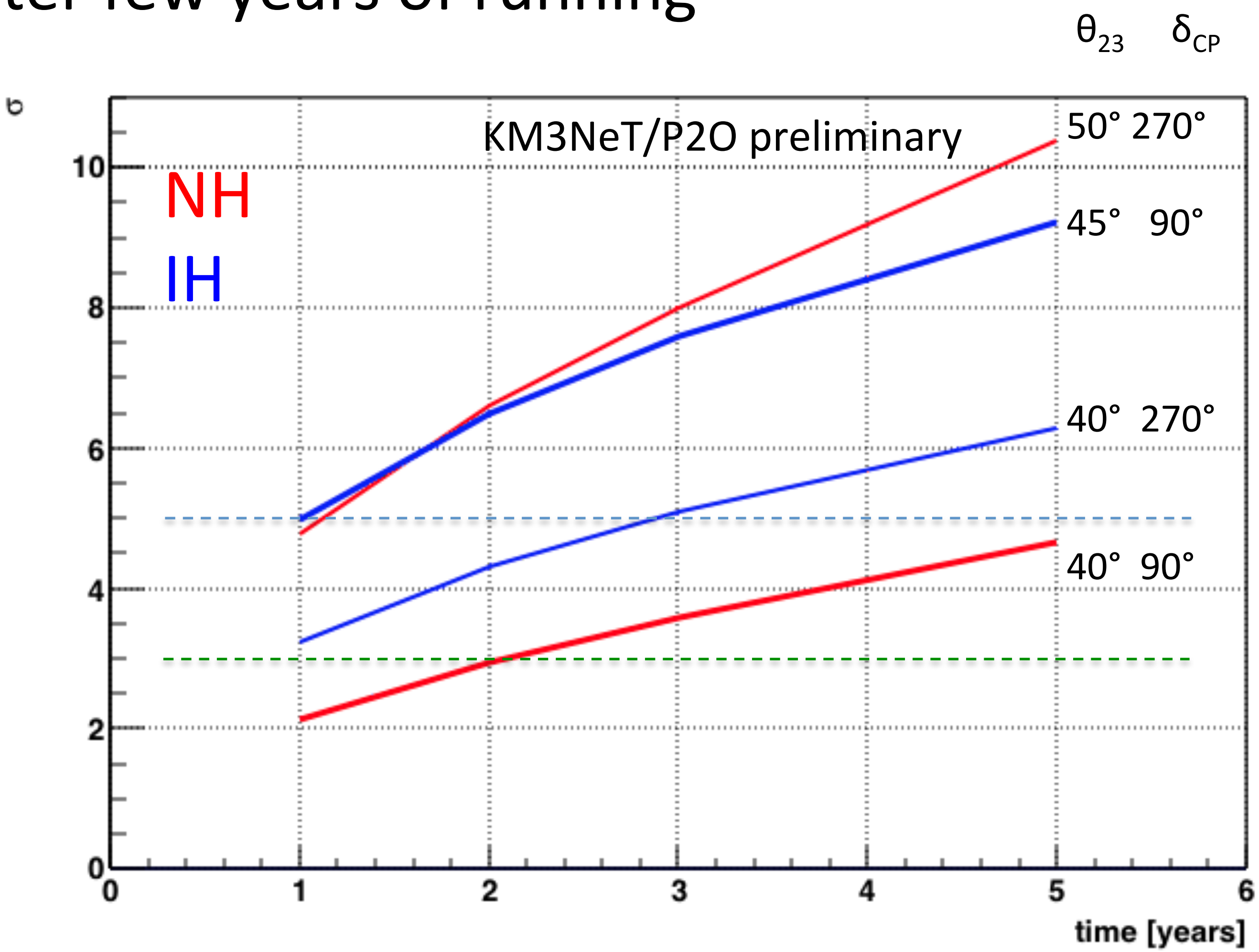
NMH - beam intensity 90kW

- 3 years - 5σ for most of the parameter space



NMH - beam intensity 90kW

- Evolution with time – decisive NMH determination after few years of running

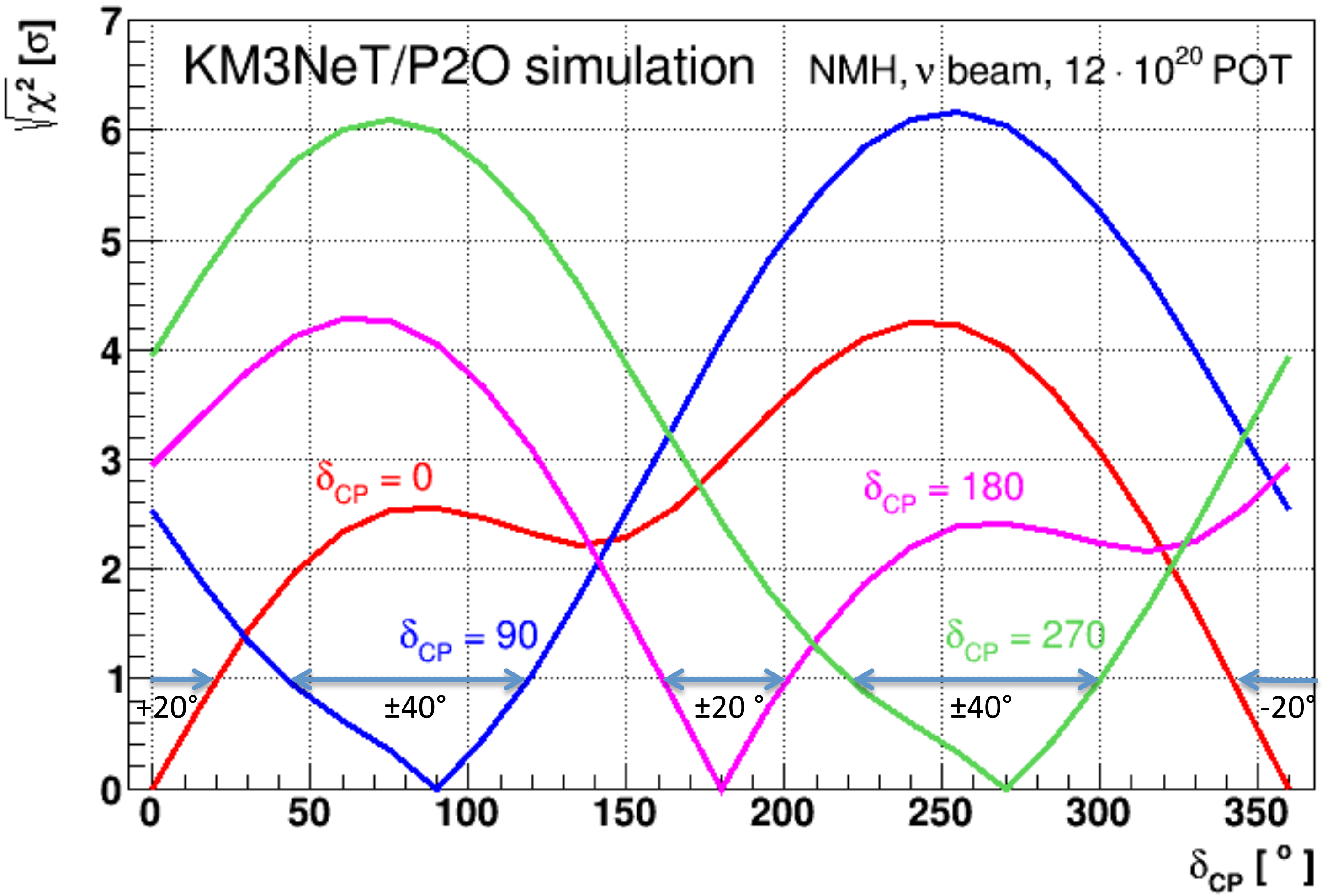


Higher Intensity

- Plots for 1.2 10^{21} proton on target
  - Either through intensity increase 90 kW → 450kW
  - Or through 5x longer run time
- 450 kW parameters
  - 10^{14} protons per pulse
  - Repetition cycle 5 sec
  - 8 months per year operation
  - 4 10^{20} protons on target per year

Measurement of to δ_{CP}

- Reachable precision : 20° (40°) after 3 years (~DUNE)



