High Energy Physics

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Seminar
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Lecture Synopsis

How do we know a particle is fundamental with no further internal structure? How do they interact with each other giving rise to the physical universe we are living in?

Particle physics studies the properties and interaction of the fundamental particles. Due to the extremely small interaction scale, a highly energetic particle is used to study the particle's fundamental structure.

This talk covers the introduction to High Energy Physics, Malaysia involvement in High Energy Physics research and discusses selected topics such as discovery of Higgs boson, ~~penta-quarks~~ and the renewed interest in the field of particle physics.

Penta-quark belongs to LHCb's, the seminar is here.

Disclaimer

High Energy Physics explores what the world made of at the smallest and largest scales. It is studied by international collaboration, I use materials stolen shamelessly from many people and sources over the years… (that is how understanding builds).

I will try to give sources as much as possible, but if not, then big thank you to so many people over the years for their content.

I may focus more on CMS because of my experience.

I will try to focus on concepts and ideas (rather than facts that you can look up).

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Introduction to High Energy Physics

High Energy Physics Pioneer in UKM

STSN3052 Fizik Tenaga Tinggi/ *High Energy Physics*

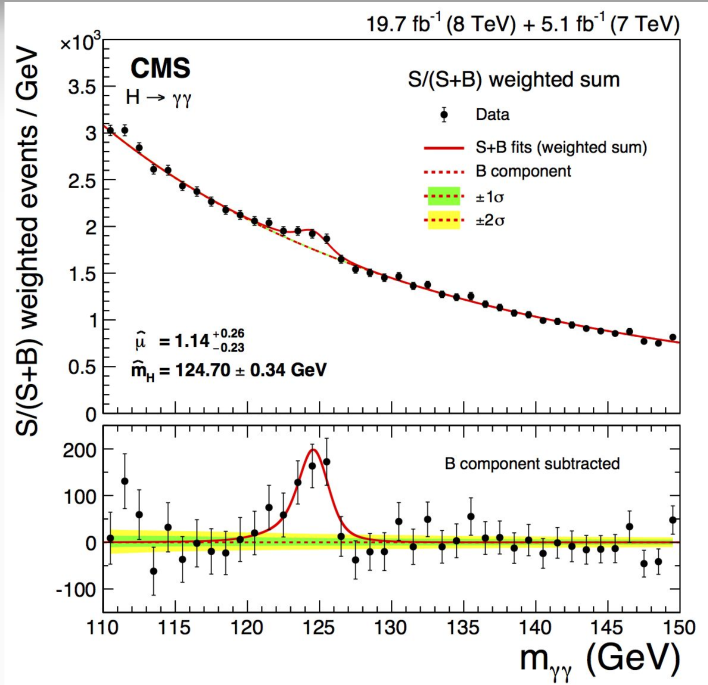
Kursus ini membincangkan sifat zarah bercas daripada pemecut zarah untuk mengkaji tindakbalas fizik tenaga tinggi. Jenis zarah dan pengkelasan (baryon dan fermion), nombor kuantum, kepelbagaian simetri (parity, konjugasi cas, Parity-G, songsangan masa) dan keinvarianan adalah di berdasarkan kepada 4 jenis daya asas: electromagnet, lemah, kuat dan gravity. Aplikasi teori Medan Kuantum dan kaedah teoretik- kumpulan untuk memahami 4 jenis daya itu (kauntum elektro dinamik lwn. Kuantum kromodinamik). Pariti dan pencabulan CP. Osilasi neutrino. 3 famililepton-quark: model SU(2) x SU(3) Gell-Mann,rajah garisquark, matriks Kobayashi-Maskawa, model Begdan lakaran Dalitz. Model Lazim dan skema Kesatuan Gedang. Melampaui model Lazim: super simetri dan teori supertali. Graviti Kuantum Lingkaran dan dimensi banyak. Kosmologi kuantum daripada Dentuman Besar ke Keremukan Besar.

This course will discuss the properties of charged particle beams from acceleratorsto study high energy physics interactions. The types of particles and their classifications (baryons and fermions), their quantum numbers, symmetries (parity, charge conjugation, G parity, time reversal) and invariance followed based on the 4 type of fundamenta lforces: electromagnet, weak, strong and gravity Applicationof Quantum field theory and group theoretic method stounder stand the four forces (quantum electro dynamic vs quantum chromo dynamics). Parity and CPviolations. Neutrino oscillations. The 3familiesoflepton-quarks: Gell-MannSU (2) x SU(3) model ,quarksline diagrams, Kobayashi Maskawa matrix quark Bag model and Dalitz plot. The Standard Model and Grand Unification schemes. Beyond the Standard Model i.e supersymmetry and String theories. Loop quantum gravity and extradimensions. Quantum cosmology of the universe from Big Bang to Big Crunch.

