Astroparticle Physics Planning in Europe

24 May 2014
Vulcano

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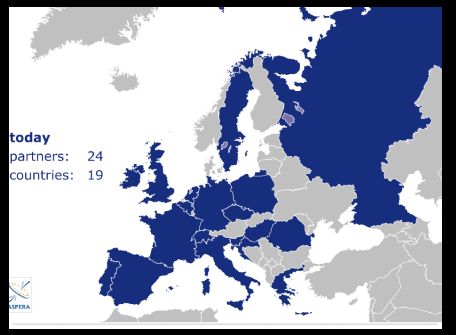
A short history of European Astroparticle Physics coordination From ApPEC to APPEC (2001-2014)



29.3.2001
ApPEC MoU

Astroparticle European **Coordination** (APPEC). Started with 5 agencies

ERANET ASPERA (FP6 and FP7) 19 countries totalling a program of 3000 researchers and 70 M€/year investment. Roadmap. Accompanying actions

29.6.2012
New APPEC MoU

Astroparticle European **Consortium**. Agency funded coordination . Currently 15 European countries.

New structure
Coordinating body
EU funding

ApPEC
ASPERA 1 2
APPEC

2003-2006 EU FP6
2007-2013 EU FP7
2014-2020 EU Horizon 2020

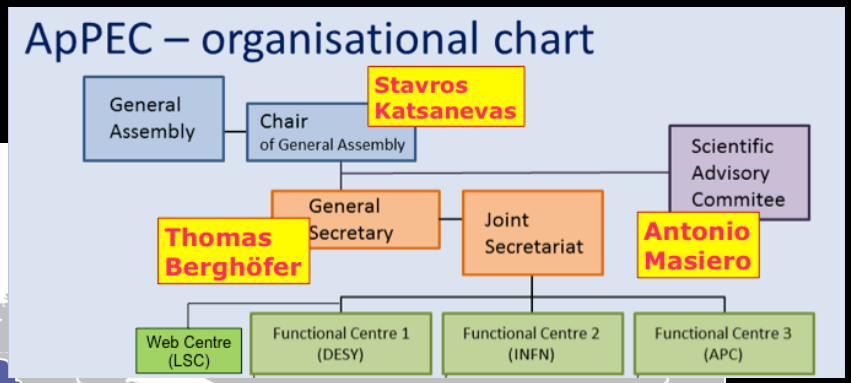
2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015

APPEC is very proactive for global coordination:

- ✓Workshops (Brussels, Paris),
- ✓OECD/GSF group APIF

Astronet (astrophysics) plans to follow a similar scheme.

APPEC Structure



APPEC 2014

Functional Centres:

APC
DESY
LNGS
LSC

International Contact, Computing, and Industrial Relations

Strategic Actions, Interdisciplinarity and Outreach

Networking, Theory and Education centre

Electronic Tools and Web

The last 6 years of roadmap exercises
From the "7 magnificent" to today

1st roadmap 2008 : dubbed « The Seven magnificent ». Essentially a definition of the field. It had an international fortune, definition adopted globally (eg APIF) with minor changes. Budget-wise optimistic (pre-crisis) 50% increase of budget available in a 10 year scale. No Dark Energy and CMB projects since it was concentrating on projects the majority of APPEC agencies had direct control.

From the Nature article

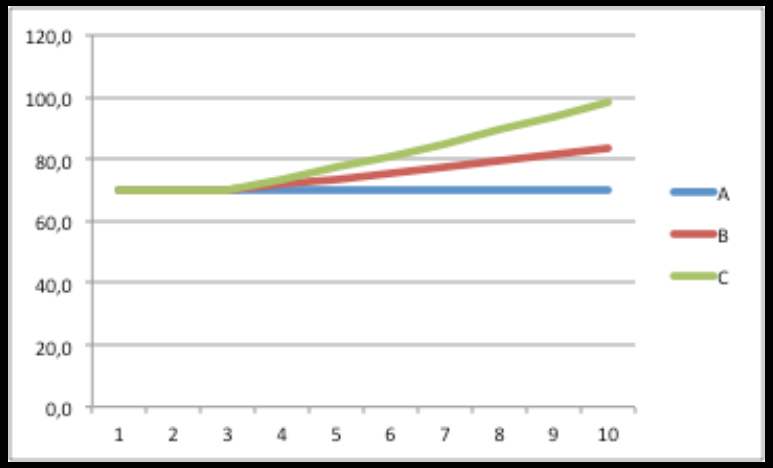
2nd roadmap 2011 : A roadmap with priorities. Still our guiding principle, further elaborated as input to the European Strategy for Particle Physics early 2013 (see later)

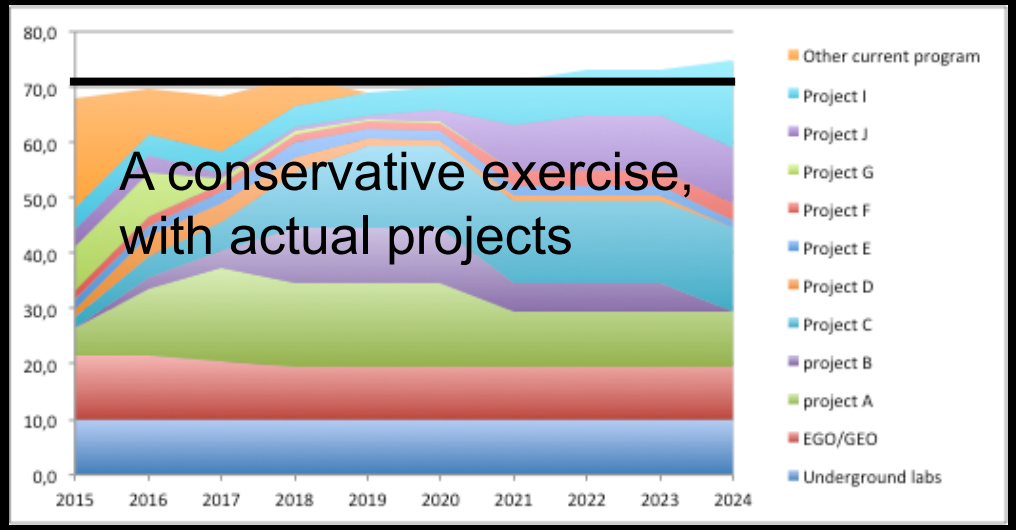
3rd roadmap end of 2014: Mandate by APPEC General Assembly: "A roadmap in accordance with available budgets." Ok, but first task, what are the available budgets ? Collection of data in progress. Approval of scenarii by GA in June 18.

➔ Final priority and milestone report by the end of the year.

What is the investment budget available in Astroparticle Physics today ?

- Difficulties of making a "distributed" roadmap. What is one to suppose for the budget?
  - Investment Astroparticle Budget in APPEC agencies in 2009 ➔ 71.8 M€ (ASPERA report) ➔ 0,7 B€ for 10 years.
- Uncertainties: How did it evolve in 5 years ? In principle this concerned only investment, were the criteria absolutely uniform? (e.g no regional funds, space agency funds, researcher salaries, etc.).
- The exercise needs to be redone. This is in progress.
- Below a « feasibility exercise » on the possibilities





3 hypothetical (not official) scenarios :

A) Flat-flat at « 2009 » levels

B) Flat-flat at « 2009 » levels till 2018 and then increase by 2,5%/year (+50 M€ overall)

C) Flat-flat at « 2009 » levels till 2018 and then increase by 5%/year (+100 M€ overall)

Astroparticle Physics is promoting the unity of fundemantal physics
Going up and down the cosmic ladder

Cosmic ladder

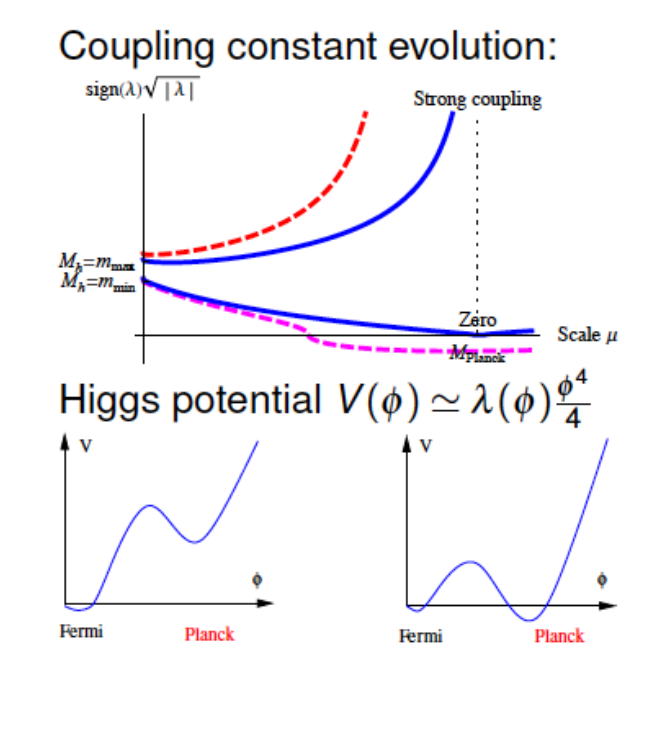
The Astroparticle domain after LHC/PLANCK/ BICEP2/ ν results can be reduced to 2 fundamental questions:

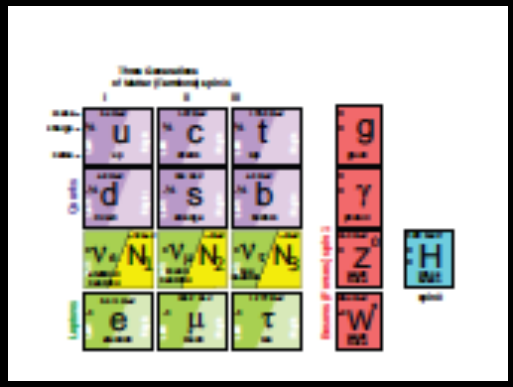
1) Are there any intermediate scales between the EW scale and Inflation ? If yes how many and where are they ?
   - Inflation, dark energy and matter
   - Neutrino properties and proton decay

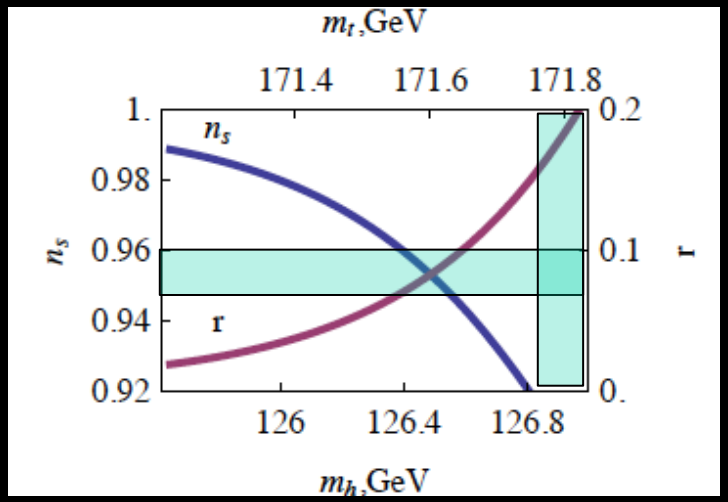
2) Are there new energy scales at work in the most violent phenomena of the Universe? How do particles and fields shape the formation and evolution of cosmic structures ?
   - High energy photons, neutrinos, CR
   - Gravitational waves

Going up and down the cosmic ladder

E.G , Bezrukov-Shaposhnikov: νMSSM or "The Higgs field is the inflaton"
Over 300 papers in arxiv, these last days, unification, susy, see-saw, axions, number of neutrinos, sterile neutrinos, …







3 neutrinos solving problems of dark matter, leptogenesis…

« Si non e vero e ben trovato »

Summary of the roadmap statements of November 2011, specified in January 2013 as input to the European Strategy of Particle Physics

APPEC supports:

I. In the category of medium scale projects: the timely completion of the 2nd generation upgrades of gravitational wave antennas, as well as the upgrades/constructions towards ton-scale detectors for dark matter and double-beta neutrino mass experiments.

II. In the category of large-scale projects a high priority is given to the construction of the Cherenkov Telescope Array (CTA), and strong support for the first phase of KM3NeT, as well as R&D towards the definition of the next generation ground-based observatory for high energy cosmic rays.

III. Finally there needs to be coordination with other European/non-European organizations for the realization of billion-euro scale projects at the 2020 horizon, in particular a 50-500 kt scale low-energy neutrino astrophysics/ proton-decay detector. Other projects on this cost scale are_dark energy surveys on ground and in space, and in a longer perspective gravitational wave antennas with cosmological sensitivity on ground and in space.

European and global programmatic context

- ESFRI: APPEC is the correspondent of ESFRI (European Strategic Forum for Research Infrastructures) for the Astroparticle physics "landscape" in view of a new roadmap of infrastructures by 2015-2016
- European Union. APPEC actively coordinates in view of H2020 calls of funds on:
  - CLUSTER ASTERICS of Astrophysics-Astroparticle infrastructures (EELT-SKA-CTA-KM3NET-VIRGO-AUGER…)
  - Two networks on Gravitational waves, Underground labs
  - A COFUND scheme on theory postdocs
  - Participation in EU-T0 on data
  - MCurie doctorate networks (e.g. MULTI-DEEP in underground labs (submitted)
- Japan roadmap exercise
- HEPAP/P5 DOE-NSF exercise (results 2 days ago) a first subjective interpretation of relevant topics
  - Call for an international neutrino program with host Fermilab
  - Postpone a decision on DM G3 after G2 results and international coordination
  - Support for CTA (at half budget)
  - Support for CMB-S4 cosmology and DESI(Dark Energy provided funding)

➔ In general a call for more international coordination/cooperation

The European Astroparticle Physics Roadmap I
Timely entry in full operation of projects in construction (2015-2020)

Gravitational waves

- advVirgo, advLigo . Commissioning start in 2015
- In space (ESA) LisaPAthfinder (integration started) launch 2015

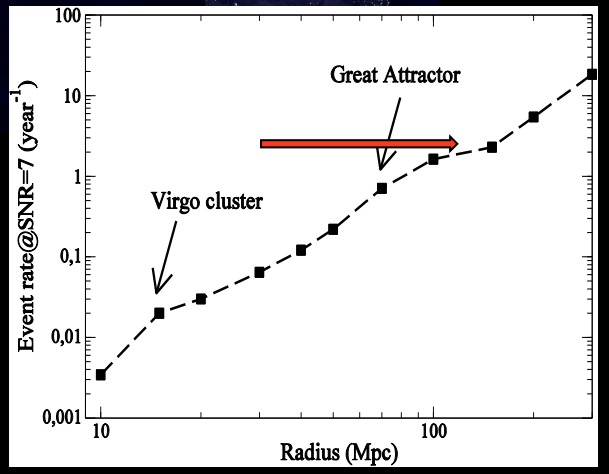
Dark matter towards σ - 10^{-12} pb^{-1} sensitivity (G2)

- Xenon 1t (data-taking by 2015), DarkSide started running, EDELWEISS III results similar sensitivity to LUX by 2015,
- *Towards G3*
  - *R&D/Conceptual Studies: a multiton experiment DARWIN, ton-scale EURECA/SCDMS*
  - *Also R&D/Conceptual Studies: Directional DM, Axions (IAXO, ALP)*

Neutrino mass

- Single β ➔ KATRIN data-taking 2016 (200 meV)
- Double β ➔ GERDA-II, Cuore, NEXT, SuperNEMO prototype (2014-2015)
- *R&D for the future: E.g. LUCIFER(Se, GSasso), LUMINEU(MO, Modane)*

