Report from ApPIC/IUPAP (Astroparticle Physics International Committee) to ICRC 2015

Michel Spiro

July 31, 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
Ani Aprahamian (USA) C12 Observer

What have we discussed so far ?

First meeeting May 9, 2014:

- 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

Meeting with ICFA neutrino panel and presentation at the 2nd International Neutrino Large Infrastructure April 21, 2015:

- Neutrino physics: interplay between accelerator and non accelerator experiments
- Cosmology and neutrinos

I will report mostly on the first point today

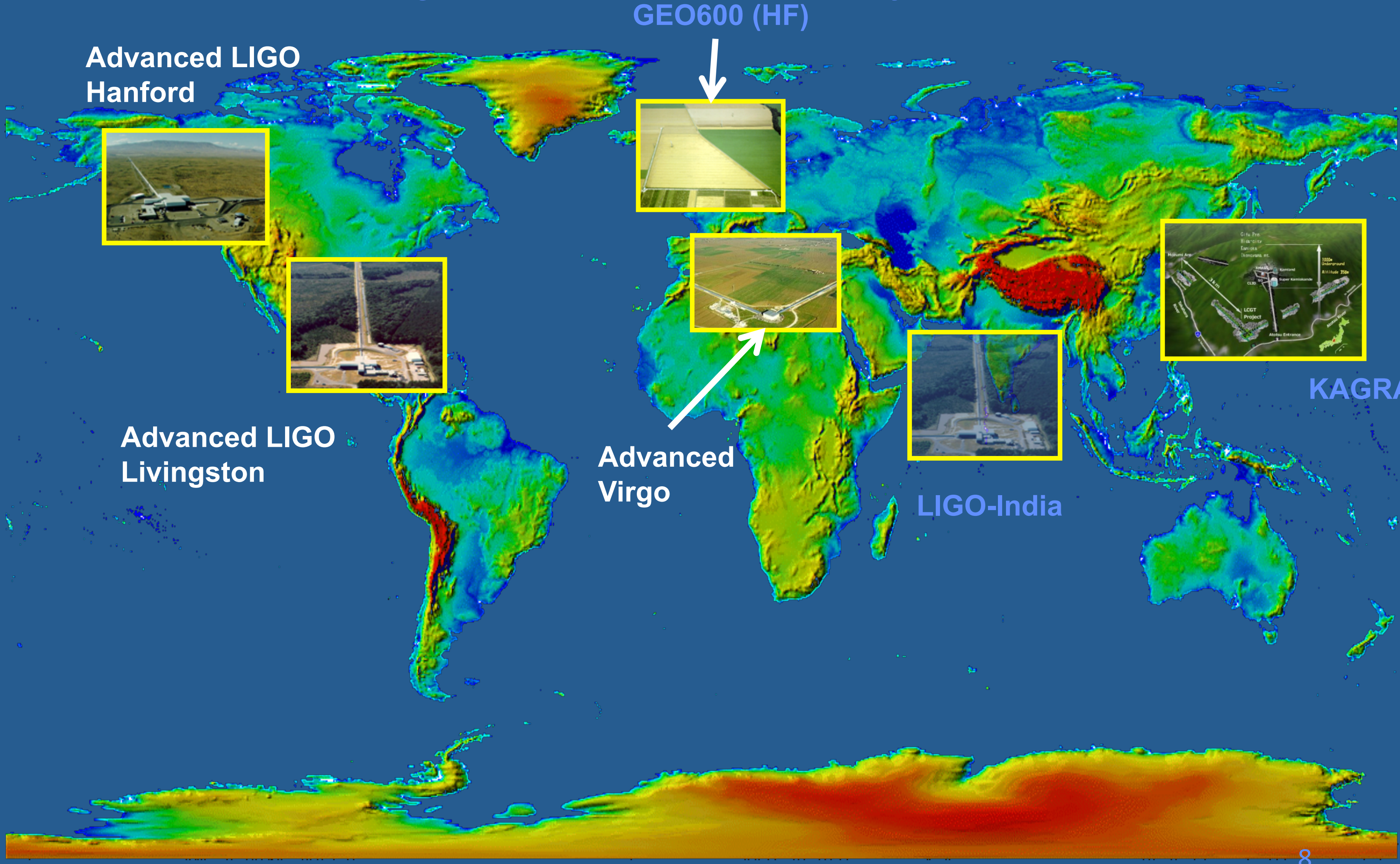
HIGH and ULTRA HIGH ENERGY MULTI-MESSENGER ASTRONOMY DATA POLICY

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

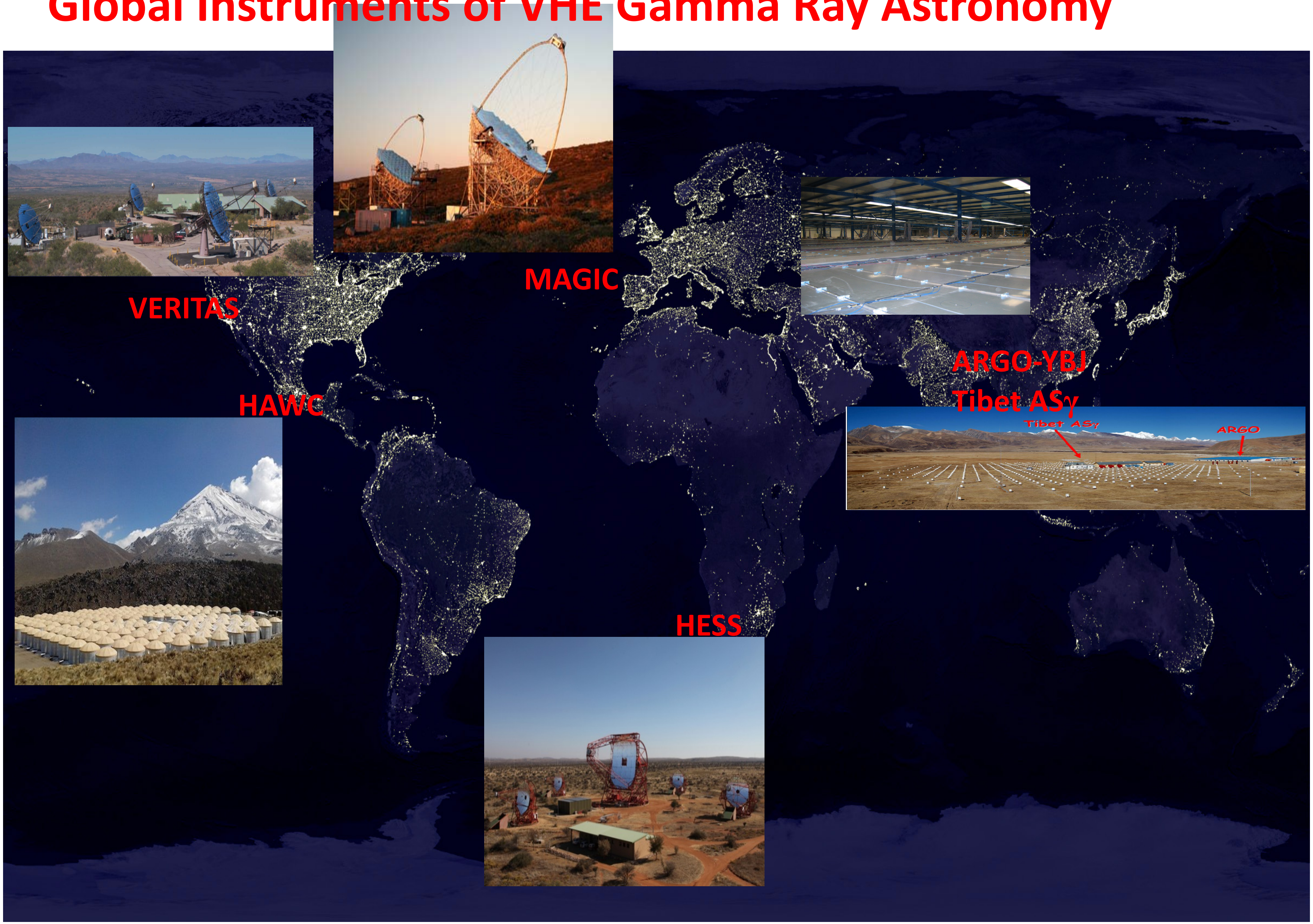
General conclusions on Data Policy taken from gravitational waves antennas remarkable practices

- 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 (largely quoted and contributing to the h-index!!!!), 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



Global Instruments of VHE Gamma Ray Astronomy



outlook

1 yr for ~ 2 sr

- Past EAS arrays (before 2014)

  Tibet ASr: 1990-2008

  Milagro: 1999-2008

  ARGO-YBJ: 2006-2013

  50~200% Icrab

- Currrent EAS arrays (~2014)

