Status and Perspectives of Astroparticle Physics in Europe

The ApPEC Roadmap

C. Spiering

Hamburg, March 20, 2007

ApPEC

- „*Astroparticle Physics European Coordination*“
- Founded 2001 (originally 6, now 13 countries)
- Why ApPEC ?
  - Astroparticle projects of the next phase (>2010) reach the 50-500 M€ scale
  - → Coordination
  - → Cooperation
  - → Convergence towards a few major projects
  - → Create necessary infrastructures (underground-labs, observatories)

Committees

- Steering Committee
  (Funding Agencies)
- Peer Review Committee (Expert Group)

- Frank Avignone
- Jose Bernabeu
- Leonid Bezrukov
- Pierre Binetruy
- Hans Bluemer
- 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
- Gerard Smadja
- Nigel Smith
- Christian Spiering (chair)
- Alan Watson
- Observer SC:
  Thomas Berghöfer

History of roadmap process

- June 2005: ApPEC SC charges PRC to write a roadmap
- *Questionnaires* from all European APP experiments
- PRC meetings, numerous presentation to AP *community (*~ 2000 physicists), CERN *strategy meetings,* etc.
- October 2006: circulation of full text
- November 2006: open meeting in Valencia
- January 2007: document submitted to SC
- February 2007: document approved by SC

Next steps

- February 2007:
  „PHASE-I“ Roadmap

  `http://www.ifh.de/~csspier/Roadmap-Jan30.pdf`

- **PHASE-II** (Feb.-Sept. 2007)**:**
  - (milestones, cost) within sub-communities
    (working groups)
- **PHASE-III** (to be completed in June 2008)**:**
  - Prioritization between fields → action plan
  - *Draft agreements* for large infrastructures
  - „Brochure“ á la European Strategy for Particle Physics

The Questions

1) What is the Universe made of ?

2) Do protons have a finite lifetime ?

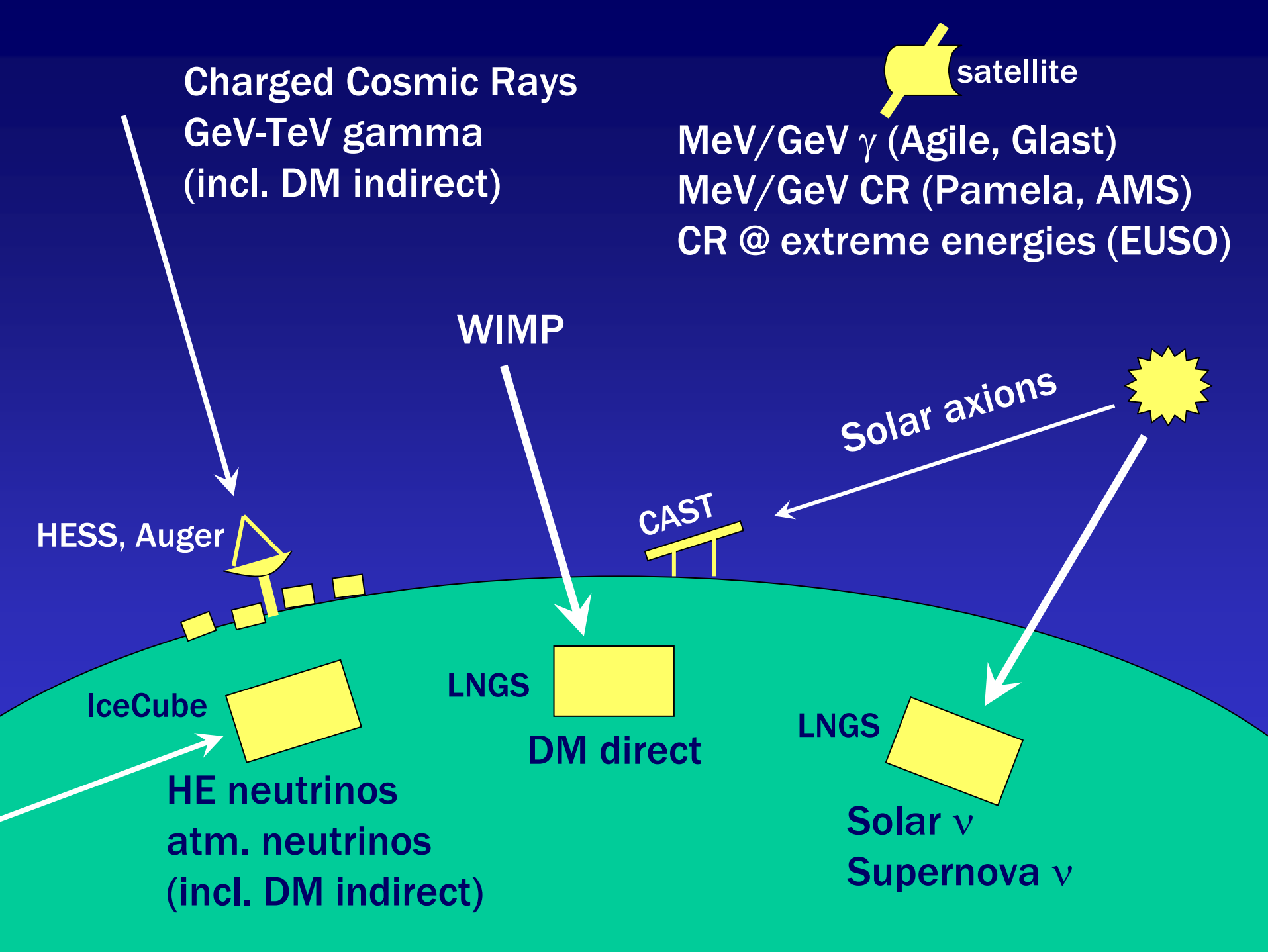
3) What are the properties of the neutrinos?
   What is their role in cosmic evolution ?

4) What do neutrinos tell us about the interior of Sun and Earth, and about Supernova explosions ?

5) What is the origin of high energy cosmic rays?
   What is the view of the sky at extreme energies?

6) Can we detect gravitational waves?
   What will they tell us about violent cosmic processes ?

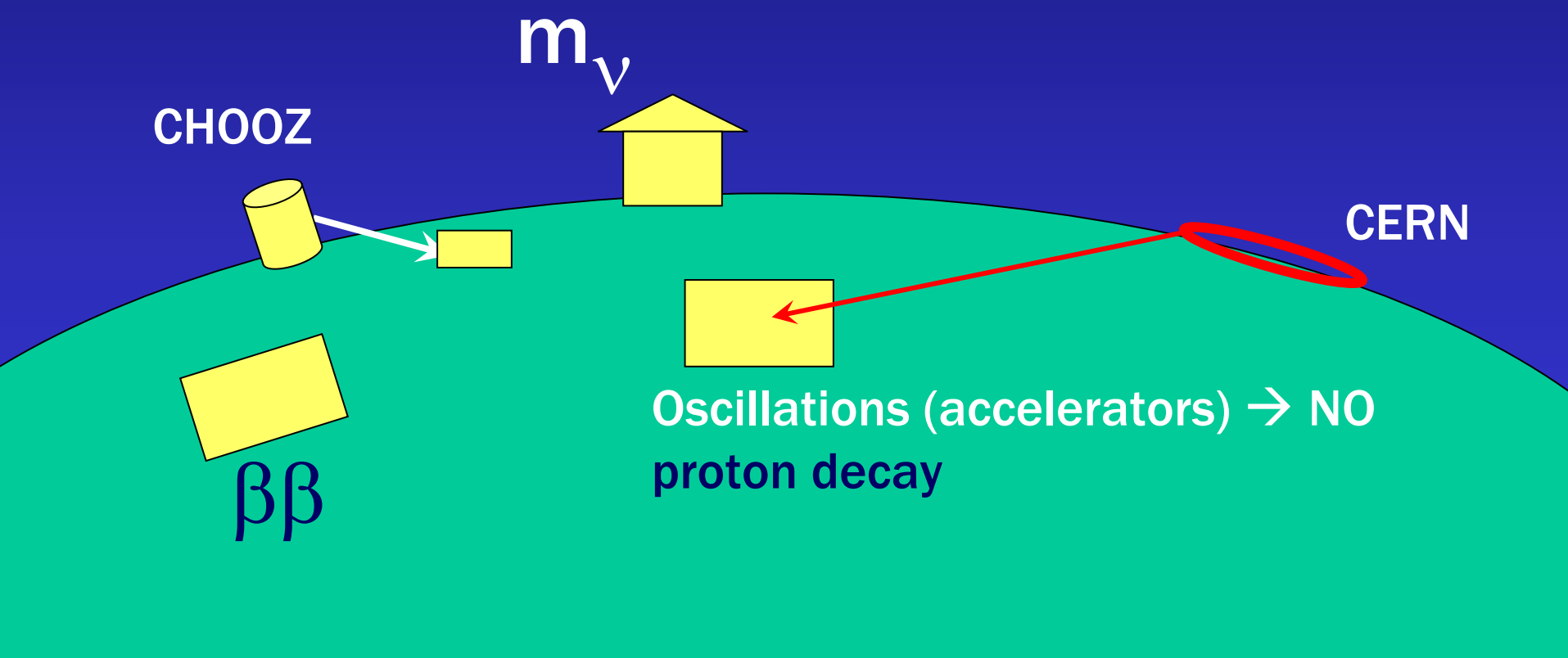
What belongs to Astroparticle Physics ?


Charged Cosmic Rays
GeV-TeV gamma
(incl. DM indirect)
satellite
MeV/GeV γ (Agile, Glast)
MeV/GeV CR (Pamela, AMS)
CR @ extreme energies (EUSO)
WIMP
Solar axions
HESS, Auger
CAST
IceCube
LNGS
DM direct
LNGS
HE neutrinos
atm. neutrinos
(incl. DM indirect)
Solar ν
Supernova ν

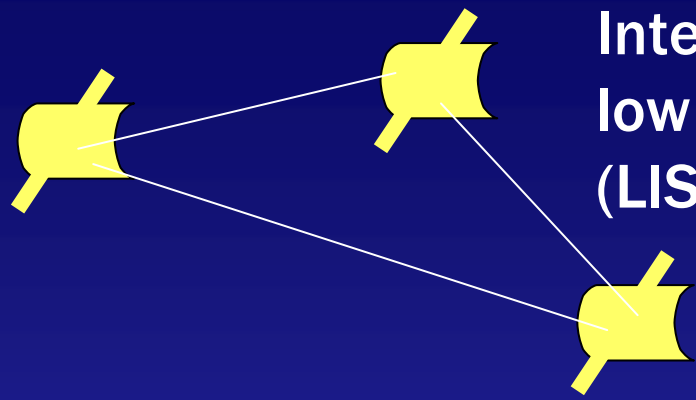
No particles from heaven but:

- same infrastructure ($\beta\beta$)
- closely related question (tritium decay)

Double Chooz ?



Gravitational Waves



Interferometer
low frequency
(LISA)

Interferometers
(Geo-600, VIRGO)

Resonance Antennas

The Questions

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What is the Universe made of ?

- Dark matter: WIMPS direct and indirect, axions
- Dark energy (not addressed in detail but closely related to dark matter)
- Other particles beyond the standard model
- Cosmic antimatter

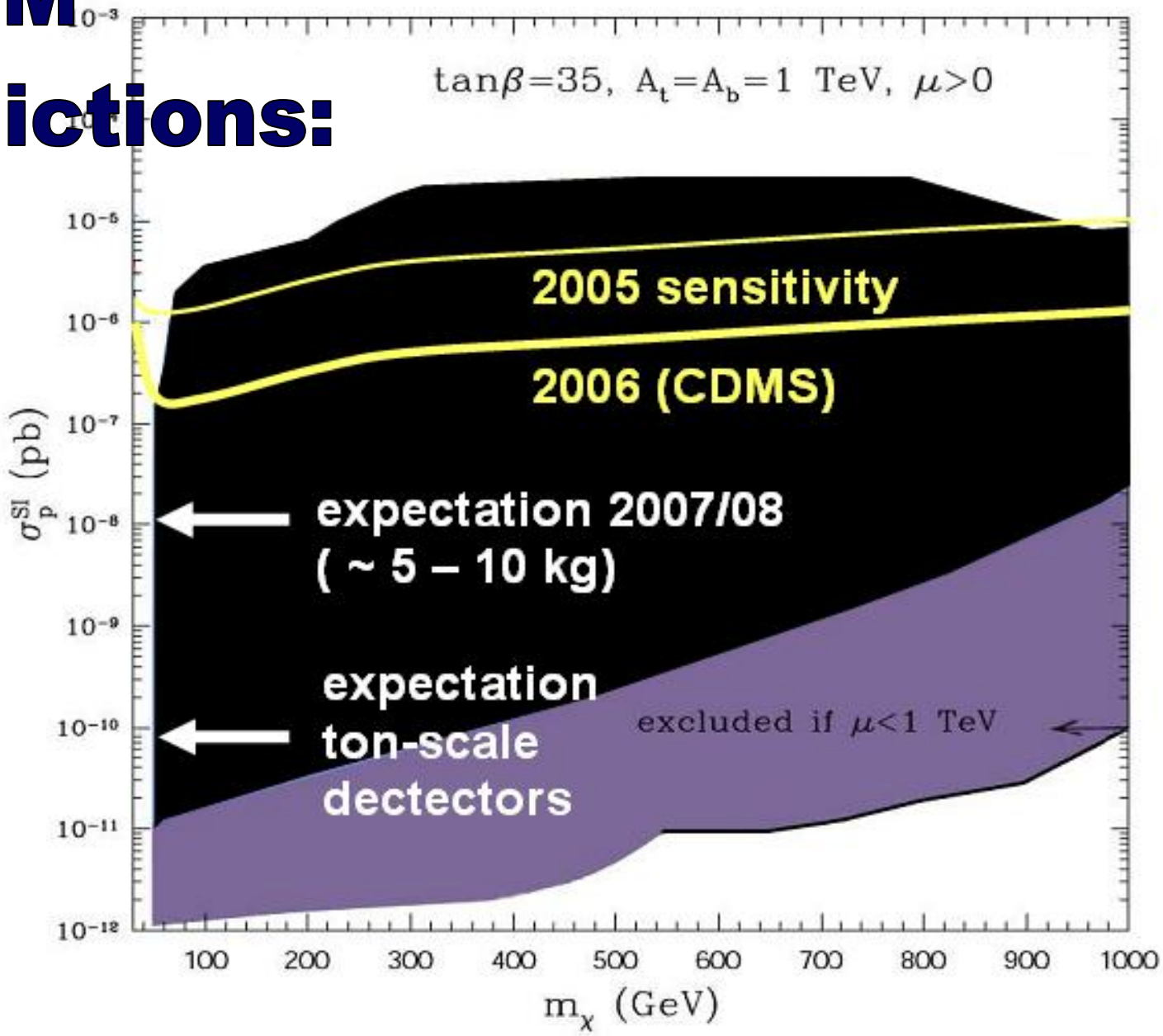
now: Pamela, later: AMS

> 2012:

Two direct-search experiments with 10^{-10} pb sensitivity

Price tag 60-100 M€

MSSM predictions:



Noble liquids

ZEPLIN, *XENON, LUX (*Xe*)*
WARP, ArDM (Ar)

Noble liquids

XMASS, DEAP,
CLEAN, **DAMA/LXe**

Ionization

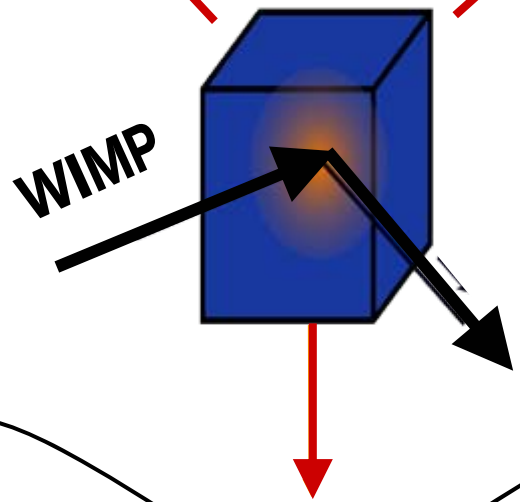
Scintillation

TPC

DRIFT
MIMAC

DAMA,
ANAIS, *KIMS*

crystals **NaI, CsI**



EDELWEISS,
CDMS

bolometric **Ge, Si**

CRESST

Heat

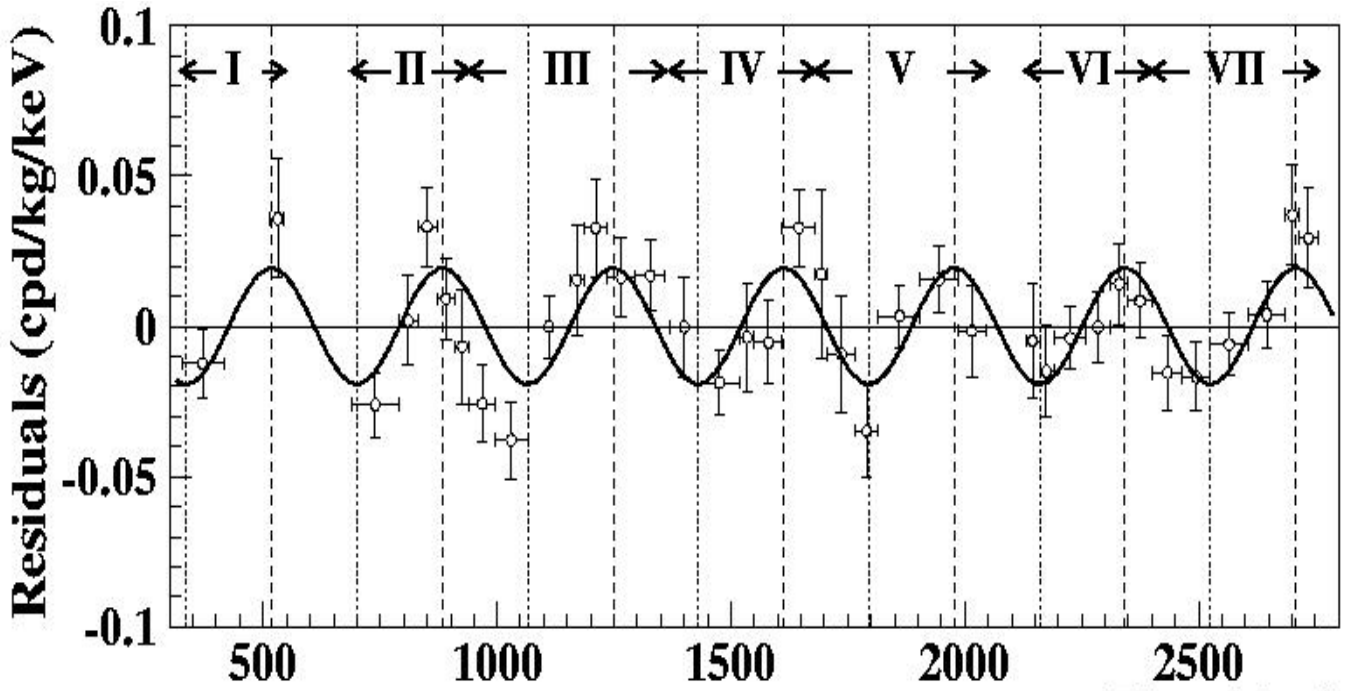
bolometric $CaWO_4$

Superheated liquids

SIMPLE, *PICASSO,*
COUPP

> 20 expt's worldwide

DAMA: annual modulation



- effect from movement through WIMP sea
- would be 7% of full signal
-100 kg
- not „zero-background“

... has not been confirmed by any other experiment.

