BAM for Life Lab Foundation QuarkNet-India

Timeline and Progress for July 2021

Tue 27 July (1 hr 15 min) LLFQNI Session #8	Wed 28 July (2 hr) LLFQNI Session #9	Fri 30 July (1 hr 30 min) LLFQNI Session #10
Particle Physics and CMS webinar 18:30 IST, 15:00 CET, 09:00 U.S. ET *CMS and the Standard Model* (A. Sharma) Q&A	**Student and teacher webinar** 18:30 IST, 15:00 CET, 09:00 U.S. ET *Introduction to CMS measurement* (M. Wadness, J. Wegner) (**slides**) • **iSpy event display** • **Data entry form** **All datasets assigned** Begin data analysis; Q&A	Student data analysis must end one hour prior to **Final discussion** webinar at... 18:30 IST, 15:00 CET, 09:00 U.S. ET Discussion of results Q&A
Homework: Watch screencasts in **BAMC page**.	Homework: Complete data analysis at home	

Times may be converted to other zones using the ***online time zone converter****.*

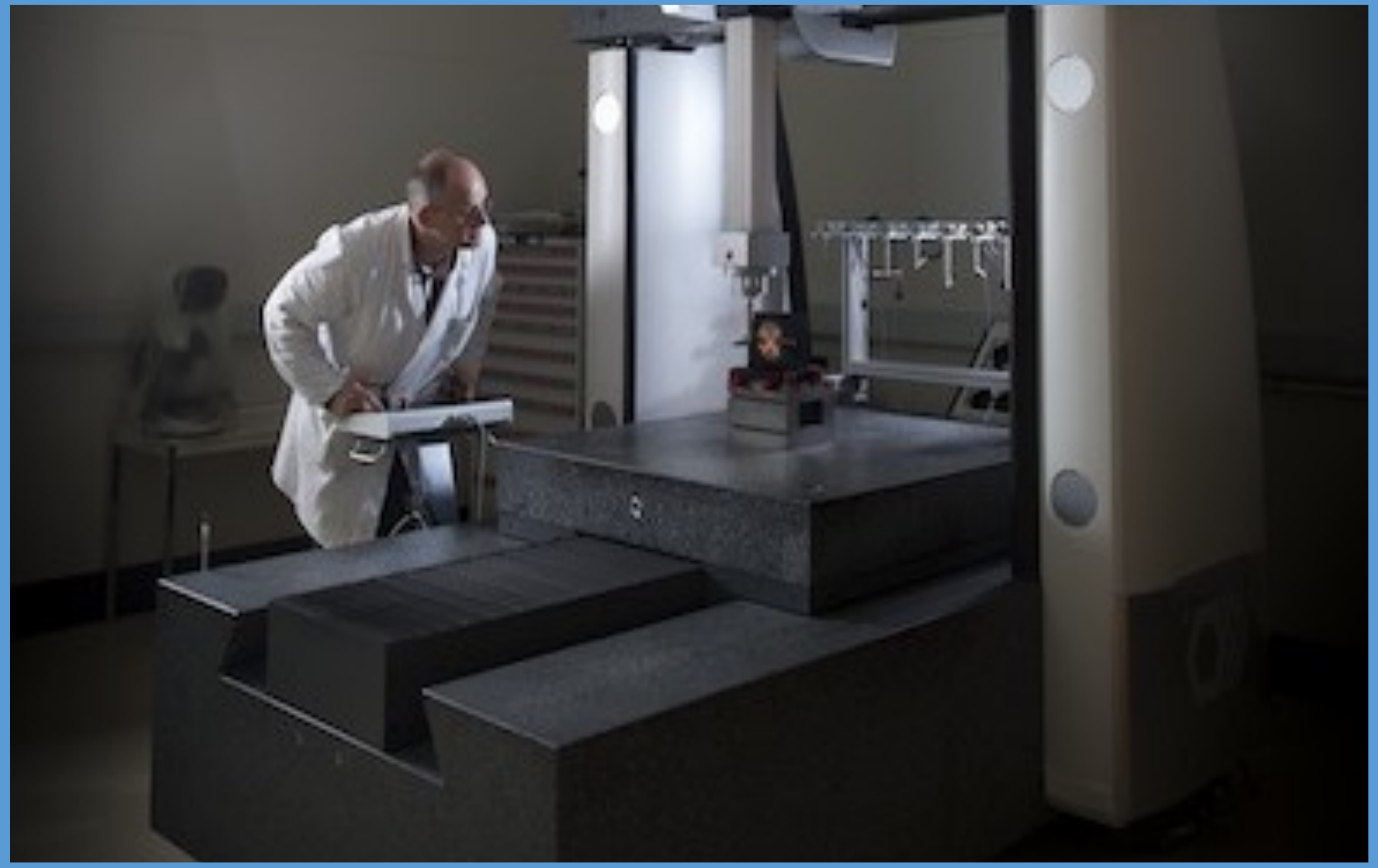
Organize students (ongoing) →

Archana Sharma CERN Geneva 27th July 2021

Unlocking Secrets of the Universe at CMS CERN

With Science and Technology

CERN: Fundamental research is a driver of innovation, and investment in basic research through mega-science projects is essential to unlock that potential with a wide societal impact

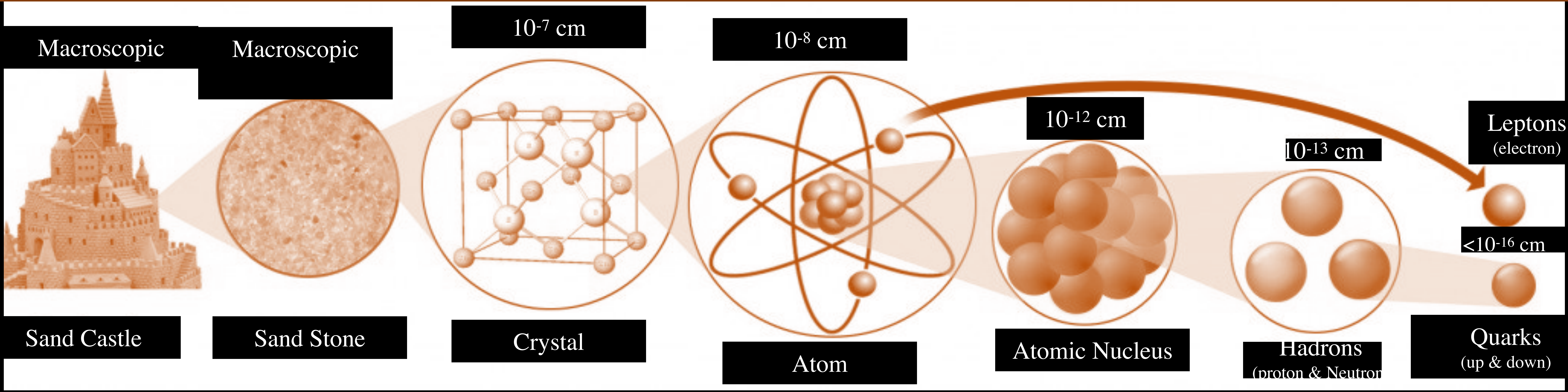


Fundamental research thrives in international collaboration, and the investment in such collaborations pays societal dividends over time.

Higgs Boson | Large Hadron Collider | Birth of the Web | Antimatter | High-Luminosity LHC

Collision Energy

OUR CURRENT UNDERSTANDING OF CONSTITUENTS OF MATTER

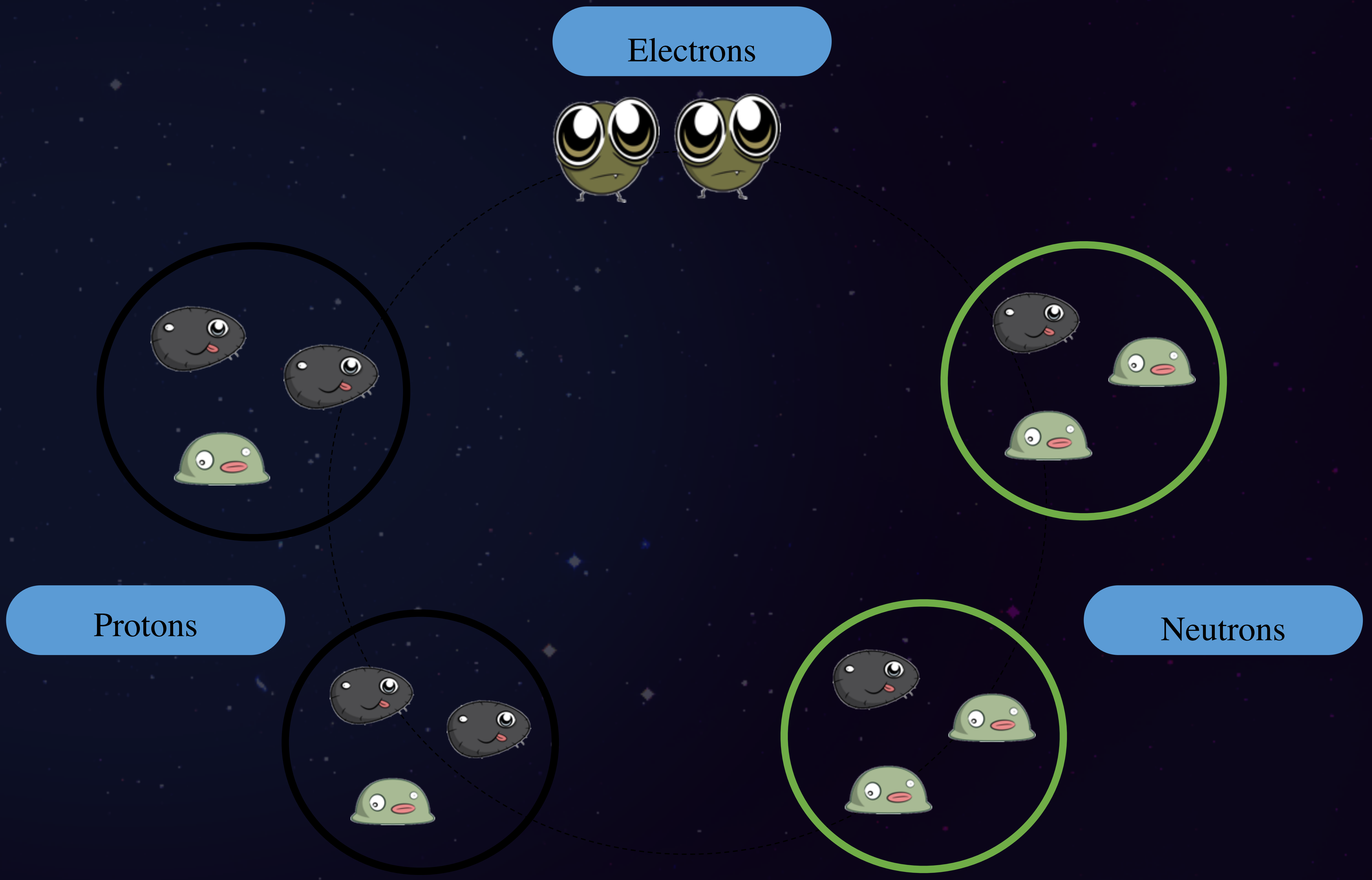


BUT HOW DO WE KNOW THIS?

Smash things together and see what happens!

UNIVERSAL BUILDING BLOCKS

BUILDING HELIUM ATOMS

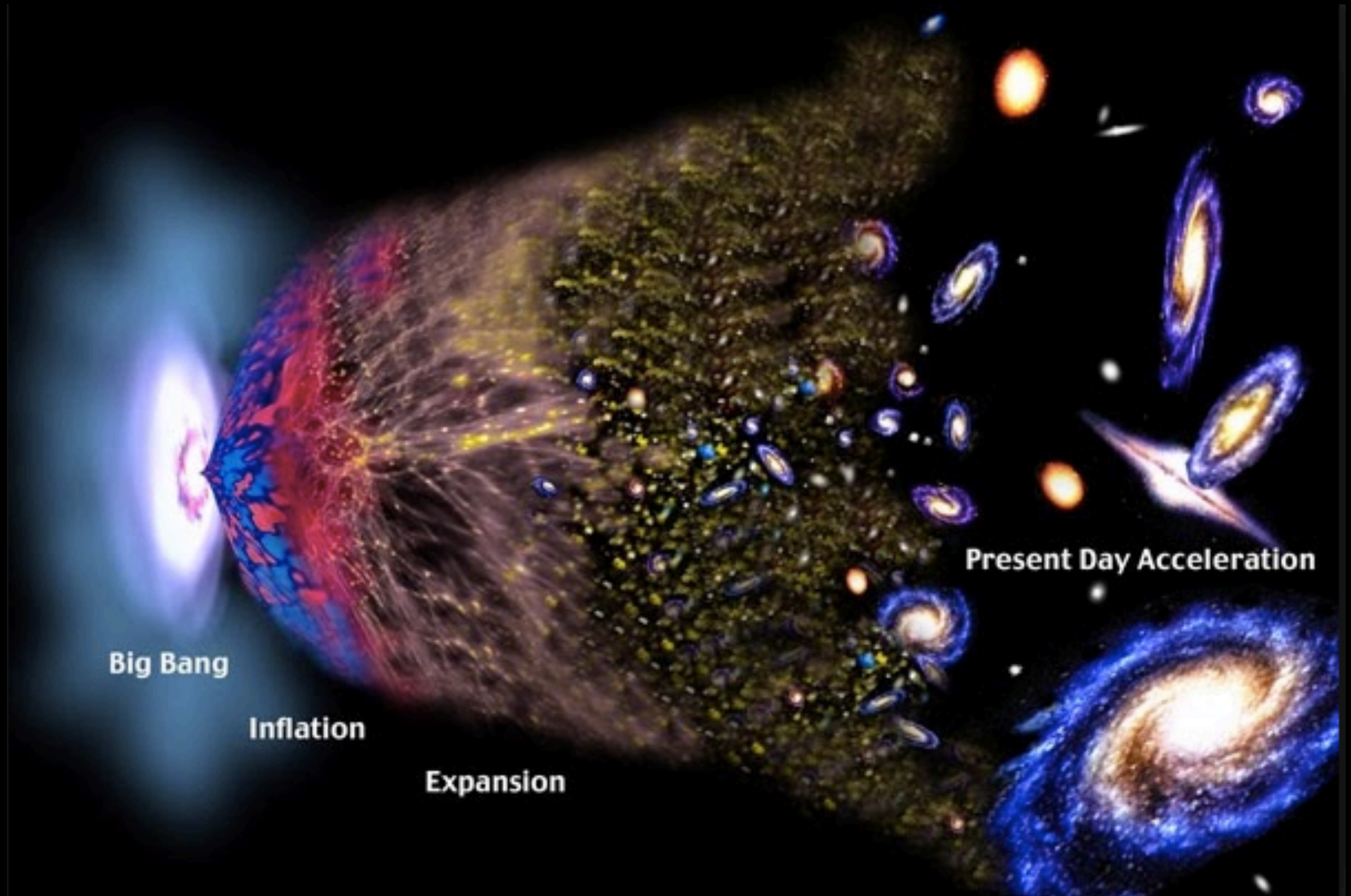


Multiply by billions and billions…

& you get…the Universe! But that is not the end of the story…

Open questions

Origin of mass?
Nature of Dark Matter?
Matter versus antimatter ?
Primordial plasma ie matter state at BB?



Dark Matter Cereal. One of the touches of humor in the book is this cartoon courtesy of NASA.

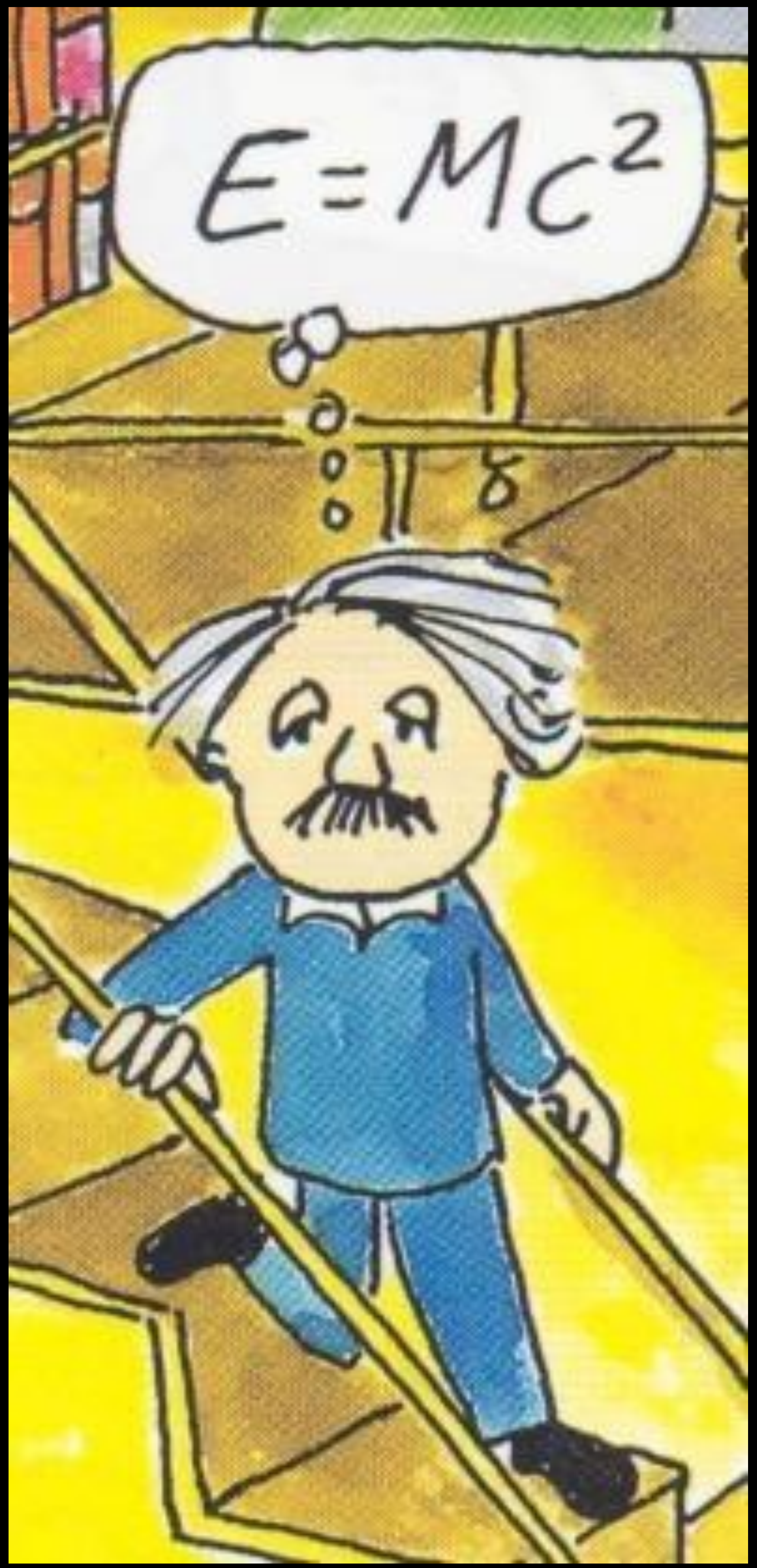
The collision energy was used
to create something new, that
did exist but does not any more!

Accelerator Energy

Accelerator Energy

Courtesy D. Barney

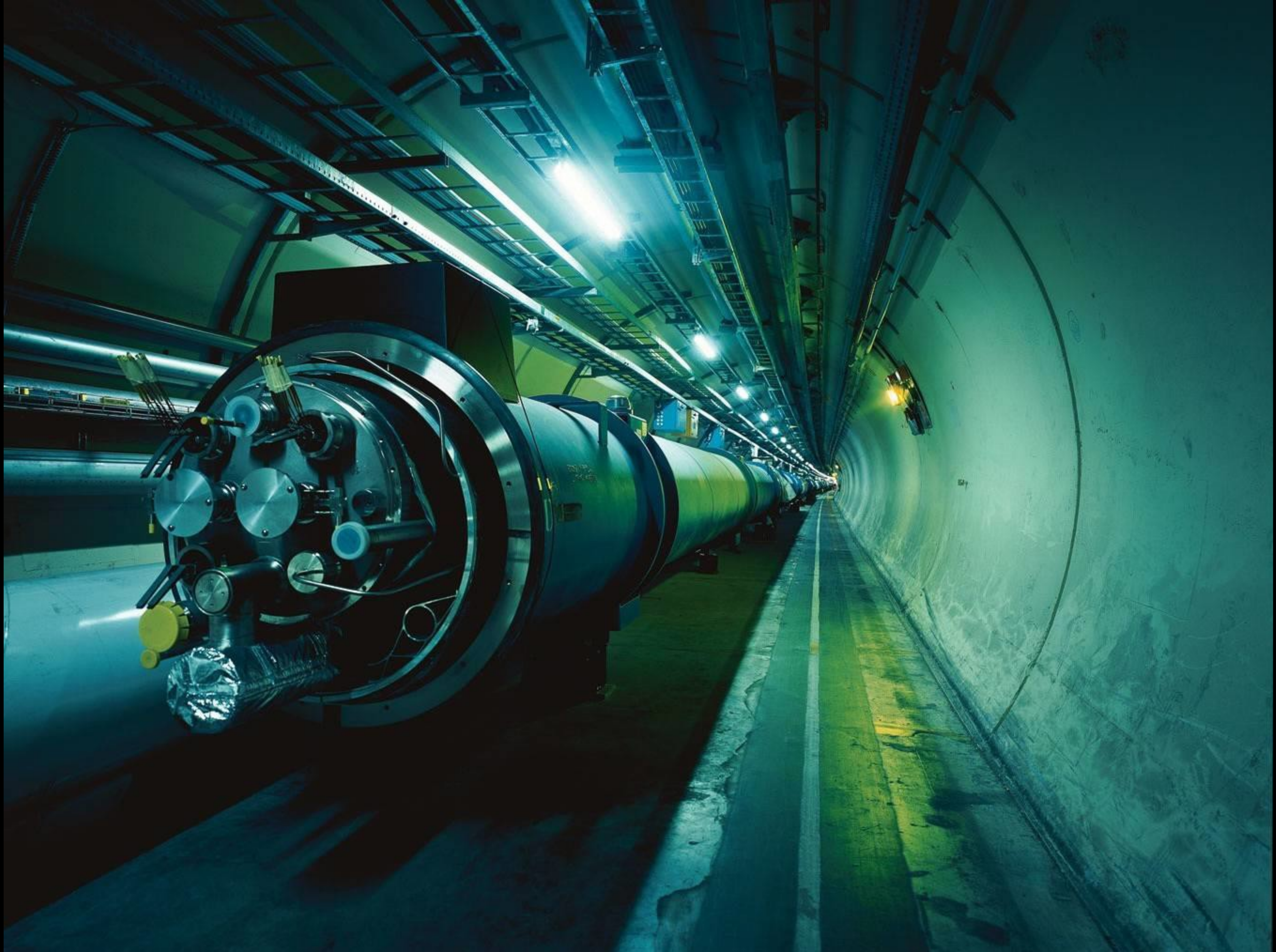
We can create particles from energy



Two beams of protons collide and generate, in a very tiny space, temperatures over a billion times higher than those prevailing at the center of the Sun.

Produce particles that may have existed at the beginning of the Universe, right after the

Big Bang



The largest microscope on the planet !

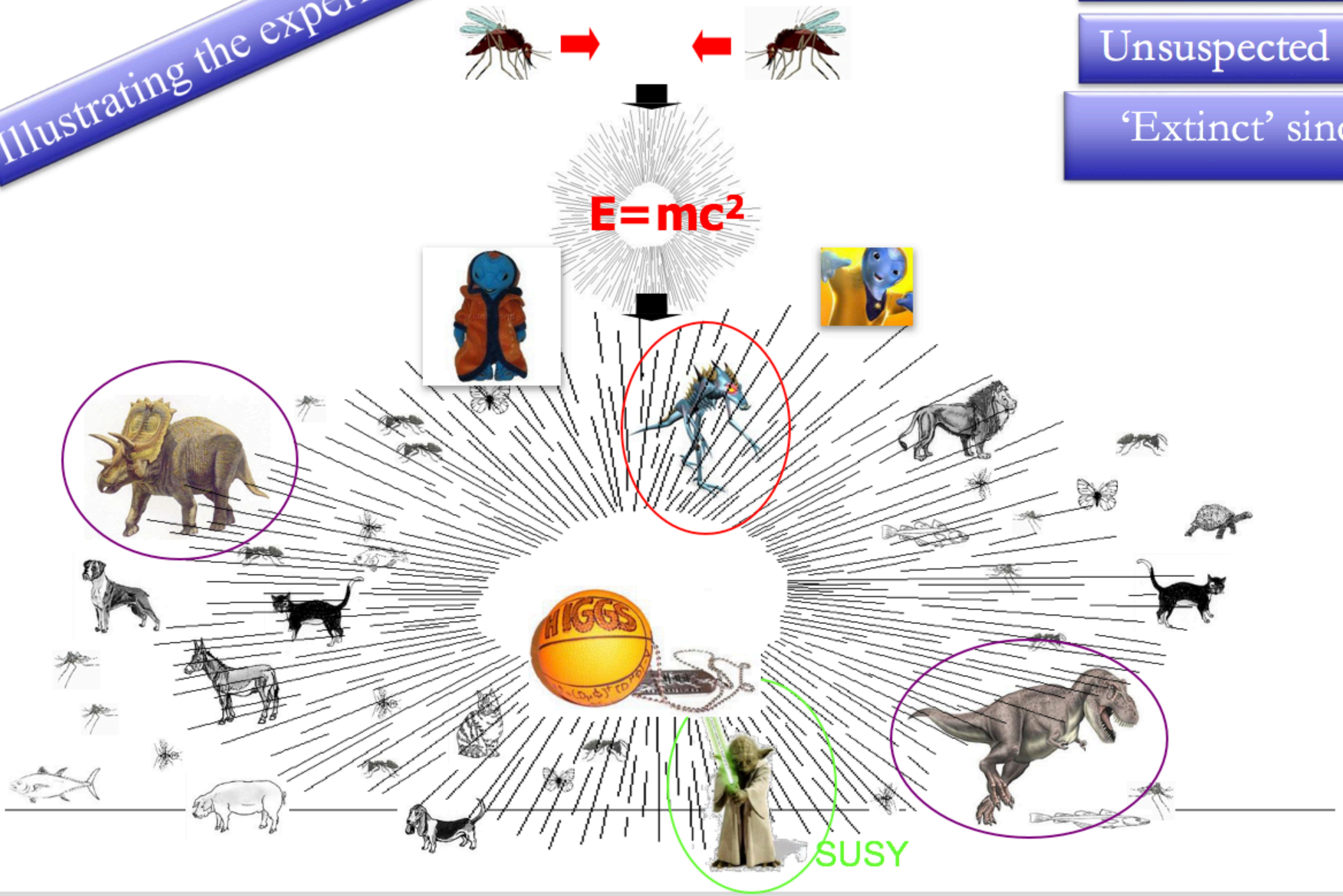
Illustrating the experiment

Highly Expected

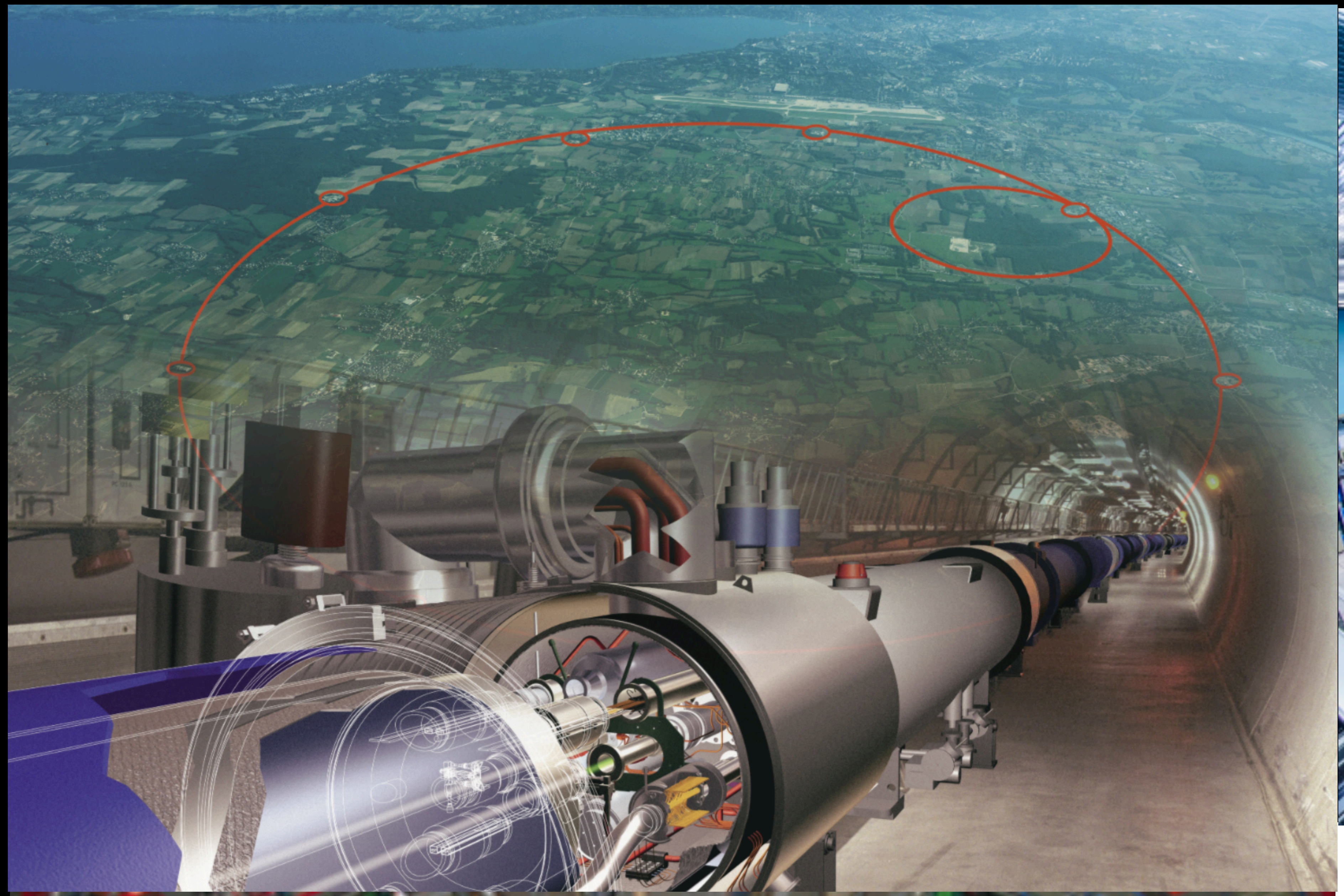
Hypothetical

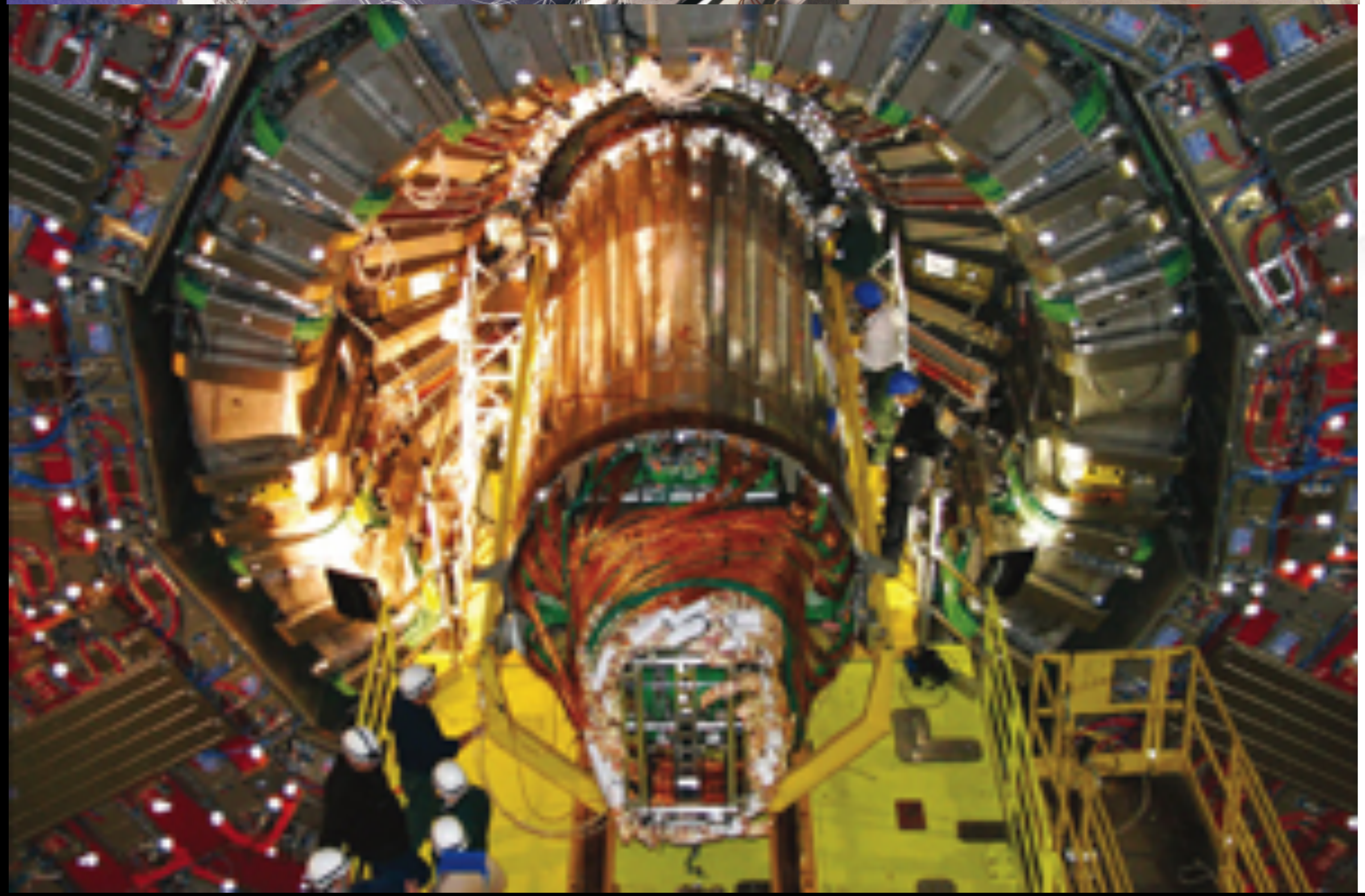
Unsuspected ?

