European Astroparticle Physics

Status and Vision

Christian Spiering, DESY

LEXI Meeting
Hamburg, Oct. 12, 2012

http://www.aspera-eu.org

European Astroparticle Physics

Vision

Modified version of Cracow talk on behalf of ASPERA

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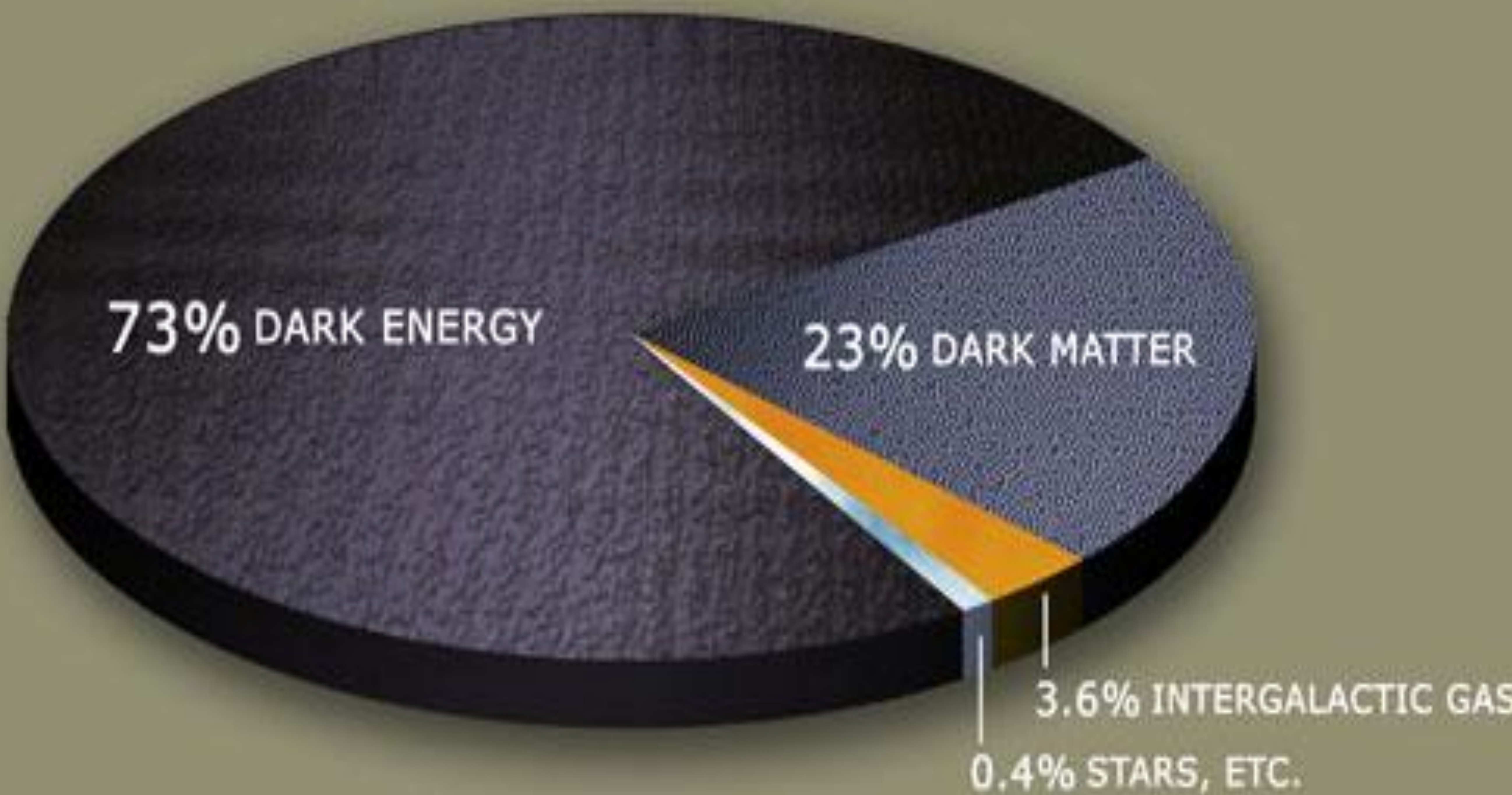
1. Dark matter searches
    a. WIMPs
    b. Axions
2. Mass and nature of neutrinos: $0\nu\beta\beta$
3. Large underground detectors
4. High-energy Universe (and the LHC)

