

KM3NeT – ORCA

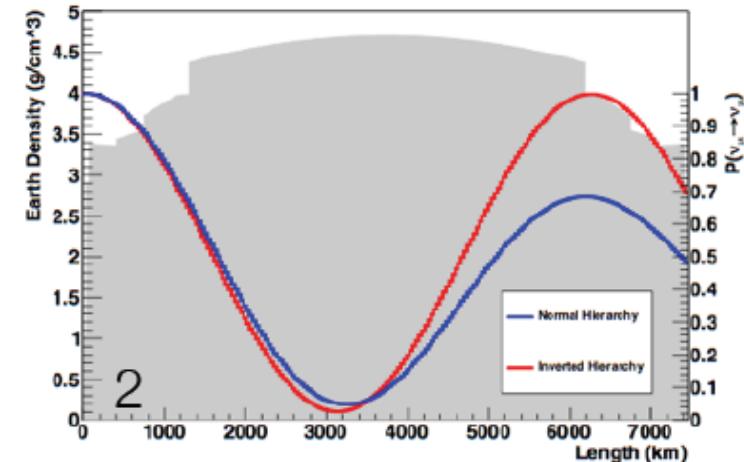
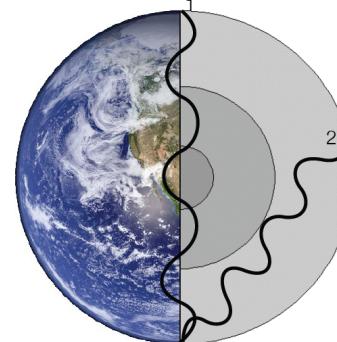
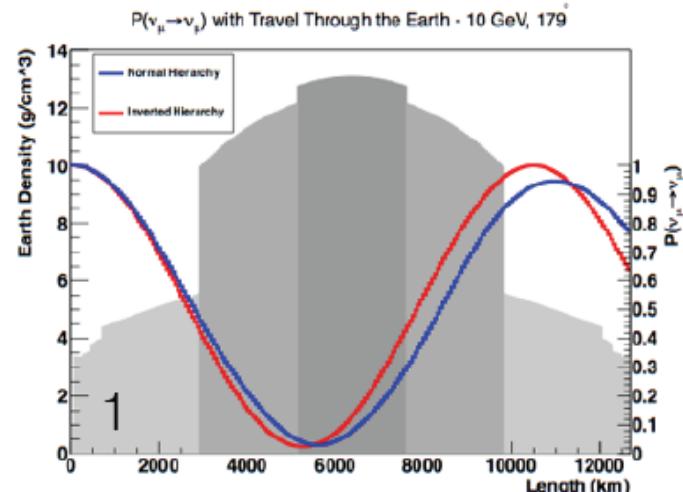
Measuring Neutrino Oscillations and the Neutrino Mass Hierarchy in the Mediterranean Sea



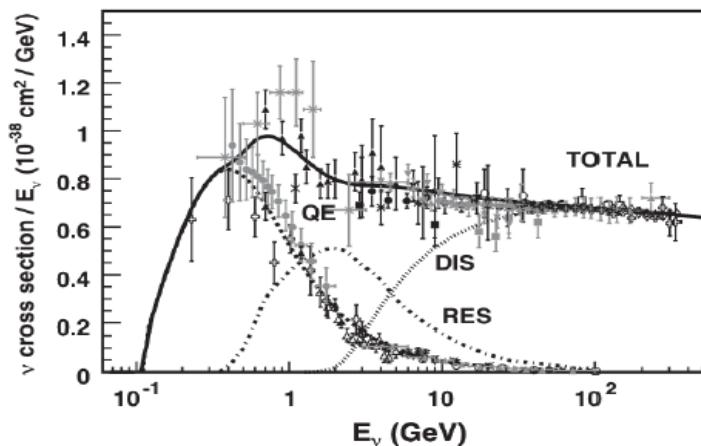
J. Brunner
CPPM



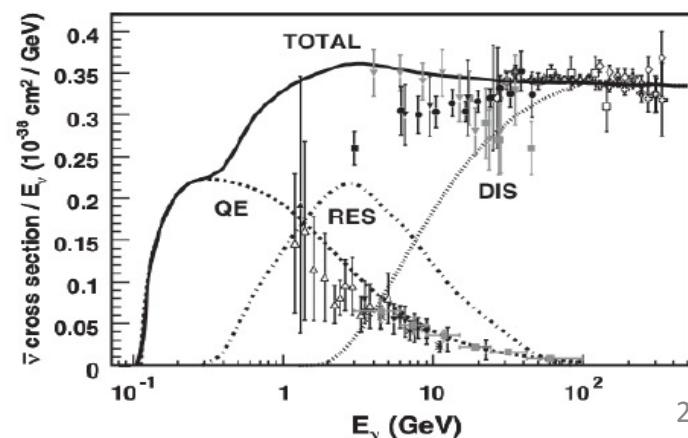
Matter Effects and Neutrino Mass Hierarchy (NMH)



- $\Delta M^2 \sim A$ matter potential must be significant
- L large enough – use atmospheric neutrinos !
- Distinction between neutrinos and anti-neutrinos → cross-sections!

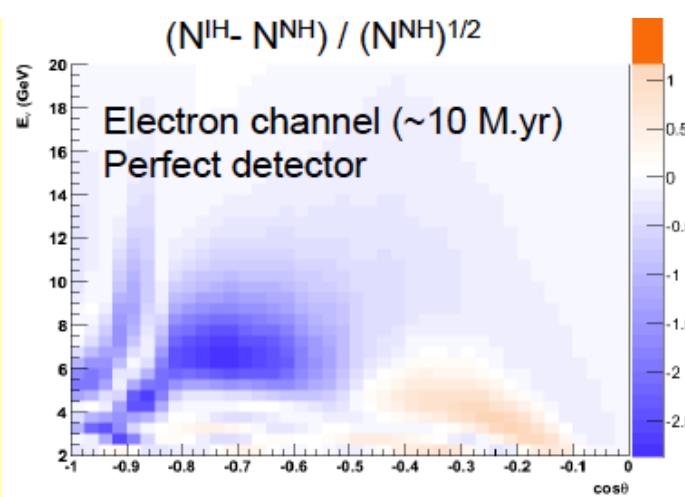
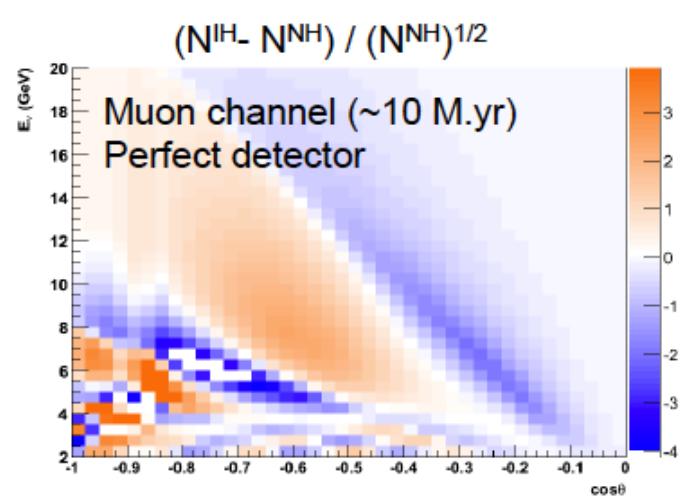


