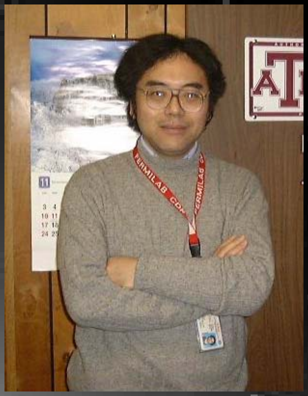
Particle Physics and Cosmology (PPC)
- Are they related? -

REU Seminar (2007)



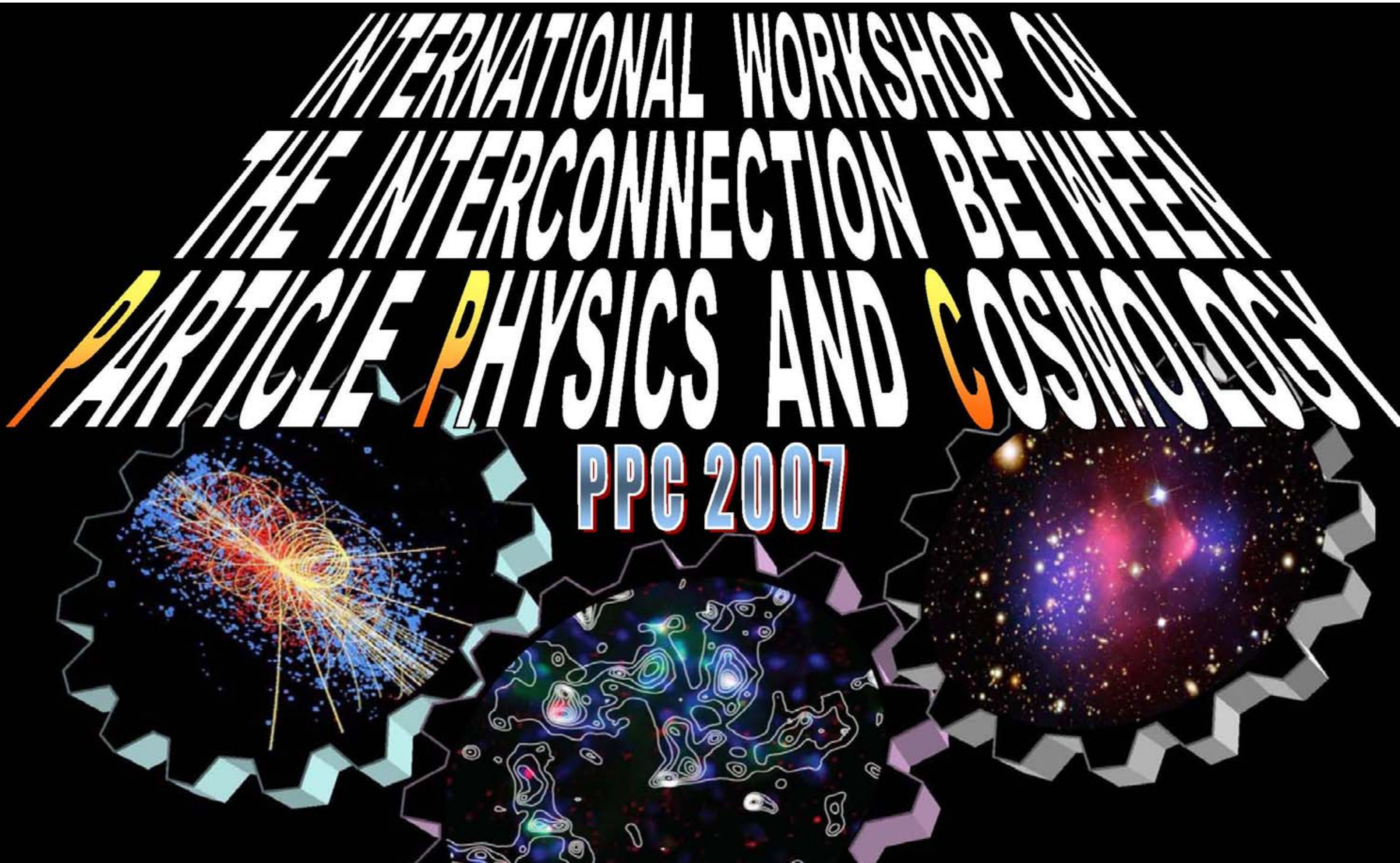
Prof. Teruki Kamon
and
Prof. Bhaskar Dutta

Department of Physics
Texas A&M University

PPC are related!!!

Can particle physics help us understanding the Early Universe and the Big Bang?

Today, we speak about the connection from a view point of upcoming collider experiment: Large Hadron Collider



http://ppc07.physics.tamu.edu/index.html

Cambridge-Mitchell (TAMU) Collaboration in Cosmology
Texas A&M University, College Station, TX, USA
May 14-18, 2007

Faculty Members and Research Areas

HEP EXPERIMENT & THEORY

[Collider Physics - CDF, CMS, International Linear Collider]

T. Kamon, P. McIntyre, A. Safonov, D. Toback

[Neutrino Physics - MINOS, NOνA]

R. Webb

[Dark Matter Detection - ZEPLIN, SIGN]

J. White

[Phenomenology]

R. Allen, R. Arnowitt, R. Bryan, B. Dutta, D. Nanopoulos

[String Theory]

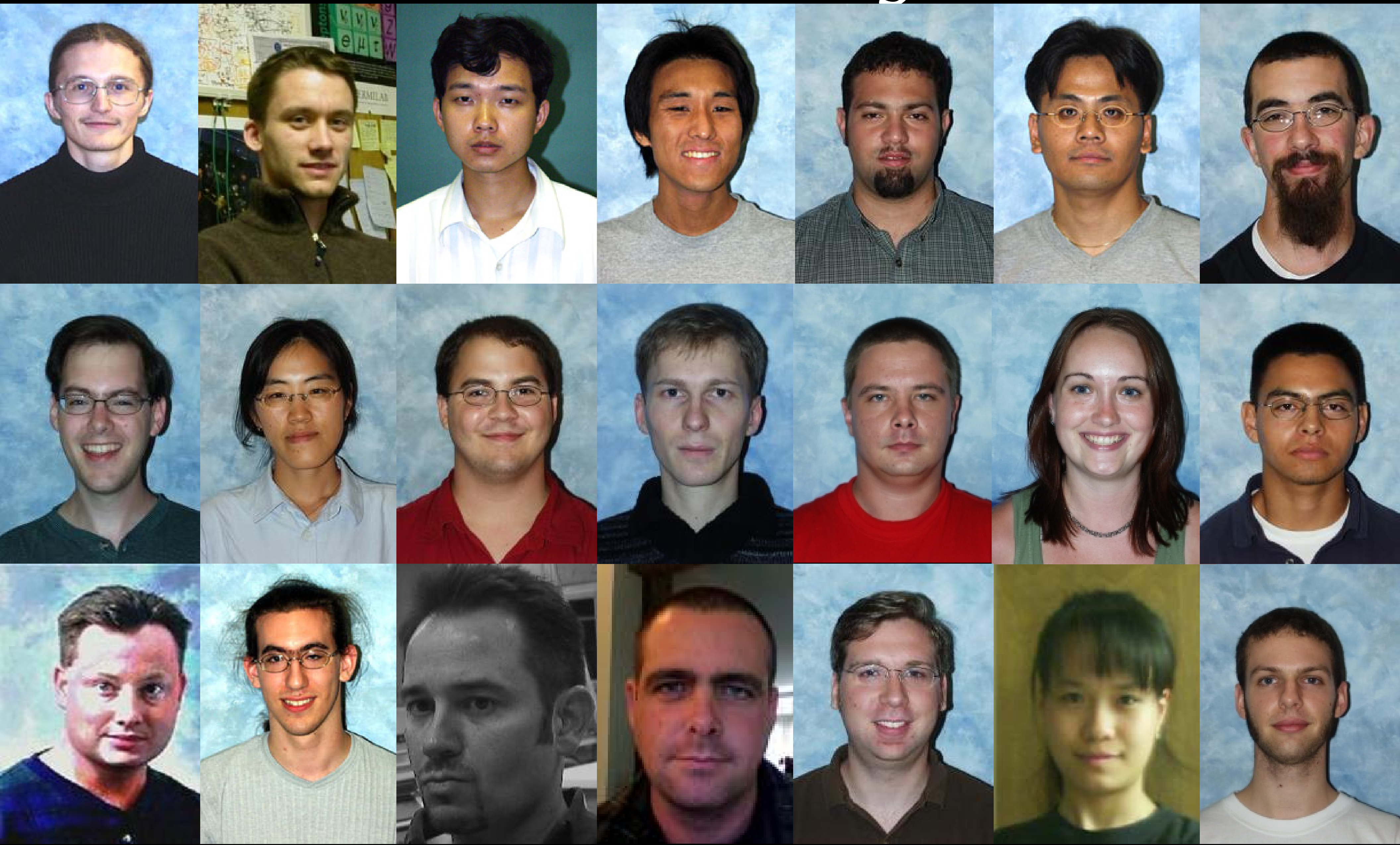
K. Becker, M. Becker, D. Nanopoulos, C. Pope, E. Sezgin

ASTRONOMY

[Observational Astronomy]

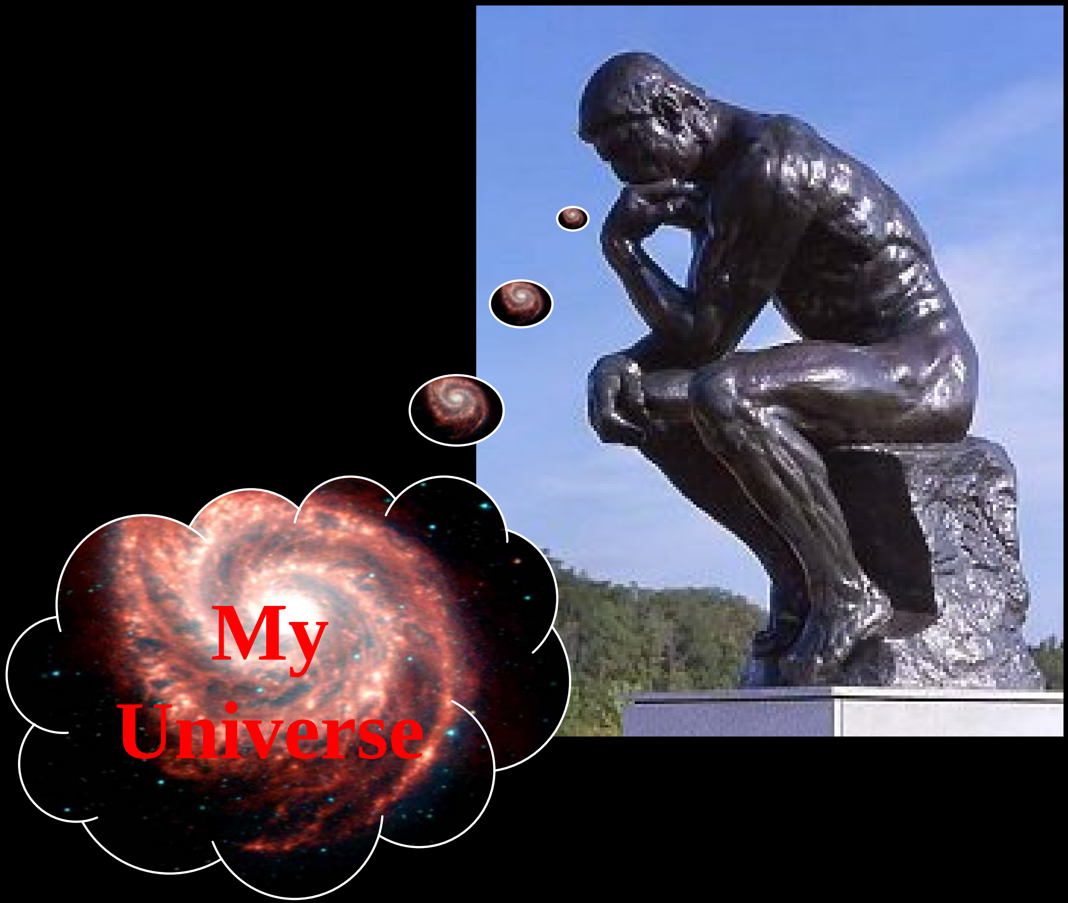
N. Suntzeff, L. Wang, at least 2 more faculty members

PPC Graduate and Undergrad. Students



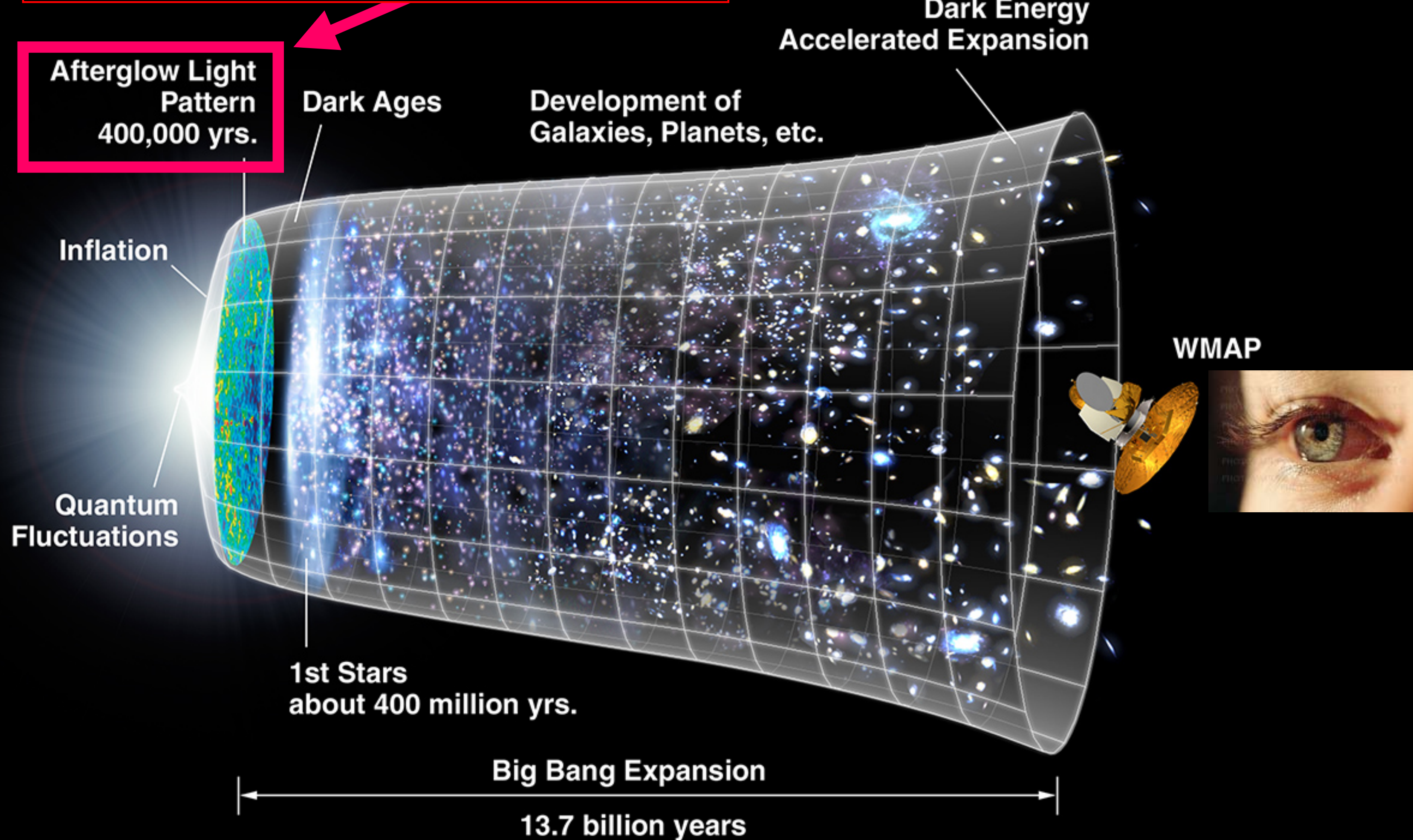
… and students working on accelerator physics and string theory.