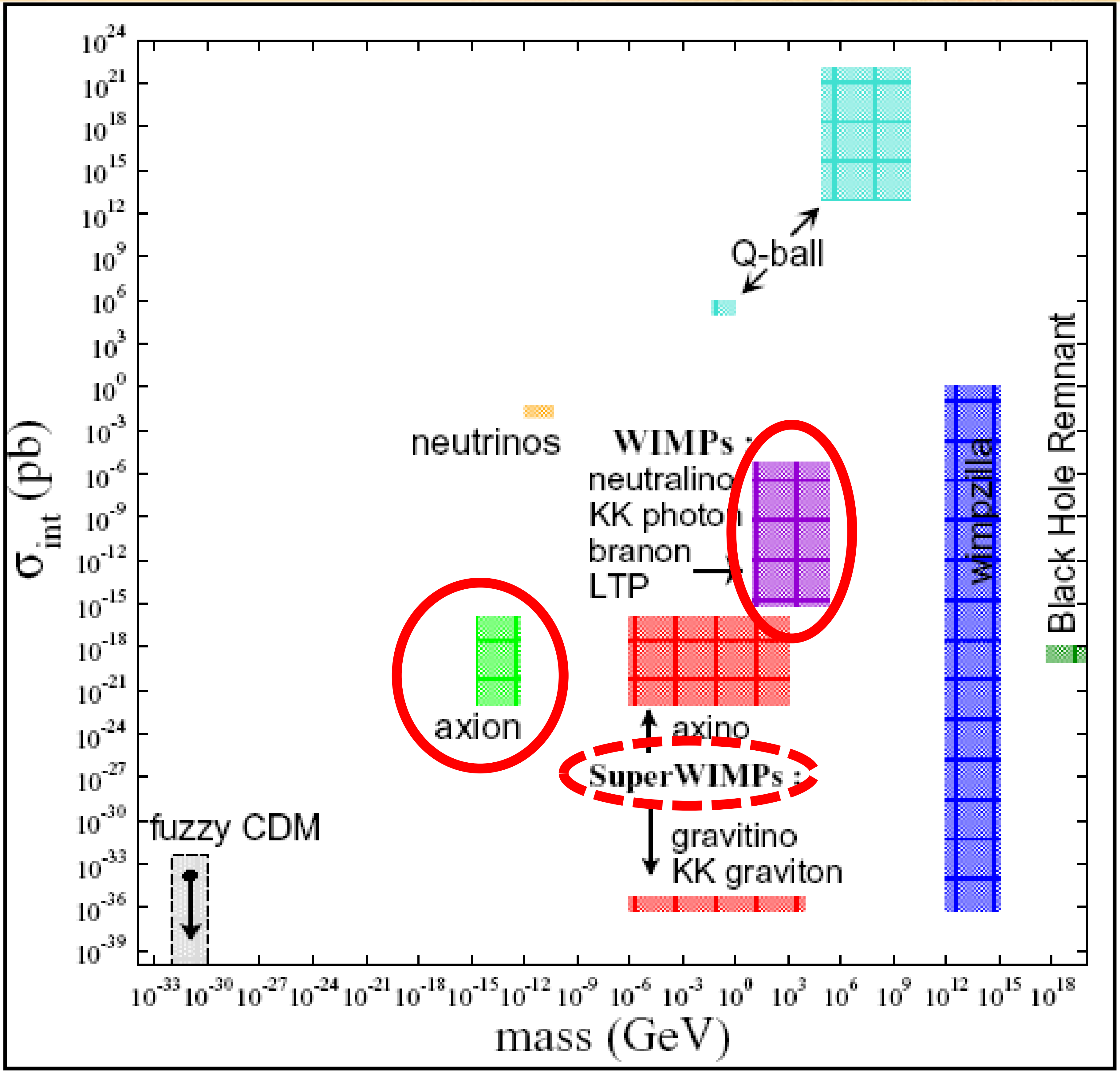
1

Dark Matter Searches

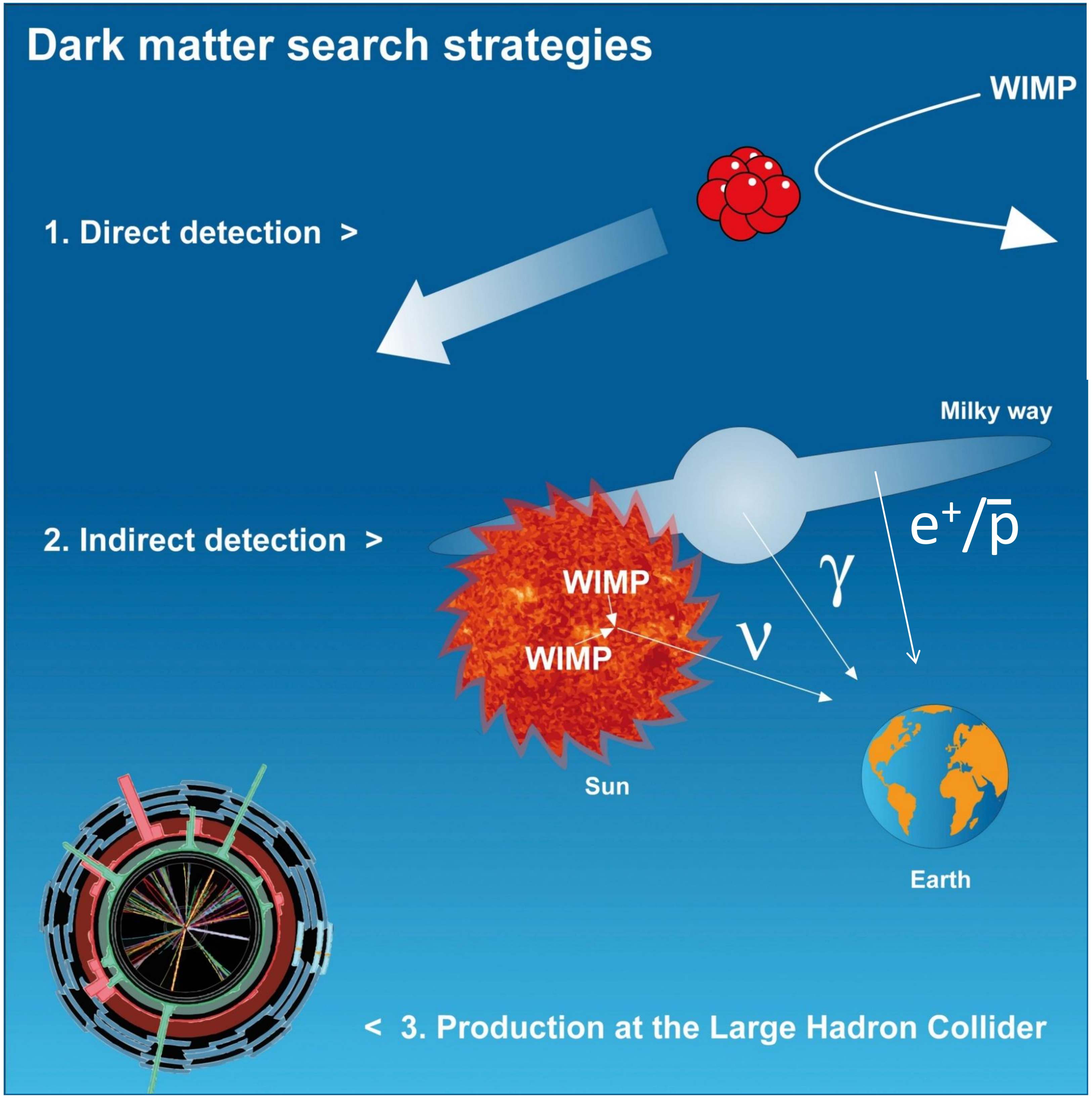
Physics case

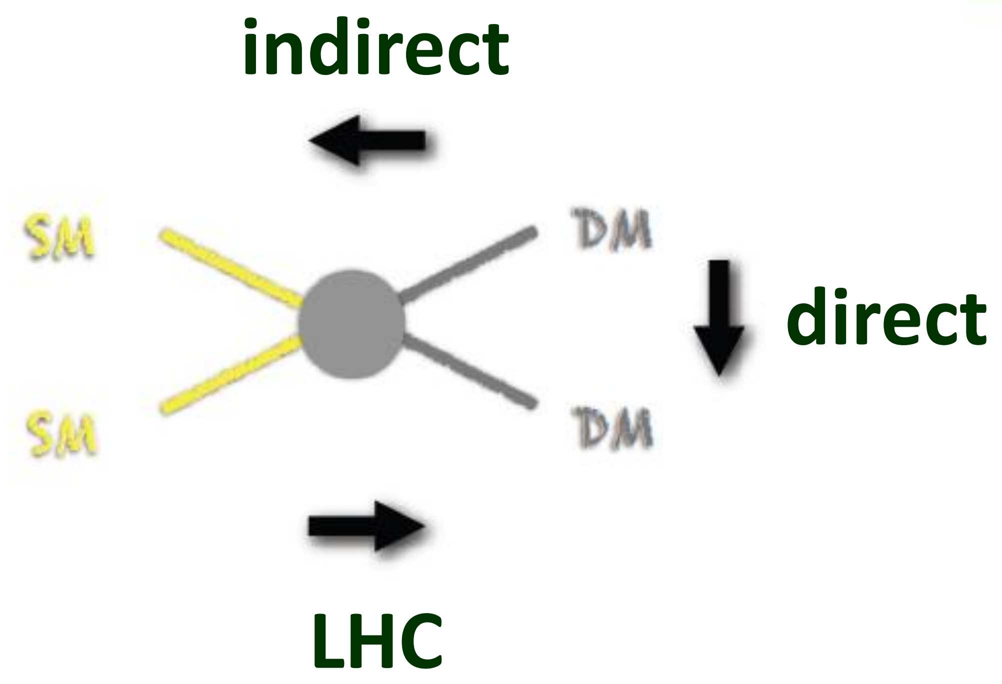


Particle Candidates



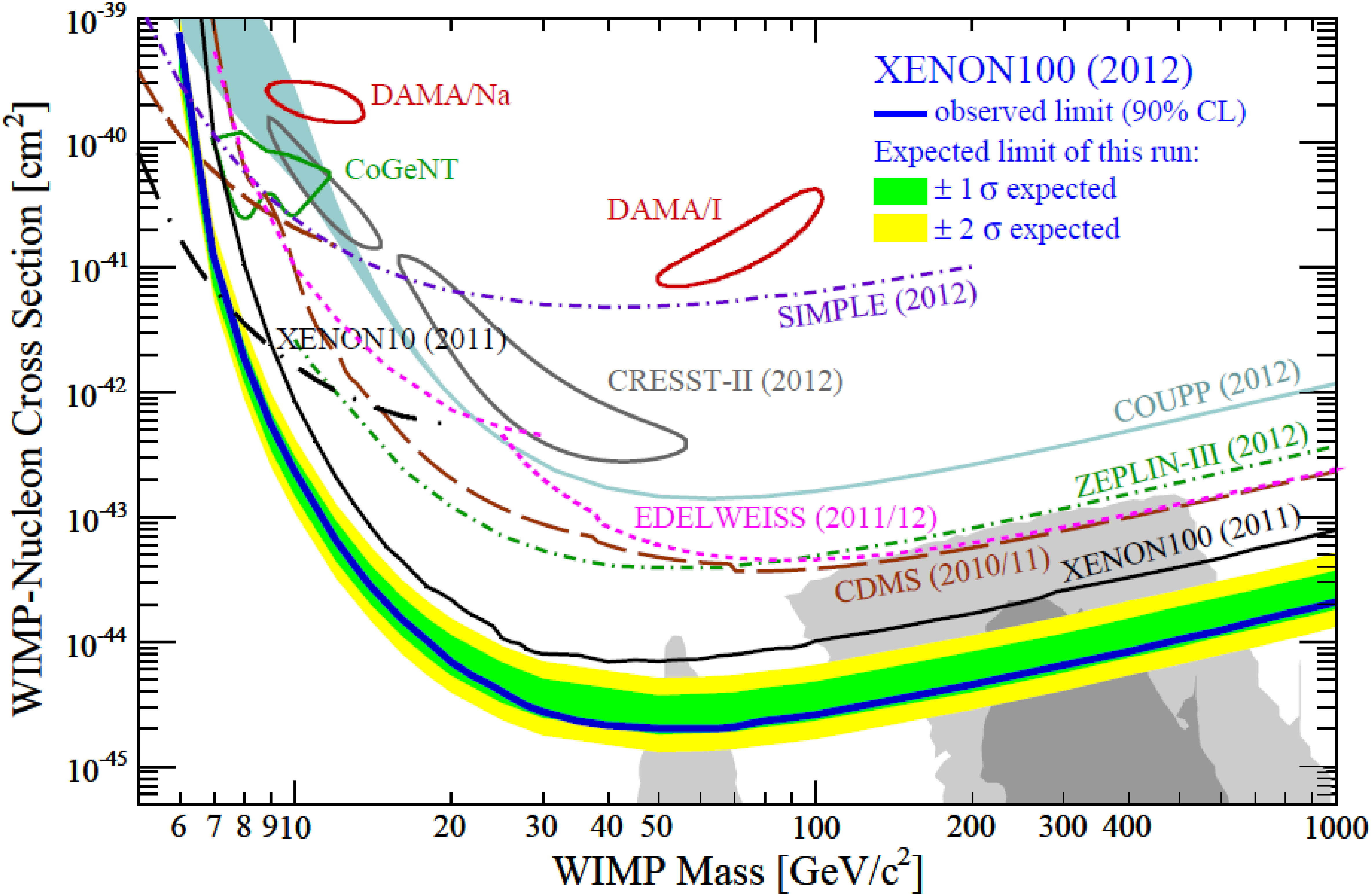
Methods to search for (SUSY) WIMPs



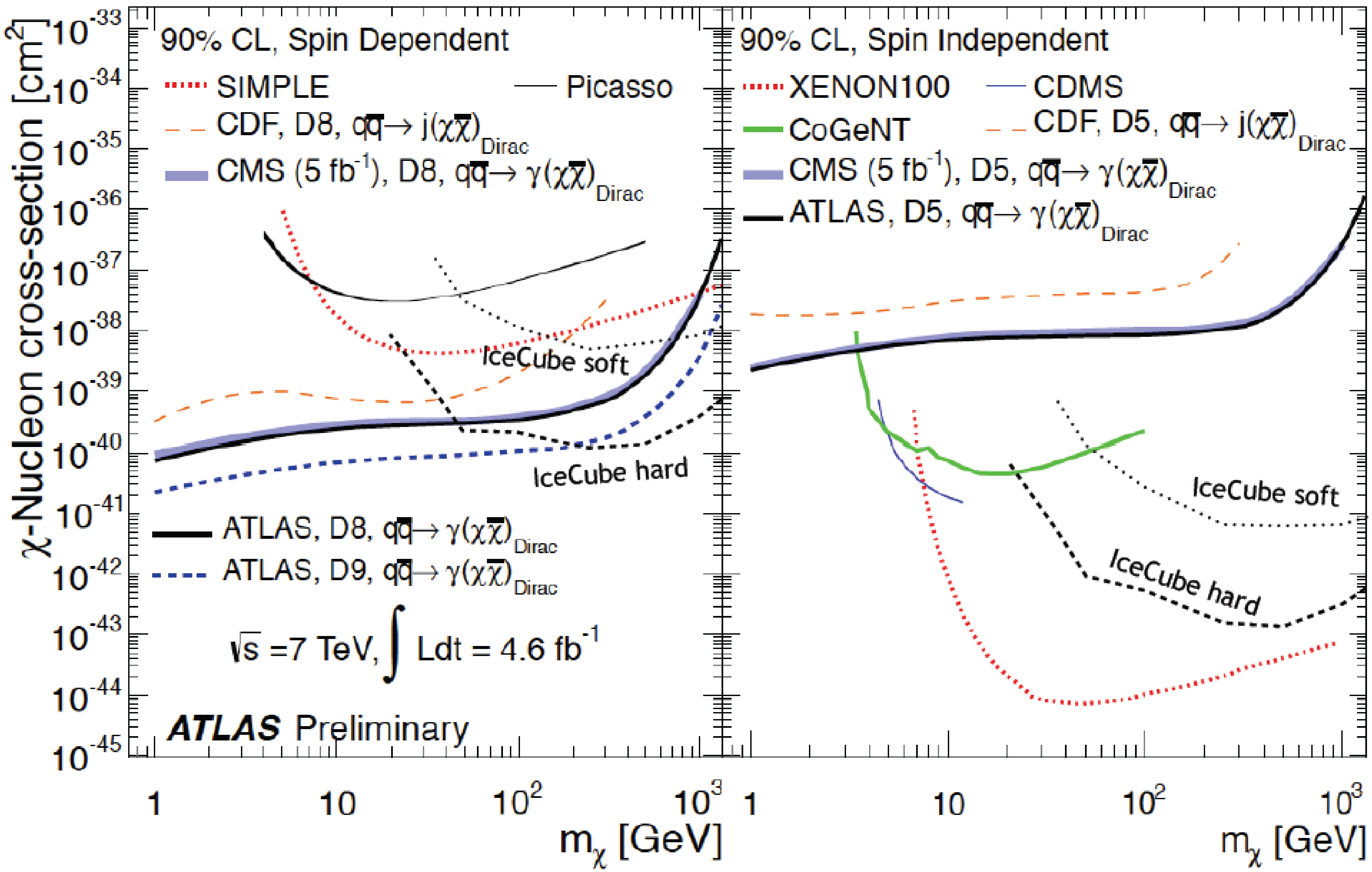


ν	IceCube, Antares
γ	HESS/MAGIC/VERITAS Agile, Fermi
e/p	balloon exp.s, Pamela, Fermi, AMS

Snapshot Summer 2012

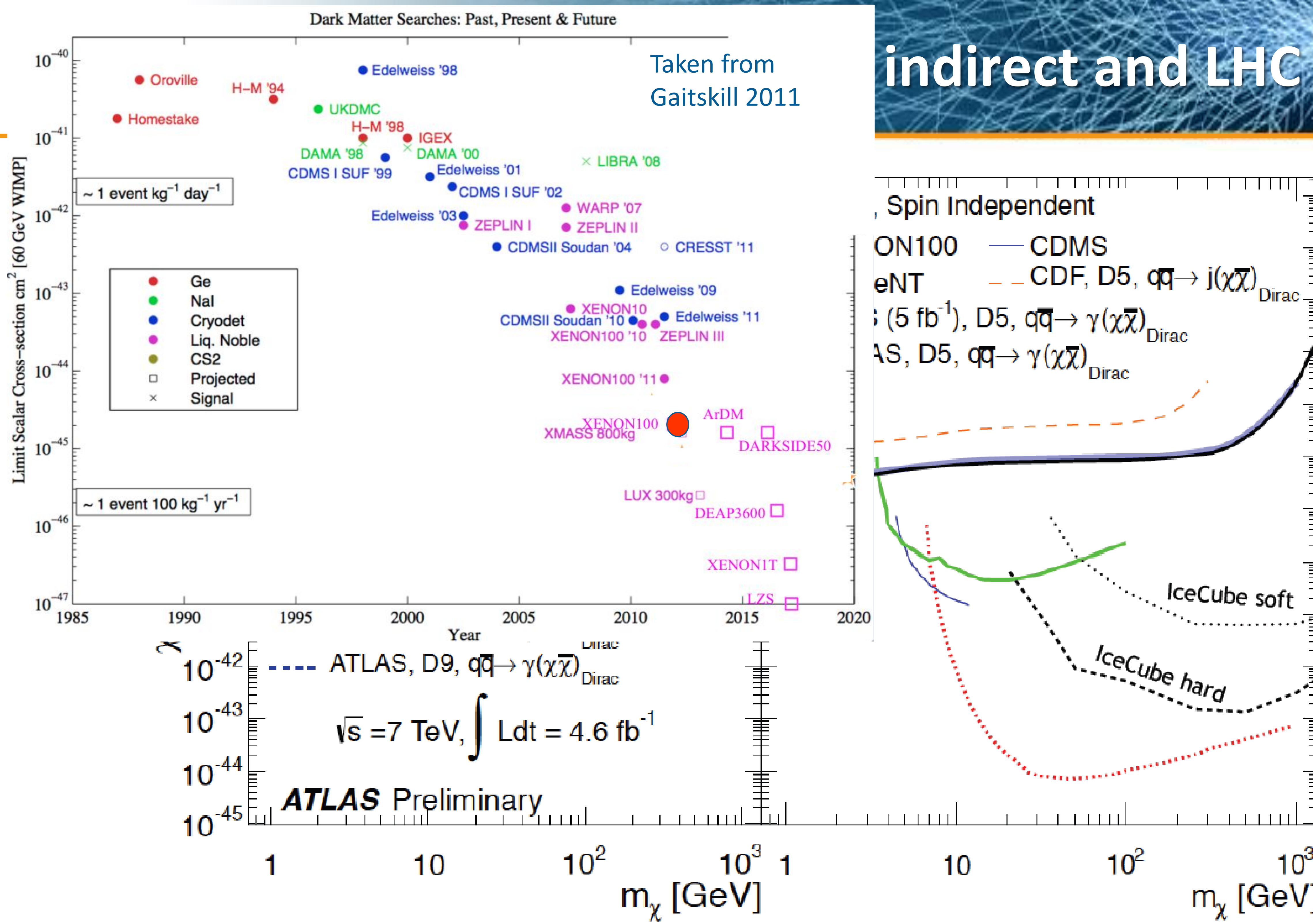


Synergy of direct, indirect and LHC searches



- Direct searches will improve sensitivity by a factor of 100 over the next 5-7 years
- Indirect searches with IceCube will improve sensitivity by a factor 10-20
- AMS results: looking forward to data release end of the year!
- LHC 7 → LHC 14: factor 300-1000

indirect and LHC searches



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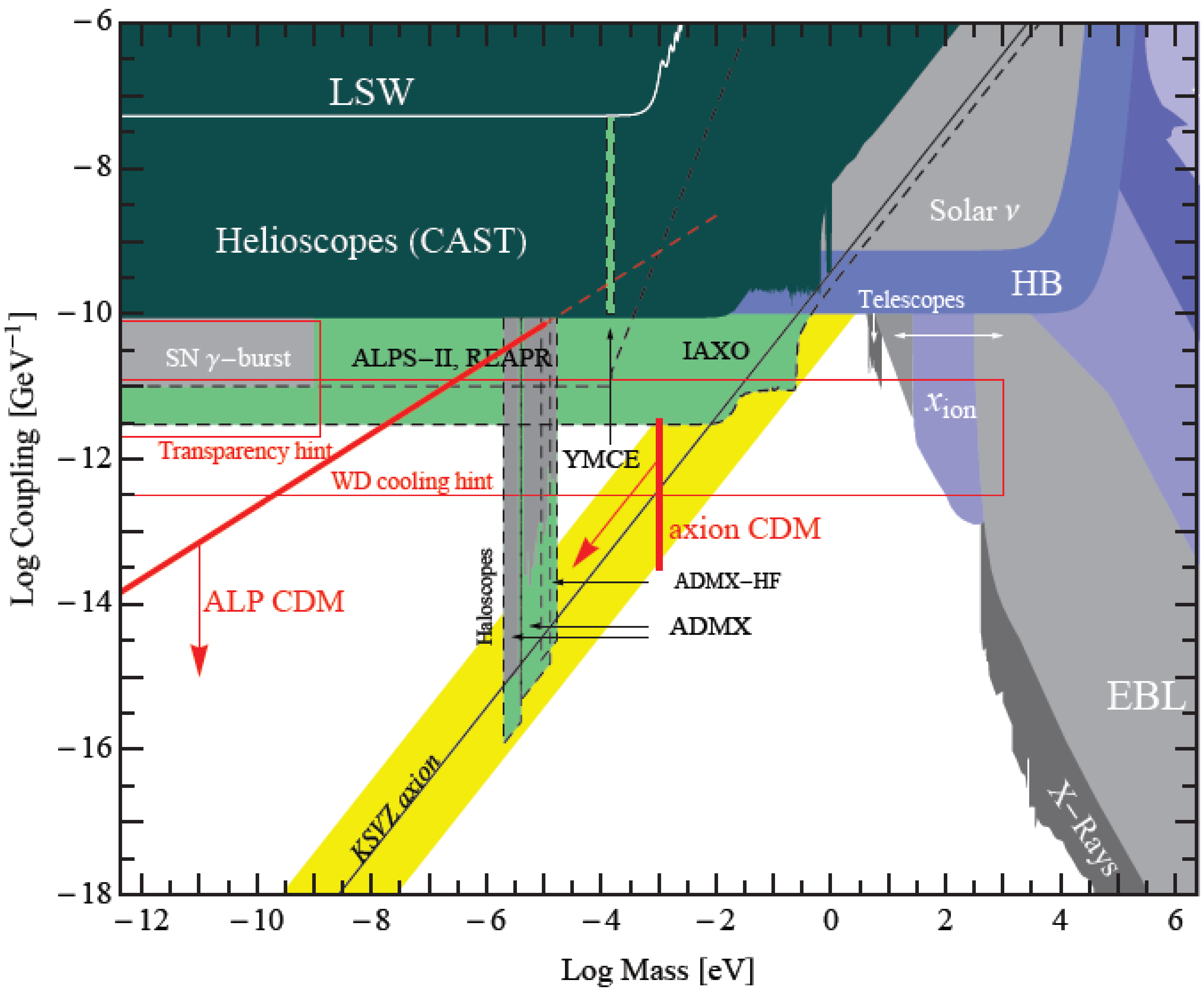
Recommendations WIMP Dark Matter

- **With the advent of the LHC and thanks to a new generation of astroparticle experiments using direct and indirect detection methods, the SUSY -WIMP dark matter hypothesis will be proven or disproven within the next 5-10 years.**
- Stormy progress of LXe technology. XENON100 with record limits. **XENON1T** under construction.
- LAr technology attracts new interest using argon depleted in ^{39}Ar. Potential of technology will be demonstrated by DarkSide-50 (50 kt, LNGS, end 2012).
- **SAC recommends that DARWIN (target mass of noble liquids up to 10-20 tons) is pursued and supported. Choice of double-target options after demonstration of LAr capabilities.**

  Other potential capabilities of DARWIN: solar ν in real time, $0\nu\beta\beta$ decay with ^{136}Xe.
- Bolometric approach remained (nearly) competitive with noble liquids in sensitivity. EDELWEISS (Ge), CRESST ($CaWO_4$). CDMS in US. Need cross-check of possible signals in noble liquids!
- **SAC supports development of EURECA (~1 ton sensitive mass) and the on-going cooperation with the CDMS follow-up projects.**
- SAC supports R&D on directional detection, as a confirmation of the galactic character of potential positive detection by high-density target detectors
- SAC supports improving DAMA/LIBRA w.r.t. lower threshold and lower background to better understand the modulation. Fully independent experiment of same/similar technology is crucial.

