DARK PARTICLE HUNTERS

SMP Lecture
(2008)

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and
Prof. Bhaskar Dutta

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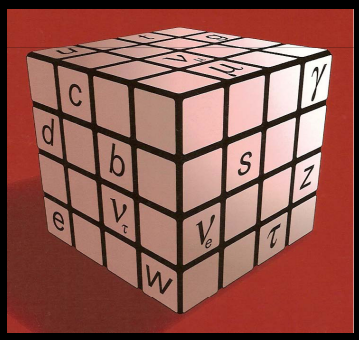
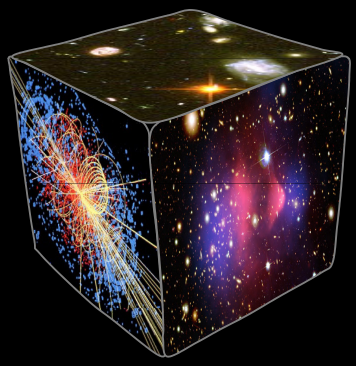
OUTLINE





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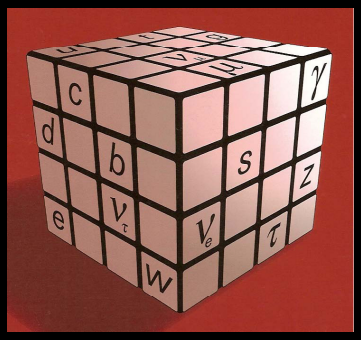
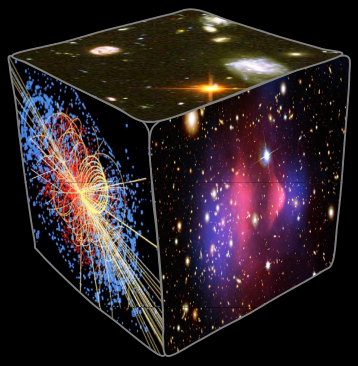
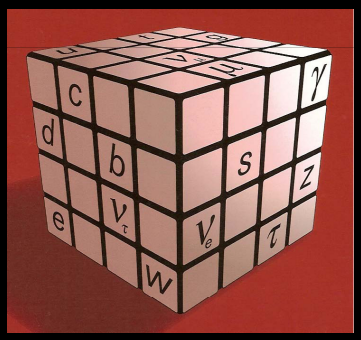
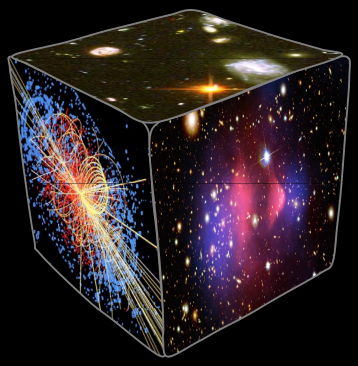




Do you know this "Cube"?

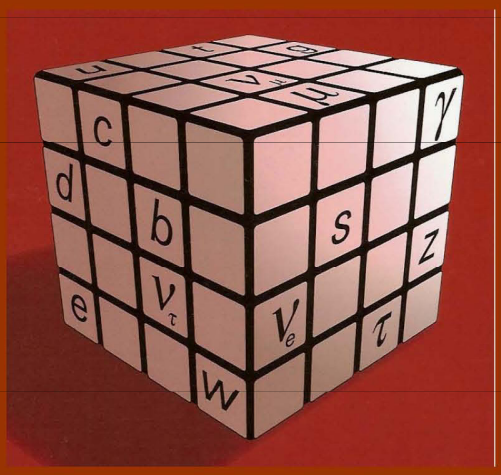
OUTLINE





Do you know this "Cube"?

Before time began,
there was the Cube.
It is filled with particles and forces.



"Standard Model" Cube

12 PARTICLE-ZOO ANIMALS AND 4 ZOO KEEPERS

12 elementary particles are known fundamental building blocks of matter. 4 fundamental forces govern the transitions between particles. **The Standard Model**, a mathematical rule, includes 12 particles and 3 forces.

6 Quarks

6 Leptons

All masses in MeV.
ANIMAL MASSES SCALE WITH PARTICLE MASSES

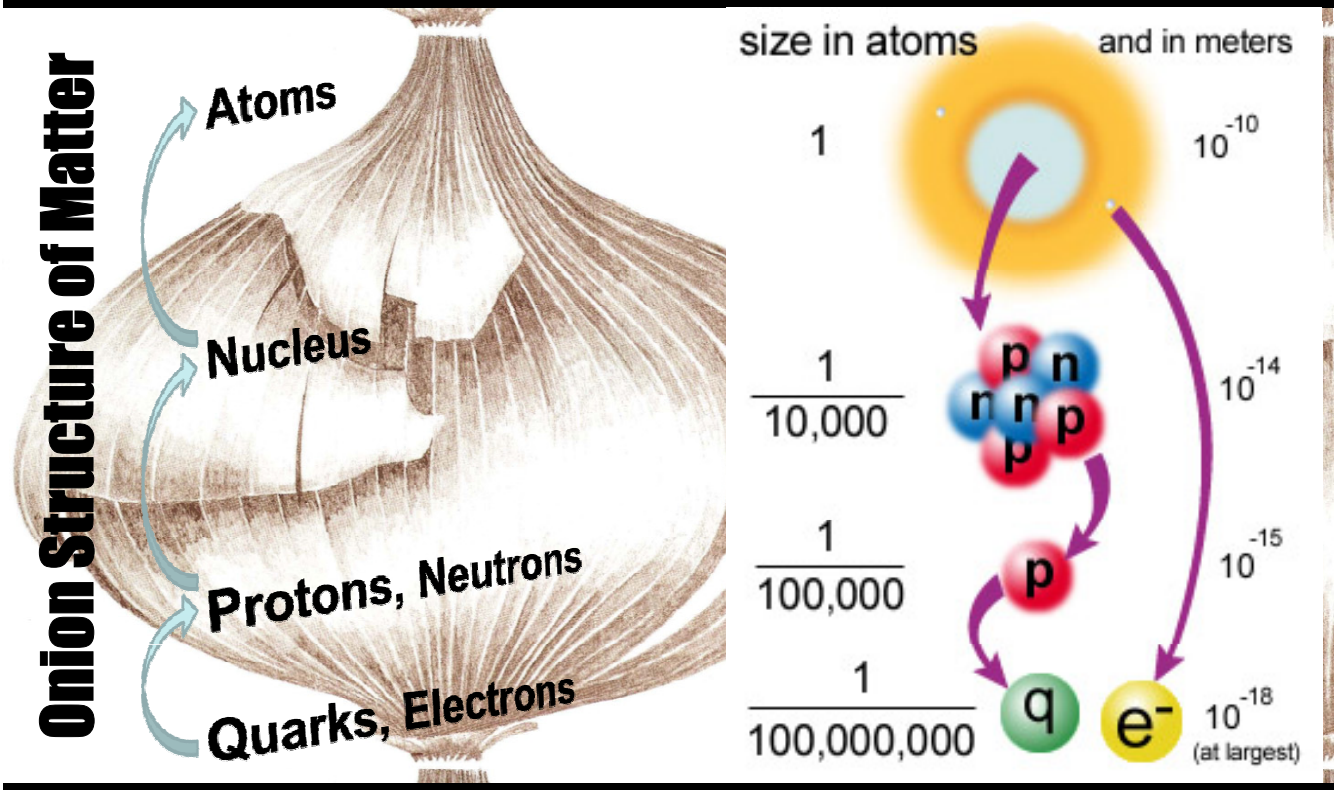
g's (gluons) → strong force
- Quarks experience them.
- Protons & neutrons are stick together.

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.

G (graviton – not found yet ☹) carries gravitational force.

FROM QUARKS TO ATOMS!



An end story of the onion structure?

FROM ATOMS TO MATTERS

Just for Your Information

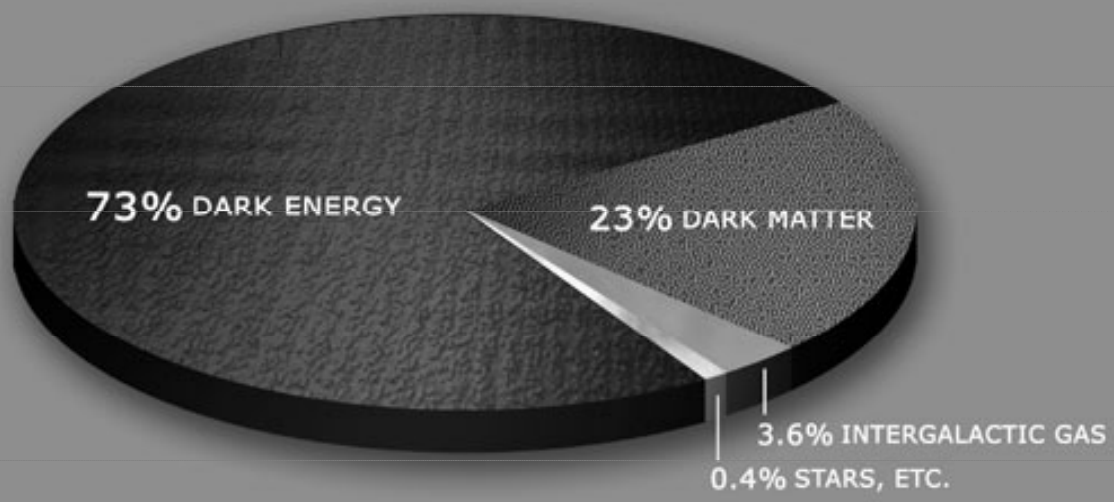
[1] Human - 99% of the mass of the human body is made up of the six elements oxygen (O), carbon (C), hydrogen (H), nitrogen (N), calcium (Ca), and phosphorus (P).