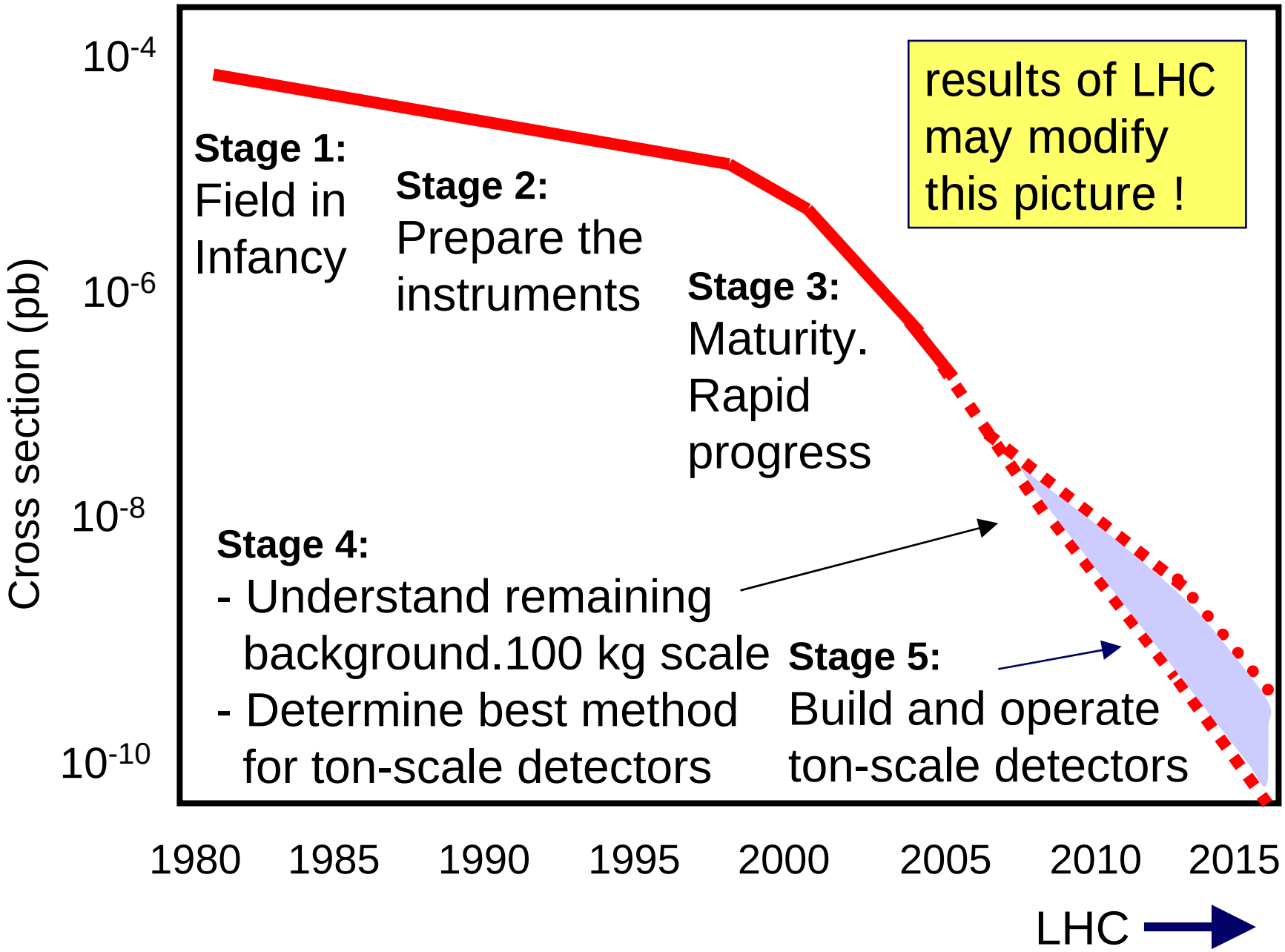
Towards 2 large "zero-background" detectors

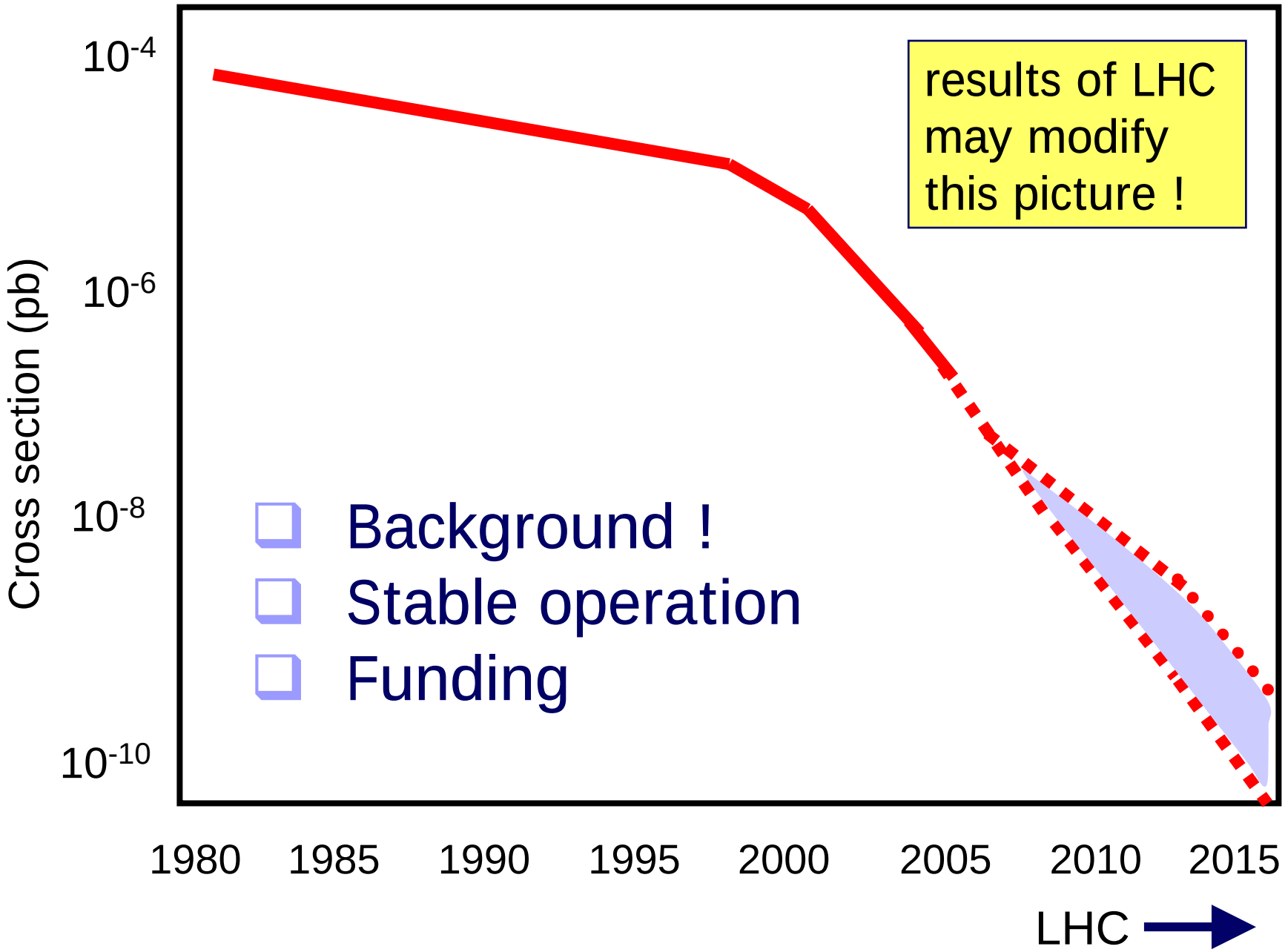
Now: 10 kg scale | 2009/11: 100 kg scale | 2012/14: ton scale

CRESST
Edelweiss
→ EURECA-100 → EURECA @ ton scale

LXe
LXe
LAr
LAr
...
→ Xe-100
→ Ar-100
→ Noble liquid @ ton scale

a possible convergence scenario


Cross section (pb)
10-4
10-6
10-8
10-10
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


Cross section (pb)
10-4
10-6
10-8
10-10
1980
1985
1990
1995
2000
2005
2010
2015
LHC
results of LHC may modify this picture !
Background !
Stable operation
Funding

What are the properties of neutrinos ?

What is their role in cosmic evolution ?

Spectrum endpoint and $\beta\beta$, oscillations at reactors

Soon: KATRIN

m_ν

Soon: Double CHOOZ

θ_{13}

≥ 2013: ~2 experiments with sensitivity to test inverted hierarchy

Majorana vs. Dirac

m_ν

Neutrino-less Double Beta Decay

$$(A,Z) \rightarrow (A,Z+2) + 2e^-$$

- Neutrino must be Majorana type
- *Plus:* non-zero rest mass or admixture of right handed currents
- Is also possible in some SUSY models (exchange of SUSY particle)

Neutrino-less Double Beta Decay

$$(A,Z) \rightarrow (A,Z+2) + 2e^-$$

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- Is also possible in some SUSY models (exchange of SUSY particle)

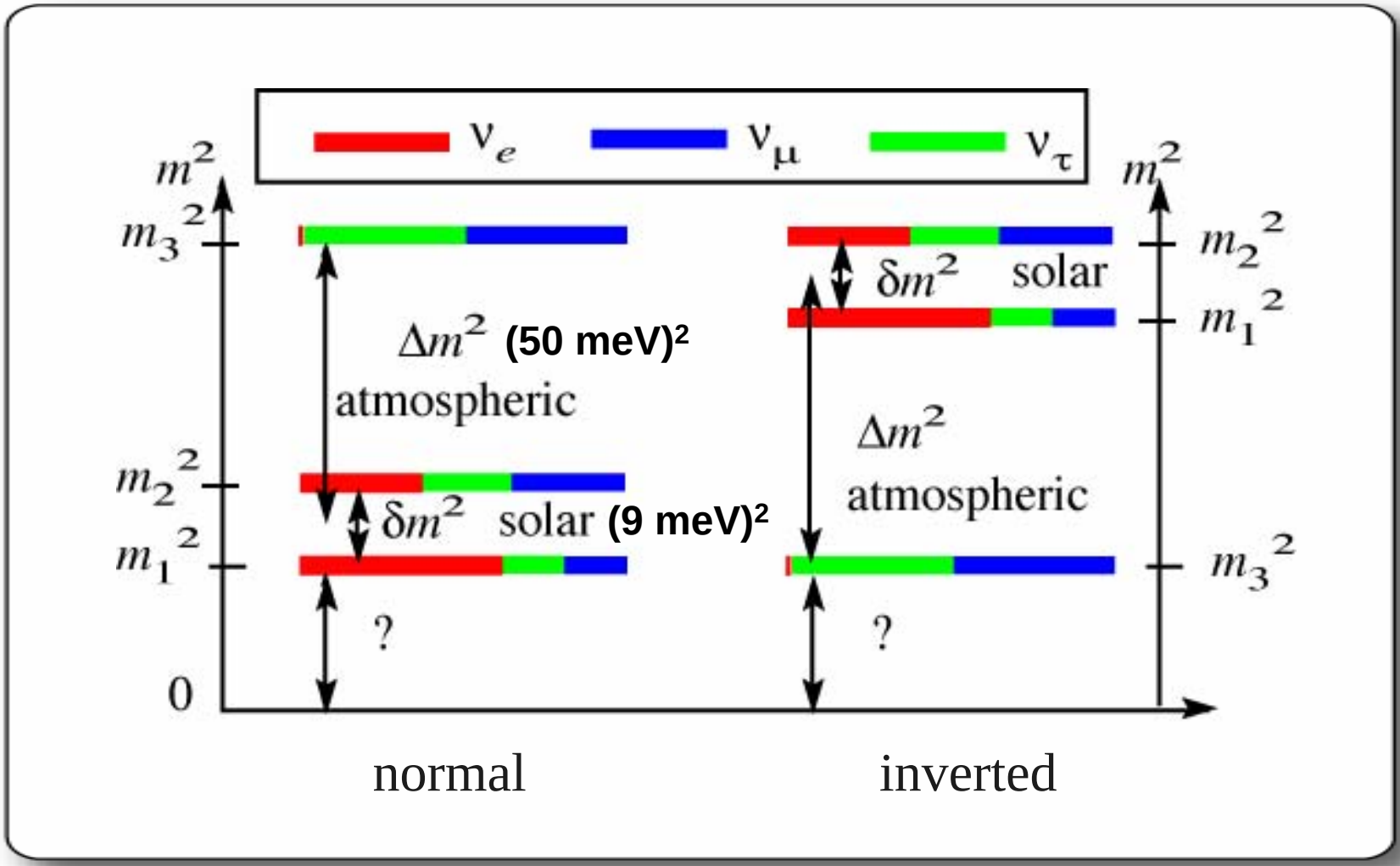
Best upper limits from ^{76}Ge (HM, IGEX):

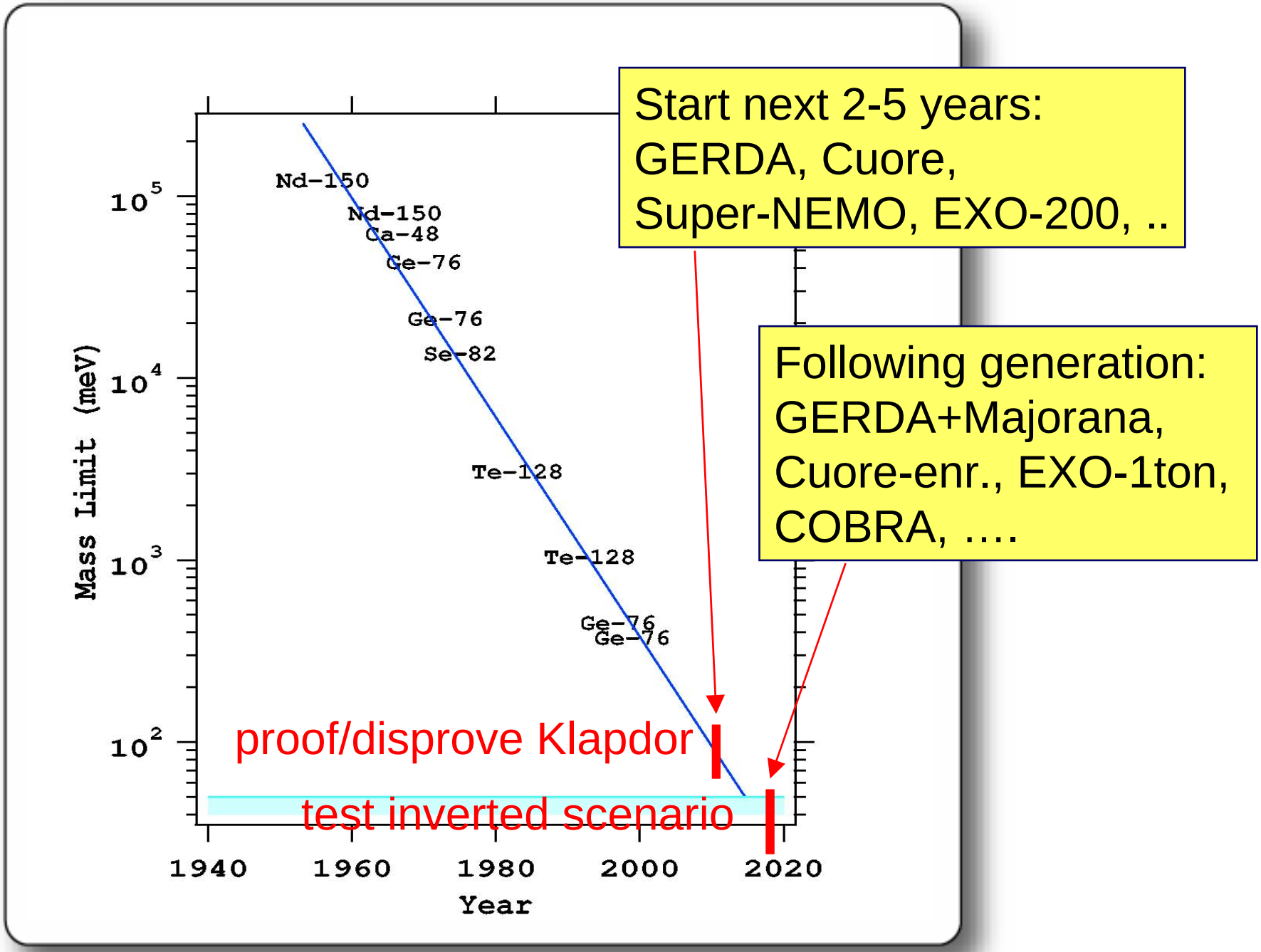
$T_{½} > 1.9/1.6 \cdot 10^{25}$ years $\rightarrow m_{\beta\beta} < 0.3\text{-}0.9$ eV