$$\sigma(v) \approx 2\sigma(\bar{v})$$

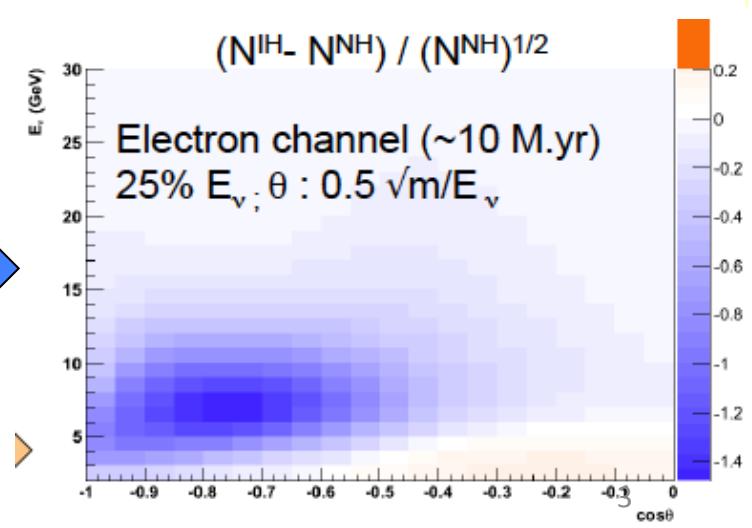
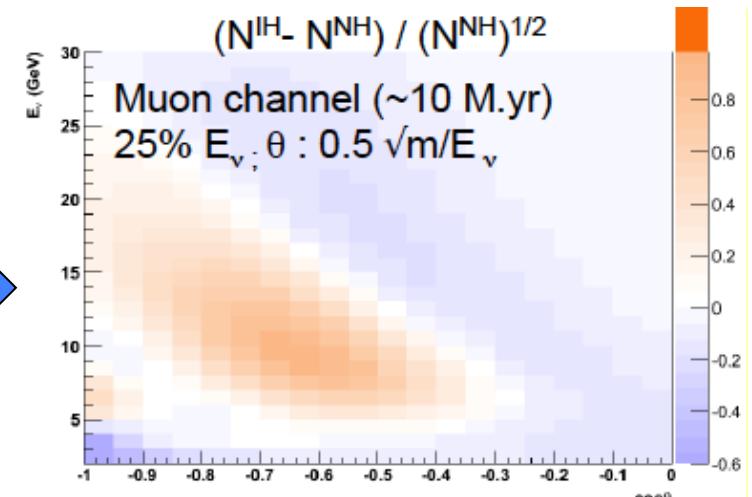


Method to Determine NMH

Both muon- and electron-channels contribute to net hierarchy asymmetry
electron channel more robust against detector resolution effects:

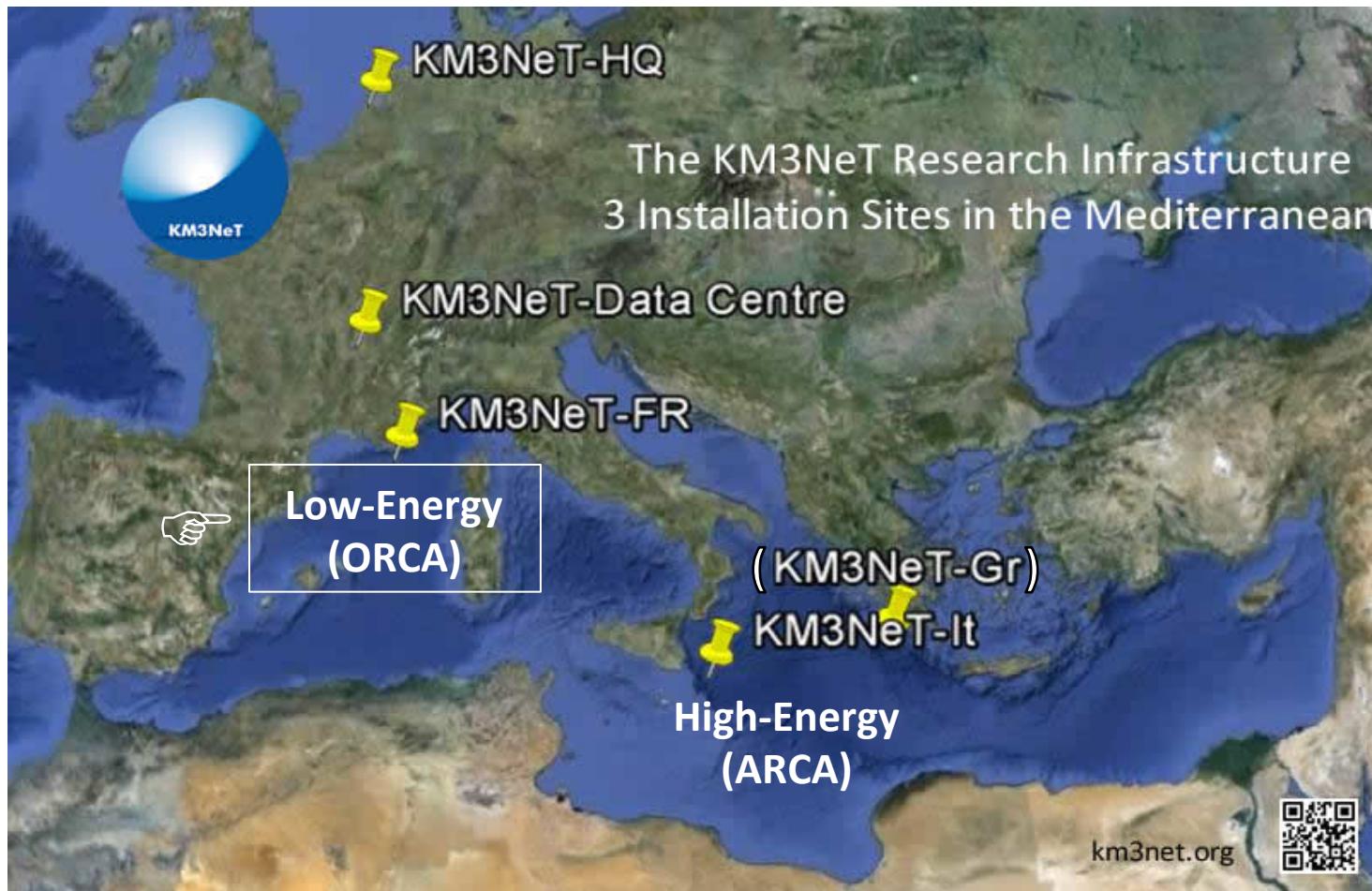


E, θ smearing
(kinematics
+ detector
resolution)

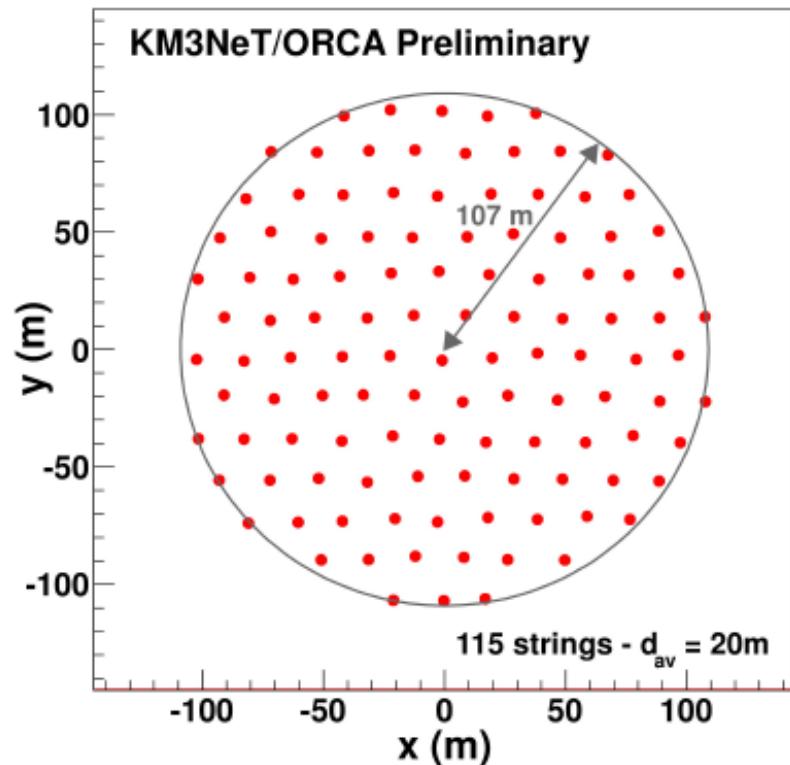


KM3NeT: Next generation Neutrino Telescope in the Mediterranean Sea

Distributed research infrastructure with **2 main physics topics**:
Low-Energy studies of atmospheric neutrinos – **High-Energy** search for cosmic neutrinos