Detector upgrade

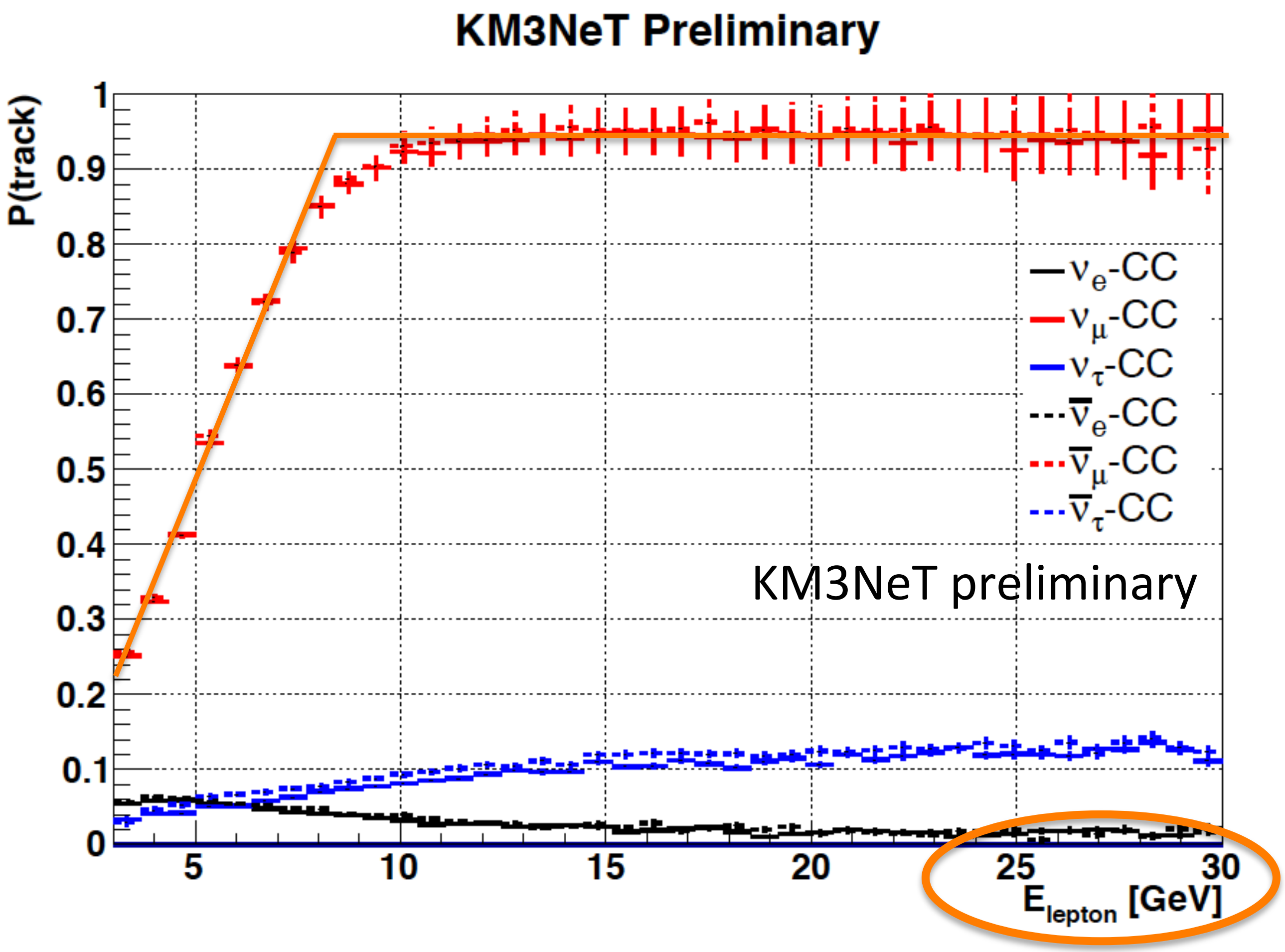
- Densified ORCA detector
- Better energy resolutions
- Particle ID improves as shorter muon tracks can be seen
- More low energy events as detection threshold decreases
- Cherenkov ring fuzziness a la SuperK can be exploited

Disclaimer

- The following plots are based on simple performance extrapolation based on the ORCA LoI detector
- No detailed simulations have been done so far
- No beam neutrino analysis chain is setup
- Both are in development

Particle ID

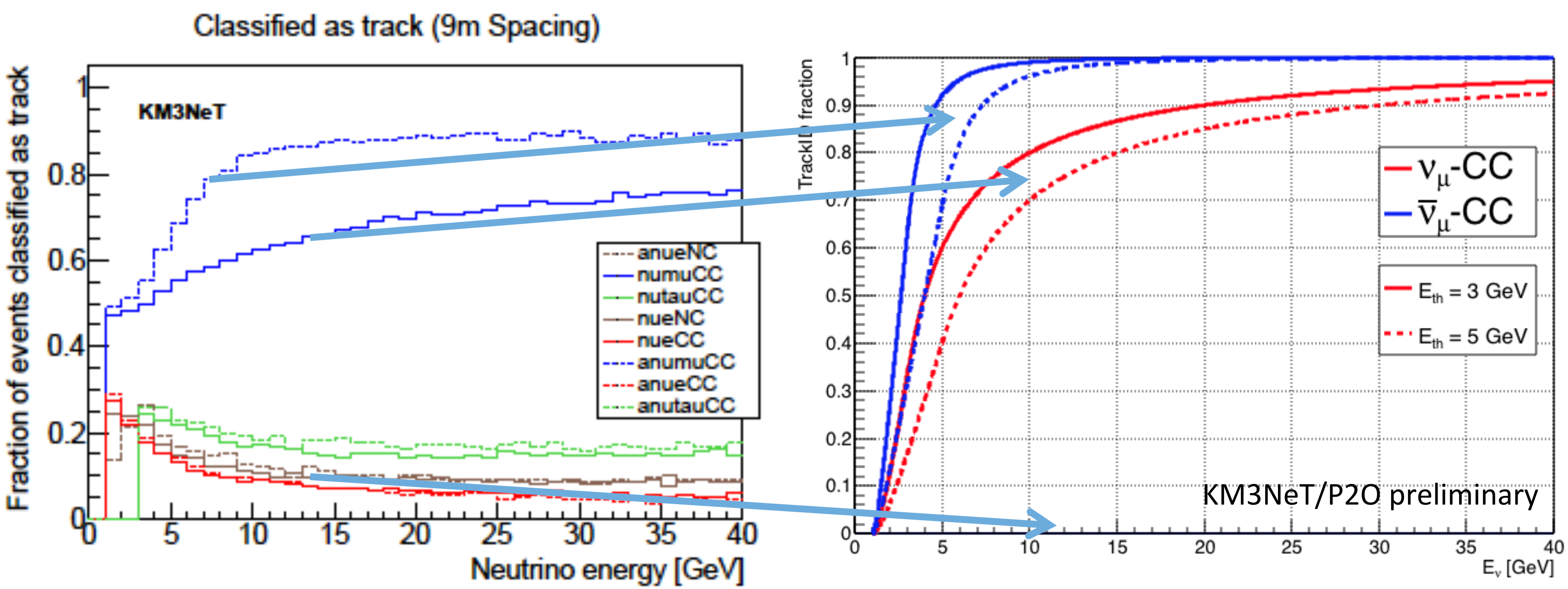
- Dominating effect : muon energy (length)
- Easy to parameterize approximately



