The ApPEC Roadmap
(Phase I)

E. Fernandez, IFAE/UAB

Ilias Network Meeting, Chambery , Feb 28, 2006

ApPEC (Astroparticle Physics European Coordinating Committee) was created on May 2, 2001, as an initiative of a few funding agencies in Europe (initially: BMBF, IN2P3,CEA, INFN, FOM, PPARC).

The ApPEC Steering Committee soon nominated a “Peer Review Committee” (PRC) to provide it with advise in scientific matters. First meeting of the PRC took place in Paris, on Jan. 21-22, 2002.

ApPEC Peer Review Committee

Ricardo Barbieri (chair)
Karsten Danzmann
Michel Davier
Maarten De Jong
Luigi Di Lella
Franz v. Feilitzsch
Enrique Fernandez
Ettore Fiorini
Joe Silk
Gerard Smadja
Nigel Smith
Christian Spiering
Alan Watson

During 2002-2005 the PRC examined the status and made recommendations on a number of topics

The focus of the PRC changed in 2005, when it was charged with making a Road-Map of the field.

The reasons for a roadmap are clear:

Experiments costing 100M€ or more are being proposed. Resources going into this field are increasing.

However there is no well defined procedure to define priorities, which will be necessary in the future.

ApPEC Peer Review Committee (Expert Group)

Frank Avignone
Jose Bernabeu
Leonid Bezrukov
Pierre Binetruy
Hans Bluemer
Werner Hofmann
Karsten Danzmann
Franz v. Feilitzsch
Enrique Fernandez
Werner Hofmann
John Iliopoulos
Uli Katz
Paolo Lipari

Manel Martinez
Antonio Masiero
Benoit Mours
Francesco Ronga
Andre Rubbia
Subir Sarkar
Guenther Sigl
Nigel Smith
Christian Spiering (Chair)
Alan Watson

Observer SC:
Thomas Berghöfer

Inputs for the roadmap:

- ApPEC work in the first phase of the committee.
- Questionnaire sent to all spokepersons of experiments in the field.

  From this, the most promising research areas and instrumental approaches were identified.
- Several meetings involving in total ~2000 people.
- Town meeting in Munich, Nov. of 2005.
- Draft report in October of 2006.
- ApPEC meeting in Valencia, Nov. 2006.

The resulting road-map should be regarded as a first stage roadmap. It describes the status and desirable options for the next decade.

A second stage roadmap, coordinated within ASPERA (ERA Network), will define priorities.

What is Astro-Particle Physics?

Mainly **particle physics** with non-accelerator means, with connections to astrophysics and cosmology.

Scientific questions:

- What is the universe made of? In particular: what is dark matter?
- Do protons have a finite lifetime?
- What are the properties of neutrinos? What is their role in cosmic evolution?
- What do neutrinos tell us about the interior of the Sun, the Earth or about Supernovae explosions?
- What is the origin of cosmic rays? What is the view of the sky at extreme energies?
- Can we detect gravitational waves? What will they tell us about violent cosmic processes and about the nature of gravity?

Dark Matter Searches

The indirect evidence for the existence of dark matter is overwhelming: rotation curves of galaxies, velocity dispersion in clusters, gravitational lensing...and cosmology:

Baryonic matter density:

- **BBN + CMB** $\Omega_b = 0.040 \pm 0.012$
- **CMB anisotropies** $\Omega_b = 0.043 \pm 0.004$

Total matter density

- **CMB anisotropies** $\Omega_m = 0.24 \pm 0.04$

Most of the dark matter should be cold, e.g., non-relativistic at the time of decoupling

$$\Omega_{CDM} = \Omega_m - \Omega_b = 0.197 \pm 0.04$$

Dark Matter Searches

Favorite candidate for Dark Matter are "beyond the SM particles": WIMPs, axions,...

One can search for dark matter

directly, by trying to detect the interaction of a dark matter particle from the halo of our galaxy in a laboratory detector, or

indirectly, e.g. by detecting, gamma-rays, neutrinos or antiparticles from annihilation of dark matter particles in sources (center of galaxies, earth, etc).

Indirect searches of Dark Matter will continue in the context of experiments with other objectives: AMS, Gamma-Ray Telescopes, others.

Dark Matter Direct Searches

Nuclear recoil produced by the elastic scattering of WIMP with detector:

$$R \approx \frac{\rho_\chi}{m_\chi} \langle v_\chi \rangle \frac{\sigma_{\chi A}}{A}$$

Very small rates (10^{-5} to 1 count per Kg-day); very small energy transferred to recoiling nucleus. Need of high background suppression.

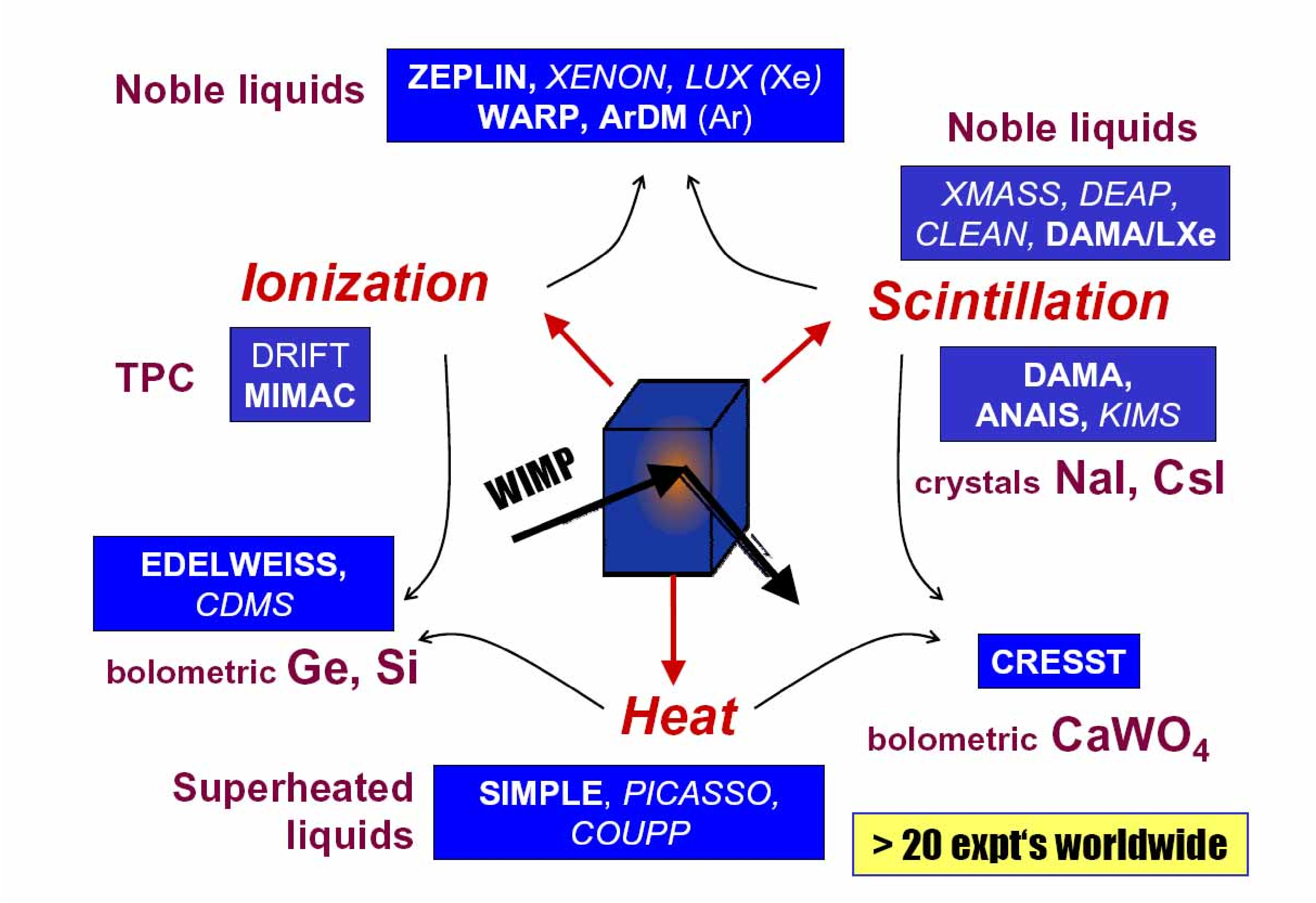
Background discrimination:

Annual modulation: $\Delta v_\chi / v_\chi \sim 0.07$

A-dependence of σ

Directionality

Direct Dark Matter Searches Techniques:



Many on-going and planned experiments world-wide

Name	Type	Status	Location	European Members	Others
DAMA/ LIBRA	NaI	running	LNGS	IT	China
ANAIS	NaI	construction	Canfranc	ES	-
KIMS	CsI	R&D	Korea	-	Korea
HDMS	Ge	running	LNGS	DE	RU
ROSEBUD	Bolom scint	R&D	Canfranc	ES, FR	-
DAMA-LXe	LXe scint	running	LNGS	IT	China
ZEPLIN-II	LXe	running	Boulby	PT, UK	RU, US
ZEPLIN-III	LXe	installation	Boulby	PT, UK	RU, US
XENON10	LXe	commissng	LNGS	DE, IT, PT	US
LUX	LXe	R&D	DUSEL	PT, UK	US
XMASS	LXe	?	Kamioka	-	Japan
WARP	LAr	running	LNGS	IT	US
ArDM	LAr	construction	Canfranc	CH, ES, PO	-
DEAP	LAr	R&D	SNOLAB	-	Can, US
CLEAN	LNe	R&D	t.b.d.	-	US, Can
DRIFT	CS_2 gas TPC	R&D	Boulby	UK	US
MIMAC	^{3}He gas TPC	R&D	t.b.d.	FR	-
EDELWEISS	bolometer	running	Frejus	FR, DE	RU
CRESST	bolometer	running	LNGS	DE, UK, IT,	-
CDMS	bolometer	running	Soudan	-	US
SIMPLE	Superheated droplet SHD	running + R&D	LSSB	PT, FR	US
PICASSO	SHD	running + R&D	SNOLAB	CZ	CA, RU, US
COUPP	SH liquid	R&D	t.b.d.	-	US

Direct Dark Matter Searches

DAMA (100 kg NaI crystals): positive result, with annual modulation over a 7-year period.

Best limit: CDMS, cross section $<1.7\times10^{-7}$ pb for $m_\chi \sim 50$GeV

Independent confirmation of DAMA result will be required to solve controversy

DAMA/LIBRA (250 kg NaI): on-going.

ANAIS (Canfranc, 100 kg NaI), different radio-purity.

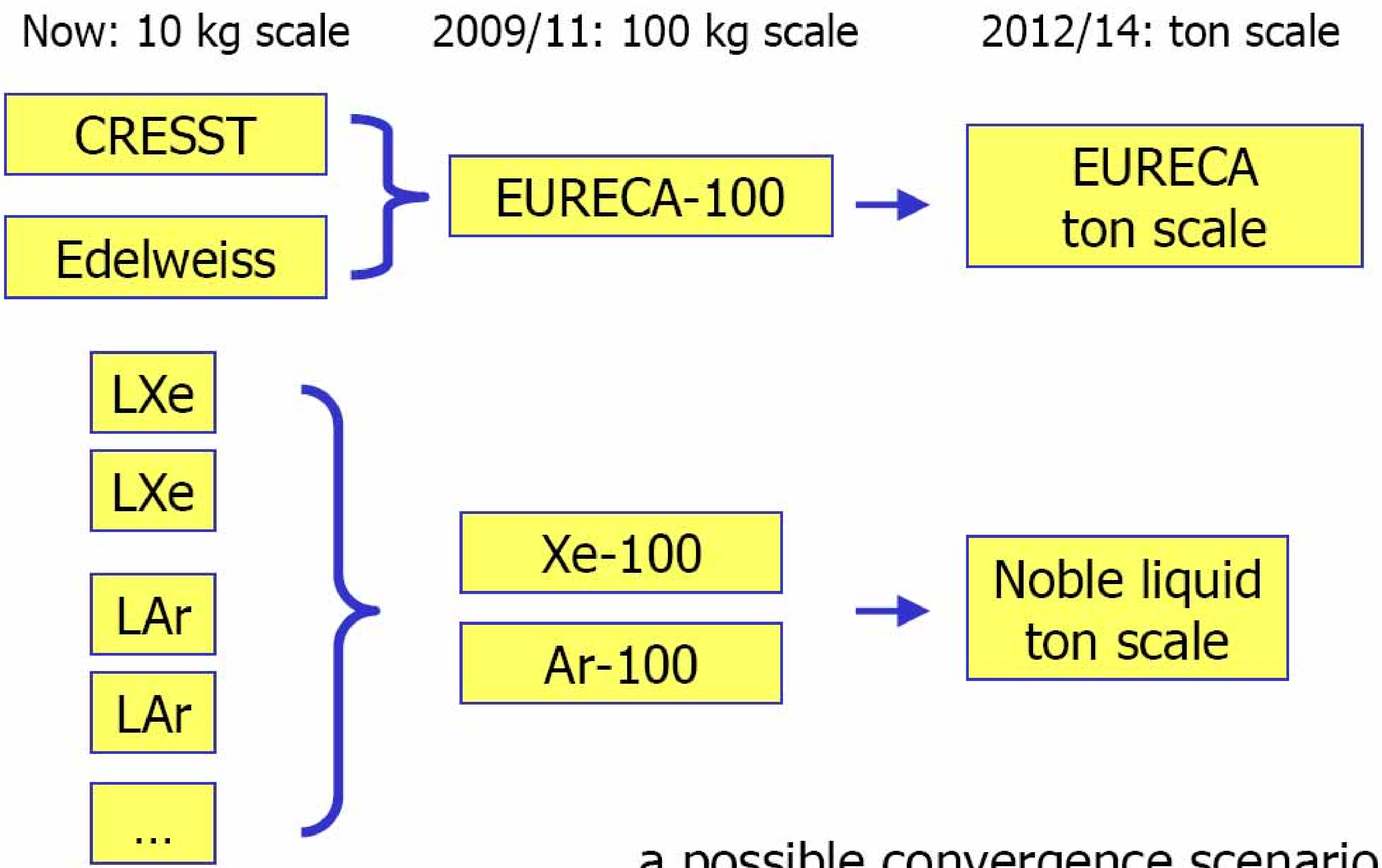
To push limit below 10^{-8} pb will require concentration of resources in two or three experiments world-wide, with masses of order 100 kg to 1 ton.

From the **recommendations**:

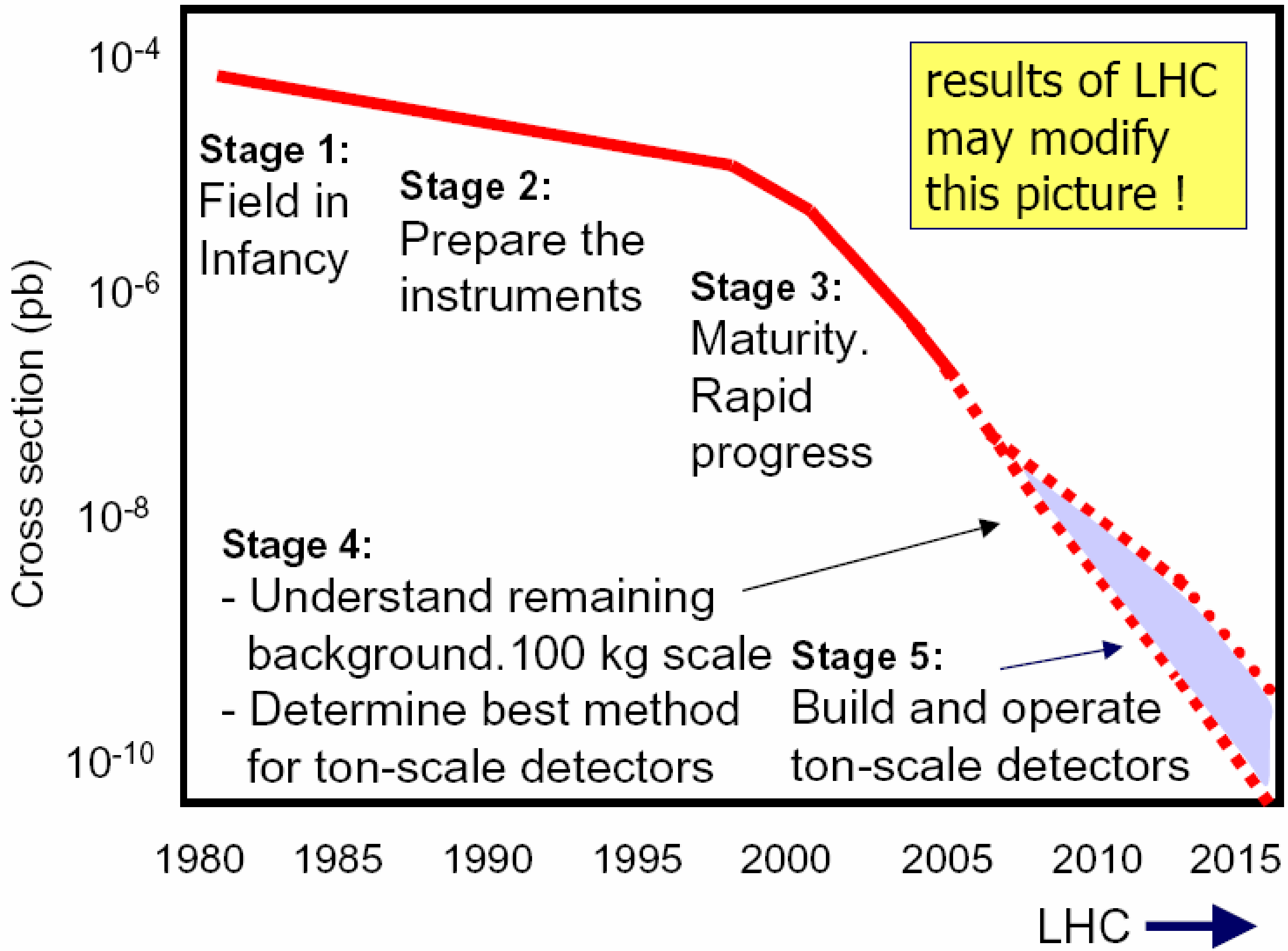
…The preferred scenario includes a cryogenic and a noble liquid low-background experiment of a one-ton scale with a European lead role, as warranted by the results from the 100kg-scale detectors.