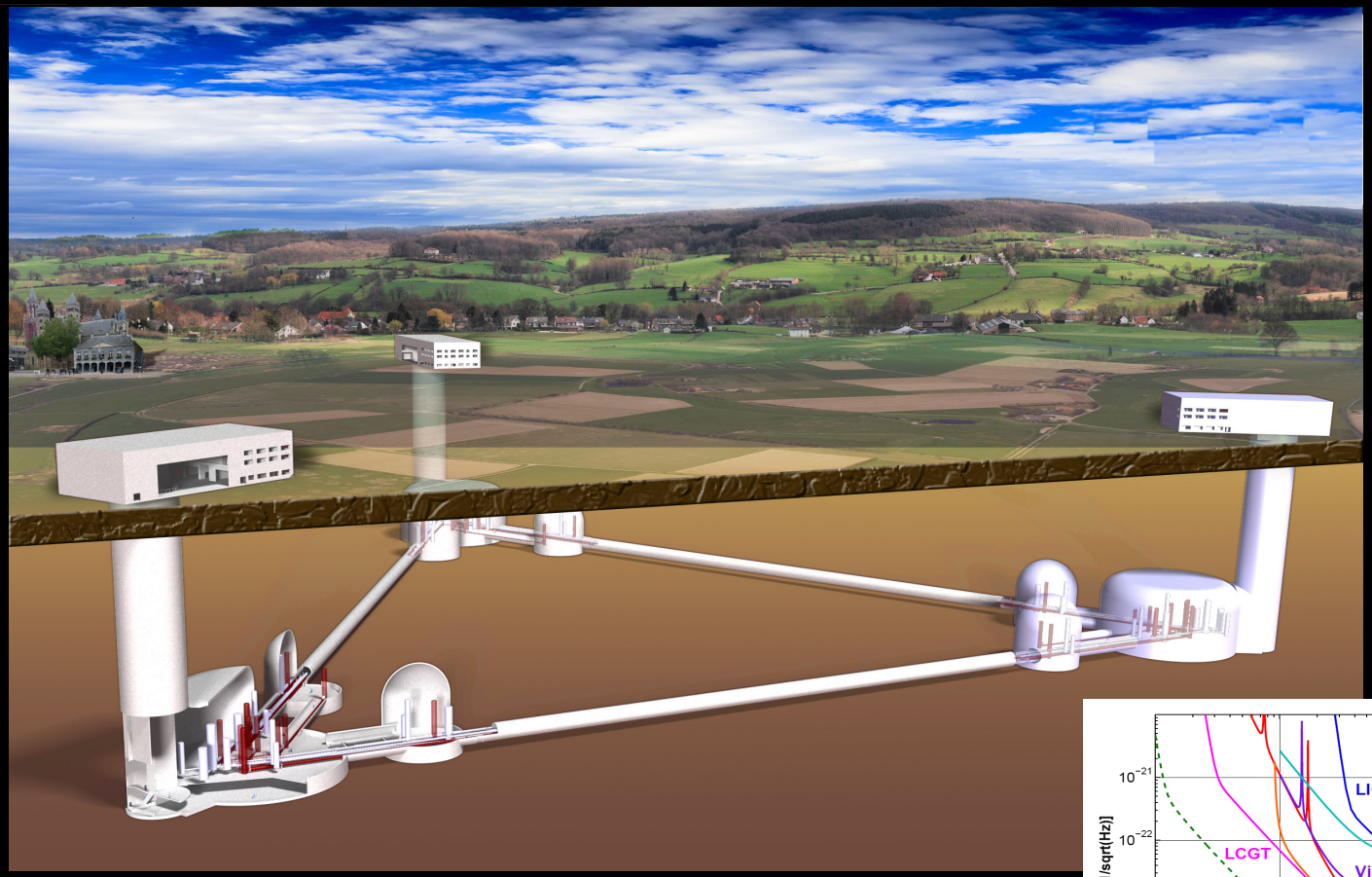
Gravitational wave antennas
A paradigmatic worldwide collaboration

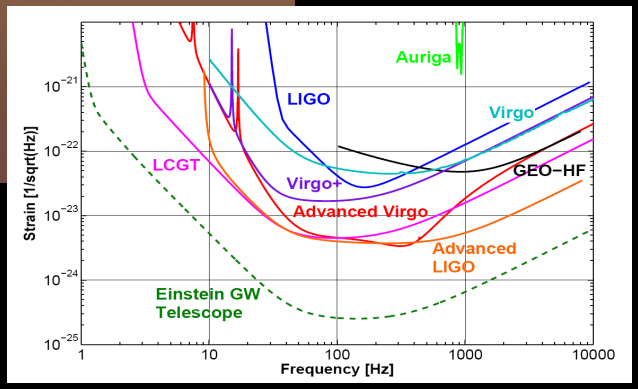


- ✓ApPEC priority: the timely completion of the 2nd generation upgrades of gravitational wave antennas (2015).
- ✓MoU VIRGO-LIGO-KAGRA
- ✓Towards a first detection in 2016-2018

GWA beyond 2020

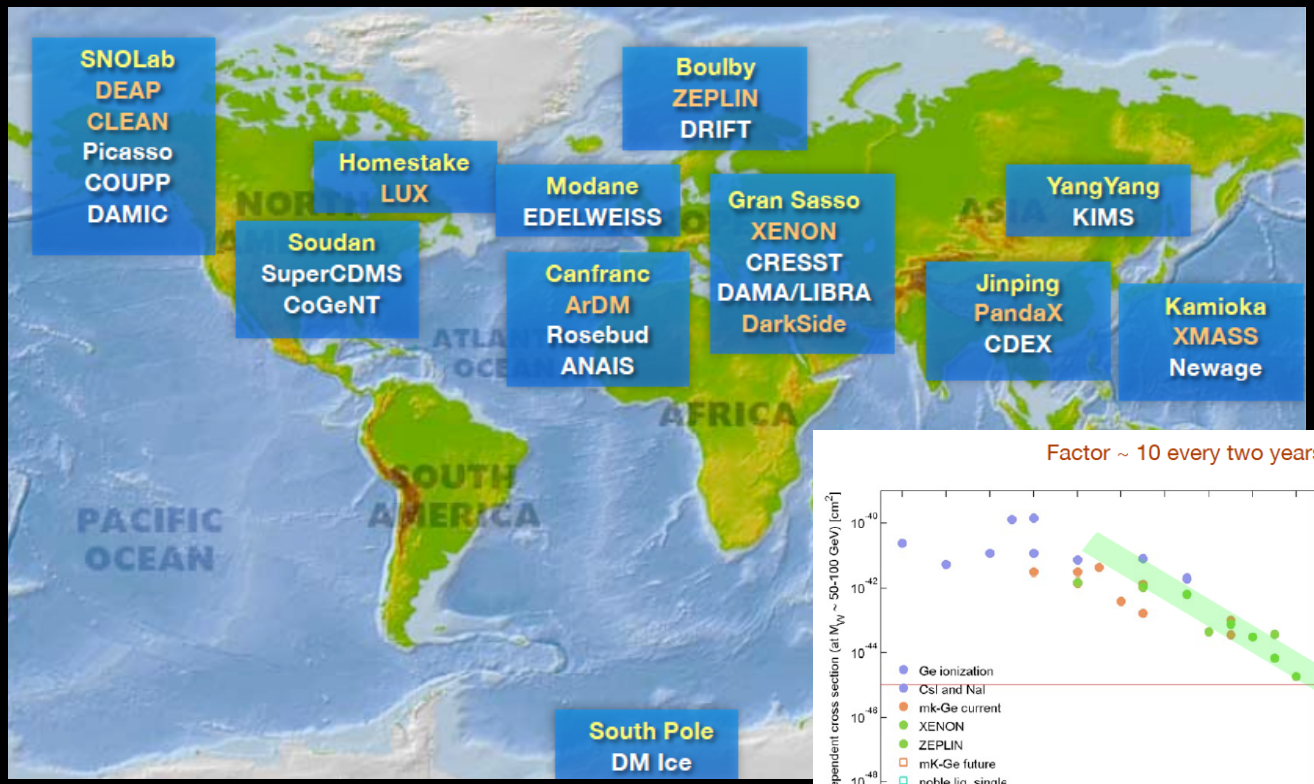
Einstein Telescope





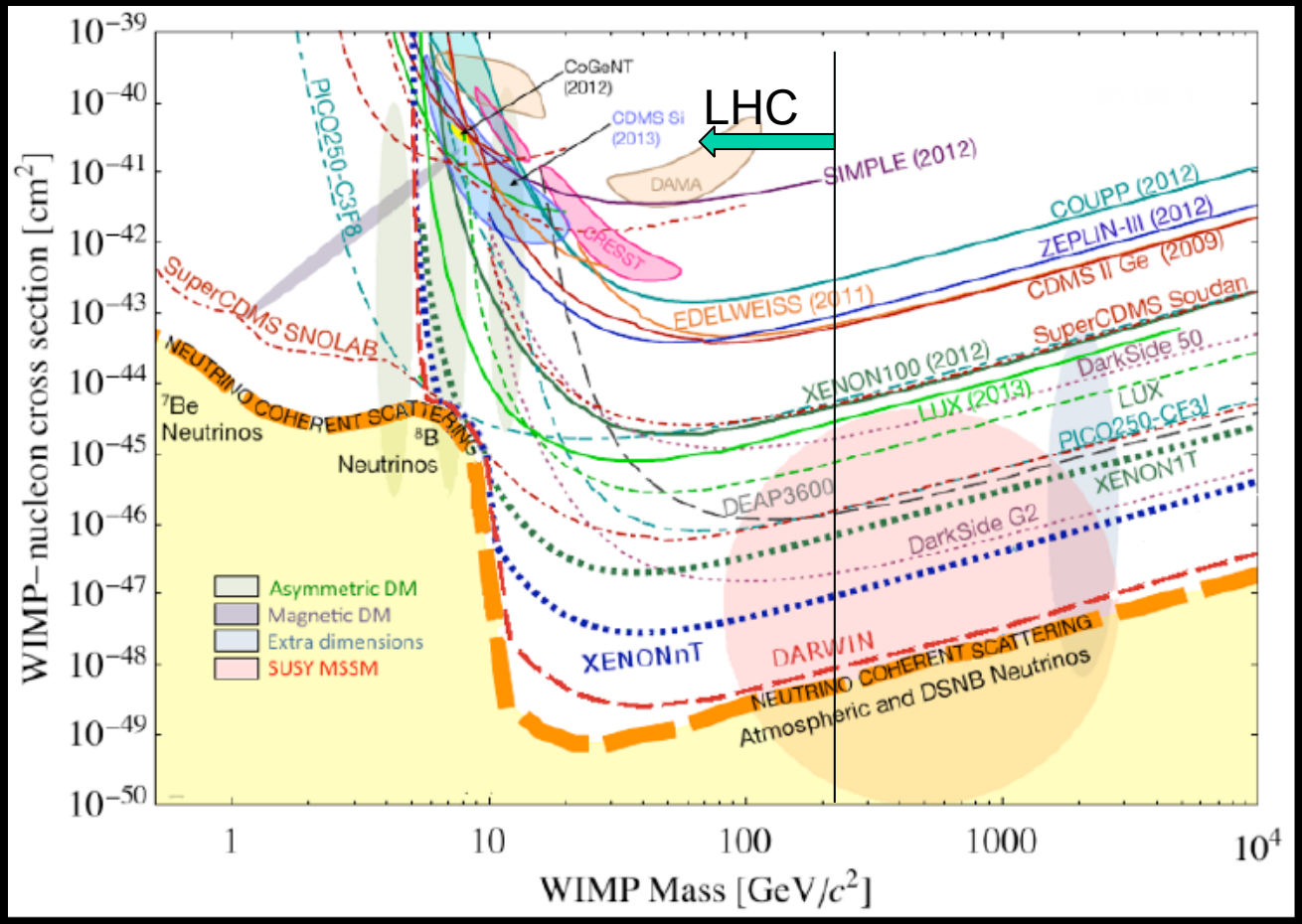
- ✓ ET: If detection by 2020 move to third generation
- ✓ASPERA/ApPEC funding for R&D

Direct dark matter detection I
Competition and progress



APPEC Roadmap: WIMPs will be put in a severe, if not conclusive, test during the next 10 years. (LHC, direct and indirect detection). In case of discovery both accelerator and non-accelerator experiments will be needed to determine the physical properties of WIMPS.

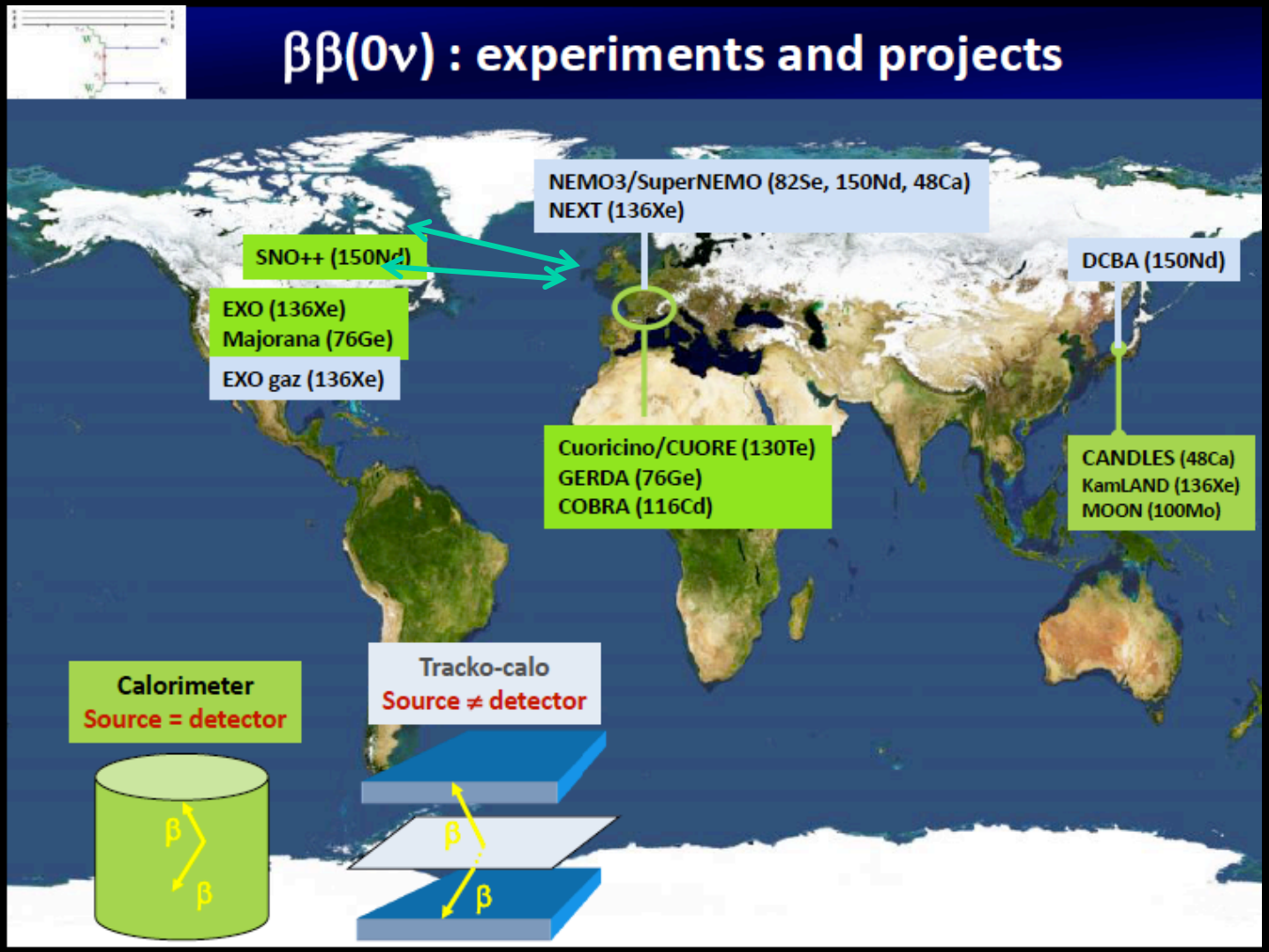
Direct Dark Matter direct detection II



- ✓ *Complementarity: Low masses ➔ bolometers , High masses ➔ Noble liquids*
- ✓ *Complementarity with LHC but also in case of high WIMP masses rationale for FCC*
- ✓ *Reaching the neutrino background ➔ directional R&D*
- ✓ *Place for 1-2 in the world, with large international collaborations*
- ✓ *APPEC SAC ➔ Decide after 3 years the (G3) multi-ton experiment.*
- ✓ *P5 similar conclusions*