The ORCA benchmark design

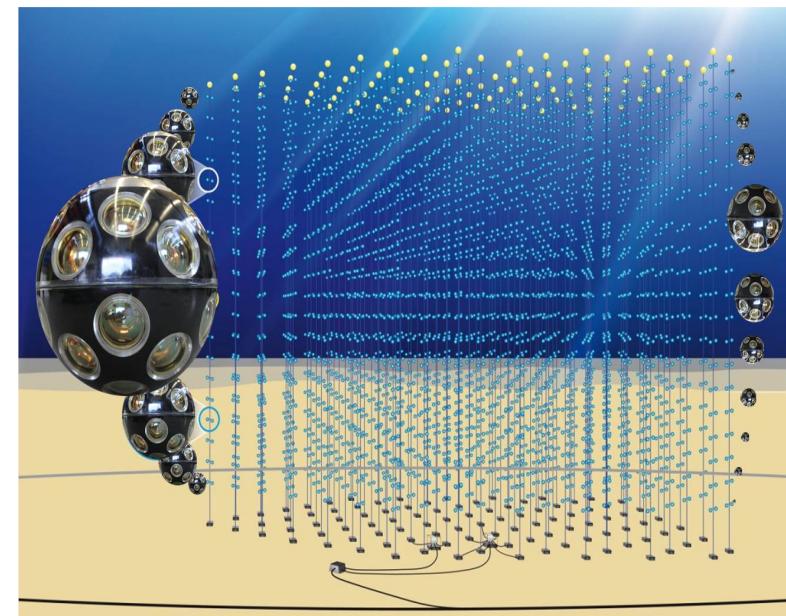


- 31 3" PMTs
- Digital photon counting
- Directional information

Poster : Ronald Bruijn

115 lines, 20m spaced,
18 DOMs/line 6m spaced

Instrumented volume ~3.8 Mtons



- Wide angle of view
- More photocathode than 1 ANTARES storey
- Cost reduction compared to ANTARES

Ingredients for NMH measurement

- Efficient and high purity trigger algorithm for neutrino and atmospheric muon events
 - Exploit excellent photon counting of multi-PMT DOMs
 - Use causality of direct photons → water almost scattering free for visible photons
- Reconstruction of cascade and track topologies
 - High efficiency down to relevant energies
 - Good resolution in energy and zenith angle
- Topology Identification (track \leftrightarrow cascades)
- Atmospheric muon rejection (no hardware veto)

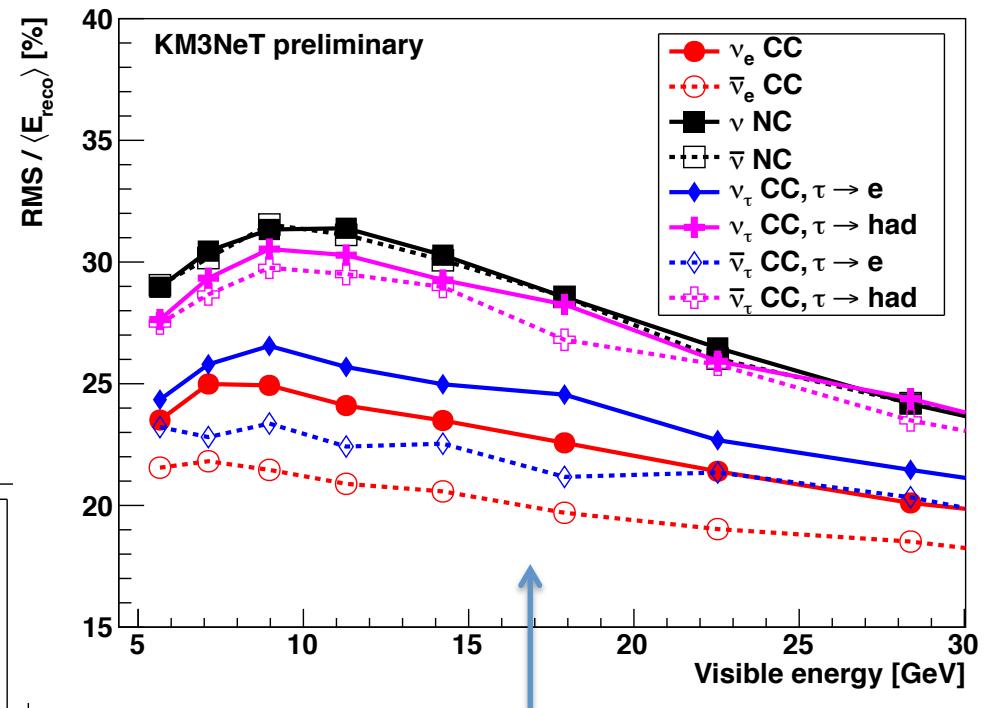
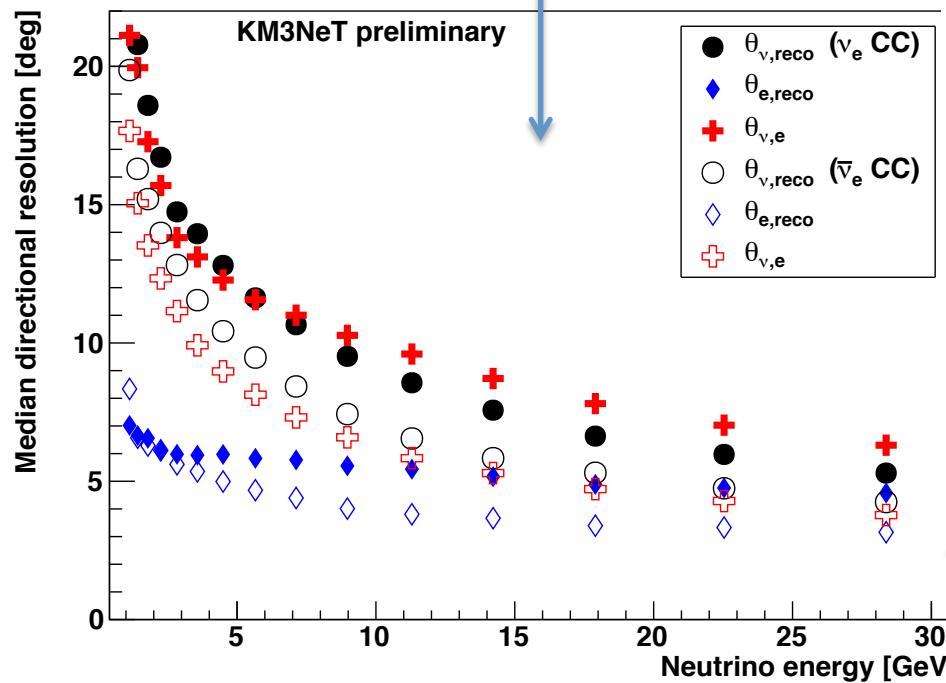
Reconstruction Methods

- Dedicated methods for tracks and cascades have been developed
- 8 parameters are determined
 - Time, position (3), direction (2), energy, inelasticity
- Step by step procedure (no brute force fit)
 - Hit selection (similar to trigger)
 - Vertex & Directional fit (timing)
 - Energy & inelasticity fit (light yield & direction/vertex)

Performances ν_e (cascades)

