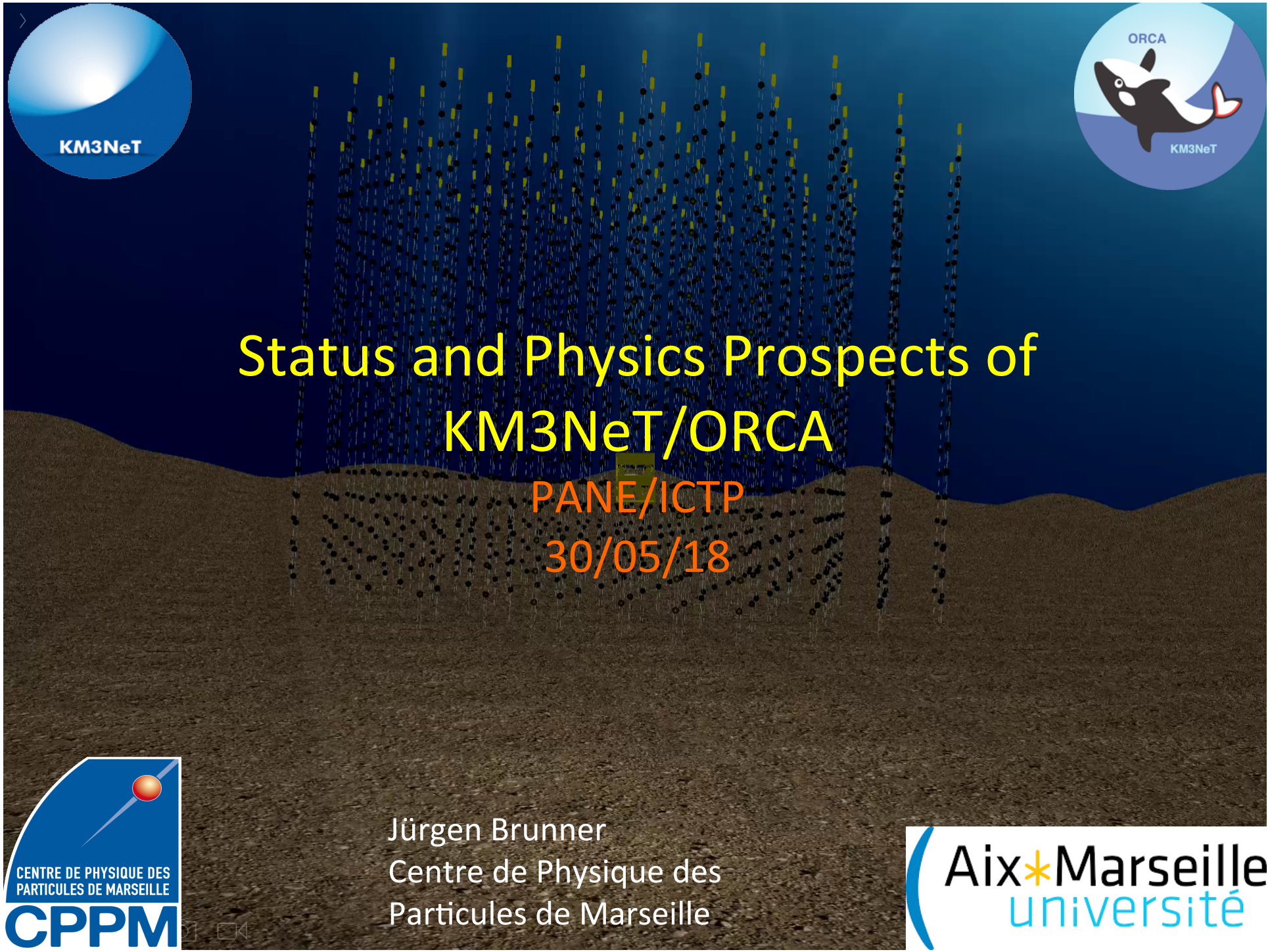


Status and Physics Prospects of KM3NeT/ORCA

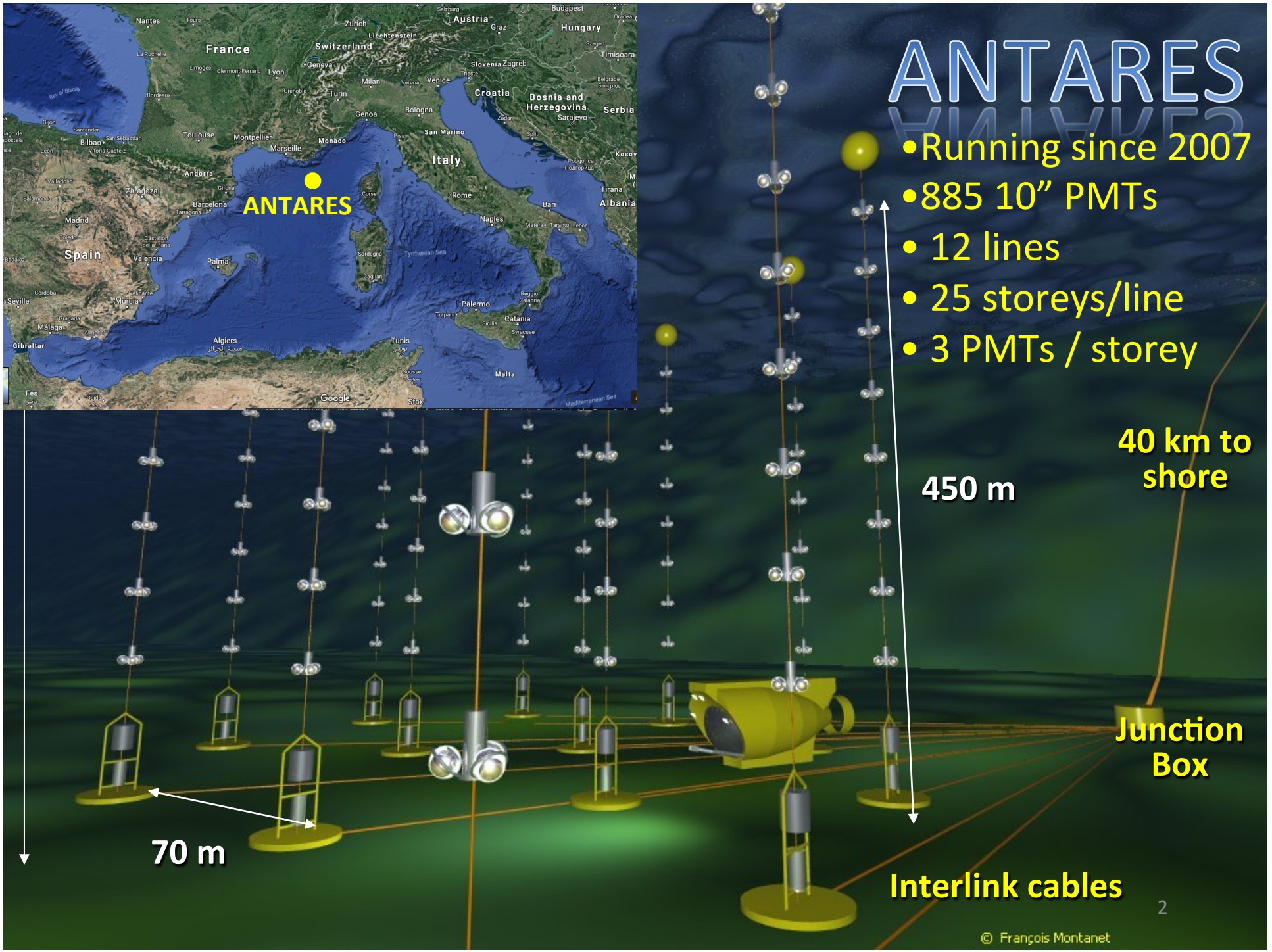
PANE/ICTP

30/05/18

Jürgen Brunner
Centre de Physique des Particules de Marseille

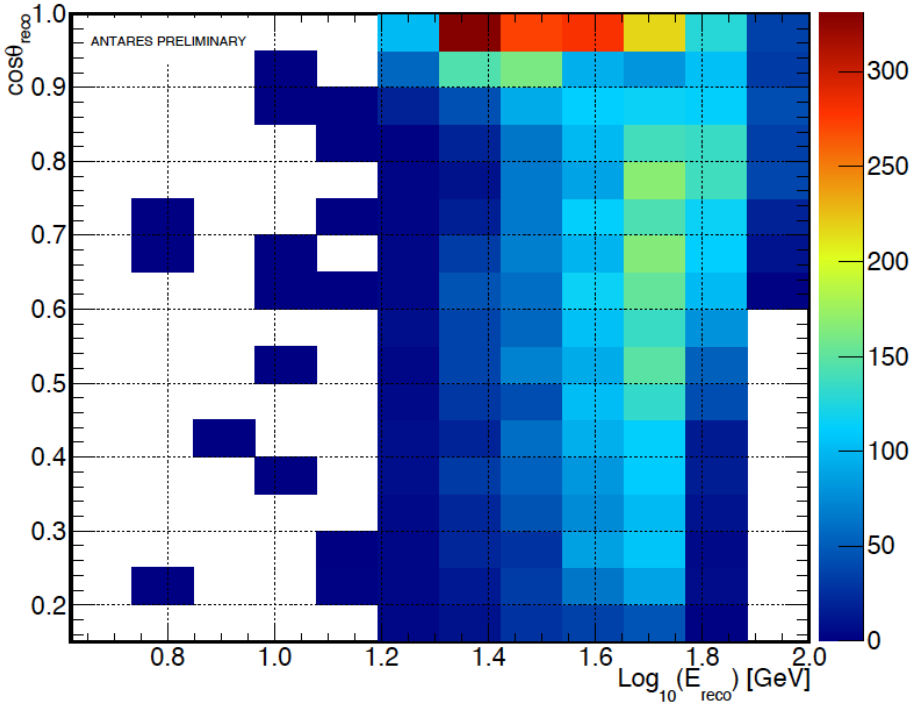
CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE
CPPM

Aix*Marseille université


ANTARES
•Running since 2007
•885 10” PMTs
• 12 lines
• 25 storeys/line
• 3 PMTs / storey
ANTARES
40 km to shore
450 m
Junction Box
70 m
Interlink cables
© François Montanet
France
Switzerland
Austria
Hungary
Slovenia
Croatia
Bosnia and Herzegovina
Serbia
Italy
Spain
Monaco
Andorra
Malta
Tunisia
Algeria
Gibraltar
Google

Data sample

- 9 years of data (2007-2016) - 2830 days of lifetime
- 7710 events selected, two reconstruction procedures
- track channel only, E_{reco} from muon range
- A binned likelihood fit (Poisson statistics) is performed in two dimensions ($\log_{10}(E_{reco})$, $\cos\theta_{23}^{reco}$)

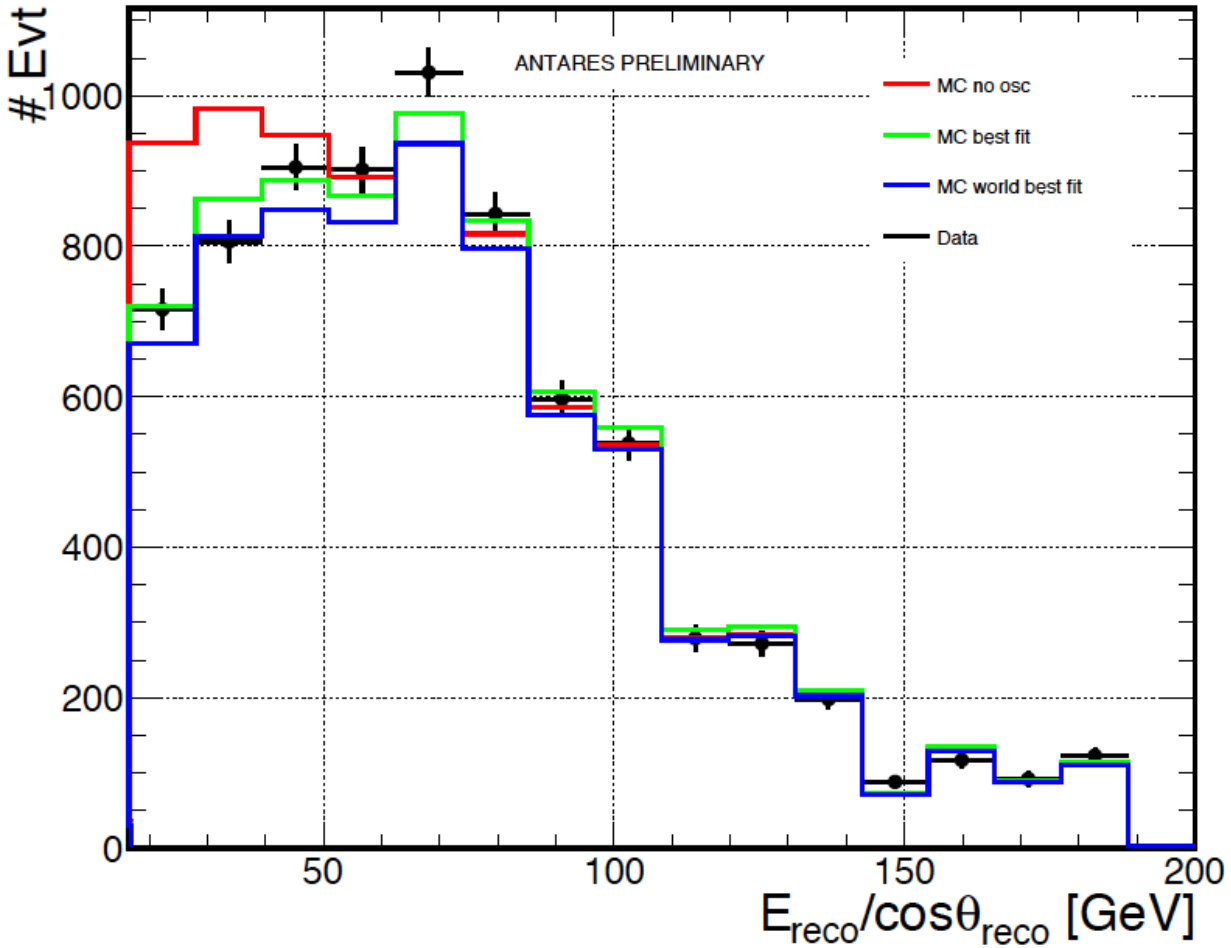


Systematics

- Unconstrained normalization for neutrinos
- Normalization for atmospheric muons
  - Prior from data
  - exponential extrapolation into signal region
- Unconstrained spectral index
- Flux shape systematics from Barr et al.
  - Implementation from IceCube
  - Kindly provided by Th. Stuttard
- Cross section from Genie
  - Leading effect M_A
- Test MC with variation in detector response
  - 15% absorption length variations
  - 10% PMT efficiencies variations
  - → both effects are well described by normalization•spectral index

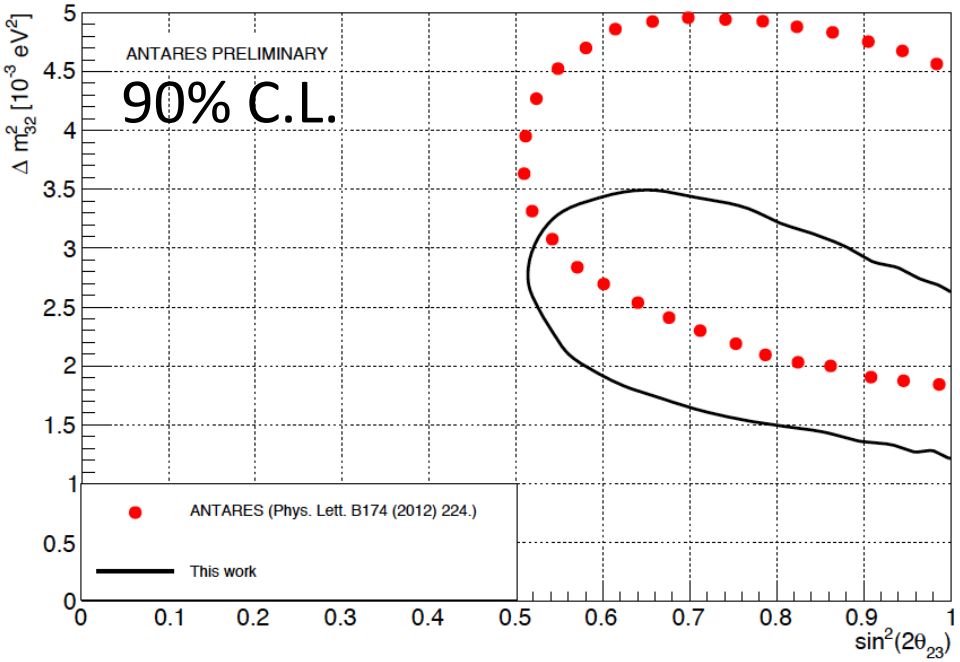
Results

- The E/cosθ plot illustrates the oscillation effect
  - The fit is NOT performed on this 1D distribution !



Comparison with earlier Antares result

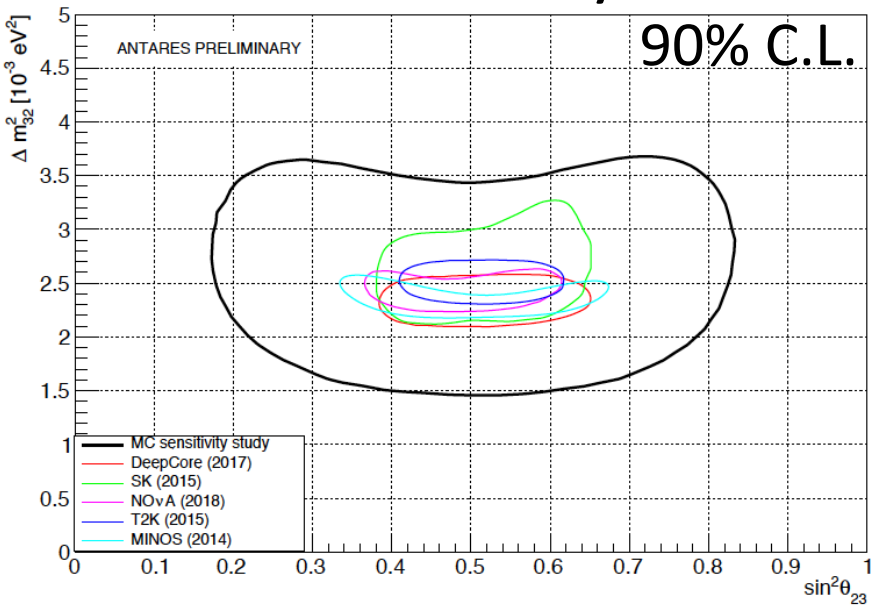
- Factor three larger data sample
- Many more systematics taken into account
- Still significant improvement
- No-oscillation hypothesis excluded at 4.6σ (was 2.2σ in former analysis)



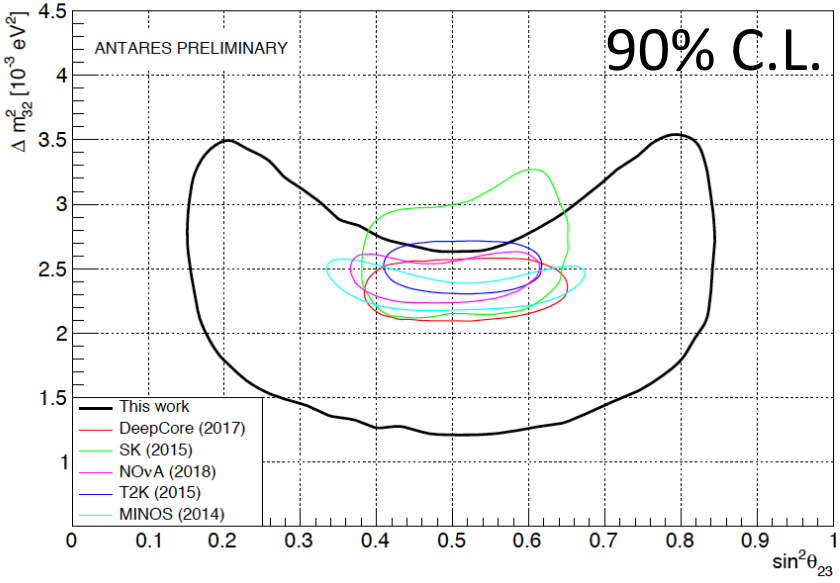
Comparison with World Data

- Result comparable to sensitivity estimate
- Data prefer slightly lower value of Δm_{32}^2

