Origin of the Universe, Particles and Structure

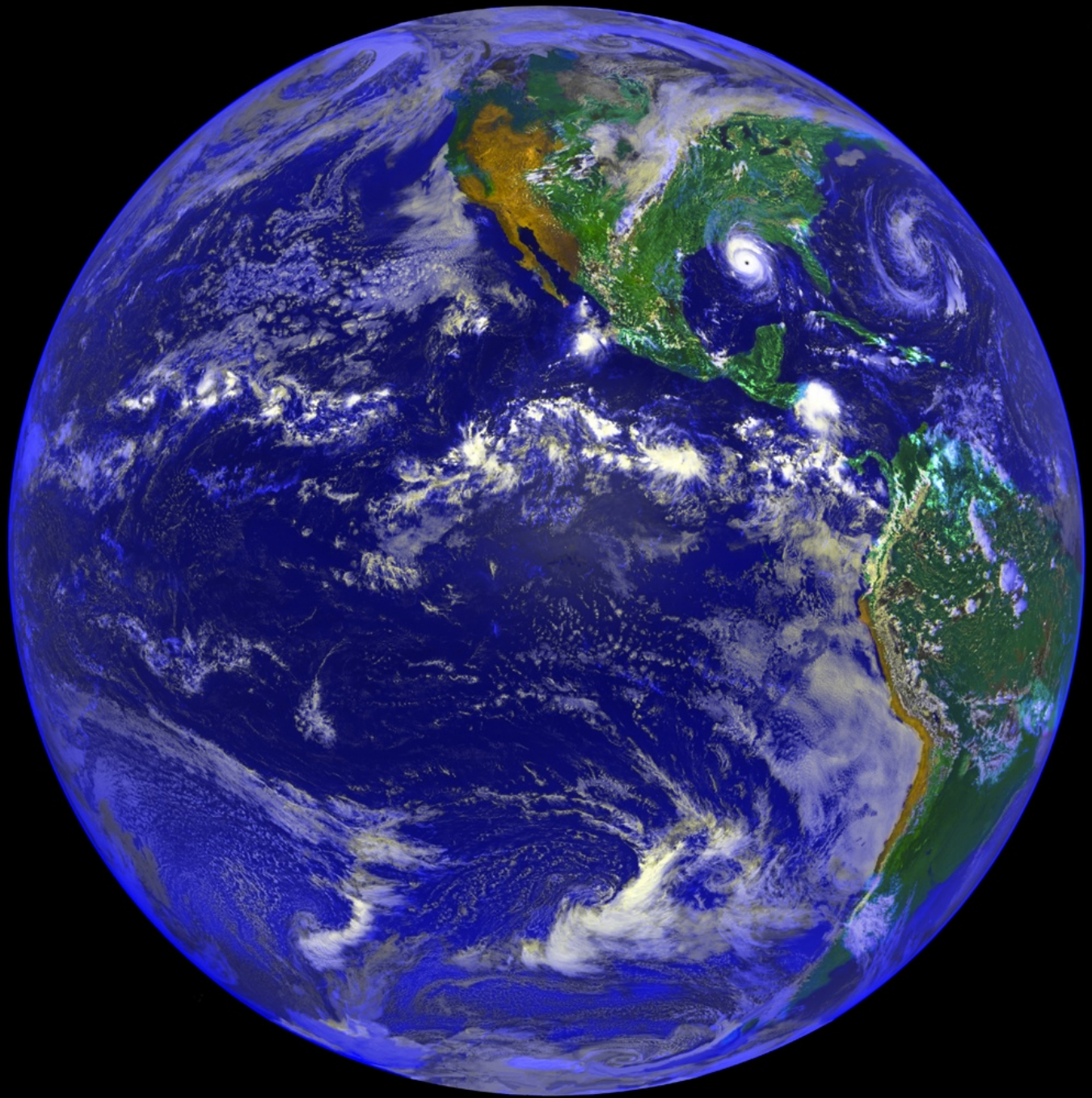
Katsushi Arisaka

University of California, Los Angeles
Department of Physics and Astronomy

arisaka@physics.ucla.edu

Talk Outline

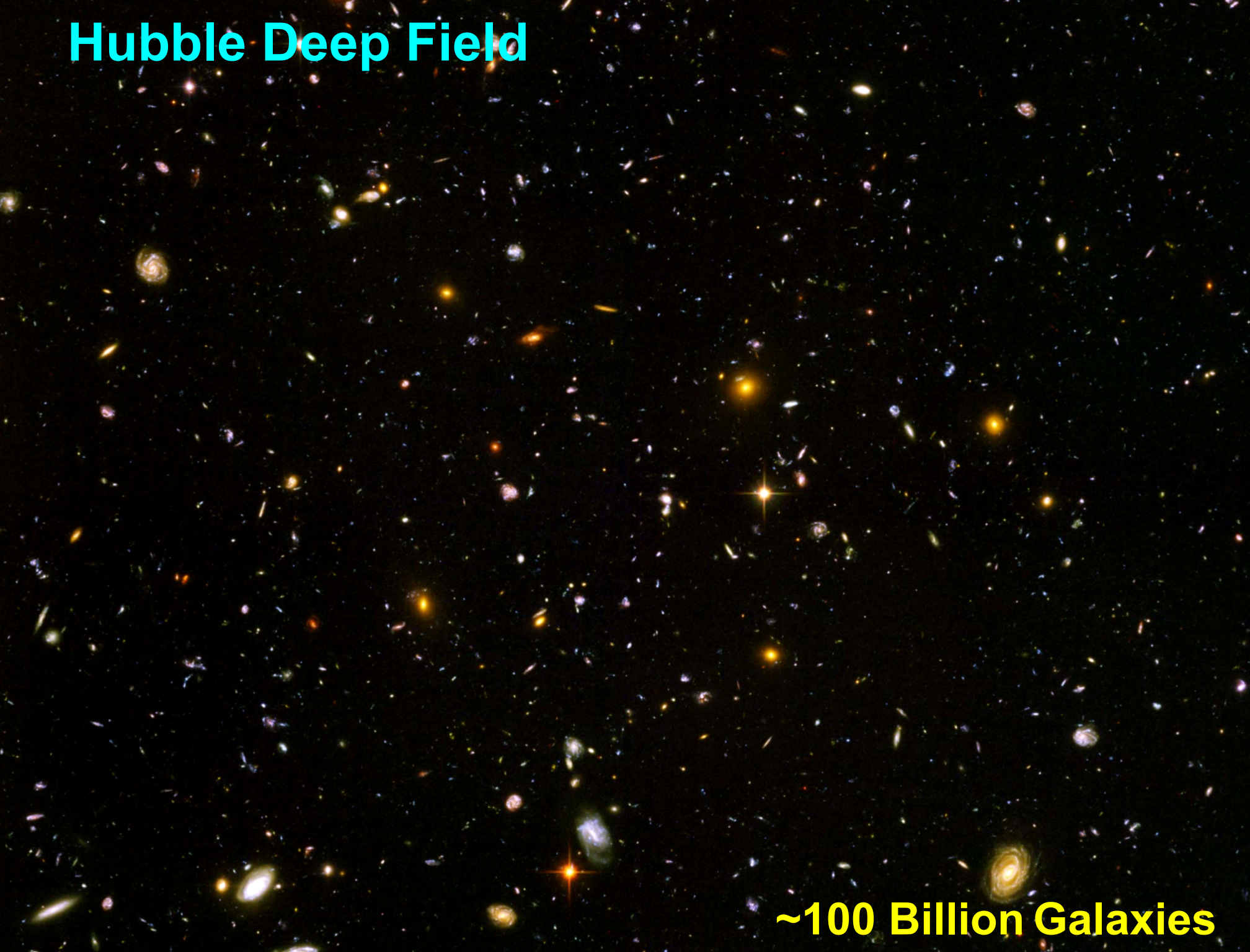
- **Part I : Particle Physics & Cosmology** ~50 min.
  - Introduction to Cosmology: Origin of Universe
  - CMS at CERN: Origin of Particles
  - Detection of Dark Matter: Origin of Structure in Universe
- Lab Tour ~15 min.
- **Part II : Bio-imaging and Neuro-physics** ~50 min.
  - Introduction to High-speed Bio-imaging
  - Single Molecule: Origin of Life
  - Neurophysics: Origin of Consciousness

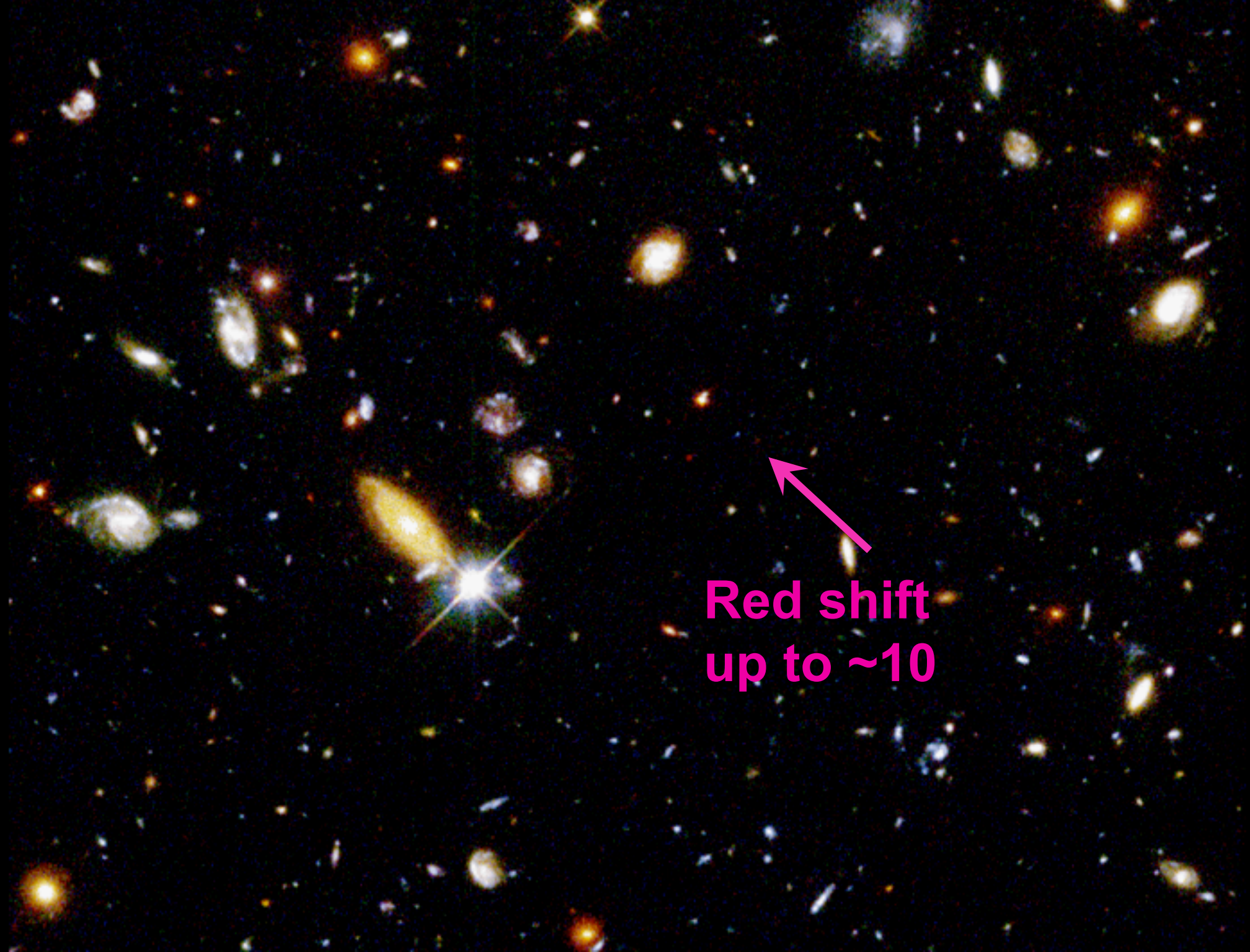


Why are we here?

Introduction to Cosmology


Andromeda
~100 Billions Stars in a Galaxy


Hubble Deep Field
~100 Billion Galaxies


Red shift
up to ~10

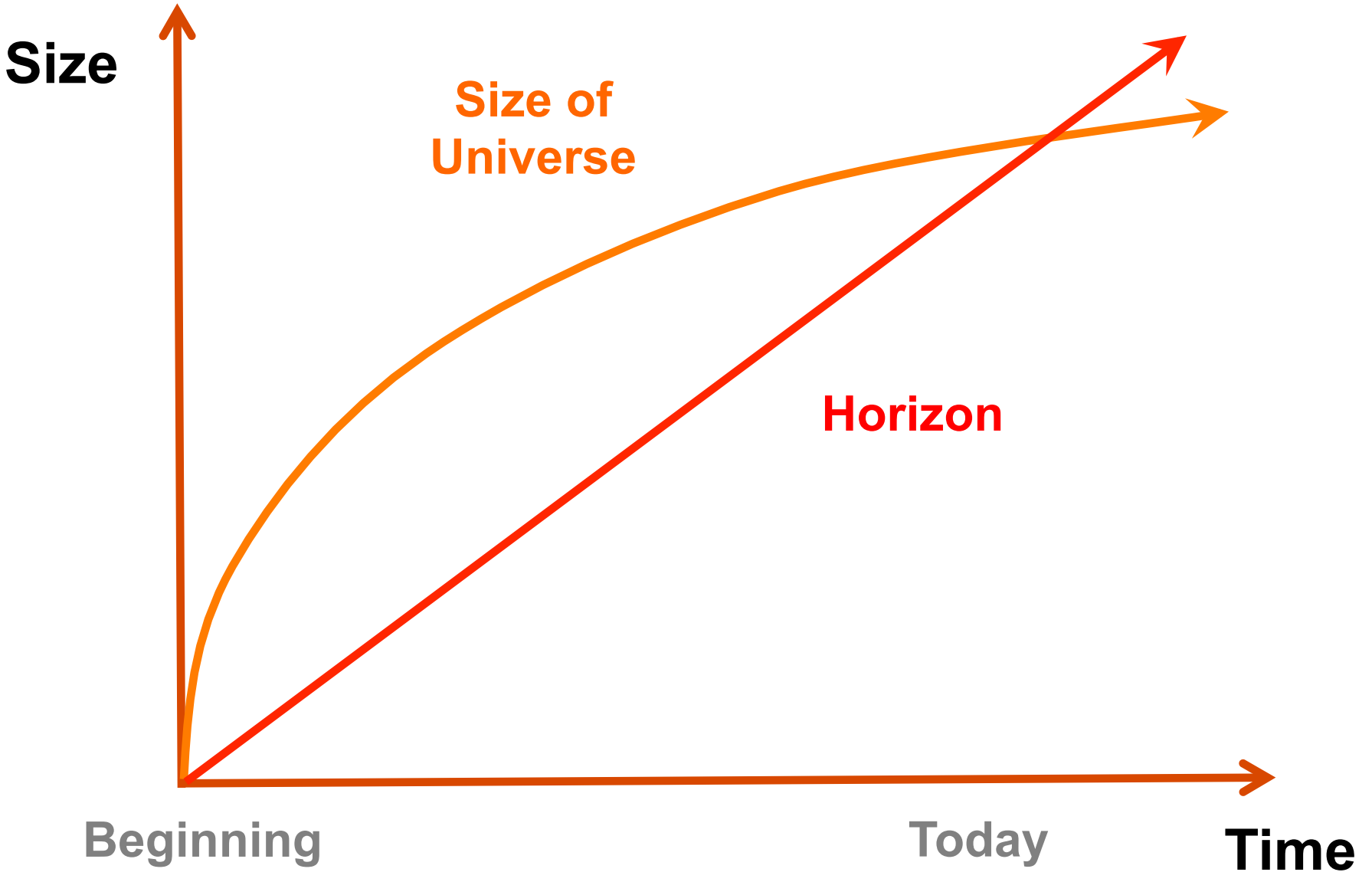
Hubble's Law: Expansion of the Universe

Horizon of Universe

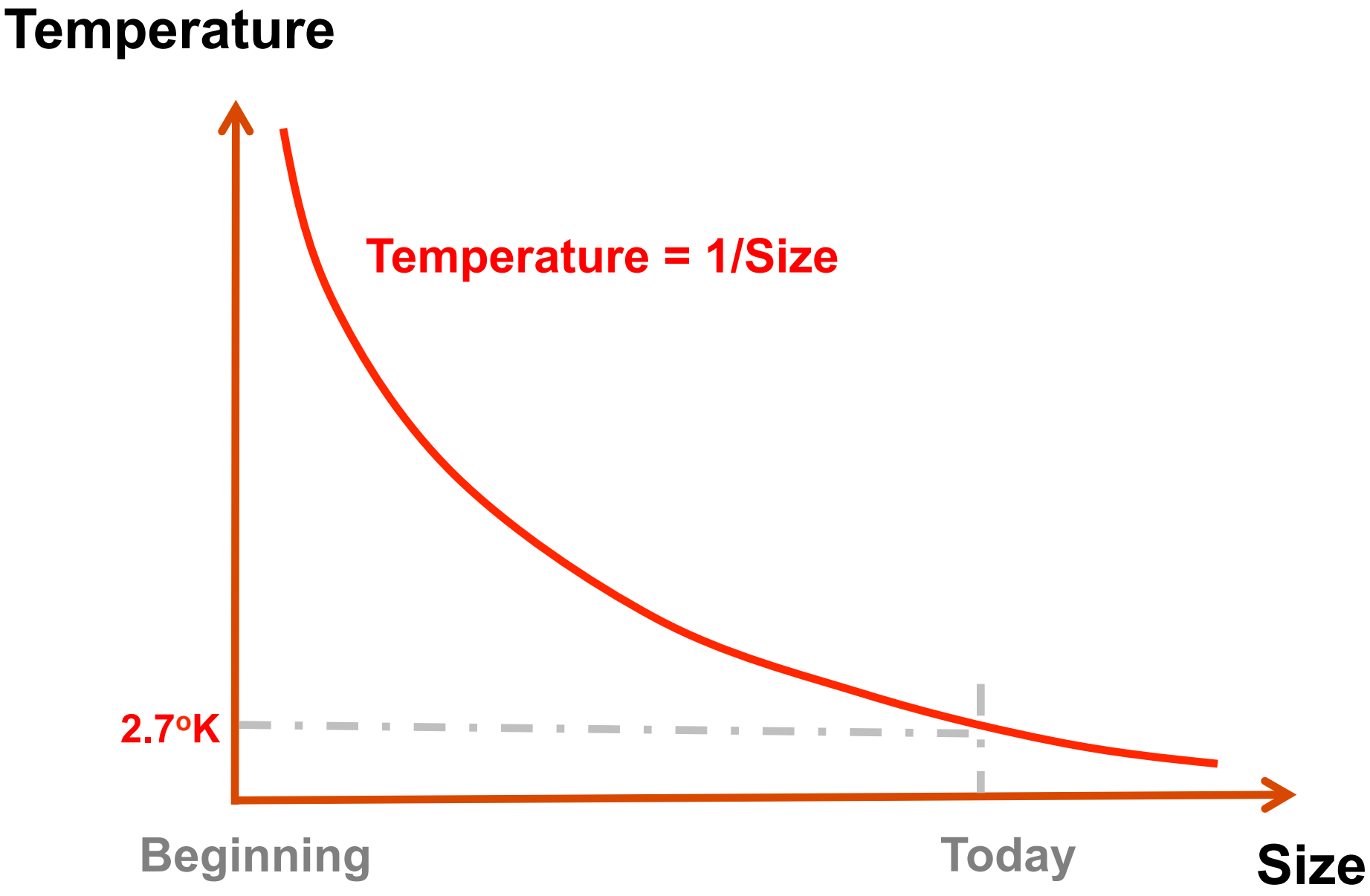
14 Billon Light Years

Moving Away at Speed of Light

Expansion of Universe

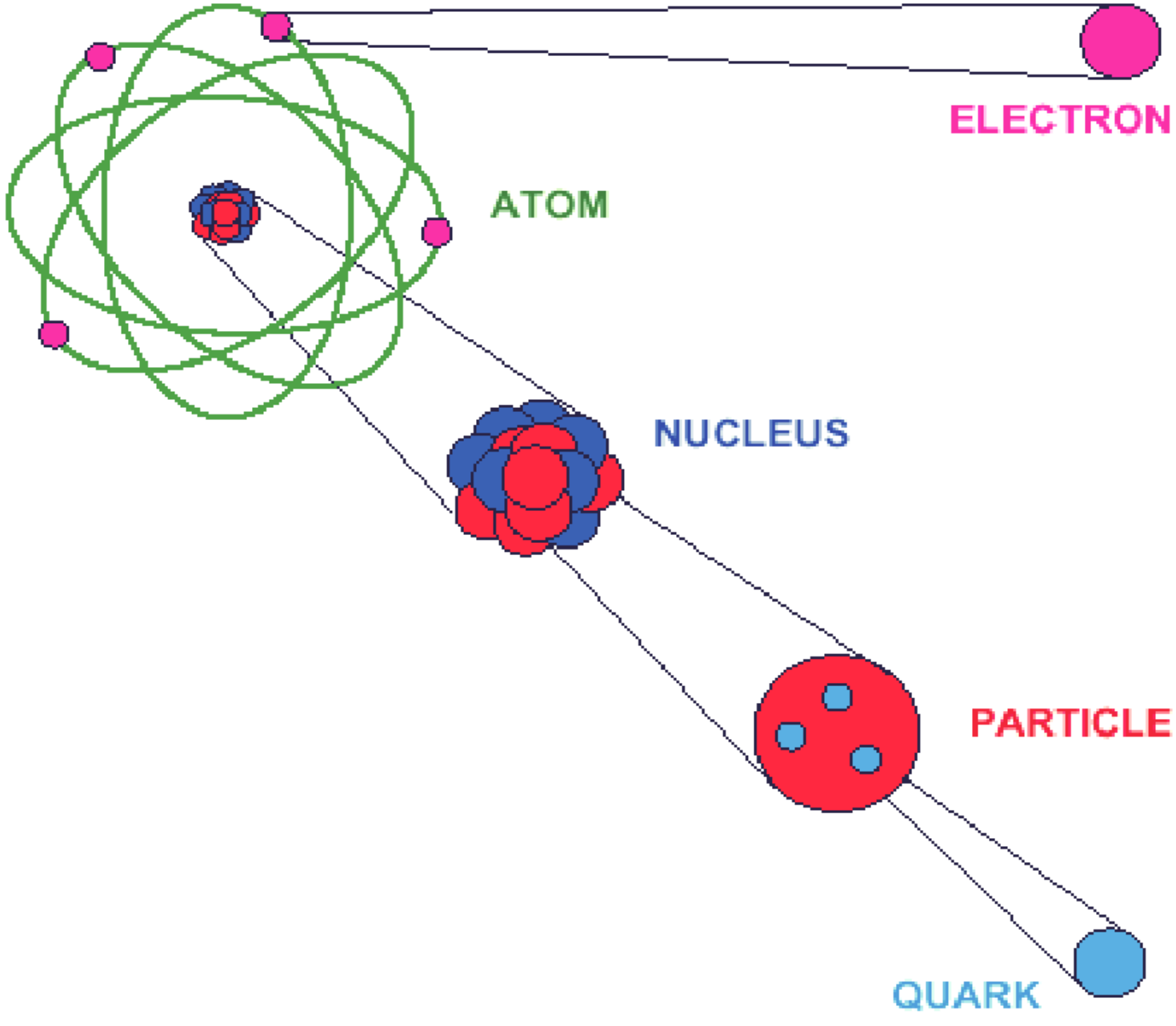


Temperature of Universe

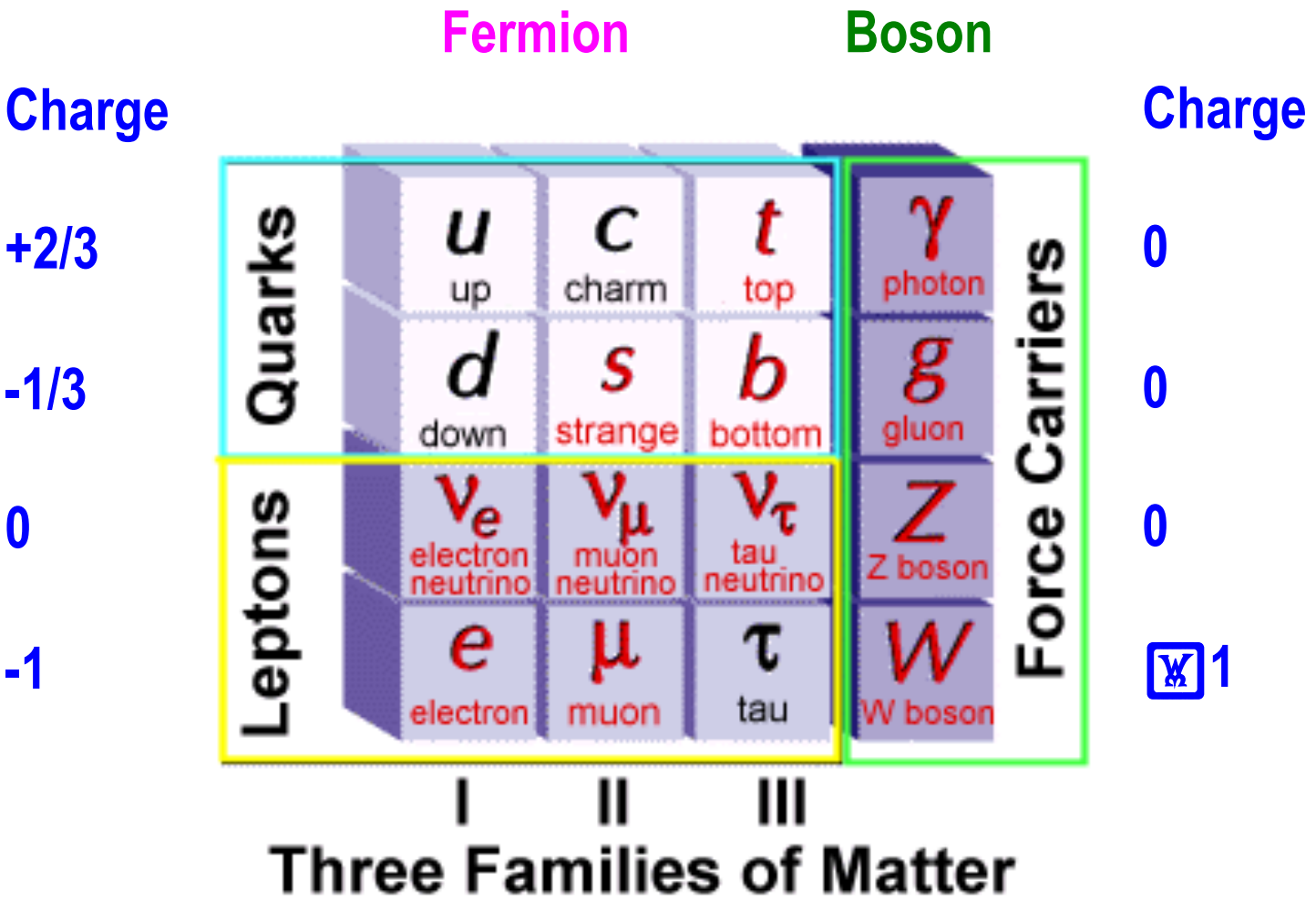


Fermi Lab near Chicago

Elementary Particles (~1970)



Elementary Particles

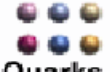


+ Anti-particles

Elementary Particles and Forces

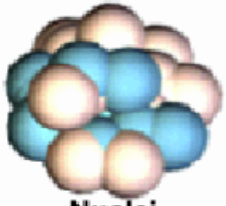
Strong

Gluons (8)



Quarks

Mesons
Baryons

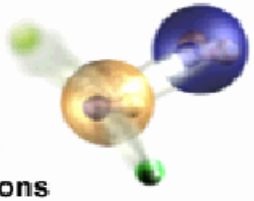


Nuclei

1

Weak

Bosons (W,Z)



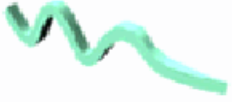
Neutron decay
Beta radioactivity
Neutrino interactions
Burning of the sun

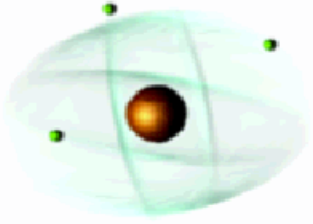
10^{-13}

10^{-2}

Electromagnetic

Photon



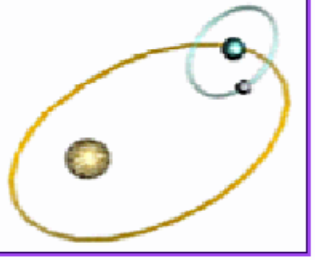


Atoms
Light
Chemistry
Electronics

10^{-38}

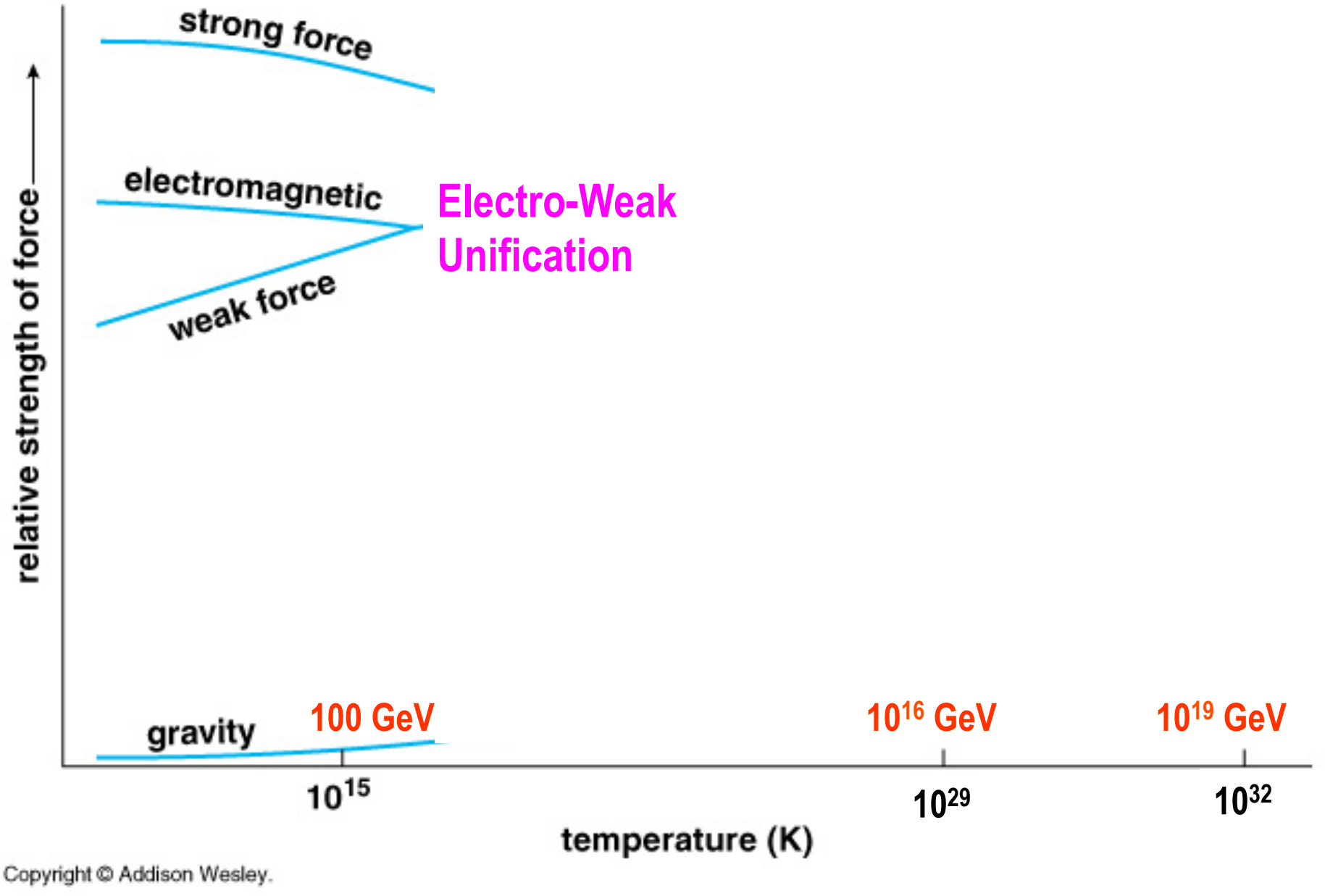
Gravitational

Graviton ?