'Extinct' since Big Bang

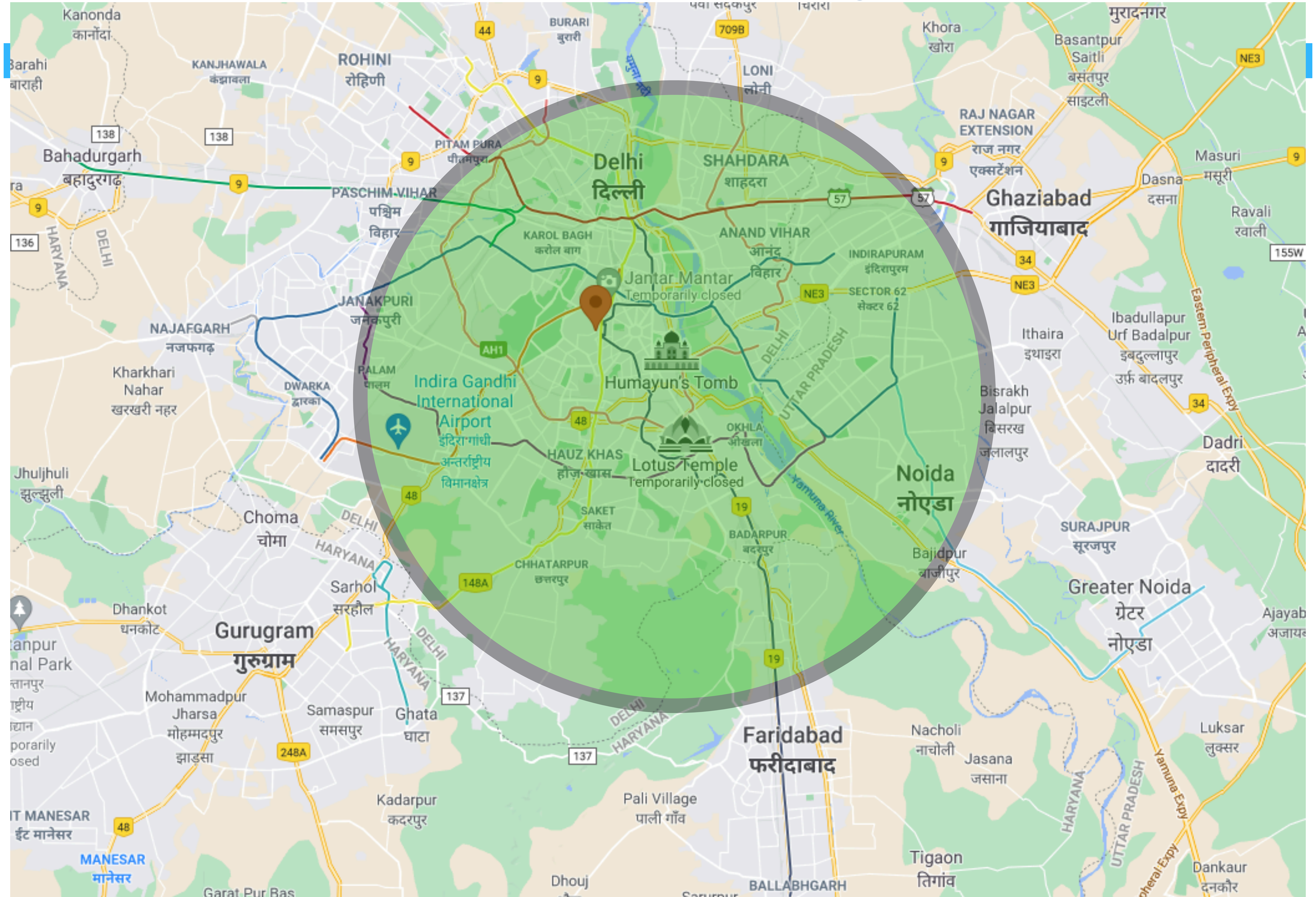


How?



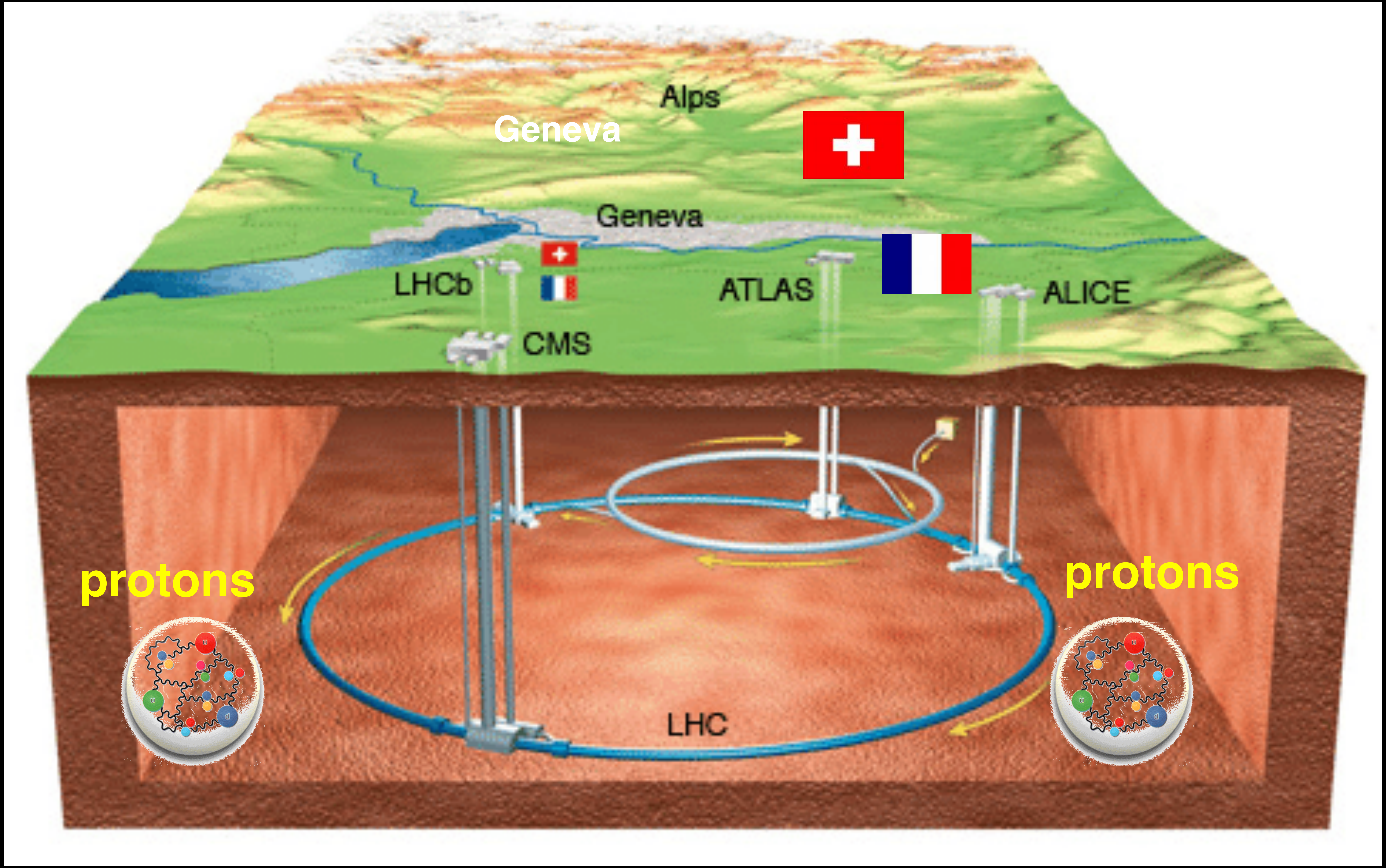


LHC – the lord of the rings

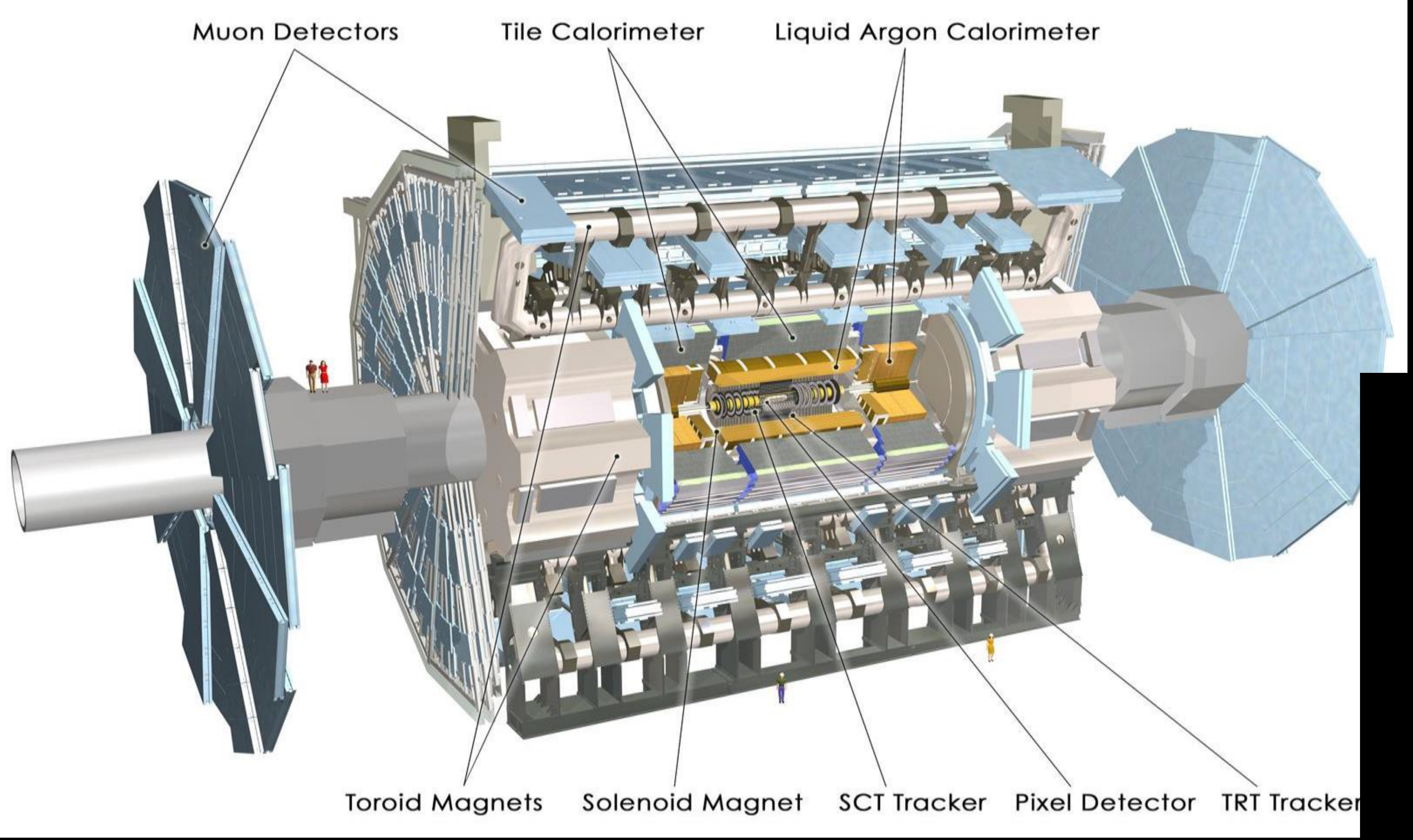


Big Bang
Proton
Atom
Radius of Earth
Earth to Sun
Radius of Galaxies
Universe
10^{-32}
10^{-28}
10^{-24}
10^{-20}
10^{-16}
10^{-12}
10^{-8}
10^{-4}
10^{4}
10^{8}
10^{12}
10^{16}
10^{20}
10^{24}
10^{28}
cm
AMS

The Large Hadron Collider – the four experiments

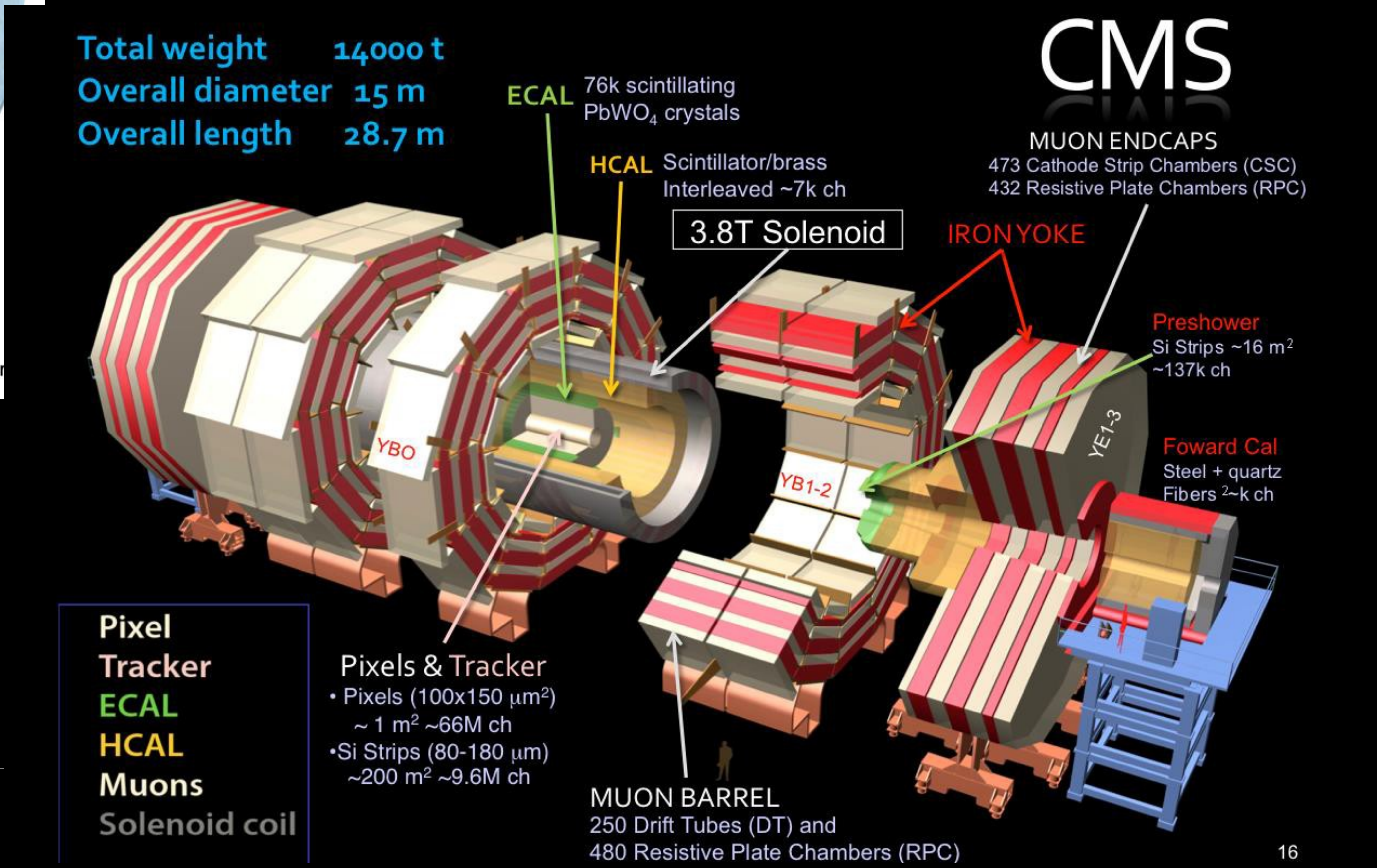


The Higgs Hunters at the LHC



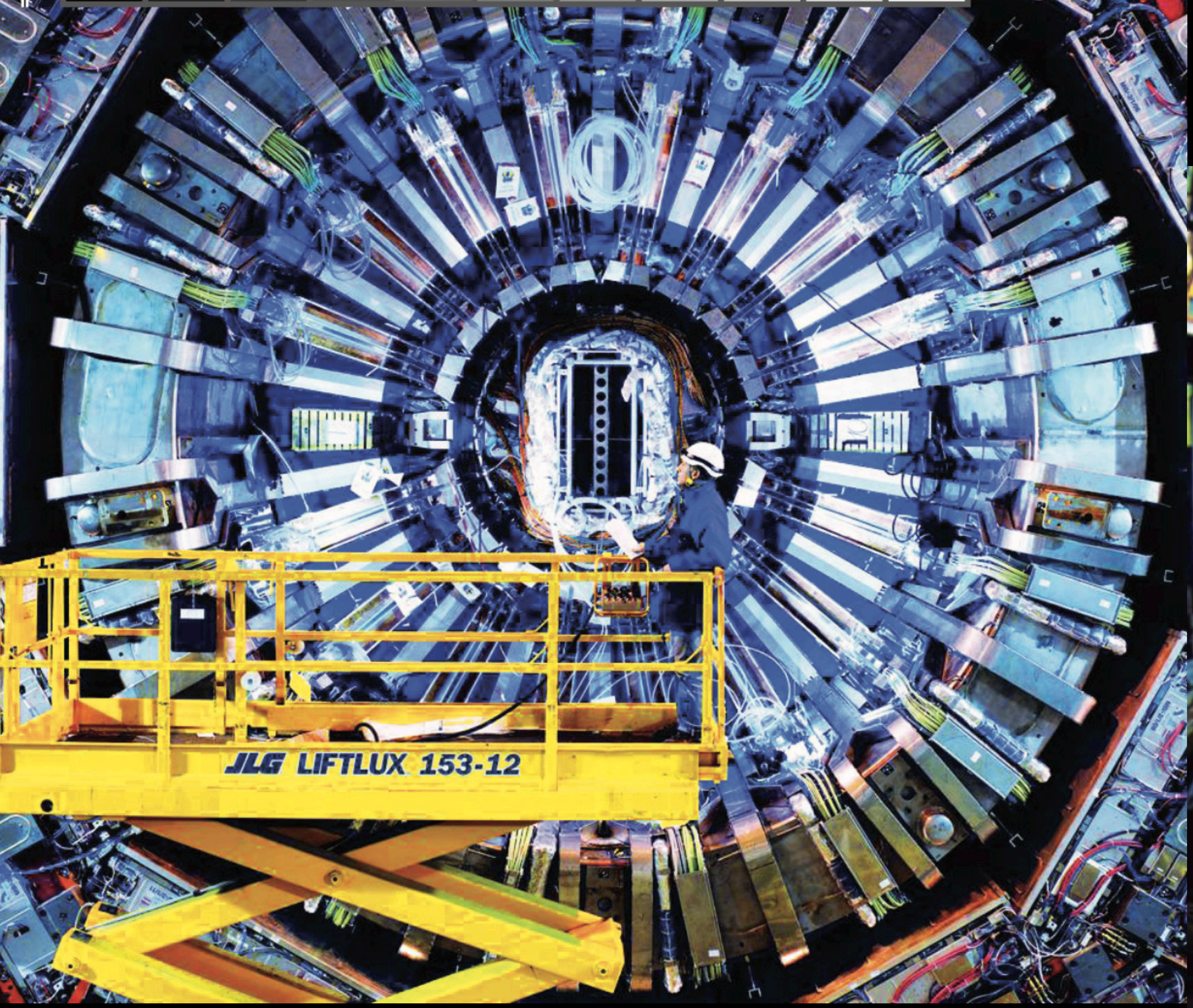
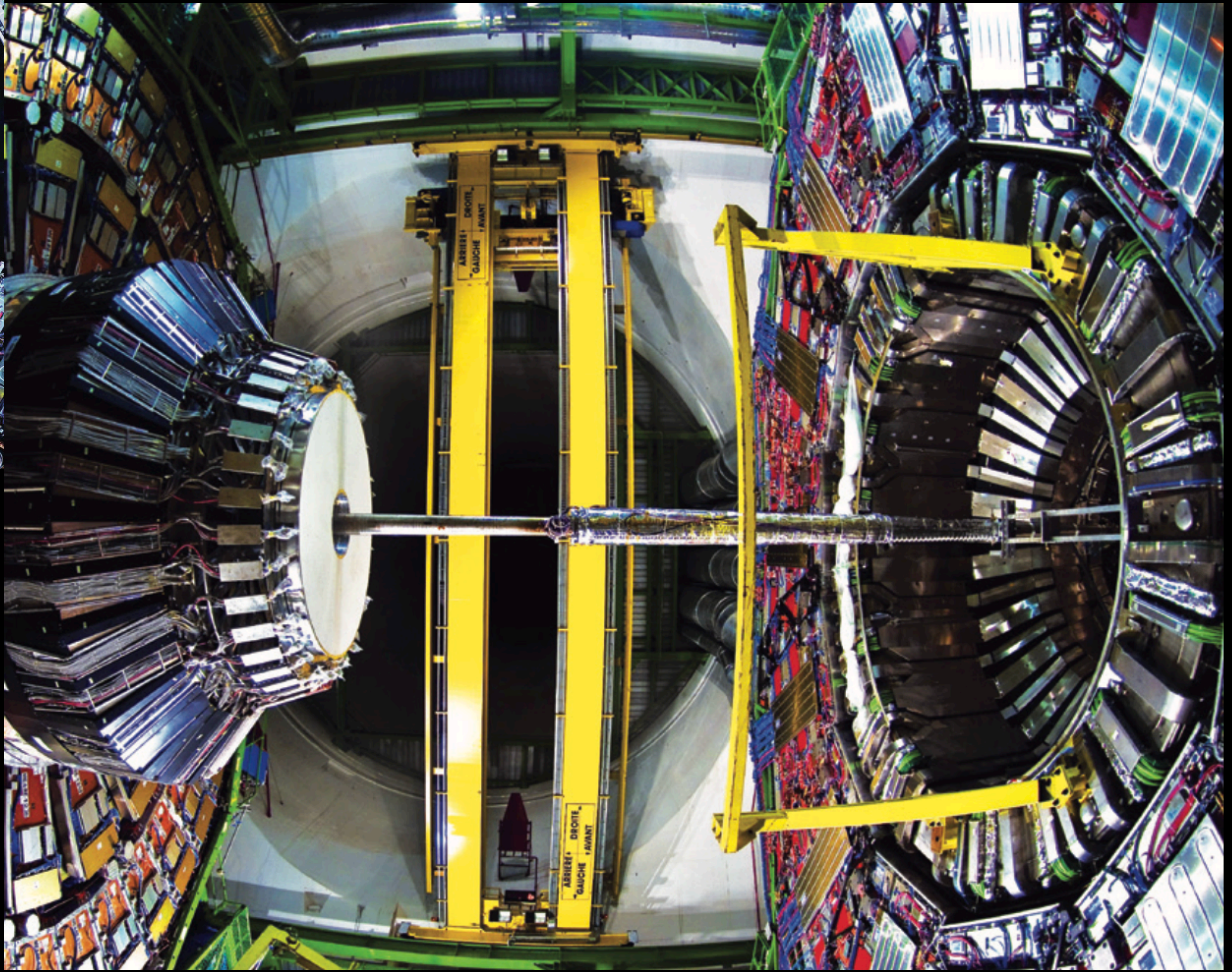
The ATLAS experiment

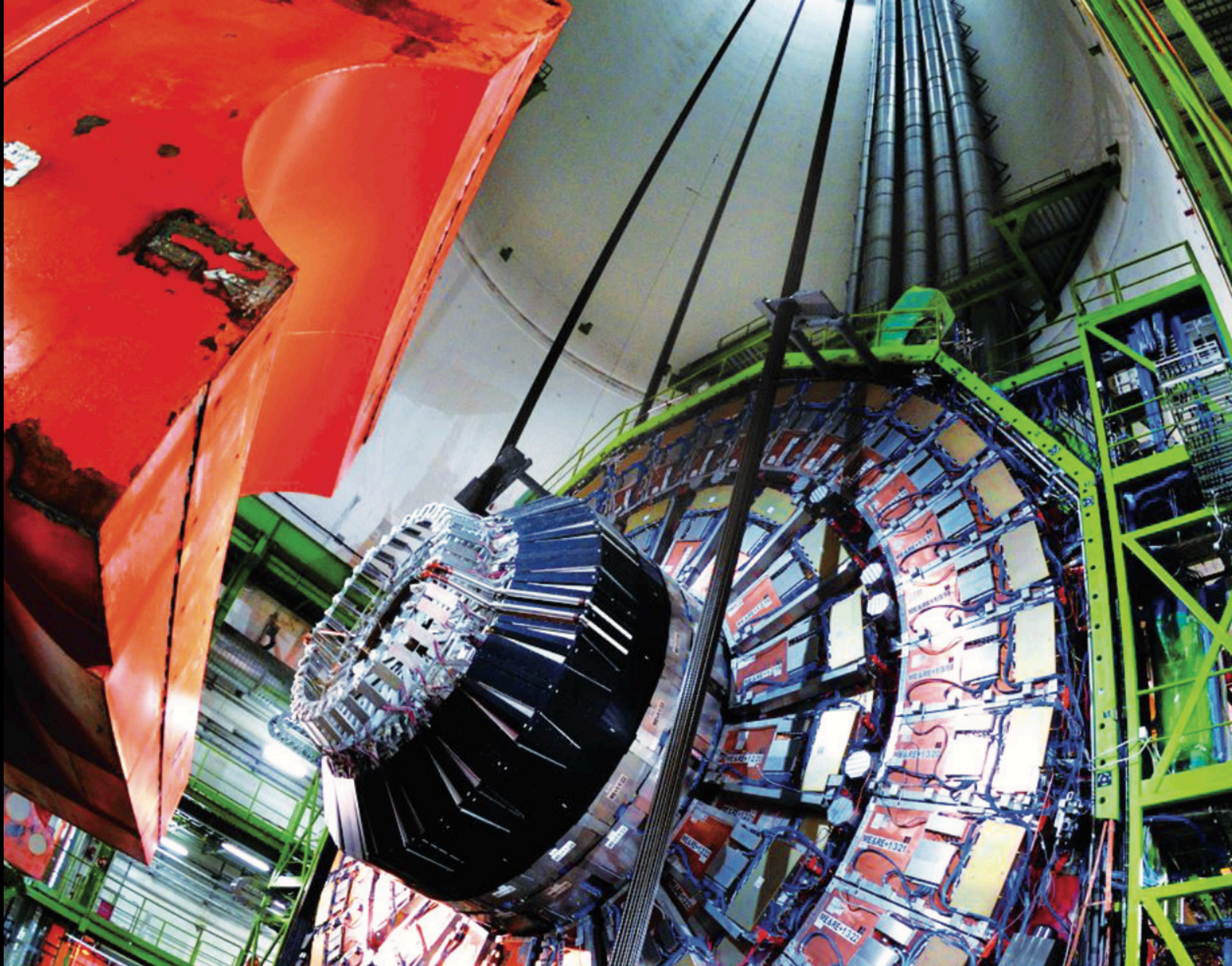
The CMS experiment



These experiments use different technologies for their detector components


HE-RBX 04
ME-1/1/07
ME-1/1/06
HE-RBX 03
ME-1/1/05
ME-1/1/04
HE- RBX 02
ME-1/1/03
ME-1/1/02
HE-RBX 01
ME-1/1/01
ME-1/1/36
ME-1/1/35
LIFTLUX

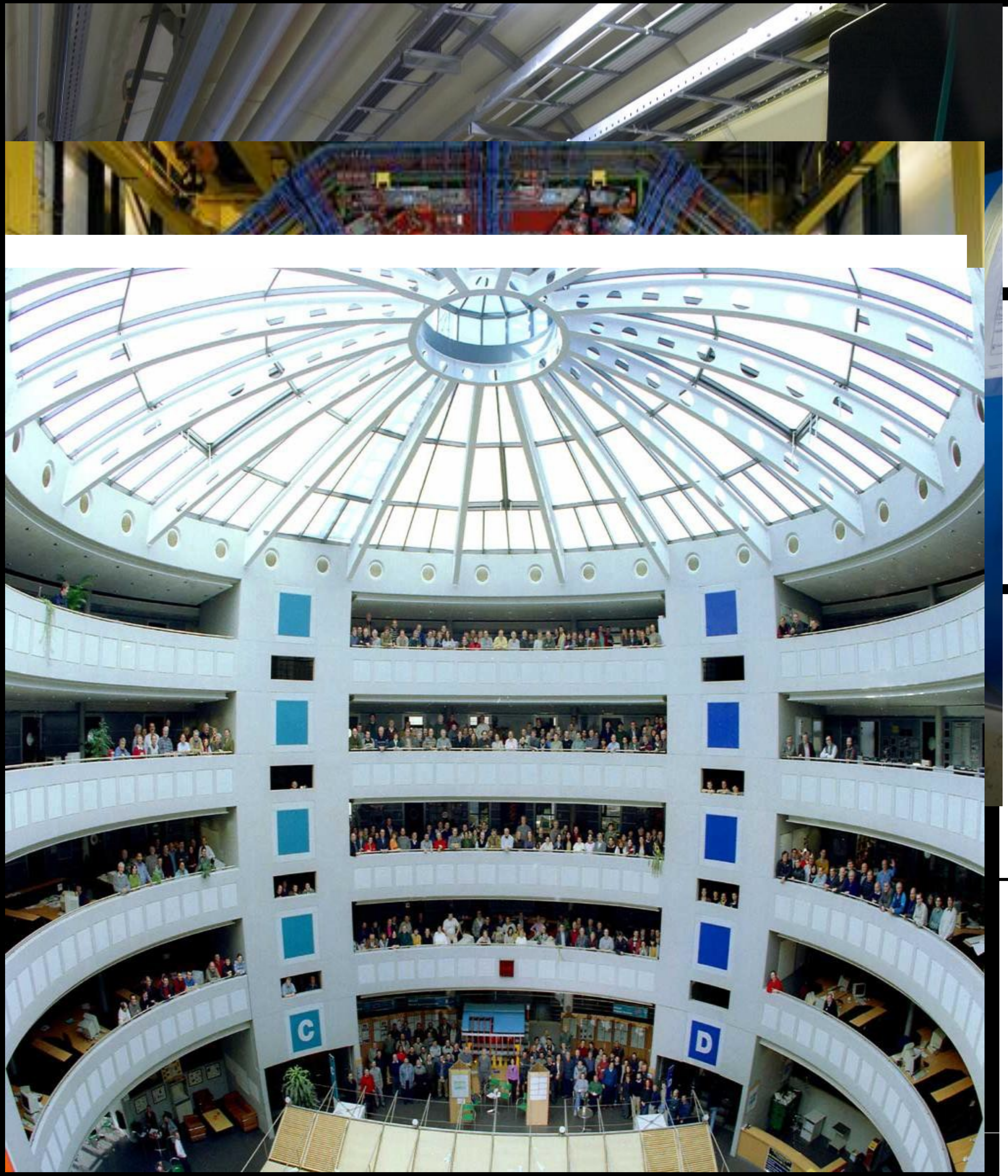

JLG LIFTLUX 153-12





BASKET
Sel 19


ME&RE-1/3/34
ME&RE-1/3/33
ME&RE-1/3/32

This Search Requires…….