Poster : Jannik Hofestdt

Excellent angular resolution
Dominated by kinematics

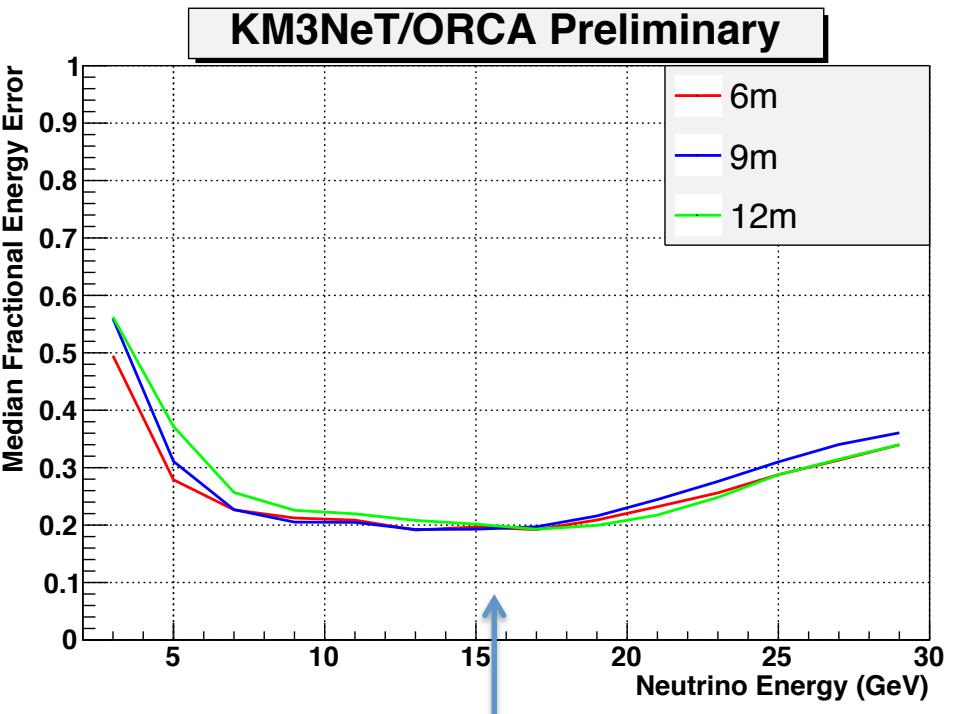
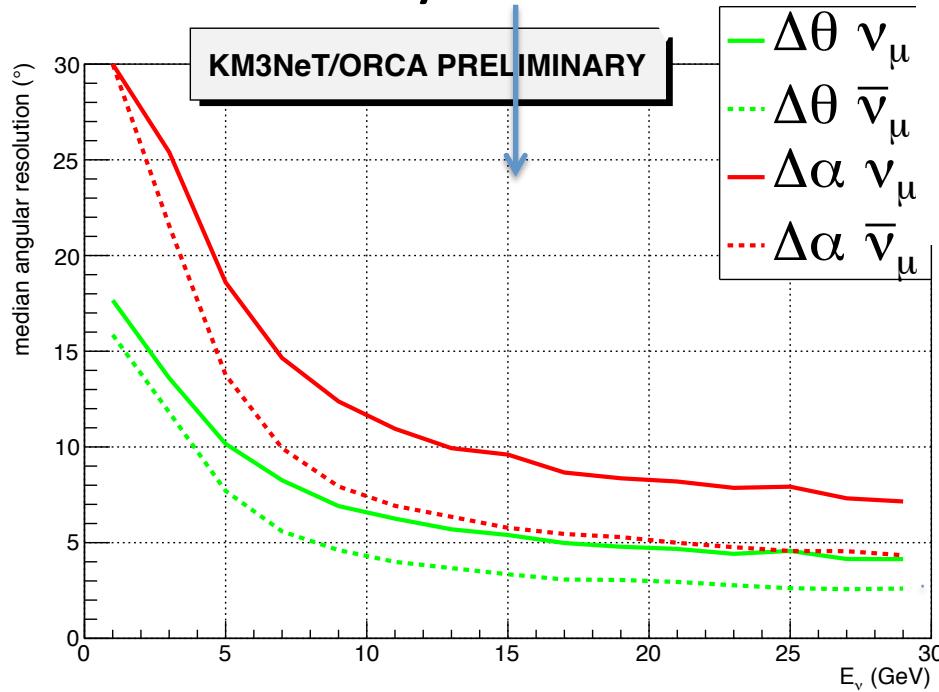


Energy resolution better than 25% in relevant range – close to Gaussian

Performances ν_μ (tracks)

Poster : Salvatore Galata

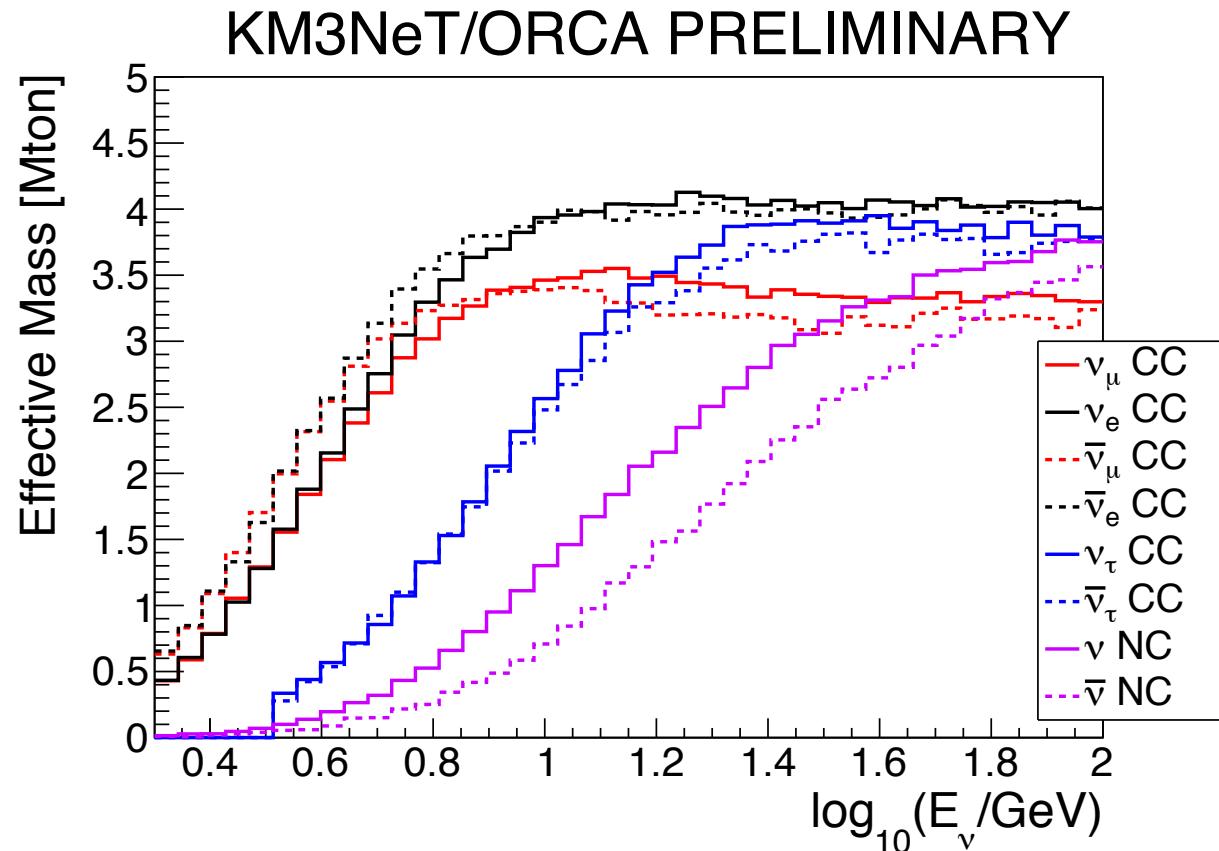
Excellent angular resolution
Dominated by kinematics