[2] Earth - http://en.wikipedia.org/wiki/Earth

[3] NGC 4414 (about 17,000 parsecs in diameter; 1 pc = 30.857×10^{15} m), a typical spiral galaxy in the constellation Coma Berenices, approximately 20 million parsecs distant. Credit: Hubble Space Telescope NASA / ESA. See http://en.wikipedia.org/wiki/Galaxy.

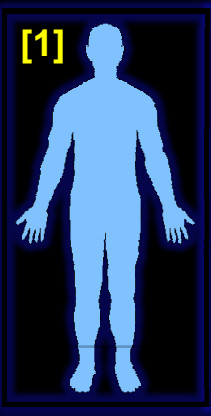
THE UNIVERSE

Do we know the content of the universe?



VISIBLE (4%) AND DARK (23%) MATTERS

[1]



[2]

[3]

[4]

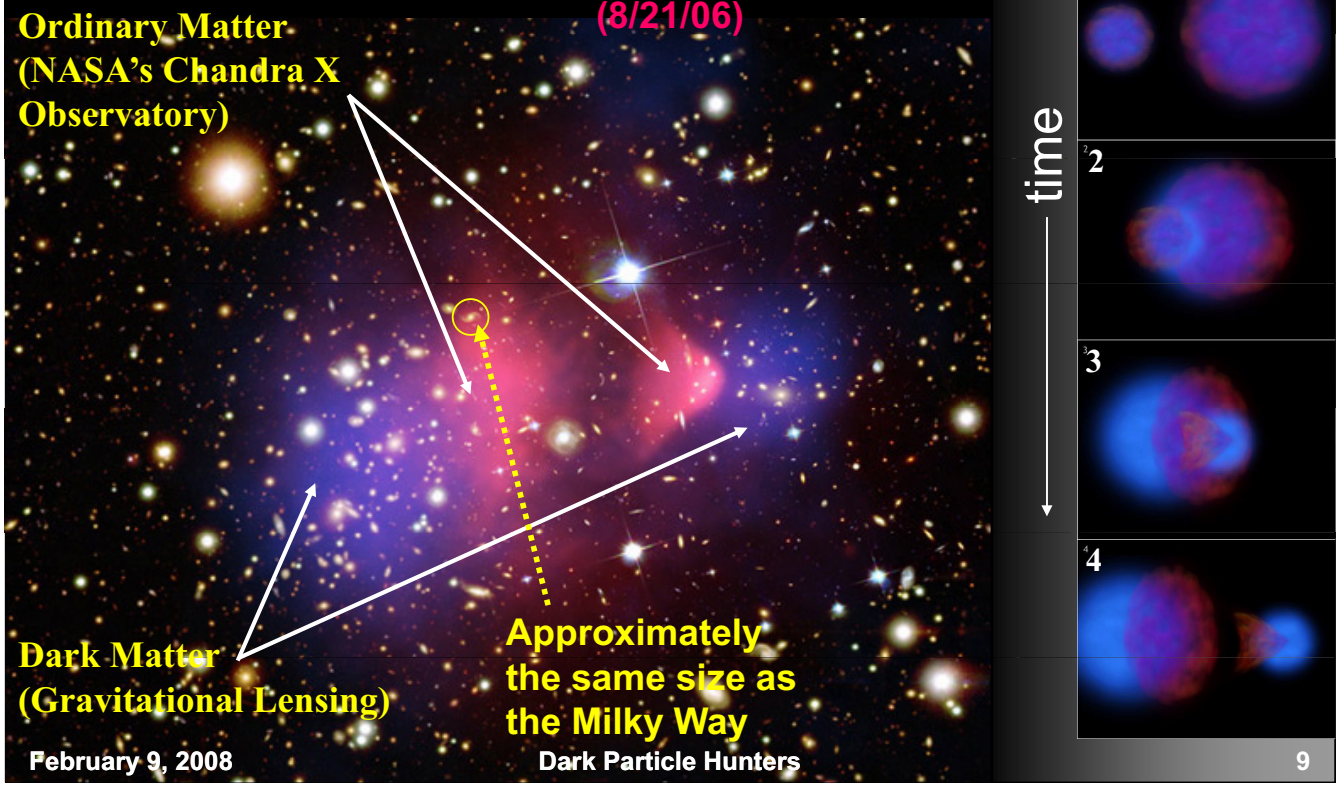
Dark Matter

EVIDENCE?

DARK MATTER IN THE UNIVERSE

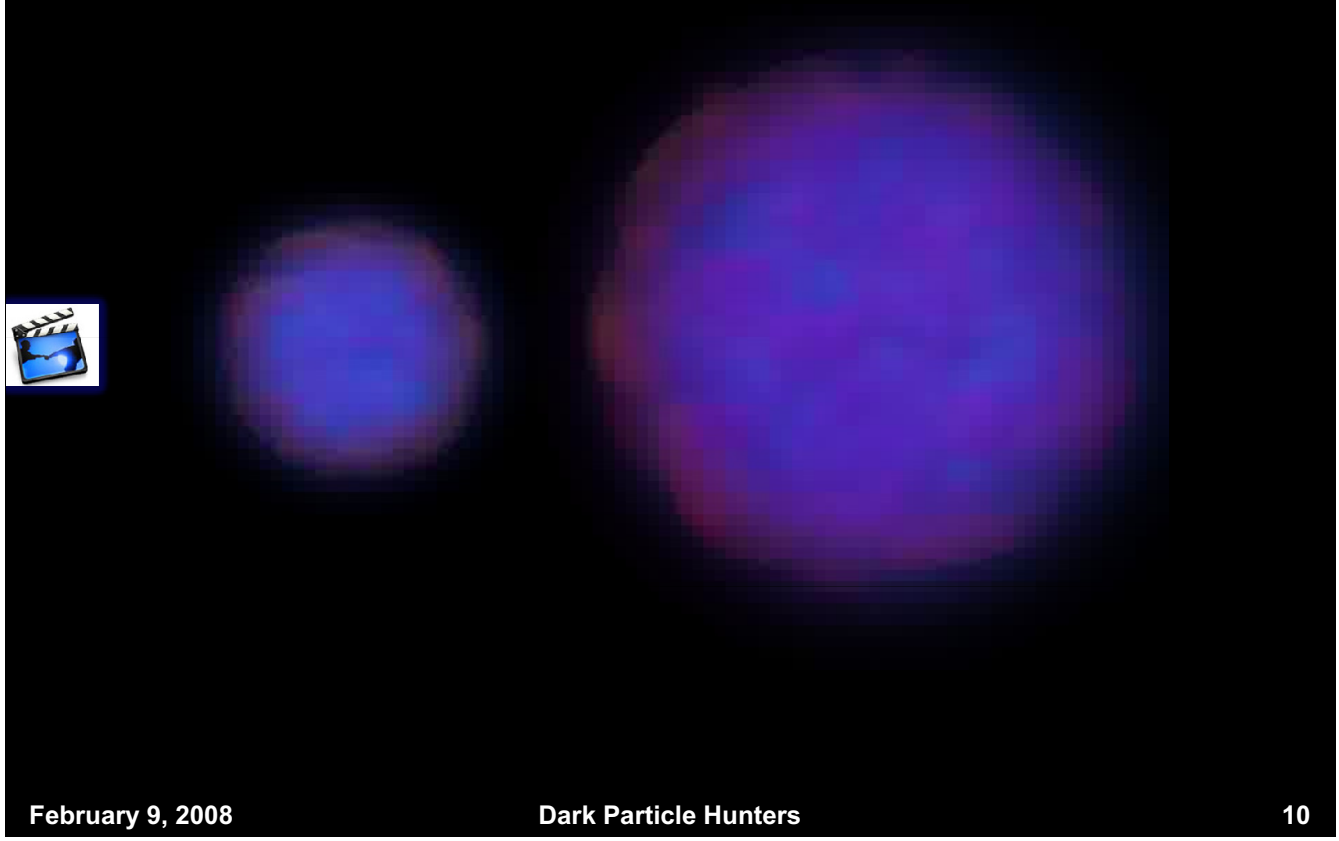
splitting normal matter and dark matter apart

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

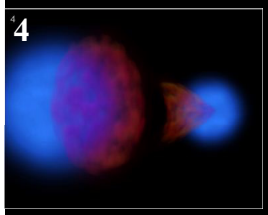


COLLISION OF 2 GALAXY CLUSTERS

splitting normal matter and dark matter apart



KNOWN PROPERTIES OF DM



It's Doesn't Matter.