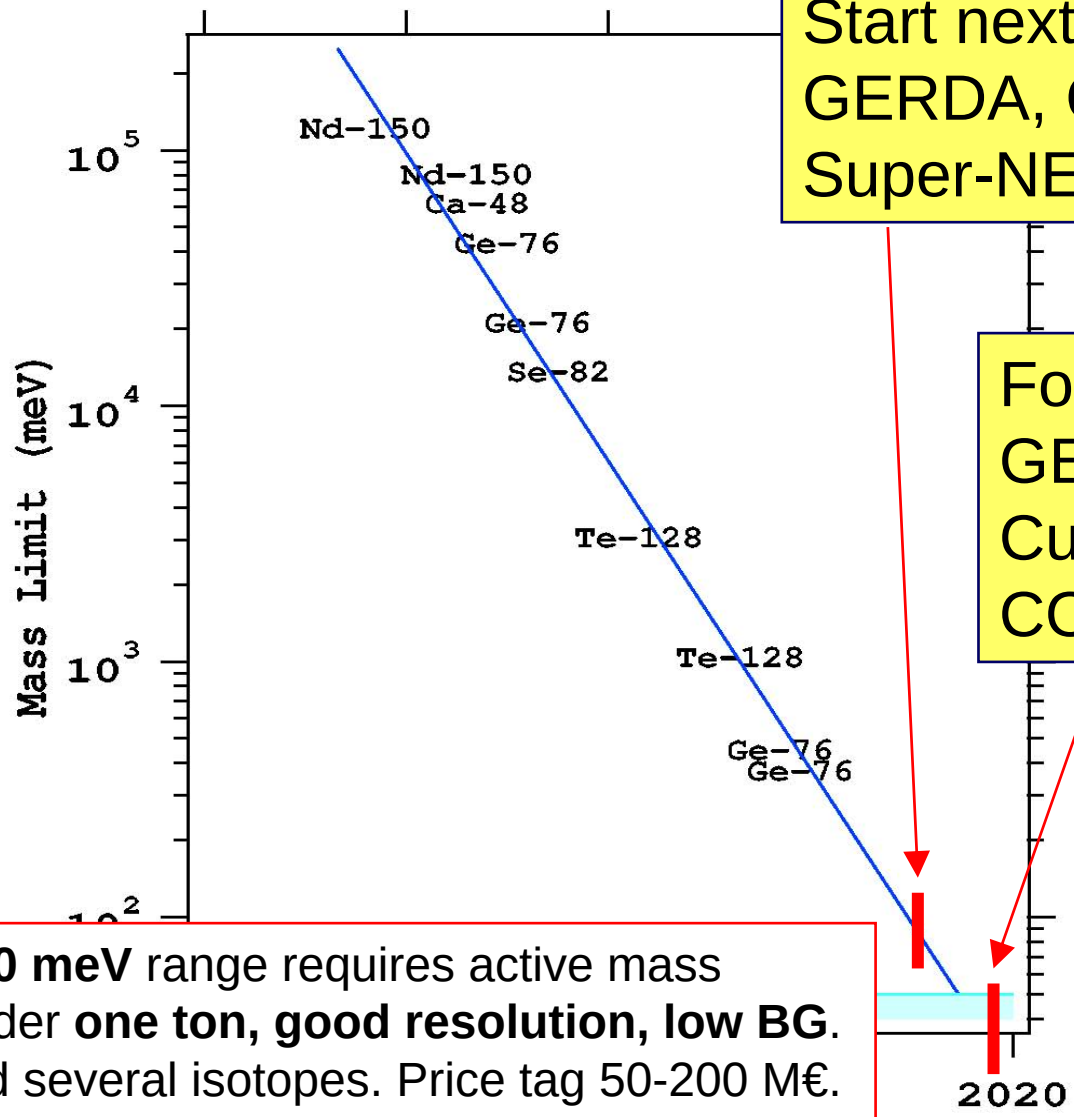
Klapdor-Kleingrothaus claim:

$T_{½} \sim 1.2 \cdot 10^{25}$ years $\rightarrow m_{\beta\beta} \sim 0.2\text{-}0.6$ eV

Mass Differences from Oscillations




Start next 2-5 years:
GERDA, Cuore,
Super-NEMO, EXO-200, ..
Following generation:
GERDA+Majorana,
Cuore-enr., EXO-1ton,
COBRA, ….
Nd-150
Nd-150
Ca-48
Ge-76
Ge-76
Se-82
Te-128
Te-128
Ge-76
Ge-76
proof/disprove Klapdor
test inverted scenario
Mass Limit (meV)
10^5
10^4
10^3
10^2
1940
1960
1980
2000
2020
Year

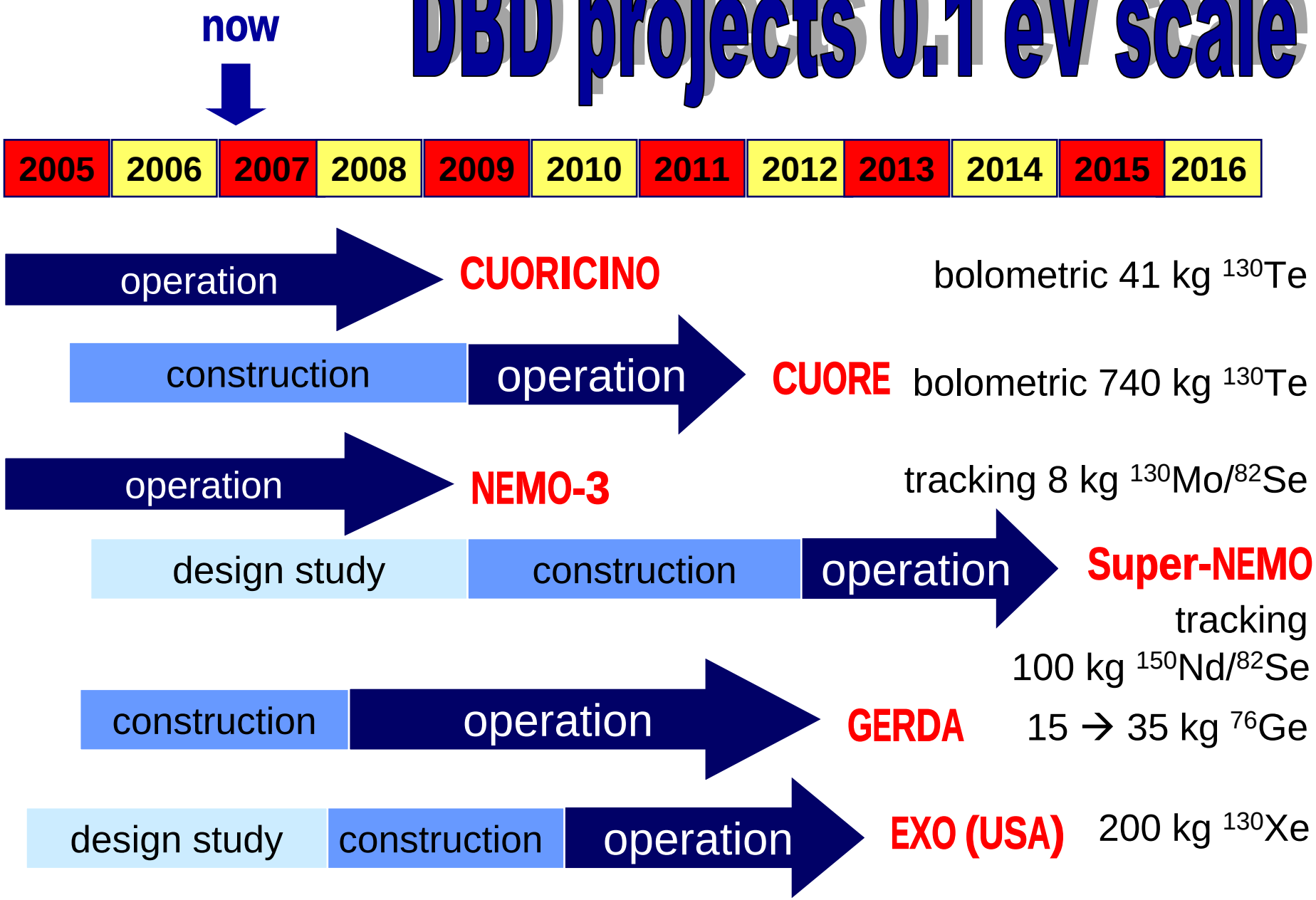


Start next 2-5 years:
GERDA, Cuore,
Super-NEMO, EXO-200, ..

Following generation:
GERDA+Majorana,
Cuore-enr., EXO-1ton,
COBRA,. ..

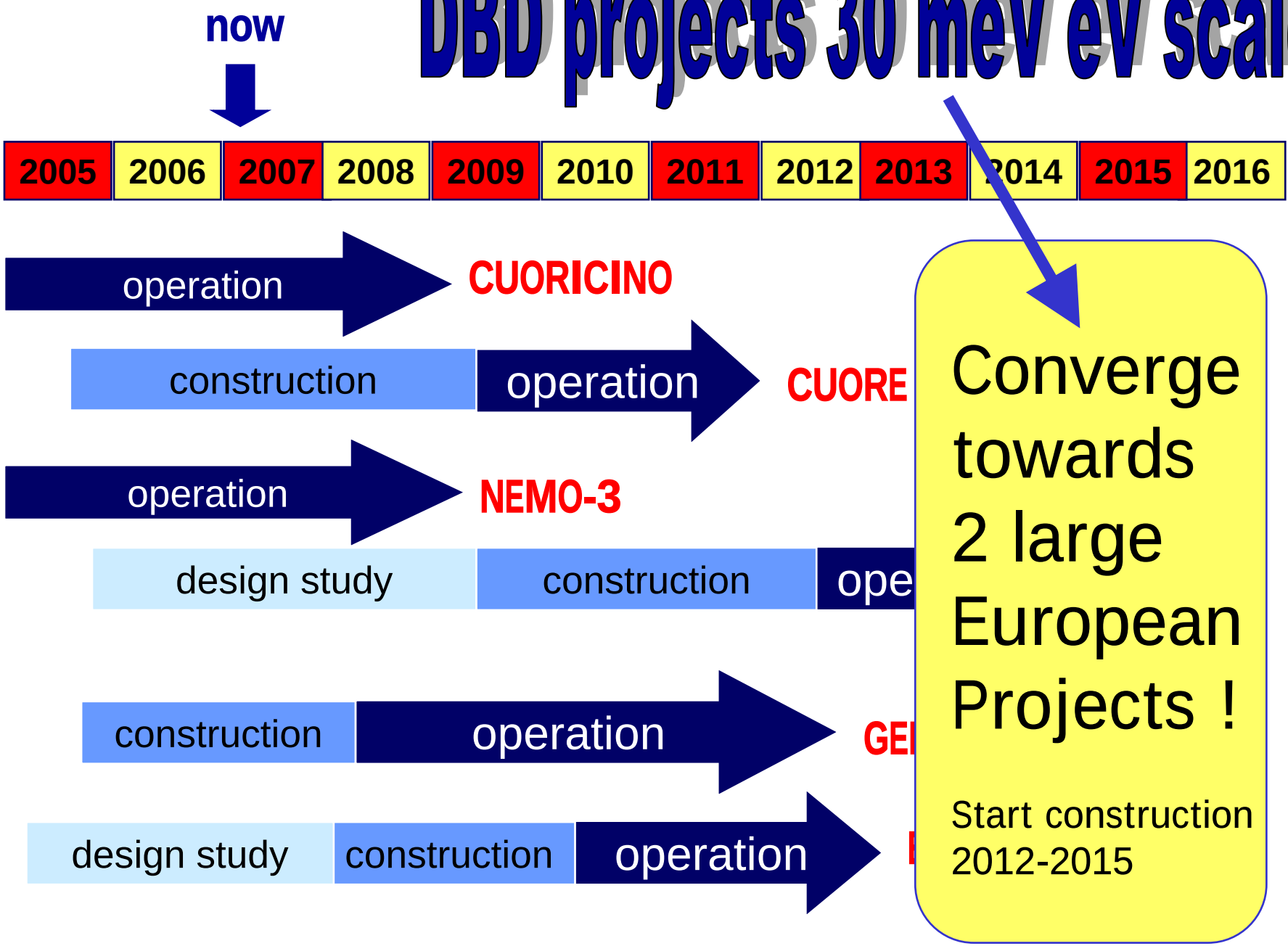
20-50 meV range requires active mass of order **one ton, good resolution, low BG**. Need several isotopes. Price tag 50-200 M€. Gain experience within next 5 years.

DBD projects 0.1 eV scale



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

DBD projects 30 meV eV scale



What do neutrinos tell us about the interior of Sun and Earth, and about Supernova explosions ?

Do protons have a finite lifetime ?

Soon: Borexino

≥ 2012 (civil engineering):

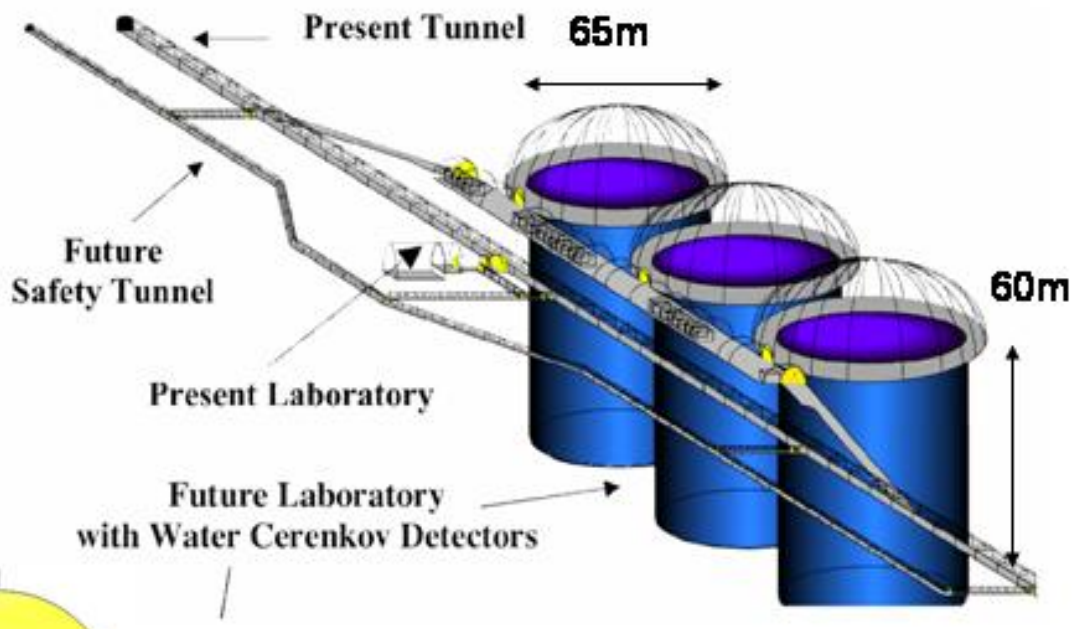
A very large multi-purpose facility

Options:

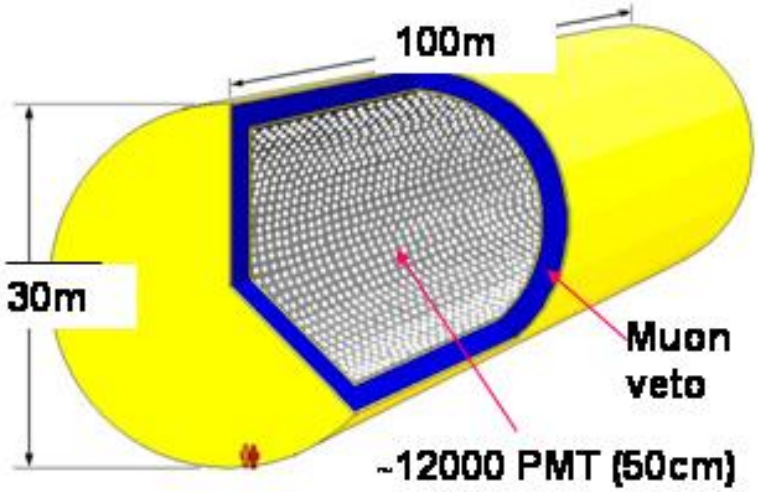
- **Water Megatonne („MEMPHYS“)**
- **100 kton Liquid Argon („GLACIER“)**
- **50 kton scintillaton detector („LENA“)**

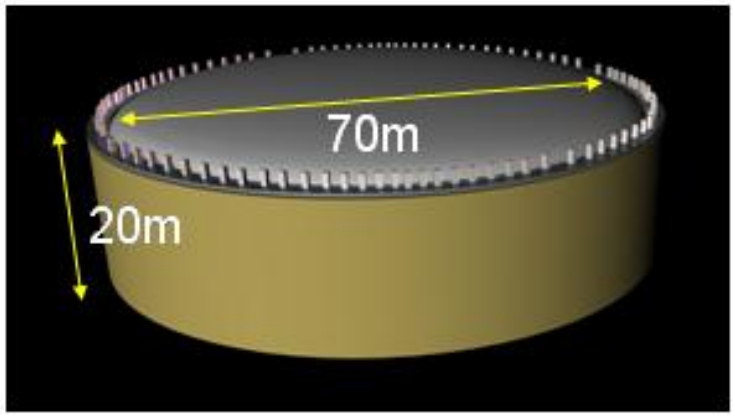
Price tag
400-800 M€

MEMPHYS:
Water Cherenkov,
(420 kton -1 Mton)



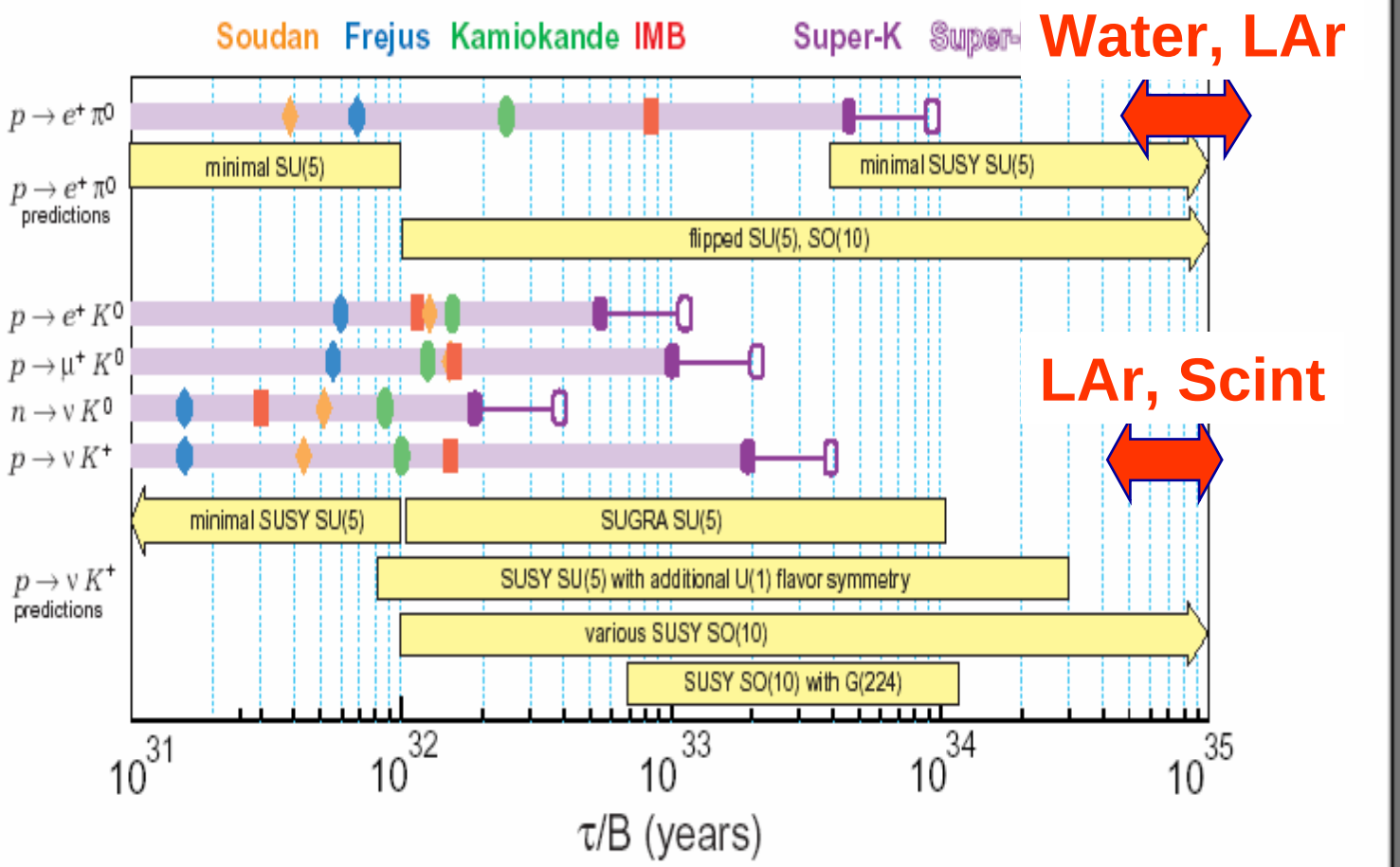
LENA:
Liquid Scintillator
(30-70 kton)



