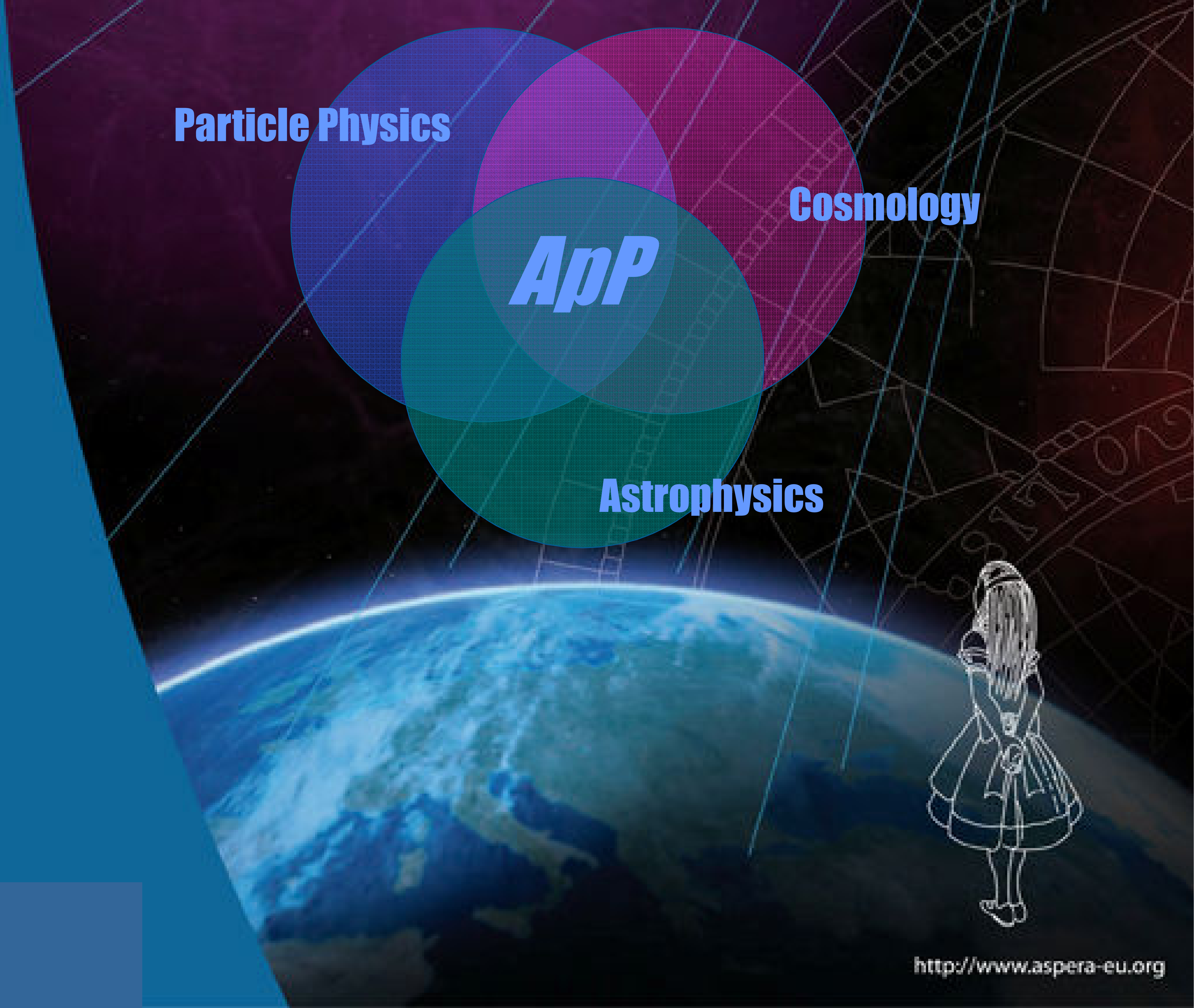
Perspectives in Astroparticle Physics

Christian Spiering, DESY

Cosmo-09
CERN, September 2009

http://www.aspera-eu.org

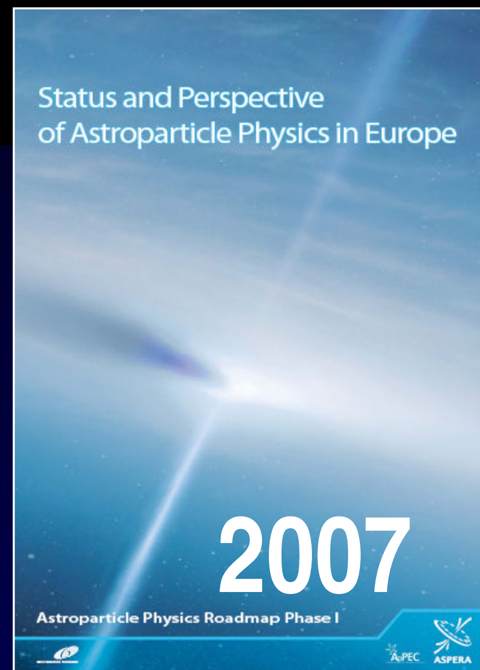

Particle Physics
Cosmology
ApP
Astrophysics
http://www.aspera-eu.org

- **Dark Matter & Dark Energy:**
  - Dark Matter: direct & indirect detection
  - Dark Energy: Earth bound, space bound
- **Low energy neutrino astronomy:**
  - neutrinos from Sun, Supernovae and the Earth, neutrino oscillations, test of fundamental principles
  - proton decay (using the same detectors!)
- **Neutrino properties:**
  - nature and mass of neutrinos, neutrino oscillations
- **The high energy universe:**
  - origin of cosmic rays, processes at highest energies, test of fundamental principles, indirect dark matter search, search for exotic particles
- **Gravitational waves:**
  - violent cosmic processes and the nature of relativity

Strategy Process

Europe

ApPEC

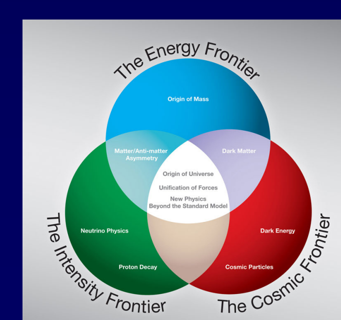


2010/11

Technology, Physics
National priorities, better funding envelopes
Global context, US strategy

European Strategy for Particle Physics (CERN Council, 2006)

ASTRONET Infrastructure Roadmap (2008)



USA

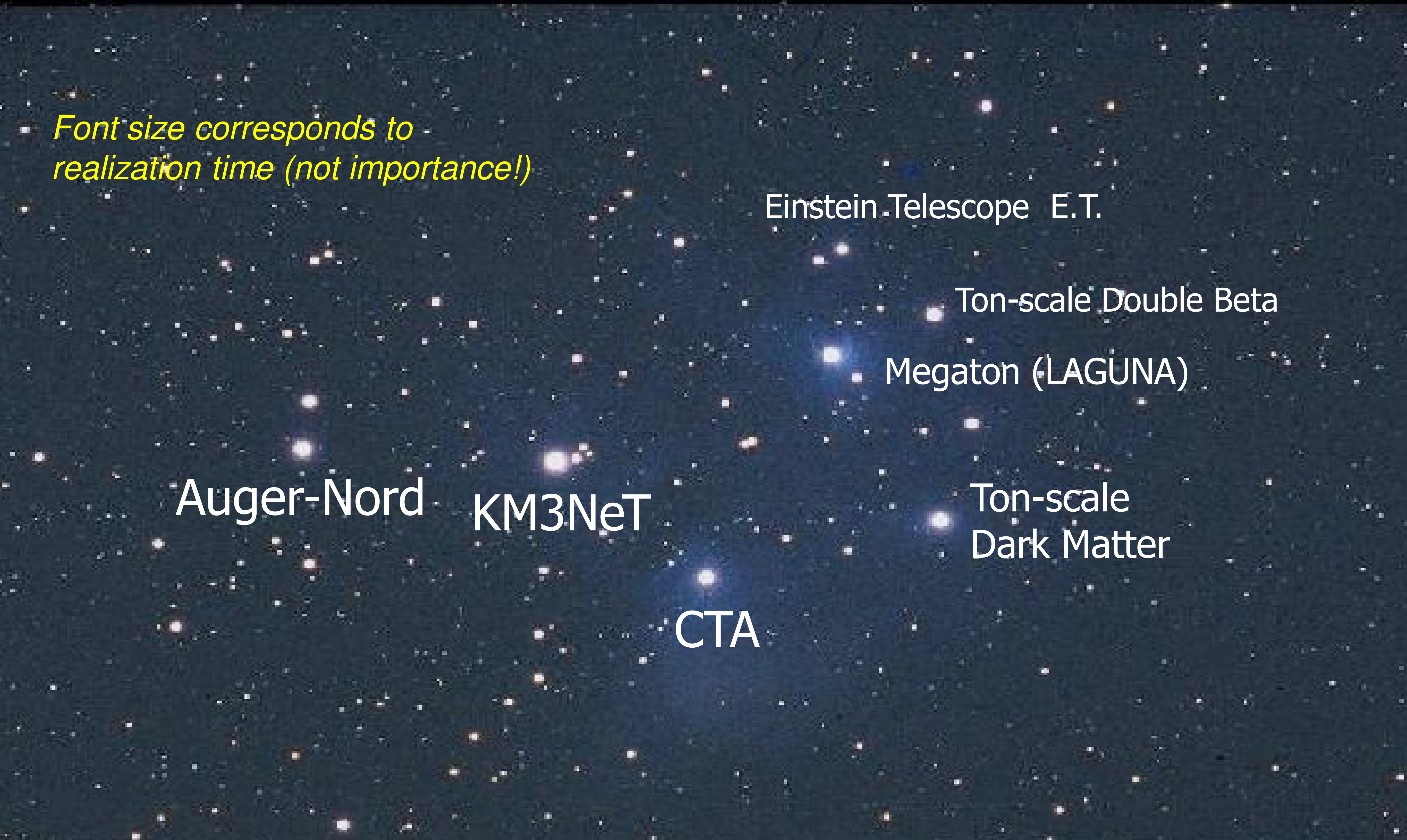
P5 Roadmap for Particle Physics (May 2008)

PASAG (Particle Astrophysics Scientific Assessment Group), **Sept. 2009**
Decadal Review Astro2010 (subpanel on Particle Astrophysics and Gravitation, PAG) **2010**

ApPEC Astroparticle Physics for Europe

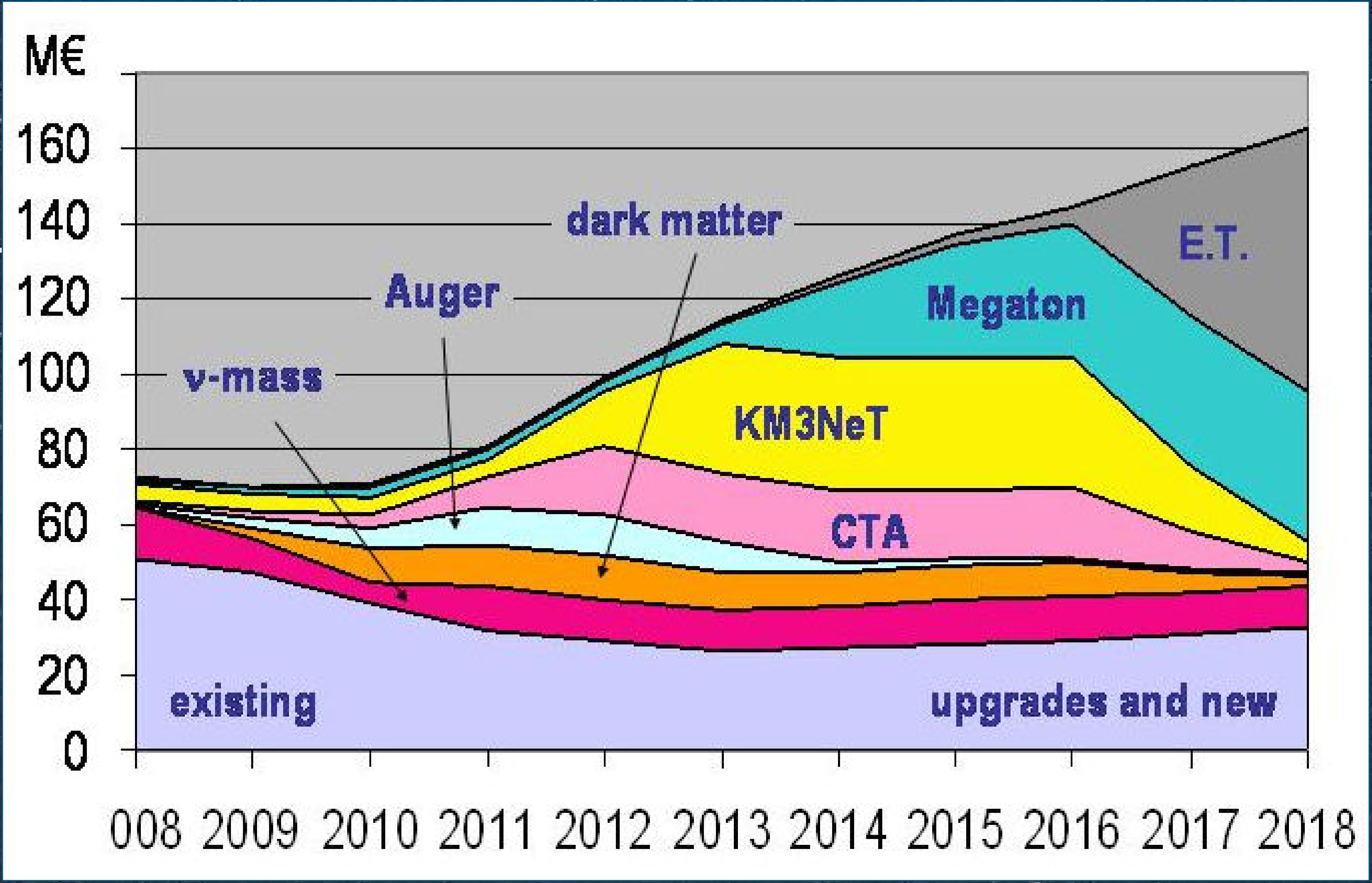
The Magnificent Seven

ApPEC/ASPERA roadmap 2008



The Magnificent Seven

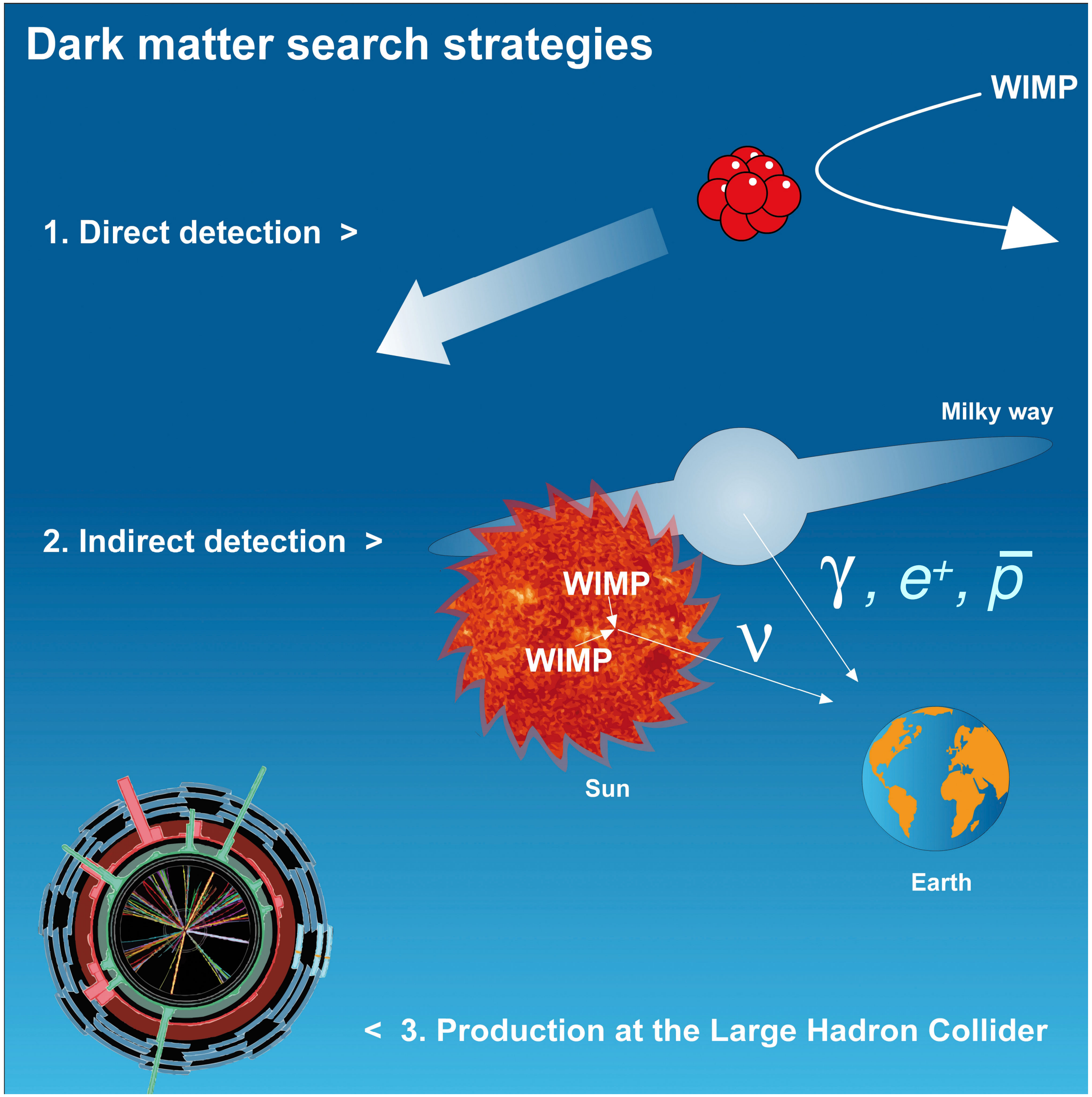
Investement, only Europe



Dark Matter

DM candidates:

- **WIMPs**
  - Neutralinos
  - Kaluza-Klein particles
  - …
- **Axinos**
- **Super-WIMPs**
- **Axions**
- **Axion-like light bosons**
- **Sterile neutrinos**
- **Q-balls**
- **WIMPzillas**
- **Elementary BHs**
- **…**



Direct Dark Matter Searches

DM candidates:

- **WIMPs**
  - Neutralinos
  - Kaluza-Klein particles

~ 20 experiments worldwide
→ Need of convergence

ApPEC Astroparticle Physics for Europe

World Map of Direct Dark Matter Searches

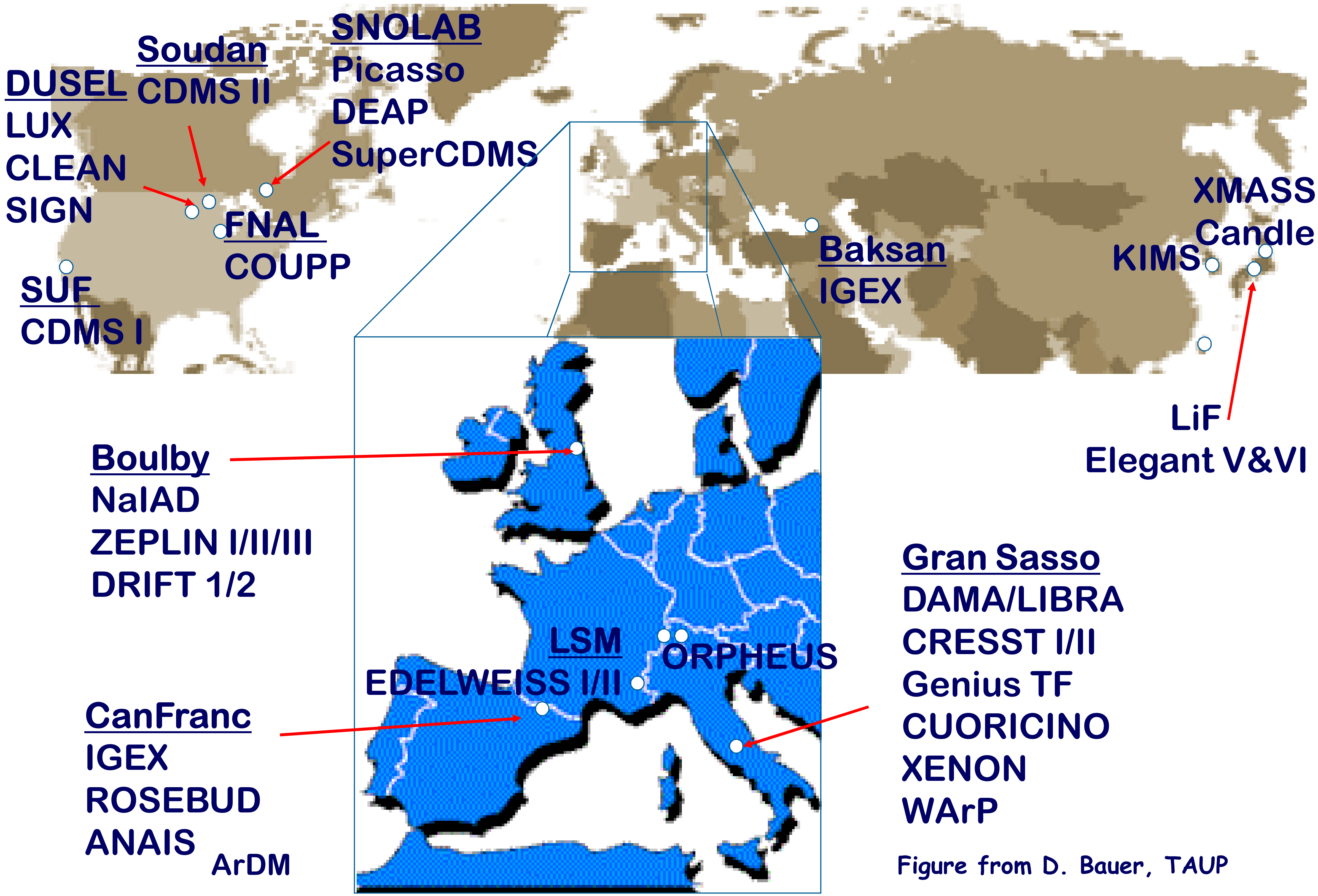
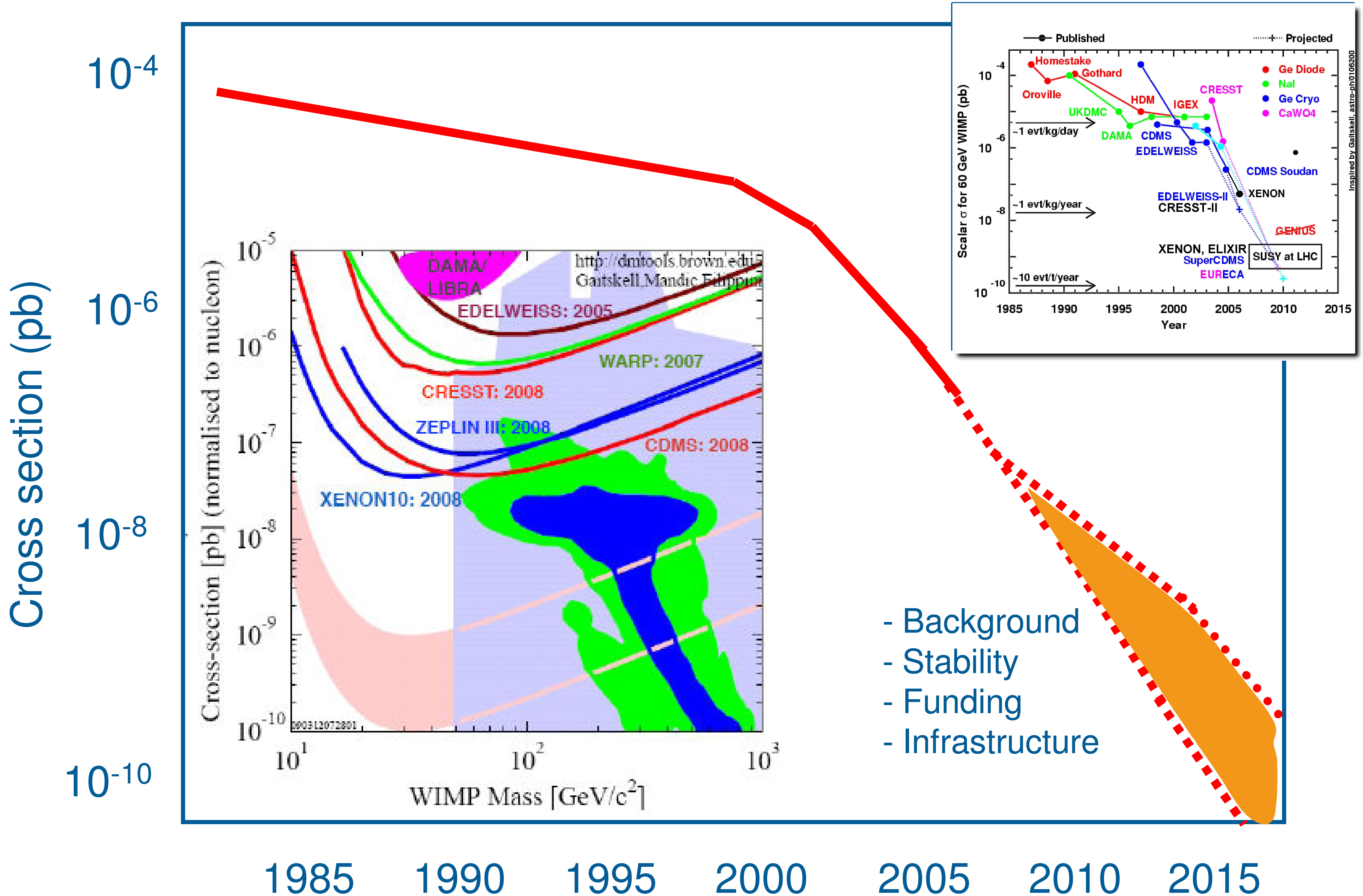