Right, it doesn't shake hand with anyone easily. Two dark matter clusters (blue balls) are just passing each other. It is a long-lived (stable) object.

It's a Cold Matter.

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

It's an Invisible Matter.

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

So, It's a COLD DARK MATTER.

Can it be one of the known particles? Let's check out.

DM IN THE STANDARD MODEL?

12 Particle-Zoo Animals and 4 Zoo Keepers. Can any of them be a candidate for the Dark Matter particle?

All masses in MeV.
ANIMAL MASSES SCALE WITH PARTICLE MASSES

[Answer] 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 are too light!

NEW IDEA BASED ON SYMMETRY

Supersymmetry or SUSY

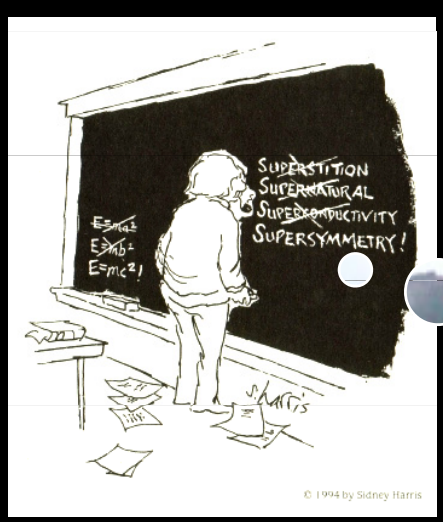
The Standard Model with SUSY predicts a new neutral particle (Neutal-ino) which is a leading candidate for the dark matter.

$$\tilde{\chi}_1^0$$

What is the new model? Attractive?

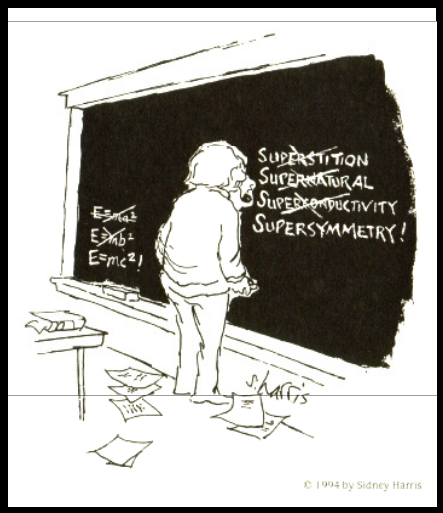
Can the neutralino be detected and consistent with the dark matter content of the Universe?

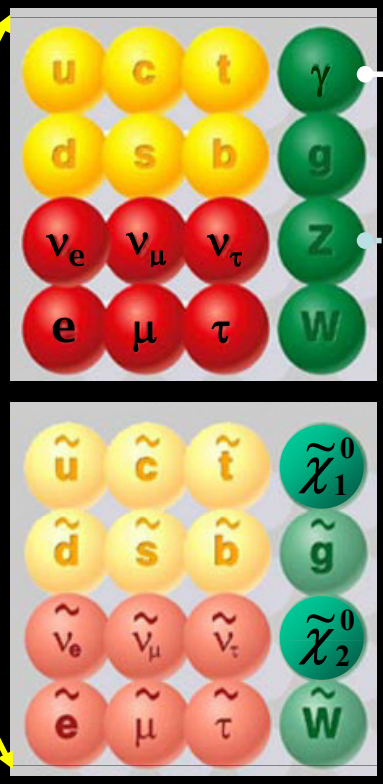
MIRROR REFLECTION



Nature loves symmetry!

SUSY REFLECTION





Nature may love this symmetry!

LOTS OF NEW PARTICLES!!!!

One of them is a neutralino.

This is a leading candidate for the DM particle.

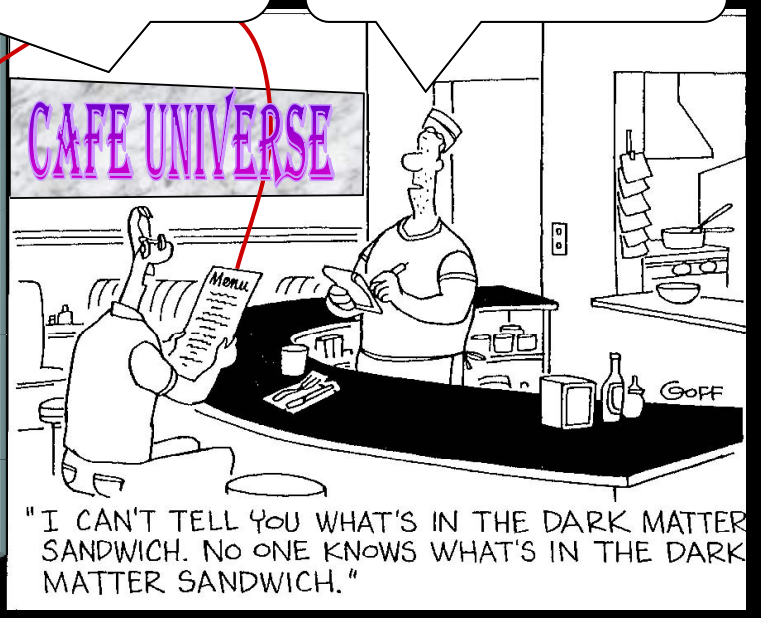
"DARK MATTER" SANDWICH

I am hungry. Can you make the DM sandwich with any Standard Model particle?

No, Sir. But with neutralino?

MENU
~SPECIALS~

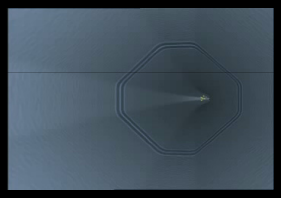
*Dark Energy Power Drink .. $73
- Chef's choice
*Dark Matter Sandwich …… $23
- Neutral, long-lived
*Atomic Soup …….. $4
- All elements in one

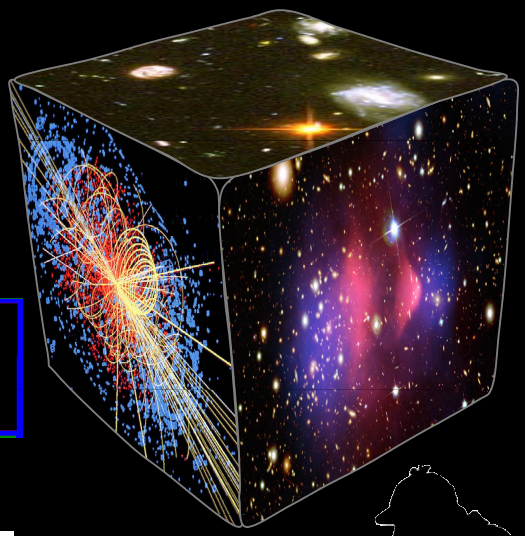


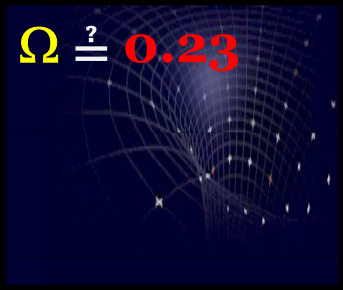
DM SANDWICH

PROBING THE SUSY DARK MATTER

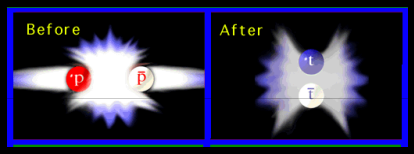
The LHC - Accelerator



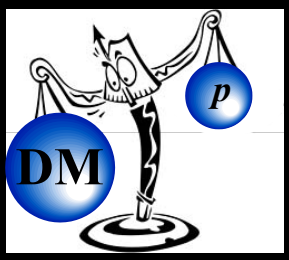




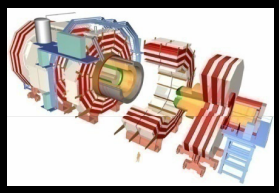
Production & Decay



DM !