Parameter space for axions or axion-like particles



- **Experimentally excluded**
- Astronomy constraints
- Cosmology constraints
- Sensitivity of planned experiments

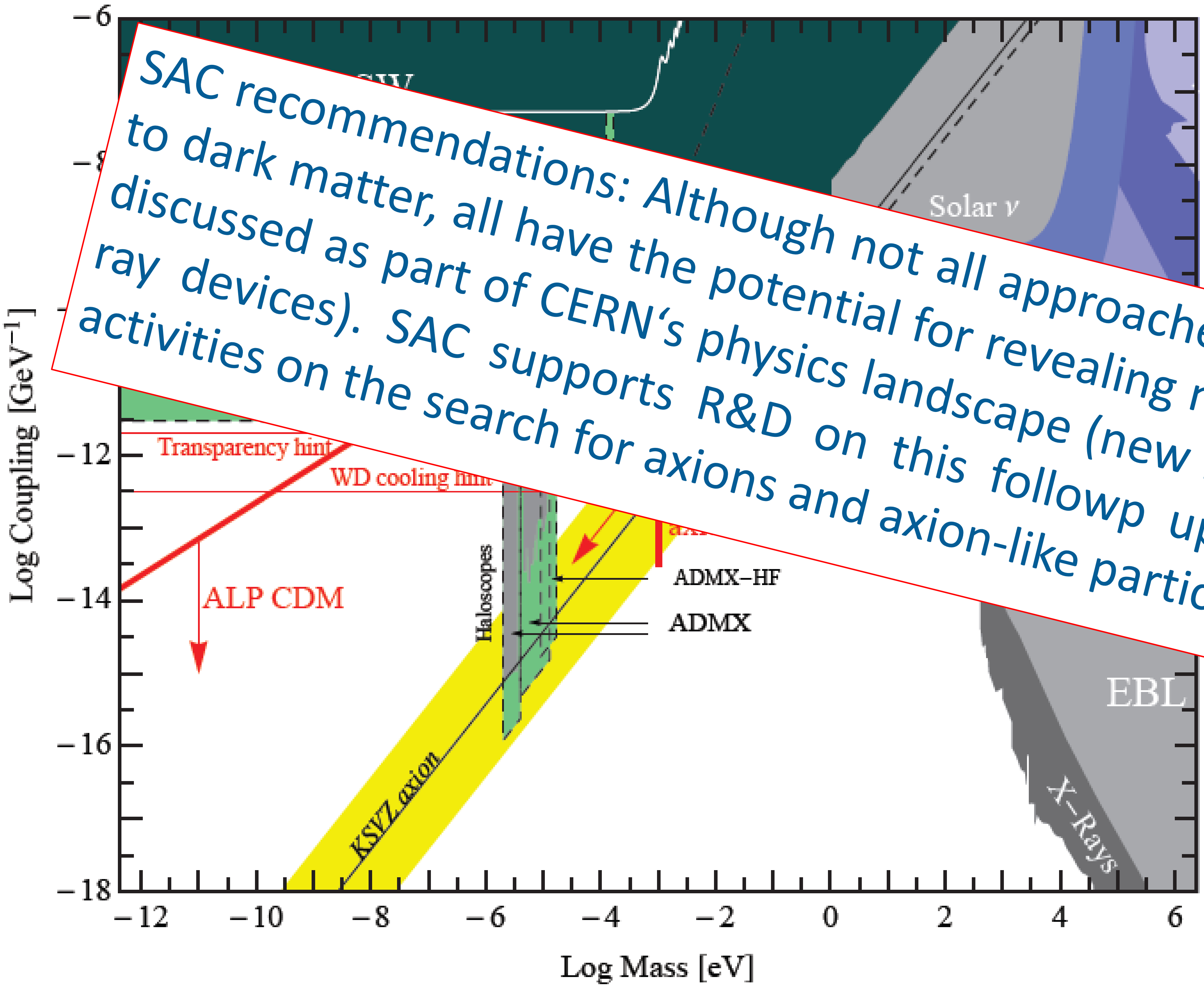
IAXO: CAST follow-up

10T magnets, 16m
low-BG/threshold X-ray detectors

50-100 M€

Axions

Parameter space for axions or axion-like particles



- **Experimentally excluded**
- **Astronomy constraints**
- **Cosmology constraints**
- **Sensitivity of planned experiments**

SAC recommendations: Although not all approaches in this field are strictly related to dark matter, all have the potential for revealing new physics. A CAST follow-up is discussed as part of CERN's physics landscape (new magnets, new cryogenic and X-ray devices). SAC supports R&D on this followp up, as well as smaller ongoing activities on the search for axions and axion-like particles.

IAXO: CAST follow...

10T magnets, 16m
low-BG/threshold X-ray detectors

50-100 M€

2

Mass and Nature of the Neutrino

m_ν $\rightarrow$ direct measurements: KATRIN

$\rightarrow$ neutrinoless double beta decay, $0\nu\beta\beta$

Majorana vs Dirac

$\rightarrow$ neutrinoless double beta decay

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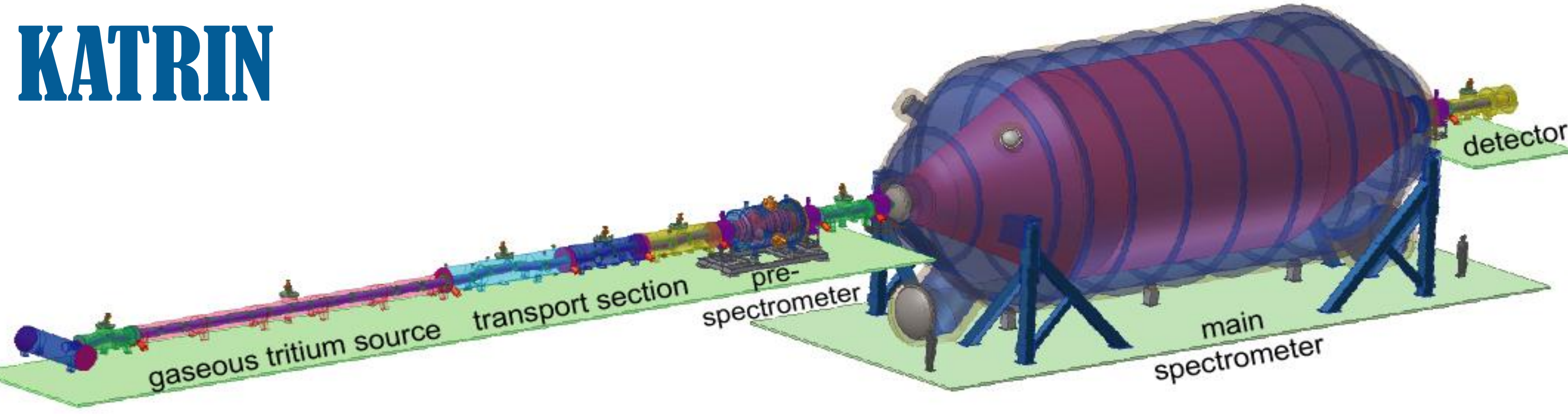
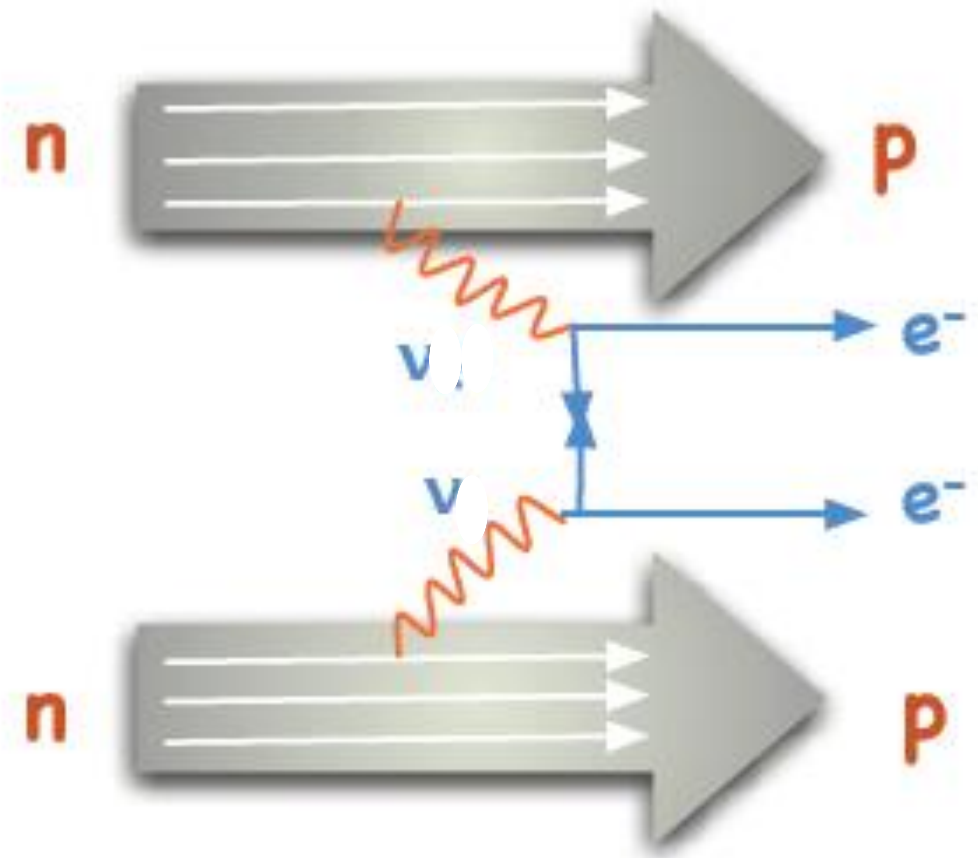
KATRIN



Expected sensitivity: 0.2 eV (90% C.L.)

$0\nu\beta\beta$: physics case

- **Majorana vs Dirac**
- mass & mass hierarchy



Physics beyond SM

Essential for Leptogenesis

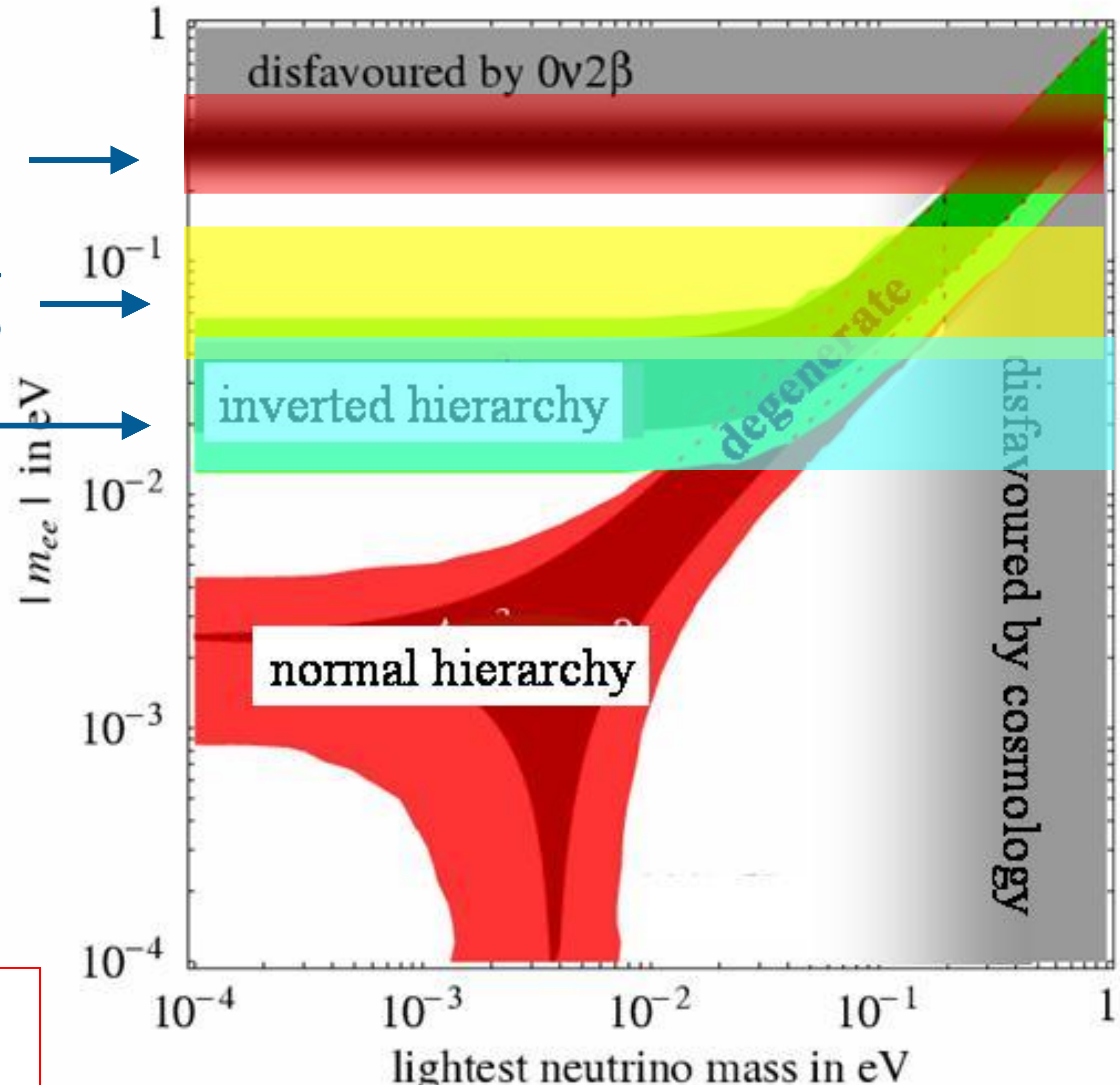
0νββ: physics case

- **Majorana vs Dirac**
- mass & mass hierarchy

KKGH claim

GERDA, EXO200, SNO+
CUORE, SuperNEMO

Ton-scale



Price tag for ton-scale
50-150 M€.