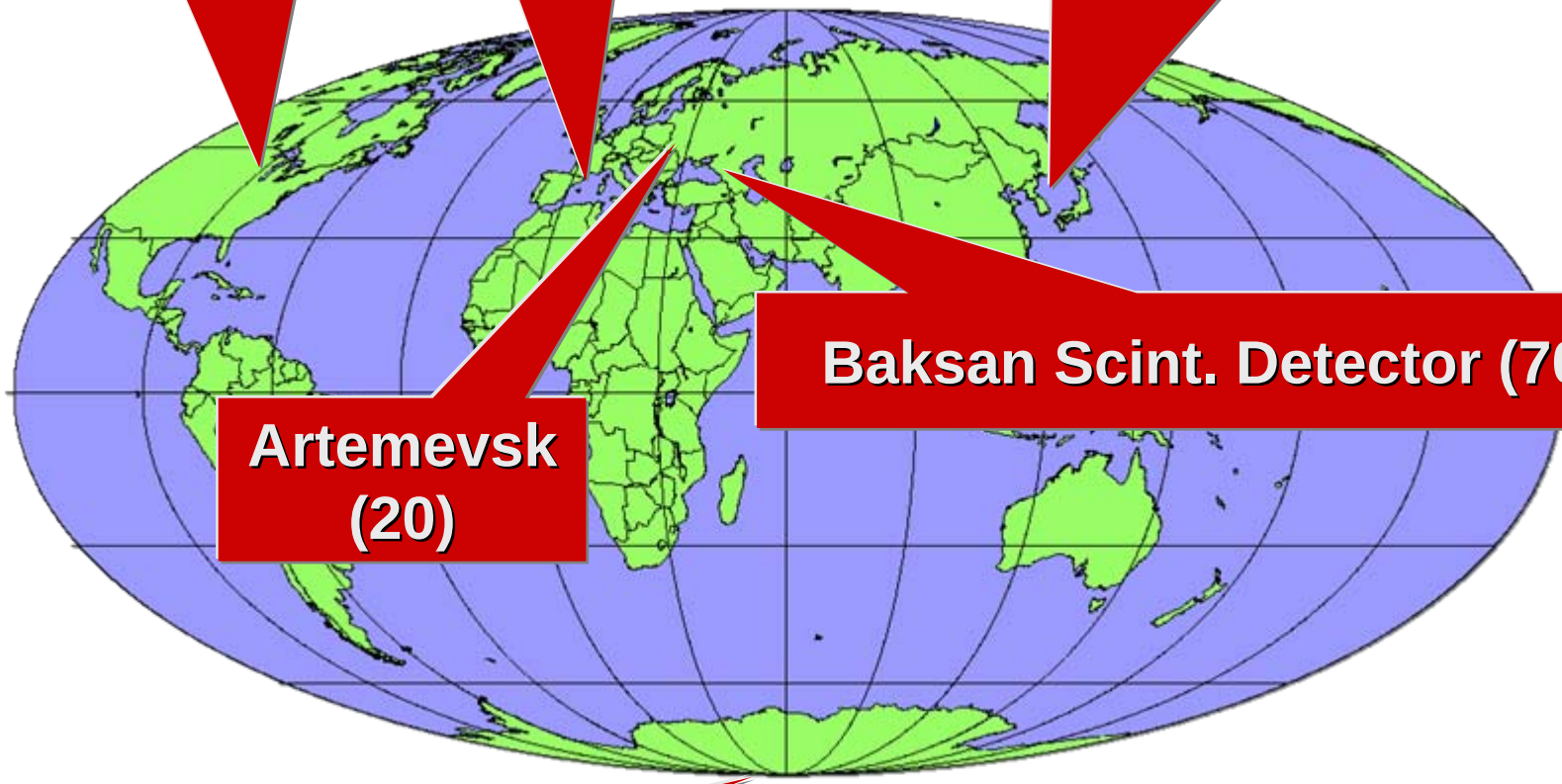


GLACIER: Liquid Argon (50 -100 kton)

p-decay: status and prospects



Large Detectors for SN Neutrinos



SNO (800)
MiniBooNE (190)

LVD (400)
Borexino(100)

Super-Kamiokande (8500)
Kamland (330)

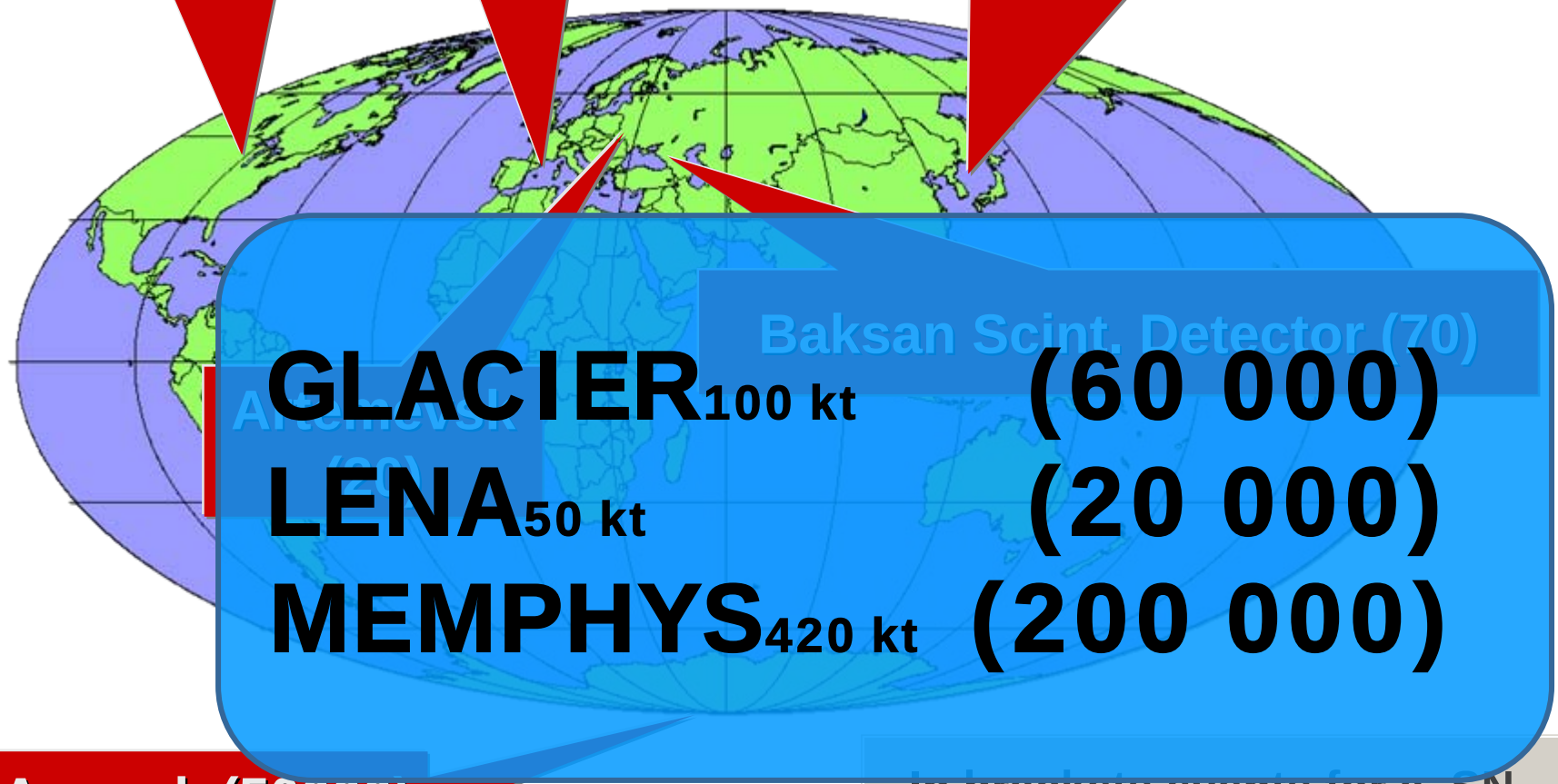
Baksan Scint. Detector (70)

Artemevsk
(20)

Amanda(50000)
IceCube(10^6)

In brackets events for a SN
at distance 10 kpc

Large Detectors for SN Neutrinos



SNO (800)
MiniBooNE (190)

LVD (400)
Borexino(100)

Super-Kamiokande (8500)
Kamland (330)

Baksan Scint. Detector (70)

GLACIER$_{100\ kt}$ (60 000)
LENA$_{50\ kt}$ (20 000)
MEMPHYS$_{420\ kt}$ (200 000)

Amanda(50000)
IceCube(10^6)

In brackets events for a SN at distance 10 kpc

Large Detectors for SN Neutrinos

Also:

- **Solar neutrinos**
- **Geo-neutrinos**
- **LBL accelerator experiments**

→ **converge to one large infrastructure, start construction ~2013**

What is the origin of high energy cosmic rays ?

What is the view of the sky at extreme energies ?

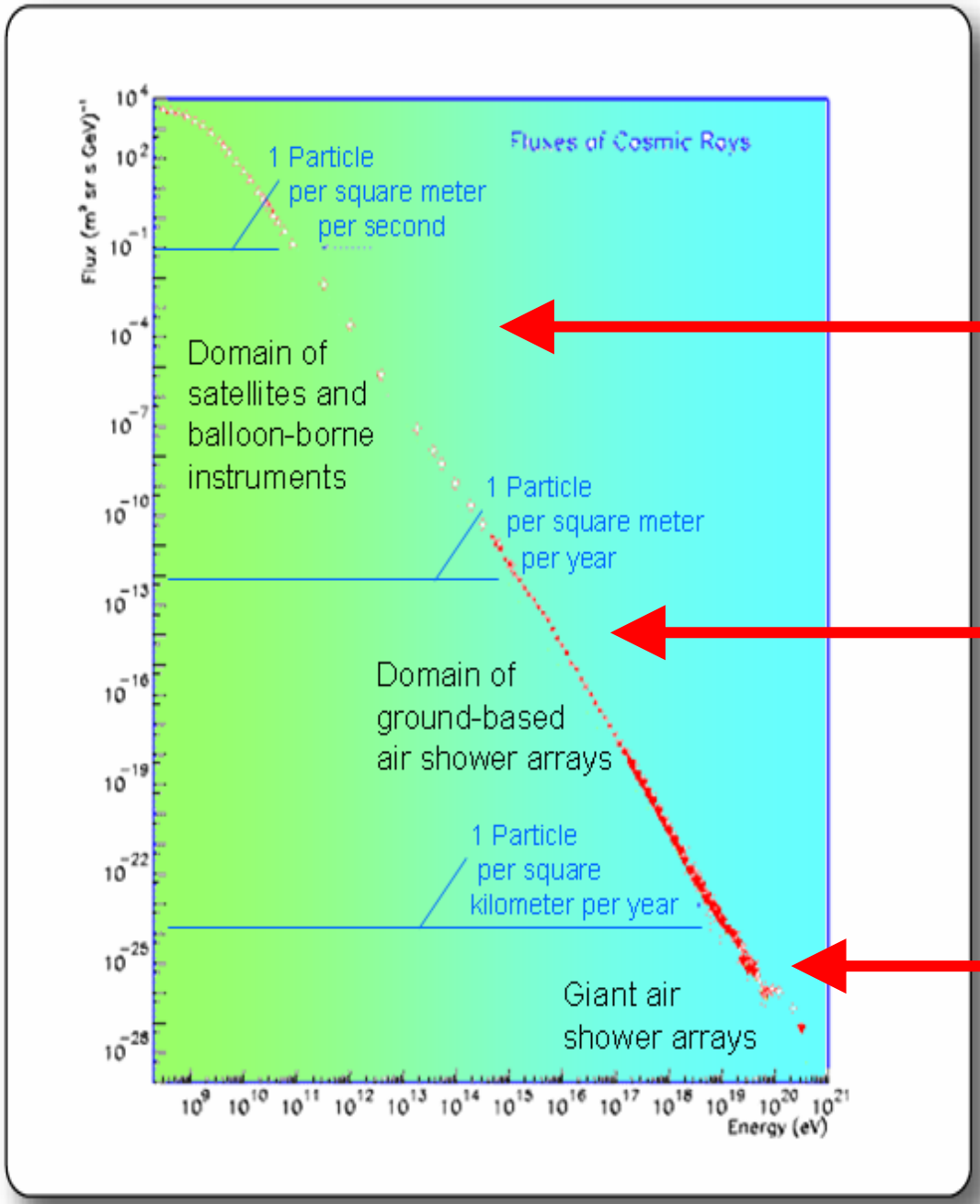
Charged cosmic rays, neutrinos, TeV γ

Started: Auger
$\geq$ 2009:
Auger North
$\geq$ 2015: EUSO ?

$\geq$ 2011: KM3NeT
under construction:
IceCube

H.E.S.S., Magic →
Very Large Array(s)
(„CTA“, $\geq$ 2010)

