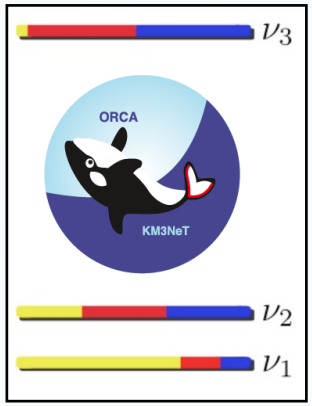
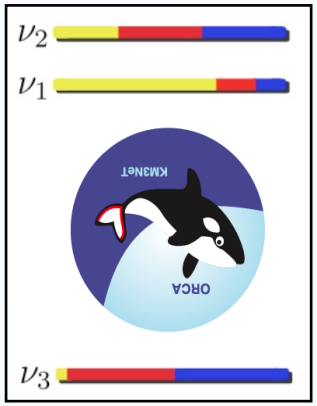




Summary of the ORCA/PINGU session at MANTs 2014

Conveners: Antoine Kouchner and Marek Kowalski

Very lively and informative sessions! Thank you all.

Apologies for the bias towards ORCA

Agenda of first session

Parallel 1 PINGU / ORCA 11:15-13:00		**105 min**
Chairs: Antoine Kouchner + Marek Kowalski		
PINGU configuration and plans Darren Grant	introduction	15
ORCA configuration and plans Jürgen Brunner		15

Agenda of first session

Parallel 1 PINGU / ORCA 11:15-13:00 **105 min**

Chairs: Antoine Kouchner + Marek Kowalski

PINGU configuration and plans 15
Darren Grant

ORCA configuration and plans 15
Jürgen Brunner

introduction

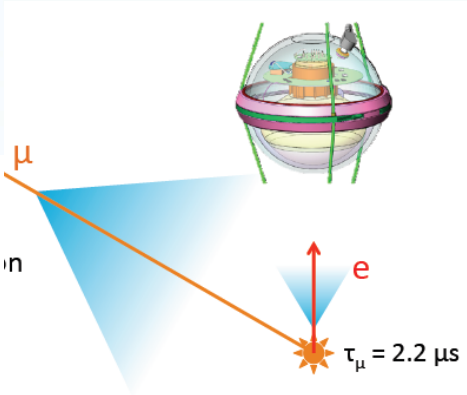
Plans →my conclusions

Reconstruction methods & performances (tracks, cascades, PID) in water
Jannik Hofestädt 20+5

Latest (not all public) achievements … work in progress

Reconstruction methods & performances (tracks, cascades, PID) in ice
Joao Pedro Athayde Marcondes de André 20+5

Agenda of second session



Parallel 3 PINGU / ORCA 14:00-15:40

Chairs: Antoine Kouchner + Marek Kowalski

Calibration strategy in ice
Martin Jurkovic → No ORCA mirror talk
Should be worked out in future 15+5
Apologies for not covering this much today

Muon rejection in ice and water
Andreas Gross + L. Fusco → Not so different approaches ! 25+5

Global analysis
Martijn Jongen, Lukas Schulte → Collaborative work – Spirit of GNN !
(Combination of track and cascade channels, systematics sensitivity comparison ORCA/PINGU)

40+10

Agenda of second session

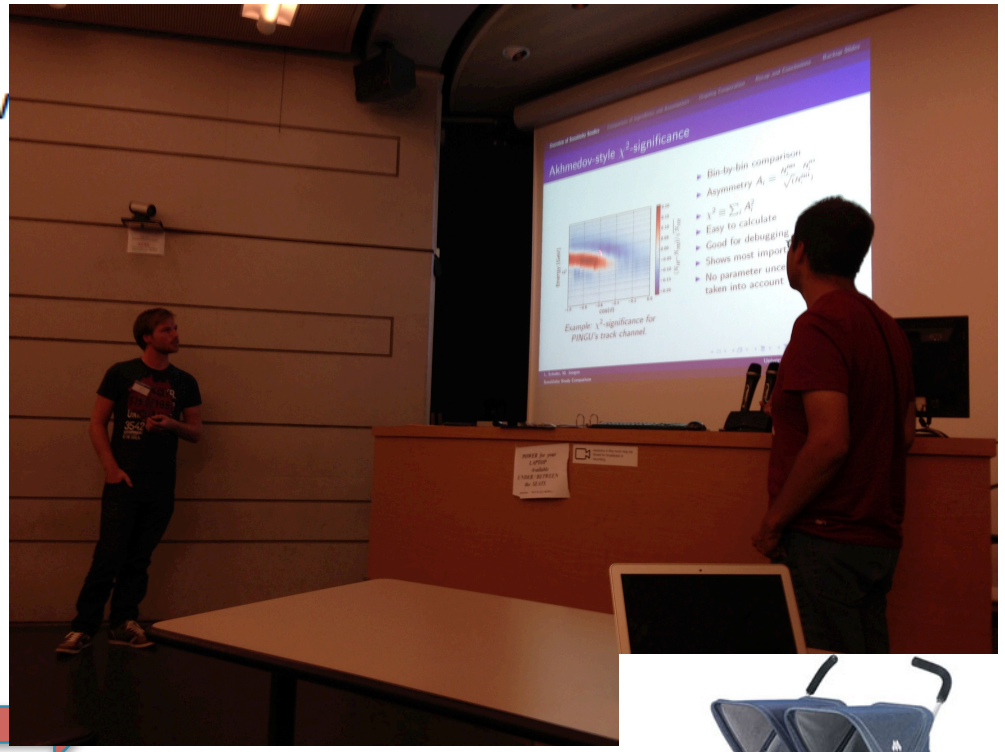
Parallel 3 PINGU / ORCA 14:00-15:40

Chairs: Antoine Kouchner + Marek Kow

Calibration strategy in ice
Martin Jurkovic

Muon rejection in ice and water
Andreas Gross + L. Fusco

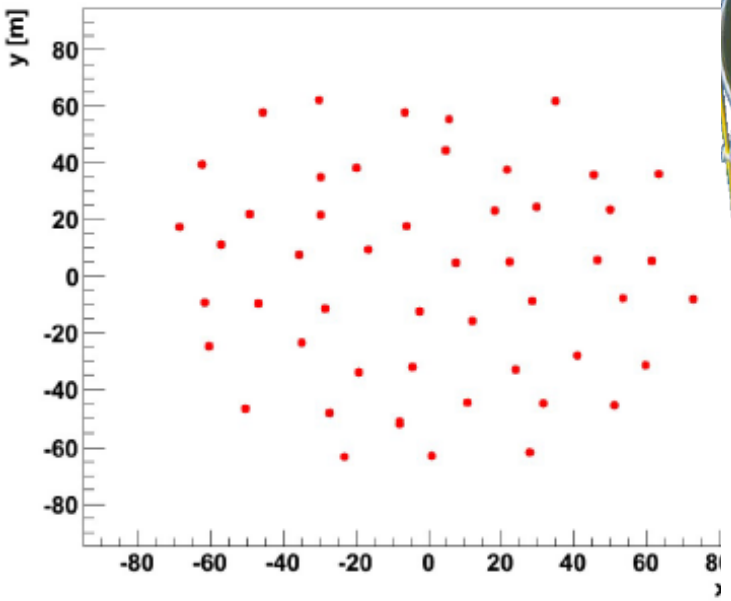
Global analysis
Martijn Jongen, Lukas Schulte
(Combination of track and cascade channels, systematics sensitivity comparison ORCA/PINGU)



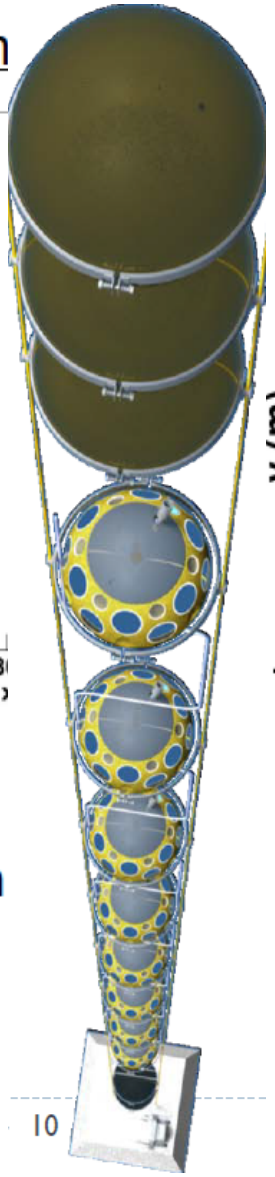
Thank you Teresa for the Organisation !

ORCA Layout evolution

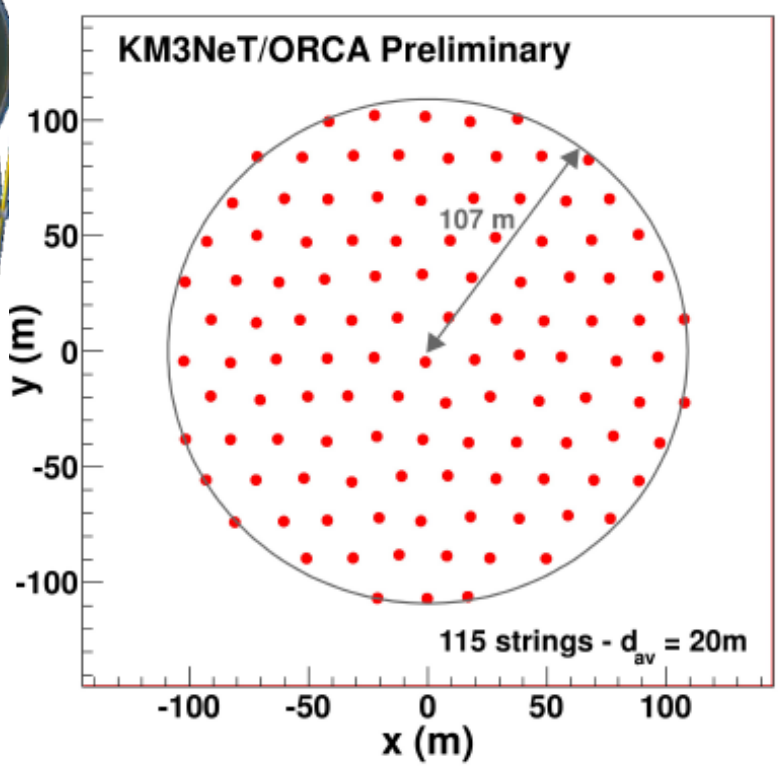
Reference detector (50strin



- inst. volume: ~1.8 Mm^3
- height 114m, diameter 140m
- 50 strings, 20m spaced
- 20 DOM/string, 6m spaced



