

Origin of the Universe, Particles and Structure

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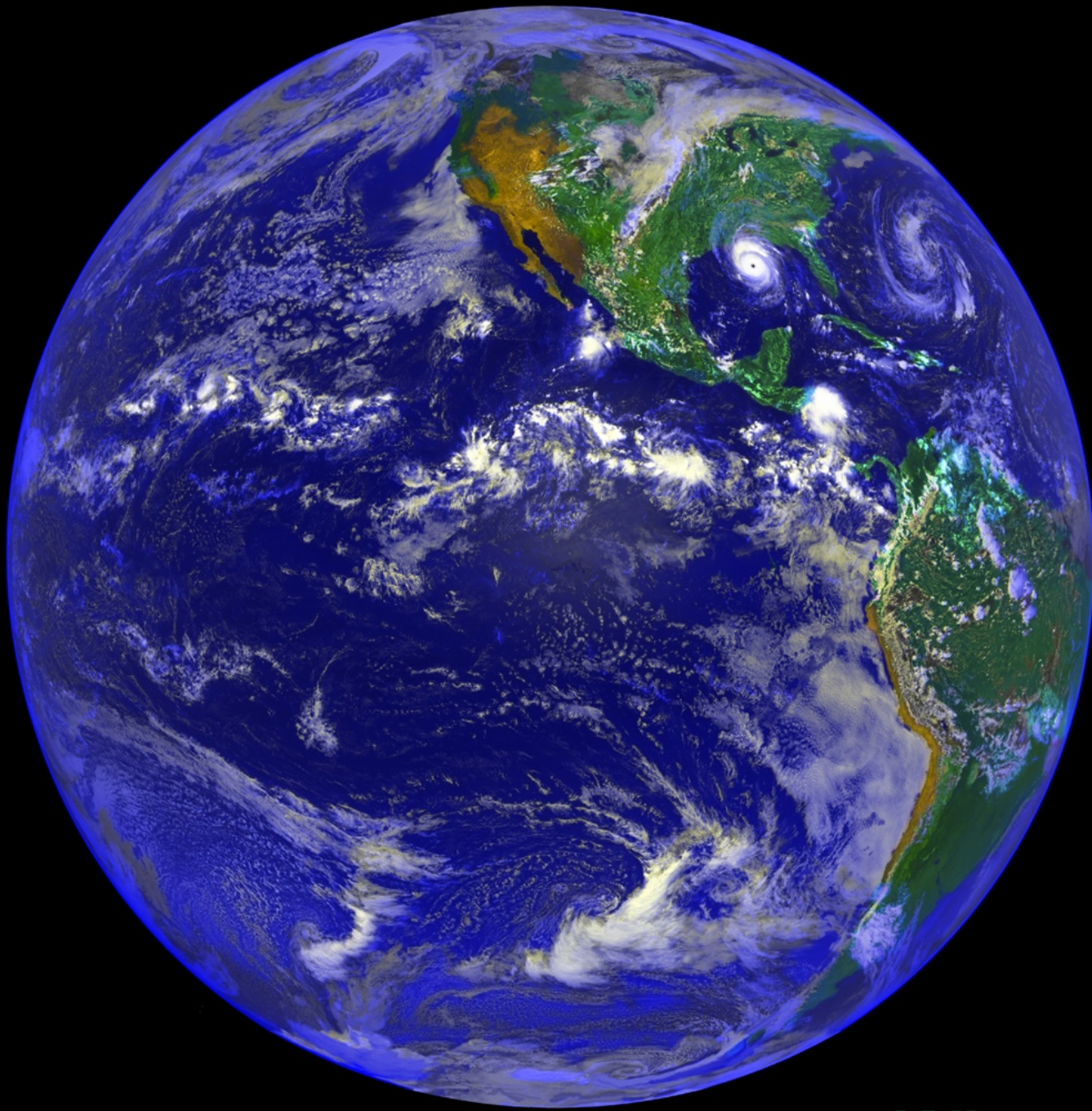
Talk Outline

➤ Last week: Bio-imaging and Neuro-physics

- Part I ~30 min.
 - Introduction to High-speed Bio-imaging
 - Single Molecule: Origin of Life
- Part II ~30 min.
 - Neurophysics: Origin of Consciousness

➤ Today: Particle Physics & Cosmology

- Part I ~30 min.
 - Introduction to Cosmology: Origin of Universe
 - CMS at CERN: Origin of Particles
- Part II ~30 min.
 - Detection of Dark Matter: Origin of Structure in Universe
- Lab Tour ~10 min.

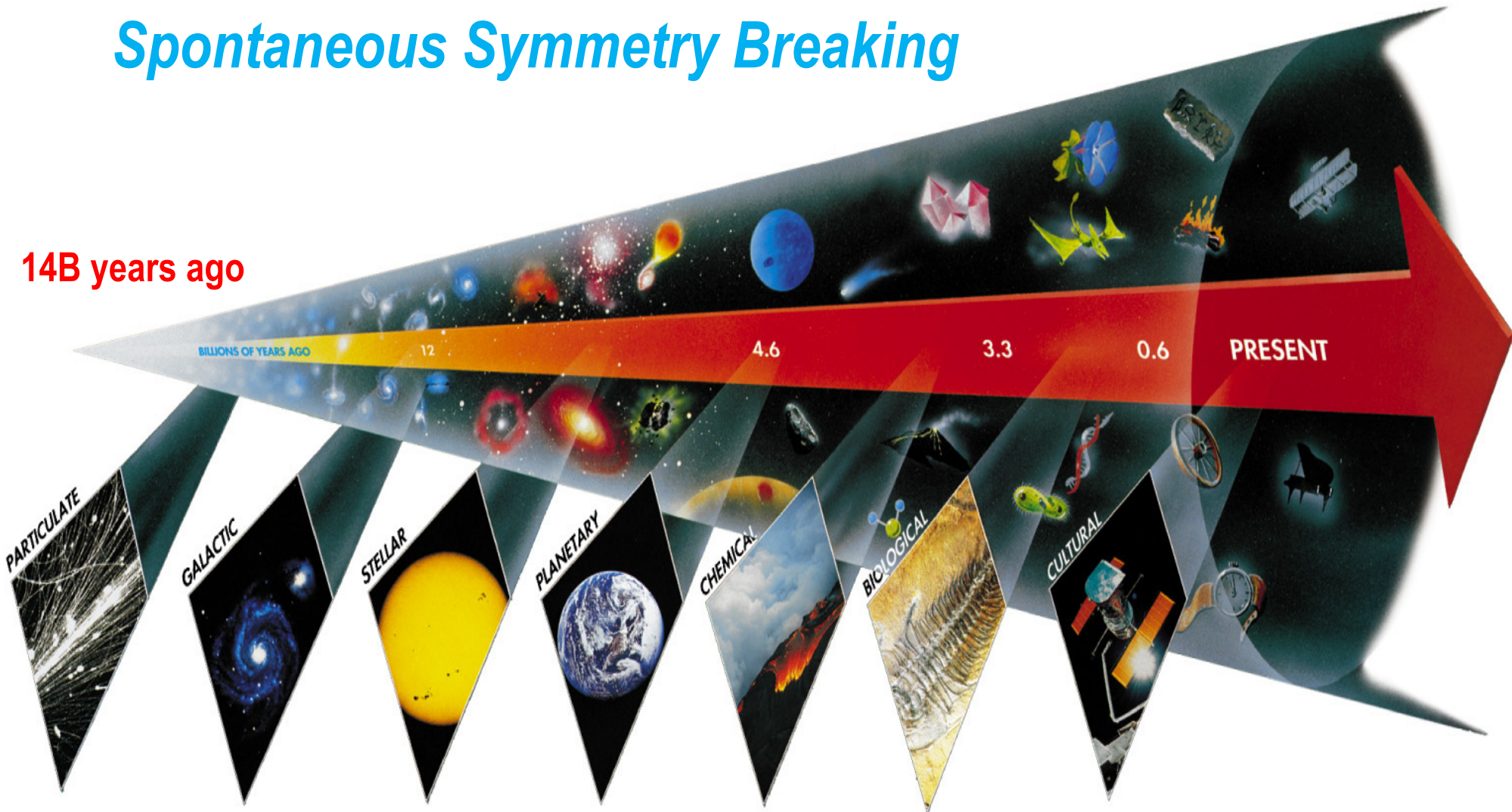


Why are we here?

Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking

14B years ago



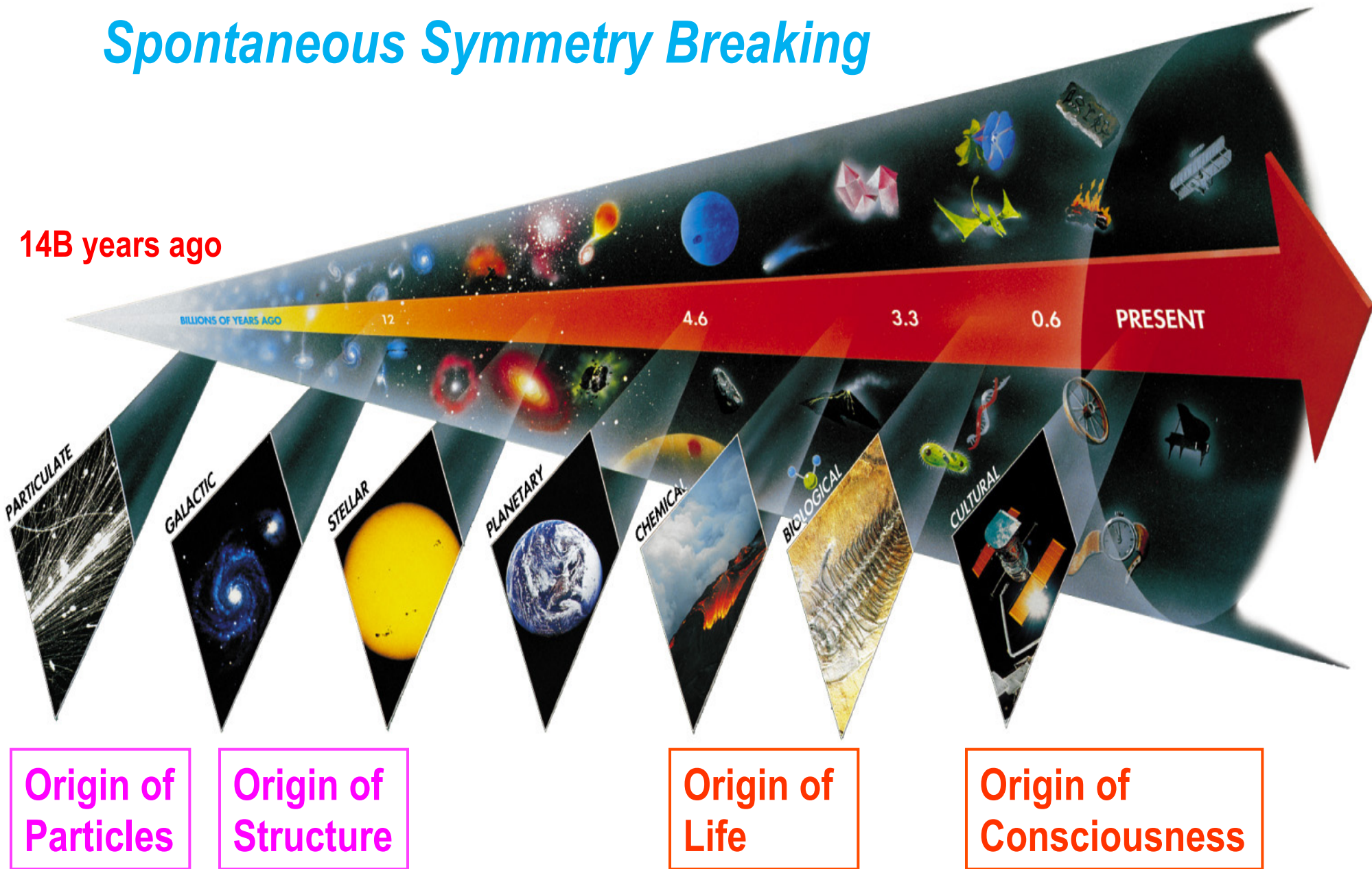
Simple



Coherent Complex System

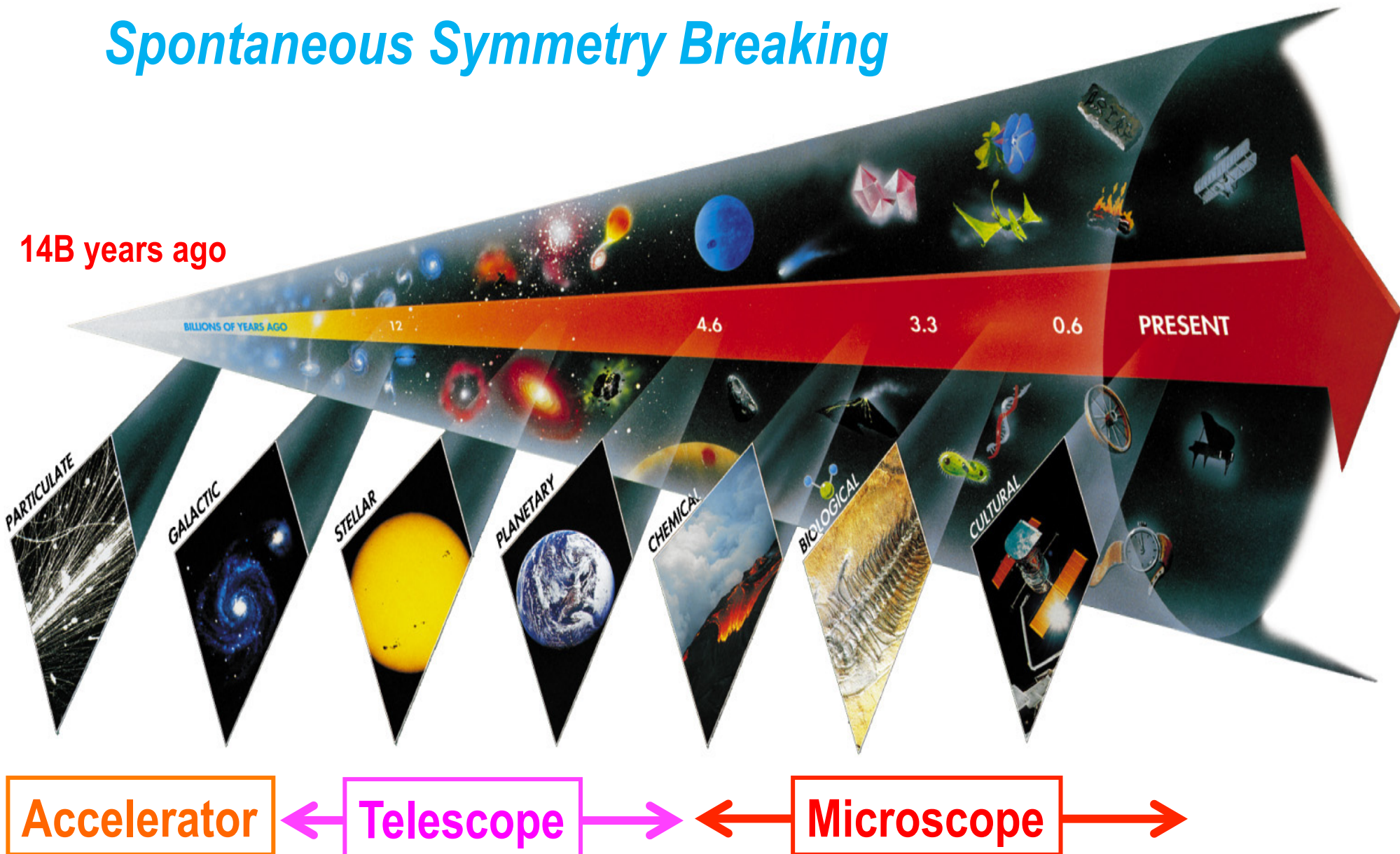
Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking



Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking



Part I

Introduction to Cosmology

Andromeda

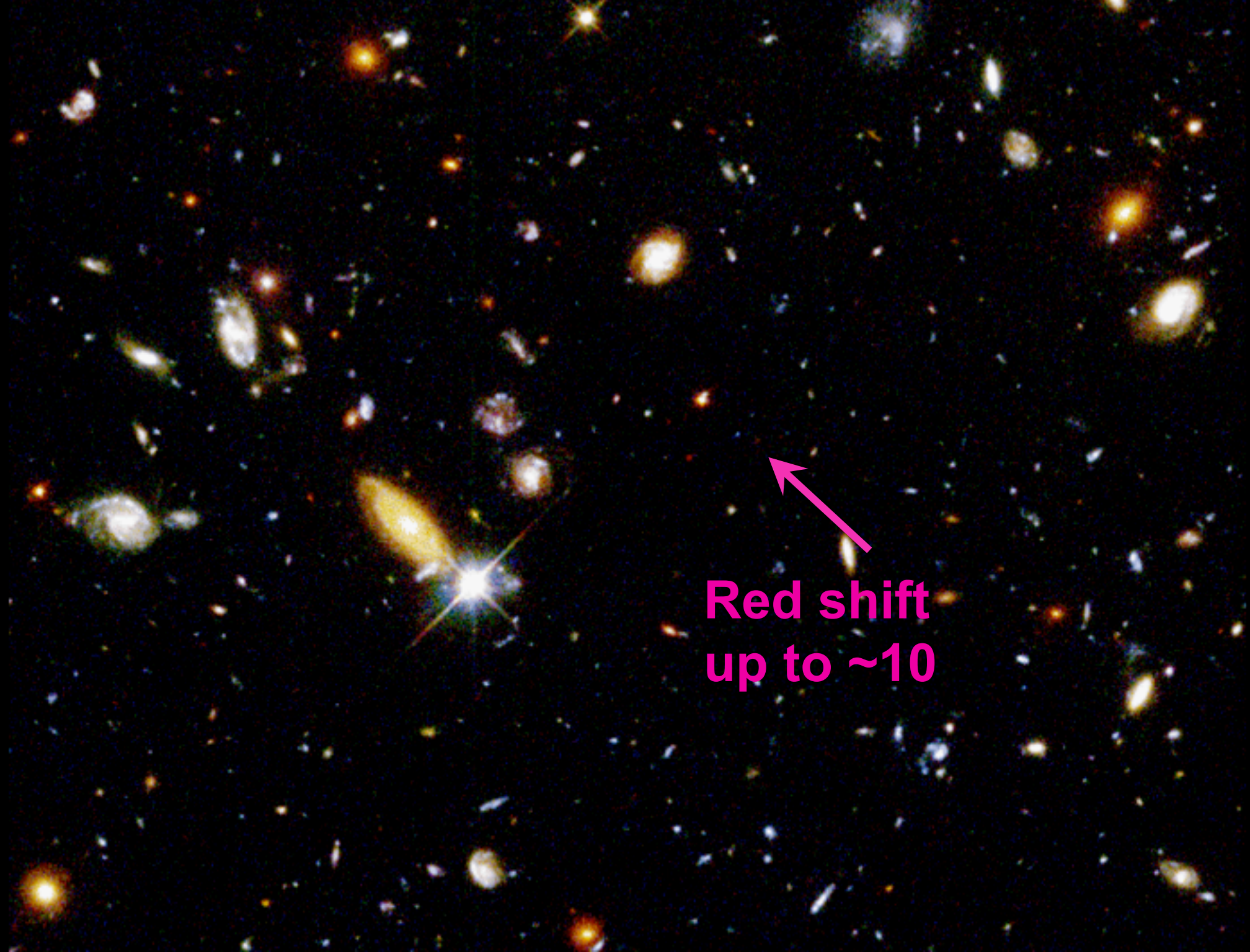


~100 Billions Stars in a Galaxy

Hubble Deep Field

The image displays a dense field of galaxies, including various types such as spirals, ellipticals, and irregular shapes, scattered across a dark background. The galaxies are concentrated in the central and lower-left regions, with some appearing as bright, distinct points of light and others as faint, diffuse structures. The overall appearance is that of a rich, multi-colored stellar population.

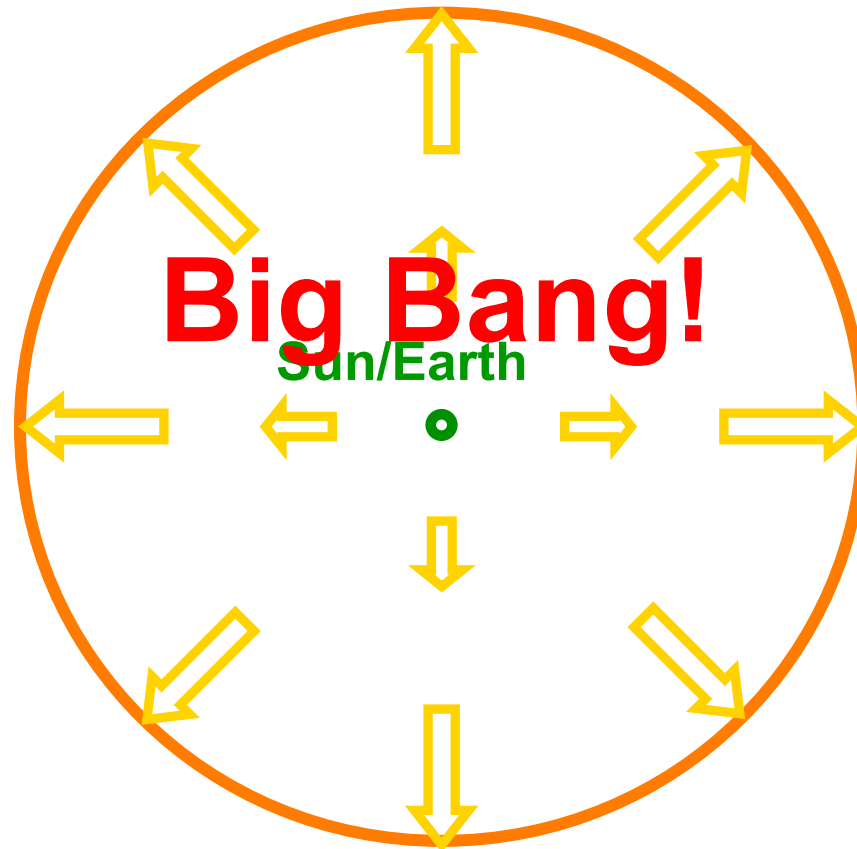
~100 Billion Galaxies



**Red shift
up to ~10**

Hubble's Law: Expansion of the Universe

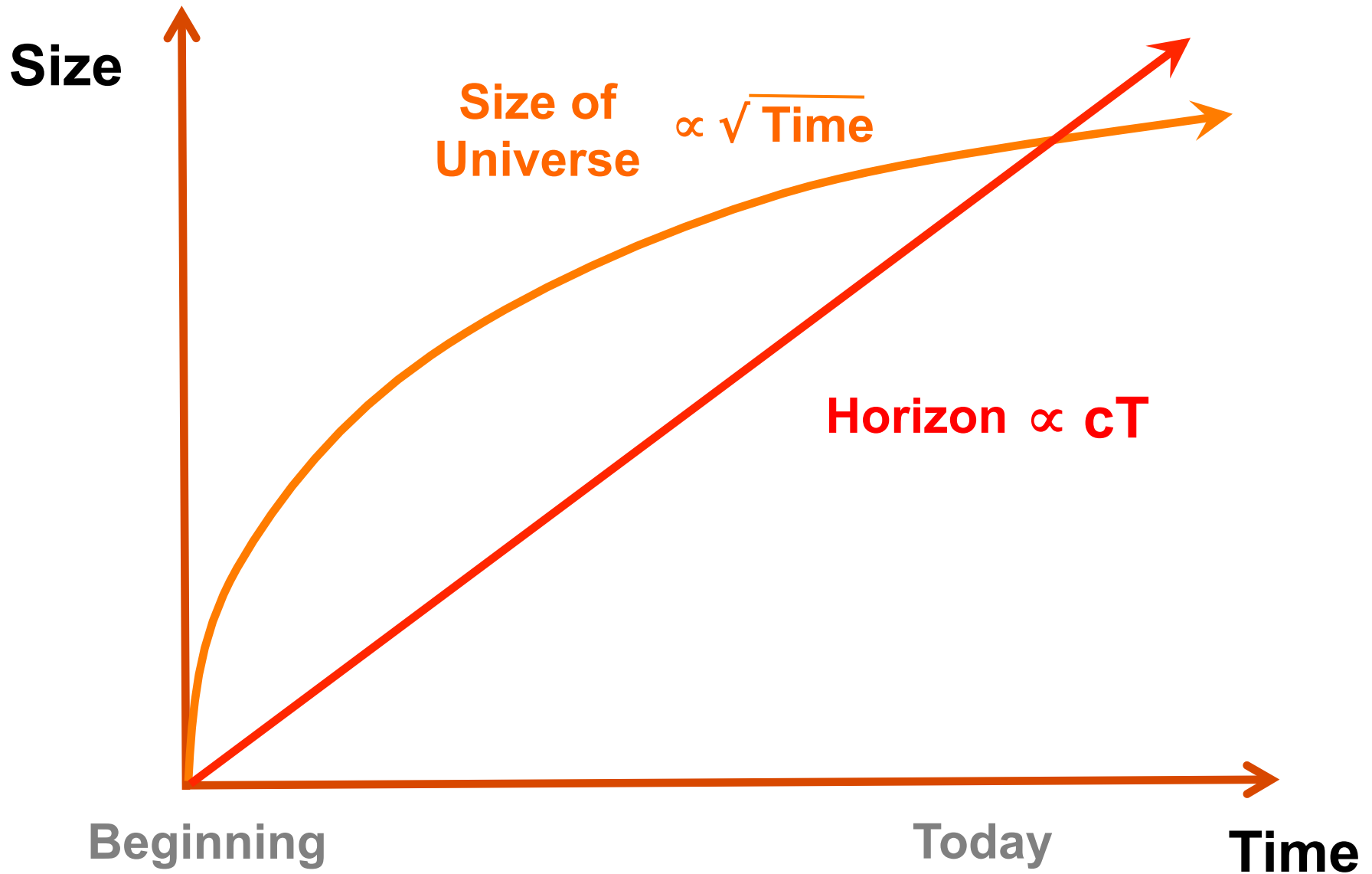
Horizon
of Universe



14 Billion
Light Years

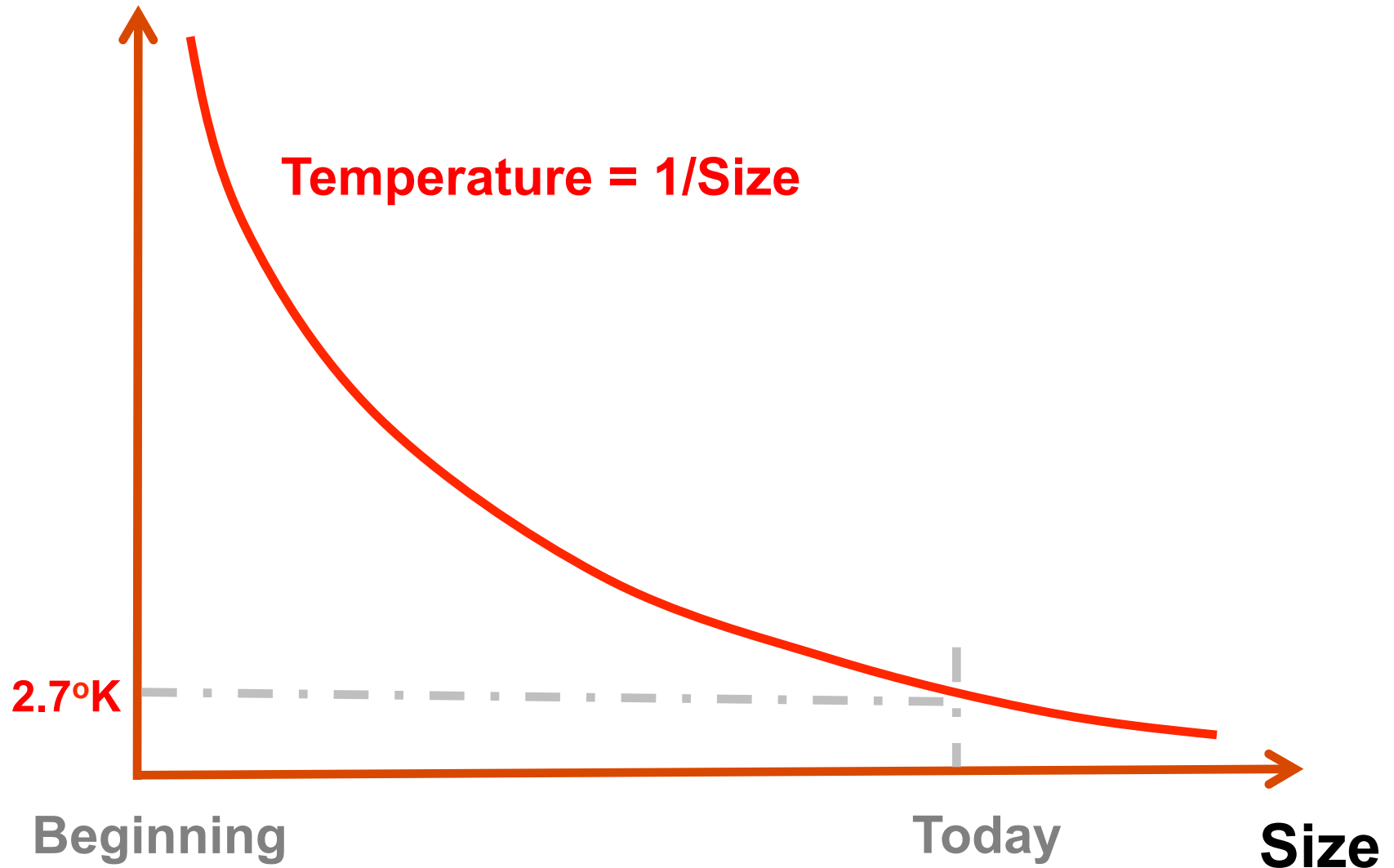
Moving Away
at Speed of Light

Expansion of Universe



Temperature of Universe

Temperature



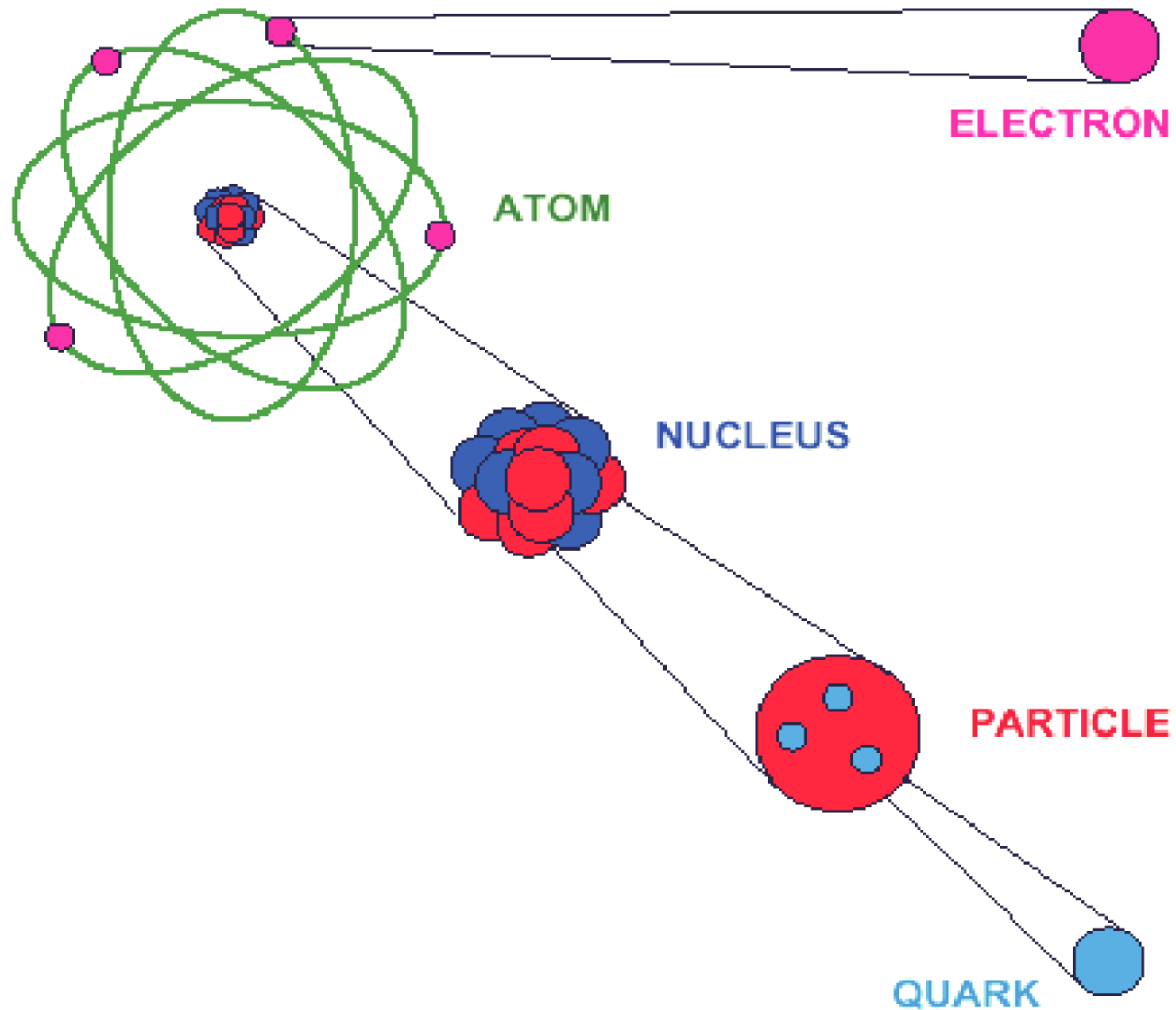
Fermi Lab near Chicago

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	Force Carriers	γ photon	0	
		d down	s strange	b bottom		g gluon	0	
-1/3	Leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino		Z Z boson	0	
		e electron	μ muon	τ tau		W W boson	± 1	
0								
-1								
		I	II	III				
		Three Families of Matter						

+ Anti-particles

Elementary Particles and Forces

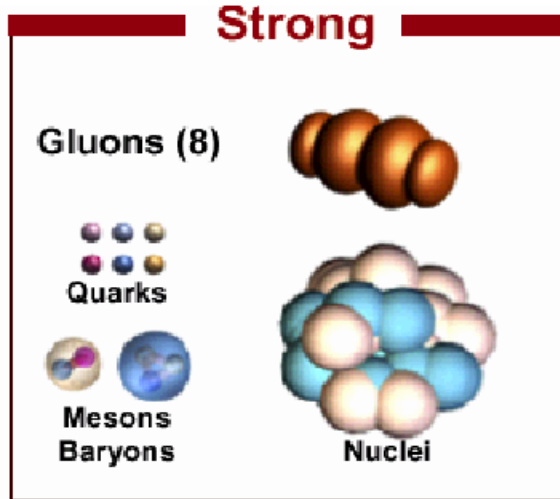
Strong

Gluons (8)

Quarks

Mesons
Baryons

Nuclei

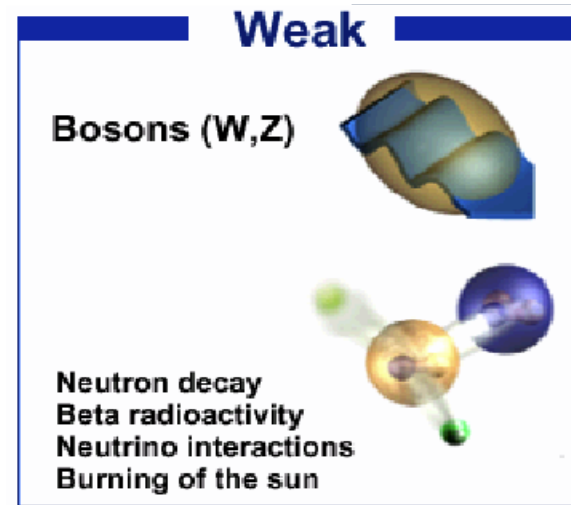
The diagram for the strong force shows various components. At the top, there are eight orange spheres representing gluons. Below them are six small colored spheres (red, green, blue, anti-red, anti-green, anti-blue) representing quarks. Further down are two pairs of quarks: one pair in a meson (one red, one anti-red) and one pair in a baryon (one red, one green, one blue). At the bottom is a large cluster of quarks representing a nucleus.

