Origin of the Universe, Particles and Structure

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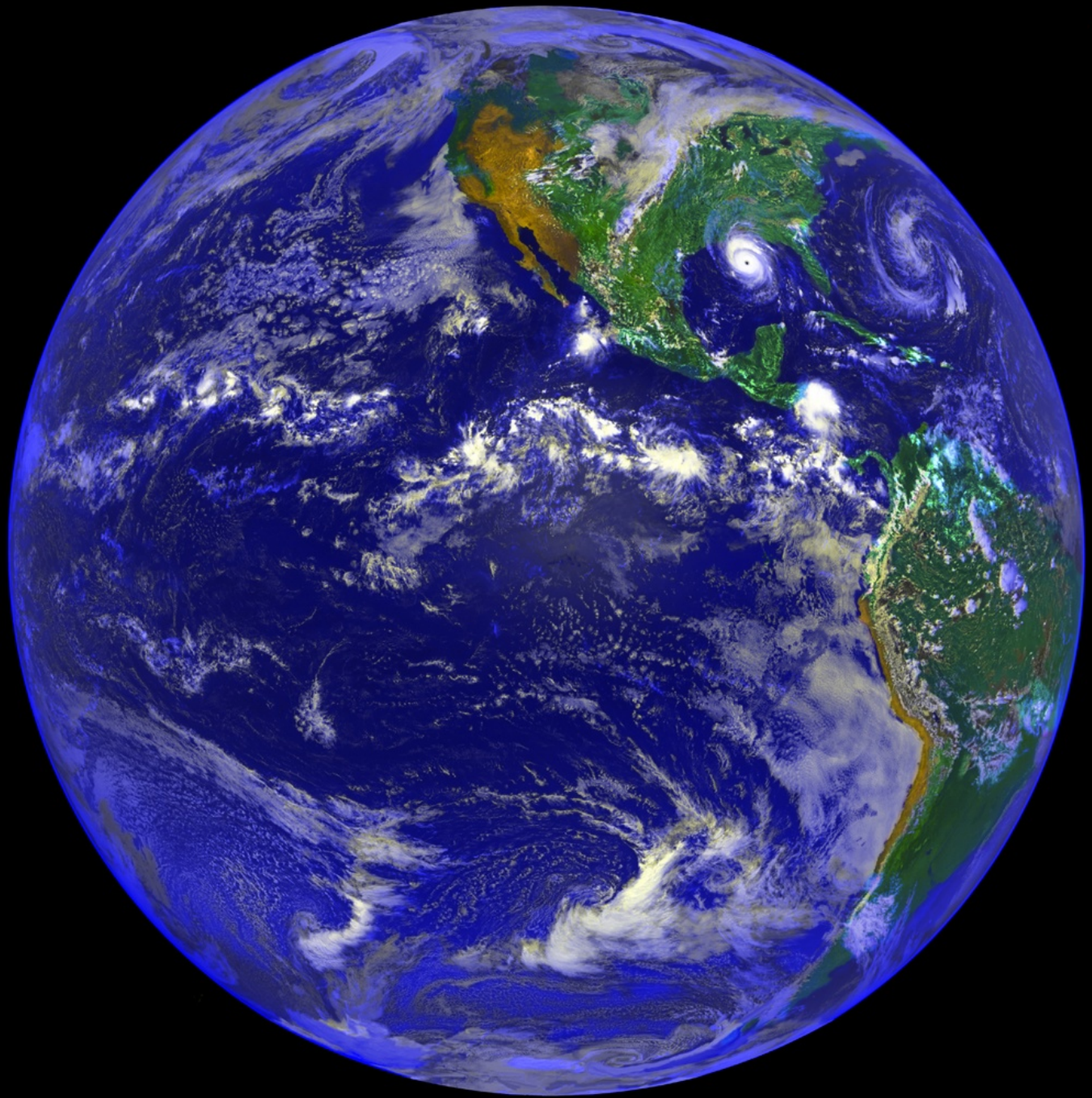
Talk Outline

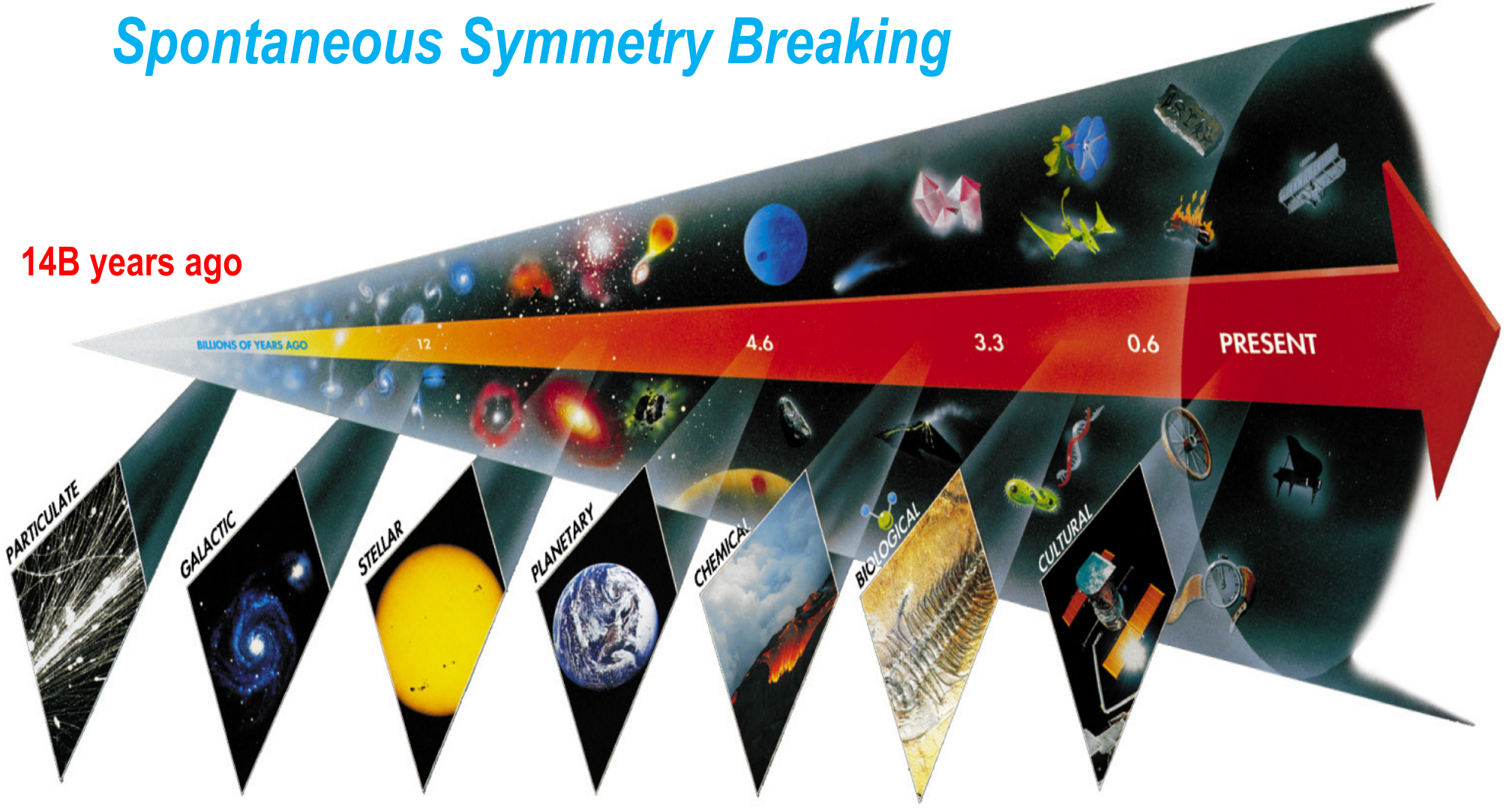
- **Last week: Bio-imaging and Neuro-physics**
  - Part I ~30 min.
    - Introduction to High-speed Bio-imaging
    - Single Molecule: Origin of Life
  - Part II ~30 min.
    - Neurophysics: Origin of Consciousness
- **Today: Particle Physics & Cosmology**
  - Part I ~30 min.
    - Introduction to Cosmology: 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

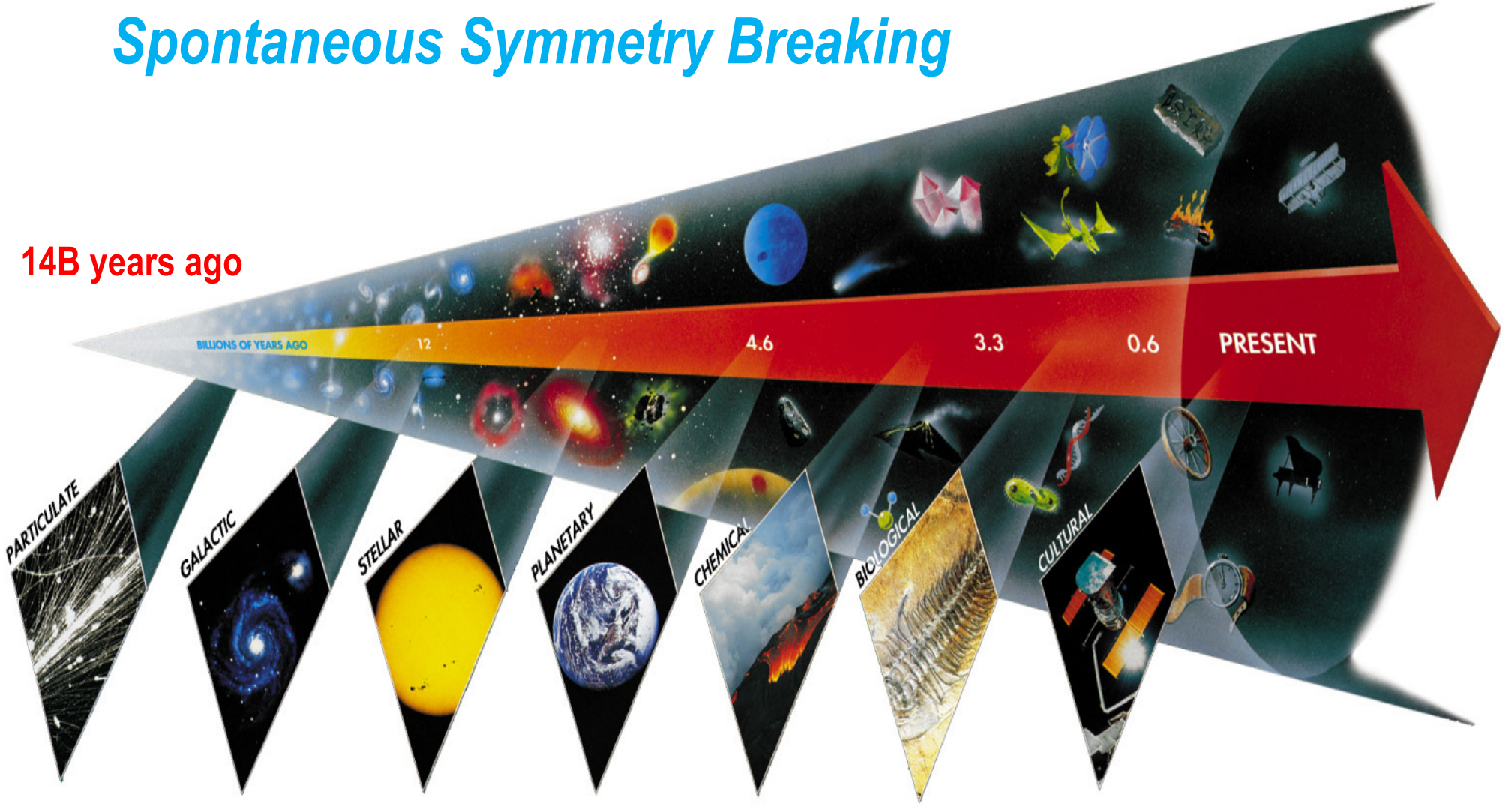
Spontaneous Symmetry Breaking



Simple ⟹ **Coherent Complex System**

Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking



Origin of Particles

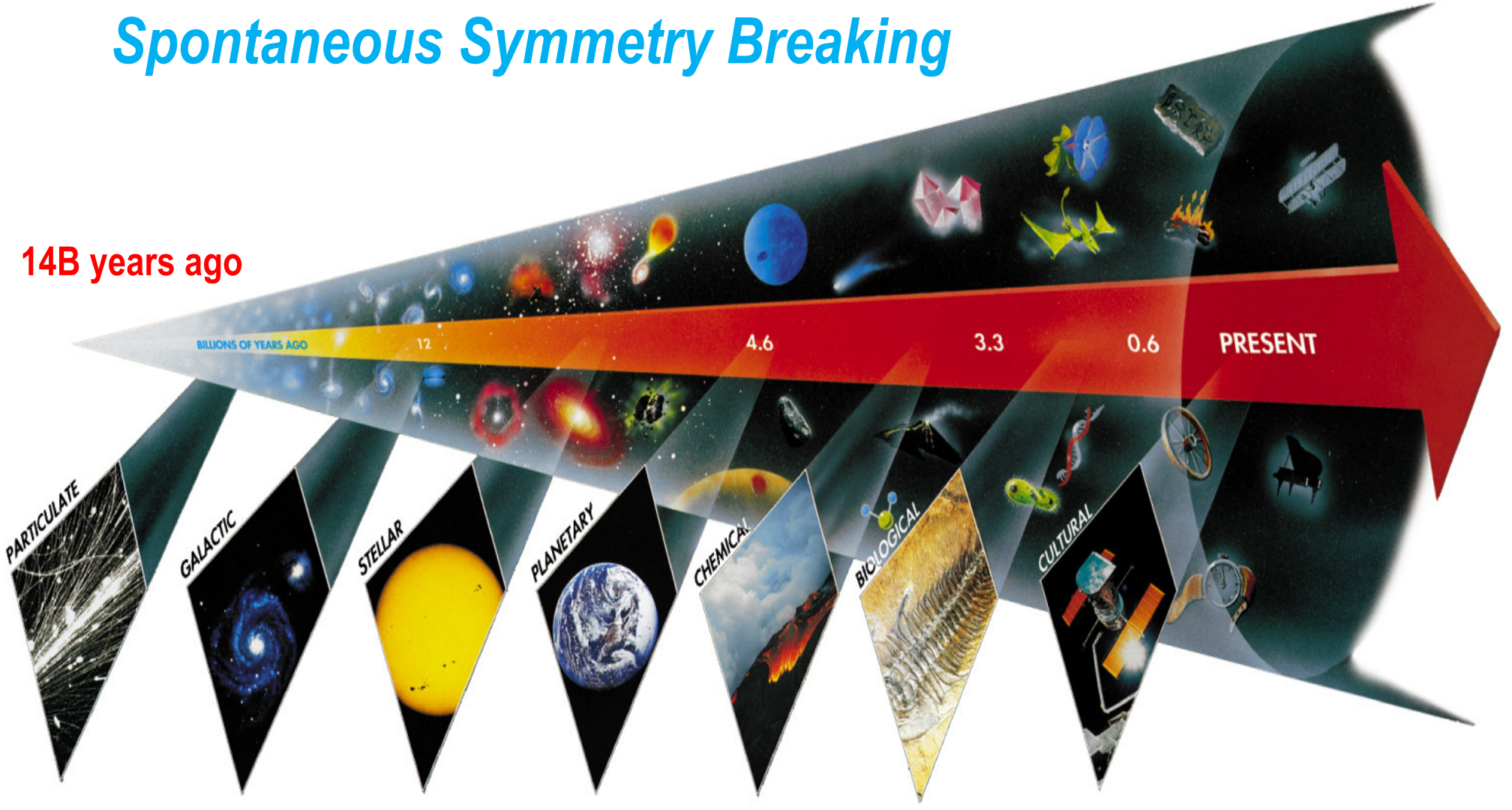
Origin of Structure

Origin of Life

Origin of Consciousness

Seven Phases of Cosmic Evolution

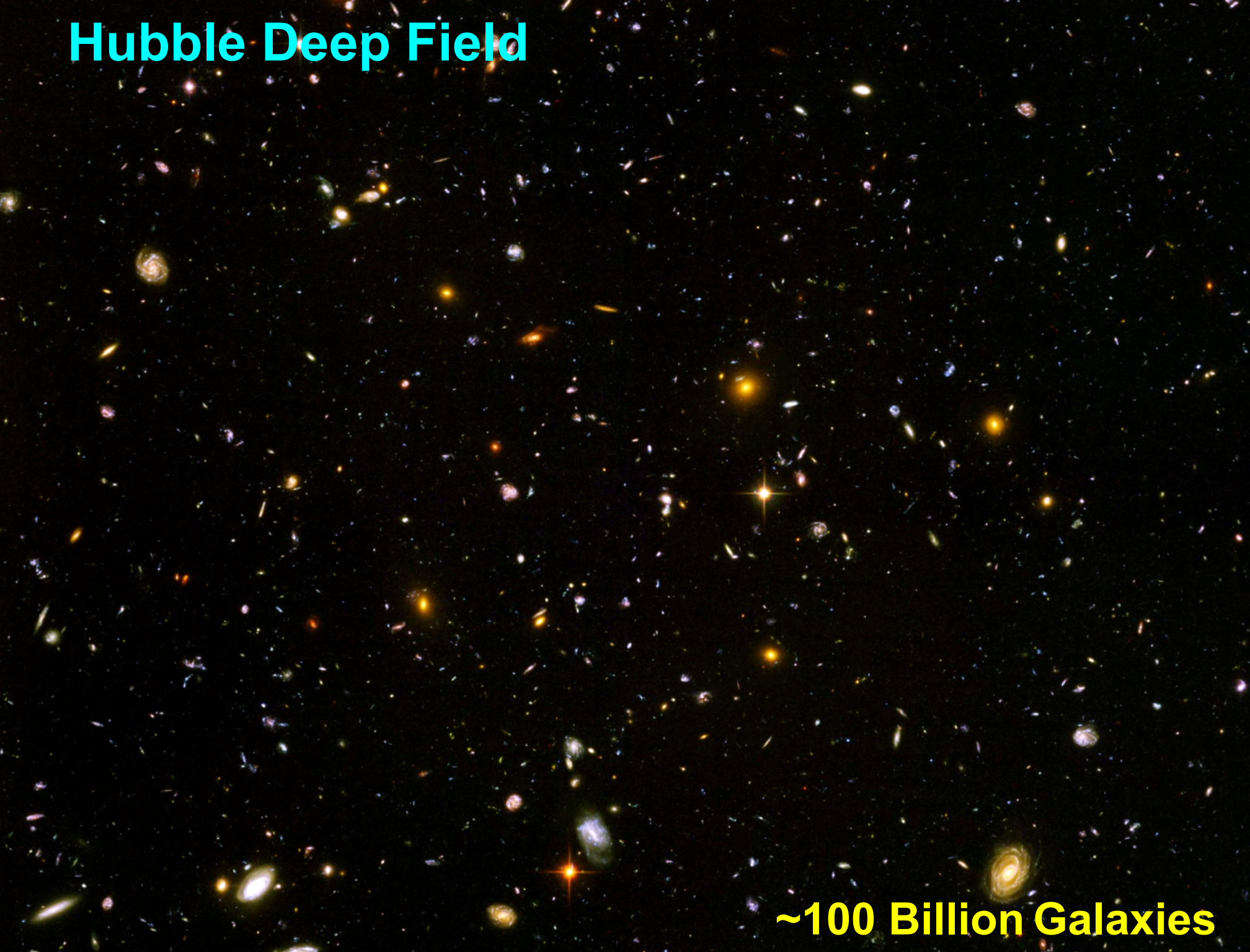
Spontaneous Symmetry Breaking

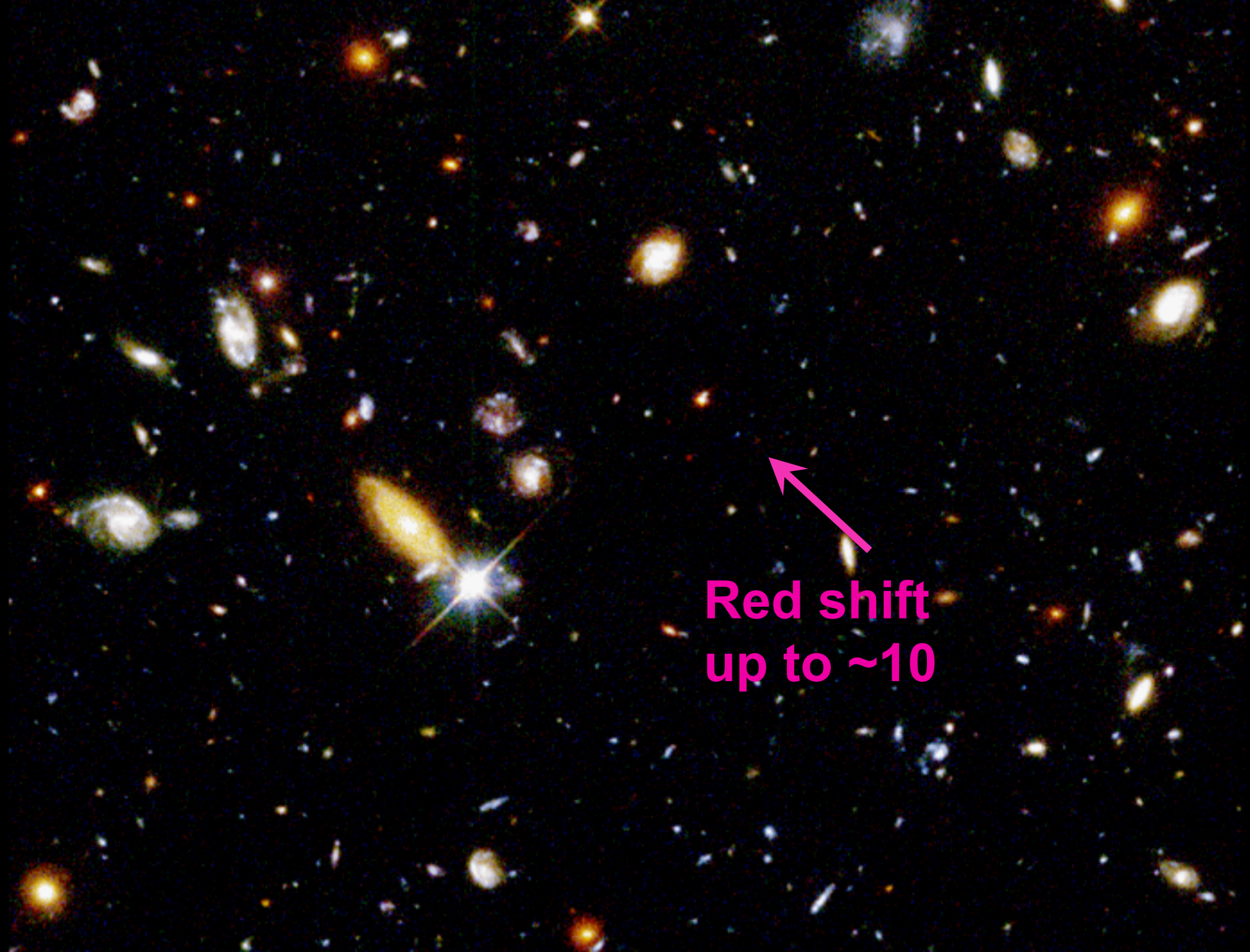


Accelerator ← **Telescope** → ← **Microscope** →

Introduction to Cosmology


Andromeda
~100 Billions Stars in a Galaxy


Hubble Deep Field
~100 Billion Galaxies


Red shift
up to ~10

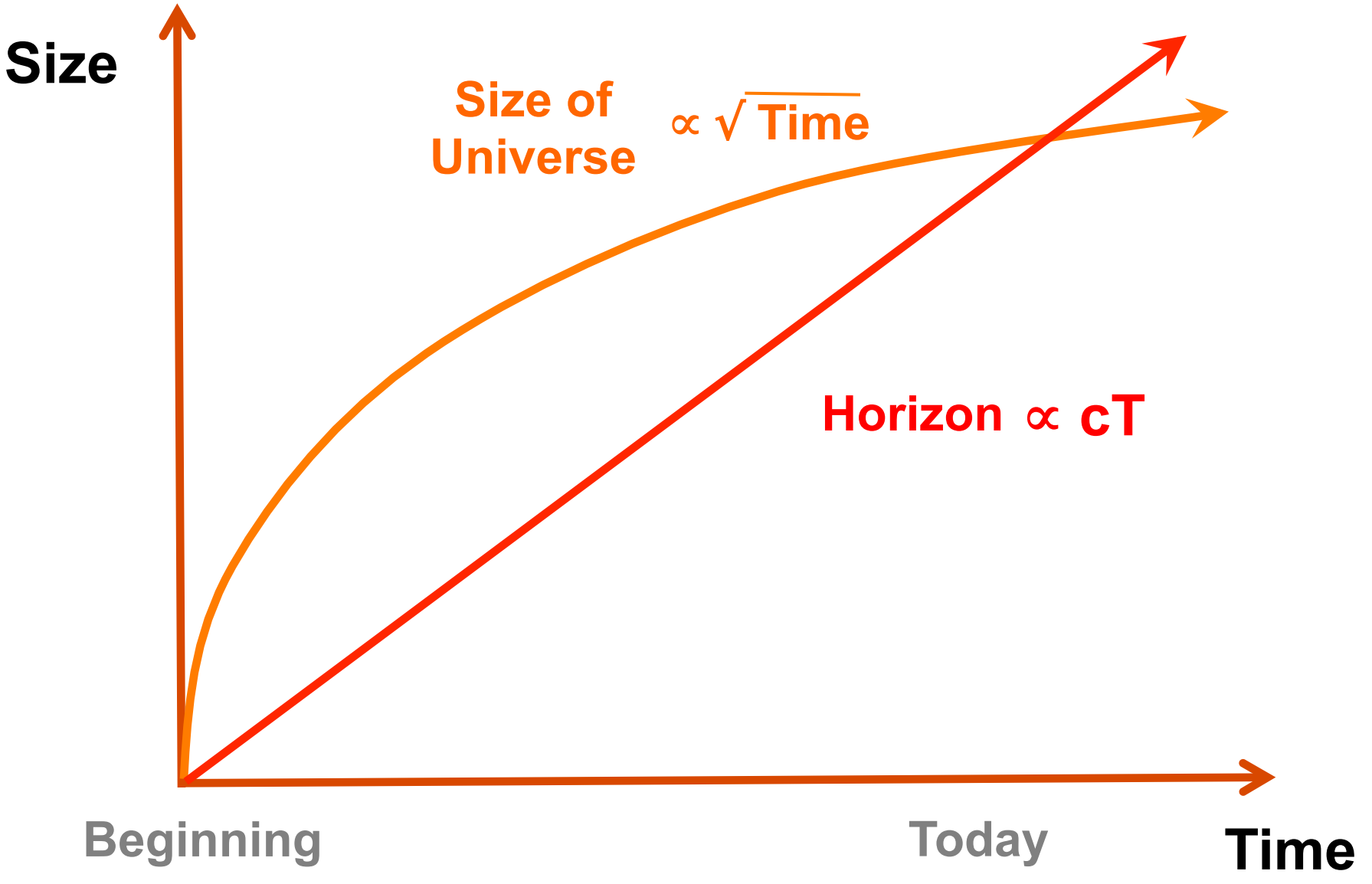
Hubble's Law: Expansion of the Universe

Horizon of Universe

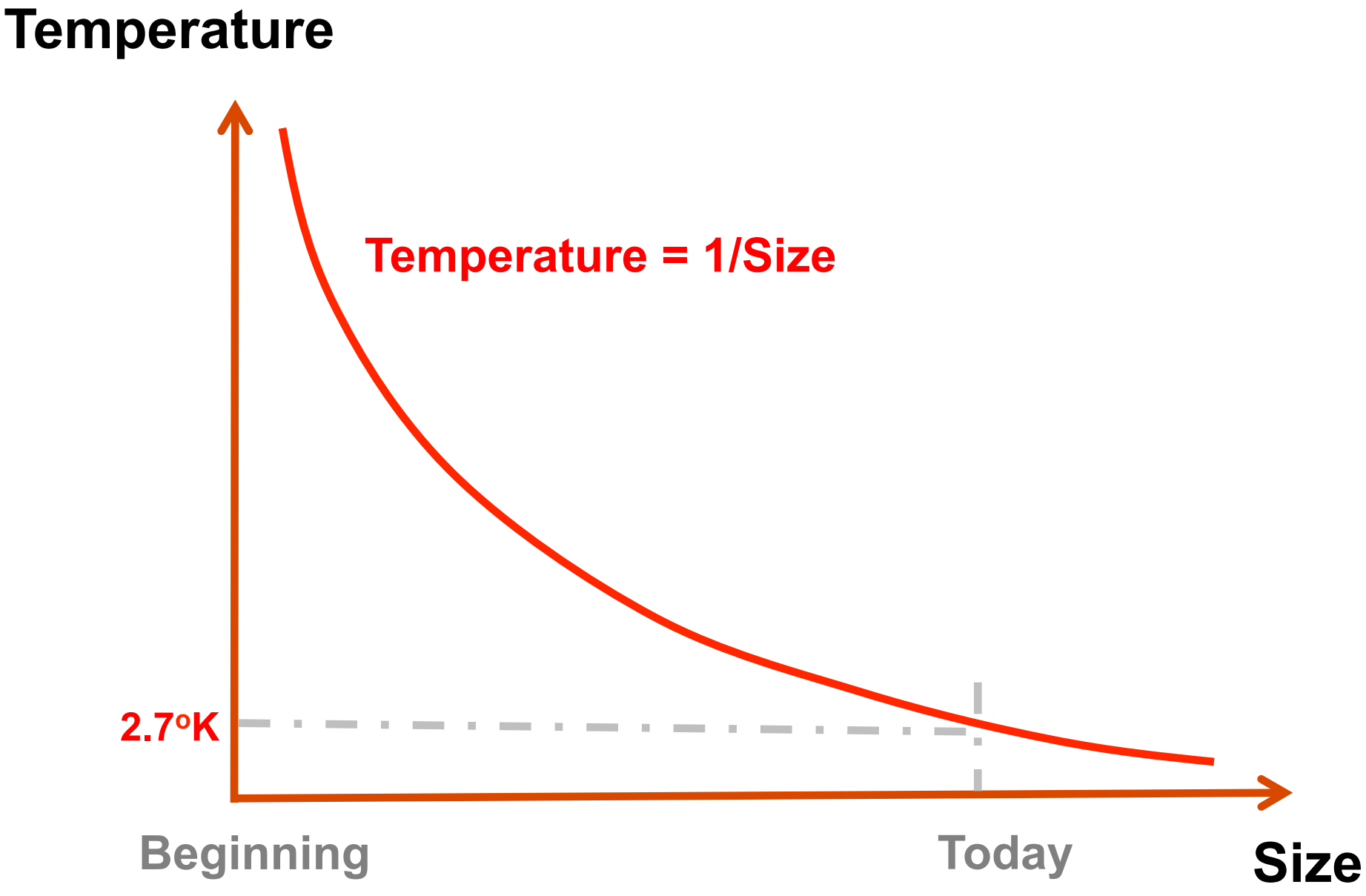
14 Billon Light Years

Moving Away at Speed of Light

Expansion of Universe

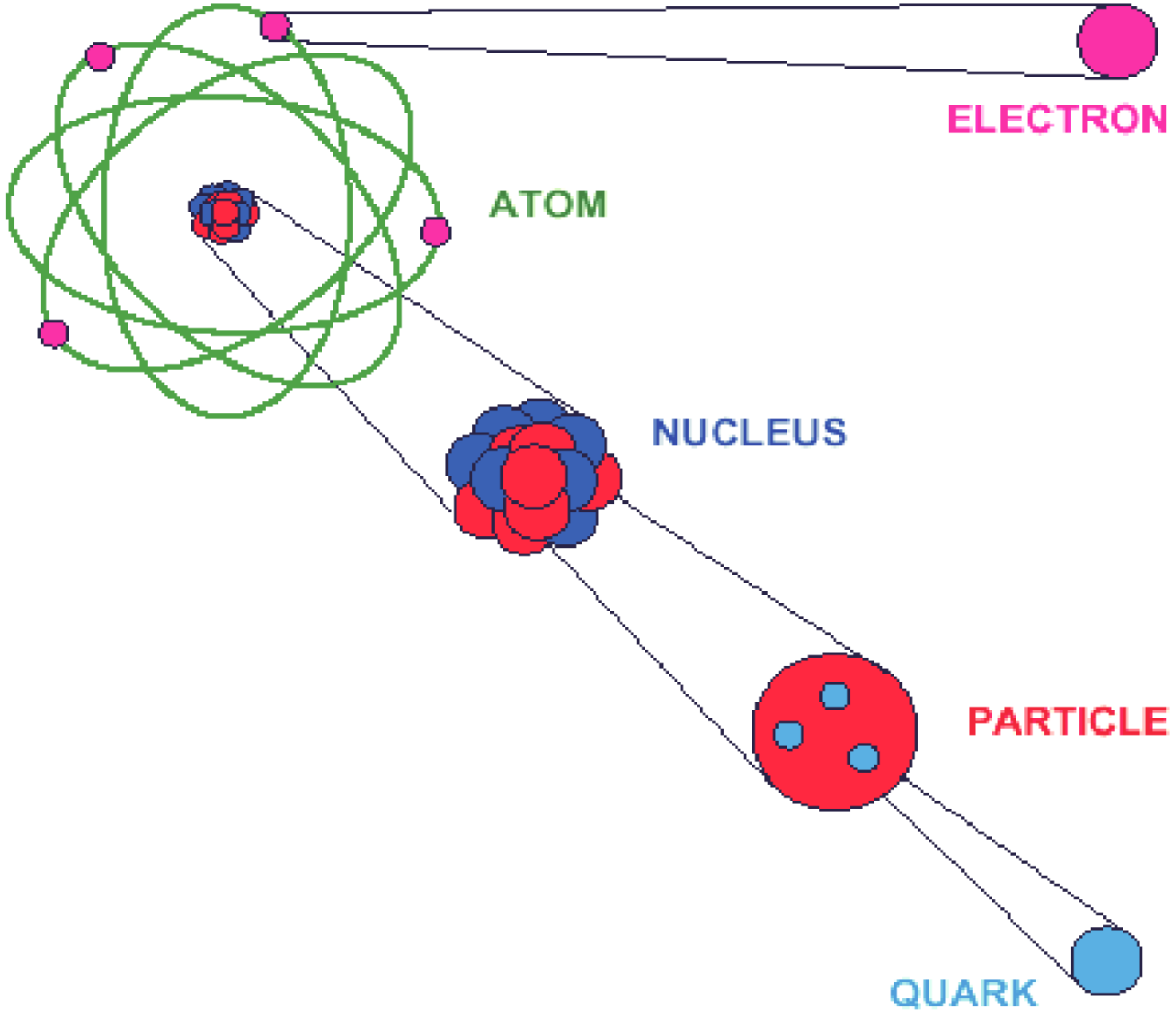


Temperature of Universe

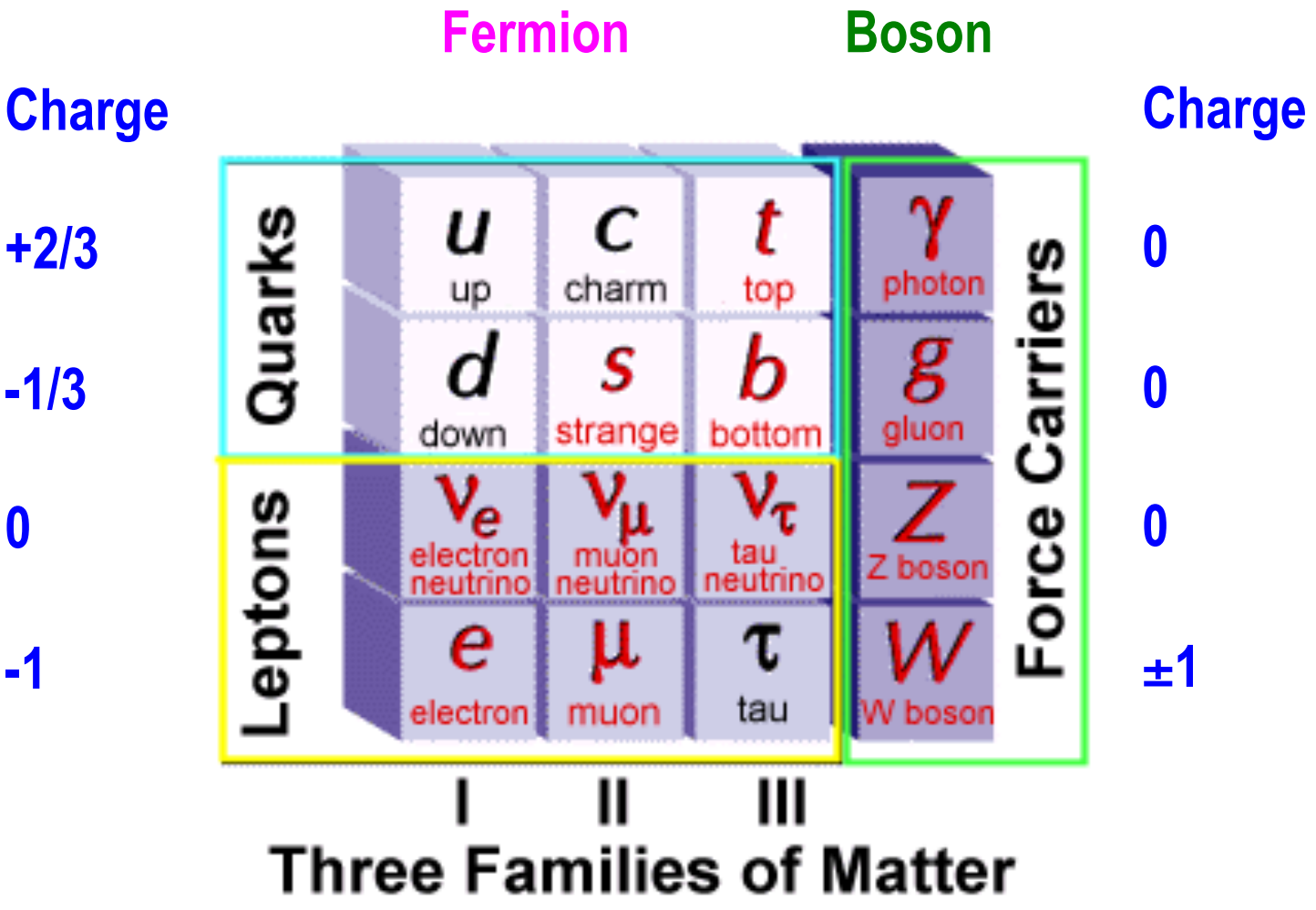


Fermi Lab near Chicago

Elementary Particles (~1970)