1.Accelerators : powerful machines that accelerate particles to extremely high energies and bring them into collision with other particles

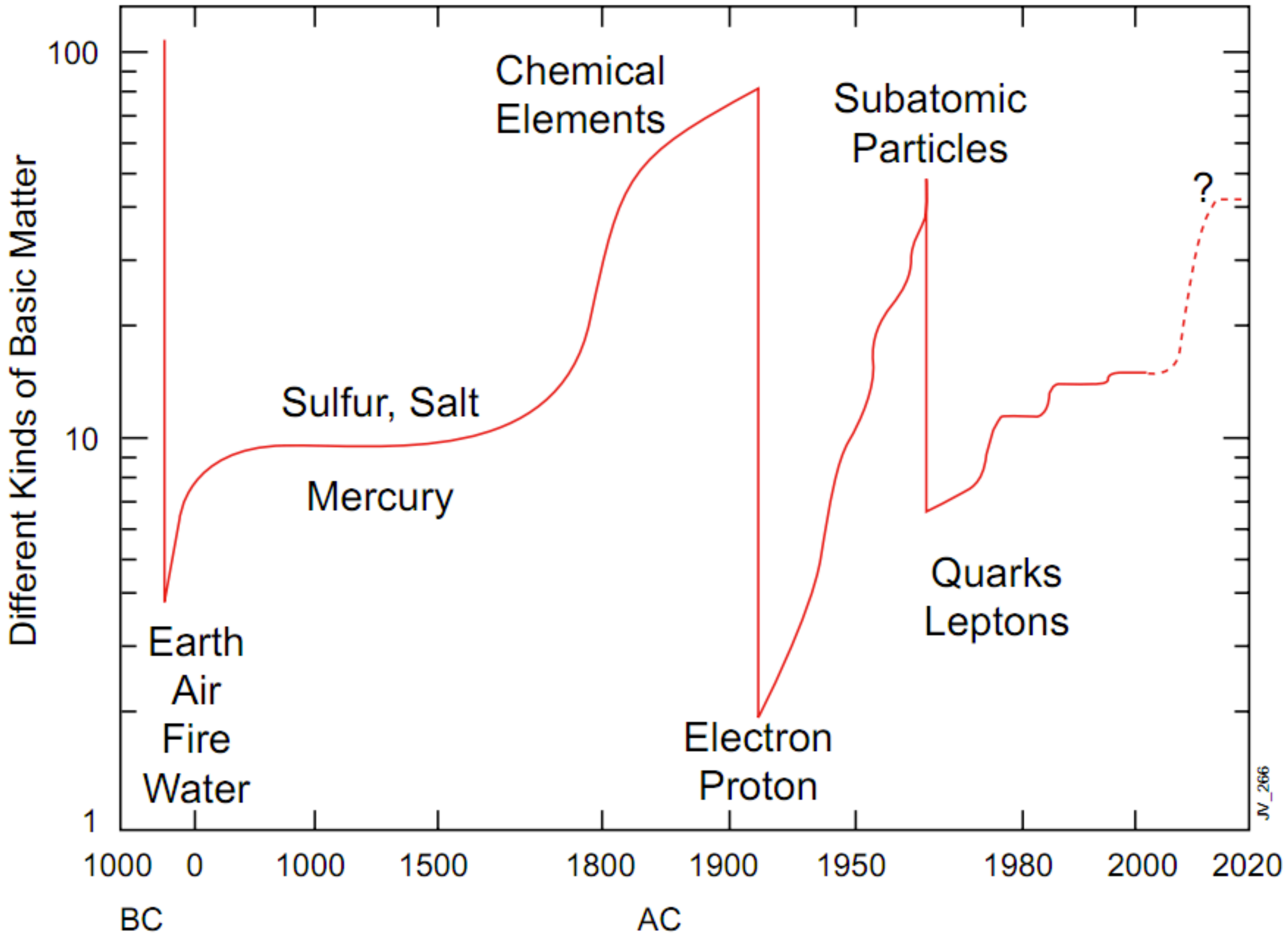
2.Detectors : gigantic instruments that record the resulting particles as they "stream" out from the point of collision.

3.Computing : to collect, store, distribute and analyse the vast amount of data produced by these detectors

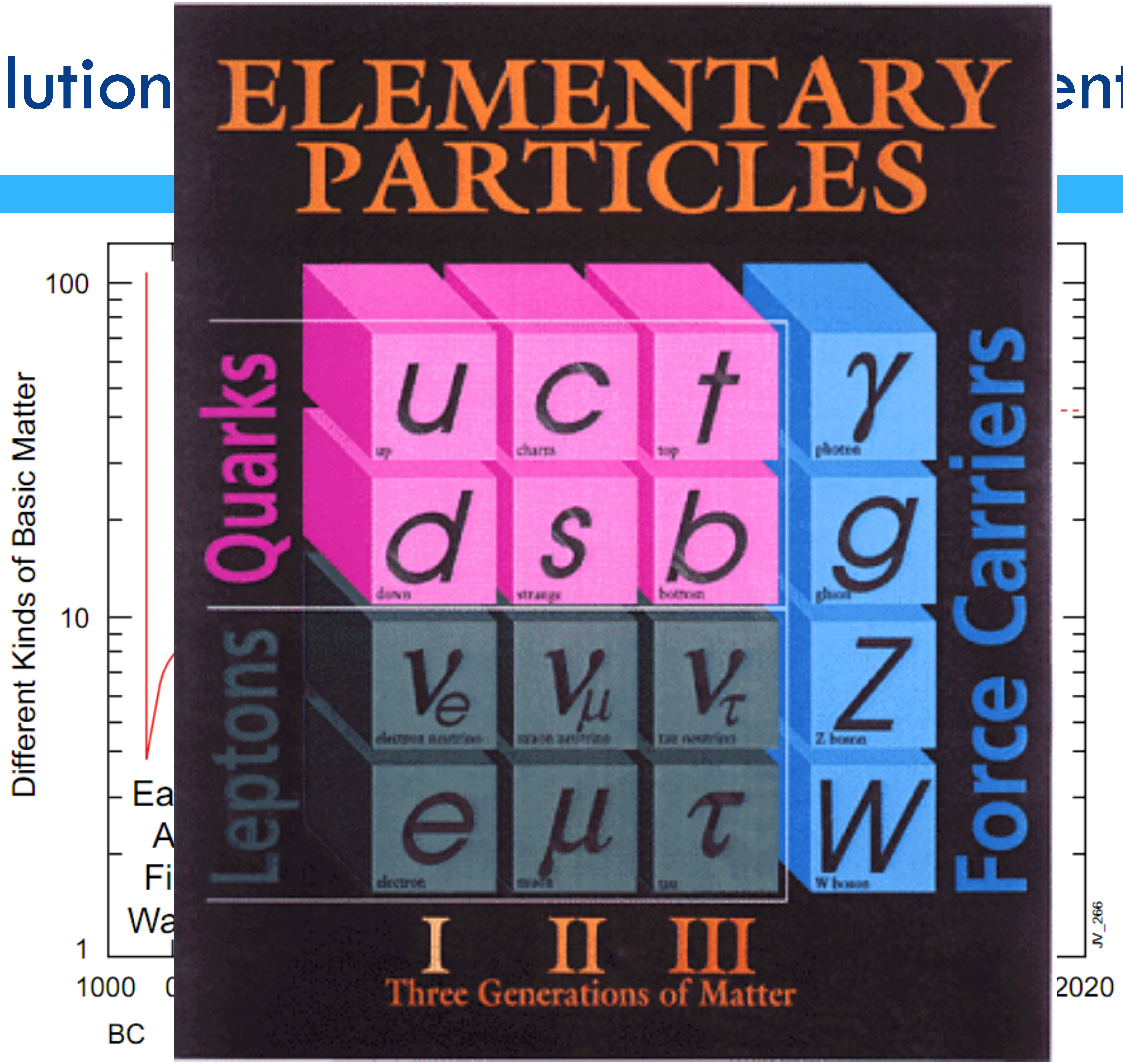
4.Collaborative Science on Worldwide scale : thousands of scientists, engineers, technicians and support staff to design, build and operate these complex "machines".


CMS

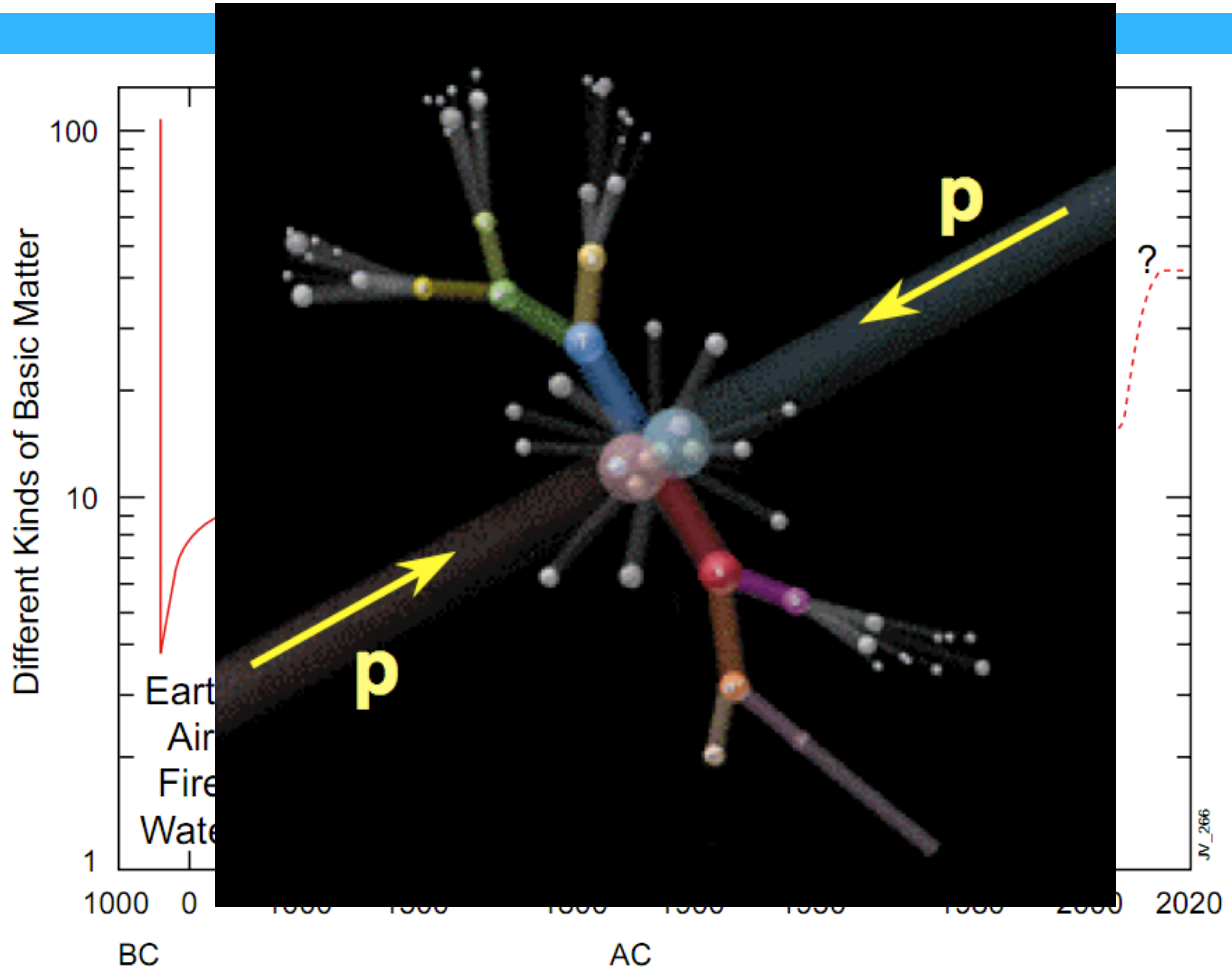
Evolutions & revolutions of the elements



Evolution … ents



Evolutions & revolutions of the elements



Standard Model of Particle Physics

[http://cern.ch/go/dW6z]

$$
\begin{aligned}
&-\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4} g_s^2 f^{abc} f^{ade} g^b_\mu g^c_\nu g^d_\mu g^e_\nu + \frac{1}{2} i g_s^2 (\bar{q}^\sigma_i \gamma^\mu q^\sigma_j) g^a_\mu + \bar{G}^a \partial^2 G^a + g_s f^{abc}\partial_\mu \bar{G}^a G^b g^c_\mu - \\
&\partial_\nu W^+_\mu \partial_\nu W^-_\mu - M^2 W^+_\mu W^-_\mu - \frac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \frac{1}{2c_w^2} M^2 Z^0_\mu Z^0_\mu - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \frac{1}{2}\partial_\mu H \partial_\mu H - \frac{1}{2} m_h^2 H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - \\
&M^2 \phi^+\phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \frac{1}{2c_w^2} M \phi^0\phi^0 - \beta_h\left[\frac{2M^2}{g^2} + \frac{2M}{g} H + \frac{1}{2}(H^2 + \phi^0\phi^0 + 2\phi^+\phi^-)\right] + \frac{2M^4}{g^2}\alpha_h - i g c_w [\partial_\nu Z^0_\mu (W^+_\mu W^-_\nu - \\
&W^+_\nu W^-_\mu) - Z^0_\nu (W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + Z^0_\mu (W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)] - i g s_w [\partial_\nu A_\mu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - \\
&A_\nu (W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + A_\mu (W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)] - \frac{1}{2} g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \frac{1}{2} g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + \\
&g^2 c_w^2 (Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) + g^2 s_w^2 (A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2 s_w c_w [A_\mu Z^0_\nu (W^+_\mu W^-_\nu - \\
&W^+_\nu W^-_\mu) - 2 A_\mu Z^0_\mu W^+_\nu W^-_\nu] - g\alpha [H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-] - \frac{1}{8} g^2 \alpha_h [H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2 \phi^+\phi^- + \\
&4H^2\phi^+\phi^- + 2(\phi^0)^2 H^2] - g M W^+_\mu W^-_\mu H - \frac{1}{2} g \frac{M}{c_w^2} Z^0_\mu Z^0_\mu H - \frac{1}{2} i g [W^+_\mu (\phi^0 \partial_\mu \phi^- - \phi^- \partial_\mu \phi^0) - W^-_\mu (\phi^0 \partial_\mu \phi^+ - \phi^+ \partial_\mu \phi^0)] + \\
&\frac{1}{2} g [W^+_\mu (H \partial_\mu \phi^- - \phi^- \partial_\mu H) - W^-_\mu (H \partial_\mu \phi^+ - \phi^+ \partial_\mu H)] + \frac{1}{2} g \frac{1}{c_w} (Z^0_\mu (H \partial_\mu \phi^0 - \phi^0 \partial_\mu H) - i g \frac{s_w^2}{c_w} M Z^0_\mu (W^+_\mu \phi^- - \\
&W^-_\mu \phi^+) + i g s_w M A_\mu (W^+_\mu \phi^- - W^-_\mu \phi^+) - i g \frac{1 - 2c_w^2}{2c_w} Z^0_\mu (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) + i g s_w A_\mu (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) - \\
&\frac{1}{4} g^2 W^+_\mu W^-_\mu [H^2 + (\phi^0)^2 + 2\phi^+\phi^-] - \frac{1}{4} g^2 \frac{1}{c_w^2} Z^0_\mu Z^0_\mu [H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2 \phi^+\phi^-] - \frac{1}{2} g^2 \frac{s_w^2}{c_w} Z^0_\mu \phi^0 (W^+_\mu \phi^- + \\
&W^-_\mu \phi^+) - \frac{1}{2} i g^2 \frac{s_w^2}{c_w} Z^0_\mu H (W^+_\mu \phi^- - W^-_\mu \phi^+) + \frac{1}{2} g^2 s_w A_\mu \phi^0 (W^+_\mu \phi^- + W^-_\mu \phi^+) + \frac{1}{2} i g^2 s_w A_\mu H (W^+_\mu \phi^- - W^-_\mu \phi^+) - \\
&g^2 \frac{s_w}{c_w} (2c_w^2 - 1) Z^0_\mu A_\mu \phi^+\phi^- - g^1 s_w^2 A_\mu A_\mu \phi^+\phi^- - \bar{e}^\lambda (\gamma\partial + m_e^\lambda) e^\lambda - \bar{\nu}^\lambda \gamma\partial \nu^\lambda - \bar{u}_j^\lambda (\gamma\partial + m_u^\lambda) u_j^\lambda - \bar{d}_j^\lambda (\gamma\partial + m_d^\lambda) d_j^\lambda + \\
&i g s_w A_\mu \left[-(\bar{e}^\lambda \gamma^\mu e^\lambda) + \frac{2}{3}(\bar{u}_j^\lambda \gamma^\mu u_j^\lambda) - \frac{1}{3}(\bar{d}_j^\lambda \gamma^\mu d_j^\lambda)\right] + \frac{ig}{4c_w} Z^0_\mu [(\bar{\nu}^\lambda \gamma^\mu (1+\gamma^5)\nu^\lambda) + (\bar{e}^\lambda \gamma^\mu (4s_w^2 - 1 - \gamma^5) e^\lambda) + (\bar{u}_j^\lambda \gamma^\mu (\frac{4}{3} s_w^2 - \\
&1 - \gamma^5) u_j^\lambda) + (\bar{d}_j^\lambda \gamma^\mu (1 - \frac{8}{3} s_w^2 - \gamma^5) d_j^\lambda)] + \frac{ig}{2\sqrt{2}} W^+_\mu [(\bar{\nu}^\lambda \gamma^\mu (1+\gamma^5) e^\lambda) + (\bar{u}_j^\lambda \gamma^\mu (1+\gamma^5) C_{\lambda\kappa} d_j^\kappa)] + \frac{ig}{2\sqrt{2}} W^-_\mu [(\bar{e}^\lambda \gamma^\mu (1 + \\
&\gamma^5)\nu^\lambda) + (\bar{d}_j^\kappa C^\dagger_{\lambda\kappa} \gamma^\mu (1+\gamma^5) u_j^\lambda)] + \frac{ig}{2\sqrt{2}} \frac{m_e^\lambda}{M} [-\phi^+ (\bar{\nu}^\lambda (1-\gamma^5) e^\lambda) + \phi^- (\bar{e}^\lambda (1+\gamma^5) \nu^\lambda)] - \frac{g}{2} \frac{m_e^\lambda}{M} [H (\bar{e}^\lambda e^\lambda) + \\
&i\phi^0 (\bar{e}^\lambda \gamma^5 e^\lambda)] + \frac{ig}{2M\sqrt{2}} \phi^+ [-m_d^\kappa (\bar{u}_j^\lambda C_{\lambda\kappa} (1-\gamma^5) d_j^\kappa) + m_u^\lambda (\bar{u}_j^\lambda C_{\lambda\kappa} (1+\gamma^5) d_j^\kappa] + \frac{ig}{2M\sqrt{2}} \phi^- [m_d^\lambda (\bar{d}_j^\lambda C^\dagger_{\lambda\kappa} (1+\gamma^5) u_j^\kappa) - \\
&m_u^\kappa (\bar{d}_j^\lambda C^\dagger_{\lambda\kappa} (1-\gamma^5) u_j^\kappa] - \frac{g}{2} \frac{m_u^\lambda}{M} H (\bar{u}_j^\lambda u_j^\lambda) - \frac{g}{2} \frac{m_d^\lambda}{M} H (\bar{d}_j^\lambda d_j^\lambda) + \frac{ig}{2} \frac{m_u^\lambda}{M} \phi^0 (\bar{u}_j^\lambda \gamma^5 u_j^\lambda) - \frac{ig}{2} \frac{m_d^\lambda}{M} \phi^0 (\bar{d}_j^\lambda \gamma^5 d_j^\lambda) + \bar{X}^+ (\partial^2 - \\
&M^2) X^+ + \bar{X}^- (\partial^2 - M^2) X^- + \bar{X}^0 (\partial^2 - \frac{M^2}{c_w^2}) X^0 + \bar{Y} \partial^2 Y + i g c_w W^+_\mu (\partial_\mu \bar{X}^0 X^- - \partial_\mu \bar{X}^+ X^0) + i g s_w W^+_\mu (\partial_\mu \bar{Y} X^- - \\
&\partial_\mu \bar{X}^+ Y) + i g c_w W^-_\mu (\partial_\mu \bar{X}^- X^0 - \partial_\mu \bar{X}^0 X^+) + i g s_w W^-_\mu (\partial_\mu \bar{X}^- Y - \partial_\mu \bar{Y} X^+) + i g c_w Z^0_\mu (\partial_\mu \bar{X}^+ X^+ - \partial_\mu \bar{X}^- X^-) + \\
&i g s_w A_\mu (\partial_\mu \bar{X}^+ X^+ - \partial_\mu \bar{X}^- X^-) - \frac{1}{2} g M [\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c_w^2} \bar{X}^0 X^0 H] + \frac{1 - 2c_w^2}{2c_w} i g M [\bar{X}^+ X^0 \phi^+ - \\
&\bar{X}^- X^0 \phi^-] + \frac{1}{2c_w} i g M [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + i g M s_w [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + \frac{1}{2} i g M [\bar{X}^+ X^+ \phi^0 - \bar{X}^- X^- \phi^0]
\end{aligned}
$$

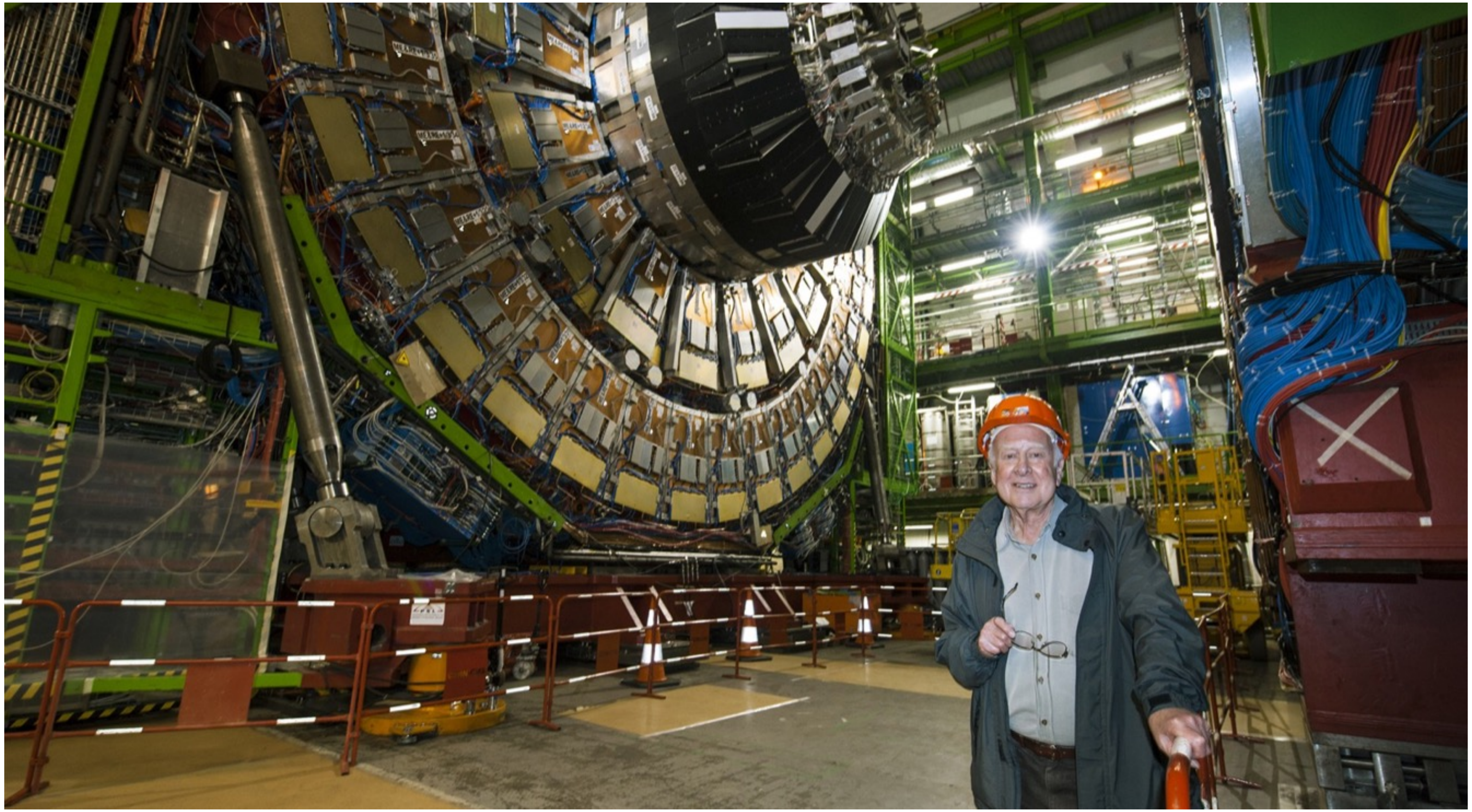
Standard Model of Particle Physics

[http://cern.ch/go/dW6z]

