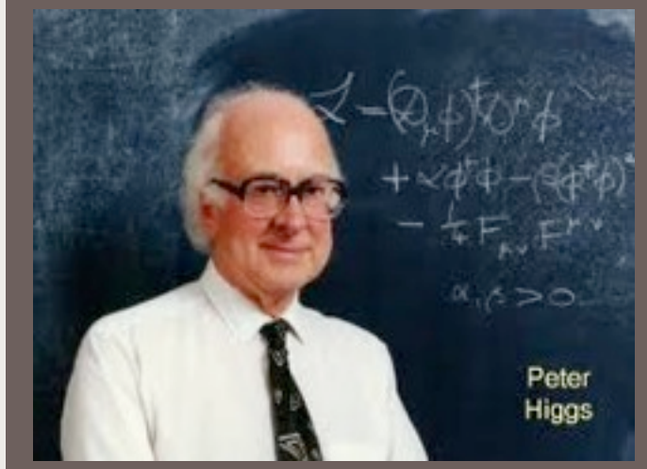
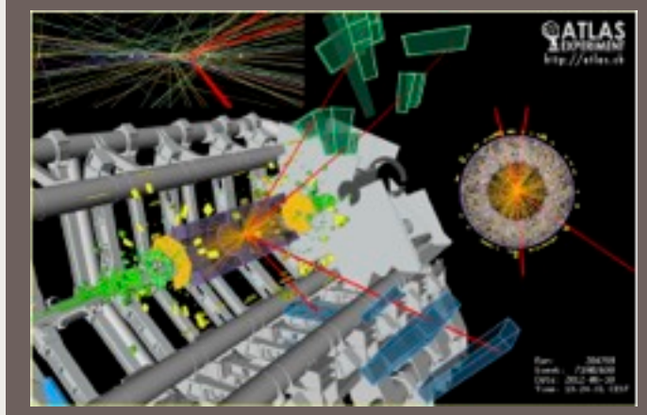
TRIUMF

Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules



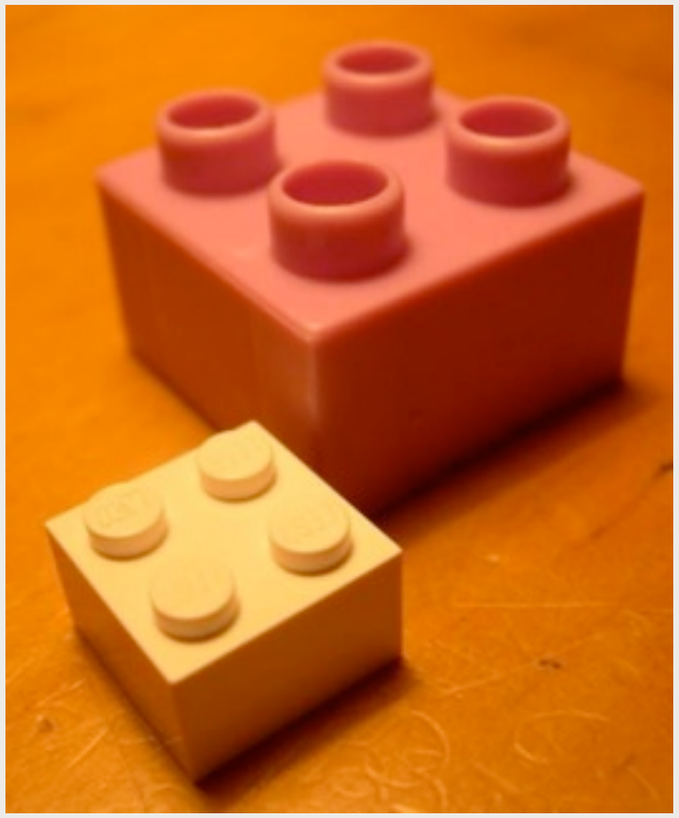


Higgs and the Origin of Matter

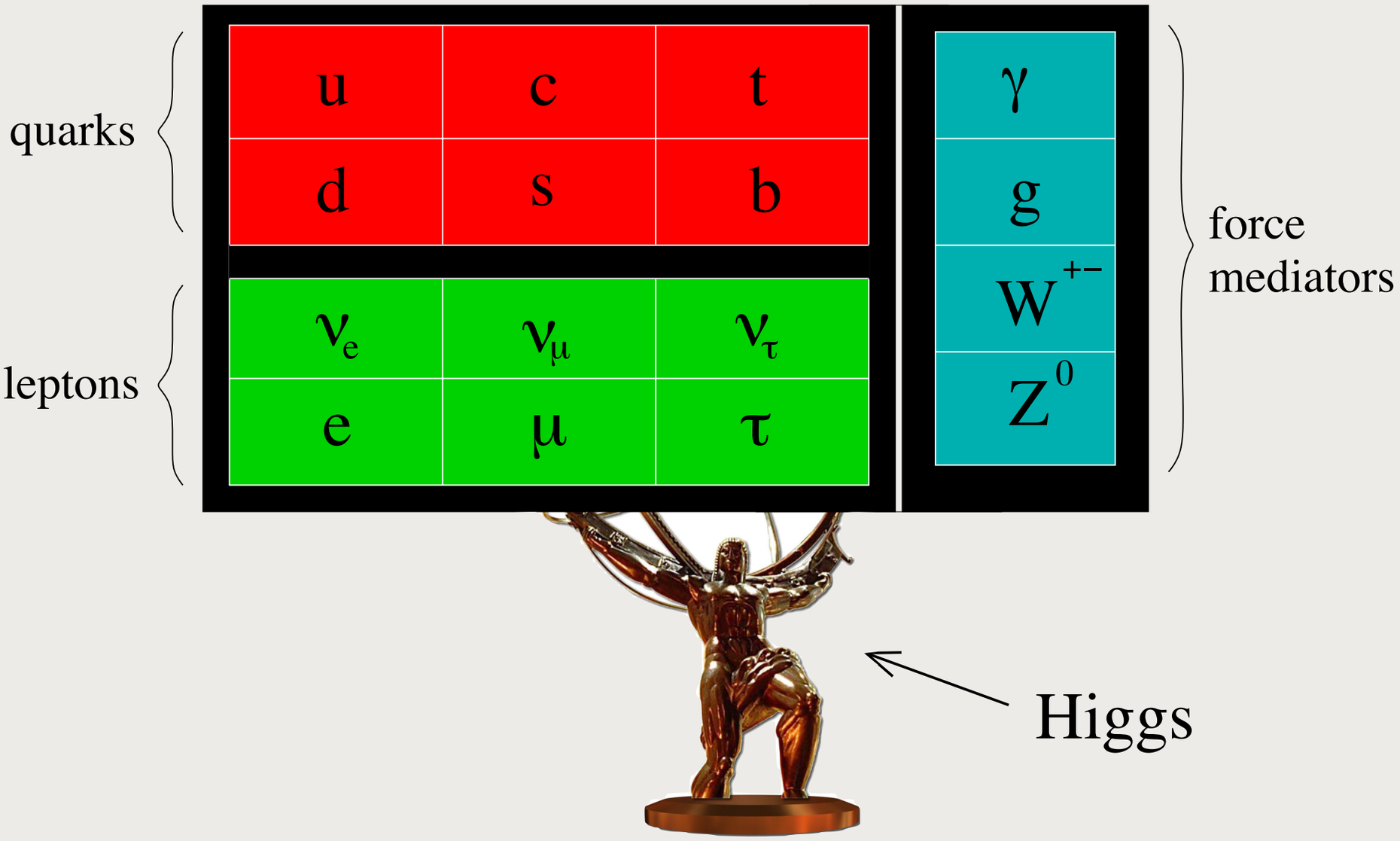
David Morrissey | Research Scientist | TRIUMF

Big Questions

- What are the building blocks of our Universe?
- What rules do they follow?
- How do they combine to make up what we see?

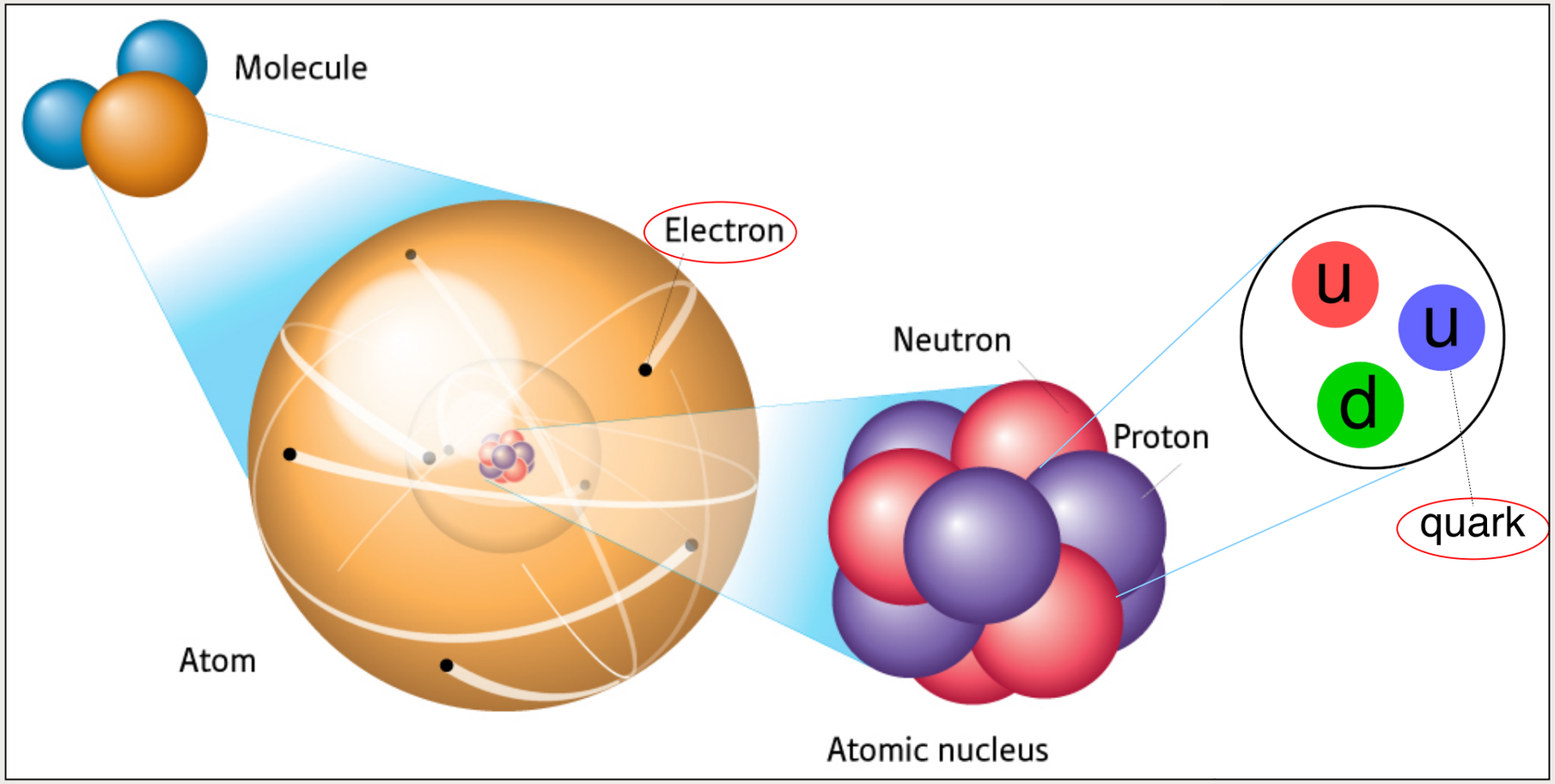


Elementary Particles



Elementary particle masses come from the Higgs.