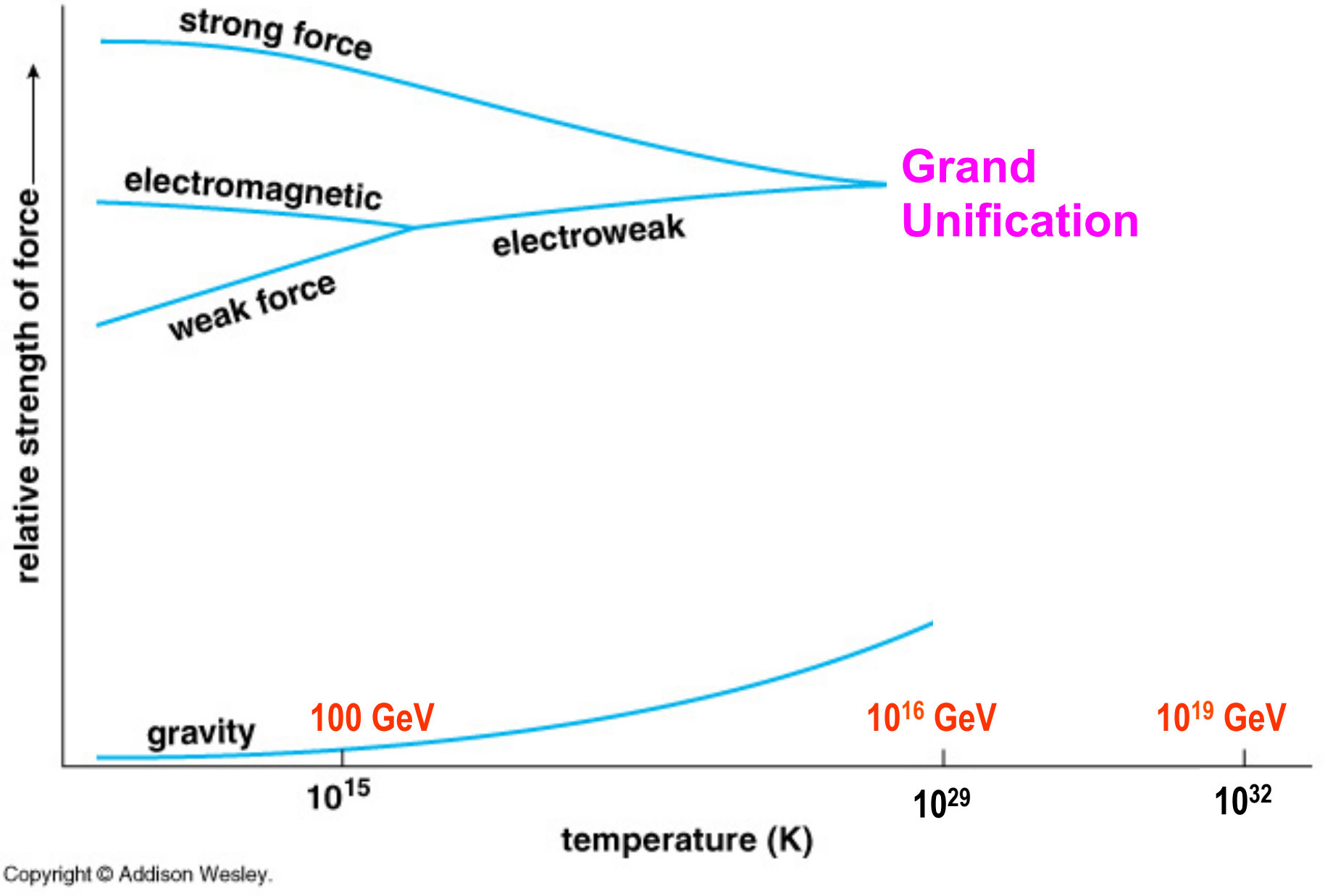


Solar system
Galaxies
Black holes

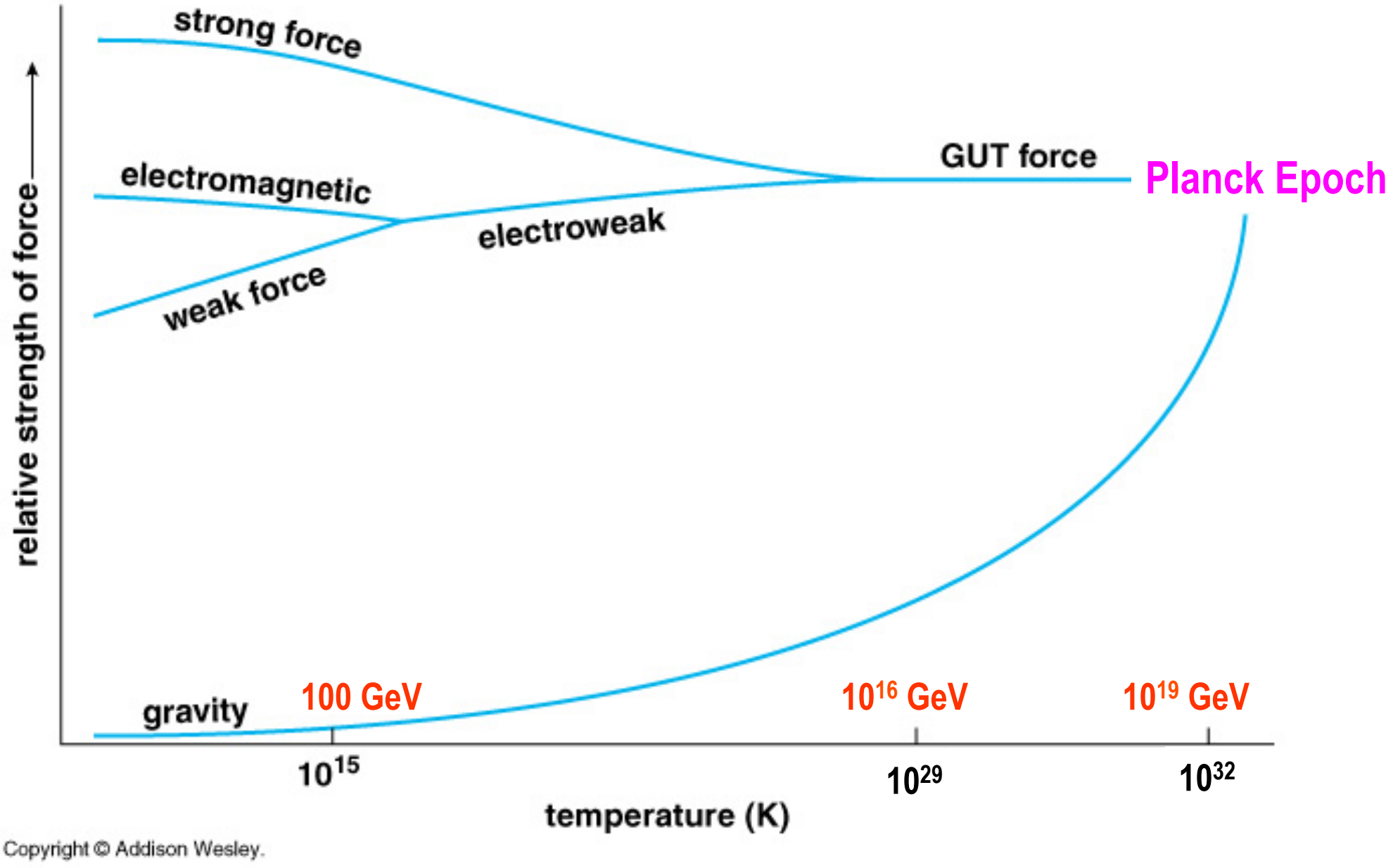
Unification of Forces



Unification of Forces



Unification of Forces



Physicists' View of Early Universe

Fiat lux

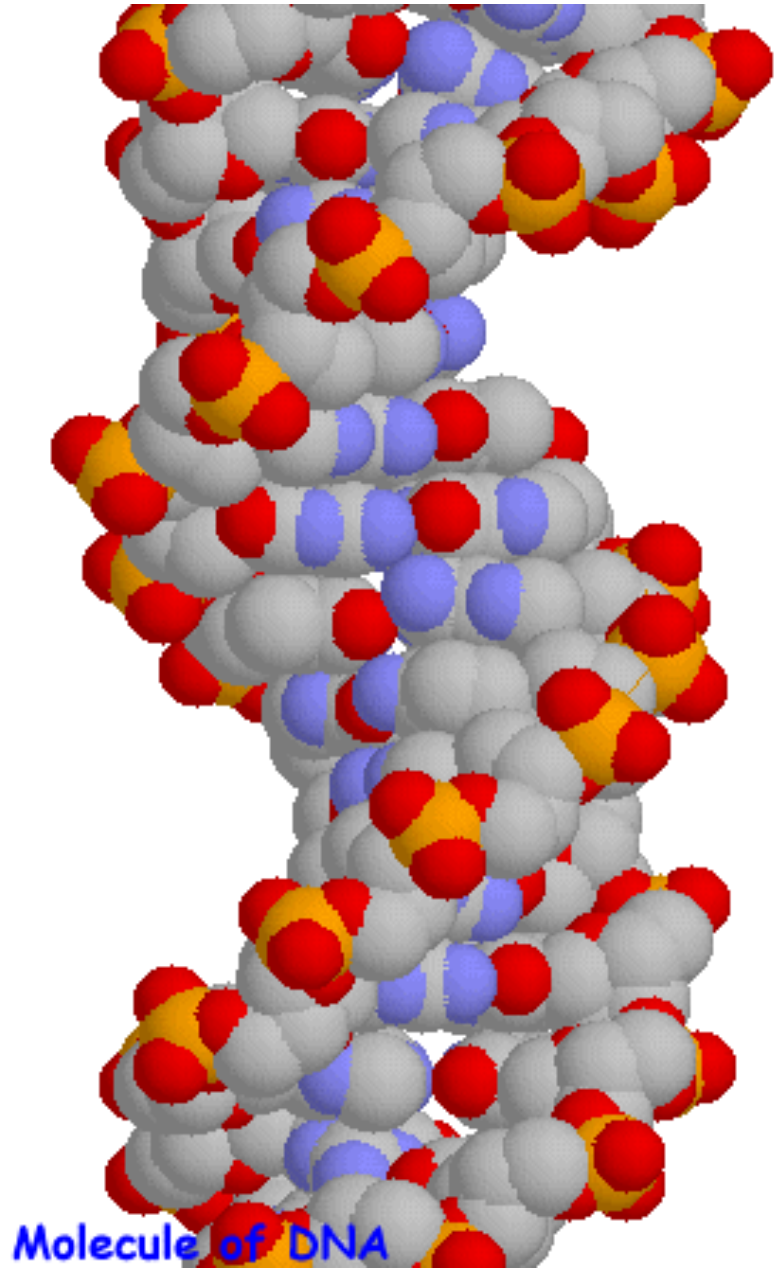
Let there be light

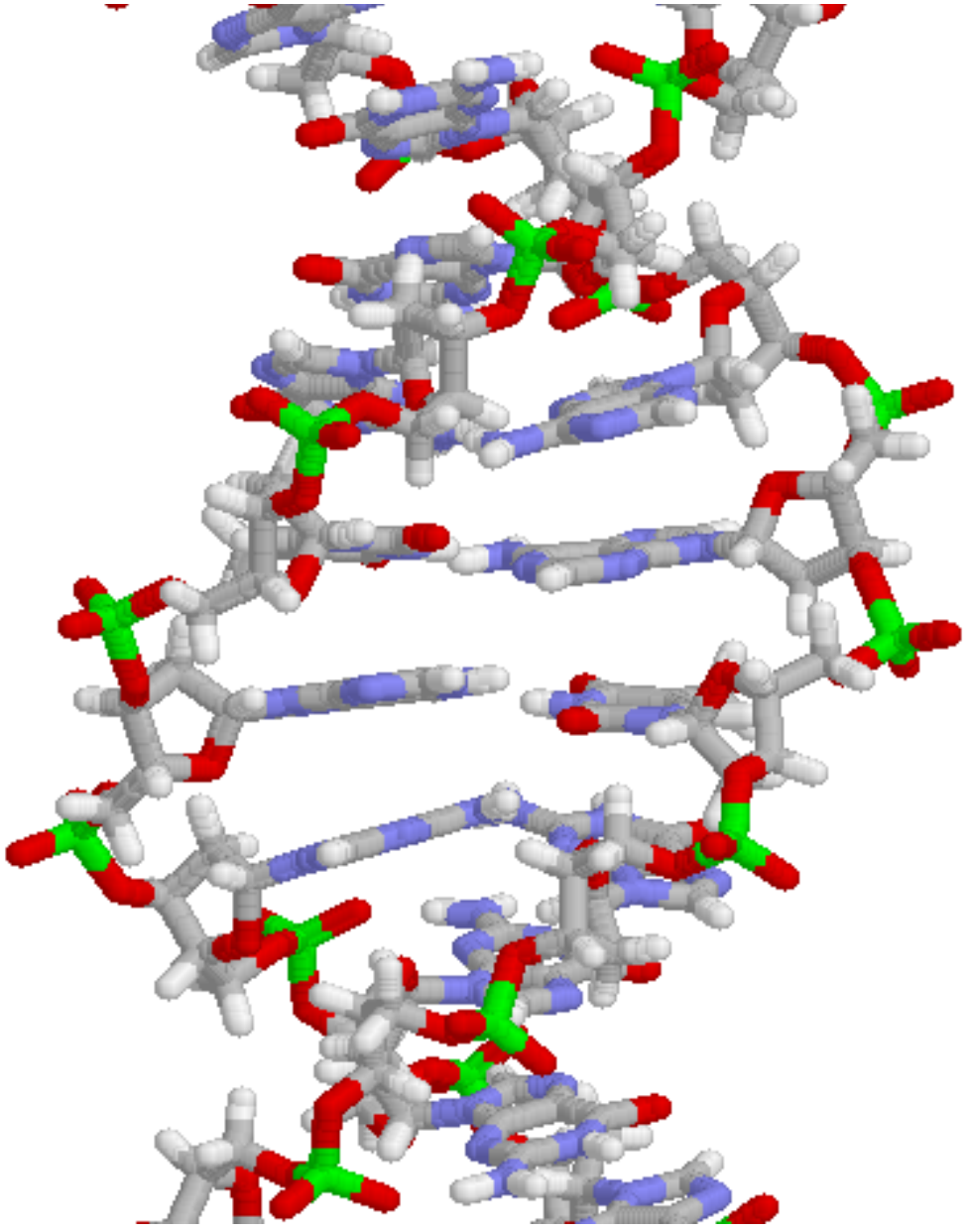
Physicists' View of Early Universe

Lorentz Invariance

Local Gauge Invariance

Structure of DNA





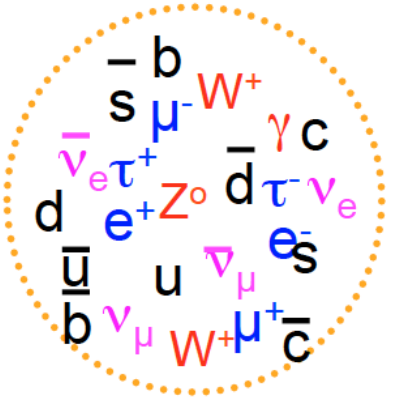
Symmetry Breaking

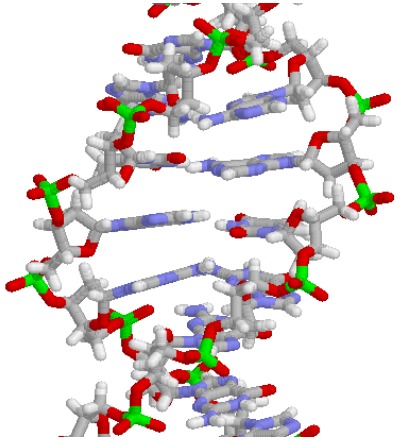
Time
0
1B years
2
3
4
5
6
7
8
9
10
11
12
13
14

Simple

Symmetry Break Down

Complex





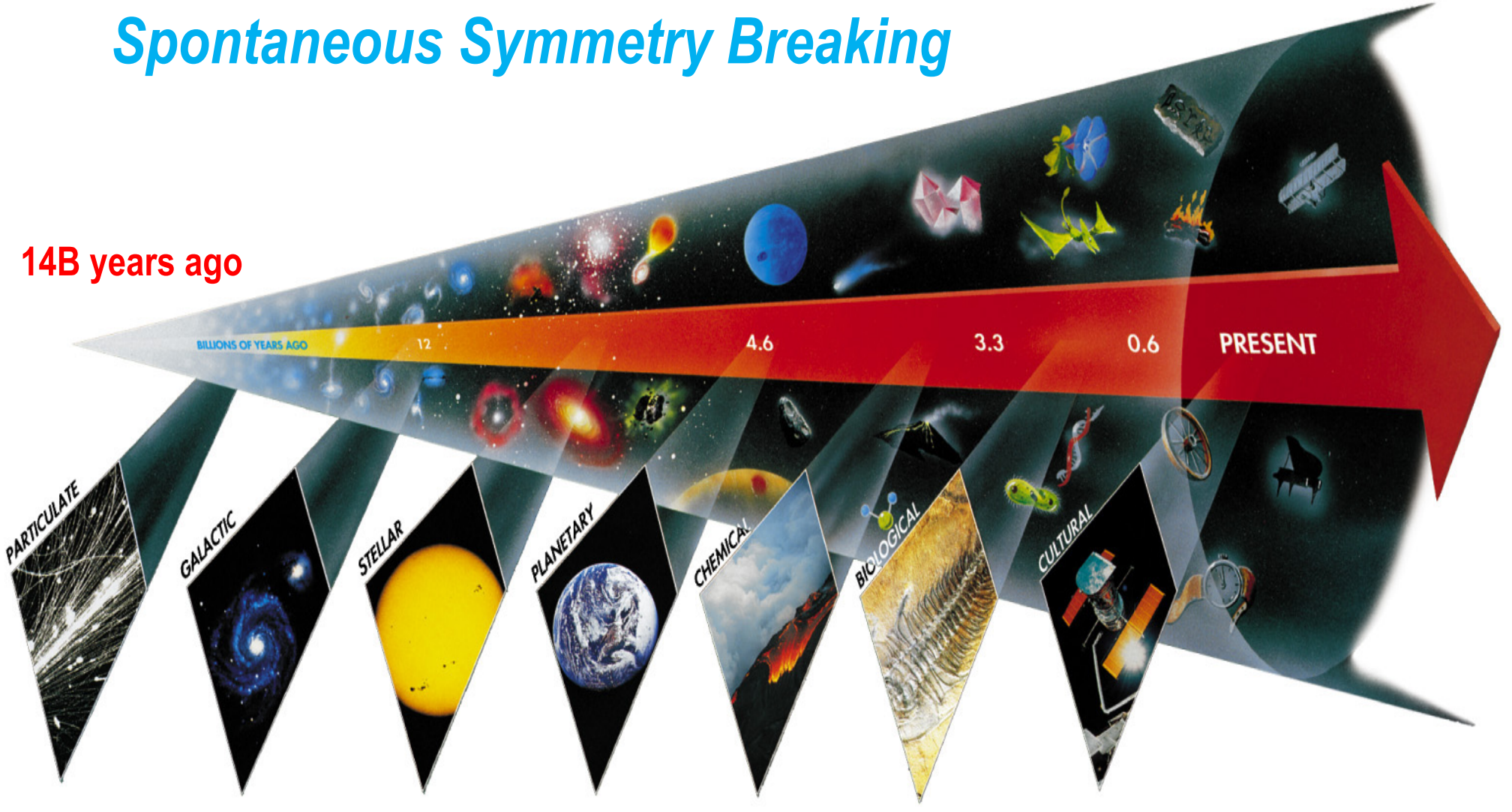
The Beginning (at t = 0)

- Everything was the same → Perfect symmetry.
  - All the particles are the same as photons.
  - All four forces are the same.

- The Universe was 10 dimension.

Seven Phases of Cosmic Evolution

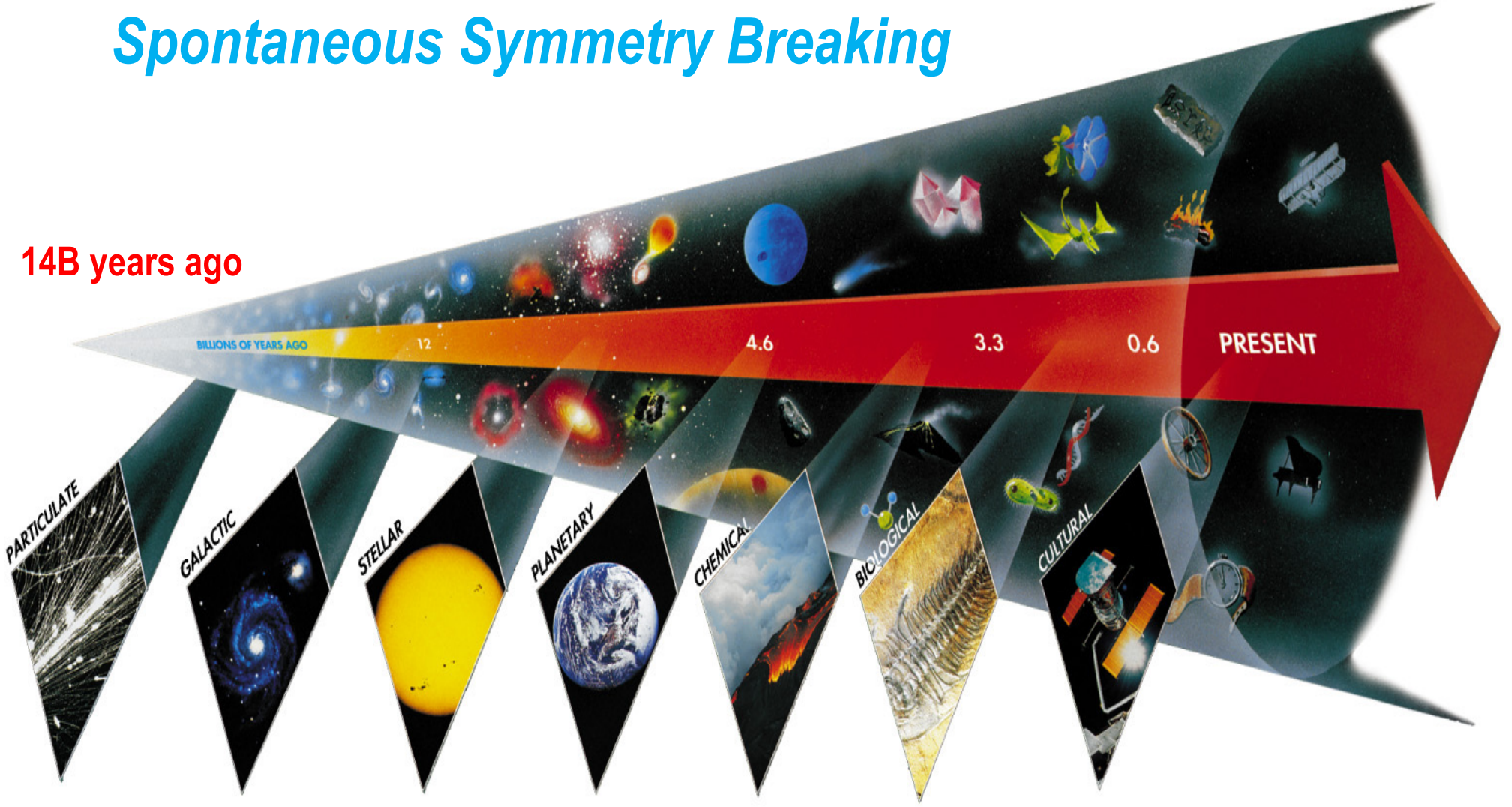
Spontaneous Symmetry Breaking



Simple ⟹ **Coherent Complex System**

Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking



Origin of Particles

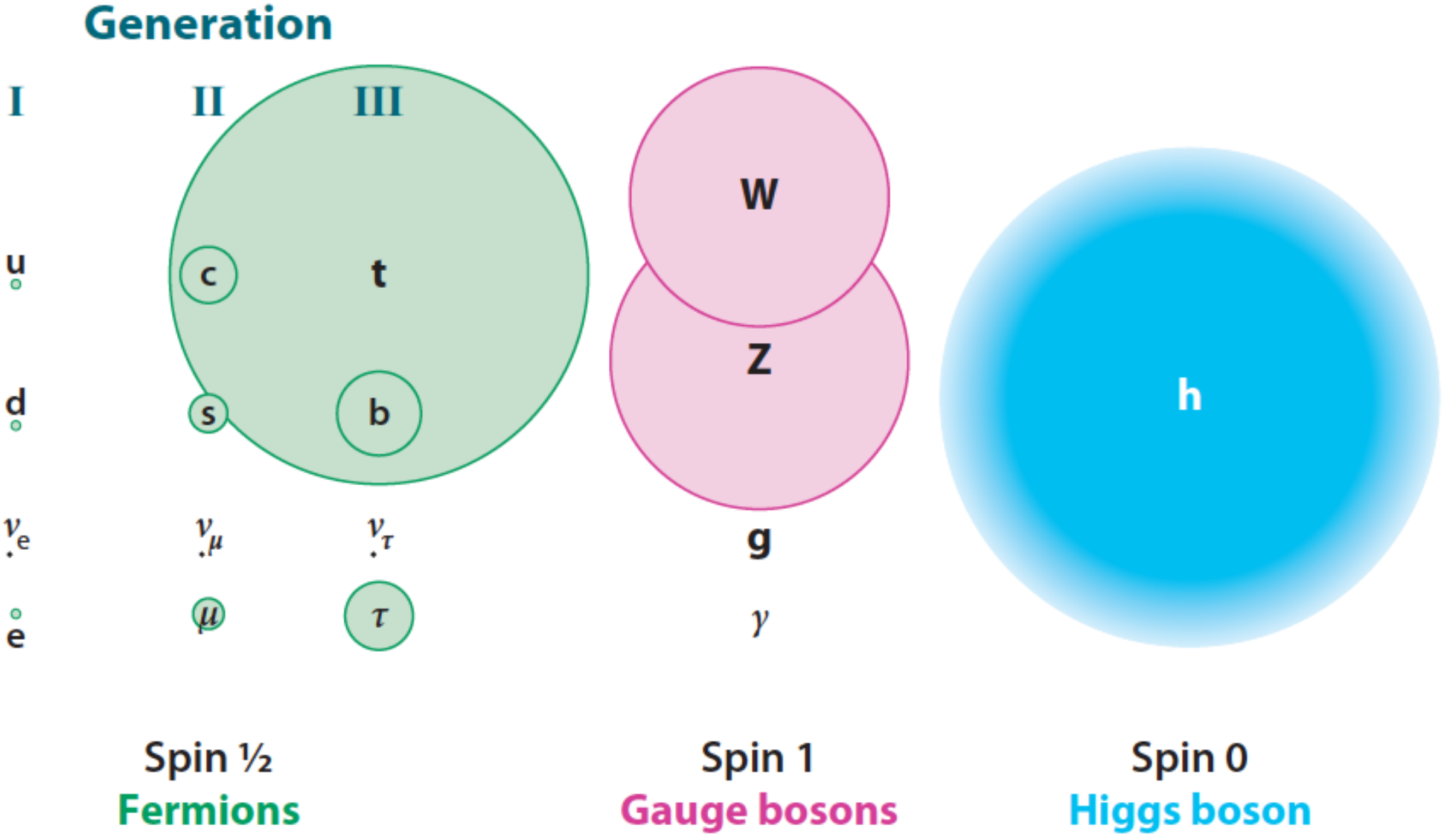
Origin of Structure

Origin of Life

Origin of Consciousness

CMS at LHC

Mass of Particles (at t = 0.1 ns)



Mystery of the Mass (since 1970)

1) How to create mass from energy?

Energy → Mass

While maintaining the initial symmetry

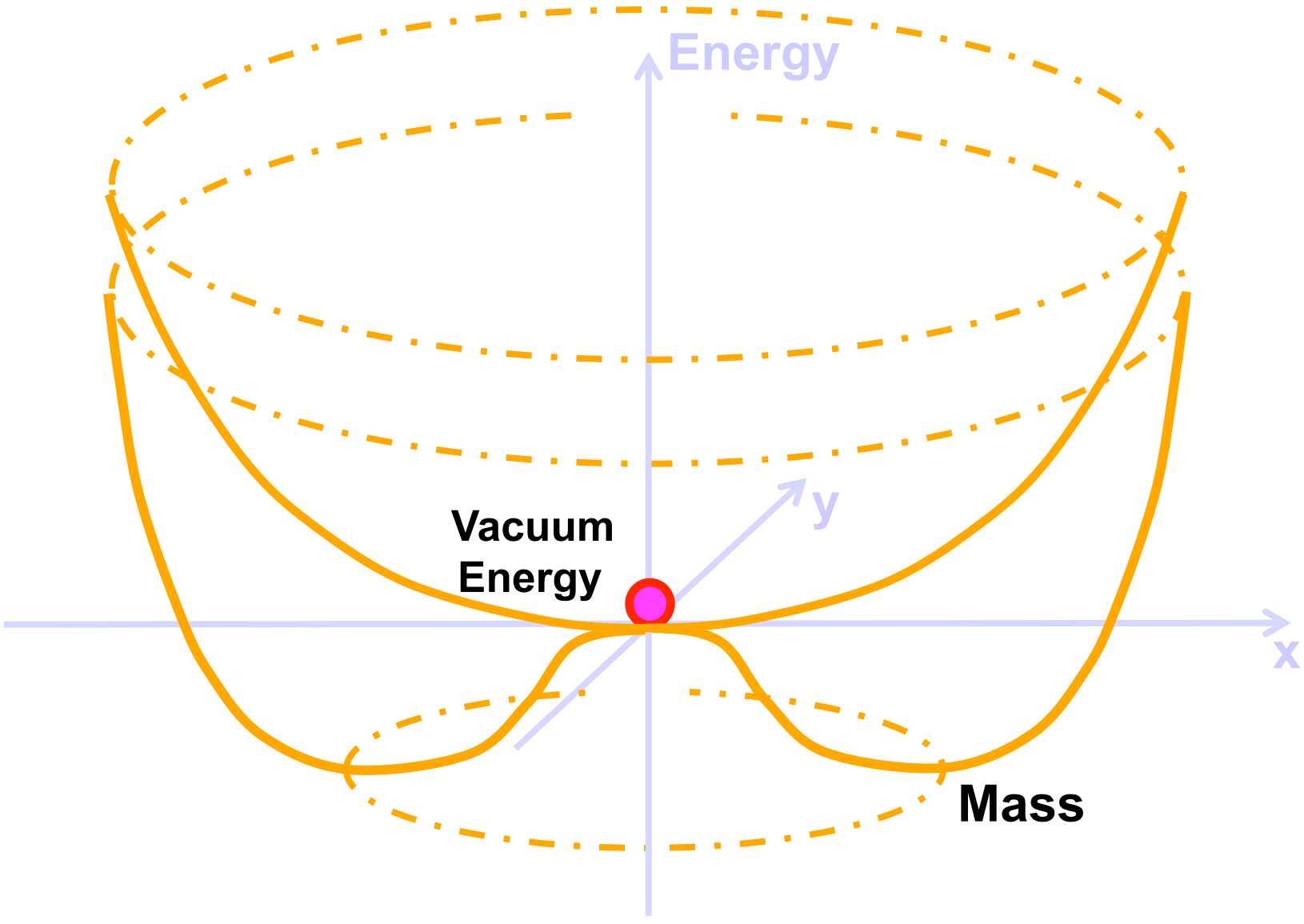
Spontaneous Symmetry Breaking

2) Particle mass << Plank Mass

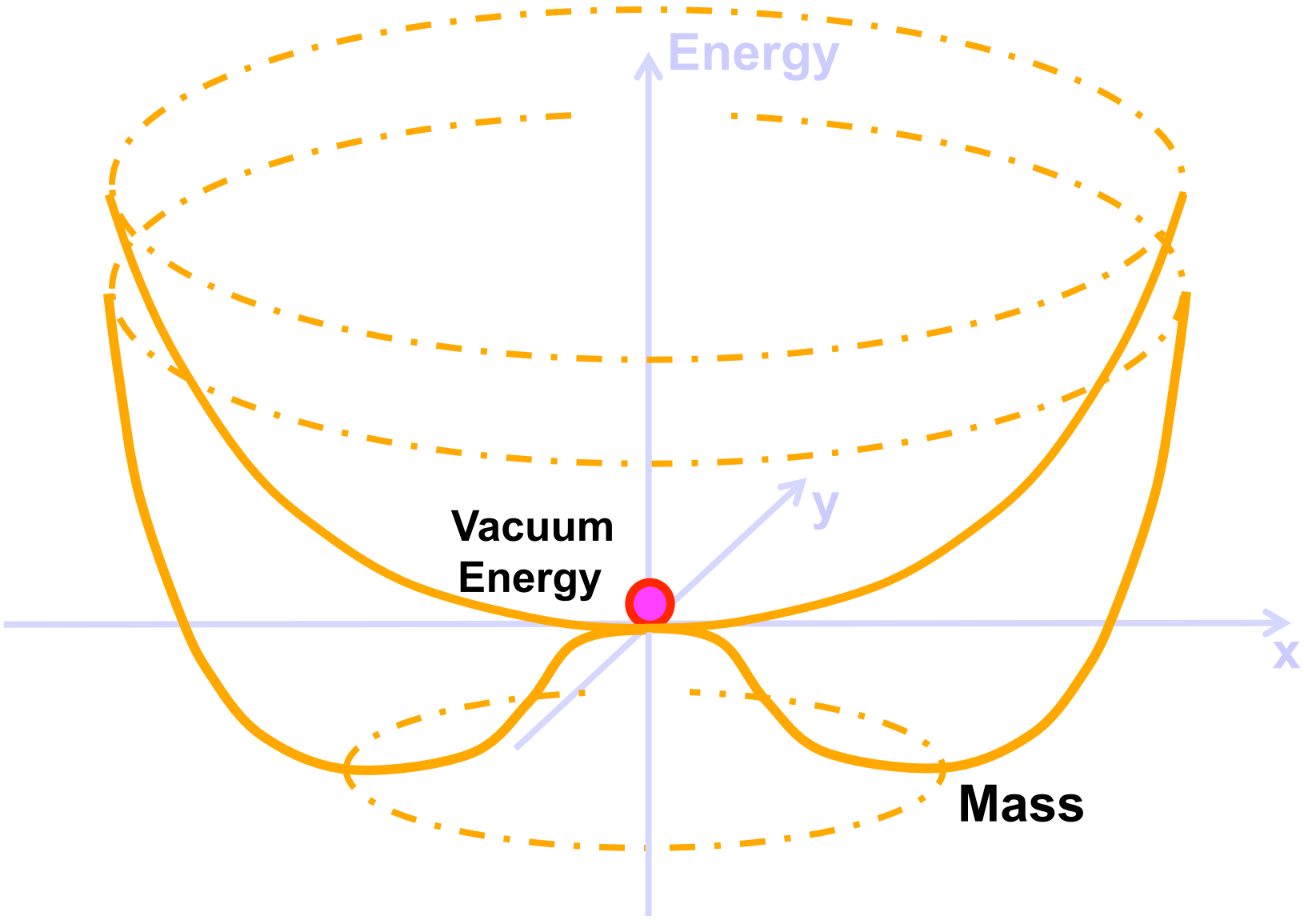
MeV – GeV 10^{19} GeV

3) Why so many particles (Generations) with different masses?