Proposed detector (115strings)



inst. volume: ~3.7 Mm^3

height 102m, diameter 214m

115 strings, 20m spaced

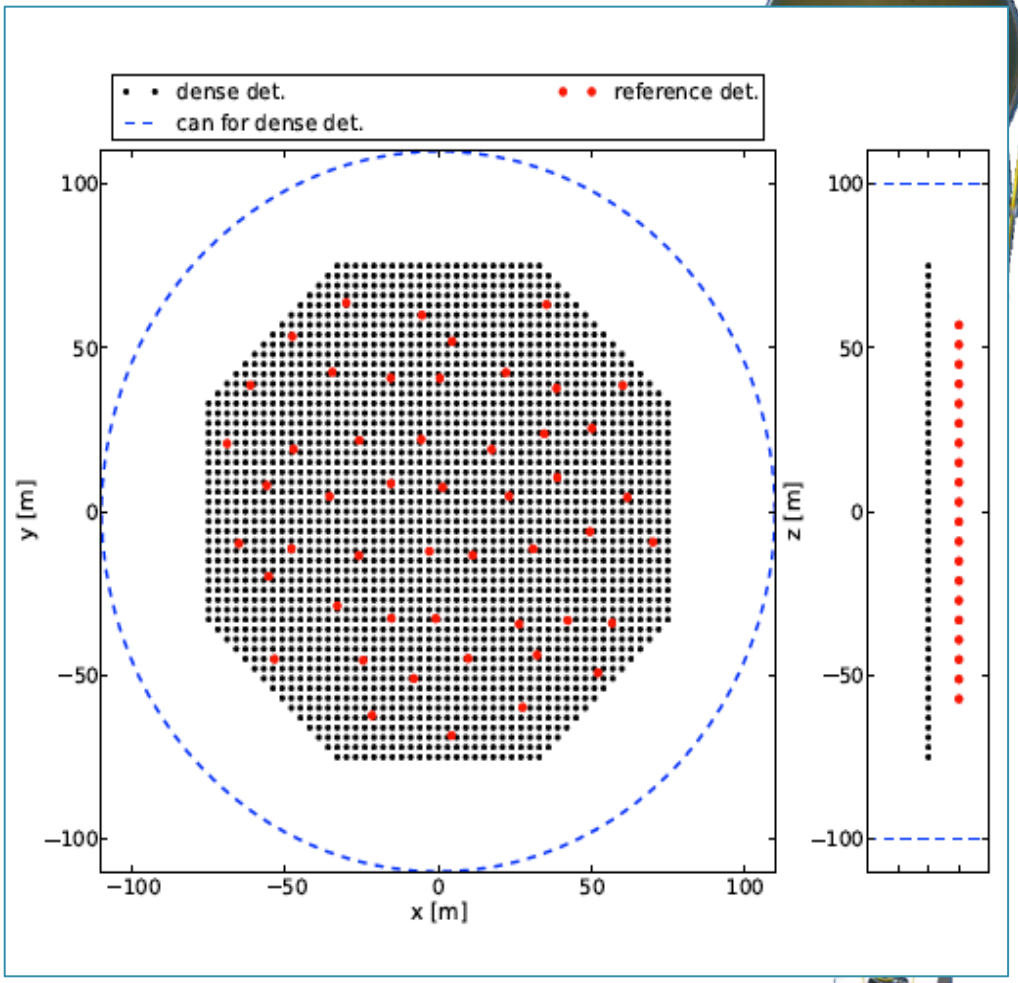
18 DOM/string, 6m spaced

- **DWDM system**
- **Launcher vehicle design**

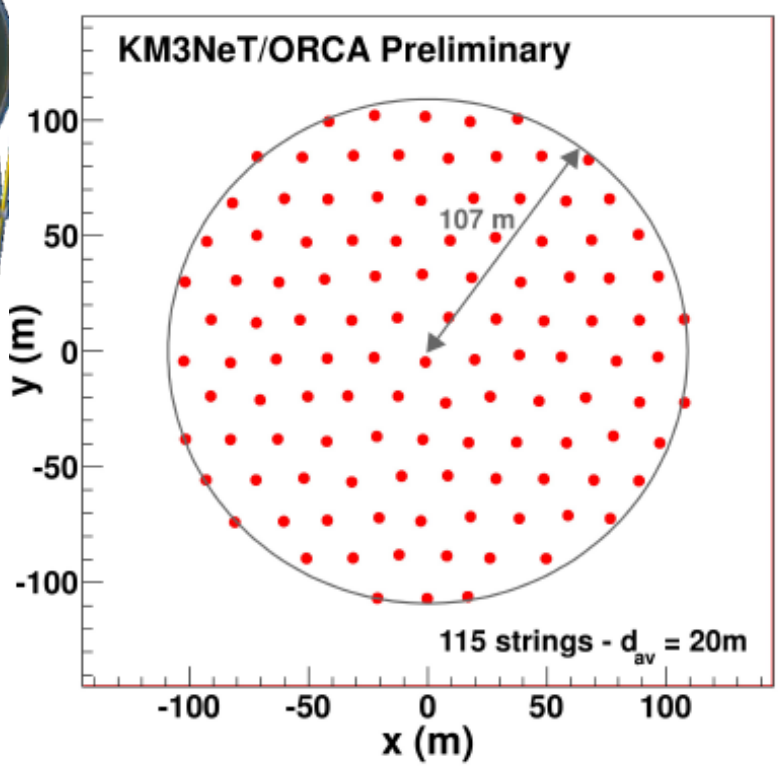
ORCA Layout evolution

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Reference detector (50strin



Proposed detector (115strings)



inst. volume: ~3.7 Mm^3

height 102m, diameter 214m

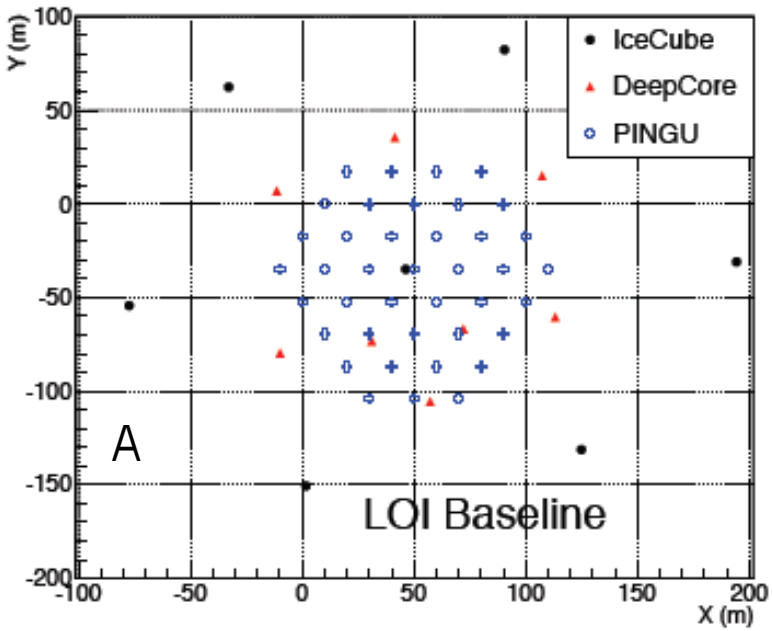
115 strings, 20m spaced

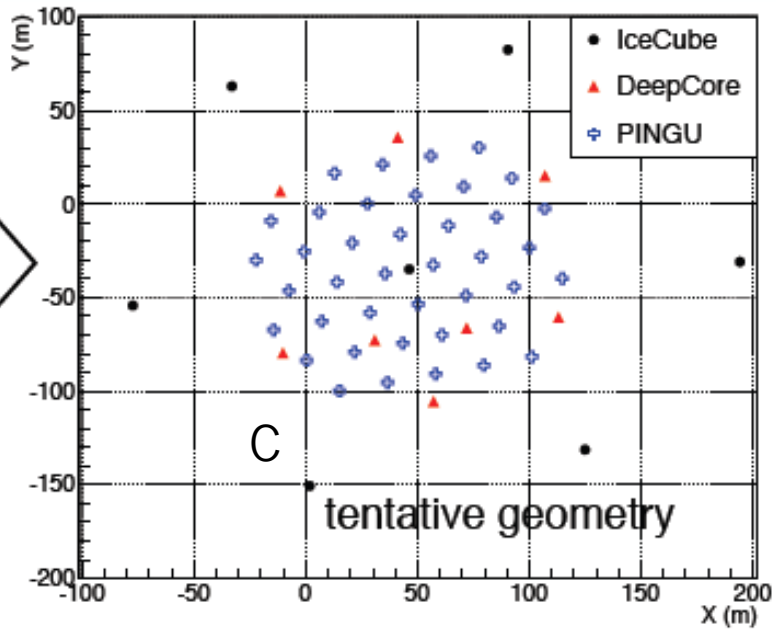
18 DOM/string, 6m spaced

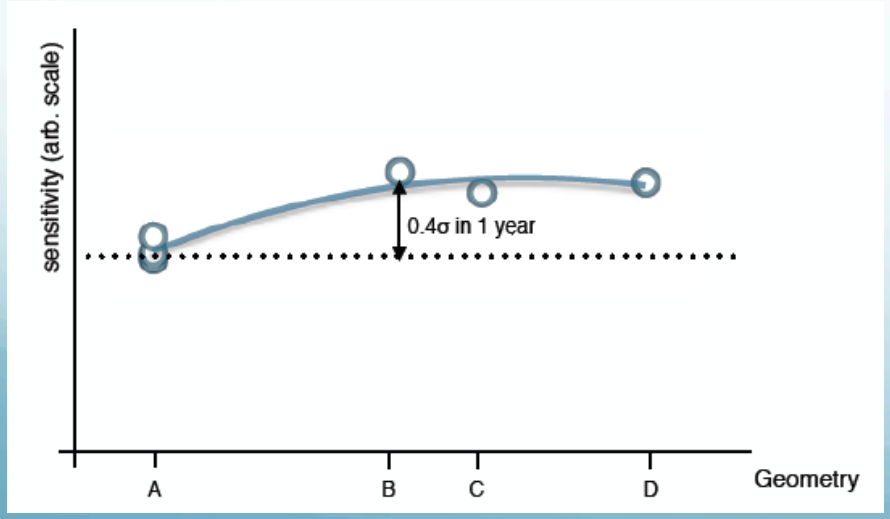
- **DWDM system**
- **Launcher vehicle design**

Overdense geometry with a 3x3x3m spacing used for further optimisation

PINGU Layout evolution







A - 40 strings (~12-30 m spacing); 60 DOMs (5 m spacing)

B - 60 strings (20 m spacing); 60 DOMs (5 m spacing)

C - 40 strings (20 m spacing); 96 DOMs (3 m spacing)

D - 40 strings (30m spacing); 120 DOMs (2.5 m spacing)

Main reasons for improvement: resolutions (including PID)

Detector performance studies

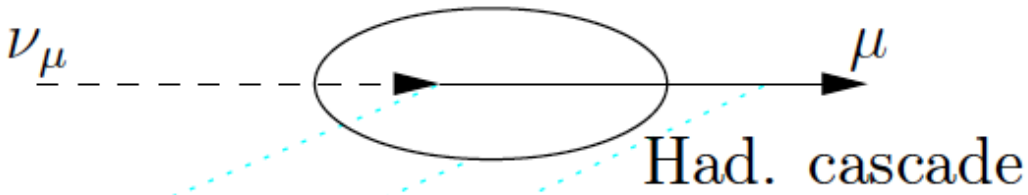
PINGU reconstruction of tracks & shower

Same fit for showers and tracks – Pid is assessed afterwards

1. Reconstruction method: HybridReco/MultiNest
   - used in our *Letter of Intent*
   - uses "hybrid" particle hypothesis and MultiNest as "minimizer"

The HybridReco/MultiNest hypothesis

- Goal: reconstruct ν_μ CC (DIS) interactions (total 8 parameters)