Energy resolution better than 25% in relevant range – close to Gaussian

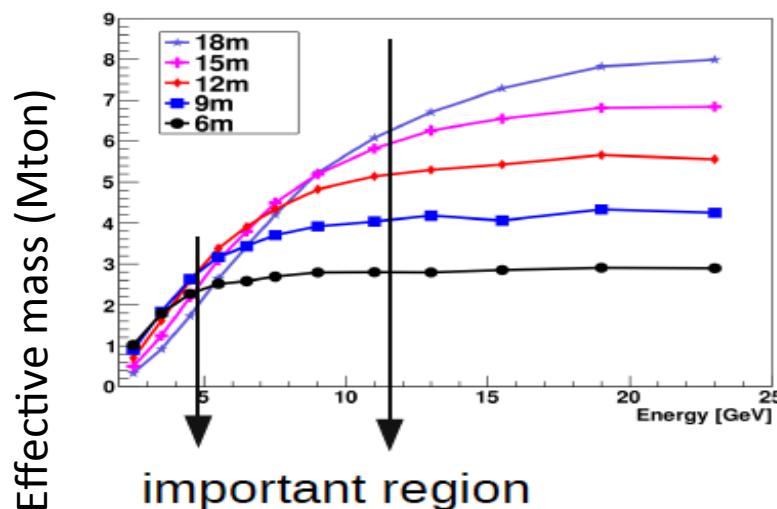
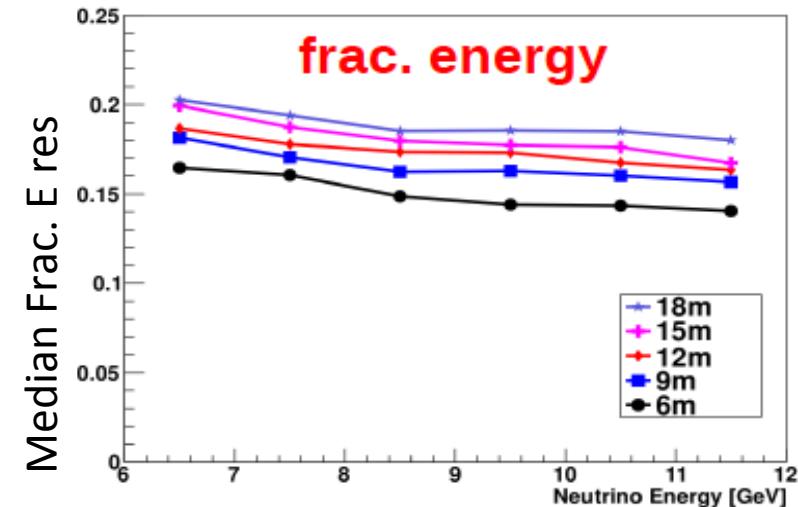
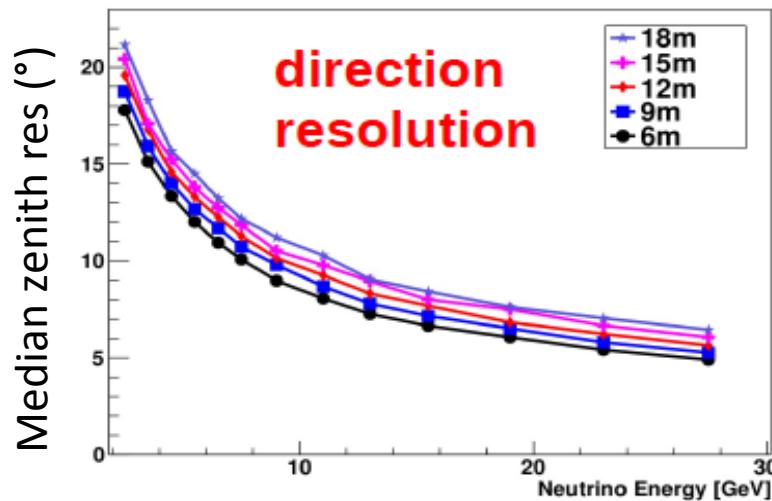
Effective Mass

- Above 10 GeV M_{eff} close to instrumented volume
- Similar for cascades and tracks



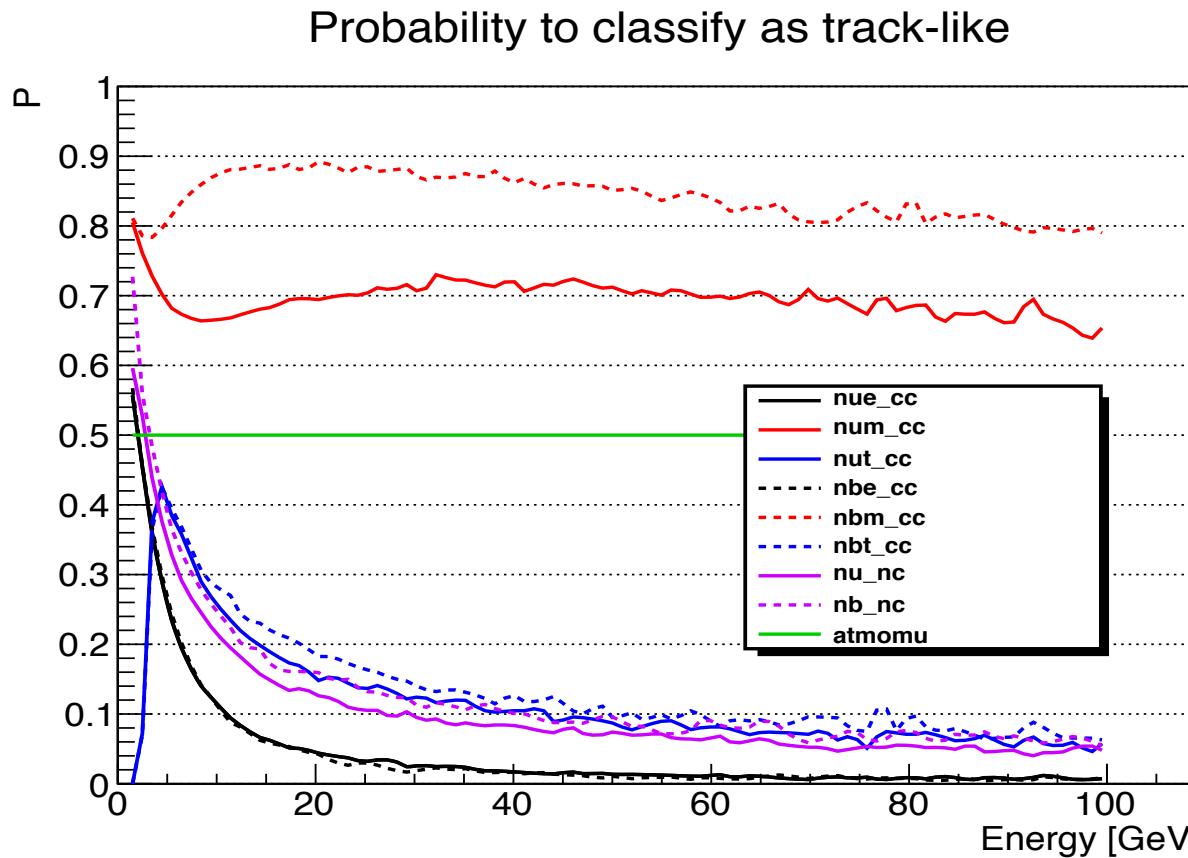
ORCA Layout Optimization

- 20m interline spacing imposed by line deployment (sea operations)
- Vertical spacing open : 6,9,12,18m spacing inter-DOM shown



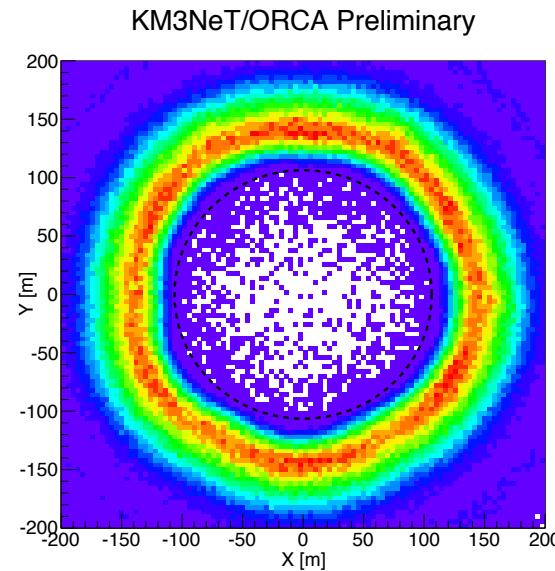
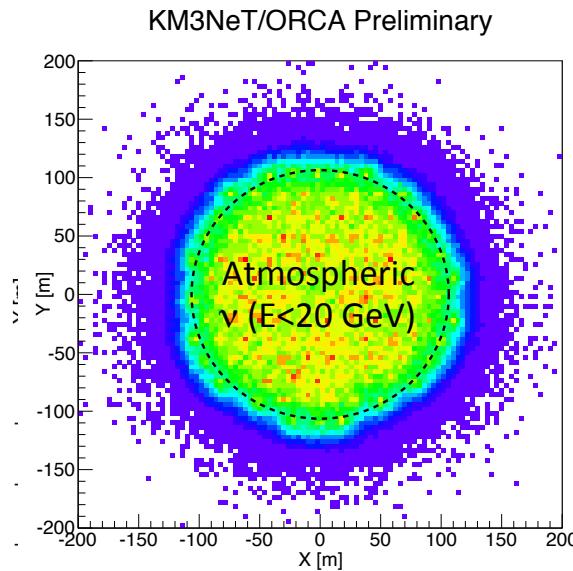
Examples for cascades
Resolutions stable
 M_{eff} 5-10 GeV crucial

