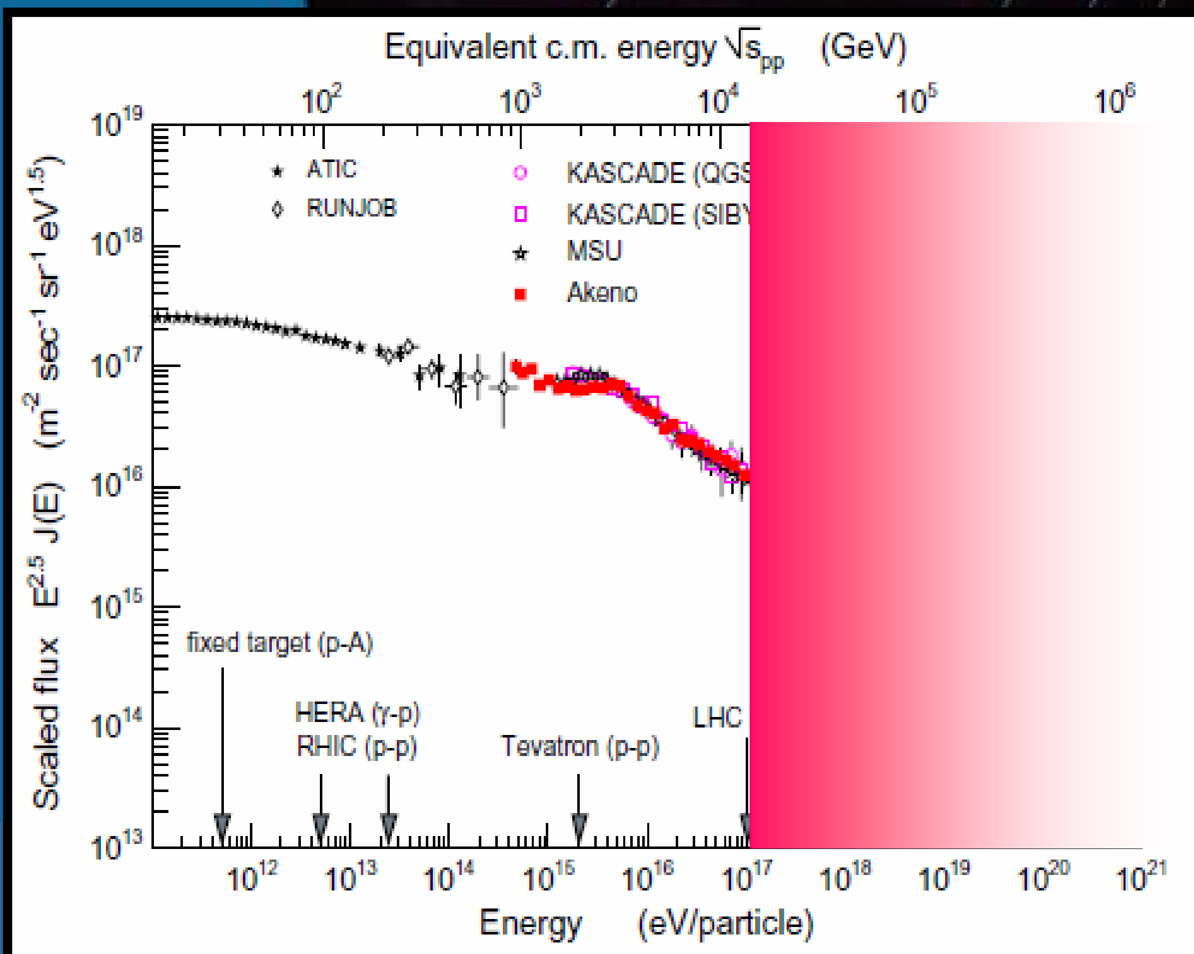
Astroparticle Physics and the LHC

Christian Spiering, DESY

EPS-ECFA 2009
Cracow, July 2009

http://www.aspera-eu.org

Astroparticle Physics helps LHC



No black holes from LHC which would eat the Earth !

http://www.aspera-eu.org

- Cross section @ high energies
  - TOTEM @ CMS
  - ATLAS forward (ALFA)
- Inelasticity and spectra
  - Zero Degree Calorimeters ATLAS, CMS, ALICE
- LHCf
  - dedicated CR-study experiment
  - individual particle, particle ID, imaging calorimetry, ….
- NA61:
  - Detailed inspection of forward region

Auger:

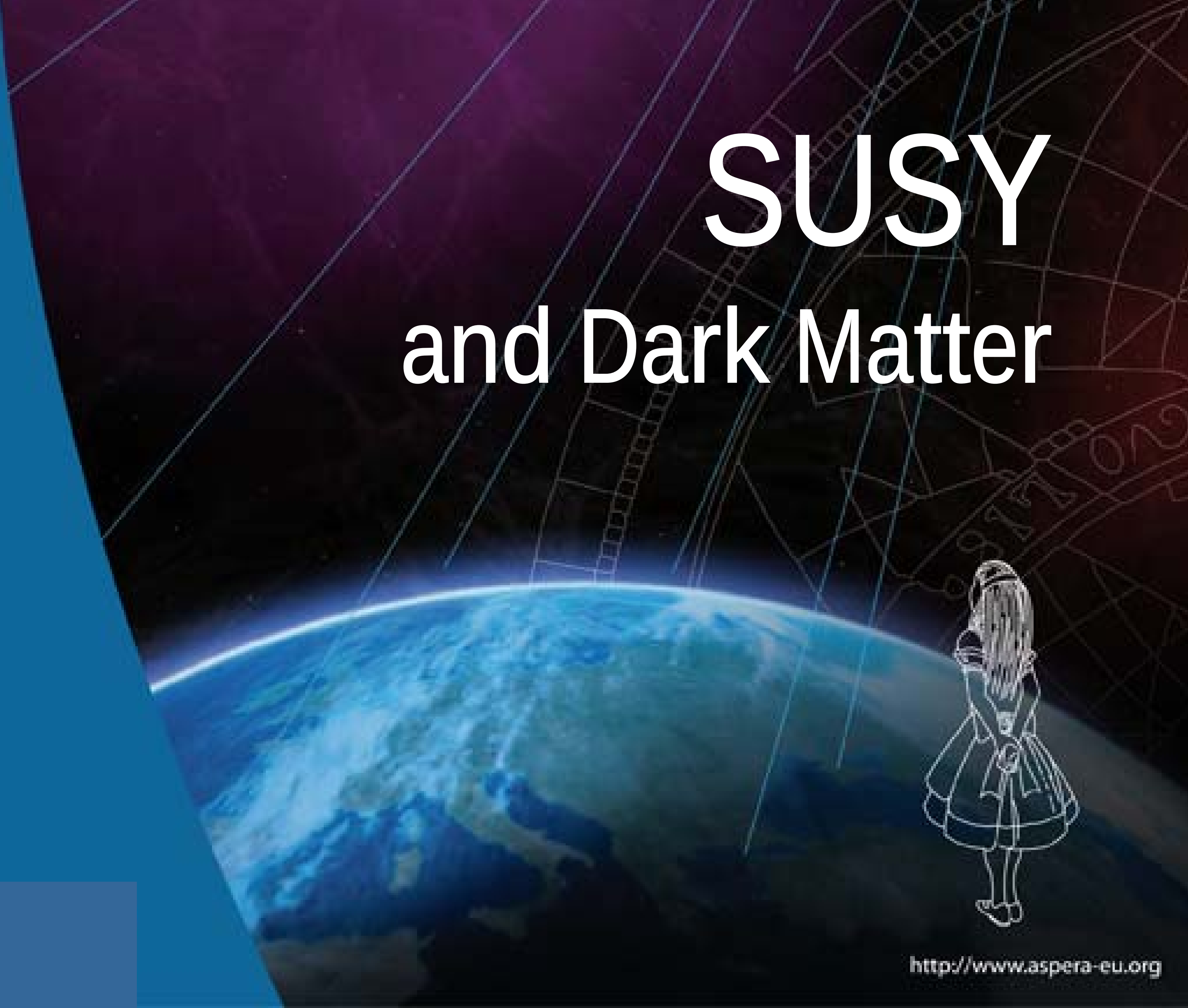
Composition seems to become heavier towards higher energies

- **Astrophysics ?**
- **„New" physics ?**
- **Details of air shower development ?**

Improve air shower simulations and understanding of CR spectra and composition at highest energy
- knee
- towards end of galactic spectrum
- GZK region

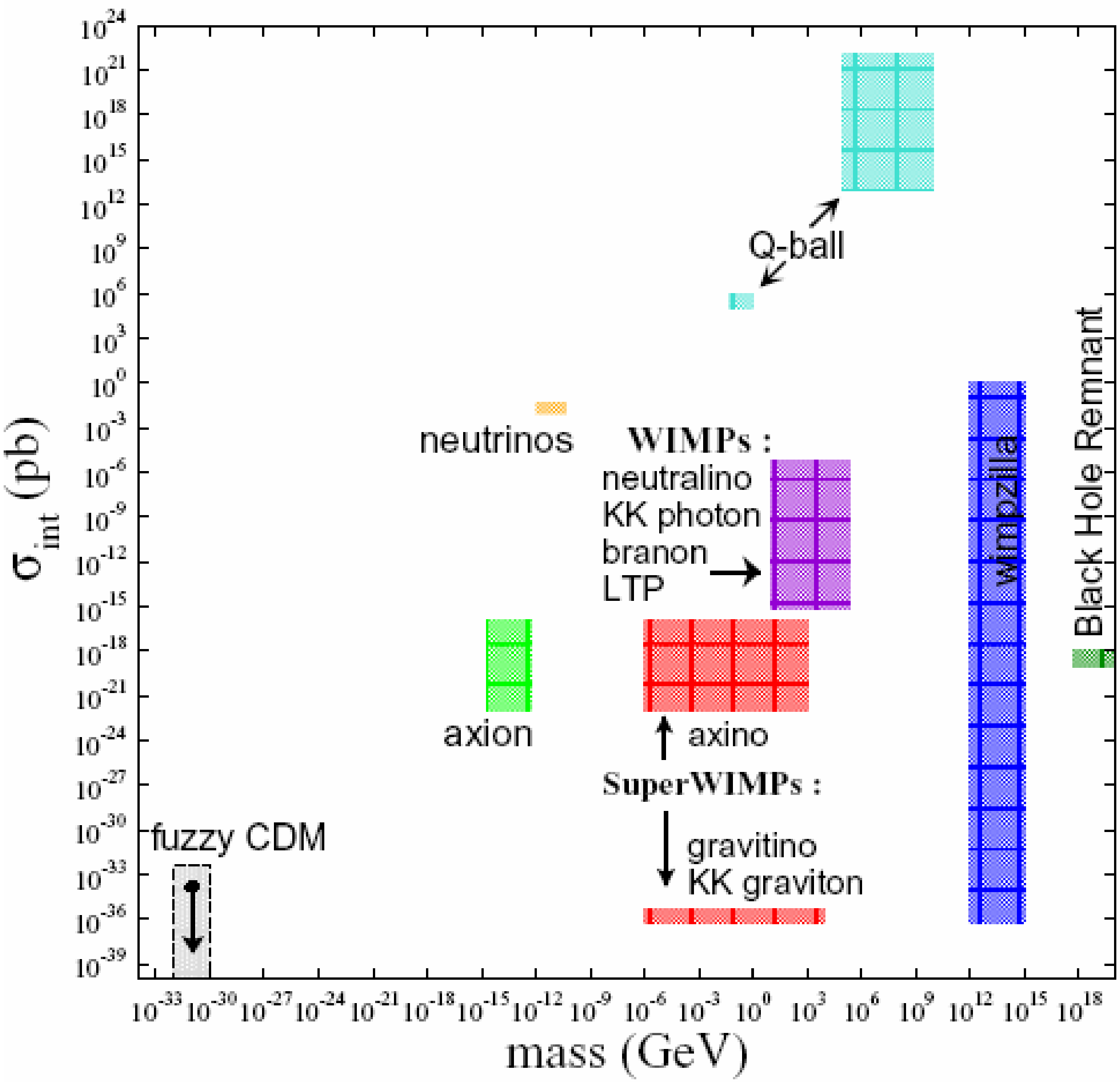
SUSY

and Dark Matter



DM candidates:

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



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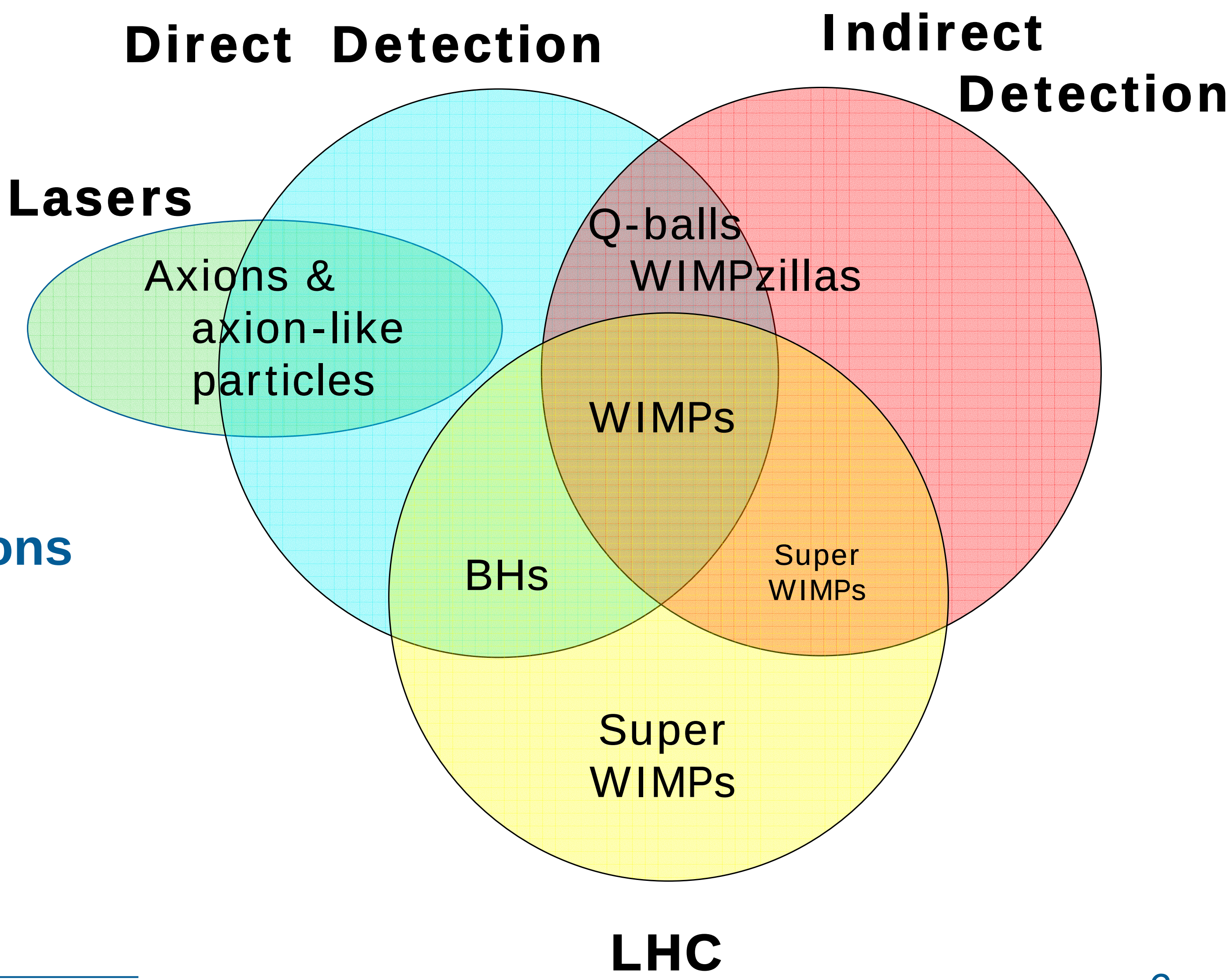