Sensitivity

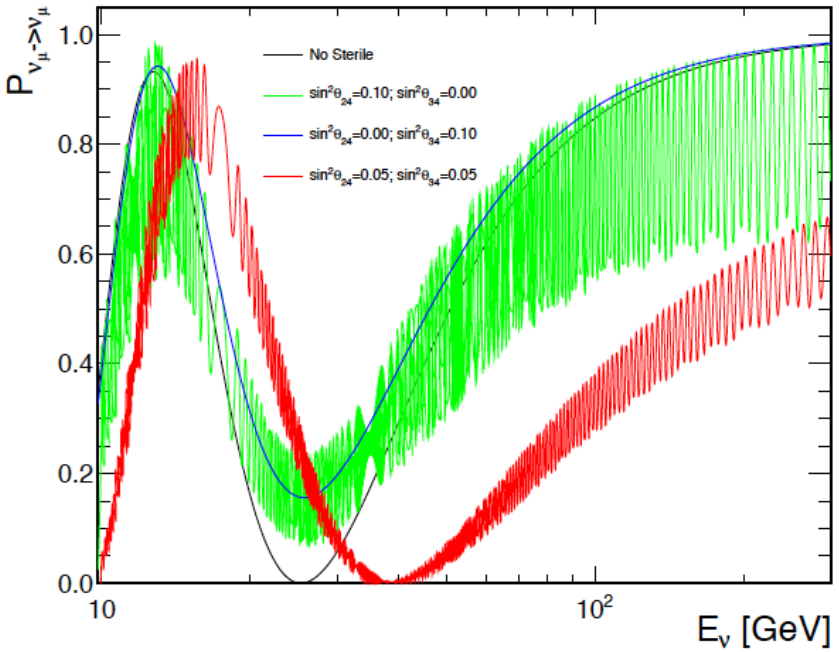


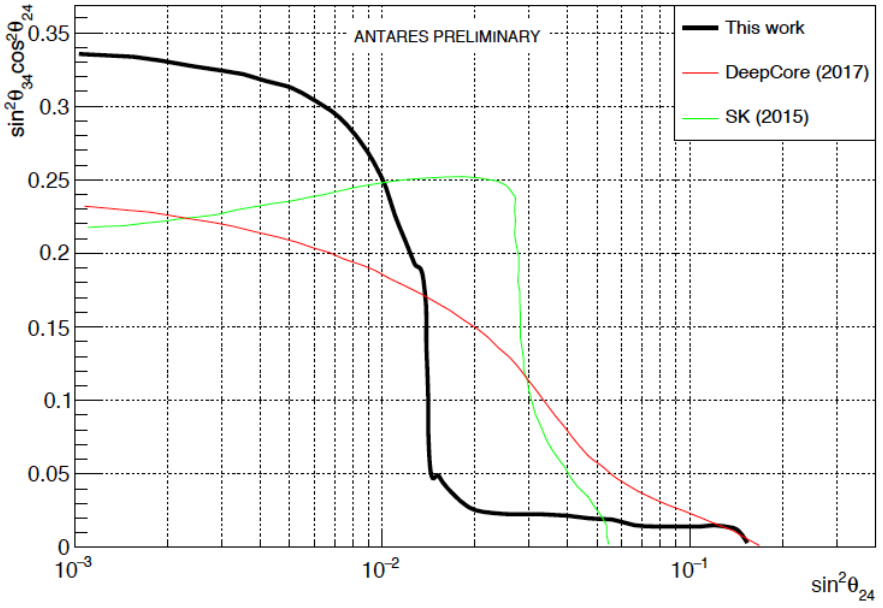
Result



Search for sterile Neutrinos

- Same data sample, similar fit
- 3+1 model with $\Delta m^2_{41} > 0.5\ eV^2$
- Modifies oscillation minimum
- Improvements of earlier SuperK and IceCube results





KM3NeT

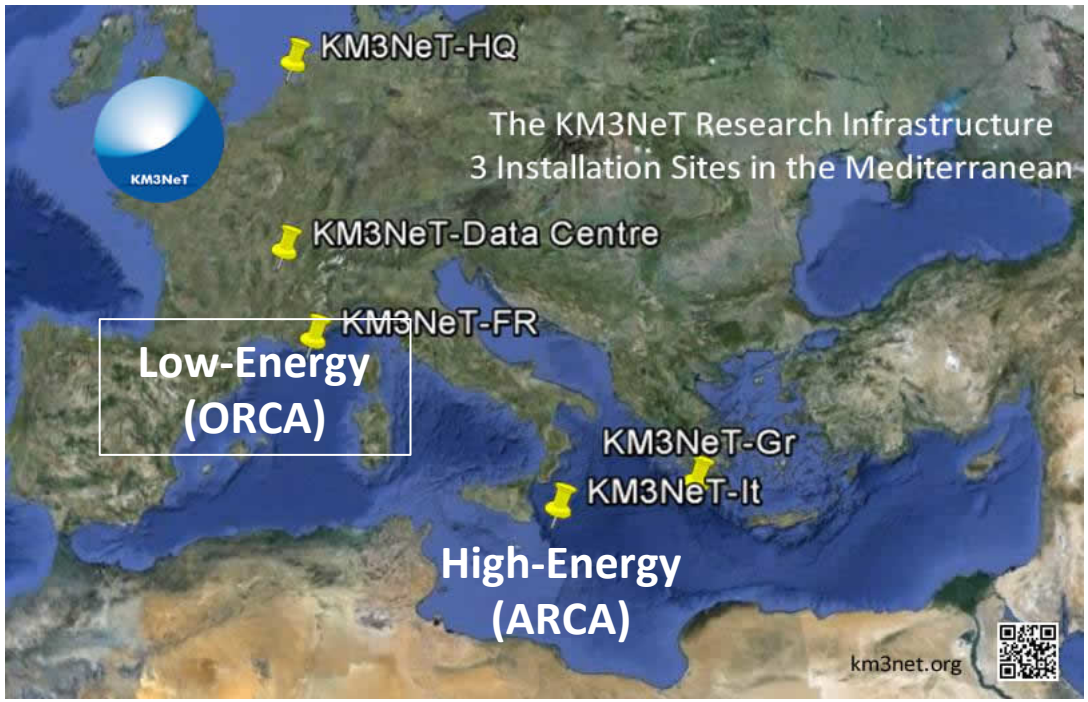
KM3NeT is a research infrastructure with 2 main physics topics:

- The origin of cosmic neutrinos (high energy)
- Measurement of fundamental neutrino properties (low energy)
- Deep Sea Observatory (Oceanography, bioacoustics, bioluminescence, seismology)

Single Collaboration

Single Technology

Single Management

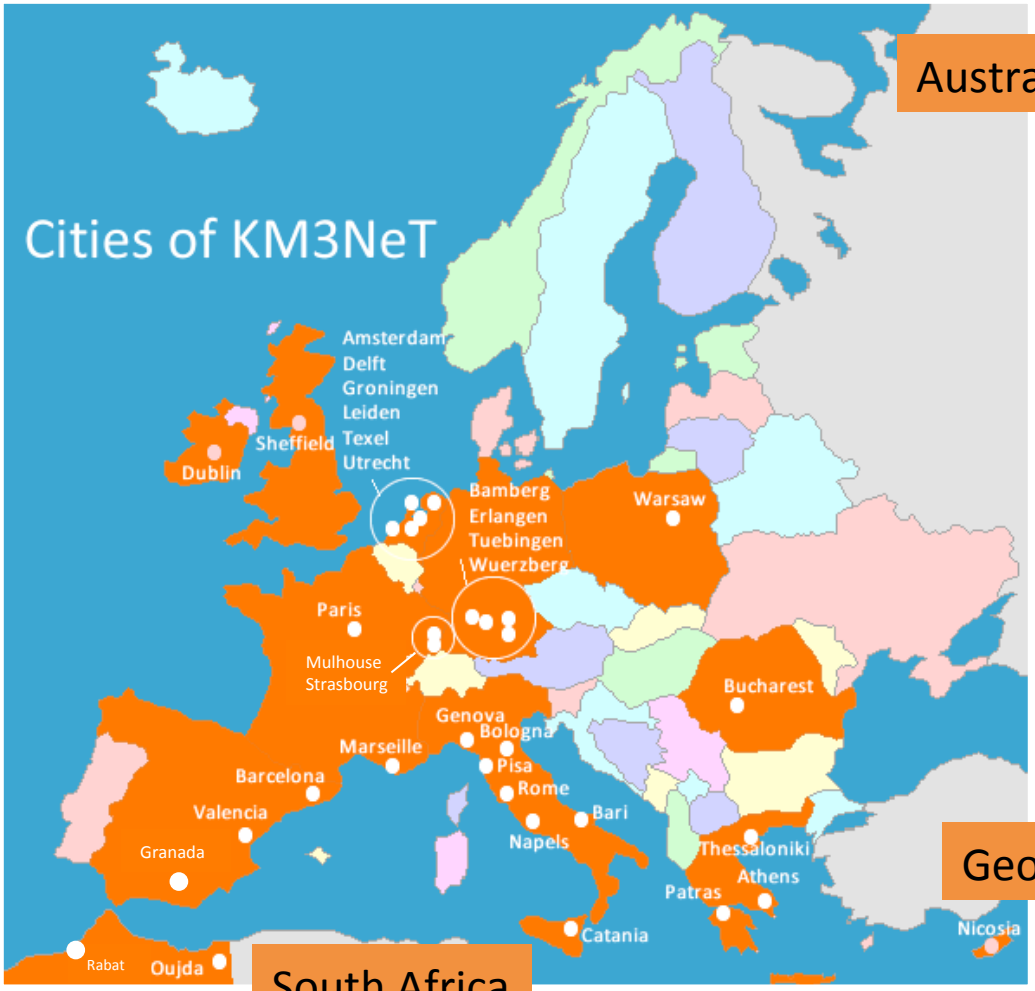


ARCA- Astroparticle Research with Cosmics in the Abyss

ORCA- Oscillation Research with Cosmics in the Abyss

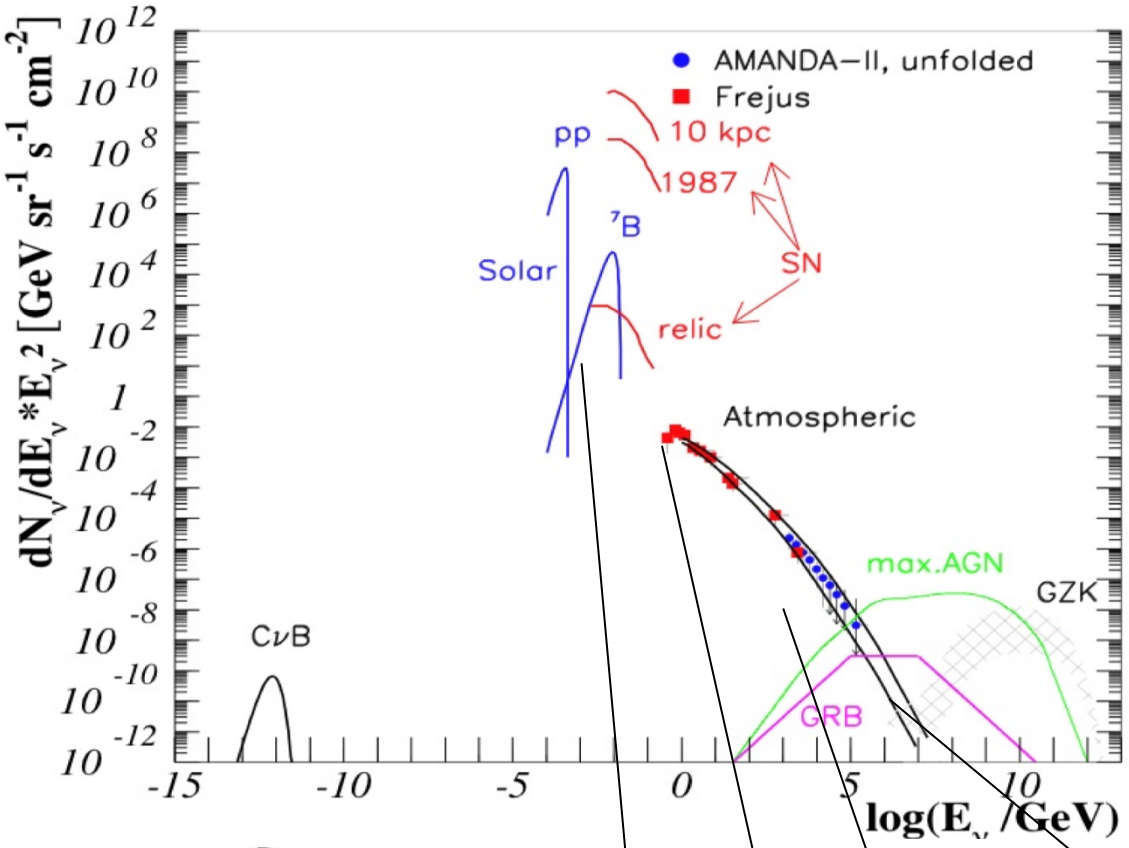
KM3NeT Collaboration

15 Countries
>40 Institutes
>220 Scientists

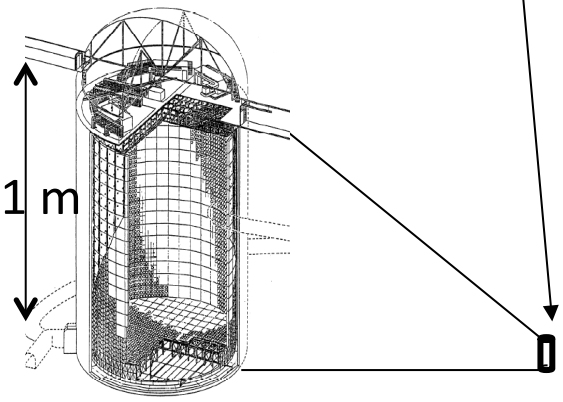


KM3NeT LoI , arXiv:1601.07459 [astro-ph.IM]
Journal of Physics G: Nuclear and Particle Physics, 43 (8), 084001, 2016

From MeV ν to PeV ν



Flux decreases with energy
Need larger and larger detectors



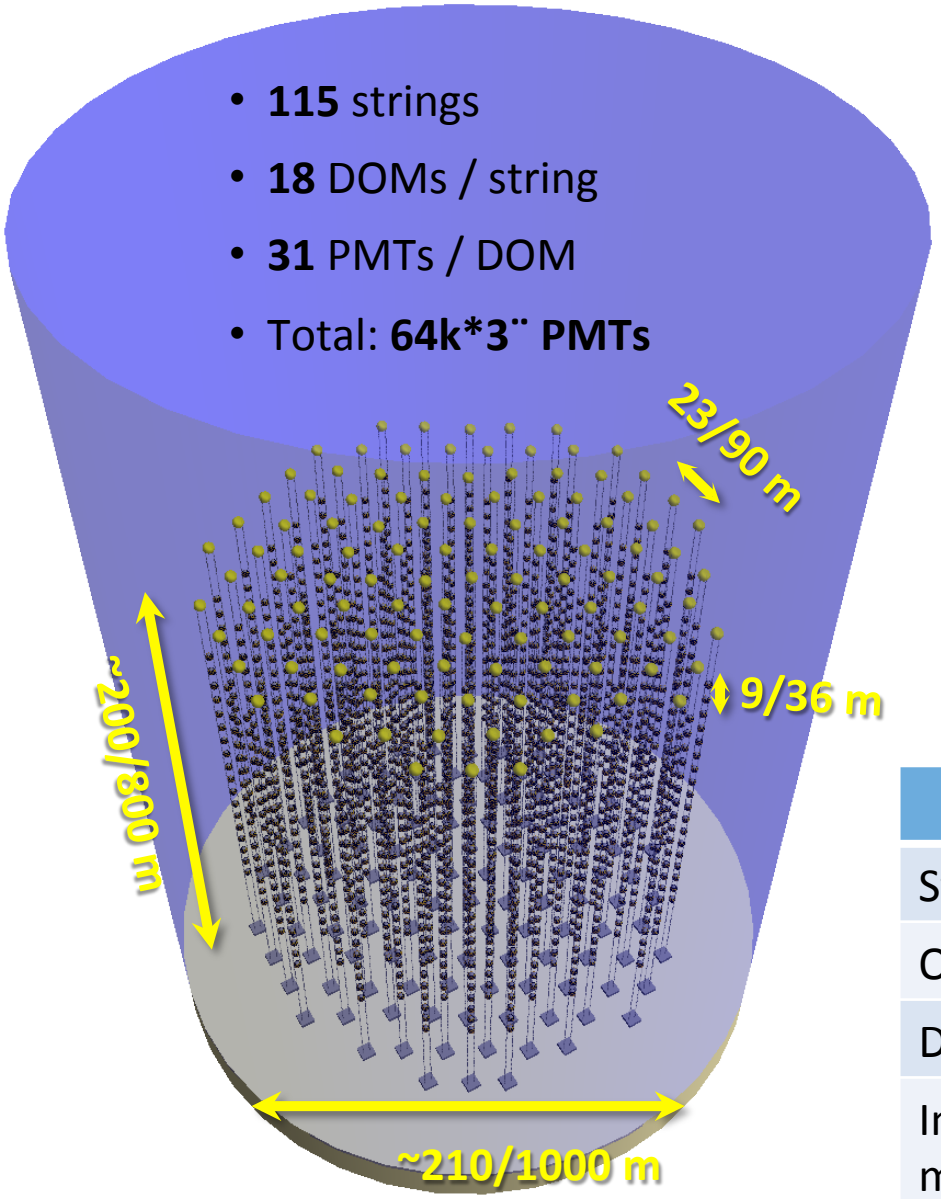
SuperK

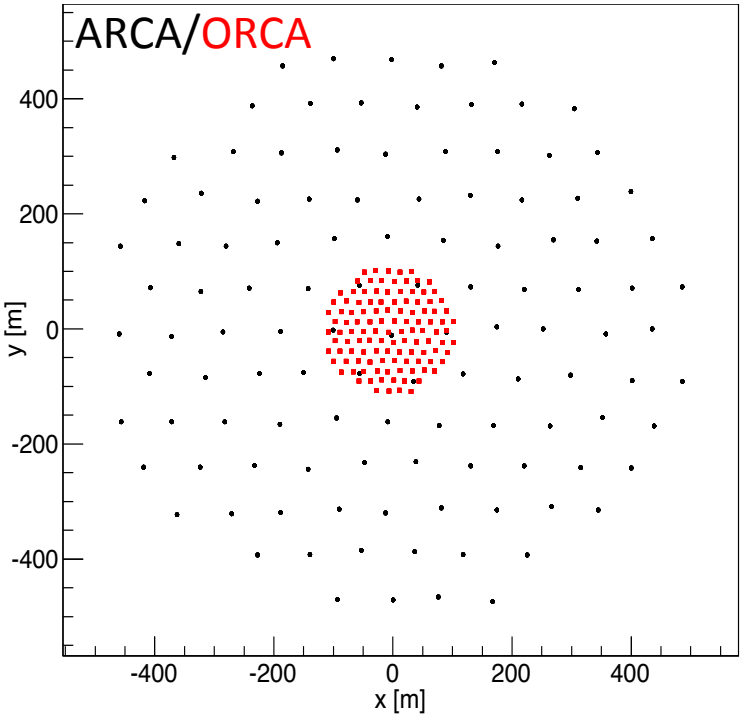
ORCA

ANTARES

ARCA

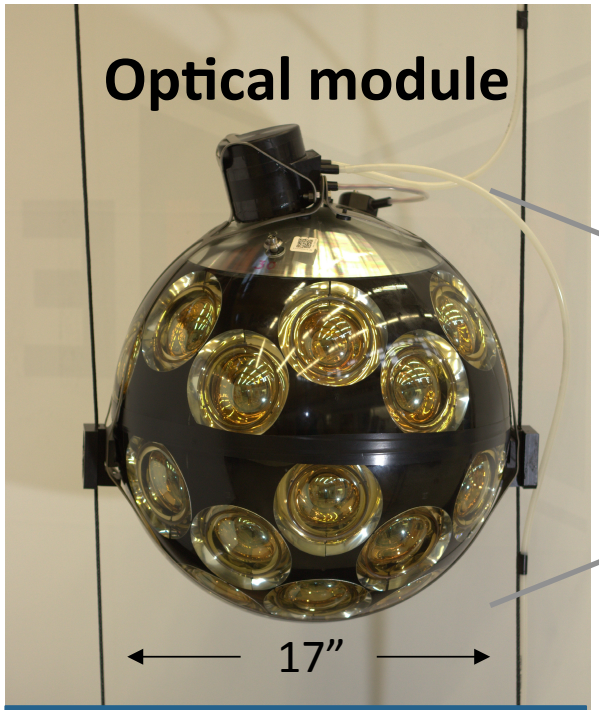
KM3NeT Building Block



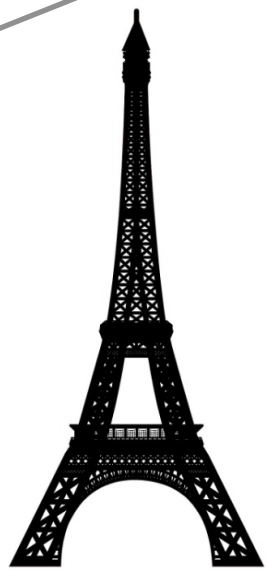


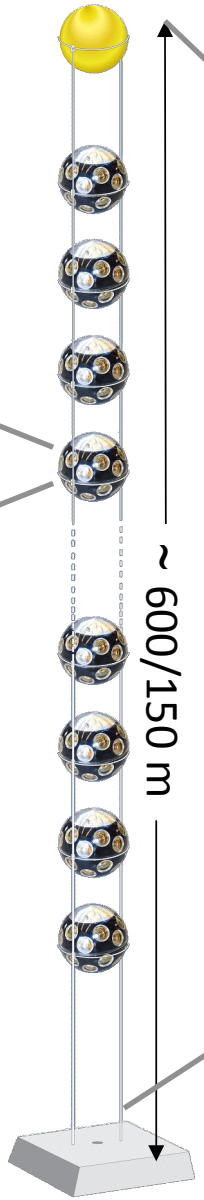
	ORCA	ARCA
String spacing	23 m	90 m
OM spacing	9 m	36 m
Depth	2470 m	3500 m
Instrumented mass	8 Mton	0.6*2 Gton

