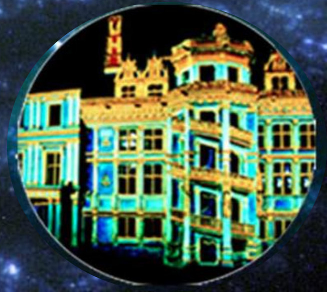
Astroparticle Physics Today and Tomorrow

Stavros Katsanevas
APPEC Chairman, Univ. Paris VII, IN2P3/CNRS

25emes Rencontres de Blois 2013



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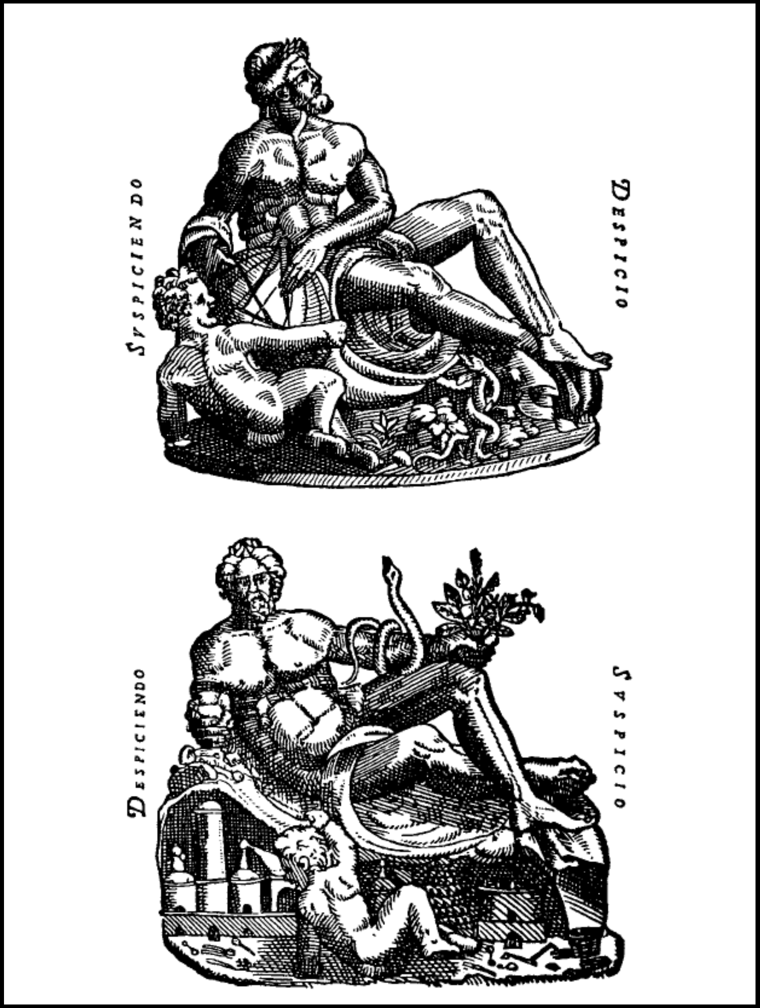
Astroparticle in focus

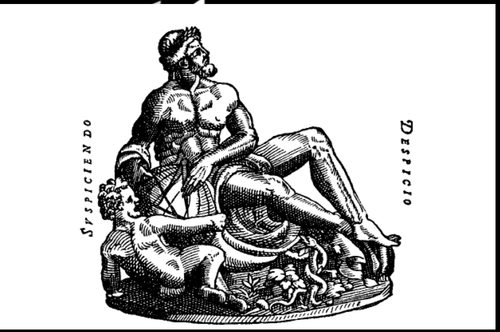
Suspiciendo
despicio

*(Looking up
I am in fact
looking down)*

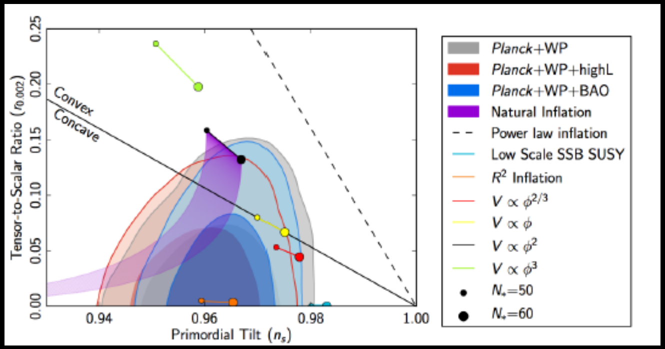


Descpiciendo
Suspicio
*(Looking down
I am in fact
looking up)*

From the frontispiece of Tycho Brahe’s Uranienborg

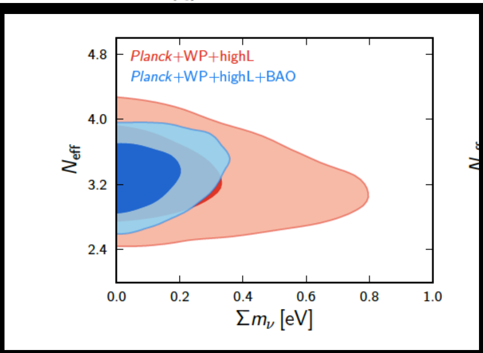


Looking up: PLANCK lessons



- n_s=1 excluded at 7 σ ➔ Inflation
  - In a year with polarisation data sensitivity r ➔ 0,03
- Number of effective neutrinos closer to 3
- Sky maps of clusters, dark matter and violent phenomena
- An example: smaller number of clusters seen (through SZ) than predicted by CMB.
  - Wrong physics scaling (Y (gas)-Mass)?

    or
  - We do not understand the transfer function ? e.g. neutrinos in quasi-degenerate region, WDM, etc. Are there "new" particles influencing cosmic structure formation?



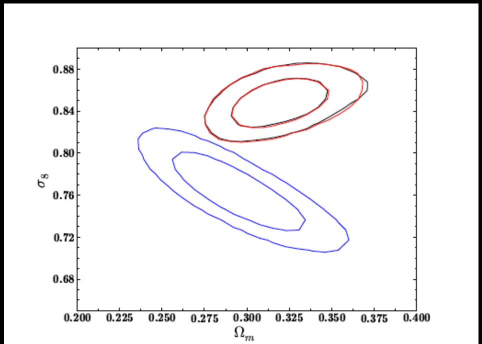
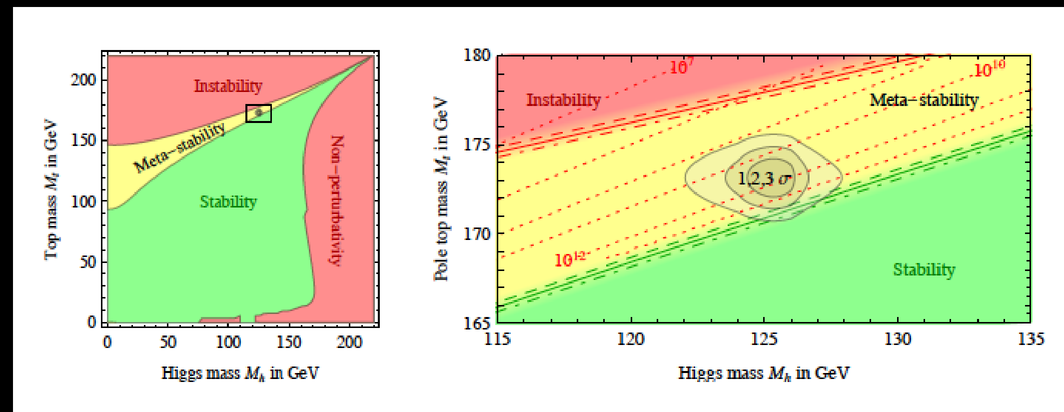


Fig. 11. 2D Ω_m–σ_8 likelihood contours for the analysis with *Planck* CMB only (red); *Planck* SZ + BAO + BBN (blue); and the combined *Planck* CMB + SZ analysis where the bias $(1 - b)$ is a free parameter (black).

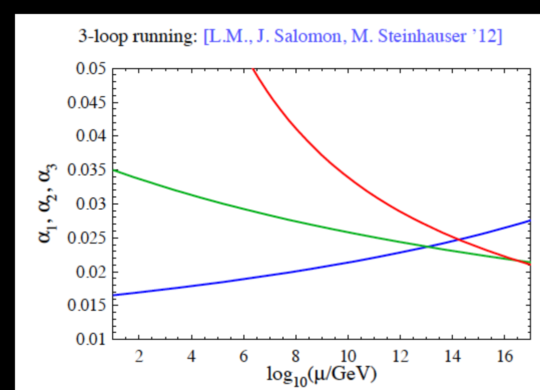
Looking down: LHC and neutrino

- There is no other scale between the EW scale (LHC) and inflation (PLANCK) ?
    - then fine-tuning ?
- If there are other scales how many ?
- Are there scales close to inflation ?
    - Neutrino points to a high scale (See Saw)
    - ν mass
    - p -decay
- Are there new scales close to the EW scale ?
    - Dark-matter (SUSY?)
- Do we understand the vacuum ?
    - Dark Energy



Degrassi et al.

$$\mathcal{L}_{SM} + \frac{1}{\Lambda}\mathcal{L}_5 + \frac{1}{\Lambda^2}\mathcal{L}_6 + \ldots$$



Astroparticle Physics in focus
Going up and down the cosmic ladder

The heavenly ladder
of St John of Klimakos , Sinai

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

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

1) How do the particles and fields of the intermediate scales shape the genesis, evolution and destruction of cosmic structures ?
   1) High energy photons, neutrinos, CR
   2) Gravitational waves

Roadmapping for Astroparticle 2013-2014 a pivotal year

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✓ **European Strategy for Astroparticle Physics.** From the first roadmap in 2008, essentially a definition of the field (dubbed the 7 magnificent) to the roadmap update in 2011 with time ordering priorities. ApPEC plan including available funds by mid-2014.

✓**European Strategy for Particle Physics.** Official signature this Thursday 30 May 2013 in Brussels. Overlaps essentially in neutrino physics but also in other fields.

✓**US Snowmass process 2013.** Document in August. P5 committee starts working in September. Prioritisation early 2014.

✓**Japan.** JAHEP recommends ILC (1st priority) and HK (2nd) . In 2013-2014 the science council of Japan will update its master plan. The government will select 25-20, candidates are HK, CTA, JEM-EUSO, Kamland, DM. KAGRA funded.

✓**China.** Daya Bay II and LHAASO among 5 large infrastructures approved

✓**Russia, India…** Discussions on funding of large infrastructures

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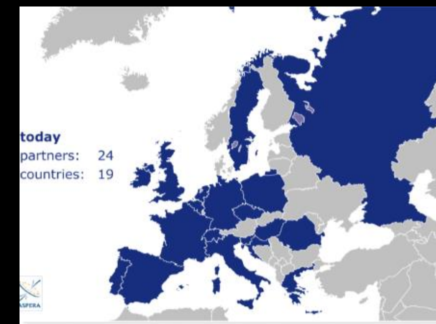
A short history of European Astroparticle Physics Coordination (2001-2013)

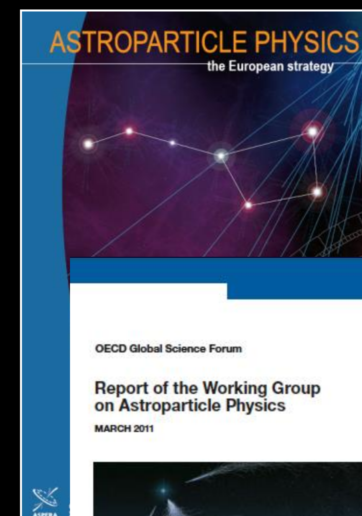


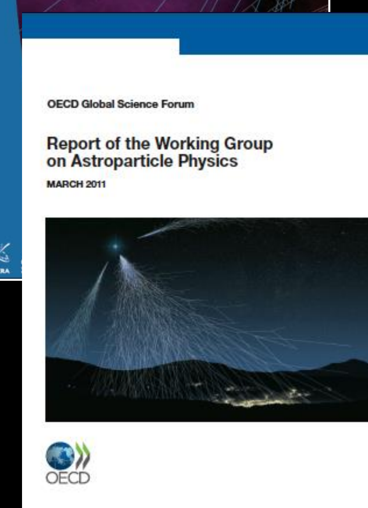
✓**2001-2012** Astroparticle European Coordination ApPEC. European Agency coordination: Main actions:

- ✓Information/Survey of the field
- ✓Launch of the EU-I3 ILIAS
- ✓Launch of ASPERA

✓**2006-2012** ERANET ASPERA (EU FP6 and FP7) 6 M€ EU funding , 19 countries, a program of 3000 researchers and 220 M€/year consolidated funds. Main actions:

- ✓ Roadmap (from definition 2008 to priorities 2011)
- ✓ Accompanying actions (next slide)
- ✓ Global coordination workshops (Brussels, Paris). Initiative for the creation (2011) of the OECD/GSF group Astroparticle International Forum (APIF)





✓**2012 (29 June)** Astroparticle European Consortium ApPEC. Agency funded coordination (MoU). 3 functional centres (France, Germany, Italy, + Spain). Initiatives in 2013

- ✓Interface with European Strategy for Particle Physics
- ✓Coordination in Theory (PACT)
- ✓Preparation for Horizon 2020 (4-5 November in Berlin)

ApPEC-ASPERA actions (highlights)

Reports and presentations in www.aspera-eu.org

- 3 calls for R&D and Design Studies (agency virtual common pot) total 9 M€
  - Dark matter (DARWIN, EURECA) and CTA (2010)
  - Neutrino mass (GERDA, LUCFIFER) and AugerNext (2011)
  - Low energy neutrino (LENA, ORCA,PINGU) and ET (2012)
- Interdisciplinary connections (Geosciences, Biodiversity, Climate, Applications)
  - **From the Geosphere to the Cosmos (Paris Dec2010)**
  - **Underwater Science (Amsterdam May2012)**
  - **Underground science (Durham Dec2012)**
- Industrial contacts and innovation
  - Photosensors and Electronics (Munich October 2010)
  - Mirrors and Lasers (Pisa Oct2011)
  - Cryogenics and Vacuum (Darmstadt March2012)
- Towards a computing model for Astroparticle
  - From signal driven(GW), through event driven (CR) to map driven (DE)
  - Lyon Oct2010, Barcelona May2011, Hannover May 2012
- Project management guidelines for large projects
  - Gran Sasso 2012

The European Astroparticle Physics Roadmap

Projects essentially approved : priority: their timely entry in full operation

- Gravitational wave antenna upgrades (advVIRGO, advLIGO)
  - ➔ detection by 2018?
- Neutrino mass
  - ➔ Quasi-degenerate and inverse hierarchy region
- Dark matter
  - ➔ 1 ton and beyond (to sensitivity σ - 10^{-12} pb^{-1})

Current challenges: the next generation of large CR programs

- High Energy photons
  - CTA, in the process of TDR submission
- High Energy neutrinos
  - KM3Net, support for phase 1
- Ultra High Energy cosmic rays
  - AUGER, upgrade proposal in discussion