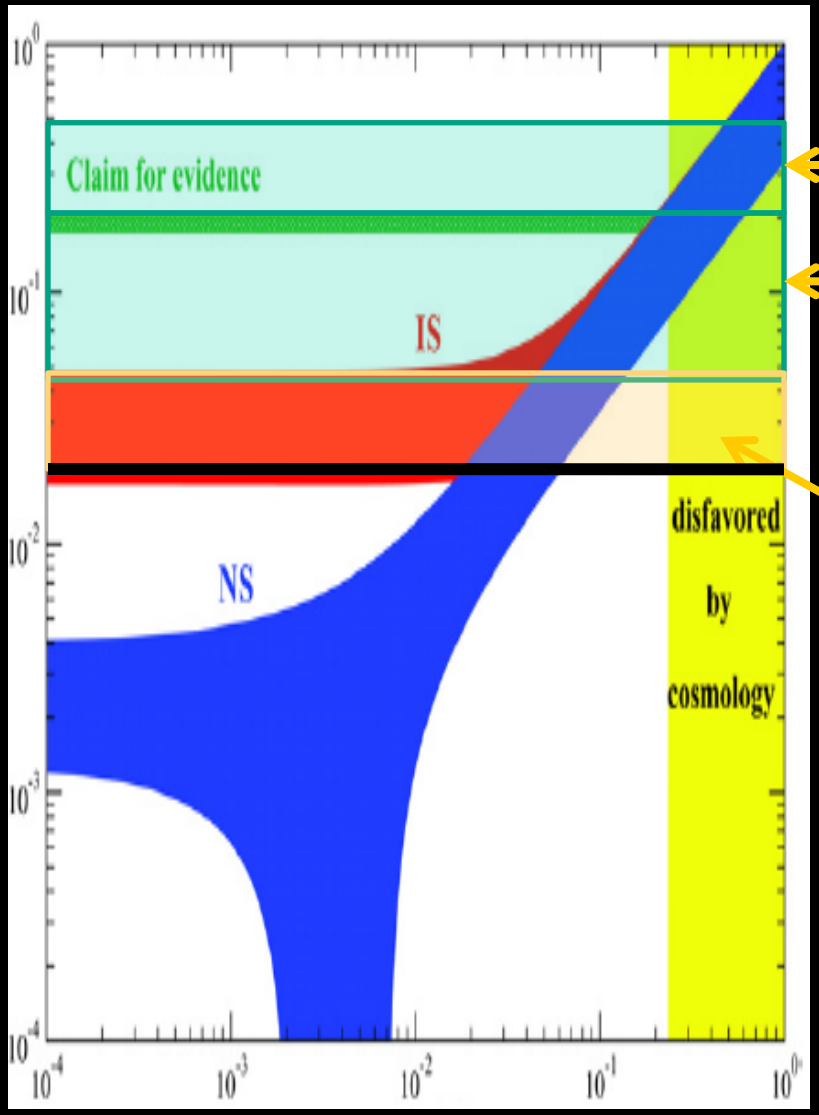
Neutrino mass and nature I

Testing the Majorana nature of neutrinos through the detection neutrinoless double beta decays. Its theoretical importance cannot be overstated.



Neutrino mass and nature II

0νββ approaching/exploring the inverted hierarchy the next decade



GERDA-1 (200-400 meV, 10^{25}y) today

GERDA-2 (75 - 129 meV, 10^{26}y)

CUORE (51 – 133 meV)

NEXT, SuperNEMO (100Kg)

In 5-6 years, by 2020

Scintillating bolometers (350 kg, 5 y) (13 – 36 meV)

Initial nEXO (EXO-200-like 5 tons, 10 y) (10 – 30 meV)

Lower limit of IS by 2025?

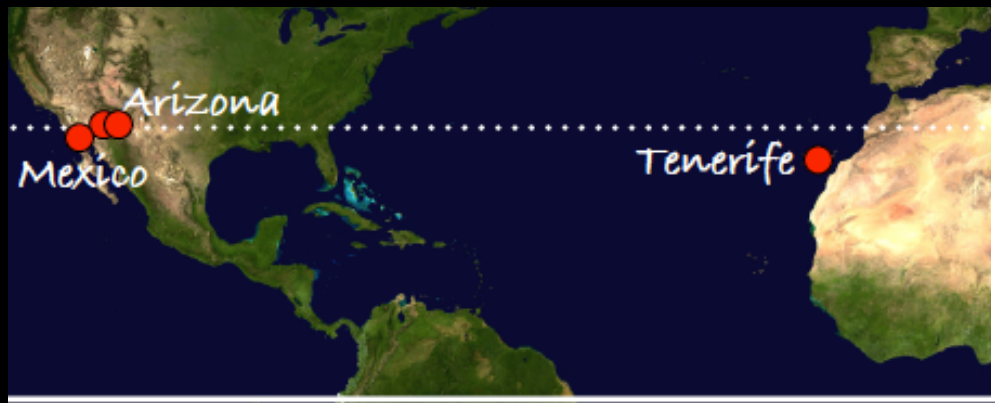
Matrix element uncertainties

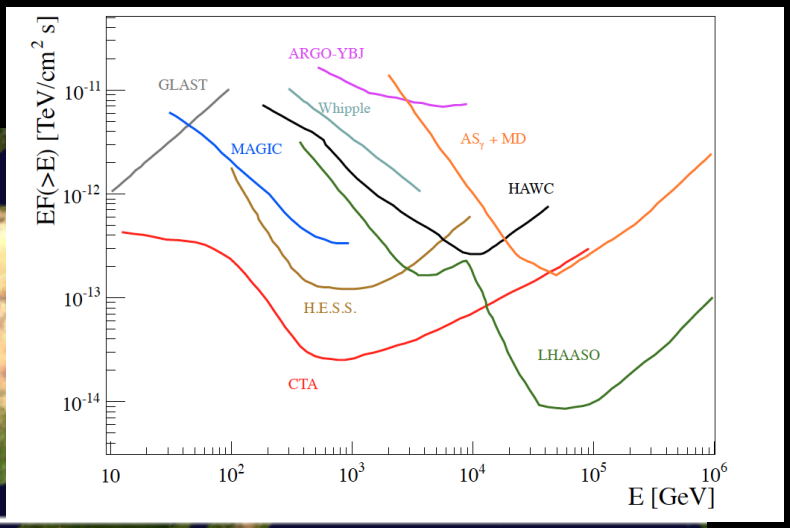
APPEC SAC ➔ Decide on the European large scale in 3 years

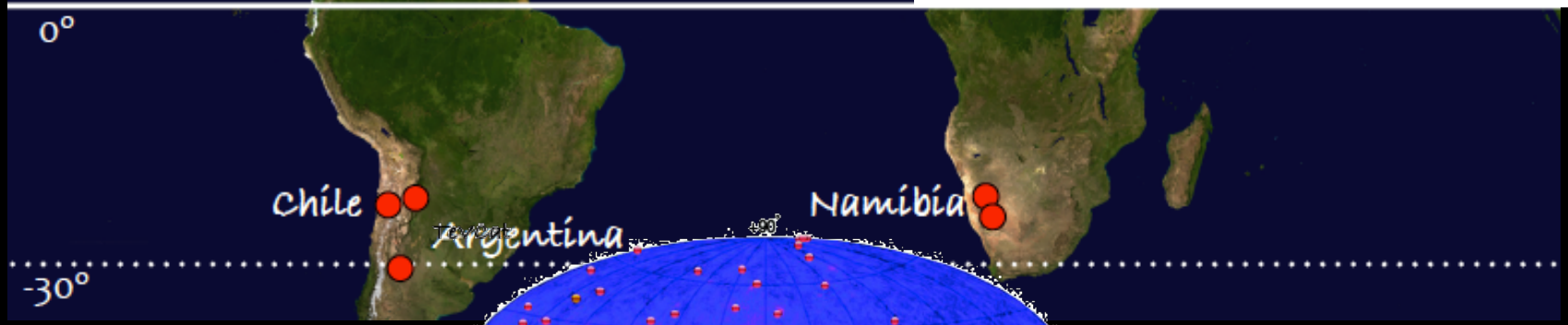
The European Astroparticle Physics Roadmap II
The High energy cosmic ray program
(2015-2025)

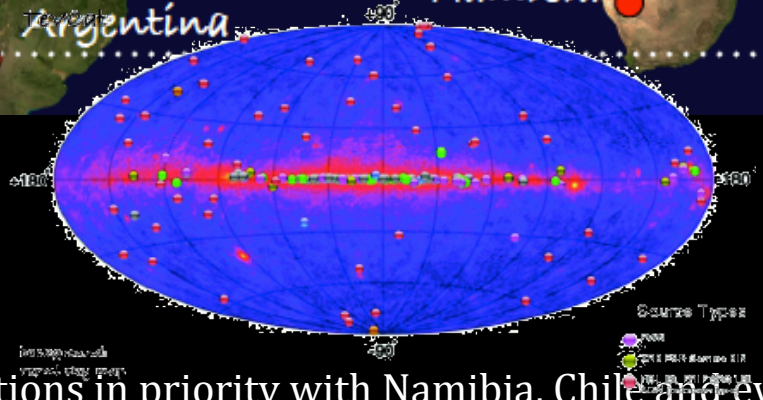
- High Energy photons
  - CTA, high priority of the APPEC roadmap, CDR by 2015
- High energy neutrinos
  - KM3Net, Phase 1 funded → Phase 1.5 ? ORCA?
  - *ICECUBE* → *DECACUBE? PINGU?*
- Ultra High Energy cosmic rays
  - Auger, medium scale upgrade to be evaluated spring 2015
  - *EUSO EUSO-balloon/CNES Aug 2014 → EUSO launch by ?*

High energy photons I



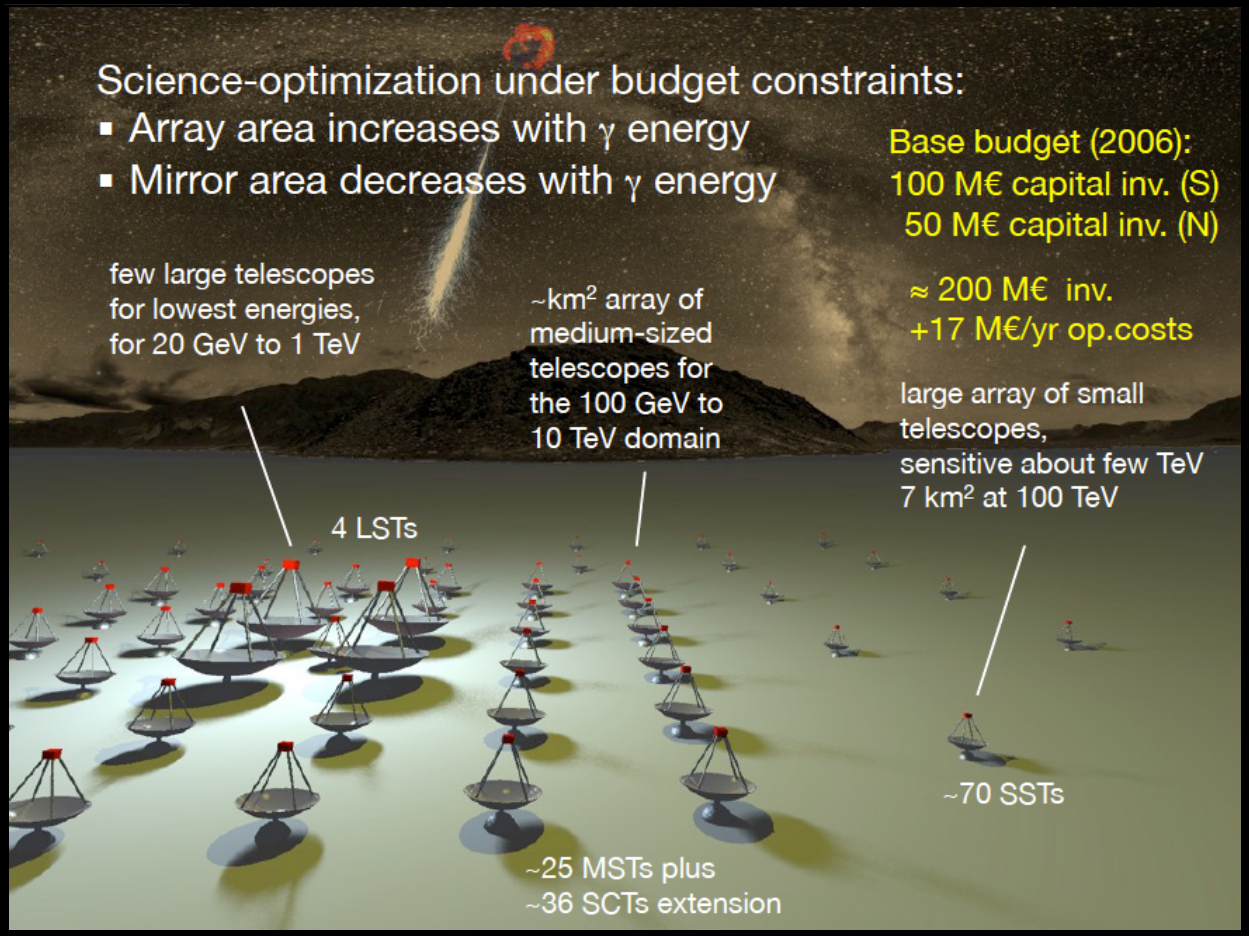






- CTA South : Start negotiations in priority with Namibia, Chile and eventually Argentina
- Energy complementarity with LHAASO

