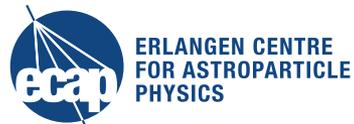


Neutrino studies in the Mediterranean: the KM3NeT/ARCA neutrino telescope

Clancy W. James, for the KM3NeT Collaboration

13th International Symposium on Cosmology & Astroparticle Physics (CosPA 2016),
Nov 2016, Sydney, Australia



Multimessenger paradigm

- Cosmic ray interactions:

$$\left. \begin{array}{l} p_{CR} + p \\ p_{CR} + \gamma \end{array} \right\} p_{CR} / n + \pi^{\pm}, \pi^0$$

- Secondaries: only neutrinos provide unambiguous signal

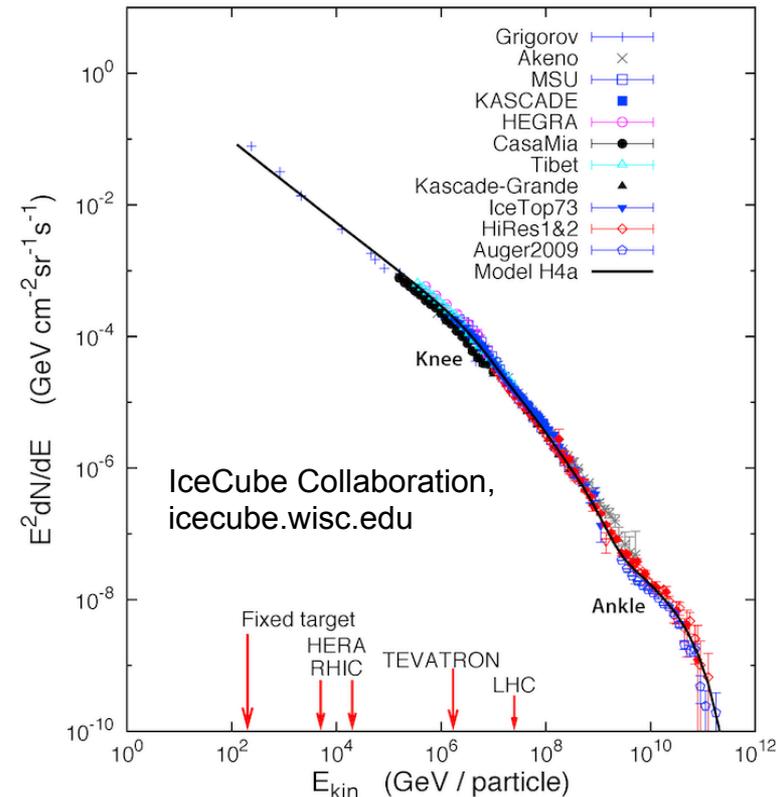
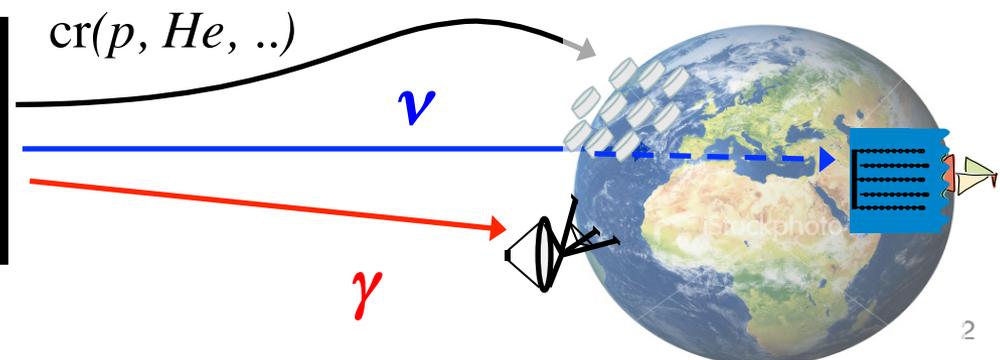
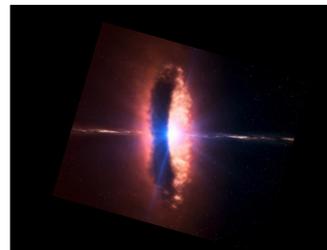
$$\pi^+ \rightarrow \mu^+ + \nu_{\mu}$$

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_{\mu}$$

$$n \rightarrow p_{CR} + e^- + \bar{\nu}_e$$

$$\pi^0 \rightarrow 2\gamma$$

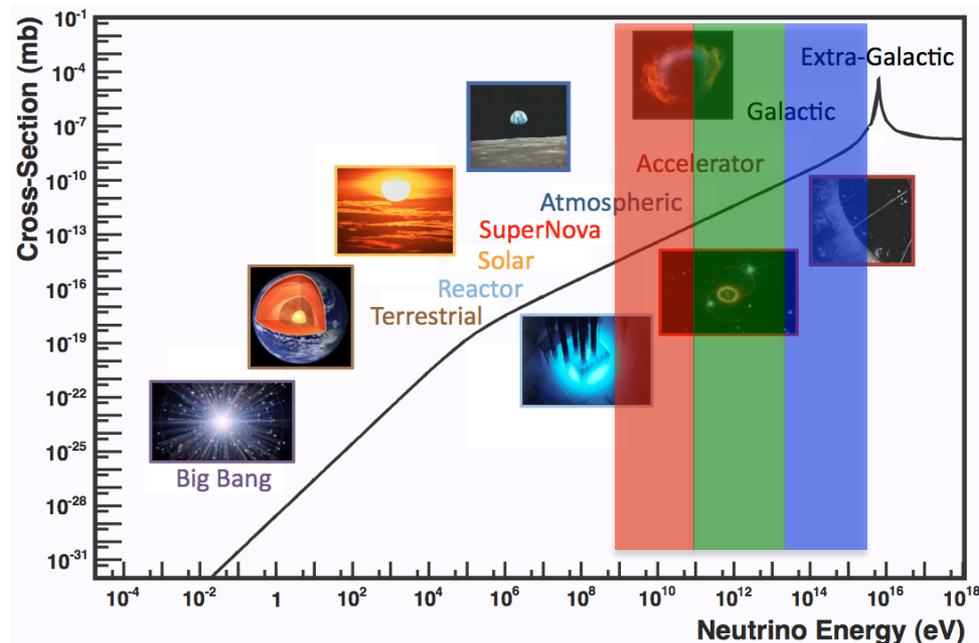
$$e^- \rightarrow \gamma_{synch}, \gamma_{IC, bremms}$$



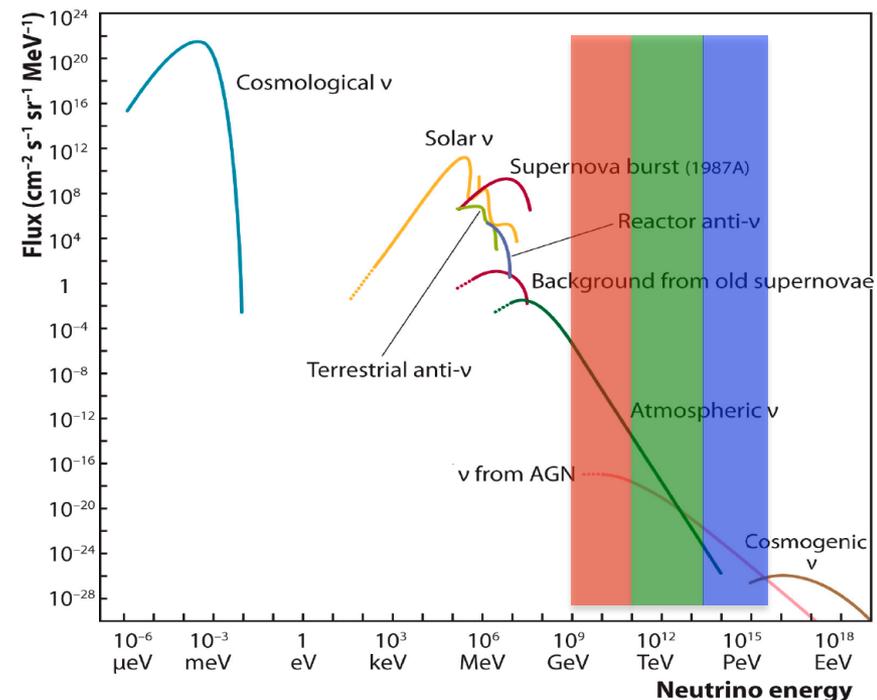
Neutrinos from cosmic rays

KM3NeT
component:

- **1 – 100 GeV**: neutrino mass hierarchy w. atmospheric flux ORCA
- **100 GeV - 30 TeV**: various galactic (TeV gamma) sources ARCA
- **30 TeV – 3 PeV**: IceCube signal (astrophysical flux) ARCA



Formaggio & Zeller, RevModPhys 84 (2012) 1307



Courtesy icecube.wisc.edu

The 'track' channel

$$\nu_{\mu} \xrightarrow{CC} \mu + \text{shower}$$

$$\nu_{\ell} \xrightarrow{NC} \nu'_{\ell} + \text{shower}$$

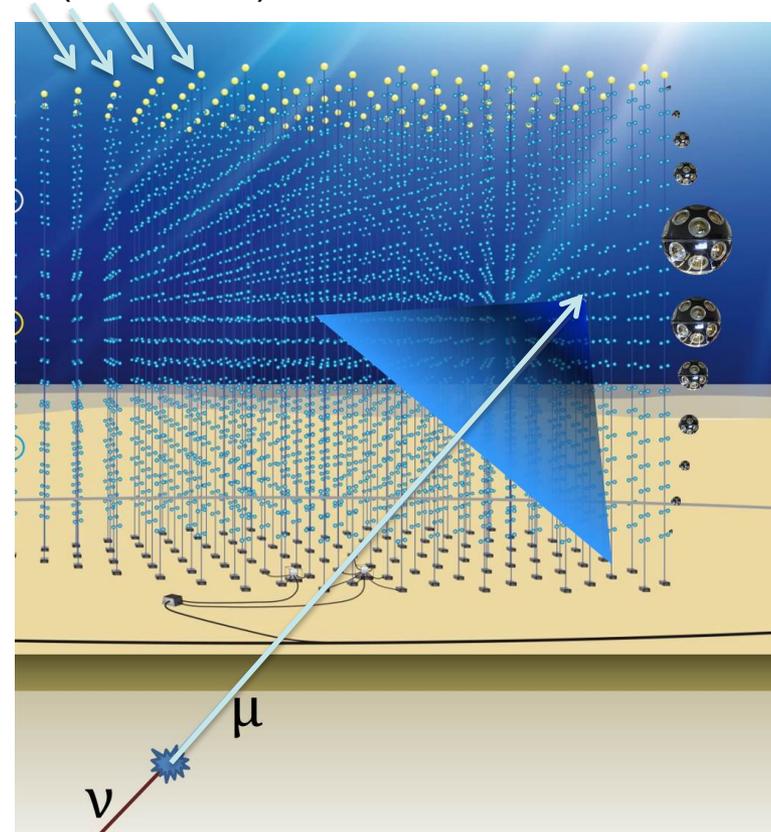
$$\nu_e \xrightarrow{CC} \text{shower}$$

$$\nu_{\tau} \xrightarrow{CC} \tau + \text{shower}$$

$$\tau \xrightarrow{\sim 83\%} \nu_{\tau} + \text{shower}$$

$$\tau \xrightarrow{\sim 17\%} \nu_{\tau} + \mu + \bar{\nu}_{\mu}$$

μ (from EAS)



- Mostly sensitive to muon neutrinos only
- Highest effective area, good angular resolution
- High atmospheric muon background: look at events from below only

Detection principles: shower-like events

$$\nu_{\mu} \xrightarrow{CC} \mu + \text{shower}$$

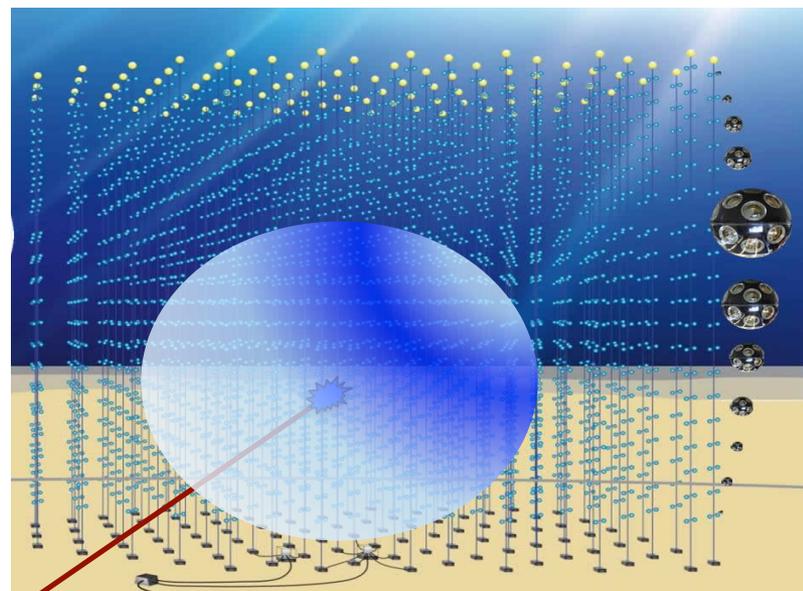
$$\nu_{\ell} \xrightarrow{NC} \nu'_{\ell} + \text{shower}$$

$$\nu_e \xrightarrow{CC} \text{shower}$$

$$\nu_{\tau} \xrightarrow{CC} \tau + \text{shower}$$

$$\tau \xrightarrow{\sim 83\%} \nu_{\tau} + \text{shower}$$

$$\tau \xrightarrow{\sim 17\%} \nu_{\tau} + \mu + \bar{\nu}_{\mu}$$



ν

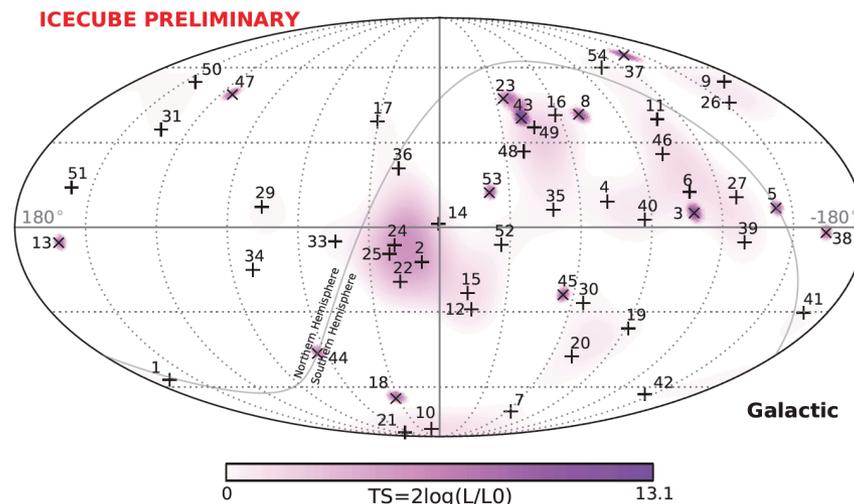
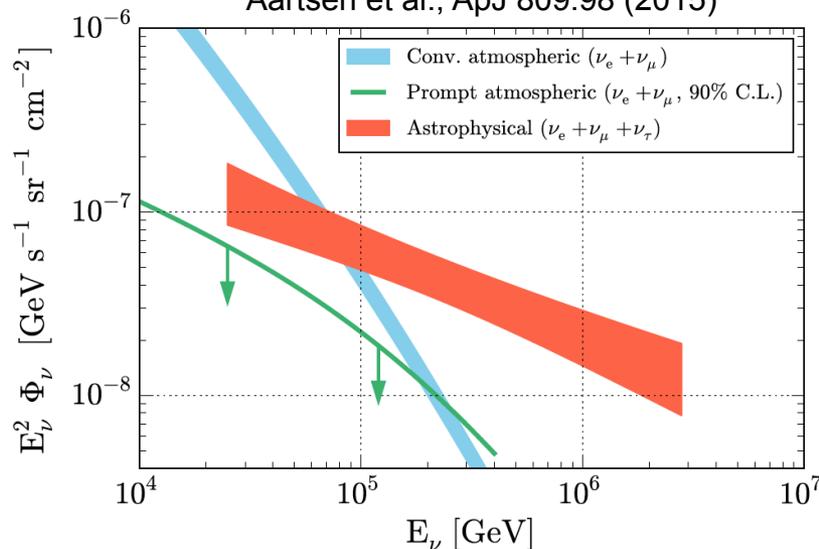
- Most sensitive to electron neutrinos
- Clean neutrino signature: studies over 4π
- ‘Good’ energy resolution, worse directional resolution: diffuse flux!

IceCube astrophysical neutrino flux

(more next talk by Jenni Adams!)

- Brief overview
 - Discovered using ‘starting events’
 - Seen from ~ 30 TeV-3 PeV
 - Detected in the muon channel
 - Tension in North/South fluxes
 - No source identified!