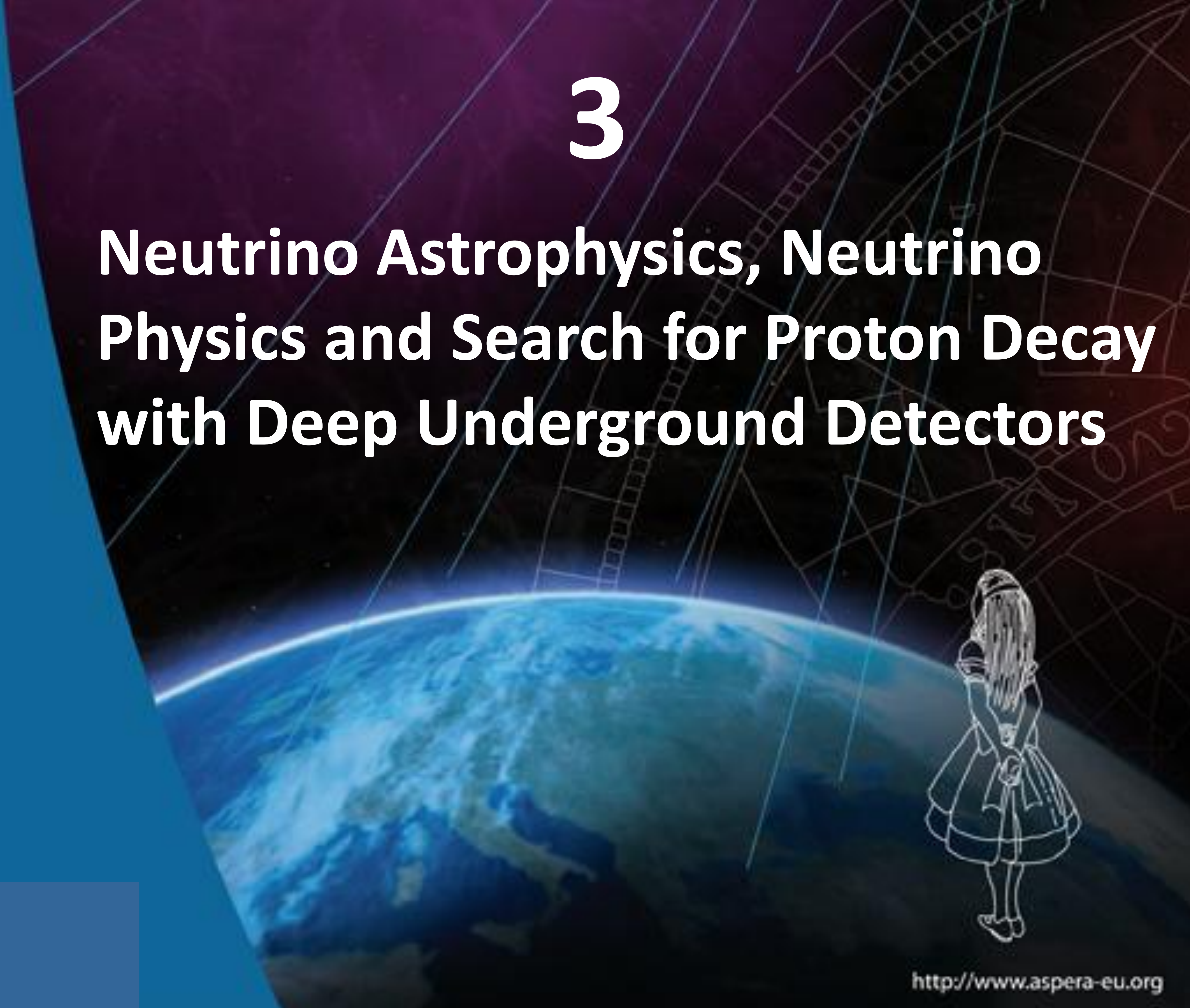

GERDA

Recommendations 0νββ decay

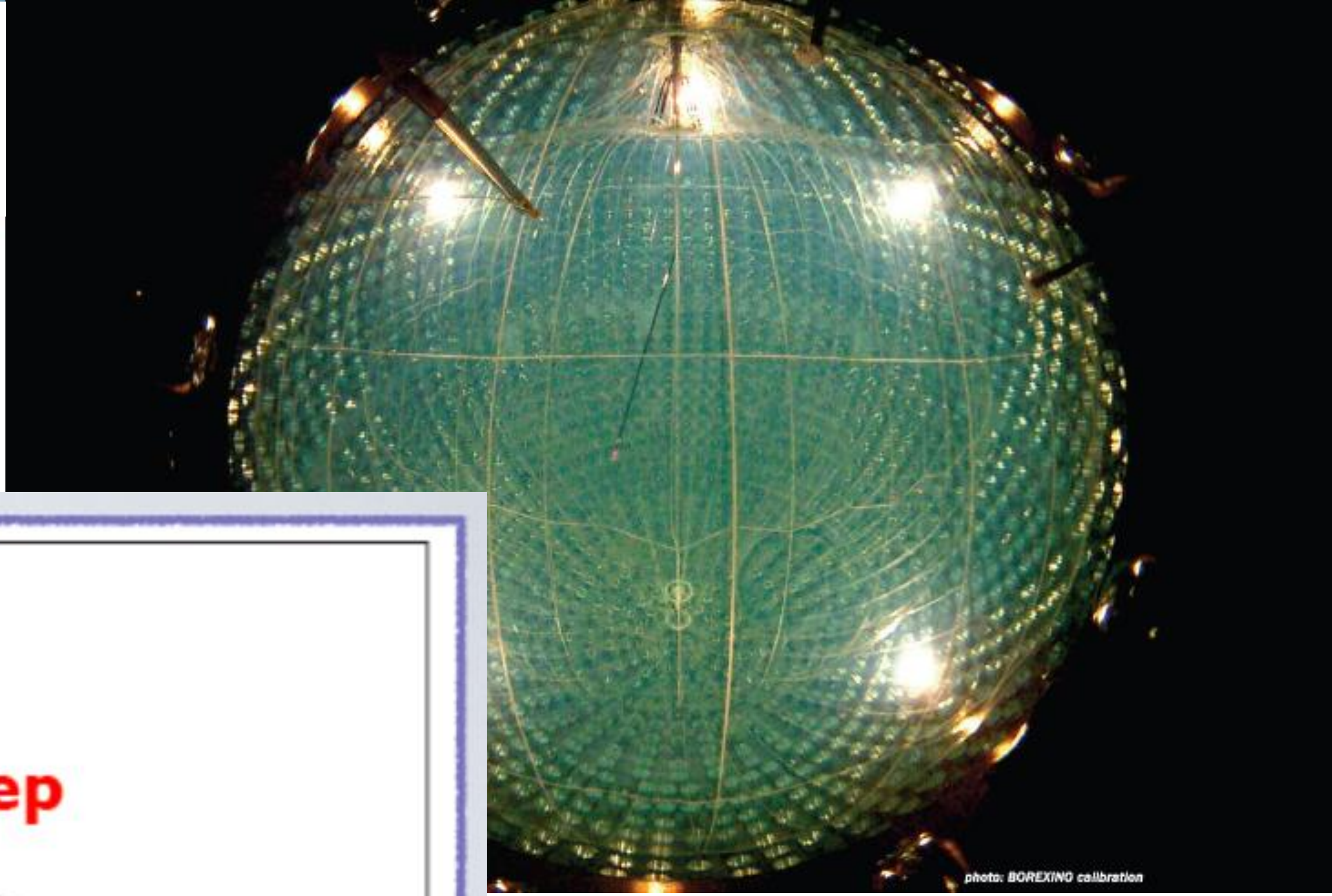
- Data taking of new generation 0νββ has started: **Kamland-Zen (**Japan), **EXO** (US), **GERDA, Cuore-0** (Europe): ***Degenerate*** region
- **CUORE** (start ≥2014) will probe part of ***Inverted Hierarchy*** region.
- Discovery on degenerate level → path to precision measurement with 3 different nuclei and the unique capabilities provided by **SuperNEMO**.
- GERDA/CUORE/SuperNEMO build on long experience and validation with precursors.
- **NEXT:** new approach, steep time gradient. SAC encourages coll. To demonstrate all aspects of technology/physics capability and to move ahead toward NEXT-100 (see input paper on NEXT).
- **SAC recommends a phased experimental approach towards ton-scale masses with a sensitivity exploring fully the mass range predicted by oscillation experiments for the Inverted Hierarchy.**
- SAC supports **R&D towards new promising technologies** (scintillating bolometers, pixel detectors, ….) in view of final assessment of most effective approach towards ton-scale
- SAC encourages companies and labs to continue R&D on new techniques for **isotope separation.**
- **High cost of ton-scale → realisation within worldwide collaborations, as e.g. pursued by GERDA and MAJORANA.**

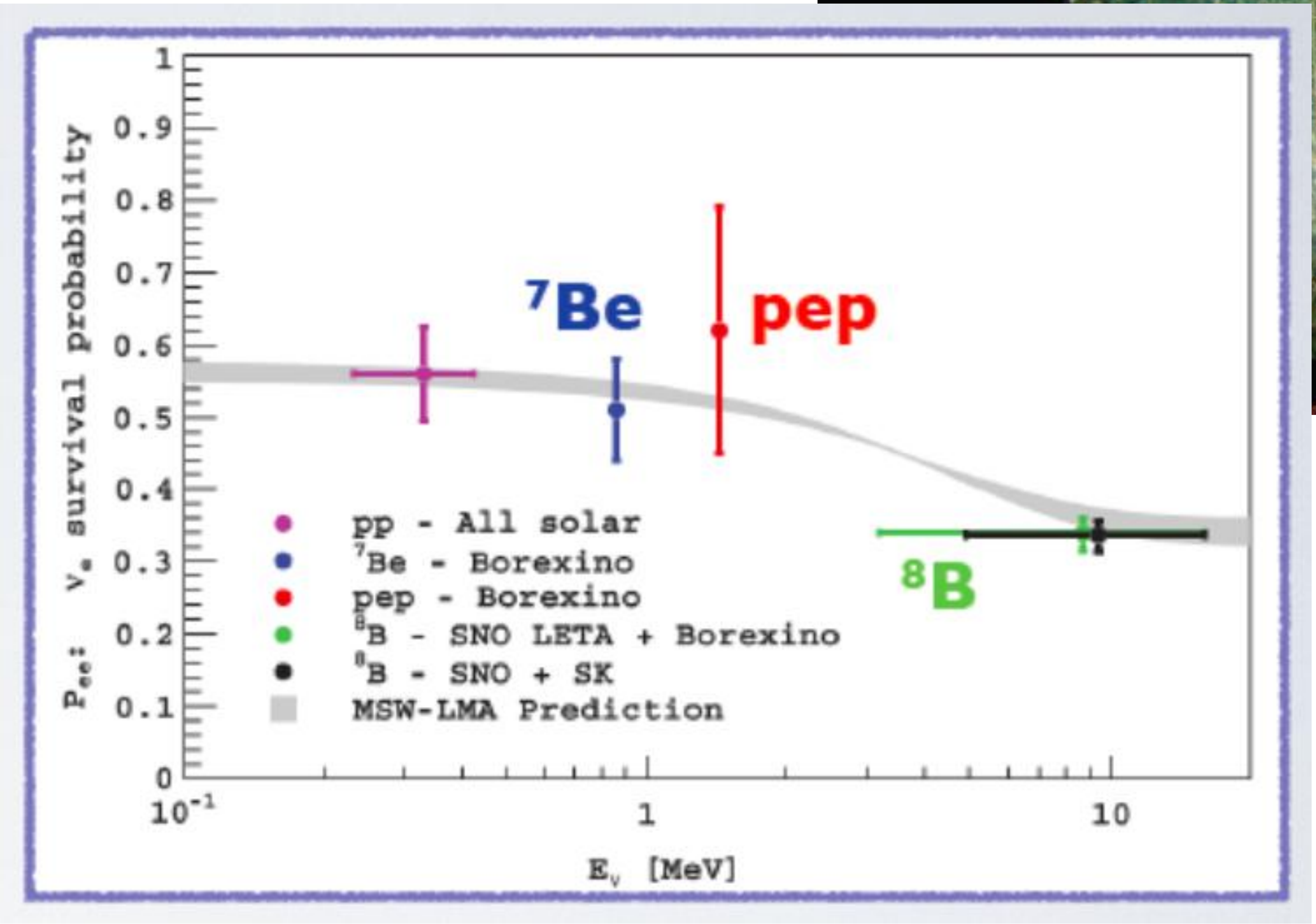
3

Neutrino Astrophysics, Neutrino Physics and Search for Proton Decay with Deep Underground Detectors



Borexino





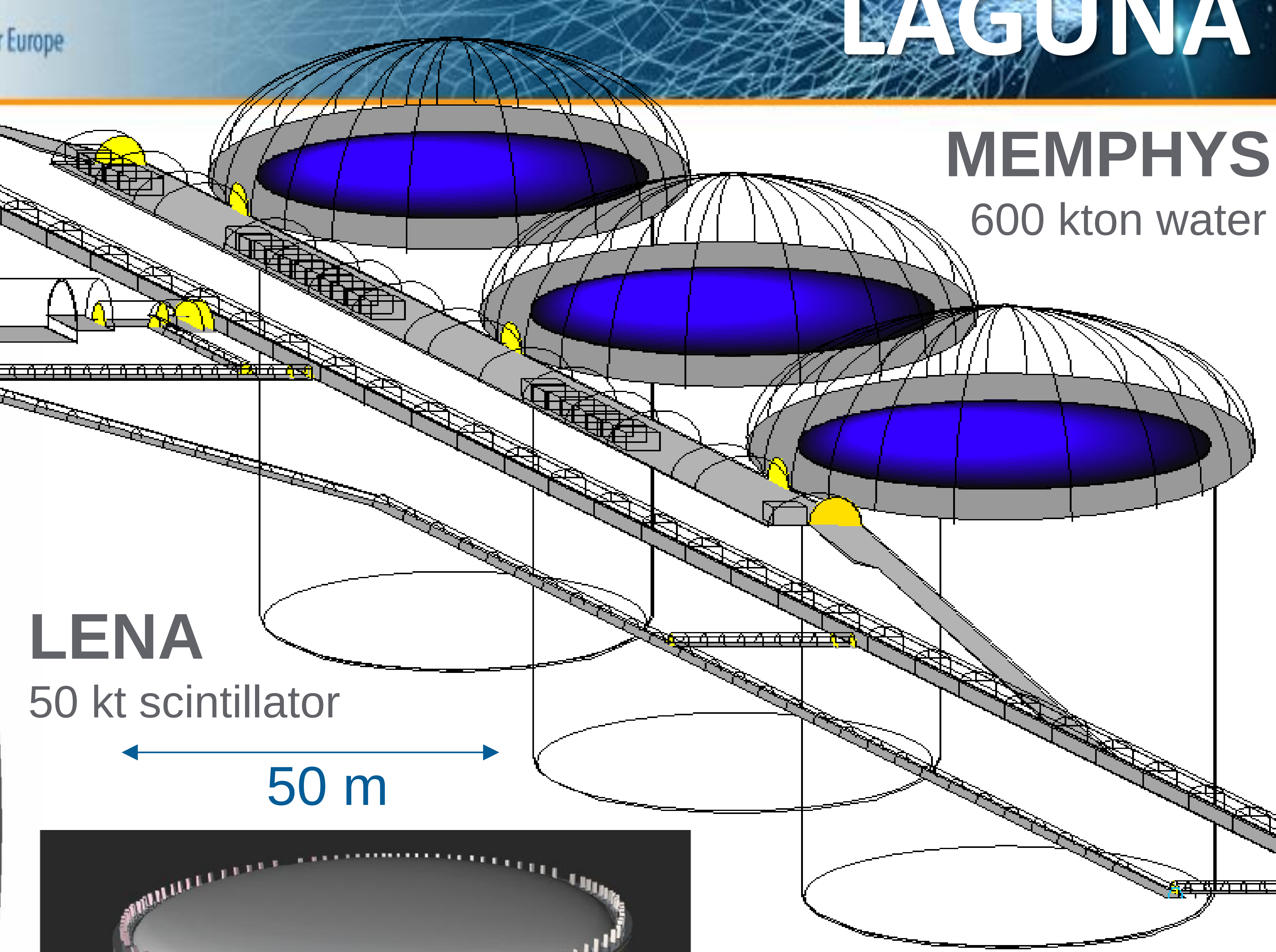
Solar nu: ^{7}Be, pep

geoneutrinos

Physics case

- **Proton decay**
  - Test further classes of SUSY models with tenfold sensitivity
- **Galactic Supernova**
  - Bonanza for astrophysics and particle physics
  - Incredibly detailed information on early SN phase and explosion mechanism
- **Solar neutrinos: details of solar model with percent accuracy**
  - Metallicity problem $\leftarrow$ ν from **CNO** cycle $\rightarrow$ burning of heavy stars
  - Time variations on the 10^{-3} level
  - Transition vacuum/matter oscillations
- **Geoneutrinos**
  - What generates the heat of the Earth (about 30-50% due to U/Th decays).
  - How much U, how much Th? Crust, mantel? (Reactor inside Earth?)
- **Diffuse background of past Supernova**
  - „average“ SN spectrum, star formation rate, „failed“ supernova
- **Indirect dark matter search**
- Oscillation physics: see talks of Hernandez, Zito and Hagner, …

LAGUNA



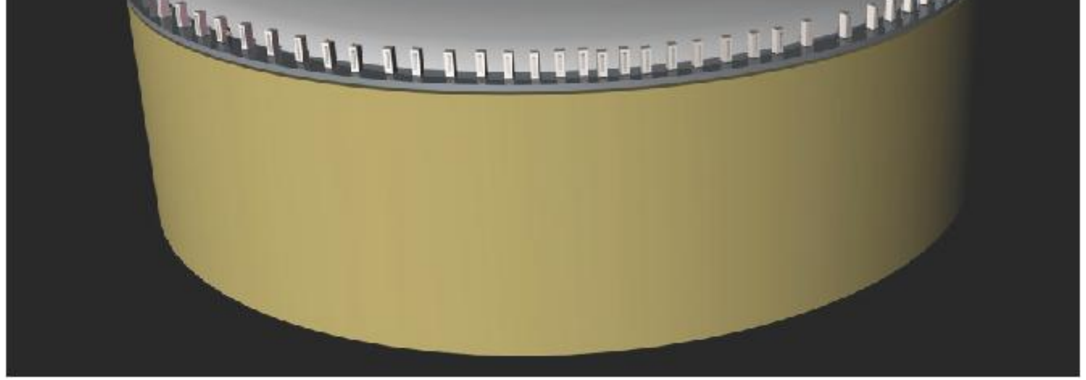
MEMPHYS

600 kton water

LENA

50 kt scintillator

50 m



GLACIER

100 kton liquid argon

*Physics potential of the 3 types of detectors for proton decay and neutrino astrophysics **

Topics	**GLACIER** (50 kt)	**LENA** (50 kt)	**MEMPHYS** (500 kt)
proton decay, sensitivity(10 years) $e^+ \pi^0$ anti-ν K^+ (**)	 2.5×10^{34} 5×10^{34}	 - 4×10^{34}	 15×10^{34} 2.5×10^{34}
SN at 10 kpc, # events CC NC ES Elastic scatt. P	 ~ 19,500 0.8×10^4 (ν_e) 1.1×10^4 0.4×10^3 (e) -	 ~16,000 1.3×10^4 (anti-ν_e) 1.0×10^3 6.2×10^2 (e) 2.6×10^3 (p)	 ~250,000 2.5×10^5 (anti-ν_e) - 1.3×10^3 (e) -
Diffuse SN #Signal/Background events (10 years)	~50/30	~60/10	~120/100 (1 module with Gd)
Solar neutrinos # events, 1 year	^{8}B ES : 1.5×10^4 Abs: 0.5×10^5 (dependent on the achievable threshold)	^{7}Be: 3.6×10^6 pep: 1.0×10^5 ^{8}B: 2.9×10^4 CNO: 7×10^4	^{8}B ES: 1.2×10^5
Atmospheric ν # events, 1 year	5×10^3	5×10^3	5×10^4
Geo-neutrinos # events, 1 year	Below threshold	1.5×10^3	Below threshold

* some numbers strongly depend on model assumptions and give a qualitative rather than an exact quantitative comparison.
** this channel is particularly prominent in SUSY theories. Indications for SUSY at the LHC would boost its importance.