Elementary Particles



+ Anti-particles

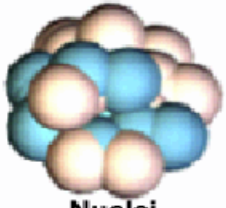
Elementary Particles and Forces

Strong

Gluons (8)

Quarks

Mesons
Baryons

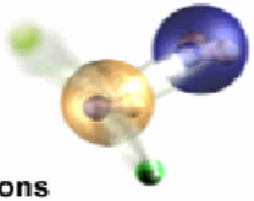


Nuclei

1

Weak

Bosons (W,Z)



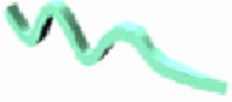
Neutron decay
Beta radioactivity
Neutrino interactions
Burning of the sun

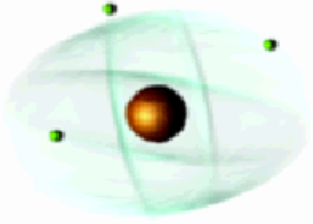
10^{-13}

10^{-2}

Electromagnetic

Photon



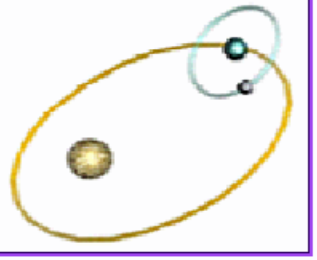


Atoms
Light
Chemistry
Electronics

10^{-38}

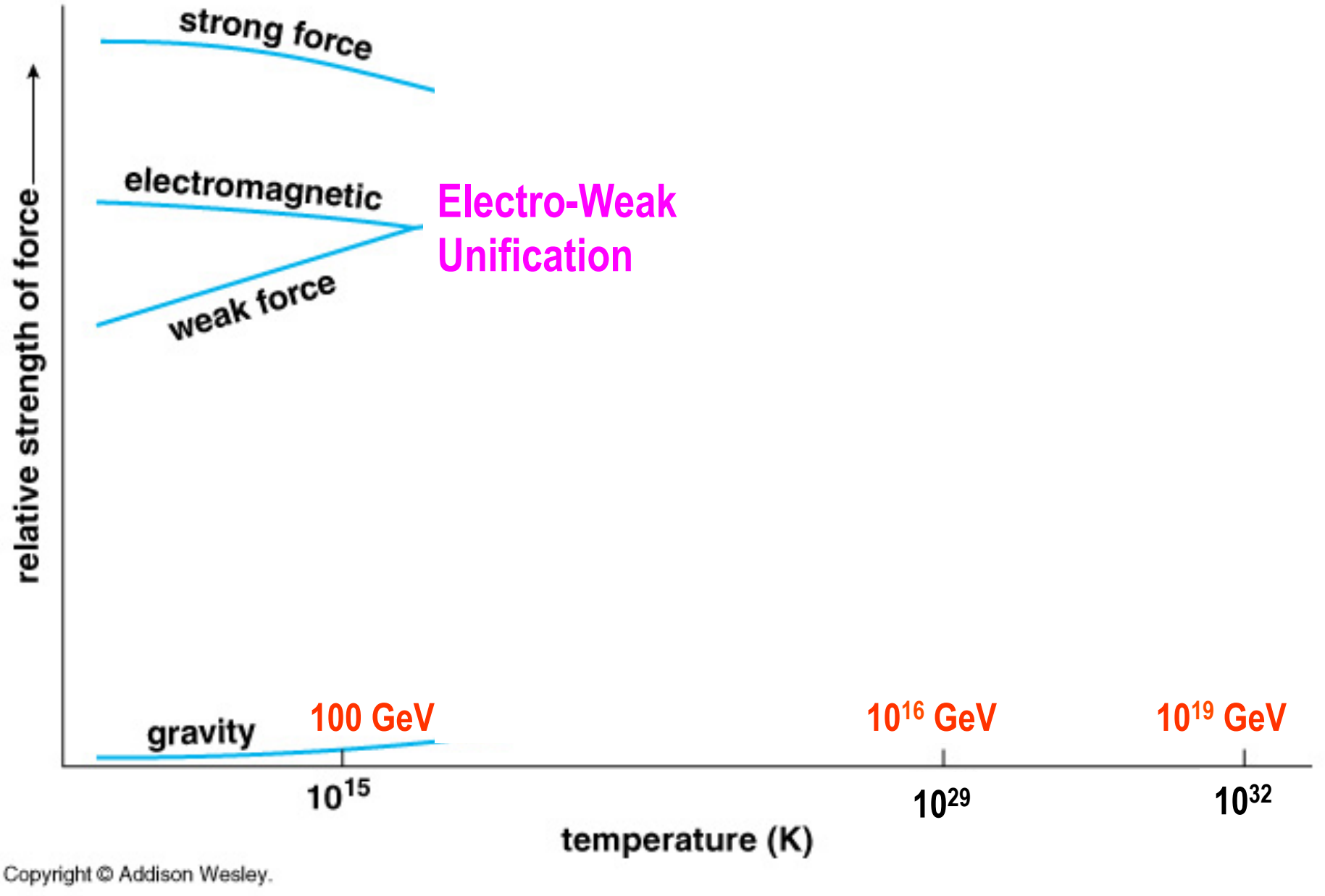
Gravitational

Graviton ?

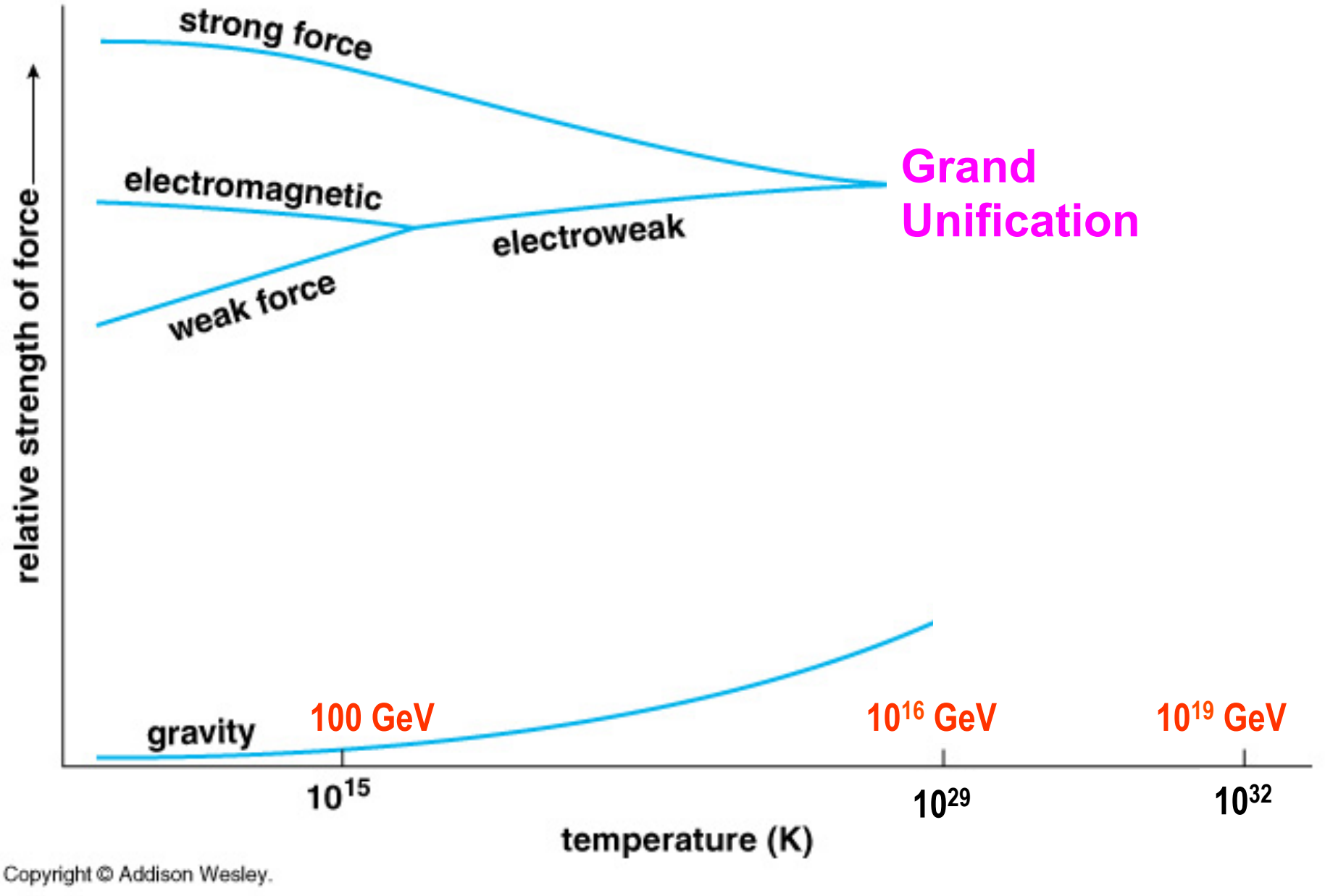


Solar system
Galaxies
Black holes

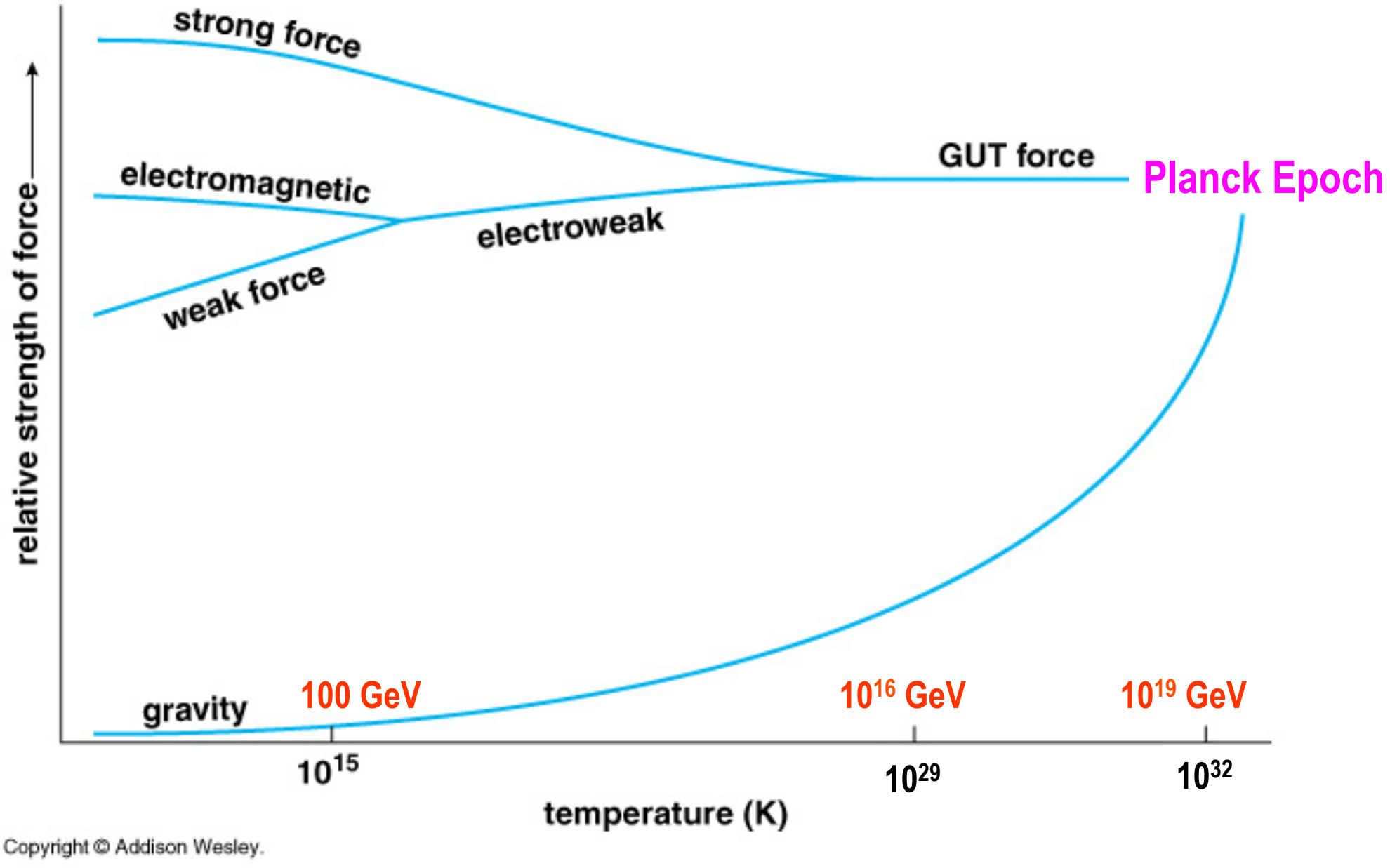
Unification of Forces



Unification of Forces



Unification of Forces



Physicists' View of Early Universe

Fiat lux

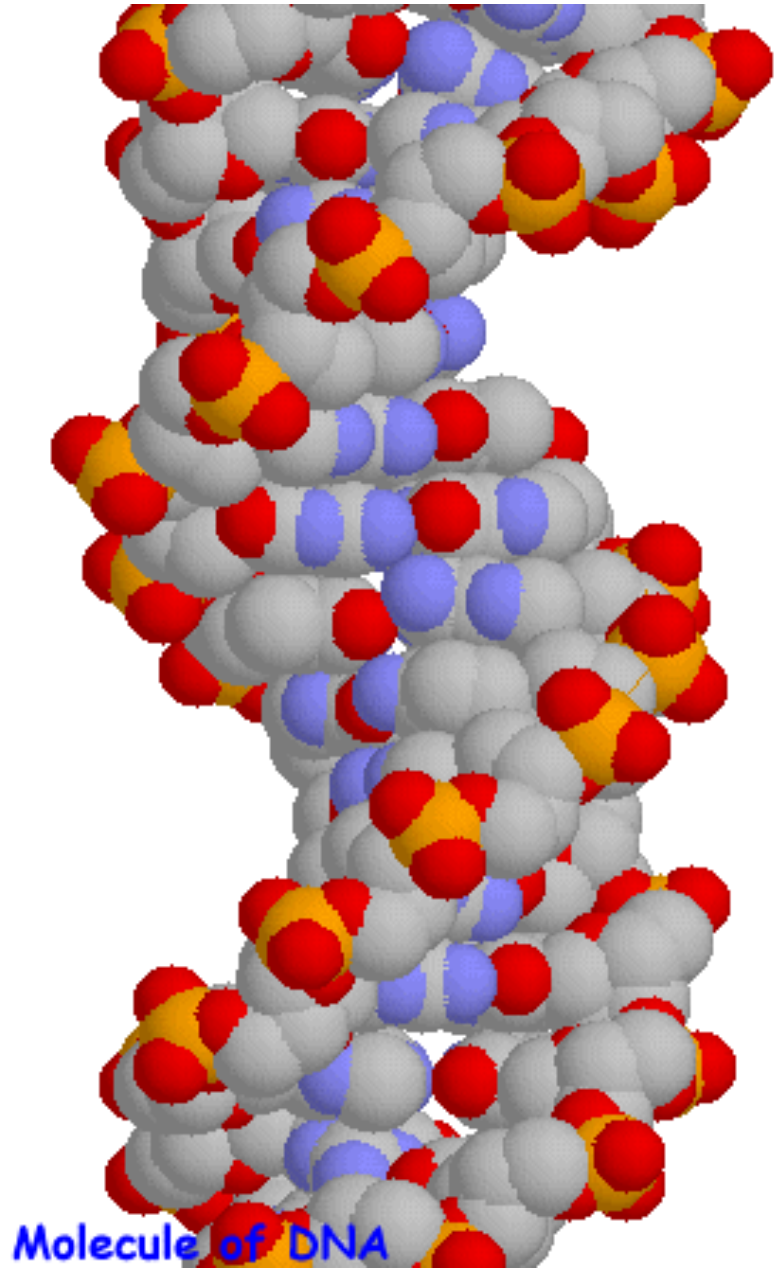
Let there be light

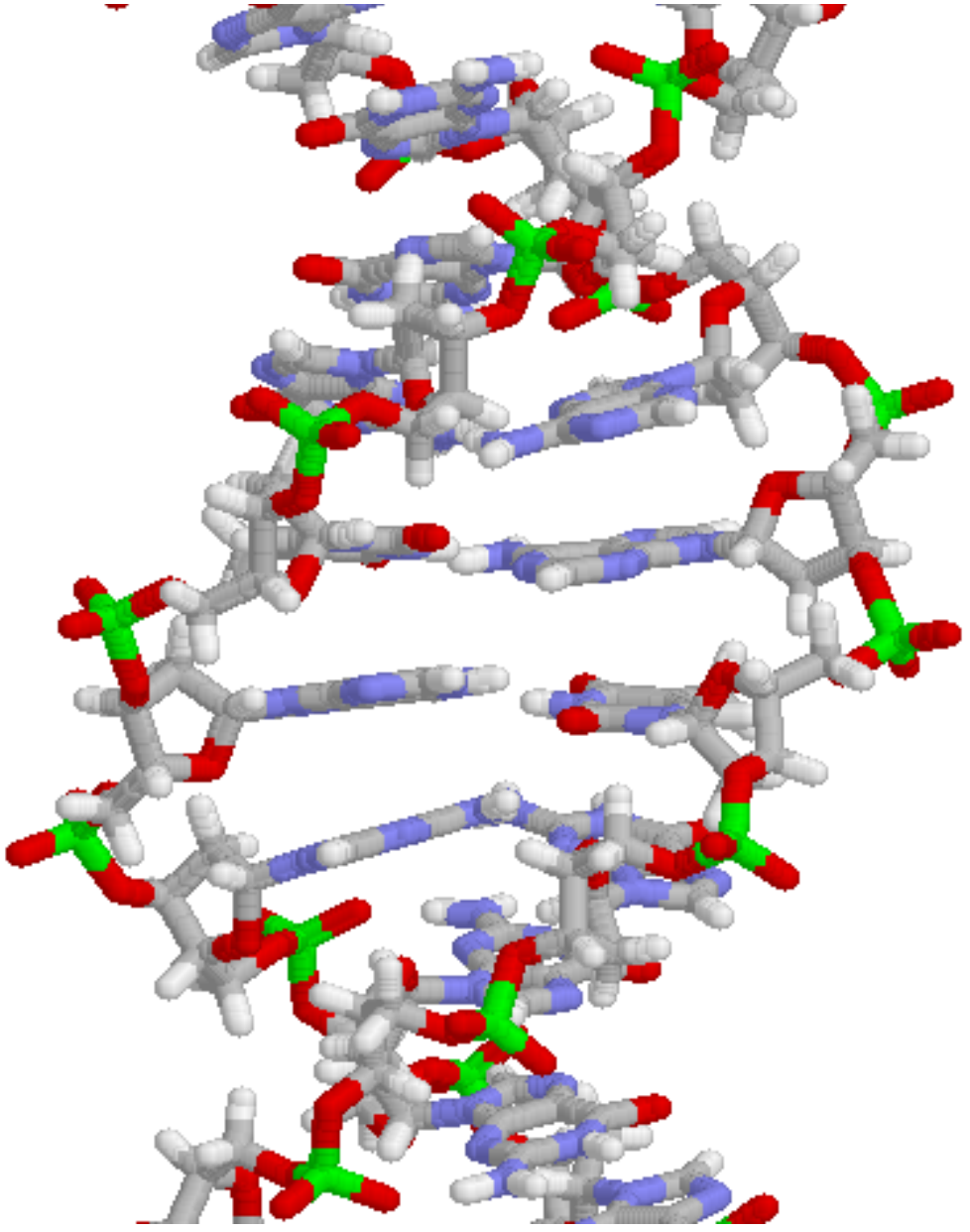
Physicists' View of Early Universe

Lorentz Invariance

Local Gauge Invariance

Structure of DNA





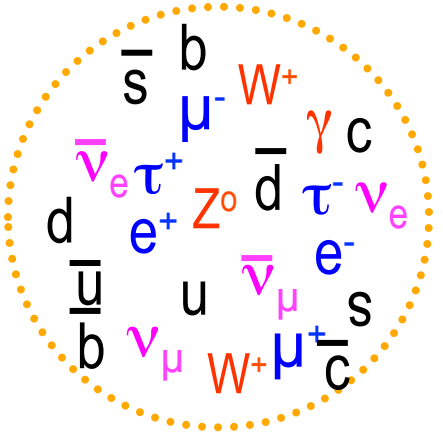
Symmetry Breaking

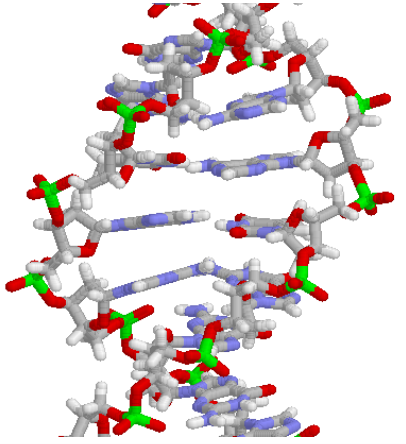
Time
0
1B years
2
3
4
5
6
7
8
9
10
11
12
13
14

Simple

Symmetry Break Down

Complex





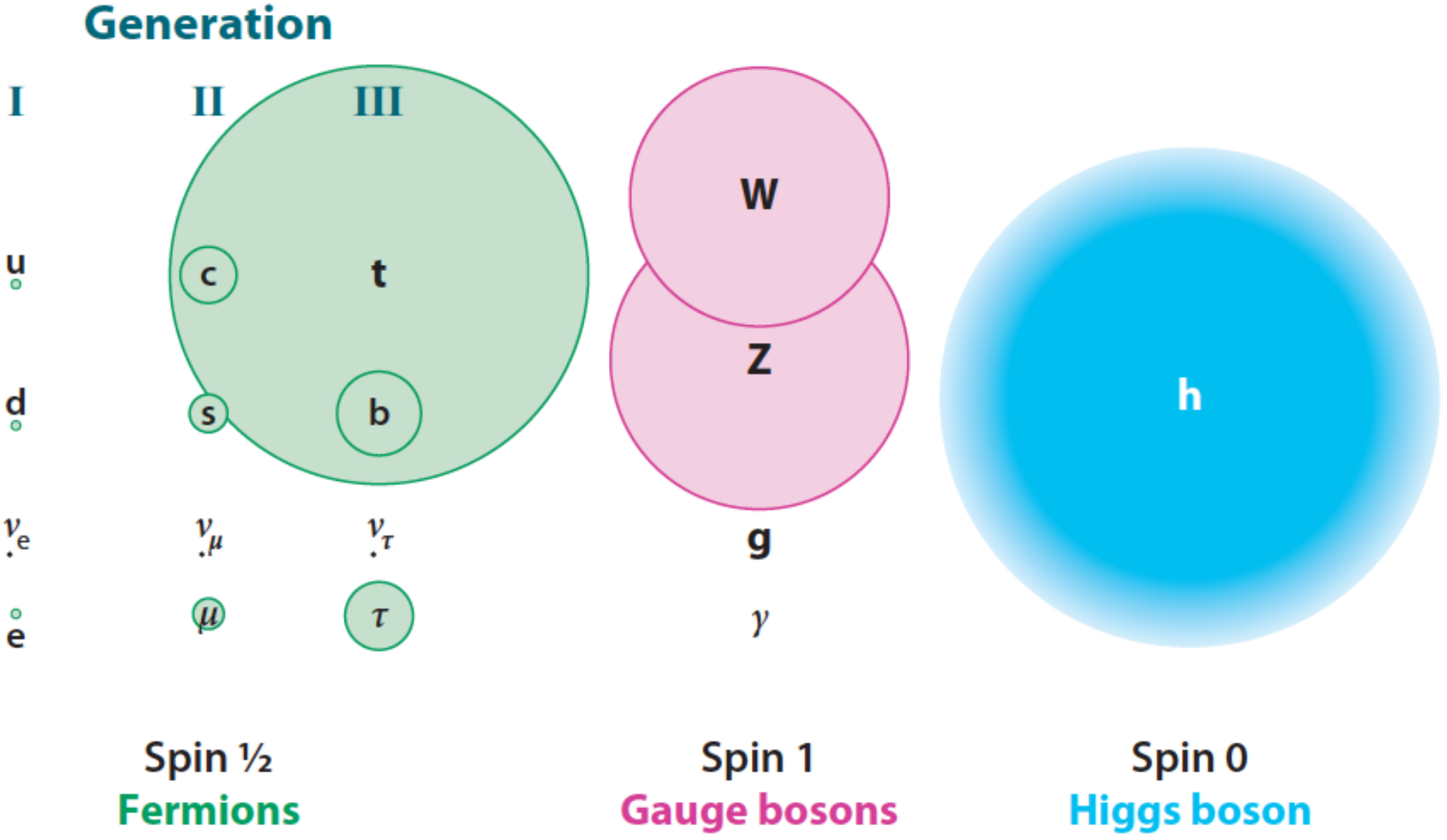
The Beginning (at t = 0)

- 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.

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

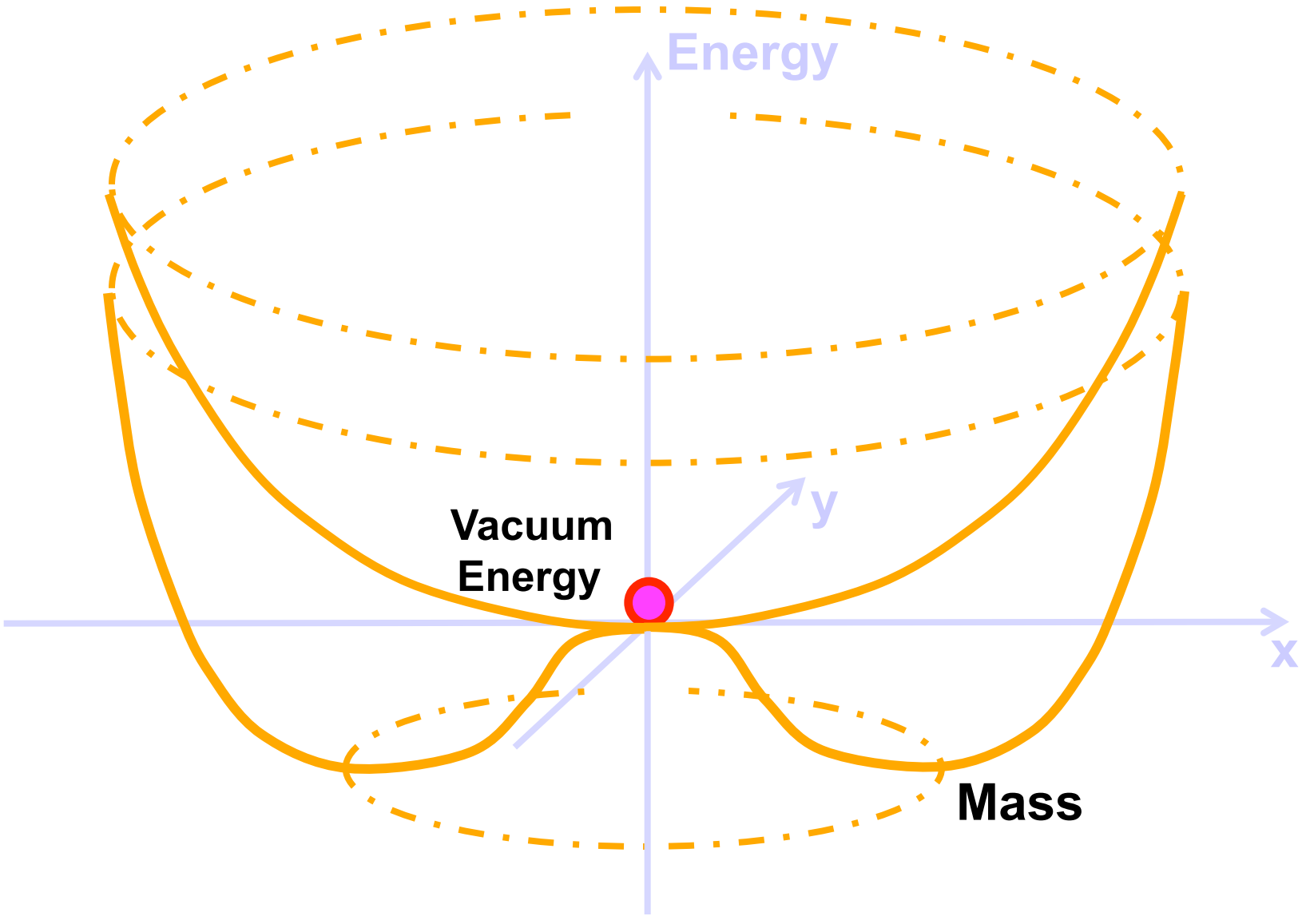
Spontaneous Symmetry Breaking

2) Particle mass << Plank Mass

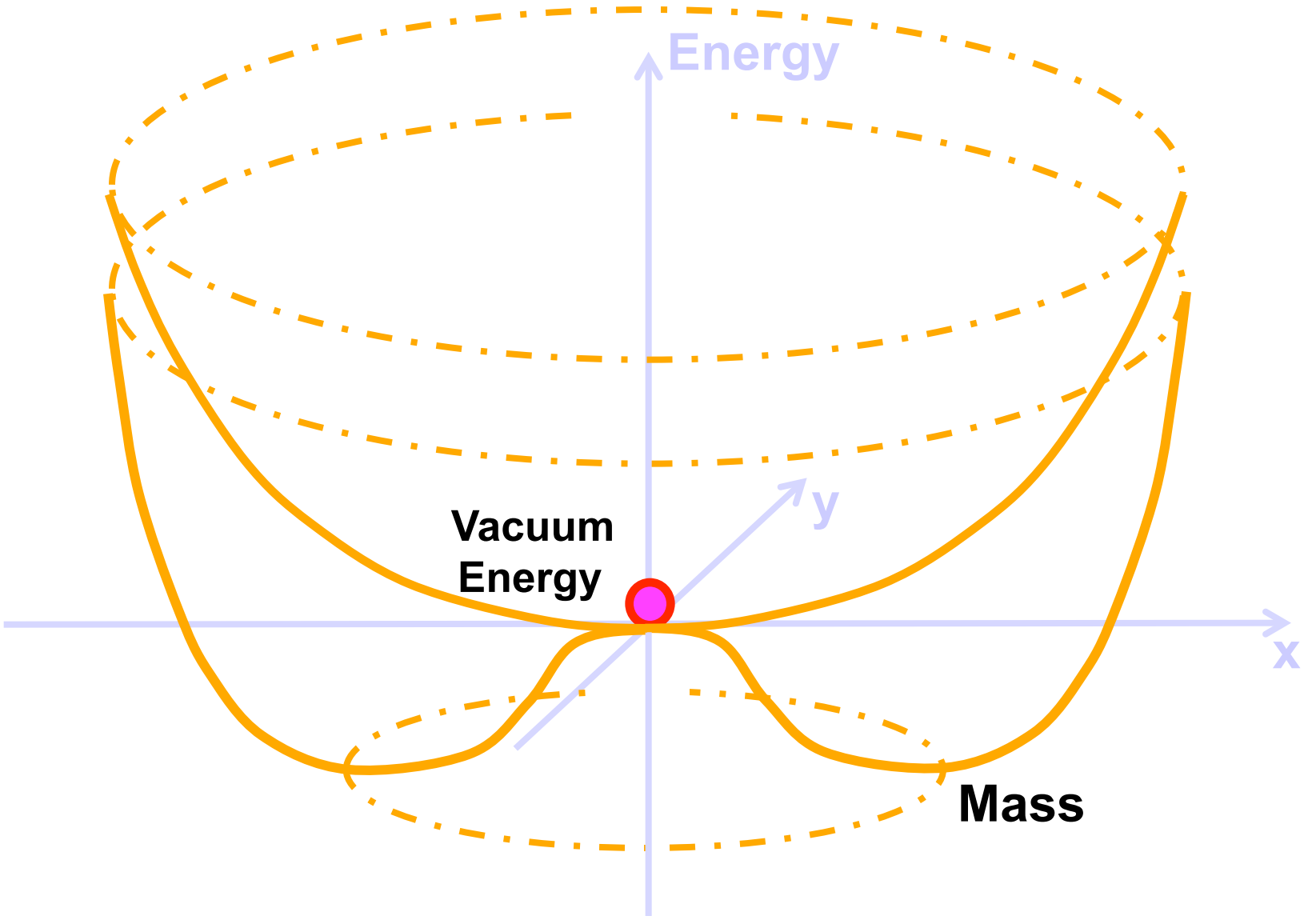
MeV – GeV 10^{19} GeV

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

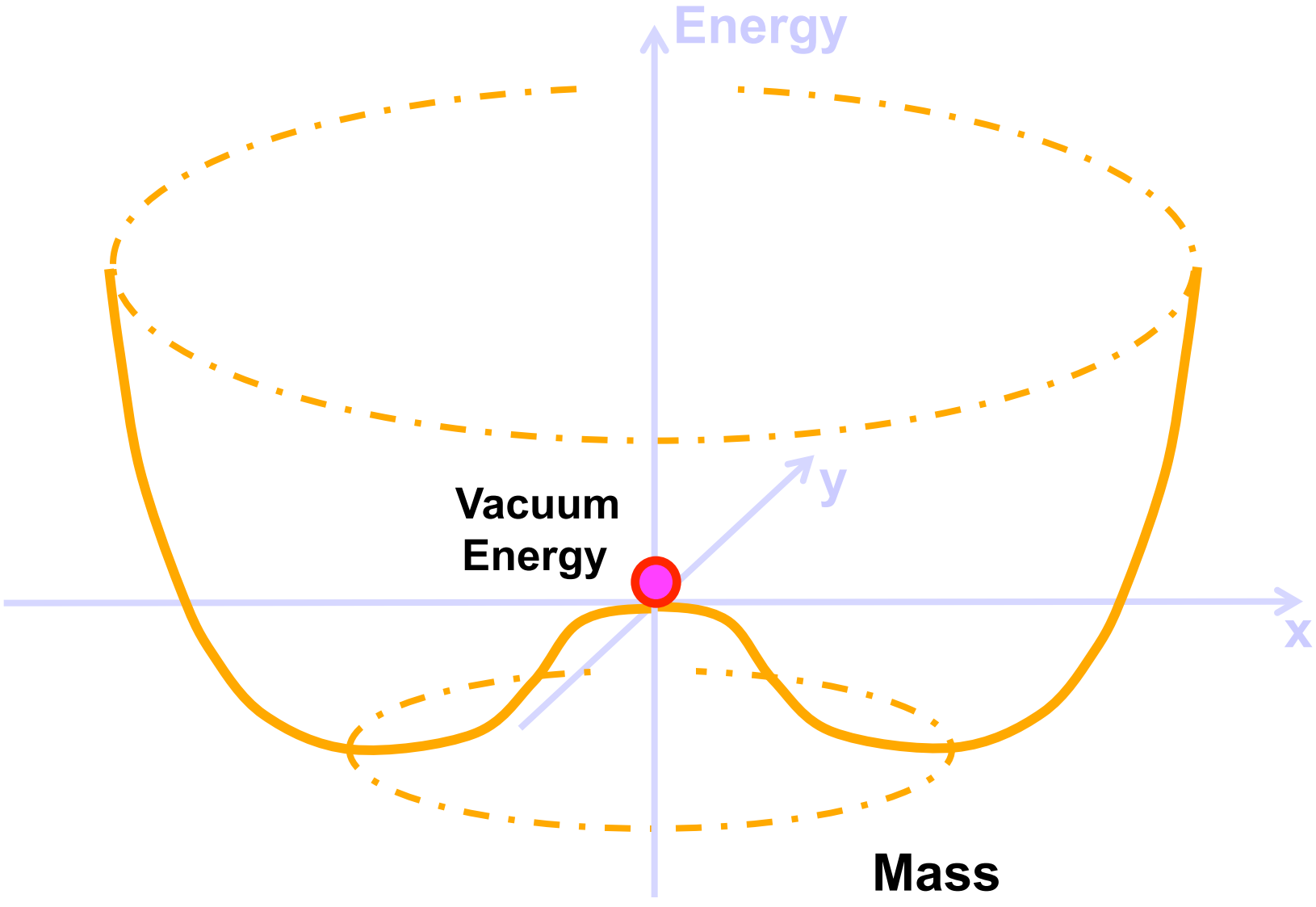
Spontaneous Symmetry Breaking
- Higgs Mechanism -