Thinking of Our Universe



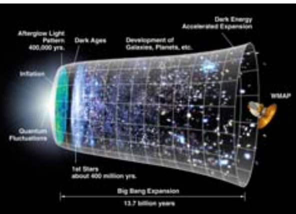
The Most Distant Light

Message from the Universe

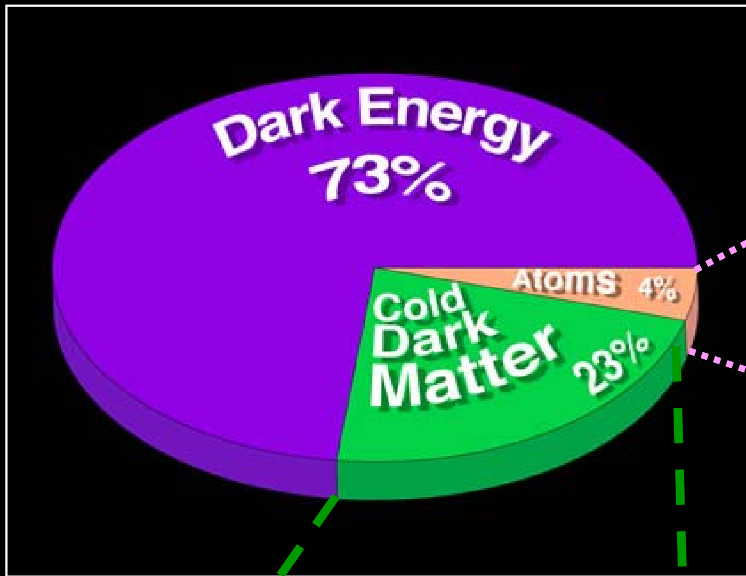


Cosmic Microwave Background (CMB) was emitted when the Universe was only 380,000 years old.

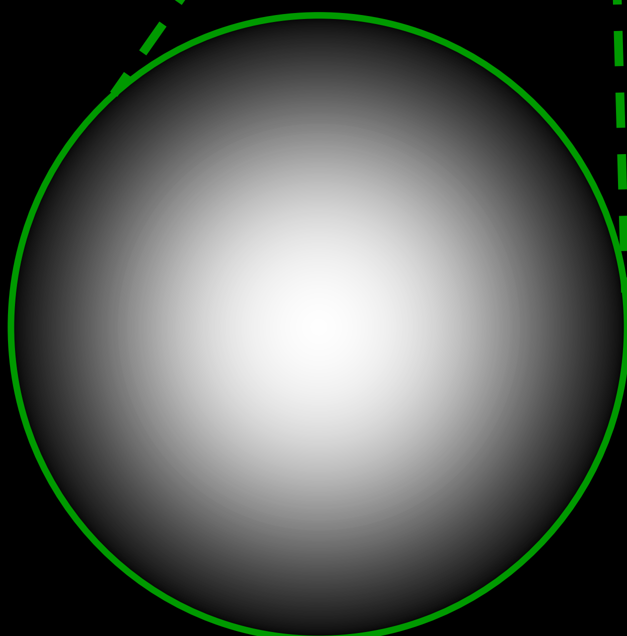
NASA/WMAP Science Team



Contents of the Universe



4%

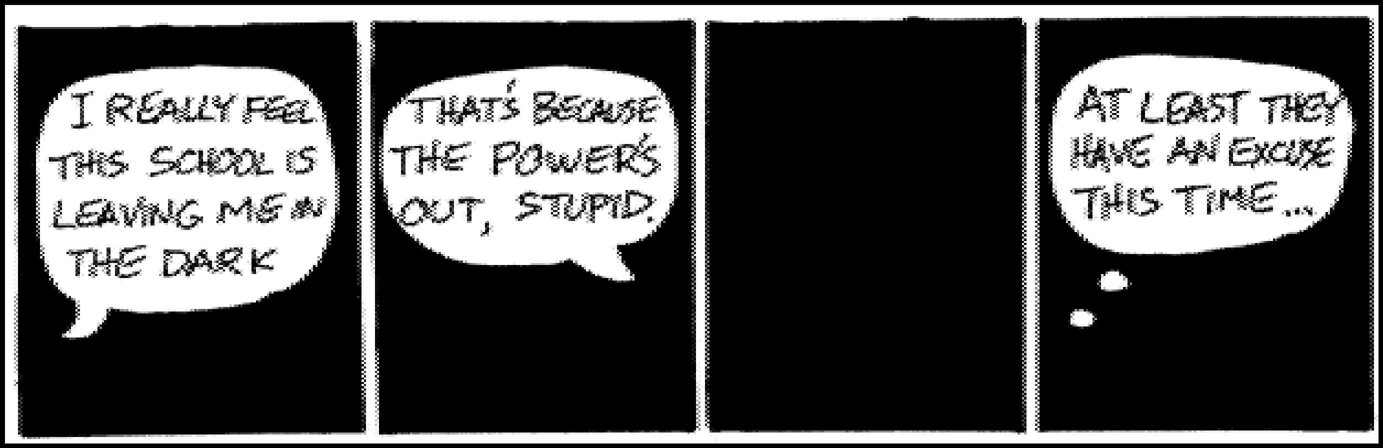


The 23% is still unobserved in the laboratory.

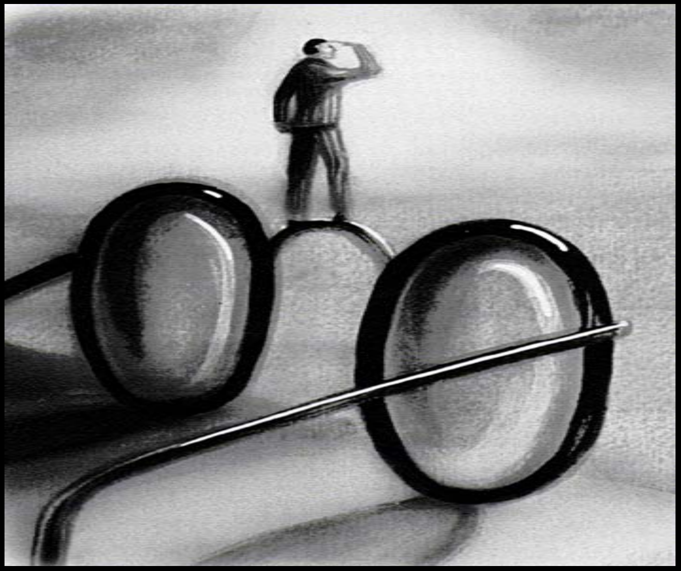
(This new matter can not be seen visually!)

We call this Cold Dark Matter.

Existence of Dark Matter



We know the dark matter exists.