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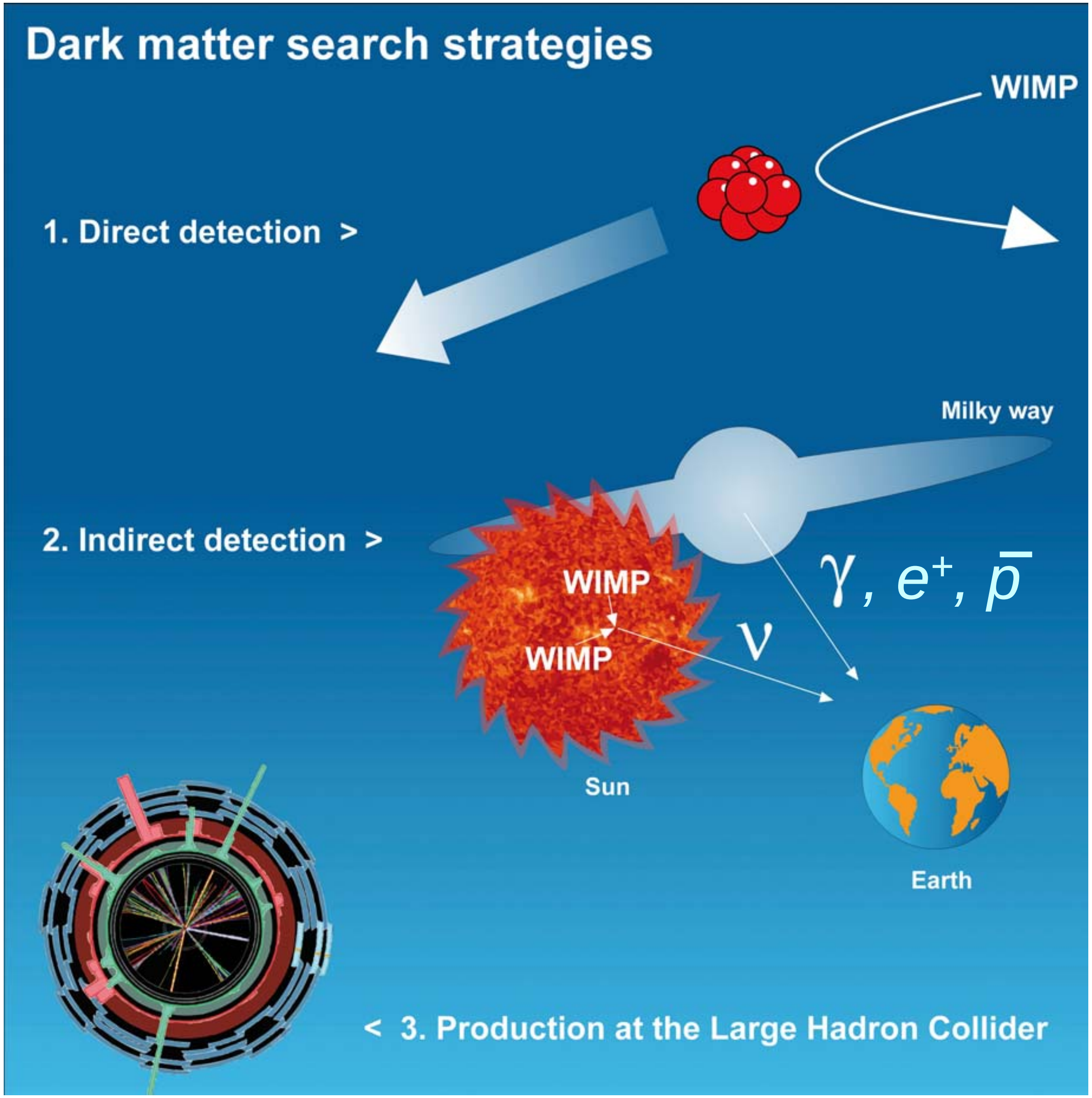

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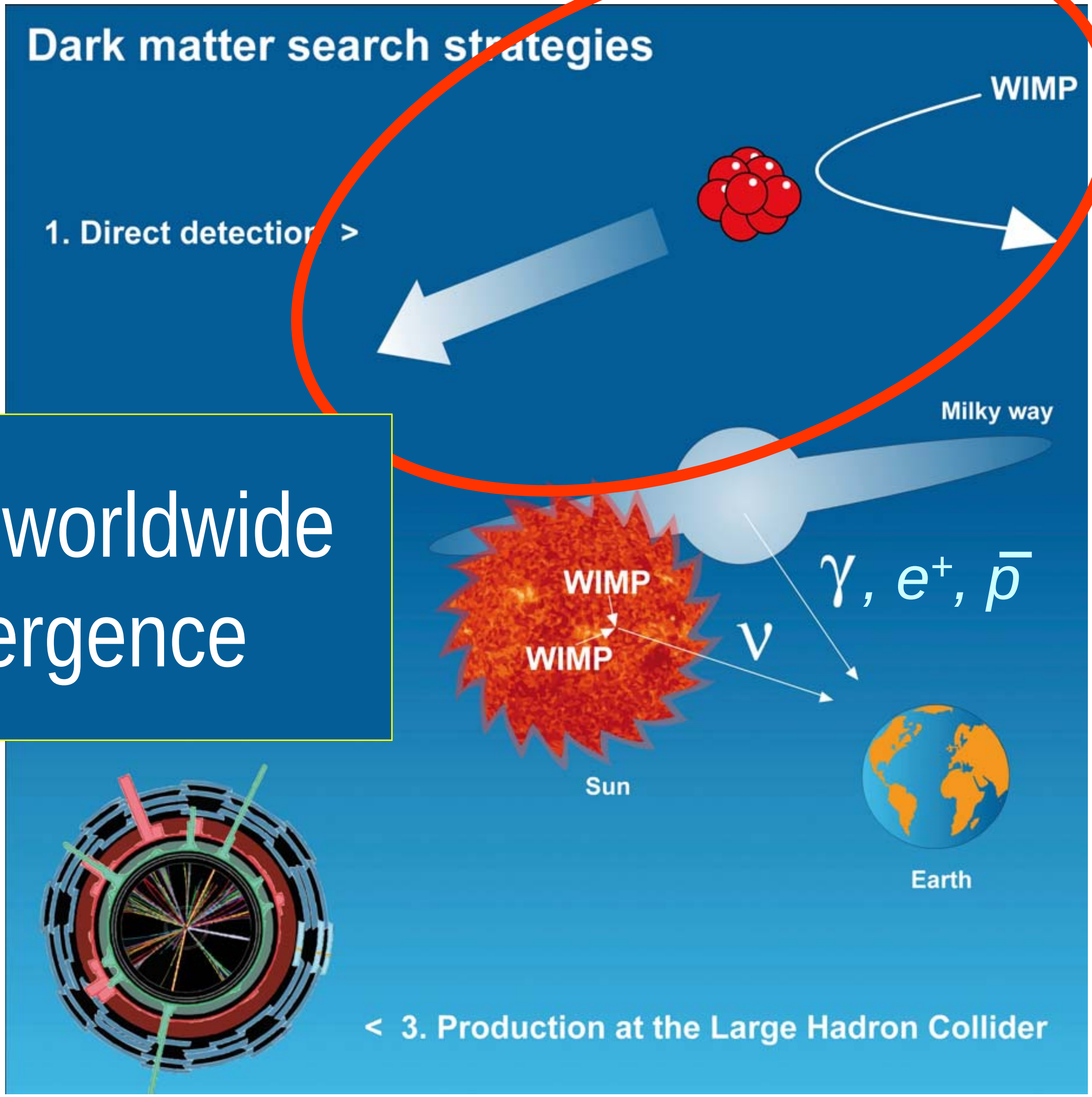
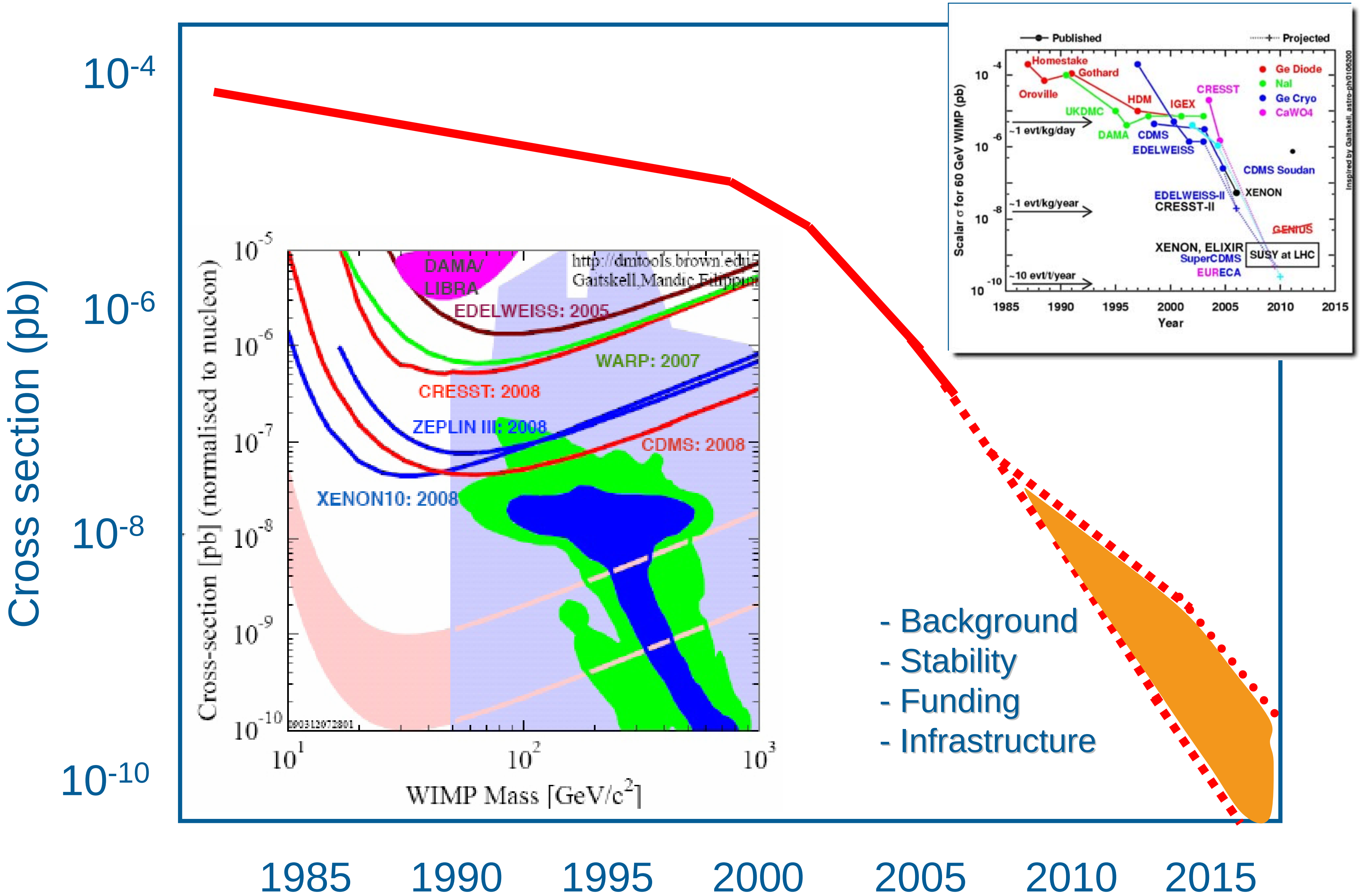