Prof. Shahidan Radiman

[Buku Panduan Prasiswazah FST UKM 2020-2021 (pg 275)]

Revolutionary Discovery



1.7 million years

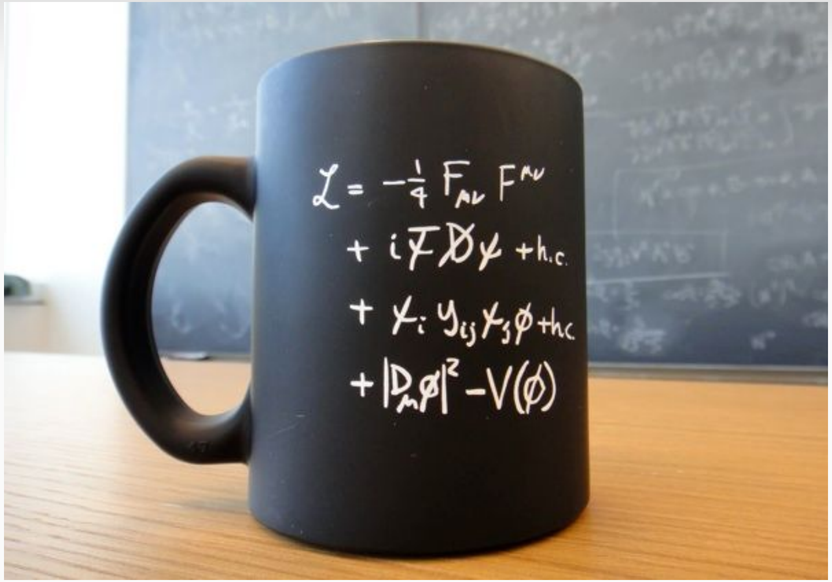
What is the common theme between these two events?

4th July 2012

https://www.journals.uchicago.edu/doi/10.1086/203705

Formulation

[Bhimbetka](), painting on the rock shelter located in central India



[CERN gift shop](), painting on the ceramic coffee mug located in geneva, switzerland