What if there was no Higgs?

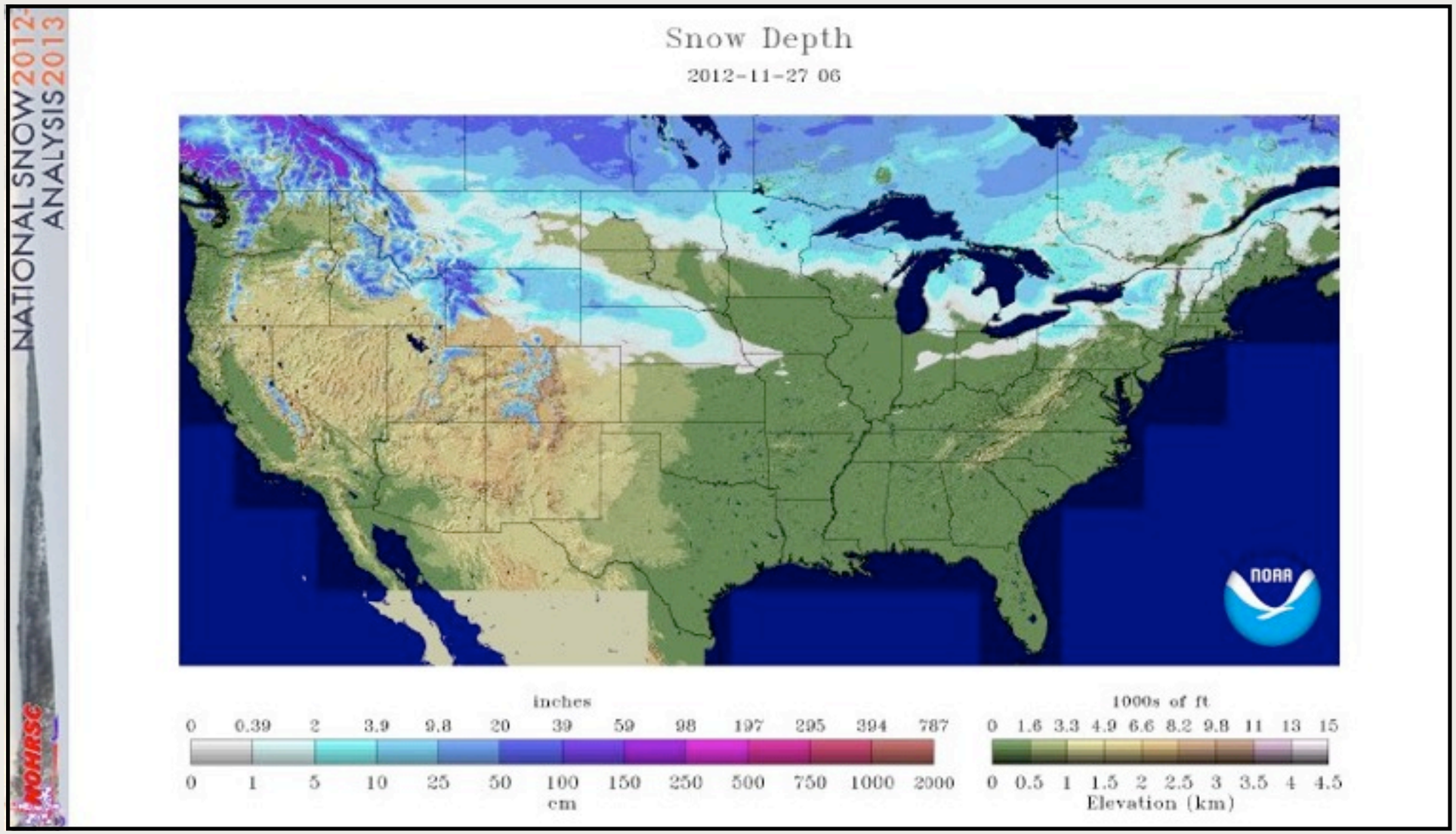


- Our Universe would be very different:
  - Electrons would be massless.
  - They would not bind into atoms.
  - No atoms, no molecules, no biology, no us!

Higgs Field vs. Higgs Particle

- Higgs Field: permeates all space, H(t,x,y,z).

  e.g. Snow Field: D(t,x,y) = snow depth



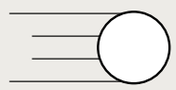
Higgs Field vs. Higgs Particle

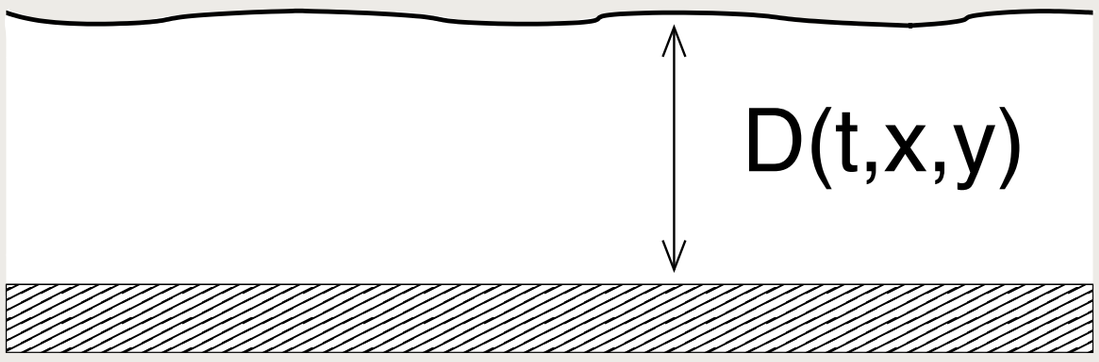
- Higgs Field: permeates all space, H(t,x,y,z)

- Ground State: H(t,x,y,z) = constant = 174 GeV

(1 GeV = 1 billion electronvolts)
(average energy of an air molecule = 1/40 eV)

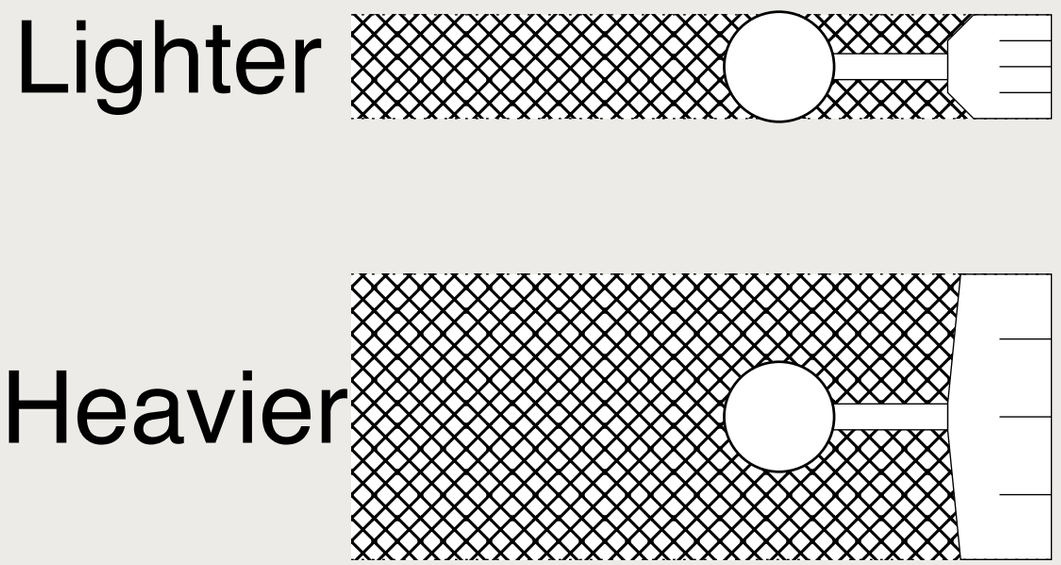
- First Excited State: Higgs boson particle





Higgs and Mass

- Elementary particles interact with the Higgs field. This gives them mass.



- Stronger interaction = larger mass

Higgs Hunting

- Observing the Higgs particle is essential for confirming that mass comes from the Higgs field.
- Until last summer, we only had hints of the Higgs.
- Over 40 years of experimental searches...
- July 4, 2012*: experiments at the CERN LHC announced the discovery of a Higgs-like particle.

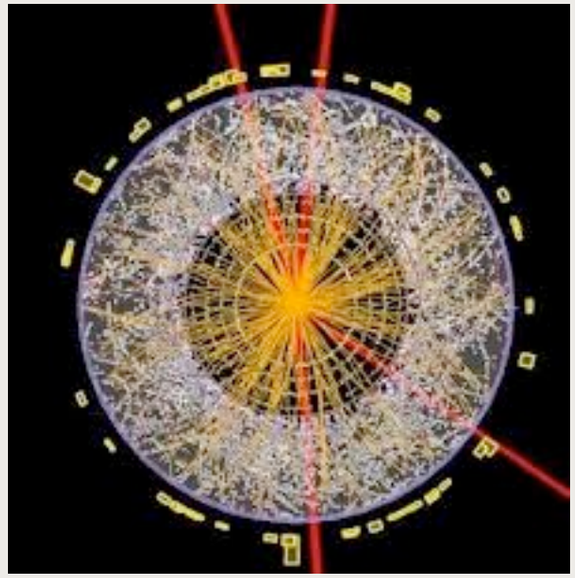
* Higgsdependence Day

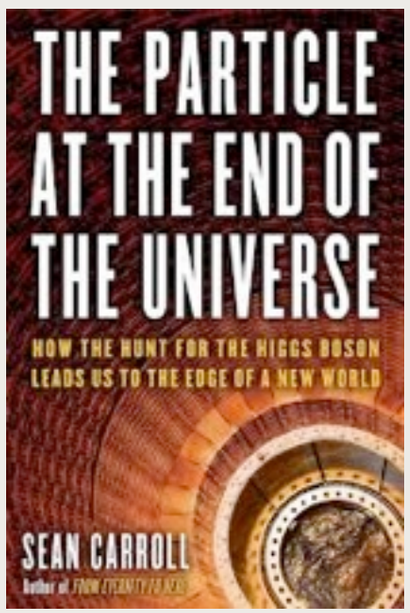
Higgs Discovery!