~ 20 experiments worldwide
→ Need of convergence

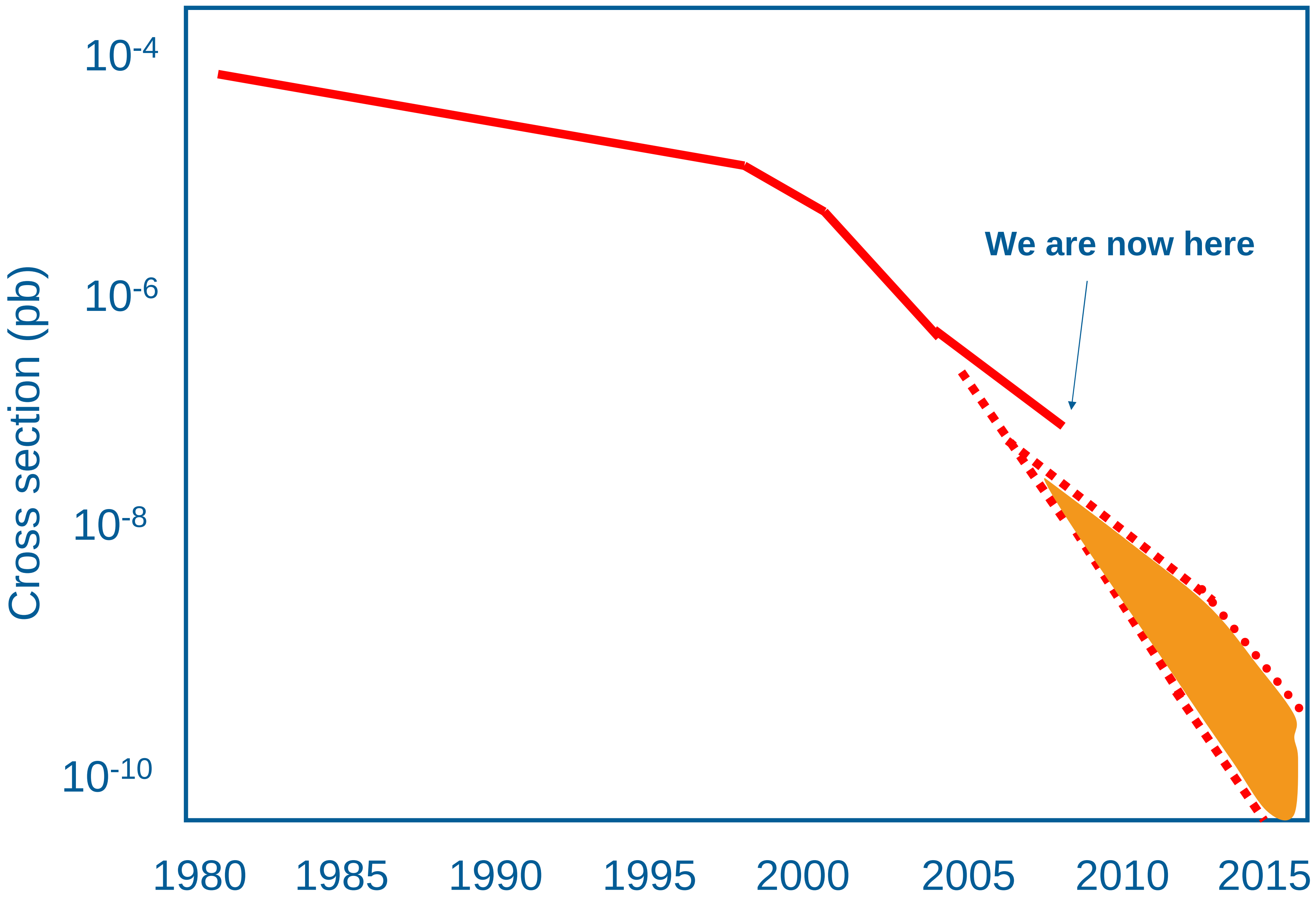
ApPEC Astroparticle Physics for Europe

Direct Dark Matter Searches



- Background
- Stability
- Funding
- Infrastructure

Direct Dark Matter Searches



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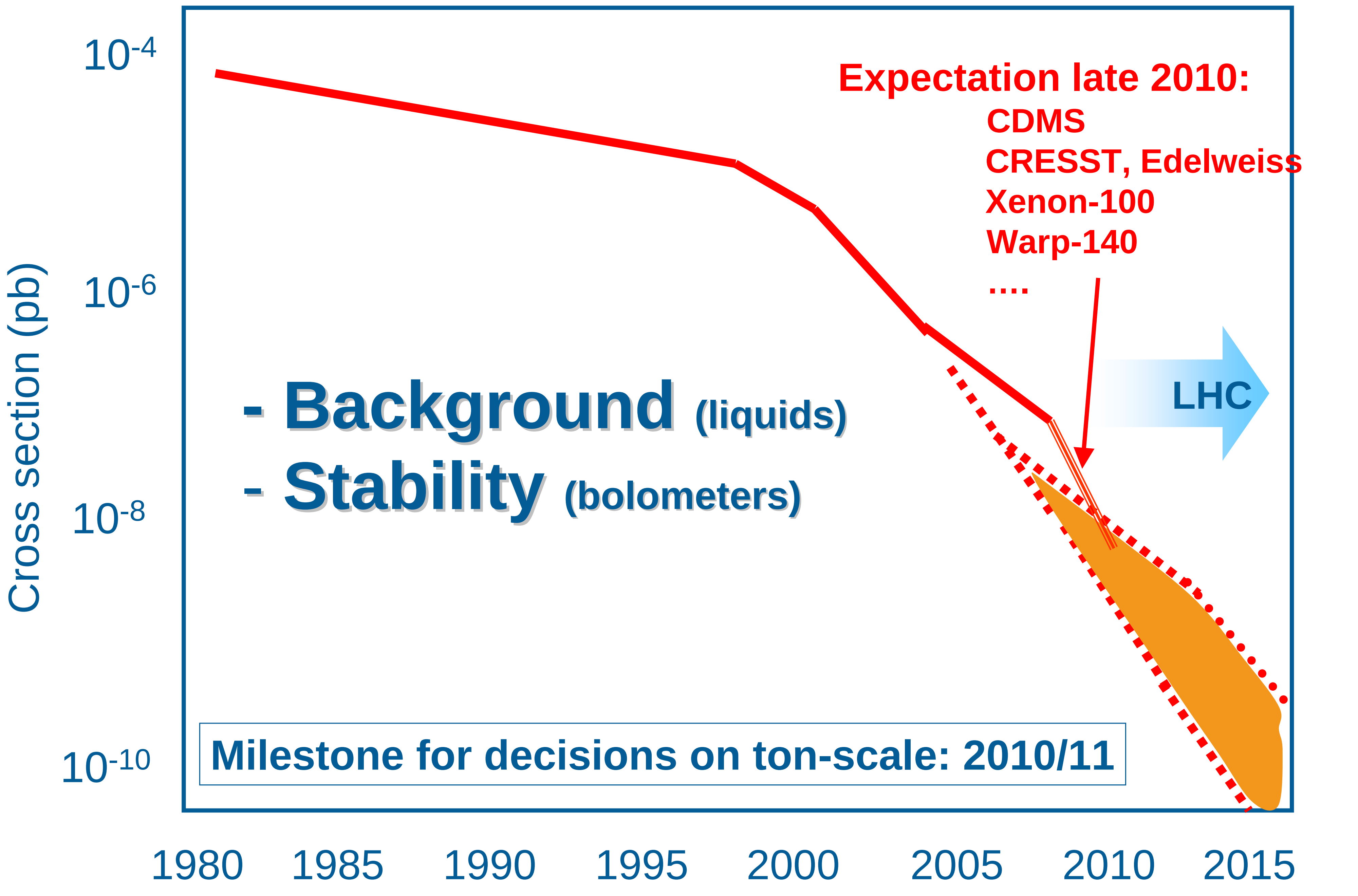

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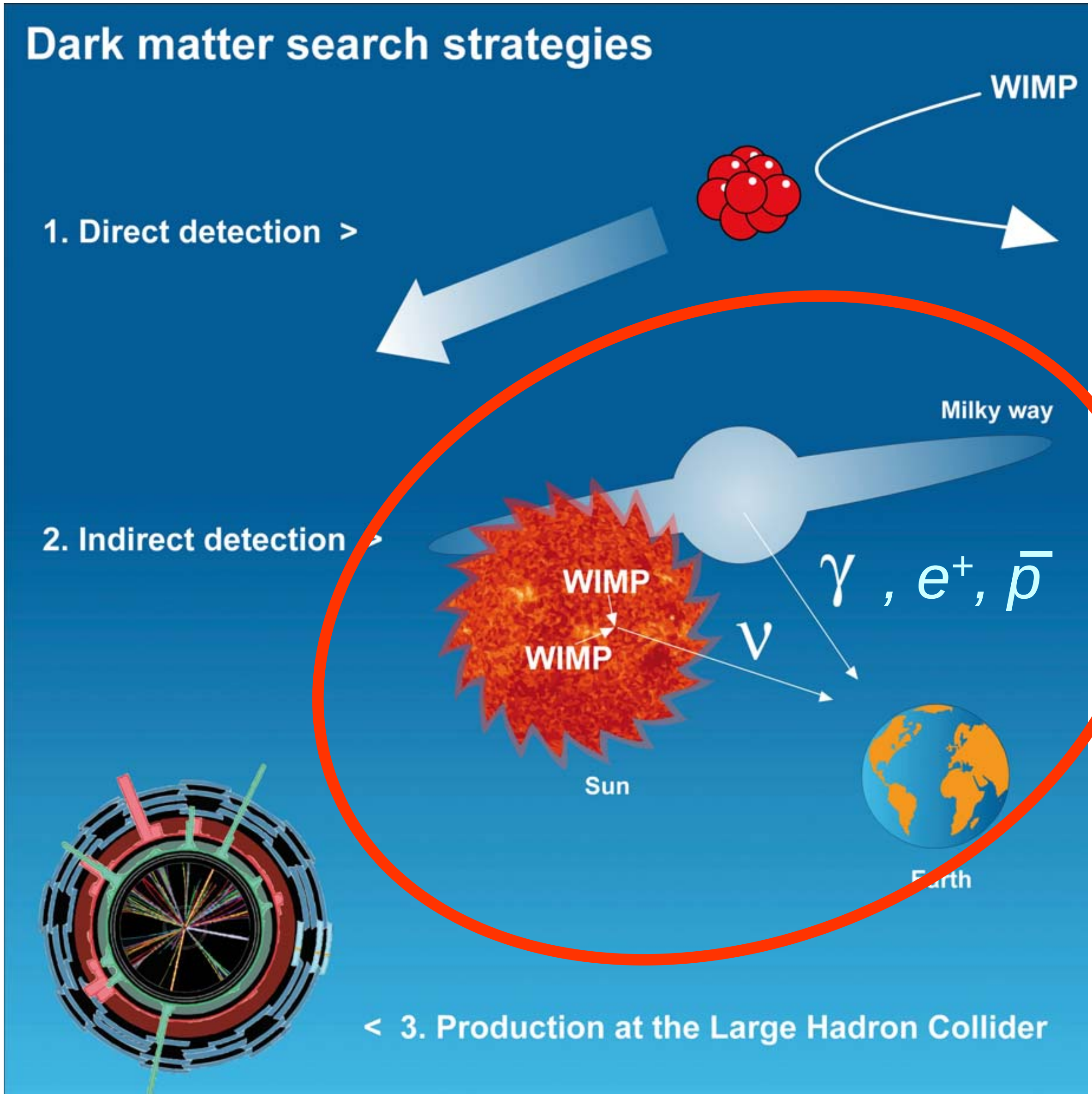
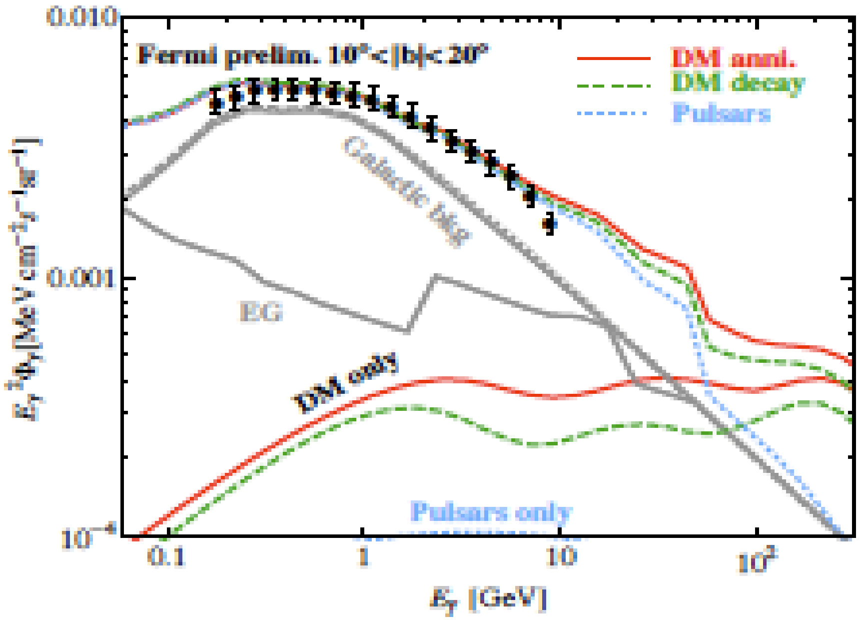


Indirect Searches: Pamela & Co.

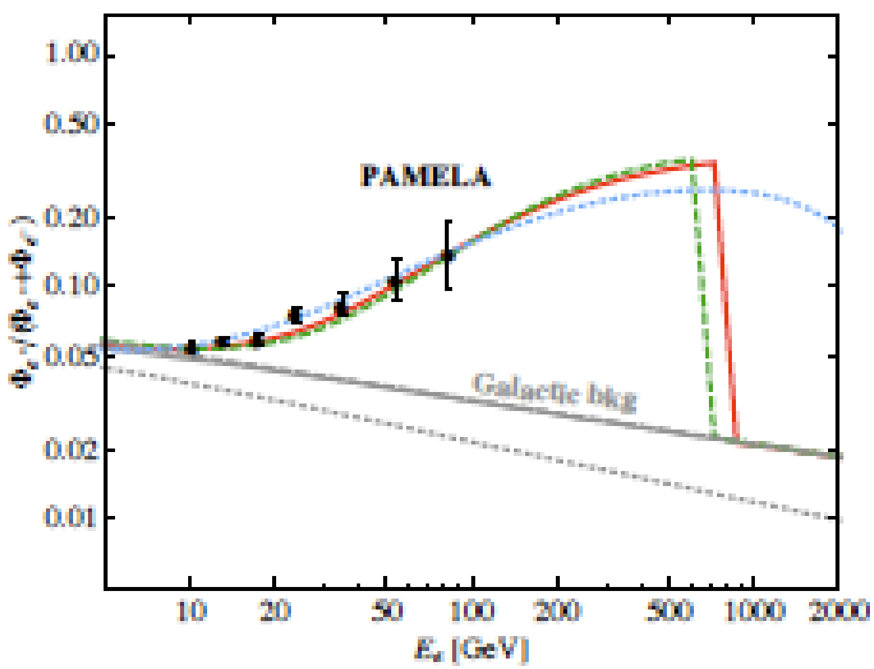


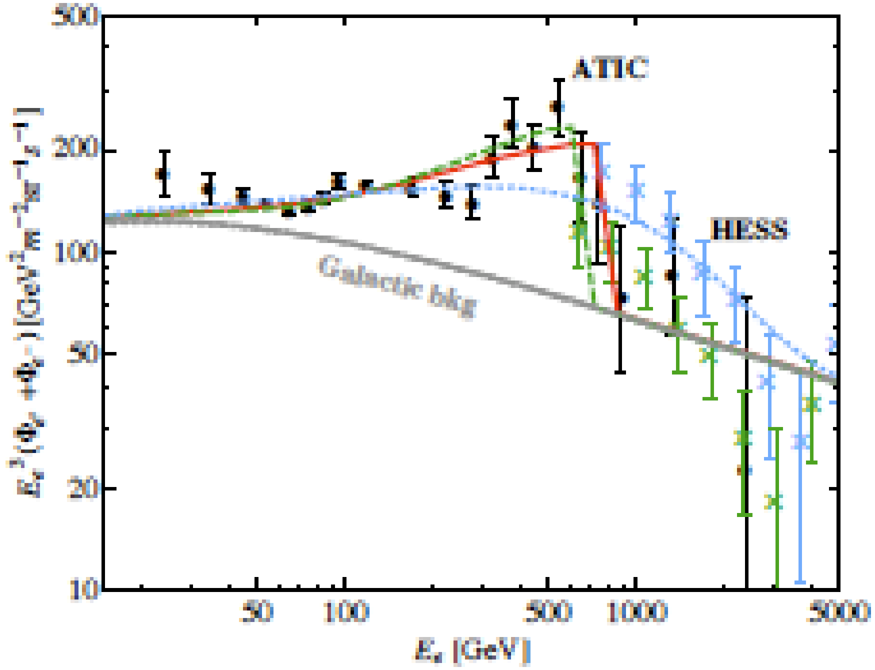
- Dark Matter annihilation ?
- Dark Matter Decay ?
- Nearby Pulsars ?

New Physics

Astrophysics

- Remember:
  Many discoveries in astroparticle and astrophysics started as puzzle !
  - Neutrino oscillations, quasars, ….





Barger et al.

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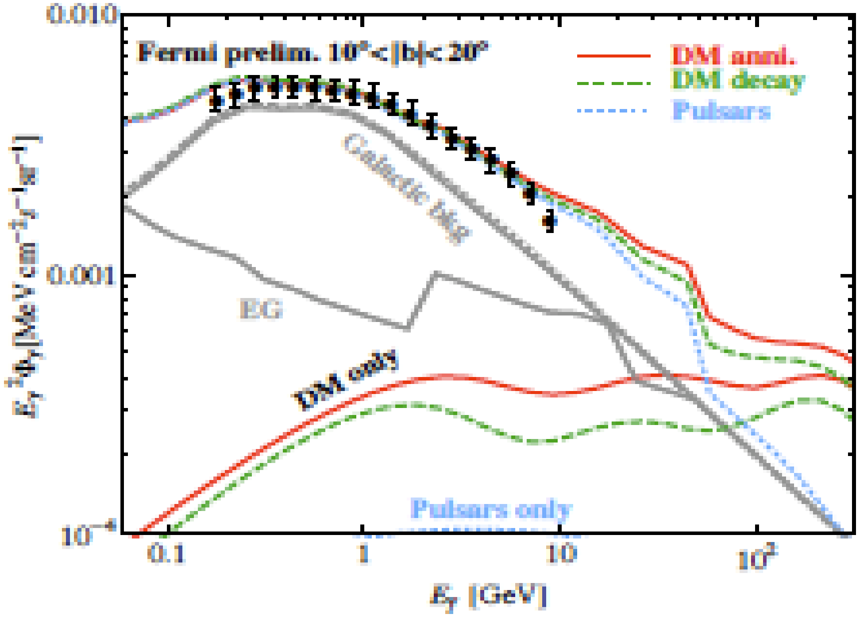

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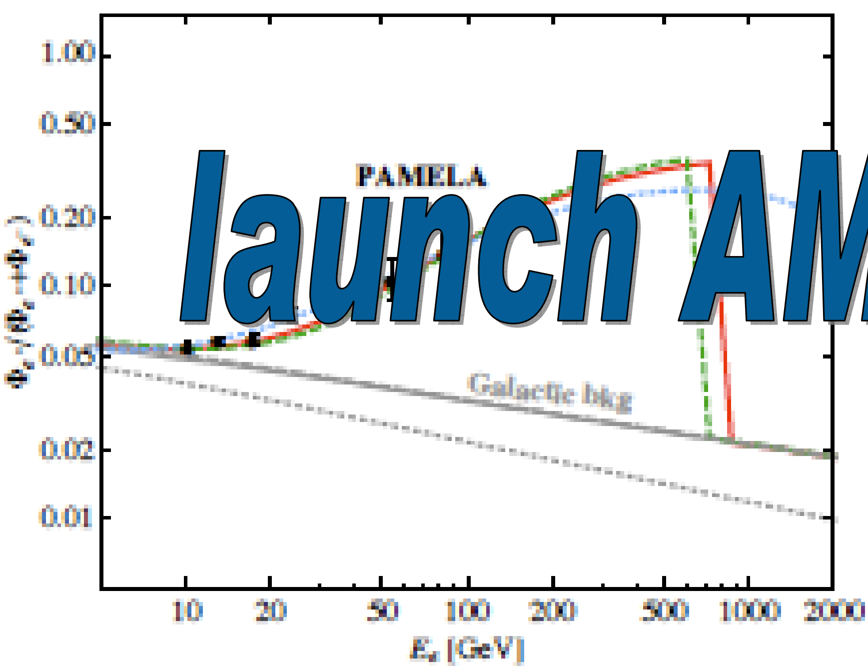
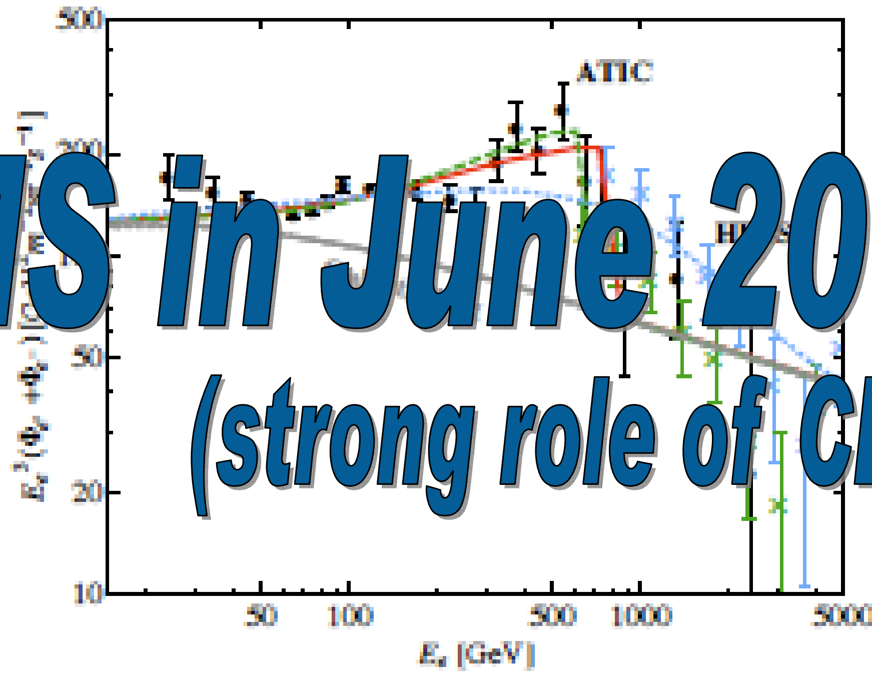


