Welcome to CERN

Prof Dr Freya Blekman
Interuniversity Institute for High Energies (IIHE)
Vrije Universiteit Brussel

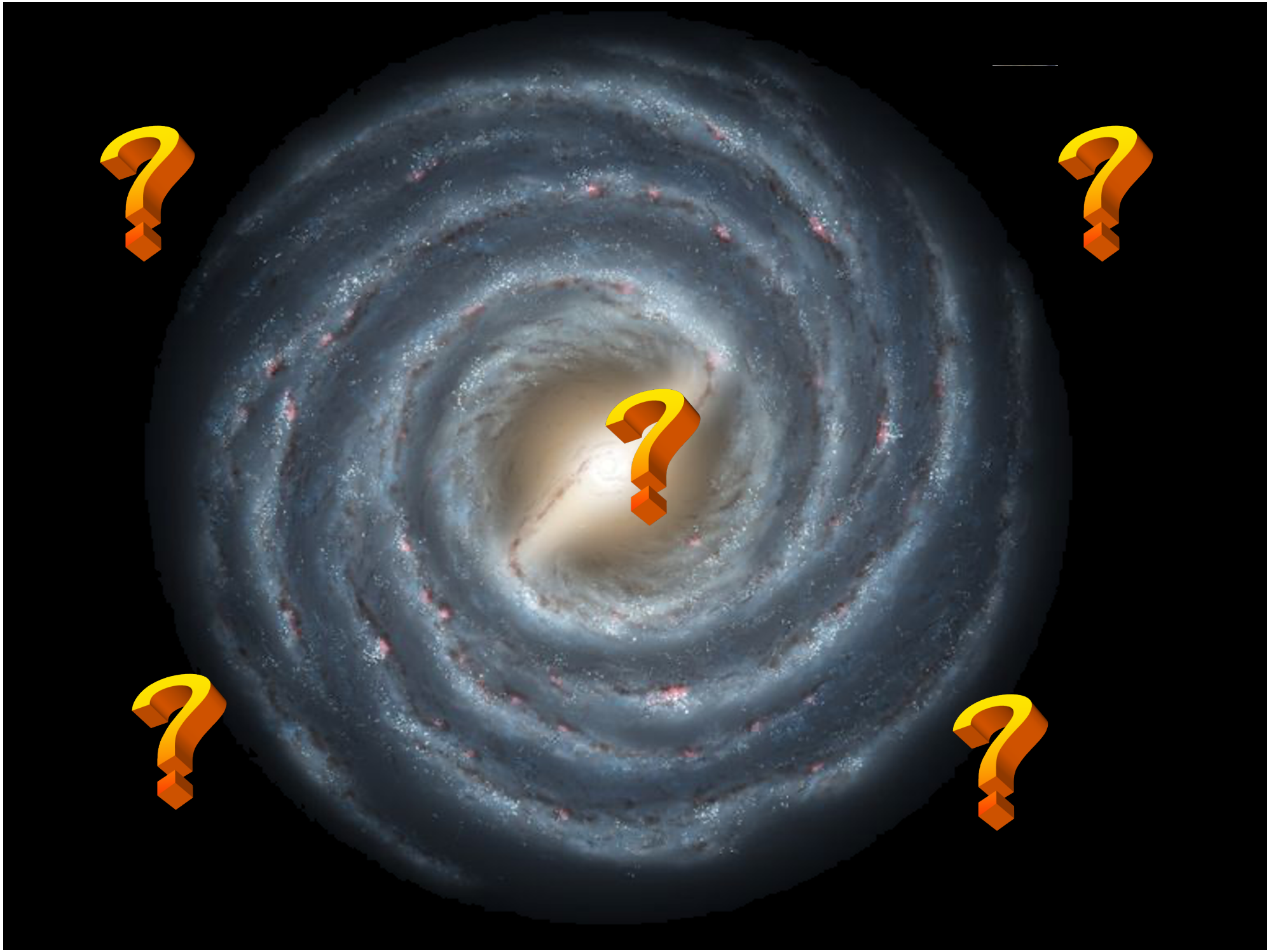
- From Amsterdam, NL
- Experimental physics at Universiteit van Amsterdam
- Ph.D. at Nikhef (NL), the Netherlands' national particle physics institute
  - Largely based in Chicago (USA)
- Imperial College London (UK)
- Cornell University (USA)
- Professor at Vrije Universiteit Brussel, Brussels (BE)
  - Visiting professor University of Oxford
  - Visiting researcher Fermilab

Twitter: freyablekman
freya.blekman@cern.ch

Physicists are world citizens

- Live in many different countries
- Travel to even more places for work
- Working with people from all over the world

Twitter: freyablekman
freya.blekman@cern.ch



- Introduction
- CERN
  - What and Where is it?
  - Who works there?
  - What do we do there?
- Particle Physics
  - Questions, answers and the theory of everything...
- The Large Hadron Collider
  - The Compact Muon Solenoid

Twitter: freyablekman
freya.blekman@cern.ch

What is CERN ?

Twitter: freyablekman
freya.blekman@cern.ch

1953

Sur le terrain du futur institut nucléaire

Sous la conduite de M. A. Picot, les membres du Conseil européen pour la recherche nucléaire se sont rendus hier à Meyrin pour reconnaître le terrain où s'élèvera le Centre nucléaire (voir en Dernière heure)

(Photo Freddy Bertrand, Genève)

La Suisse du 30 octobre 1953

Twitter: freyablekman
freya.blekman@cern.ch

Important dates

- 1949: first steps towards civilian research in nuclear technology
- 1952: foundation of CERN under auspices of UNESCO
- 1953: Signing of the CERN charta
- 1954 Completion of the ratification of the 12 member states

Twitter: freyablekman
freya.blekman@cern.ch

Finances & member states

Contributions from Member States in 2019

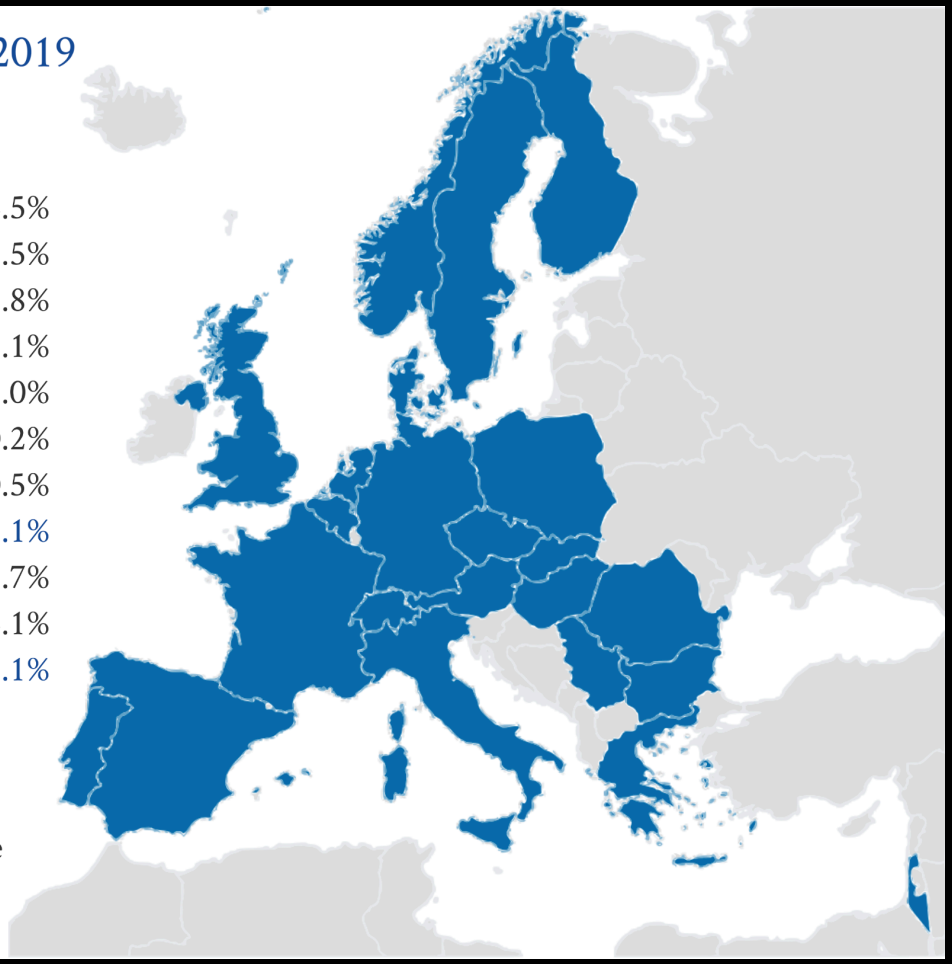
Annual budget: 1.17 billion CHF

Austria	2.1%	Netherlands	4.5%
Belgium	2.7%	Norway	2.5%
Bulgaria	0.3%	Poland	2.8%
Czech Republic	0.9%	Portugal	1.1%
Denmark	1.8%	Romania	1.0%
Finland	1.3%	Serbia	0.2%
France	14.0%	Slovakia	0.5%
Germany	20.6%	Spain	7.1%
Greece	1.0%	Sweden	2.7%
Hungary	0.6%	Switzerland	4.1%
Israel	1.7%	United Kingdom	16.1%
Italy	10.4%		

Associate Member States (~25 MCHF)

India, Lithuania, Pakistan, Turkey, Ukraine

Cyprus, Slovenia



Twitter: freyablekman

freya.blekman@cern.ch

Belgium at CERN

One of the twelve CERN founding member states

- Belgium nowadays one of the 22 CERN member states
- CERN membership of 27 M€/year funded by Belgian Federal Government (FOD Economie)
- CERN Mandate:
  - Fundamental scientific research
  - Technology transfer
  - Training and educating STEM professionals of the future
  - International collaboration

Twitter: freyablekman
freya.blekman@cern.ch

Who works at CERN?

- 3000 people employed by CERN
  - Physicists, engineers, computer scientists, mathematicians, firemen, cooks, builders, technicians, secretaries, security, etc
- >10000 physicists associated with CERN
  - Including yours truly

Twitter: freyablekman
freya.blekman@cern.ch

Who works at CERN?

Twitter: freyablekman
freya.blekman@cern.ch

Who visits CERN

- CERN is an open laboratory
- Anyone is welcome to visit, ask questions, take photographs, etc
- Every year, 25,000 people visit CERN
- Open days September 2019, 75000 people visited in 2 days!!!

Twitter: freyablekman
freya.blekman@cern.ch

What do we do at CERN?

Twitter: freyablekman
freya.blekman@cern.ch

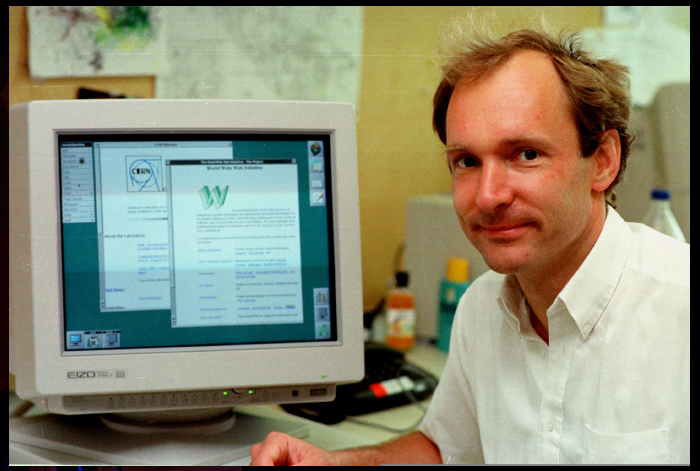
Basic vs applied research

- Two types of science research
  - Basic research (how do things work)
  - Applied research (how do I make...)

- CERN only does basic research
  - But usually we need to build things that do not exist yet...
- Applied research needs basic research

Twitter: freyablekman
freya.blekman@cern.ch

CERN - where the web was born

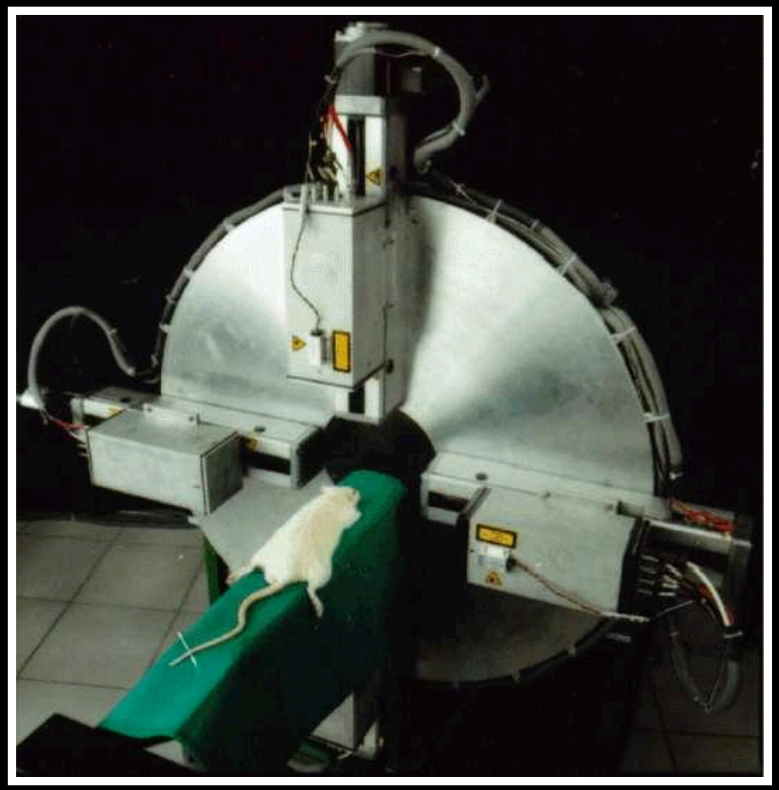


Tim Berners-Lee

Twitter: freyablekman
freya.blekman@cern.ch

But also...