KM3NeT Technology

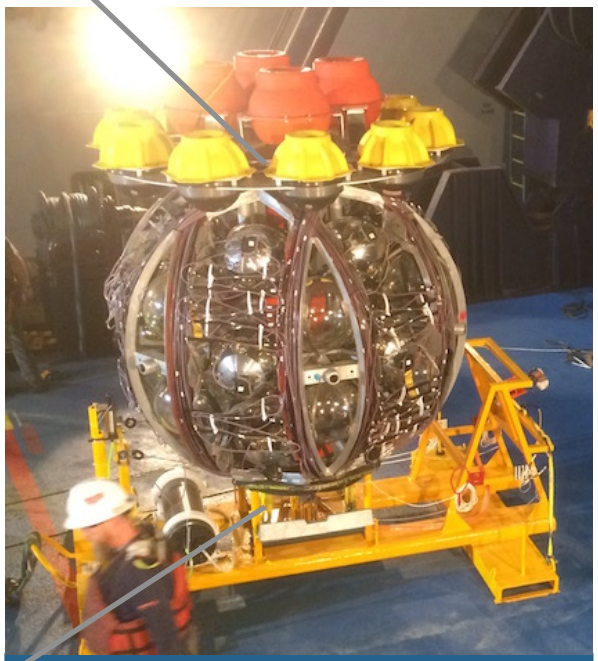


31 x 3” PMTs
PMT HV
LED & piezo inside
FPGA readout
Photon counting
Directional information



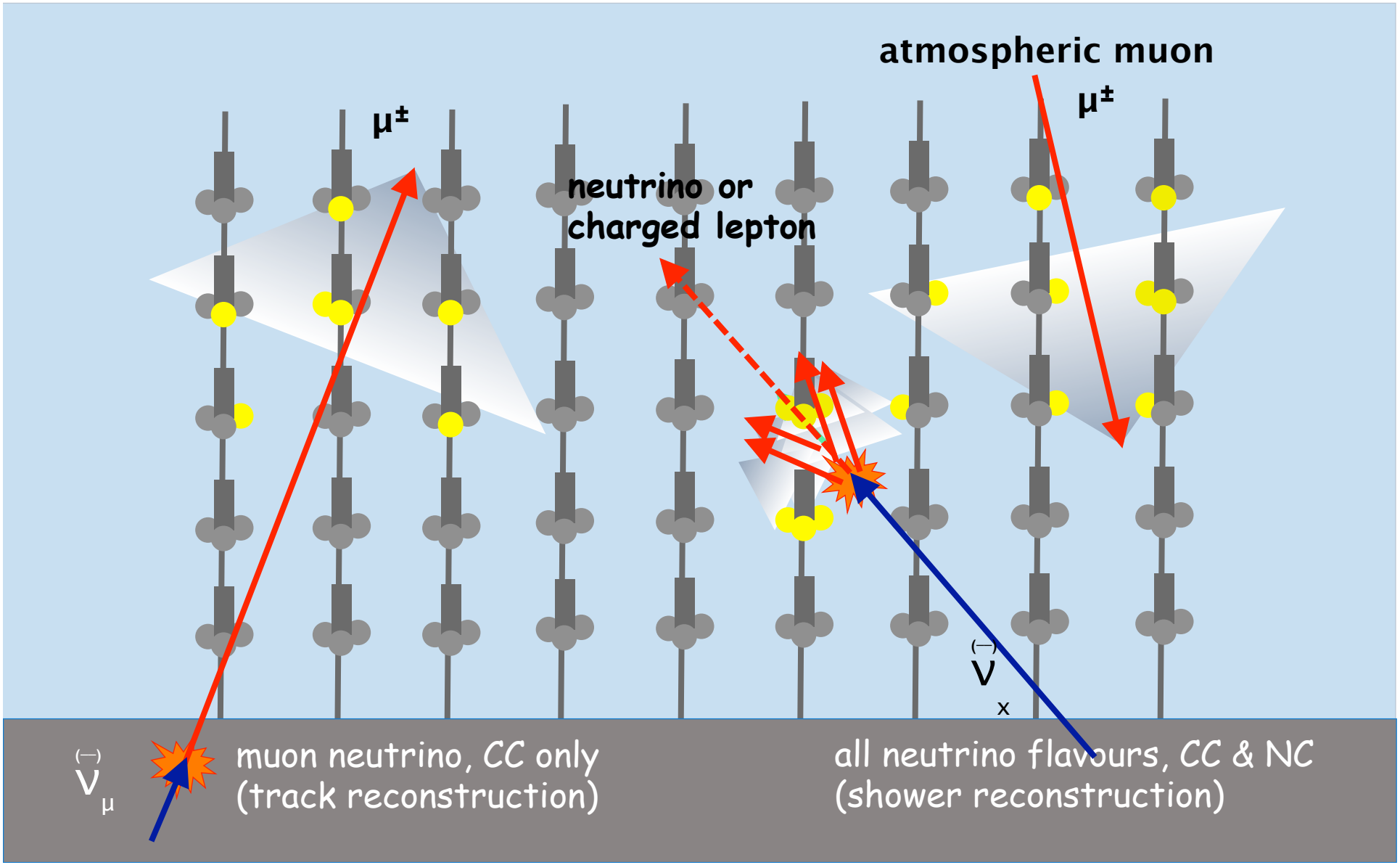


Launcher vehicle



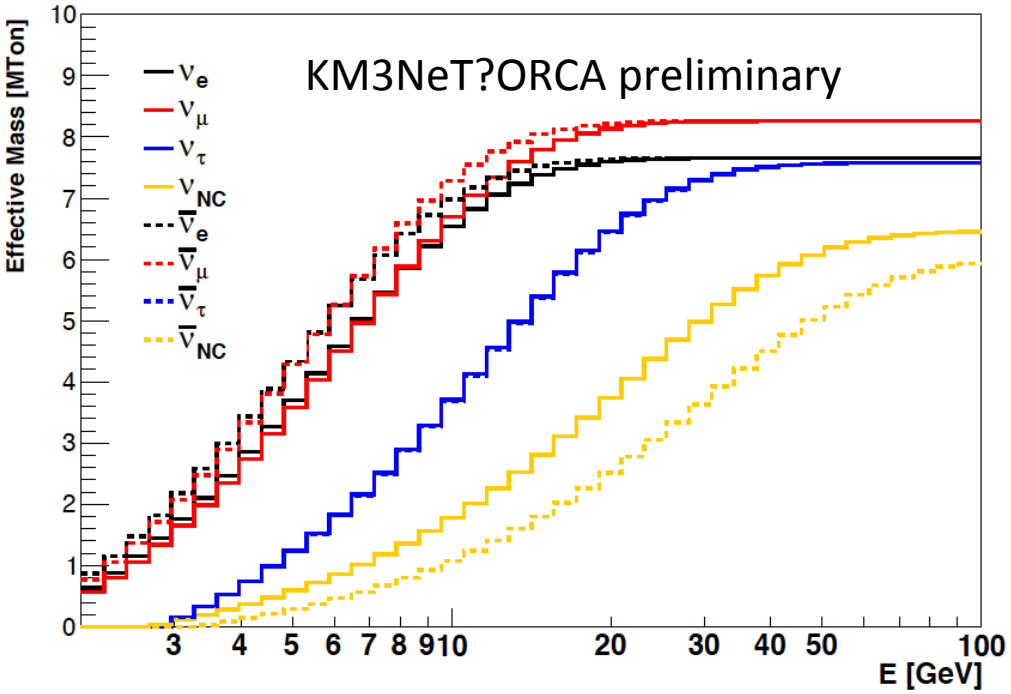
rapid deployment
autonomous unfurling
recoverable

Neutrino Signatures



Effective Mass

After triggering, atmospheric muon rejection and containment cuts:



Events/yr (atm):

ν_eCC: 20,000

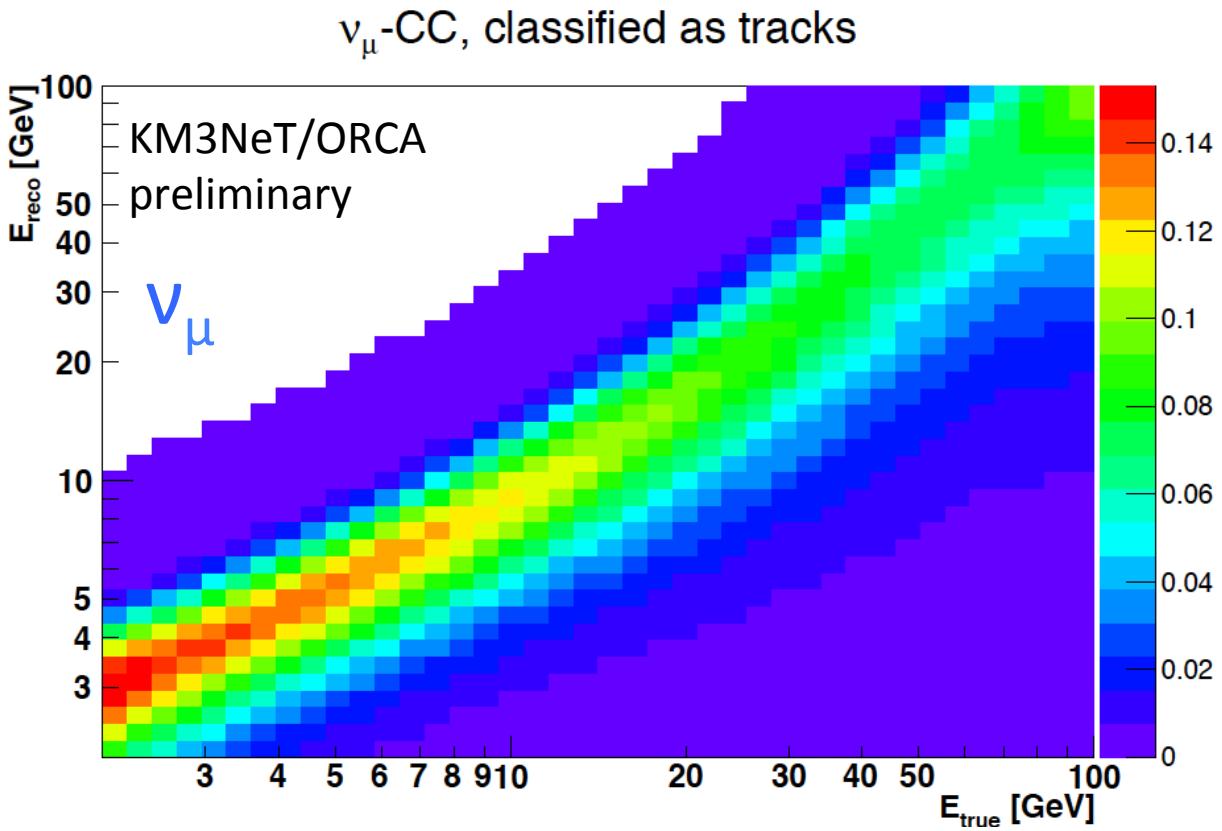
ν_μCC: 25,000

ν_τCC: 3,000

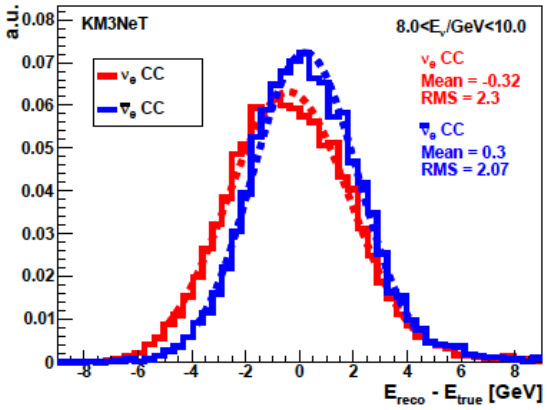
NC: 5,000

- Energy threshold determined by DOM spacing
- 8 Mton@10 GeV
- 50% Efficiency at 5 GeV

Energy Resolutions

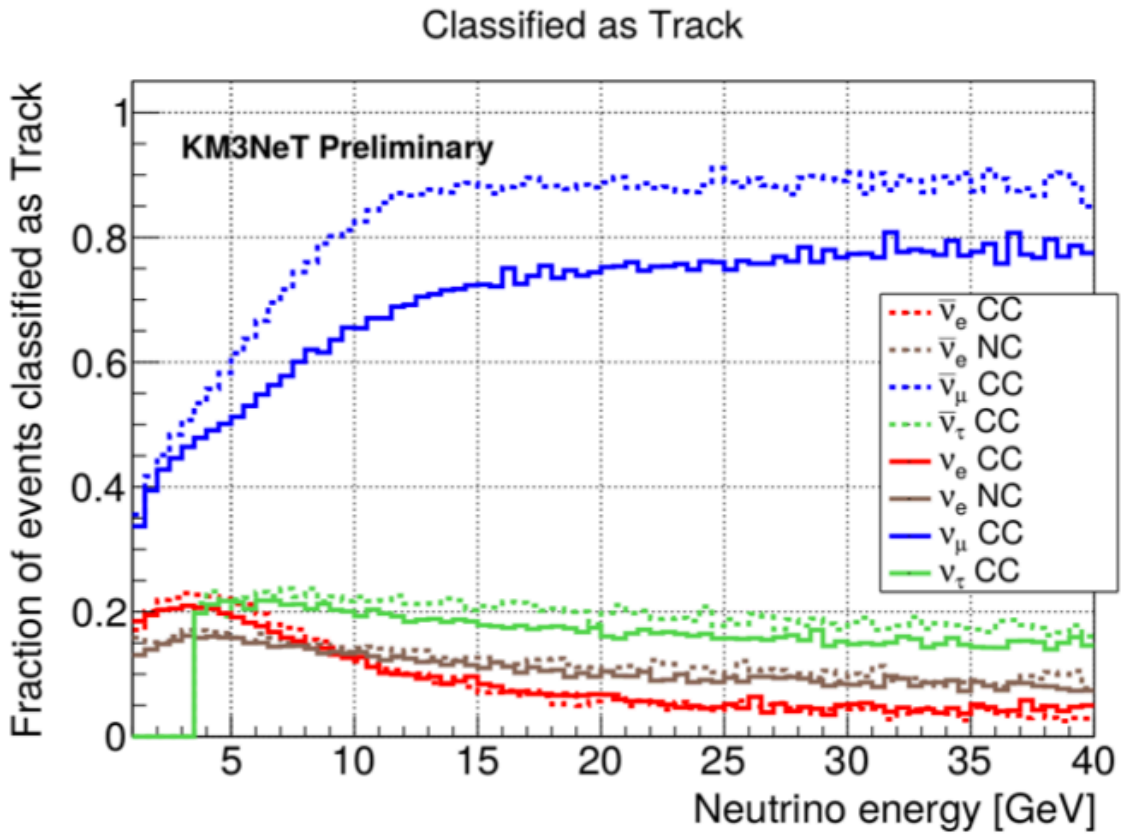


- Energy resolution better than 30% in relevant range
- Close to Gaussian



Shower/Track Identification

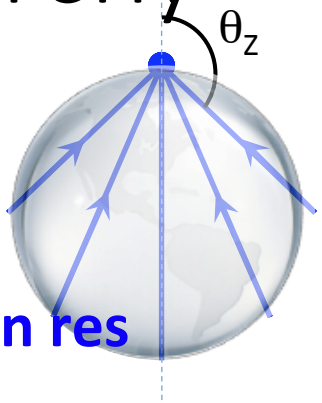
Discrimination of track-like and shower-like events via Random Decision Forest



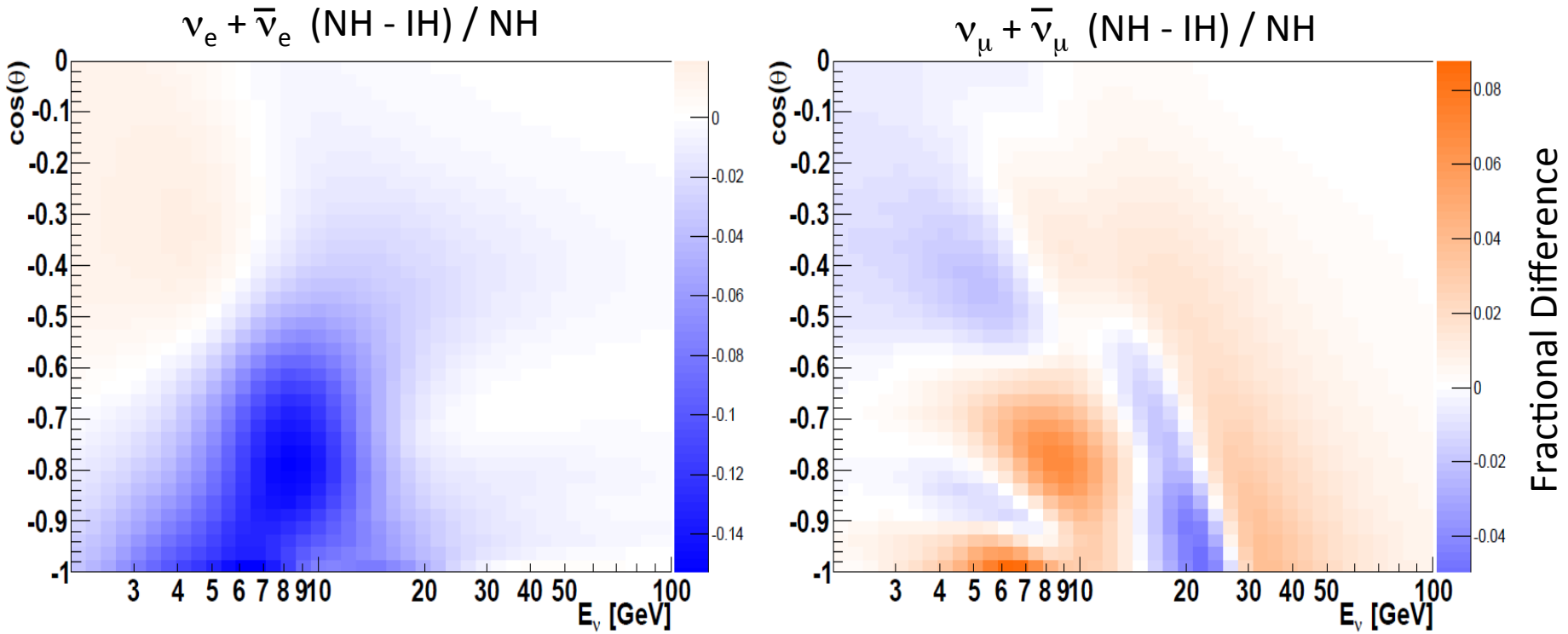
At 10 GeV:

- 90% correct identification of ν_e^{CC}
- 70% correct identification of ν_μ^{CC}

Measuring NeutrinoMassHierarchy



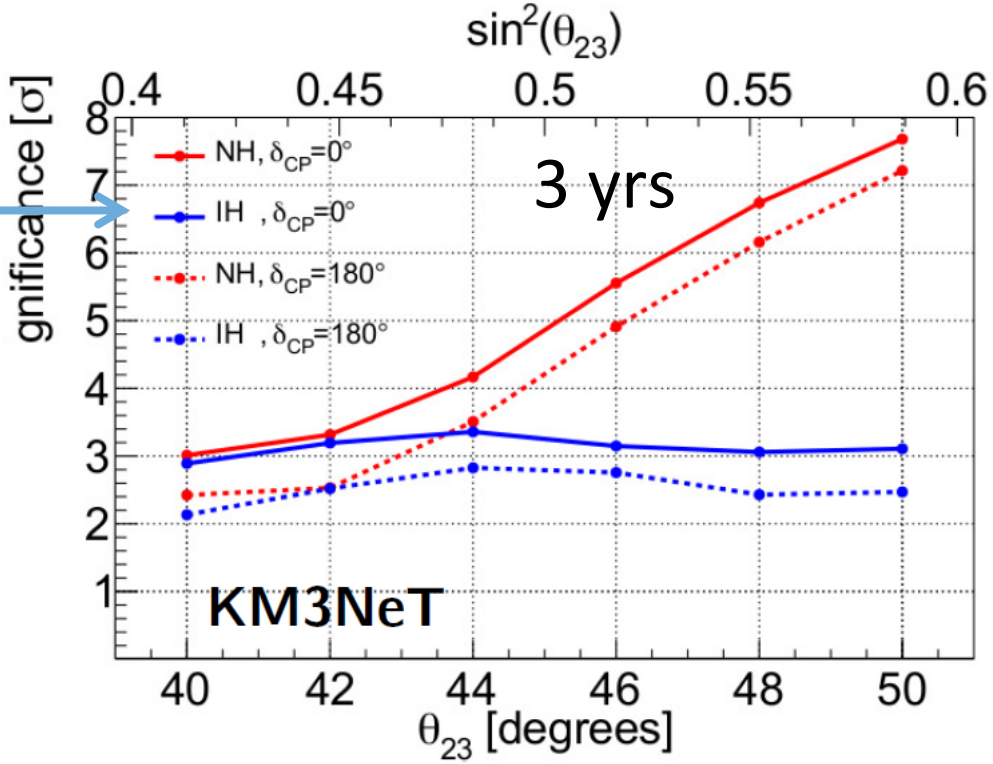
- Measure neutrino direction and energy
- Search for **oscillation patterns** from **matter effects**
- Requires **large statistics** and good **energy and direction res**

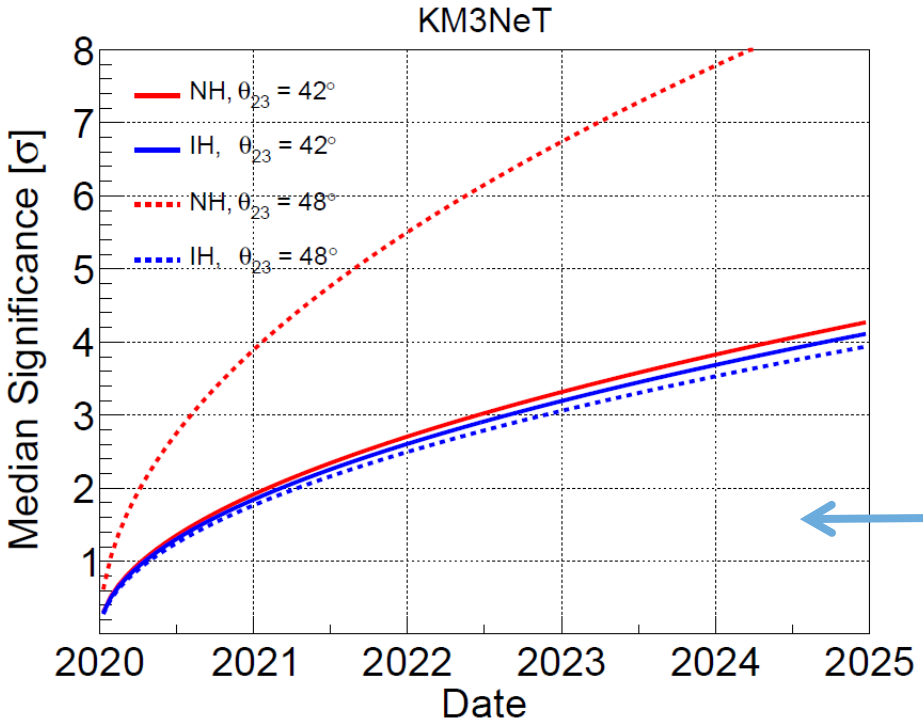


E_{resol} = 25% $\theta_{resol} = (m_p/E)^{1/2}$

Neutrino Mass Hierarchy

Sensitivity to measure
Neutrino Mass Hierarchy

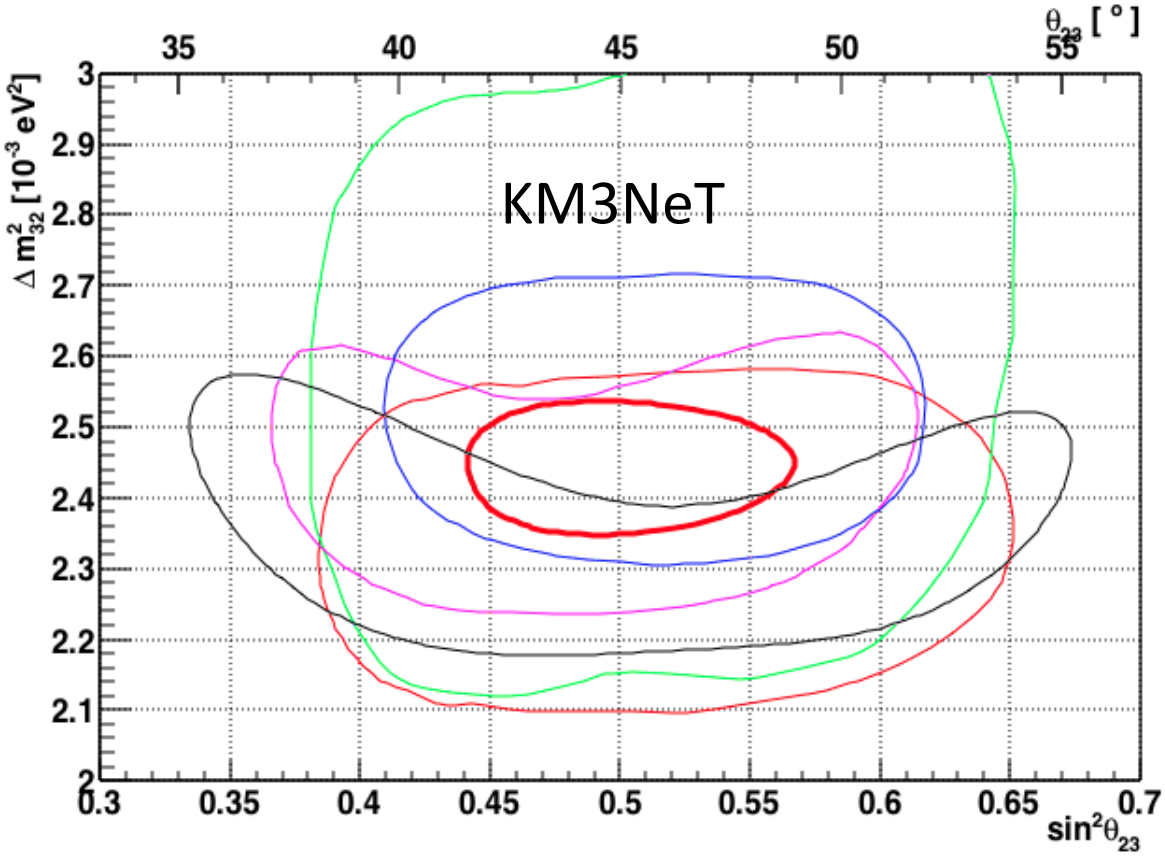




Time evolution of this sensitivity

Measuring Oscillation Parameters

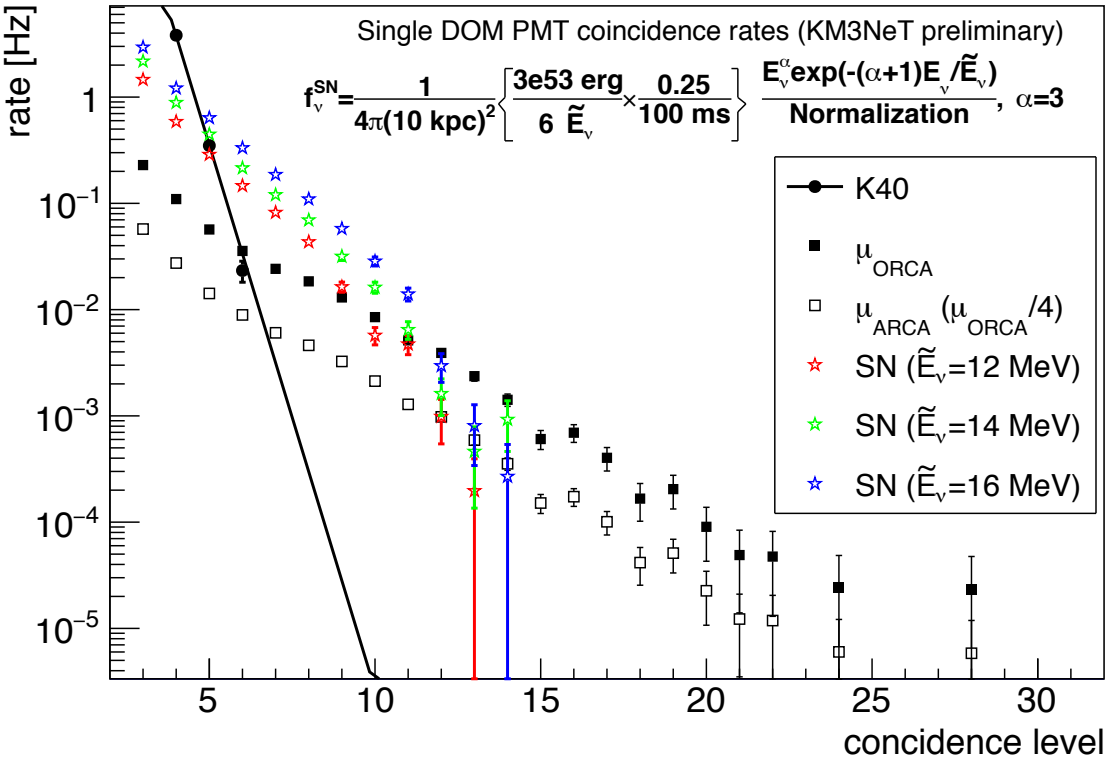
90% measurement contours for Δm^2_{32} and $\sin^2\theta_{23}$
2% in Δm^2_{32} and 5% in θ_{23}



SuperK (2015)
T2K (2015)
NOVA (2018)
IceCube (2017)
MINOS (2014)

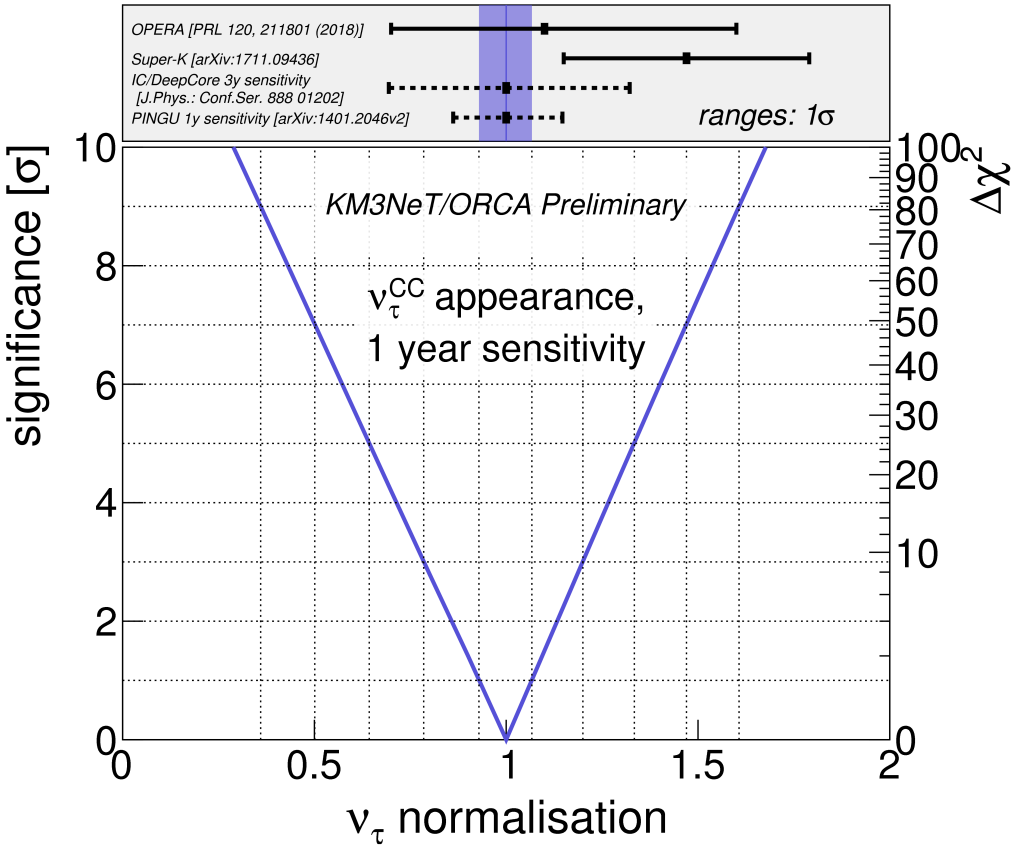
SuperNovae

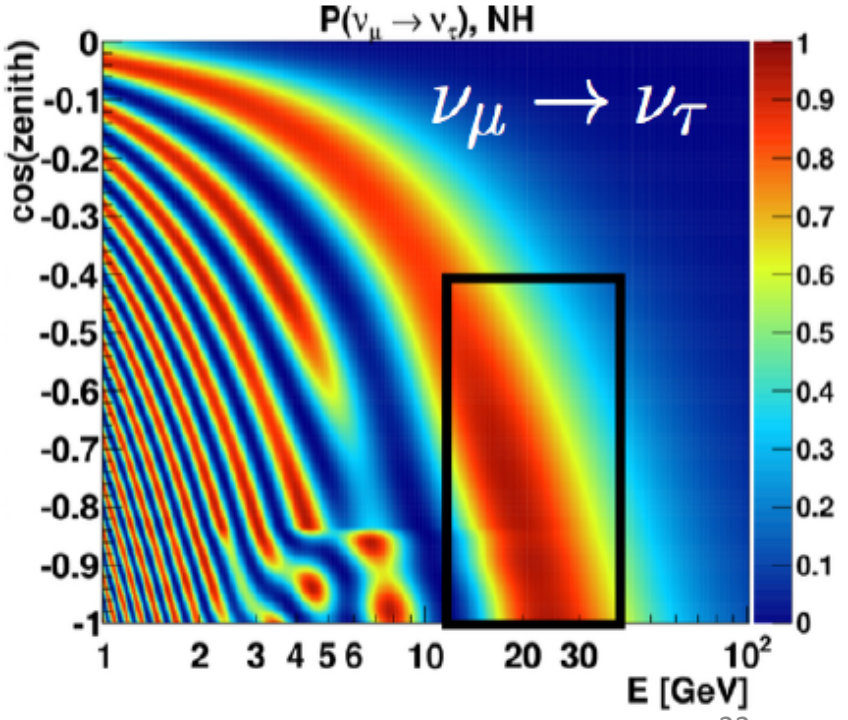
Count coincidence signals on individual Optical Modules
Excess of DOMs where 6-10 PMTs fire together
10 MeV anti-nu e from core-collapse SN
>80% of all Galactic SN with single building block



Tau Appearance

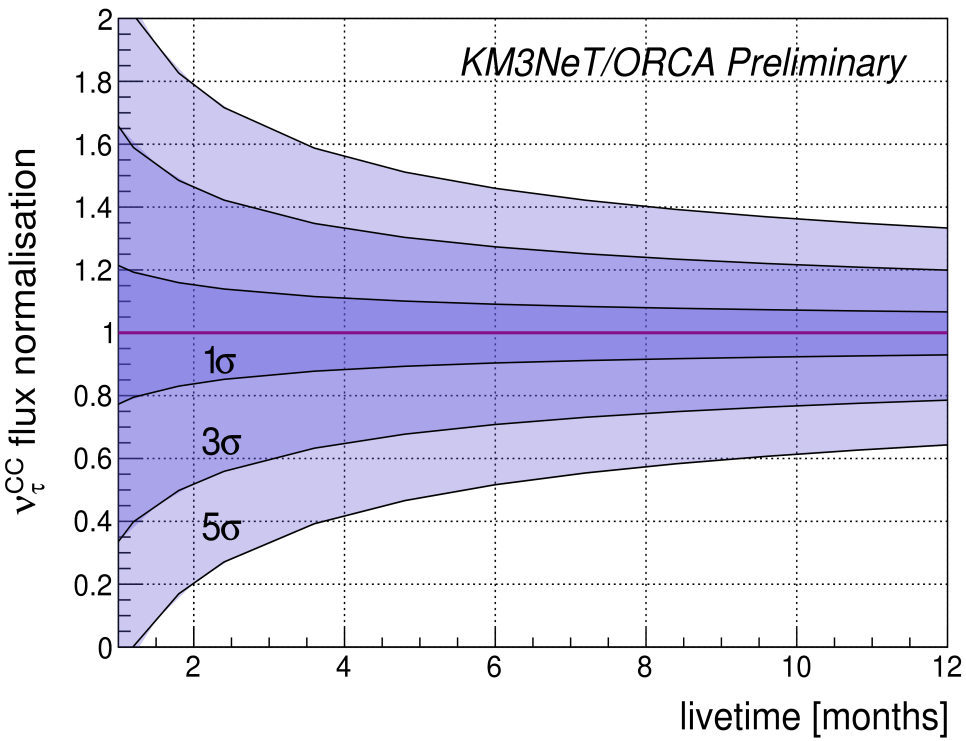
- About 3000 ν_τ CC events/year detected
- Rate constrained within 10% in 1 year
- Weak constraints from other experiments

