INTRODUCTION TO PARTICLE PHYSICS

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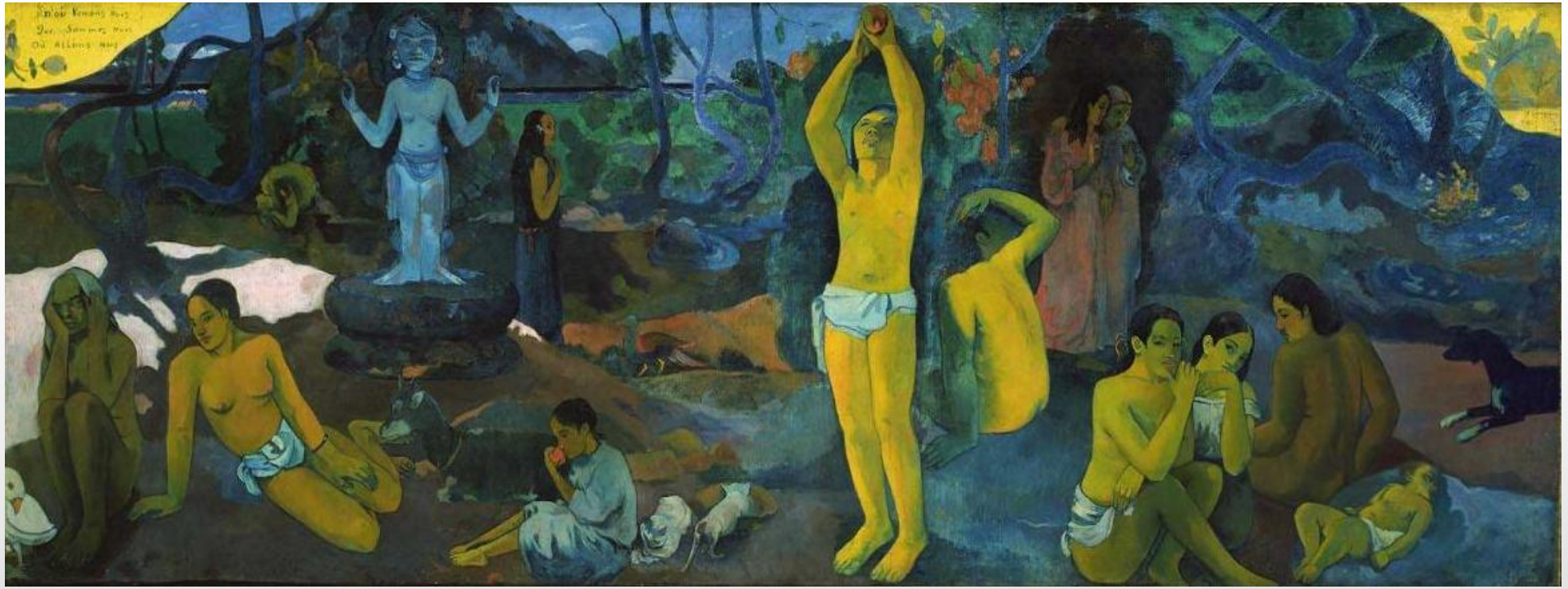
Agenda …

- Introduction to particle physics
- Virtual visits to ATLAS and CMS Experiments
- Questions / answers session

What are we?

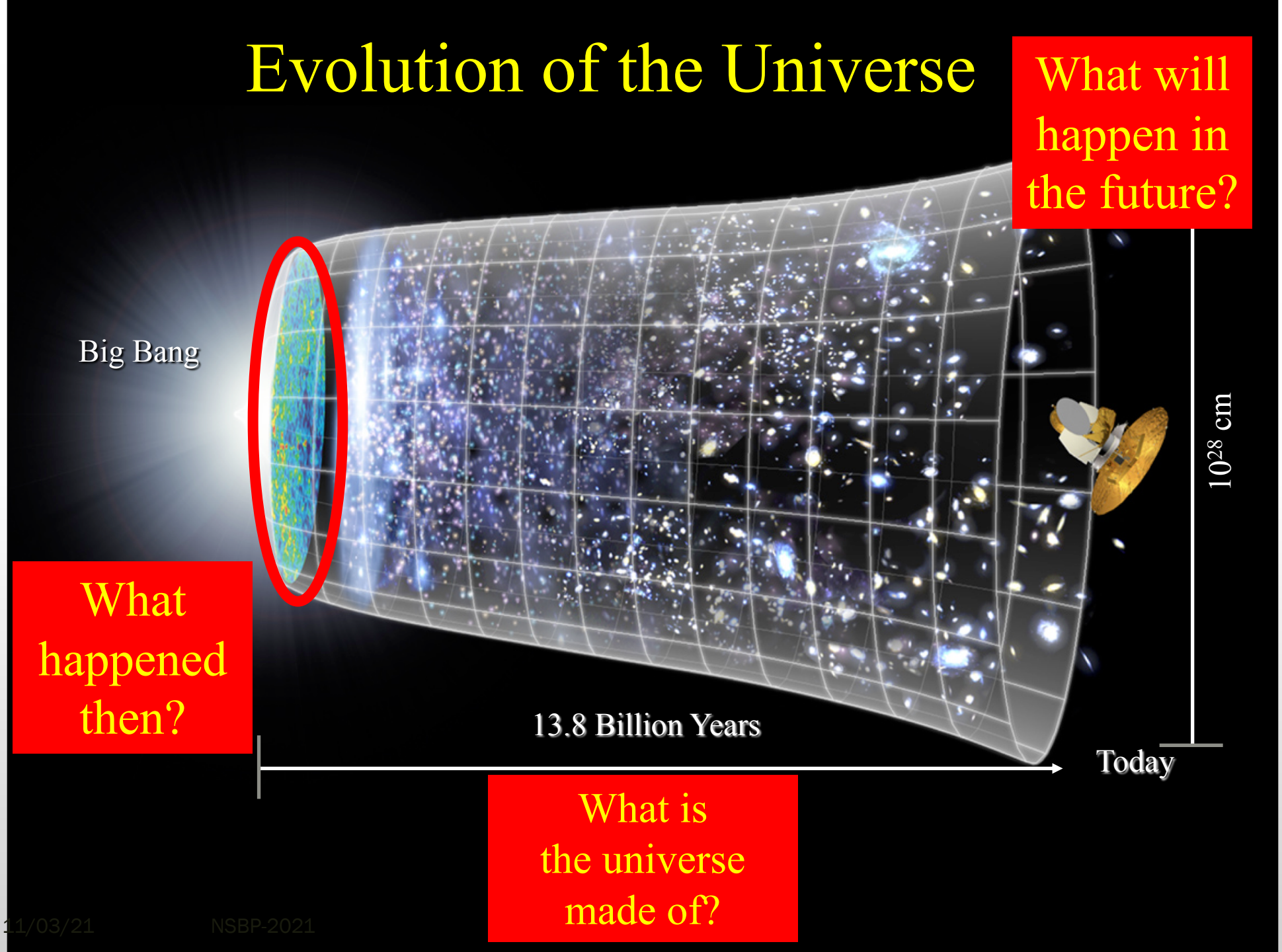
Where do we come from?

Where are we going?



The aim of particle physics:
What is matter in the Universe made of?

Evolution of the Universe



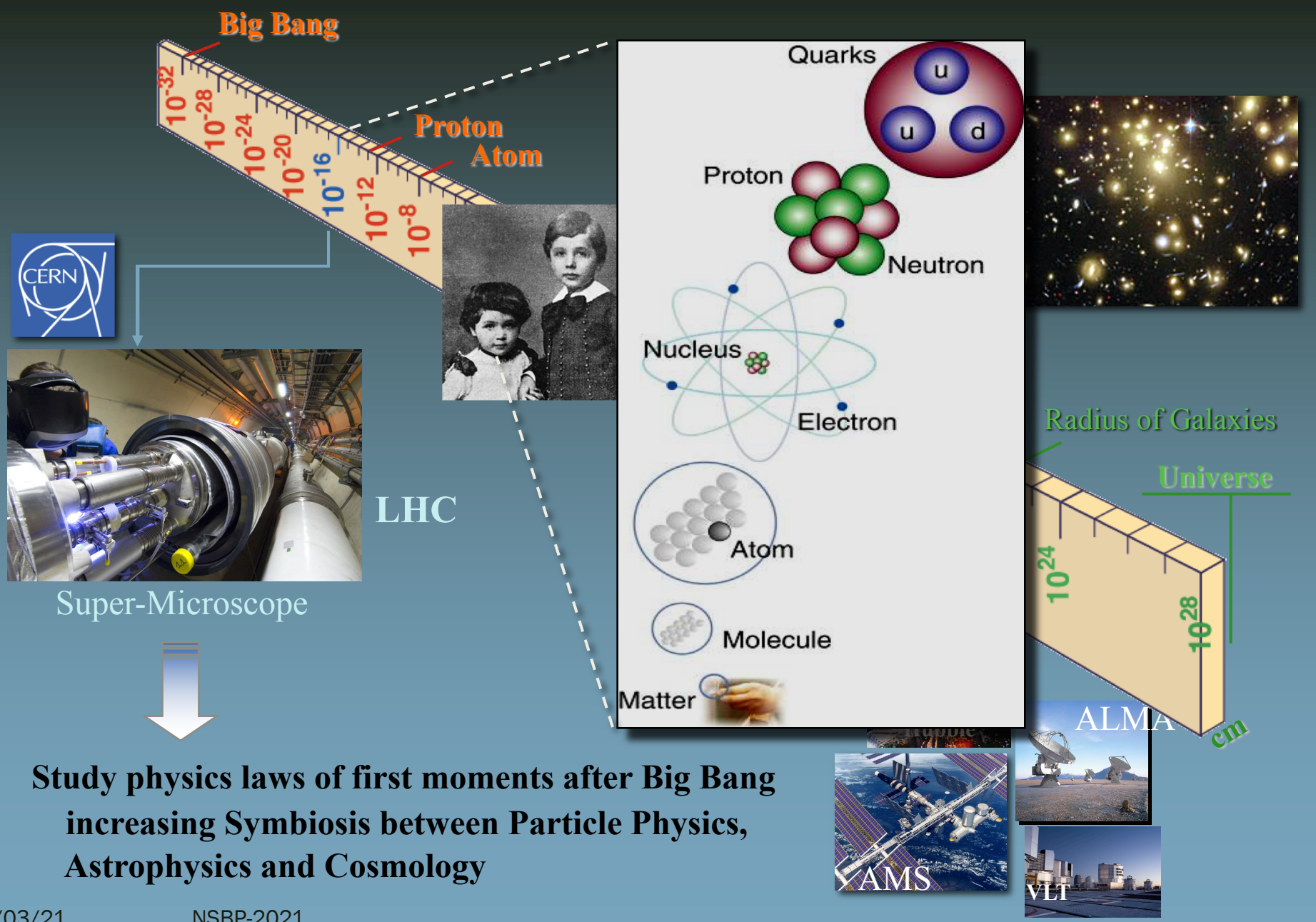
Big Questions in the Language of Particle Physics