Cosmic Rays

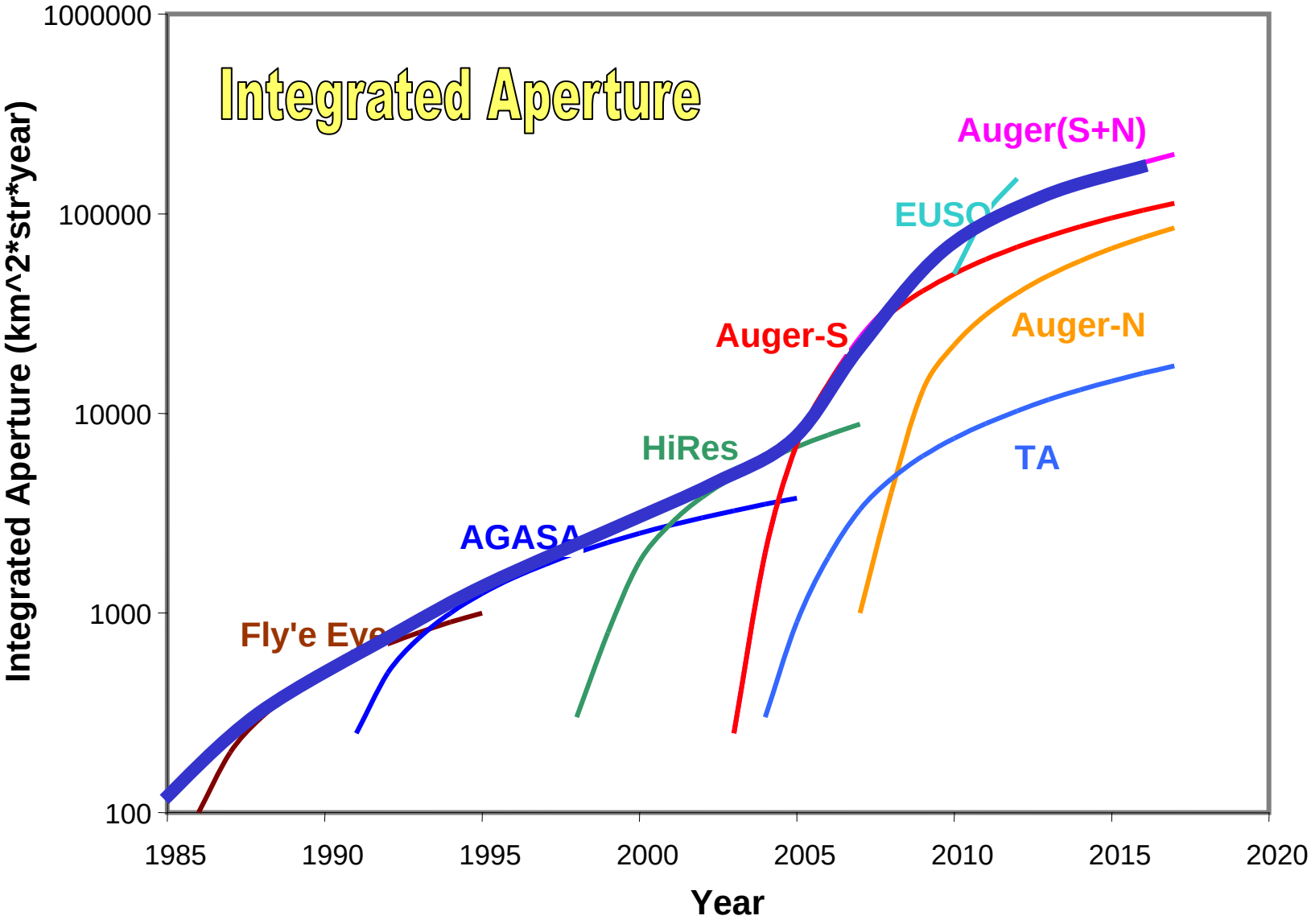


Balloons,
PAMELA
AMS

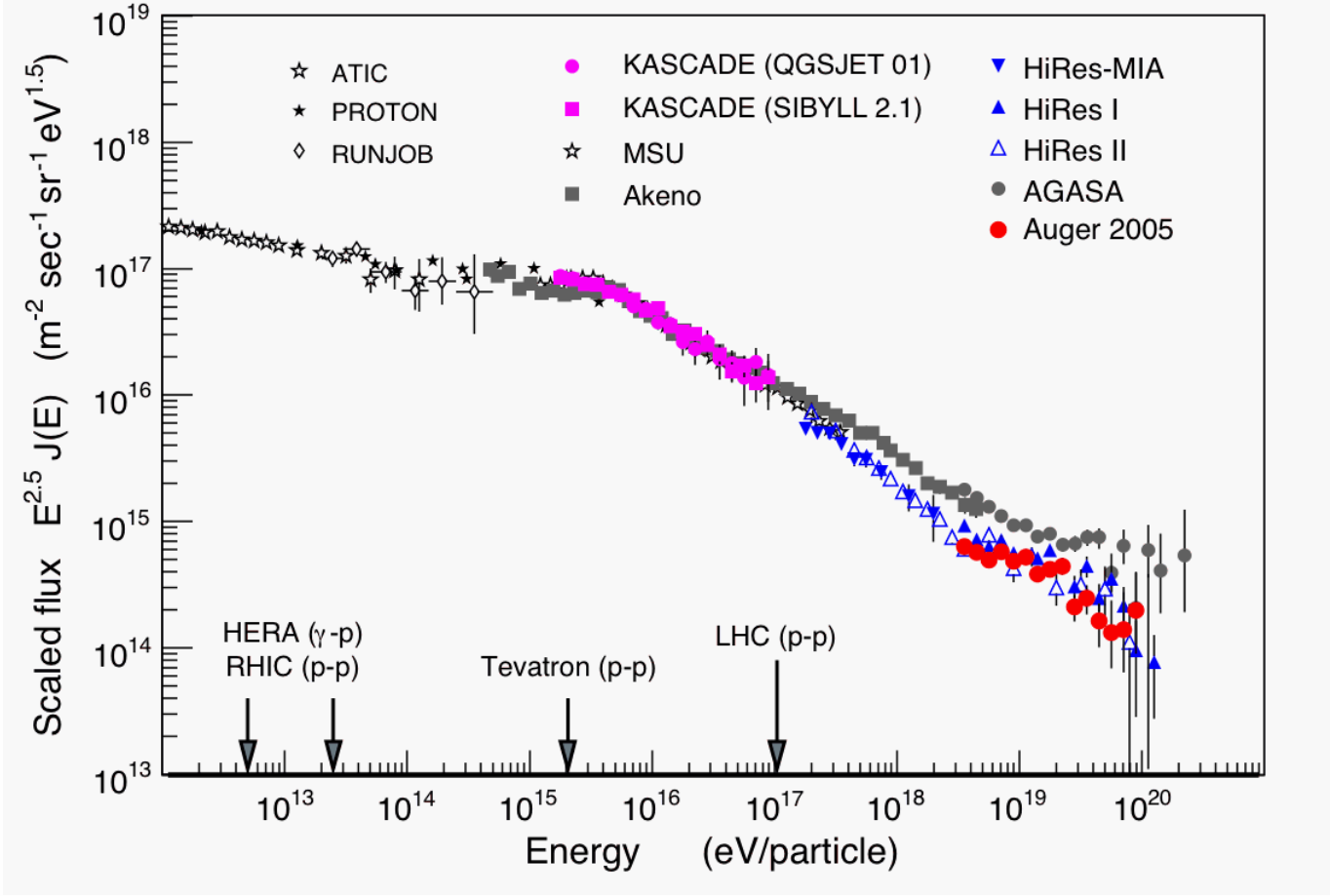
Kascade-Grande
IceTop/IceCube
Tunka-133

Telescope Array
Pierre Auger
Observatory

Cosmic Rays at the Highest Energies



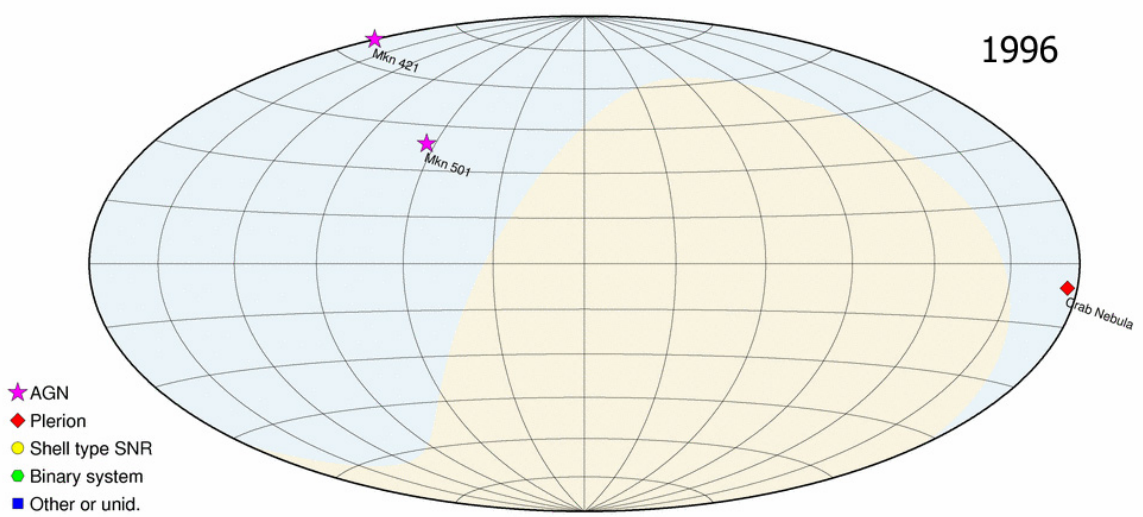
Auger-South indicates GZK cut-off



Auger North

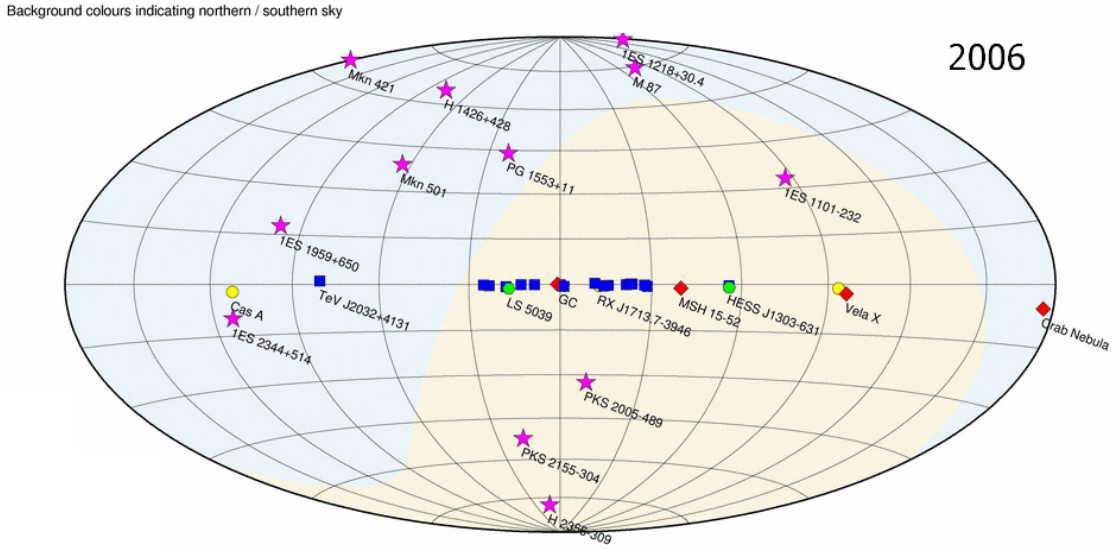
- Site: Colorado
- Estimated cost 85 M€
  (30 M€ from Europe)
- Full sky coverage
- Expect confirmation of
  physics case by Auger-South
  → need first point sources
- Start construction 2009 ?

TeV-Gamma: from dawn to daylight



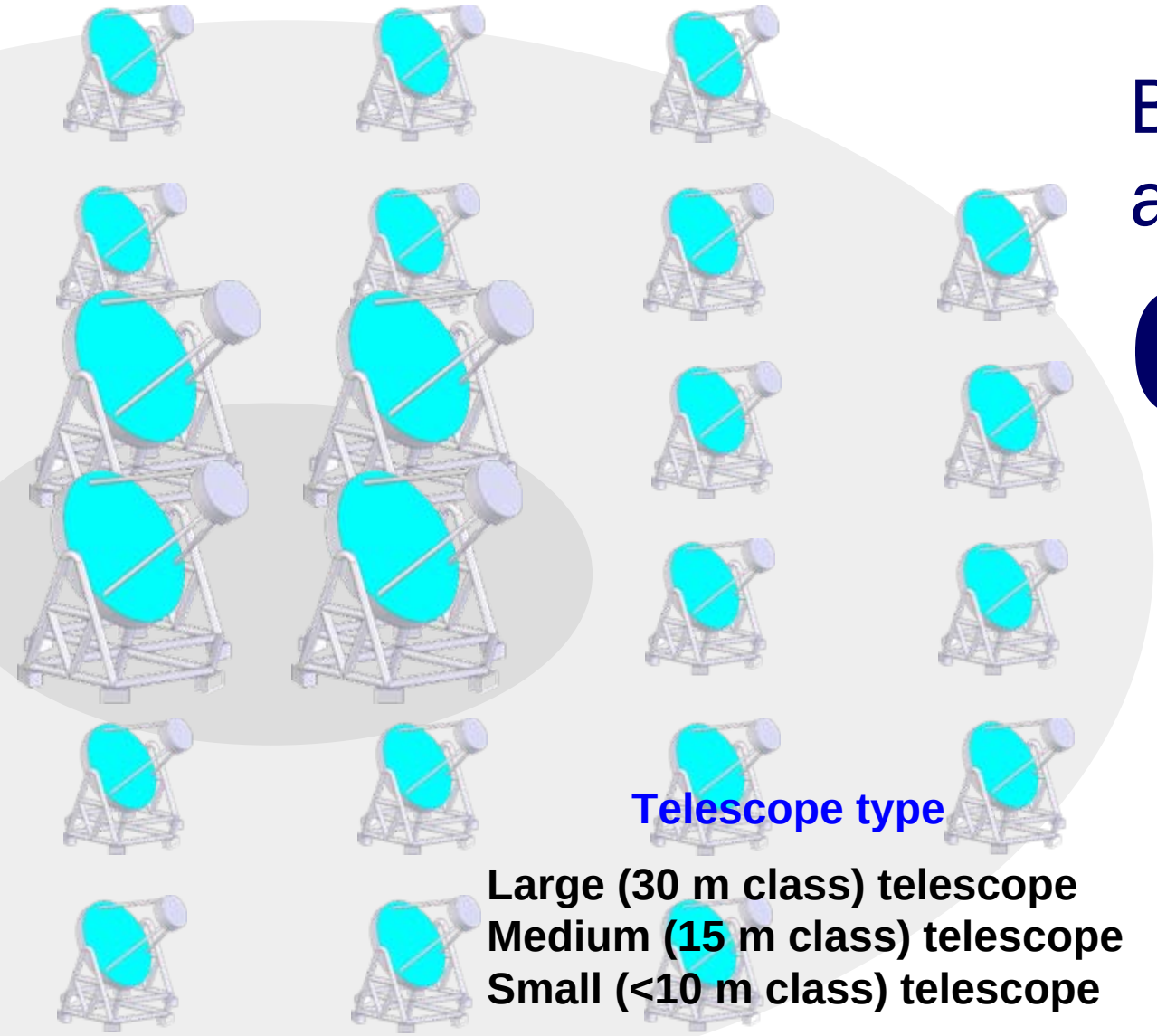
1996:

2 sources



2006:

~ 40 sources



Beyond H.E.S.S. and MAGIC:

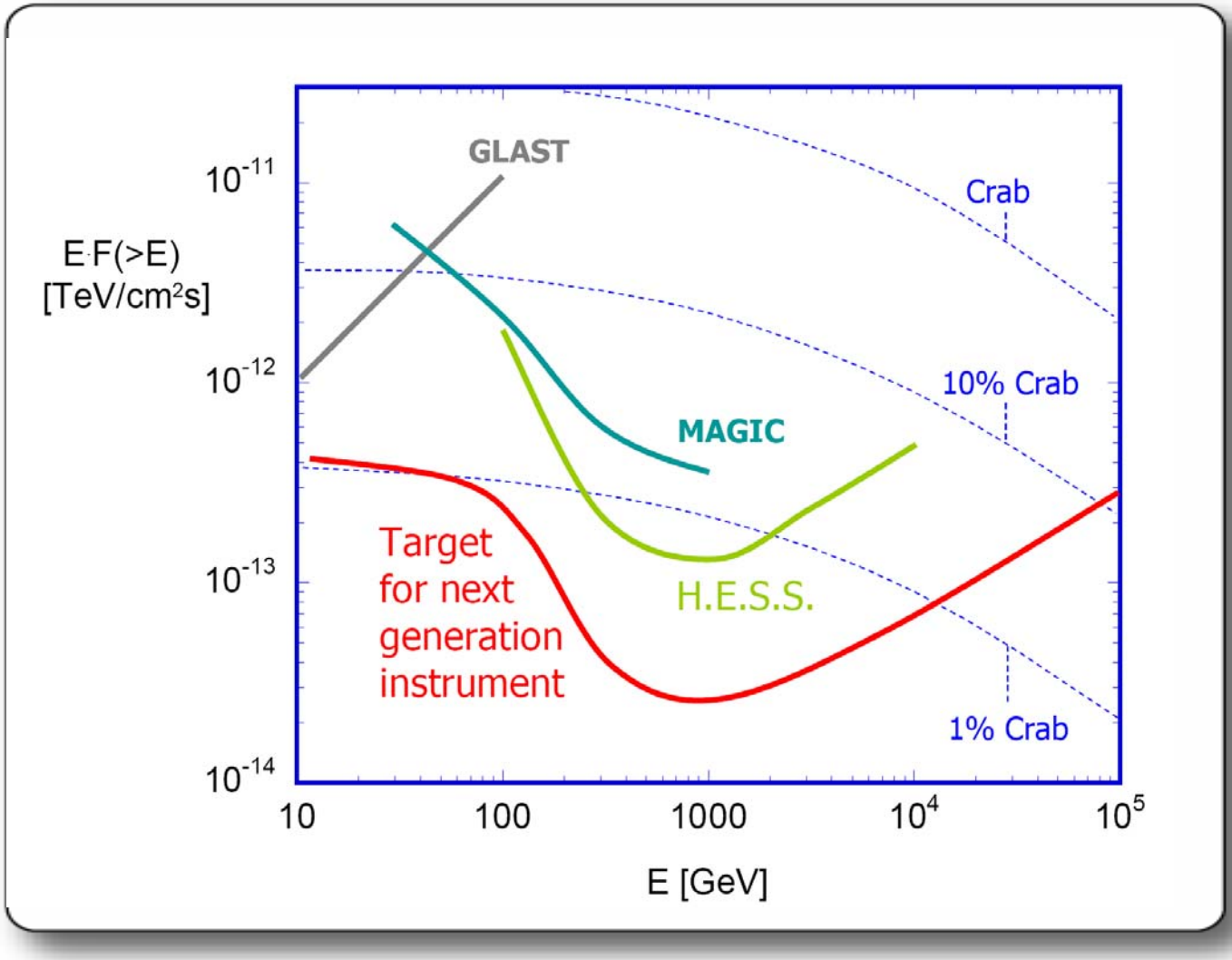
CTA

Telescope type	Cost/Unit	Units
Large (30 m class) telescope	10 – 15 M€	~ 3-4
Medium (15 m class) telescope	2.5 – 3.5 M€	~ 15-20
Small (<10 m class) telescope	0.5-1.0 M€	~ many

Total ~ 100 M€ for general-purpose southern site
~ 50 M€ for “extragalactic” northern site

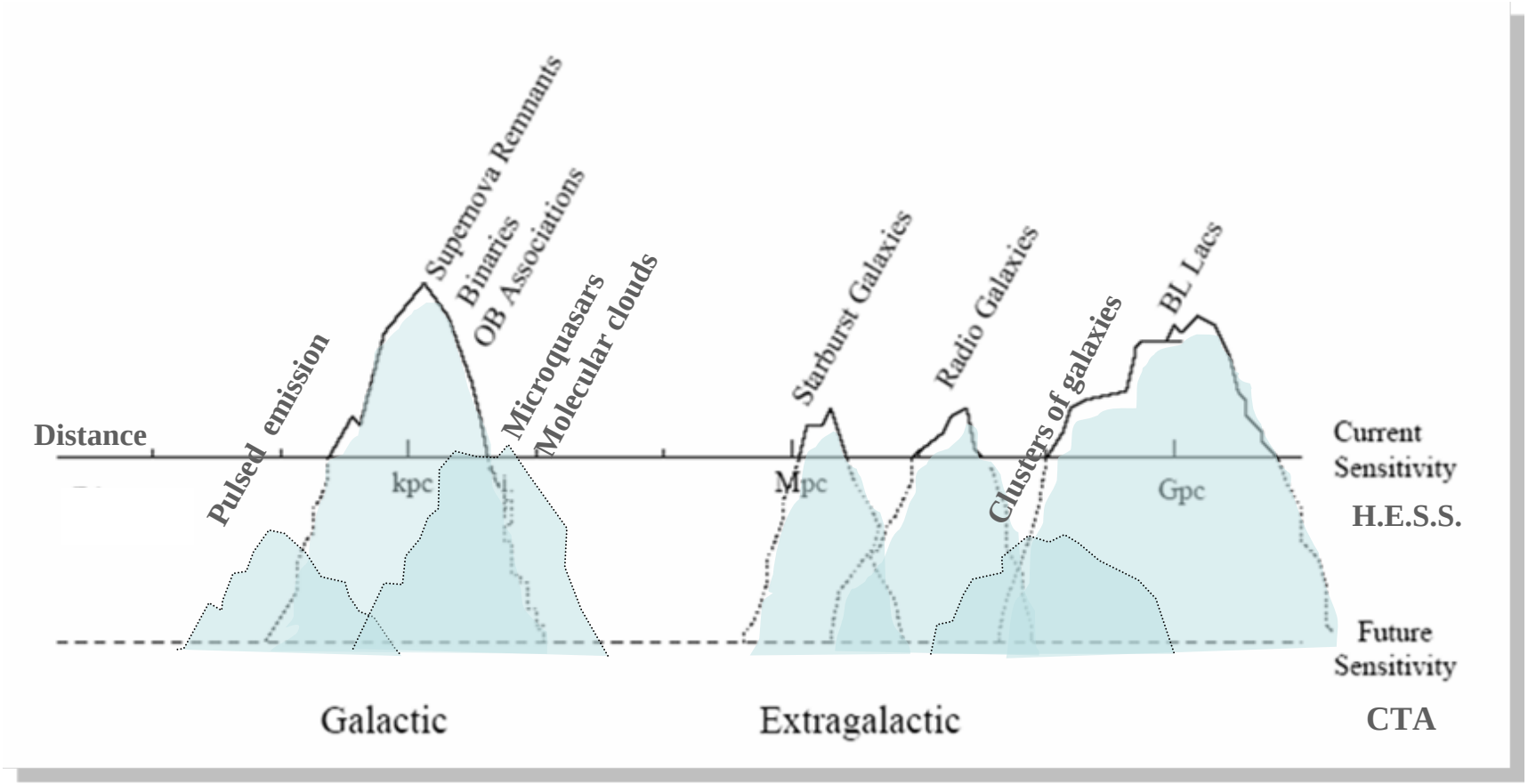
Not to scale !