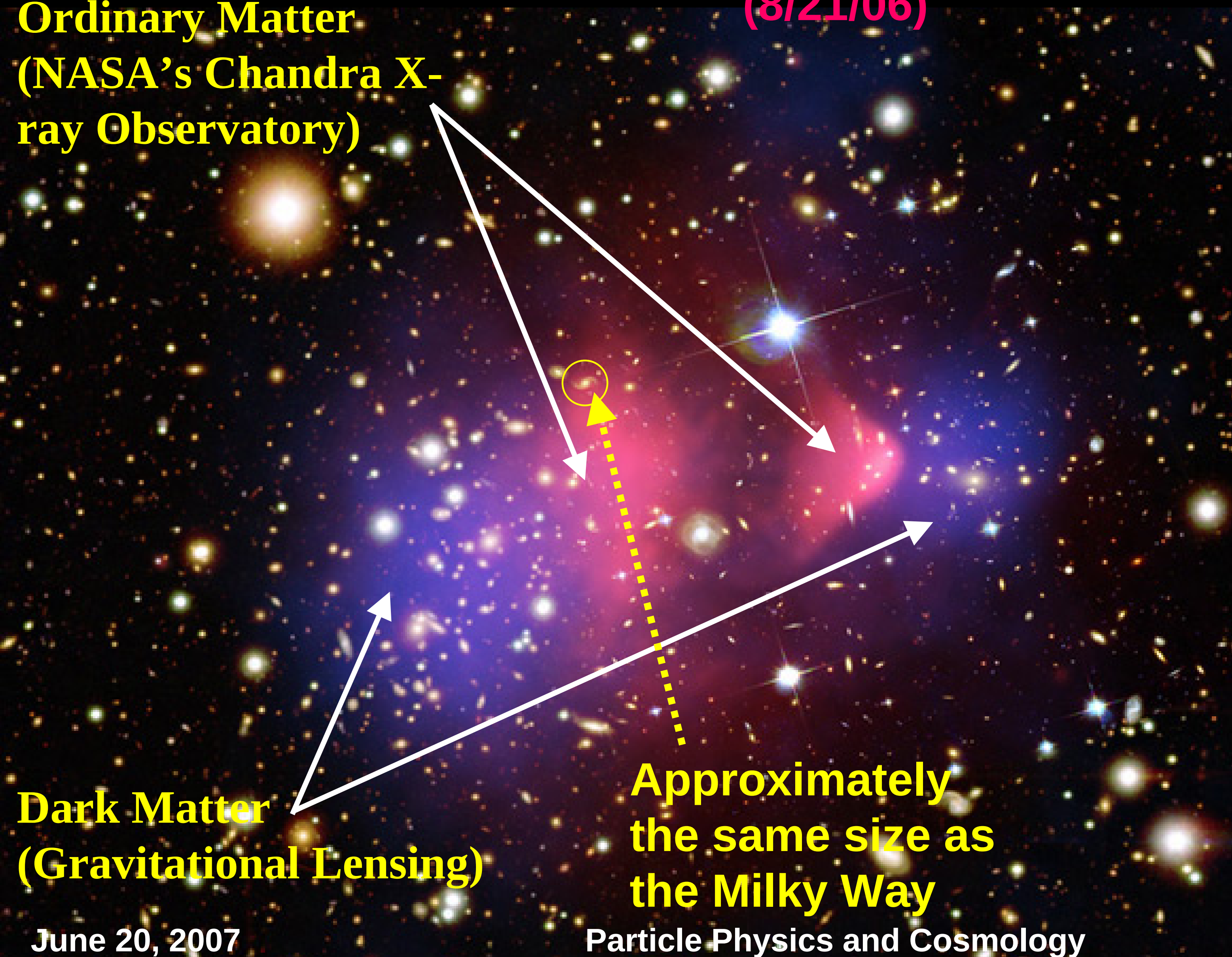
Rotation curves of the galaxies

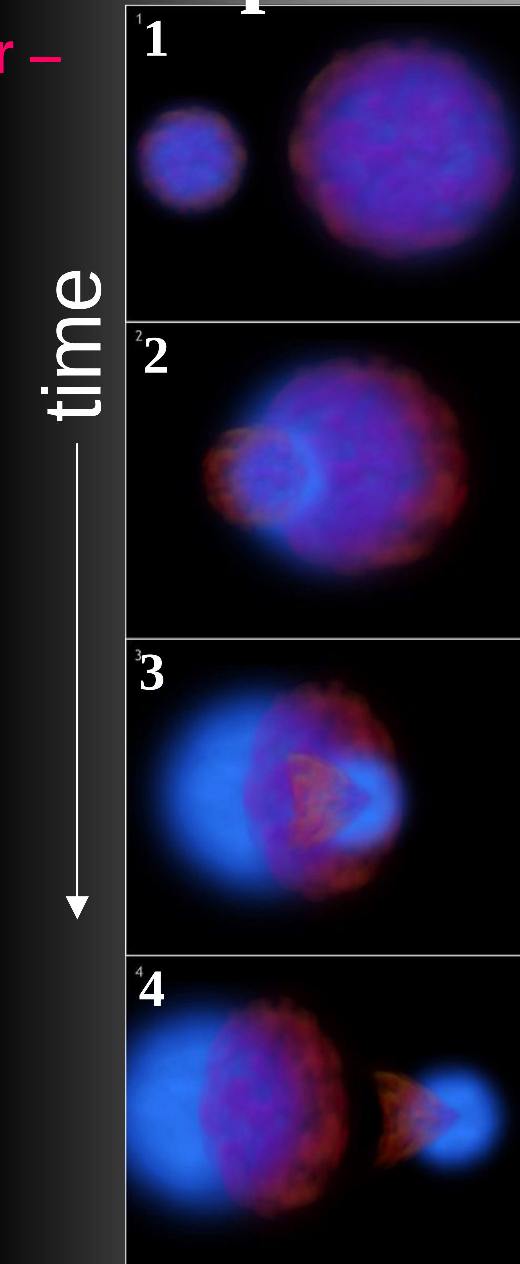
Collision of the galaxies

Cosmic Collision of 2 Galaxy Clusters

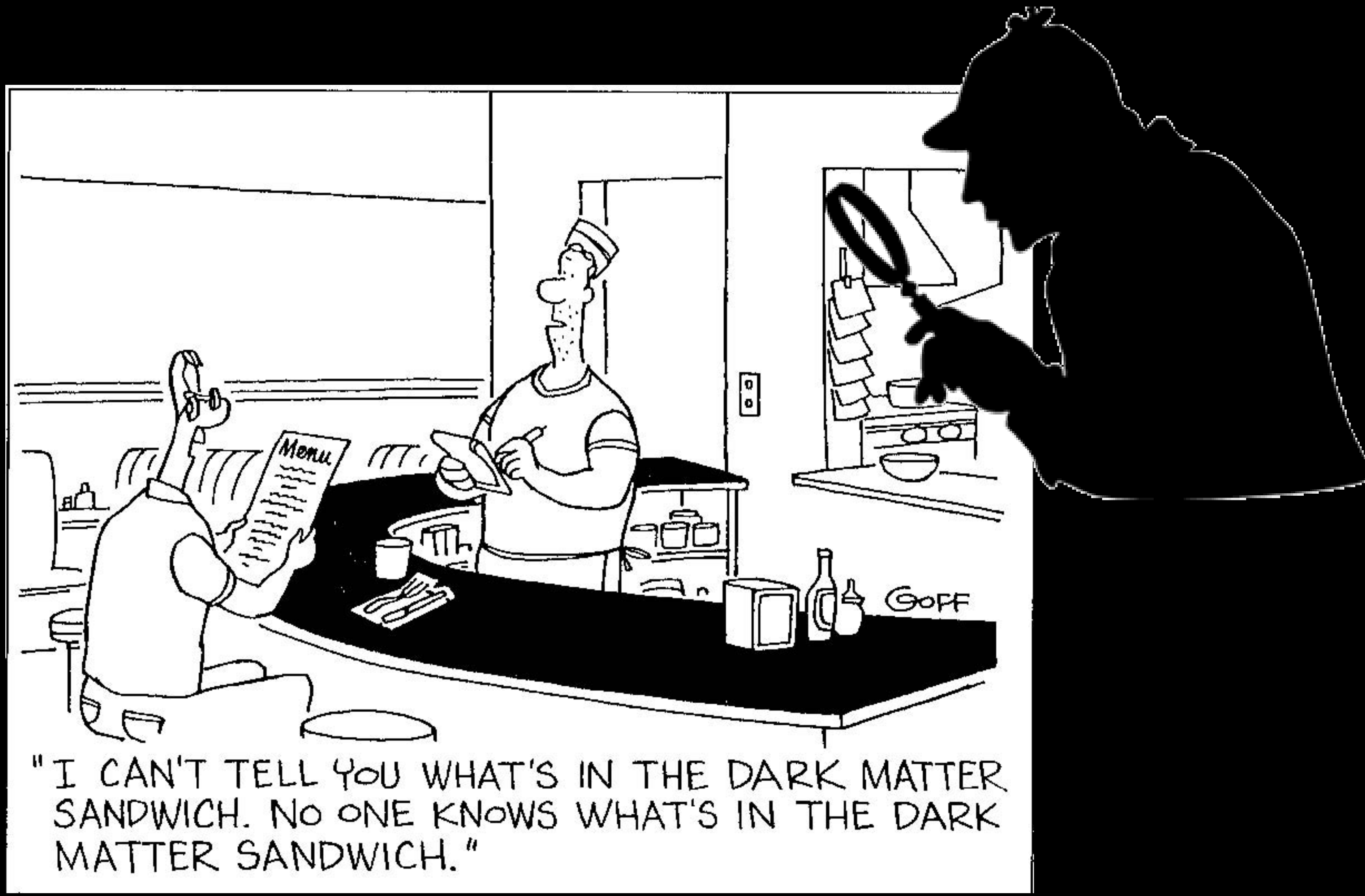
splitting normal matter and dark matter apart

– Another Clear Evidence of Dark Matter – (8/21/06)





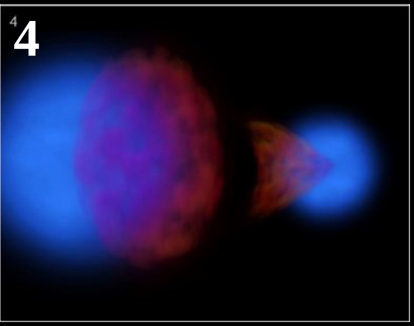
Dark Matter Sandwich



But we have a few clues.

Let's check what we know.

What is Cold Dark Matter?

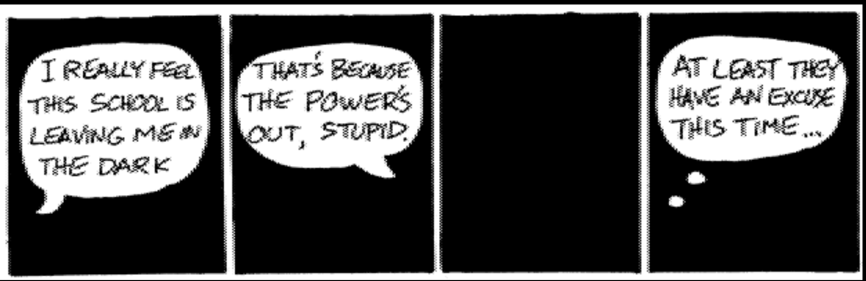


It's Doesn't Matter.

Right, it doesn't shake hands with anyone easily. Two dark matter clusters (blue balls) are just passing each other.

It's a Cold Matter.

Yes, it is a "relativistically" slowly moving ("cold") object.



It's a Charge-less Matter.

Right, it doesn't respond to your flash light. This means it is a neutral object.

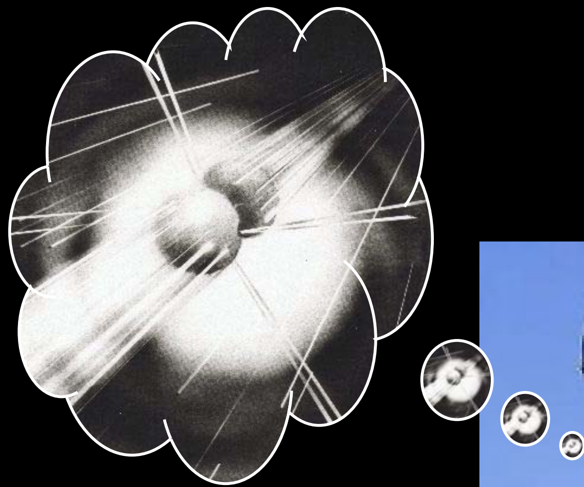
So, It's a Cold Dark Matter.

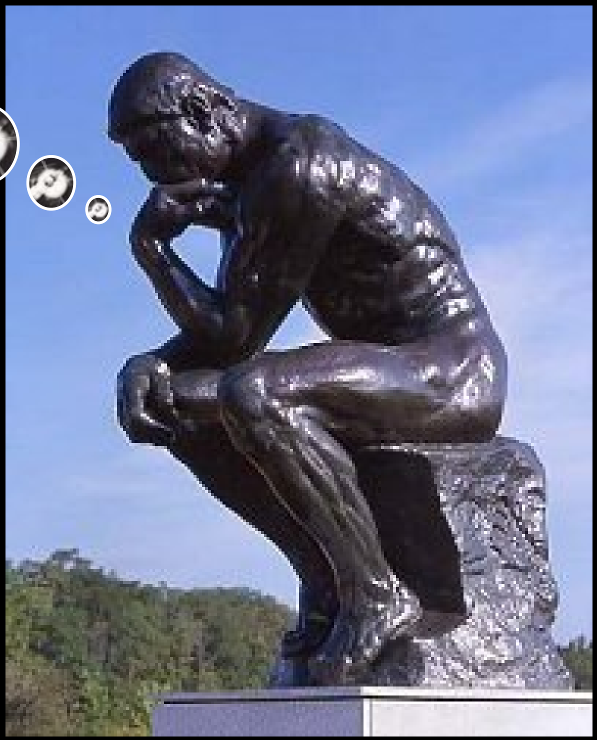
Right, it is a neutral and long-lived (stable) object.

Can it be one of the known particles?

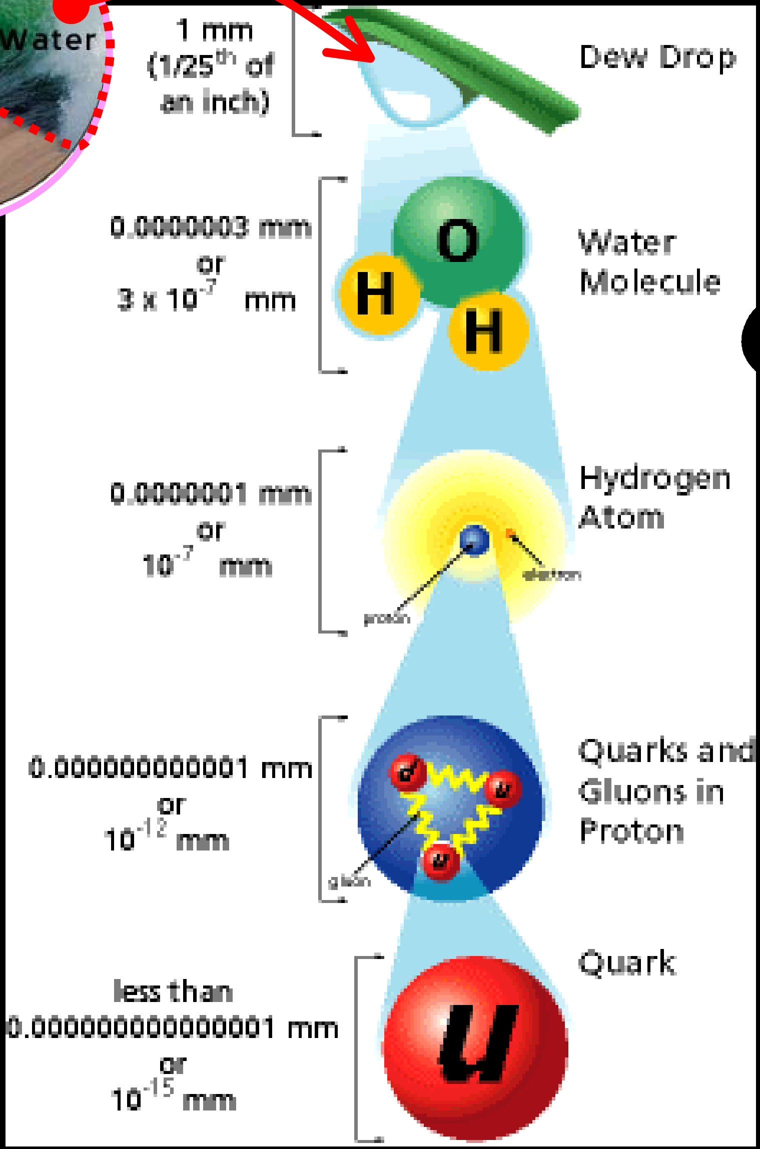
Let's check what we know.

Thinking of Elementary Particles





Known Matter Particles



How many?

12 Particle-Zoo Animals

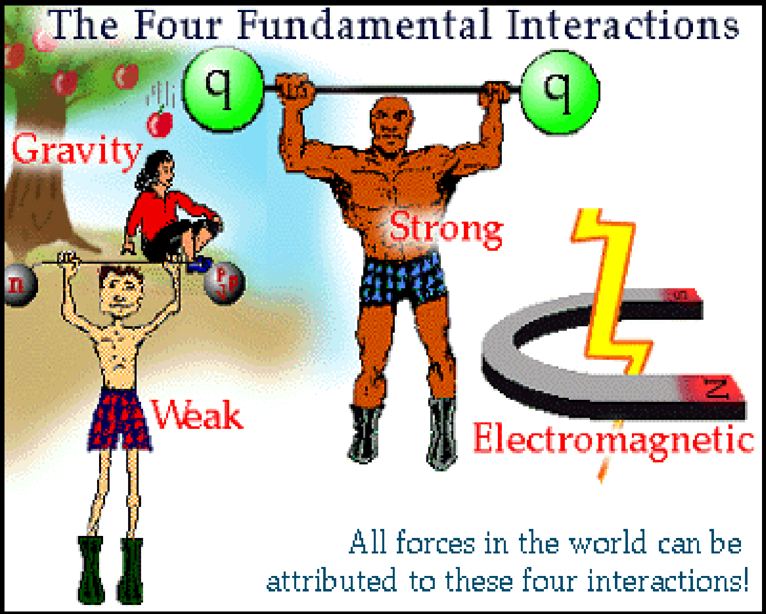
The 12 elementary particles are fundamental building blocks of matter.

6 Types of Quarks

6 Types of Leptons

All masses in MeV.
ANIMAL MASSES SCALE WITH PARTICLE MASSES

4 Zoo Keepers



g's (gluons) → strong force

Quarks experience them.

Protons & neutrons are stick together.

γ's (photons) → electromagnetic force

Quarks, leptons (other than neutrinos) experience this force.