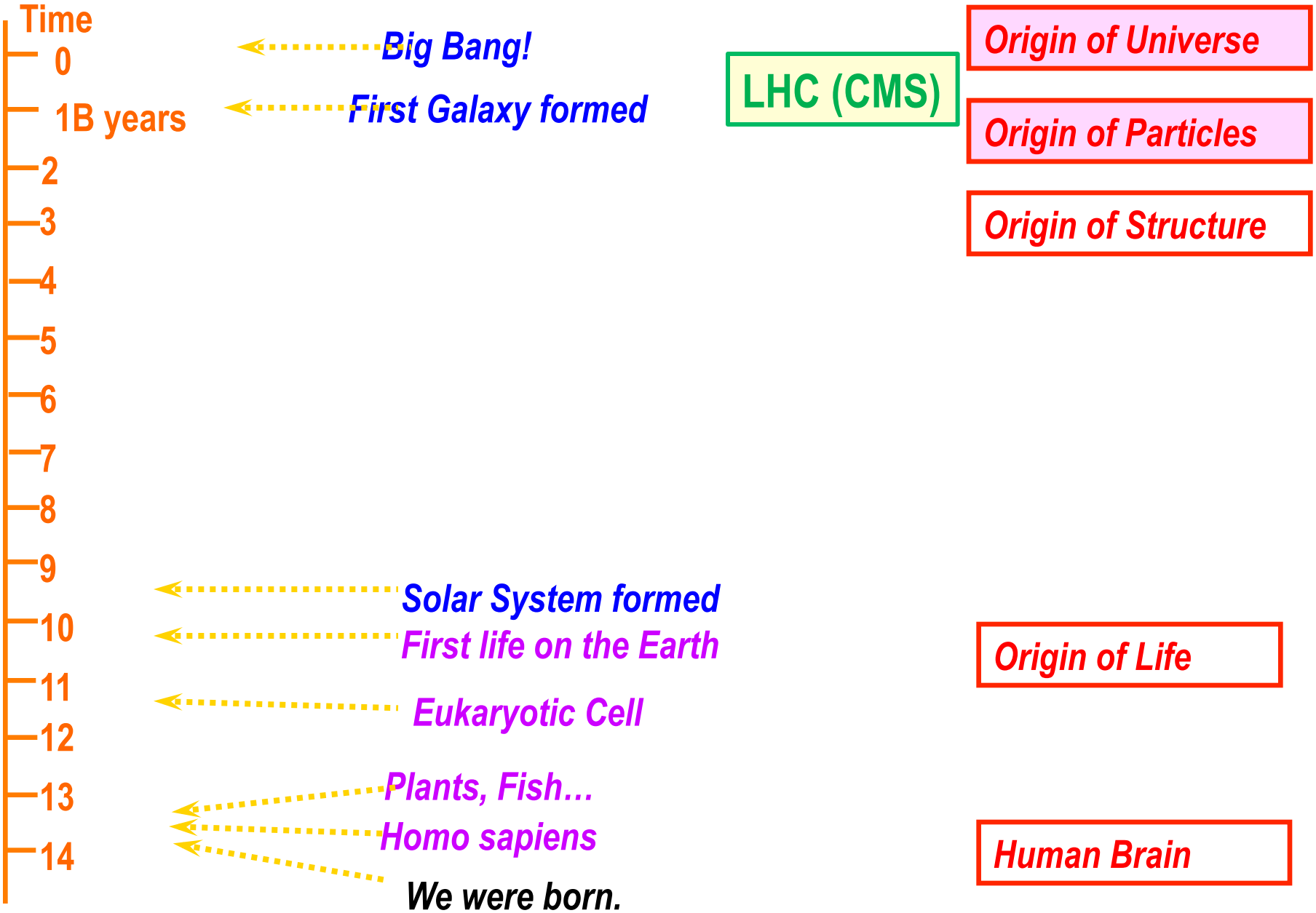
Spontaneous Symmetry Breaking - Higgs Mechanism -



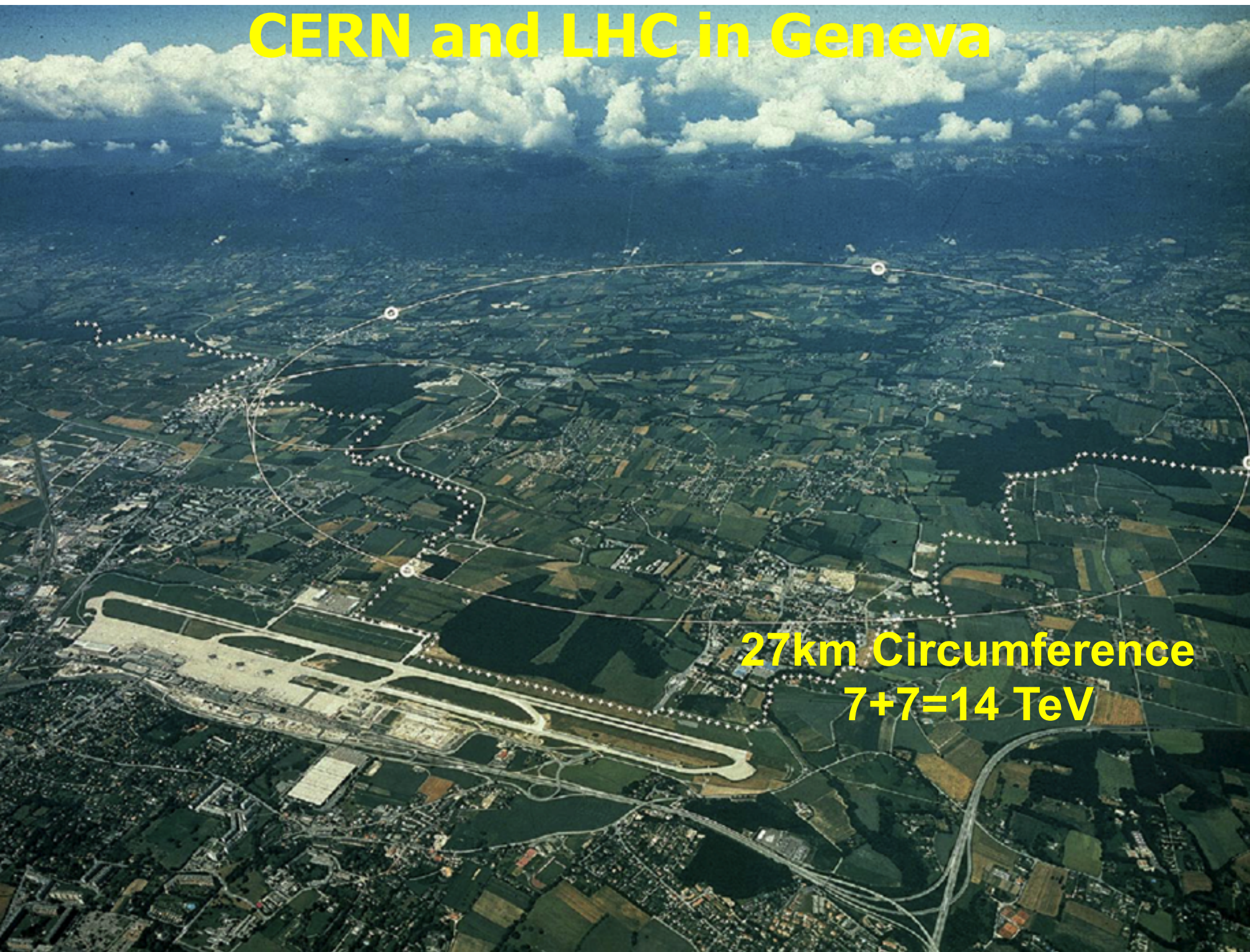
Spontaneous Symmetry Breaking - Higgs Mechanism -



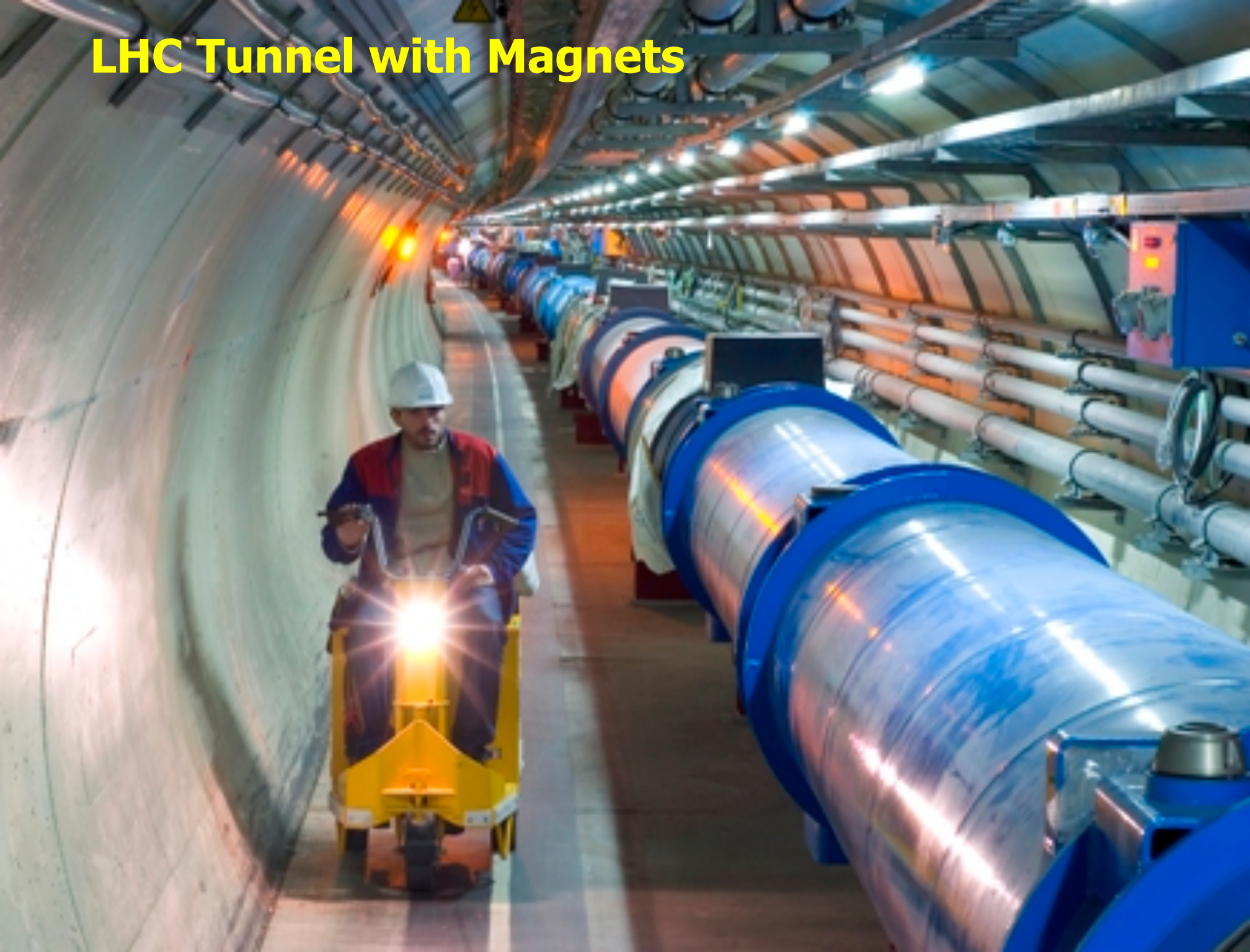
The Five Largest Mysteries in Nature

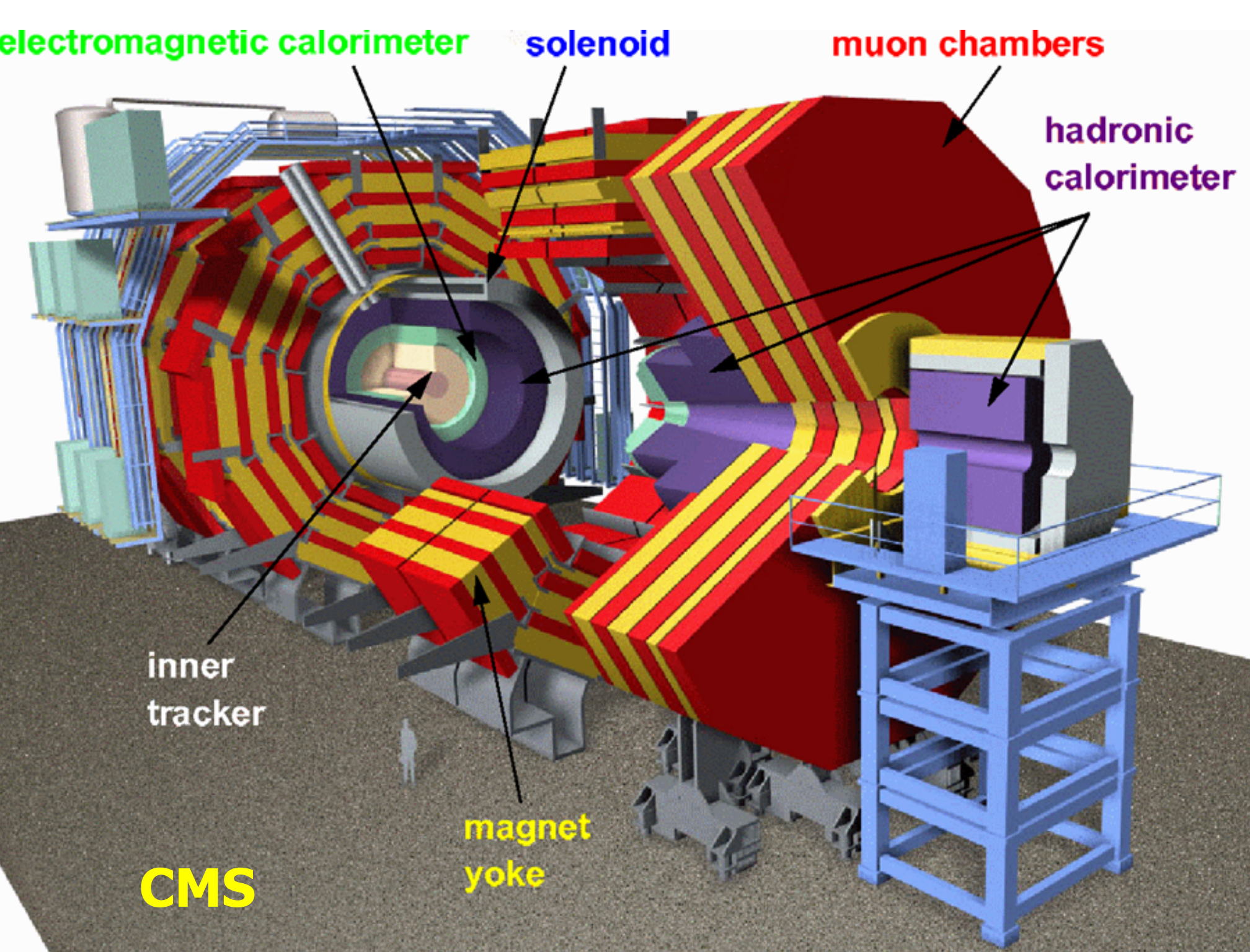


CERN and LHC in Geneva

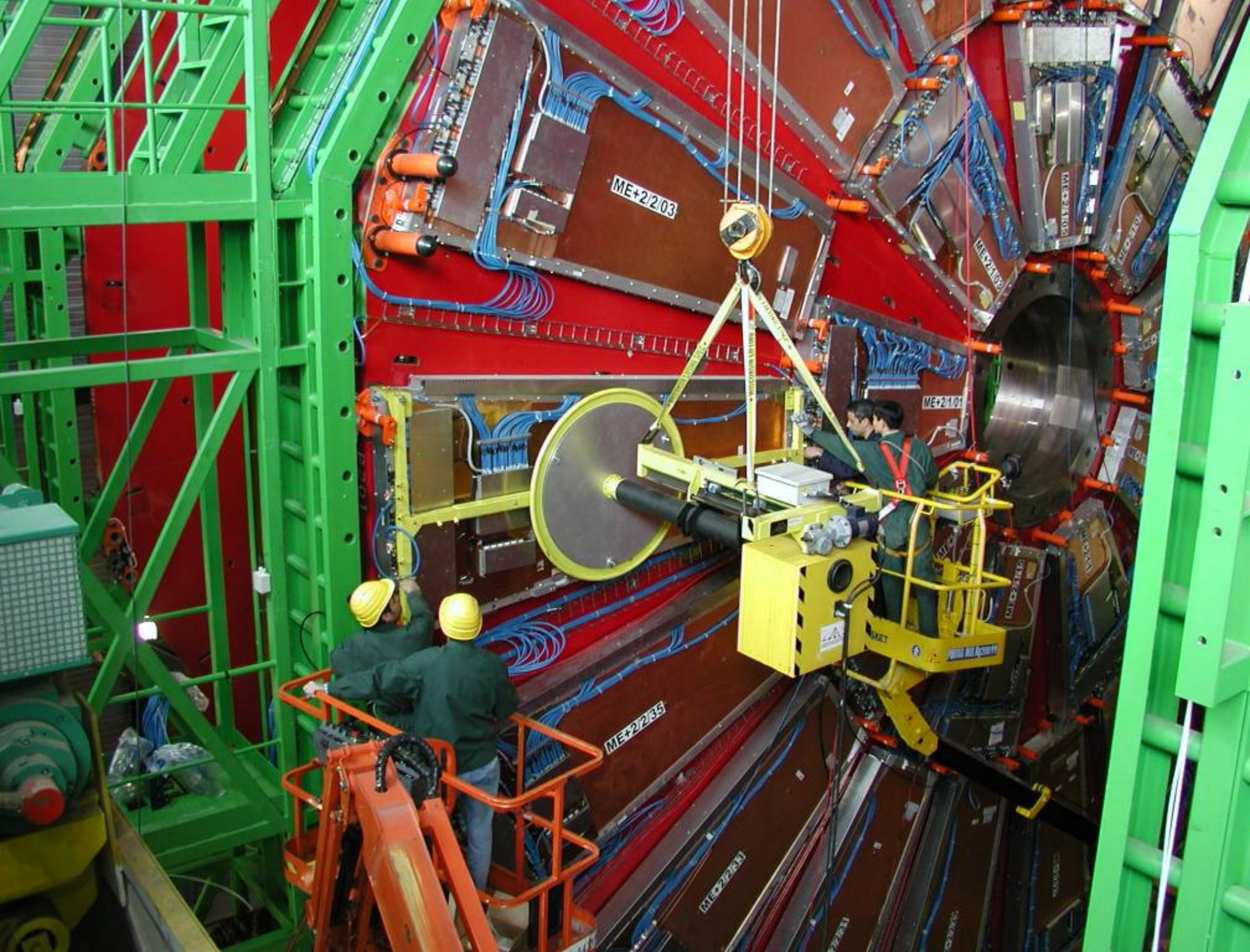


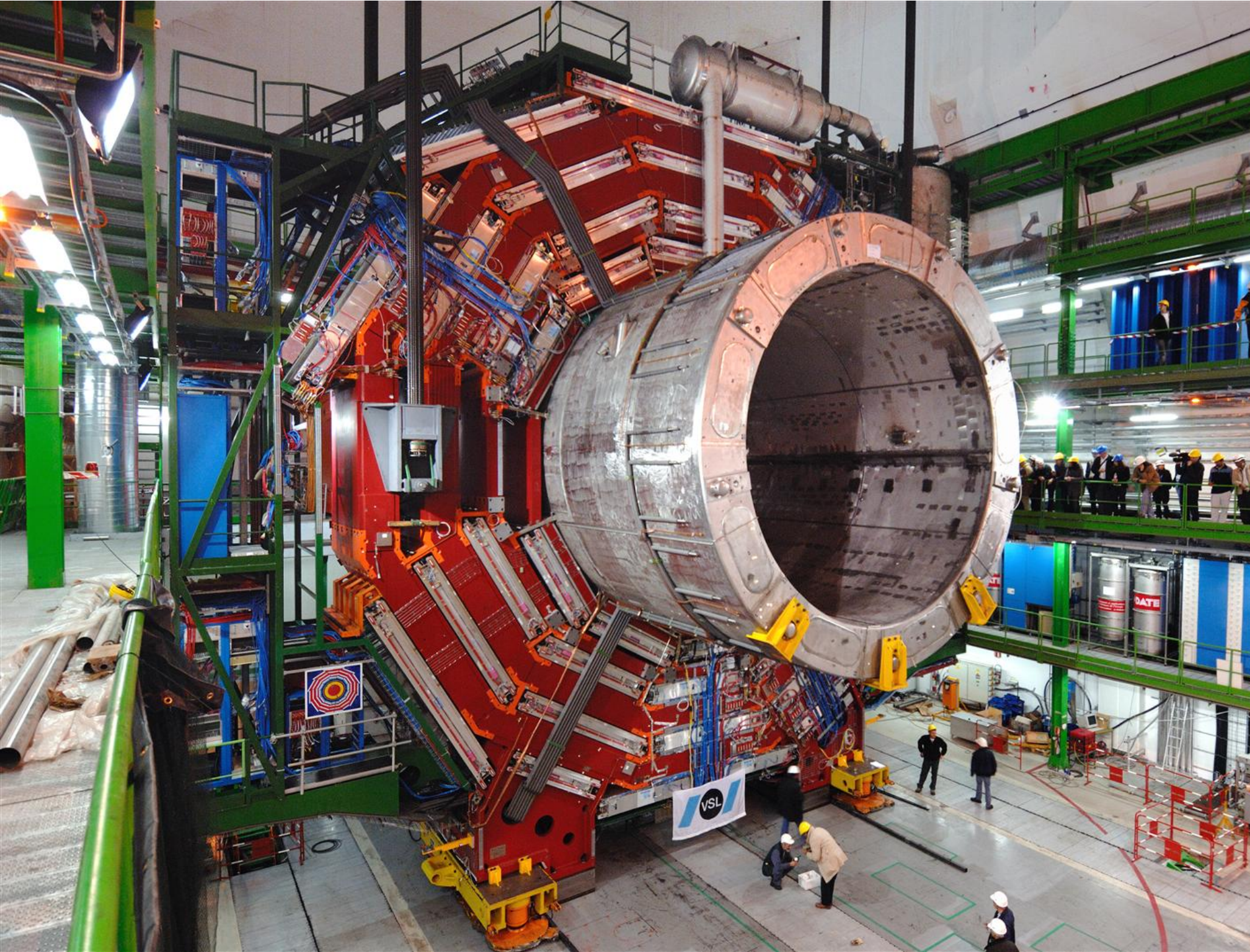
LHC Tunnel with Magnets

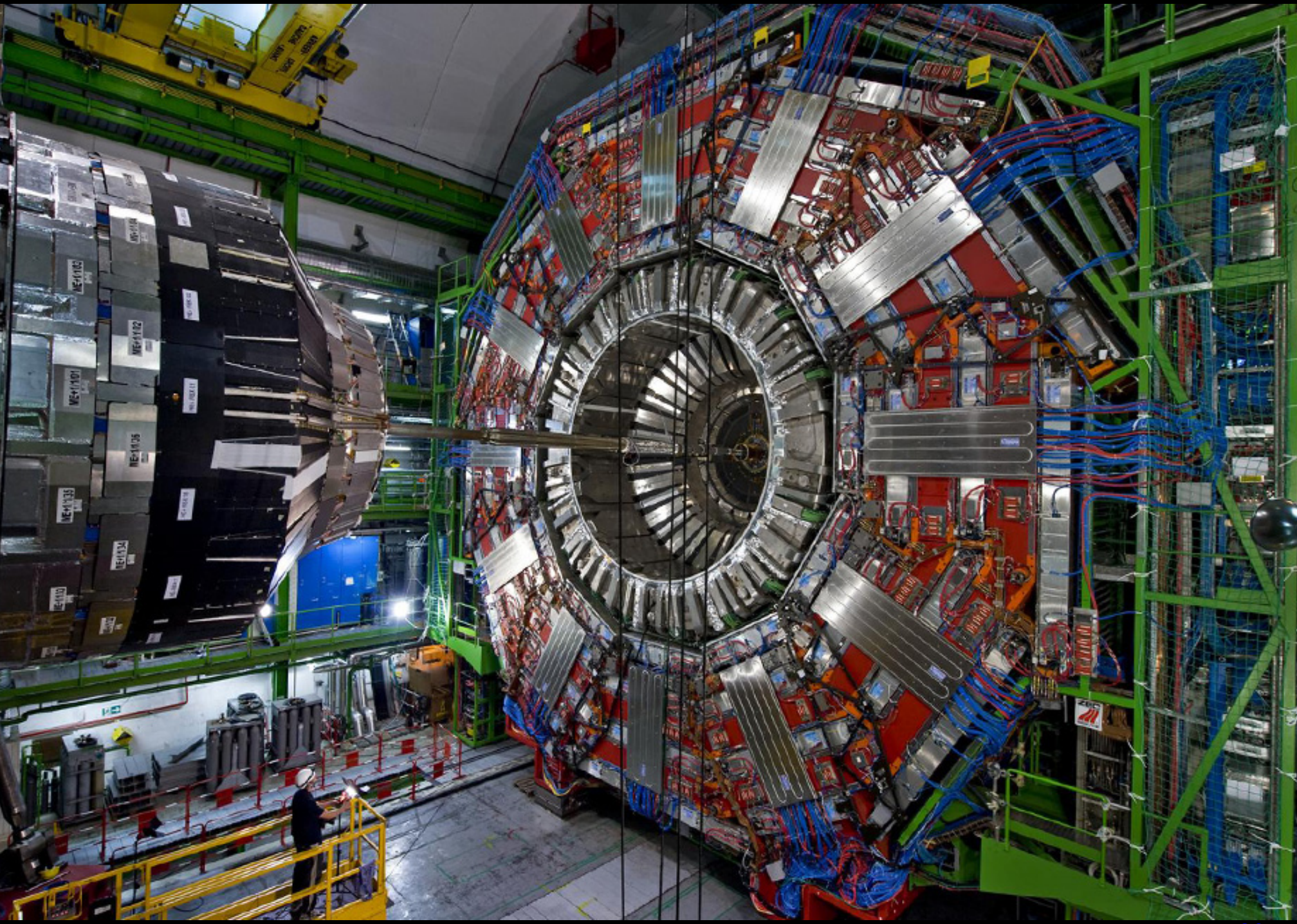



electromagnetic calorimeter
solenoid
muon chambers
hadronic calorimeter
inner tracker
magnet yoke
CMS

CMS Barrel Yoke

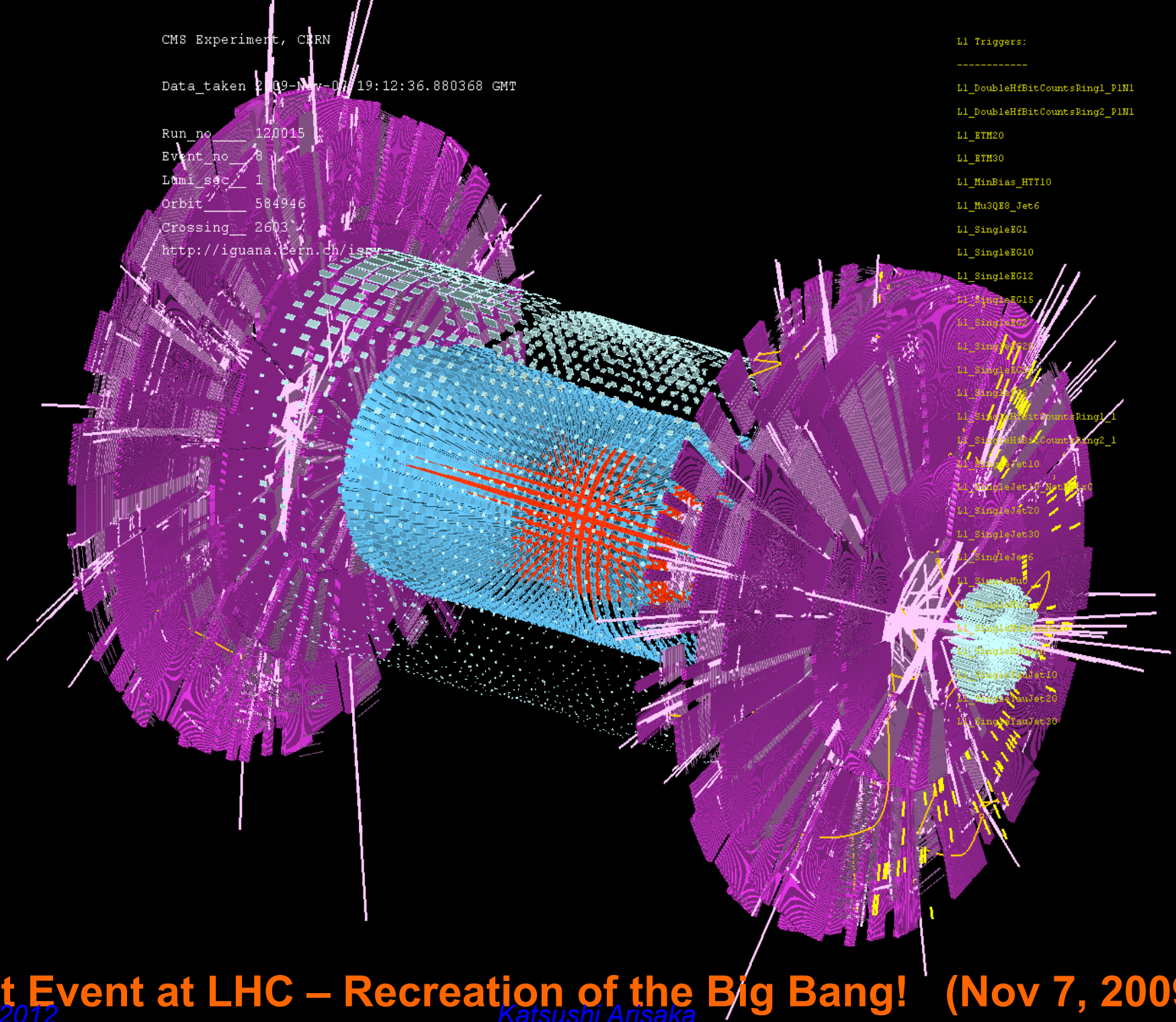

ME+2/2/03
ME+2/1/01
ME+2/2/35


VSL



Particle detectors constructed at Westwood, now at LHC, CERN

Sept 15, 2008 Issue

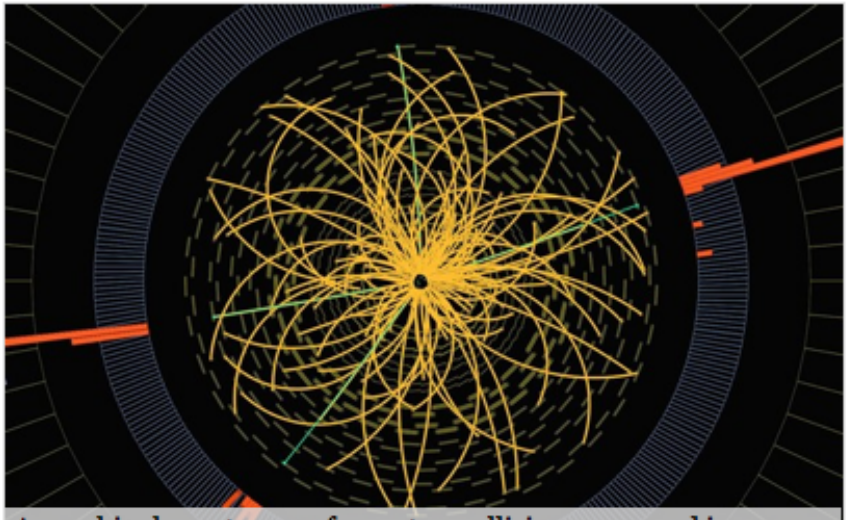


First Event at LHC – Recreation of the Big Bang! (Nov 7, 2009)

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

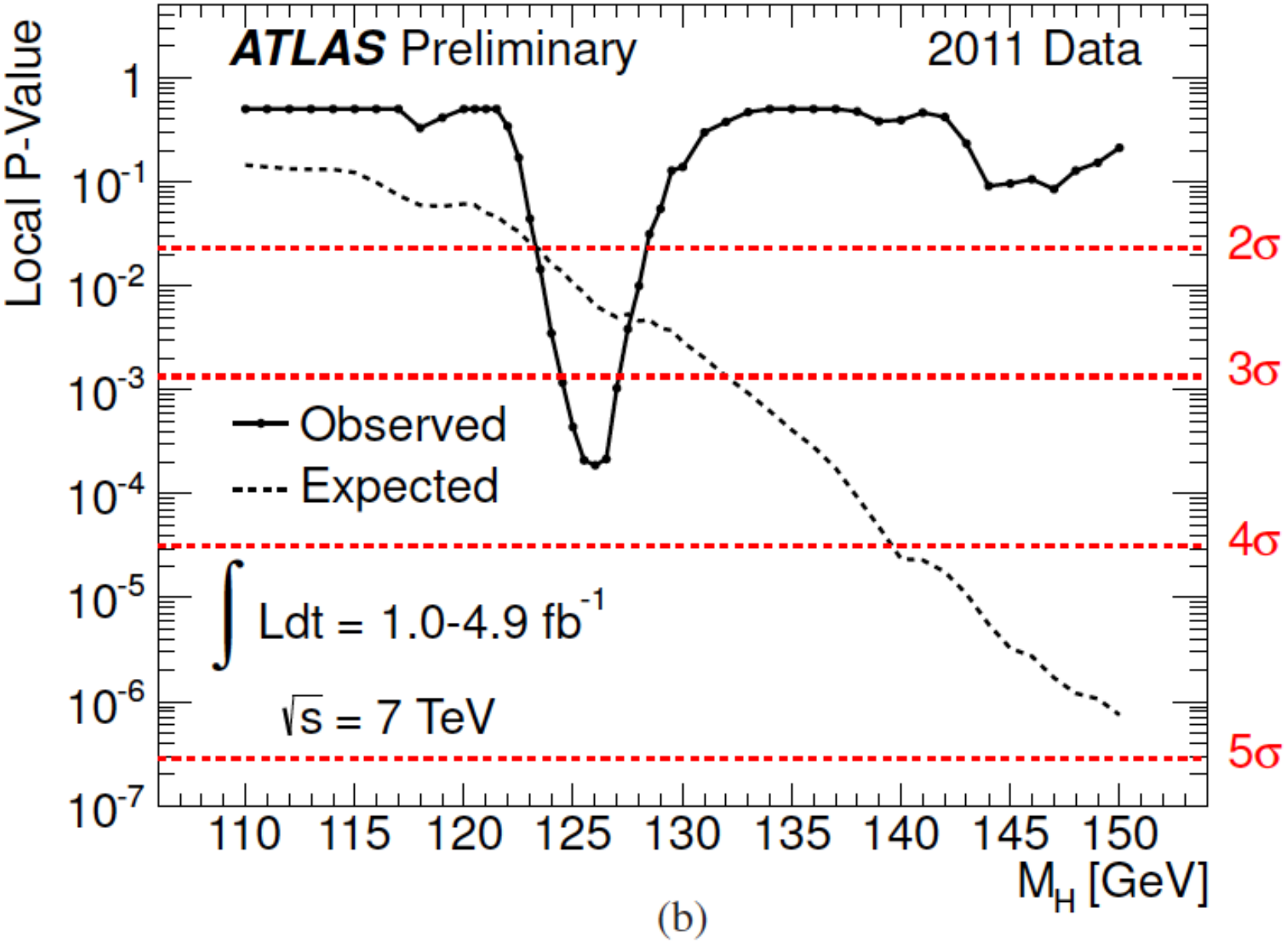


A graphic shows traces of a proton collision measured in a detector at the... (CERN)

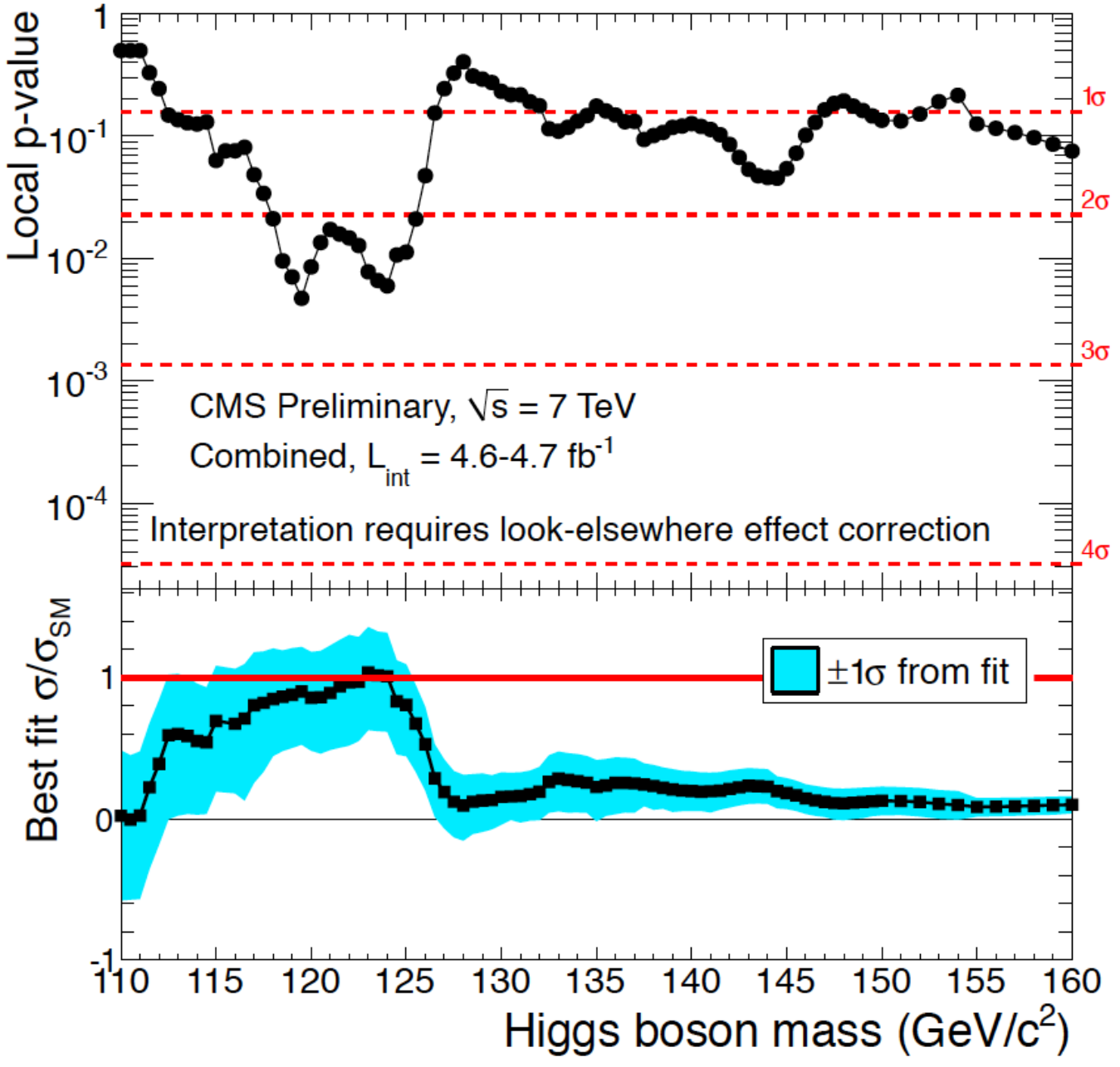
Physicists announced Tuesday that they had detected "tantalizing hints," but not definitive proof, of the long-sought Higgs boson, the so-called God particle that is crucial to physicists' understanding of why mass exists in the universe.