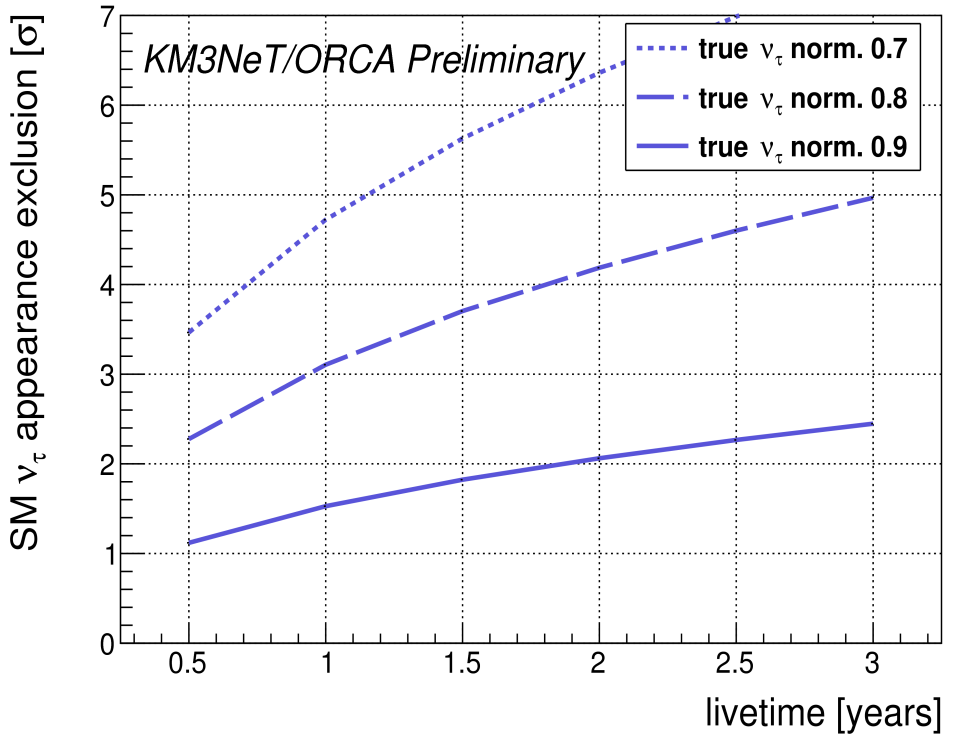




Tau Appearance

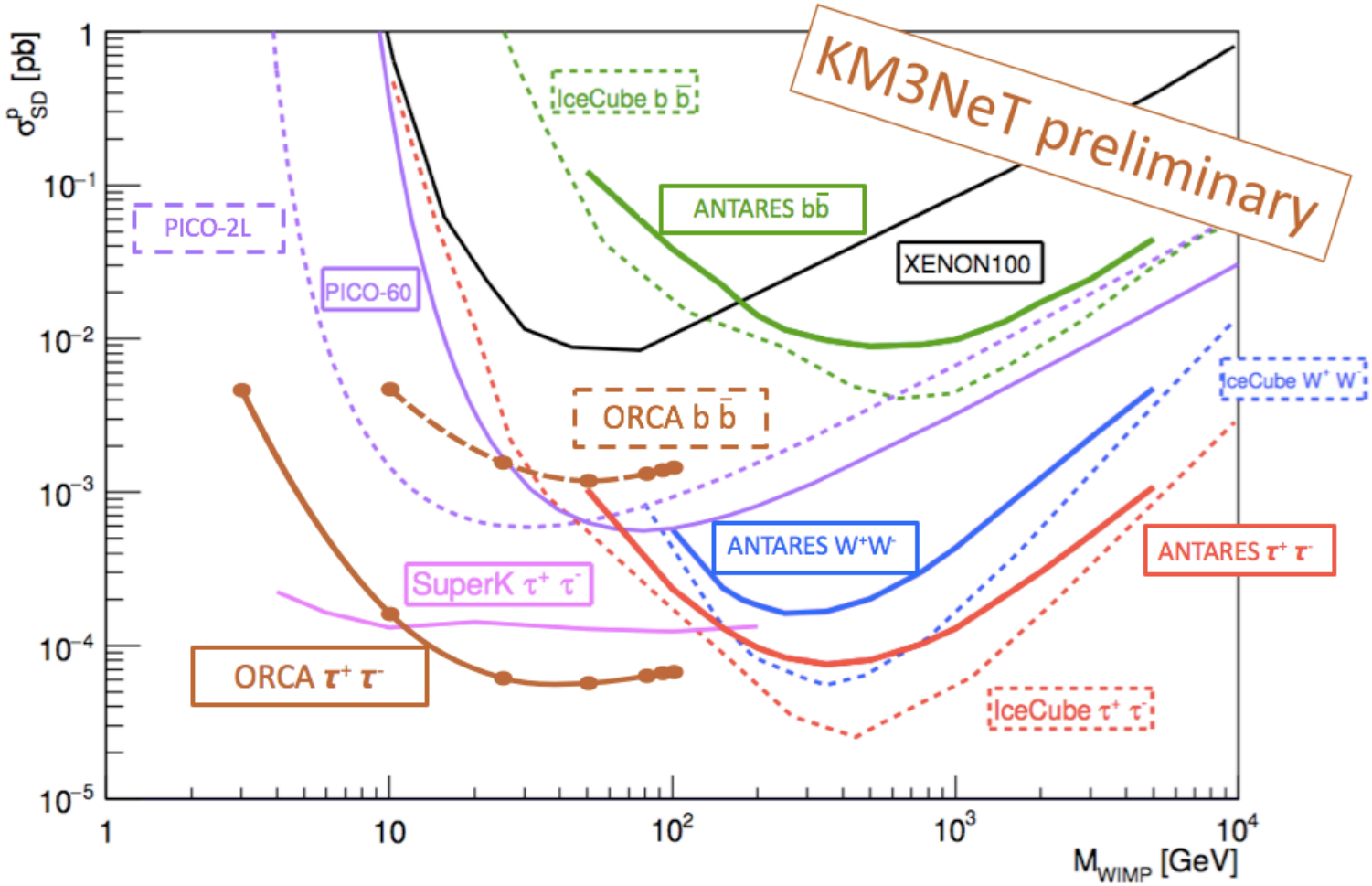
- ν_τ appearance tests PMNS unitarity and BSM theories
- 20% deviation of unitarity can be detected with 5σ in 3y





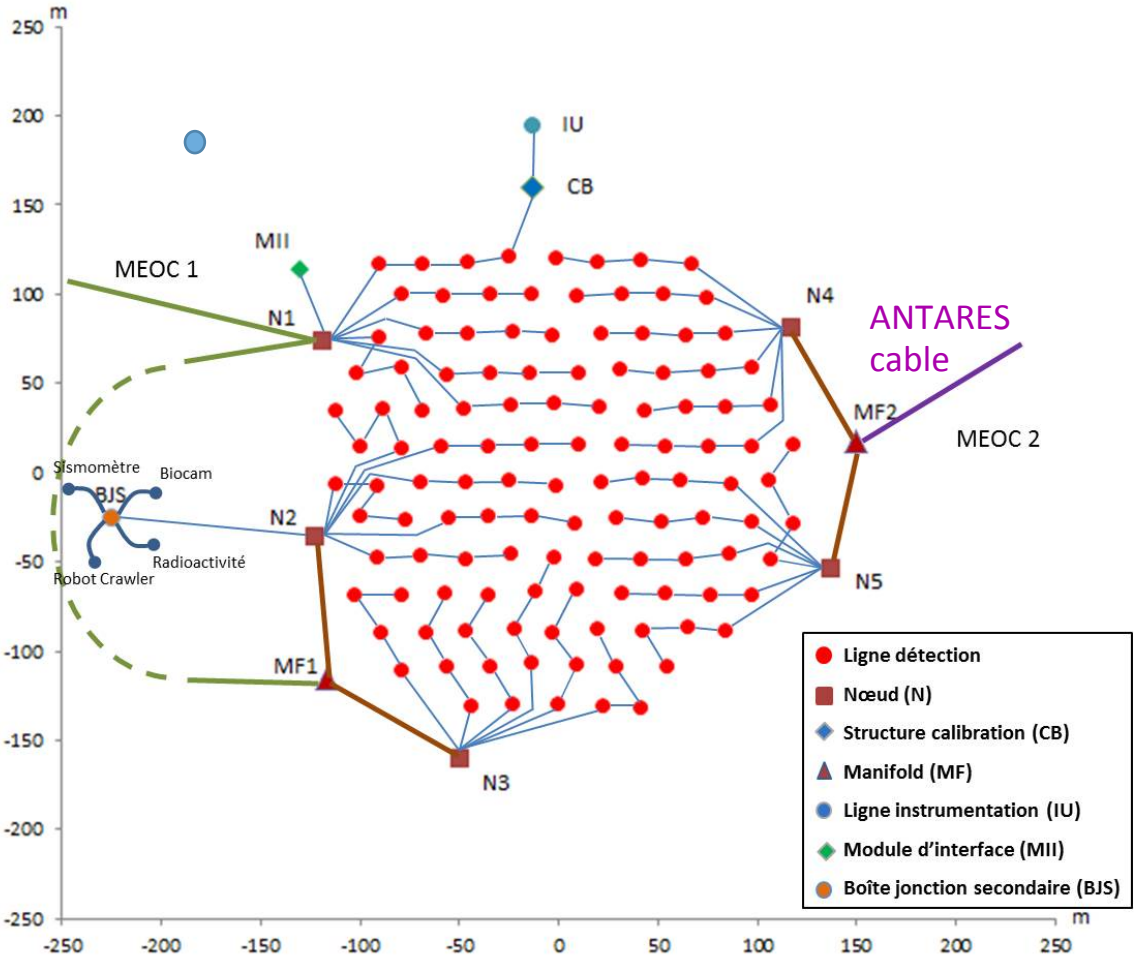
Dark Matter

ORCA 3 years, track+showers
Competitive for Spin Dependent coupling



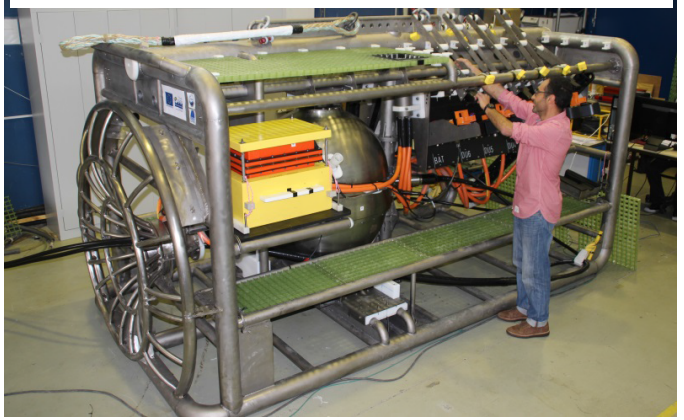
ORCA Status

Construction started
First Data arrived in 2017



Main Cable, 2015

Junction Box, Sept 2016

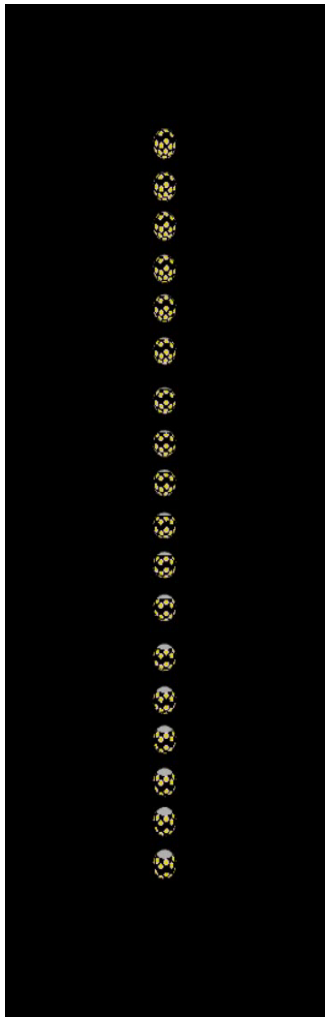


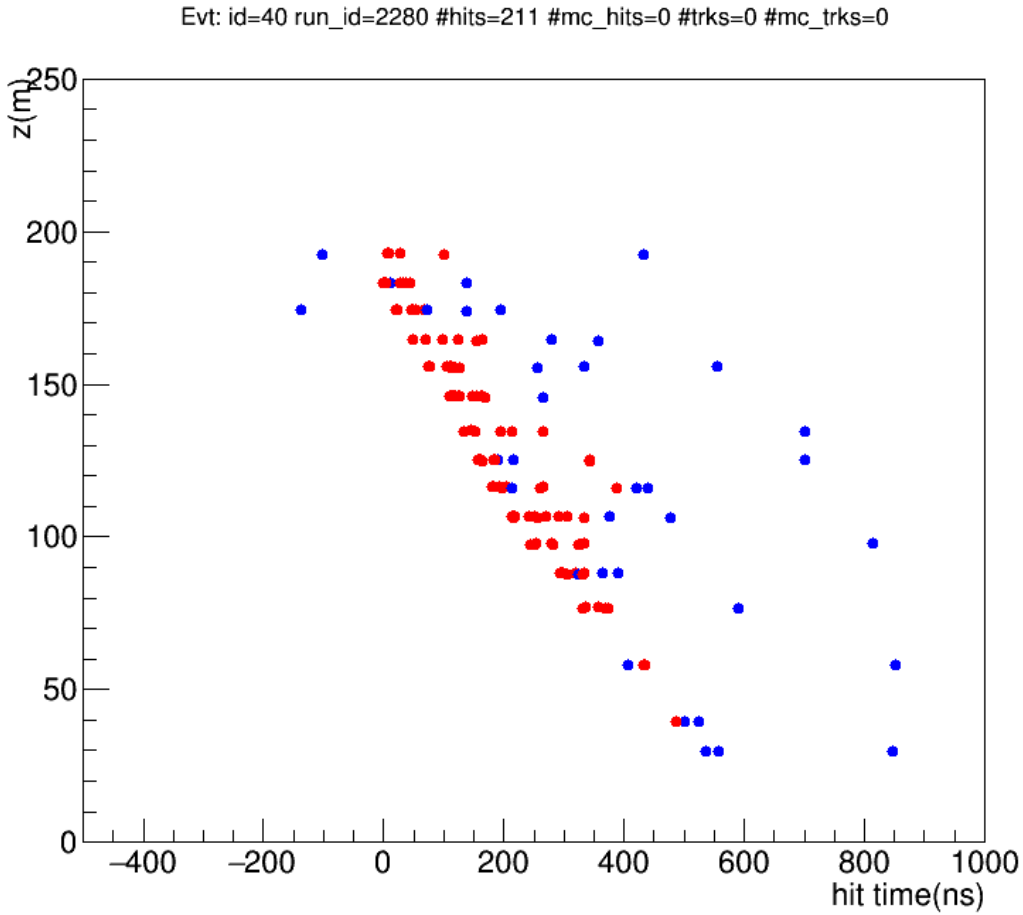
First ORCA string: Sep 2017

Deployment First Line 22/09/2017

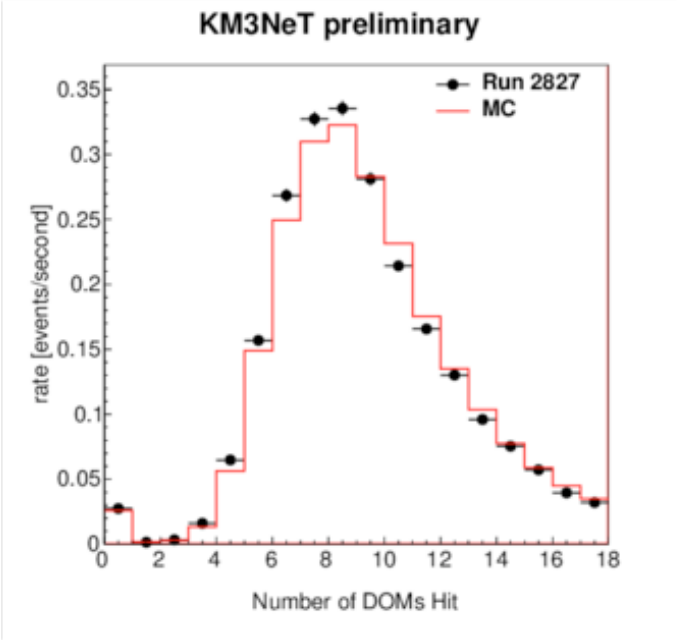
https://www.youtube.com/watch?v=omlFkdCkbYk