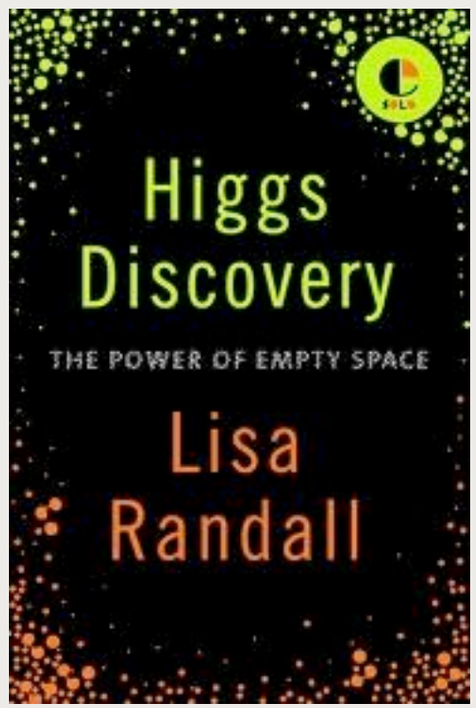
Physicists Find Elusive Particle Seen as Key to the Universe

By DENNIS OVERBYE 8:18 PM ET

Researchers said they had discovered what looked for all the world like the Higgs boson, a long-sought particle that

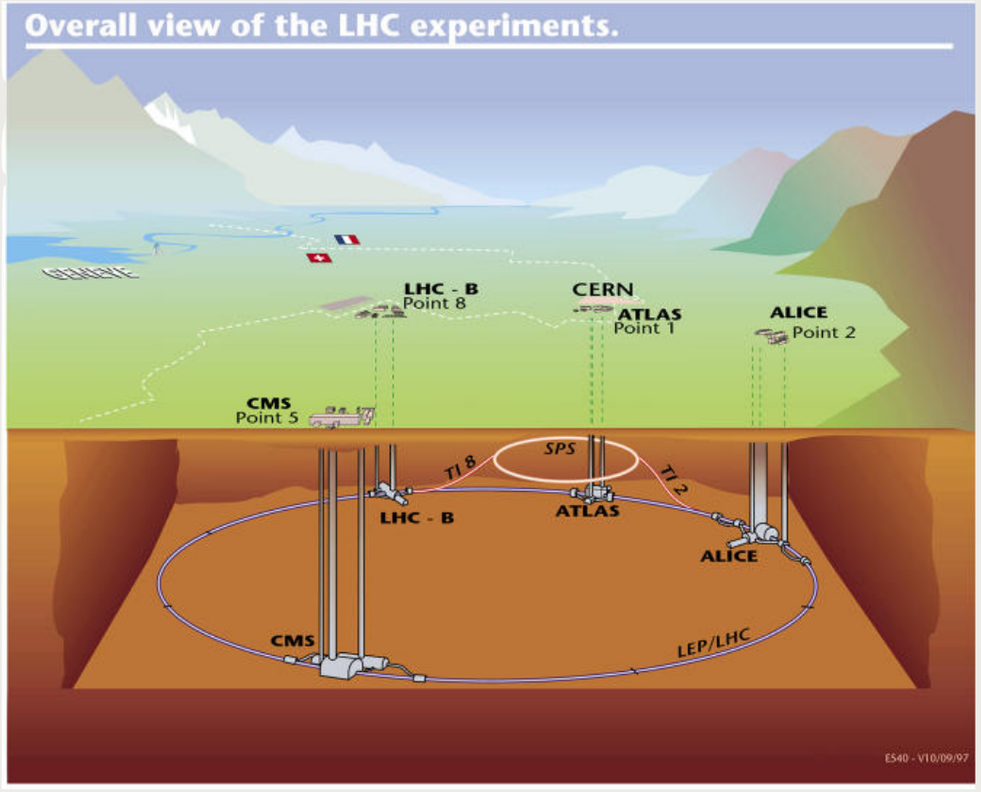


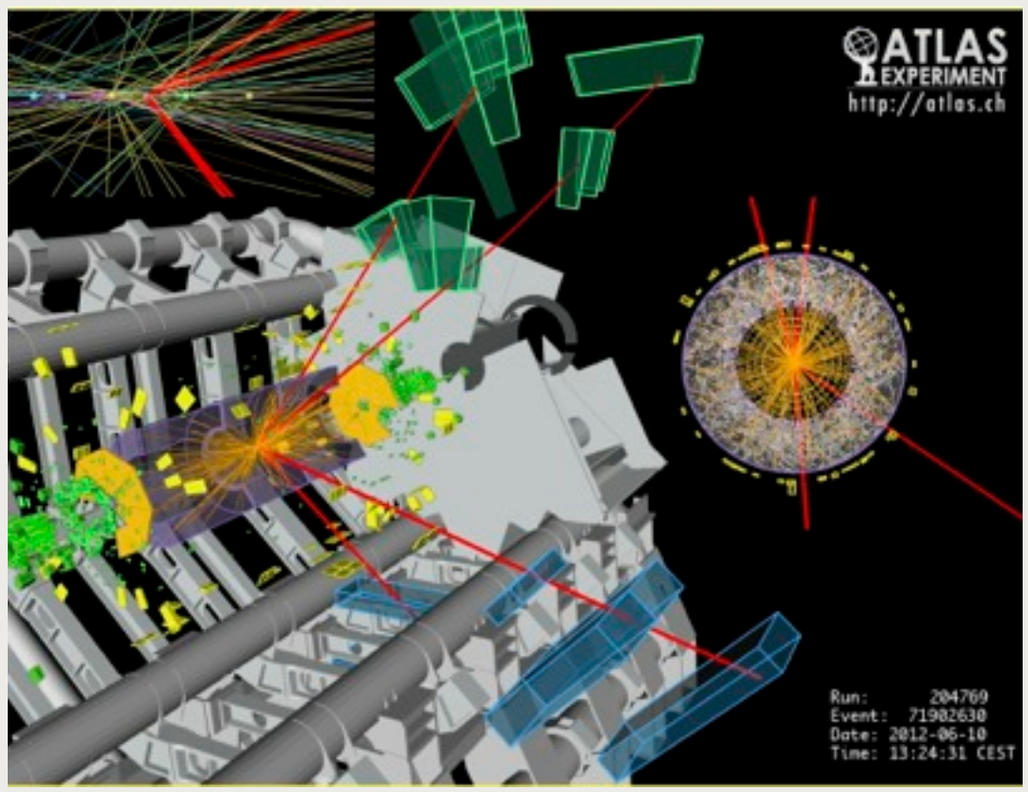




Creating the Higgs

- LHC: collide protons at high energy
- Not so easy:
  - requires a very high collision energy, > 10^{12} eV
  - low probability: two Higgs per ten billion collisions

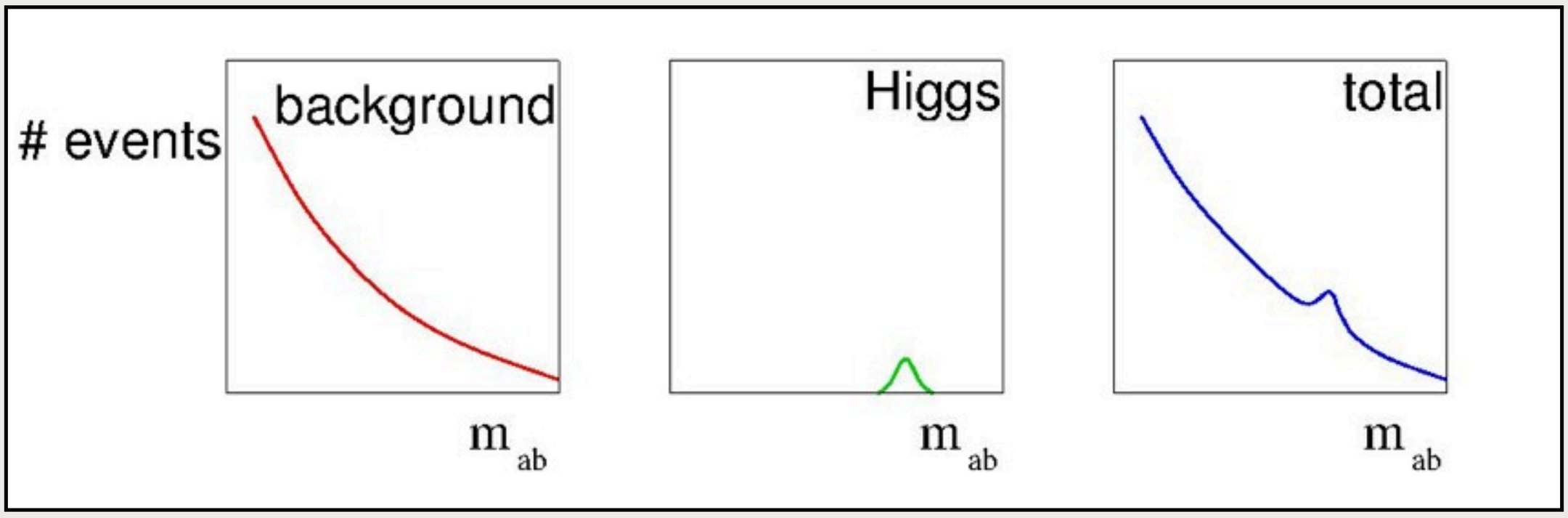




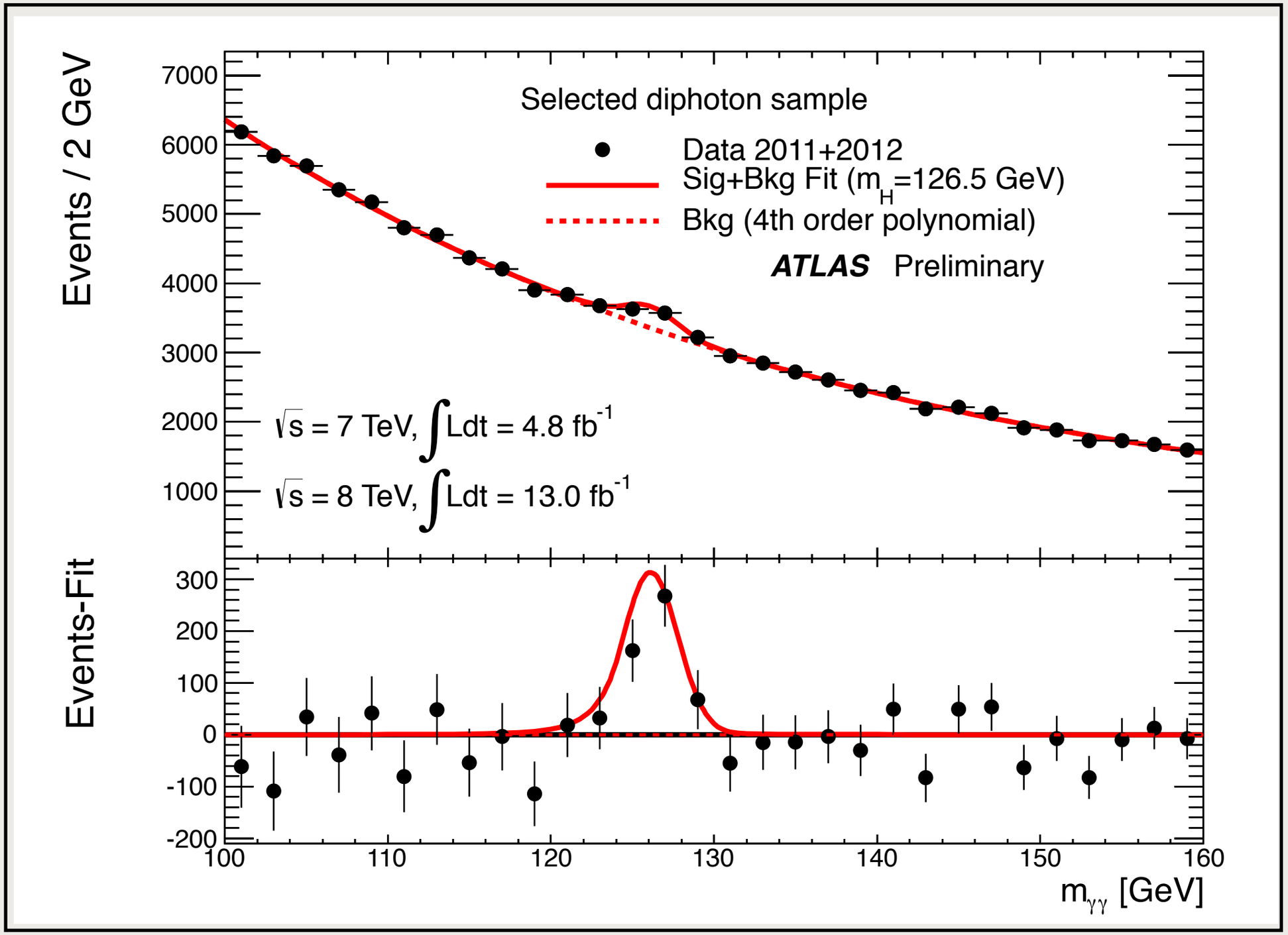
Finding the Higgs

- The Higgs decays almost immediately.
- Measure the particles that it decays to, h → a+b.
- Use energy conservation to identify it:

$$m_{ab} = \sqrt{(E_a + E_b)^2 + (\vec{p}_a + \vec{p}_b)^2} = \text{Higgs mass}$$

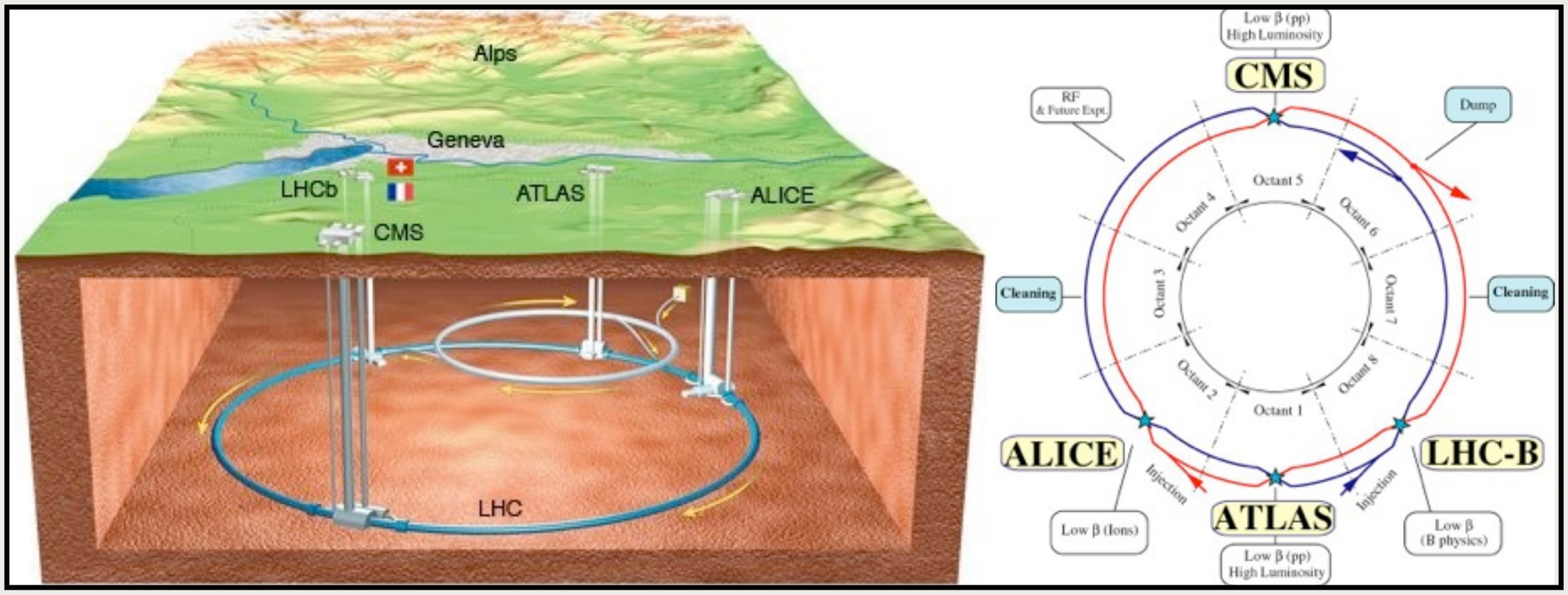


Discovery!


Selected diphoton sample
Data 2011+2012
Sig+Bkg Fit (m_H=126.5 GeV)
Bkg (4th order polynomial)
ATLAS Preliminary
$\sqrt{s}$ = 7 TeV, $\int$Ldt = 4.8 fb^{-1}
$\sqrt{s}$ = 8 TeV, $\int$Ldt = 13.0 fb^{-1}
Events / 2 GeV
Events-Fit
$m_{\gamma\gamma}$ [GeV]

TRIUMF and the Higgs

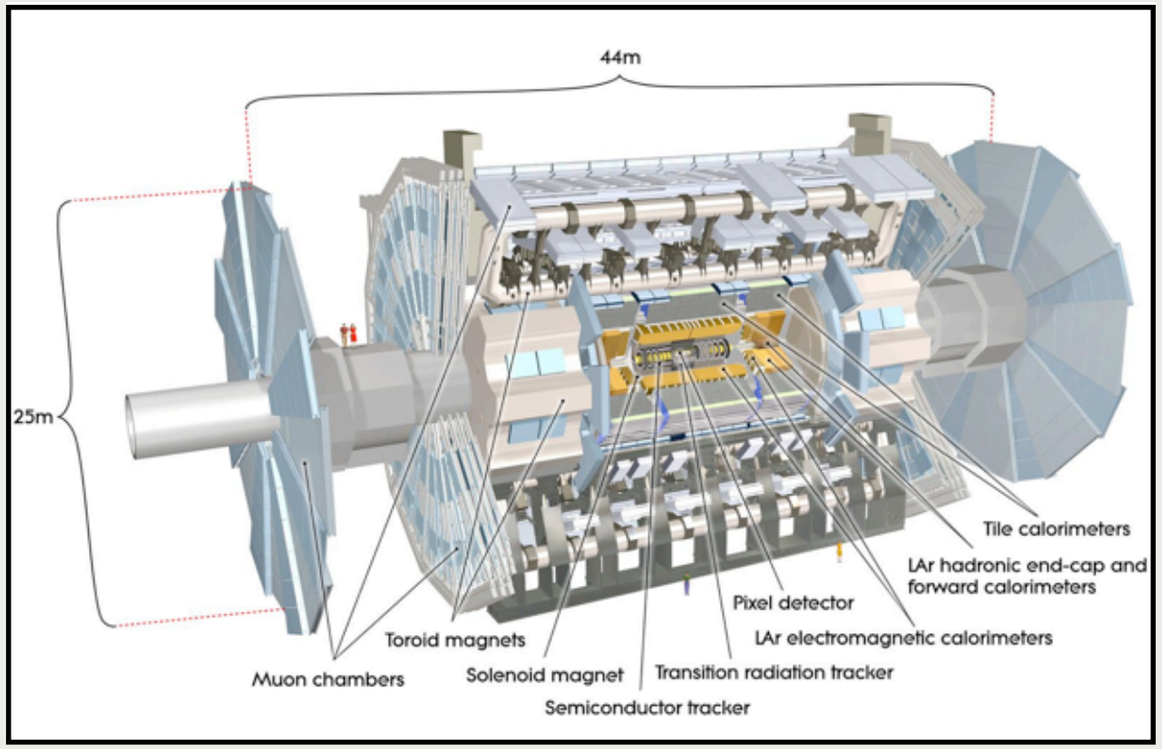
- LHC = Large Hadron Collider
  → accelerate protons to high energies and collide them



- Parts of the accelerator system were designed and built here.

TRIUMF and the Higgs

- Detectors are placed at the collision points. ATLAS and CMS are designed to measure the Higgs.
- Key components of ATLAS were built at TRIUMF.



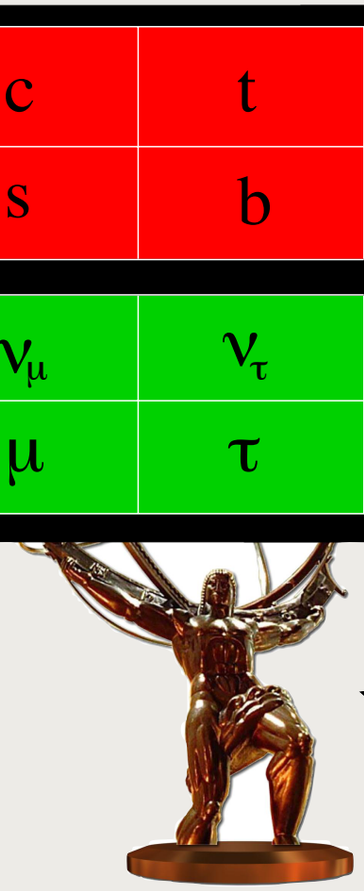
- TRIUMF Tier-1 handles 10% of ATLAS data. Distribution and analysis hub for ATLAS Canada.

Beyond the Higgs: Elements

- How does this ...