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German Recommendation

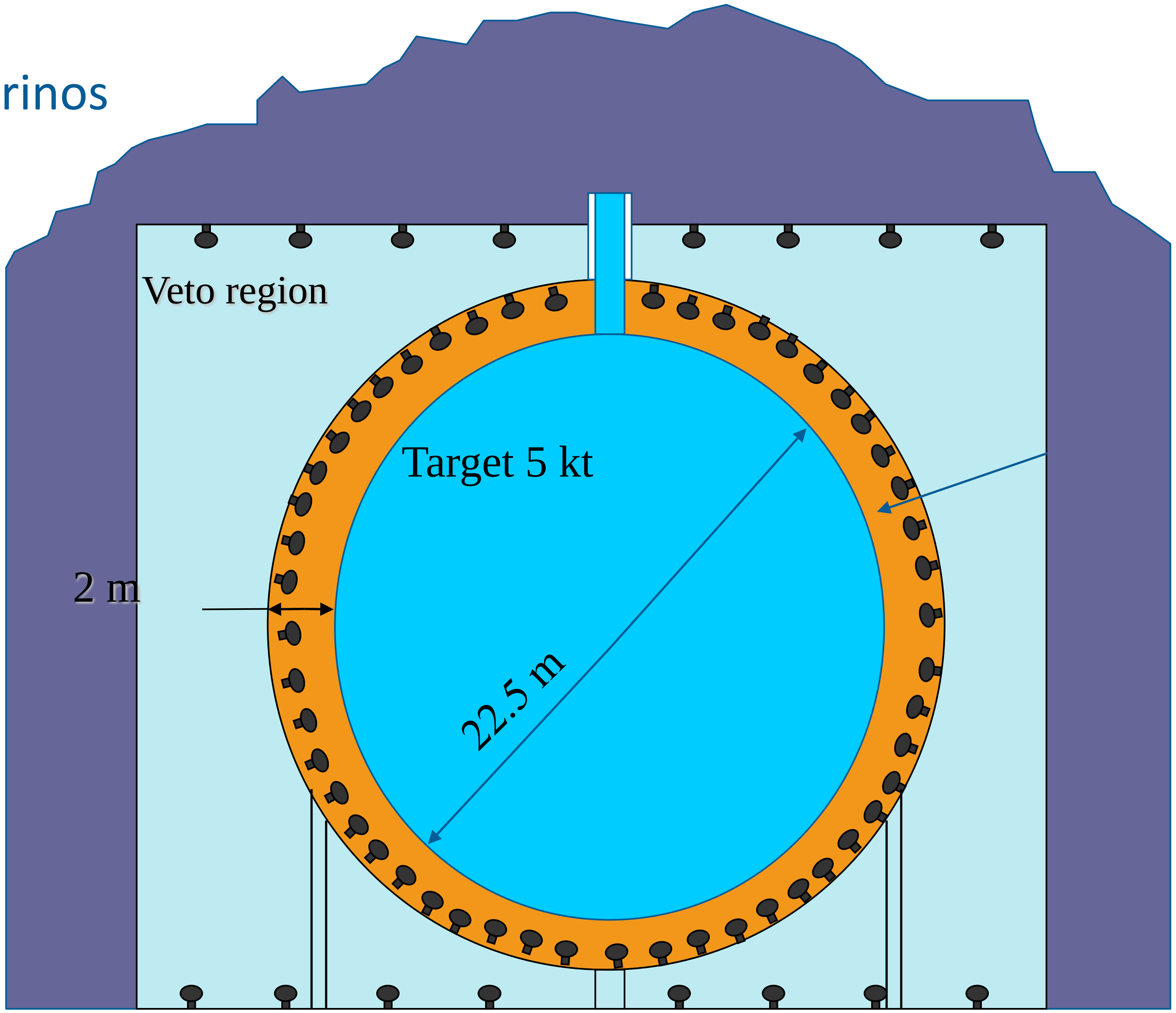
Guided by the superior astroparticle capabilities of LENA, by its proven principal feasibility and by the strong German tradition in this field, we recommend pursue the LENA project on an equal footing as GLACIER (with its superior potential for beam physics).

Given the enormous cost of such detectors and the obvious worldwide interest, we support the ASPERA/ApPEC recommendation 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 this field, including relevant astroparticle physics issues".*

We emphasize that the high cost poses a high threshold for firm commitments to any of these projects. A solution can be only found via global coordination and by attracting new partners (from neighbouring fields like geophysics or solar physics, or from the same field but new countries).

Russian Plans for a Large Underground Neutrino Detector

- **Baksan Valley, Caucasus**
- **Liquid Scintillator 5-50 kt**
  - 5 kt option:
    geo-neutrinos, solar neutrinos, SN neutrinos
  - 50 kt option: full LENA program



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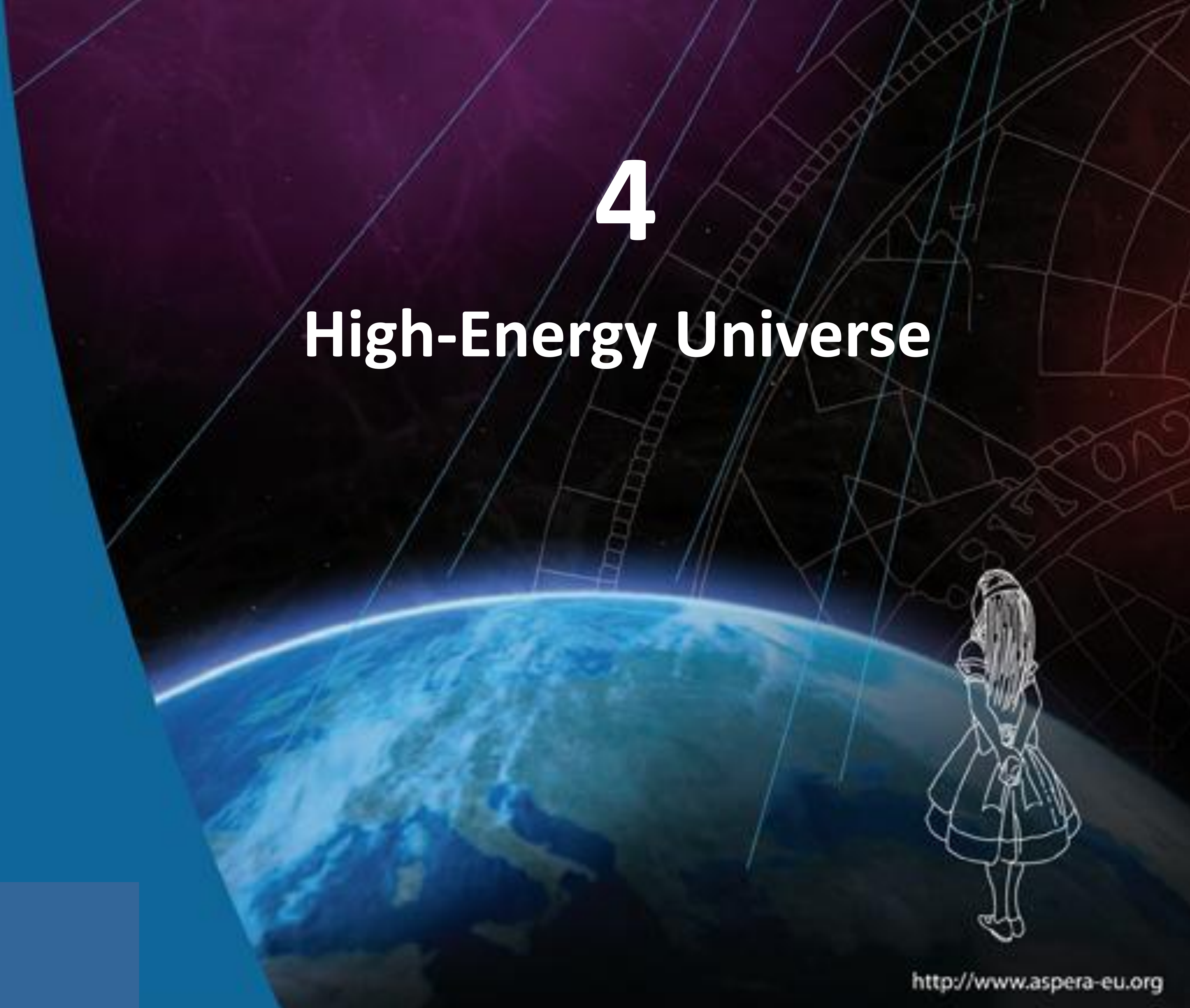
High-Energy Universe

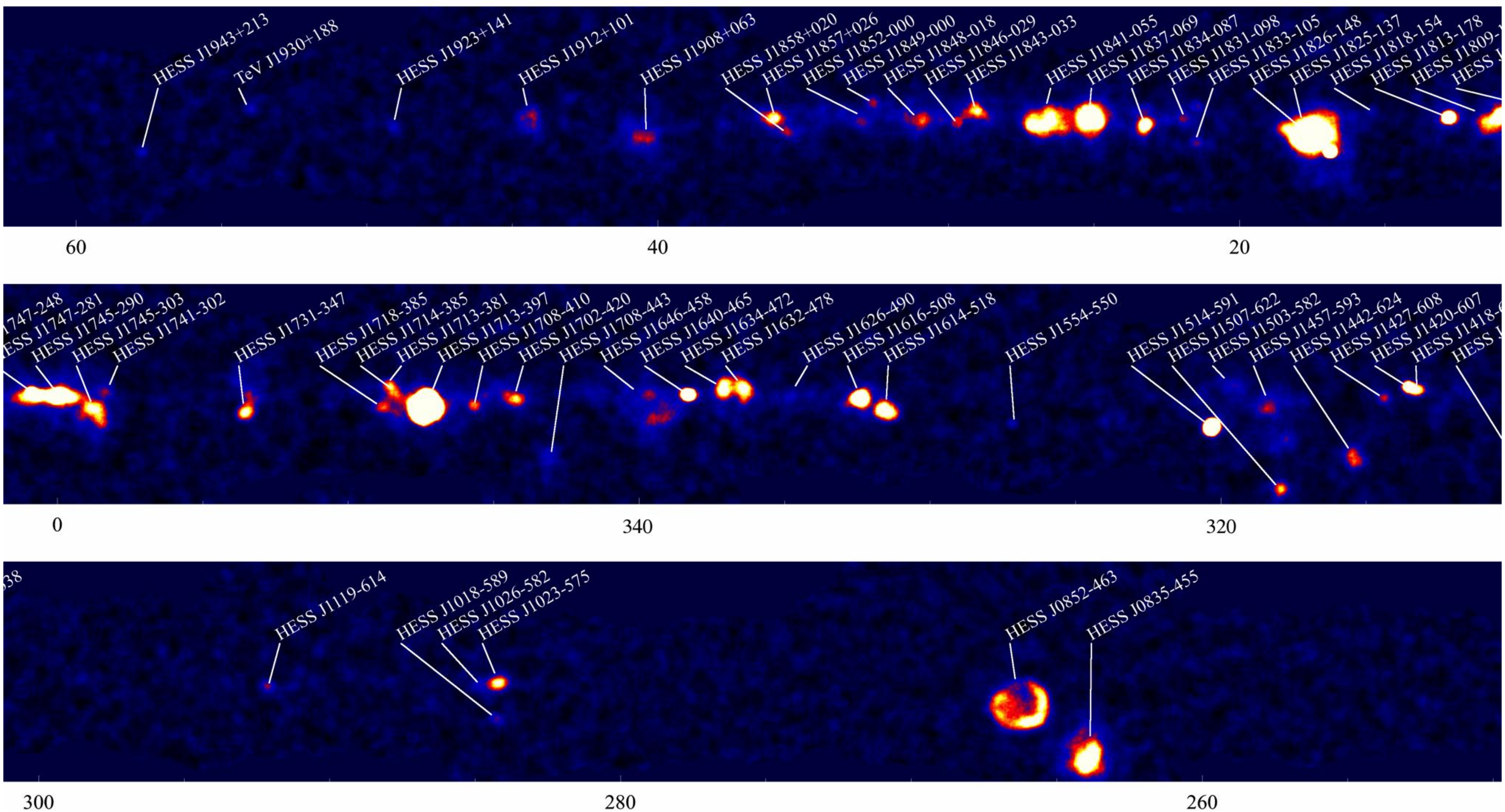


ApPEC ASPERA Astroparticle Physics for Europe

High-Energy Universe

- TeV gamma-ray astrophysics: CTA
  - worldwide priority project of gamma astronomy
  - ~200M€, 2 sites (N/S), start construction 2014
- High energy neutrinos: KM3NeT
  - Note: oscillations physics with IceCube/PINGU & KM3NeT/ORCA
- High energy cosmic rays: 30,000 km^2 ground based array
  - Closely related to fixed target and LHC physics

The Milky Way seen with H.E.S.S.



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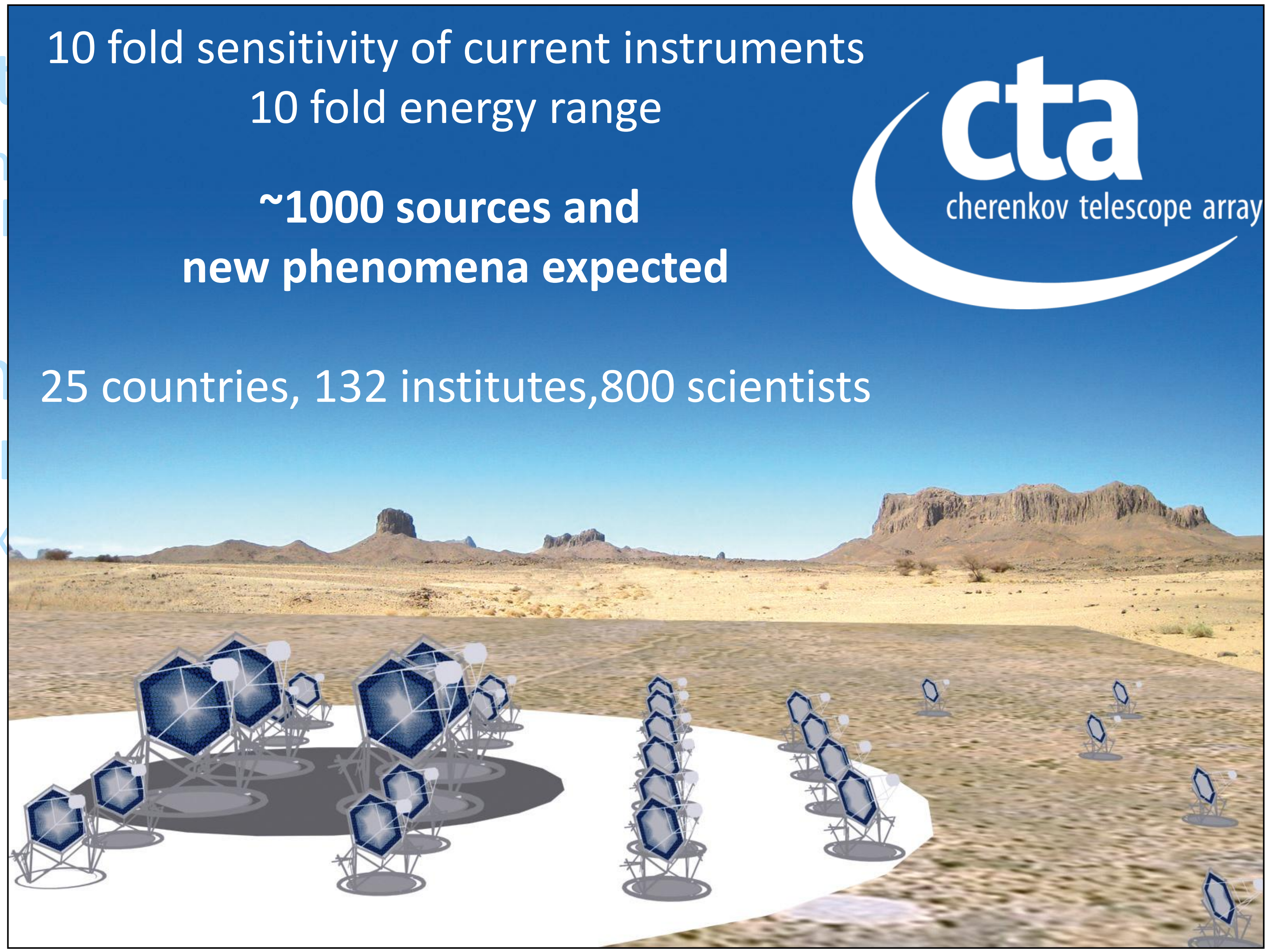
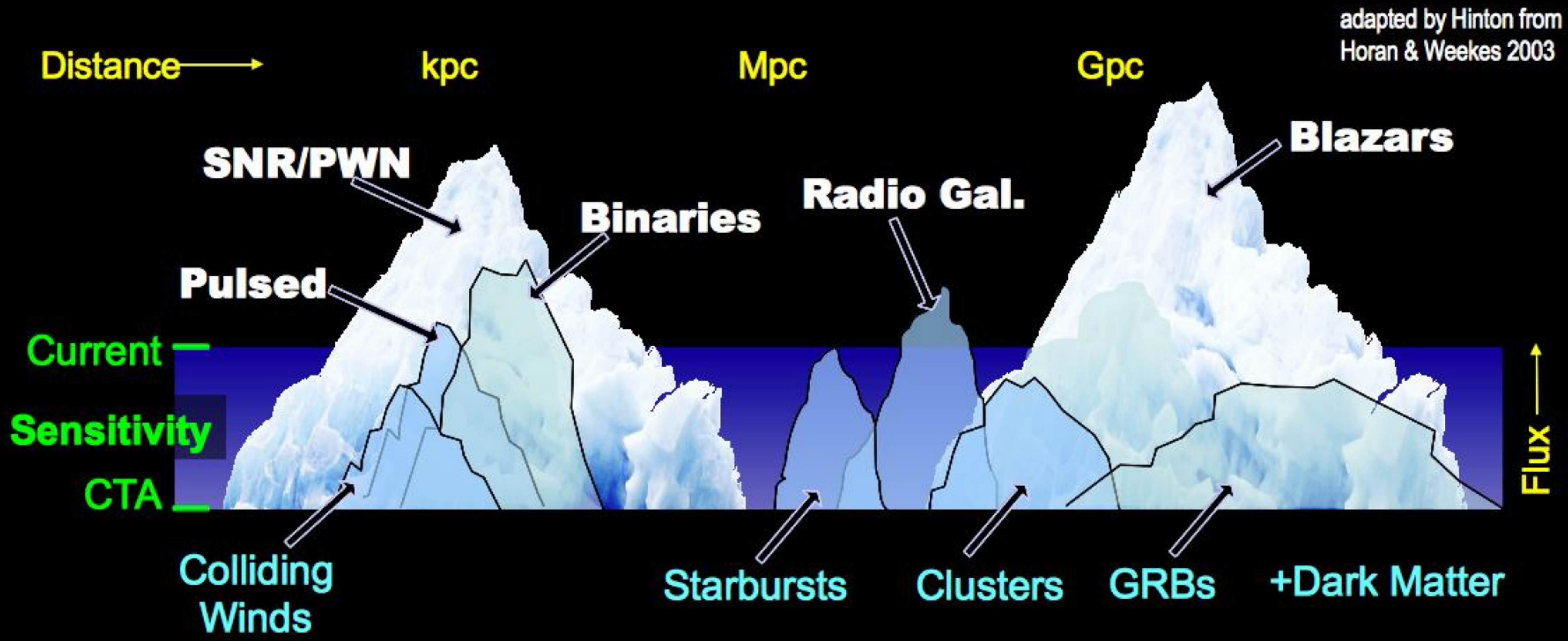