- PET scans
- Radiation therapy

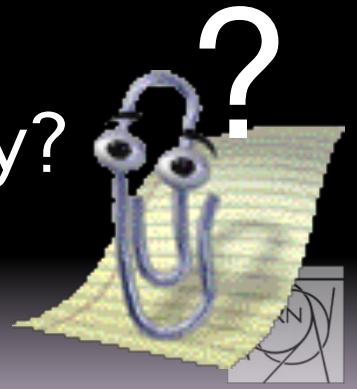


- Loads of computing/internet development
  - cloud, fast internet, quantum computing

Twitter: freyablekman
freya.blekman@cern.ch

Basic Questions

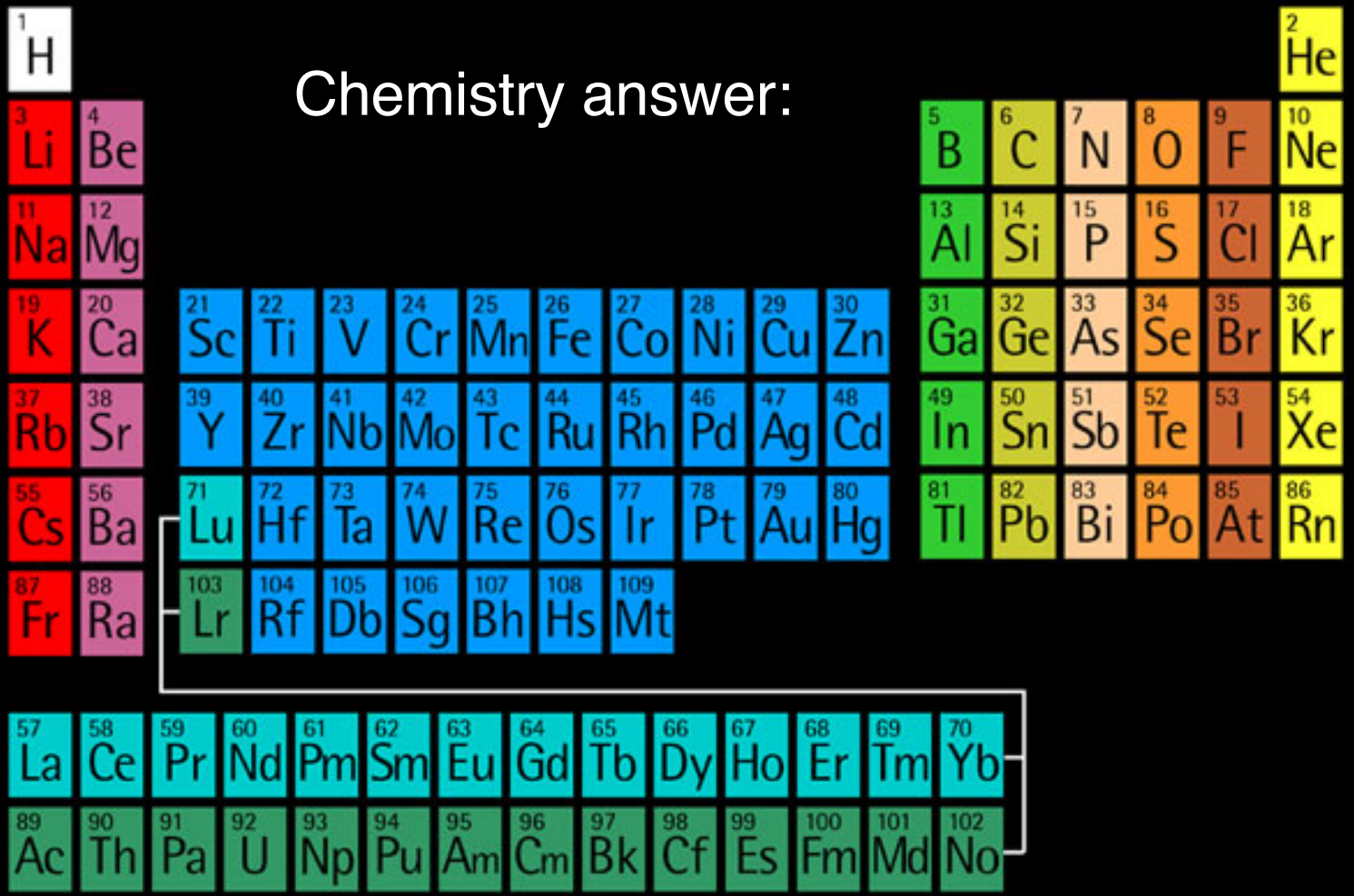
- What is everything around us made of?
- How does matter stick together?
- What, really, is mass?
  - And does the Higgs particle indeed play a role in the creation of mass?
- Are there really only 3 spatial dimensions?
- Are the smallest particles we know fundamental?
- Where did the anti-matter go?
- Where's the rest of the matter anyway?



Twitter: freyablekman
freya.blekman@cern.ch

What is everything around us made of?

Chemistry answer:

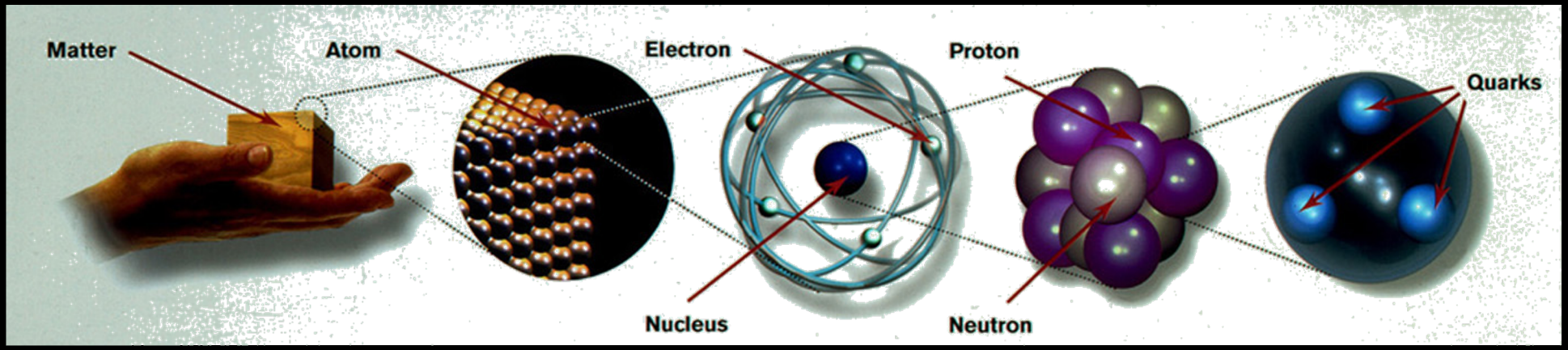


Twitter: freyablekman

freya.blekman@cern.ch

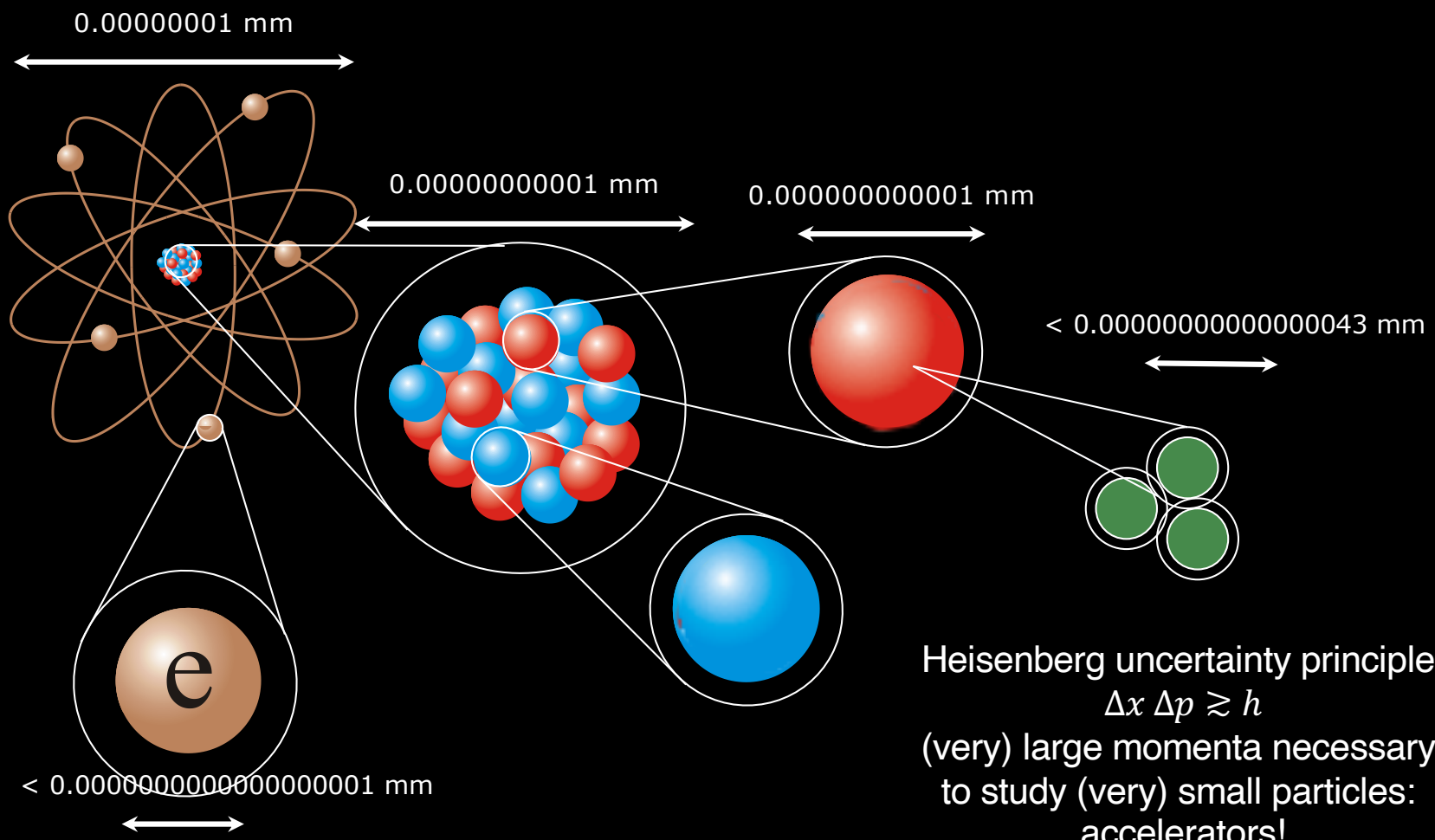
What is everything around us made of?

Physics answer:



Twitter: freyablekman
freya.blekman@cern.ch

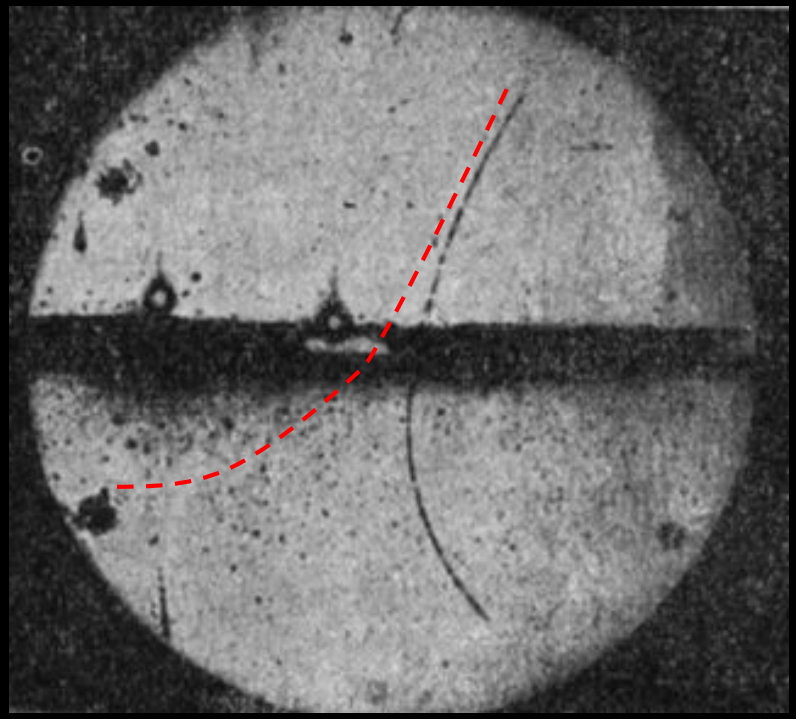
Scales of the subatomic world



Heisenberg uncertainty principle:
$\Delta x \, \Delta p \gtrsim h$
(very) large momenta necessary
to study (very) small particles:
accelerators!