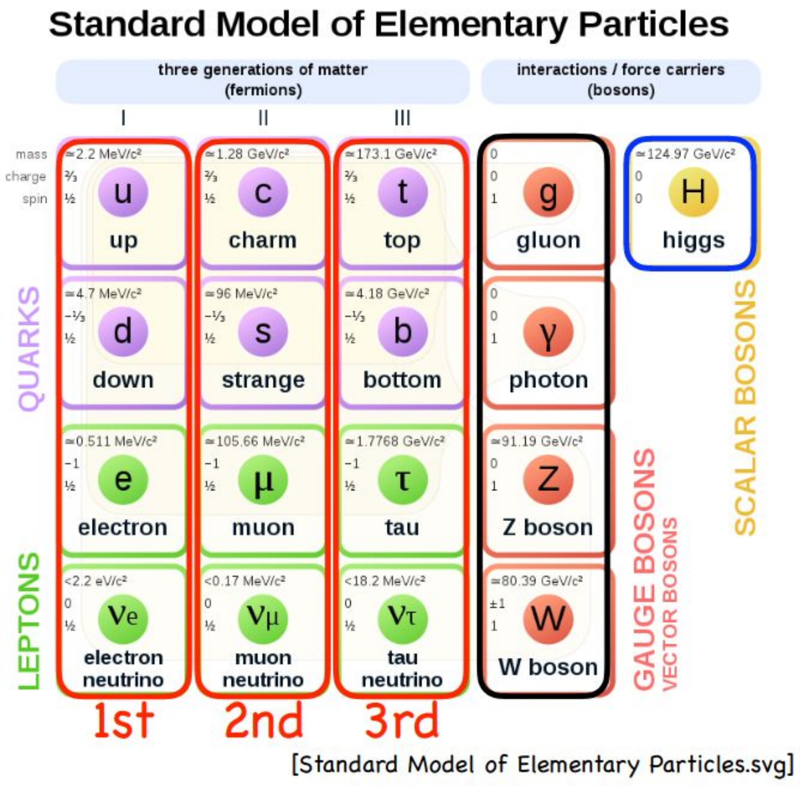
Full Lagrangian of the Standard Model

$$
\begin{gathered}
\mathcal{L}_{SM} = -\tfrac{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 - \tfrac{1}{4}g_s^2 f^{abc}f^{ade}g^b_\mu g^c_\nu g^d_\mu g^e_\nu - \partial_\nu W^+_\mu \partial_\nu W^-_\mu - \\
M^2 W^+_\mu W^-_\mu - \tfrac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \tfrac{1}{2c_w^2}M^2 Z^0_\mu Z^0_\mu - \tfrac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - 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)) - \tfrac{1}{2}g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \tfrac{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) - \tfrac{1}{2}\partial_\mu H \partial_\mu H - 2M^2\alpha_h H^2 - \partial_\mu\phi^+\partial_\mu\phi^- - \tfrac{1}{2}\partial_\mu\phi^0\partial_\mu\phi^0 - \\
\beta_h\left(\tfrac{2M^2}{g^2} + \tfrac{2M}{g}H + \tfrac{1}{2}(H^2 + \phi^0\phi^0 + 2\phi^+\phi^-)\right) + \tfrac{2M^4}{g^2}\alpha_h - \\
g\alpha_h M\left(H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-\right) - \\
\tfrac{1}{8}g^2\alpha_h\left(H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2H^2\right) - \\
gMW^+_\mu W^-_\mu H - \tfrac{1}{2}g\tfrac{M}{c_w^2}Z^0_\mu Z^0_\mu H - \\
\tfrac{1}{2}ig\left(W^+_\mu(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) - W^-_\mu(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)\right) + \\
\tfrac{1}{2}g\left(W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) + W^-_\mu(H\partial_\mu\phi^+ - \phi^+\partial_\mu H)\right) + \tfrac{1}{2}g\tfrac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) + \\
M\left(\tfrac{1}{c_w}Z^0_\mu\partial_\mu\phi^0 + W^+_\mu\partial_\mu\phi^- + W^-_\mu\partial_\mu\phi^+\right) - ig\tfrac{s_w^2}{c_w}MZ^0_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) + igs_w MA_\mu(W^+_\mu\phi^- - \\
W^-_\mu\phi^+) - ig\tfrac{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^+) - \\
\tfrac{1}{4}g^2 W^+_\mu W^-_\mu\left(H^2 + (\phi^0)^2 + 2\phi^+\phi^-\right) - \tfrac{1}{8}g^2\tfrac{1}{c_w^2}Z^0_\mu Z^0_\mu\left(H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2\phi^+\phi^-\right) - \\
\tfrac{1}{2}g^2\tfrac{s_w^2}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) - \tfrac{1}{2}ig^2\tfrac{s_w^2}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \tfrac{1}{2}g^2 s_w A_\mu\phi^0(W^+_\mu\phi^- + \\
W^-_\mu\phi^+) + \tfrac{1}{2}ig^2 s_w A_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) - g^2\tfrac{s_w}{c_w}(2c_w^2 - 1)Z^0_\mu A_\mu\phi^+\phi^- - \\
g^2 s_w^2 A_\mu A_\mu\phi^+\phi^- + \tfrac{1}{2}ig_s\,\lambda^a_{ij}(\bar{q}^\sigma_i\gamma^\mu q^\sigma_j)g^a_\mu - \bar{e}^\lambda(\gamma\partial + m^\lambda_e)e^\lambda - \bar{\nu}^\lambda(\gamma\partial + m^\lambda_\nu)\nu^\lambda - \bar{u}^\lambda_j(\gamma\partial + \\
m^\lambda_u)u^\lambda_j - \bar{d}^\lambda_j(\gamma\partial + m^\lambda_d)d^\lambda_j + igs_w A_\mu\left(-(\bar{e}^\lambda\gamma^\mu e^\lambda) + \tfrac{2}{3}(\bar{u}^\lambda_j\gamma^\mu u^\lambda_j) - \tfrac{1}{3}(\bar{d}^\lambda_j\gamma^\mu d^\lambda_j)\right) + \\
\tfrac{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{d}^\lambda_j\gamma^\mu(\tfrac{4}{3}s_w^2 - 1 - \gamma^5)d^\lambda_j) + \\
(\bar{u}^\lambda_j\gamma^\mu(1 - \tfrac{8}{3}s_w^2 + \gamma^5)u^\lambda_j)\} + \tfrac{ig}{2\sqrt{2}}W^+_\mu\left((\bar{\nu}^\lambda\gamma^\mu(1 + \gamma^5)U^{lep}{}_{\lambda\kappa}e^\kappa) + (\bar{u}^\lambda_j\gamma^\mu(1 + \gamma^5)C_{\lambda\kappa}d^\kappa_j)\right) + \\
\tfrac{ig}{2\sqrt{2}}W^-_\mu\left((\bar{e}^\kappa U^{lep\dagger}{}_{\kappa\lambda}\gamma^\mu(1 + \gamma^5)\nu^\lambda) + (\bar{d}^\kappa_j C^\dagger_{\kappa\lambda}\gamma^\mu(1 + \gamma^5)u^\lambda_j)\right) + \\
\tfrac{ig}{2M\sqrt{2}}\phi^+\left(-m^\kappa_e(\bar{\nu}^\lambda U^{lep}{}_{\lambda\kappa}(1 - \gamma^5)e^\kappa) + m^\lambda_\nu(\bar{\nu}^\lambda U^{lep}{}_{\lambda\kappa}(1 + \gamma^5)e^\kappa\right) + \\
\tfrac{ig}{2M\sqrt{2}}\phi^-\left(m^\lambda_e(\bar{e}^\lambda U^{lep\dagger}{}_{\lambda\kappa}(1 + \gamma^5)\nu^\kappa) - m^\kappa_\nu(\bar{e}^\lambda U^{lep\dagger}{}_{\lambda\kappa}(1 - \gamma^5)\nu^\kappa\right) - \tfrac{g}{2}\tfrac{m^\lambda_\nu}{M}H(\bar{\nu}^\lambda\nu^\lambda) - \\
\tfrac{g}{2}\tfrac{m^\lambda_e}{M}H(\bar{e}^\lambda e^\lambda) + \tfrac{ig}{2}\tfrac{m^\lambda_\nu}{M}\phi^0(\bar{\nu}^\lambda\gamma^5\nu^\lambda) - \tfrac{ig}{2}\tfrac{m^\lambda_e}{M}\phi^0(\bar{e}^\lambda\gamma^5 e^\lambda) - \tfrac{1}{4}\,\bar{\nu}_\lambda\,M^R_{\lambda\kappa}\,(1 - \gamma_5)\hat{\nu}_\kappa - \\
\tfrac{1}{4}\,\bar{\nu}_\lambda\,M^R_{\lambda\kappa}\,(1 - \gamma_5)\hat{\nu}_\kappa + \tfrac{ig}{2M\sqrt{2}}\phi^+\left(-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\right) + \\
\tfrac{ig}{2M\sqrt{2}}\phi^-\left(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\right) - \tfrac{g}{2}\tfrac{m^\lambda_u}{M}H(\bar{u}^\lambda_j u^\lambda_j) - \\
\tfrac{g}{2}\tfrac{m^\lambda_d}{M}H(\bar{d}^\lambda_j d^\lambda_j) + \tfrac{ig}{2}\tfrac{m^\lambda_u}{M}\phi^0(\bar{u}^\lambda_j\gamma^5 u^\lambda_j) - \tfrac{ig}{2}\tfrac{m^\lambda_d}{M}\phi^0(\bar{d}^\lambda_j\gamma^5 d^\lambda_j) + \bar{G}^a\partial^2 G^a + g_s f^{abc}\partial_\mu\bar{G}^a G^b g^c_\mu + \\
\bar{X}^+(\partial^2 - M^2)X^+ + \bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 - \tfrac{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^-) - \tfrac{1}{2}gM\left(\bar{X}^+ X^+ H + \bar{X}^- X^- H + \tfrac{1}{c_w^2}\bar{X}^0 X^0 H\right) + \tfrac{1-2c_w^2}{2c_w}igM\left(\bar{X}^+ X^0\phi^+ - \bar{X}^- X^0\phi^-\right) + \\
\tfrac{1}{2c_w}igM\left(\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-\right) + igMs_w\left(\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-\right) + \\
\tfrac{1}{2}igM\left(\bar{X}^+ X^+\phi^0 - \bar{X}^- X^-\phi^0\right).
\end{gathered}
$$

