Report from ApPIC/IUPAP (Astroparticle Physics International Committee) to the second international meeting for large neutrino infrastructures

Michel Spiro

April 21, 2015

ApPIC terms of reference (discussed by APIF and IUPAP in 2013)

- Review on a regular basis the scientific status of the field of Astroparticle Physics;
- Engage in a continuous dialogue with "The Astroparticle Physics International Forum (APIF)" of the Global Science Forum (GSF) and provide scientific advice to APIF, whose members are appointed by funding agencies;
- Comment on and liaise with similar national and international organizations on assessment and road-mapping activities as the need may arise, e.g. for promoting the global coherence of plans, priorities and projects in AstroparticlePhysics.

- Here the term « astroparticle physics » is defined in a broad sense to include investigations related to the properties of the high-energy universe as well as the dark universe and issues with cosmic relevance – at the interface of astrophysics, nuclear physics, particle physics and cosmology. It also pursues the relevant research in theory and technology development.

Members of ApPIC (IUPAP WG 10)

Pierre Binetruy (France)
Roger Blandford (USA)
Zhen Cao (China)
Eugenio Coccia (Italy)
Don Geesaman (USA)
Kunio Inoue (Japan)
Naba Mondal (India)
Angela Olinto (USA)

Natalie Roe (USA)
Sheila Rowan (GB)
Valery Rubakov (Russia)
Bernard Sadoulet (USA)
Subir Sarkar (GB/Denmark)
Christian Spiering (Germany)
Michel Spiro (France) - Chair
Yoichiro Suzuki (Japan)

Karl-Heinz Kampert (C4 IUPAP Chair, Germany) ex-officio

What have we discussed so far, before this meeting?

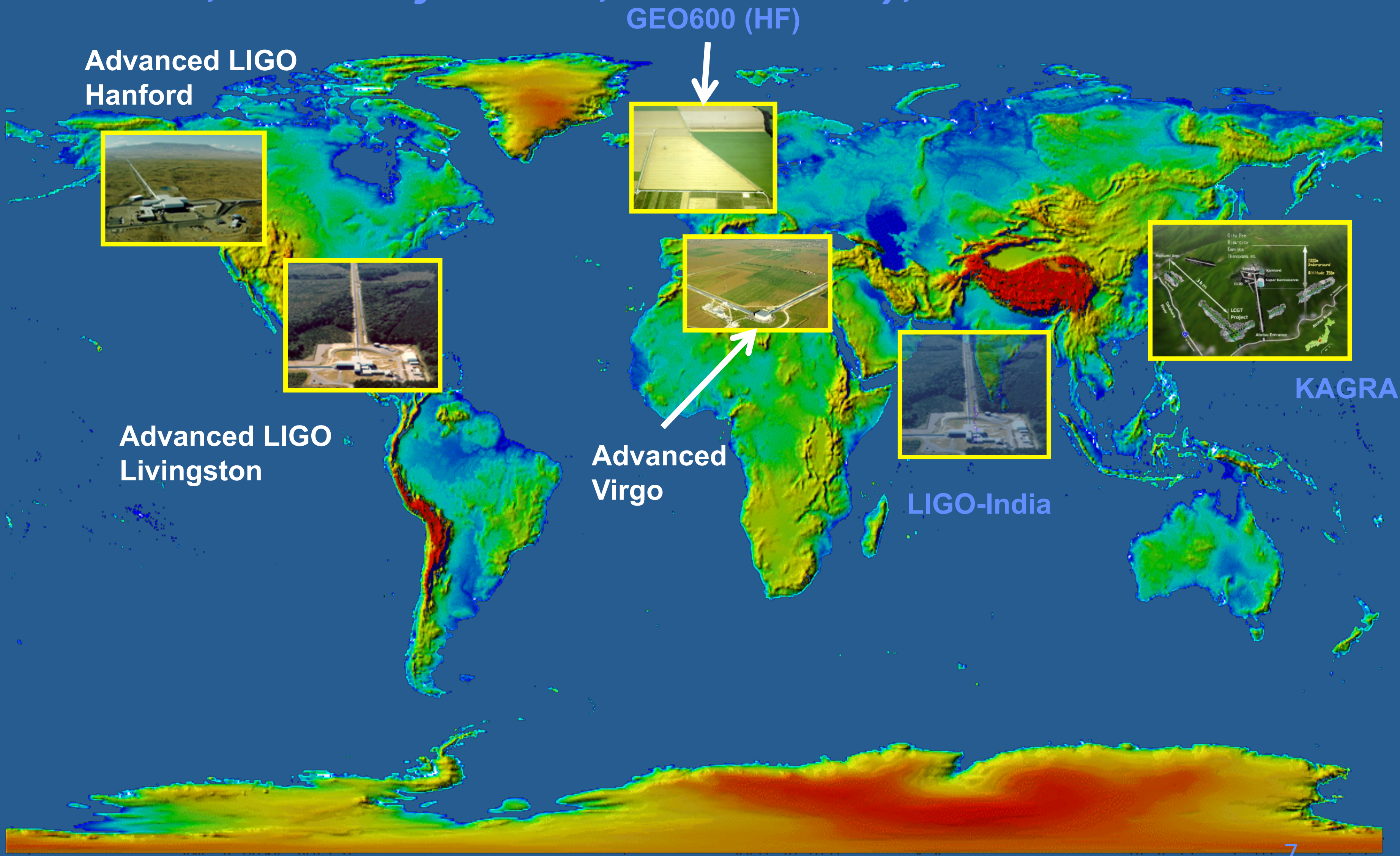
- Data policy in AstroParticle Physics (data sharing, data access), starting with multi messenger high energy astronomy
- High energy and ultra-high energy multi-messenger astronomy (neutrinos, gamma rays, cosmic rays, gravitational waves)
- Messages to APIF
- Plans for next meetings

General conclusions on Data Policy taken from gravitational waves antennas remarkable practices

- Ground gravitational antennas: bottom-up approach, science driven data policy
- LISA (space gravitational antenna): space agency data policy (public funding implies open data policy like in the US)
- General considerations: avoid false discoveries, give proper credit by quoting properly the used data release (collaboration), resources have to be planned from the very beginning with funding agencies

The Advanced GW Detector Network and Lisa examples

E. Coccia, chair of GWIC, P. Binetruy, APC



Data policy (5 tempos) for high energy multimessenger astronomy

- Data validation (Collaboration)
- First data releases for joint analysis (Collaborations)
  - For combinations and mutual cross-checks
  - For complementary approaches
- Open trigger on or off line (for collaborations of gravitational antennas or multi-messenger astronomy)
- Data in open access for the community (get the collaboration and the community prepared, virtual observatory model and help-desk?)
- Data preservation and legacy

How to implement?

- ApPIC has a session on this topic in the next TAUP 2015 and ICRC
- This would be a discussion with the community on guiding rules for data policy in Astroparticle Physics (more tricky for dark matter, double beta decay..)
- ApPIC would come back to APIF and serve on this item as an interface between APIF and the community (one of the roles of ApPIC)

Plans for next ApPIC meeting

- 2015, April 19, 20 and 21th: global neutrino meeting in Fermilab. Joint meeting of ApPIC and ICFA-Neutrino panel. ApPIC will focus on astroparticle physics capabilities and opportunities of the discussed proposals, beyond measuring neutrino properties (now done).
- ICRC and TAUP 2015 august and september 2015: astroparticle physics data policy (interaction with the community), coherence and priorities in high and ultrahigh energy neutrino astronomy (interaction with the community)

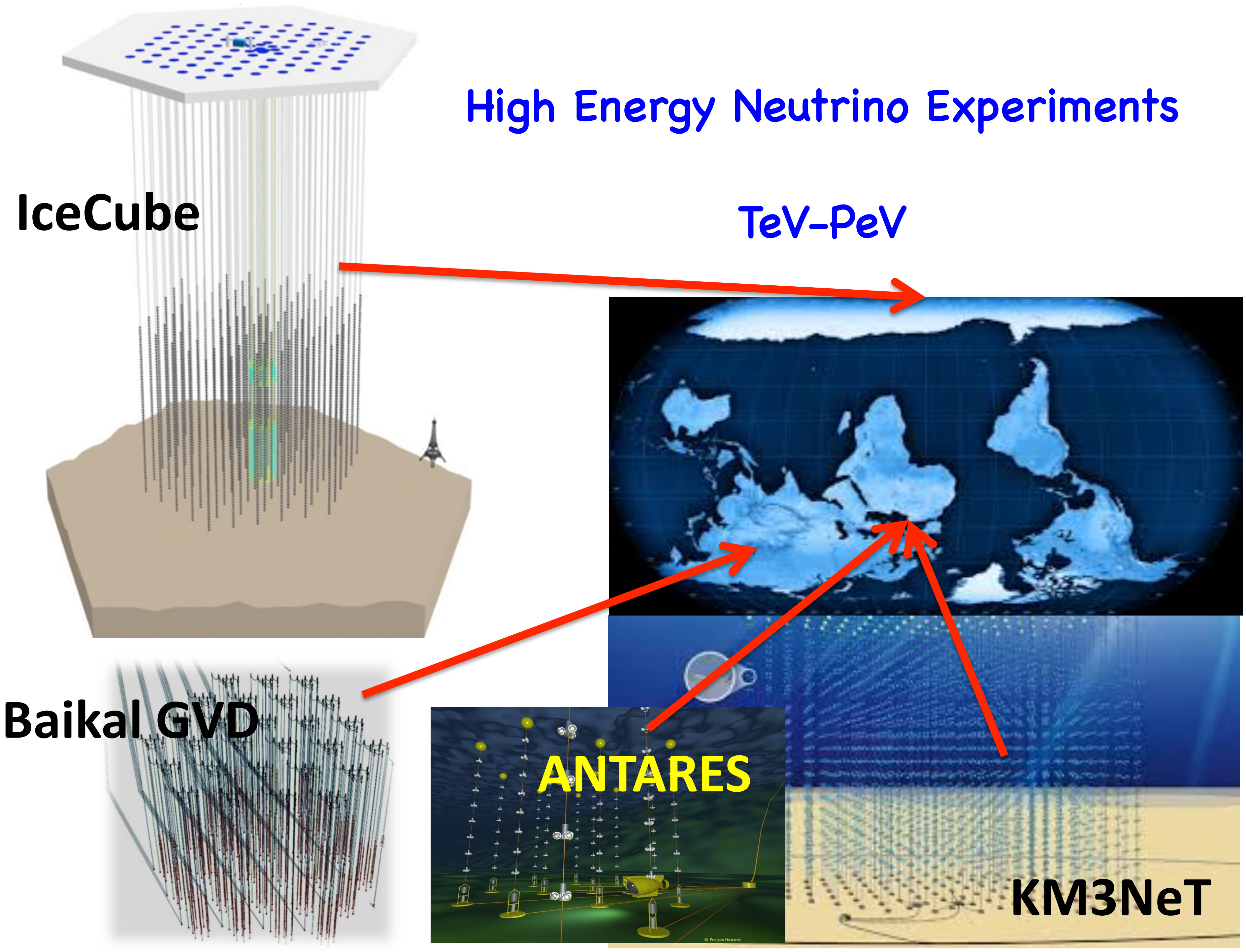
ApPIC report today: interplay between the neutrino programe and the cosmic frontier