4 parameters: vertex(3), time

3 parameters: direction(2), energy

3 parameters: direction(2), energy/length

assume same direction for μ and cascade

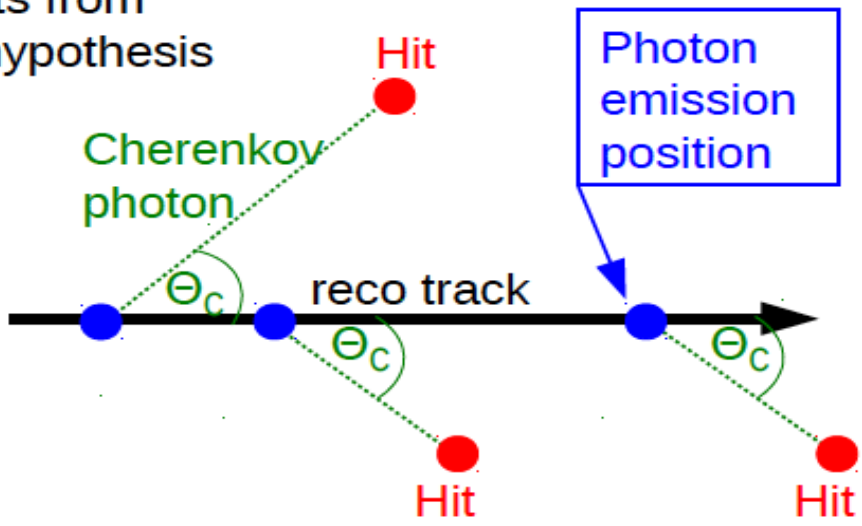
Detector performance studies

ORCA reconstruction of muon tracks

ANTARES-inspired reconstruction

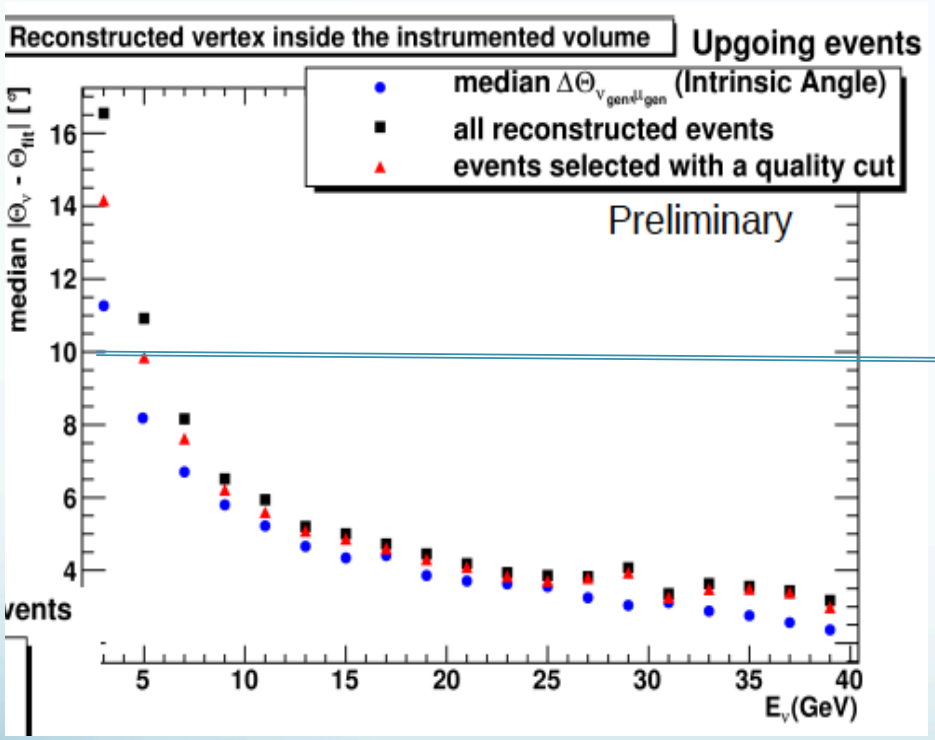
No improvement since last year

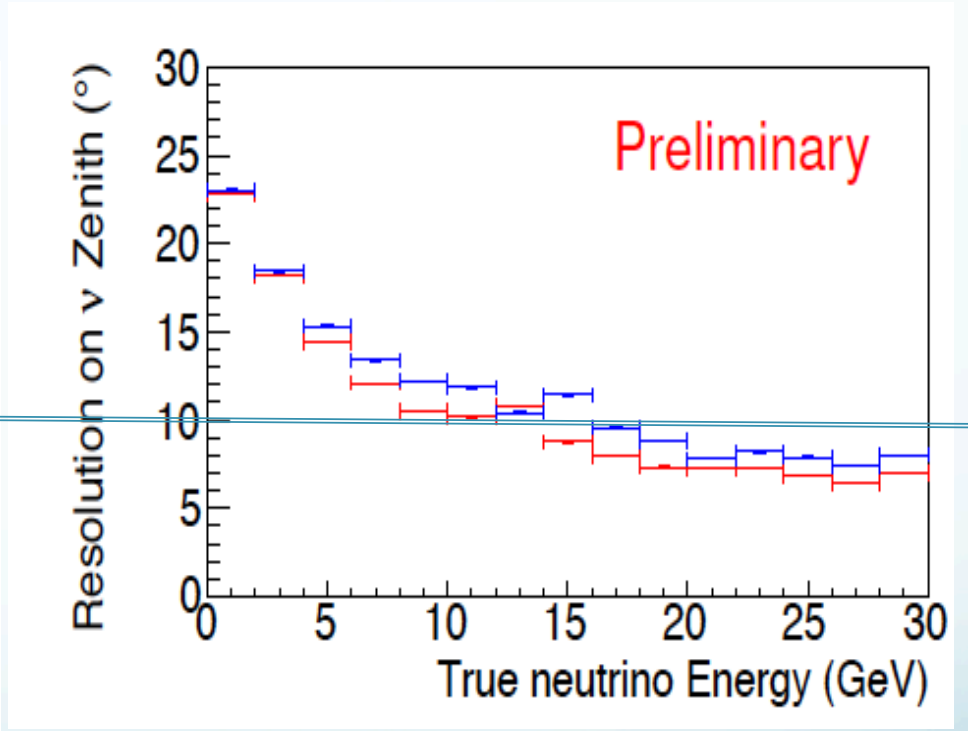
- Procedure:
  - hit selection based on coincidences and causality
  - track fit: maximum likelihood based on hit time residuals
    similar to AAFit
  - track length estimation:
    1. first / last hit emission point
    2. vertex fit by identifying hits from had. shower and fit vertex hypothesis along reconstructed track



Detector performance studies

ORCA /PINGU muon tracks

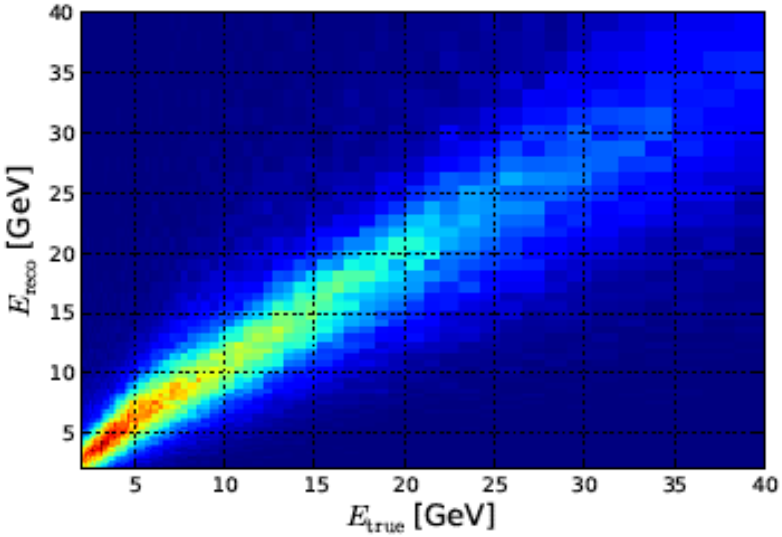




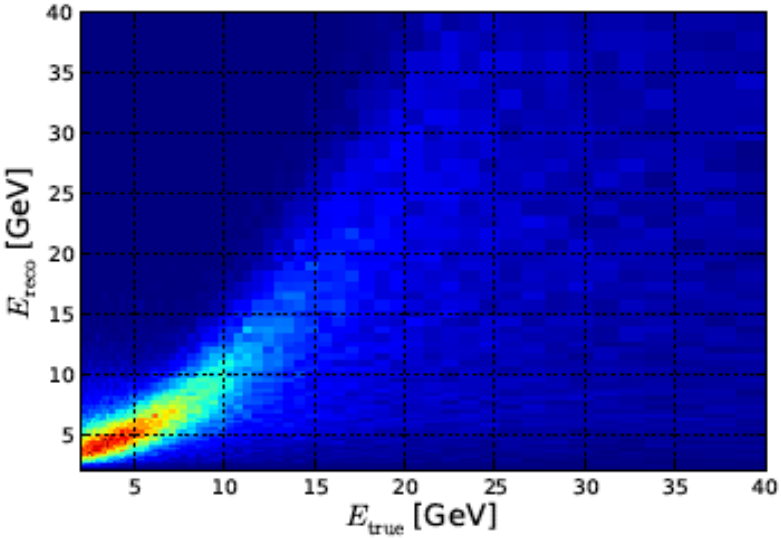
New tentative geometry
Similar to LoI?

Detector performance studies

ORCA /PINGU muon tracks



Projection of PINGU's resolution in the log(E_{true})-log(E_{reco}) plane. See talk by J.P. de André.



Energy smearing used for ORCA analysis. Based on track-fitting algorithm. See talk by Jannik Hofestädt.

Full response matrix used for sensitivity studies

ORCA: using the hits (from the hadronic shower) should improve (on going)

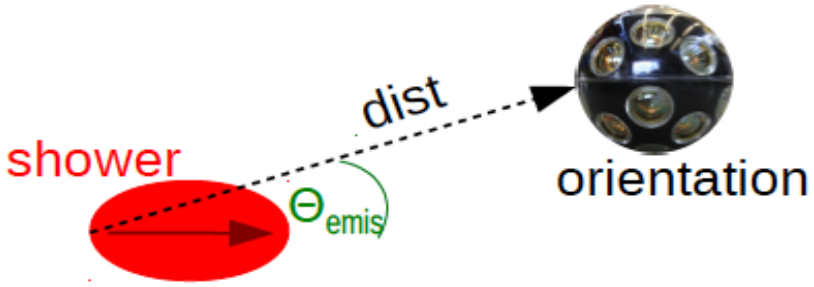
Shower reconstruction (ν_e)

ORCA on going work

Method

- 1. Vertex fit:
  - maximum likelihood method based on time residuals
  - two fits: first robust prefit then more precise fit

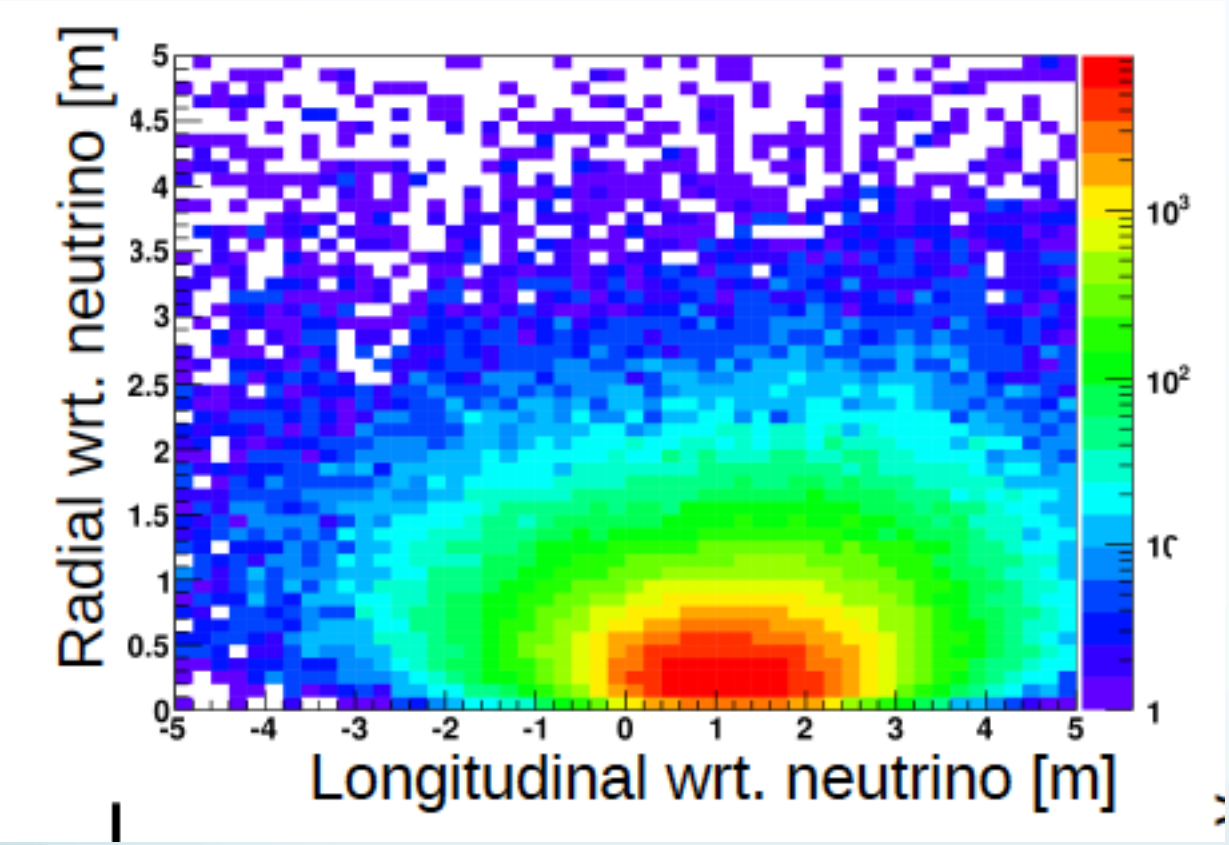
- 2. Energy + direction fit:
  - PDF for number of expected photons depending on:
    E_ν , Bjorken y, emission angle,
    OM orientation, distance(OM,vertex)