Track Identification improvement

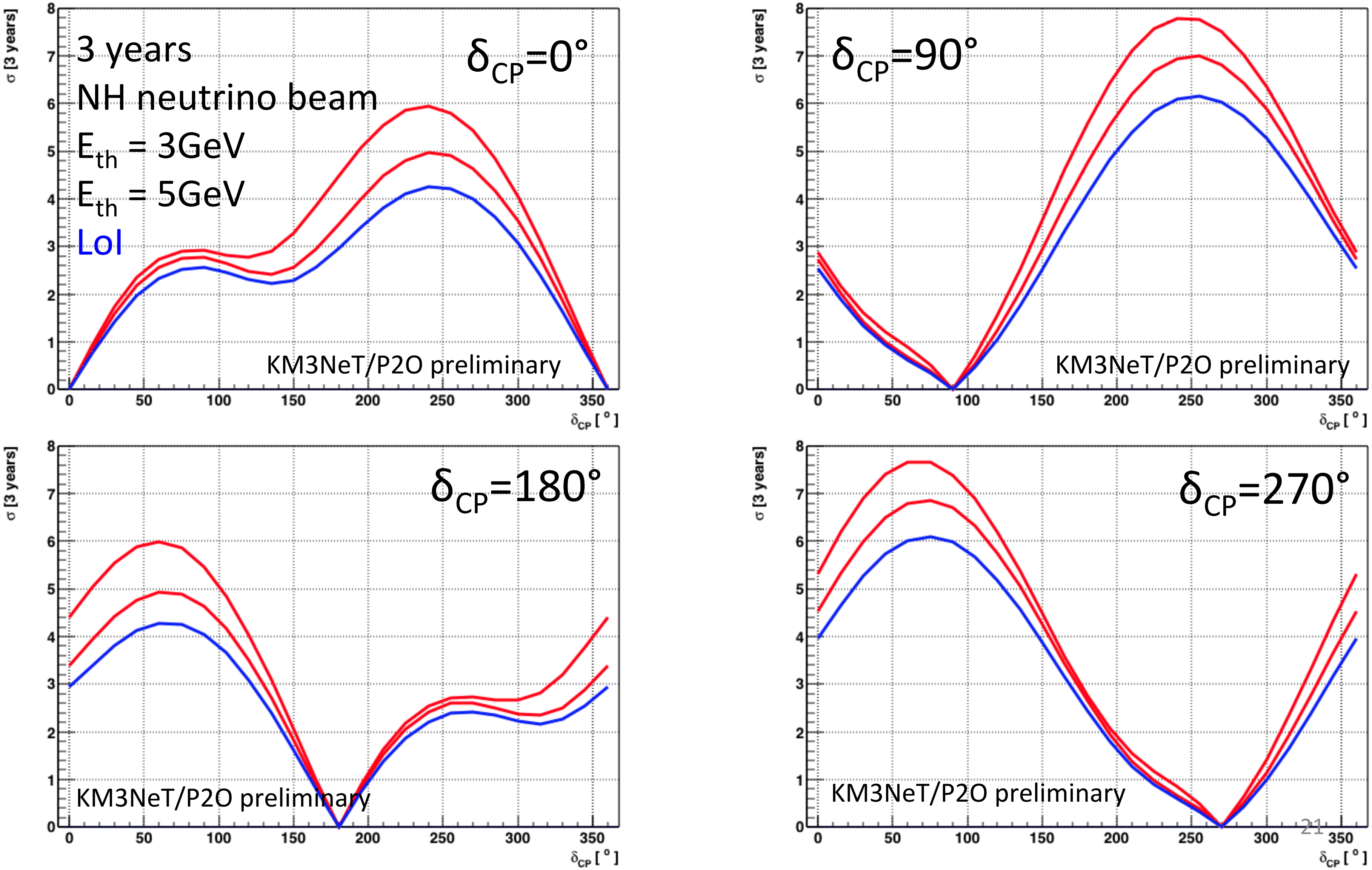
Assume that muons can be identified 100% above E_{th}