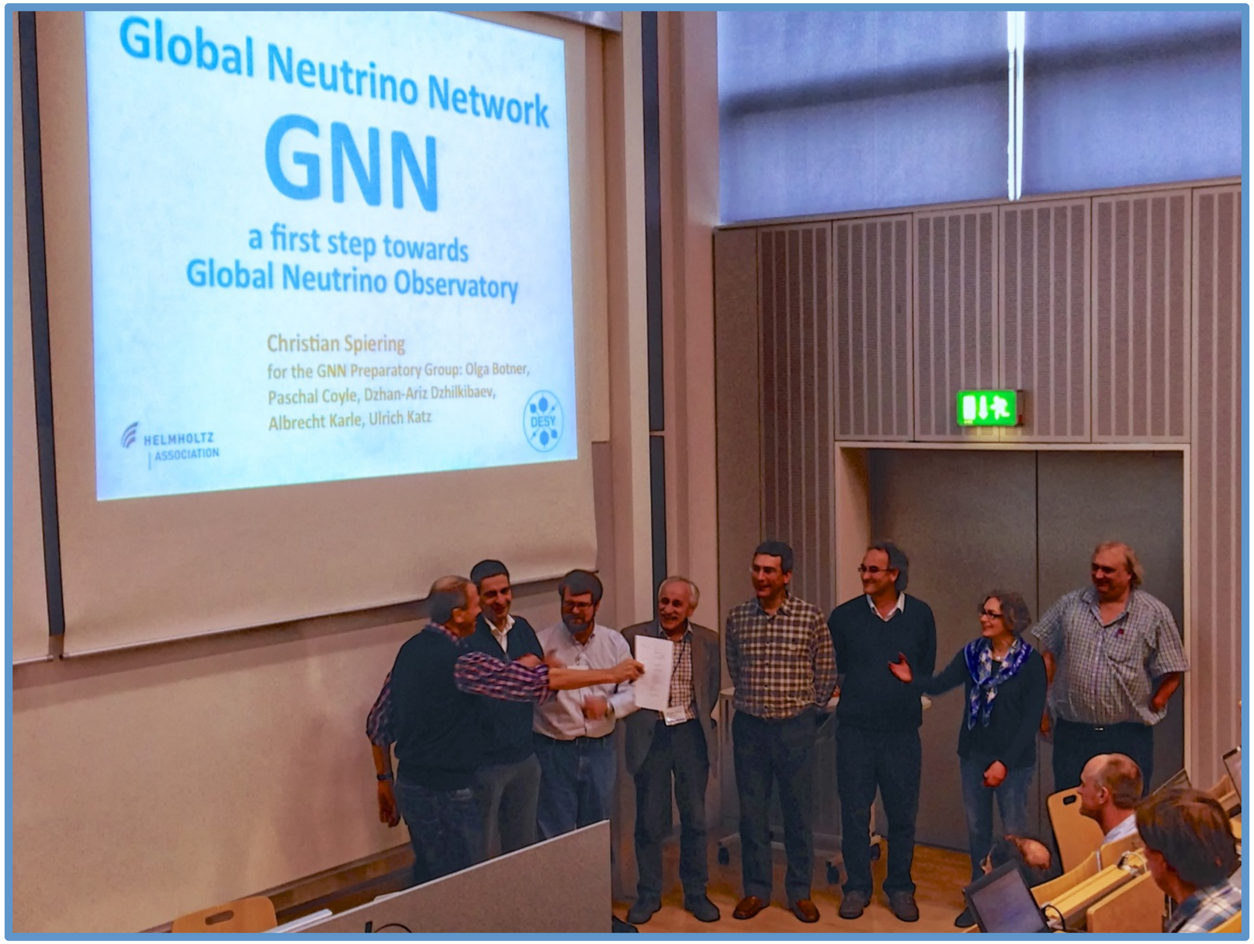
- Multi Messenger High energy astronomy : High energy phenomena in the Universe, violent phenomena, interplay with neutrino experiments
- Atmospheric neutrino experiments and mass hierarchy, p decay, SN searches capabilities: historical interplay between these subjects. Complementarity with reactor, double beta decay, accelerator approaches

- Cosmology and neutrinos: a promising frontier

HIGH and ULTRA HIGH ENERGY MULTI-MESSENGER ASTRONOMY

- Gravitational waves astronomy
- Gamma-ray astronomy
- High energy cosmic ray astronomy
- Neutrino astronomy ← today