Twitter: freyablekman
freya.blekman@cern.ch

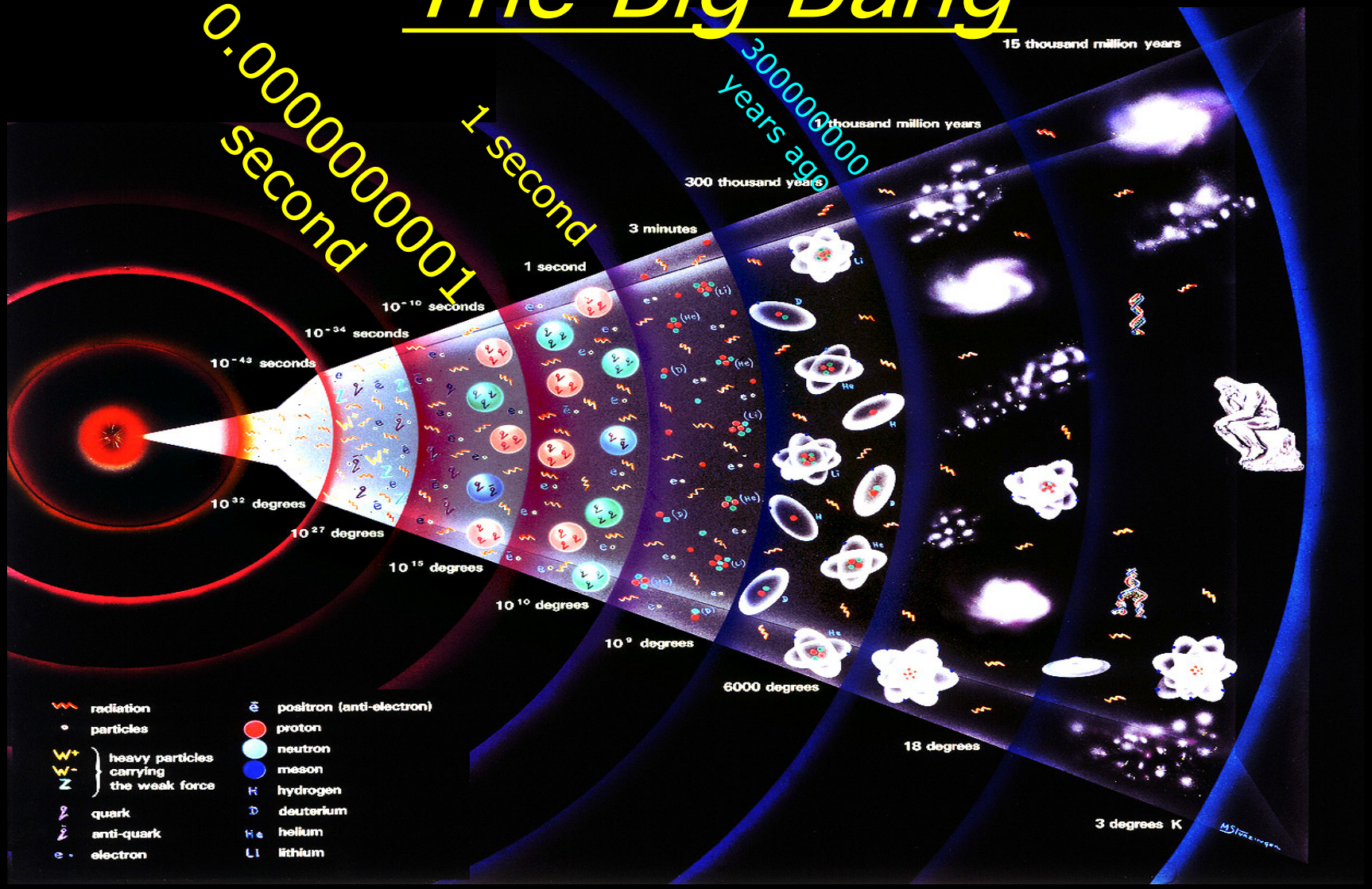
Anti-matter



- Anti-matter: discovered in 1923
  - Predicted by theory
- *Almost* same as matter... But oppositely charged
- Problem: at big bang there was just as much matter as anti-matter... Where did it go?

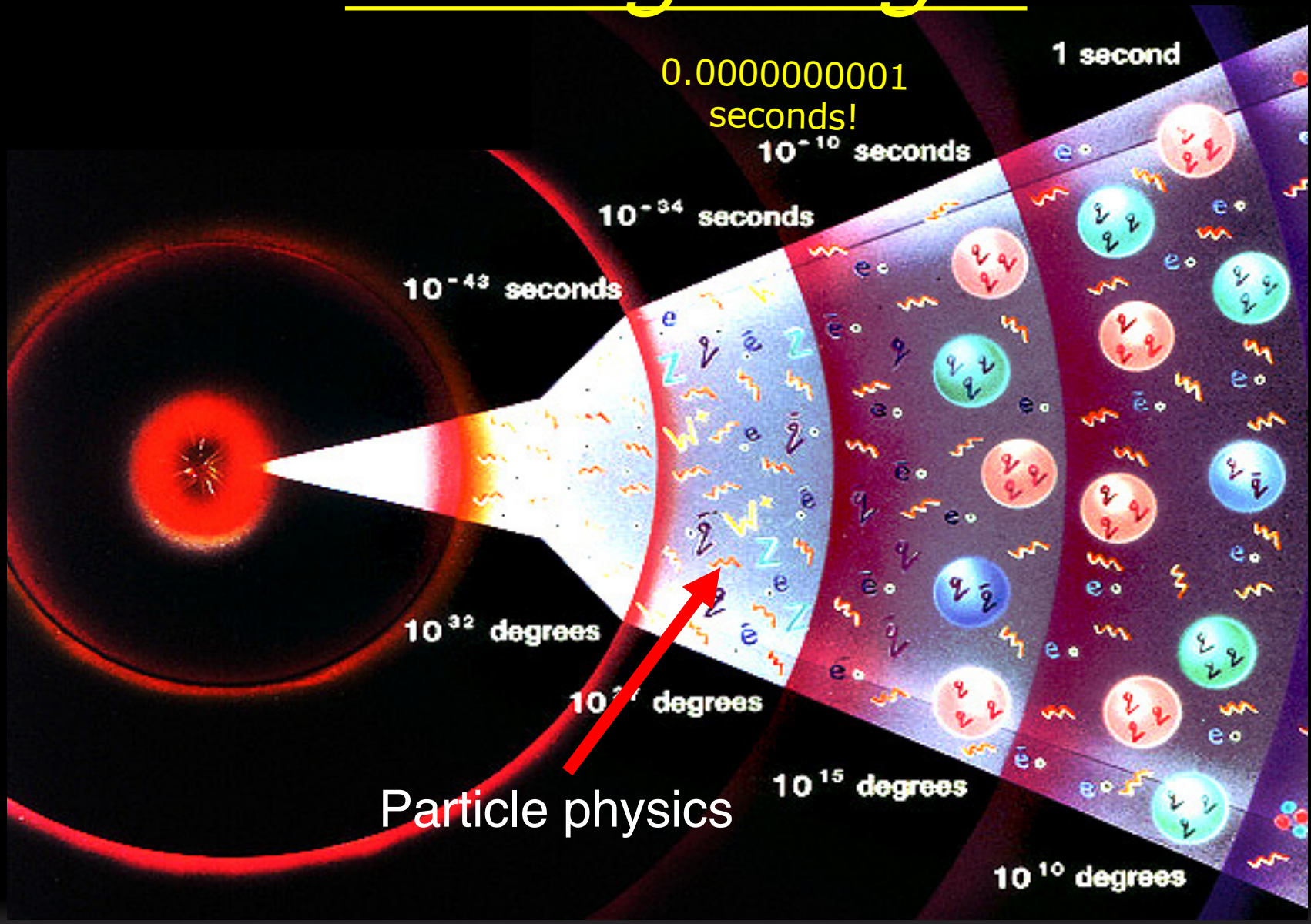
Twitter: freyablekman
freya.blekman@cern.ch

The Big Bang



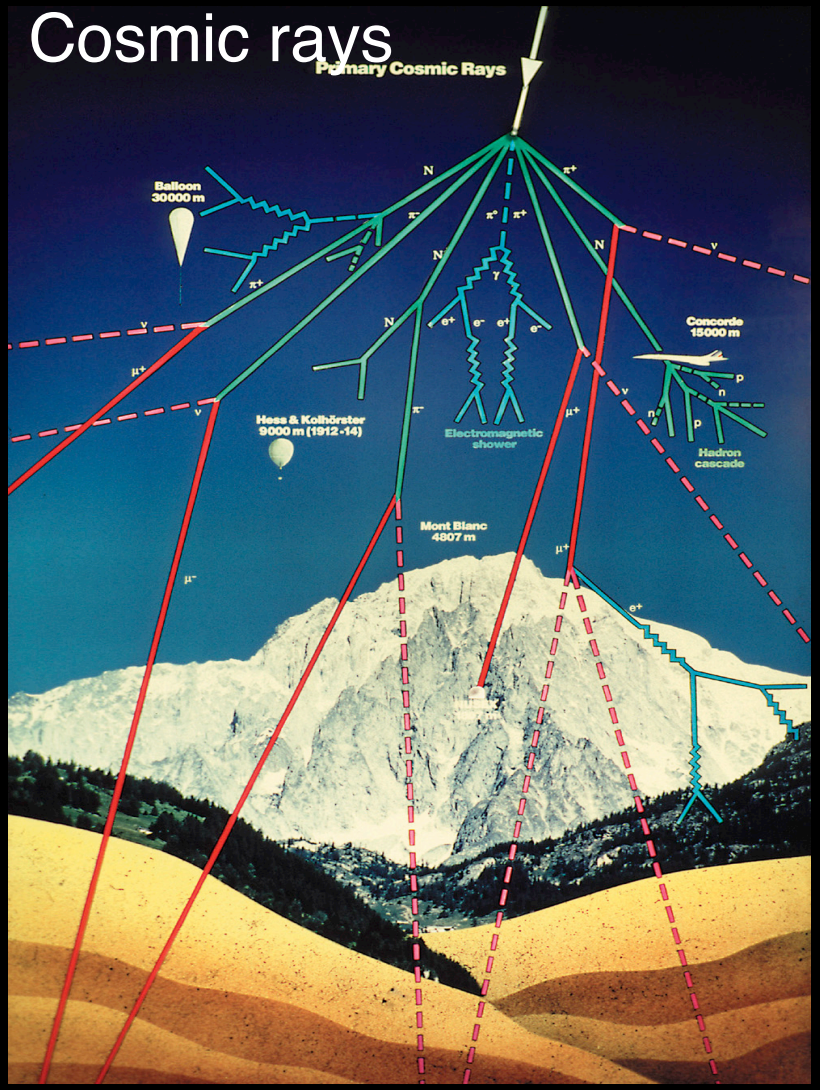
Twitter: freyablekman
freya.blekman@cern.ch

The Big Bang...



Twitter: freyablekman
freya.blekman@cern.ch

How do we know all this?



Accelerator experiments
Radioactivity experiments

And about 100 years of hard work by many people...

Twitter: freyablekman
freya.blekman@cern.ch

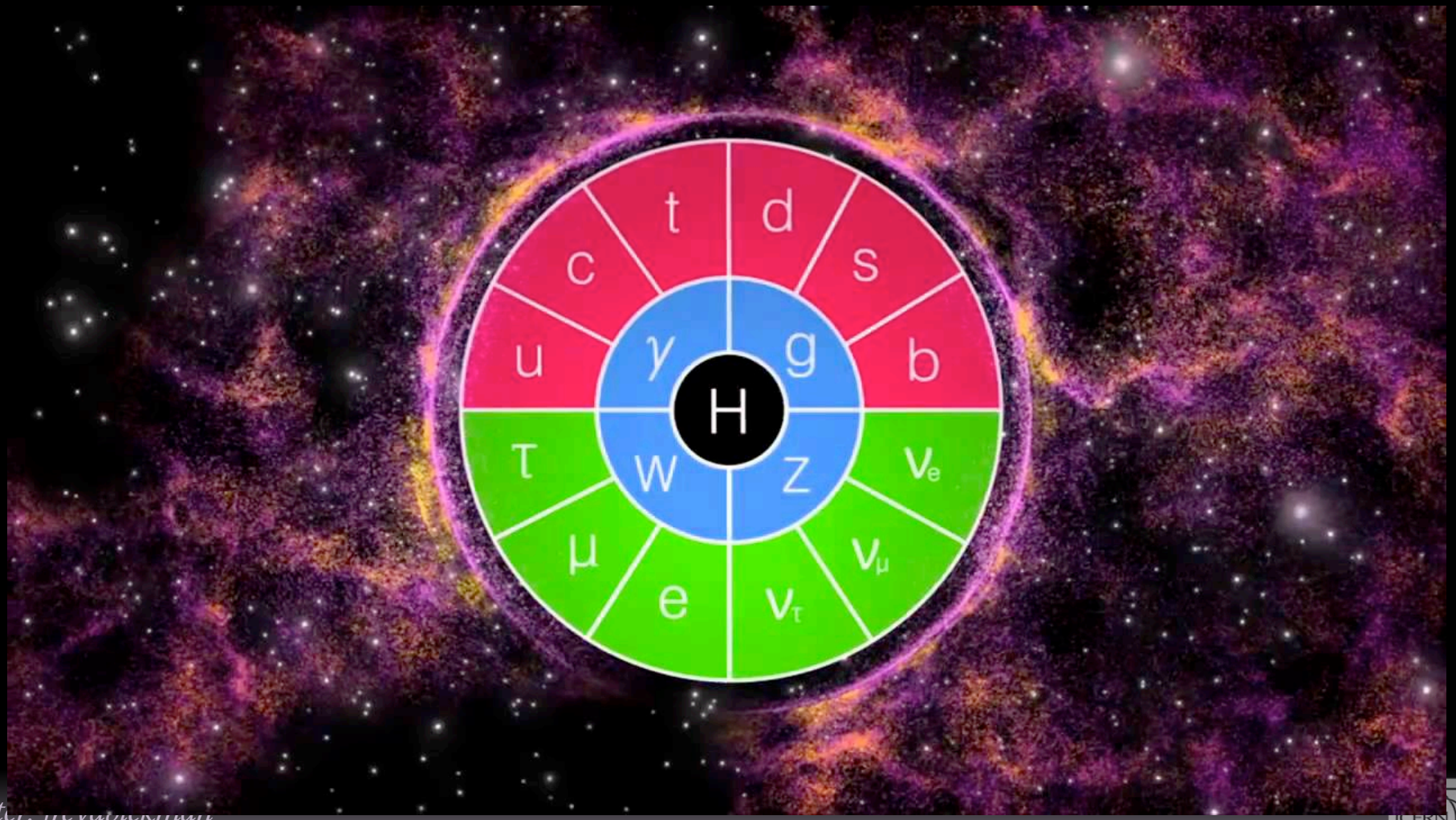
Needed: machine for searching

Twitter: freyablekman
freya.blekman@cern.ch

The Large Hadron Collider

Twitter: freyablekman
freya.blekman@cern.ch

The Standard Model!