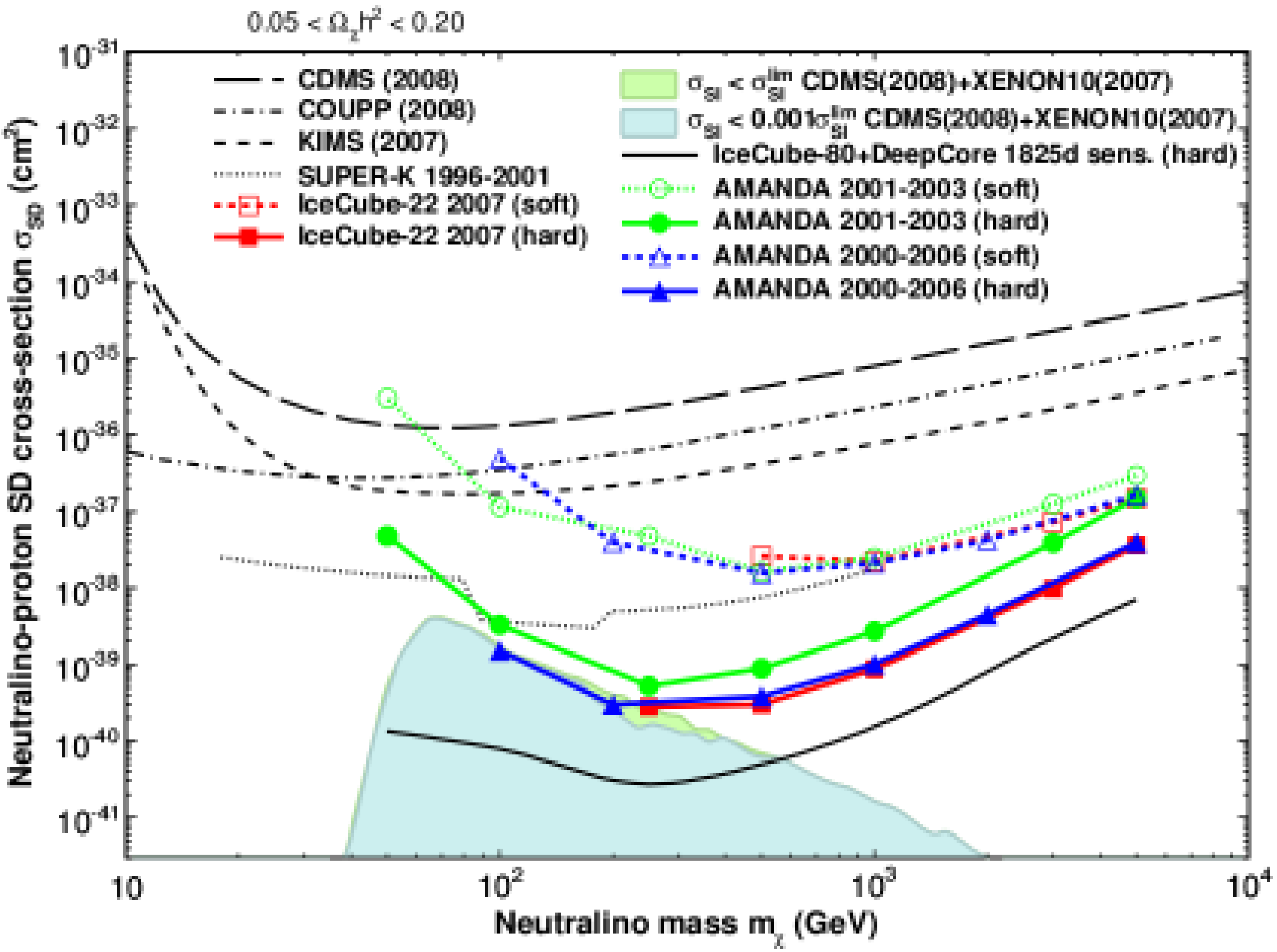


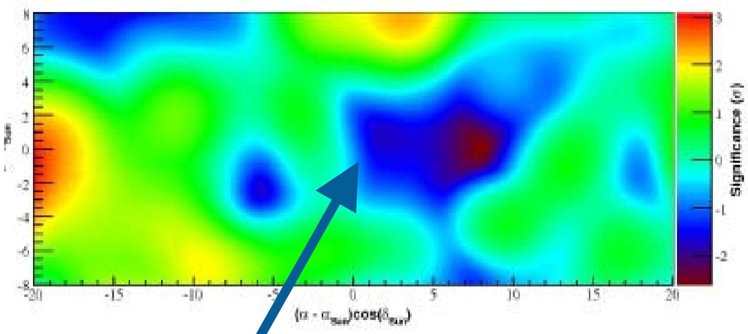
launch AMS in June 2010

(strong role of CERN)

Barger et al.

Indirect Searches: Example IceCube

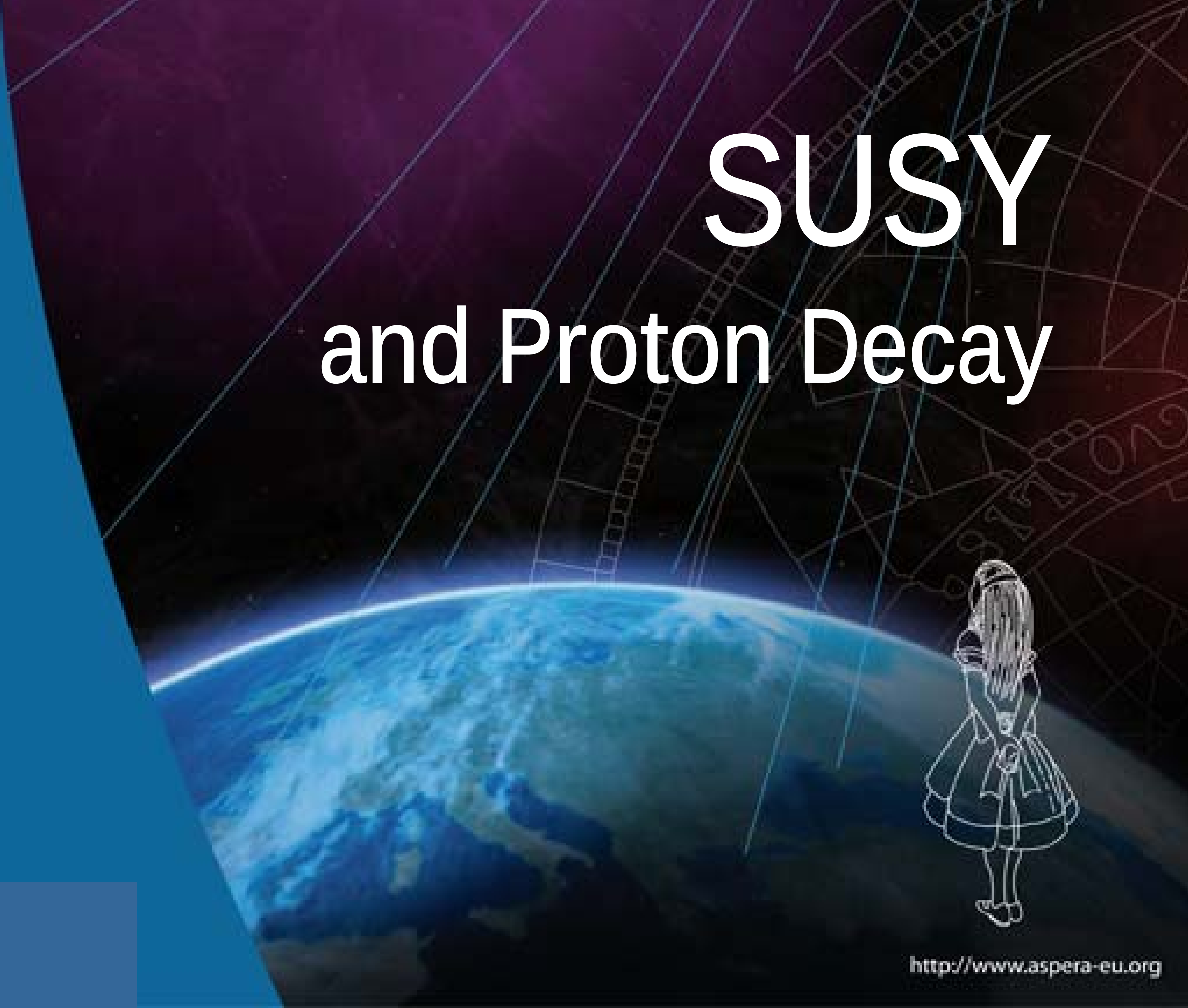




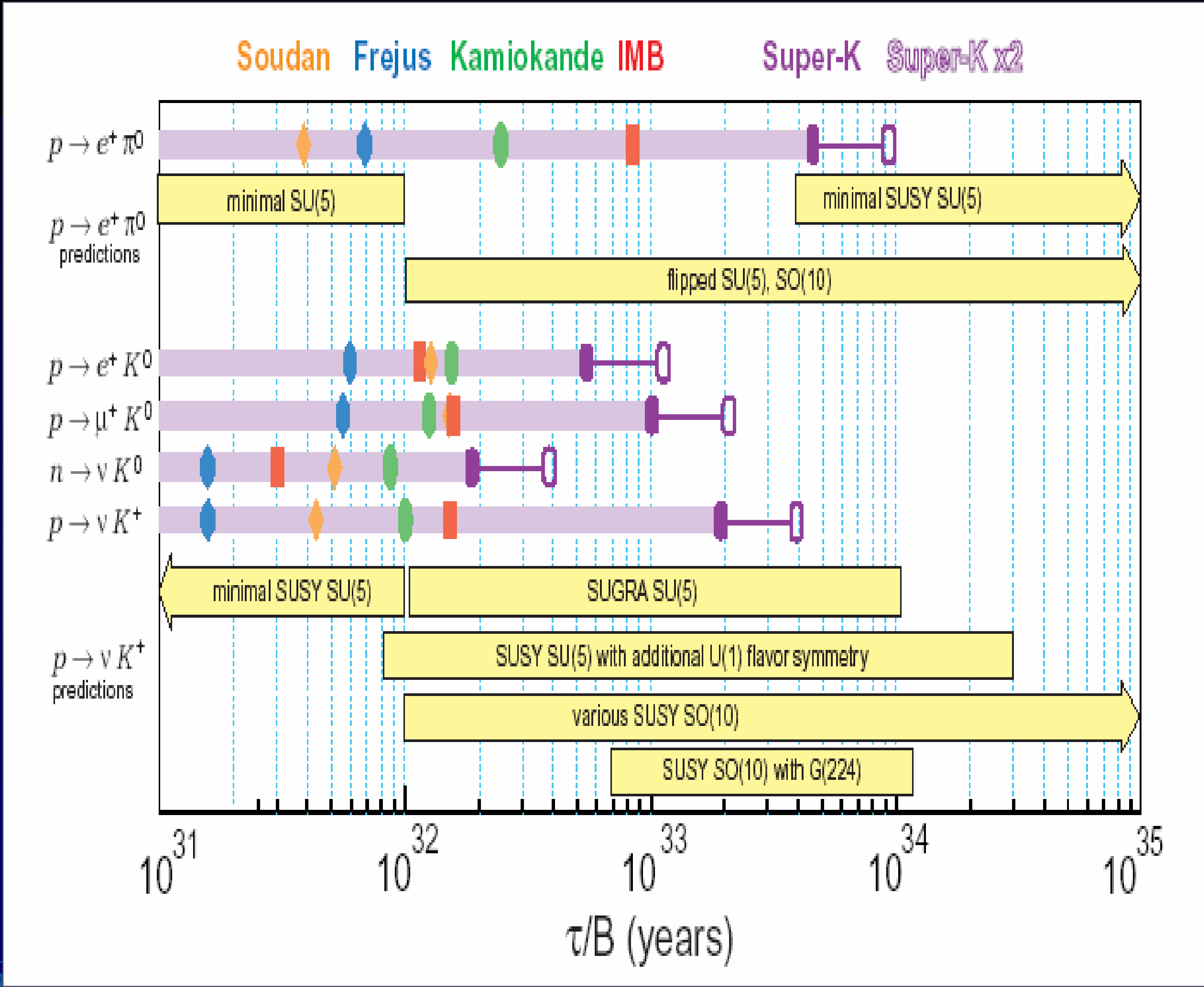
Sun position (Amanda skymap)

- 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)