- What is matter made of?
  - *Why do things weigh?*

- What is the origin of matter? LHC
- What is the dark matter that fills the Universe? LHC
- How does the Universe evolve?
- Why is the Universe so big and old? LHC
- What is the future of the Universe? LHC

Our job is to ask - and answer - these questions

Need physics beyond what we know



Study physics laws of first moments after Big Bang increasing Symbiosis between Particle Physics, Astrophysics and Cosmology

300,000 years

Formation of atoms

3 minutes

Formation of nuclei

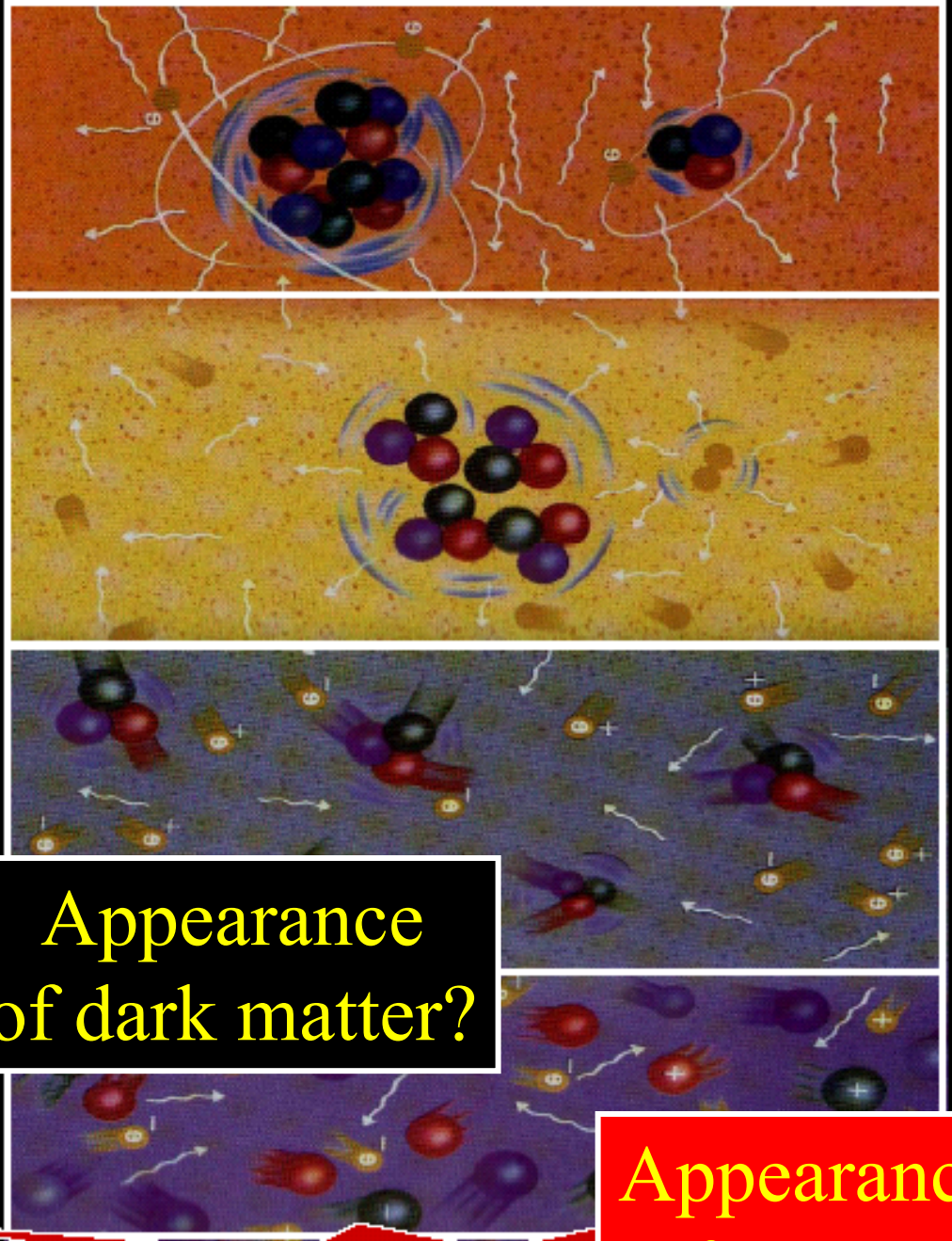
1 micro-second

Formation of protons & neutrons

Appearance of dark matter?

1 pico-second

Appearance of mass?

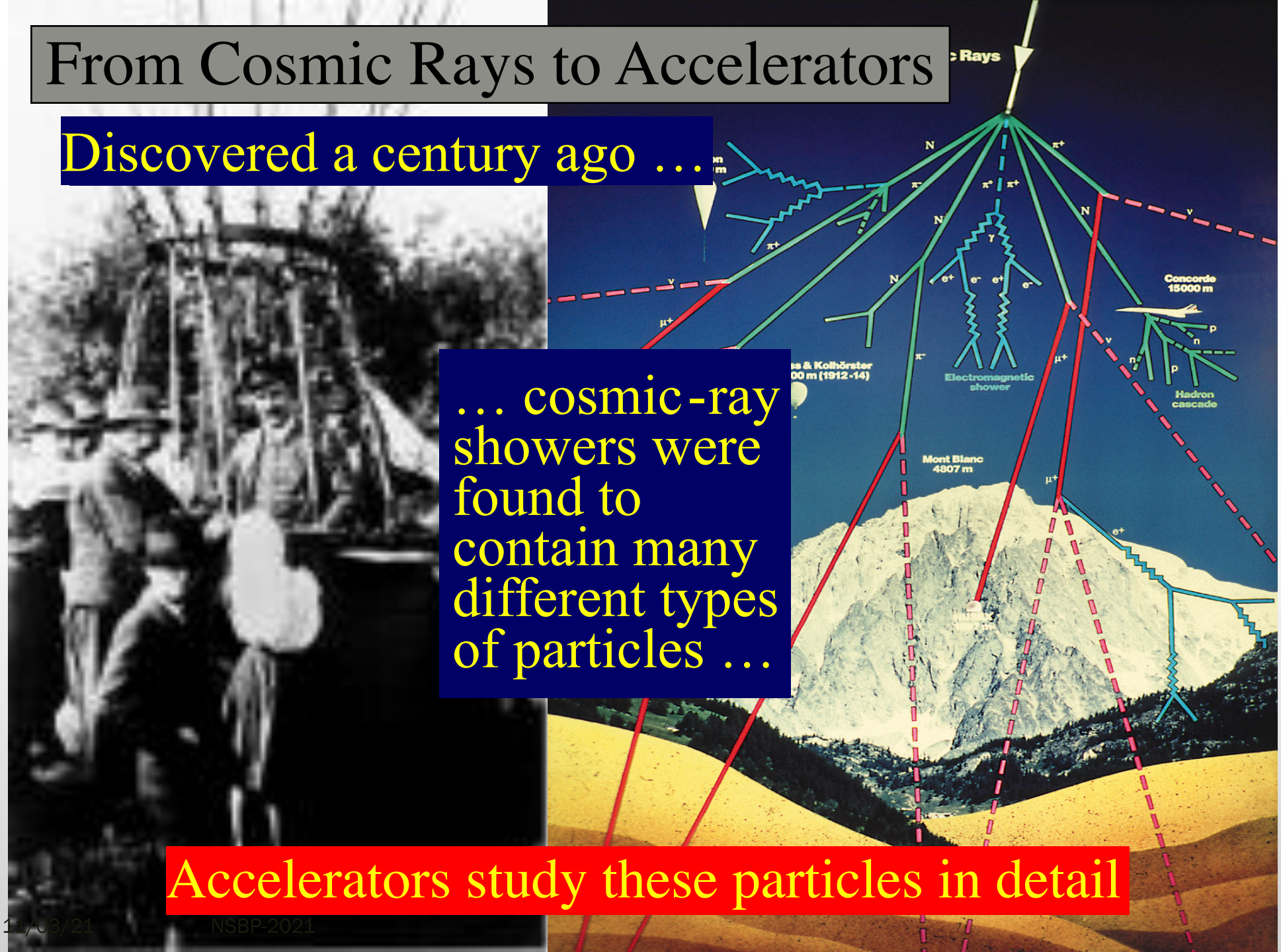


BANG!

Appearance of matter?