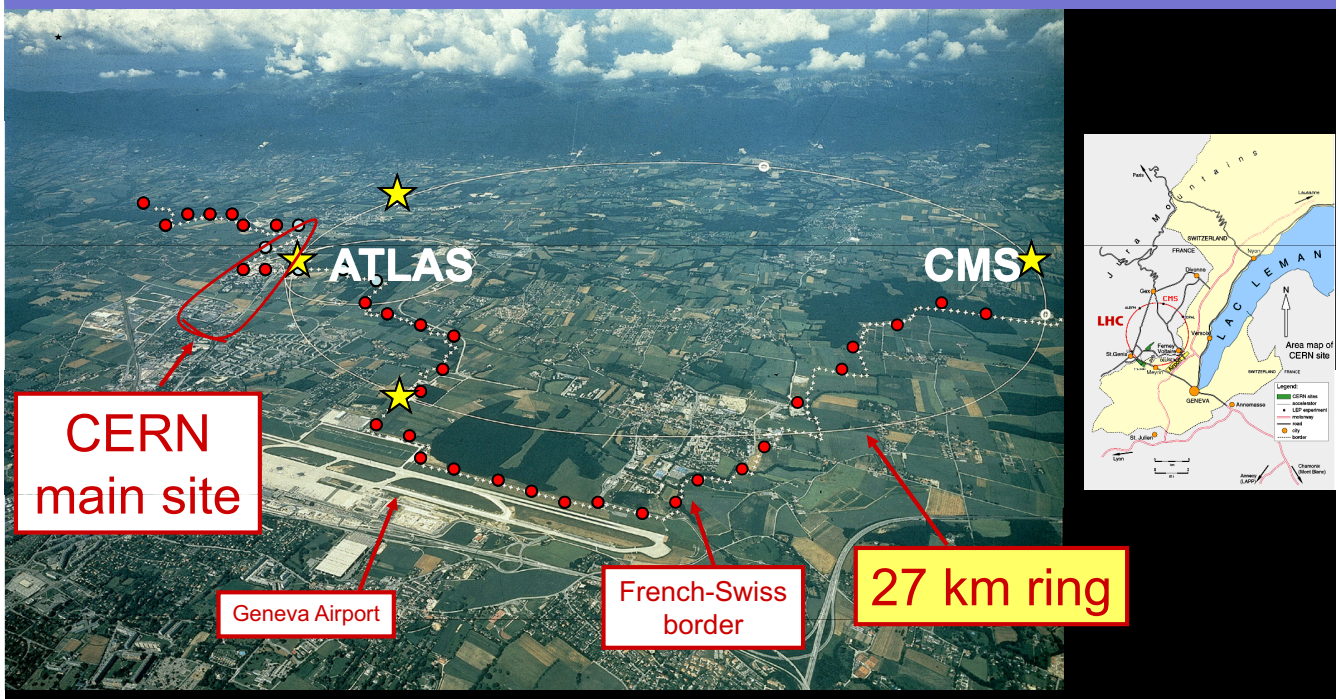
Detector



DM Hunters - Analyzer

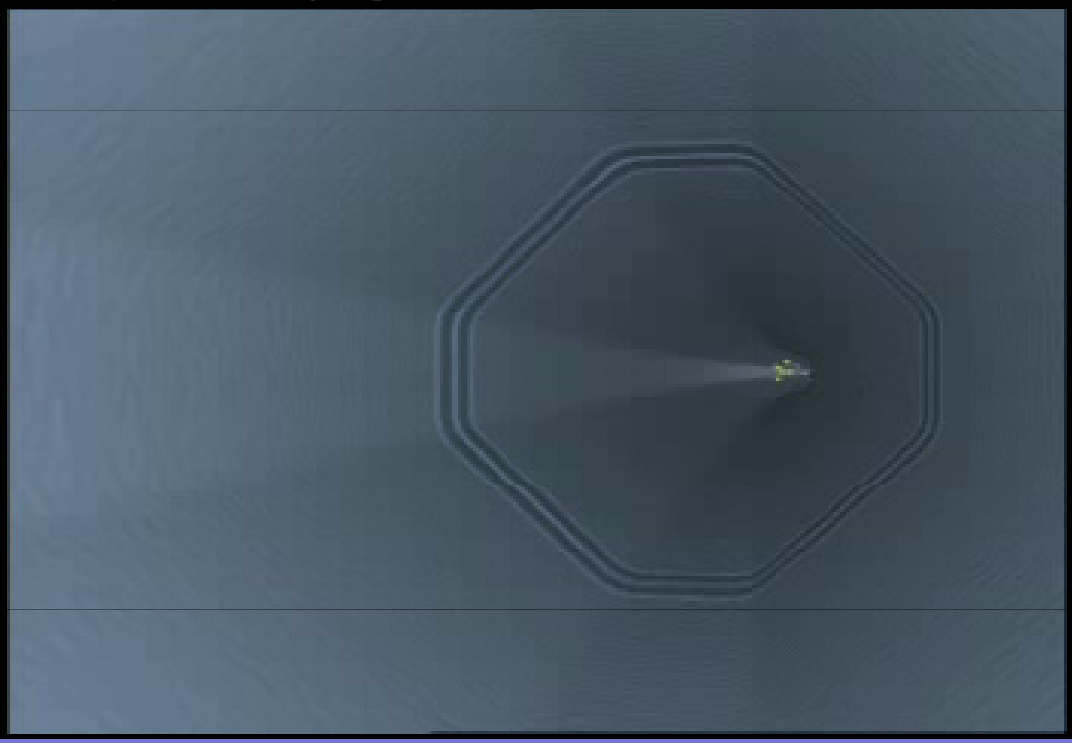
LARGE HADRON COLLIDER (LHC)

The LHC at CERN will provide the first proton-proton (pp) collisions in 2008. The smashing power is 7.1 times larger than that of the Tevatron at Fermilab (Batavia, IL, USA).



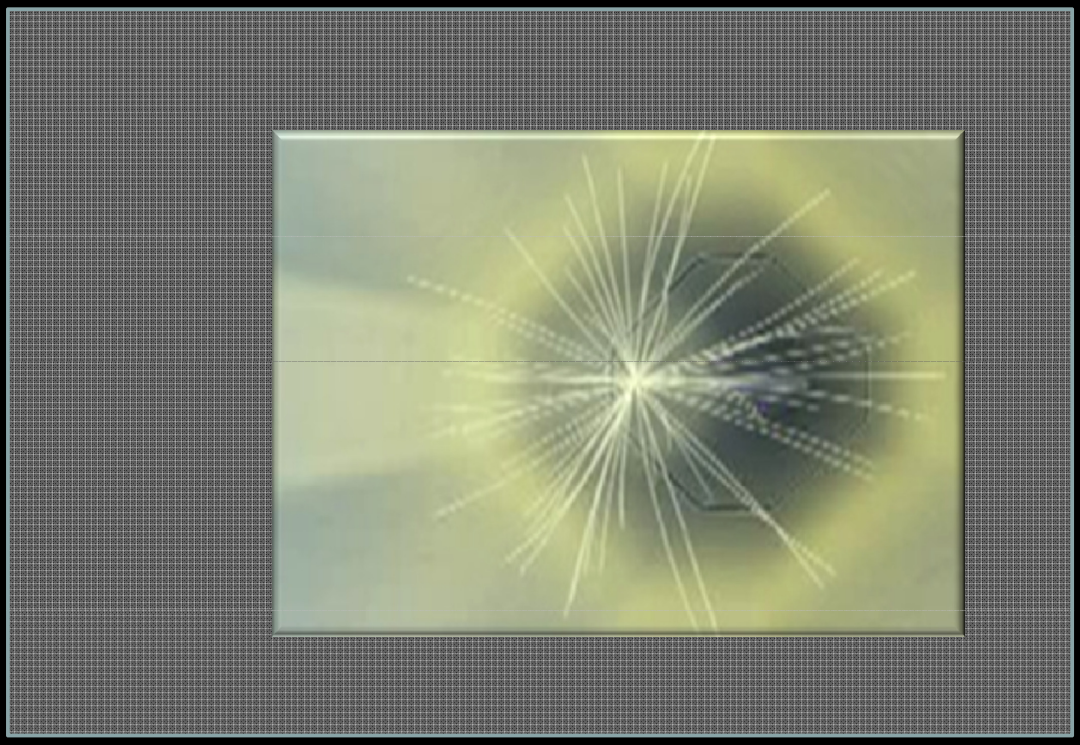
PROTONS ARE CIRCULATING ...

Proton velocity relative to light speed: 99.9999991% (LHC) vs. 99.9999542% (Tevatron)



Note: this animation is to show protons (positive charge) and antiprotons (negative charge) are circulating in the same vacuum pipe.

COLLISIONS!