1

Weak

Bosons (W,Z)

Neutron decay
Beta radioactivity
Neutrino interactions
Burning of the sun

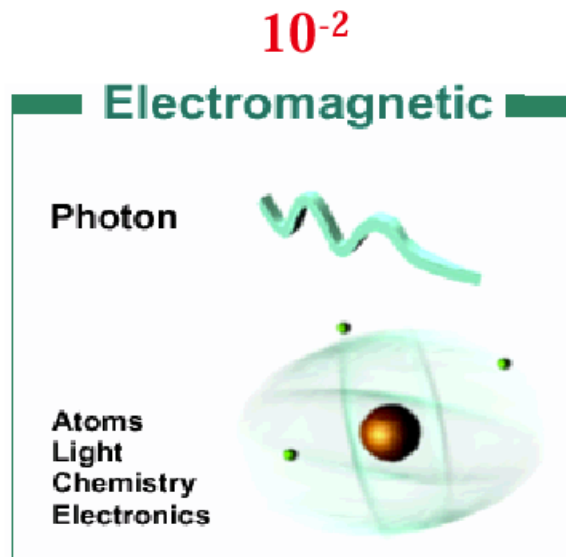
The diagram for the weak force shows two bosons, W and Z, represented as blue and green spheres. Below them is a diagram of a neutron decaying into a proton and an electron, with a neutrino also shown. This illustrates beta radioactivity and neutrino interactions.

10^{-13}

Electromagnetic

Photon

Atoms
Light
Chemistry
Electronics

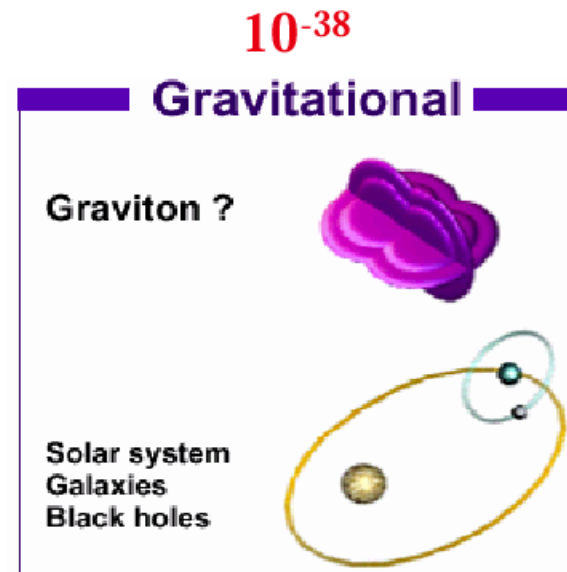
The diagram for the electromagnetic force shows a green wavy line representing a photon. Below it is a diagram of an atom with a central nucleus and orbiting electrons.

10^{-2}

Gravitational

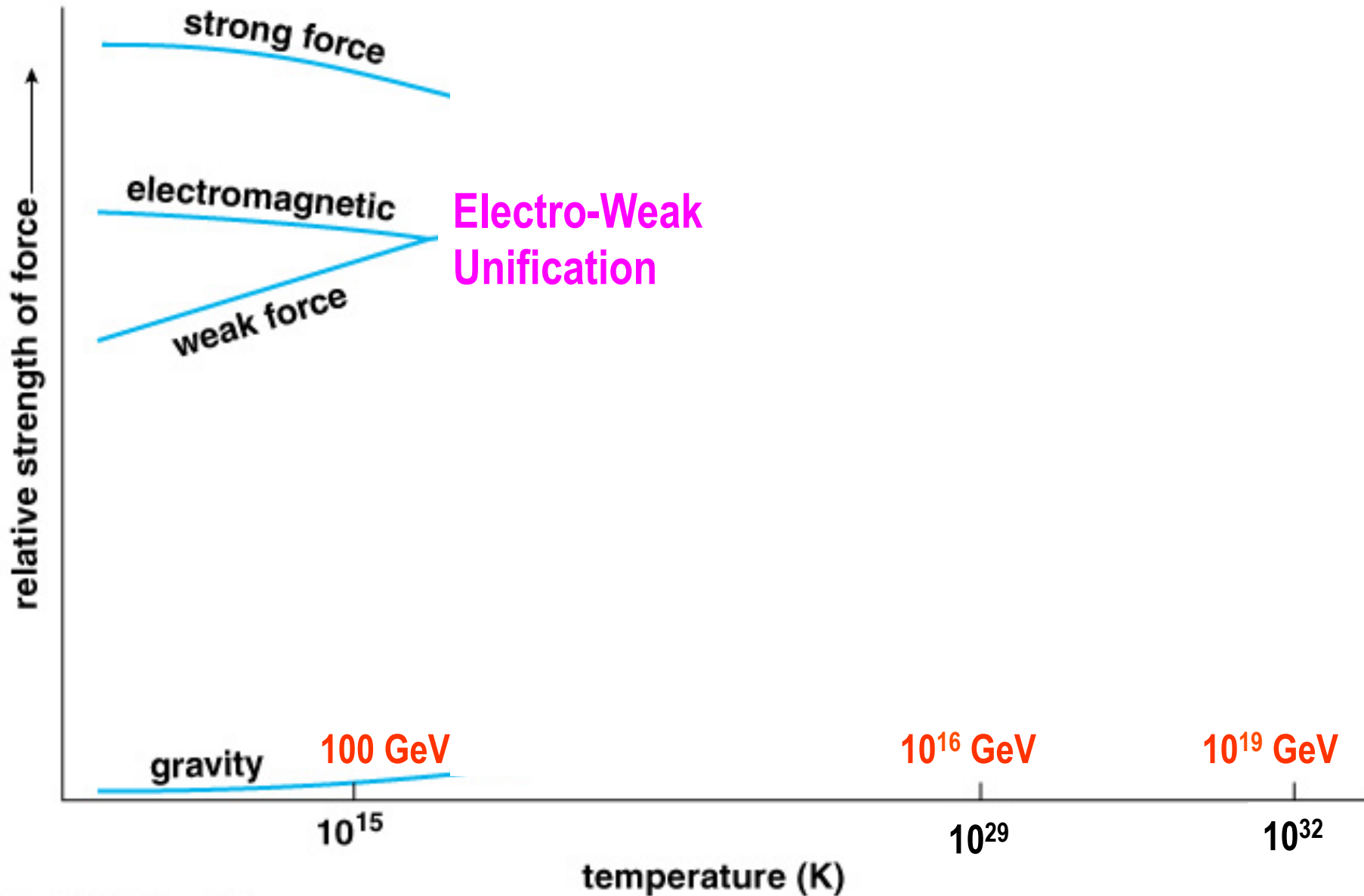
Graviton ?

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.

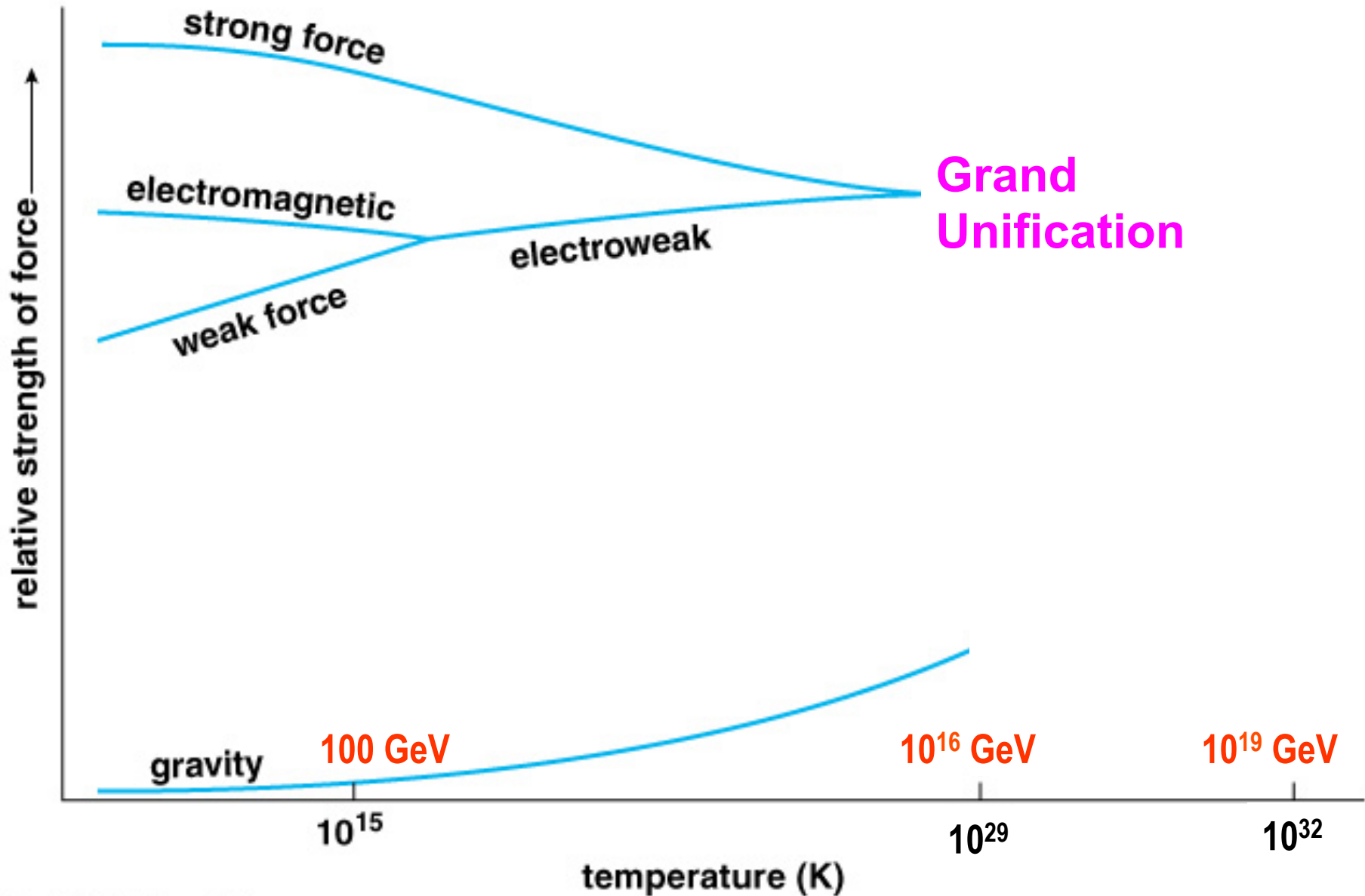
10^{-38}

Unification of Forces



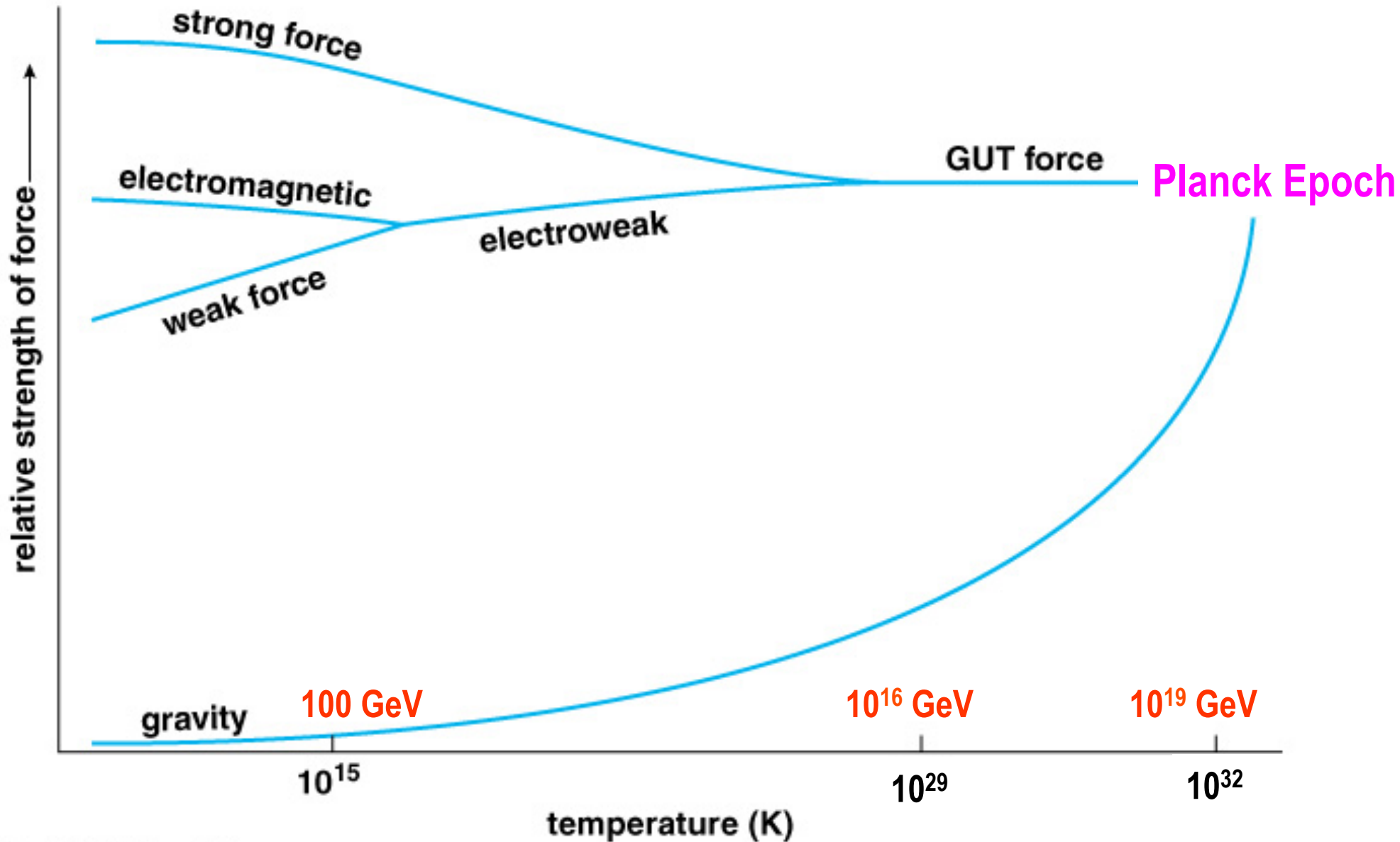
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Unification of Forces



Copyright © Addison Wesley.

Unification of Forces



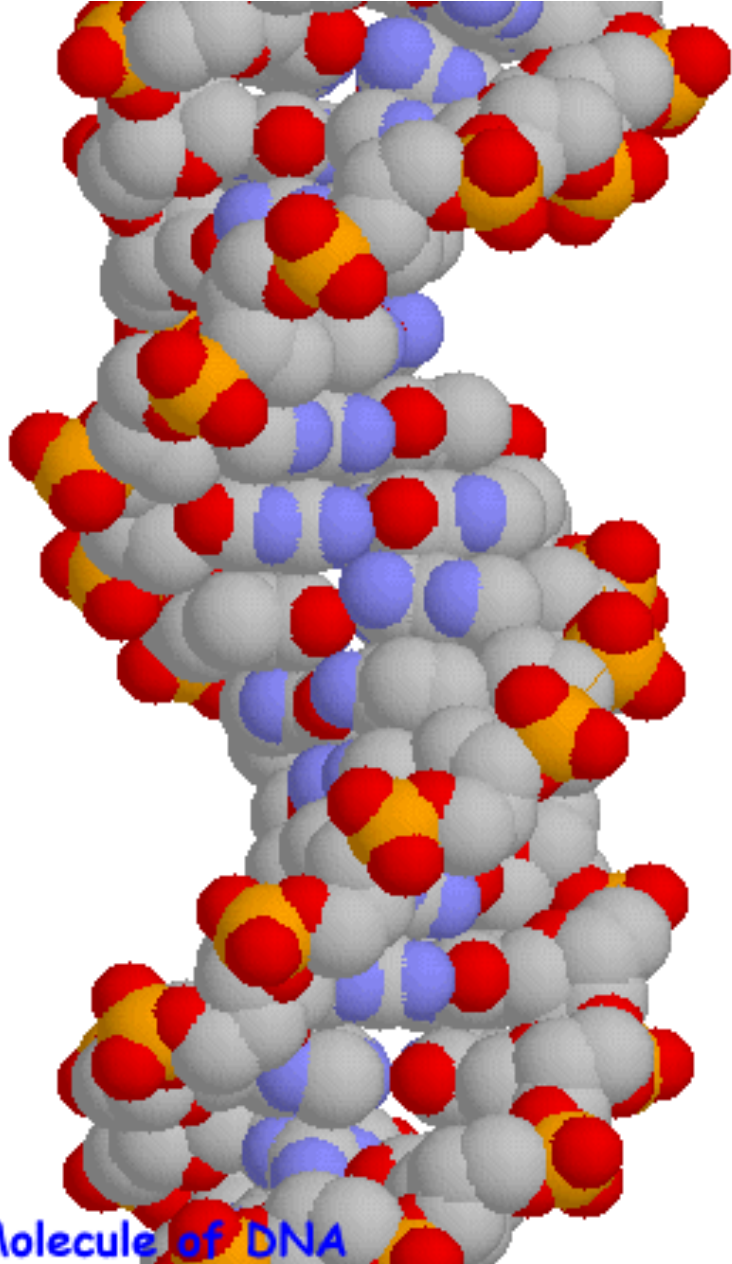
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Physicists' View of Early Universe

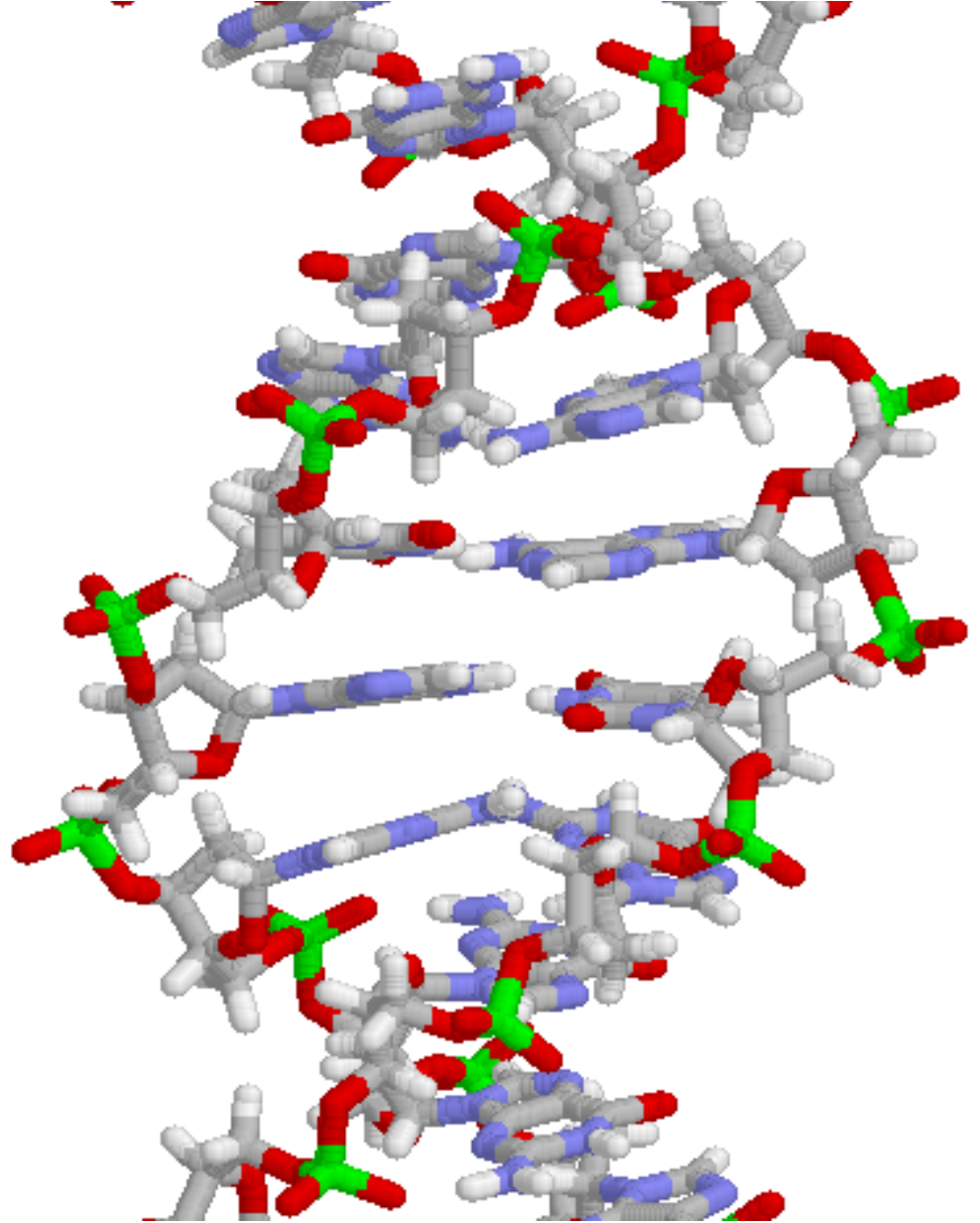
Lorentz Invariance

Local Gauge Invariance

Structure of DNA

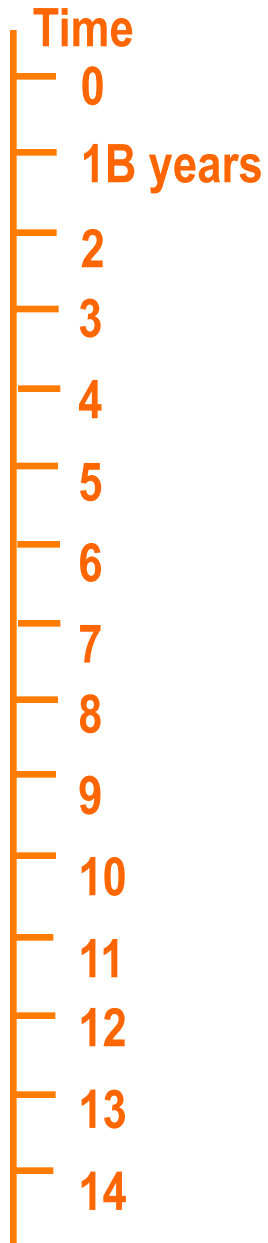


©Rothamsted Experimental Station, 1997, 1998



Molecule of DNA

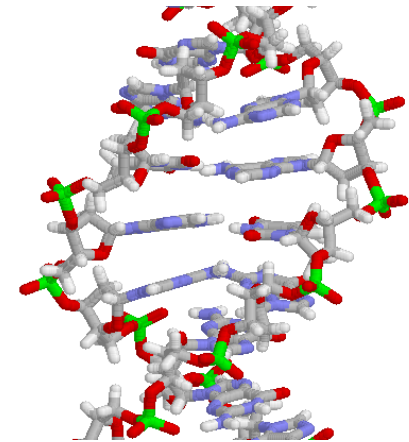
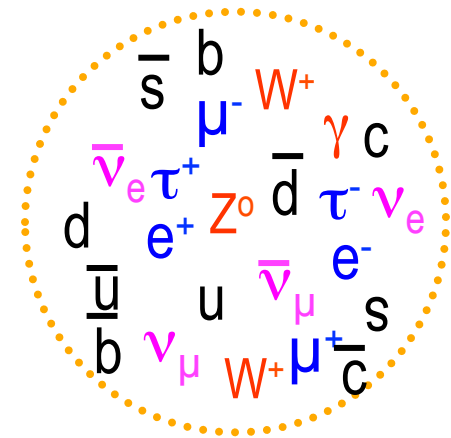
Symmetry Breaking



Simple

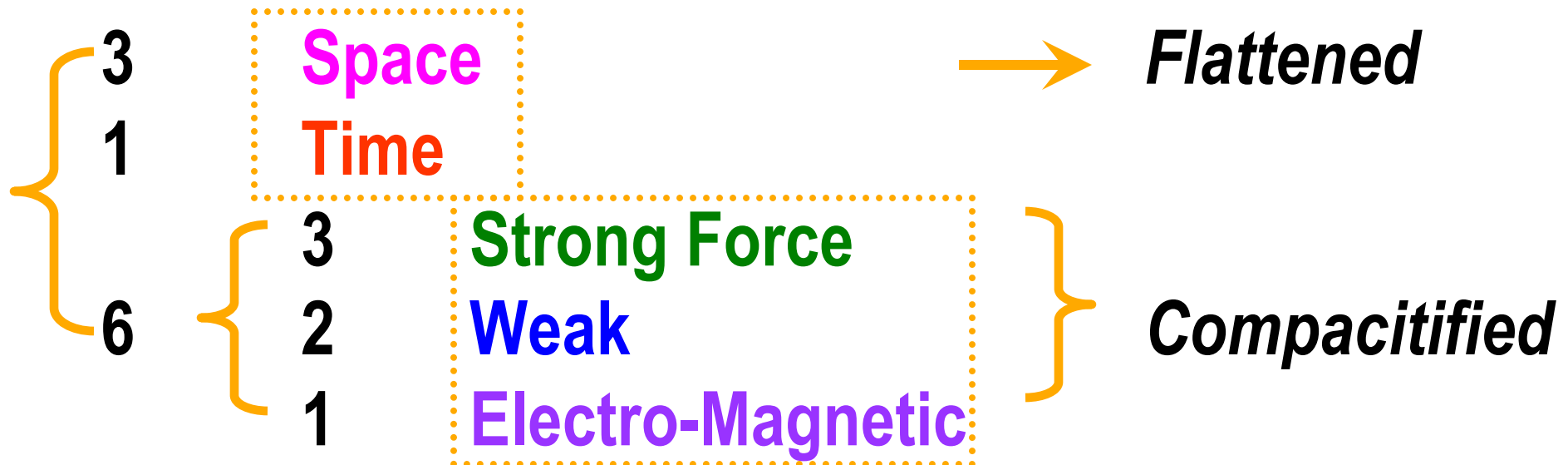
*Symmetry
Break Down*

Complex



The Beginning (at $t = 0$)

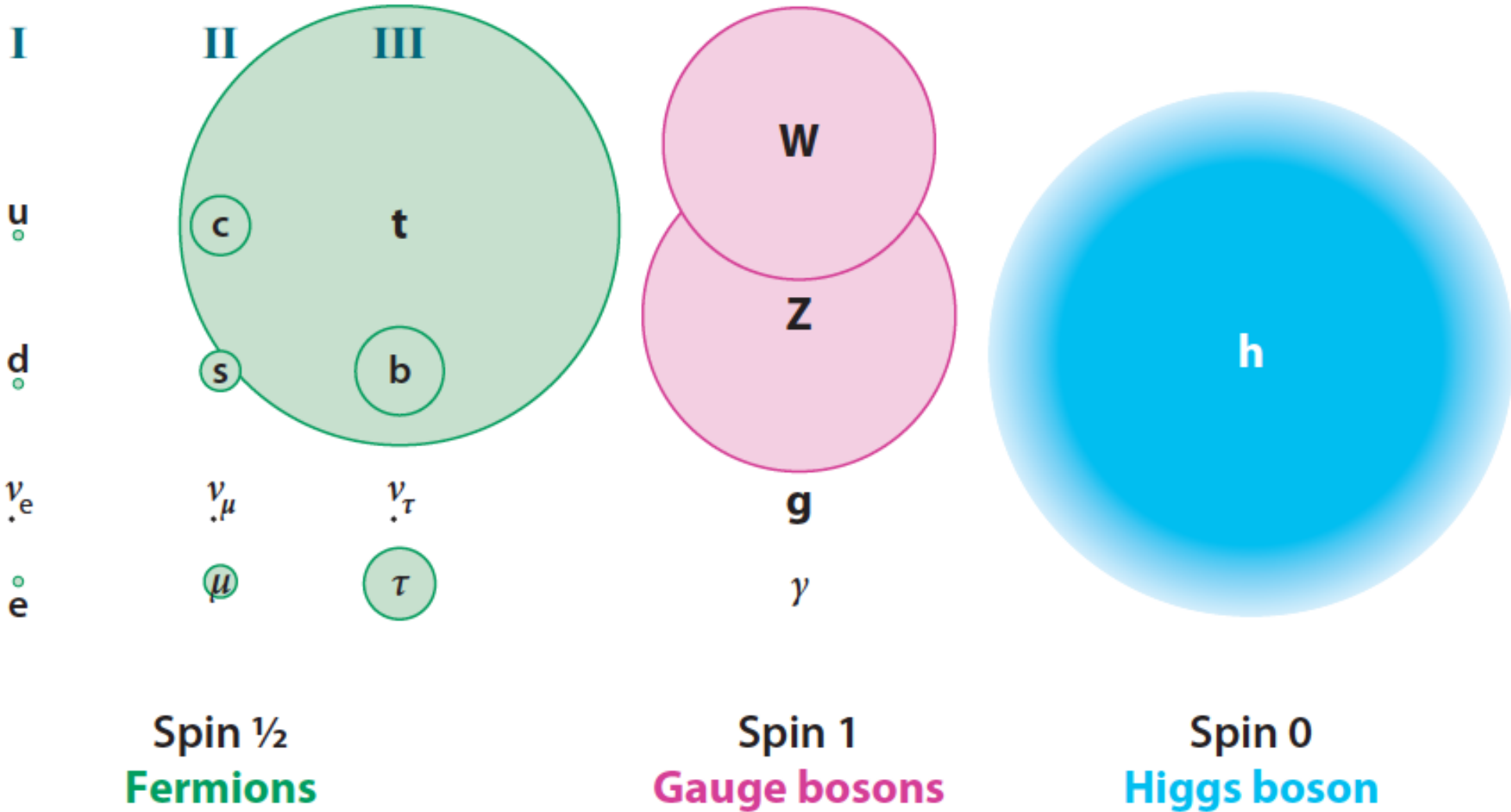
- Everything was the same \leftrightarrow Perfect symmetry.
 - All the particles are the same as photons.
 - All four forces are the same.
- The Universe was 10 dimension.



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

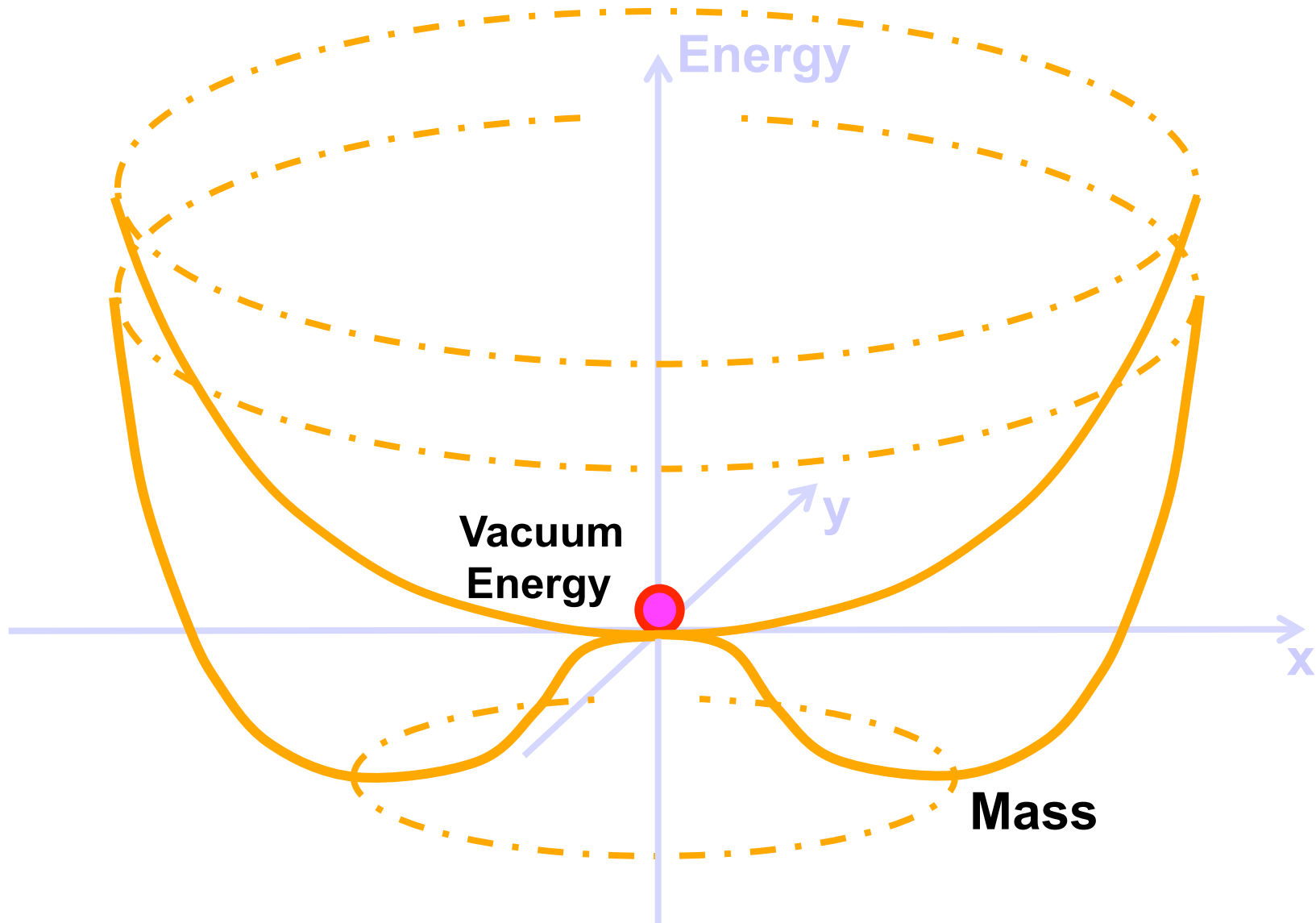
2) Particle mass \ll Plank Mass

MeV – GeV

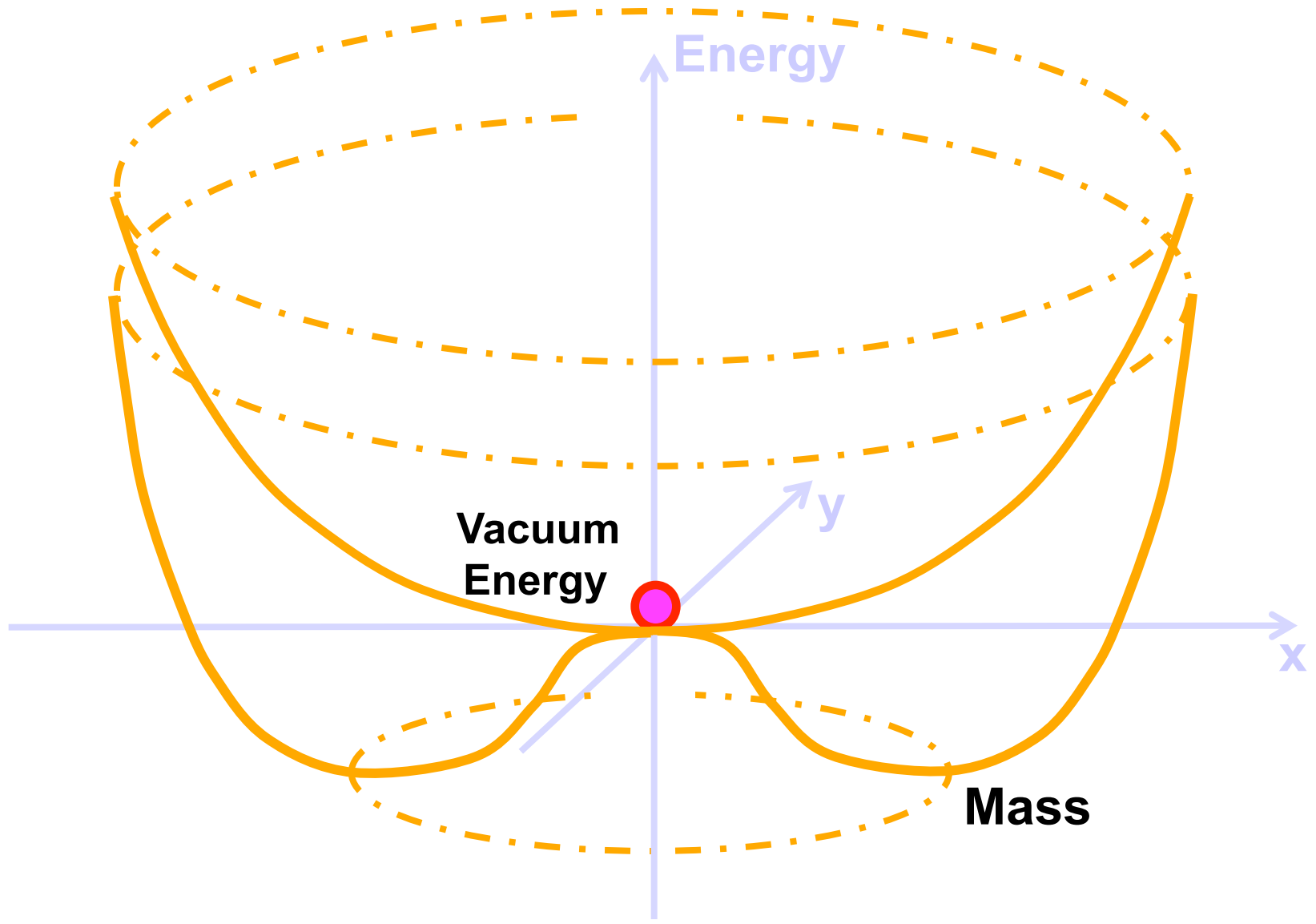
10^{19} GeV

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

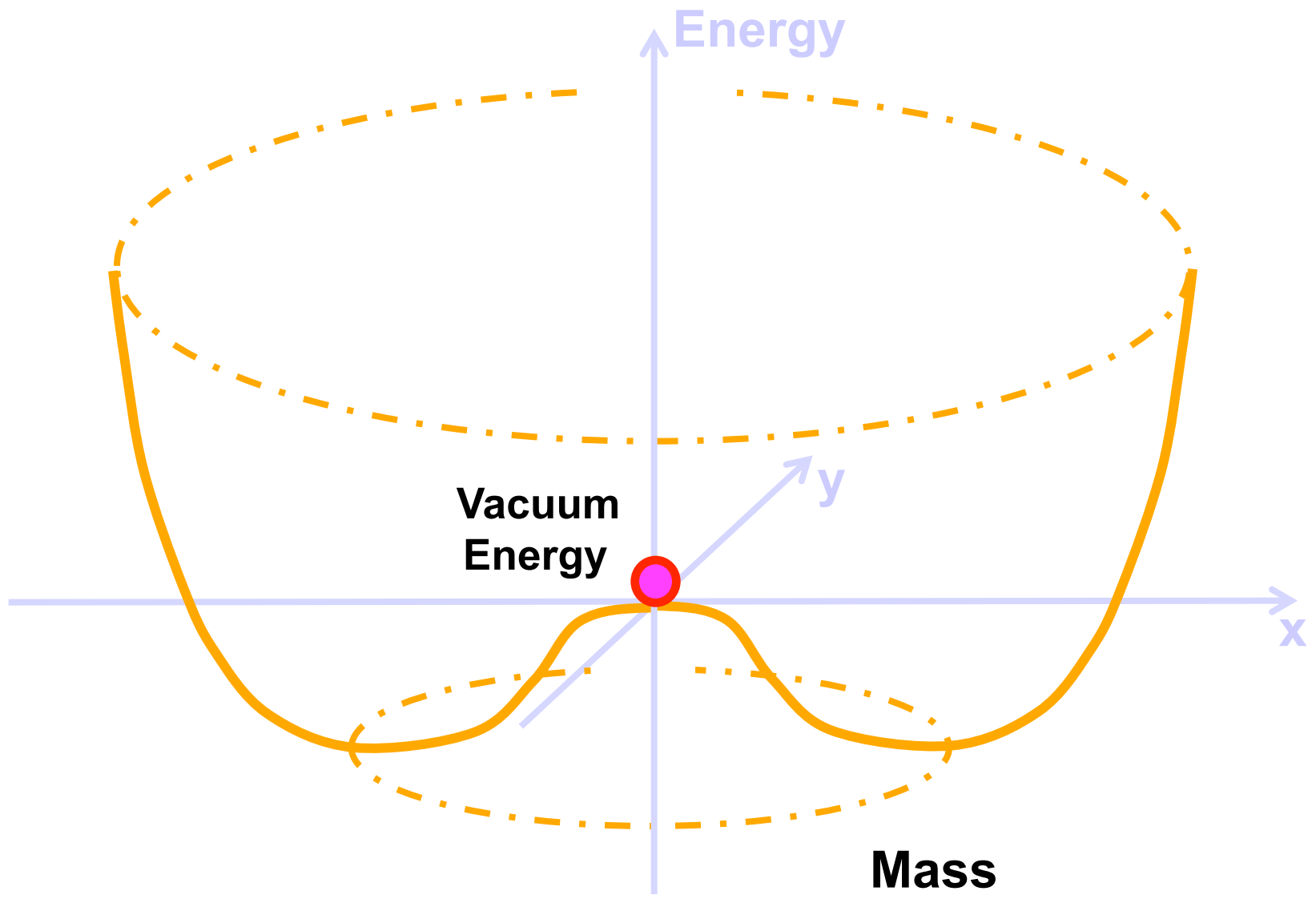
Spontaneous Symmetry Breaking - Higgs Mechanism -