↓

u	c	t	γ	
d	s	b	g	
ν_e	ν_μ	ν_τ	W^{+-}	
e	μ	τ	Z^0	



Higgs

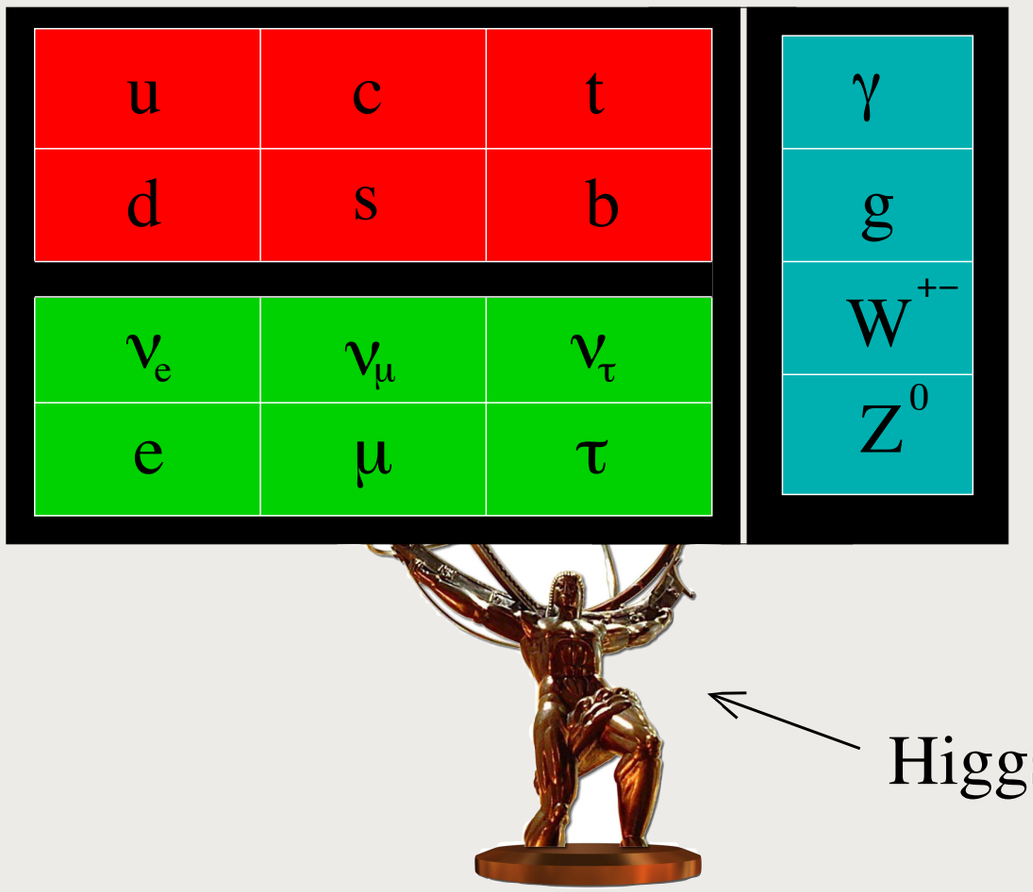
↑

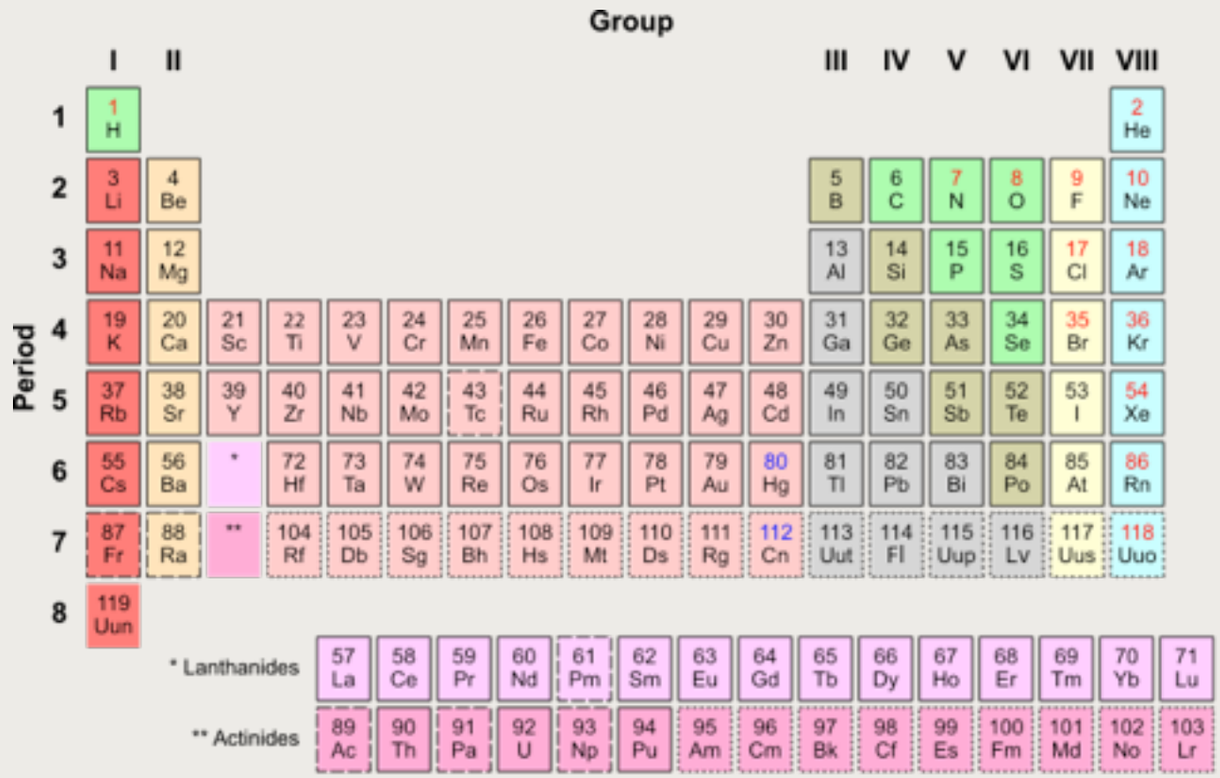
... produce that?

Beyond the Higgs: Elements

- How does this ...

↓



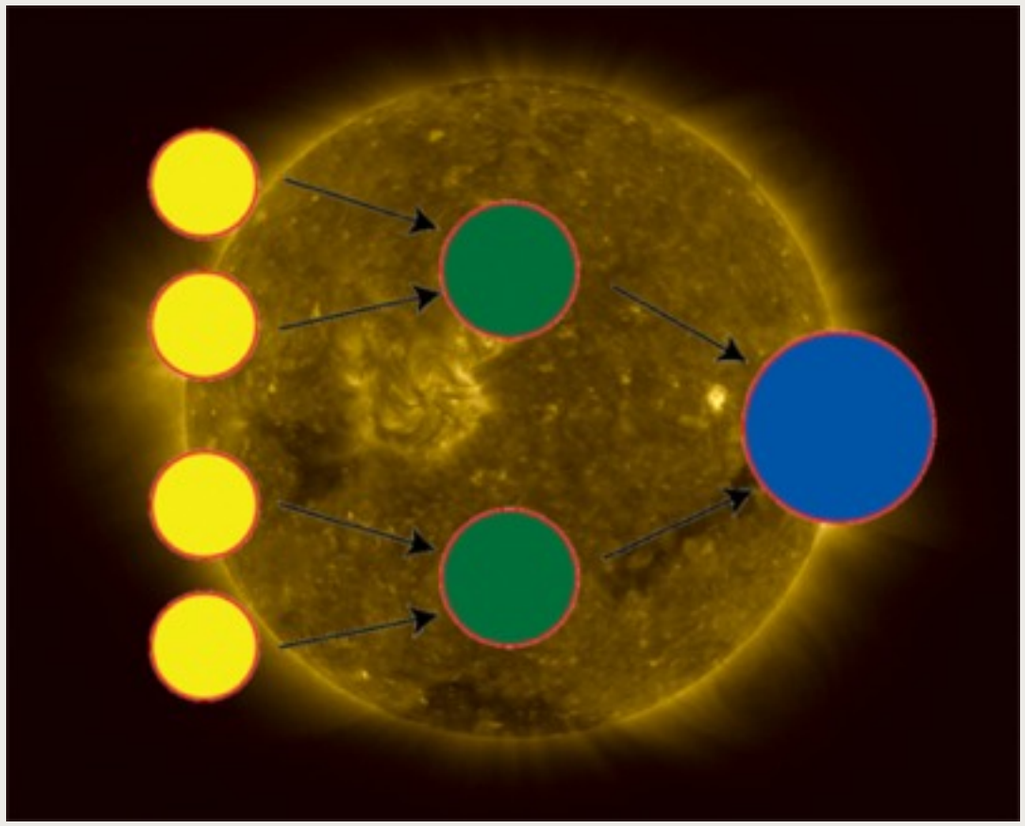


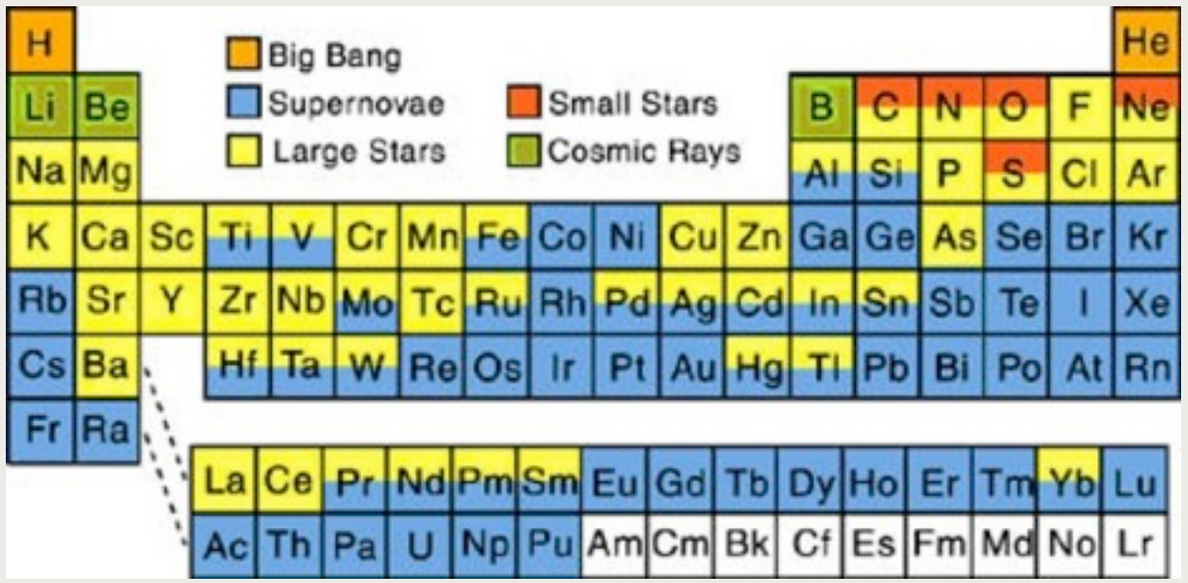
↑

... produce that?