$$
\begin{aligned}
&-\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4}g_s^2 f^{abc}f^{ade}g^b_\mu g^c_\nu g^d_\mu g^e_\nu + \frac{1}{2}ig_s^2(\bar{q}^\sigma_i\gamma^\mu q^\sigma_j)g^a_\mu + \bar{G}^a\partial^2 G^a + g_s f^{abc}\partial_\mu \bar{G}^a G^b g^c_\mu - \\
&\partial_\nu W^+_\mu \partial_\nu W^-_\mu - M^2 W^+_\mu W^-_\mu - \frac{1}{2}\partial_\nu Z^0_\mu\partial_\nu Z^0_\mu - \frac{1}{2c_w^2}M^2 Z^0_\mu Z^0_\mu - \frac{1}{2}\partial_\mu A_\nu\partial_\mu A_\nu - \frac{1}{2}\partial_\mu H\partial_\mu H - \frac{1}{2}m_h^2 H^2 - \partial_\mu\phi^+\partial_\mu\phi^- - \\
&M^2\phi^+\phi^- - \frac{1}{2}\partial_\mu\phi^0\partial_\mu\phi^0 - \frac{1}{2c_w^2}M\phi^0\phi^0 - \beta_h\left[\frac{2M^2}{g^2} + \frac{2M}{g}H + \frac{1}{2}(H^2+\phi^0\phi^0+2\phi^+\phi^-)\right] + \frac{2M^4}{g^2}\alpha_h - igc_w[\partial_\nu Z^0_\mu(W^+_\mu W^-_\nu - \\
&W^+_\nu W^-_\mu) - Z^0_\nu(W^+_\mu\partial_\nu W^-_\mu - W^-_\mu\partial_\nu W^+_\mu) + Z^0_\mu(W^+_\nu\partial_\nu W^-_\mu - W^-_\nu\partial_\nu W^+_\mu)] - igs_w[\partial_\nu A_\mu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - \\
&A_\nu(W^+_\mu\partial_\nu W^-_\mu - W^-_\mu\partial_\nu W^+_\mu) + A_\mu(W^+_\nu\partial_\nu W^-_\mu - W^-_\nu\partial_\nu W^+_\mu)] - \frac{1}{2}g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \frac{1}{2}g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + \\
&g^2c_w^2(Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) + g^2 s_w^2(A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2 s_w c_w[A_\mu Z^0_\nu(W^+_\mu W^-_\nu - \\
&W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu] - g\alpha[H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-] - \frac{1}{8}g^2\alpha_h[H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + \\
&4H^2\phi^+\phi^- + 2(\phi^0)^2H^2] - gMW^+_\mu W^-_\mu H - \frac{1}{2}g\frac{M}{c_w^2}Z^0_\mu Z^0_\mu H - \frac{1}{2}ig[W^+_\mu(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) - W^-_\mu(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)] + \\
&\frac{1}{2}g[W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) - W^-_\mu(H\partial_\mu\phi^+ - \phi^+\partial_\mu H)] + \frac{1}{2}g\frac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) - ig\frac{s_w^2}{c_w}MZ^0_\mu(W^+_\mu\phi^- - \\
&W^-_\mu\phi^+) + igs_wMA_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) - ig\frac{1-2c_w^2}{2c_w}Z^0_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) + igs_wA_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \\
&\frac{1}{4}g^2W^+_\mu W^-_\mu[H^2+(\phi^0)^2+2\phi^+\phi^-] - \frac{1}{4}g^2\frac{1}{c_w^2}Z^0_\mu Z^0_\mu[H^2+(\phi^0)^2+2(2s_w^2-1)^2\phi^+\phi^-] - \frac{1}{2}g^2\frac{s_w^2}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- + \\
&W^-_\mu\phi^+) - \frac{1}{2}ig^2\frac{s_w^2}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \frac{1}{2}g^2s_wA_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) + \frac{1}{2}ig^2s_wA_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) - \\
&g^2\frac{s_w}{c_w}(2c_w^2-1)Z^0_\mu A_\mu\phi^+\phi^- - g^1 s_w^2 A_\mu A_\mu\phi^+\phi^- - \bar{e}^\lambda(\gamma\partial + m_e^\lambda)e^\lambda - \bar\nu^\lambda\gamma\partial\nu^\lambda - \bar u^\lambda_j(\gamma\partial+m_u^\lambda)u^\lambda_j - \bar d^\lambda_j(\gamma\partial+m_d^\lambda)d^\lambda_j + \\
&igs_wA_\mu\left[-(\bar e^\lambda\gamma^\mu e^\lambda) + \frac{2}{3}(\bar u^\lambda_j\gamma^\mu u^\lambda_j) - \frac{1}{3}(\bar d^\lambda_j\gamma^\mu d^\lambda_j)\right] + \frac{ig}{4c_w}Z^0_\mu[(\bar\nu^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar e^\lambda\gamma^\mu(4s_w^2-1-\gamma^5)e^\lambda) + (\bar u^\lambda_j\gamma^\mu(\frac{4}{3}s_w^2 - \\
&1-\gamma^5)u^\lambda_j) + (\bar d^\lambda_j\gamma^\mu(1-\frac{8}{3}s_w^2-\gamma^5)d^\lambda_j)] + \frac{ig}{2\sqrt2}W^+_\mu[(\bar\nu^\lambda\gamma^\mu(1+\gamma^5)e^\lambda) + (\bar u^\lambda_j\gamma^\mu(1+\gamma^5)C_{\lambda\kappa}d^\kappa_j)] + \frac{ig}{2\sqrt2}W^-_\mu[(\bar e^\lambda\gamma^\mu(1+ \\
&\gamma^5)\nu^\lambda) + (\bar d^\kappa_j C^\dagger_{\lambda\kappa}\gamma^\mu(1+\gamma^5)u^\lambda_j)] + \frac{ig}{2\sqrt2}\frac{m_e^\lambda}{M}[-\phi^+(\bar\nu^\lambda(1-\gamma^5)e^\lambda) + \phi^-(\bar e^\lambda(1+\gamma^5)\nu^\lambda)] - \frac{g}{2}\frac{m_e^\lambda}{M}[H(\bar e^\lambda e^\lambda) + \\
&i\phi^0(\bar e^\lambda\gamma^5 e^\lambda)] + \frac{ig}{2M\sqrt2}\phi^+[-m_d^\kappa(\bar u^\lambda_j C_{\lambda\kappa}(1-\gamma^5)d^\kappa_j) + m_u^\lambda(\bar u^\lambda_j C_{\lambda\kappa}(1+\gamma^5)d^\kappa_j] + \frac{ig}{2M\sqrt2}\phi^-[m_d^\lambda(\bar d^\lambda_j C^\dagger_{\lambda\kappa}(1+\gamma^5)u^\kappa_j) - \\
&m_u^\kappa(\bar d^\lambda_j C^\dagger_{\lambda\kappa}(1-\gamma^5)u^\kappa_j] - \frac{g}{2}\frac{m_u^\lambda}{M}H(\bar u^\lambda_j u^\lambda_j) - \frac{g}{2}\frac{m_d^\lambda}{M}H(\bar d^\lambda_j d^\lambda_j) + \frac{ig}{2}\frac{m_u^\lambda}{M}\phi^0(\bar u^\lambda_j\gamma^5 u^\lambda_j) - \frac{ig}{2}\frac{m_d^\lambda}{M}\phi^0(\bar d^\lambda_j\gamma^5 d^\lambda_j) + \bar X^+(\partial^2 - \\
&M^2)X^+ + \bar X^-(\partial^2-M^2)X^- + \bar X^0(\partial^2 - \frac{M^2}{c_w^2})X^0 + \bar Y\partial^2 Y + igc_wW^+_\mu(\partial_\mu\bar X^0X^- - \partial_\mu\bar X^+X^0) + igs_wW^+_\mu(\partial_\mu\bar YX^- - \\
&\partial_\mu\bar X^+Y) + igc_wW^-_\mu(\partial_\mu\bar X^-X^0 - \partial_\mu\bar X^0X^+) + igs_wW^-_\mu(\partial_\mu\bar X^-Y - \partial_\mu\bar YX^+) + igc_wZ^0_\mu(\partial_\mu\bar X^+X^+ - \partial_\mu\bar X^-X^-) + \\
&igs_wA_\mu(\partial_\mu\bar X^+X^+ - \partial_\mu\bar X^-X^-) - \frac{1}{2}gM[\bar X^+X^+H + \bar X^-X^-H + \frac{1}{c_w^2}\bar X^0X^0H] + \frac{1-2c_w^2}{2c_w}igM[\bar X^+X^0\phi^+ - \\
&\bar X^-X^0\phi^-] + \frac{1}{2c_w}igM[\bar X^0X^-\phi^+ - \bar X^0X^+\phi^-] + igMs_w[\bar X^0X^-\phi^+ - \bar X^0X^+\phi^-] + \frac{1}{2}igM[\bar X^+X^+\phi^0 - \bar X^-X^-\phi^0]
\end{aligned}
$$

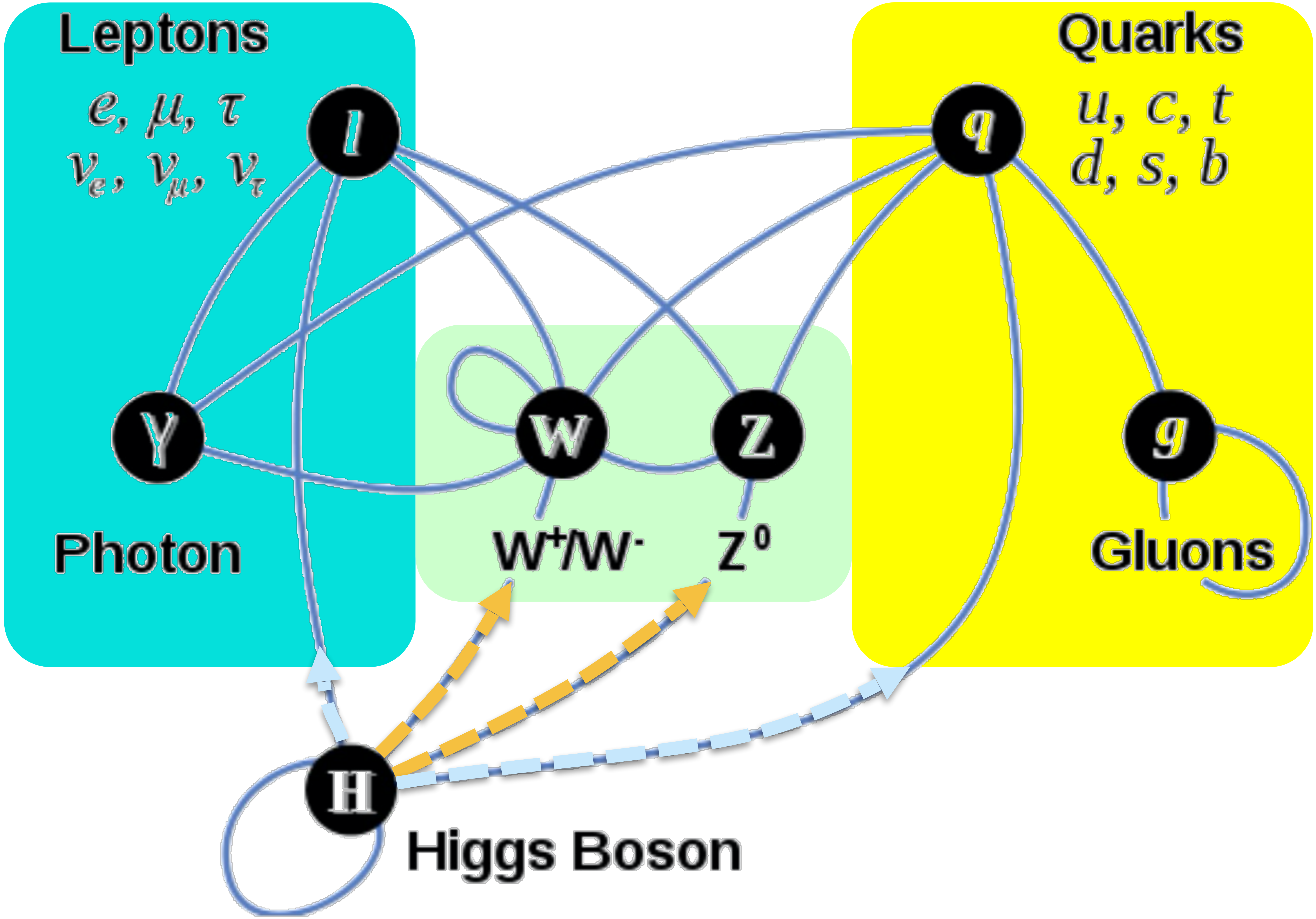
Higgs spotted in CMS

[http://cern.ch/go/dJf7][http://cern.ch/go/Sx8m]

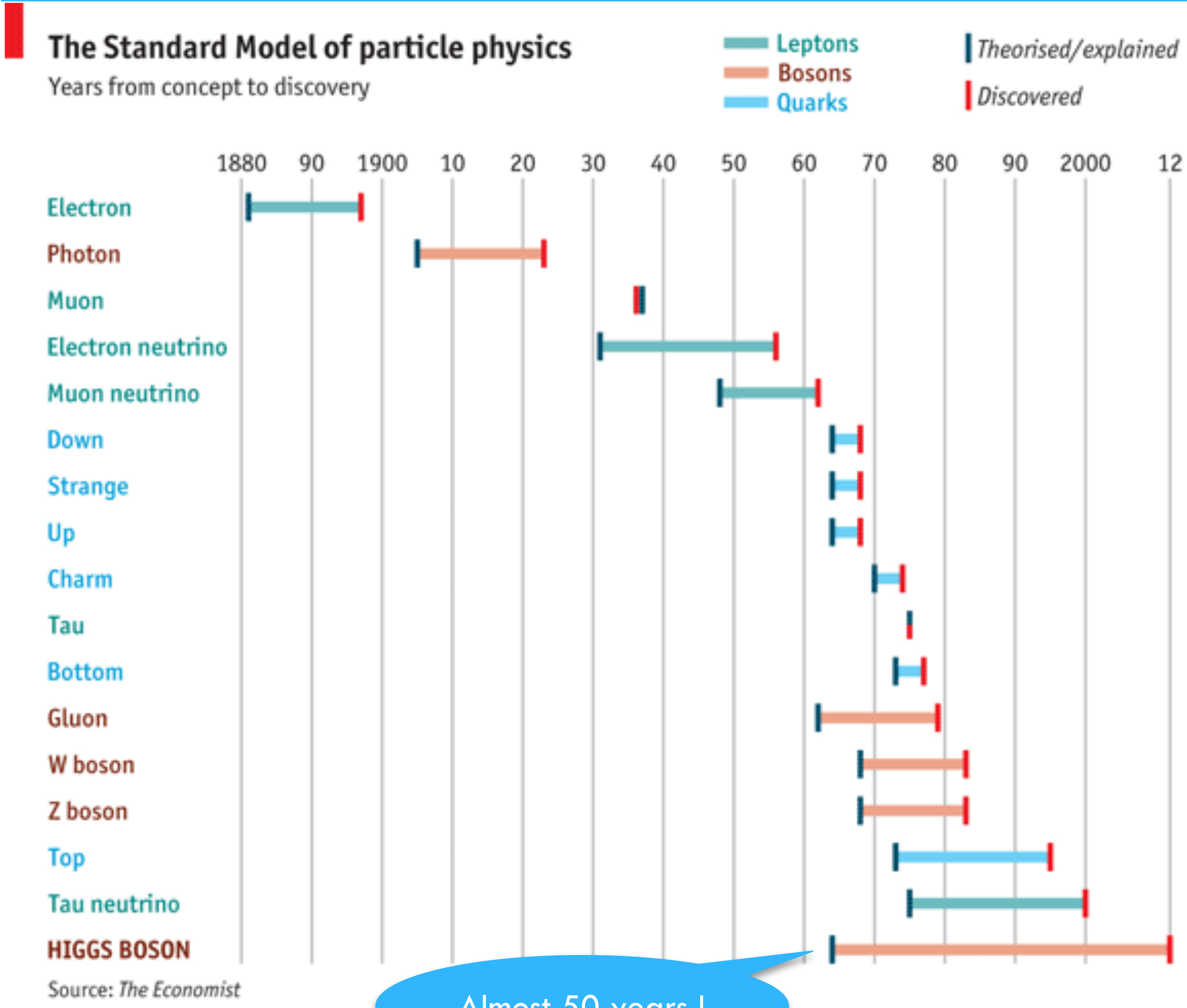


The Standard Model of Particle Physics

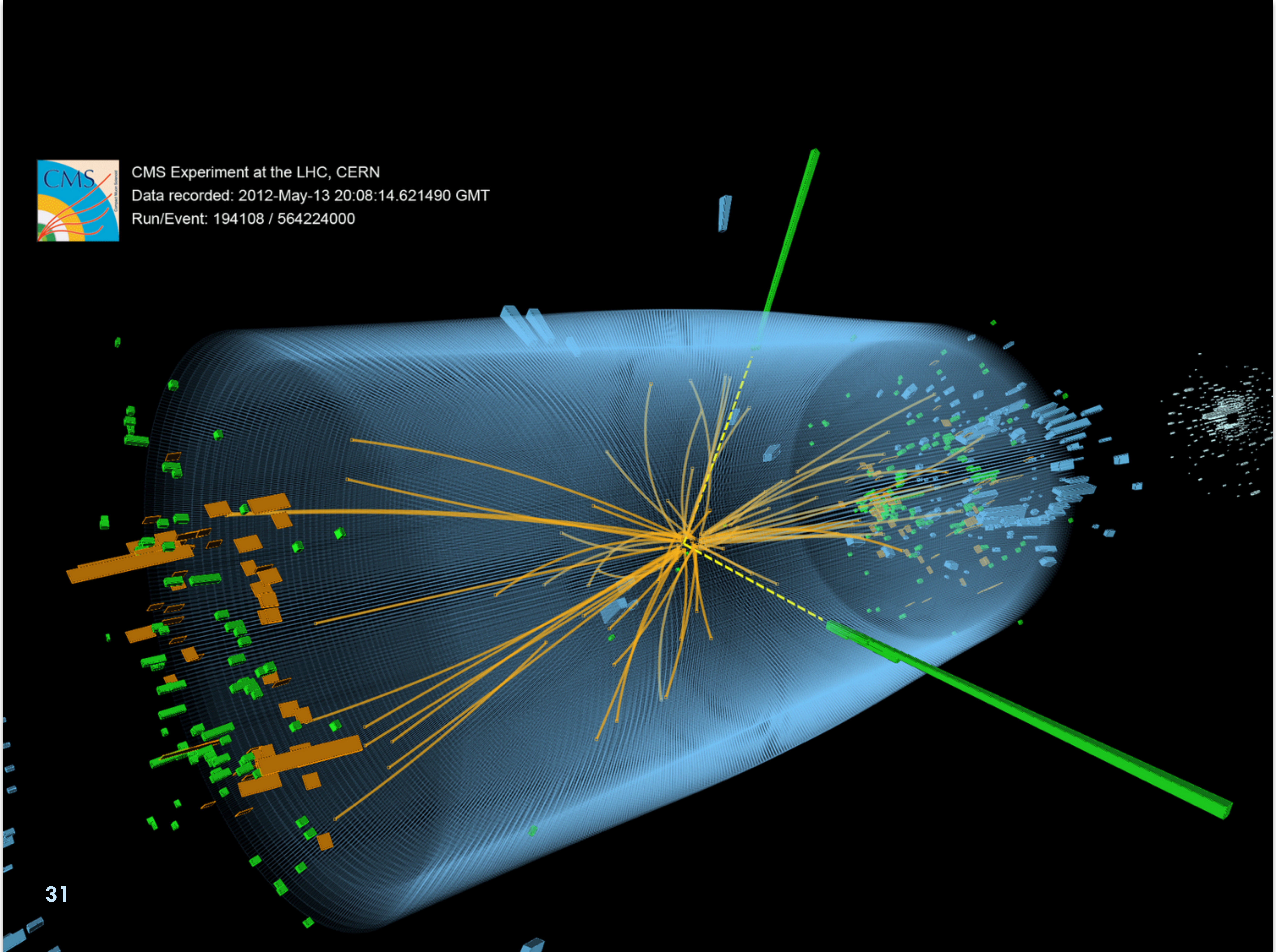
Electromagnetic force – light Weak force – star combustion Strong force – protons and neutrons



Evolutions & revolutions of the elements

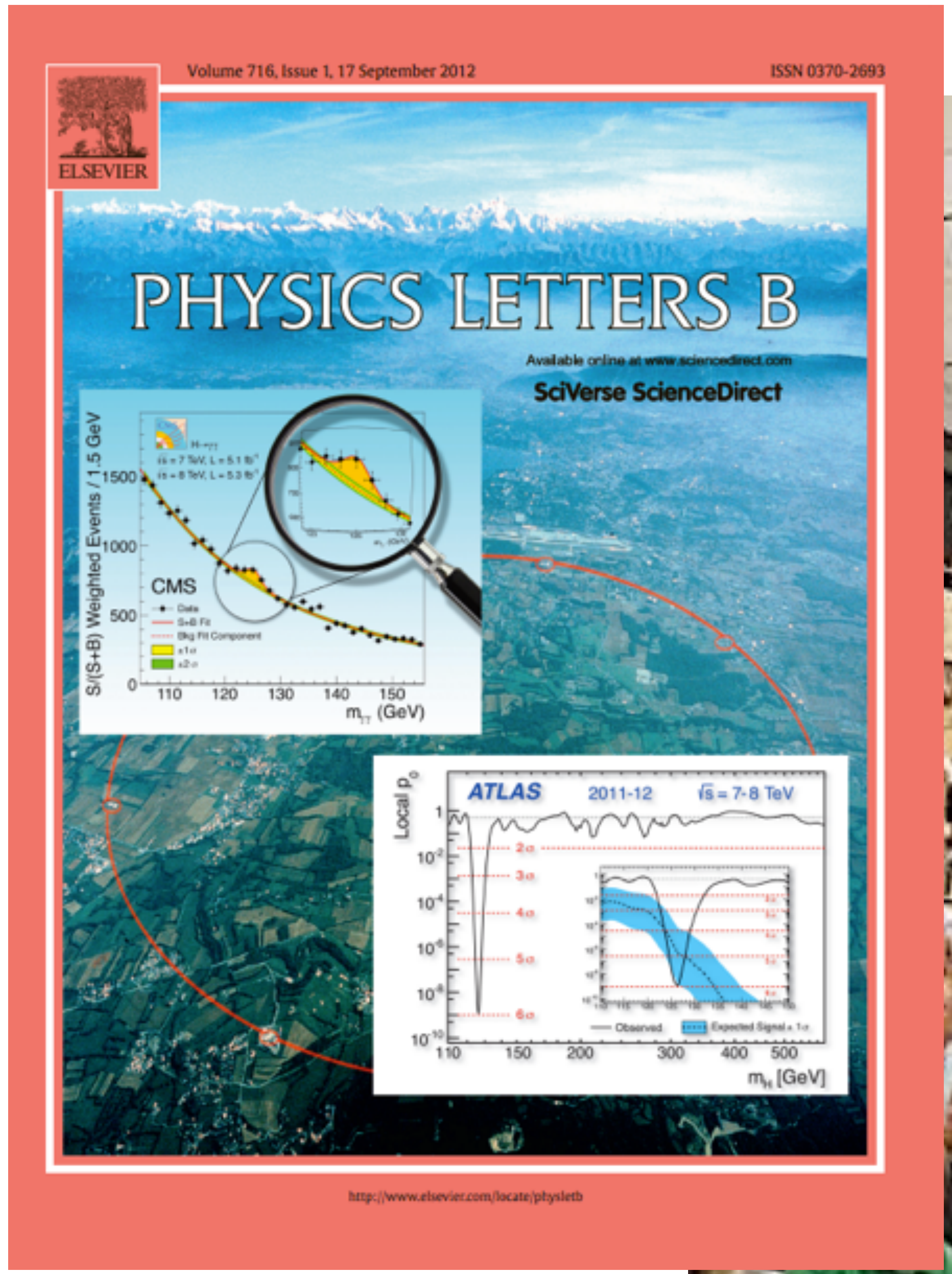


Almost 50 years !


CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000

July 4, 2012: looking up to a new boson

[http://cern.ch/go/q8jx]



For the record

- ~5 kiloauthors.
- Found that there are two:
  - Archana Sharma (both in CMS)
  - Andrea Bocci
  - Muhammad Ahmad
  - F. M. Giorgi (one in CMS, one in ATLAS)

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NATURE | NEWS

Physics paper sets record with more than 5,000 authors

Detector teams at the Large Hadron Collider collaborated for a more precise estimate of the size of the Higgs boson.

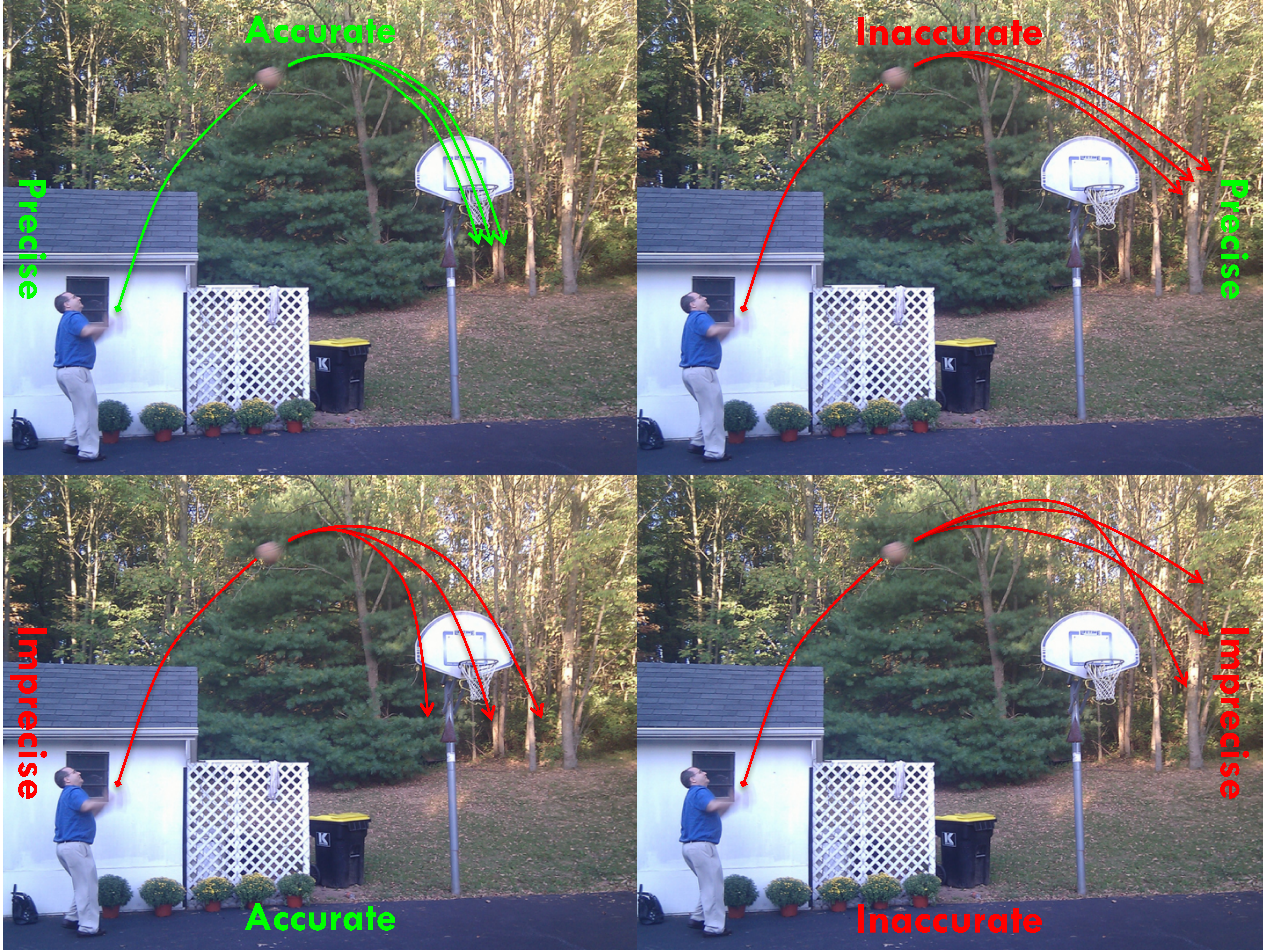
Davide Castelvecchi

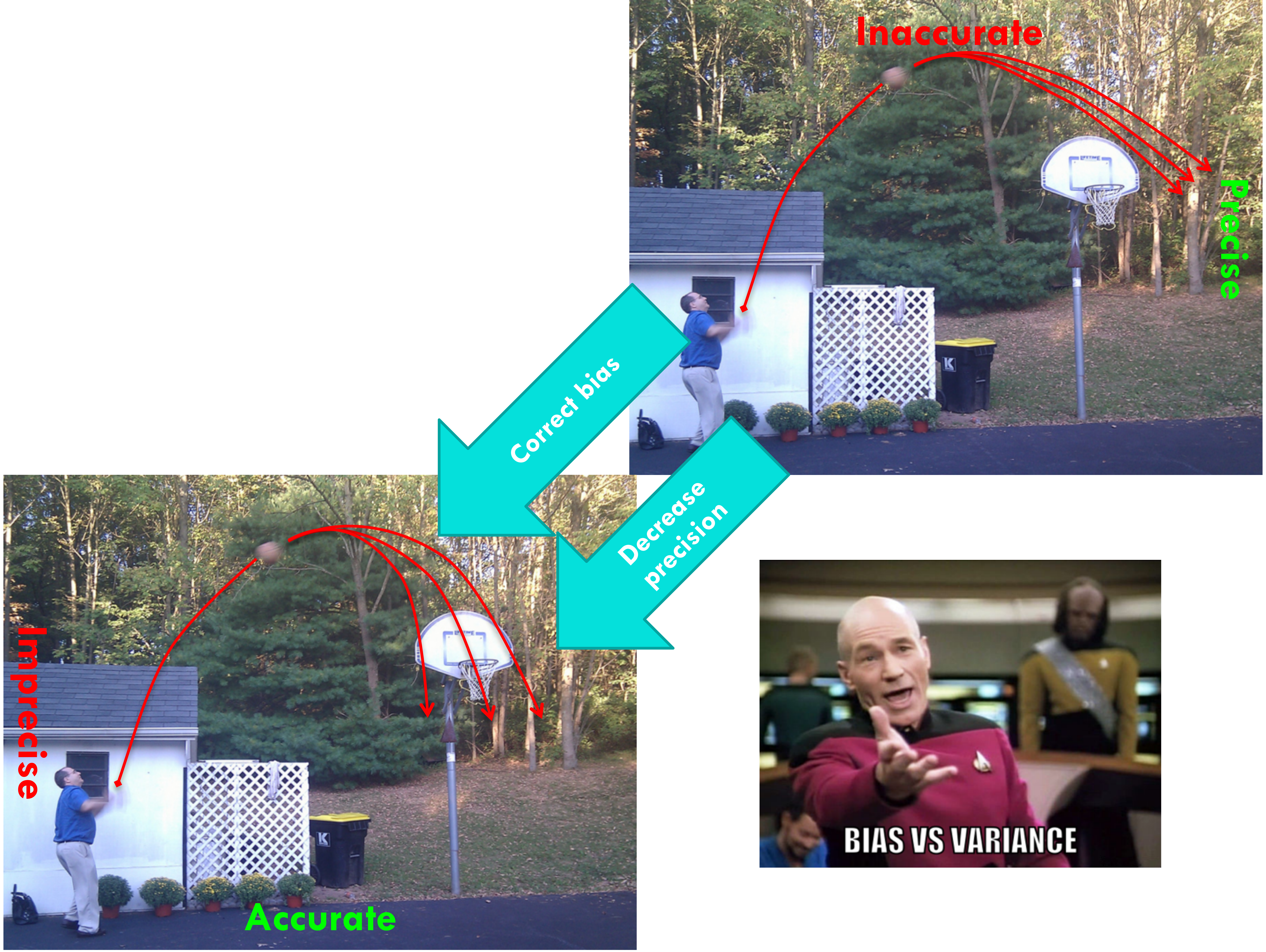
15 May 2015

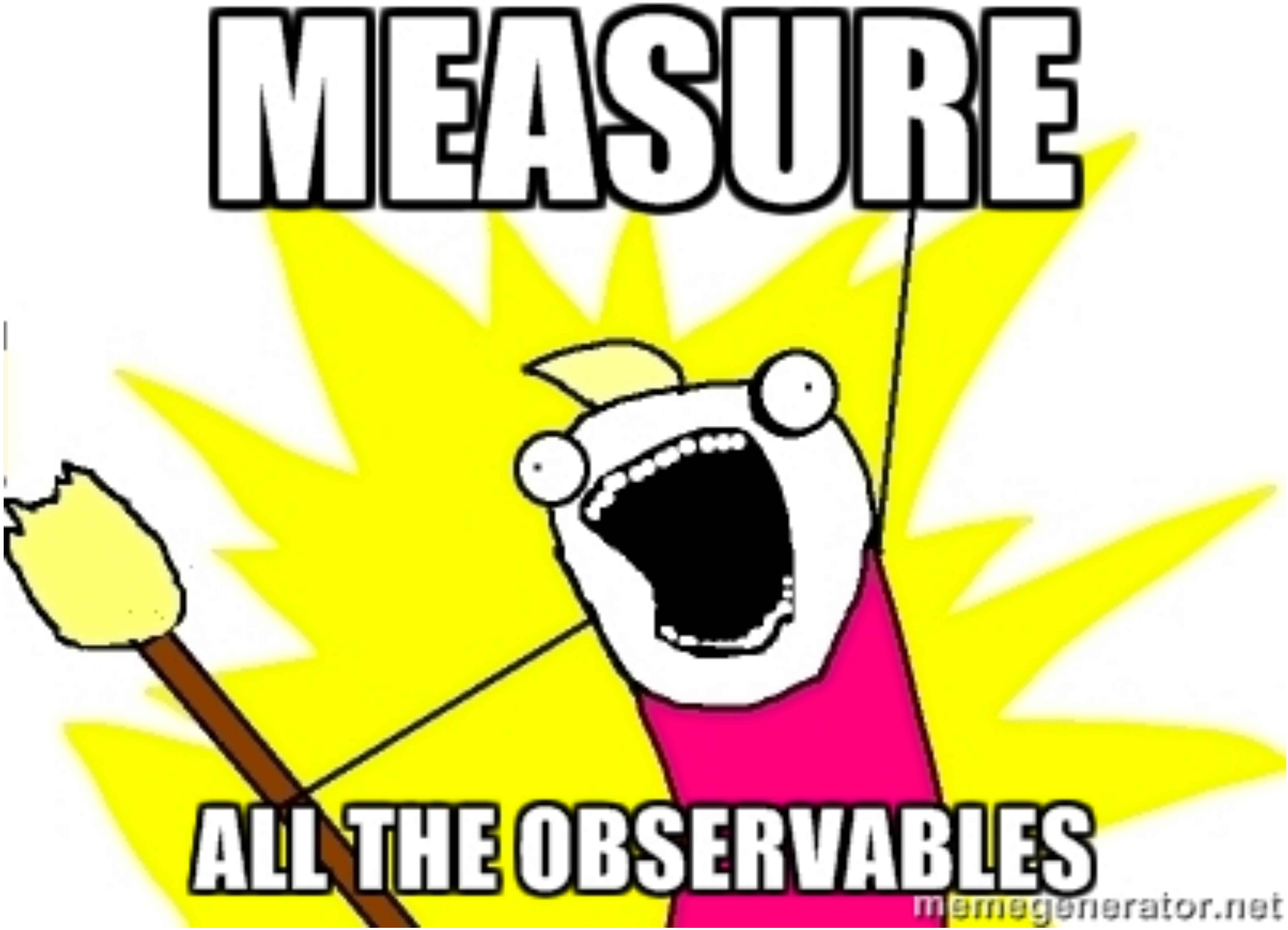
CERN

Thousands of scientists and engineers have worked on the Large Hadron Collider at CERN.

