Astroparticle Physics

The 2011 ASPERA Roadmap

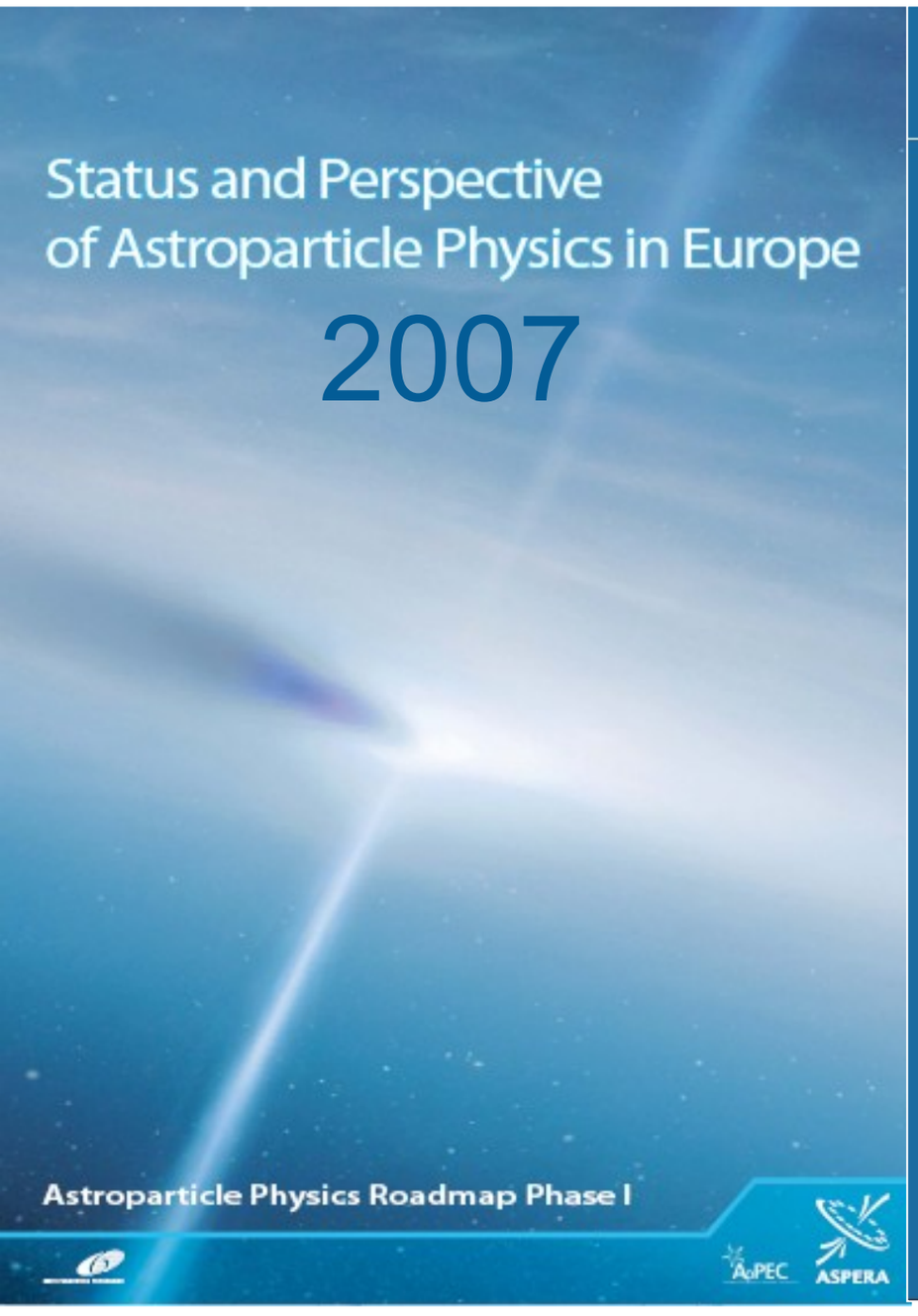
Christian Spiering, DESY

Zaragoza, June 30, 2011

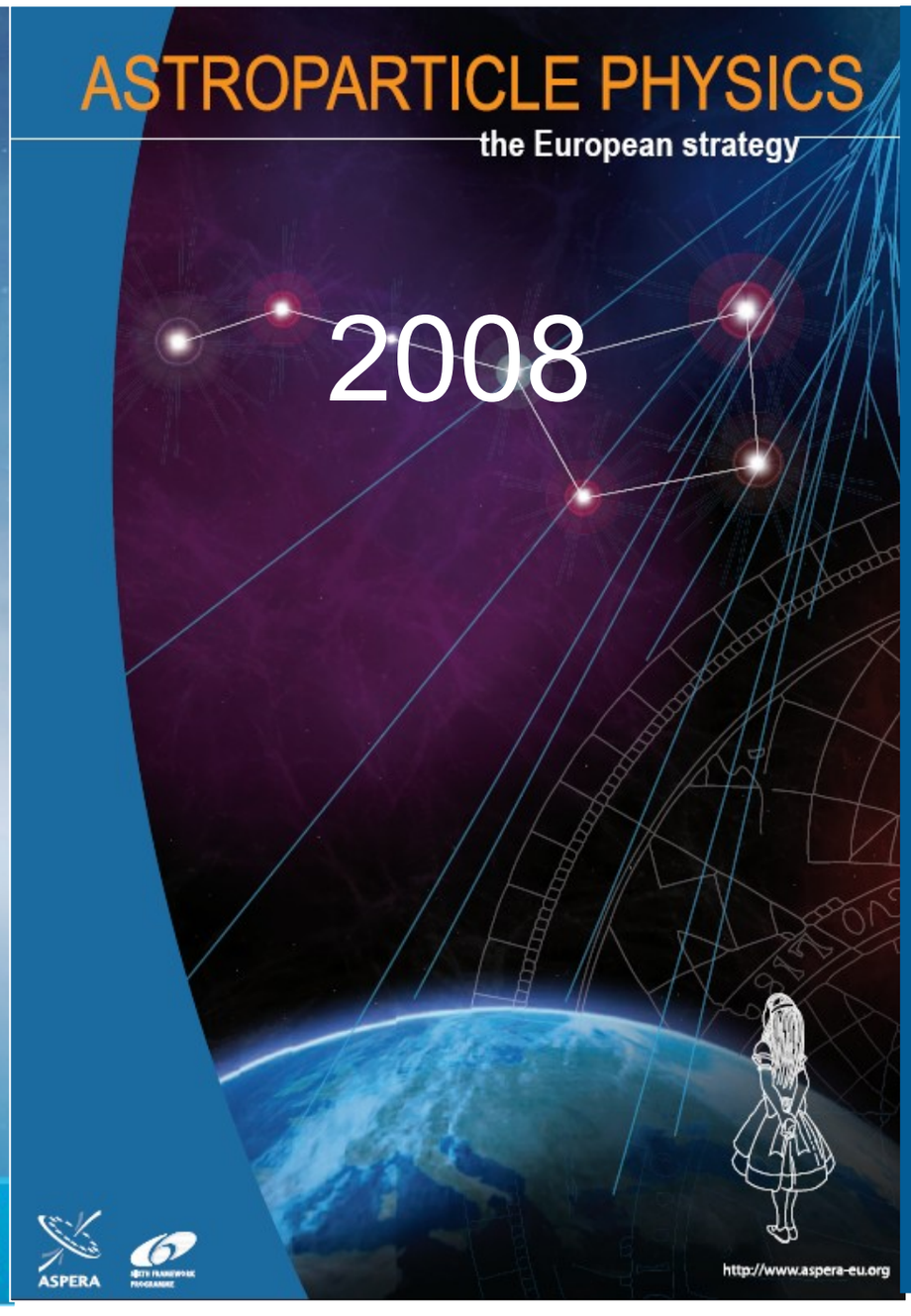
http://www.aspera-eu.org

AppEC Astroparticle Physics for Europe — AppEC/ASPERA Roadmap process

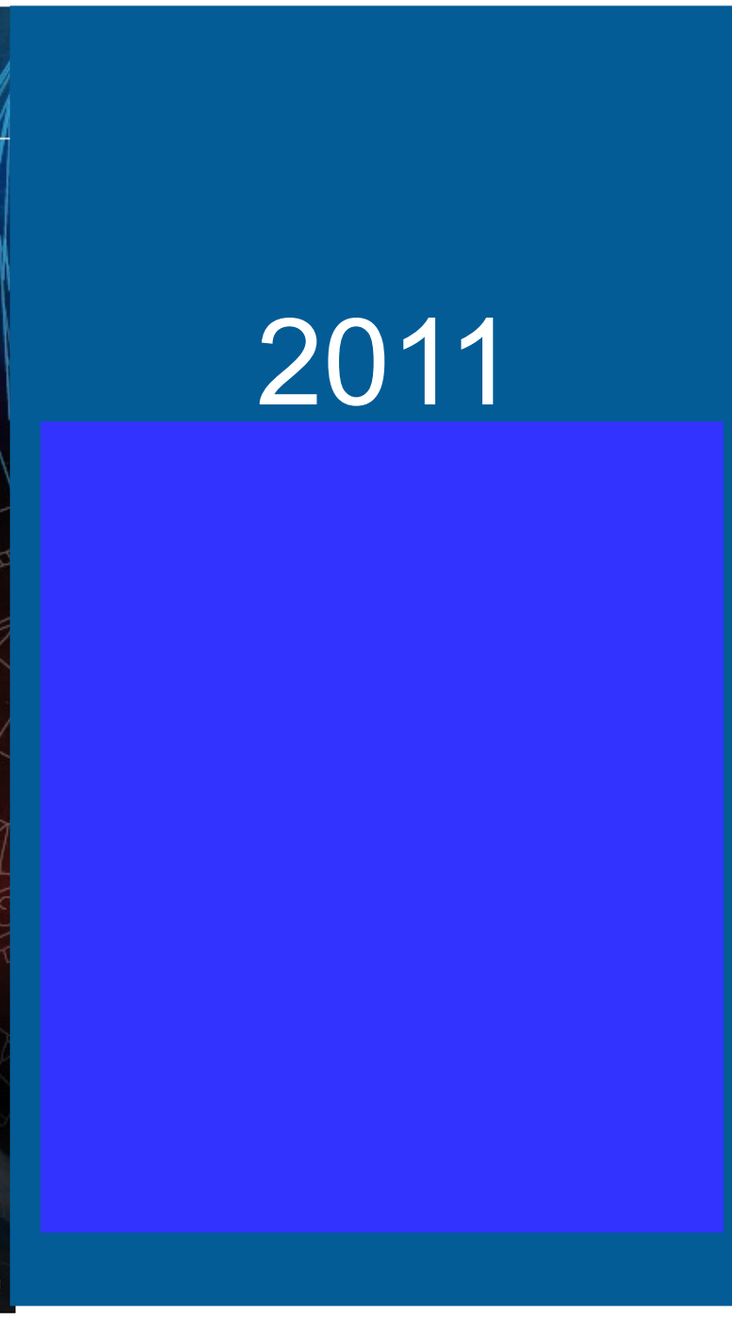
Detailed Description of the Field



Glossy Paper „The Magnificent Seven“



Actual Status & Extrapolation



Content 2011 Roadmap

Content 2011 Roadmap

For the quick reader

2008

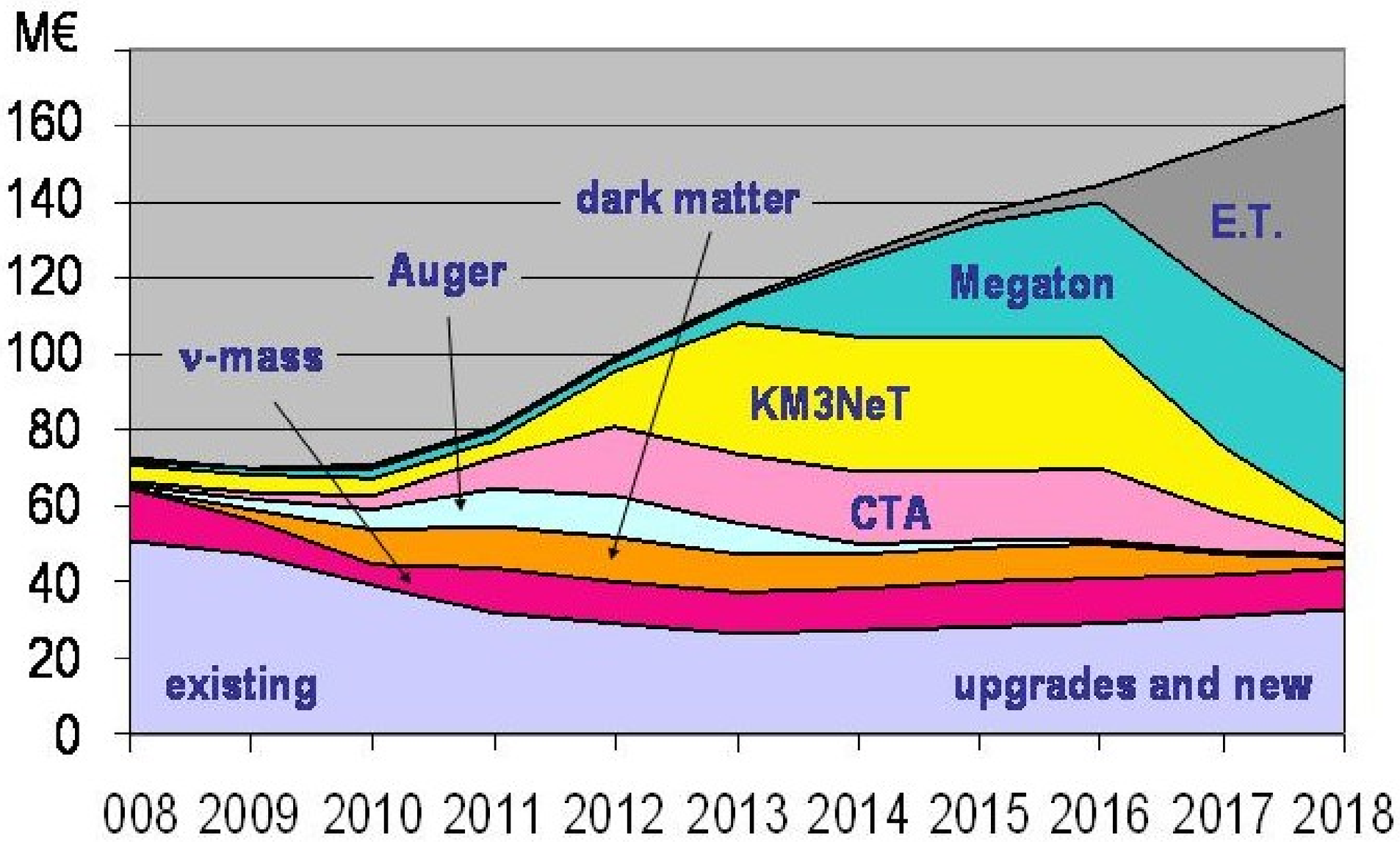
The Magnificent Seven

- **Cosmic rays:** A large array for the detection of charged cosmic rays (Auger North)
- **Gamma rays:** A large array of Cherenkov Telescopes for detection of cosmic high energy gamma-rays (CTA)
- **High energy neutrinos:** A cubic kilometre-scale neutrino telescope in the Mediterranean (KM3NeT)
- **Dark matter search:** Ton-scale detectors which probe a large part of the parameter space of Minimal Supersymmetric Models (i.e. reach a sensitivity range of 10^{-44} cm for the spin-independent cross section)
- **Neutrino-less double beta decay:** A ton-scale detector for the determination of the fundamental nature and mass of neutrinos with the goal to test inverted hierarchy scenarios.
- **Proton decay and low-energy neutrino astrophysics:** A Megaton-scale detector for the search for proton decay, for neutrino astrophysics and for the investigation of neutrino properties
- **Gravitational waves:** A third-generation underground gravitational antenna (E.T.)