W's (weak bosons) for weak forces

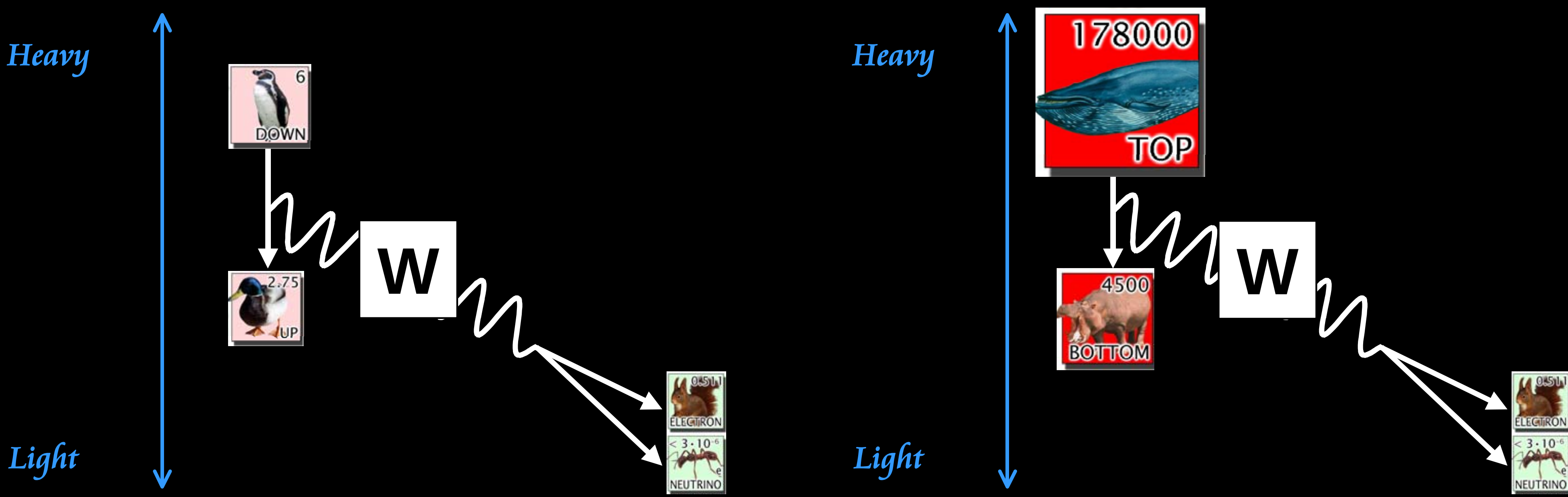
Quarks, leptons experience this force.

NOTE : Graviton (G) (☹ *not found*) carries gravitational force.

Picture of Interaction

d → W + u
W → e ν

t → W + b
W → e ν

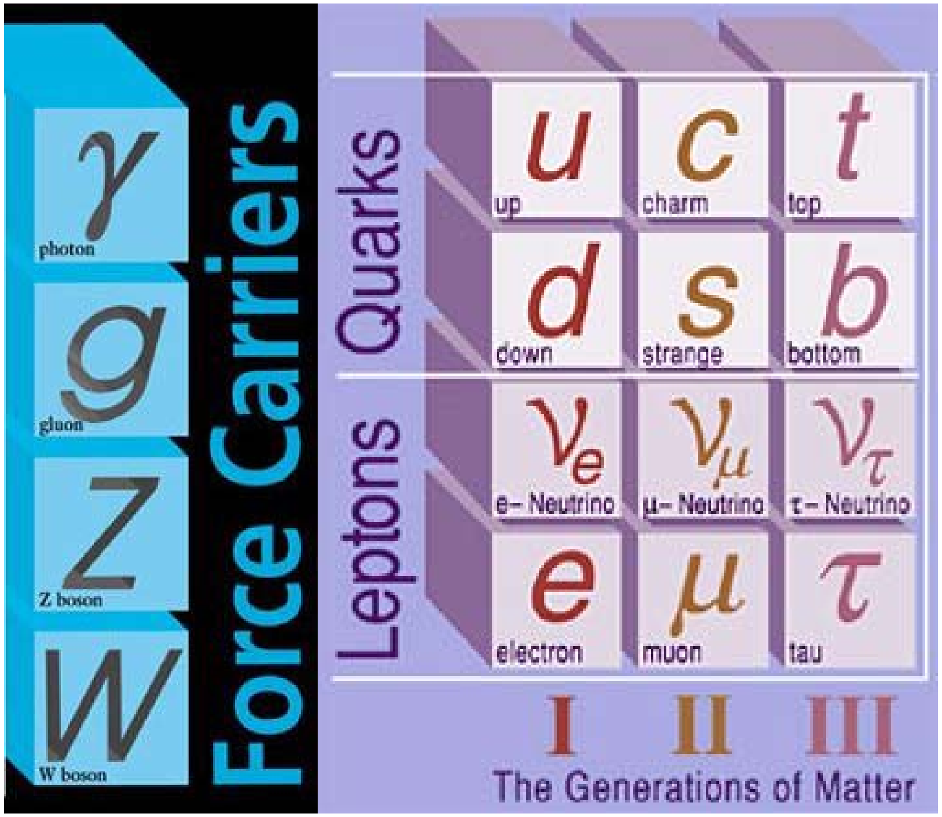


Same force for all generations

All reactions are explained by a single description (= theory).

CDM in The Standard Model?

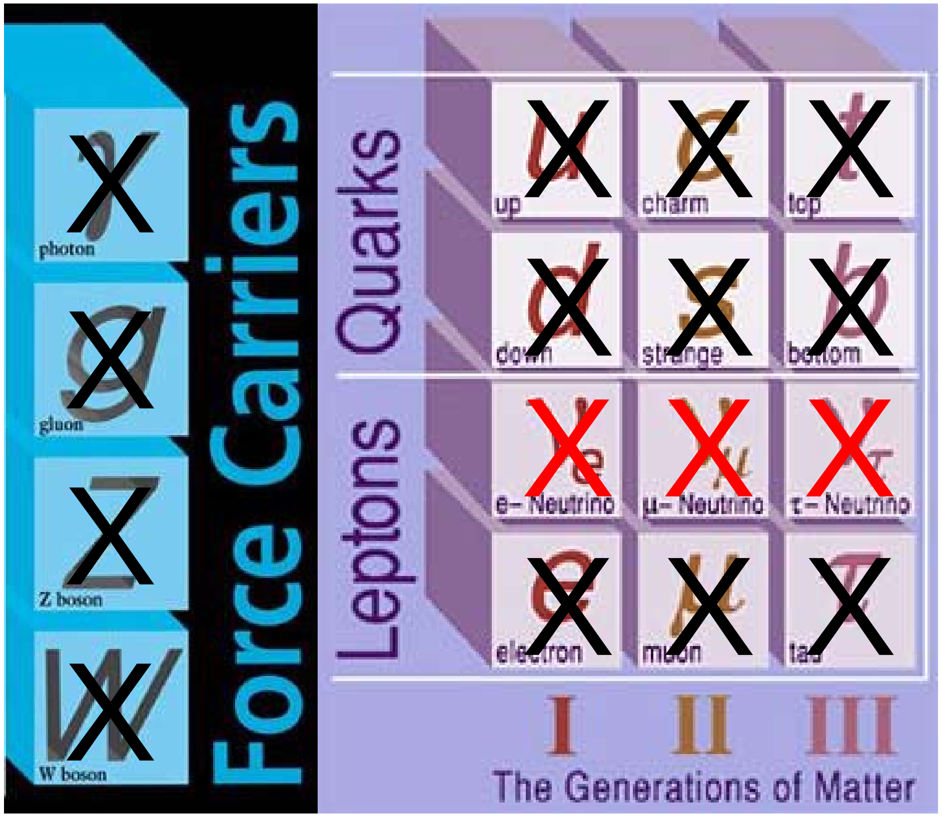
[100 points] The Standard Model describes all these particles and 3 of 4 forces by paring two elementary particles. We have confirmed the existence of those in the laboratory experiments. Choose a candidate for the Dark Matter particle. Explain why.



No!

Quarks, electron, muon, tau particles, and force carriers can not be the dark matter, since their interactions are stronger than what we expect.

Neutrinos can, but they have other problems.



We need a new model.

New Idea

We need an idea, based on a new symmetry.

Supersymmetry* or *SUSY

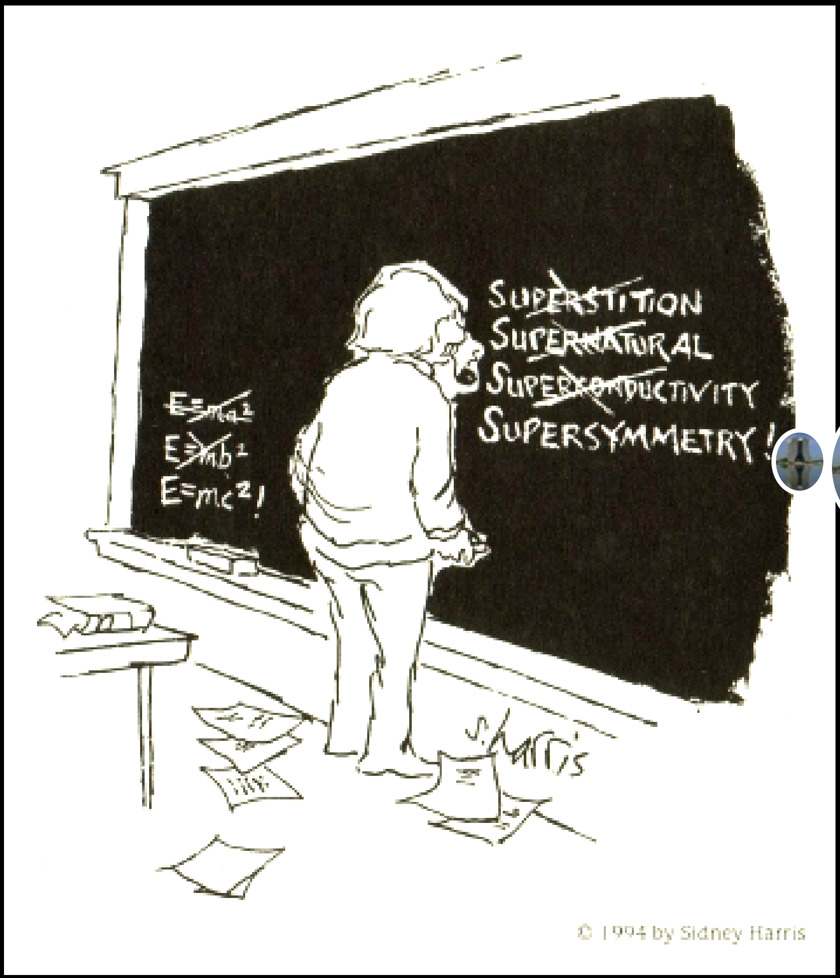
Supersymmetrizing the Standard Model

Neutral-ino

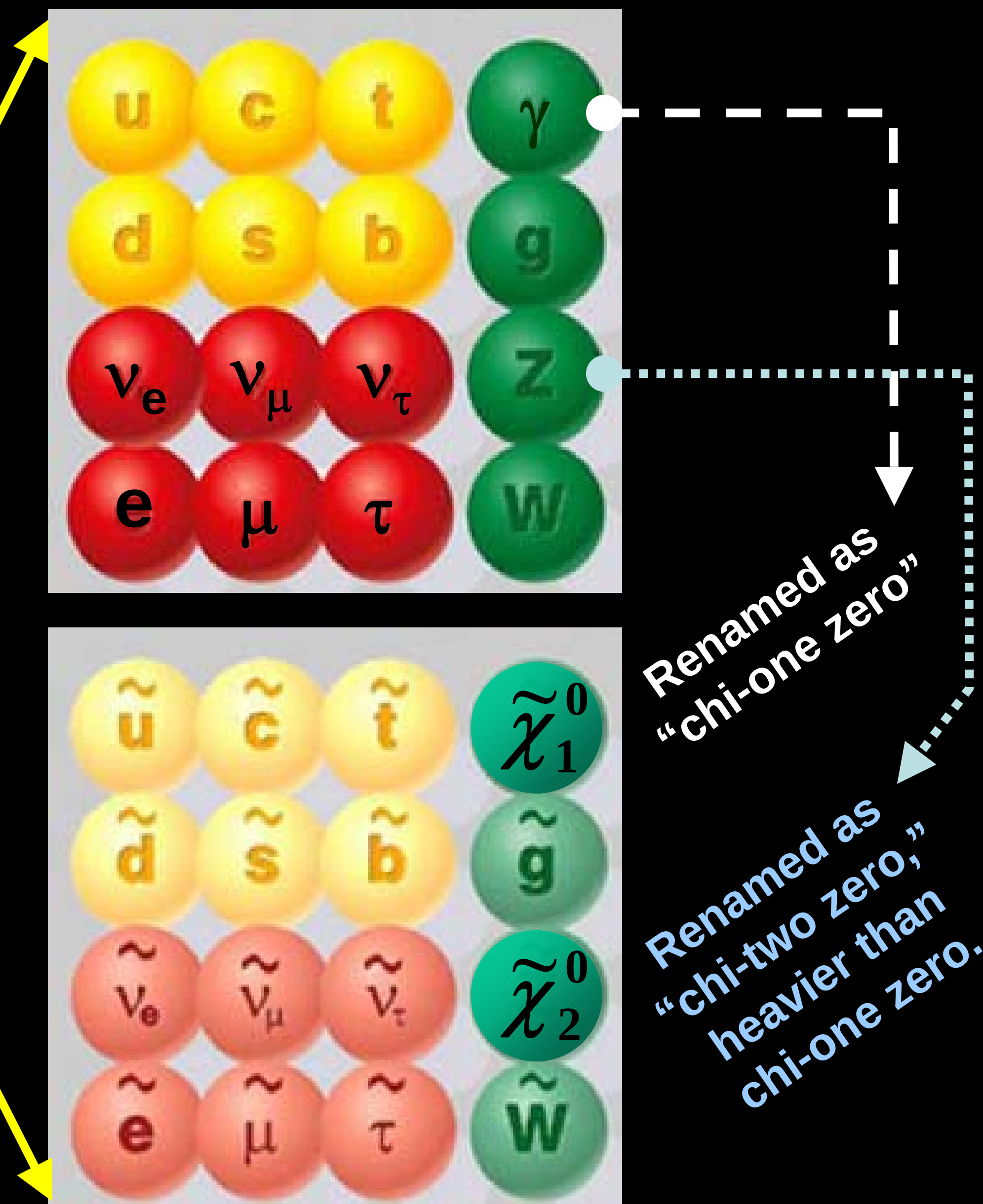
This new charge-less (neutral) particle is the leading candidate for the dark matter.

1) **What is the new model?**
2) **Attractive?**
3) **Can the neutralino be detected and consistent with the dark matter content of the Universe?**

Mirror Reflection



Supersymmetric Reflection



But, one of them is neutralino.
This is the lightest SUSY particle and stable.