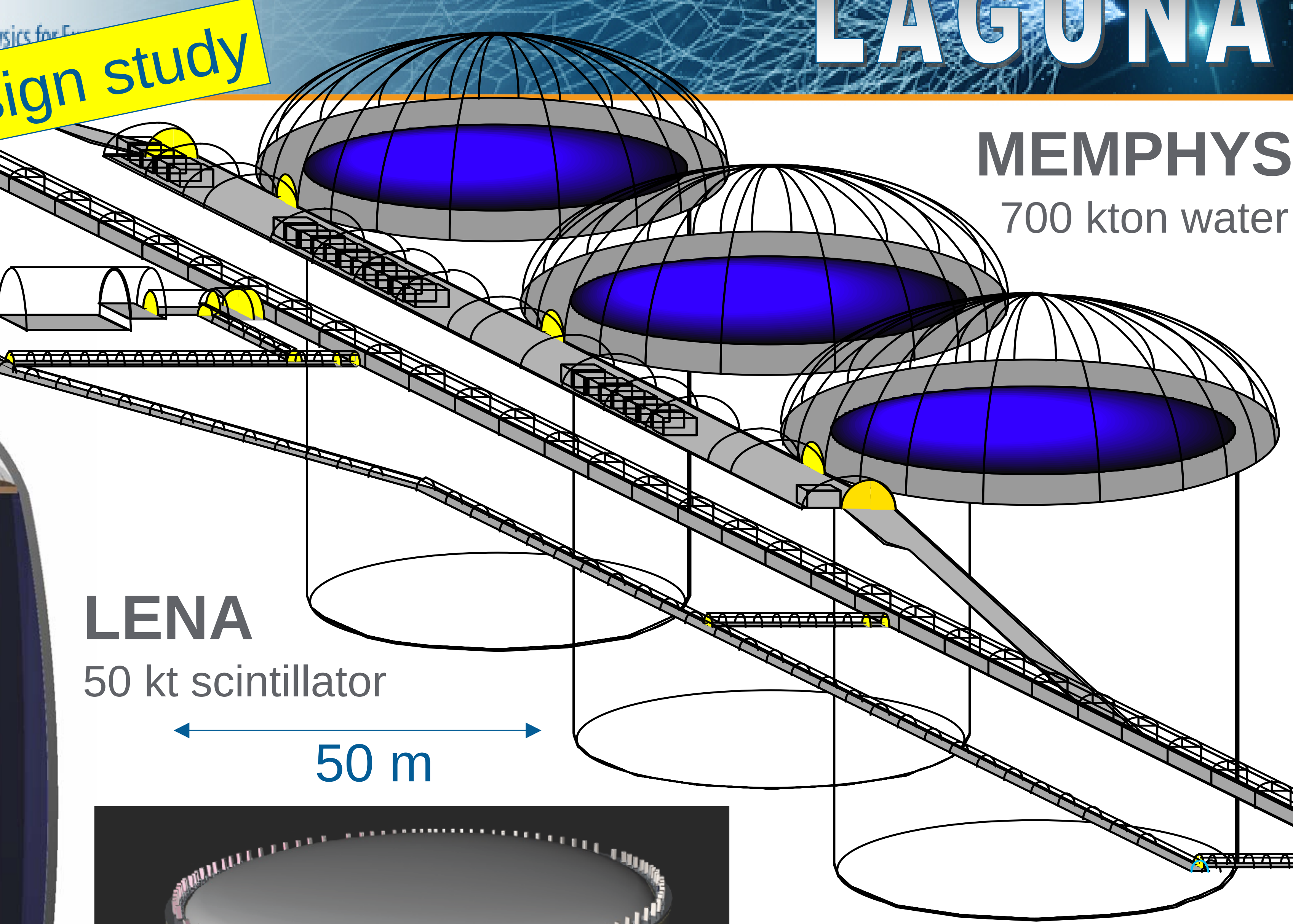
SUSY
and Proton Decay



Proton Decay



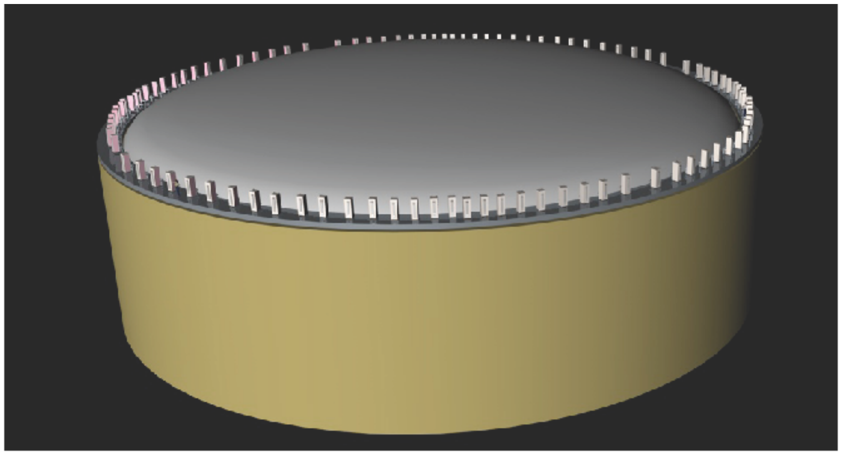
FP7 design study



MEMPHYS
700 kton water

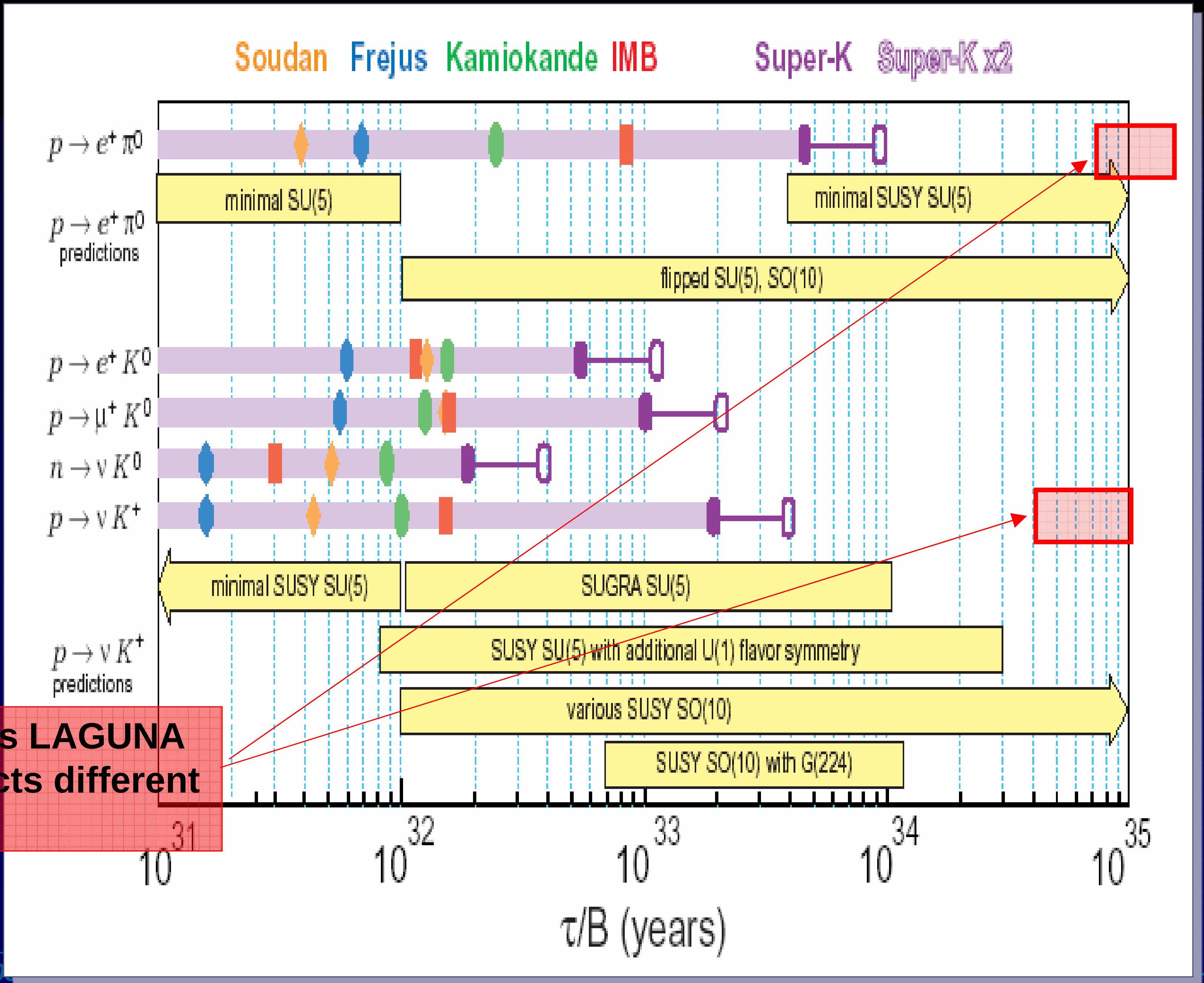
LENA
50 kt scintillator

50 m



GLACIER
100 kton liquid argon

Proton Decay



Design goals LAGUNA (range reflects different techniques)

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

Properties of Neutrinos

Majorana nature, mass & mass hierarchy

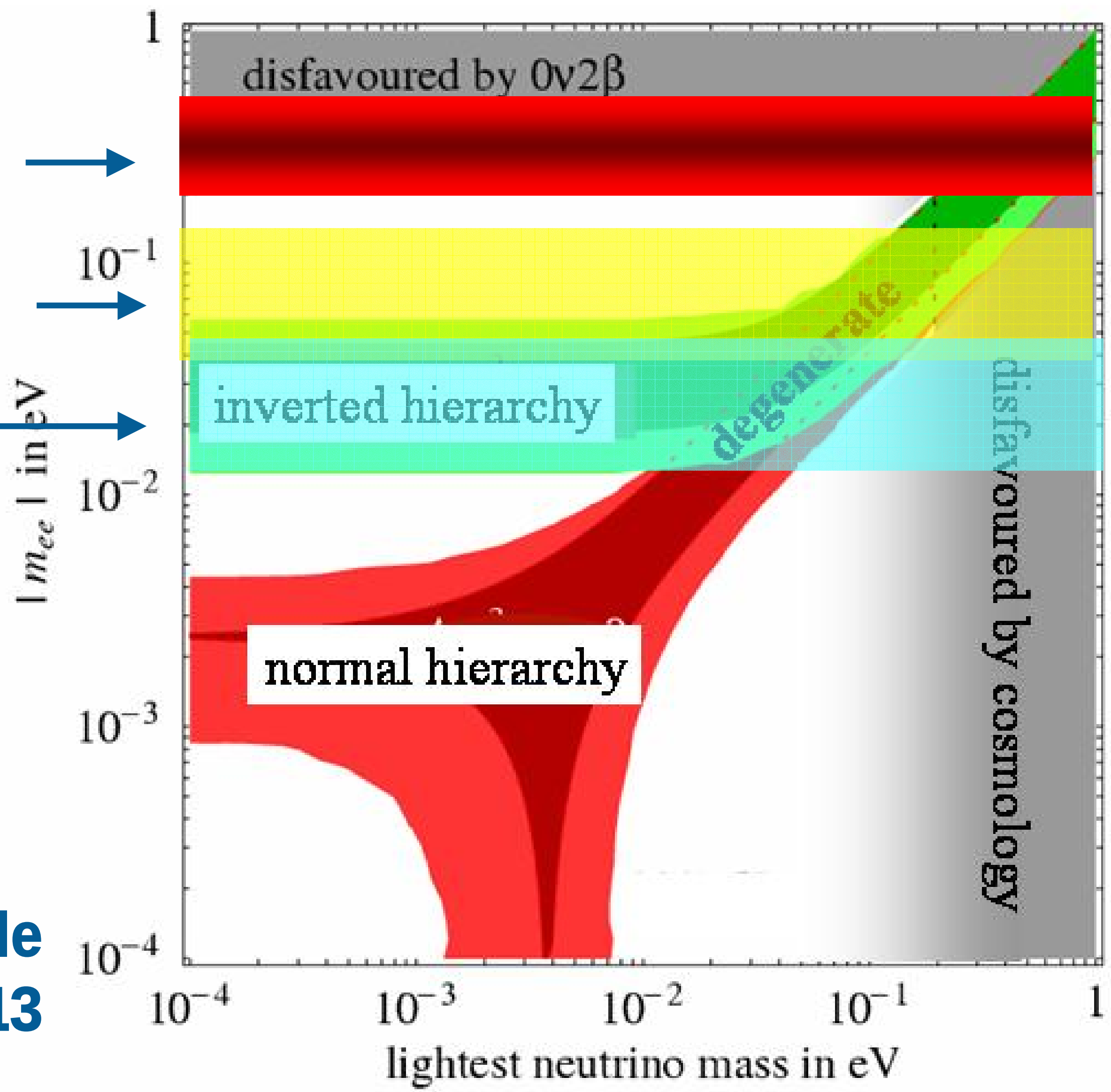
.. may be related to GUT scale via see-saw mechanism and to matter-antimatter asymmetry via Majorana decay

Double Beta Decay

KKGH claim →

GERDA, EXO200, SNO+
CUORE, SuperNEMO →

Ton-scale →

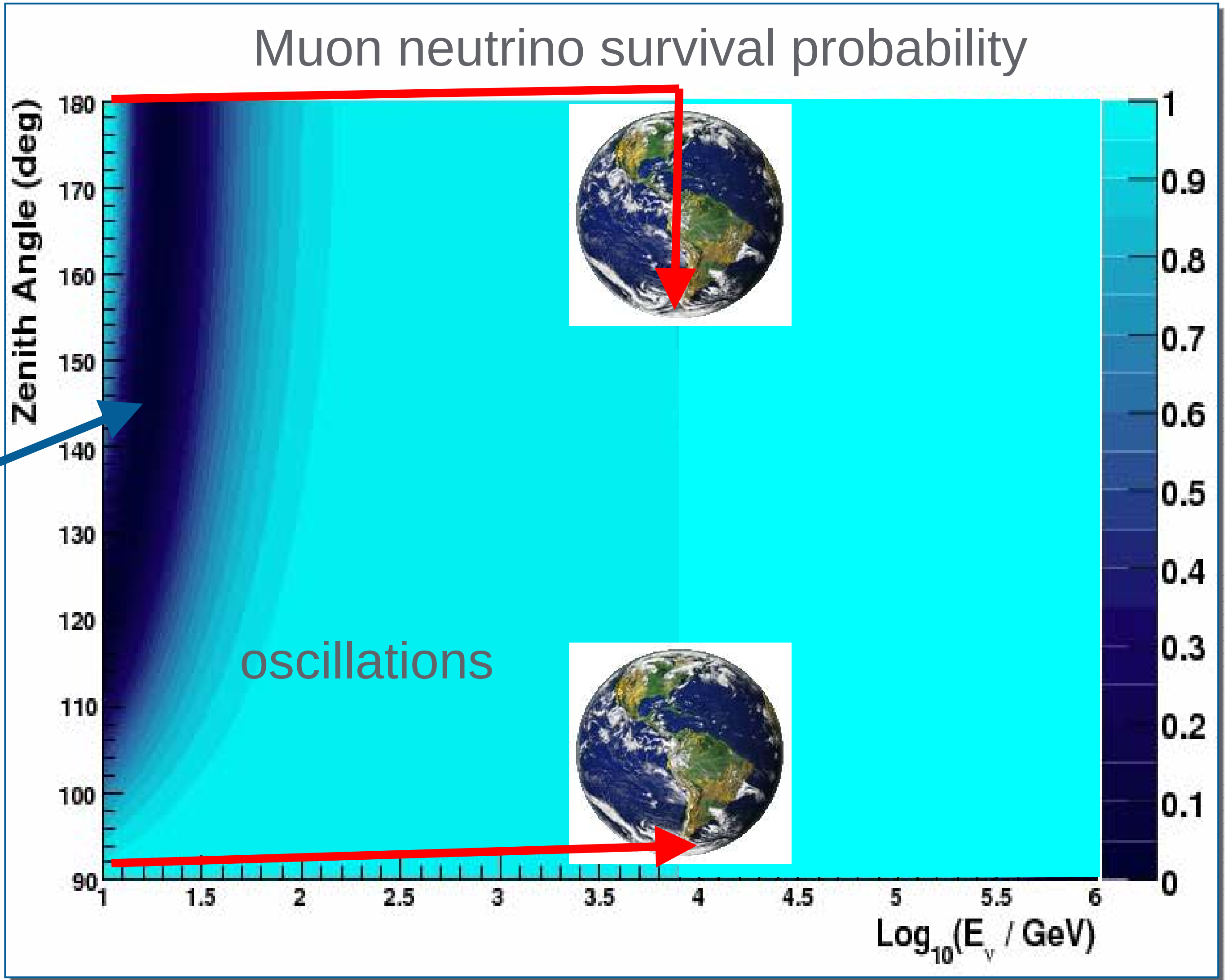


Decision on ton scale >2013

Oscillation physics with atmospheric neutrinos

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

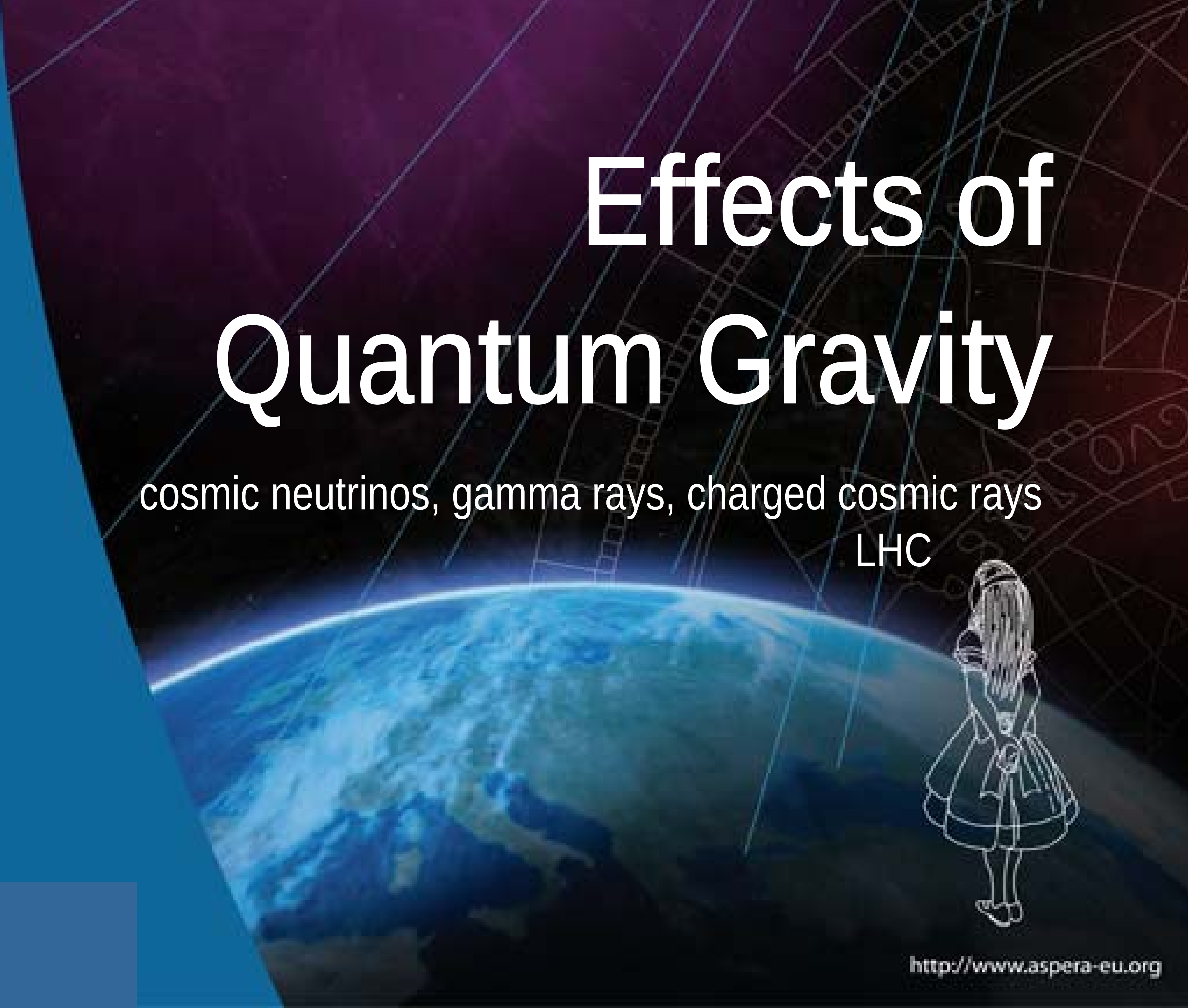
Sensitive to mass hierarchy ?