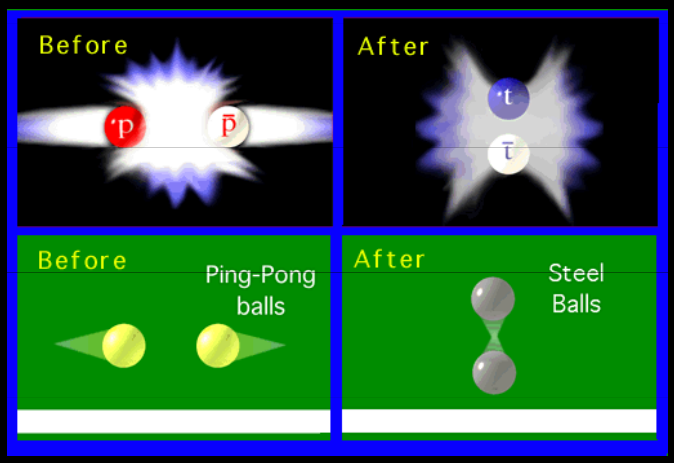


PRODUCTION - PHYSICS MAGIC

Fast Ping-pong balls → Slow Steel Balls

$$E = mc^2$$

Proton (p) and antiproton ($\bar{p}$) collision can produce the Standard Model particles like heavy **top (t) quarks** (~180 times heavier than a proton!) as well as **SUSY dark matter particles**.

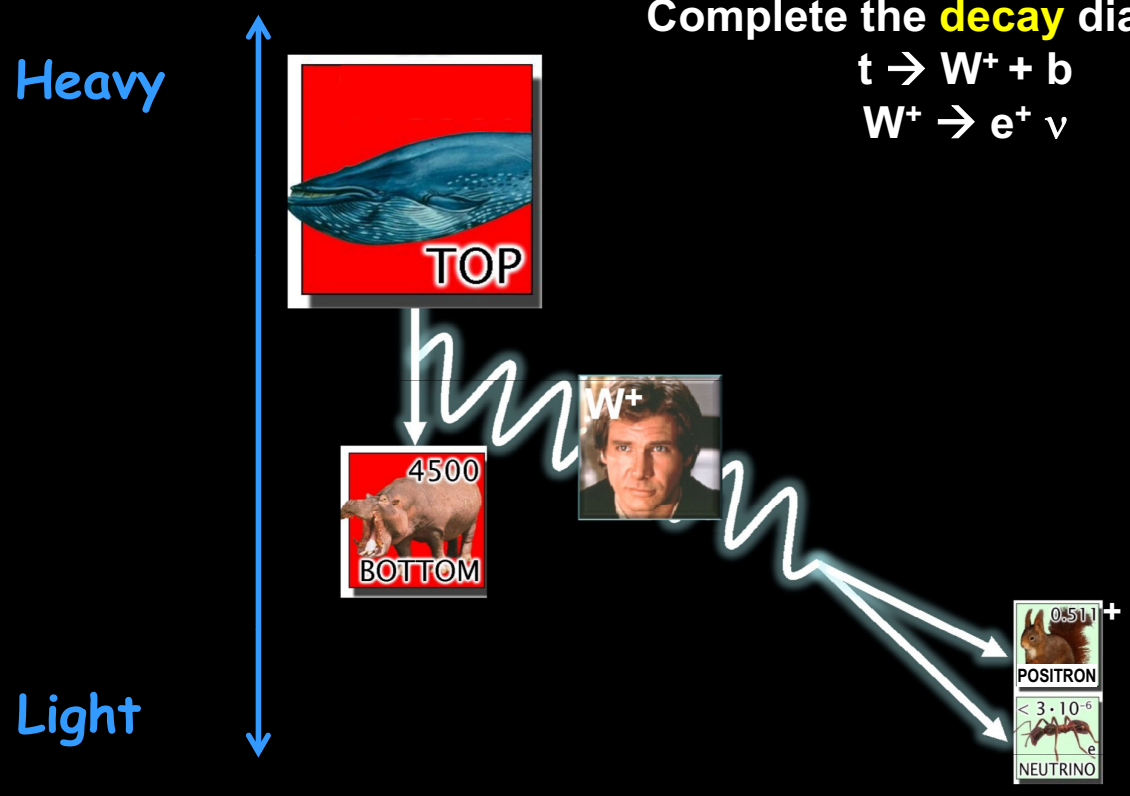


"TOP" QUARK TRANSITION

Complete the decay diagram.

$t \rightarrow W^+ + b$

$W^+ \rightarrow e^+ \nu$

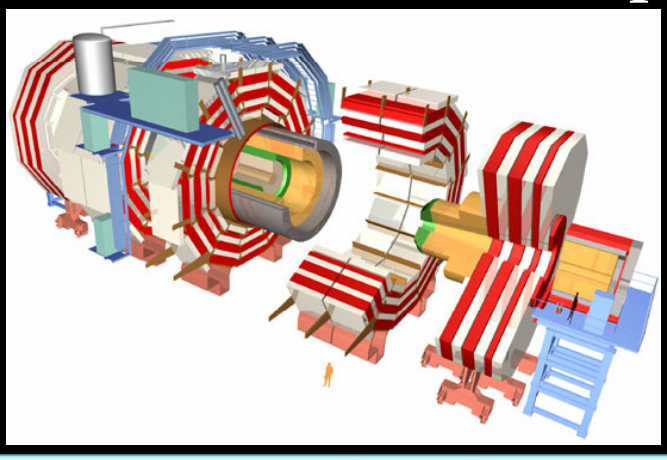


SUSY "TOP" QUARK TRANSITION

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

DETECTORS

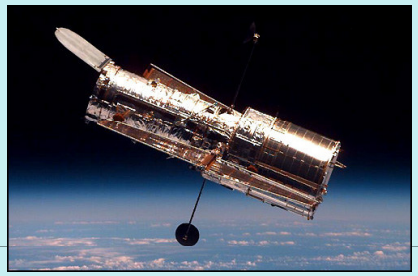
Particle-Collision Telescope



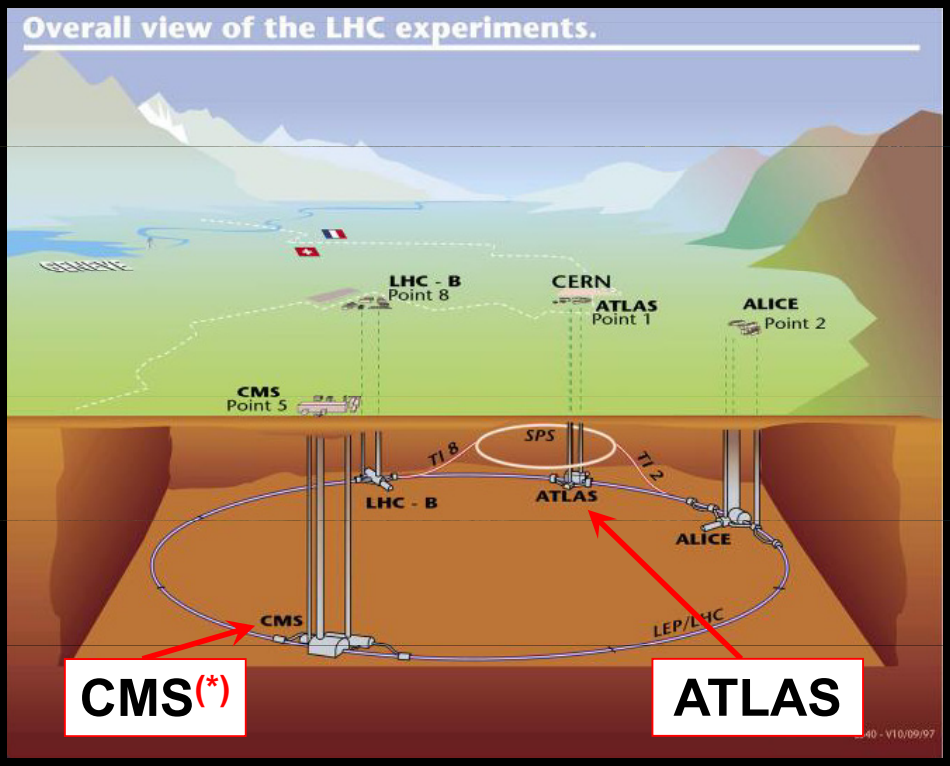
The CMS (21 m x 15 m x 15 m, 12,500 tonnes) is one of two super-fast & super-sensitive detectors, consisting of 15 heavy elements, collecting derbies from the collision and converting a visual image for us.