Beyond the Higgs: Elements

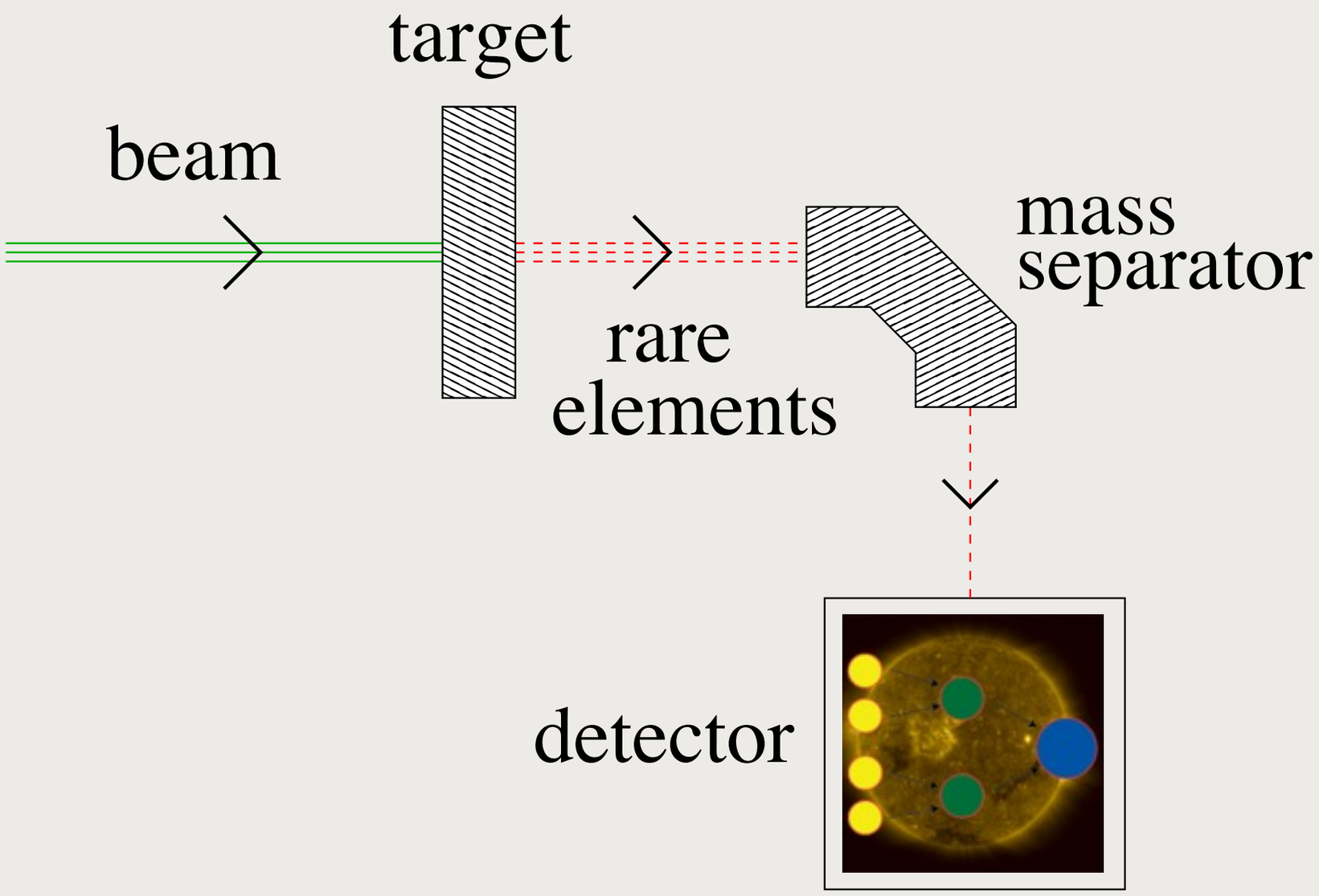
- All heavier elements are created by stars.
- Protons and neutrons fuse to form nuclei.
- The energy released powers the star.





Elements at TRIUMF

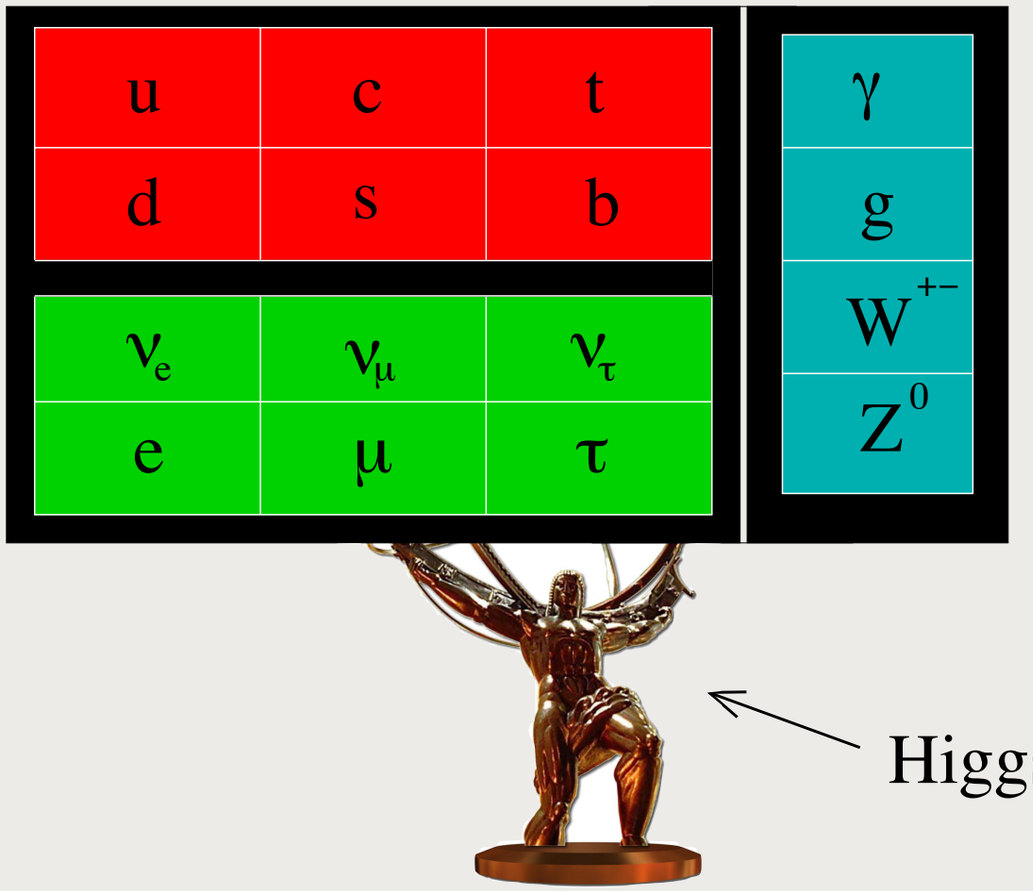
- TRIUMF ARIEL and ISAC experiments recreate these reactions.



Beyond the Higgs: Dark Matter

- How does this ...

↓



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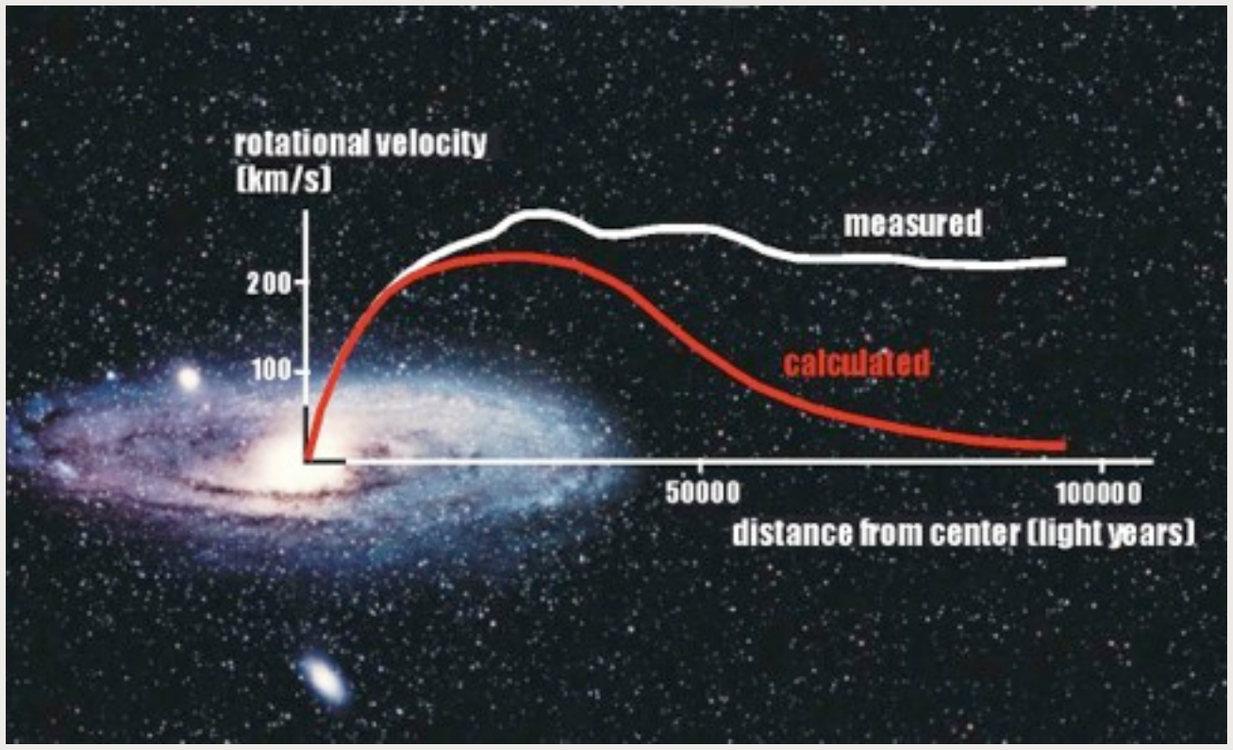
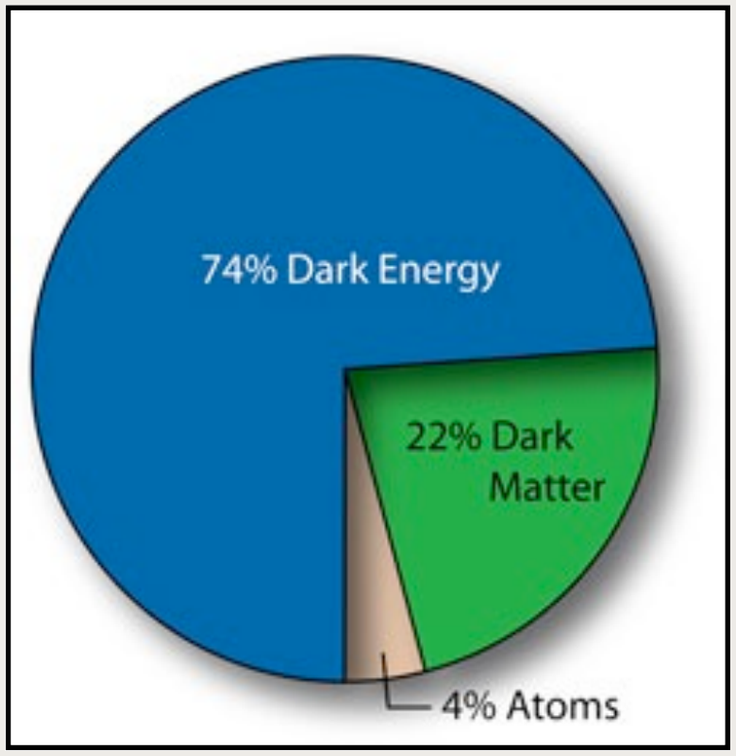
... produce that?

Beyond the Higgs: Dark Matter

- It does not.