  Tibet ASr+MD,

  HAWC

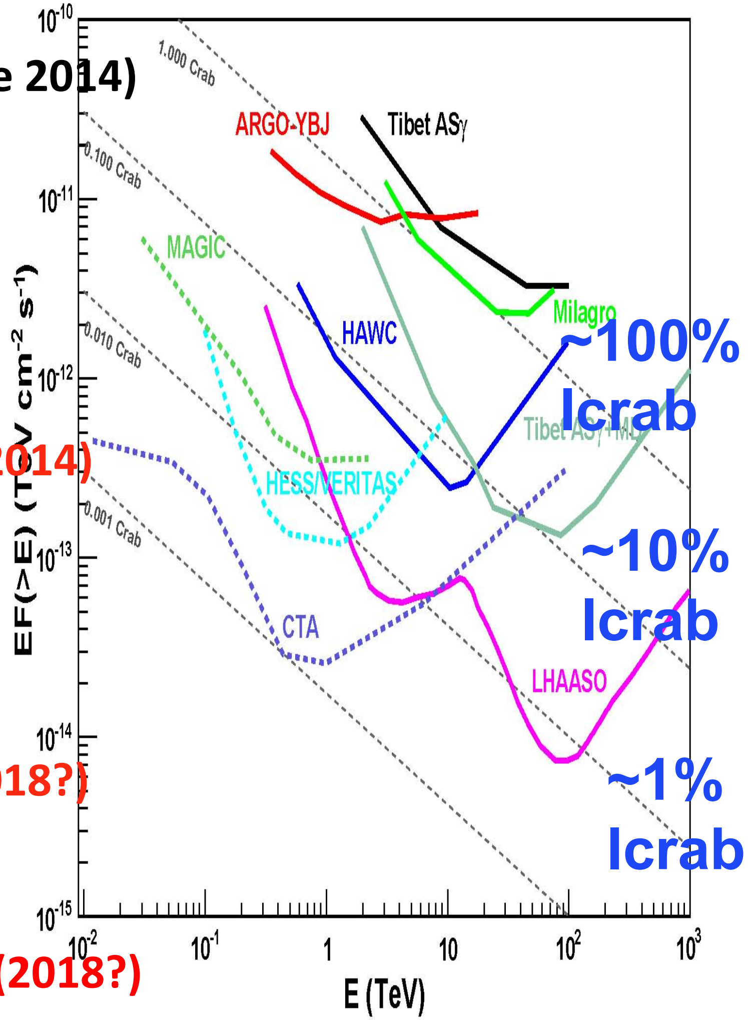
  ~10% Icrab

- Future EAS arrays (~2018?)

  LHAASO

  ~1% Icrab, 0.3~1000 TeV

  HiSCORE (2016) / TAIGA(2018?)



50 hrs for single source

- Past IACT arrays (before 2014)

  few percent of Icrab

- Current IACT arrays (~2014)

  HESS (I + II)

  MAGIC (I + II)

  VERITAS (upgraded)

  ~1% Icrab

- Future IACT arrays (~2018?)