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.

ATLAS Higgs Results

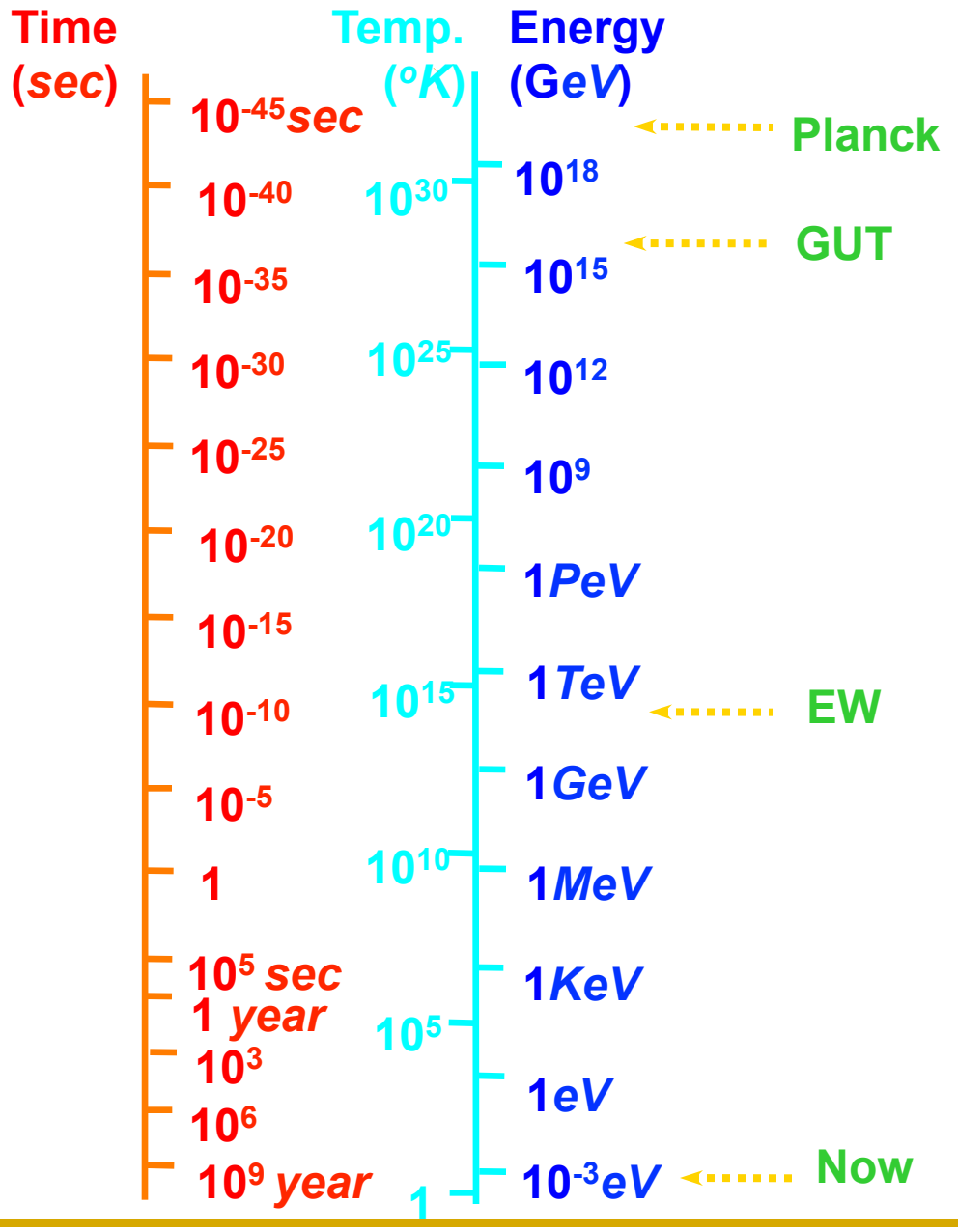


CMS Higgs Results



Dark Matter and Dark Energy

“Fossils” from the Earliest Universe



The Big Bang!

Gravitational Wave

GUT Particle

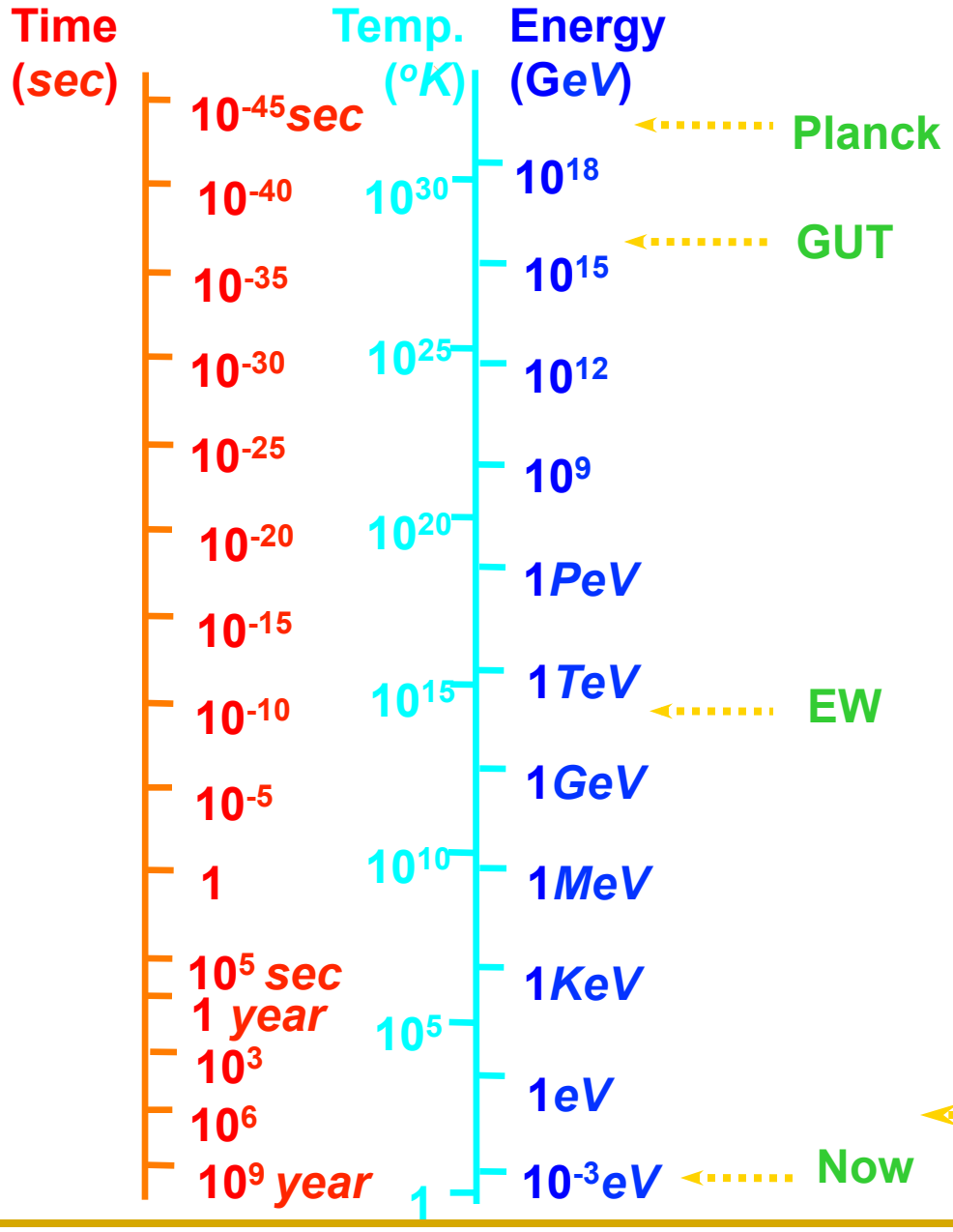
Decoupling of “Fossils”

Neutralino
(Cold Dark Matter)

Relic Neutrino
(Hot Dark Matter)

CMB

Cosmic Microwave Background (CMB)
Matter-Radiation Decoupling



Time = 300,000 *years*

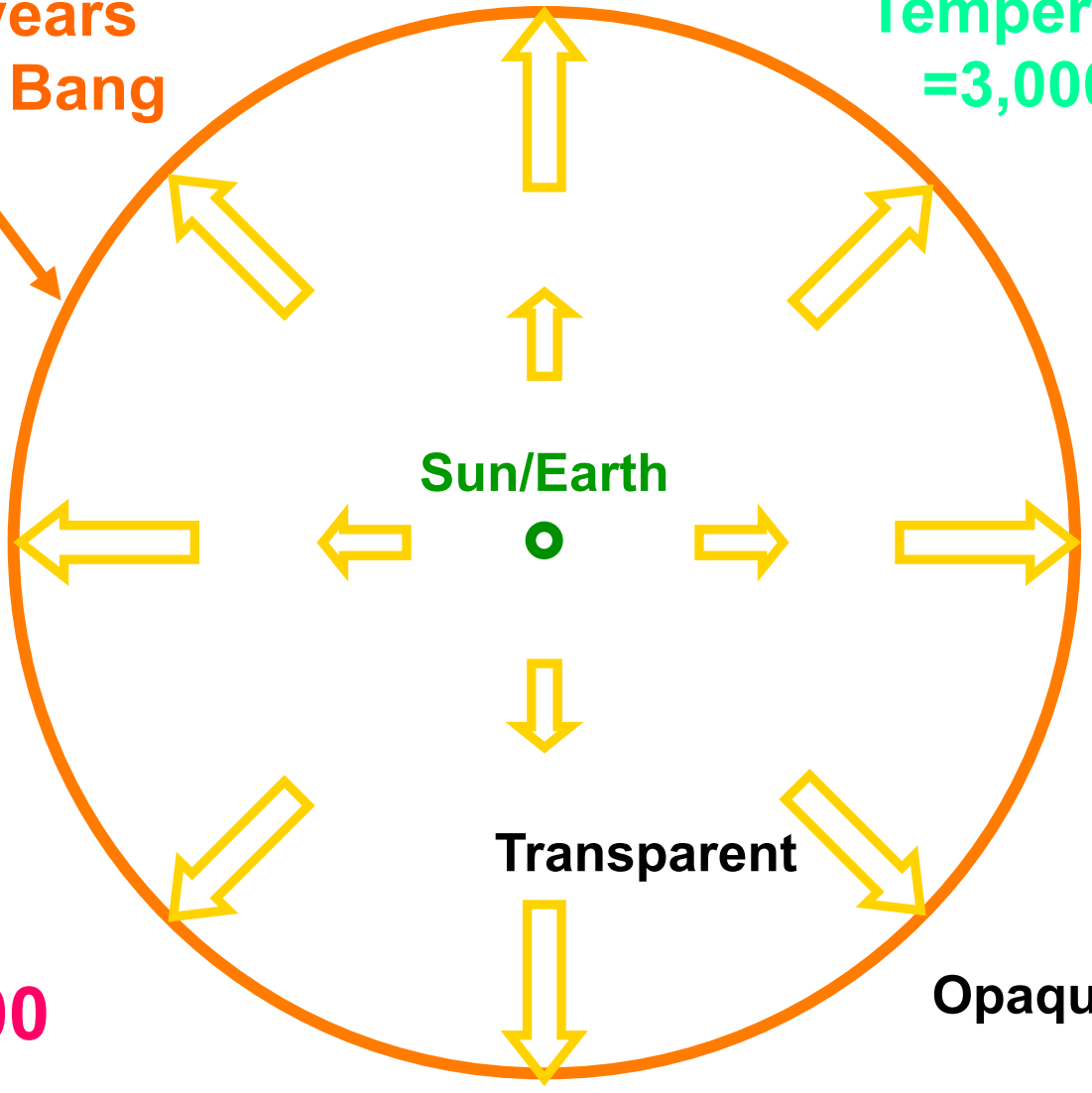
Temperature = 3,000 ^oK

Energy = 0.3 *eV*

Z = 1,100

Matter-Radiation Decoupling ⇒ ***CMB***

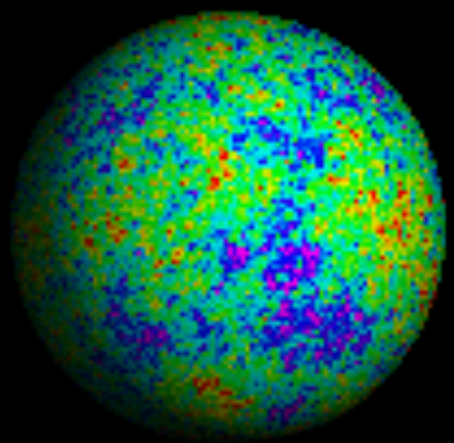
Cosmic Microwave Background
(Discovered in 1964)



Today:
3000°K/1,100
=2.7°K

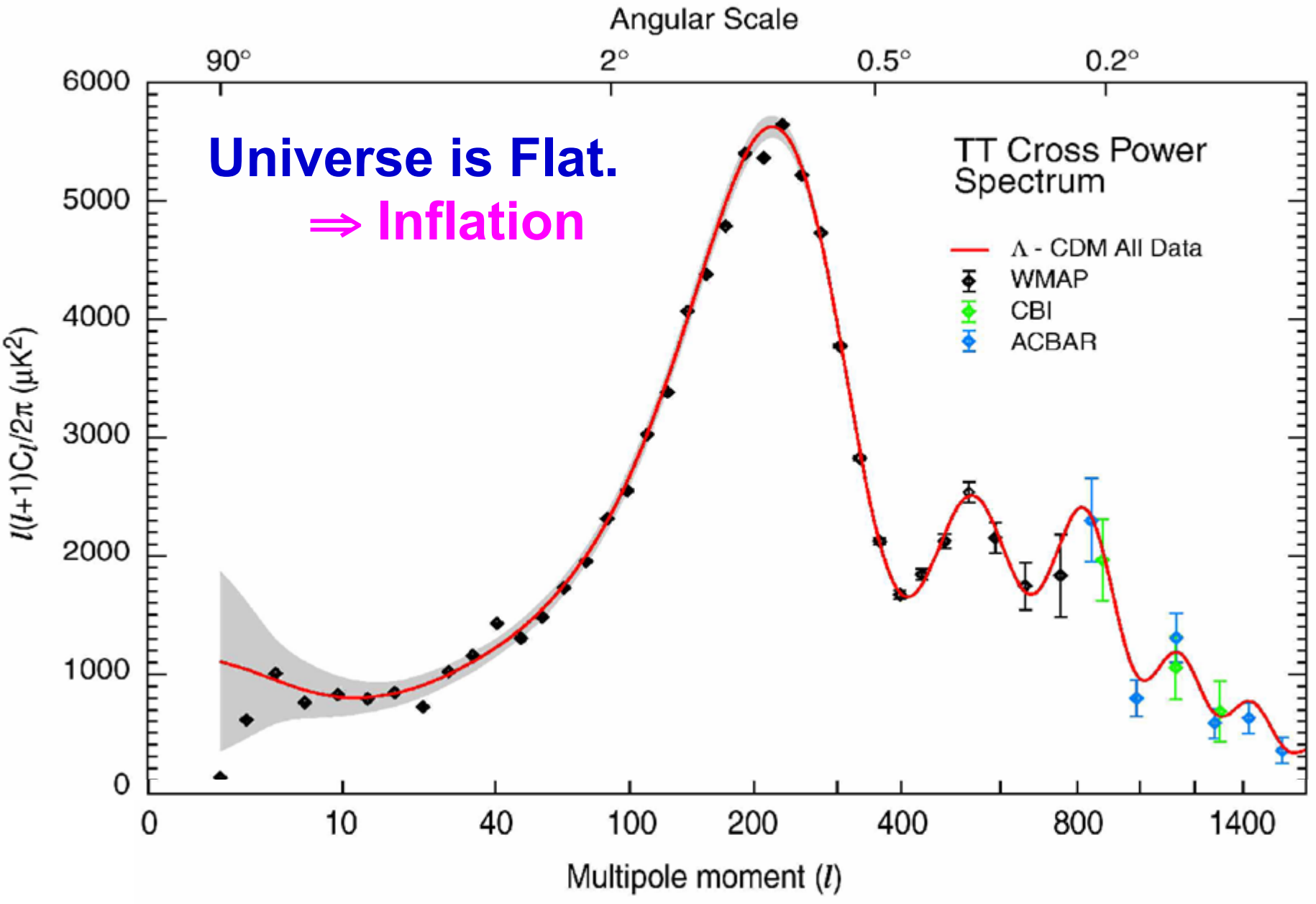
WMAP

Ned Wright



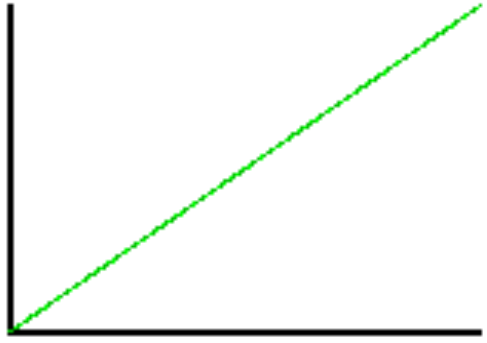
P map from Tegmark, de Oliveira-Costa & Hamilton, astro-ph/0302496

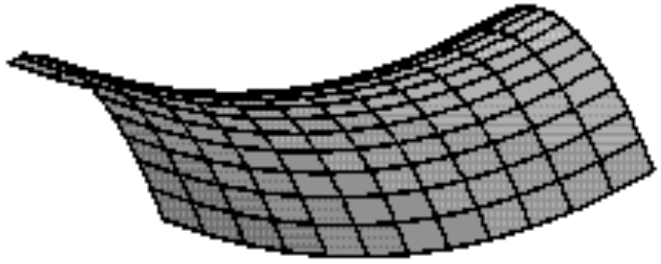
WMAP Power Spectrum



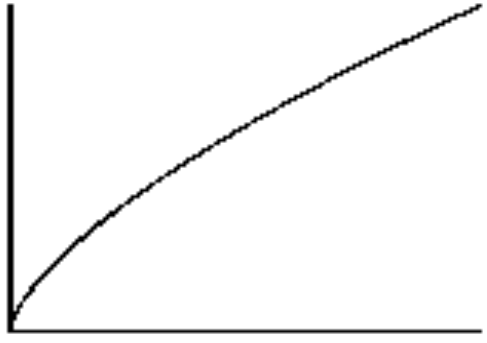
Geometry of the Universe

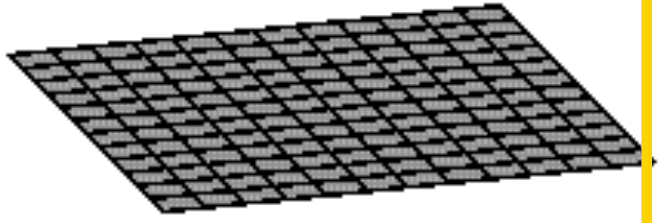
Open $\Omega<1$



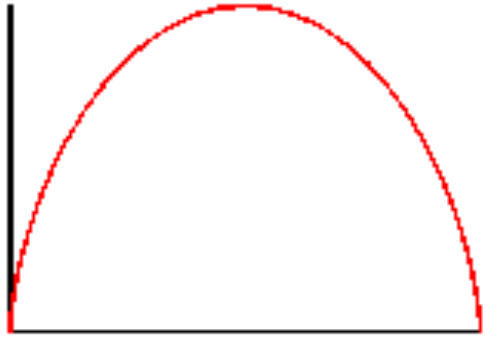


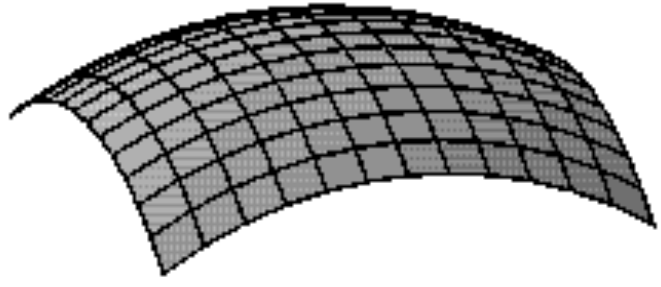
Flat $\Omega=1$
(predicted by Inflation)



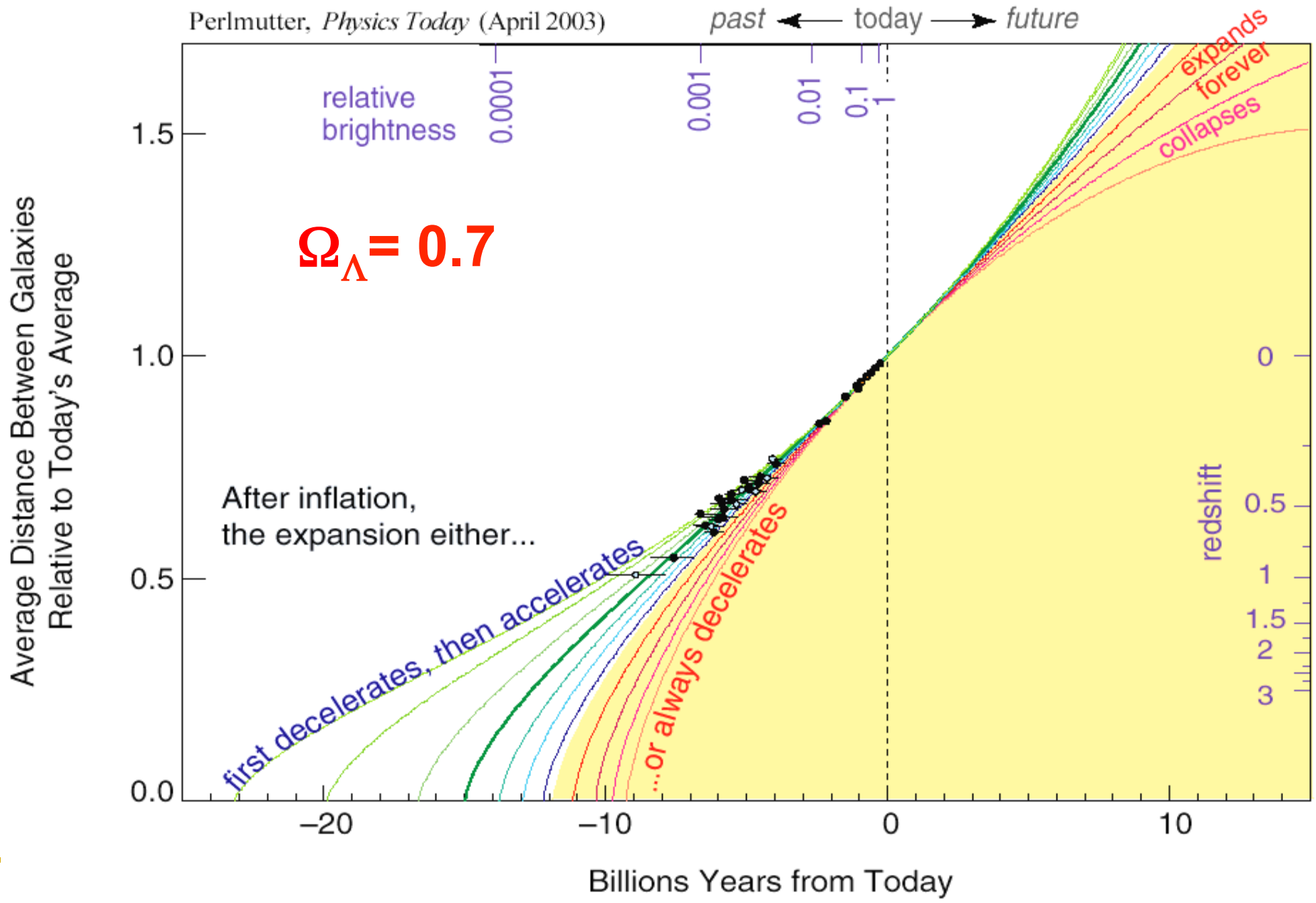


Closed $\Omega>1$



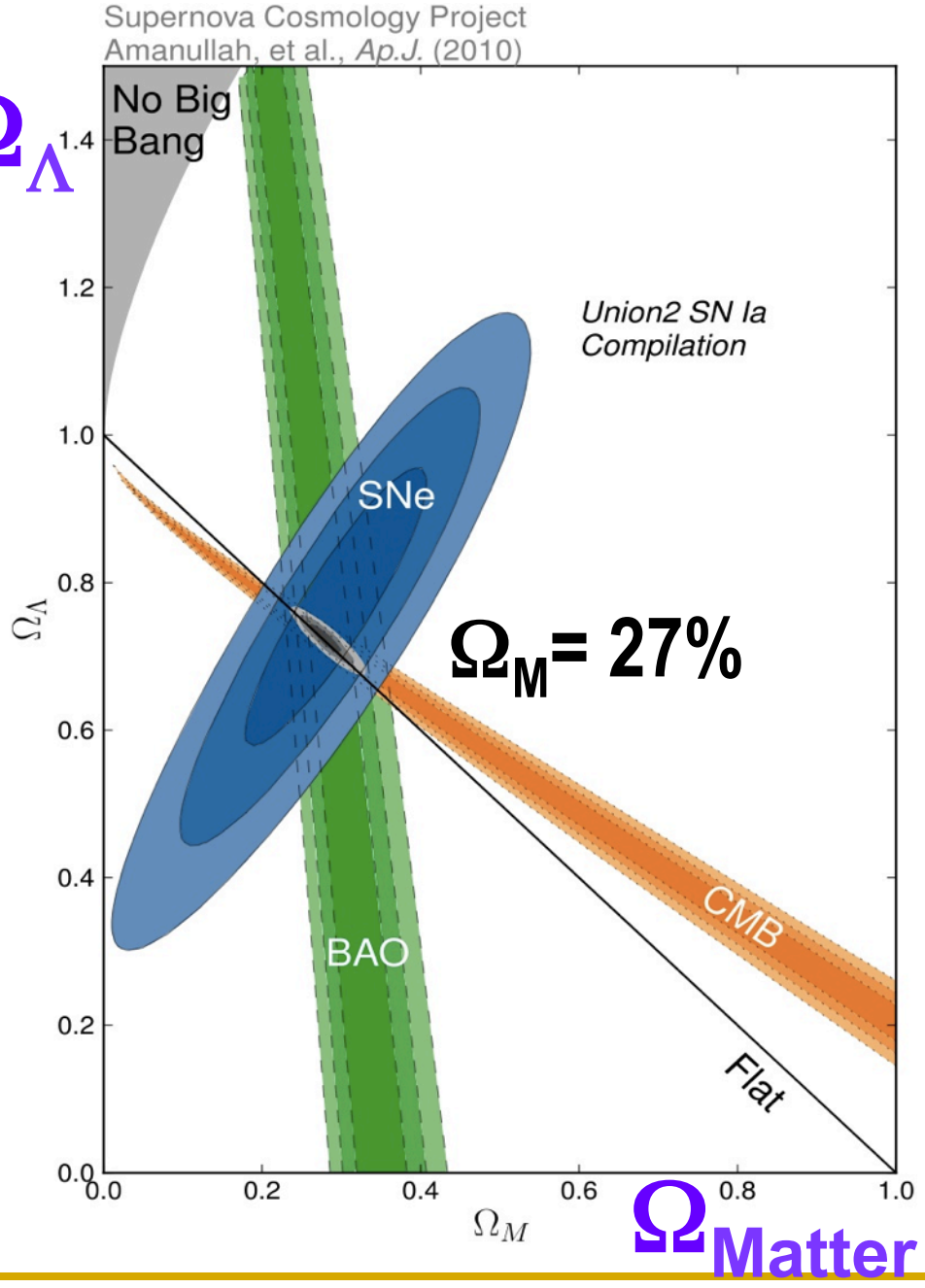


The Accelerating Universe (1998)

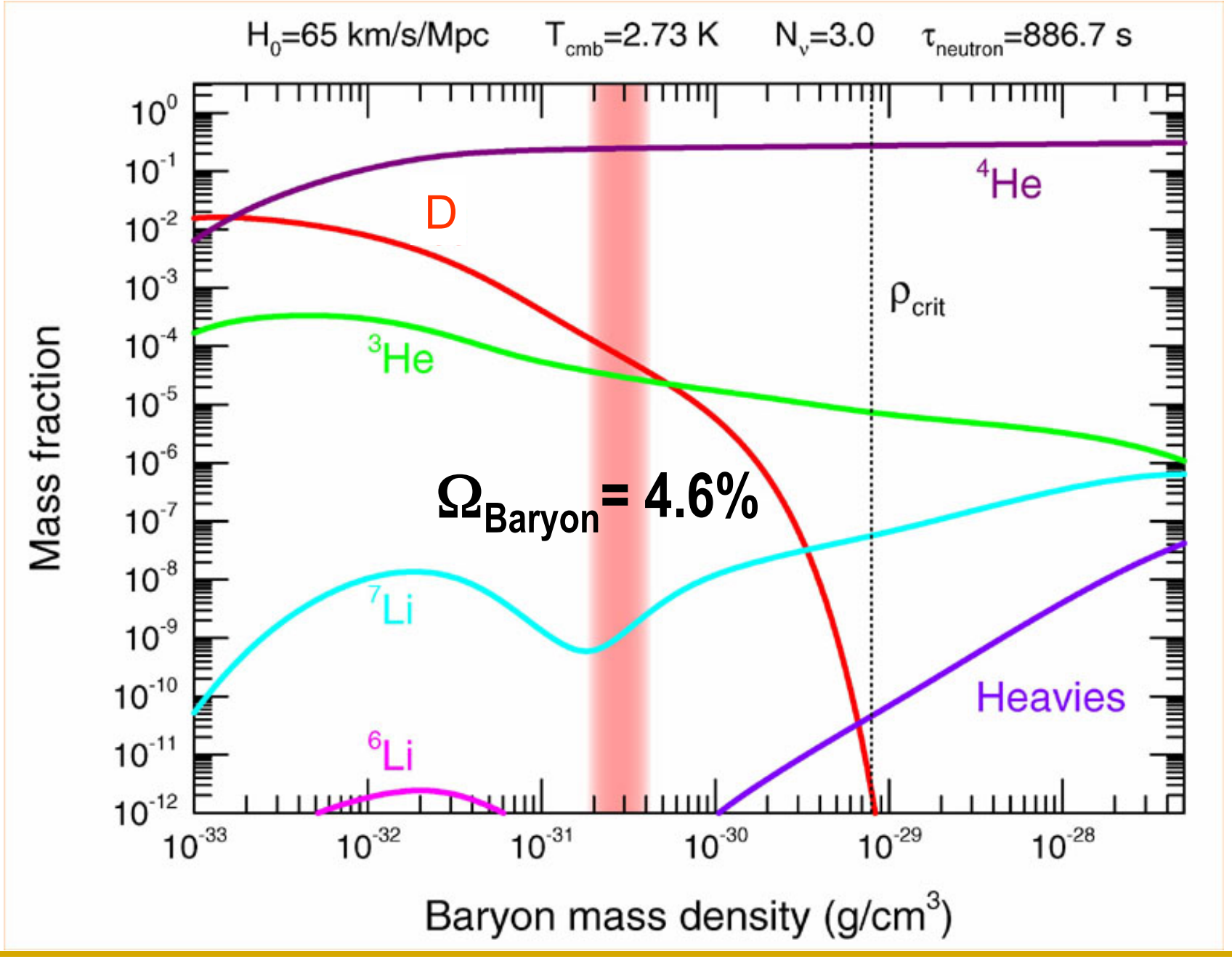


Density of Our Universe

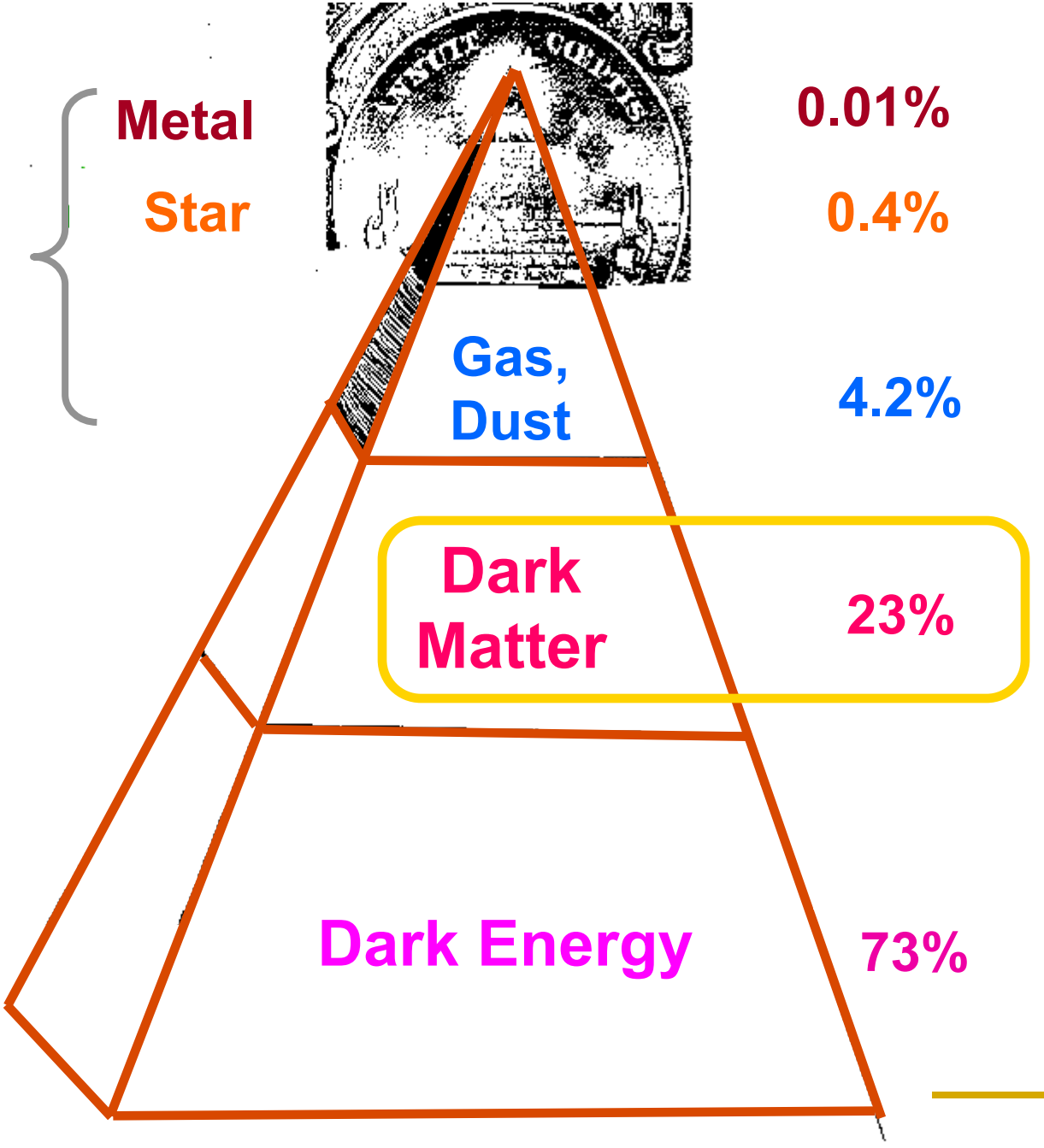
- $\Omega_{Total}=\Omega_{\Lambda}+\Omega_{Matter}=1.0$
- Universe is Flat.
  - ⇒ Inflation
- 73% is Dark Energy.
  - ⇒ Accelerating