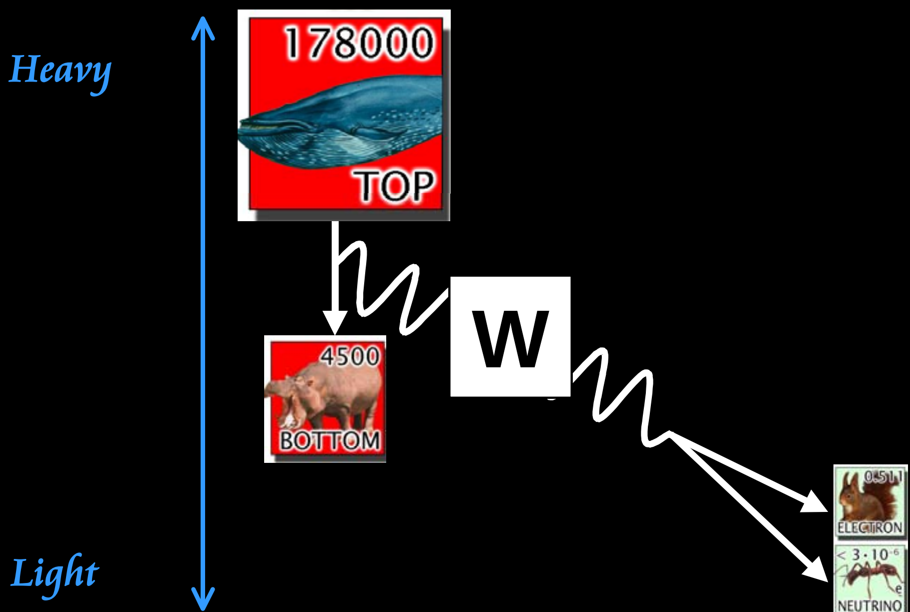
Picture of Interaction (Again)

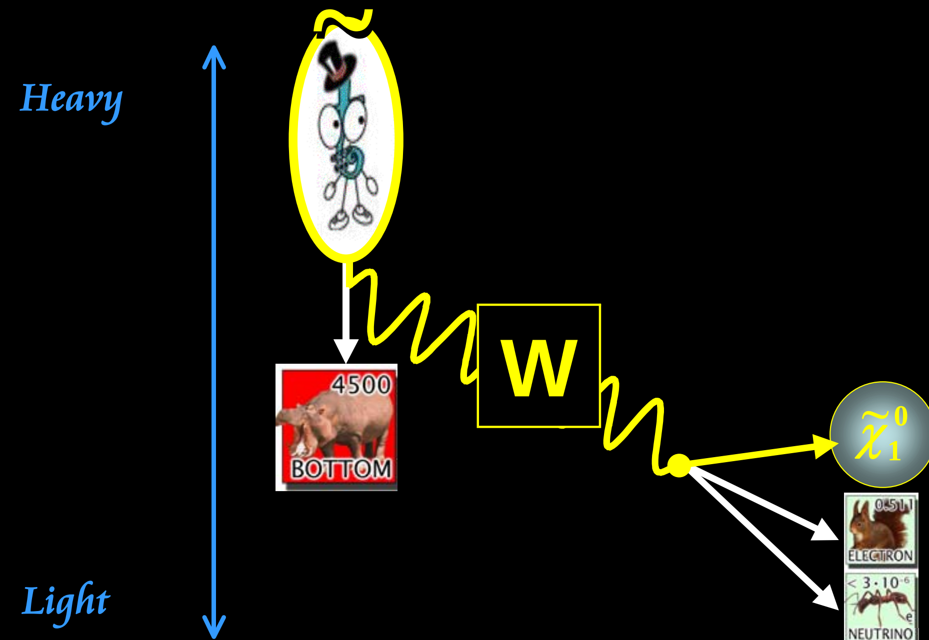
t → W + b

W → e ν

t_{SUSY} → W_{SUSY} + b

W_{SUSY} → χ_{SUSY} + e ν



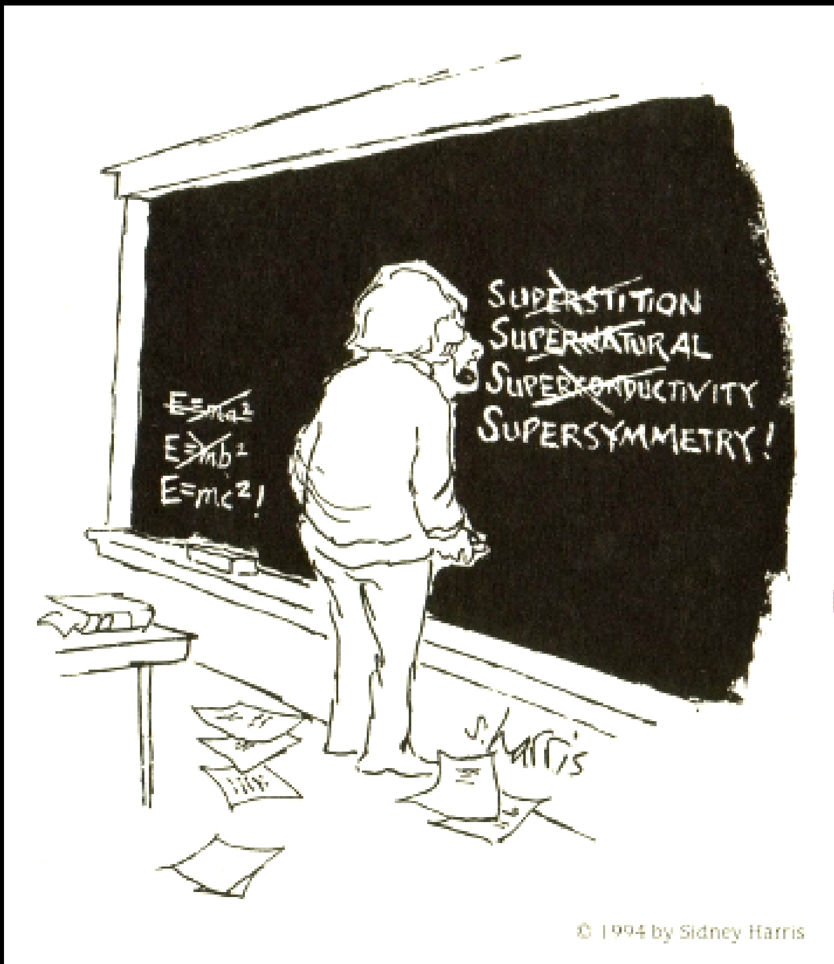


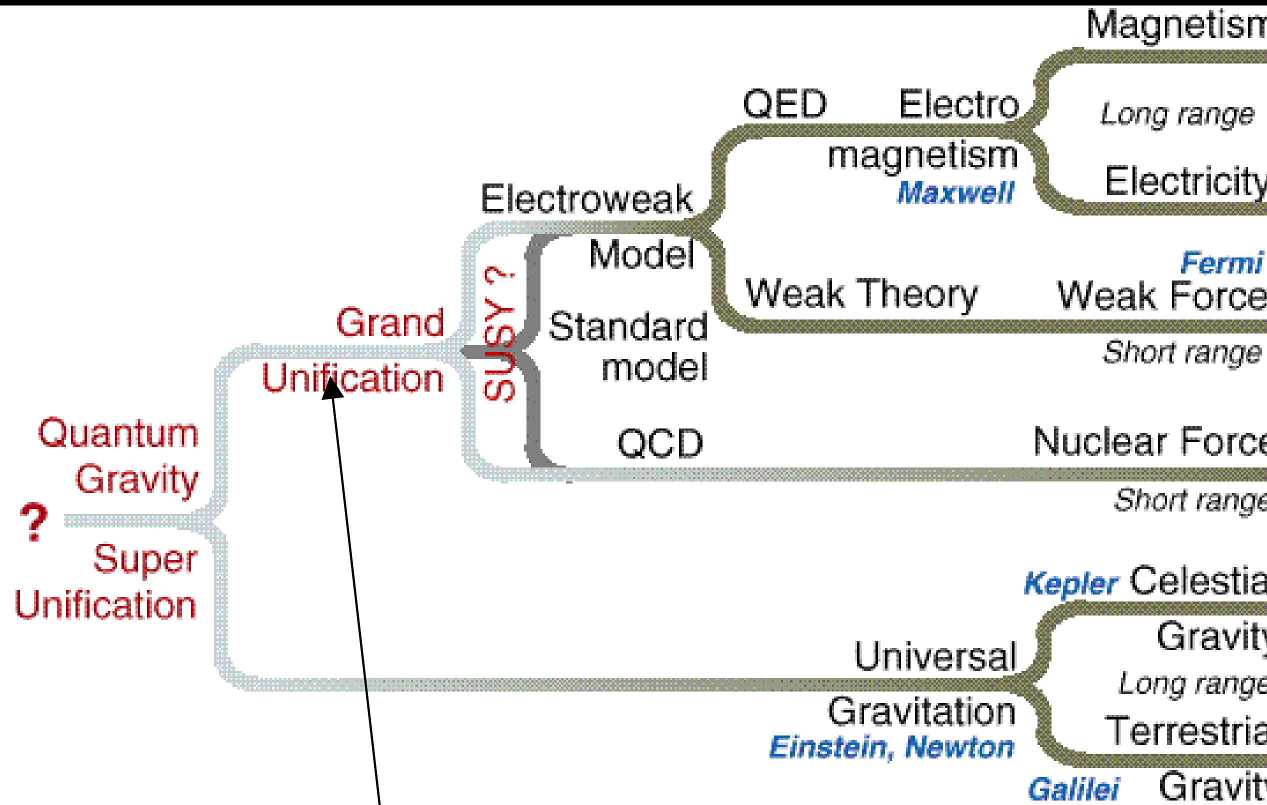
The SUSY nature will be preserved through the entire decay chain. We graphically show this by yellow lines from the beginning to the ending.

SUSY decays can be described in the same way as the Standard Model.

Attractive?

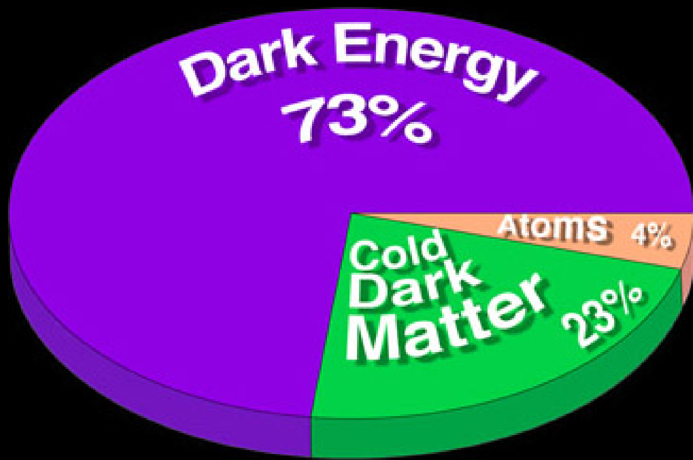
YES. **Physicists always dream about unification of all the forces.**





We can construct a SUSY model with a stable neutralino to have the grand unification of the forces.

Particle Physics and Cosmology



$$\underbrace{\Omega_{\tilde{\chi}_1^0} h^2}_{0.23} \sim \int_0^{x_f} \frac{1}{\langle \sigma_{\text{ann}} v \rangle} dx$$

$$\underbrace{\langle \sigma_{\text{ann}} v \rangle}_{0.9\,\text{pb}} = \frac{\pi \alpha^2}{8 M^2}$$

CDM = Neutralino ($\tilde{\chi}_1^0$)

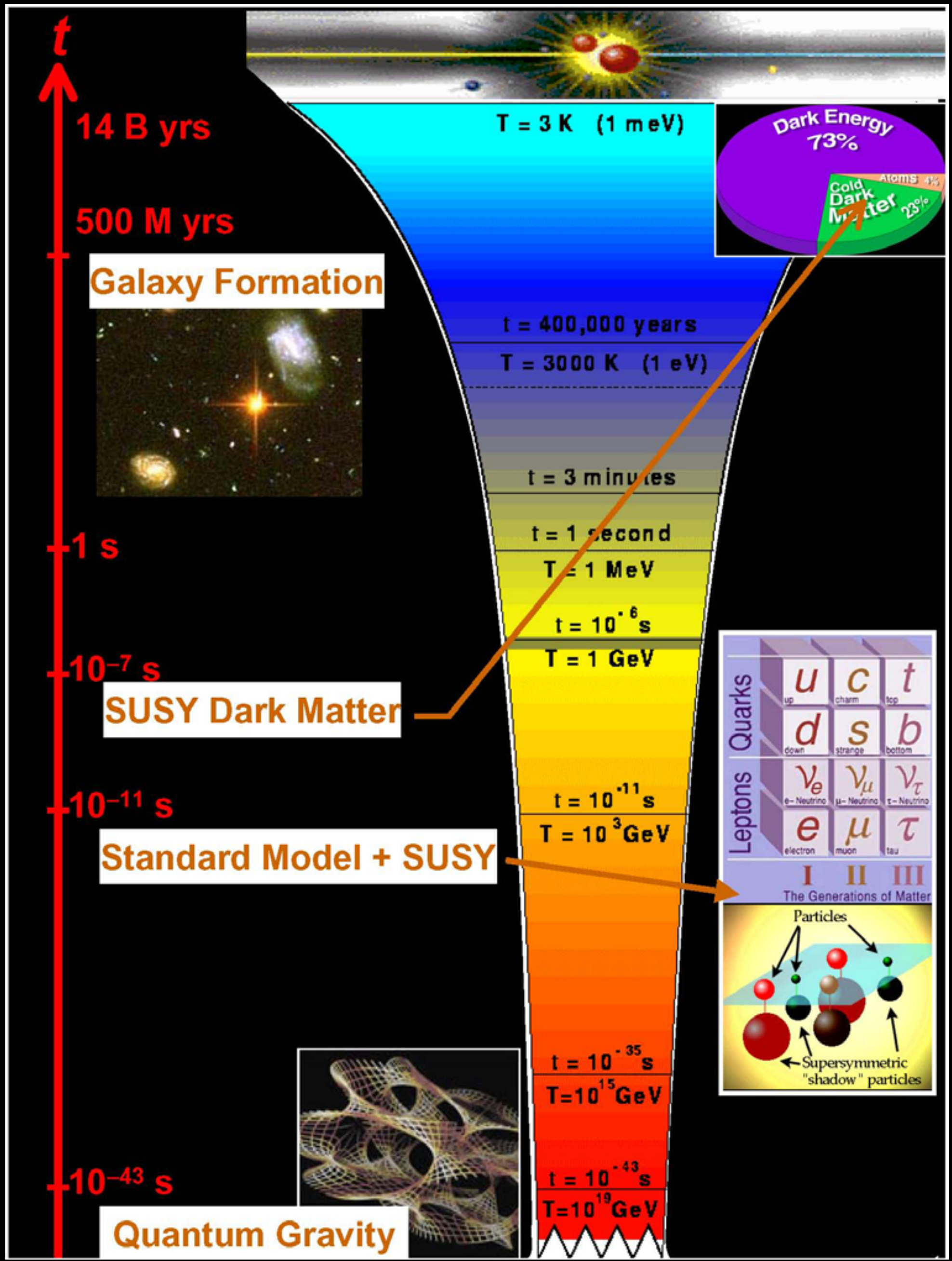
SUSY is an interesting class of models to provide a massive neutral particle (*M* ~ 100 GeV) and weakly interacting (WIMP).