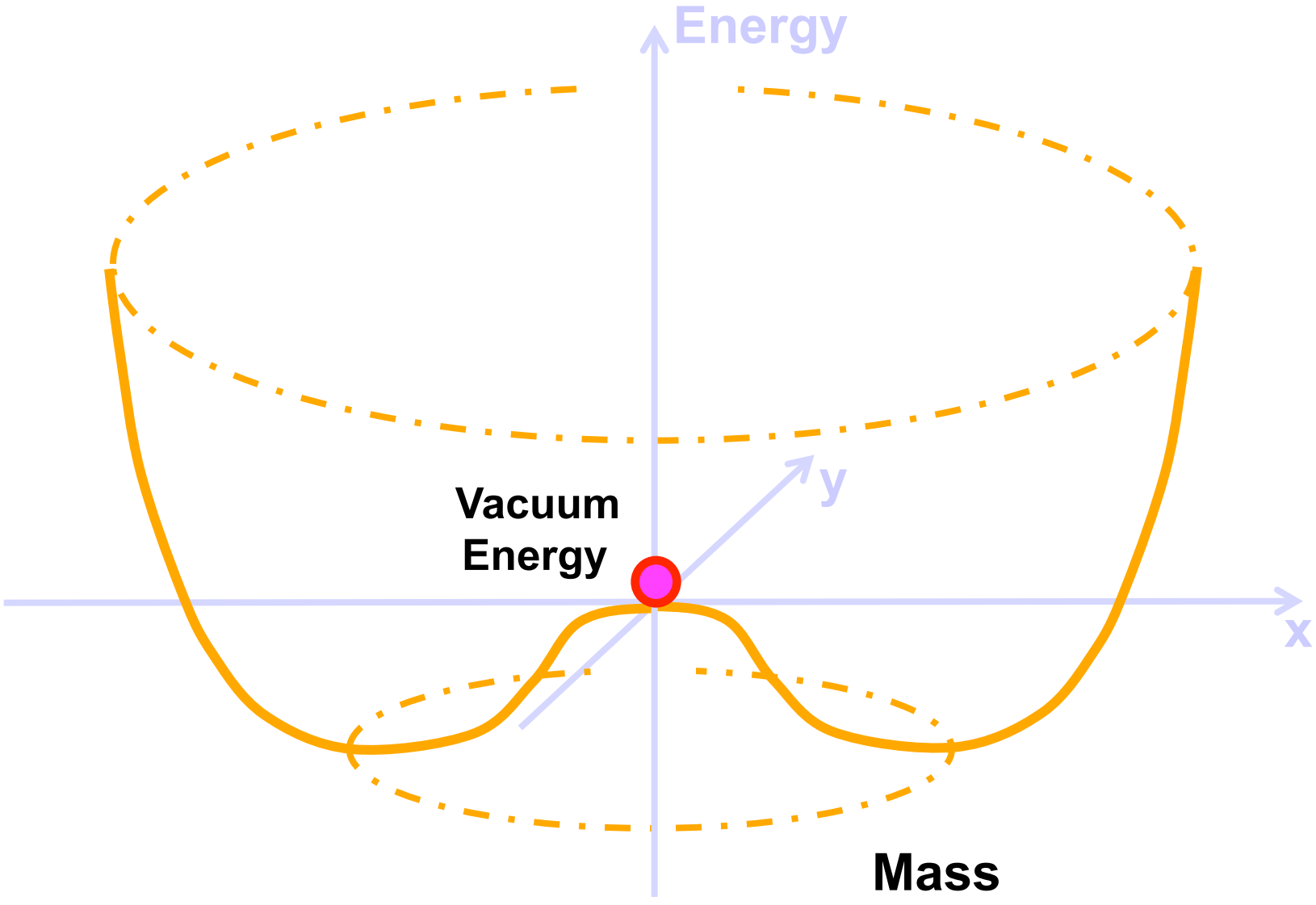
Spontaneous Symmetry Breaking
- Higgs Mechanism -



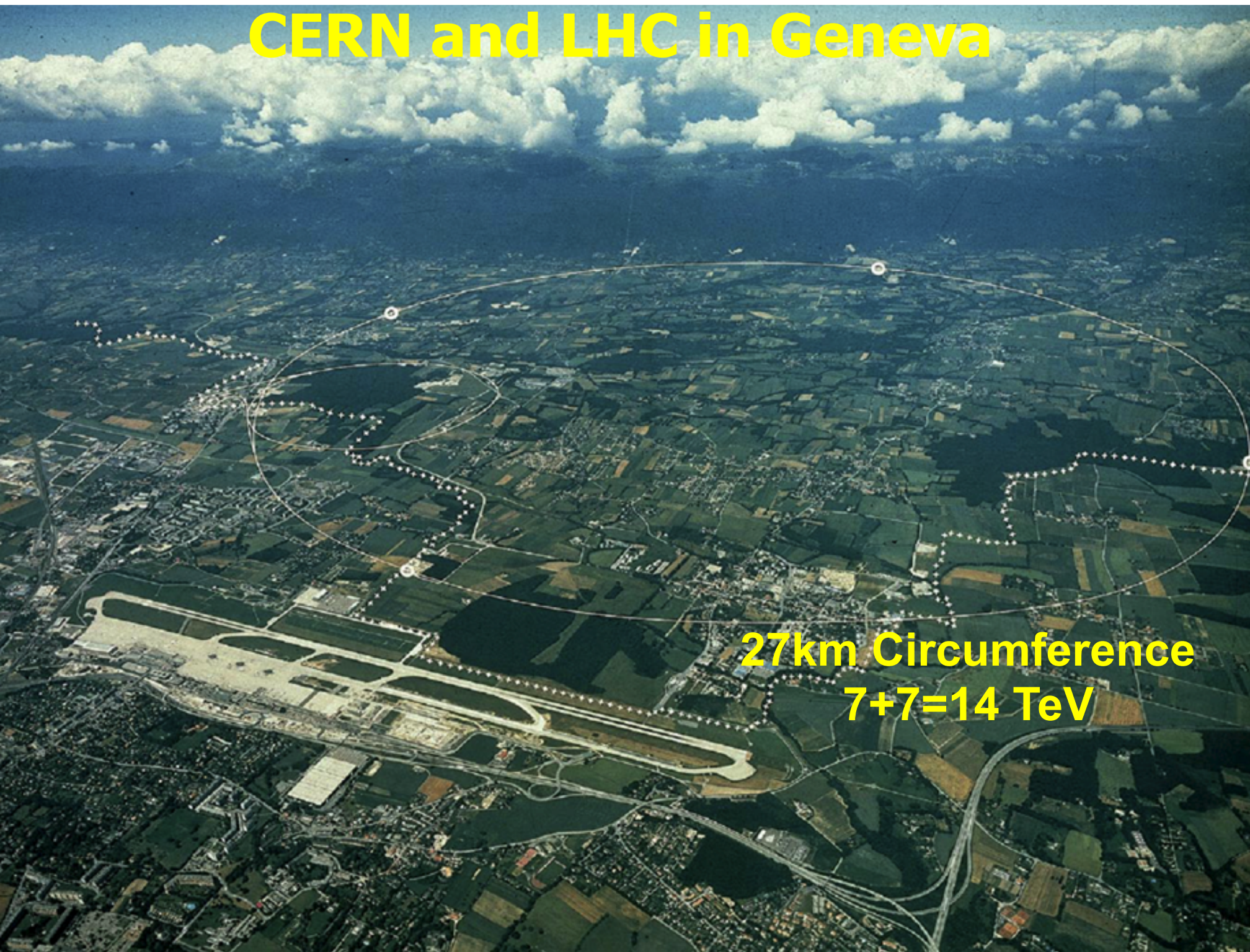
Spontaneous Symmetry Breaking - Higgs Mechanism -



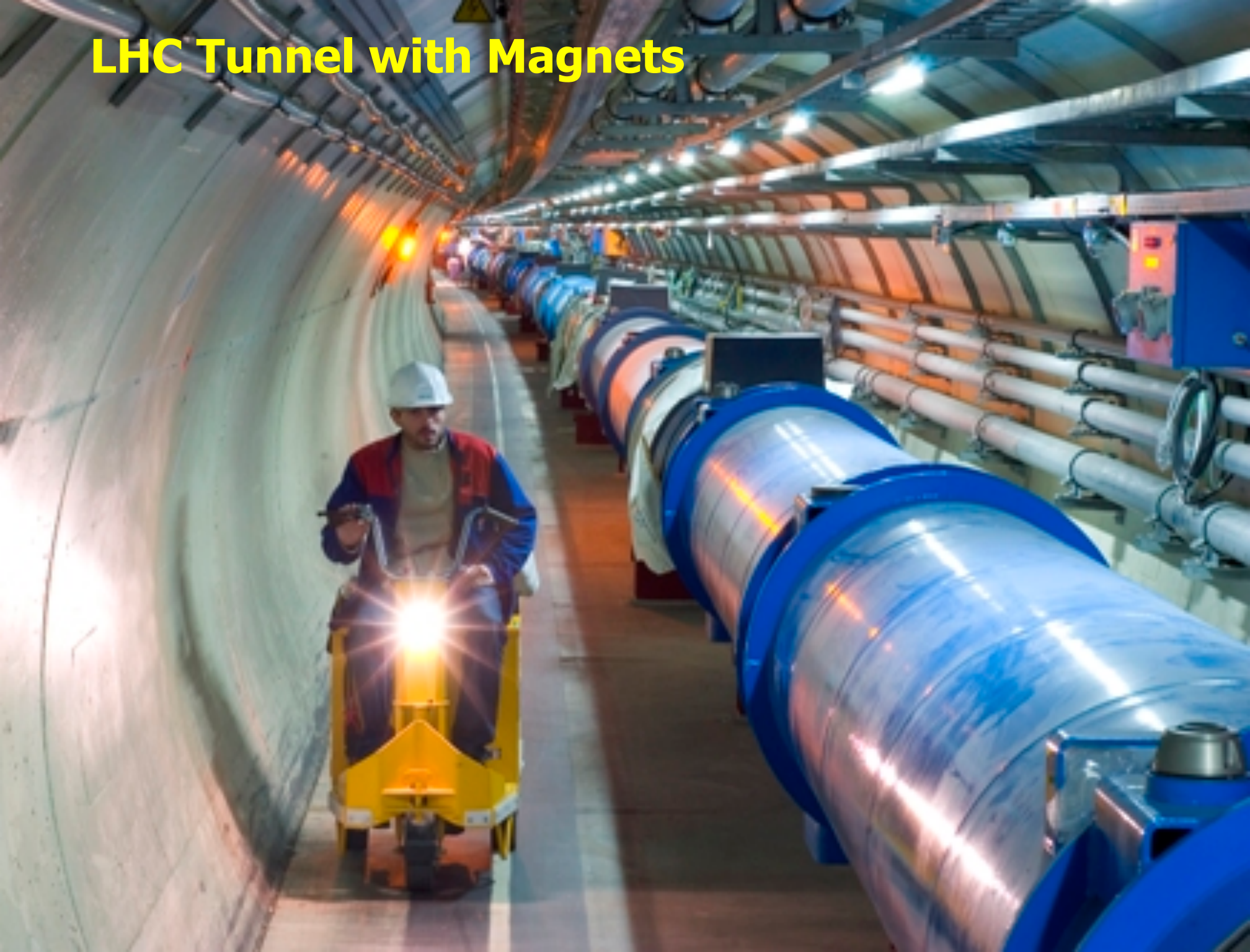
Spontaneous Symmetry Breaking - Higgs Mechanism -

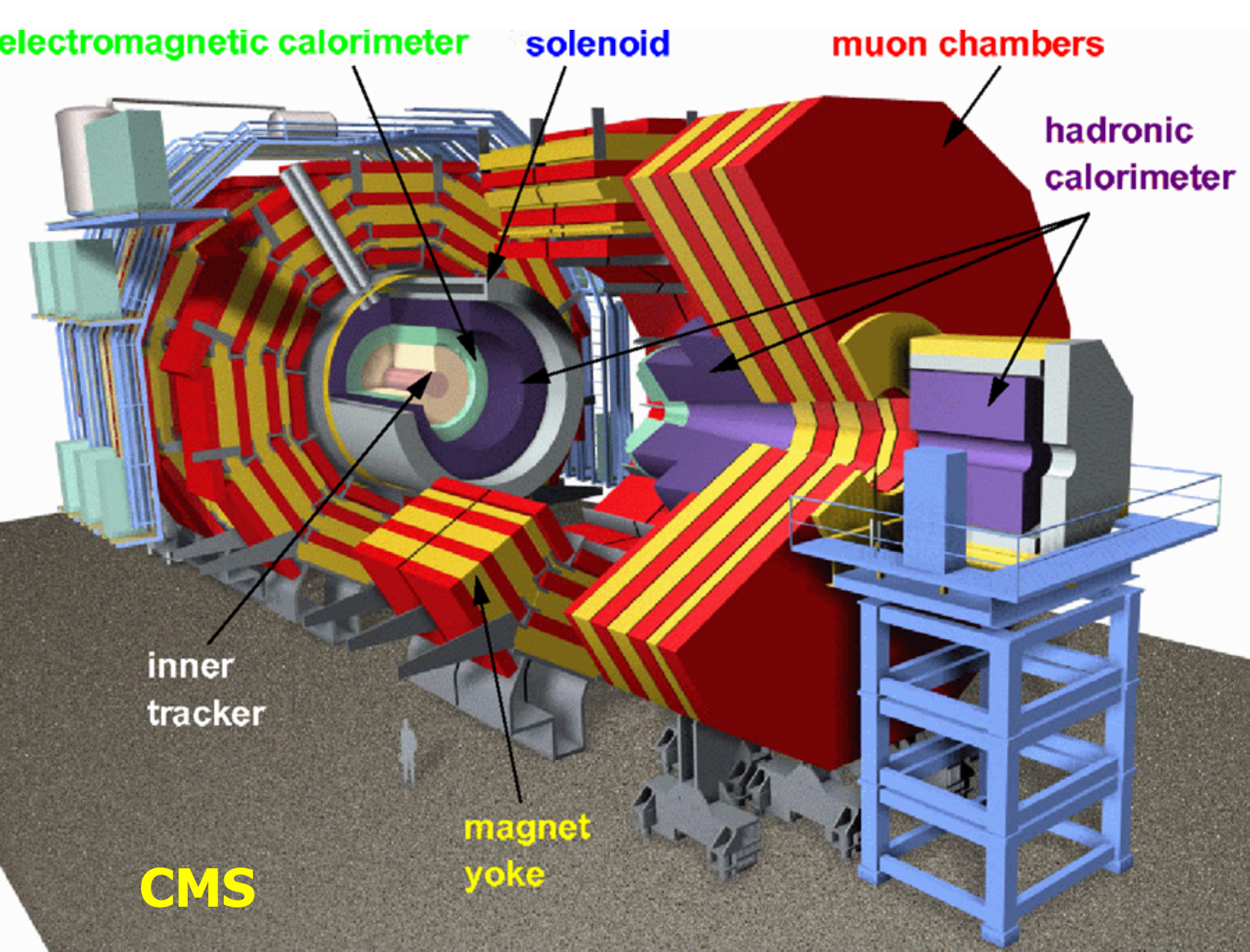


CERN and LHC in Geneva

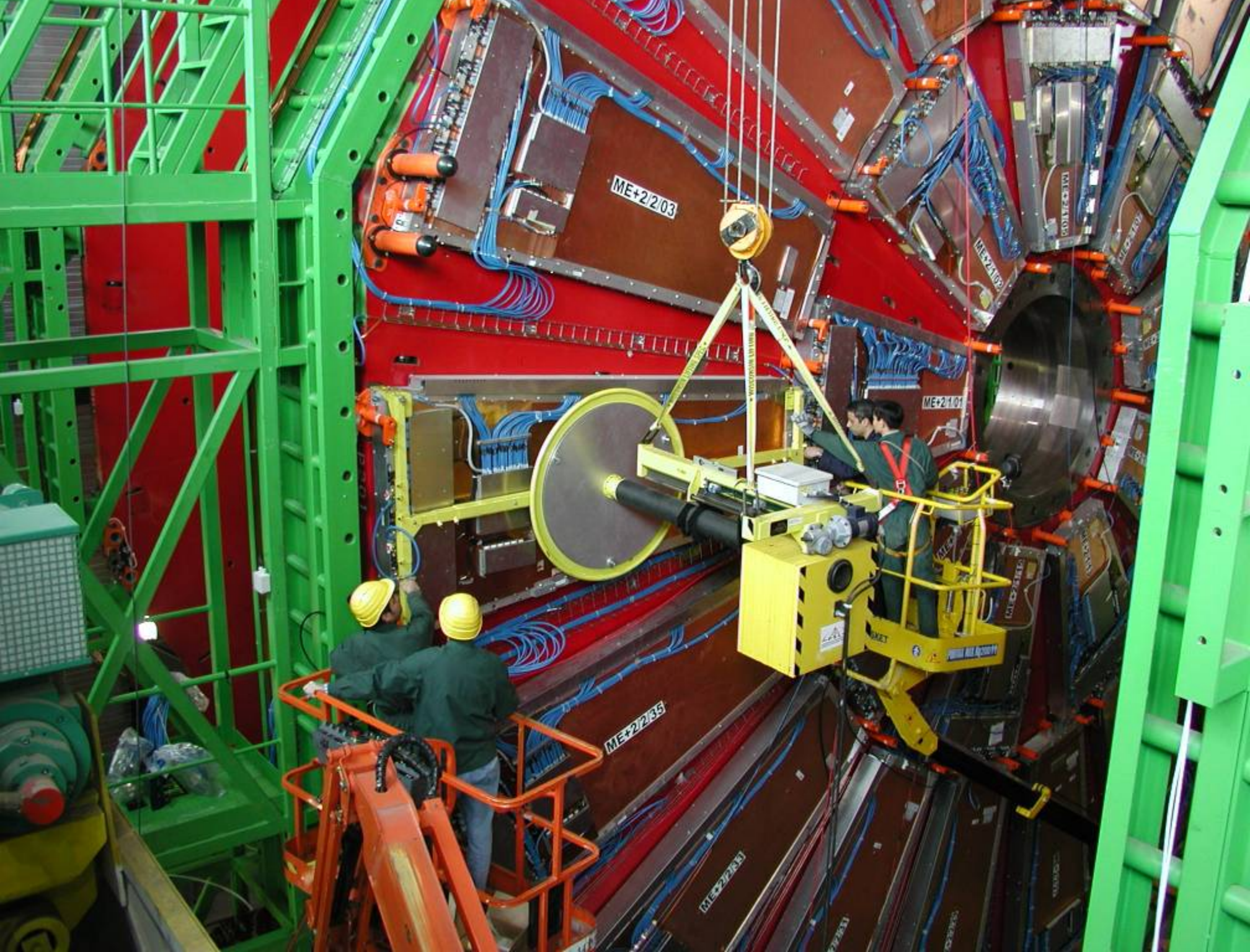


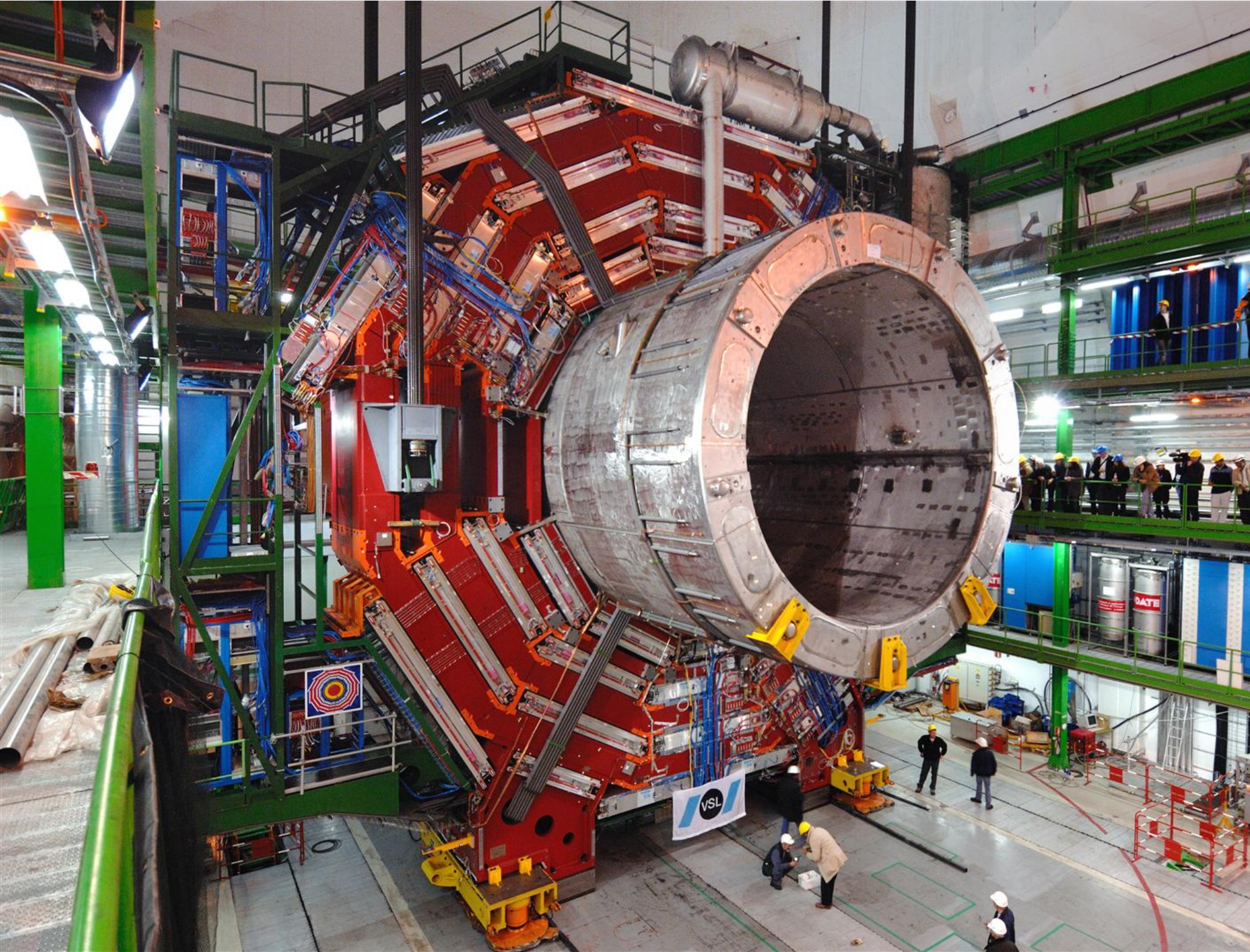
LHC Tunnel with Magnets

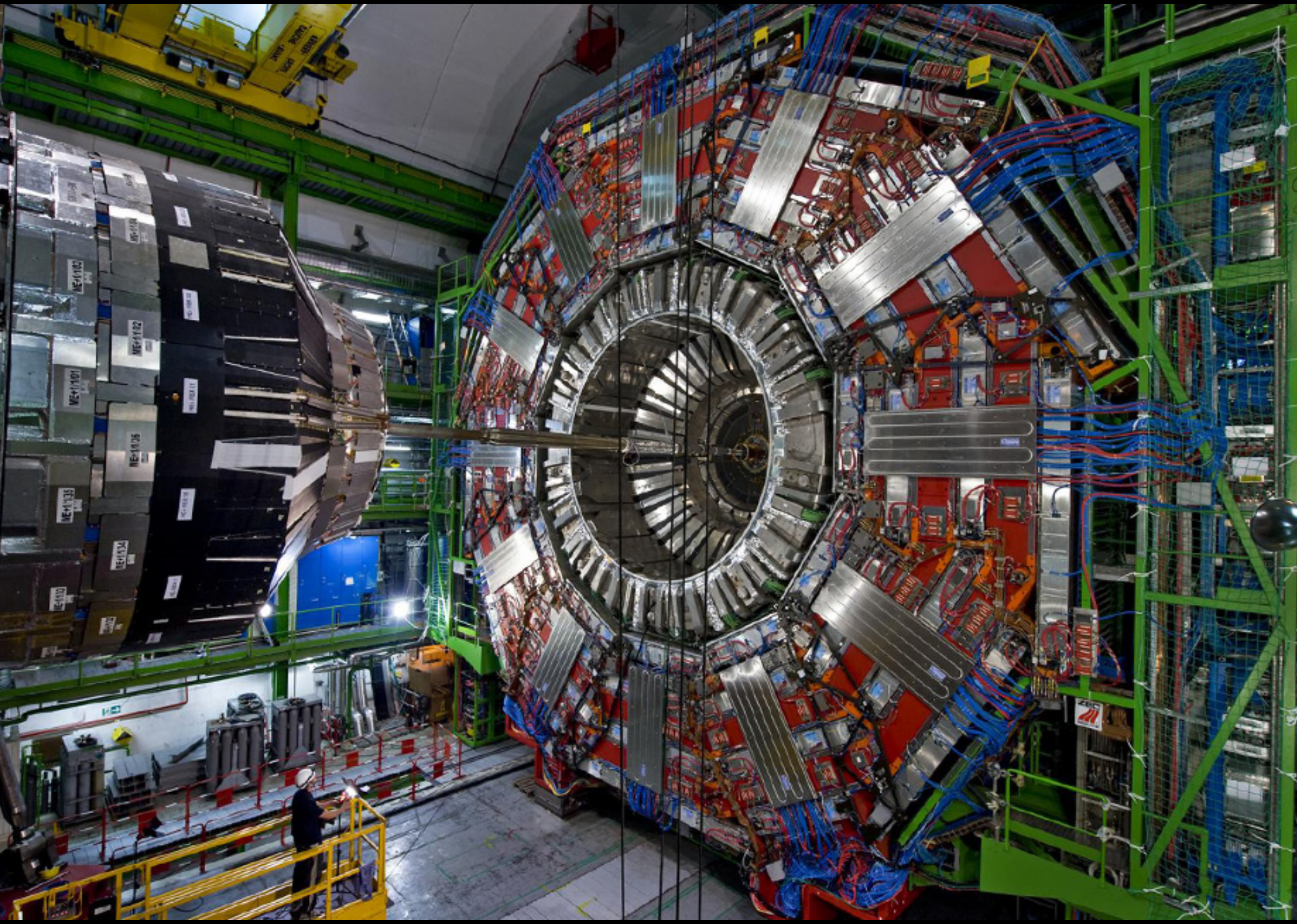



electromagnetic calorimeter
solenoid
muon chambers
hadronic calorimeter
inner tracker
magnet yoke
CMS

CMS Barrel Yoke


ME+2/2/03
ME+2/1/01
ME+2/2/35

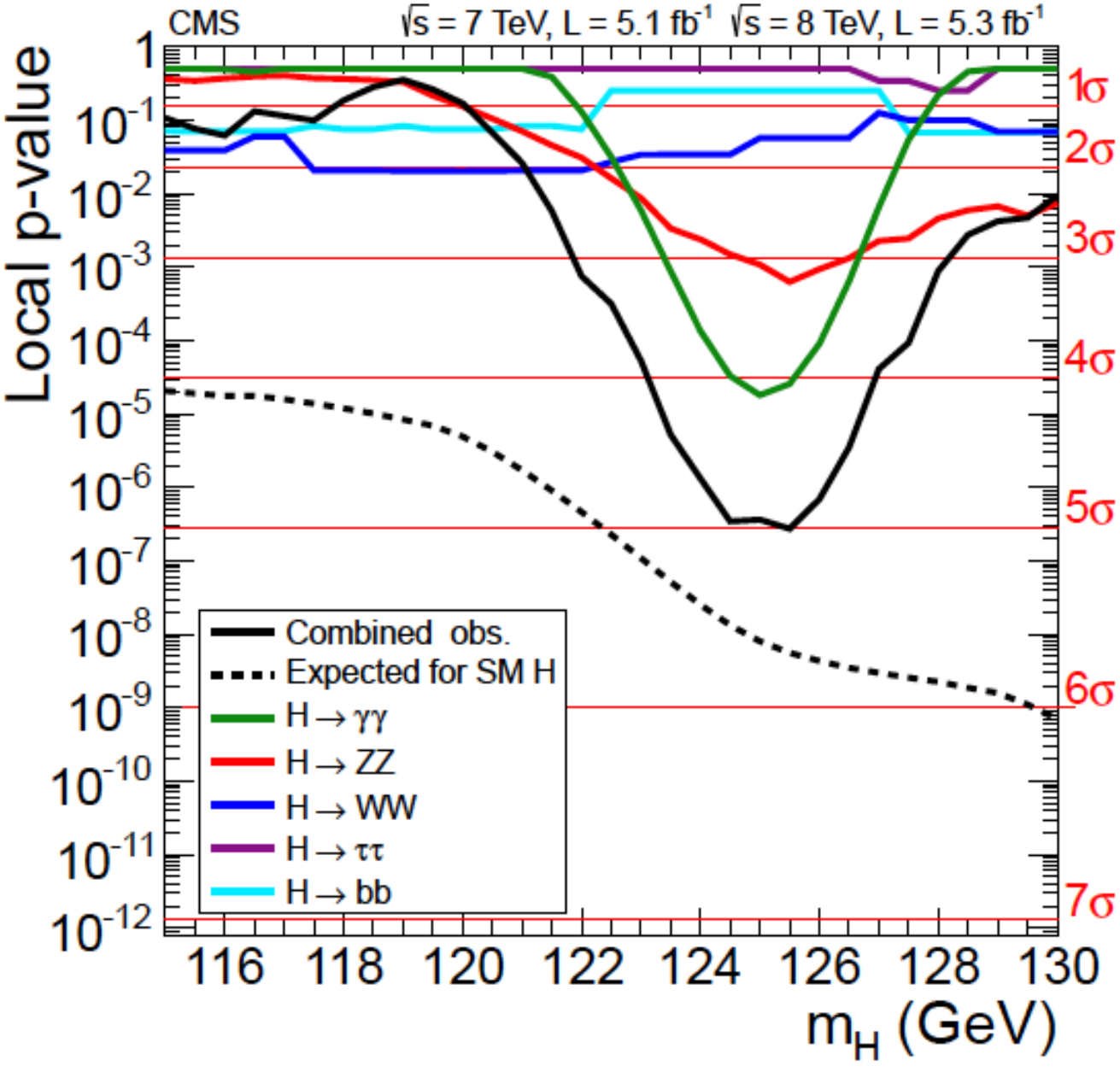

VSL



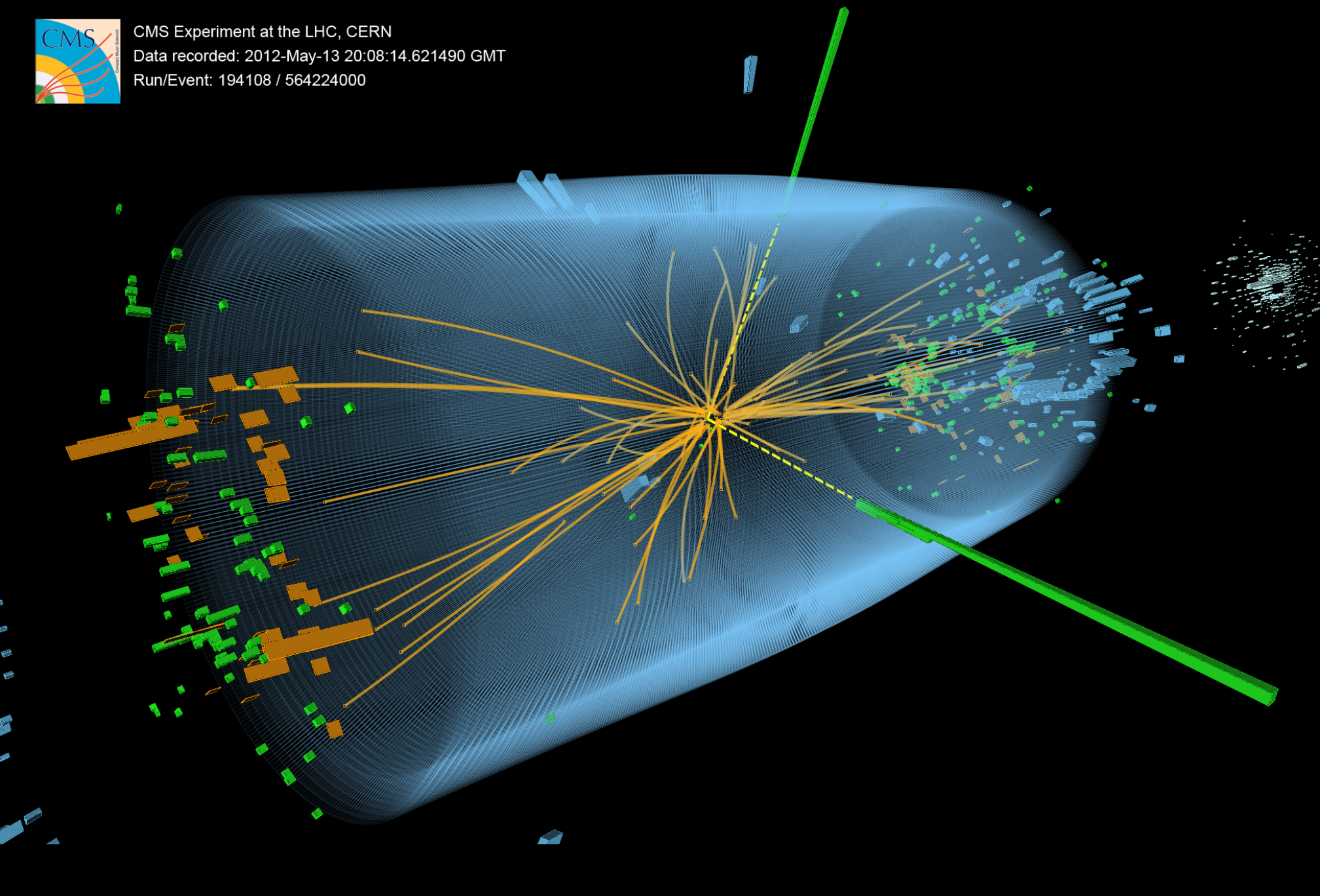
Particle detectors constructed at Westwood, now at LHC, CERN

Sept 15, 2008 Issue

Higgs Discovery by CMS (July 4, 2012)



Higgs particle → 2 gamma rays



The New York Times

Science

News release on July 4th !

Physicists Find Elusive Particle Seen as Key to Universe

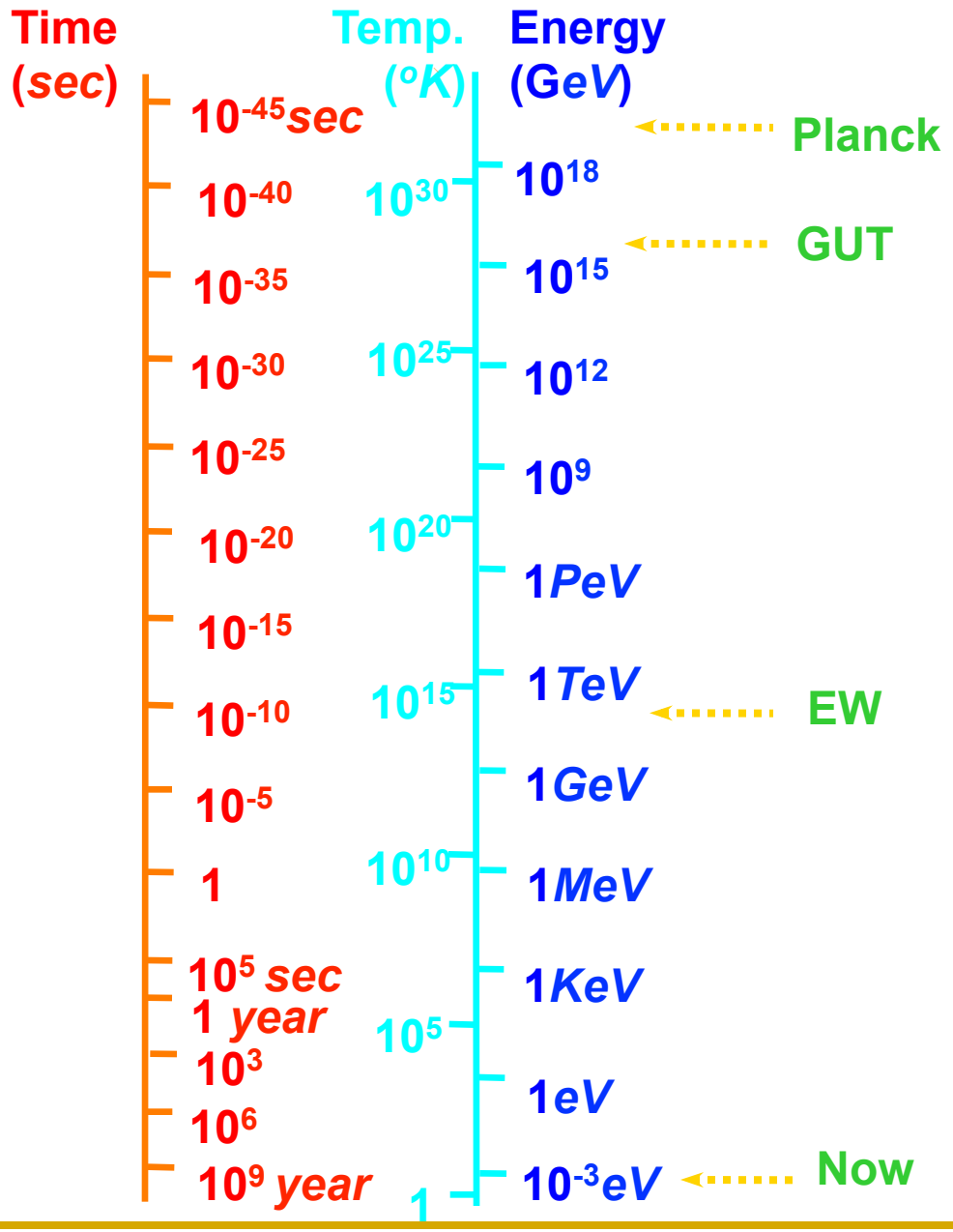
Pool photo by Denis Balibouse

Scientists in Geneva on Wednesday applauded the discovery of a subatomic particle that looks like the Higgs boson.

By DENNIS OVERBYE
Published: July 4, 2012 | 122 Comments

Dark Matter and Dark Energy

“Fossils” from the Earliest Universe



The Big Bang!