Large future projects in synergy with other agencies (ca 2020):

- Neutrino properties and astrophysics, proton decay (with CERN, …?)
  - LAGUNA, currently support for LAr prototype test at CERN NH
- Dark Energy
  - EUCLID, LSST (with ESA, DOE,NSF,…)
- Next generation Gravitational wave detection (ET, eLisa)

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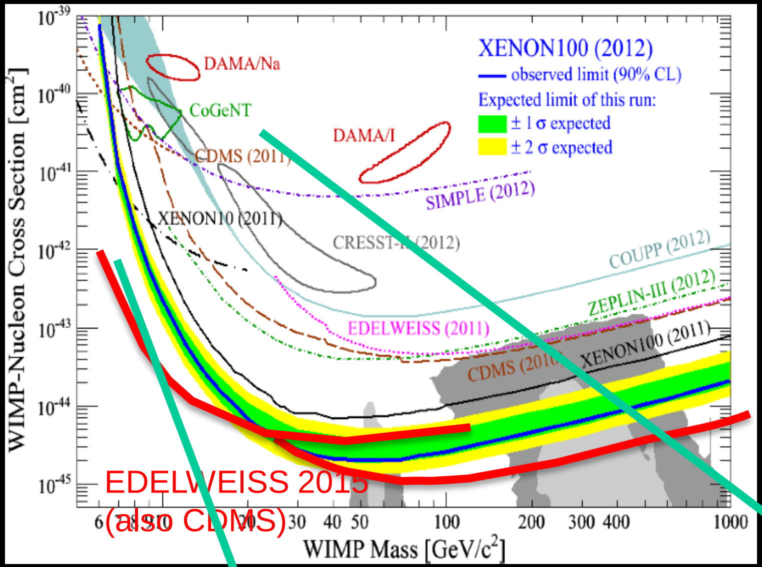
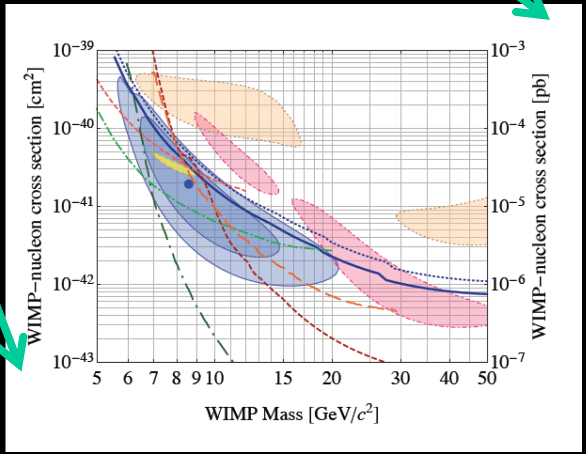
Dark Matter I

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.

Dark Matter II
direct detection today

✓ World leading European-US experiment XENON presently in its 100 kg phase and preparing its upgrade to 1ton of detecting material,
✓ Bolometric detectors gathered in the EURECA ((EDELWEISS, CRESST) immediately following in sensitivity and advancing in coordination with their US counterpart CDMS (intense negotiations),
✓ Developments in liquid-argon, using e.g. argon depleted in ^{39}Ar , (DarkSide, ArDM).
✓ The low energy regime (asymmetric dark matter) needs to be clarified (DAMA/LIBRA, CoGENt, CRESST, Xenon, CDMS,…in Europe or elsewhere in the world.
✓Spin dependent studiesCOUPP





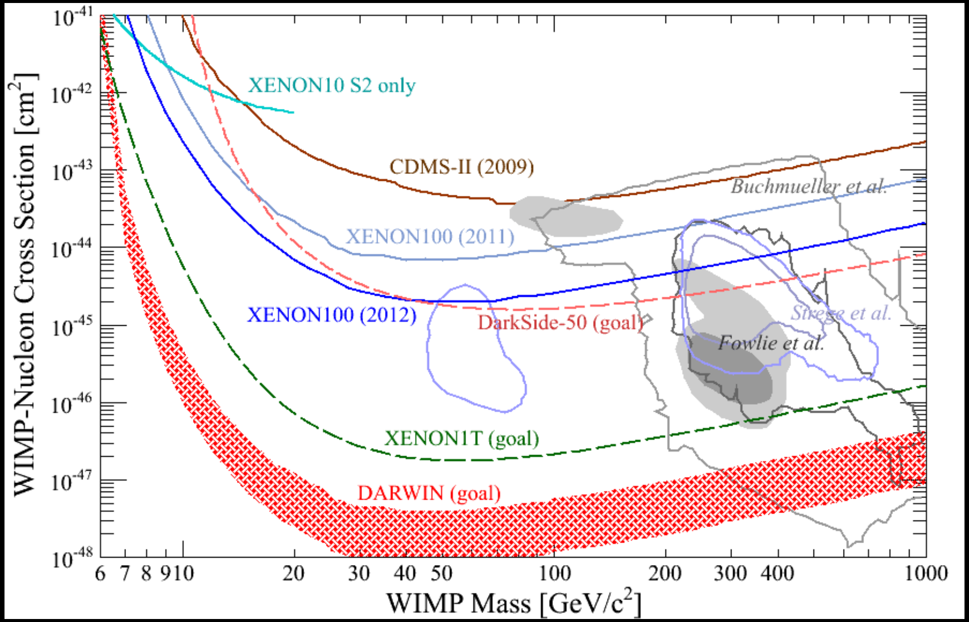
Dark Matter III

XENON 1t (2015-2017) ➔DARWIN(2020➔)*

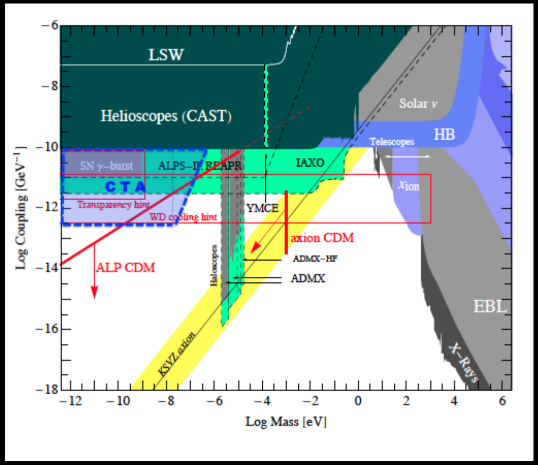
✓ A program to extend the target mass of noble liquids to a few tons (e.g. DARWIN). The choice in favour of a double-target option should be taken after a clear experimental confirmation that a liquid argon target is competitive with liquid xenon. To the limits of solar ν.

✓In the US LUX and Canada DEAP-CLEAN

✓In Japan single signature XMASS



✓Axion dark matter also a serious candidate (ADMX, CAST, but also CTA …)



* ApPEC funded design study

Dark Matter IV

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$2x10^{-45}cm^2$
Xenon
Bolometres,
LAr
catching up
in 2 years?

Xenon 1T → $2x10^{-47}cm^2$
Low energy

If observed

Go to ton –scale
experiments
Ge,
Multiton, Xenon, LAr

If not observed

Multiton
~2 experiments worldwide
$2x10^{-48}$

If observed

Check with LHC
Indirect detection

If not observed

Susy WIMPS in
serious trouble
We hit solar ν
background

Area of
Global
Coordination

now

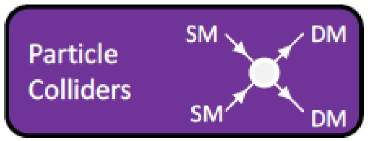
2017-2020

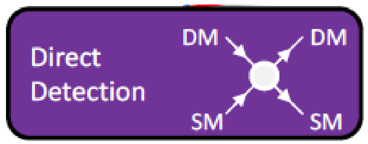
2025-2030

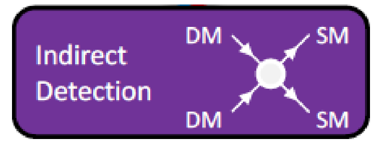
Dark Matter V

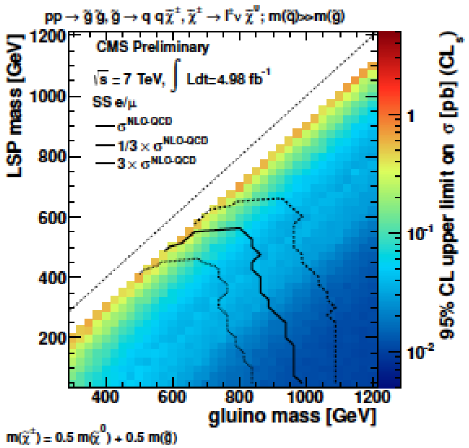
Richness of data permits to go beyond SUSY paradigm. Treat separately couplings to hadrons, leptons, photons etc, through effective field theory.

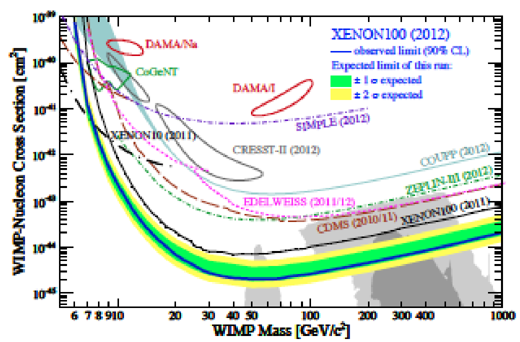
Complementarity of LHC, direct and indirect searches and astrophysical studies

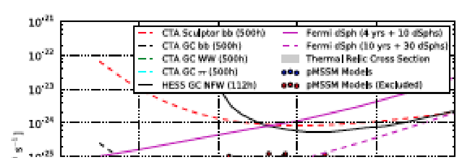


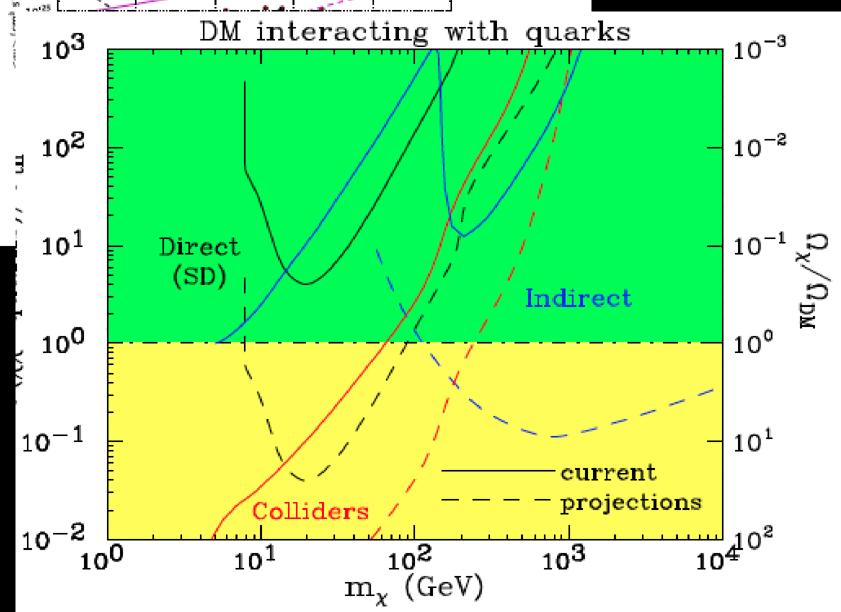












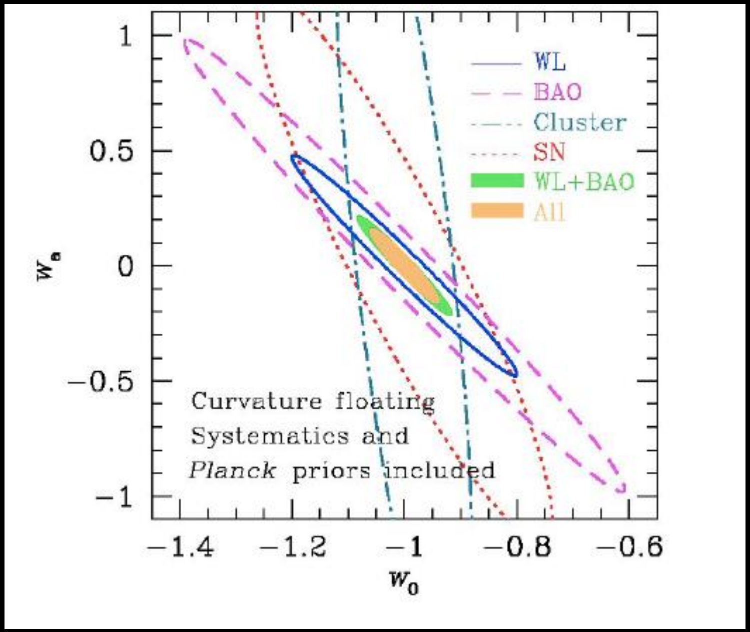
Also signals to be clarified, tested:

- Fermi130 GeV γ line
- PAMELA,FERMI, AMS positron excess

From Snowmass paper on complementarities

Dark Energy

APPEC



The communities and agencies have converged to large sky surveys (FoM > 800) with telescopes (first light 2019-2020) :

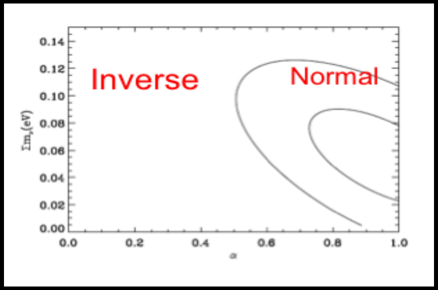
•on ground **(LSST, NSF/DOE, European participation, 8.4m)**

and

• in space **(EUCLID, ESA, NASA joined, 1.2m)**

•Intermediate program: DES, SUMIRE,MS-DESI

• LSST and EUCLID are complementary in systematics (superior spectroscopy vs absence of atmospheric distortion)



LSST/Euclid will be sensitive to the neutrino mass hierarchy (2022)

From the global coordination point of view:

- *The field has finally a clear long term program with complementary aspects*
- *The data management of e.g. the LSST is challenging and could be scaled in LHC units.*

Under discussion is the issue of data-availability and exchange between LSST and EUCLID, and of course the rest of the world…

Large scale projects I
for proton decay and neutrino physics

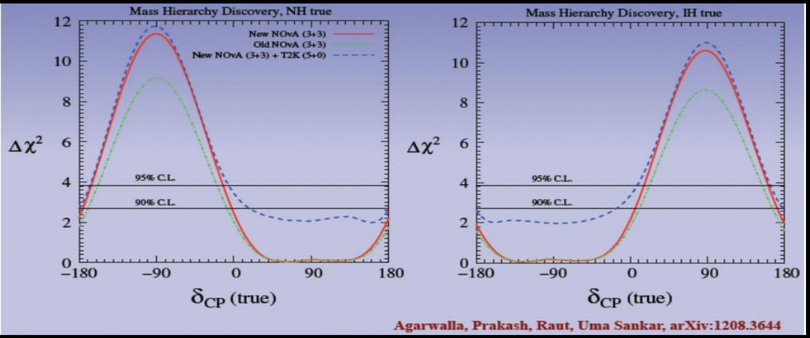
Tasks and Open Questions in ν physics

- **Mass hierarchy**
- **θ_{23} octant**
- **CP-violating phase δ**
- **Absolute masses**
- **Dirac or Majorana**
- **Sterile Neutrinos**

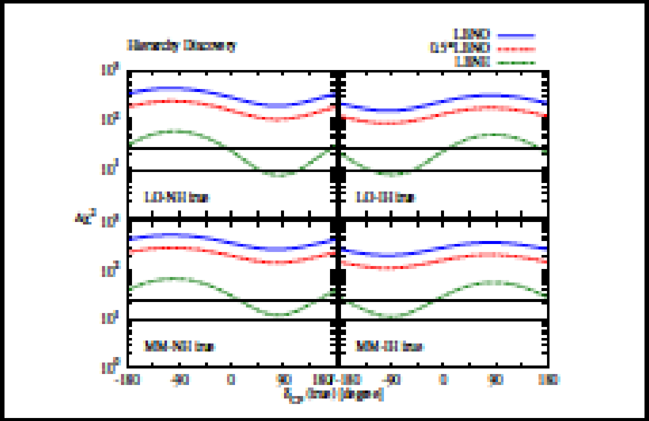
ApPEC statemens to ESG: It is recommended that CERN, together with key European agencies and ApPEC, enter into discussions with their US and Asian counterparts in order to develop a coherent international strategy for the field.