CTA sensitivity



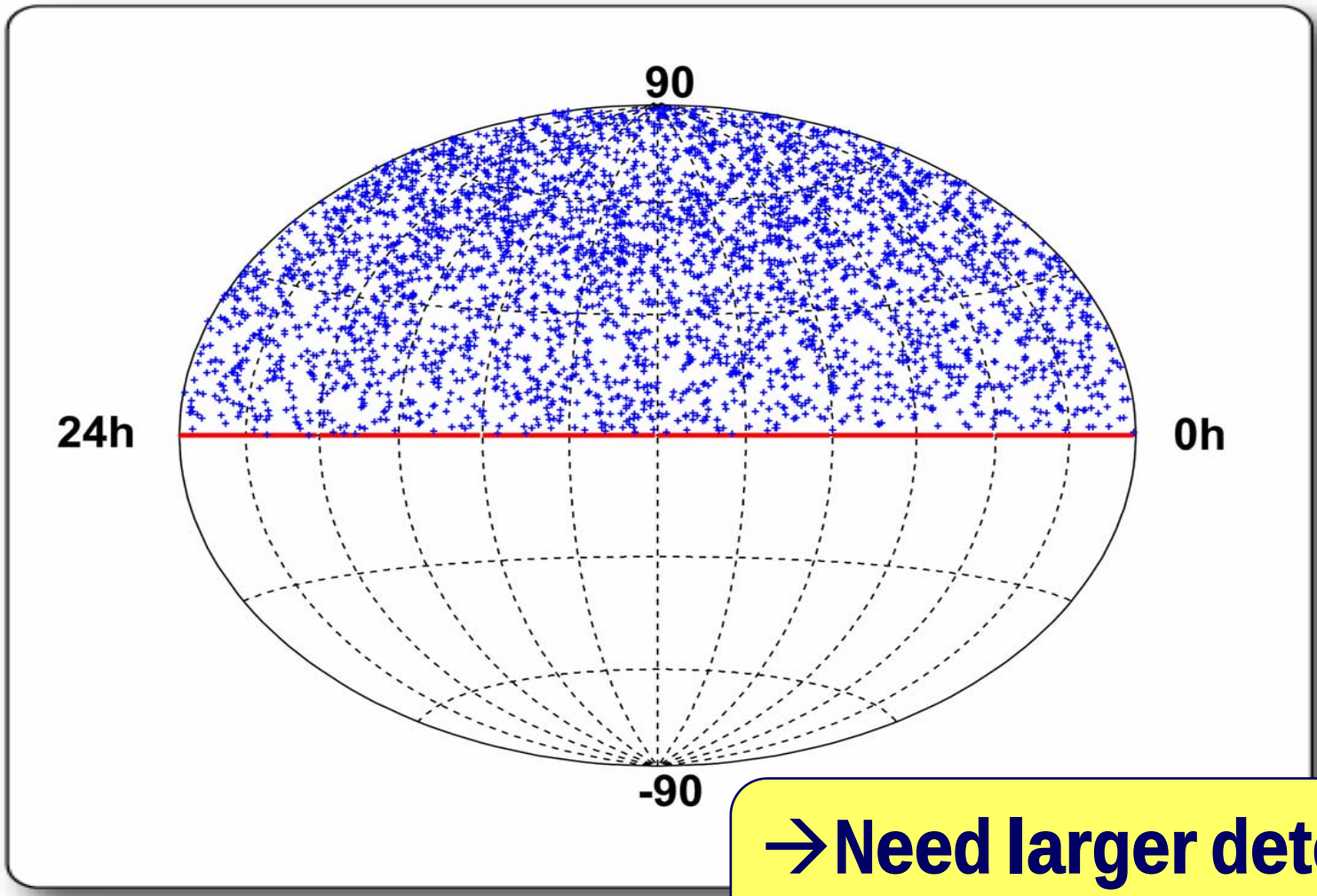
expect about
10^3 sources

The new worlds of CTA



European IACT projects

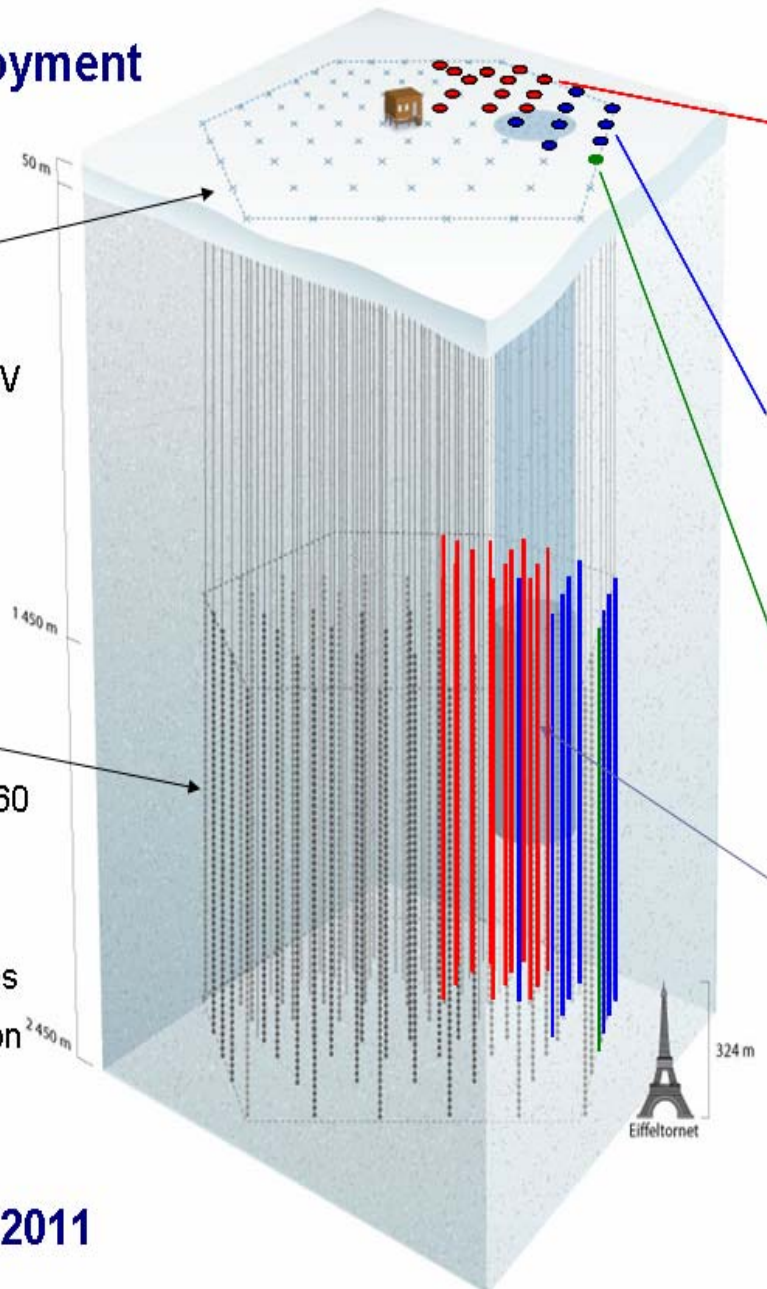
Neutrino Telescopes: AMANDA skymap



→Need larger detectors: IceCube, KM3NeT

IceCube

IceCube Deployment



IceTop

Air shower detector

Threshold ~ 300 TeV

InIce

planned 80 strings of 60 optical modules each

17 m between modules

125 m string separation

2006-2007:

13 strings deployed

Altogether: 22 strings
52 surface tanks

2005-2006: 8 strings

2004-2005 : 1 string

First data in 2005
first upgoing muon:
July 18, 2005

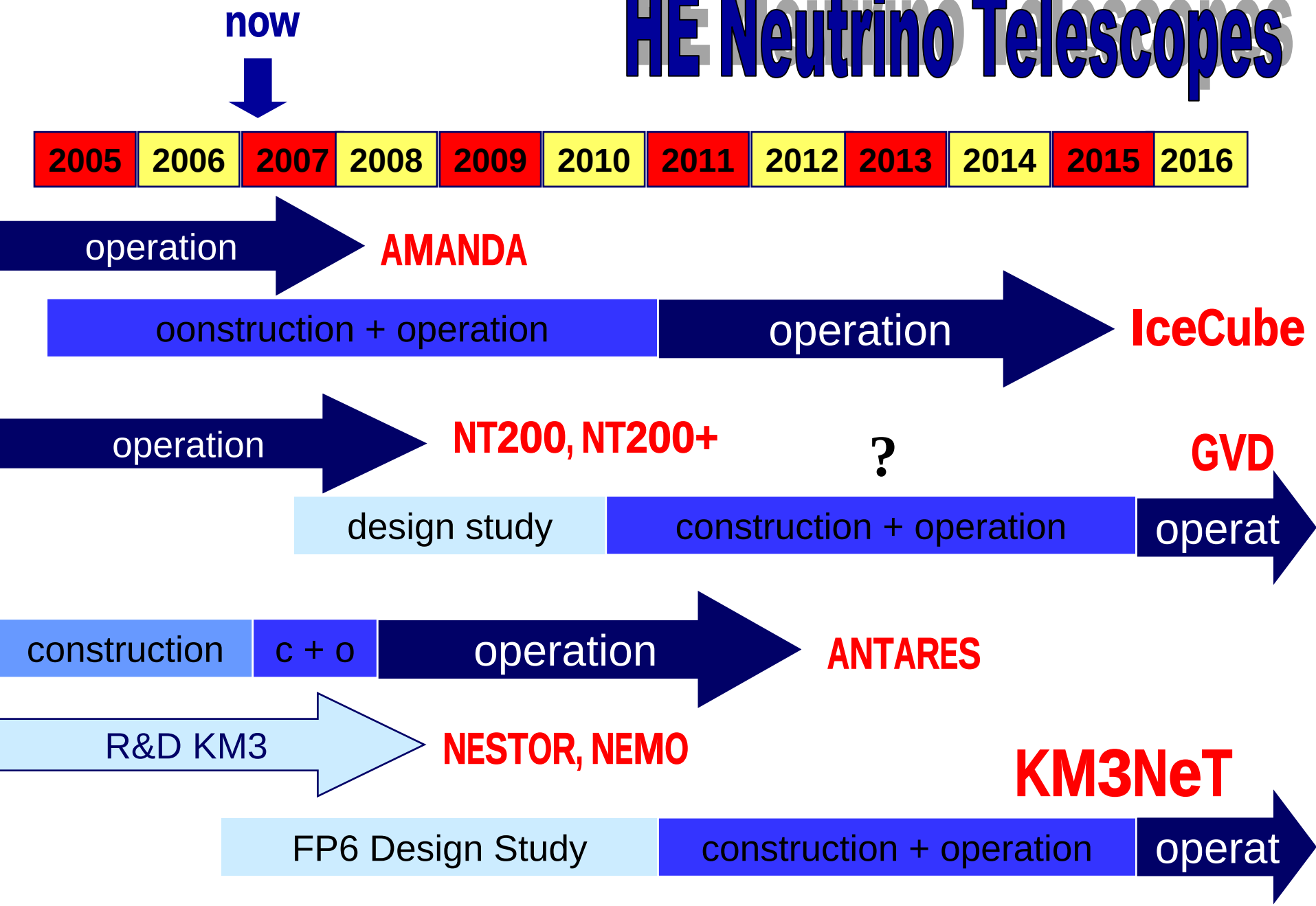
AMANDA

19 strings

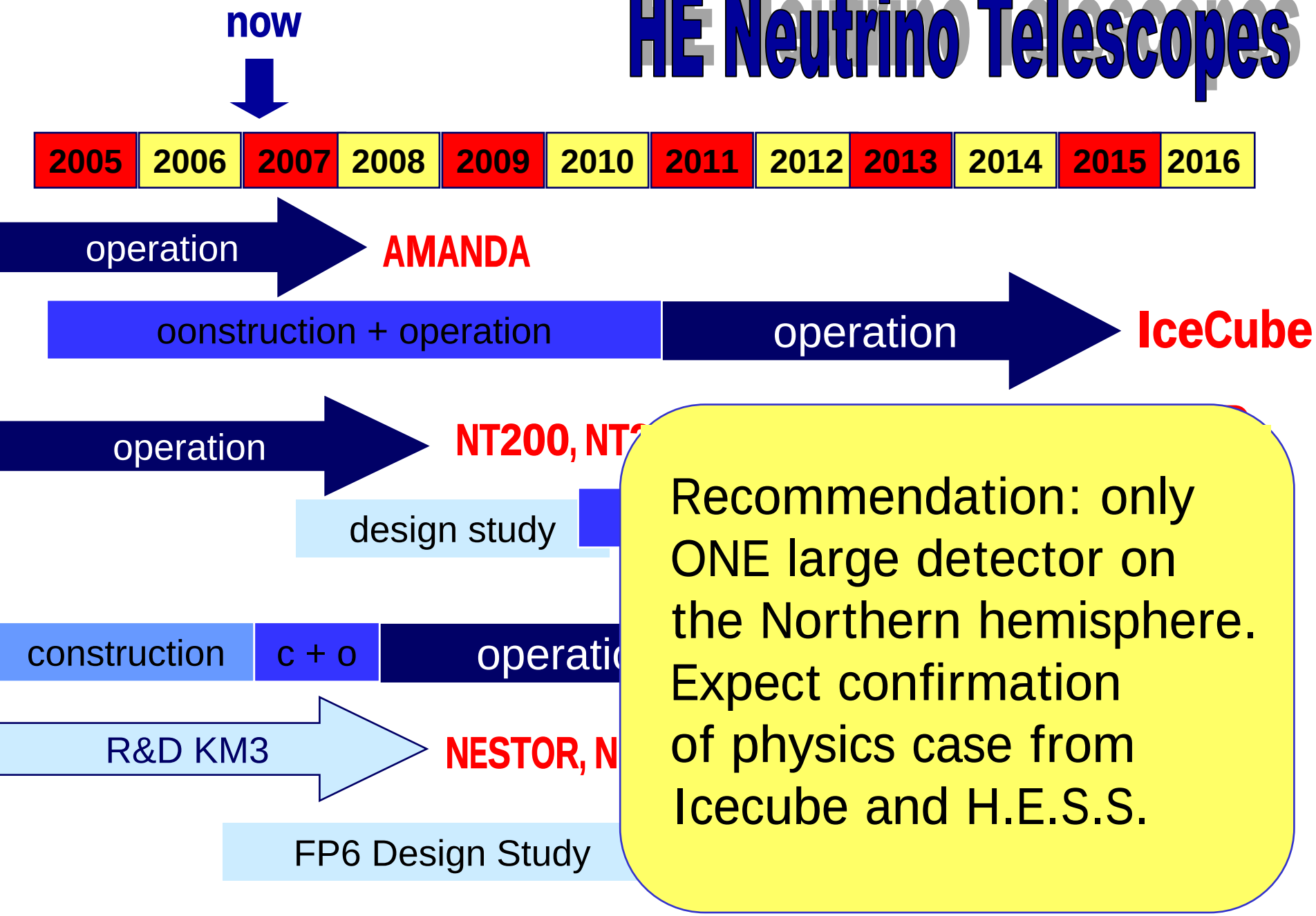
677 modules

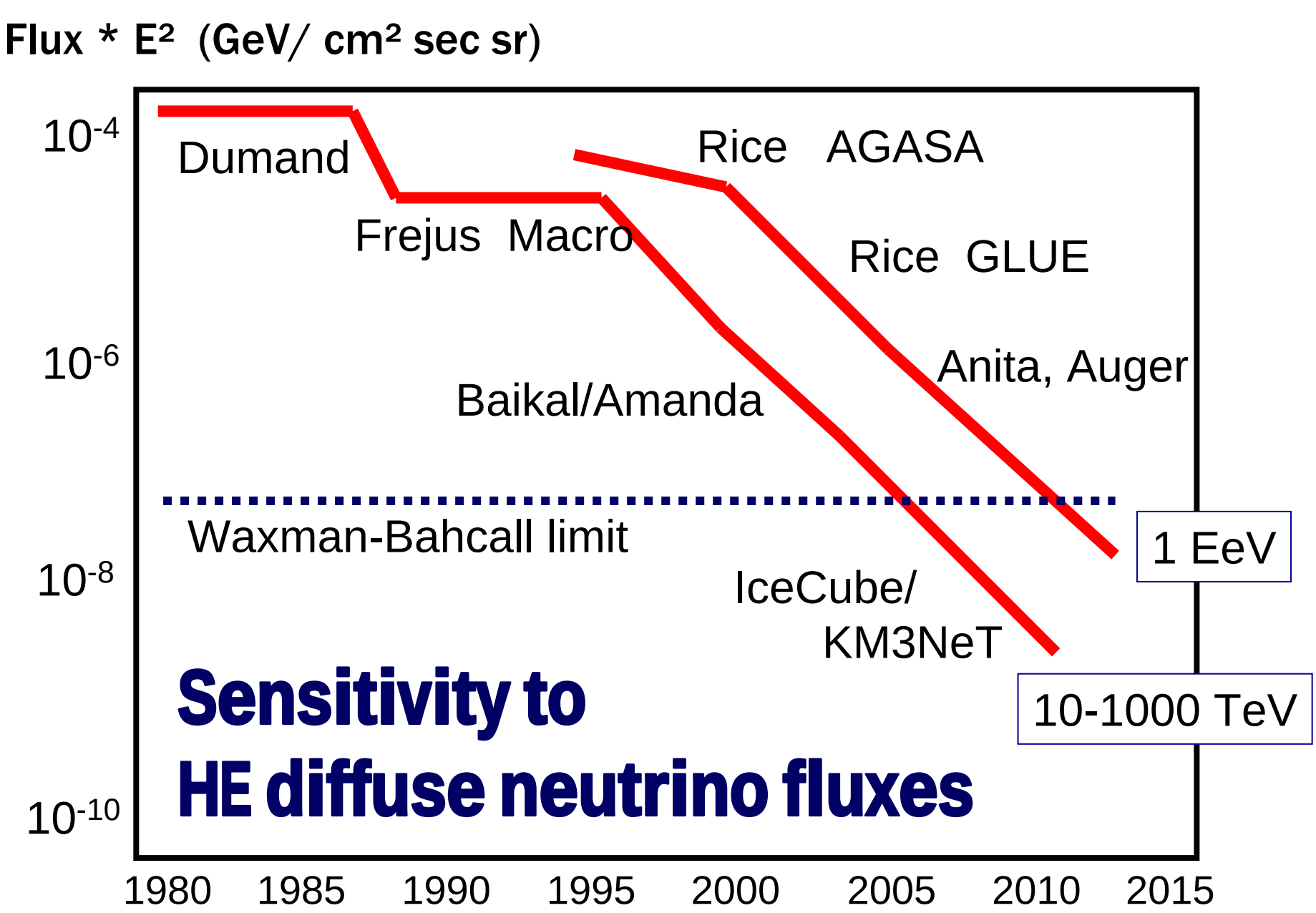
Completion by 2011

HE Neutrino Telescopes



HE Neutrino Telescopes




Flux * E² (GeV/ cm² sec sr)
10-4
10-6
10-8
10-10
Dumand
Frejus
Macro
Rice
AGASA
Rice GLUE
Anita, Auger
Baikal/Amanda
Waxman-Bahcall limit
IceCube/
KM3NeT
1 EeV
10-1000 TeV
Sensitivity to
HE diffuse neutrino fluxes
1980
1985
1990
1995
2000
2005
2010
2015

New methods

- Radio detection of air showers
- Radio detection of showers at the moon
- Radio detection of neutrinos in ice or salt
- Acoustic detection of neutrinos in water and ice
- Detection of cosmic ray & neutrino interactions from space (by fluorescence)
- Wide angle Gamma detection
- New photosensors
- ....