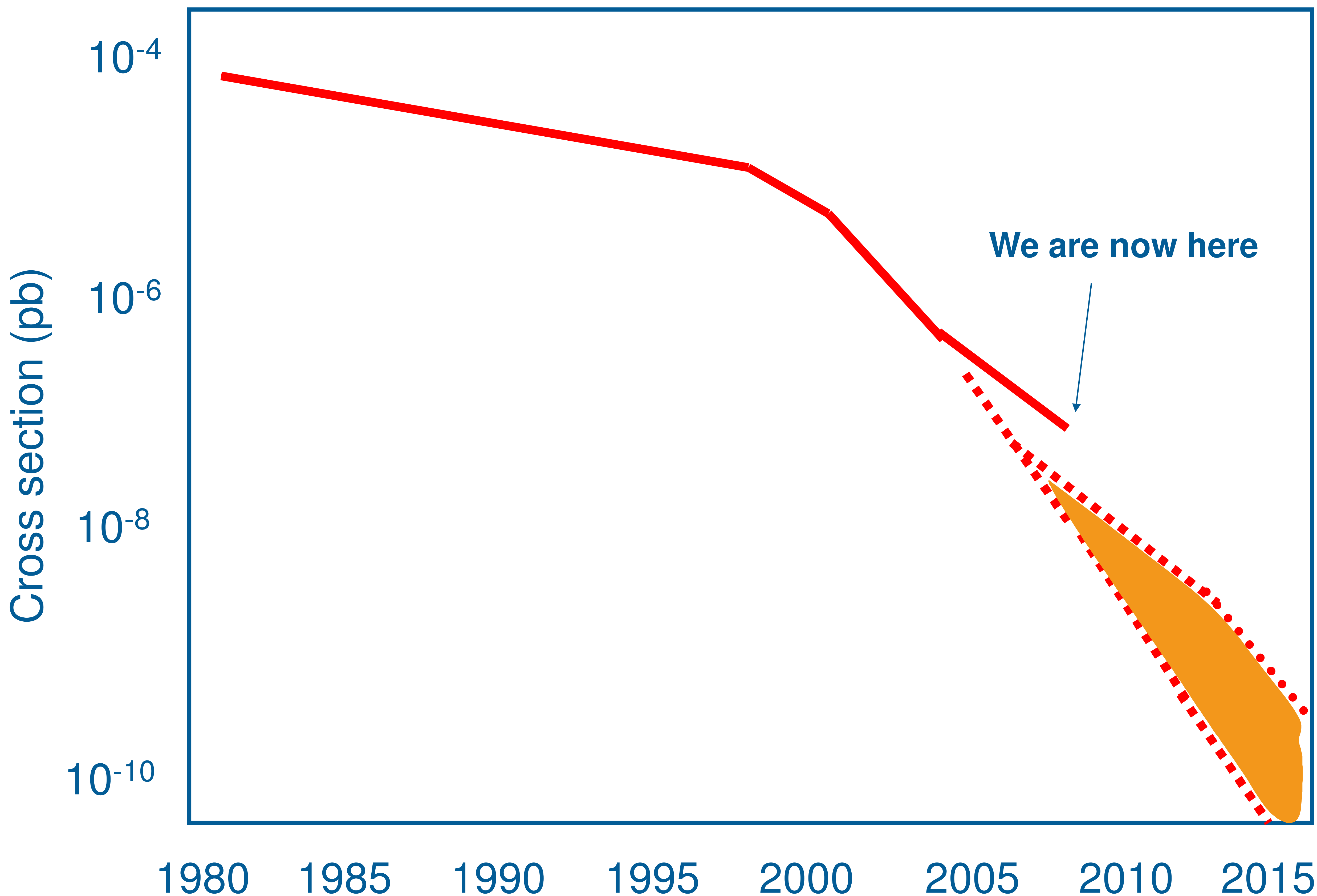
Figure from D. Bauer, TAUP

Direct Dark Matter Searches

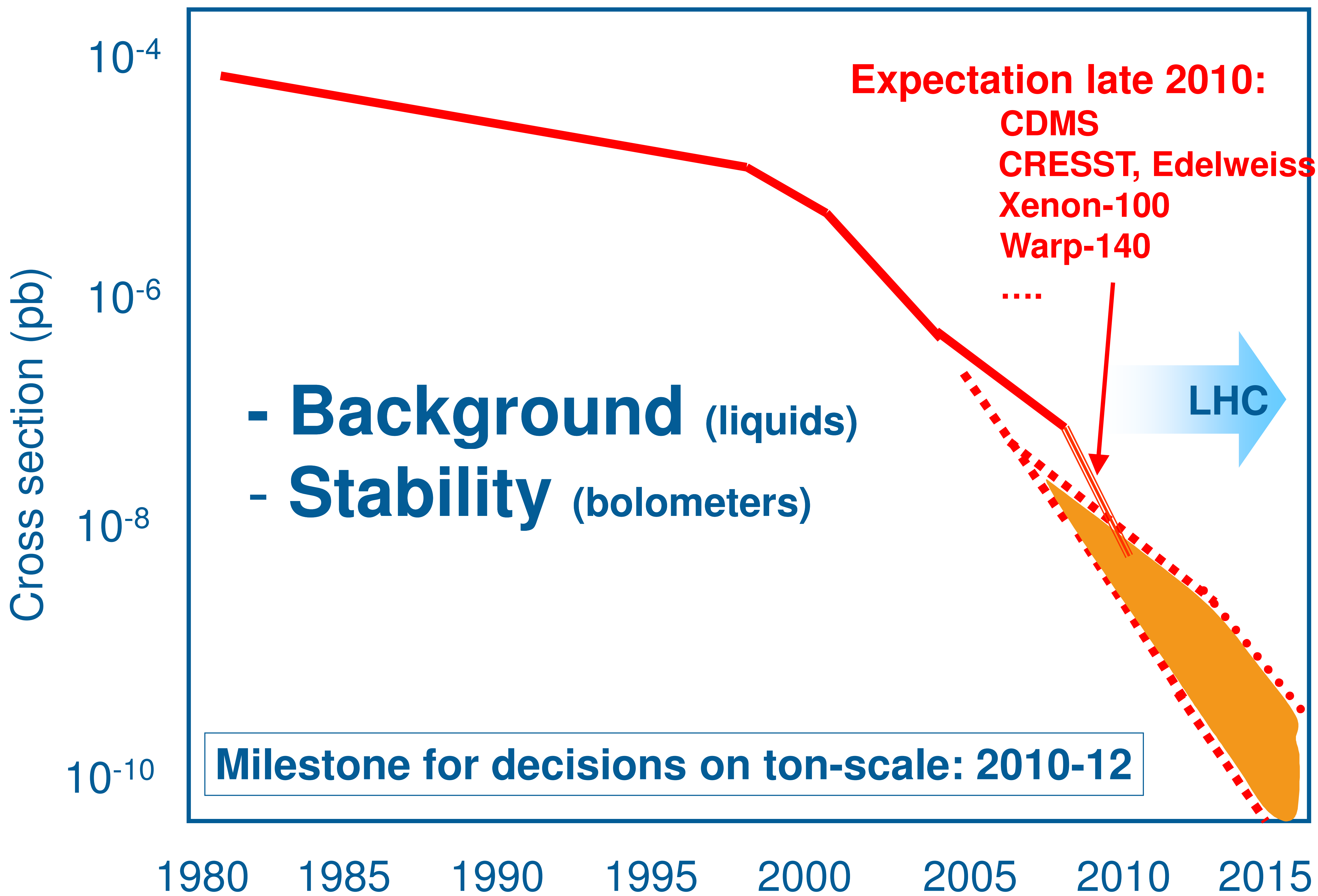
ApPEC Astroparticle Physics for Europe



Direct Dark Matter Searches



Direct Dark Matter Searches

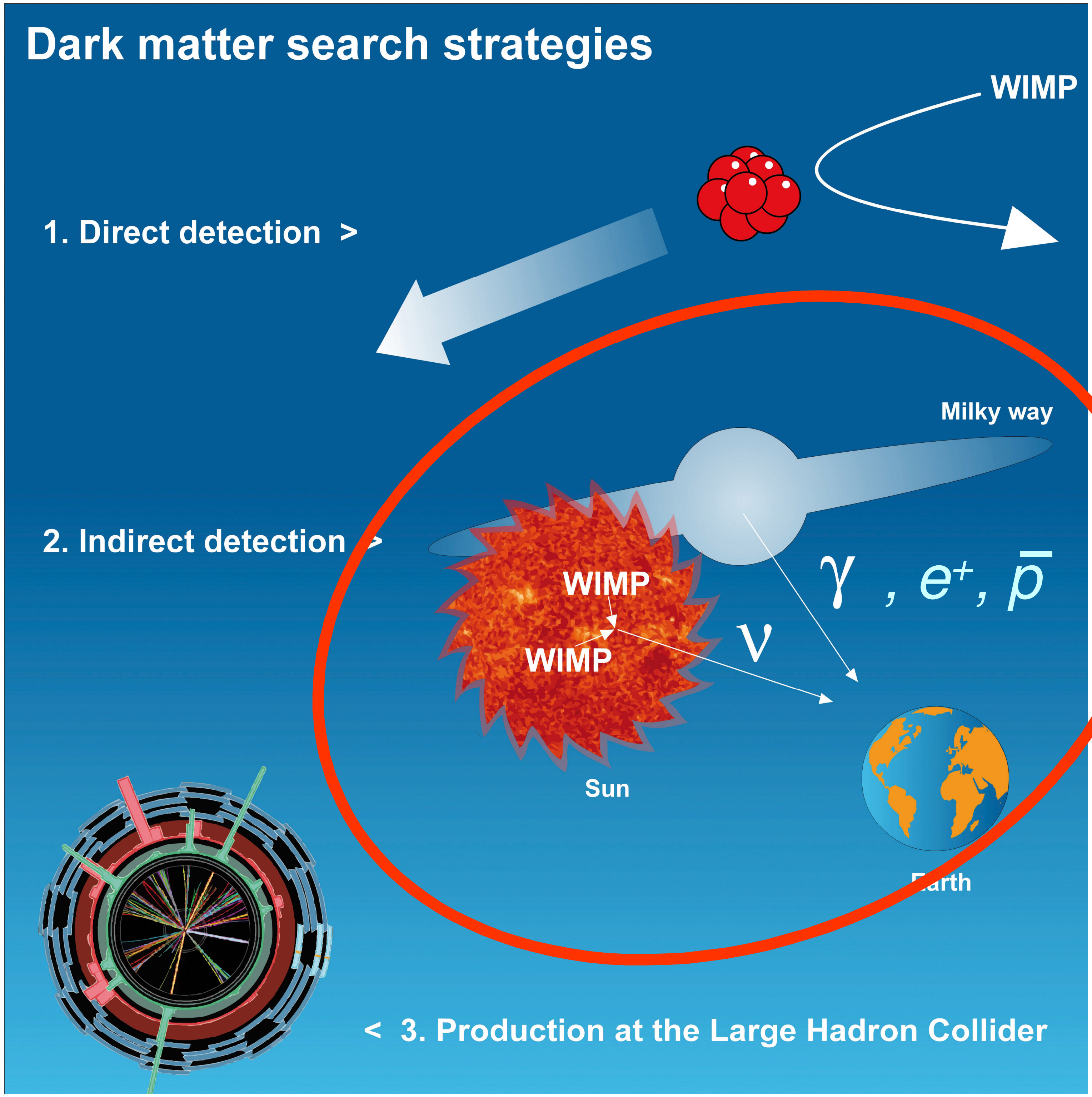


Dark Matter Searches

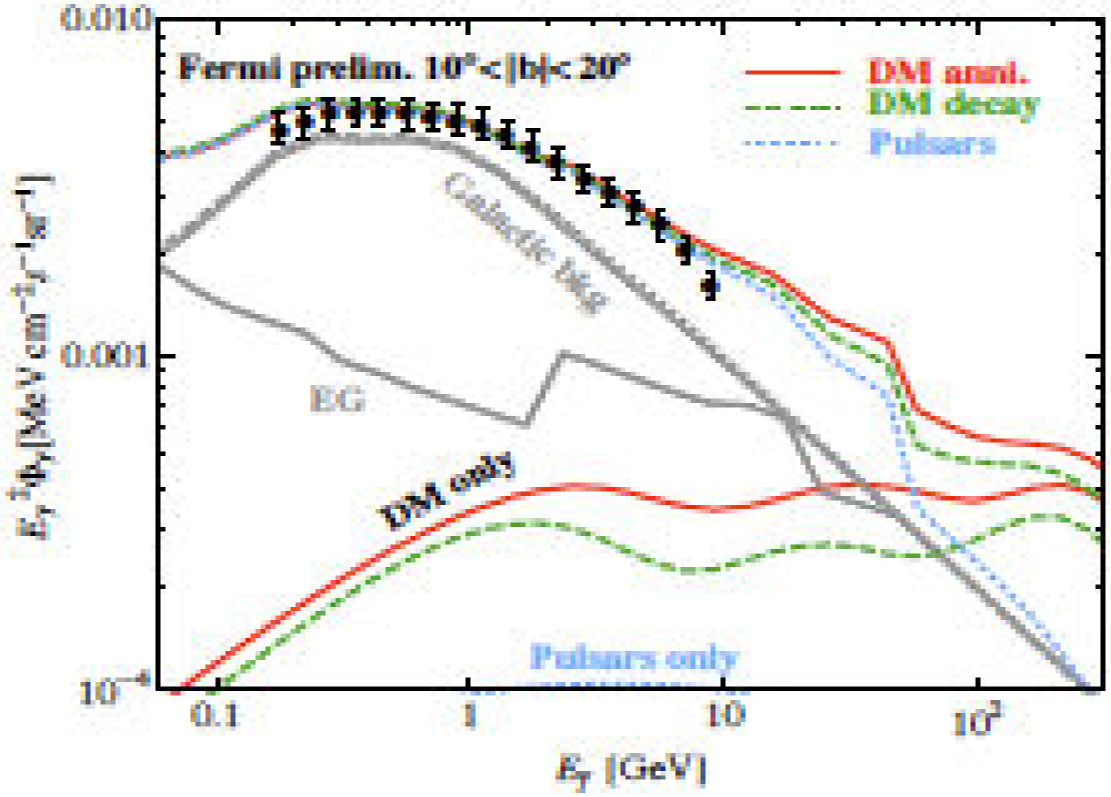
- Support **current round of experiments at high priority**, also technology development towards their next-generation versions
- A **recommendation on which of the technologies should first move to a next stage can only be made after first results from present experiments with 10-100 kg target mass become available** and after noise rejection and sensitivity/cost ratio for ton-scale detectors can be judged on a more realistic basis.
- **This milestone can be reached by 2010 to 2012.**
- As soon as one of the technologies turns out to be clearly **superior in sensitivity, cost, and timing → Promote it with priority!**
  At the same time, a **second technology must be systematically prepared** since a possible positive observation by the first method would call for a prompt, independent confirmation.
- In an ideal scenario, **LHC observations** of new particles at the weak scale could place these observations in a well-confined particle physics context. Also, direct detection would be supported by indirect signatures. In case of a discovery, "smoking-gun signatures" of direct detection such as directionality and annual variations would be measured in detail.

DM candidates:

- **WIMPs**
  - Neutralinos
  - Kaluza-Klein particles
  - …



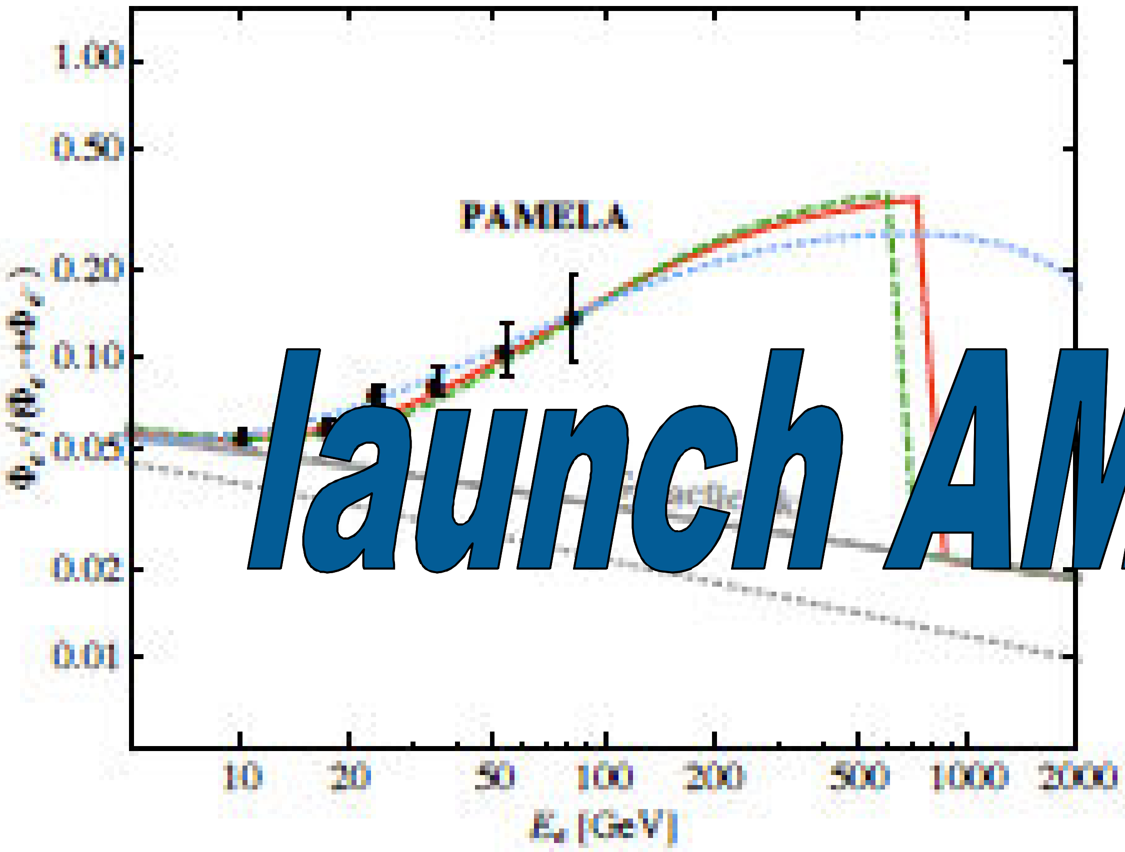
Indirect Searches: Pamela & Co.

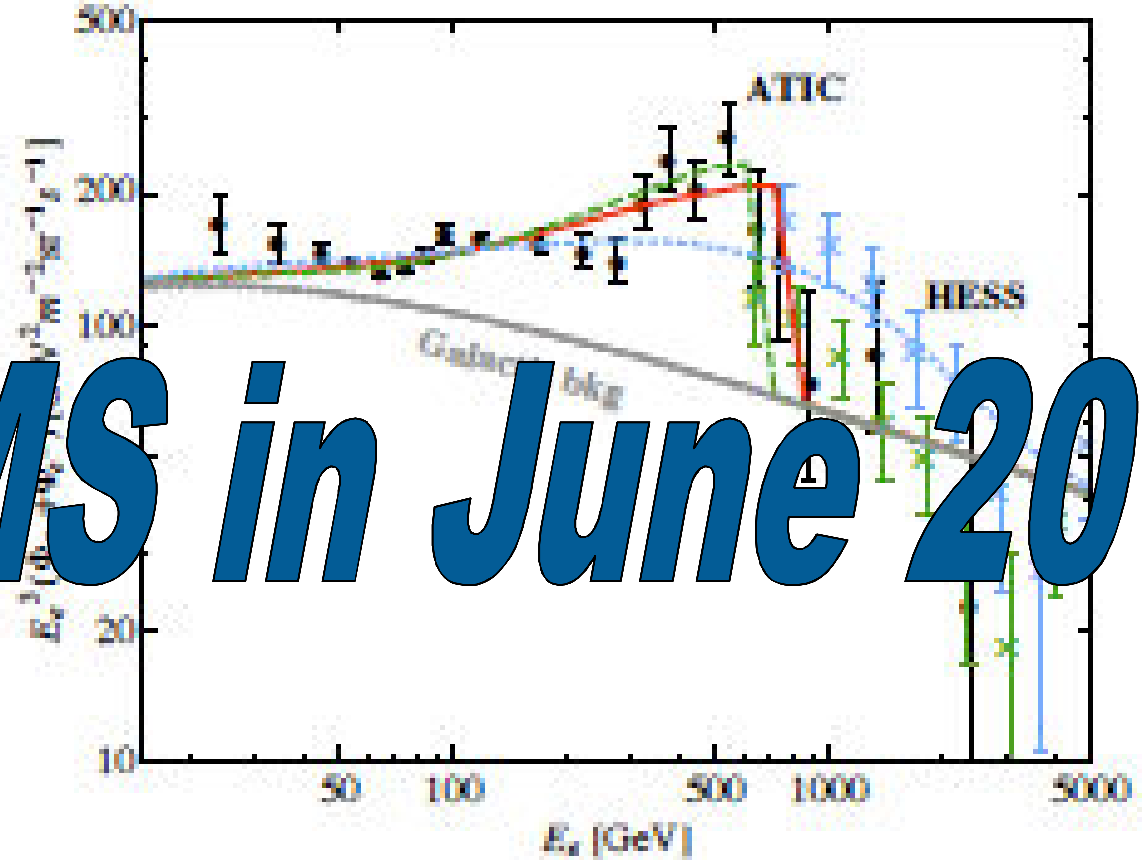


- Dark Matter annihilation ?
- Dark Matter Decay ?
- Nearby Pulsars ?