A physics paper with 5,154 authors has — as far as anyone knows — broken the record for the largest number of contributors to a single research article.


Accurate
Precise
Inaccurate
Precise
Imprecise
Accurate
Imprecise
Inaccurate


Inaccurate
Precise
Correct bias
Decrease precision
Imprecise
Accurate
BIAS VS VARIANCE


MEASURE
ALL THE OBSERVABLES
memegenerator.net


EVERY SINGLE
ONE ?
memegenerator.net

Higgs Hunting Basics

Needle-in-the-hay-stack problem

- need high energy:

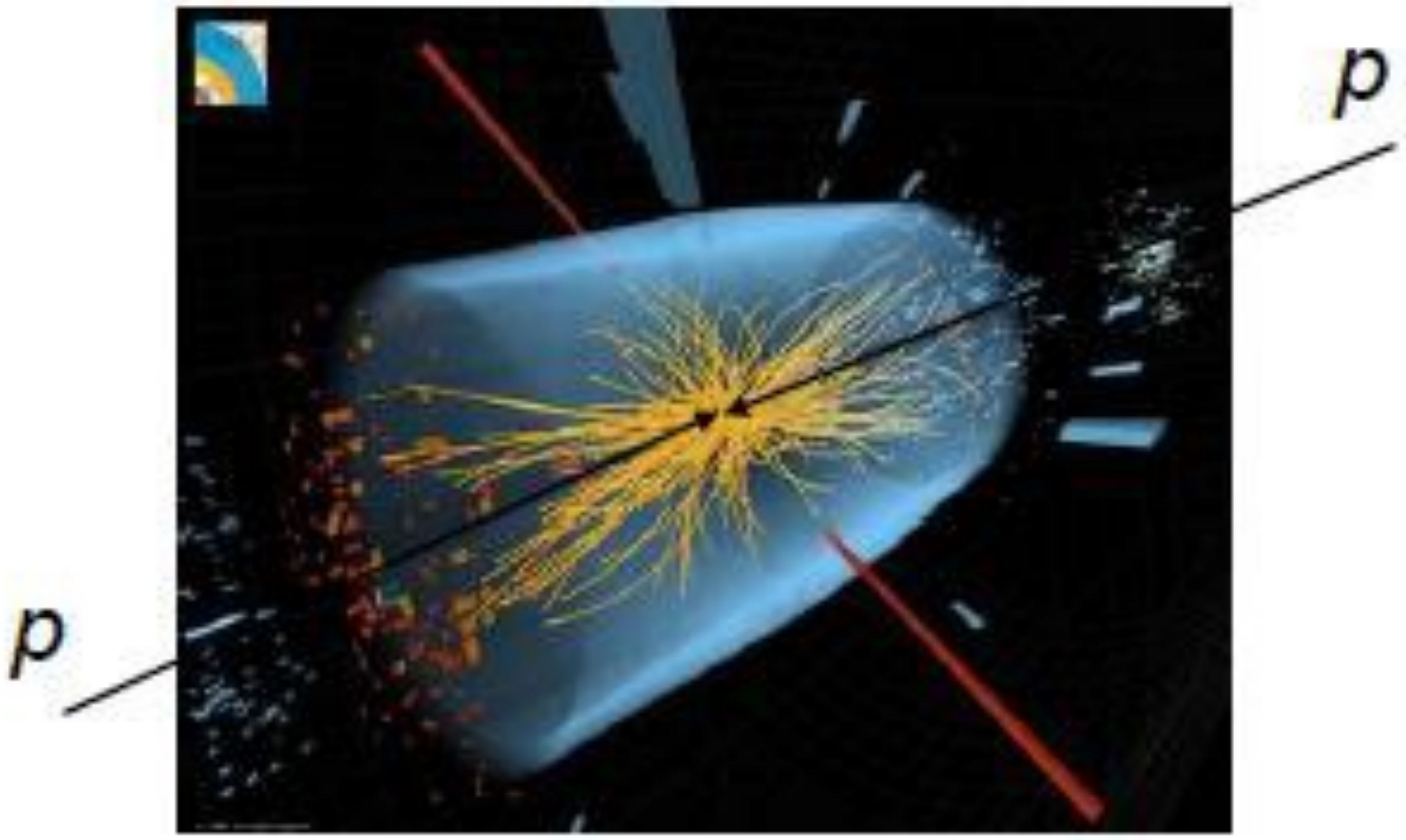
  $E = mc^2$

- need lots of data

non-deterministic and very rare

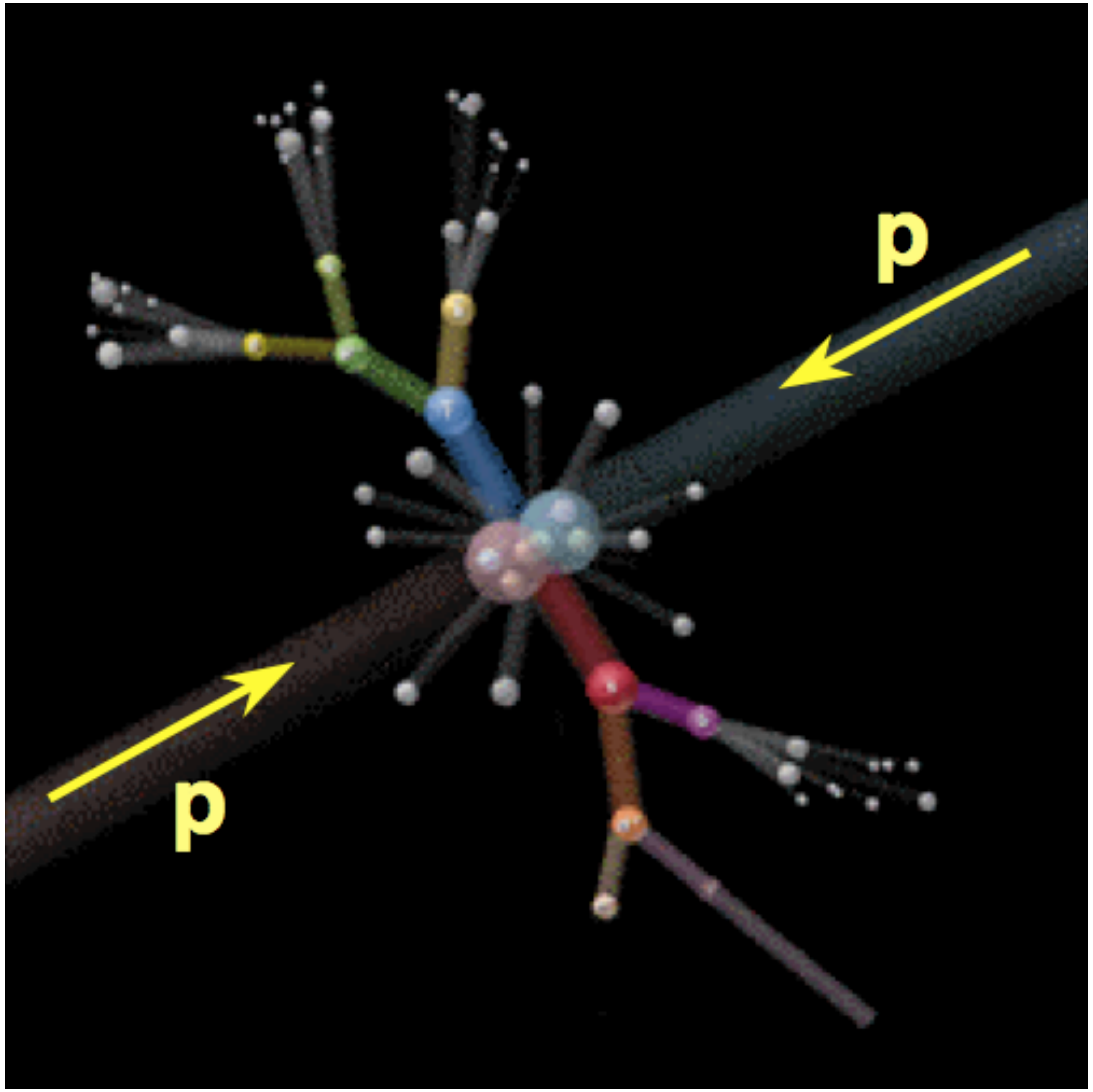
order 1 in 10^{11}

1
0

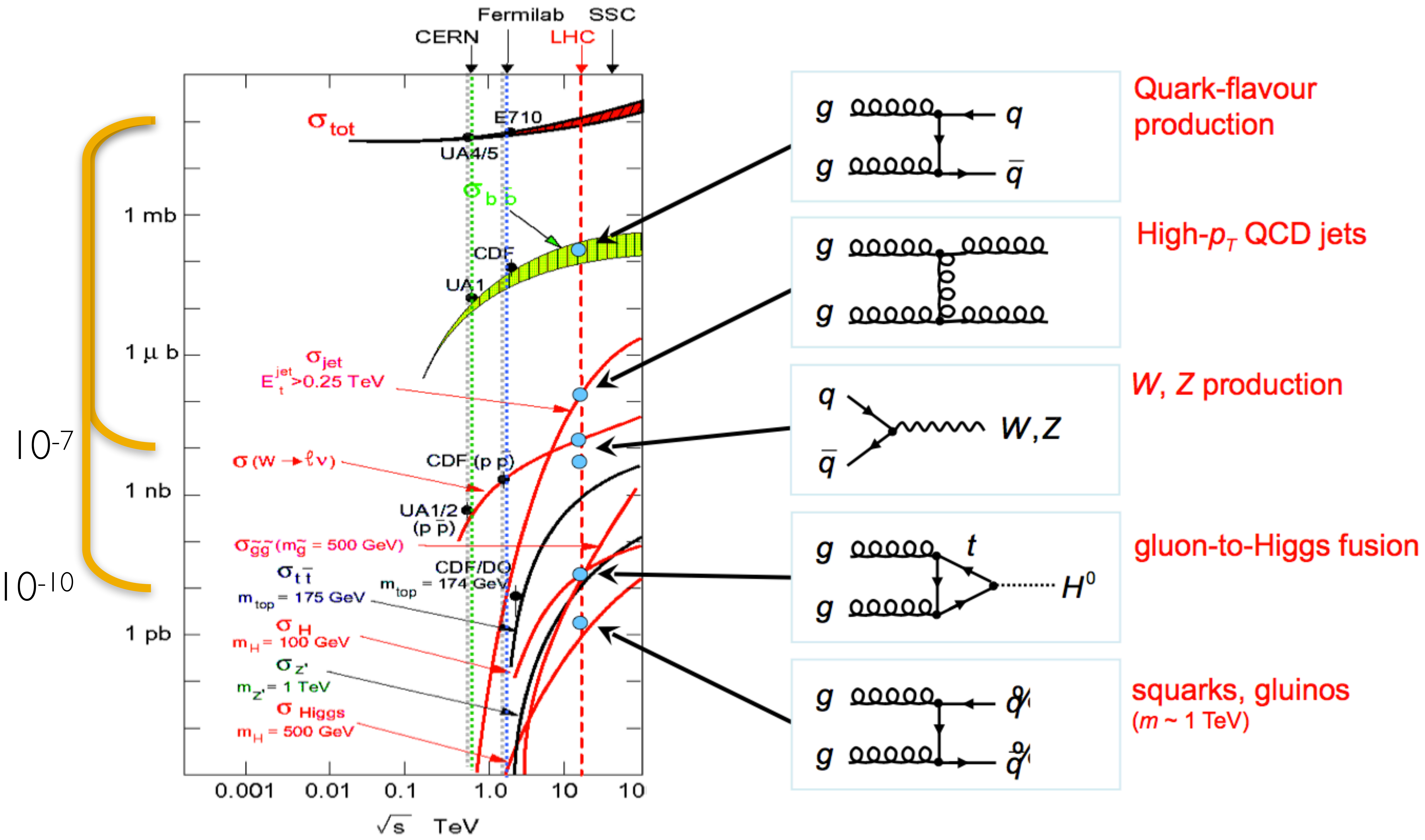


* for us finding the Higgs it was 48 years = 1,513,728,000 sec

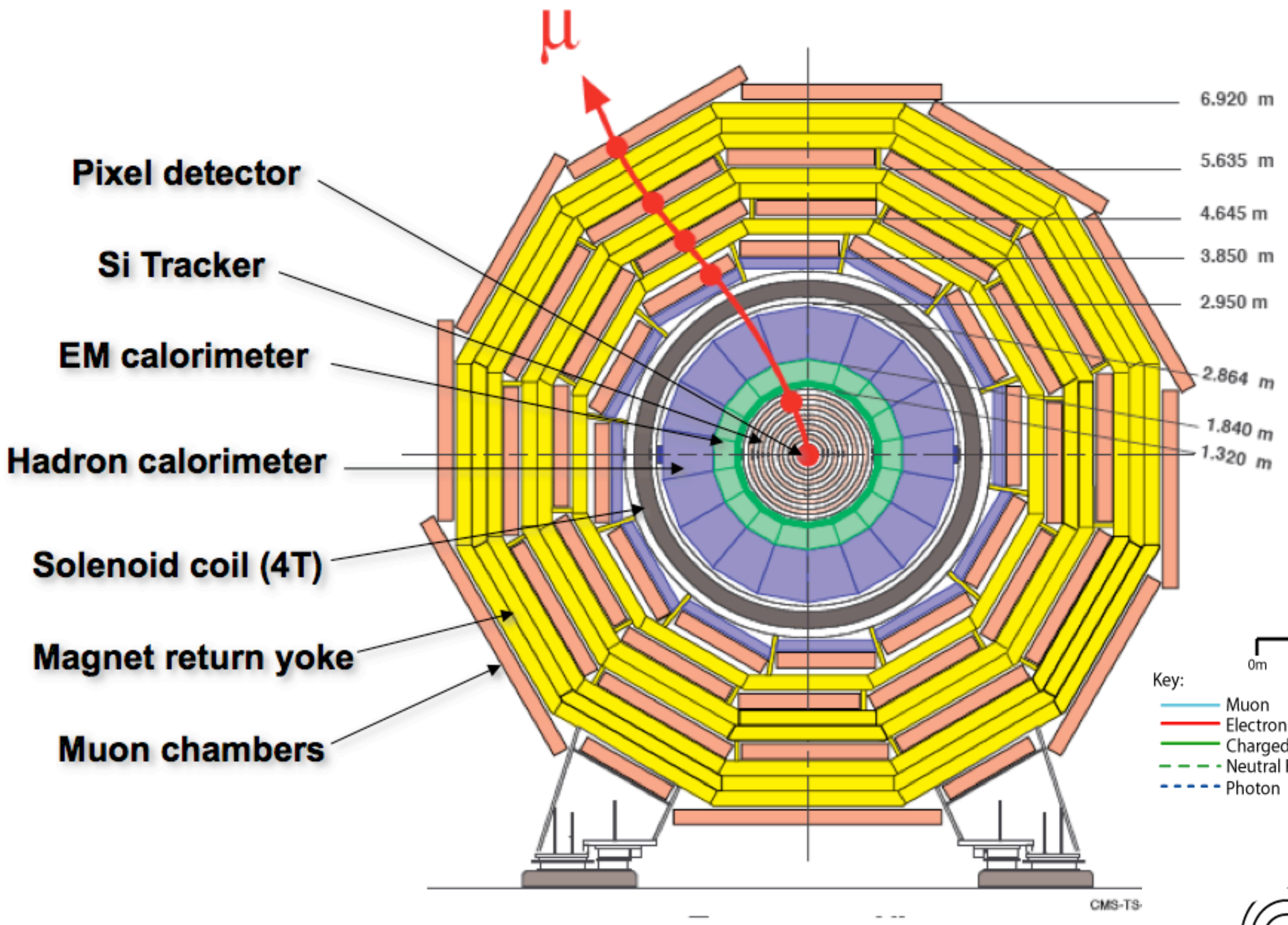
What gets produced in collisions

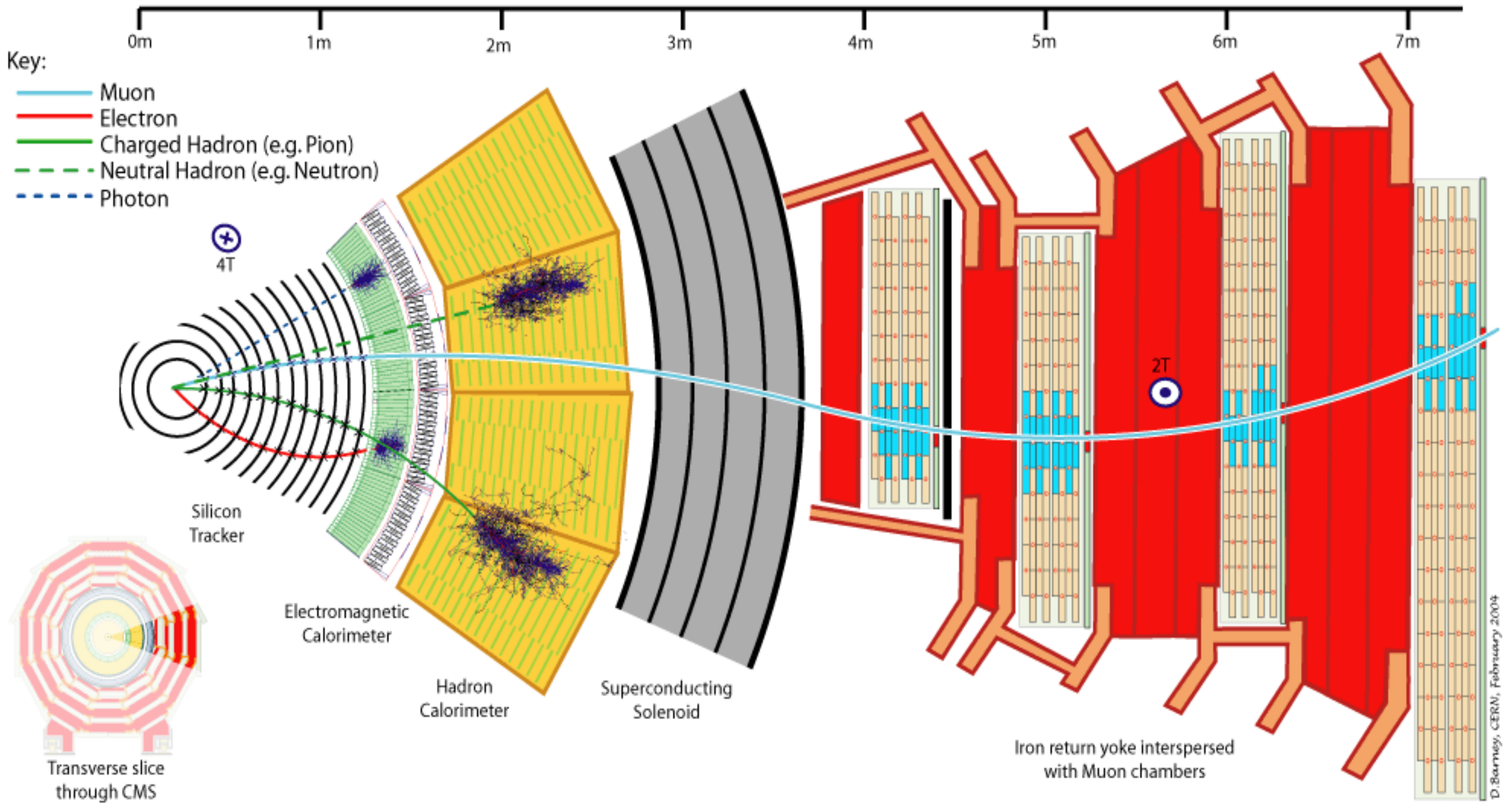


What gets produced in collisions



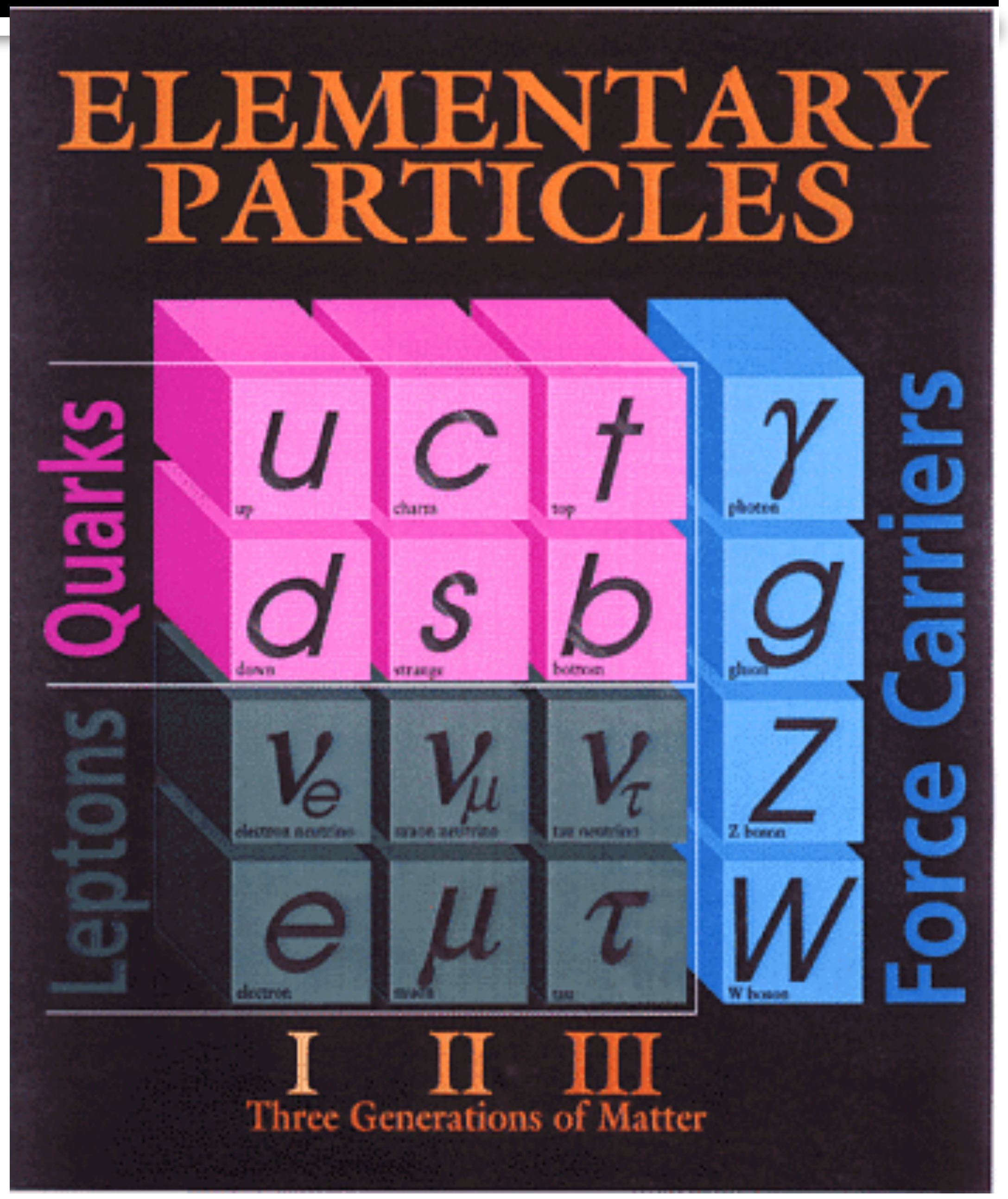
CMS example


μ
Pixel detector
Si Tracker
EM calorimeter
Hadron calorimeter
Solenoid coil (4T)
Magnet return yoke
Muon chambers
6.920 m
5.635 m
4.645 m
3.850 m
2.950 m
2.864 m
1.840 m
1.320 m
CMS-TS-


