

Origin of the Universe, Particles and Structure

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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.**

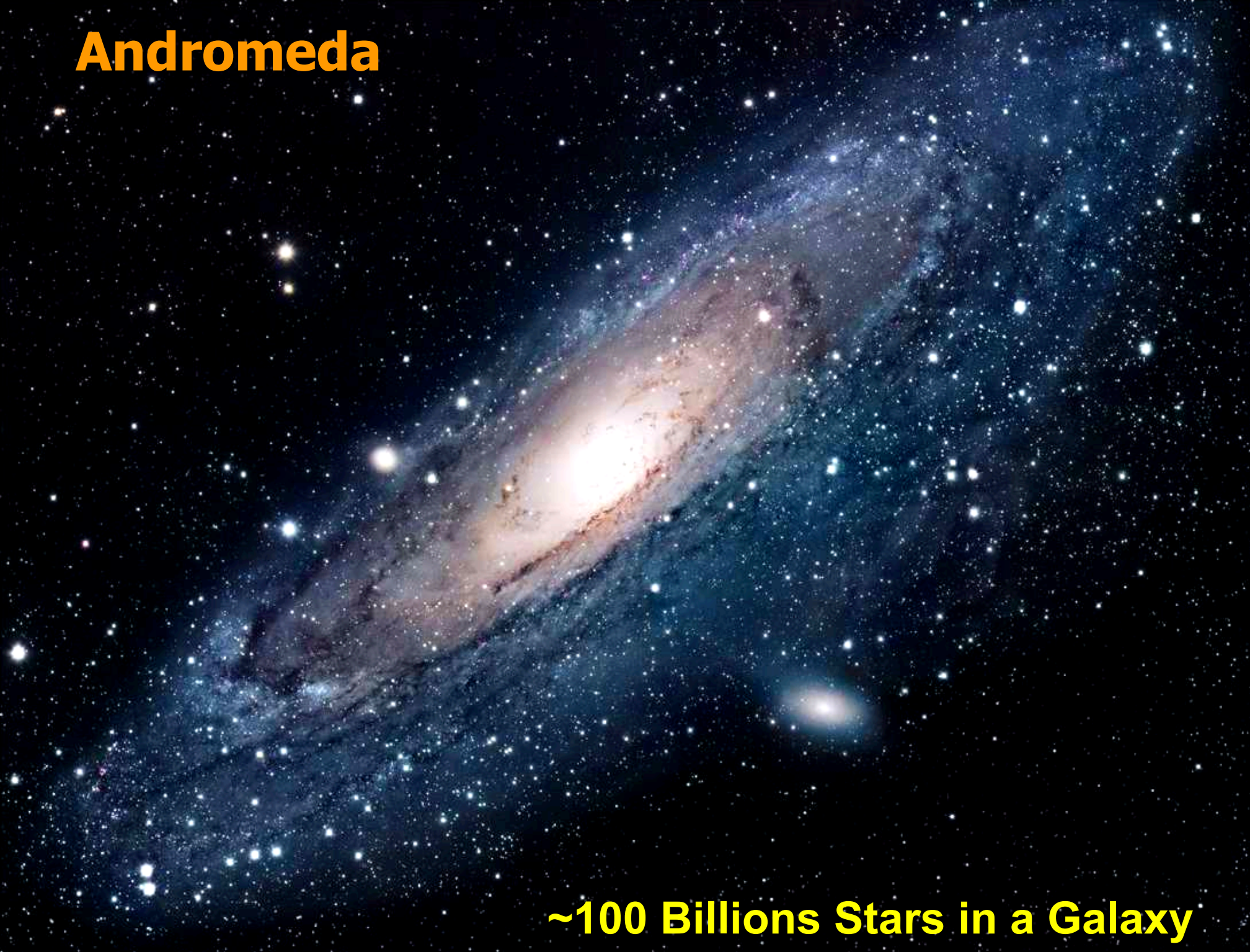
- **Part II : Bio-imaging and Neuro-physics** **~50 min.**
 - Introduction to High-speed Bio-imaging
 - Single Molecule: Origin of Life
 - Neurophysics: Origin of Consciousness



Why are we here?

Introduction to Cosmology

Andromeda

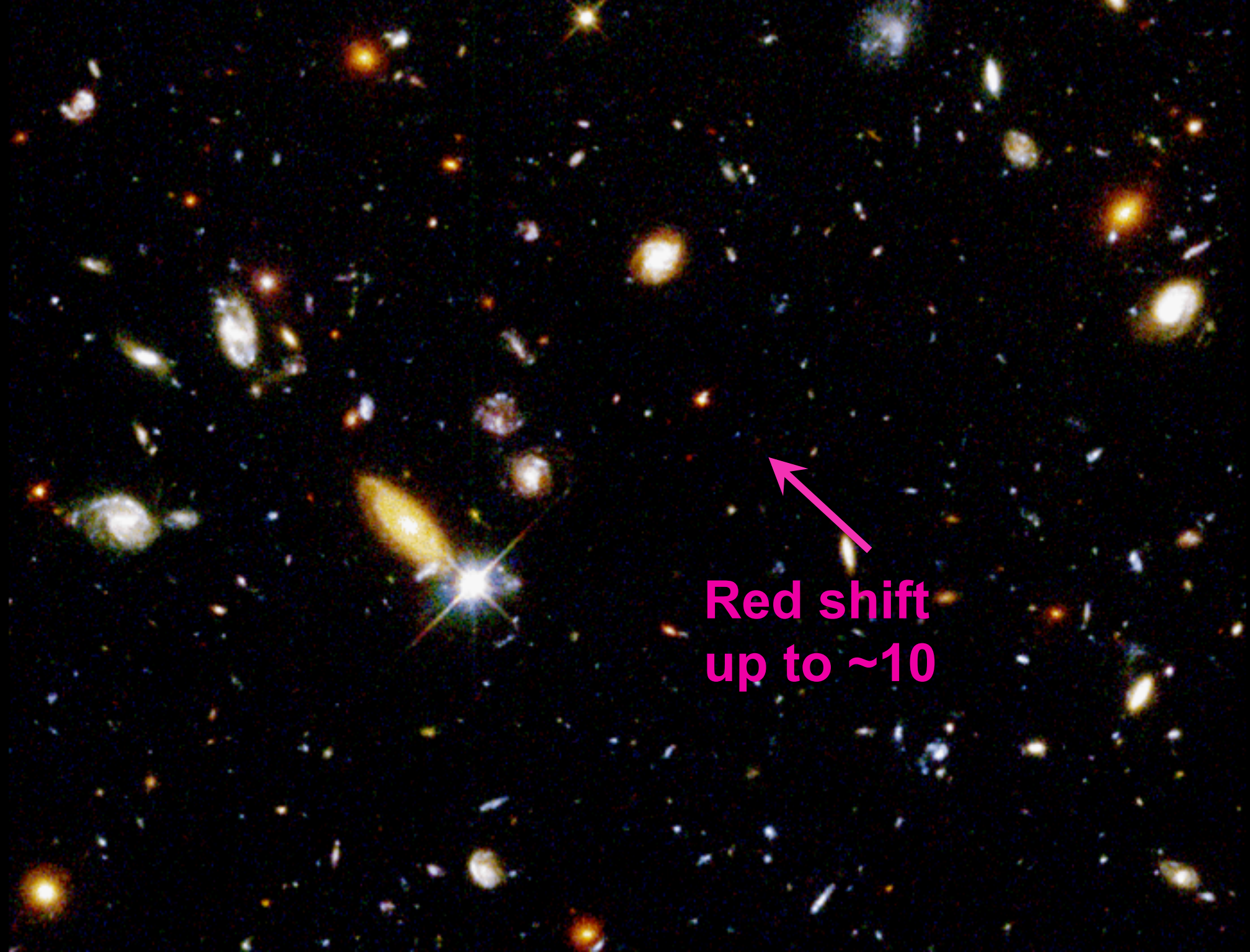


~100 Billions Stars in a Galaxy

Hubble Deep Field

The image displays a dense field of galaxies, including spiral, elliptical, and irregular shapes, scattered across a dark background. The galaxies vary in size and color, with some appearing as bright yellow or orange points and others as more complex, multi-colored structures. The overall appearance is that of a rich, multi-colored stellar population.

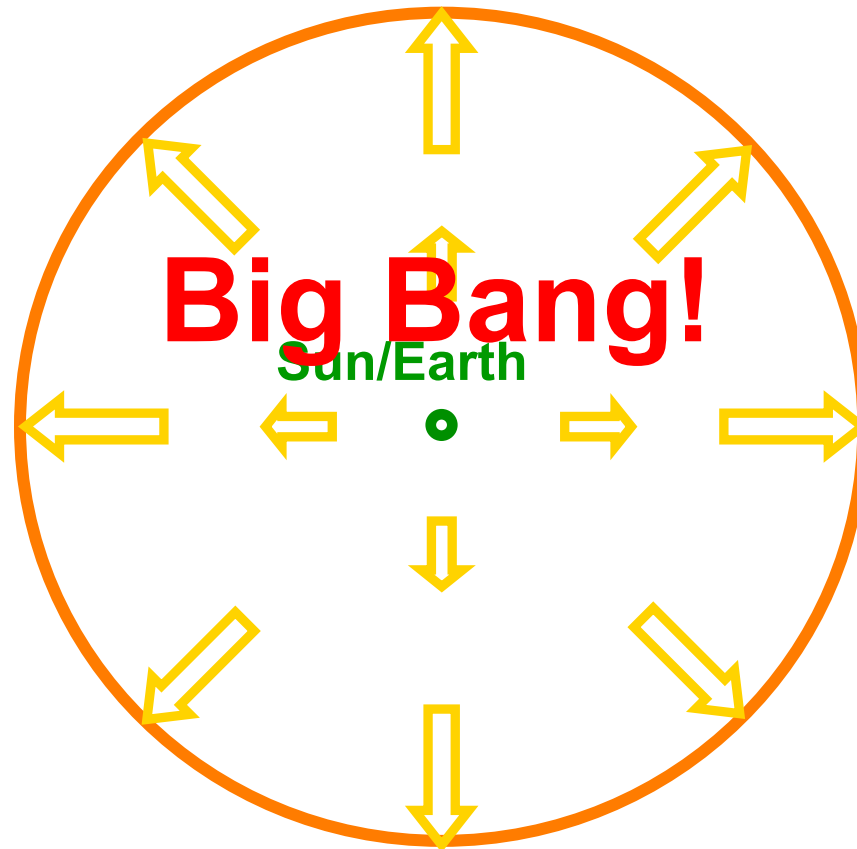
~100 Billion Galaxies



**Red shift
up to ~10**

Hubble's Law: Expansion of the Universe

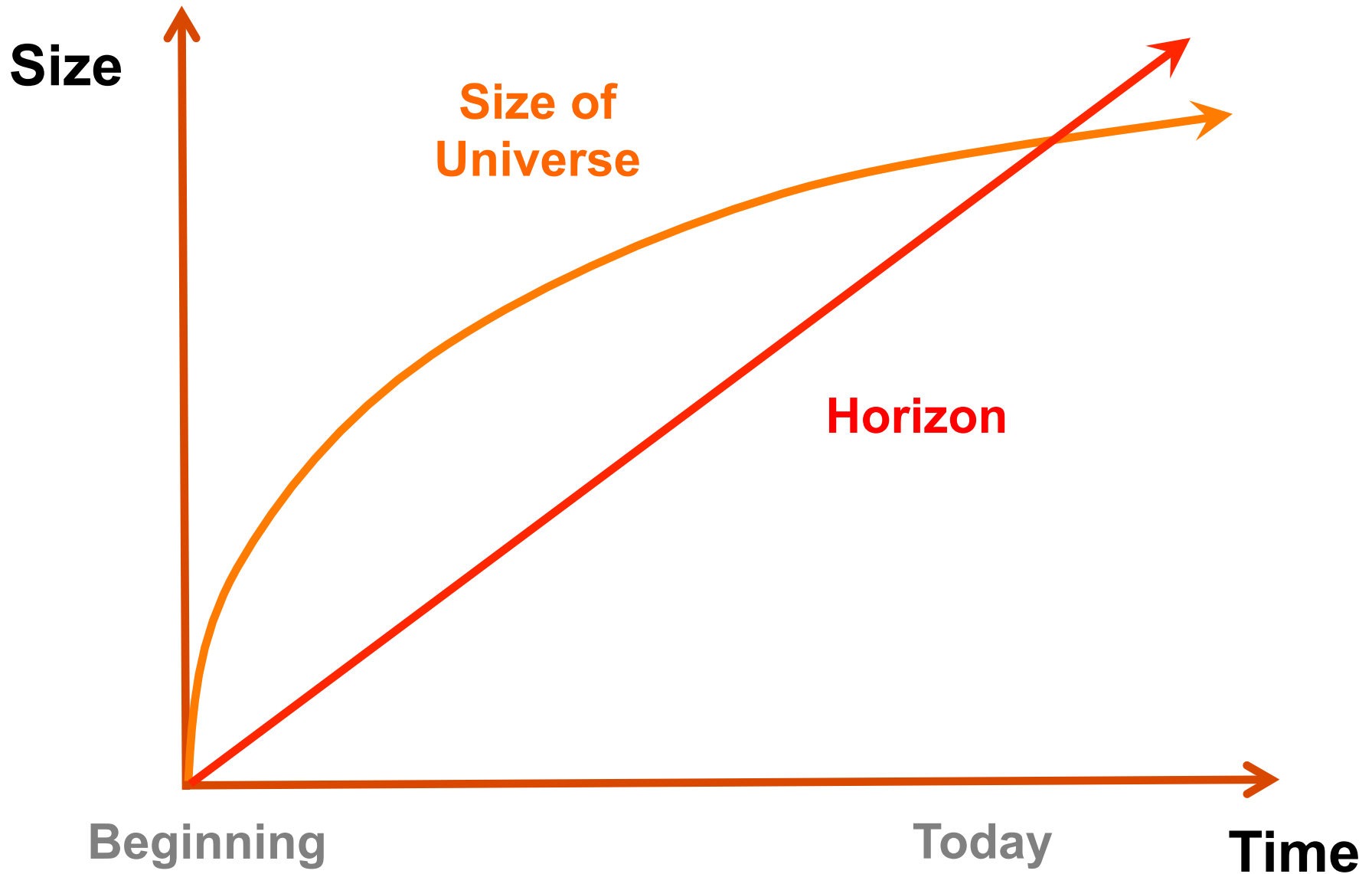
Horizon
of Universe



14 Billion
Light Years

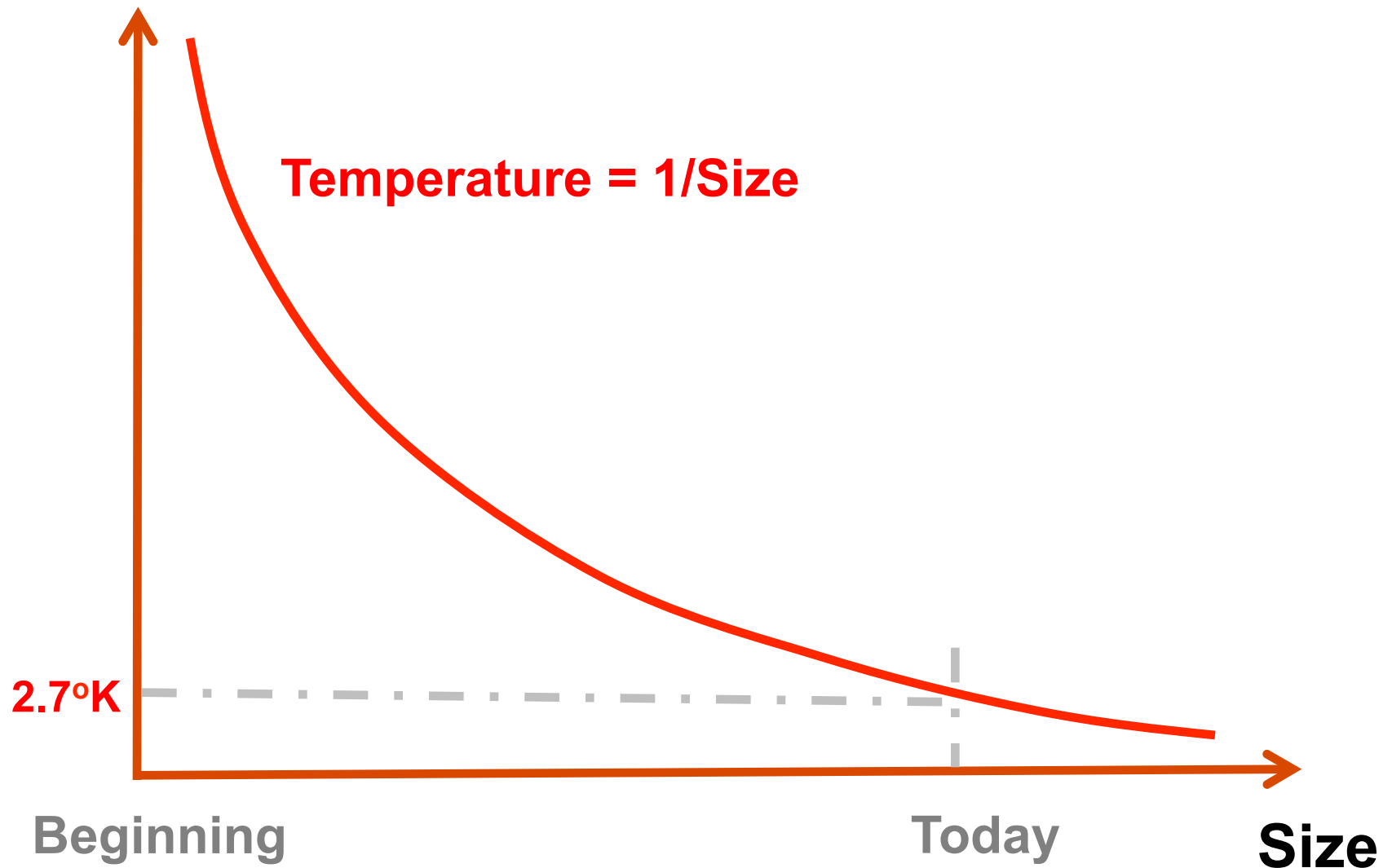
Moving Away
at Speed of Light

Expansion of Universe



Temperature of Universe

Temperature



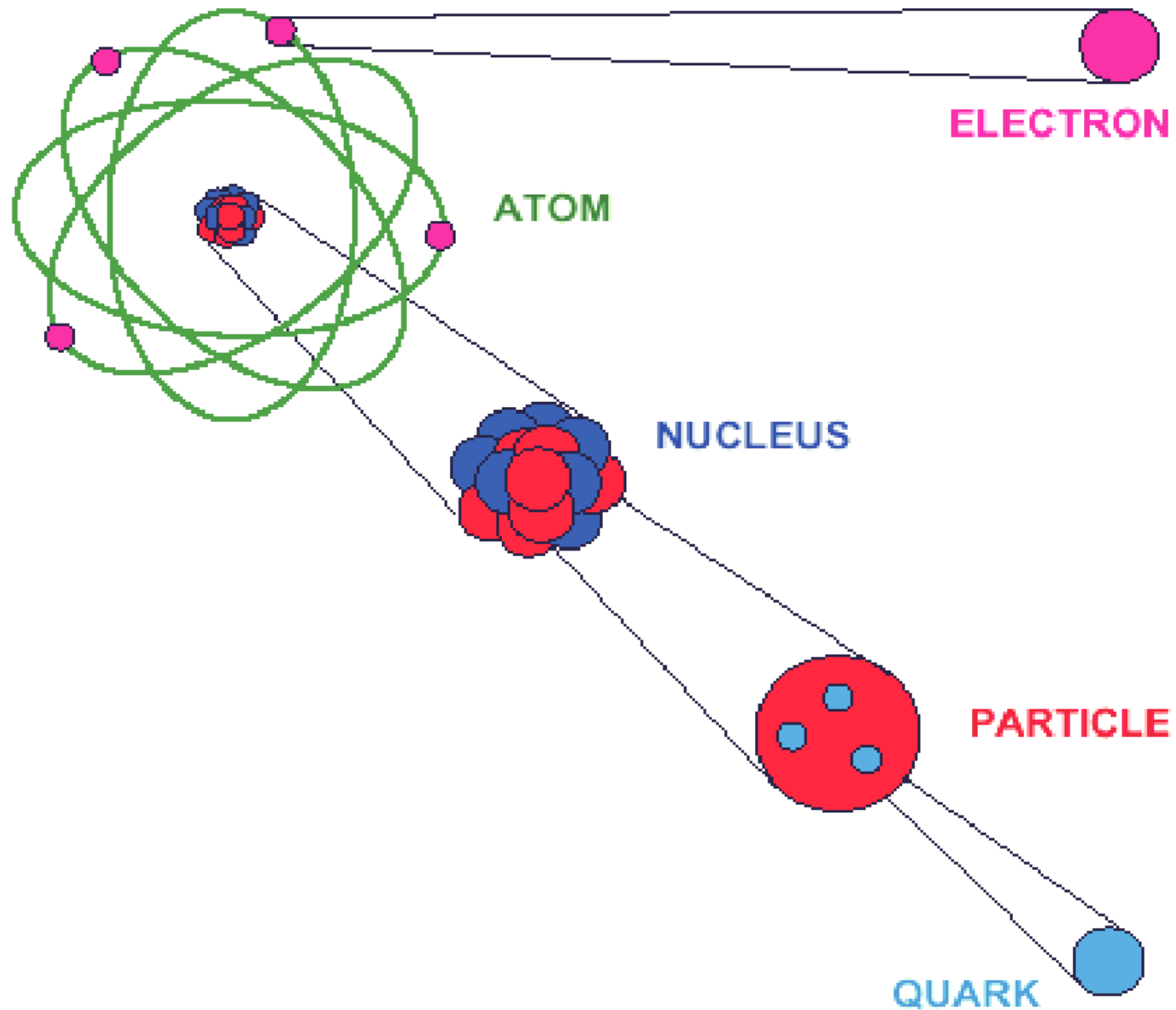
Fermi Lab near Chicago

6km Circumference
 $1+1=2$ TeV

$p + p^-$



Elementary Particles (~1970)



Elementary Particles

		Fermion			Boson			
Charge							Charge	
+2/3	Quarks	u up	c charm	t top	γ photon	g gluon	0	0
		d down	s strange	b bottom				
-1/3	Leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	Z Z boson	W W boson	0	1
0		e electron	μ muon	τ tau				
-1								
		I	II	III				
		Three Families of Matter						

+ Anti-particles

Elementary Particles and Forces

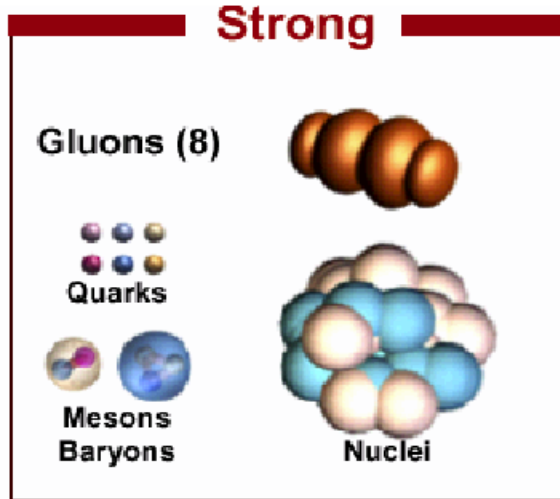
Strong

Gluons (8)

Quarks

Mesons
Baryons

Nuclei

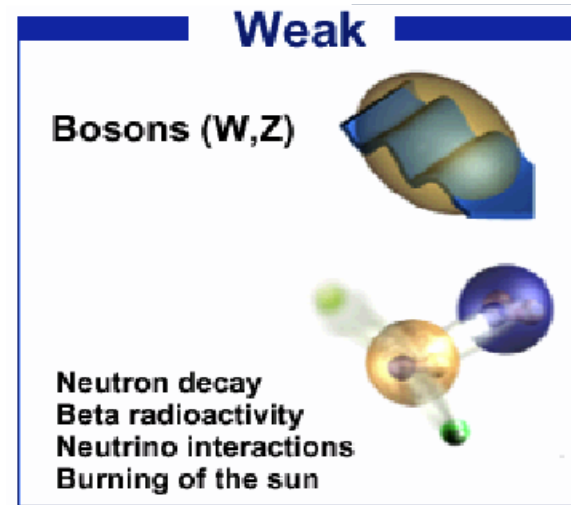
The diagram for the strong force shows various components. At the top, there are eight orange spheres representing gluons. Below them are six small colored spheres representing quarks. Further down are two larger spheres representing mesons and two more representing baryons. At the bottom is a large cluster of spheres representing a nucleus.

1

Weak

Bosons (W,Z)

Neutron decay
Beta radioactivity
Neutrino interactions
Burning of the sun

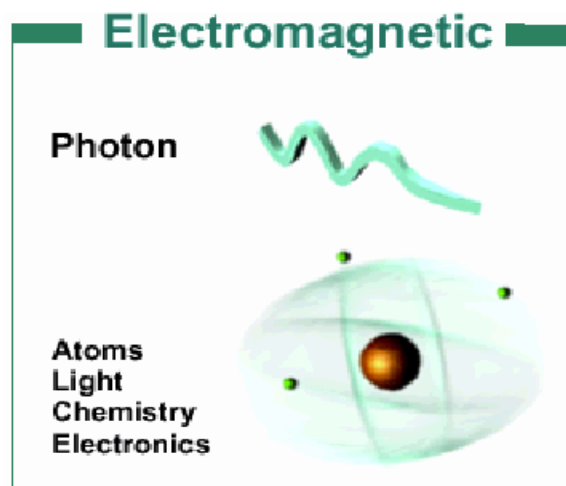
The diagram for the weak force shows two large blue and yellow spheres representing W and Z bosons. Below them is a diagram of a neutron decaying into a proton and an electron, with a neutrino also shown.

10^{-13}

Electromagnetic

Photon

Atoms
Light
Chemistry
Electronics

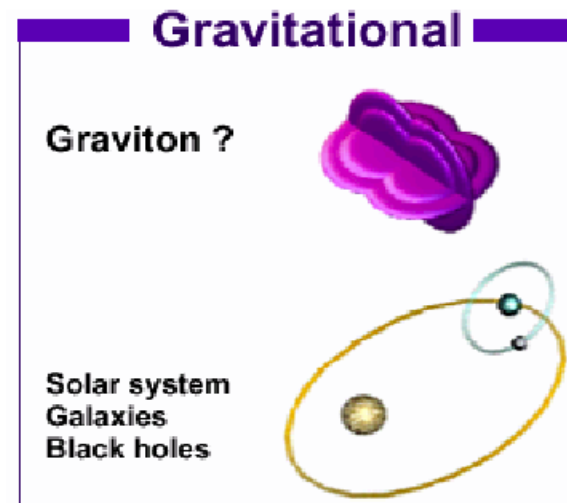
The diagram for the electromagnetic force shows a green wavy line representing a photon. Below it is a diagram of an atom with a central nucleus and orbiting electrons.

10^{-2}

Gravitational

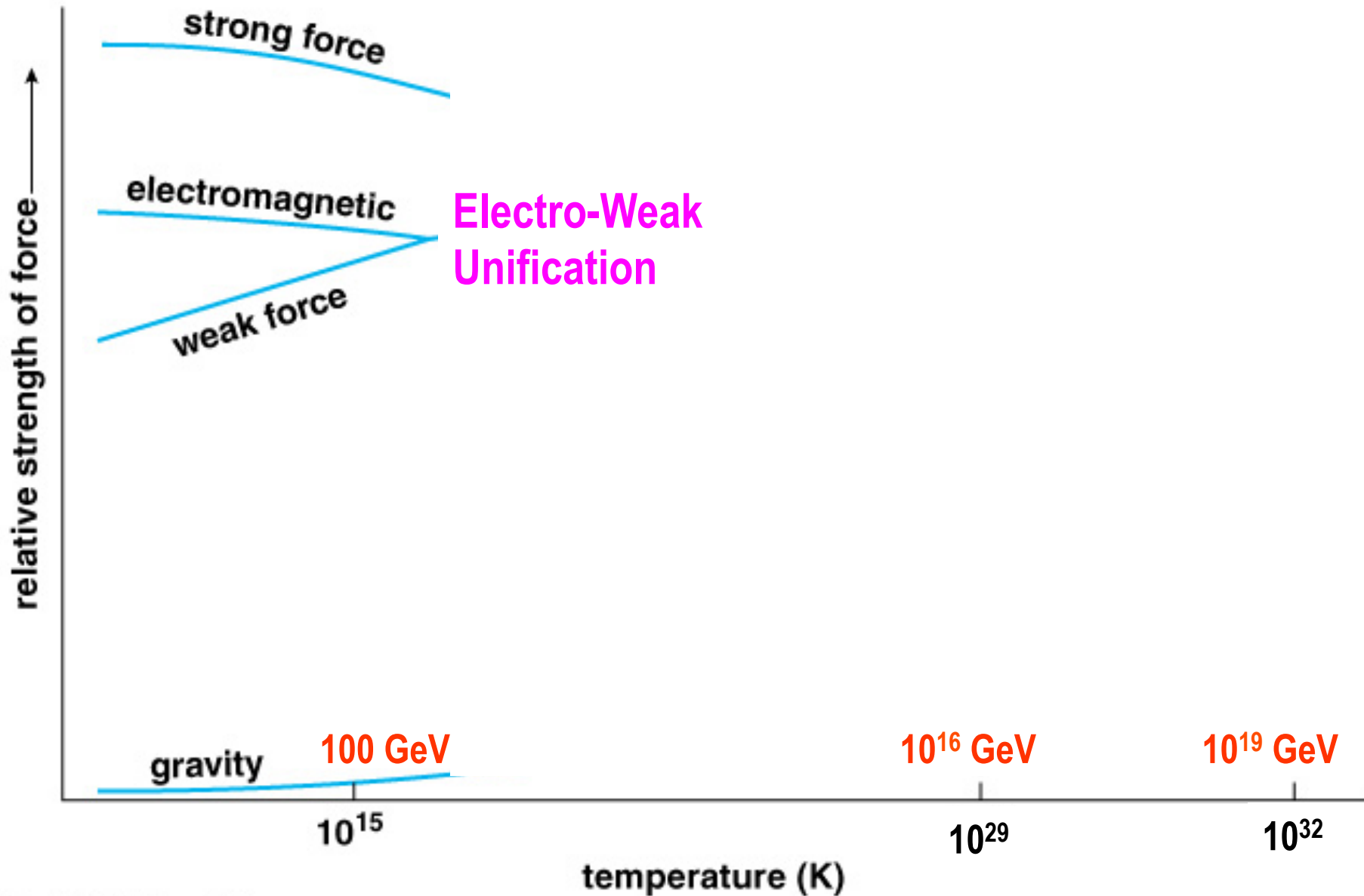
Graviton ?

Solar system
Galaxies
Black holes

The diagram for the gravitational force shows a purple cloud-like shape representing a graviton. Below it is a diagram of a solar system with a central star and orbiting planets, and a diagram of a galaxy.