New Physics

Astrophysics

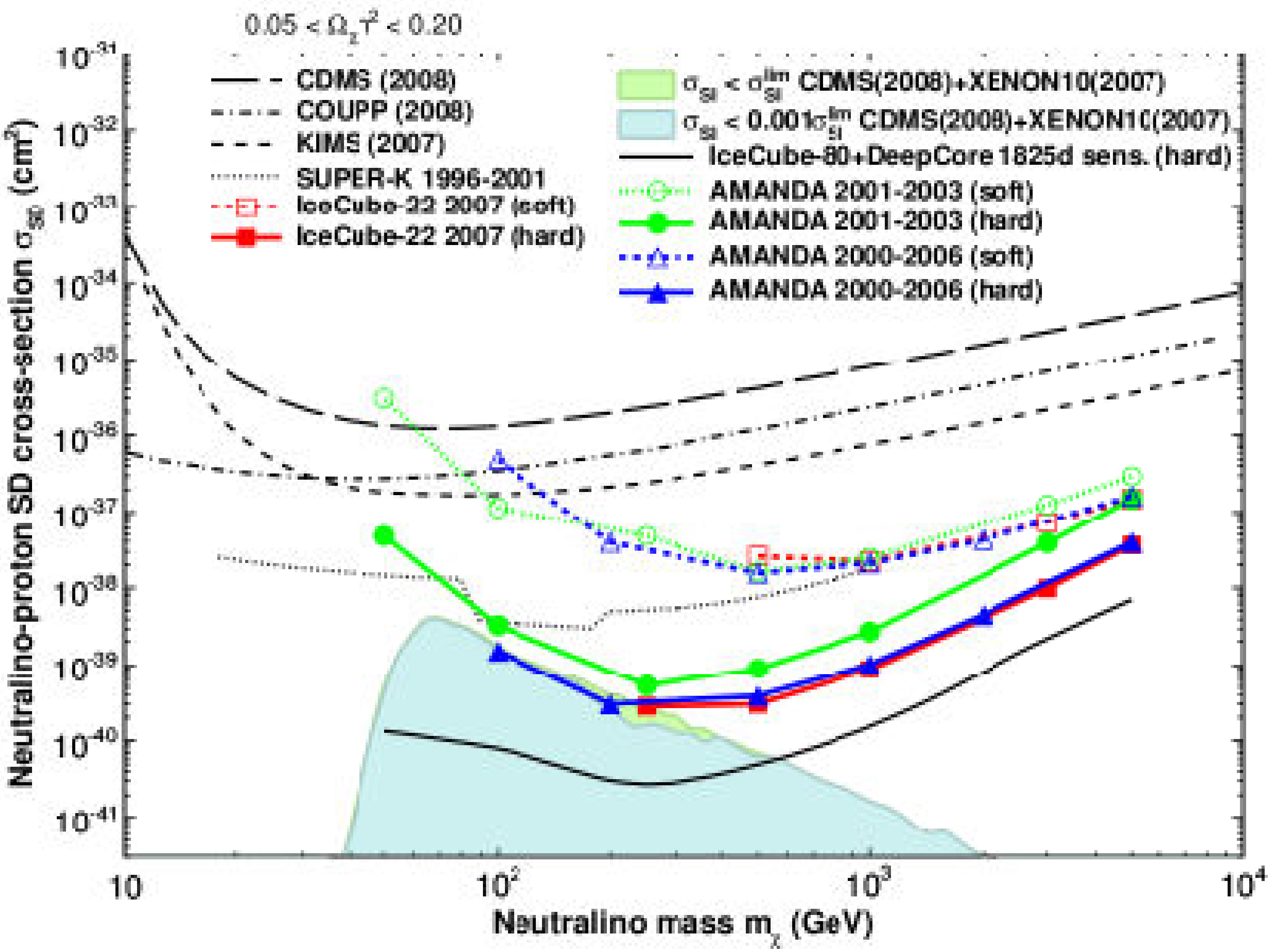


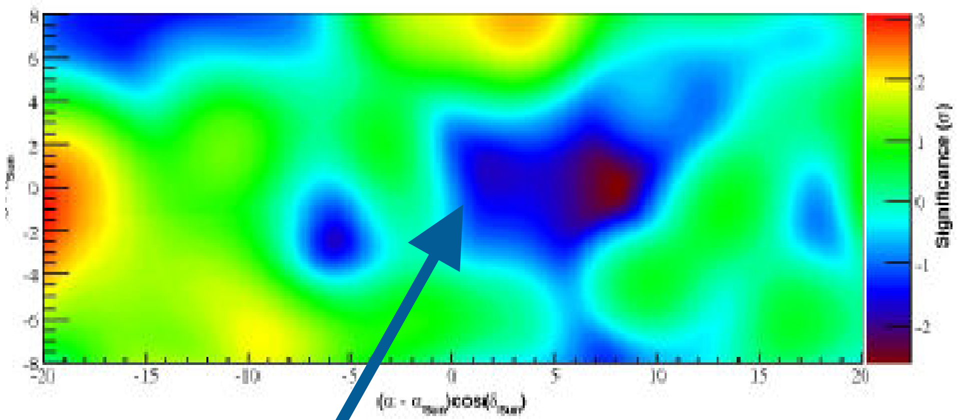


launch AMS in June 2010

Barger et al.

Indirect Searches: Example IceCube





Sun position (Amanda skymap)

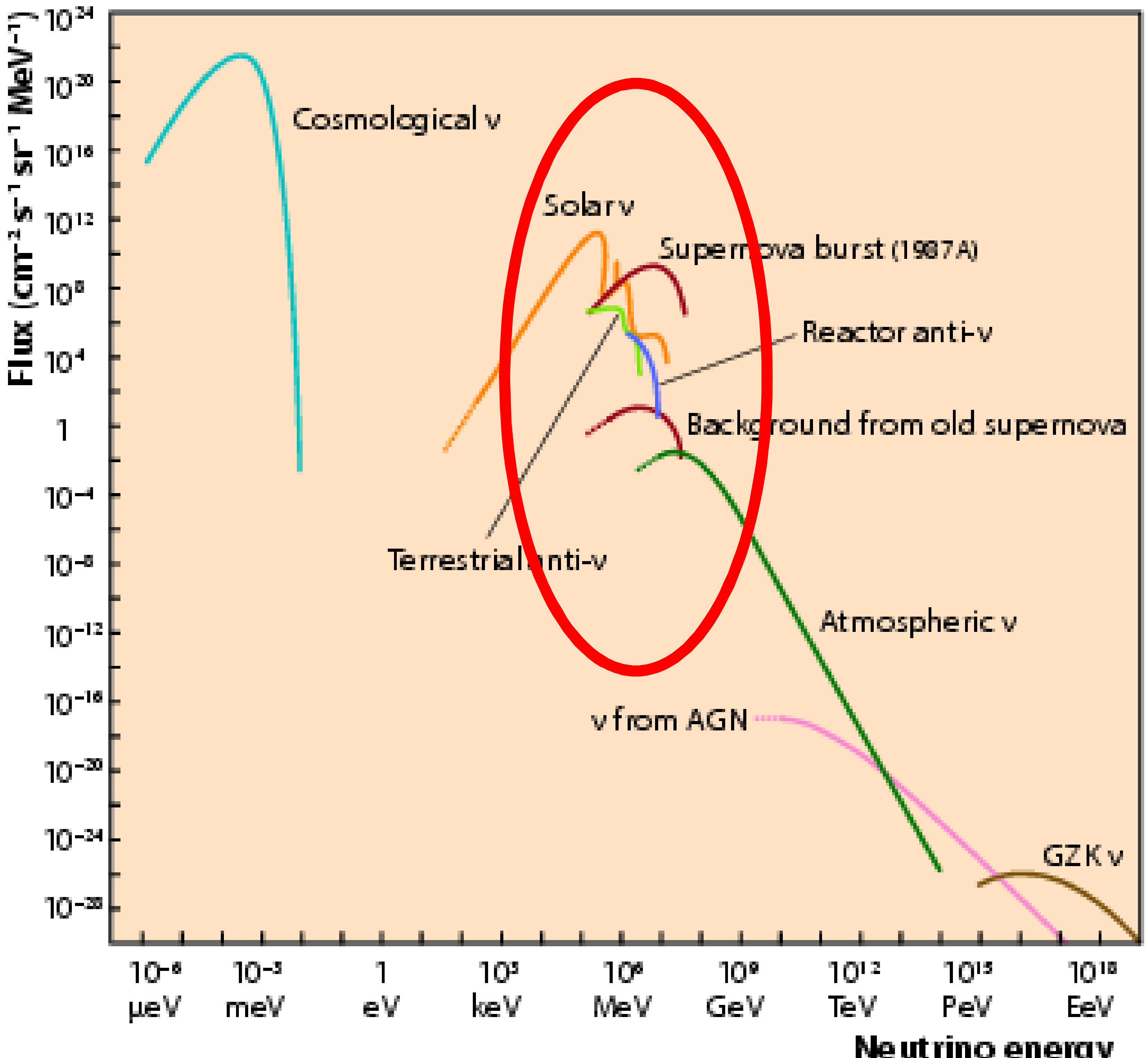
- Models with strong spin-dependent coupling are the least constrained by direct DM searches.
- W.r.t. spin-dependent coupling, underice/underwater detectors are ~100 times more sensitive than direct search experiments (Sun is mostly hydrogen)

Low-energy neutrino astronomy

Proton decay

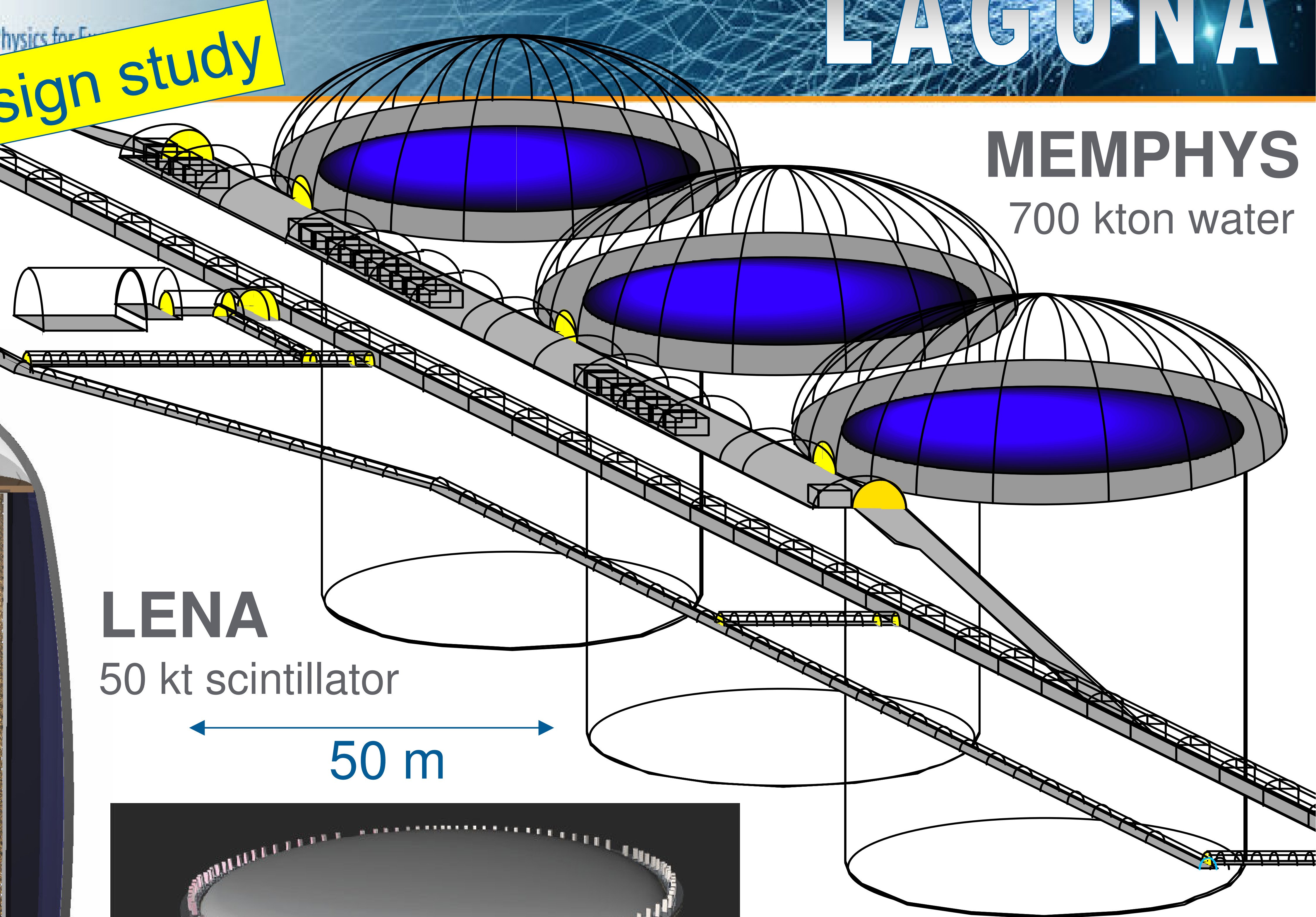
Neutrino Astrophysics & p-decay

- **Super-Kamiokande KAMLand**
- **Borexino, LVD**
- **SAGE, Baksan**
- **ICARUS, SNO+, ….**
- **10-kt scale** (non-H_2O)
  - INO (India)
  - Modular (LNGS)
  - …
- **Megaton scale**
  - Europe
  - USA
  - East Asia



LAGUNA

FP7 design study



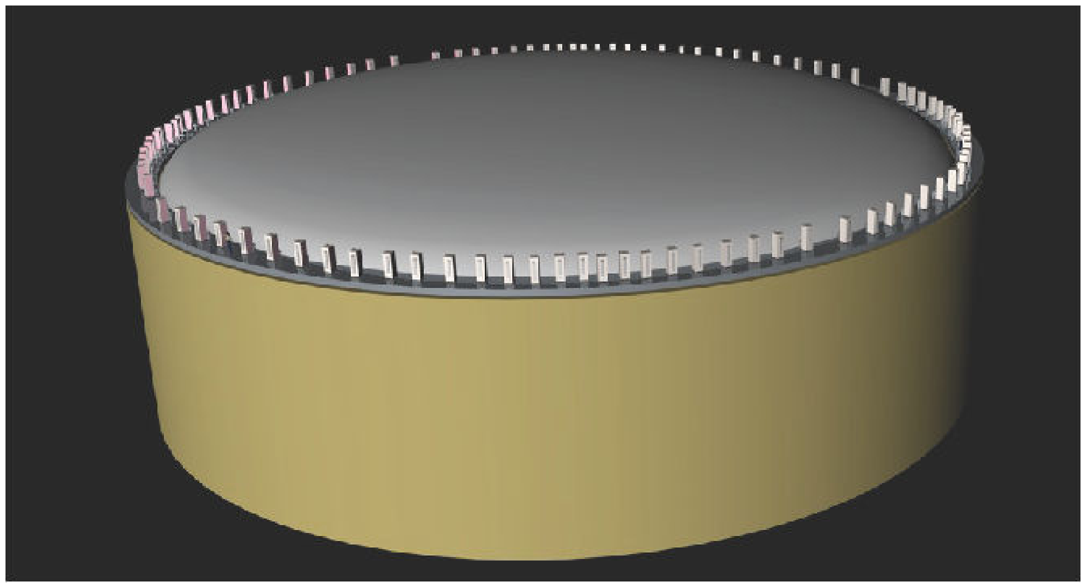
MEMPHYS

700 kton water

LENA

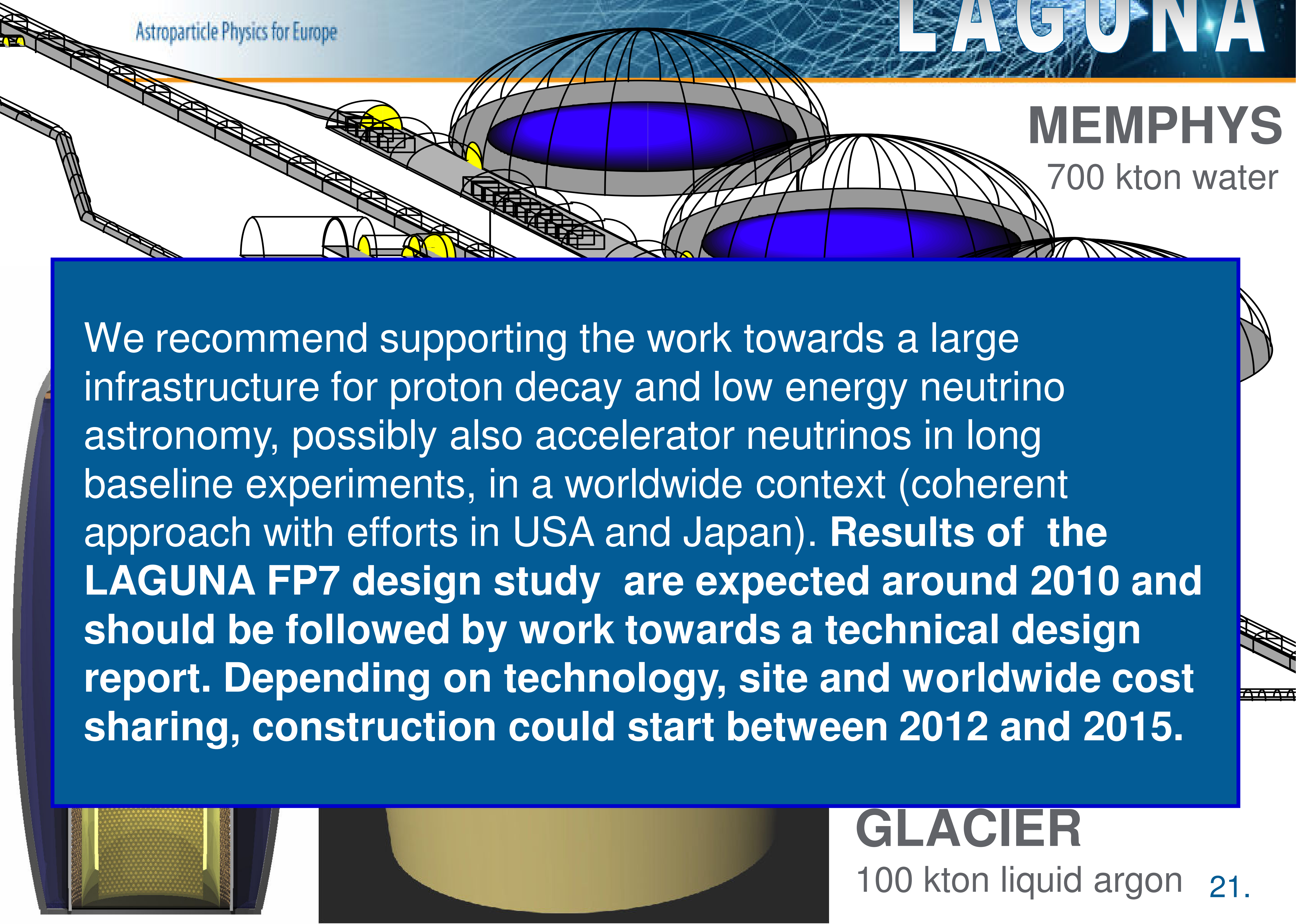
50 kt scintillator

50 m



GLACIER

100 kton liquid argon



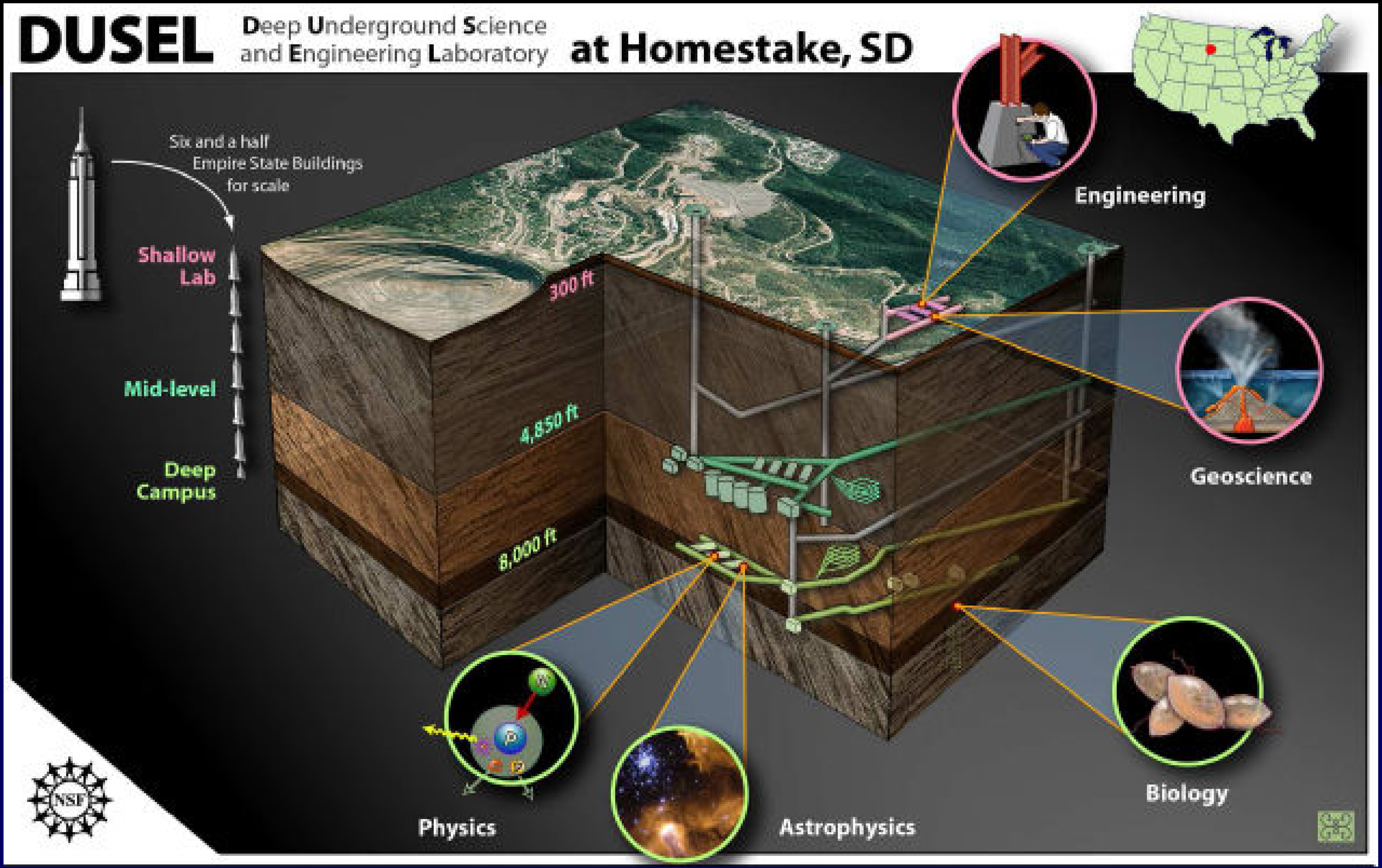
We recommend supporting the work towards a large infrastructure for proton decay and low energy neutrino astronomy, possibly also accelerator neutrinos in long baseline experiments, in a worldwide context (coherent approach with efforts in USA and Japan). **Results of the LAGUNA FP7 design study are expected around 2010 and should be followed by work towards a technical design report. Depending on technology, site and worldwide cost sharing, construction could start between 2012 and 2015.**

ApPEC Astroparticle Physics for Europe

Particle Physics at the Megaton scale

- **Proton decay:** improve sensitivity by > factor 10 and test a new class of Supersymmetry models
- **Galactic Supernova:** 10^4- 10^5 events
  Incredibly detailed information on the early SN phase
- **Diffuse flux from past SN:** probe cosmological star formation rate
- **Solar neutrinos:** details of the Standard Solar Model determined with percent accuracy
- **Atmospheric neutrinos:** high statistics would improve knowledge neutrino mixing and provide unique information on the neutrino mass hierarchy
- **Geo-neutrinos:** improve understanding of the Earth interior
- **Indirect WIMP search**
- **Neutrinos from accelerators** over a long baseline (also with dedicated smaller detectors): neutrino properties

Particle Physics at the Megaton scale



Particle Physics at the Megaton scale

DUSEL Deep Underground Science and Engineering Laboratory at Homestake, SD

- Direct Detection of Dark Matter
- Neutrino-less Double-Beta Decay
- Nuclear Astrophysics
  - Accelerator-based cross-section measurements
- Solar Neutrinos
- Long Baseline Experiment, Proton Decay, and Supernovae Remnants (Mega-Detector)

300 kt water ?

DUSEL MREFC funding would support the construction of forefront experiments in nuclear- and astro-physics, and in particle physics using the Fermilab accelerator as a high intensity neutrino source.