Flavour (mis)-identification



- Discrimination of track-like (ν_μ^{CC}) and cascade-like (ν^{NC} , ν_e^{CC}) events
- Classification uses “Random Decision Forest”
- Better than 80% above 10 GeV for all channels but ν_μ^{CC}

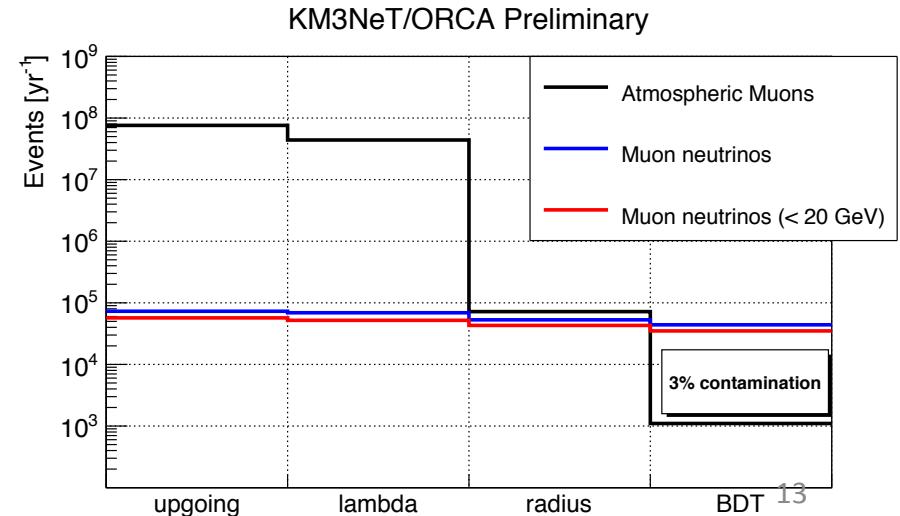
Atmospheric muon rejection



Instrumental veto
not mandatory

Few % contamination achievable
without too strong signal loss

Poster : Luigi Fusco



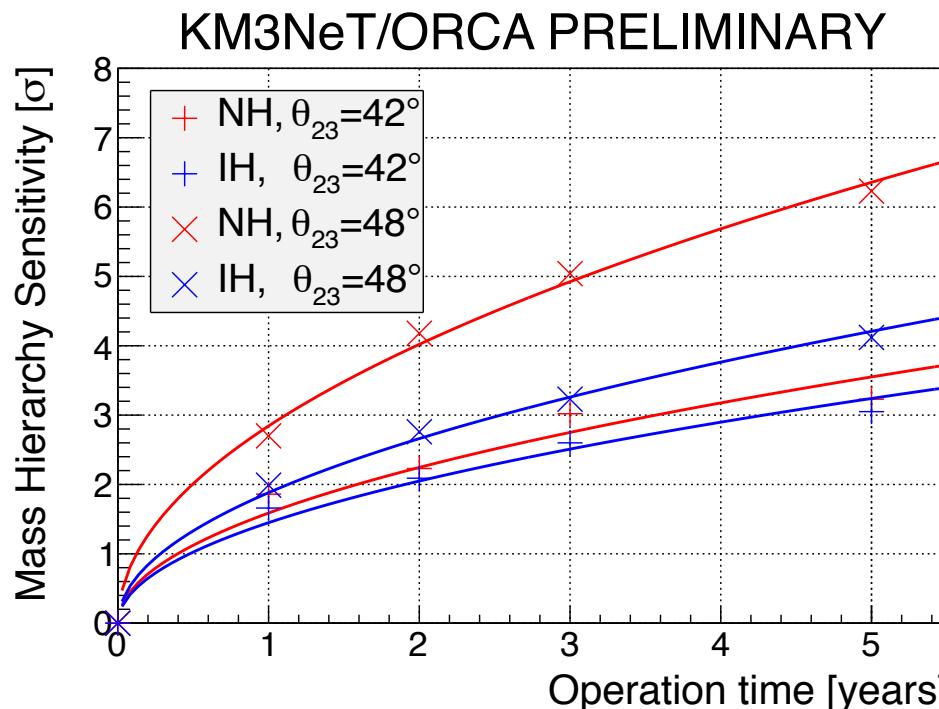
Systematic Effects

- Various systematic effects taking into account
 - Oscillation parameters
 - Δm^2 , θ_{12} fixed; θ_{13} fitted within its error
 - ΔM^2 , θ_{23} , δ_{CP} → fitted **unconstrained**
 - Flux, cross section , detector related
 - (average fluctuation w.r.t. nominal)
 - Overall normalisation (2.0%)
 - $\nu/\bar{\nu}$ ratio (4.0%)
 - e/μ ratio (1.2%)
 - NC scaling (11.0%)
 - Energy slope (0.5%)
 - → Fitted **unconstrained**

Sensitivity to Neutrino Mass Hierarchy

Poster : Martijn Jongen

Dependence of sensitivity on time for fixed θ_{23} values
 δ_{CP} fixed to zero for easy comparison with other experiments



- ✓ Track vs shower event classification
- ✓ Full MC detector response matrices including misidentified and NC events
- ✓ Atmospheric muon contamination
- ✓ Neutral current event contamination
- ✓ Various Systematic uncertainties