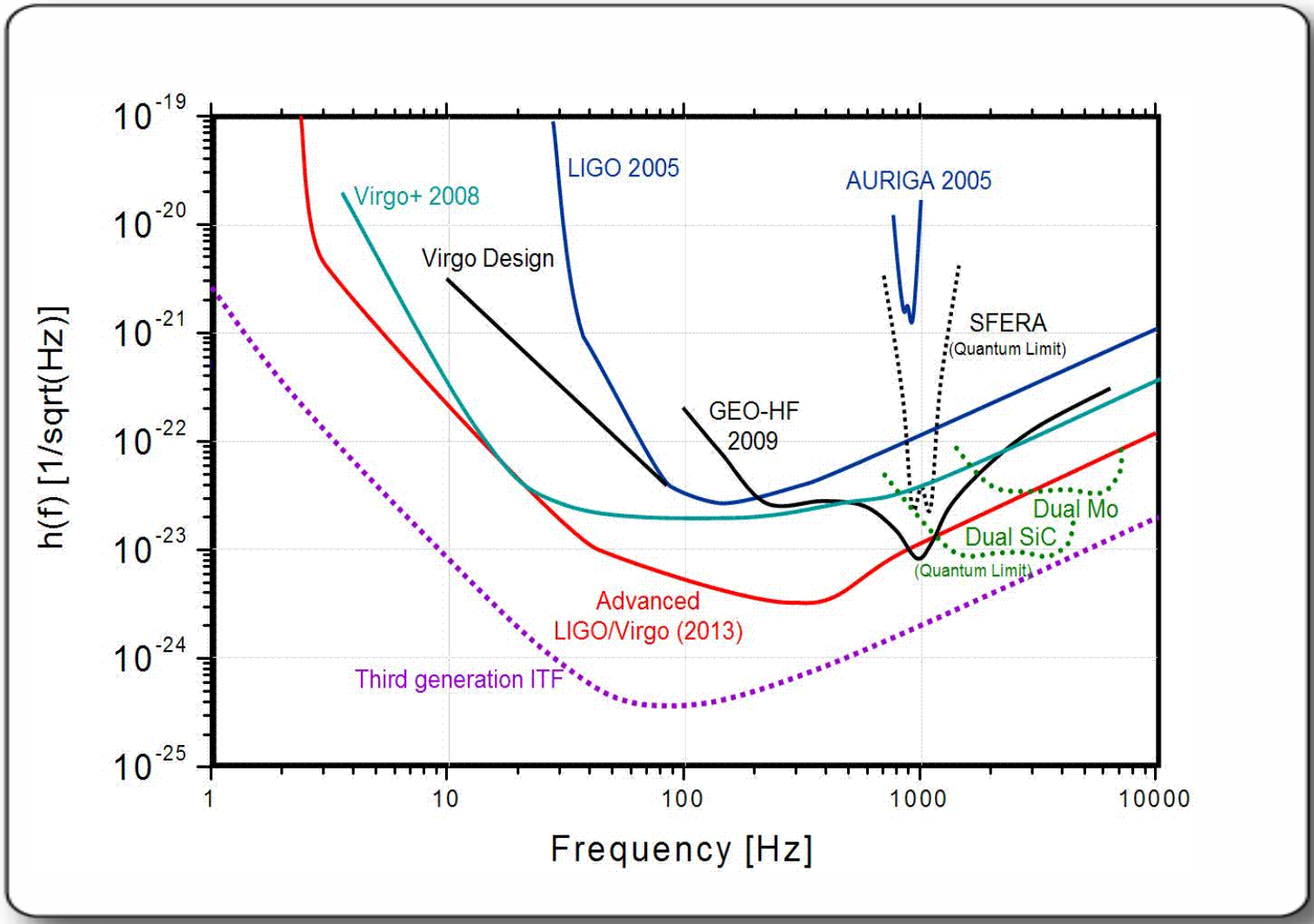
Can we detect gravitational waves ?

What will they tell us about violent cosmic processes ?

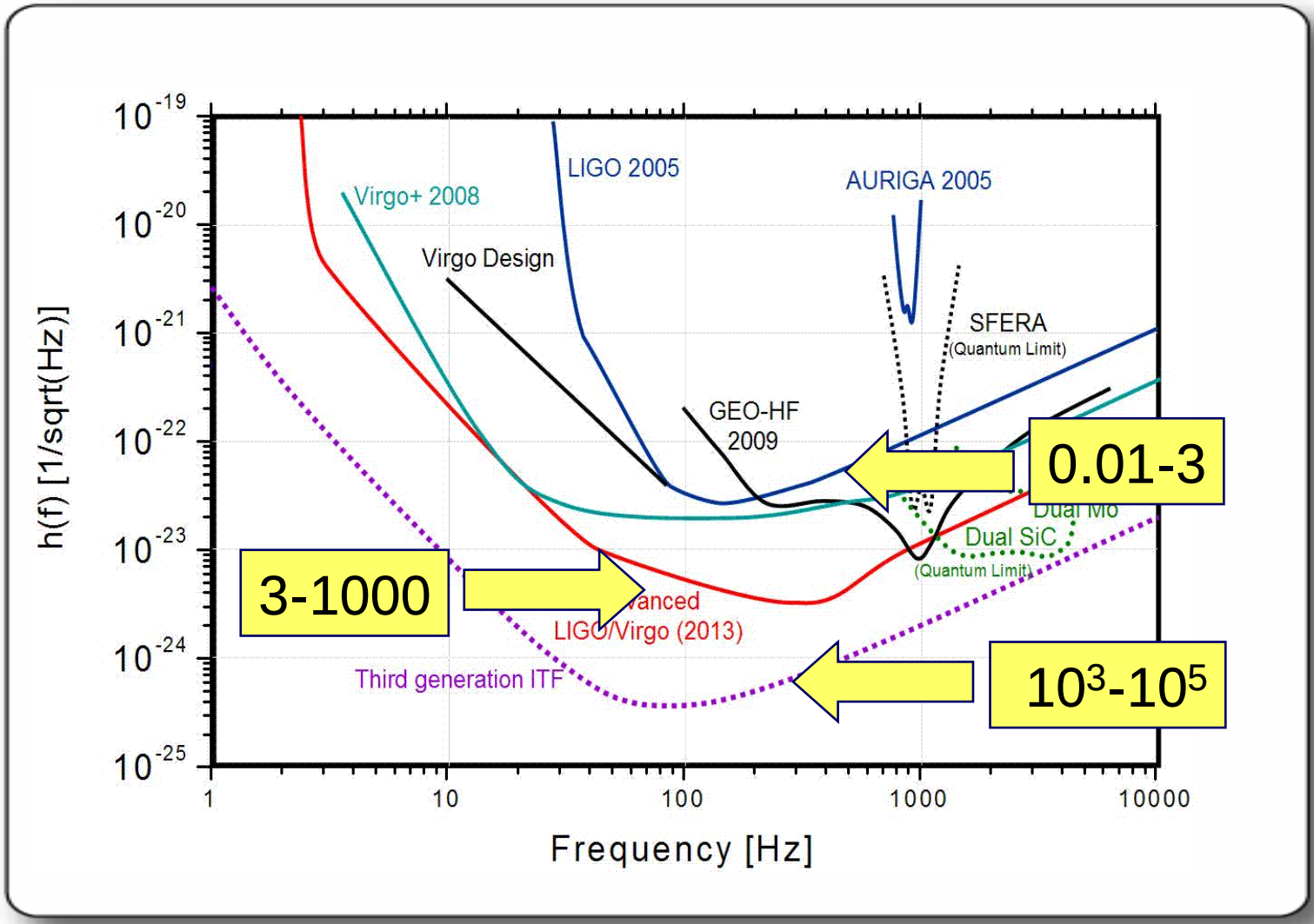
- Ground based Interferometers (here: VIRGO) 10 Hz – 10 kHz

- Resonant antennas: ~ 1 kHz
- Space based interferometer (LISA): < mHz - 1 Hz

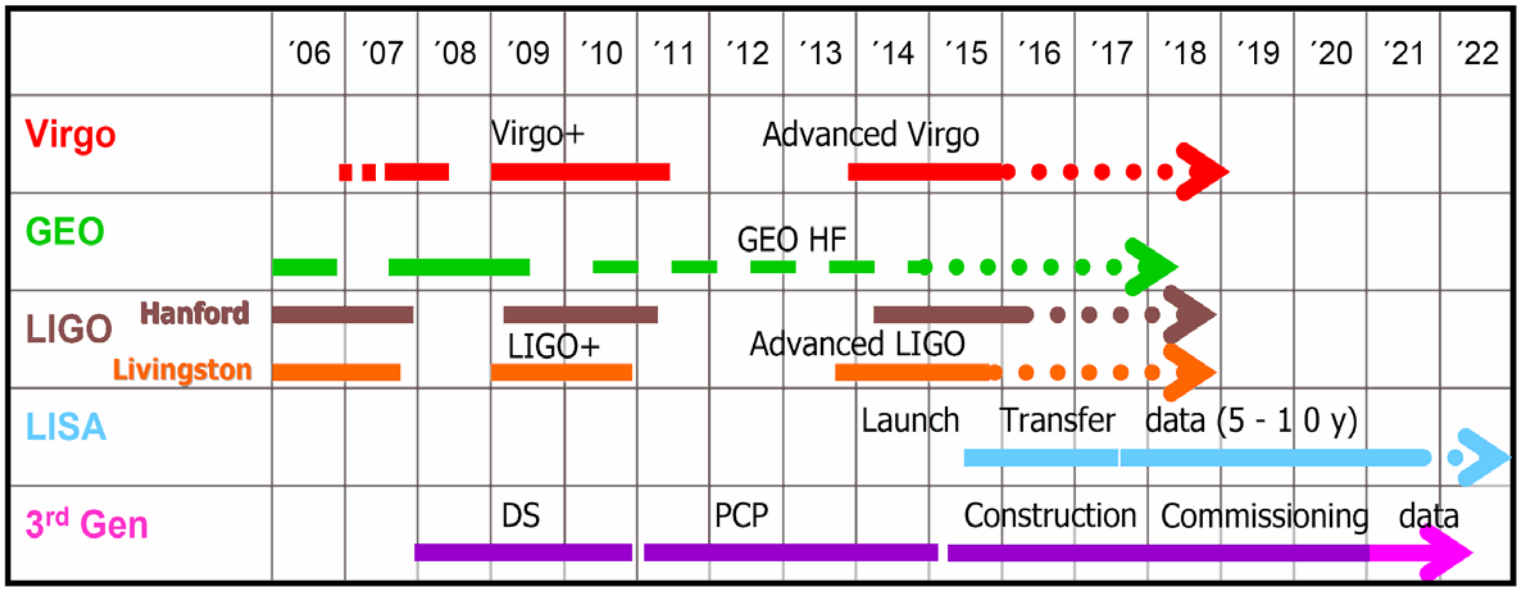
Sensitivities



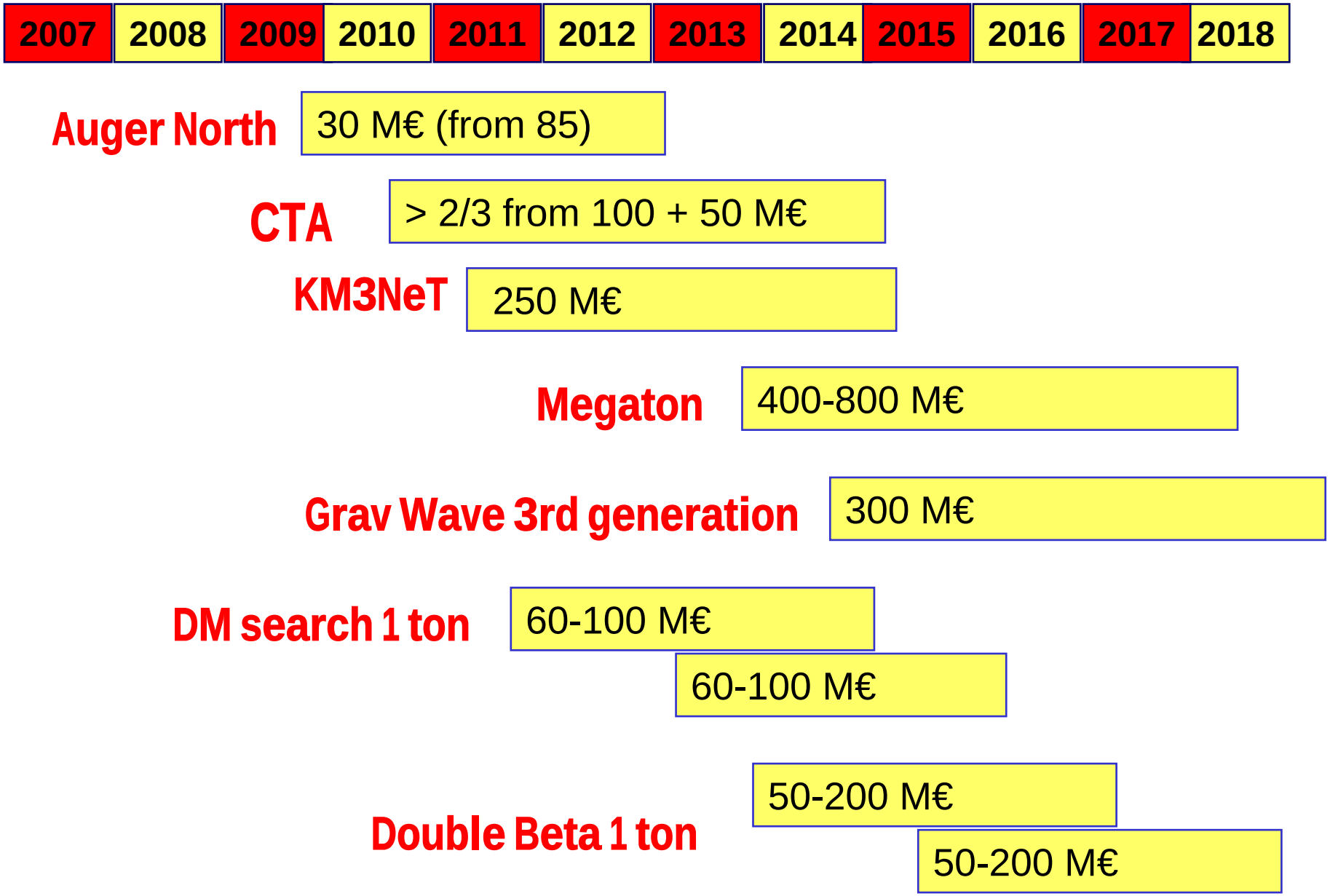
Events per year

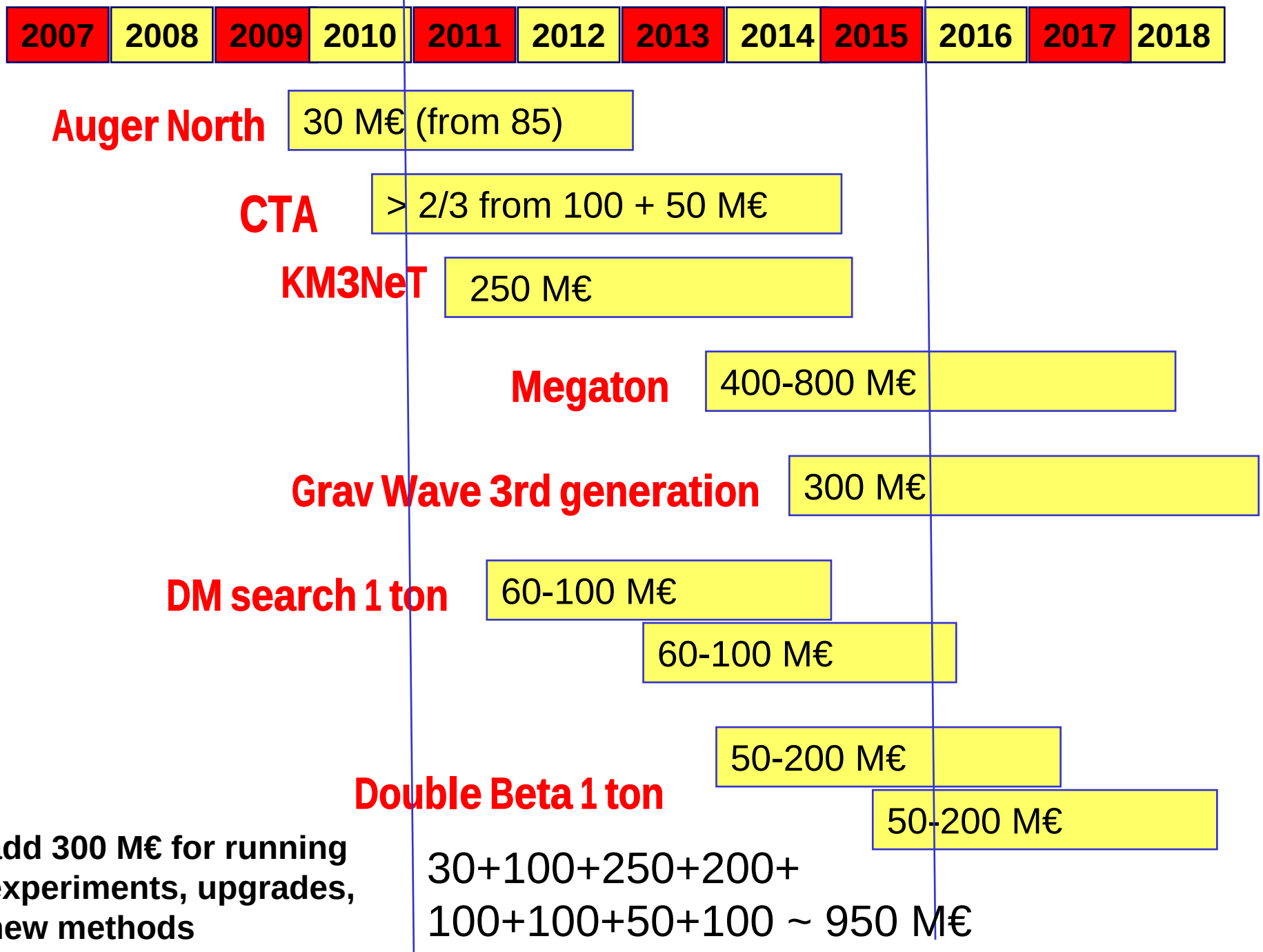


Gravitational Waves: Time chart



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€
Double Beta 1 ton
50-200 M€
50-200 M€


2007
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400-800 M€
Grav Wave 3rd generation
300 M€
DM search 1 ton
60-100 M€
60-100 M€
Double Beta 1 ton
50-200 M€
50-200 M€
add 300 M€ for running experiments, upgrades, new methods
30+100+250+200+
100+100+50+100 ~ 950 M€