Effects of Quantum Gravity

cosmic neutrinos, gamma rays, charged cosmic rays

LHC

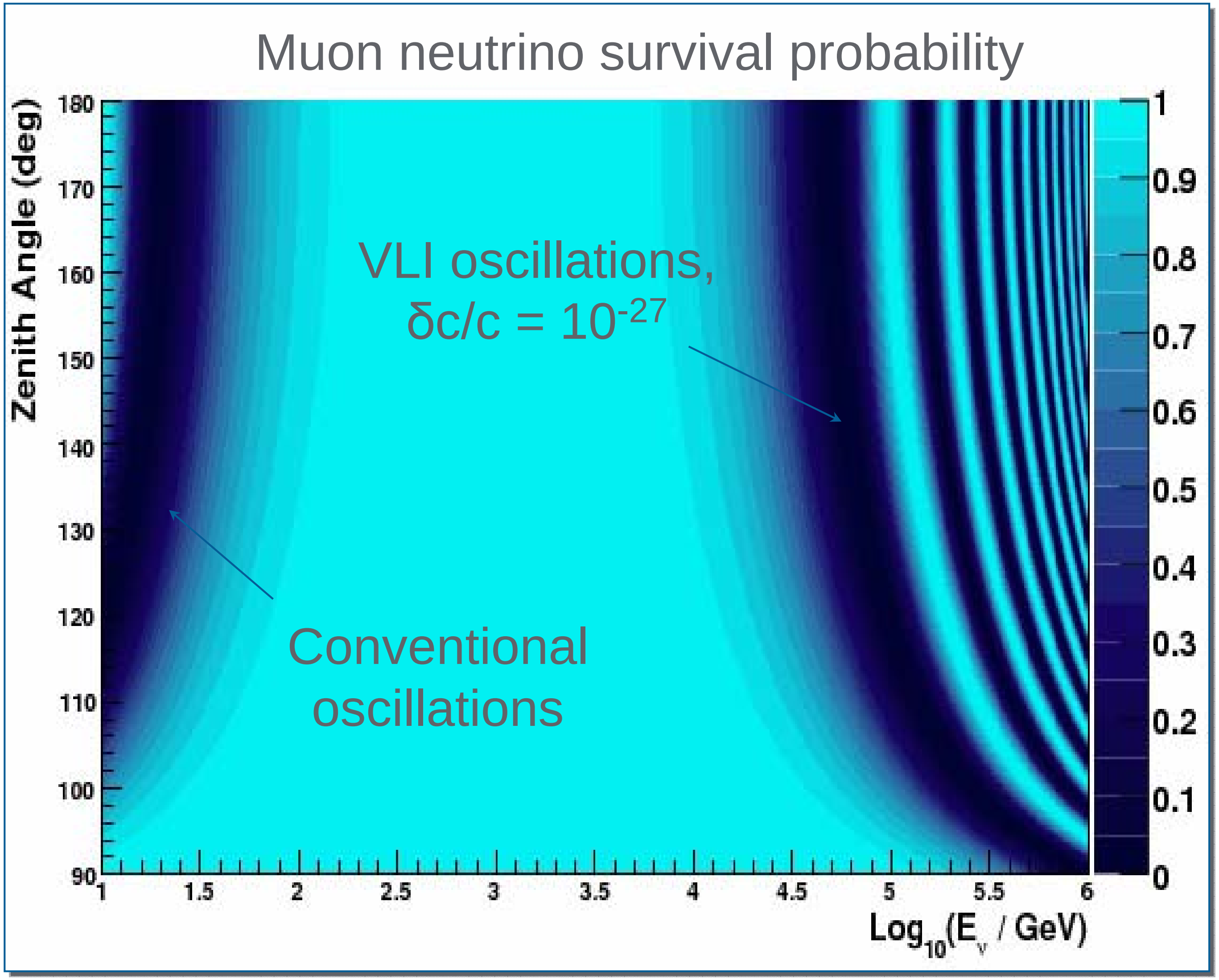


Exotic Oscillations

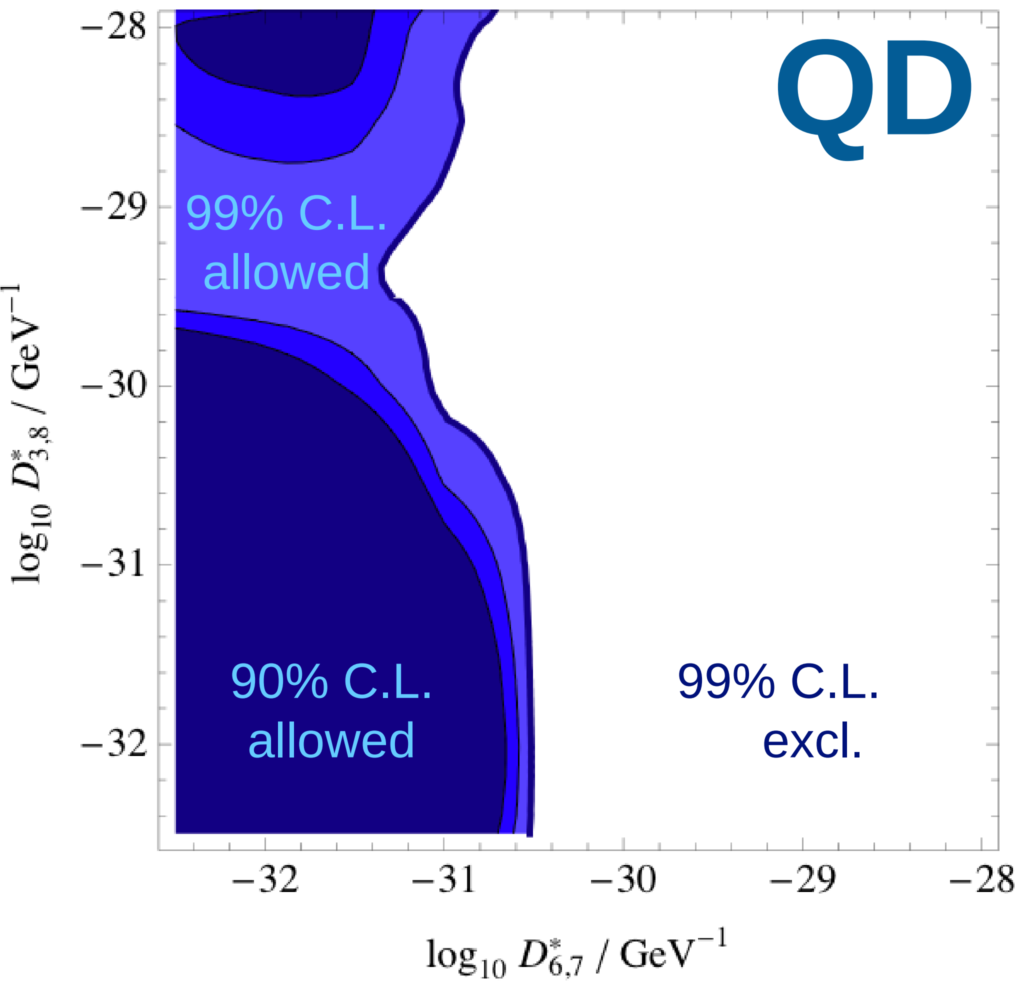
- Violation of Lorentz invariance
- Quantum decoherence
- (both appear in quantum gravity theories)

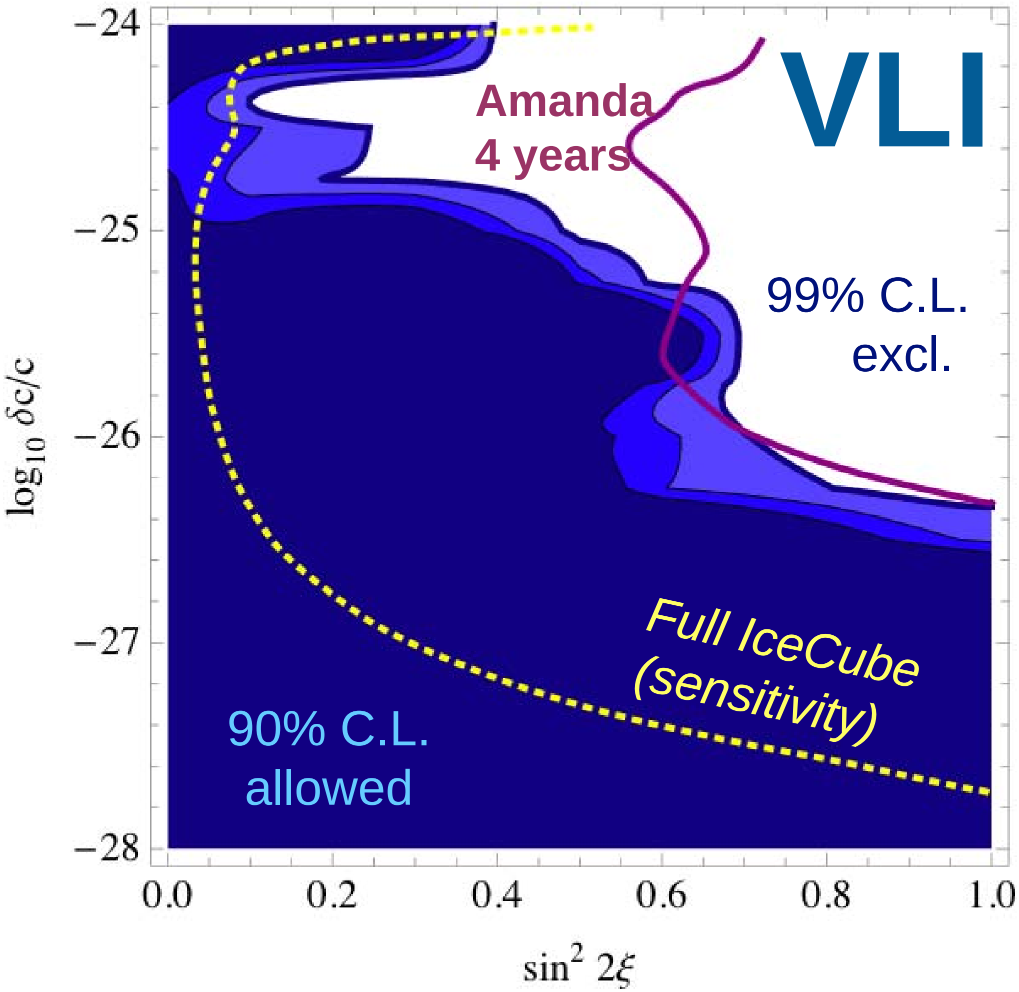
parameters of interest:
VLI: $\delta c/c$, sin 2ξ, phase η
QD: D_3 and D_8, D_6 and D_7

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



Limits from 7 years AMANDA (2000-2006)

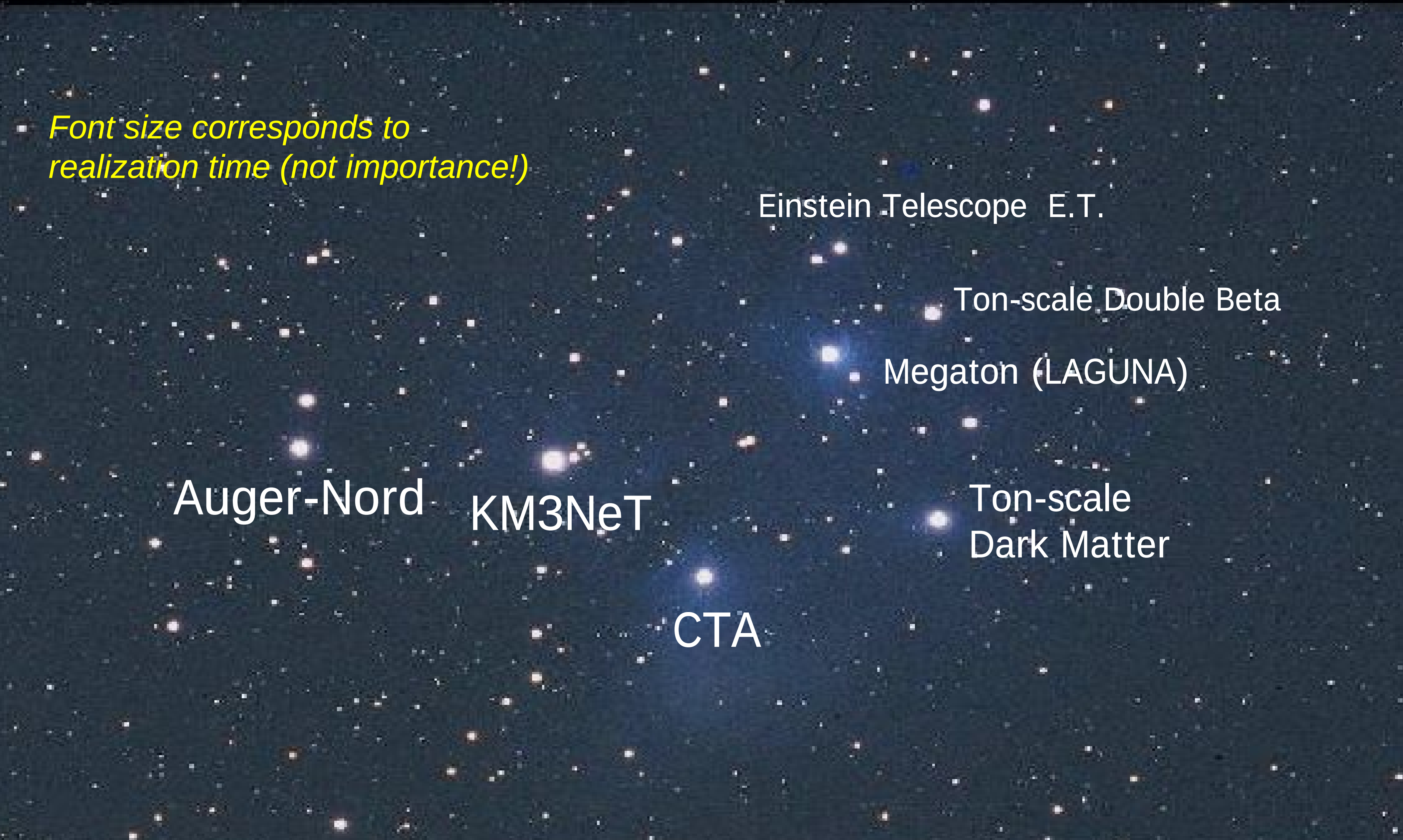




The ApPEC Roadmap and the Magnificent Seven

ApPEC Astroparticle Physics for Europe

The Magnificent Seven



ApPEC Astroparticle Physics for Europe

The Magnificent Seven

Particle Physics → Astrophysics

Double Beta | **Dark Matter** | **LAGUNA** | **KM3NeT** | **Auger** | **CTA** | **E.T.**

Double Beta:
Majorana nature
(→ leptogenesis)
ν mass

Dark Matter:
Cosmology
SUSY, KK, …

LAGUNA:
proton decay
ν astronomy
dark matter
accelerator beam
ν oscillations (hierarchy?)