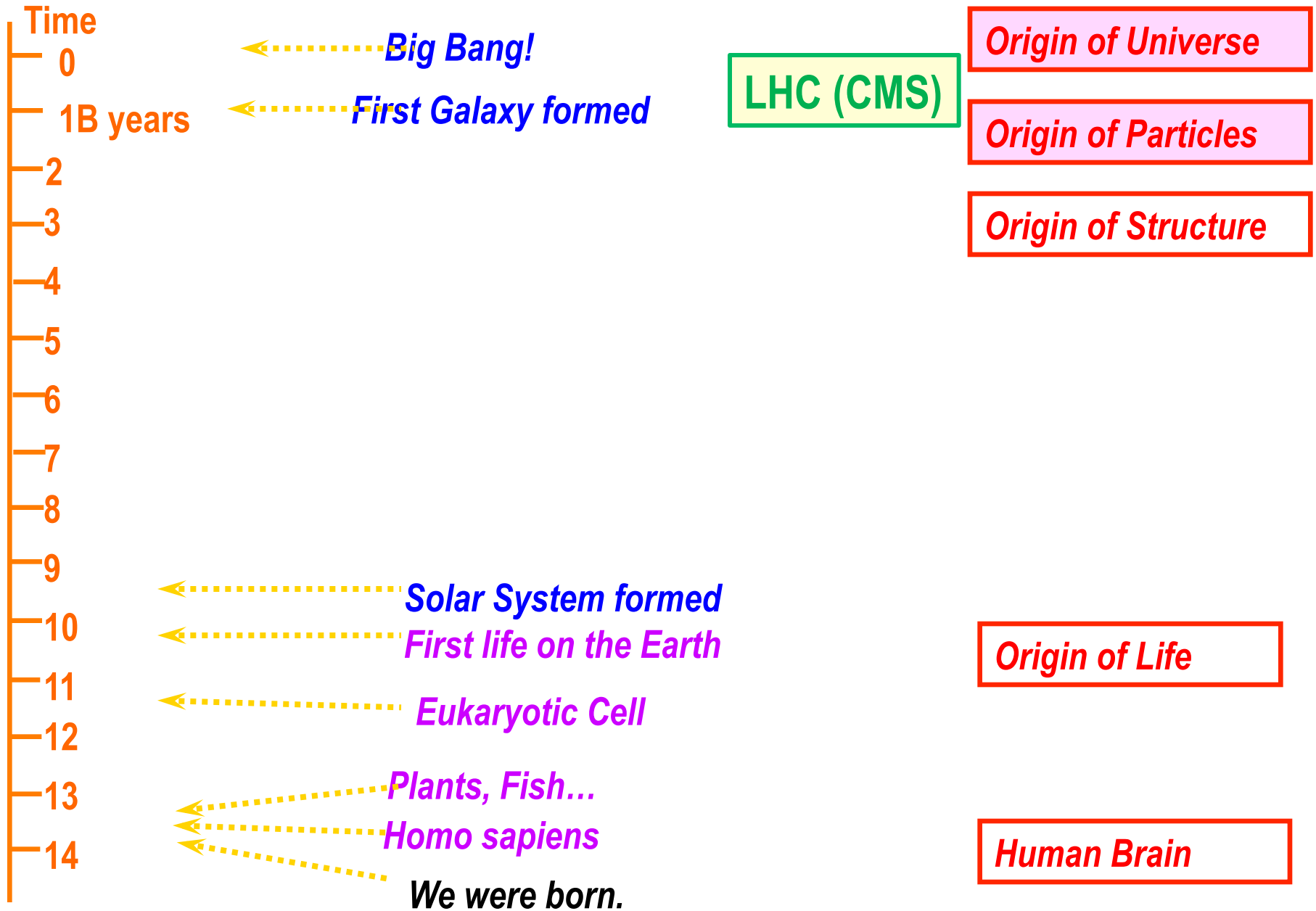
Spontaneous Symmetry Breaking - Higgs Mechanism -



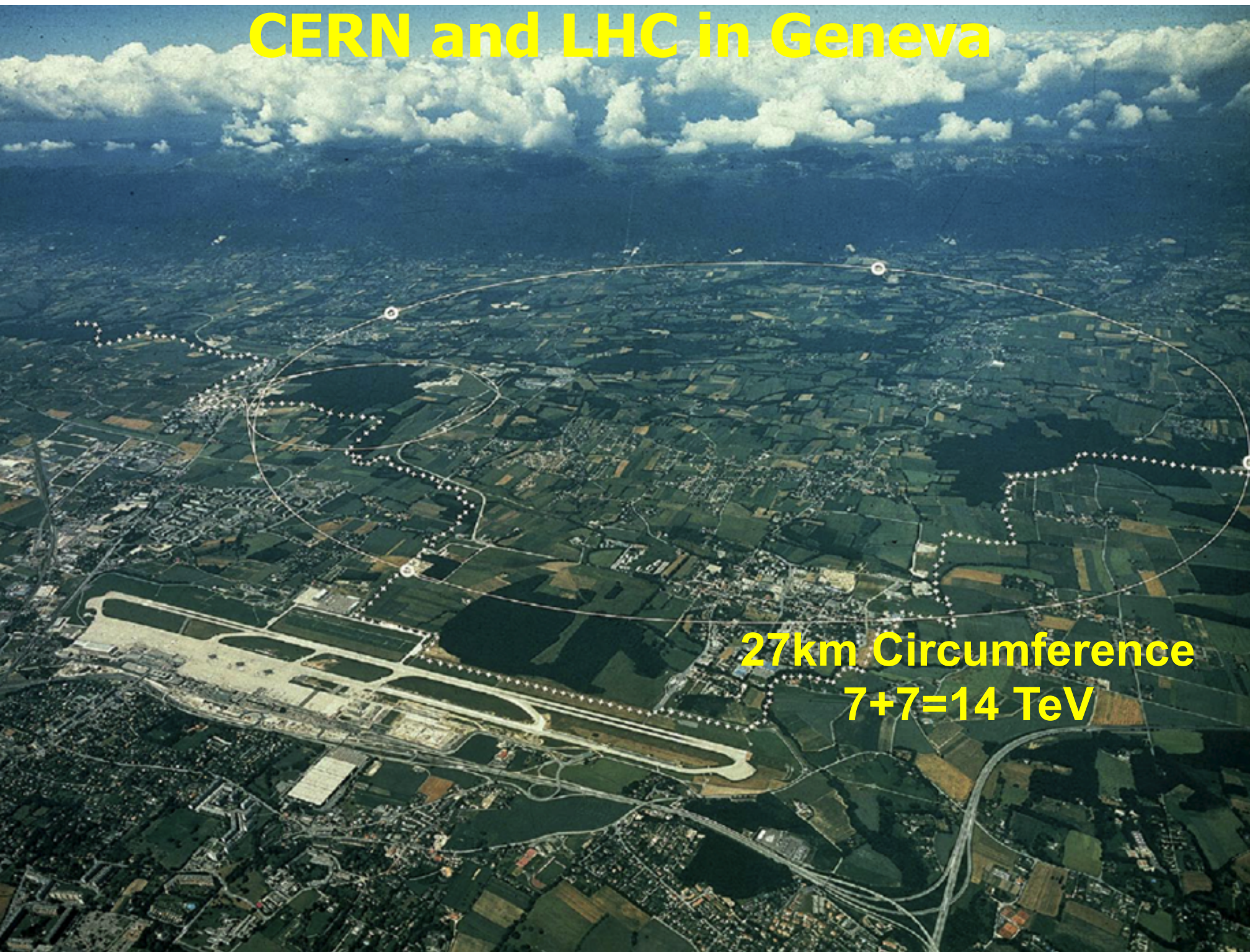
Spontaneous Symmetry Breaking - Higgs Mechanism -



The Five Largest Mysteries in Nature

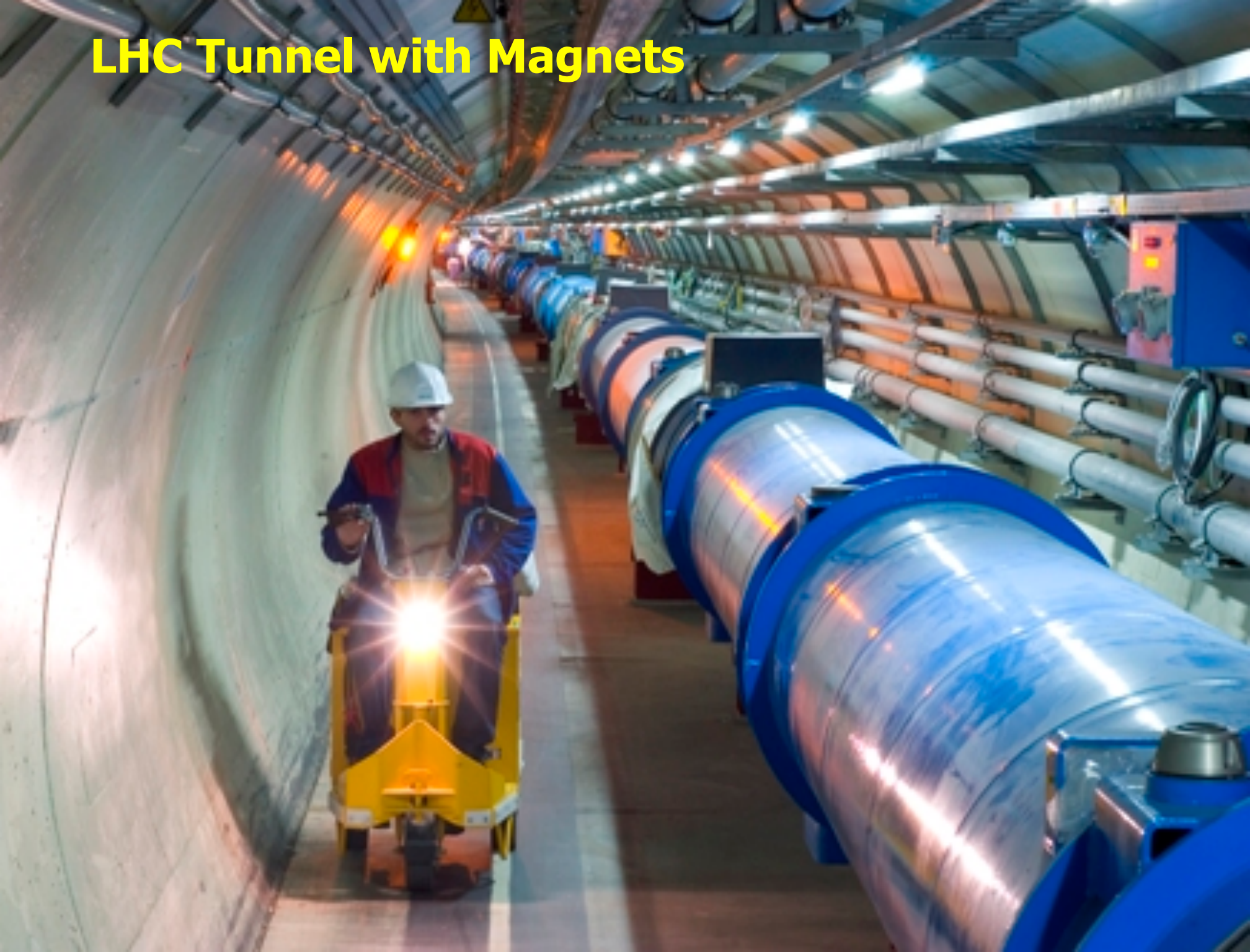


CERN and LHC in Geneva



27km Circumference
7+7=14 TeV

LHC Tunnel with Magnets



electromagnetic calorimeter

solenoid

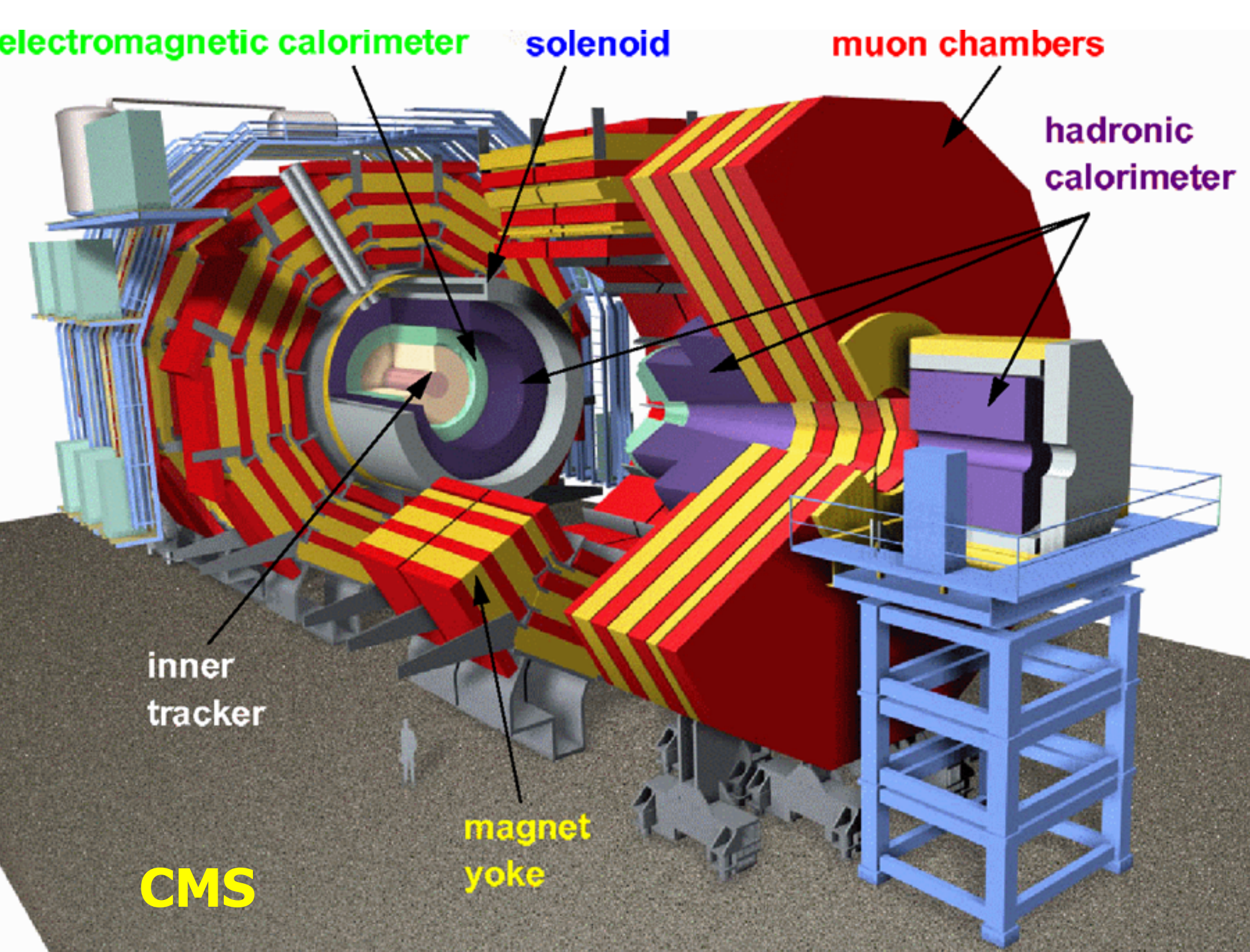
muon chambers

hadronic calorimeter

inner tracker

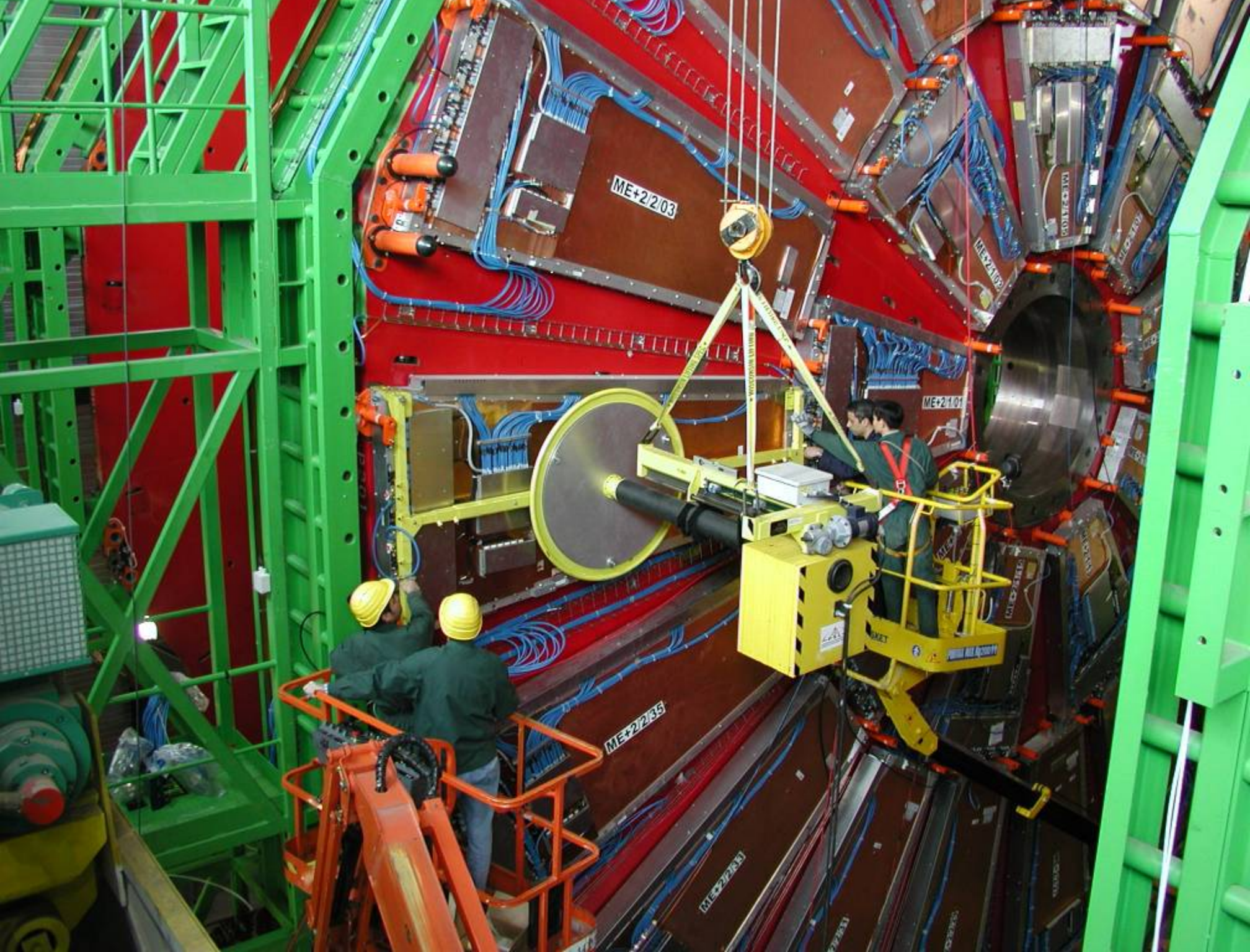
magnet yoke

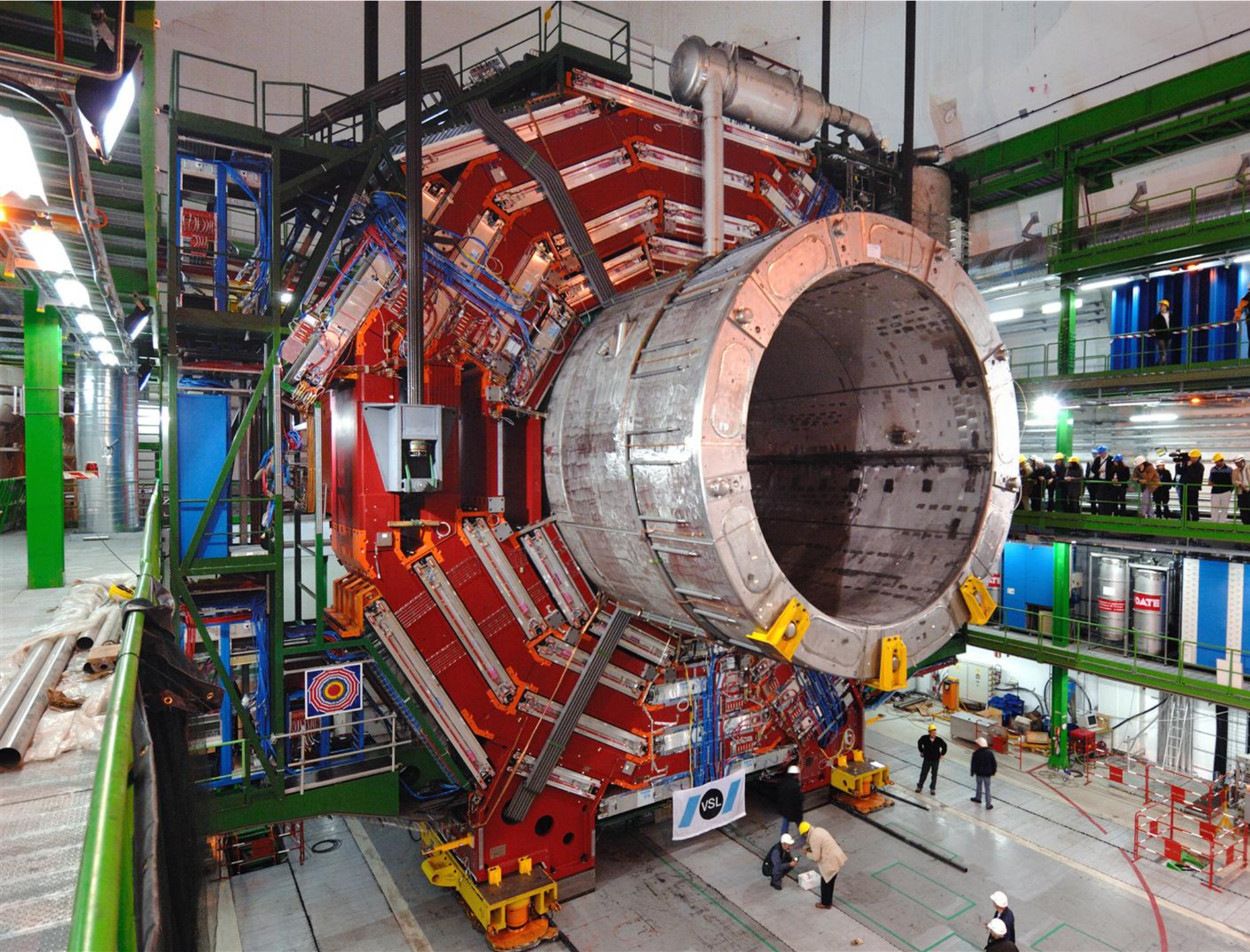
CMS

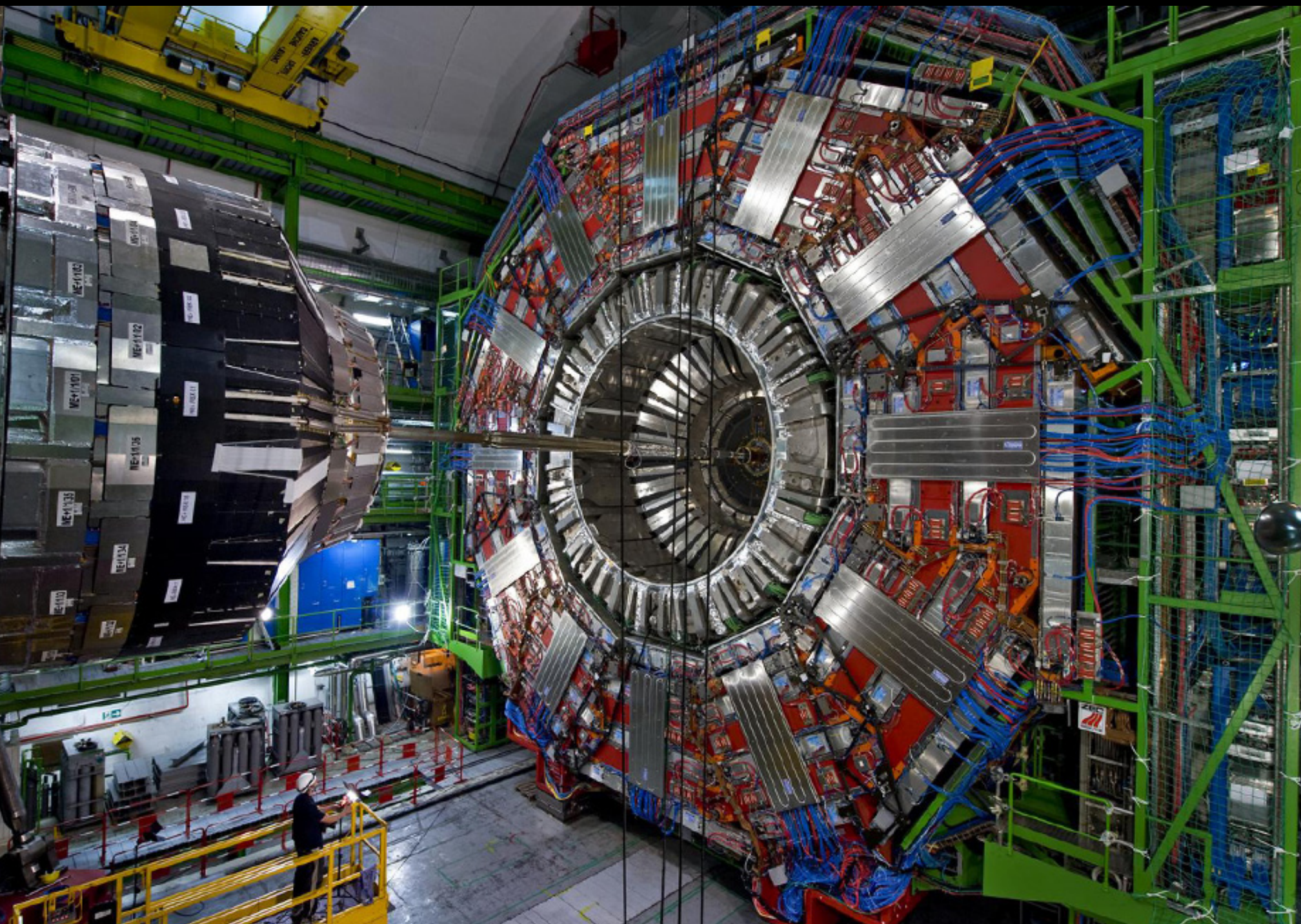


CMS Barrel Yoke









Newsweek

The Biggest Experiment Ever (And It's European)



Particle detectors
constructed
at Westwood,
now at LHC, CERN



NEWSWEEK.COM SEPTEMBER 15, 2008 PHOTOGRAPH BY MARTIAL TREZZINI-AP

The new CERN collider in Geneva

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 €4.40	Slovakia SK 120.00/€3.98	U.S. Forces \$3.25

Sept 15, 2008 Issue

CMS Experiment, CERN

Data_taken 2009-11-07 19:12:36.880368 GMT

Run_no 120015

Event_no 8

Lumi_sec 1

Orbit 584946

Crossing 2603

<http://iguana.cern.ch/iss/>

L1 Triggers:

L1_DoubleHEBitCountsRing1_P1N1

L1_DoubleHEBitCountsRing2_P1N1

L1_ETM20

L1_ETM30

L1_MinBias_HTT10

L1_Mu3QE8_Jet6

L1_SingleEG1

L1_SingleEG10

L1_SingleEG12

L1_SingleEG15

L1_SingleEG20

L1_SingleEG25

L1_SingleEG30

L1_SingleEG35

L1_SingleHEBitCountsRing1_1

L1_SingleHEBitCountsRing2_1

L1_SingleJet10

L1_SingleJet15

L1_SingleJet20

L1_SingleJet30

L1_SingleJet6

L1_SingleMu

L1_SingleMu10

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Los Angeles Times

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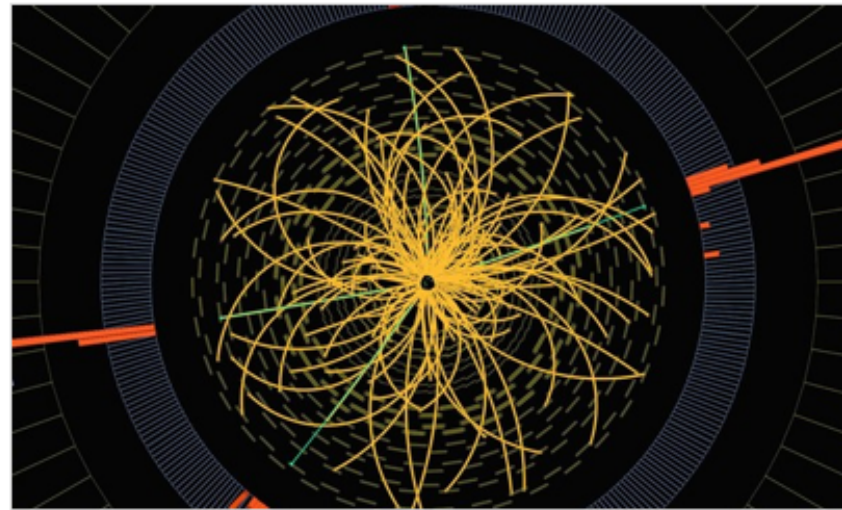
Physicists find 'tantalizing hints' of Higgs boson 'God particle'

Two teams of scientists at the Large Hadron Collider near Geneva say they detected 'tantalizing hints' of the elusive Higgs boson, or 'God particle,' but no definitive proof.

December 13, 2011 | By Eryn Brown, Los Angeles Times

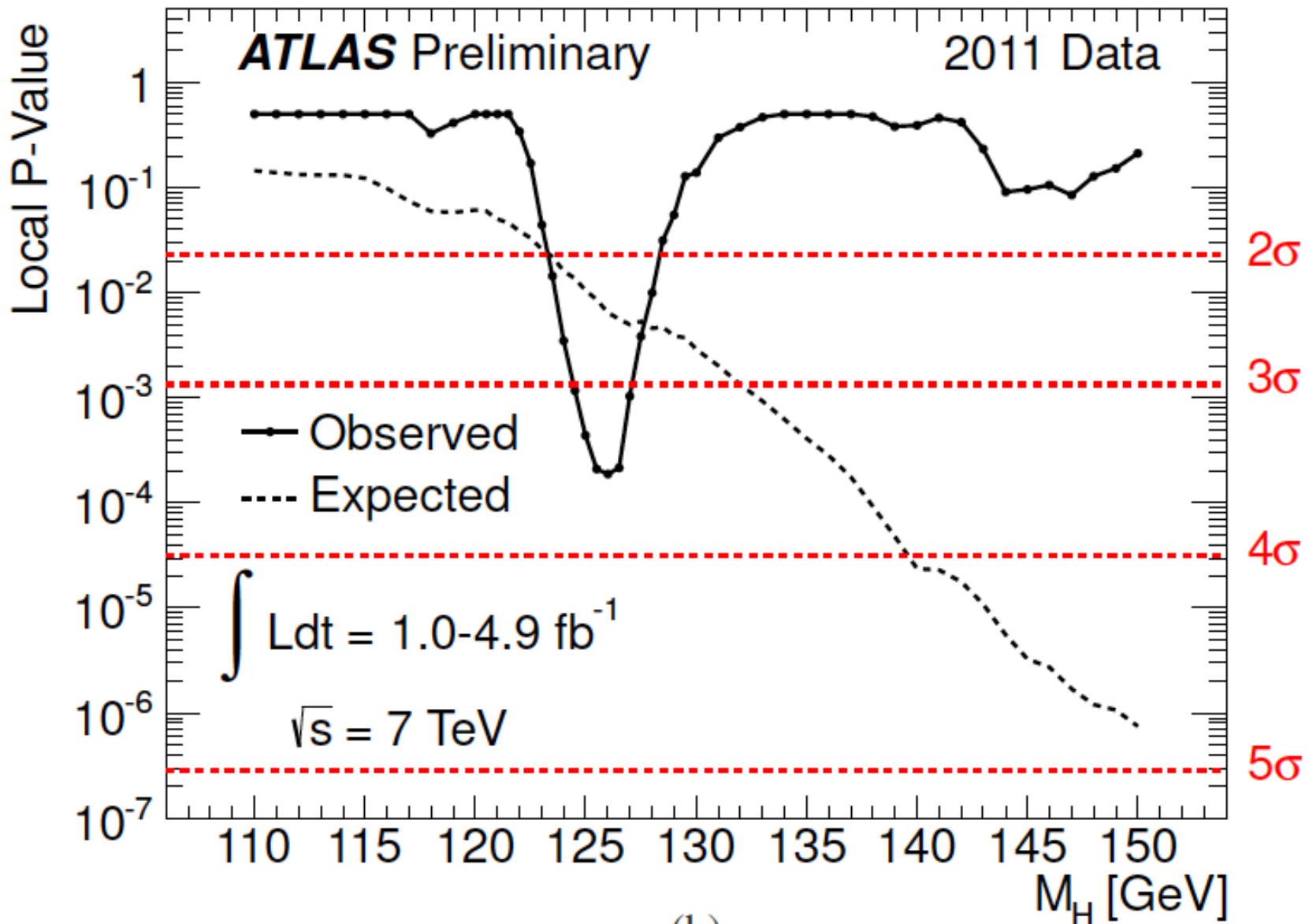
Physicists announced Tuesday that they had detected "tantalizing hints," but not definitive proof, of the long-sought Higgs boson, the so-called God particle that is crucial to physicists' understanding of why mass exists in the universe.