Large scale projects II
How soon can we measure the mass hierarchy ?

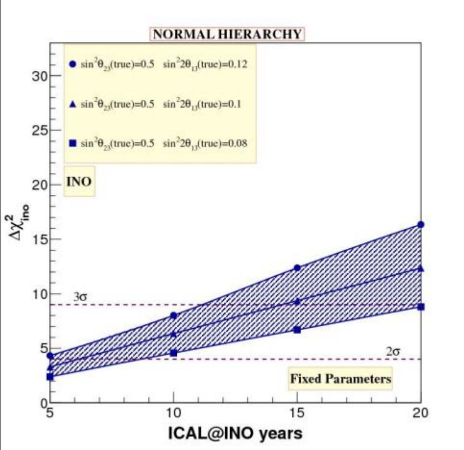
3 ν Fits → will give hints but need to measure



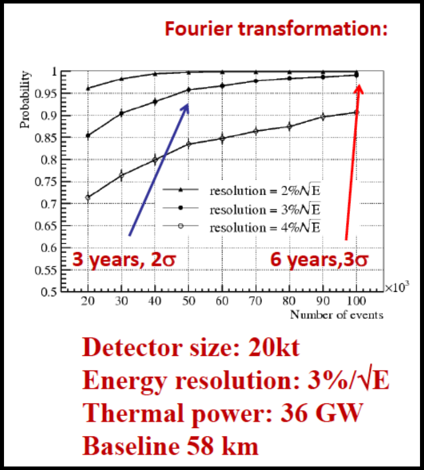
T2K + NOVA 50% chance @ 3σ



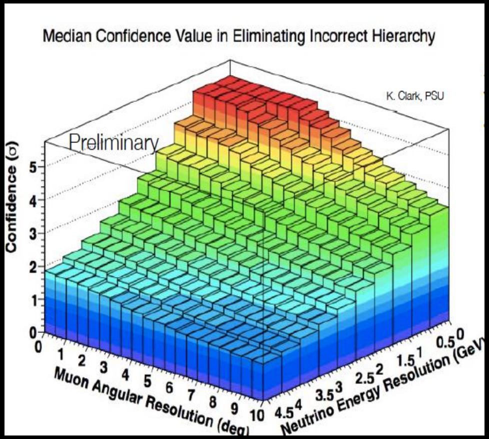
beam experiments 2300 km better than 1300 km for mass hierarchy



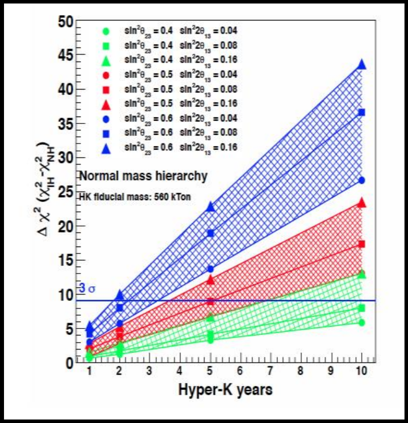
INO in 10+ years @2σ



Daya-Bay-II in 6 years, @3-6 σ



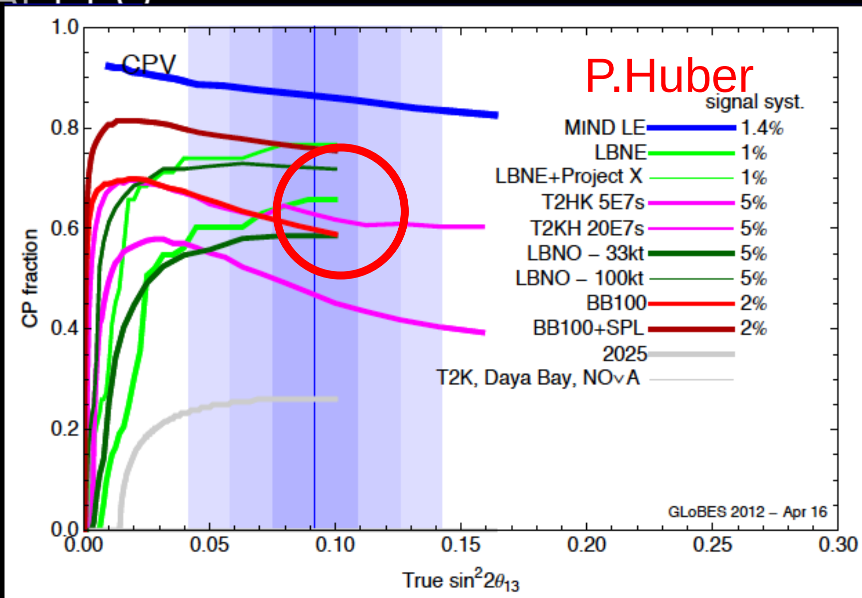
ORCA-PINGU in 5 years ?Under study



HyperK 3σ in 3 years

Large scale projects III

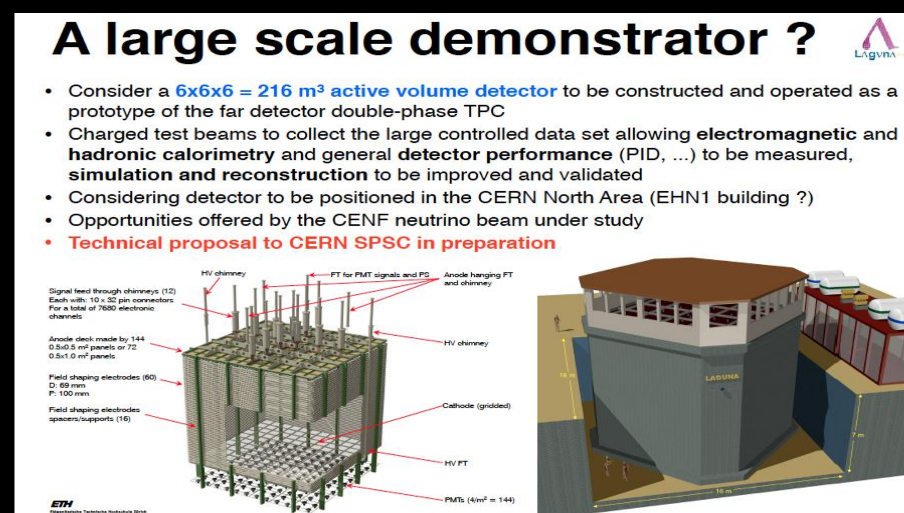
CP violation potential



Projects in 3 regions
CPV 60% phase space @ 5σ

see talk by K. McFarland

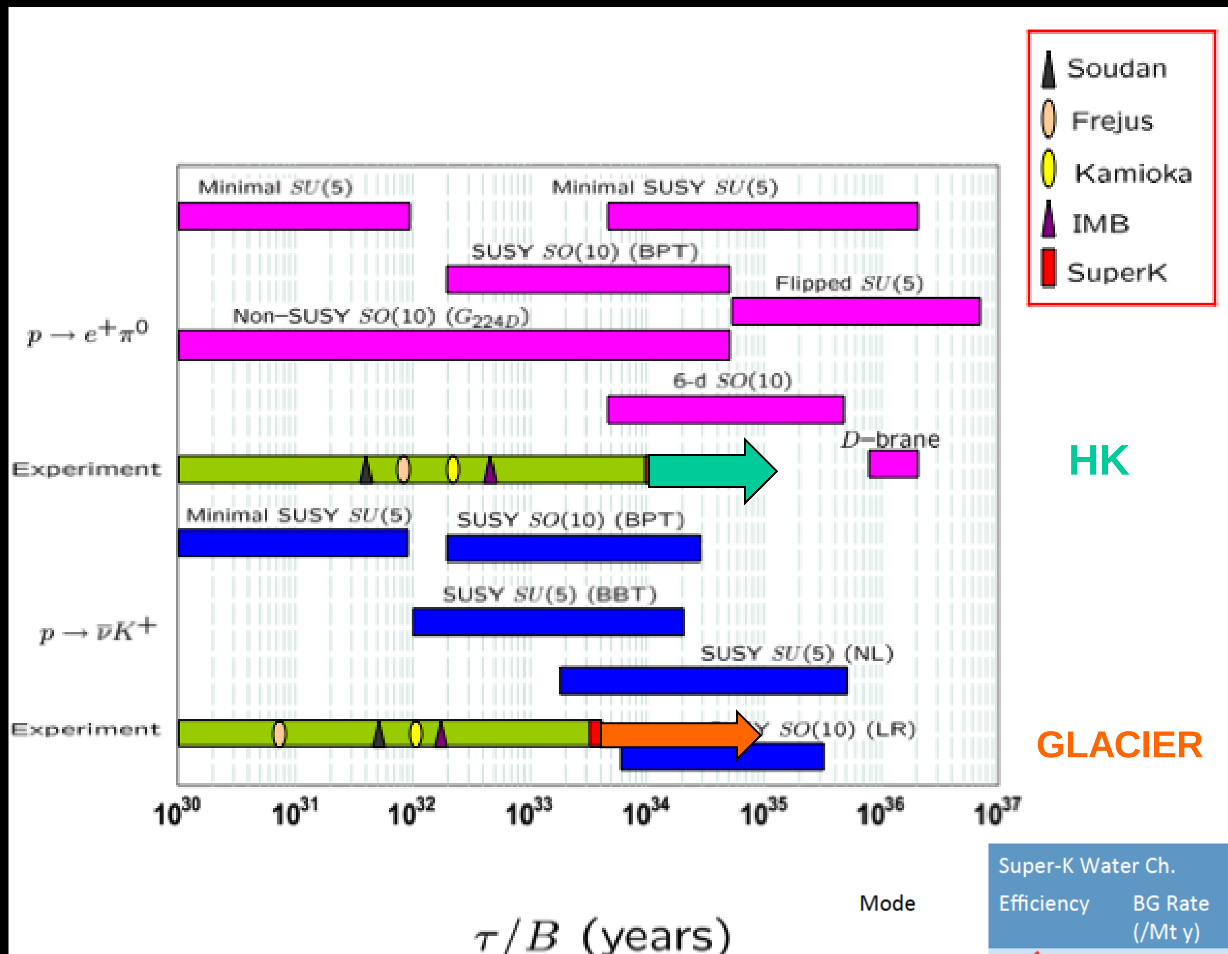
ApPEC supports: a vigorous R&D program and prototyping on the liquid argon detector technique and beam design studies in anticipation of a critical decision in 2015-16 for a strong European participation in a long baseline experiment outside Europe or an experiment in Europe



A large scale demonstrator ?

- Consider a **6x6x6 = 216 m³ active volume detector** to be constructed and operated as a prototype of the far detector double-phase TPC
- Charged test beams to collect the large controlled data set allowing **electromagnetic** and **hadronic calorimetry** and general **detector performance** (PID, ...) to be measured, **simulation and reconstruction** to be improved and validated
- Considering detector to be positioned in the CERN North Area (EHN1 building ?)
- Opportunities offered by the CENF neutrino beam under study
- **Technical proposal to CERN SPSC in preparation**

Also 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. We also support studies of the possibility to determine the mass hierarchy with underwater/ice detectors and atmospheric neutrinos.



	Mode	Super-K Water Ch. Efficiency	Super-K Water Ch. BG Rate (/Mt y)	LAr (generic) Efficiency	LAr (generic) BG Rate (/Mt y)
B-L	$e^+\pi^0$	~~45%~~ → 40%	2	45%	1
	νK^+	19%	4	**97%**	**1**
	$\mu^+ K^0$	10%	5-10	**47%**	**<2**

Proton decay studies jn view of LHC/PLANCK/ν have to come back into

Large scale projects V
Low energy neutrino astrophysics (and physics)

MiniBooNE (200)