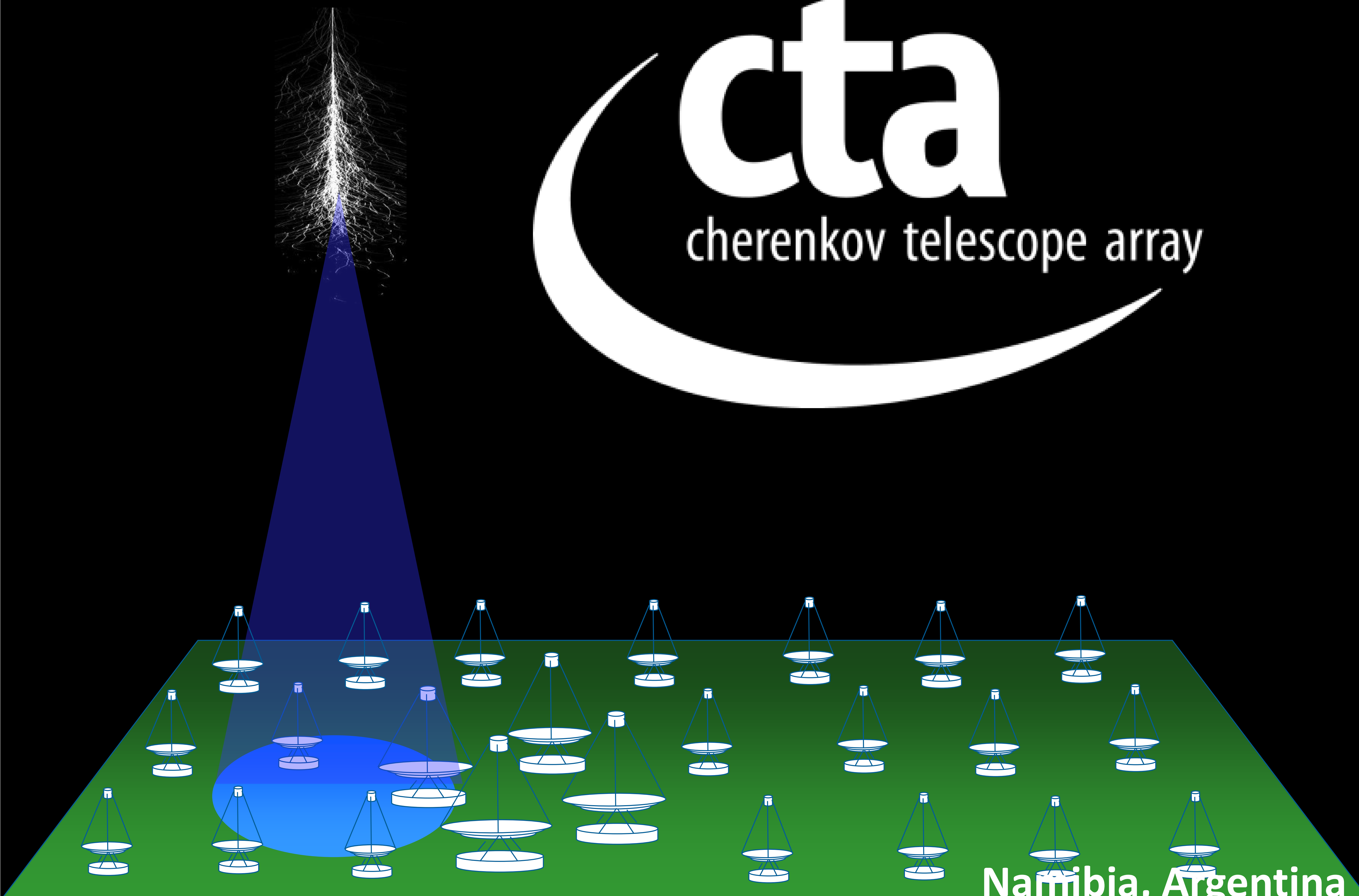
Potential of an observatory with 10x higher sensitivity



- Current instruments have passed the critical sensitivity threshold and reveal a rich panorama, but this is clearly only the tip of the iceberg
- What big science questions remain ?

cta

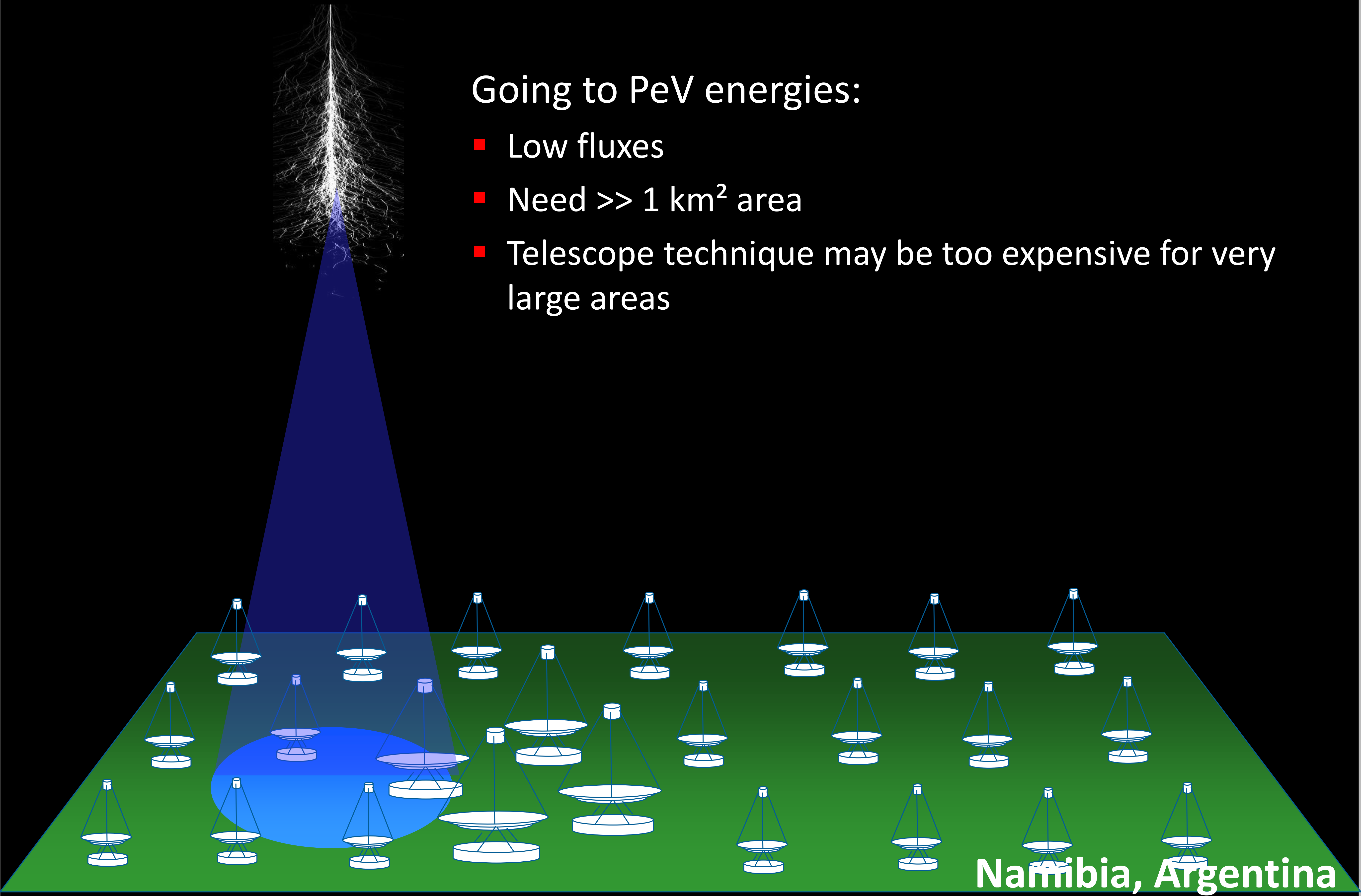
cherenkov telescope array



Namibia, Argentina

Going to PeV energies:

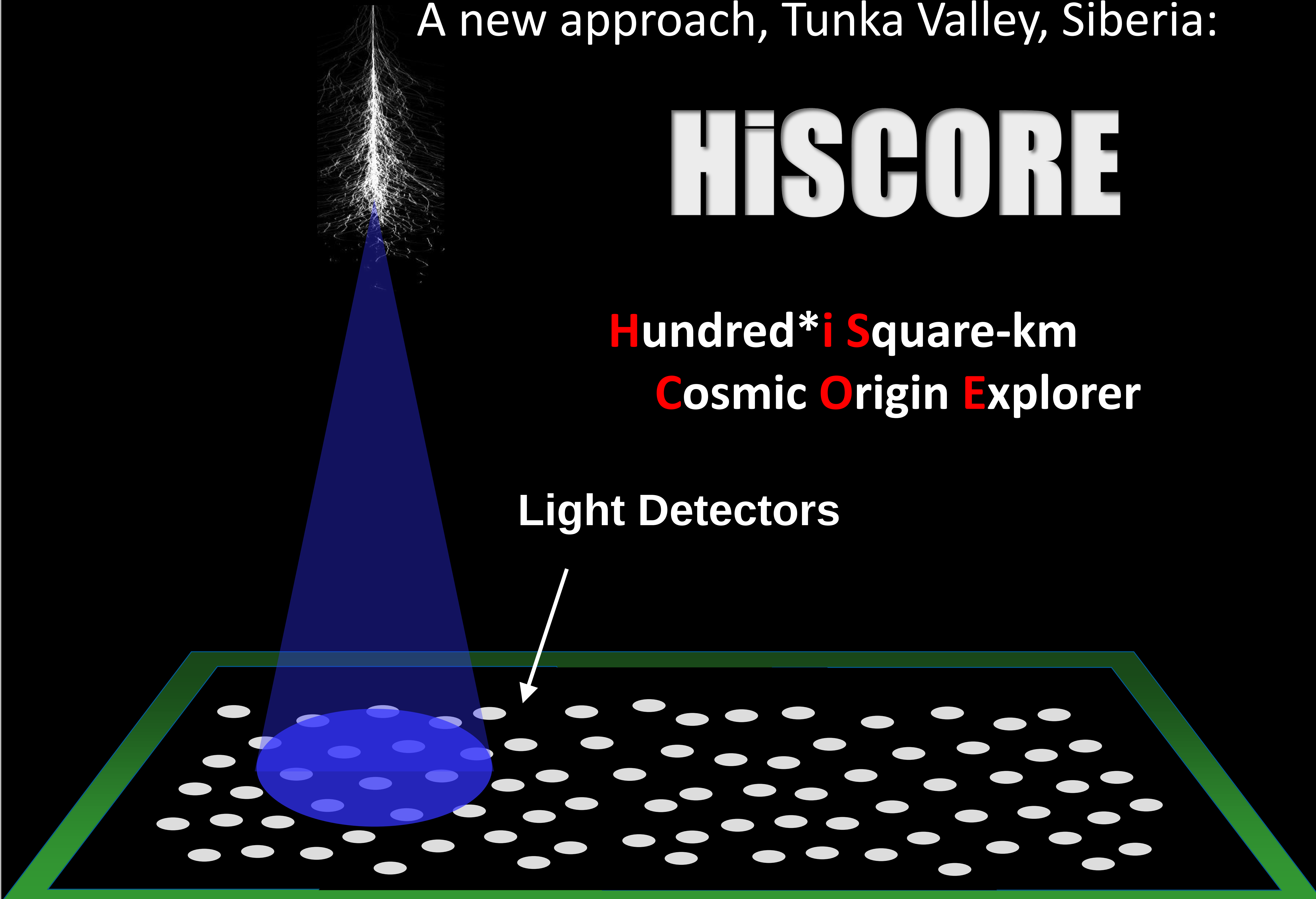
- Low fluxes
- Need >> 1 km² area
- Telescope technique may be too expensive for very large areas