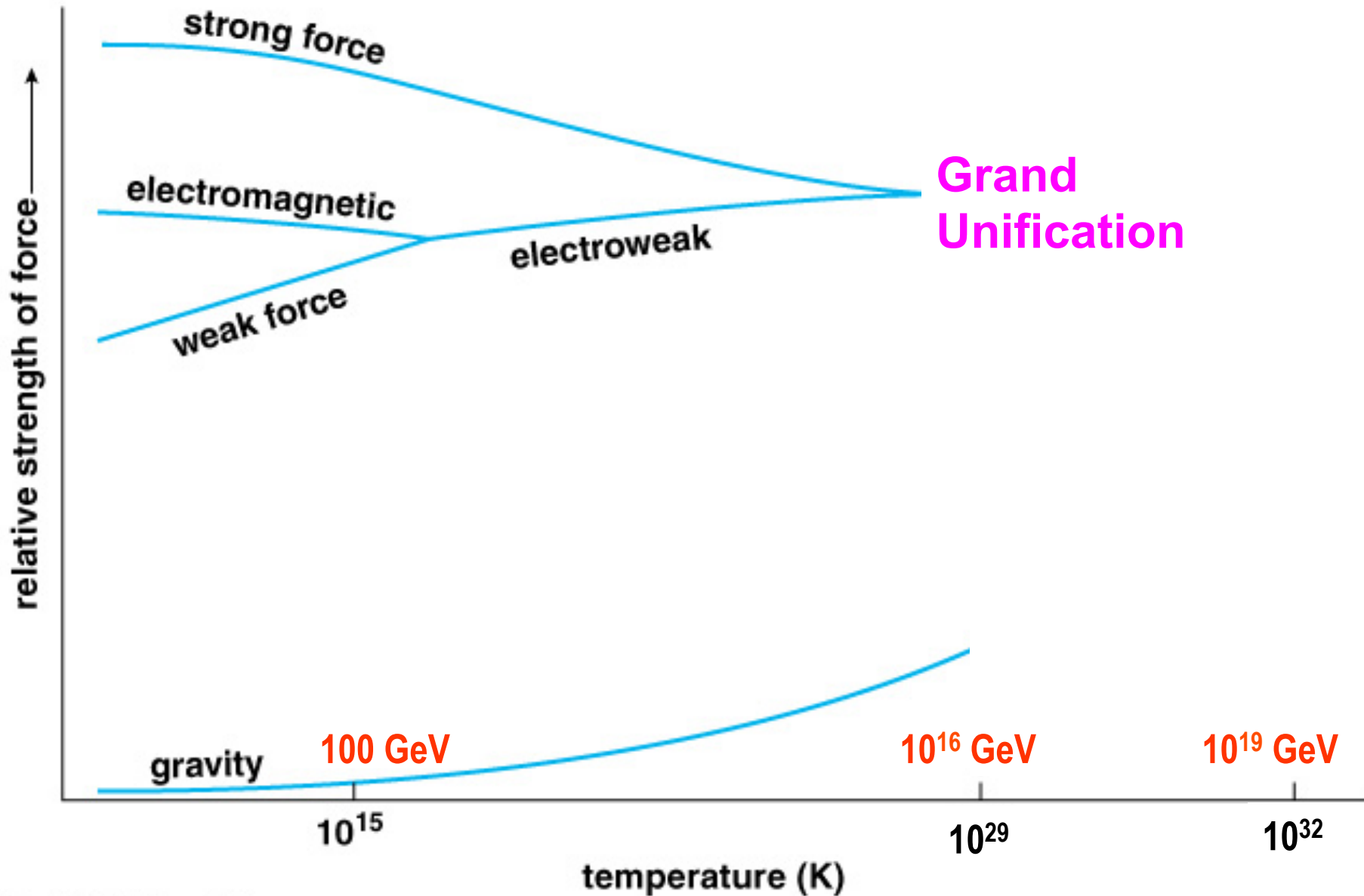
10^{-38}

Unification of Forces



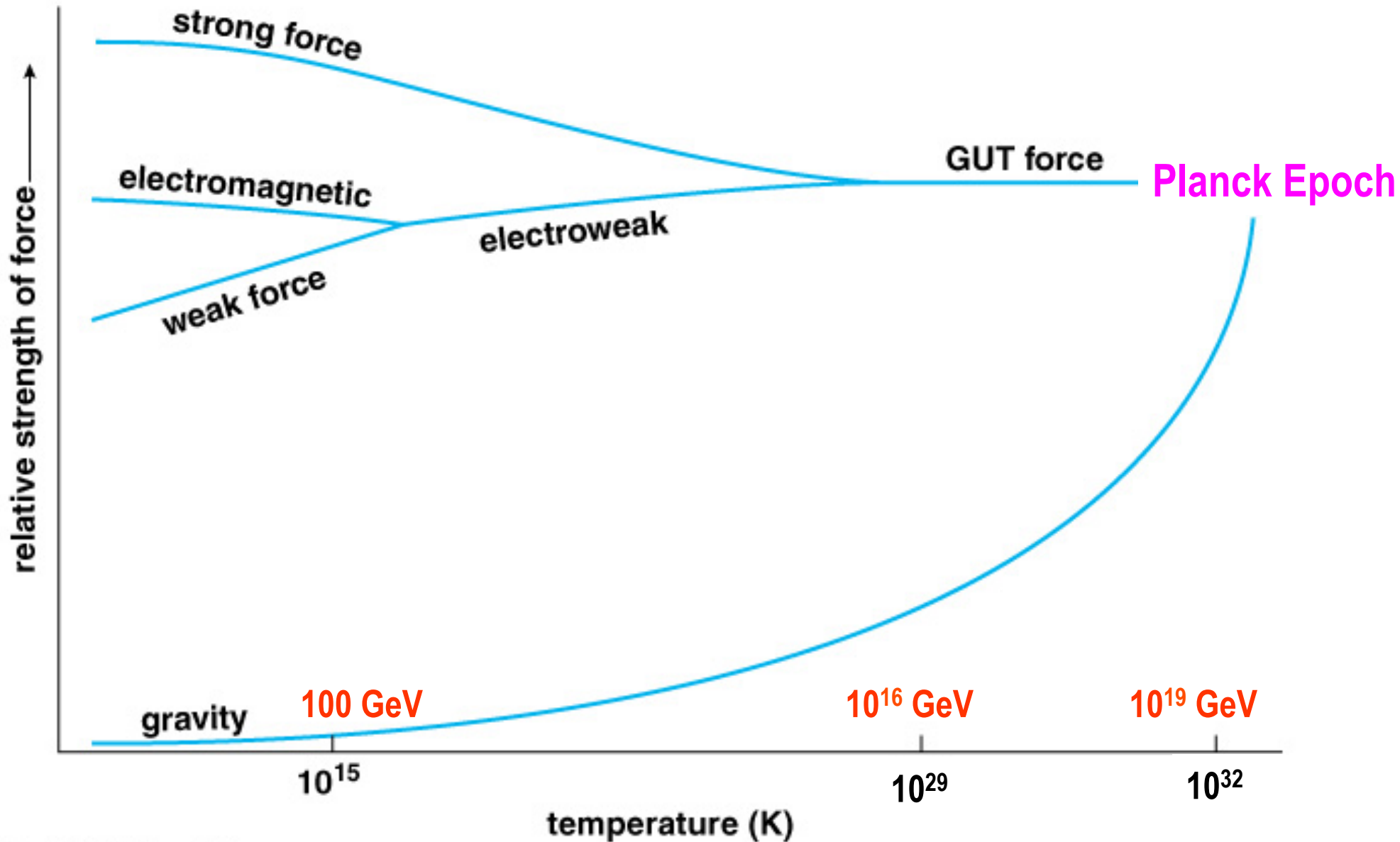
Copyright © Addison Wesley.

Unification of Forces



Copyright © Addison Wesley.

Unification of Forces



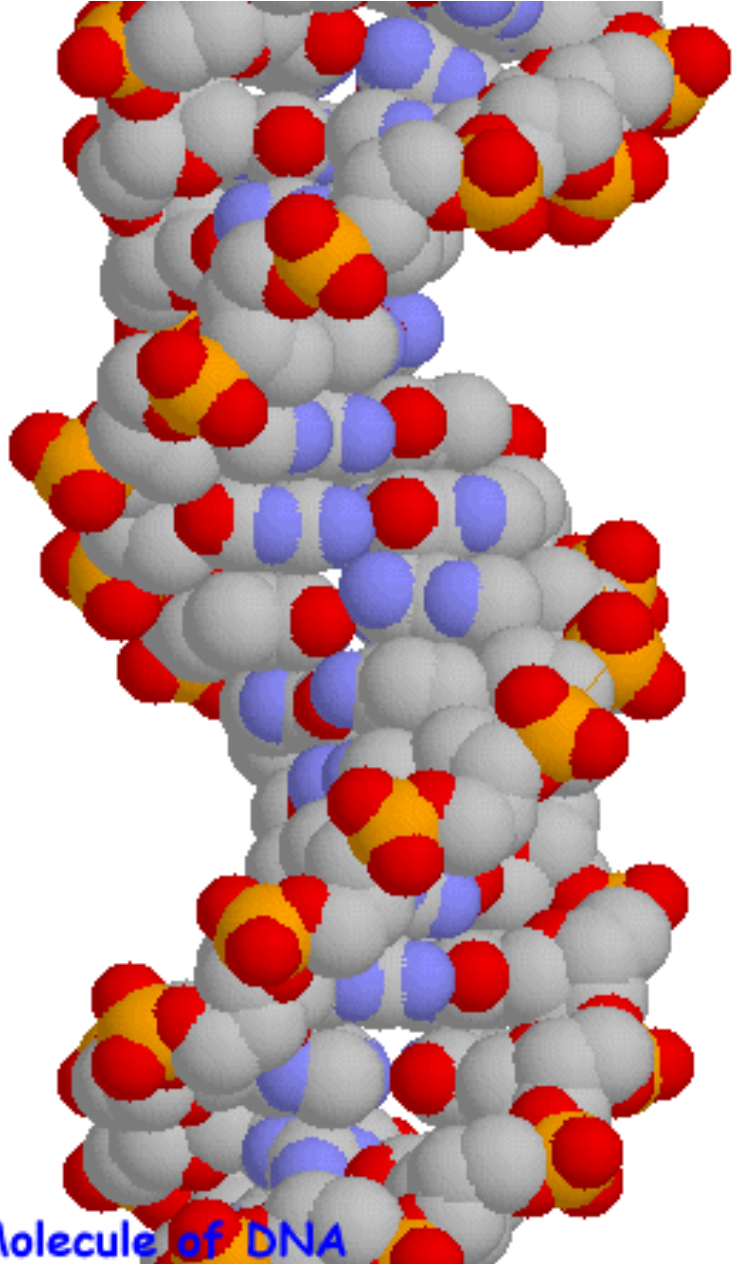
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Physicists' View of Early Universe

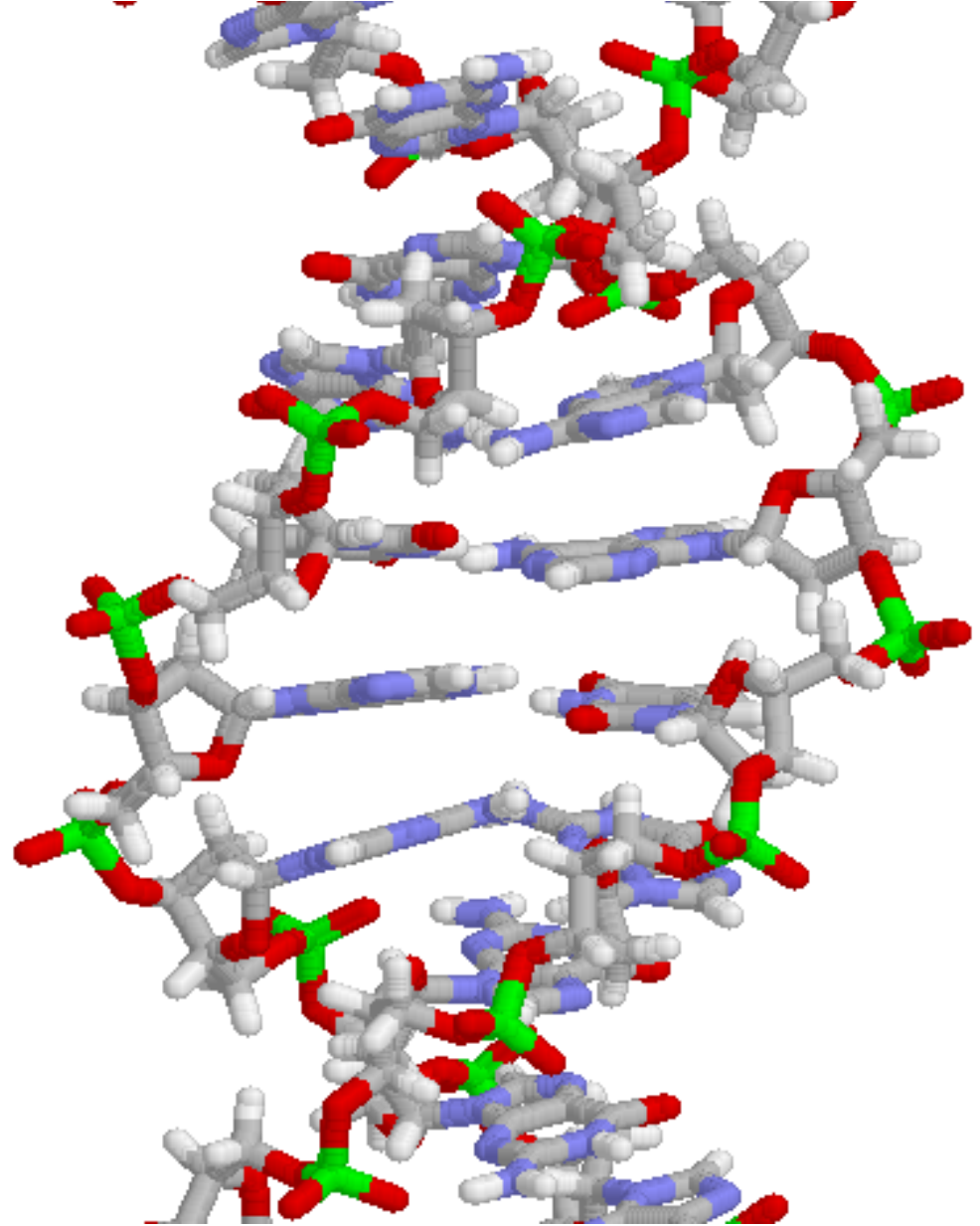
Lorentz Invariance

Local Gauge Invariance

Structure of DNA

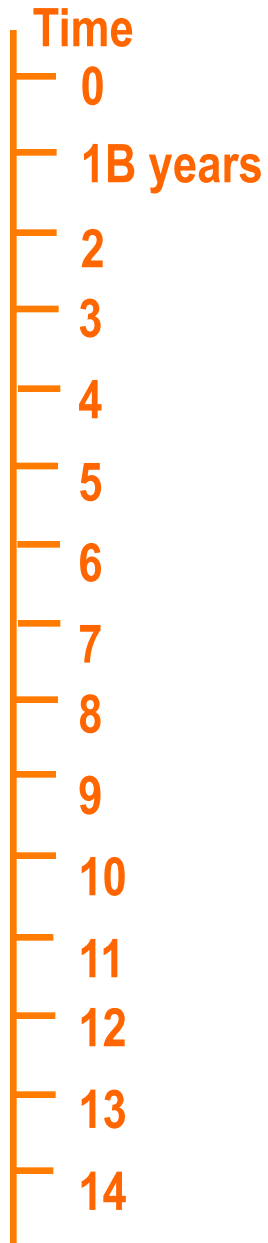


©Rothamsted Experimental Station, 1997, 1998



Molecule of DNA

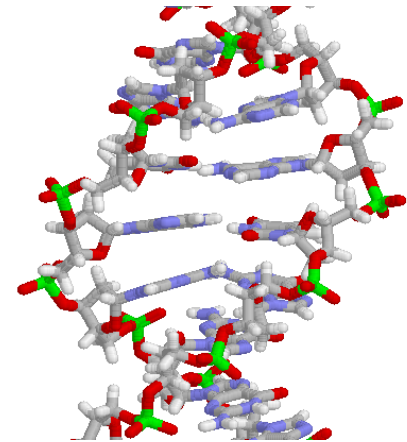
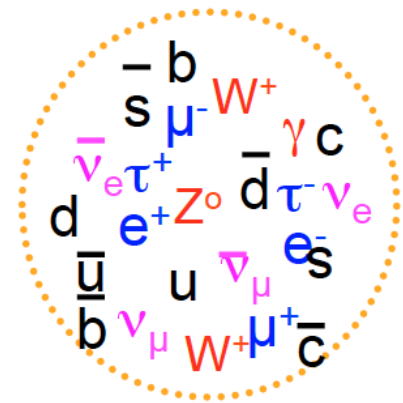
Symmetry Breaking



Simple

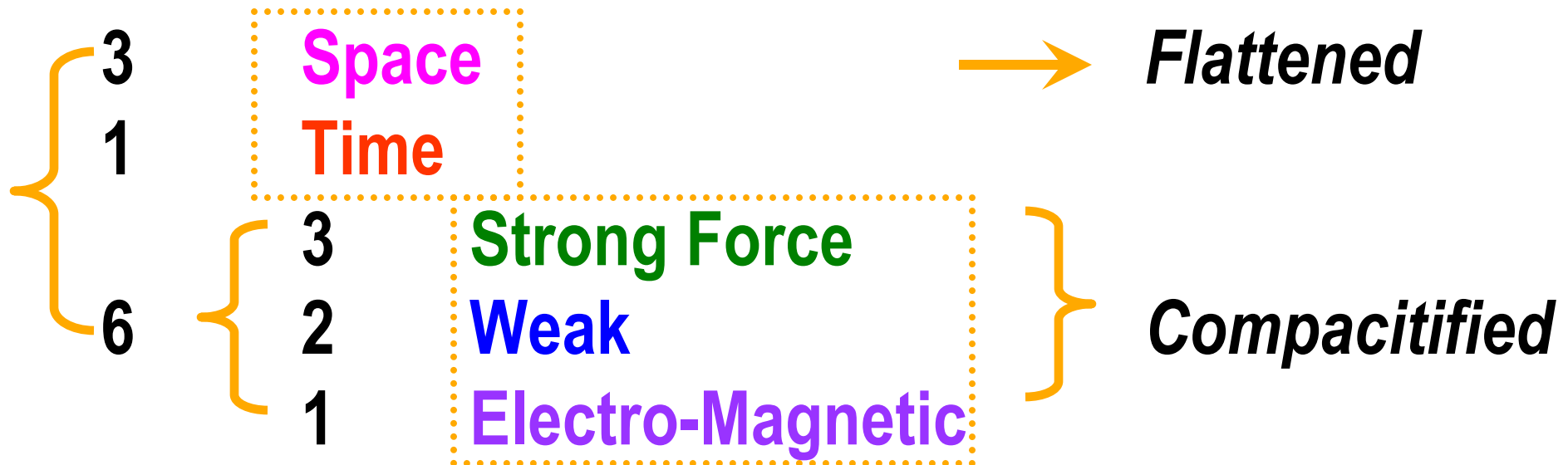
*Symmetry
Break Down*

Complex



The Beginning (at $t = 0$)

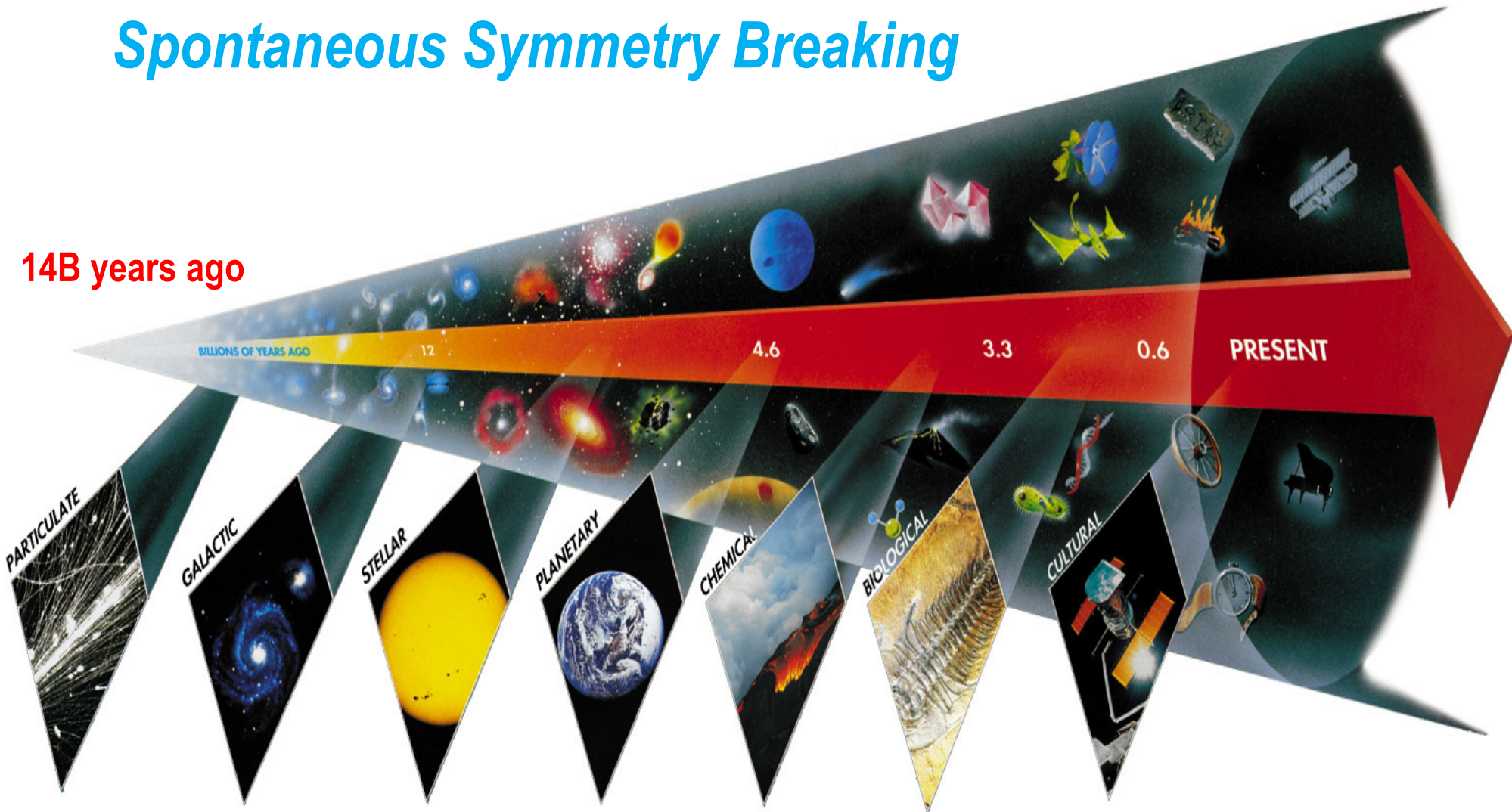
- Everything was the same → Perfect symmetry.
 - All the particles are the same as photons.
 - All four forces are the same.
- The Universe was 10 dimension.



Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking

14B years ago



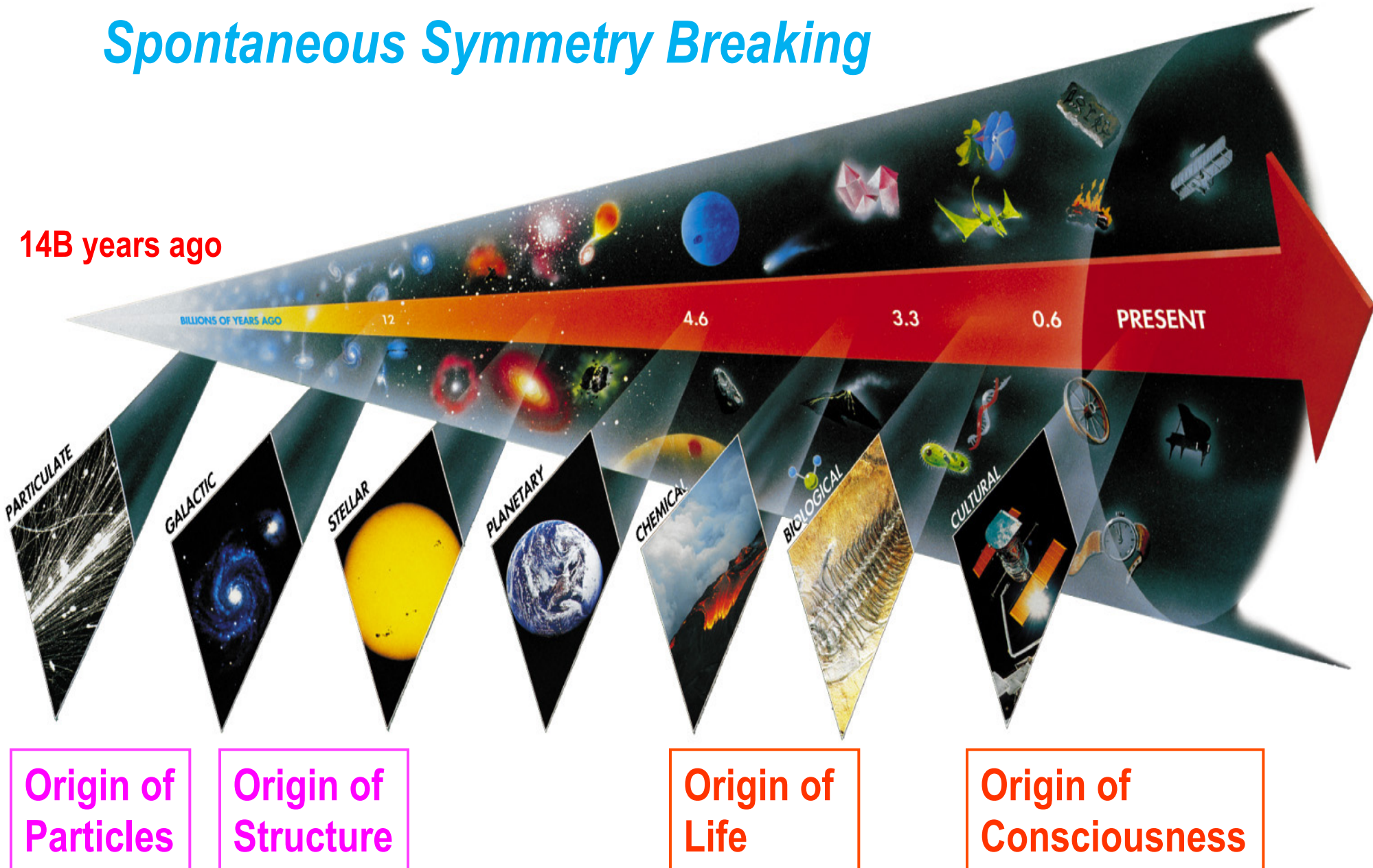
Simple



Coherent Complex System

Seven Phases of Cosmic Evolution

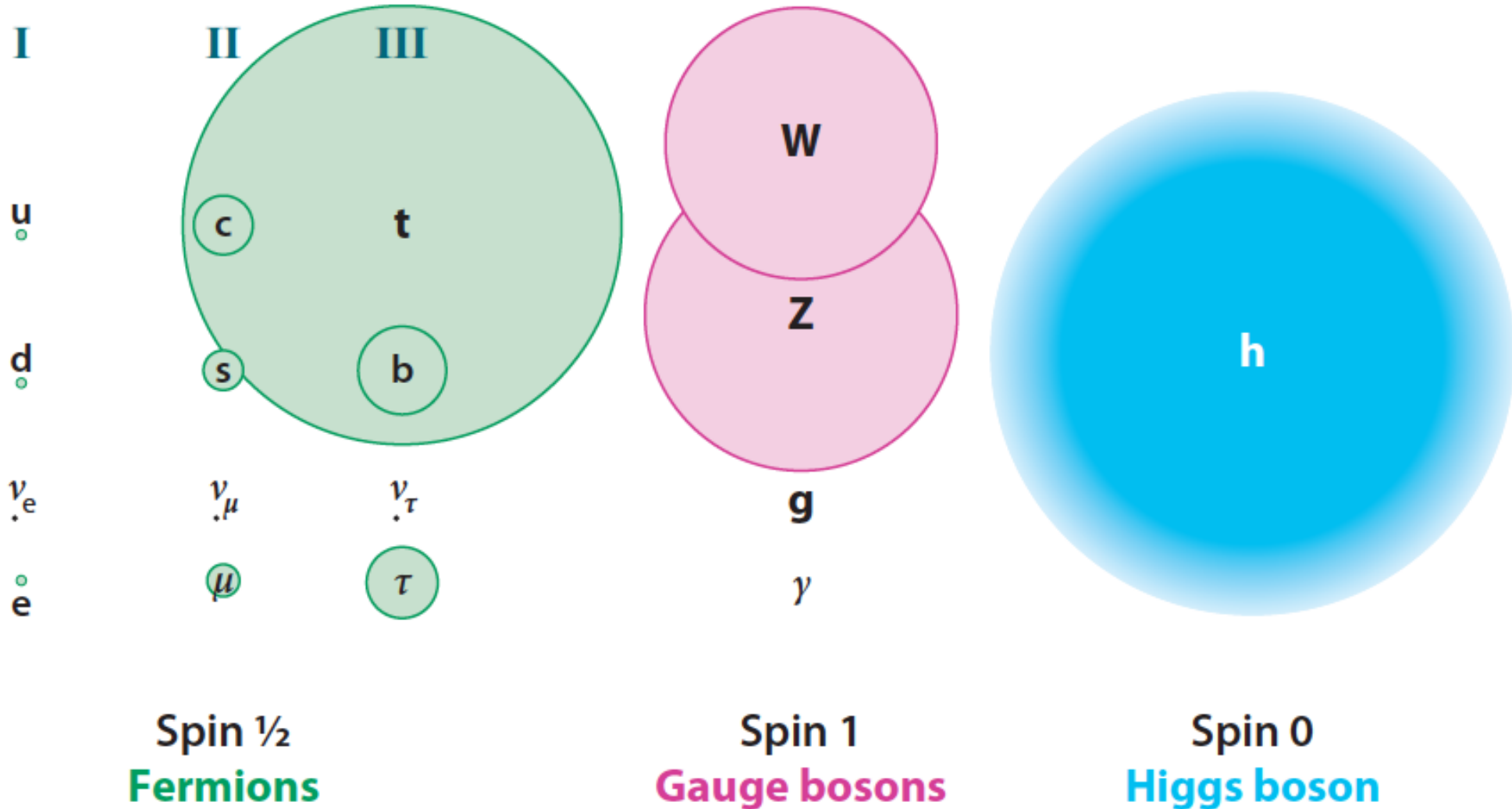
Spontaneous Symmetry Breaking



CMS at LHC

Mass of Particles (at $t = 0.1$ ns)

Generation



Mystery of the Mass (since 1970)

1) How to create mass from energy?

Energy \rightarrow Mass

While maintaining the initial symmetry
Spontaneous Symmetry Breaking

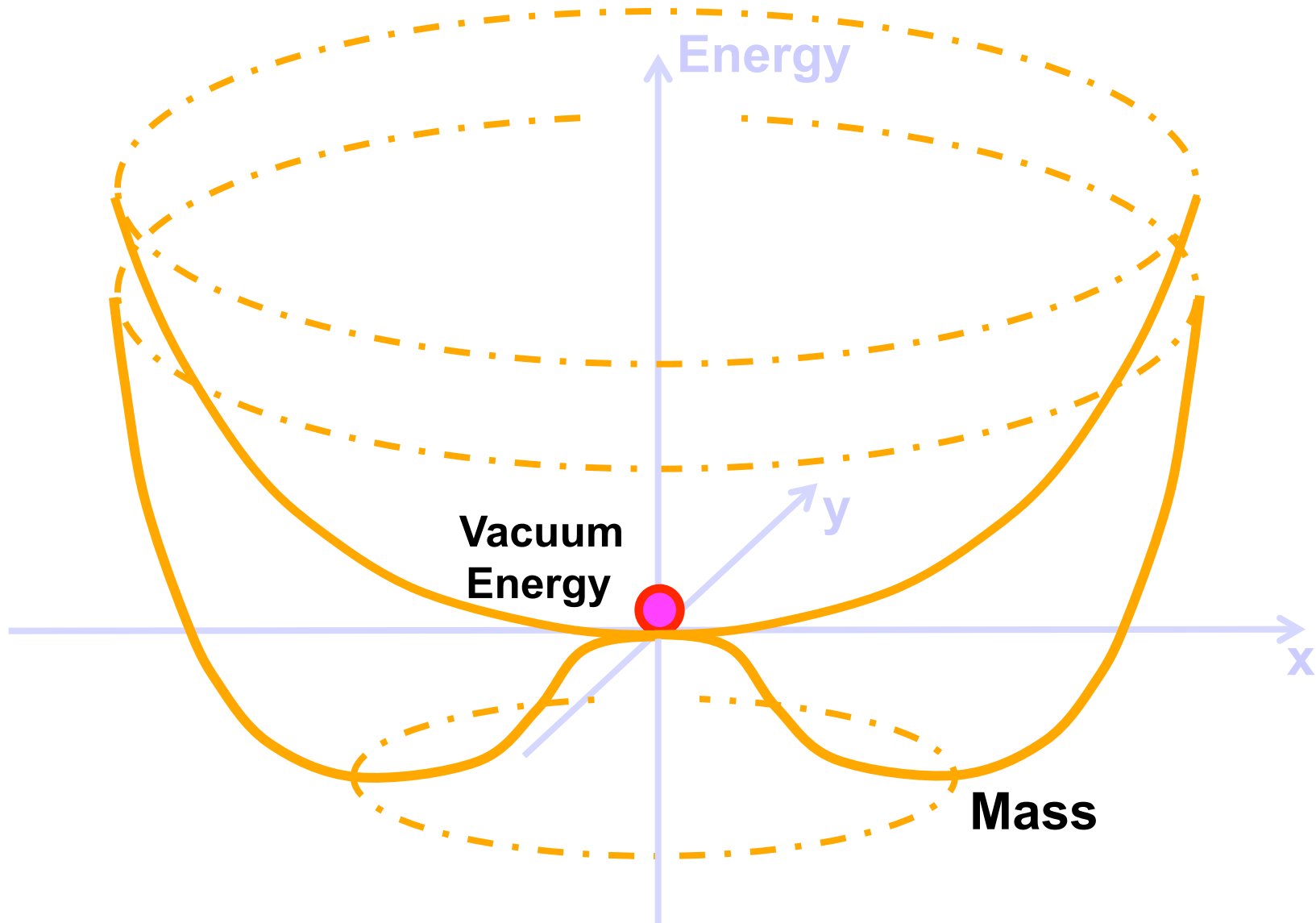
2) Particle mass \ll Plank Mass

MeV – GeV

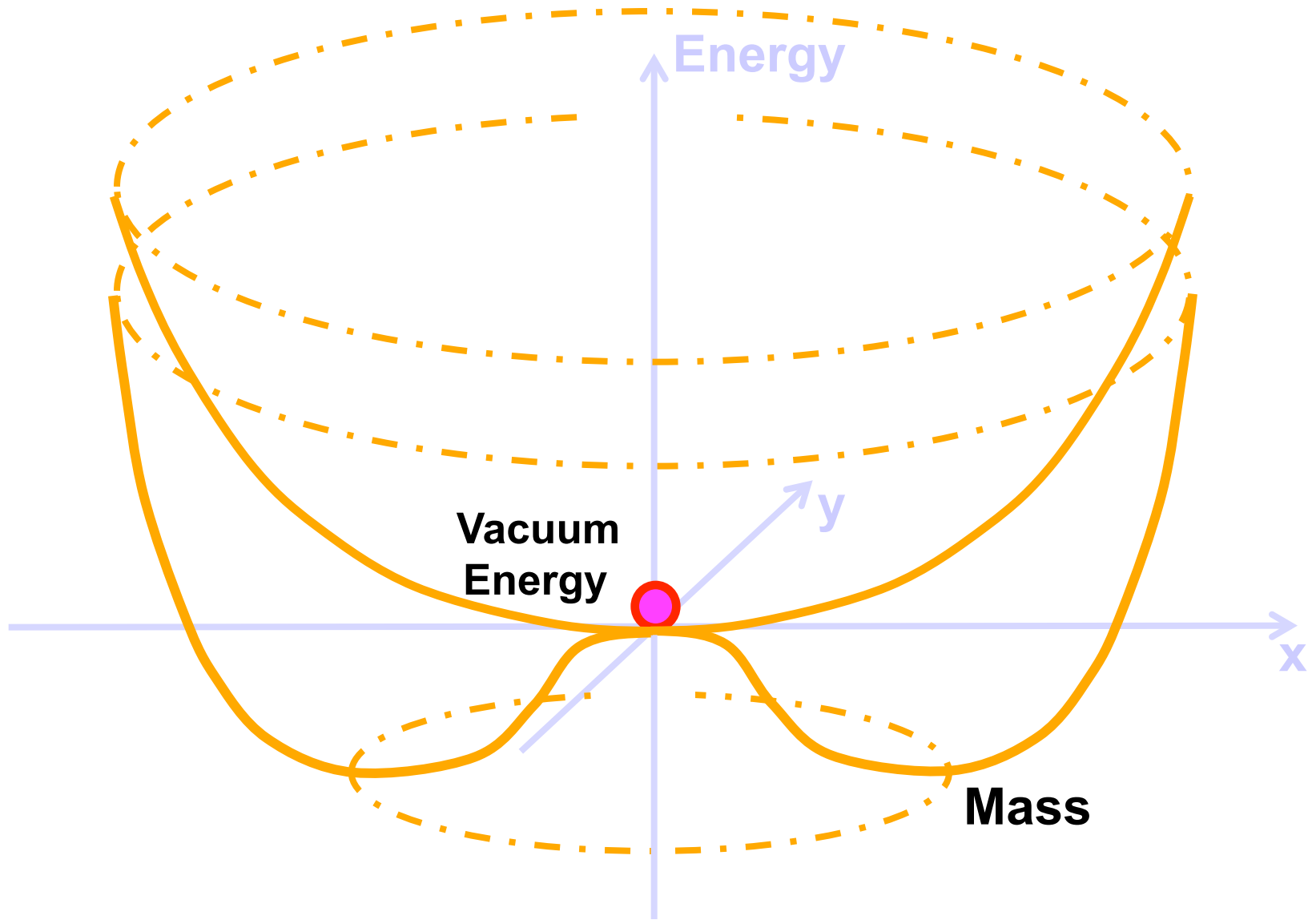
10^{19} GeV

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

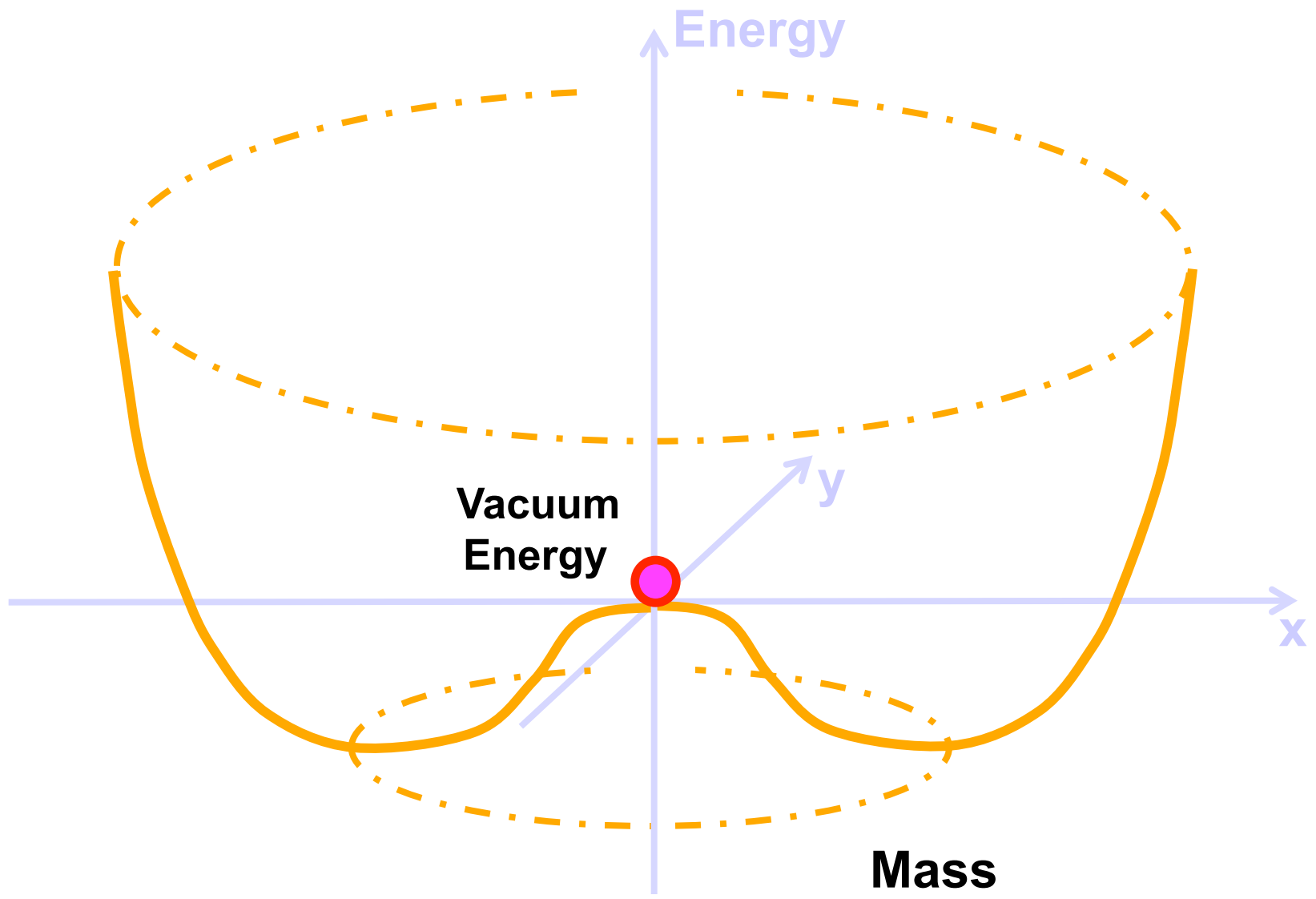
Spontaneous Symmetry Breaking - Higgs Mechanism -