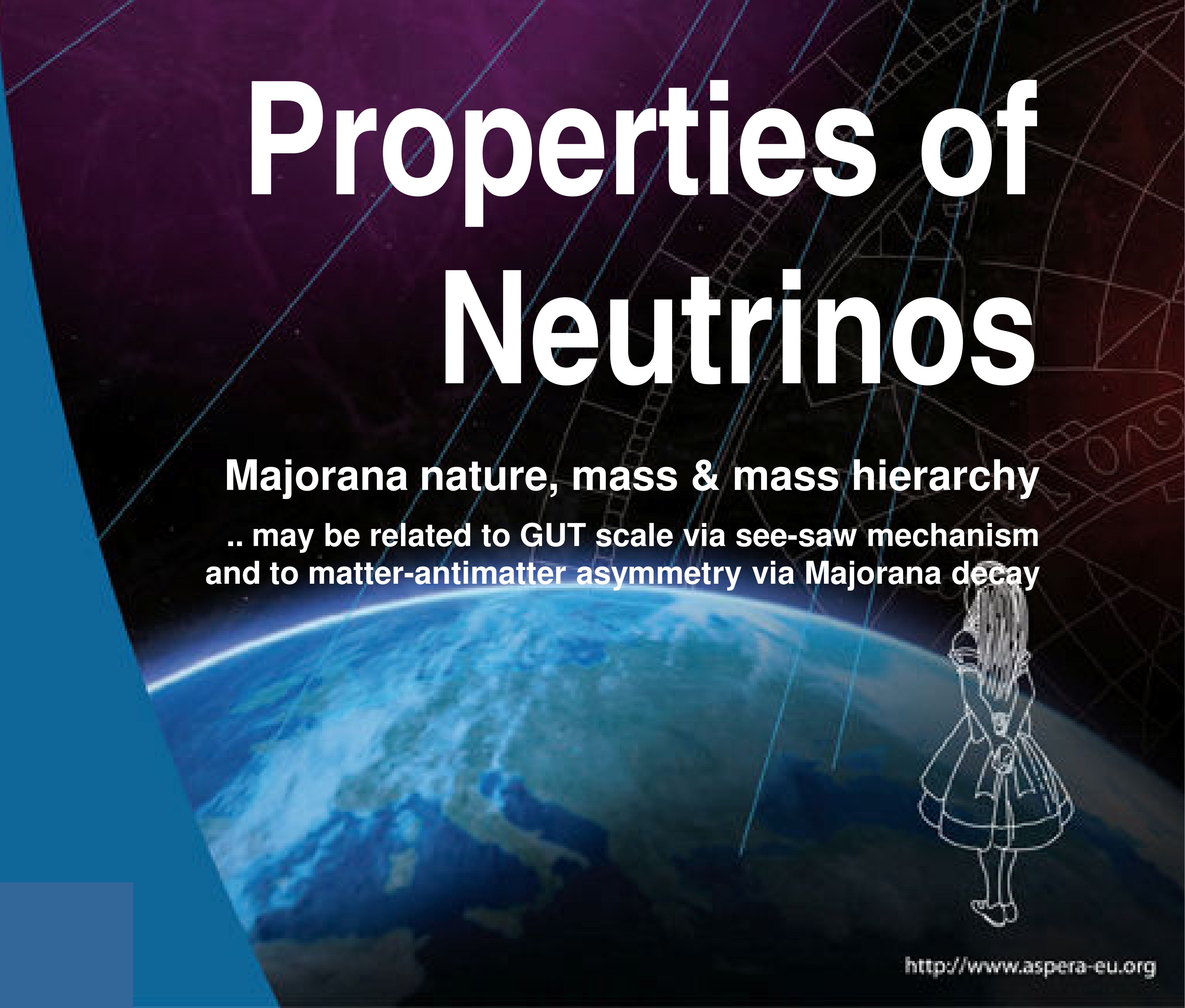
Physics

Astrophysics

Properties of Neutrinos

Majorana nature, mass & mass hierarchy

.. may be related to GUT scale via see-saw mechanism and to matter-antimatter asymmetry via Majorana decay



KATRIN

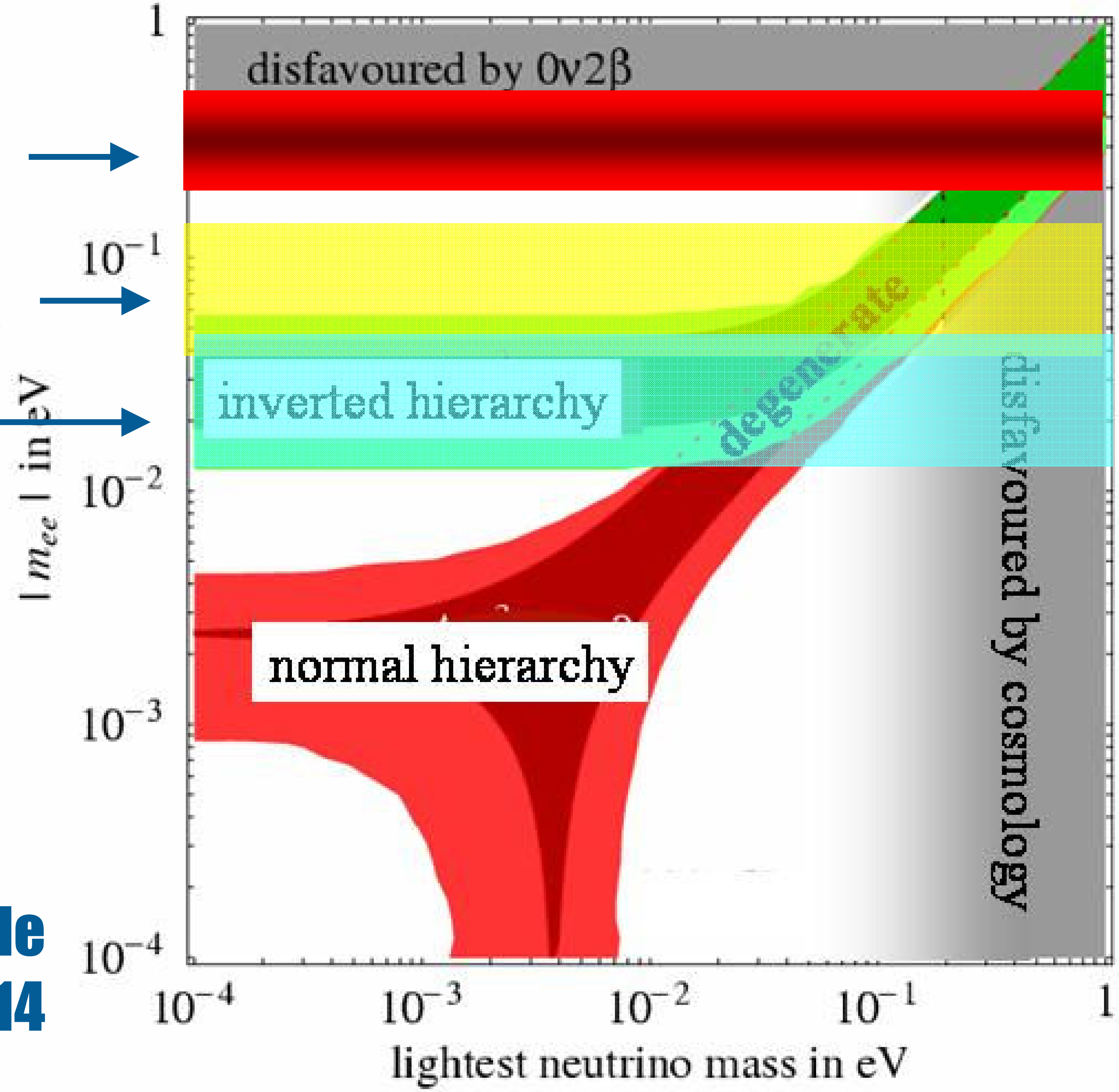
- start 2012
- down to 0.2 eV

Double Beta Decay

KKGH claim →

GERDA, EXO200, SNO+
CUORE, SuperNEMO →

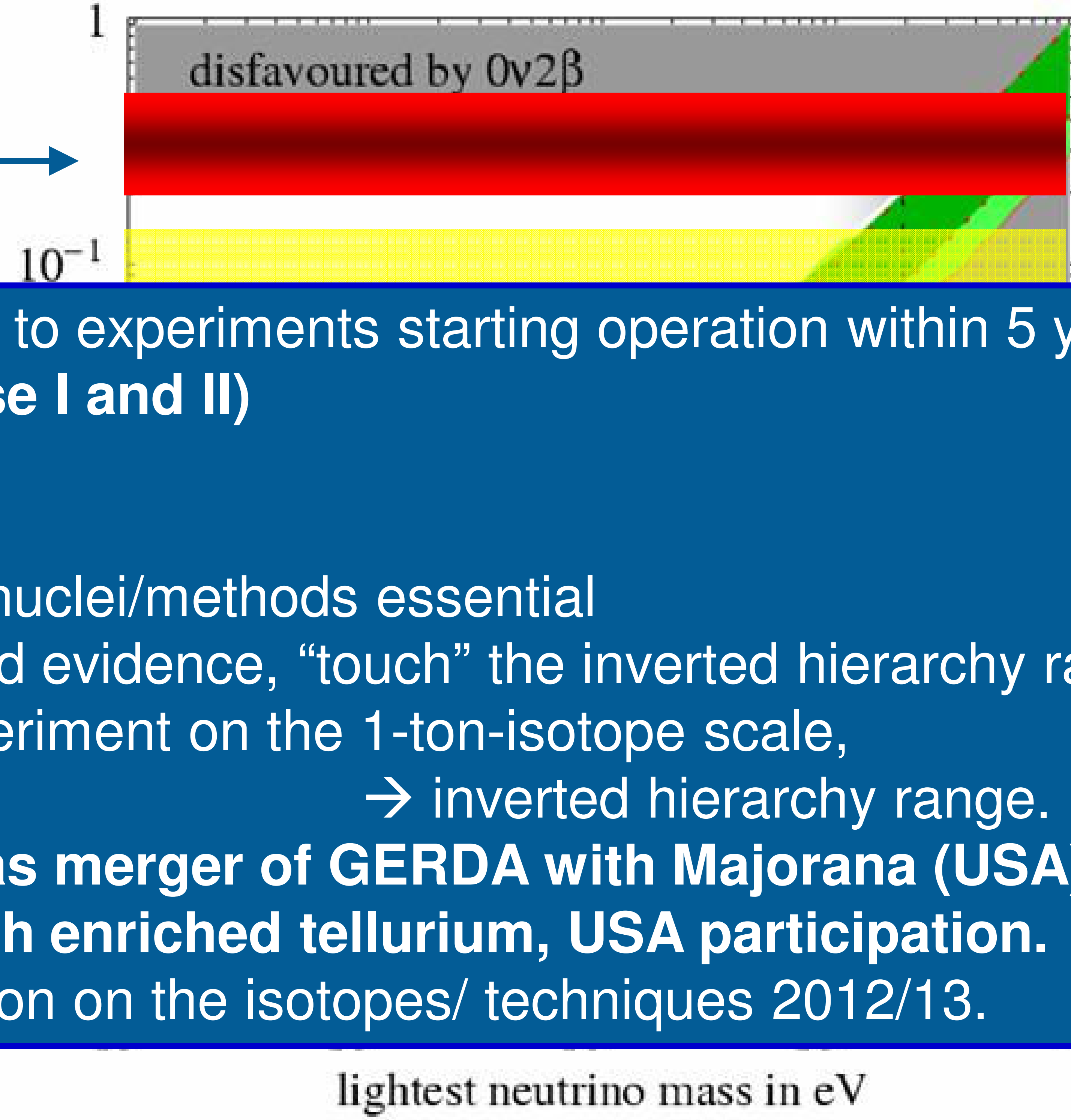
Ton-scale →



Decision on ton scale 2012/14

Double Beta Decay

KKGH claim →



GERDA, EXO200, SNO+,
CUO

European priority to experiments starting operation within 5 years

- **GERDA (phase I and II)**
- **CUORE**
- **Super-NEMO**

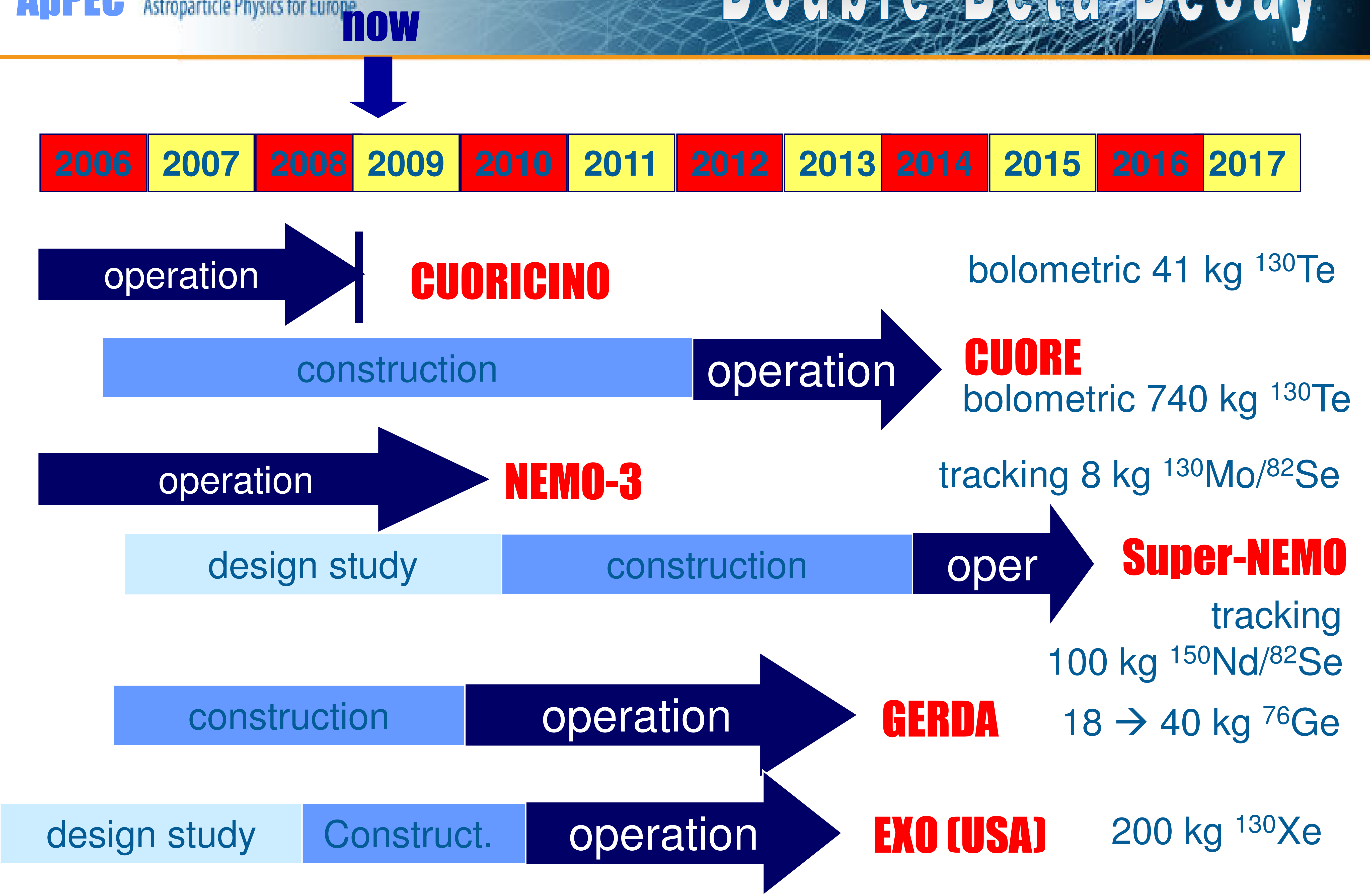
Complementary nuclei/methods essential
Scrutinize claimed evidence, “touch” the inverted hierarchy range.
Envisage an experiment on the 1-ton-isotope scale,
→ inverted hierarchy range.

e.g. GERDA III as merger of GERDA with Majorana (USA)
CUORE with enriched tellurium, USA participation.

Milestone: Decision on the isotopes/ techniques 2012/13.

Pric
50-200 M€.

Double Beta Decay



(Projects running, under construction or with substantial R&D funding)

Double Beta Decay

now

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017

commisioning early 2010

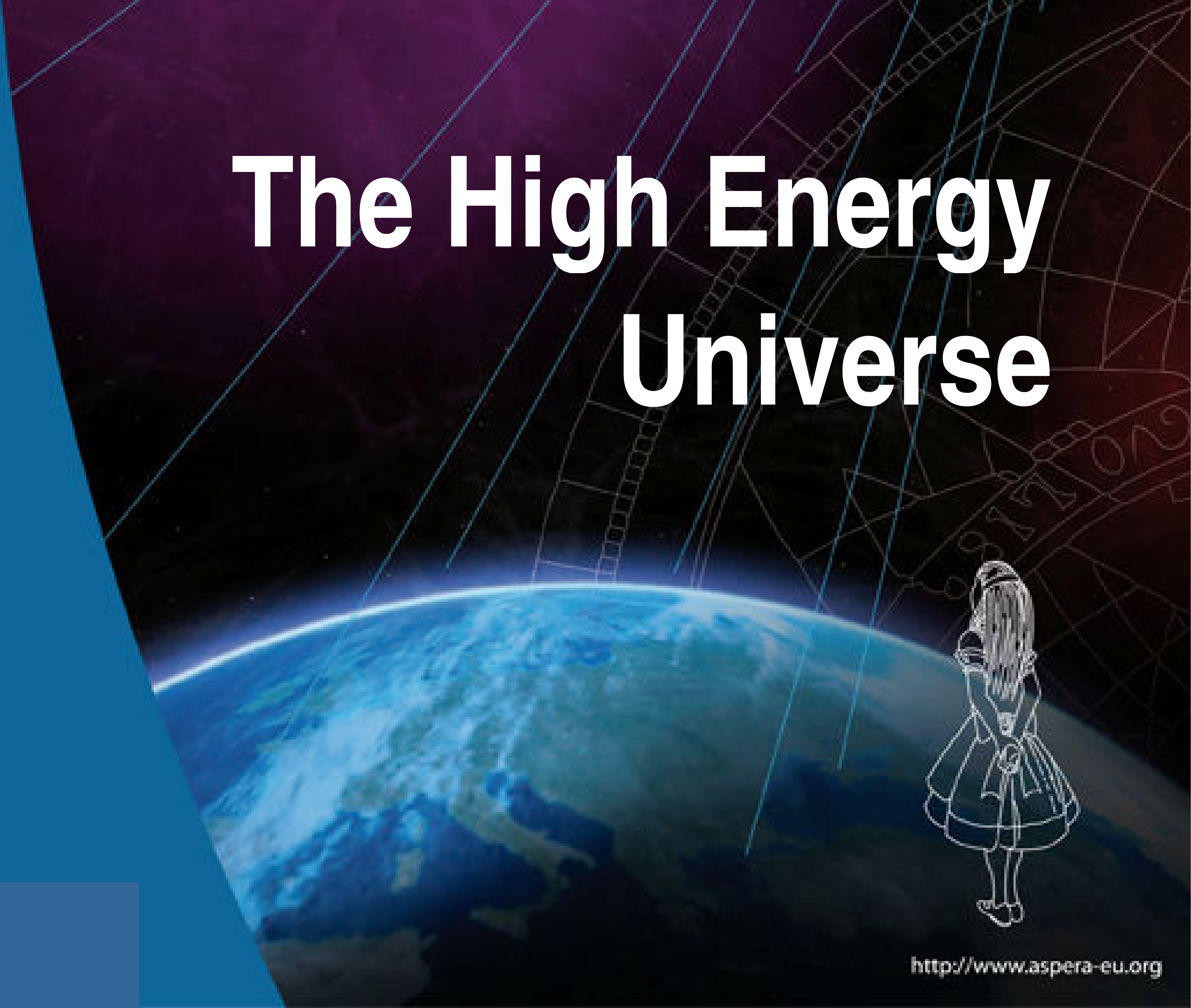
construction → operation

GERDA 18 → 40 kg ^{76}Ge

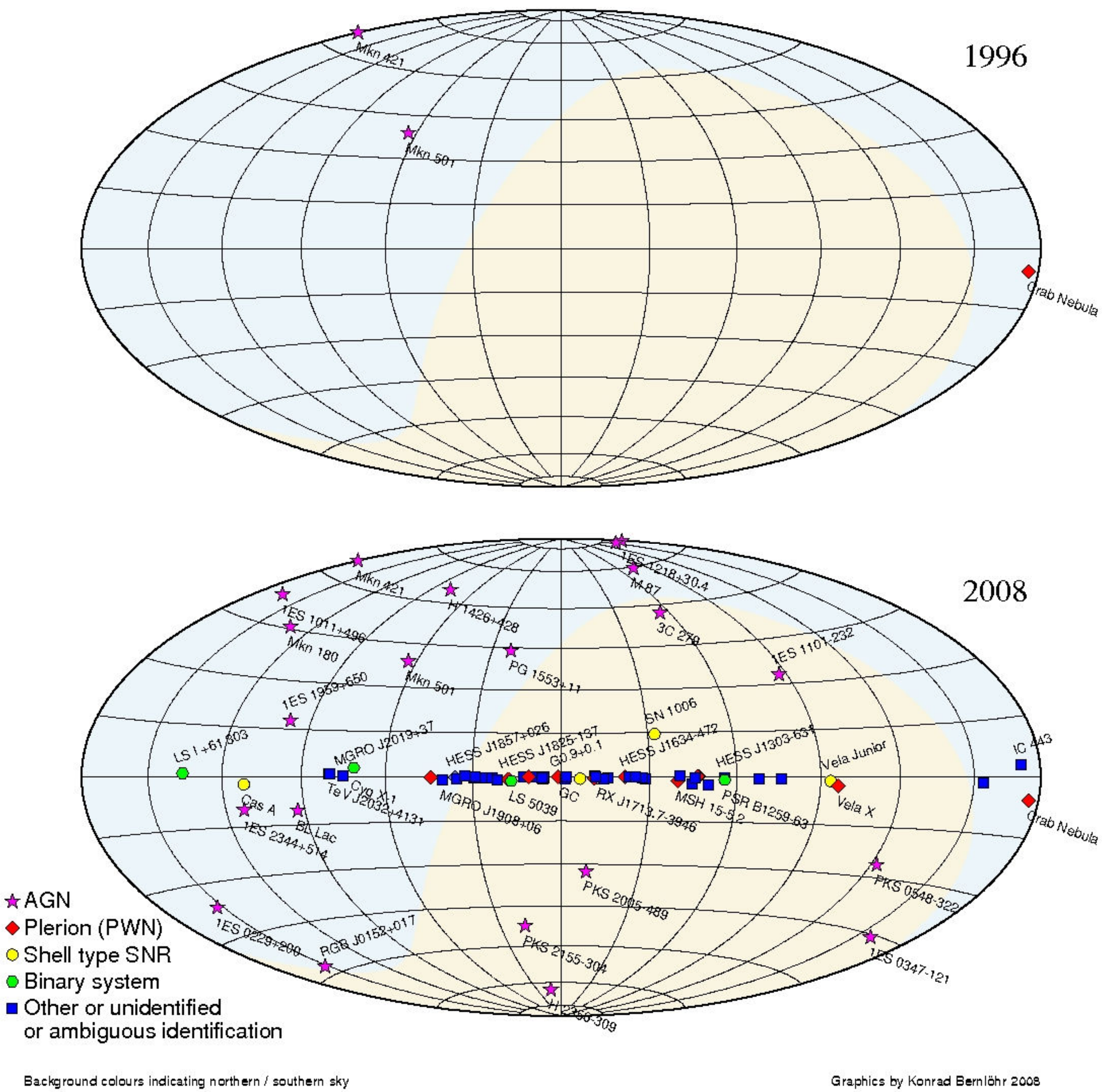
ApPEC Astroparticle Physics for Europe

World Map of Double Beta Experiments

The High Energy Universe



High Energy Gamma Rays



1996: 3 sources

(Whipple, HEGRA)