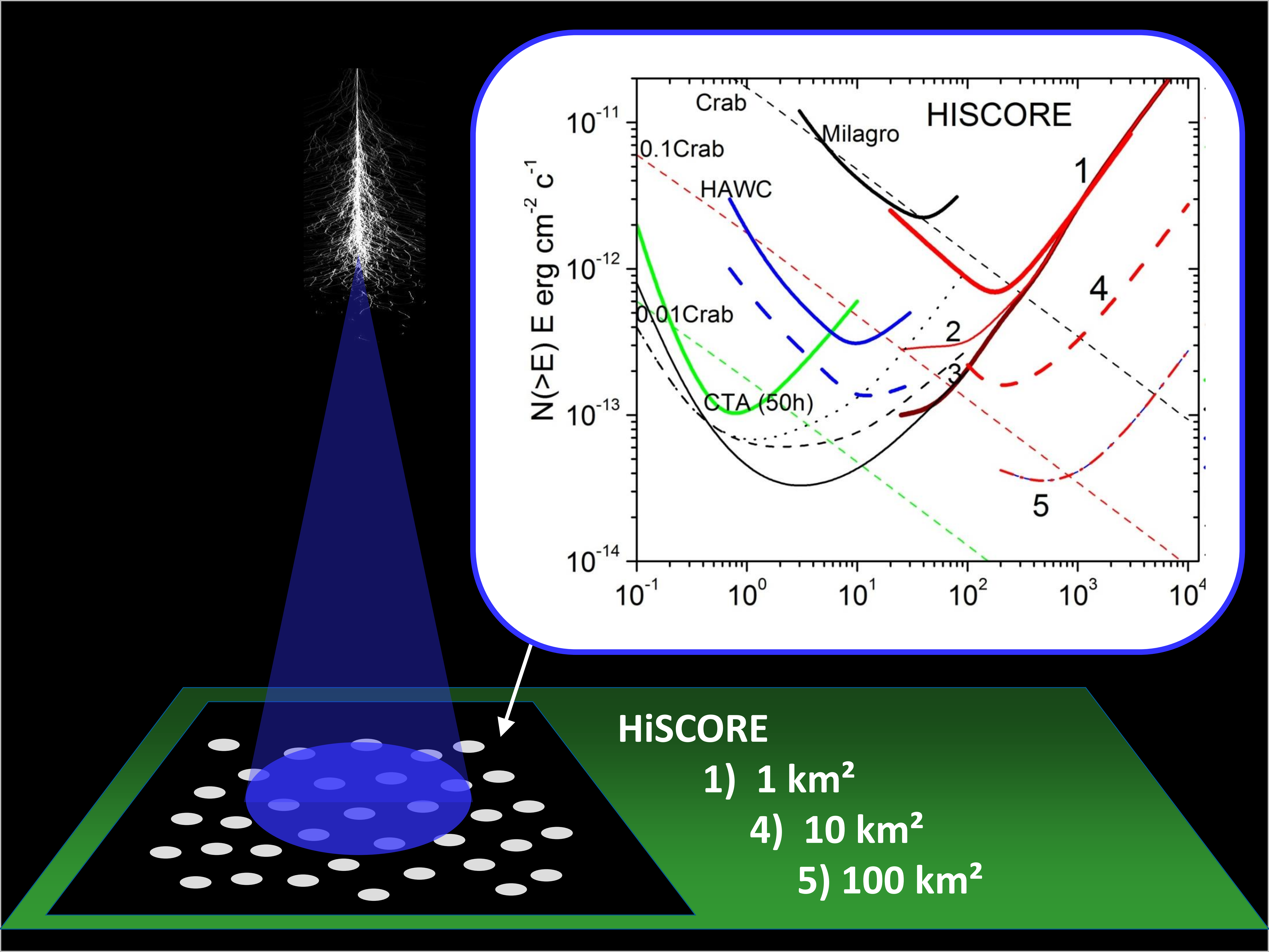


A new approach, Tunka Valley, Siberia:

HiSCORE

Hundred*i Square-km
Cosmic Origin Explorer




HISCORE
Crab
Milagro
0.1Crab
HAWC
0.01Crab
CTA (50h)
1
2
3
4
5
N(>E) E erg cm^{-2} c^{-1}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
HiSCORE
1) 1 km²
4) 10 km²
5) 100 km²

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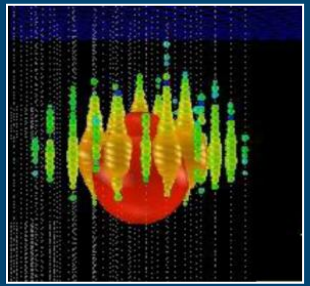
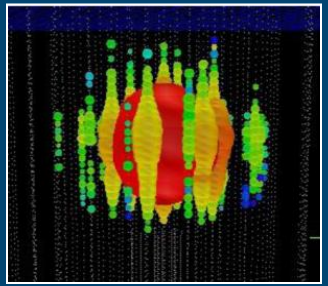
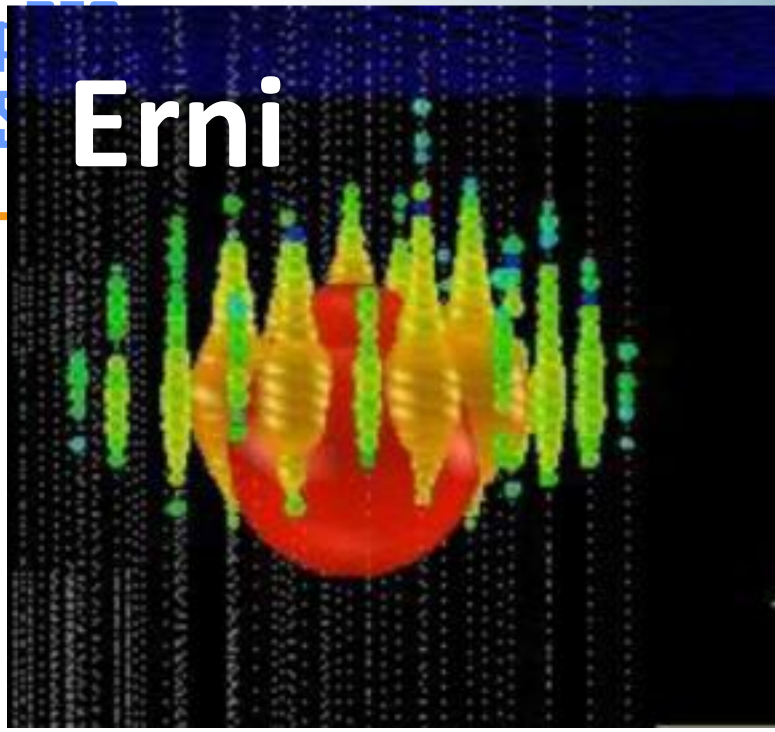
- **IceCube providing data with unprecedented quality and statistics!**

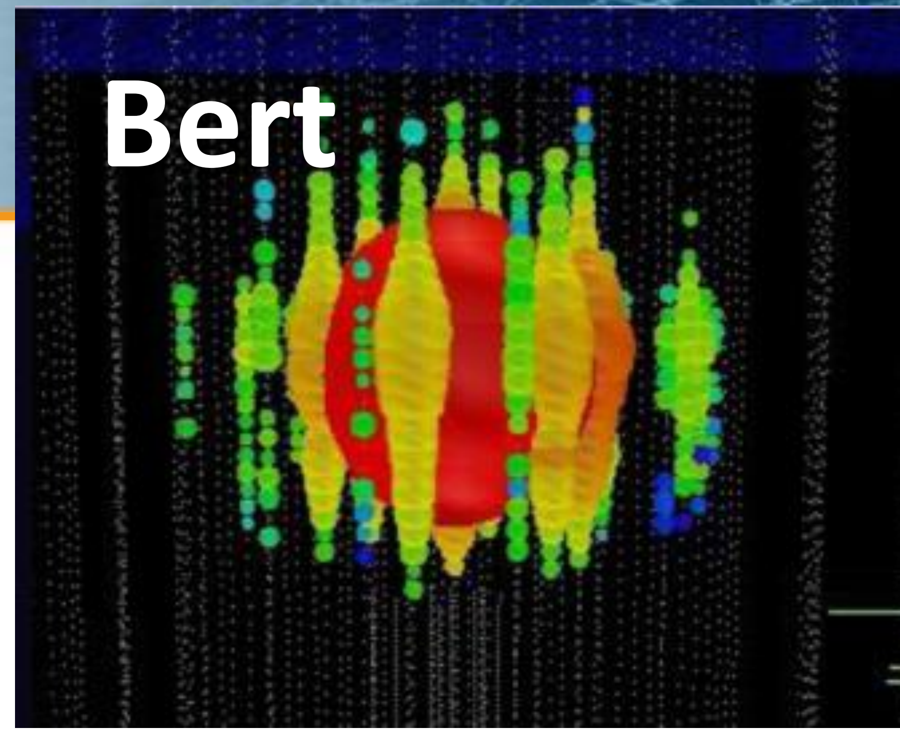



2 events with 1-2 PeV energy

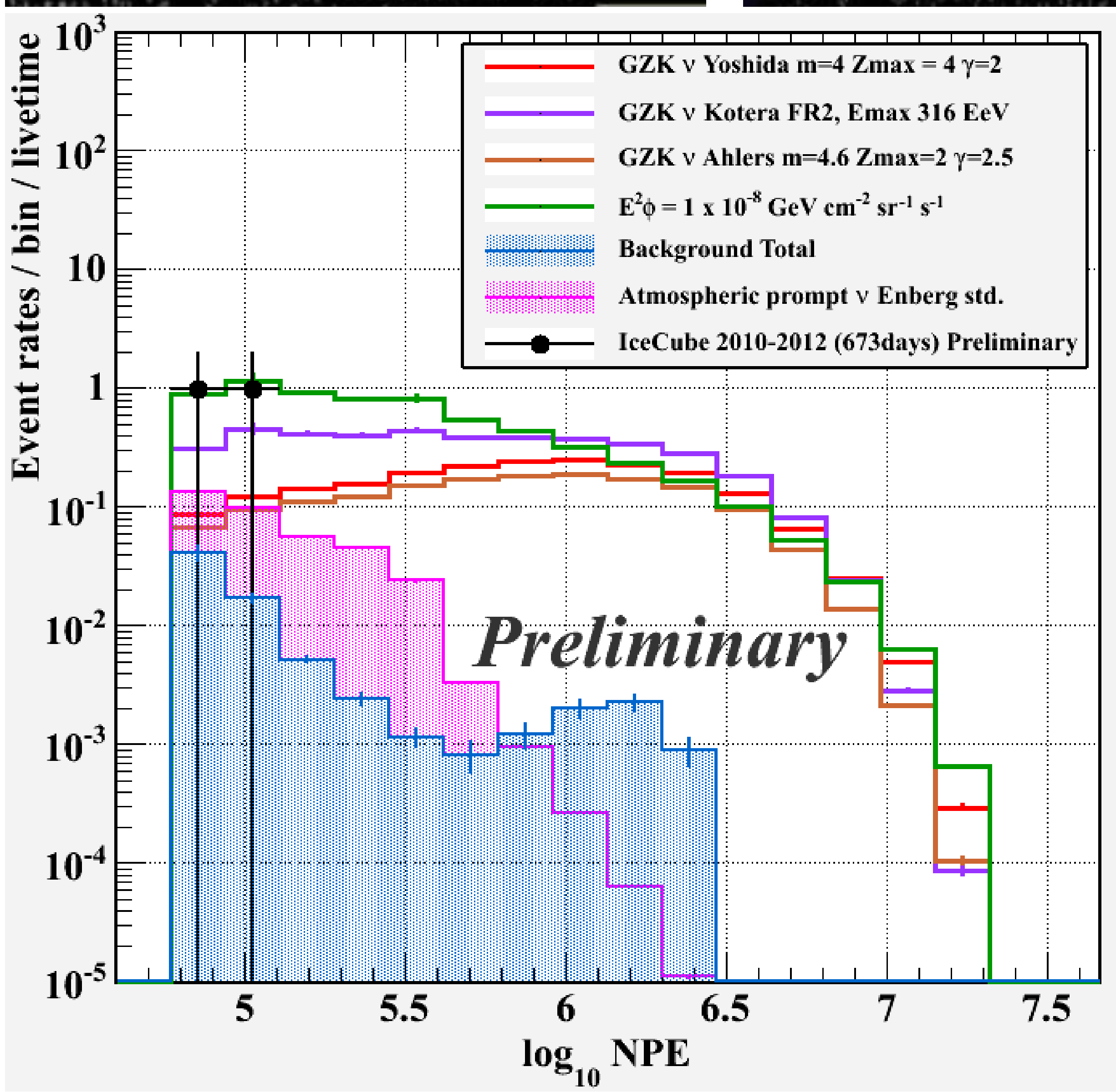
First extraterrestrial high-energy neutrinos?

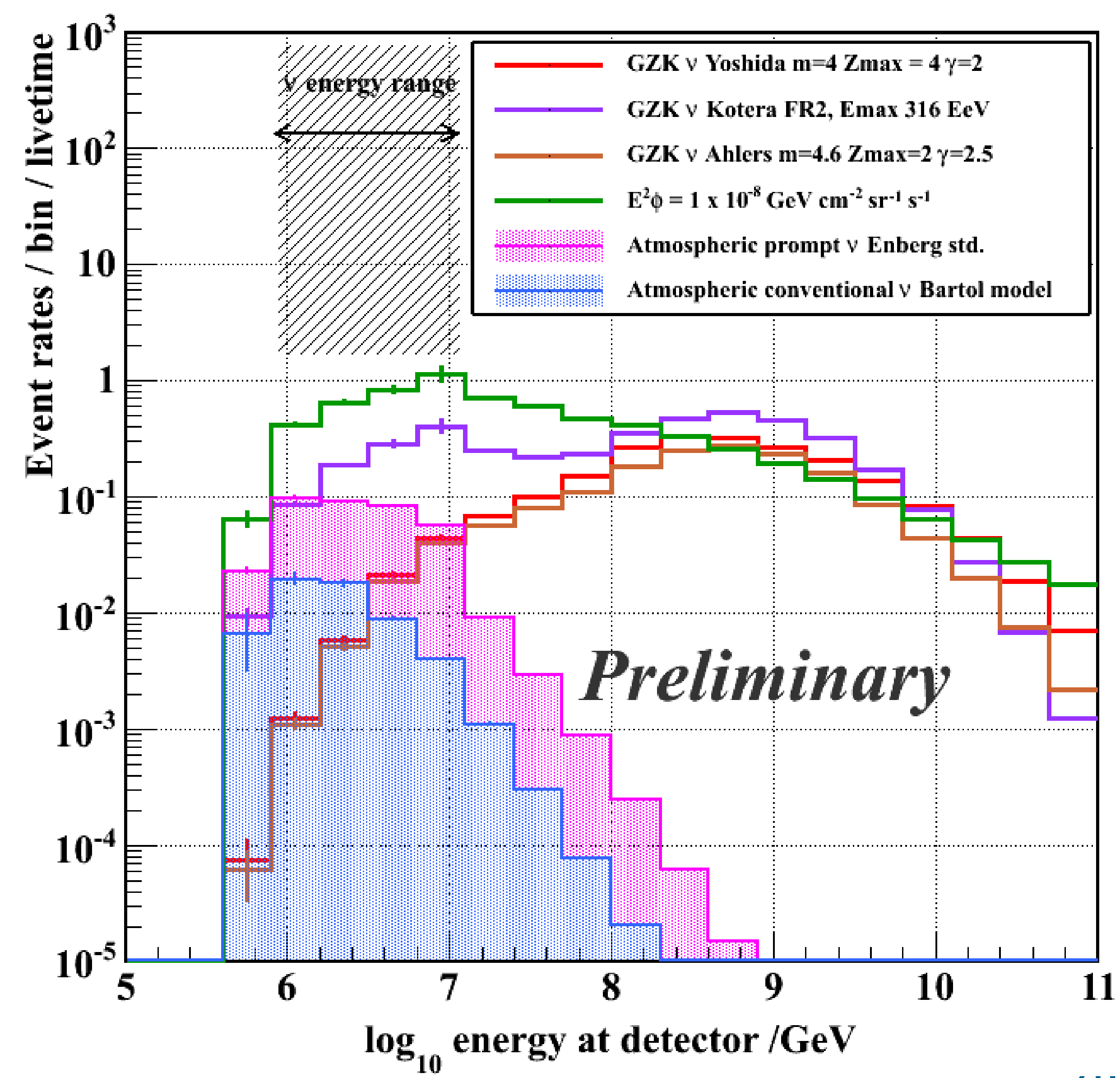
- **Strong scientific case for a Northern detector, but with substantially larger sensitivity than IceCube.**
- **Pool resources in single design for a large research infrastructure. ~250 M€**
- **Start of construction in 2014 (~40 M€ available).**
- **IceCube, ANTARES /KM3NeT, GVD-Baikal → future Global Neutrino Observatory.**