From Cosmic Rays to Accelerators

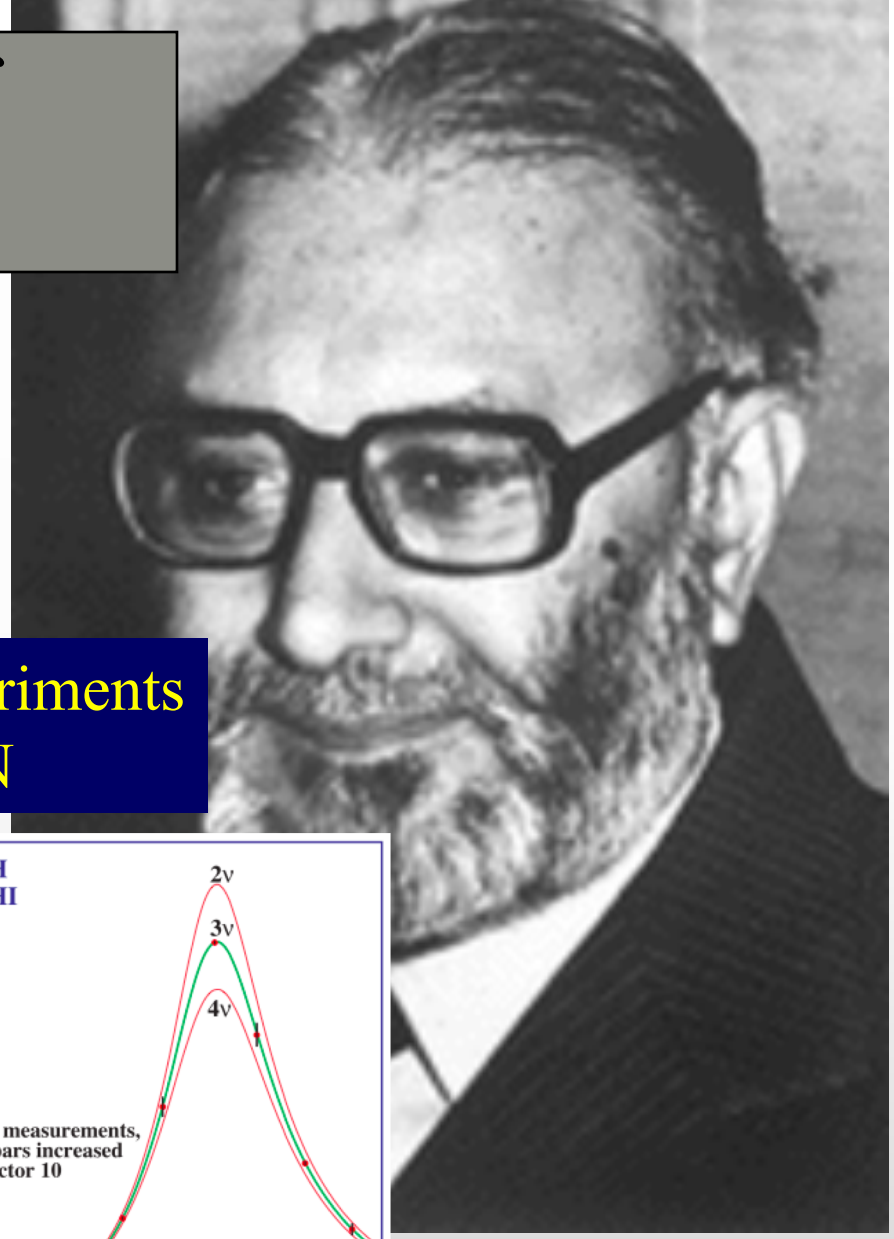
Discovered a century ago …



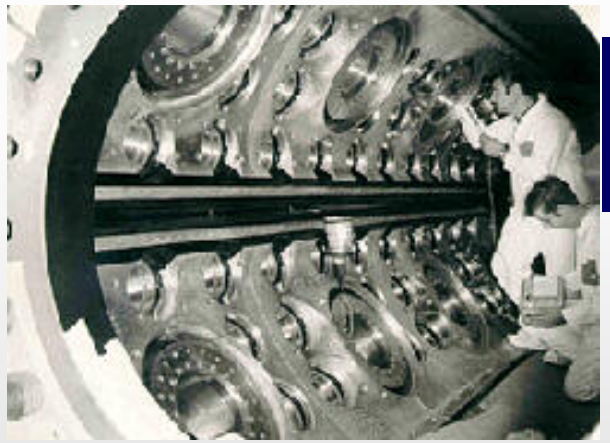
… cosmic-ray showers were found to contain many different types of particles …

Accelerators study these particles in detail

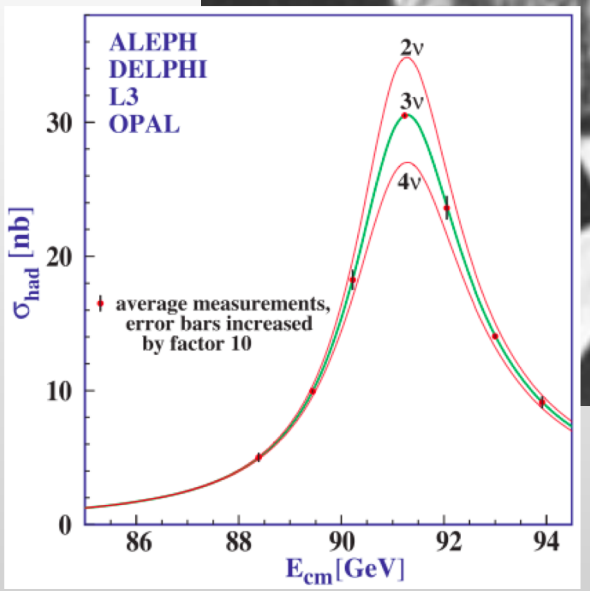
The ‘Standard Model’ of Particle Physics



Developed by Abdus Salam, Glashow, Weinberg, Feynman, Gell Mann et al.



Tested by experiments at CERN

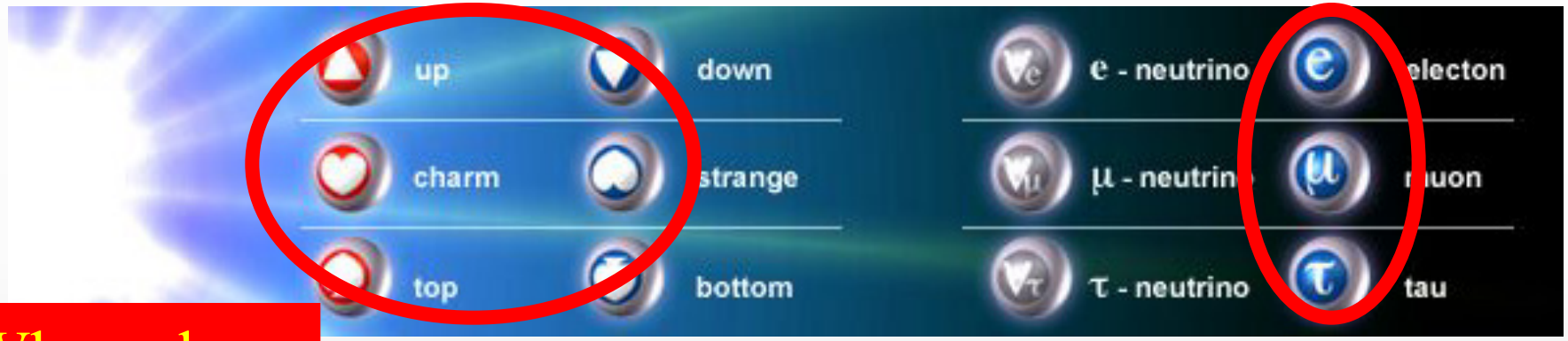


Perfect agreement between theory and experiments in all laboratories

The ‘Standard Model’

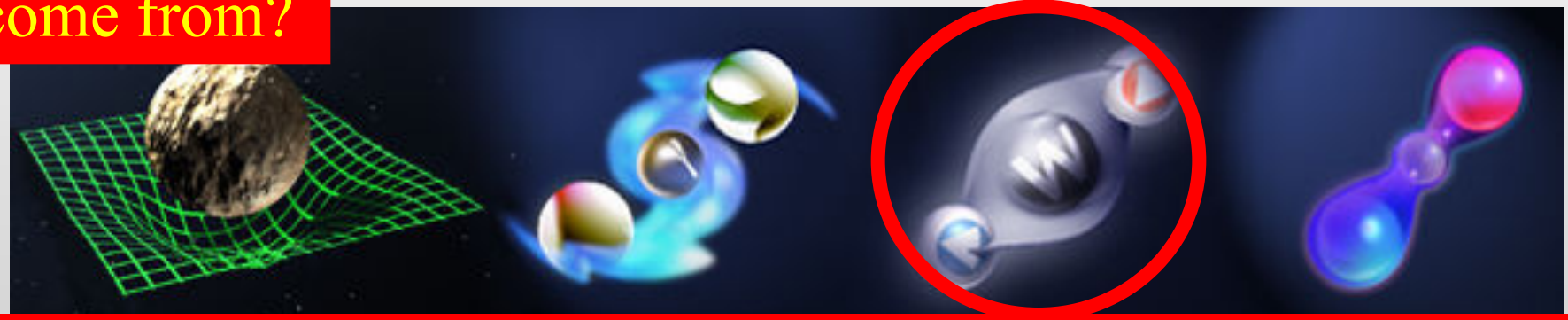
= Cosmic DNA

The matter particles



Where does mass come from?

The fundamental interactions



Gravitation electromagnetism weak nuclear force strong nuclear force

Why do Things Weigh?

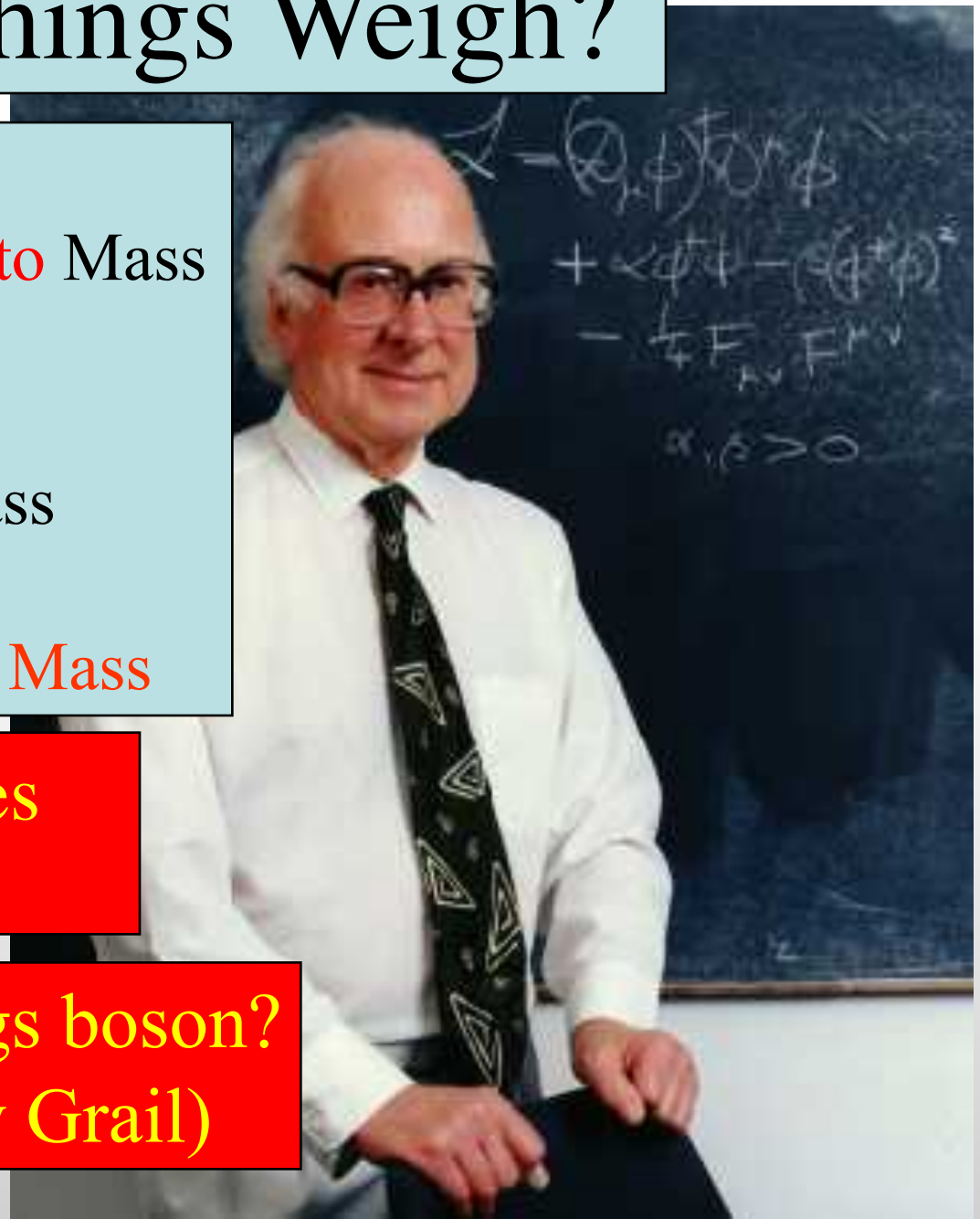
Newton:

Weight proportional to Mass

Einstein:

Energy related to Mass

Neither explained origin of Mass



Where do the masses come from?