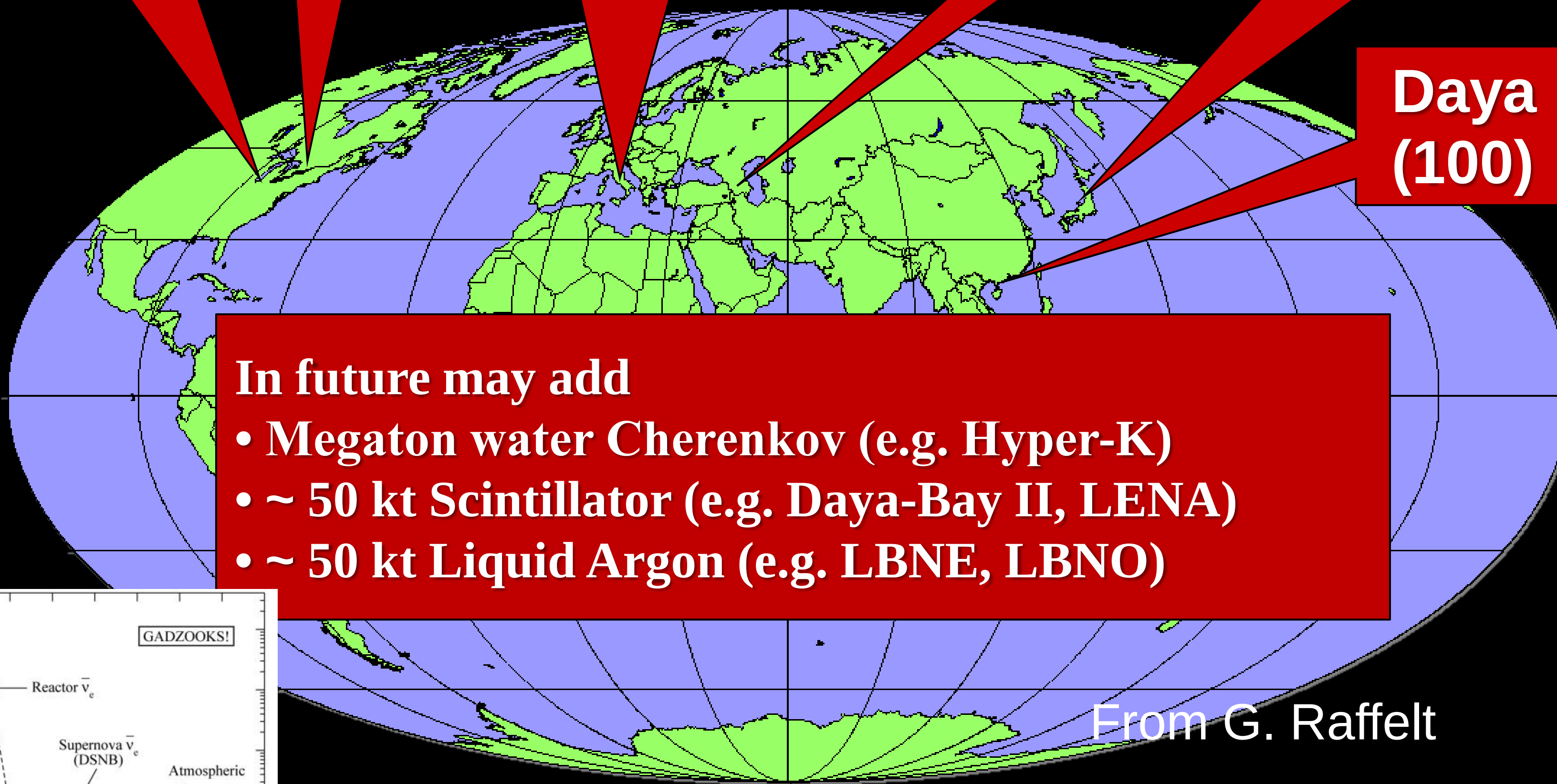
HALO (tens)

LVD (400)
Borexino (100)

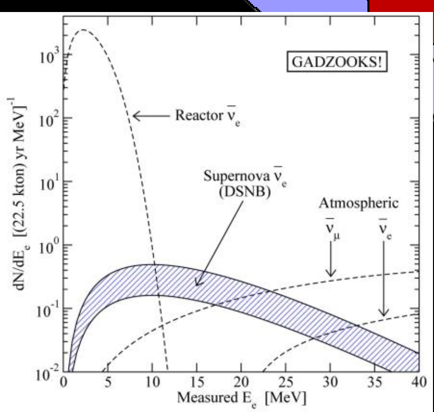
Baksan (100)

Super-K (10^4)
KamLAND (400)

Daya Bay (100)



In future may add
- **Megaton water Cherenkov (e.g. Hyper-K)**
- **~ 50 kt Scintillator (e.g. Daya-Bay II, LENA)**
- **~ 50 kt Liquid Argon (e.g. LBNE, LBNO)**



IceCube (10^6)

From G. Raffelt

In brackets events for a "fiducial SN" at distance 10 kpc

Neutrino mass and nature I

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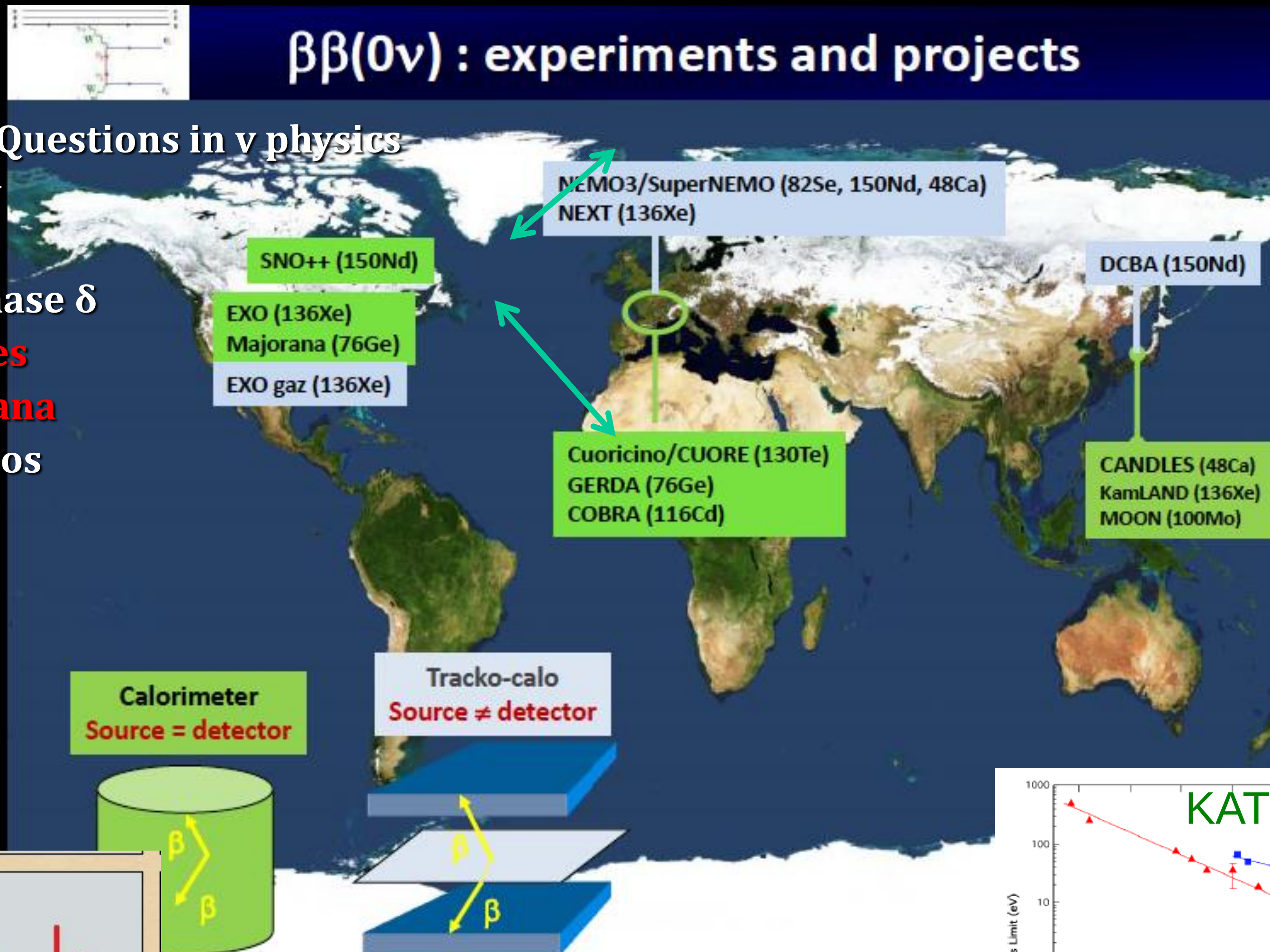
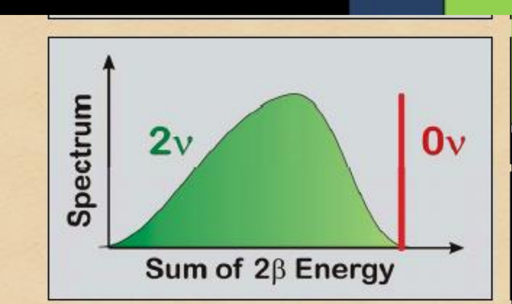
Testing the Majorana nature of neutrinos through the detection neutrinoless double beta decays. Its theoretical importance cannot be overstated.

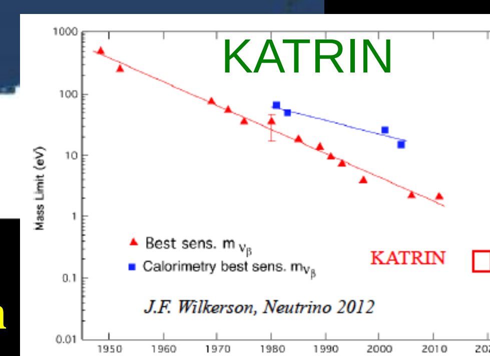
Tasks and Open Questions in ν physics

- Mass hierarchy
- θ_{23} octant
- CP-violating phase δ
- Absolute masses
- Dirac or Majorana
- Sterile Neutrinos



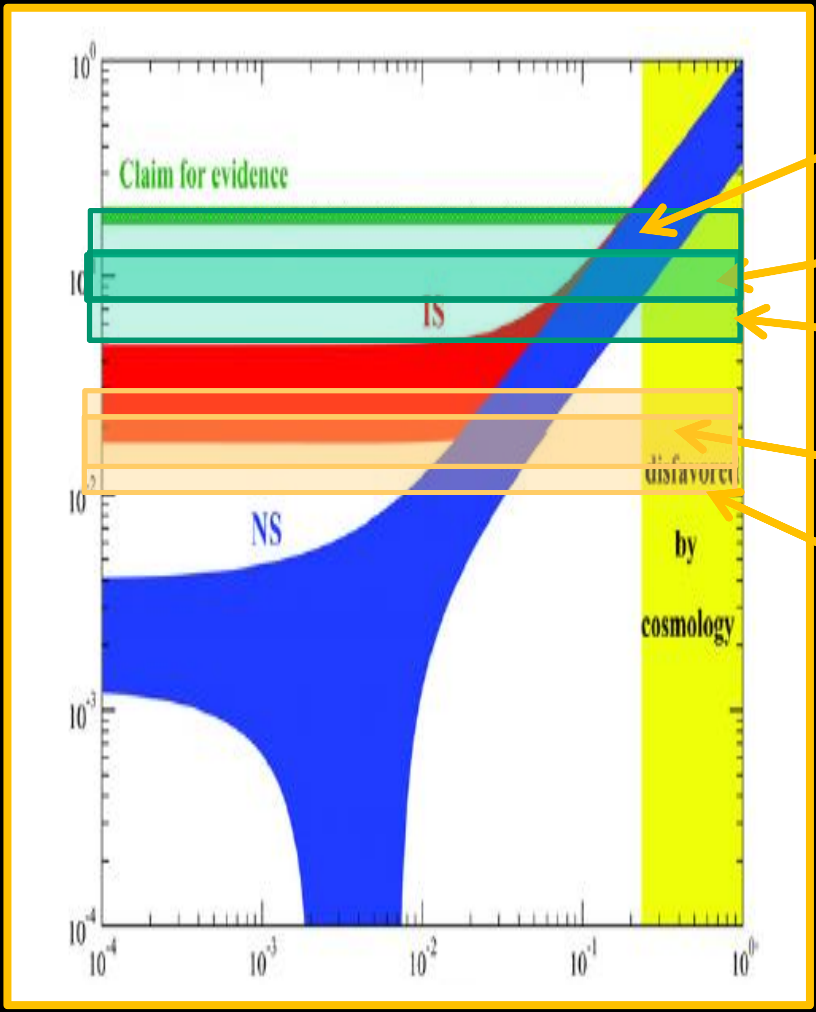


Also single beta



Neutrino mass and nature II

$0\nu\beta\beta$ approaching/exploring the inverted hierarchy



Ultimate EXO-200 (80-200 meV) (4 y + Rn removal)

GERDA phase-2 (75 - 129 meV)

CUORE (51 – 133 meV)

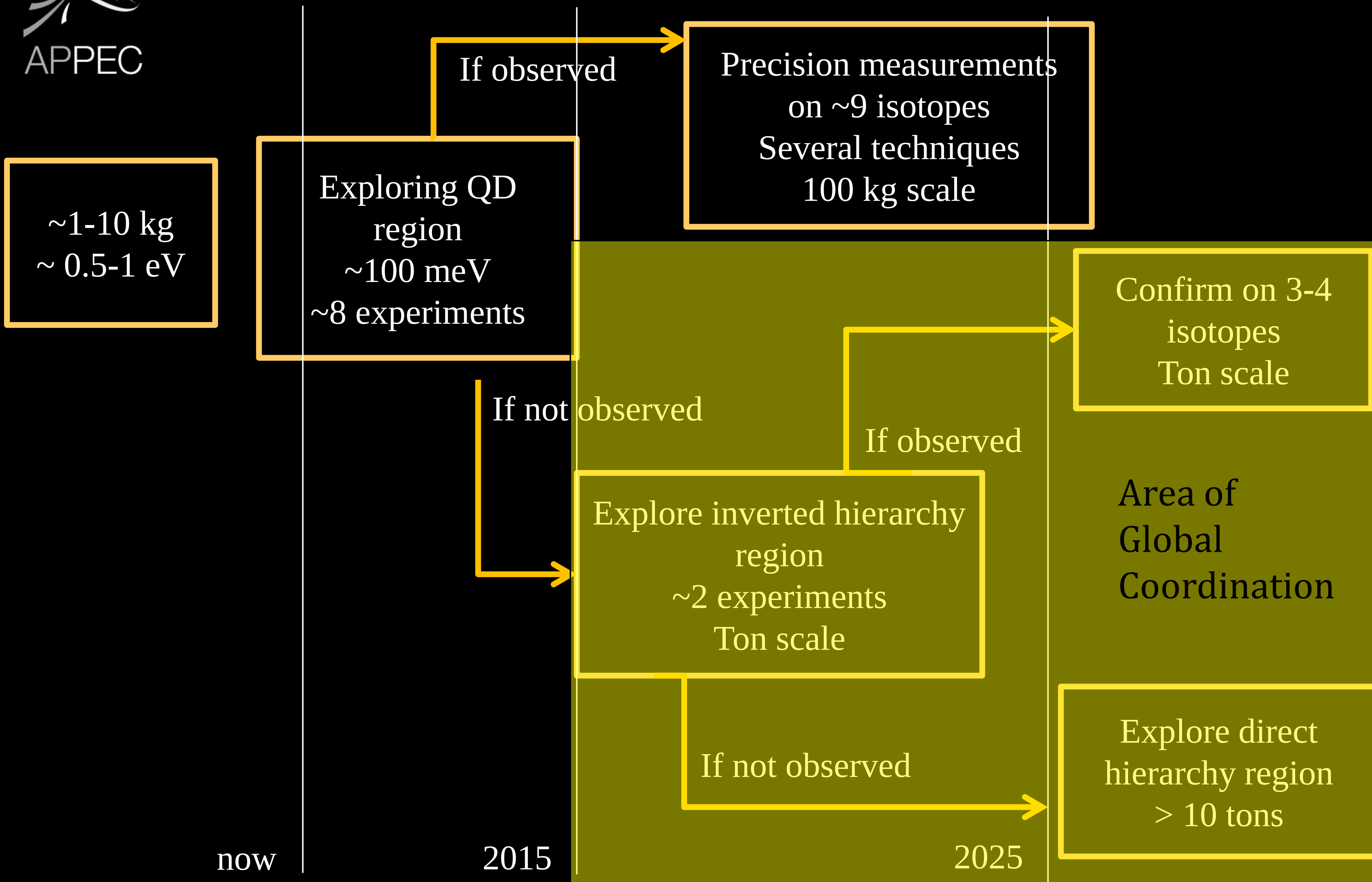
SuperNEMO (100Kg,5y)