May 31, 2010 - May 14, 2012





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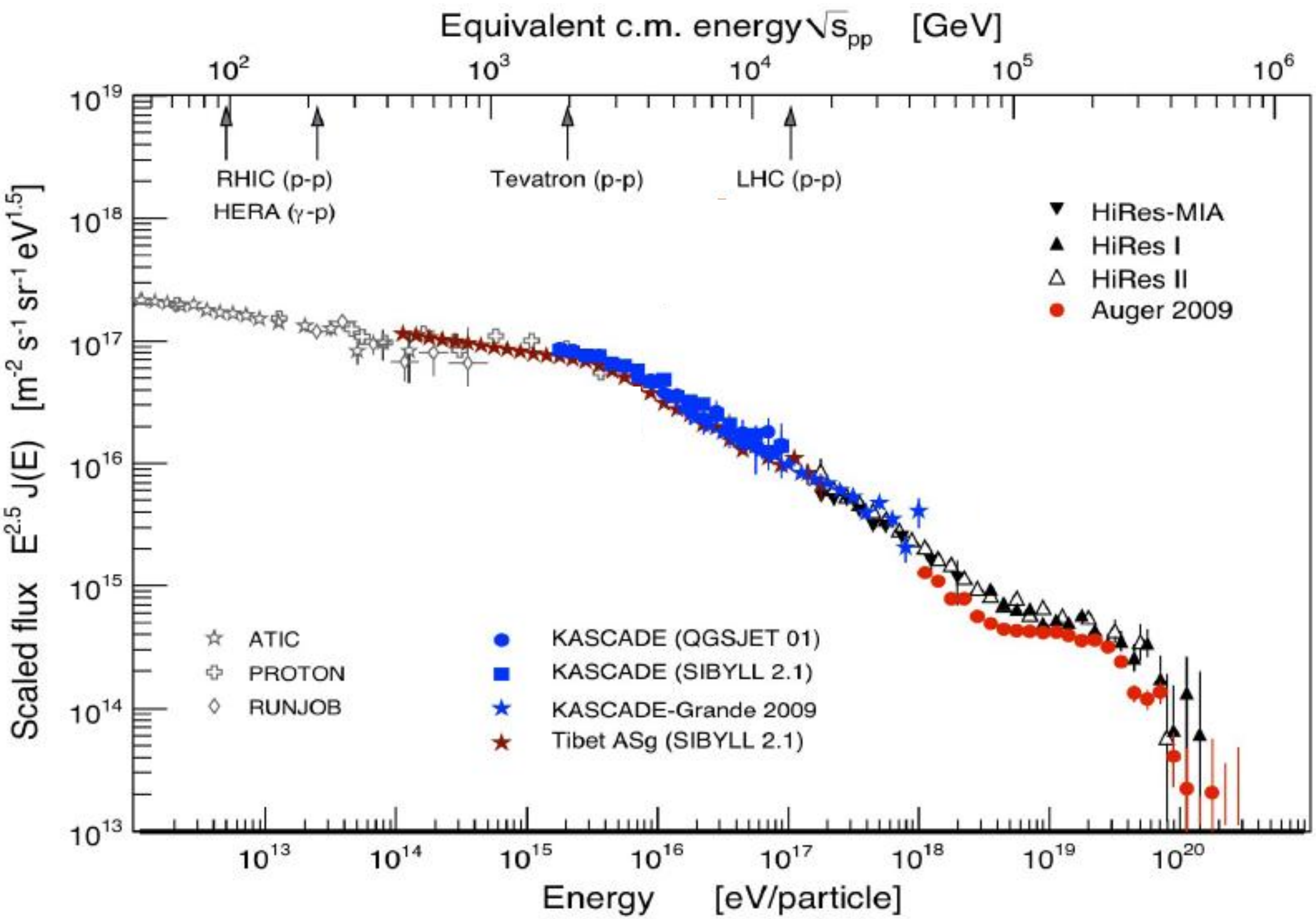
  - Closely related to fixed target and LHC physics, see the following

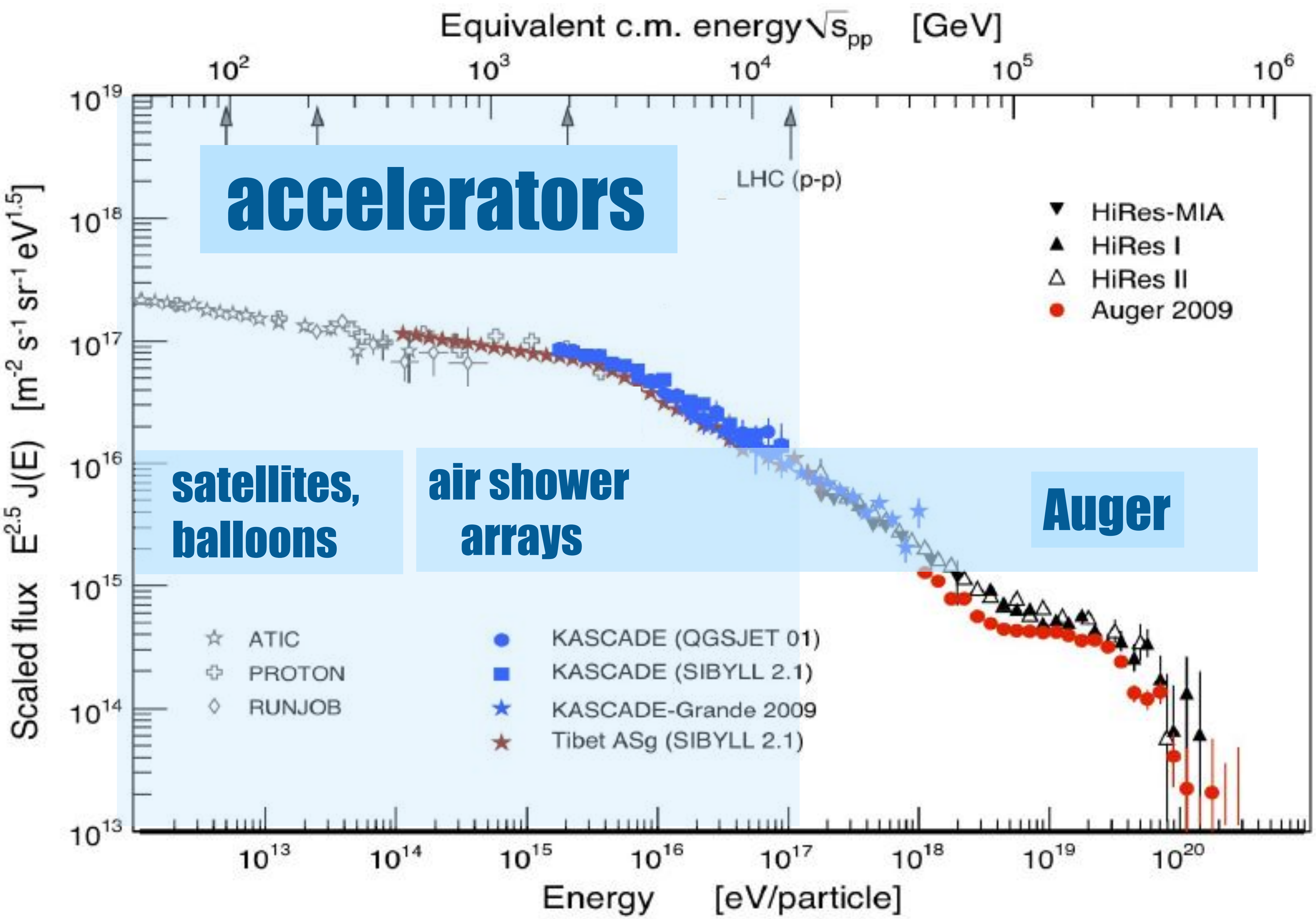
- **Understanding the high-energy Universe**
- **Sources of cosmic rays**
- Indirect dark matter search
- Exotic particle physics
- Test basic physics principles

Cosmic Rays



R. Engel (KIT)

Cosmic Rays and LHC



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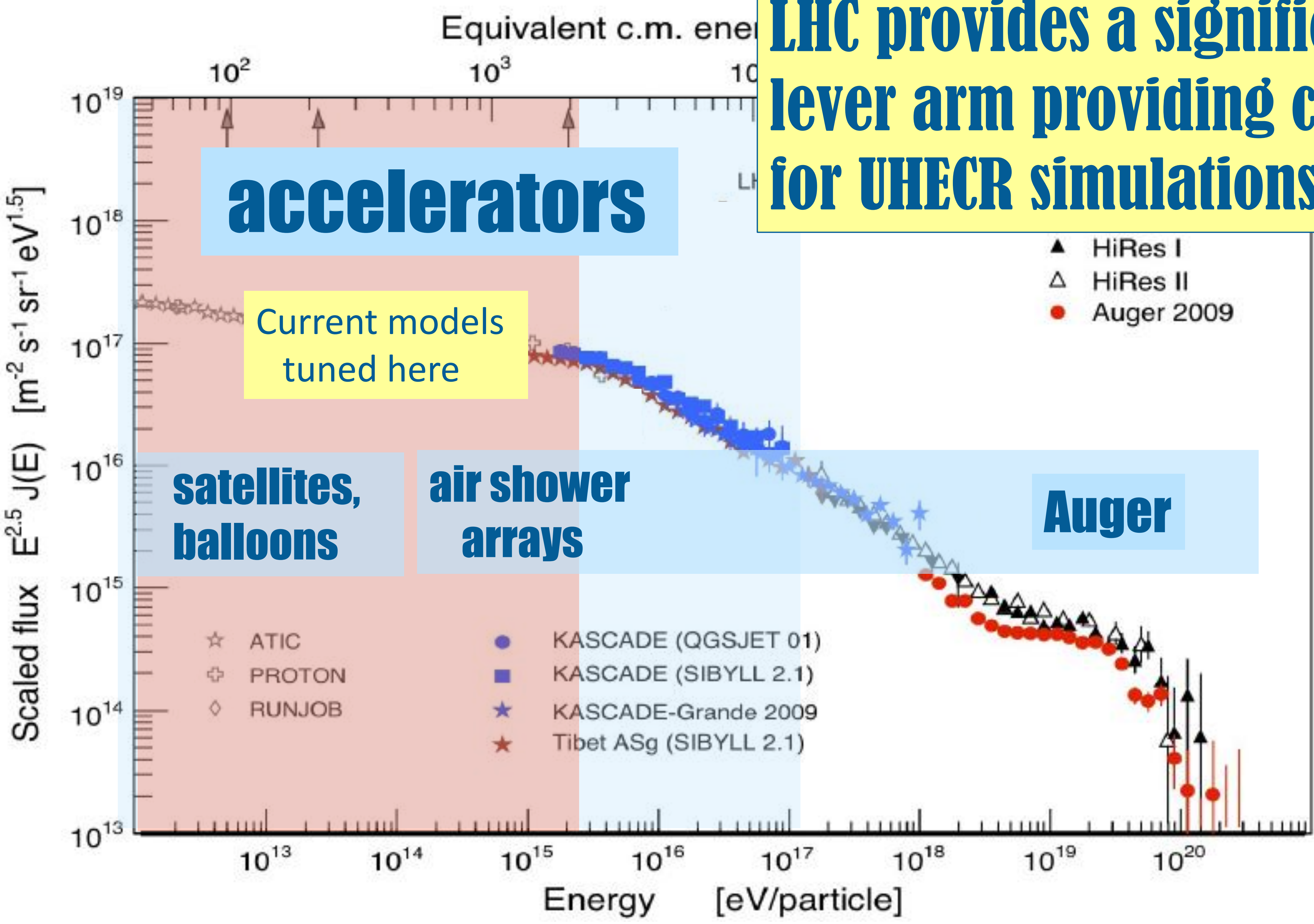
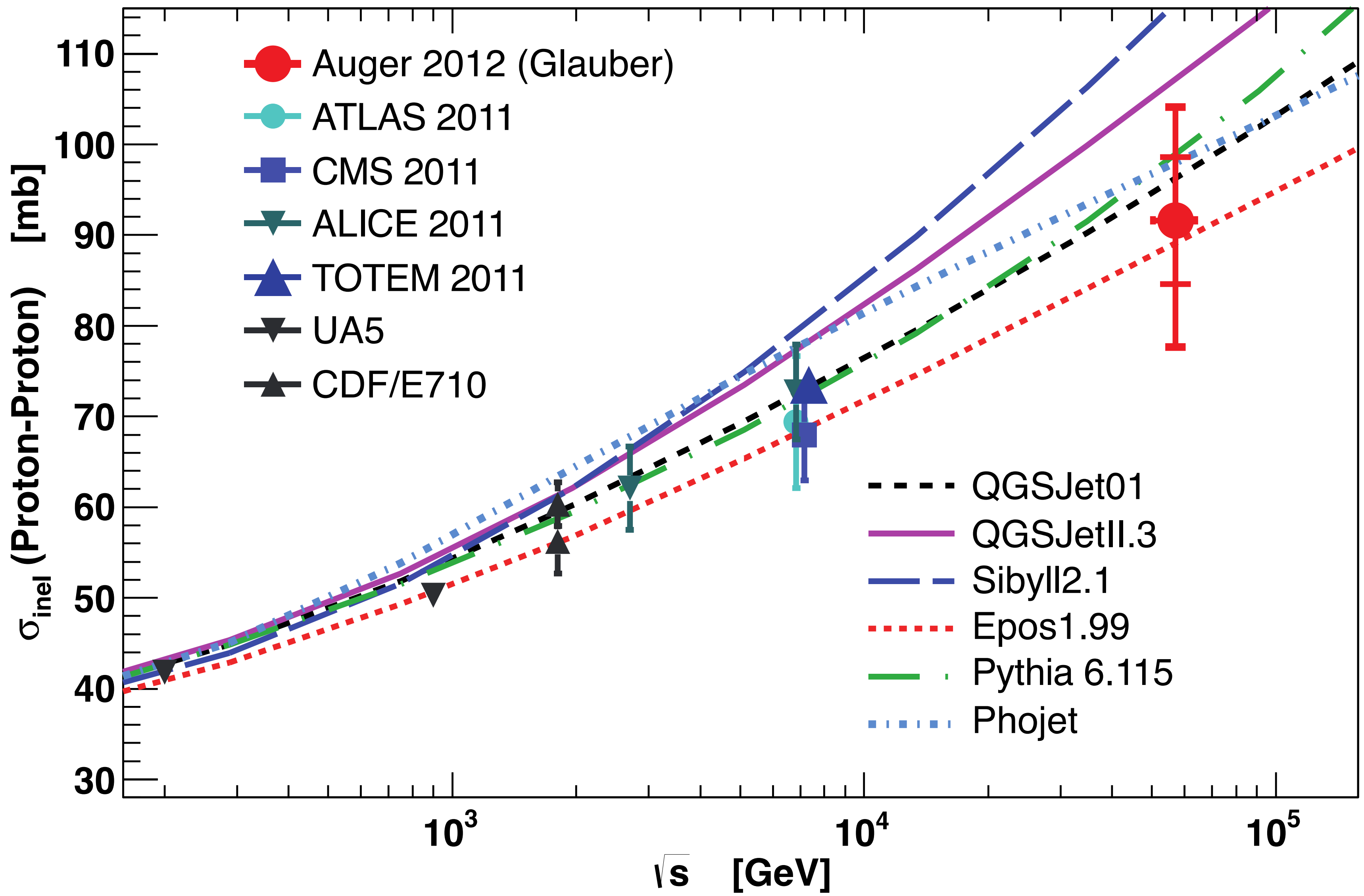


LHC provides a significant lever arm providing constraints for UHECR simulations !

R. Engel (KIT)

pp inel. cross section at sqrt(s)=57 TeV



- Test Glauber model
- Tune EAS simulations

Cosmic Rays and LHC: Summary

- Cooperation of particle- and CR-physicists has been intensified over the last years.
- This is extremely useful for understanding CR nature; accelerator data already helped improving shower models.
- Tools of CR community may also help better understanding HE particle interactions: bulk LHC data are well described by EAS models, sometimes even better than by HEP models
- Need common approach to understand muons in CR.
- NA61/SHINE (SPS Heavy Ion and Neutrino Experiment):
  important input data for cosmic ray and neutrino experiments.
  Submitted paper #21 for plans beyond the approved program.

- **Establishing an „Astroparticle Physics Forum" at CERN would intensify co-operation and synergies.**

Summary

- **Dark Matter: prove or disprove SUSY WIMP hypothesis**
  - close synergy "direct – indirect – LHC"
  - Direct measurements: → … → DARWIN, EURECA
- **Double Beta Decay: cover inverted hierarchy region**
  - Phased approach to one-ton detector(s)
- **Nu astronomy and p-decay: quantum leap in sensitivity**
  - Combines fundamental discovery physics and precision physics
  - Combines astro- and particle physics
- **High energy Universe: identify sources of cosmic rays**

Plus:

- Strong interaction physics (↔ LHC)
- Indirect dark matter search
- Test of fundamental principles