Linear decrease of performance below E_{th}



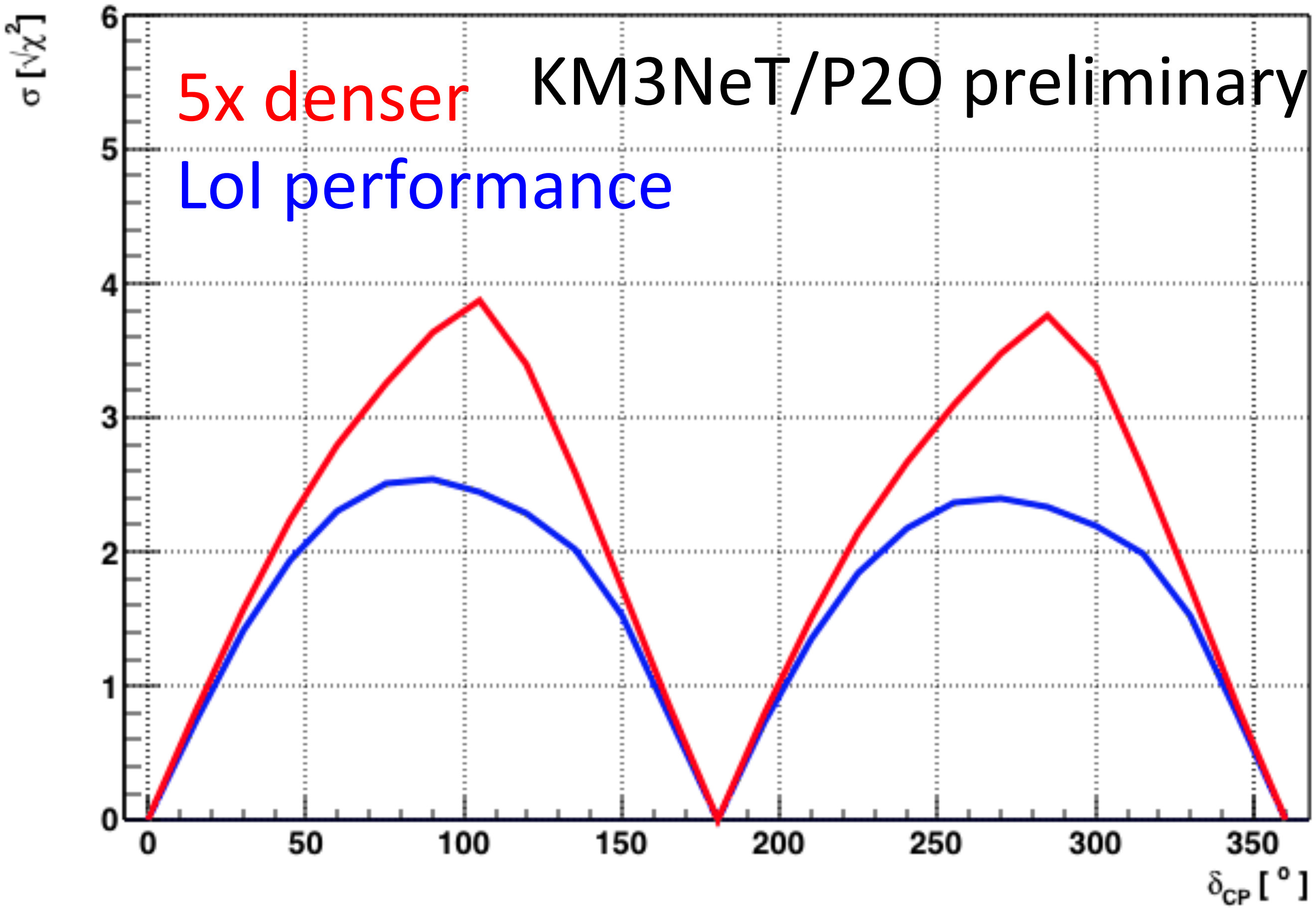
Different behaviour of neutrino and anti-neutrino due to difference in momentum transfer to hadronic system (Bjorken-y)