Twitter: freyablekman
freya.blekman@cern.ch


$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$
$+ i \not{F} \not{D} \not{F} + h.c$
$+ \chi_i y_{ij} \chi_j \phi + h.c$
$+ |D_\mu \phi|^2 - V(\phi)$

1 $-\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4}g_s^2 f^{abc} f^{ade} g^b_\mu g^c_\nu g^d_\mu g^e_\nu +$
$\frac{1}{2}ig_s^2(\bar{q}^\sigma_i \gamma^\mu q^\sigma_j) g^a_\mu + \bar{G}^a \partial^2 G^a + g_s f^{abc}\partial_\mu \bar{G}^a G^b g^c_\mu - \partial_\nu W^+_\mu \partial_\nu W^-_\mu -$

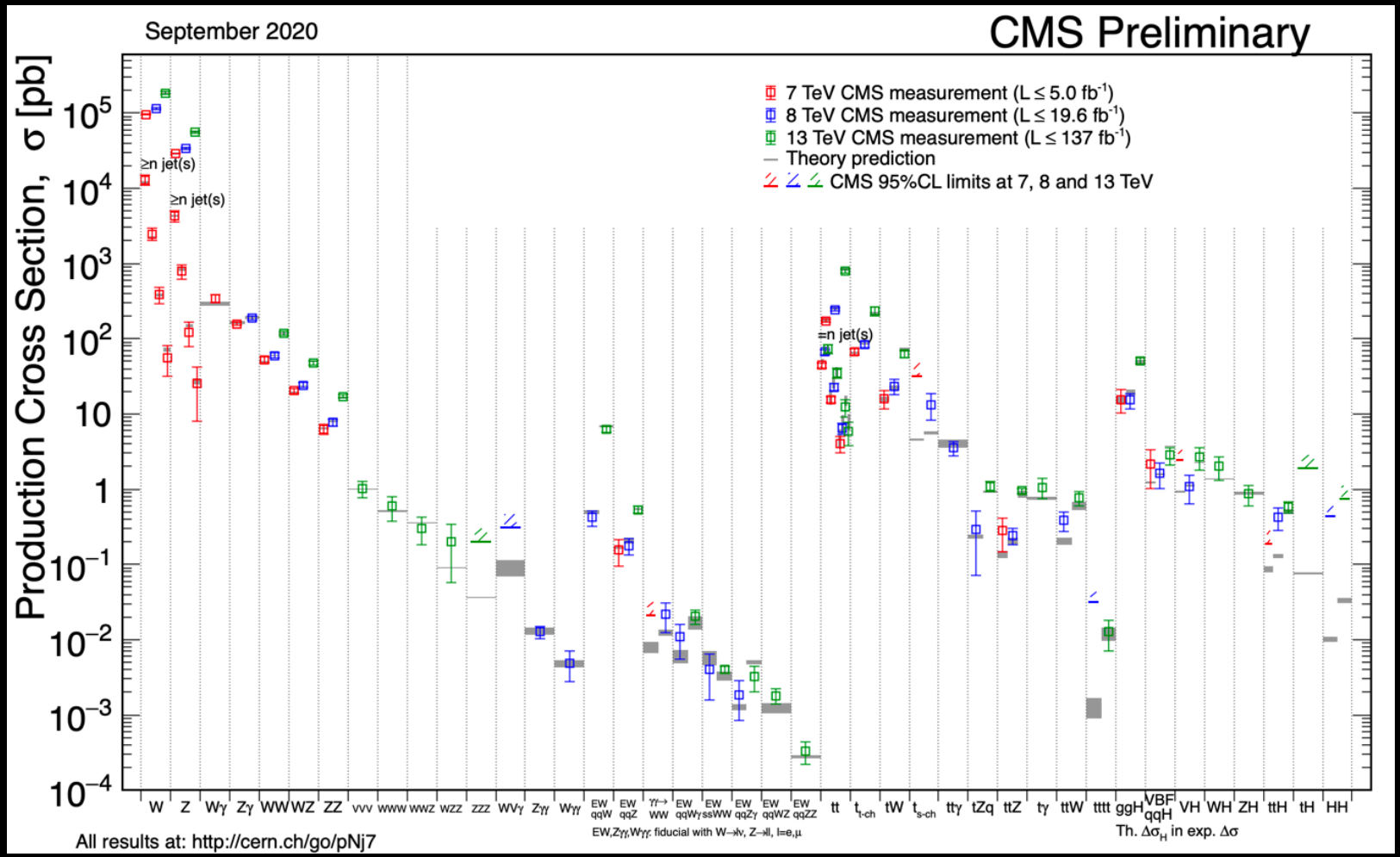
2 $M^2 W^+_\mu W^-_\mu - \frac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \frac{1}{2c_w^2} M^2 Z^0_\mu Z^0_\mu - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \frac{1}{2}\partial_\mu H \partial_\mu H -$
$\frac{1}{2}m_h^2 H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - M^2 \phi^+ \phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \frac{1}{2c_w^2} M \phi^0 \phi^0 - \beta_h [\frac{2M^2}{g^2} +$
$\frac{2M}{g} H + \frac{1}{2}(H^2 + \phi^0 \phi^0 + 2\phi^+ \phi^-)] + \frac{2M^4}{g^2}\alpha_h - igc_w[\partial_\nu Z^0_\mu (W^+_\mu W^-_\nu -$
$W^+_\nu W^-_\mu) - Z^0_\nu (W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + Z^0_\mu (W^+_\nu \partial_\nu W^-_\mu -$
$W^-_\nu \partial_\nu W^+_\mu)] - igs_w[\partial_\nu A_\mu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu (W^+_\mu \partial_\nu W^-_\mu -$
$W^-_\mu \partial_\nu W^+_\mu) + A_\mu (W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)] - \frac{1}{2}g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu +$
$\frac{1}{2}g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2 c_w^2 (Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) +$
$g^2 s_w^2 (A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2 s_w c_w [A_\mu Z^0_\nu (W^+_\mu W^-_\nu -$
$W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu] - g\alpha[H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-] -$
$\frac{1}{8}g^2\alpha_h[H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2 H^2] -$
$gMW^+_\mu W^-_\mu H - \frac{1}{2}g\frac{M}{c_w^2} Z^0_\mu Z^0_\mu H - \frac{1}{2}ig[W^+_\mu(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) -$
$W^-_\mu(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)] + \frac{1}{2}g[W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) - W^-_\mu(H\partial_\mu\phi^+ -$
$\phi^+\partial_\mu H)] + \frac{1}{2}g\frac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) - ig\frac{s_w^2}{c_w} M Z^0_\mu (W^+_\mu\phi^- - W^-_\mu\phi^+) +$
$igs_w M A_\mu (W^+_\mu\phi^- - W^-_\mu\phi^+) - ig\frac{1-2c_w^2}{2c_w} Z^0_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) +$
$igs_w A_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \frac{1}{4}g^2 W^+_\mu W^-_\mu [H^2 + (\phi^0)^2 + 2\phi^+\phi^-] -$
$\frac{1}{4}g^2\frac{1}{c_w^2} Z^0_\mu Z^0_\mu [H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2\phi^+\phi^-] - \frac{1}{2}g^2\frac{s_w^2}{c_w} Z^0_\mu \phi^0 (W^+_\mu\phi^- +$
$W^-_\mu\phi^+) - \frac{1}{2}ig^2\frac{s_w^2}{c_w} Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \frac{1}{2}g^2 s_w A_\mu \phi^0 (W^+_\mu\phi^- +$
$W^-_\mu\phi^+) + \frac{1}{2}ig^2 s_w A_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) - g^2\frac{s_w}{c_w}(2c_w^2 - 1) Z^0_\mu A_\mu \phi^+\phi^- -$
$g^1 s_w^2 A_\mu A_\mu \phi^+\phi^- - \bar{e}^\lambda(\gamma\partial + m^\lambda_e)e^\lambda - \bar{\nu}^\lambda\gamma\partial\nu^\lambda - \bar{u}^\lambda_j(\gamma\partial + m^\lambda_u)u^\lambda_j -$

3 $\bar{d}^\lambda_j(\gamma\partial + m^\lambda_d)d^\lambda_j + igs_w A_\mu[-(\bar{e}^\lambda\gamma^\mu e^\lambda) + \frac{2}{3}(\bar{u}^\lambda_j\gamma^\mu u^\lambda_j) - \frac{1}{3}(\bar{d}^\lambda_j\gamma^\mu d^\lambda_j)] +$
$\frac{ig}{4c_w} Z^0_\mu[(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{e}^\lambda\gamma^\mu(4s_w^2 - 1 - \gamma^5)e^\lambda) + (\bar{u}^\lambda_j\gamma^\mu(\frac{4}{3}s_w^2 -$
$1 - \gamma^5)u^\lambda_j) + (\bar{d}^\lambda_j\gamma^\mu(1 - \frac{8}{3}s_w^2 - \gamma^5)d^\lambda_j)] + \frac{ig}{2\sqrt{2}} W^+_\mu[(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)e^\lambda) +$
$(\bar{u}^\lambda_j\gamma^\mu(1+\gamma^5)C_{\lambda\kappa}d^\kappa_j)] + \frac{ig}{2\sqrt{2}} W^-_\mu[(\bar{e}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{d}^\kappa_j C^\dagger_{\lambda\kappa}\gamma^\mu(1 +$
$\gamma^5)u^\lambda_j)] + \frac{ig}{2\sqrt{2}}\frac{m^\lambda_e}{M}[-\phi^+(\bar{\nu}^\lambda(1-\gamma^5)e^\lambda) + \phi^-(\bar{e}^\lambda(1+\gamma^5)\nu^\lambda)] -$

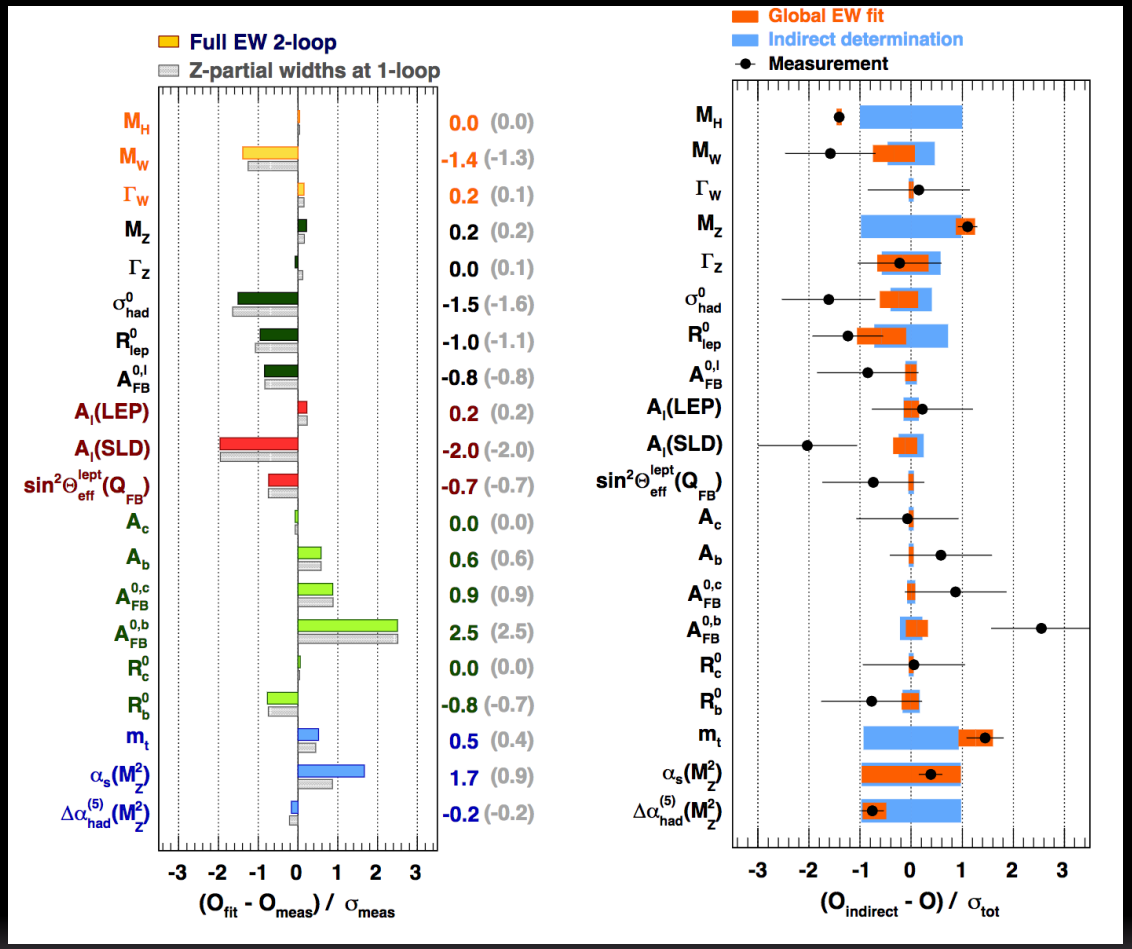
4 $\frac{g}{2}\frac{m^\lambda_e}{M}[H(\bar{e}^\lambda e^\lambda) + i\phi^0(\bar{e}^\lambda\gamma^5 e^\lambda)] + \frac{ig}{2M\sqrt{2}}\phi^+[-m^\kappa_d(\bar{u}^\lambda_j C_{\lambda\kappa}(1-\gamma^5)d^\kappa_j) +$
$m^\lambda_u(\bar{u}^\lambda_j C_{\lambda\kappa}(1+\gamma^5)d^\kappa_j] + \frac{ig}{2M\sqrt{2}}\phi^-[m^\lambda_d(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1+\gamma^5)u^\kappa_j) - m^\kappa_u(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1-$
$\gamma^5)u^\kappa_j] - \frac{g}{2}\frac{m^\lambda_u}{M}H(\bar{u}^\lambda_j u^\lambda_j) - \frac{g}{2}\frac{m^\lambda_d}{M}H(\bar{d}^\lambda_j d^\lambda_j) + \frac{ig}{2}\frac{m^\lambda_u}{M}\phi^0(\bar{u}^\lambda_j\gamma^5 u^\lambda_j) -$
$\frac{ig}{2}\frac{m^\lambda_d}{M}\phi^0(\bar{d}^\lambda_j\gamma^5 d^\lambda_j) + \bar{X}^+(\partial^2 - M^2)X^+ + \bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 -$