2009: ~ 100 sources

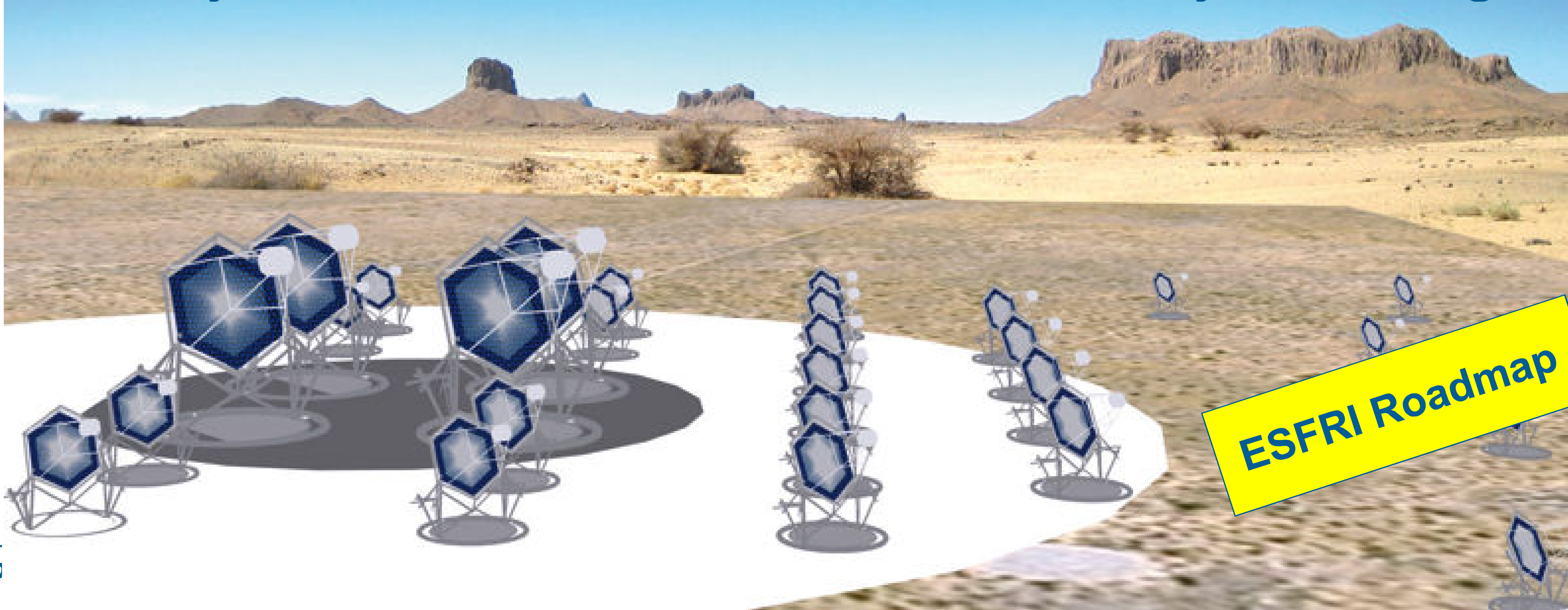
(mostly H.E.S.S., Magic VERITAS, but also MILAGRO)

Next Generation CTA/AGIS: expect ~ 1000 sources

Cherenkov Telescope Array

- Increased sensitivity
- Extended energy range
- Improved angular resolution
- Observatory with flexible and robotic operation
- Arrays in North and South for full sky coverage

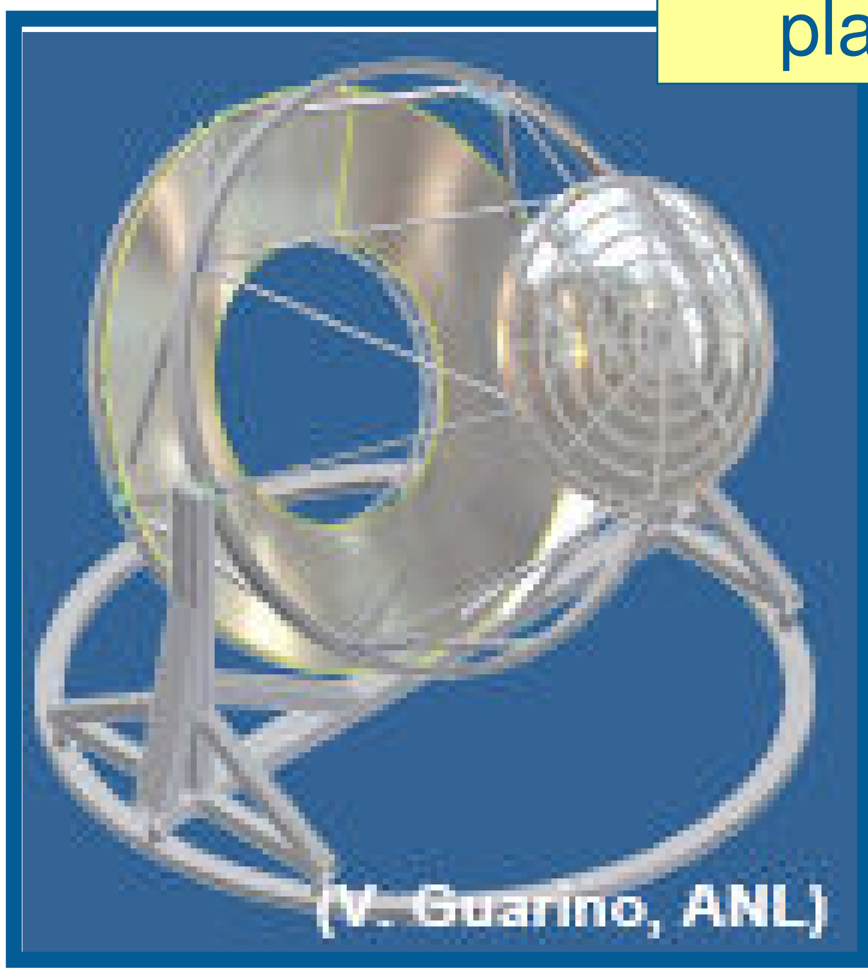
50 to 100 large, medium and small telescopes



Cherenkov Telescope Array

- Increased sensitivity
- Extended energy range

50 to 100 large, medium
s

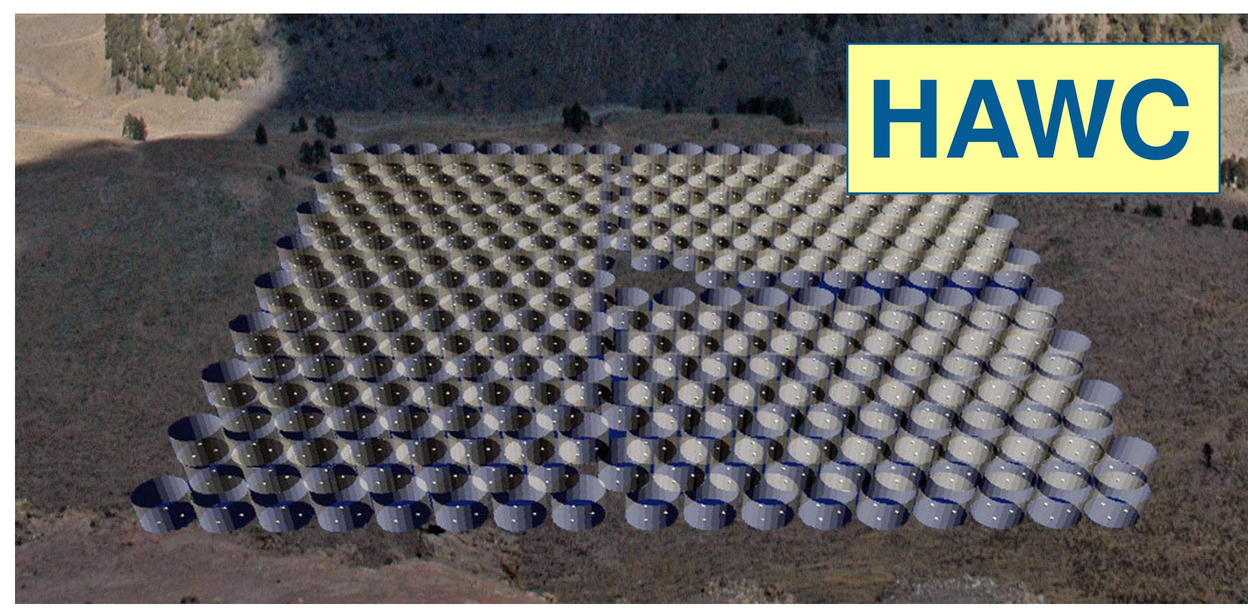


AGIS, USA
plan merger with CTA

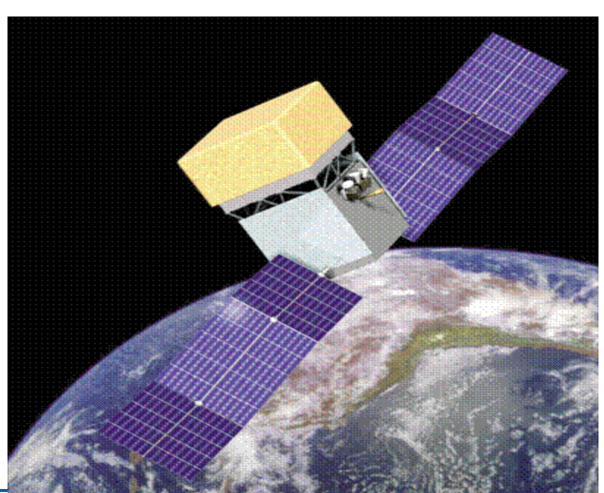
8° FOV

MILAGRO

~ 1.5 π FOV



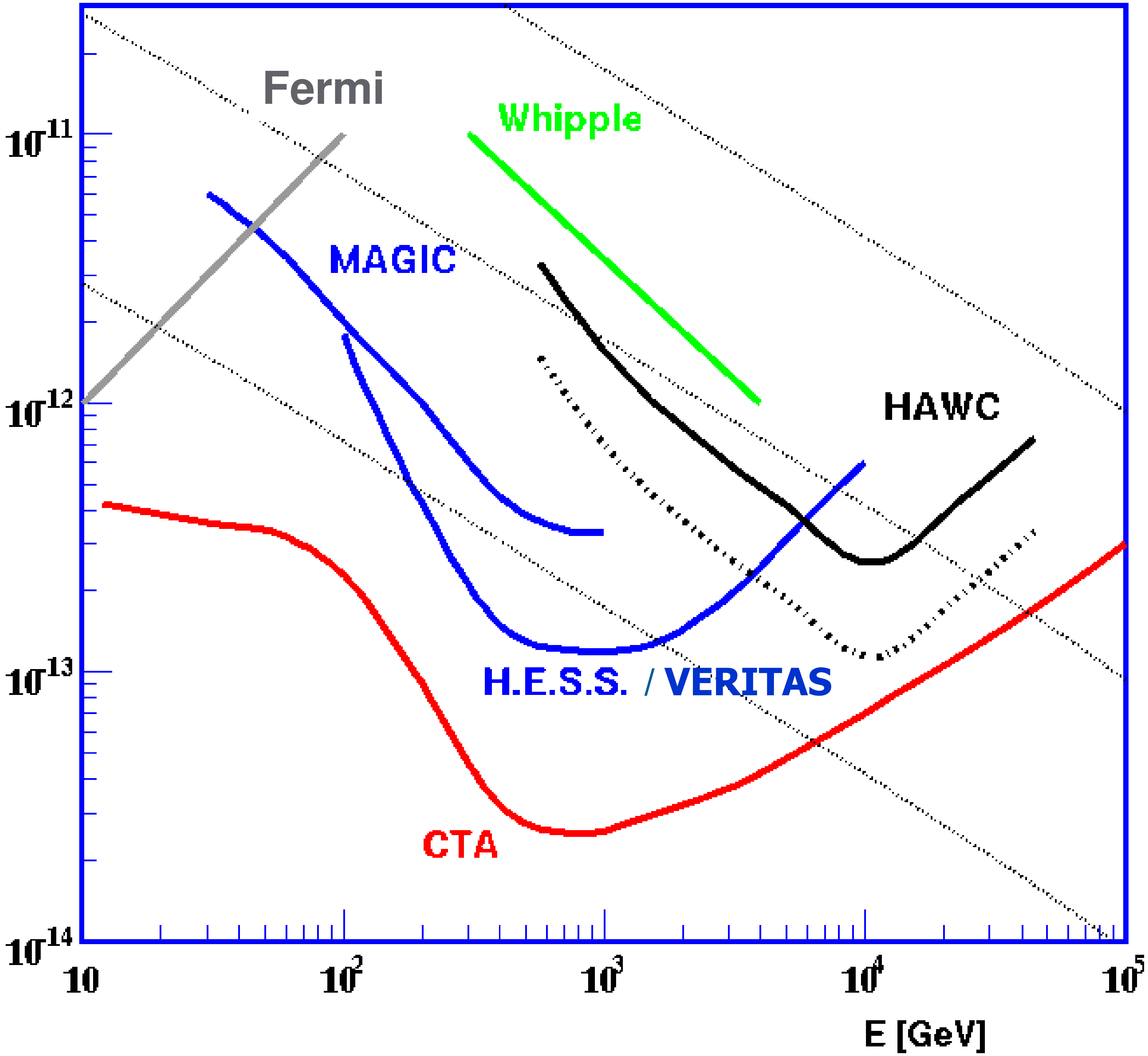
HAWC



Low energies:
FERMI

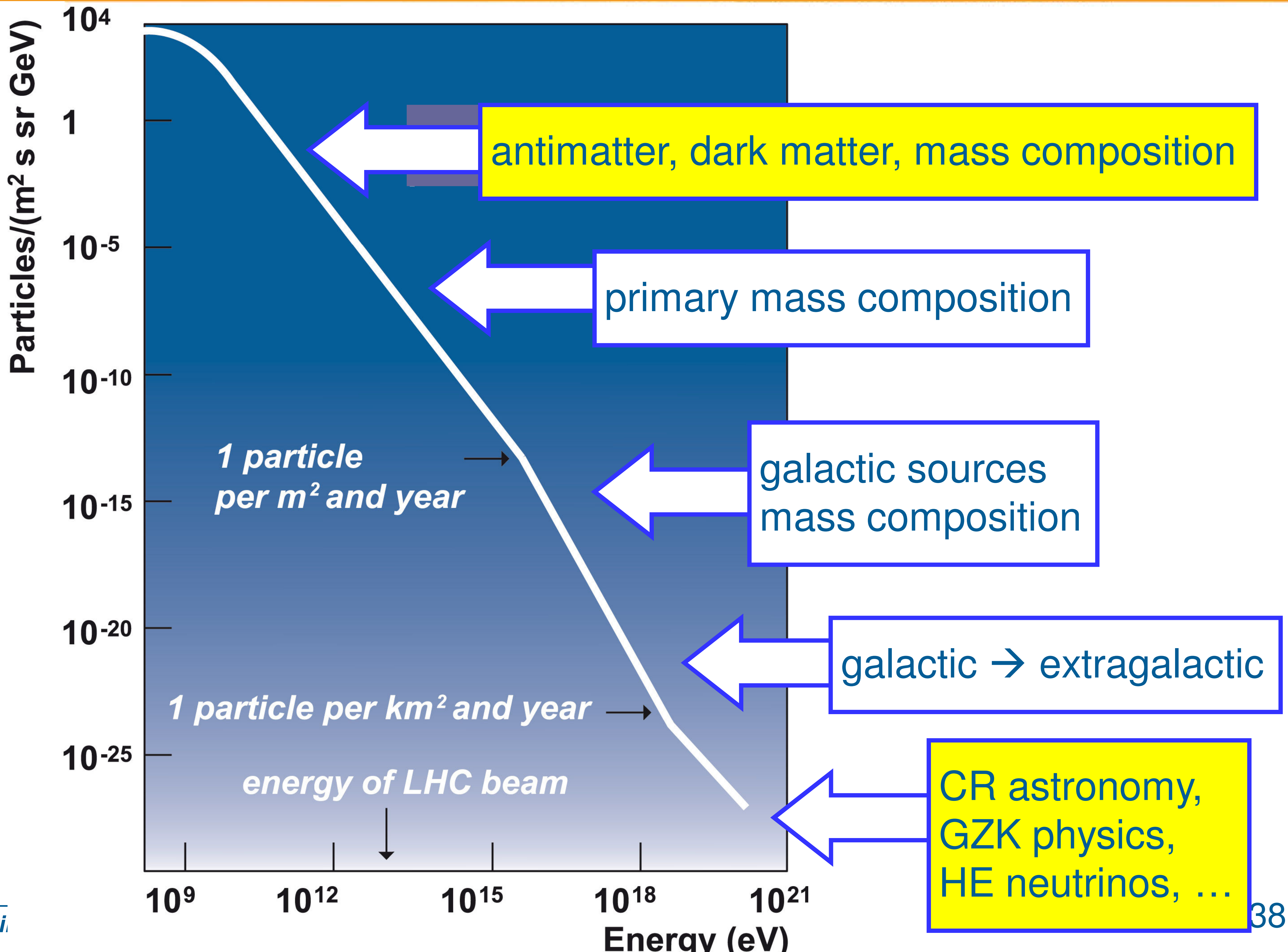
(China plans an even bigger
wide-angle array in Tibet.
Time scale not yet clearly defined)

High Energy Gamma Rays



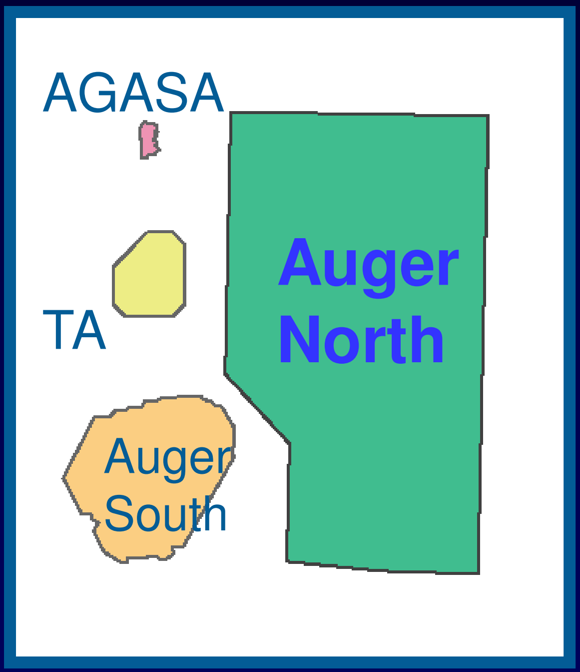
- **HESS/VERITAS, MAGIC, Whipple, CTA** sensitivity in 50 hours, (~0.2 sr/year)
- **GLAST** sensitivity in 1 year (4π sr)
- **HAWC** sensitivity in 1(5) years shown as solid (dashed) line (2π sr)

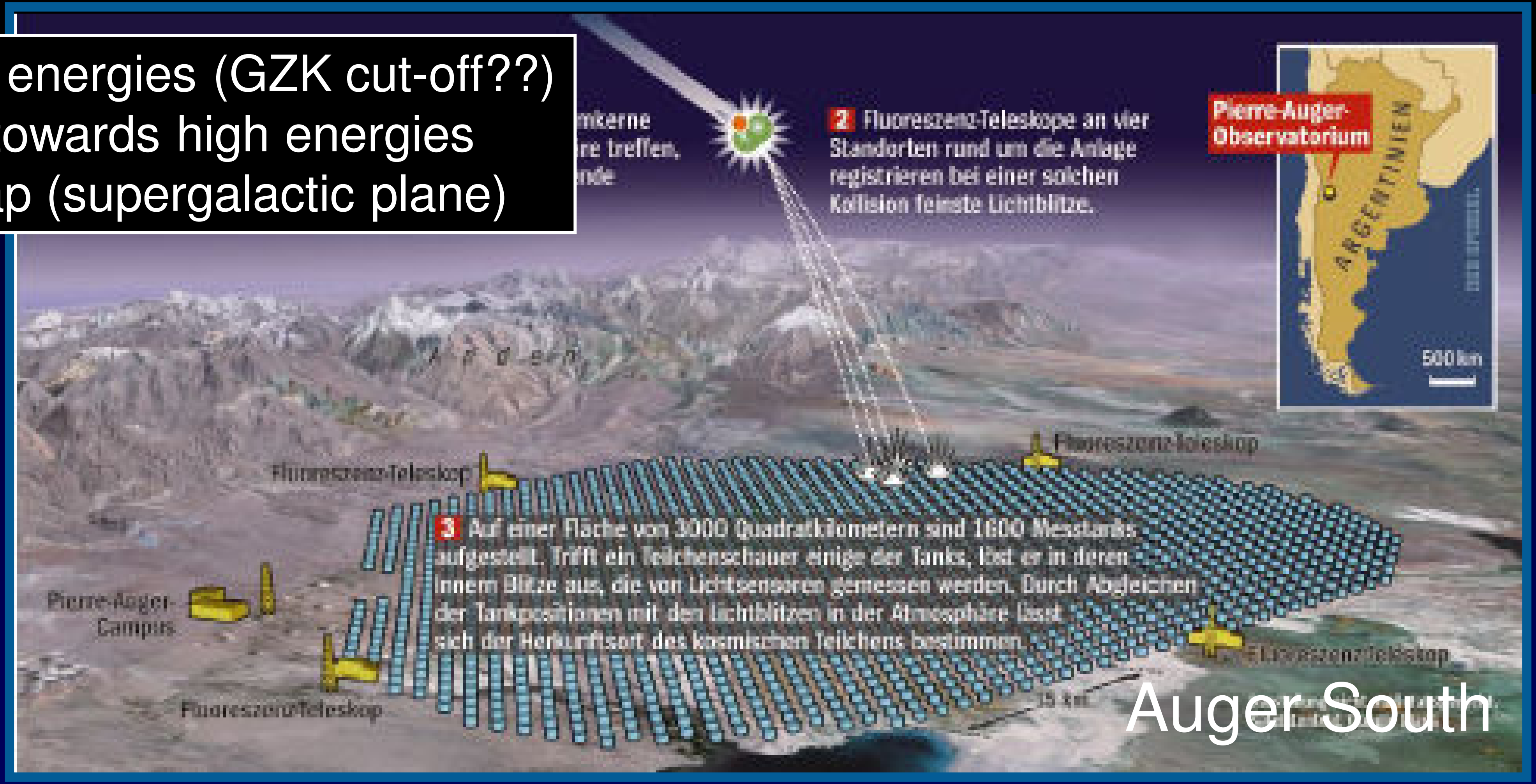
Charged Cosmic Rays



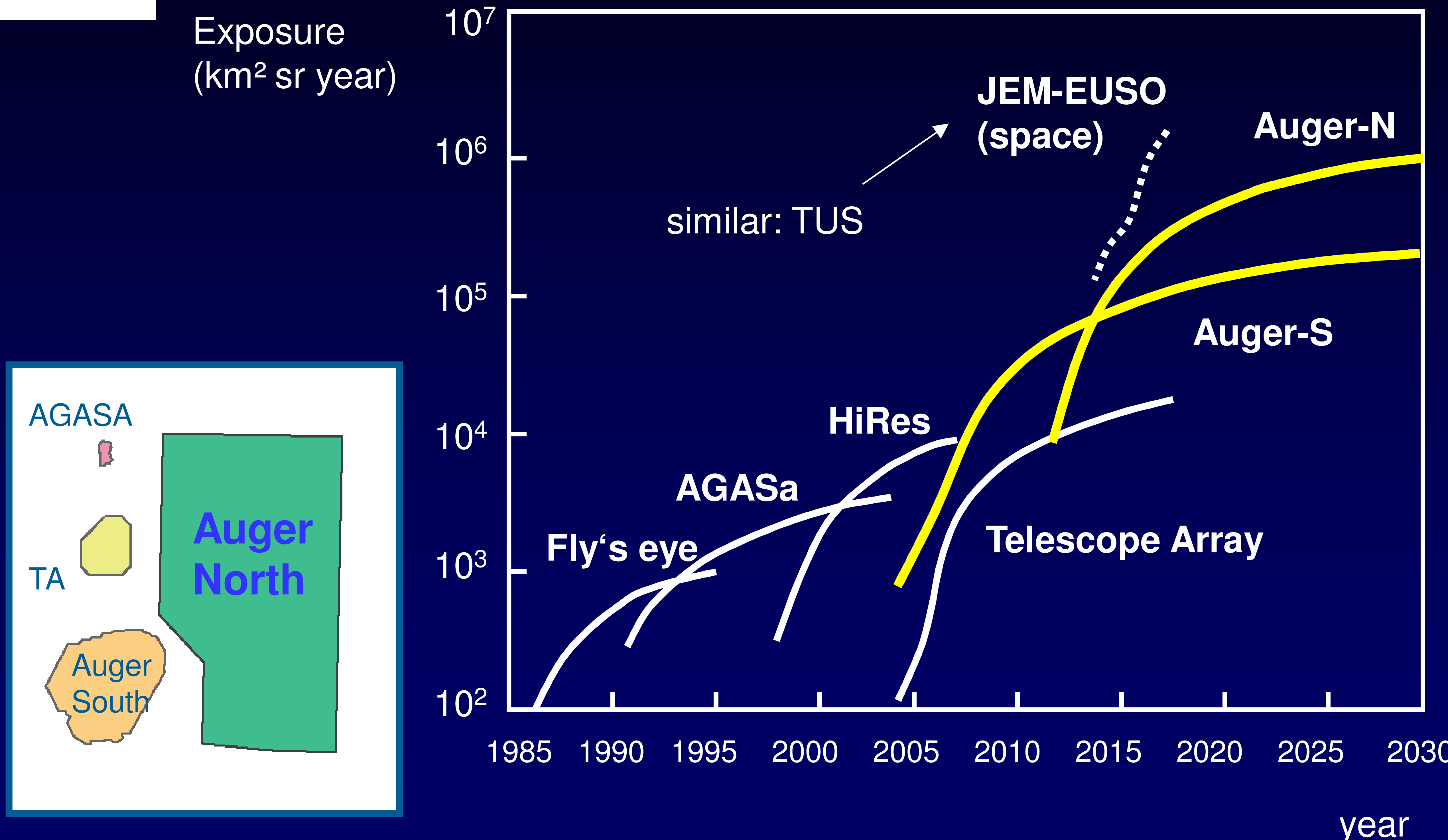
Pierre Auger Observatory

- Suppression at high energies (GZK cut-off??)
- Heavy composition towards high energies
- Non-isotropic skymap (supergalactic plane)