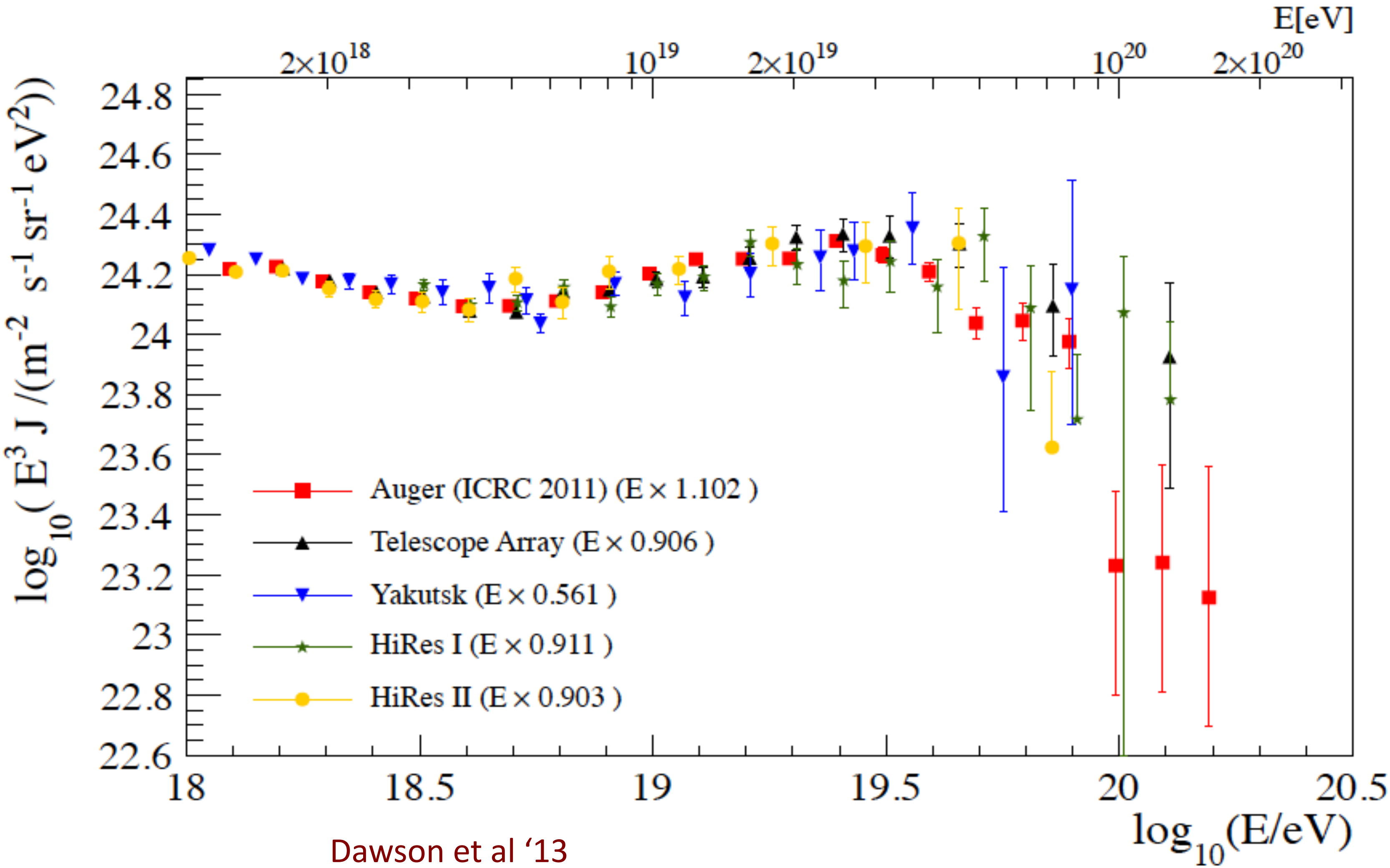
  CTA

  ~0.1% Icrab, 10GeV~10 TeV

AUGER plus Telescope array CR

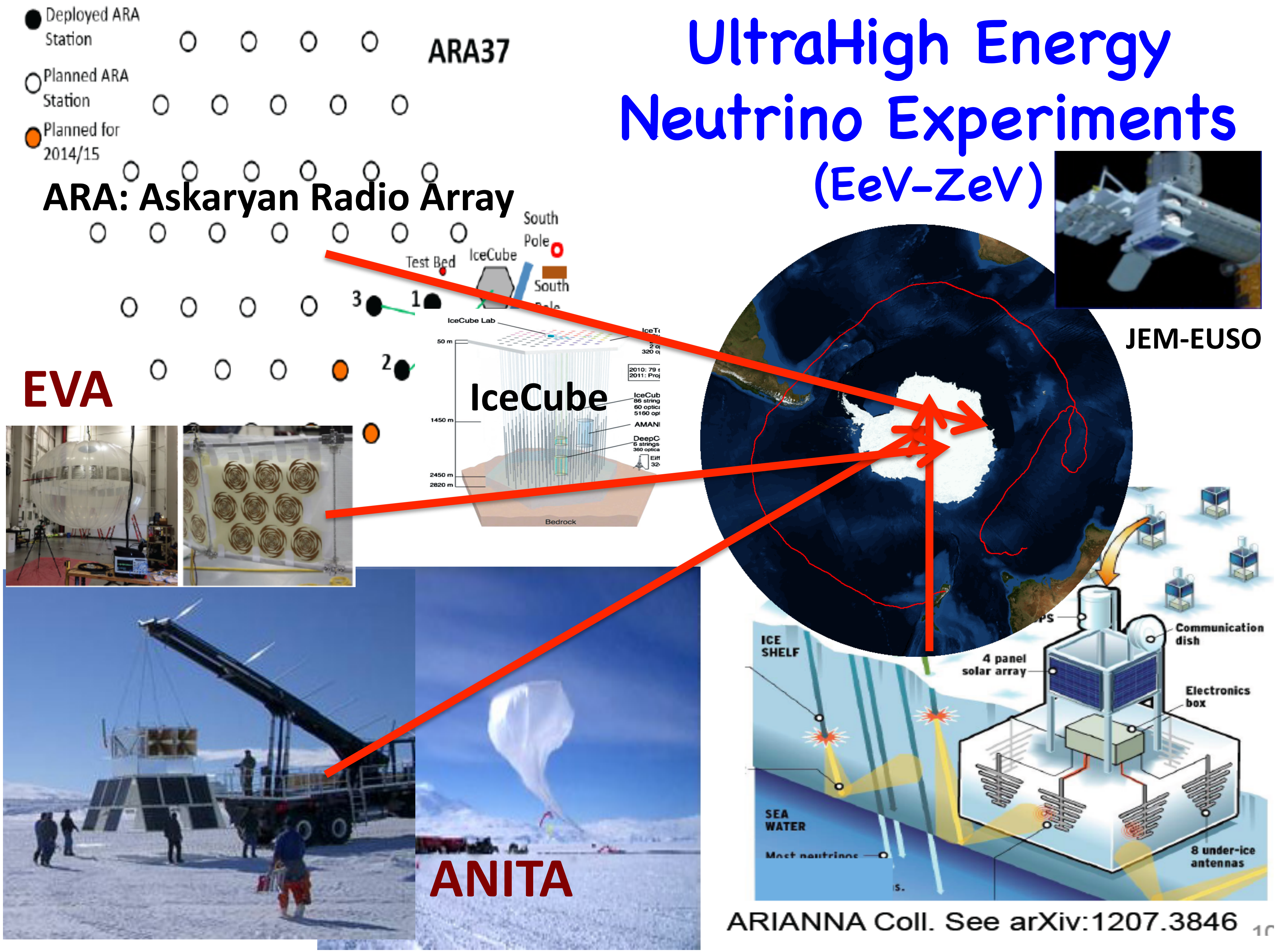
Unified Spectrum

Energies re-scaled ~10%



Dawson et al '13

UltraHigh Energy Neutrino Experiments (EeV-ZeV)



EeV Neutrino Detectors

Current Limits

Ground: IceCube, Rice, Auger

Space: ANITA

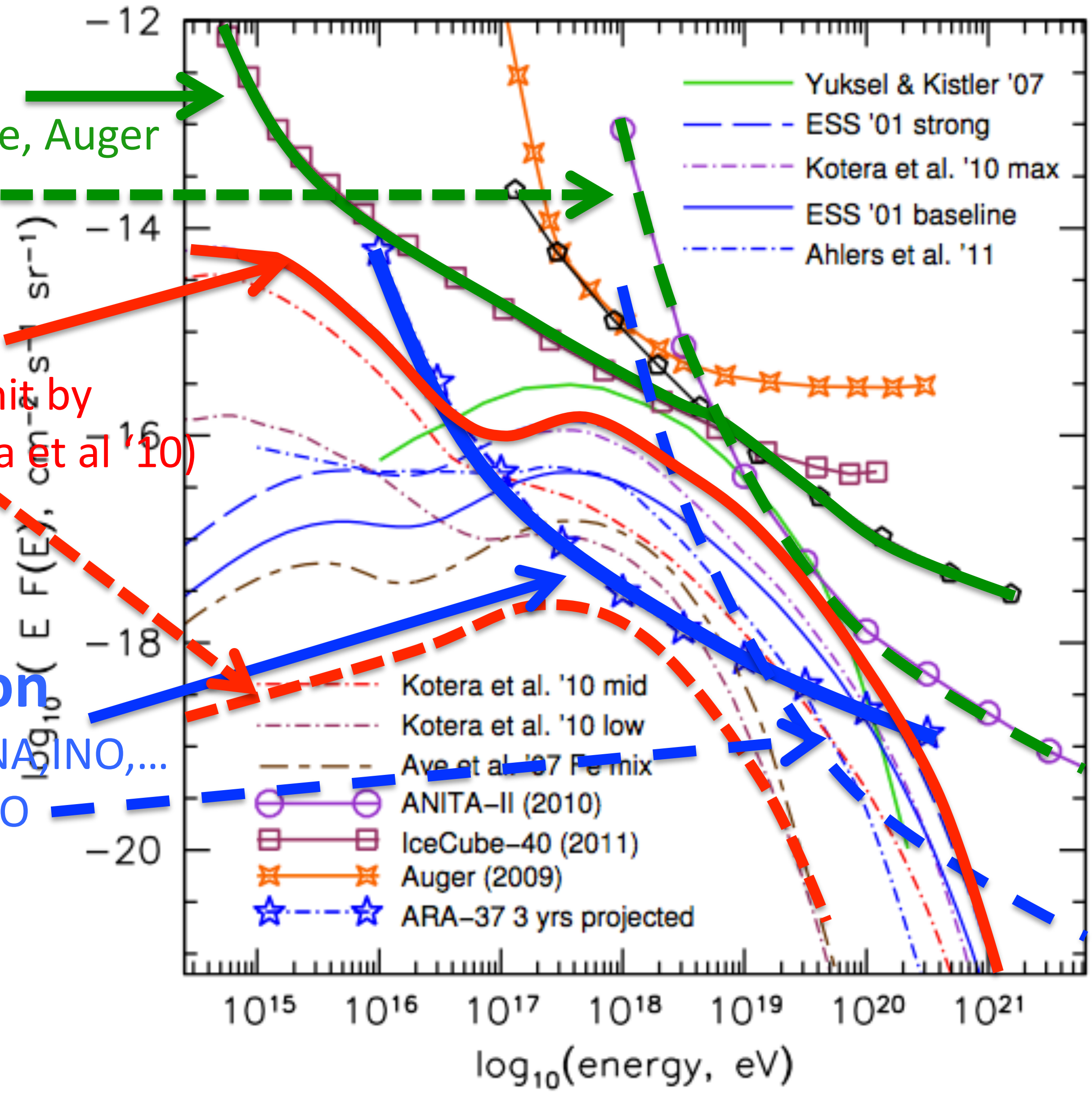
Models range,

above flux Lower Limit by UHECR comp. (Kotera et al '10)