5 $\frac{M^2}{c_w^2})X^0 + \bar{Y}\partial^2 Y + igc_w W^+_\mu(\partial_\mu\bar{X}^0 X^- - \partial_\mu\bar{X}^+ X^0) + igs_w W^+_\mu(\partial_\mu\bar{Y}X^- -$
$\partial_\mu\bar{X}^+ Y) + igc_w W^-_\mu(\partial_\mu\bar{X}^- X^0 - \partial_\mu\bar{X}^0 X^+) + igs_w W^-_\mu(\partial_\mu\bar{X}^- Y -$
$\partial_\mu\bar{Y}X^+) + igc_w Z^0_\mu(\partial_\mu\bar{X}^+ X^+ - \partial_\mu\bar{X}^- X^-) + igs_w A_\mu(\partial_\mu\bar{X}^+ X^+ -$
$\partial_\mu\bar{X}^- X^-) - \frac{1}{2}gM[\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c_w^2}\bar{X}^0 X^0 H] +$
$\frac{1-2c_w^2}{2c_w} igM[\bar{X}^+ X^0\phi^+ - \bar{X}^- X^0\phi^-] + \frac{1}{2c_w} igM[\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-] +$
$igMs_w[\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-] + \frac{1}{2}igM[\bar{X}^+ X^+\phi^0 - \bar{X}^- X^-\phi^0]$

Standard Model at the LHC: orders of magnitude



Standard Model (scarily) good at describing everything

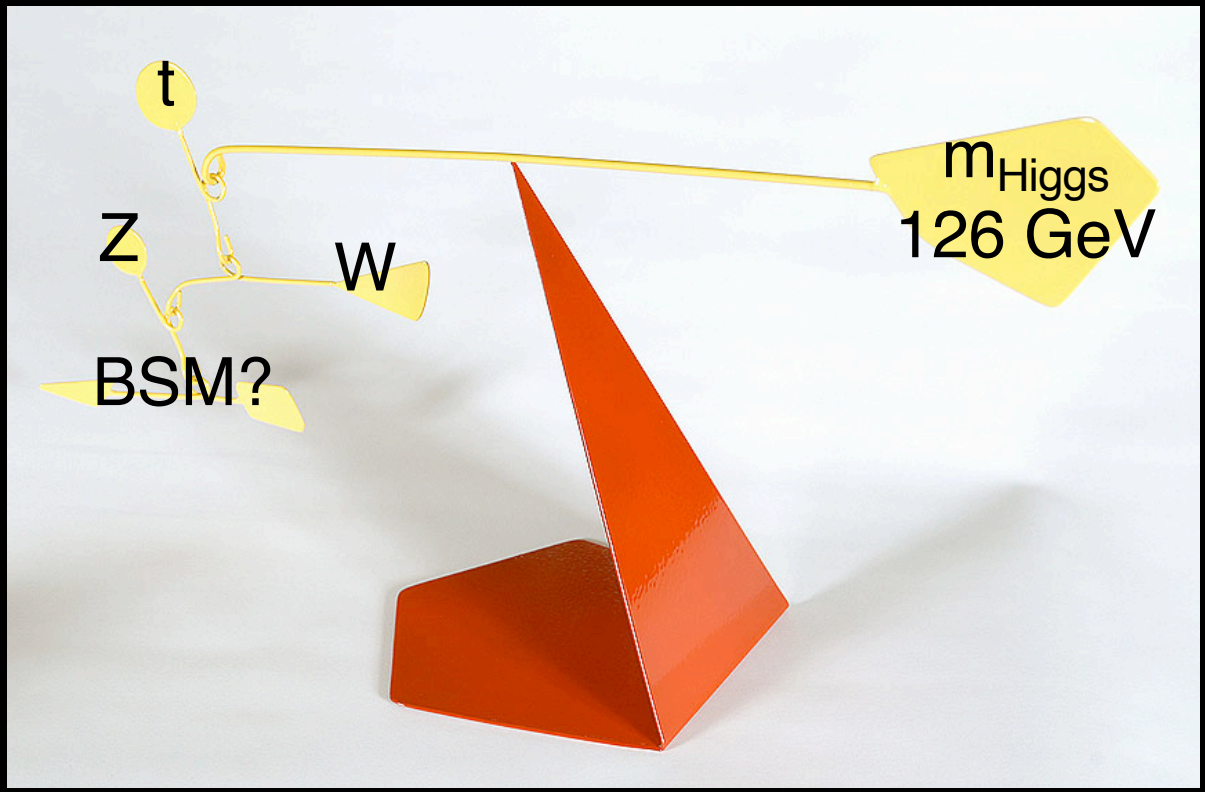


See also:
arXiv:1407.3792
(Gfitter group)

Problems with the Standard Model – experimentalist perspective

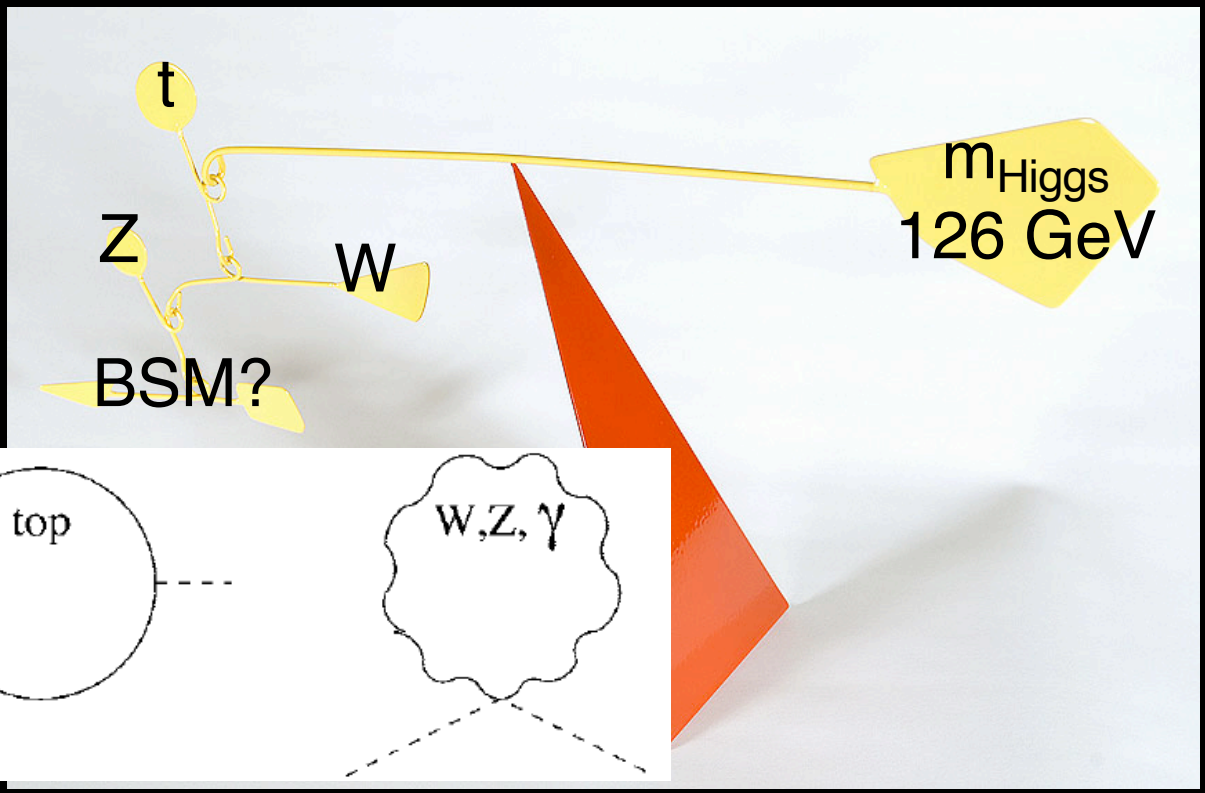
- Matter vs antimatter asymmetry
  - Standard Model cannot provide enough CP violation to explain dominance of matter
- Dark Matter
  - if it exists, it is very likely not described by the Standard Model
  - Neither is dark energy
- Standard Model neutrinos are massless
  - The 2015 Nobel Prize (Kajita and McDonald) was for neutrino oscillations, directly proving that neutrinos have mass
- Structure is not really explained

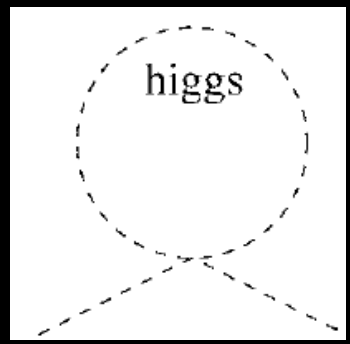
Little Hierarchy problem, Naturalness



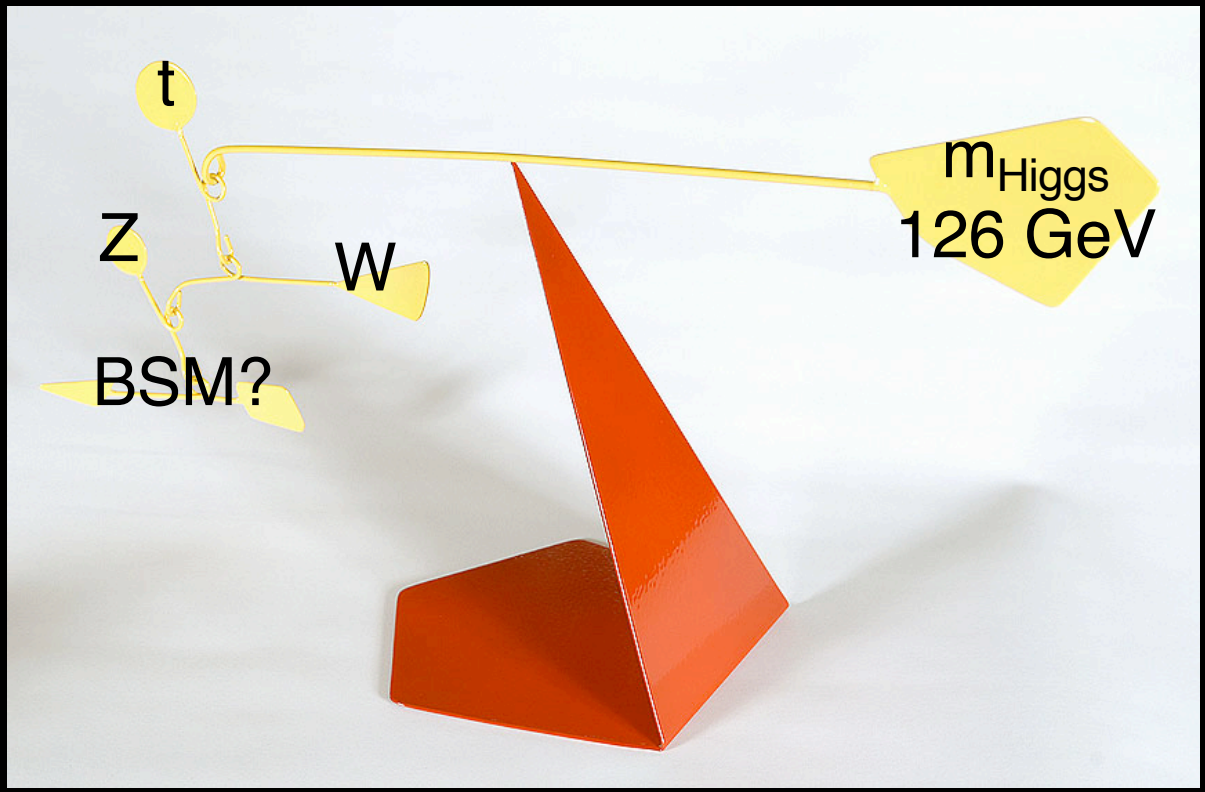
Twitter: freyablekman
freya.blekman@cern.ch