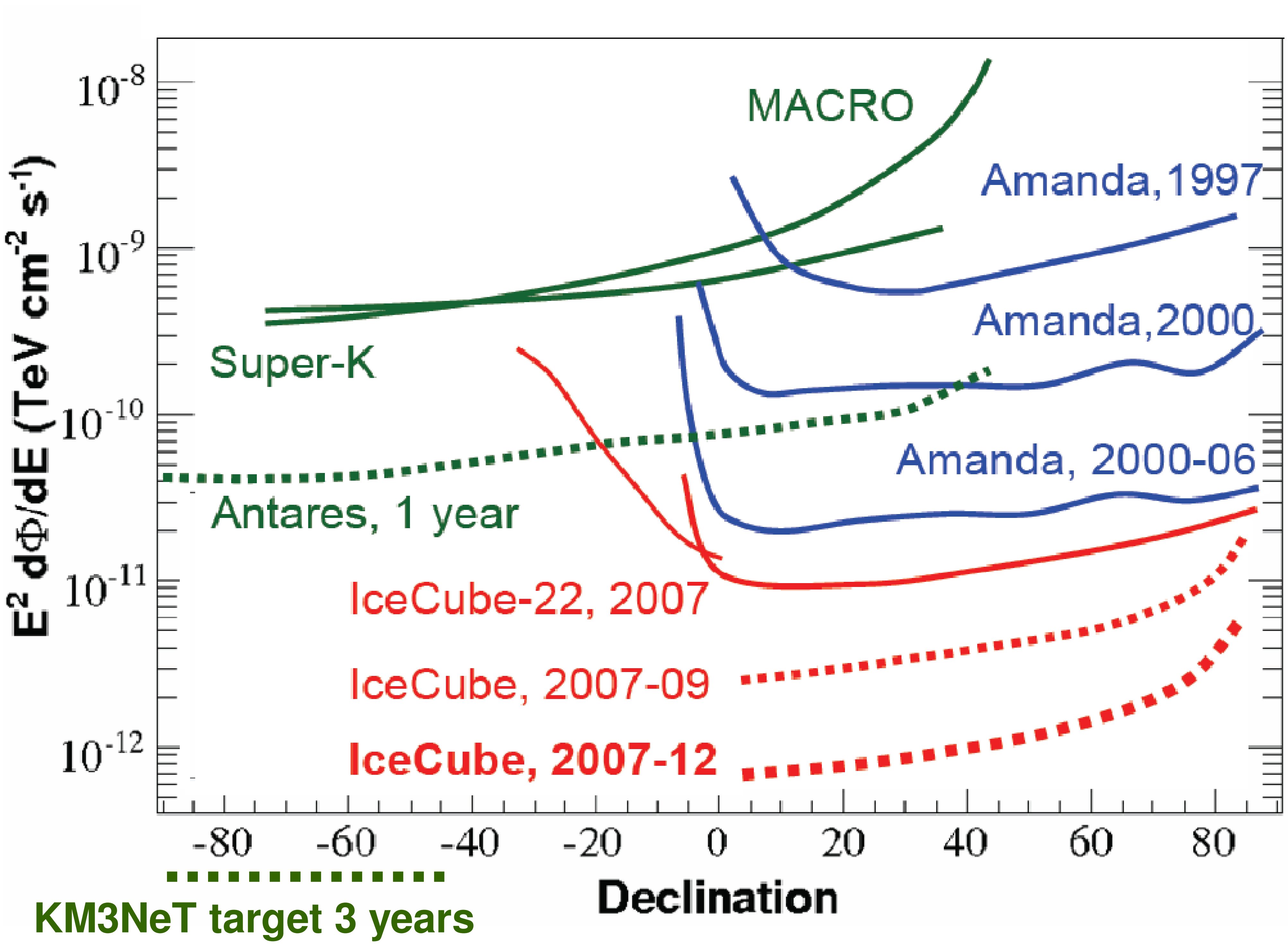




Auger-North: **high statistics astronomy** with reasonably fast data collection calls for a substantially larger array than Auger South, full sky coverage calls for a Northern site. A larger array would also allow a more detailed inspection of the **high energy cut-off** of the particle spectrum, which recently has been firmly established by Auger-South.

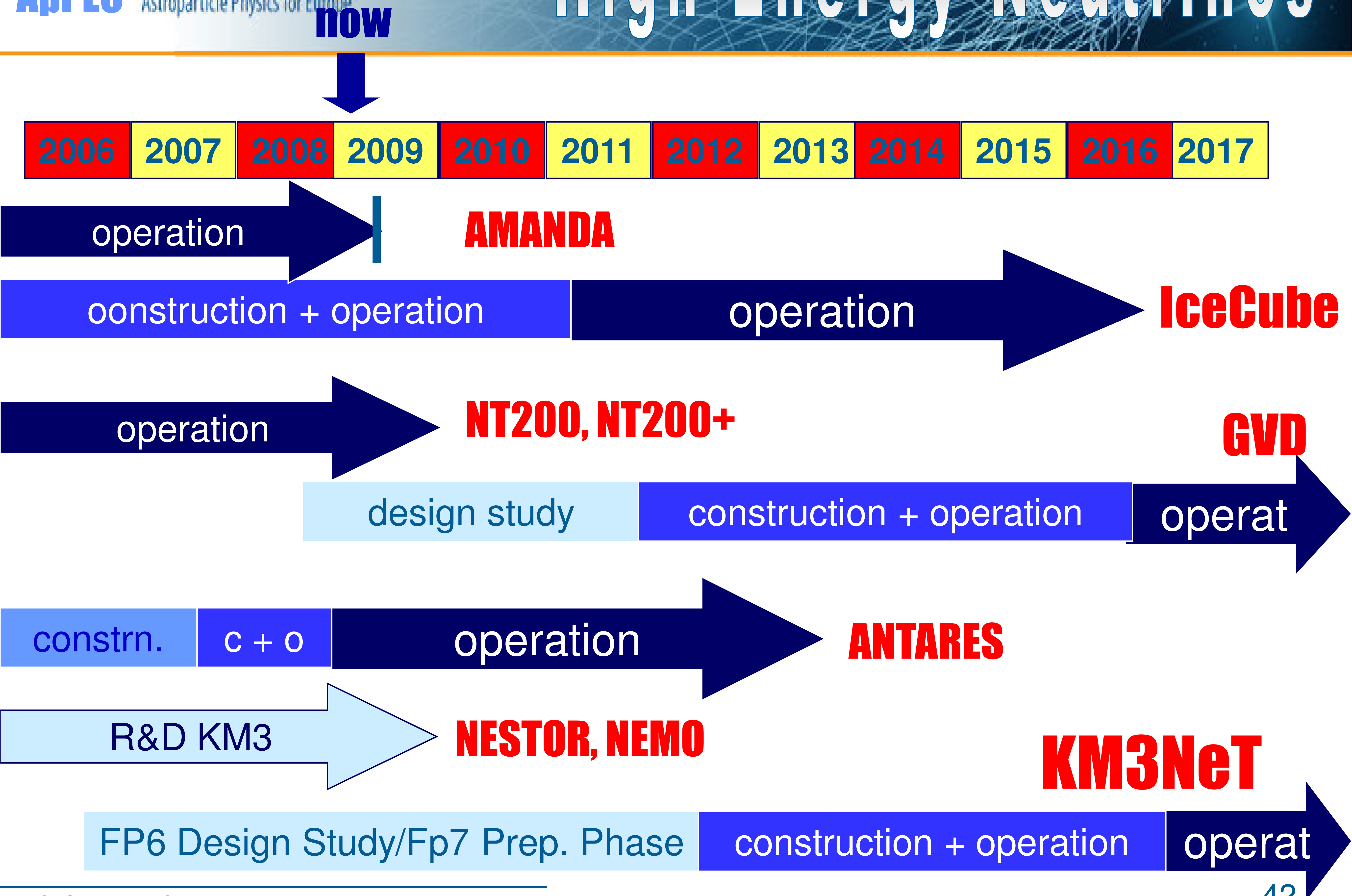

Exposure
(km² sr year)
10^7
10^6
10^5
10^4
10^3
10^2
JEM-EUSO
(space)
similar: TUS
Auger-N
Auger-S
HiRes
AGASa
Fly's eye
Telescope Array
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
year
AGASA
TA
Auger
North
Auger
South

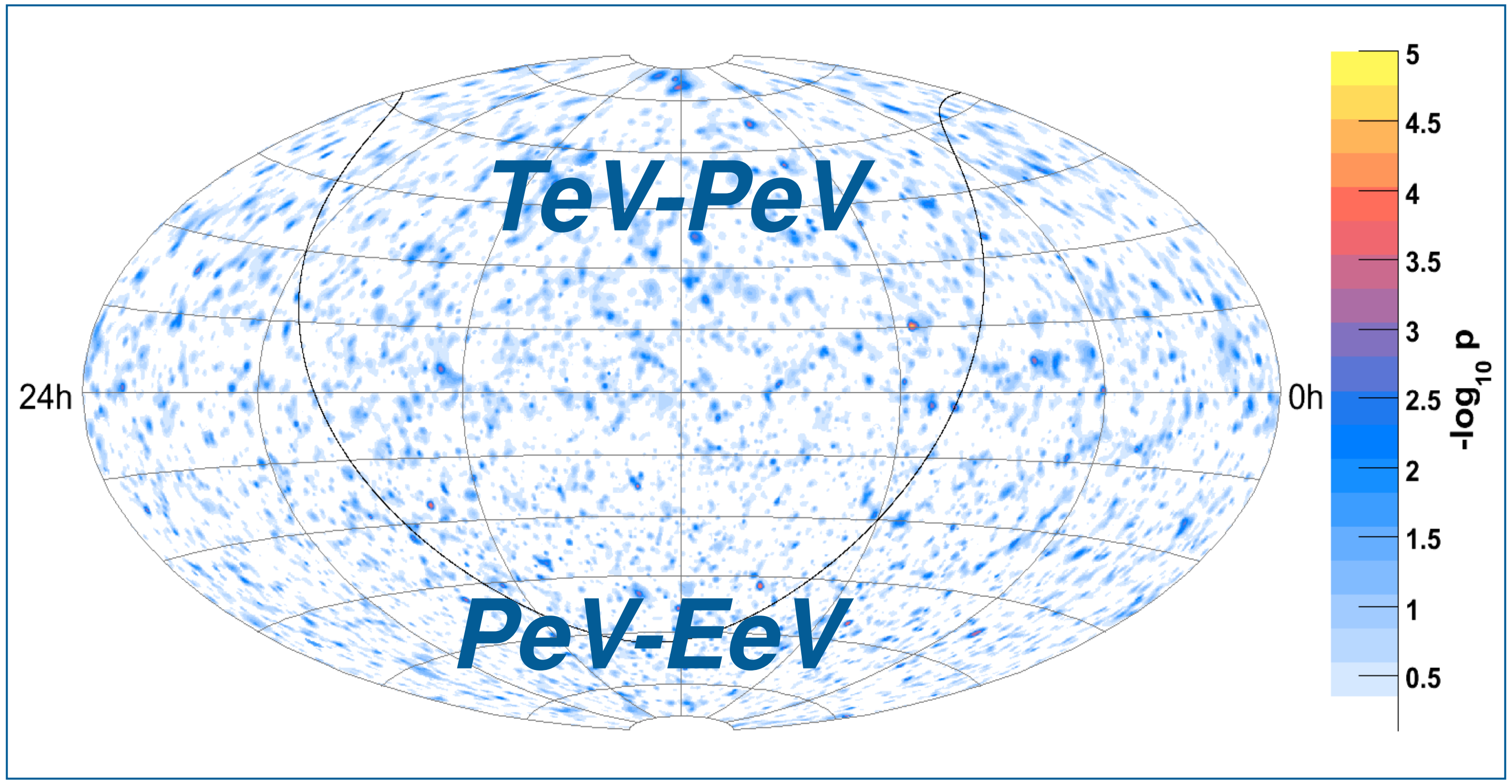
Point sources: Tremendous progress in sensitivity over last decade



factor 1000 in 15 years !

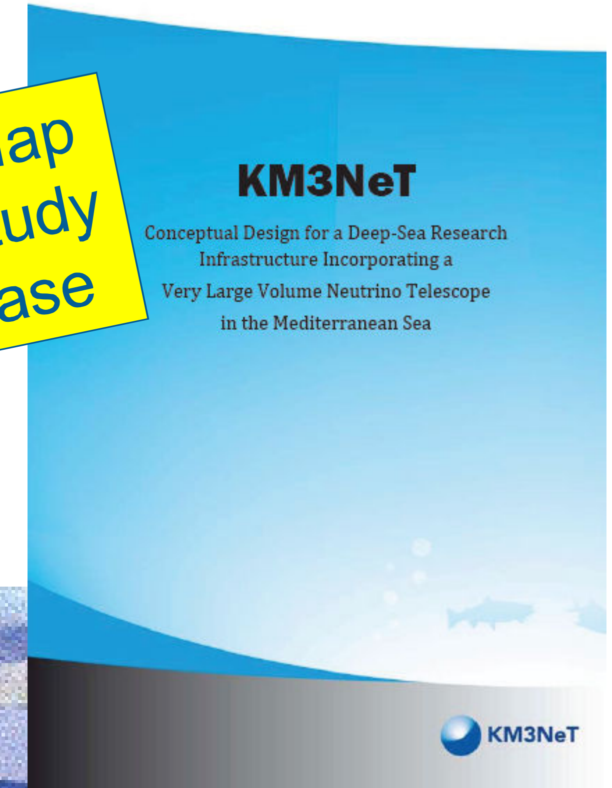
High Energy Neutrinos

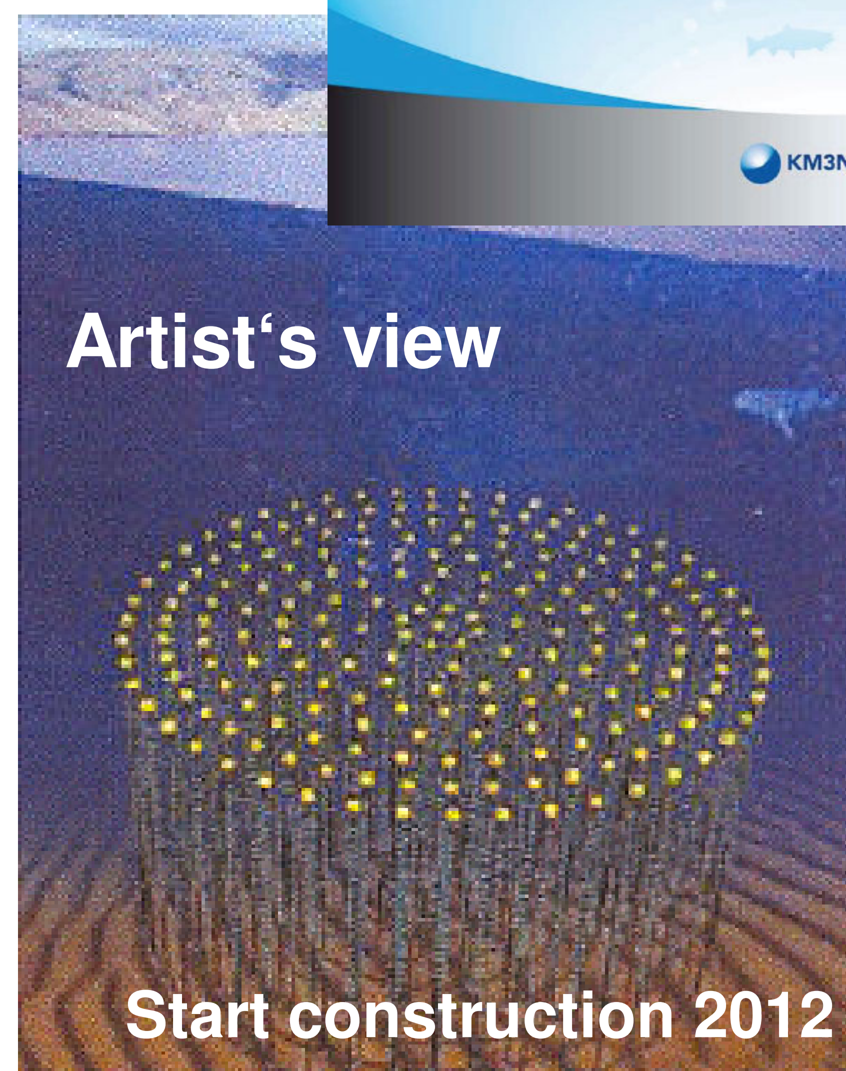




First full-sky IceCube skymap (40 strings, 6 months)
challenges KM3NeT sensitivity !

ESFRI Roadmap
FP6 design study
FP7 prep. phase

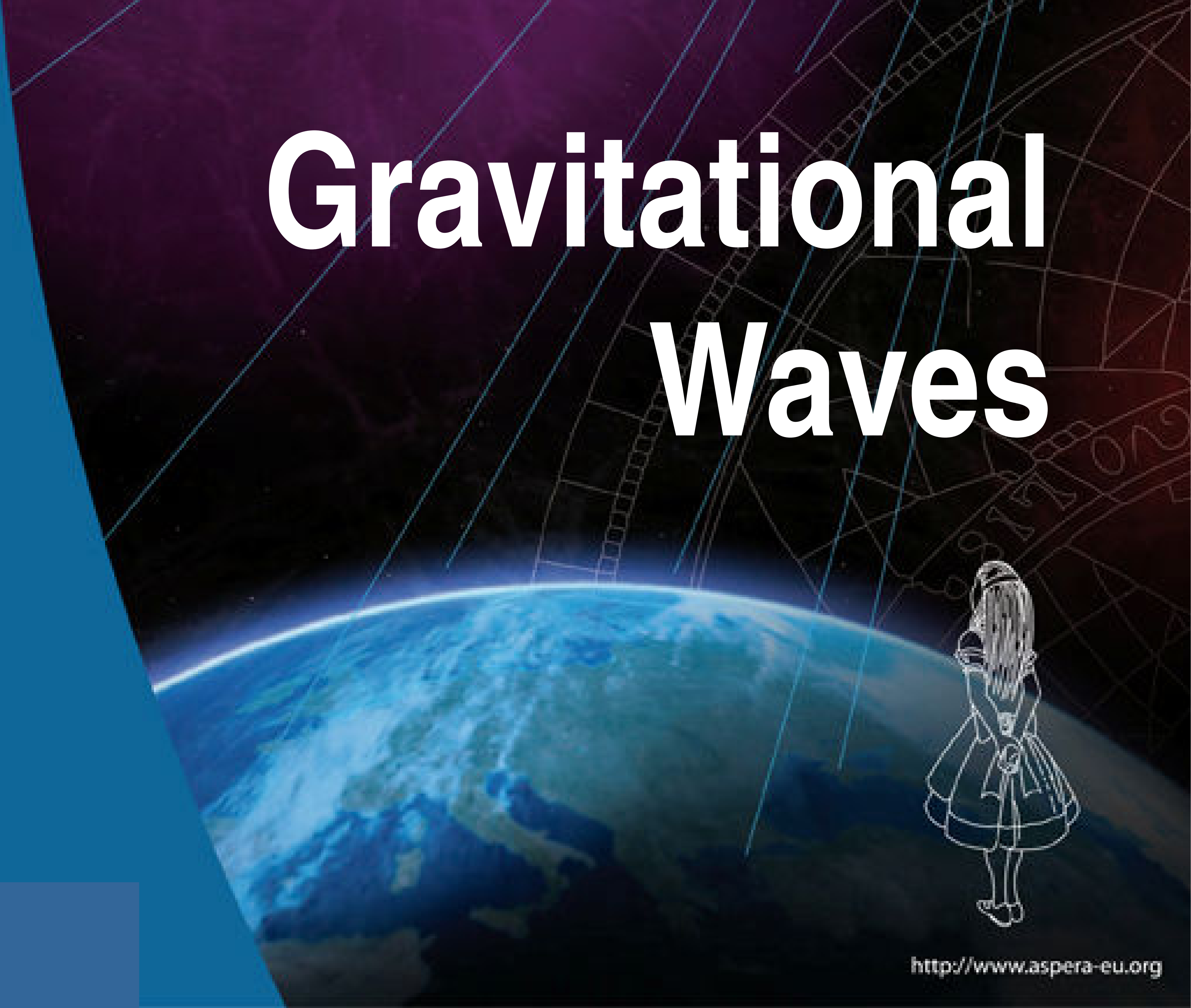




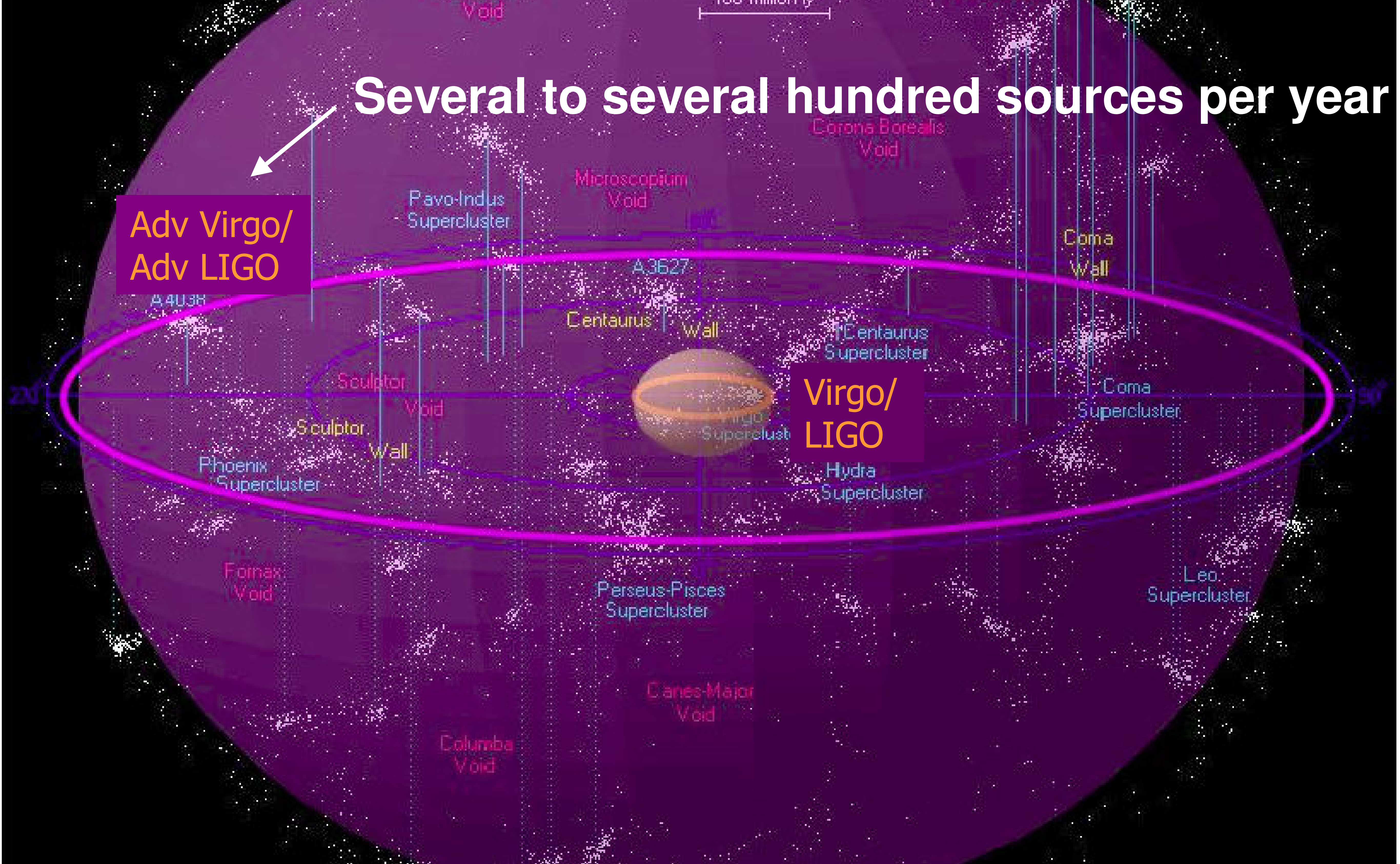
Resources for a Mediterranean detector should be **pooled into a single optimised design for a large research infrastructure**, with installation starting in 2012.