High Energy Neutrino Experiments
TeV-PeV
IceCube
Baikal GVD
ANTARES
KM3NeT

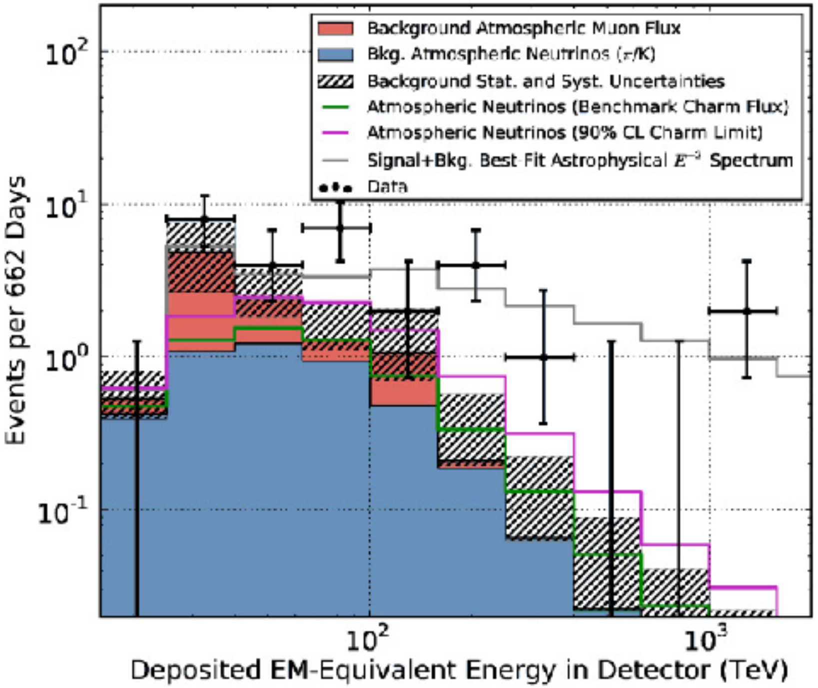


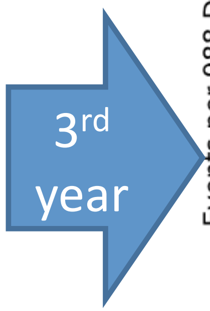
- Oct. 2013, Munich

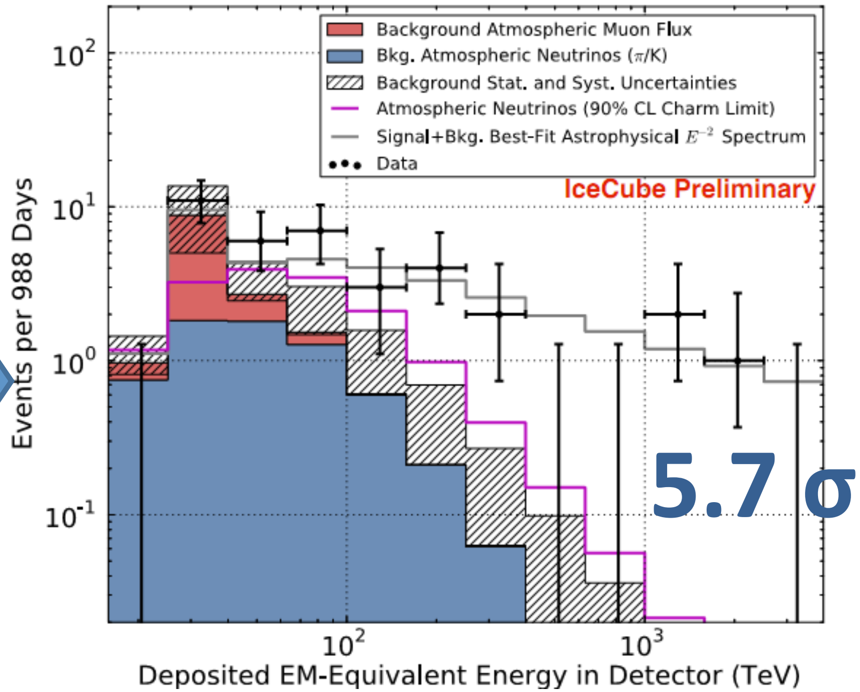
- Antares
- Baikal
- IceCube
- KM3NeT

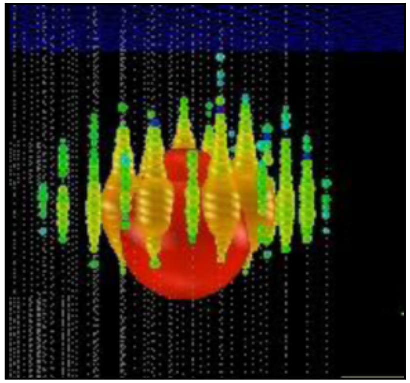
- http://www.globalneutrinonetwork.org/

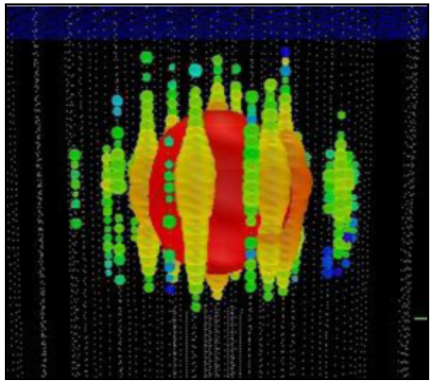
HE neutrino astronomy results IceCube

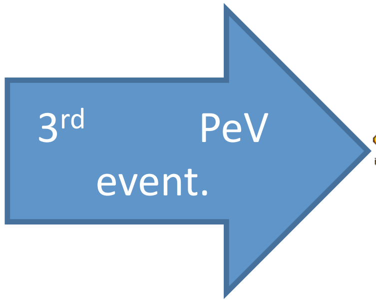


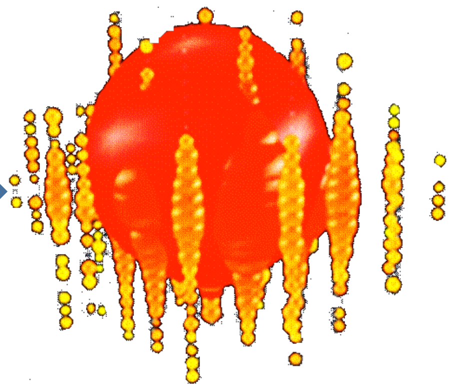








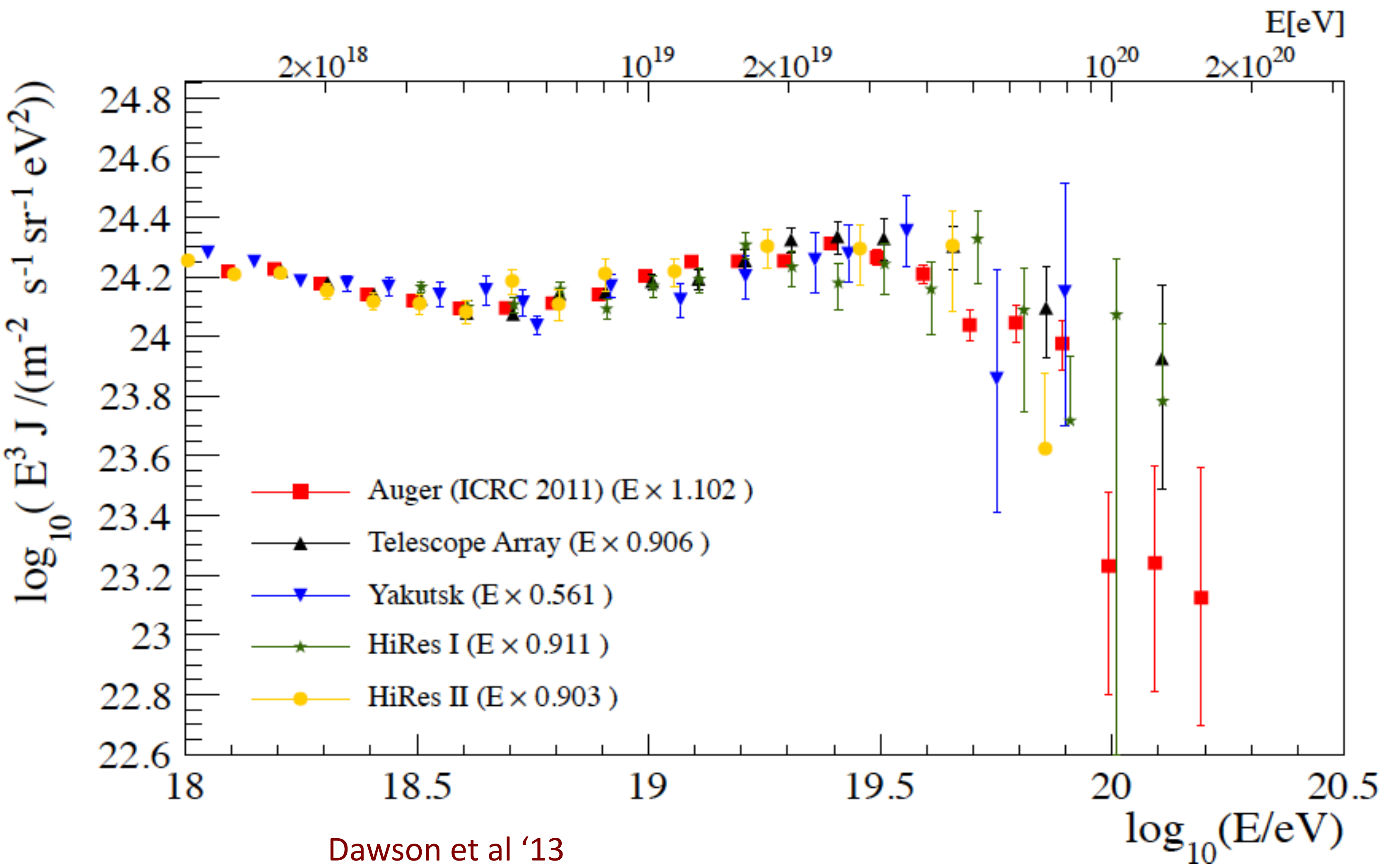




AUGER plus Telescope array CR

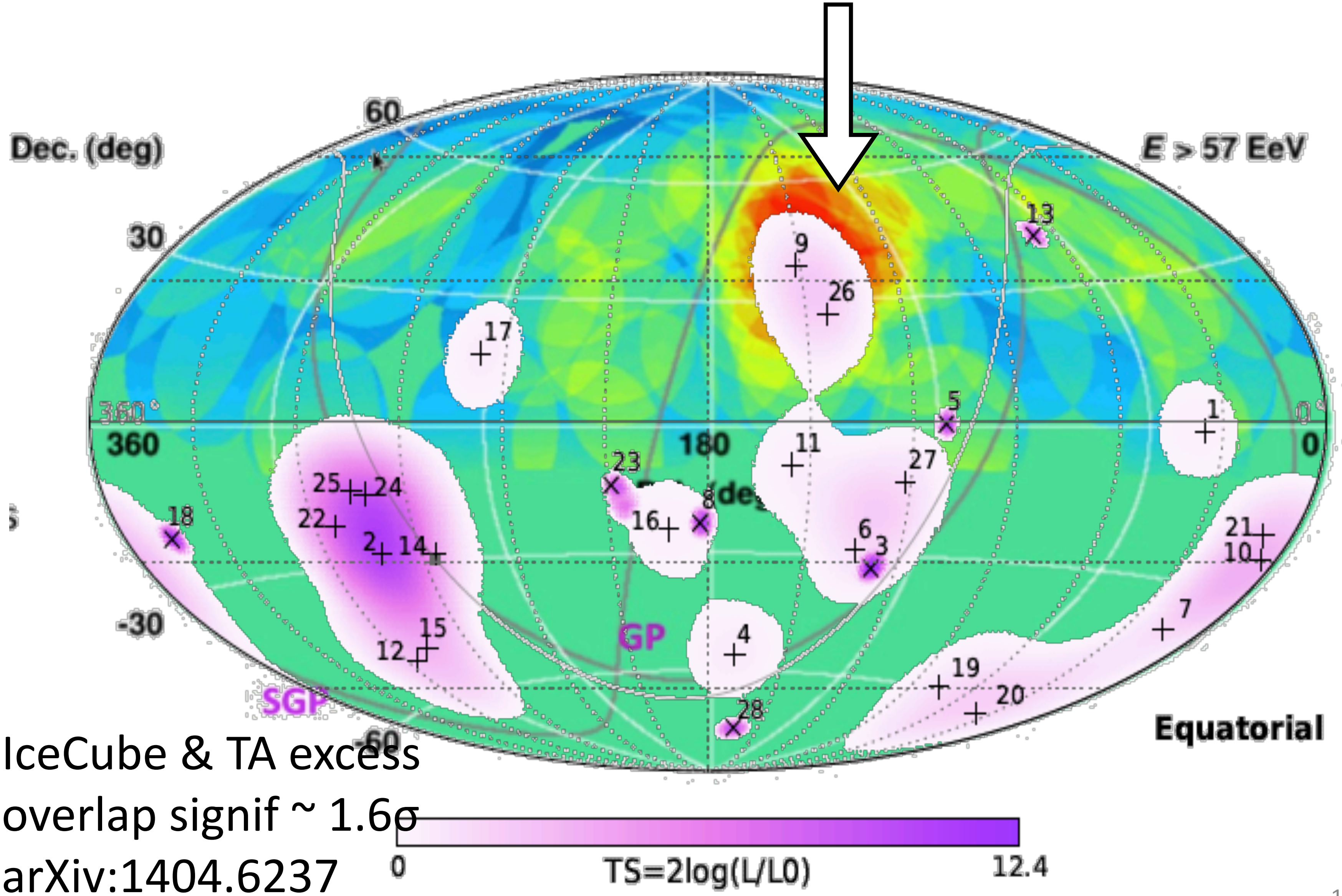
Unified Spectrum

Energies re-scaled ~10%

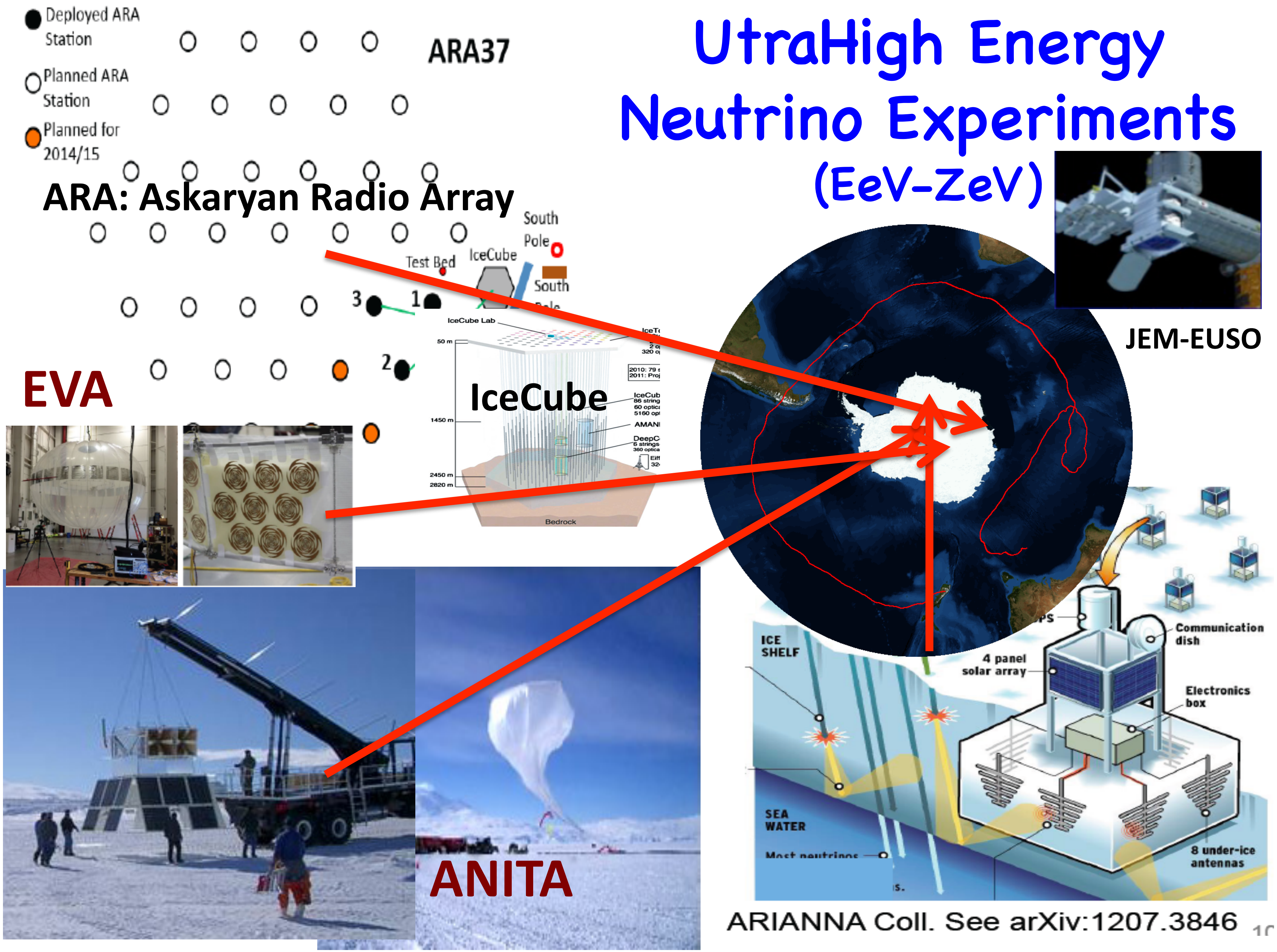


Dawson et al ‘13

Neutrino & UHECR Coincidence

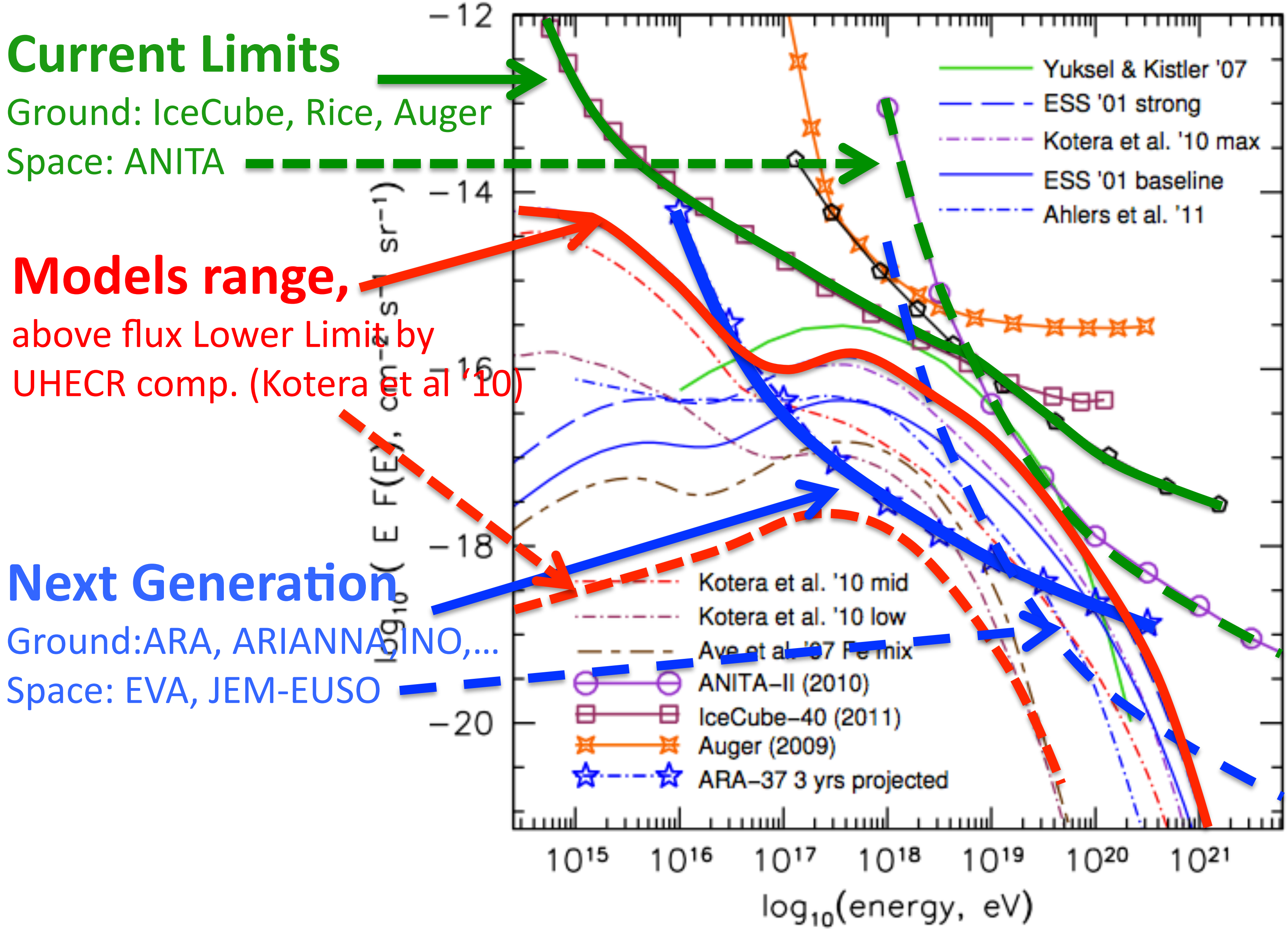


IceCube & TA excess
overlap signif ~ 1.6σ
arXiv:1404.6237



UtraHigh Energy
Neutrino Experiments
(EeV-ZeV)
Deployed ARA Station
Planned ARA Station
Planned for 2014/15
ARA37
ARA: Askaryan Radio Array
South Pole
Test Bed
IceCube
South
3
1
2
EVA
IceCube Lab
50 m
1450 m
2450 m
2820 m
IceCube
Bedrock
JEM-EUSO
ICE SHELF
SEA WATER
4 panel solar array
Communication dish
Electronics box
8 under-ice antennas
ANITA
ARIANNA Coll. See arXiv:1207.3846

EeV Neutrino Detectors



High and ultra high energy multi-messenger astronomy

- Gamma ray astronomy paves the way, gives the reference map of the high energy sky (Thousands of sources): CTA next very large infrastructure
- Strong evidence for extraterrestrial TeV to PeV neutrinos. Origin unknown.