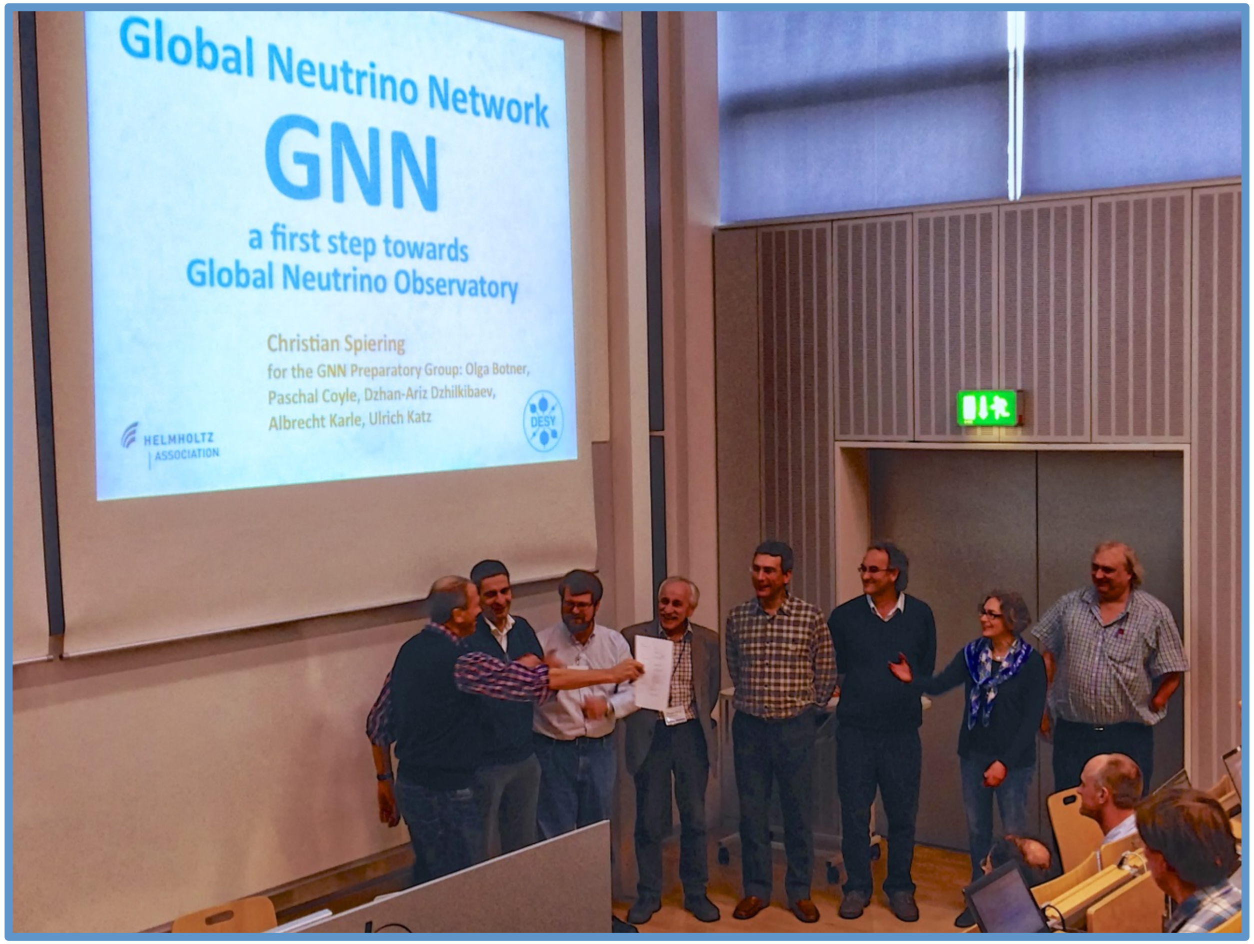
Next Generation

Ground:ARA, ARIANNA,INO,…

Space: EVA, JEM-EUSO



GNN
The Global Neutrino Network



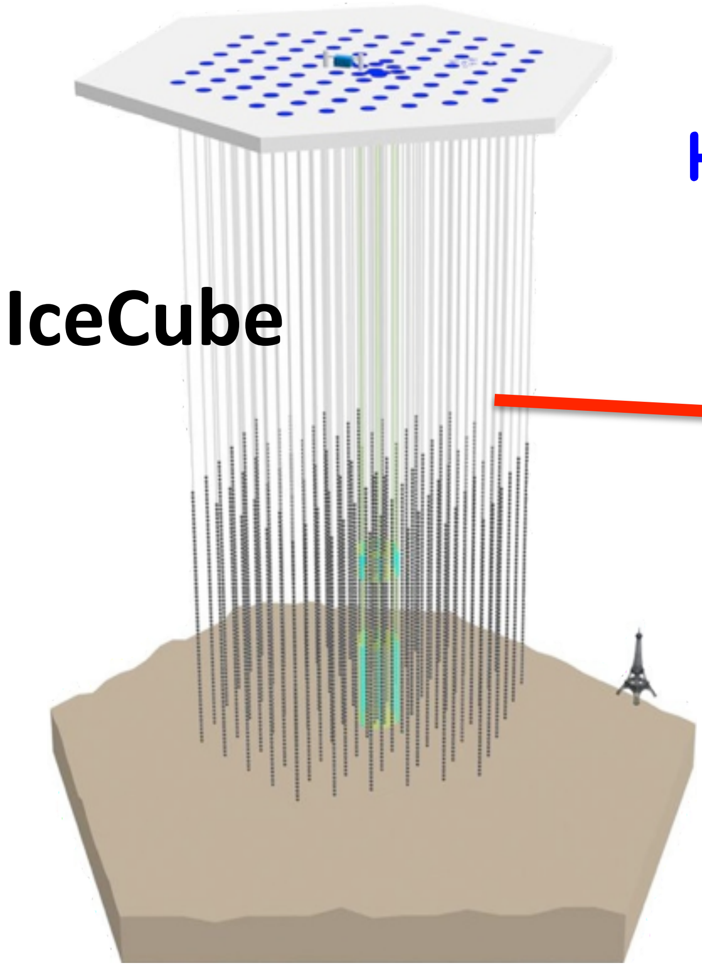
- Oct. 2013, Munich

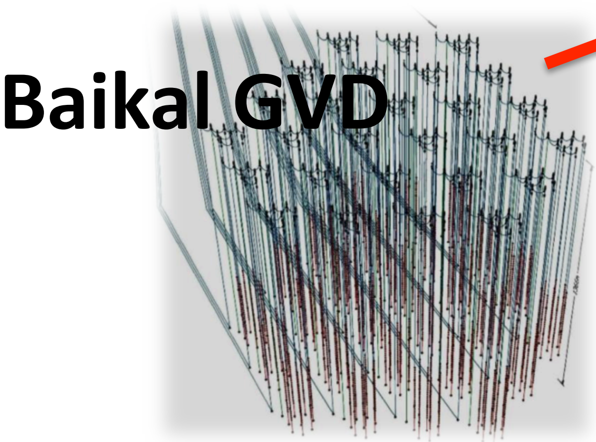
- Antares
- Baikal
- IceCube
- KM3NeT

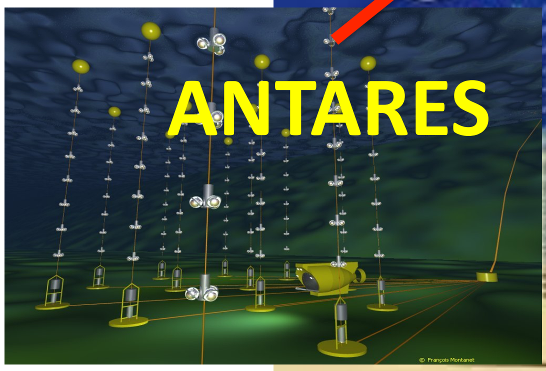
- http://www.globalneutrinonetwork.org/

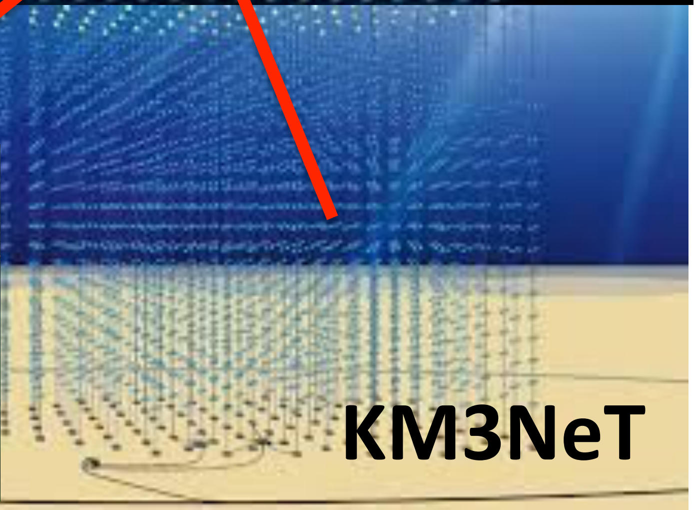
High Energy Neutrino Experiments

TeV-PeV

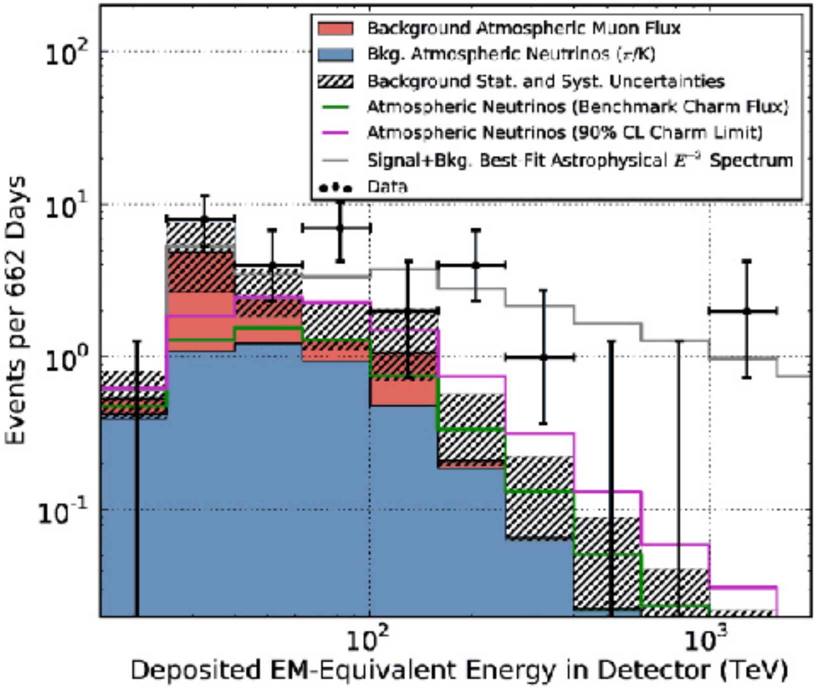




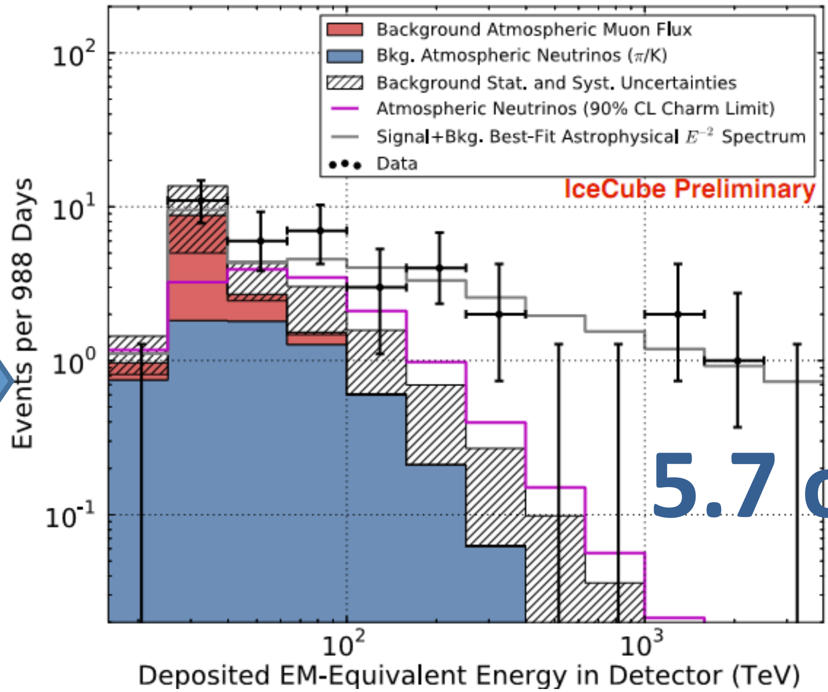




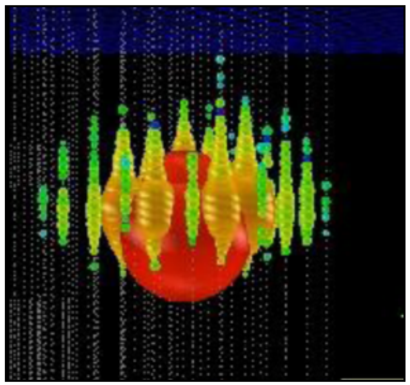