The sensitivity of KM3NeT must substantially exceed that of all existing neutrino detectors including IceCube.

Gravitational Waves



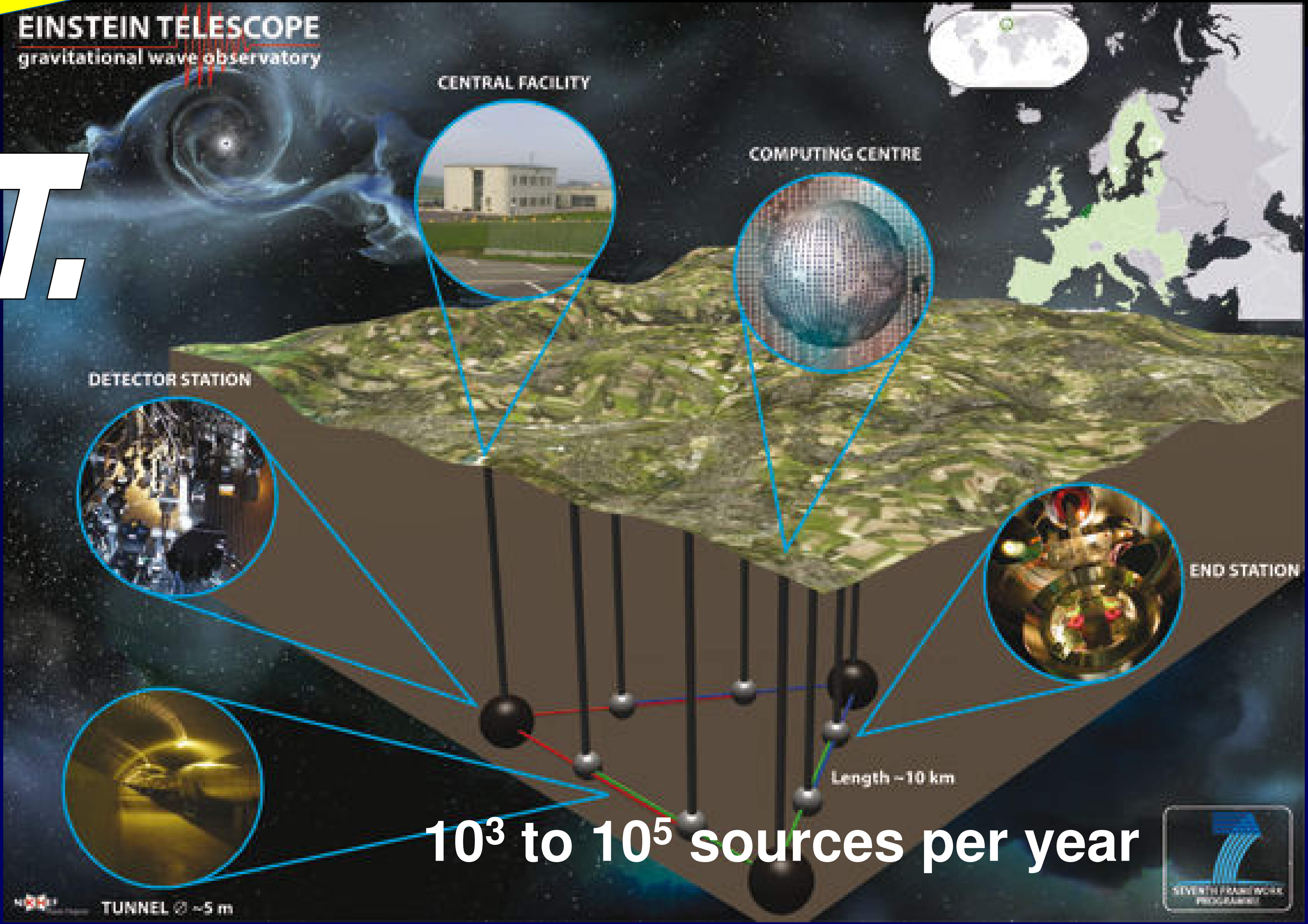
Gravitational Waves: towards E.T.



Einstein Telescope

FP7 design study

E.T.



10^3 to 10^5 sources per year

Einstein Telescope

ApPEC Astroparticle Physics for E

FP7 design study

E.T. is the long-term future project of ground-based gravitational wave astronomy in Europe.

A **decision on funding** for the construction of E.T. will **earliest after first detections with enhanced LIGO/Virgo** but is most likely after collecting about a year of data with advanced LIGO/Virgo in approximately 2014/15.

Targeted start of E.T. construction ~ 2017.

Conclusions

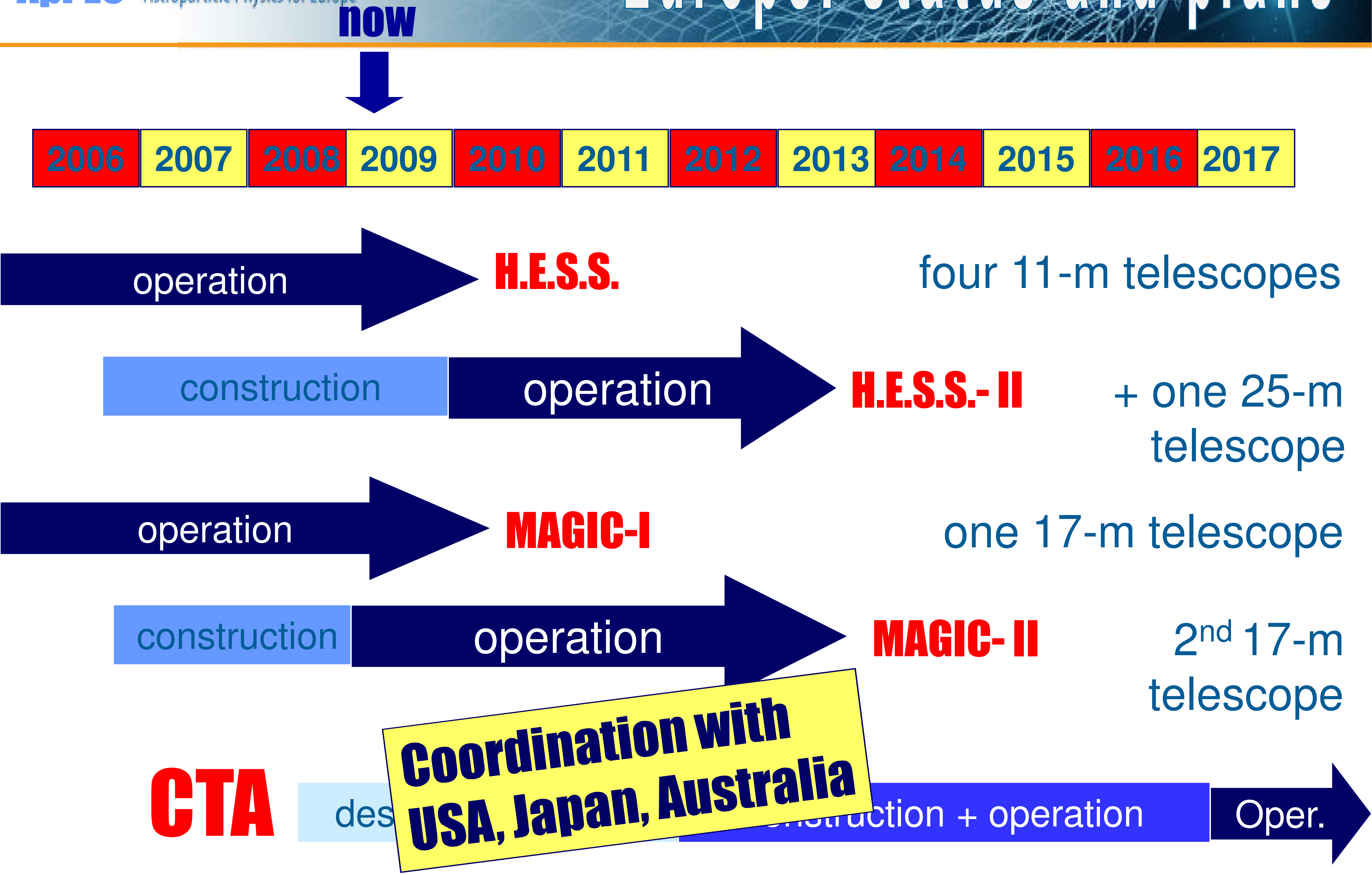
- Moving into regions **with fair/high discovery potential.**
- **Accelerated increase of sensitivity** in nearly all fields.
- ApPEC has defined **milestones** for decisions on best technologies and has initiated a process of **convergence.**
- Need a substantial **increase in funding** to make the possibilities a reality
- **PASAG/Decadal Review**: Expect important new recommendations for USA

End 2010

- Important funding decisions in many countries taken
- Decadal review/PASAG, other national roadmaps, role of CERN, OECD, …
- DM: $\sim 10^{-8}$ pb by *several* experiments
- DBD: first results from GERDA-I
- Important DUSEL decisions taken
- LAGUNA: DS finished, concept on sites and technologies
- Cosmic rays:
  - First results from AMS
  - Auger: 1.5x more data from Auger South
- HE gammas
  - MAGIC-II results, hopefully HESS-2 operating
  - CTA prototype telescopes being constructed
- HE neutrinos
  - 2 km^3 years with IceCube
  - Details of KM3NeT: converging to final decisions
- Grav. Waves: Virgo+, Ligo+ delivering first data, advanced detectors being prepared

Backups

Europe: status and plans



Dark Matter Candidates

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- **WIMPs**
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- **Axinos**
- **Super-WIMPs**
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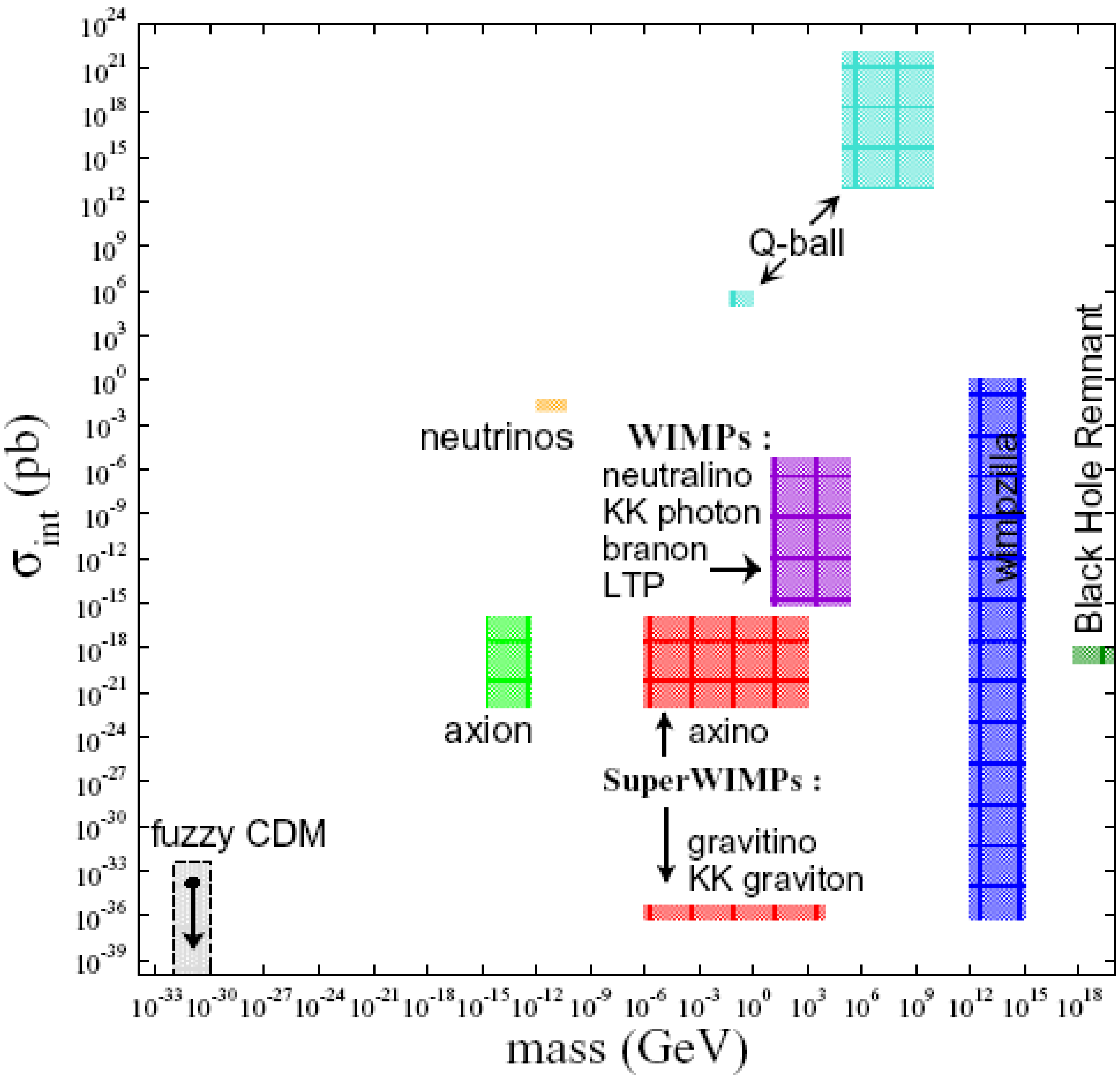
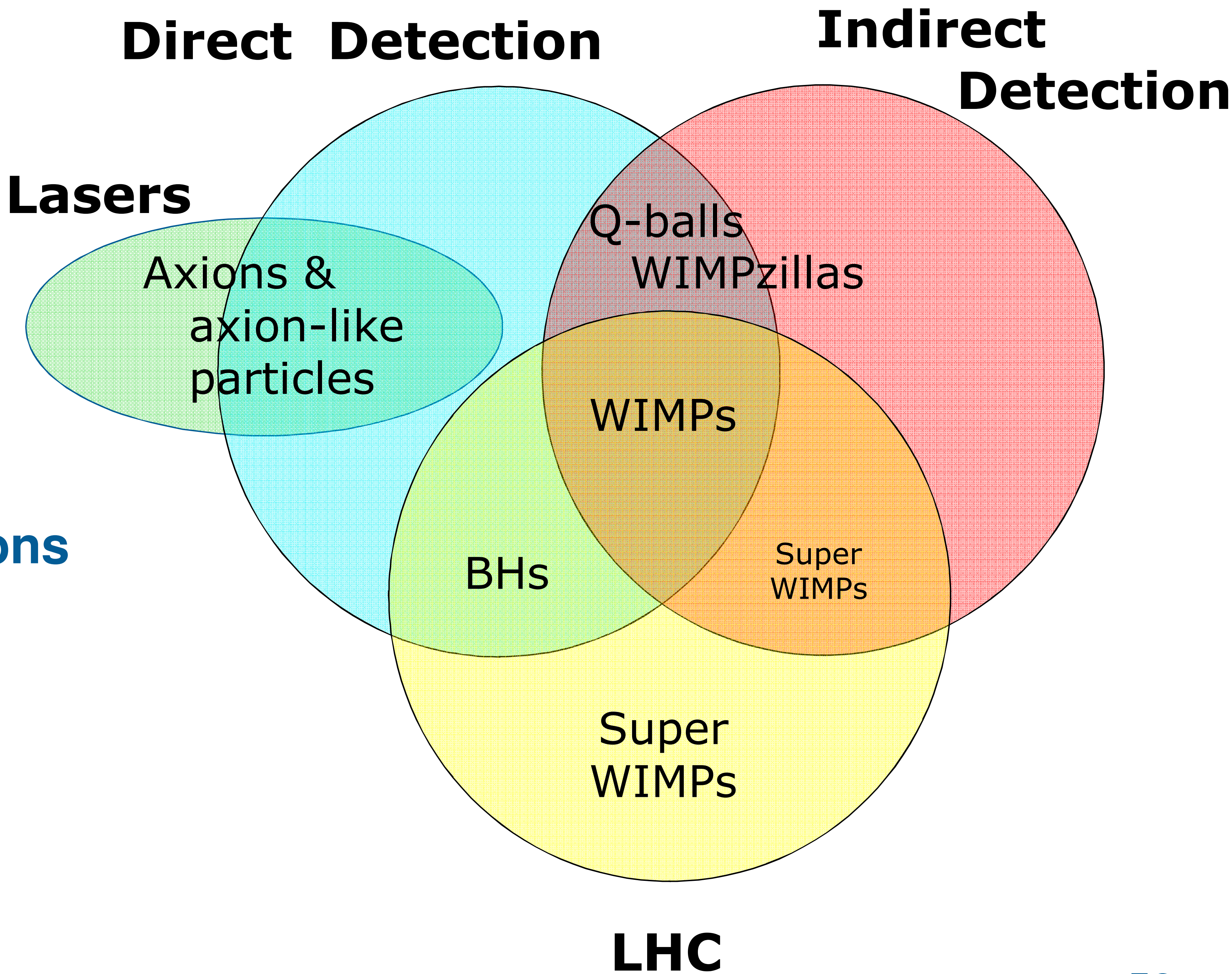
- **Q-balls**
- **WIMPzillas**
- **Elementary BHs**
- **…**



DM candidates:

- **WIMPs**
  - Neutralinos
  - Kaluza-Klein particles
  - …
- **Axinos**
- **Super-WIMPs**
- **Axions**
- **Axion-like light bosons**
- **Sterile neutrinos**
- **Q-balls**
- **WIMPzillas**
- **Elementary BHs**
- **…**



Dark Energy

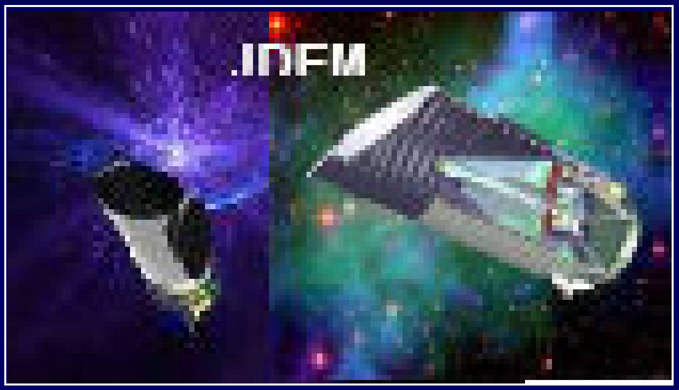
Dark Energy

- Particle physicists engaged since the beginning.
- Implications for fundamental physics are profound.