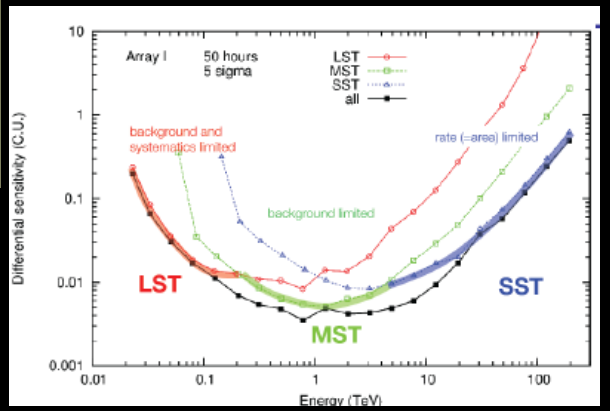
High energy photons II
CTA



- Sensitivity X10
- Energy range X10
- FOV and ang resol. X2-3

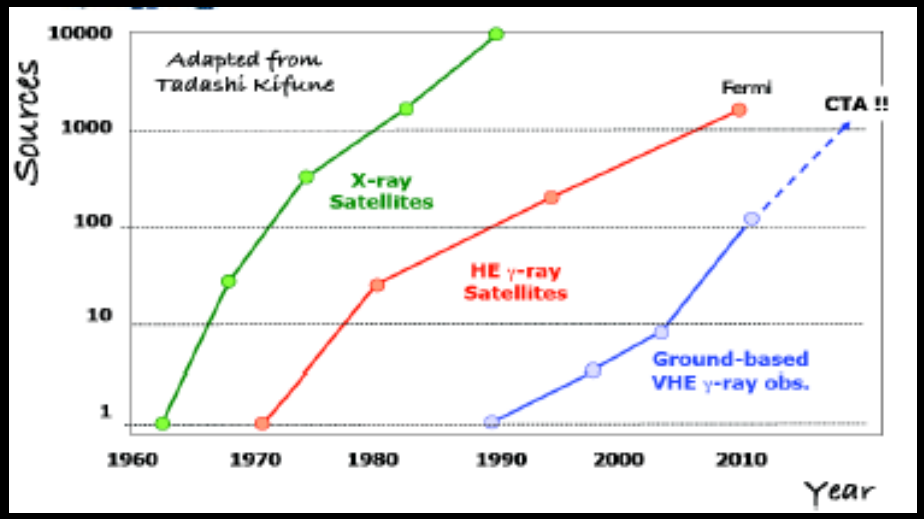
- Physics potential
  - Cosmic accelerators
  - HE astrophysics
  - Fundamental physics (DM, ALP, LIV, …)

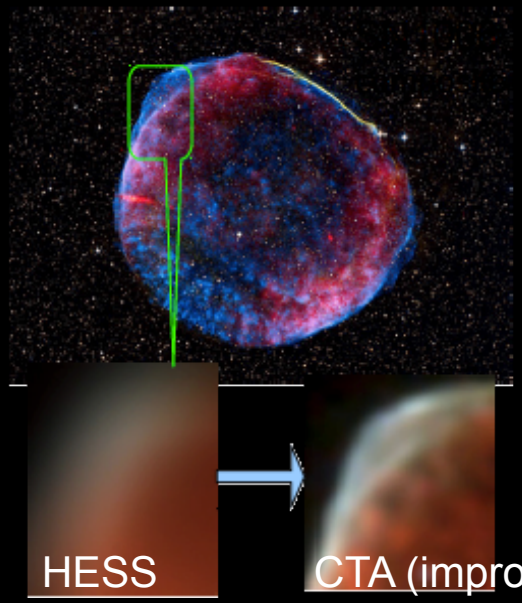
- Construction 2016-2020 ?
- Observations by 2017 ?
- ISSUE: What legal entity for an international Infrastructure? Intermediary Legal Entity: German GmbH

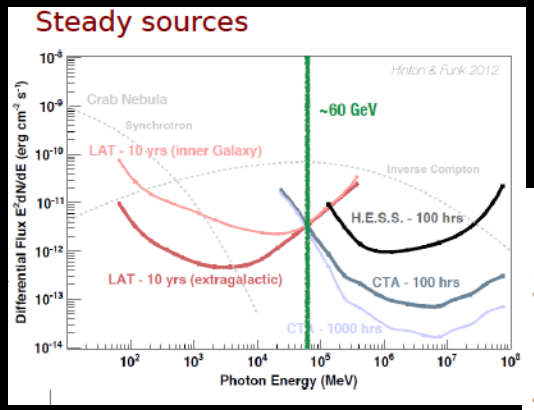


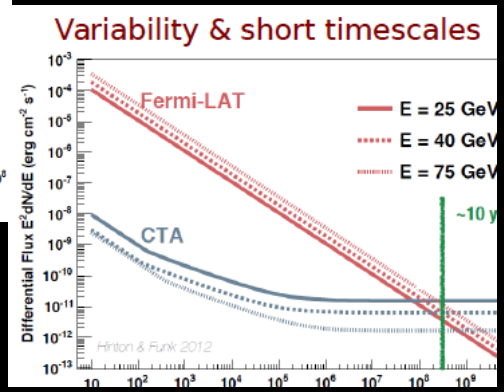
APPEC priority since 2008

High energy photons III
CTA improvements over FERMI and HESS

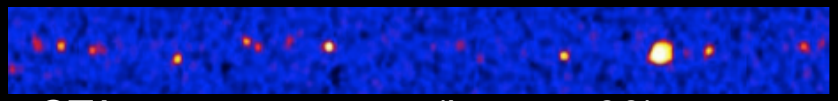




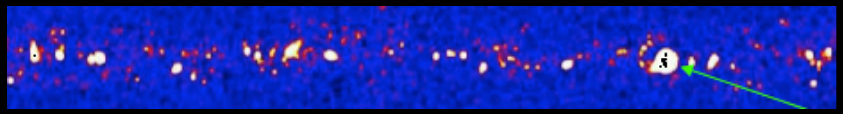




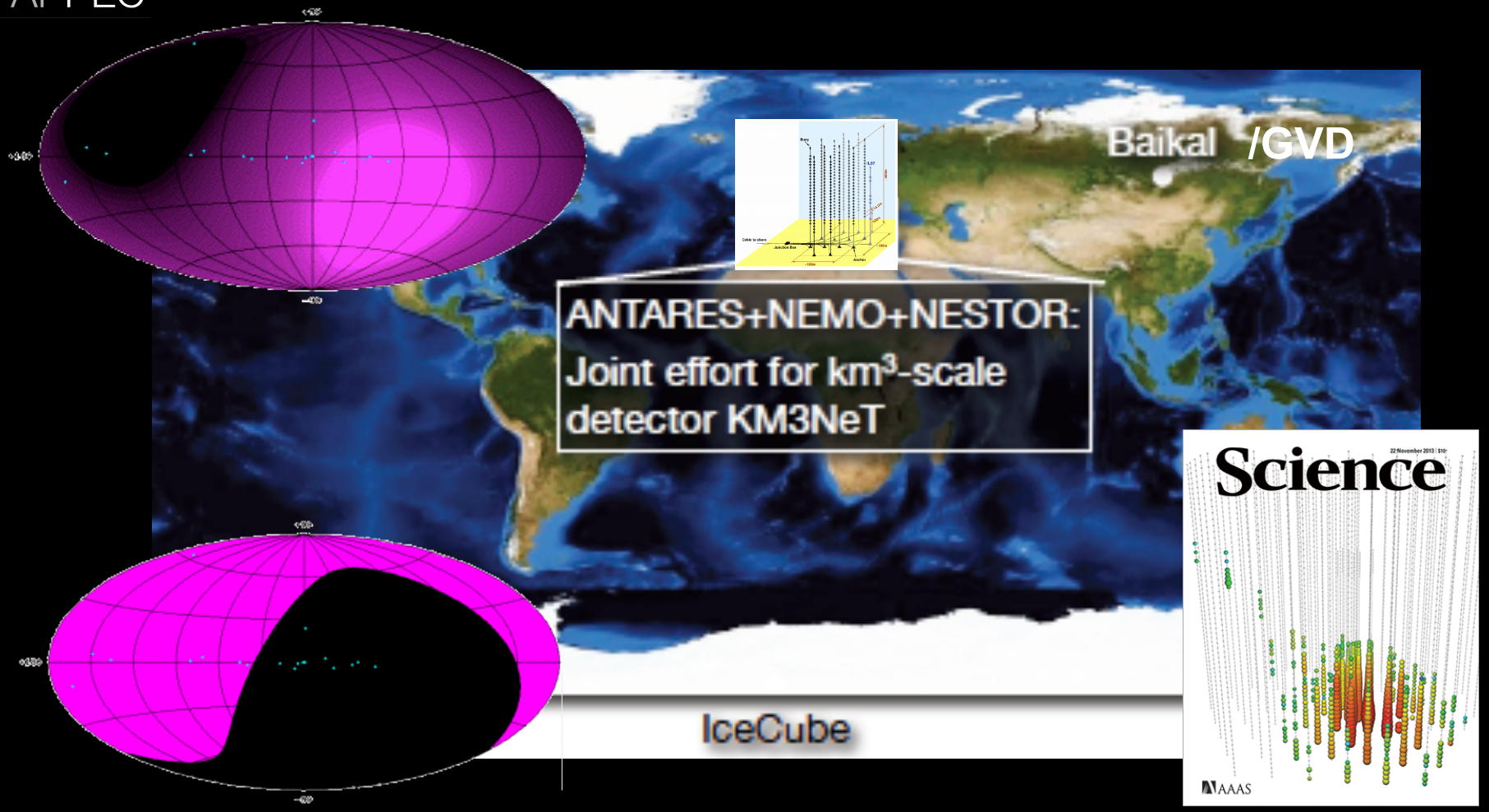
HESS



CTA same exposure (improvx30)



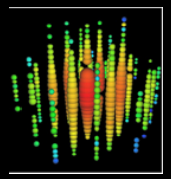
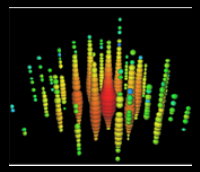
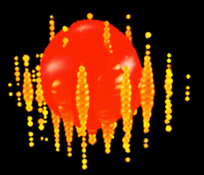
High Energy Neutrinos I



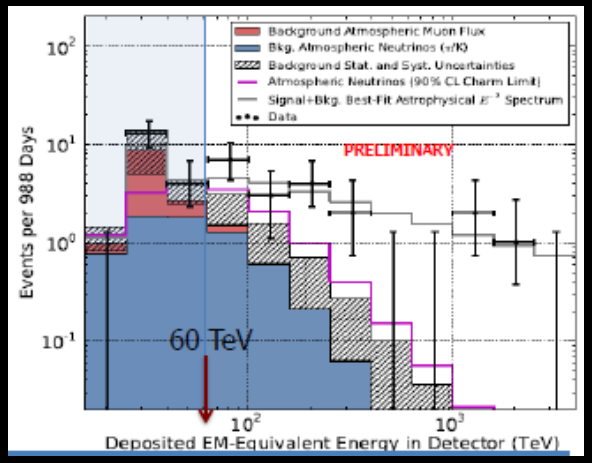
Neutrino telescopes have signed (October 2013) an MoU for a Global Neutrino Network (GNN)

High Energy Neutrino II

Recent results

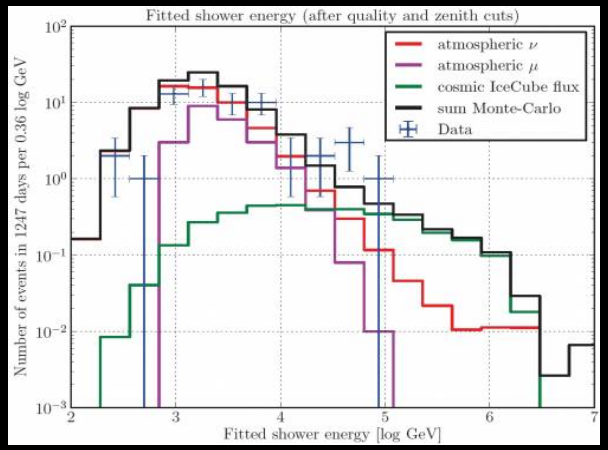




ICECUBE 78 lines 5160 PM

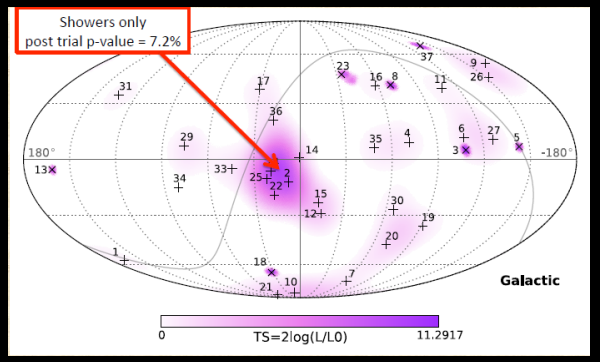


1000days: 37 events ➔ 5,7 σ
~ (0.95+-0.3)*10^{-8} E^{-2} GeV/cm^2/s/sr
Angular resolution 15-16°

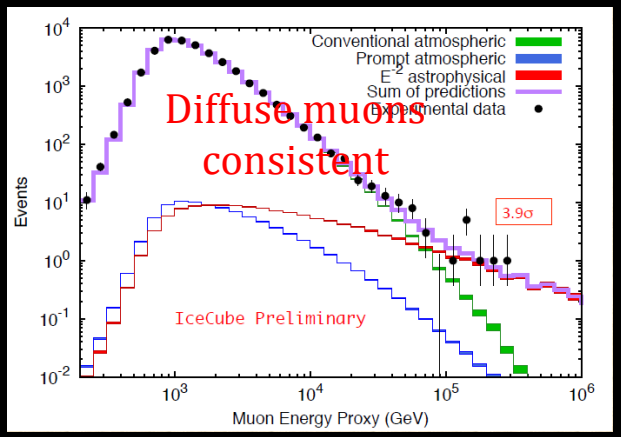
ANTARES 12 lines 900 PM

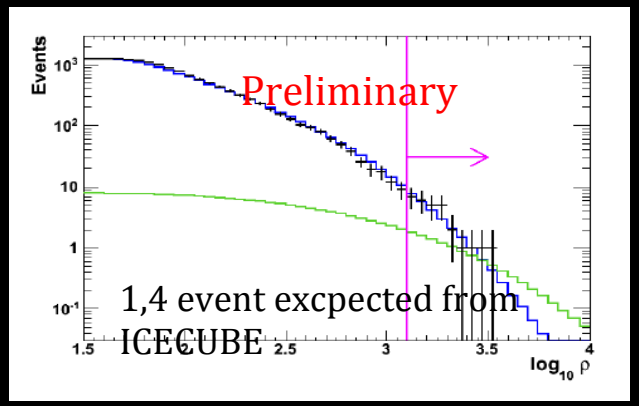


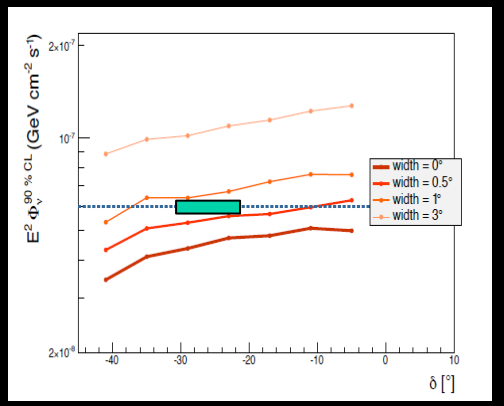
1250 days: 1,5 σ,
~ 1,32 *10^{-8} E^{-2} GeV/cm^2/s/sr
Angular resolution 6-7°



ICECUBE cluster at GC?