A cost scenario 2011-2015

- Estimated total cost to be spent between 2011 and 2015 in Europe

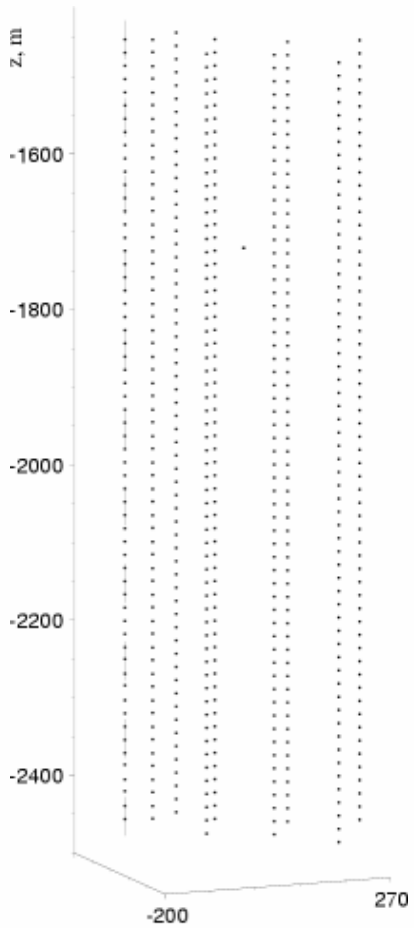
~ 1250 M€

  - 250 M€ per year (now 135 M€) → ***factor 2***
  - Manpower not always included → more than factor 2

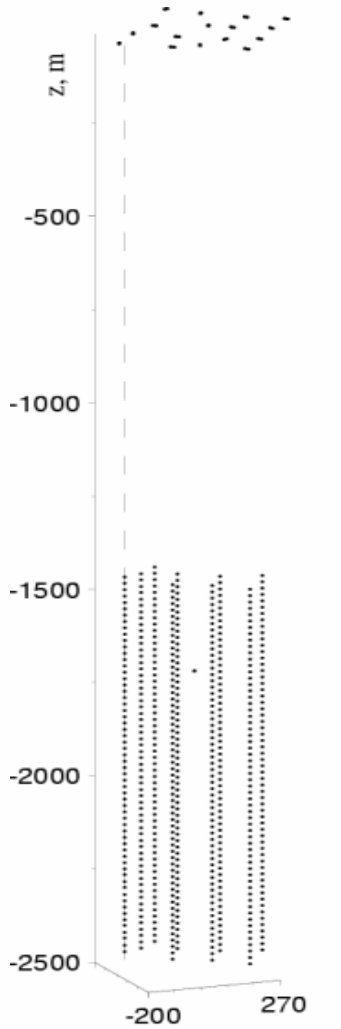
- Solutions:
  - Increased funding → **„factor-2 pressure“**
  - Further internationalization
  - Staging

Summary

- From infancy to maturity: the past 1-2 decades have born the instruments & methods for doing science with **high discovery potential.**
- **Accelerated increase in sensitivity** in nearly all fields.
- A lot of advanced, interesting world-class projects. **Europeans lead in many fields**.
- **Physics harvest has started** (TeV gamma) or is in reach. Most techniques are mature.
- **Need increased funding**
- **Need radical process of convergence**
- **Detailed milestones** (until 2008), **technical design reports** (2008-2011)



run 1 event 288



run 86758 event 24379

Tables of proposed experiments with cost > 50 M€

Field/ Experiment	**cost scale (M€)**	**Desirable start of construction**	**Remarks**
Dark Matter Search: Low background experiments with 1-ton mass	60-100 M€	2011-2013	two experiments (different nuclei, different tech-niques), e.g. → 1 bolometric → 1 noble liquid more than 2 expt's worldwide

Expect technical proposals ~ 2009/10

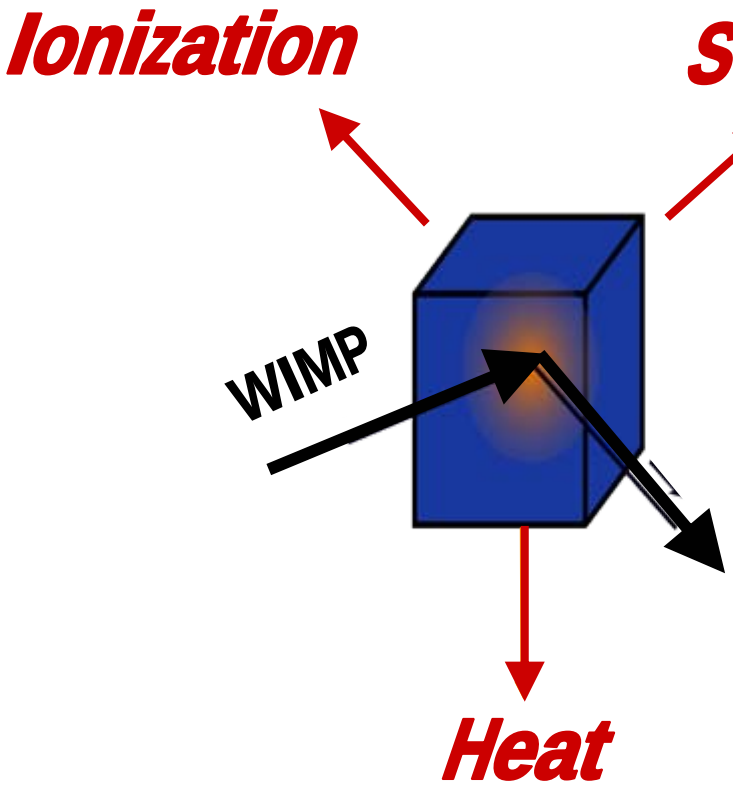
Field/ Experiment	**cost scale (M€)**	**Desirable start of construction**	**Remarks**
Properties of neutrinos: Double beta experiments	50-200 M€	2012-2015	1) Explore inverted hierarchy scenario 2) two experiments with different nuclei (and desirably more worldwide)

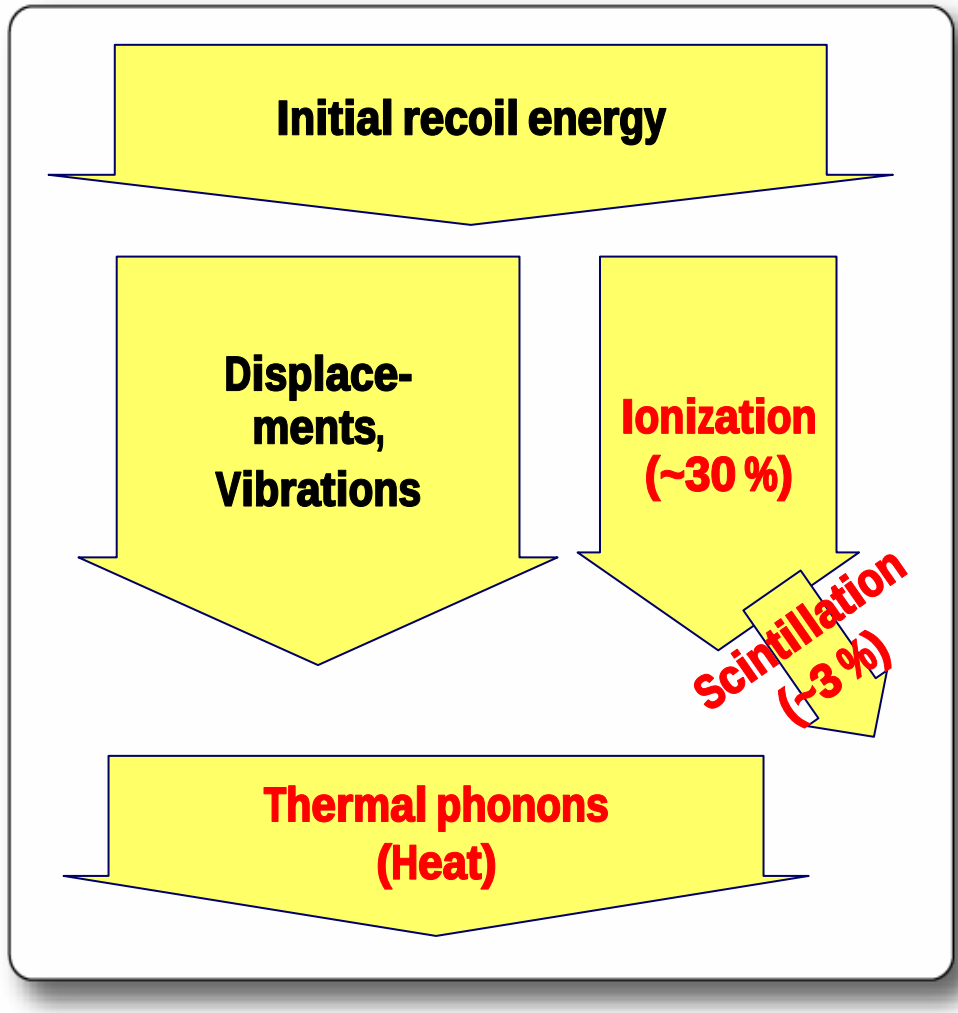
For instance: - GERDA + MAJORANA
- advanced CUORE

Field/ Experiment	**cost scale (M€)**	**Desirable start of construction**	**Remarks**
Proton decay and low energy neutrino astronomy: Large infrastructure for p-decay and ν astronomy on the 100kt-1 Mton scale	400-800 M€	Civil engineering: 2012-2013	- multi-purpose - 3 technological options - needs huge new excavation - most of expen-ditures likely after 2015 - worldwide sharing

Field/ Experiment	**cost scale (M€)**	**Desirable start of construction**	**Remarks**
High Energy Univ.			
Gamma Rays			Physics potential well defined by rich physics from present γ exp's
Cherenkov Telescope Array CTA	100 M€ South 50 M€ North	First site 2010	
Charged Cosmic Rays	85 M€	2009	Confirmation of physics potential from Auger South expected in 2007
Auger North			
Neutrinos	250 M€	2011	FP6 design study Confirm. of physics potential expected from IceCube and gamma telescopes Proposal in 2009
KM3NeT			

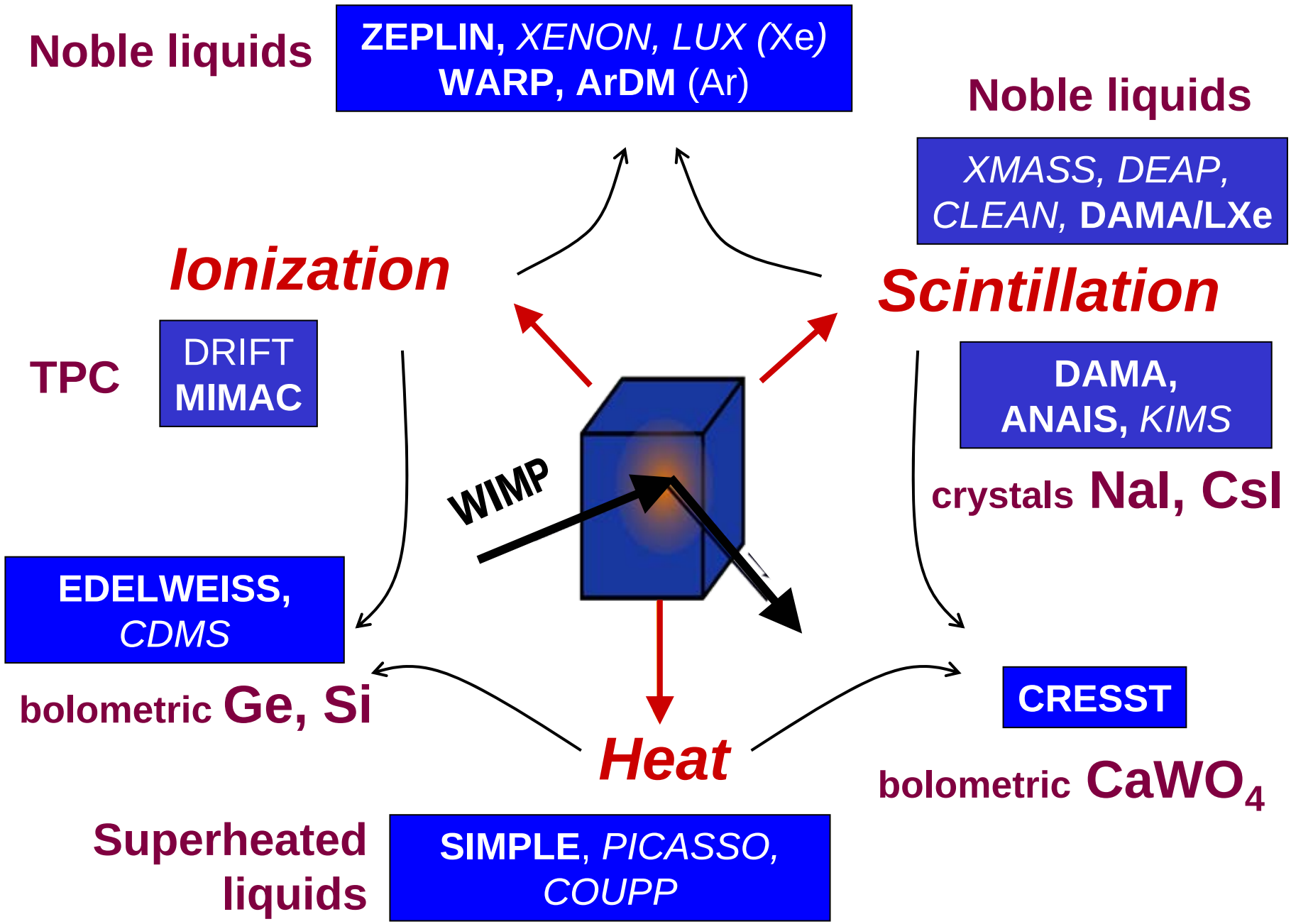
Field/ Experiment	**cost scale (M€)**	**Desirable start of construction**	**Remarks**
Gravitational waves: Third generation interferometer	250-300 M€	Civil engineering 2012	Conceived as underground laboratory

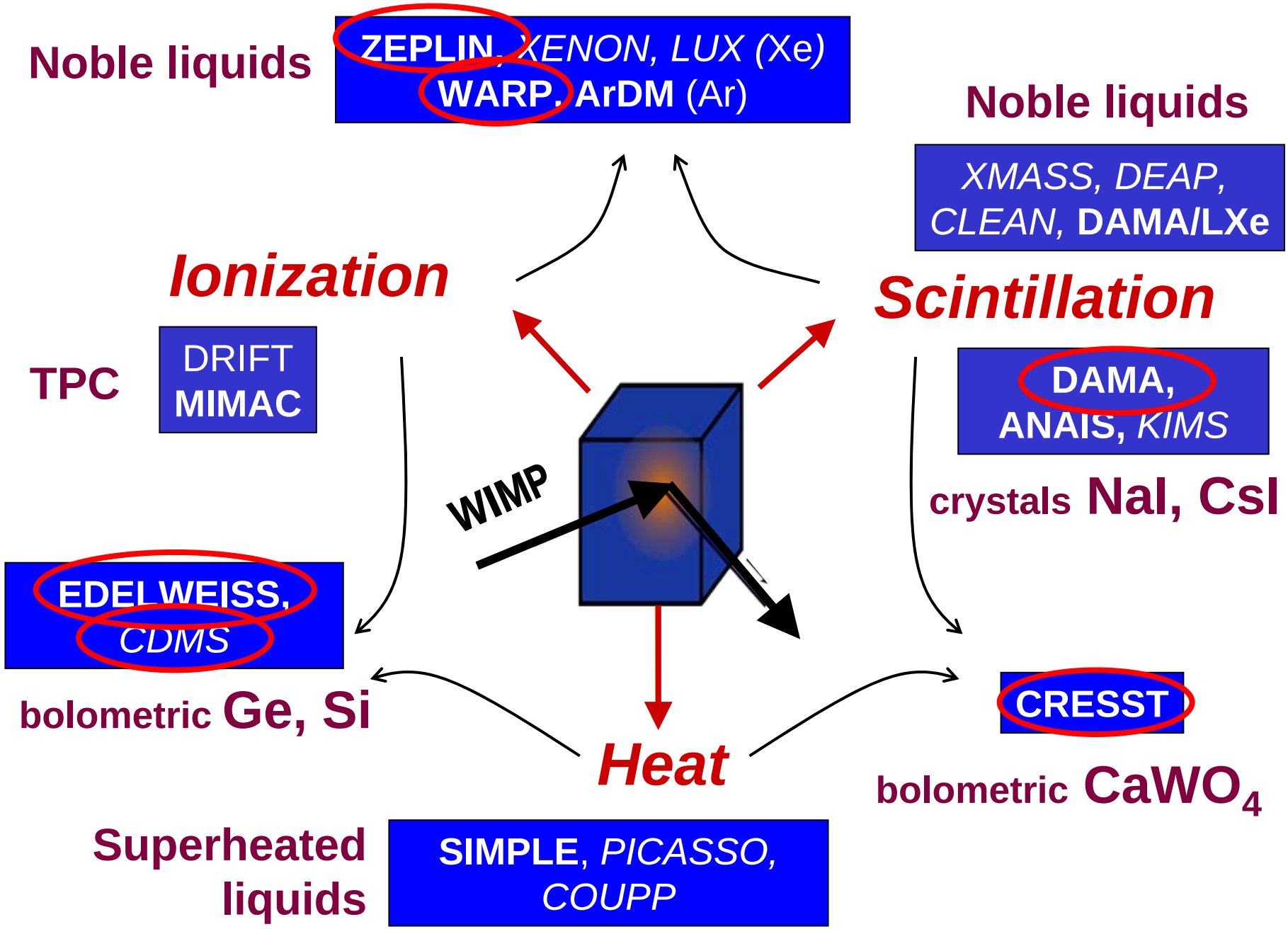




Smoking guns:

- annual modulation
- directionality
- target dependence


Noble liquids
ZEPLIN, XENON, LUX (Xe)
WARP, ArDM (Ar)
Noble liquids
XMASS, DEAP,
CLEAN, DAMA/LXe
Ionization
Scintillation
TPC
DRIFT
MIMAC
DAMA,
ANAIS, KIMS
crystals NaI, CsI
WIMP
EDELWEISS,
CDMS
bolometric Ge, Si
CRESST
bolometric CaWO4
Heat
Superheated
liquids
SIMPLE, PICASSO,
COUPP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DAMA, ANAIS, KIMS
crystals NaI, CsI
WIMP
EDELWEISS, CDMS
bolometric Ge, Si
CRESST
Heat
bolometric CaWO4
Superheated liquids
SIMPLE, PICASSO, COUPP

Original CTA plan

	06	07	08	09	10	11	12	13
Site exploration								
Array design								
Component prototypes								
Telescope prototypes								
Array construction								
Partial operation								
Full operation								

GLAST

New methods

- Radio detection of air showers: LOPES, LOFAR,...
- Hybrid: water-C [+ fluorescence] + radio @ Auger & SP
- Radio detection of showers at the moon: GLUE, NuMOON, LORD, LIFE
- Radio detection of neutrinos in ice/salt: RICE, AURA, SALSA
- Acoustic detection of neutrinos in water and ice: SPATS @ SP
  + many water approaches
- Hybrid (optical + acoustic [+radio]): South Pole "CONDOR"
- Detection of cosmic ray & neutrino interactions
  from space (by fluorescence): EUSO
- New photosensors
- ...

DBD mass vs. mass of lightest neutrino

Klapdor-Kleingrothaus claim