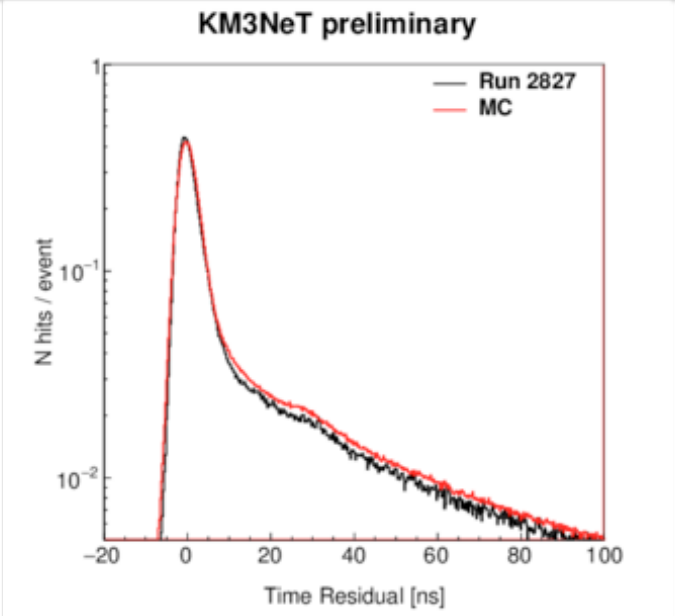
Early Muon bundle

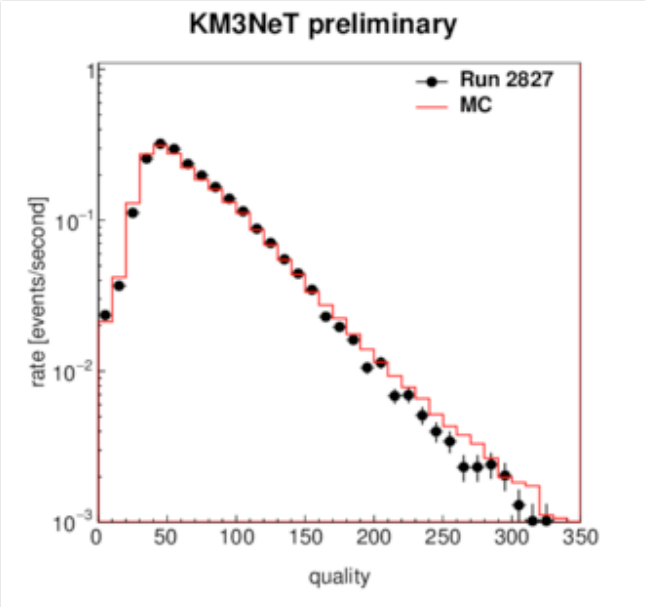


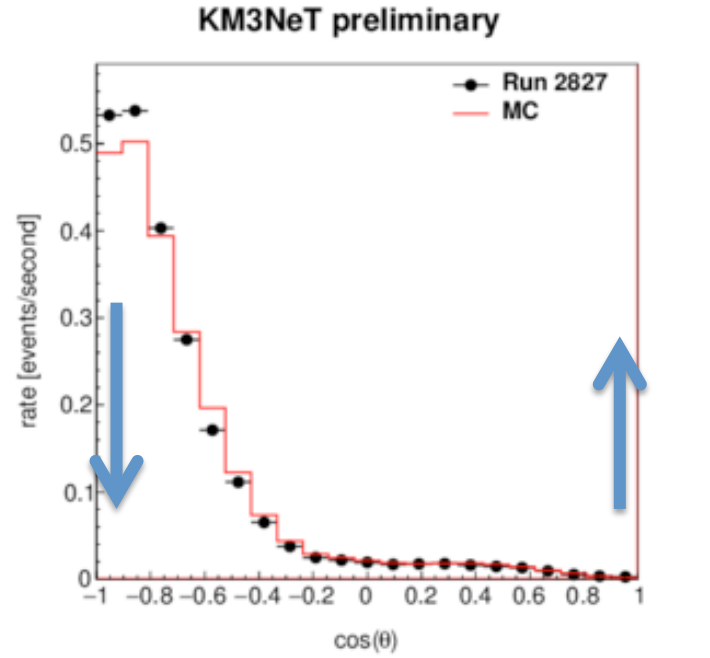


ORCA1: Data vs MC

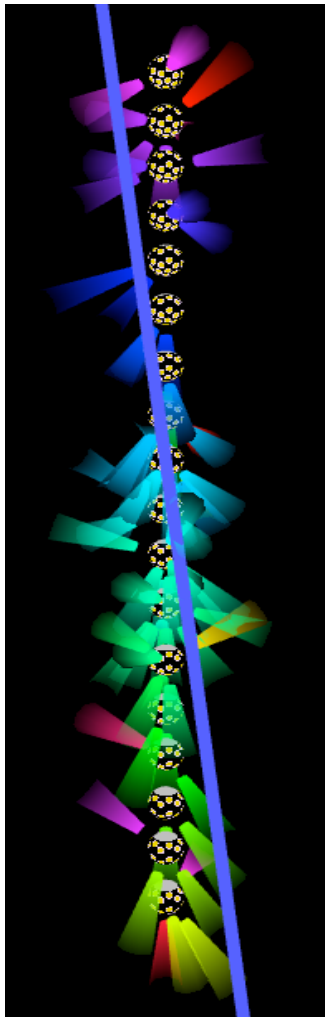


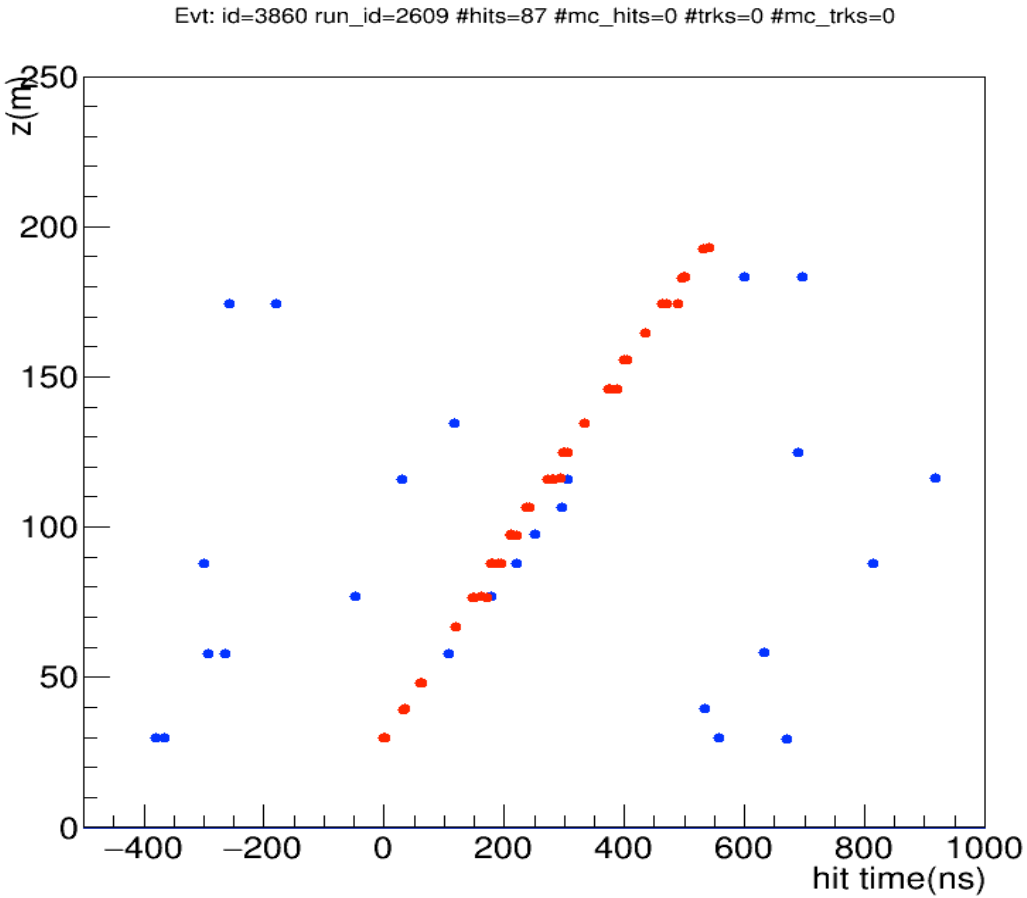






Early Neutrino Candidate





First Neutrino Analysis

82 days of data taking with first ORCA line

cos(theta) > 0 [0.5]

---

observed : 13 [10]

atm. muon: 1 [0]

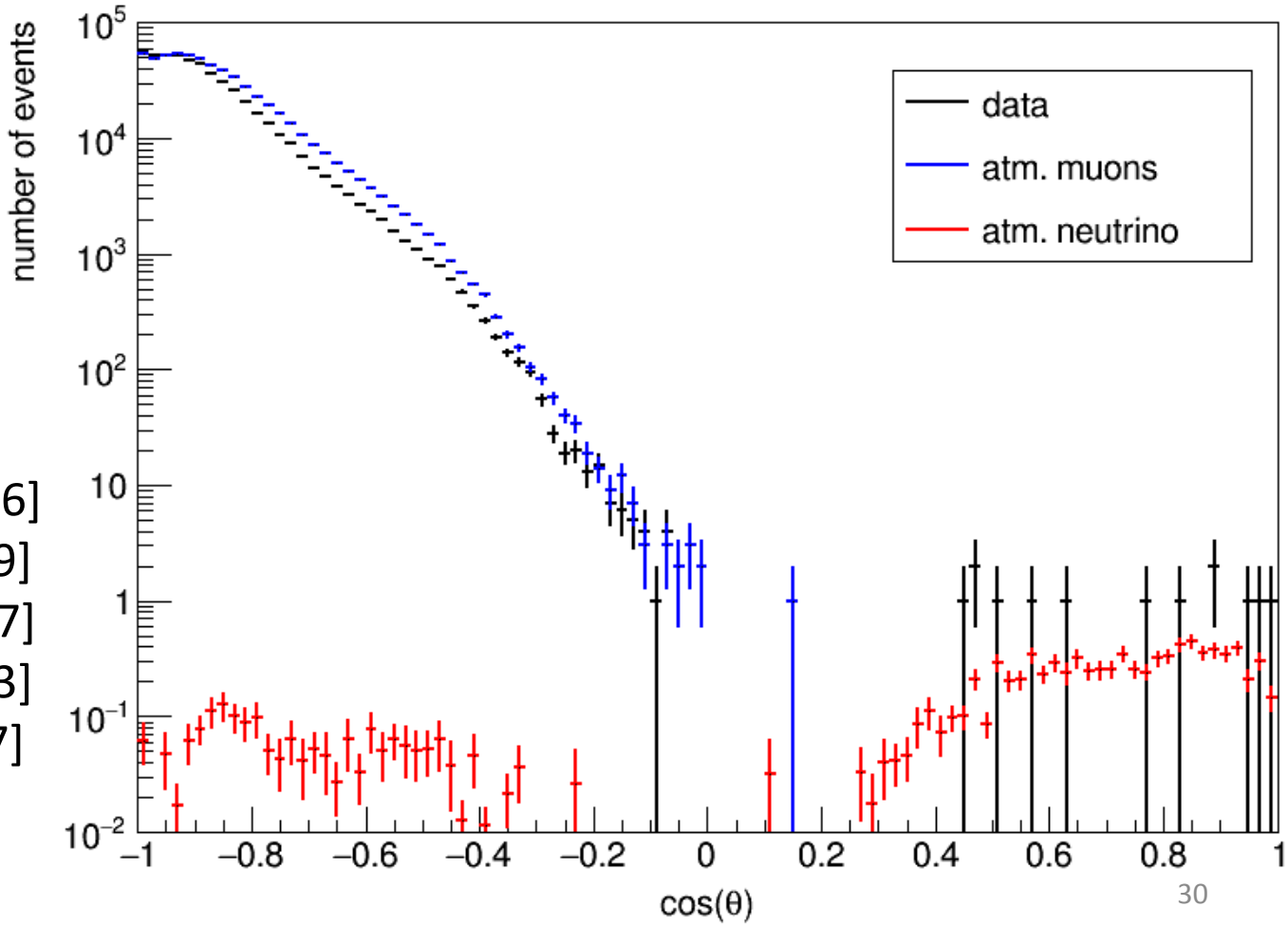
neutrino : 8.33 [7.36]

nu_mu : 5.44 [4.89]

nu_e : 1.36 [1.17]

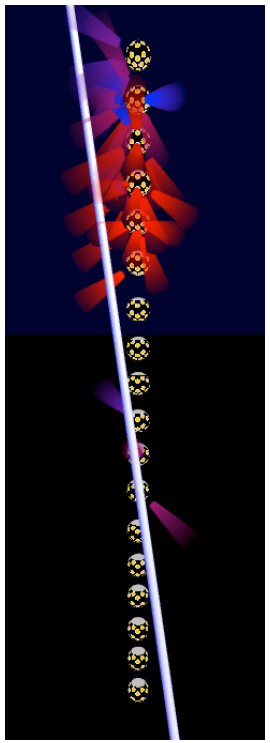
nu_tau : 0.96 [0.83]

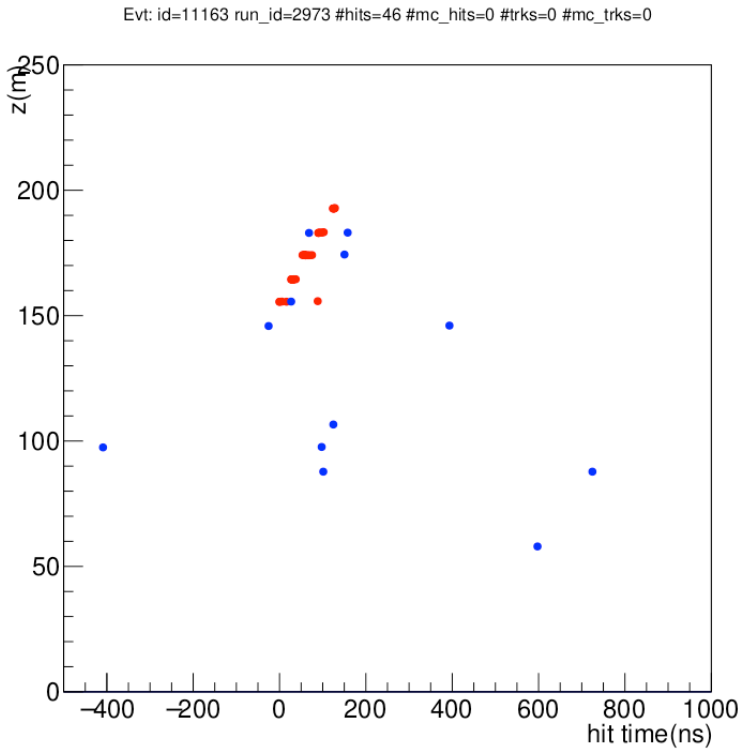
nu_nc : 0.57 [0.47]



Typical Neutrino Candidate

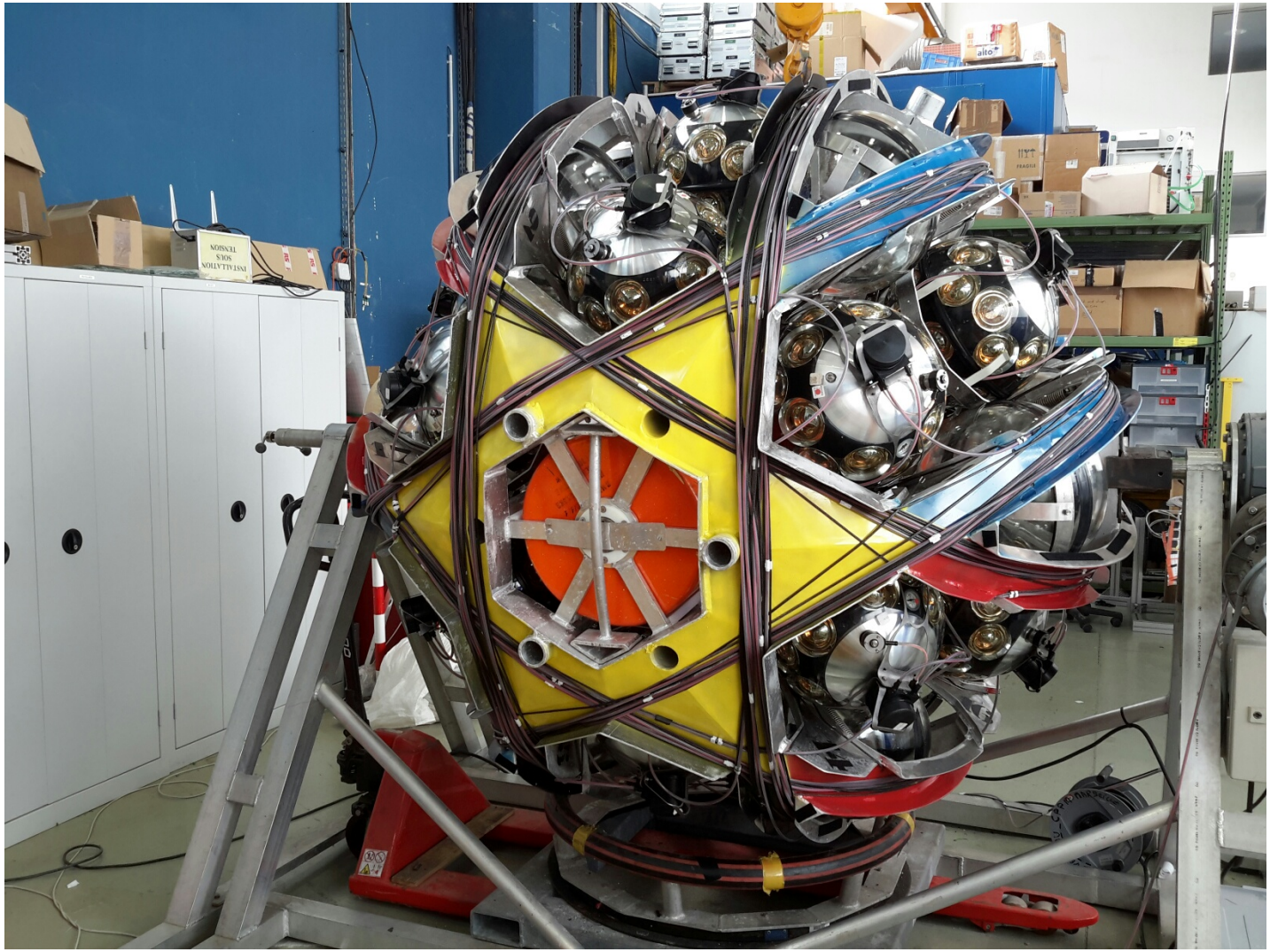
- From the selected sample
- Estimated neutrino energy : 5-15 GeV





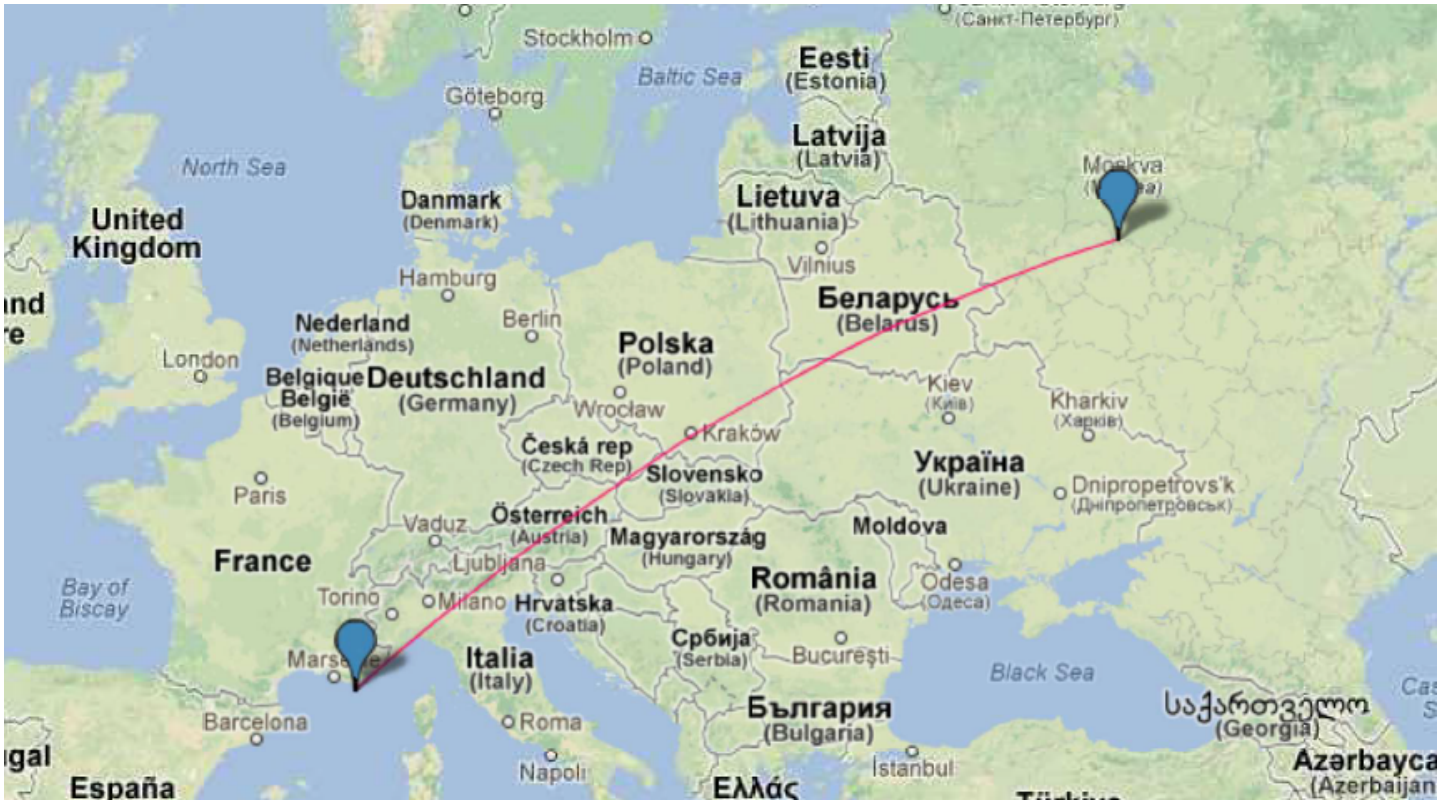
2nd Line ready for deployment

Deployment of 4 lines planned after summer 2018 in a single sea operation

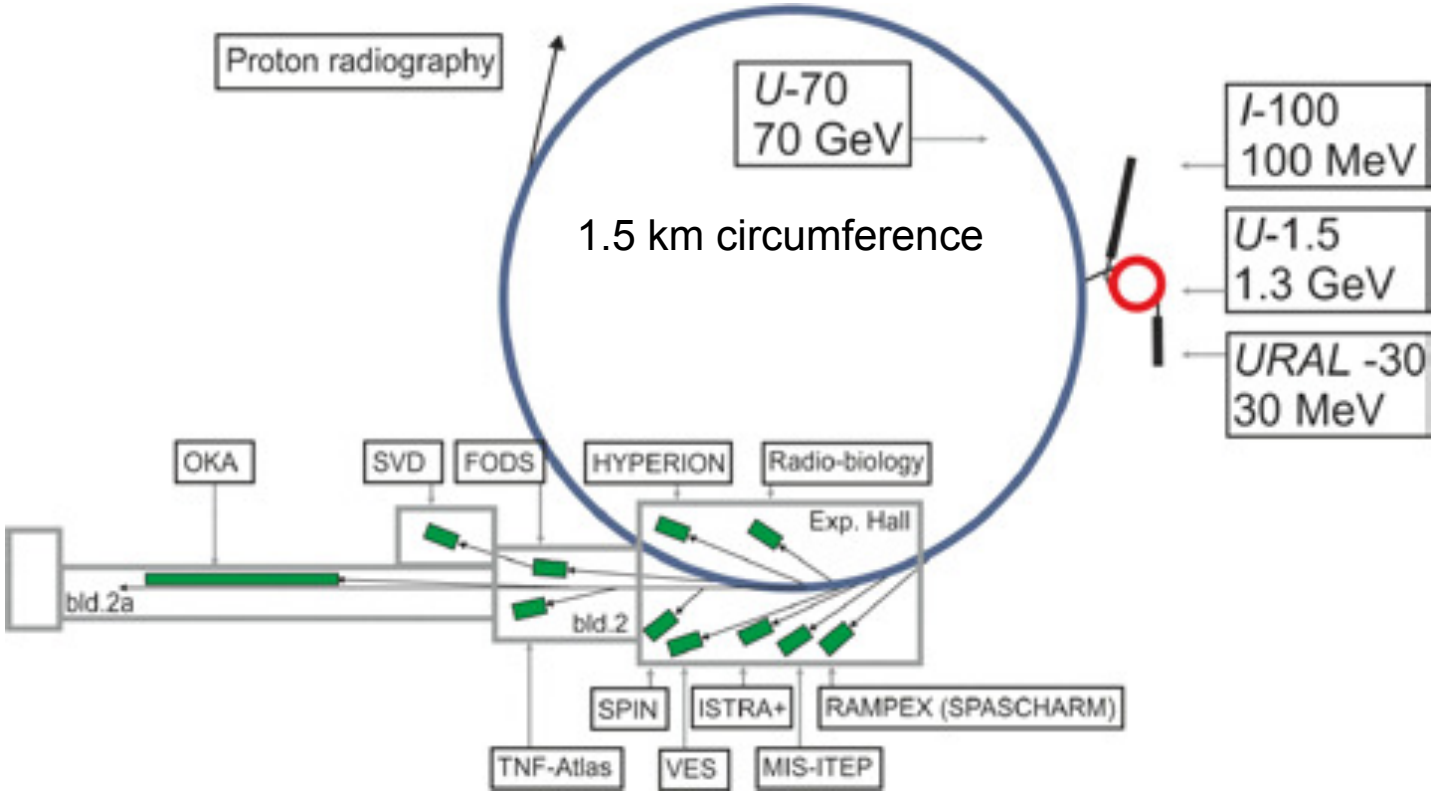


P2O : Protvino to ORCA

- Baseline 2588km ; beam inclination : 11.7˚ ($\cos\theta = 0.2$)
- First oscillation maximum 5.1 GeV
- Matter resonance maximum 3.8 GeV