Improvement in δ_{CP} determination



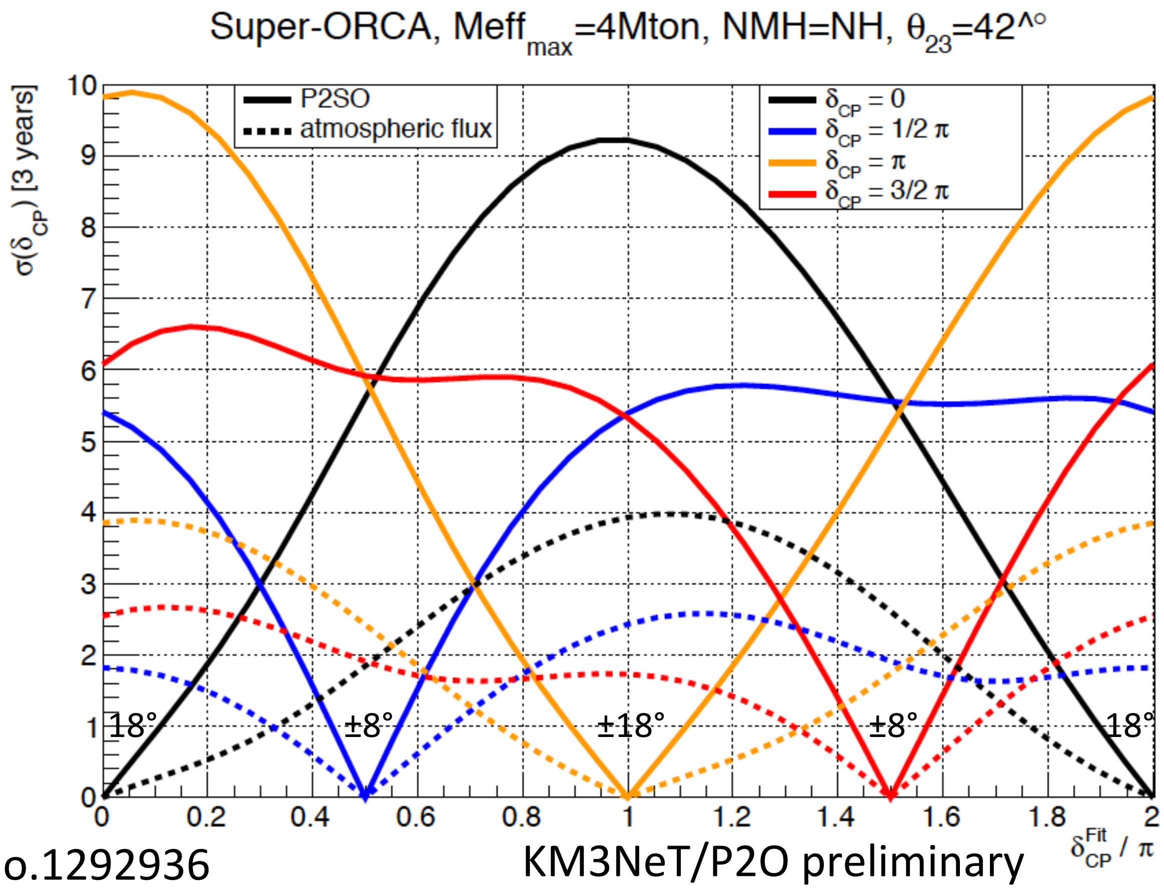
Non-CP exclusion

- 450 kW, 3 years, 5x denser ORCA
- PID, Meff, Resolutions scaled $f(E_\nu) \rightarrow f(5E_\nu)$



CP measurement

- 450 kW, 3 years, 10x denser ORCA → setup also used to study CP-violation with atmospheric ν
- Beam improves significantly over atmospheric !