...Development of the directional technique (e.g. like that of the DRIFT collaboration) is important and should be supported.

Towards 2 large detectors



a possible convergence scenario



10-4
10-6
10-8
10-10
Cross section (pb)
Stage 1:
Field in Infancy
Stage 2:
Prepare the instruments
Stage 3:
Maturity. Rapid progress
results of LHC may modify this picture !
Stage 4:
- Understand remaining background. 100 kg scale
- Determine best method for ton-scale detectors
Stage 5:
Build and operate ton-scale detectors
1980
1985
1990
1995
2000
2005
2010
2015
LHC

Axions: another candidate particles for cold dark matter

Axions introduced to explain the lack of CP violation in strong interactions. They can be produced in the early universe (in a condensate) and therefore be non-relativistic despite their low mass, 10^{-6} to 10^{-3} eV/c^2.

Traditional method of detection: axion + $\gamma_{virt.} \rightarrow \gamma_{real}$

γ_{real} in the microwave range for small axion masses. Only negative results so far.

Axions produced in a source (e.g. the SUN)

The axions will be produced relativisticaly (broad spectrum ~ 4 keV). They will interact in the magnetic field producing again real photons. The CAST experiment at CERN has looked photons from converted axions coming from the Sun in the B field of a LHC solenoid.

PVLAS claim: observation of a rotation of the polarization plane of photons in a 6.6 T magnetic field. This implies the existence of a scalar particle. Experiment will be repeated at the VUV FEL at DESY.

From the recommendations:

The CAST experiment should be continued to cover the full range of axion masses that is accessible by this technique.

On dark energy:

There is growing activity in the astroparticle physics community in Europe in this area, and initiatives to address this question together with the astrophysics and cosmology communities are strongly encouraged.

Proton Decay Experiments

Search for proton-decay well motivated theoretically.

GUT predict proton decay. The simplest SU(5) theory, $\tau_p \sim 10^{31}$-10^{32} years, already ruled-out by present experiments. SUSY models predict decay times of the order of 10^{35}years.

1 Mton of water contains $3\text{x}10^{35}$ protons (and $3\text{x}10^{35}$ n)

Favorite decay channels:

$p \rightarrow e^+ \pi^0$ (SK limit: $5.4\text{x}10^{33}$ years)

$p \rightarrow$ anti-ν k^+ (SK limit: $2.2\text{x}10^{33}$ years)

Proton-decay detectors will be multi-purpose, in particular they will also be neutrino detectors.

Neutrino Physics

Neutrino properties
- Mixing parameters
- Absolute mass
- Dirac or Majorana

Role of neutrinos
- Solar model
- Geo-Neutrinos
- Supernova, other sources

Neutrino Physics

Mixing parameters:

CNGS (Opera, ICARUS): on-going experiments.
Will prove that oscillation is ν_μ to ν_τ.

Double-Chooz: can improve present upper limit on $\sin^2\theta_{13}$ from 0.12 to 0.04 in a 3-year run.

BOREXINO: will measure the ^{7}Be and pep lines.

Vacuum to MSW transition

pp flux uncertainty $\Leftrightarrow$ pep uncertainty $\Rightarrow$solar luminosity to 10%.

Geo-neutrino flux to 30% (similar to KAMLAND)

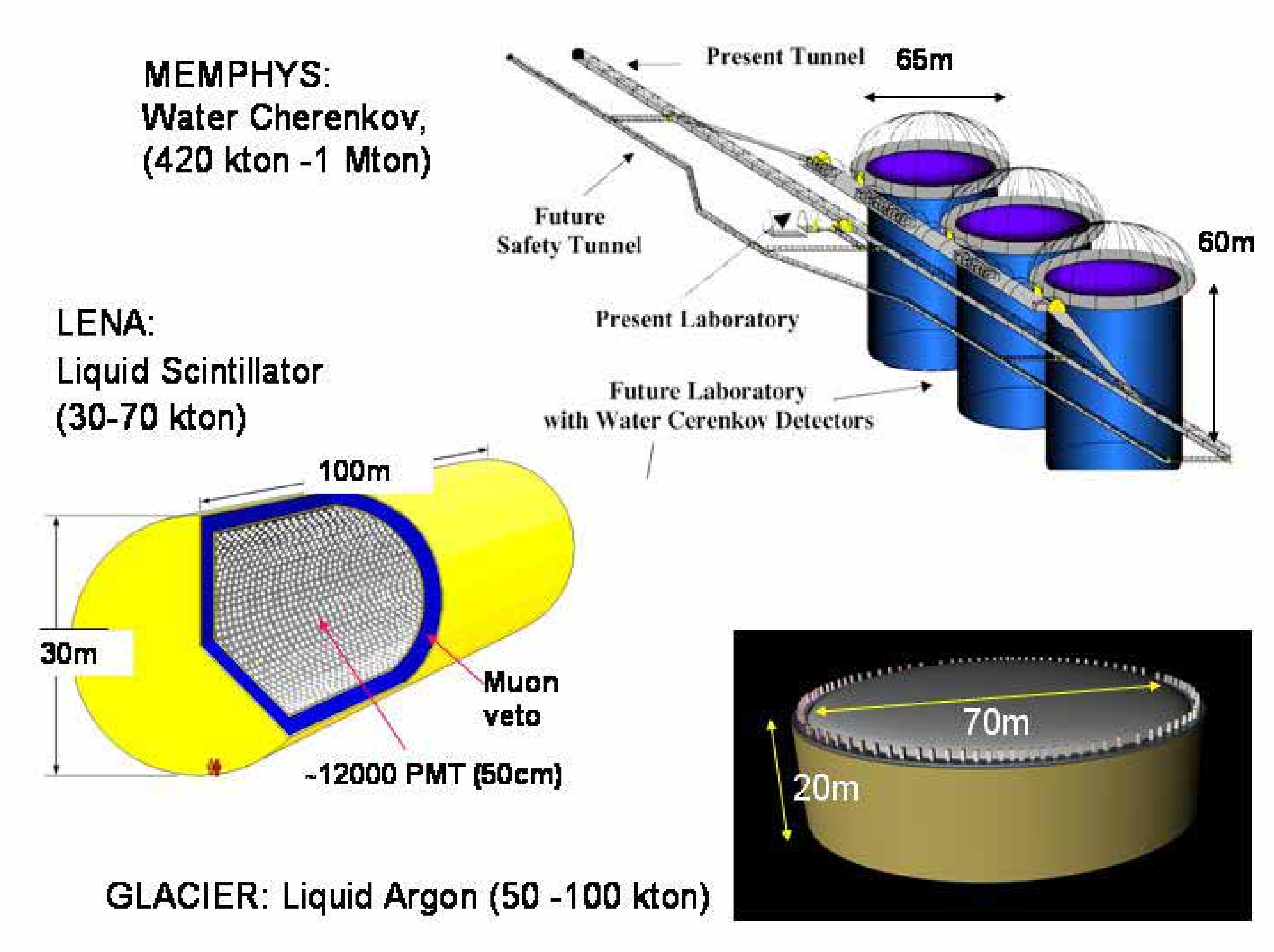
Supernova neutrinos (~50 NC events for SN at10kpc)

Neutrino Physics

Double-Chooz: Full support. Do it a.s.p.

BOREXINO: Full support. Do it a.s.p.