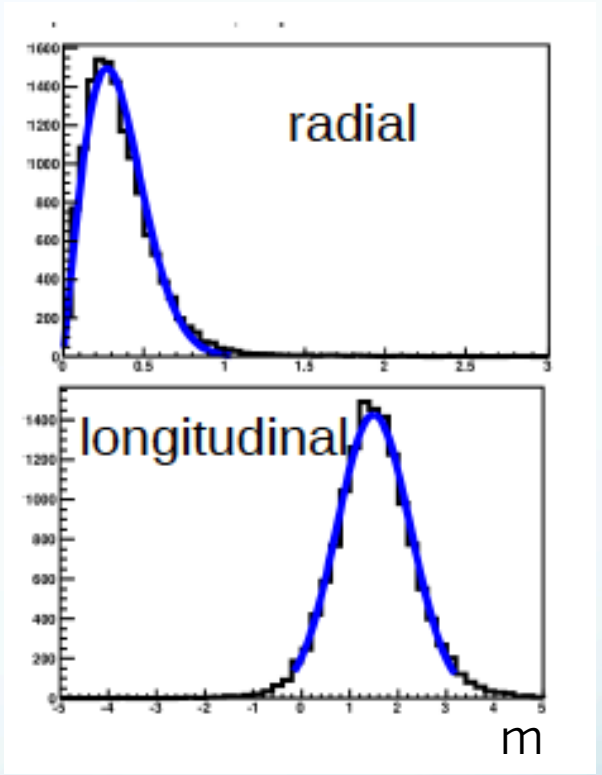


- maximum likelihood method based probability that hits have been created by certain shower hypothesis (E_ν, Bjorken y, direction)

Shower reconstruction (ν_e)

Vertex resolution

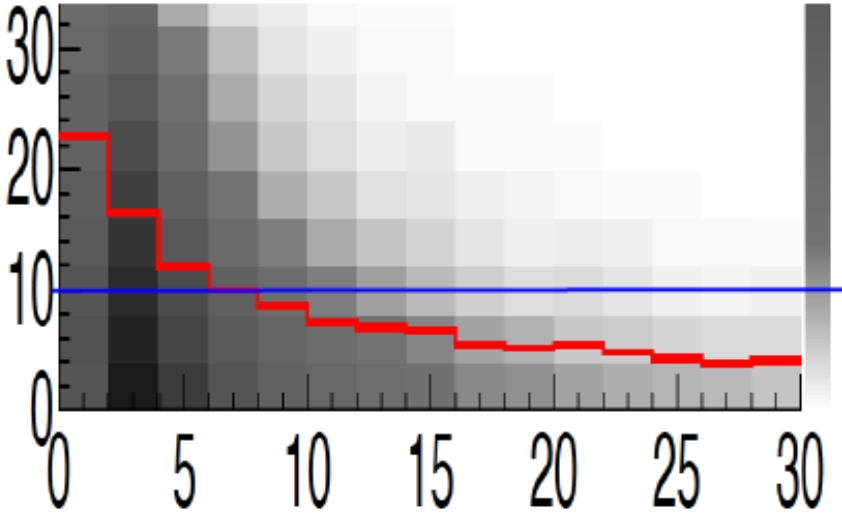




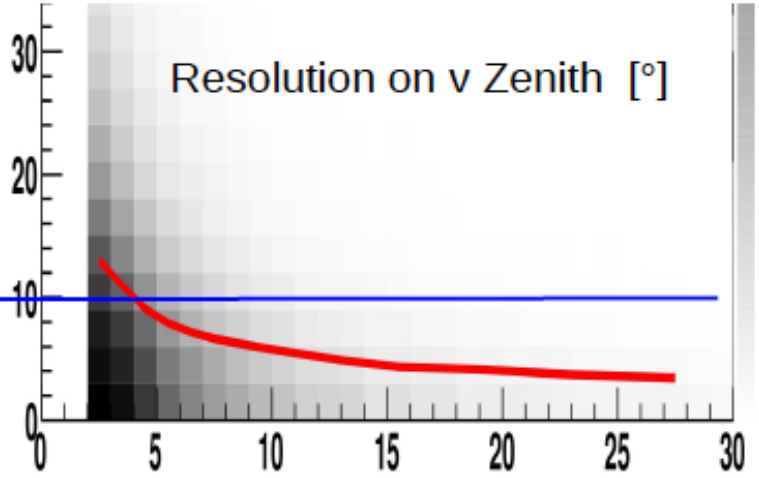
- Vertex resolution 0.5-1 m (longitudinal error dominates)

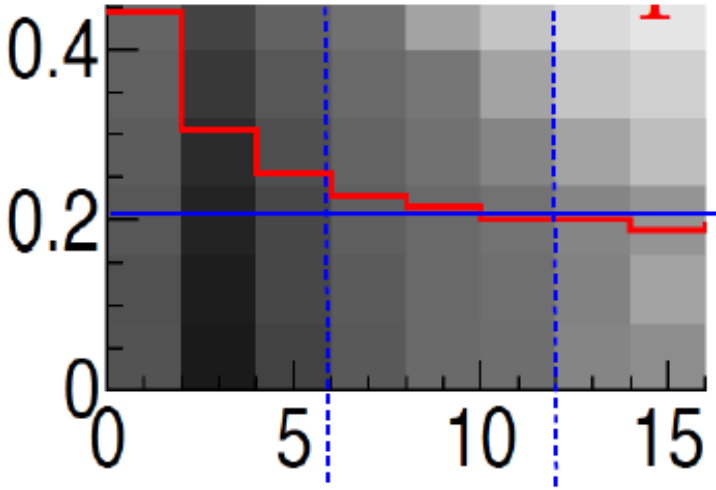
Shower reconstruction (ν_e)

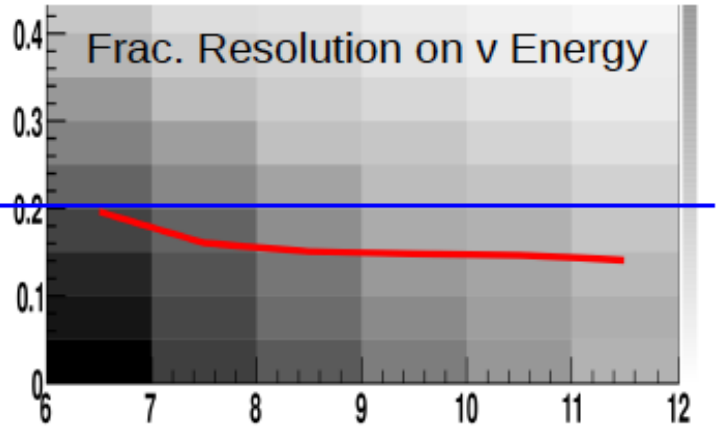
PINGU (LoI, 2014)



ORCA

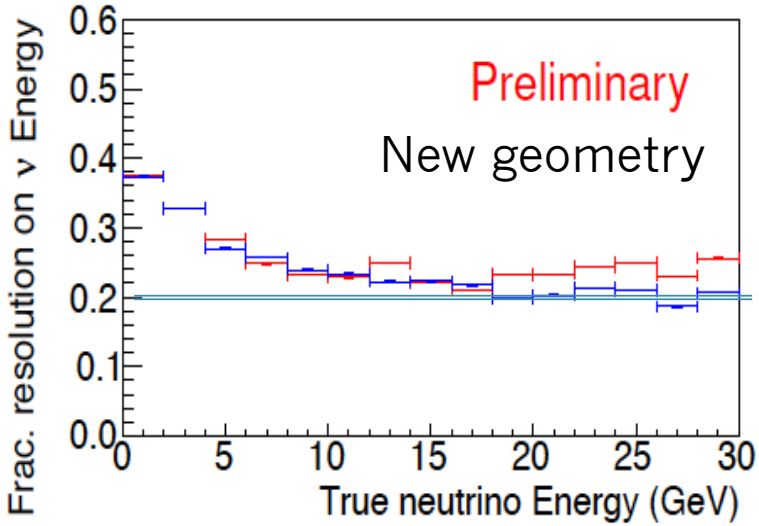




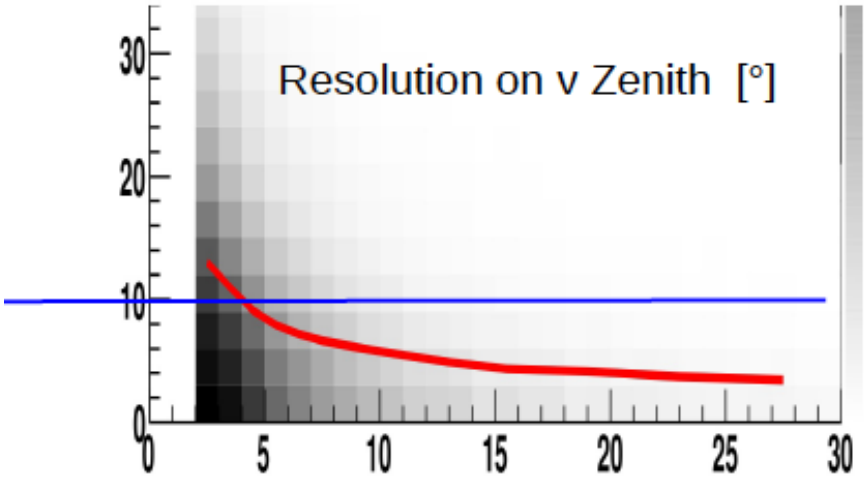


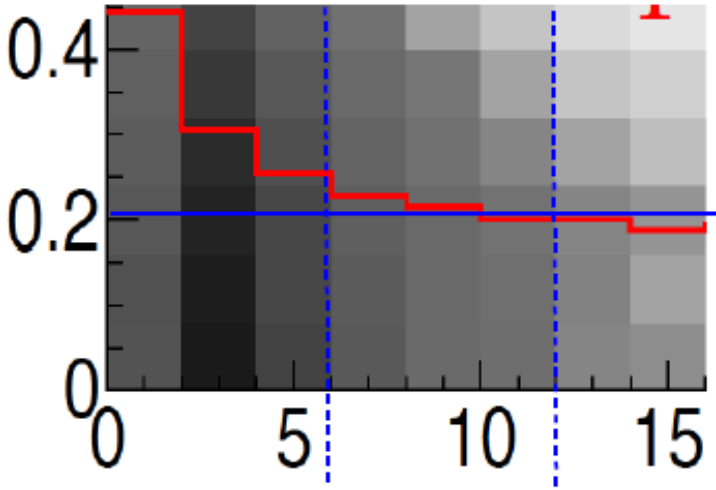
Shower reconstruction (ν_e)