HE neutrino astronomy results IceCube plus more –see this conference

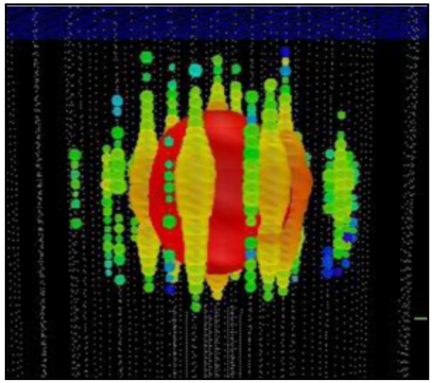


3rd year

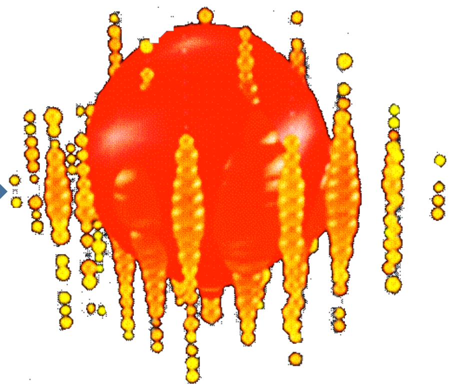


5.7 σ

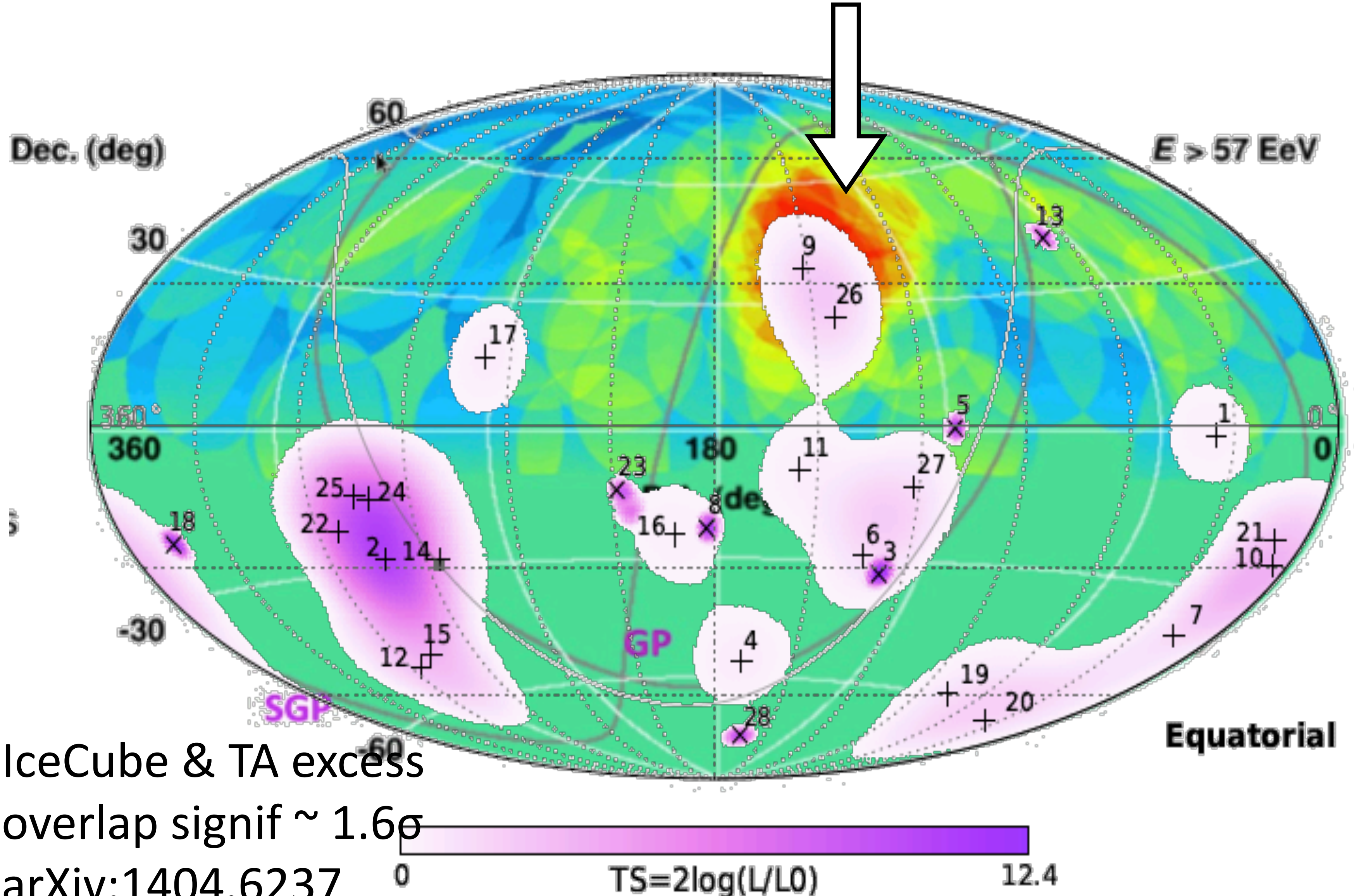




3rd PeV event.



Neutrino & UHECR Coincidence

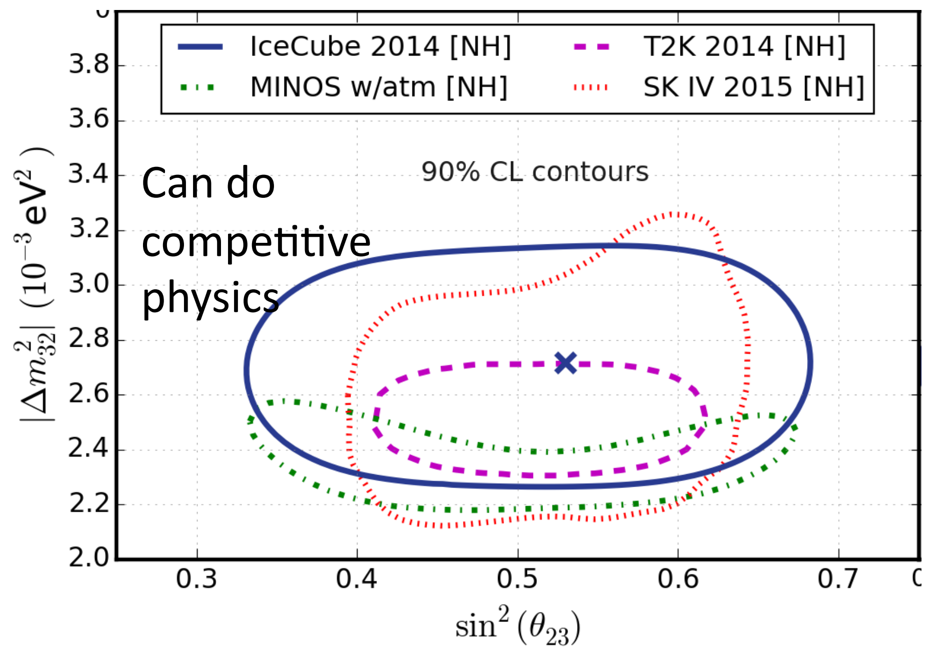


IceCube & TA excess
overlap signif ~ 1.6σ
arXiv:1404.6237

PINGU and ORCA

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

- Predecessor
  - ANTARES
- Part of KM3NeT
  - ORCA (for mass hierarchy)
  - ARCA for high energy ν astronomy