[Deconstructing standard model equation]

Standard Model of Particle Physics

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



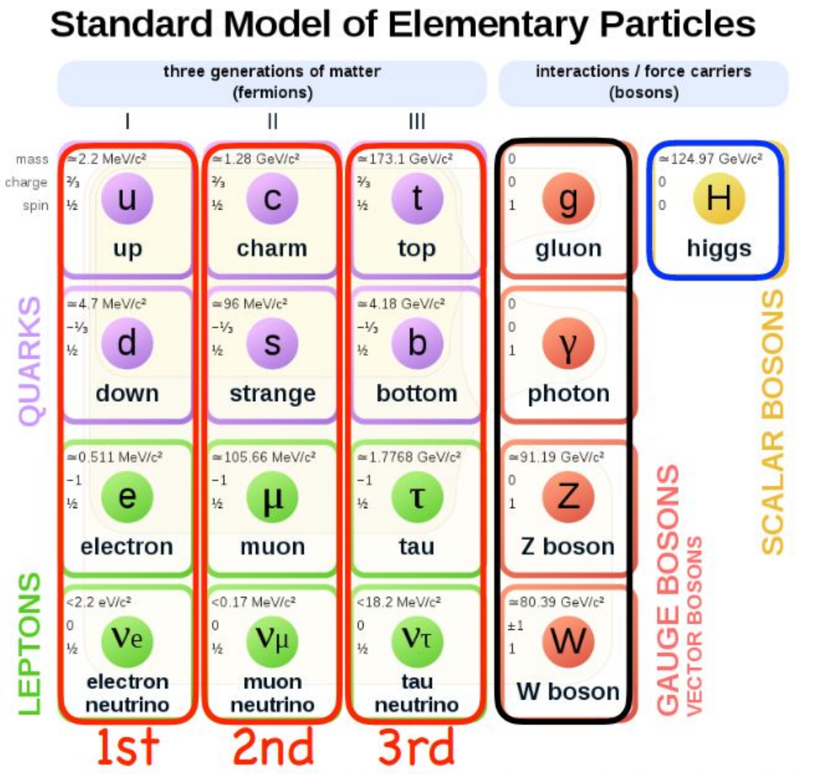
https://iopscience.iop.org/article/10.1088/1361-6552/aa5b25

Standard Model of Particle Physics

- Standard Model (SM) is a quantum field theory, describing the properties of particles and their fundamental interactions.

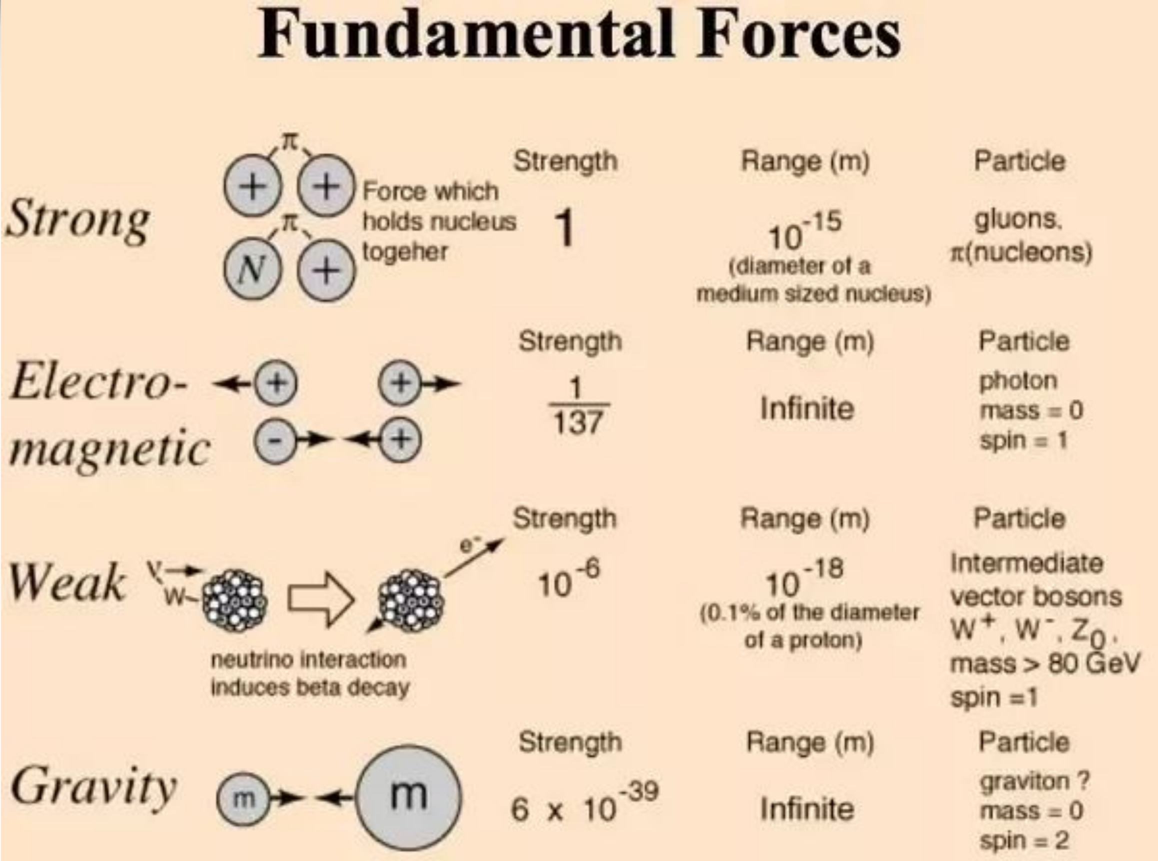
$$SU(3) \otimes SU(2)_L \otimes U(1)_Y$$