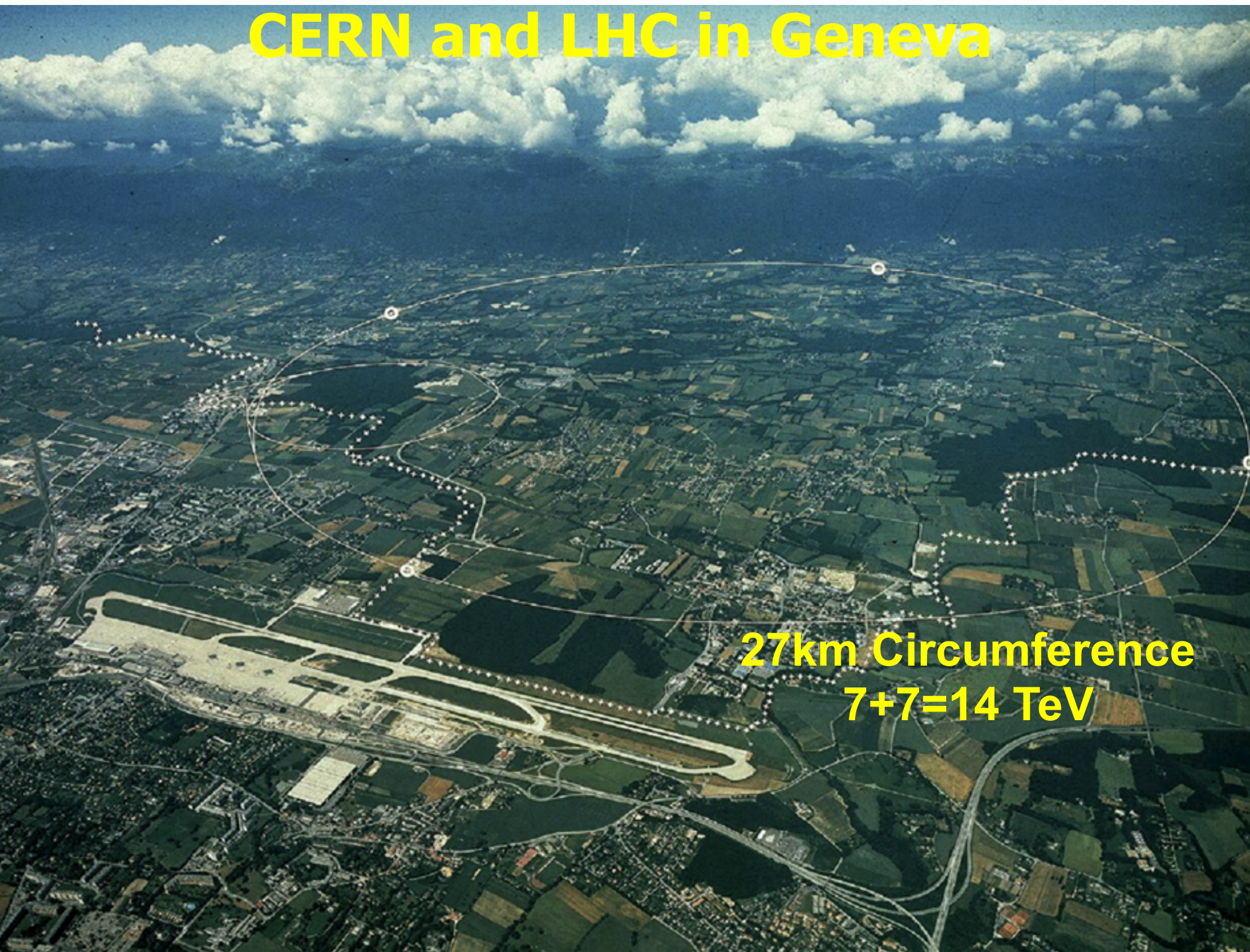
Spontaneous Symmetry Breaking - Higgs Mechanism -



Spontaneous Symmetry Breaking - Higgs Mechanism -

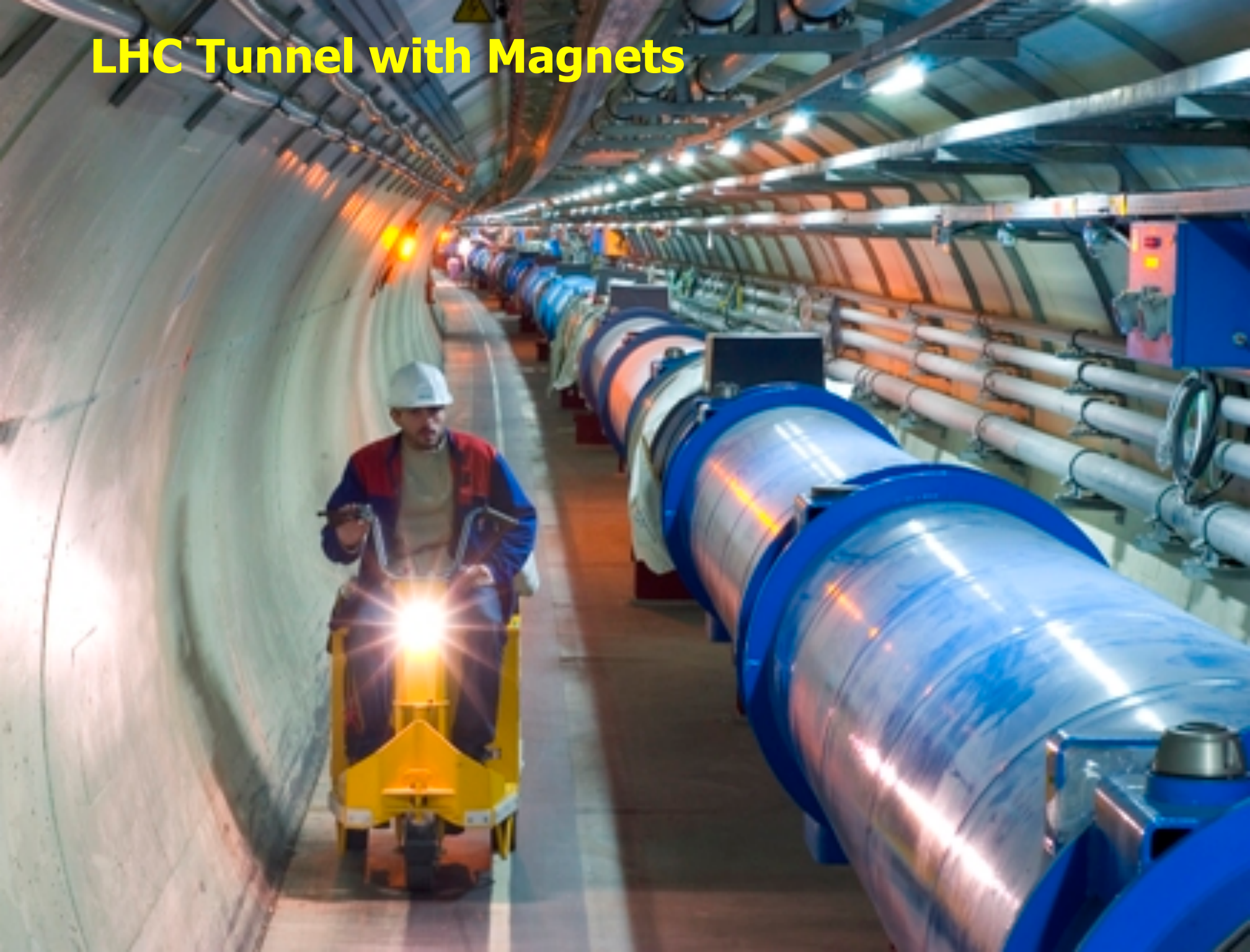


CERN and LHC in Geneva



27km Circumference
7+7=14 TeV

LHC Tunnel with Magnets



electromagnetic calorimeter

solenoid

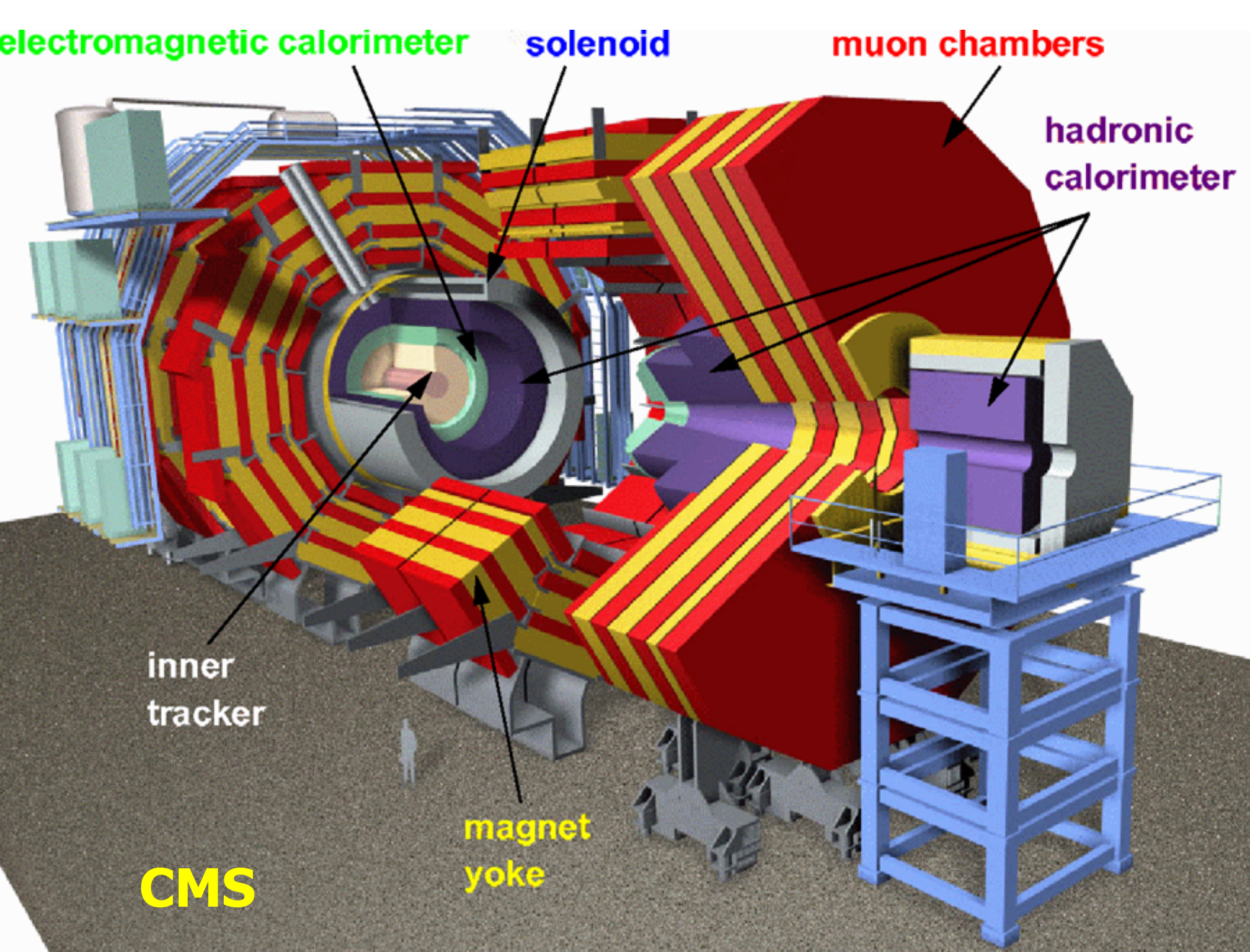
muon chambers

hadronic calorimeter

inner tracker

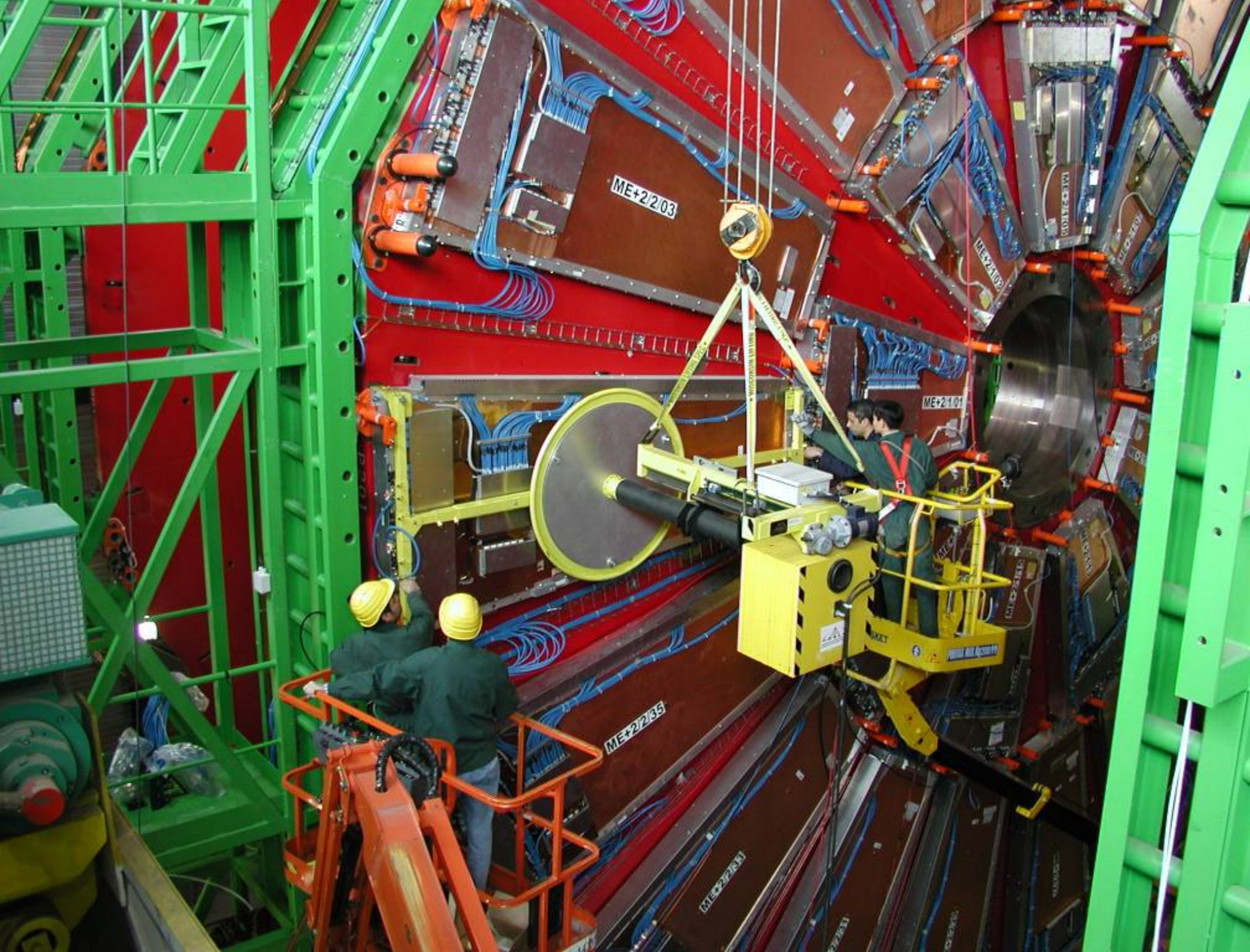
magnet yoke

CMS



CMS Barrel Yoke





ME+2/2/03

ME+2/1/01

ME+2/2/05

ME+2/2/08

ME+2/2/10

ME+2/2/12

ME+2/2/14

ME+2/2/16

ME+2/2/18

ME+2/2/20

ME+2/2/22

ME+2/1/02

ME+2/1/04

ME+2/1/06

ME+2/1/08

ME+2/1/10

ME+2/1/12

ME+2/1/14

ME+2/1/16

ME+2/1/18

ME+2/1/20

ME+2/1/22

ME+2/1/24

ME+2/1/26

ME+2/1/28

ME+2/1/30

ME+2/1/32

ME+2/1/34

ME+2/1/36

ME+2/1/38

ME+2/1/40

ME+2/1/42

ME+2/1/44

ME+2/1/46

ME+2/1/48

ME+2/1/50

ME+2/1/52

ME+2/1/54

ME+2/1/56

ME+2/1/58

ME+2/1/60

ME+2/1/62

ME+2/1/64

ME+2/1/66

ME+2/1/68

ME+2/1/70

ME+2/1/72

ME+2/1/74

ME+2/1/76

ME+2/1/78

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ME+2/1/84

ME+2/1/86

ME+2/1/88

ME+2/1/90

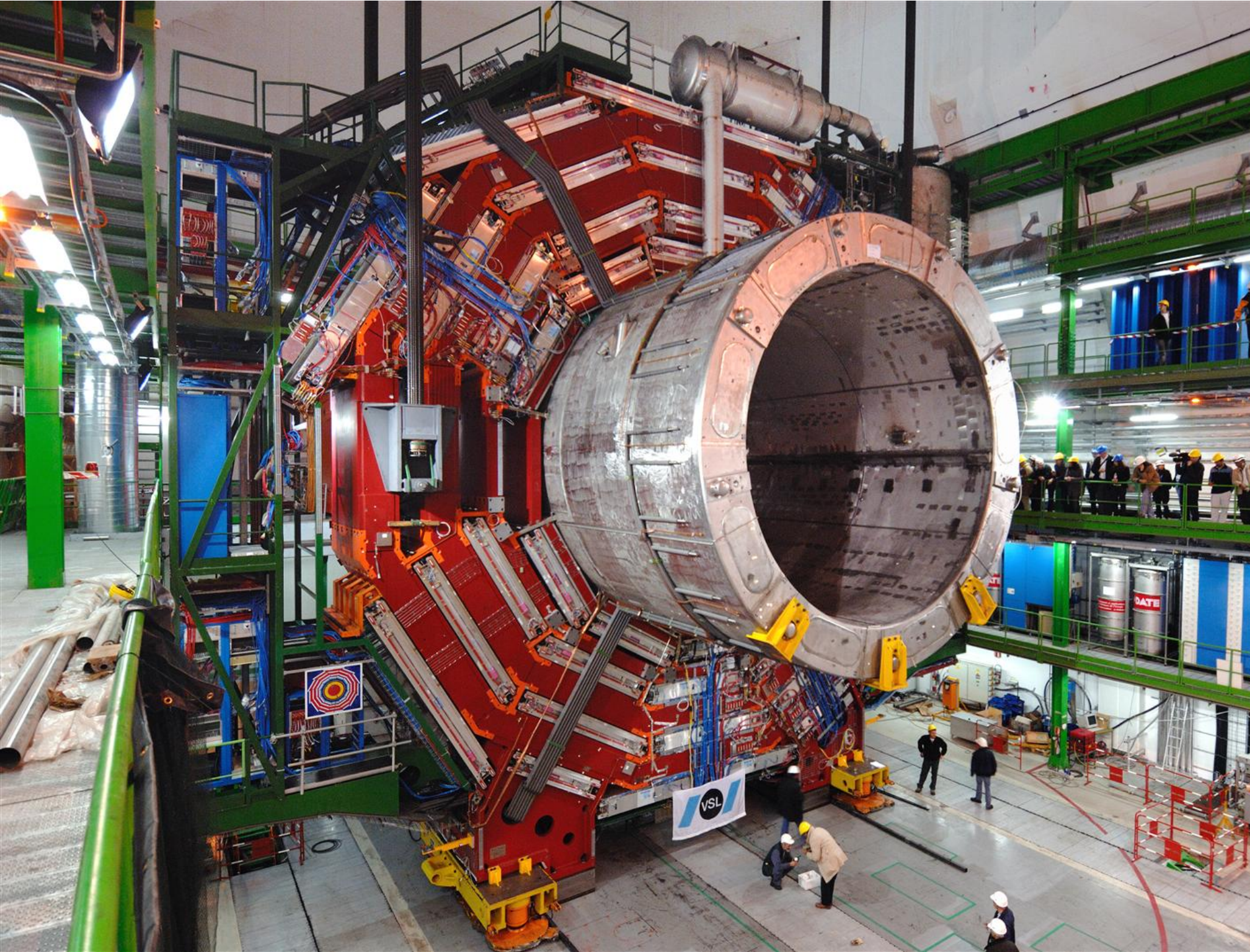
ME+2/1/92

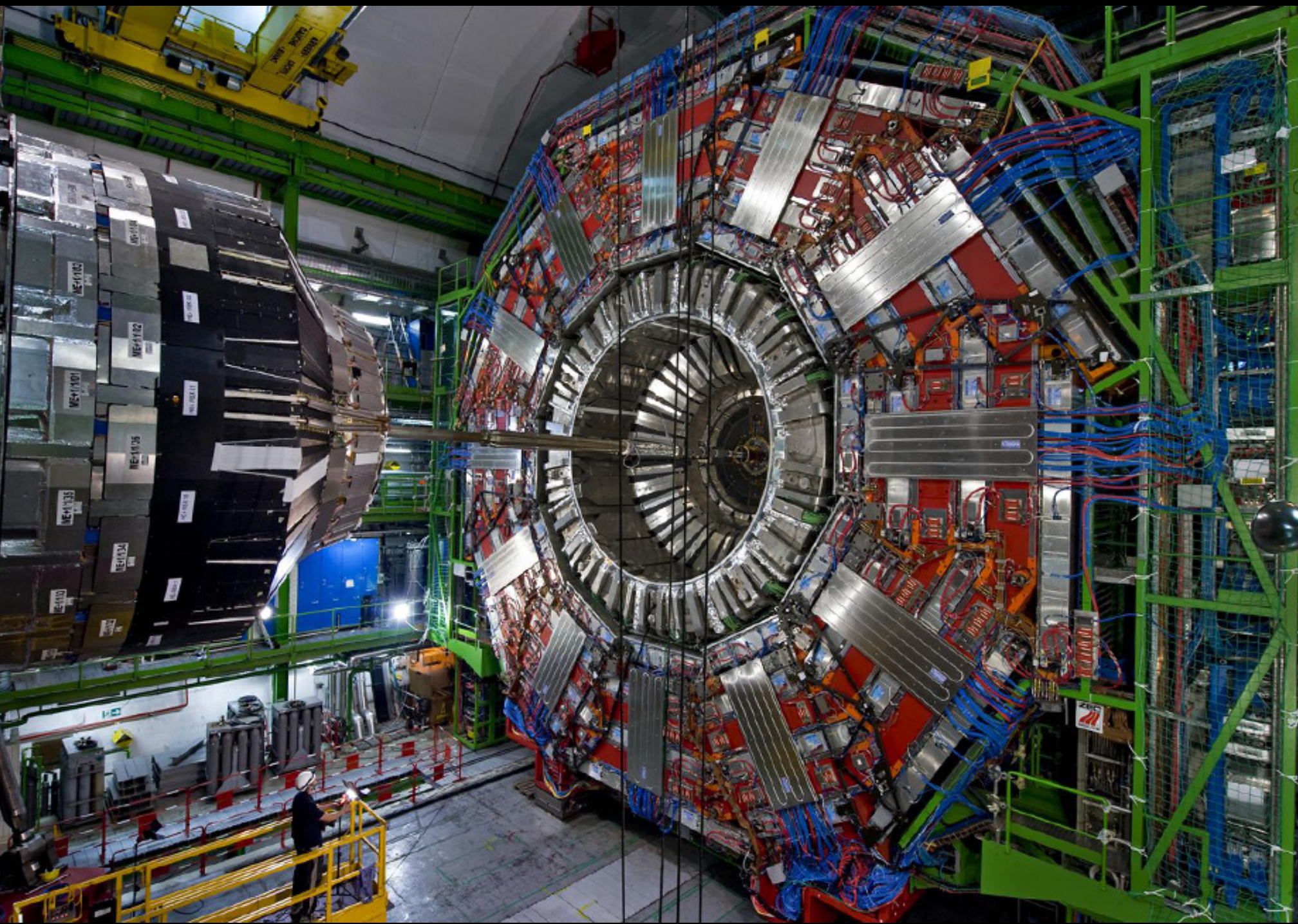
ME+2/1/94

ME+2/1/96

ME+2/1/98

ME+2/1/100





Newsweek

The Biggest Experiment Ever (And It's European)



Particle detectors
constructed
at Westwood,
now at LHC, CERN



The new CERN collider in Geneva

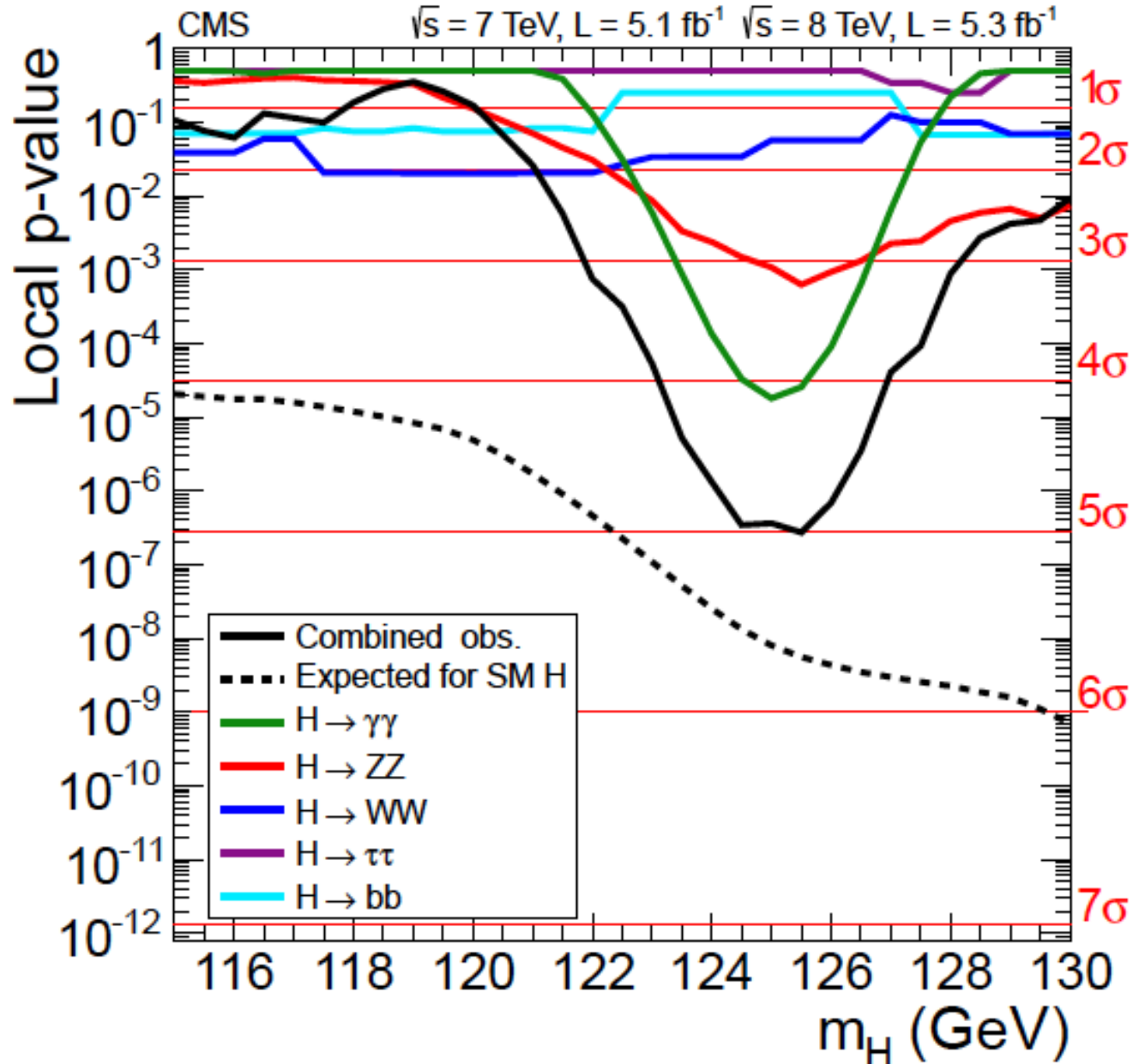
newsweek.com SEPTEMBER 15, 2008 PHOTOGRAPH BY MARTIAL TREZZINI-AP



Albania	Lek 600	Finland	€4.40	Israel	NIS 20.00	Netherlands	€4.40	Slovenia	€3.40
Austria	€4.40	France	€4.40	Italy	€4.40	Norway	Kr 41.00	Spain	€4.40
Belgium	€4.40	Germany	€4.40	Kazakhstan	€4.40	Poland (incl tax)	PLN 12.30	Sweden	SKr 34.00
Bulgaria	BGL 4.50	Gibraltar	€2.90	Latvia	€4.40	Portugal Cont	€4.40	Switzerland	SF 7.70
Croatia	KN 22.00	Greece	€4.40	Lithuania	€4.40	Romania	Lei 11.00	Turkey	YTL 4.00
Cyprus	€2.58/€4.40	Hungary	FL 700.00	Luxembourg	€4.40	Russia	€4.40	Ukraine	€4.40
Czech Republic	Czk 115.00	Iceland	IKR 390.00	Malta	Lm 1.70/€3.96	Serbia	DIN 240	United Kingdom	£2.80
Denmark	Kr 38.00	Ireland (incl tax)	€4.40	Montenegro	DIN 240	Slovakia	SK 120.00/€3.98	U.S. Forces	\$3.25

Sept 15, 2008 Issue

Higgs Discovery by CMS (July 4, 2012)



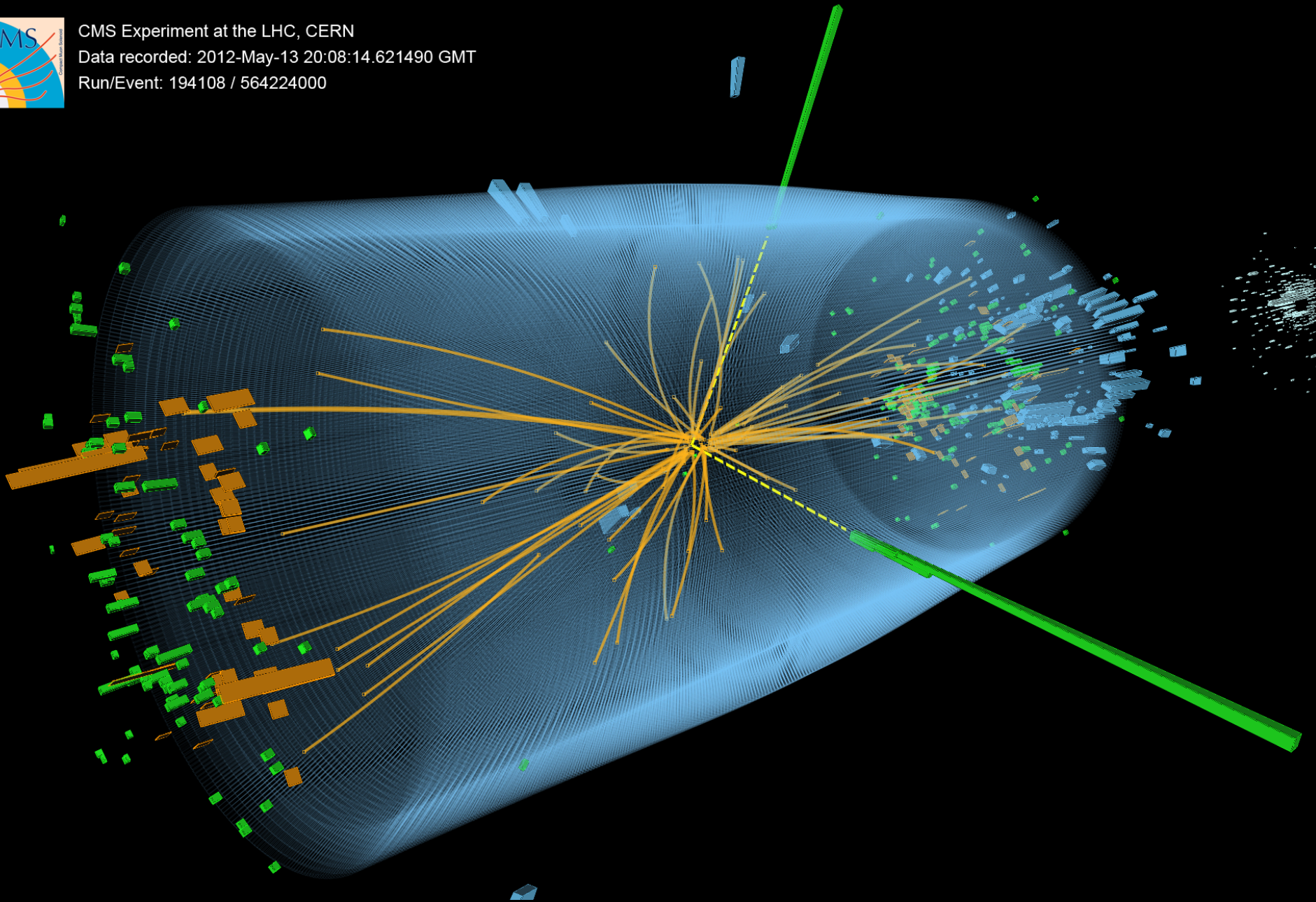
Higgs particle \rightarrow 2 gamma rays



CMS Experiment at the LHC, CERN

Data recorded: 2012-May-13 20:08:14.621490 GMT

Run/Event: 194108 / 564224000



News release on July 4th !