0m
1m
2m
3m
4m
5m
6m
7m
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS

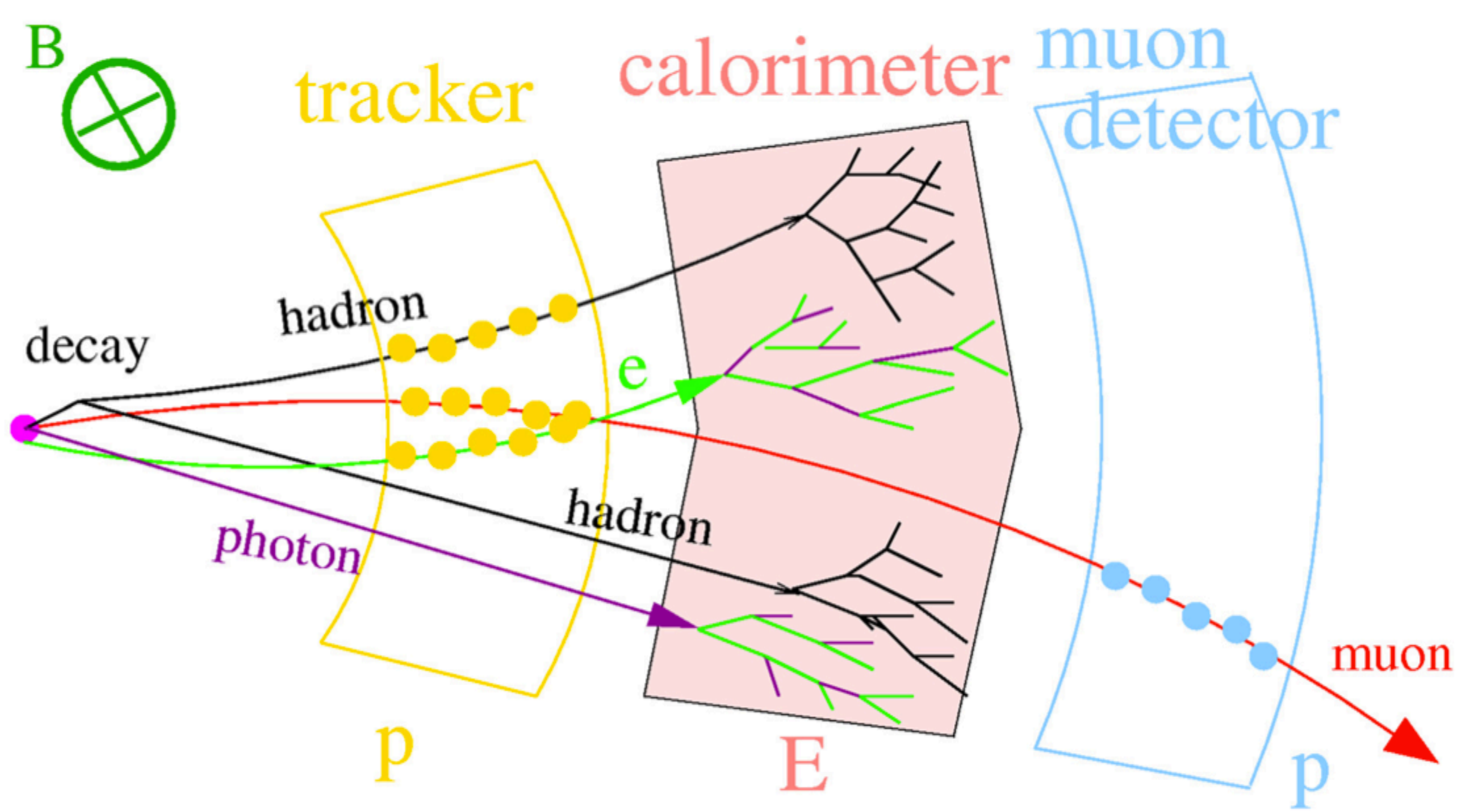
What we can detect

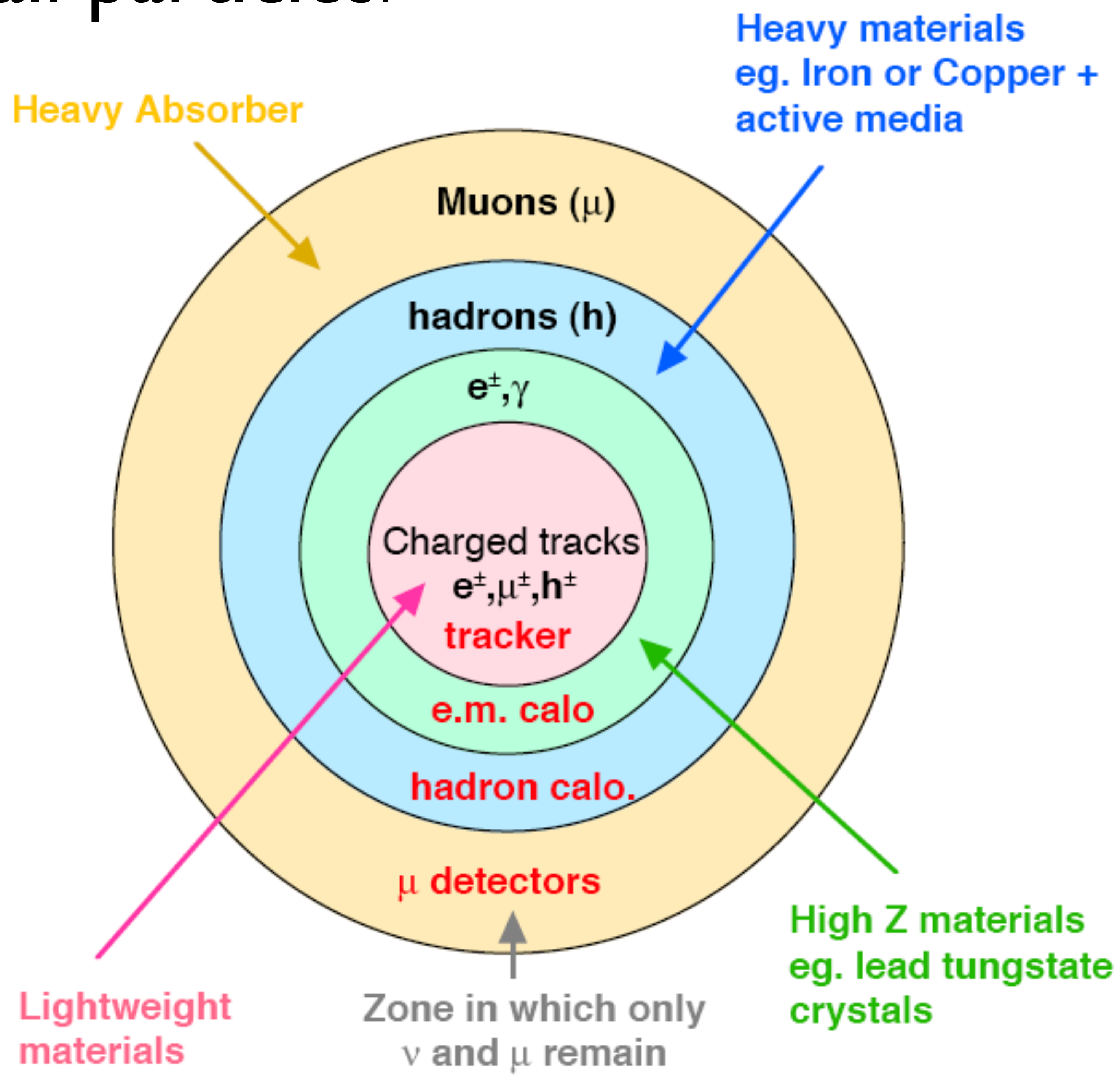
- Directly observable particles must:
  - Undergo strong or EM interactions.
  - Be sufficiently long-lived to pass the detectors.
- We can directly observe:
  - Electrons, **muons**, photons.
  - Neutral or charged hadrons:
    - Pions, protons, kaons, neutrons, …
    - Many physics analyses treat **jets** from quark hadronization collectively as single objects.
    - Use **displaced secondary vertices** to identify jets originating from b-quarks.
- We can indirectly observe long lived weakly interacting particles (e.g. neutrinos) through **missing transverse energy**.



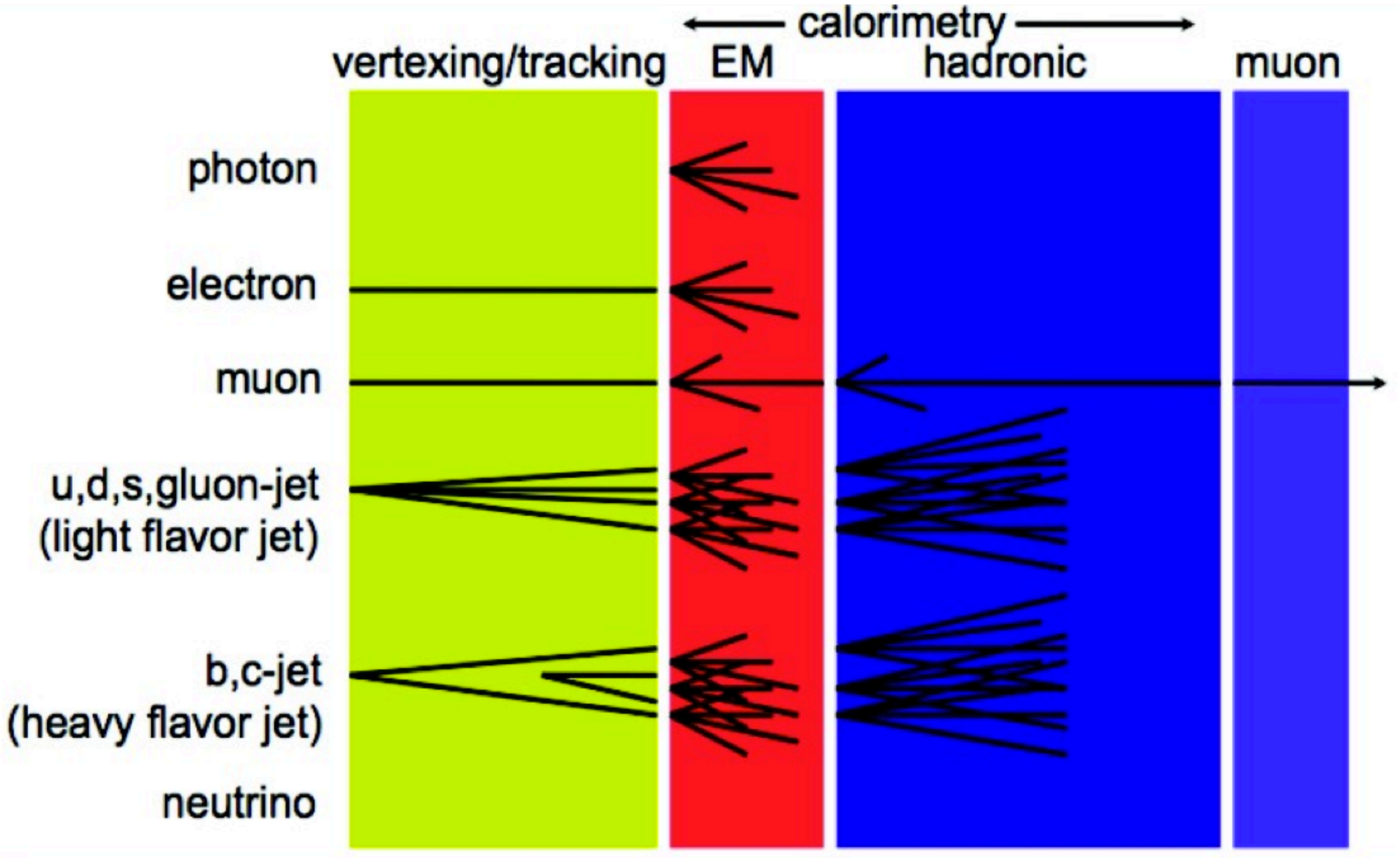
Peeling the hermetic onion

- Inner tracking
  - Measure charged particles **disturbing them the least possible**.
- Calorimetry
  - Measure as much as possible the energy of **all particles**.
- Outer tracking
  - Measure **muons**.





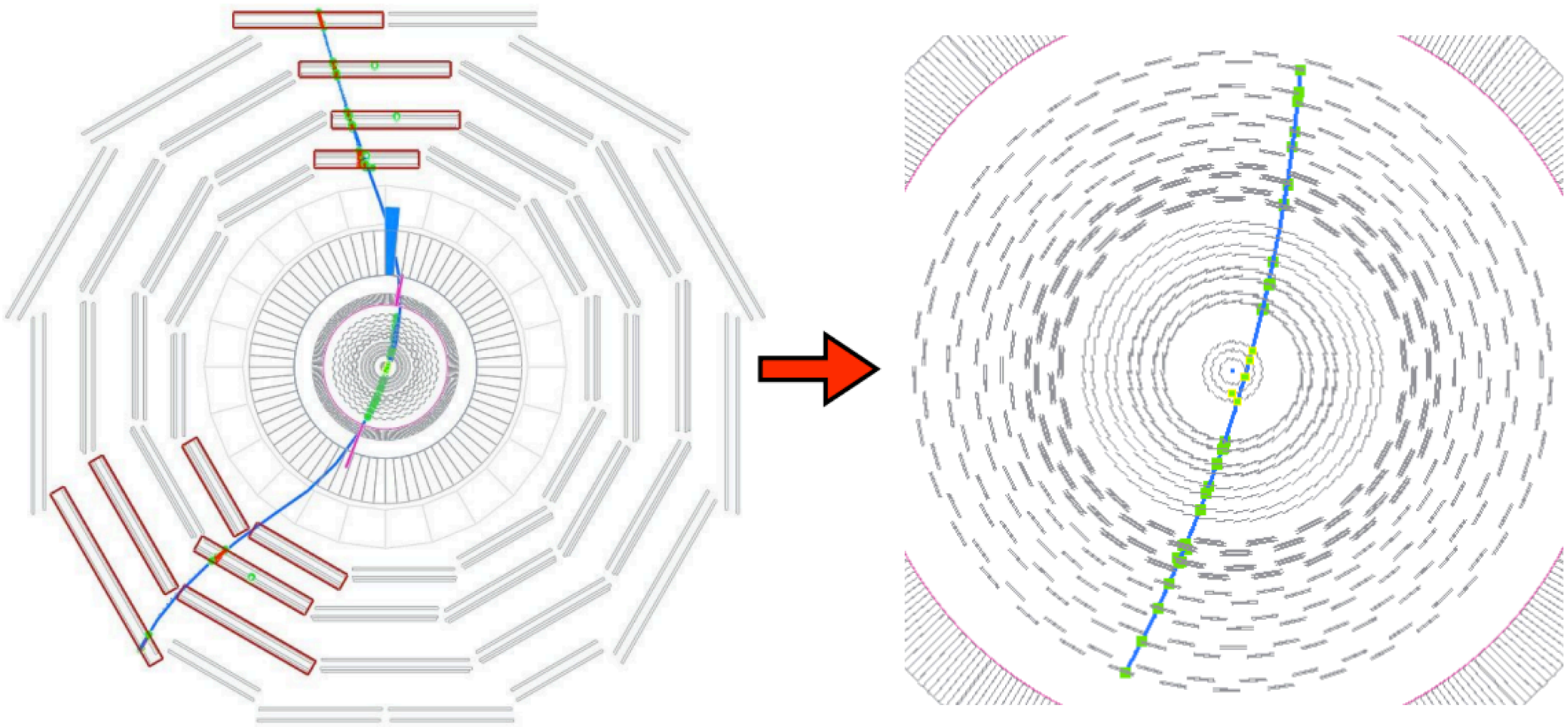
Particles and their decays



In the end it is all charged particles

- Ultimately all detectors end up detecting charged particles:
  - Photons are detected via electrons produced in different ways.
  - Neutrons are detected through transfer of energy to charged particles in the detector medium (shower of secondary hadrons).
- Charged particles are detected via EM interaction with electrons or nuclei in the detector material:
  - Inelastic collisions with atomic electrons → energy loss.
  - Elastic scattering from nuclei → change of direction.

The cosmic muon that crossed all



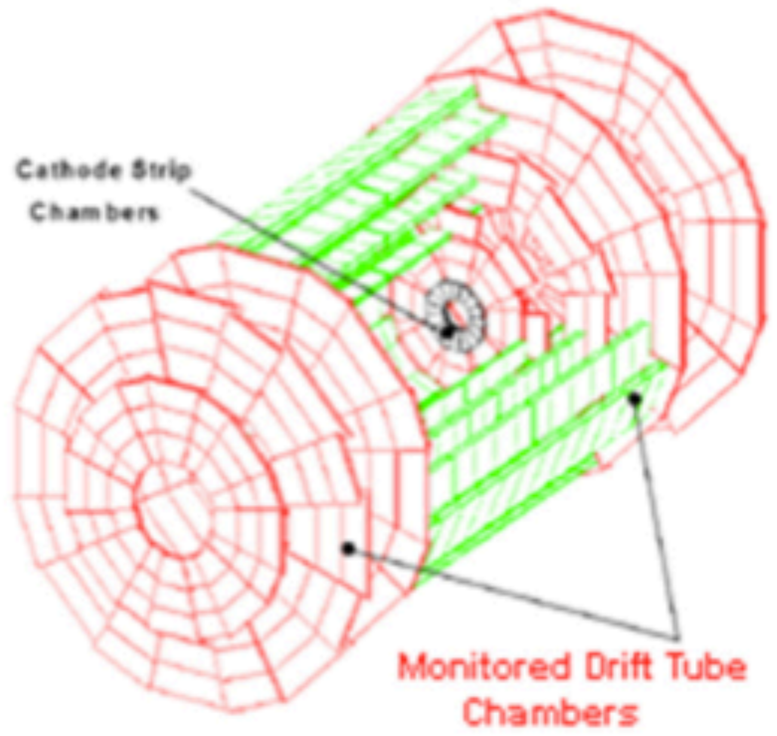
Momentum resolution

ATLAS

B = 0.7 T

L ~ 5 m

N = 3 Stations * 8 Points



$$s = \frac{0.3 \cdot B[T] \cdot L[m]^2}{8 \cdot p[GeV]}$$

$$\frac{\Delta p_T}{p_T} \propto \frac{1}{s} \cdot \delta_{spatial} \cdot \sqrt{\frac{720}{N_{Stat}}}$$

s = 750 μm for 1 TeV Track

10% → σ = 75 μm

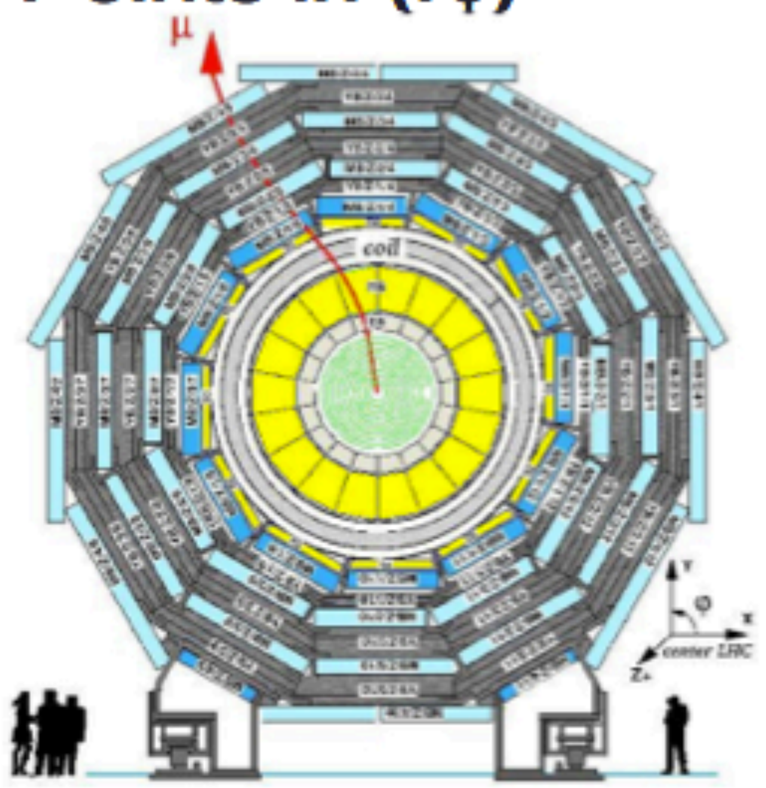
Δp/p ~ 6%

CMS

B ~ 2 T (B-Field in Fe)

L ~ 3.5 m

N = 4 Stations * 8 Points in (rϕ)



s = 900 μm for 1 TeV Track

10% → σ = 90 μm

Δp/p ~ 12 %

(Multiple scattering in Fe ~100 μm)

Combine with Tracker Δp/p ~ 2 %

GASEOUS DETECTORS

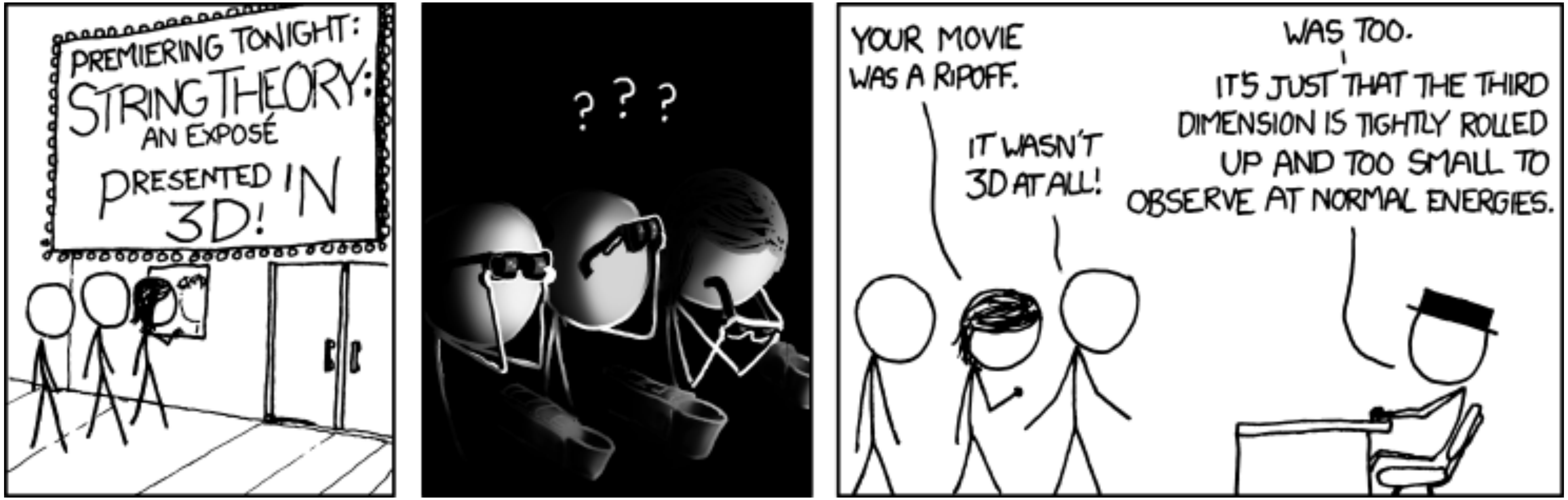
ATLAS vs. CMS – classroom exercise

- **7000 tonnes**
  in a cylinder about **26 m long**
  and **25 m in diameter**.
- **Average density of 0.6 g/cm³**
  or 30% less than an apple.

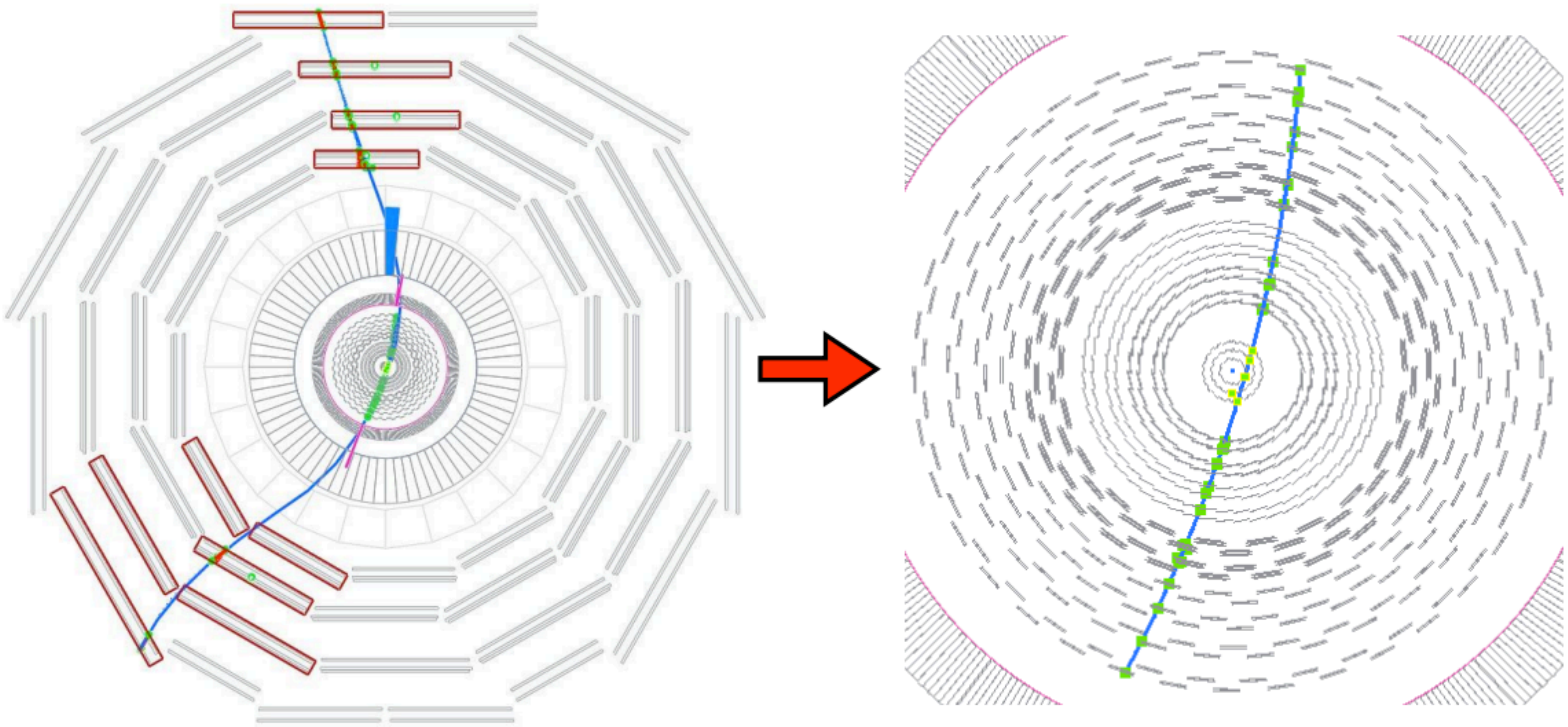
- **14000 tonnes**
  in a cylinder about **21.5 m long**
  and **15 m in diameter**.
- **Average density of 3.7 g/cm³**
  just like a diamond.

- **ATLAS would float in water but CMS would sink.**
  CMS is 7 times denser than ATLAS, hence the C for Compact.
- But first you'd need to get them out of the caverns. ☺

- [http://cern.ch/go/BXt9]
- [http://cern.ch/go/Rfq9]


PREMIERING TONIGHT:
STRING THEORY:
AN EXPOSÉ
PRESENTED IN 3D!
???
YOUR MOVIE WAS A RIPOFF.
IT WASN'T 3D AT ALL!
WAS TOO.
IT'S JUST THAT THE THIRD DIMENSION IS TIGHTLY ROLLED UP AND TOO SMALL TO OBSERVE AT NORMAL ENERGIES.

The cosmic muon that crossed all



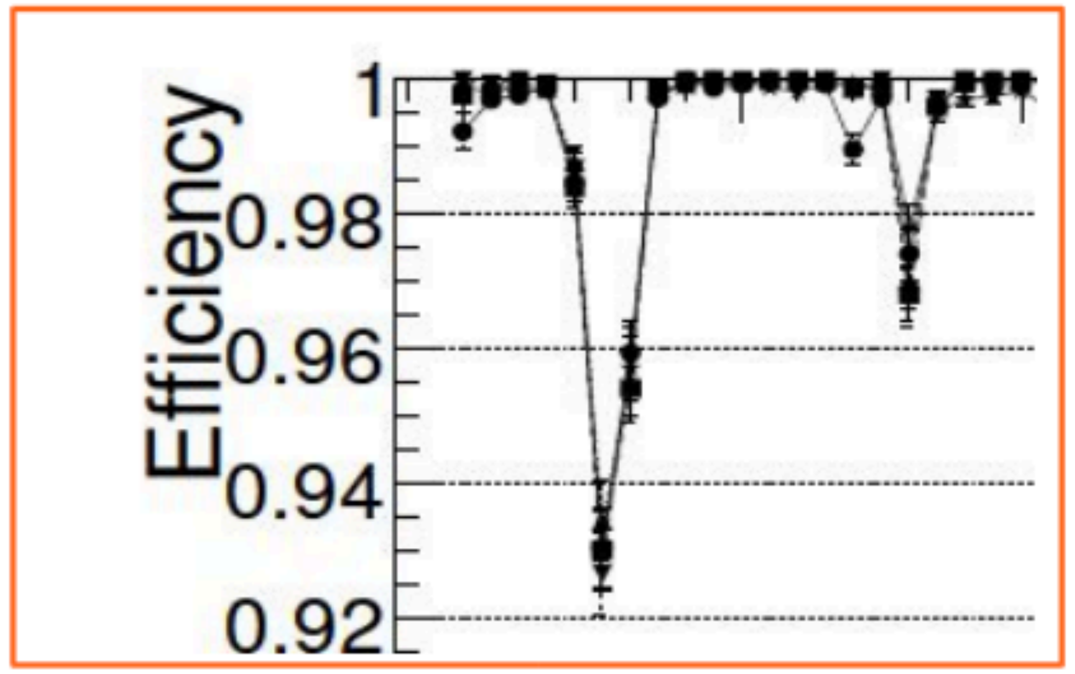
Finding muons: not just outside in

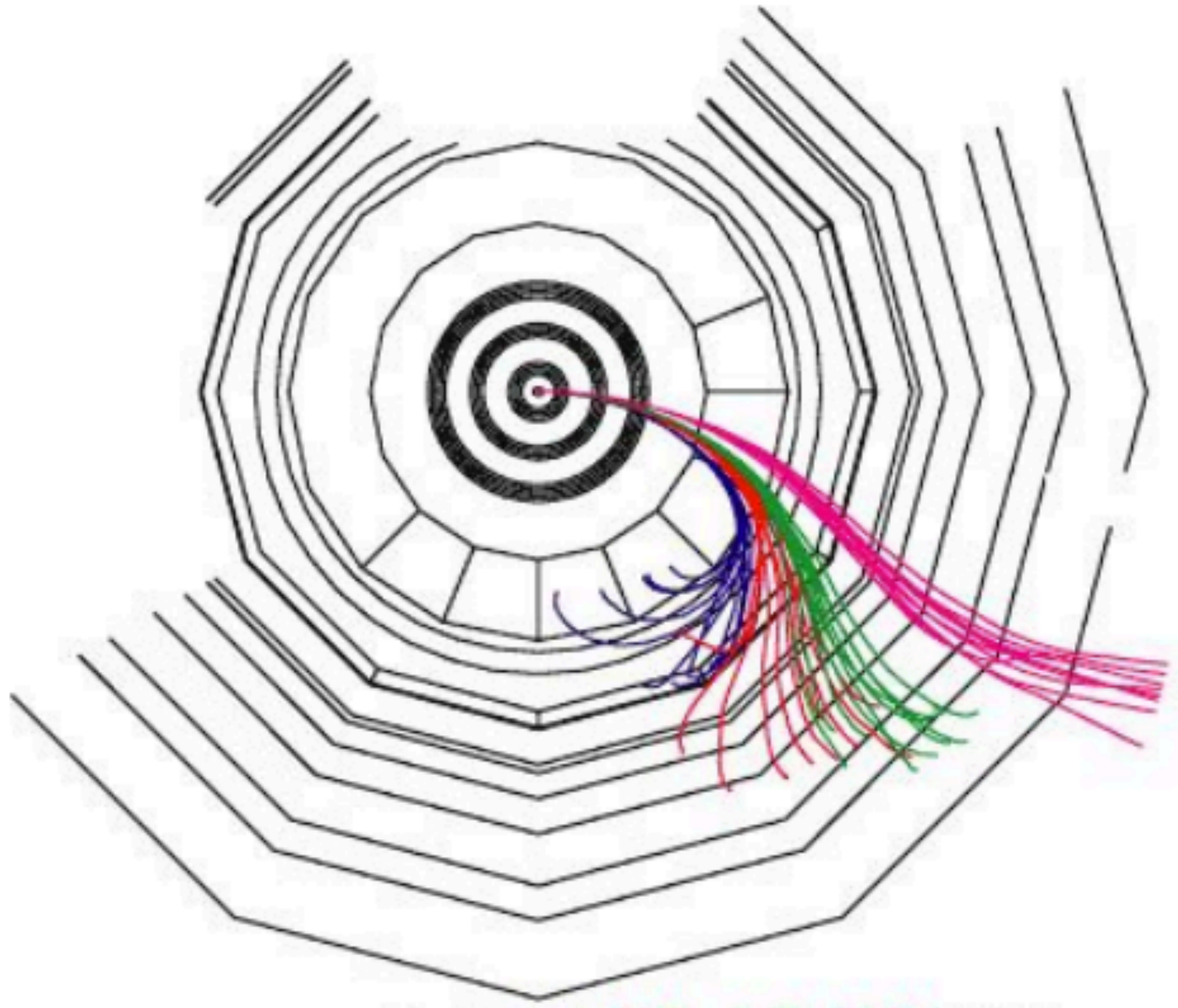
- Standard approach: Outside-in
  - Standalone Muon
  - Combine with tracker track to fit GlobalMuon