- Fermions (spin=1/2) are divided in 3 generations of quarks and leptons.
- Vector bosons (spin=1) are force carriers:
  - Strong force
  - Electromagnetic force
  - Weak force



[Standard Model of Elementary Particles.svg]

Fundamental Forces



Fundamental Forces

Force	Description	Strength	Range (m)	Particle
Strong	Force which holds nucleus togeher	1	10^{-15} (diameter of a medium sized nucleus)	gluons, π(nucleons)
Electro-magnetic		$\frac{1}{137}$	Infinite	photon mass = 0 spin = 1
Weak	neutrino interaction induces beta decay	10^{-6}	10^{-18} (0.1% of the diameter of a proton)	Intermediate vector bosons W^+, W^-, Z_0, mass > 80 GeV spin =1
Gravity		6×10^{-39}	Infinite	graviton ? mass = 0 spin = 2

Standard Model of Particle Physics

SM was established by Glashow, Slam and Weinberg.

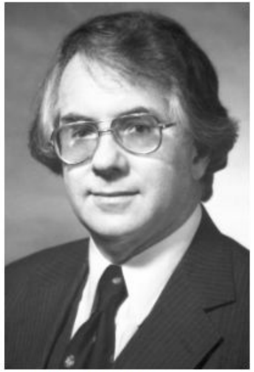


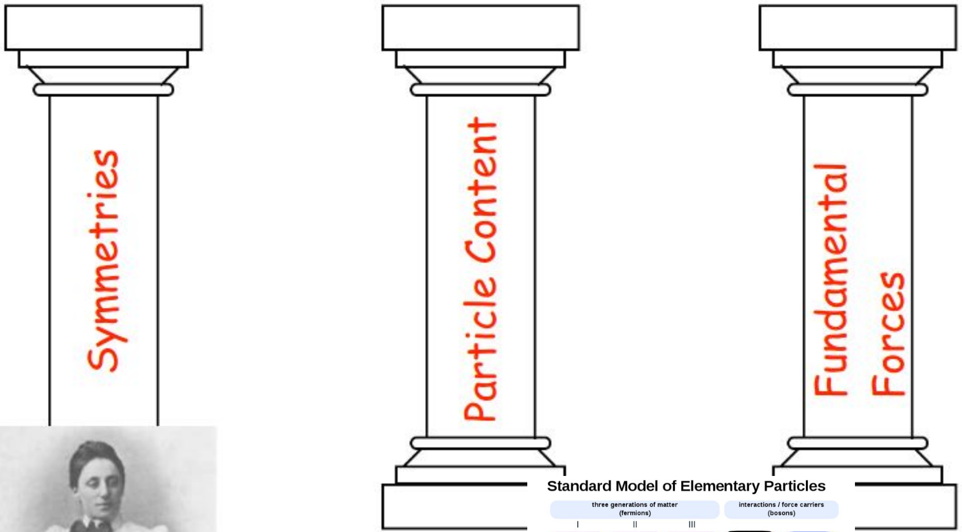
Photo from the Nobel Foundation archive.
Sheldon Lee Glashow
Prize share: 1/3

Photo from the Nobel Foundation archive.
Abdus Salam
Prize share: 1/3

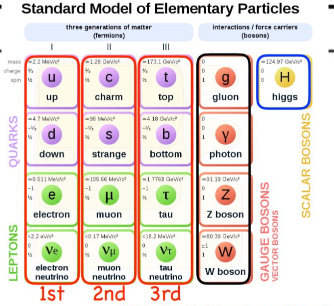
Photo from the Nobel Foundation archive.
Steven Weinberg
Prize share: 1/3

The Nobel Prize in Physics 1979 was awarded jointly to Sheldon Lee Glashow, Abdus Salam and Steven Weinberg "for their contributions to the theory of the unified weak and electromagnetic interaction between elementary particles, including, inter alia, the prediction of the weak neutral current."