Are masses due to Higgs boson? (the physicists' Holy Grail)

THINK OF A SNOWFIELD

Skier moves fast:
Like particle without mass
e.g., photon = particle of light

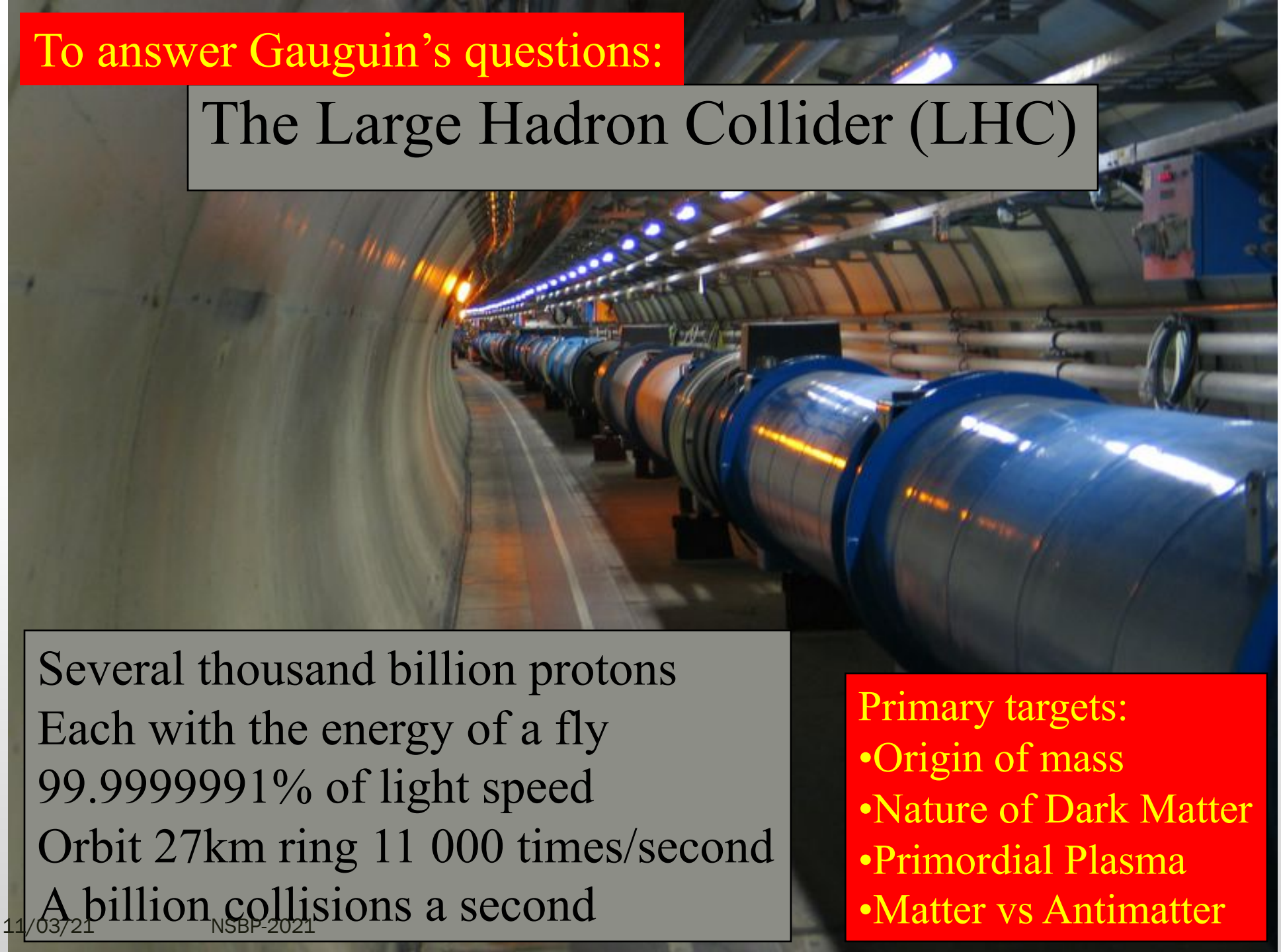
Snowshoer sinks into snow,
moves slower:
Like particle with mass
e.g., electron

The LHC discovered the snowflake: The Higgs Boson

Hiker sinks deep,
moves very slowly:
Particle with large mass

To answer Gauguin's questions:

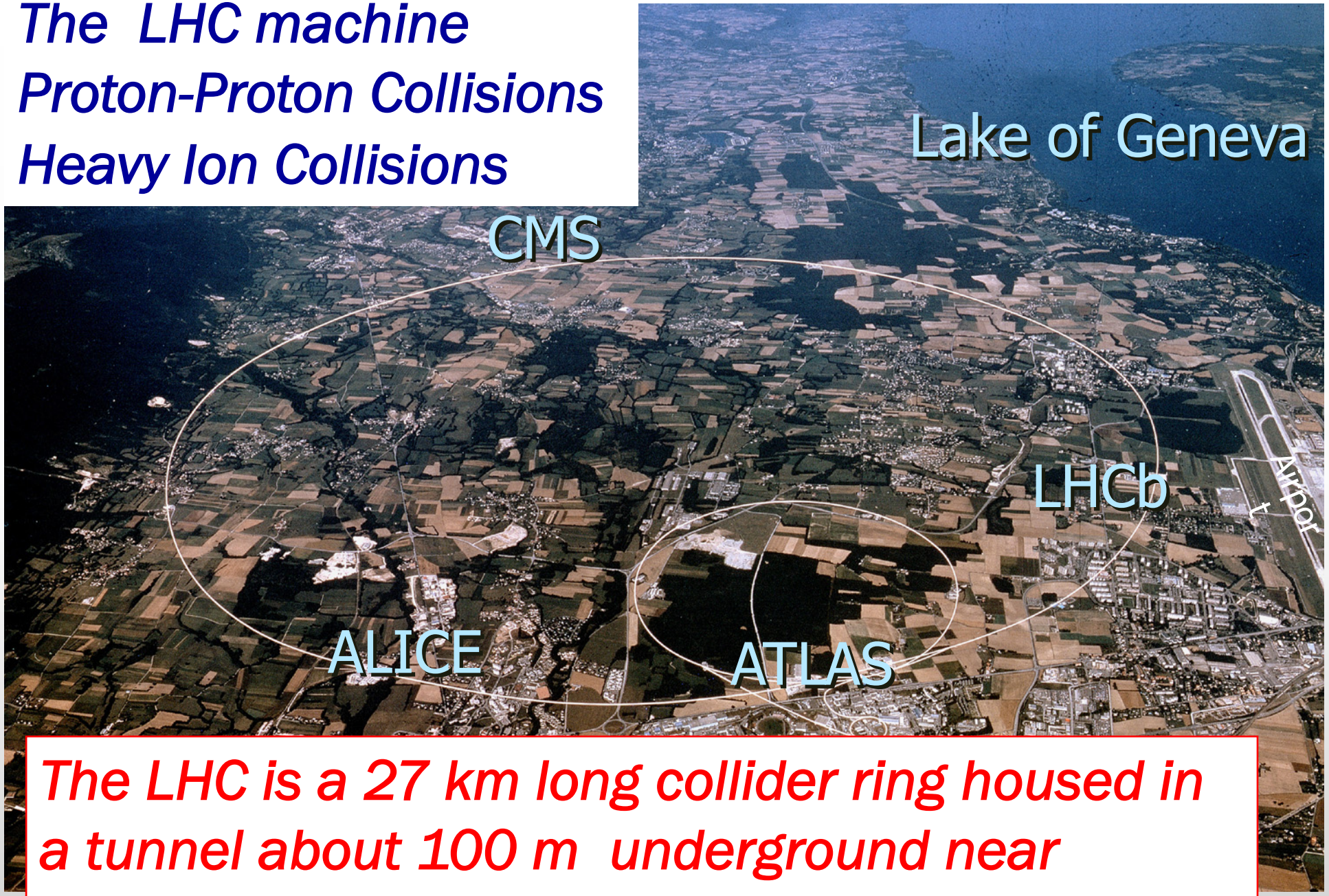
The Large Hadron Collider (LHC)



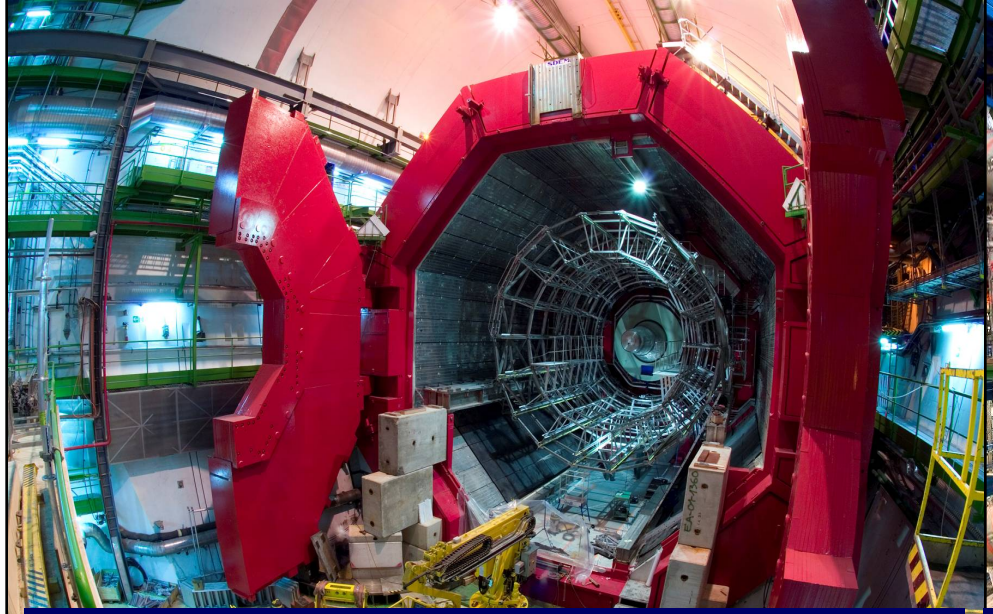
Several thousand billion protons
Each with the energy of a fly
99.9999991% of light speed
Orbit 27km ring 11 000 times/second
A billion collisions a second

Primary targets:
- Origin of mass
- Nature of Dark Matter
- Primordial Plasma
- Matter vs Antimatter