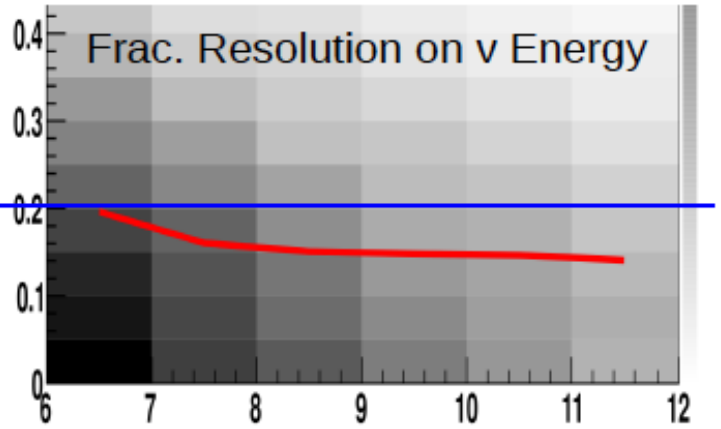
PINGU (LoI. 2014)



ORCA

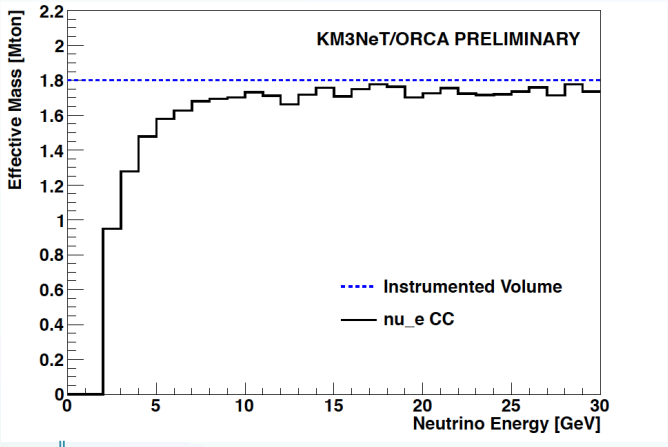






Shower reconstruction (ν_e)

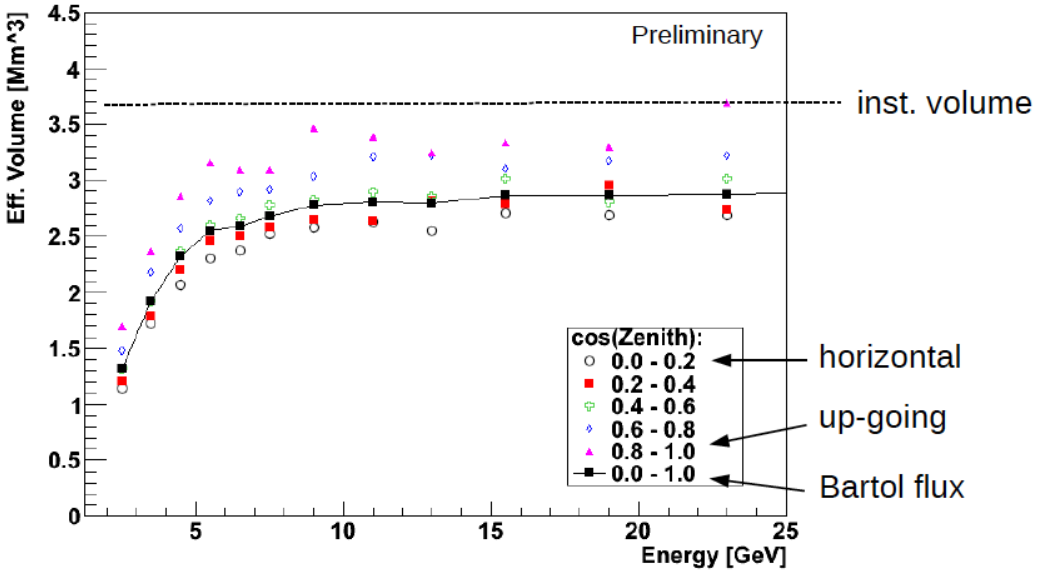
ORCA Effective volume



~20% less

Current input for sensitivity estimates

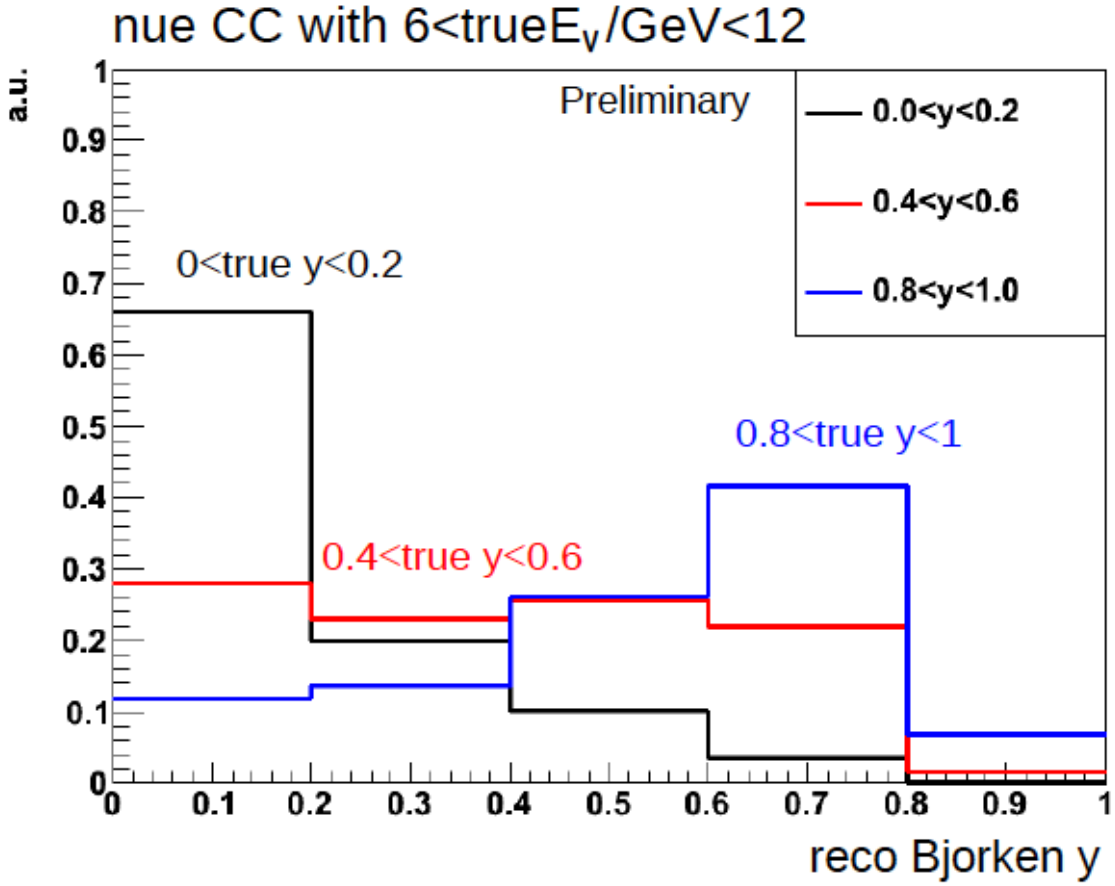
- Proposed detector (115 strings), MC: 'KM3Sim'



- Plateau: 2.6–3.3 Mm^3 (zenith angle dependent), for Bartol flux ~2.8 Mm^3
- Turn-on: 90% of plateau reach at ~6 GeV

Shower reconstruction (ν_e)

ORCA Bjorken y Sensitivity

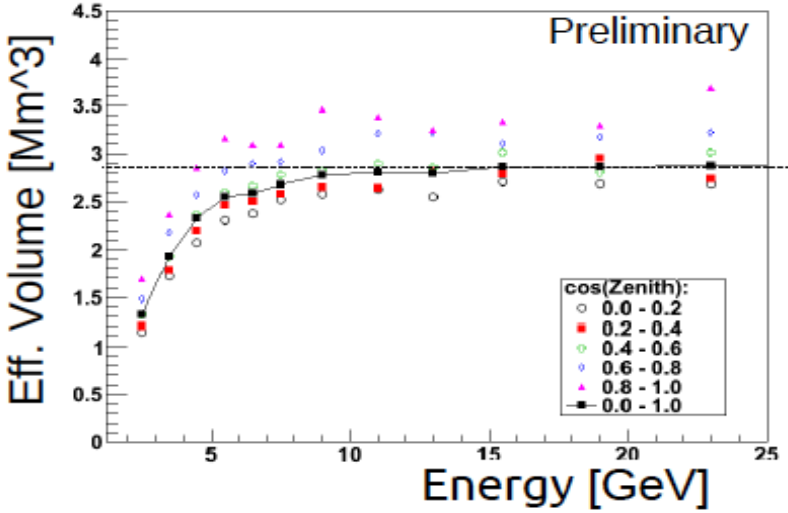


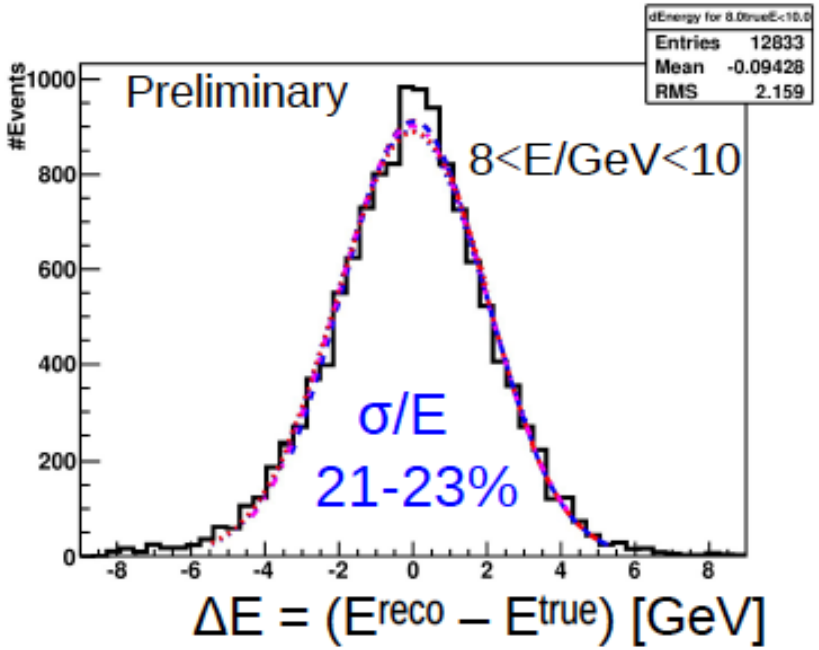
- Sensitivity to Bjorken y in nue CC events
- Maybe even CC vs NC separation → looks promising