Aartsen et al., ApJ 809:98 (2015)

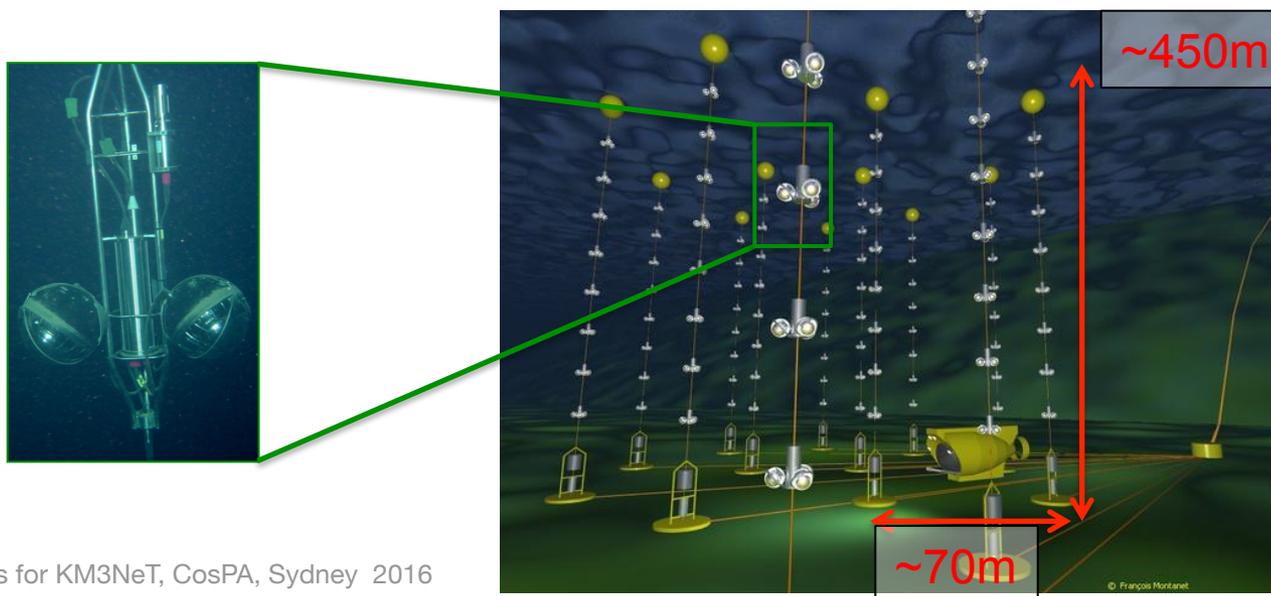
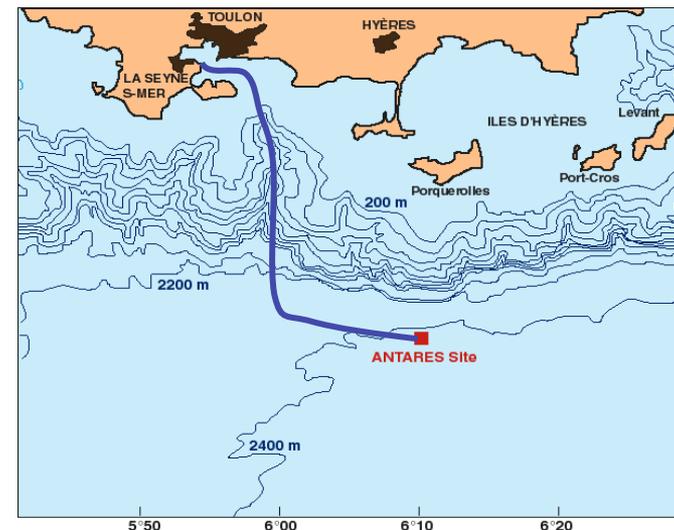


arXiv:1510.05223v2

- Questions:
 - What are the sources?
 - Galactic vs extragalactic?
 - Is there a spectral break?
 - Flavour composition?
 - All constrained, but weakly

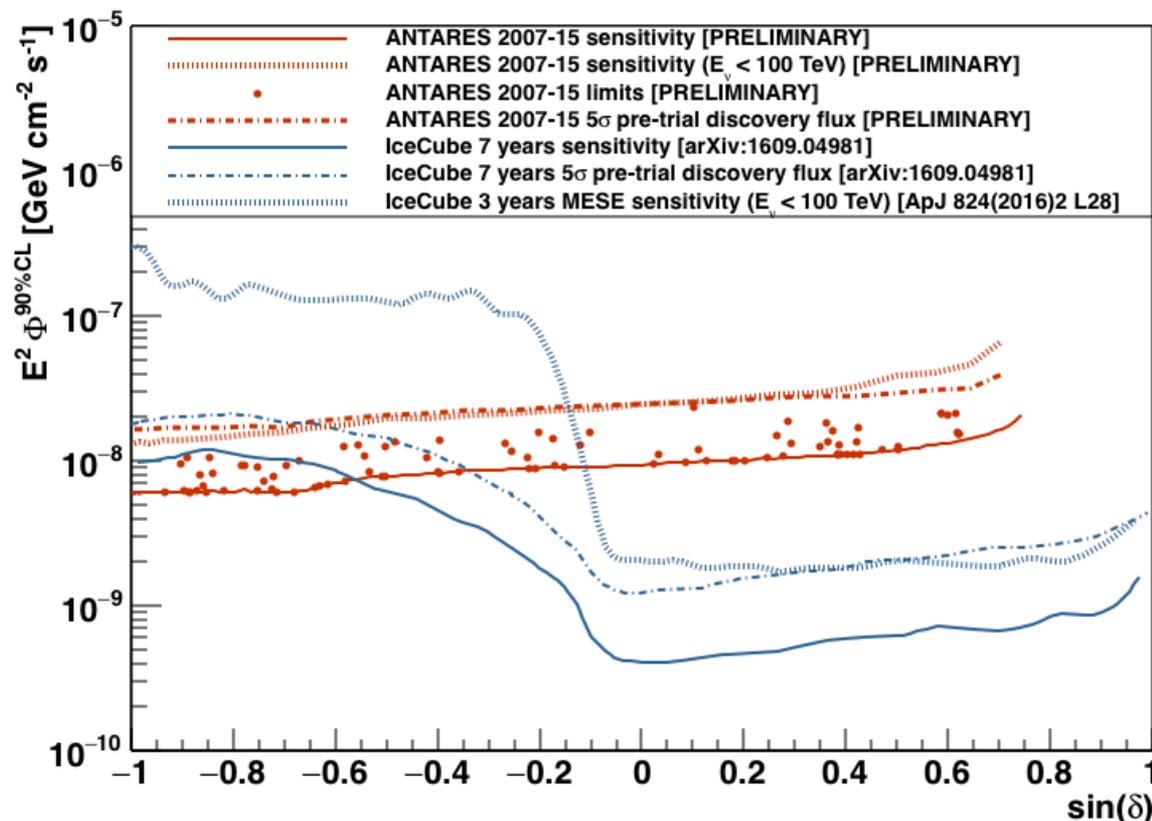
The ANTARES neutrino telescope

- Located off Southern French Coast
 - Completed 2008
 - 12 lines, 60-70m spacing
 - 25 storeys per line
 - 3 x 10-inch PMTs per storey
 - $O \sim 0.02 \text{ km}^3$



Results – point-source limits

- E^{-2} point sources
 - **ANTARES**
 - IceCube



- ANTARES: combined track (0.3-0.4°) and cascade analysis (3°)
- Limits origin of IceCube flux at southern declinations

What to do next?

- In Antarctica: Build IceCube Gen2 (more next talk)
 - 5-10 x current IceCube detector
 - Sparser layout: large number of HE events
 - Current design stage – white paper in preparation
- In Mediterranean: Build KM3NeT
 - IceCube-scale detector
 - Improved angular resolution of seawater: neutrino astronomy
 - Similar event rate, higher precision
 - View of the southern hemisphere: target Galactic accelerators



KM3NeT: an undersea research infrastructure

KM3NeT: digital optical module

- Optical module:
 - 31 x 3" PMTs
 - 4π sr coverage
 - directional resolution
 - dynamic range
- Launcher vehicle:
 - rapid deployment
 - autonomous unfurling
 - recoverable



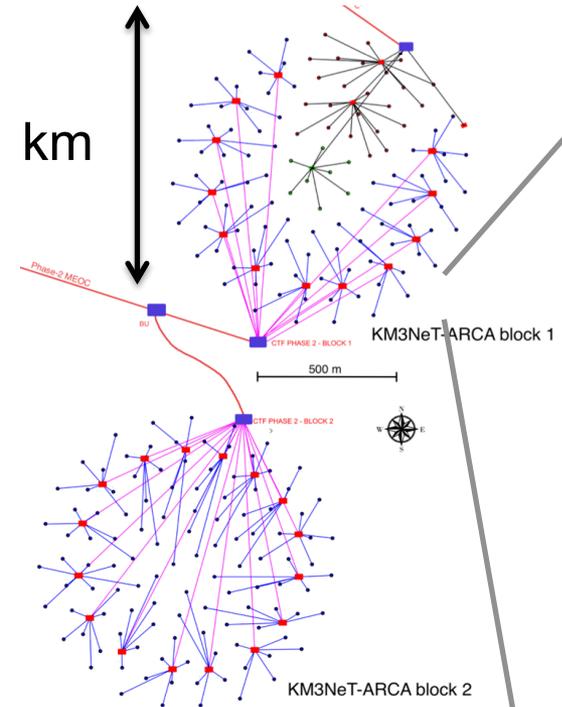
← 17" →



ARCA: TeV-PeV

- ARCA: 2 blocks:
 - 115 'detection units' per block
 - 90m horizontal spacing
- Detection unit:
 - Line anchored to the sea floor
 - 18 optical modules
 - 36m spacing
- Total volume: 1.2 km³
 - Site: 3.5 km depth
 - Shore station:
Capo Passero
(Sicily)

~1 km



612 m

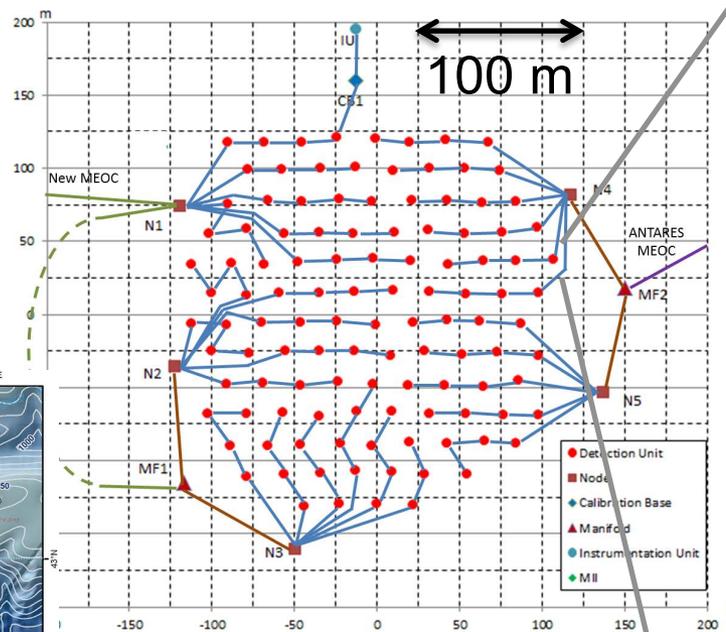
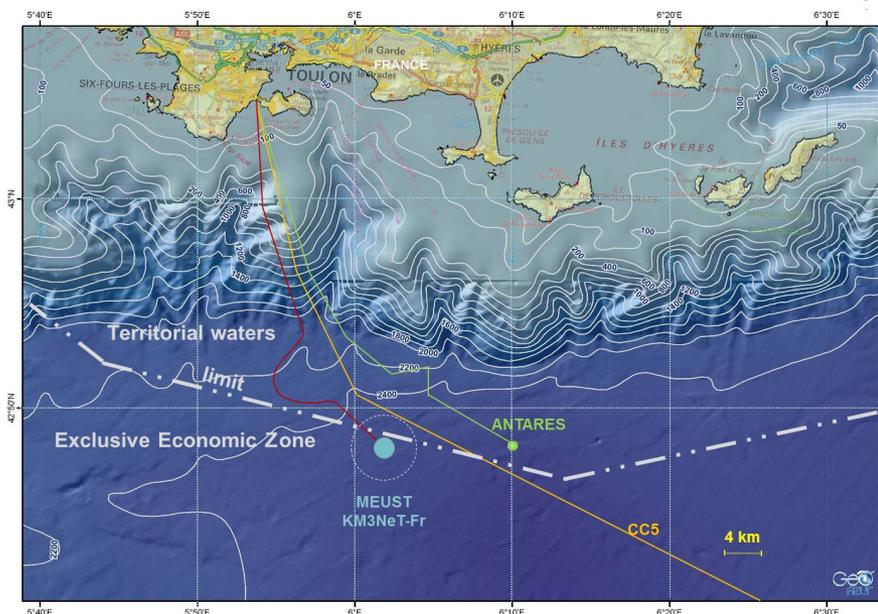


3.5 km
under
da sea!!



ORCA: 3-100 GeV *Antoine Kouchner (Monday)*

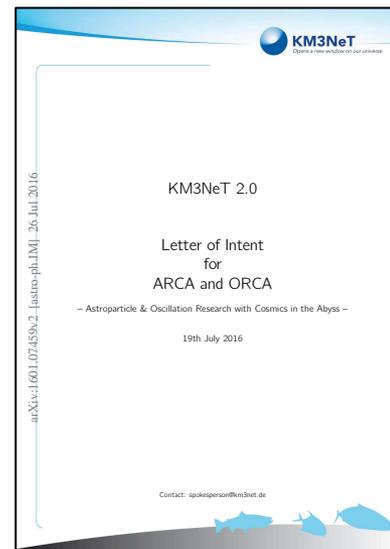
- 1 ORCA block:
 - 115 lines
 - 20 m horizontal spacing
 - 9 m vertical DOM spacing



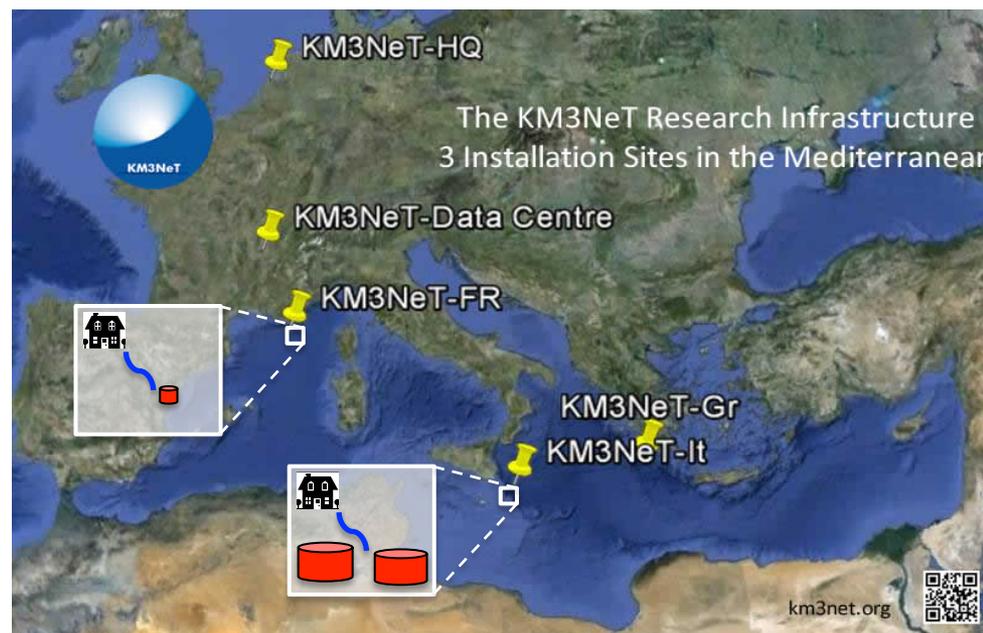
150 m

KM3NeT 2.0: ARCA & ORCA

- Letter of Intent for KM3NeT 2.0:
 - *J. Phys. G*, **43** (2016) 084001
 - <https://arxiv.org/abs/1601.07459>
- KM3NeT 2.0: ESFRI roadmap



C.W. James for KM3NeT, CosPA, Sydney 2016





Amsterdam
Delft
Groningen
Leiden
Texel
Utrecht

Dublin

Sheffield

Münster

Bamberg
Erlangen
Tübingen
Würzburg

Warsaw

Moscow

Paris

Muhlhouse
Strasbourg

Bucharest

Genova
Bologna

Marseille

Barcelona

Valencia

Granada

Pisa

Rome

Naples

Bari

Thessaloniki

Athens

Patras

Catania

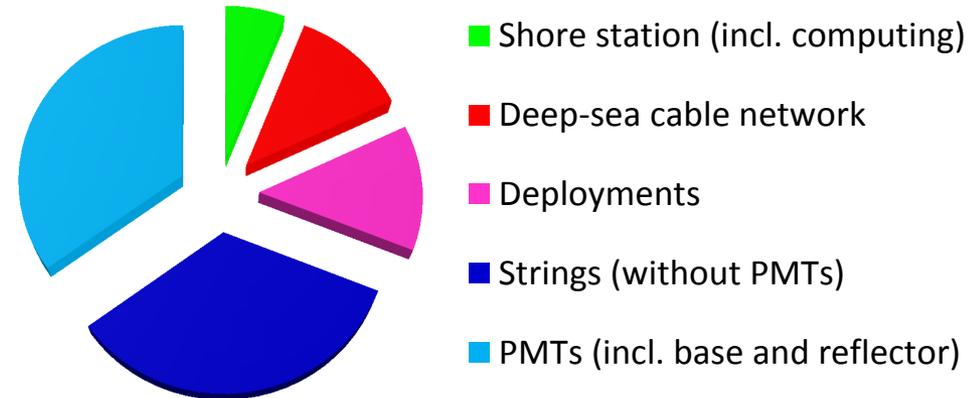
Nicosia

Rabat

Oujda

Cost breakdown

- Phase 1: funded!
- Phase 2: ESFRI roadmap
- Phase 3: neutrino astronomy



Phase	Total costs (cumulative) M€	Building blocks	Start	Primary deliverables
1	31	0.2	2013	Proof of feasibility and first science results.
2.0	125	2 1	2017	Study of the neutrino signal reported by IceCube; Determination of the neutrino mass hierarchy.
3	220–250	6	2025	Neutrino astronomy including Galactic sources.

KM3NeT Phase 1 (2013-2017)

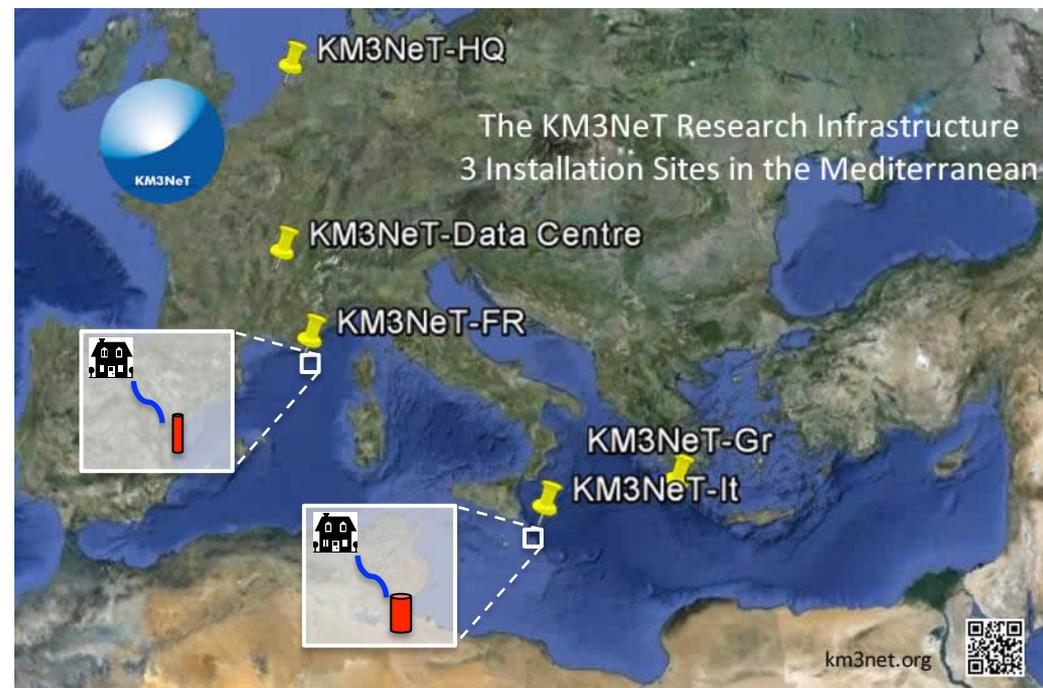
- 24 ARCA lines at KM3NeT-It (Capo Passero)
- 7 ORCA lines at KM3NeT-Fr (Toulon)
- Status:

- Funded!
- Construction begun

- Goals:

- Proof of technology
- Prototype module
EPJC (2014) 74:3056
- 3-DOM test line:
EPJC (2016) 76:54
- 3 Lines deployed: 1
recovered for testing