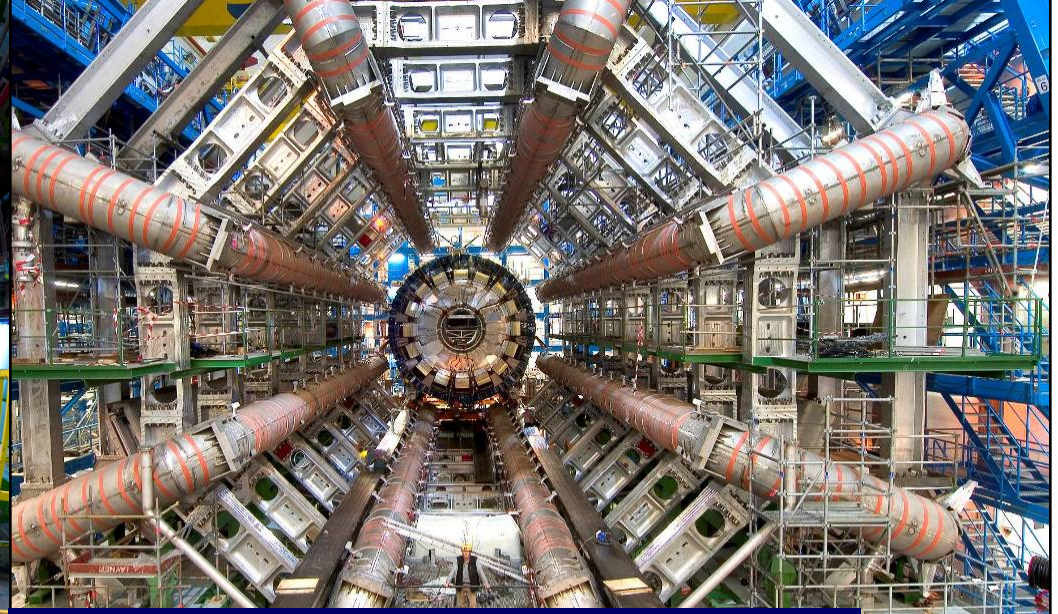
The LHC machine
Proton-Proton Collisions
Heavy Ion Collisions



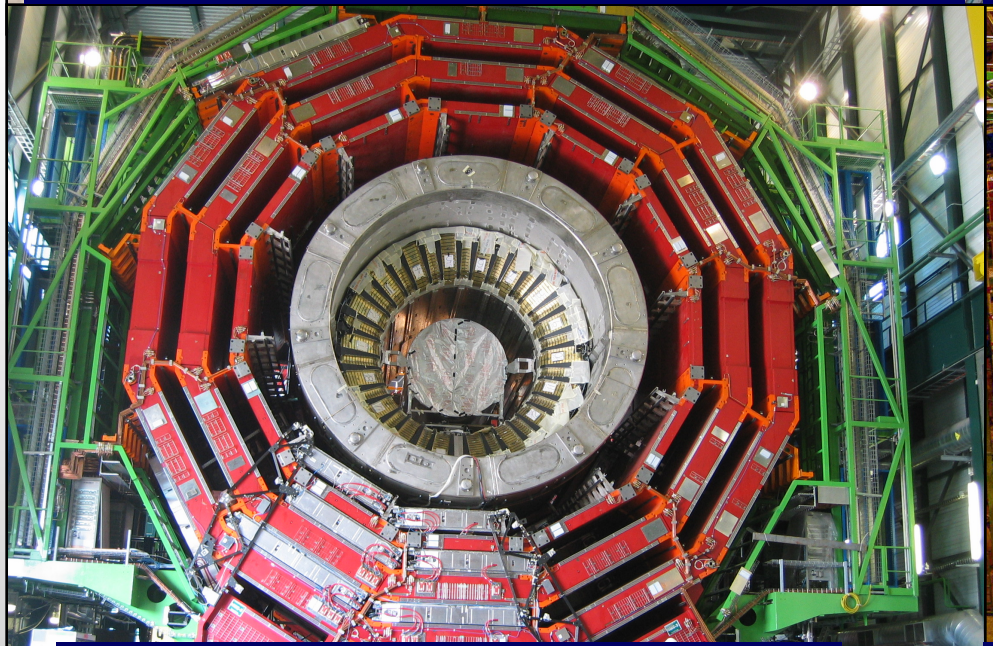
The LHC is a 27 km long collider ring housed in a tunnel about 100 m underground near Geneva