ORCA Detector Layout

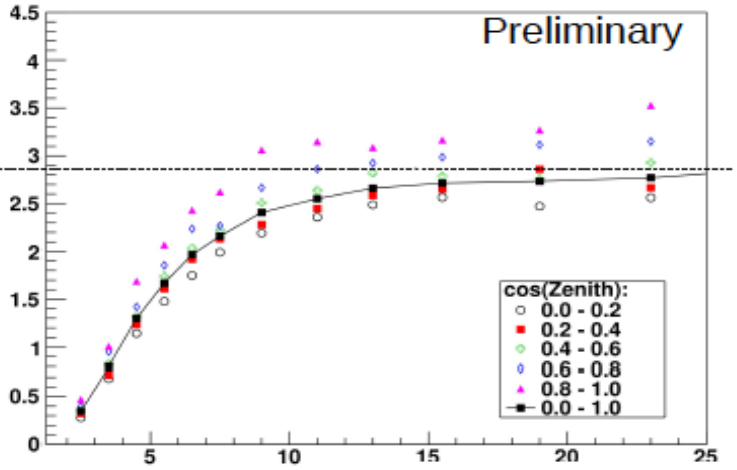
But PID has to be studied

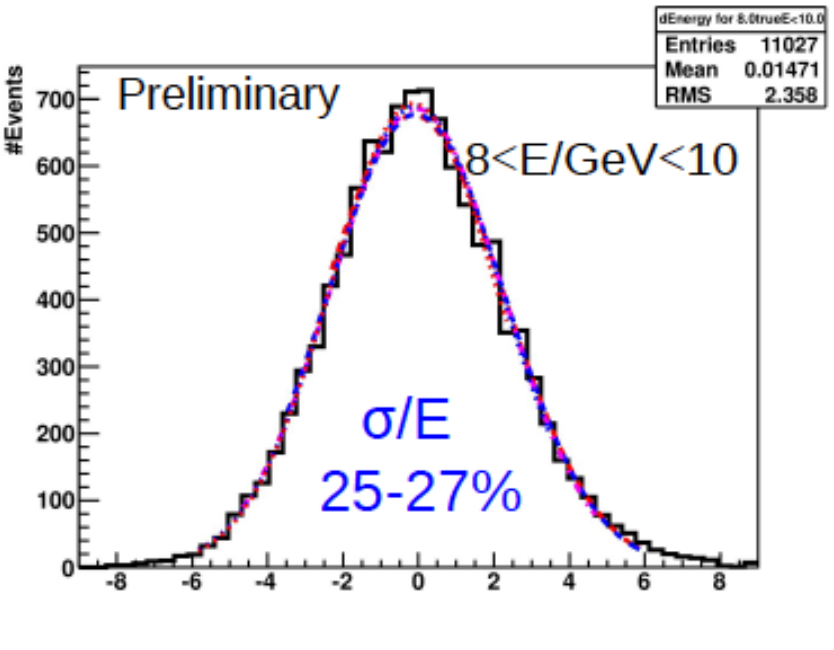
6m spacing



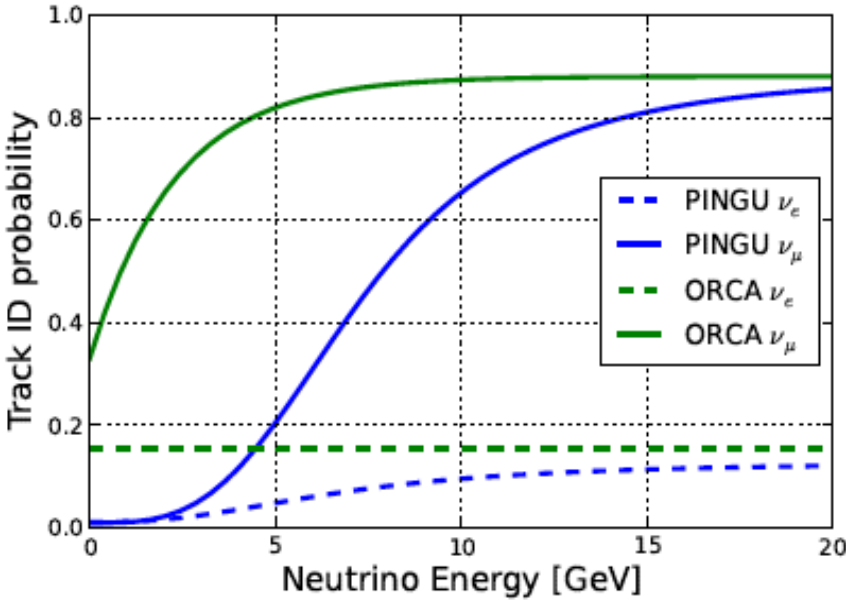


12m spacing





Flavour (mis)-identification



Probability to identify an event as a track.

- PINGU
  - At lower energies no separation by single variable
    $\rightarrow$ use multivariate analysis (TMVA) with 6 variables
  - HybridReco/MultiNest provides some variables
    1. Reconstructed track (μ) length
    2. Reconstructed $\frac{E_\mu}{E_\nu} = 1 - Y$ (Y is Bjorken-y parameter)
    3. LLH difference between best fit and cascade only hypothesis
  - Other variables by looking at hit timing (see next slide)
- ORCA:
  - Random Decision Forest
  - First study using Premium Events
  - Optimistic
  - To be improved

Details presented last MANTs

Muon background rejection

PINGU strategies

Reconstruction based

- Reconstruct event under neutrino hypothesis
- Remove events with
  - Reconstructed direction downgoing
  - reconstructed vertex outside PINGU
  - Reconstructed energy below 1 GeV

Veto hit based (topologic)

- Calculate topologic variables based on hits in fiducial volume and veto volume
  - Number of hits in veto region causally connected to fiducial hits
  - Number of hits in veto region around track candidate
  - Number of hits in top layers

Muon background rejection

PINGU strategies

Reconstruction based

- Reconstruct event under neutrino hypothesis
- Remove events with
  - Reconstructed direction ~~down~~ up going
  - reconstructed vertex outside PINGU
  - Reconstructed energy below ~~1~~ few GeV

~ ORCA strategy

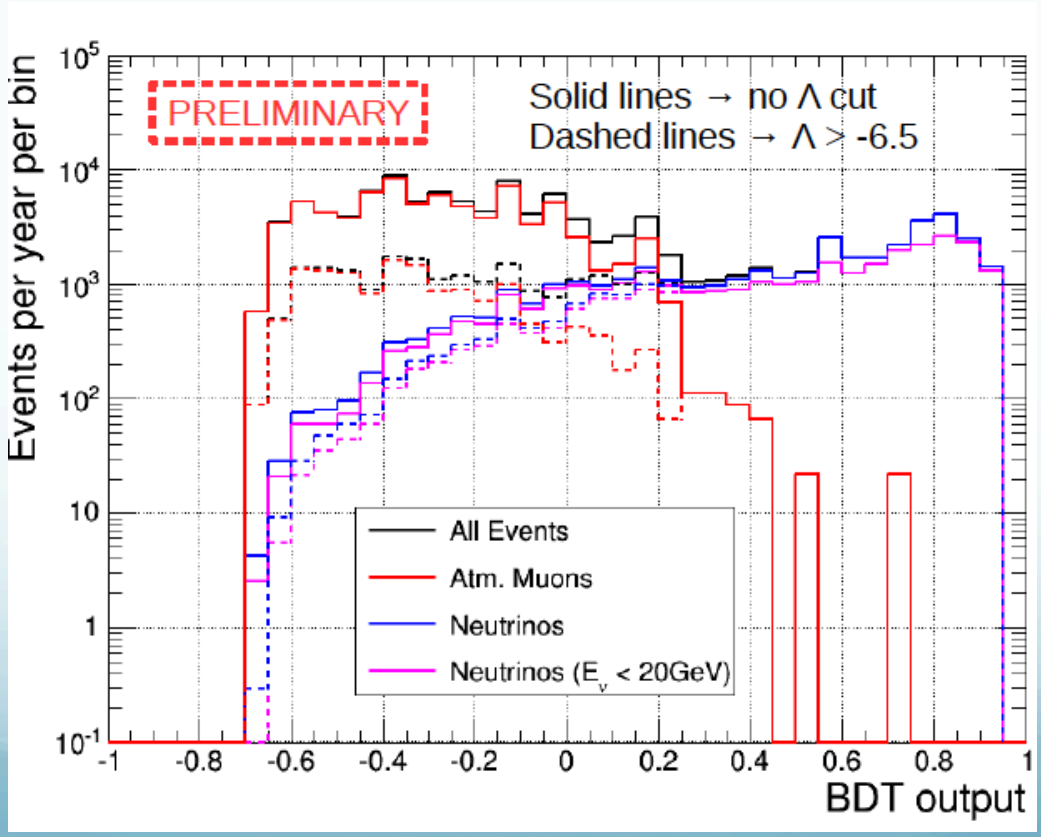
Veto hit based (topologic)

- Calculate topologic variables based on hits in fiducial volume and veto volume
  - Number of hits in veto region causally connected to fiducial hits
  - Number of hits in veto region around track candidate
  - Number of hits in top layers

Muon background rejection

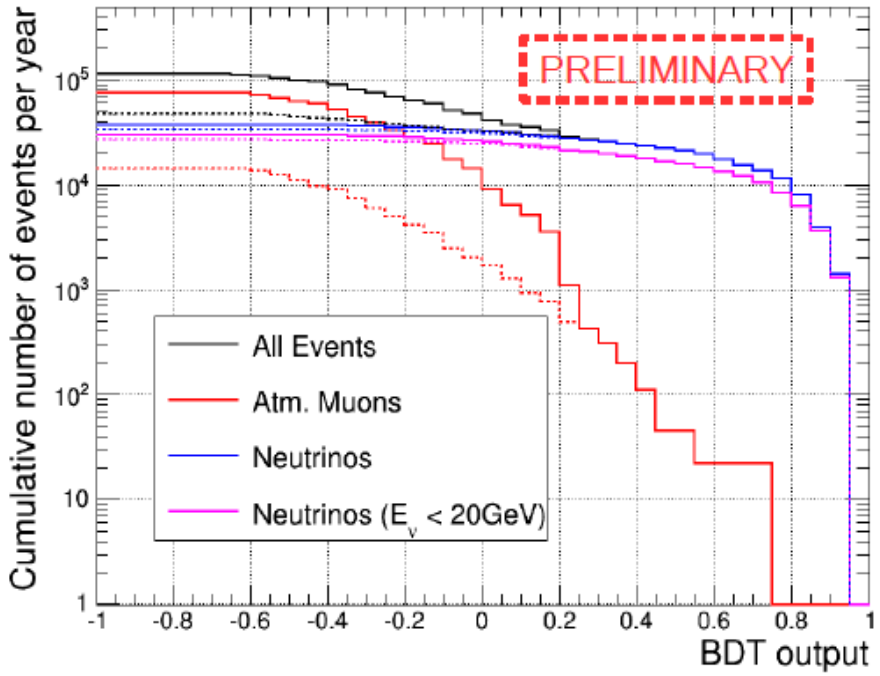
ORCA implementation

- Use a combination of reconstruction parameters
  - Events with reconstructed vertex inside the instrumented volume
  - Simply, again, Λ, β and R_v, as we yet know that they are effective
  - Can be improved with further studies/more complicated things