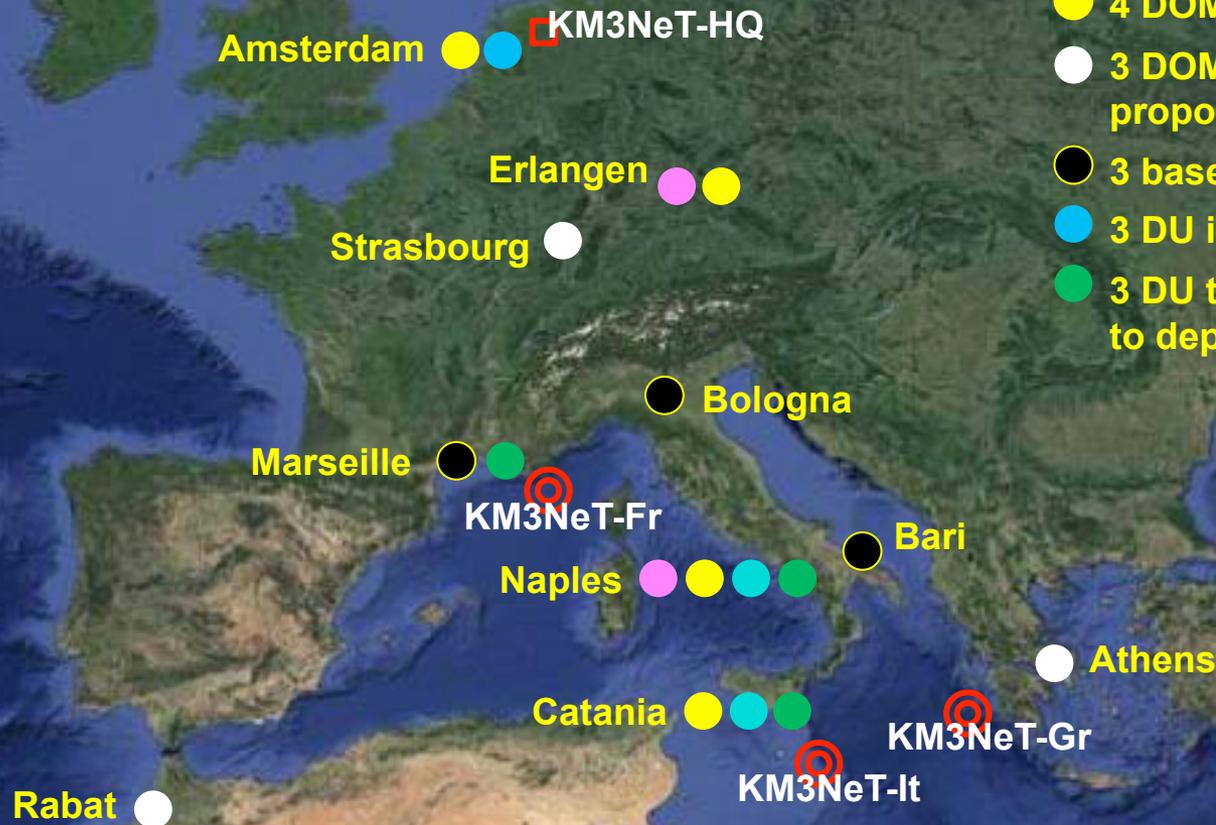
ARCA Phase 1: largest neutrino telescope in the Northern Hemisphere





KM3NeT Phase-1 Infrastructure (March 2016):

- 3 Installation sites
- 2 PMT preparation sites
- 4 DOM integration sites
- 3 DOM integration sites proposed/planned
- 3 base module integration sites
- 3 DU integration sites
- 3 DU test and preparation to deployment sites



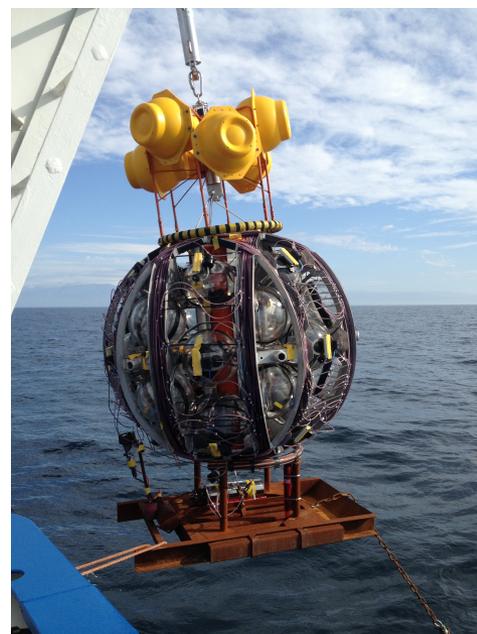
I'm on
a boat!

Deployment

- Sea-level deployment
- Remote unfurling (acoustic signal)
- ROV connection to underwater cable

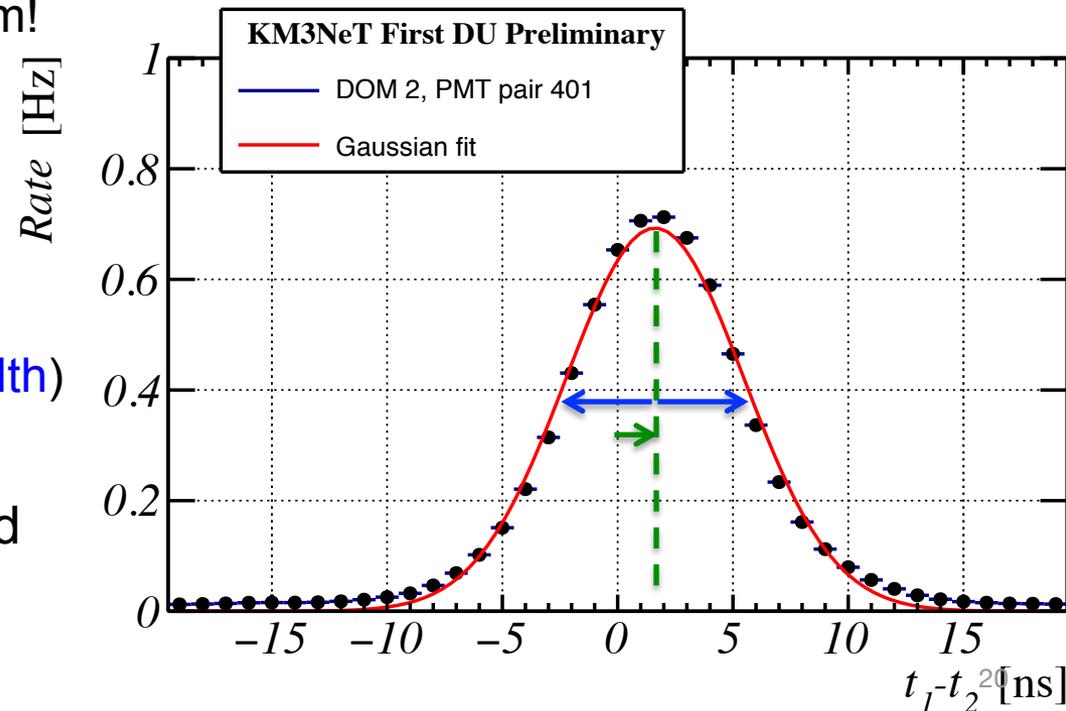
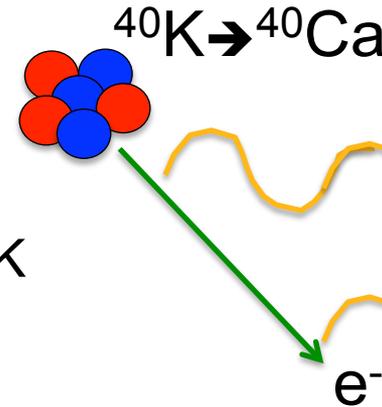


- Deployment test (2013):
- <https://youtu.be/7HKHW0hLxt4?t=44s>



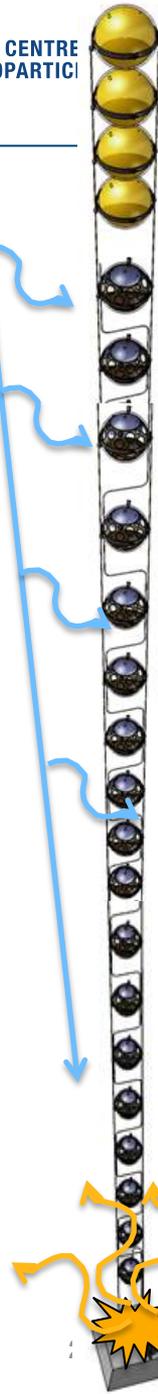
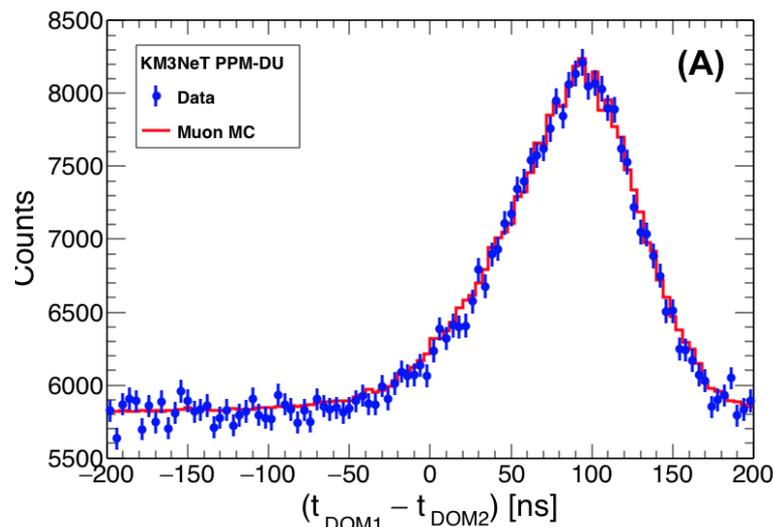
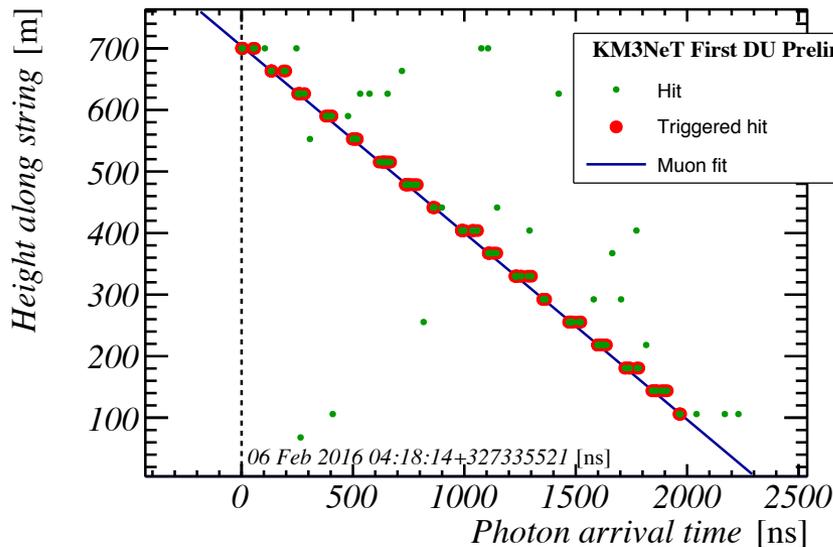
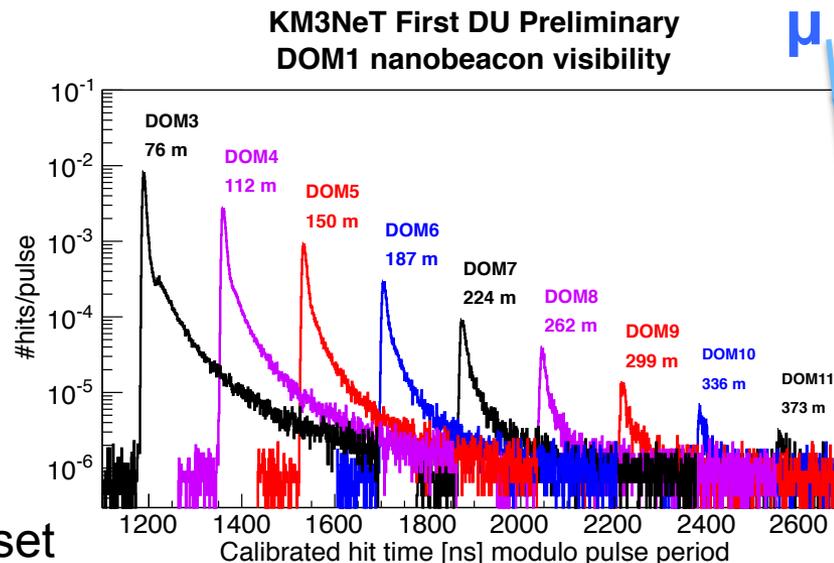
Self-calibration: ^{40}K

- Natural radioactive decays from ^{40}K
 - Cherenkov light
 - ~ 5 kHz rate in PMTs
 - Filtered by CPUs at on-shore DAQ
 - Self-calibration mechanism!
- Calibration tells us:
 - Time offset (**centre**)
 - Efficiency (**area**)
 - Single-photon spread (**width**)
- Long-term stability observed



Further calibration

- **Nanobeacons:**
 - Flashers at line base
 - Scattering, absorption, time
- **Muon calibration:**
 - $v=c \Rightarrow$ most precise time offset

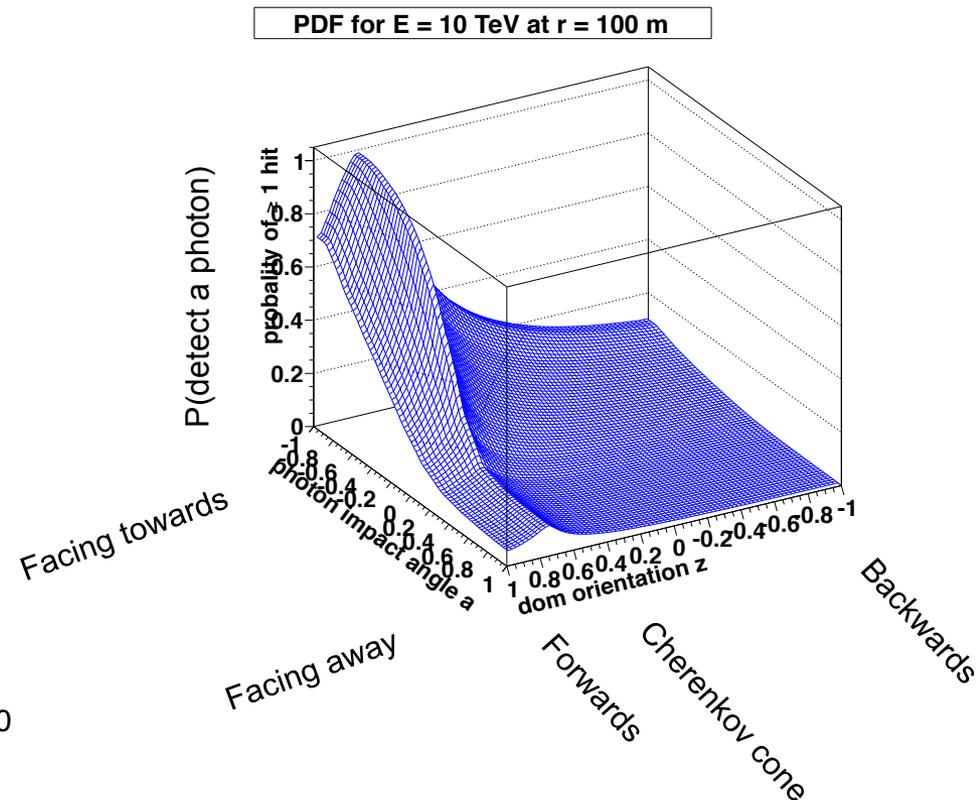
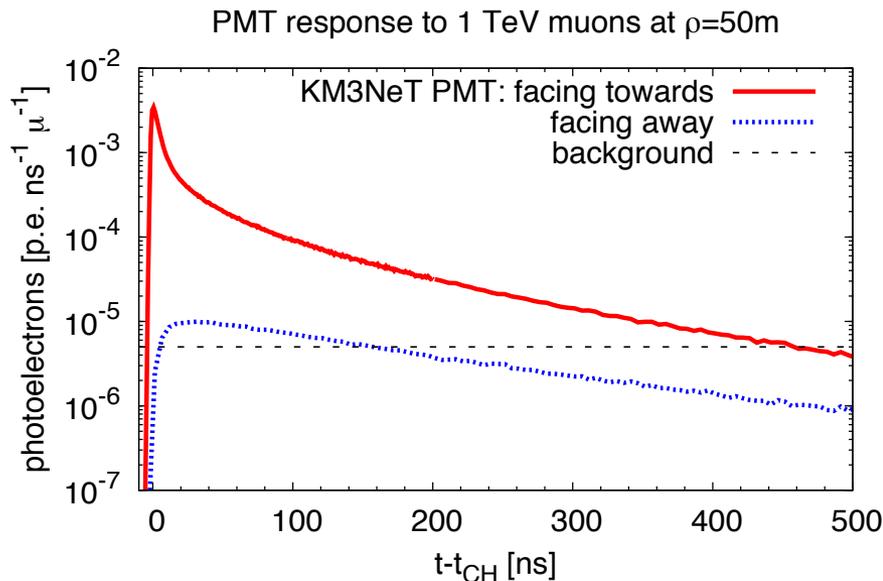


The top of the slide features a dark blue header with a pattern of small, light blue decorative elements on the left and a large, semi-transparent ARCA logo on the right. The logo consists of the letters 'ARCA' in a bold, sans-serif font, with a stylized circular graphic behind it.

ARCA: Event reconstruction performance

DOM response ↔ reconstruction accuracy

- Multi-PMT DOM: uniform coverage, high dynamic range
- Low scattering in water:
 - Most photons w/in 10 ns
 - Excellent event topology



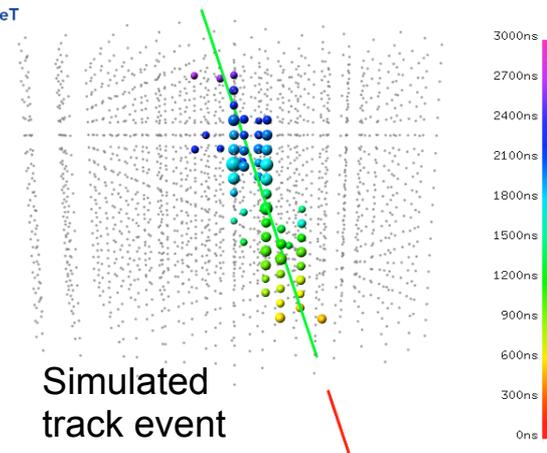
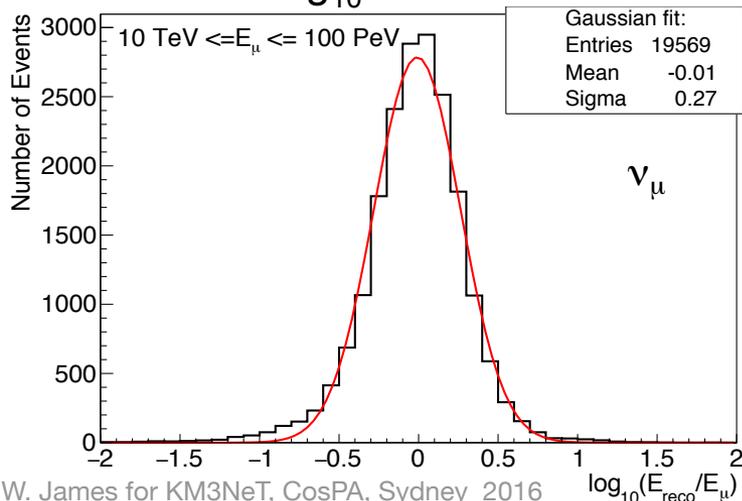
Track channel: direction reconstruction

- Step 1: use timing for position/direction

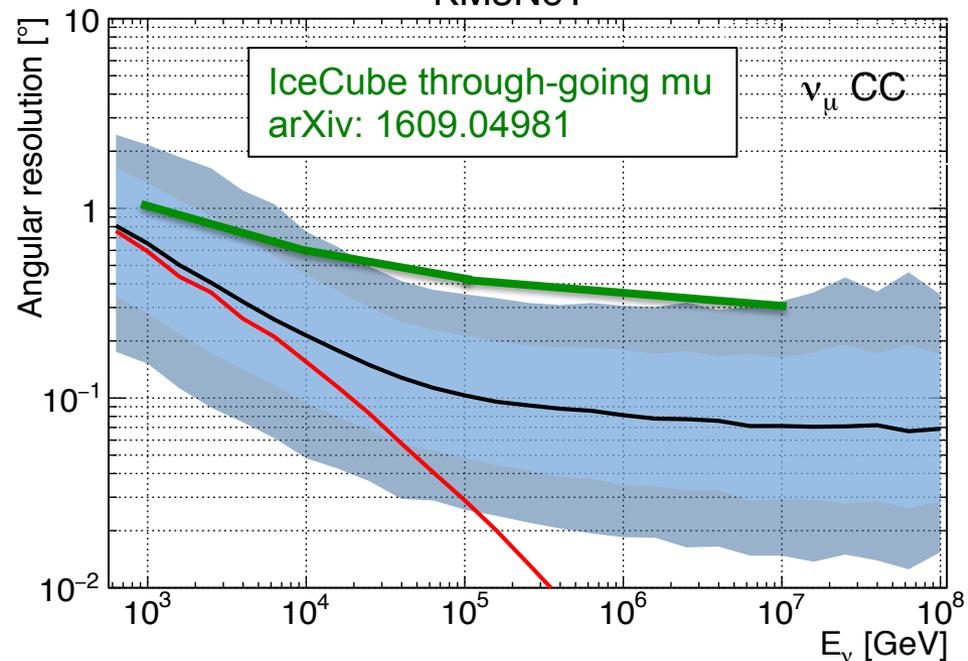
- Limit from interaction kinematics
- Median, 68%, 90% quantiles
- 0.1° at 100 TeV (~astro flux)
- 0.2° at 10 TeV (~Galactic)