- Cut-off of the cosmic ray high energy spectrum seen: composition (p or Fe) near the cut-off debated. Origin unknown.
- Gravitational waves will enter the game soon and open new questions
- Multi messenger approach crucial, including gravitational waves and conventional astronomy (open data policy, virtual observatories including these new messengers will help)

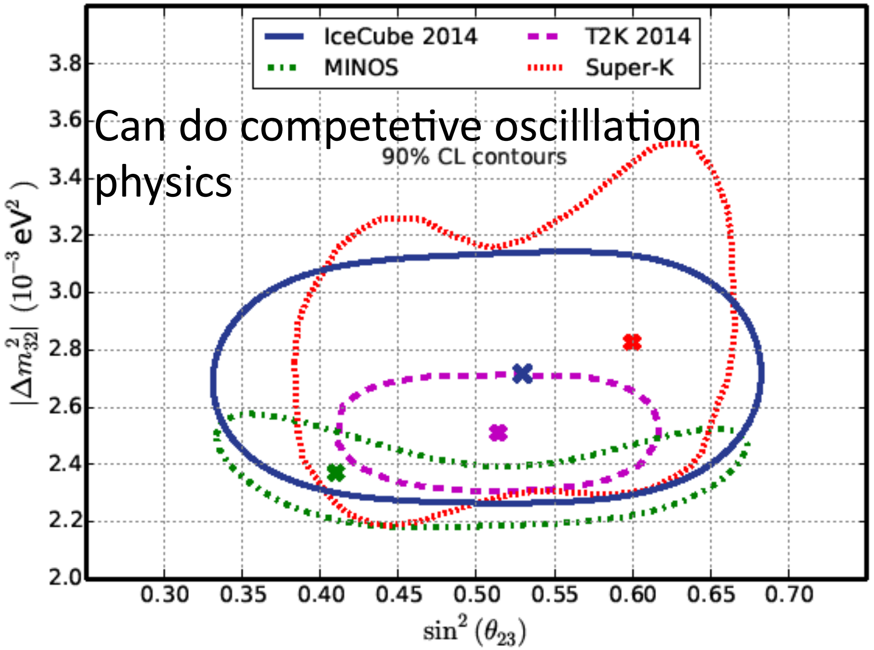
NEUTRINO PROPERTIES AND BSM

- Mass hierarchy and atmospheric neutrinos
- P decay, SN
- Double beta decay, single beta decay not discussed yet by ApPIC

PINGU and ORCA

- Predecessors
  - Amanda (turned of 2009)
  - IceCube with DeepCore
- Part of IceCube-Gen2
  - PINGU
  - High-energy extension
  - Surface veto

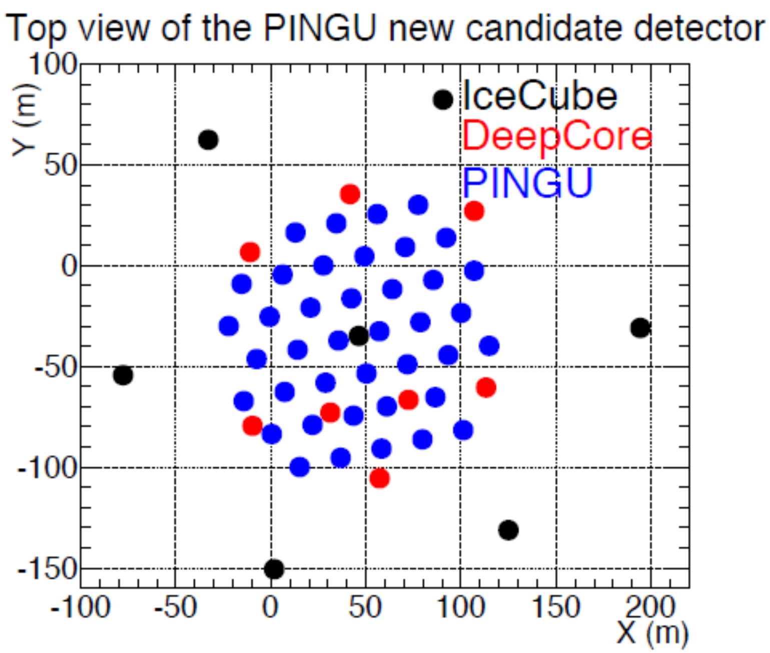
- Predecessor
  - ANTARES
- Part of KM3NeT
  - ORCA
  - ARCA for high energy ν astronomy



Design

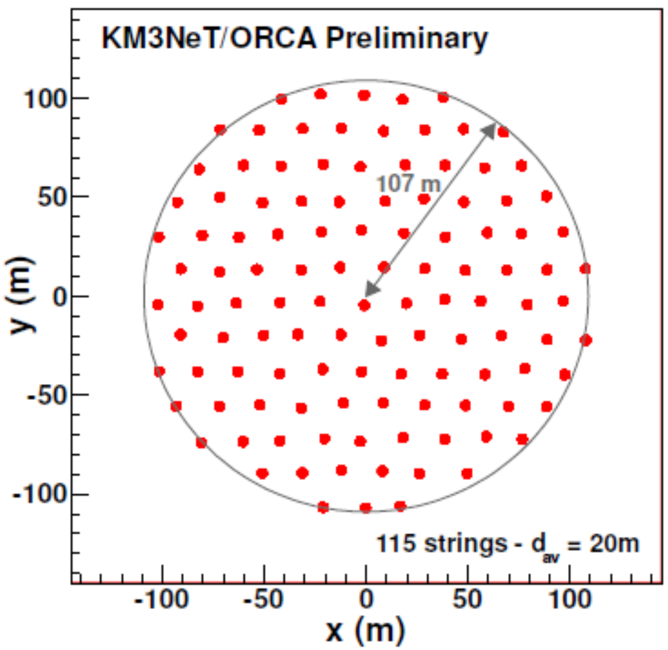
PINGU

- 40 new strings + 9 old strings
- 60 → 80-96 DOM/string



ORCA

- 115 strings
- 18 mDOMs/string



Design

PINGU

- 40 new strings + 9 old strings
- 60 → 80-96 DOM/string
- Effective mass ~ 2.5 Mt (5 GeV)
  3.5 Mt (10 GeV)
- Construction 2020-2023
- Cost ~ 70 M$

ORCA

- 115 strings
- 18 mDOMs/string
- Effective mass ~ 2.5 Mt
  ~ 3.5 Mt
- Construction 2017-2020
- Cost ~ 50 M€

Design

PINGU

- 40 new strings + 9 old strings
- 60 → 80-96 DOM/string
- Effective mass ~ 2.5 Mt (5 GeV)
  3.5 Mt (10 GeV)
- Construction 2020-2023
- Cost ~ 70 M$

ORCA

- 115 strings
- 18 mDOMs/string
- Effective mass ~ 2.5 Mt
  ~ 3.5 Mt
- Construction 2017-2020