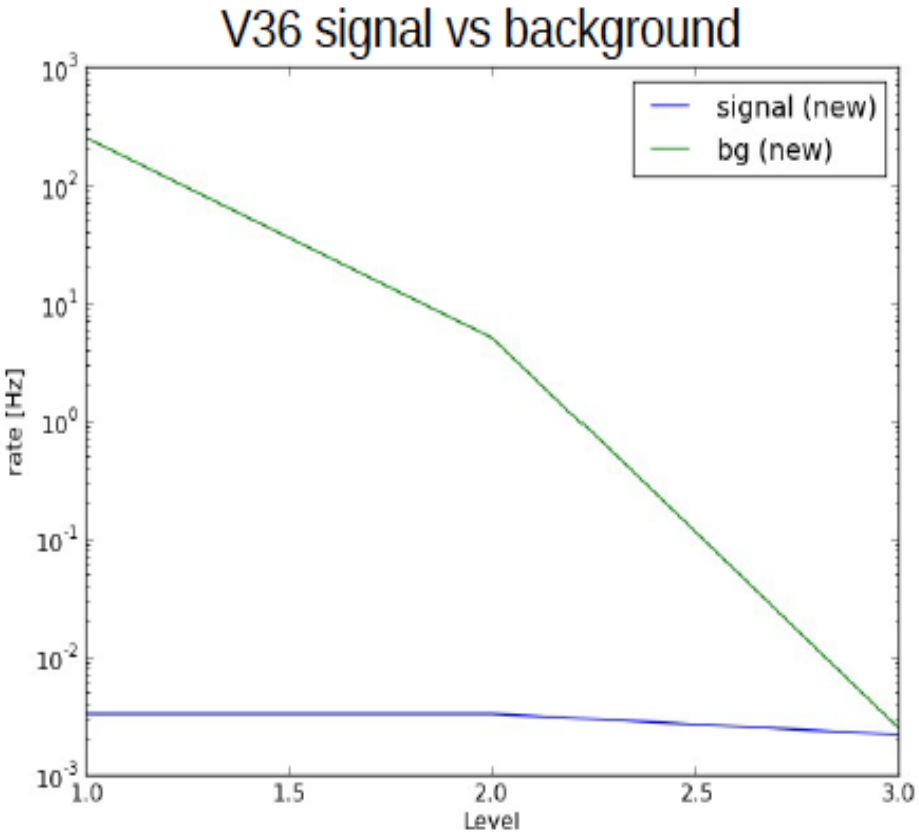


Muon background rejection

ORCA /PINGU



Solid lines → no Λ cut
Dashed lines → Λ > -6.5



10% contamination
for 90% efficiency (contained events)

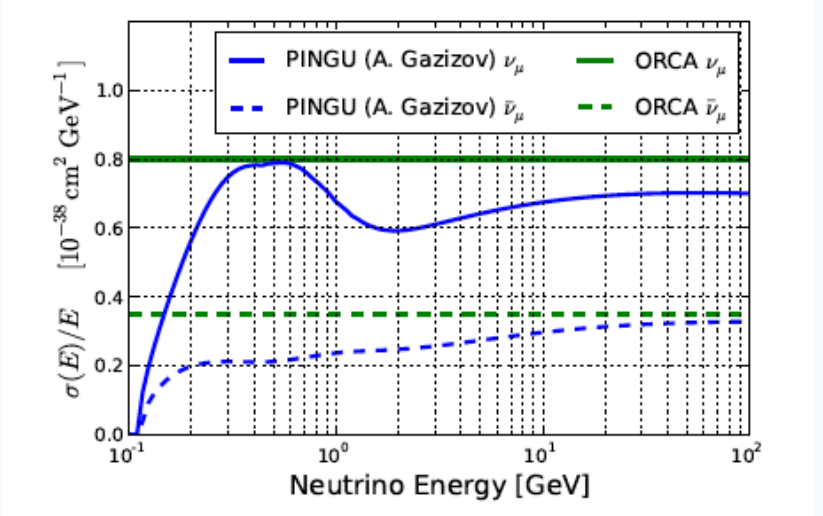
The presented cuts achive 70% signal efficiency @ 50% purity

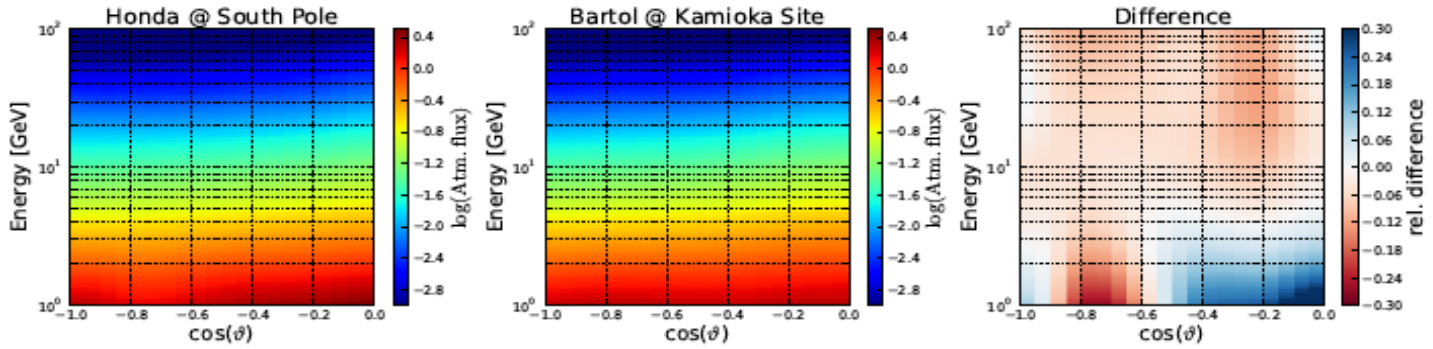
Encouraging...but should be pursued
Evaluate impact on sensitivity to NMH

Powerful cut-variables still not used: topological veto + reco LLH

Sensitivity studies

- Step 1: calculate expected number of events
  - Physics: atmospheric flux, oscillation, cross-sections etc.
  - Detector-specific: resolution, effective mass, particle ID etc.
  - More details on this later on in this presentation.





Comparison of the atmospheric neutrino fluxes used by either analysis. Shown is the **muon neutrino** *flux as a function of neutrino energy and zenith angle.*
Relative differences up to 30%.

Sensitivity studies

- Step 2: extract mass hierarchy significance
  - χ^2-significance
  - Fisher Information Matrix (PINGU main)
  - Pseudo-experiments and log likelihood-ratio (ORCA main, PINGU cross-check)

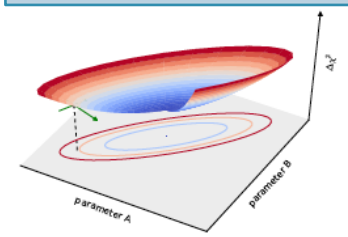
L. Schulte, M. Jongen
Sensitivity Study Comparison

Nice for debugging
But not for sensitivity

Fisher Information Matrix (FIM)

- Used in PINGU analysis
- Use 'fiducial' values (fixed true values)
- Evaluate bin-by-bin first-order derivatives of expected number of events
  $\Rightarrow$ probe small region around fiducial values
- Covariance matrix from derivatives
- Yields individual and combined uncertainties
- Requires that probed region is sufficiently linear
  - This was checked to be the case
- Quick and easy to add many parameters

PINGU LoI



Making a linear extrapolation in a multi-parameter space.

Sensitivity studies

ORCA Global Fit

- Used by PINGU to cross-check FIM results

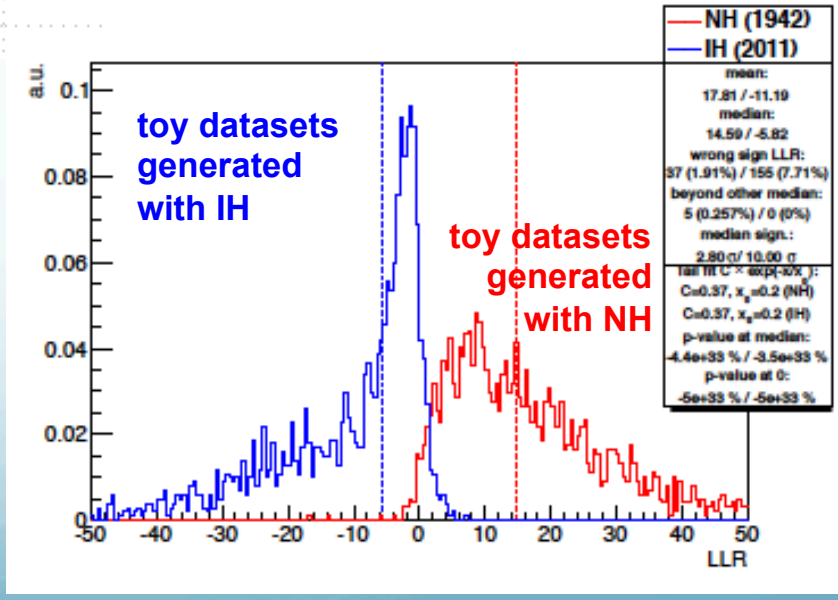
The performance of ORCA for the determination of the NMH is assessed by means of a likelihood ratio test:

$$\Delta \log(L^{\max}) = \sum_{\text{bins}} \log P(\text{data}|\hat{\theta}^{\text{NH}}, \text{NH}) - \log P(\text{data}|\hat{\theta}^{\text{IH}}, \text{IH})$$

$\hat{\theta}^{\text{H}} =$ maximum-likelihood estimates for the Δm^2's and angles using both data and constraints from global fit.
nb: constraints are different for H=IH and H=NH

1) fit mixing parameters assuming NH
2) fit mixing parameters assuming IH
3) compute ΔlogL = log(L(NH)/L(IH))

θ_{23} , Δm^2 and δ_{CP} can be fitted from data.

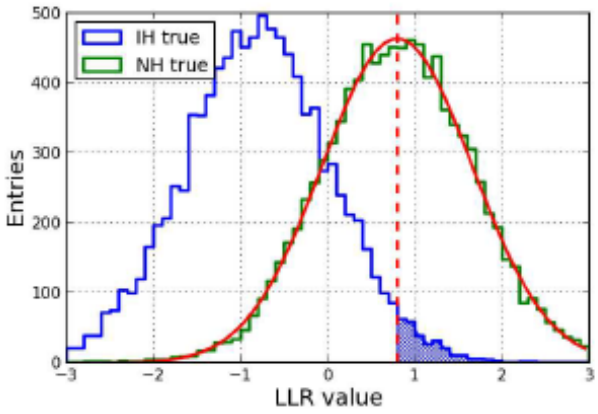


Sensitivity studies

Are the Fisher Matrix and LLR-Method Equivalent?

Toy study from PINGU

- Templates computed on 2D grid in θ_{23} and Δm^2_{31}.
- Other parameters kept fixed
- Pseudo-experiments drawn from one of the templates
- Minimization on grid for NH and IH hypothesis
- Median significance from Gaussian fit to LLR distribution
- Significance **equal to Fisher Matrix result**.
- Differences could still be possible in more complicated cases.



Log likelihood-ratio distributions for true NH and true IH pseudo-experiments.

Sensitivity studies

Are the Fisher Matrix and LLR-Method Equivalent?

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- Other parameters kept fixed
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- Significance **equal to Fisher Matrix result**.
- Differences could still be possible in more complicated cases.

Recent more extensive study by Tim Arlen (PINGU)

- Compares Fisher method and LLR-method
- Full minimization
- Five most important systematics: Δm^2_{31}, θ_{23}, θ_{13}, ν and $\bar{\nu}$ cross-section
- Sensitivity
  - 1.717σ (LLR)
  - 1.638σ (FIM)

  Compatible within expected statistical uncertainty (10% @ 2.1k trials)

Sensitivity studies

Intermediate step – Simple Toy Model

- Don't compare yet! Results are not the same when exchanging inputs.

Intermediate step

- Trying to get identical results for simple toy model
- Have converged up to few percent differences
- Getting similar values for hierarchy significance and measurement of δM^2 and θ_{23}.