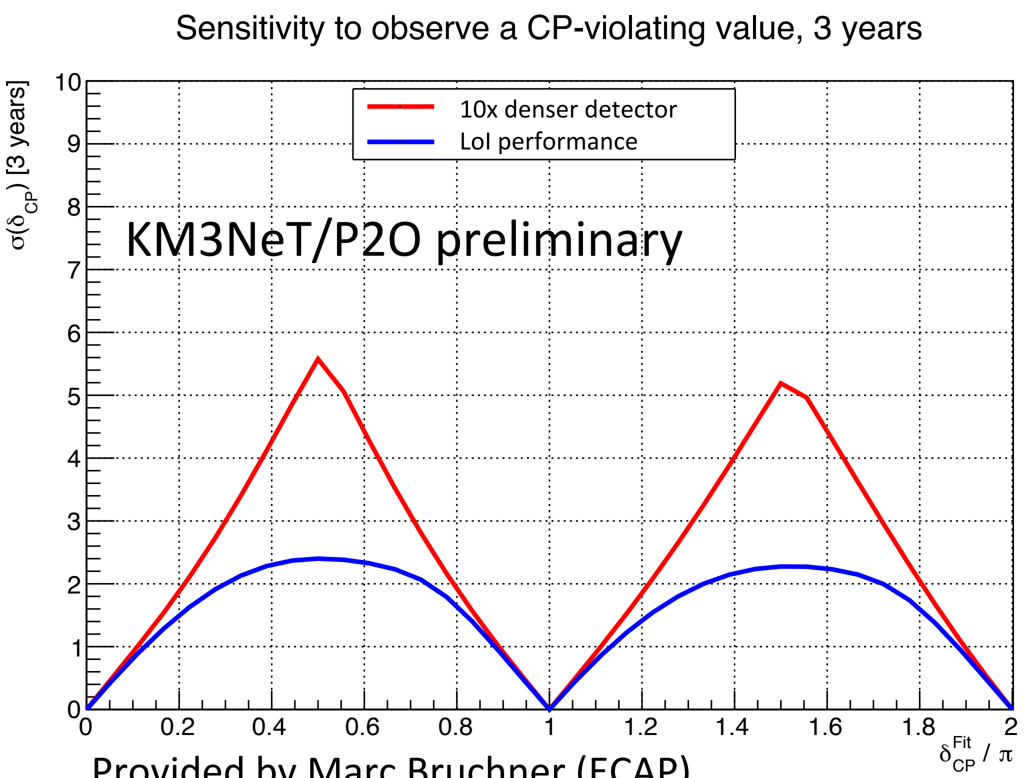


KM3NeT/P2O preliminary

10.5281/zenodo.1292936

Non-CP exclusion

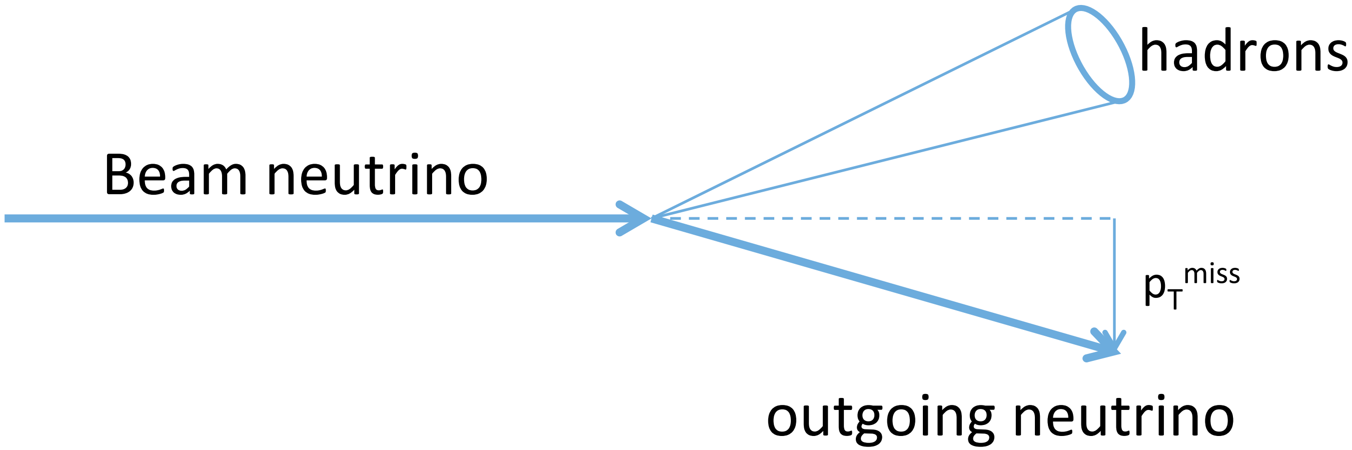
- 450 kW, 3 years, 10x denser ORCA → setup also used to study CP-violation with atmospheric ν
- Time residuals & fuzziness of Cherenkov rings for e/μ separation



Provided by Marc Bruchner (ECAP)

Further improvements

- beam neutrinos ←→ atmospheric neutrinos
  - Arrival direction known
  - Background free due to short beam spill
- → new analysis chain to be developed
- Example : identify NC by "missing p_T"