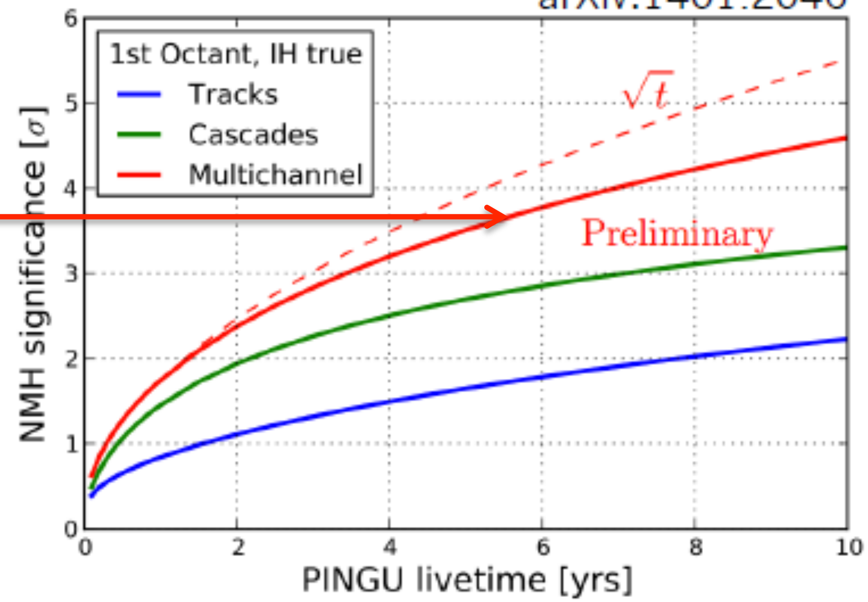
Chance to get the first 3σ effect on NMH from a single experiment in 2023

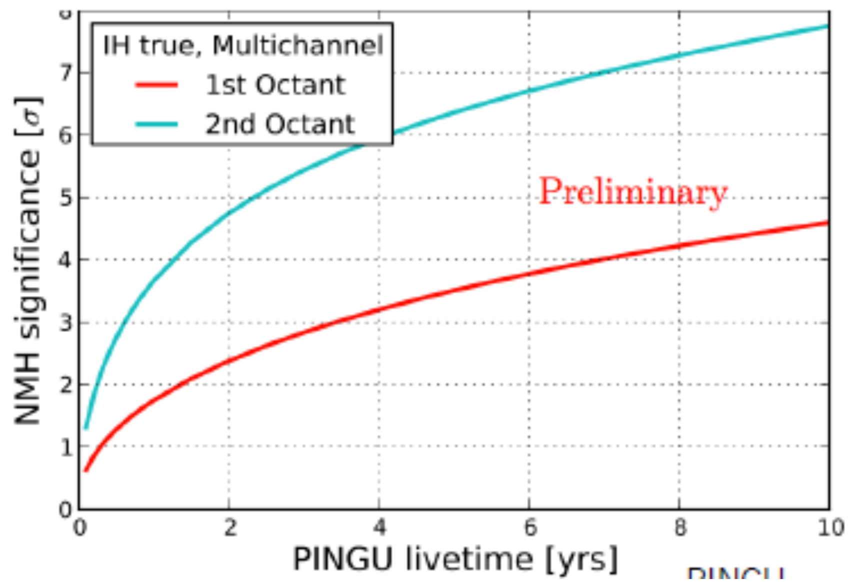
Significance vs. time

From PINGU LoI

- Need both tracks and cascades
- 3 σ after 3 years for $\sin^2\vartheta_{23} \sim 0.4$
- 3 σ after 2 years for $\sin^2\vartheta_{23} \sim 0.5$
- 3 σ after 1 year for $\sin^2\vartheta_{23} \sim 0.6$
- Would improve with better input on cross section and spectral shape
- Would improve with better analysis, detector optimization
- Could slightly worsen due to systematics

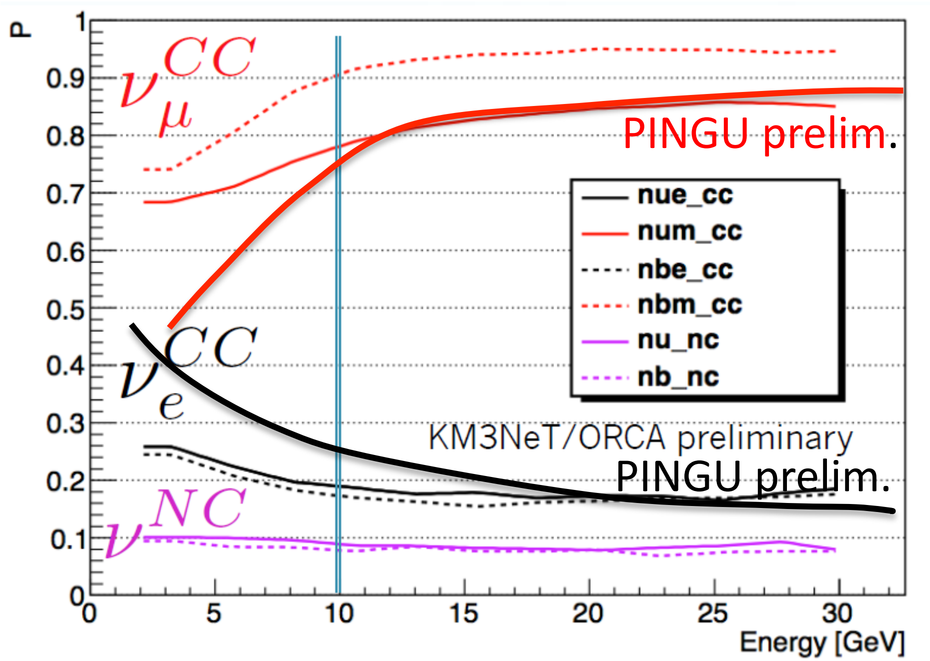
arXiv:1401.2046





Detector specific systematics

- Example Flavor identification:
  ORCA:
  less light scattering, homogeneous medium
  → better pattern recogniction
  → better flavor ID below 10 GeV

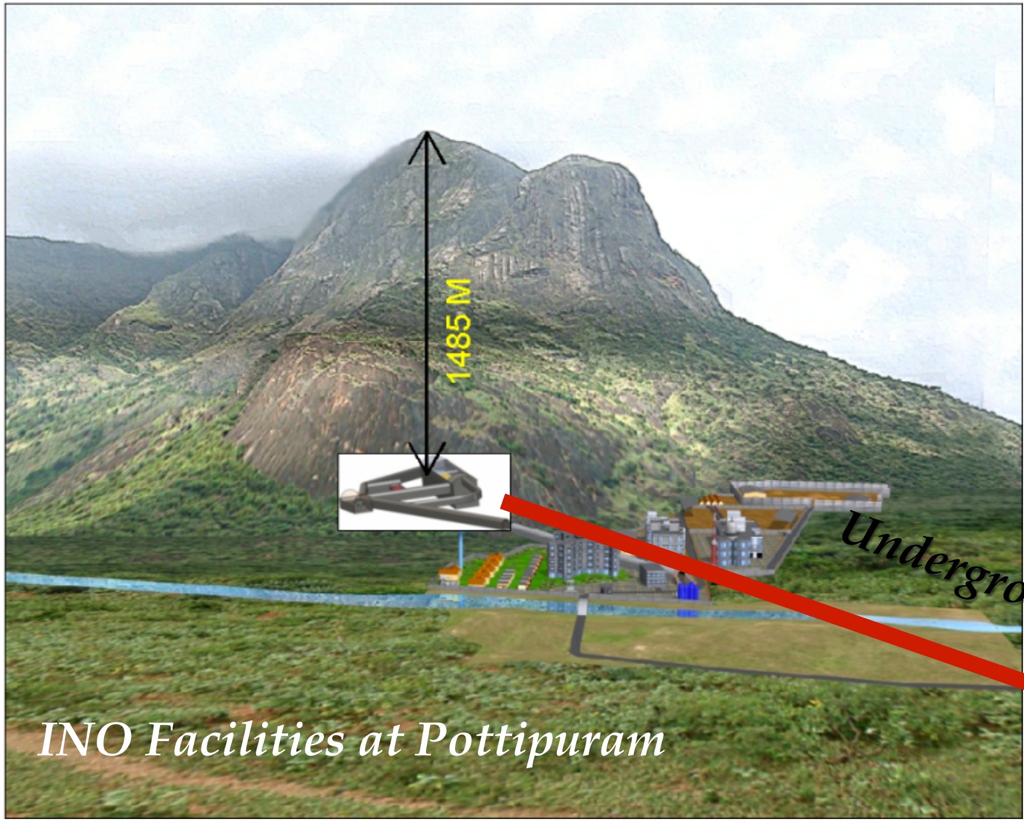


- Example downward mu veto, extrapolation to higher energies:
  - PINGU is embedded in DeepCore
  - DeepCore is embedded in IceCube
  - Both act as extremely efficient veto against downward muons
  - Atm ν spectrum is measured with high statistics/accuracy toward high energies
    → normalization

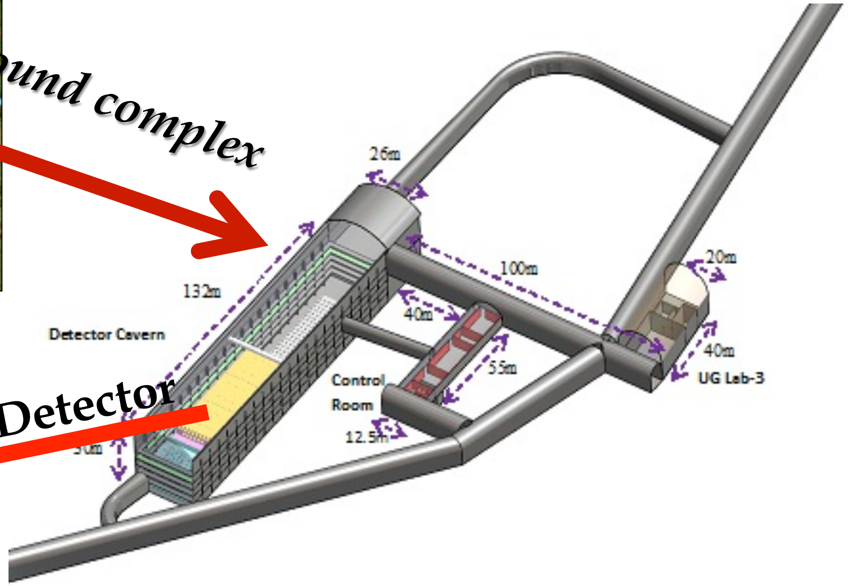
Complementary systematics due to detection medium and to detector configuration!

Conclusion on ORCA and PINGU

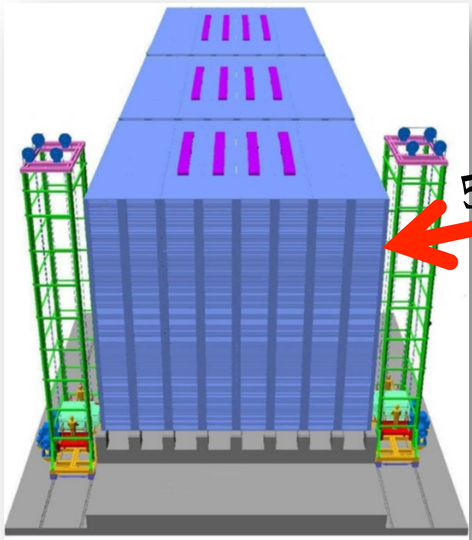
- PINGU and ORCA have different systematics – high complementarity!
- Both with ~ 2 to 5 σ after 3 years
- PINGU and ORCA will continue their successful cooperation on systematic effects and significance calculation
- Prototype results from 6 strings ORCA expected in 2016/17
- Milestone 2017/18: Comparative process on science and technology, in particular the performance of prototypes and systematics.
- Very likely that two detectors at 2 different sites turn out to be the optimum approach.