- "Muon-ID": complementary Inside-out approach
  - Extrapolate every track outward
  - Find compatible deposits in ECAL, HCAL, HO, muon hits
  - Determine muon 'compatibility'

Recover inefficiencies at muon chamber boundaries and low p_T (e.g. Muons which only reach the first muon station)

Inefficiency at eta cracks

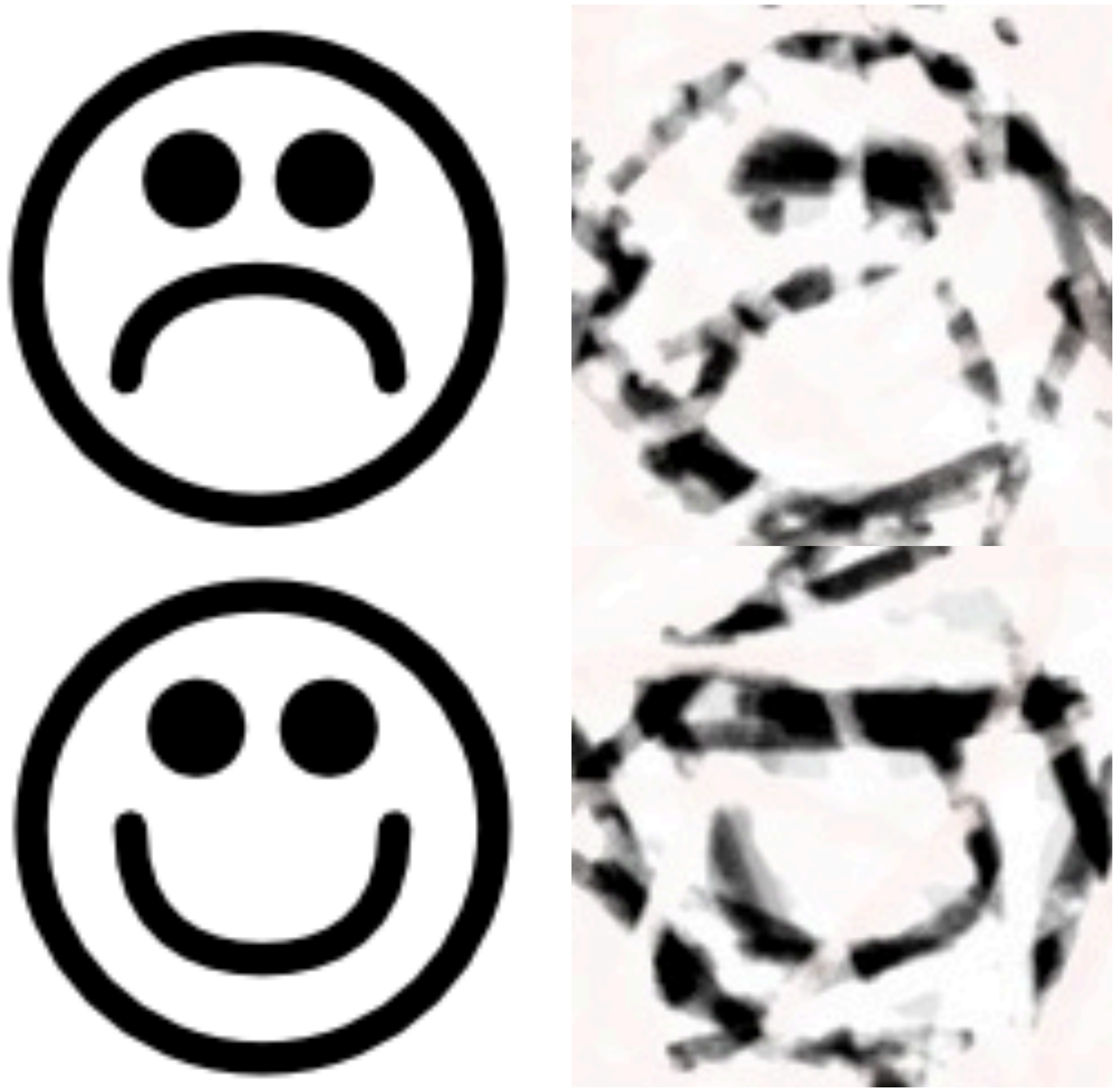




p_t = 3.5, 4.0, 4.5, 6.0 GeV

Level-1: a sufficient look

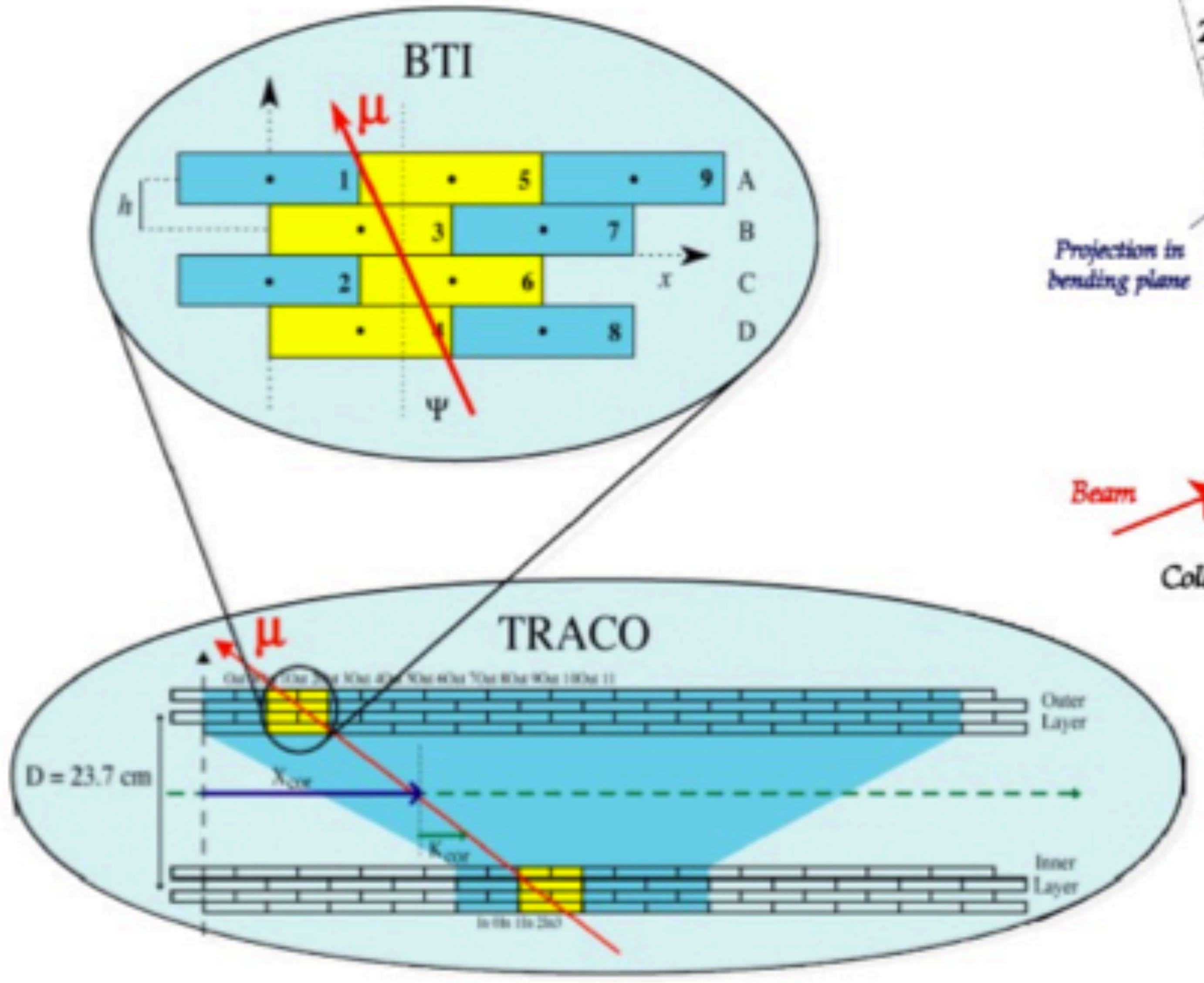
- Not all information is needed to decide to if an event should be kept.

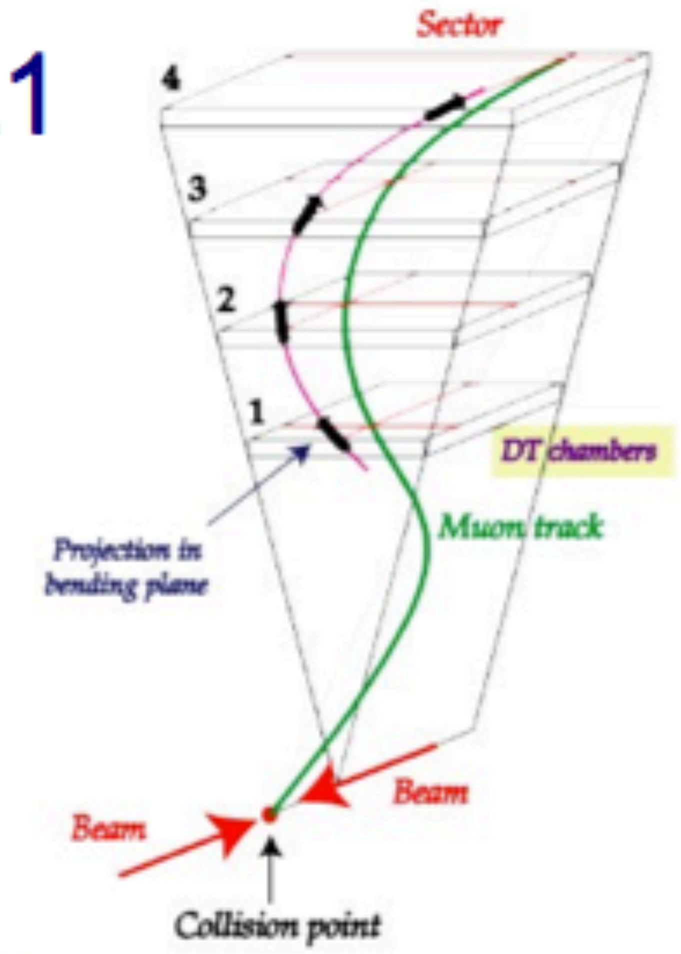


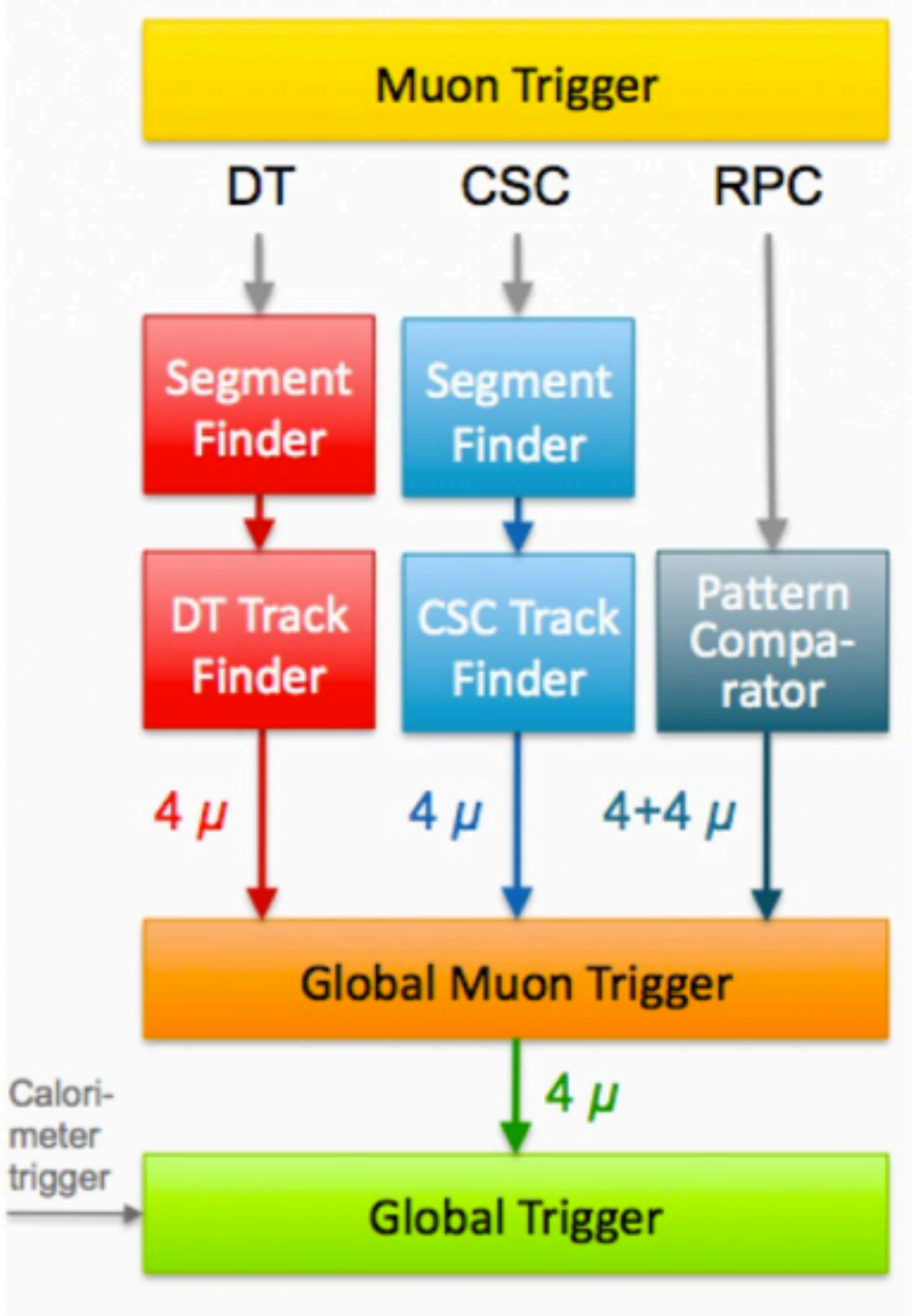
Level-1 Muon trigger

Reconstruct segments in each muon chamber
Combine segments to form track
and measure p_T (rough)

Example: CMS Muon L1



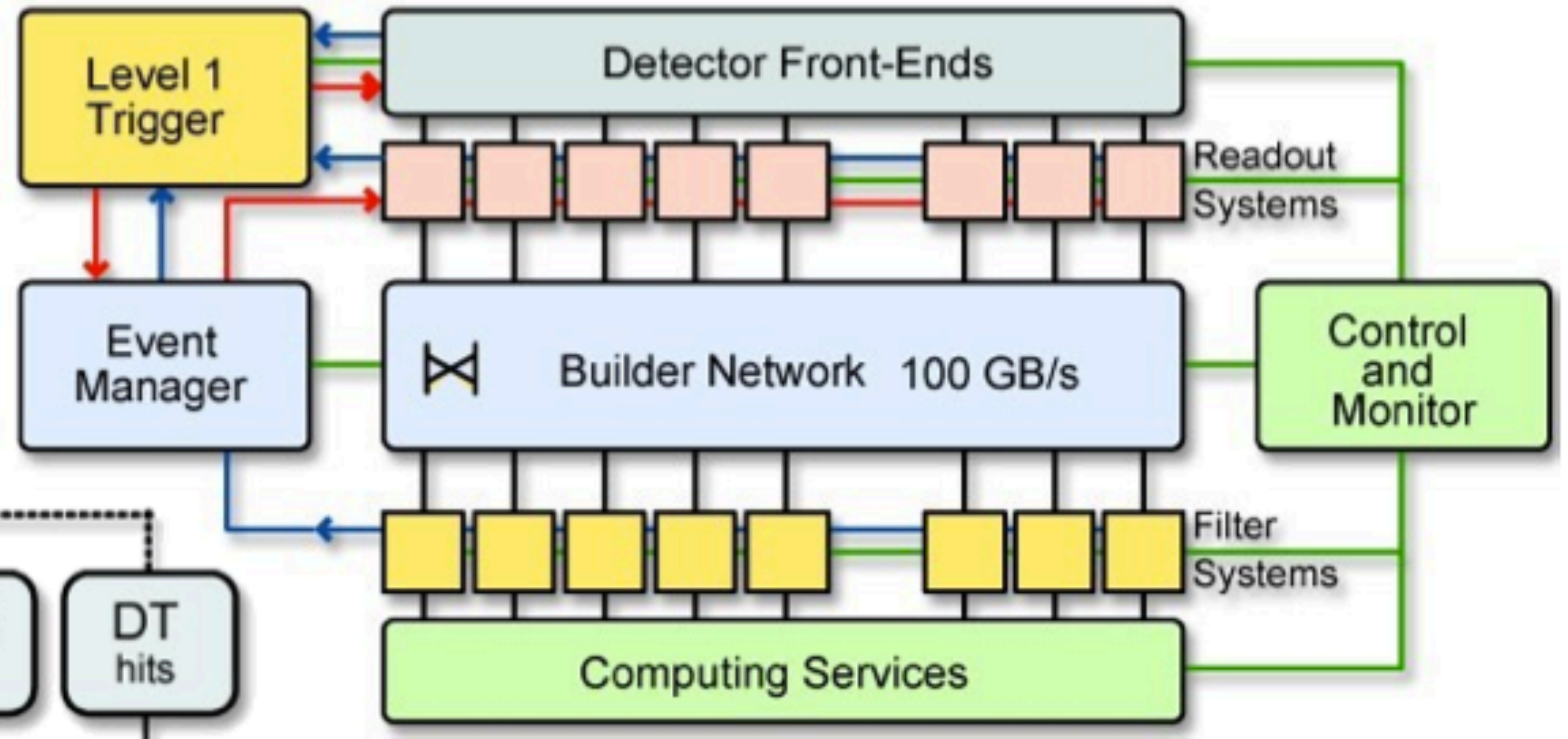


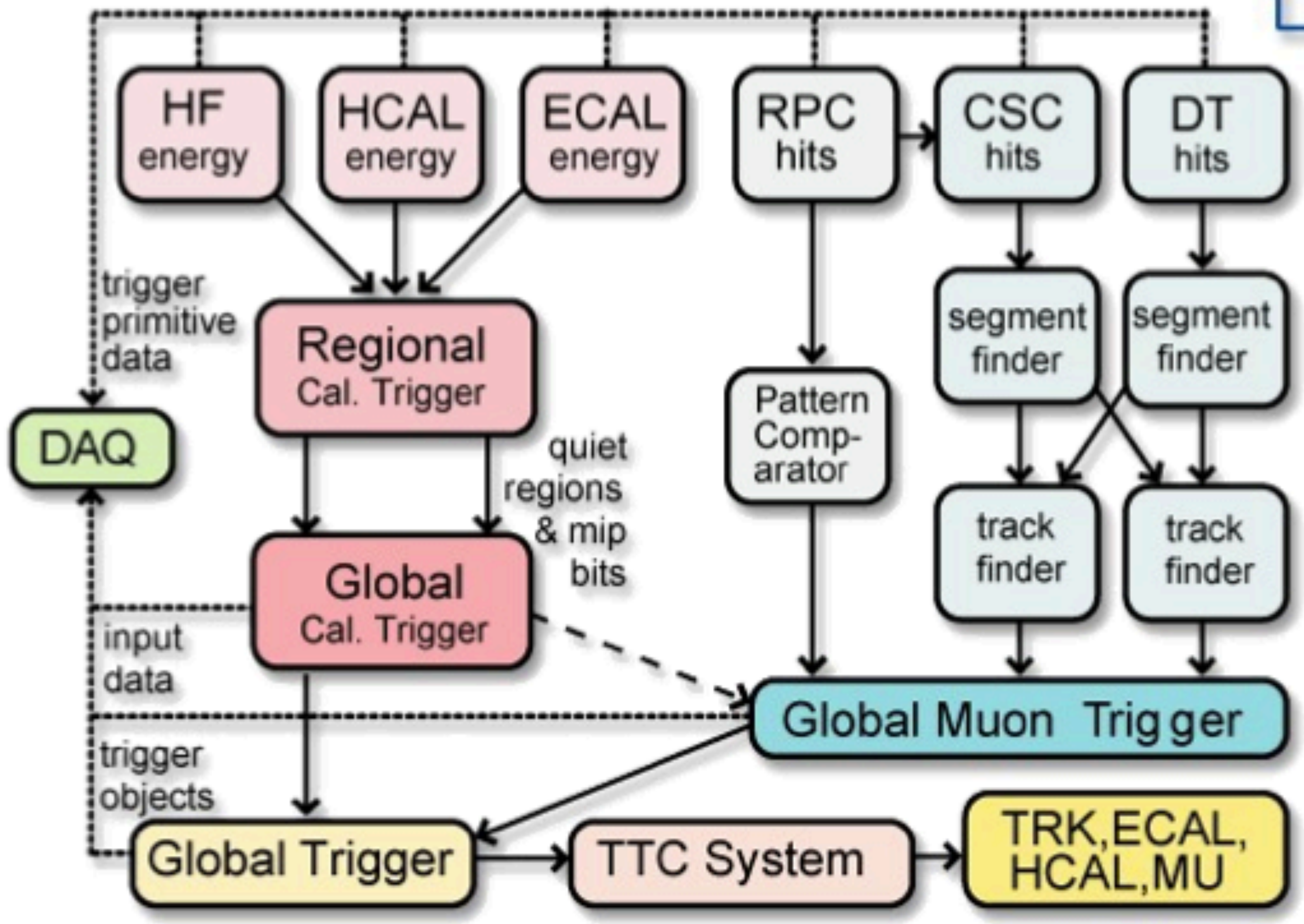


Event building

Overall Trigger & DAQ Architecture: 2 Levels

Level-1 Trigger:
- 3.2 μs latency
- 100 kHz output

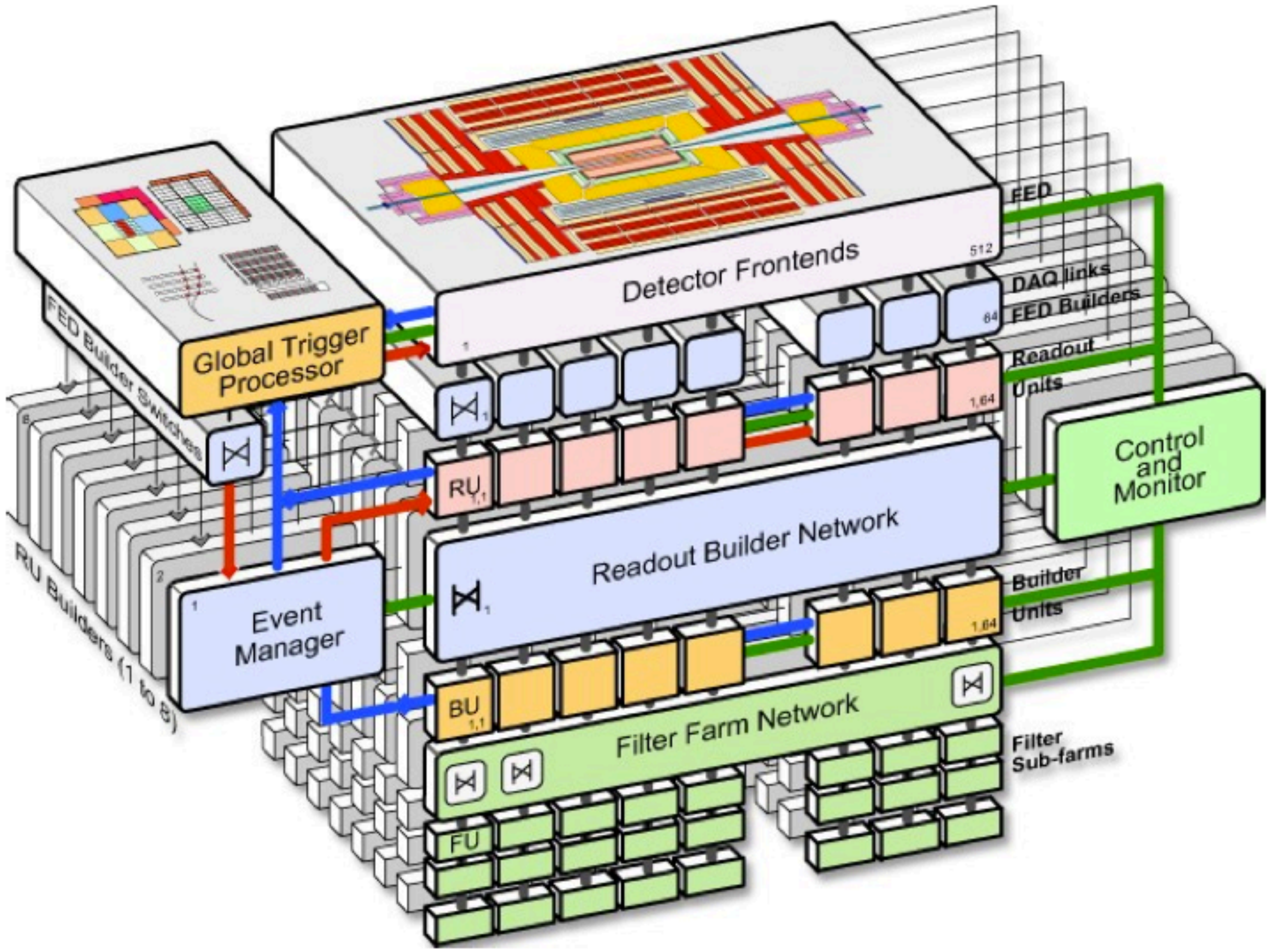




DAQ/HLT:
- Event building at full L1 rate
- Average event size: 1 MB
- Average HLT time: 50 ms
- Output rate: 100-300 Hz

CMS 3D event builder

Event building and filtering done in 8 independent "slices" to facilitate 100 kHz rate



Trigger menus

Each physics signature will one or more "trigger lines" to select it
Collection of trigger lines is "trigger menu" which defines all of the physics the experiment wants to collect events for

Illustrative example of a trigger menu

signature	Level-1	Level-2	Level-3
e20	L1_e15	L2_e20	EF_e20
2e15	L1_2e10	L2_2e15	EF_2e15
mu20	L1_mu20	L2_mu20	EF_mu20
2mu15	L1_2mu10	L2_mu15	EF_mu15
j100	L1_j50	L2_j80	EF_j100
2j50	L1_2j30	L2_2j40	EF_2j50
3j30	L1_3j20	L2_3j25	EF_3j30
j30_met50	L1_j20_met40	L2_j25_met50	EF_j25_met50
....	...	...	...