- Step 2: fit hits to determine energy

- 0.27 in $\log_{10} E$

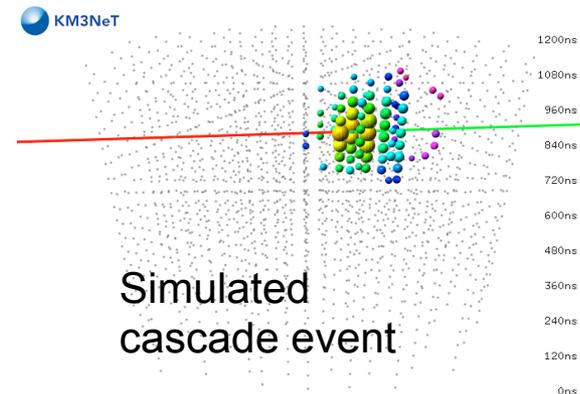


KM3NeT

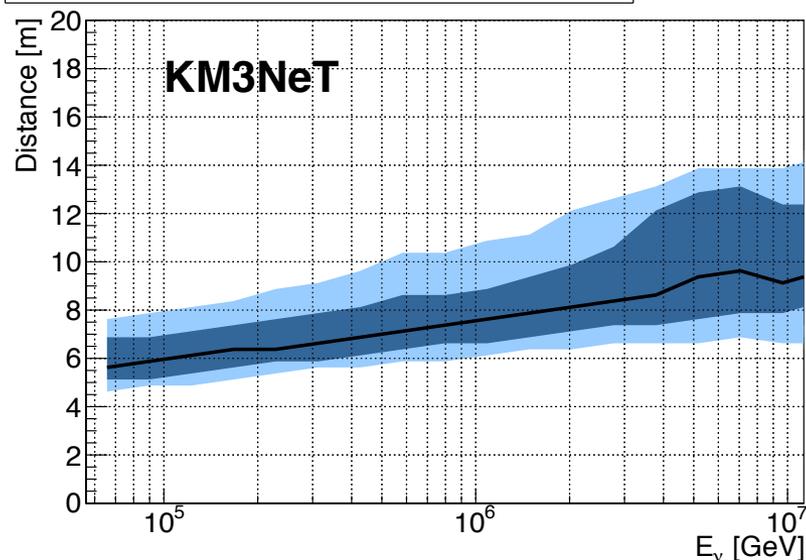


Resolutions on cascades

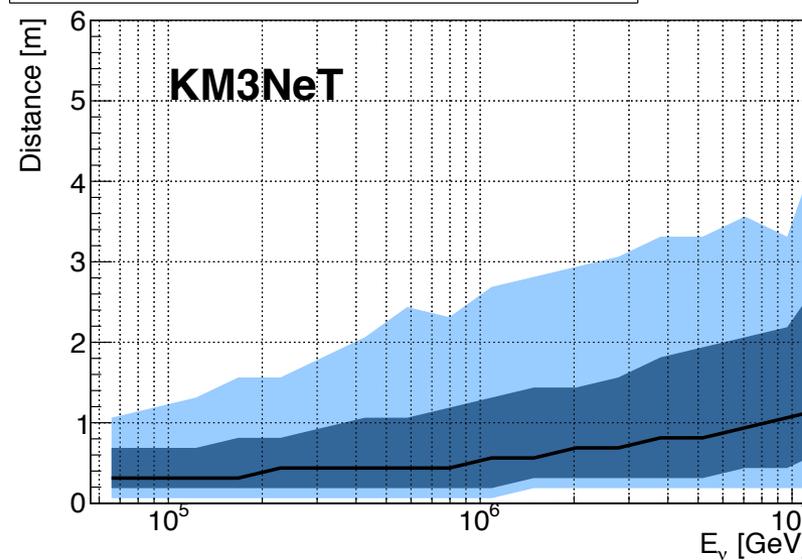
- Step 1: fit a point-like origin!
 - Resolution on neutrino interaction vertex:



Distance to interaction along the shower axis vs E_ν



Distance to interaction perpendicular to the shower axis vs E_ν

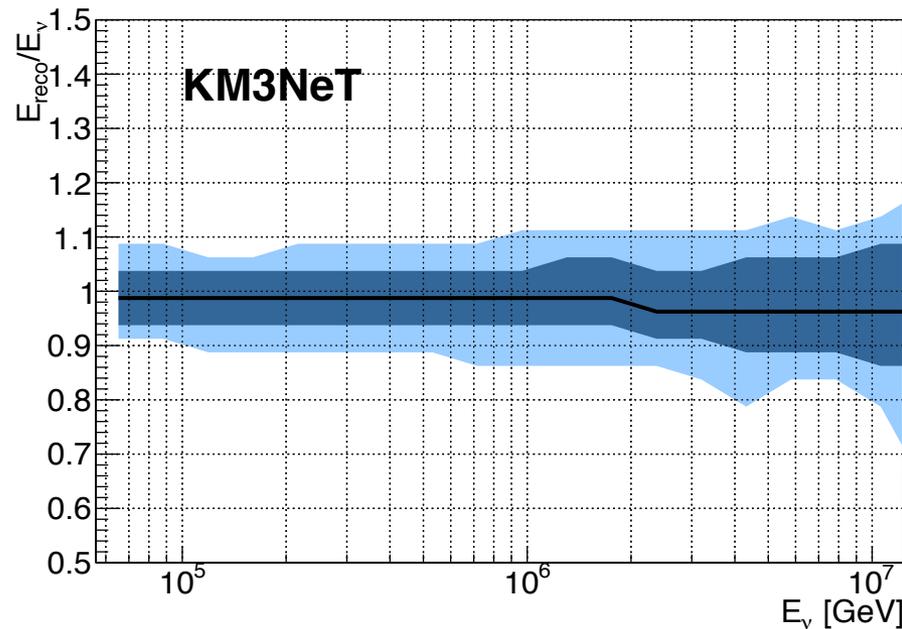


- Vertex resolution limited by shape of cascade

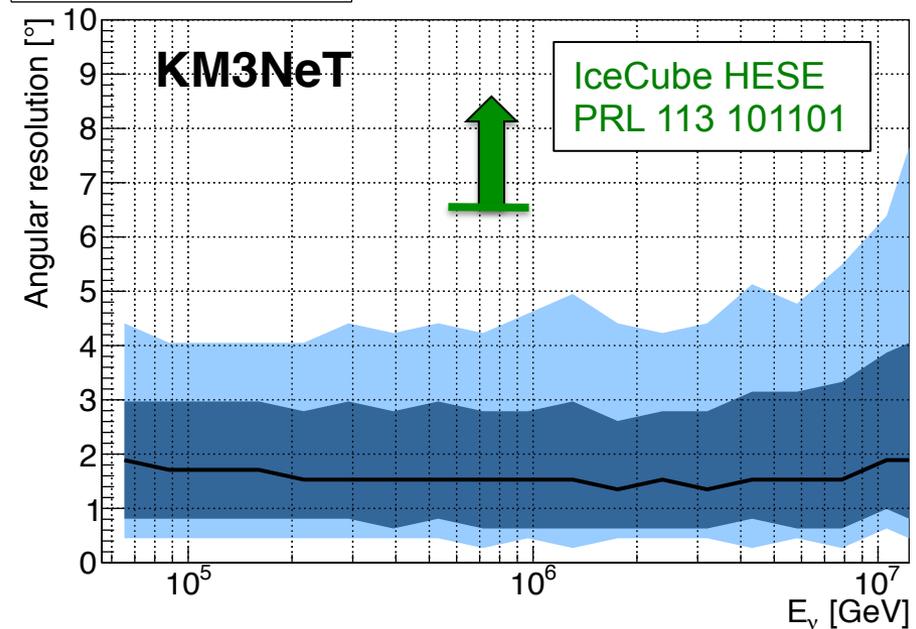
Resolutions on cascades

- Step 2: fit for direction/energy:
 - 1.5 degree resolution on cascade events (insensitive to systematics)
 - 5% energy reconstruction error (sensitive to systematics)

E_{reco}/E_{ν} vs E_{ν}



Ang. resolution vs E_{ν}

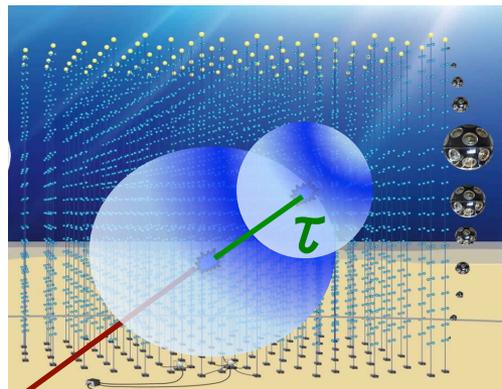


PRELIMINARY

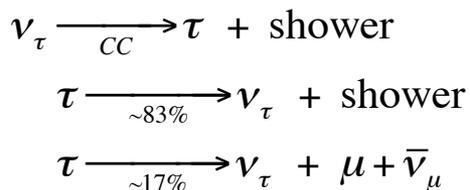


ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS

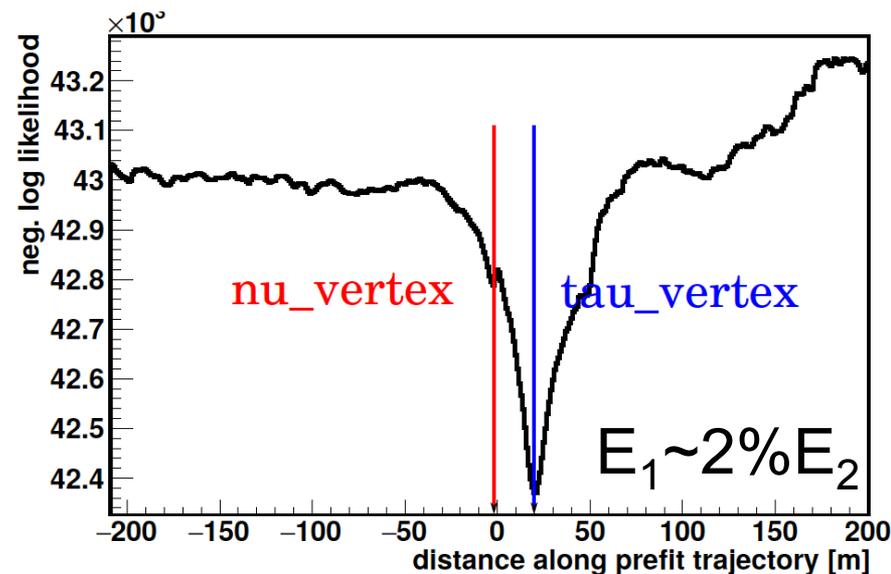
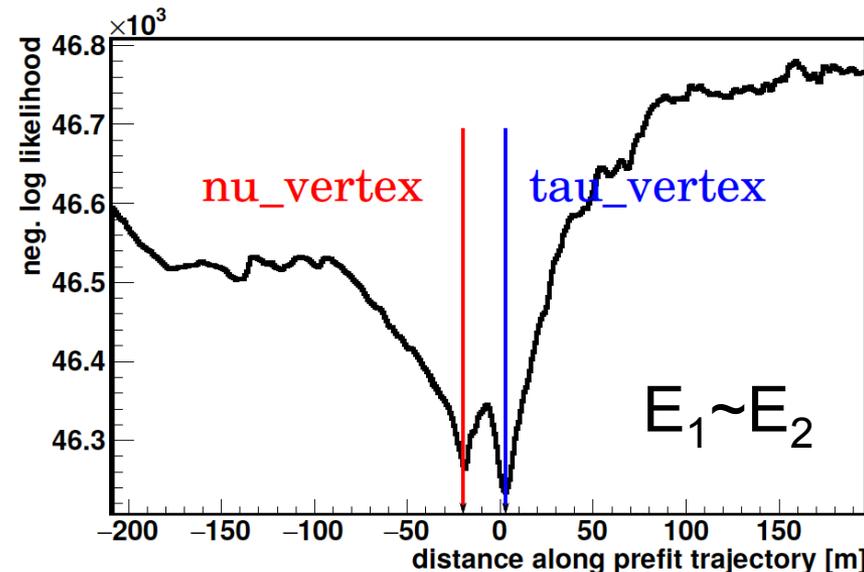
Tau ID



$$\ell = 4.9\text{m} \frac{E_\tau}{100 \text{ TeV}}$$



- ~no atmospheric tau: clean signal!
- Resolves ν_e and ν_τ fluxes
- Two-vertex reconstruction:
 - Begin with single vertex
 - Scan along direction
 - Search for secondary peaks
 - Use excellent timing!
 - Resolution to 5m decay distance

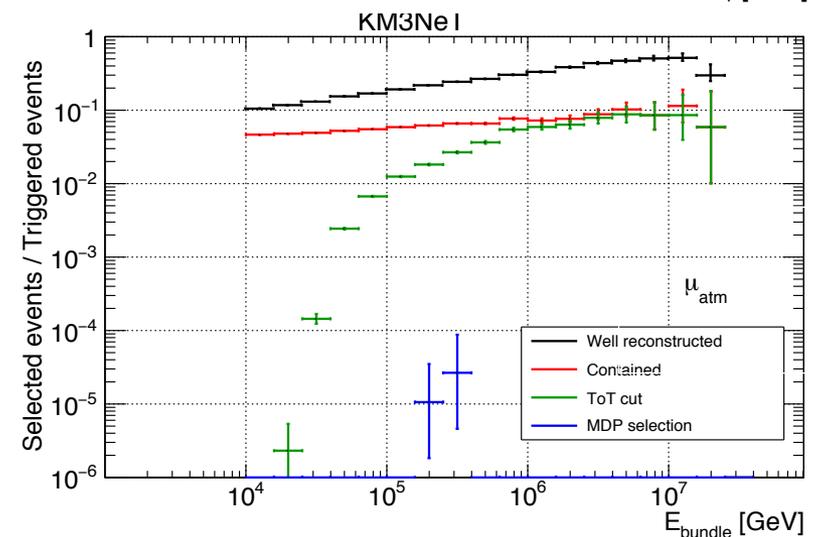
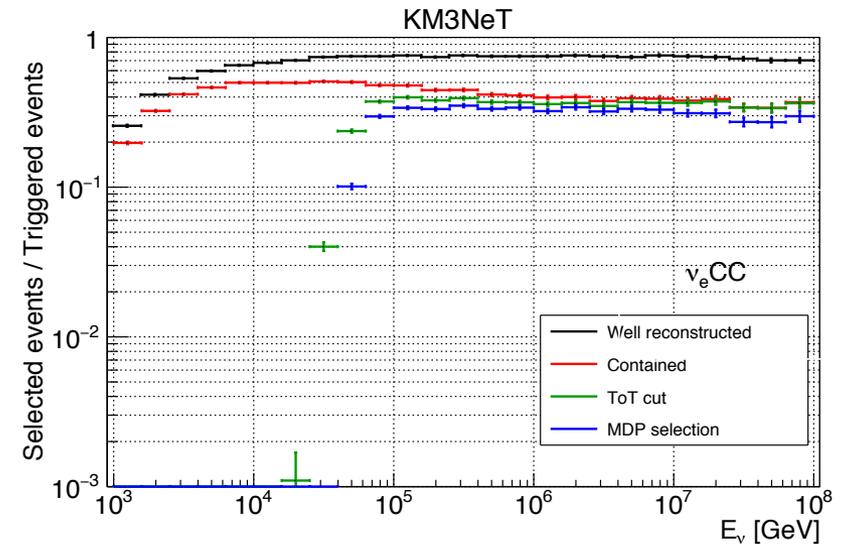
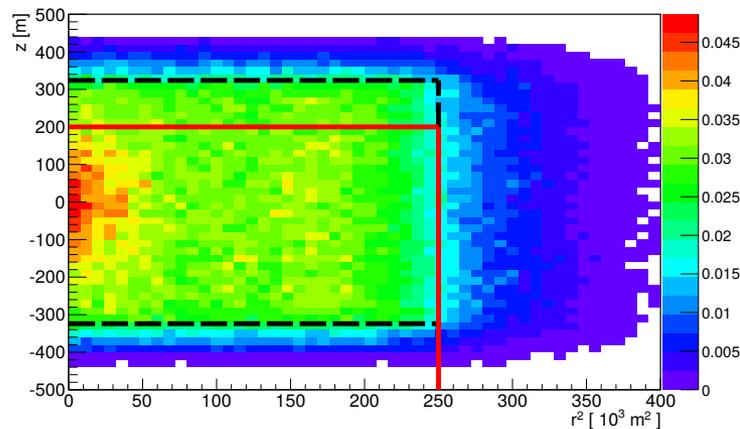


The top of the slide features a dark blue header with a pattern of small, faint icons. On the right side, the letters 'ARCA' are displayed in a large, bold, light blue font, partially obscured by a circular graphic element. The main body of the slide is white.

ARCA: Expected sensitivity

(simulated) KM3NeT analysis example: Diffuse astrophysical flux in the cascade channel

- Cosmic flux appears near 100 TeV
 - **Well-reconstructed**
 - **Containment criteria**
 - **Energy/direction-based cut**
 - **Machine-learning (event topology)**
- Maximally efficient above 60 TeV
- Strong muon suppression



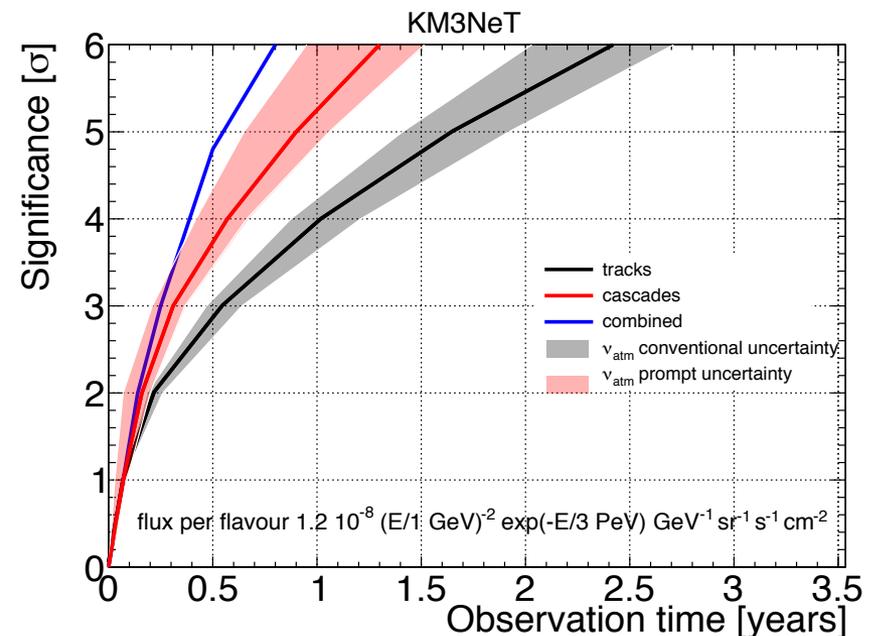
Total diffuse flux

- ‘Cut and count’ event numbers:
 - +self-veto effect: -25% atm nu

	reconstruction level	after preselection cuts	after final cuts
μ_{atm}	2.4×10^7	5.5×10^4	6
ν_{atm}^{μ}	1.0×10^5	49	20
ν_{atm}^e	7.1×10^3	23	19
ν_{cosm}^{μ}	352	34	11
ν_{cosm}^e	304	49	41
ν_{cosm}^{τ}	250	34	26

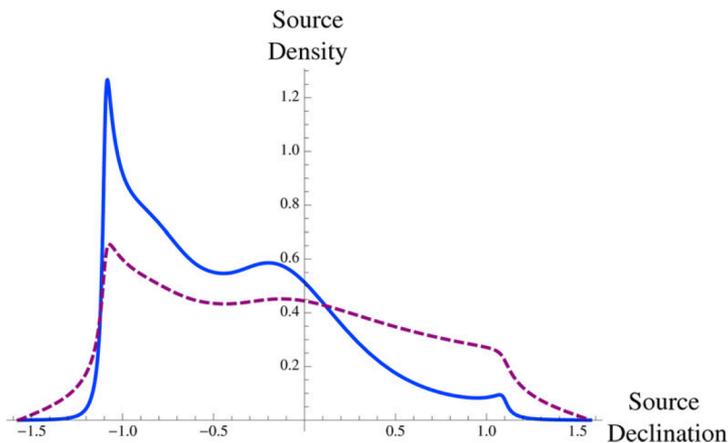
5-yr event numbers

- Full sensitivity:
 - 5σ in 6 months of ARCA
 - Major uncertainties: atm. neutrino fluxes
- Goal: don't just re-discover the IceCube flux, investigate it!