Physicists Find Elusive Particle Seen as Key to Universe



Pool photo by Denis Balibouse

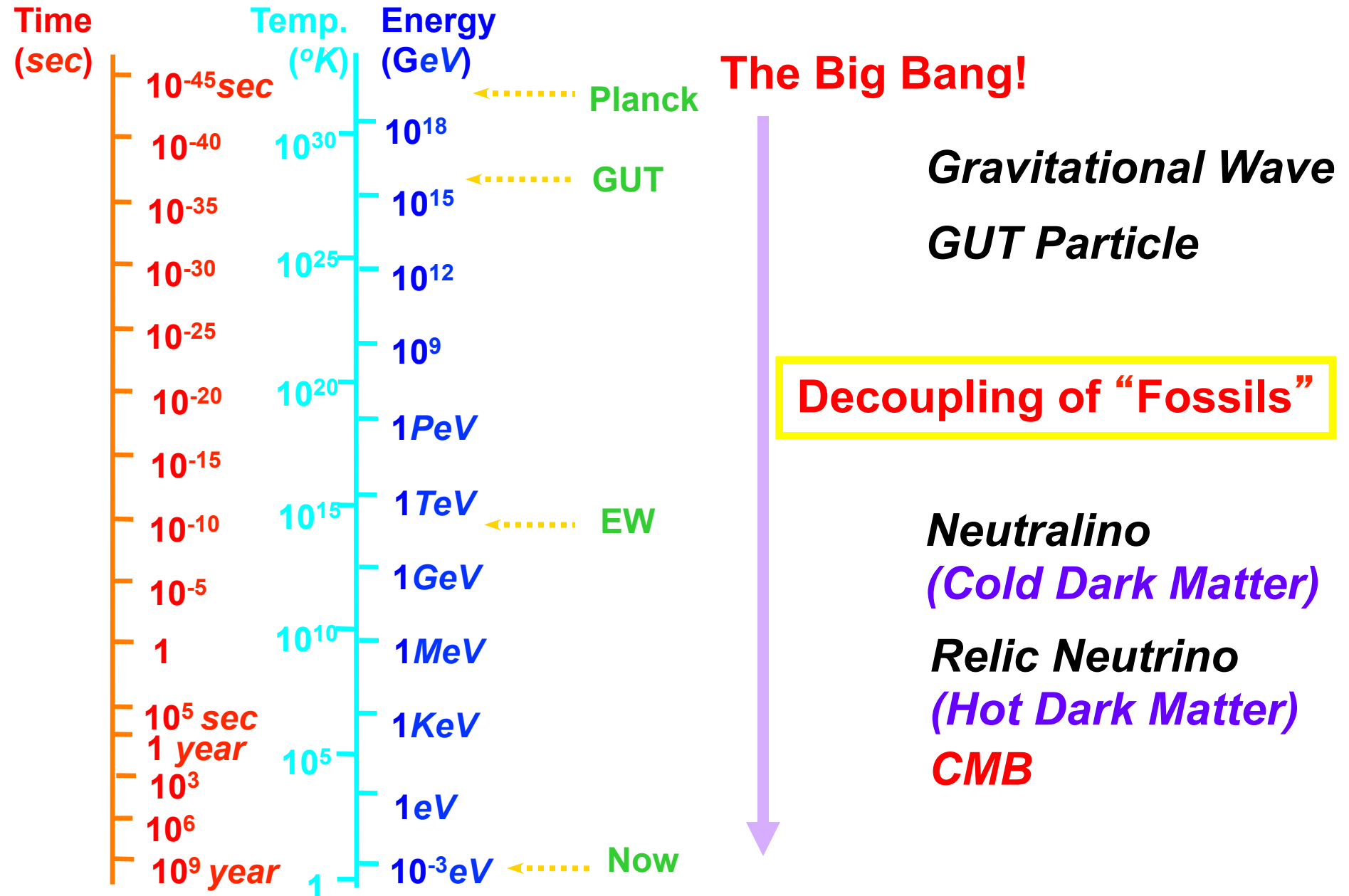
Scientists in Geneva on Wednesday applauded the discovery of a subatomic particle that looks like the Higgs boson.

By DENNIS OVERBYE

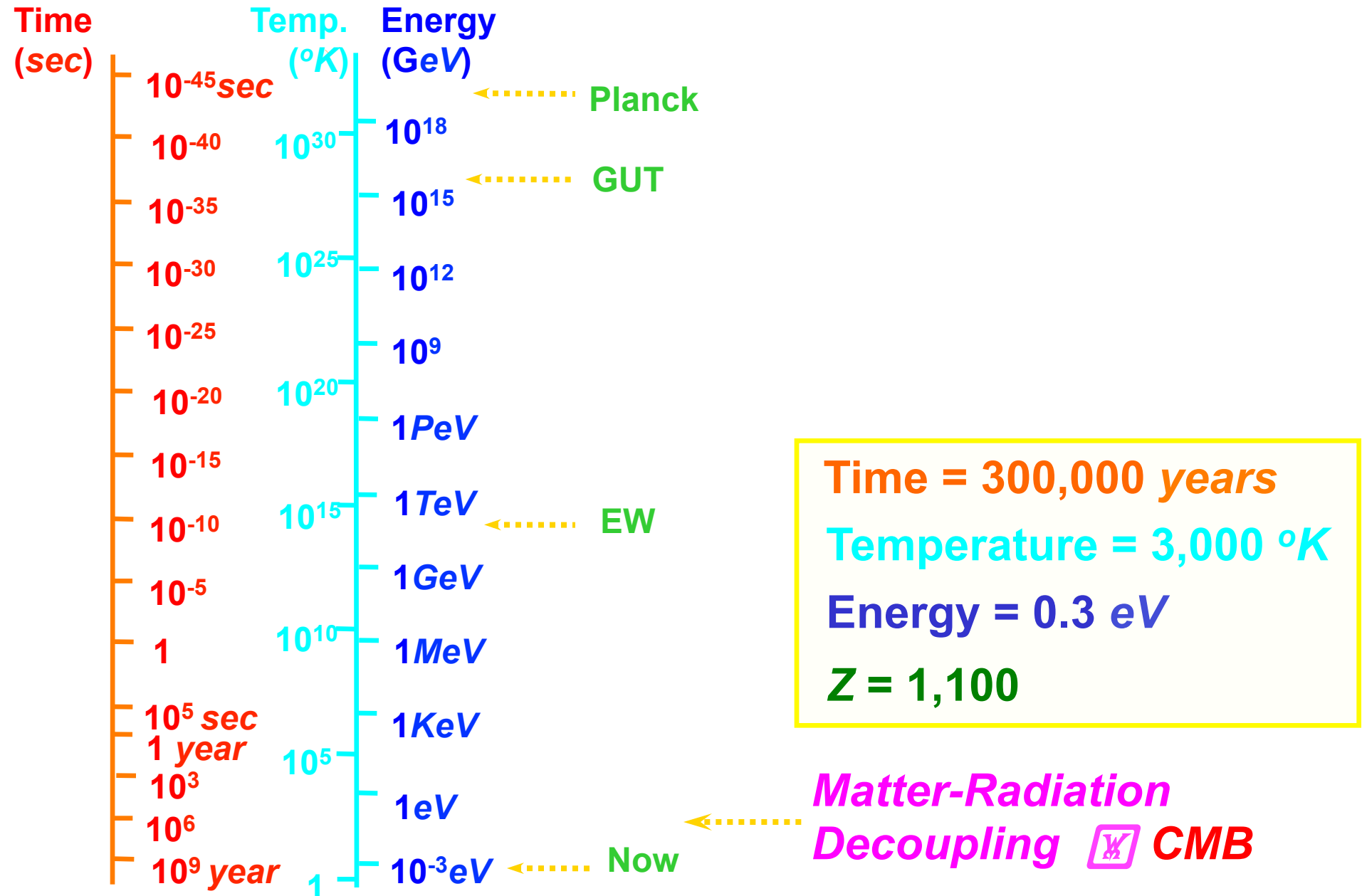
Published: July 4, 2012 | 122 Comments

Dark Matter and Dark Energy

“Fossils” from the Earliest Universe

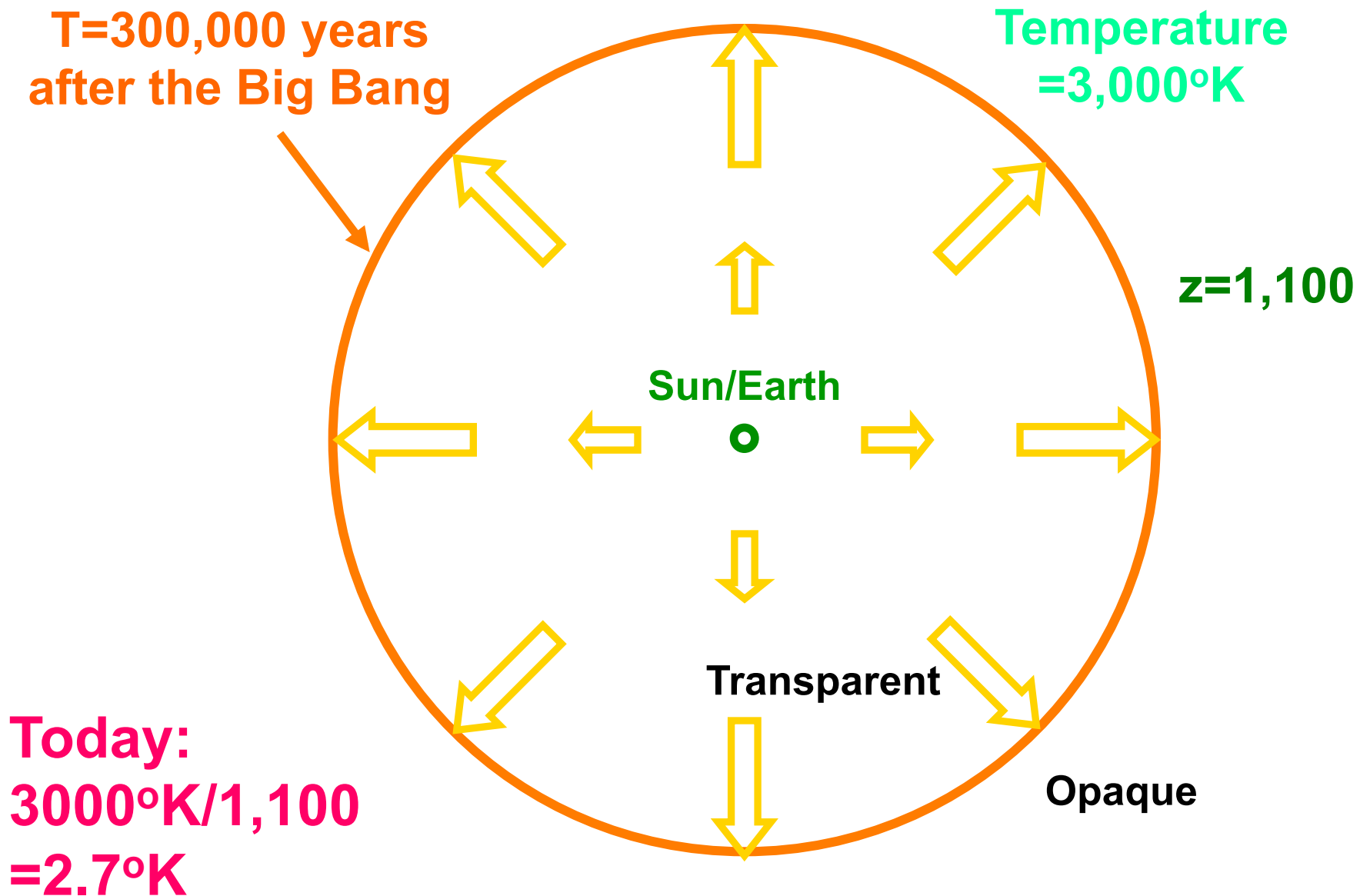


Cosmic Microwave Background (CMB) Matter-Radiation Decoupling





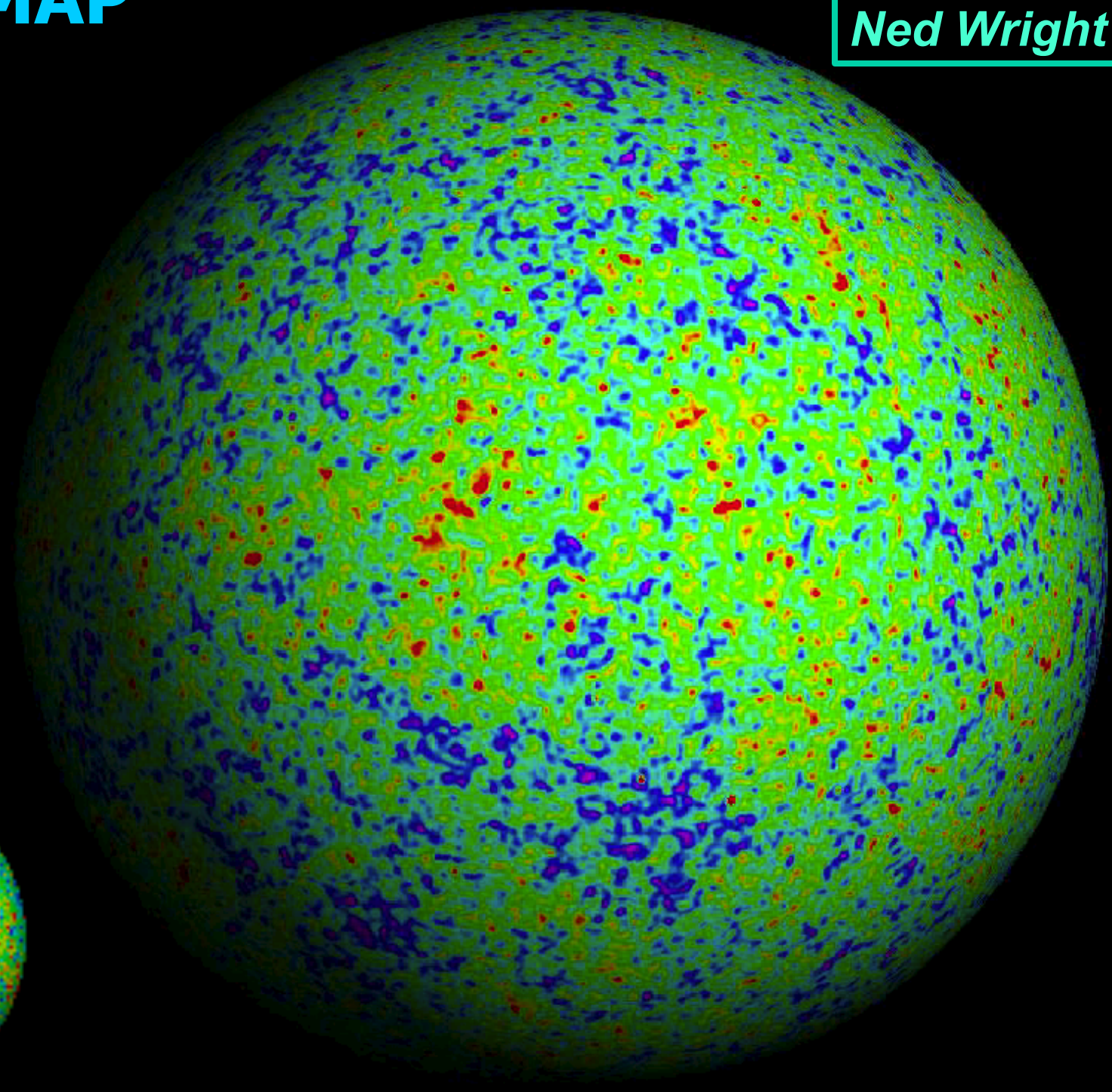
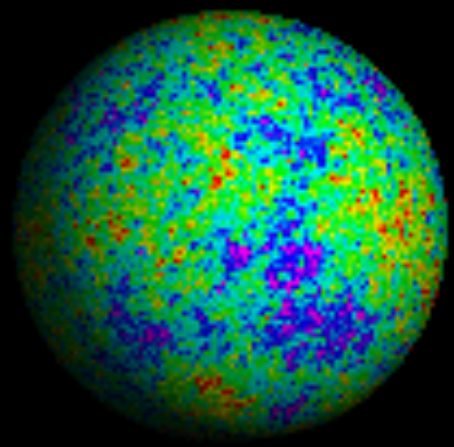
Cosmic Microwave Background (Discovered in 1964)



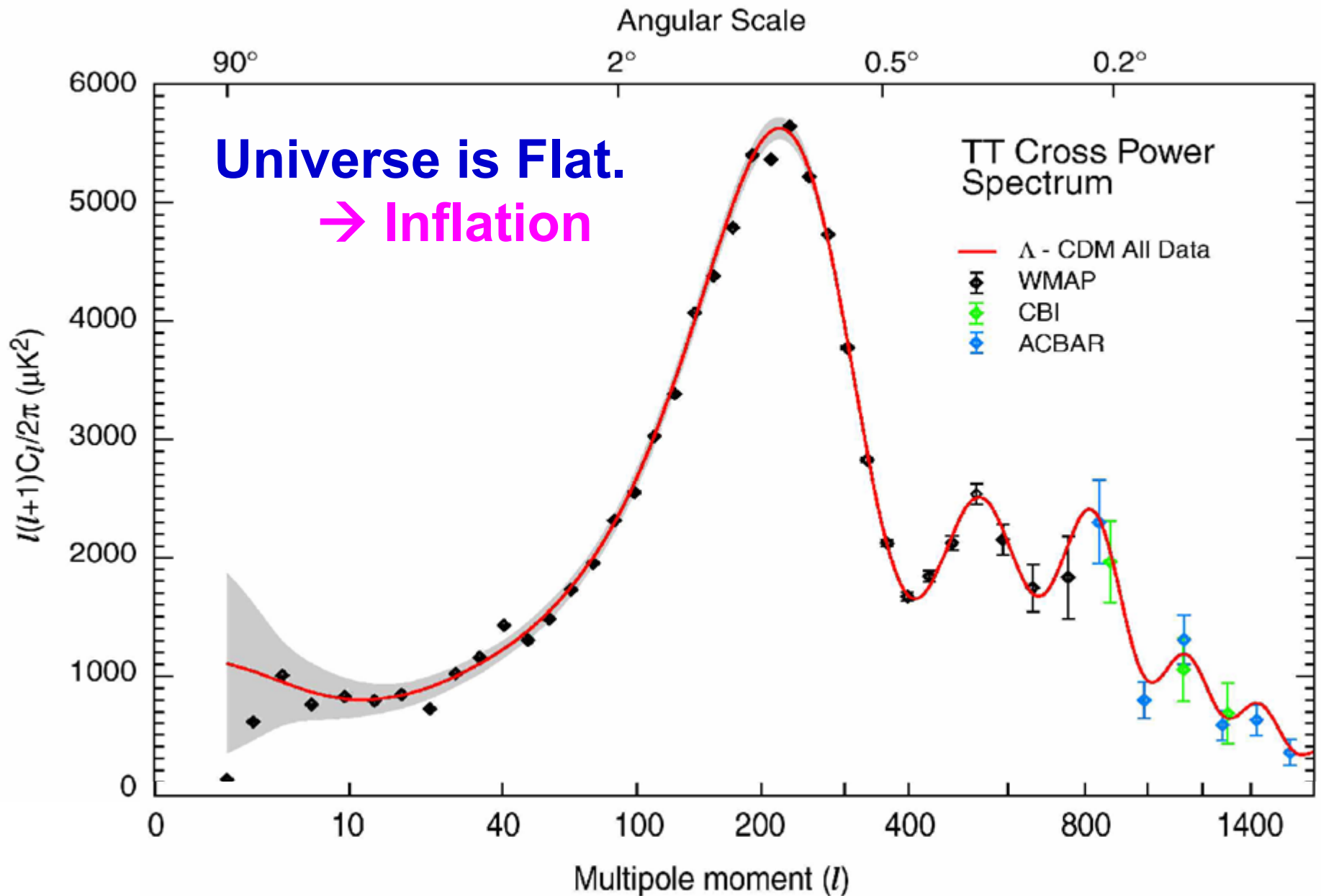
WMAP

Ned Wright

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



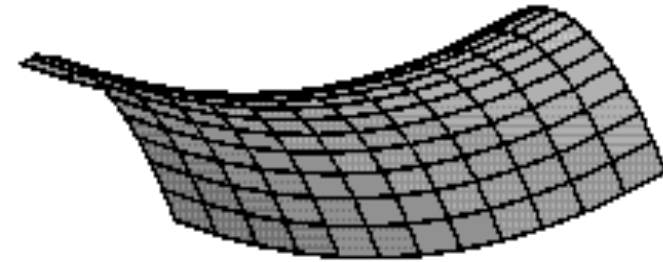
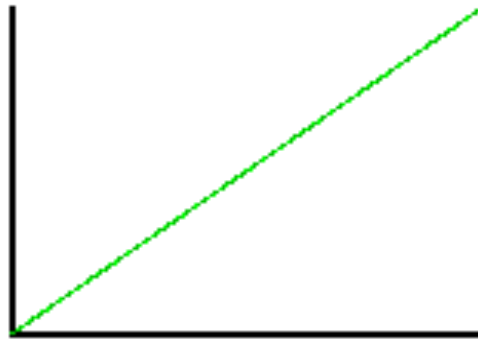
WMAP Power Spectrum



Geometry of the Universe

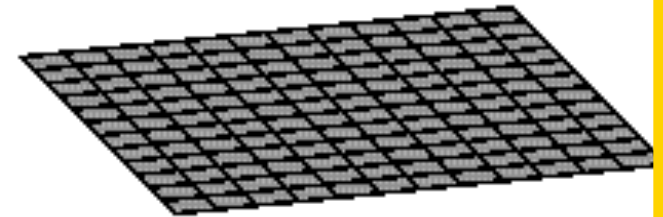
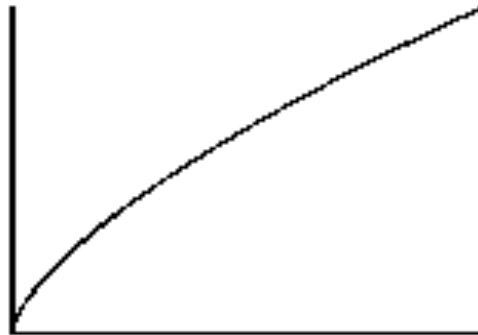
Open

$$\Omega < 1$$



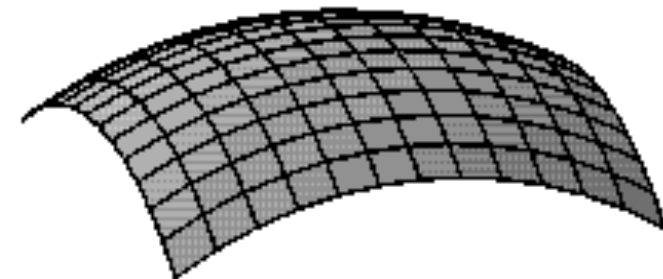
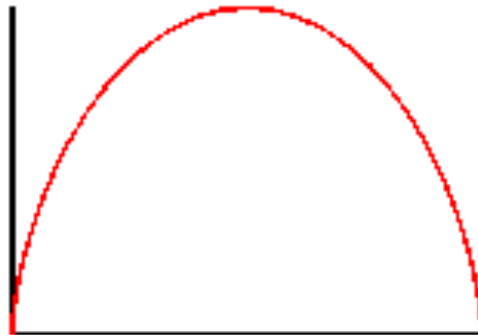
Flat
(predicted by
Inflation)

$$\Omega = 1$$

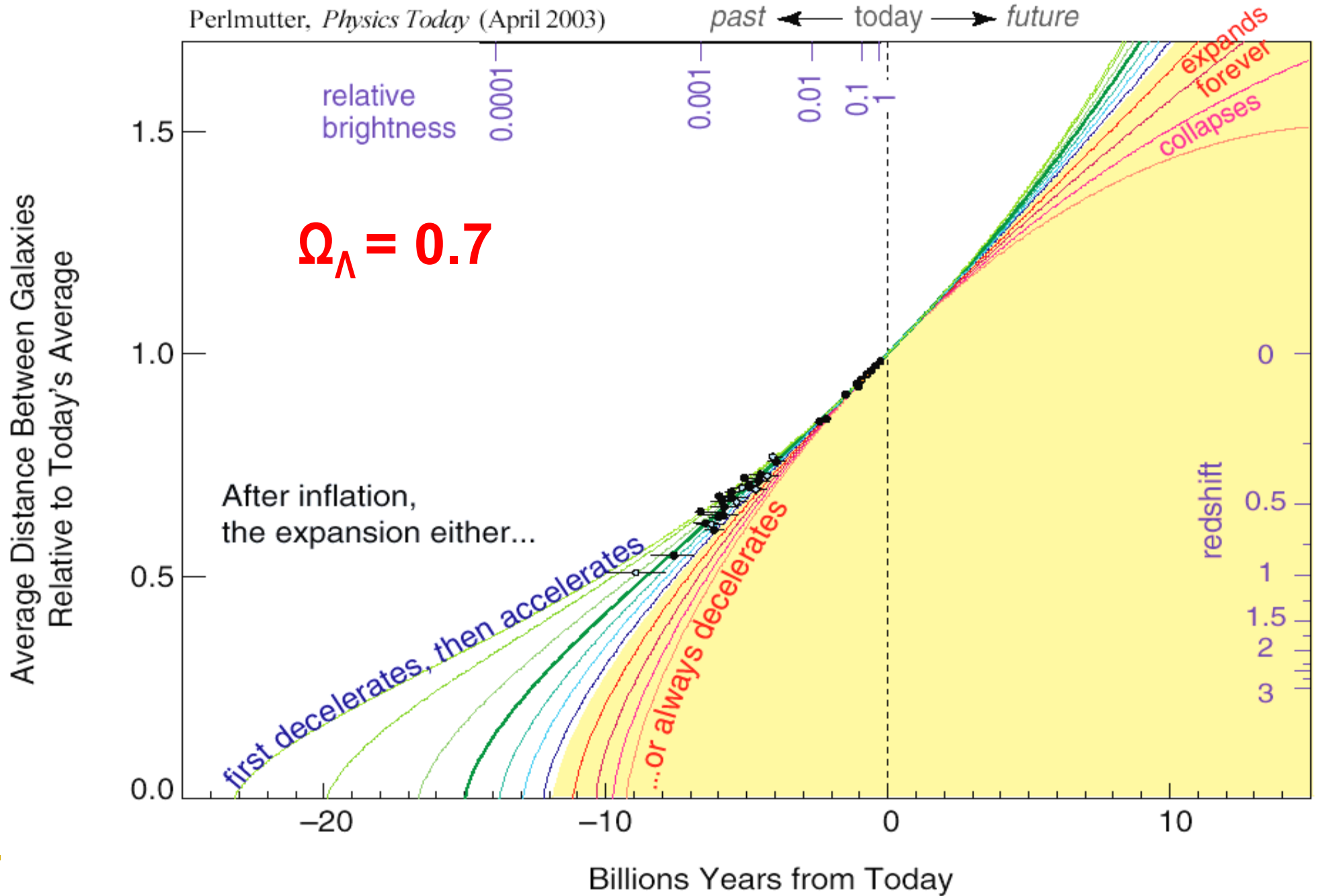


Closed

$$\Omega > 1$$



The Accelerating Universe (1998)

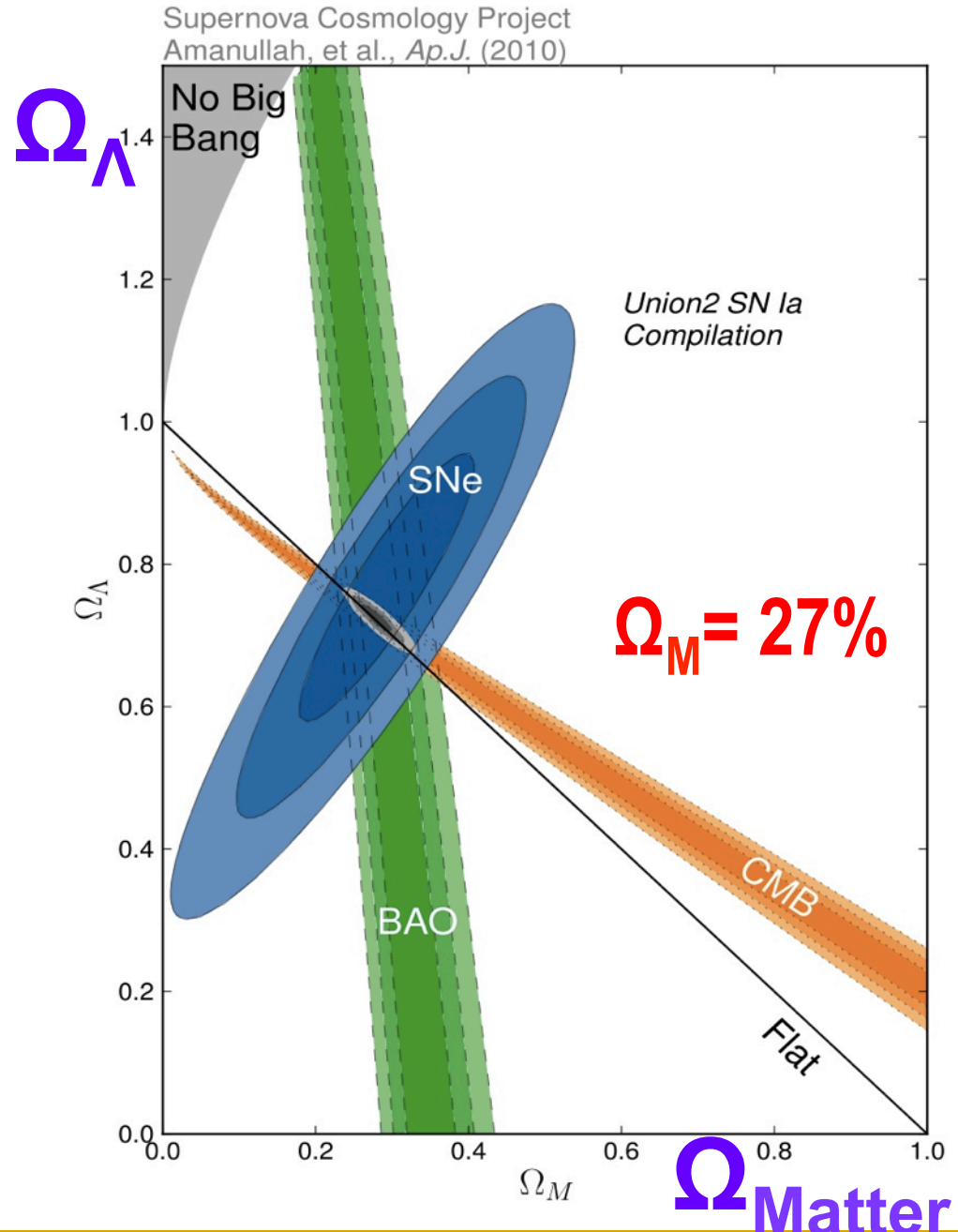


Density of Our Universe

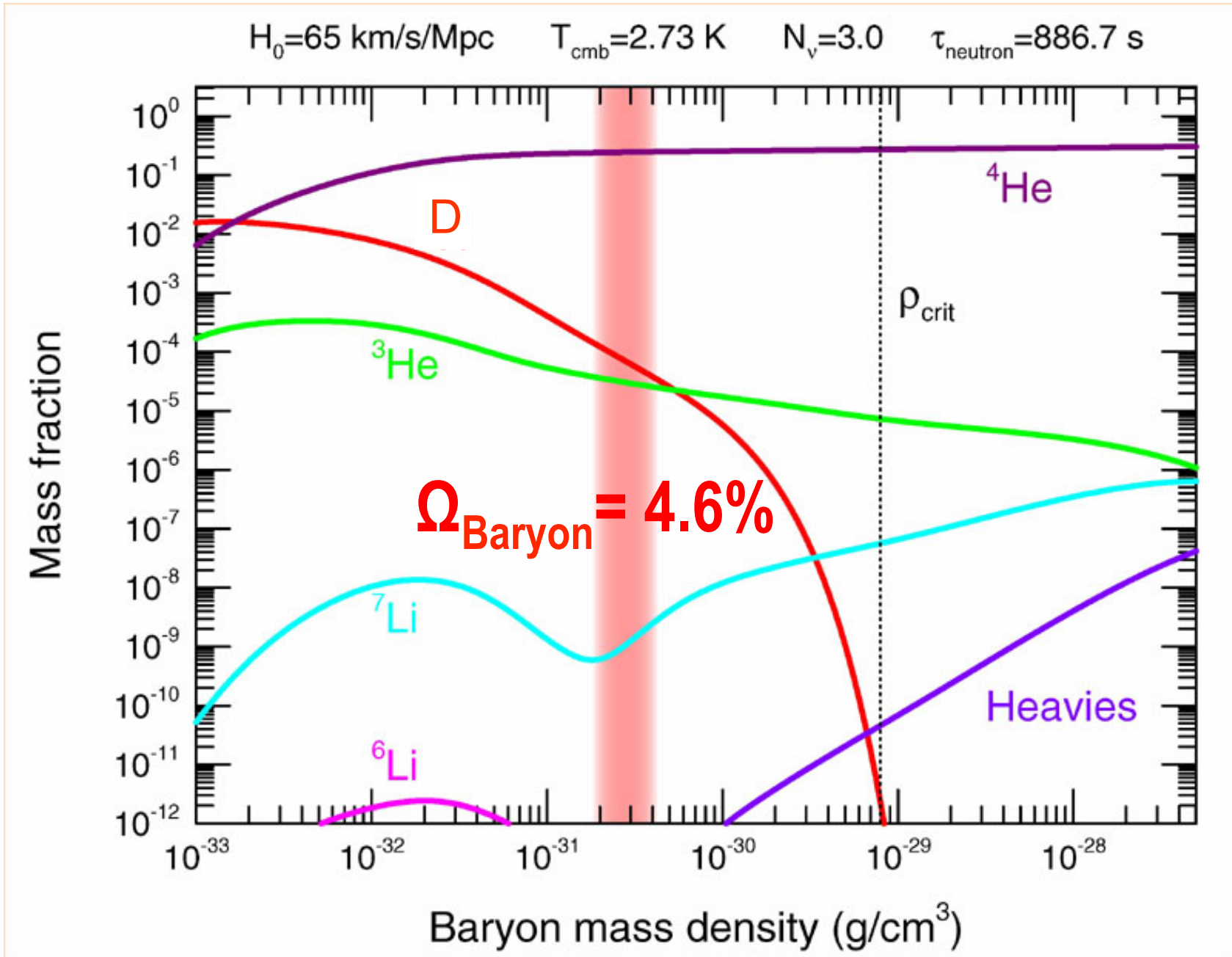
➤ $\Omega_{\text{Total}} = \Omega_{\Lambda} + \Omega_{\text{Matter}}$
 $= 1.0$