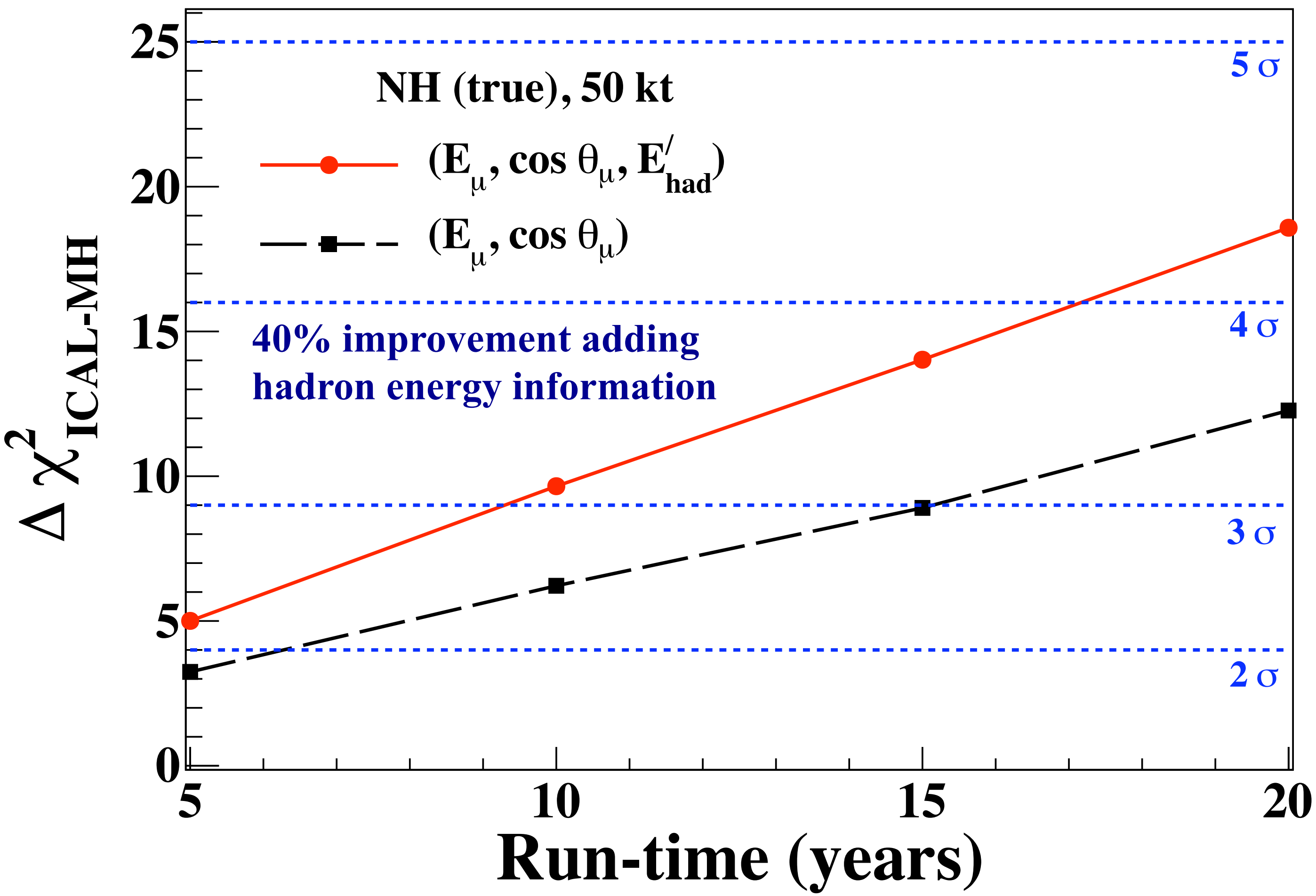
Underground complex



50 kton ICAL Neutrino Detector



Identifying Neutrino Mass Hierarchy with INO-ICAL

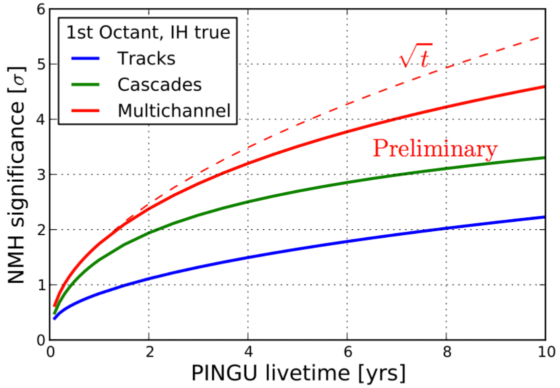


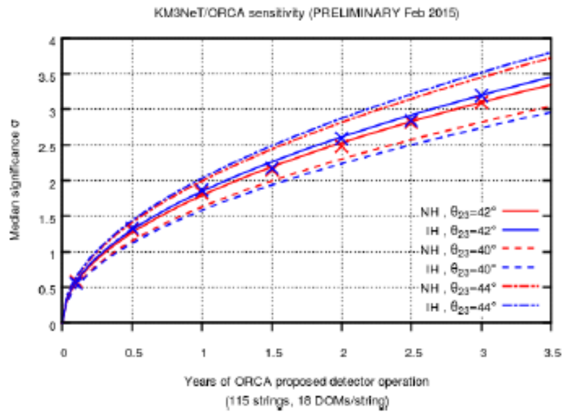
Median Sensitivity

Devi, Thakore, Agarwalla, Dighe, arXiv:1406.3689 [hep-ph] (INO Collaboration)

50 kt ICAL can rule out the wrong hierarchy with $\Delta\chi^2 \approx 9.5$ in 10 years

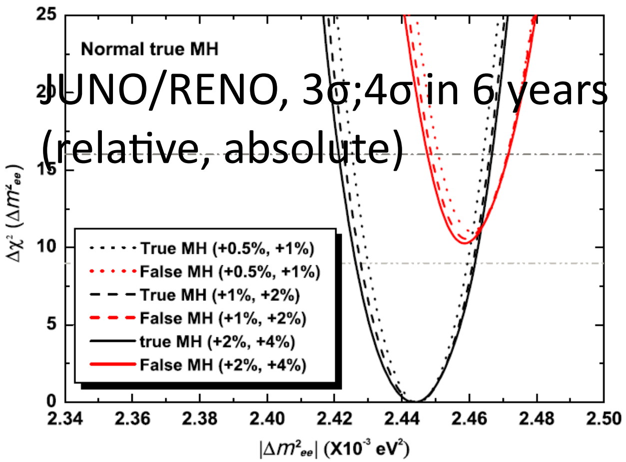
Mass hierarchy with atmospheric and reactor neutrinos

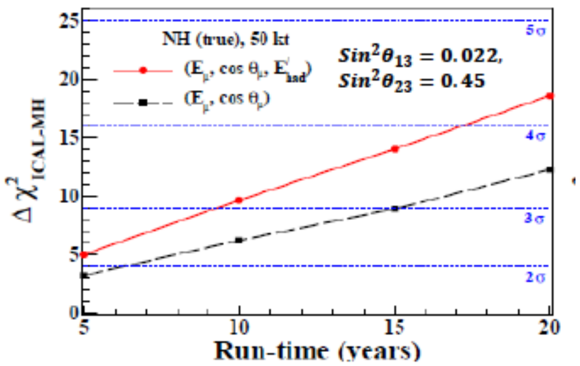


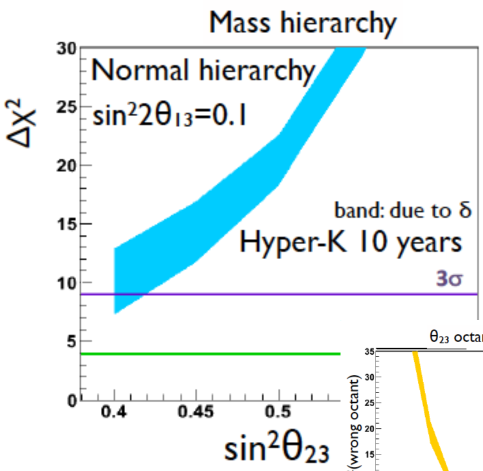


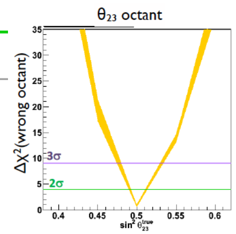
1. ORCA/PINGU 3σ in 3 years, (early 20's) 5σ in 10 years 60 M$
2. JUNO/RENO 3-4 σ in 6 years (2025) 500 M$
3. DUNE, HK , INO 3-5σ ca 2035 ca G$

JUNO/RENO, 3σ;4σ in 6 years (relative, absolute)









Cao, Majumder, Boser, Eberl

Non-oscillation vibrant programs

- **PINGU and ORCA:**
  - SN neutrinos (just time profile and mean ν-energy)
  - low-energy GRB
  - WIMPs, Exotic particles (Magn. Monopoles etc.)
- **JUNO and RENO-50:**
  - p-decay
  - SN neutrinos
  - Geo-neutrinos
- **Hyper-K:**
  - Solar neutrinos
  - p-decay
  - SN neutrinos (incl. relic SN)
  - WIMPs, Exotics (magnetic monopoles etc.)
- **INO:**
  - Atm. nu and anti-nu separately
  - Precision study of HE muon energy loss
  - SN neutrinos
  - WIMPs, Exotics (Magnetic Monopoles etc.)
- **DUNE:**
  - p-decay
  - SN neutrinos (incl. relic neutrinos)
  - Solar neutrinos