Little Hierarchy problem, Naturalness





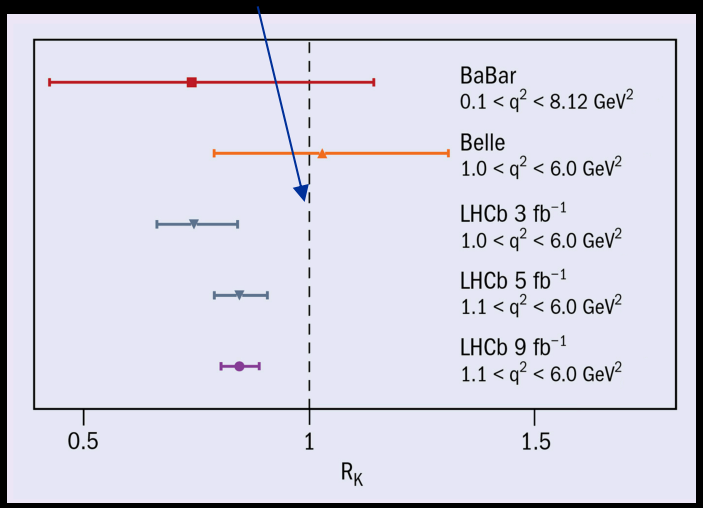
Little Hierarchy problem, Naturalness



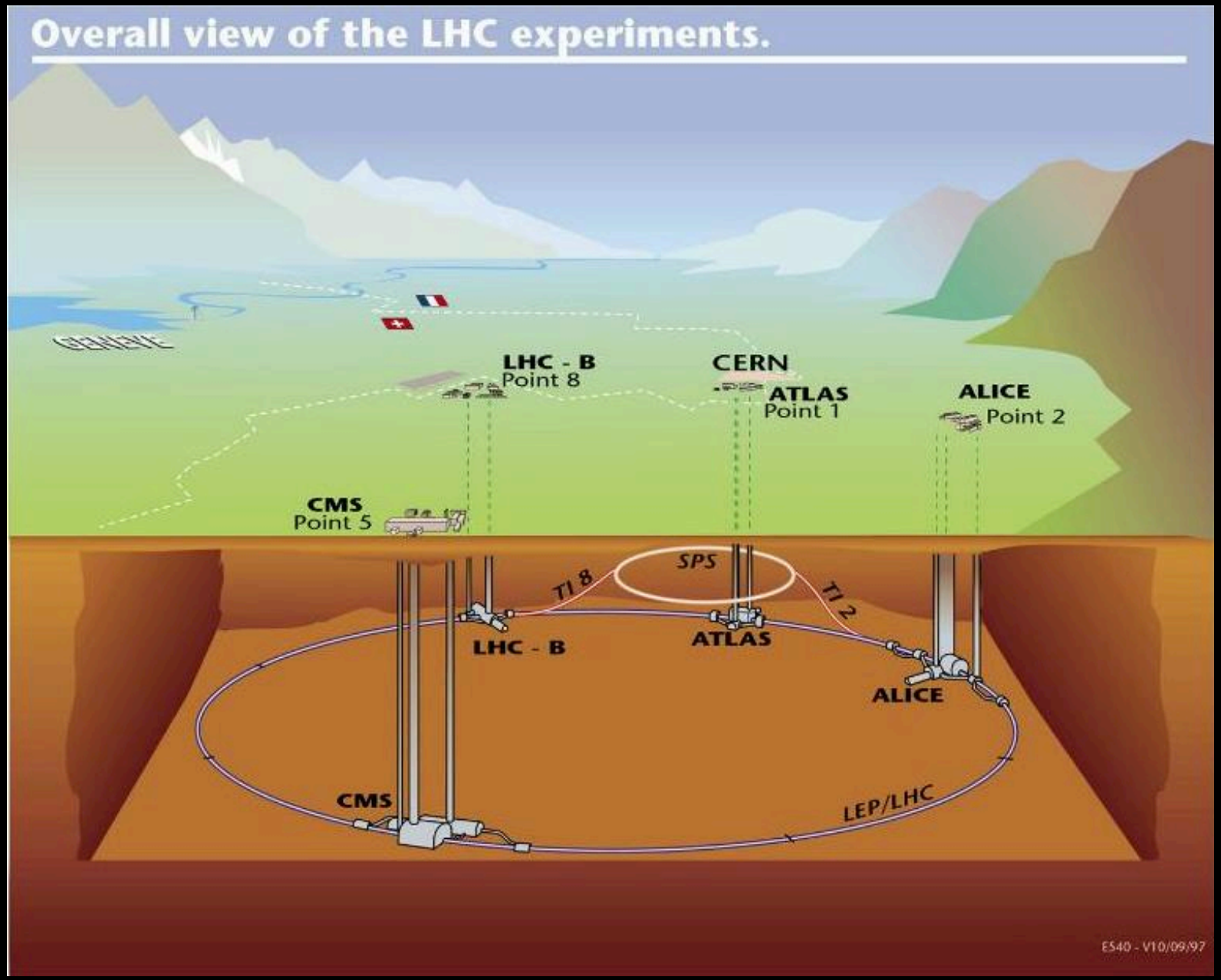
If fine tuning <=10%:
Restrictions:
$\Lambda_{quarks} \sim< 2$ TeV
$\Lambda_{gauge} \sim< 5$ TeV

Other ways : precision vs direct production

SM predicts 1 if no new particles

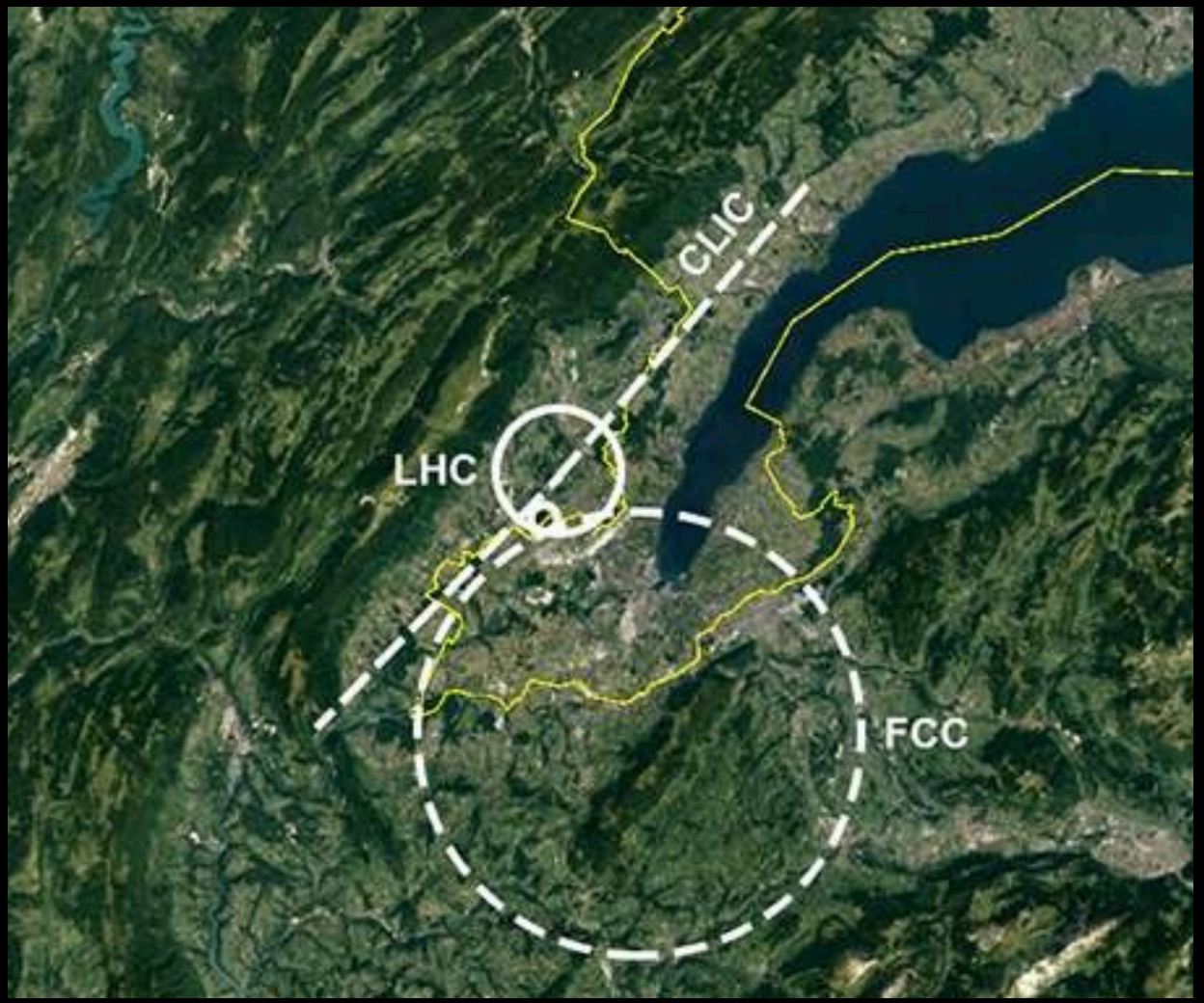


- The other way to measure is to find something that the standard model predicts accurately and that is sensitive to extra particles
- This way you can go to much higher mass but you cannot 'see' the particles themselves, just their quantum effects on measurement
- Examples in recent media (and tomorrow, Thursday): LHCb R(K) and g-2 experiments

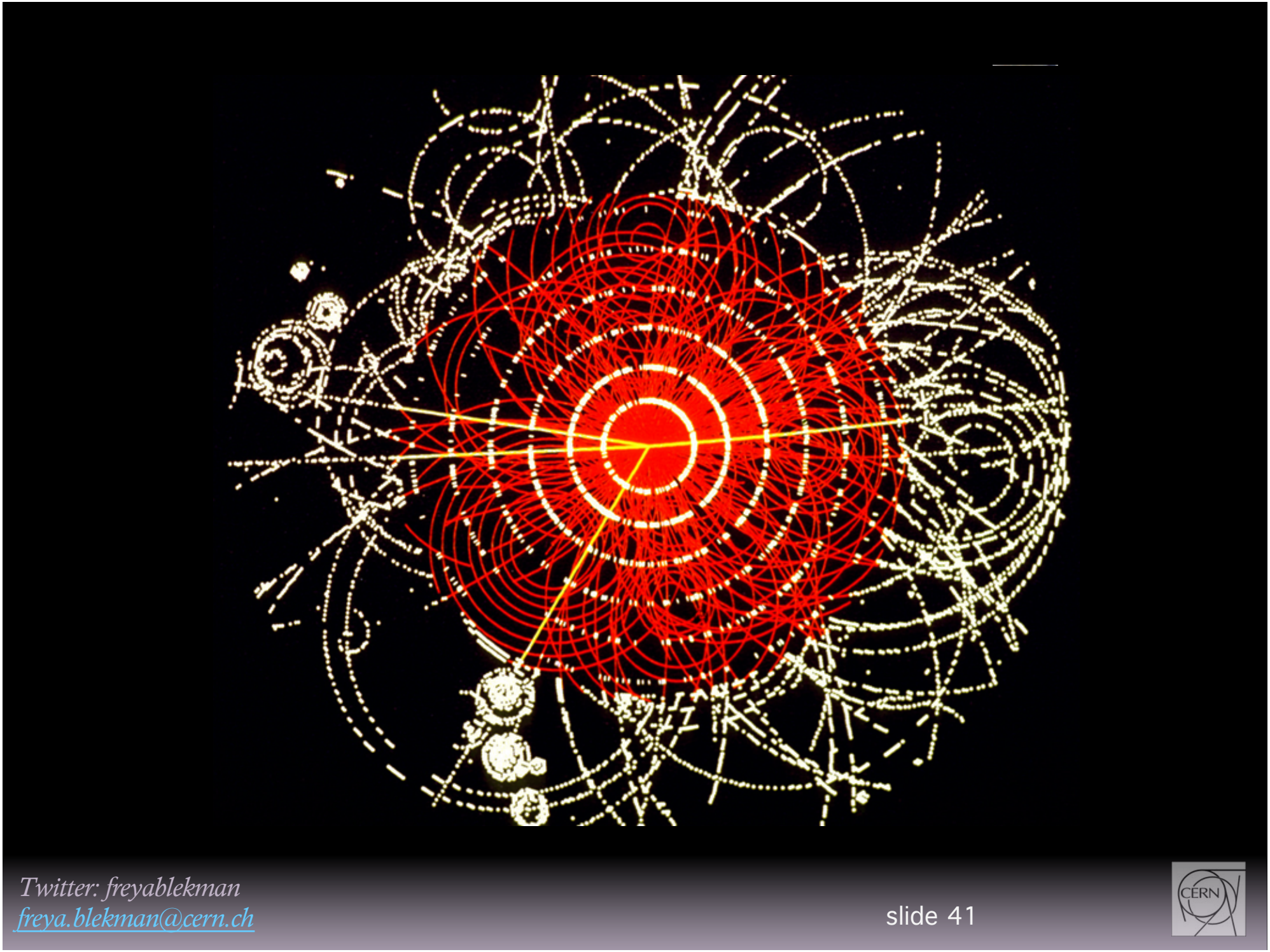


Twitter: freyablekman
freya.blekman@cern.ch

The future?