The Magnificent Seven

2008

- CTA
- Auger-North
- KM3NeT
- Megaton
- ton DM
- ton DBD
- E.T.



We started with a factor 3.5 Scenario (the „wishes“)

Even a factor 2 must be considered the most optimistic scenario !

New since 2008

Plans vs. Reality

- We were – and continue to be! – convinced that the prospects of astroparticle physics merit a factor-2 increase over the next decade. On the other hand we are aware that funding realities in most countries have become more challenging. An aggressive "factor-2 pressure" appears presently beyond realistic expectations. Instead, we propose to proceed with the most advanced projects as fast as possible and to exploit their discovery potential. The expected successes will then hopefully translate into additional momentum for the remaining priority projects.

- The SAC is also aware, that research priorities will differ from country to country, depending, e.g., on their local infrastructures, or on their traditions and historically grown strengths in particular fields. The SAC ranks scientific arguments highest but at the same time keeps in mind that there are also historical and political aspects. We are careful not to define priorities in such a way that they might limit the phase space of national funding agencies for substantial, positive funding decisions, once such possibilities for a certain project may appear on a national level.

New since 2008

- Cosmic rays:
  - AMS detector launched, very good performance.
  - Medium energies: Tunka-133 & IceTop completed, Auger LE extensions
  - Anisotropy of TeV CR confirmed by ARGO/YBJ in 2008 and by IceCube in 2009.
  - Auger firmly established the high-energy depression (GZK?)
  - USA committees did not prioritize Auger North, US funding will not give funding to the Colorado site. Auger Collaboration concluded that a new proposal for a next generation observatory with full sky coverage and considerably enlarged area should be envisaged. This requires 3-5 years of preparation.
- Gamma rays:
  - A huge number of new sources detected by H.E.S.S., MAGIC and VERITAS
  - MAGIC-II started stereoscopic operation.
  - CTA collaboration formed, meanwhile including all relevant players in the world.
  - CTA on ESFRI list, the construction of prototype telescopes has started.
  - Construction of wide angle detector HAWC in Mexico (USA/Mexico) has started.
  - China is planning a new high altitude air shower array (LHAASO).
- High energy neutrinos:
  - IceCube with its low-energy extension was completed in December 2010 and shows excellent performance.
  - 2 years smooth operation of ANTARES. KM3NeT TDR finalized.
  - Russian CDT for GVD

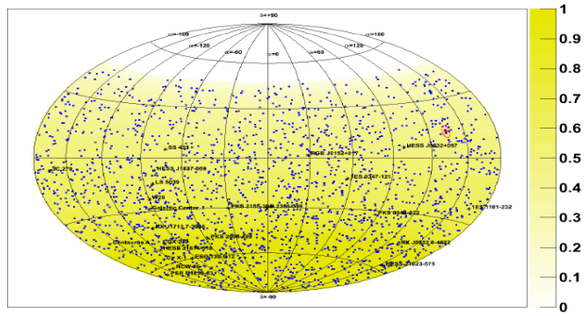
AppEC Astroparticle Physics for Europe

The Cherenkov Telescope Array

cta cherenkov telescope array

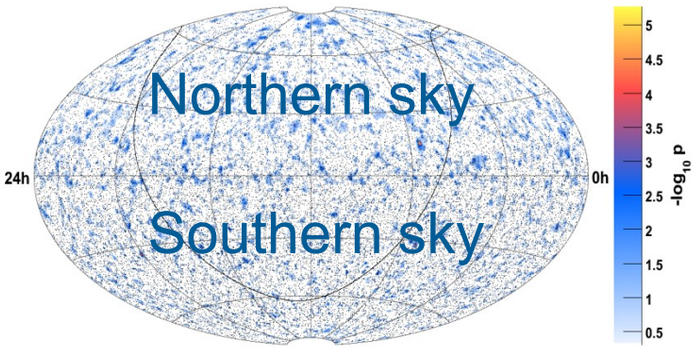
- **Compared to present telescopes**
  - **10-times better sensitivity at 1 TeV**
  - **Energy range extended to smaller and higher energies**
  - **Better angular resolution**
  - **Larger field of view (→ extended sources)**
- **Gamma astronomy with ~1000 sources, Search for dark matter, violation of Lorentz invariance, ...**

A factor 1000 in 12 years!



ANTARES

IceCube-40



①/● Super-K, 14 years
②/▲ ANTARES, 295 d.
③ AMANDA, 7 years
④/▲ IC-40, 376 days
⑤ IC-59 (prelim)
⑥ IC40+59 (prelim)
⑦ KM3NeT, 1 year (expected)

southern sky *northern sky*

$E^2\, dN/dE$ [TeV cm^{-2} s^{-1}]

10^{-9}
10^{-10}
10^{-11}
10^{-12}

-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1

sin(δ) [degrees]