Optical Telescope

Hubble Space Telescope

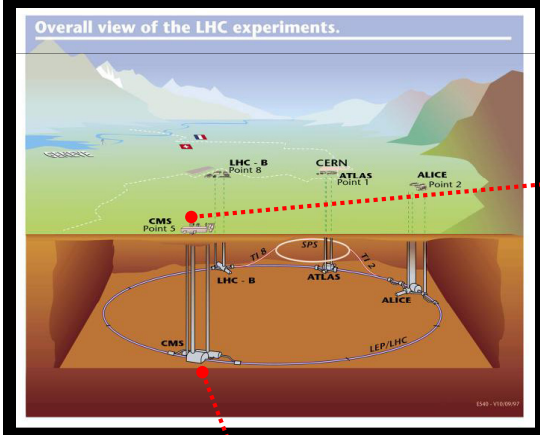


"UNDERGROUND" EXPERIMENTS

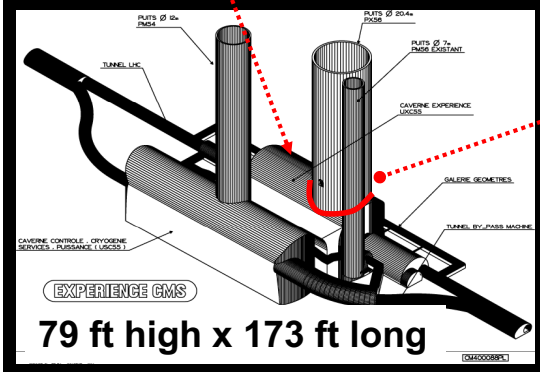


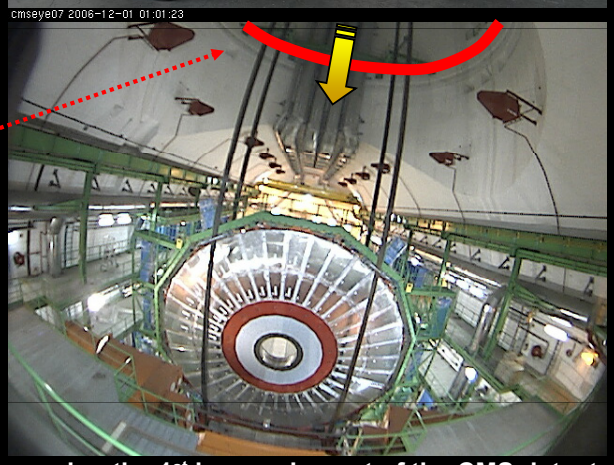
(*) The TAMU group is a member of the CMS collaboration.

December 2006



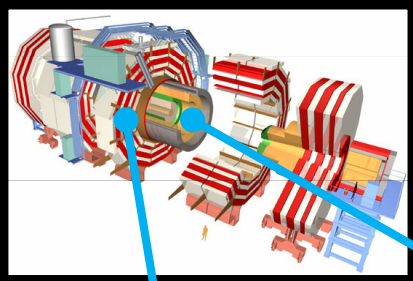
Prof. Steve Hawking, visiting the CMS experimental site.

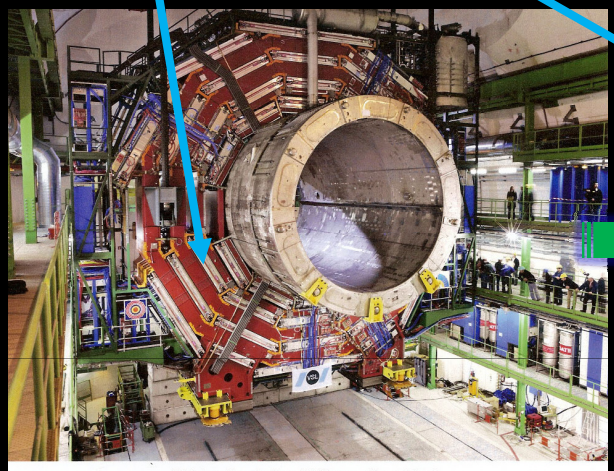




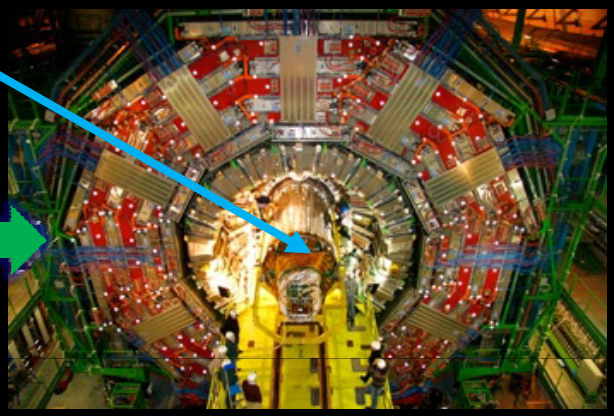
Lowering the 1st heavy element of the CMS detector