Ideas for Future Facilities in Europe (multi-purpose detectors, ν and proton-decay)



Topics	GLACIER (100 kt)	LENA (50 kt)	MEMPHYS (400 kt)
proton decay, sensitivity $e^+ \pi^0$ anti-ν K^+	$0.5 \cdot 10^{35}$ $1.1 \cdot 10^{35}$	- $0.4 \cdot 10^{35}$	$1.0 \cdot 10^{35}$ $0.2 \cdot 10^{35}$
SN at 10 kpc, # events CC NC ES	$2.5 \cdot 10^4$ (ν_e) $3.0 \cdot 10^4$ $1.0 \cdot 10^3$ (e)	$9.0 \cdot 10^3$ (anti-ν_e) $3.0 \cdot 10^3$ $7.0 \cdot 10^3$ (p)	$2.0 \cdot 10^5$ (anti-ν_e) - $1.0 \cdot 10^3$ (e)
Diffuse SN # Signal/Background events (5 years)	60/30	(10-115)/4	(40-110)/50 (with Gadolinium)
Solar neutrinos # events, 1 year	^{8}B ES : $4.5 \cdot 10^4$ Abs: $1.6 \cdot 10^5$	^{7}Be: $2.0 \cdot 10^6$ pep: $7.7 \cdot 10^4$ ^{8}B: $3.6 \cdot 10^2$	^{8}B ES: $1.1 \cdot 10^5$
Atmospheric ν **# events, 1 year**	$1.1 \cdot 10^4$	TBD	$4.0 \cdot 10^4$
Geo-neutrinos # events, 1 year	Below threshold	$1.7 \cdot 10^4$	Below threshold

Recommendation

We recommend that a new large European infrastructure is put forward, as a future international multi-purpose facility on the 10^5-10^6 ton scale for improved studies proton decay and of low-energy neutrinos from astrophysical origin. The three detection techniques being studied for such large neutrino detectors in Europe, Water-Cherenkov (like MEMPHYS), liquid scintillator (like LENA) and liquid argon (like GLACIER), should be evaluated in the context of a common design study which should also address the underground infrastructure and the possibility of an eventual detection of future accelerator neutrino beams. This design study should take into account worldwide efforts and converge, on a time scale of 2010, to a common proposal.

Absolute neutrino masses

From oscillations:

$m_\nu > 0.05$ eV/c^2

From cosmology (WMAP + 2dFGRS + SDSS) :

$\sum m_\nu < 0.68$ eV/c^2 $\rightarrow$ 0.1 eV/c^2 in the future

(but other analysis gives $m_\nu < 0.5$ eV/c^2 for each ν)

KATRIN (spectrometer) aims at 0.2 eV/c^2 for effective mass, to start running in 2009/2010.

Calorimetric techniques (bolometers) are far from this, but possible in principle to reach low limits (MARE-2).

The other approach to measure the absolute mass is

neutrinoless double-beta decay

Netrinoless double beta decay will prove that the neutrino is a Majorana particle. The lifetime is inversely proportional to the square of the effective mass:

$$m_{\beta\beta} = \mathrm{abs}\left(|U_{e1}|^2 m_1 + |U_{e2}|^2 m_2 \exp(i\Phi_2) + |U_{e3}|^2 m_3 \exp(i\Phi_3) \right)$$

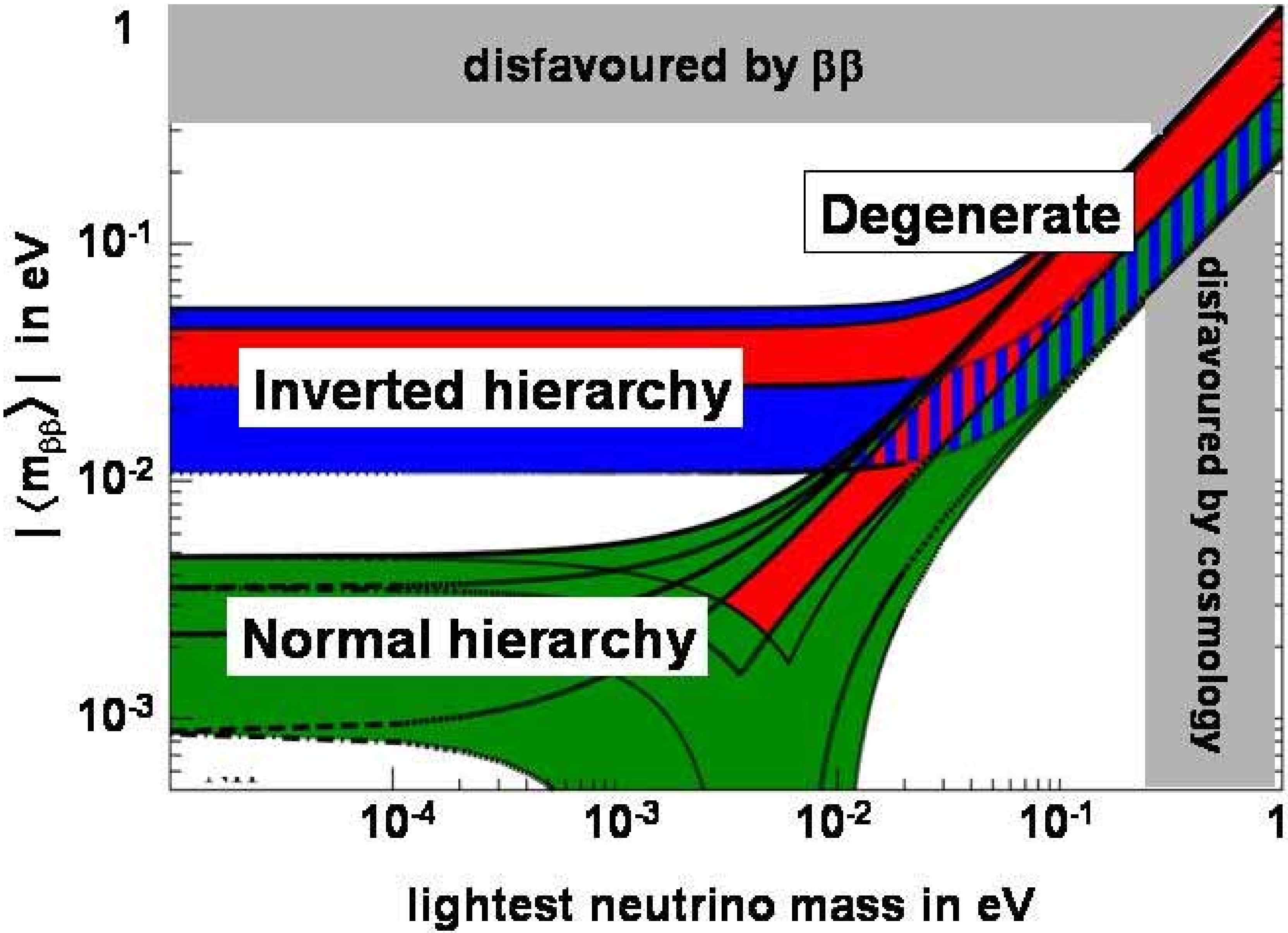
$$m_{\beta\beta} = \sum U_{ej}^2 \cdot m_j \text{ (for zero Majorana phases)}$$

Present best limits come from crystal ^{76}Ge detectors:

Heidelberg-Moscow : $T_{1/2} > 1.9 \times 10^{25}$ y $\Rightarrow m_{\beta\beta} < 0.33\text{-}0.84$ eV/c^2

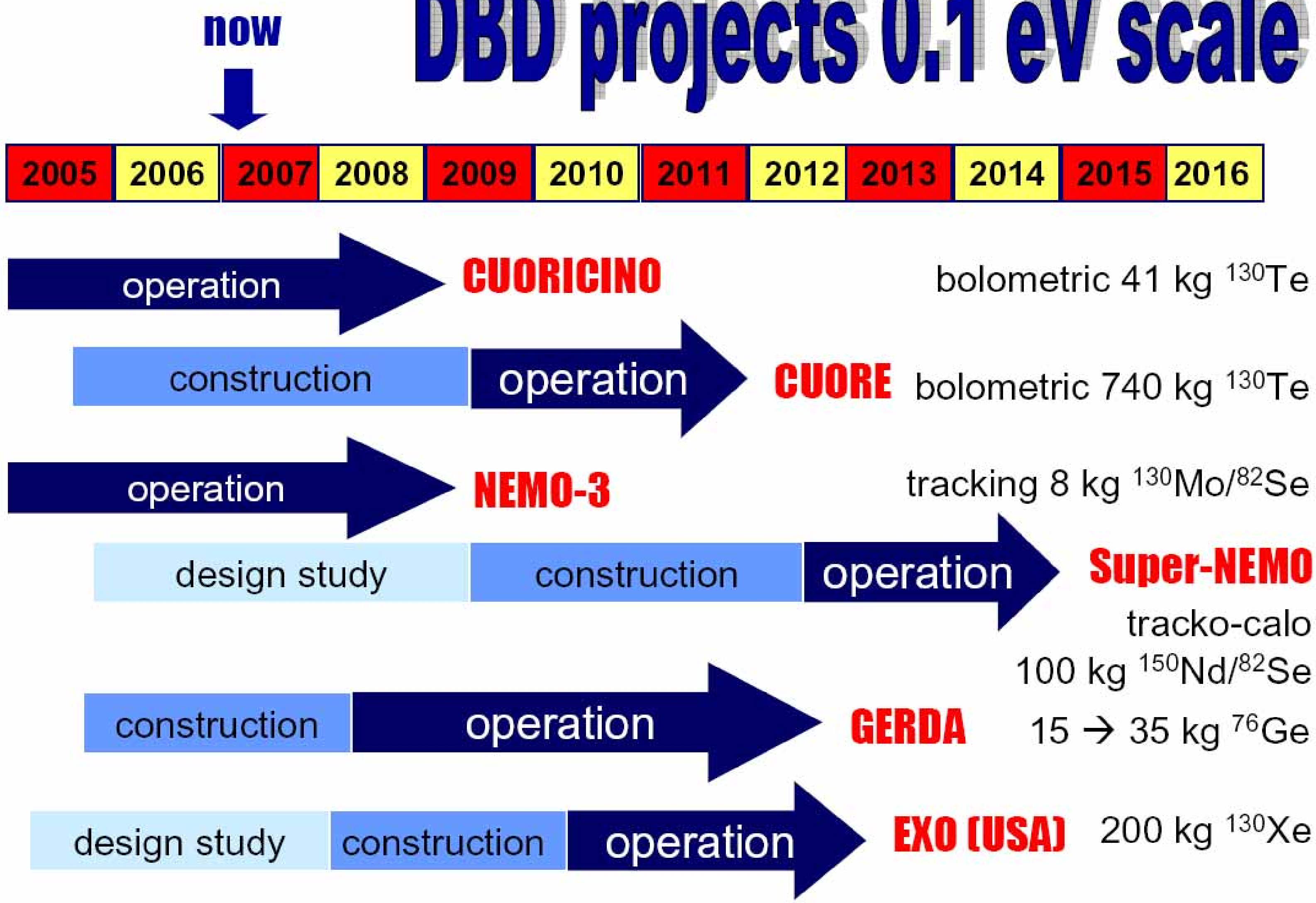
IGEX (Canfranc): $T_{1/2} > 1.6 \times 10^{25}$ y $\Rightarrow m_{\beta\beta} < 0.36\text{-}0.92$ eV/c^2