➤ Universe is Flat.
→ Inflation

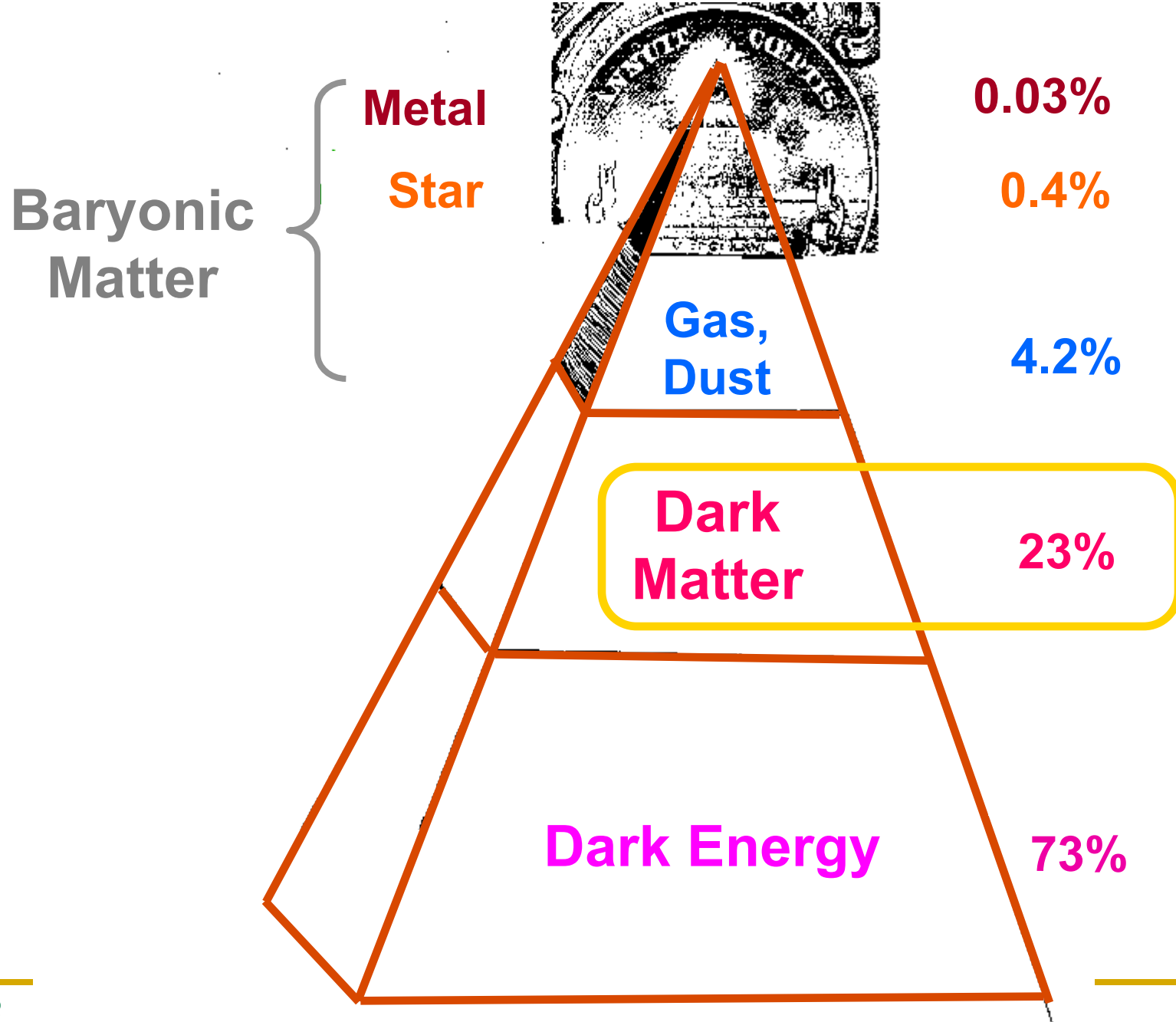
➤ 73% is Dark Energy.
→ Accelerating



Abundance vs. Density



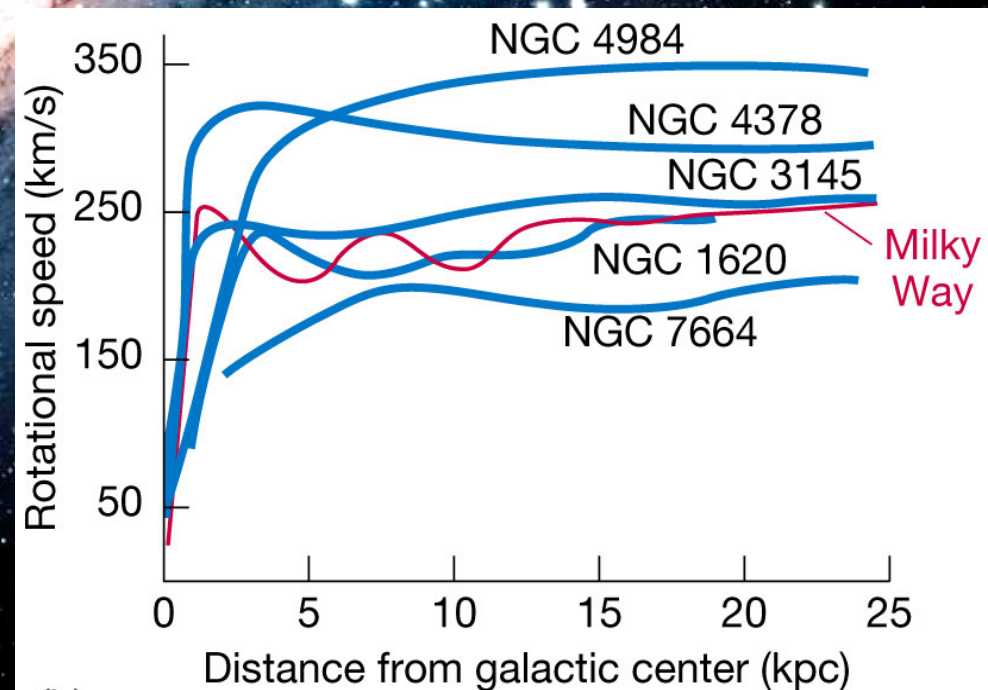
Cosmic Pyramid



Search for Dark Matter

Andromeda Galaxy

known since 1932 (Jan Oort)



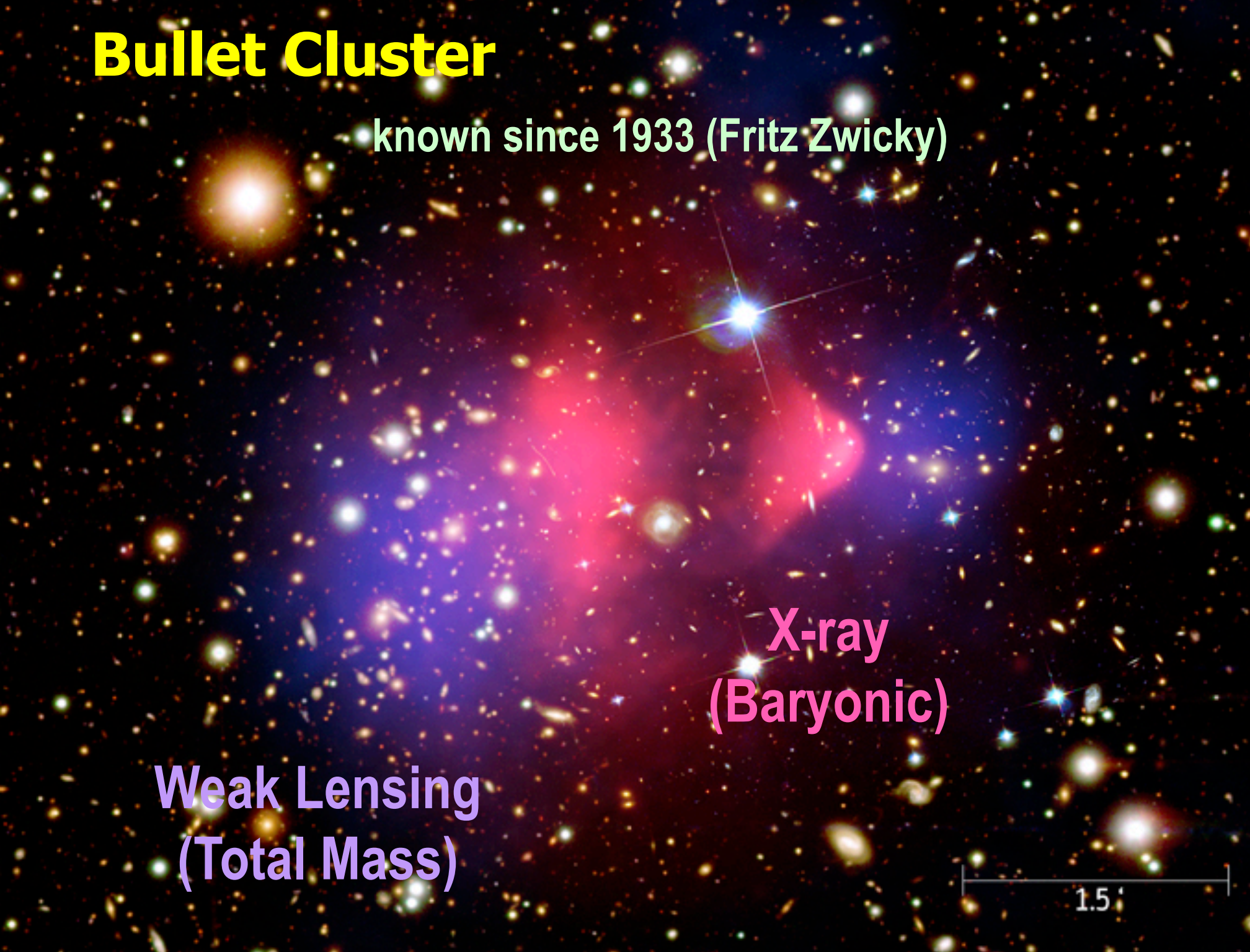
Bullet Cluster

known since 1933 (Fritz Zwicky)

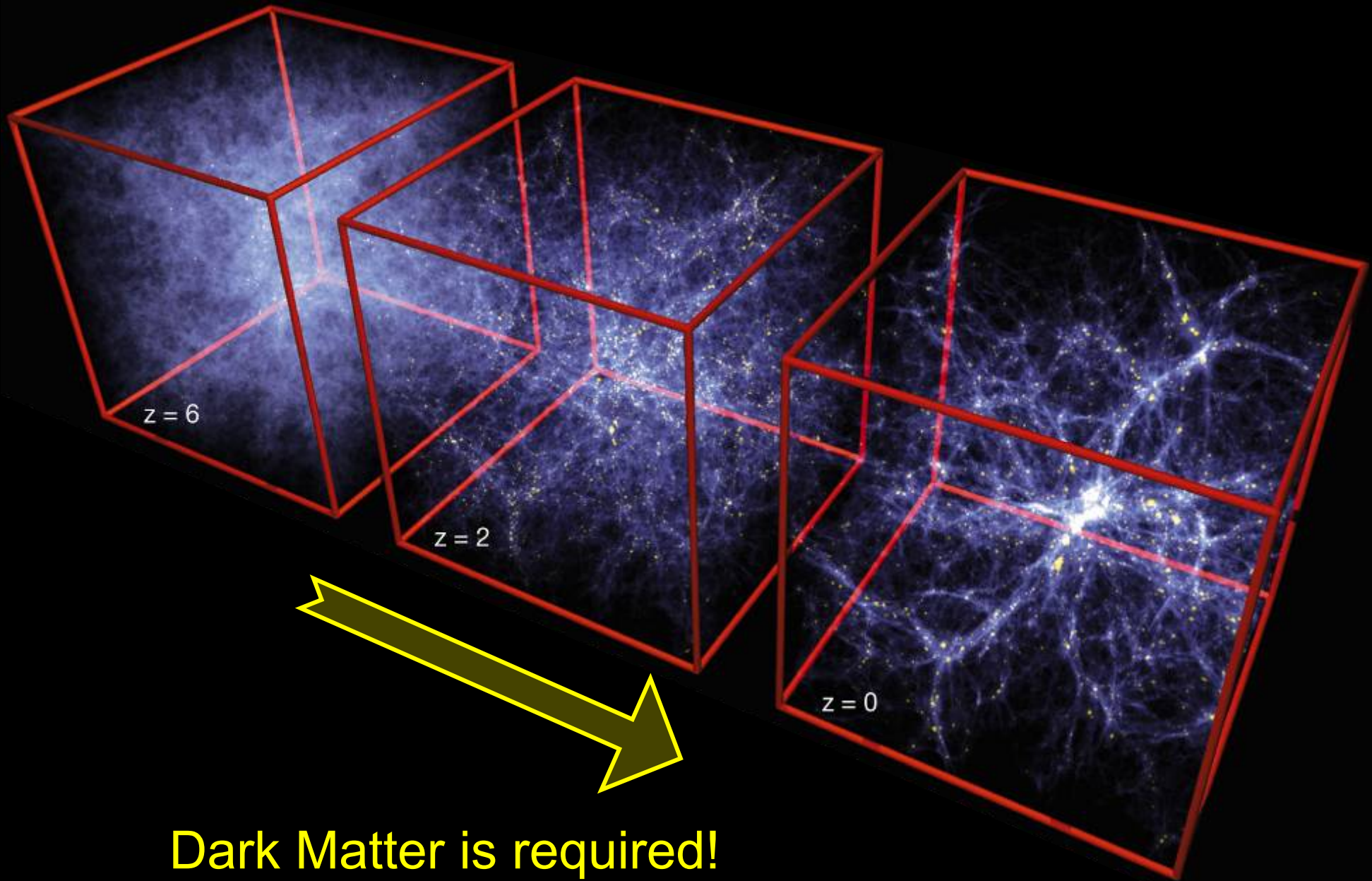
X-ray
(Baryonic)

Weak Lensing
(Total Mass)

1.5'

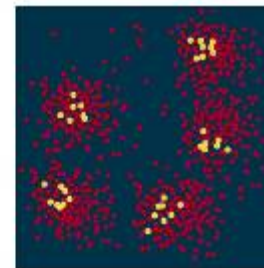
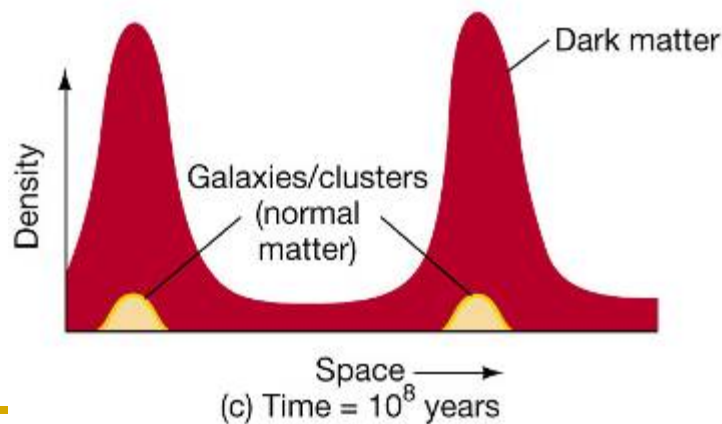
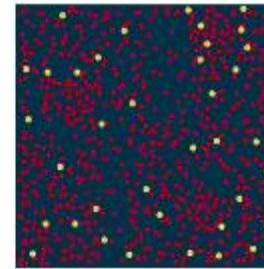
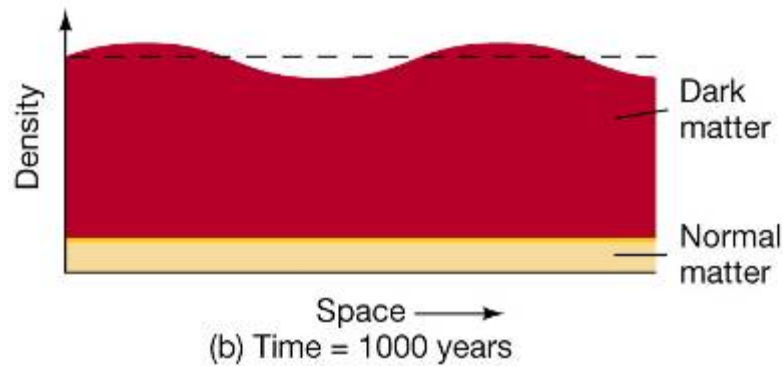
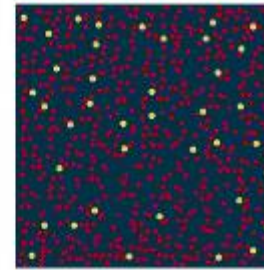
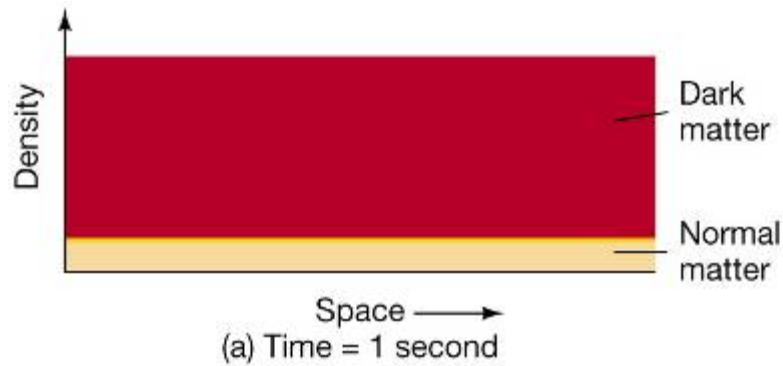


Formation of Structure in the Universe

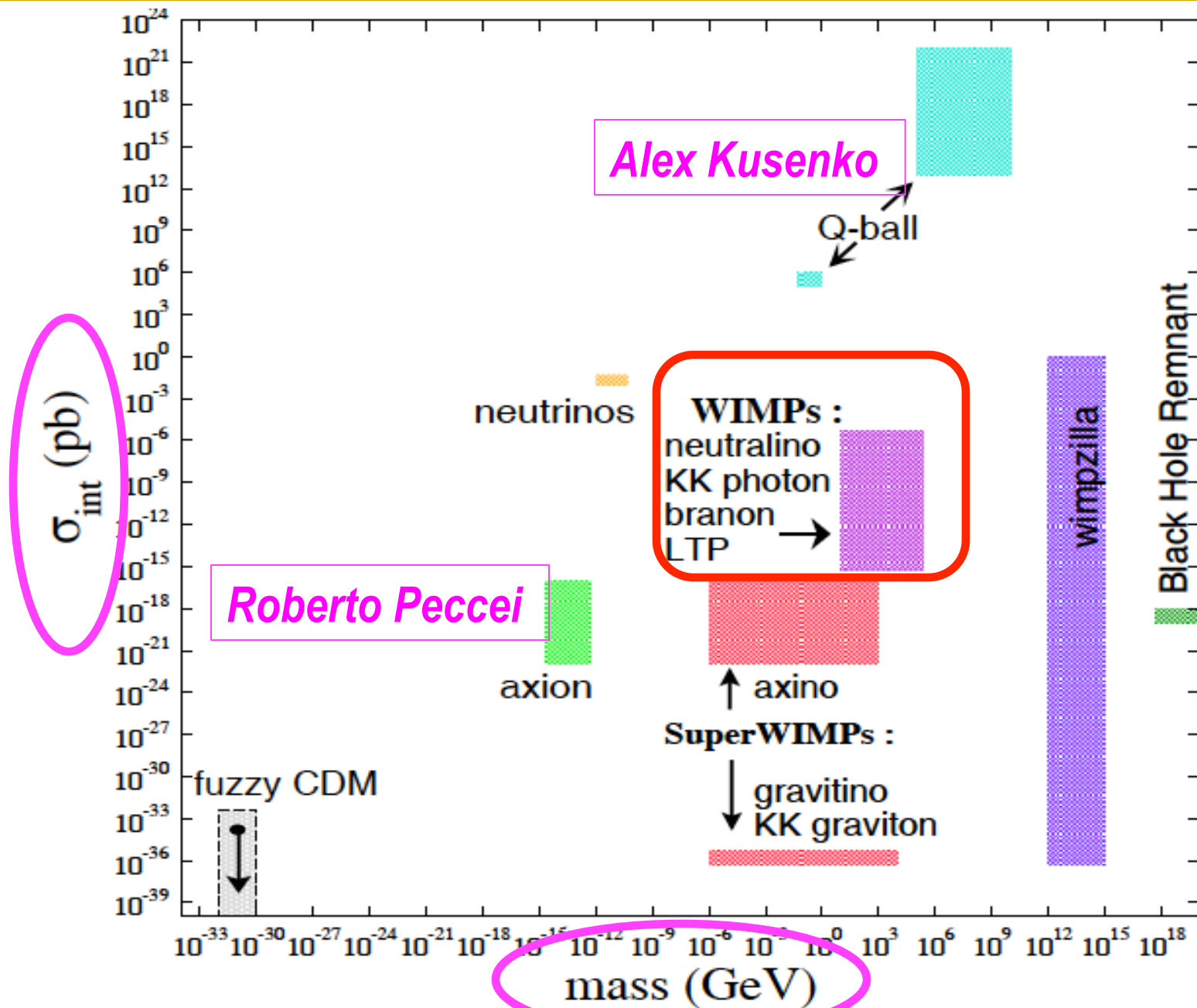


Dark Matter is required!

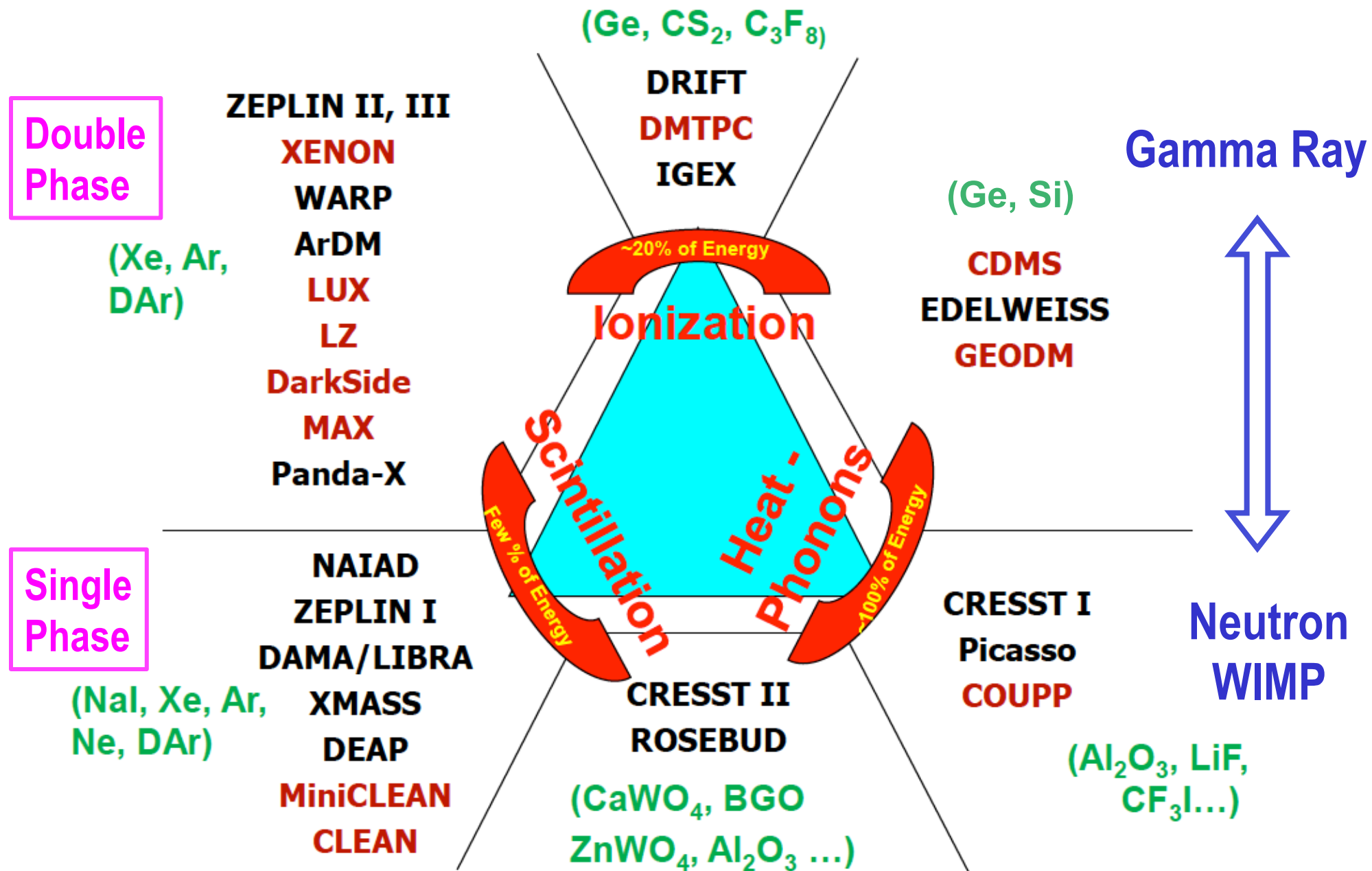
Evolution of Large Structure



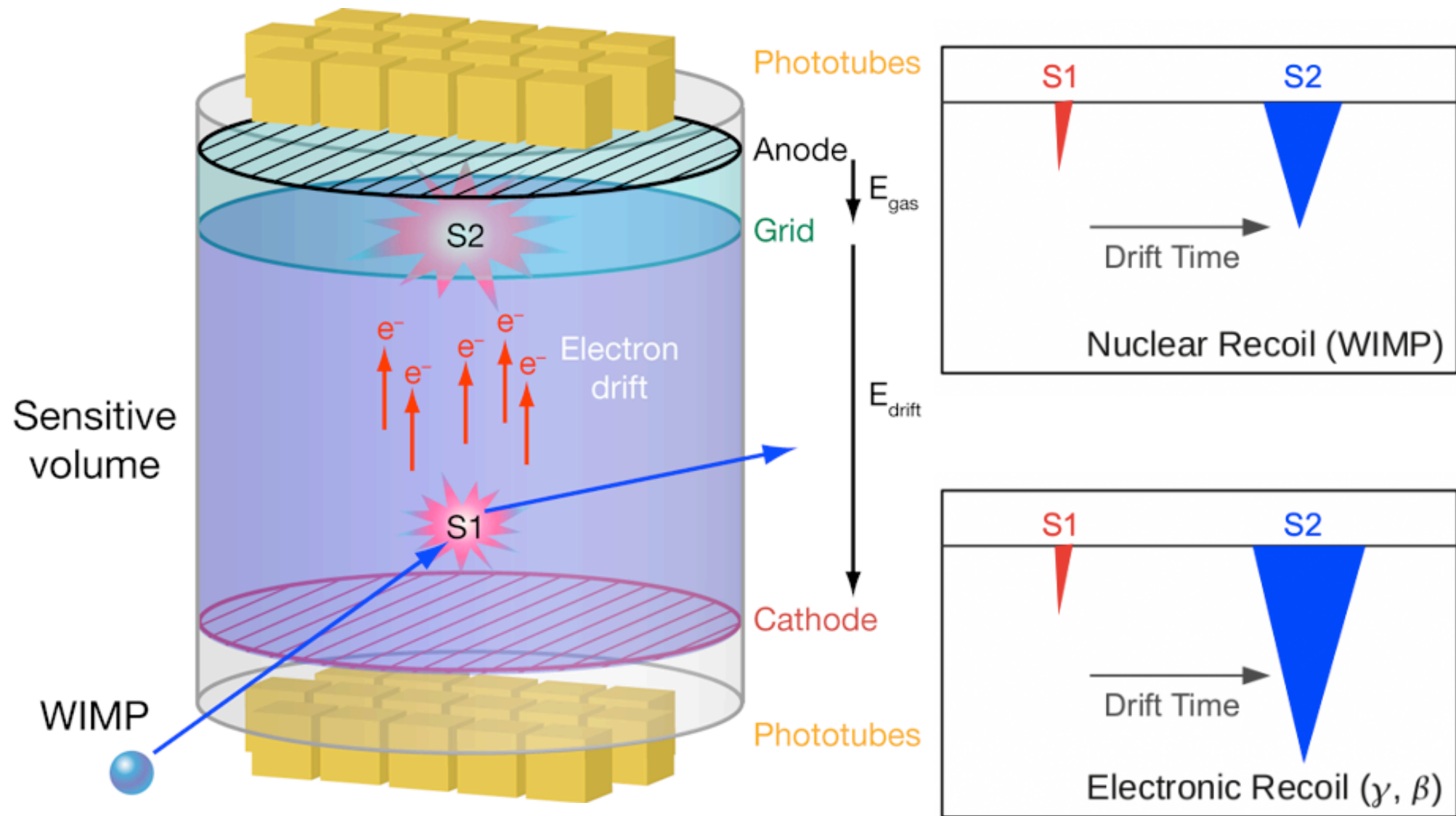
What is Dark Matter?