Gravitational Wave

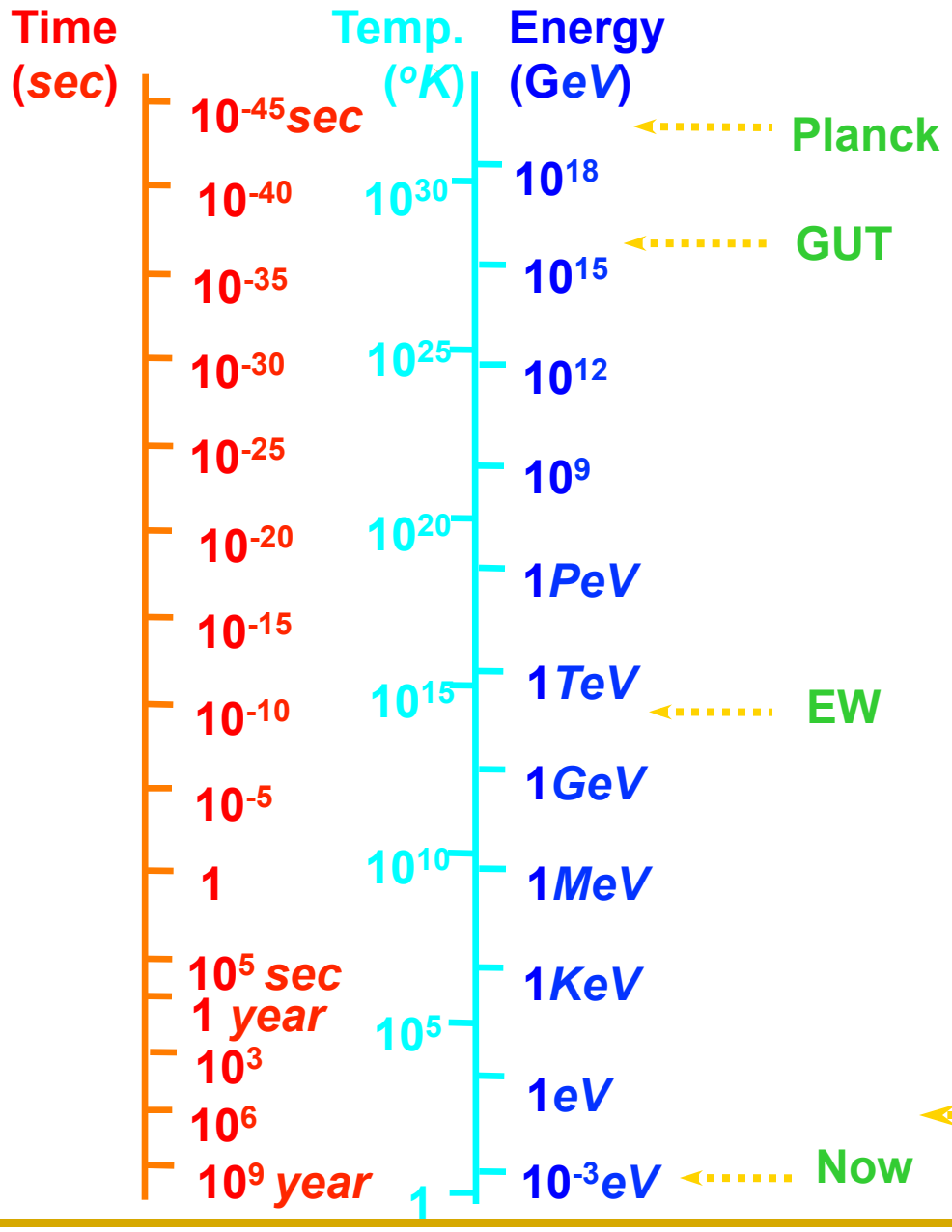
GUT Particle

Decoupling of “Fossils”

Neutralino
(Cold Dark Matter)

Relic Neutrino
(Hot Dark Matter)
CMB

Cosmic Microwave Background (CMB)
Matter-Radiation Decoupling



Time = 300,000 *years*

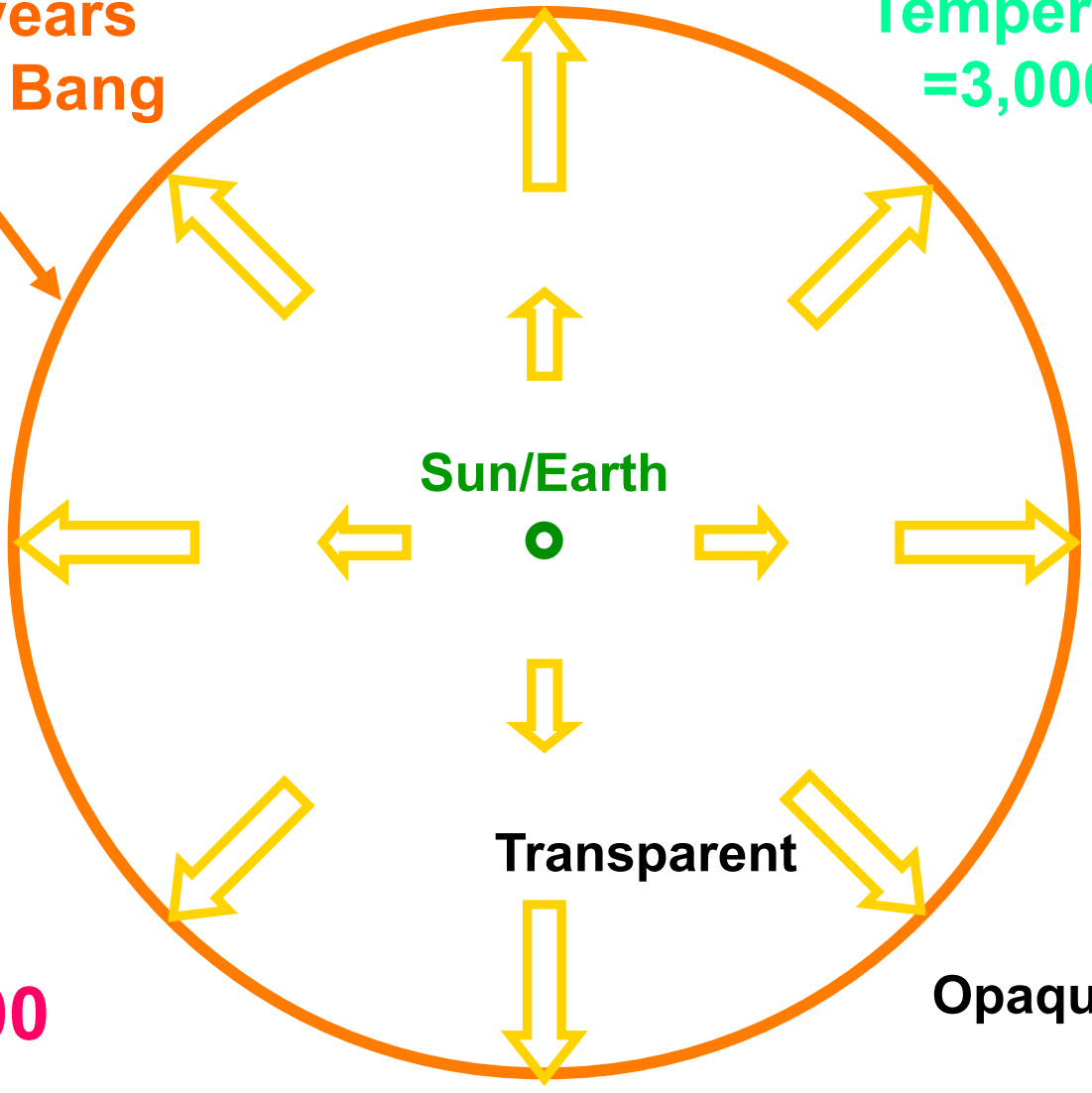
Temperature = 3,000 °*K*

Energy = 0.3 *eV*

Z = 1,100

Matter-Radiation Decoupling ***CMB***

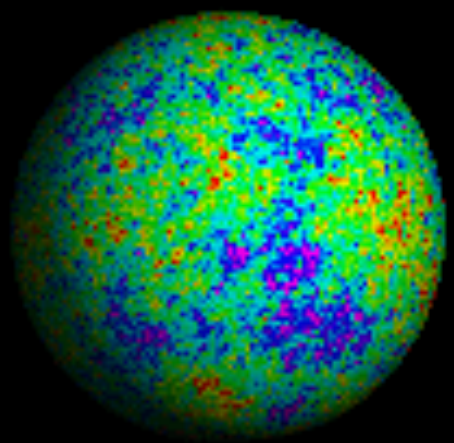
Cosmic Microwave Background
(Discovered in 1964)



Today:
3000°K/1,100
=2.7°K

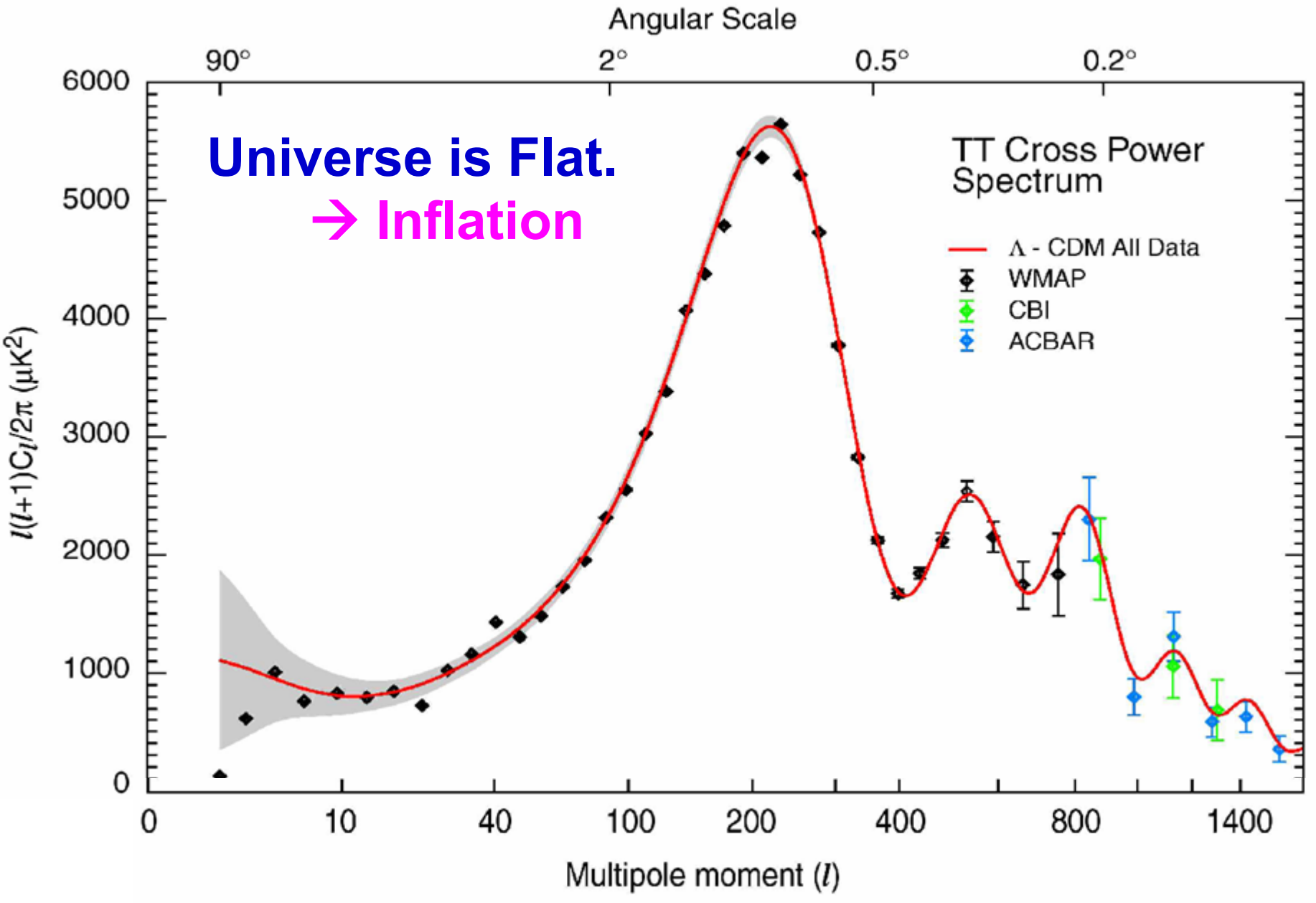
WMAP

Ned Wright



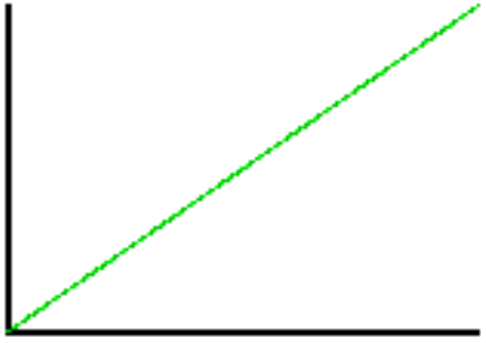
P map from Tegmark, de Oliveira-Costa & Hamilton, astro-ph/0302496

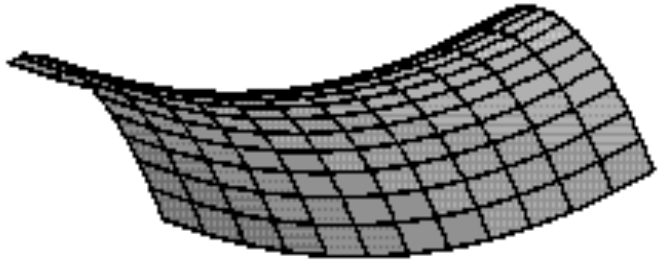
WMAP Power Spectrum



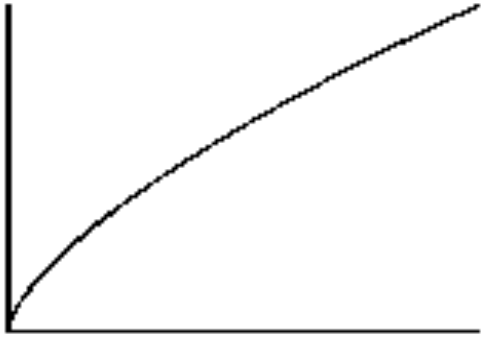
Geometry of the Universe

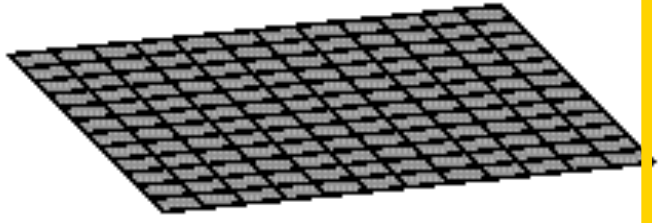
Open $\Omega<1$



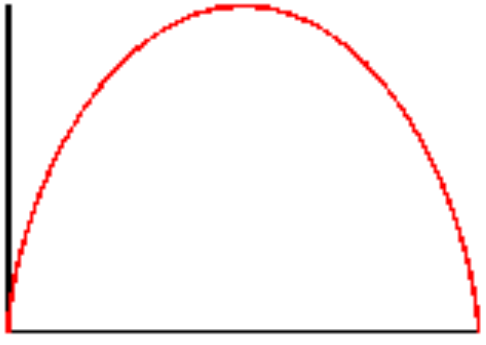


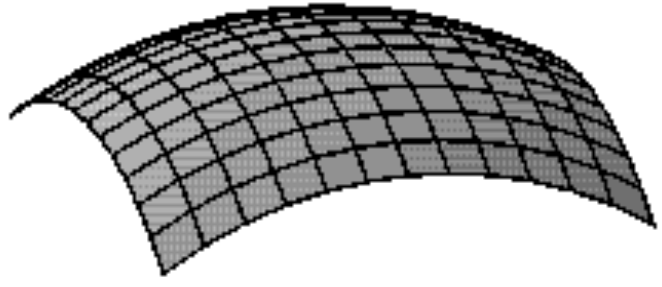
Flat $\Omega=1$
(predicted by Inflation)



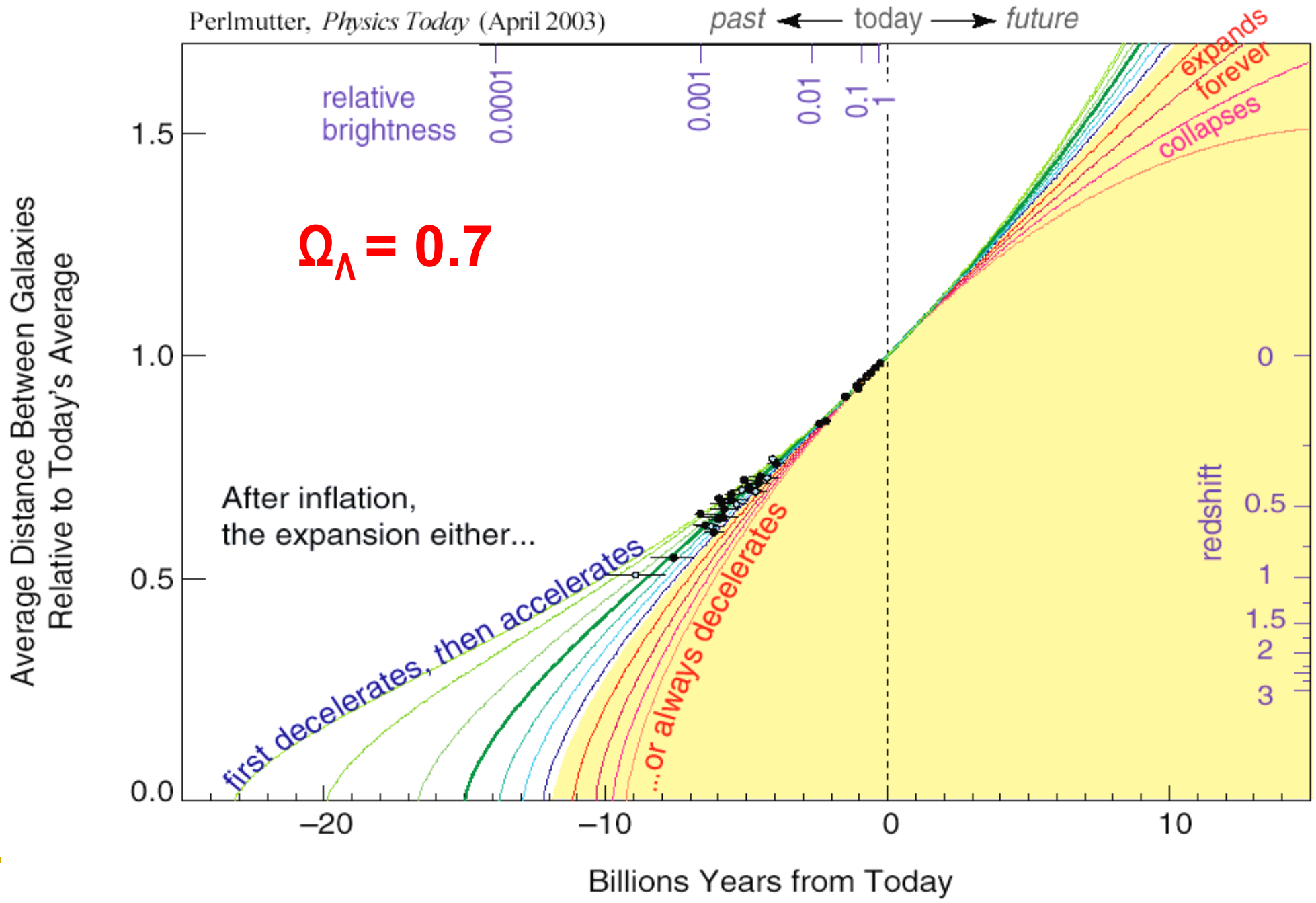


Closed $\Omega>1$



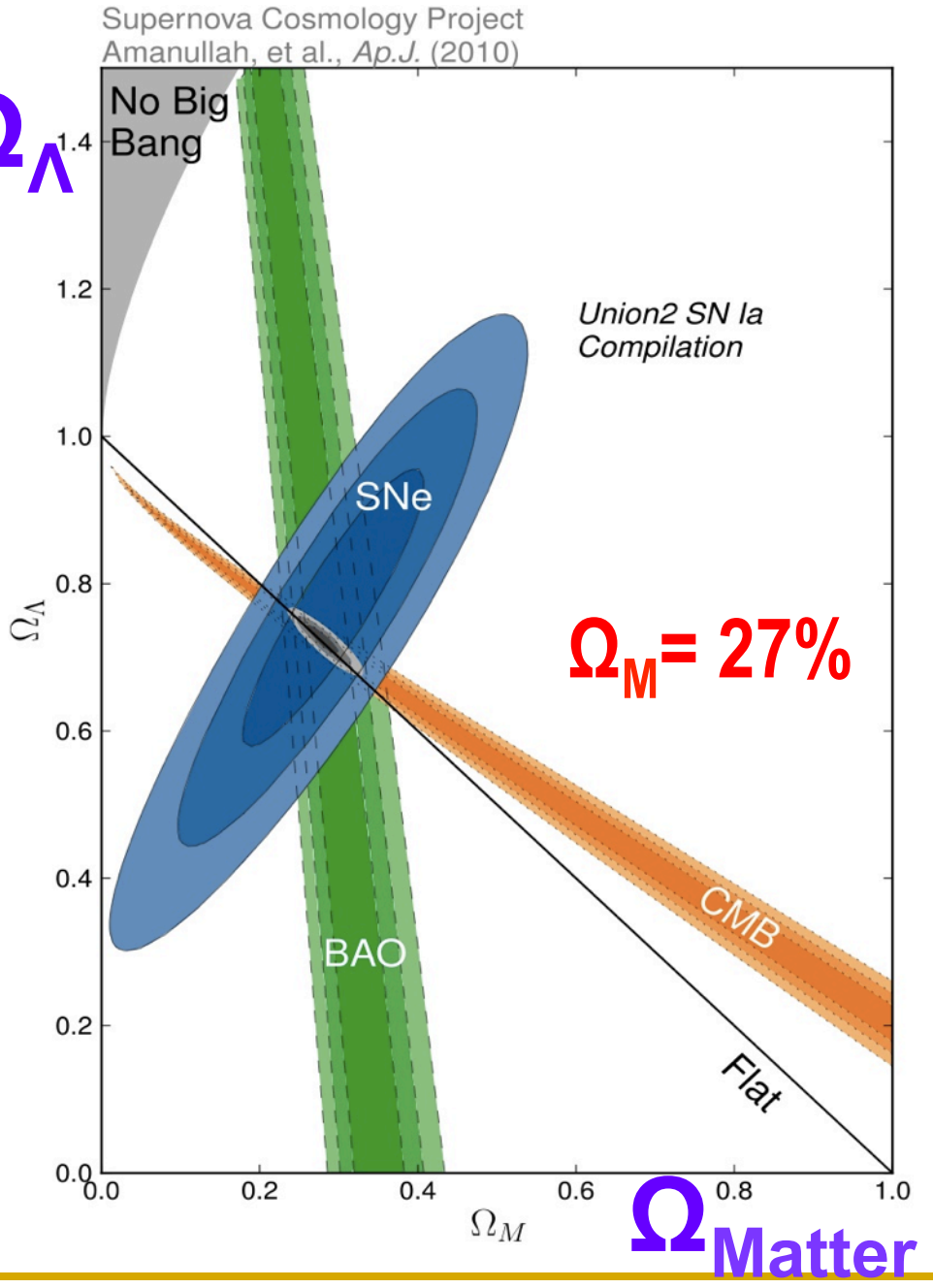


The Accelerating Universe (1998)

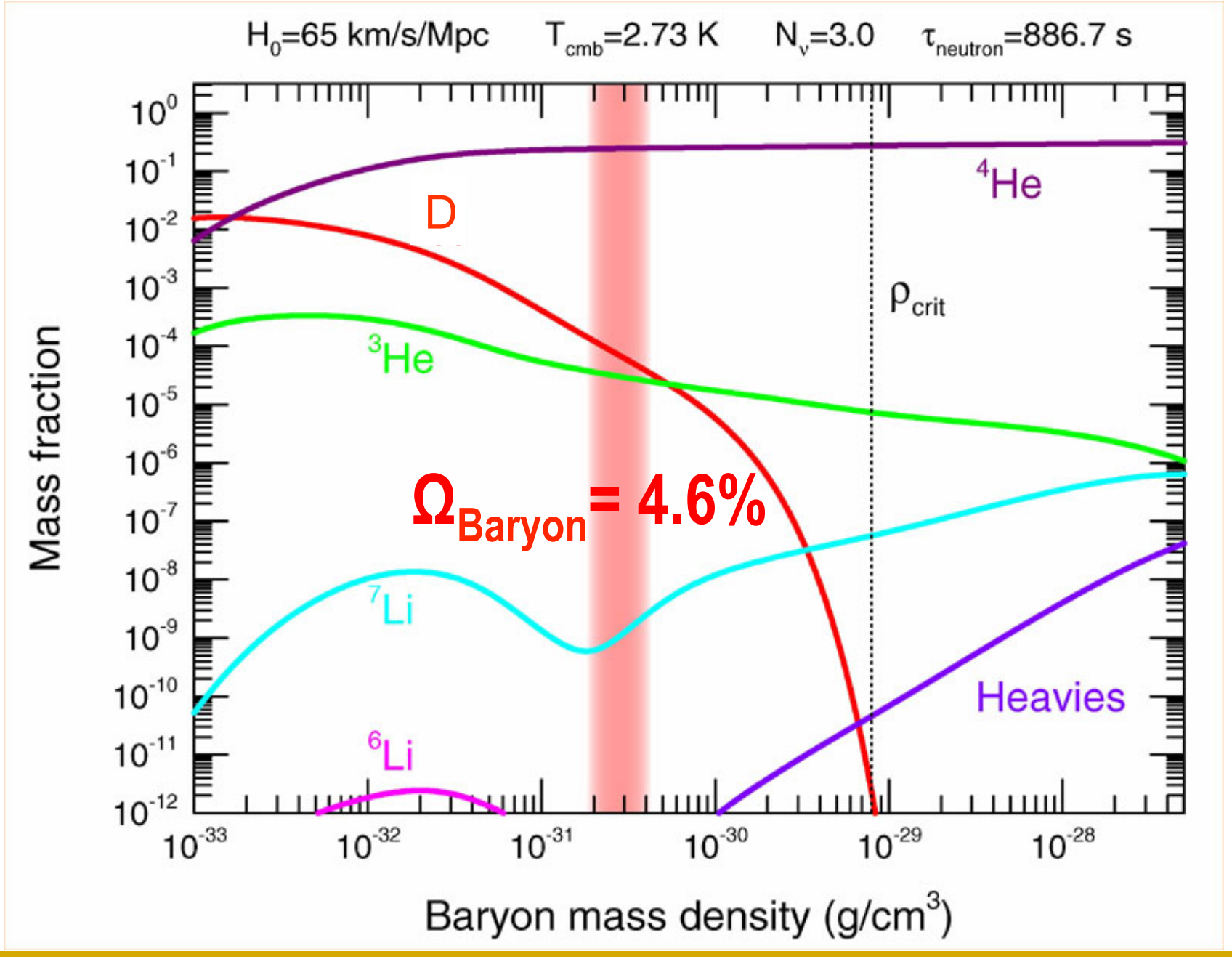


Density of Our Universe

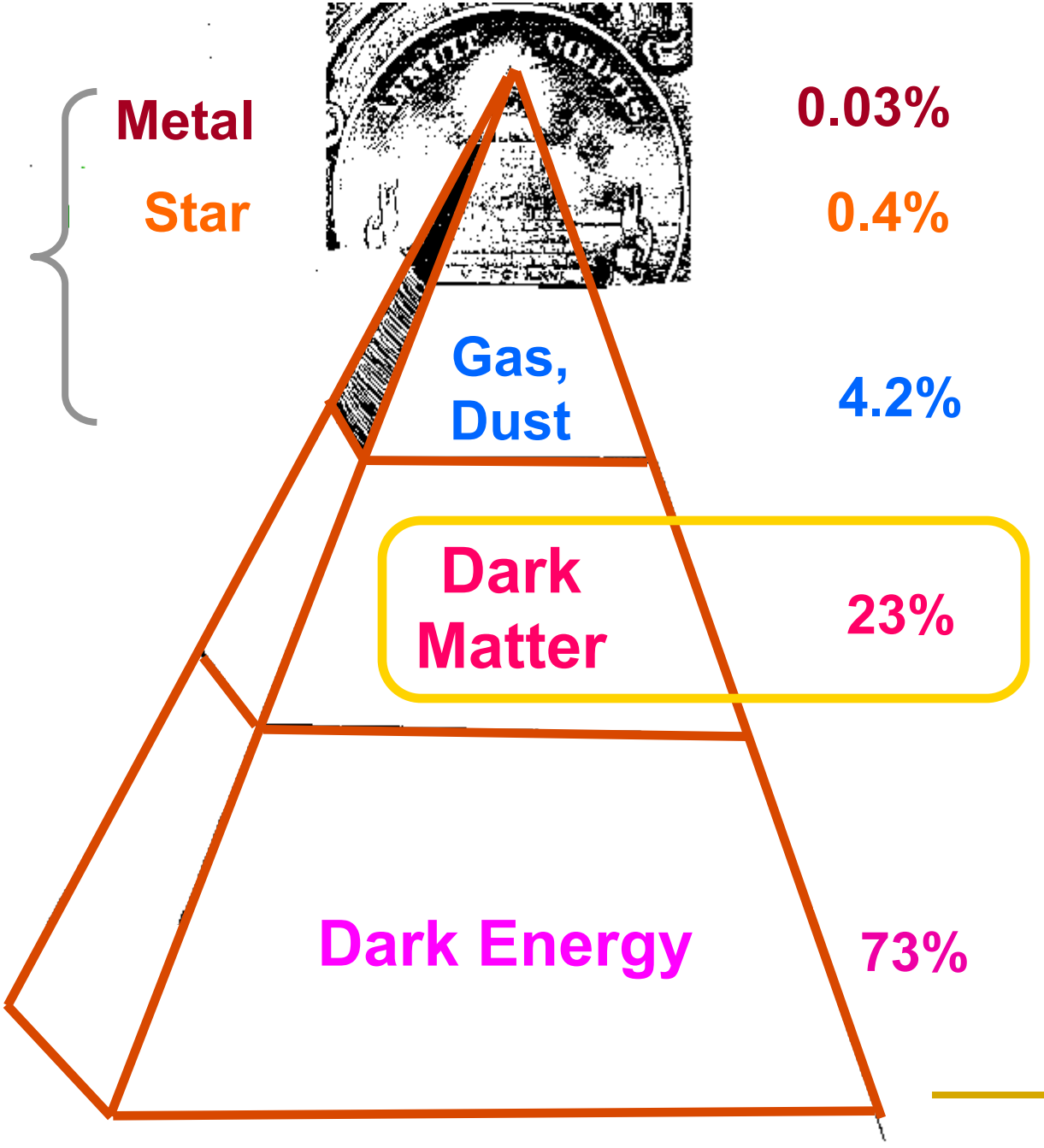
- $\Omega_{Total} = \Omega_{\Lambda} + \Omega_{Matter} = 1.0$
- Universe is Flat.
  → Inflation
- 73% is Dark Energy.
  → Accelerating



Abundance vs. Density



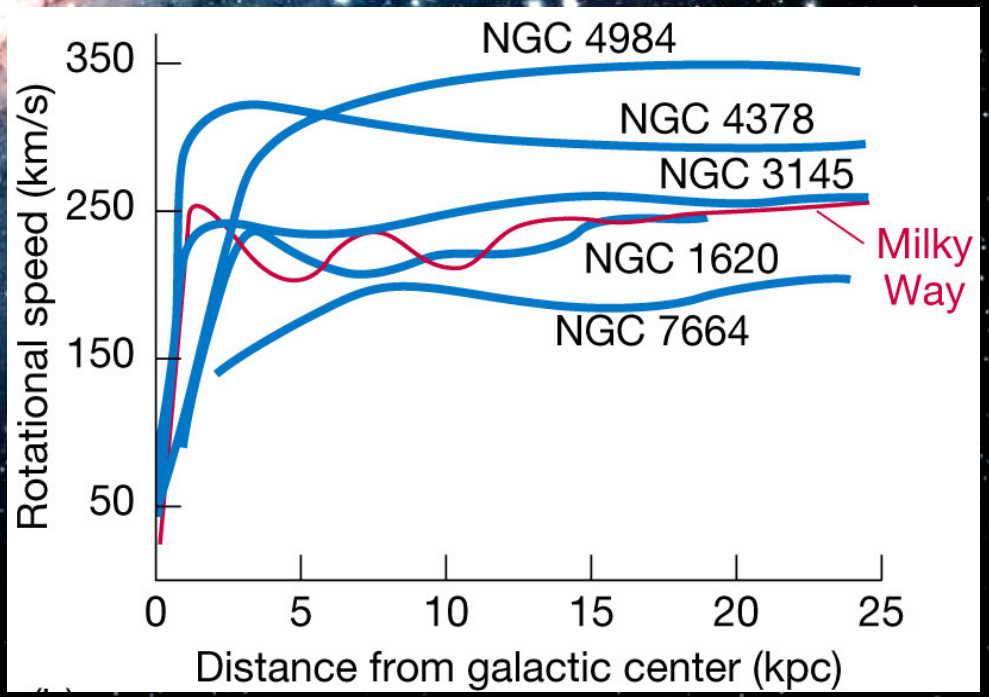
Cosmic Pyramid

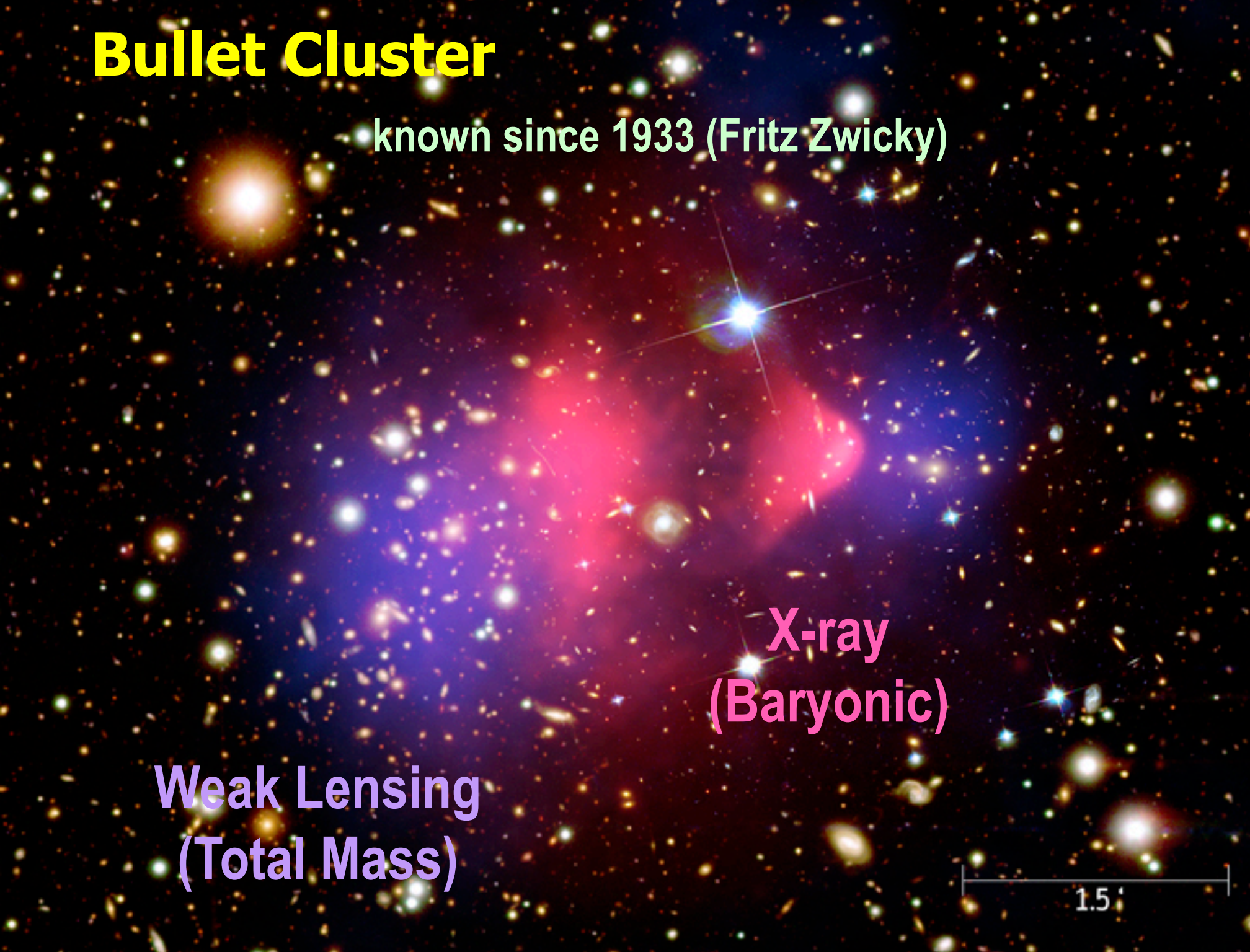


Search for Dark Matter

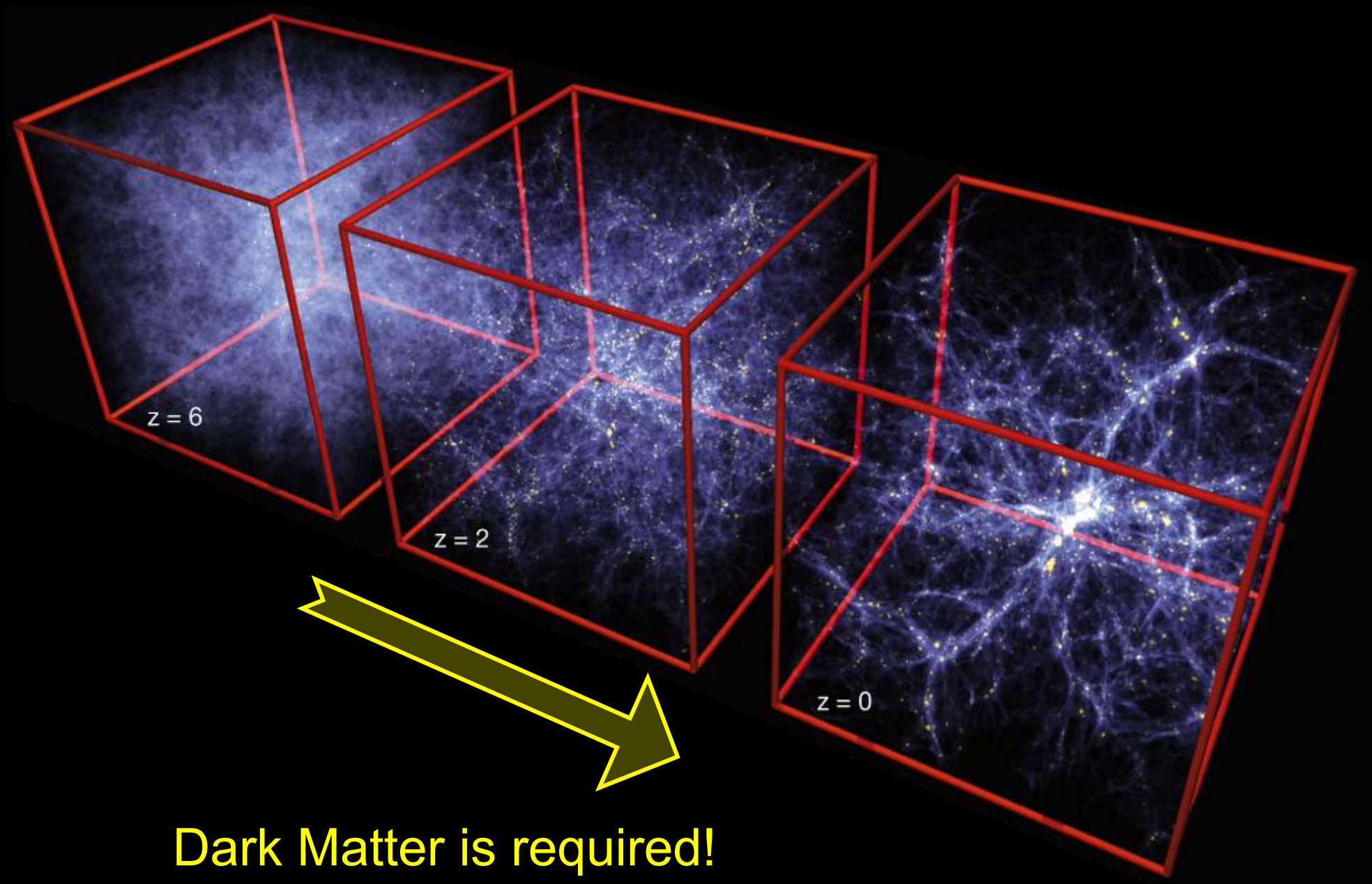
Andromeda Galaxy

known since 1932 (Jan Oort)