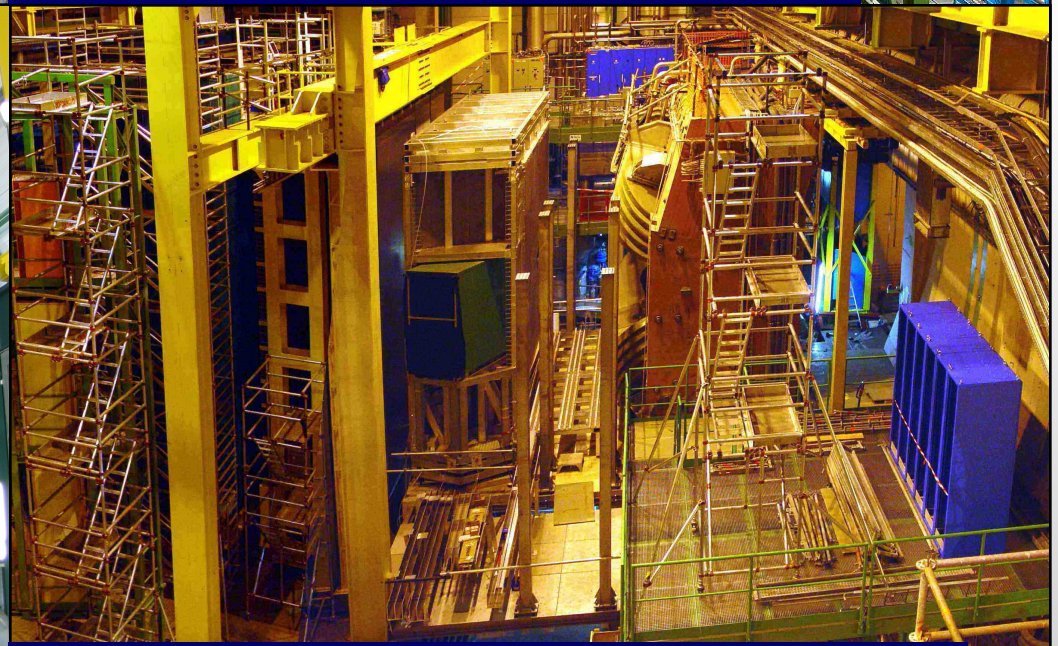
ALICE: Primordial cosmic plasma



ATLAS: Higgs and dark matter

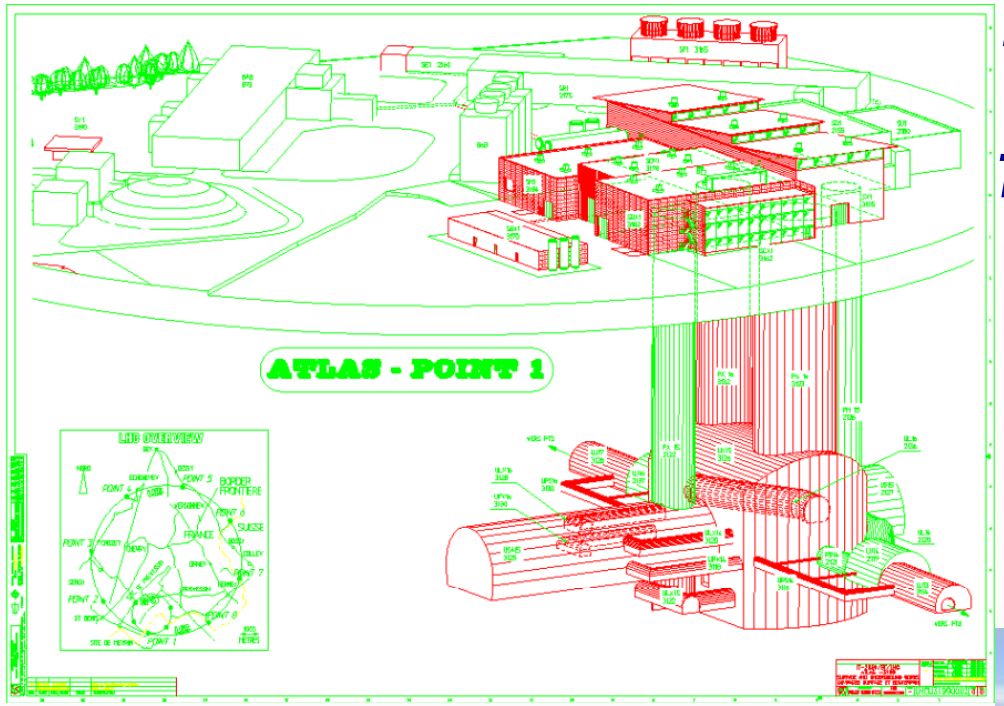


CMS: Higgs and dark matter

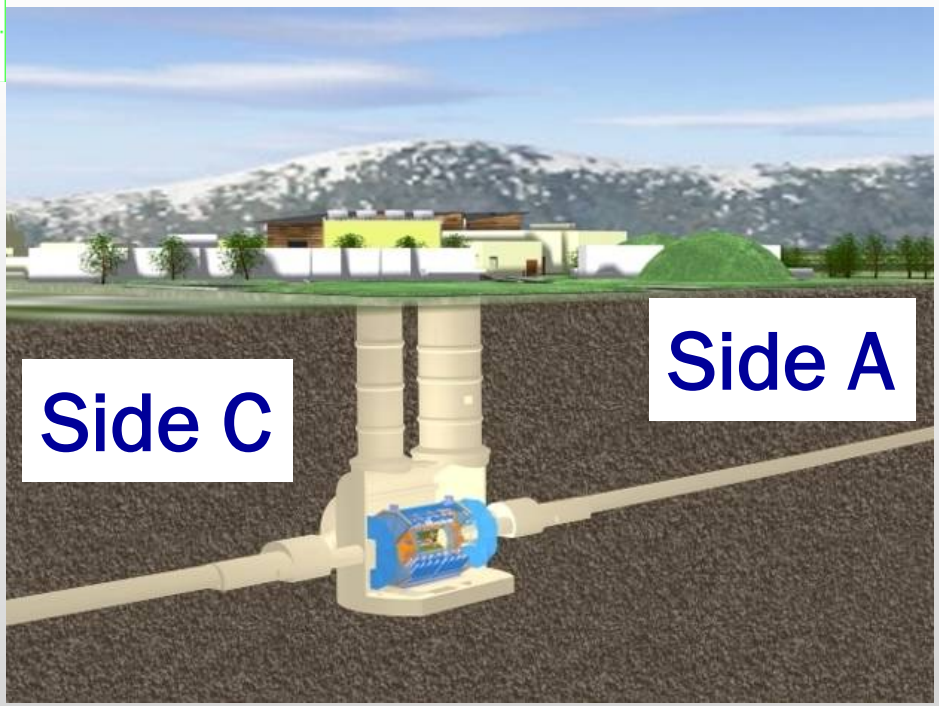


LHCb: Matter-antimatter difference

The Underground Cavern for the ATLAS Detector



Length = 55 m
Width = 32 m
Height = 35 m

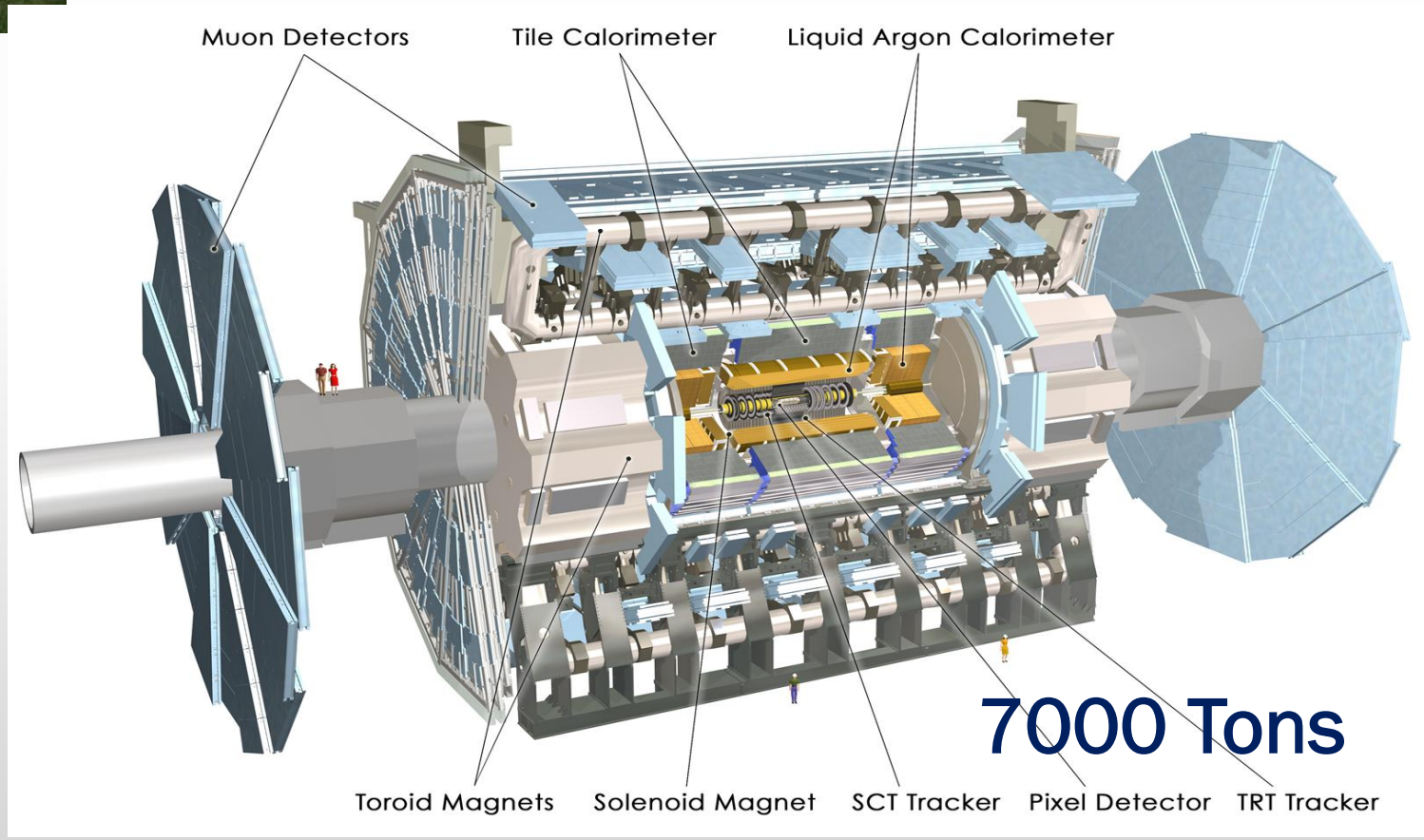


ATLAS Detector at the LHC

3300 Physicists
550M Suisse Franks

45 m

24 m



SCIENTISTS' HOME COUNTRIES

MEMBER STATES **7 246**

Austria	100
Belgium	114
Bulgaria	72
Czech Republic	221
Denmark	50
Finland	72
France	773
Germany	1 207
Greece	221
Hungary	78
Israel	58
Italy	1 886
Netherlands	169
Norway	62
Poland	317
Portugal	97
Romania	145
Serbia	49
Slovakia	129
Spain	411
Sweden	75
Switzerland	204
United Kingdom	736

OBSERVERS **2 518**

Japan	273
Russia	1 129
USA	1 116

ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP **54**

Cyprus	21
Slovenia	33

ASSOCIATE MEMBERS **771**

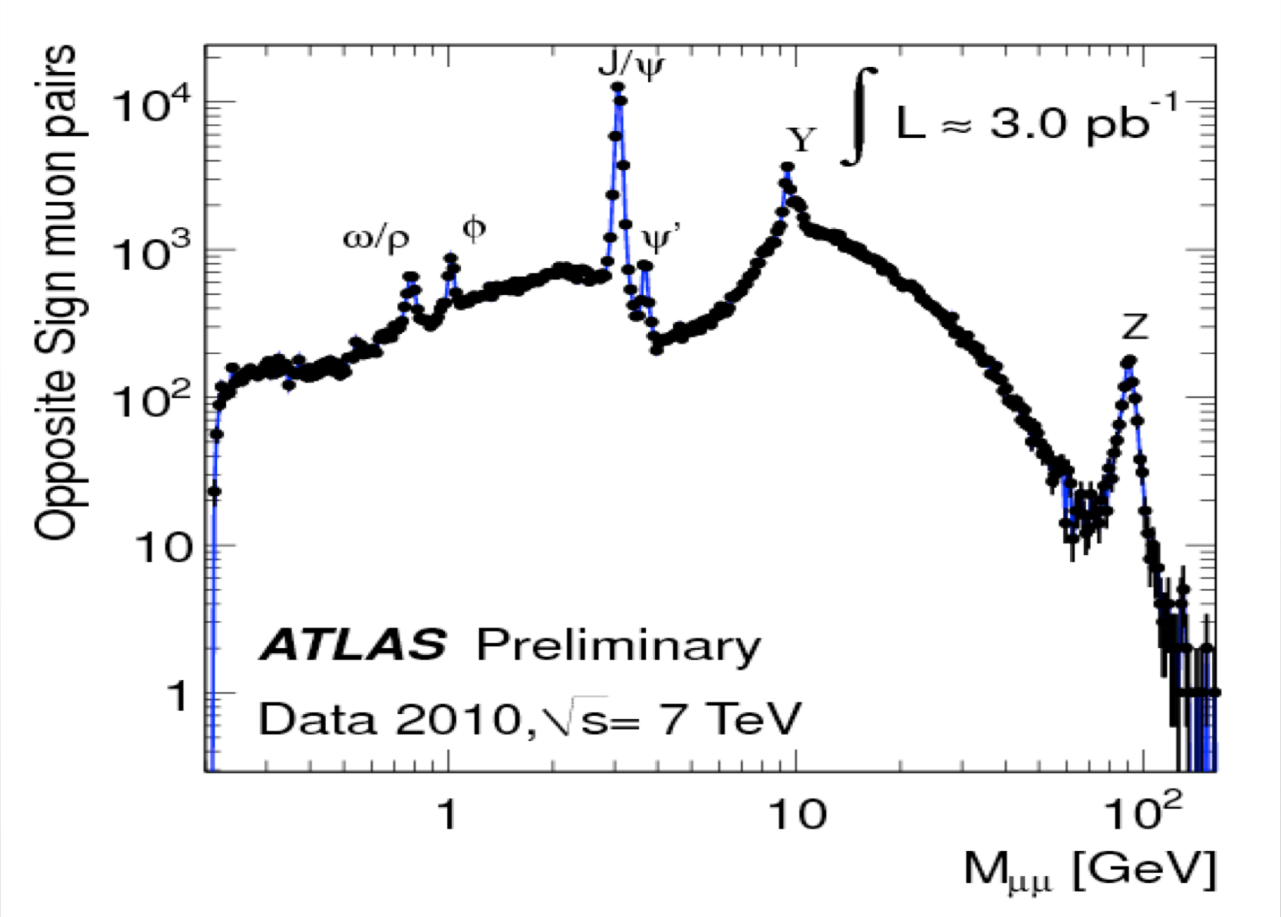
Croatia	46
India	370
Lithuania	31
Pakistan	63
Turkey	164
Ukraine	97

OTHERS **1 837**

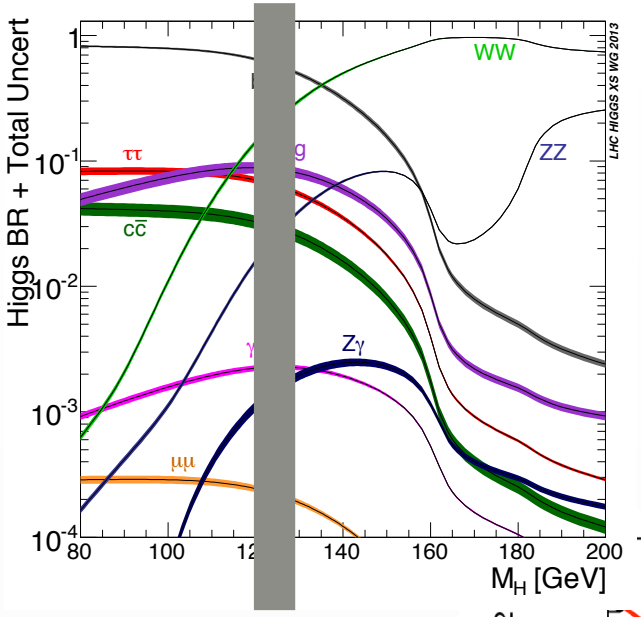
Albania	4	Bolivia	2	Ecuador	10	Iraq	1	Malaysia	19	Palestine	7	Taiwan	47
Algeria	9	Bosnia & Herzegovina	2	Egypt	26	Ireland	14	Malta	5	Paraguay	1	Thailand	23
Argentina	22	Bostwana	1	El Salvador	1	Jamaica	1	Mexico	81	Peru	6	Tunisia	5
Armenia	18	Brazil	121	Estonia	16	Jordan	1	Mongolia	2	Philippines	3	Uruguay	1
Australia	29	Burundi	1	Georgia	53	Kazakhstan	12	Montenegro	8	Saint Kitts		Uzbekistan	3
Azerbaijan	8	Cameroon	1	Ghana	1	Kenya	1	Morocco	26	and Nevis	1	Venezuela	10
Bahrain	3	Canada	161	Gibraltar	1	Korea	158	Myanmar	1	Saudi Arabia	3	Viet Nam	9
Bangladesh	5	Chile	20	Guatemala	1	Kyrgyzstan	1	Nepal	8	Senegal	1	Yemen	1
Belarus	49	China	570	Hong Kong	1	Latvia	4	New Zealand	6	Singapore	4	Zambia	1
Benin	1	Colombia	36	Honduras	1	Lebanon	23	Nigeria	2	South Africa	58	Zimbabwe	2
		Congo	1	Iceland	5	Lesotho	1	North Korea	3	Sri Lanka	6		
		Costa Rica	1	Indonesia	11	Luxembourg	3	North Macedonia	2	Sudan	2		
		Cuba	16	Iran	48	Madagascar	1	Oman	1	Syria	2		