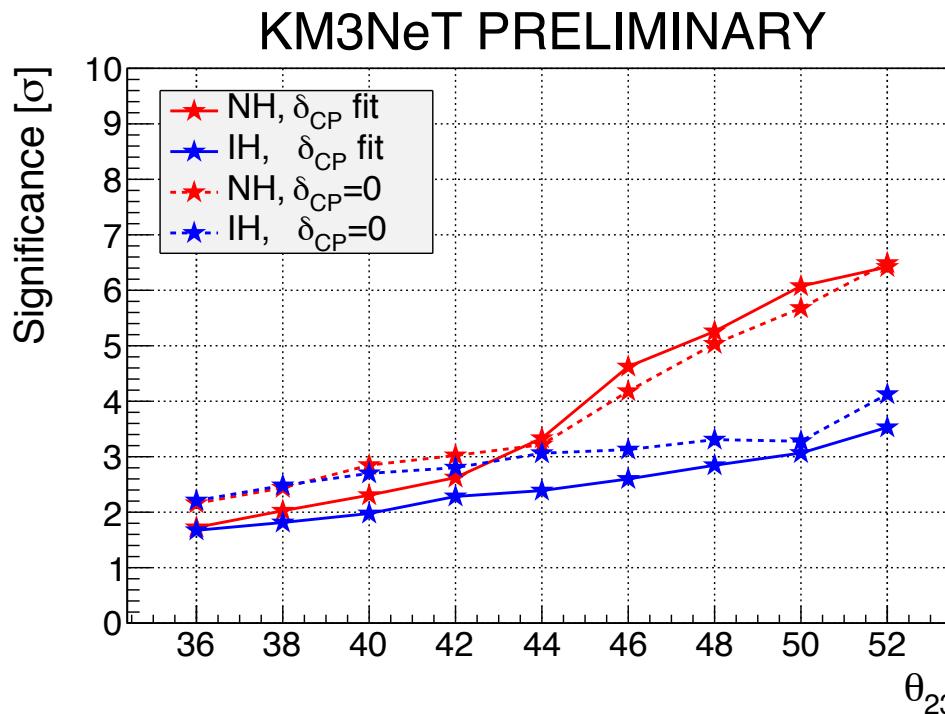
Sensitivity to Neutrino Mass Hierarchy

Dependency of sensitivity on θ_{23} for **3 years**

NH easier to determine than IH

Second octant easier than first octant

When fixing δ_{CP} to zero sensitivity increases by $\sim 0.5\sigma$



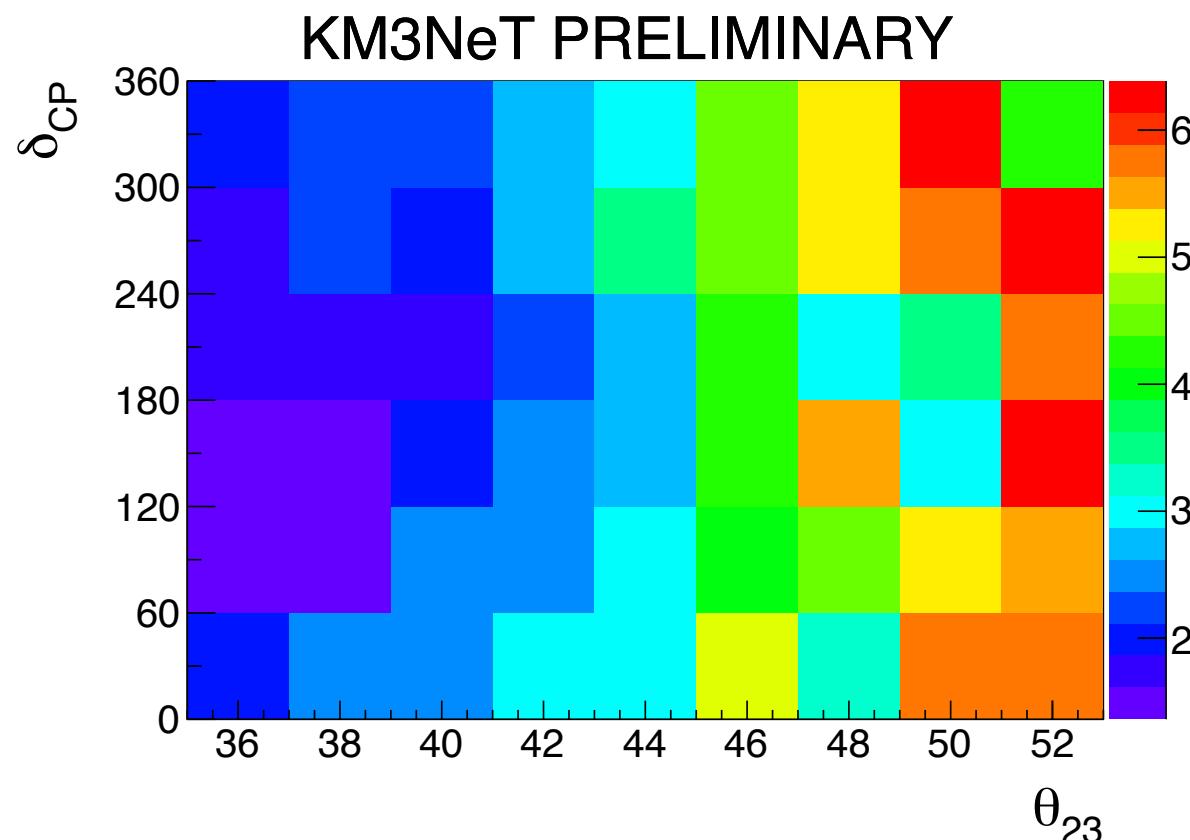
- ✓ Track vs shower event classification
- ✓ Full MC detector response matrices including misidentified and NC events
- ✓ Atmospheric muon contamination
- ✓ Neutral current event contamination
- ✓ Various Systematic uncertainties

Sensitivity to Neutrino Mass Hierarchy

Dependency of sensitivity on θ_{23} and δ_{CP} **for NH and 3 years**

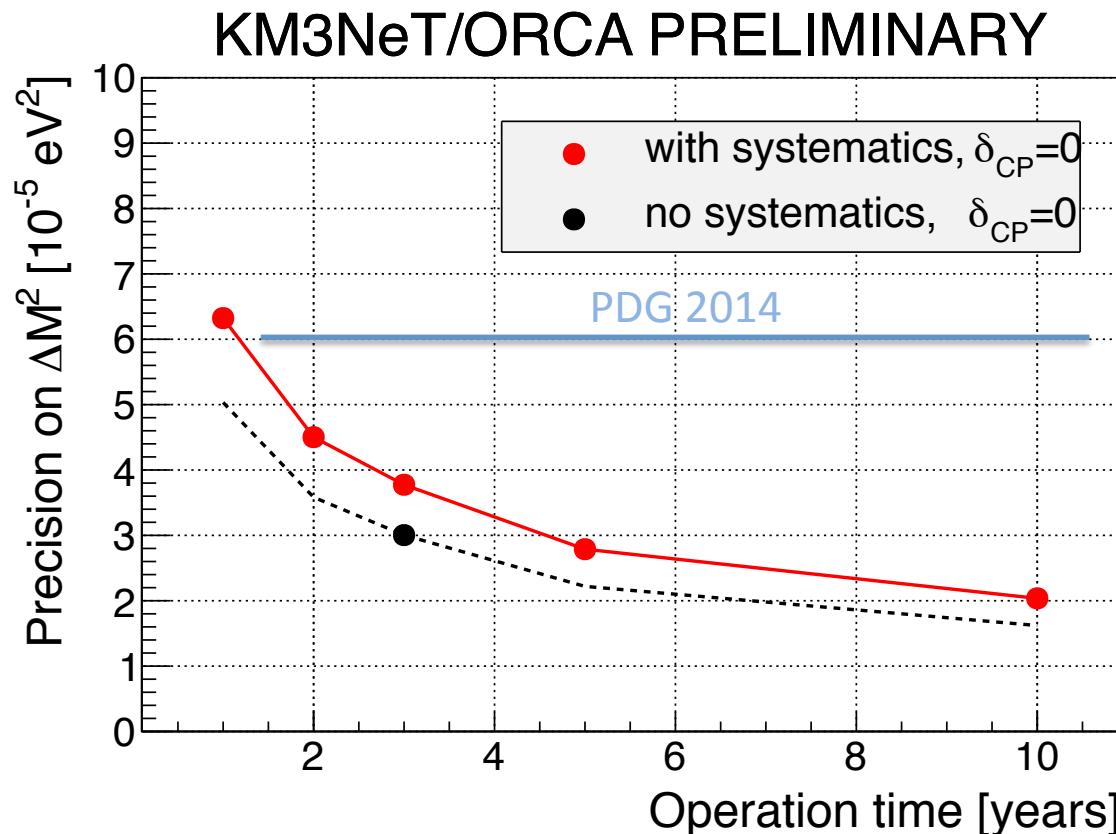
Best case : large θ_{23} and $\delta_{CP} = 0^\circ$