(Positive signal, $T_{1/2} > 1.9 \times 10^{25}$y $\Leftrightarrow m_{\beta\beta} = 0.2\text{-}0.6$ eV claimed)



disfavoured by ββ
Degenerate
Inverted hierarchy
Normal hierarchy
disfavoured by cosmology
1
10^{-1}
10^{-2}
10^{-3}
$|\langle m_{\beta\beta}\rangle|$ in eV
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
lightest neutrino mass in eV

DBD projects 0.1 eV scale



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

Other ideas:

COBRA (LNGS, CdZnTe semiconductor crystals, ^{116}Cd, ^{130}Te)

MAJORANA (US; 120kg enriched ^{76}Ge)

SNO++ (SNO; ^{150}Nd - loaded scintillator)

MOON (Japan; ^{100}Mo)

CANDLES (Japan: ^{48}Ca)

TGV (LSM; ^{106}Cd)

Recommendations:

The European detectors which are expected to start operation within the next 5 years are GERDA, CUORE, Super-NEMO and possibly COBRA (mass range 50-100 meV). With these detectors, Europe will be in the best position to improve sensitivity and maintain its leadership in this field and clearly prove or disprove the mentioned claim.

Only even larger, future-generation detectors, with an active mass of order one ton, good resolution and very low background, can cover the second possible mass range (inverted mass hierarchy) and reach the level of 20-50 meV. Different nuclear isotopes and different experimental techniques are needed to establish the effect and extract a neutrino mass value. We recommend a strong participation of Europeans in the future-generation detectors with a sensitivity down to 20 meV. Decisions on these detectors are due in the first half of the next decade.

We also recommend a vigorous program, based on both theoretical and experimental investigations, to assess and to reduce the uncertainty of nuclear matrix elements, at least for a few key nuclei.