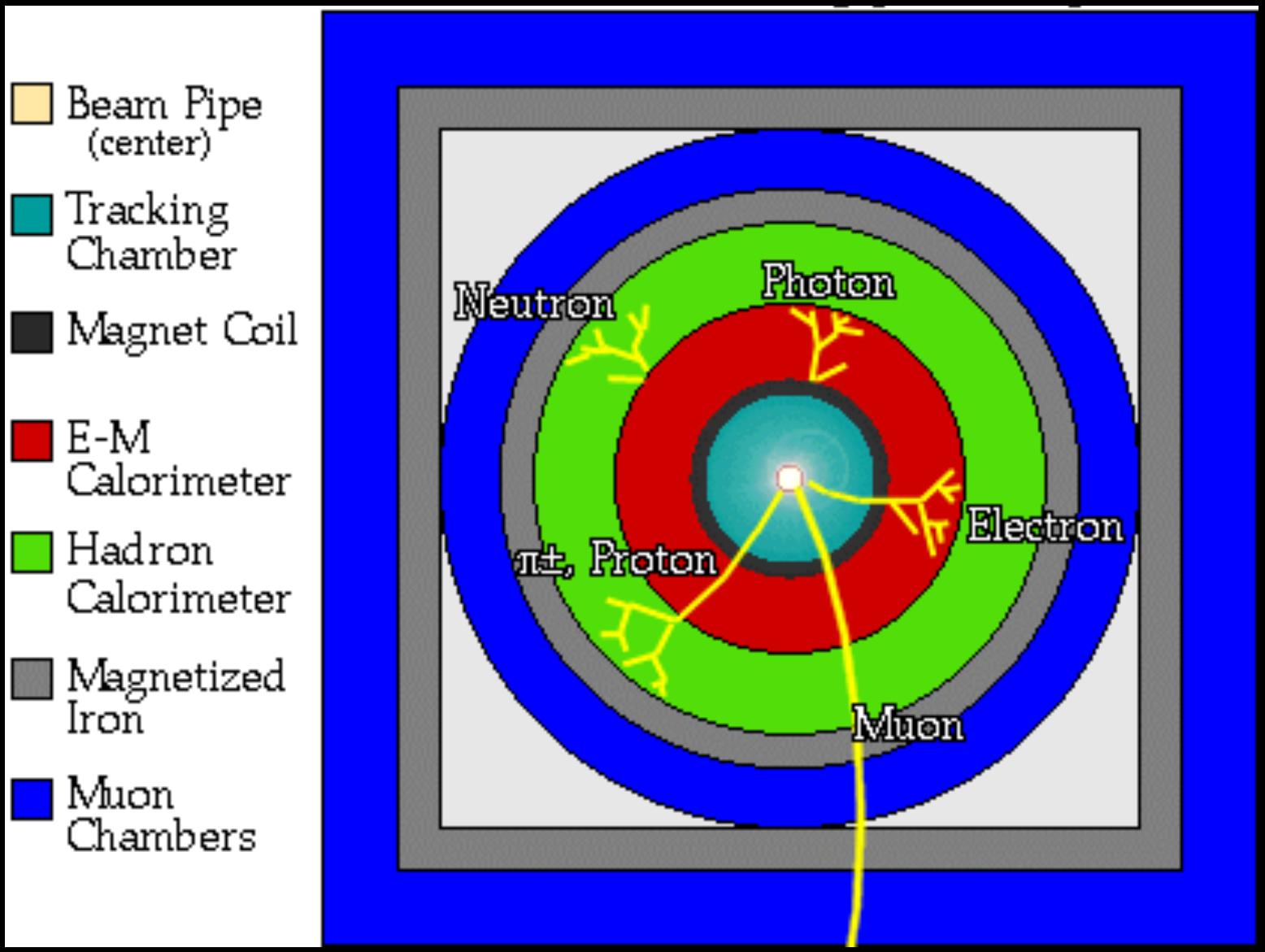


Twitter: freyablekman
freya.blekman@cern.ch

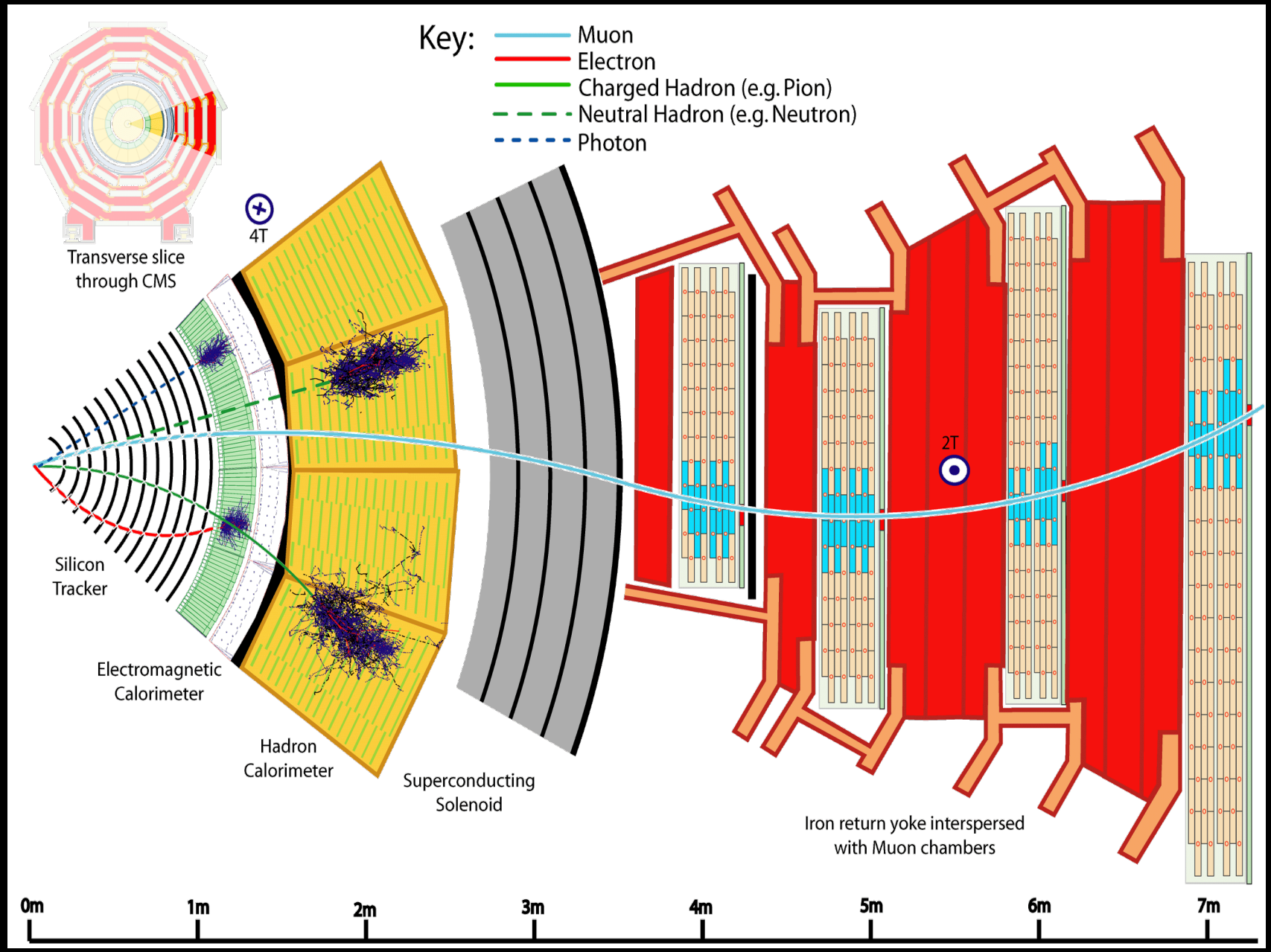


Twitter: freyablekman
freya.blekman@cern.ch

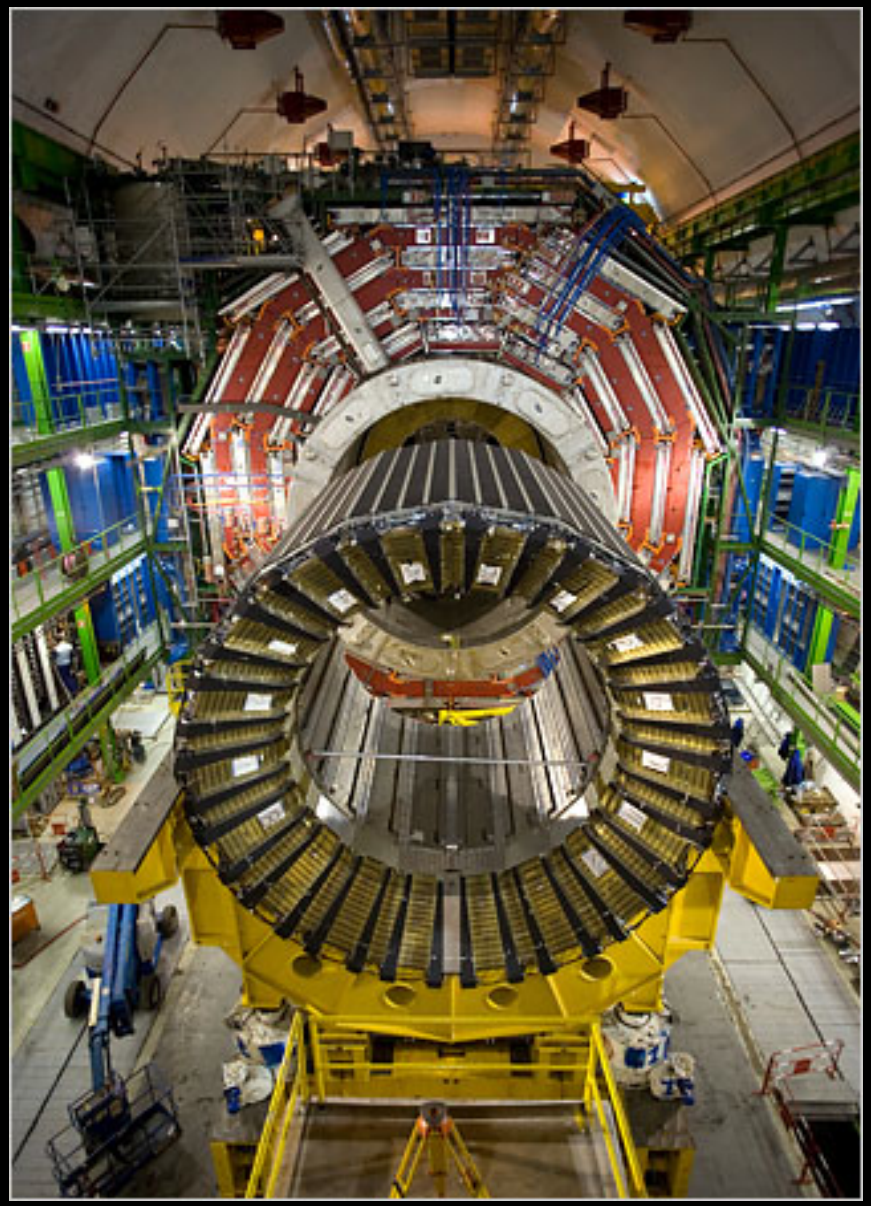
Experiment at particle accelerator: schematic



Twitter: freyablekman
freya.blekman@cern.ch



Twitter: freyablekman
freya.blekman@cern.ch



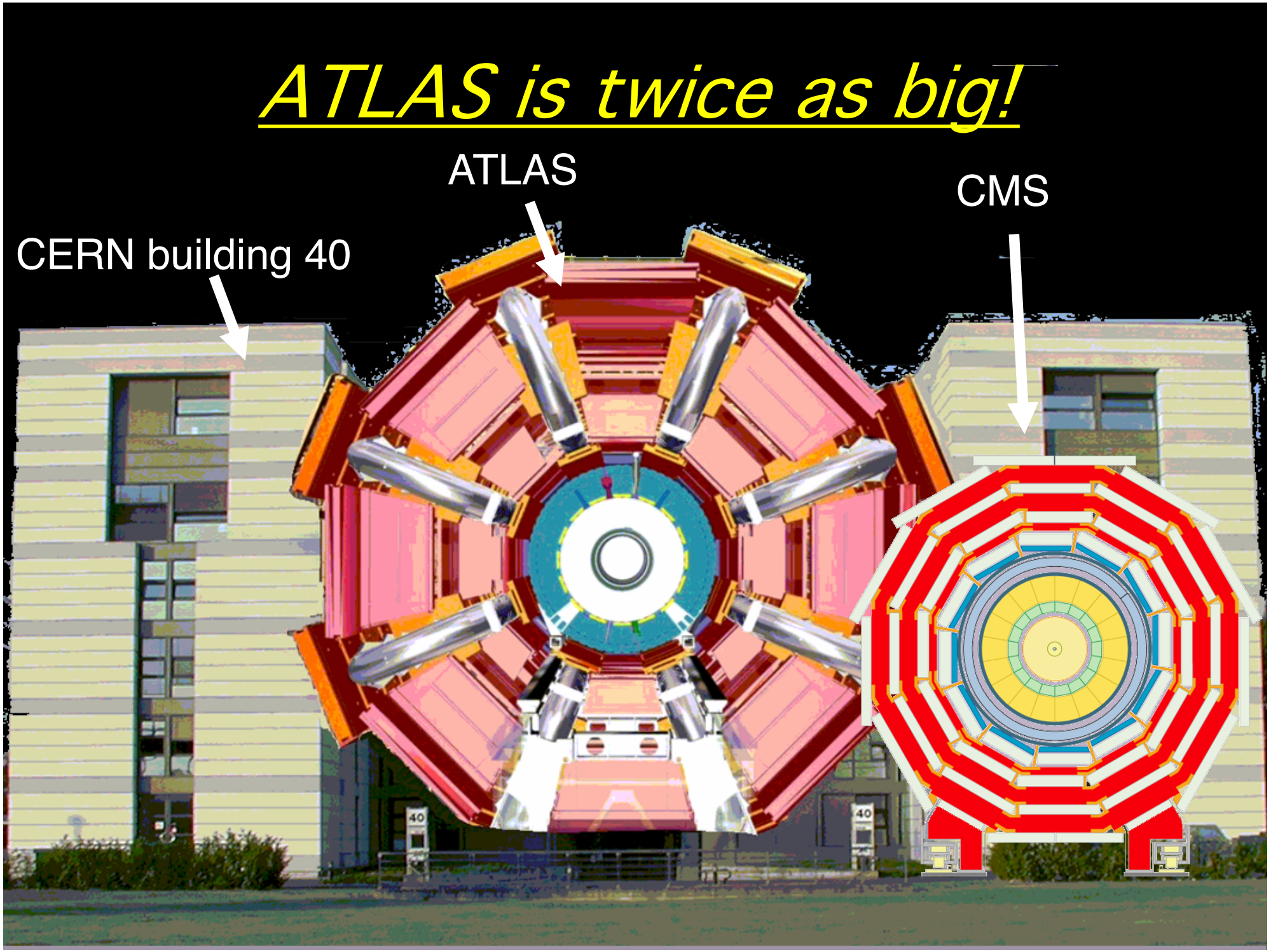
CMS

- Compact
- Muon
- Solenoid

- "Compact" is relative...