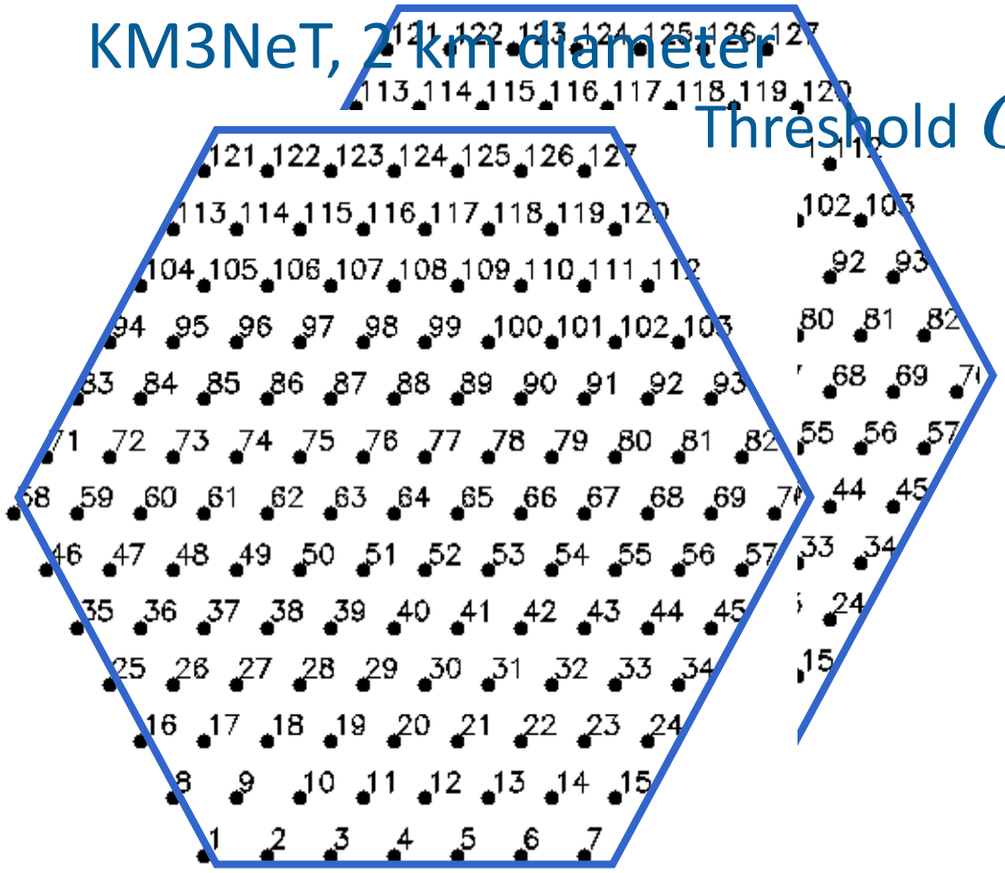
2000

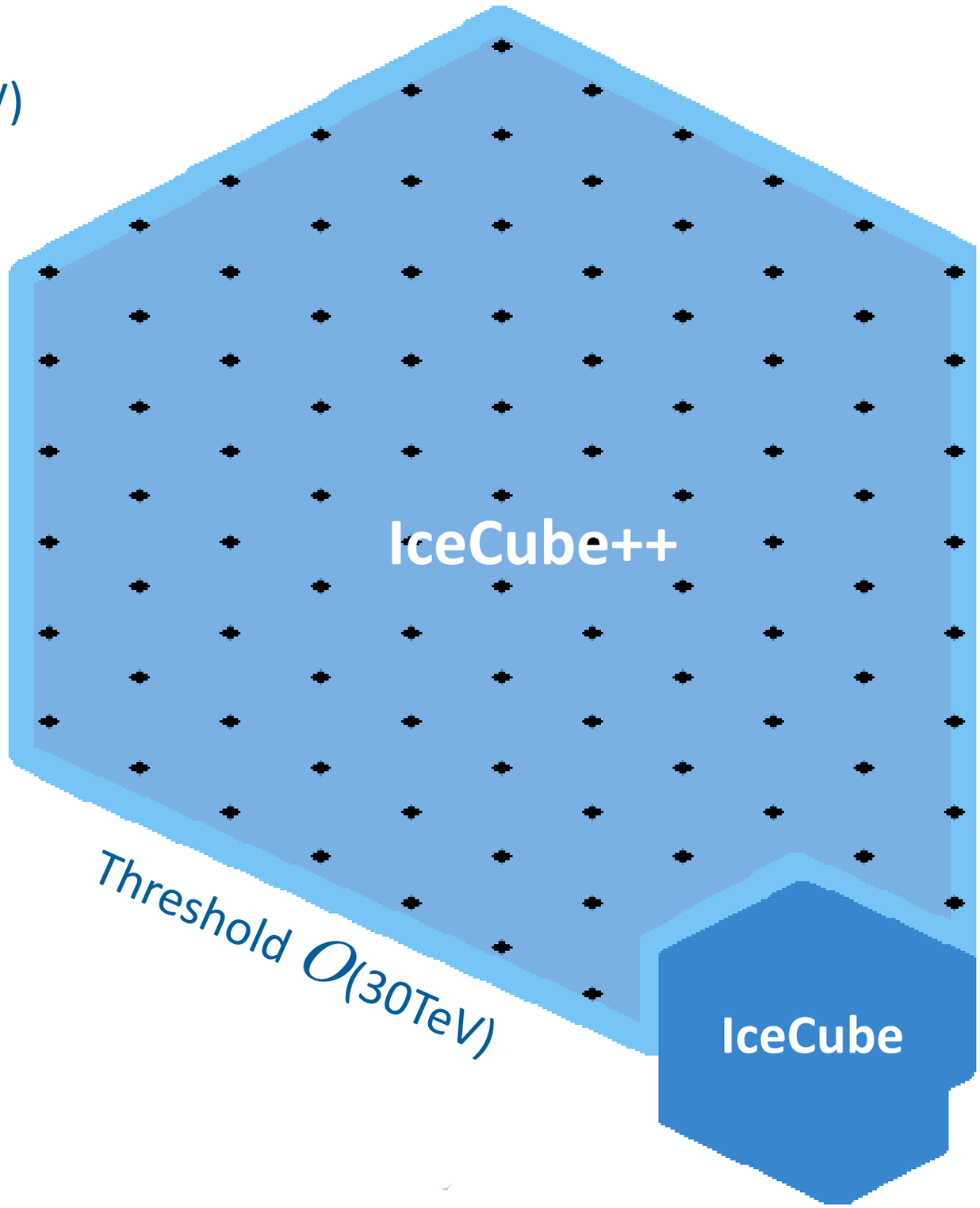
2012

KM3NeT, GVD, IceCube++

KM3NeT, 2 km diameter

Threshold $\mathcal{O}$(1TeV)





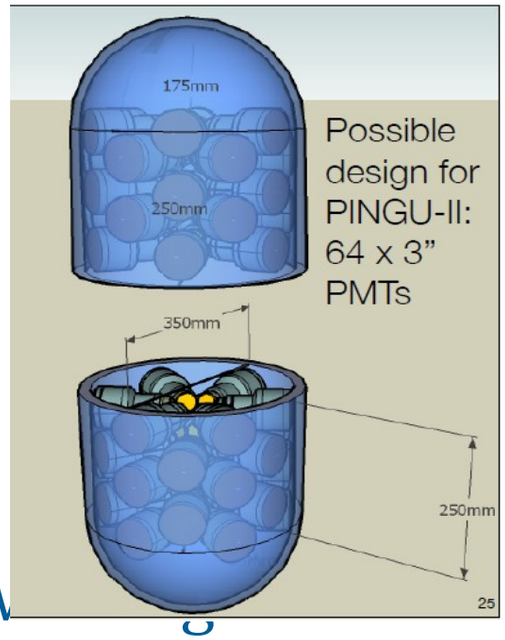
Lake Baikal
GVD

Threshold
$\mathcal{O}$(30TeV)

DeepCore extensions

- Phase-I:
  new strings, down to 1-2 GeV, matter oscillatio

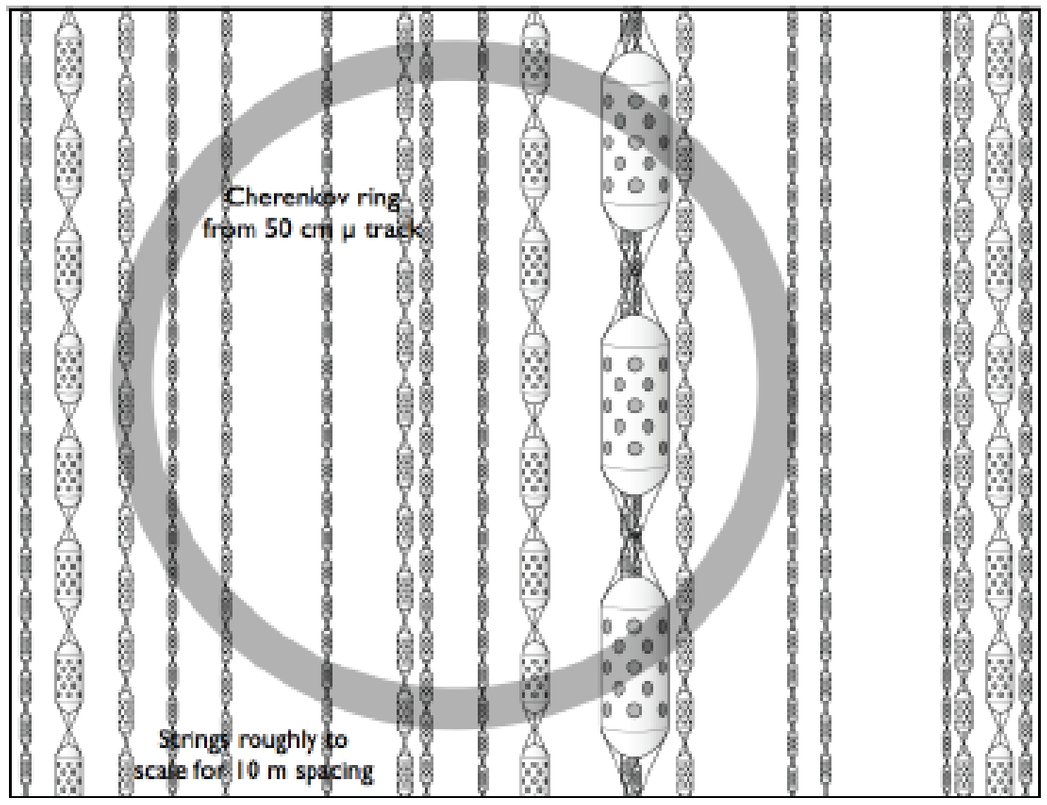
- Phase-II:



- Simulations
- PMT & el.
- Drilling

...