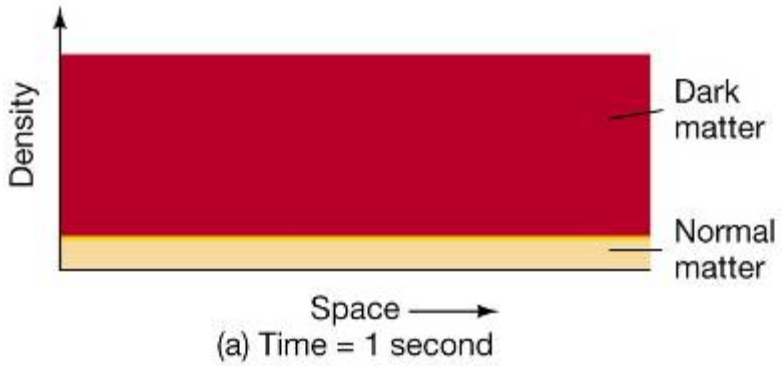

Bullet Cluster
known since 1933 (Fritz Zwicky)
X-ray
(Baryonic)
Weak Lensing
(Total Mass)
1.5

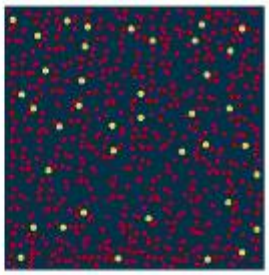
Formation of Structure in the Universe

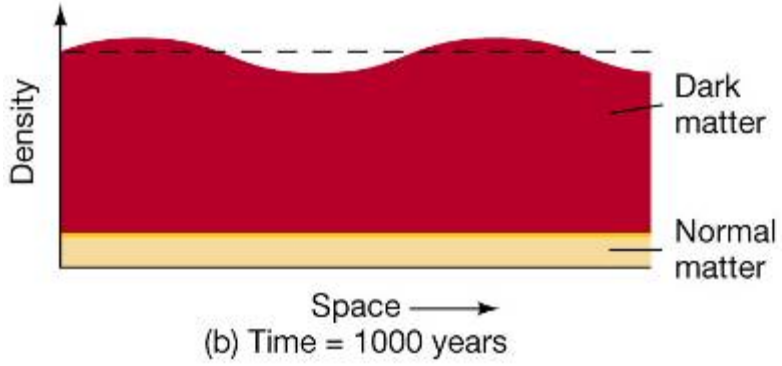


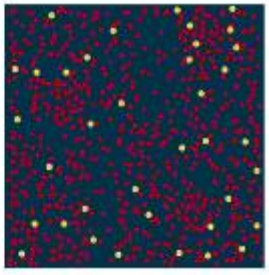
Dark Matter is required!

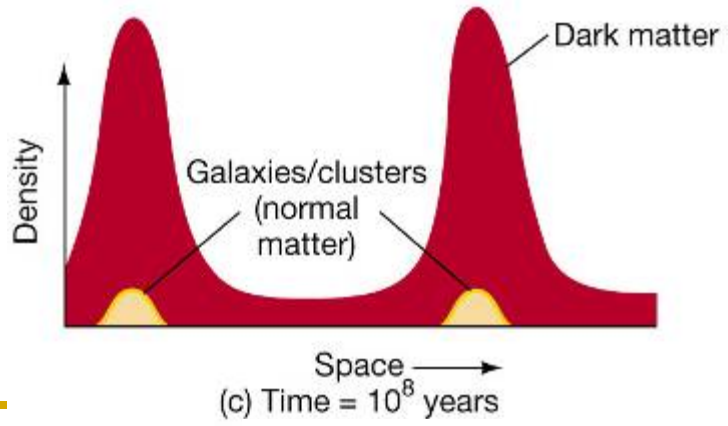
Evolution of Large Structure

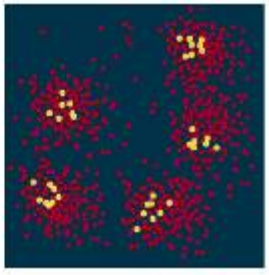




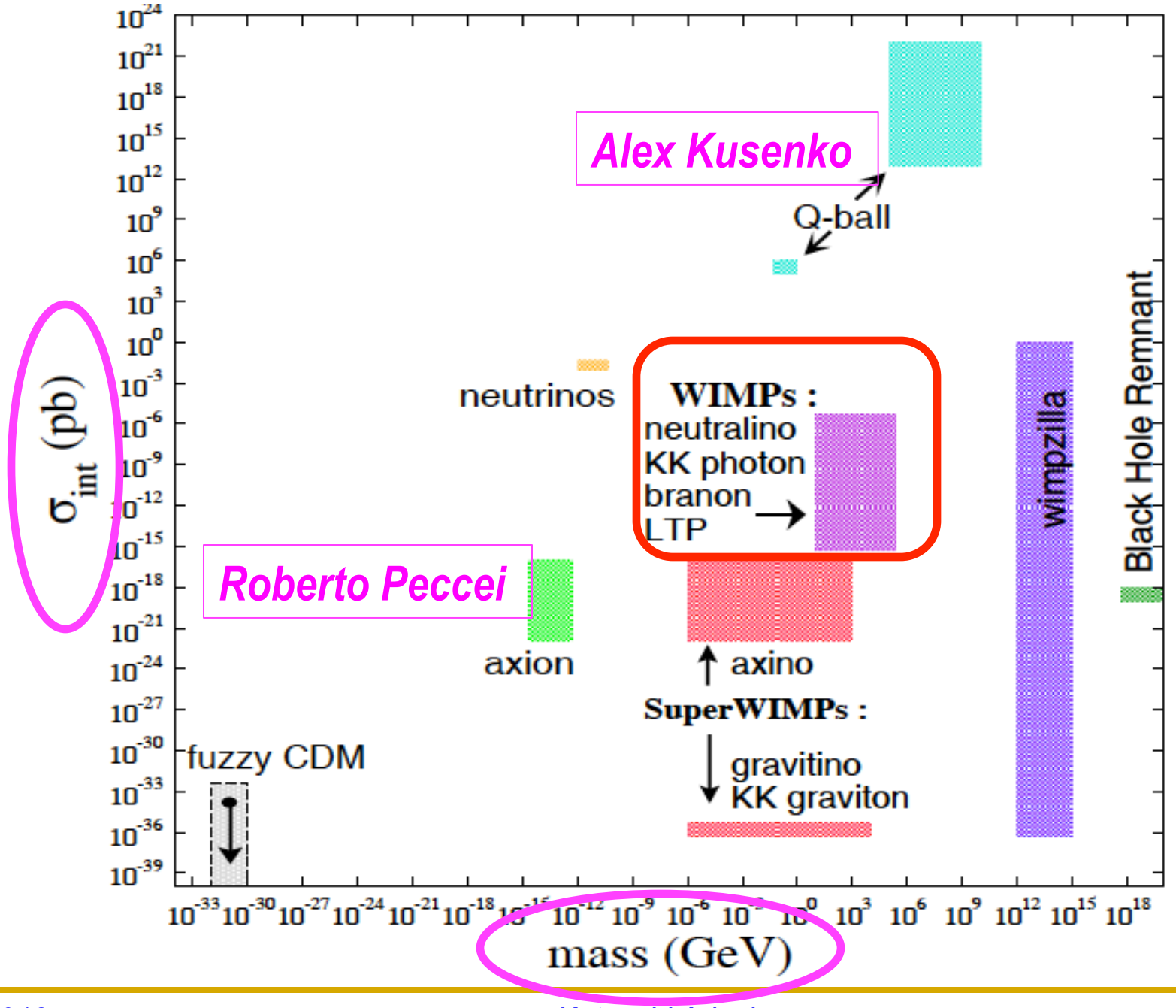




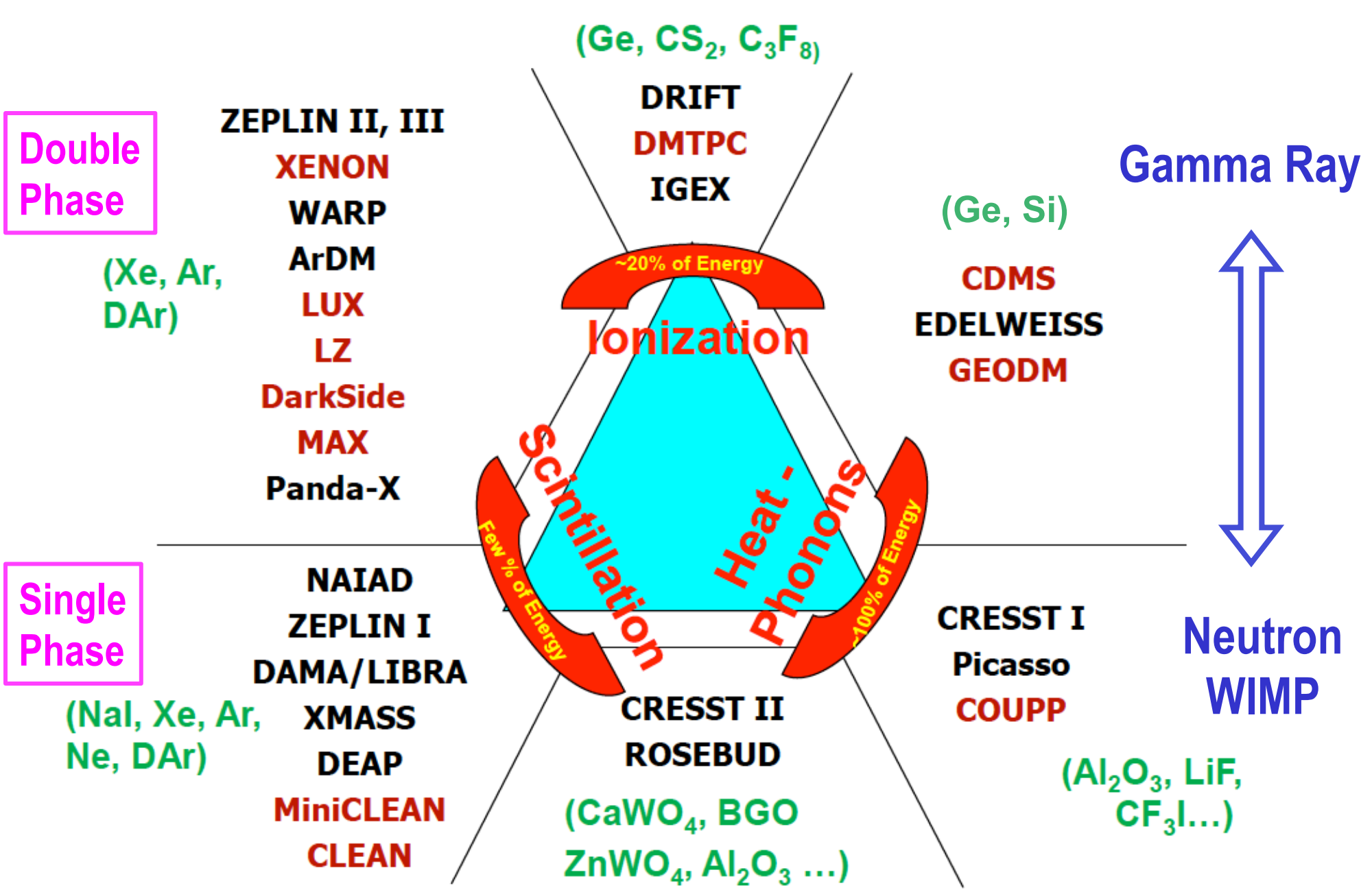




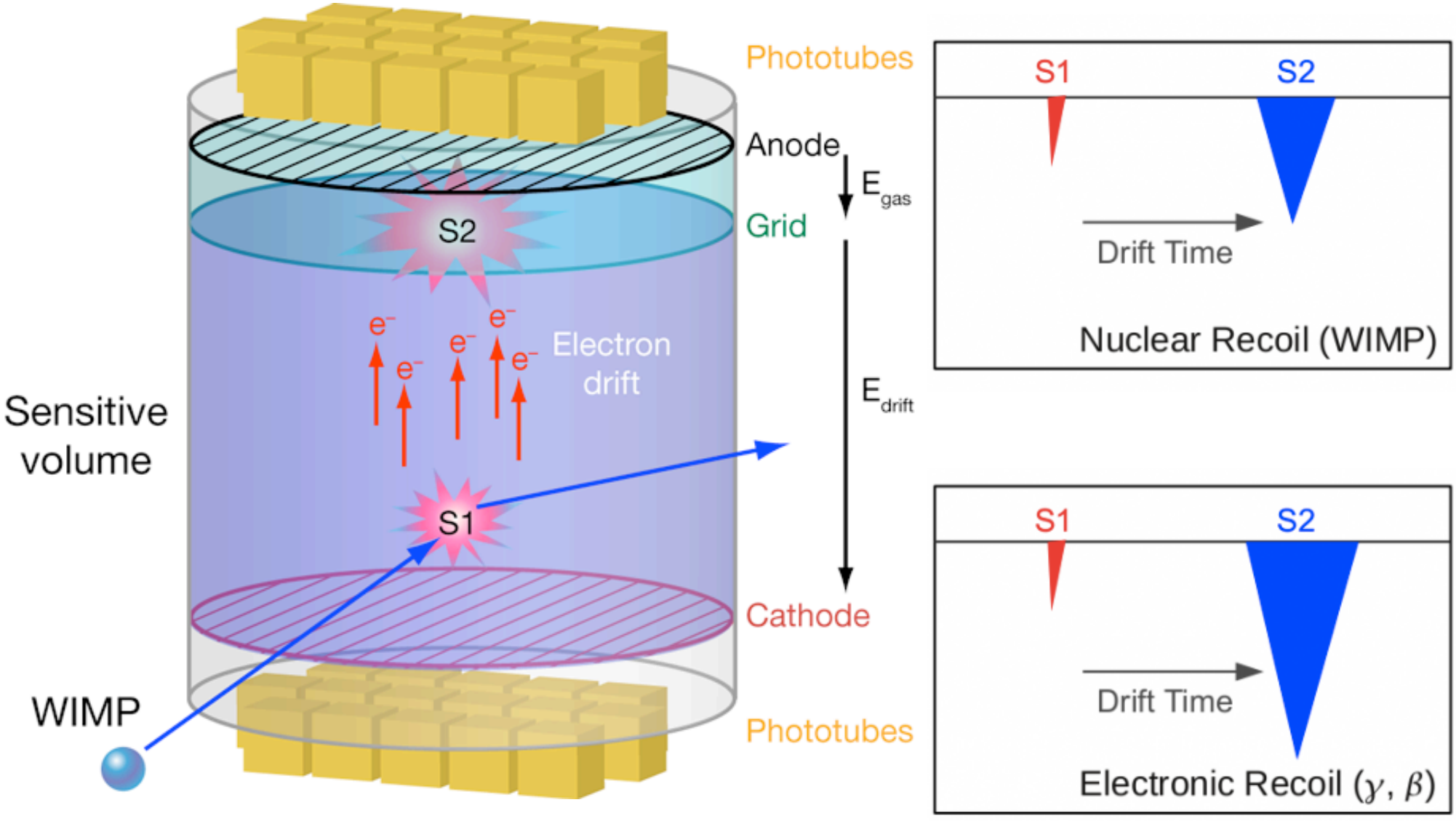
What is Dark Matter?



Detection Technique

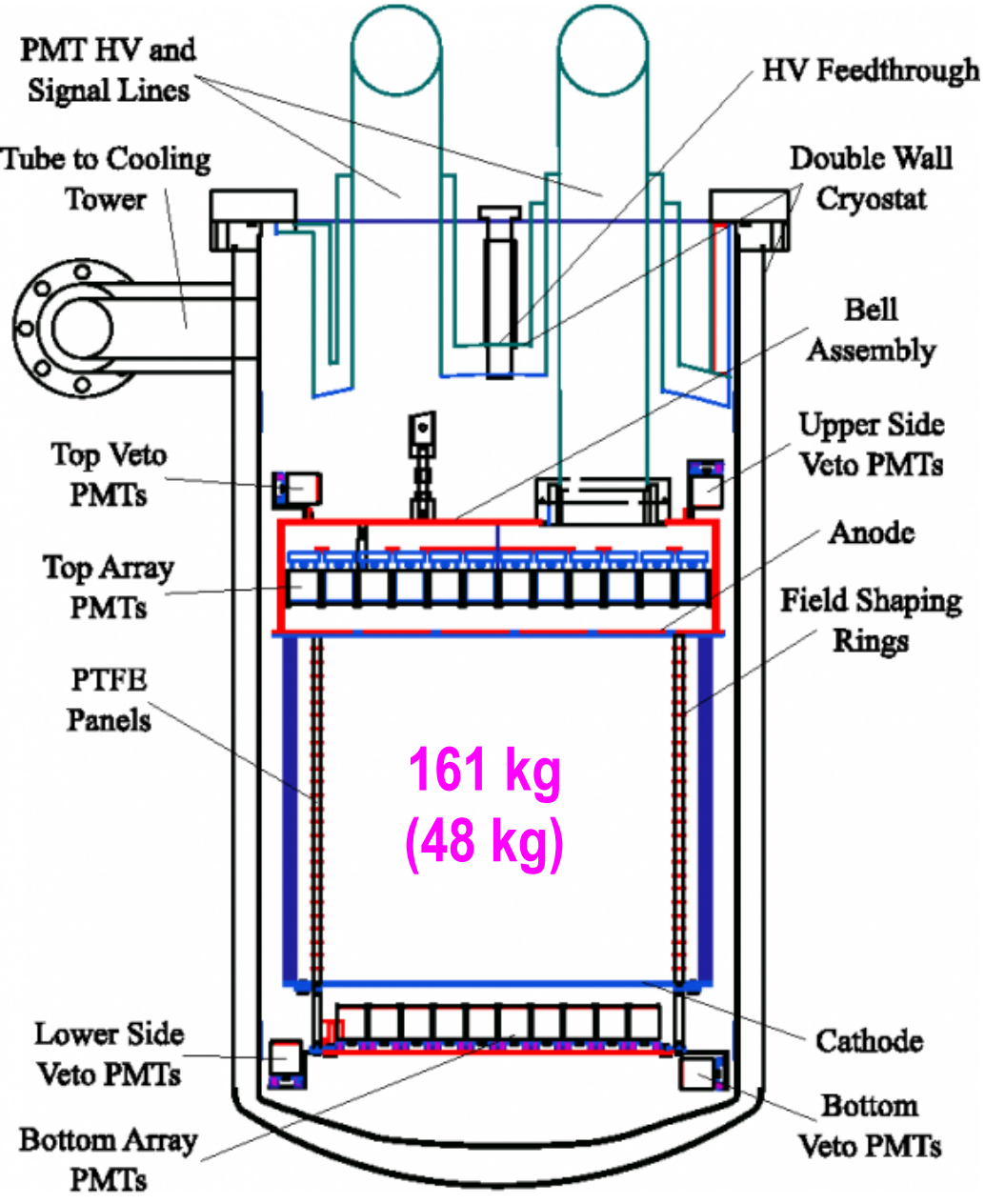


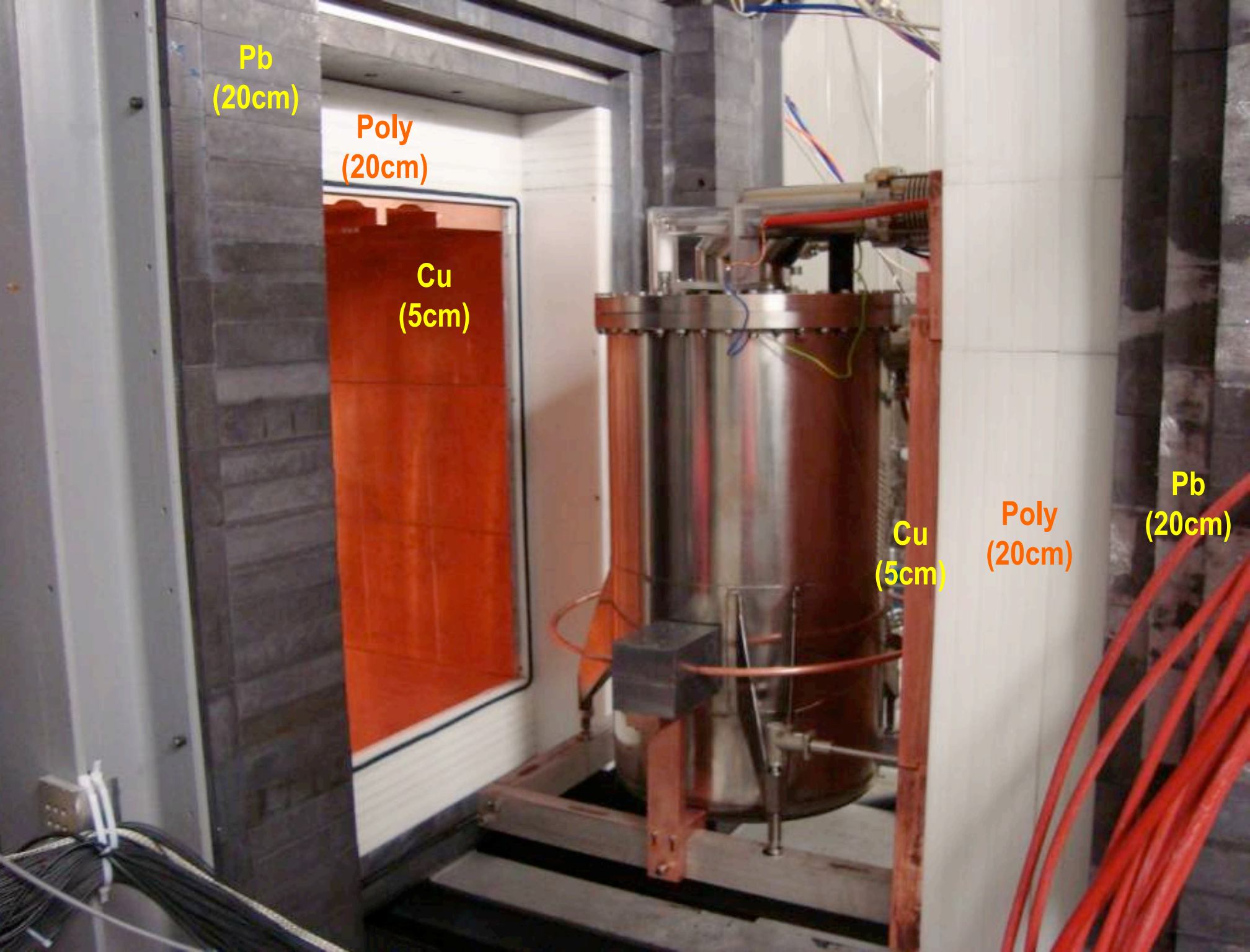
Double-Phase Noble Liquids



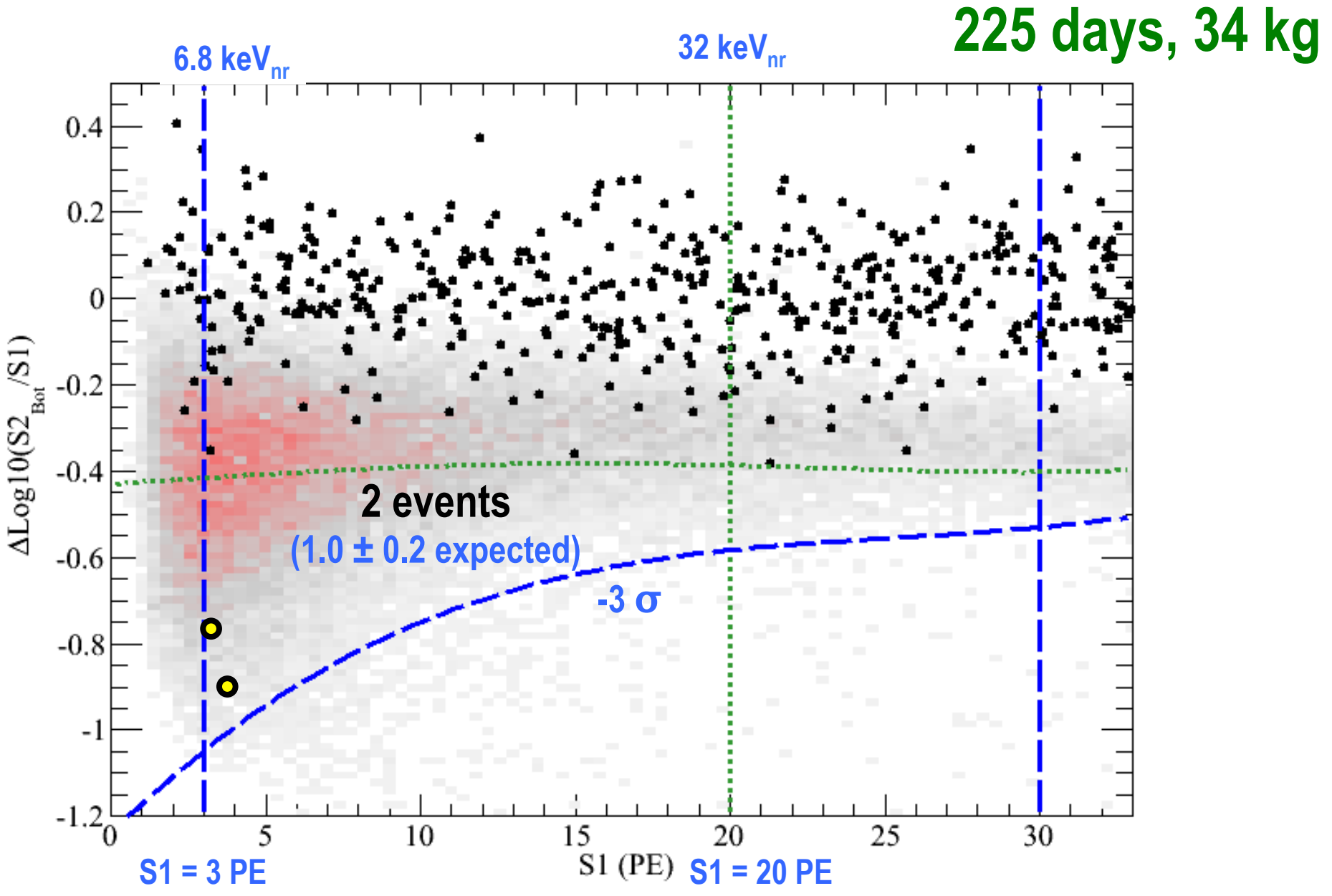
XENON Collaboration at Gran Sasso

XENON100 Detector

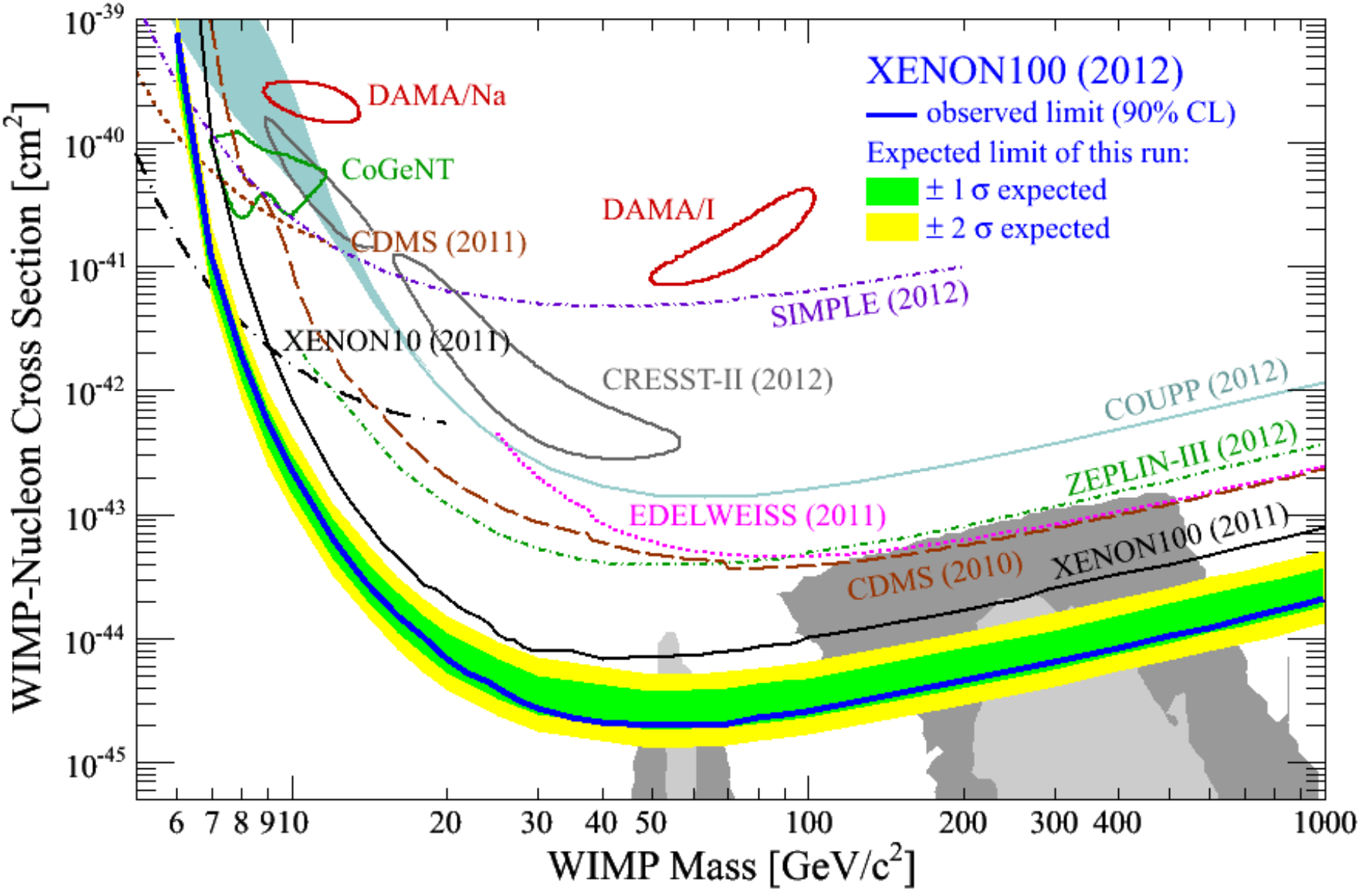



Pb
(20cm)
Poly
(20cm)
Cu
(5cm)
Cu
(5cm)
Poly
(20cm)
Pb
(20cm)