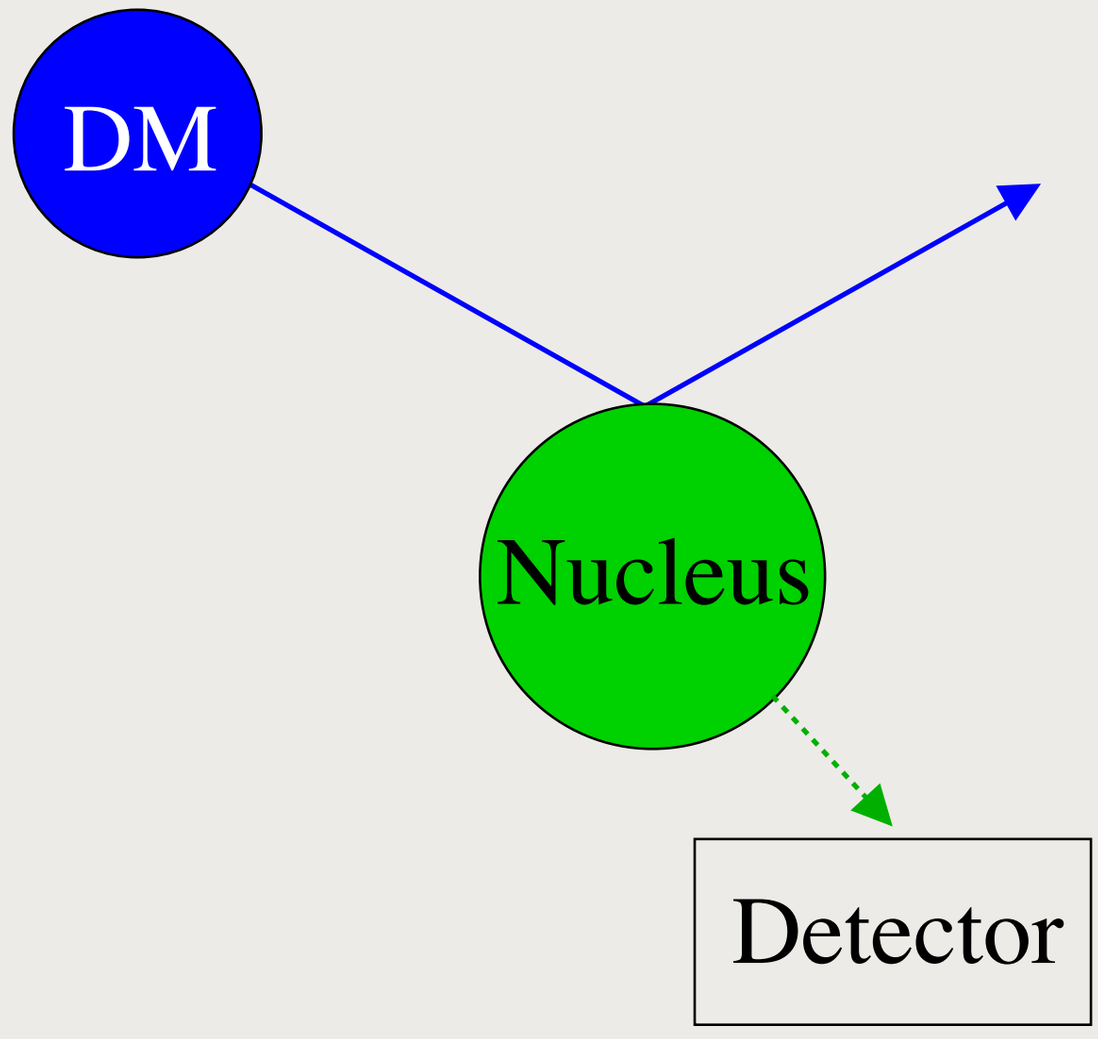




- A new type of matter is needed: Dark Matter. What kind of particle is it?

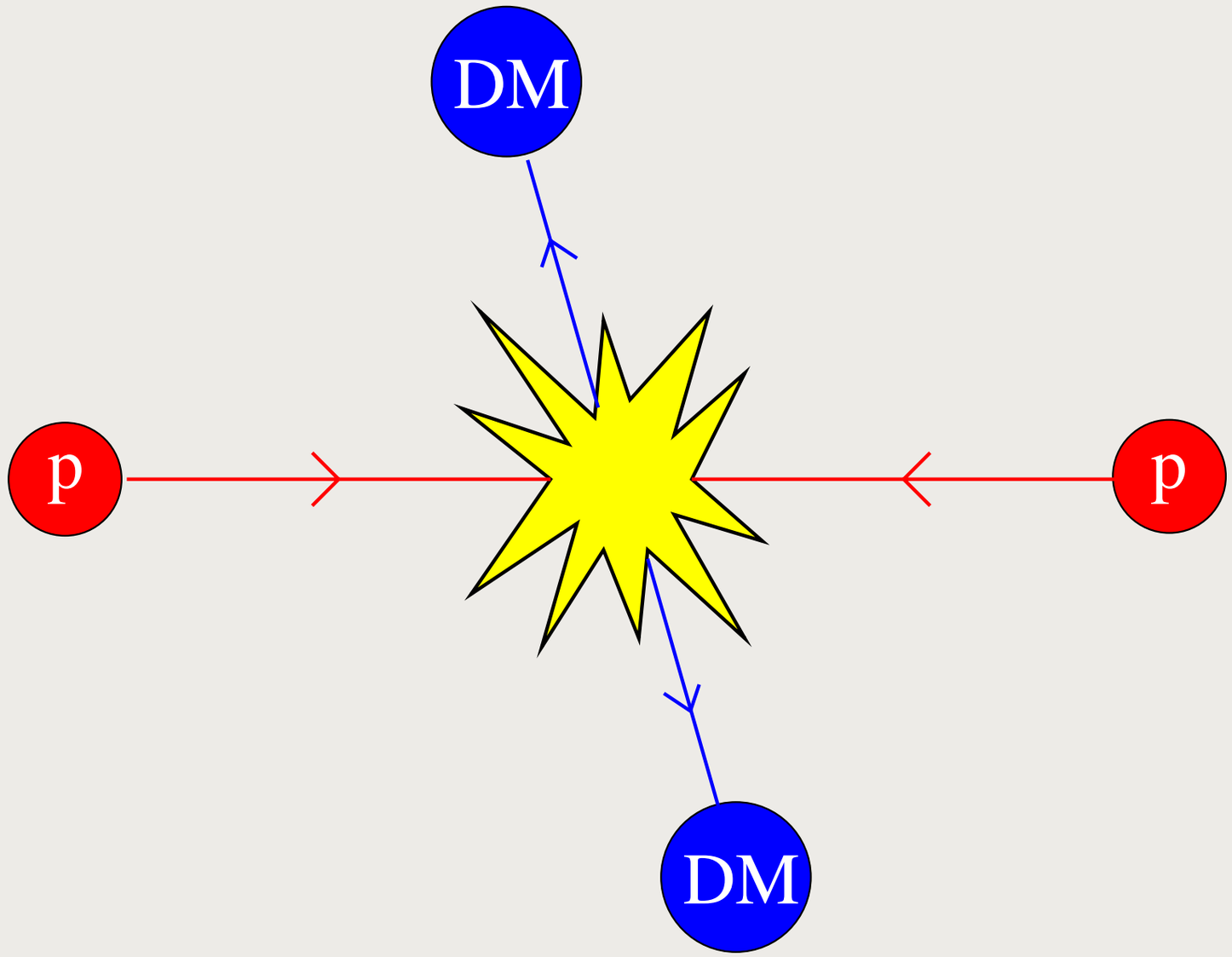
Dark Matter at TRIUMF

- Look for Dark Matter in underground detectors.
  → CDMS and DEAP experiments at SNOLAB



Dark Matter at TRIUMF

- Create Dark Matter in particle colliders.
  → LHC and future Linear Collider



Higgs and Matter

- We think we know the building blocks of matter.

  The Higgs gives them mass.
- They come together in stars to make the elements.
- A new particle is needed to explain dark matter.
- TRIUMF is searching!

TRIUMF

Thank You! Merci!

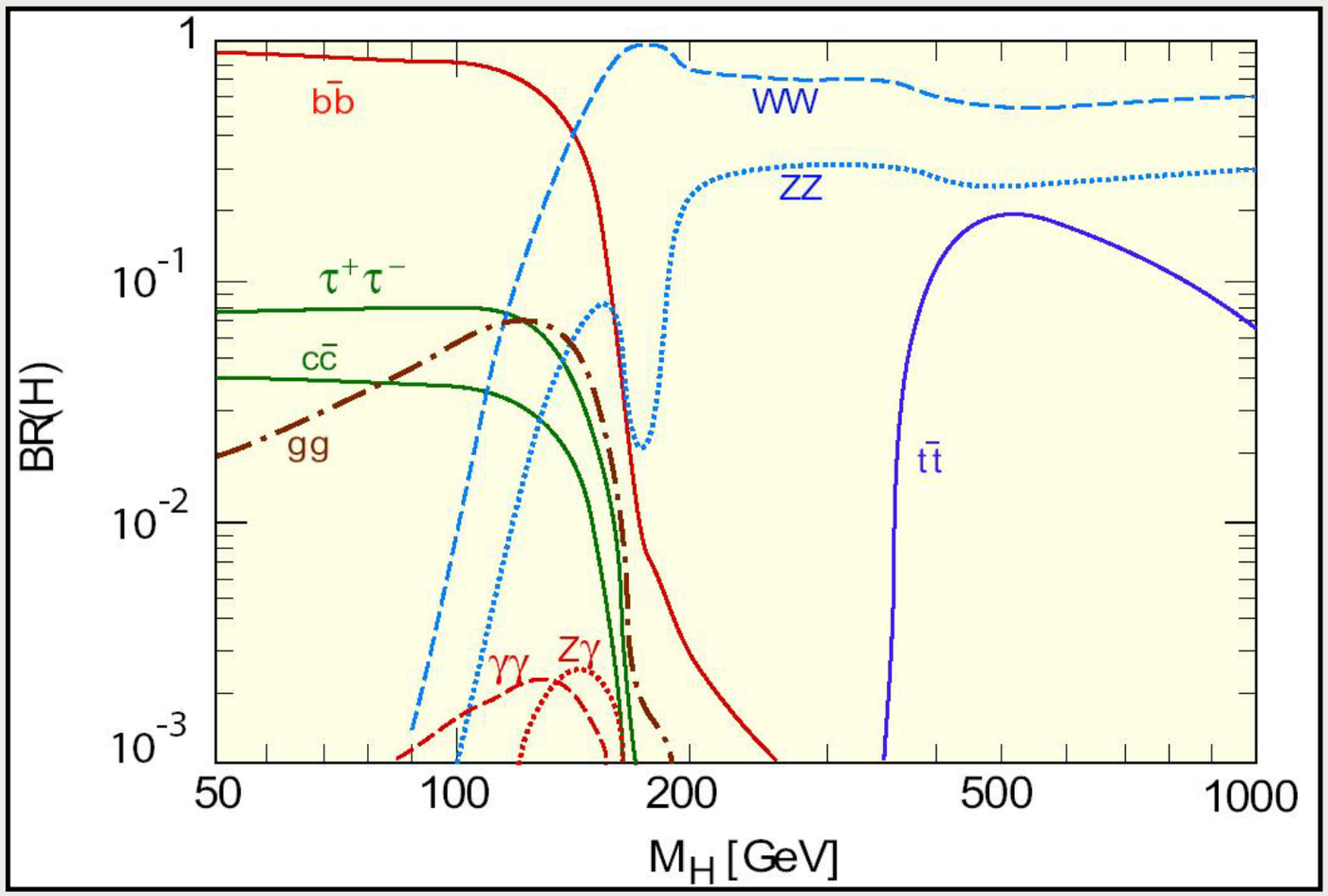
4004 Wesbrook Mall | Vancouver BC | Canada V6T 2A3 | Tel 604.222.1047 | www.triumf.ca

Extra Slides

Is It Really the Higgs?