Detection Technique



Double-Phase Noble Liquids



XENON Collaboration at Gran Sasso

UCLA joined in 2008



Columbia



Rice



UCLA



U Zürich



Coimbra



LNGS



Mainz



SJTU



Bologna



MPIK



NIKHEF



Purdue



Subatech

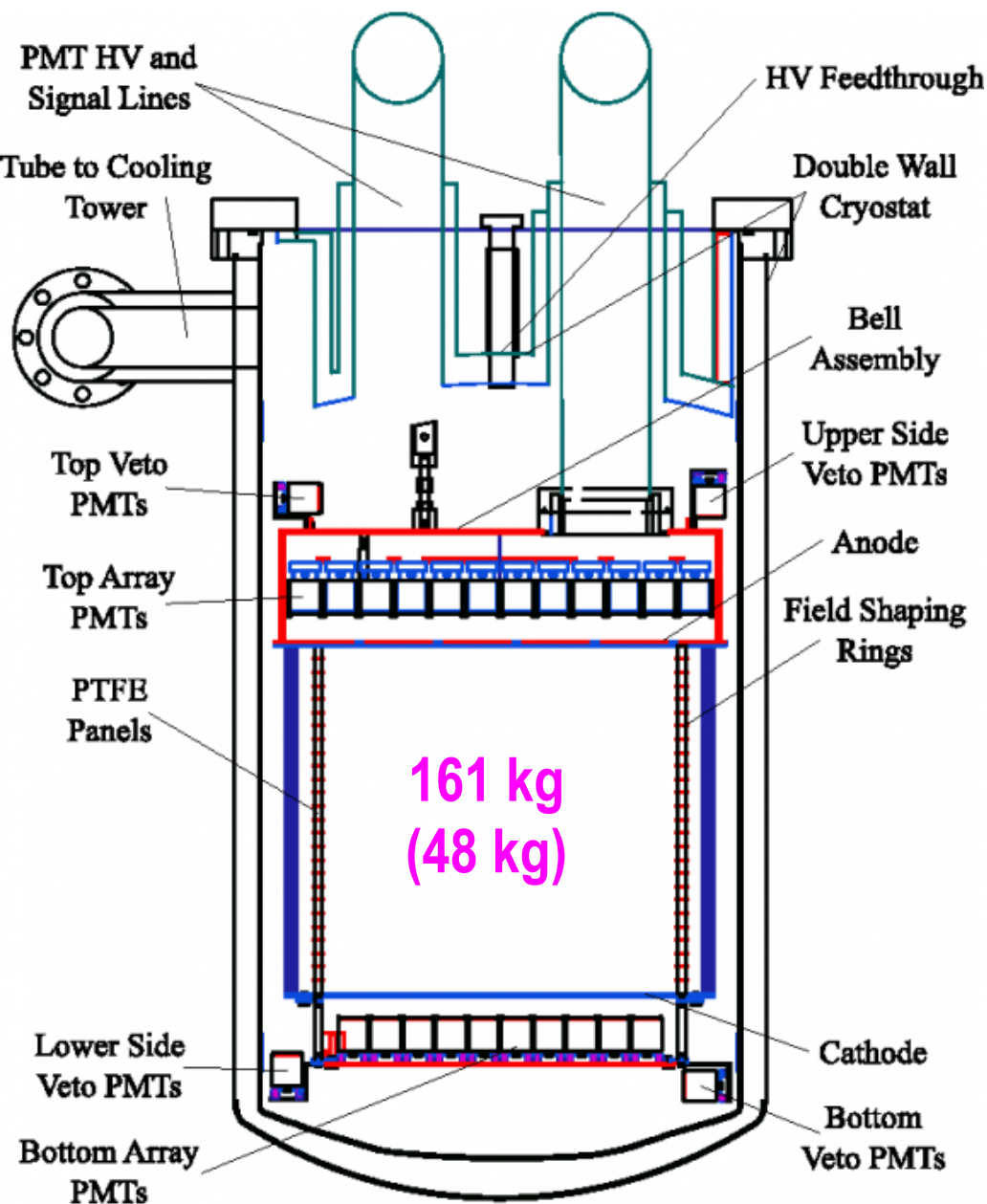


Münster



WIS

XENON100 Detector



Pb
(20cm)

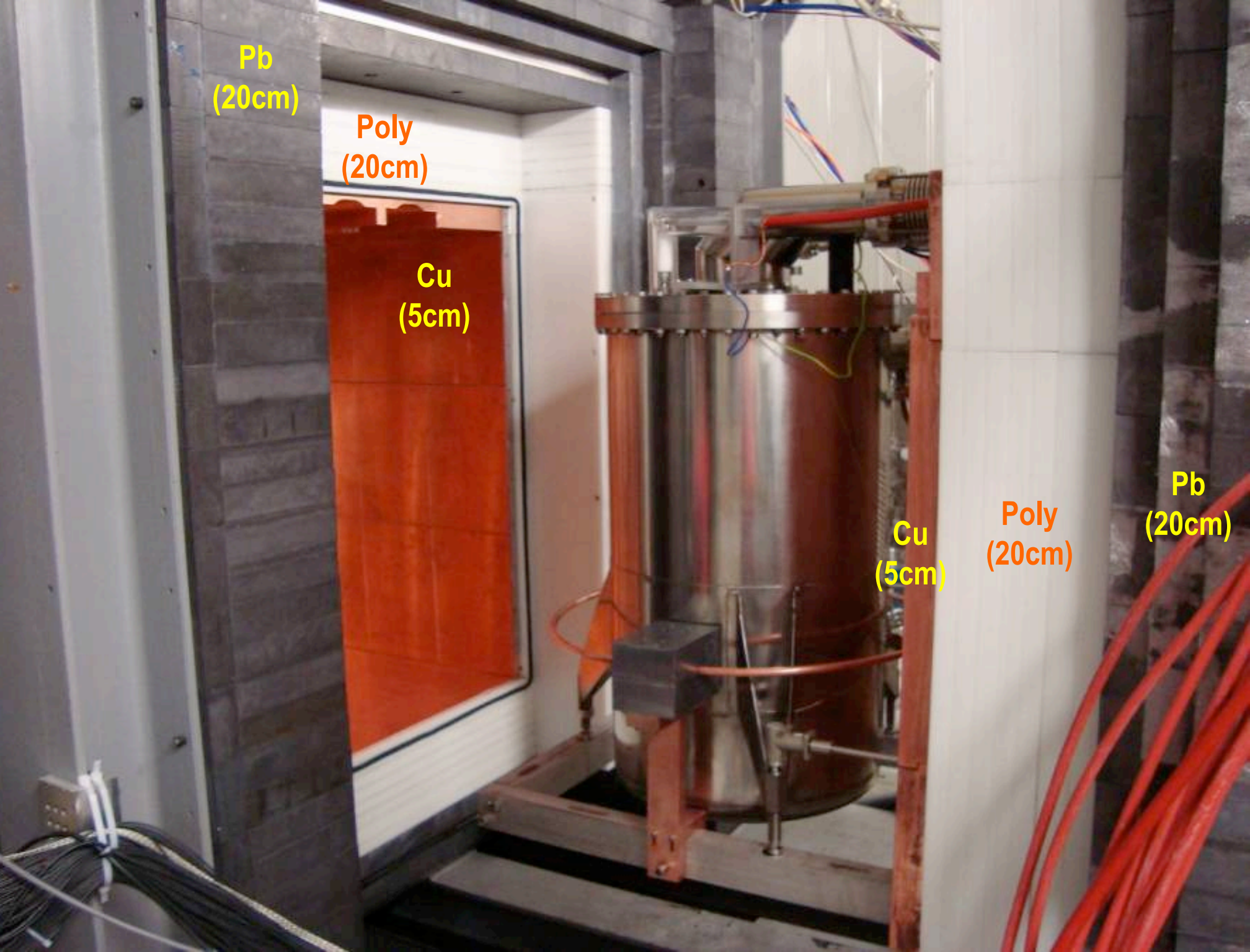
Poly
(20cm)

Cu
(5cm)

Cu
(5cm)

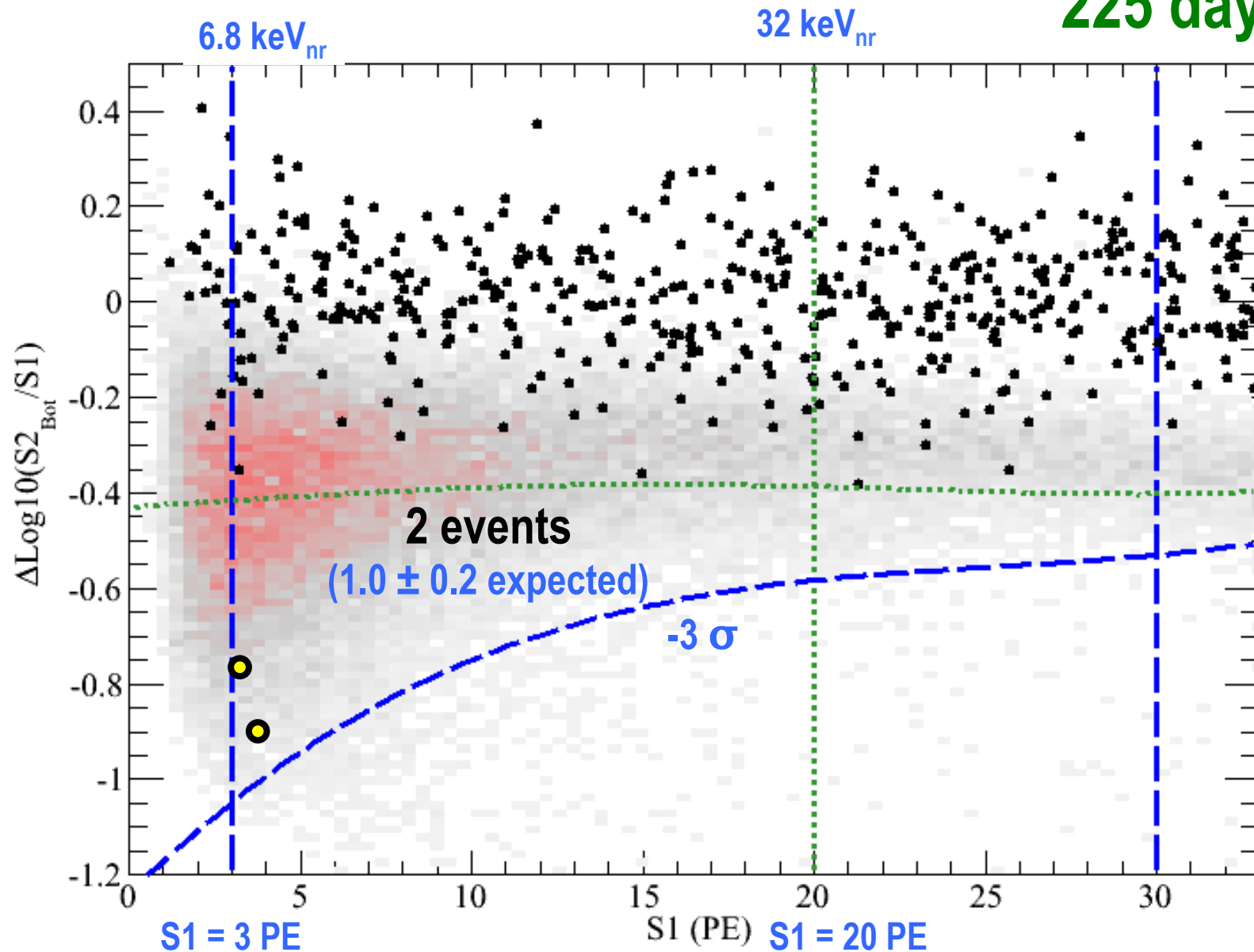
Poly
(20cm)

Pb
(20cm)

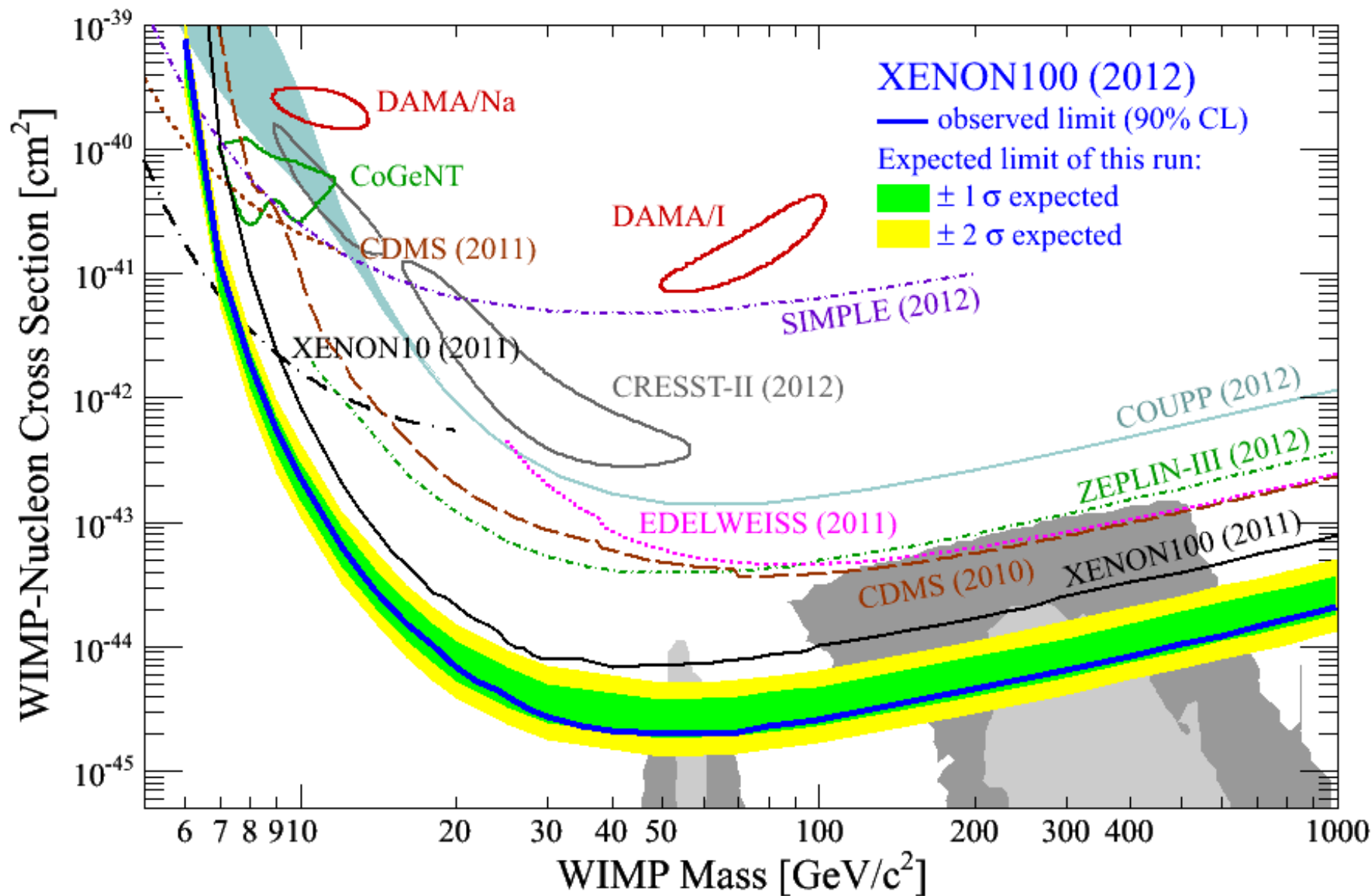


XENON0100 New Results

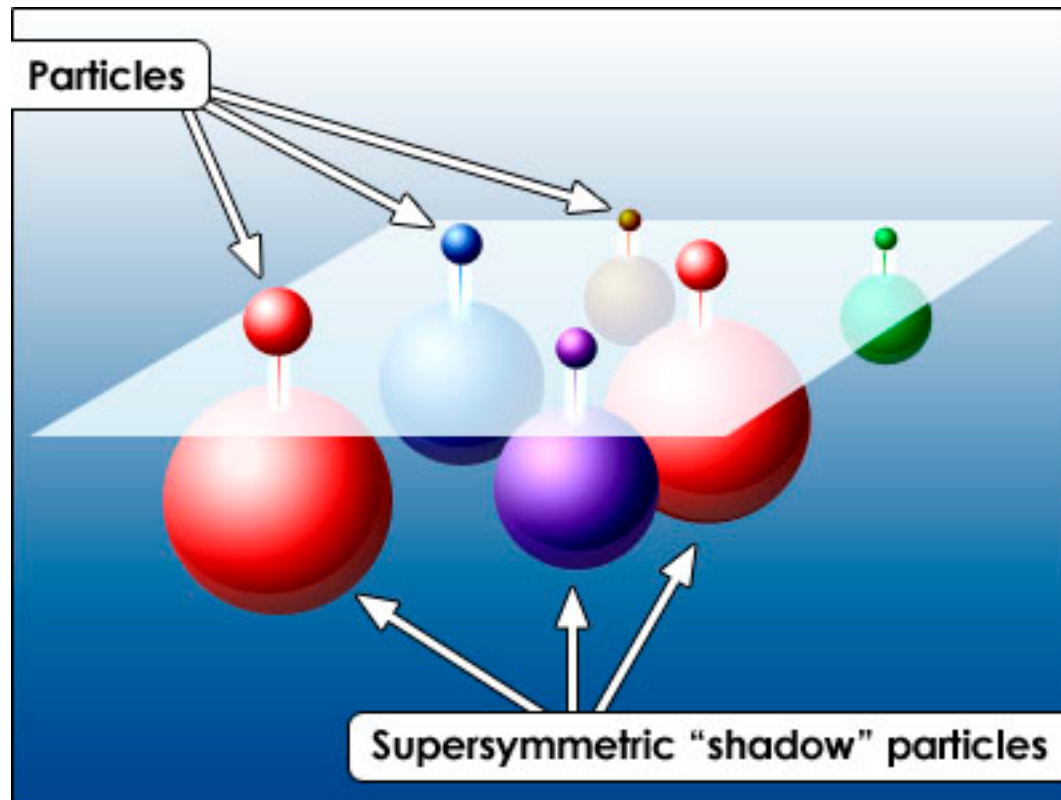
225 days, 34 kg



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

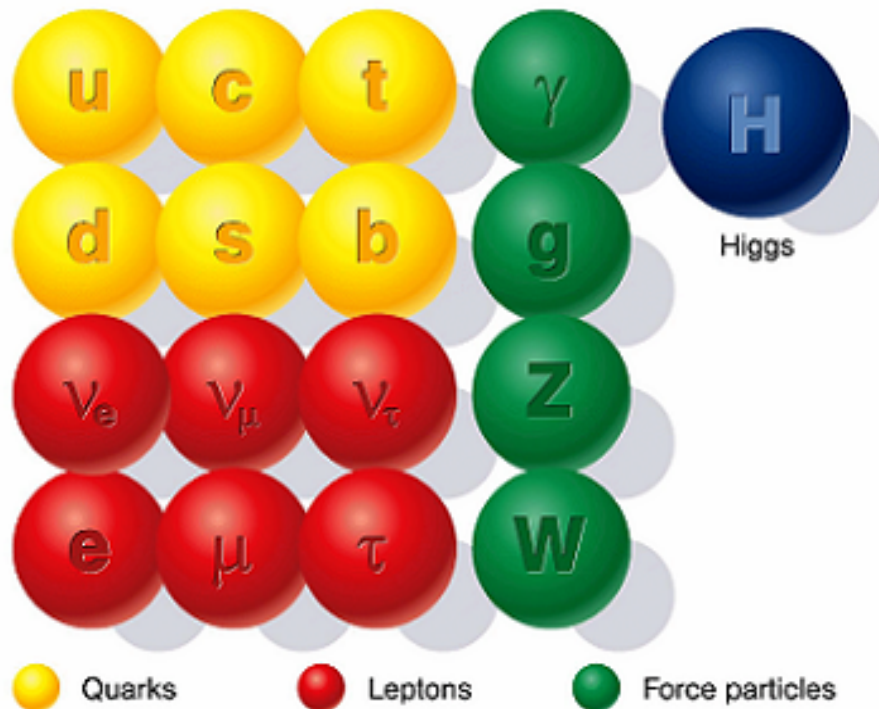


SUSY Neutralino



SUSY Particles and Neutralino

Standard particles



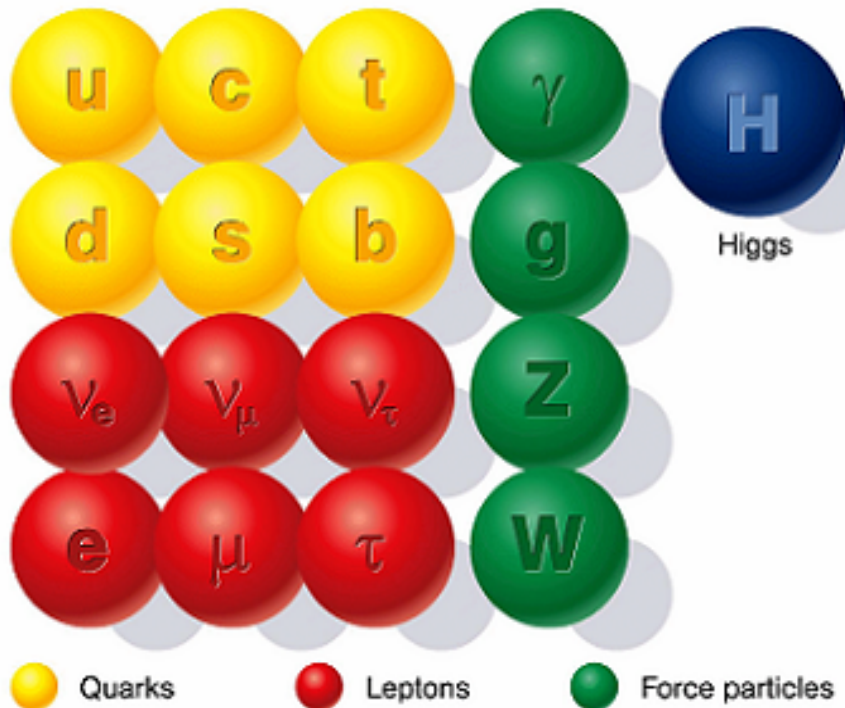
Spin 1/2 1 0

SUSY Particles and Neutralino

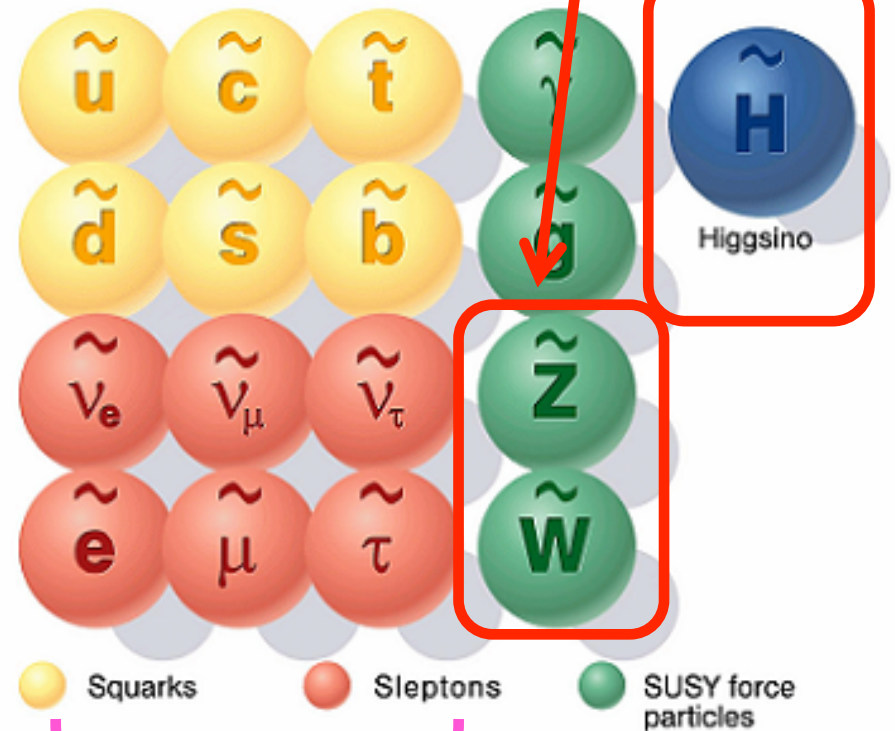
Super Symmetry

Neutralino

Standard particles



SUSY particles



Spin: 1/2, 1, 0, 0, 1/2, 1/2

Hierarchy Problem

Higgs mass

$m_b^2 = m_{b0}^2 + \Delta m_b^2$, where m_{b0}^2 is the tree-level mass, and

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

SUSY :
$$\Delta m_b^2 \sim \frac{\lambda^2}{16\pi^2} \int^\Lambda \frac{d^4 p}{p^2} \Big|_{\text{SM}} - \frac{\lambda^2}{16\pi^2} \int^\Lambda \frac{d^4 p}{p^2} \Big|_{\text{SUSY}}$$

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

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

MSSM: > 100 parameters

Minimal Flavour Violation: 13 parameters
(+ 6 violating CP)

SU(5) unification: 7 parameters

NUHM2: 6 parameters

NUHM1 = SO(10): 5 parameters

CMSSM: 4 parameters

mSUGRA: 3
parameters

String?

Mass Spectra at the best fit points (before LHC)

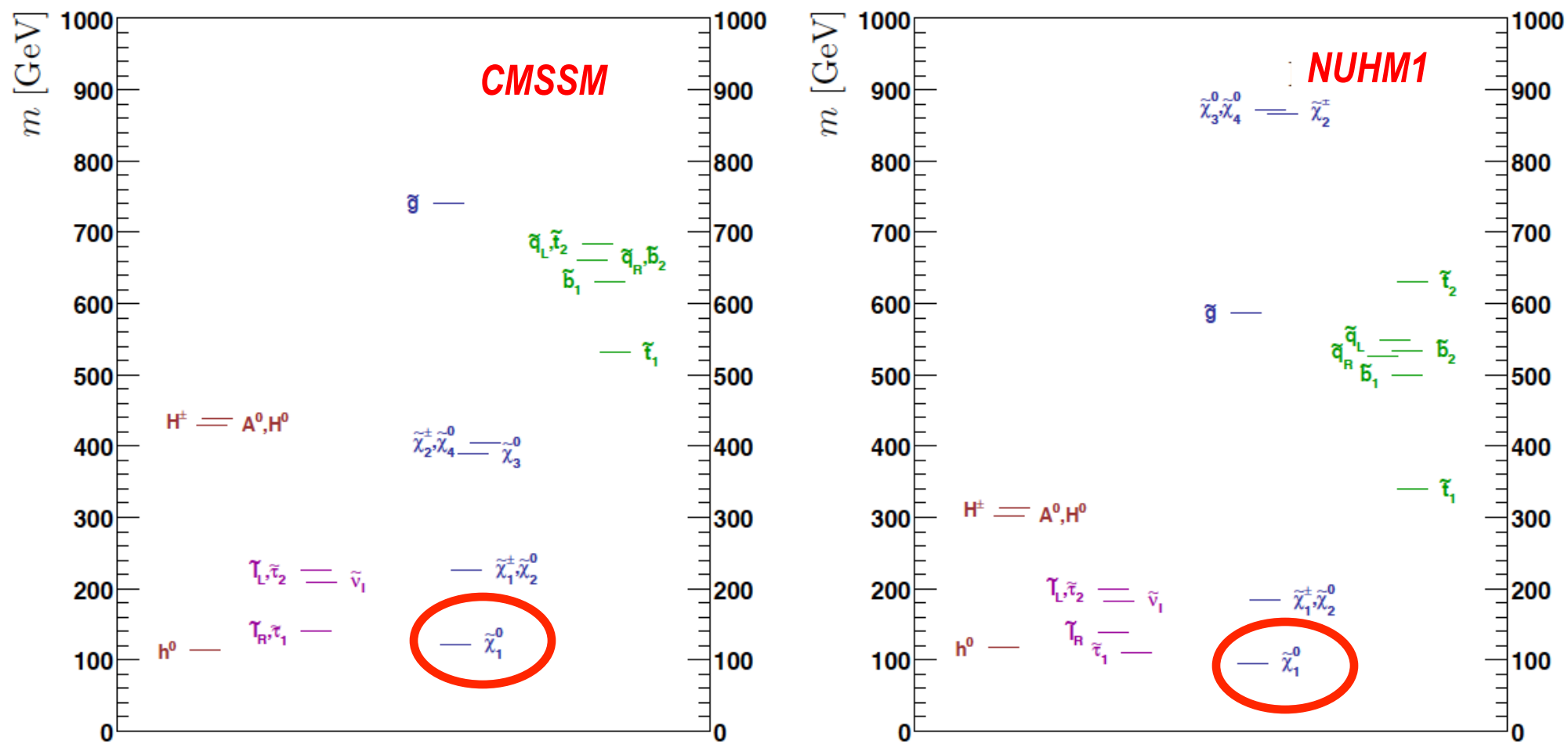
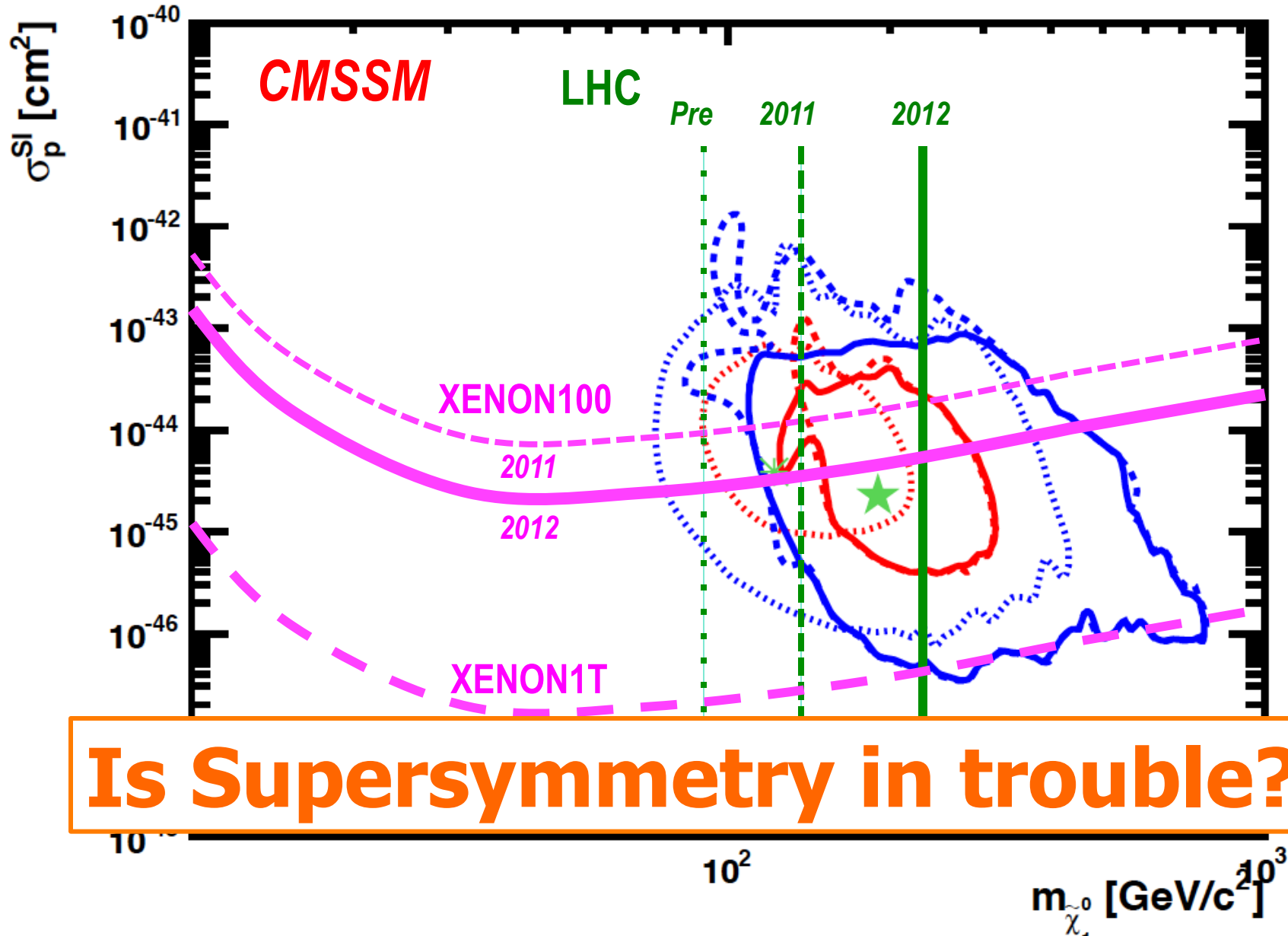


Figure 2. The spectra at the best-fit points: left — in the CMSSM with $m_0 = 60$ GeV, $m_{1/2} = 310$ GeV, $A_0 = 240$ GeV, $\tan\beta = 11$, and right — in the NUHM1 with $m_0 = 100$ GeV, $m_{1/2} = 240$ GeV, $A_0 = -930$ GeV, $\tan\beta = 7$, $m_H^2 = -6.9 \times 10^5$ GeV² and $\mu = 870$ GeV.

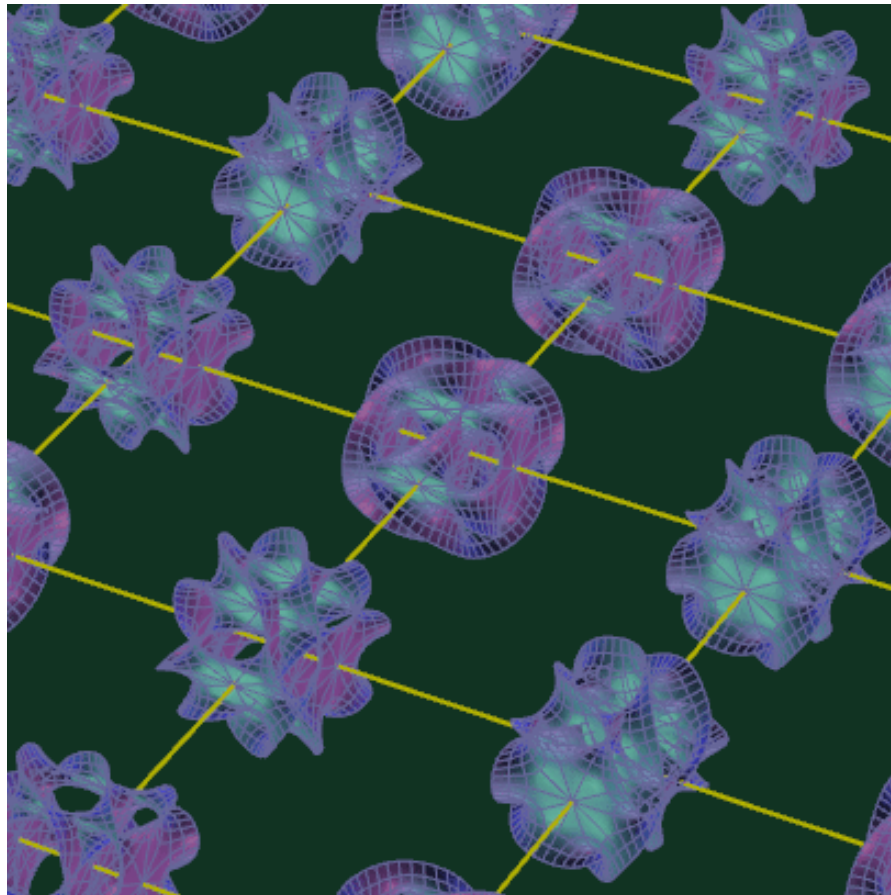
SI Cross Section vs. Mass

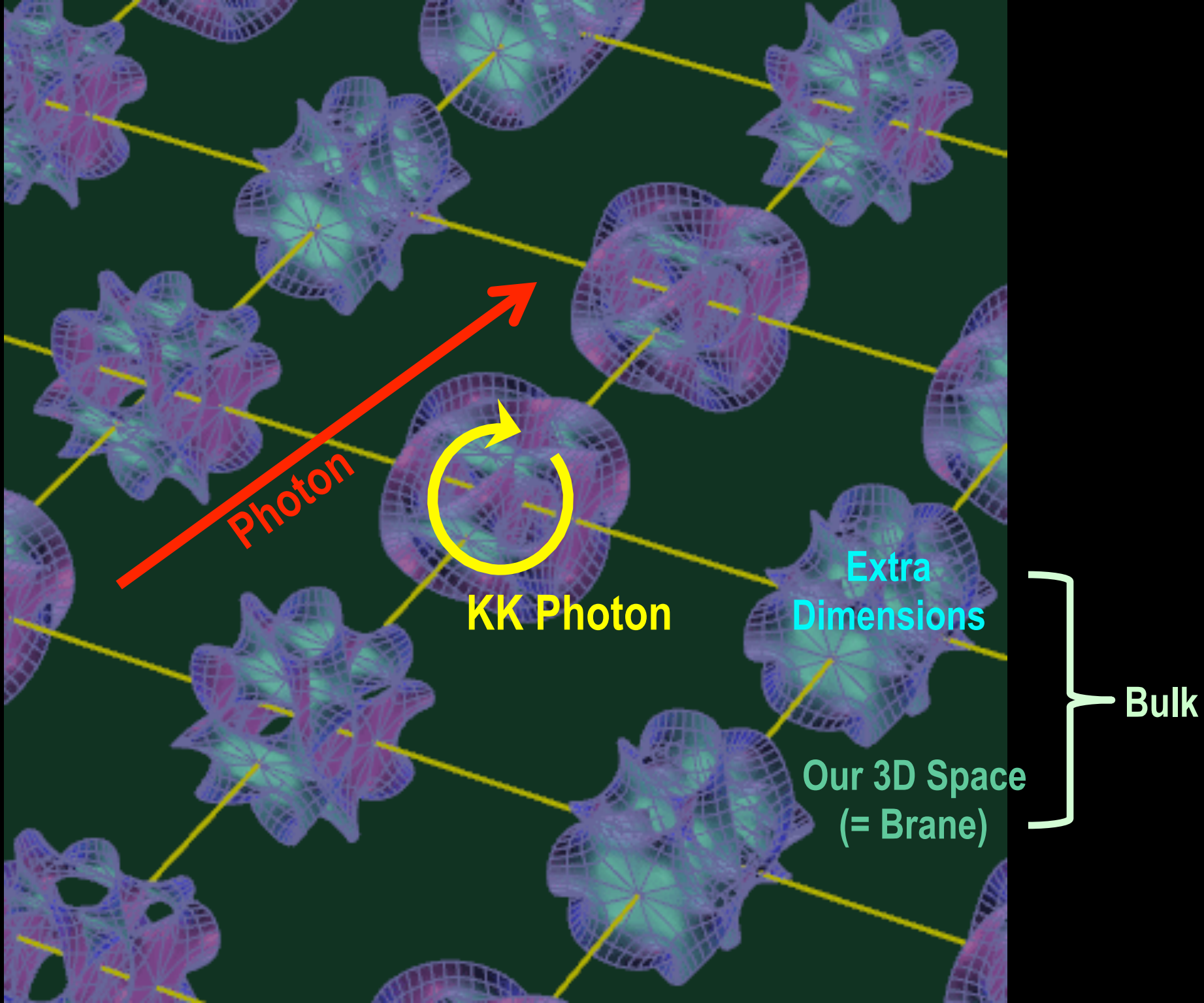


Is Supersymmetry in trouble?