Abundance vs. Density



Cosmic Pyramid

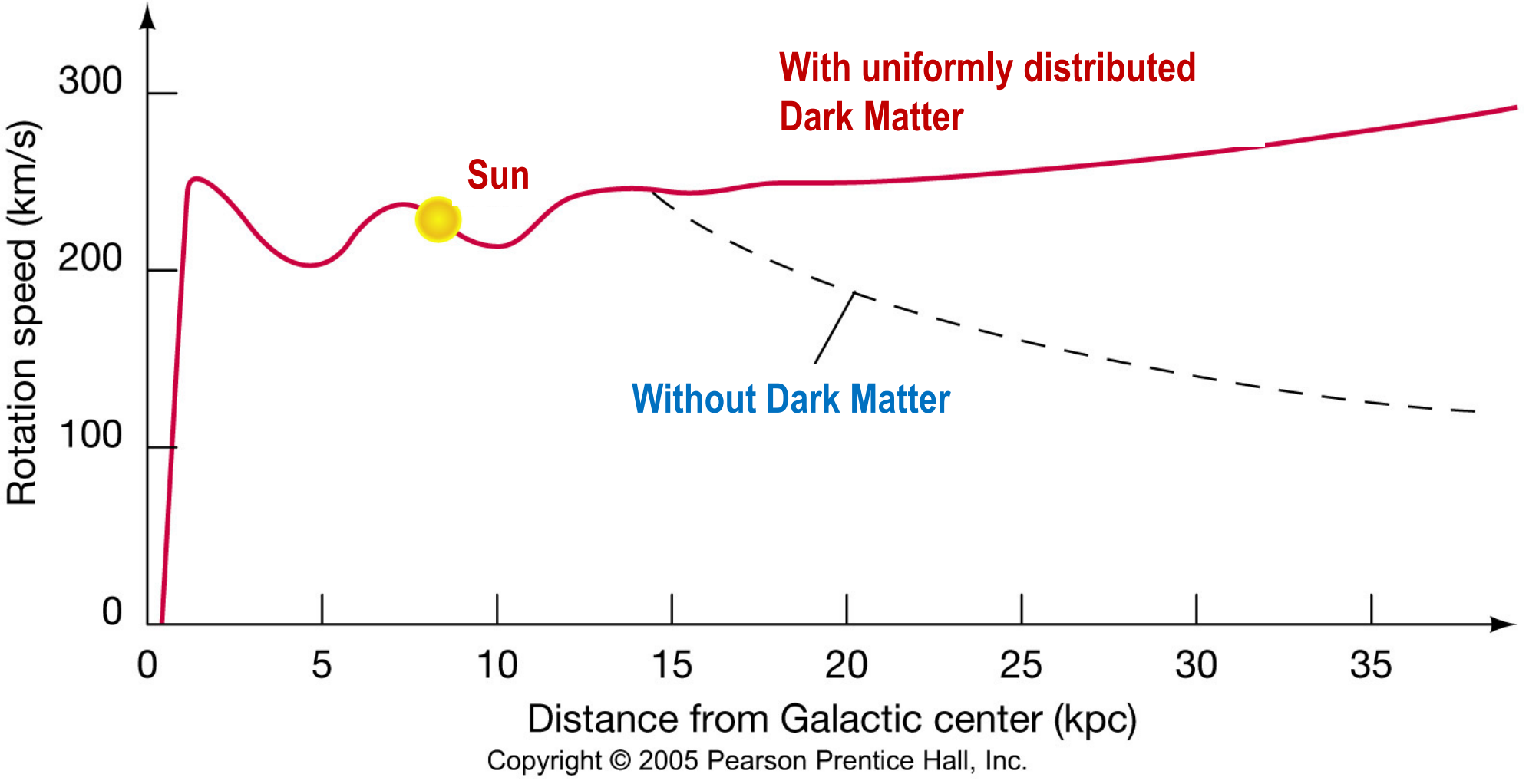


Part II

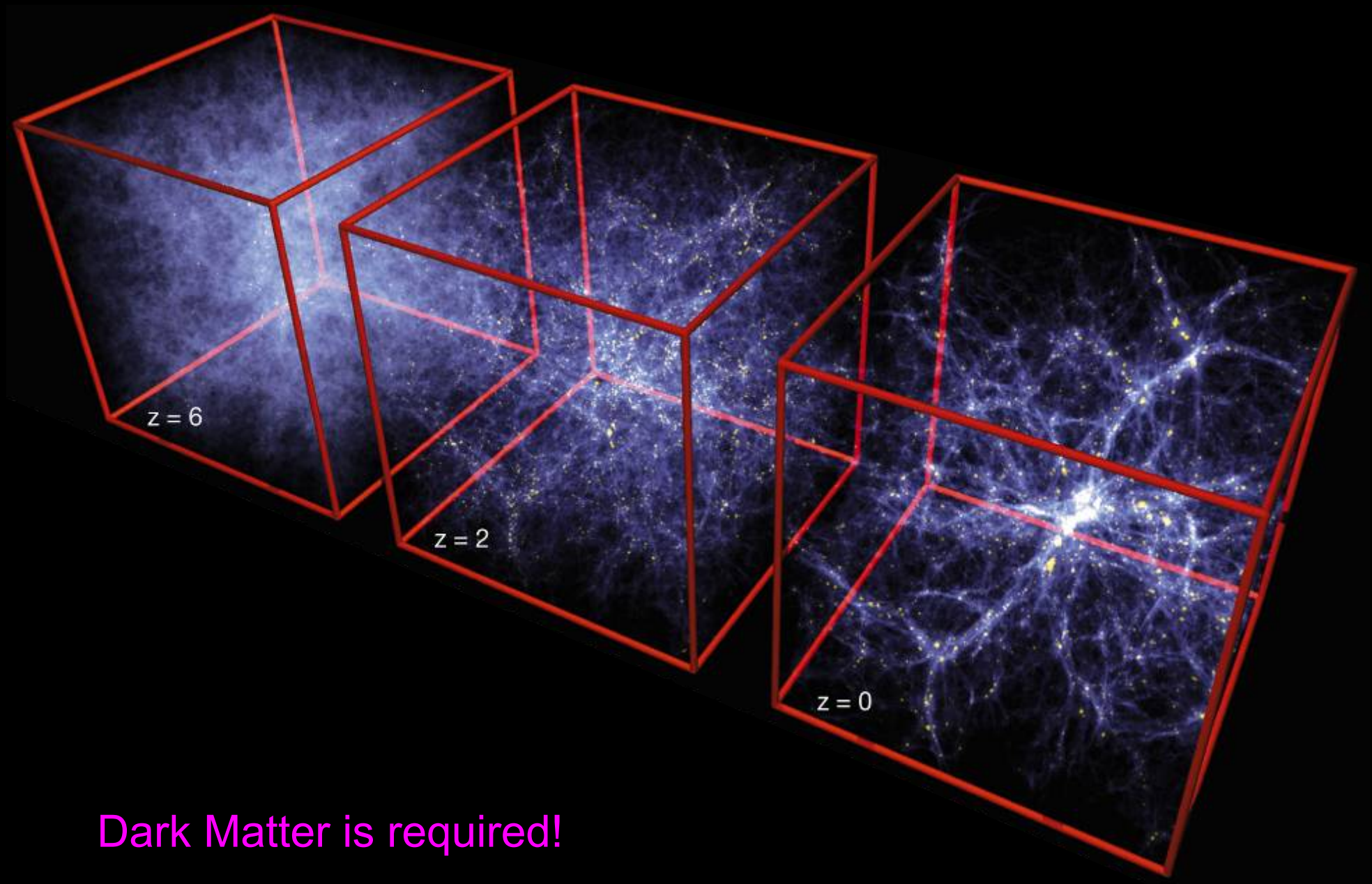
Search for Dark Matter


Dark Matter is required!
ANDROMEDA
GALAXY

Rotational Velocity of Galaxies

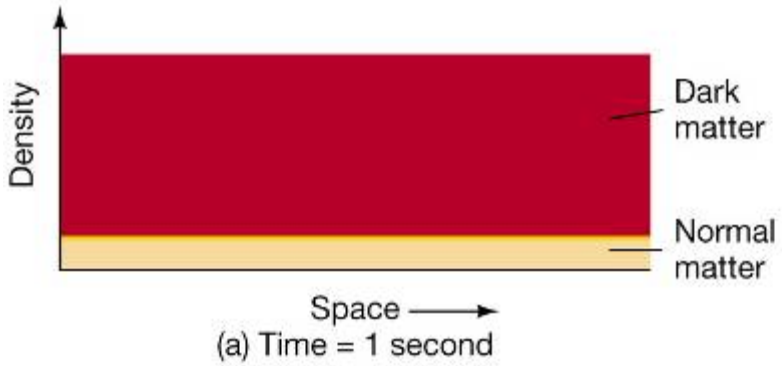


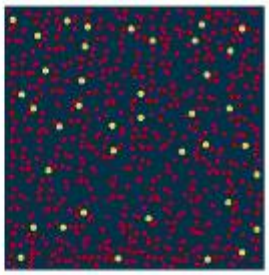
Formation of Structure in the Universe

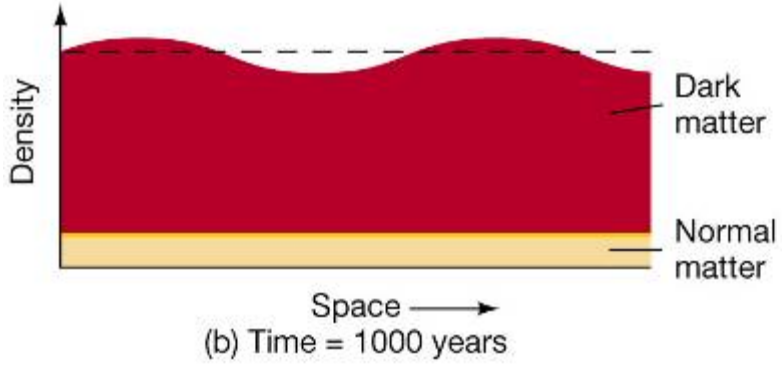


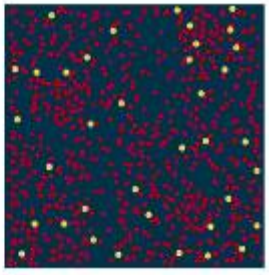
Dark Matter is required!

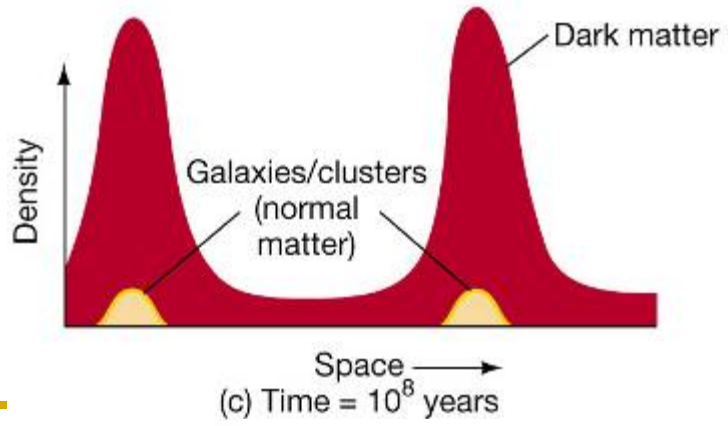
Evolution of Large Structure

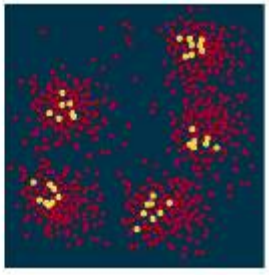




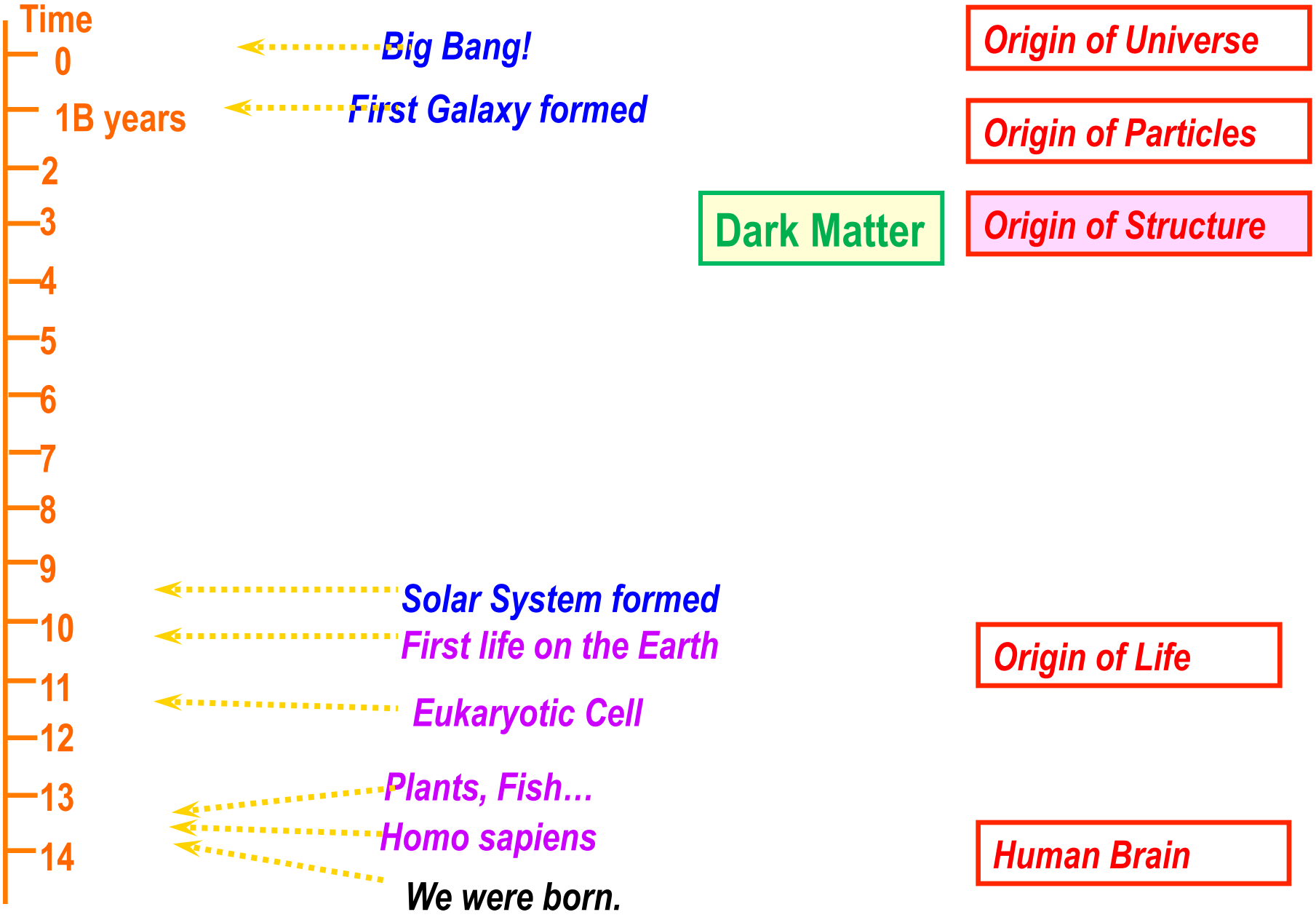




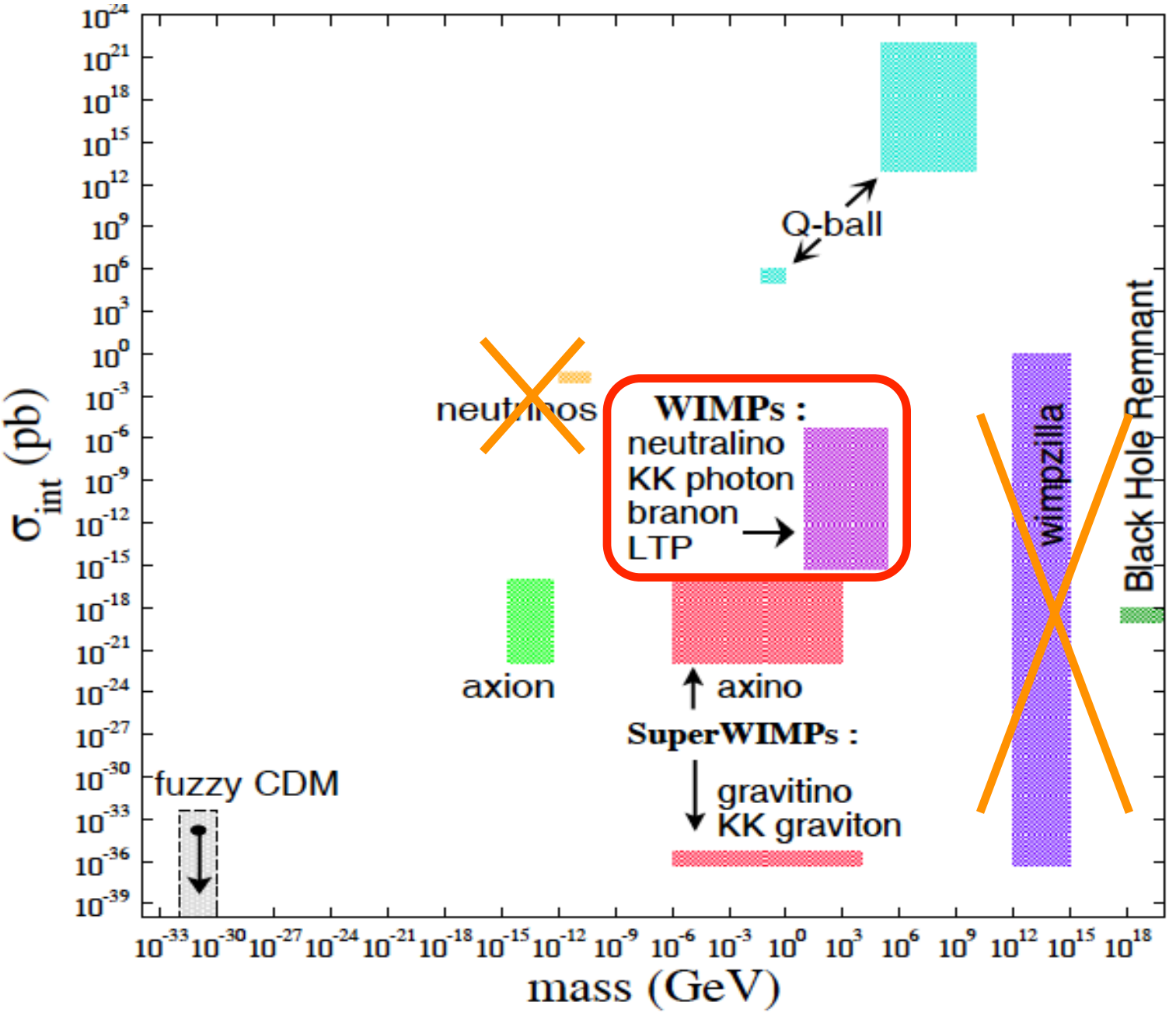




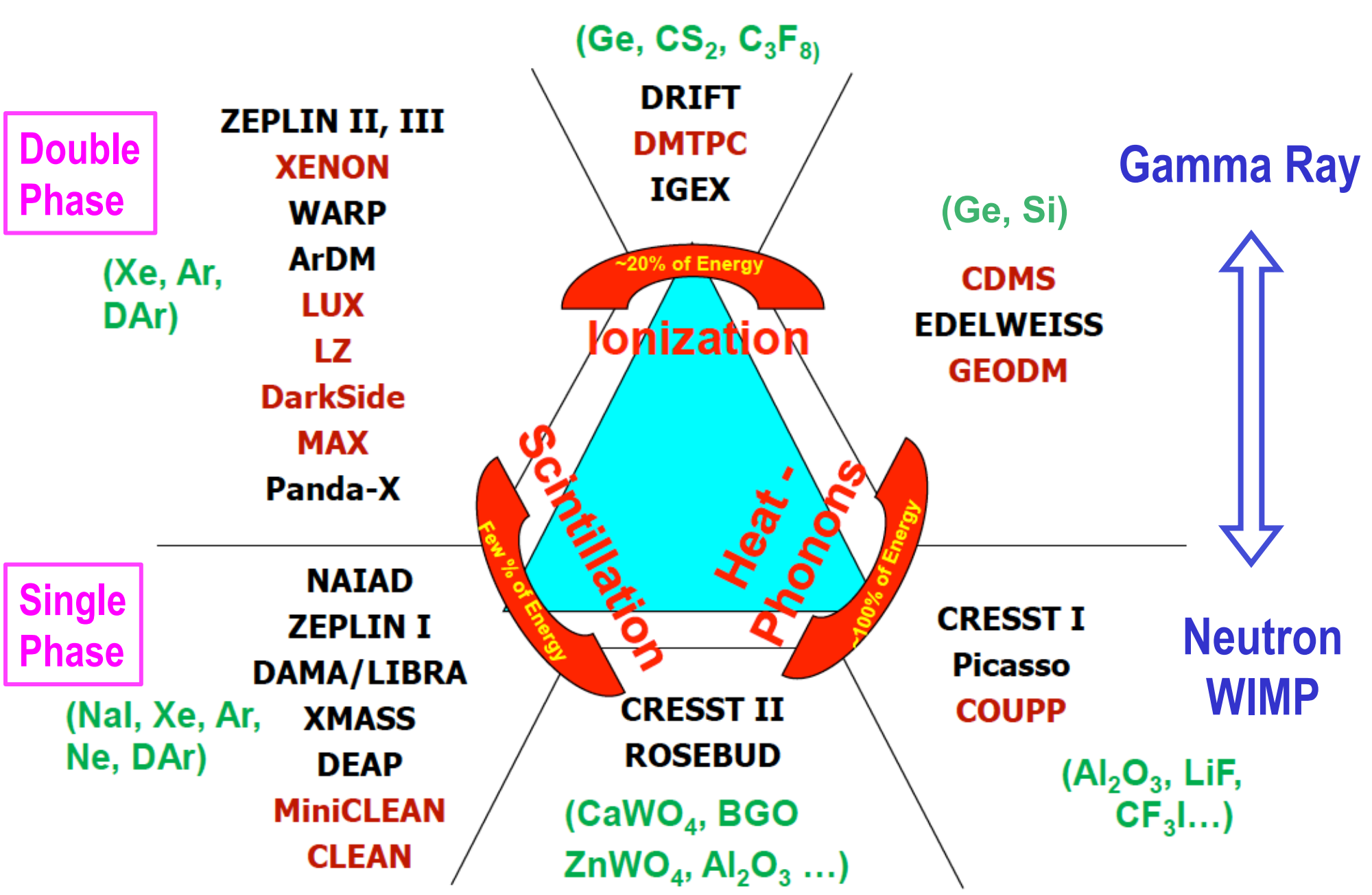
The Five Largest Mysteries in Nature



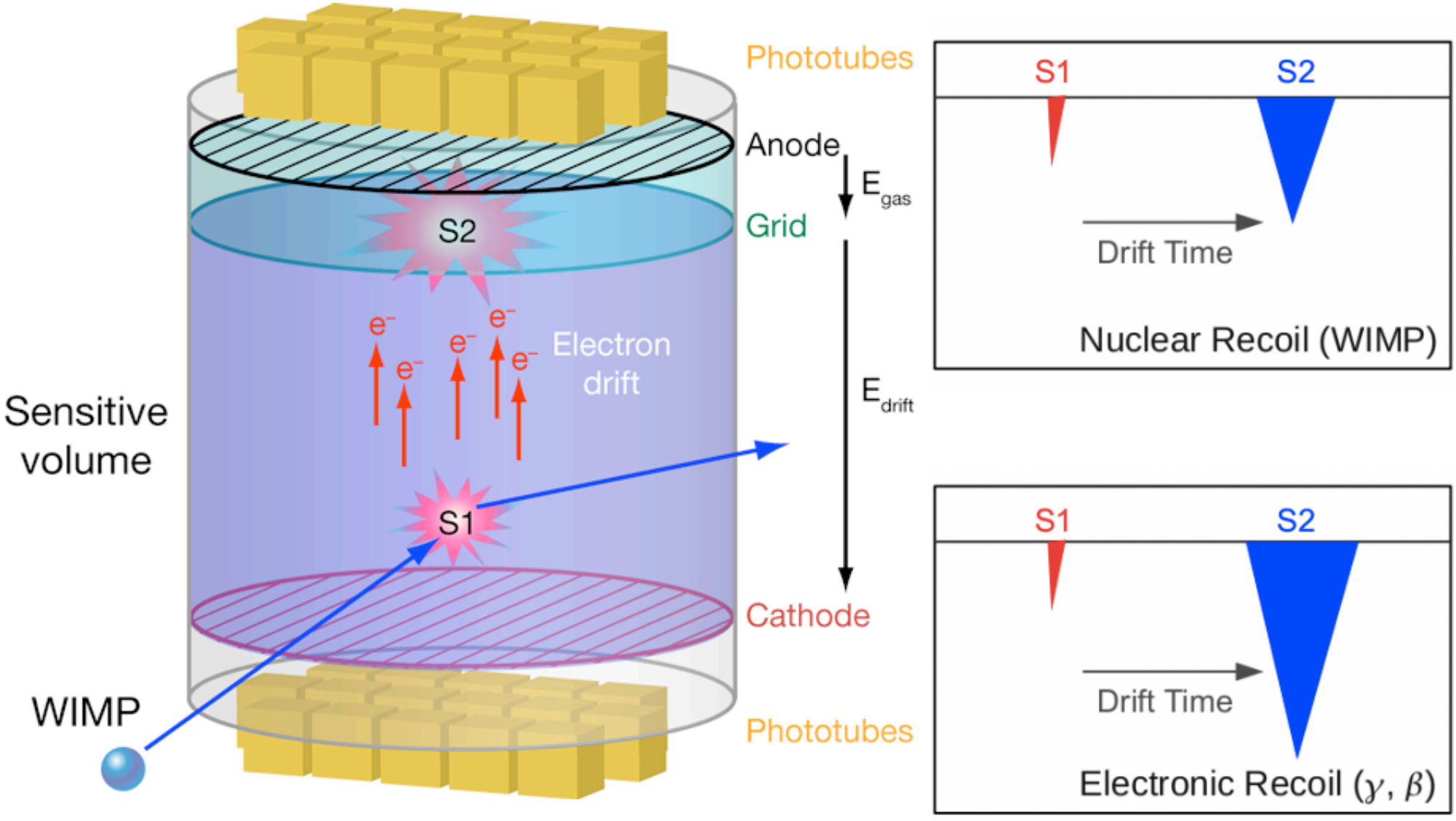
What is Dark Matter?



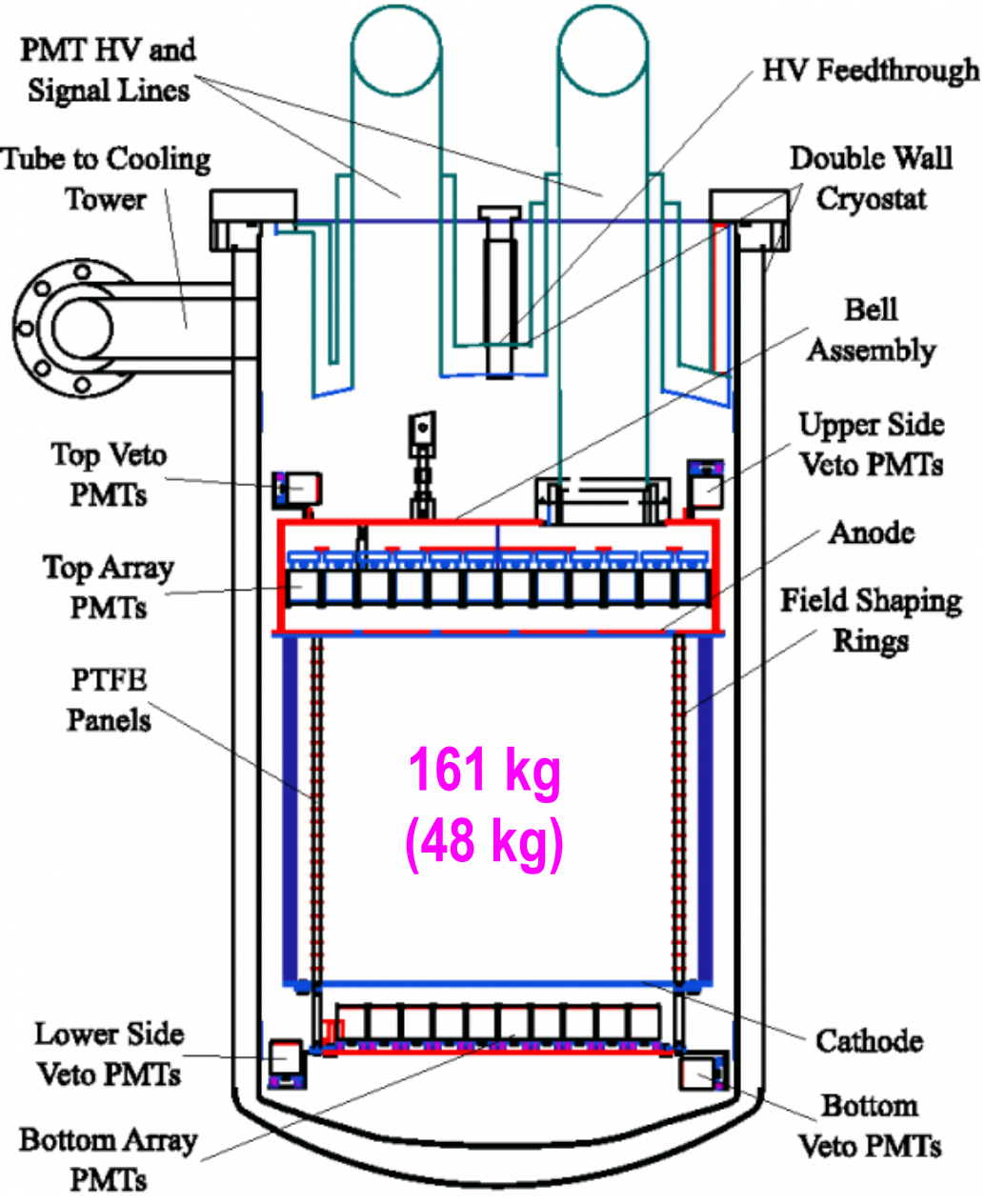
Detection Technique

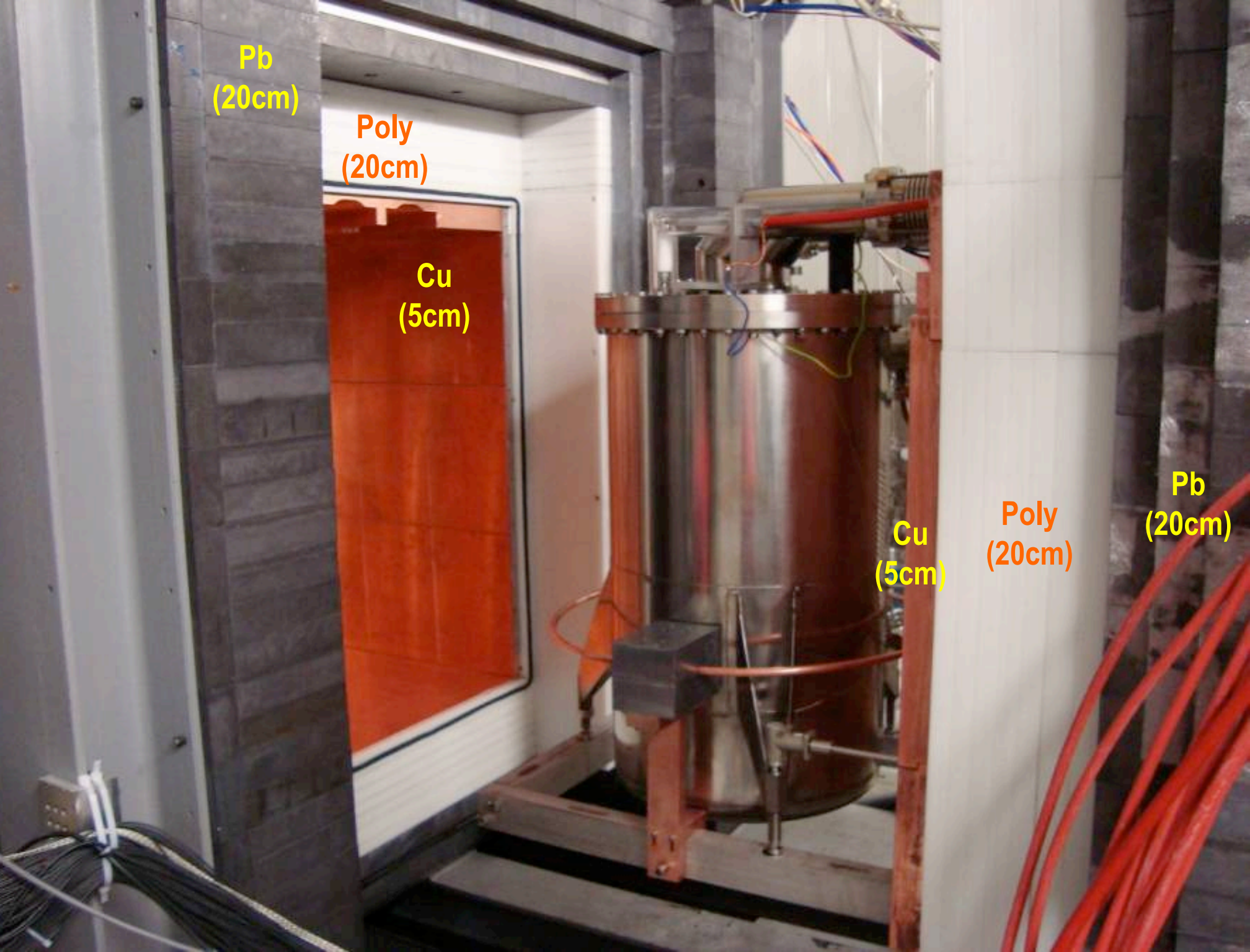


Double-Phase Noble Liquids



XENON100 Detector

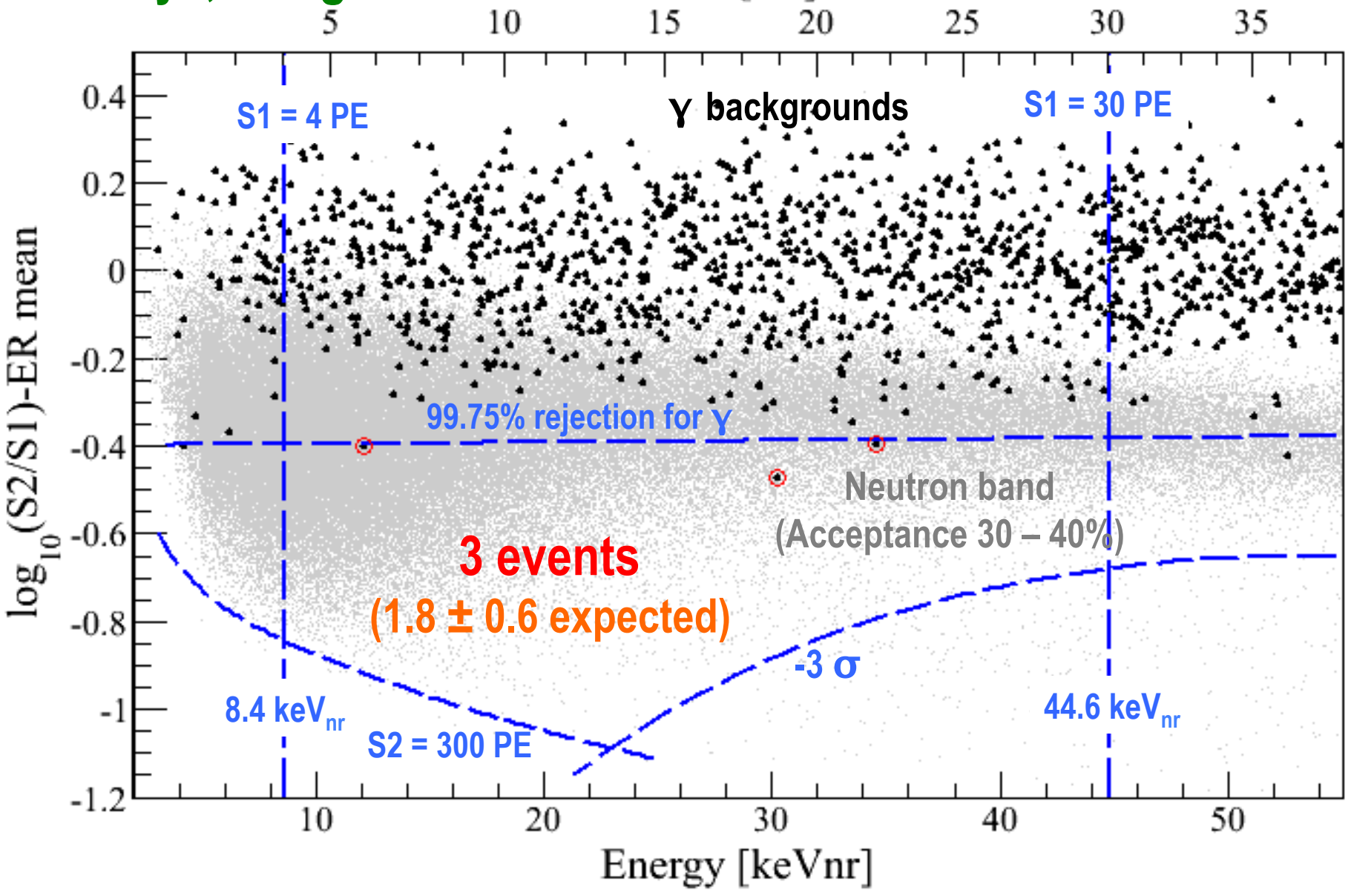



Pb
(20cm)
Poly
(20cm)
Cu
(5cm)
Cu
(5cm)
Poly
(20cm)
Pb
(20cm)