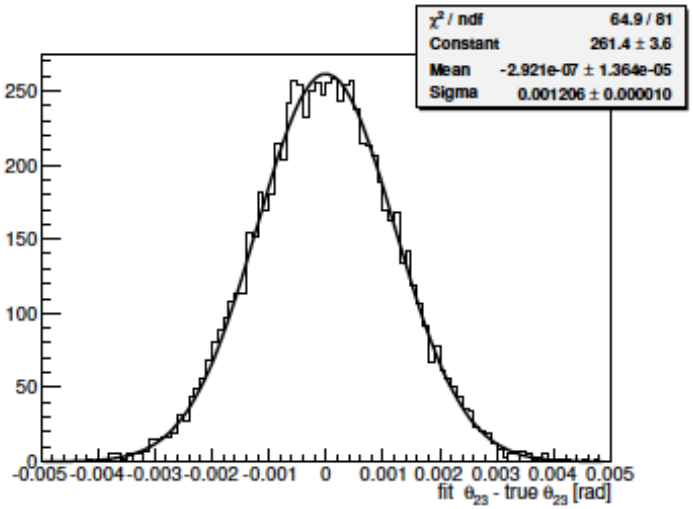
χ^2-significance from ORCA/PINGU code:
22.09/22.15 $\Rightarrow$ **0.27% difference**

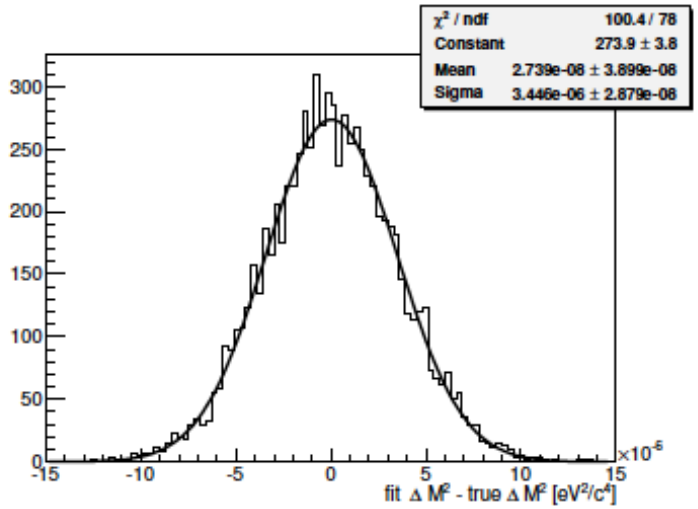
	No free pars.	θ_{23} free	ΔM^2 free	both free
LLR	22.50	19.11	17.76	13.971
FIM	22.15	19.61	17.44	14.21
difference	**1.6%**	**2.6%**	**1.8%**	**-1.7%**

Hierarchy significance in σ for the toy model. With current statistics, the estimated error on the LLR method is $\sim$2%.

Sensitivity studies

Intermediate step – Simple Toy Model

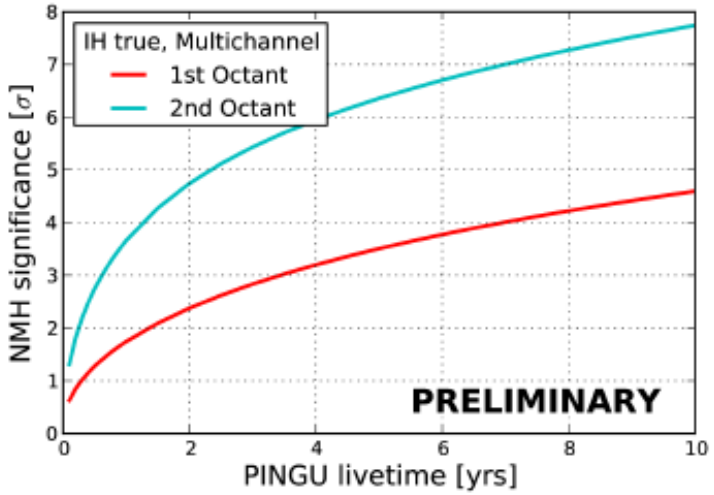




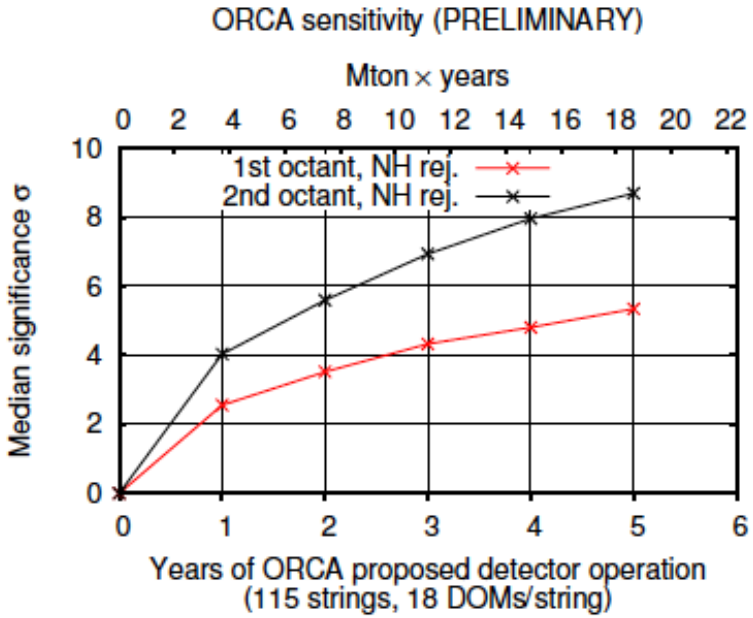
	fitting both	fitting only one parameter
$\sigma(\theta_{23})$ 10^{-2} deg	6.910/8.284 (**-17%**)	6.807/6.732 (**1.1%**)
$\sigma(\Delta M^2)$ 10^{-6} eV^2	3.446/4.765 (**-28%**)	3.403/3.208 (**6.1%**)

Uncertainty on parameters as fitted from data. Format:
*Martijn (LLR)/Lukas (FIM) (**relative difference**)*
The estimated error on the fitted values of the LLR method is ∼2%
The discrepancies are still to be resolved.

Current Sensitivities



PINGU official hierarchy significance plot for first and second octant (from LoI)



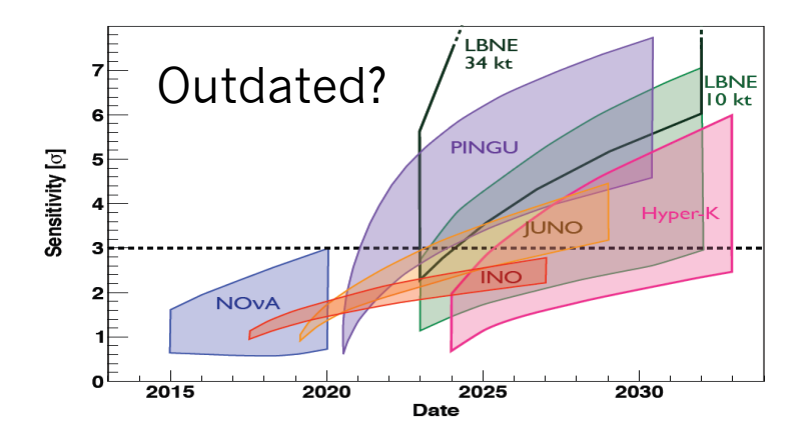
ORCA **preliminary** *plot for illustration purposes only.*

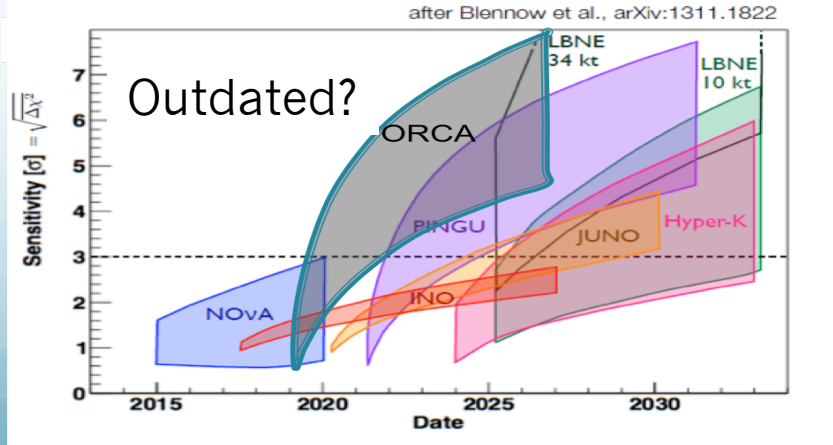
Lukas and Martijn : don't compare yet !

Conclusions

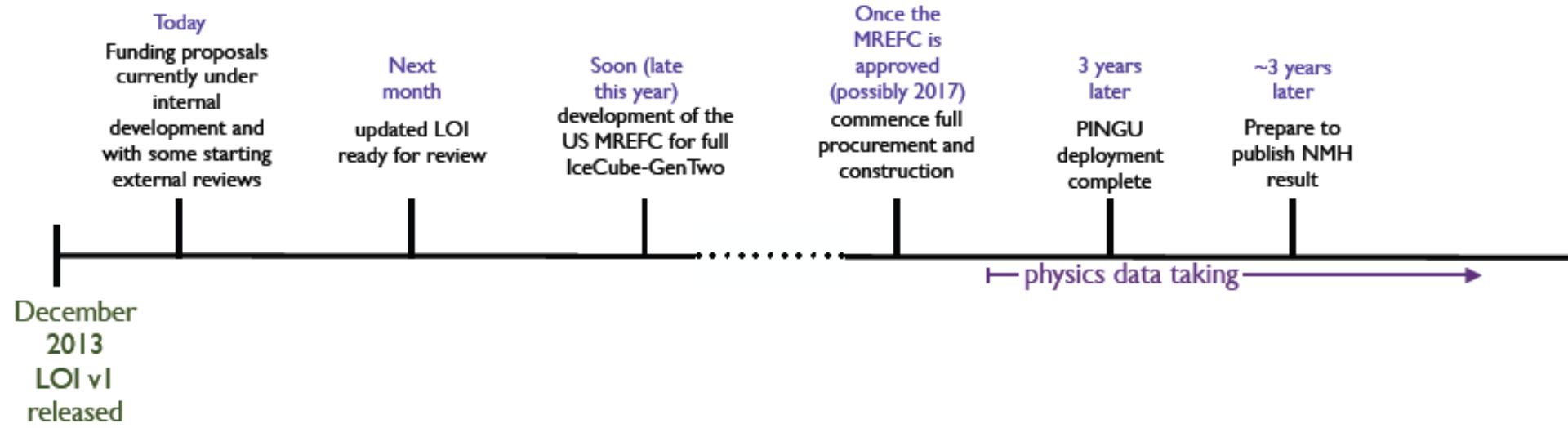
- Many progresses made since last MANTs meeting
  - Inclusion of cascade channel
  - Design Optimisation strategies in progress, but need some more work for ORCA
  - Fruitful exchanges – more to come, e.g:
    - Hybrid reco used in IC → try in ORCA (need to seat together)
    - List of systematics to address

- Message from Lukas and Martijn:
  - Don't compare PINGU and ORCA sensitivity.
  - No reason to withdraw any of the current official plots (should be accompanied with proper list of caveats – NC, sys,... at least for ORCA)
  - But the external people will do the comparison





PINGU plans



- PINGU continues to advance at a rapid pace; done with geometry optimization
- We are continuing to work on responses received from P5; this involves evaluating the remaining important (but time consuming) systematics
- newly incorporated systematics have not significantly diminished the PINGU sensitivity
- We are addressing the remaining questions of detector performance in the calibrations and analysis technique developments
- Our timeline (similar to ORCA/JUNO/RENO50…) remains aggressive but realistic; driven now by funding agency responses

ORCA plans

- ORCA is becoming an integral part of the KM3NeT physics program and planning

- Cost optimisation by
  - Phased construction
  - Complete share of technological solutions between Neutrino telescope and ORCA
  - Solutions based on published TDR of KM3NeT

Phase	Total costs [M€]	Planned Installations	Status
a	Funds Phase 1	6-10 ORCA lines, proof of - Deployment of dense detector - Detection of low energy ν	Being discussed within KM3NeT
b	40	1 building block, parallel to HE Phase 1.5, funds permitting	Feasibility study
c	?	Beam from Protvino Extensions for CP-phase sensibility	Feasibility study

Multi-Site concept allows for parallel construction of ORCA & HE phase 1.5 detector, one candidate site for ORCA : Toulon