When Were the Dark Matter Particles Created?

Now (You = 20 yrs old)

~380,000 years CMB (You = 4.8 hrs old)

~0.0000001 seconds



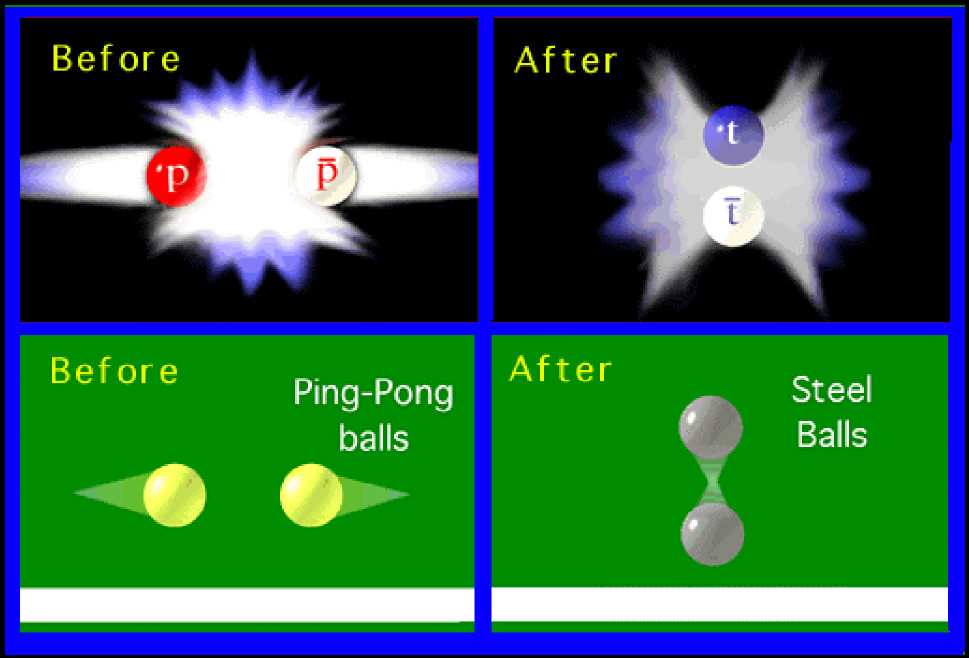
Thinking of Dark Matter Detection

Physics Magic: Ping-pong balls → Steel Balls

One promising way: In particle collisions

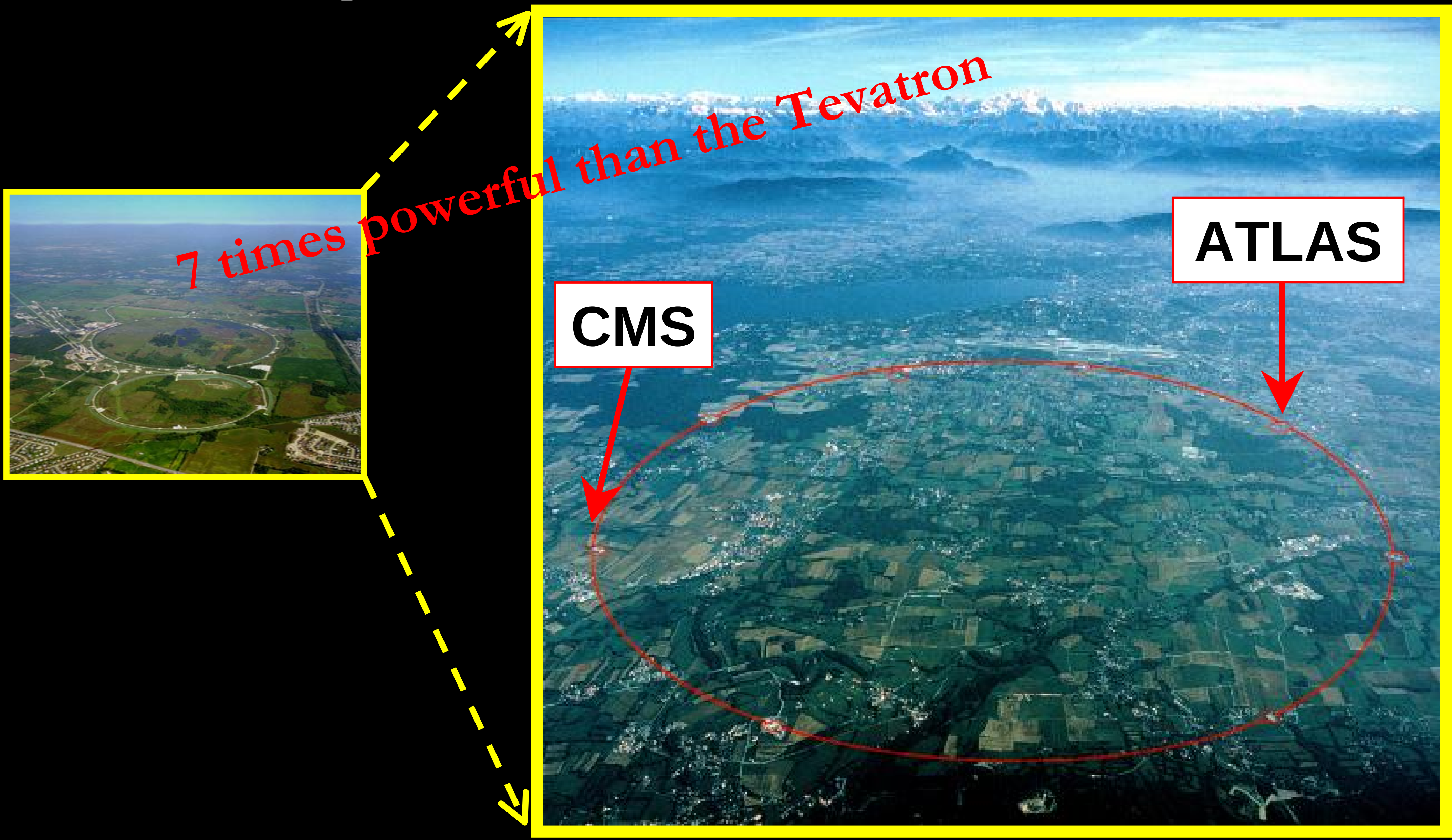
$$E = Mc^2$$

Proton and ant-proton collision can produce the Standard Model particles like heavy top quarks (~180 times heavier than a proton!)



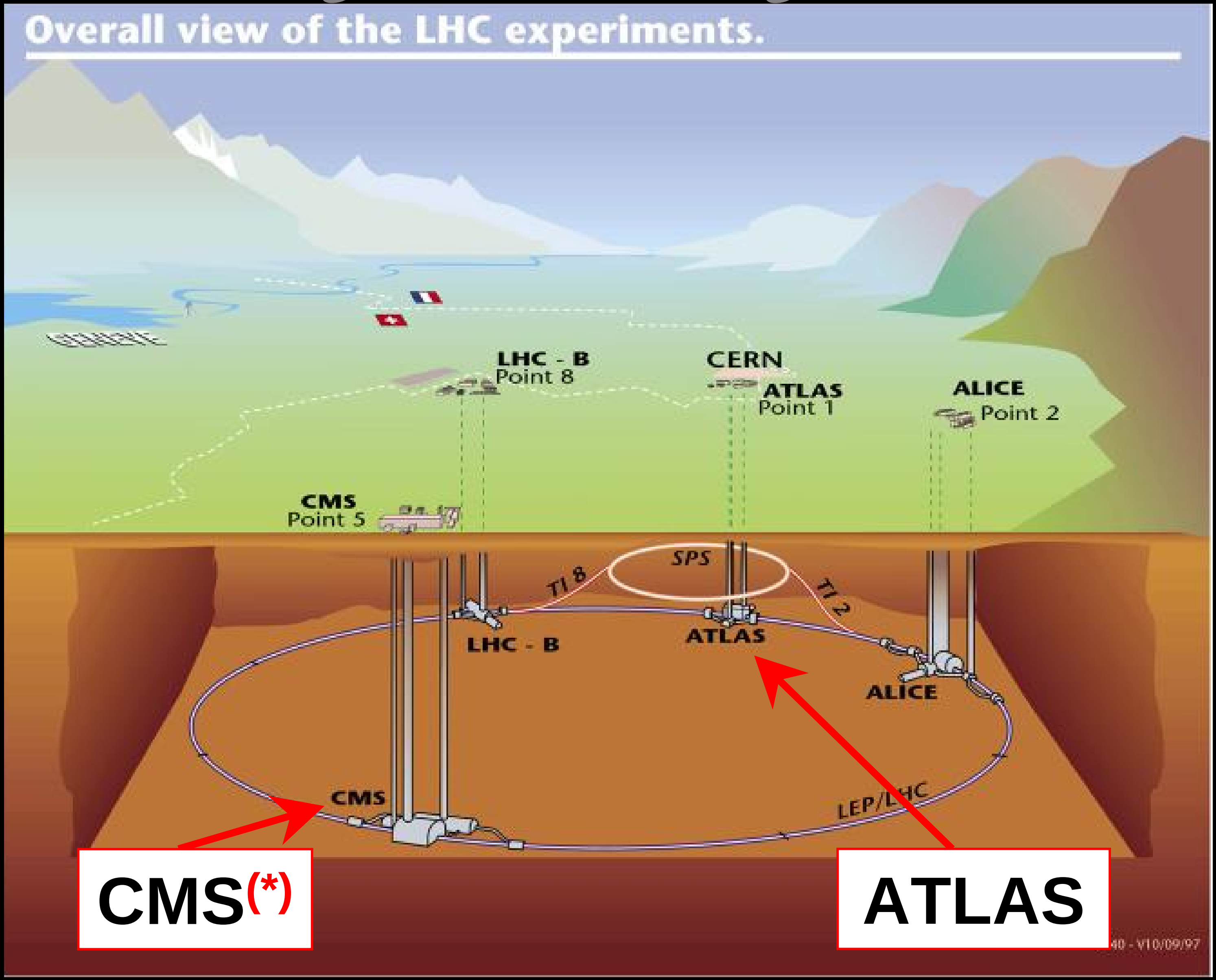
- ⇨ Tevatron
- ⇨ *Large Hadron Collider*
- ⇨ Linear Collider

Large Hadron Collider (LHC)



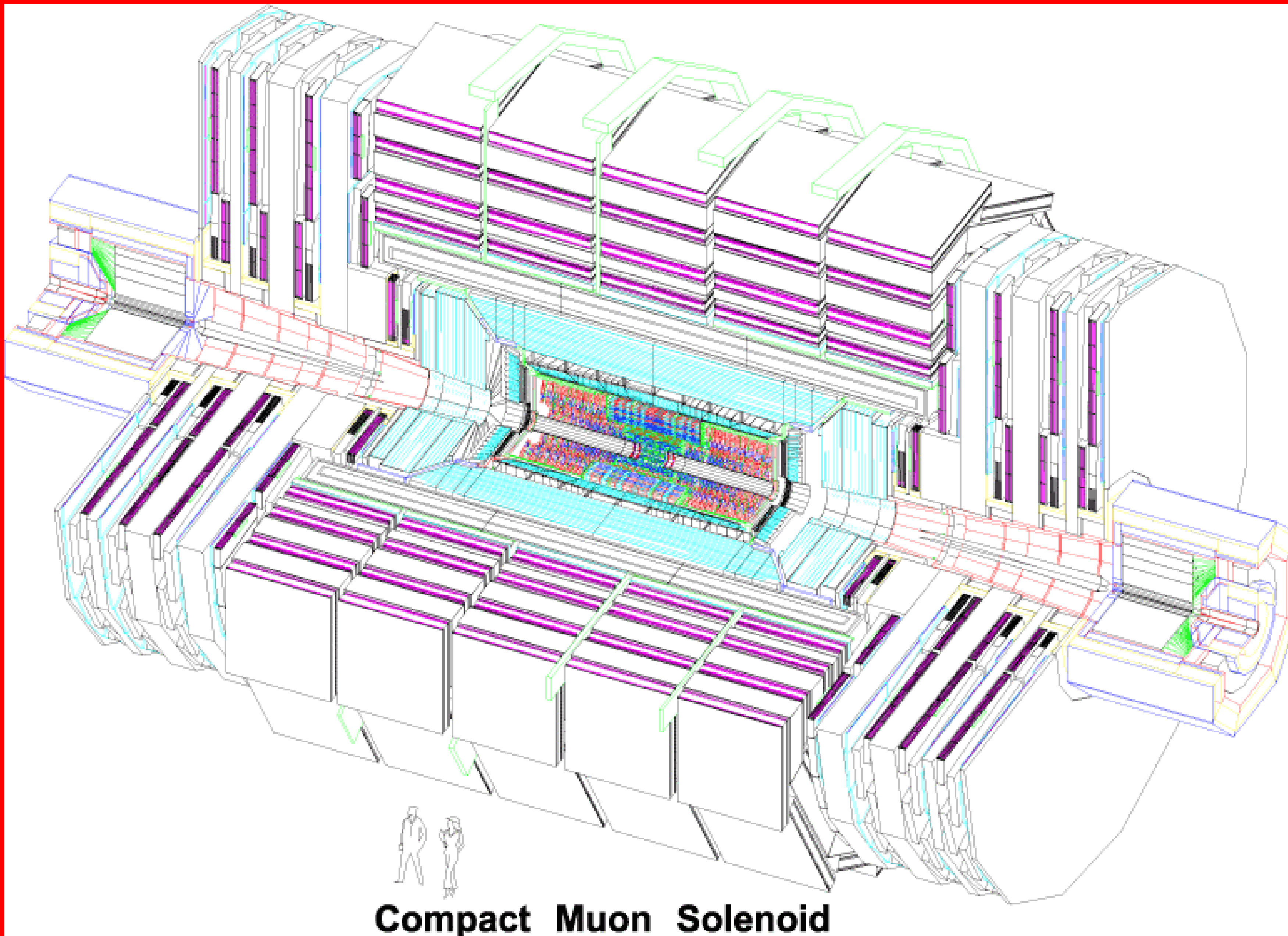
Two large international collaborations.