  - 50-100 new
  - SN from distant galaxies ?
  - Proton decay ???



New since 2008

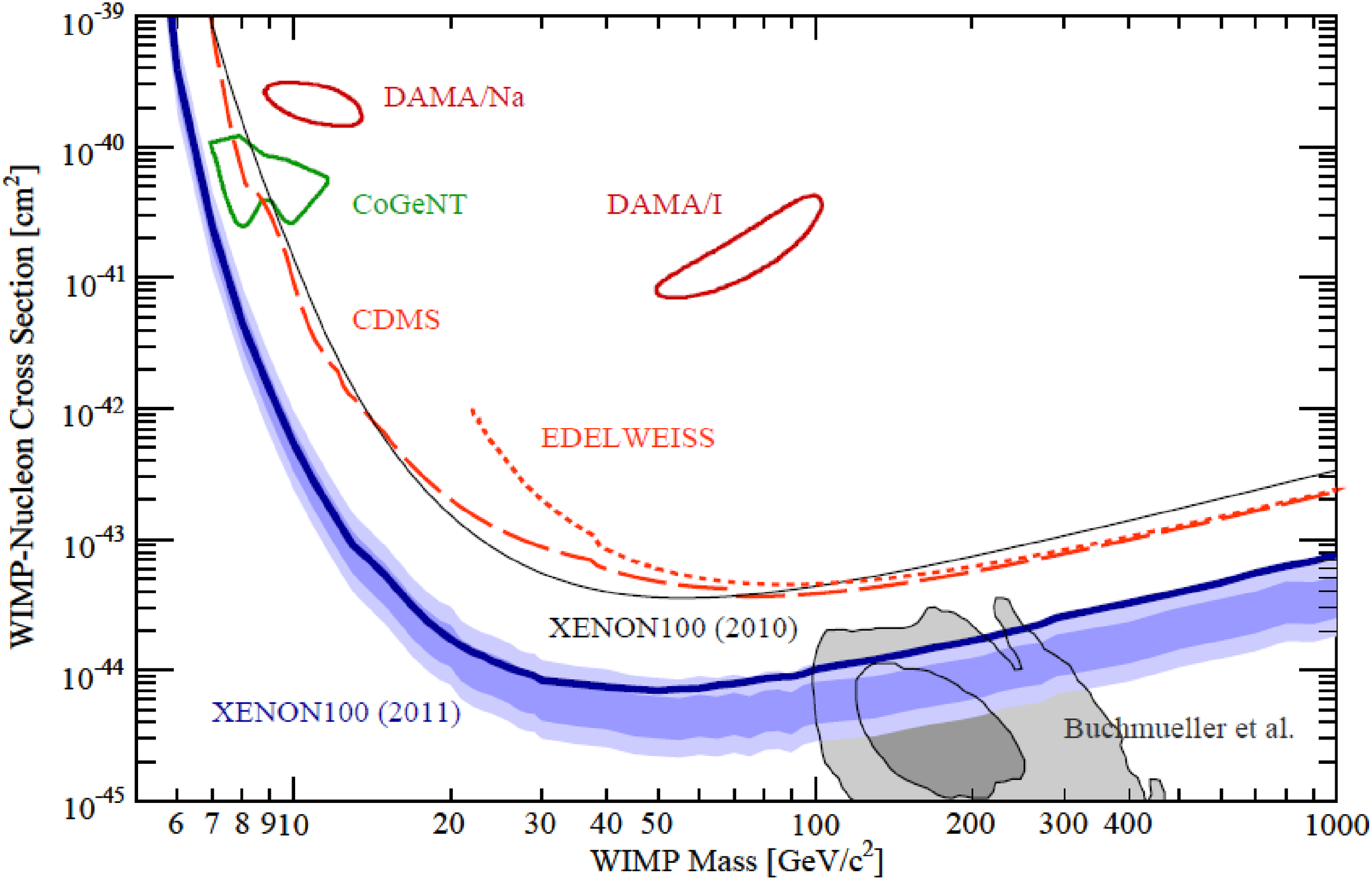
- Dark Matter:
  - XENON100, EDELWEISS and CDMS have improved sensitivity with a gradient which eventually appears to be nearly as steep as optimistic extrapolations ten years ago suggested.
  - Construction of a 1ton XENON detector is under preparation.

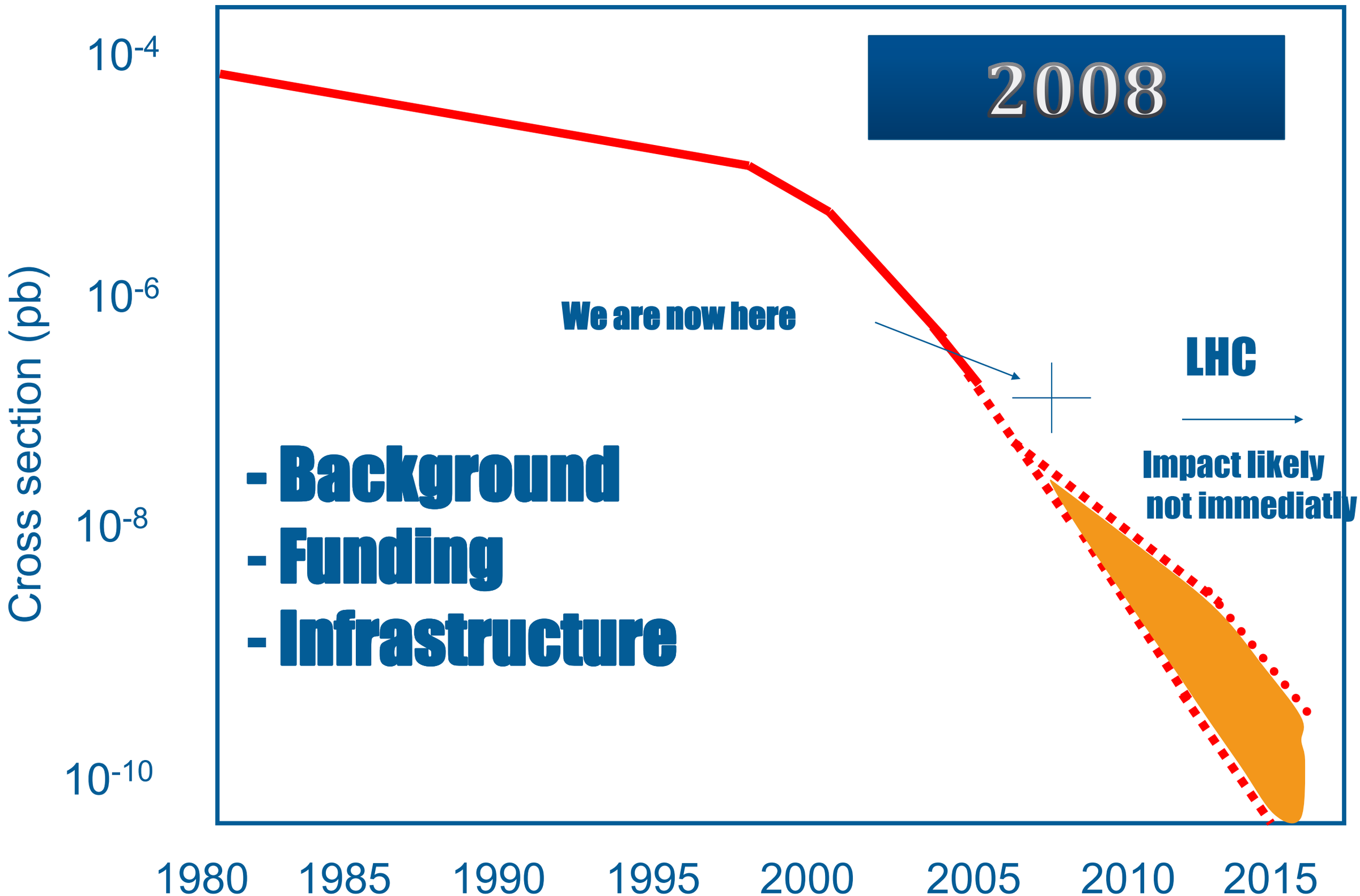
- Neutrino-less Double Beta Decay:
  - GERDA-I in commissioning phase.
  - CUORE-0, the first CUORE tower, will be assembled and cooled down in 2011.