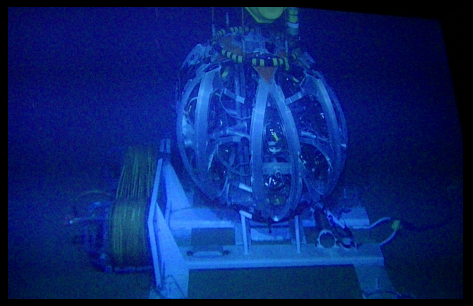




ANTARES Exclude IceCube 'cluster' due to a point source up to 1°extension

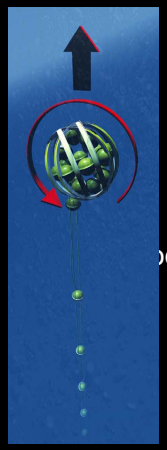
High Energy Neutrino III

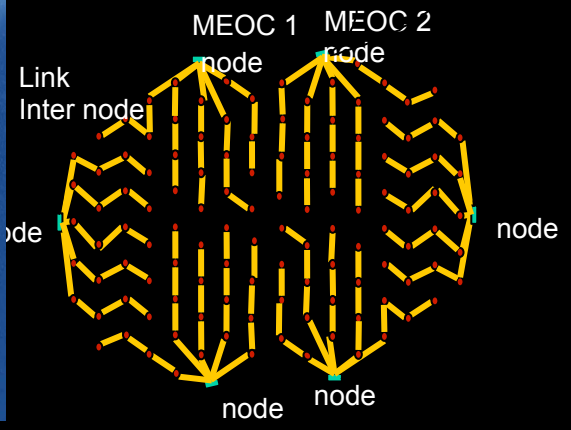
Neutrino telescope projects



KM3NeT: **6 x 0.6 km^3**

- Phase 1 (~3xANTARES, 30 M€): complete 2016,
- Phase 1.5? (2 x 0.6 km^3, +50M€): complete 2020?
  - Check ICECUBE signal
  - ORCA? (115 Strings, 20m apart, 6 m vertical)
- Phase 2? (6 x 0.6 km^3, 220 M€): complete 2025





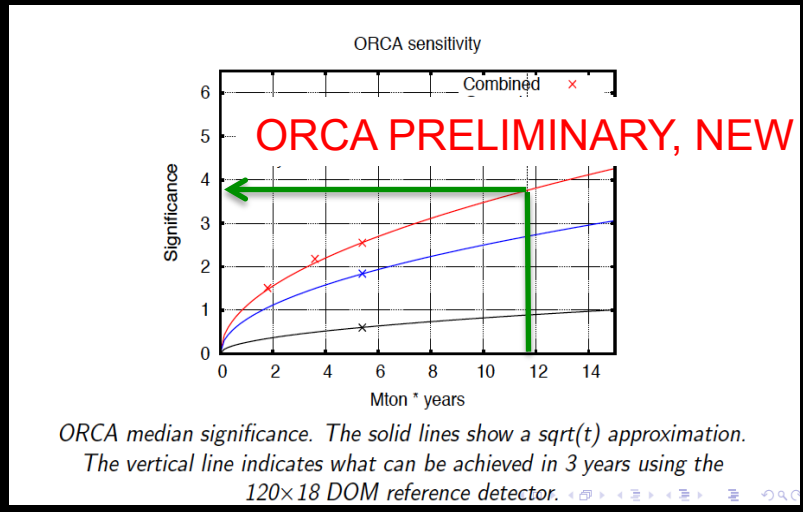
Current optimisation: 0.6 KM3 Blocks of 115 strings, 90m apart, 18 DOM/String, spacing between DOM's 36 m

DecaCube: **5-10 km^3**

- Start 2018/19-Complete 2027?
- Including PINGU with the 3 first of the 8 seasons?
- P5 ➔ PINGU need more conceptual studies

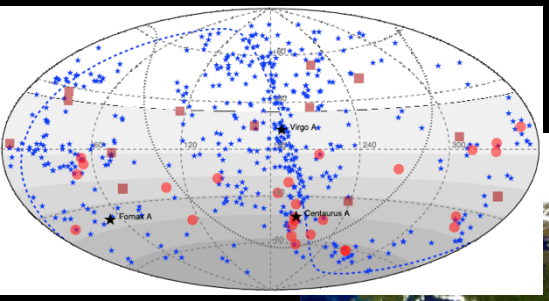
GVD (Baikal): **0.4 km^3**

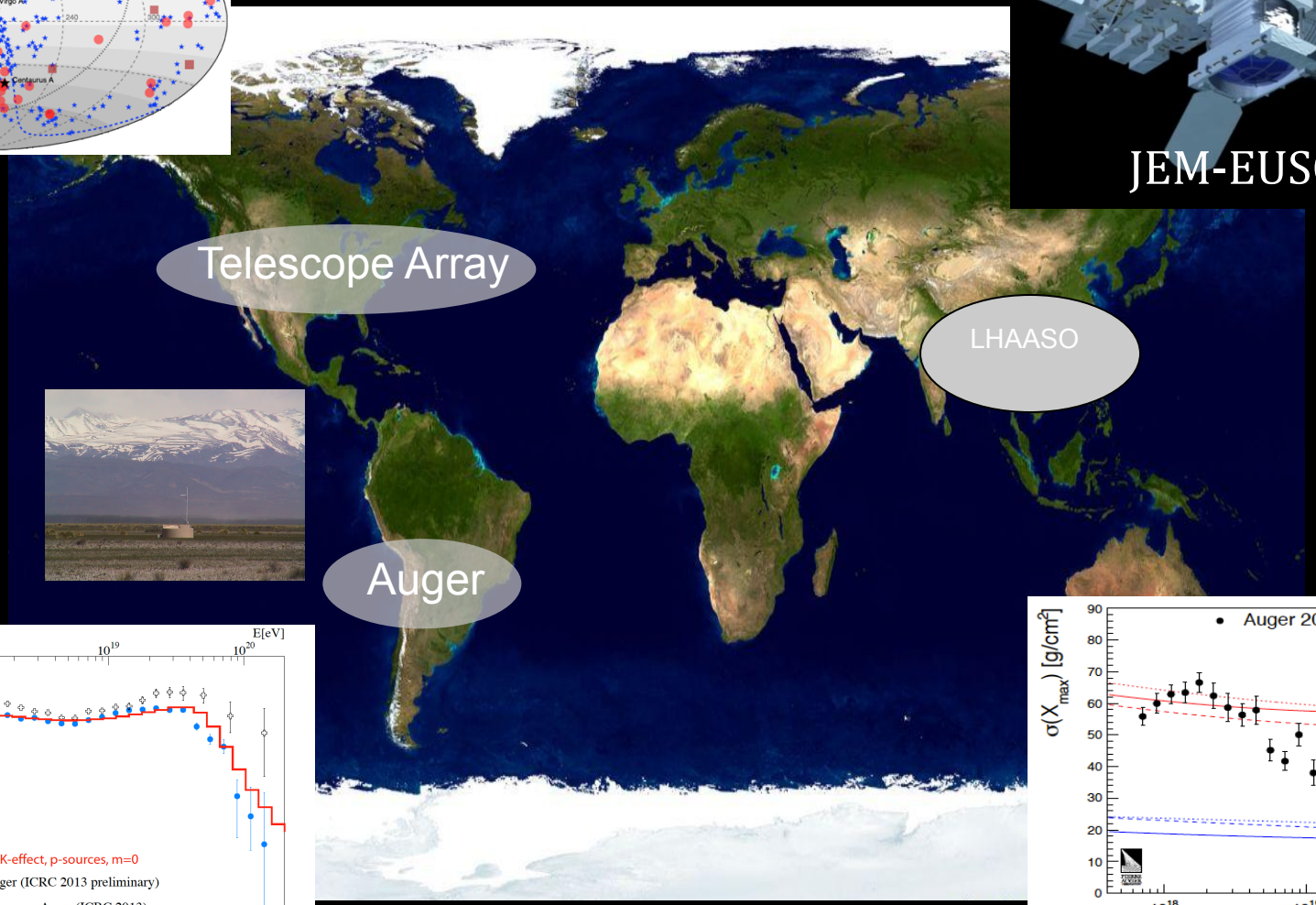
- First of 10 clusters in early 2015? complete 2020



ORCA median significance. The solid lines show a sqrt(t) approximation. The vertical line indicates what can be achieved in 3 years using the 120×18 DOM reference detector.

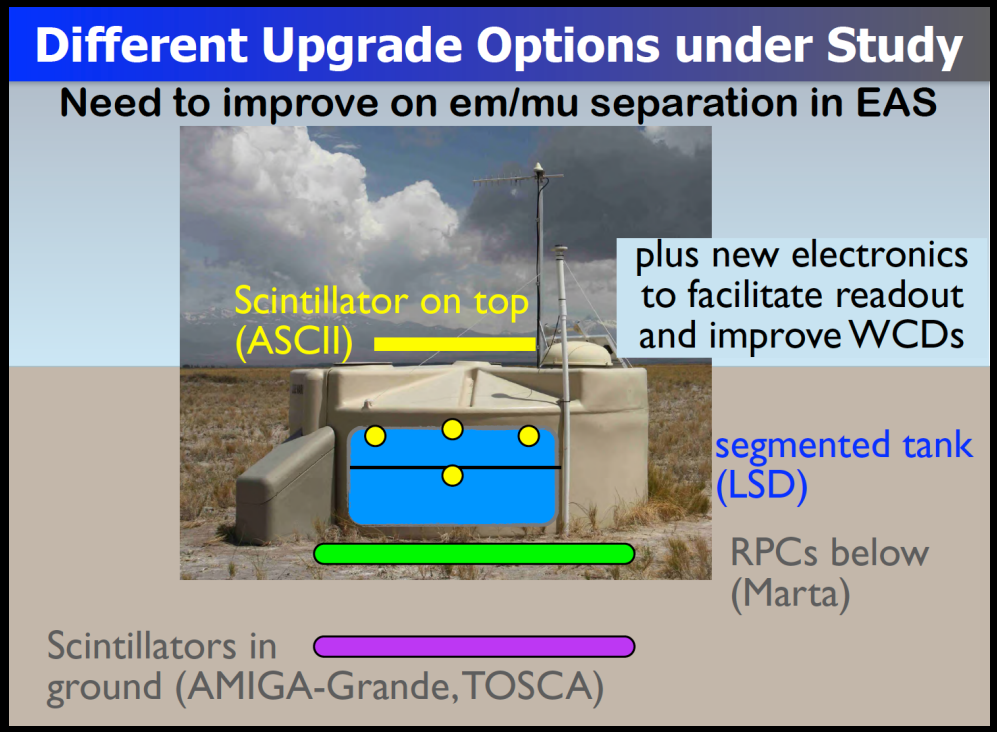
High energy cosmic ray observatories I

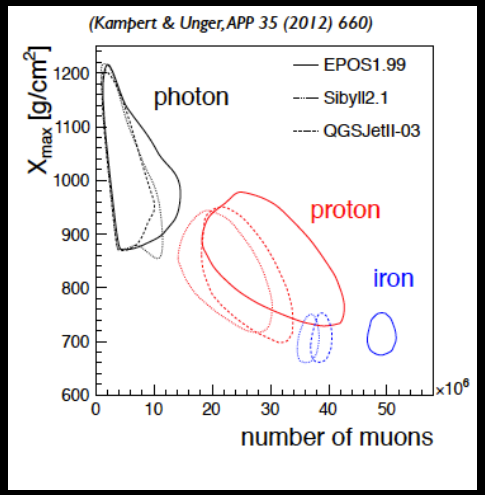


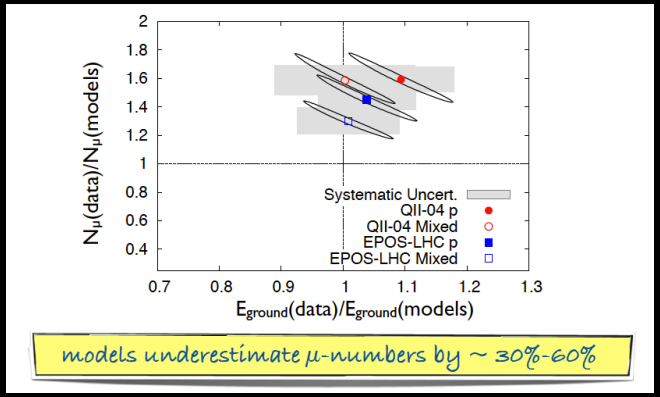


- Spectrum: GZK cutoff or end of the energy reach of the accelerators?
- Composition: fraction of protons? Anisotropy ?

High energy cosmic ray observatories II
Auger upgrade





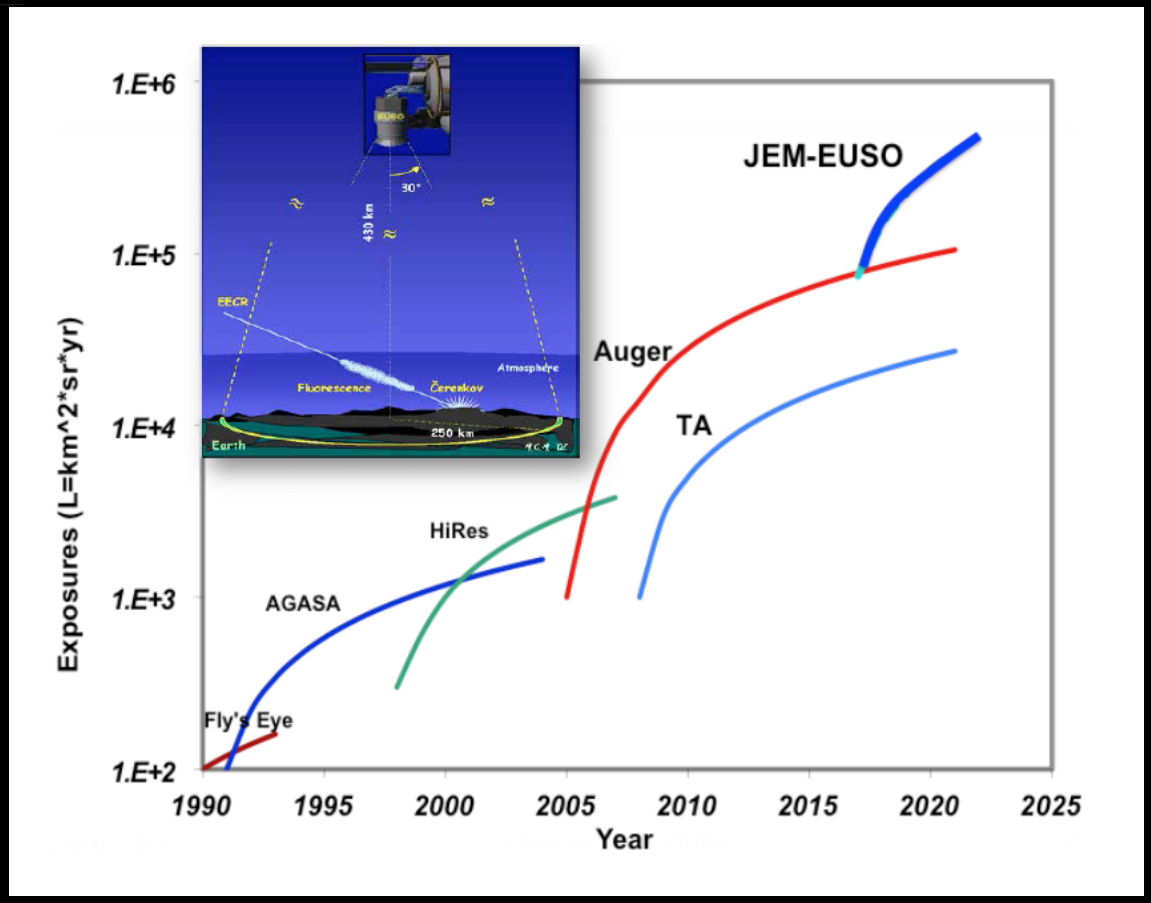


Auger collaboration prepares a medium upgrade proposal to be evaluated by an international STAC in Spring 2015

In parallel one needs to understand the MC-data differences. A collaboration with LHC teams is an urgent matter.