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)

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 on 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 ICRC 2015 and TAUP 2015
- This would be an opportunity to present to the community, guiding rules for data policy in Astroparticle Physics (based on multi messenger astronomy, 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)

NEUTRINO PROPERTIES: non accelerator and accelerator based experiments interplay
2nd international workshop on large neutrino infrastructure: ApPIC presentation

- Mass hierarchy
- P decay, SN

PS: Double beta decay, single beta decay not discussed yet by ApPIC

Mass eigenstates - Flavour eigenstates

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & -s_{12} & 0 \\ s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & e^{i\alpha} & 0 \\ 0 & 0 & e^{i(\beta+\delta)} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

if Majorana

9 quantities to be measured: 3 masses, 3 angles, 3 phases

4 known + 1 in absolute value

What we know and what we do not

$\sin^2\theta_{12} = 0.307 \pm 0.017$ $\qquad \theta_{12} \simeq 33°$

$\sin^2\theta_{23} = 0.390 \pm 0.033$ $\qquad \theta_{12} \simeq 40°–50°$

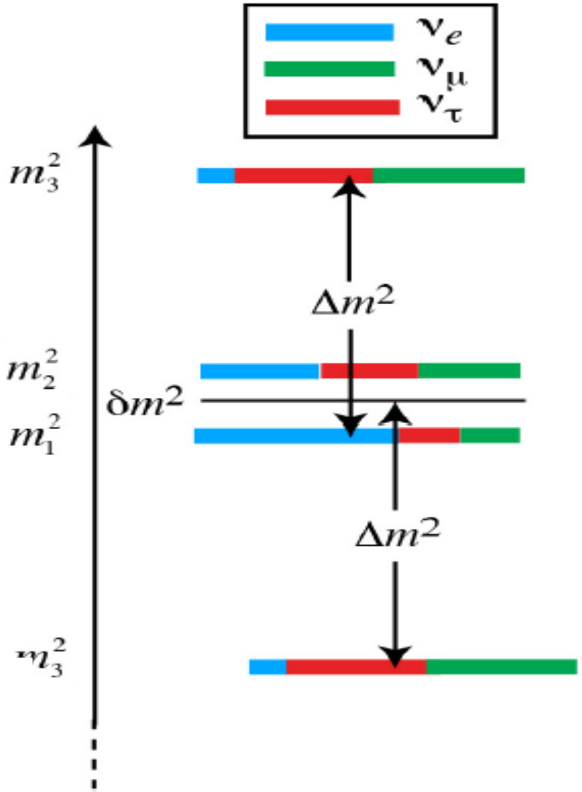
$\sin^2\theta_{13} = 0.0242 \pm 0.0026$ $\qquad \theta_{12} \simeq 9°.$

$\delta m^2 = 75.4 \pm^{2.6}_{2.2}\ \text{meV}^2$ $\qquad 2.6\%$

$|\Delta m^2| = 2430^{+70}_{-90}\ \text{meV}^2$ $\qquad 3.5\%$

Indirect upper limits from cosmology
$m_i < 100\text{-}150$ meV

We do not know
The sign of the larger mass difference
The absolute values of the masses
The three phases (one if Dirac, the other
two do not appear in oscillations or MSW)

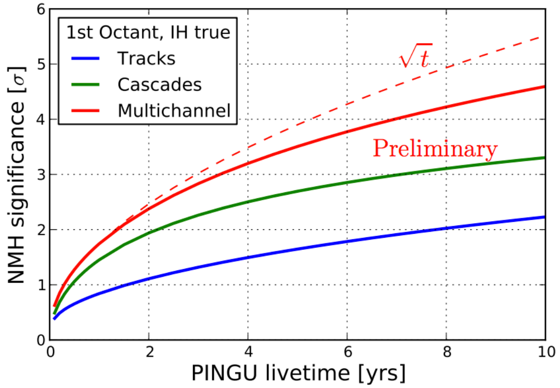


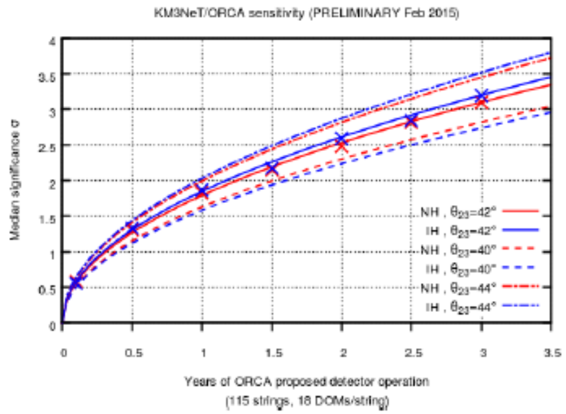
$$M_{ee} = |\sum U_{ei}^2 m_i| \approx |0.67 m_1 + 0.30 m_2 e^{i2\alpha} + 0.03 m_3 e^{i2(\beta-\delta)}|$$

For Majorana neutino: double beta decay

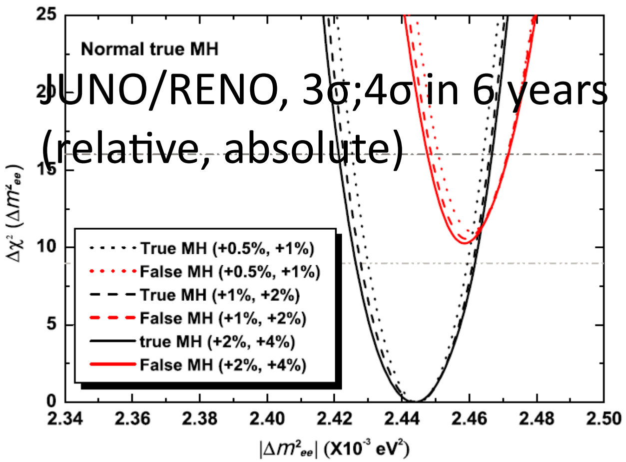
G. L. Fogli et al. 1205.5254

Mass hierarchy with atmospheric and reactor neutrinos

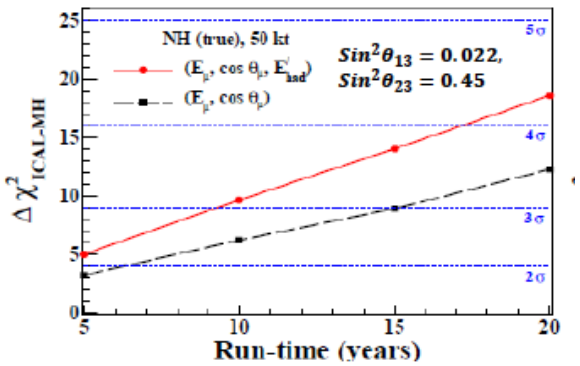


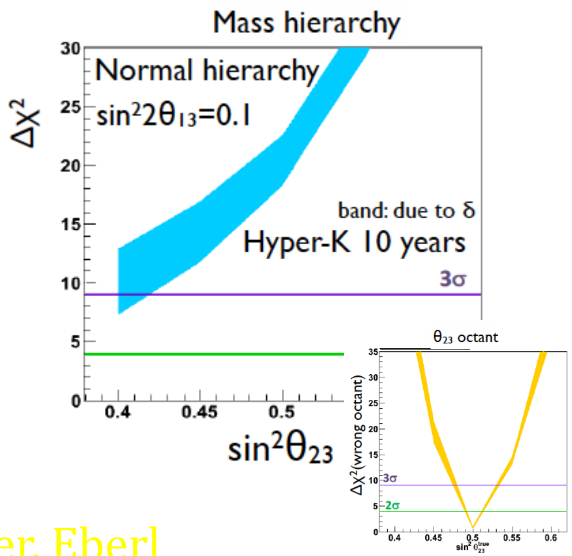


1. T2K + NovA mass hierarchy sensitivity?
2. ORCA/PINGU 3σ in 3 years, (early 20's) 5σ in 10 years 60 M$
3. JUNO/RENO 3-4 σ in 6 years (2025) 500 M$
4. DUNE, HK , INO 3-5σ ca 2035 ca G$