Confirming previous measurements or discoveries

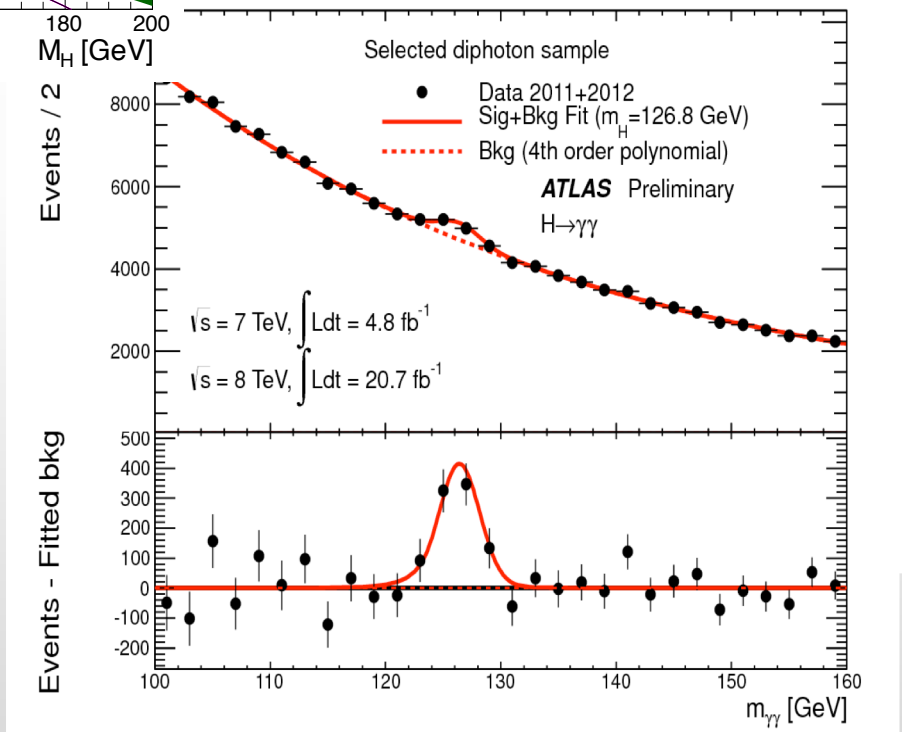
- Before we do new searches, we have to show that we measure accurately what is already known

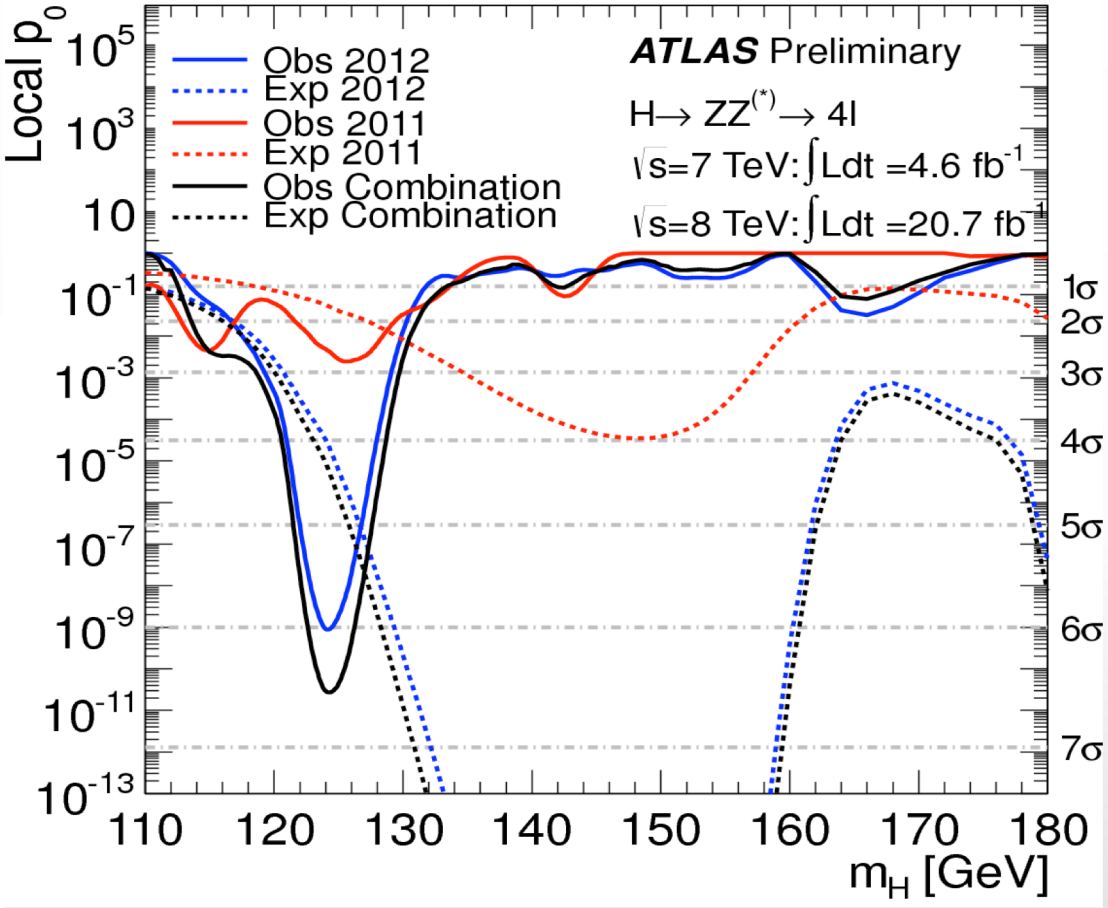


The Higgs Boson Discovery



In July 2012

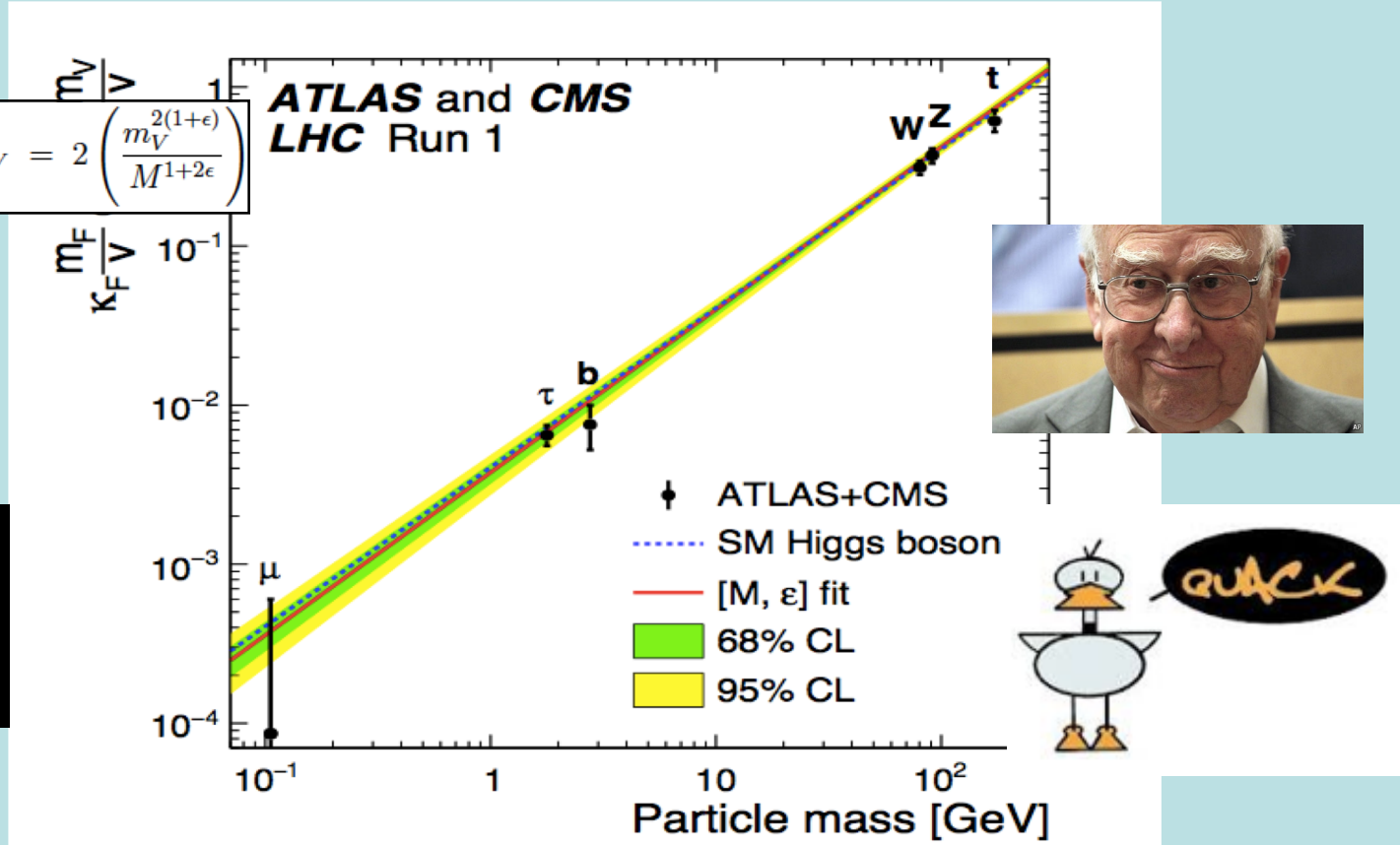




It Walks and Quacks like a Higgs

- Do couplings scale ~ mass? With scale = v?

$$\lambda_f = \sqrt{2}\left(\frac{m_f}{M}\right)^{1+\epsilon}, \; g_V = 2\left(\frac{m_V^{2(1+\epsilon)}}{M^{1+2\epsilon}}\right)$$