Twitter: freyablekman
freya.blekman@cern.ch

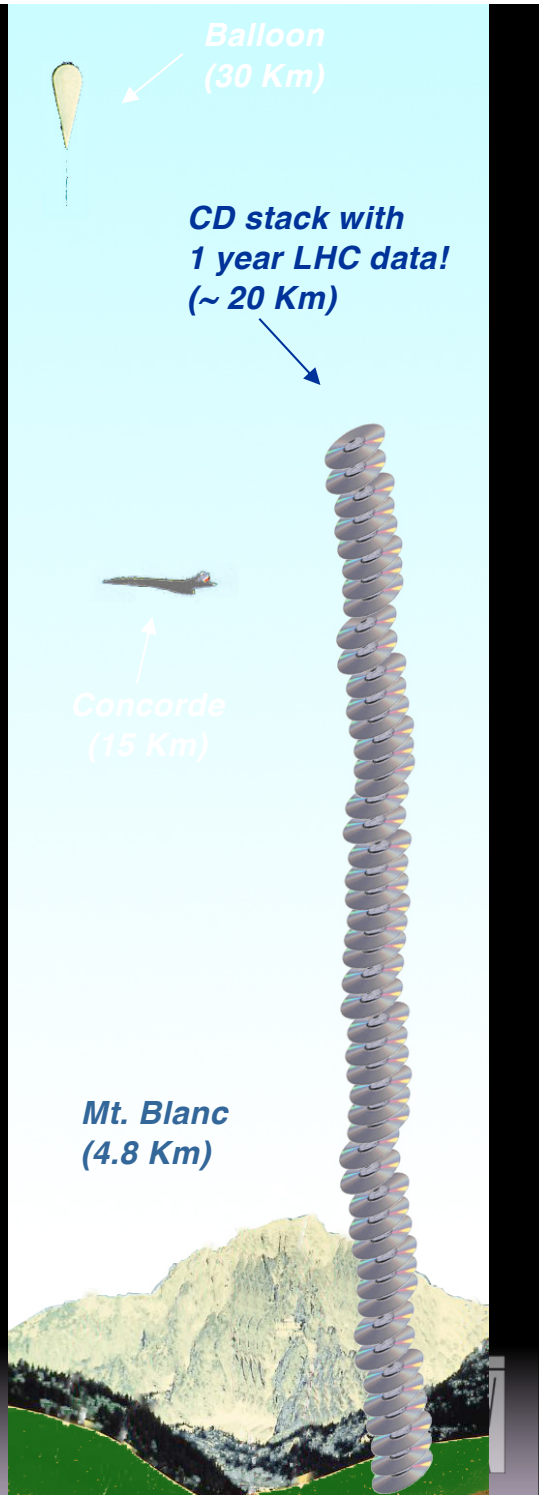
ATLAS is twice as big!



LHC experiments will produce **10-15 million GB** of data each year (about 20 million CDs!)

LHC data analysis requires a computing power equivalent to **~100,000 of today's fastest PC processors**.

And that is only because we throw away data to only collect 1 GB/s per experiment!



Twitter: freyab
freya.blekman@cern.ch

More open questions

- Are the quarks and leptons elementary particles?
- Are there other particles we have not seen yet?
- Why are the masses different?
- Matter/Antimatter asymmetry in universe?
- What about gravity? Or superstrings? Or extra dimensions?
- Properties of the neutrino?

Answering any *one* of these questions is worthy o a Nobel Prize!

Twitter: freyablekman
freya.blekman@cern.ch

Normally

- visiting CERN is something tha
physics studer
remember for
time
- Personally: I ch
my research d
(biophysics-> particle physics) after a CERN visit
- Normally it also is fun socially

Twitter: freyablekman
freya.blekman@cern.ch

Instead

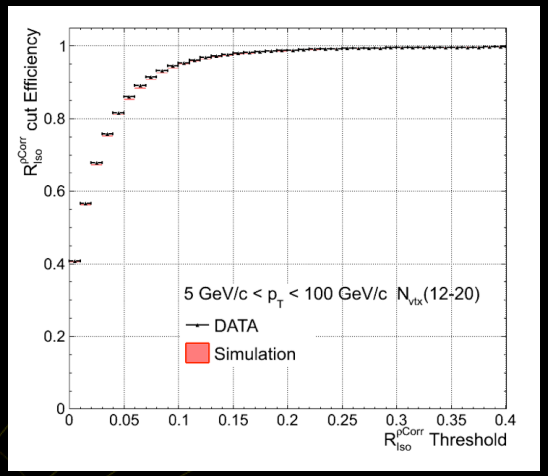
- Virtual vists only work if YOU ask questions
- I know this is scary, but without questions this visit will be extremely boring and you could spend your Easter break better
- So I propose that everyone asks ONE question
  (more of course allowed)

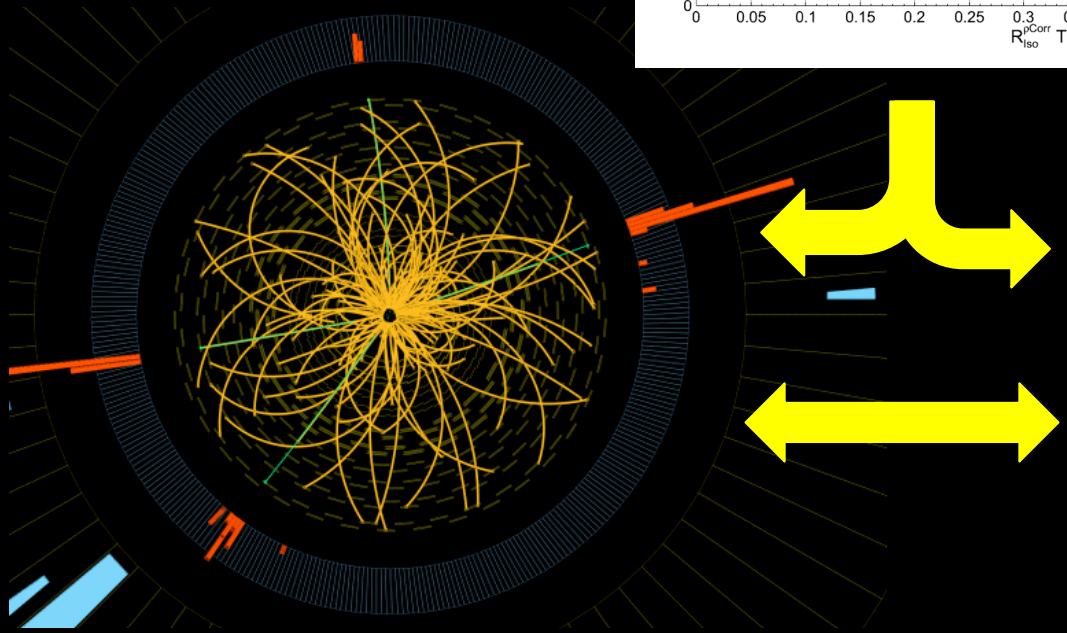
Twitter: freyablekman
freya.blekman@cern.ch

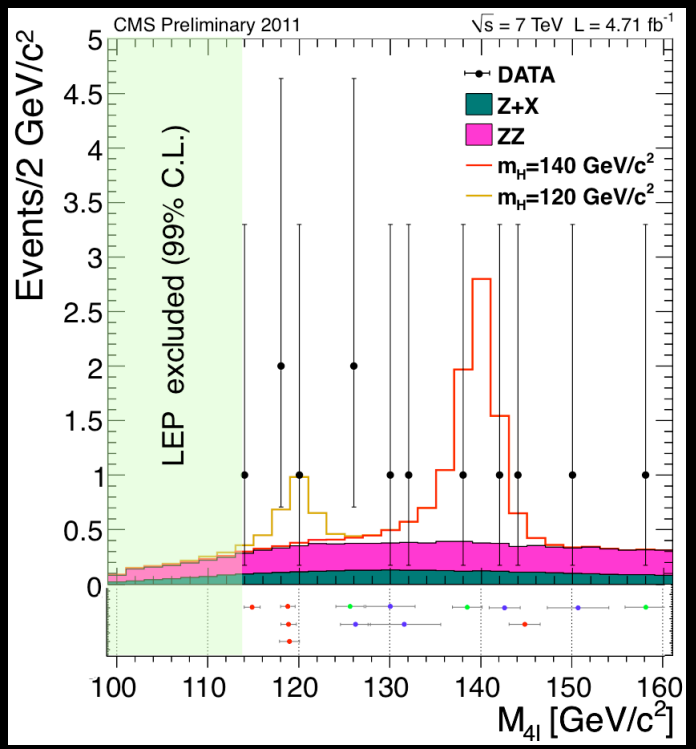
Don't forget to have fun!

Twitter: freyablekman
freya.blekman@cern.ch

What do we actually do?







Twitter: freyablekman
freya.blekman@cern.ch

Belgium at CERN

One of the twelve CERN founding member states

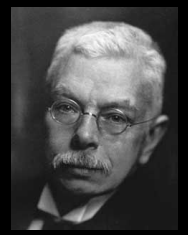
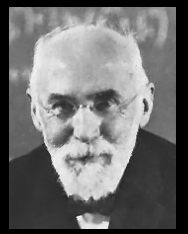
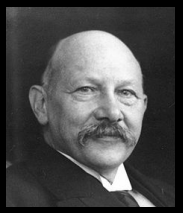
- Belgium nowadays one of the 22 CERN member states
- CERN membership of 27 M€/year funded by Belgian Federal Government (FOD Economie)
- CERN Mandate:
  - Fundamental scientific research
  - Technology transfer
  - Training and educating STEM professionals of the future
  - International collaboration

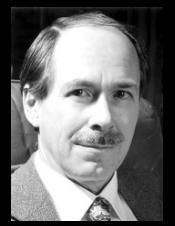
Twitter: freyablekman
freya.blekman@cern.ch

Nederland en Cern

Nederland is een van de 12 oprichters van Cern.

- Cornelis Jan Bakker Director General 1955-1960
  - Walter Hoogland Director of research 1989 -1994
  - Jos Engelen Director of research 2004 - 2008

Nederlandse wetenschappers hebben belangrijke bijdragen geleverd aan de ontdekkingen in deeltjes fysica en het onderzoek op CERN.

Nobel prijzen in de Natuurkunde codeeltjes fysica

1902 P. Zeeman & H. Lorenz: Zeeman effect (structuur in spectrale lijnen, kwantisatie van elektronenbanen)

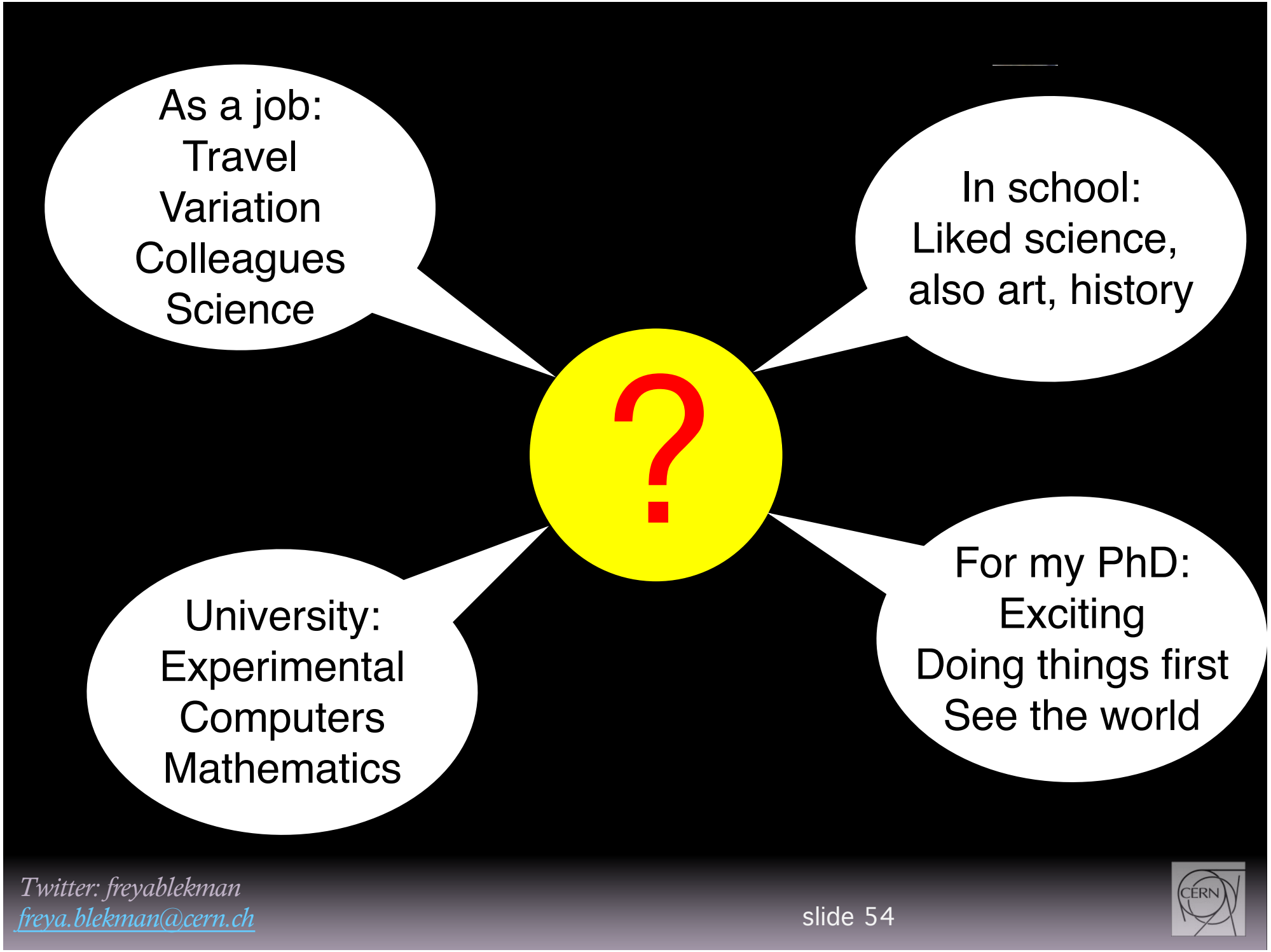
1913 H. Kamerling Onnes: Superconductiviteit

1984 S. van der Meer: Cern Accelerator fysicus, stochastisch koeling

1999 M. Veltman and G. ‘ t Hooft: Renormalisatie theorie van electro-zwakke interacties

Directe rijksoverheidfinanciering voor CERN contributie
Experimenten op CERN wordt gesteund via NWO/FOM

Twitter: freyablekman
freya.blekman@cern.ch



Twitter: freyablekman
freya.blekman@cern.ch