Buchmueller et al [arXiv:1106.2529](https://arxiv.org/abs/1106.2529)

KK particles in Extra Dimensions





Origin of Mass in Extra Dimensions

$$E = mc^2 \rightarrow m = E/c^2$$

- 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

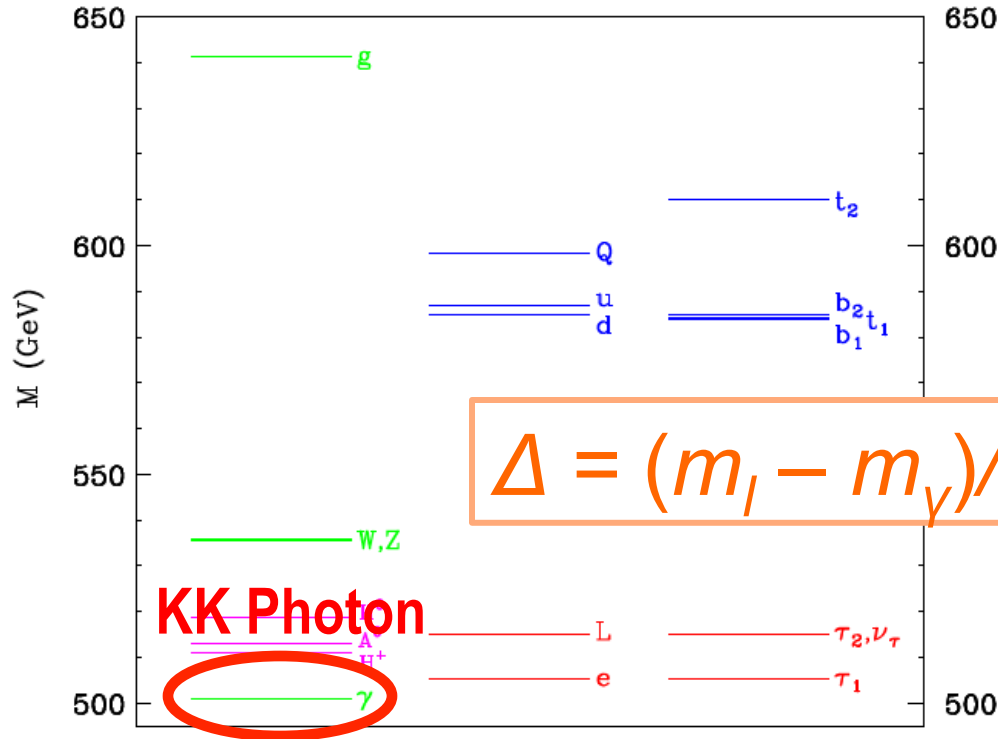


FIG. 1: One-loop corrected mass spectrum of the first KK level in MUEDs for $R^{-1} = 500$ GeV, $\Lambda R = 20$ and $m_h = 120$ GeV.

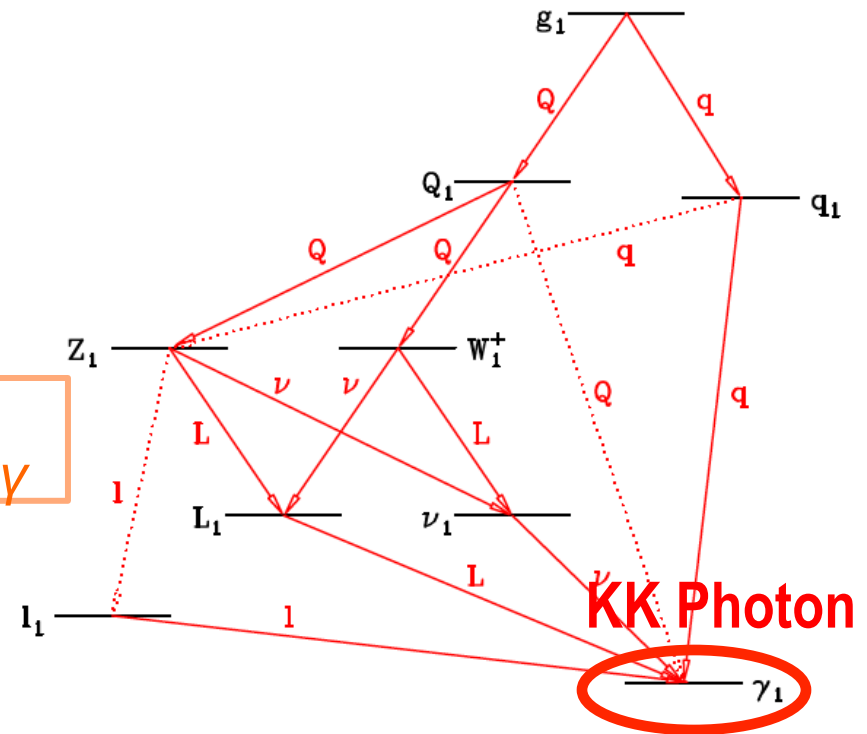
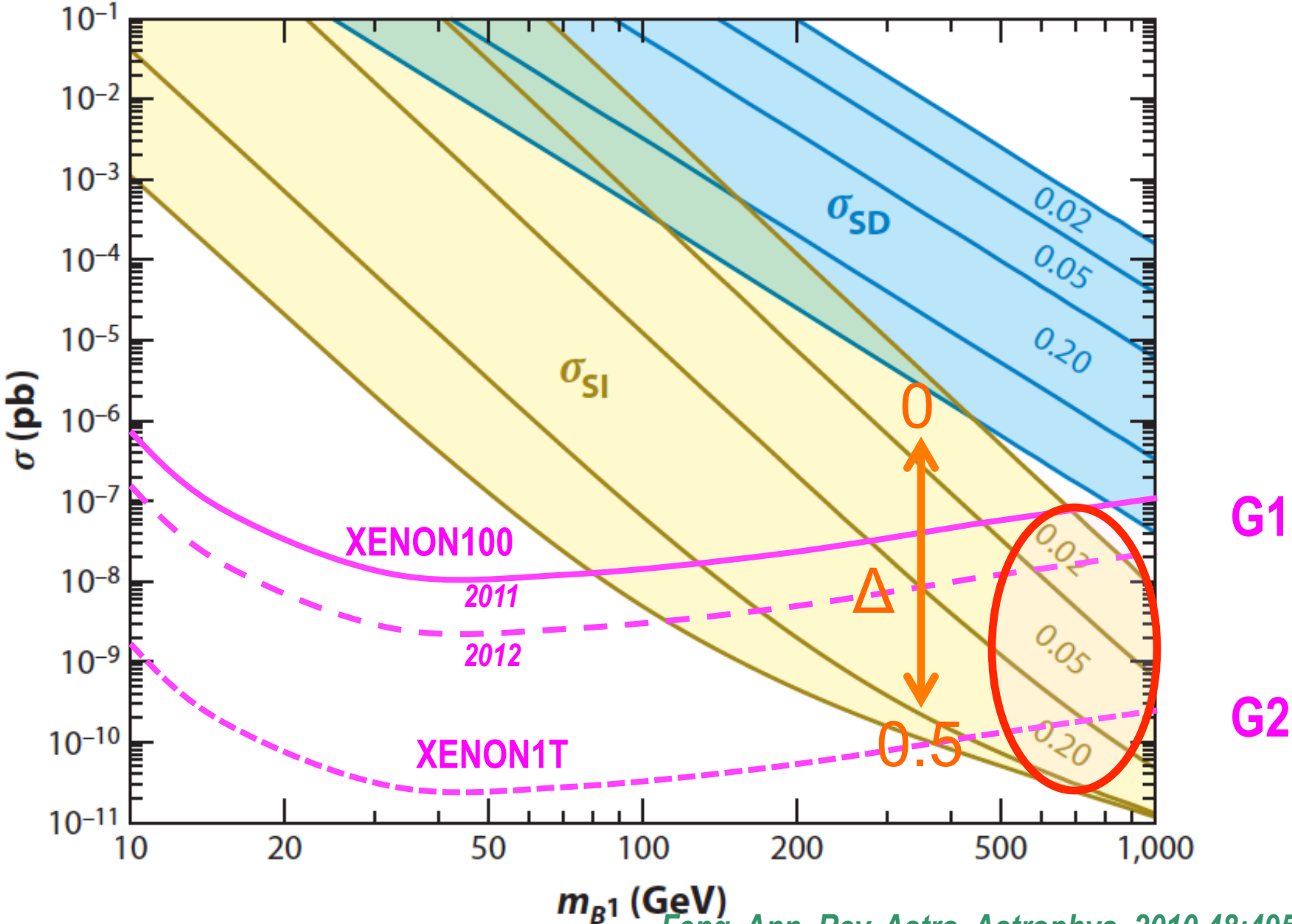


FIG. 3: Qualitative sketch of the level 1 KK spectroscopy depicting the dominant (solid) and rare (dotted) transitions and the resulting decay product.

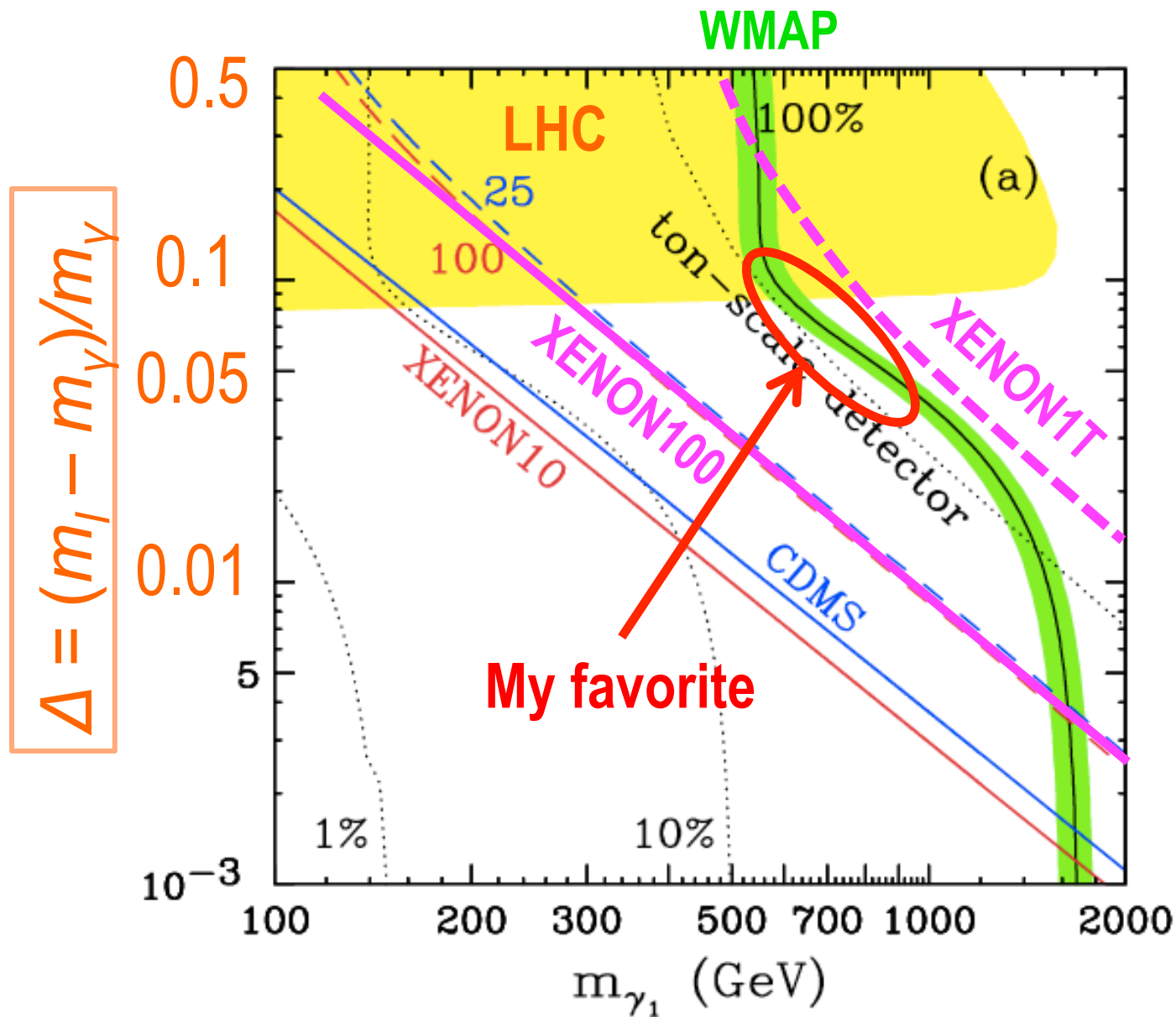
Cheng 2002 [arXiv:hep-ph/0205314v1](https://arxiv.org/abs/hep-ph/0205314)

Predicted Cross Section of Kaluza-Klein Dark Matter



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

Sensitivity to KK particles



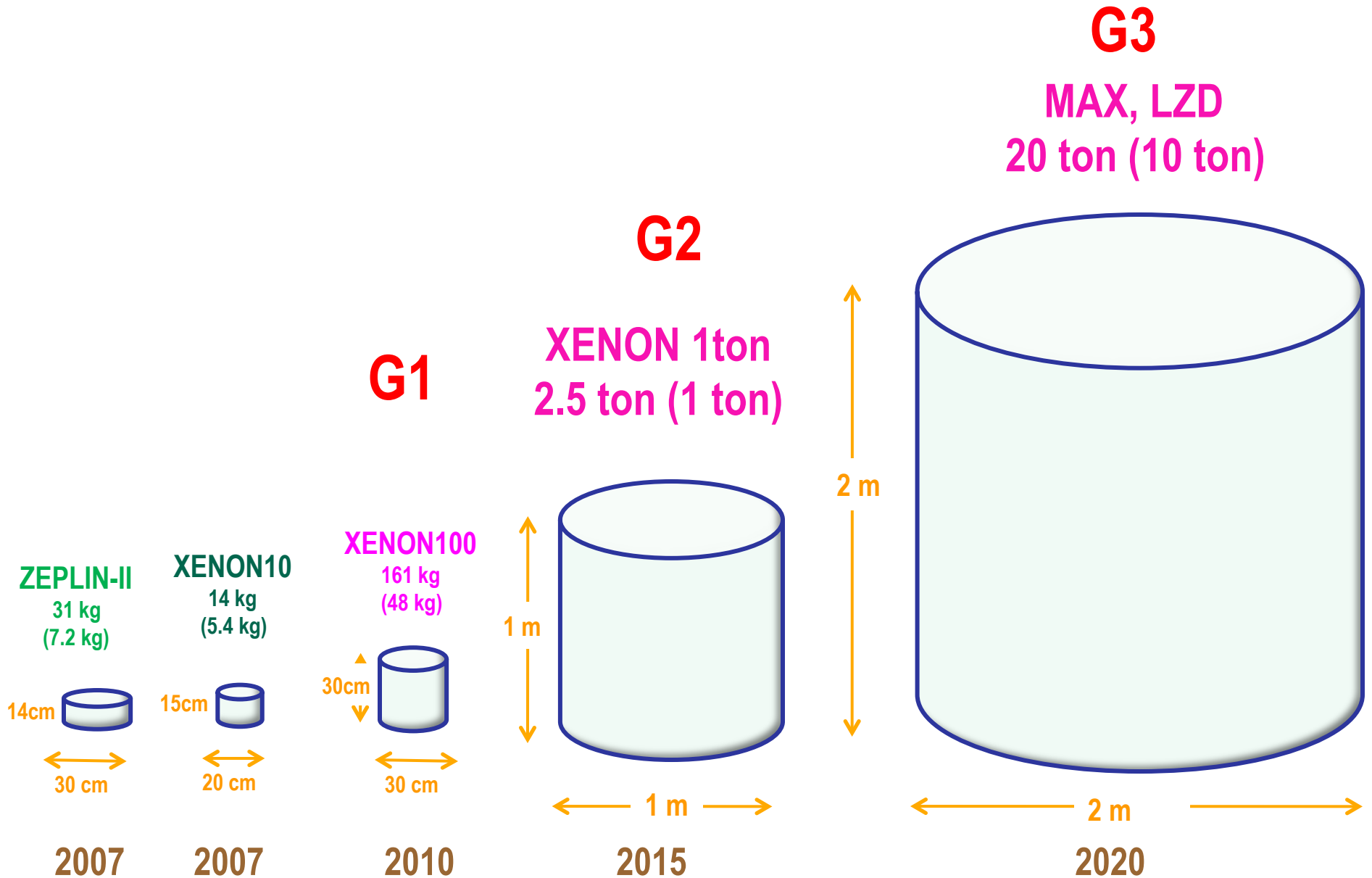
Arrenberg 2008

Summary on “Science Cases”

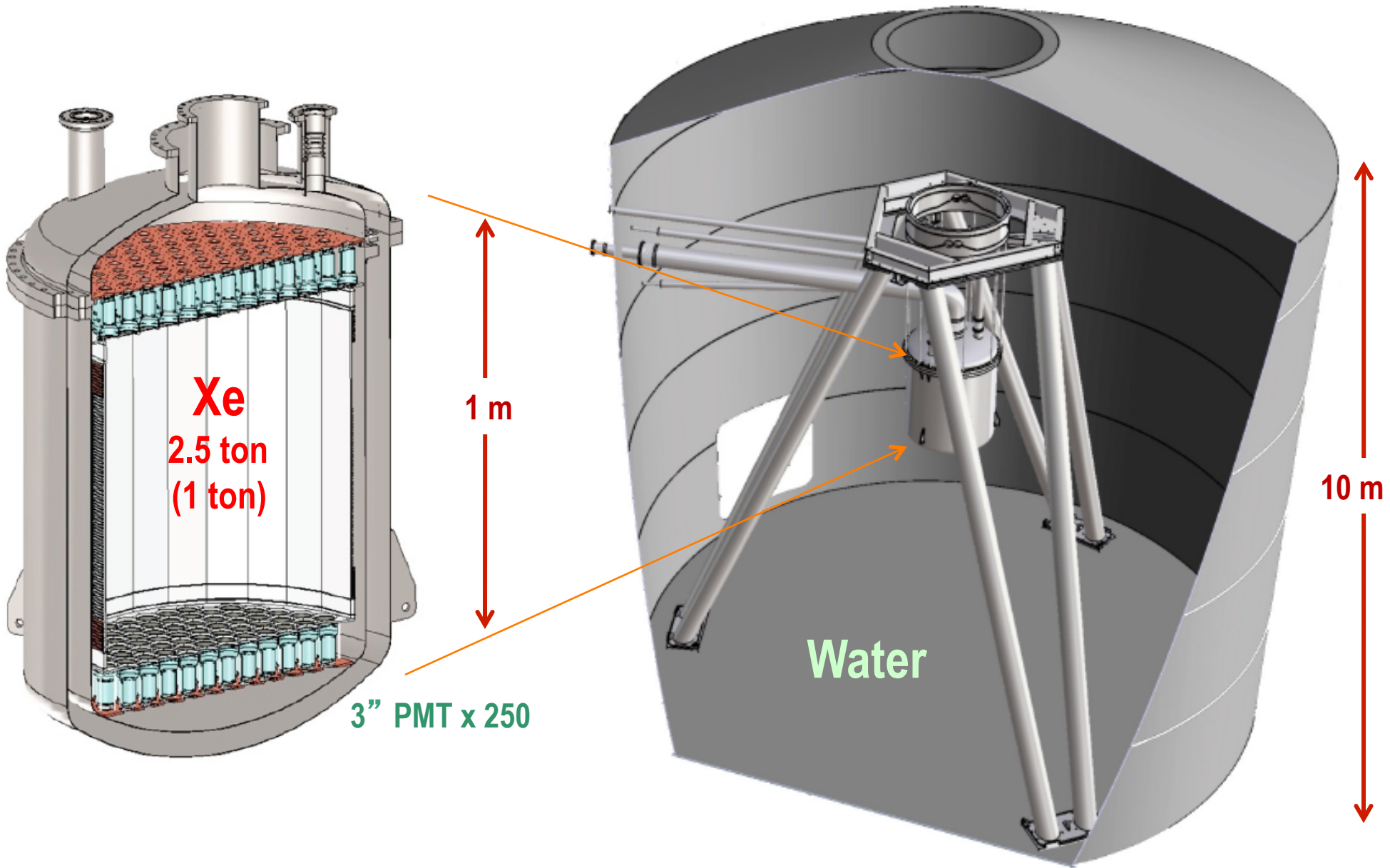
- XENON program (~\$10M) is extremely timely and competitive to LHC (~\$10B)
 - XENON100 ~ Current LHC
 - XENON1T ~ Future LHC
- If new physics at 100 – 1000 GeV (as it should be), LHC and/or XENON1T will discover WIMPs.
 - SUSY - **Neutralino**
 - Extra Dimensions – **KK photon**
- By combining LHC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

G2 & G3 Detectors

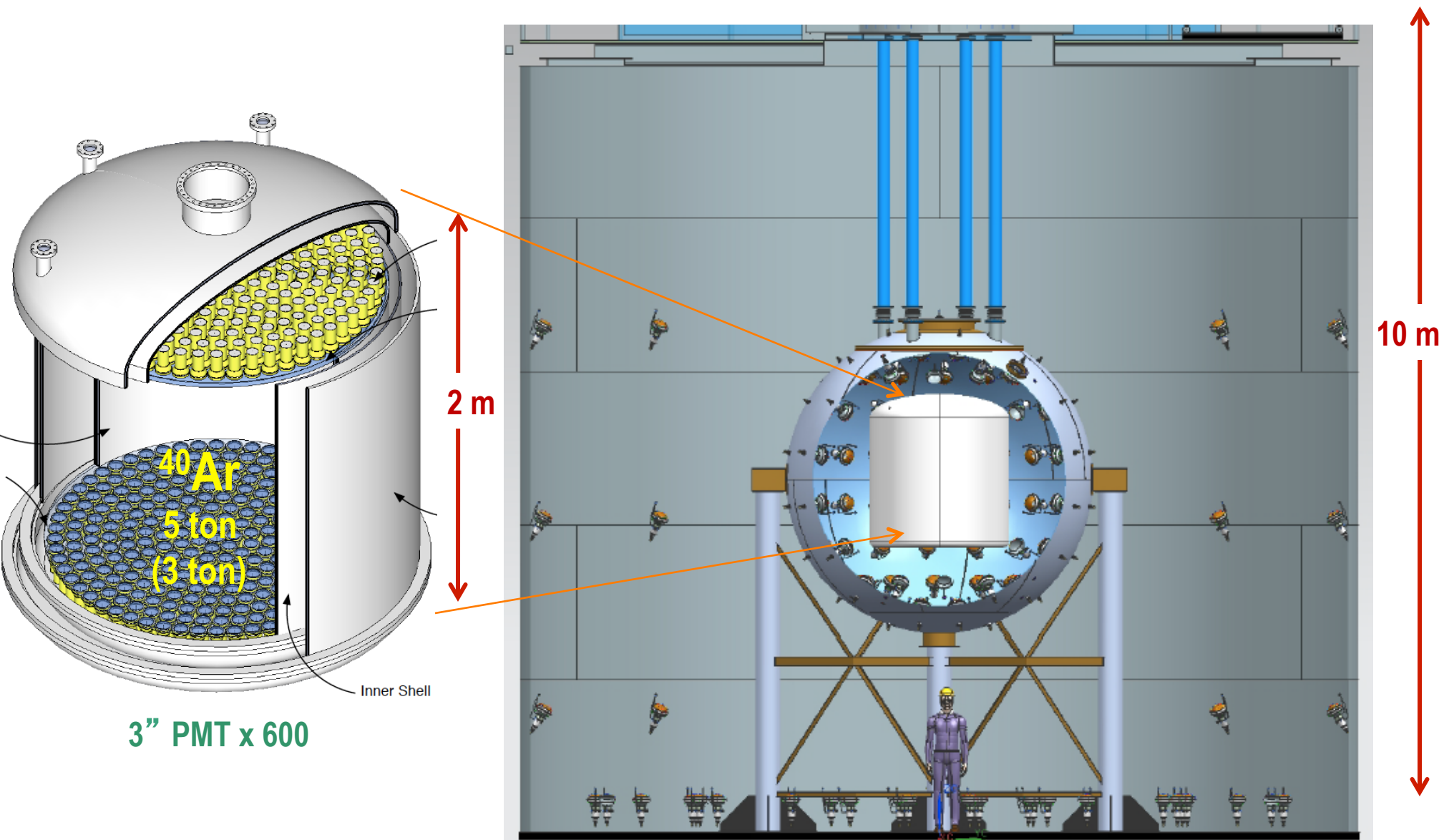
Comparison of Xenon Detector Size



XENON 1T (G2) at Gran Sasso



DarkSide 5T (G2) at Gran Sasso



Roadmap to MAX

2012 2013 2014 2015 2016 2017 2018 2019 2020

Gran Sasso → DUSEL



G1

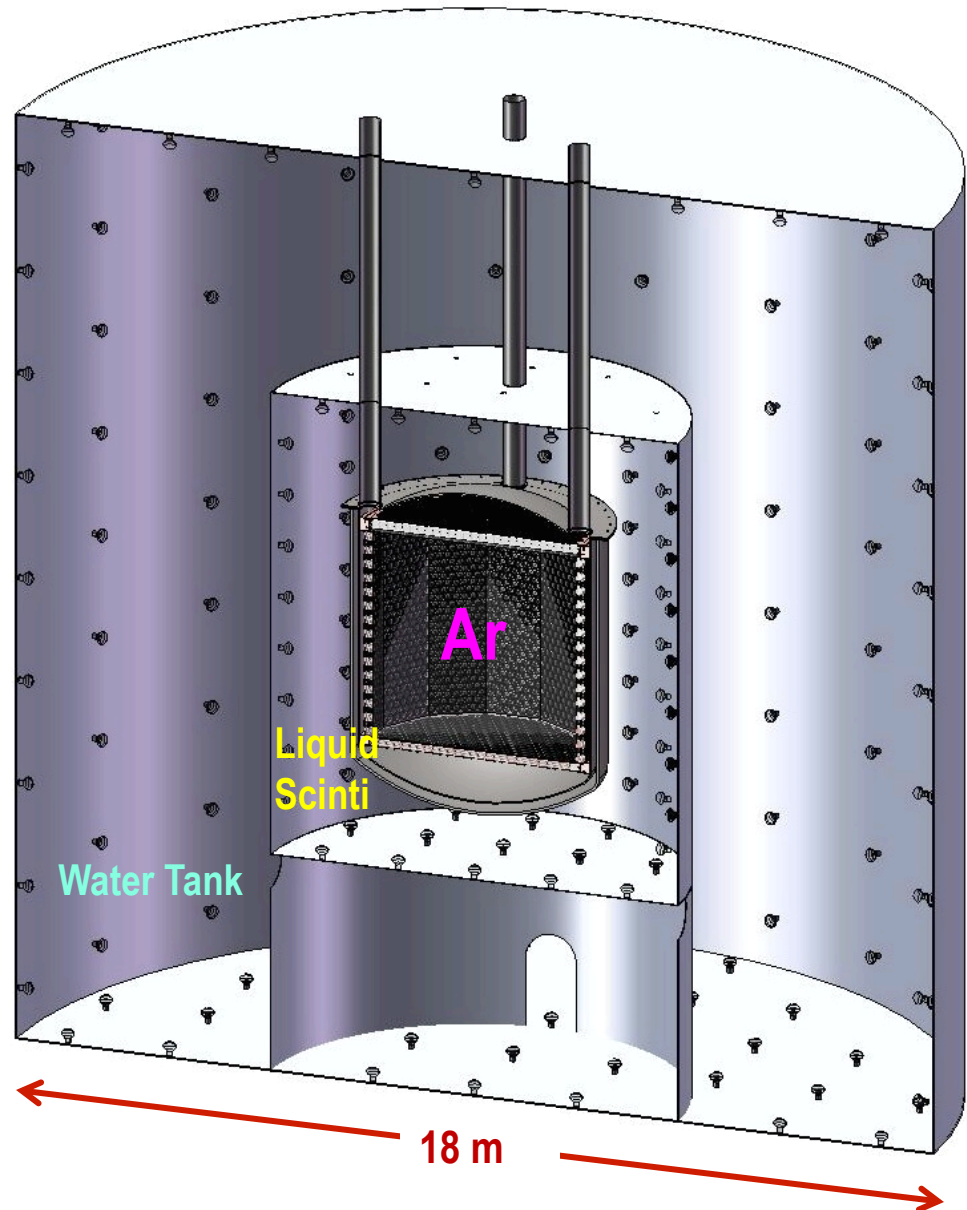
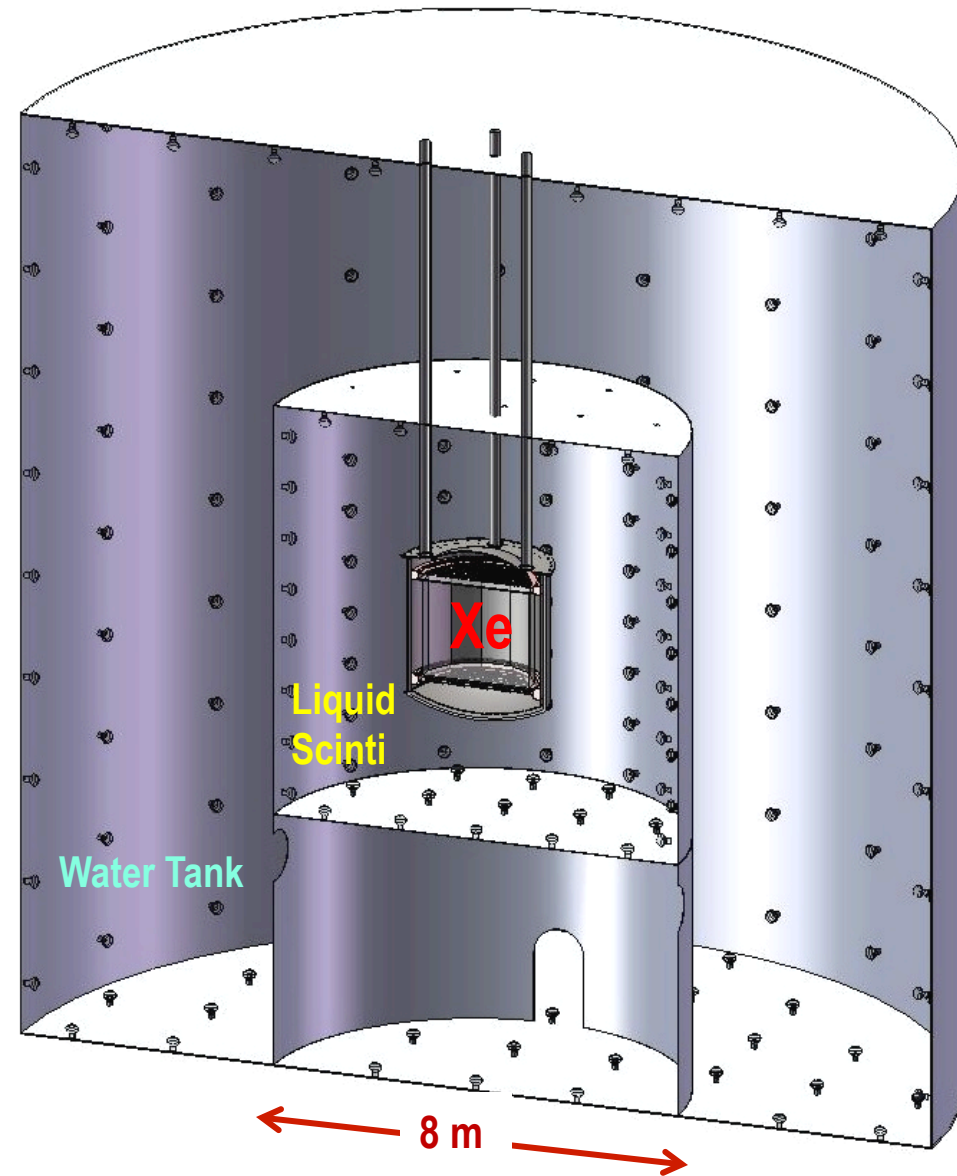
G2