Global fit

Blue dashed line = Standard Model

The Dark Matter Hypothesis

- Proposed by Fritz Zwicky, based on observations of the Coma galaxy cluster
- The galaxies move too quickly
- The observations require a

stronger gravitational field

than provided by the visible matter

- **Dark matter?**

The Rotation Curves of Galaxies

- Measured by Vera Rubin
- The stars also orbit ‘too quickly’
- Her observations also required a

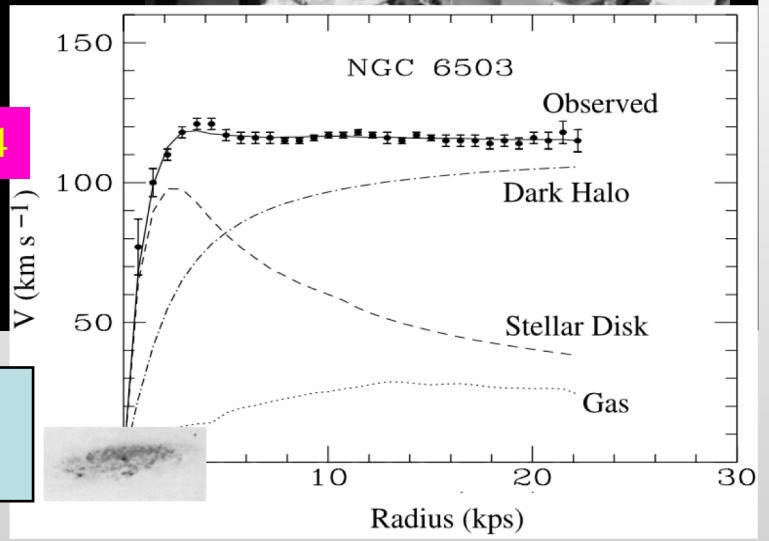
stronger gravitational field

than provided by the visible matter

- **Further strong evidence for dark matter**

Tkachev, arXiv:1802.02414

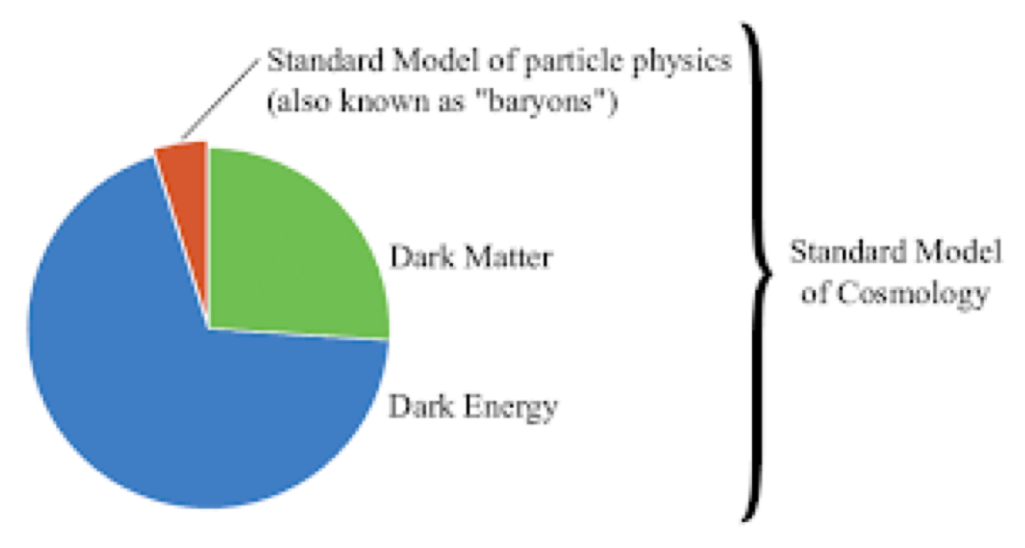
Much larger than visible galaxy

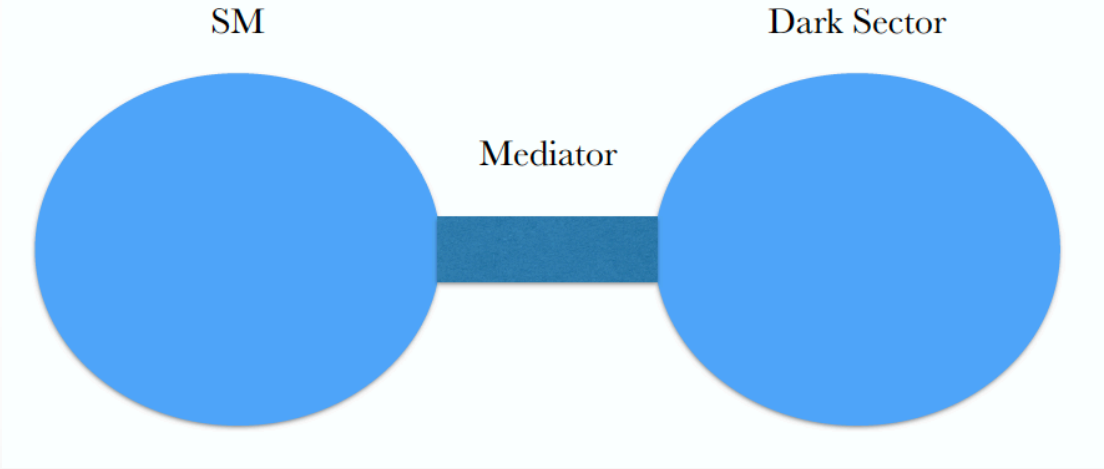


Sample Rotation Curve: NGC 6503

Dark Sector

- Dark Sector as ”New Physics” beyond the Standard Model of particle physics (SM)





Need new force / interaction
to connect SM to Dark Sector

Dark Matter could just be one example of Dark Sector State

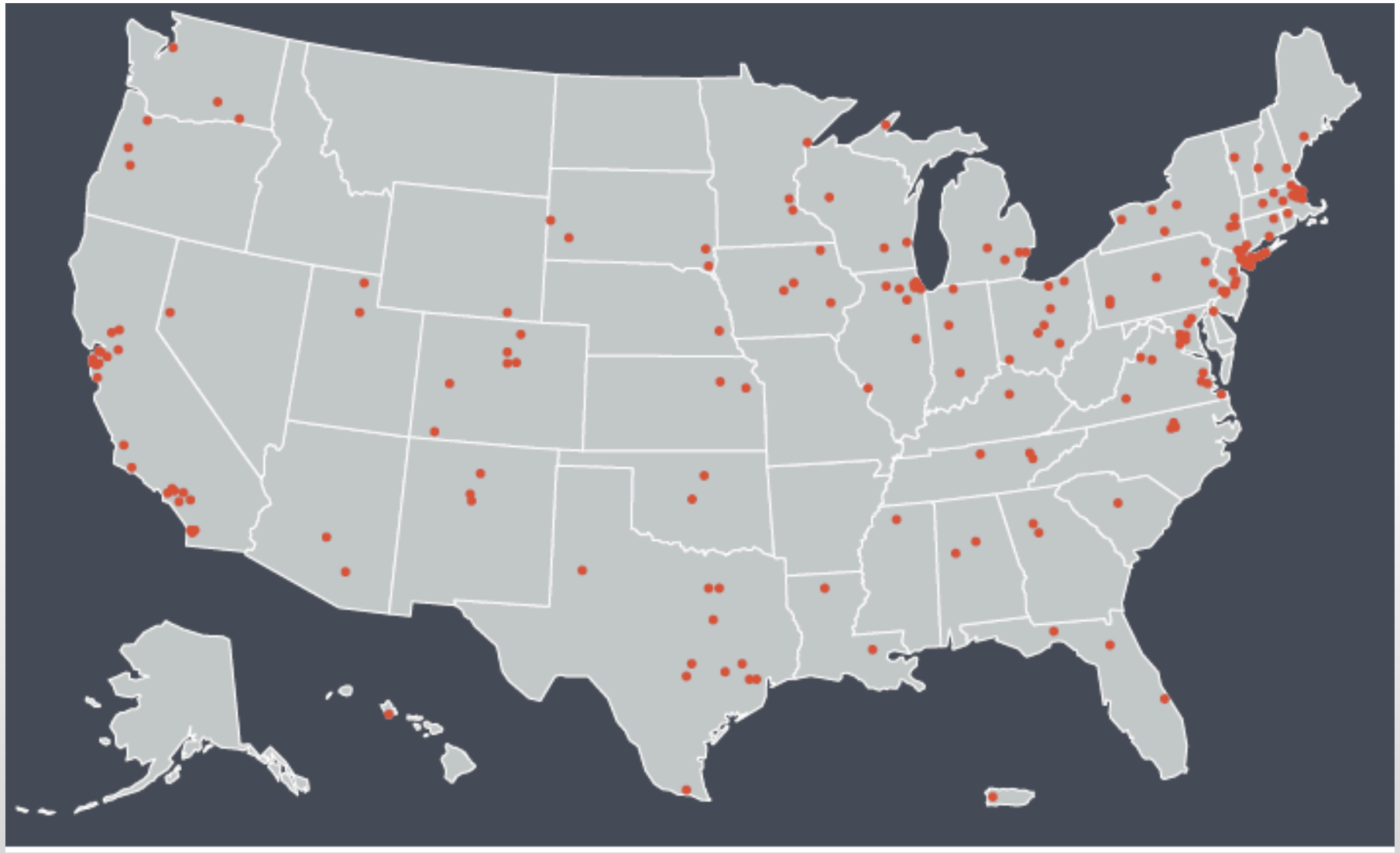
RESEARCH AND INTERNSHIP OPPORTUNITIES WITH U.S. LHC

Students can participate in opportunities offered by U.S. LHC universities and national labs.

Students at all levels can engage in research and develop skills to enter America's technological workforce.

Teachers can access resources and develop skills to bring real research experience to science class rooms.

U.S. HEP Institutions



Looking for something to do in Summer 2022?

Visit the U.S. CMS Exhibit Booth

Are you interested in contributing to the next stage in humanity's understanding of Nature at the smallest scales?

Are you interested in getting paid while working with other scientists and engineers to push the envelope with cutting-edge instrumentation?

The CMS experiment is looking for undergrad students to work with us to upgrade the detector for the next generation of LHC experiments

Scan this QR code and fill out the form and we'll email you information on how to apply!

SCAN ME

Research Experience for Undergraduates:
https://sites.google.com/a/umich.edu/um-cern-reu/

Conclusions

- The Higgs boson, the particle responsible for the masses of elementary particles, was discovered in 2012
- Since then, nothing new has been discovered
- At the Large Hadron Collider, we are preparing for a new batch of data taking, Run3
- US-ATLAS and US-CMS offer many opportunities for education, research, and skills development useful to enter the technological workforce

For further questions / inquiries

- CMS
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