March 2007 →December 2007





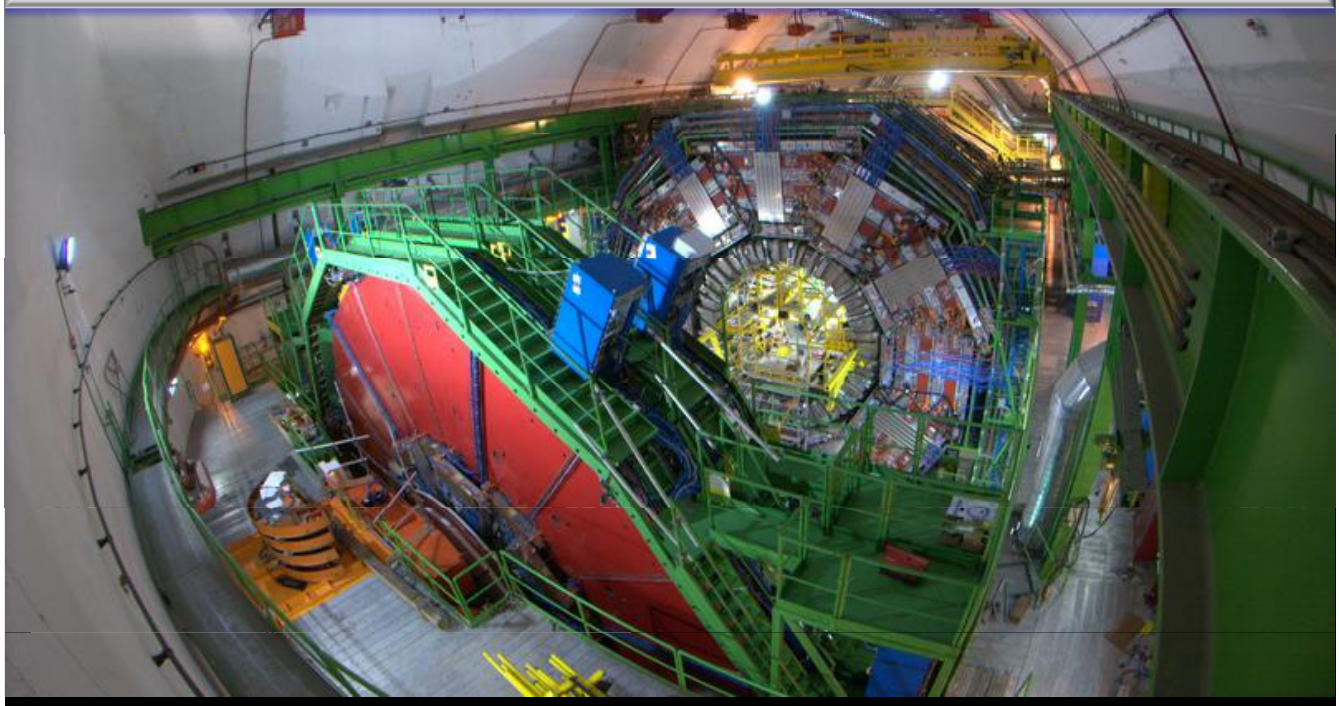
YB0 landing in the CMS experiment hall



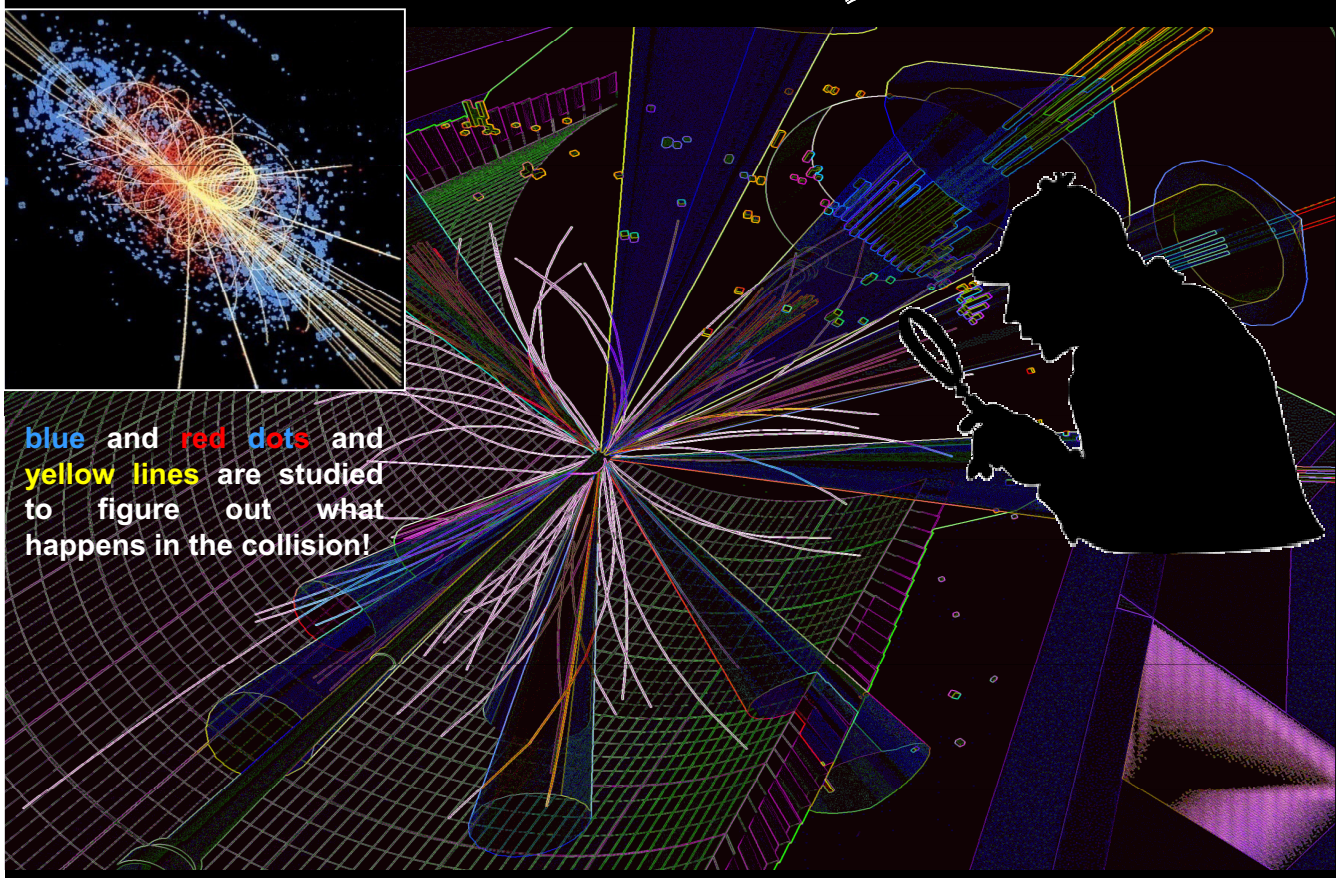
January 22, 2008

CMSeye 22 January 2008 14:30

The fifteenth and the last heavy element of CMS was successfully lowered in the experiment cavern around 5:30 pm. The CMS detector will be ready for the first collisions!



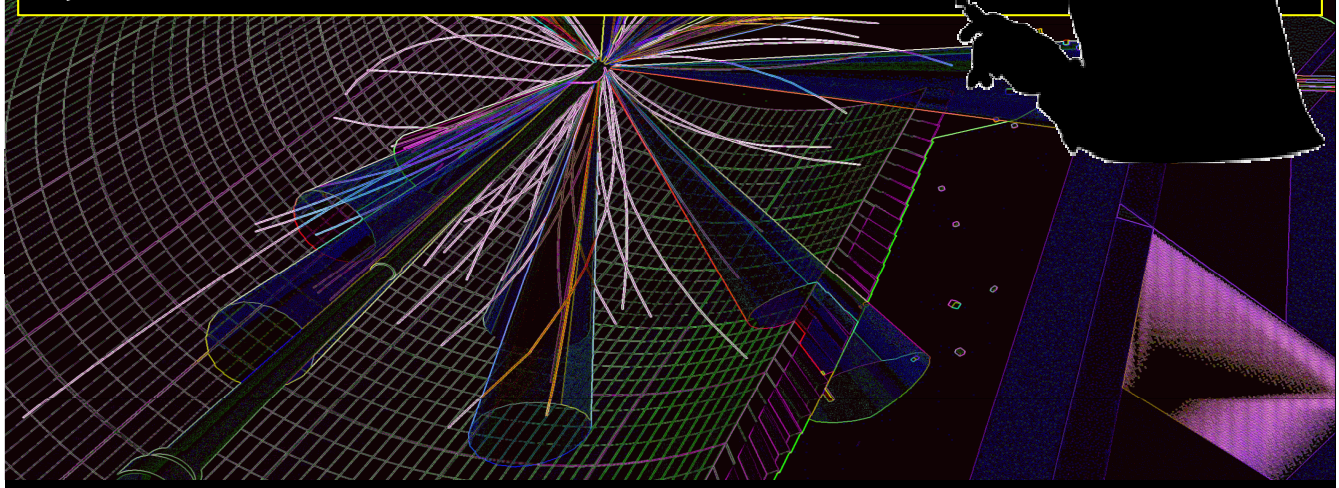
ANALYZER



blue and red dots and yellow lines are studied to figure out what happens in the collision!

TO BE A GOOD SCIENCE-DETECTIVE

1) Pose questions.
2) Develop a new idea(s).
3) Design a controlled experiment.
4) Collect the data.
5) Interpret the data.
6) Draw conclusion.



DARK PARTICLE HUNTING

PREDICTION: The dark matter particles and the Standard Model particles will be produced in pp collisions at the LHC.

CONTROLLED EXPERIMENTS: Two super-fast & super-sensitive detectors will be ready by May 2008 to record those particles in each collision (a.k.a. event) at the LHC.

ANALYSIS: Each event will be "reconstructed" and examined using a mathematical technique.

IF WE WERE IN 90'S, THEN ...

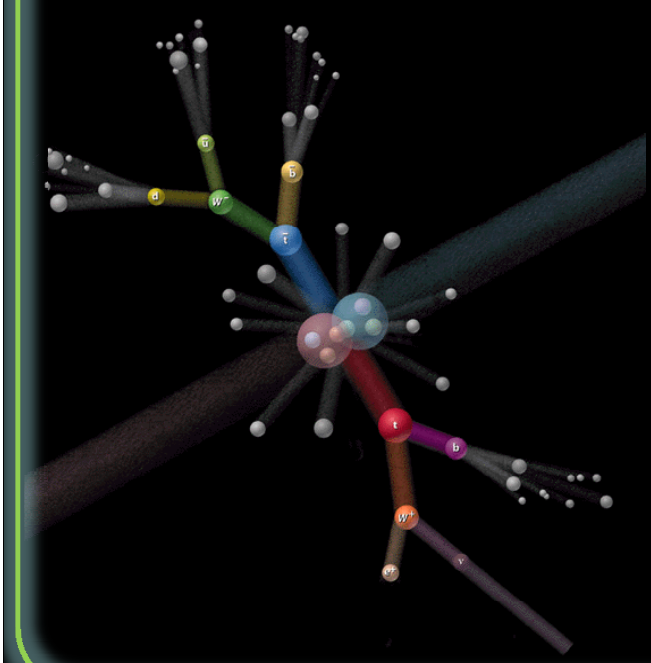
PREDICTION: The top quarks would be produced in $p\bar{p}$ collisions.

CONTROLLED EXPERIMENTS: Two fast & sensitive detectors were collecting the data.

ANALYSIS: Each event was "reconstructed" and examined using various mathematical techniques.

TOP QUARK

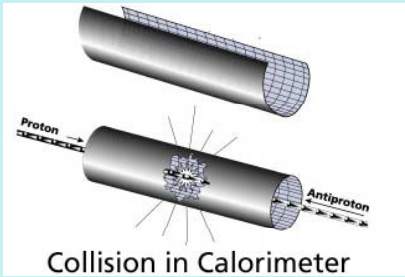
One of the key reactions to discover the top quarks at the Tevatron.

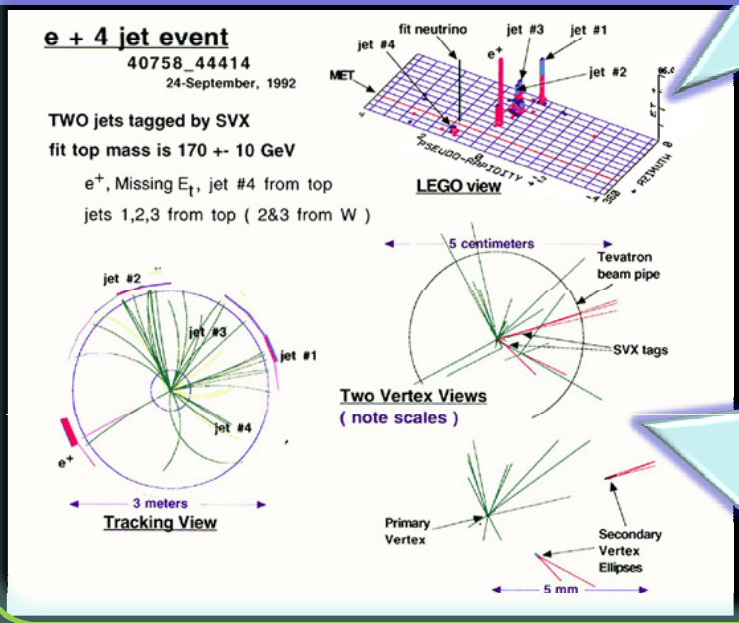


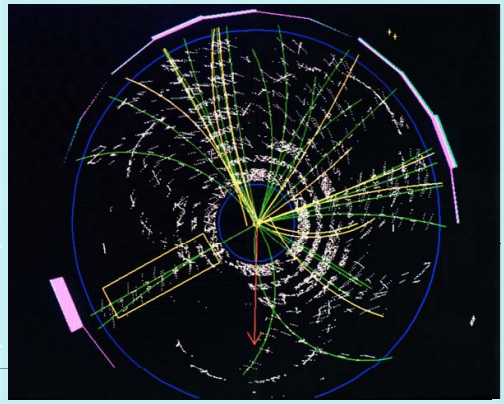
We had to extract this reaction out of 5 trillion $p\bar{p}$ collisions.