VHE

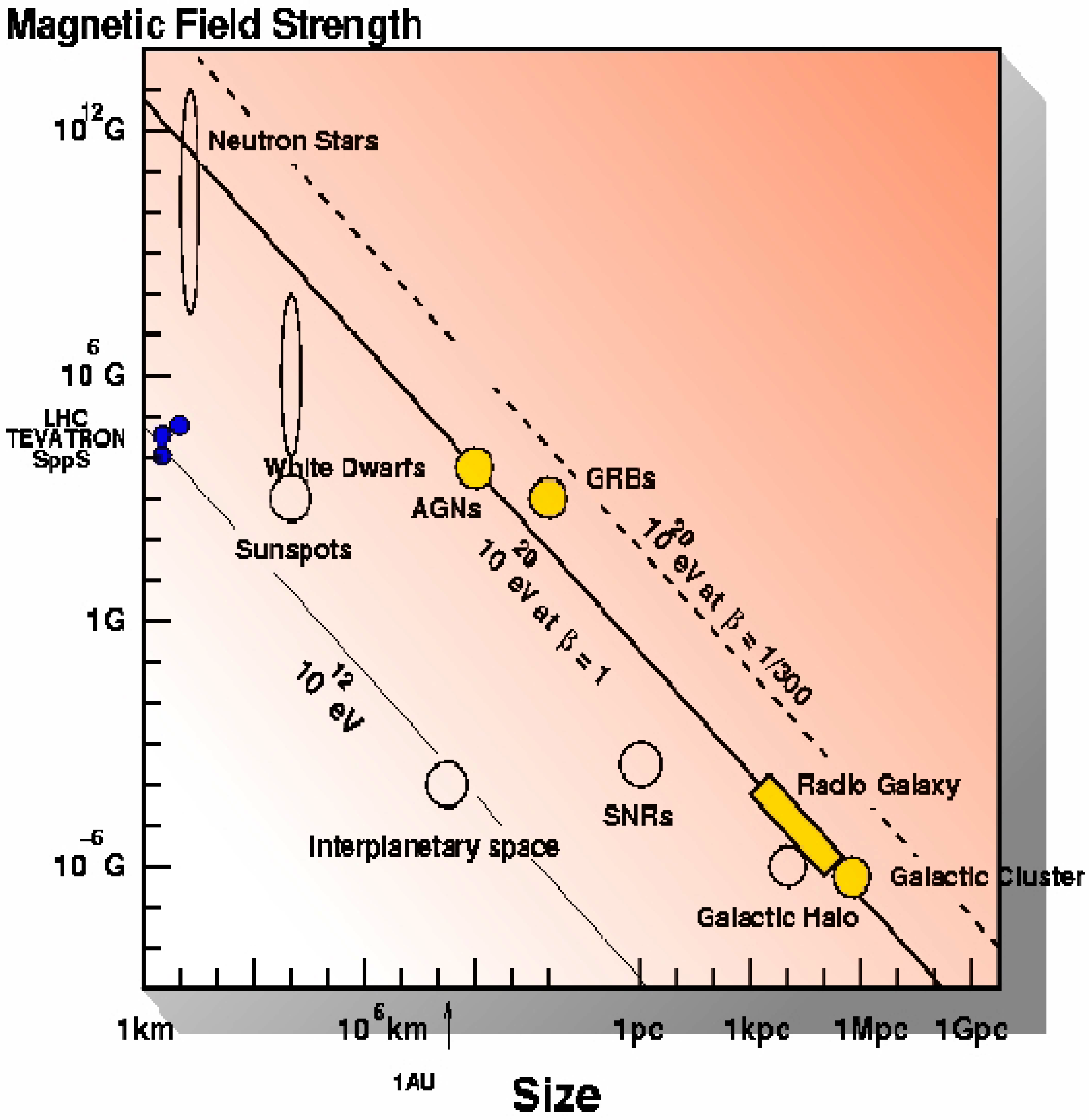
Cosmic Rays,

Gamma Rays,

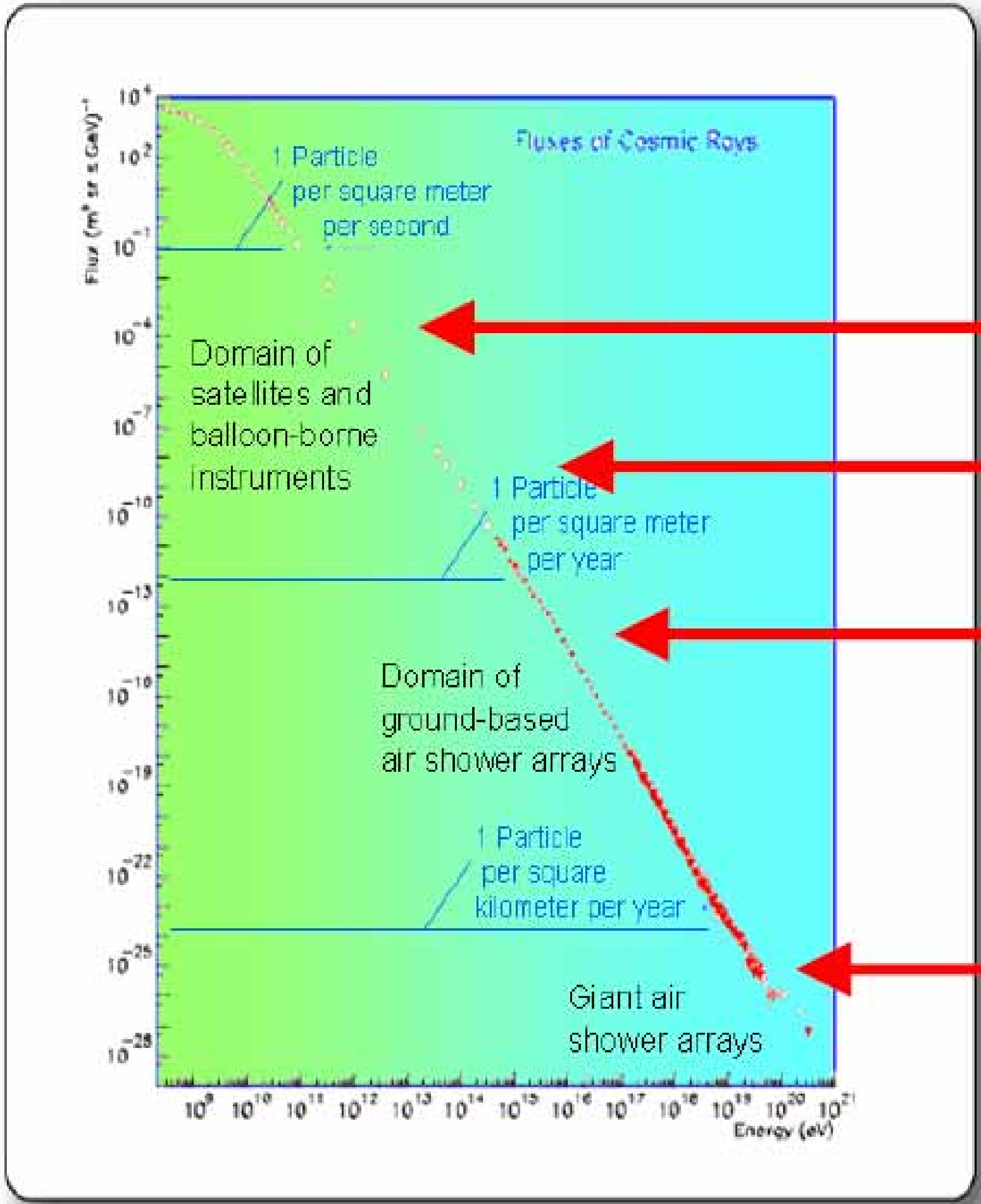
and Neutrinos

(Non-thermal universe)

$E_{max} \sim Z \times L \times B \times \beta$



Cosmic Rays



Balloons, CREAM, TRACER
PAMELA, AMS

ARGO ?