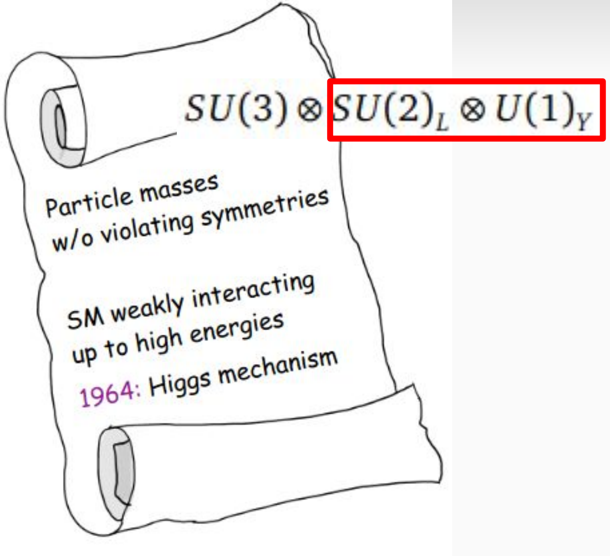
Four pillars of the Standard Model



Conservation of charges



[Standard Model of Elementary Particles.svg]



$$\mathscr{L} = i\bar{\Psi}_L \gamma_\mu D^\mu \Psi_L - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}W_{\mu\nu}W^{\mu\nu}$$

Electroweak sector does not contains mass term : $\frac{1}{2}m^2 W^\mu W_\mu$

Higgs Mechanism

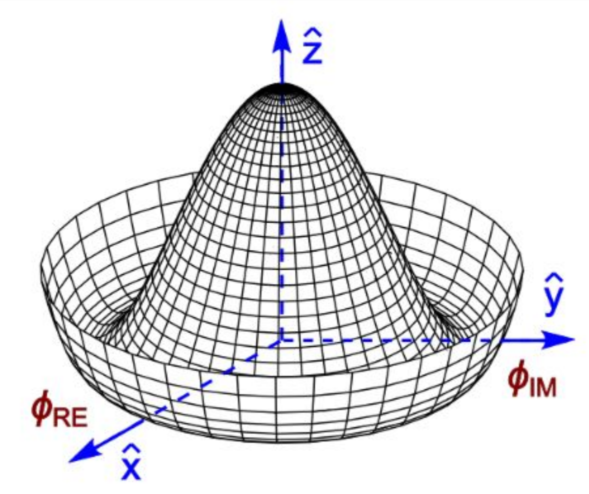
- Choosing one minimum vacuum state from the minimized Higgs potential spontaneously break the symmetry:

$$\boxed{V(\Phi) = \mu^2 \Phi^\dagger \Phi + \lambda(\Phi^\dagger \Phi)^2} \longrightarrow \phi_{min} = \pm \frac{1}{\sqrt{2}} v e^{i\varphi}$$

v = 246 GeV

AKA Vacuum Expectation Value (VEV)

$$\boxed{\Phi_{min} = \begin{pmatrix} \phi^{+}_{min} \\ \phi^{0}_{min} \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix}}$$



- Perturbatively expanding the fluctuating field around the chosen minimum:

$$\Phi_{un}(x) = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + h(x) \end{pmatrix}$$

Higgs Boson!!!

Mass Generating Particle (Boson)

- Expressing the Higgs Lagrangian in term of VEV and Higgs Fields:

Reminder: mass term

$\frac{1}{2}m^2 W^\mu W_\mu$

$$\mathscr{L} = \mathscr{L}_{Higgs} + \mathscr{L}_{gauge}$$

$$\mathscr{L} = (D_\mu \Phi_{un})^\dagger (D^\mu \Phi_{un}) - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}W_{\mu\nu}W^{\mu\nu}$$

$$= \frac{1}{2}\partial_\mu h \partial^\mu h + \boxed{\mu^2 h^2} + \frac{\mu^2}{\nu}h^3 + \frac{\mu^2}{4\nu^2}h^4$$

$$- \frac{1}{2}(W^+)_{\mu\nu}(W^-)^{\mu\nu} + \boxed{\frac{1}{4}g'^2\nu^2(W^+)_\mu(W^-)^\mu} - \left(\frac{h^2}{4} + \frac{\nu h}{2}\right)g'^2(W^+)_\mu(W^-)^\mu$$

$$- \frac{1}{4}Z_{\mu\nu}Z^{\mu\nu} - \boxed{\frac{1}{8}\nu^2(g^2 + g'^2)Z_\mu Z^\mu} - \left(\frac{h^2}{8} + \frac{\nu h}{4}\right)(g^2 + g'^2)Z_\mu Z^\mu$$

$$- \frac{1}{4}A_{\mu\nu}A^{\mu\nu}$$

$$\boxed{m_h = \nu\sqrt{2\lambda}}$$

$$\boxed{m_W = \left(\frac{g'\nu}{2}\right)}$$

$$\boxed{m_Z = \frac{1}{2}\nu\sqrt{g^2 + g'^2}}$$

$$\boxed{m_\gamma = 0}$$

Interacting or coupling with Higgs field, through the VEV, generates mass term for electroweak!!!

Mass Generating Particle (Fermion)