ANALYZER : A TOP QUARK EVENT

Name	Top
ID No.	40758-44414
Date of Birth	Sep. 24, 1992
Place of Birth	Batavia, IL, USA







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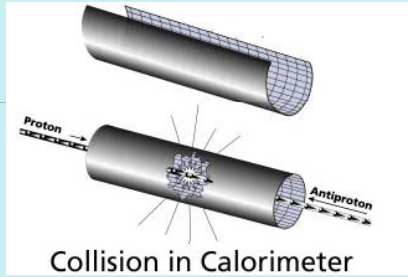
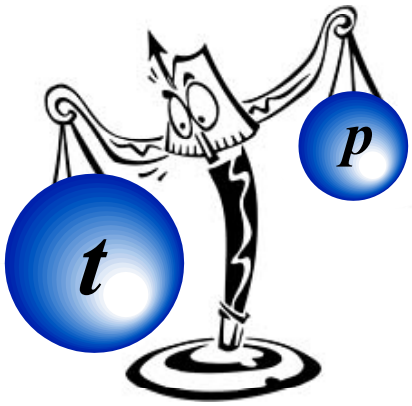
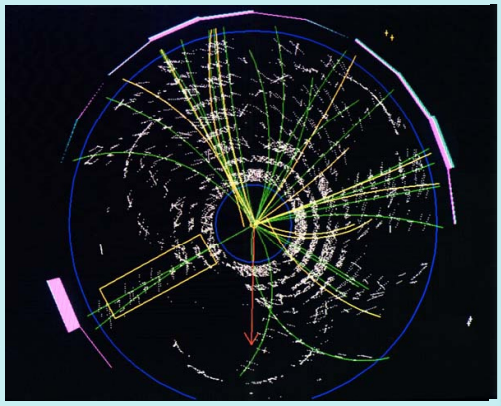
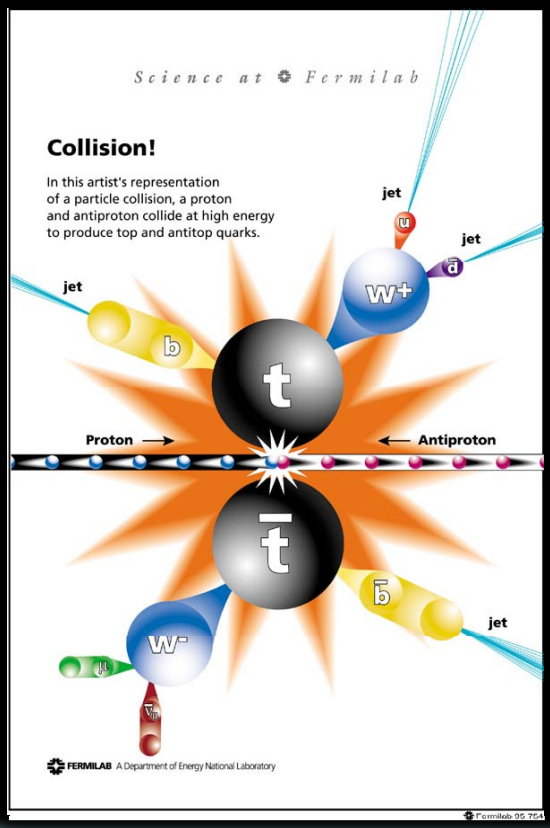




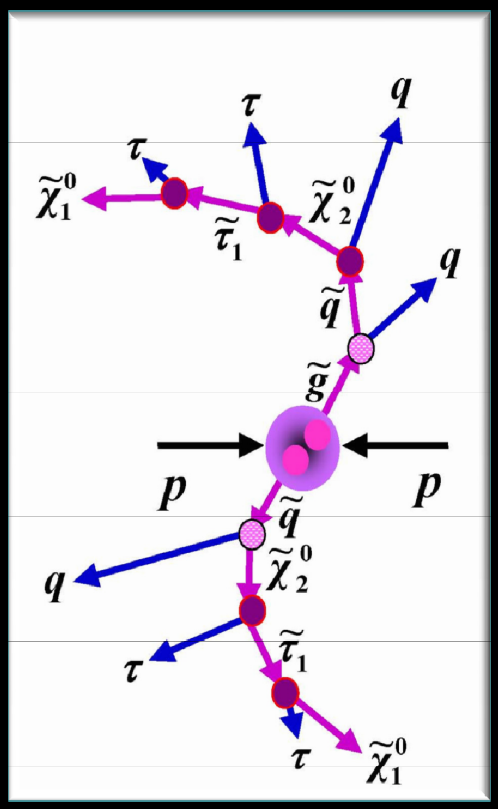
$M_{top} \sim 182 \times M_{proton}$



"Top Quark" Discovery in 1995



Most Wanted!

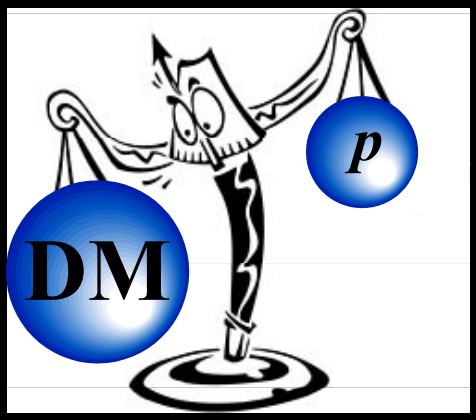


This is one of the key reactions to discover the neutralinos at the LHC.

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

A joint team of theorists and experimentists at TAMU is developing a new technique.

DISCOVERY OF "SUSY DARK MATTER"



DARK PARTICLE HUNTING

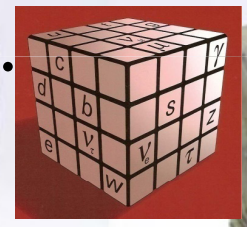
[SUSY DM particles at the LHC]
$\stackrel{?}{=}$ [Dark Matter in the Universe]

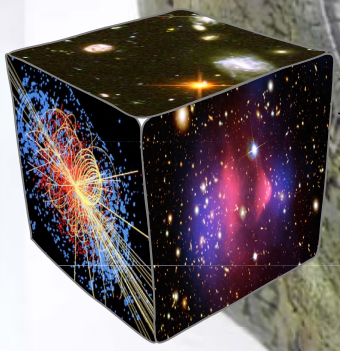
Well, I (a theorist) can calculate the amount of the SUSY dark matter (Ω) in the Universe (using a model of the Universe).

$\Omega \stackrel{?}{=} 0.23$

SUMMARY

4% OF THE UNIVERSE : has been accounted for by the particles in the Standard Model.



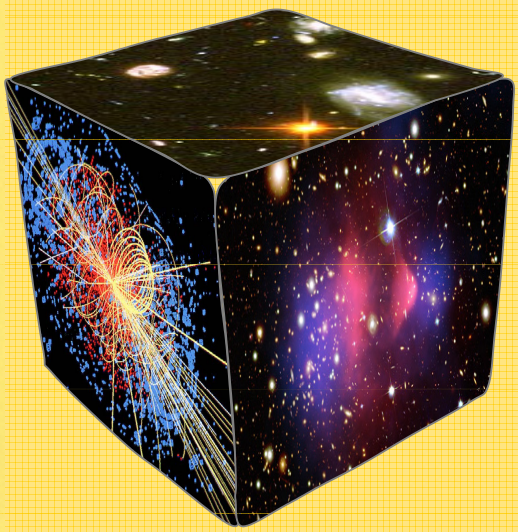
23% :  will be probed at the LHC.

"Dark Matter" Cube

73% : still a major **PUZZLE**.

HTTP://PHYSICS.TAMU.EDU/

TAMU Collider Group URL
http://txpc1.fnal.gov/



Slides and animations can be found at URL:
http://faculty.physics.tamu.edu/kamon/research/talk/

Particle SUDOKU

Symbol	Particle Name
e	electron
μ	muon
τ	tau
u	up
d	down
s	strange
c	charm
b	bottom
t	top

	s		t		μ	b		u
	d			b		μ		s
μ		b		τ	s	c	e	
d							μ	b
t			s			d		
	b	τ			d	t		c
c				s	τ	u	d	e
	u	e	d		c		b	t
		d		t		s	c	

Solution will be posted at URL:
http://faculty.physics.tamu.edu/kamon/research/talk/