Kascade-Grande
IceTop/IceCube
Tunka-133

Telescope Array
Pierre Auger Observatory

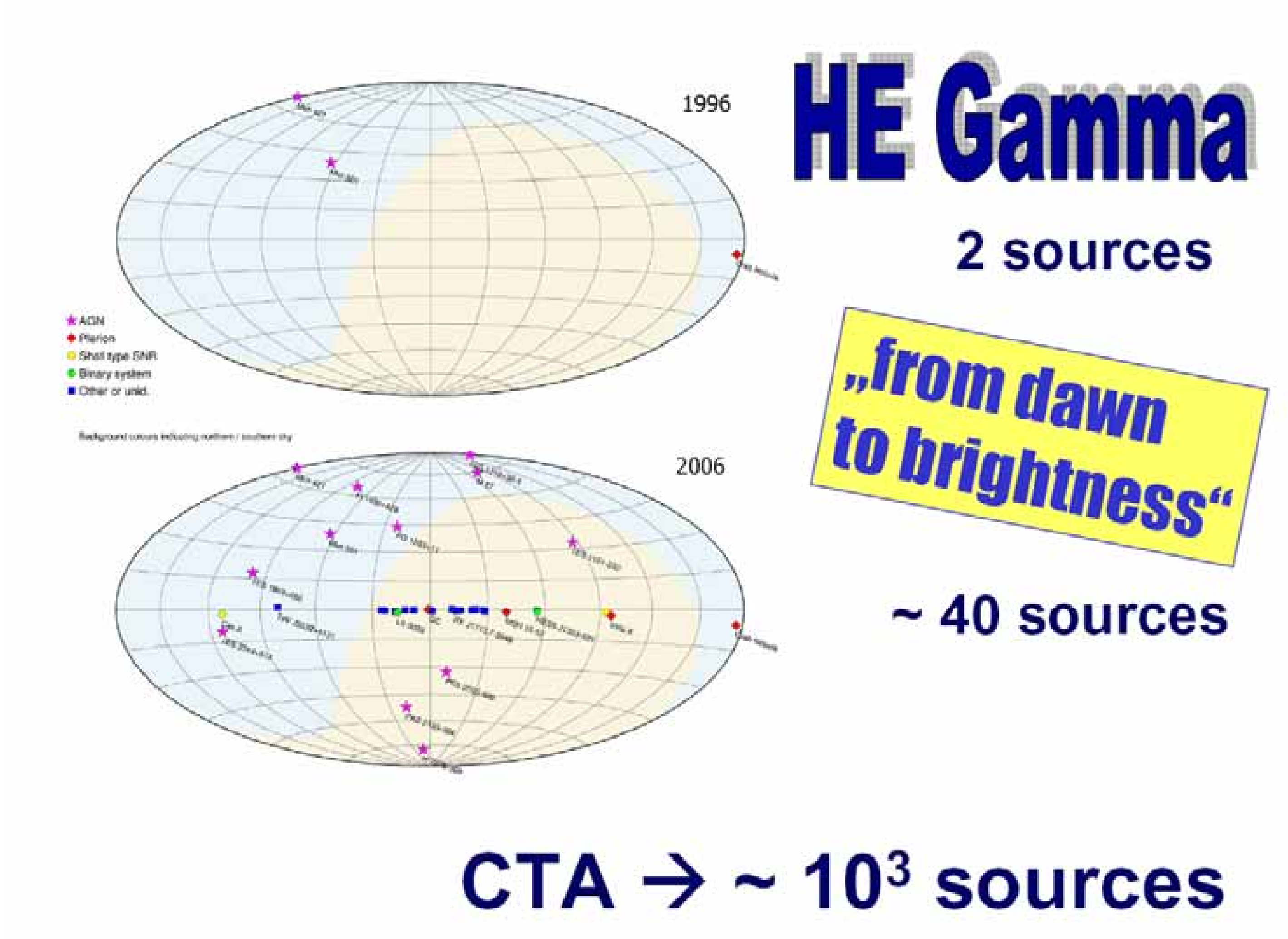
Recommendations

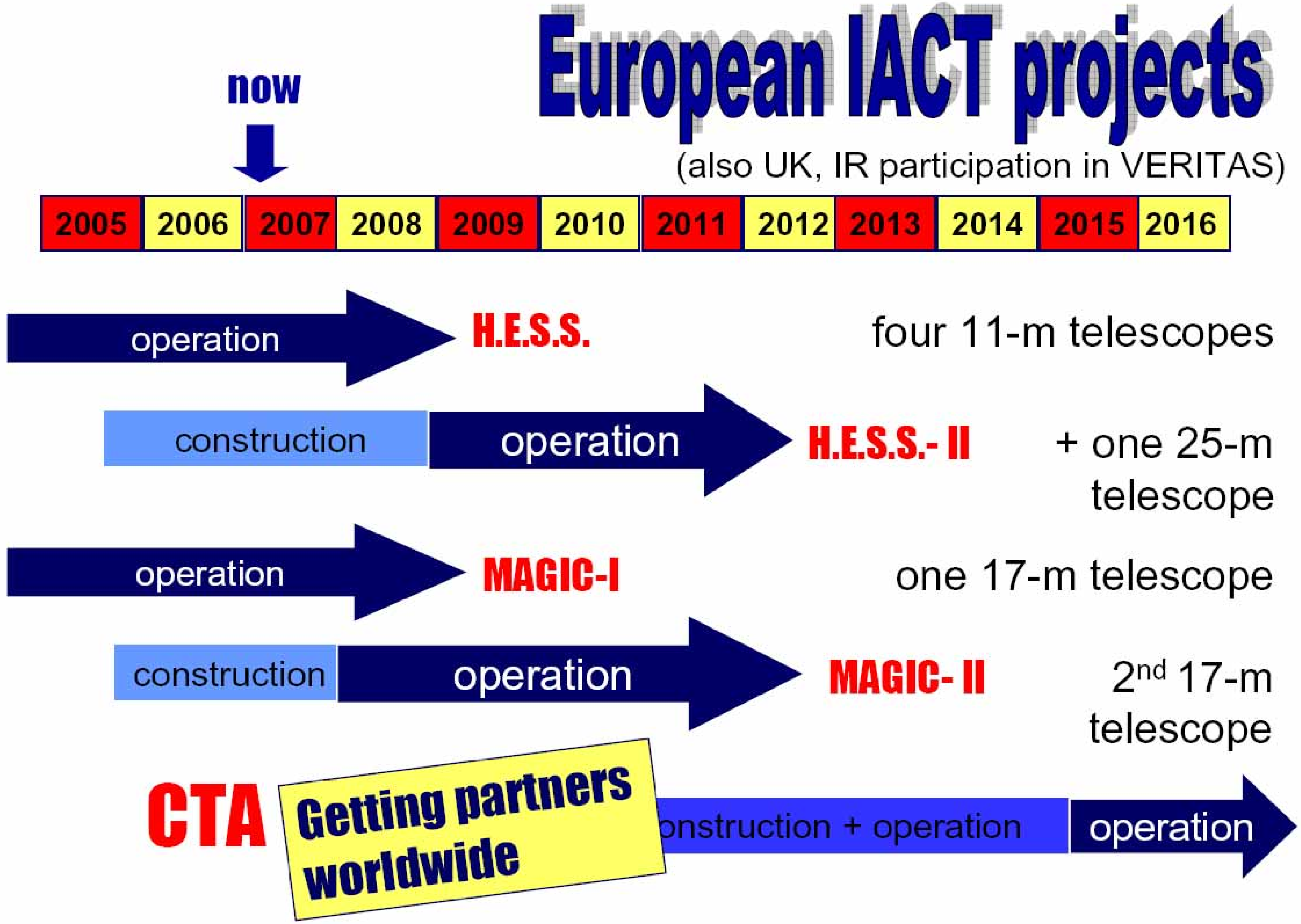
HE CR

- We recommend that the present efforts, mainly focused in the Southern Pierre Auger Observatory with a 50% European contribution, be pursued with vigor.
- We recommend that European groups play a significant role to establish the scientific case, and, after its consolidation, make a significant contribution to the design and construction of a Northern Auger Observatory.
- The development of novel cost effective techniques with large aperture and particle identification would provide a useful redundancy to the present detectors. One such approach could be the radio detection of air showers as pursued by the LOPES (later LOFAR) and CODALEMA collaborations. We recommend support of R&D for these new technologies.
- We appreciate the inclusion of ultra-high energy cosmic rays into the ESA *Cosmic Vision 2015* programme, which provides a frame to study the scientific case, technical design and timeliness of space based detectors for ultra high energy radiation
- The impact of measurements at accelerators, particularly at the LHC, should be evaluated in close cooperation with the particle physics community.
- Efforts to bridge the gap between present direct and air shower detection methods (with large-aperture, long duration flight missions above the atmosphere and/or by ground detectors with sufficient particle identification placed at highest altitudes) should be encouraged.

Gamma Ray Astronomy

4 major detectors world-wide: HESS, MAGIC, CANGAROO, VERITAS (Imaging Cherenkov Telescopes)



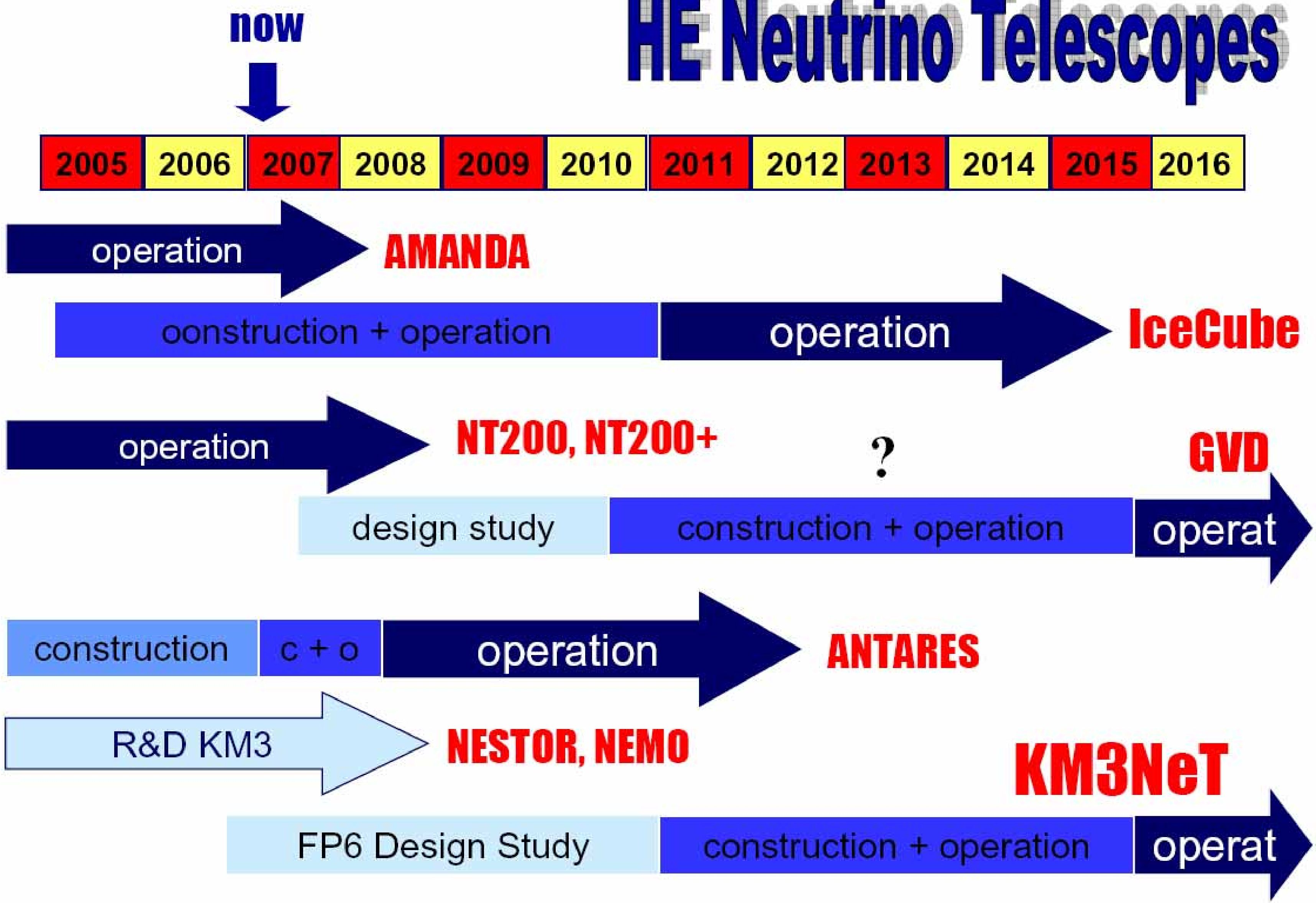

European IACT projects
(also UK, IR participation in VERITAS)
now
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
operation
H.E.S.S.
four 11-m telescopes
construction
operation
H.E.S.S.- II
+ one 25-m telescope
operation
MAGIC-I
one 17-m telescope
construction
operation
MAGIC- II
2nd 17-m telescope
CTA
Getting partners worldwide
onstruction + operation
operation

Recommendations

HE Gamma

- To further explore the diversity of galactic and extragalactic gamma ray sources, construction of a next-generation facility for ground-based very-high-energy gamma ray astronomy (CTA – Cherenkov Telescope Array) is very strongly recommended. It builds on the demonstrated technical maturity and physics case of Cherenkov telescopes. CTA should both boost the sensitivity by another order of magnitude and enlarge the usable energy range. The technology to build arrays of highly sensitive telescopes is available or under advanced development, and deployment should start at the beginning of the next decade, overlapping with the operation of the GLAST satellite.
- It is desirable to cover both hemispheres, with one site each. While low-threshold capability is of interest for both, a southern site of the facility should also provide improved detection rate at very high energies, given the flat spectra of galactic sources; this aspect may be less crucial for a northern site concentrating more on extragalactic physics. The instruments should be prepared by a common European consortium and share R&D, technologies and instrument designs to the extent possible. Cooperation with similar efforts underway in the US and in Japan should be explored.
- The development of alternative detection techniques, for example techniques based on detection of shower particles at ground level, should be pursued, in particular concerning approaches for wide angle instruments which are complementary to the conventional Cherenkov instruments with their limited field of view.