KM3NeT:
ν astronomy
ν oscillations
Q.G., TD, …
indirect DM and
other exotic particles

Auger:
Astrophysics
Q.G., TD, …
GZK physics
cross sections

CTA:
Astrophys.
Indirect DM
Q.G, …

E.T.:
Test Relativity
Extreme objects

Particle Physics | Astrophysics

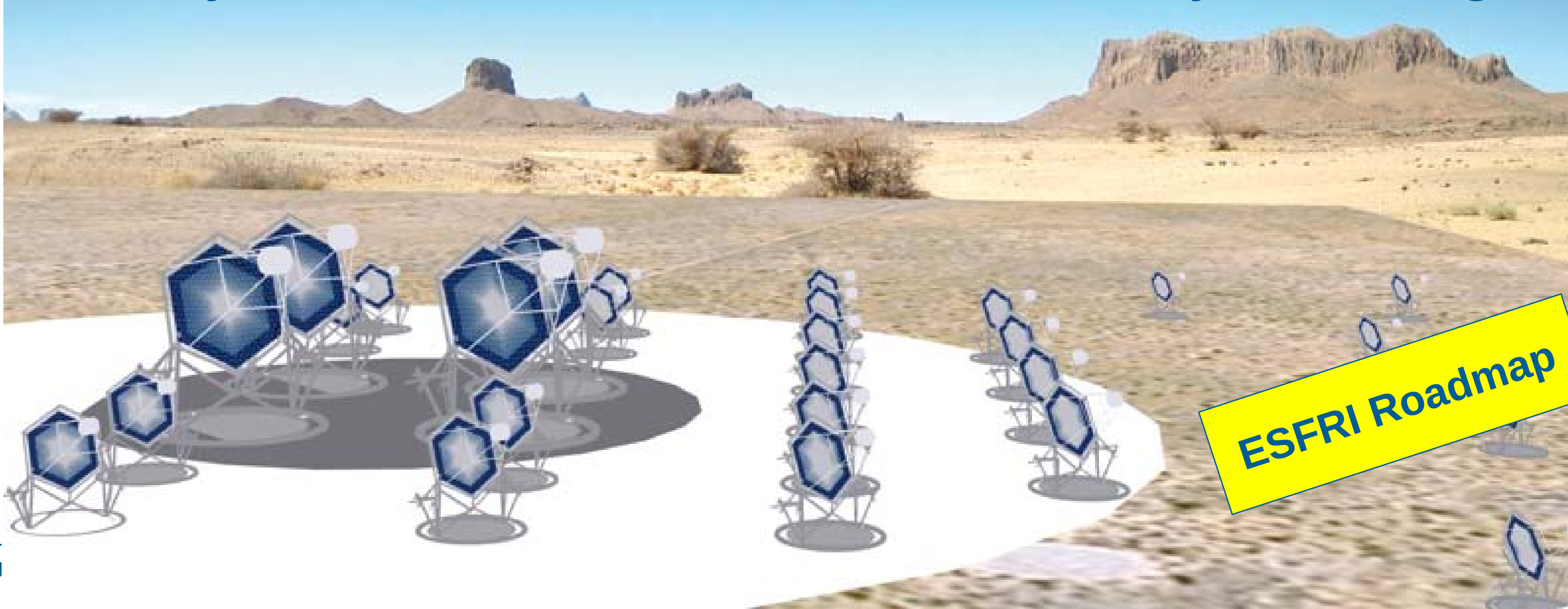
Double Beta Dark Matter LAGUNA KM3NeT Auger CTA E.T.

- A **European Centre for Astroparticle Theory** could be established at CERN. Given the synergy between LHC physics and astroparticle physics, CERN would be a natural host, particularly in view of several astroparticle experiments being CERN recognized experiments.

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



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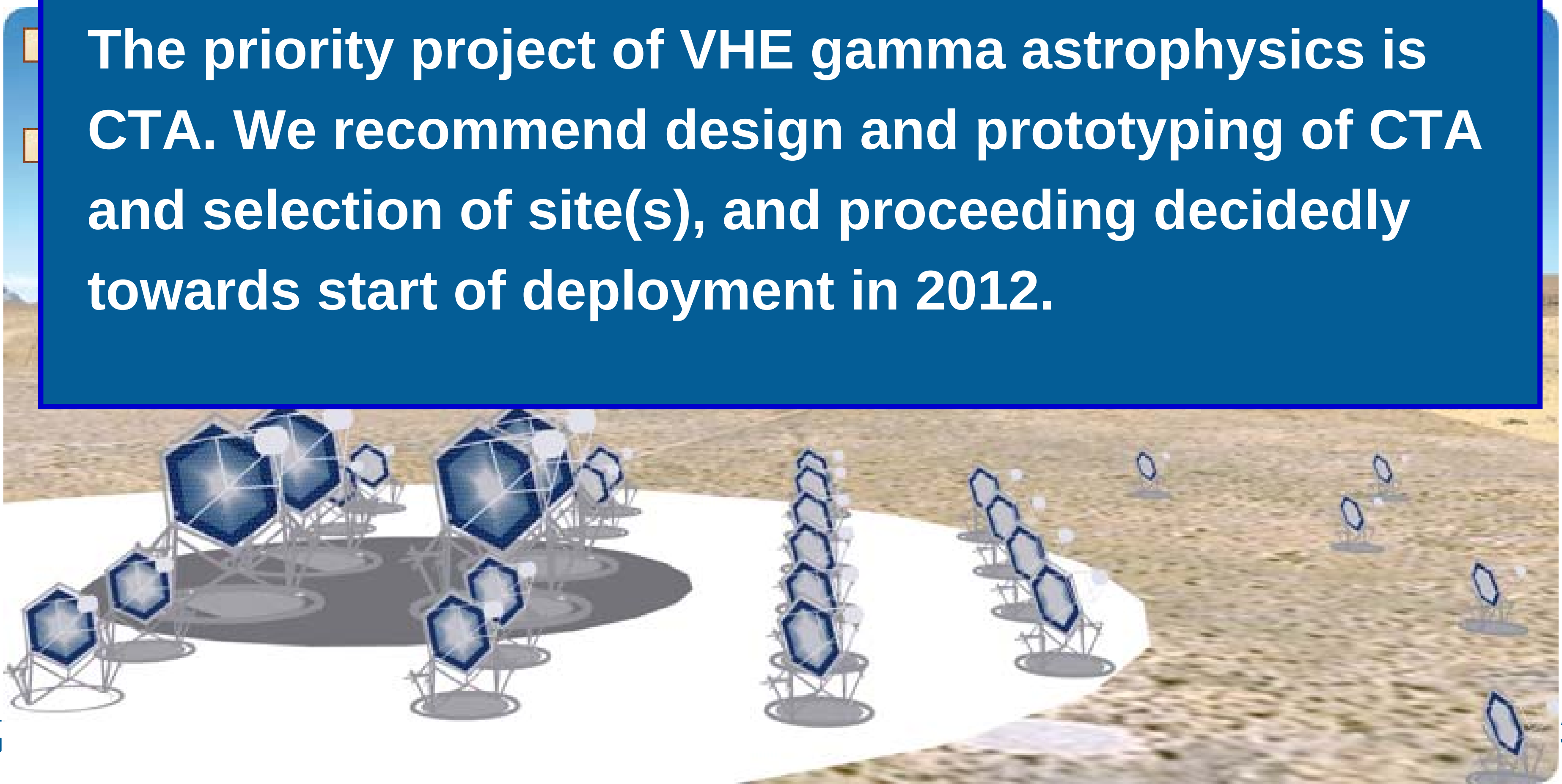
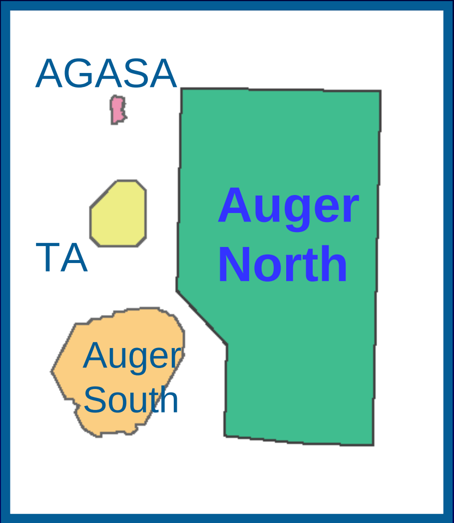
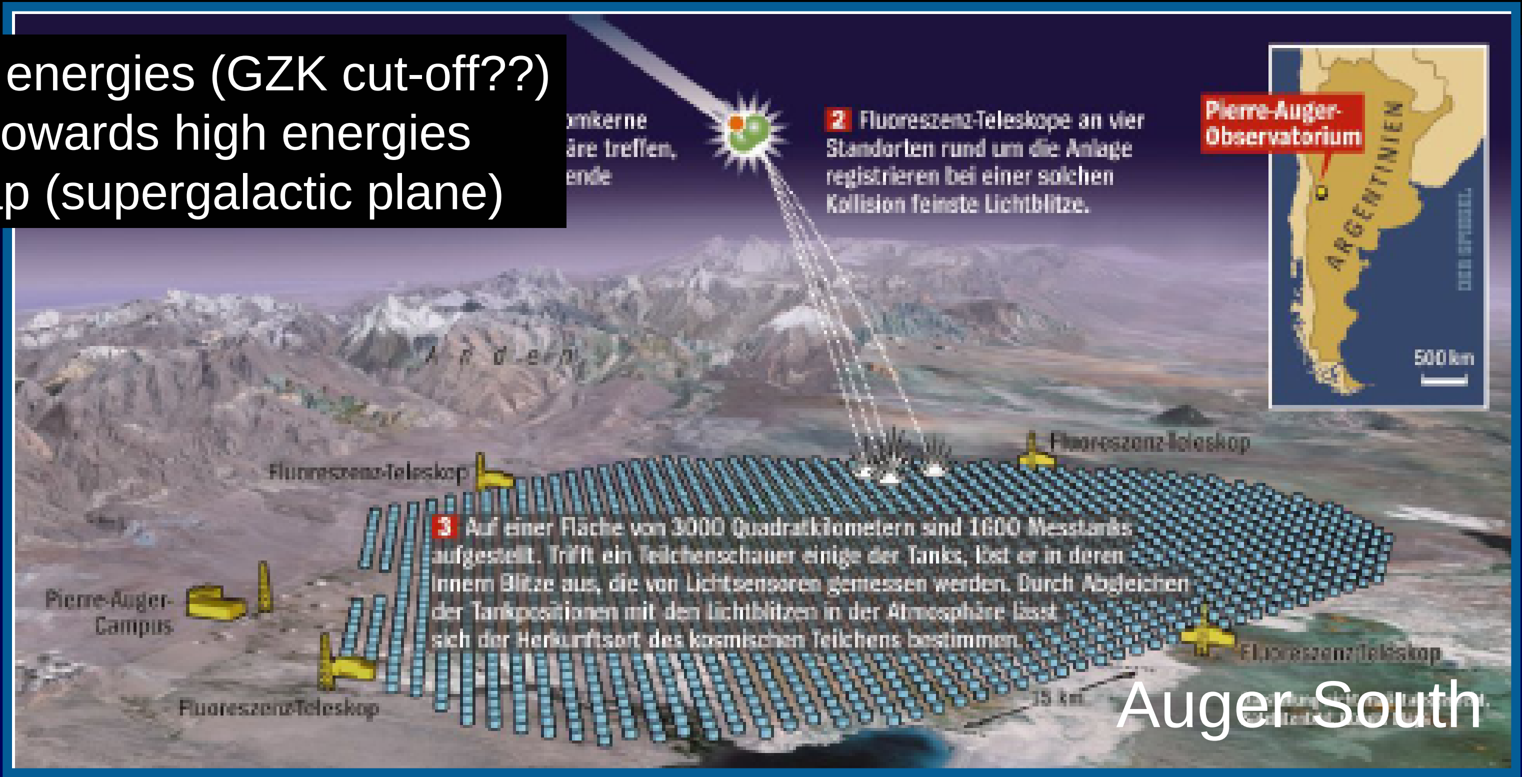


The priority project of VHE gamma astrophysics is CTA. We recommend design and prototyping of CTA and selection of site(s), and proceeding decidedly towards start of deployment in 2012.

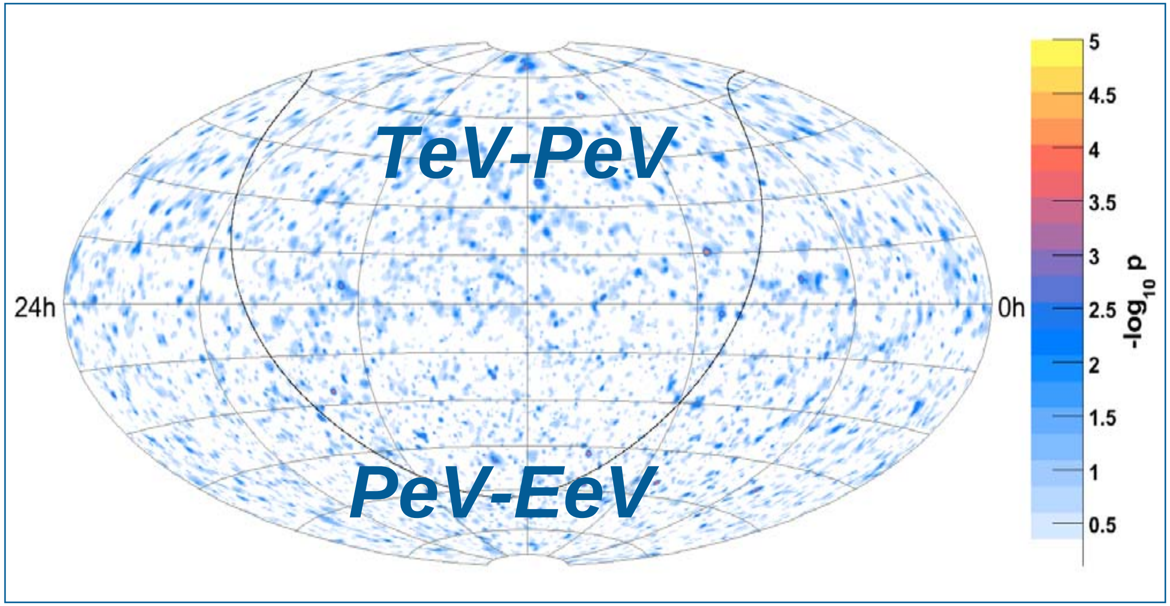
Pierre Auger Observatory

- 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.