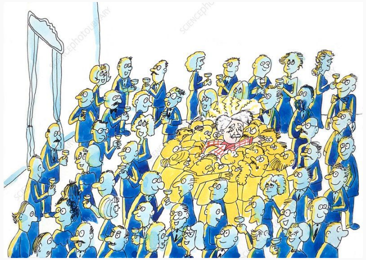
- By the same merit, substituting the Higgs doublet into the fermion sector of the Lagrangian:

$$\mathcal{L}^{quark}_{Yukawa} = -\lambda^i_d\left(\bar{q}^i_L \Phi d^i_R\right) - \lambda^i_u\left(\bar{q}^i_L \tilde{\Phi} u^i_R\right) + h.c.$$
$$= -\boxed{\frac{\lambda^i_d v}{\sqrt{2}}}\left(\bar{d}^i_L d^i_R\right) - \boxed{\frac{\lambda^i_u v}{\sqrt{2}}}\left(\bar{u}^i_L u^i_R\right) - \boxed{\frac{\lambda^i_d h}{\sqrt{2}}}\left(\bar{d}^i_L d^i_R\right) - \boxed{\frac{\lambda^i_u h}{\sqrt{2}}}\left(\bar{u}^i_L u^i_R\right) + h.c.$$

$$\mathcal{L}^{lepton}_{Yukawa} = -\lambda^i_1\left(\bar{l}^i_L \Phi_{un} e^i_R\right) + h.c.$$
$$= -\boxed{\frac{\lambda^i_1 v}{\sqrt{2}}}\left(\bar{e}^i_L e^i_R\right) - \boxed{\frac{\lambda^i_1 h}{\sqrt{2}}}\left(\bar{e}^i_L e^i_R\right) + h.c.$$

The coupling strength of the fermion is proportional to the mass of the fermion!!

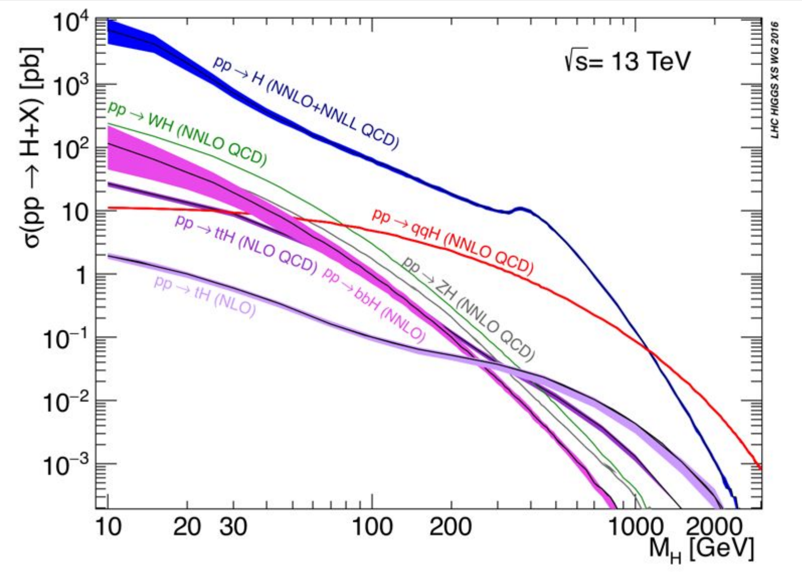
$$\lambda = \frac{\sqrt{2} m_f}{v}$$



Higgs Boson Mass Prediction

Nani ????

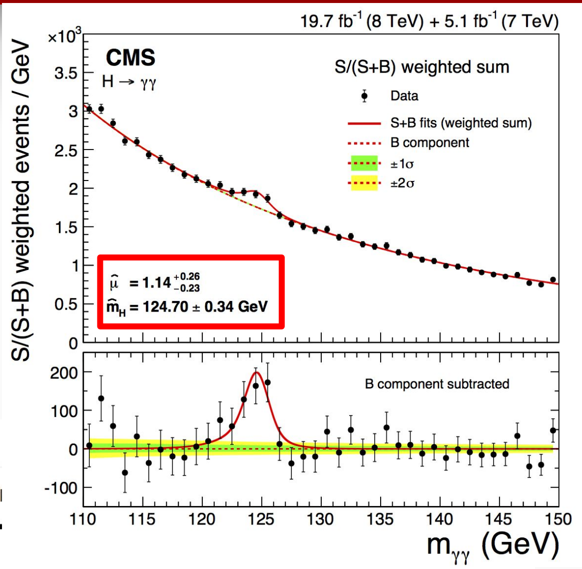
$$m_h = v\sqrt{2\lambda}$$



No theoretical prediction!!!

https://www.businessinsider.com/why-the-higgs-is-called-the-god-particle-2015-5

Discovery of Higgs Boson at LHC



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A portrait of the Higgs boson by the CMS experiment ten years after the discovery

The CMS Collaboration

Nature 607, 60–68 (2022) | Cite this article

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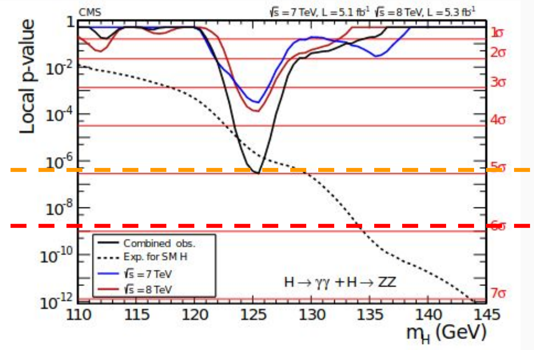
4th July 2012

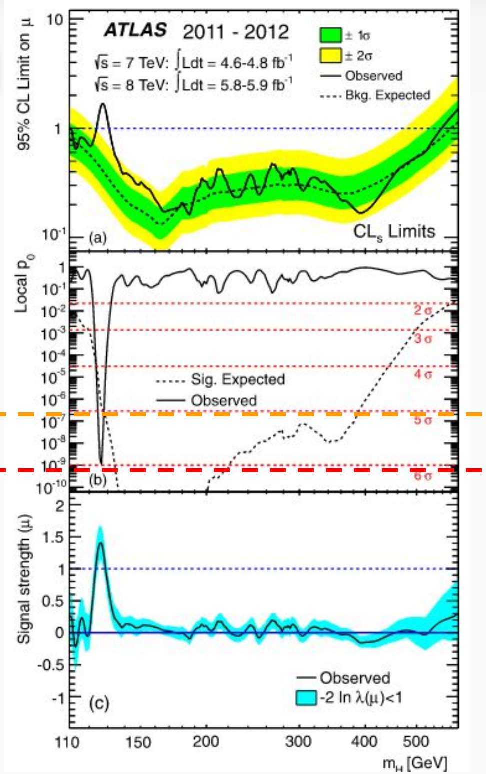
But We Found it!!! And the Evidence is still Strong!!!