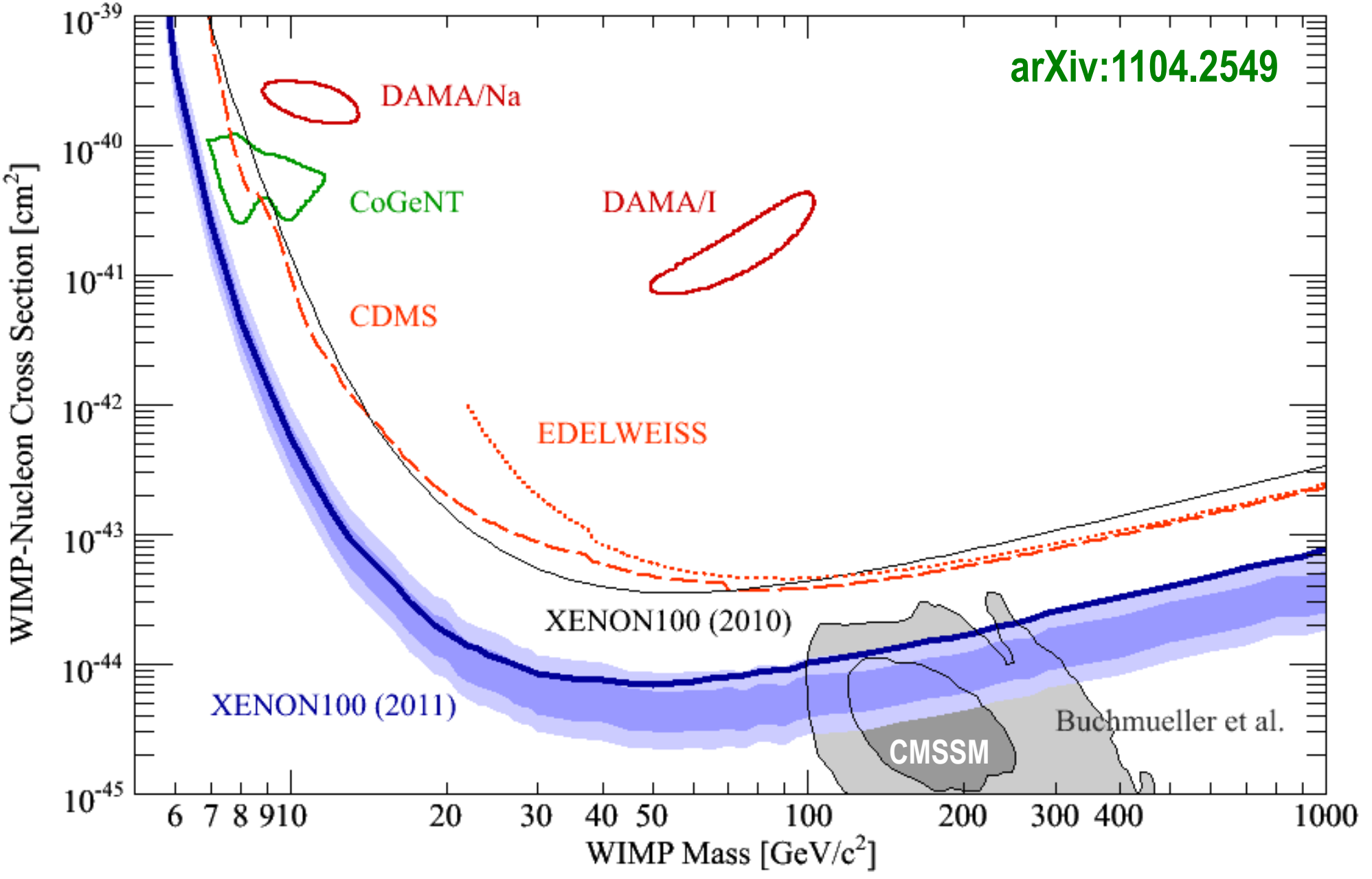
Log(S2/S1) vs. Energy

100.9 days, 48 kg

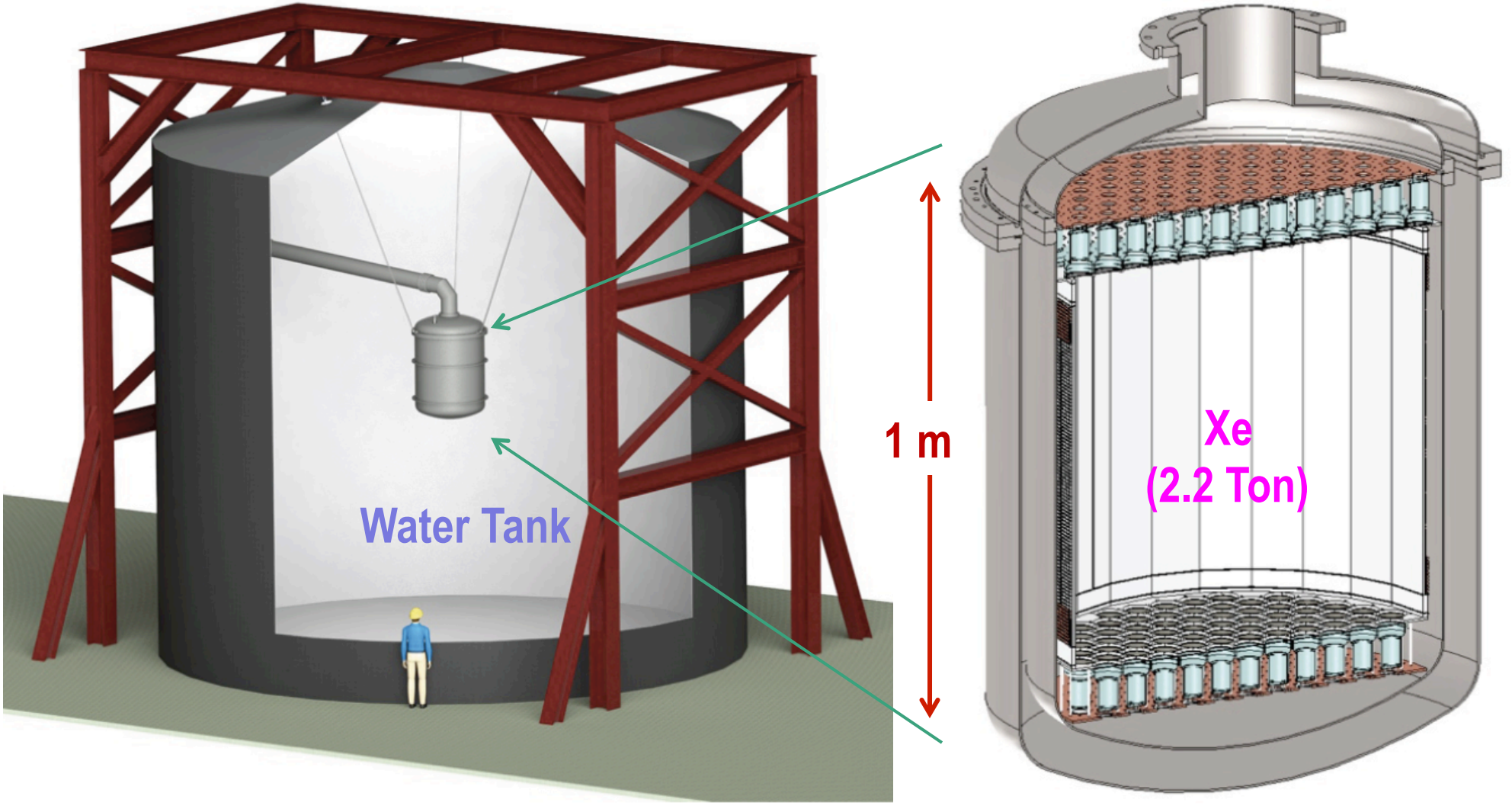
arXiv:1104.2549

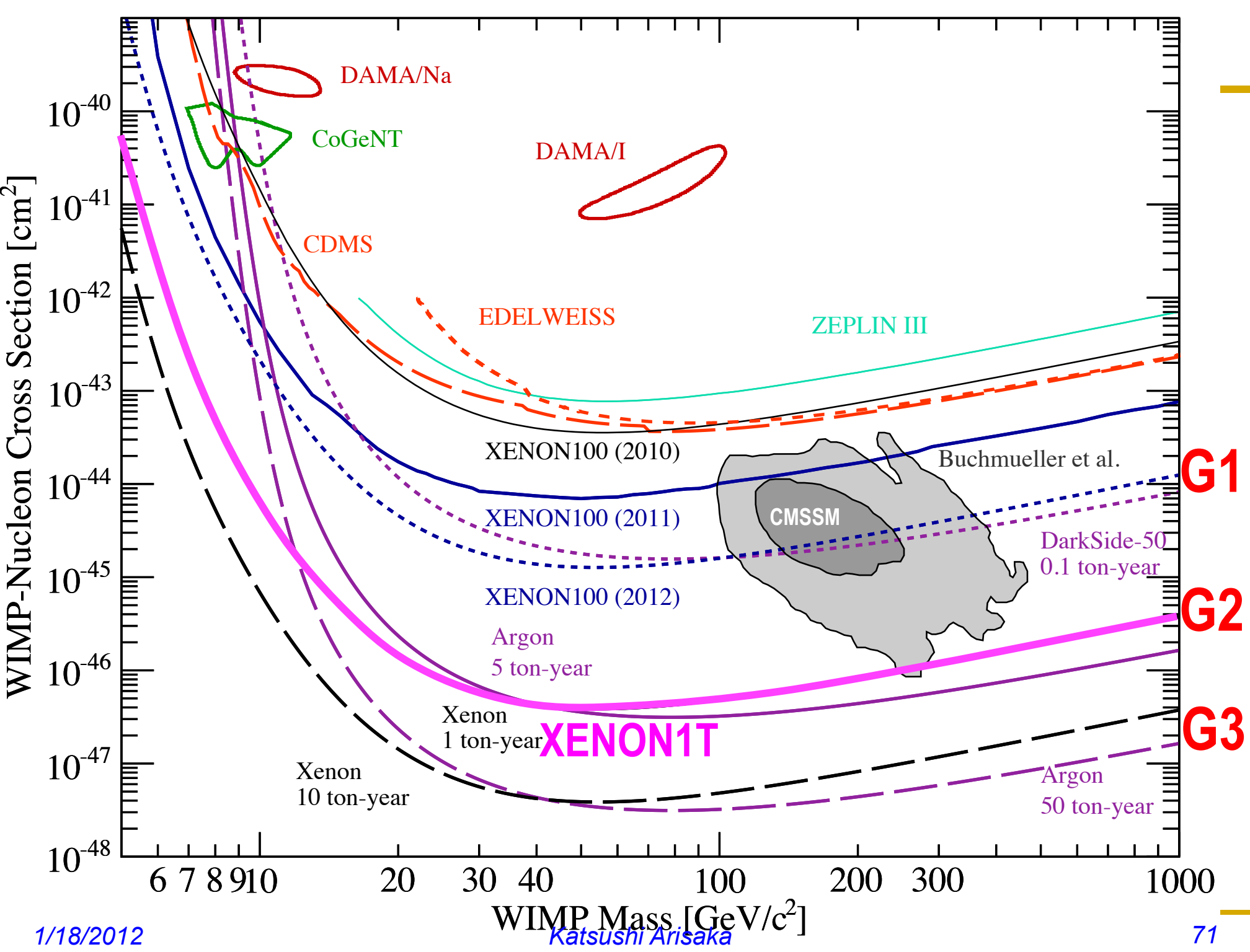


90% CL Limits of SI Cross Section (April, 2011)

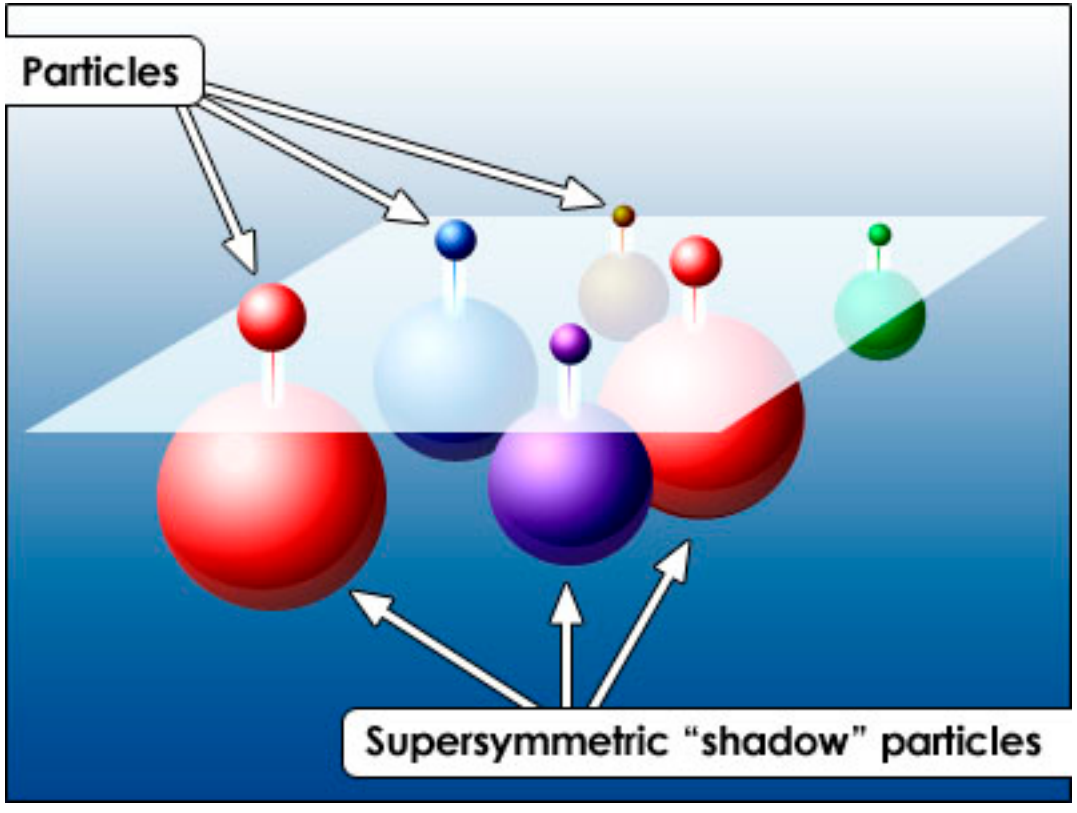


XENON1T (G2) at LNGS

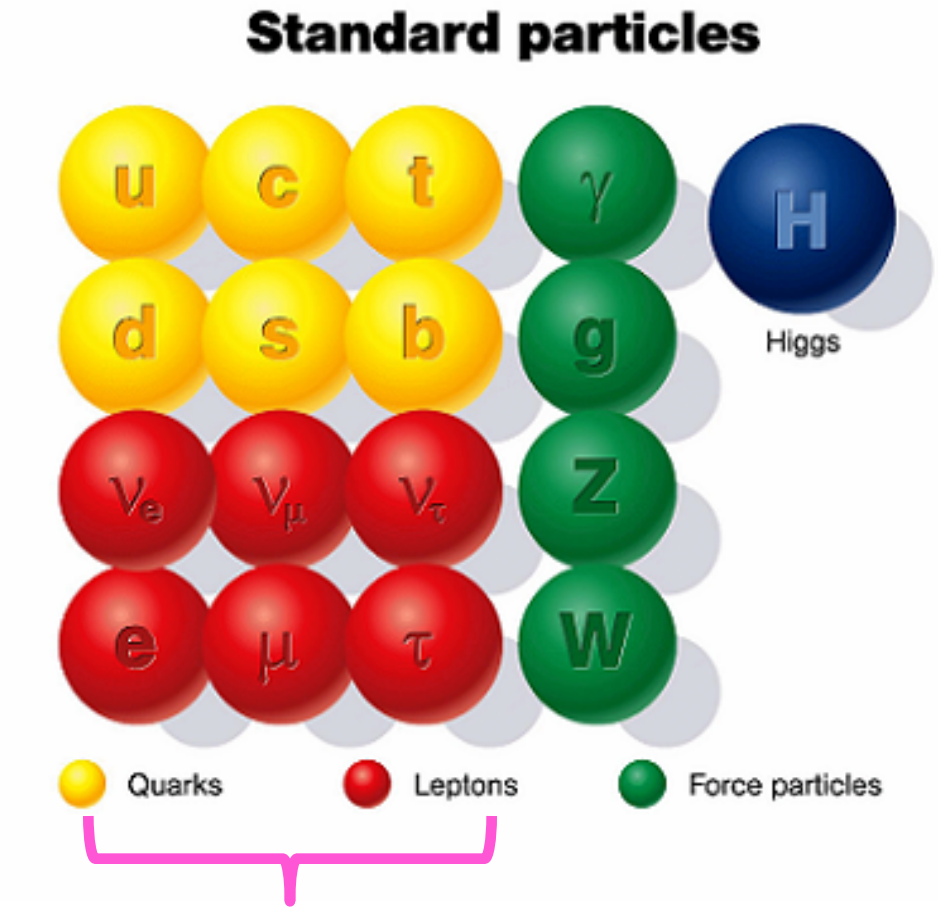



DAMA/Na
CoGeNT
DAMA/I
CDMS
EDELWEISS
ZEPLIN III
XENON100 (2010)
XENON100 (2011)
XENON100 (2012)
Buchmueller et al.
CMSSM
DarkSide-50
0.1 ton-year
Argon
5 ton-year
Xenon
1 ton-year
XENON1T
Xenon
10 ton-year
Argon
50 ton-year
G1
G2
G3
WIMP-Nucleon Cross Section [cm^2]
WIMP Mass [GeV/c^2]
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
6 7 8 9 10 20 30 40 100 200 300 1000

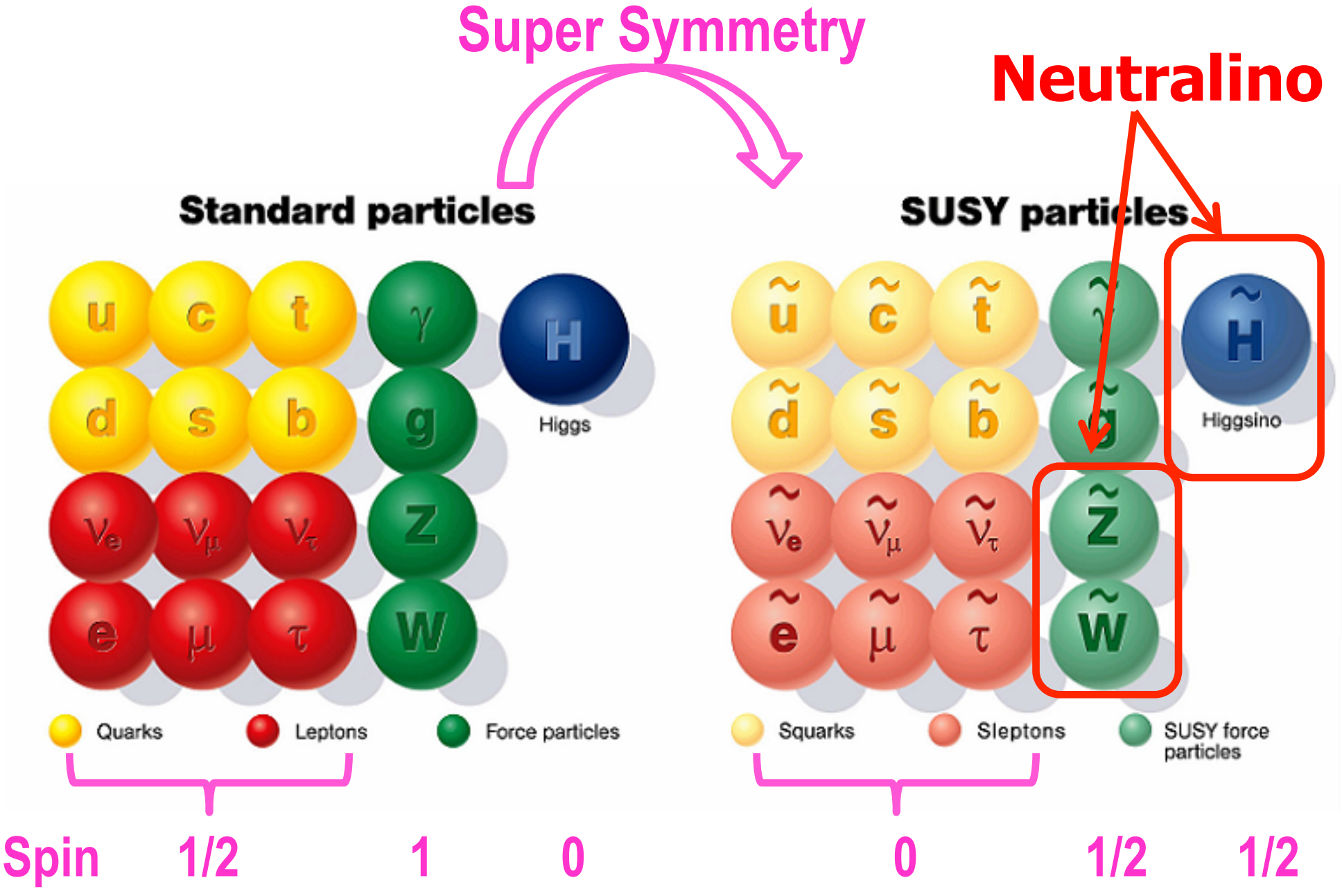
SUSY Neutralino



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

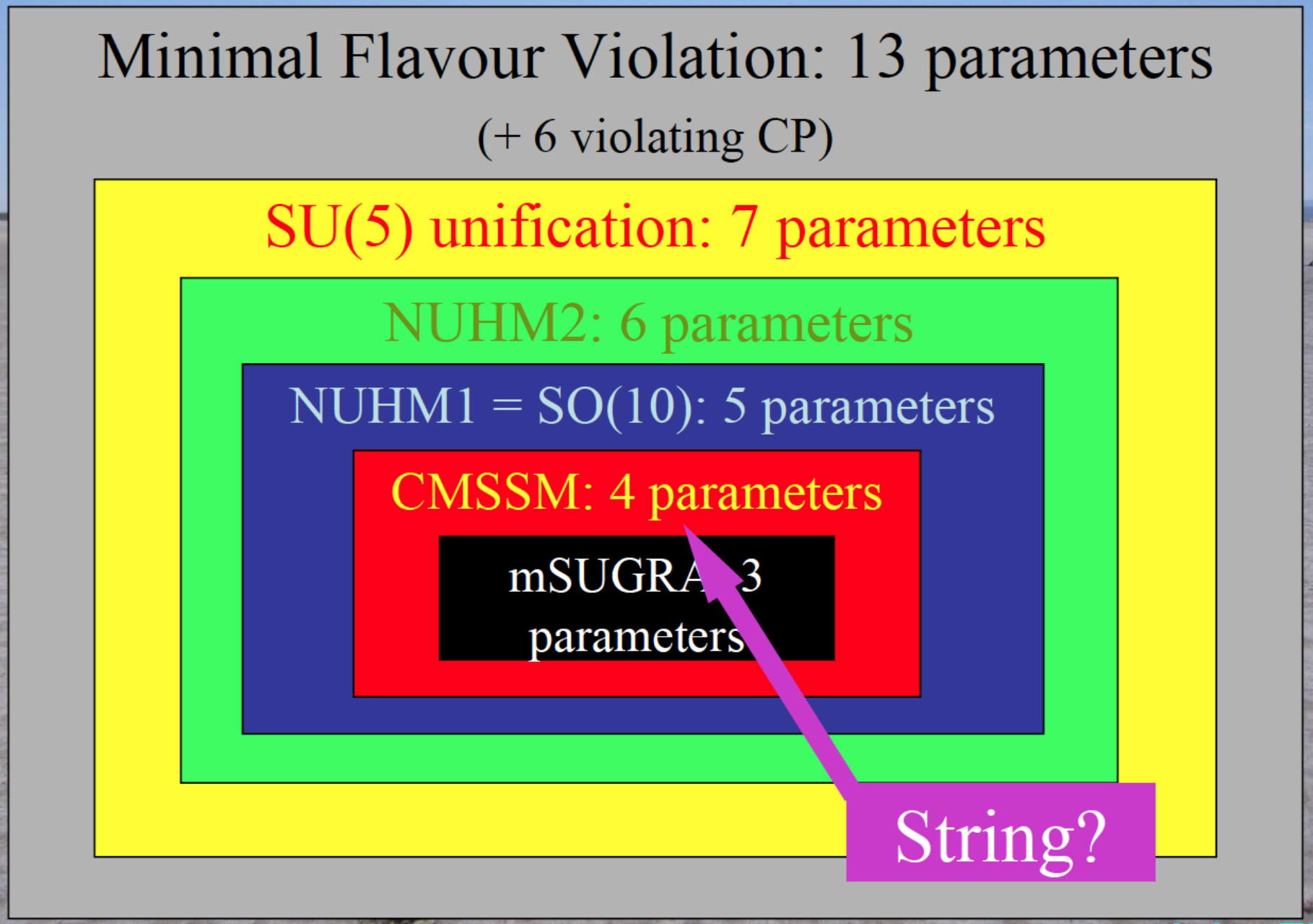
SM :
$$\Delta m_h^2 \sim \frac{\lambda^2}{16\pi^2}\int^{\Lambda}\frac{d^4p}{p^2} \sim \frac{\lambda^2}{16\pi^2}\Lambda^2$$

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)

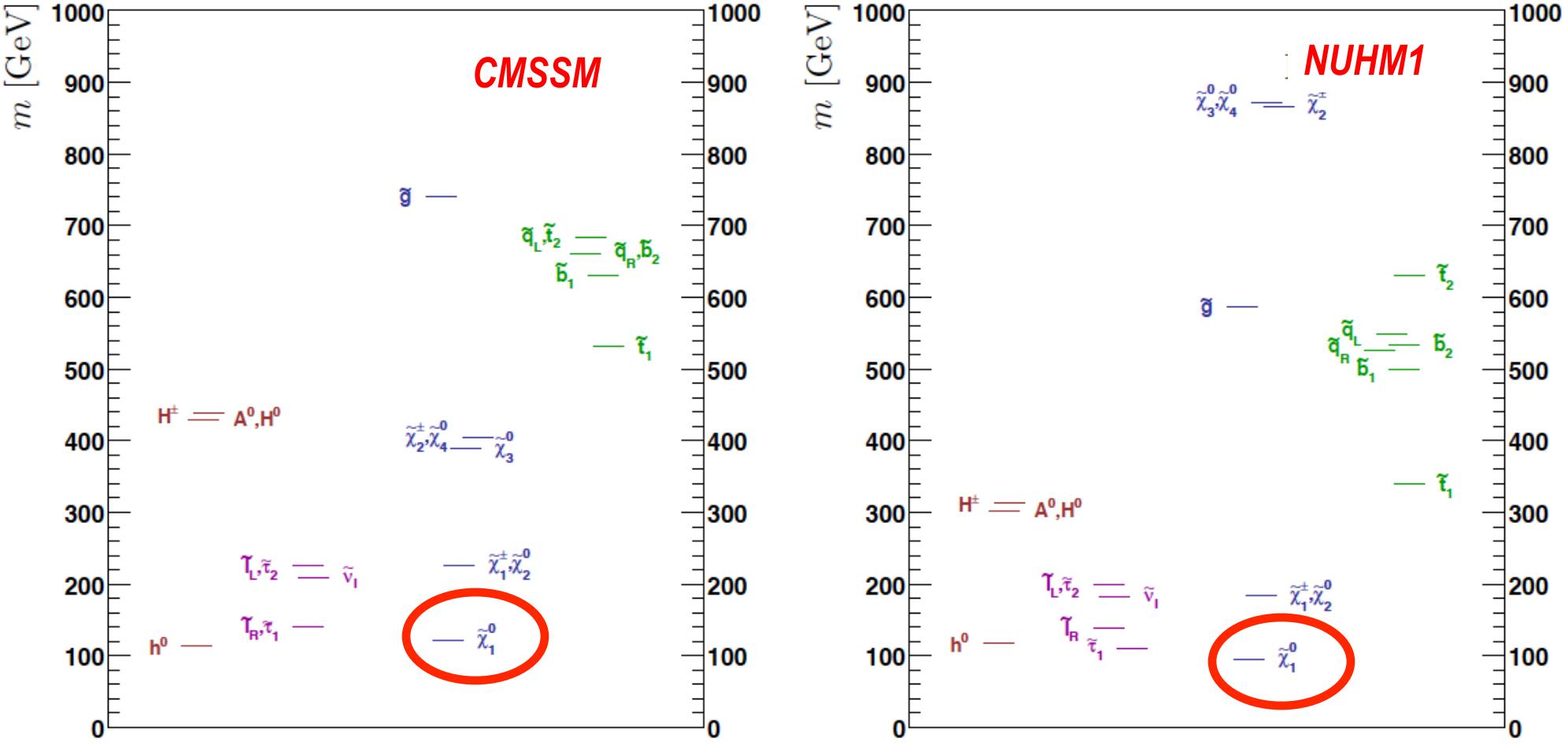
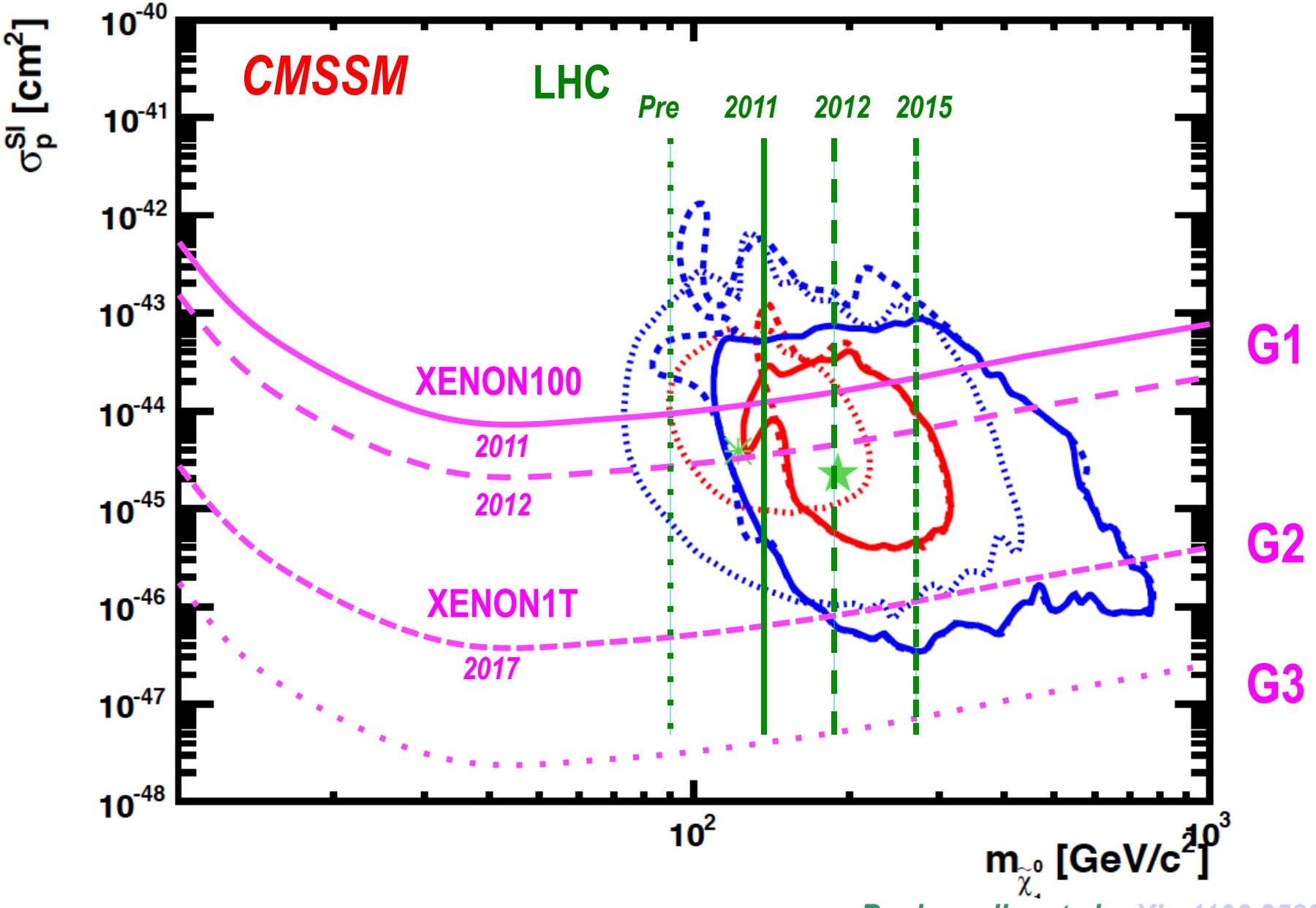


Figure 2. The spectra at the best-fit points: left — in the CMSSM with $m_0 = 60$ GeV, $m_{1/2} = 310$ GeV, $A_0 = 240$ GeV, $\tan\beta = 11$, and right — in the NUHM1 with $m_0 = 100$ GeV, $m_{1/2} = 240$ GeV, $A_0 = -930$ GeV, $\tan\beta = 7$, $m_H^2 = -6.9 \times 10^5$ GeV^2 and $\mu = 870$ GeV.