Two large teams of scientists based at the Large Hadron Collider near Geneva separately saw what they believe are telltale tracks of the maddeningly elusive particle in the aftermath of about 400 trillion proton collisions carried out since January.



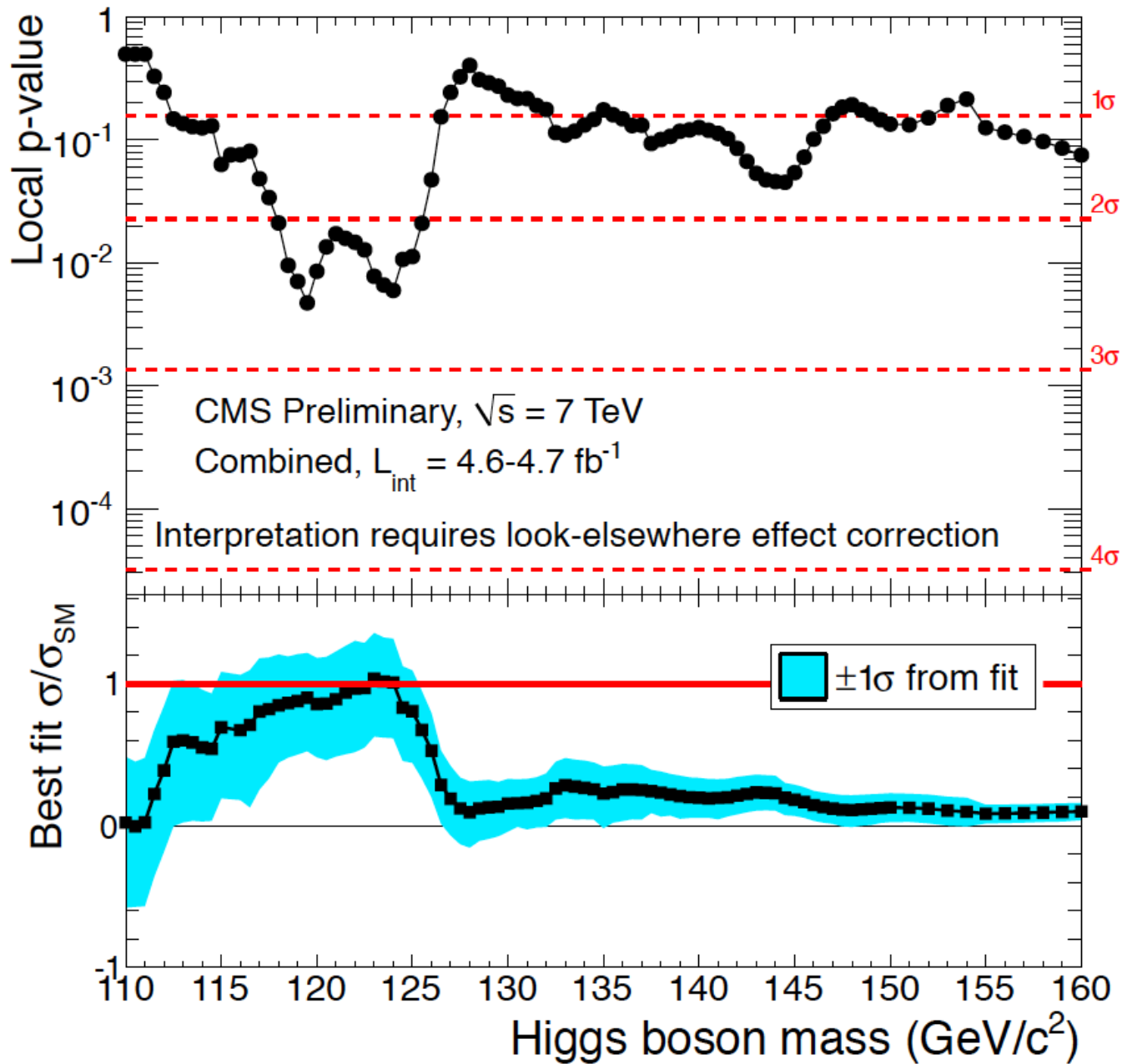
A graphic shows traces of a proton collision measured in a detector at the... (CERN)

ATLAS Higgs Results



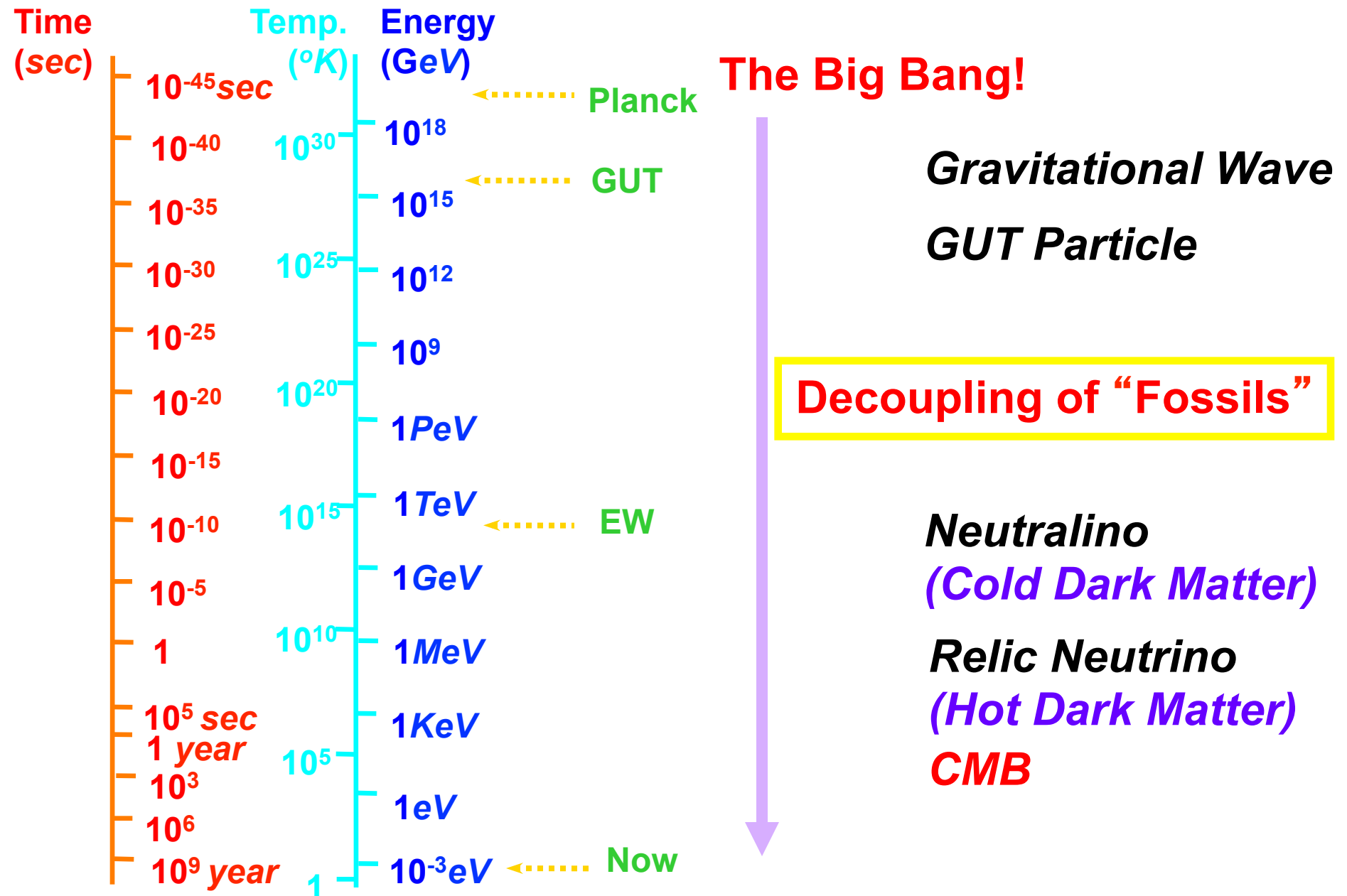
(b)

CMS Higgs Results

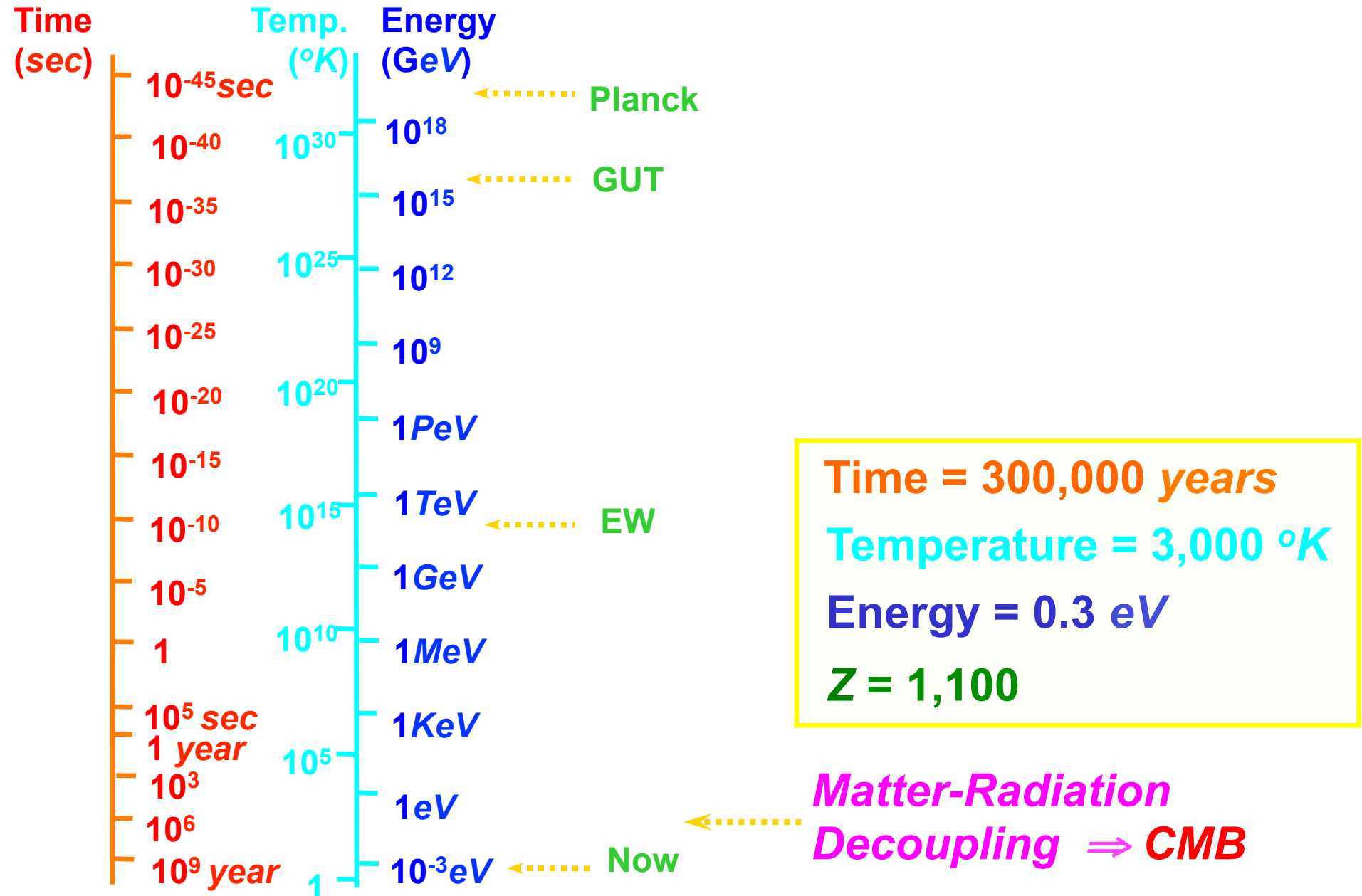


Dark Matter and Dark Energy

“Fossils” from the Earliest Universe

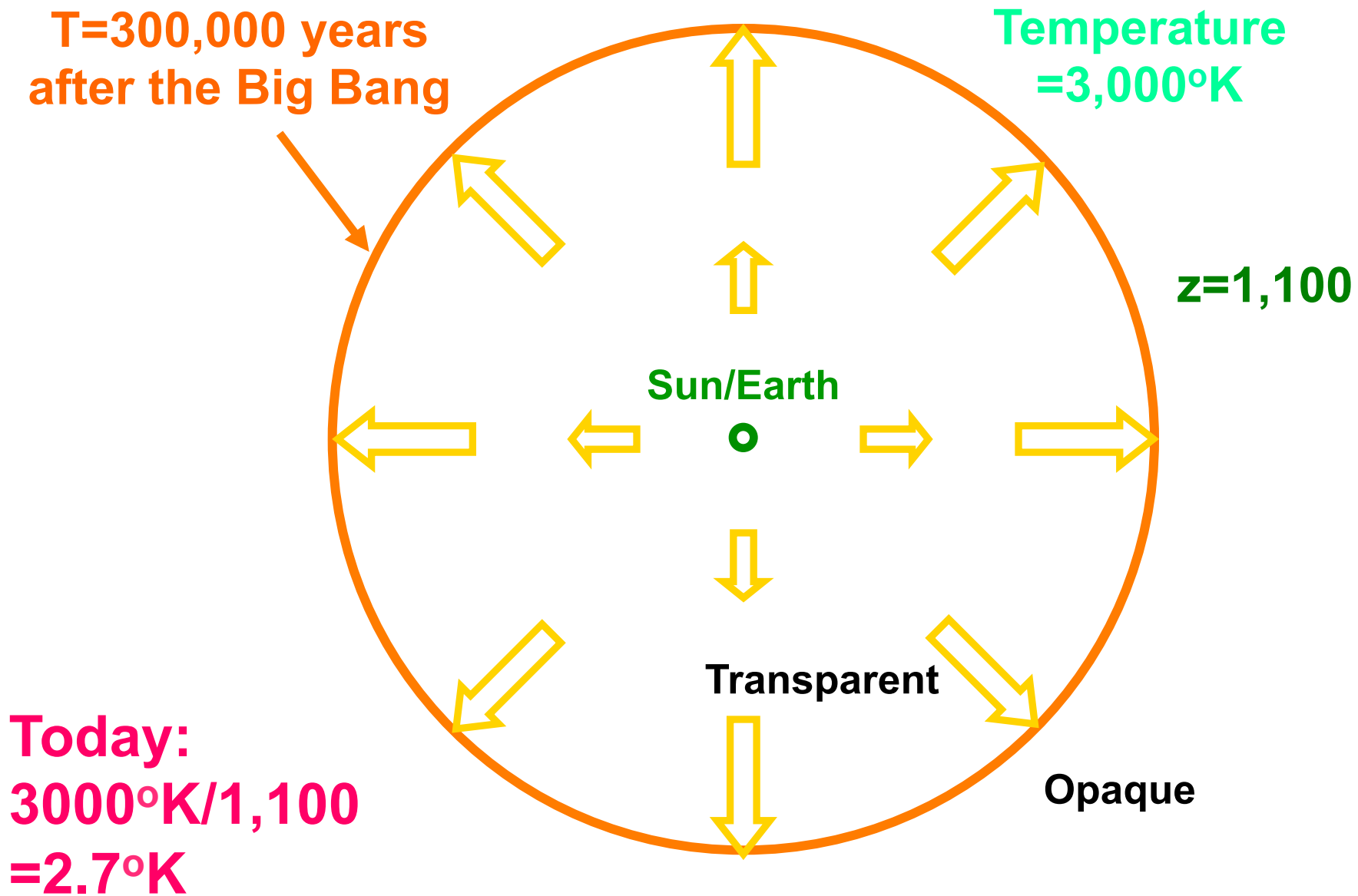


Cosmic Microwave Background (CMB) Matter-Radiation Decoupling





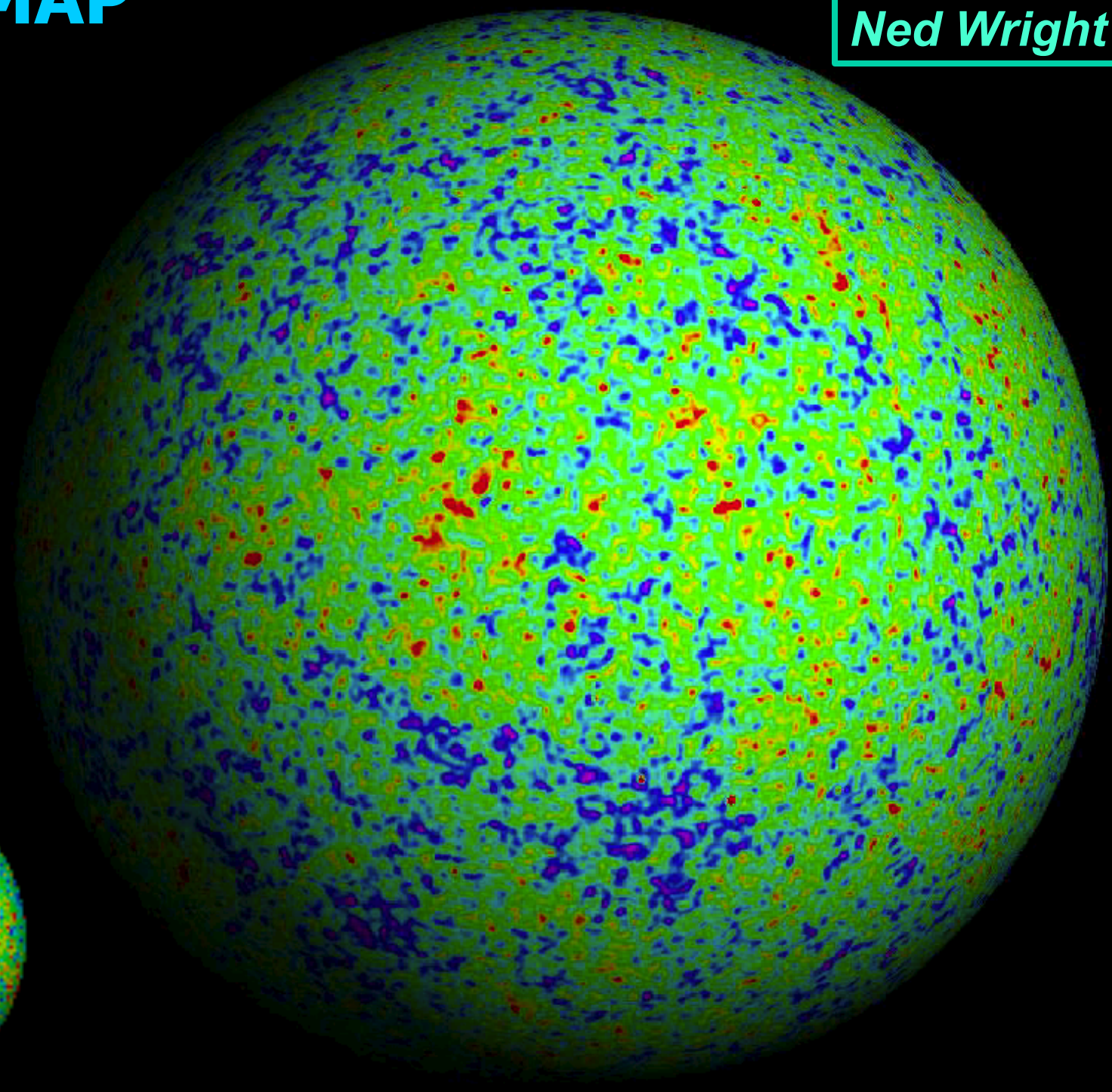
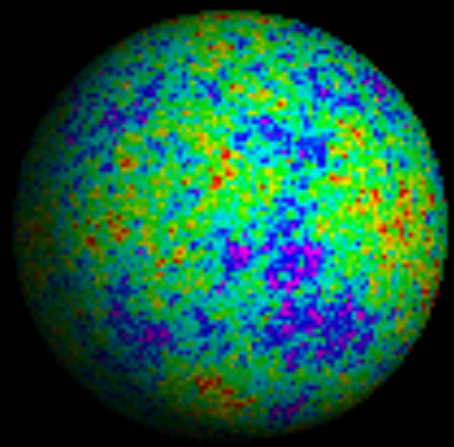
Cosmic Microwave Background (Discovered in 1964)



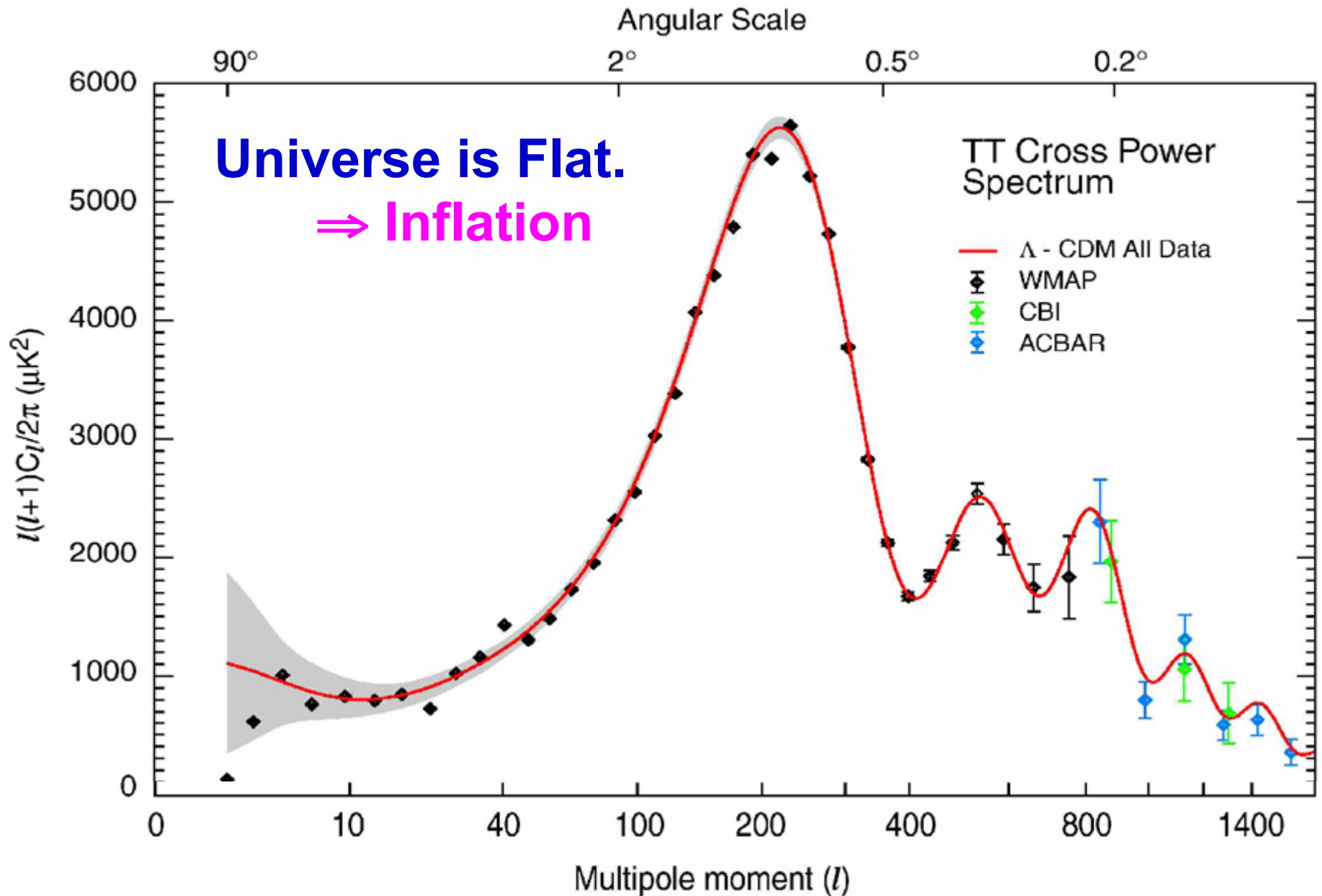
WMAP

Ned Wright

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



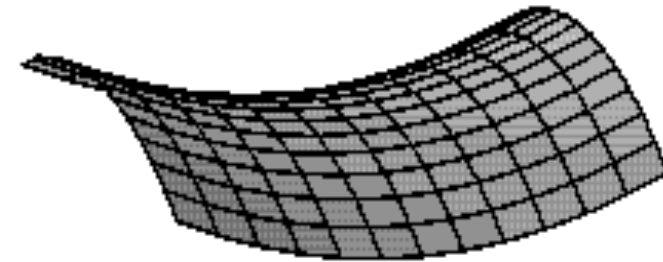
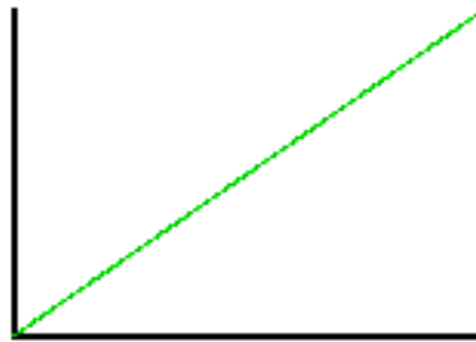
WMAP Power Spectrum



Geometry of the Universe

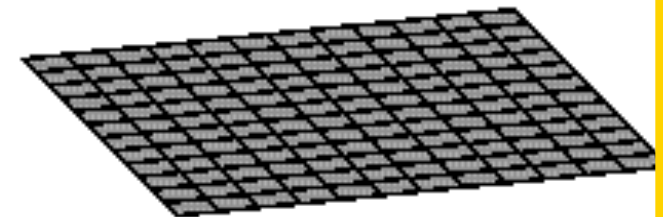
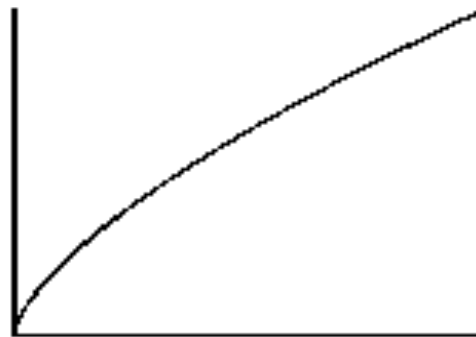
Open

$$\Omega < 1$$



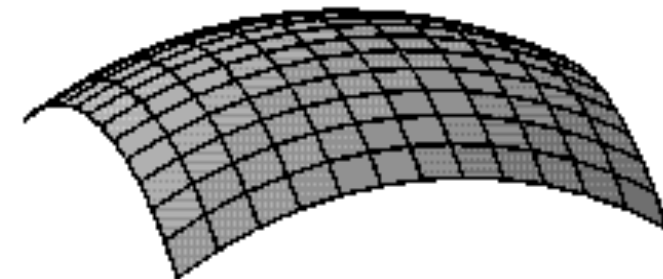
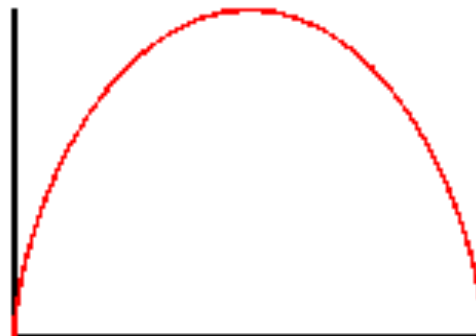
Flat
(predicted by
Inflation)

$$\Omega = 1$$

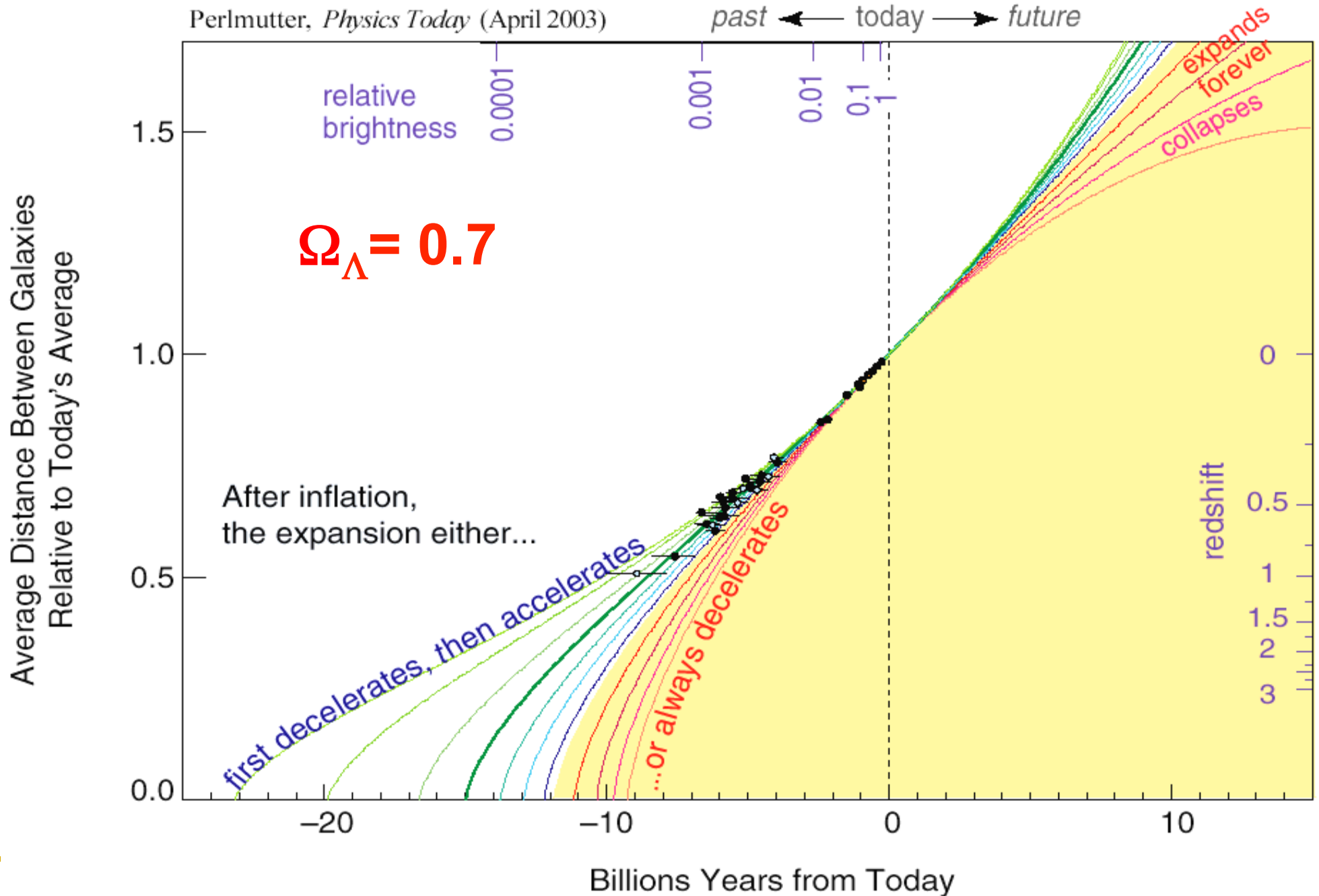


Closed

$$\Omega > 1$$



The Accelerating Universe (1998)

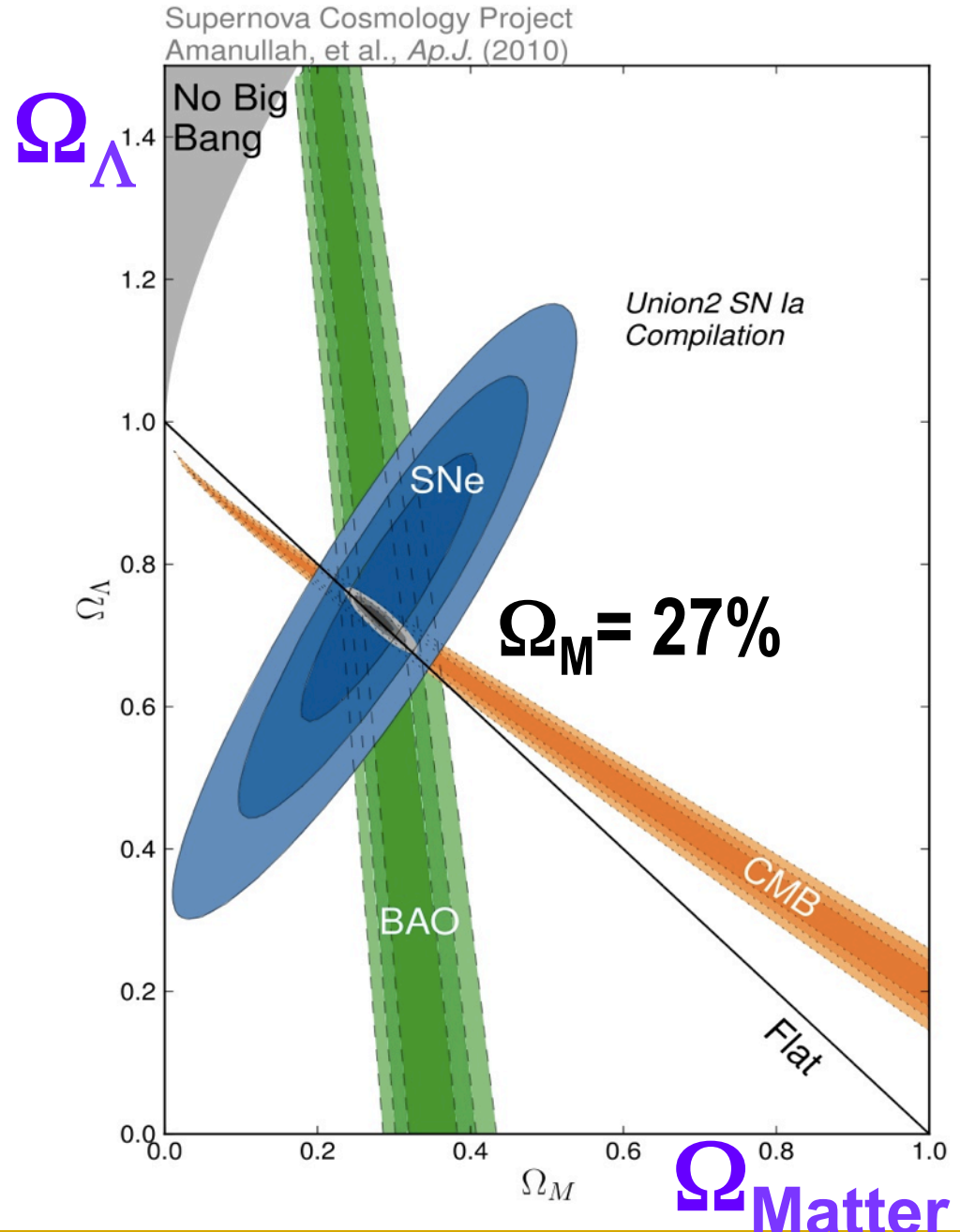


Density of Our Universe

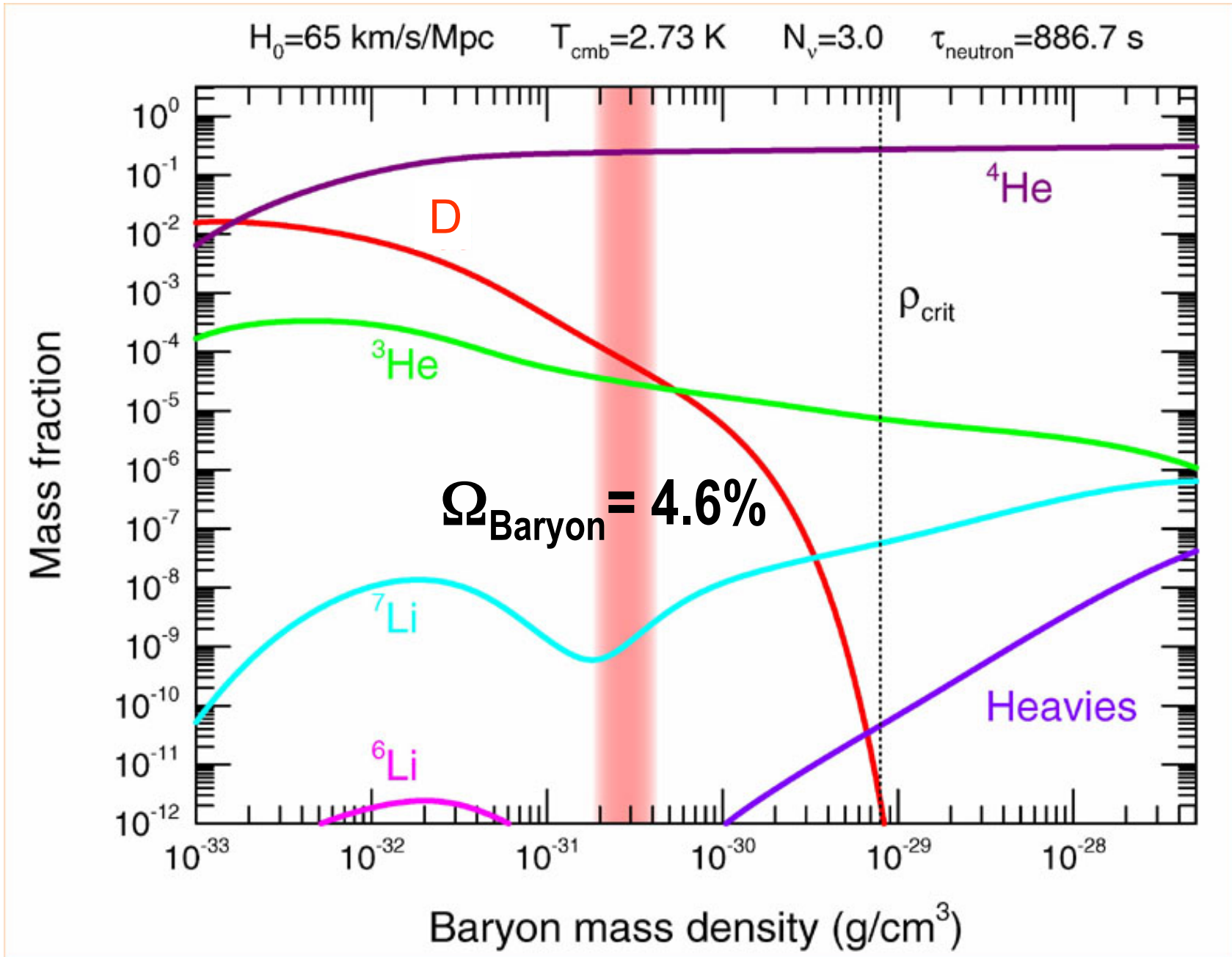
➤ $\Omega_{\text{Total}} = \Omega_{\Lambda} + \Omega_{\text{Matter}} = 1.0$