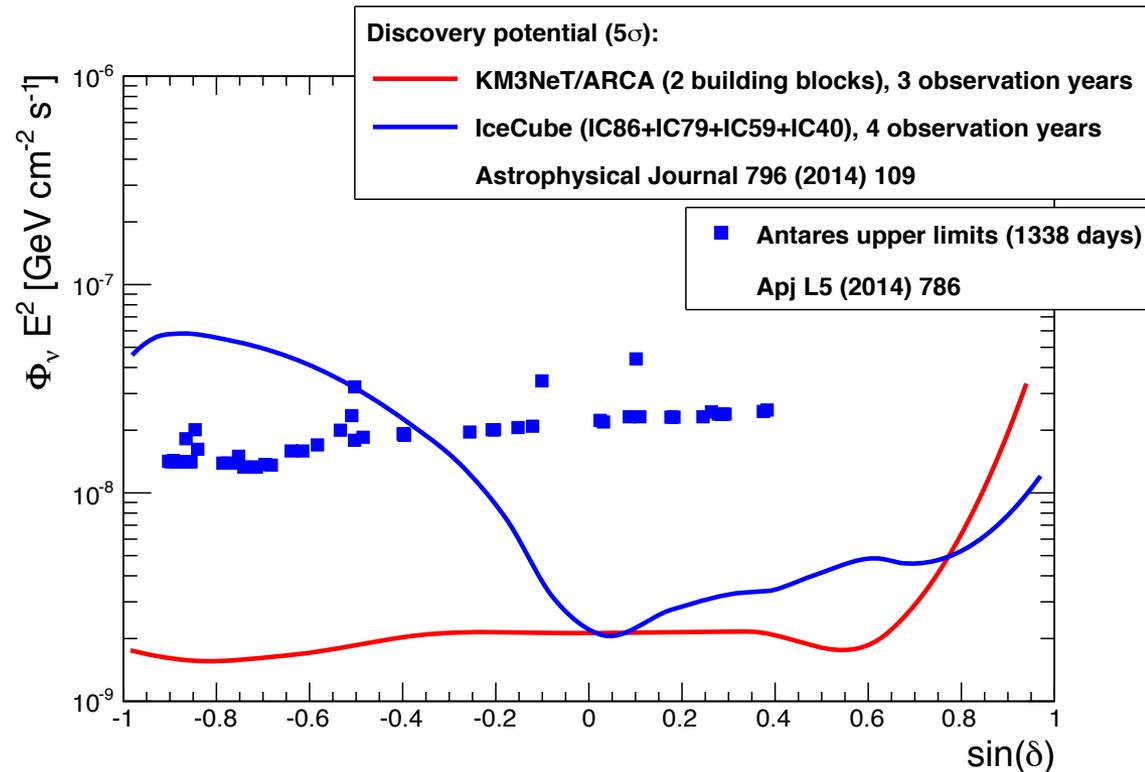


Sensitivity to point source with E^{-2} spectra

- Broad coverage
- Fills 'southern gap'
- Galactic sources!



Vissani, Aharonian, Sahakyan, *Astroparticle Physics* 34 (2011) 778–783



Not most up-to-date results!
(by anyone)

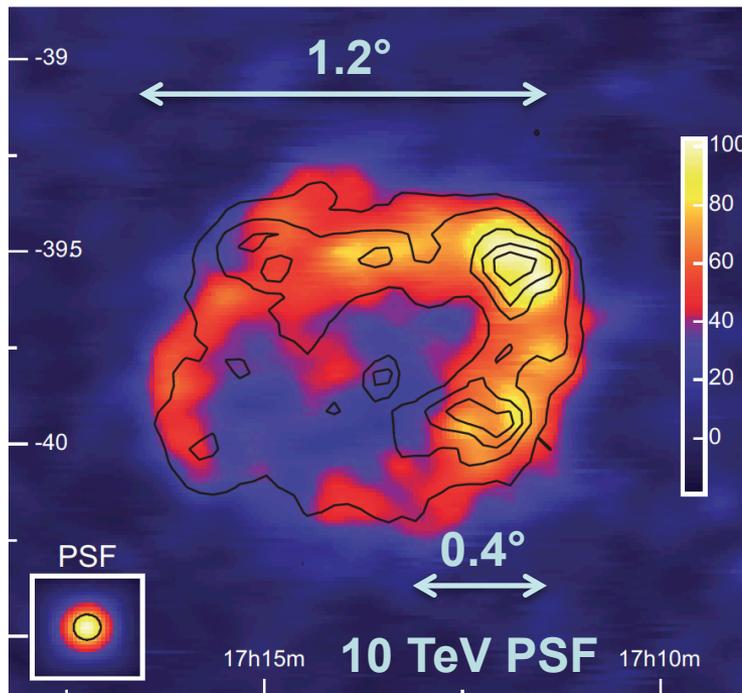
Specific sources

Neutrino flux prescriptions:

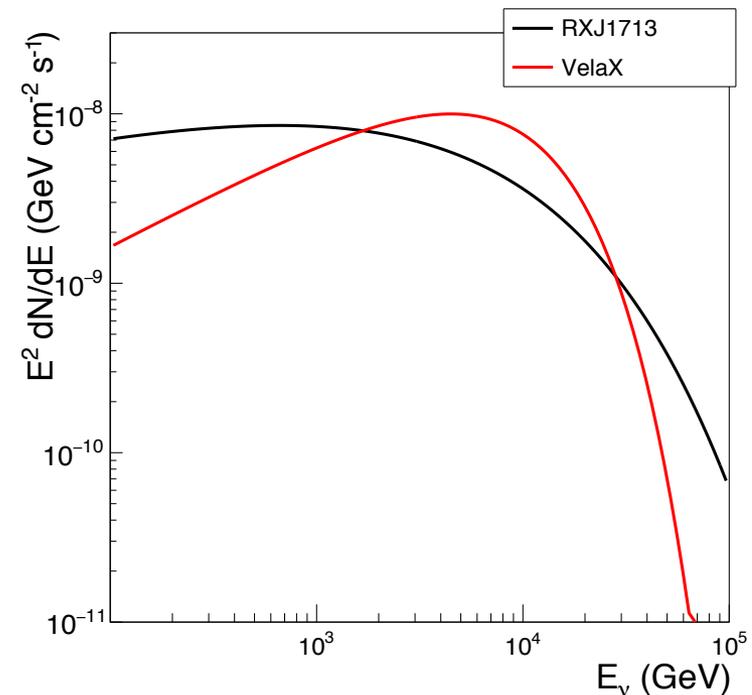
RX J1713: Kelner et al, Phys. Rev. D74, 034018 (2006)

VelaX: Villante & Vissani, Phys. Rev. D78, 103007 (2008).

- RX J1713, Vela X, Galactic centre



F. Aharonian et al, A&A 464 (2007) 235



$$\frac{d\phi}{dE_\nu} = 16.8 \times 10^{-15} \left[\frac{E_\nu}{1 \text{ TeV}} \right]^{-1.72} \cdot \exp \left(-\sqrt{\frac{E_\nu}{2.1 \text{ TeV}}} \right) \text{ GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$$

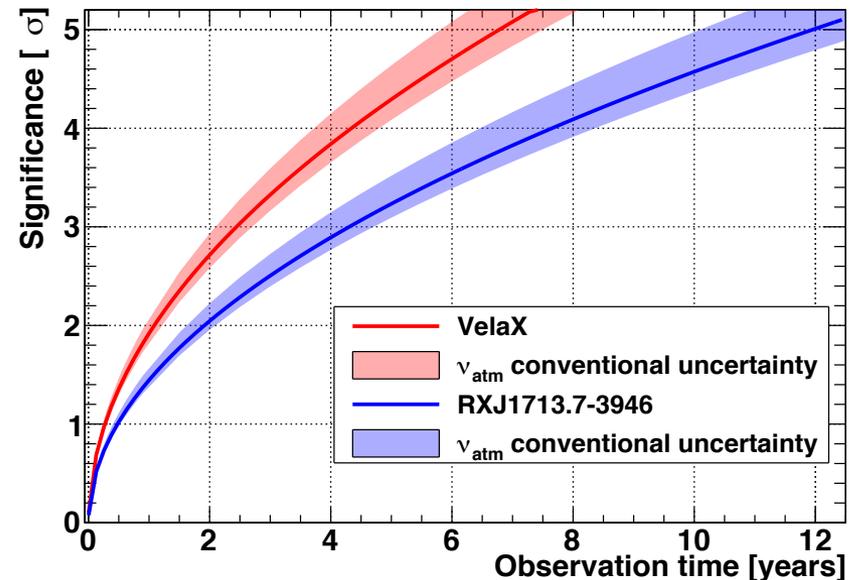
$$\frac{d\phi}{dE_\nu} = 7.2 \times 10^{-15} \cdot \left[\frac{E_\nu}{1 \text{ TeV}} \right]^{-1.36} \cdot \exp \left(-\frac{E_\nu}{7 \text{ TeV}} \right) \text{ GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$$

Sensitivity

- Neutrino spectra cut off near 10 TeV

5 yr event numbers

	reconstructed tracks	after preselection cuts	after final cuts
μ_{atm}	2.7×10^8	1.5×10^5	≈ 2.0
ν_{atm}^{μ}	1.6×10^6	1.2×10^4	11.6
ν_{atm}^e	6.0×10^4	545	0
ν_{RXJ}^{μ}	33.4	23.5	8.1
ν_{RXJ}^e	12.5	0.8	0
ν_{RXJ}^T	12.3	2.55	0.57

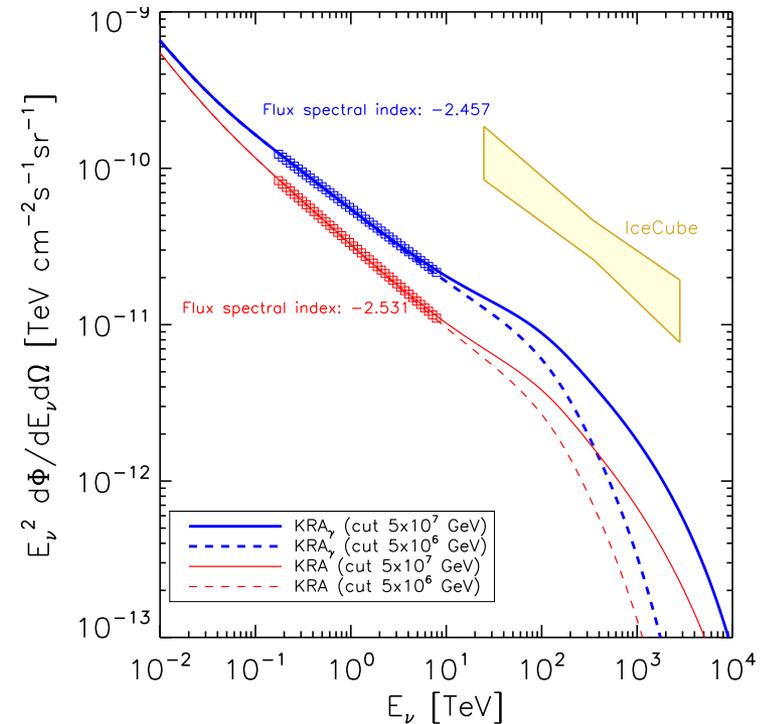
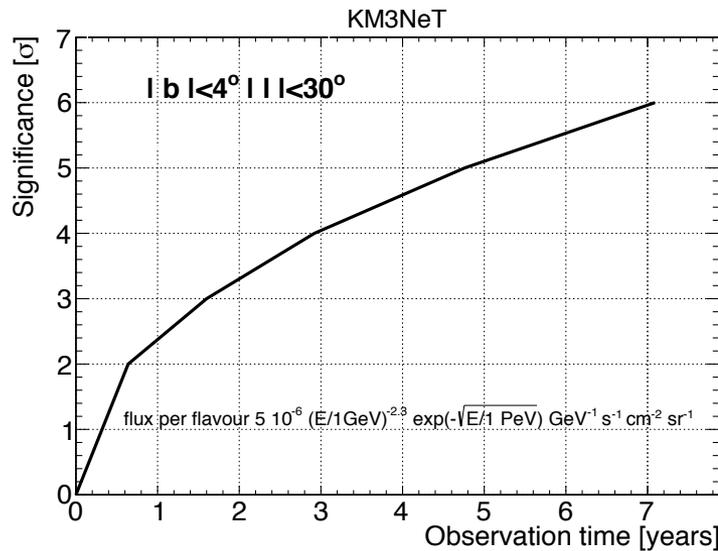


- Low background, low source flux
- We resolve the sources – discovery \Leftrightarrow morphology
- Comprehensive studies of galactic sources: need more sensitivity
- KM3NeT Phase 3: expand ARCA to 6 blocks ($\sim 3.5 \text{ km}^3$)

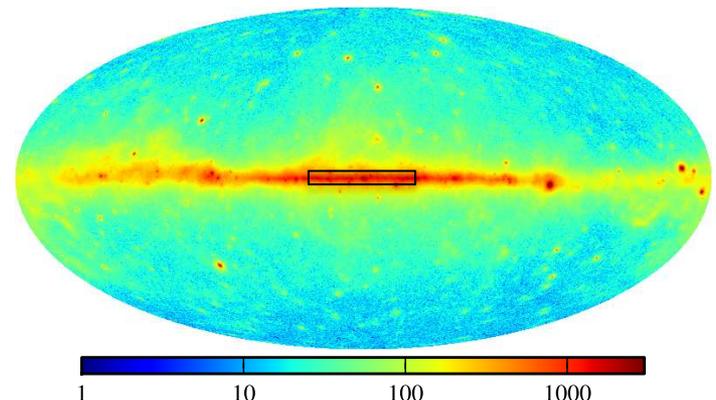
Gaggero et al, arXiv: 1507.07796

Galactic plane

- Inner region, muon tracks only



- Improvements:
 - Add cascades (resolve GP!)
 - Include structure



M. Ackermann et al, ApJ 730 (2012) 3

Neutrinos and Transients

- General paradigm:
 - Short transient from black hole creation (e.g. hypernovae, merger of compact objects)
 - Jet formation: EM & hadronic acceleration
 - Messengers: Neutrinos, gamma rays, radio, GWs
 - Phenomena: GRBs (short and long), GWs, FRBs, Unknown phenomena?

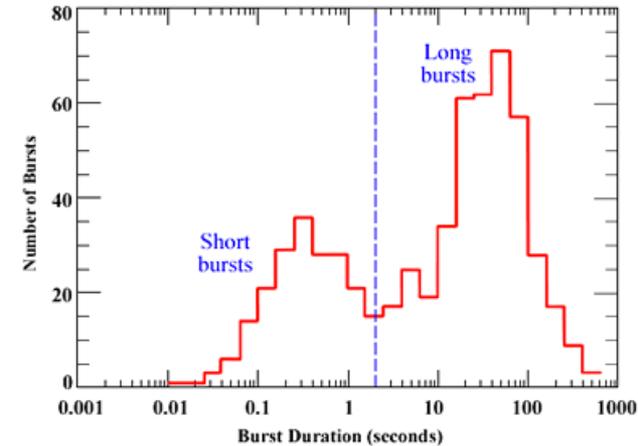
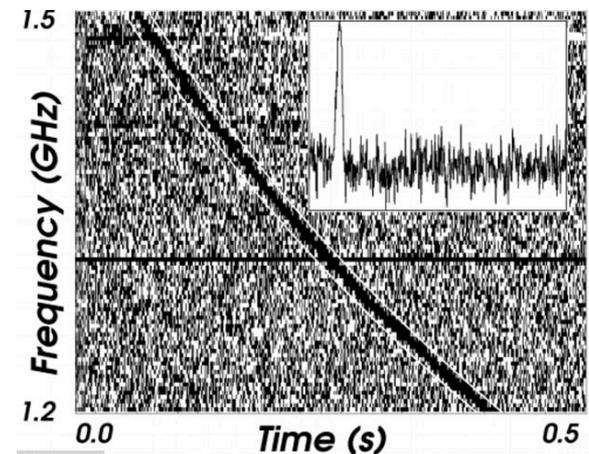


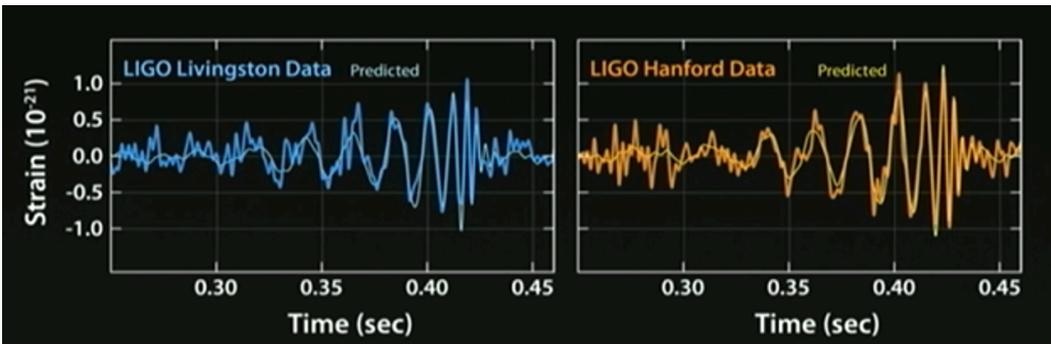
Image credit: Swinbourne U. Tech

FRBs: e.g. Lorimer et al.