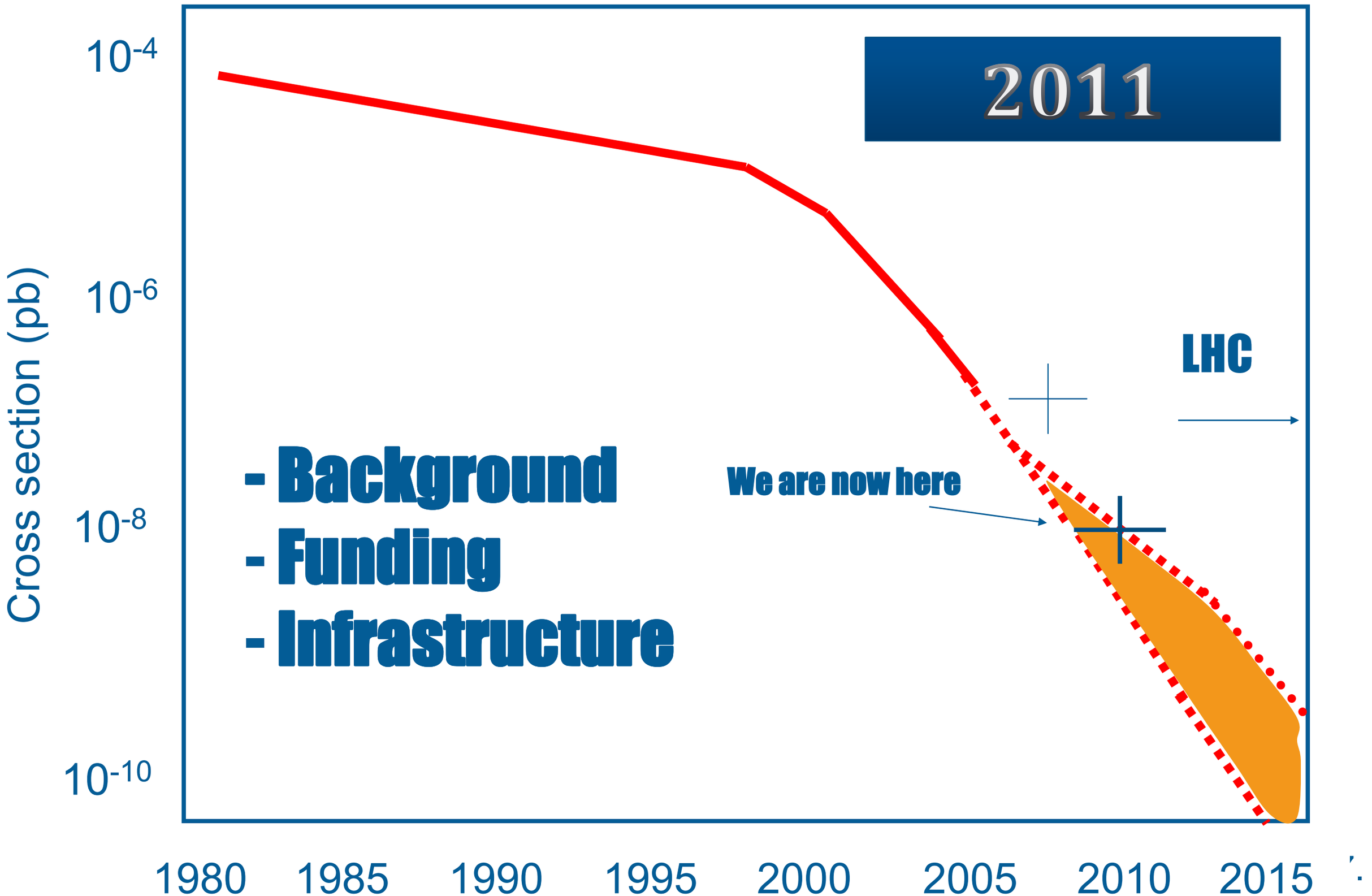
- Low energy neutrino astronomy:
  - BOREXINO: excellent performance, solar neutrinos but also geo-neutrinos,
  - The E7 design study LAGUNA is completed and the follow-up study LAGUNA-LBNO was positively evaluated.

- Gravitational Waves:
  - Advanced VIRGO and Advanced LIGO perform as a single antenna. Their advanced phase has been approved.
  - The E7 Design Study ET has been completed.
  - Worldwide effort to develop an array of ground interferometers (Europe, USA, Asia and Australia) demonstrated by the GWIC roadmap

DM Limits 2011




2008
We are now here
LHC
Impact likely
not immediatly
- Background
- Funding
- Infrastructure
Cross section (pb)
10-4
10-6
10-8
10-10
1980
1985
1990
1995
2000
2005
2010
2015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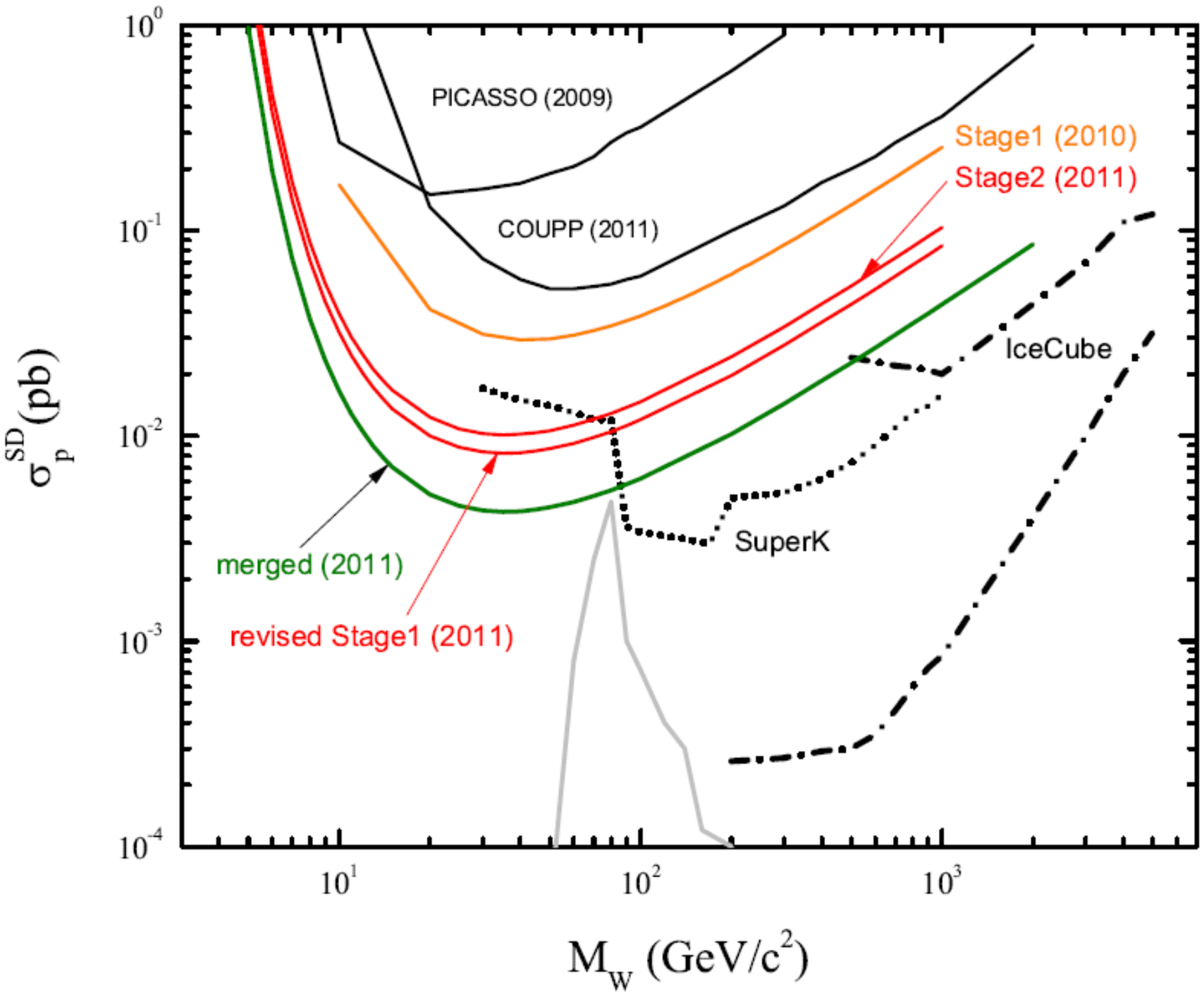