The DUNE Sandscape for p→Kν

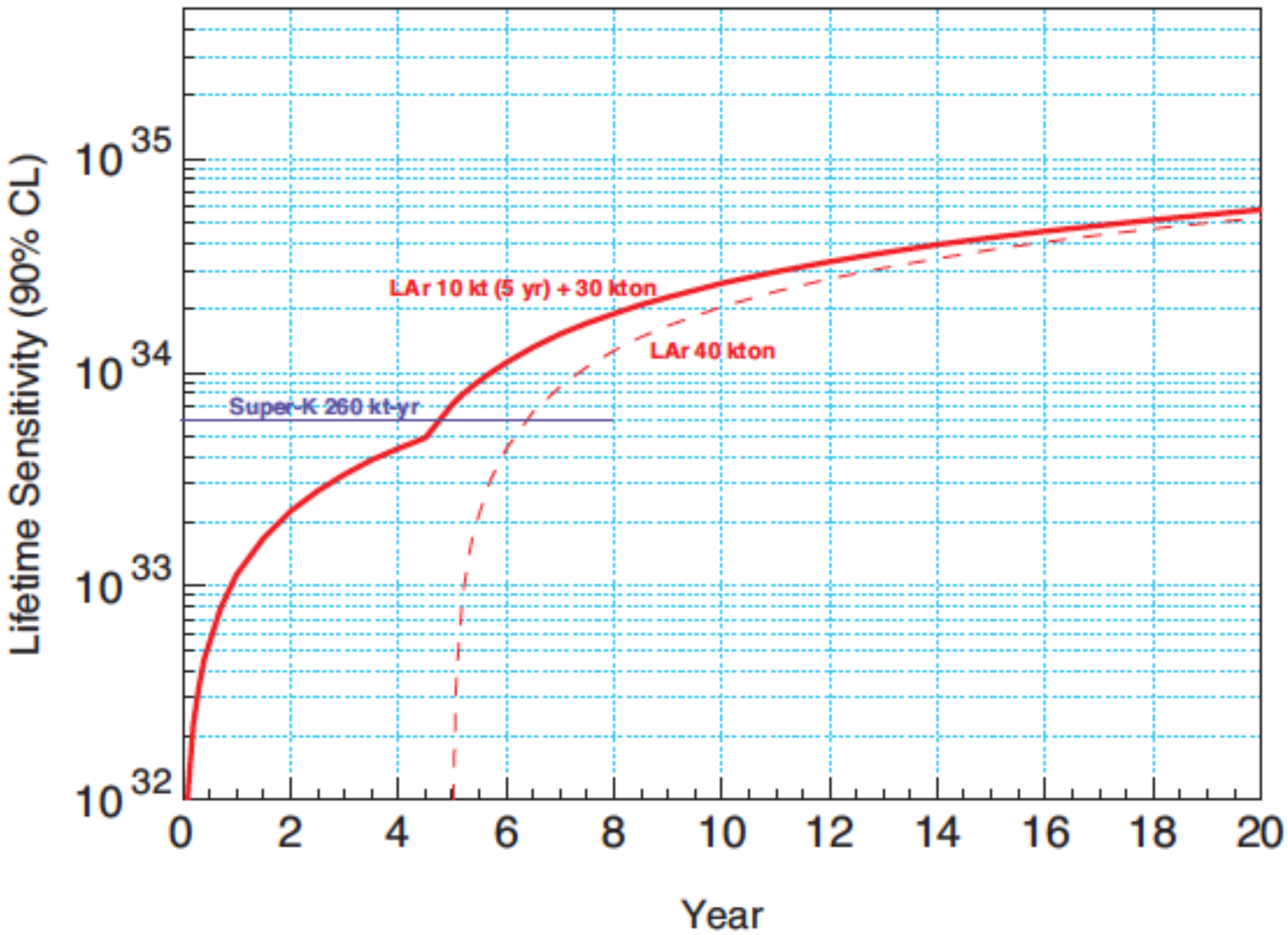
- Recently (c. LOI) updated plot from Ed Kearns:

Assumptions:

Efficiency = 97 %
Background = 1 evt/Mt-y
(from Bueno et al 2007)

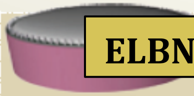
It is clear we will never be able to do (much) better than this, short of adding more fiducial mass.

Note: should partial lifetime be at 1 x 10^{34}, There will be ~10 events in 400 kt-yr DUNE run w/ < 1 background event



Again, the 3 techniques give complementary information SK in Venice

Outstanding physics goals

	 ELBNF x 2,5	 JUNO x 2,5	 HK
Total mass	100 Kton	50 kton	500 Kton
p -> $e\pi^0$ in 10 y	0.5 x 10^{35} y ε = 45%, ~1 BG event	?	1.2 x 10^{35} y ε = 17%, ~1 BG event
p -> ν K in 10 y	1.1 x 10^{35} y ε = 97%, ~1 BG event	0.4 x 10^{35} y ε = 65%, <1 BG event	0.15 x 10^{35} y ε = 8.6%, ~30 BG events
SN cool off at 10 Kpc	38·500 (all flavors) (64·000 if NH-L mixing)	20·000 (all flavors)	194·000 (mostly ν_ep->e $^+$n)
Sn in Andromeda	7 - (12 if NH-L mixing)	4 events	40 events
SN burst at 10 Kpc	380 ν_e CC (flavor sensitive)	~ 30 events	~ 250 ν-e elastic scattering
DSN	50	20-40	250 (2500 with Gd)
Atm. neutirnos	~1·100 events/y	5600/y	56·000 events/y
Solar neutrinos	324·000 events/y	?	91·250·000/y
Geo-neutirnos	0	~ 3·000 events/y	0

T. Patzak, APC, University Paris Diderot, TAUP2011, 5 – 9 September 2011, Munich, Germany

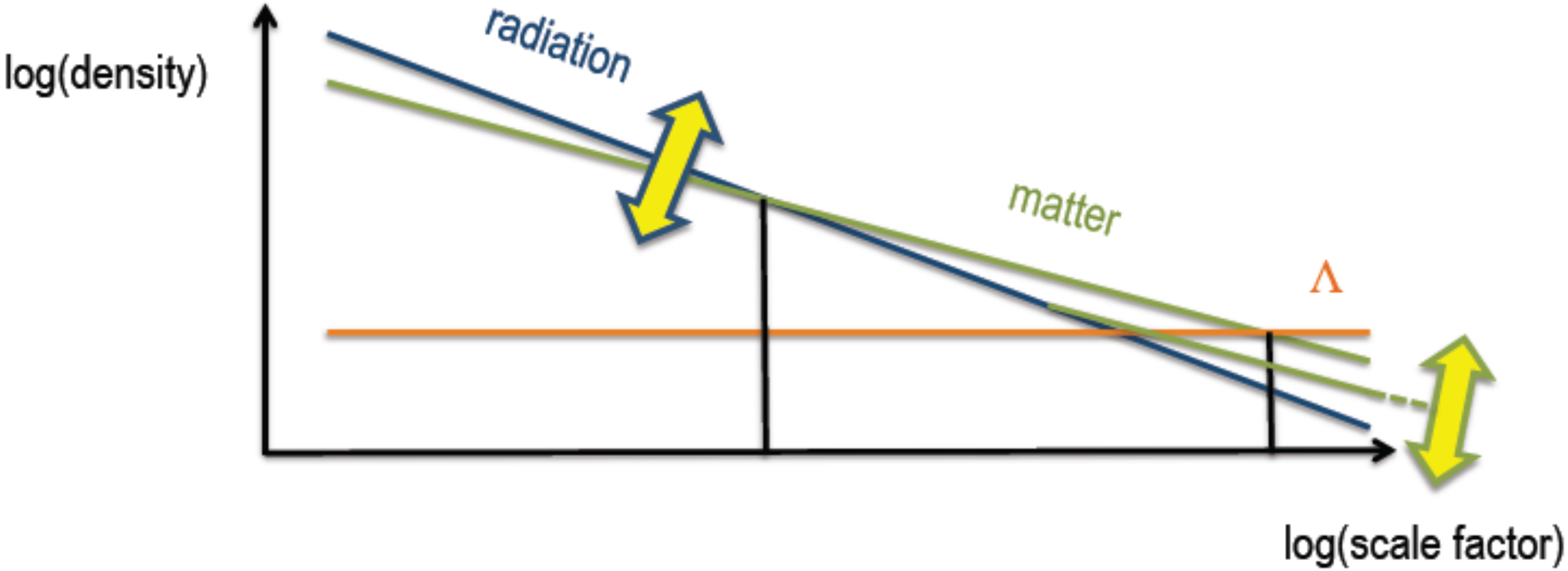
COSMOLOGY AND NEUTRINOS

- Dark matter: not discussed yet by ApPIC
- Constraints from cosmology on neutrinos

What does cosmology actually probes?

TWO independent questions:

- Is there extra radiation on top of photons and standard neutrinos?
- Is part of the radiation content becoming non-relativistic at late times (HDM) ?

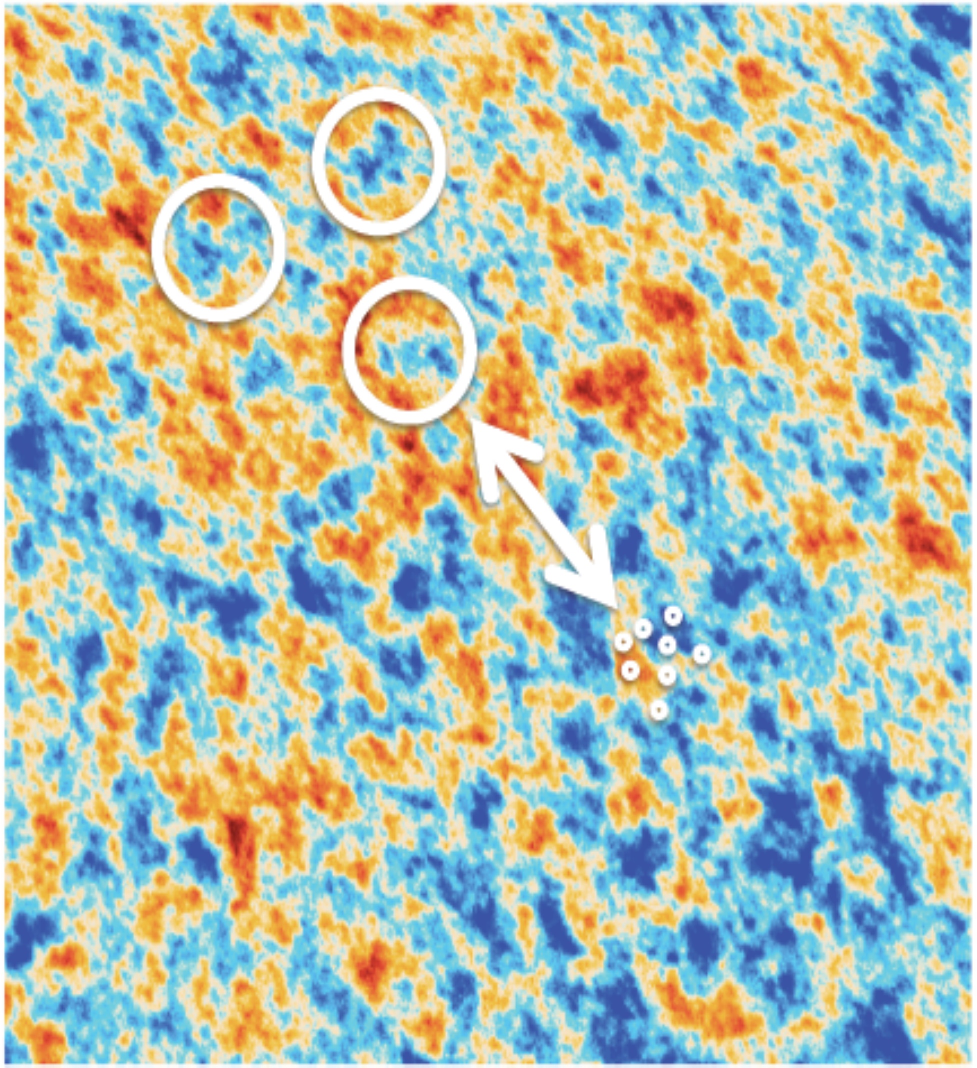


Different observables

- Is there extra radiation on top of photons and standard neutrinos?