(*image credit: The Daily Mail!*)



© Lorimer et al



GWs: Advanced Ligo Scientific Collaboration

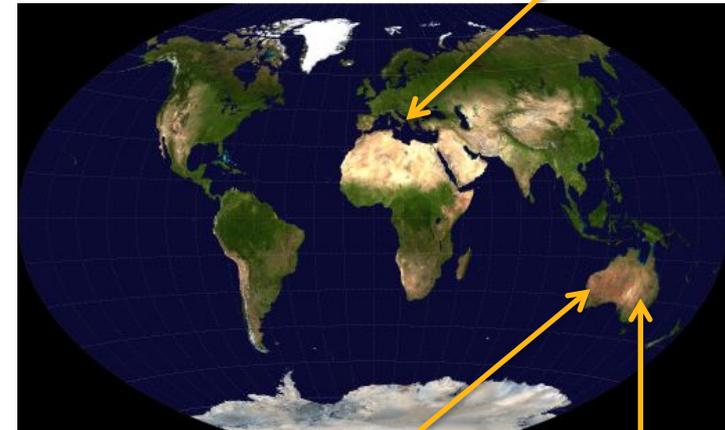
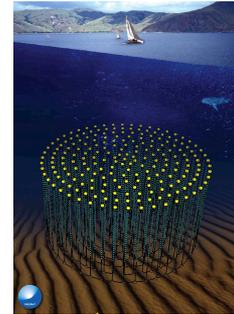
Transients – same sky, all the time

- ARCA & transient alerts
 - Rapid reconstruction (few seconds)
 - Good resolution: limit field of search
 - Northern hemisphere: view Southern sky
 - Sydney: 46.5° from ARCA antipode

- ANTARES multi-messenger follow-ups:
 - Optical: ROTSE, TAROT, Zadko
 - X-ray: *Swift* XRT
 - Radio: MWA, Parkes
 - GWs: Ligo/Virgo

- Next-generation instruments:
 - SKA1-low, CTA...

ANTARES,
KM3NeT



ASKAP
MWA
SKA1-low
Parkes
ATCA

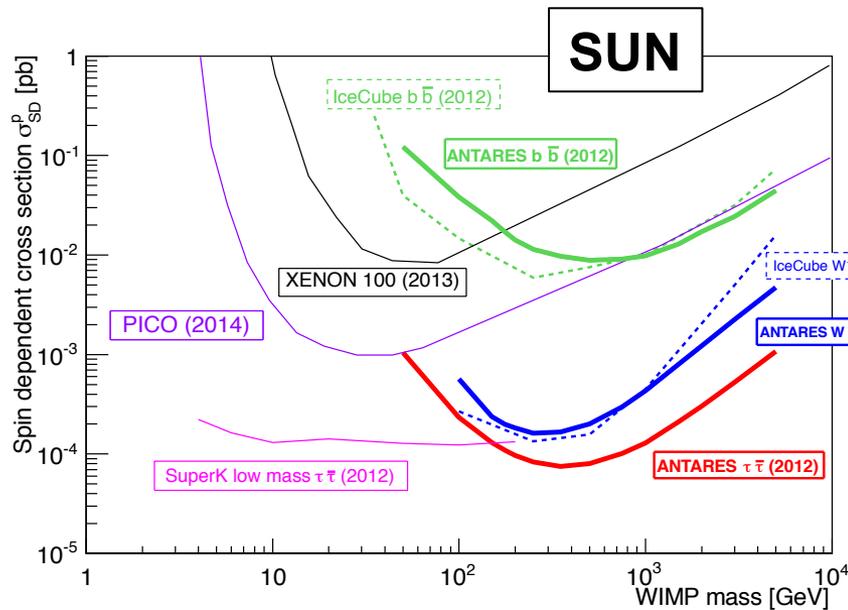




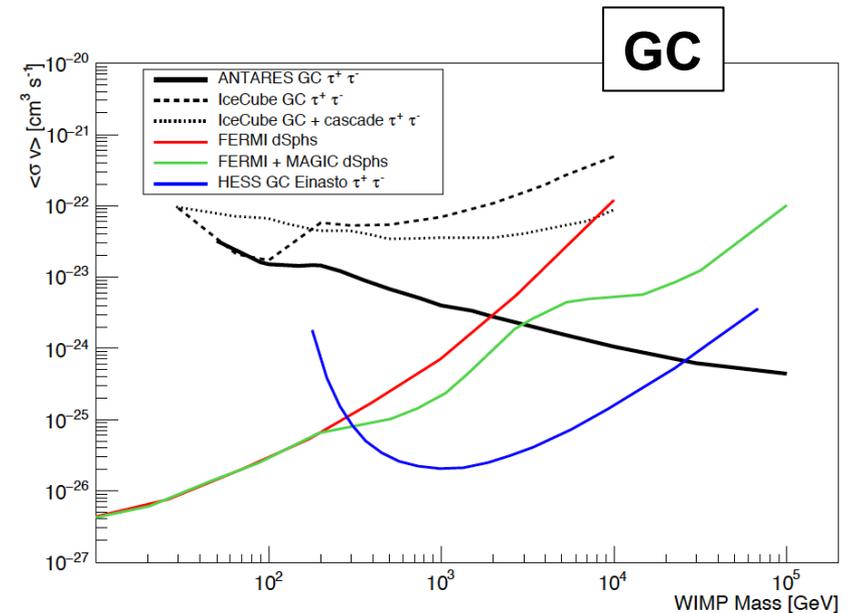
Other stuff KM3NeT will do

Indirect dark-matter searches (A. Margiotta, Pat Scott)

- Search with WIMP annihilation signature: $X_{\text{WIMP}} \bar{X}_{\text{WIMP}} \rightarrow \nu\bar{\nu}, b\bar{b}, W^-W^+, \tau^-\tau^+, \mu^-\mu^+$

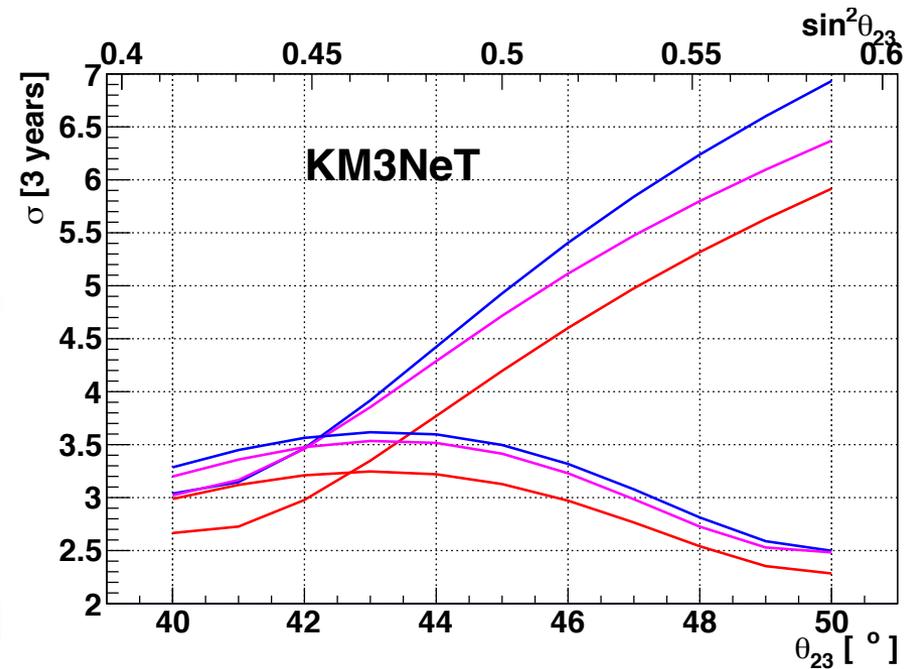
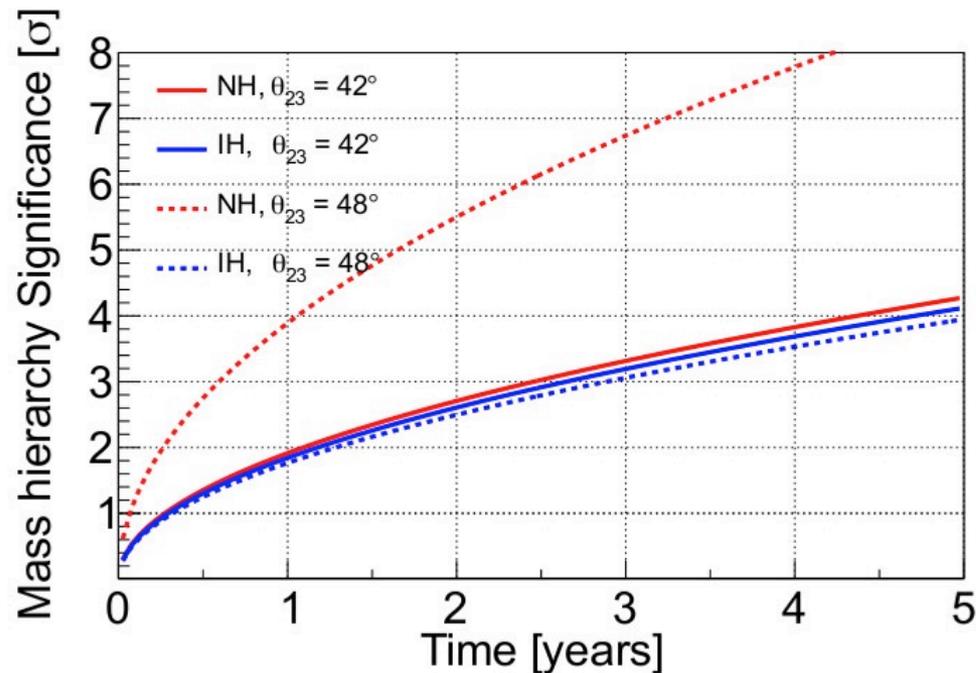


Adrian-Martinez et al, PhysLett B 759 (2013) 69



Sensitivity to the mass hierarchy

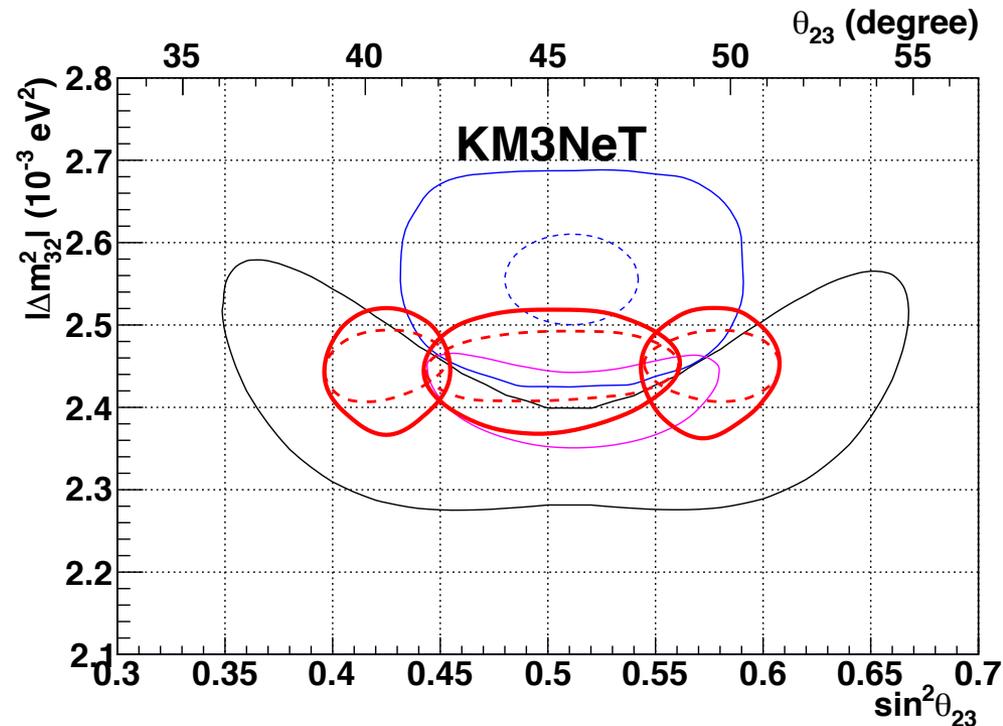
- Depends on CP-violating phase, true hierarchy, mixing phase



- Baseline message: 3 sigma hierarchy measurement in 3 years

Sensitivity to mass splitting and mixing

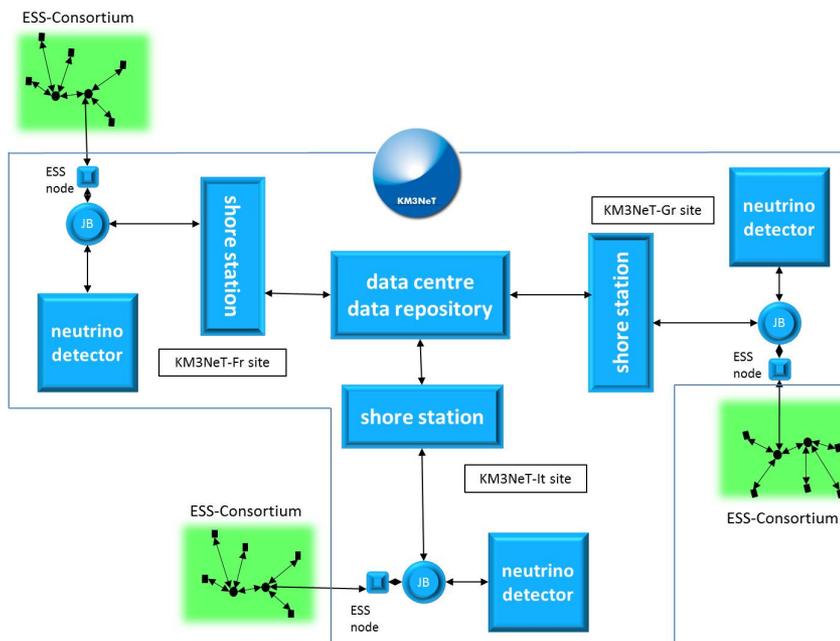
- ORCA (3 possible true values shown), Minos, T2K (2020), NOvA (2020)



- Dashed: with energy-scale uncertainty in ORCA

Earth and Sea Sciences (ESS)

- ESS nodes on each station:



- Climate, marine biology, tracking whales,...

- From ANTARES (~KM3NeT-Fr)

Deep-Sea Research I 58 (2011) 875–884

Contents lists available at ScienceDirect

Deep-Sea Research I

ELSEVIER journal homepage: www.elsevier.com/locate/dsri

Acoustic and optical variations during rapid downward motion episodes in the deep north-western Mediterranean Sea

Ocean Dynamics (2014) 64:507–517
DOI 10.1007/s10236-014-0702-0

High-frequency internal wave motions at the ANTARES site in the deep Western Mediterranean

Hans van Haren · The ANTARES Collaboration

OPEN ACCESS Freely available online

PLOS ONE

Deep-Sea Bioluminescence Blooms after Dense Water Formation at the Ocean Surface

- From NEMO (~KM3NeT-It)

nature COMMUNICATIONS

ARTICLE

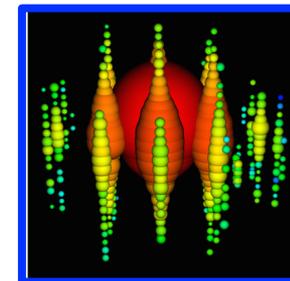
Received 17 Aug 2011 | Accepted 11 Apr 2012 | Published 15 May 2012 DOI: 10.1038/ncomms1936

Abyssal undular vortices in the Eastern Mediterranean basin

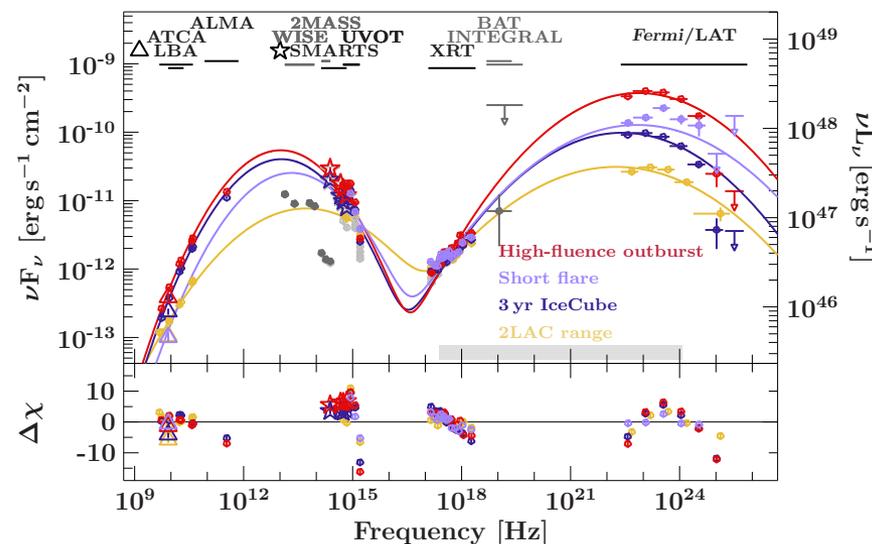
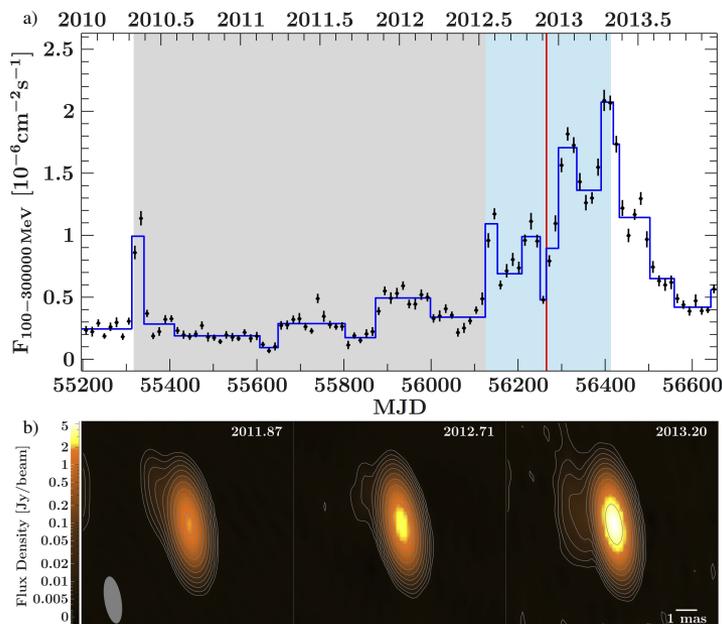
Blazars – multimessenger paradigm

- Neutrino production \Leftrightarrow flaring activity
- Reduce background using blazar light curves
- ‘Big Bird’ coincides with flare from Pks B1424-418
- 5% chance coincidence. ARCA: rule it out – or 0.05% (3.5σ) discovery

“BigBird”



$$\Delta\theta = 15.9^\circ$$



M. Kadler et al, Nature Physics 3715 (2016)

Conclusion

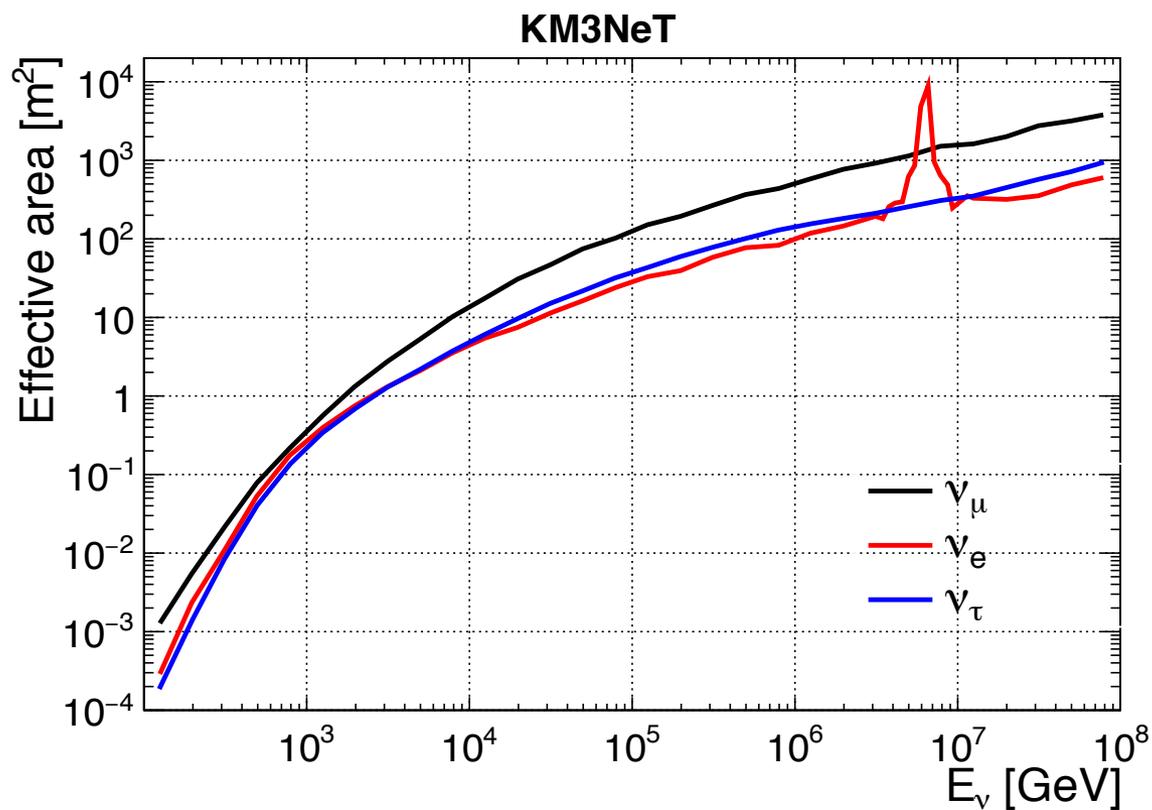
- **Neutrino detection in the deep Mediterranean sea**
 - Successfully established by ANTARES
 - KM3NeT: next-generation instrument
 - Includes ORCA – resolve the neutrino mass hierarchy!
 - Phase 1: currently being deployed!
- **KM3NeT/ARCA: HE neutrino astrophysics**
 - Excellent angular resolution: perform neutrino astronomy
 - Study IceCube flux from a different hemisphere
 - Discover galactic plane emission, and galactic sources
- **Letter of Intent for KM3NeT Phase 2.0 published**
 - First sensitivity estimates extremely promising
 - Many improvements still to come: galactic centre, tau searches, starting events, extended source templates, optimisation...
 - Phase 2: completion as early as 2020 – stay tuned!