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

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

Similar sensitivites from GERDA-3 Majorana and upgrade of KamLAND-Zen

Neutrino mass and nature III



A.Giuliani Adapted from Wilkerson, NuMass 2013

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Astroparticle Physics in focus
Going up and down the cosmic ladder

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

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

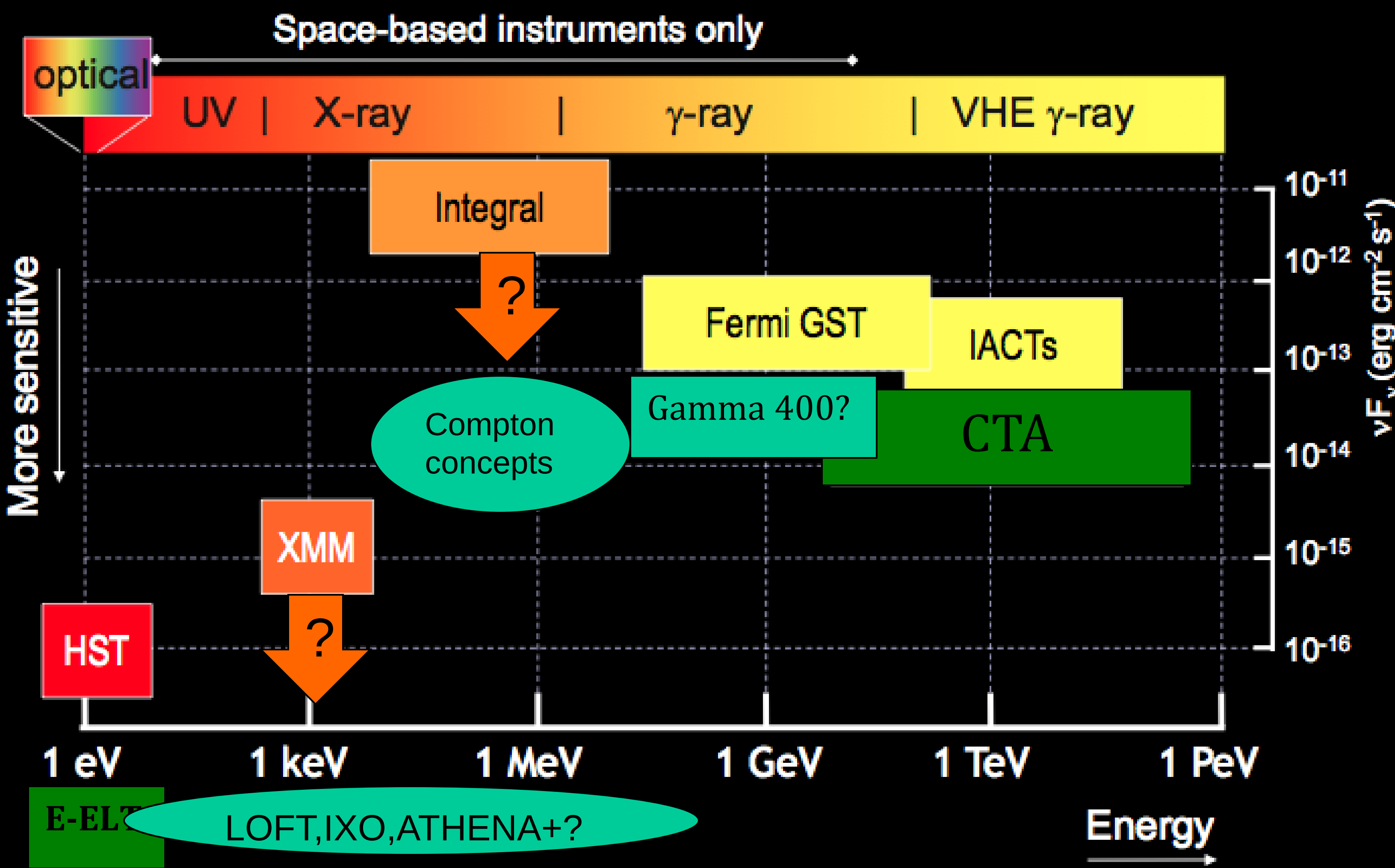
1) How do the particles and fields of the intermediate scales shape the genesis, evolution and destruction of cosmic structures ?
    1) High energy photons, neutrinos, CR
    2) Gravitational waves

Dark matter, neutrinos and dark energy are not sufficient, one needs the feedback of violent phenomena to explain cosmic structures

High energy photons I

In the domain of TeV gamma-ray astrophysics the **Cherenkov Telescope Array (CTA)** is a worldwide priority project. The ambitious time schedule for technical design and prototype development of CTA, as well as the selection of the site(s), is aiming at a start of construction by the middle of the decade. HAWC in mexico and LHAASO in China will have a complementary coverage (100 TeV—PeV)

High Energy photons II
The last decade: golden age of HE photons



Using a Hinton graph shown at ECRS Turku

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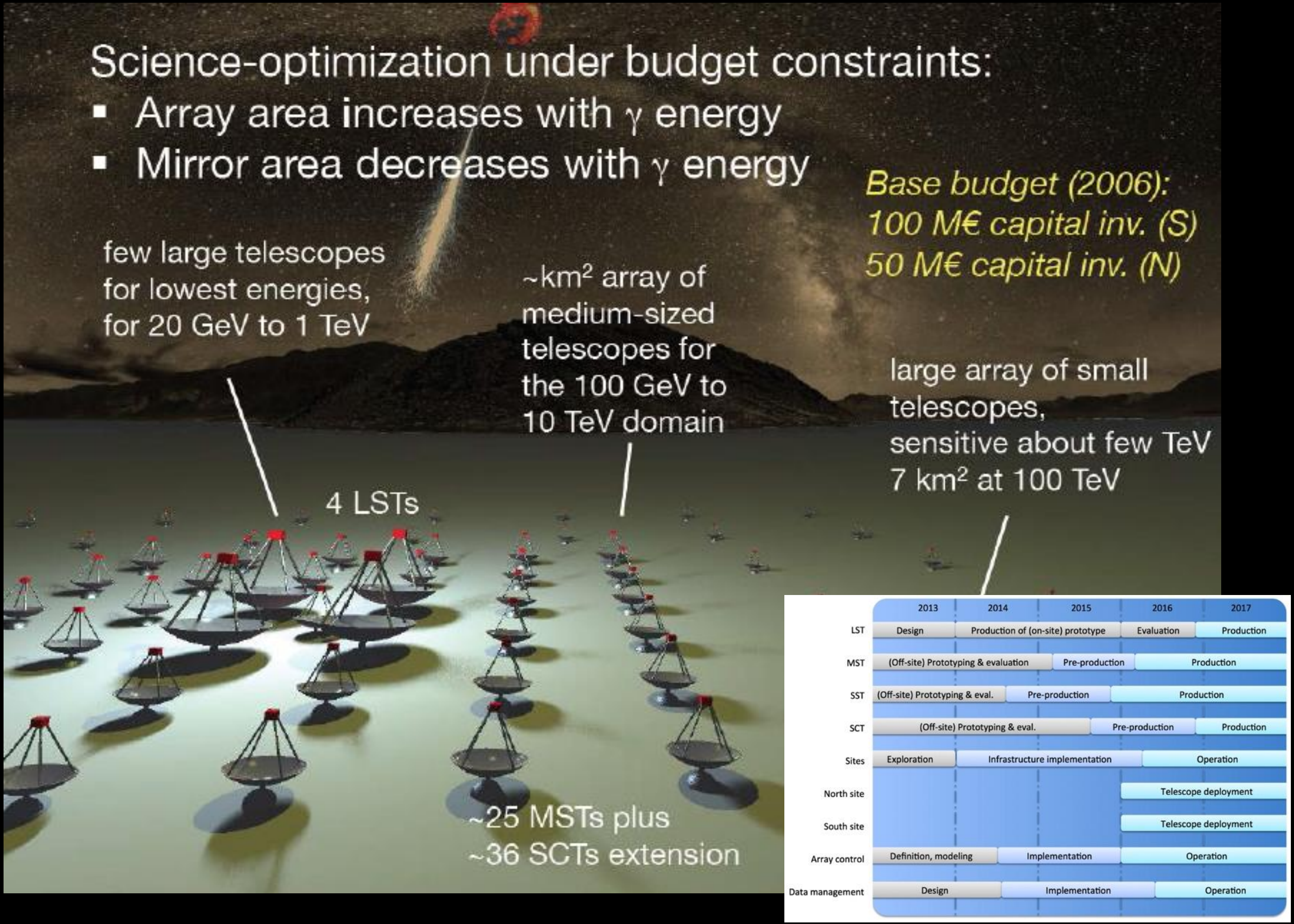
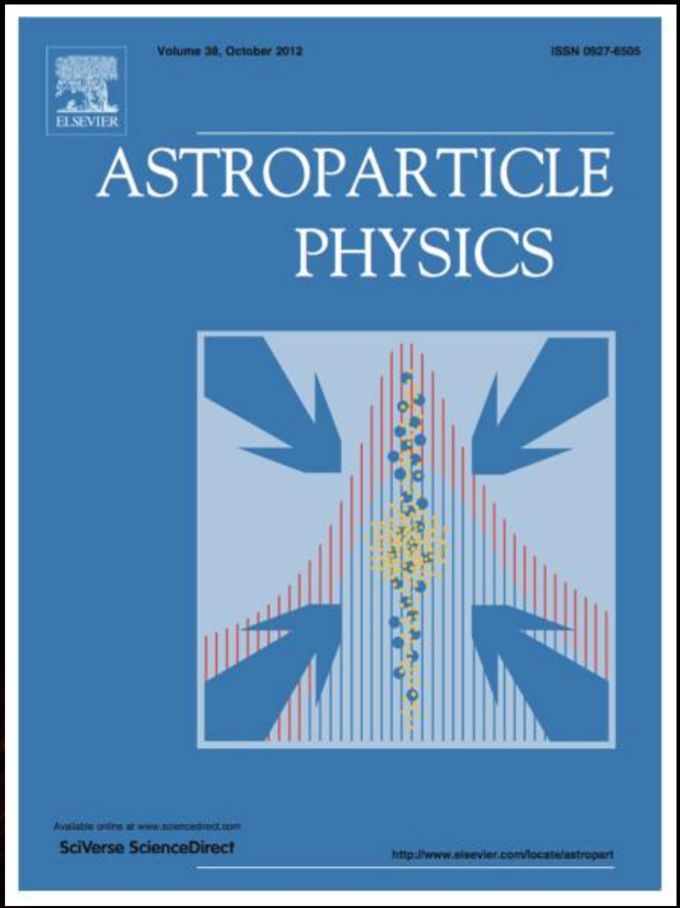
High Energy photons III
CTA (27 countries > 1000 researchers)



High Energy photons IV
CTA physics potential

Addressing key science questions

1. **Where and how are the bulk of CR particles accelerated in our Galaxy and beyond?** Understanding transitions in the CR spectra. *(one of the oldest surviving questions of astrophysics)*
2. **How cosmic-rays propagate, interact, and heat the environment?** Which are the consequences from Galactic to cosmological scenarios?
3. **What makes black holes of all sizes such efficient particle accelerators?**
4. **What do high-energy gamma-rays tell us about the star formation history of the Universe, the structure of spacetime, or the fundamental laws of physics?**
5. **What is the nature of dark matter?** Can it be discovered via indirect searches? Can we map dark matter halos?
6. **Are there short-timescale phenomena at very high energies? Are GRBs gamma-ray emitter? Is there new Galactic phenomenology to uncover?**



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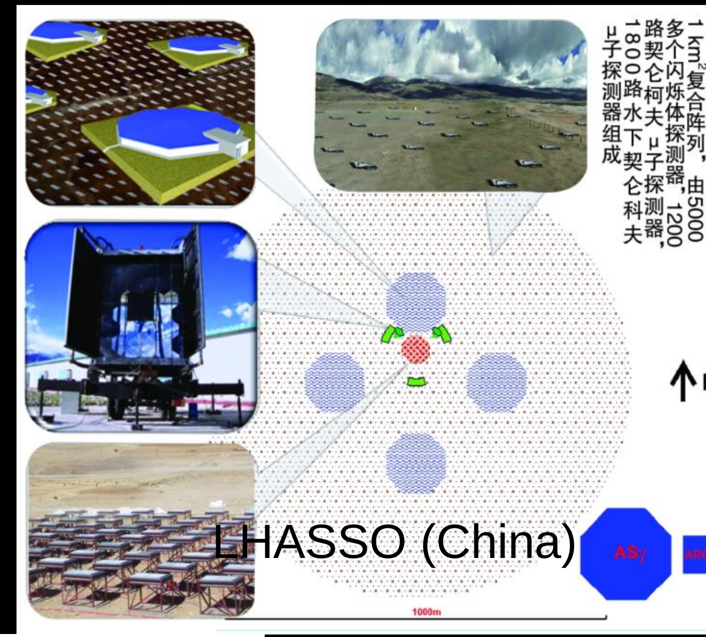
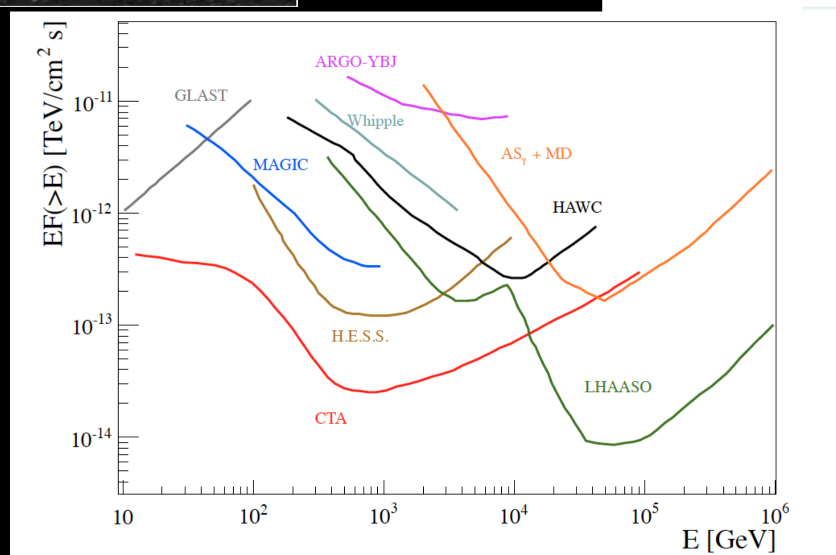
High Energy photons V
all sky surveys (into the PeV)



300 tanks by end of 2014
Sensitivity 15x Milagro
Asymetries, Flares, GRB..