Limit on spin-dependent cross section

New result from 2011

Doubts from PICASSO Authors (arXiv)

Answer of SIMPLE in preparation

Recommendations

From Executive Summary

Recommendations

- There are a few large projects which need immediate and substantial funding,
  - be it that they have an impressing momentum which needs to be maintained;
  - that they enter a region with high discovery potential; that they go hand in hand with LHC physics;
  - that they are technologically ready and have a worldwide community behind them;
  - or, finally, that a delay of decision and funding could jeopardize or even definitely kill the project.
- In this spirit, we prioritize the following projects for immediate funding, and urge the agencies to join their forces for an effective, substantial support:

Recommendations

- **Advanced detectors for gravitational waves:**
  - GW detection would be centennial discovery – a really new window to the Universe
  - With advanced VIRGO, advanced LIGO and GEO-HF, a discovery in 5 years is highly probable.
  - We urge the agencies to continue substantially supporting the advanced detectors.
- **Dark Matter:**
  - One of the most fundamental problems in physics and cosmology. Relations to LHC !
  - Dramatic progress of liquid Xe technology over the past 2-3 years demonstrates a high momentum, which must be maintained. **XENON1t** at Gran Sasso laboratory could start operation in 2014/15.
  - Bolometric experiments **CDMS** and **Edelweiss** have recently provided competitive upper limits and move towards a closer US-Europe coordination.
  - We recommend supporting the development of **EURECA**, which envisages one ton of sensitive mass, eventually in a common US-Europe framework. Looking beyond the scale of one ton, we strongly recommend that **DARWIN,** a program to extend the target mass of noble liquids to several tons, is pursued and supported.
- **Neutrino properties:**
  - Several highly important experiments in the commissioning phase or final years of construction:
  - ν-mass: GERDA, CUORE, SuperNEMO (DBD), KATRIN (SBD).
  - θ_{13}: Double CHOOZ (imagine if T2K is not just a fluctuation !!!)
  - We renew our strong support for these experiments and look forward to first results. Beyond this, we recommend a phased experimental approach in neutrino-less double beta decay with a sensitivity (ton scale masses) exploring fully the mass range predicted by oscillation experiments for the inverted mass hierarchy.
- **Extension of the Modane Underground Laboratory (LSM):**
  - Unique window of opportunity to extend the present underground LSM.
  - New lab with of 60000 m^3 could host EURECA, DARWIN, SuperNEMO… which do not fit in the available space of existing underground labs in Europe.
  - We strongly recommend the timely support for this infrastructure.

Recommendations

Four large-scale infrastructures whose construction should start towards middle of current decade include 3 high-energy projects and one on low-energy ν astrophysics

- **TeV gamma-ray astrophysics:**
  - The Cherenkov Telescope Array (CTA) is the worldwide priority project of this field. It combines proven technological feasibility with a high speed towards prototyping, with a guaranteed scientific perspective and a mode of operation and wealth of data similar to mainstream astronomy. The cost scale of CTA is 200 M€. **We recommend to design and to prototype CTA, to select the site(s), and to proceed vigorously towards start of construction in 2014.**
- **High energy neutrinos:**
  - In the high-energy neutrino domain, the requirements on the necessary sensitivity have tightened, but the scientific case for a large neutrino detector in the Northern hemisphere remains high. The KM3NeT collaboration is working towards a technical proposal for a neutrino telescope with a substantially larger sensitivity than IceCube. The expected cost scale is 250 M€ and, based on pioneering technical work by the European astroparticle community, also provides access to deep-sea research.
- **High energy cosmic rays:**
  - In the cosmic-ray domain the Pierre Auger collaboration is working towards a next-generation ground-based observatory including the development of new detection technologies, the search for appropriate sites, and the possibility to attract new partners. We reiterate the definition of a substantially enlarged ground-based observatory as the priority project of high-energy cosmic ray physics. The cost scale is 100-150 M€, with a substantial contribution from Europe.

Recommendations

Four large-scale infrastructures whose construction should start towards middle of current decade include 3 high-energy projects and one on low-energy ν astrophysics

- **Low-energy neutrino astrophysics and proton decay:**
  - A megaton-scale detector is addressed by the LAGUNA design study.
  - The scientific goals combine high-risk research addressing several fundamental questions of physics (proton decay, CP violation) with exciting neutrino astrophysics (e.g. supernova, solar, geo- and atmospheric neutrinos).
  - The committee recommends that the study be pursued within the LAGUNA-LBNO program, including options with and without a new neutrino beam. Due to the high cost (350-700 M€, depending on site and type of detector) and the long development time, the committee recommends that this program be pursued in a global context.
  - Given the close relation to beam-related neutrino oscillation projects, the urgency of its realization depends strongly on the output of the current accelerator and reactor programs and in particular on whether the missing neutrino-mixing parameters are in the range that would permit a series of very exciting new measurements (neutrino mass hierarchy, CP violation etc). LAGUNA is therefore clearly at the interface with the CERN European Strategy Update to be delivered by the end of 2012. As such the LAGUNA project constitutes a high astroparticle physics priority to be discussed within the CERN strategy update process.

Recommendations

- The presently conceived start of construction of KM3NeT, "AugerNEXT" and LAGUNA is between 2014 and 2016. It seems likely that this does not fit into a realistic funding scheme.