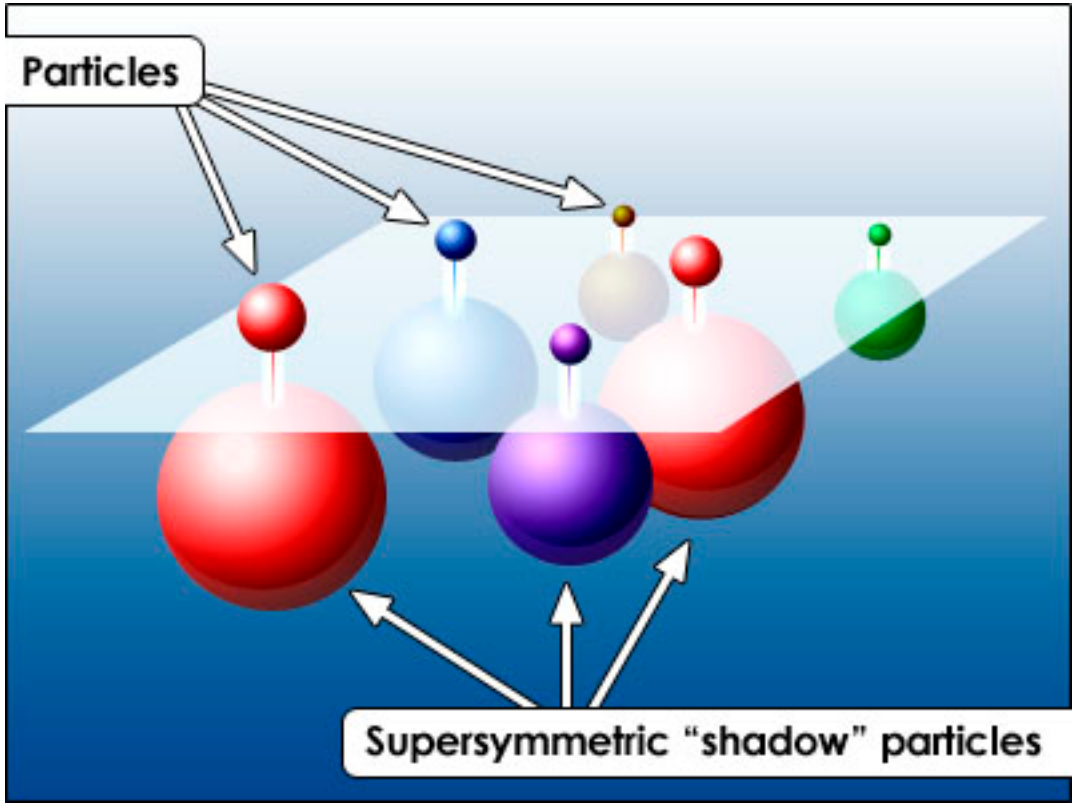
XENON0100 New Results



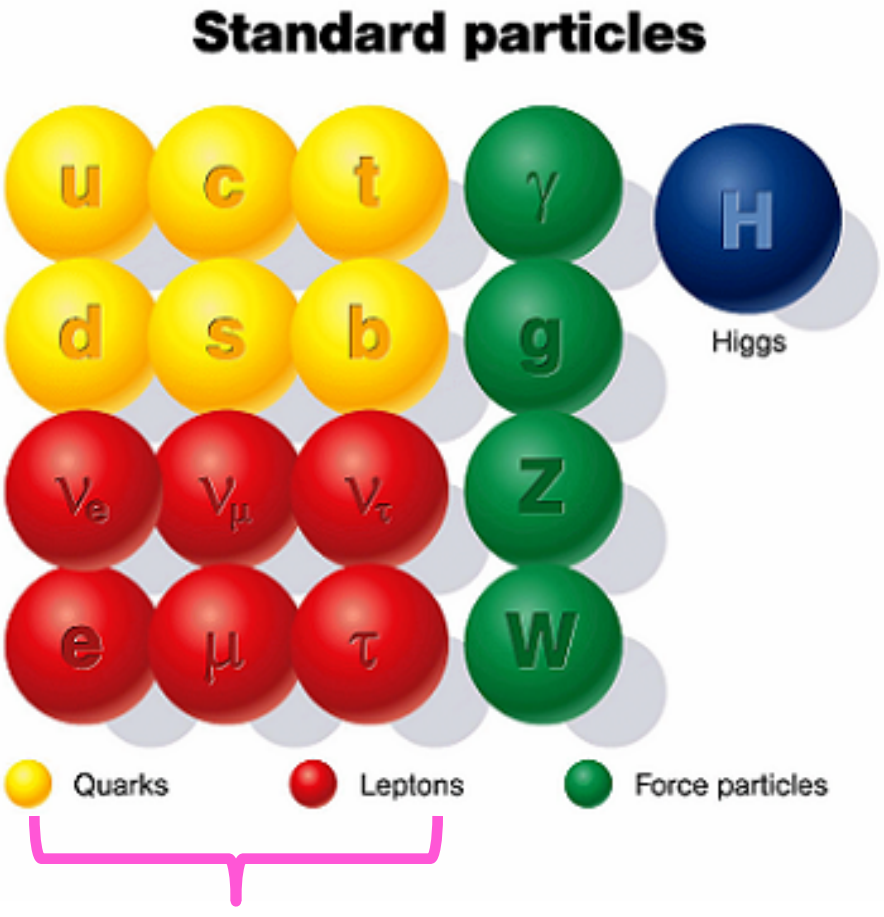
90% CL Limits of SI Cross Section (July, 2012)



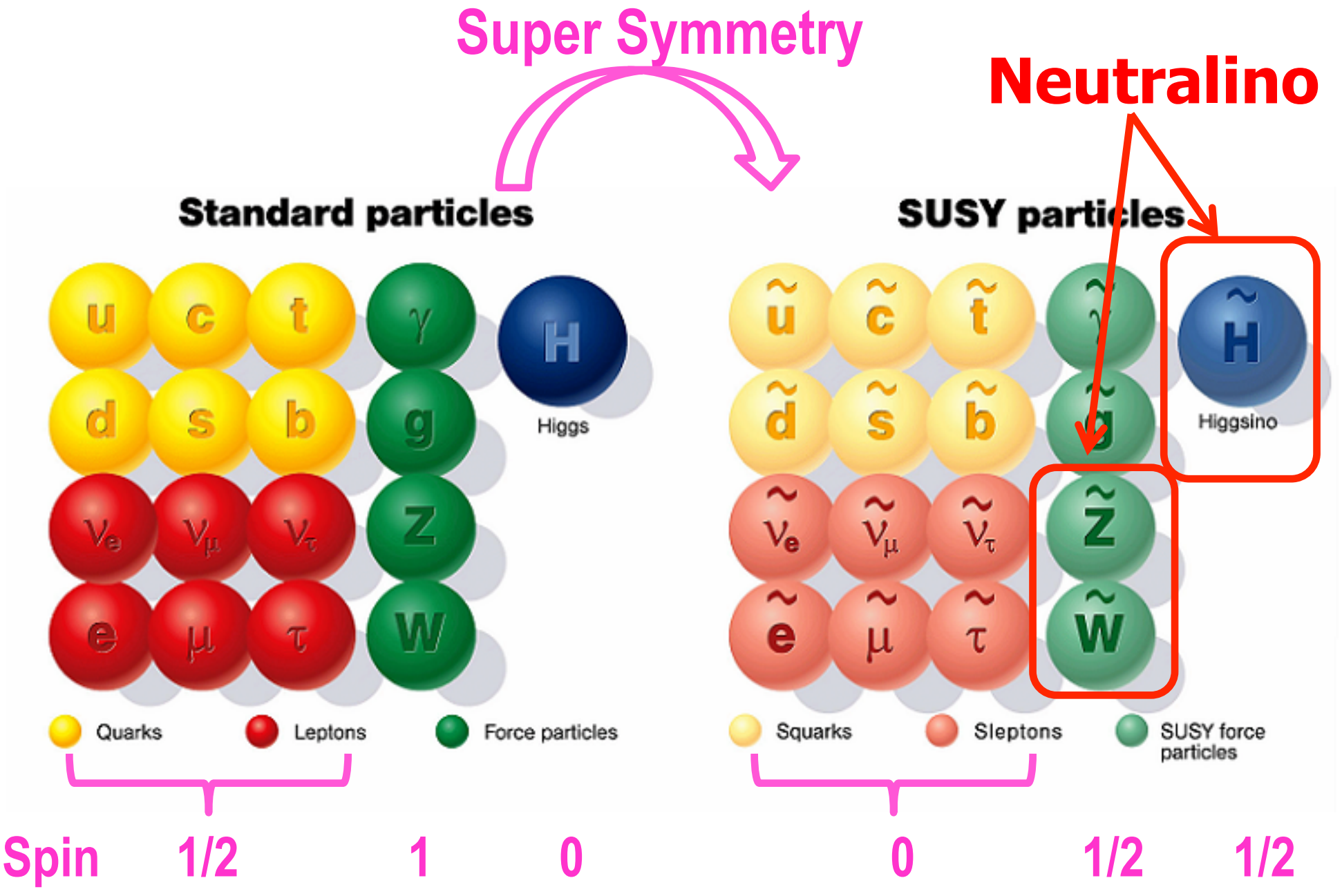
SUSY Neutralino



SUSY Particles and Neutralino



SUSY Particles and Neutralino



Hierarchy Problem

Higgs mass

$m_h^2 = m_{h\,0}^2 + \Delta m_h^2$, where $m_{h\,0}^2$ is the tree-level mass, and

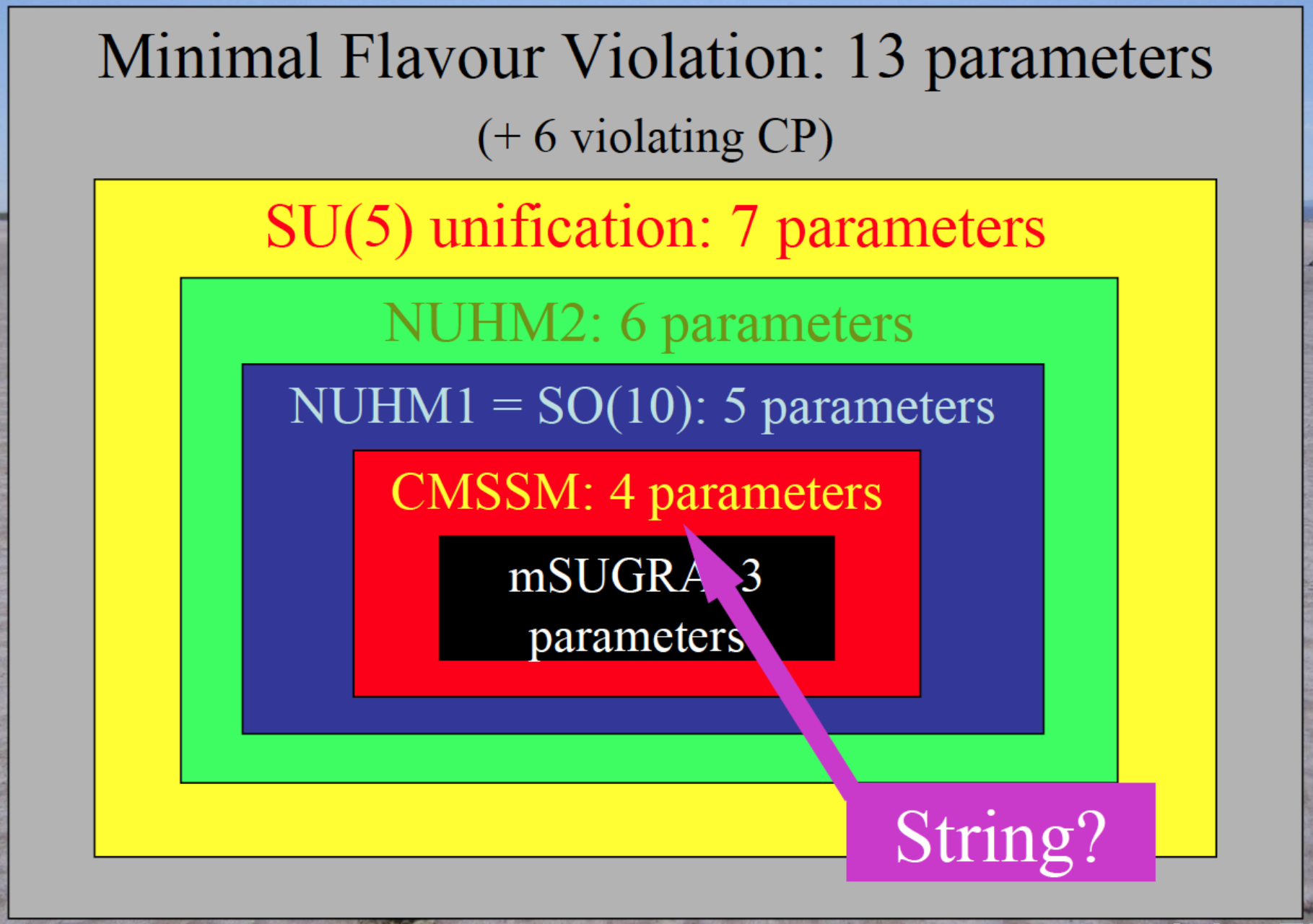
SM :
$$\Delta m_h^2 \sim \frac{\lambda^2}{16\pi^2}\int^{\Lambda}\frac{d^4p}{p^2} \sim \frac{\lambda^2}{16\pi^2}\Lambda^2$$

SUSY :
$$\Delta m_h^2 \sim \frac{\lambda^2}{16\pi^2}\int^{\Lambda}\frac{d^4p}{p^2}\bigg|_{\rm SM} - \frac{\lambda^2}{16\pi^2}\int^{\Lambda}\frac{d^4p}{p^2}\bigg|_{\rm SUSY}$$

$$\sim \frac{\lambda^2}{16\pi^2}(m_{\rm SUSY}^2 - m_{\rm SM}^2)\ln\frac{\Lambda}{m_{\rm SUSY}}$$

or : new physics at the energy scale of $\Lambda \sim 1$ TeV

MSSM: > 100 parameters



Mass Spectra at the best fit points (before LHC)

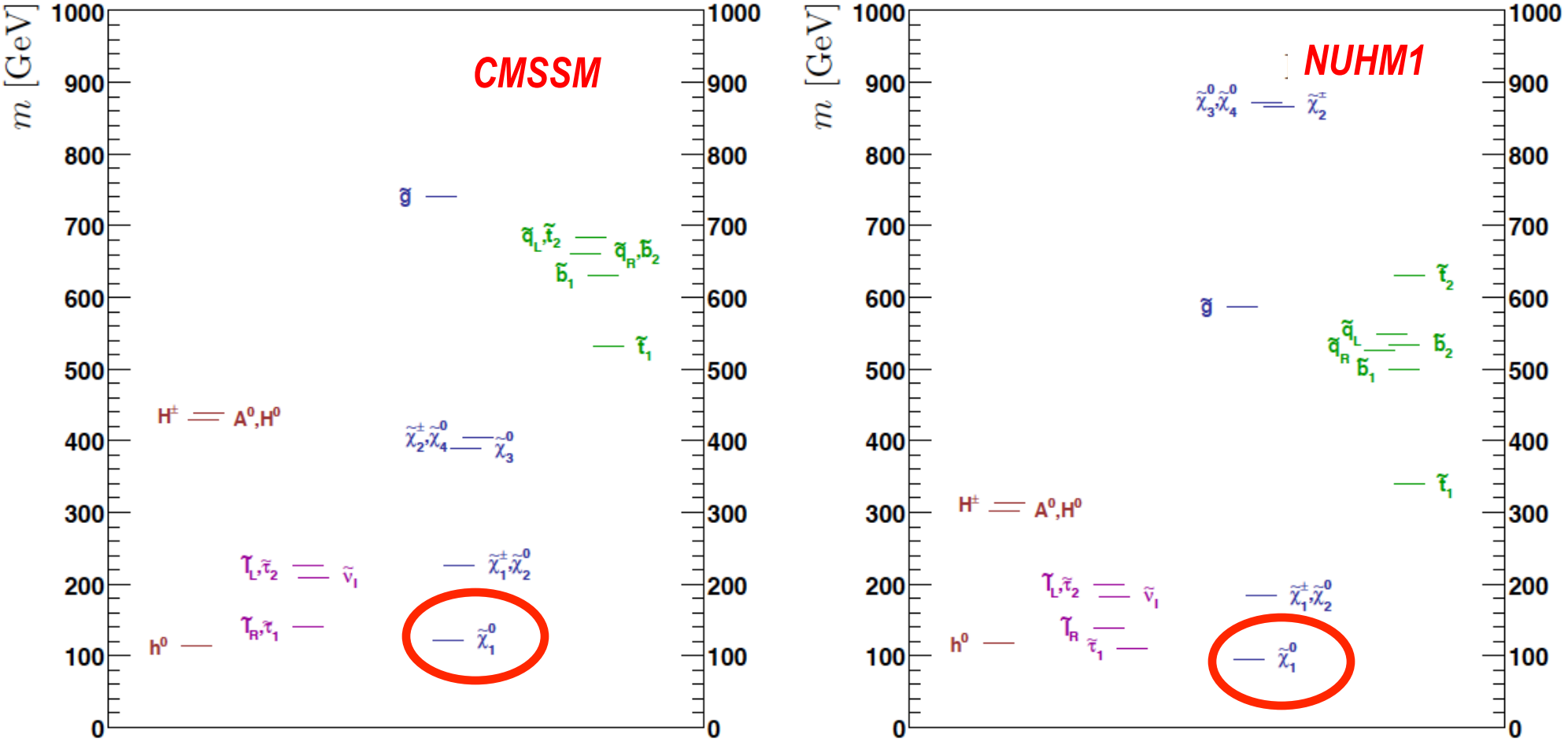
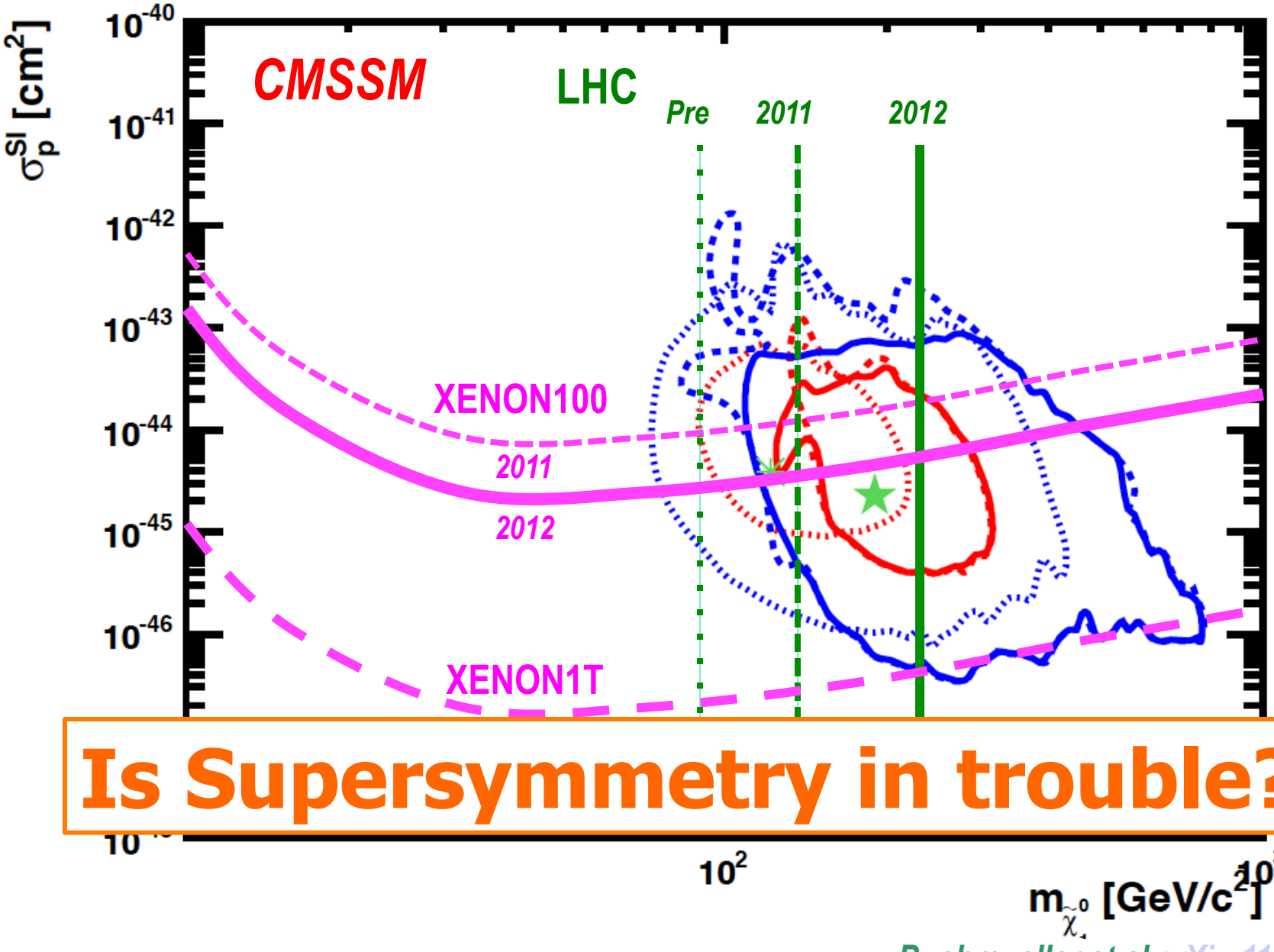


Figure 2. The spectra at the best-fit points: left — in the CMSSM with $m_0 = 60$ GeV, $m_{1/2} = 310$ GeV, $A_0 = 240$ GeV, $\tan\beta = 11$, and right — in the NUHM1 with $m_0 = 100$ GeV, $m_{1/2} = 240$ GeV, $A_0 = -930$ GeV, $\tan\beta = 7$, $m_H^2 = -6.9 \times 10^5$ GeV^2 and $\mu = 870$ GeV.

Buchmueller et al arXiv: 0808.4218

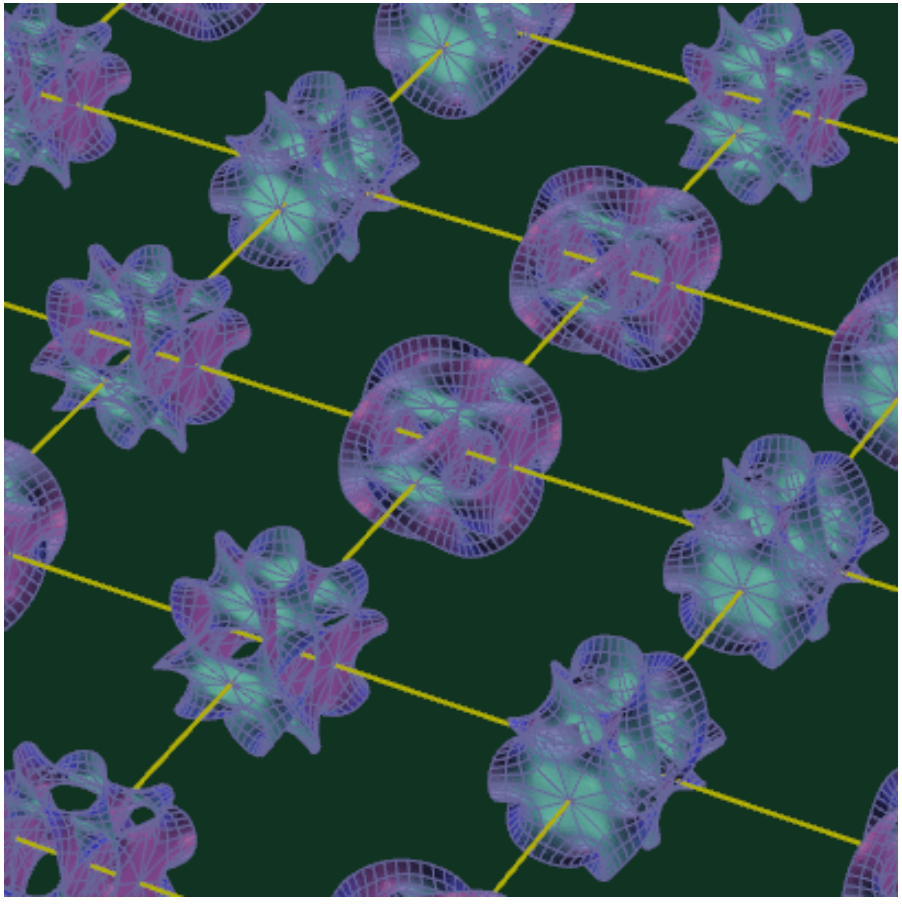
SI Cross Section vs. Mass

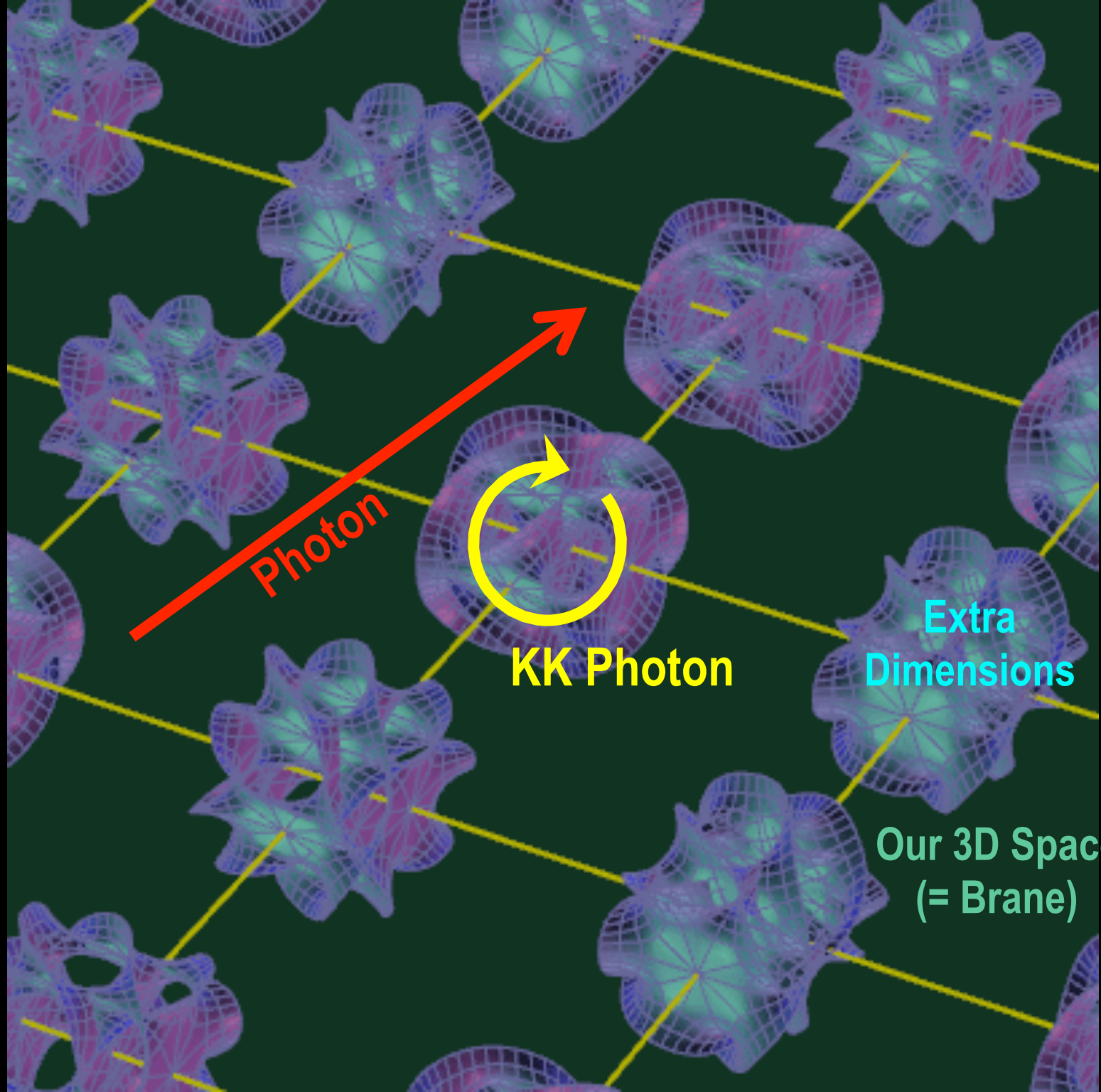


Is Supersymmetry in trouble?

Buchmueller et al arXiv:1106.2529

KK particles in Extra Dimensions




Photon
KK Photon
Extra
Dimensions
Bulk
Our 3D Space
(= Brane)

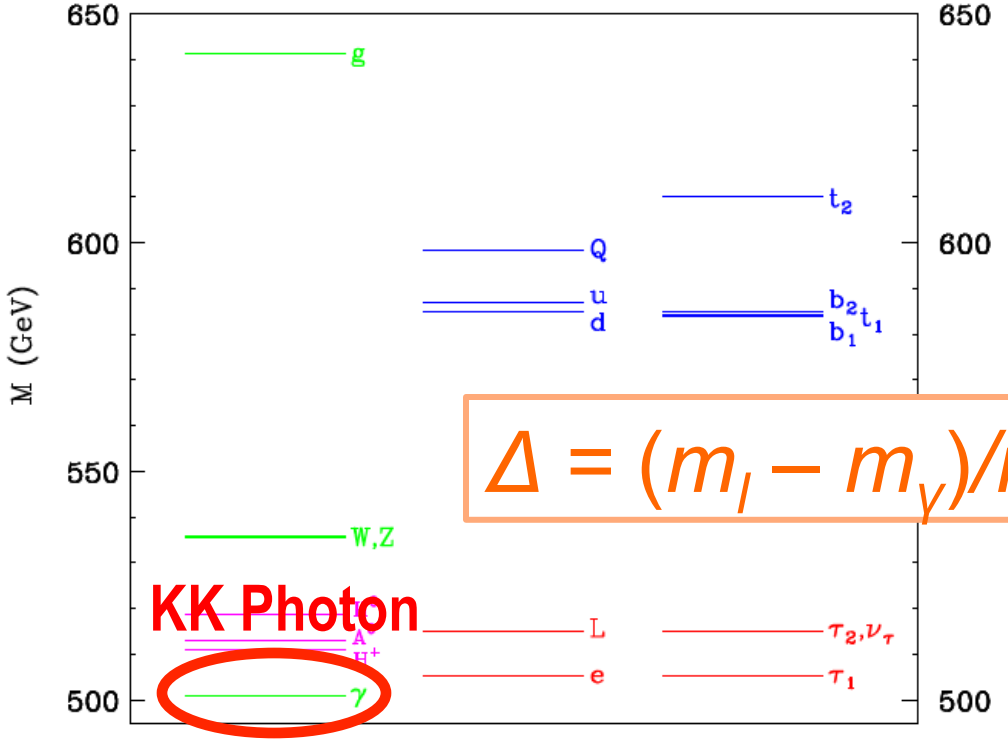
Origin of Mass in Extra Dimensions

$$E = mc^2 \rightarrow \boxed{m = E/c^2}$$

- **Mass can be generated as kinetic energy in extra dimensions.**
  - Origin on mass
  - Dark matter is running in the extra dimensions
- **Gravity can escape into the extra dimensions.**
  - Why gravity is so small
  - Origin of dark energy

Mass Spectrum of the first KK level

Similar to the SUSY mass spectrum



$$\Delta = (m_l - m_\gamma)/m_\gamma$$

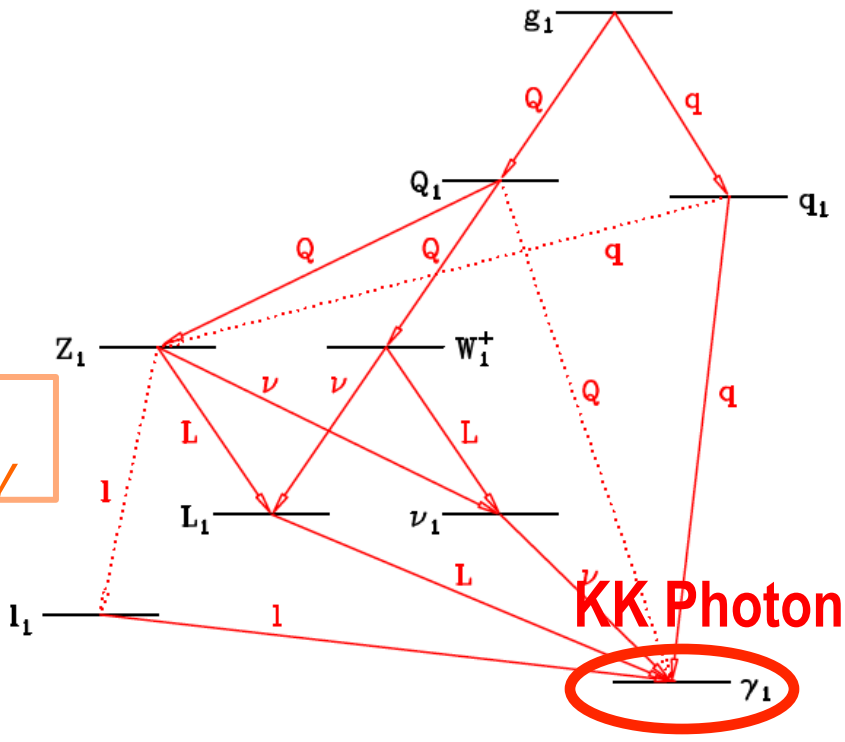
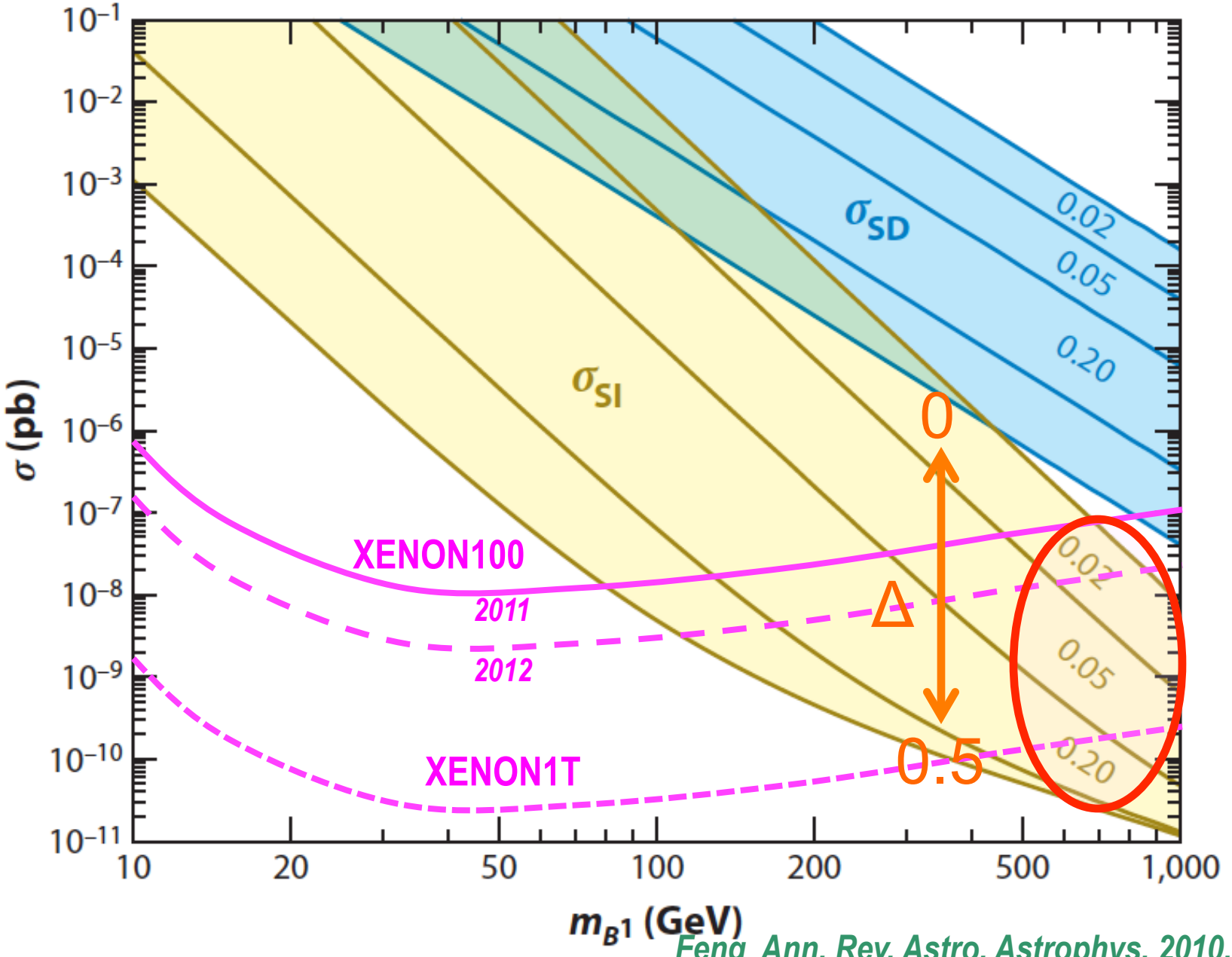