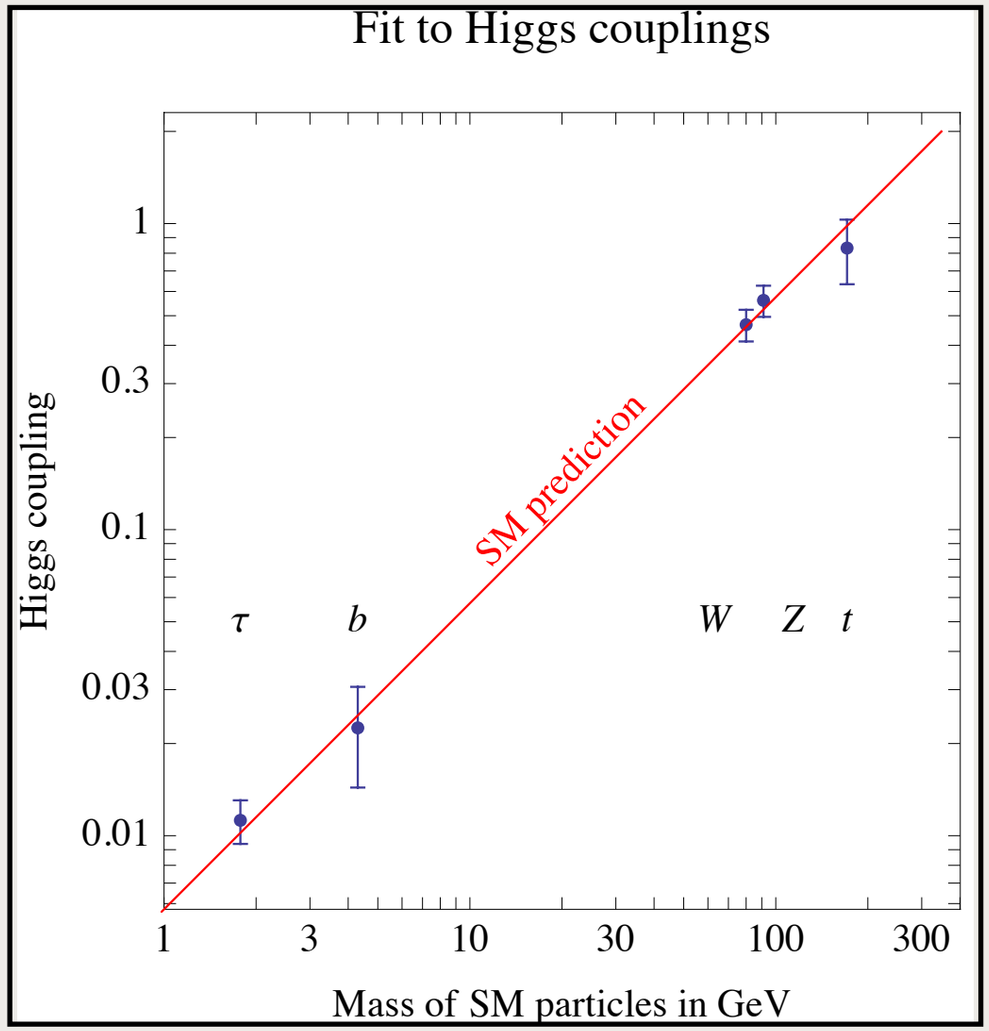
- The Higgs decays most often into the particles that it interacts with the most strongly.
- Interaction Strength ~ Particle Mass

Pattern:



Is It Really the Higgs?

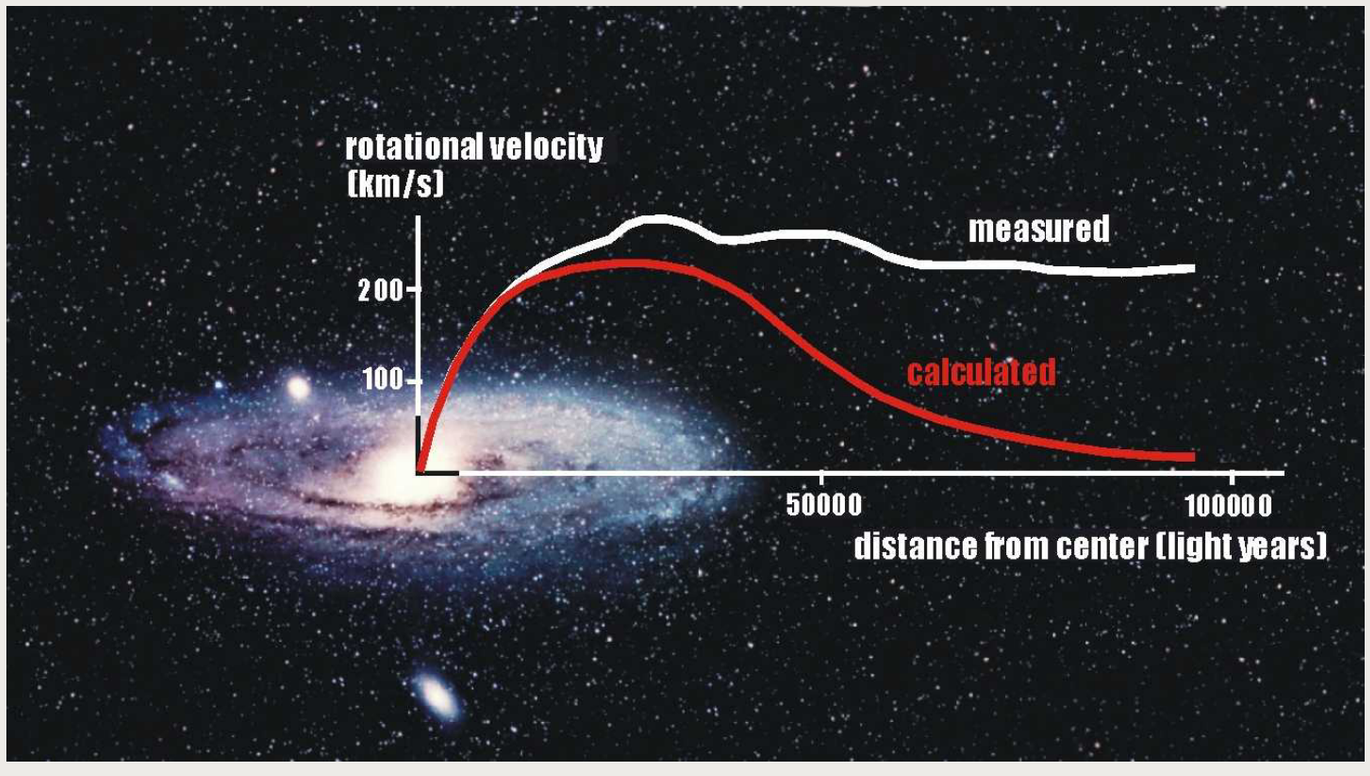
- Looks good :



- More precise measurements are needed.
  → LHC and future Linear Collider

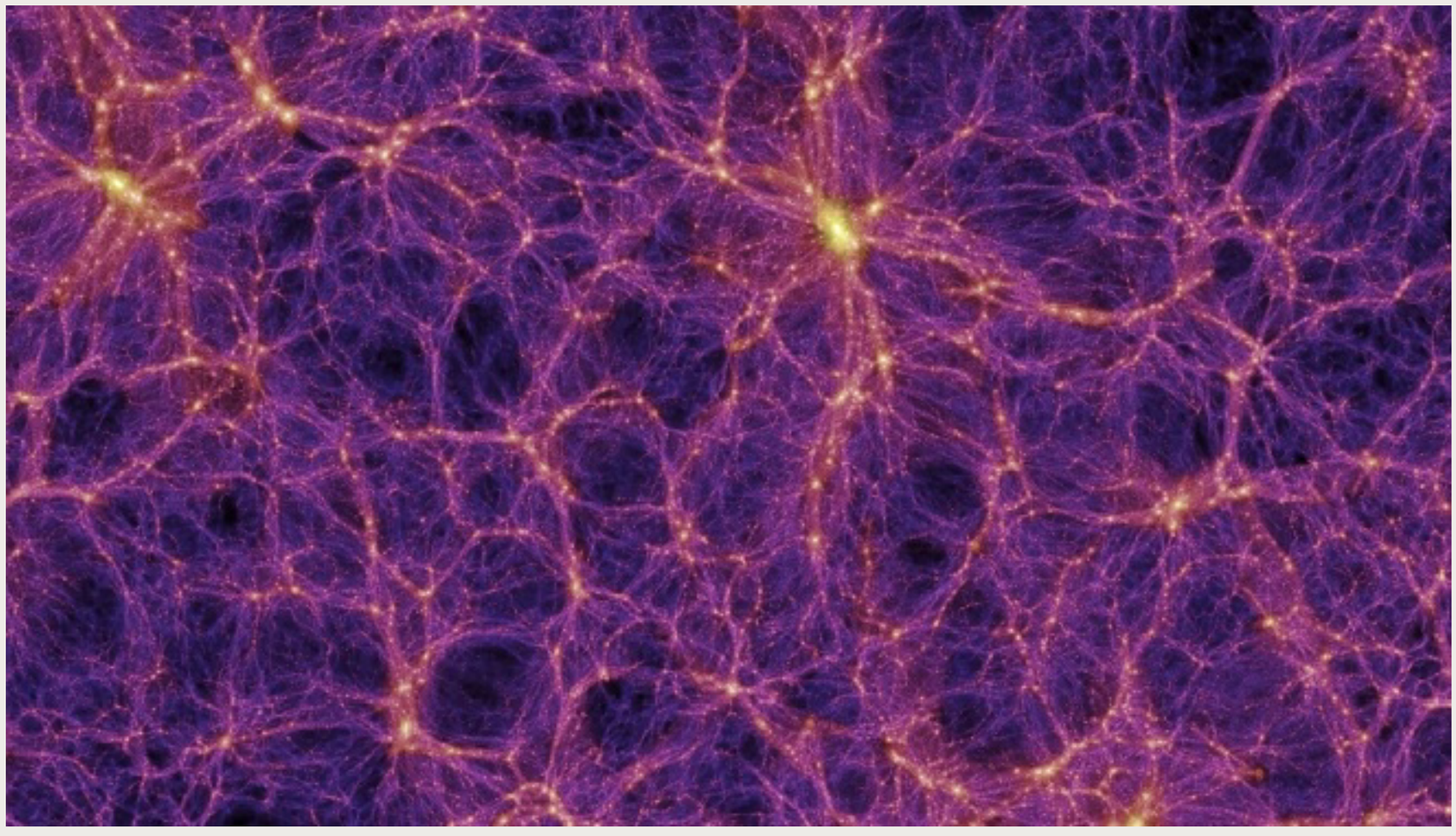
Evidence for Dark Matter #1

- Galaxy = collection of stars and dust
- Galactic rotation is supported by the gravitational attraction of the matter in it.
- Measure the rotational speeds of galaxies. Compare to rotation predicted from visible matter.



Evidence for Dark Matter #2

- "Structure" = distribution of galaxies in space
- Compare the observed pattern to simulations.
- Dark Matter is needed for agreement.



Evidence for Dark Matter #3

- CMB = light left over from the Big Bang, T = 2.73K
  (CMB = cosmic microwave background)
- Very uniform with small 0.01% fluctuations.
- Fluctuation pattern depends on matter density.
  Visible matter is not nearly enough.