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





Cao, Majumder, Boser, Eberl

Non-oscillation vibrant programs

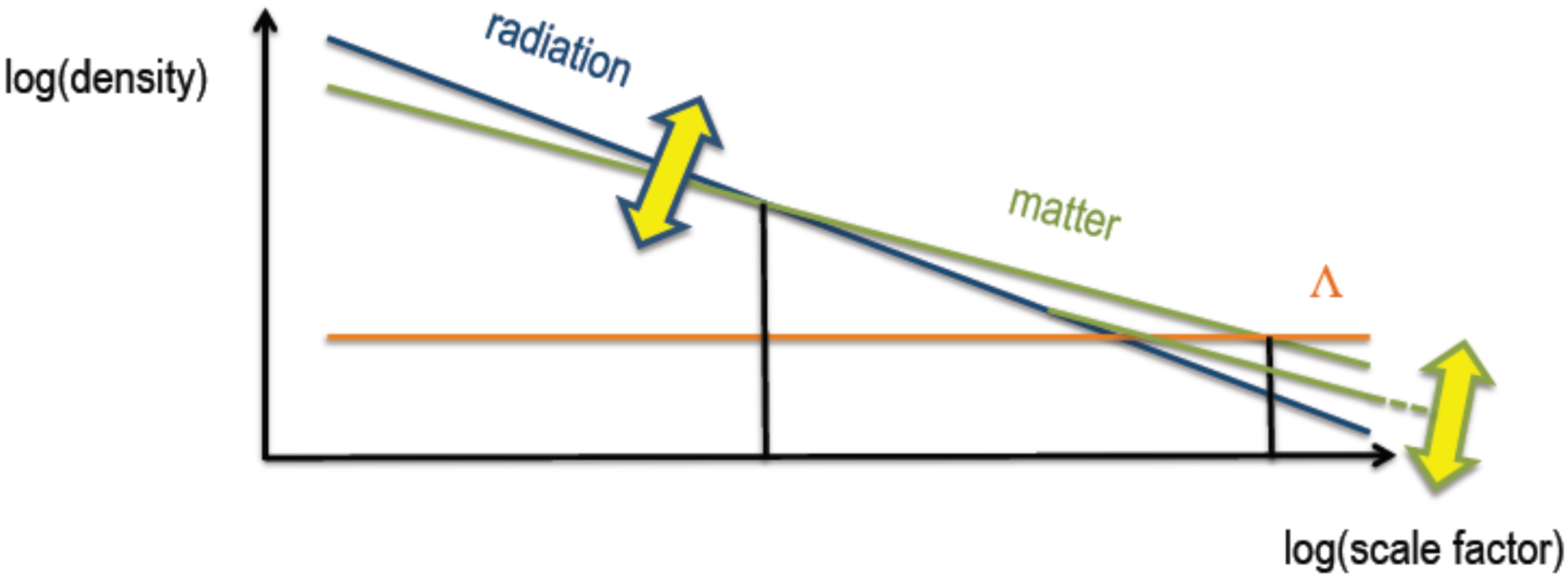
- **PINGU and ORCA:**
  - SN neutrinos (just time profile and mean ν-energy)
  - low-energy GRB
  - WIMPs, Exotic particles (Magn. Monopoles etc.)
- **JUNO and RENO-50:**
  - p-decay
  - SN neutrinos
  - Geo-neutrinos
- **Hyper-K:**
  - Solar neutrinos
  - p-decay
  - SN neutrinos (incl. relic SN)
  - 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

What does cosmology actually probes?

Neutrinos:

TWO independent questions:

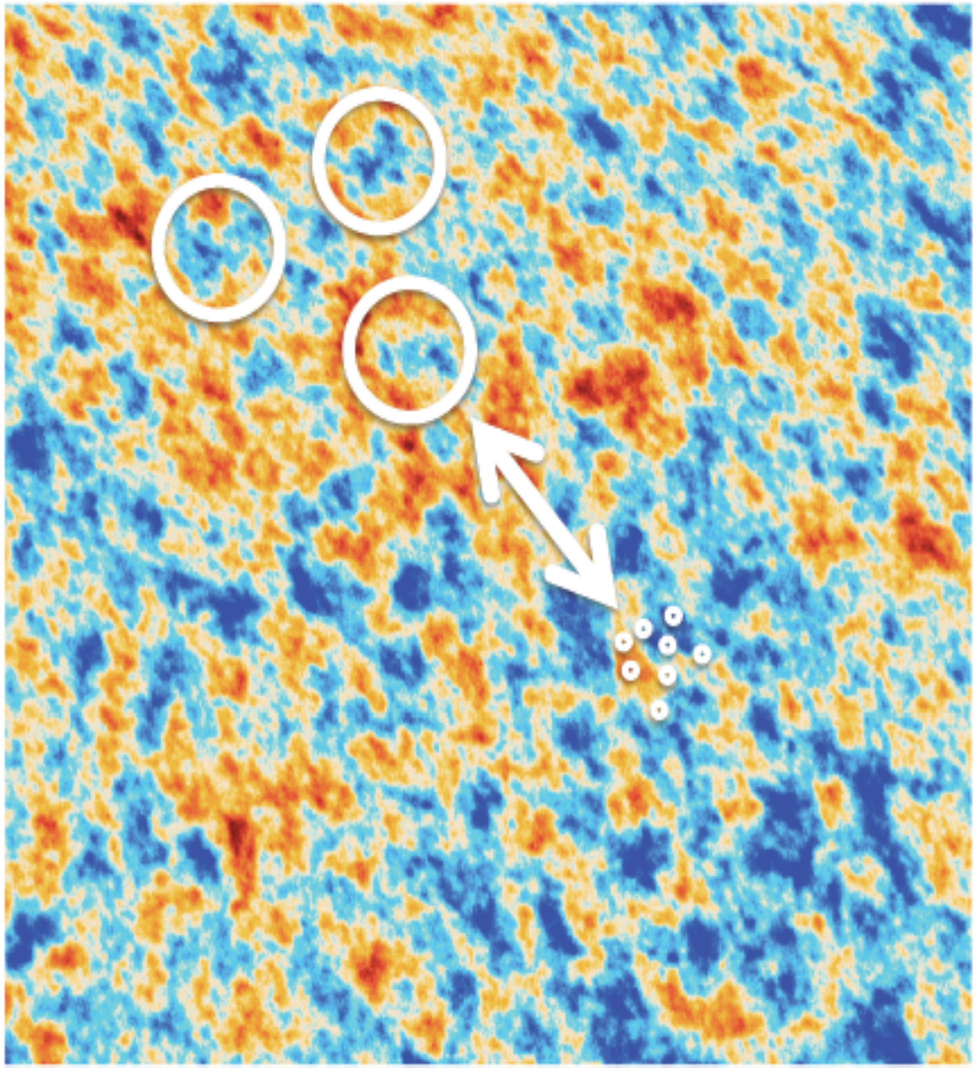
- Is there extra radiation on top of photons and standard neutrinos?
- Is part of the radiation content becoming non-relativistic at late times (HDM) ?