Trigger Line

Typical to have several hundred trigger lines at hadron collider

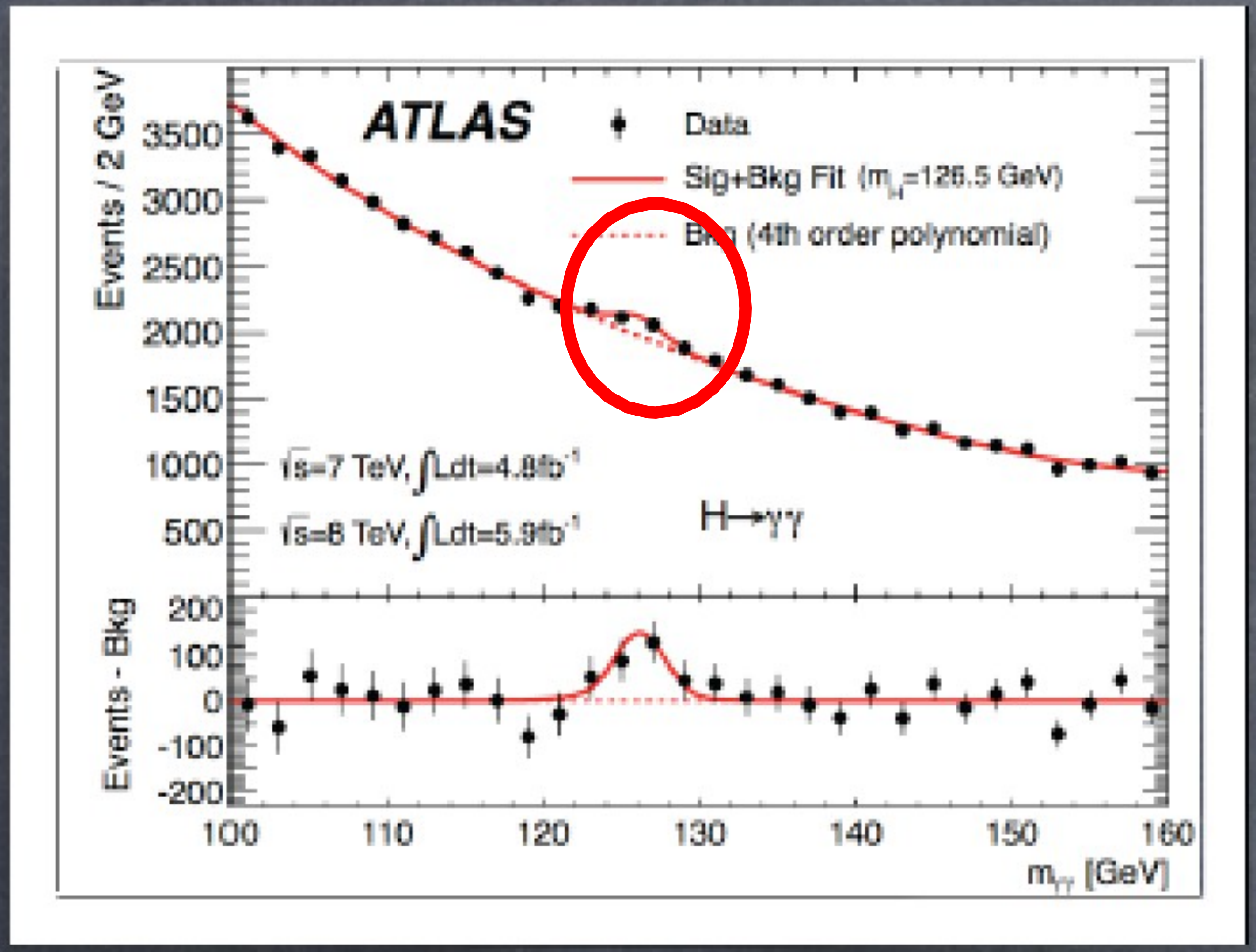
Trigger menu varies with luminosity and time

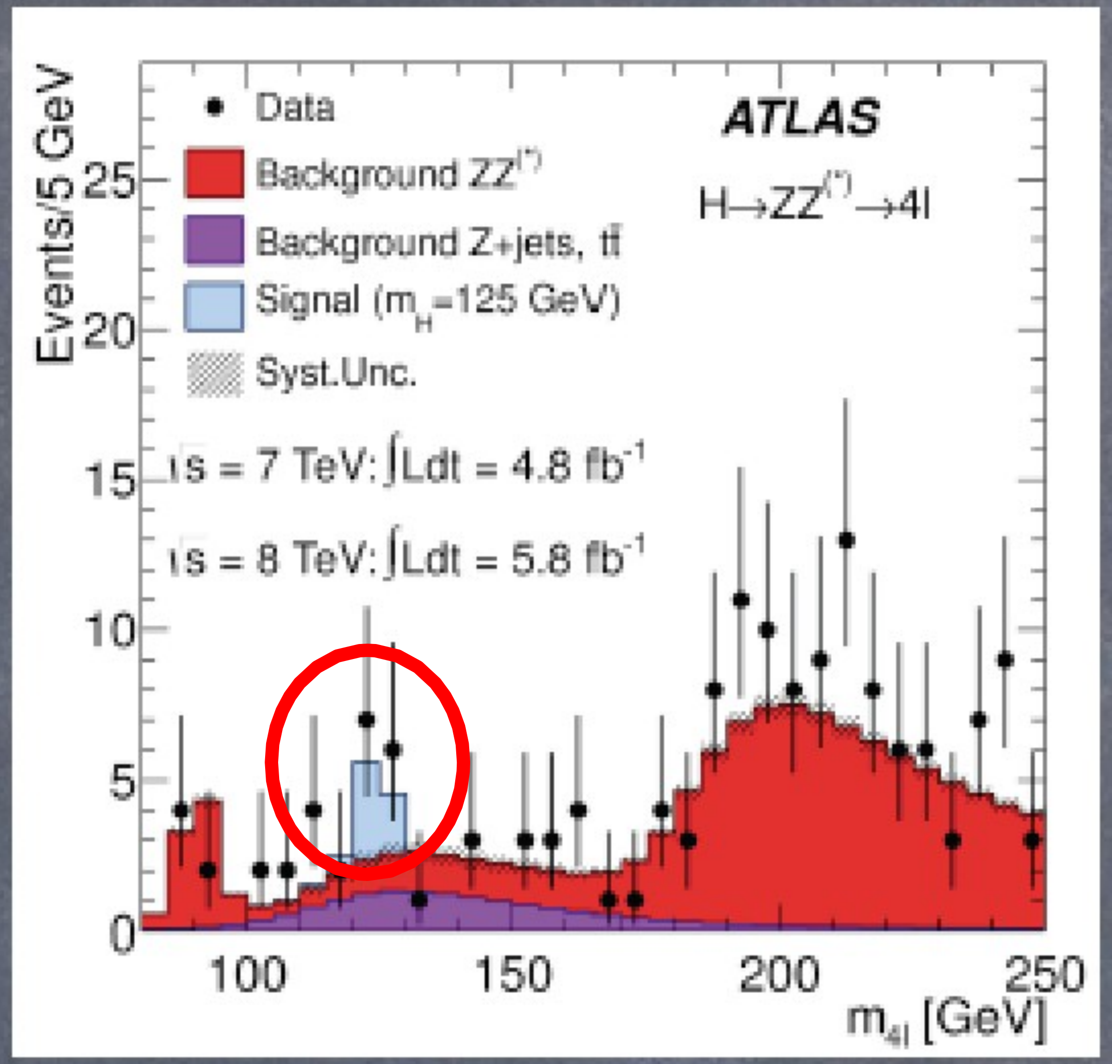
Summer 2012: Results

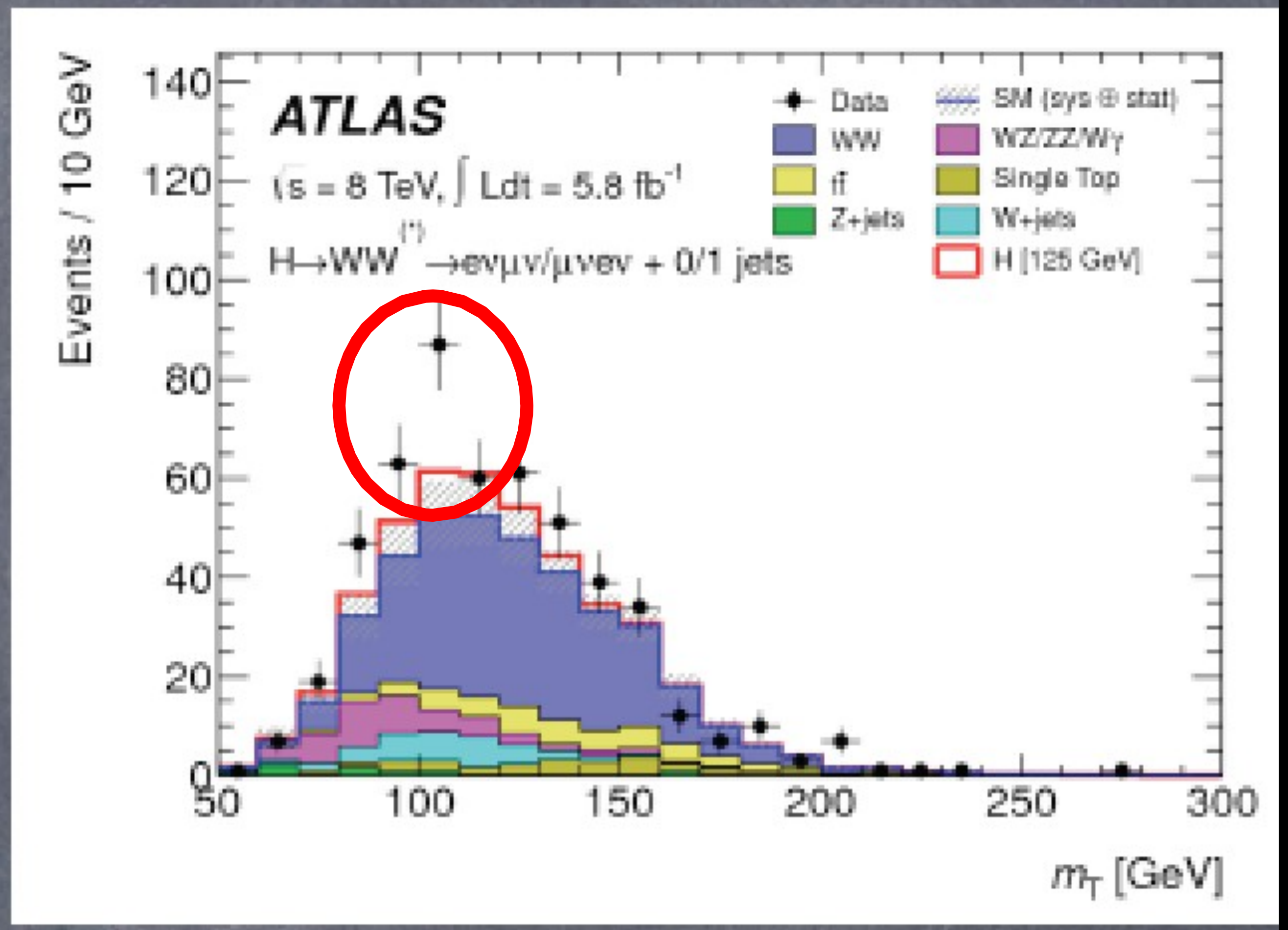
Higgs → 2 photons!!

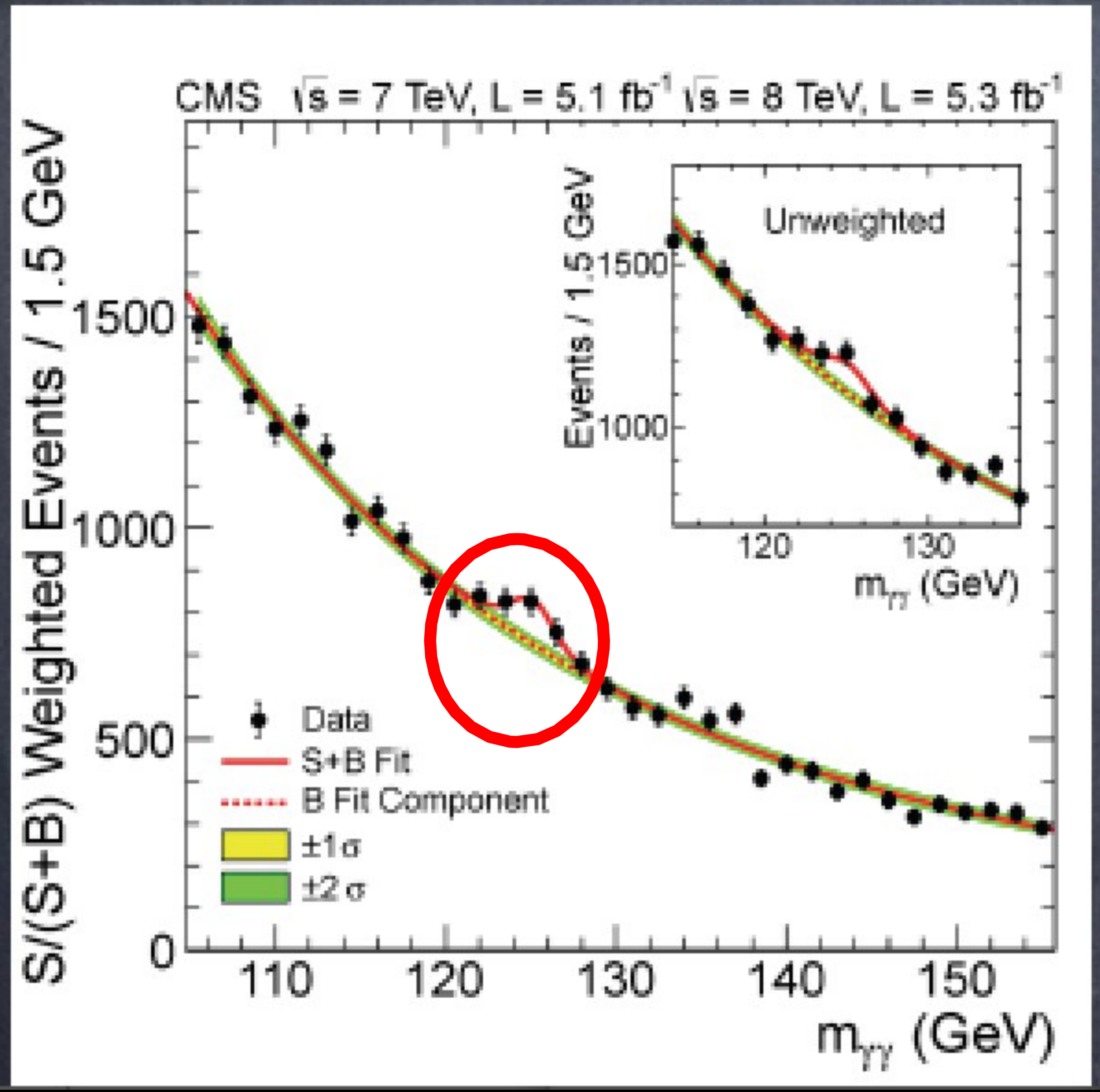
Higgs → 2Z →4 leptons!!

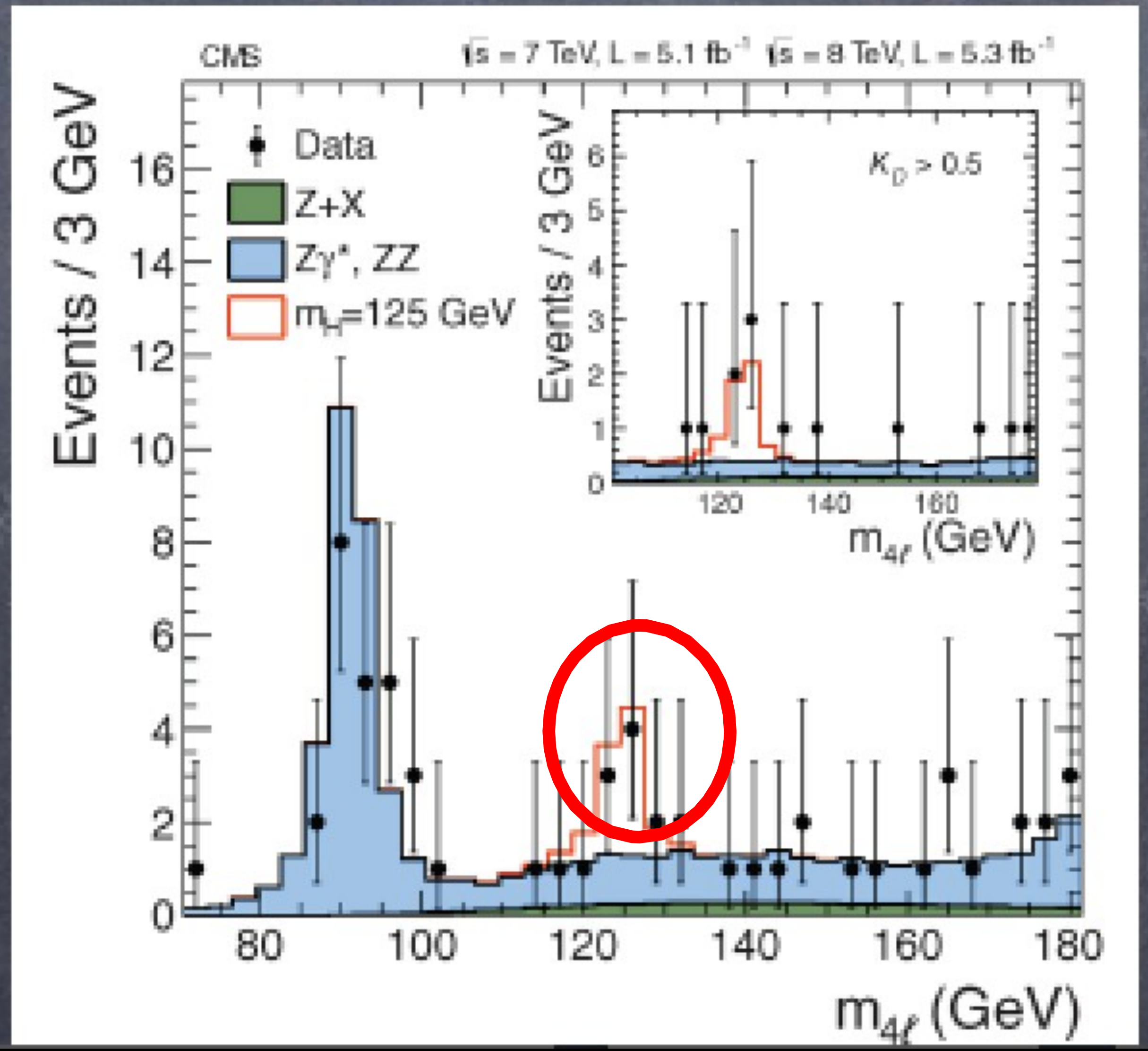
Higgs → 2W →2l2v!!

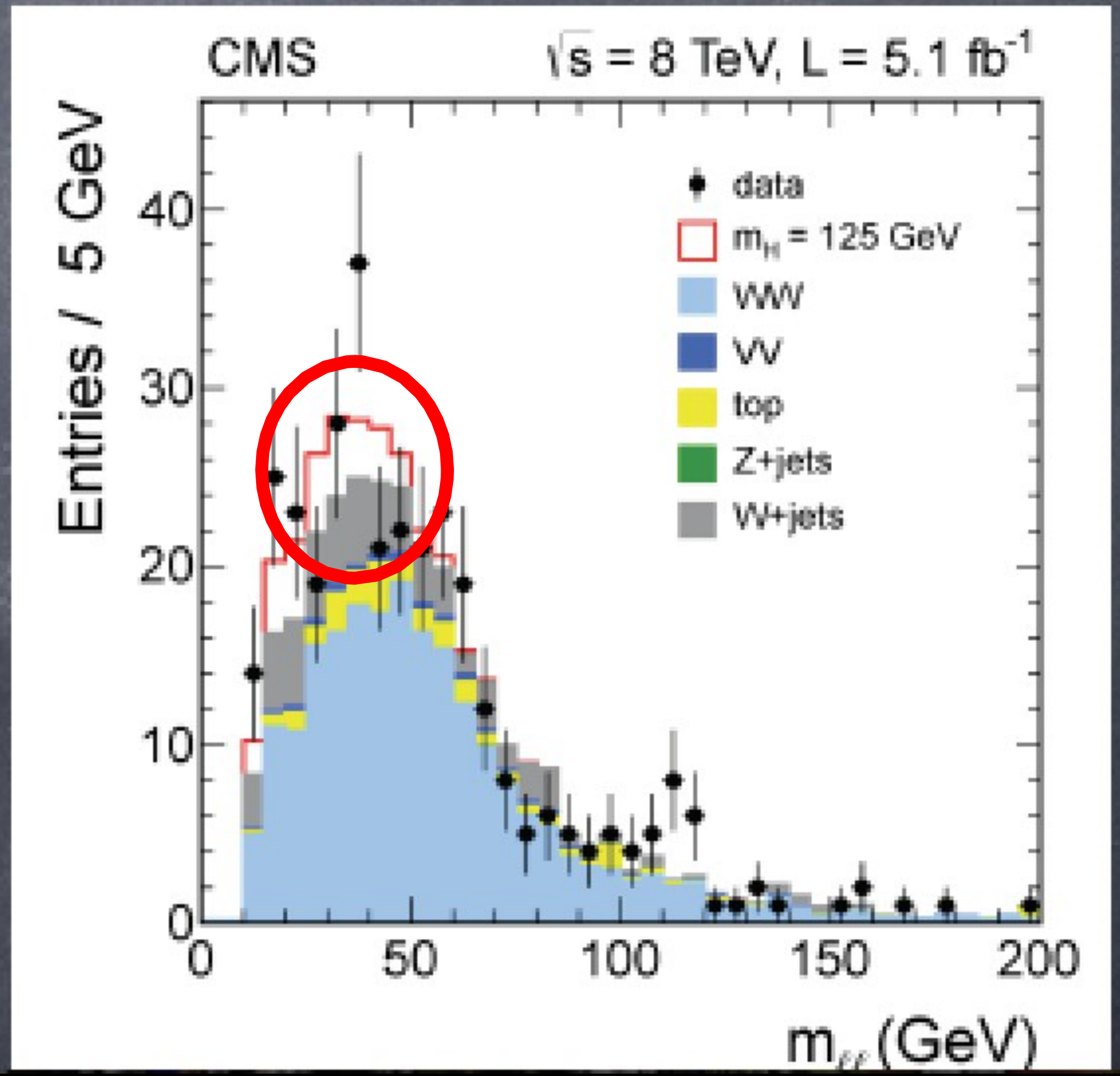












July 4th **2012**

- Official announcement of the discovery of a Higgs-like particle with mass of 125-126 GeV by CMS and ATLAS.
- Historic seminar at CERN with simultaneous transmission and live link at the large particle physics conference of 2012 in Melbourne, Australia

CERN

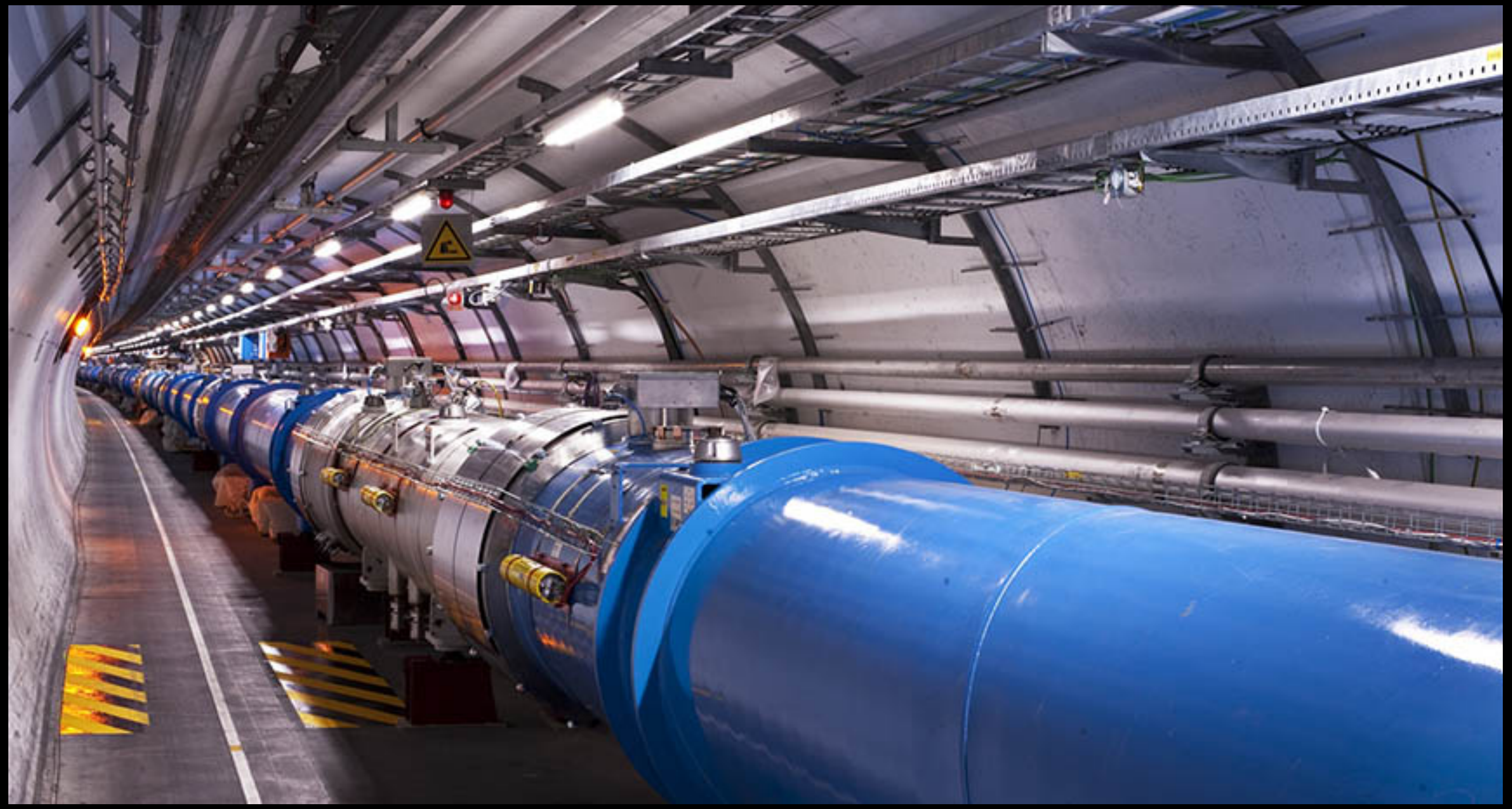
Melbourne

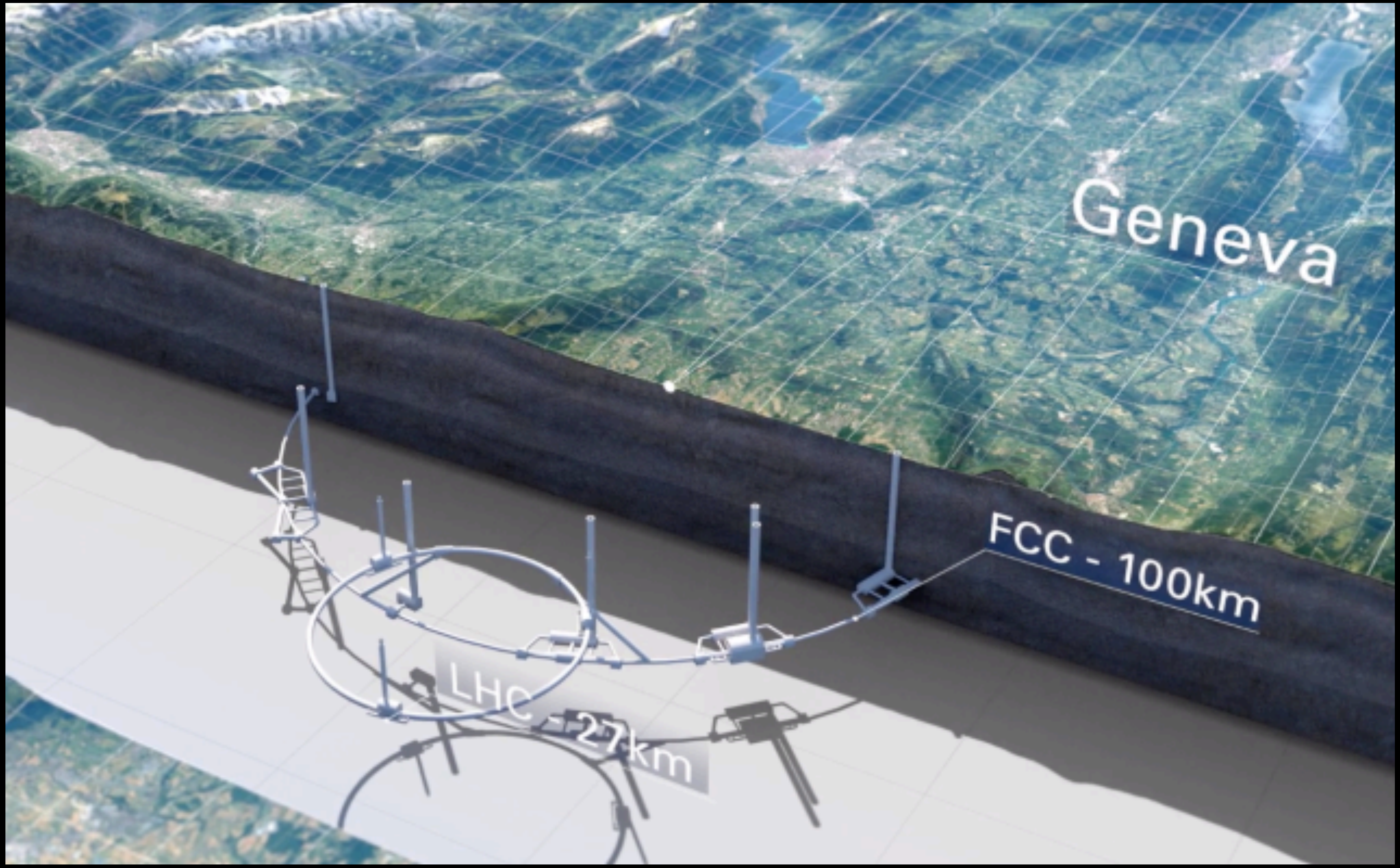
Followed live around the world…

Tuesday 8 October 2013 Nobel Prize


ALFR· NOBEL
NAT· MDCCC XXXIII OB· MDCCC XCVI
INDIA CMS

New projects at CERN on the horizon … until 2050



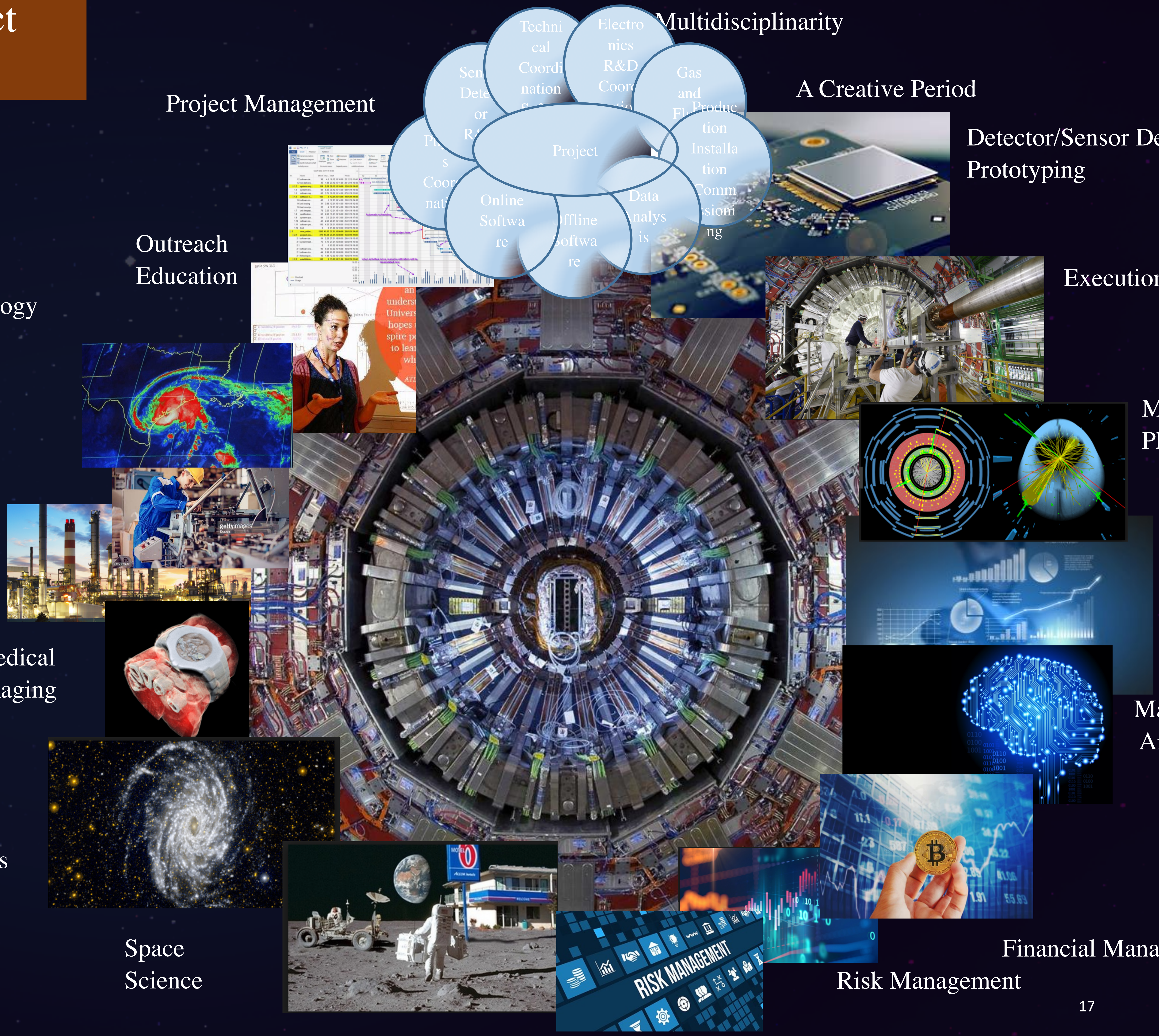


A Mega Science Project like CERN is a vehicle

Anyone can with Collaboration

Particle physicists / Scientists are sought after in every domain.

The skill set is unique – “a new value” creation: Multidimensional Growth



Thank you for your attention !