HE Neutrino Telescopes

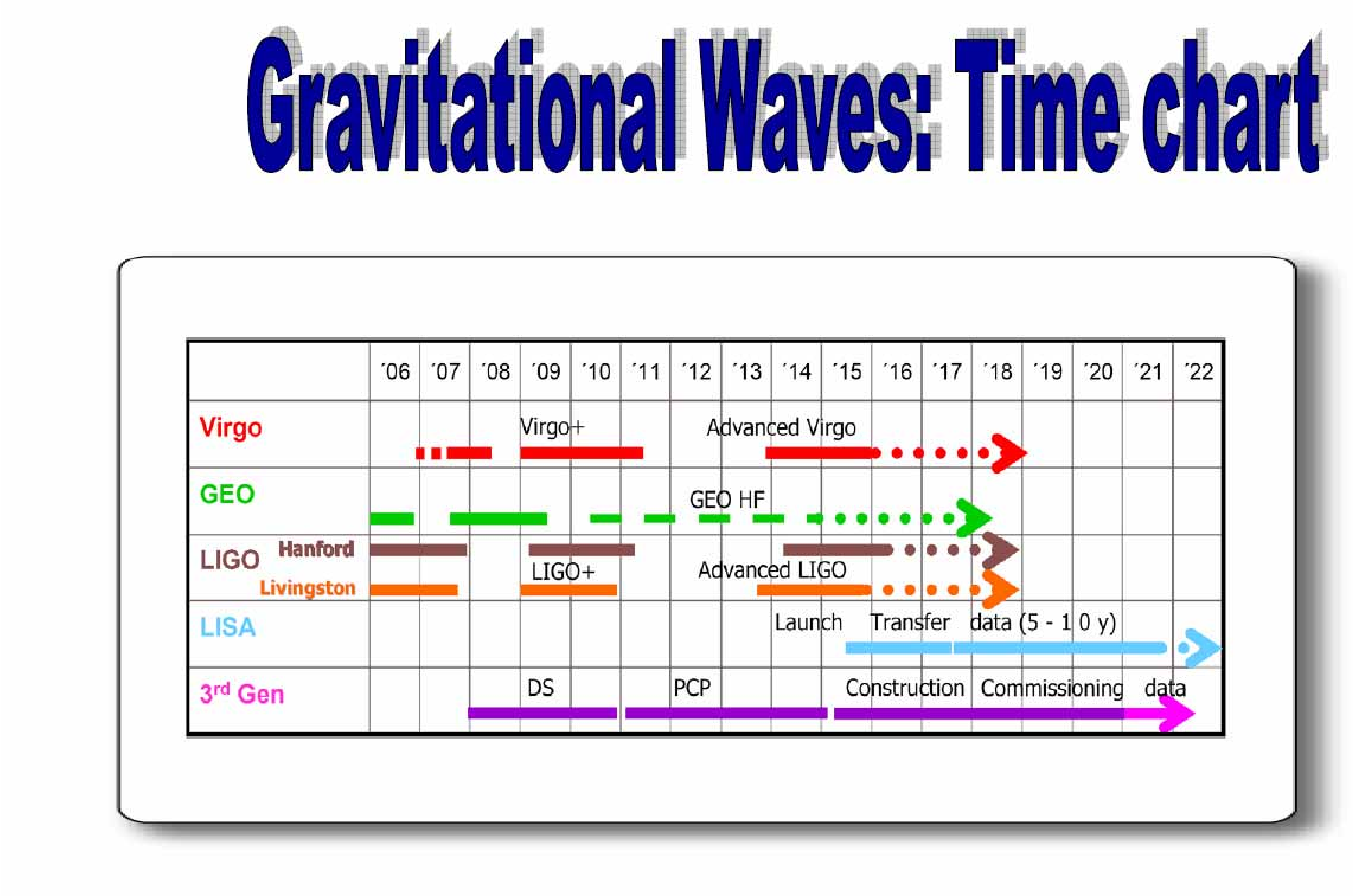


Recommendations

HE neutrinos

- For a complete sky coverage, in particular of the central parts of the Galaxy with many promising sources, we strongly recommend to work towards a cubic kilometre detector in the Northern Hemisphere which will complement the IceCube detector. Resources for a Mediterranean detector should be pooled in a single, optimized large research infrastructure "KM3NeT". Start of the construction of KM3NeT is going to be preceded by the successful operation of small scale or prototype detector(s) in the Mediterranean. It's design should also incorporate the improved knowledge on galactic sources as provided by H.E.S.S. and MAGIC gamma ray observations, as well as initial results from IceCube. Still, the time lag between IceCube and KM3NeT detector should be kept as small as possible.
- Based on AMANDA experience, the construction of IceCube with its early high discovery potential is planned to be completed in 2011. Since long, European partners have been playing a strong role in AMANDA/IceCube. They should be supported in order to ensure the appropriate scientific return, as well as a strong contribution to the considered extension of IceCube.
- Several promising techniques to detect cosmic neutrinos of highest energy – like radio Cherenkov detection in ice, in the atmosphere or in the moon crust – will be tested with existing detectors; others, like acoustic detection, or radio detection in salt domes, are still in an R&D phase. In order to cover the full range of all possible energies of cosmic neutrinos, exploitation of these techniques is mandatory. The ongoing coordinated R&D work should be supported.

Gravitational Waves



Gravitational Waves Recommendations

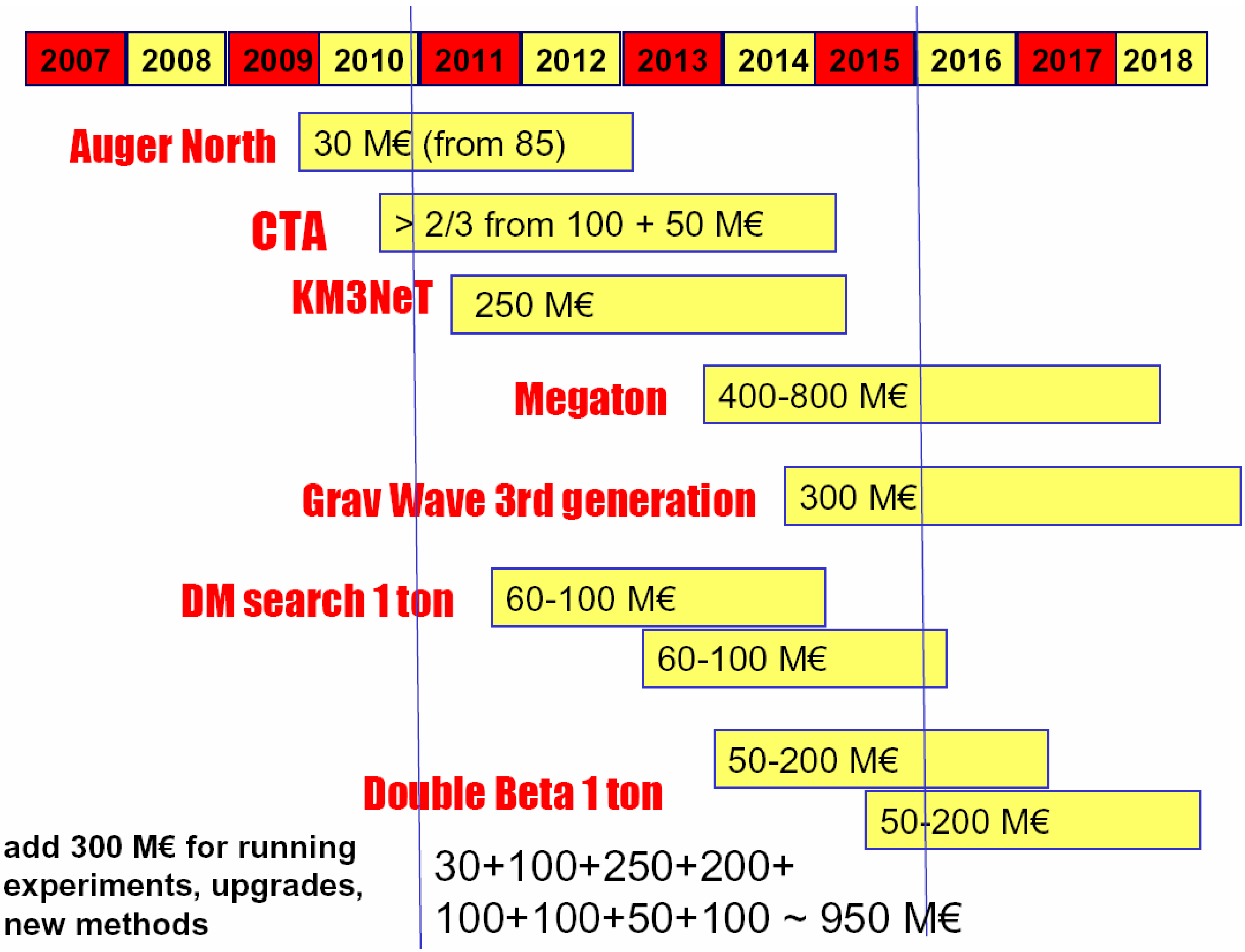
GEO and VIRGO should turn to observation time, with a fraction of the time devoted to improvements

Continued operation of existing resonant detectors

Start the design study of a European third-generation interferometer facility.

Actively support the LISA mission

The Big Picture


2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Auger North
30 M€ (from 85)
CTA
> 2/3 from 100 + 50 M€
KM3NeT
250 M€
Megaton
400-800 M€
Grav Wave 3rd generation
300 M€
DM search 1 ton
60-100 M€
60-100 M€
50-200 M€
Double Beta 1 ton
50-200 M€
add 300 M€ for running experiments, upgrades, new methods
30+100+250+200+
100+100+50+100 ~ 950 M€