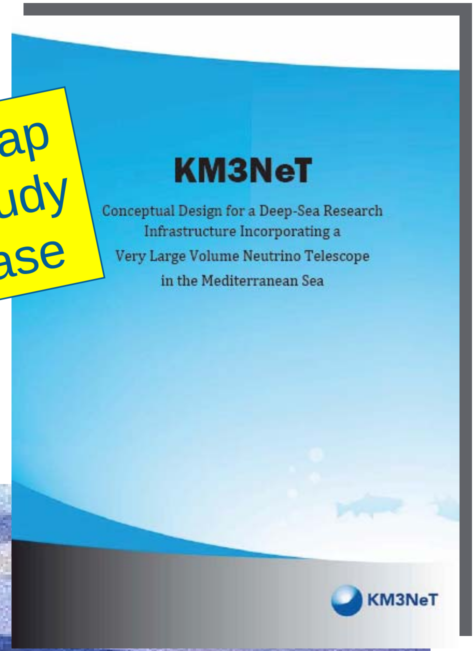


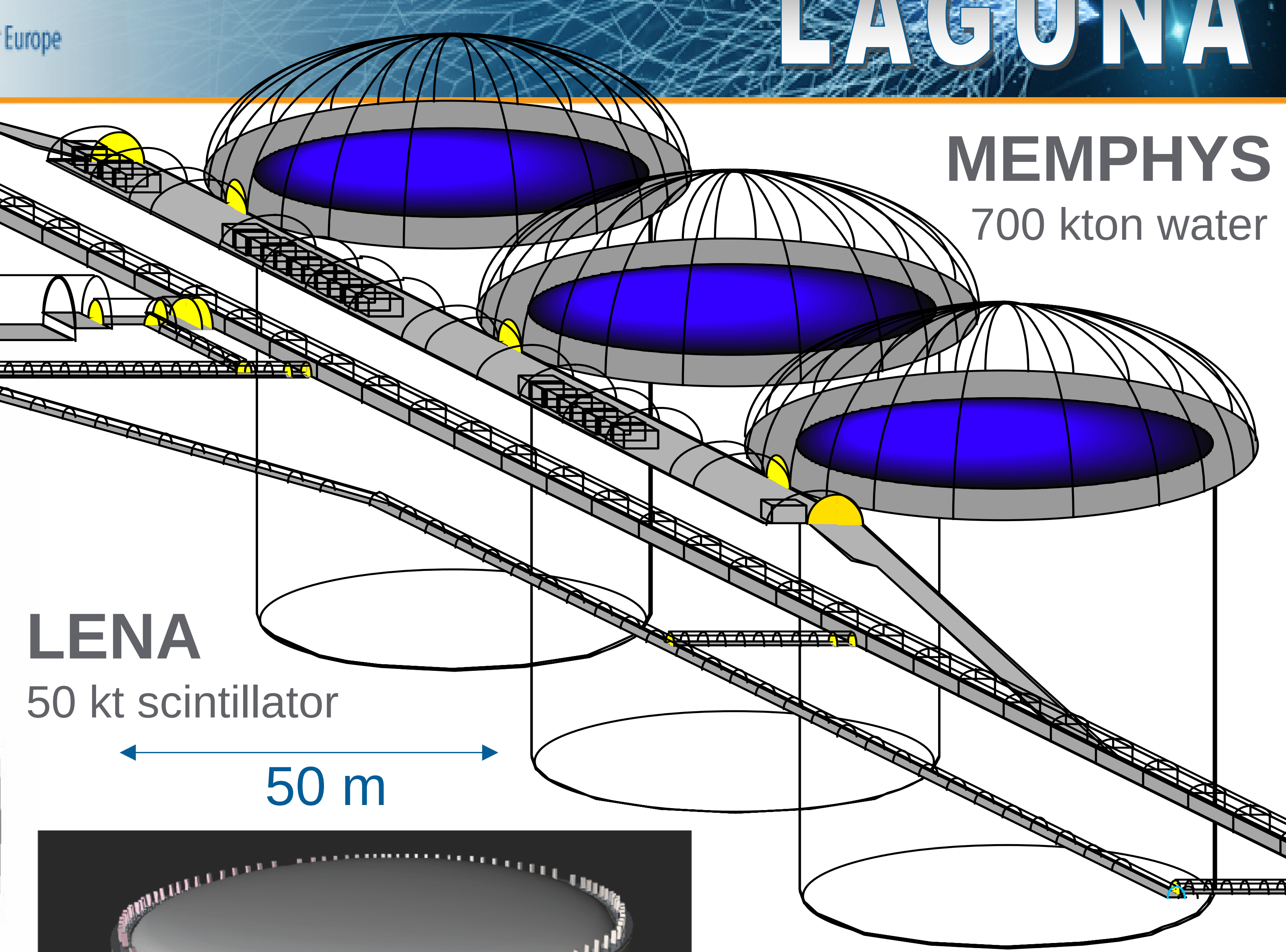
First full-sky IceCube skymap (40 strings, 6 months)
challenges KM3NeT sensitivity !

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.

ESFRI Roadmap
FP6 design study
FP7 prep. phase





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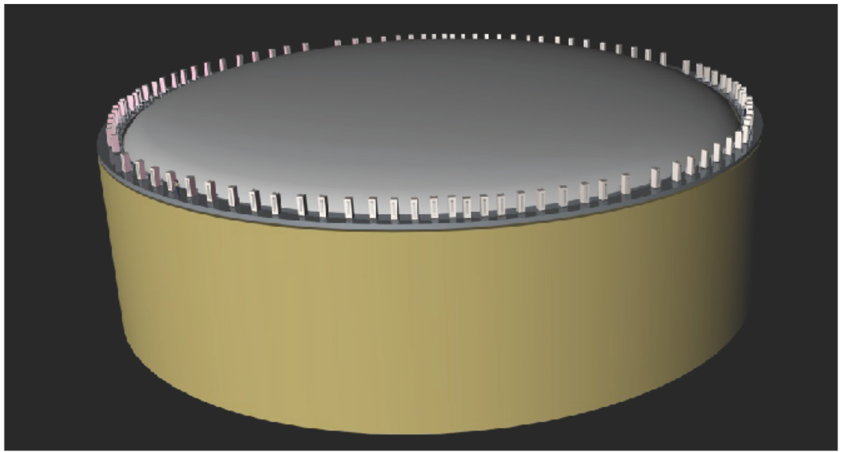
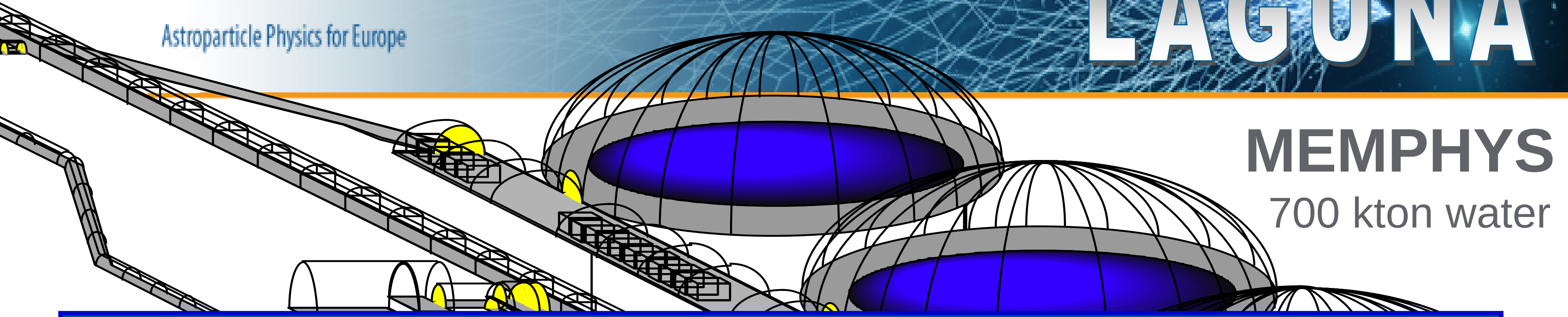


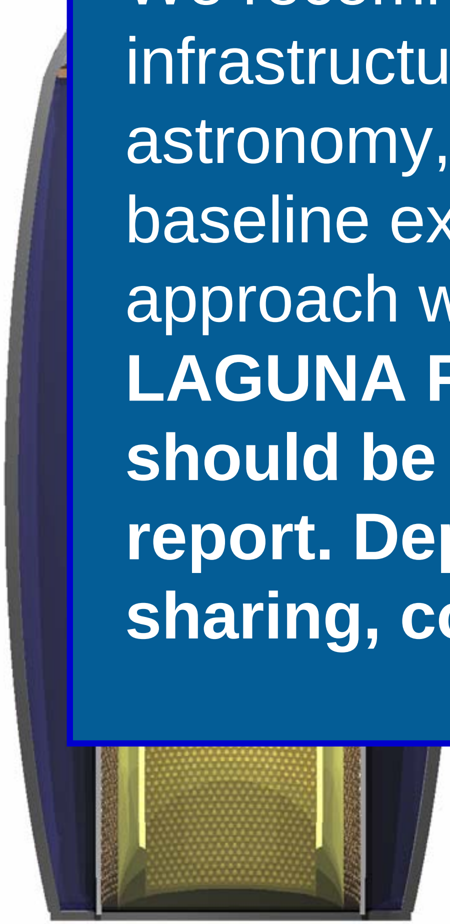
GLACIER
100 kton liquid argon



MEMPHYS

700 kton water

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.**



GLACIER

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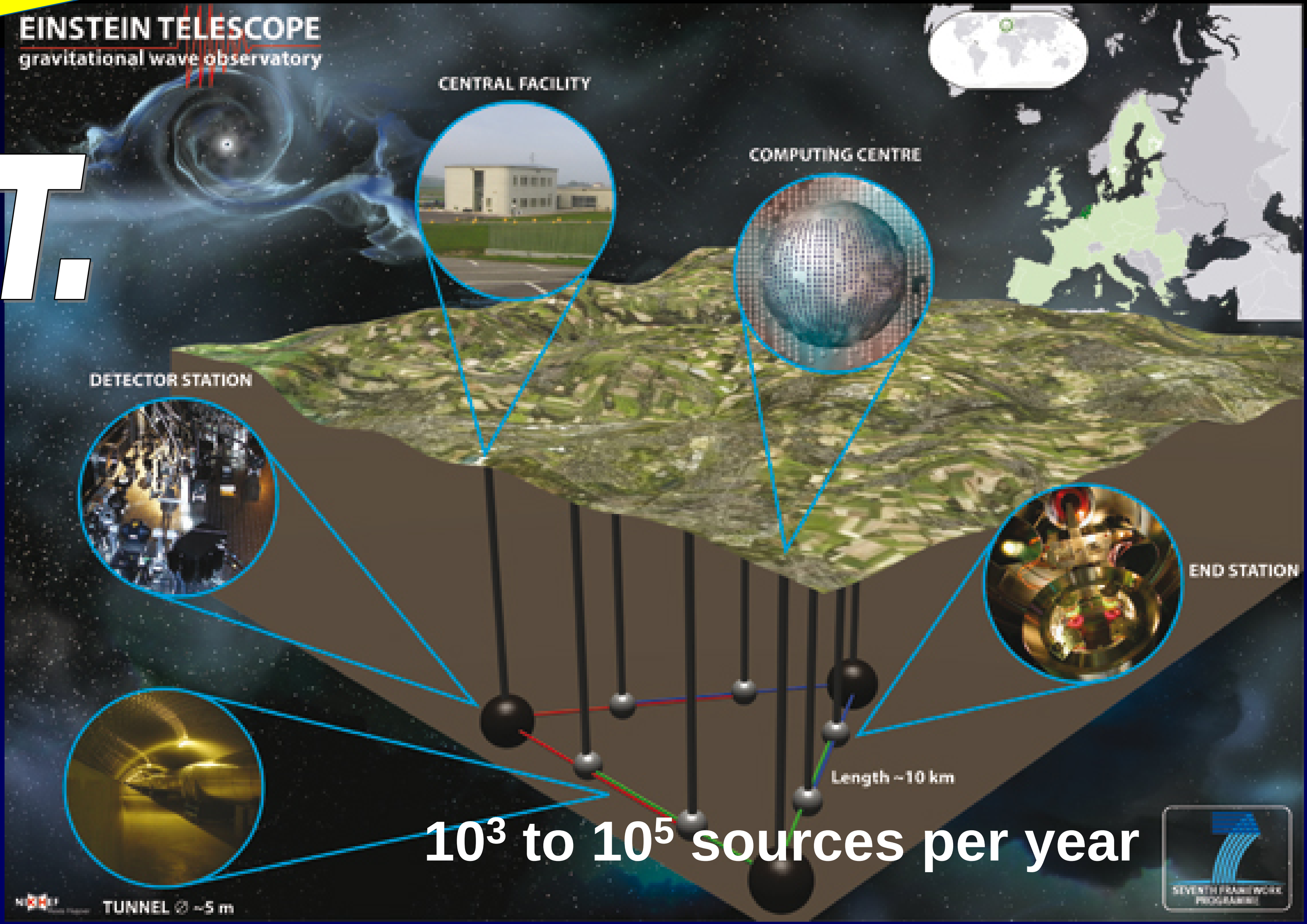
Einstein Telescope

FP7 design study

E.T.

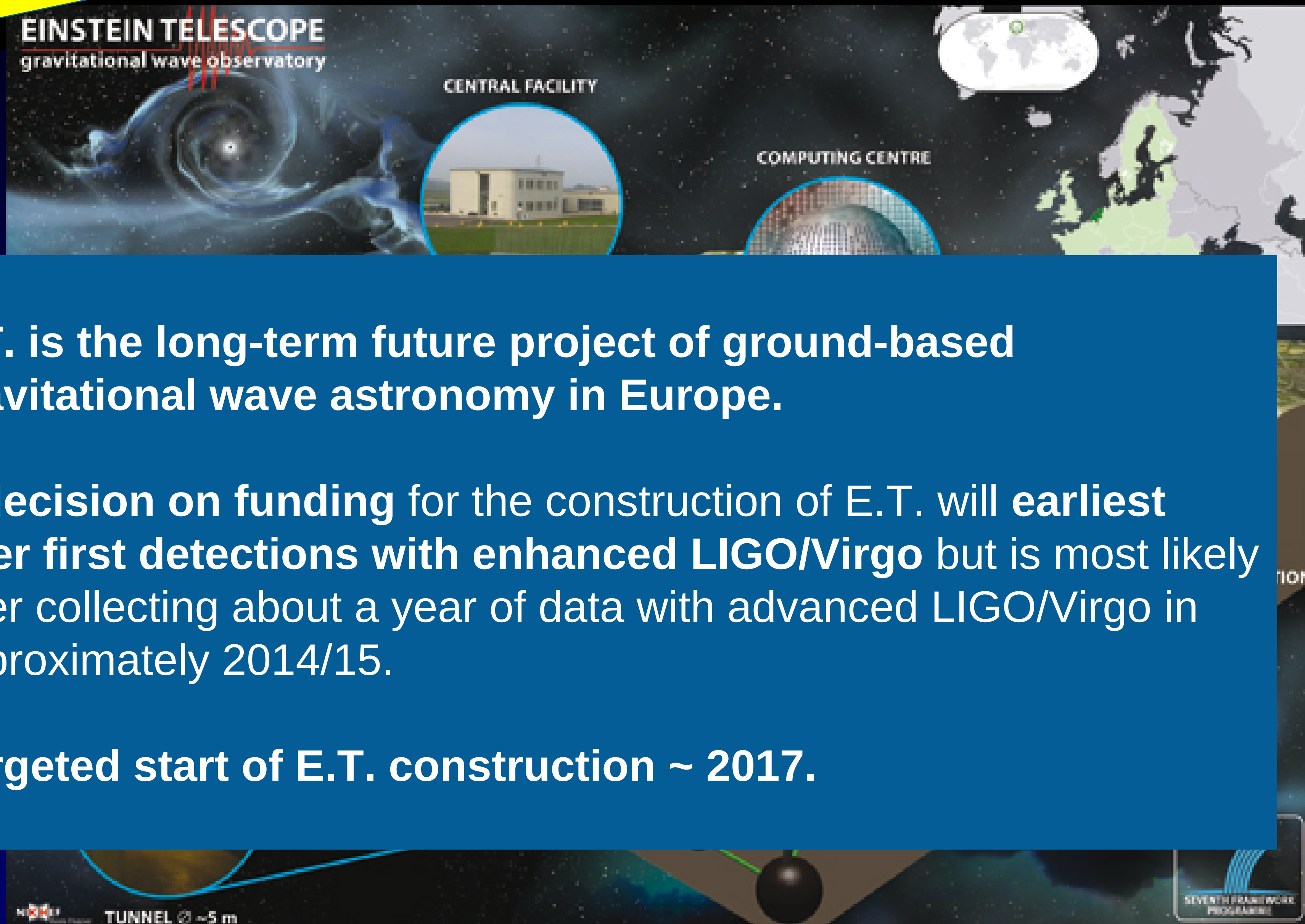


10^3 to 10^5 sources per year

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

- **Astroparticle and LHC physics are closely linked.**
- Several questions can be **convincingly answered only if astroparticle searches are combined with LHC results.**

- **Astroparticle Physics:**
  - 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
  - ApP could enhance the scientific portfolio of CERN