High energy cosmic ray observatories III

EUSO

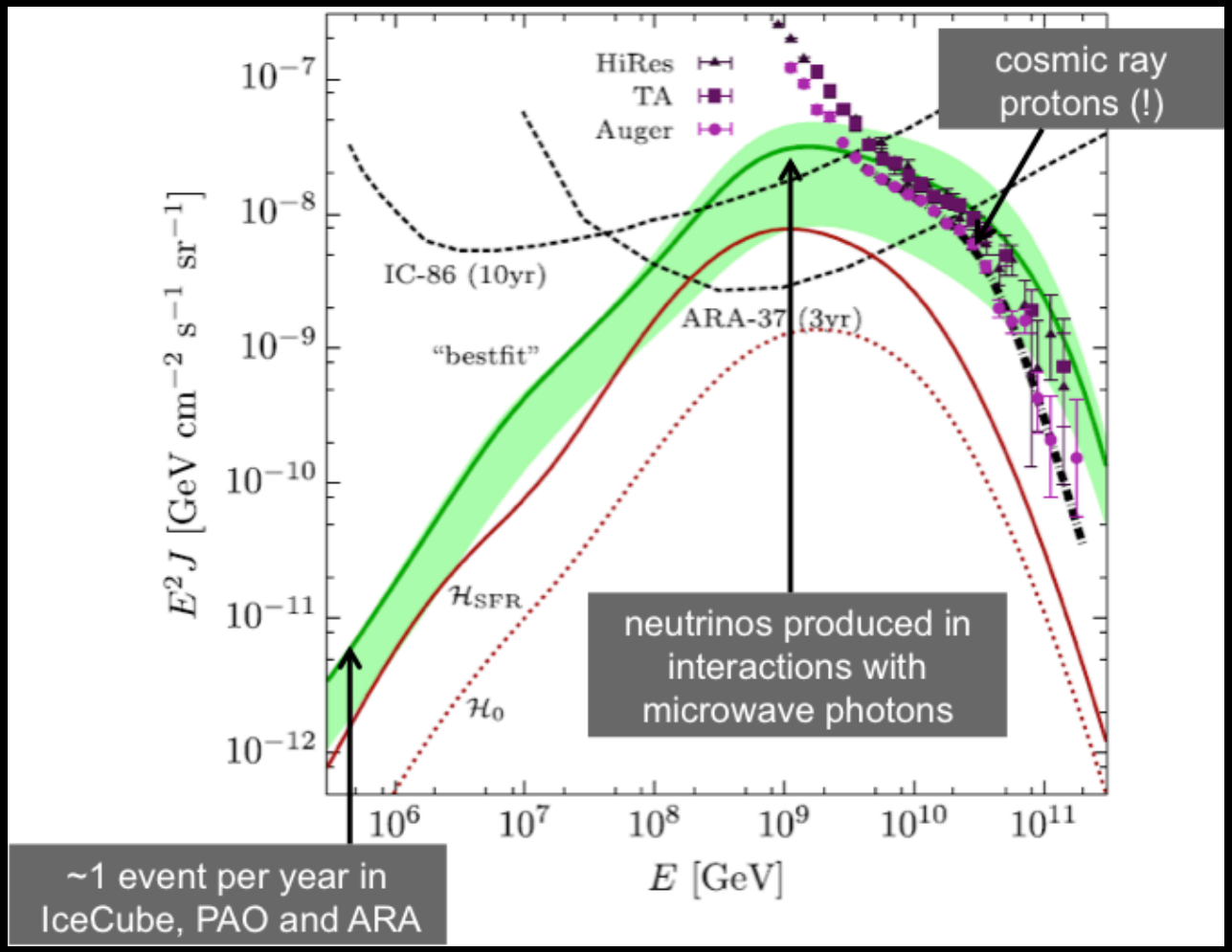


JEM-EUSO
~200 events > 60 EeV/ yr

EUSO-Ballon,
Aug 2014

- Large international collaboration
- But also large programmatic uncertainty: Who and how will launch.
- Multipurpose cosmic ray observatory at the ISS?

High Energy mutimessenger sensitivities start to be comparable: an example (courtesy F. Halzen)



Understanding the UHECR composition is a key parameter to test the coherence of our High Energy picture.

The European Astroparticle Physics Roadmap III (2015-2025 and beyond to 2035)

- Large underground detectors for proton decay, neutrino physics and astrophysics
  - LiqAr. LBNE (➔ LBNF), LBNO,
  - Water Cherenkov HK,
  - Liq. Scintillator JUNO (Solid Scint INO)

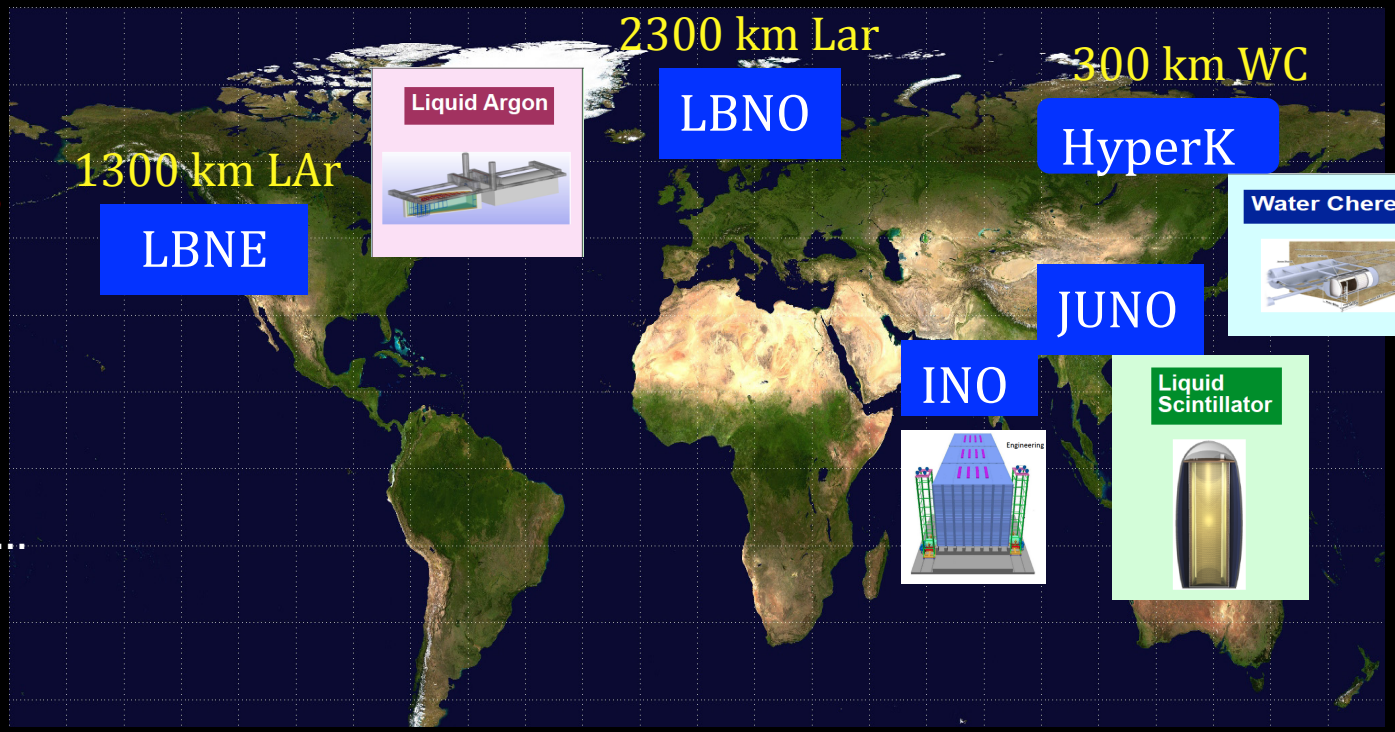
- Dark Energy and CMB
  - *In Space: EUCLID (ESA, NASA)*
  - *On ground: participation to LSST*
  - *CMB: An ESA space mission M4?*

- Gravitational waves
  - Einstein Telescope ET (provided detection by advGW)
  - eLISA (ESA, L3 mission 2034)

Large underground detectors for proton decay, neutrino physics and astrophysics I

- **Mass hierarchy**
- **θ_{23} octant**
- **CP-violating phase δ**
- **Proton decay**
- **Supernova**
- **Solar and**
- **Geo neutrinos**

Also ESSnu, RENO, …



- ApPEC to ESG: It is recommended that CERN, together with key European agencies and ApPEC, enter into discussions with their US and Asian counterparts in order to develop a coherent international strategy for the field.
- HEPAP: Form a new international collaboration to design and execute a highly capable Long-Baseline Neutrino Facility (LBNF) hosted by the U.S. To proceed, a project plan and identified resources must exist to meet the minimum requirements…
- Japan in process of prioritising HK with respect to other projects

A meeting involving world-wide agency responsibles to set-up instruments for the follow-up and encouragement of global convergence

- Agencies
- P5
- ICFA

APPEC

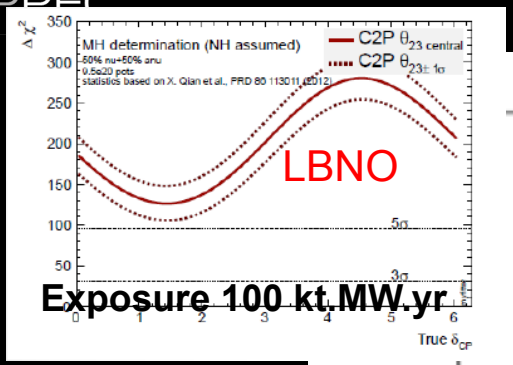
International Meeting for Large Neutrino Infrastructures

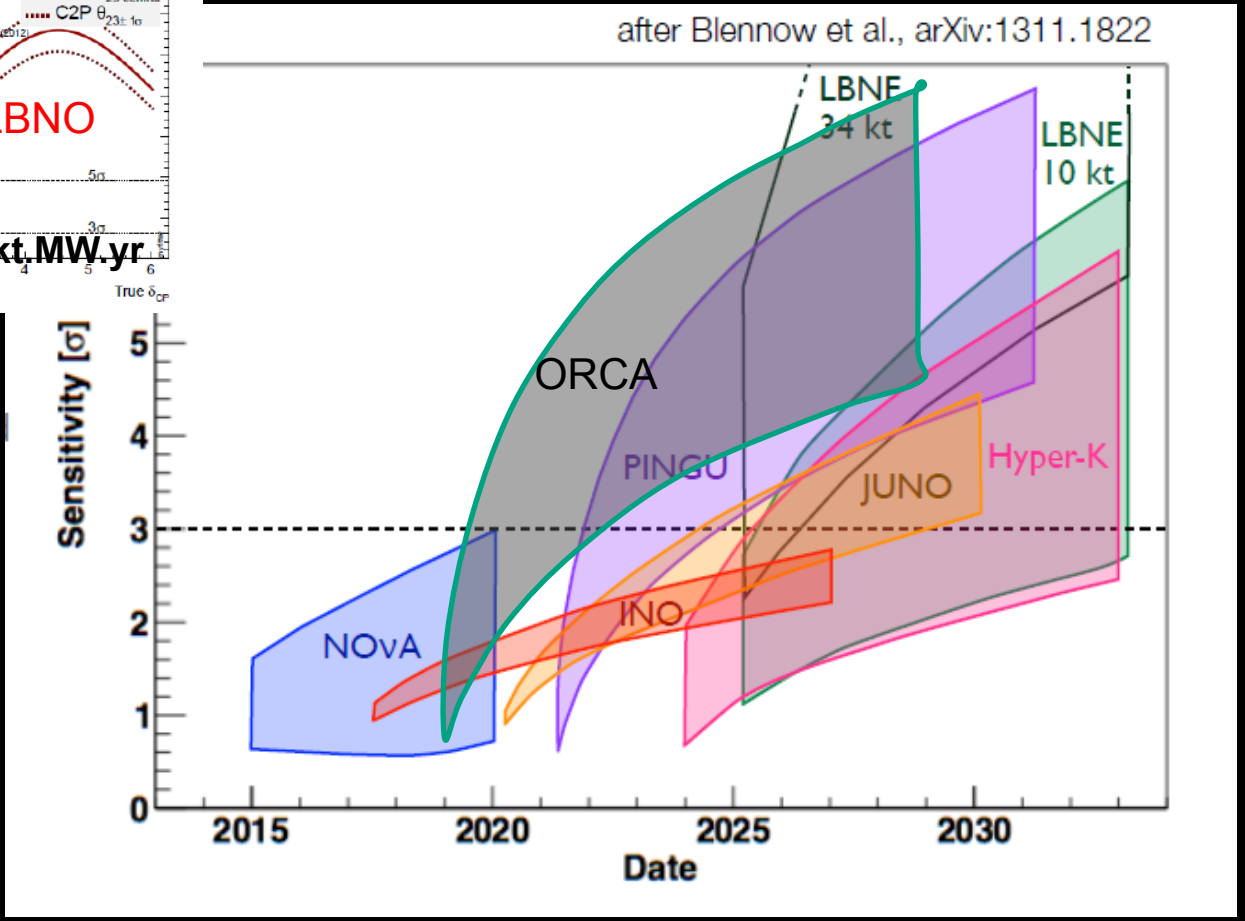
23-24 June 2014
Ecole d'Architecture Paris
3 Quai Panhard et Levassor
Paris, 75013