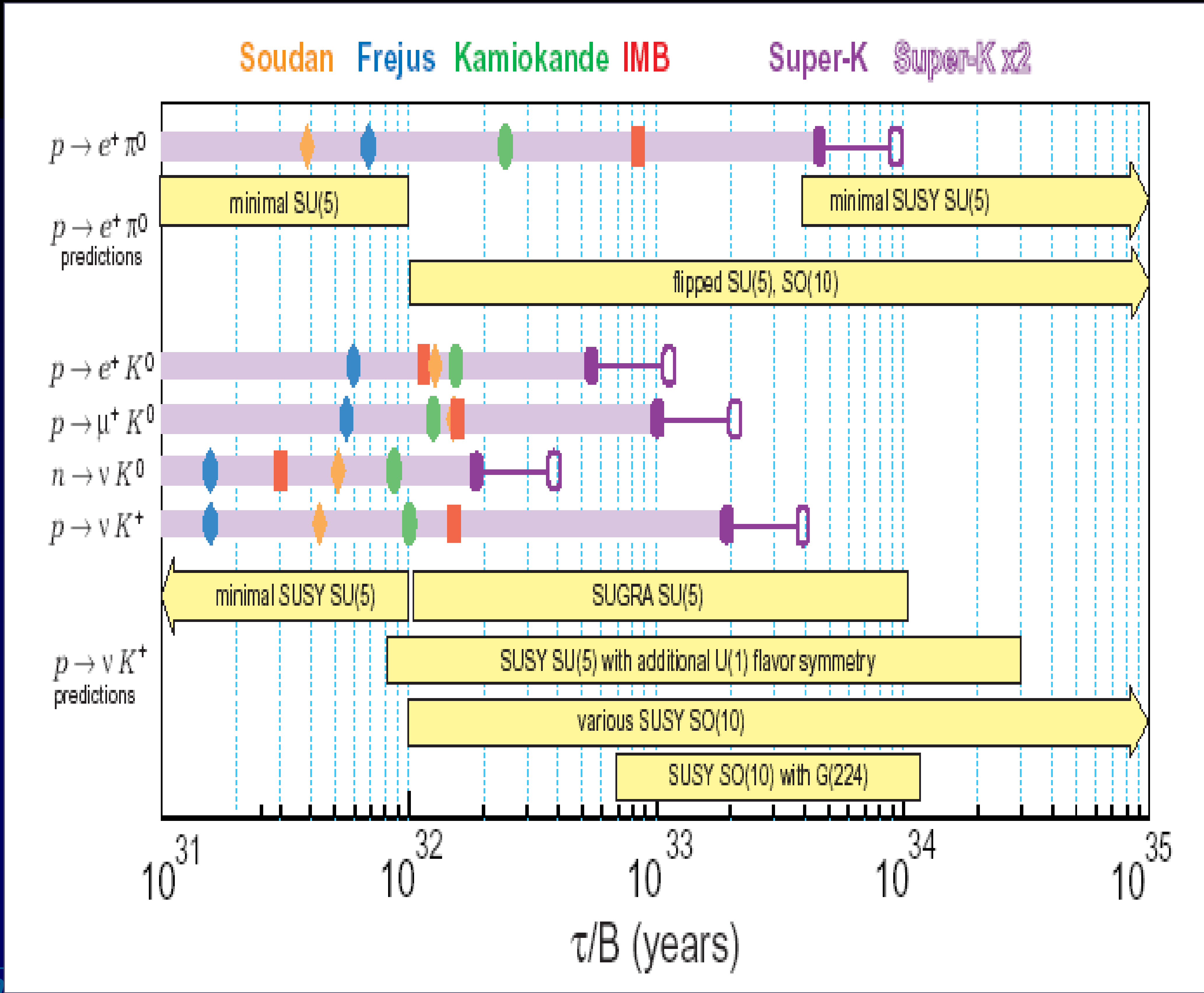
Europe

CMBR: Planck

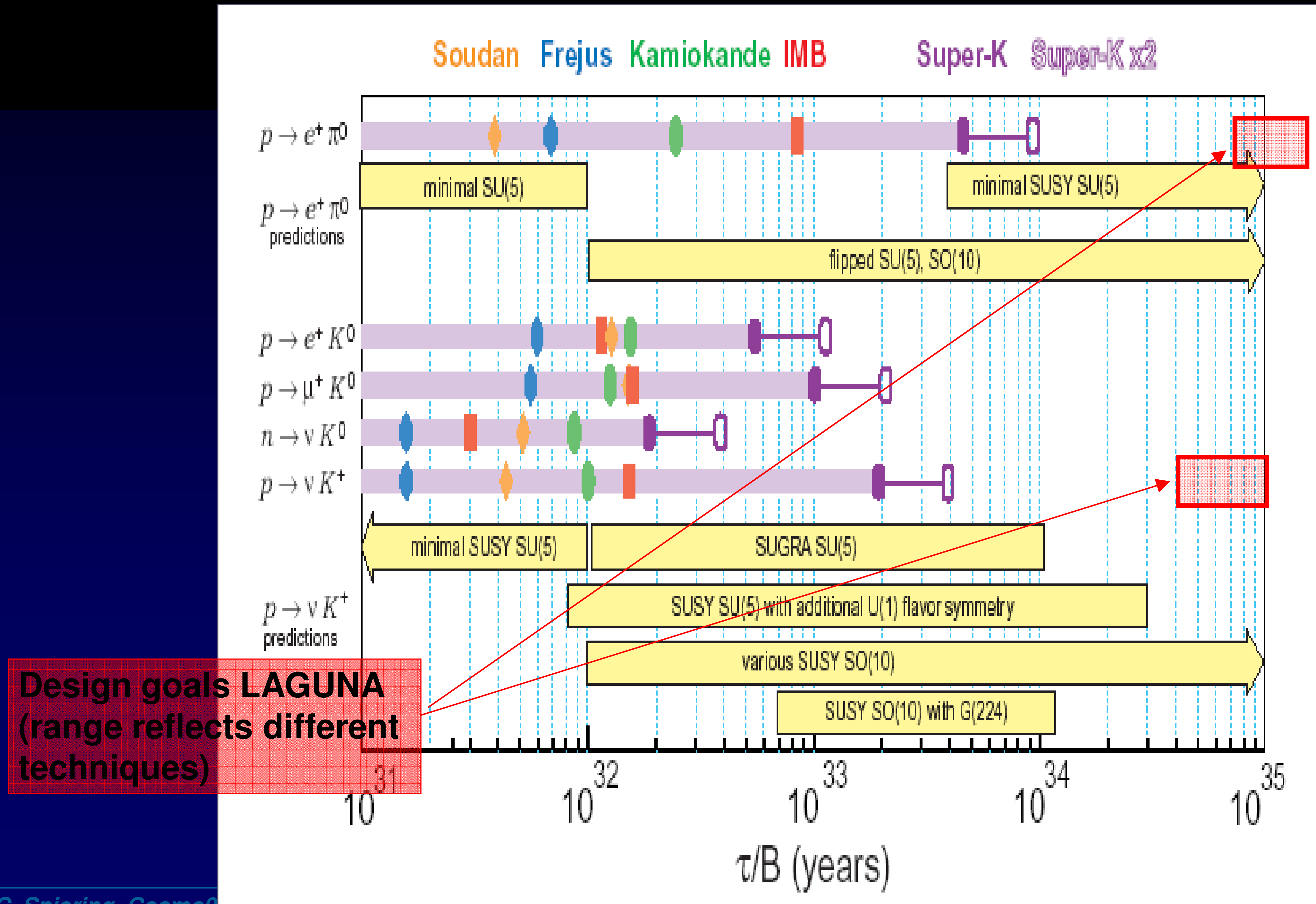
- **USA**



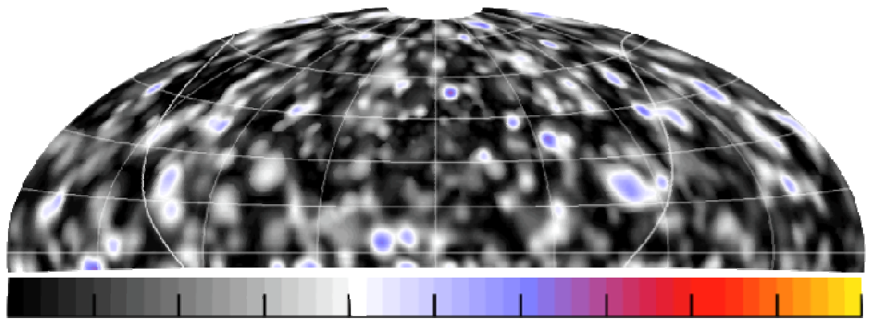
Proton Decay



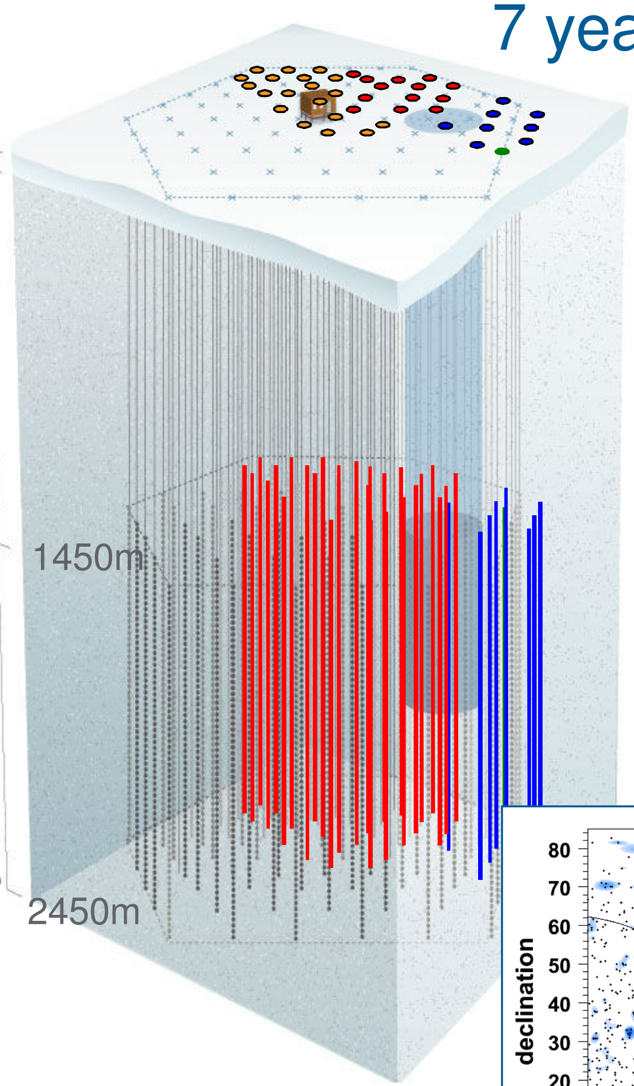
Proton Decay



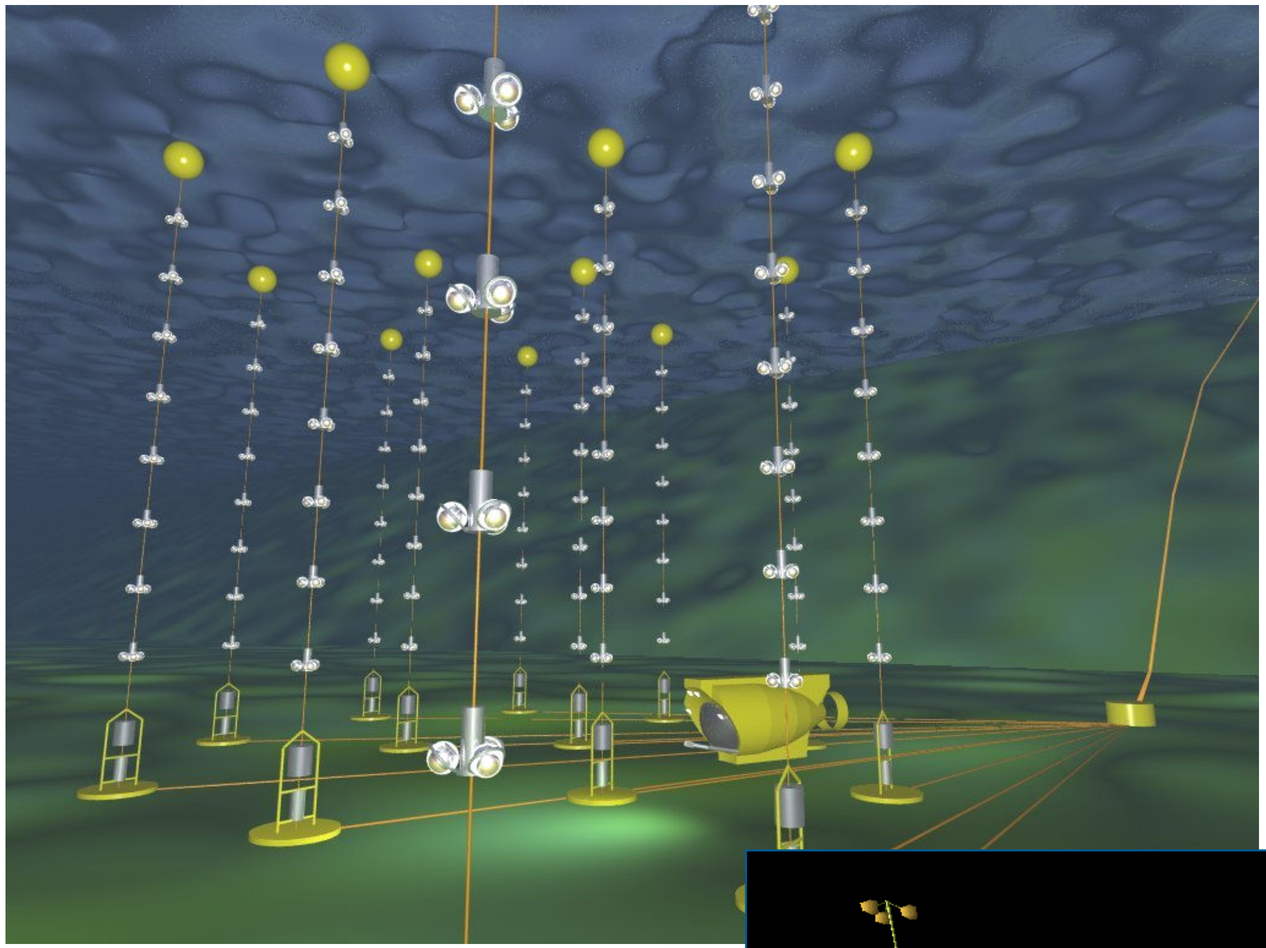
A fantastic year 2008



7 year skymap AMANDA

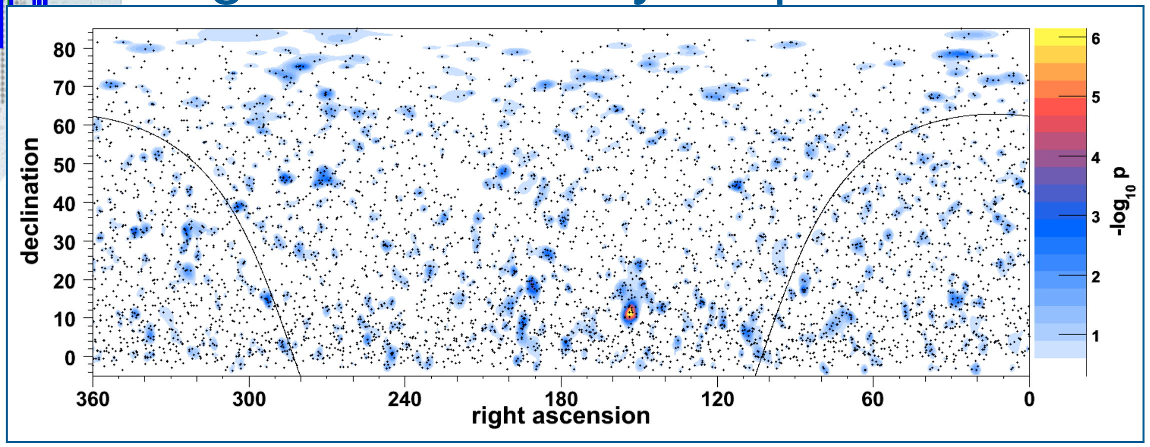


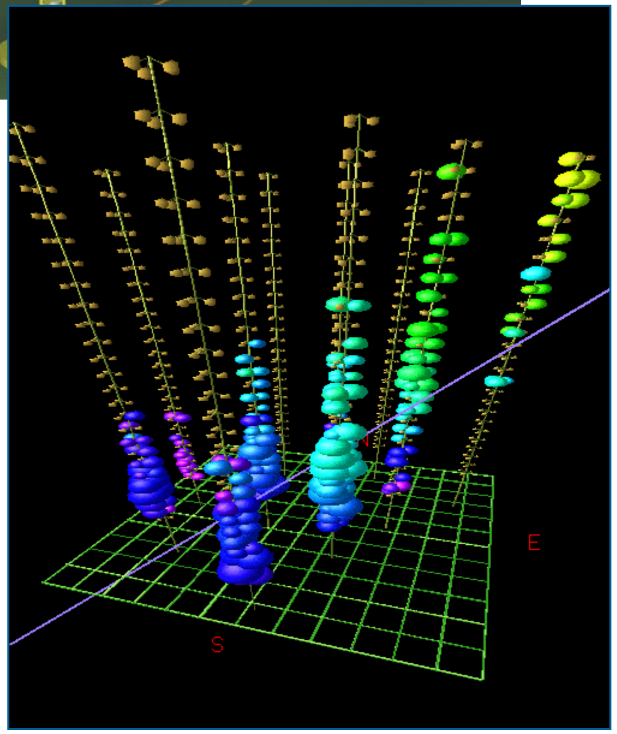
IceCube
3/4 complete



ANTARES fully
operational

High-statistics sky-map IceCube



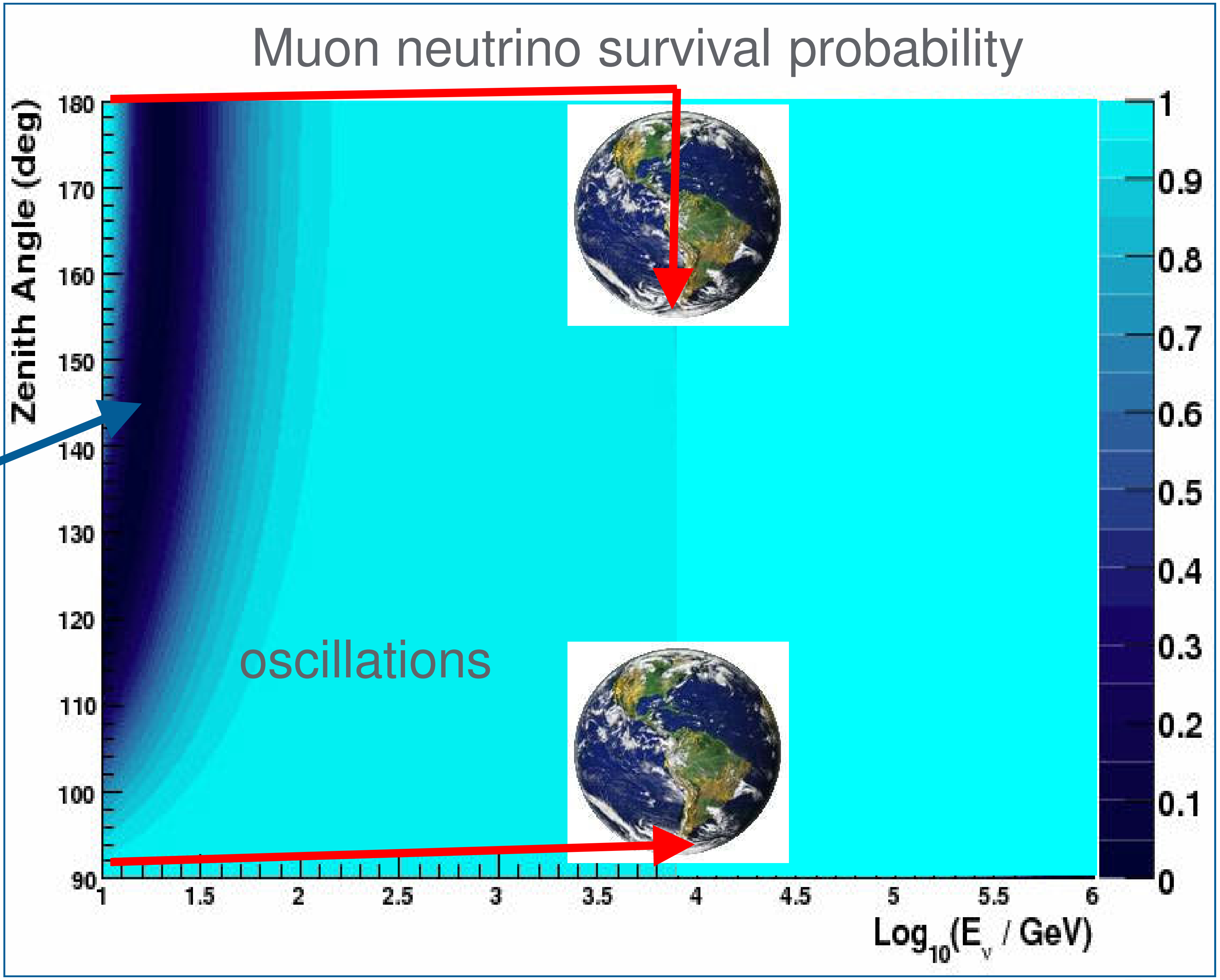


High statistics
of neutrinos
in ANTARES

Oscillation physics with atmospheric neutrinos

- ν_μ disappearance (less muon tracks)
- "appearance" of ν_τ (more cascade-like events)

Sensitive to mass hierarchy ?

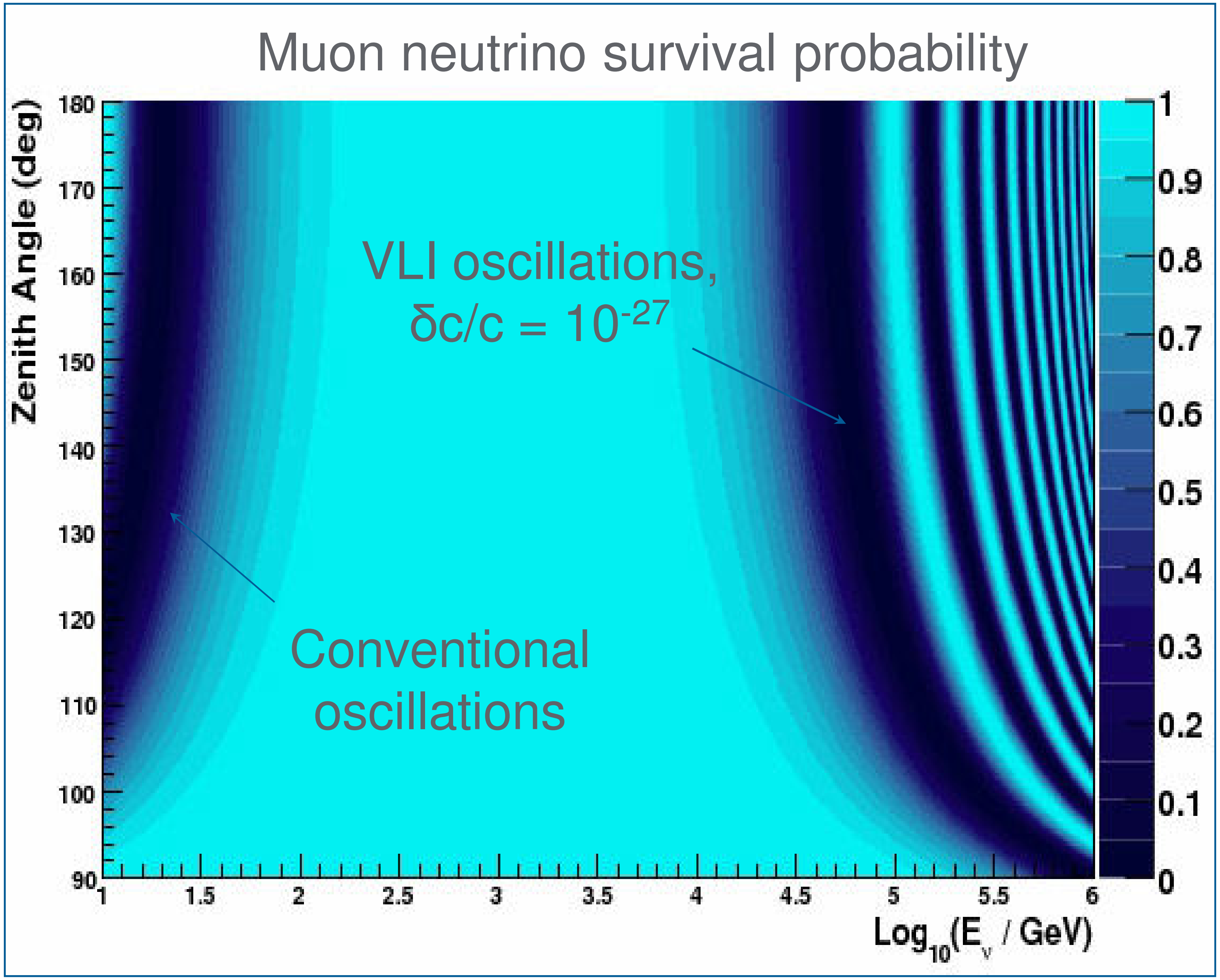


Exotic Oscillations

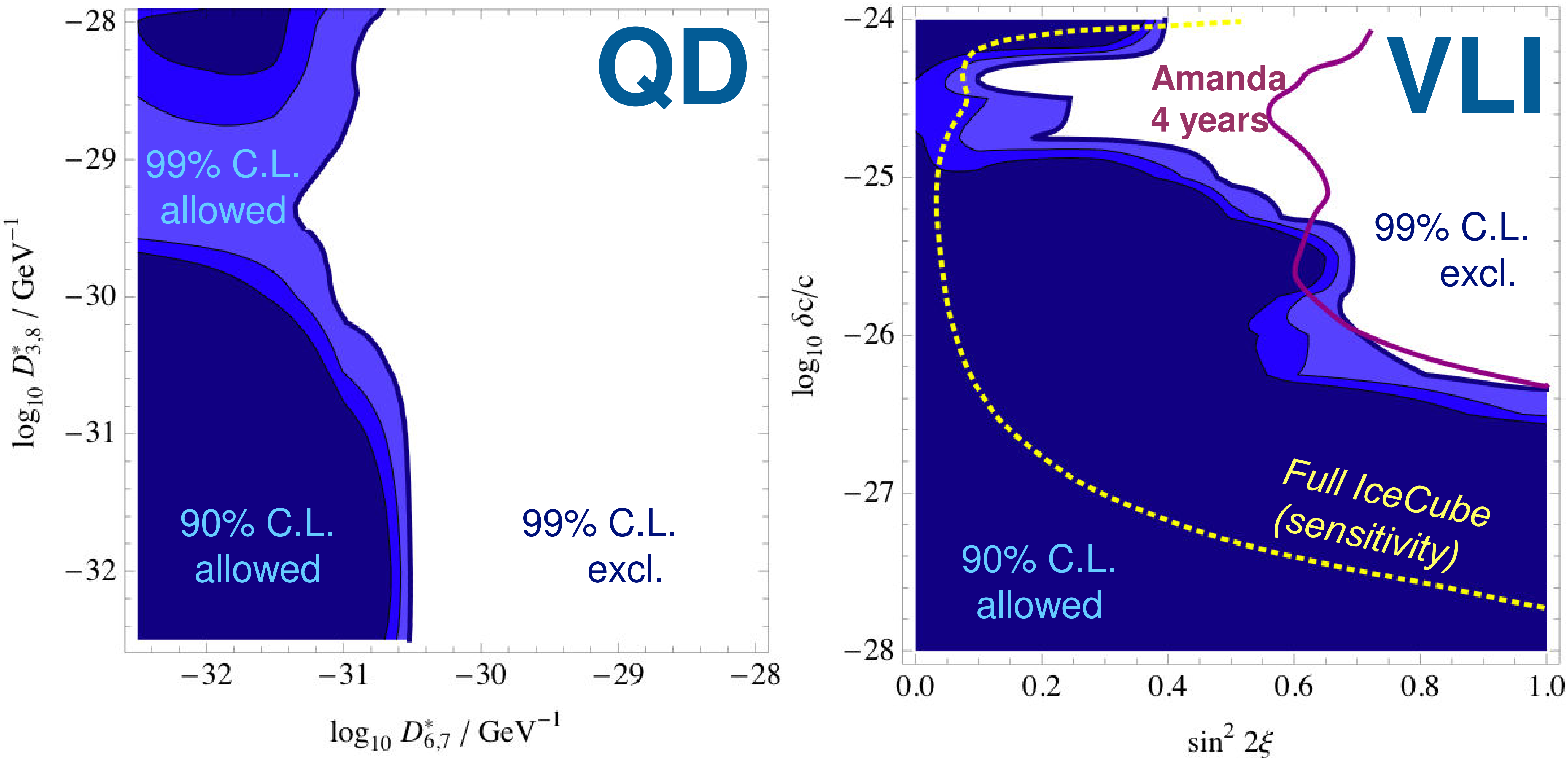
- Violation of Lorentz invariance
- Quantum decoherence
- (both appear in quantum gravity theories)

parameters of interest:
VLI: δc/c, sin 2ξ, phase η
QD: D_3 and D_8, D_6 and D_7

Different to standard oscillations (~ 1/E), effects of QG oscillations go ~ E



Limits from 7 years AMANDA (2000-2006)



Gravitational Waves