- **"We would support a strategy to search for funding opportunities for these projects – both in Europe and worldwide – and promote any one of these projects as soon as a corresponding window appears."**

Aspera Gov. Board asked to define decisions points and milestones for KM3NeT, AugerNEXT and Laguna

Recommendations

- **E.T. and LISA:**
  - **Acknowledge the progress of the E.T. Design Study.**
  - Propose an ASPERA call for related R&D. From today's perspective E.T. construction would start at the end of the decade.
  - Look forward to the results of LISA-Pathfinder and **renew strong support for LISA**.
- **Dark Energy:**
  - Astroparticle physicists play a major role in many international **dark energy programs,** as e.g. the dominantly US-funded **LSST** observatory (first light ca 2016) or the ESA satellite **EUCLID** (launch ca. 2018). **The committee recommends a strong support for these participations.**
- **Transversal aspects:**
  - **Theoretical research:**. Similar to experimental activities, theoretical studies will strongly benefit from a strengthened and more coordinated support. In turn, this will also help to maximally exploit the impact of astroparticle physics experiments.
  - **Smaller projects and innovative R&D activities** are essential for the progress of our field and profit from international cooperation. ASPERA addressed this by a series of calls for R&D activities. (*see once more on one of the following slides!)*
  - Most astroparticle observatories, whether they are located underwater/ice (neutrino telescopes) or underground (underground laboratories) or on the ground (air-shower detectors), have developed strong **synergies with geo-science and environmental studies.** They provide state-of-the-art technologies and attractive infrastructures to the corresponding communities, which in turn will increase the support of these infrastructures.

Recommendations

From the text,

and only for underground projects

Dark Matter

- The last two-three years saw a dramatic progress of the liquid-xenon based technology for the direct detection of WIMPs. The 100 kg scale has been realised with a low background level and the 1-ton scale is currently being planned. **On this basis, the committee recommends that DARWIN, a program to further extend the target mass of noble liquids to several tons, is pursued and supported. 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 in terms of rejection efficiency, background and operation reliability.**

- The bolometric techniques have remained competitive with the noble liquid approach in terms of sensitivity to WIMP interactions. The results of the EDELWEISS collaboration showed a clear technological advancement with germanium detectors regarding the rejection of surface beta background, which was the main limitation in the "ionisation+heat" option. The CRESST experiment showed the power of identifying nuclear recoils from light and heavy nuclei using $CaWO_4$ **The committee recommends therefore supporting the development of the multi-target approach EURECA, an apparatus capable of housing 1 ton of bolometric sensitive mass, and the ongoing cooperation with the CDMS follow-up projects. This facility is complementary to the solution provided by noble liquids, and is versatile enough to provide a multi-target approach (including low Z targets tailored to test the low-mass WIMP region) and to possibly house other rare event searches based on the bolometric technology.**

Dark Matter

- **The committee strongly supports improving the DAMA/LIBRA experiment in terms of a lower threshold and a lower background, with the goal to better understand the observed modulation signal. A fully independent experiment based on the same or on a similar technology would be crucial to cross-check the DAMA/LIBRA effect.**
- **The committee endorses an expansion of the experiment SIMPLE with a lower background level in order to further increase its sensitivity to spin-dependent interactions.** This search can be done in synergy with the possibilities provided by xenon (about 50% nuclei have half integer may become essential to confirm the galactic dark matter origin of the signal in case of a positive signal from the high-density target detectors.
- **The committee recommends supporting the R&D activities related to the directional detection of WIMPs, in particular aiming at a substantial background reduction, as this continuation of the corresponding programs.**
- ***Axions:***
  The committee supports the continuation of the corresponding programs.

Double Beta Decay

- The European detectors GERDA and CUORE will explore in the next years the degenerate region of the neutrino mass pattern. CUORE will probe also part of the mass range predicted by neutrino oscillation experiments for the case of the inverted mass hierarchy.

- In case of discovery at the degenerate mass level, there is a **clear path for "precision measurements"**, with possible evidence in three different nuclei and with the unique opportunity provided by SuperNEMO to investigate the leading DBD mechanism. **The committee recommends therefore a prompt realization of the SuperNEMO demonstrator**.

Double Beta Decay

- The community is working to improve the sensitivity with the aim to fully cover the **inverted hierarchy region**, a crucial element for the determination of the neutrino mass hierarchy in synergy with the next stages of the neutrino oscillation program. The general requirement for this task is 1 ton of isotope and a background at the level or below 1 count/(y ton-isotope) in the region of interest. This challenging objective can be accomplished either by the technologies of the experiments running or in construction (this option would provide the advantage of a phased approach) or by new promising technologies which are currently under study (LUCIFER, NEXT, COBRA pixel detectors, pulse shape discrimination in bolometer experiments, argon instrumentation in GERDA, Cherenkov light in TeO_2).**The committee recommends that these options are pursued at the R&D level in view of a final assessment of the most effective approaches for the 1 ton scale.**
- **As the required financial resources are substantial for ton scale experiments, the committee endorses their realisation in the framework of worldwide collaborations. This would allow the investigation of more than one double beta isotope, which is essential to provide an unambiguous signature of neutrino-less double beta decay and to determine the effective Majorana mass.**
- The committee notes progress in the calculation of the nuclear matrix elements for $0\nu\beta\beta$ decay, with clear signs of convergence and with a validation of the traditional methods through a new approach. **The committee confirms therefore the importance of continuing this fruitful program, which is based on both theoretical and experimental investigations.**

LE neutrinos

- **The committee strongly endorses further support the BOREXINO program**, which is now unique in the world. BOREXINO could be able to detect pep and CNO neutrinos at 30% level in a timescale of two years.
- **It is recommended that the program with OPERA and ICARUS be continued as planned** in order to obtain a more significant evidence for tau appearance.
- To achieve full sensitivity and to be competitive with other experiments worldwide, **it is critical that the Double CHOOZ Near Detector be completed as soon as possible.**
- Several anomalies in the neutrino sector and in cosmology have been noted over the last 15 years and generated increased interest in **sterile neutrinos** as a possible explanation. **This makes new experimental campaigns imperative, with the goal to either falsify the anomalies or indeed discover physics beyond the Standard Model.**
- Neutrino astronomy would benefit from the measurements of nuclear cross-sections of astrophysical interest using underground nuclear accelerators. **We recommend therefore supporting the update of the ongoing programs with LUNA and follow-up projects at higher energy.**

LE neutrinos

- ***LAGUNA*** is the European effort to develop neutrino detectors on the "Megaton scale" both for accelerator-based and astroparticle neutrino measurements. The scientific goals are both broad and ambitious. The LAGUNA site study is almost completed, showing that there are possible sites in Europe that could host such experiments. **The committee recommends that the study be pursued with LAGUNA-LBNO focusing on detector designs to lead to a better understanding of the costs of the various detector technology options and on the prospects for a new long baseline neutrino beam from CERN.**
- **Due to the high cost and long development time necessary to realize this program, the committee recommends that it be pursued in a global context. It is also recommended that programs with and without a new neutrino beam are considered in order to preserve possible science opportunities.**

- In the context of long-baseline measurements of neutrino oscillations, of the detection of supernova burst neutrinos and of the search for proton decay, we also mention a **further infill of the DeepCore detector nested in IceCube** at the South Pole. A moderate infill of 15-20 strings would results in a threshold of ~1 GeV and might allow to measure matter oscillation effects which are sensitive to the neutrino mass hierarchy. **A massive infill of 50-100 strings might lead to a 20 Megaton detector sensitive to supernova bursts from much beyond our own galaxy and possibly even to proton decay. The committee encourages the ongoing Monte-Carlo studies and related photo-sensor developments.**

Small projects and R&D

- Emphasize enormous importance of smaller projects and R&D activities for the progress of our field. Astroparticle physics would not be where it is now without the continuous spirit of innovation which is so characteristic for our field. Clearly, the field has reached a phase where concentration of funding to a few huge-scale projects is inevitable, but also clearly, a portion of the order of 25% must be available for small and new projects.

Time schedule 2011 Roadmap

- Presentation to Aspera Gov Board (10 day ago)
- Presentation to ApPEC Steering Comm. (July 4)
- Modifications
- Post on website (July 14).
- Opinion from Community.
- Last minute update w.r.t. very recent results and community requests (September)
- Printing
- Ready for ceremony in November in Paris and as input for CERN European strategy process (2012)