➤ Universe is Flat.
⇒ Inflation

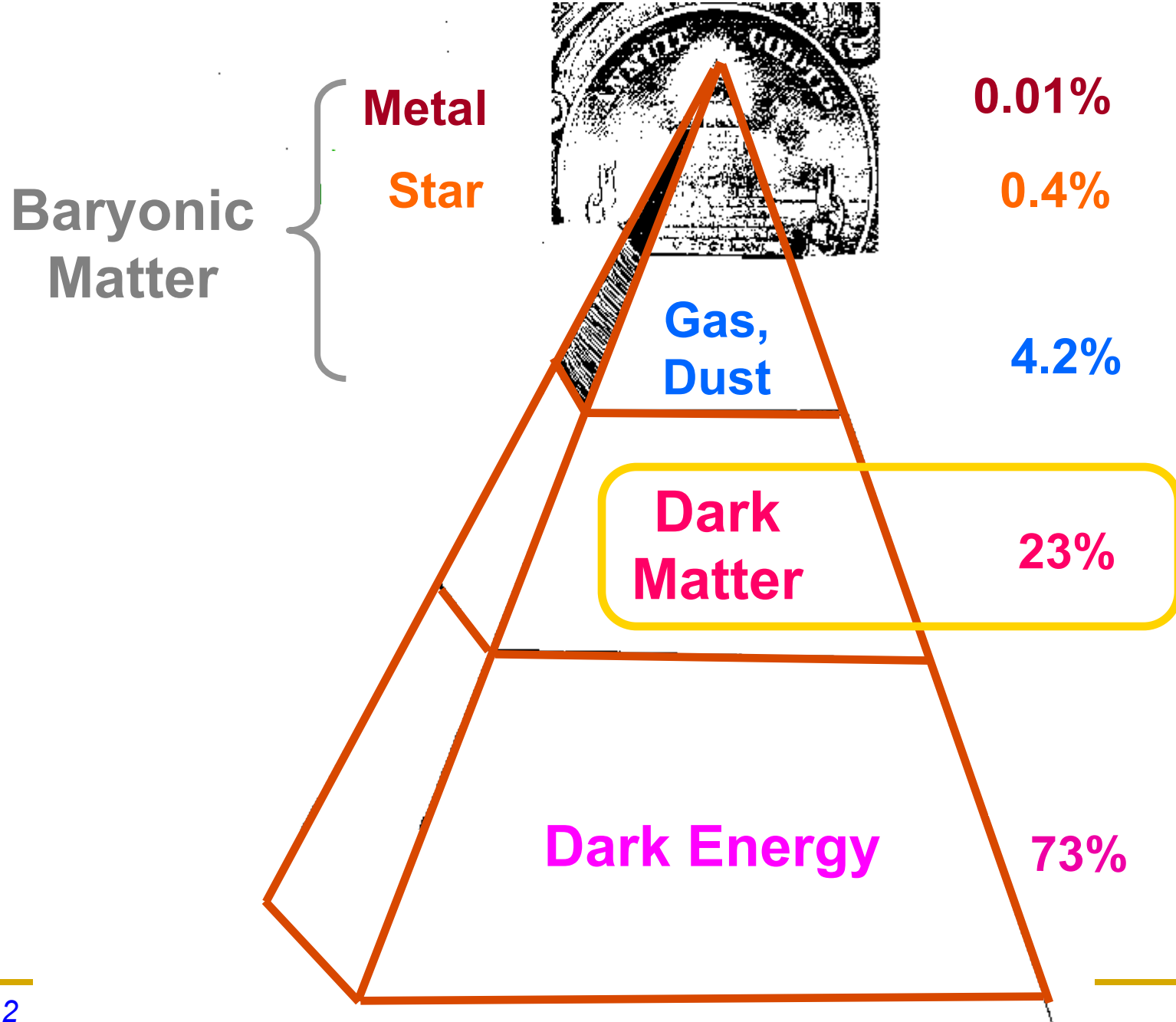
➤ 73% is Dark Energy.
⇒ Accelerating



Abundance vs. Density



Cosmic Pyramid



Part II

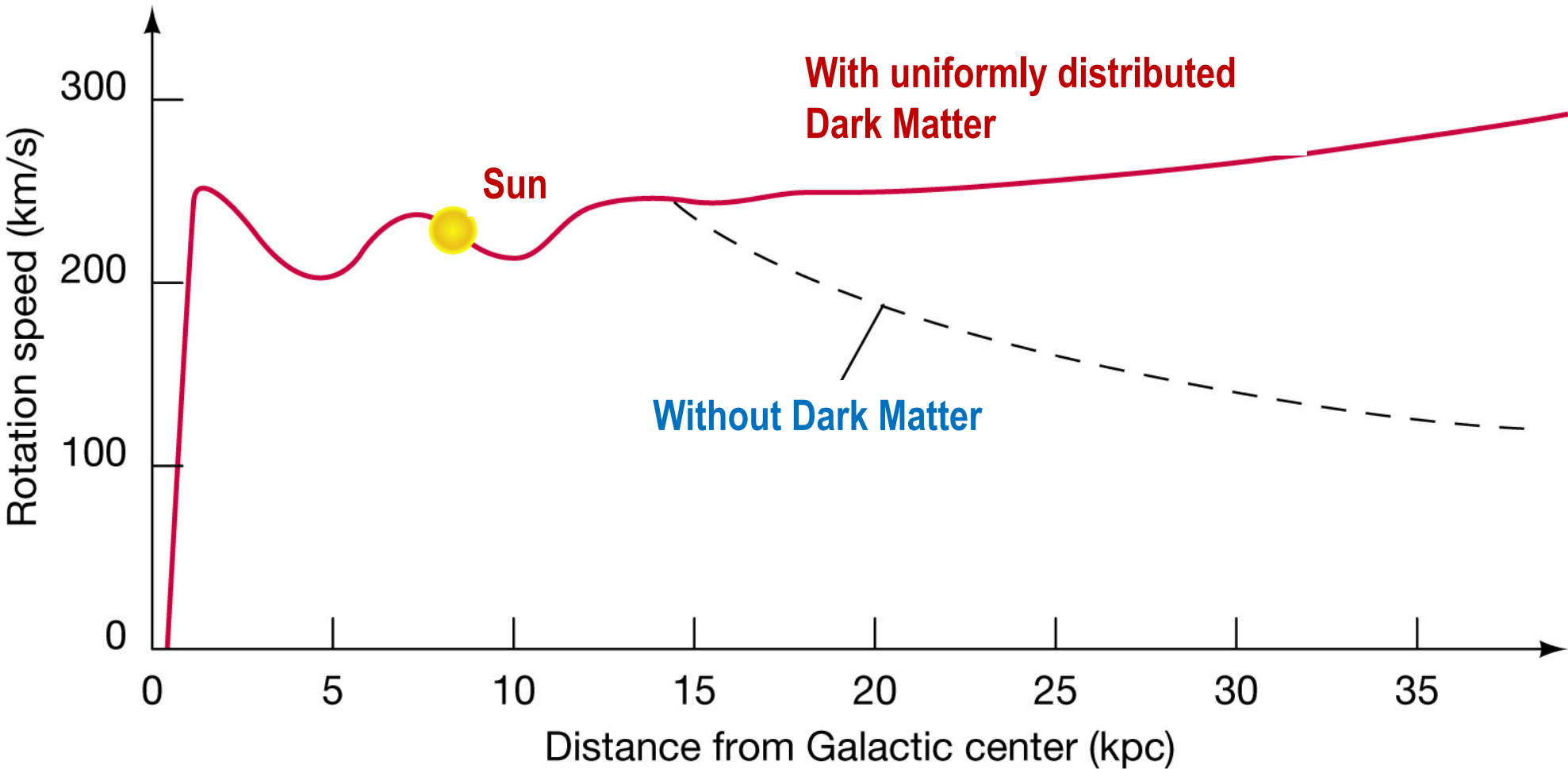
Search for Dark Matter



Dark Matter is required!

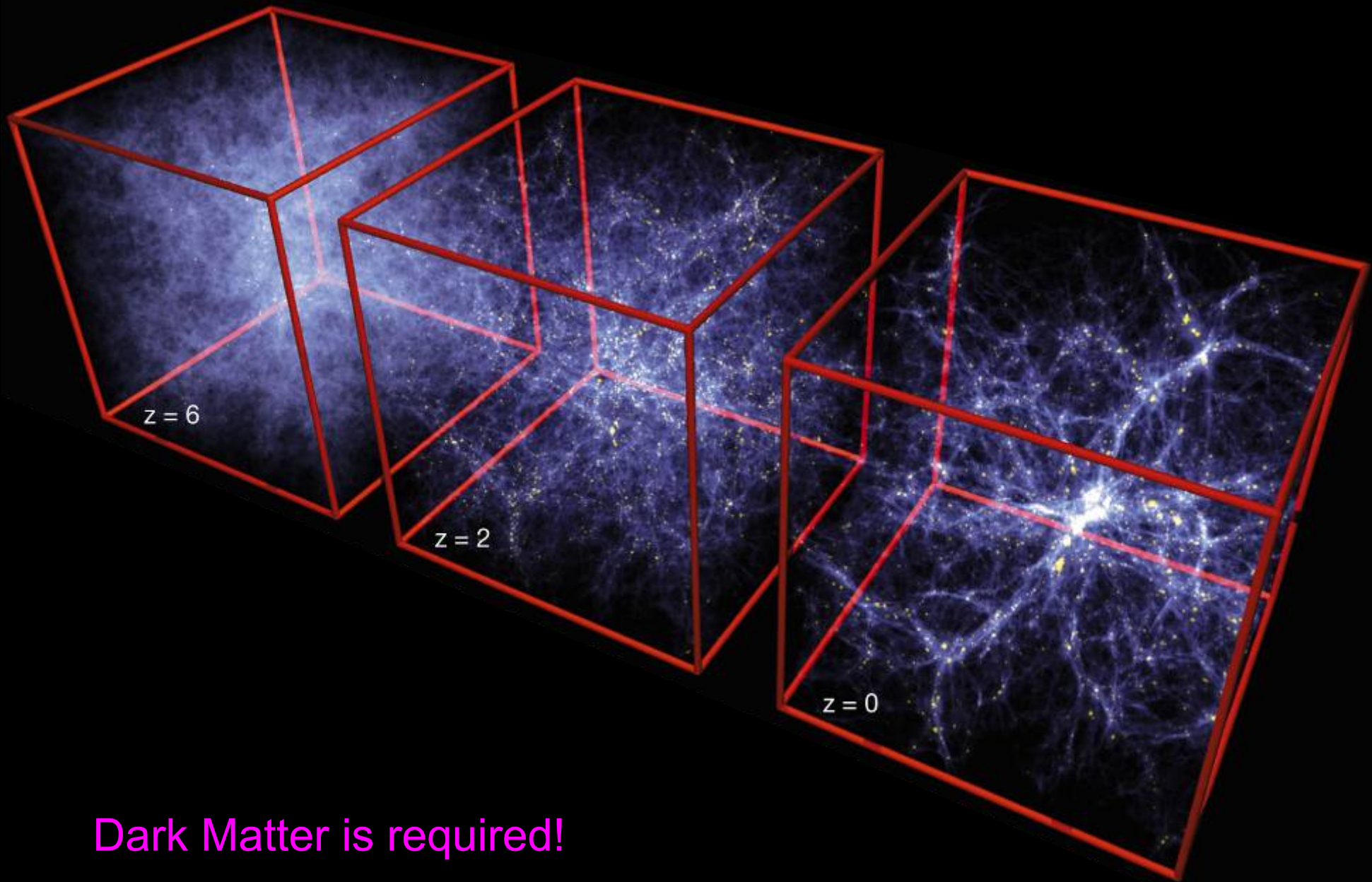
ANDROMEDA
GALAXY.

Rotational Velocity of Galaxies



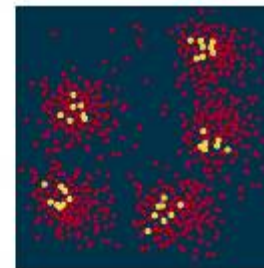
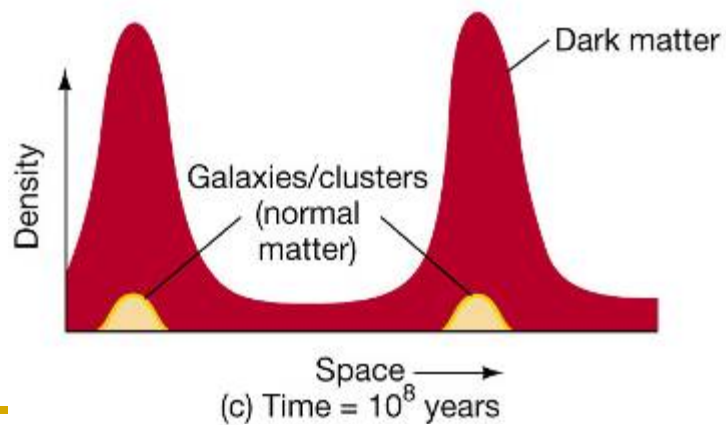
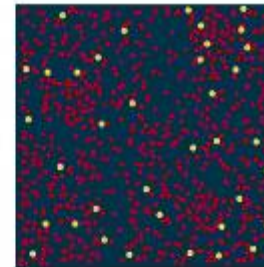
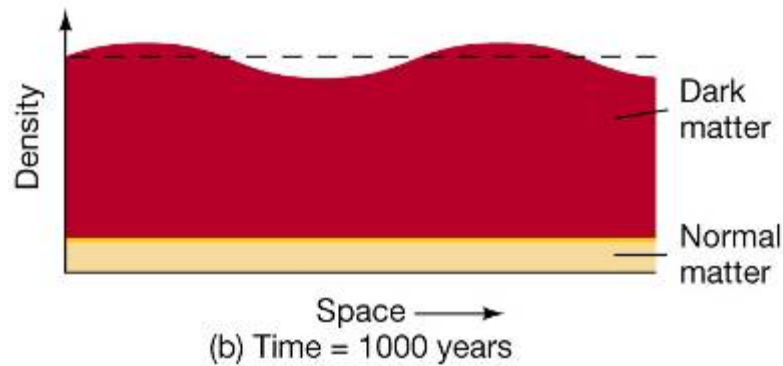
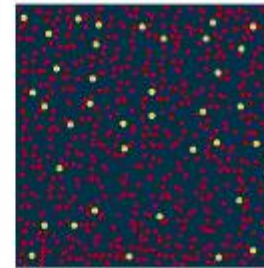
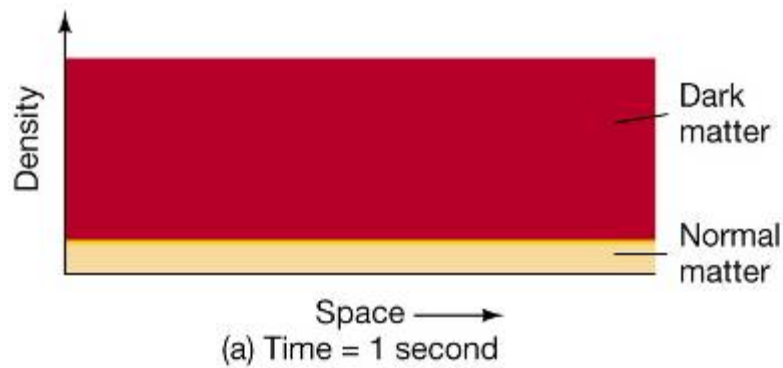
Copyright © 2005 Pearson Prentice Hall, Inc.

Formation of Structure in the Universe

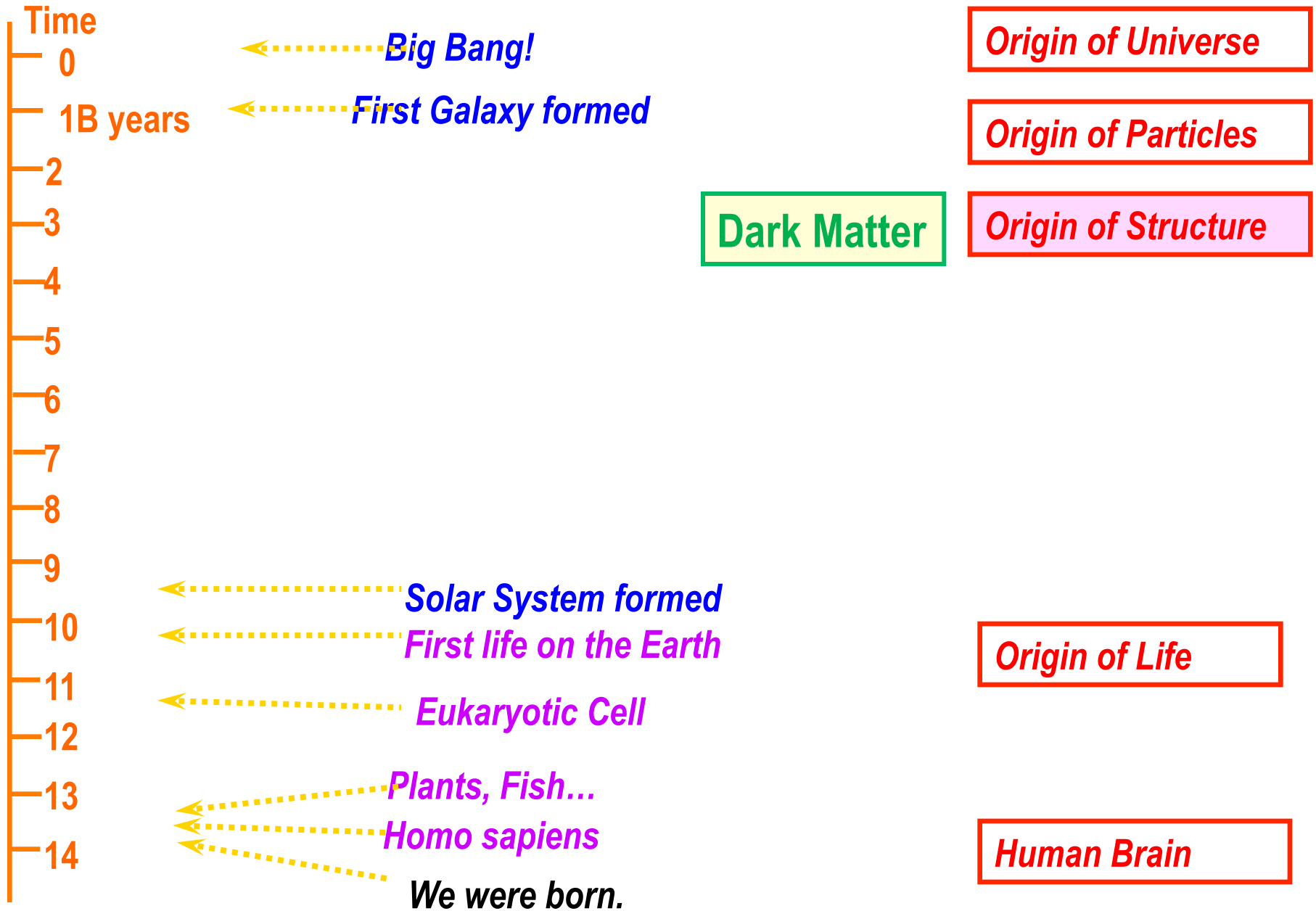


Dark Matter is required!

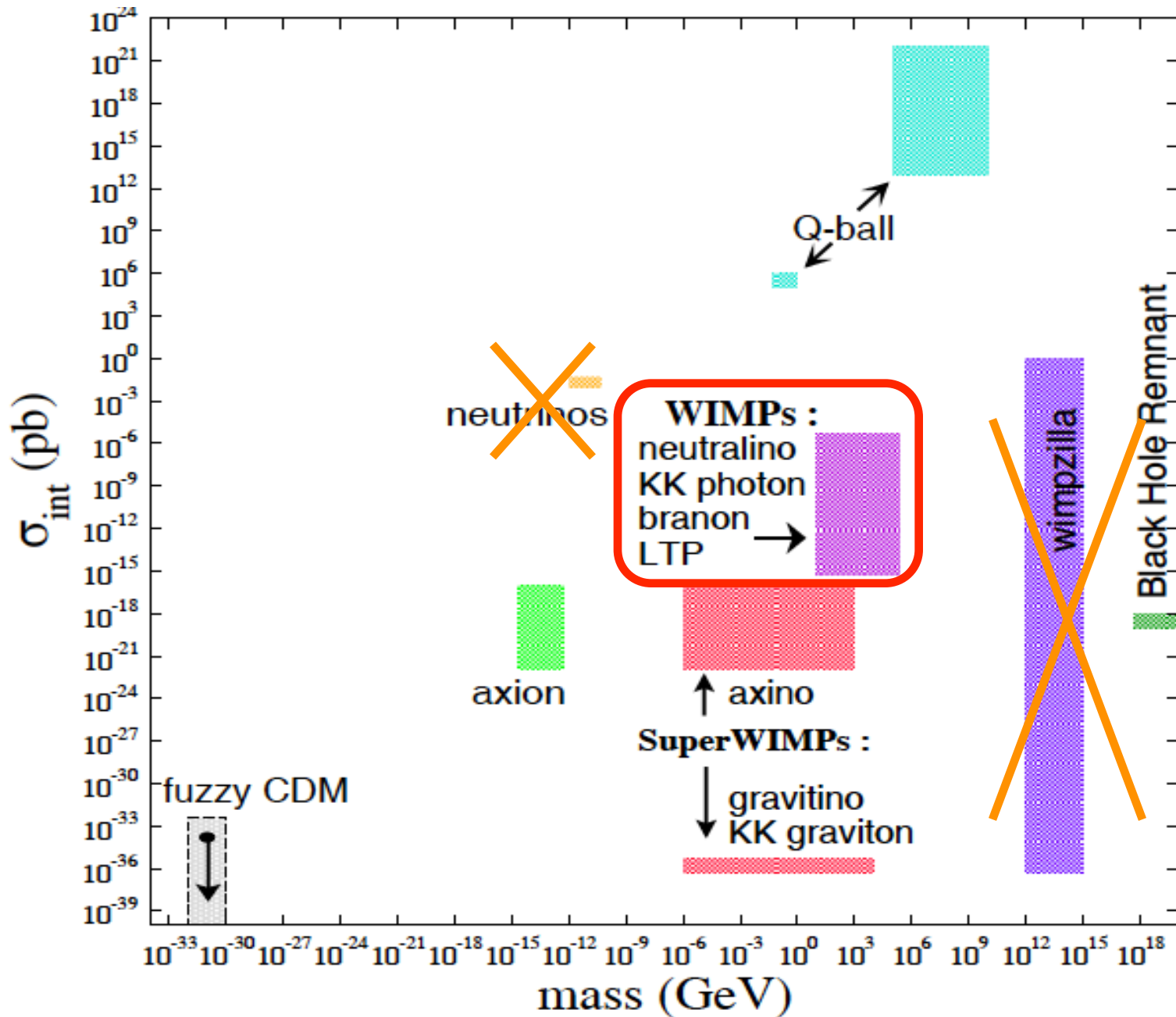
Evolution of Large Structure



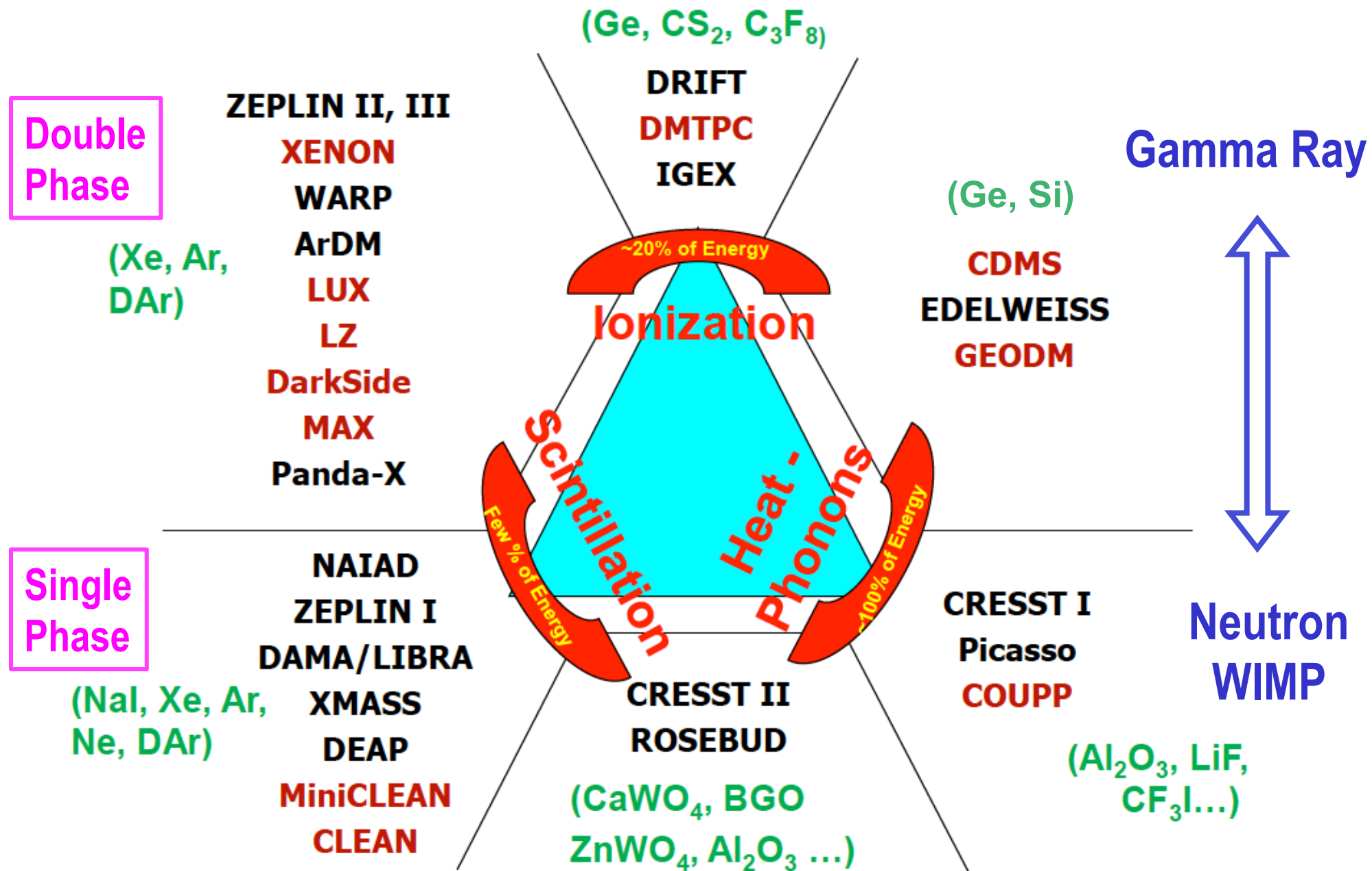
The Five Largest Mysteries in Nature



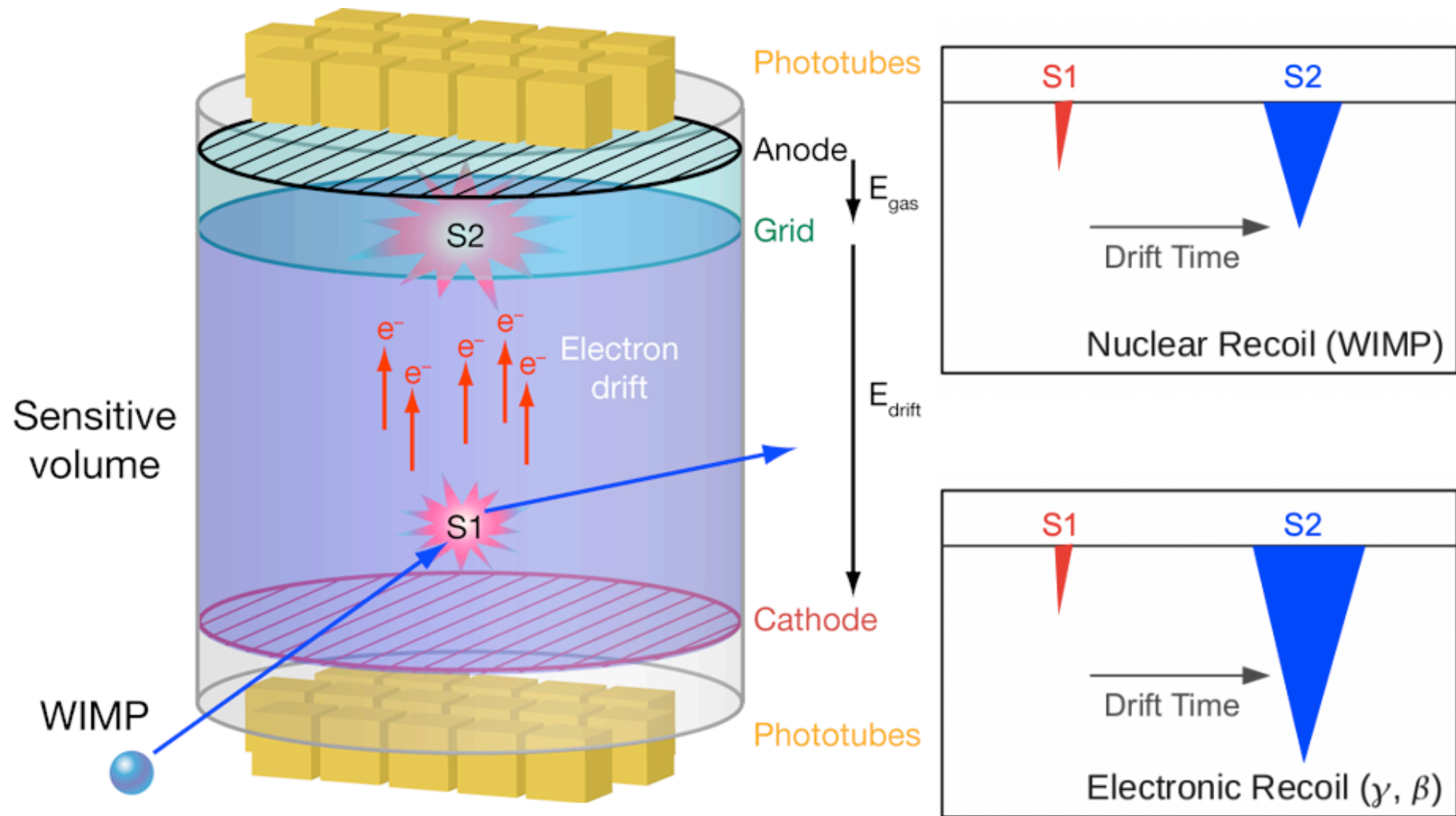
What is Dark Matter?