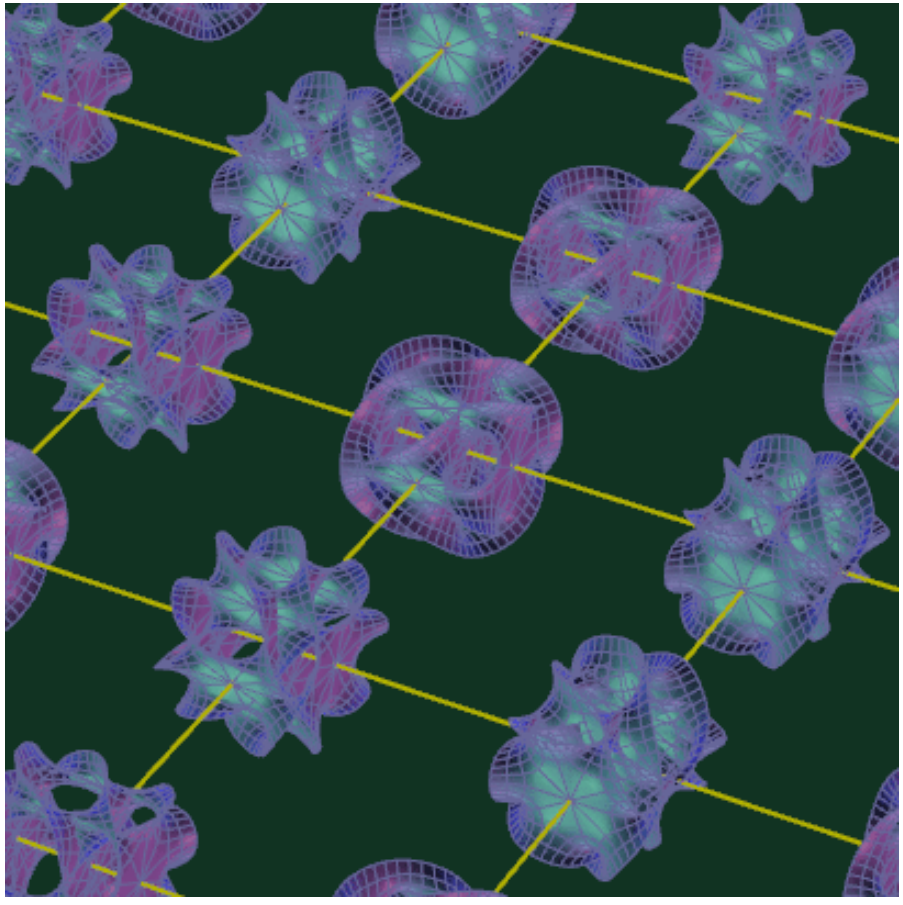
Buchmueller et al arXiv: 0808.4218

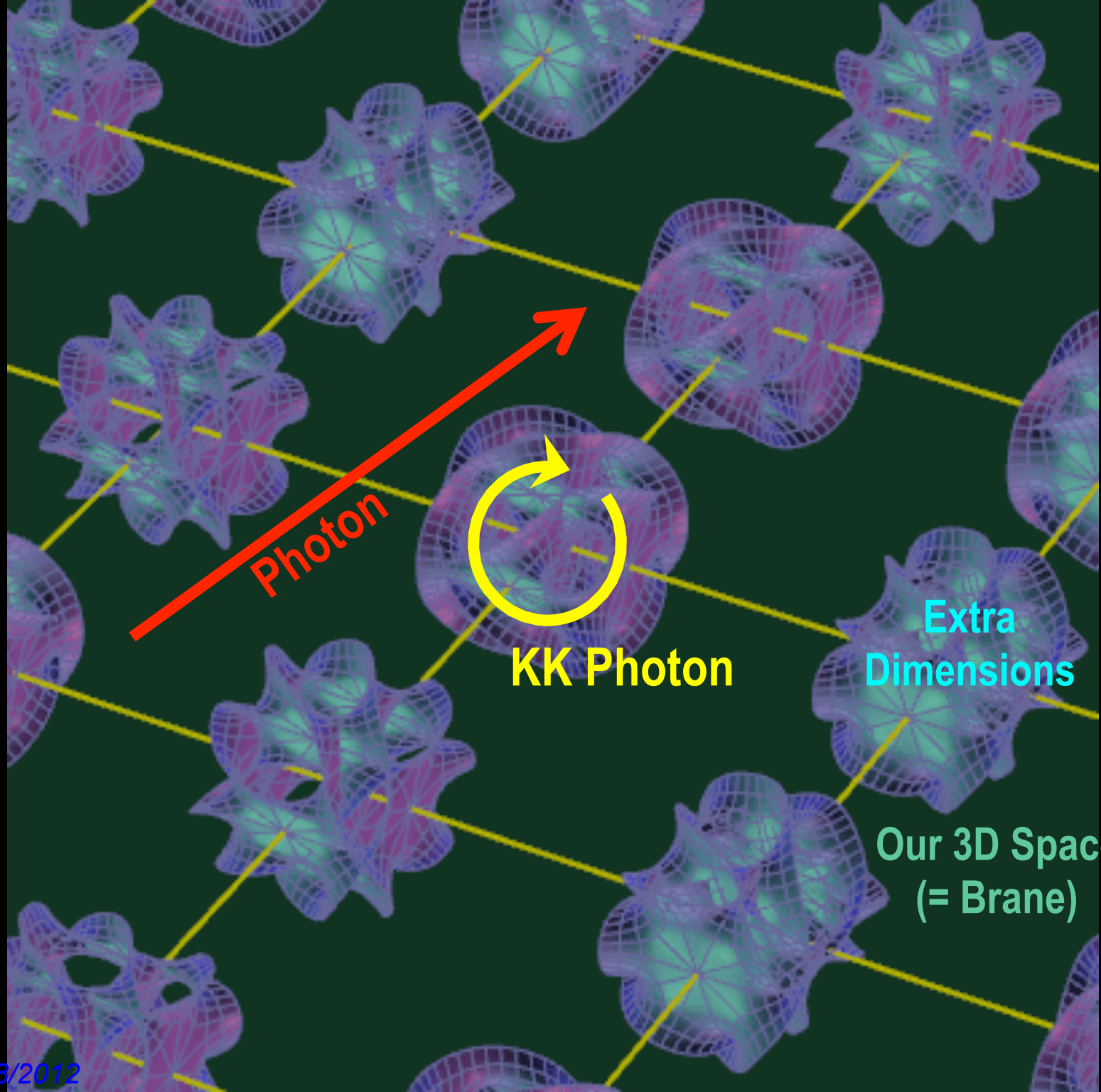
SI Cross Section vs. Mass



Buchmueller et al arXiv:1106.2529

KK particles in Extra Dimensions




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

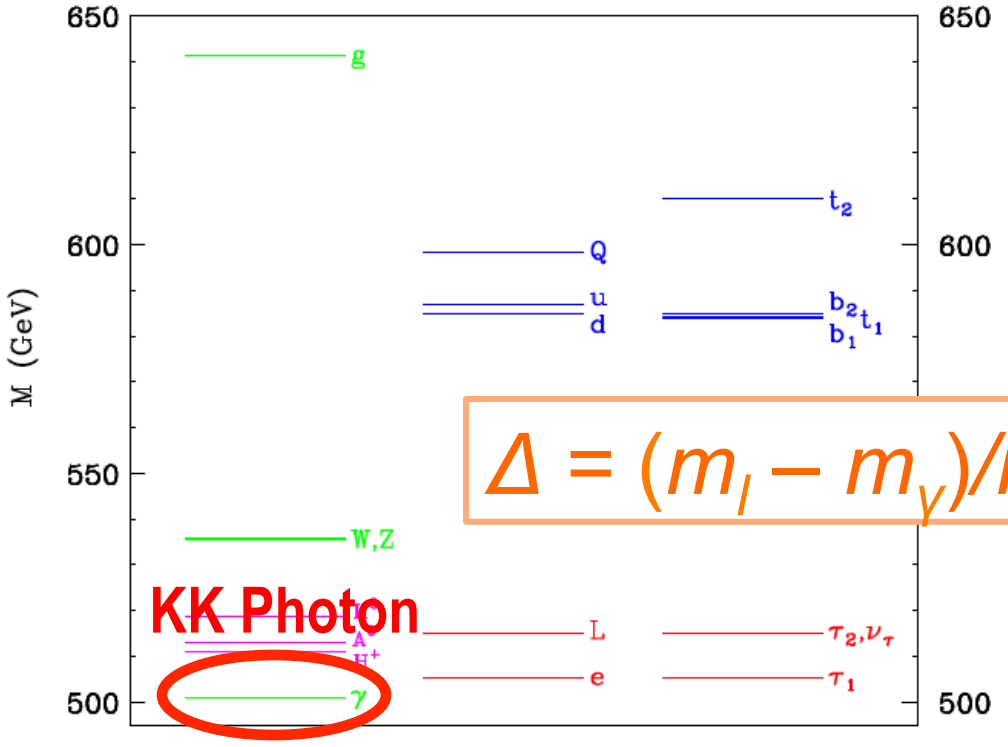
Origin of Mass in Extra Dimensions

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

- **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



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

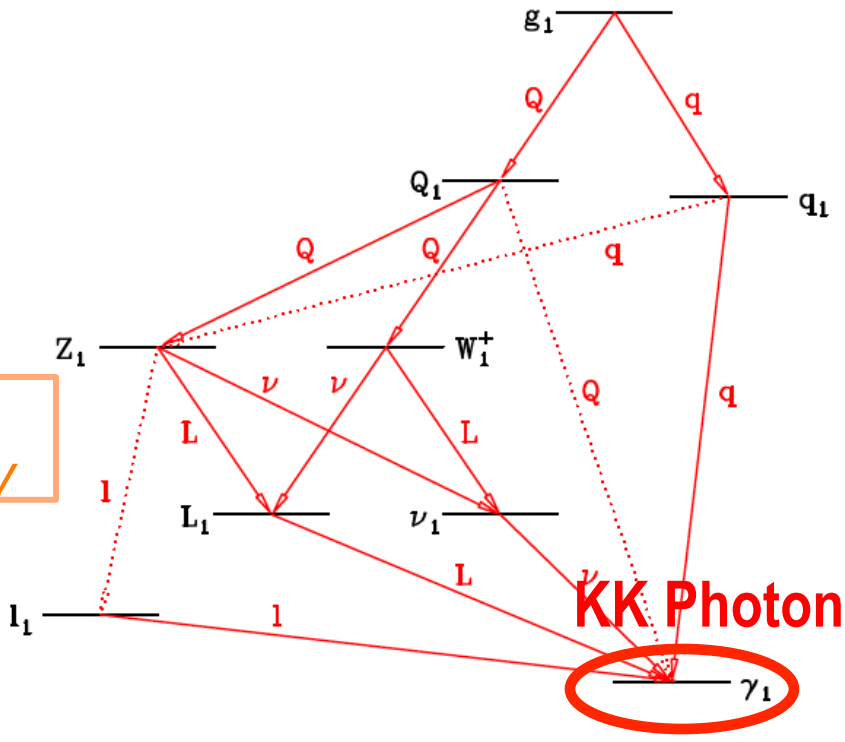
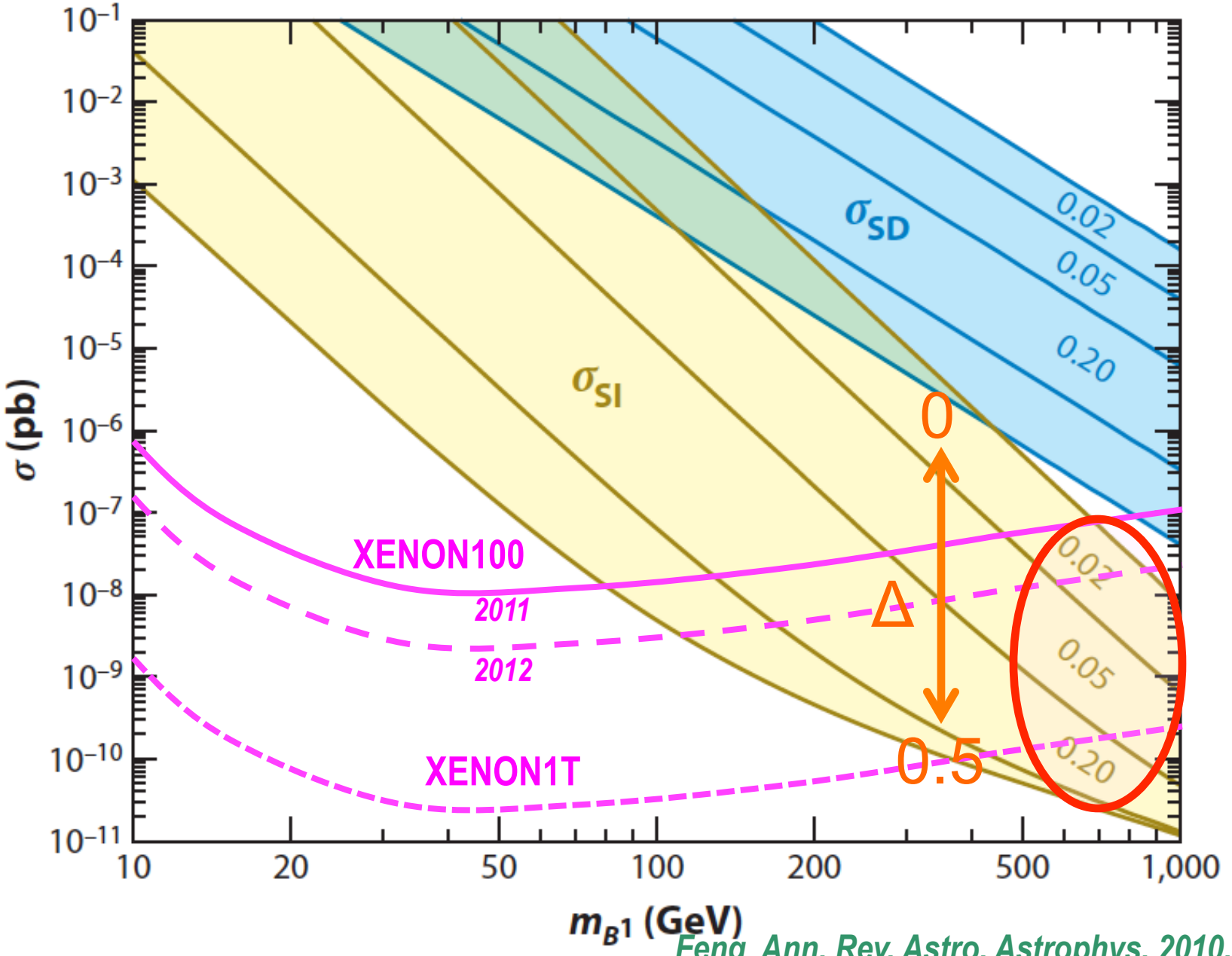


FIG. 1: *One-loop corrected mass spectrum of the first KK level in MUEDs for* $R^{-1} = 500\ GeV$, $\Lambda R = 20$ *and* $m_h = 120\ GeV$.

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

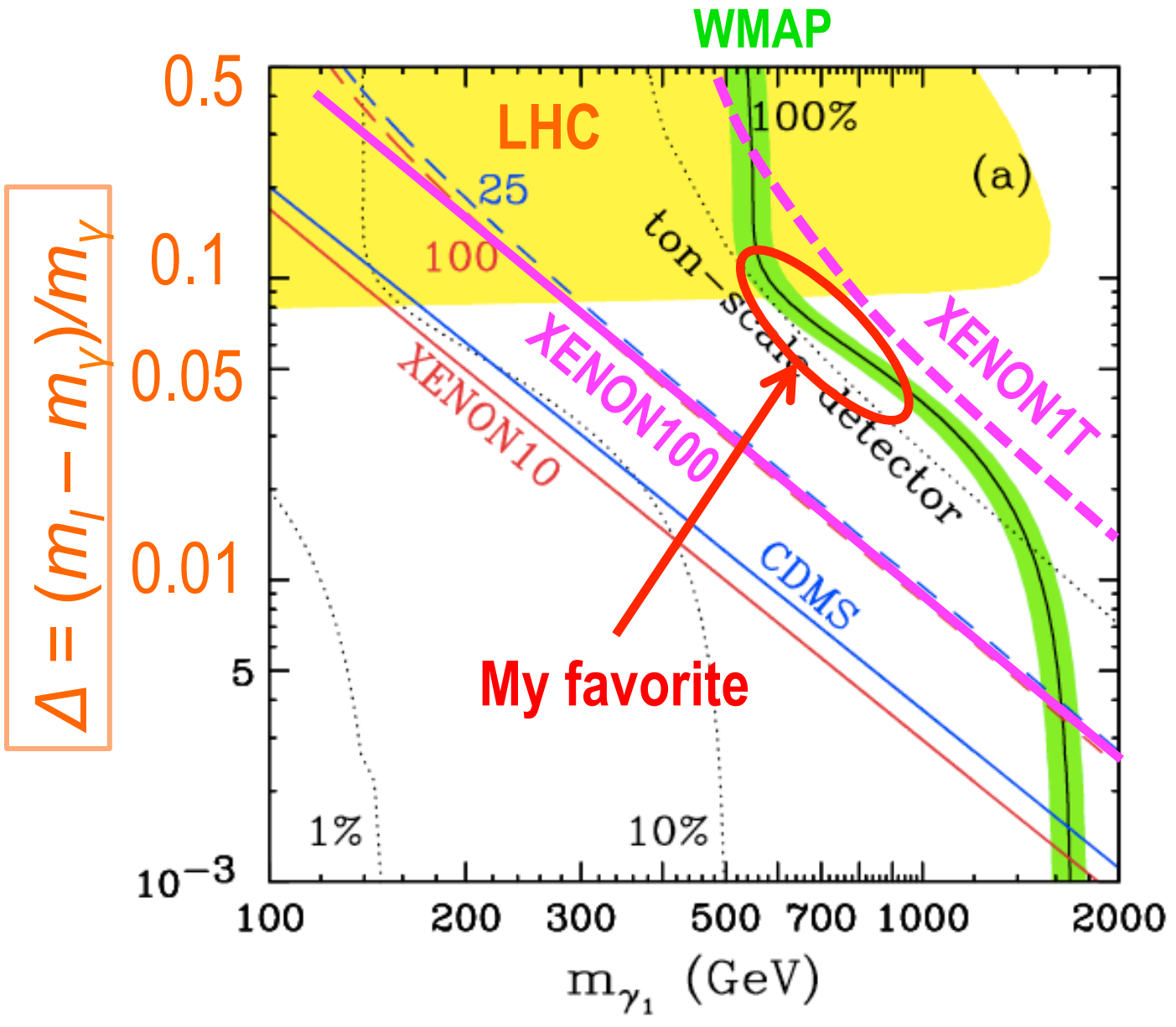
Cheng 2002 arXiv:hep-ph/0205314v1

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"

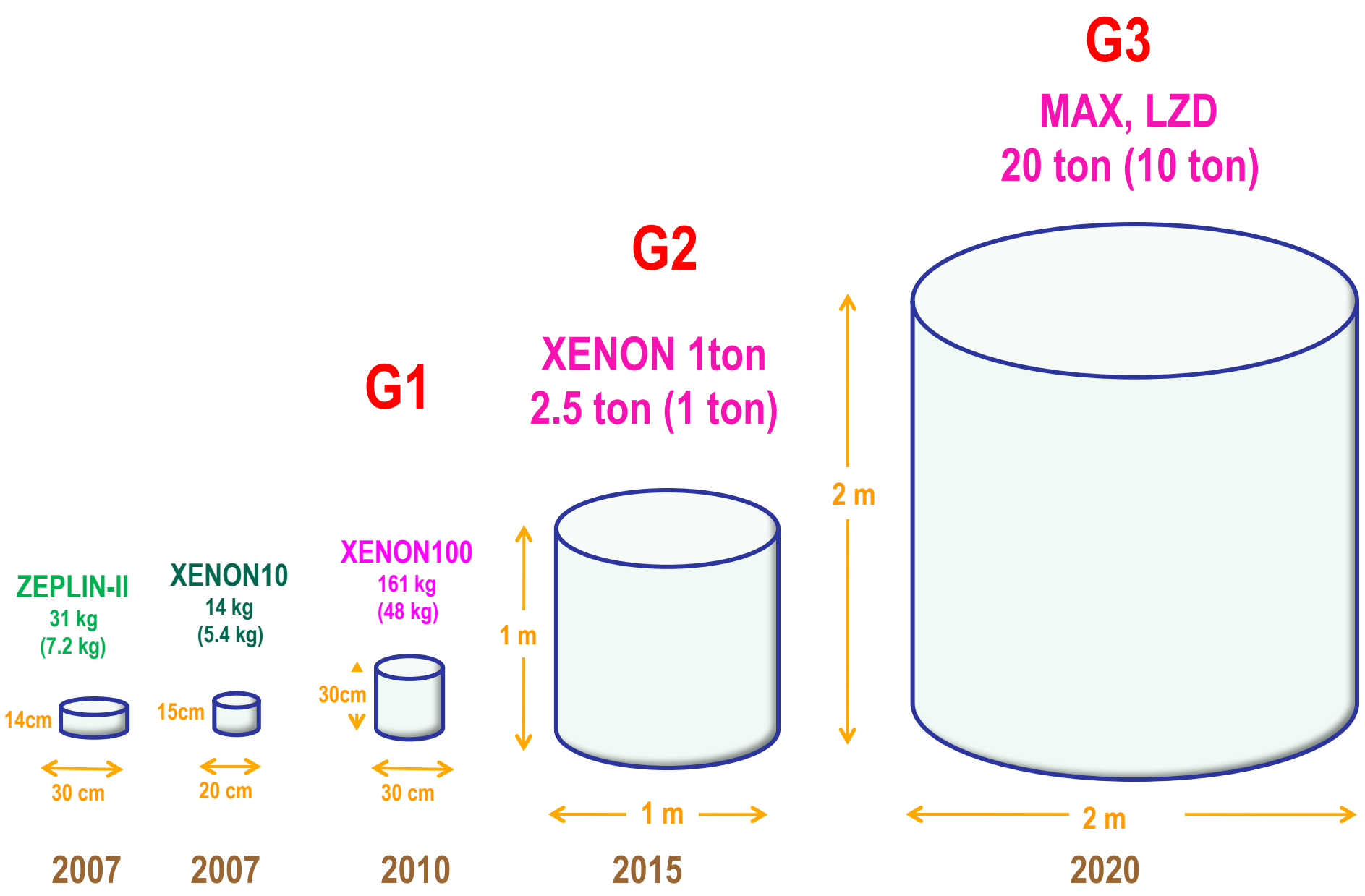
- XENON program (~$10M) is extremely timely and competitive to LHC (~$10B)
  - XENON100 ~ Current LHC
  - XENON1T ~ Future LHC
- If new physics at 100 – 1000 GeV (as it should be), LHC and/or XENON1T will discover WIMPs.
  - SUSY - Neutralino
  - Extra Dimensions – KK photon
- By combining LHC and XENON1T,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

G2 & G3 Detectors

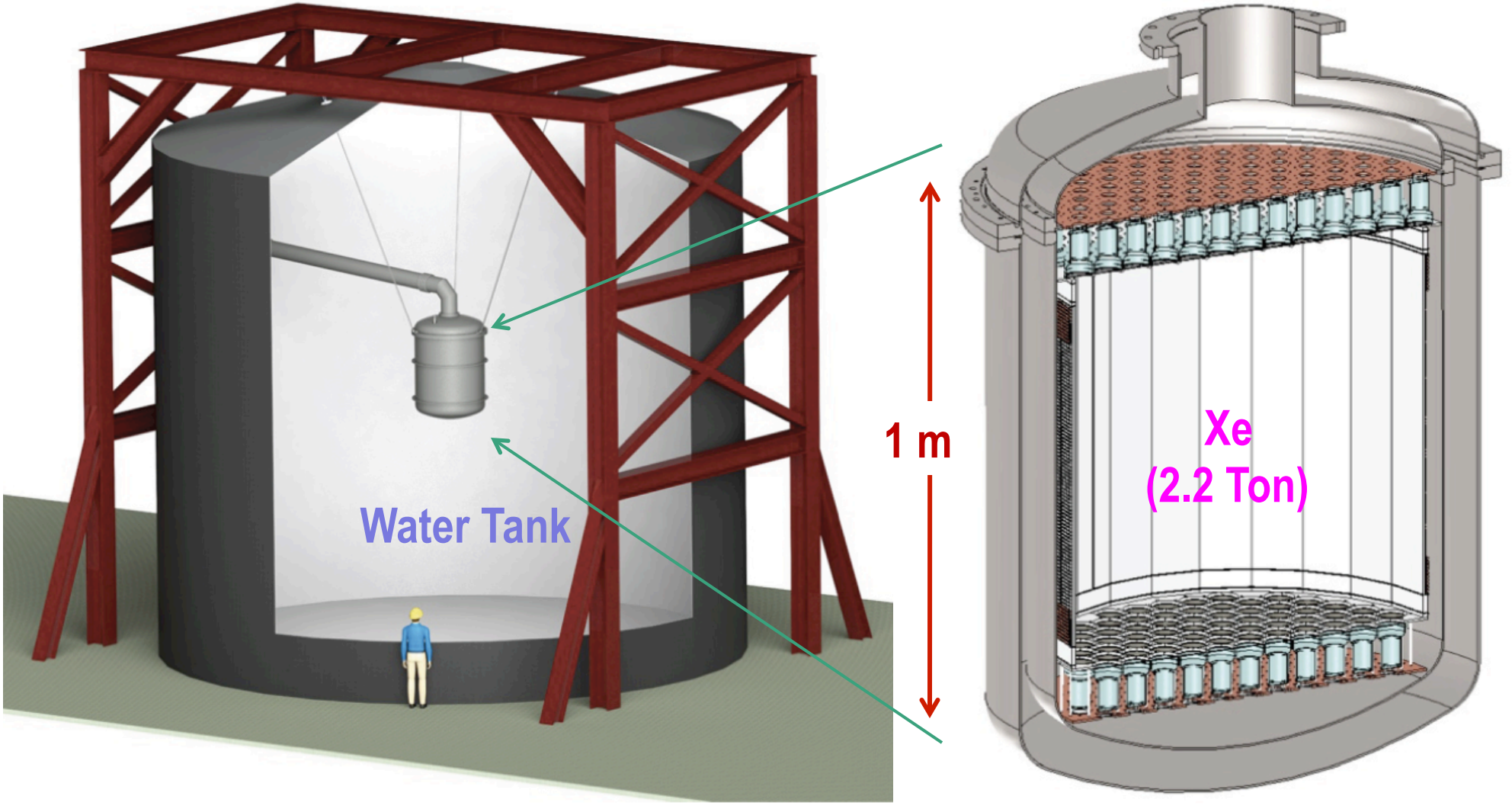
G2 and G3 facilities defined by PASAG (2009)

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

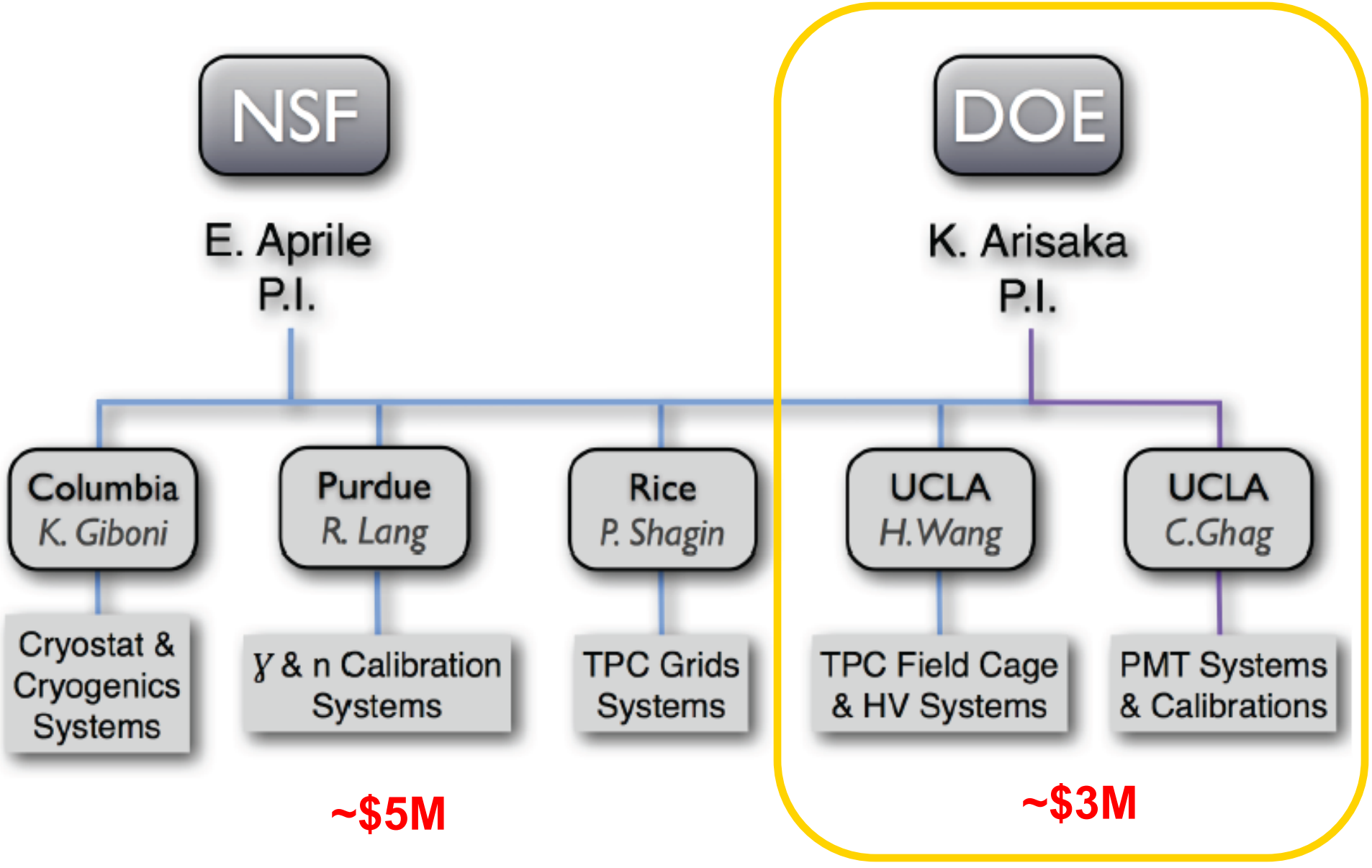
Comparison of Xenon Detector Size



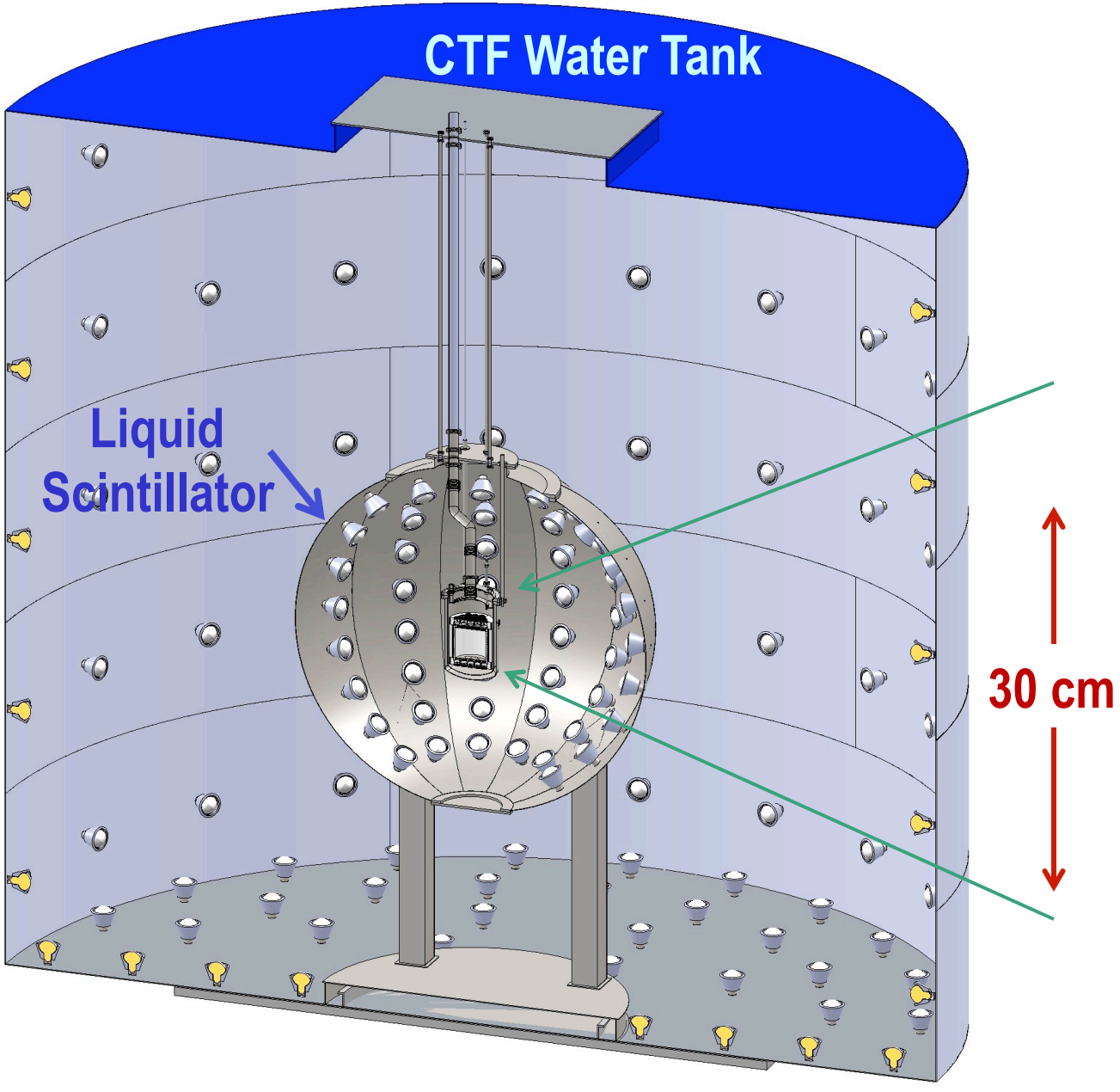
XENON1T (G2) at LNGS

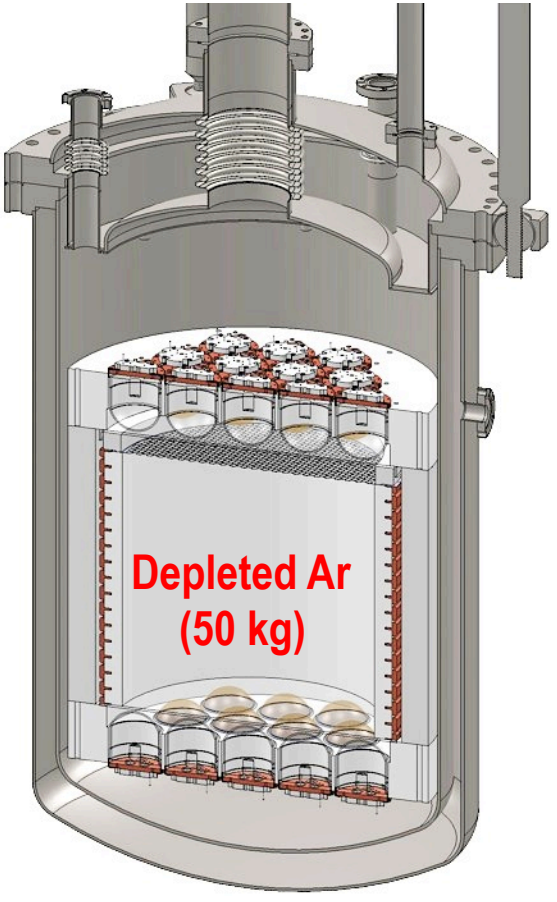


XENON1T – US Responsibility

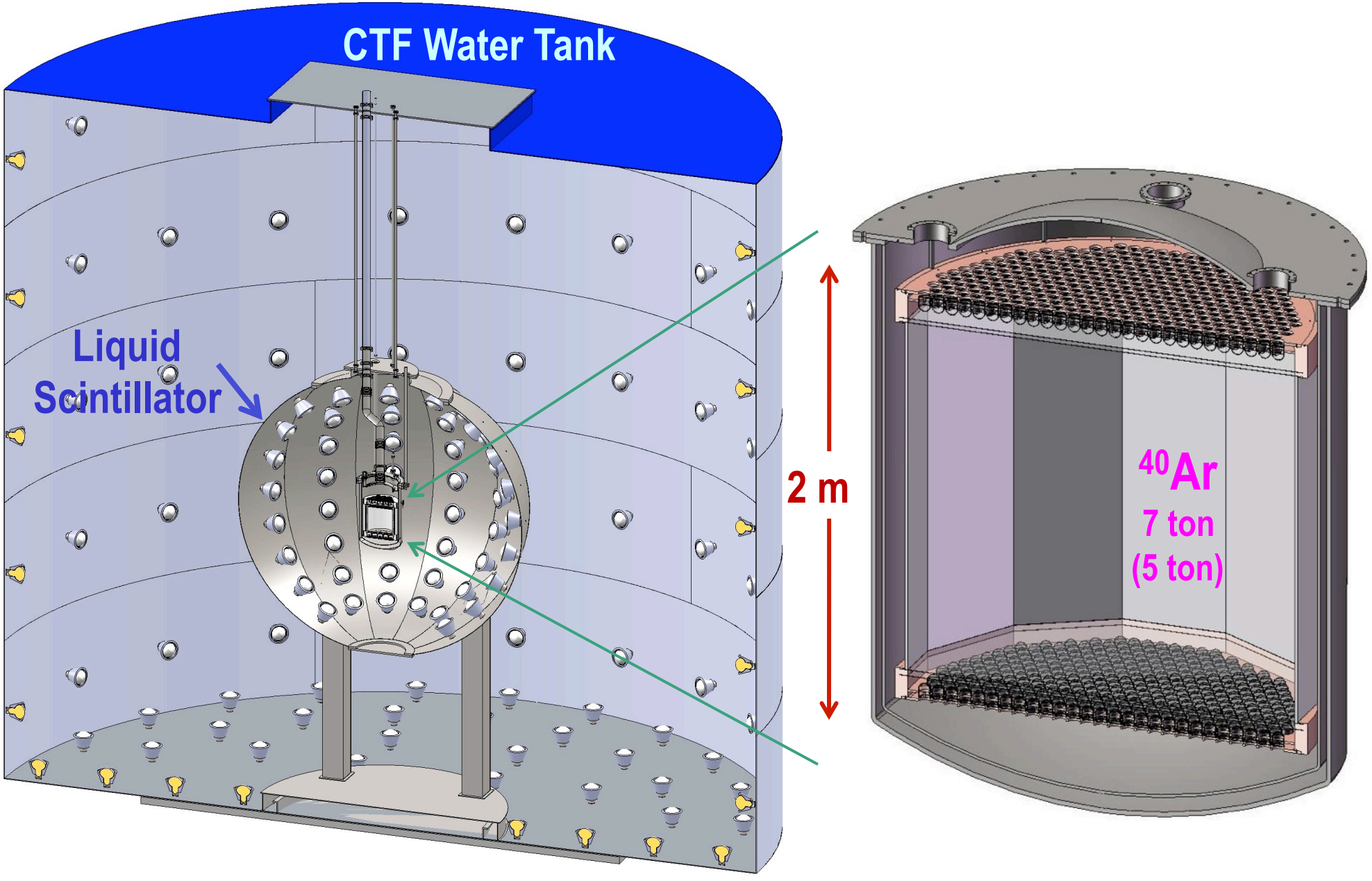


DarkSide 50 (G1) at LNGS

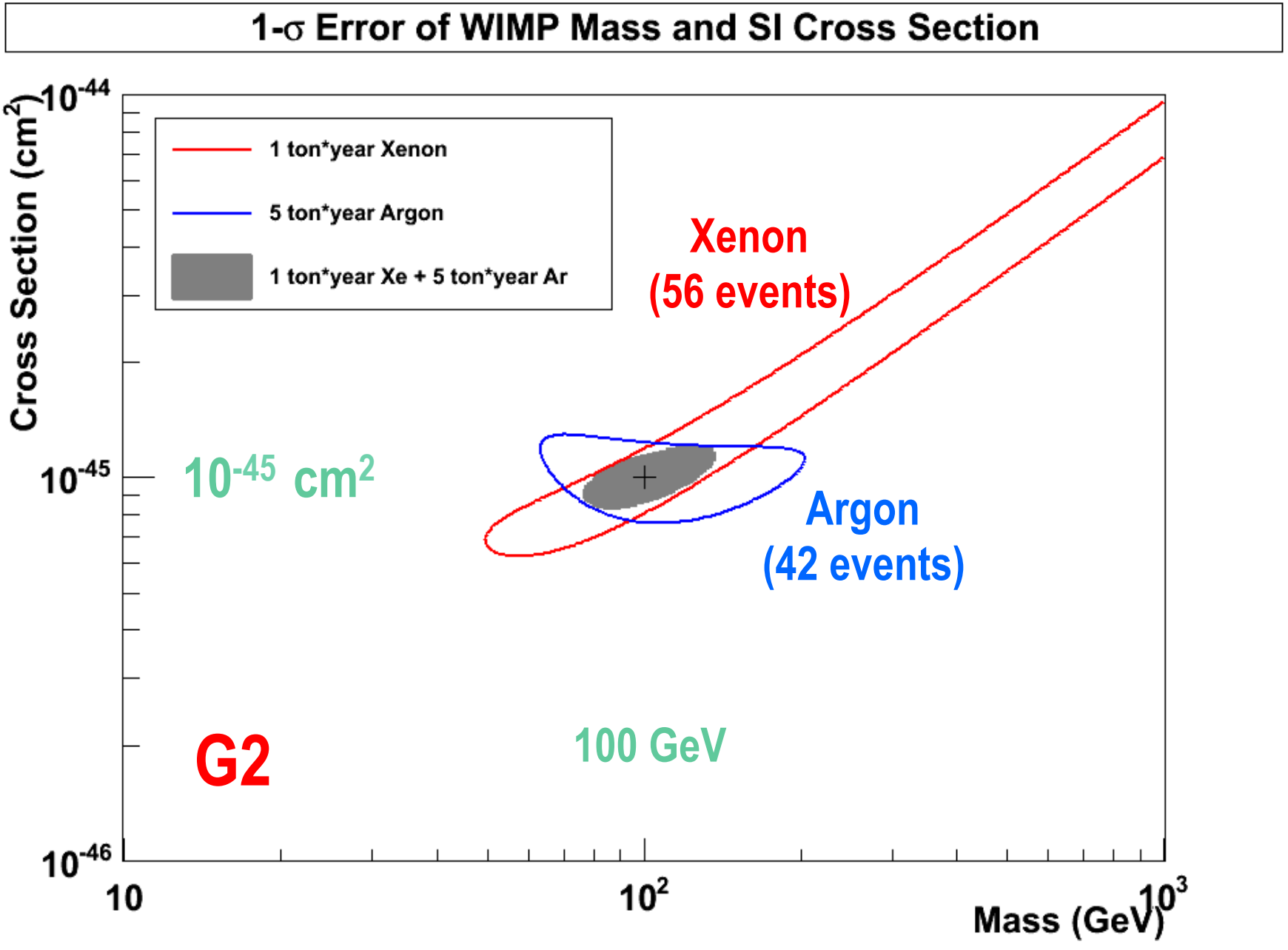




DarkSide 5T (G2) at LNGS

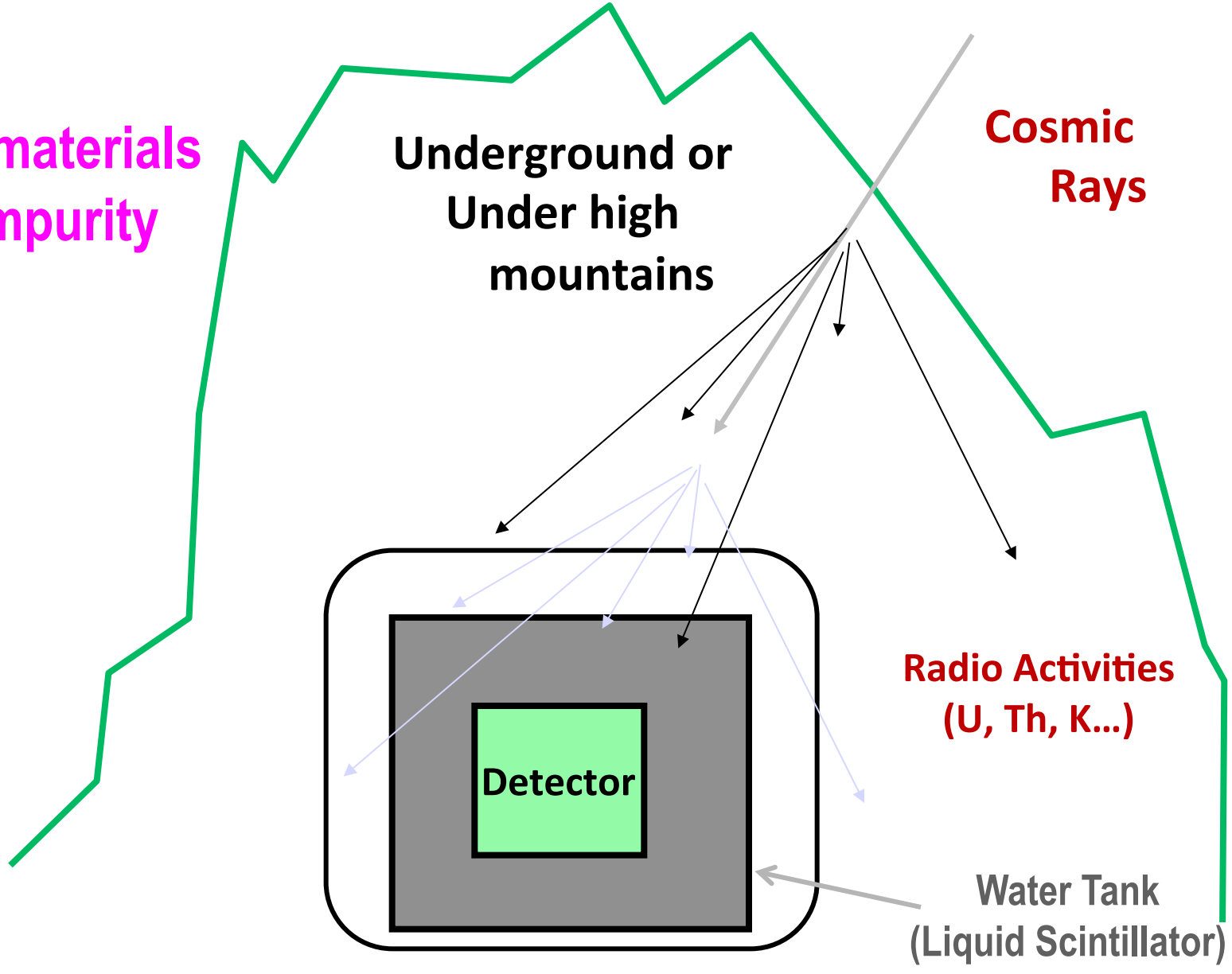


1-σ Error of WIMP Mass vs SI Cross Section (1 ton*year Xe and 5 ton*year Ar)