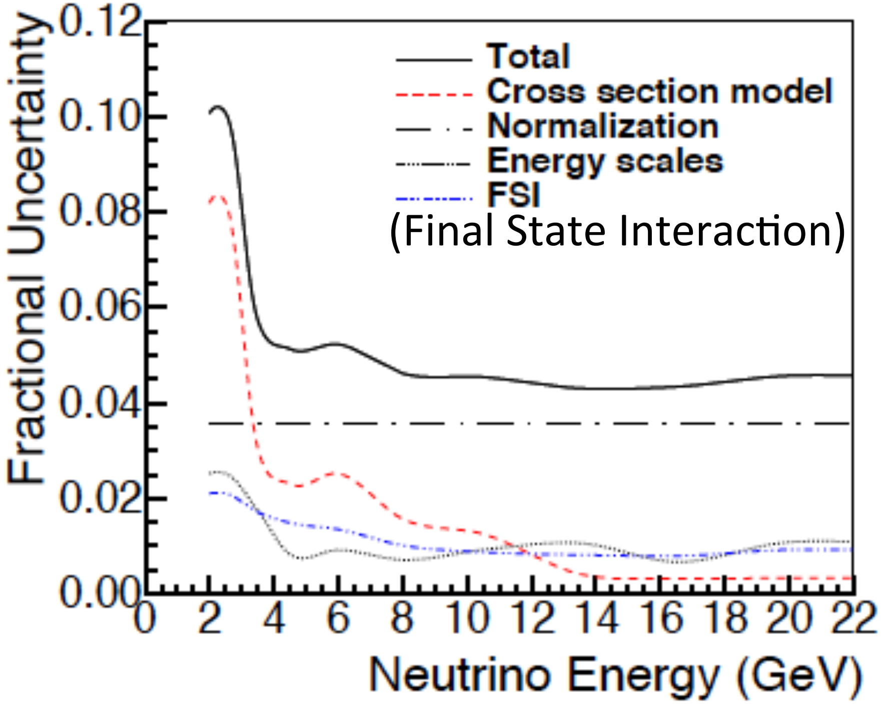
Comparison of Future projects

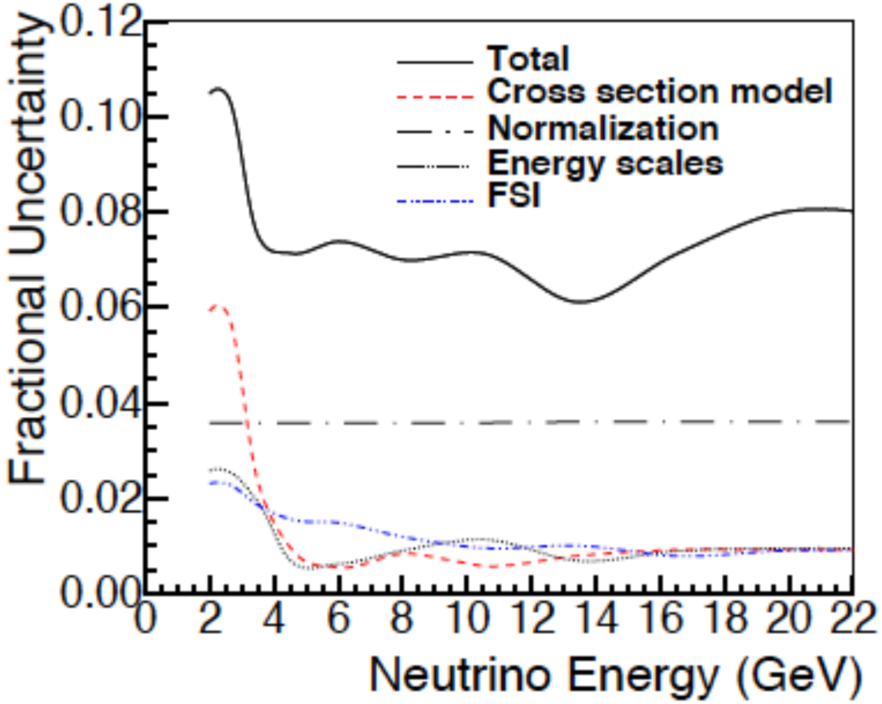
- Advantages / challenges are complementary

Experiment	Baseline Energy	Detector	Advantages	Challenges
Dune	1300km 2.4 GeV	Liquid Ar 40 kton	Resolution Particle ID	Technology Scalability
HyperK	295 km 0.6 GeV	Pure Water 0.3 Mton	Proven concept	Cavern, phototube production
P2O	2600km 5 GeV	Sea Water 8 Mton	Low cost High statistics	Particle ID E-resolution

Cross section

- Below 3 GeV uncertainty strongly enhanced





Minerva arXiv:1701.04857

Roadmap for the international, accelerator-based neutrino programme

The ICFA Neutrino Panel

arXiv:1704.08181

4.3. Detector Development

4.3.7 Deep sea multi-Megaton detectors

[106] C. Vallee, "Pacific Neutrinos: Towards a High Precision Measurement of CP Violation ?," 2016. http://inspirehep.net/record/1494807/files/arXiv:1610.08655.pdf.

[107] J. Brunner, "Counting Electrons to Probe the Neutrino Mass Hierarchy," arXiv:1304.6230 [hep-ex].

[108] KM3Net Collaboration, S. Adrian-Martinez et al., "Letter of intent for KM3NeT 2.0," J. Phys. **G43** no. 8, (2016) 084001, arXiv:1601.07459 [astro-ph.IM].

Physics goals

The concept for a detector that exploits a large volume of sea water to produce a multi-megaton-scale detector illuminated by a powerful neutrino beam has been described in [106]. The KM3NeT collaboration is currently validating second generation, compact, modular instrumentation that is suited for the detection in sea water of neutrinos with energies of a few GeV [107, 108]. This technology would allow volumes of order tens of Megatons to be instrumented. Such a large detector located at a sufficiently long baseline (≥ 2500 km to yield a first oscillation maximum above ~ 5 GeV) would have the potential to measure oscillation parameters with high precision.

Opportunities for such programs would rely on the feasibility of a neutrino beam from, for example, Fermilab to the existing infrastructures NEPTUNE and OOI offshore of British Columbia, which have been established as deep-sea observatories; this project is referred to as the "Pacific Neutrinos" project [106]. Alternatively, a beam might be sent to the KM3NeT/ORCA detector that is being developed offshore of Toulon (see 6.1.4). To assess the potential of such configurations, quantitative studies must be performed with an optimised detector configuration. An in-situ validation of the technology with the ORCA detector should be carried out, prototypes should be deployed in NEPTUNE/OOI and an investigation of the characteristics of the deep-sea candidate sites should be carried out.

Conclusion

- Running ORCA in a neutrino beam is promising
- First high statistics long baseline experiment

- Phased Approach might facilitate financing

- ORCA (LoI) + low intensity beam
  - NMH determination better than 5σ after few years
  - Neutrino/anti-neutrino mode decided from NMH
  - No need to run both polarities !

- Densified ORCA + higher intensity
  - Highly competitive for CP-phase measurement
  - Complementary detector systematics
  - Small cross section systematic