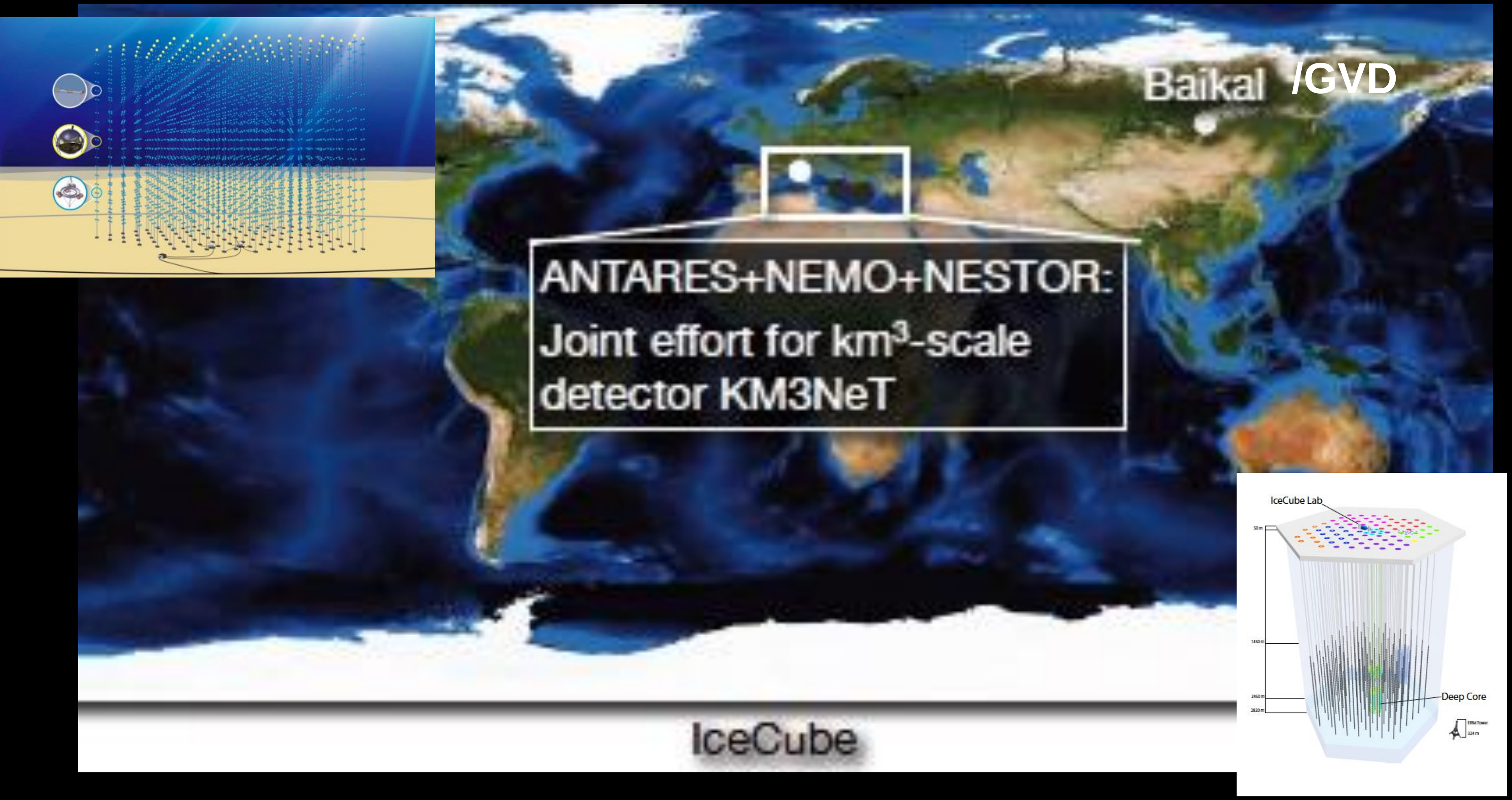


Site selection, Shangri-La?
starting construction

Where are the
PeV photons?

High Energy Neutrinos I

TeV to PeV



Nothern Hemisphere projects and IceCube move through coordination towards a future Global Neutrino Observatory. First exemple PINGU-ORCA

High Energy Neutrino II

ICECUBE, start of HE neutrino astronomy ?

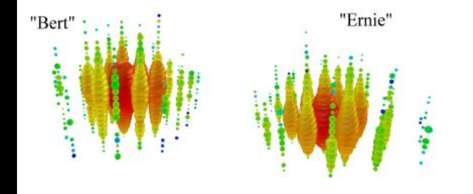
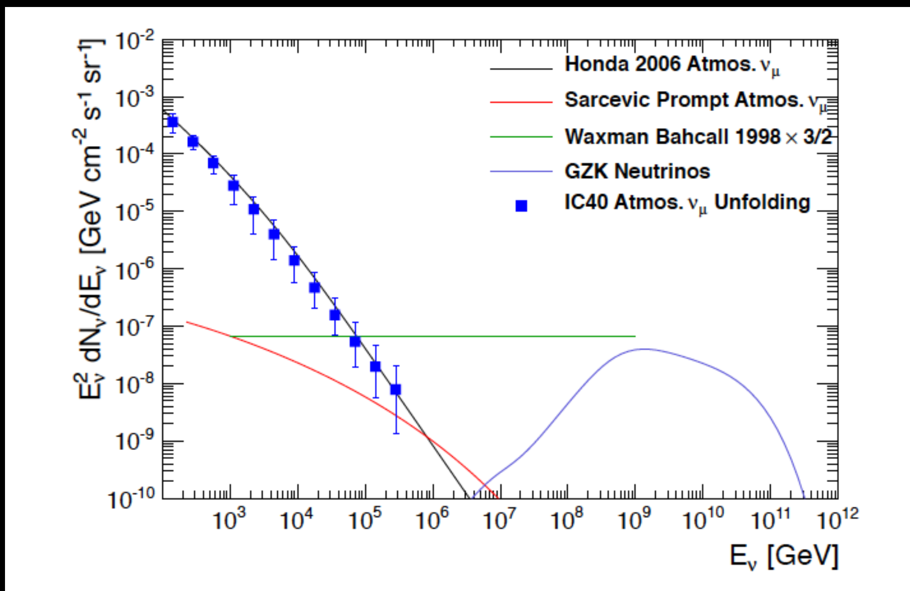
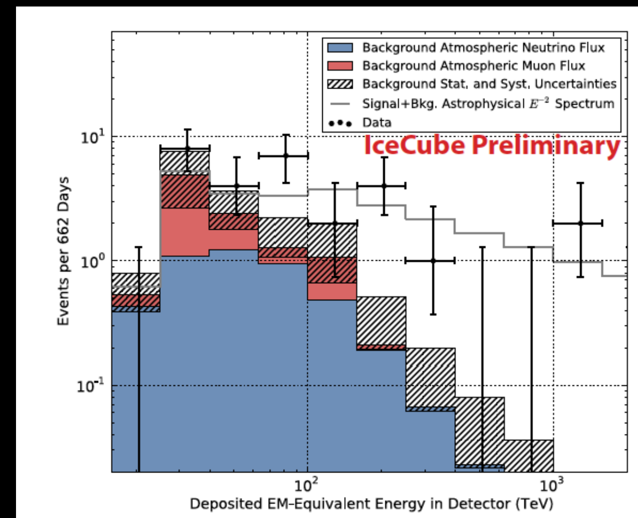
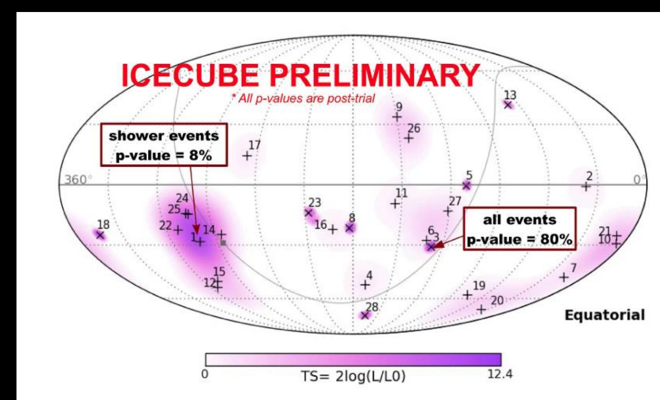


FIG. 4. The two observed events from August 2011 (left panel) and January 2012 (right panel). Each sphere represents a DOM. Colors represent the arrival times of the photons where red indicates early and blue late times. The size





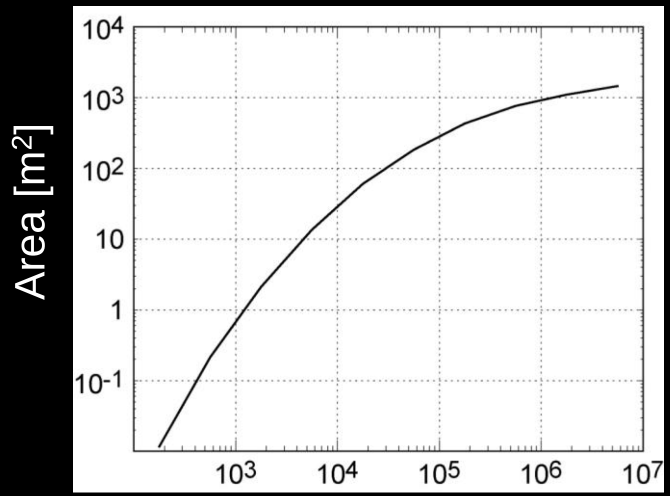


- 28 events (background 10)
- $E^2\Phi(E) = (3.6\pm1.2)\cdot10^{-8}$ GeVcm^{-2}s^{-1}sr^{-1}
- Compatible with isotropic flux, minor excess in south
- Compatible with 1:1:1 composition (21 shower:7 μ)
- No significant pointing
- At the limits of Antares sensitivity (work in progress)
- If confirmed great news for KM3net, extensions of ICECUBE

High Energy Neutrino III

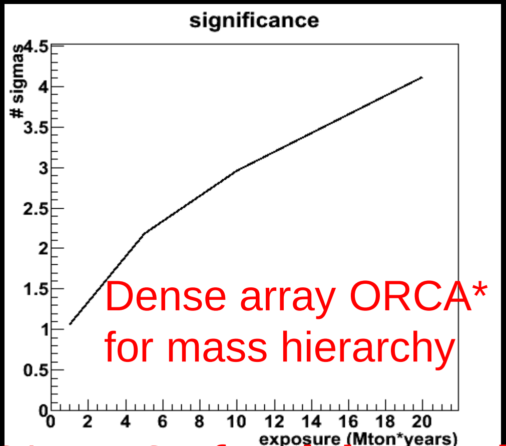
KM3Net, Project progress

Effective neutrino area



E_ν [GeV]

- Implementation
  - phase-1 (40 M€) granted (majority structural funds)
  - phase-2 (220–250 M€) subject to future funding
- Management structure set up
- Technology agreed
- Successful deployments of engineering lines
- Feasibility studies of a smaller array ORCA (equivalent of PINGU) to meaasure the mass hierarchy



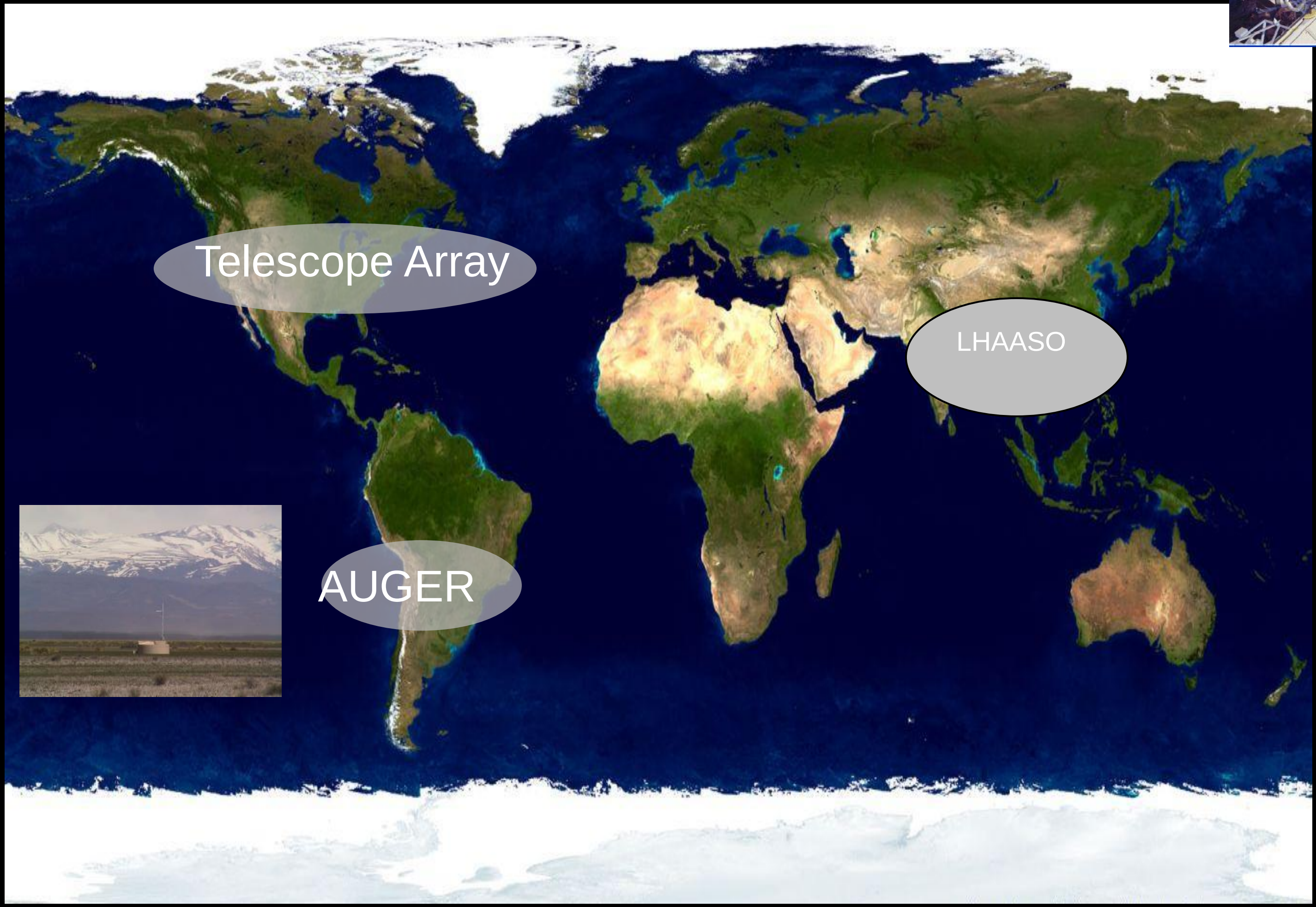
ApPEC: strong support for the first phase of KM3NeT