Appendices

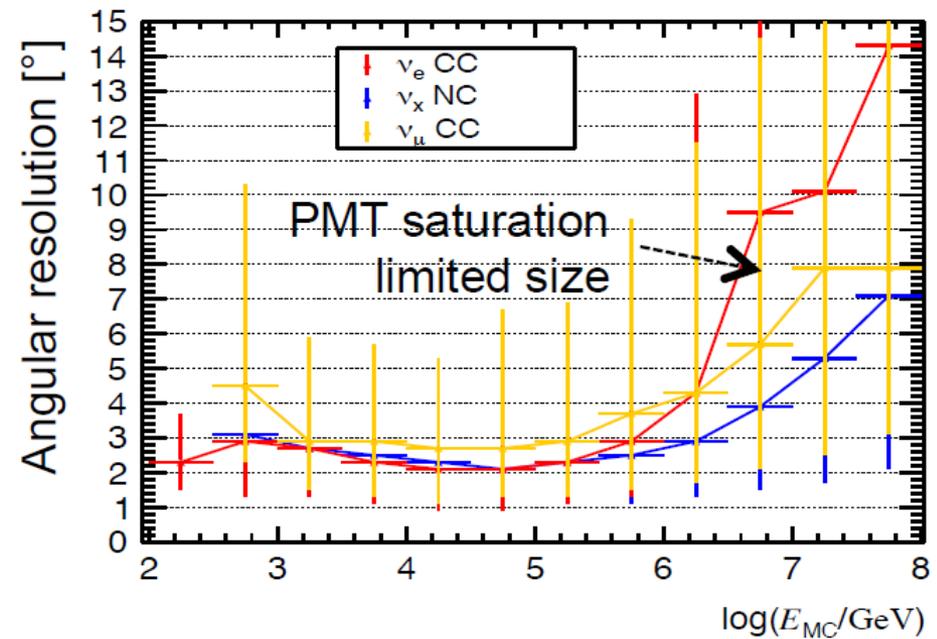
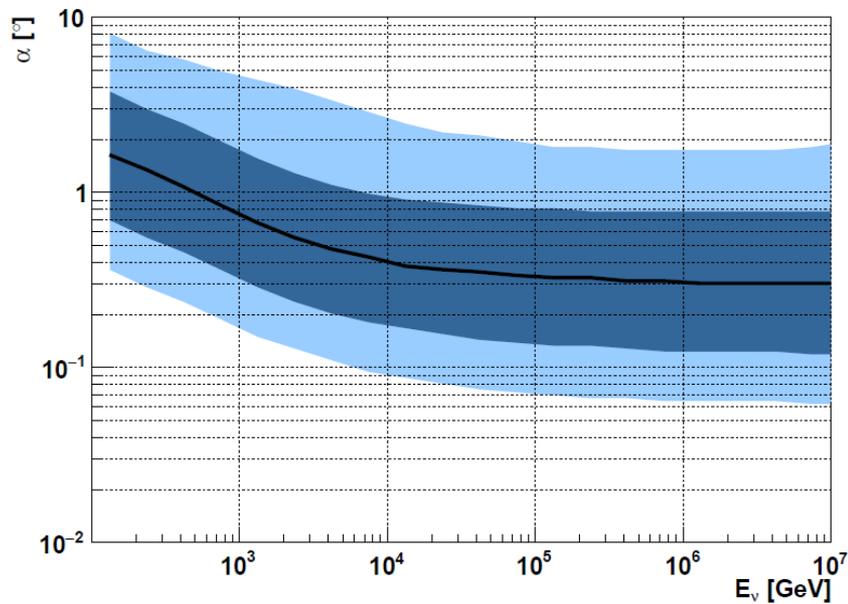
Trigger-level effective area (ARCA)

- Effective area at trigger level to neutrinos



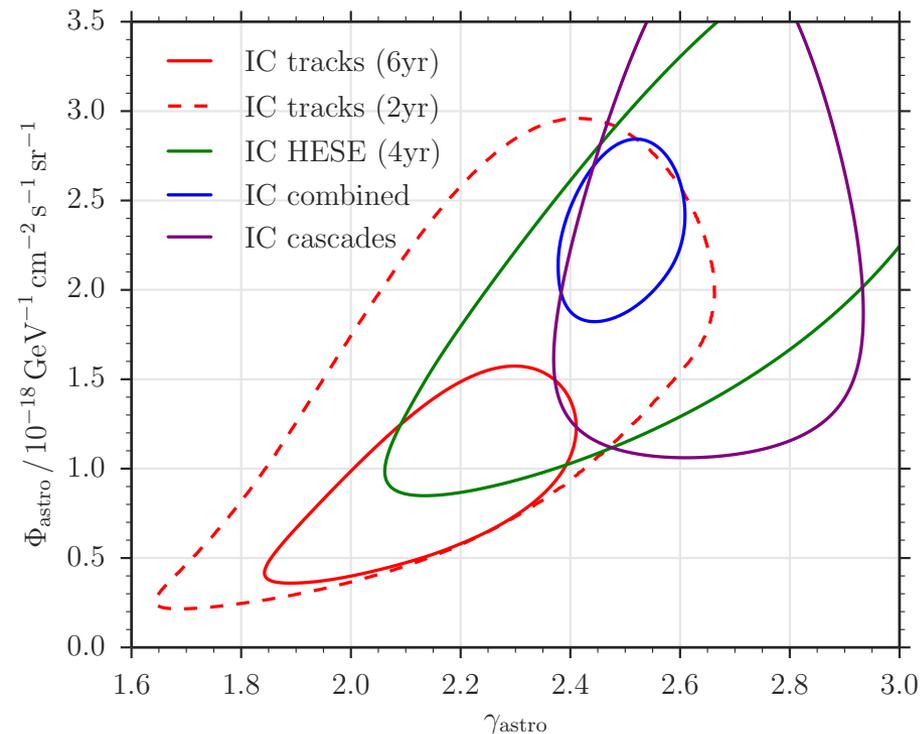
ANTARES resolutions (A. Margiotta, Monday)

- Tracks and cascades

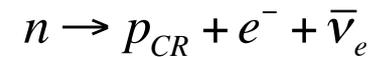
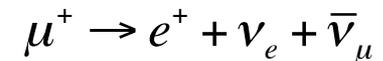
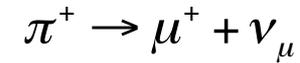


IceCube results – tension

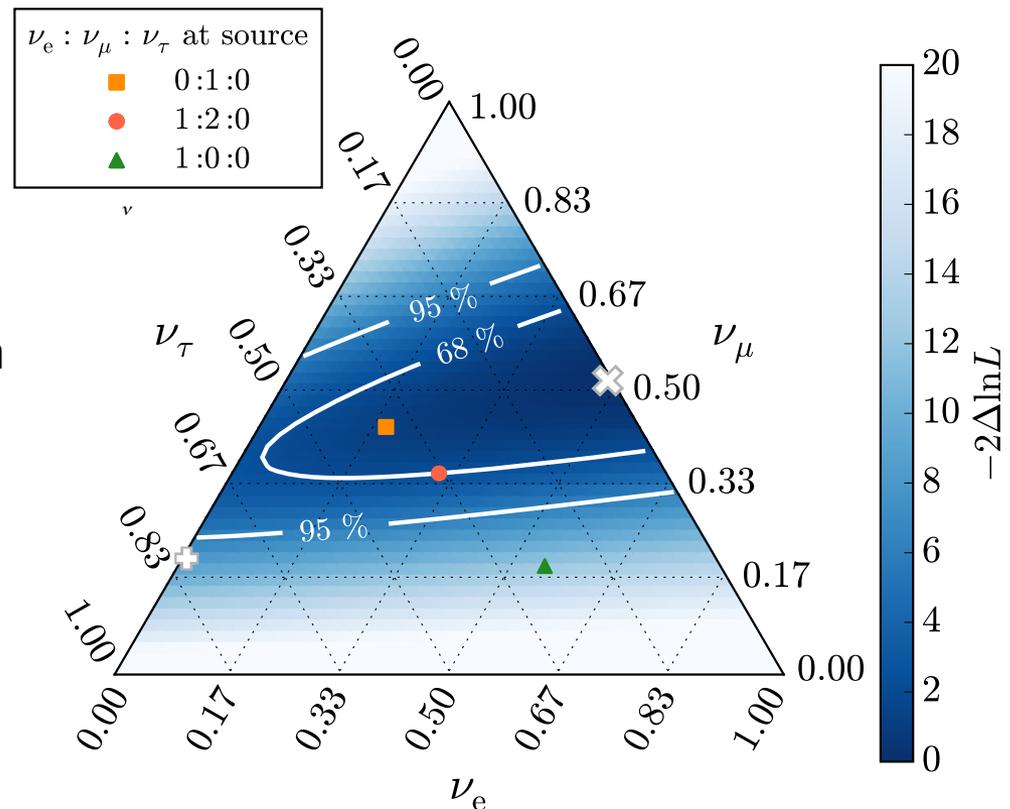
- Different analyses of astrophysical signal
 - IC Combined: mostly sensitive to Southern Hemisphere
 - IC tracks: Northern Hemisphere track sample
 - Tension at ~ 3.3 sigma



Flavour uniformity?

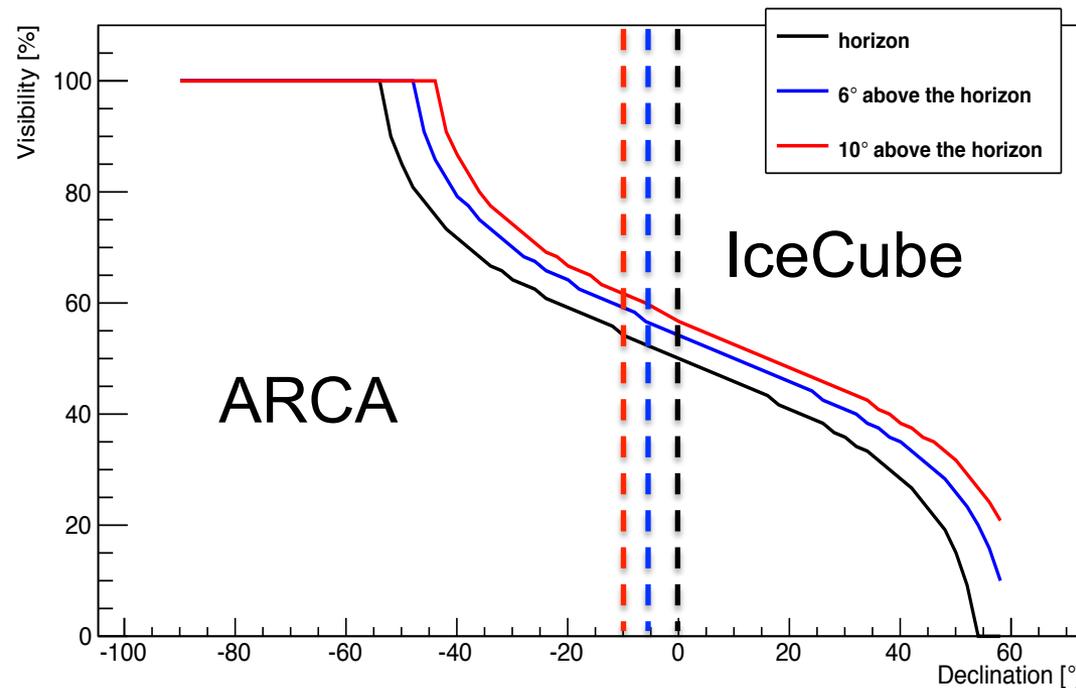


- Initial flavour ratios: $\nu_e : \nu_\mu : \nu_\tau$
 - 1:0:0 (neutronisation)
 - 1:2:0 (pion decay)
 - 0:1:0 (muon damped)
- Astrophysical distances
 - Maximal mixing
 - ν_τ holds most information



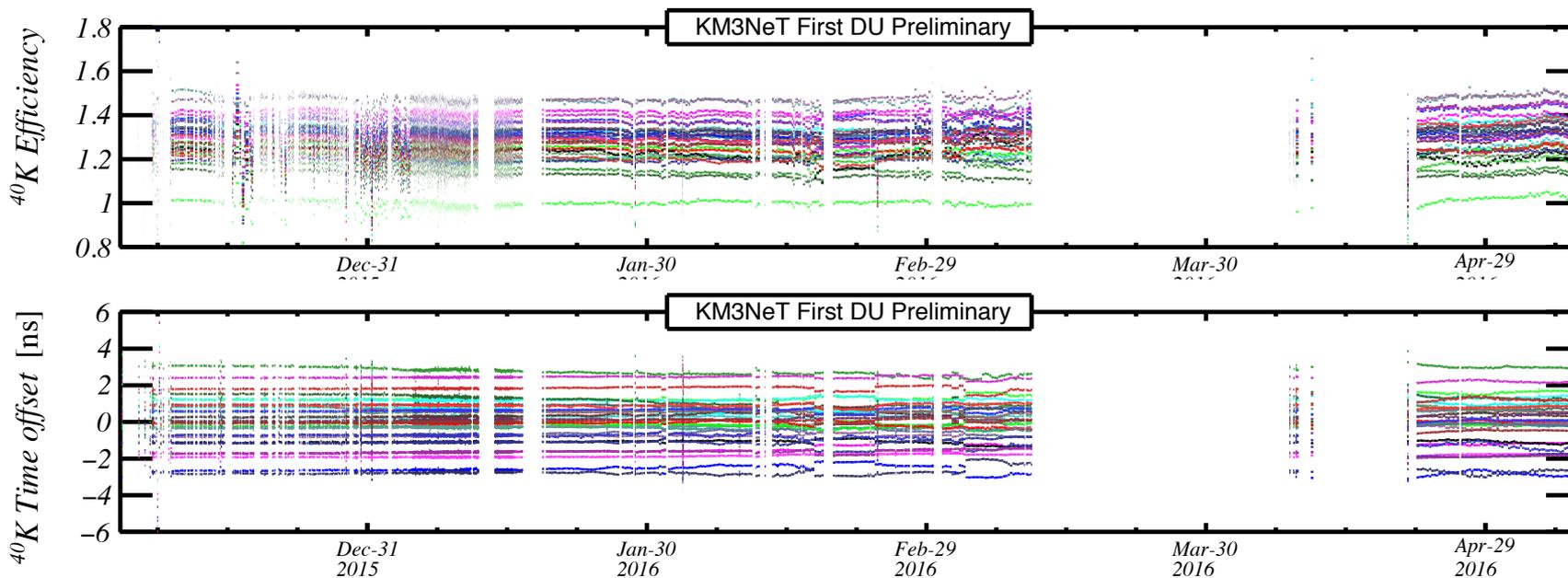
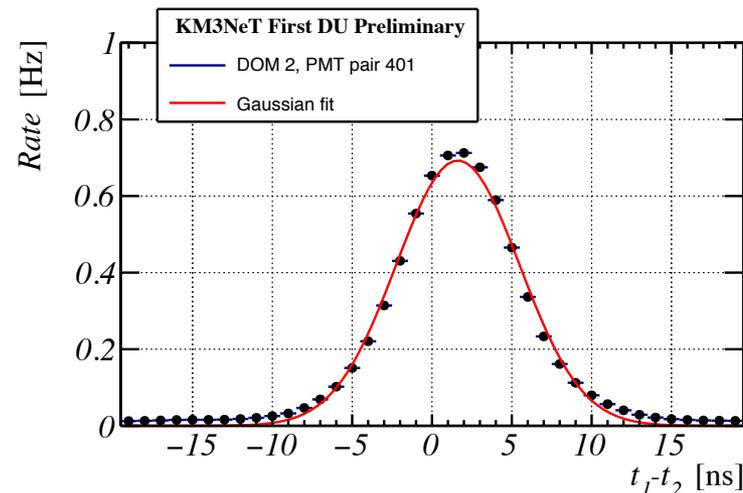
ARCA visibility (c.f. IceCube)

- Source visibility as a function of declination
 - Horizon-limited
 - 6° above horizon
 - 10° above horizon