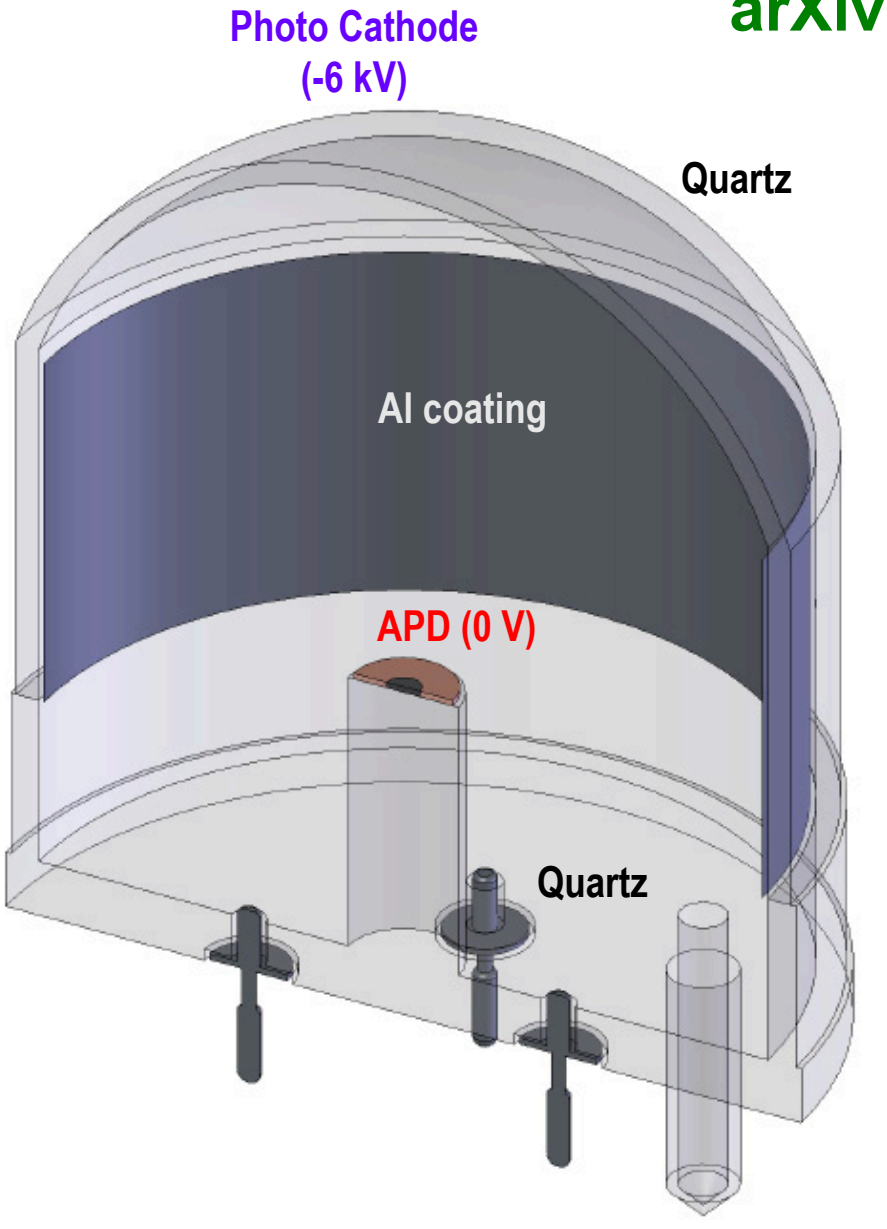
Where backgrounds come from?

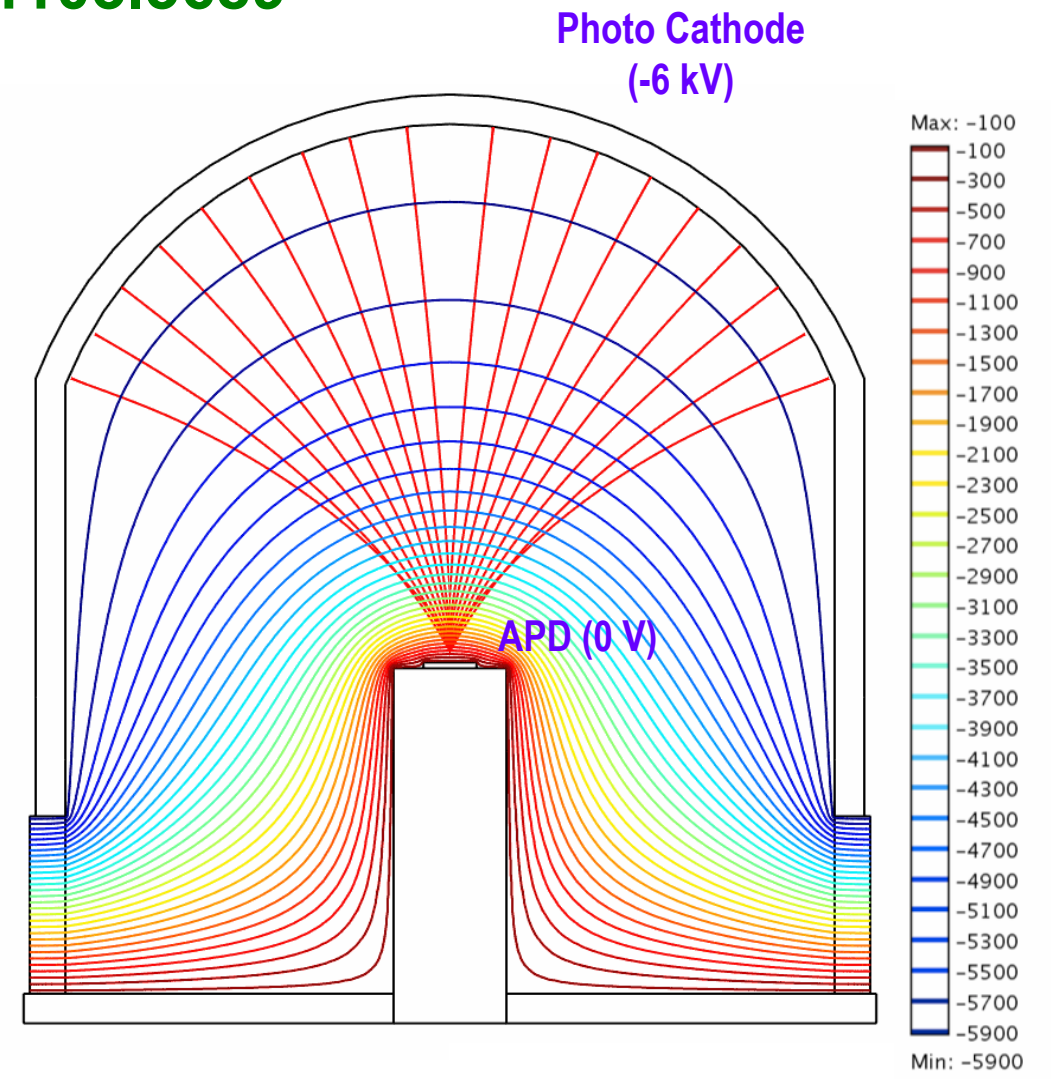
- External
- Detector materials
- Internal impurity



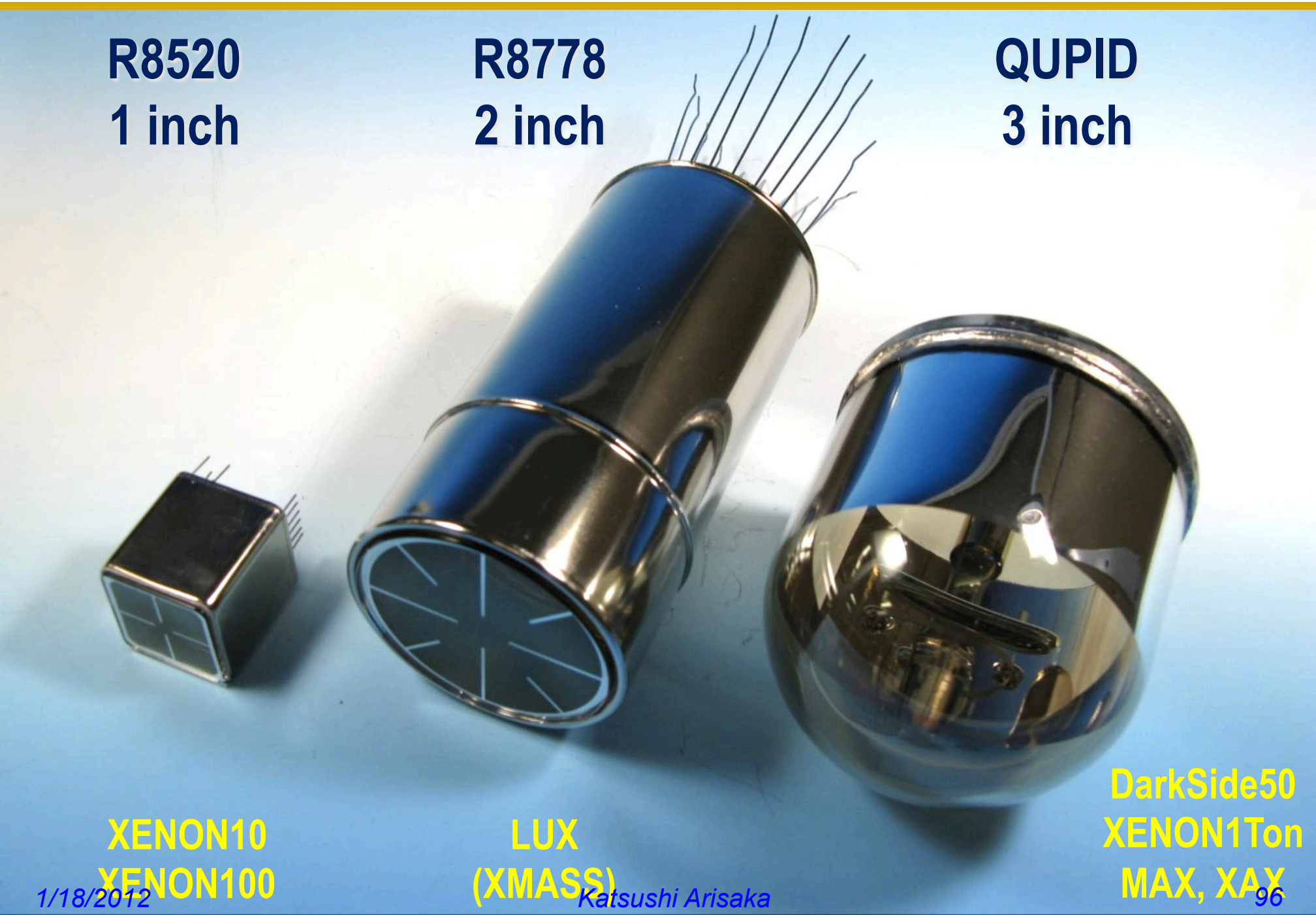
QUPID (QUartz Photon Intensifying Detector)

arXiv:1103.3689

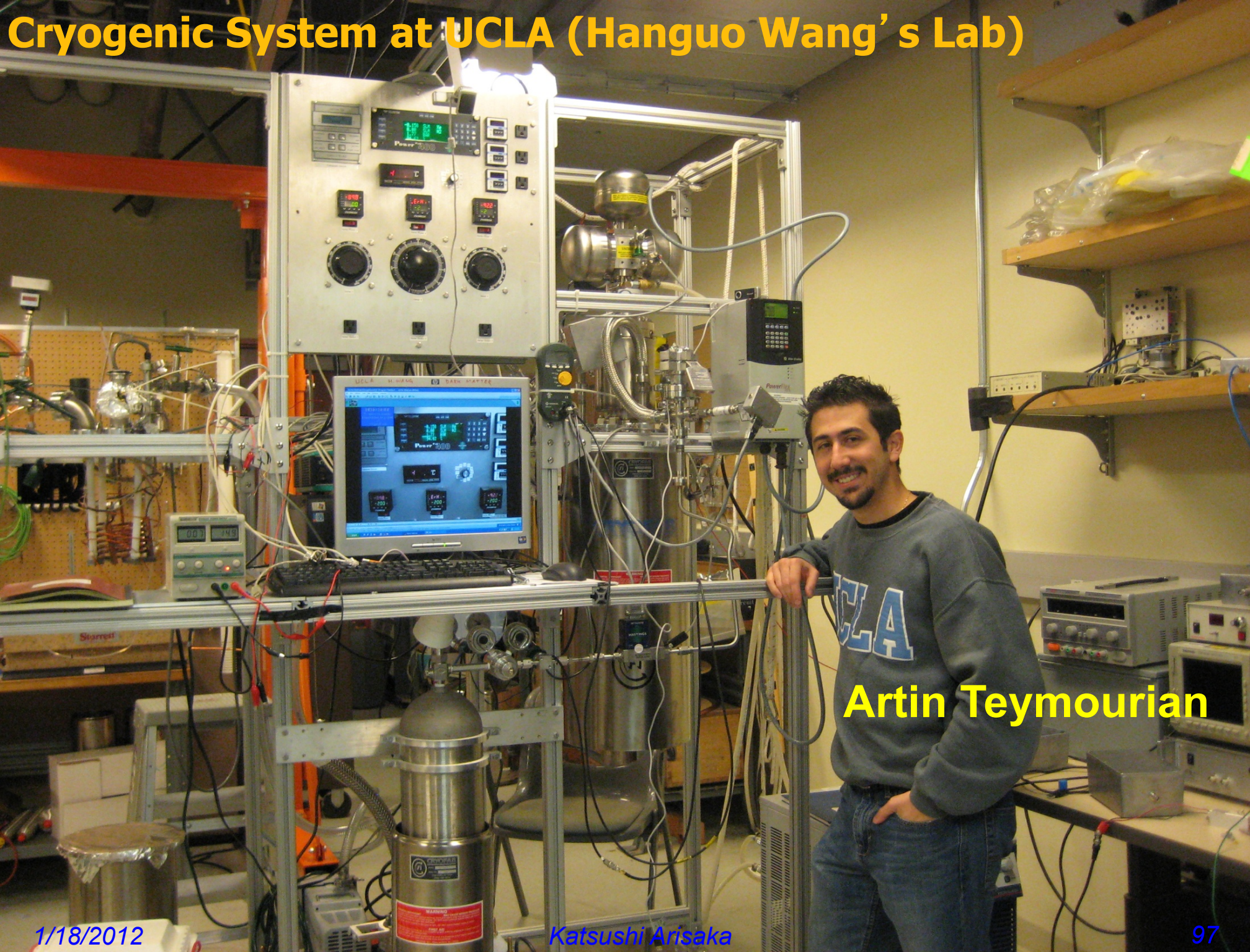


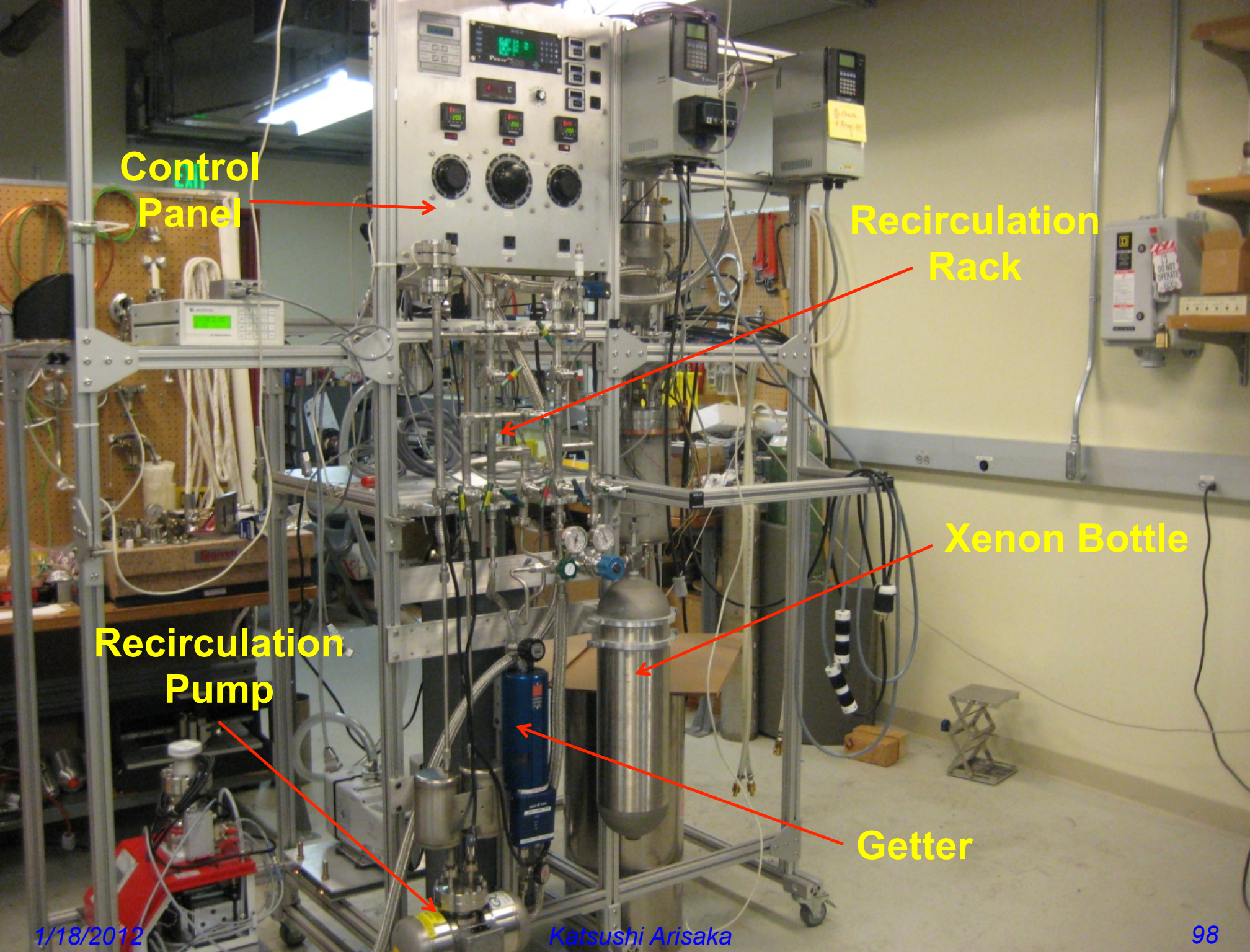


Comparison of Low-radioactive Photon Detectors from Hamamatsu

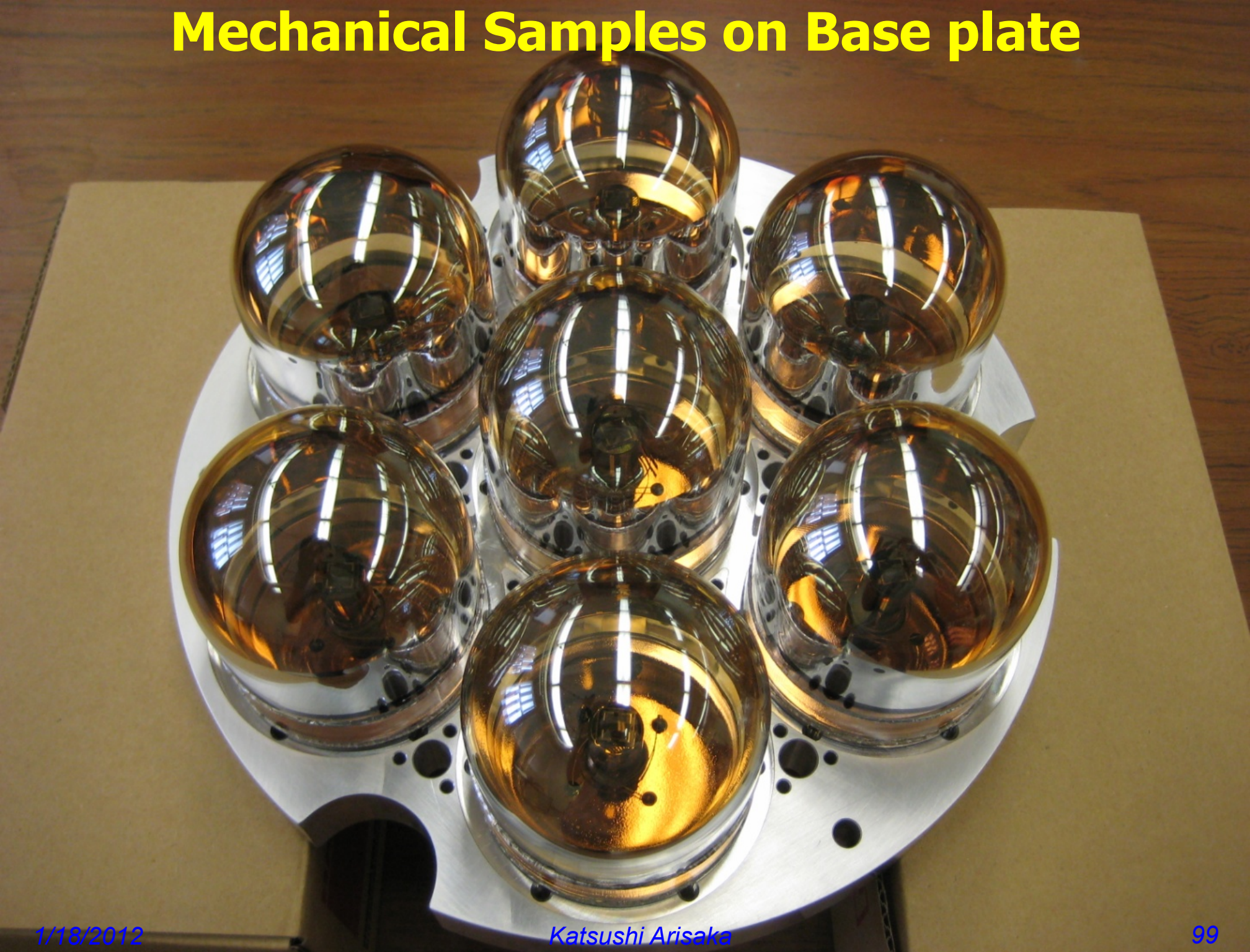


Cryogenic System at UCLA (Hanguo Wang's Lab)




Control Panel
Recirculation Rack
Xenon Bottle
Recirculation Pump
Getter

Mechanical Samples on Base plate

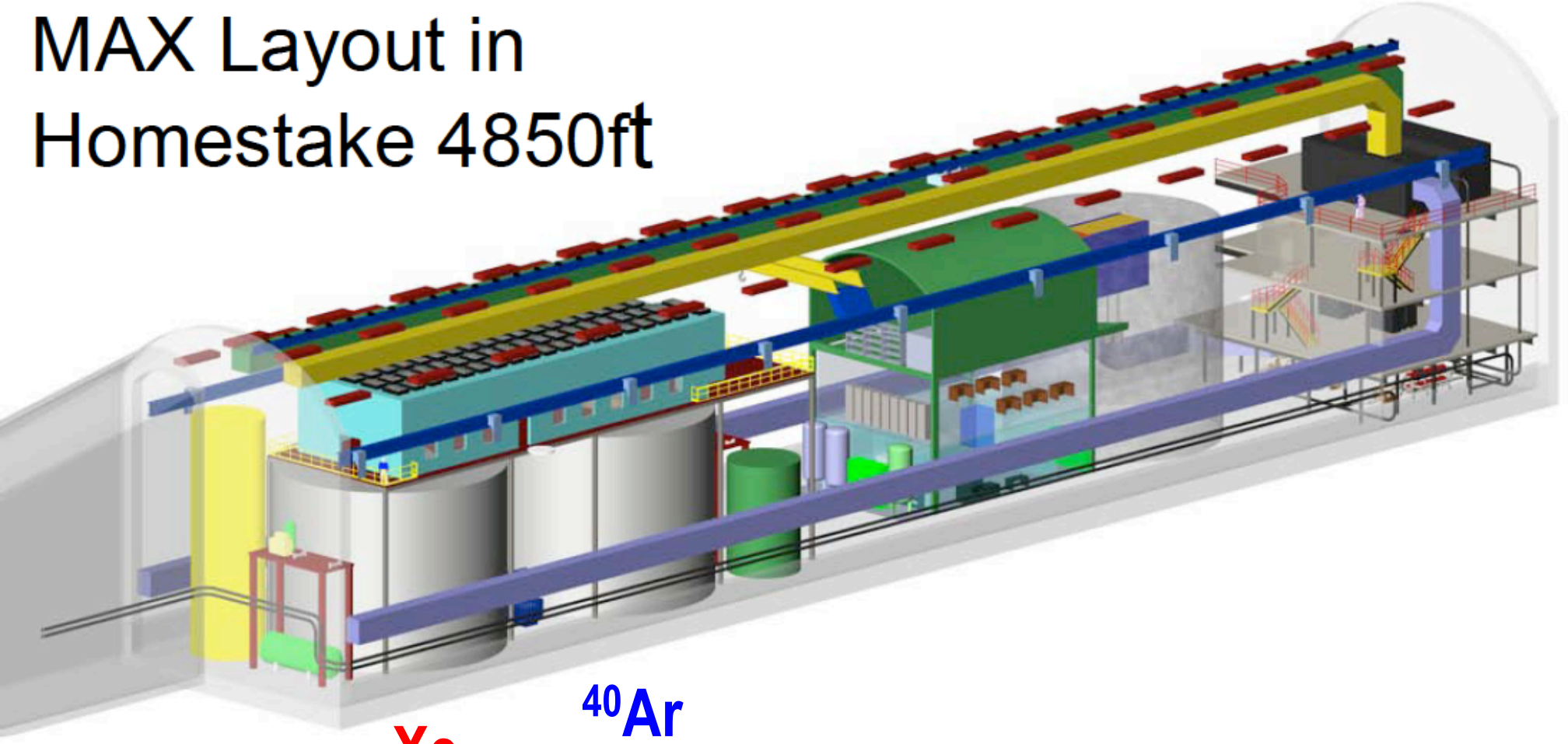


Some Remarks

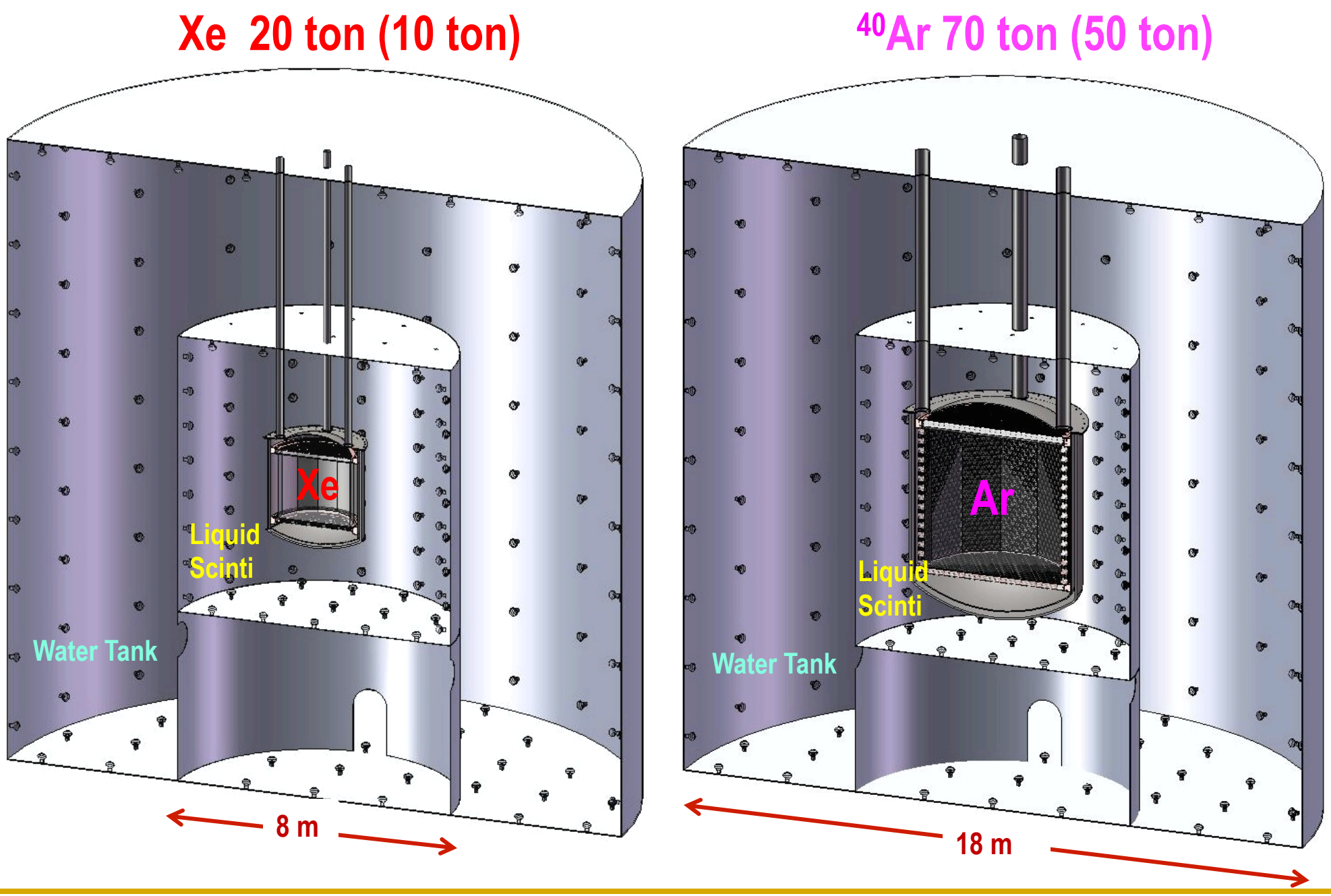
- **Xenon is optimum up to 1 Ton scale**
  - Largest discovery potential
  - Background ~ 1 / ton-year
  - Good sensitivity to low mass WIMP

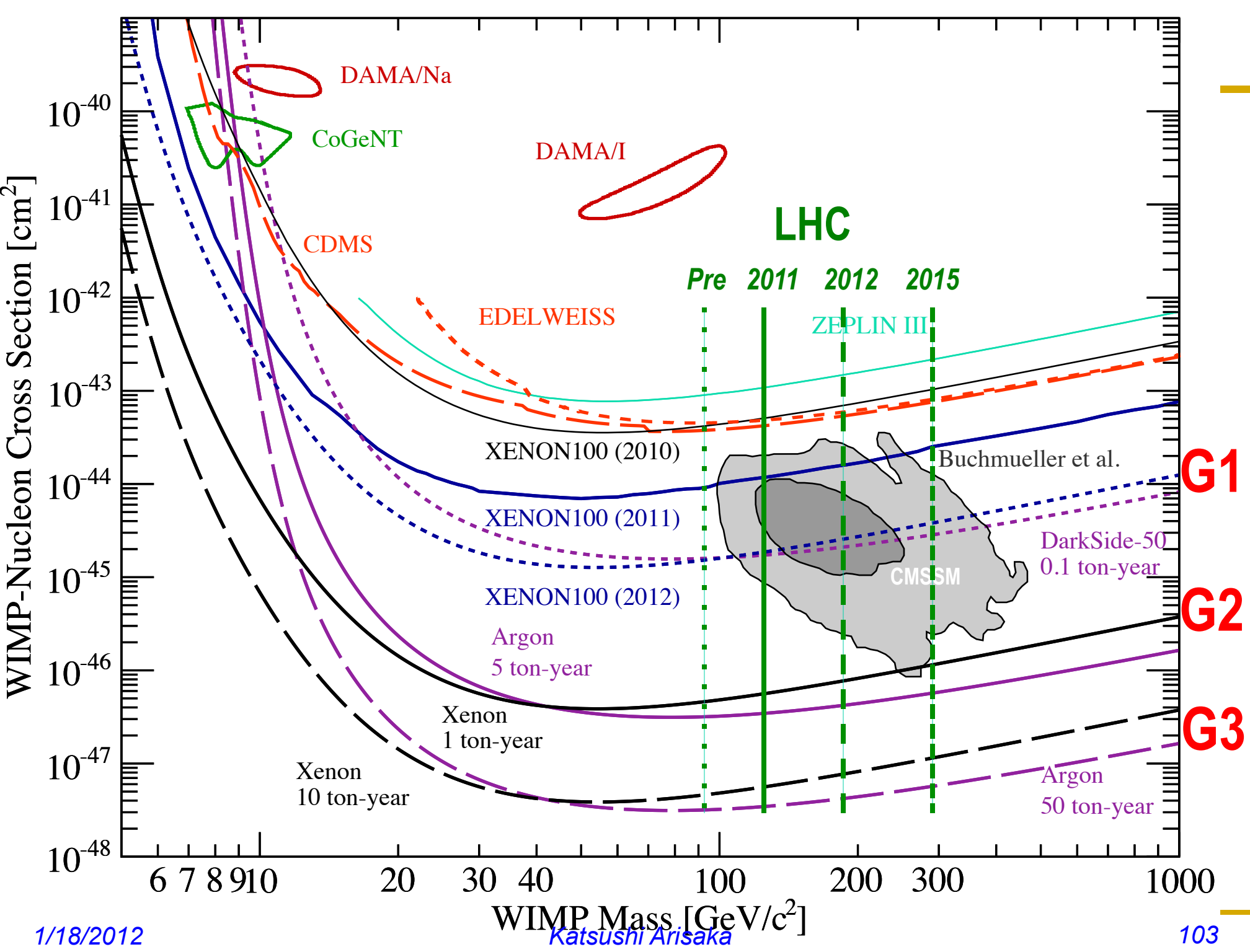
- **At > 10 ton scale, Argon is more appealing**
  - No gamma ray backgrounds
  - Mass determination up to 200 GeV
  - Large annual modulation

MAX (G3) (at DUSEL)



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




DAMA/Na
CoGeNT
DAMA/I
CDMS
EDELWEISS
LHC
Pre
2011
2012
2015
ZEPLIN III
XENON100 (2010)
XENON100 (2011)
XENON100 (2012)
Buchmueller et al.
CMSSM
DarkSide-50
0.1 ton-year
Argon
5 ton-year
Xenon
1 ton-year
Xenon
10 ton-year
Argon
50 ton-year
G1
G2
G3
WIMP-Nucleon Cross Section [cm^2]
WIMP Mass [GeV/c^2]
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 40 100 200 300 1000

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 (Δ = 5%)
  - No SUSY
  - Katsushi happily retires at age 65.