* APPEC funded ORCA-PINGU feasibility study

High energy cosmic ray observatories I

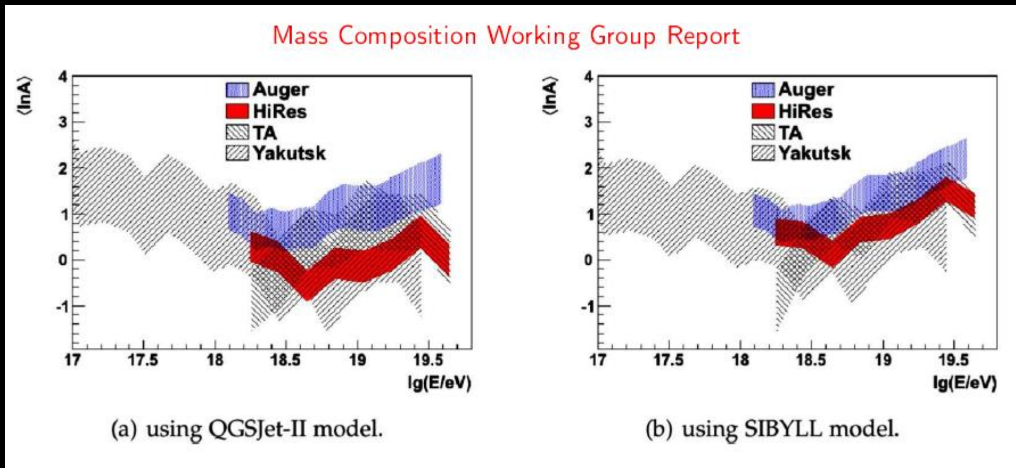
PAMELA
ATIC
CREAM

AMS
JEM-
EUSO

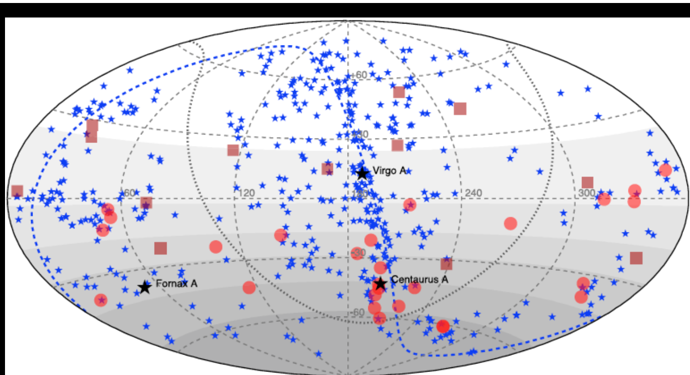


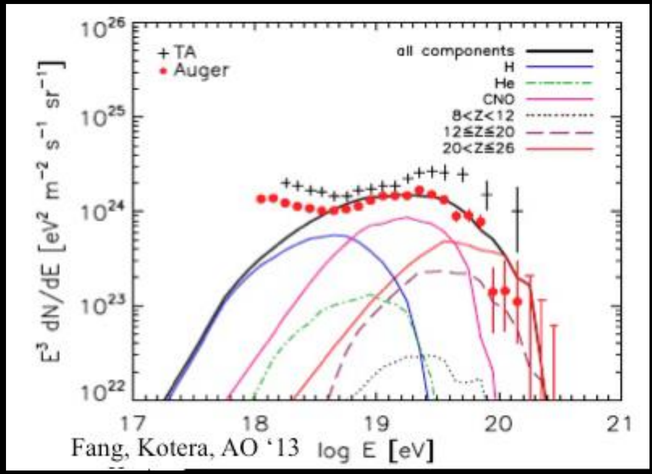
Understanding the CR composition ? (AUGER upgrades)
or
identify sources independently of the composition ? (JEM-EUSO)

High energy cosmic ray observatories II
Where do we stand in UHECR?



- A trend towards heavier composition at highest energies
➔AUGER ≠ TA interpretation although the data are compatible within errors
- A weak correlation towards nearby matter distribution (14%)
➔AUGER ≈ TA





Are we seeing the GZK or in large part the exhaustion of the acceleration mechanism ? (Peters cycles)

Synergy with LHC crucial (LHC-CR workshop) ➔ Common Astroparticle Forum.

High energy cosmic ray observatories II
Auger upgrade plans

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Upgrade Plans

PIERRE AUGER

Michigan Tech — Create the Future

The FD only operates $\approx 10\%$ of the time $\Longrightarrow$ focus on upgrading the SD

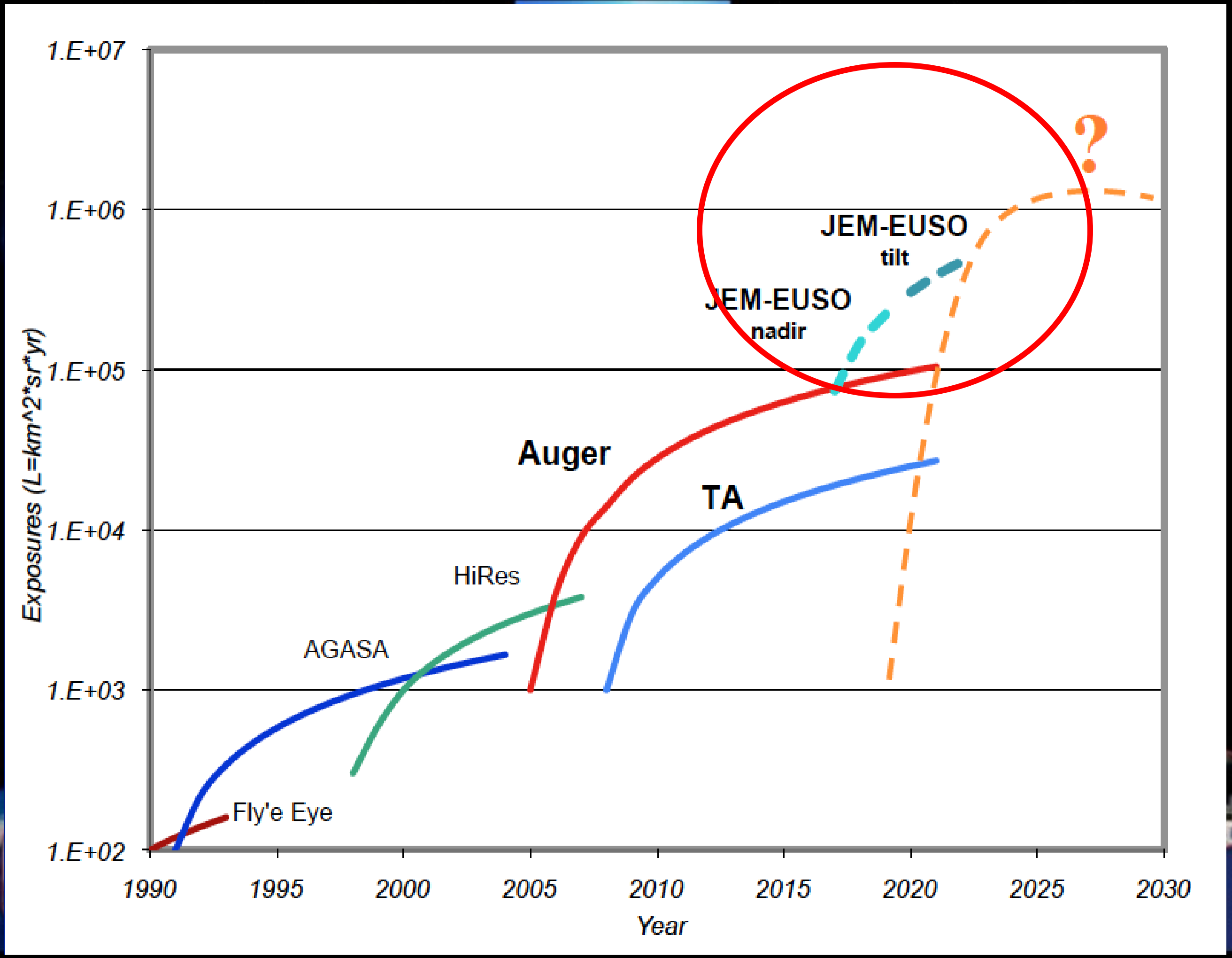
Detector upgrades being discussed include:

- Upgraded SD electronics
  - Faster FADCs
  - More powerful FPGA and processor
  - Better timing
  - Increased dynamic range
- Dedicated muon counting additions to the SD

Increased measurement capabilities include:

- Composition (& interaction) measurements to the highest energies
  - Faster FADCs, increased dynamic range, & dedicated muon detection
- Improved photon limits
  - Better photon/hadron separation through improved muon counting
- Improved neutrino limits
  - Increased aperture via more sensitive triggers implemented in powerful FPGA

High energy cosmic ray observatories III
Try to identify sources ?

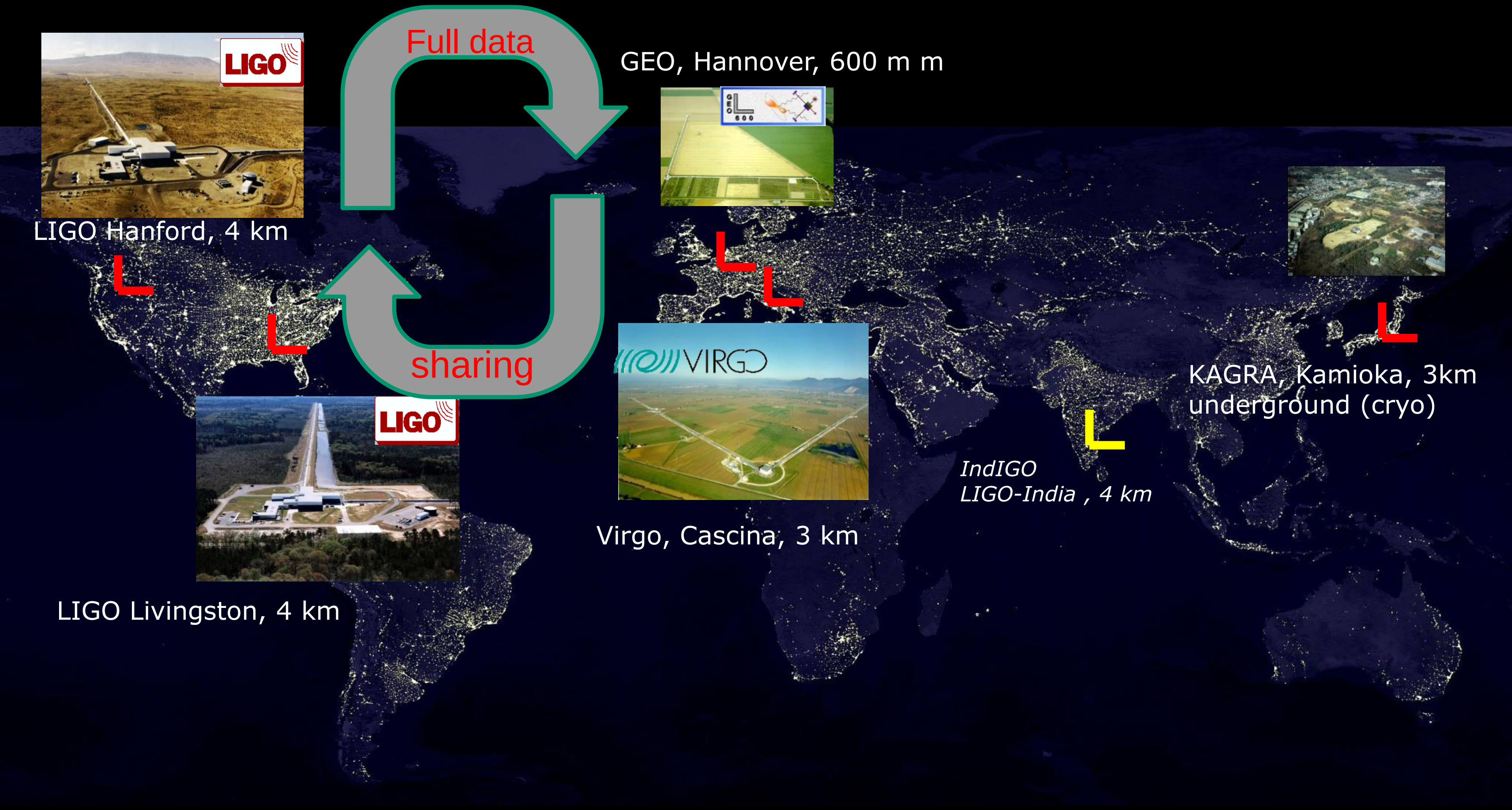


JEM-EUSO
~200 events > 60 EeV/ yr

on ISS in 2007? (JAXA)

GWA interferometric detectors I

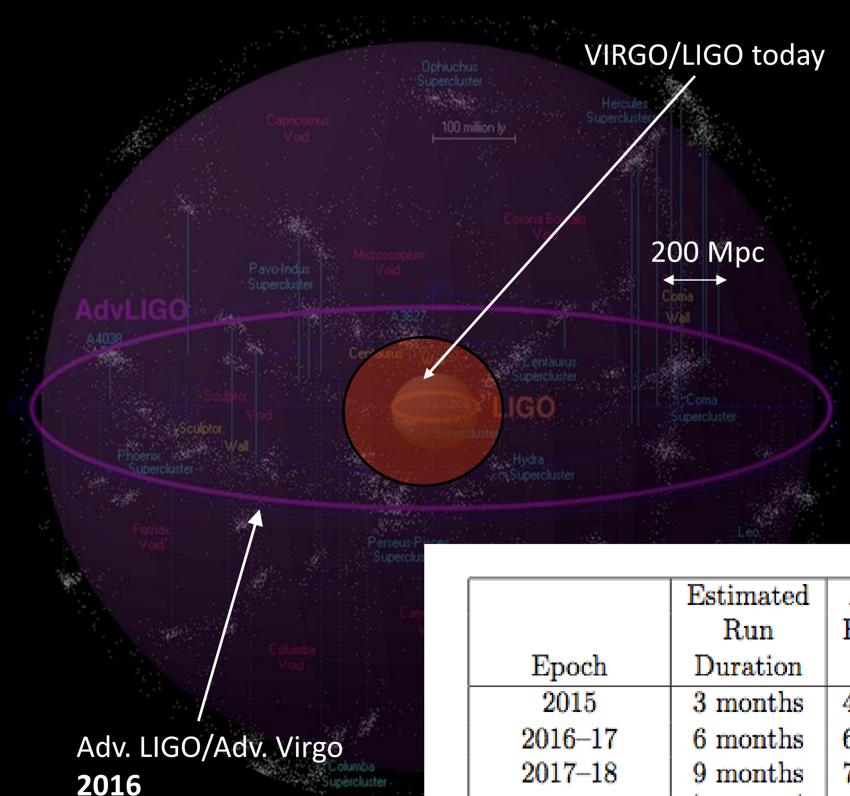
A network of detectors is/will be active in the World