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,

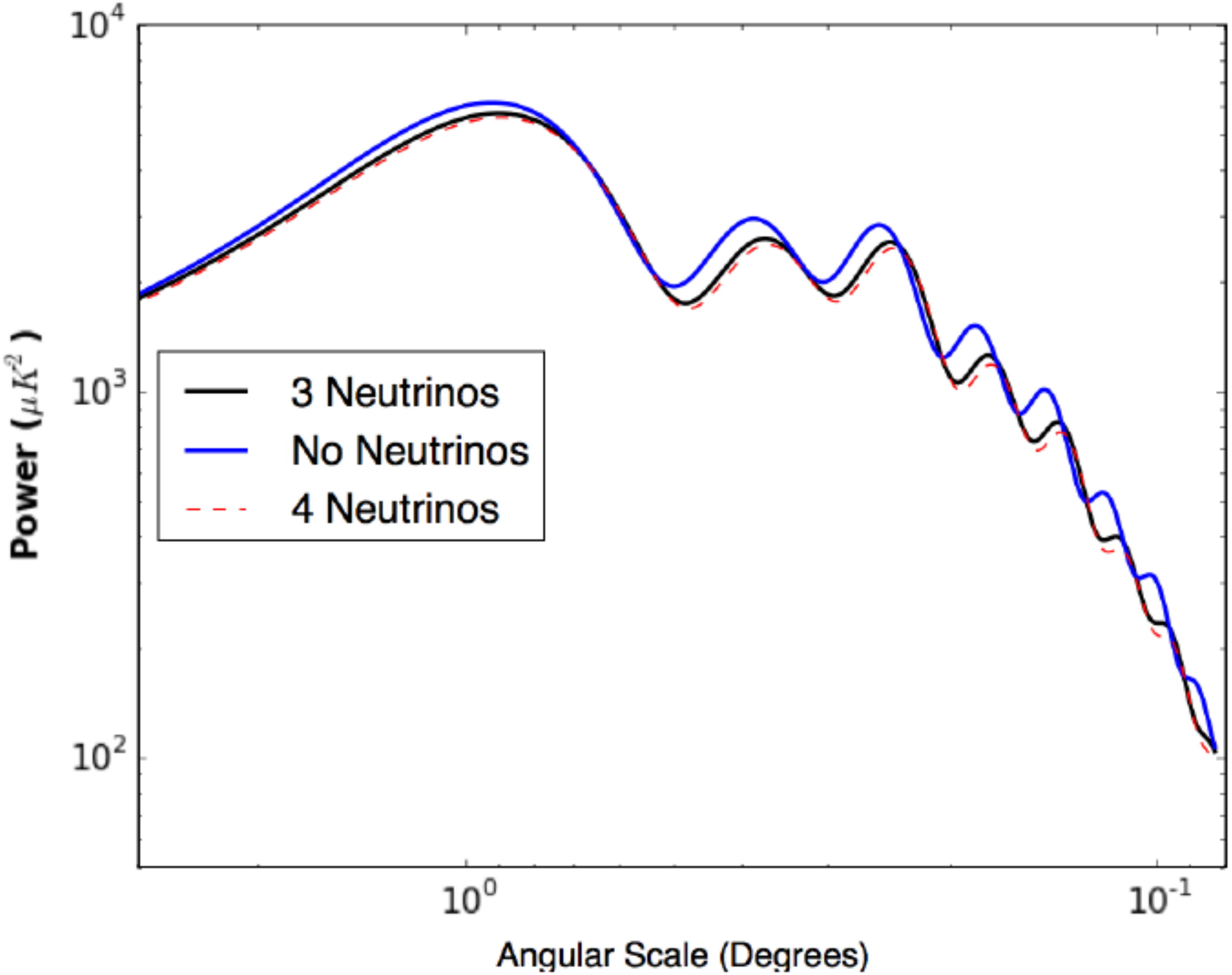
  peak amplitude patterns

- LSS:

  BAO peak patterns

  X-ray clusters

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

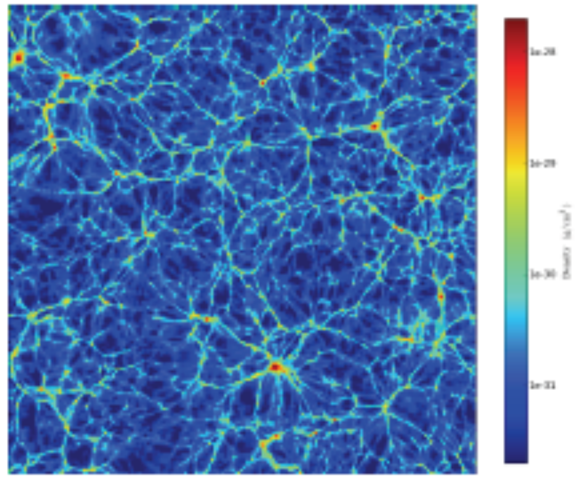
    Depends on scale and time/redshift

Also observations of the growth of massive, X-ray flux-selected galaxy clusters enter the game

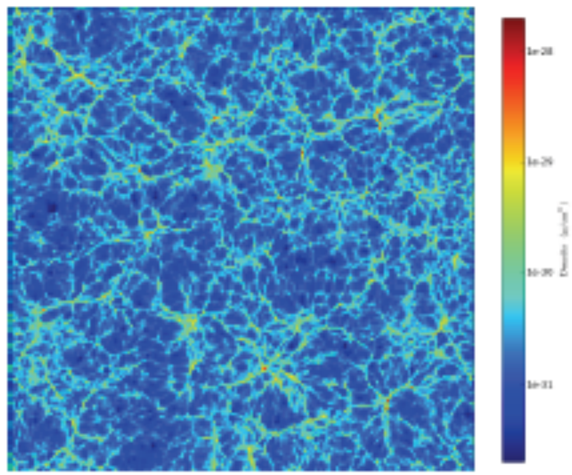
  - Primary CMB

    depletion from eISW

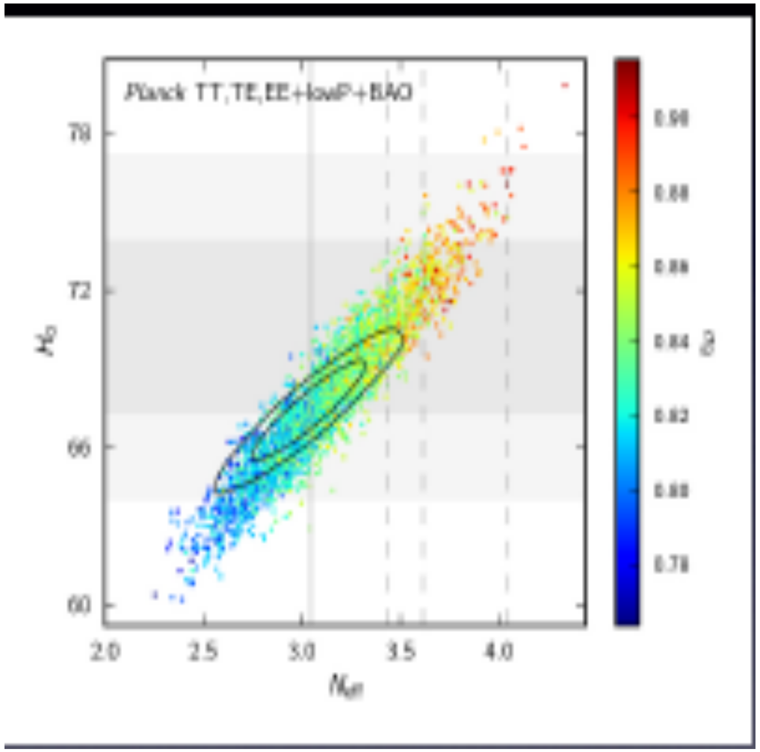
reference

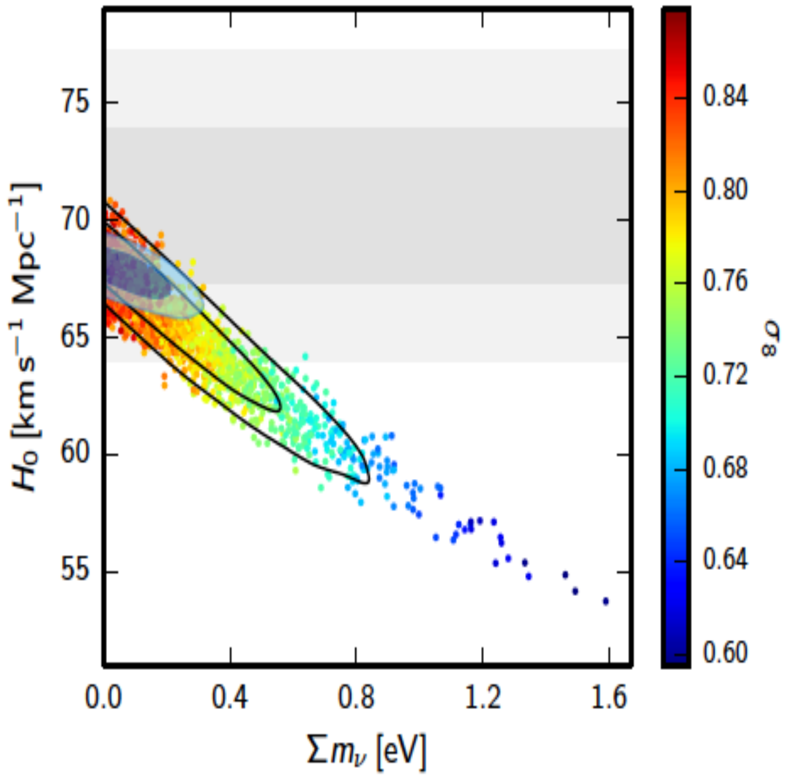


with hot component



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 (and X-ray clusters?)
- 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 cosmology and particle physics SM prediction of N_{eff} = 3.046 to +/- 0.02 and sum of masses= 58 or 106 meV!
- Cosmology measurements are complementary to reactor and accelerator experiments, 0v2beta experiments, and single beta−decay experiments
- We recommend increased dialogue between these communities

Thank you