FIG. 1: *One-loop corrected mass spectrum of the first KK level in MUEDs for* $R^{-1} = 500$ *GeV,* $\Lambda R = 20$ *and* $m_h = 120$ *GeV.*

FIG. 3: *Qualitative sketch of the level 1 KK spectroscopy depicting the dominant (solid) and rare (dotted) transitions and the resulting decay product.*

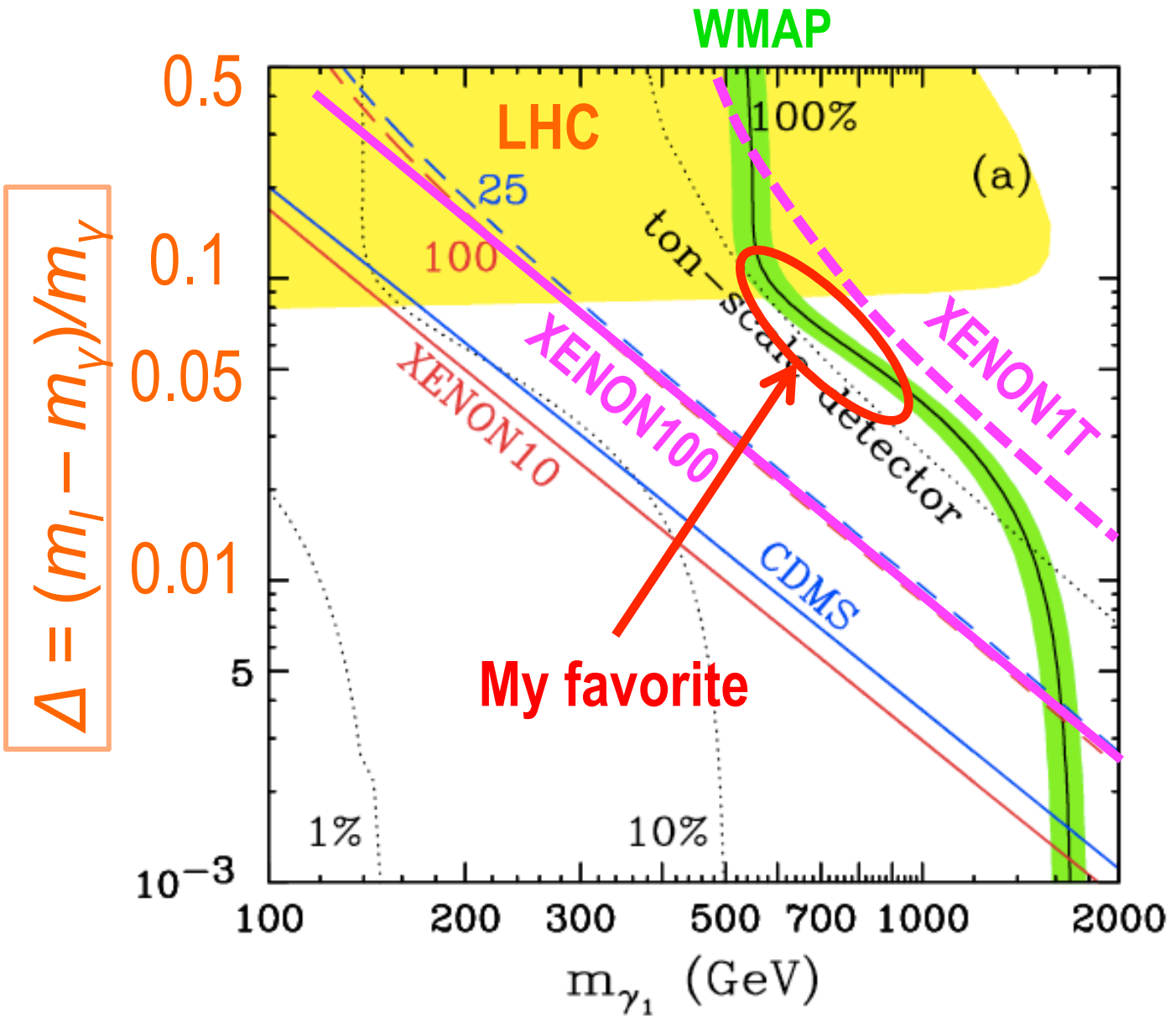
Cheng 2002 arXiv:hep-ph/0205314v1

Predicted Cross Section of Kaluza-Klein Dark Matter



Feng Ann. Rev. Astro. Astrophys. 2010.48:495-545

Sensitivity to KK particles



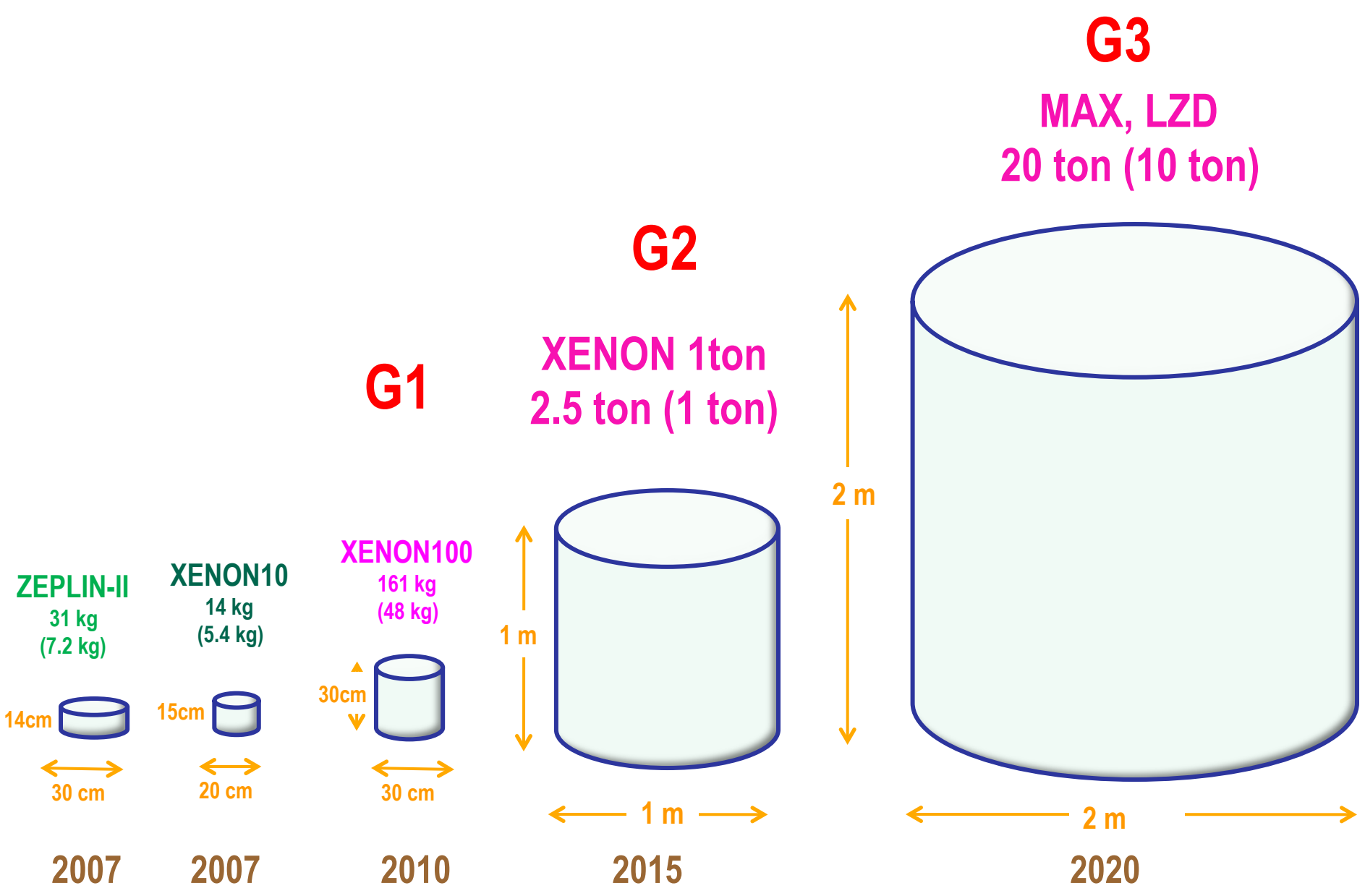
Arrenberg 2008

Summary on "Science Cases"

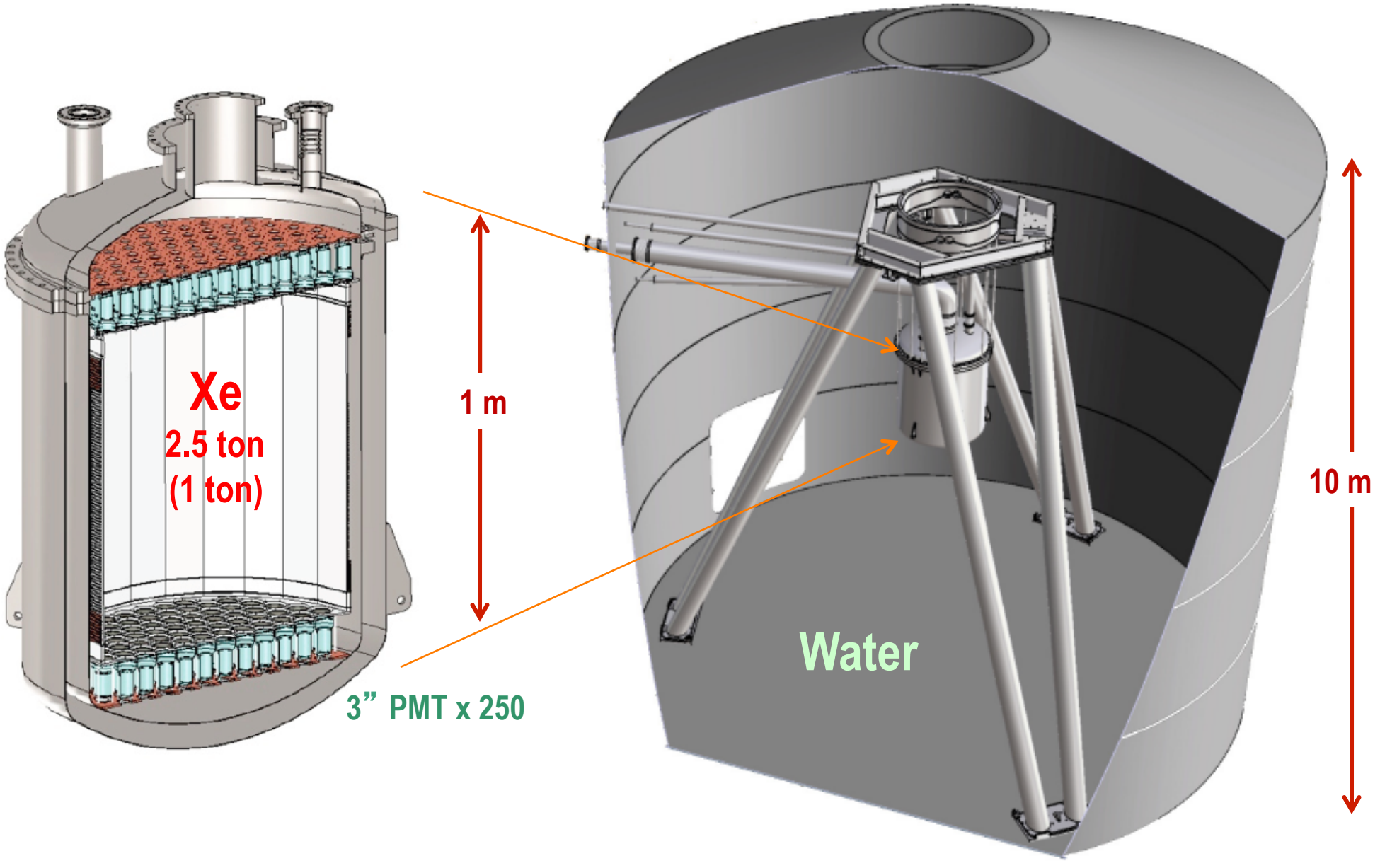
- XENON program (~$10M) is extremely timely and competitive to LHC (~$10B)
  - XENON100 ~ Current LHC
  - XENON1T ~ Future LHC
- If new physics at 100 – 1000 GeV (as it should be), LHC and/or XENON1T will discover WIMPs.
  - SUSY - Neutralino
  - Extra Dimensions – KK photon
- By combining LHC and XENON1T, we have a better chance to untangle large parameter spaces.