^{40}K self-calibration: stability

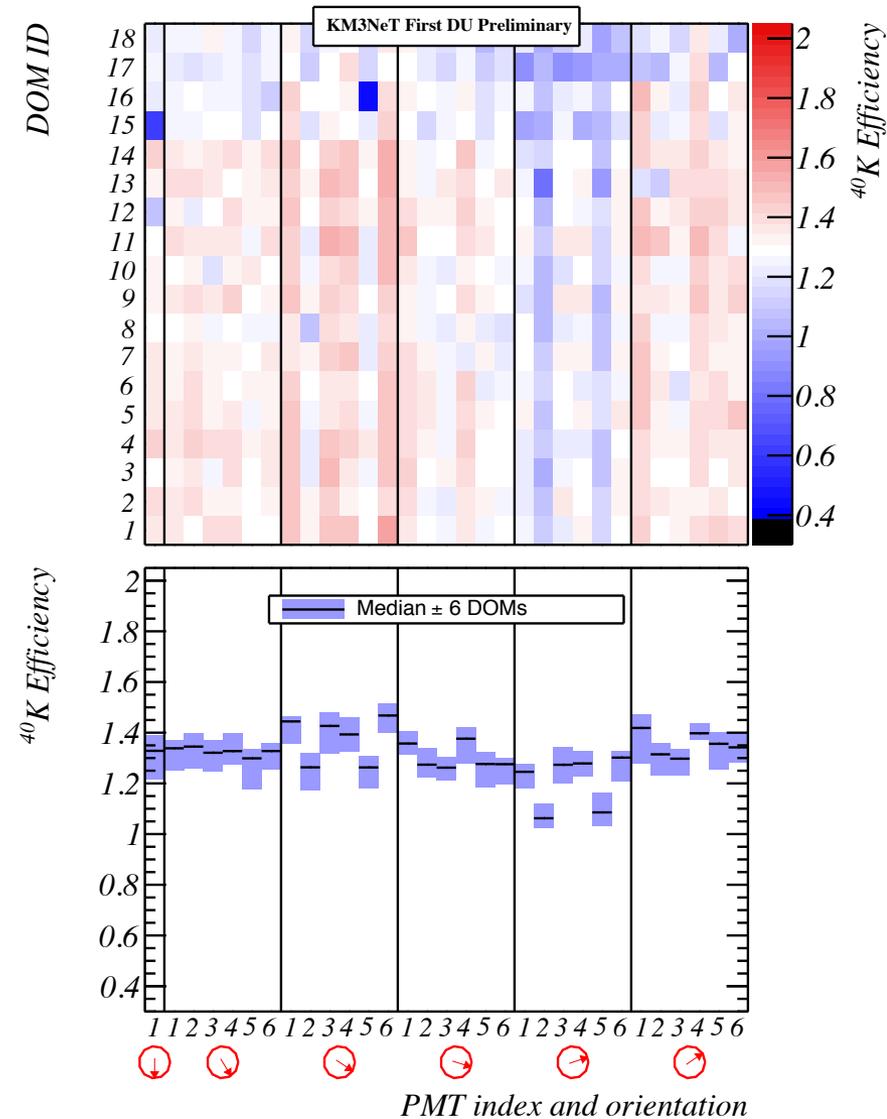
- 18 DOMs, 6 months



Run date

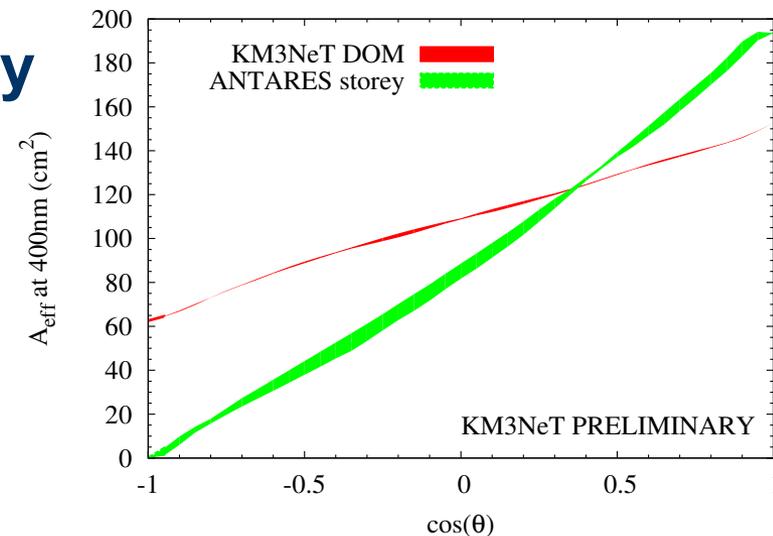
K40 calibration DU1 results

- 18 DOMs, 31 PMTs/DOM
- Systematic trends due to support structure

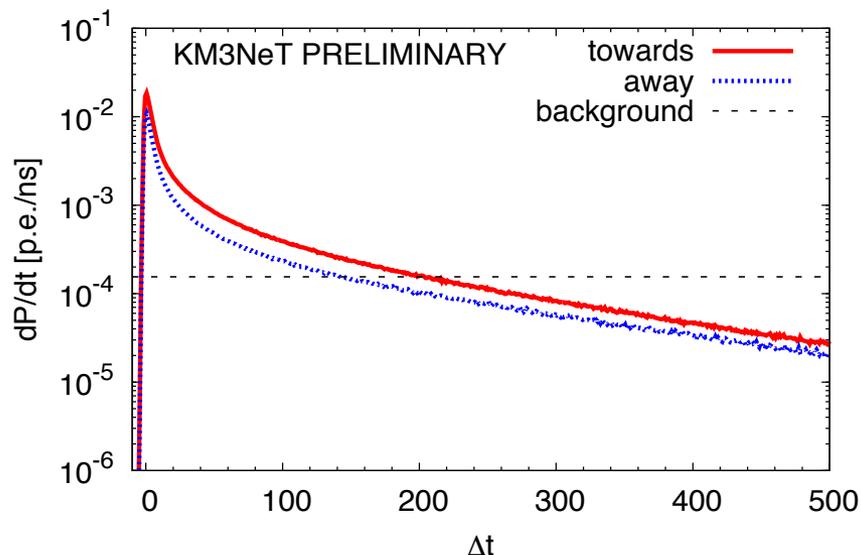


DOM response ↔ Reco accuracy

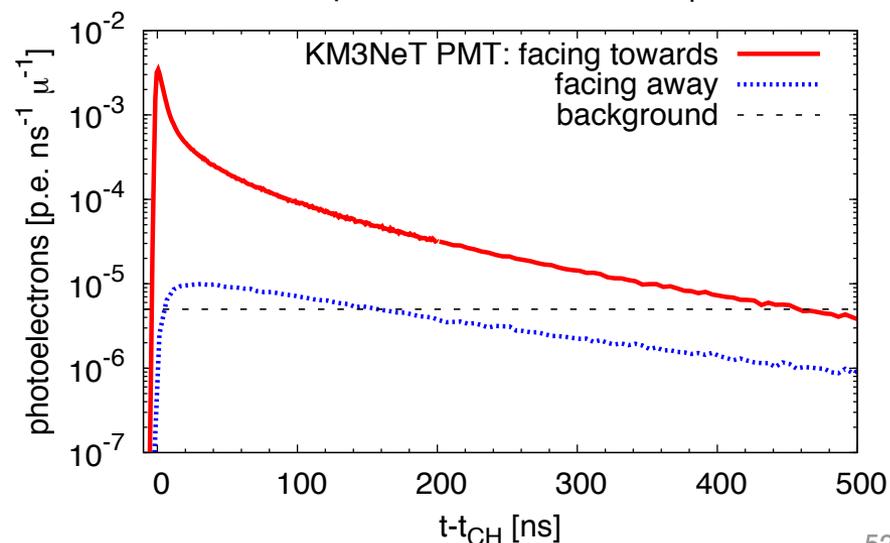
- Uniform coverage
- High dynamic range
- Low scattering in water:
 - Most photons w/in 10 ns
 - Excellent event topology



DOM at R=50m



PMT response to 1 TeV muons at $\rho=50m$



Multimessenger paradigm – issues

- Gamma rays: leptons vs. hadrons
 - Hadronic models: high-energy gamma rays from pi0 decay
 - Leptonic models: direct e- acceleration, brems., inverse compton, ...
 - See talk by Nigel Maxted on trying to disentangle this

- Cosmic ray sources: != gamma/nu sources?

- CRs made visible through interactions
- DSA is slow – too many interactions kills the CR spectrum
- Strong B-fields: secondaries may radiate their energy before decaying

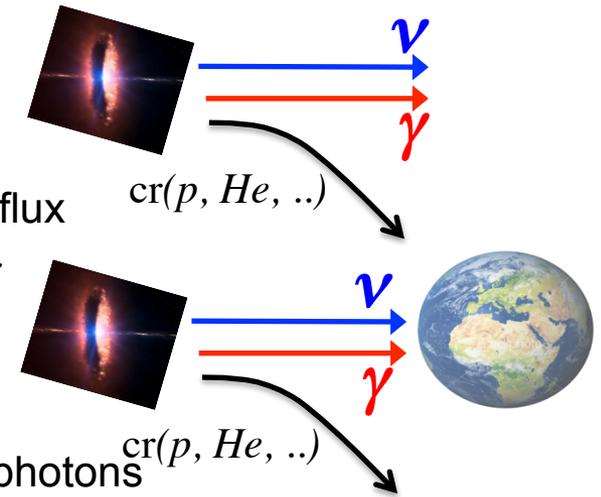
$$\left. \begin{array}{l} p_{CR} + p \\ p_{CR} + \gamma \end{array} \right\} p_{CR} / n + \pi^{\pm}, \pi^0$$

$$\pi^+ \rightarrow \mu^+ + \nu_{\mu}$$

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_{\mu}$$

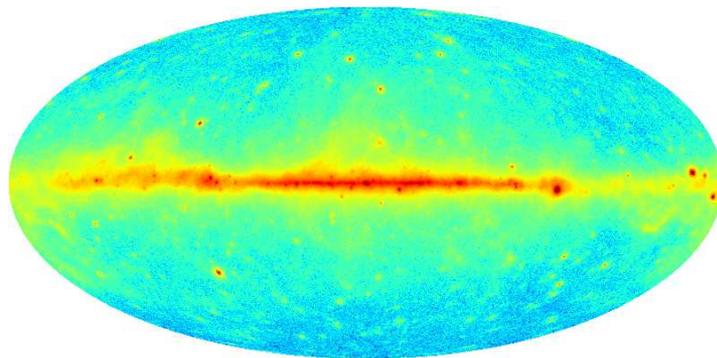
Multimessenger paradigm – issues

- Beaming vs bending:
 - Beamed sources produce beamed gamma/neutrino flux
 - Cosmic rays diffuse – observable sources may differ
- Horizon problem
 - CR diffusion timescale are long; UHE CR see CMB photons
 - TeV gammas attenuated by photon backgrounds
 - Neutrinos have no horizon!
- Cosmic ray paradigm:
 - Galactic sources at PeV energies, extragalactic at EeV (Jose Bellido)
 - What about ‘galactic’ neutrino sources from all galaxies in the observable universe?

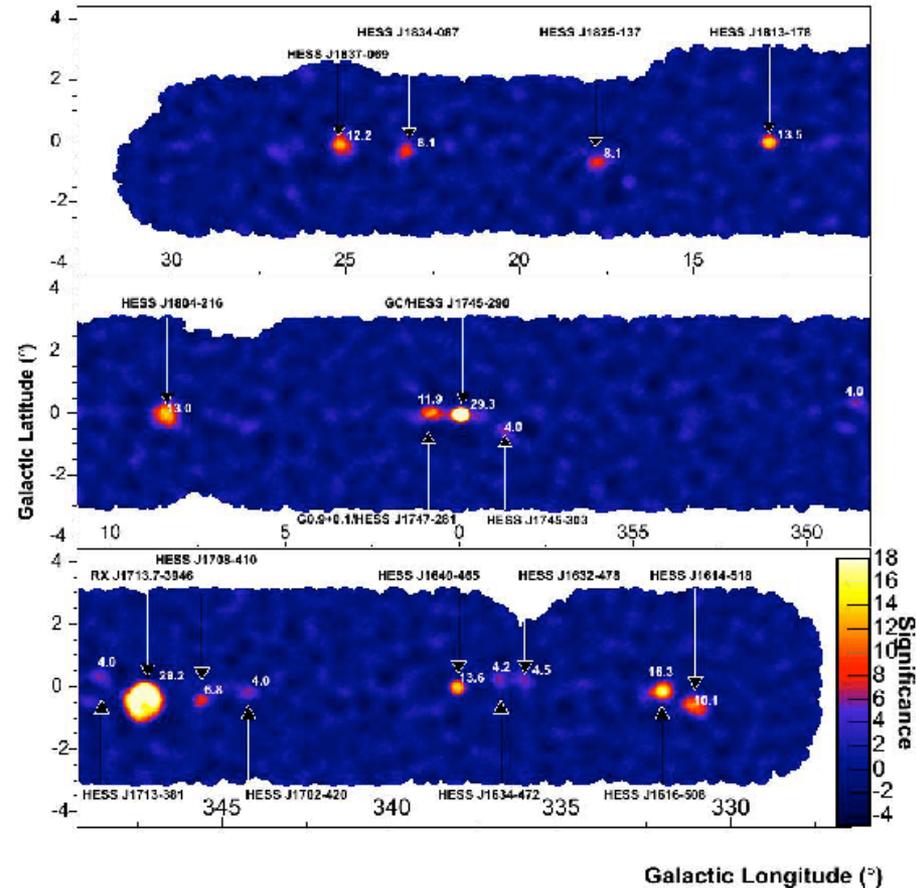


Sources of neutrinos? Galactic CR acceleration

- Wide variety of sources
 - SNR (RX J1713)
 - PWN (Crab, Vela X)
 - Galactic Centre
 - ...
- Diffuse flux from CR propagation
 - (e.g. traced by Fermi)



M.Ackermann et al, ApJ 730 (2012) 3



Aharonian et al, ApJ 636 (2006) 777

Starting tracks

- Channels:

$$\nu_{\mu} \xrightarrow{CC} \mu + \text{shower}$$

$$\nu_{\ell} \xrightarrow{NC} \nu'_{\ell} + \text{shower}$$

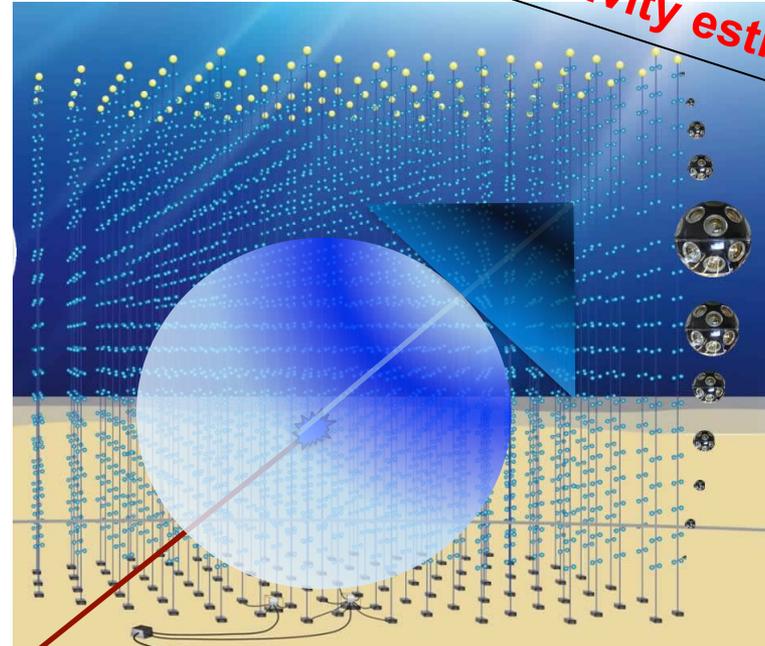
$$\nu_e \xrightarrow{CC} \text{shower}$$

$$\nu_{\tau} \xrightarrow{CC} \tau + \text{shower}$$

$$\tau \xrightarrow{\sim 83\%} \nu_{\tau} + \text{shower}$$

$$\tau \xrightarrow{\sim 17\%} \nu_{\tau} + \mu + \bar{\nu}_{\mu}$$

- Good energy and directional resolution!
- Currently: not a track, not a cascade...



Not optimally used in
KM3NeT Lol
sensitivity estimates

Tau 'double-bang'

- Channels:

$$\nu_\mu \xrightarrow{CC} \mu + \text{shower}$$

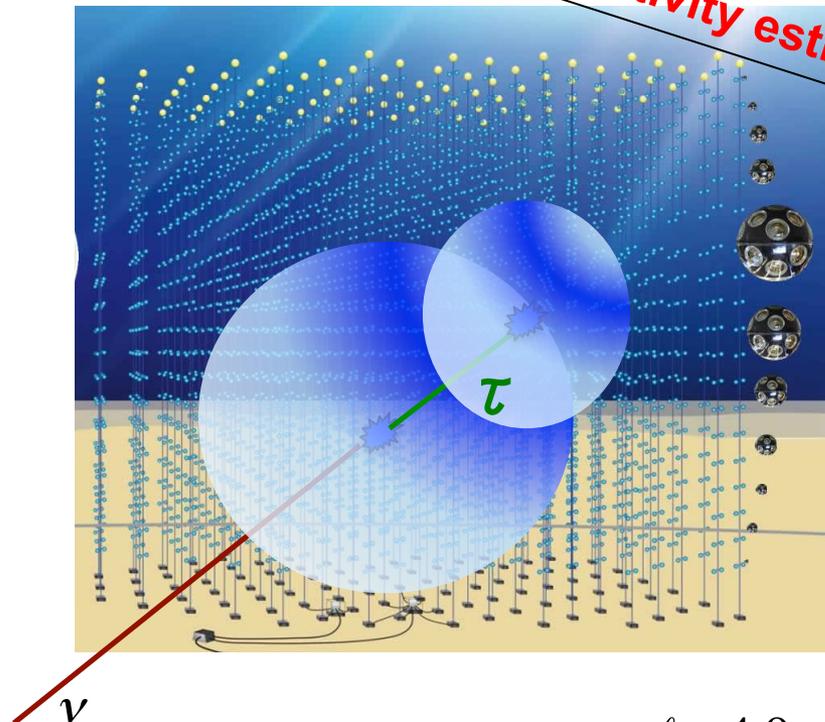
$$\nu_\ell \xrightarrow{NC} \nu'_\ell + \text{shower}$$

$$\nu_e \xrightarrow{CC} \text{shower}$$

$$\nu_\tau \xrightarrow{CC} \tau + \text{shower}$$

$$\tau \xrightarrow{\sim 83\%} \nu_\tau + \text{shower}$$

$$\tau \xrightarrow{\sim 17\%} \nu_\tau + \mu + \bar{\nu}_\mu$$



Not optimally used in
KM3NeT Lol
sensitivity estimates

$$\ell = 4.9\text{m} \frac{E_\tau}{100 \text{ TeV}}$$

- Background free ~no tau neutrinos in atmospheric flux
- Identification difficult: no tau 'double-bangs' identified in IC signal

Tau 'double-bang' => muon!

- Channels:

$$\nu_{\mu} \xrightarrow{CC} \mu + \text{shower}$$

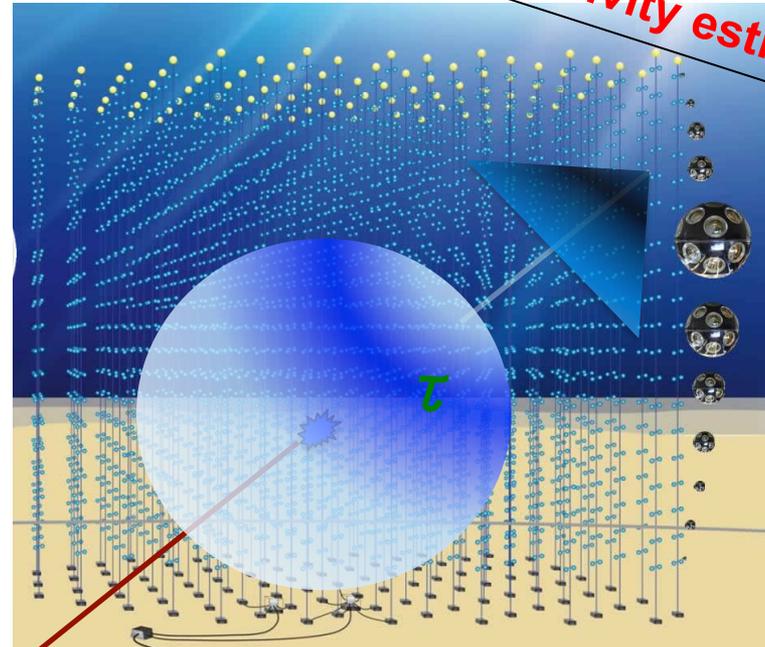
$$\nu_{\ell} \xrightarrow{NC} \nu'_{\ell} + \text{shower}$$

$$\nu_e \xrightarrow{CC} \text{shower}$$

$$\nu_{\tau} \xrightarrow{CC} \tau + \text{shower}$$

$$\tau \xrightarrow{\sim 83\%} \nu_{\tau} + \text{shower}$$

$$\tau \xrightarrow{\sim 17\%} \nu_{\tau} + \mu + \bar{\nu}_{\mu}$$



Not optimally used in
KM3NeT Lol
sensitivity estimates

- Background free ~no tau neutrinos in atmospheric flux
- Good energy and direction reco – but rare

Particle fluxes

- Background particle fluxes:
 - Muons from cosmic rays
 - Neutrinos from cosmic rays