"Underground" Experiments



(*) The TAMU group is a member of the CMS collaboration.

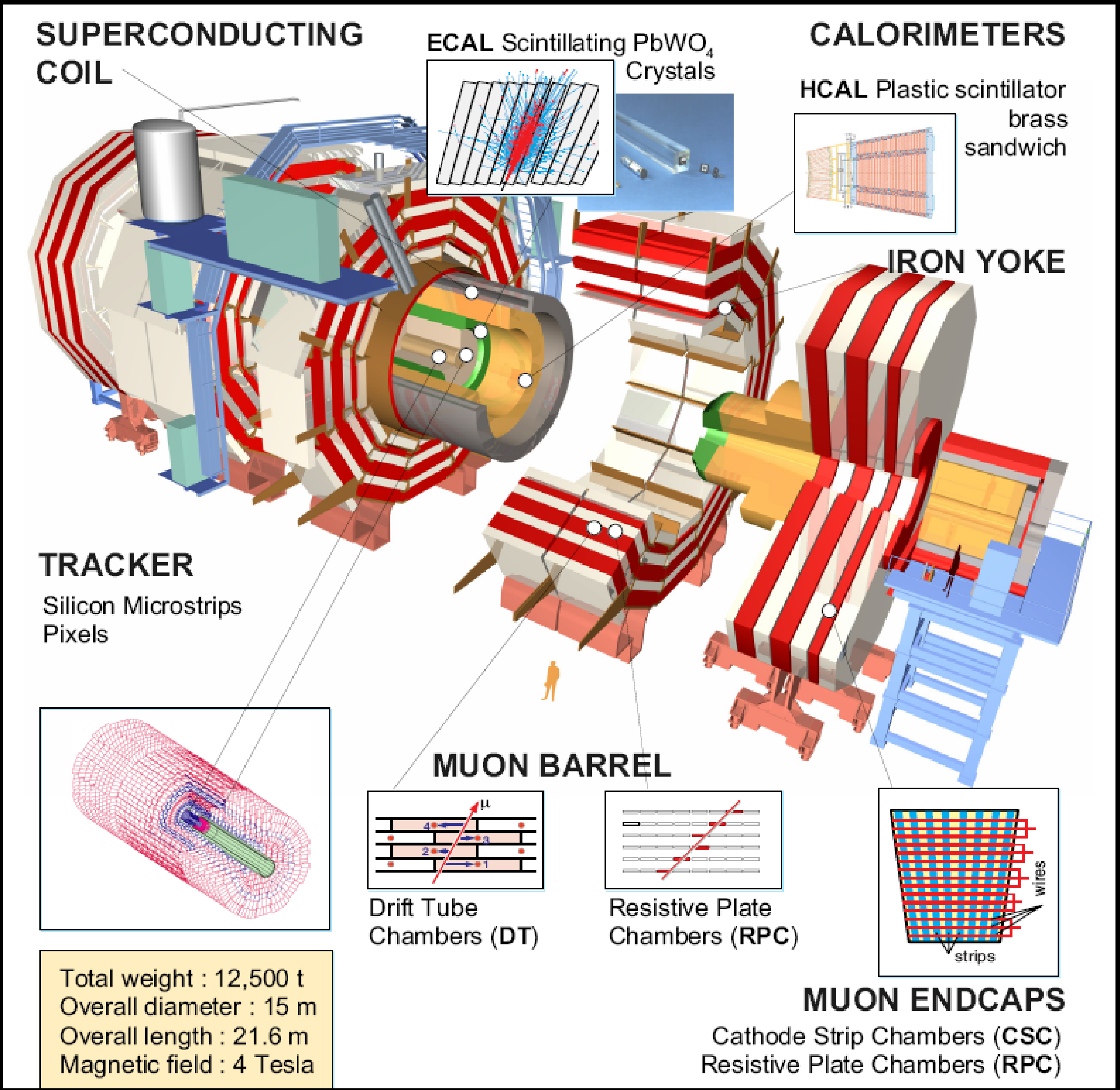
CMS - Particle Detector



Anatomy of CMS

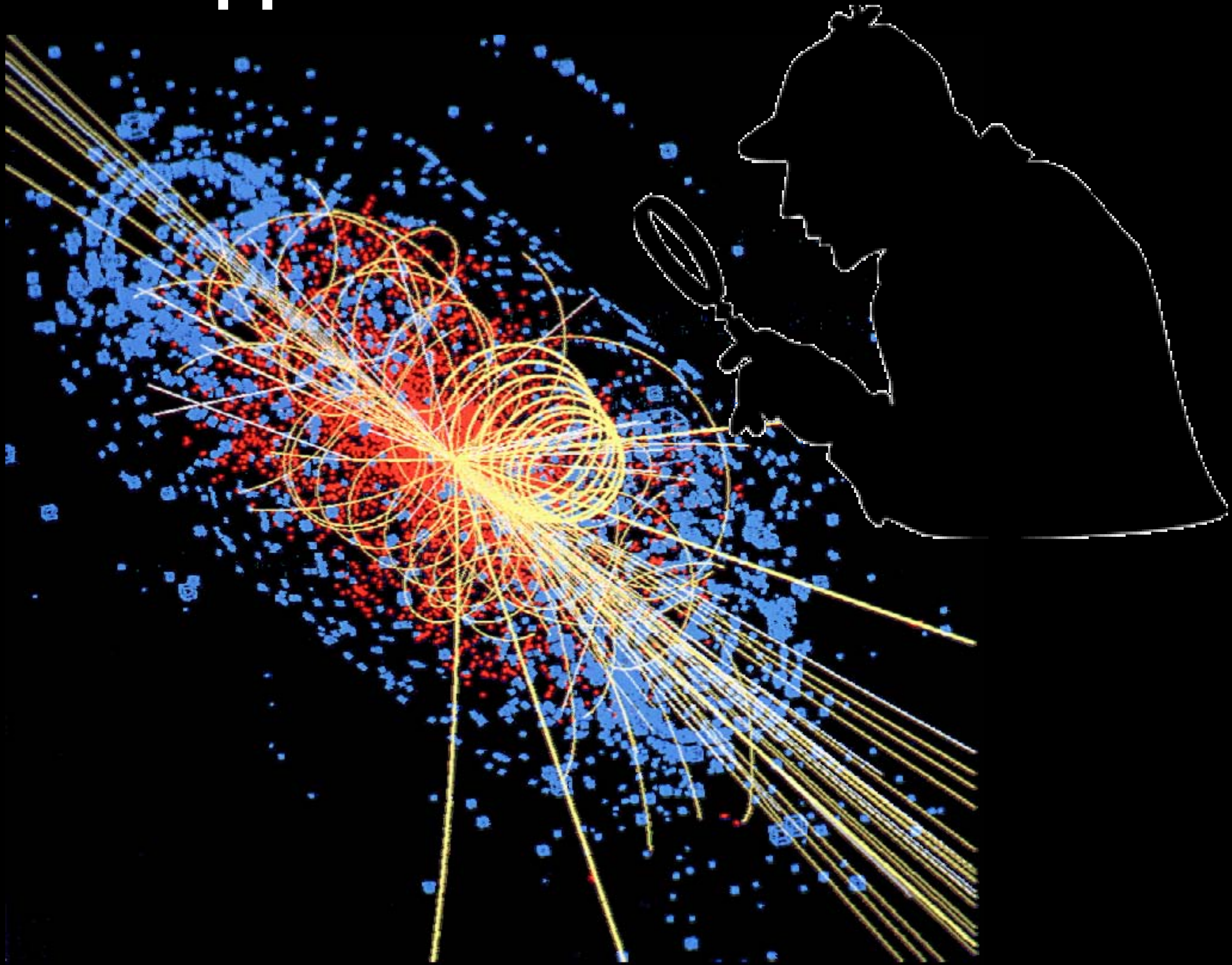
Compact is a Relative Term

CMS is significantly smaller than ATLAS but heavier

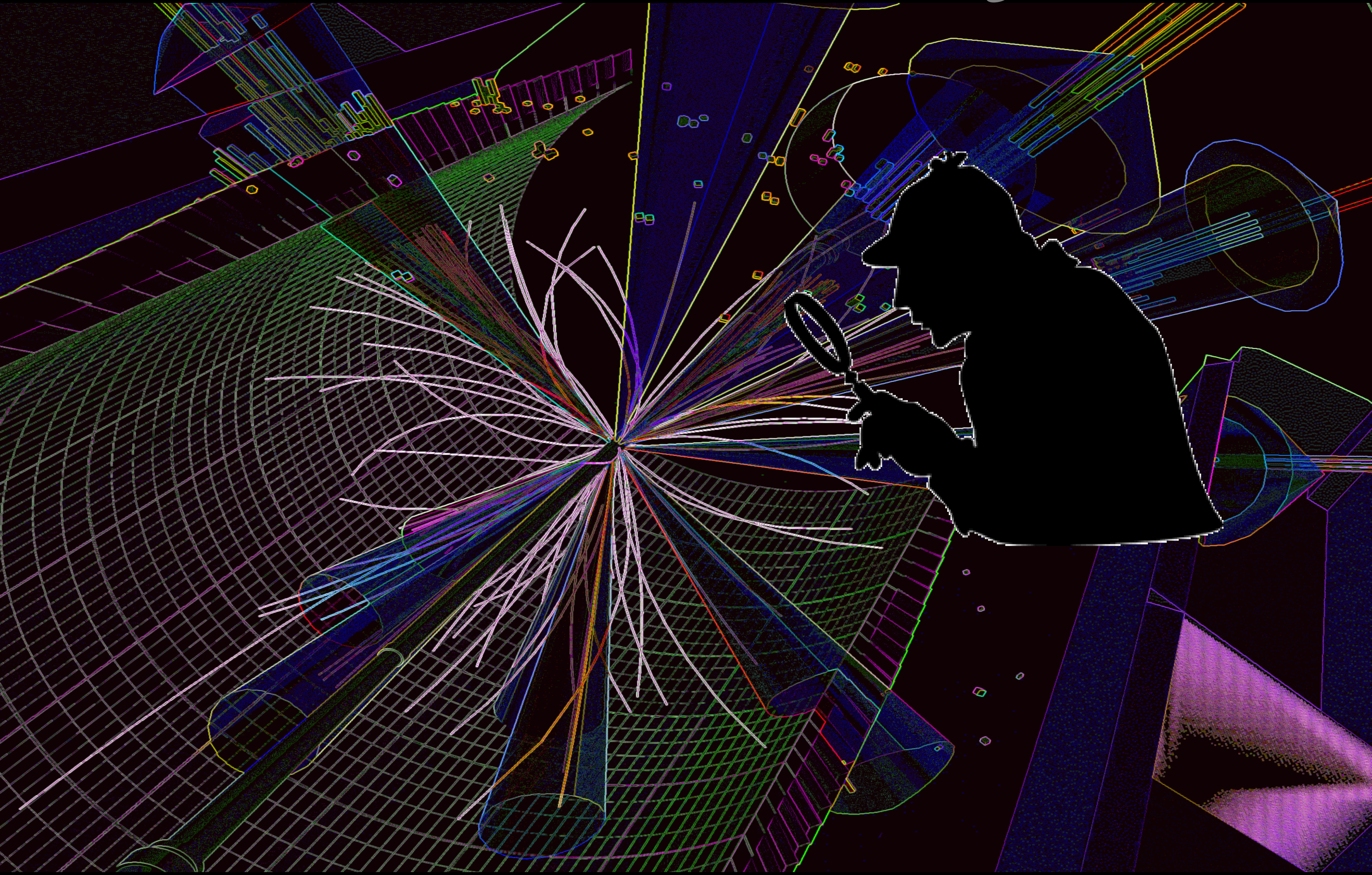


Collision as We Imagine …

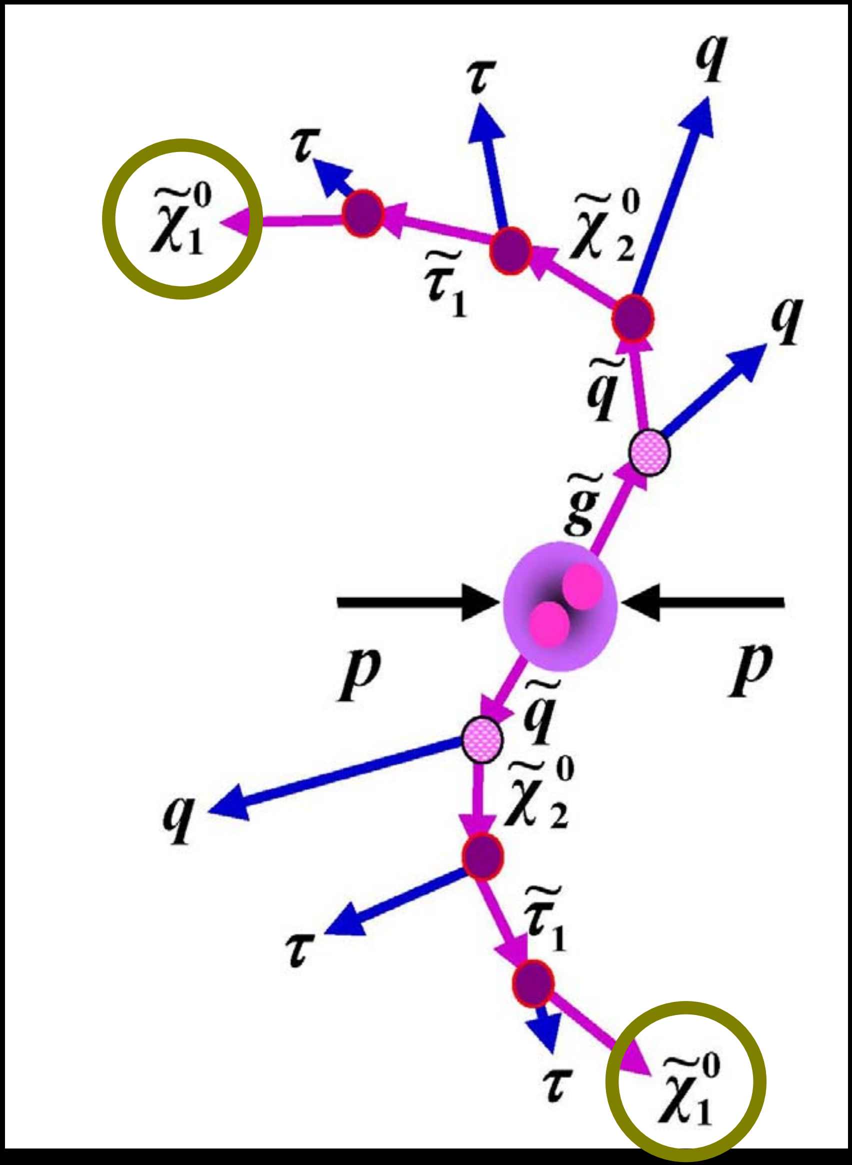
We study blue and red dots and yellow lines to figure out what happens in the collision!