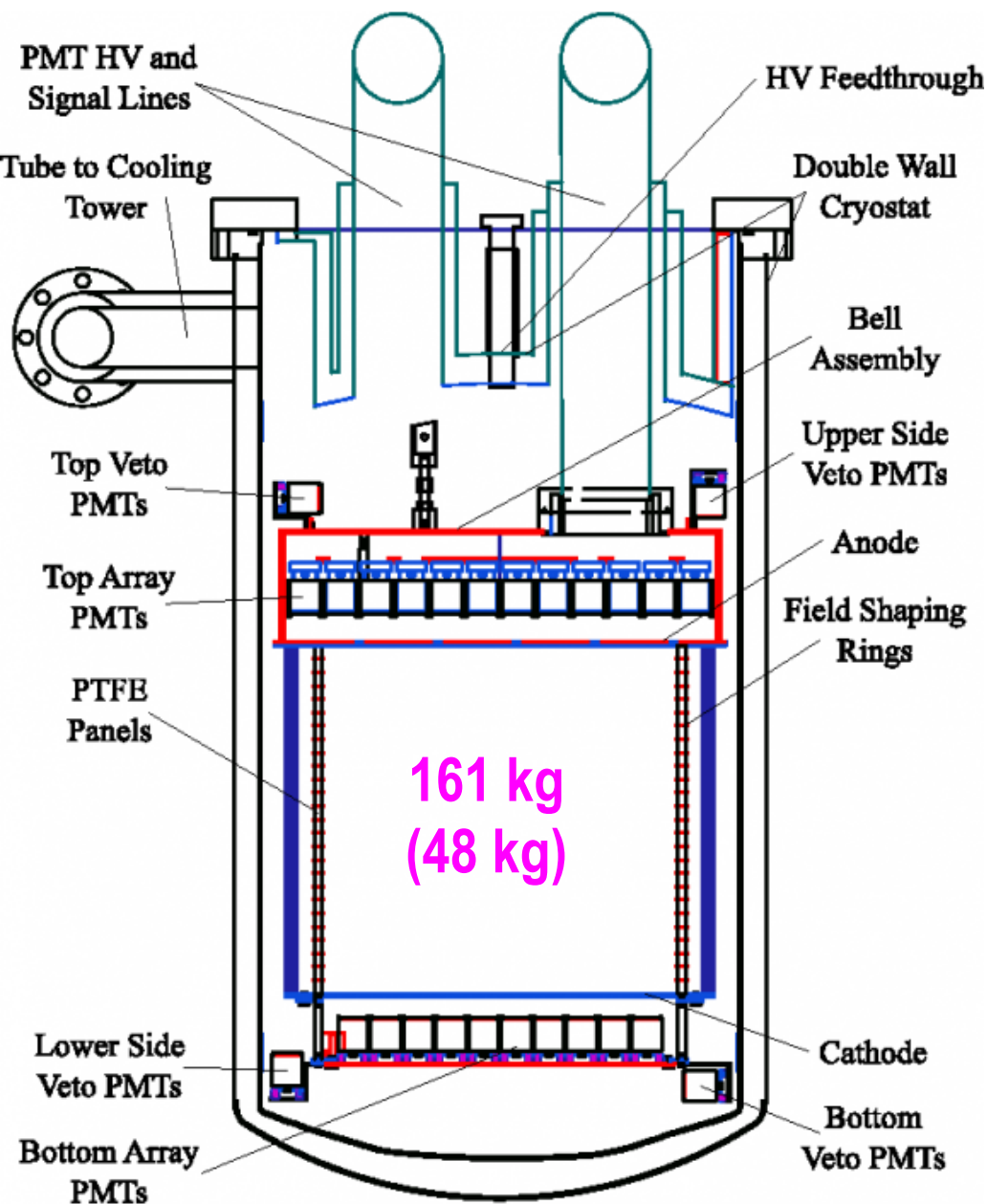
Detection Technique



Double-Phase Noble Liquids



XENON100 Detector



Pb
(20cm)

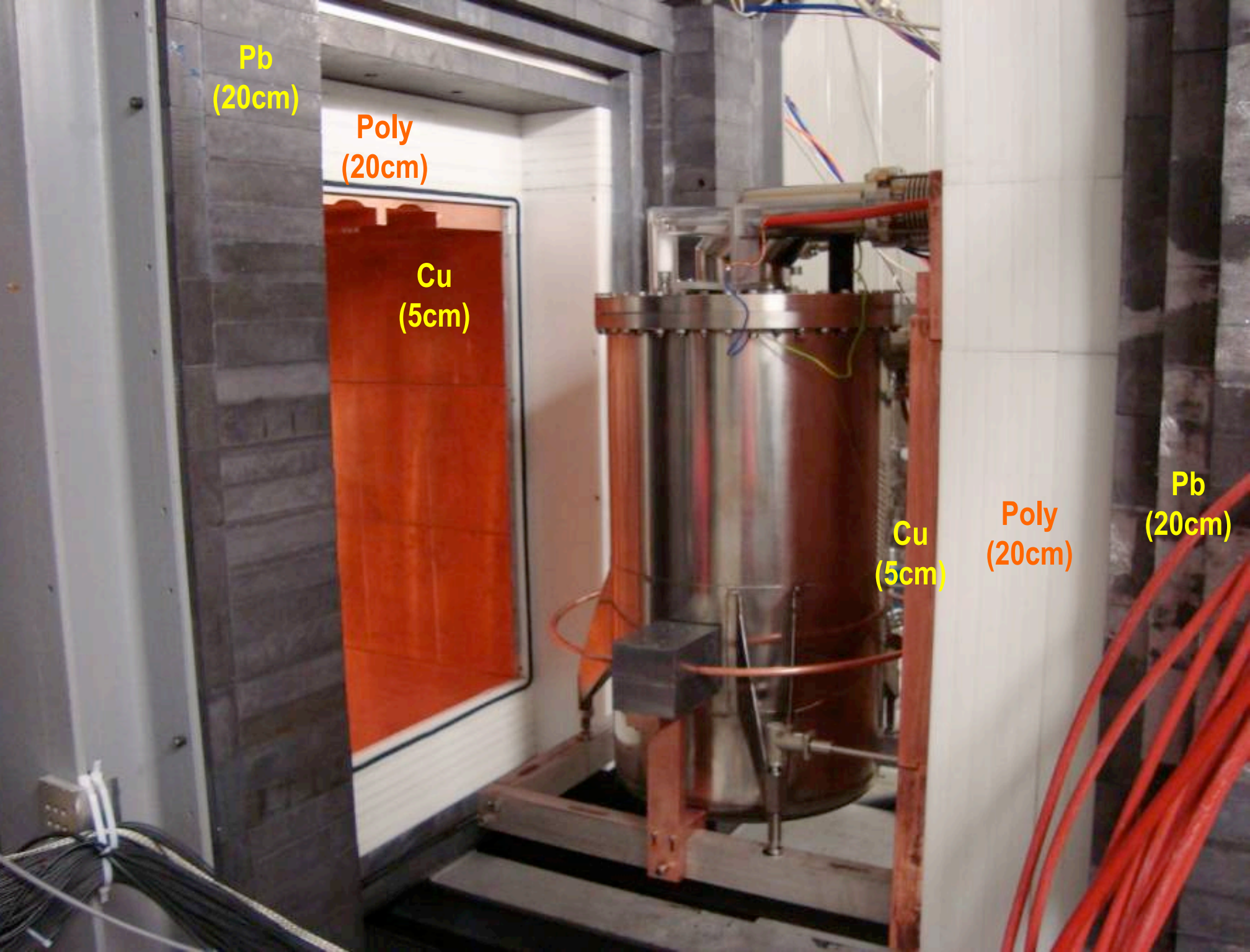
Poly
(20cm)

Cu
(5cm)

Cu
(5cm)

Poly
(20cm)

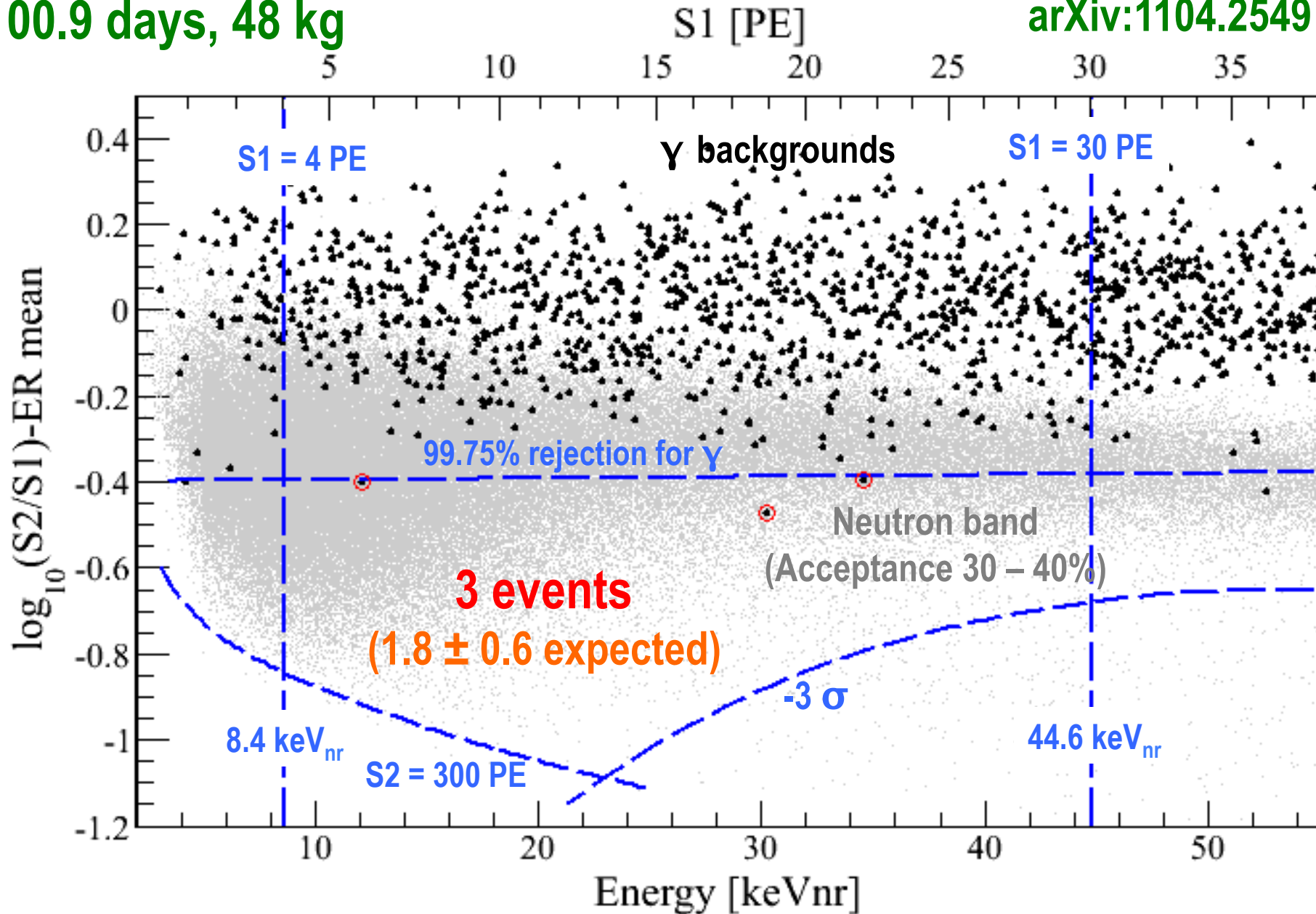
Pb
(20cm)



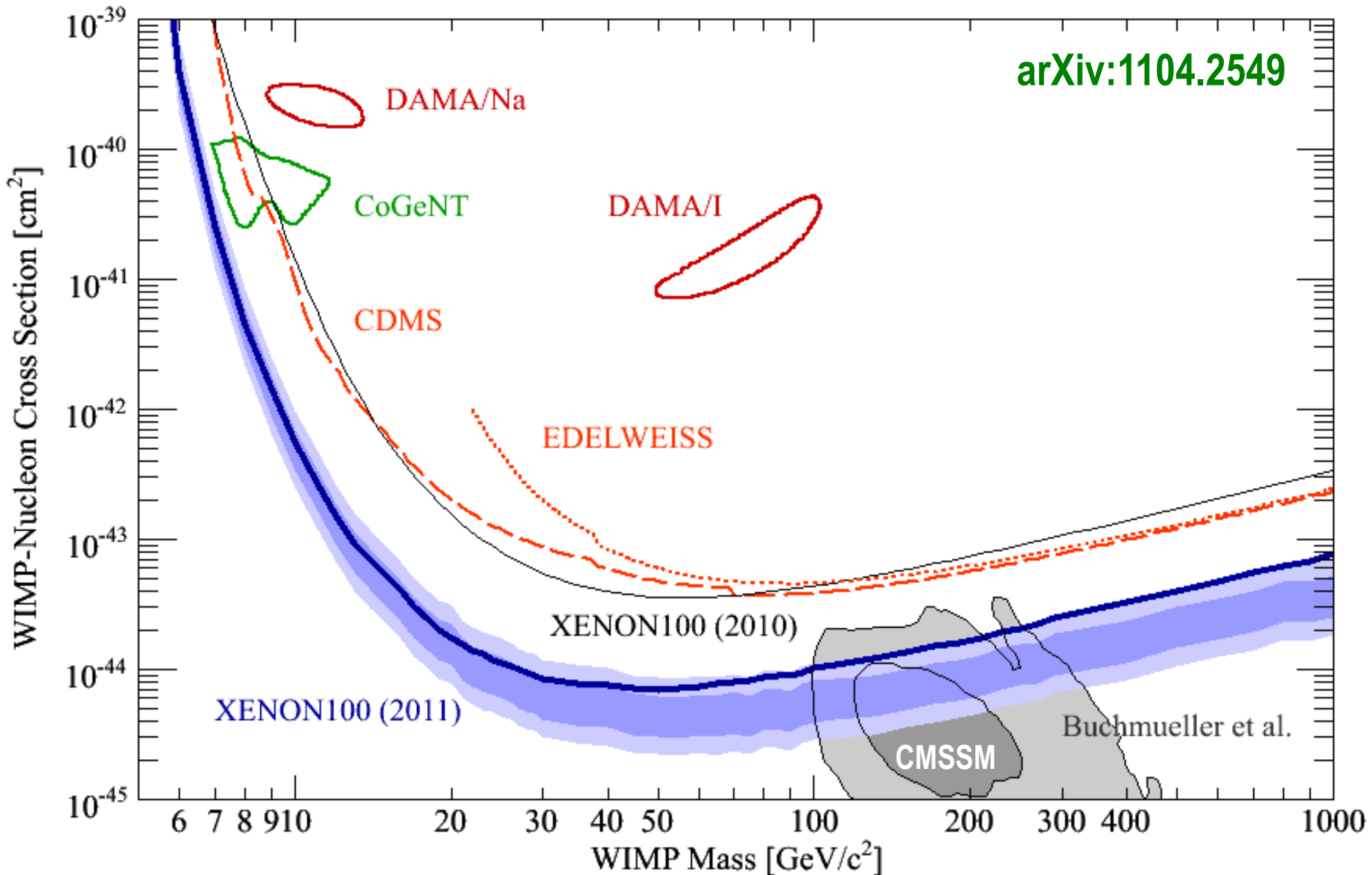
Log(S2/S1) vs. Energy

100.9 days, 48 kg

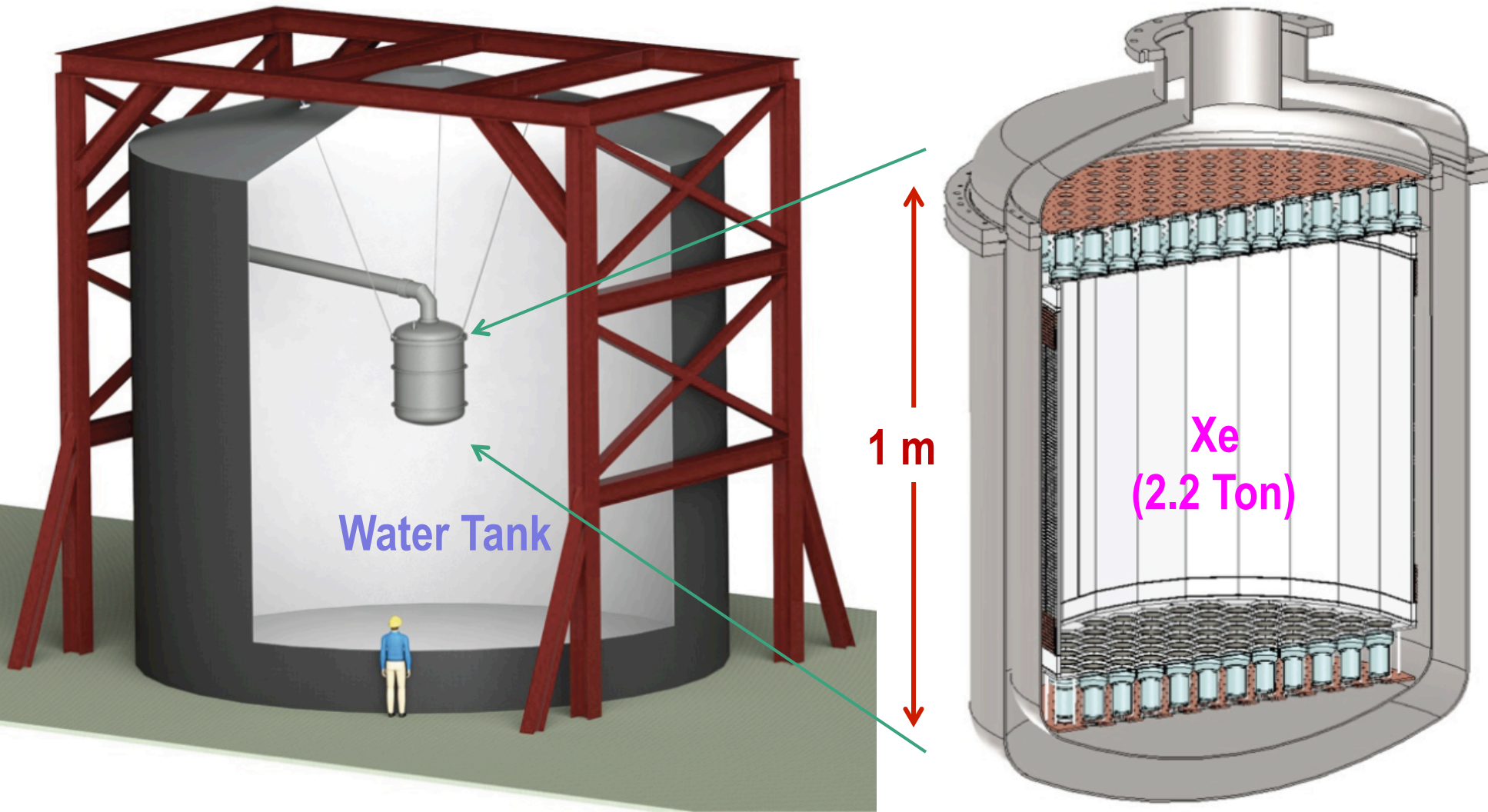
arXiv:1104.2549

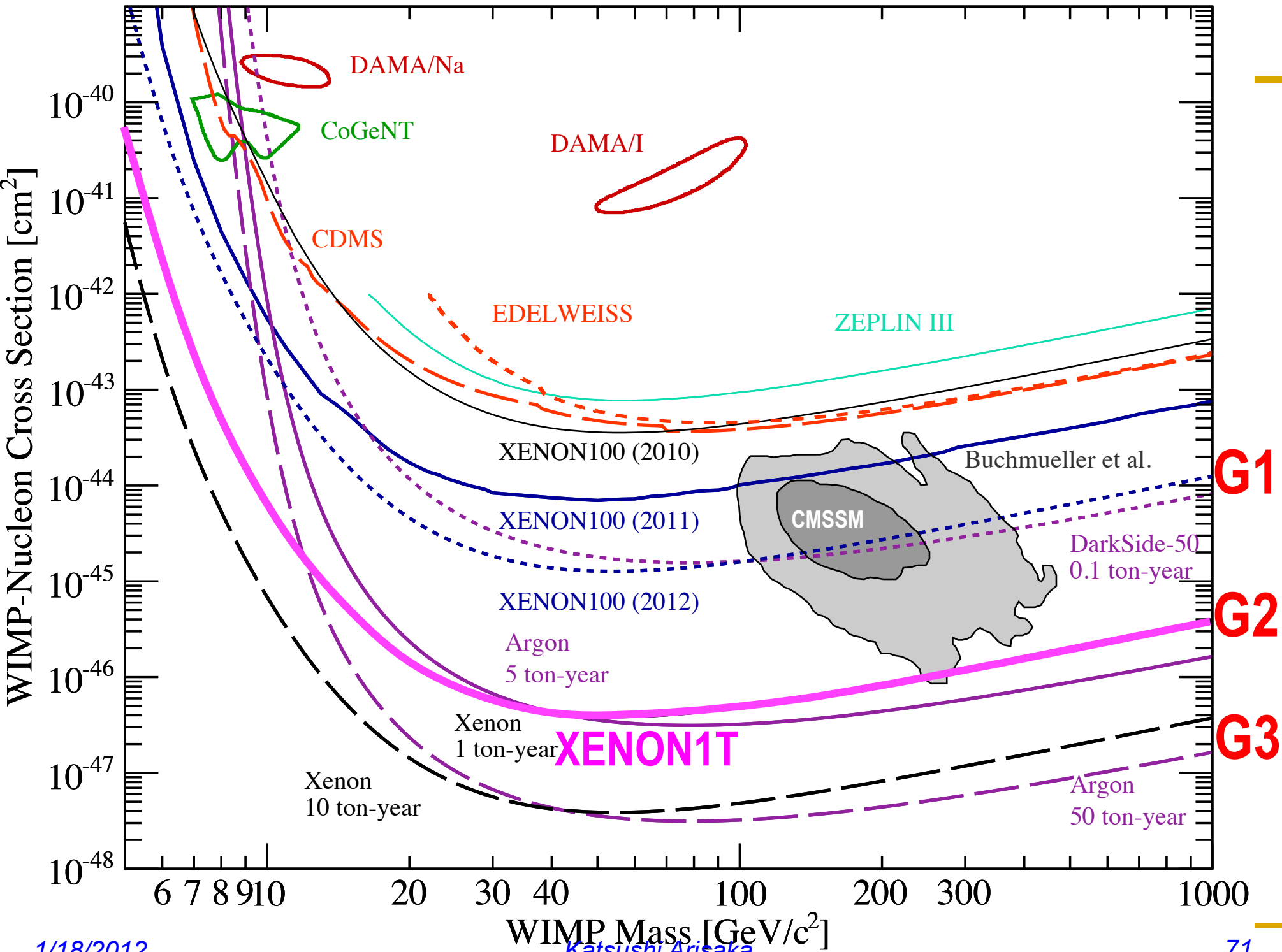


90% CL Limits of SI Cross Section (April, 2011)

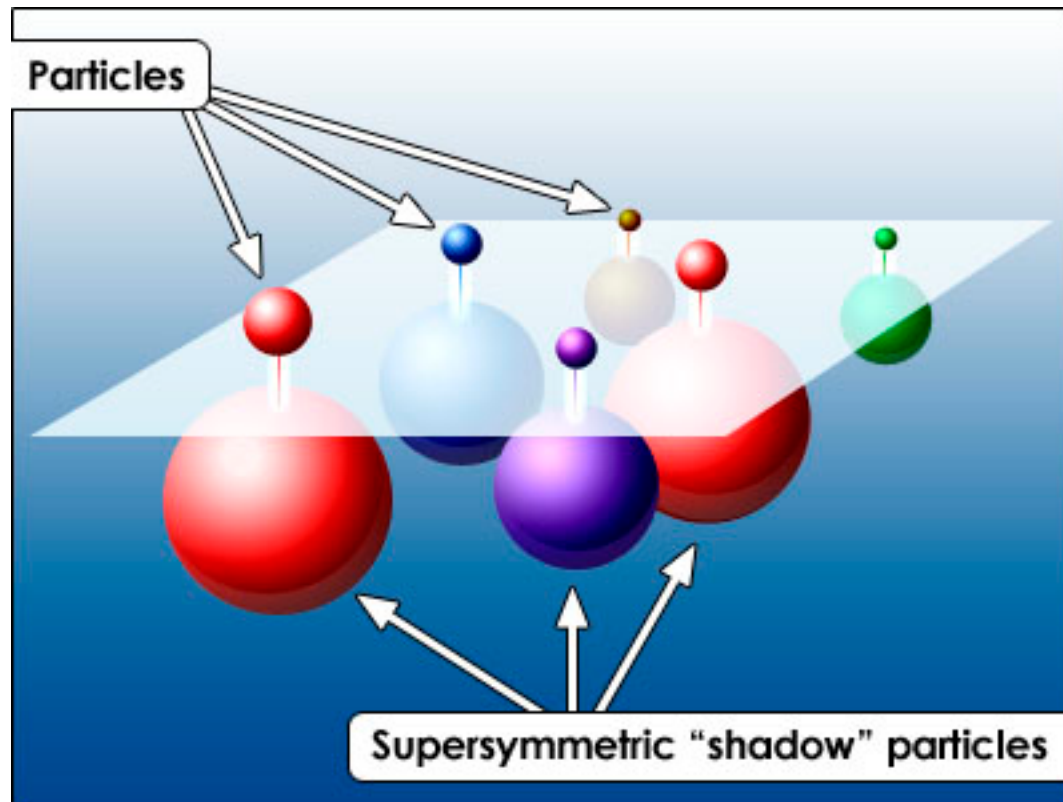


XENON1T (G2) at LNGS



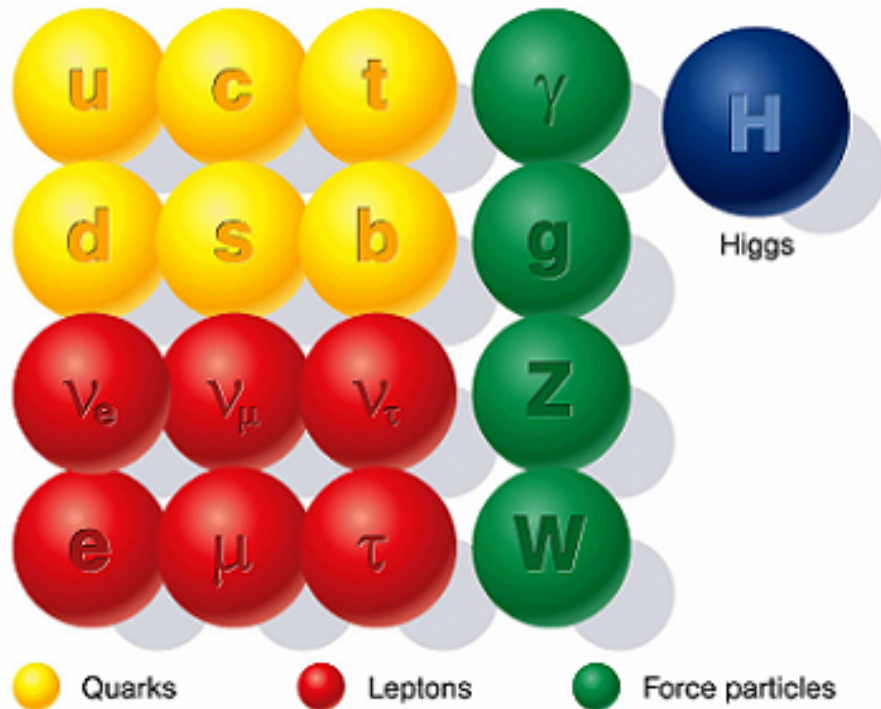


SUSY Neutralino



SUSY Particles and Neutralino

Standard particles



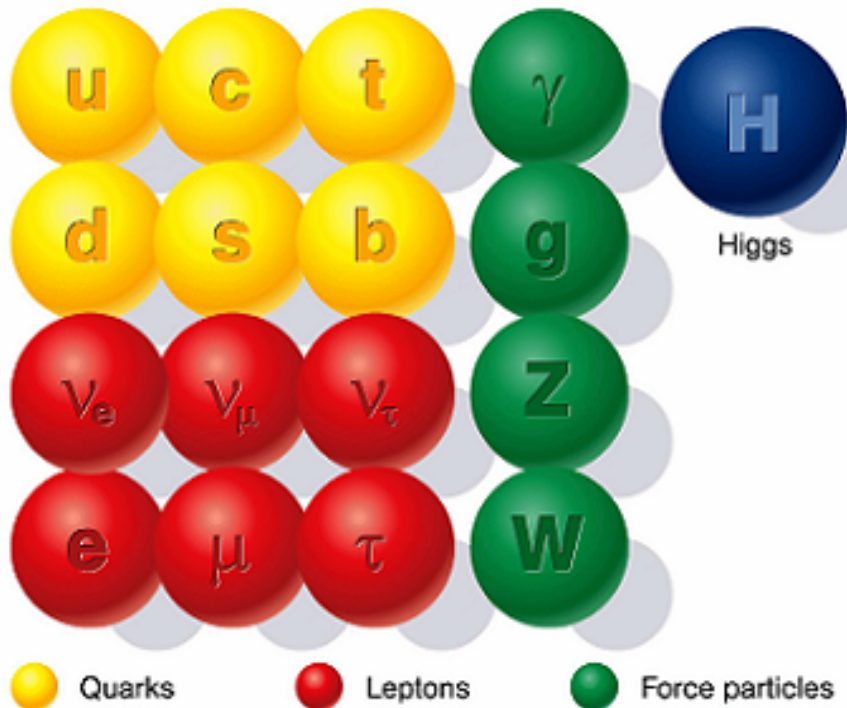
Spin 1/2 1 0

SUSY Particles and Neutralino

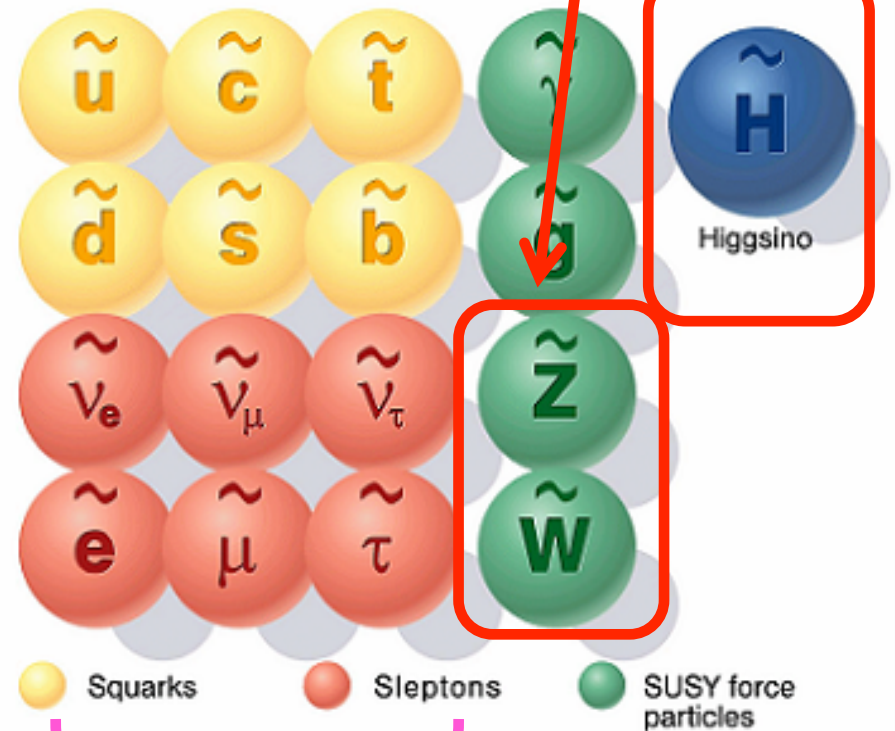
Super Symmetry

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)

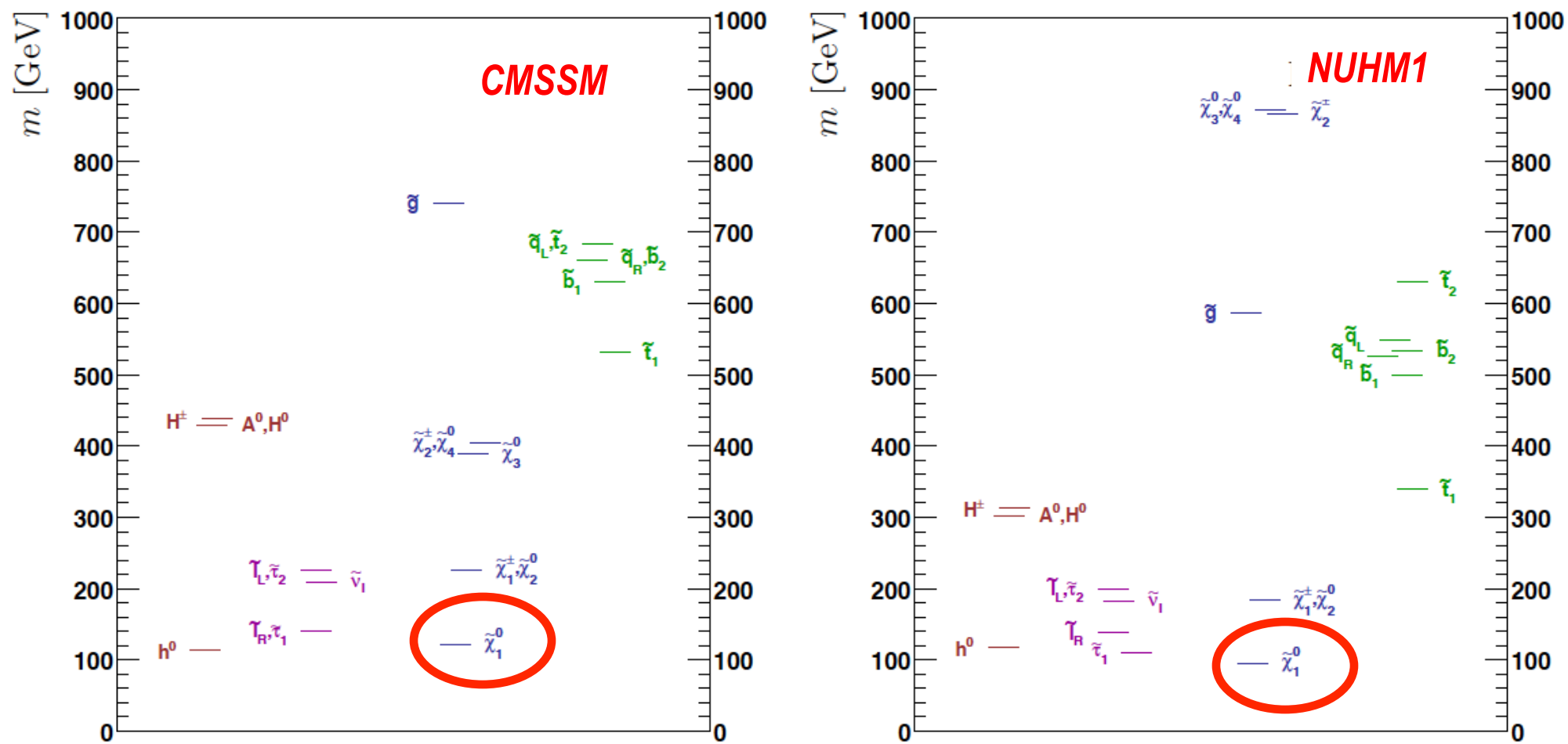
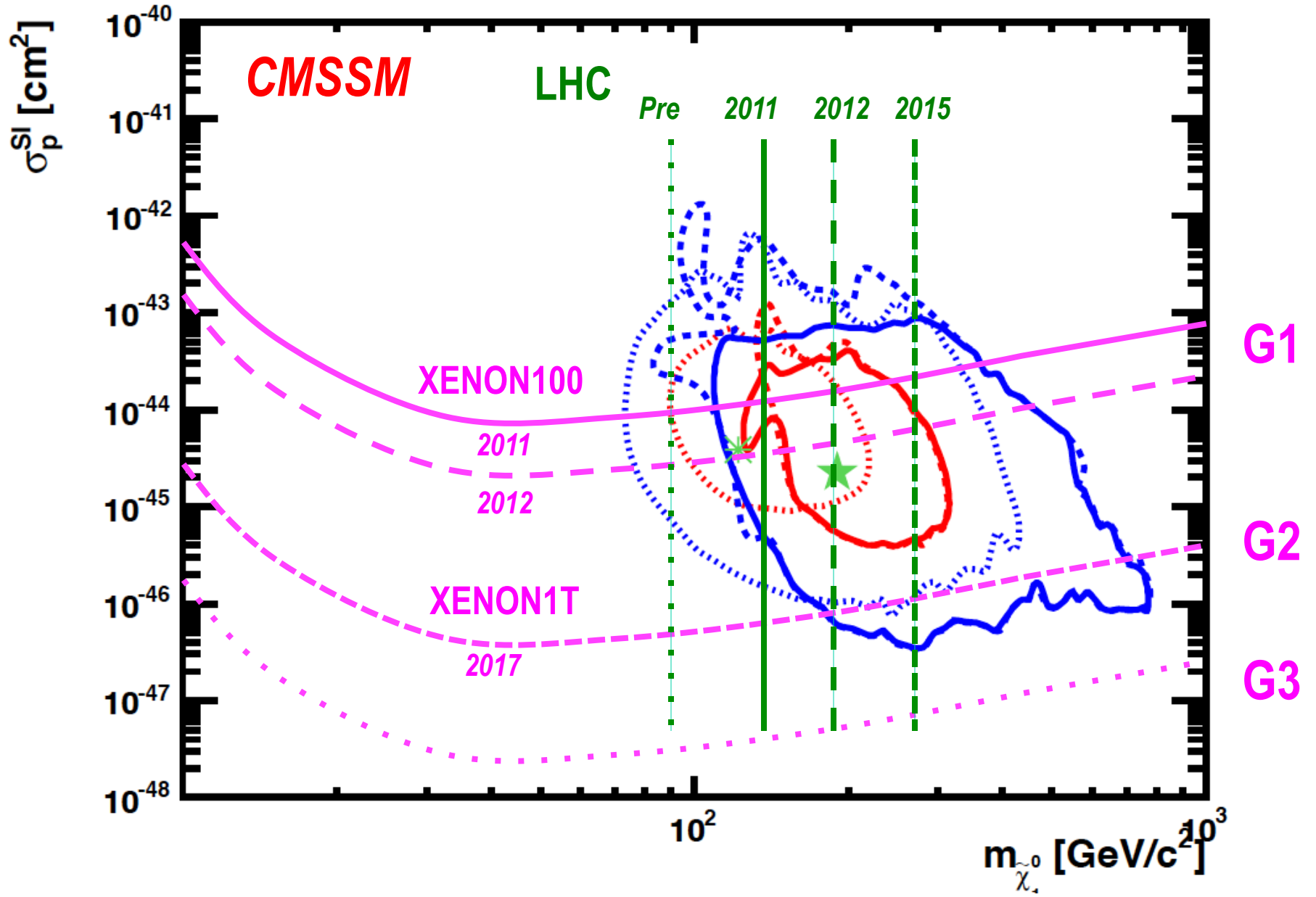


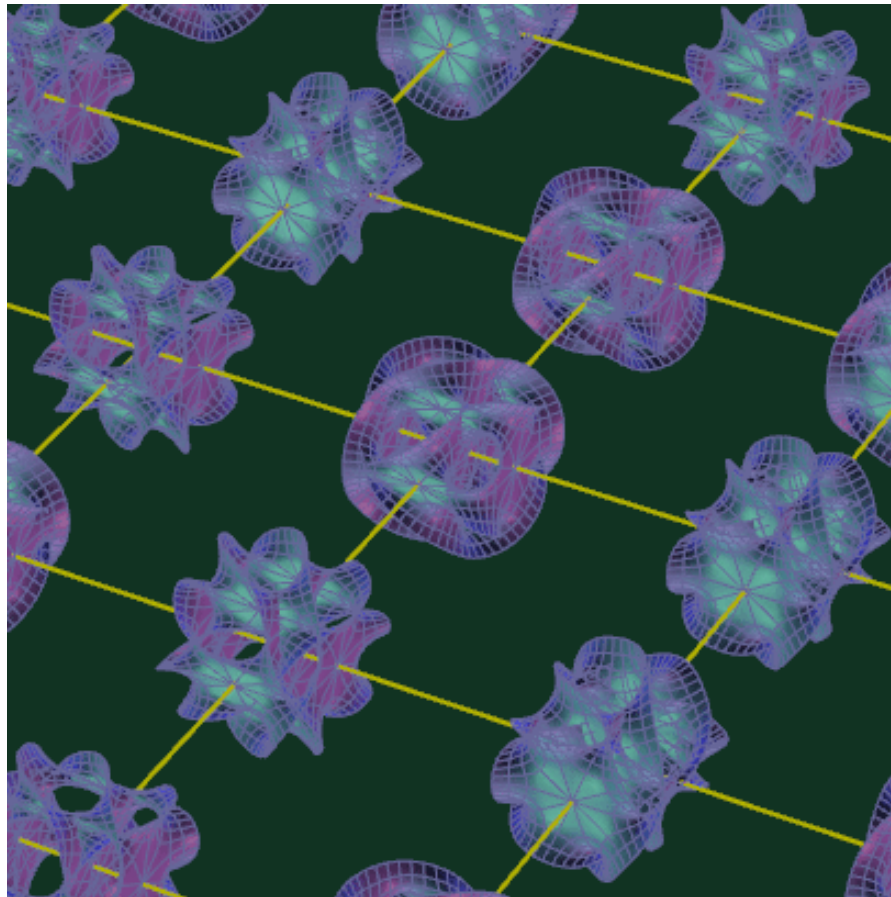
Figure 2. The spectra at the best-fit points: left — in the CMSSM with $m_0 = 60$ GeV, $m_{1/2} = 310$ GeV, $A_0 = 240$ GeV, $\tan\beta = 11$, and right — in the NUHM1 with $m_0 = 100$ GeV, $m_{1/2} = 240$ GeV, $A_0 = -930$ GeV, $\tan\beta = 7$, $m_H^2 = -6.9 \times 10^5$ GeV² and $\mu = 870$ GeV.