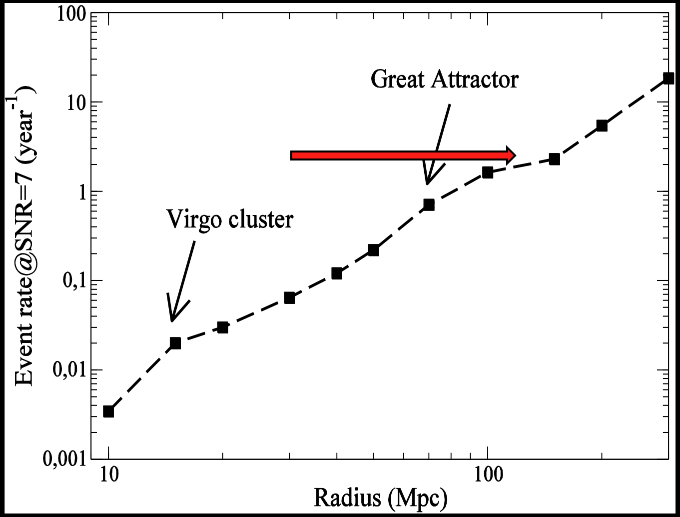


GWA Towards the first detection II

✓ 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

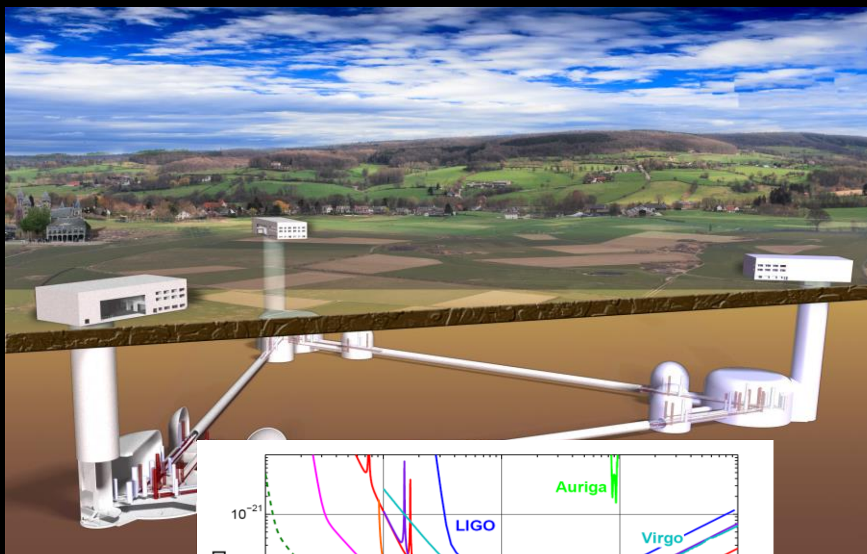


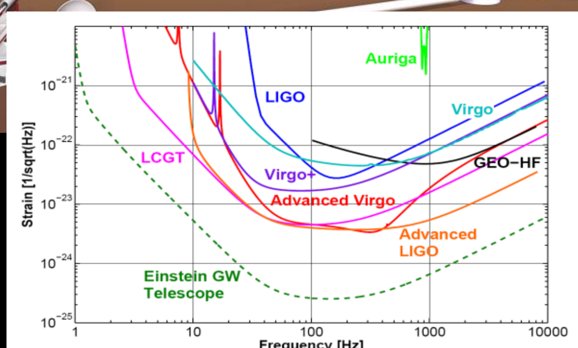


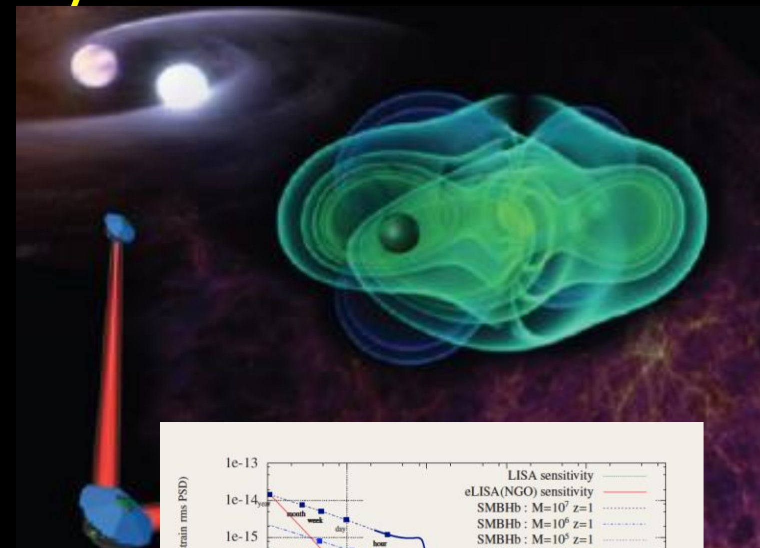
Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_\odot c^2$ Burst Range (Mpc) LIGO	Virgo	BNS Range (Mpc) LIGO	Virgo	Number of BNS Detections	% BNS Localized within 5 deg^2	20 deg^2
2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20	2	5 – 12
2017–18	9 months	75 – 90	40 – 50	120 – 170	60 – 85	0.04 – 100	1 – 2	10 – 12
2019+	(per year)	105	40 – 80	200	65 – 130	0.2 – 200	3 – 8	8 – 28
2022+ (India)	(per year)	105	80	200	130	0.4 – 400	17	48

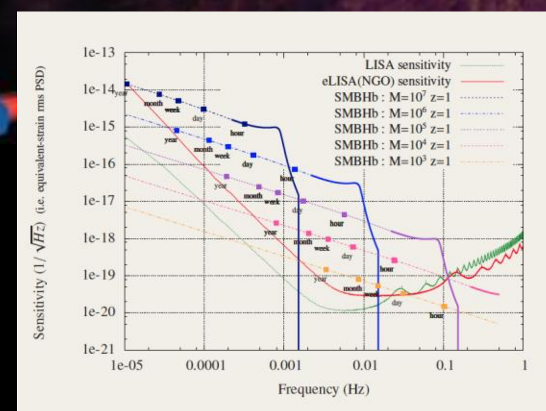
GWA Further in the future III

EU funded Design Study Einstein Telescope (ET) and Elisa/NGO









- ✓ ET: If detection by 2018 move to third generation (ca 2020)
  - ✓ASPERA/ApPEC funding for R&D
- ✓LisaPathfinder mission launch in 2015
- ✓eLISA biding for L2 (large subscription 1000 signatures)

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GWA Further in the future IV

eLisa and the ESA schedule

Beyond 2013:

- Roadmap for eLISA (Expected by eLISA Consortium)
  - Preselection of eLISA for L2 in November 2013
  - Call for L2 Mission concept mid 2014 (eLISA: very mature concept)
  - Assessment study during 2015 (Had several before w. LISA)
  - Also 2015: LISA Pathfinder launch (31. July 2015)
  - Selection of L2 scheduled for February 2016 SPC meeting
  - Launch 2028

From G. Mueller

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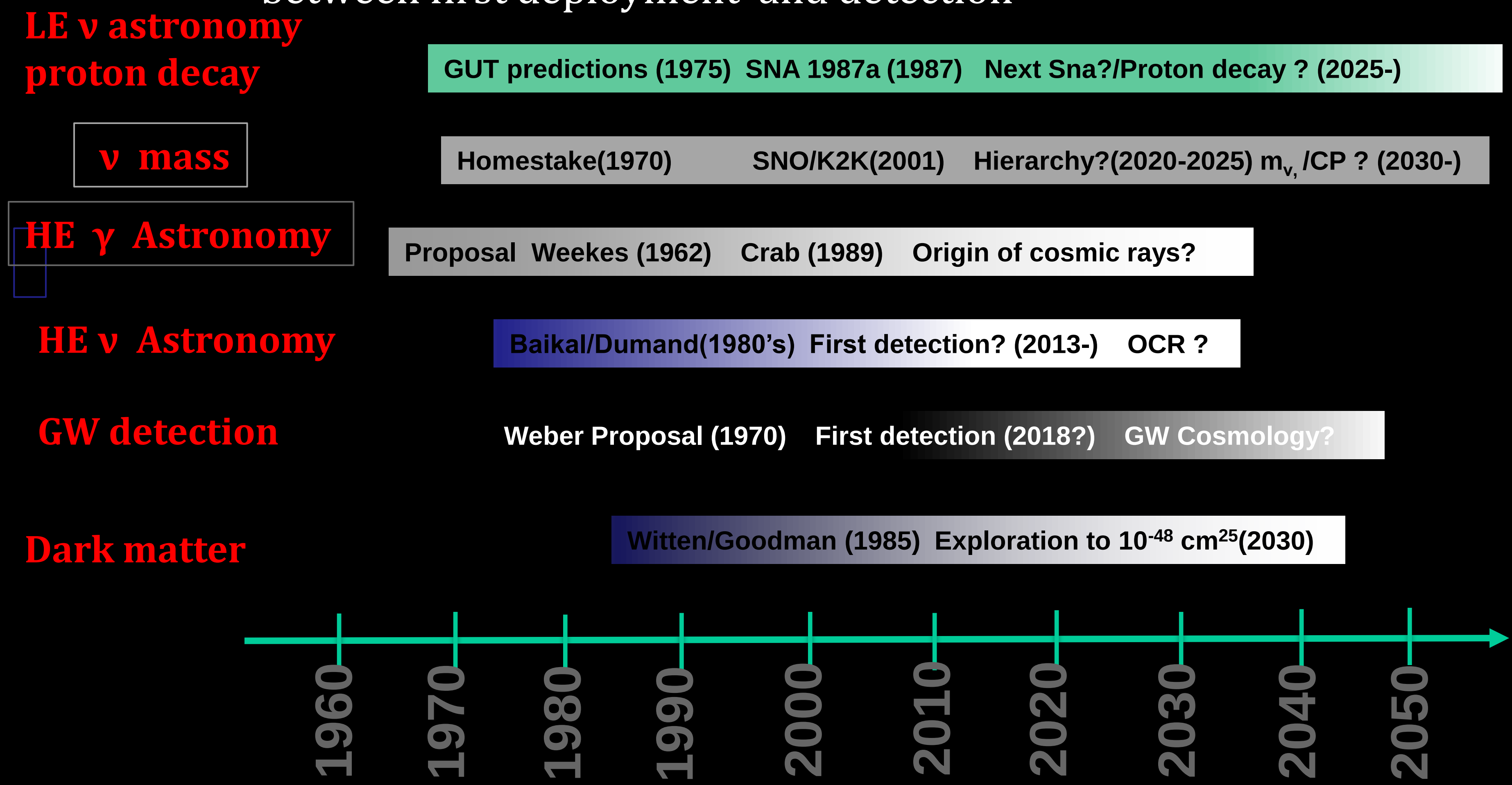
As Pauli said: all things come in time for those that know how to wait

Astrparticle Physics, physics for the patient: Usually 30-40 years between first deployment and detection



But then, wasn't it the same for Higgs ?

Conclusions

- We live exciting times, new data bring new physics on focus, the coronation of standard model(s) brings closer the opportunity to overthrow them, should be patient.
- Astroparticle Physics enters into a period of internationalisation but also focusing to a few large projects
- Astroparticle Physics despite the diversity and adverse economic climate has the possibility to fund its way into the future
- Concerning the physics themes
  - Dark matter international cooperation will be needed
  - Proton decay + neutrino mass should be given again the central position in the searches for new physics
  - High energy gamma ray physics will most probably give the first very large infrastructure of Astroparticle physics
  - Neutrino astronomy started ?
  - Gravitational astronomy soon ?
  - For the above the composition of cosmic rays is a key issue

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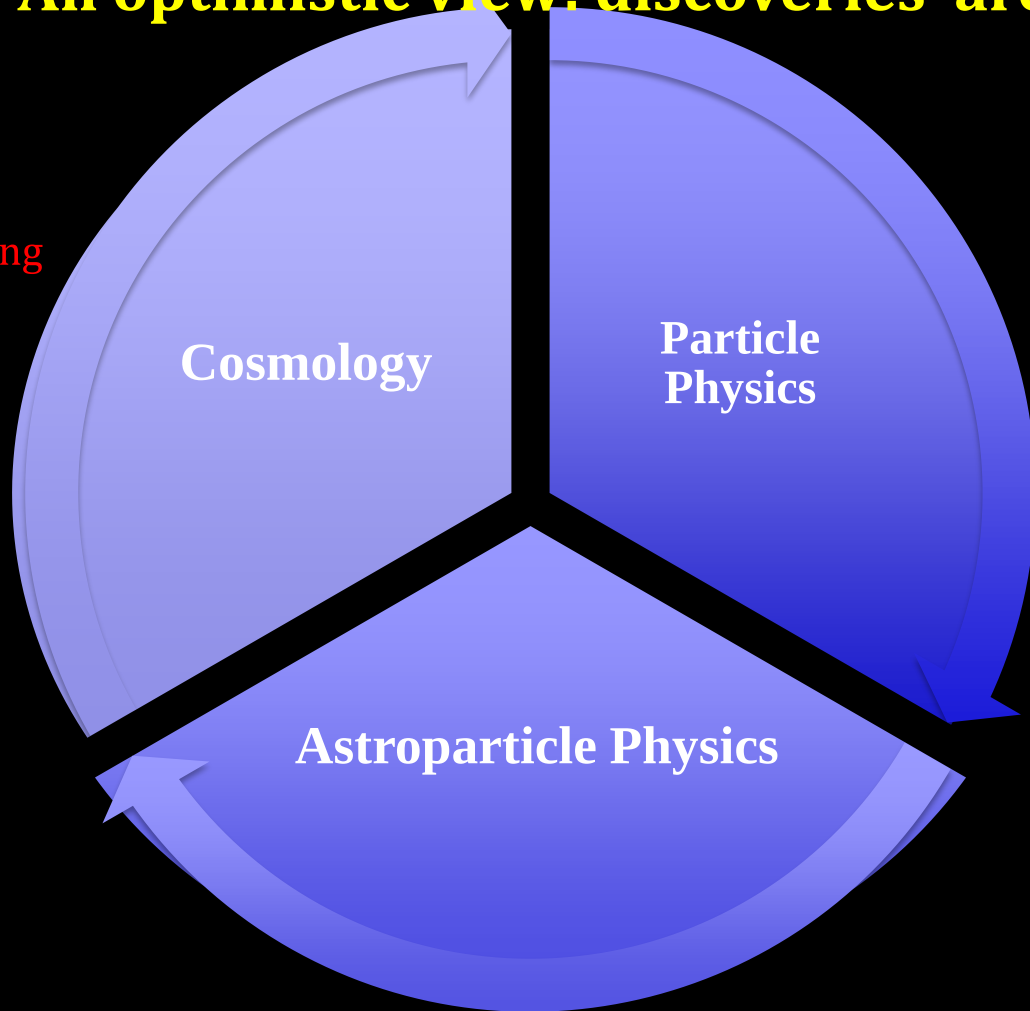
And what about the financial crisis ?
An optimistic view: discoveries around 1929



- ✓Universe Expanding (Hubble,1929)
- ✓Priemeval atom(Friedman-Lemaitre,1927)
- ✓My biggest error (1928, Einstein)
- ✓Dark Matter (1930, Zwicky)

- ✓ QFT Equation (1928, Dirac)
- ✓neutron (1930, Chadwick)
- ✓Isospin (1931, Heisenbeg)
- ✓Neutrino (1931, Pauli, Fermi)

- ✓Positron (Anderson, 1932)
- ✓CR and showers (Rossi, Auger, 1931)
- ✓Origin of Cosmic rays (Zwicky, 1930)