Speakers
E. Lisi, J.Strait,
M. Nessi, T. Kobayashi,
S.K. Agarwalla, M. Diwan,
M. Shiozawa, A. Rubbia,
T. Ekelof, K. Long,
S. Ritz, J. Lesgourgues,
A. Smirnov, A. McDonald,
P. Huber, T. Laserre,
Y. Wang, SB Kim,
N. Mondal, M. Kowalski

http://appec.org/9-features/78-gnm.html

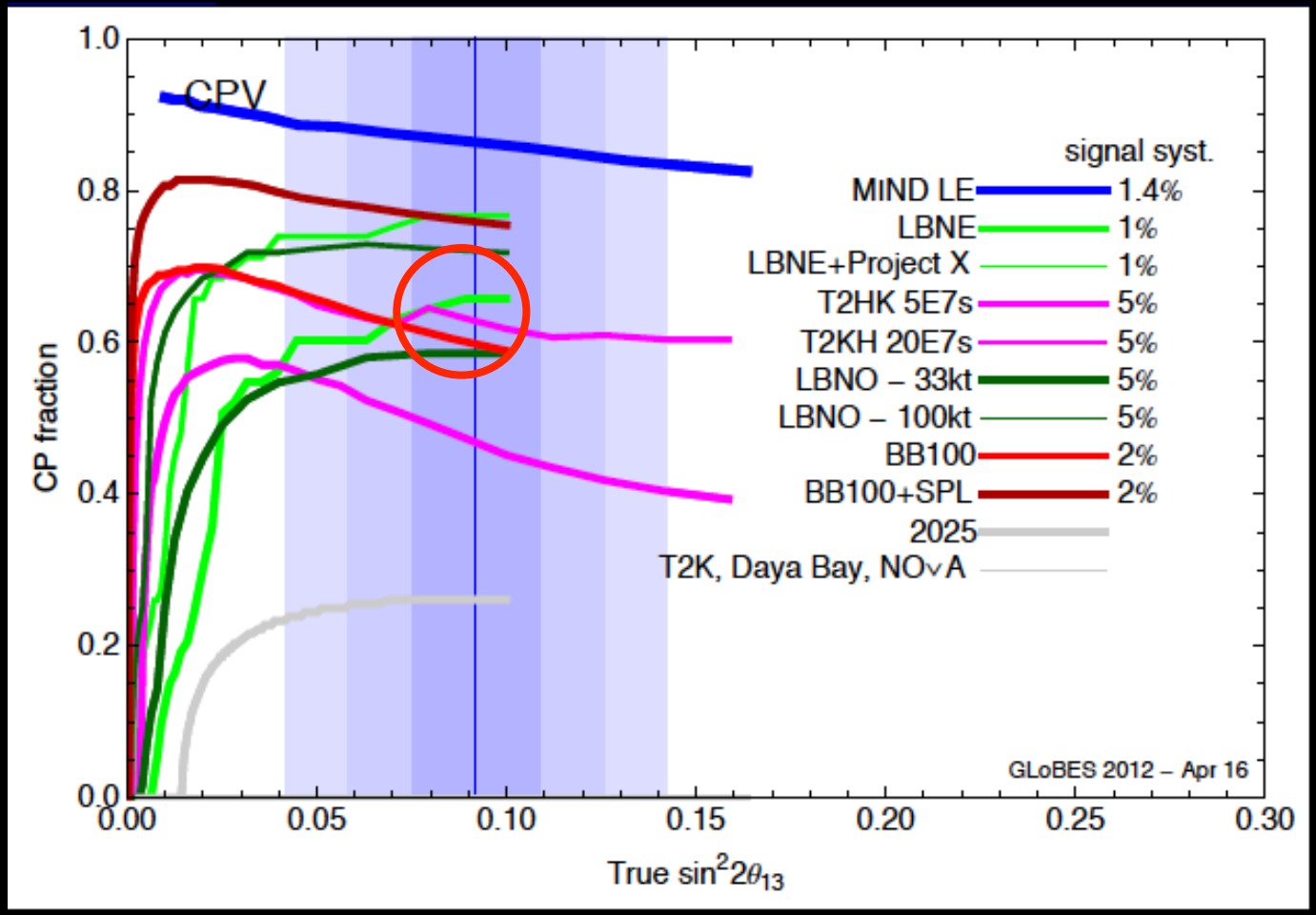
Large scale neutrino detectors II
How soon and at how many sigma should we measure the mass hierarchy ?





Mass hierarchy is an important input in Cosmology.
Many indirect determinations and/or consistency checks , starting 2020, in large cosmological surveys

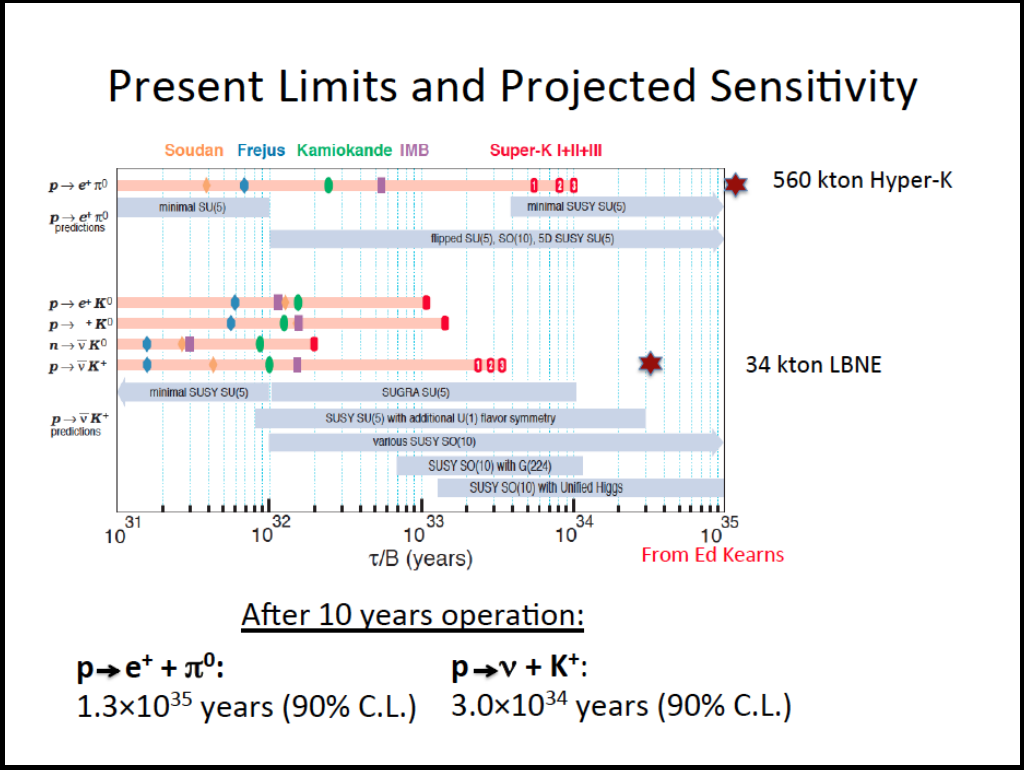
Large scale neutrino detectors III
What part % of the phase space should we cover in the meaurement of the CP violation parameter δ ?



Still need to agree on systematics

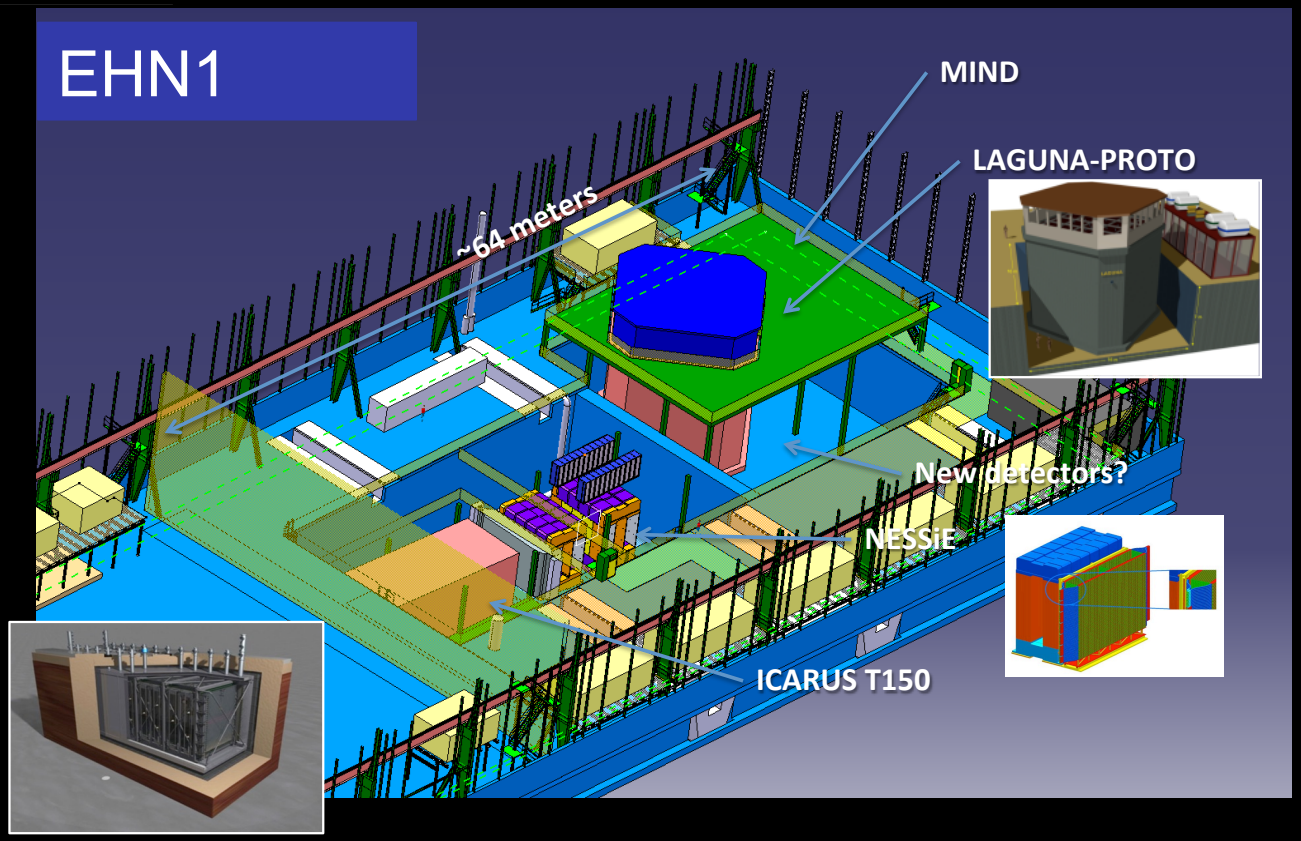
Large scale projects IV
Proton Decay

Vanilla SU(5) and SO(10) unification consistent with BICEP2
➔ $10^{36\text{-}37}$ years for $e^+\pi^0$



- APPEC supports the design and cost studies of very large neutrino detectors optimised for proton decay and astroparticle physics using the techniques of liquid scintillator or water in view of the construction of at least one of these detectors somewhere in the world.
- P5: The experiment should have the demonstrated capability to search for supernova (SN) bursts and for proton decay, providing a significant improvement in discovery sensitivity over current searches for the proton lifetime.

APPEC Support for a neutrino program for R&D and prototyping @ CERN



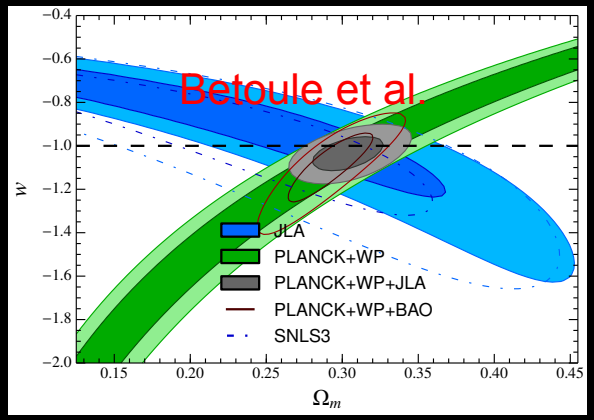
- WA105 (LAGUNA-LBNO), 2-phase LAr prototype
  - Joint task force with LBNE on physics program
- WA104 (ICARUS)
  - Refurbish ICARUS and R&D for a sterile neutrino experiment
  - Discussions for common R&D with LBNE

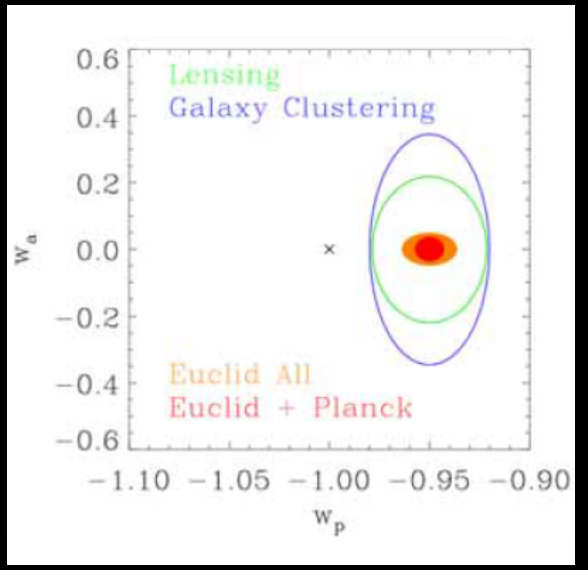
ApPEC supports: a vigorous R&D program and prototyping on the liquid argon detector technique and beam design studies in anticipation of a critical decision in 2015-16 for a strong European participation in a long baseline experiment outside Europe or an experiment in Europe

Other European: ESS study for an intense low energy beam, Protvino beam

Dark energy
From the Legacy Survey to EUCLID and LSST

- SNLS has been a key element in the determination of dark energy parameters.
- EUCLID is an ESA M2 mission (NASA participation) a 1.2 m telescope at L2 with visible and NIR imaging,and spectroscopy.
  - Launch 2020, 6(+1) years of operation
  - Probes: cosmic shear, BAO, galaxy cluster, CMB cross-correlations, SN1a. Legacy science.
  - Measure through redshift and lensing the sum of neutrino masses with σ=25 meV
  - Needs ground-based optical imaging for photo-z estimates
- Complementary in systematics to LSST: superior spectroscopy (LSST) vs absence of atmospheric distortion (EUCLID)
- APPEC recommended since 2011 the participation to both LSST and EUCLID. Biggest challenge the data exchange in accordance with priority rights

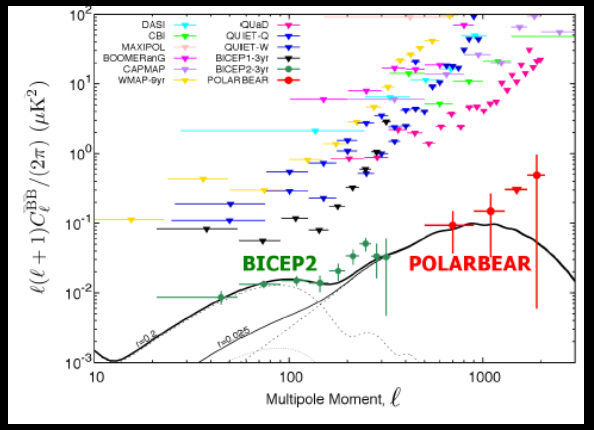




Cosmological Microwave Background
A coordinated European effort towards a middle scale space mission

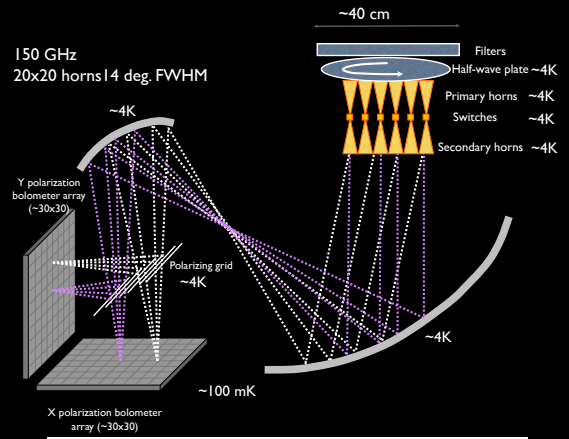
APPEC

APPEC SAC: CMB missions should enter the perimeter of coordination of APPEC agencies, in collaboration with space and astrophysics agencies ofcourse.
P5: Strong recommendation for CMB-S4.
Japan: Litebird space mission under consideration

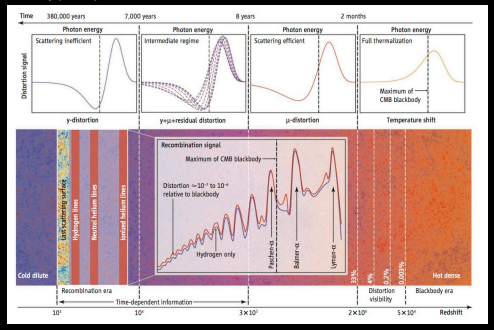


Tasks at hand in the next few years:

- Confirm/infirm BICEP2
  - A large US program (SPT,ACT,PolarBear, Simons Array,…)
  - In Europe QUBIC (Fr-It-UK-China)



- Define a space mission (M4 upcoming ESA call) to measure:
  - r_s, n_s , r_t, n_t of scalar and tensor spectrum
  - Black body spectral distortions



ESA Cosmic Vision 2015-2035

Space : 2 golden decades for fundamental science
(M=0.5 M€, L=1.5 M€)

L2: ATHENA (2028)

M7(2035)

M6(2032)

L3: eLISA (2034)

CMB?