Worst case : small θ_{23} and $\delta_{CP} = 180^\circ$



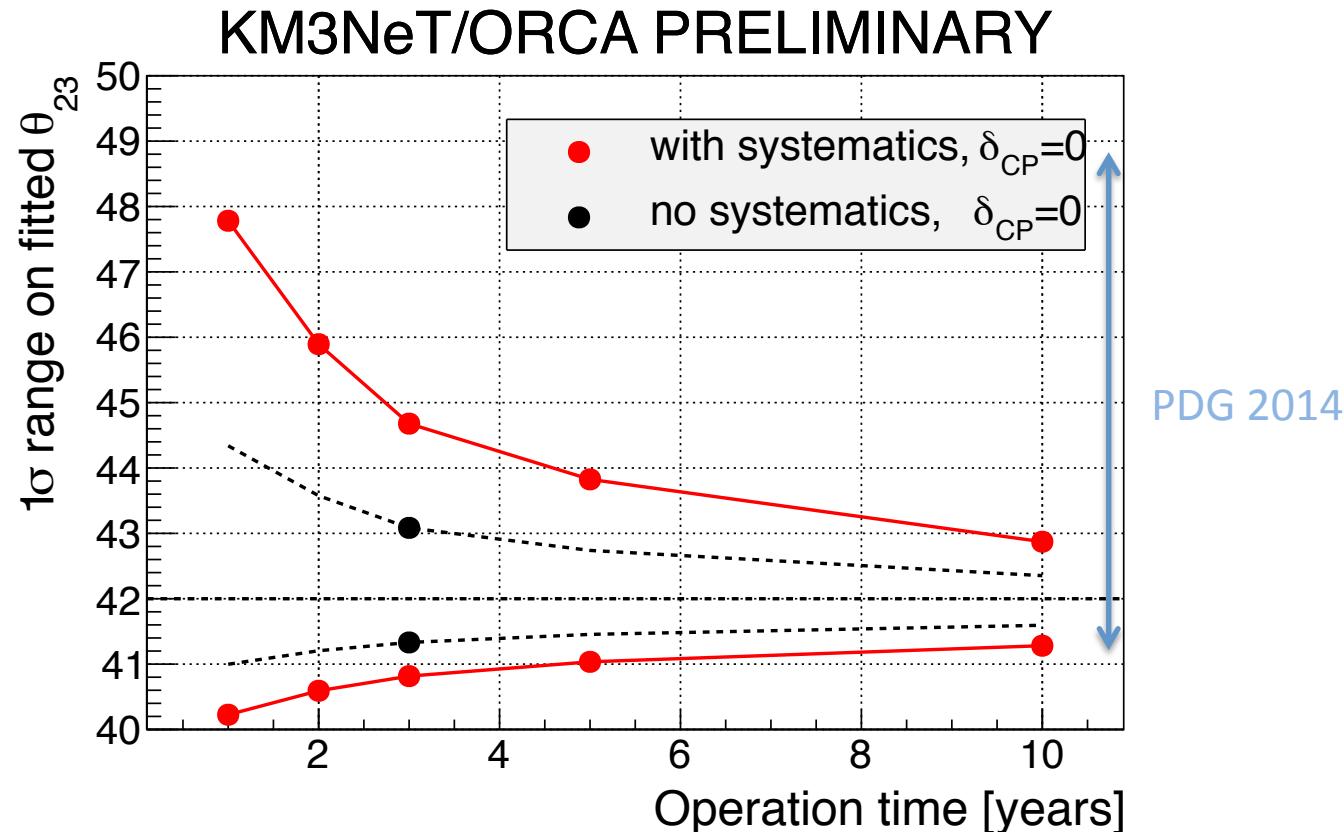
Sensitivity to PMNS parameters

ΔM^2 – unconstrained fit in conjunction to mass hierarchy hypothesis testing
→ Significant improvement of precision achievable



Sensitivity to PMNS parameters

Θ_{23} – unconstrained fit in conjunction to mass hierarchy hypothesis testing
World best measurement after few years of data taking

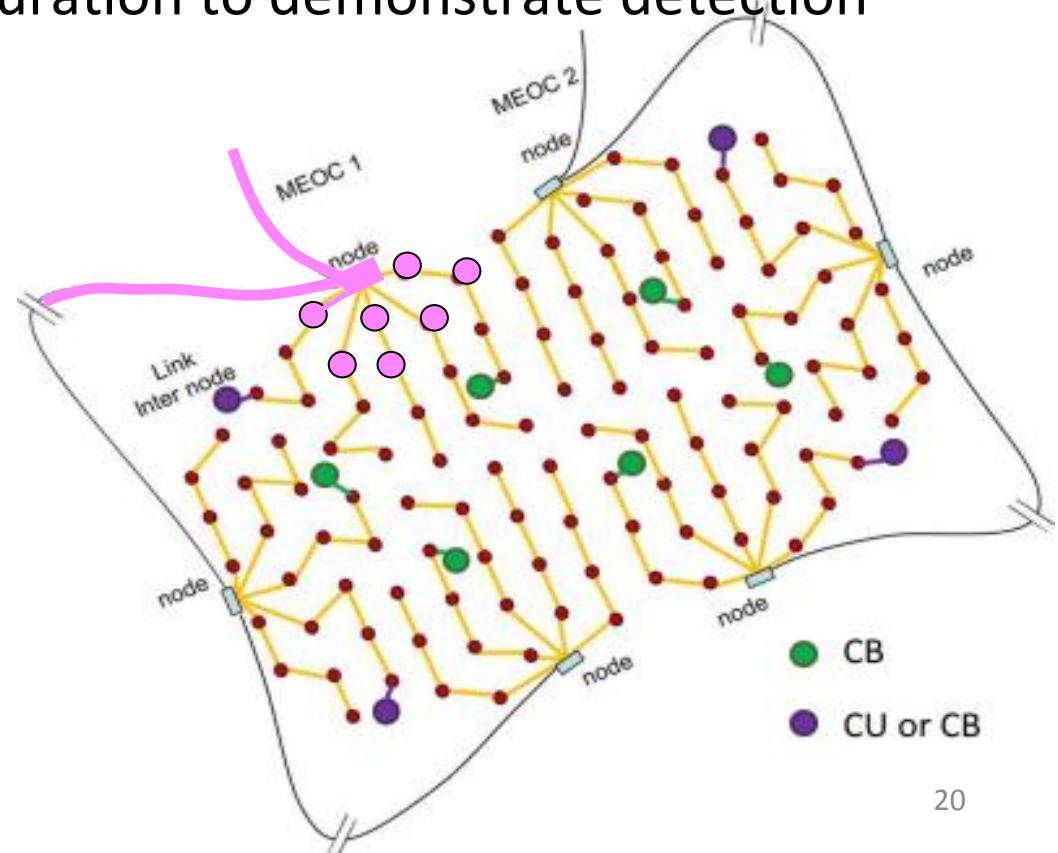


ORCA costs & timeline

Modular ring of up to 5-6 nodes via two cables to shore for up to 120 detection units + sea science instruments

Possibility to redirect the ANTARES cable to ORCA as second main cable

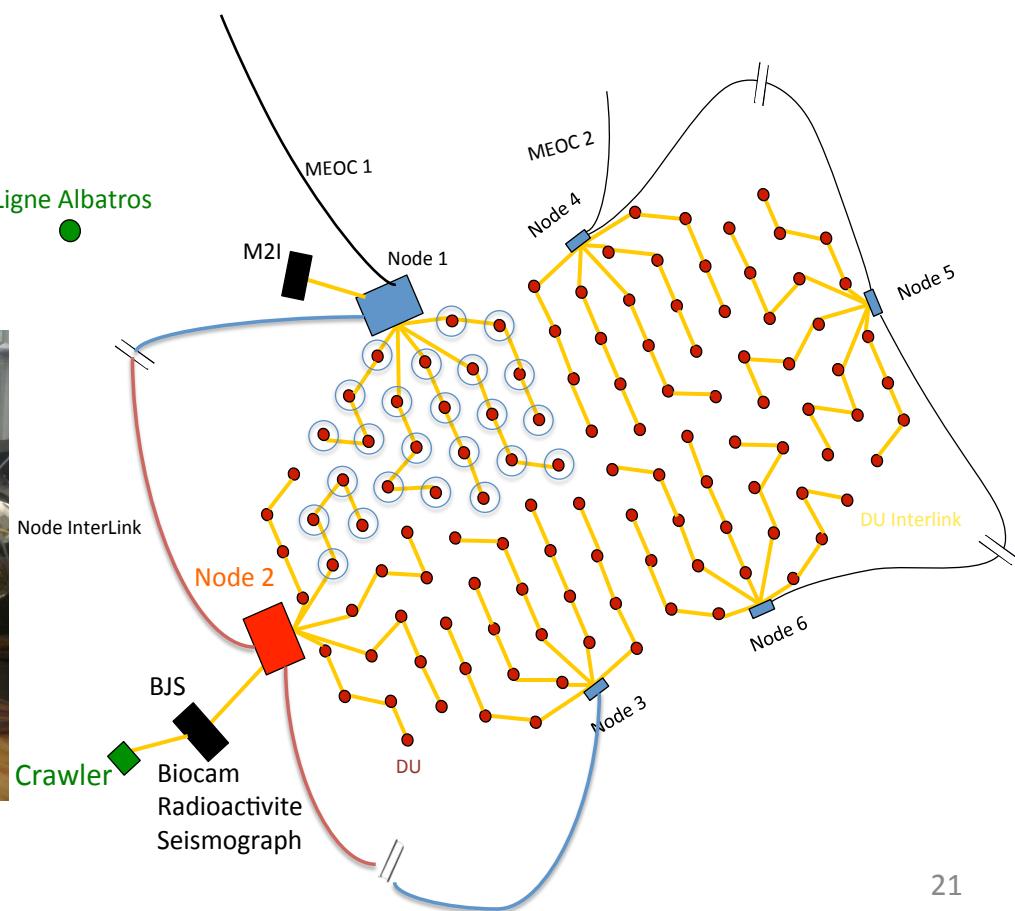
Phase 1 (funded) Deploy new main cable, junction box and a 6-7 string array in the ORCA configuration to demonstrate detection method in the GeV range.



ORCA costs & timeline

Next Step

- 24-30 lines & second junction box
- equipment for sea science



Conclusion

- ORCA started detector construction
- Budget situation promising
- Full simulation and reconstruction framework available
- Systematic uncertainties under control
- Further improvements possible using inelasticity
- NMH determination feasible on unequalled time scale
- Improvement of measurement precision for atmospheric oscillation parameters



END