Protvino accelerator complex
(100 km South of Moscow)

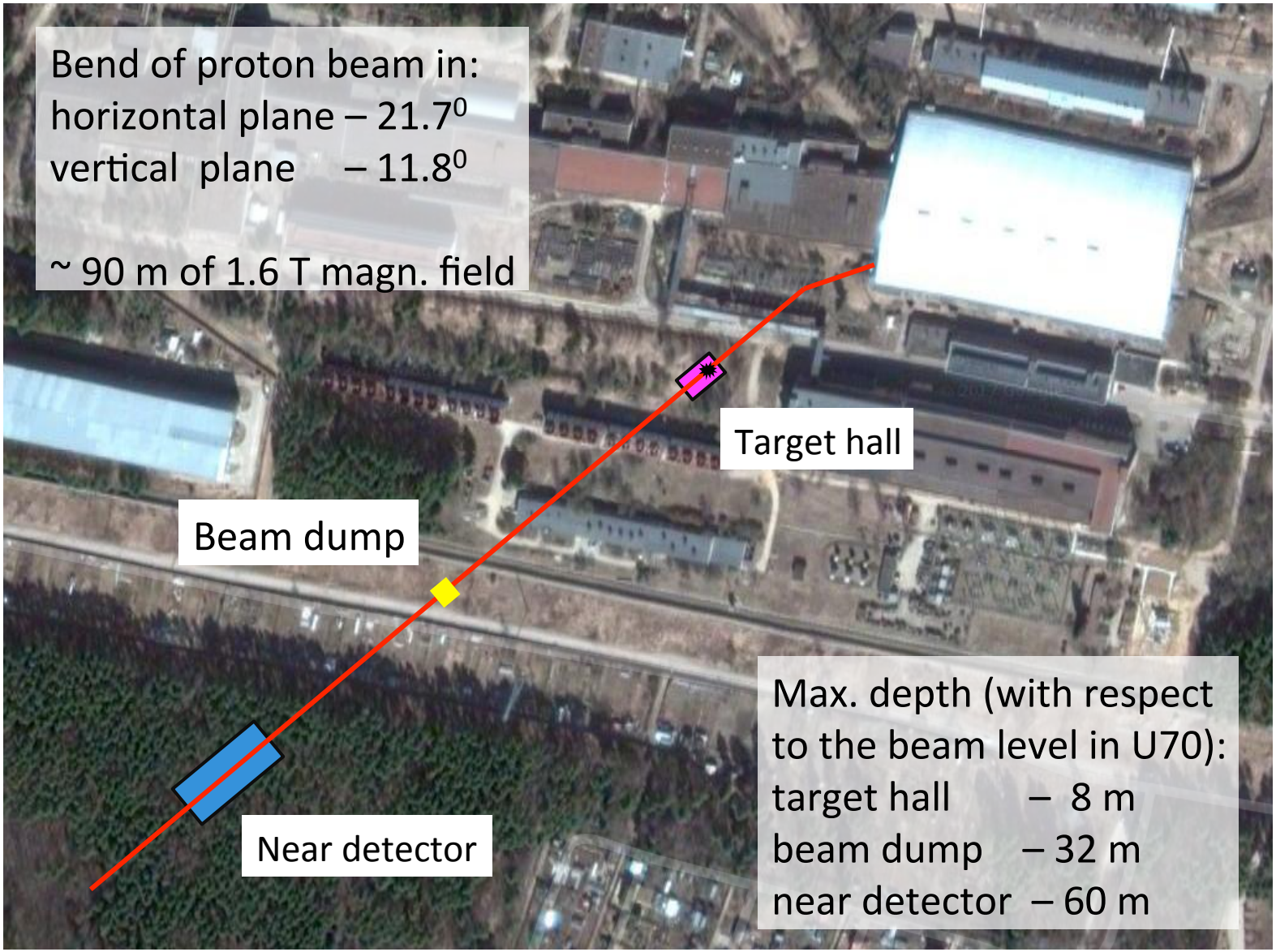


U-70 accelerator constructed in 1967

Now operates at 8 - 15 kW for ~ 60 days / yr

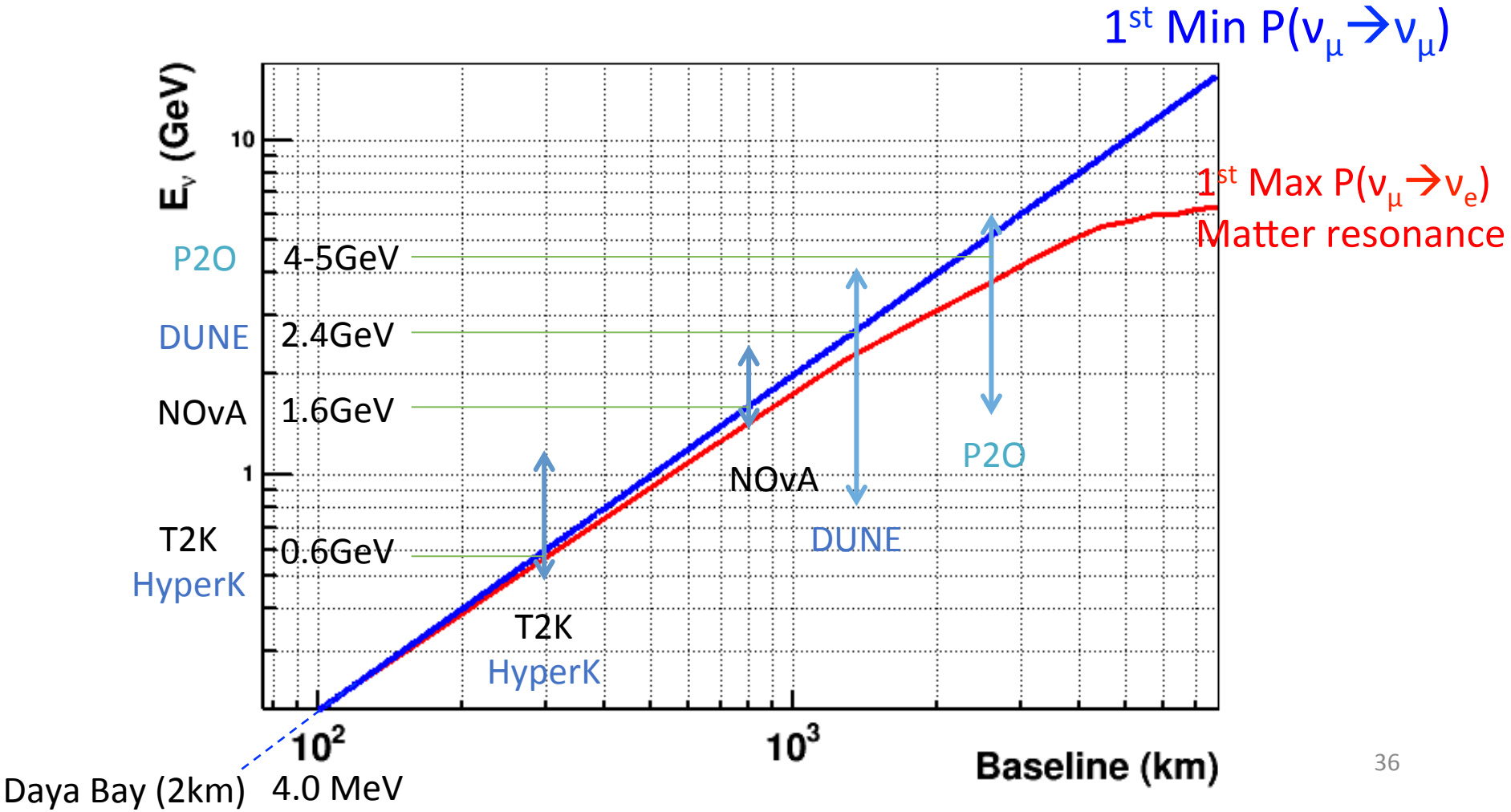
Upgrade to 450 kW feasible

Possible location of the near beam detector



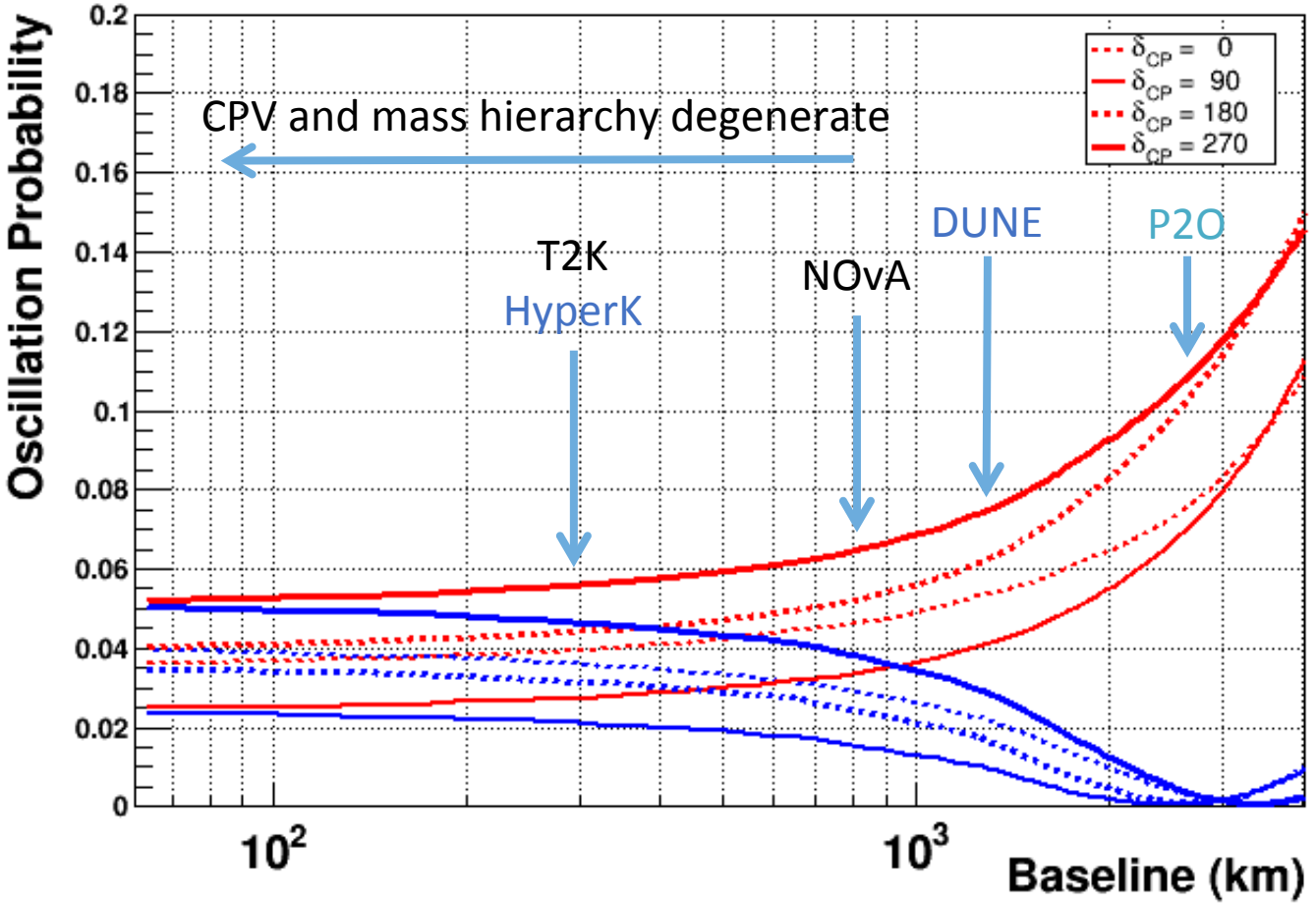
Comparison of LBL Projects

- Energy versus baseline

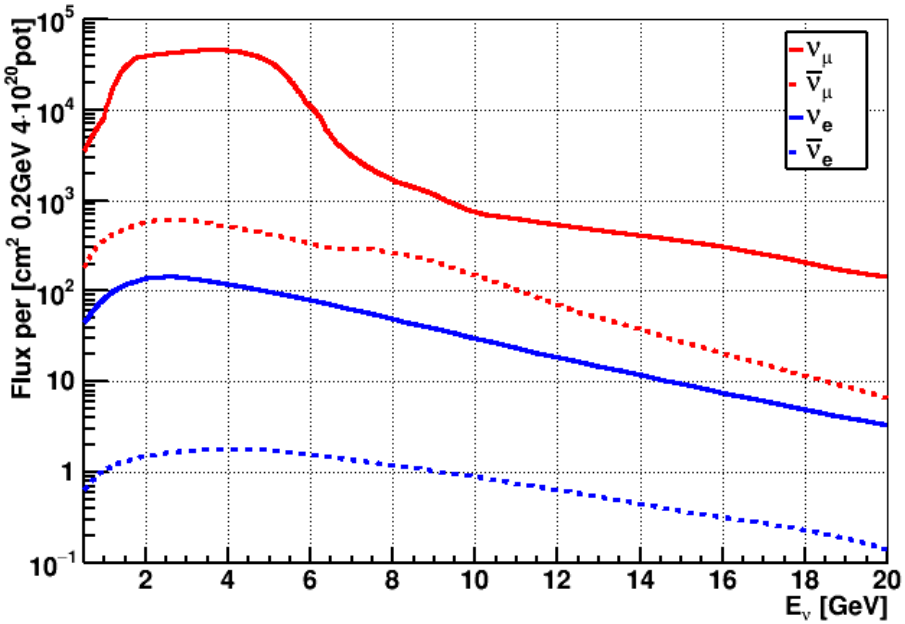


Comparison of LBL Projects

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



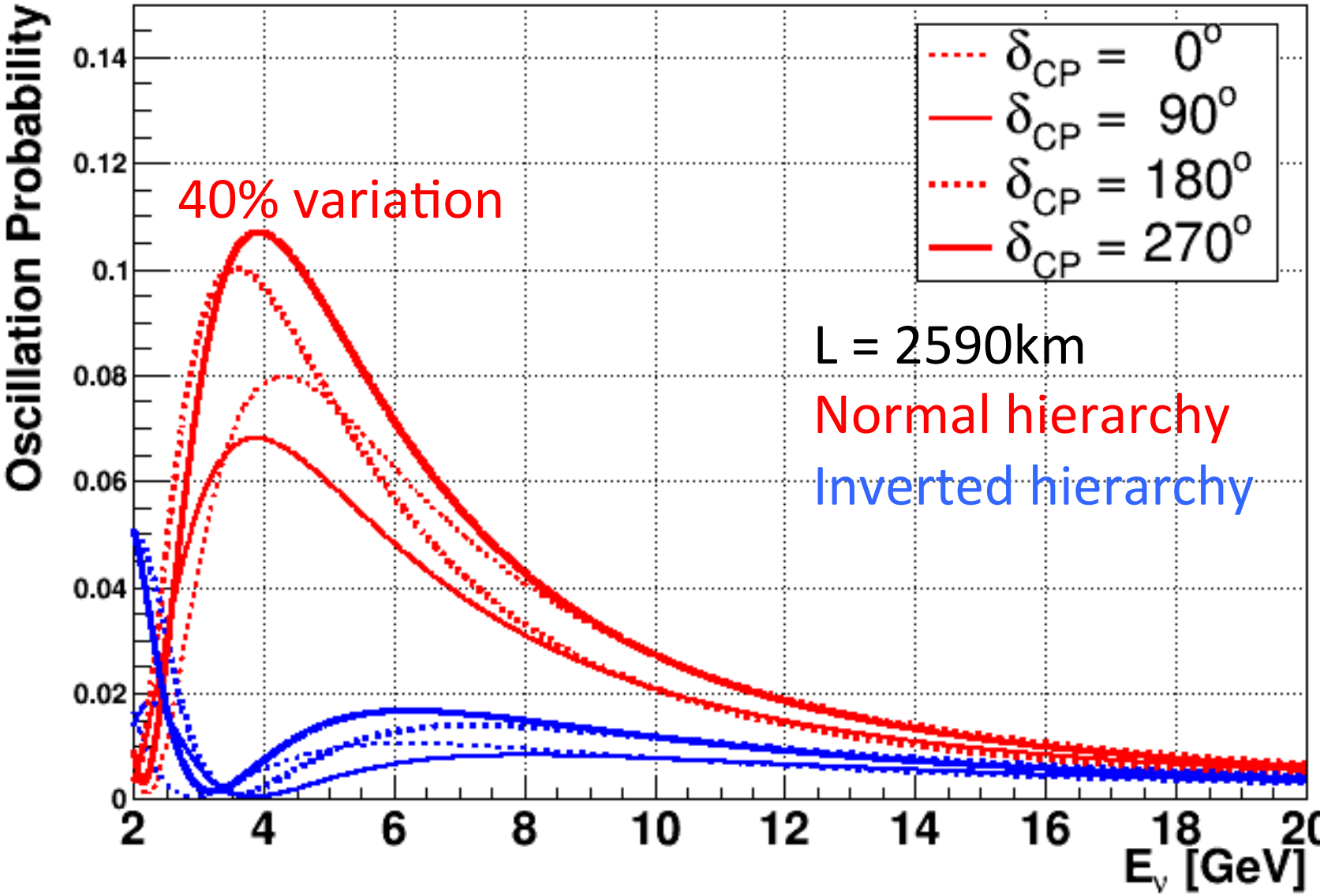
Neutrino Flux



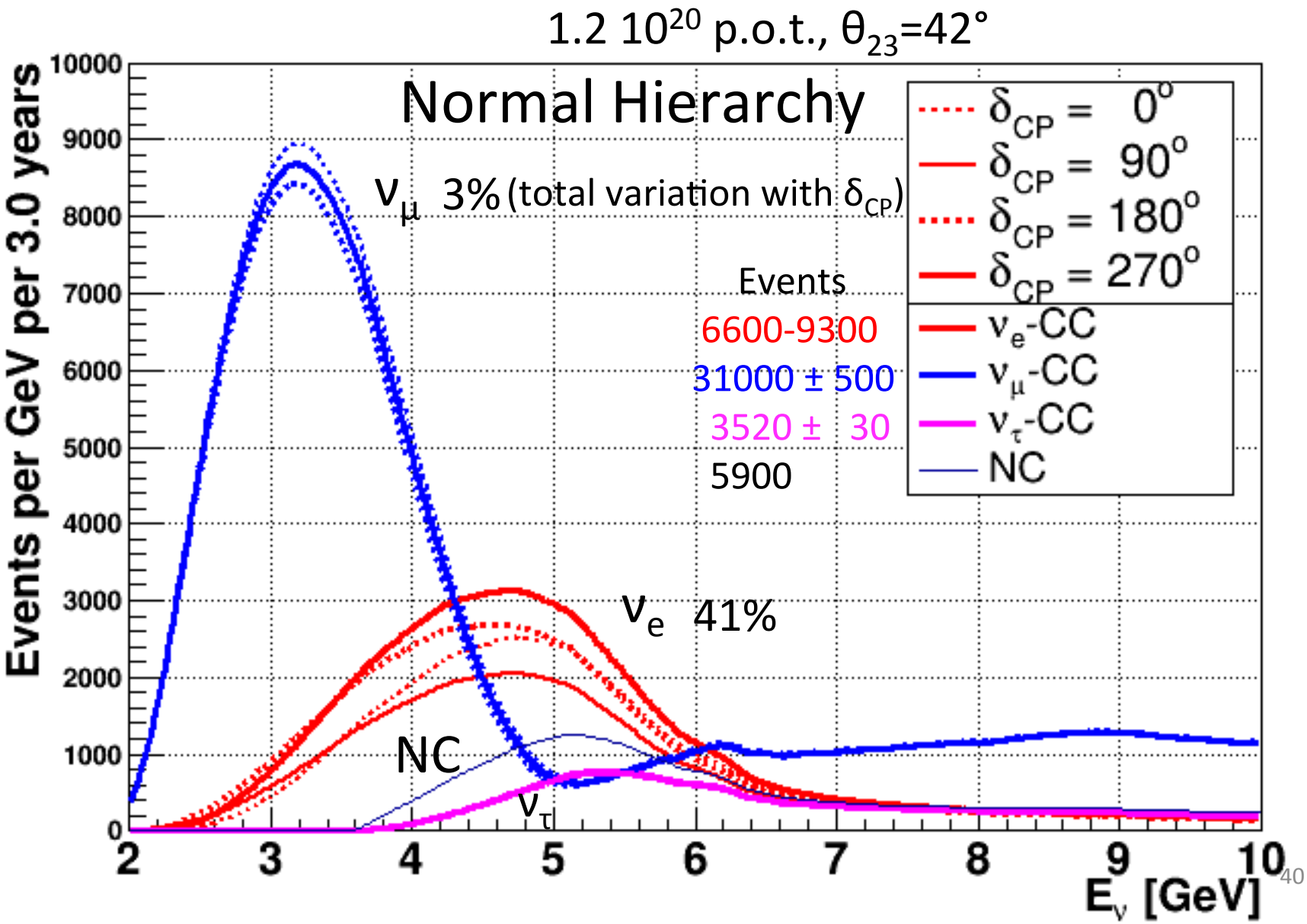
Focus π^+ (Neutrino beam)

- Used for current study : IHEP Protvino internal note 2015-5
- Designed for Beam to Gran Sasso (2200km)
- Beam power 450kW → $4 \bullet 10^{20}$ p.o.t. per year
- Fermilab-Nova : 700kW → $6 \bullet 10^{20}$ p.o.t. per year

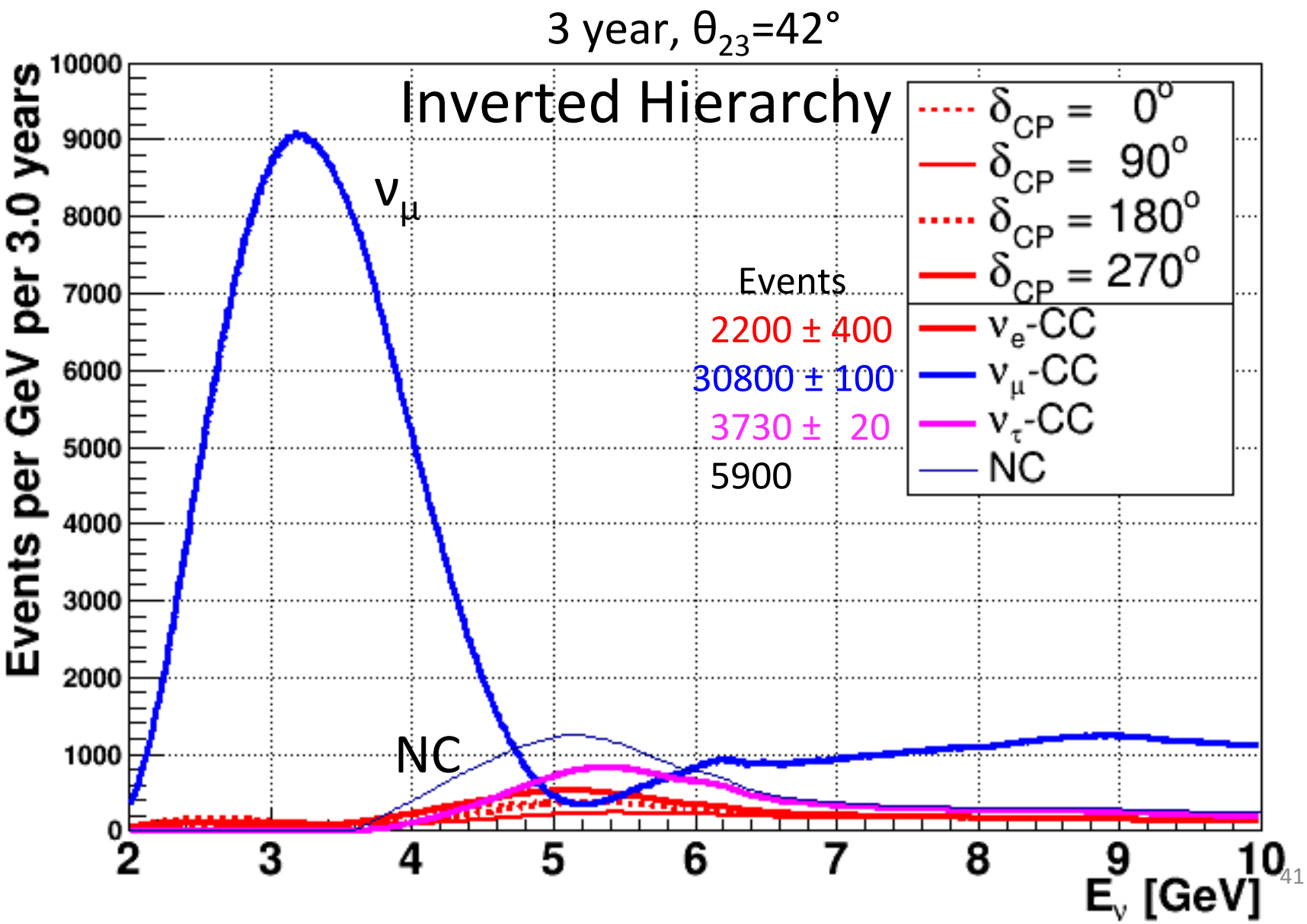
Oscillation Probabilities $P(\nu_\mu \rightarrow \nu_e)$



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

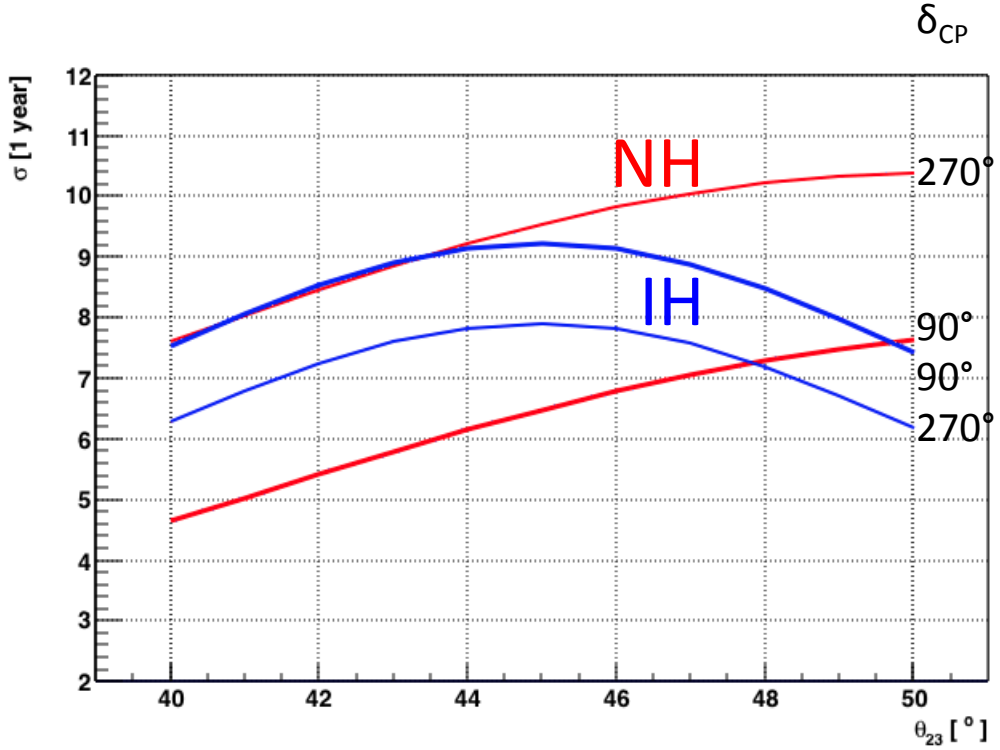
Parameter	True value	Prior	Start value
θ_{12}	33.4°	fix	fix
Δm^2 [eV^2]	7.53 10^{-5}	fix	fix