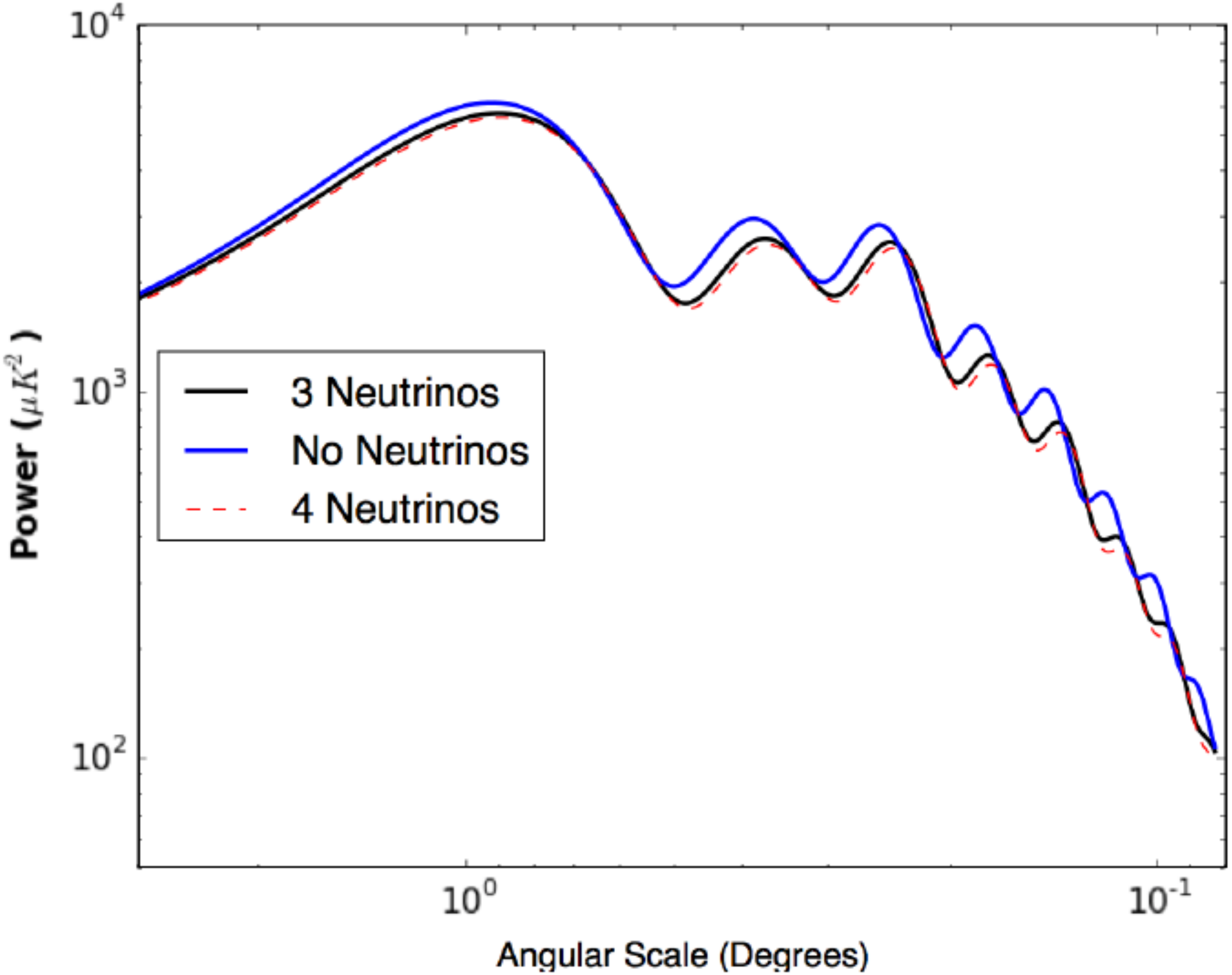
More species, more rate of expansion,
age at recombination smaller

- CMB:
  peak scale relative to diffusion scale,
  peak amplitude patterns



- LSS:
  BAO peak patterns

More neutrinos → More Damping
→ Less power on small scales



Different observables

- Is part of the radiation content becoming non-relativistic at late times (HDM) ?

  - LSS

    less dark matter fluctuations on small scales

    Probed by:

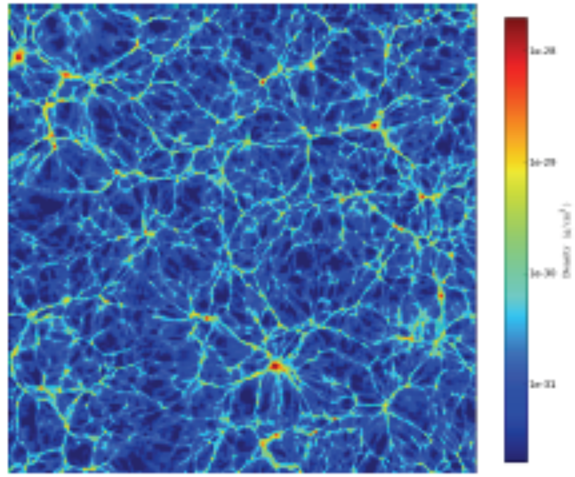
    - galaxy correlation
    - galaxy cosmic shear
    - cluster abundance
    - CMB lensing
    - Lyα forests in quasar spectra

    Depends on scale and time/redshift

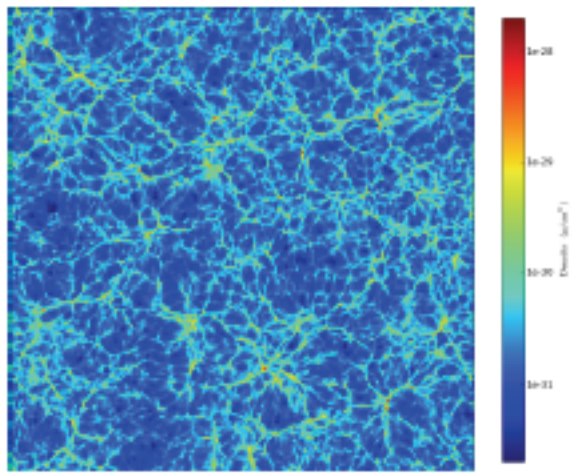
  - Primary CMB

    depletion from eISW

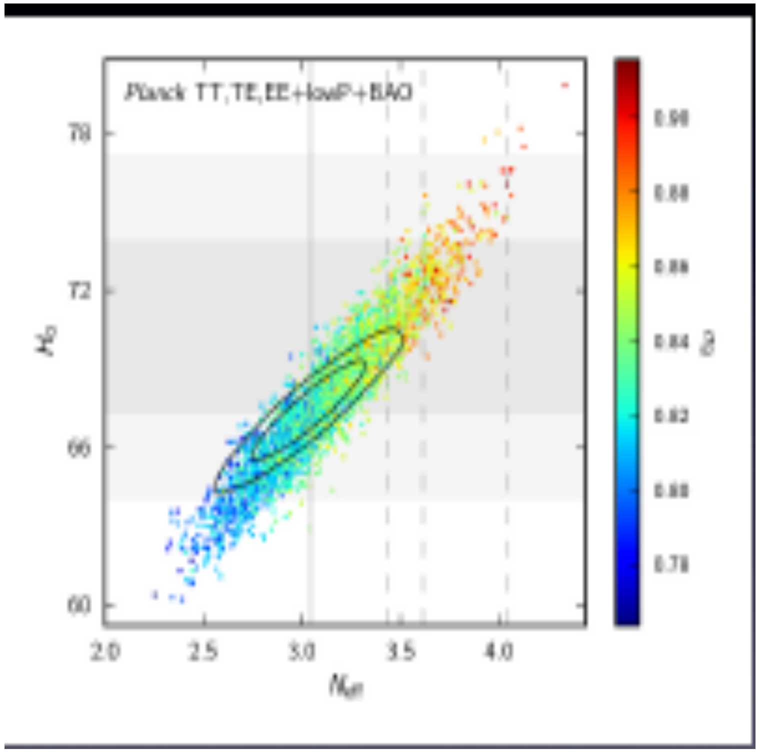
reference

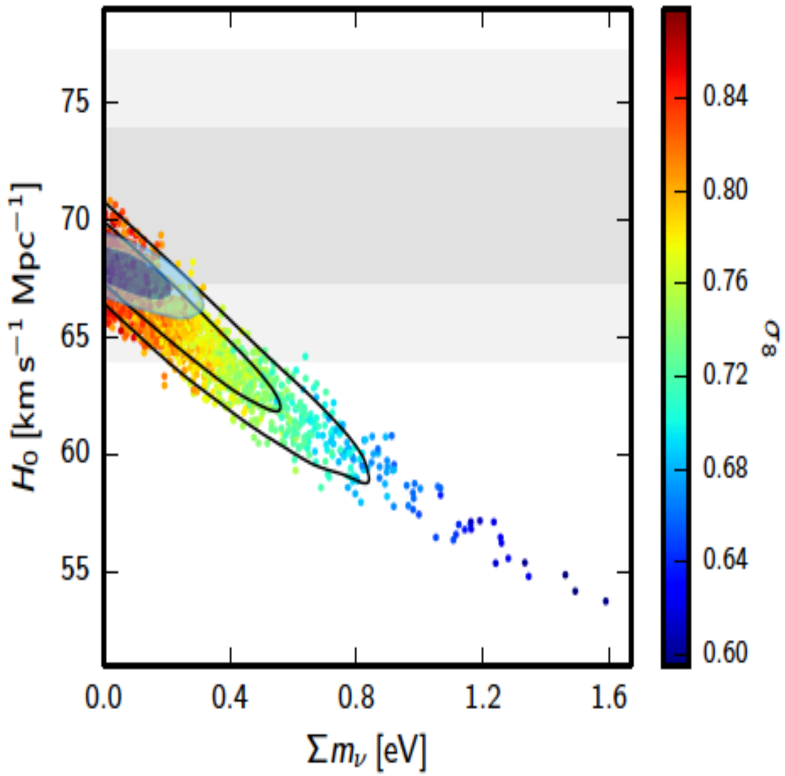


with hot component



Neff and Σm_ν from Cosmology





Conclusions

- The current constraints on $\sum m_\nu$ from cosmology are already stringent:
  - $\sum m_\nu < 0.25$ eV (95% CL) from combination of Planck + BAO
  - $\sum m_\nu < 0.14$ eV (95% CL) from Ly-alpha forest + CMB+ BAO
- In the future these limits will improve significantly to < 20 meV (1sigma) and may allow detection of $\sum m_\nu$ determination of the mass hierarchy with two or more independent probes:
  - DESI matter power spectrum
  - S4 CMB polarization + DESI BAO
  - Galaxy lensing from LSST/Euclid
- Cosmology will test SM prediction of N_{eff} = 3.046 to +/- 0.02
- Cosmology measurements are complementary to reactor and accelerator experiments, 0v2b experiments, and b−decay experiments
- We recommend increased dialogue between these communities

Future Σm_ν and Neff measurements (2025-2030): SK in Venice

- **What if we do not detect the minimal model?**

If the minimal neutrino sector, with $\Sigma m_\nu = 58$ meV and $N_{eff} = 3.046$, is **not** *robustly detected, it would imply something is "broken" in another aspect or aspects of cosmology, including possibly:* non-constant dark energy, a non-power-law primordial perturbation spectrum, extra particle or radiation species, non-zero curvatu[re], as well as other possibilities, e.g., a nonthermal cosmological

$\sigma(\Sigma m_\nu) = 16$ meV &
$\sigma(N_{eff}) = 0.020$

An order of magnitude

Conclusion (from Carlo statements)

- In conclusion, the neutrino is so far the only elementary fermion whose basic properties are still largely unknown and promises new physics beyond the Standard Model of Particle Physics while at the same time explores avenues beyond Standard astrophysics and the Standard Model of Cosmology, through neutrino astronomy and through the comparison of laboratory measurements with measurements of neutrino number and masses obtained with increased precision by cosmological surveys.

IMPORTANCE OF THIS MEETING

- Gather scientists, decision makers, different regions
- A look forward to Large neutrino infrastructures
- Help to have an integrated vision of the field: (Manfred Lindner): accelerator and non-accelerator, particle physics and the cosmic frontier

- mega-projects (road maps etc.)
- medium size projects (training of young people, attractiveness, diversity, …)
- R&D (new methods) while we do big and medium size projects : only a few of many new ideas will work