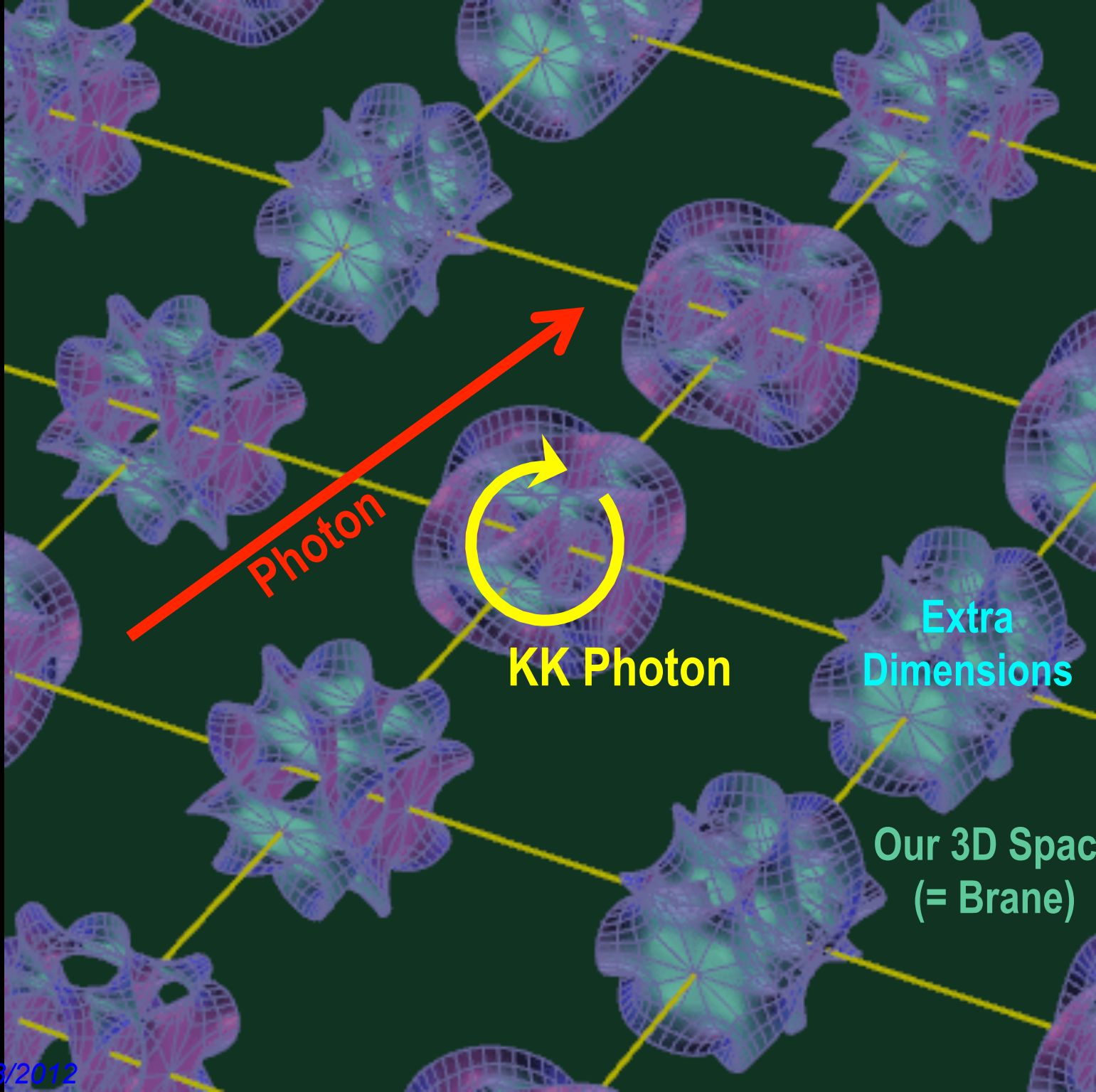
SI Cross Section vs. Mass



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

KK particles in Extra Dimensions





Photon

KK Photon

Extra
Dimensions

Our 3D Space
(= Brane)

Bulk

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

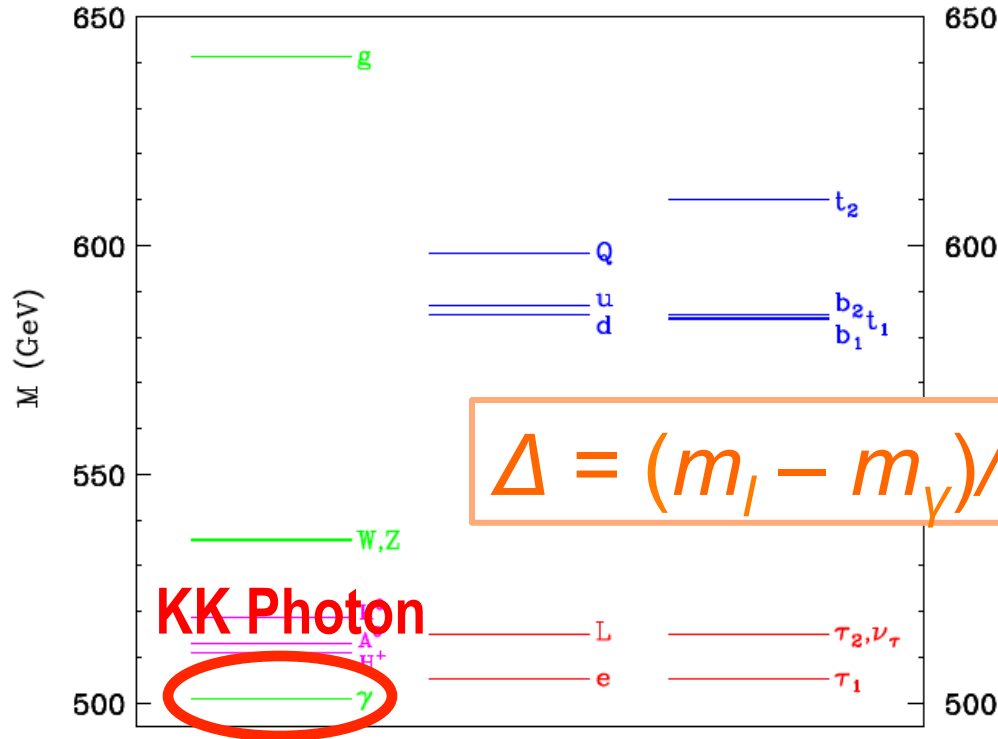


FIG. 1: One-loop corrected mass spectrum of the first KK level in MUEDs for $R^{-1} = 500$ GeV, $\Lambda R = 20$ and $m_h = 120$ GeV.

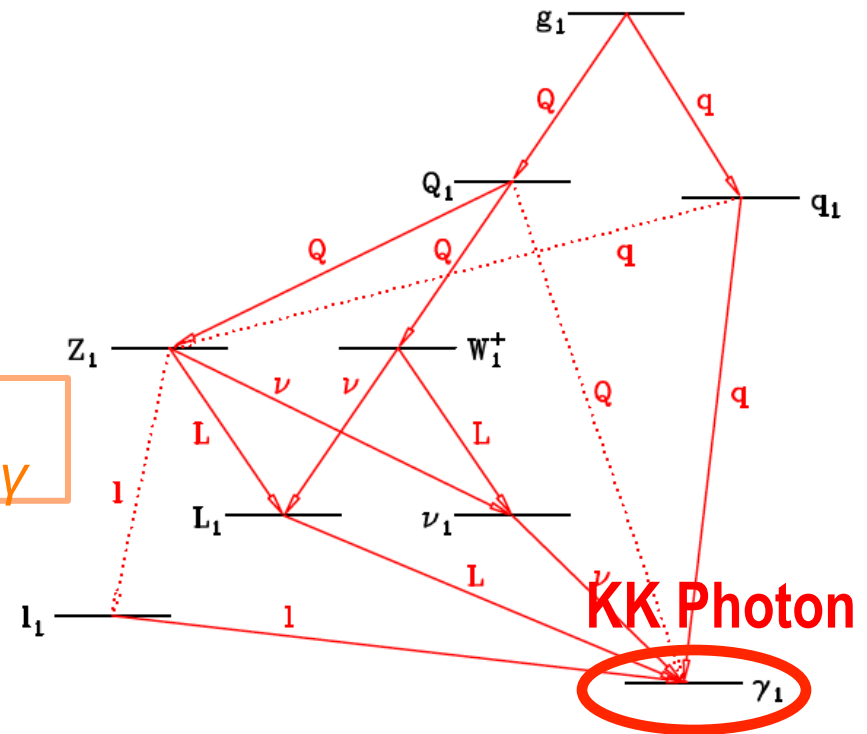
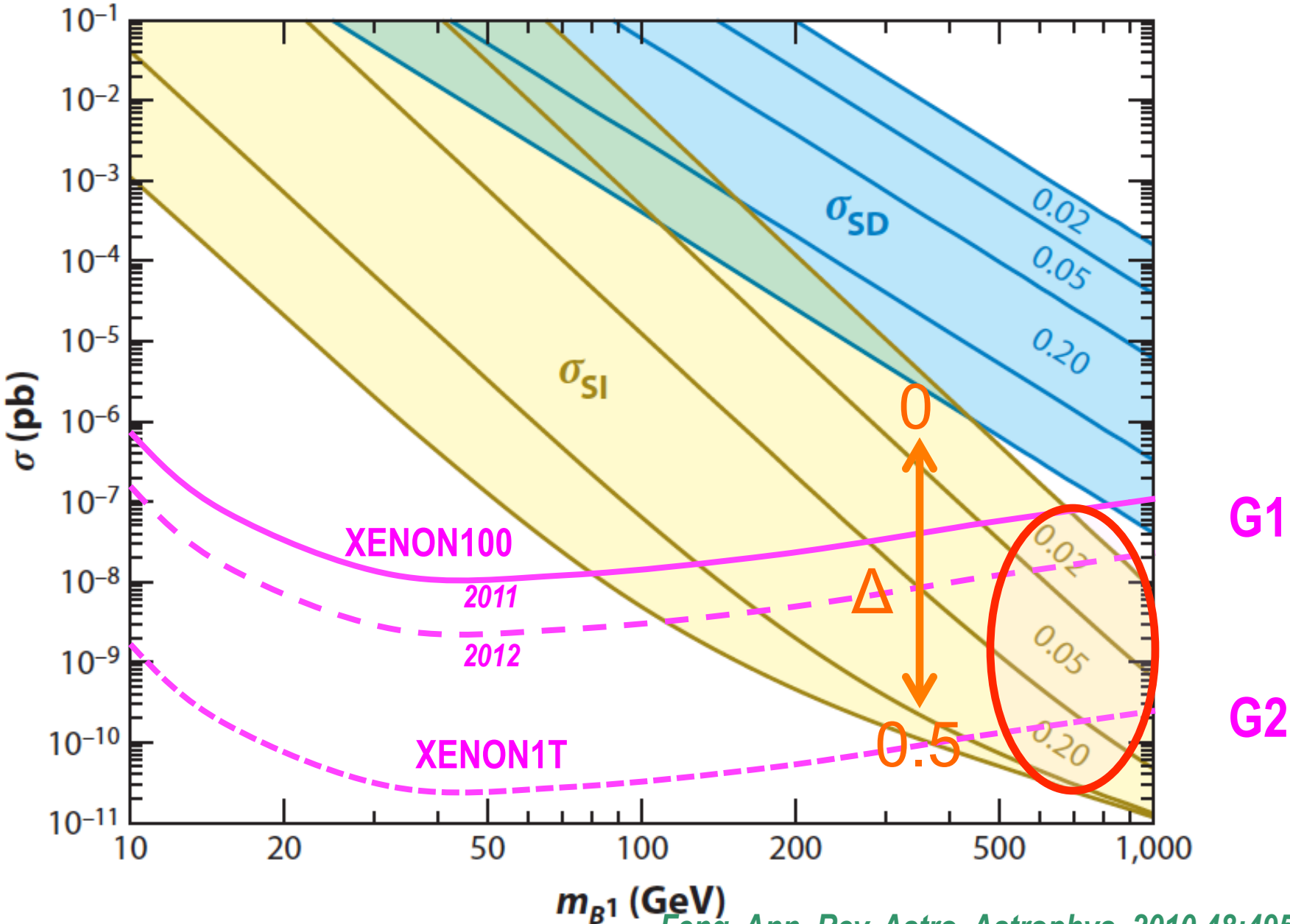


FIG. 3: Qualitative sketch of the level 1 KK spectroscopy depicting the dominant (solid) and rare (dotted) transitions and the resulting decay product.

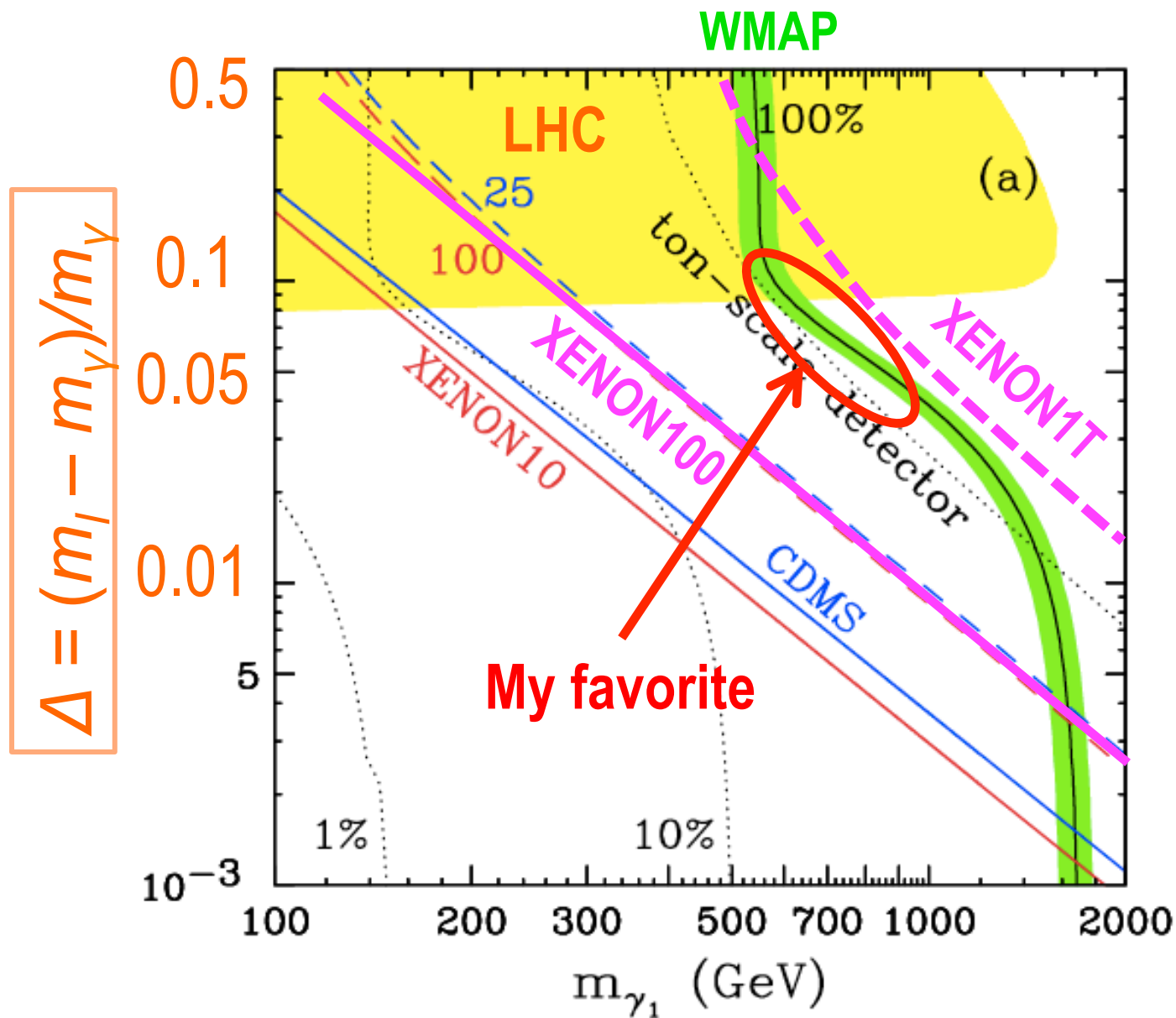
Cheng 2002 [arXiv:hep-ph/0205314v1](https://arxiv.org/abs/hep-ph/0205314)

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”

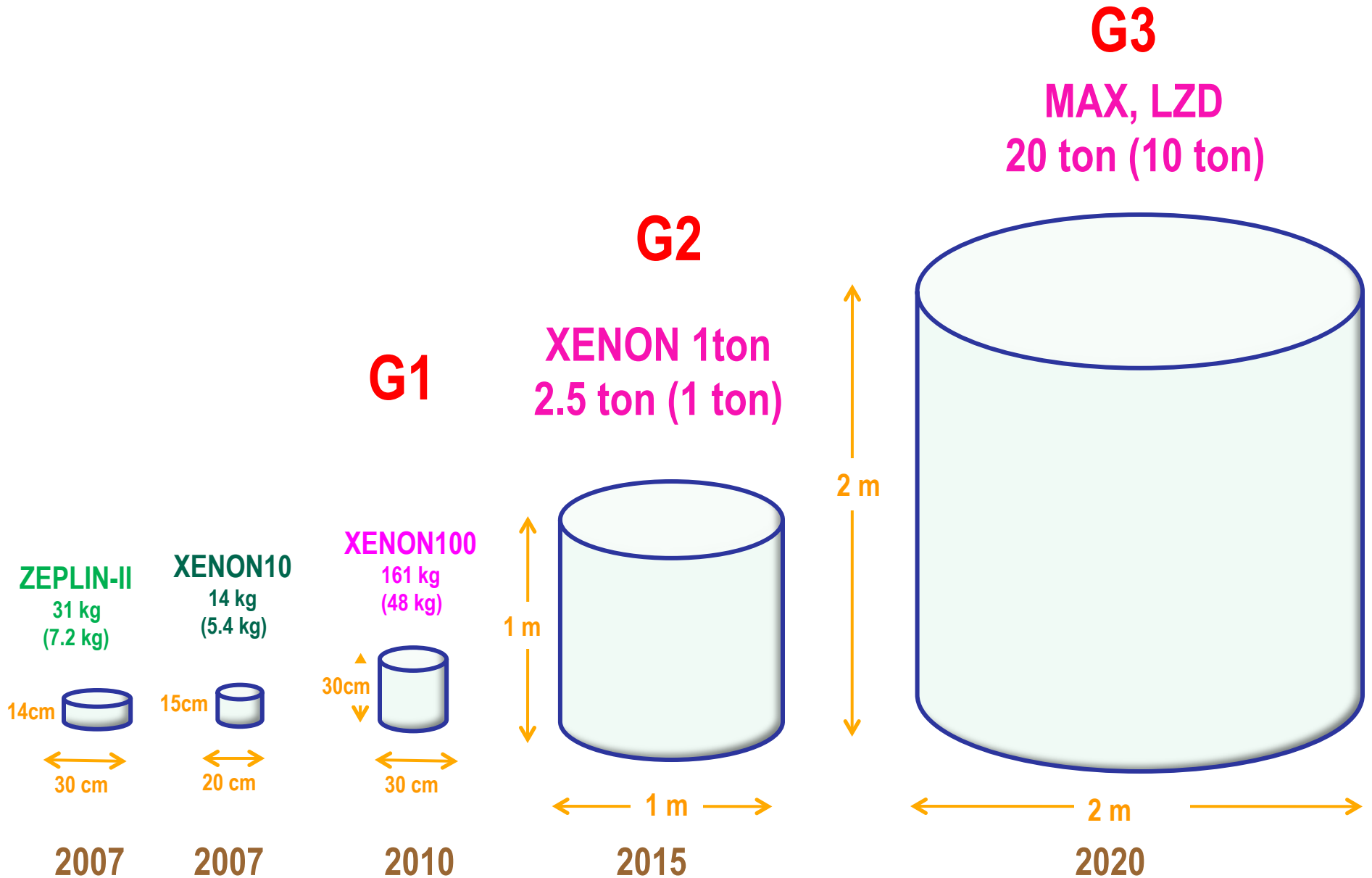
- XENON program (~\$10M) is extremely timely and competitive to LHC (~\$10B)
 - XENON100 ~ Current LHC
 - XENON1T ~ Future LHC
- If new physics at 100 – 1000 GeV (as it should be), LHC and/or XENON1T will discover WIMPs.
 - SUSY - Neutralino
 - Extra Dimensions – KK photon
- By combining LHC and XENON1T,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

G2 & G3 Detectors

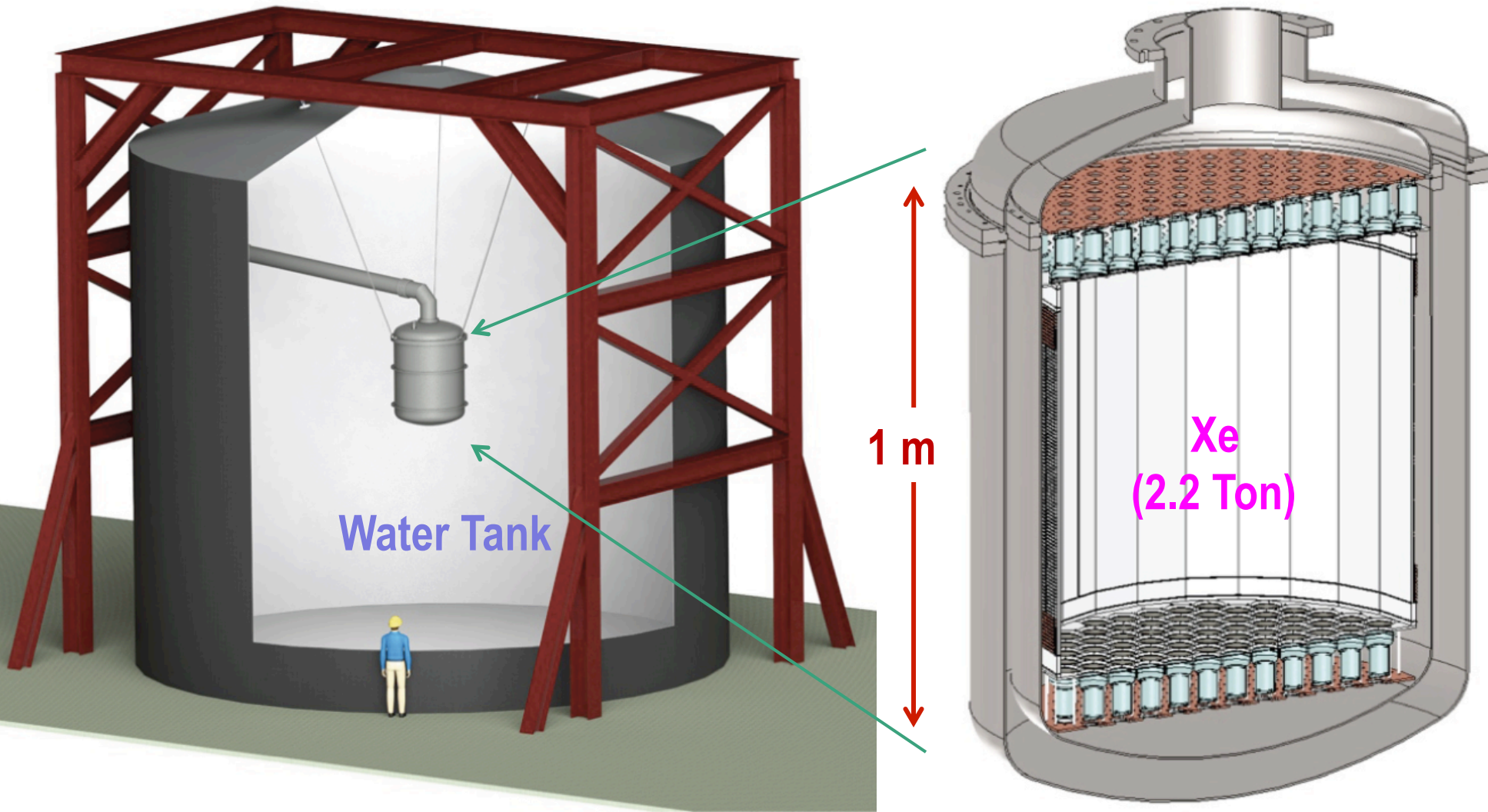
G2 and G3 facilities defined by PASAG (2009)

	G1	G2	G3
Sensitivity	$< 10^{-44} \text{ cm}^2$	$< 10^{-46} \text{ cm}^2$	$< 10^{-47} \text{ cm}^2$
Target Mass	10 – 100 kg	~ 1 Ton	~ 10 Ton
Cost	\$1M – 5M	\$10 – 20M	~ \$100M