θ_{13}	8.42°	0.15°	8.42°
θ_{23}	41.5°	1.3°	41.5°
ΔM^2 [eV^2]	2.44 10^{-3}	0.06	2.44 10^{-3}
δ_{CP}	many	no	many

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

Only used for CP fits, not for NMH

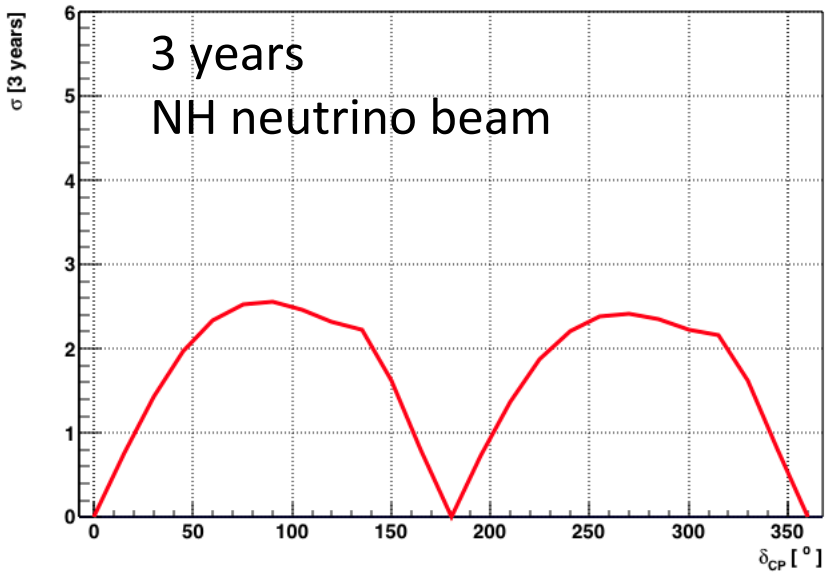
NMH determination

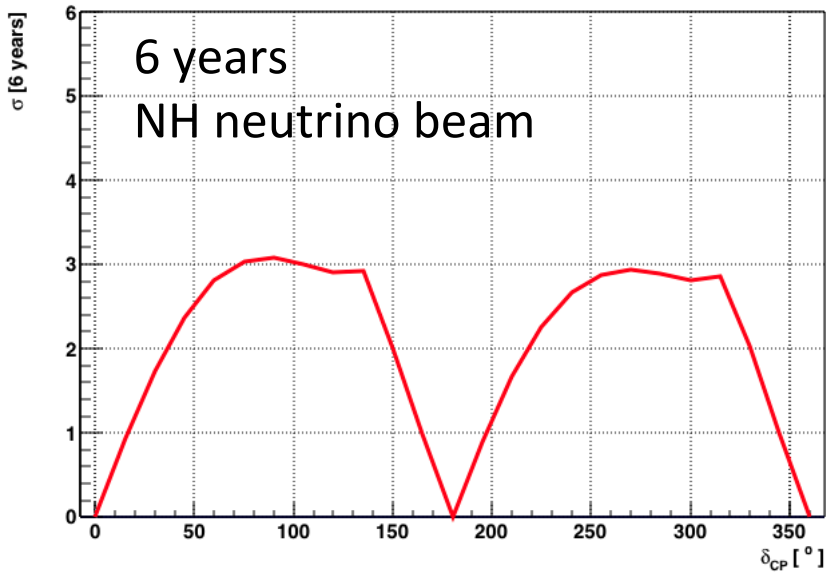
- ORCA detector, 1 year neutrino beam
- Better than 5σ for all combination of parameters



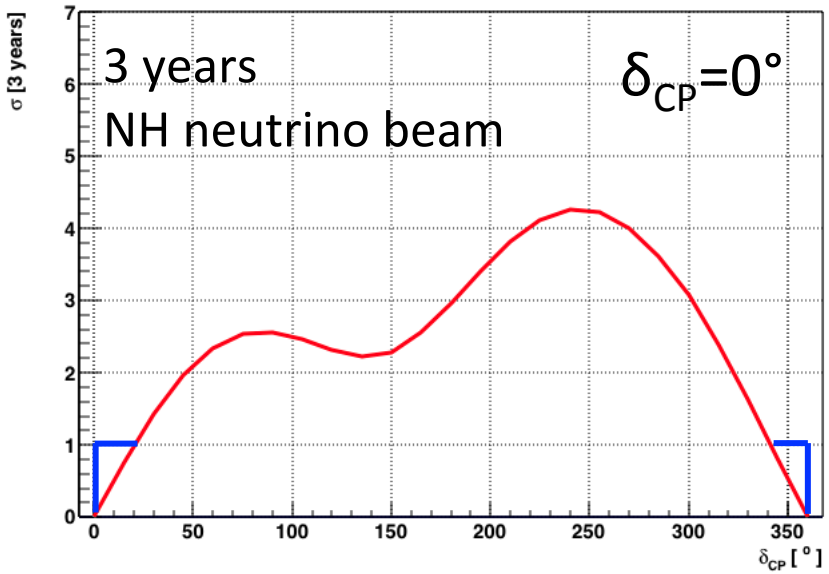
Sensitivity to δ_{CP}

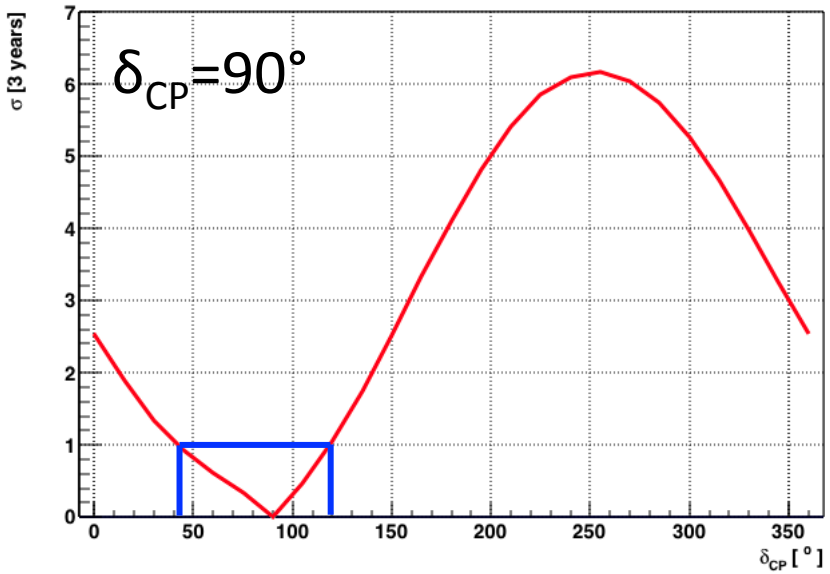
- Sensitivity of measuring non-zero CP-violation, i.e. δ_{CP} different from 0° AND 180°
- After 6 years non CP-violation excluded for 35% of δ_{CP} values at about 3σ

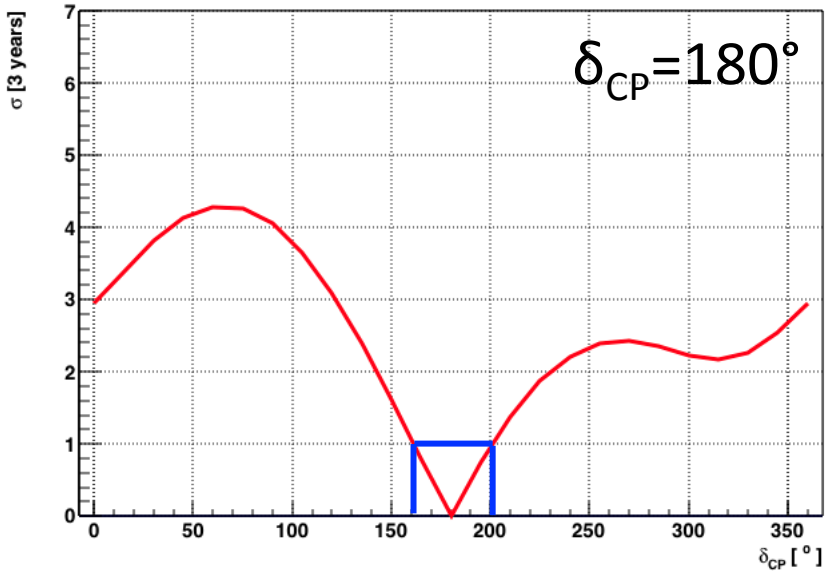


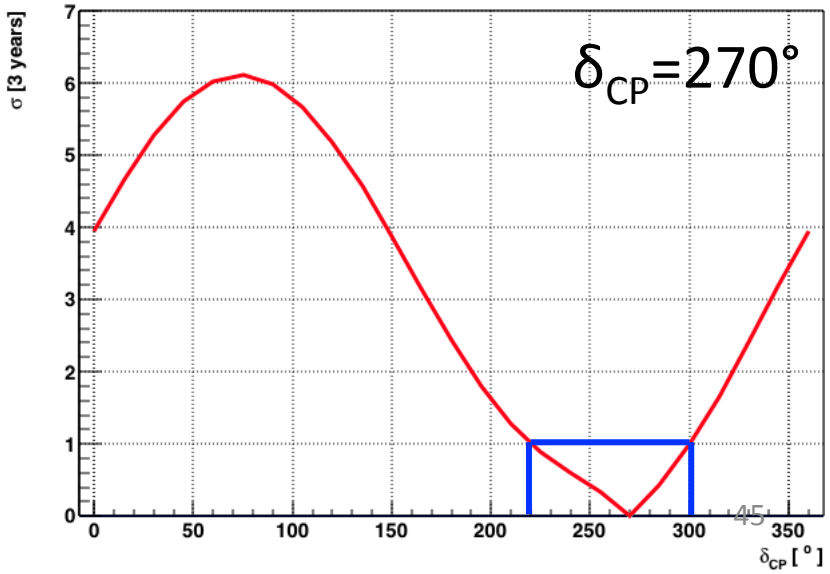


Measurement of δ_{CP}









Conclusion

- KM3NeT / ORCA construction has started
- First atmospheric neutrino signal has been seen
- End 2018 : several detector lines operational
- 2021 : detector completed
- Rich physics program beyond determination of neutrino mass hierarchy
- Interesting options for “Phase 3” → CP violation
  - Neutrino Beam from Protvino
  - Denser detector SuperORCA → Jannik Hofestaedt