G2 & G3 Detectors

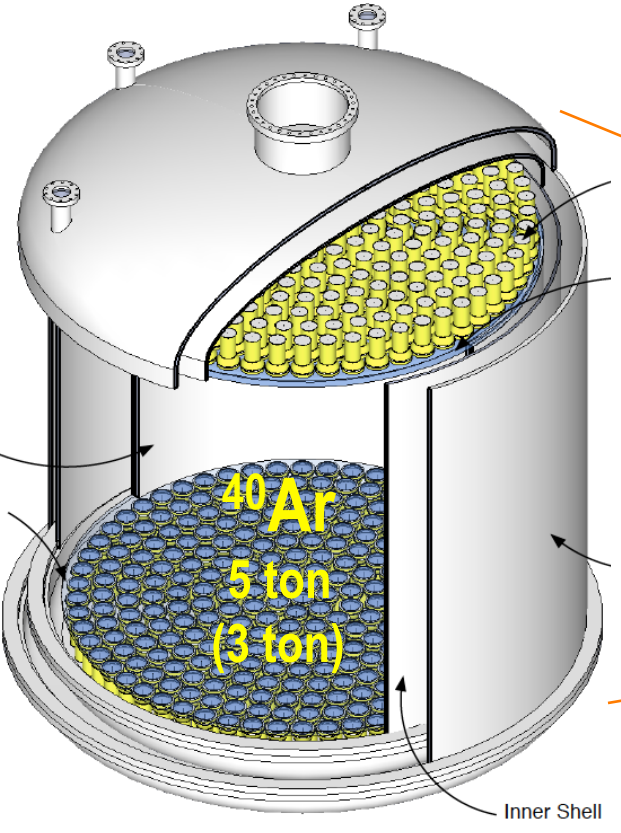
Comparison of Xenon Detector Size



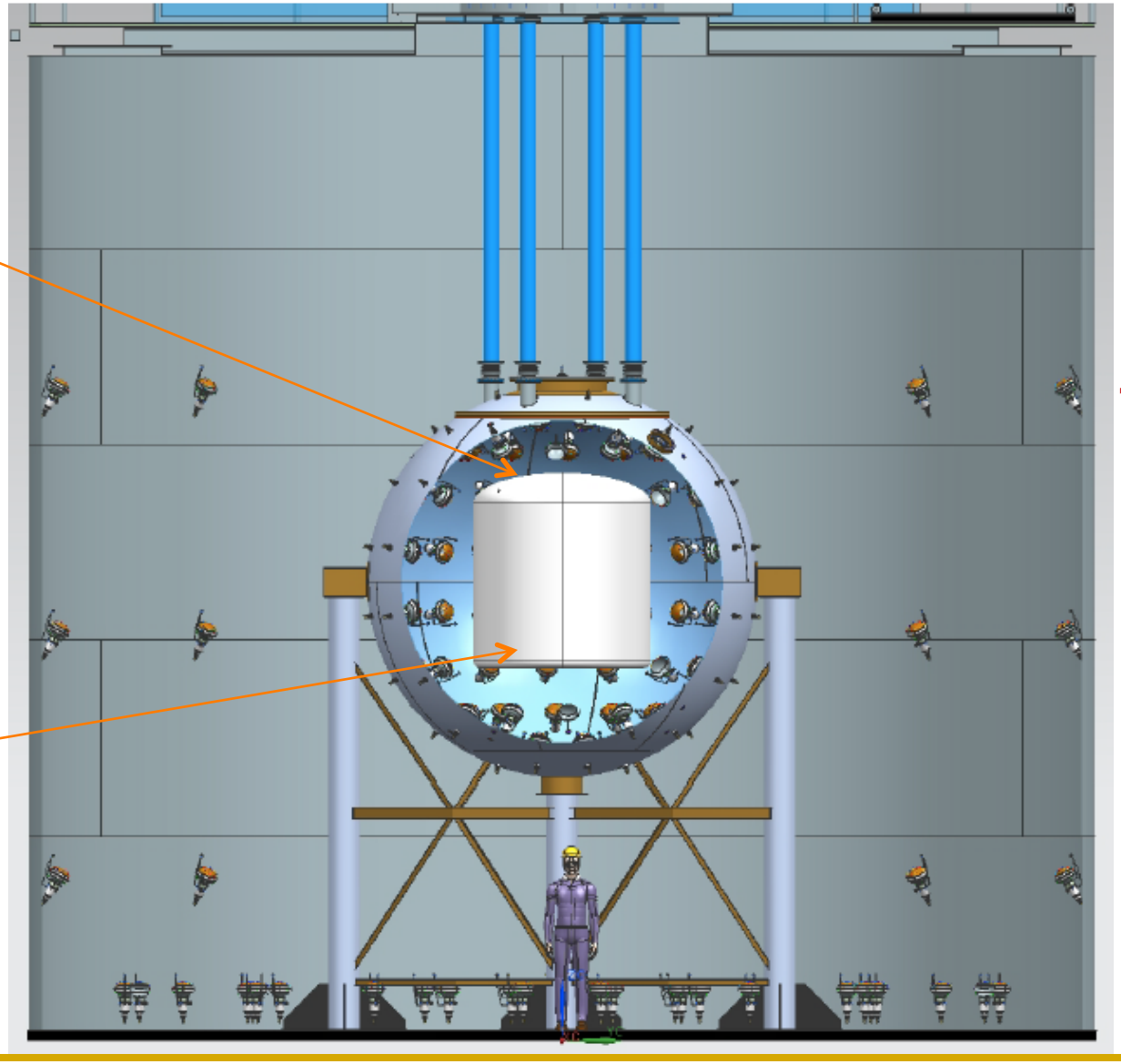
XENON 1T (G2) at Gran Sasso



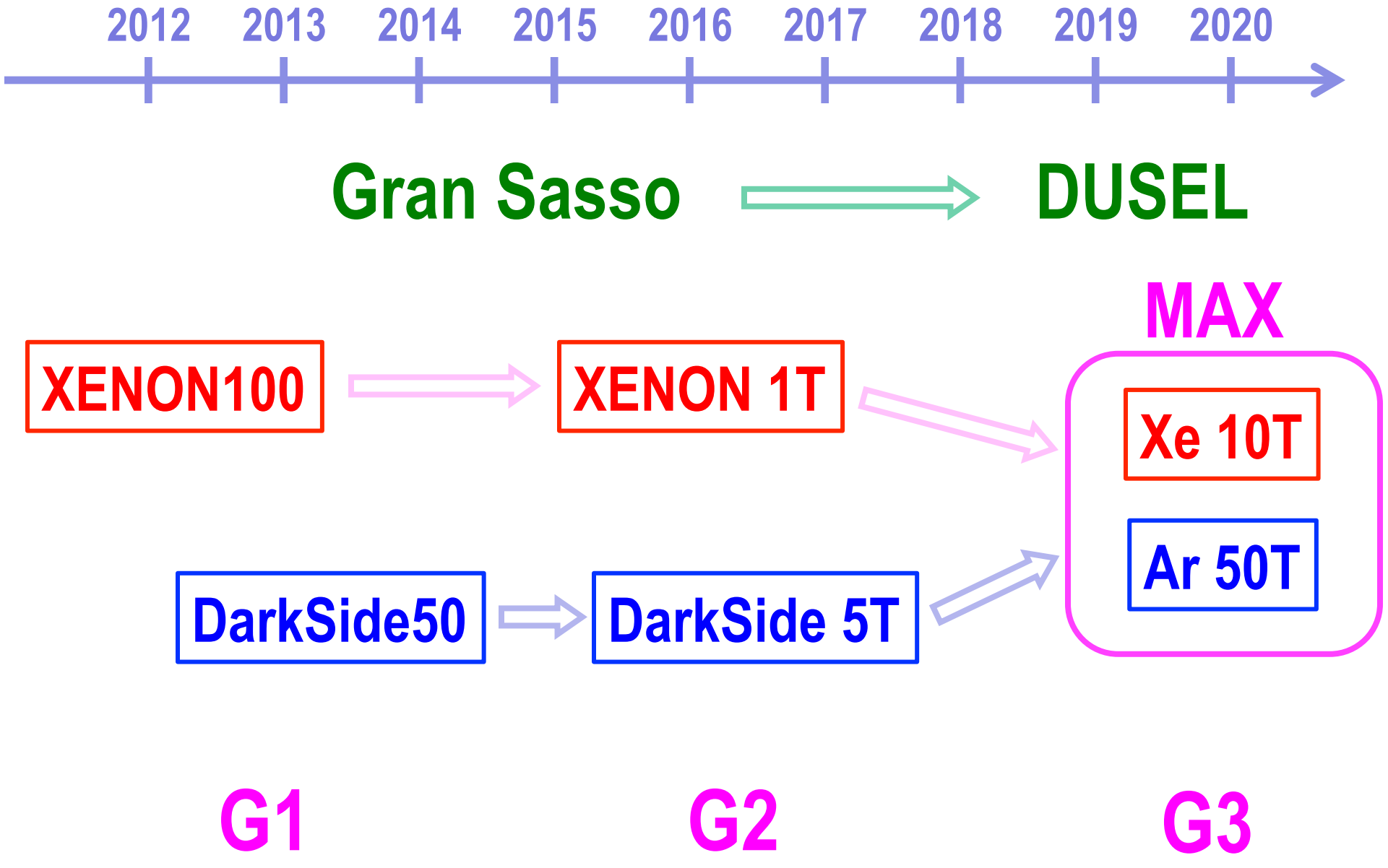
DarkSide 5T (G2) at Gran Sasso



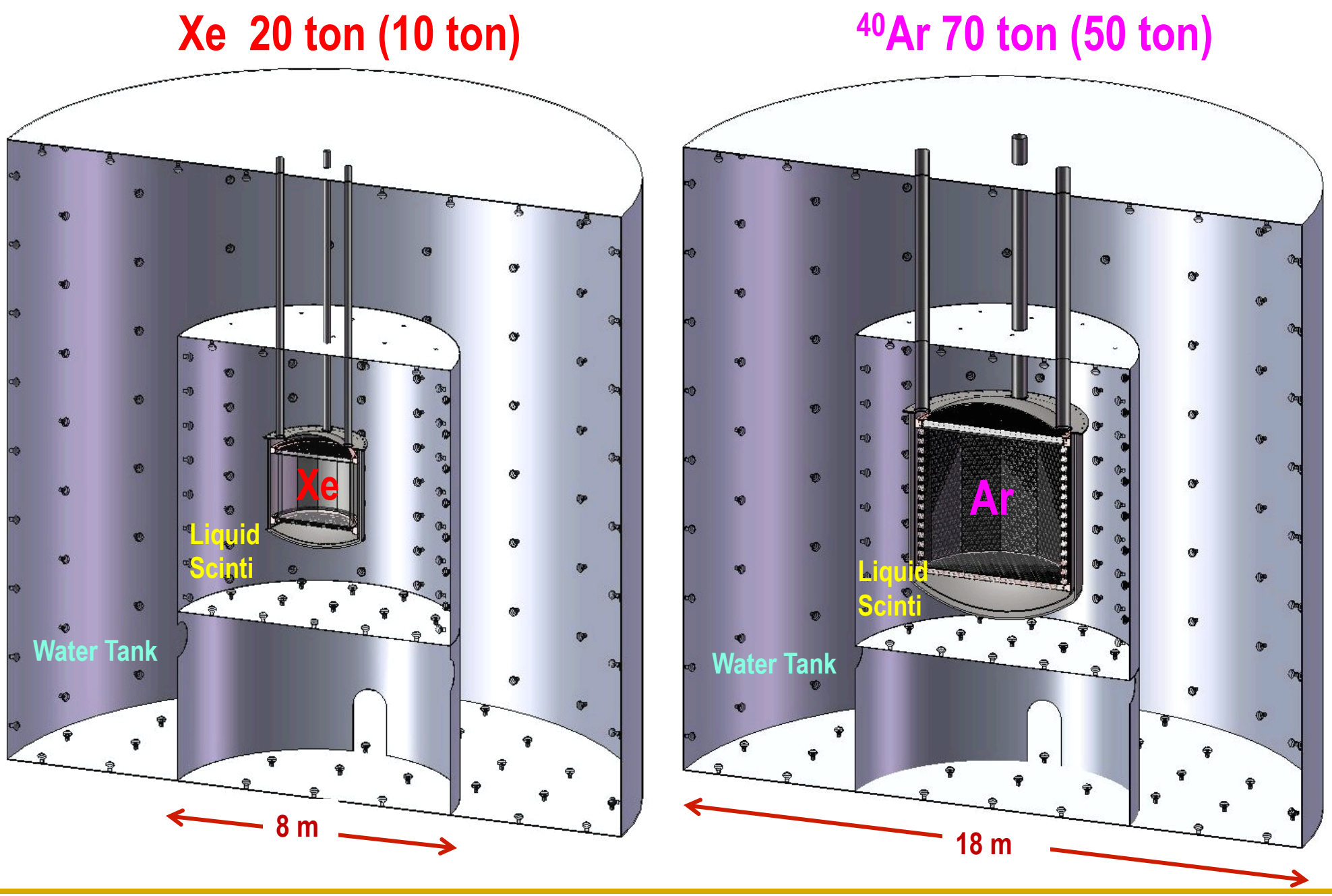
3" PMT x 600

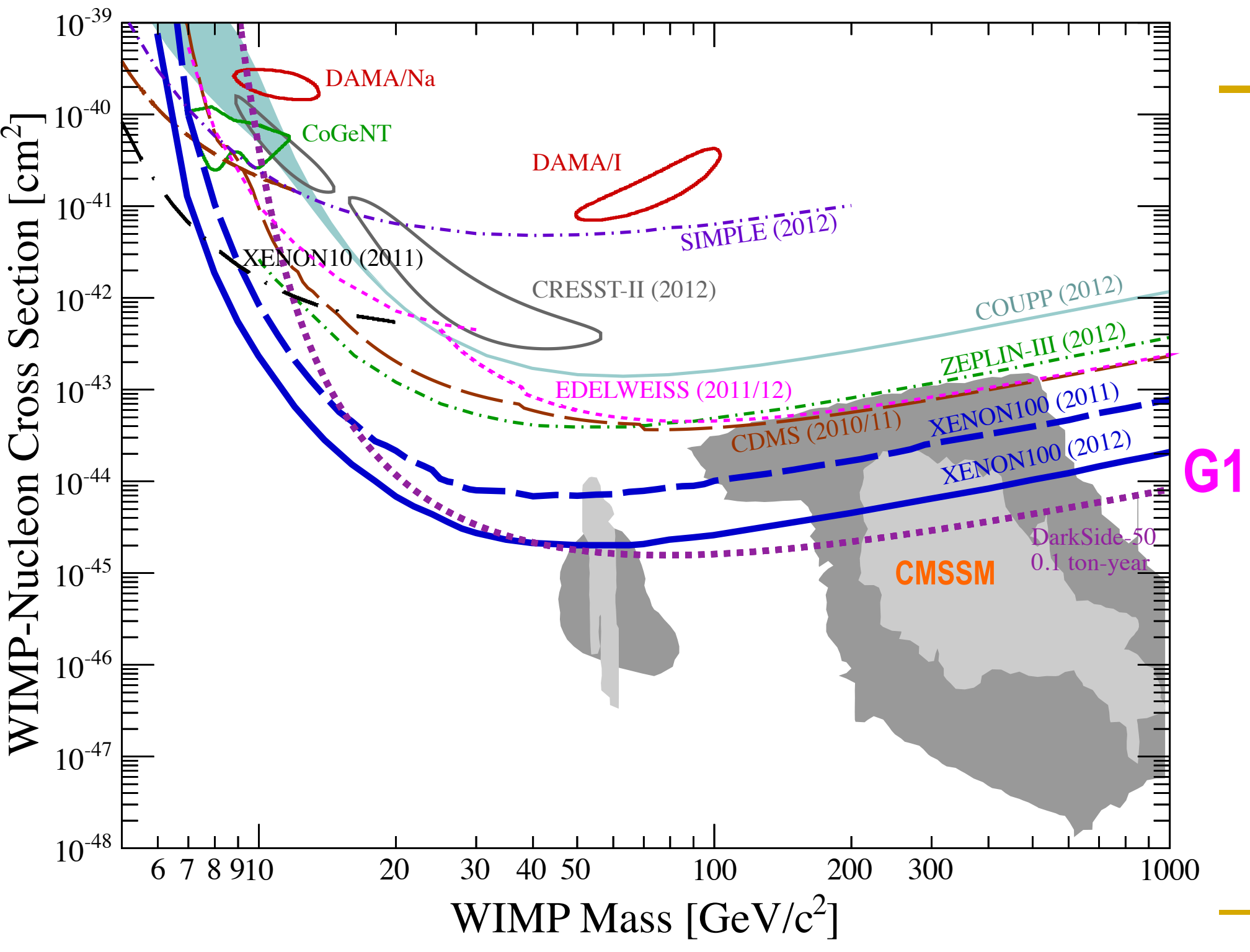


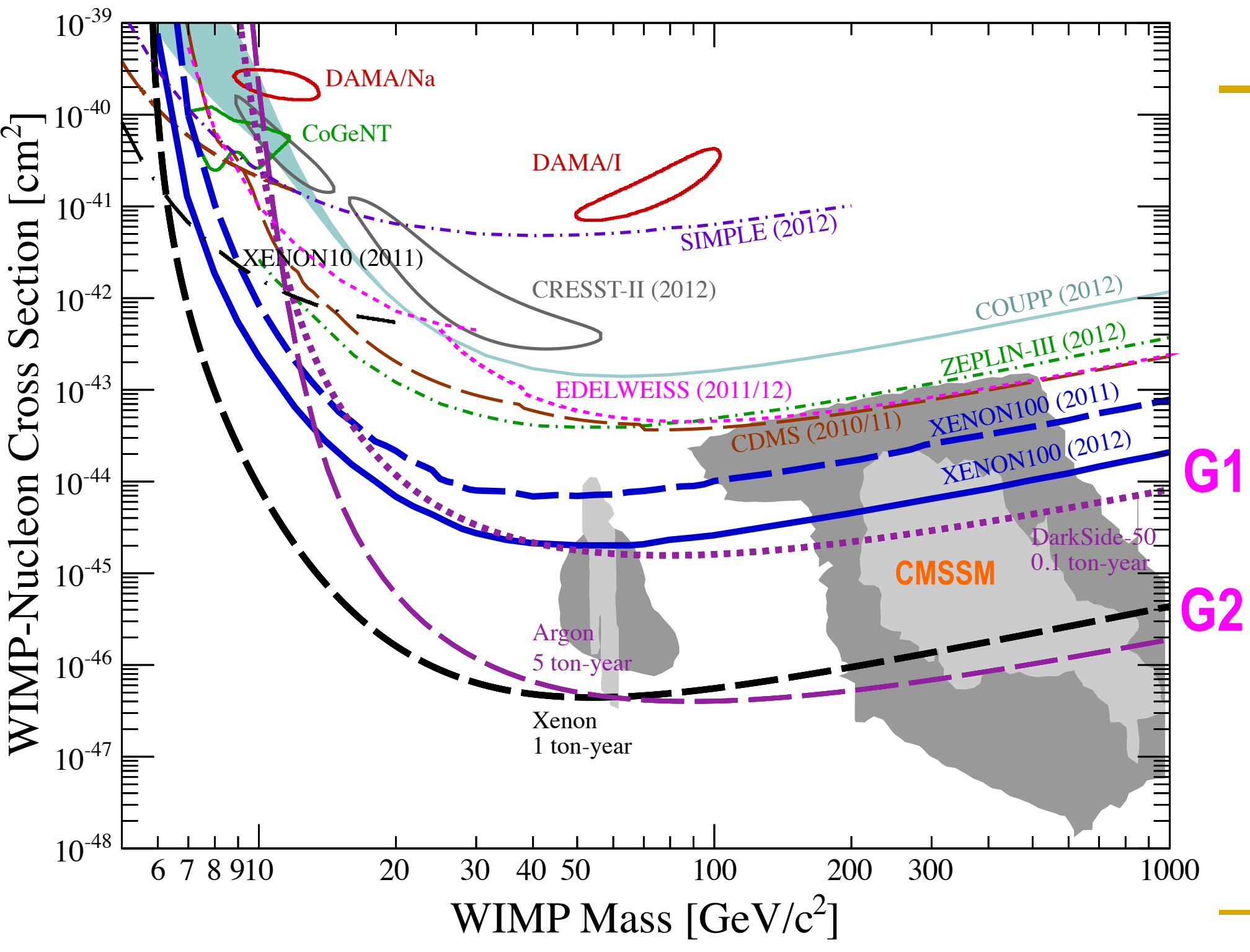
Roadmap to MAX

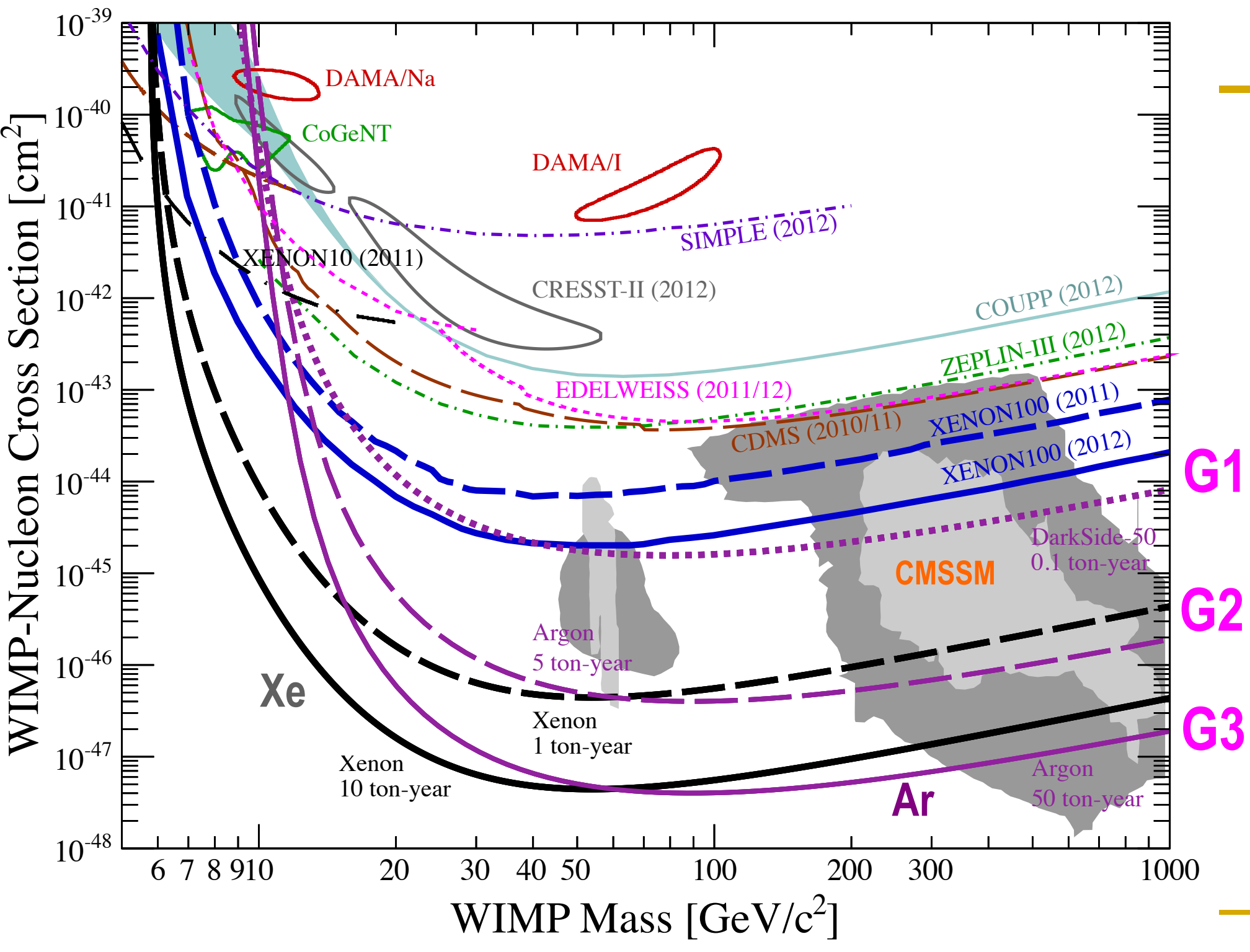


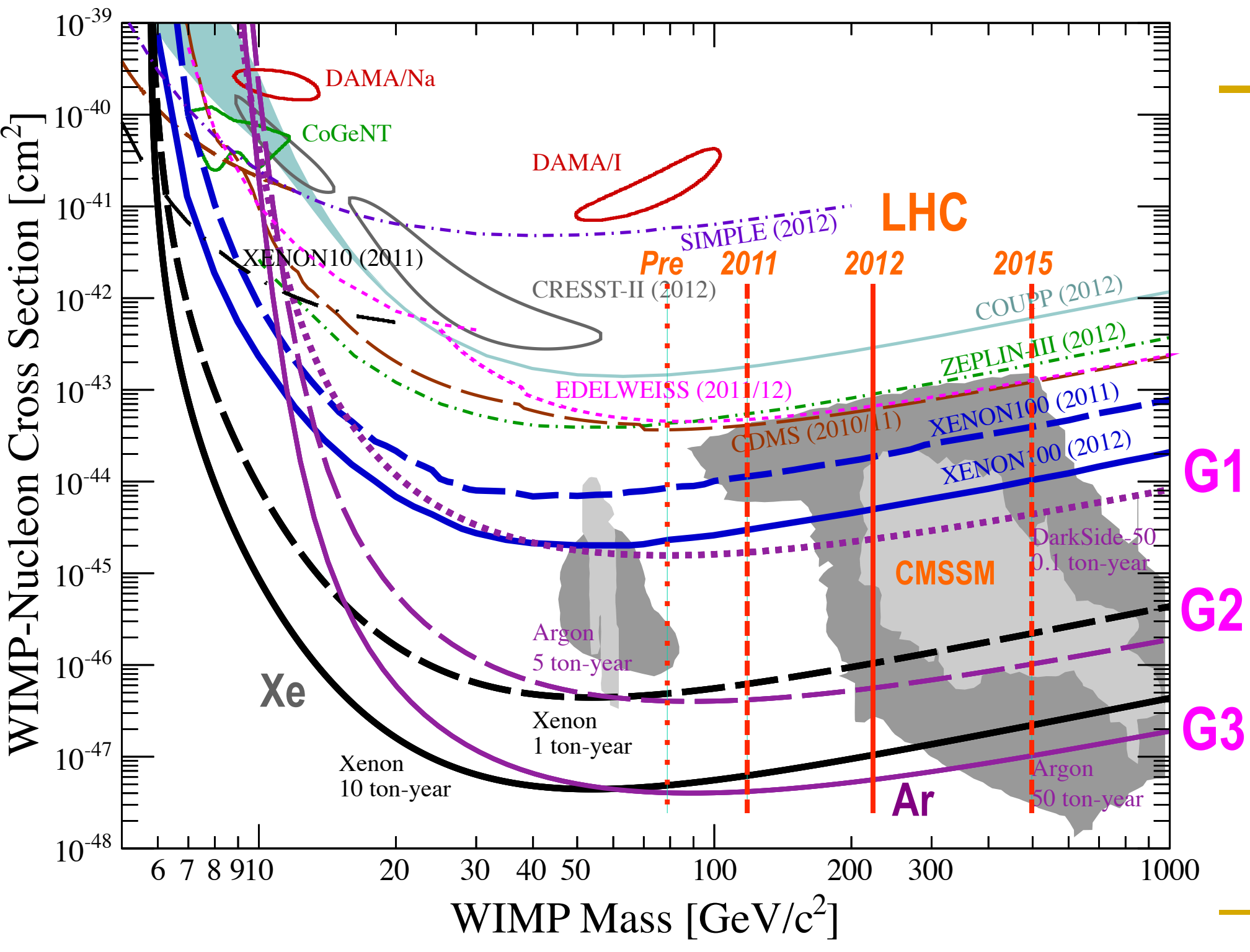
MAX+LZD = "Ultimate G3" Detector (at DUSEL)



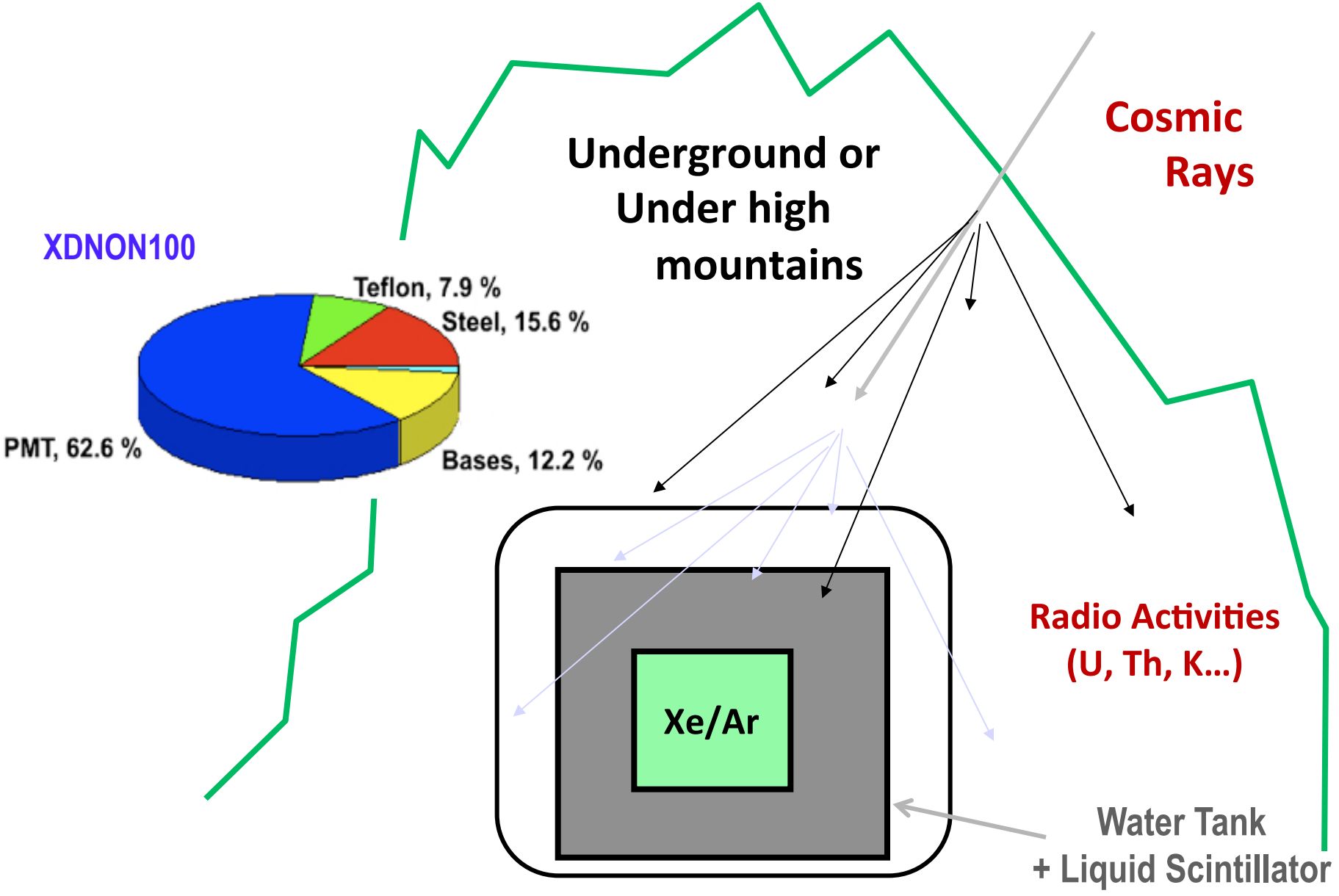

WIMP-Nucleon Cross Section [cm^2]
WIMP Mass [GeV/c^2]
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
6 7 8 9 10 20 30 40 50 100 200 300 1000
DAMA/Na
CoGeNT
DAMA/I
SIMPLE (2012)
XENON10 (2011)
CRESST-II (2012)
COUPP (2012)
ZEPLIN-III (2012)
EDELWEISS (2011/12)
CDMS (2010/11)
XENON100 (2011)
XENON100 (2012)
DarkSide-50
0.1 ton-year
CMSSM
G1


WIMP-Nucleon Cross Section [cm^2]
WIMP Mass [GeV/c^2]
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
6 7 8 9 10 20 30 40 50 100 200 300 1000
DAMA/Na
CoGeNT
DAMA/I
SIMPLE (2012)
XENON10 (2011)
CRESST-II (2012)
COUPP (2012)
ZEPLIN-III (2012)
EDELWEISS (2011/12)
CDMS (2010/11)
XENON100 (2011)
XENON100 (2012)
G1
DarkSide-50
0.1 ton-year
CMSSM
G2
Argon
5 ton-year
Xenon
1 ton-year


WIMP-Nucleon Cross Section [cm^2]
WIMP Mass [GeV/c^2]
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
6 7 8 9 10 20 30 40 50 100 200 300 1000
DAMA/Na
CoGeNT
DAMA/I
SIMPLE (2012)
XENON10 (2011)
CRESST-II (2012)
COUPP (2012)
ZEPLIN-III (2012)
EDELWEISS (2011/12)
CDMS (2010/11)
XENON100 (2011)
XENON100 (2012)
G1
DarkSide-50
0.1 ton-year
CMSSM
G2
Argon
5 ton-year
Xe
Xenon
1 ton-year
G3
Xenon
10 ton-year
Argon
50 ton-year
Ar


WIMP-Nucleon Cross Section [cm^2]
WIMP Mass [GeV/c^2]
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
6 7 8 9 10 20 30 40 50 100 200 300 1000
DAMA/Na
CoGeNT
DAMA/I
SIMPLE (2012)
LHC
Pre
2011
2012
2015
XENON10 (2011)
CRESST-II (2012)
COUPP (2012)
ZEPLIN-III (2012)
EDELWEISS (2011/12)
CDMS (2010/11)
XENON100 (2011)
XENON1T (2012)
G1
DarkSide-50
0.1 ton-year
CMSSM
G2
Argon
5 ton-year
Xe
Xenon
1 ton-year
G3
Xenon
10 ton-year
Ar
Argon
50 ton-year

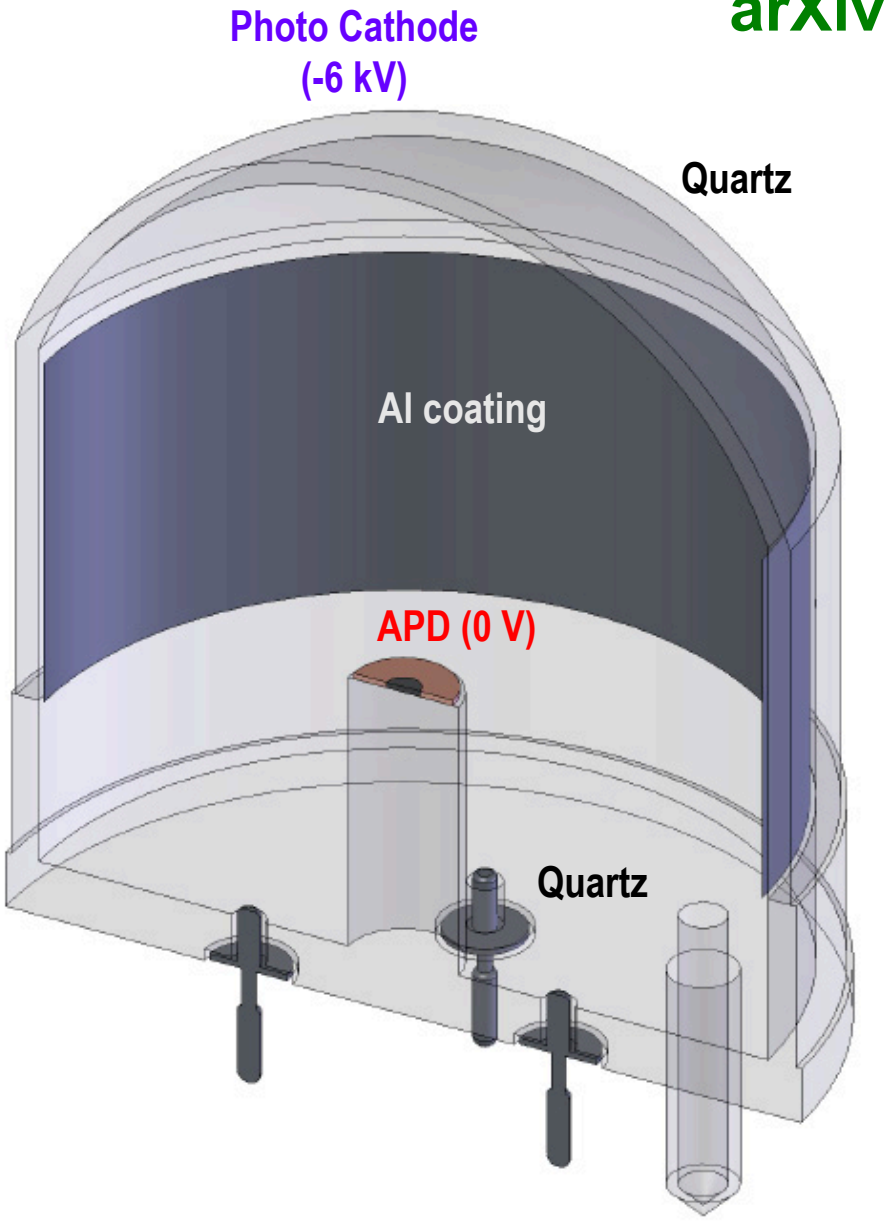
Where backgrounds come from?

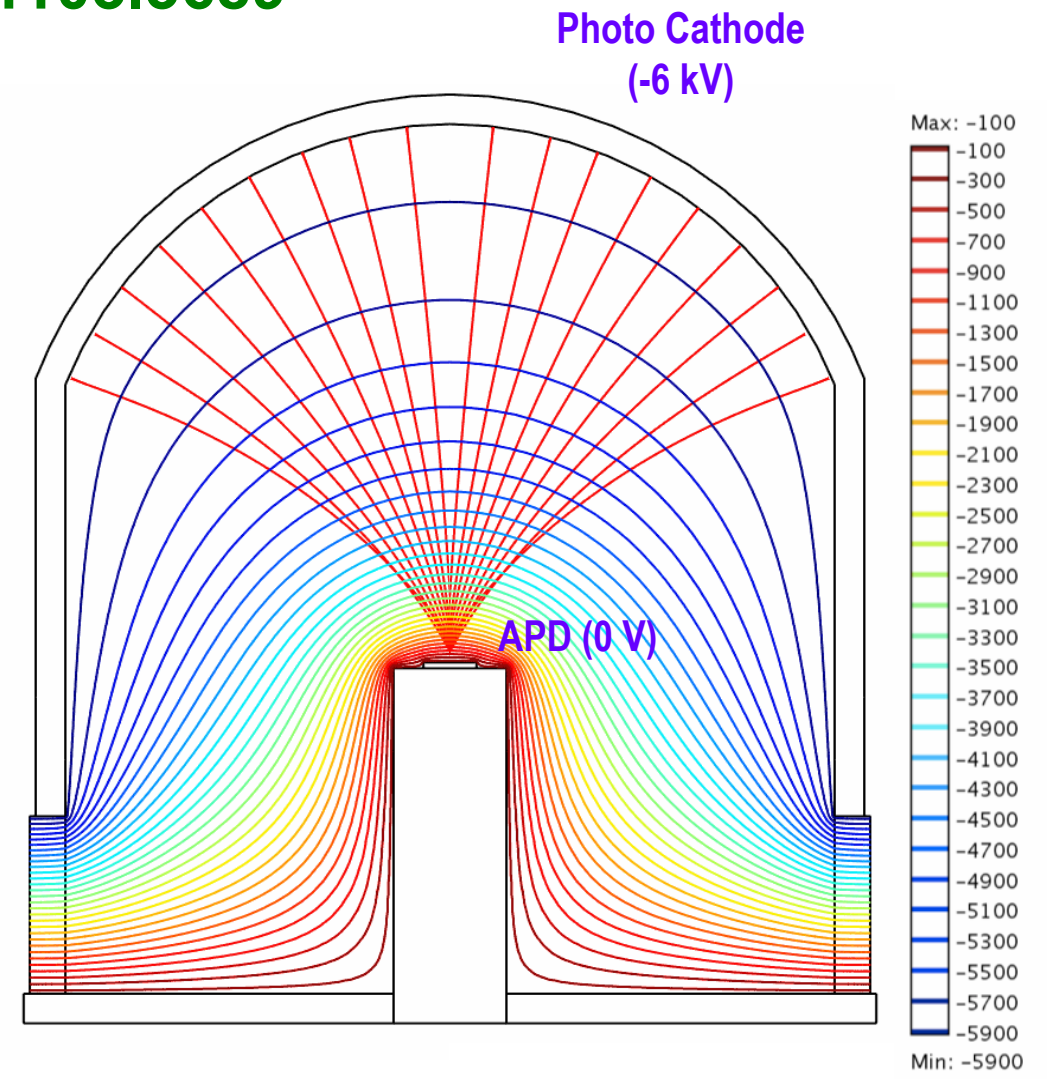


Photon detectors are the major source of backgrounds.

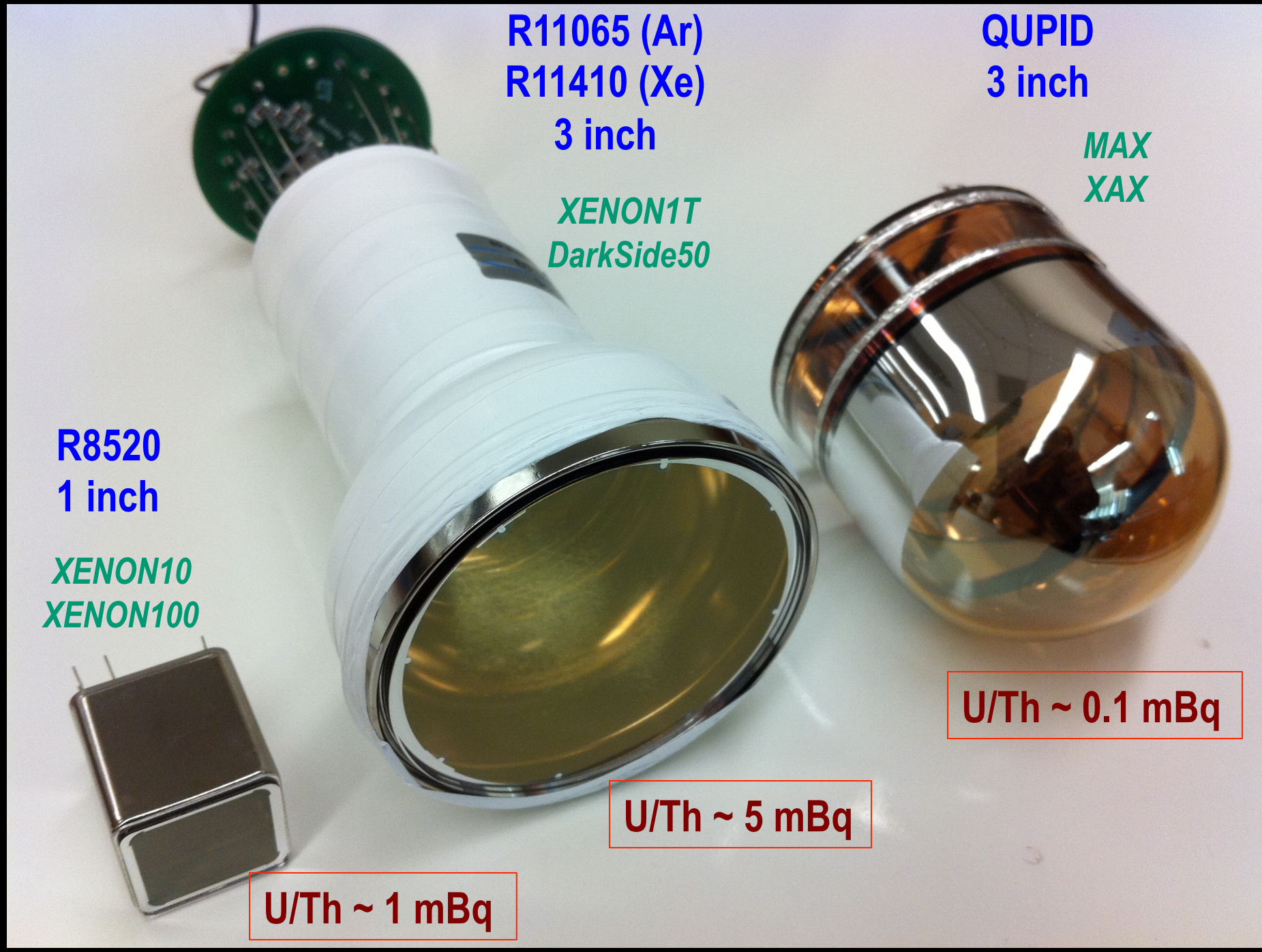
QUPID (QUartz Photon Intensifying Detector)

arXiv:1103.3689



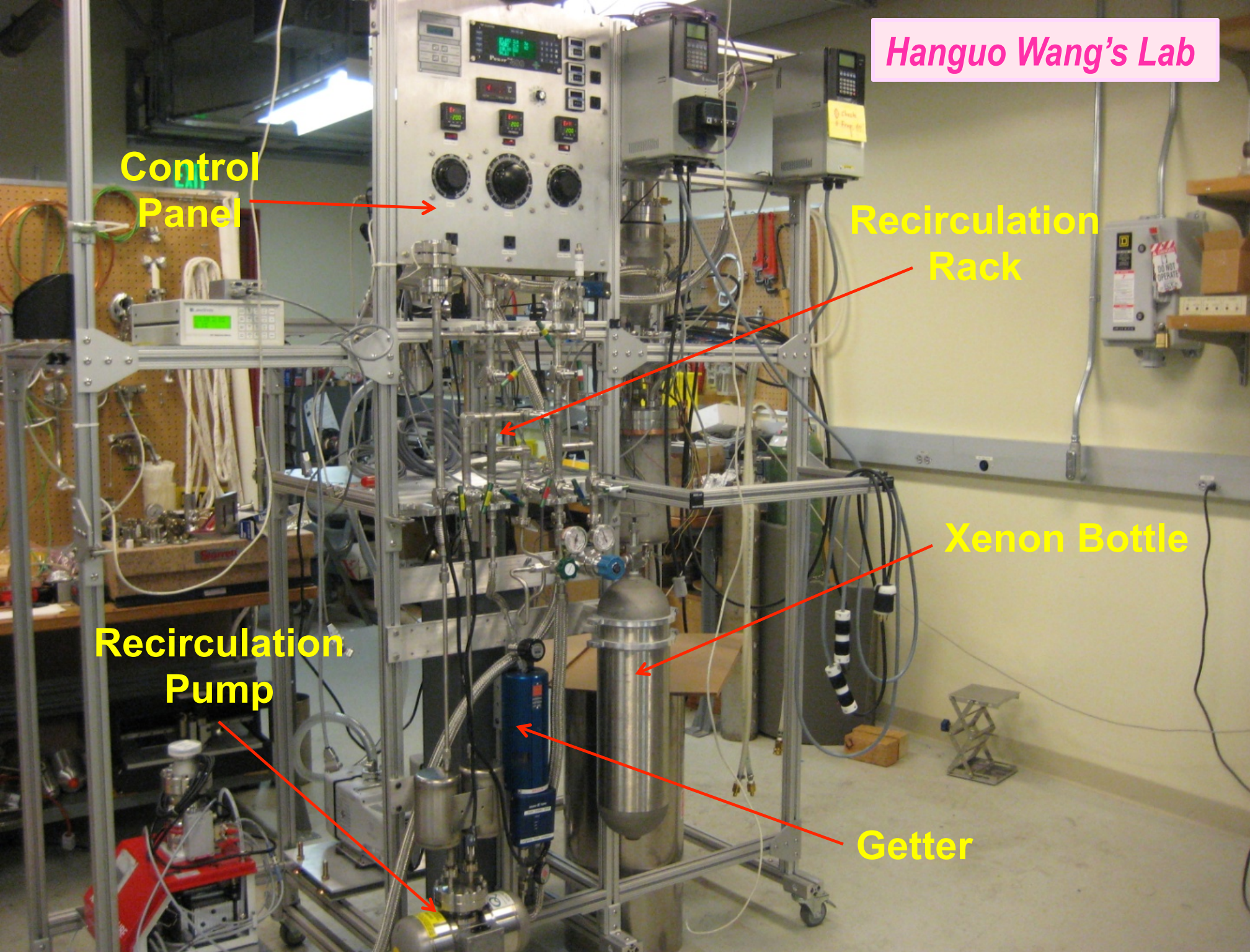


Comparison of Photon Detectors from Hamamatsu



7 QUPID with Holder

Tested in both Xe and Ar


Hanguo Wang's Lab
Control Panel
Recirculation Rack
Xenon Bottle
Recirculation Pump
Getter

Conclusions

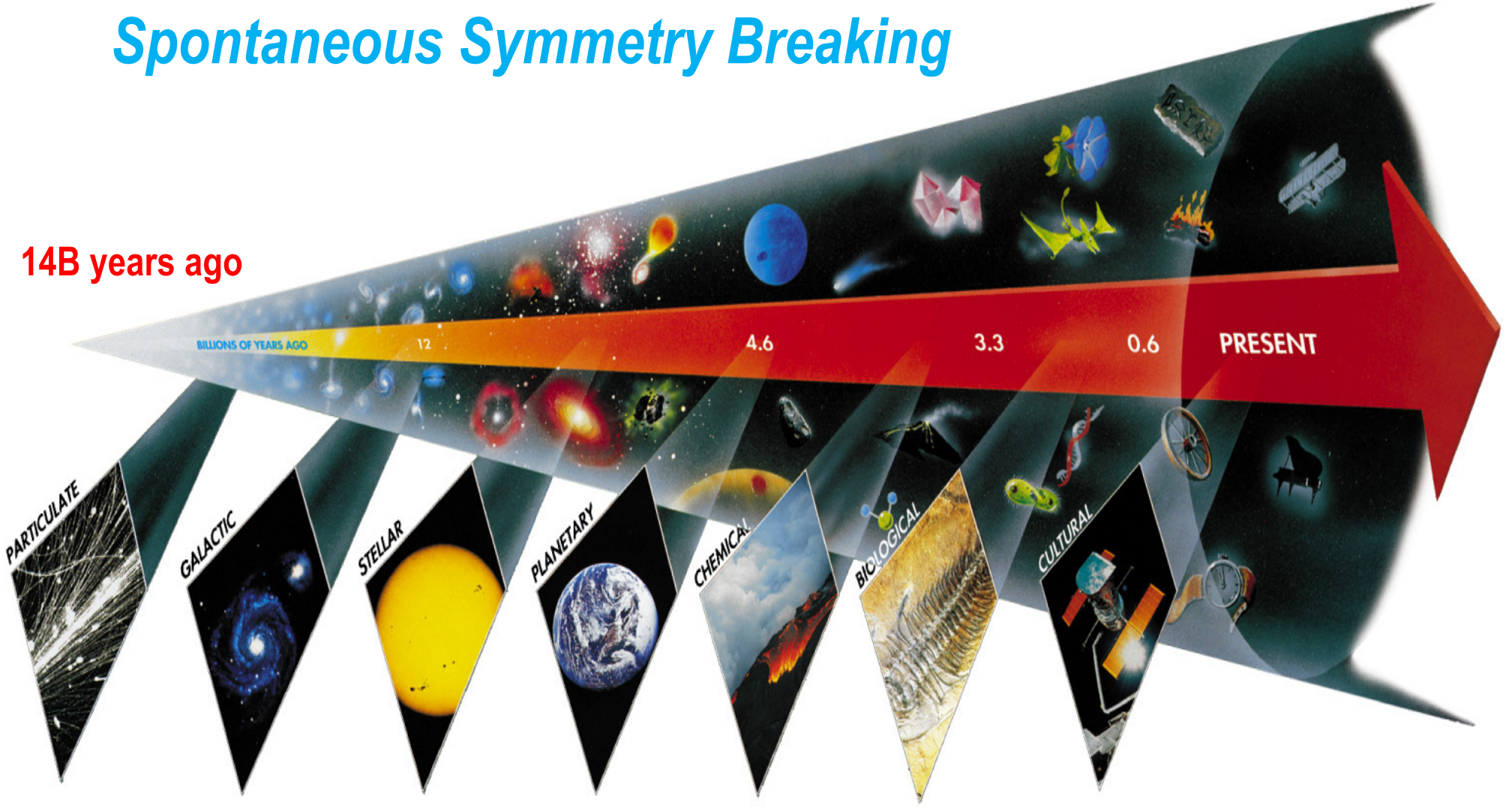
- **Science Cases**
  - Overwhelming – Astronomy and Cosmology
  - Beyond Standard Model – SUSY, Extra Dimensions…
- **Experimental Status**
  - Healthy competition between LHC ($10B) and XENON ($10M)
  - SUSY is pushed to the corner, *or* about to be discovered.
- **Future Direct Searches**
  - G2 : XENON 1T and DarkSide 5T at Gran Sasso.
  - G3 : MAX (Xe 10T + Ar 50T) at DUSEL

Katsushi's Speculations in Nov 2011

- 2012 LHC (ATLAS+CMS) announces
  - ~~120 GeV Higgs (at 3σ)~~
  - 125 GeV Higgs (at 5σ)
- 2017 XENON1T announces
  - Observation of 10 WIMP signals (> 200 GeV)
- 2022 G3 (Xe+Ar) and LHC jointly confirm
  - Extra Dimensions
  - WIMP = 700 GeV KK Photon (Δ = 5%)
  - No Supersymmetry
  - Katsushi happily retires at age 66.

Seven Phases of Cosmic Evolution

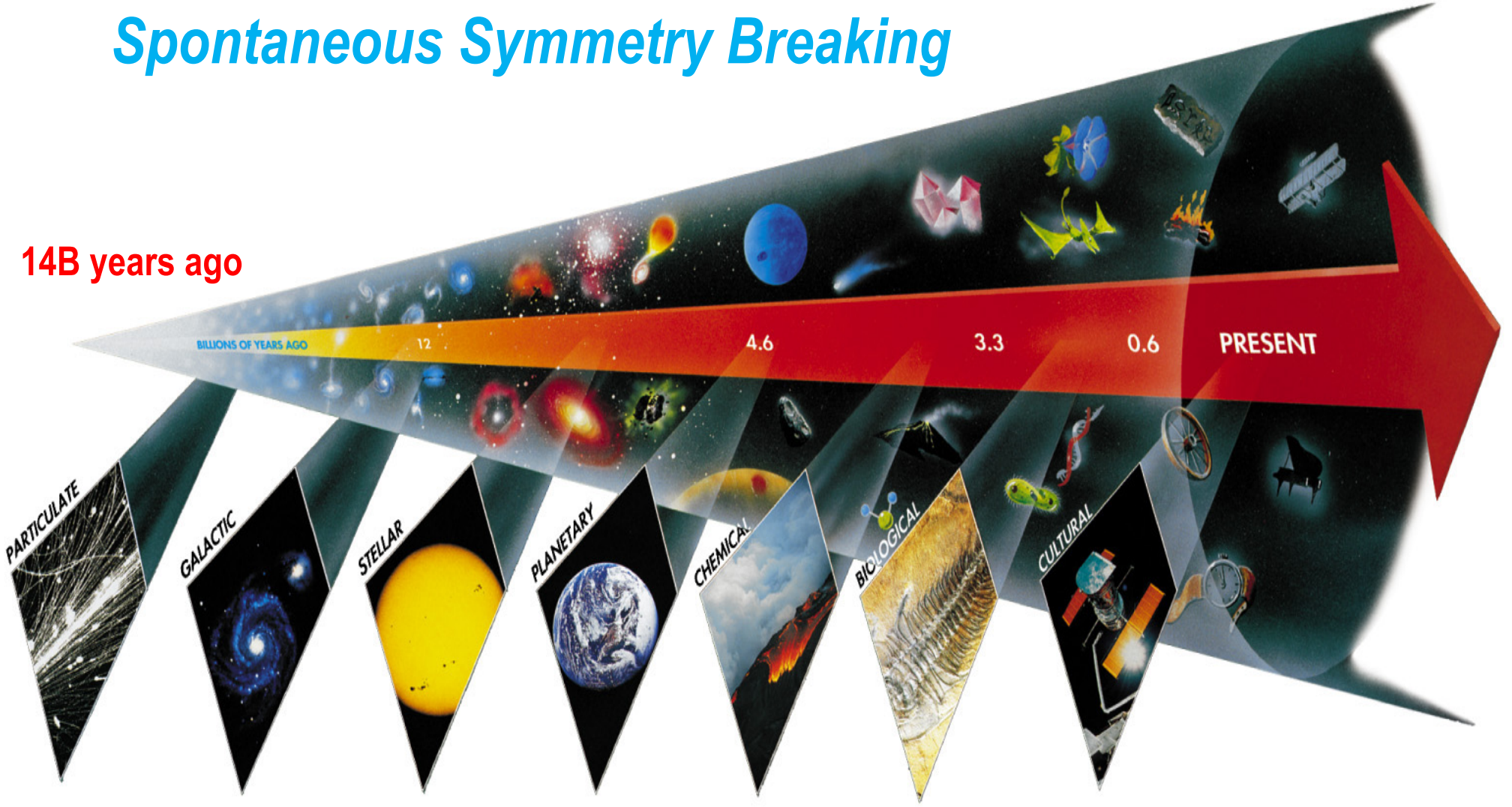
Spontaneous Symmetry Breaking



Simple ⟹ **Coherent Complex System**

Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking



Origin of Particles

Origin of Structure

Origin of Life

Origin of Consciousness

Talk Outline

- **Part I : Particle Physics & Cosmology** ~50 min.
  - Introduction to Cosmology: Origin of Universe
  - CMS at CERN: Origin of Particles
  - Detection of Dark Matter: Origin of Structure in Universe
- Lab Tour ~15 min.
- **Part II : Bio-imaging and Neuro-physics** ~50 min.
  - Introduction to High-speed Bio-imaging
  - Single Molecule: Origin of Life
  - Neurophysics: Origin of Consciousness