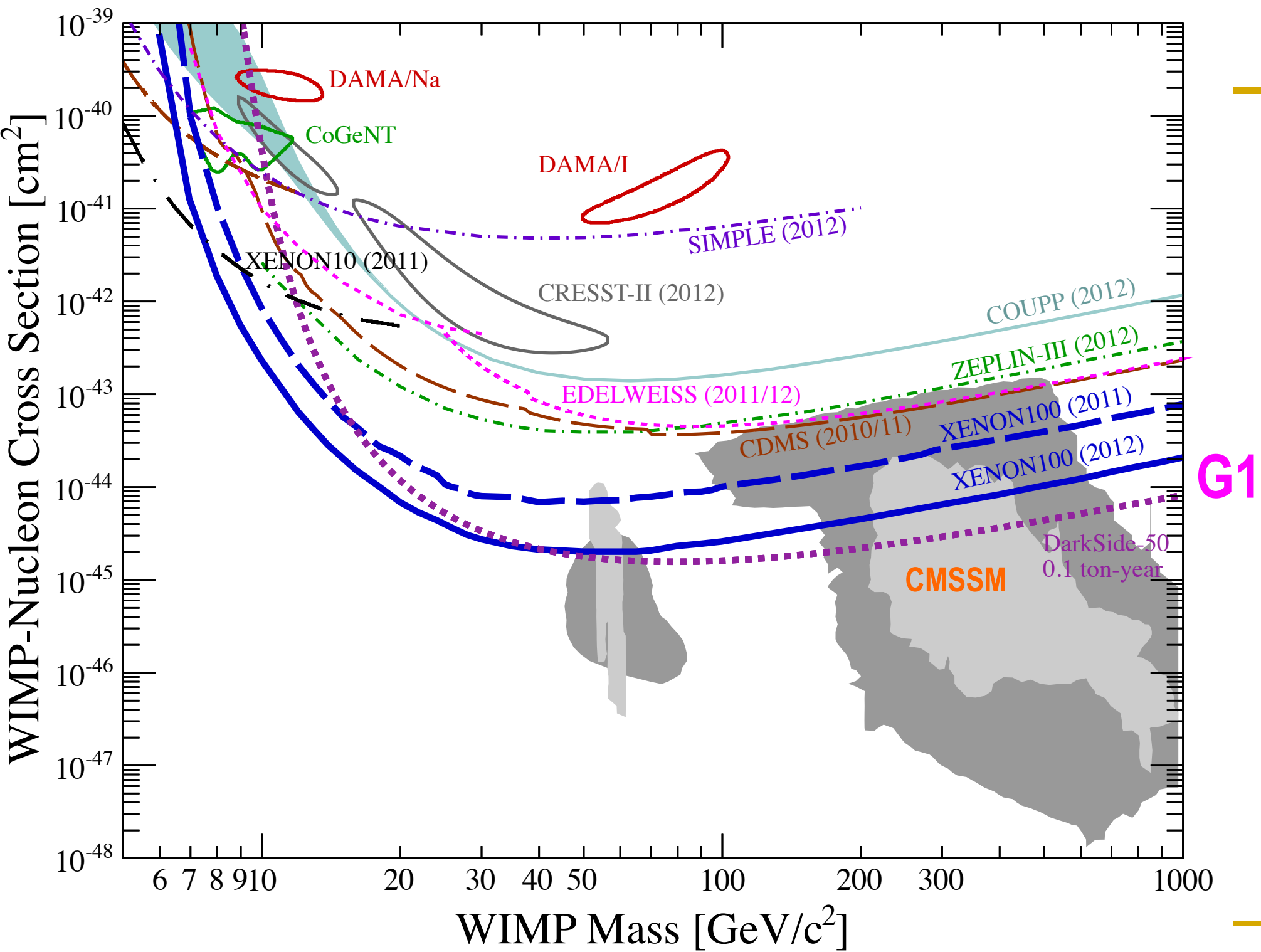
G3

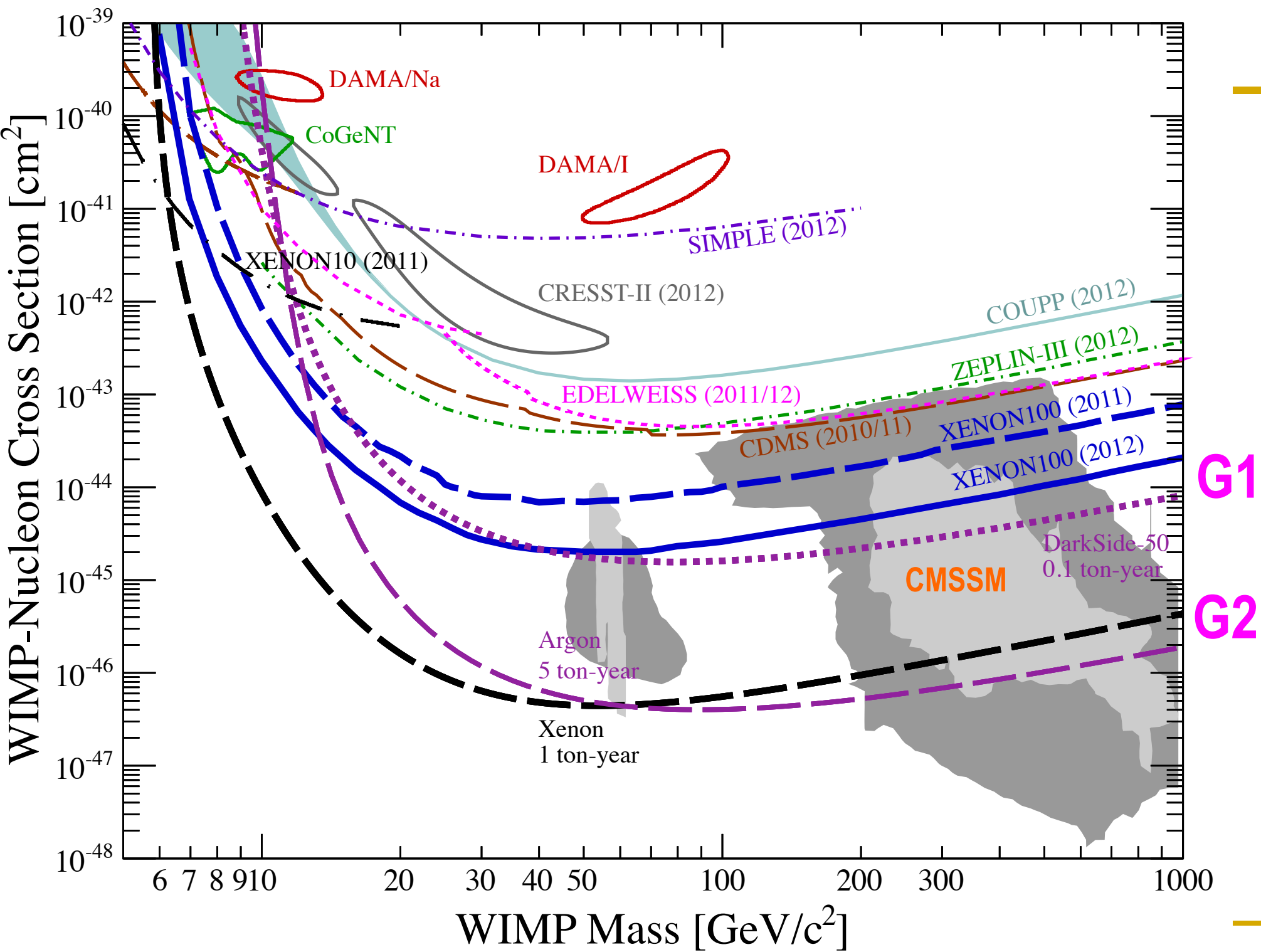
MAX+LZD = "Ultimate G3" Detector (at DUSEL)

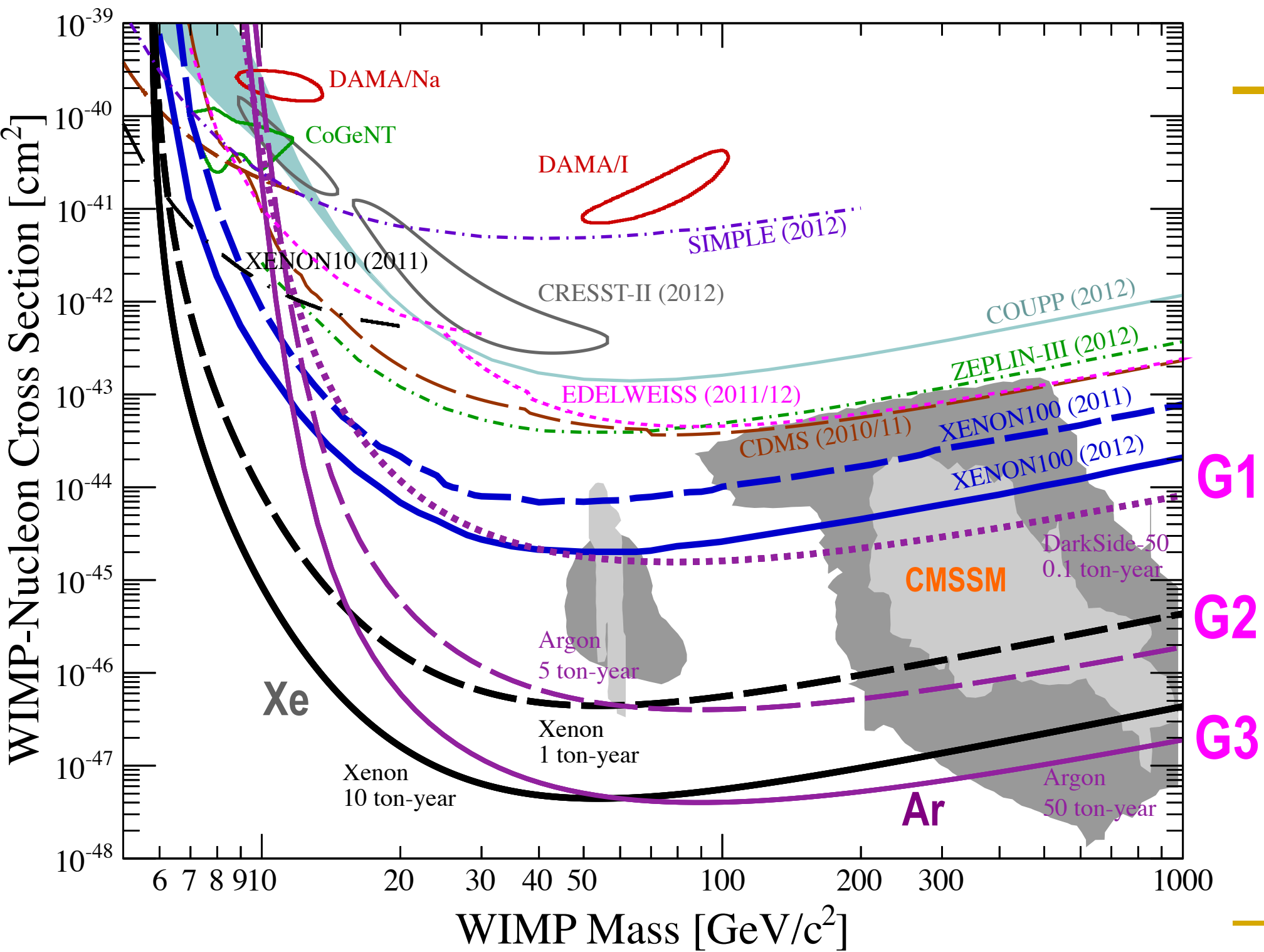
Xe 20 ton (10 ton)

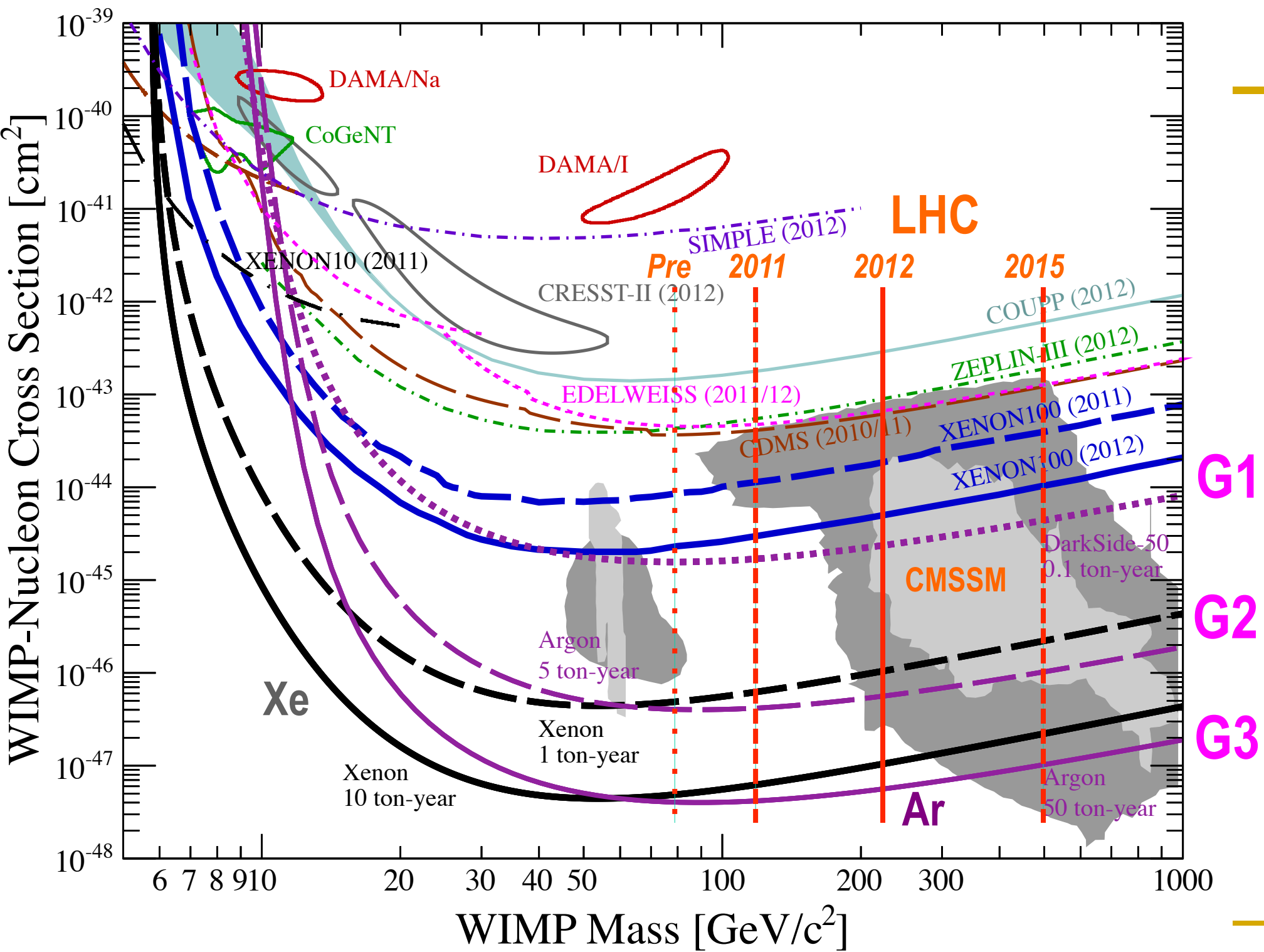
^{40}Ar 70 ton (50 ton)



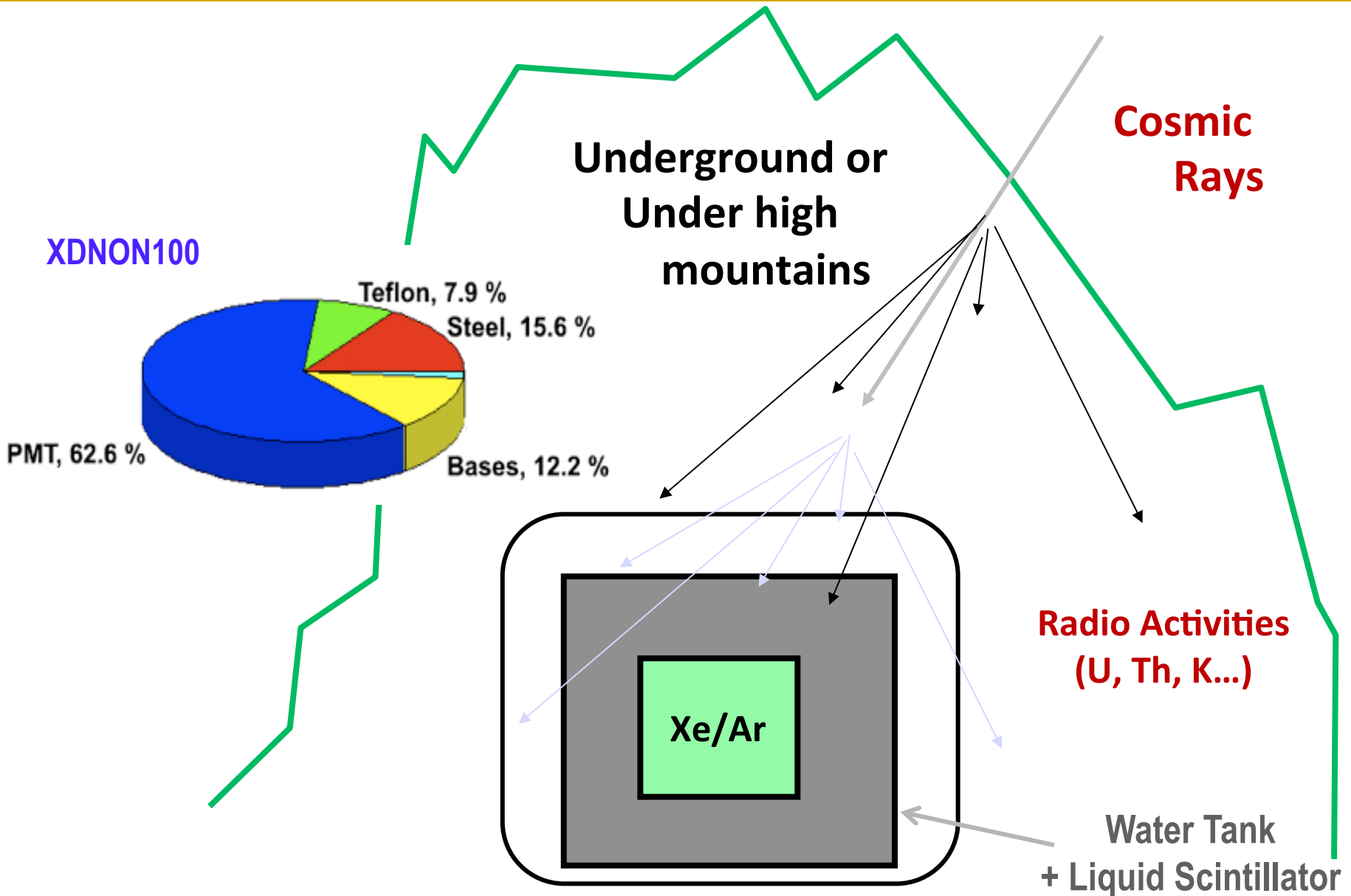








Where backgrounds come from?



Photon detectors are the major source of backgrounds.

QUPID (QUartz Photon Intensifying Detector)

arXiv:1103.3689

Photo Cathode
(-6 kV)

Photo Cathode
(-6 kV)

Quartz

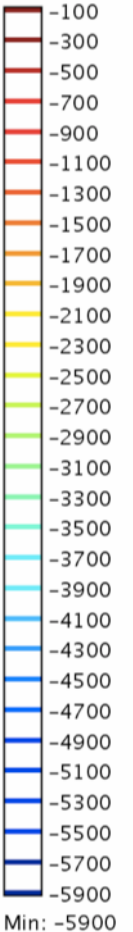
Al coating

APD (0 V)

Quartz

APD (0 V)

Max: -100



Comparison of Photon Detectors from Hamamatsu

R11065 (Ar)
R11410 (Xe)
3 inch

XENON1T
DarkSide50

QUPID
3 inch

MAX
XAX

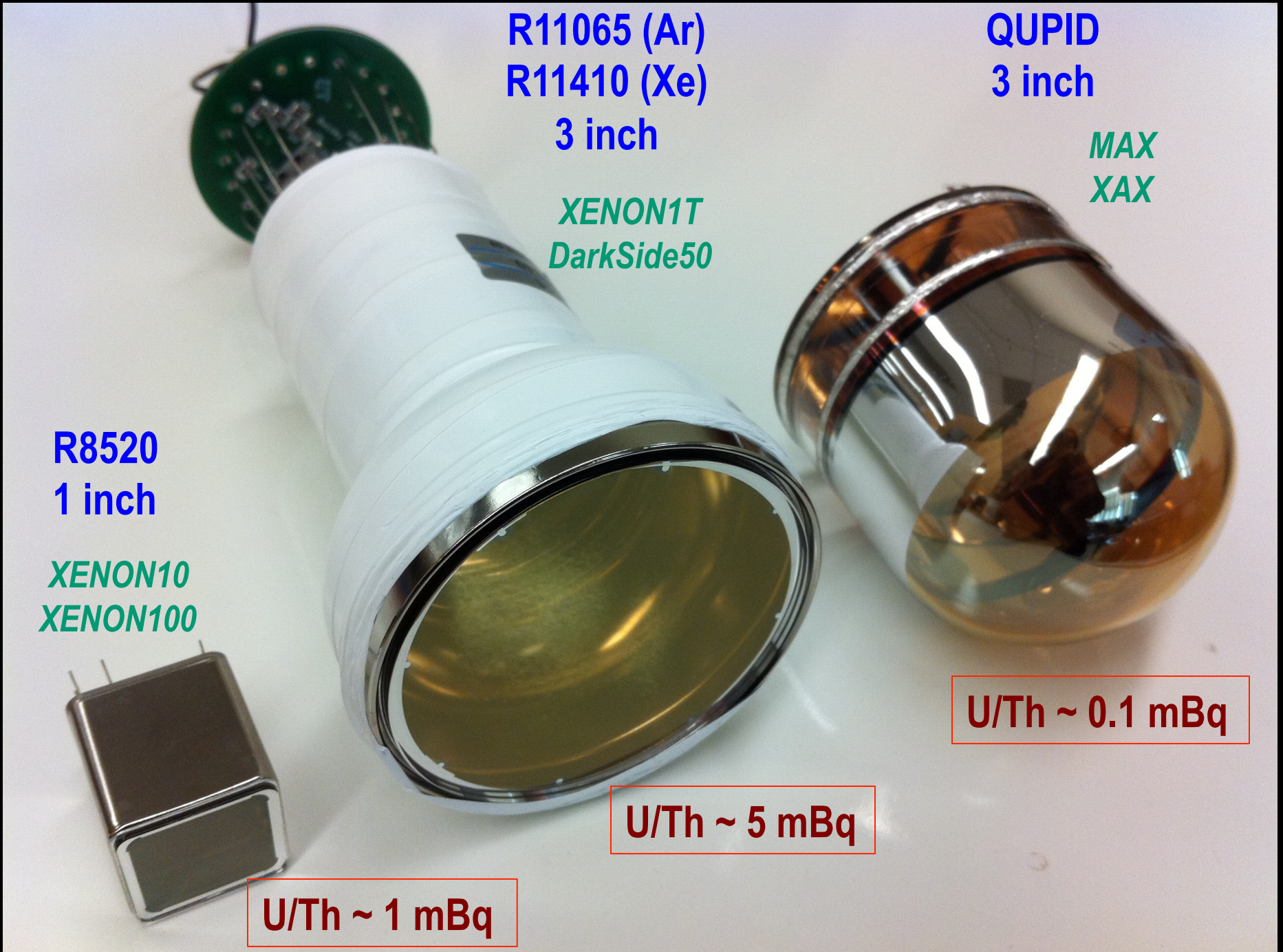
R8520
1 inch

XENON10
XENON100

U/Th ~ 0.1 mBq

U/Th ~ 5 mBq

U/Th ~ 1 mBq



7 QUPID with Holder

Tested in both Xe and Ar



Hanguo Wang's Lab

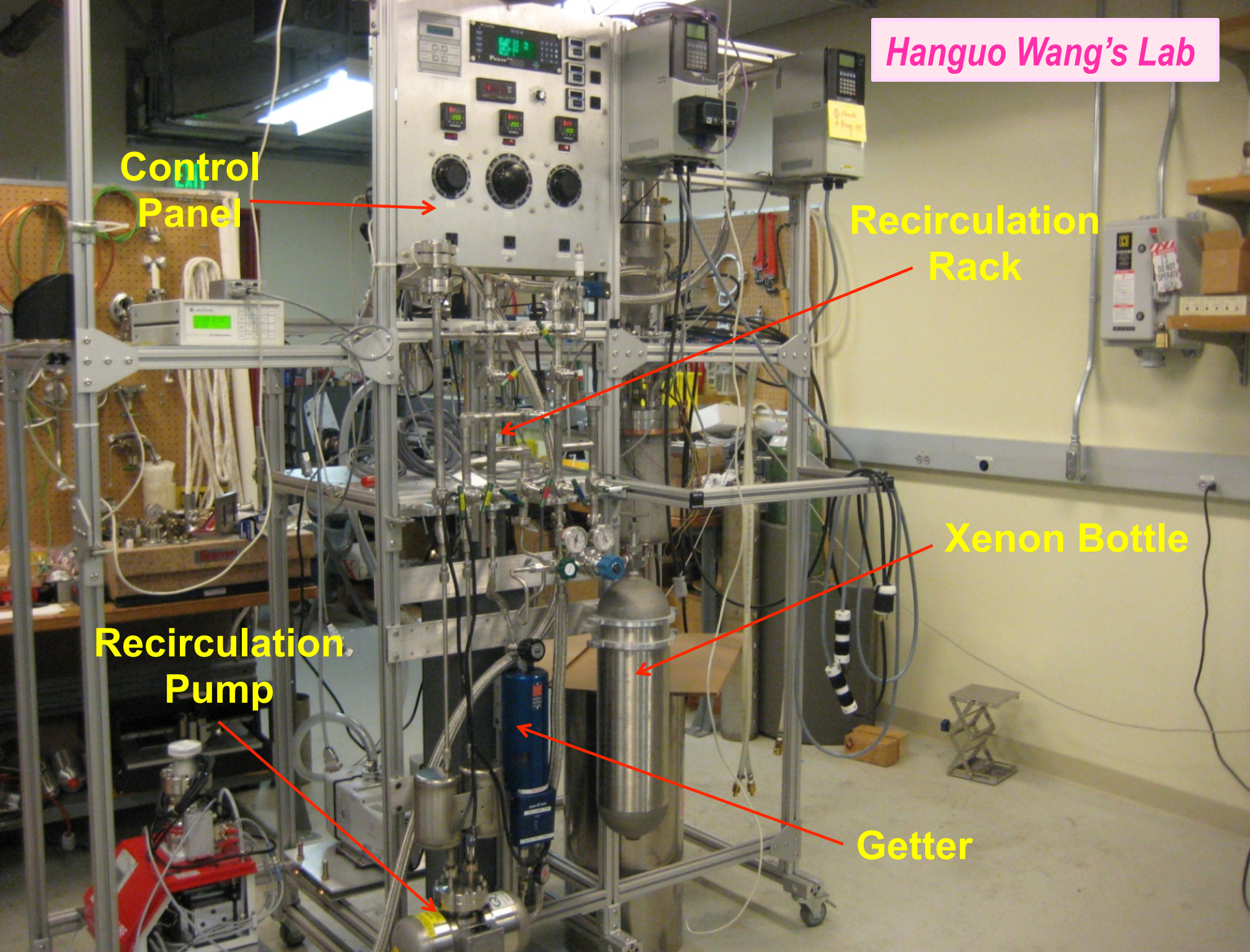
Control Panel

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

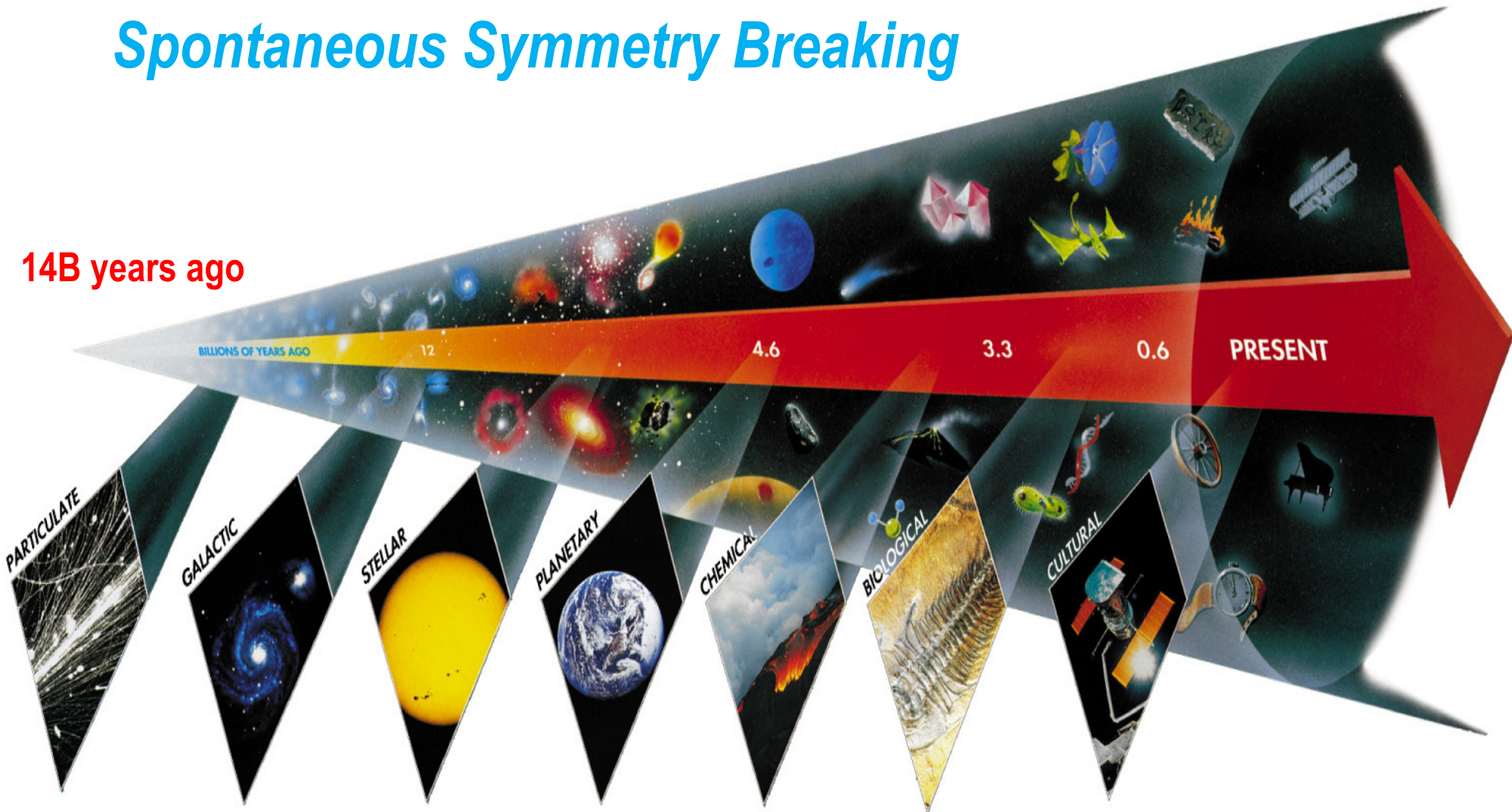
Katsushi's Speculations in Nov 2011

- **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 ($\Delta = 5\%$)
 - No Supersymmetry
 - Katsushi happily retires at age 66.

Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking

14B years ago



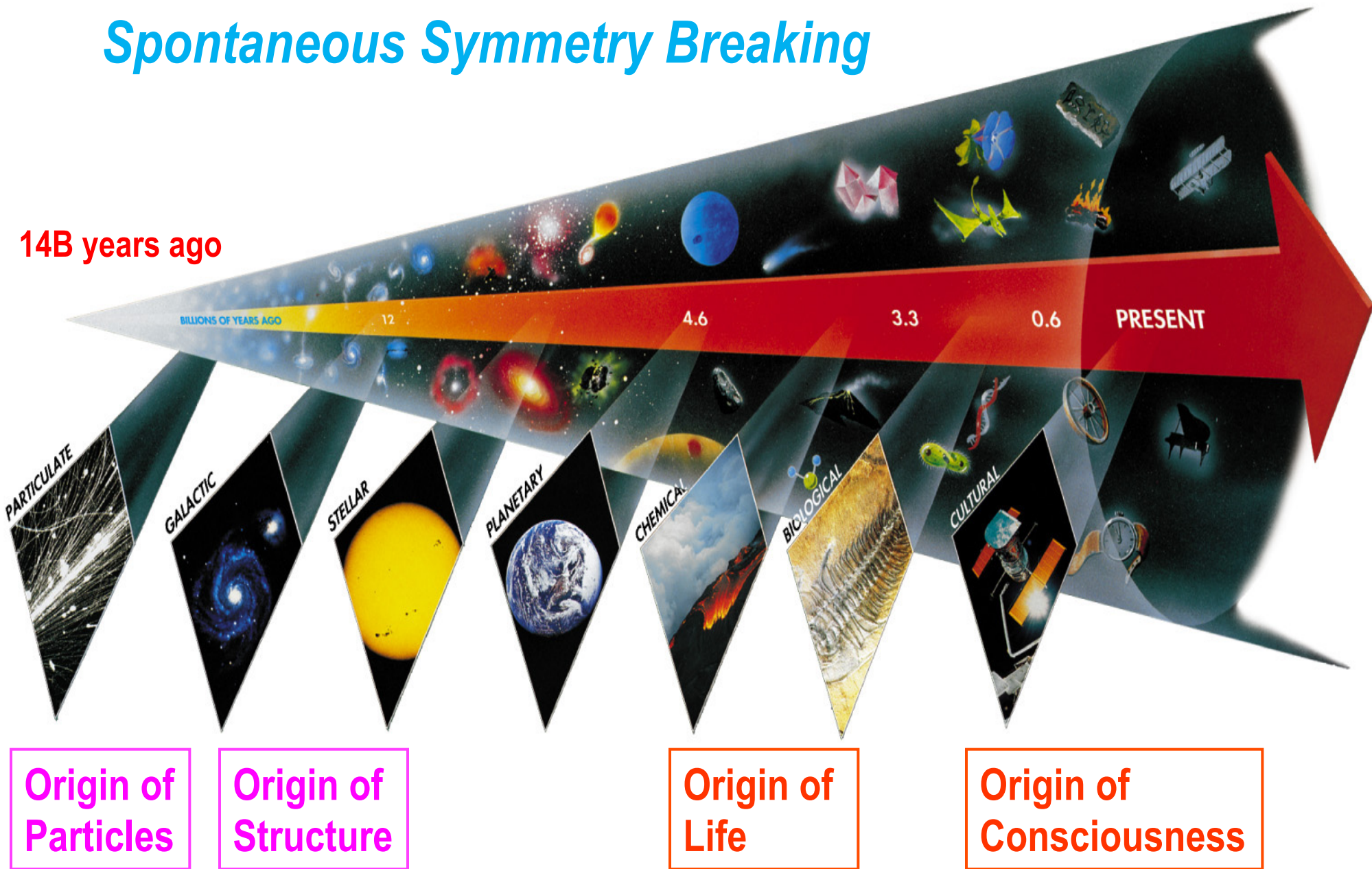
Simple



Coherent Complex System

Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking



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