M5 (2030)

M4(2026)

S1…

M3:PLATO (2024)

M2:EUCLID (2020)

L1: JUICE (2022)

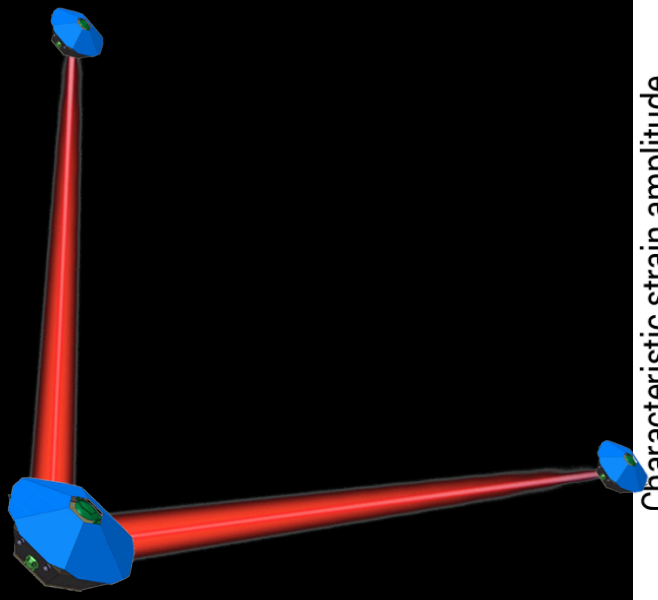
M1 Solar Orbiter

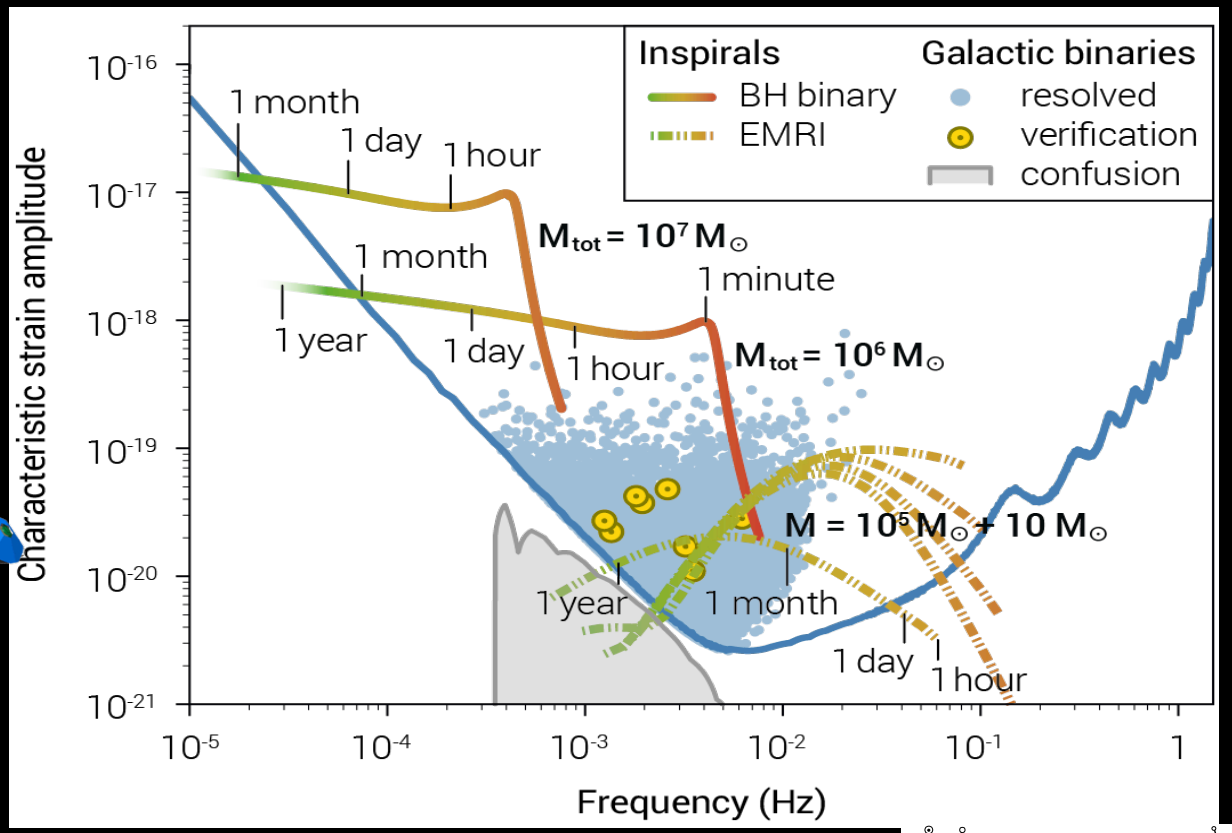
JWST

BEPI COLOMBO

GWA further in the future

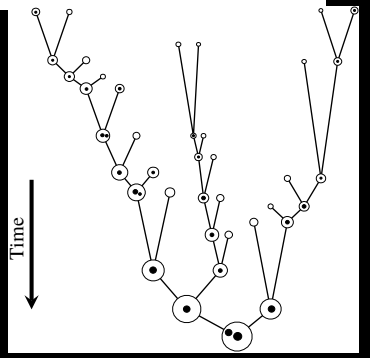
eLISA(2034)



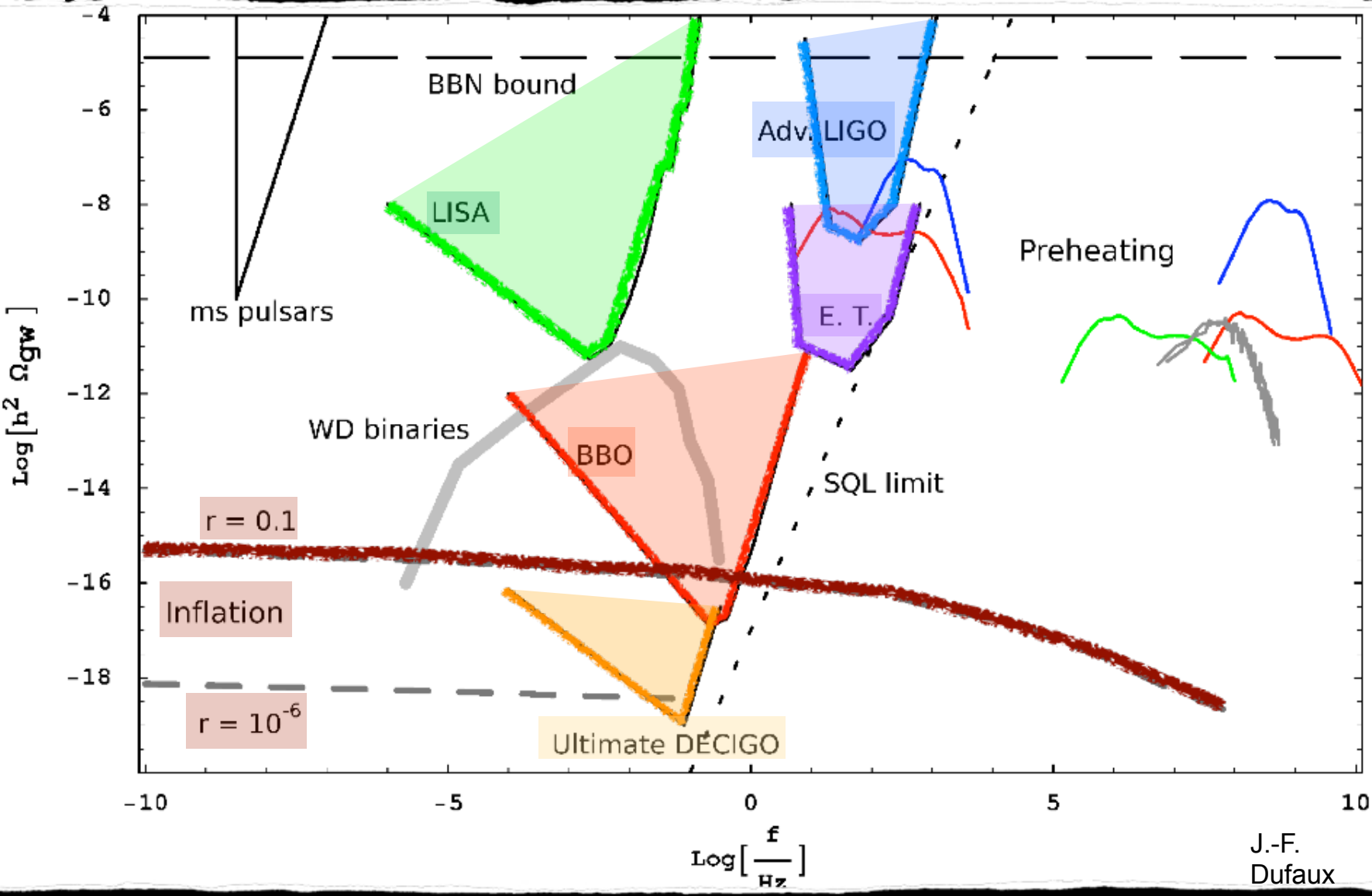


eLISA band

- 0.1-100 mHz ⟹ 1-1000 TeV (LHC)
- Phase transitions, Topological defects…
- Higgs self-couplings and potential
- Supersymmetry
- Extra dimensions, Strings



ET and eLISA milestones in the way towards the direct detection of primordial gravitational waves



J.-F. Dufaux

Conclusions

- *Exciting times: new data brings focus to physics connecting the different scales of the Universe*

- *Astroparticle Physics enters into a period of globalisation and focusing to a few large projects. Good atmosphere for international collaboration.*

- *APPEC is preparing a roadmap "consistent with available budgets" for the end of the year 2014*

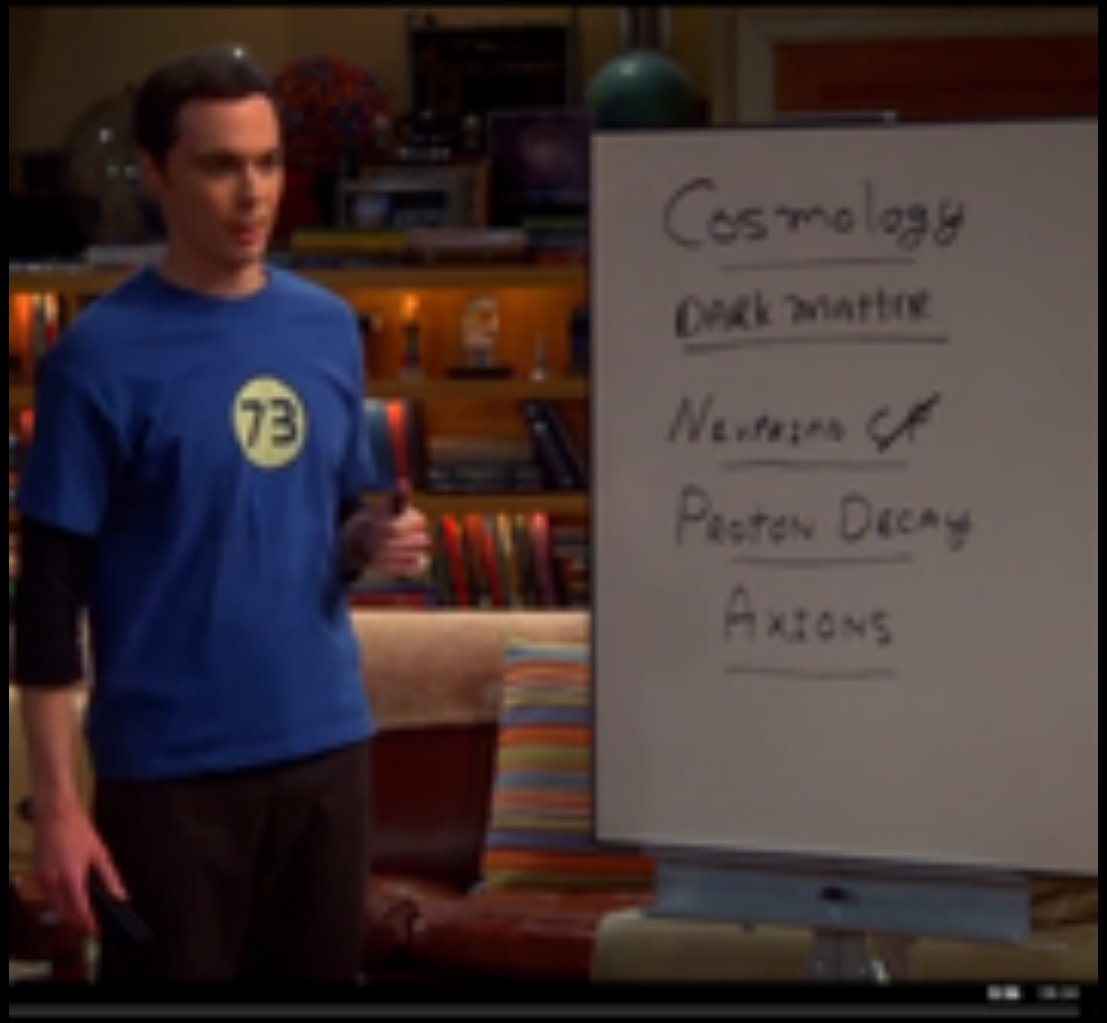
- *Great expectations from the Advanced Gravitational antennas in the coming years*

- *A high energy astroparticle physics program is in deployment*

- *Increase of sensitivities and design studies in progress demand a re-evaluation in 2-3 years of neutrino program, multi-ton DM and ton Double-β experiments , in collaboration with our international partners*

- *Cosmology in CMB and Dark surveys are closely linked with the rest of the program*

From the “Big Bang Theory”, Sheldon’s dilemma :
We need a roadmap



Courtesy Ino Agrafioti

Spare slides

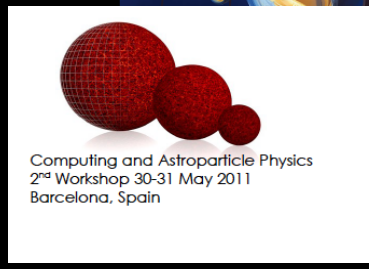
APPEC (ASPERA) actions

Reports and presentations in www.appec.org

- R&D (common funding, total 9 M€; 2010-2012)
  - Dark matter (DARWIN, EURECA) , CTA, Neutrino mass (GERDA, LUCFIFER) , Auger, Low energy neutrino (LENA, ORCA,PINGU) and ET (GW)

- Industrial contacts (Munich, Pisa, Darmstadt; 2010-2012)
  - Photosensors, Electronics, Mirrors, Lasers, Cryogenics, Vacuum

- Computing (Lyon, Barcelona, Hannover; 2010-2012)
  - Astroparticle computing ranges from signal analysis (GW) through event crunching (CR) to large surveys (DE).
  - Towards a white paper (2014). Discussions with CERN and others for a "new" computing model.



- Interdisciplinarity (Paris, Amsterdam, Durham; 2010-2012)
  - Geosciences, Biodiversity, Climate,…

- Theory (Particle Astrophysics, Cosmology Program, PACT, 2013)
  - ✓ Workshops, School, common funding of postdocs