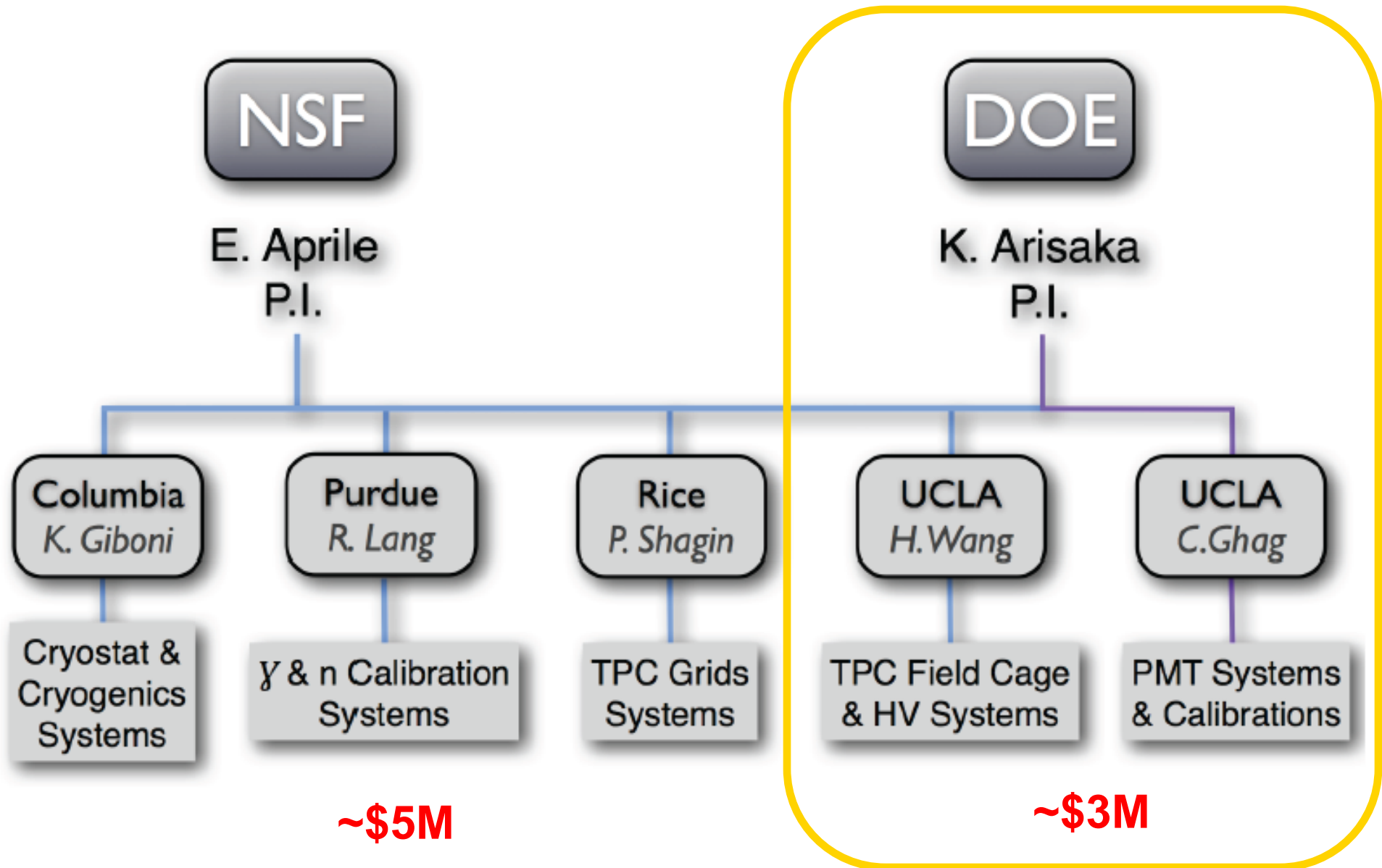
Comparison of Xenon Detector Size



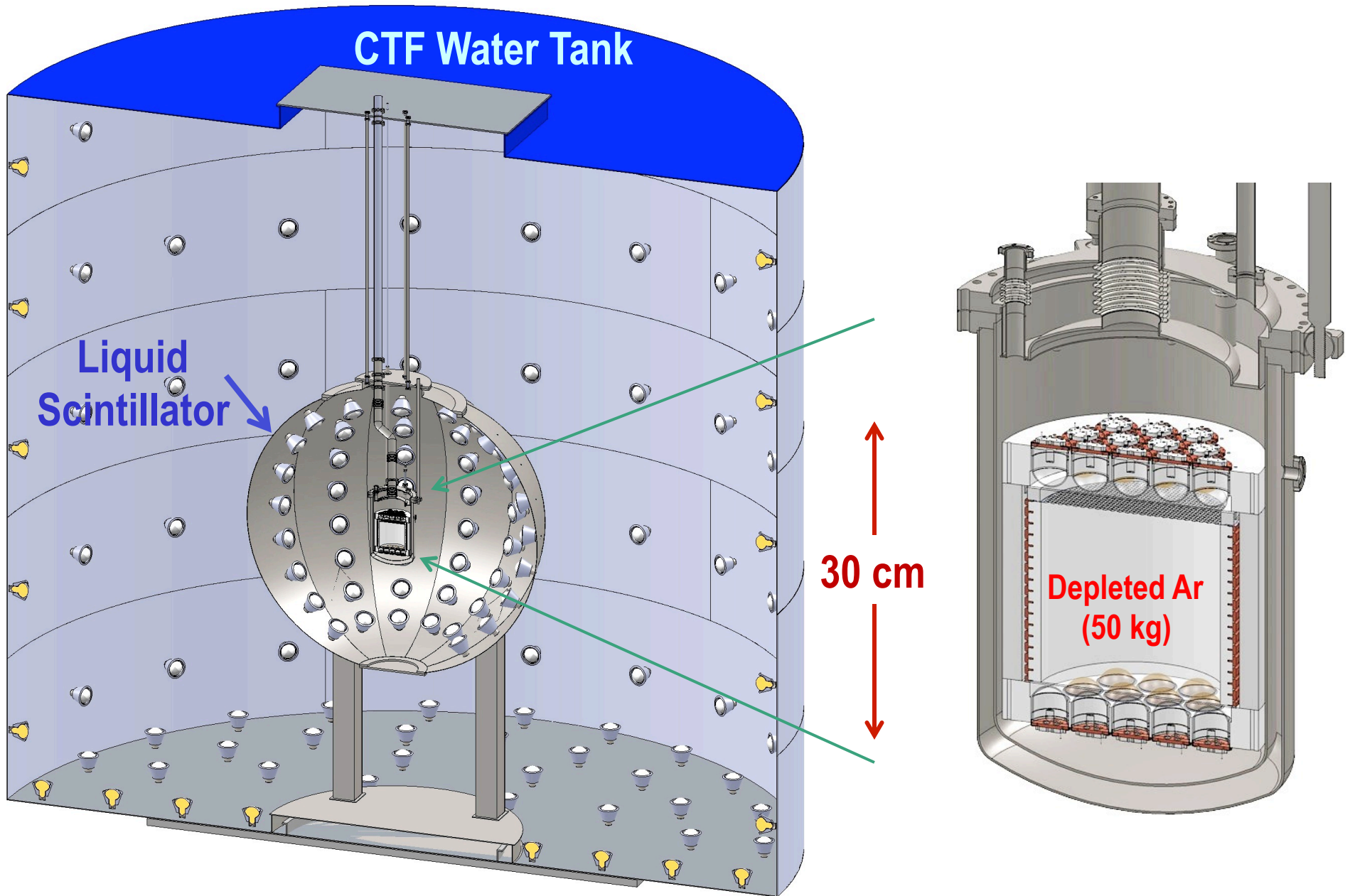
XENON1T (G2) at LNGS



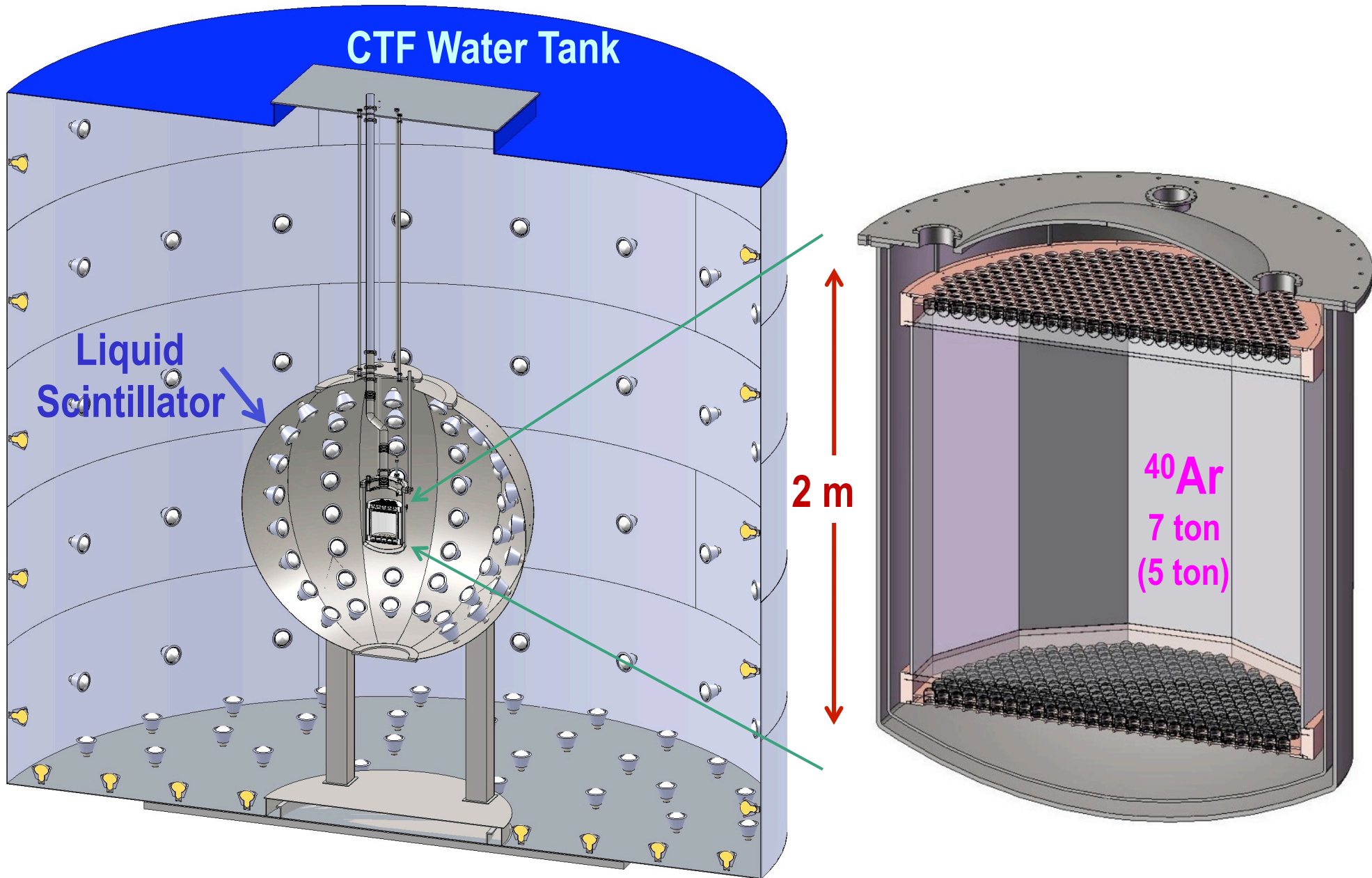
XENON1T – US Responsibility



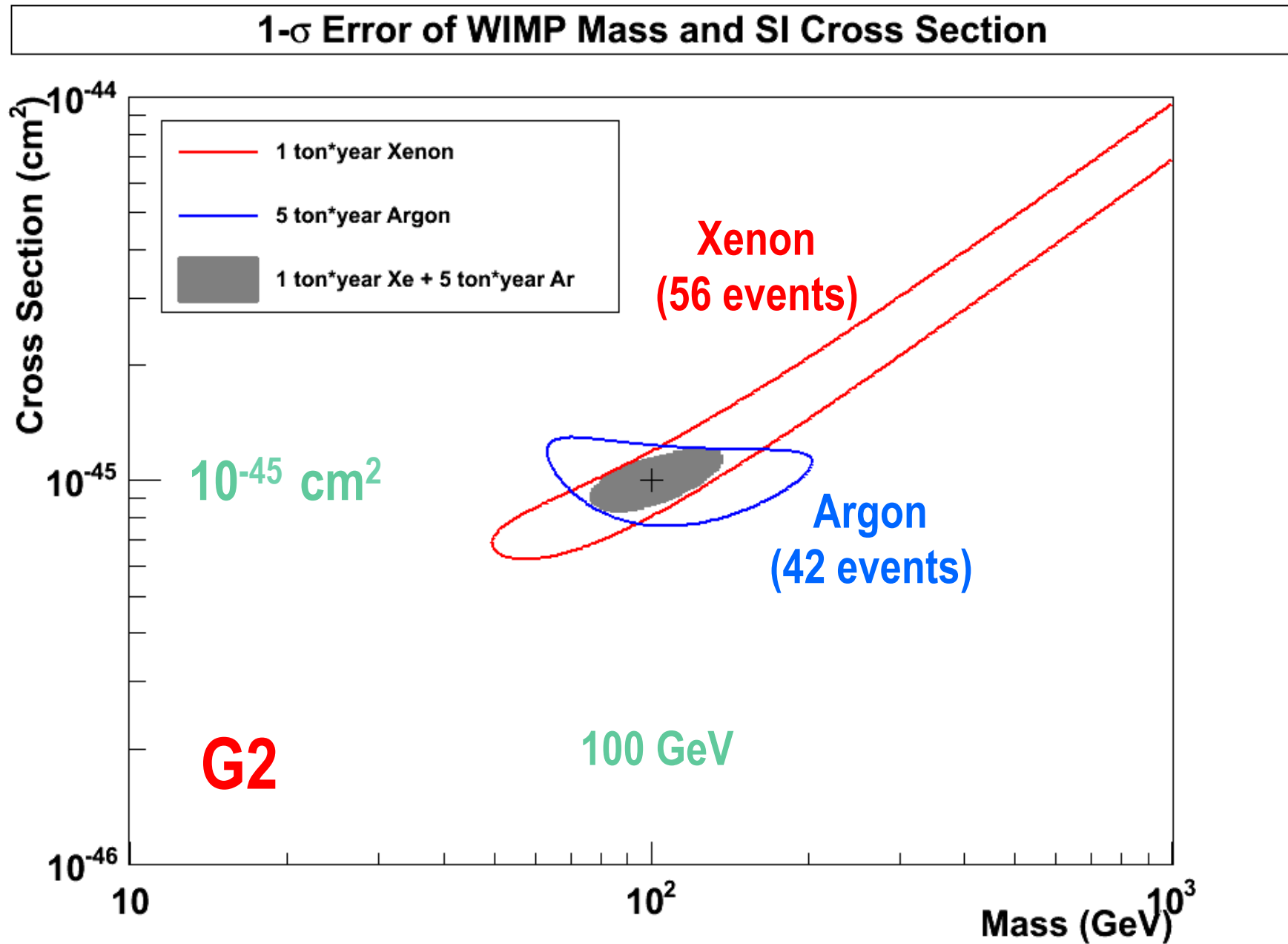
DarkSide 50 (G1) at LNGS



DarkSide 5T (G2) at LNGS

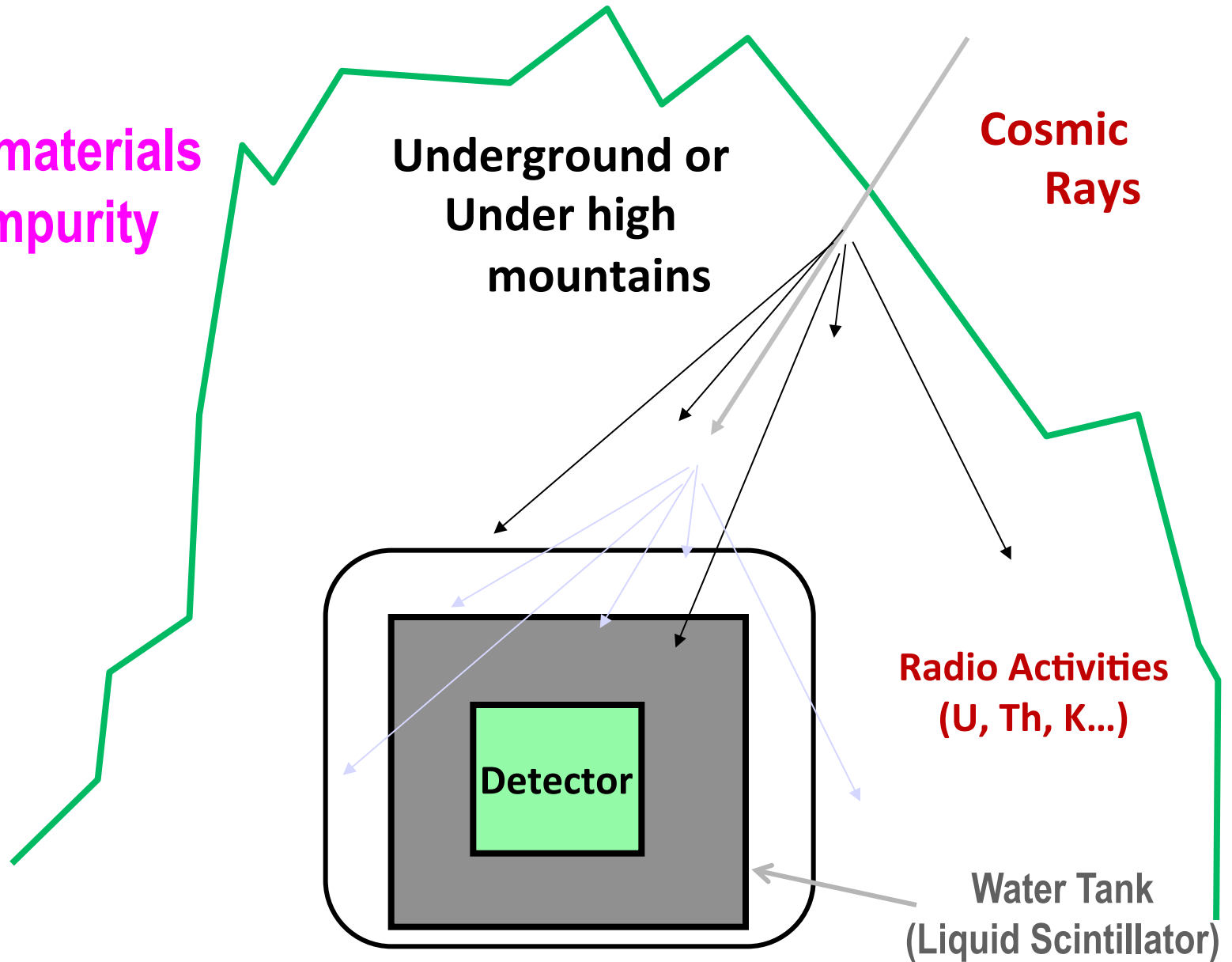


1- σ Error of WIMP Mass vs SI Cross Section (1 ton*year Xe and 5 ton*year Ar)



Where backgrounds come from?

- External
- Detector materials
- Internal impurity



QUPID (QUartz Photon Intensifying Detector)

arXiv:1103.3689

Photo Cathode
(-6 kV)

Photo Cathode
(-6 kV)

Quartz

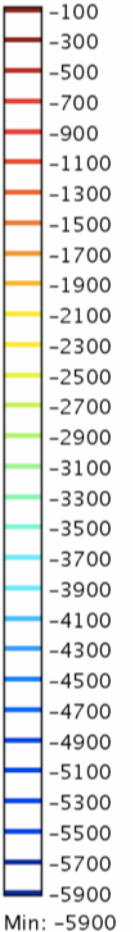
Al coating

APD (0 V)

Quartz

APD (0 V)

Max: -100



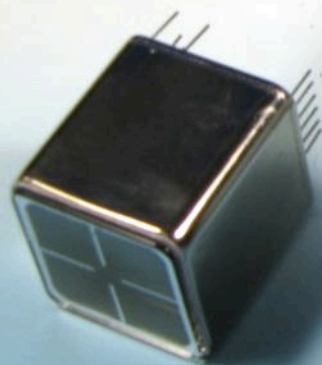
Min: -5900

Comparison of Low-radioactive Photon Detectors from Hamamatsu

R8520
1 inch

R8778
2 inch

QUPID
3 inch

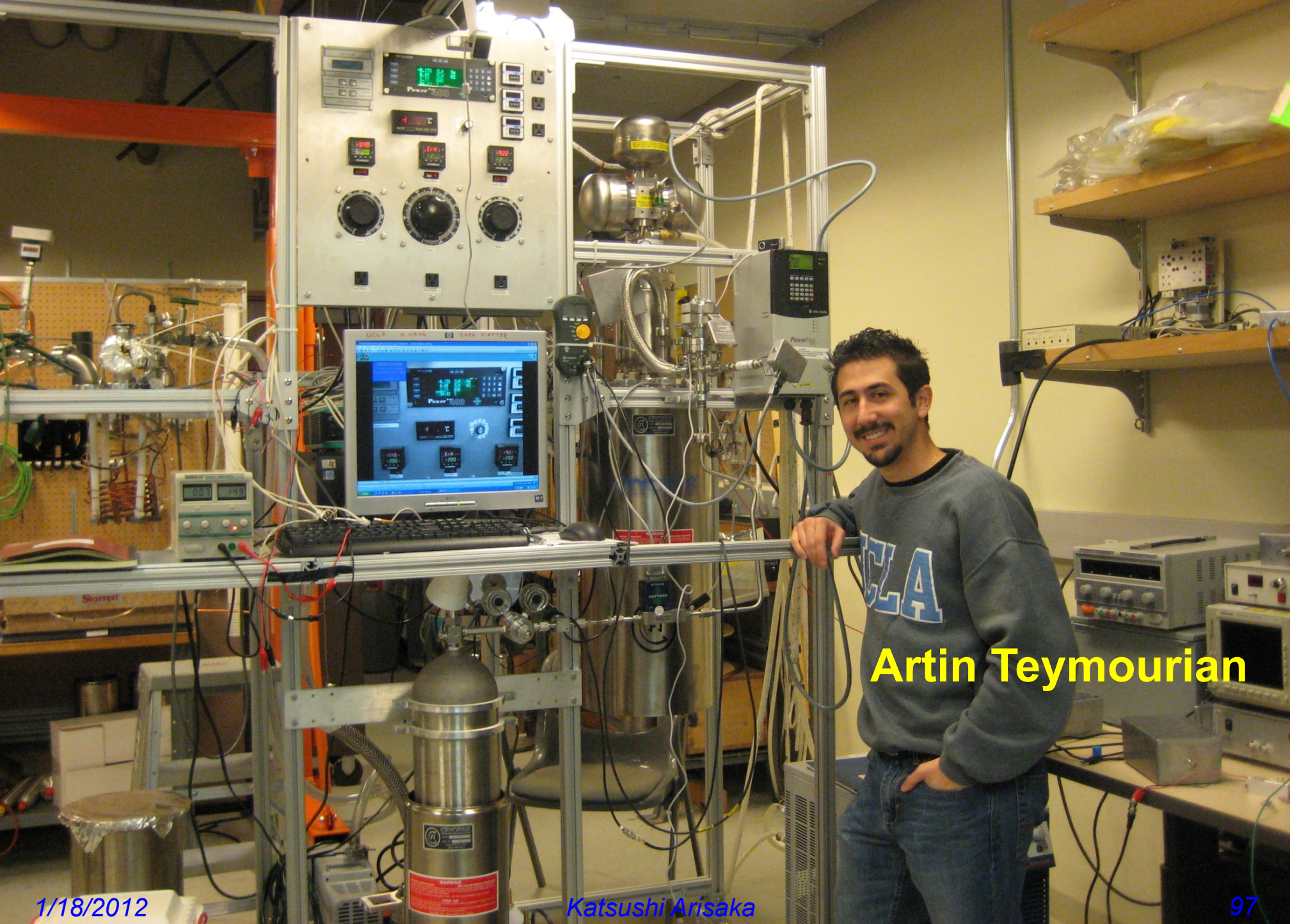


XENON10
XENON100

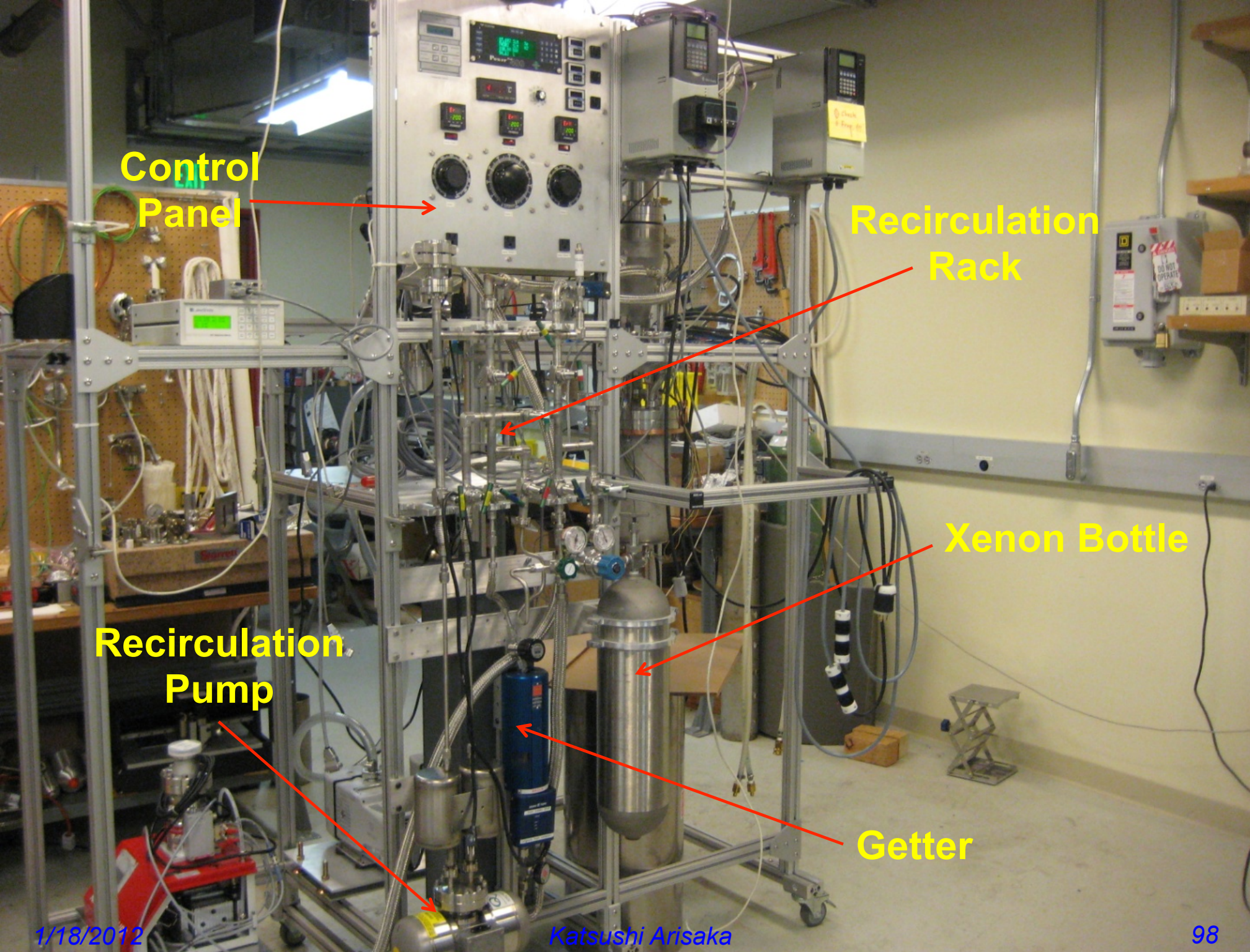
LUX
(XMASS)

DarkSide50
XENON1Ton
MAX, XAY

Cryogenic System at UCLA (Hanguo Wang's Lab)



Artin Teymourian



**Control
Panel**

**Recirculation
Rack**

Xenon Bottle

**Recirculation
Pump**

Getter

Mechanical Samples on Base plate



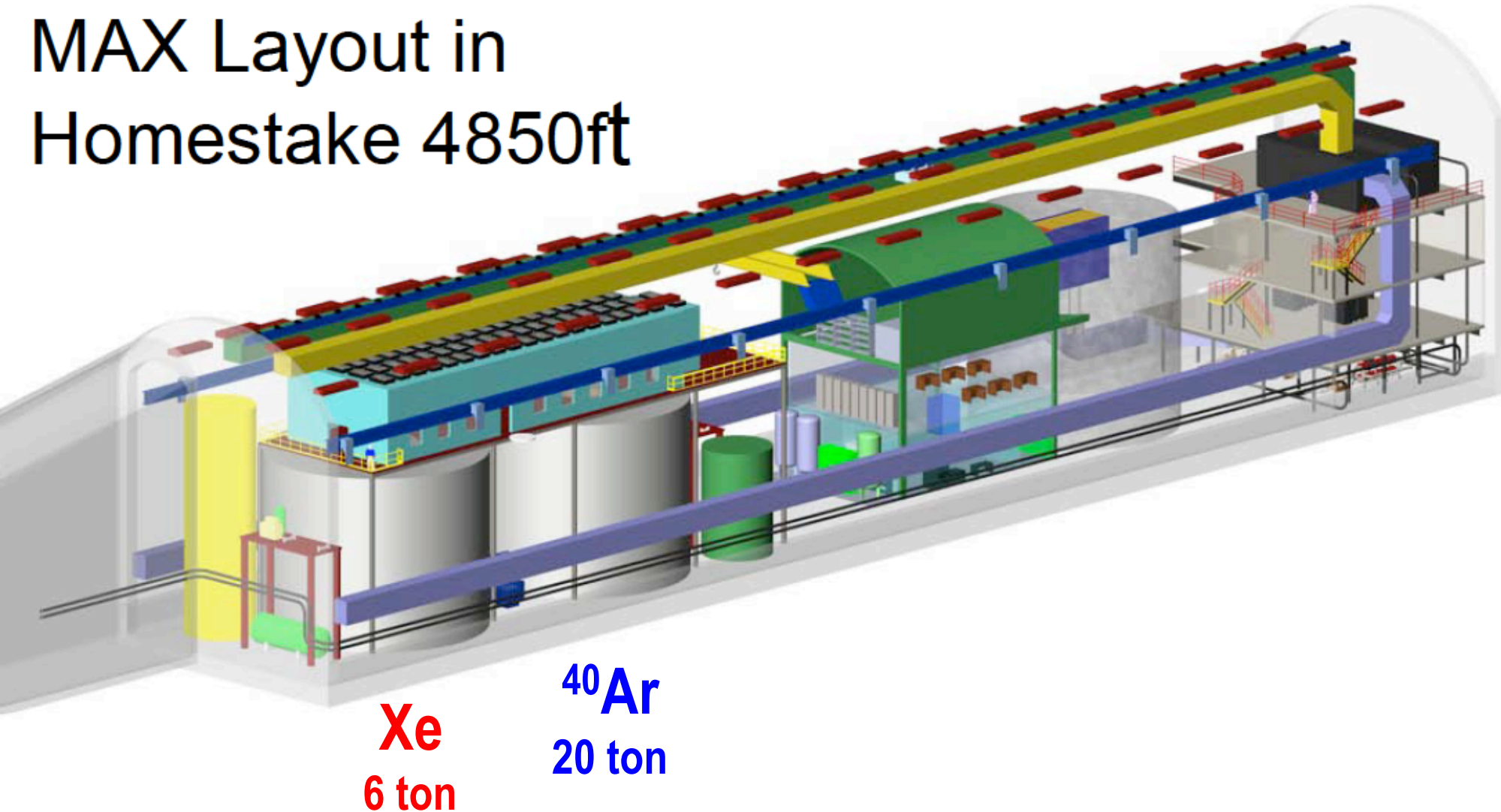
Some Remarks

- **Xenon** is optimum up to 1 Ton scale
 - Largest discovery potential
 - Background ~ 1 / ton-year
 - Good sensitivity to low mass WIMP

- **At > 10 ton scale, Argon** is more appealing
 - No gamma ray backgrounds
 - Mass determination up to 200 GeV
 - Large annual modulation

MAX (G3) (at DUSEL)

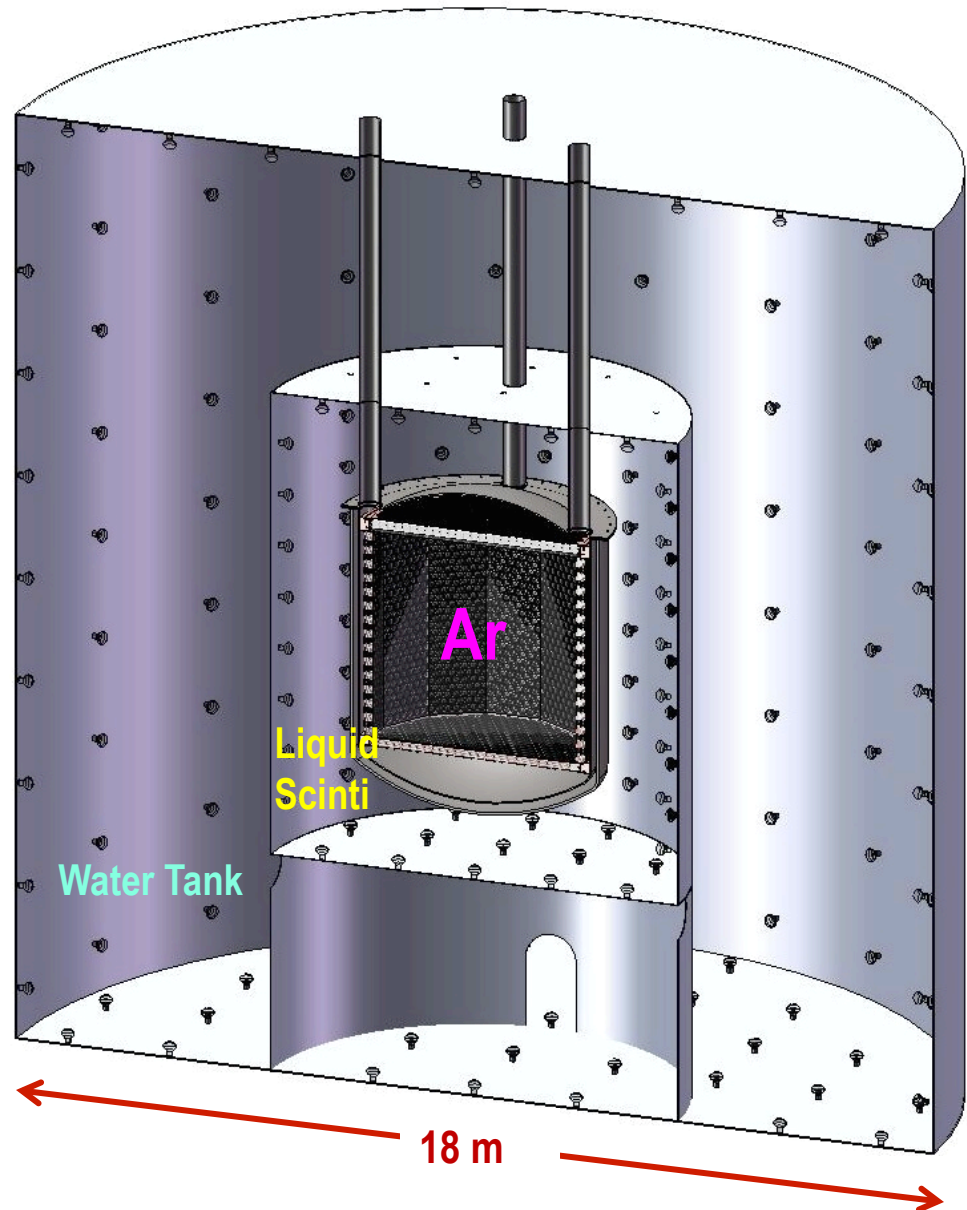
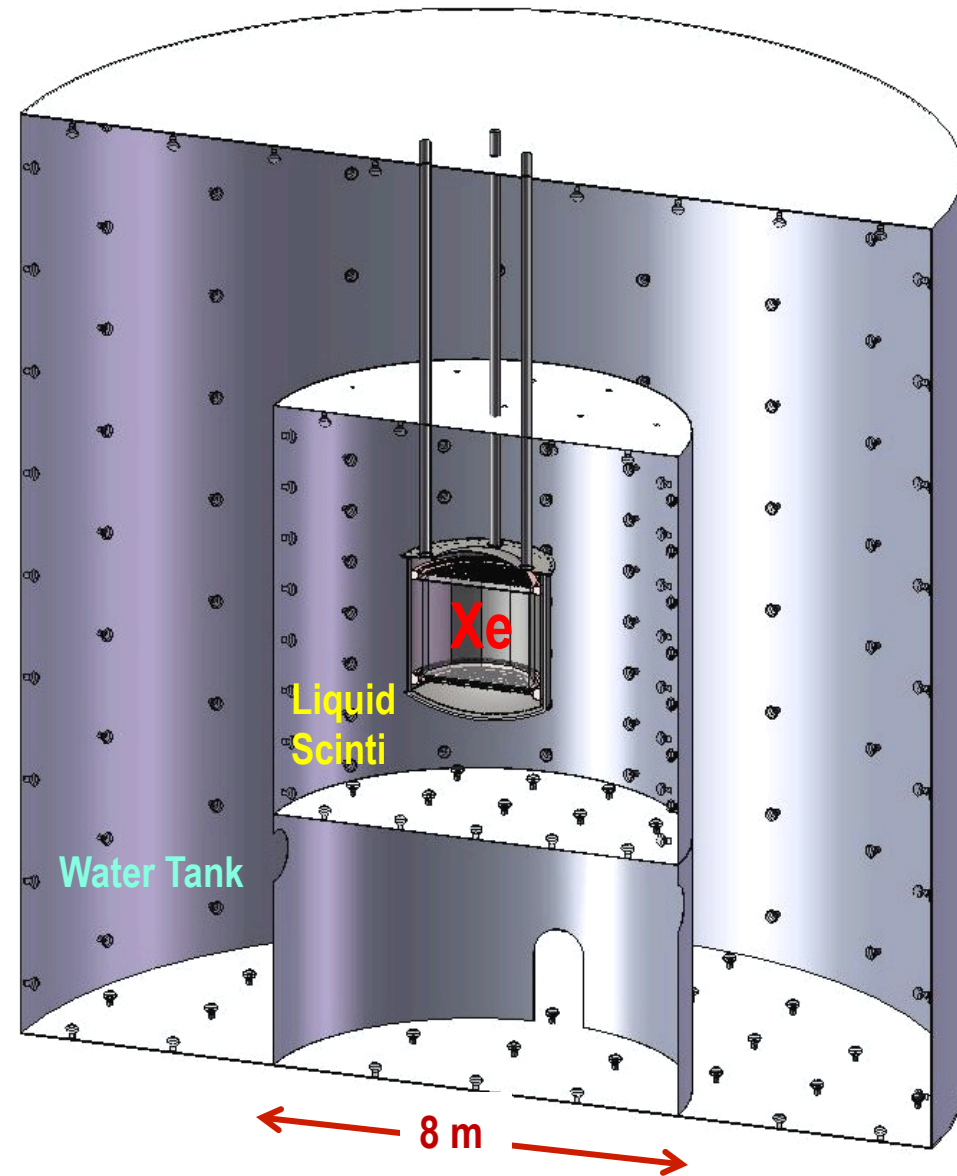
MAX Layout in
Homestake 4850ft

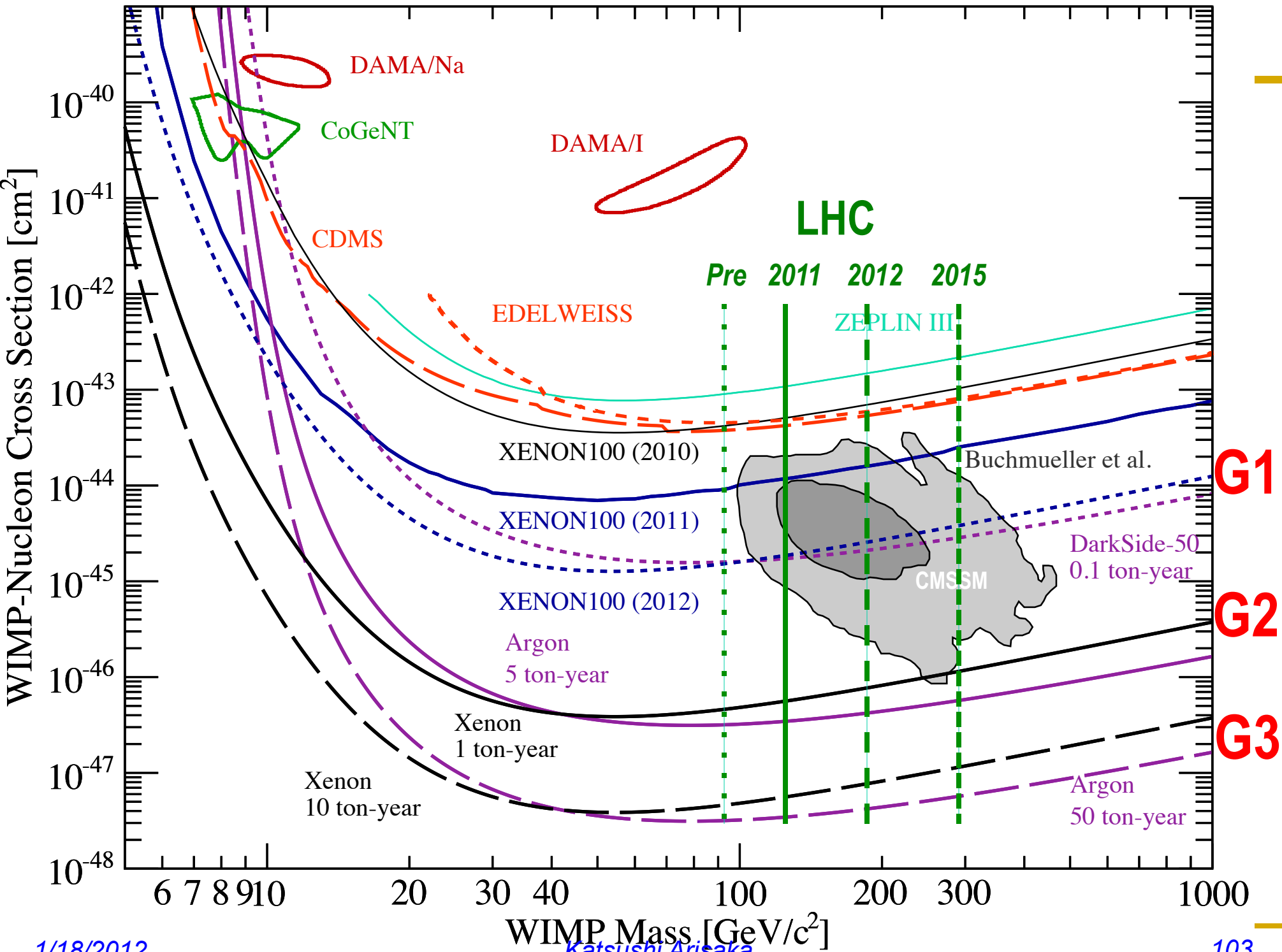


MAX+LZD = "Ultimate G3" Detector (at DUSEL)

Xe 20 ton (10 ton)

^{40}Ar 70 ton (50 ton)





Conclusions

➤ Science cases

- Stronger than ever - SUSY, Extra Dimensions...
- Competitive and complementary to LHC
- Extremely timely

➤ Technical challenges

- Xe-G1 (100 kg) well demonstrated by XENON100
- New photon detector (QUPID) developed
- Radioactivity (^{39}Ar , ^{85}Kr , Rn) major challenges

➤ Future directions

- G2 : **XENON 1T** and **DarkSide 50 / 5T** at Gran Sasso.
- G3 : MAX + LZD (**Xe 10T** + **Ar 50T**) at DUSEL

Katsushi's Speculations

- **2012** **LHC (ATLAS+CMS) announces**
 - 124 GeV Higgs (at 5σ)
- **2016** **XENON1T announces**
 - Observation of 10 WIMP signals (> 200 GeV)
- **2021** **G3 (Xe+Ar) and LHC jointly confirm**
 - Extra Dimensions
 - WIMP = 600 GeV KK Photon ($\Delta = 5\%$)
 - No SUSY
 - Katsushi happily retires at age 65.