Reconstruction as We Imagine …

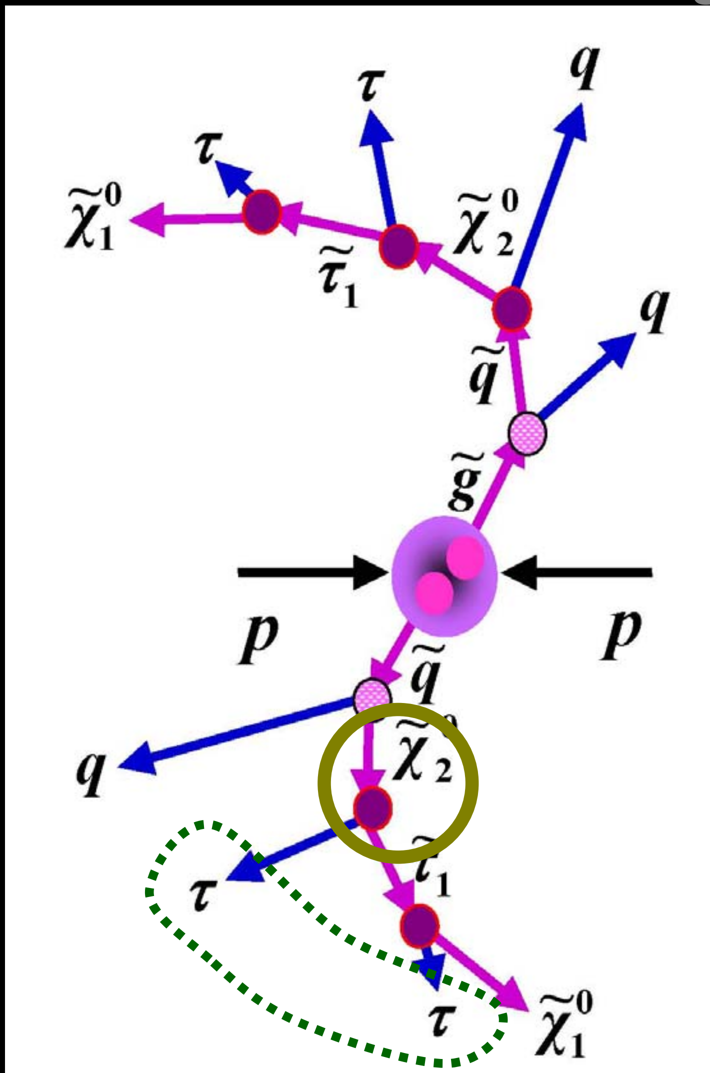


Key Reaction at the LHC



We have to extract this reaction out of many trillion pp collisions.

Anatomy – Mass Distribution



$$M_{\tau\tau}^{\max} = M_{\tilde{\chi}_2^0}\sqrt{1-\frac{M_{\tilde{\tau}_1}^2}{M_{\tilde{\chi}_2^0}^2}}\sqrt{1-\frac{M_{\tilde{\chi}_1^0}^2}{M_{\tilde{\tau}_1}^2}}$$

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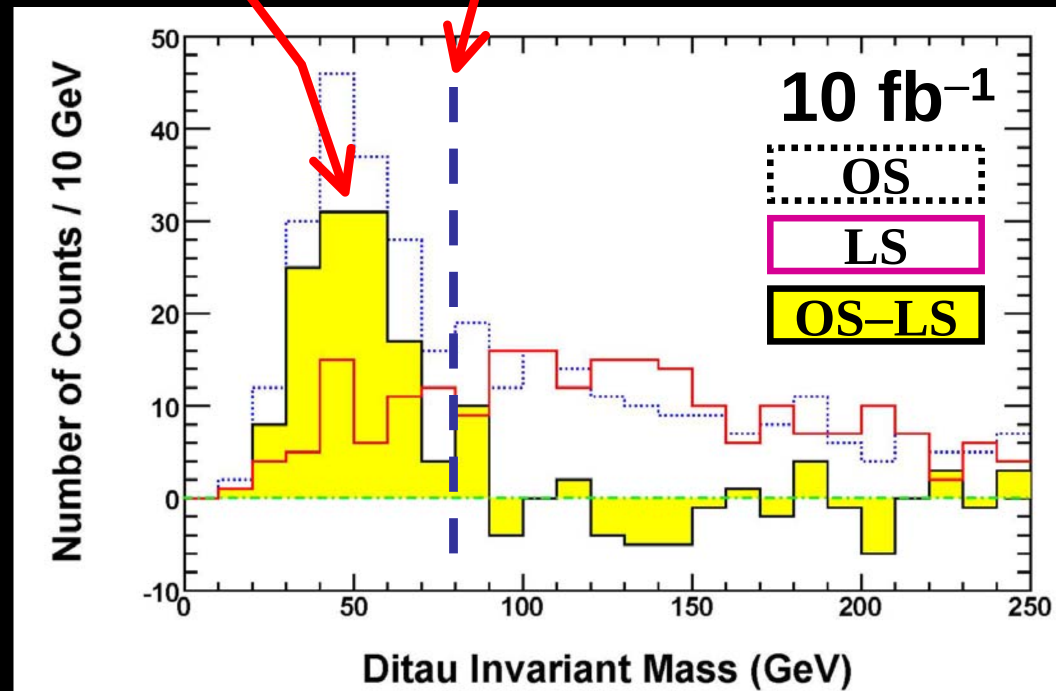
M^{max}(true) = 78.7 GeV

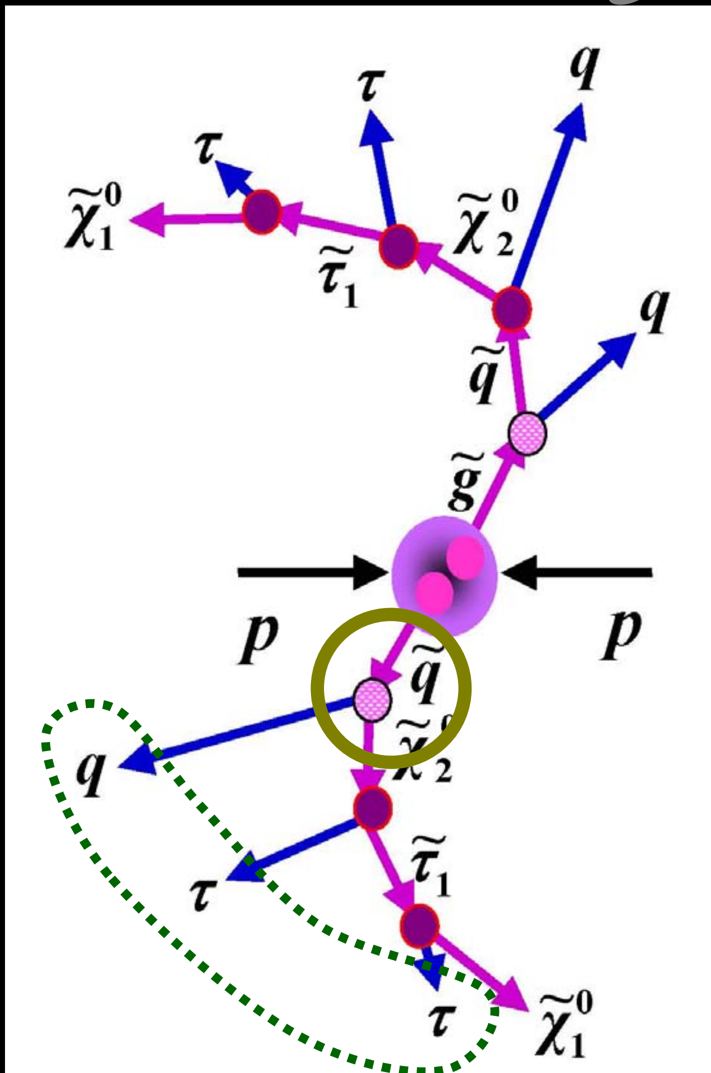
M^{peak} = 47.1 GeV

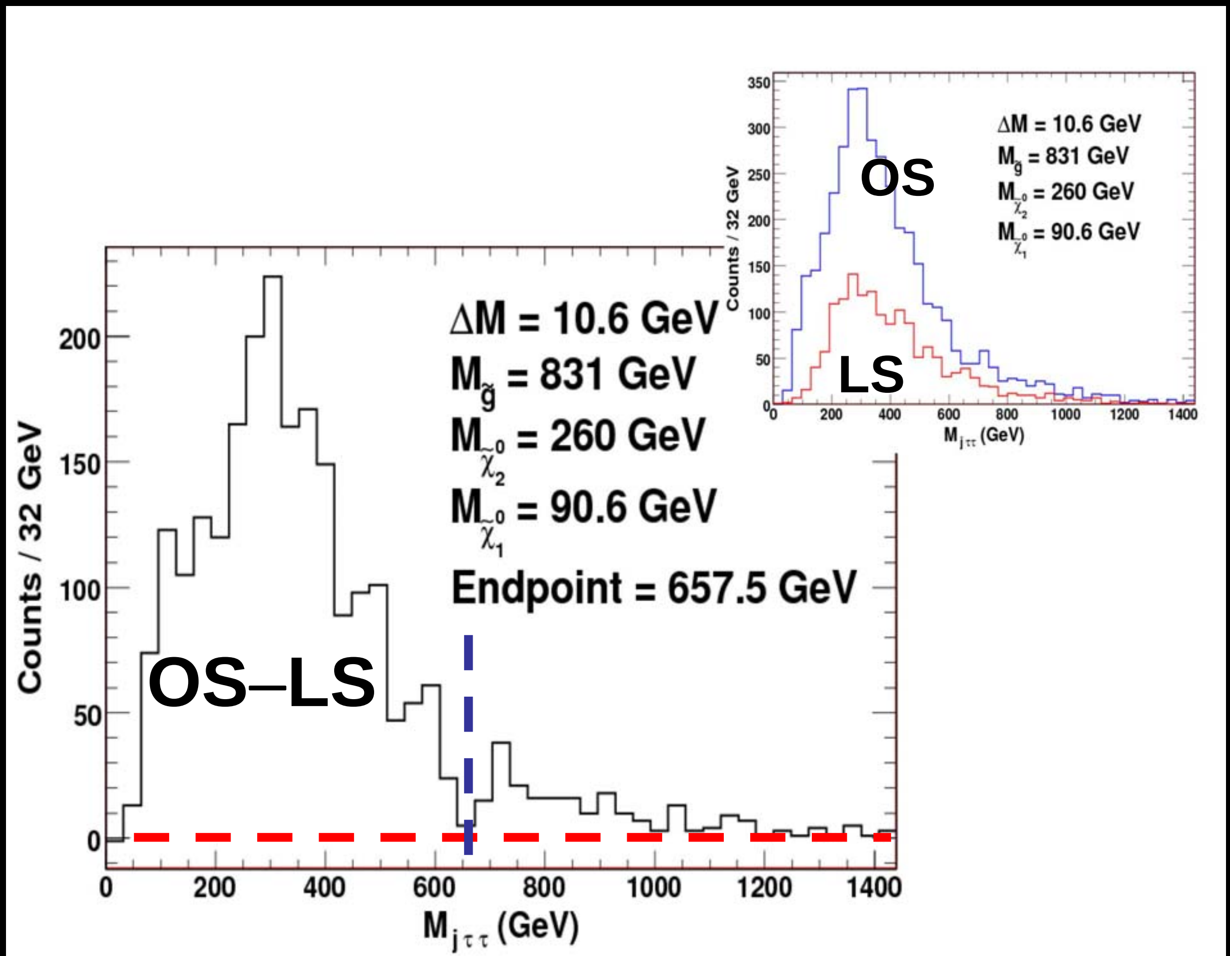


OS–LS counts with $M_{\tau\tau}$ < 100 GeV:

Top	:	6 counts
W+jets	:	1 count
SUSY	:	125 counts

Anatomy – Mass Distribution (2)





Probing ***squark*** mass

GOAL: Establish the technique before the experiment starts in 2008.

How do you know that the neutralinos (we will observe) at the collider are responsible for the dark matter content?

We measure the masses (*M*) of the particles at the LHC.

We calculate the dark matter content (Ω) in the new model of the Universe.

$$\underbrace{\Omega_{\tilde{\chi}_1^0}}_{0.23} h^2 \sim \int_0^{x_f} \frac{1}{\langle \sigma_{\text{ann}} v \rangle} dx$$

Example Translation

$$M_{\tilde{g}} = 830\,\text{GeV}$$
$$M_{\tilde{\chi}_2^0} = 260\,\text{GeV}$$
$$M_{\tilde{\tau}} = 151\,\text{GeV}$$
$$M_{\tilde{\chi}_1^0} = 141\,\text{GeV}$$

We establish the dark allowed regions from the detailed features of the signals, and accurately measure the masses.

SUSY Model

We calculate the relic density and compare with WMAP.

$$\Omega_{\tilde{\chi}_1^0} h^2 = 0.1$$

With R. Arnowitt, B. Dutta, T. Kamon, D. Toback

Work in progress

Conclusion

So far in the laboratories we have seen the particles responsible for 4% of the universe.

The upcoming experiments (e.g., LHC) will try to probe the nature of 23 % of the universe: dark matter.

Challenge:

73% of the universe is still a major puzzle.
Not yet understood theoretically!

So far in t … e seen the particles re … universe.

The upcon … to probe the natur … erse: dark matter.

73% of the … puzzle.

Not yet unc …