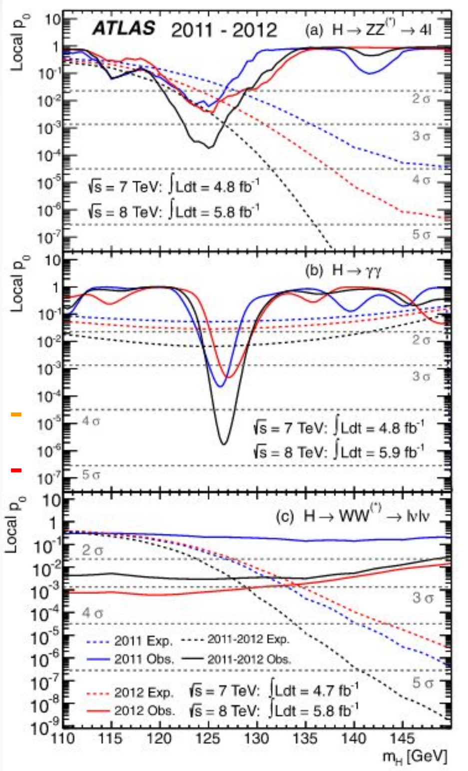
Discovery Significance

CMS ; ATLAS = 5σ ; 6σ

[5 sigma, whats that?]

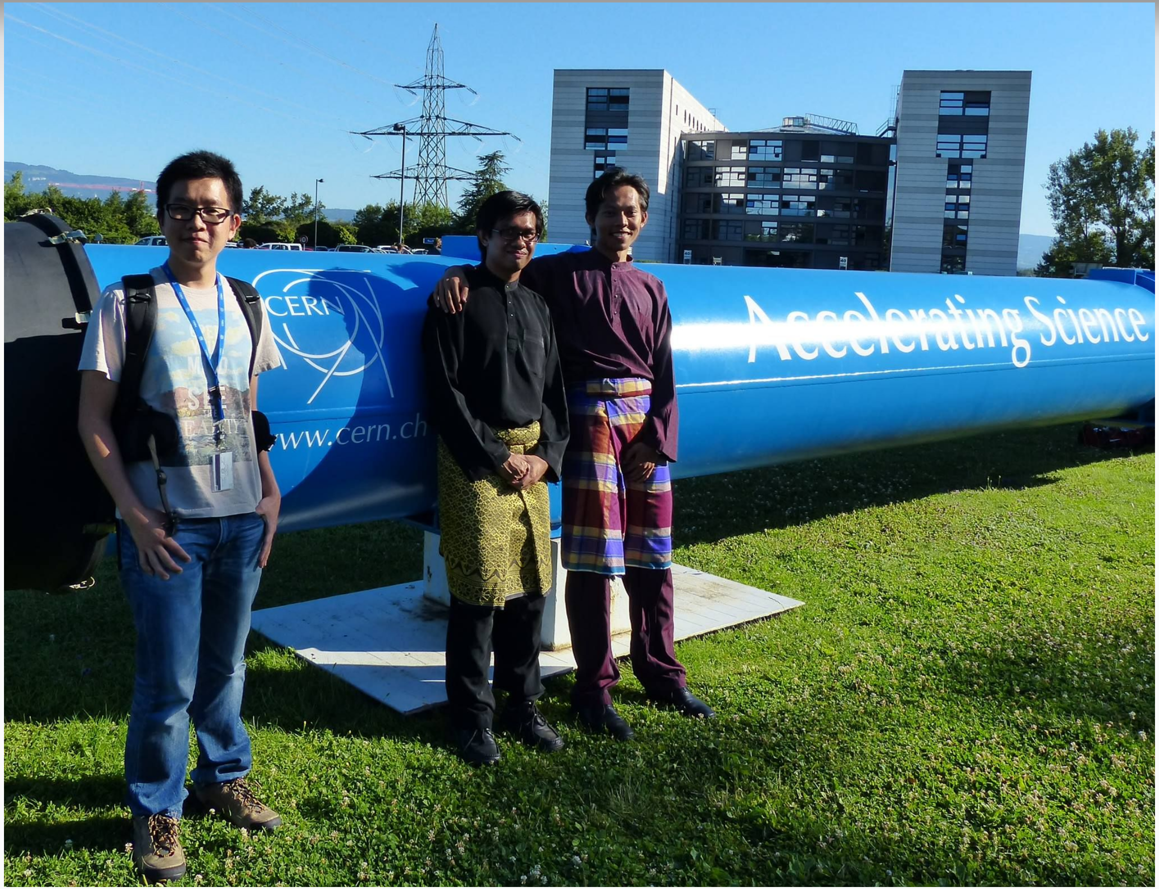






https://www.sciencedirect.com/science/article/pii/S0370269312008581?via%3Dihub
https://www.sciencedirect.com/science/article/pii/S037026931200857X

Me @ CERN



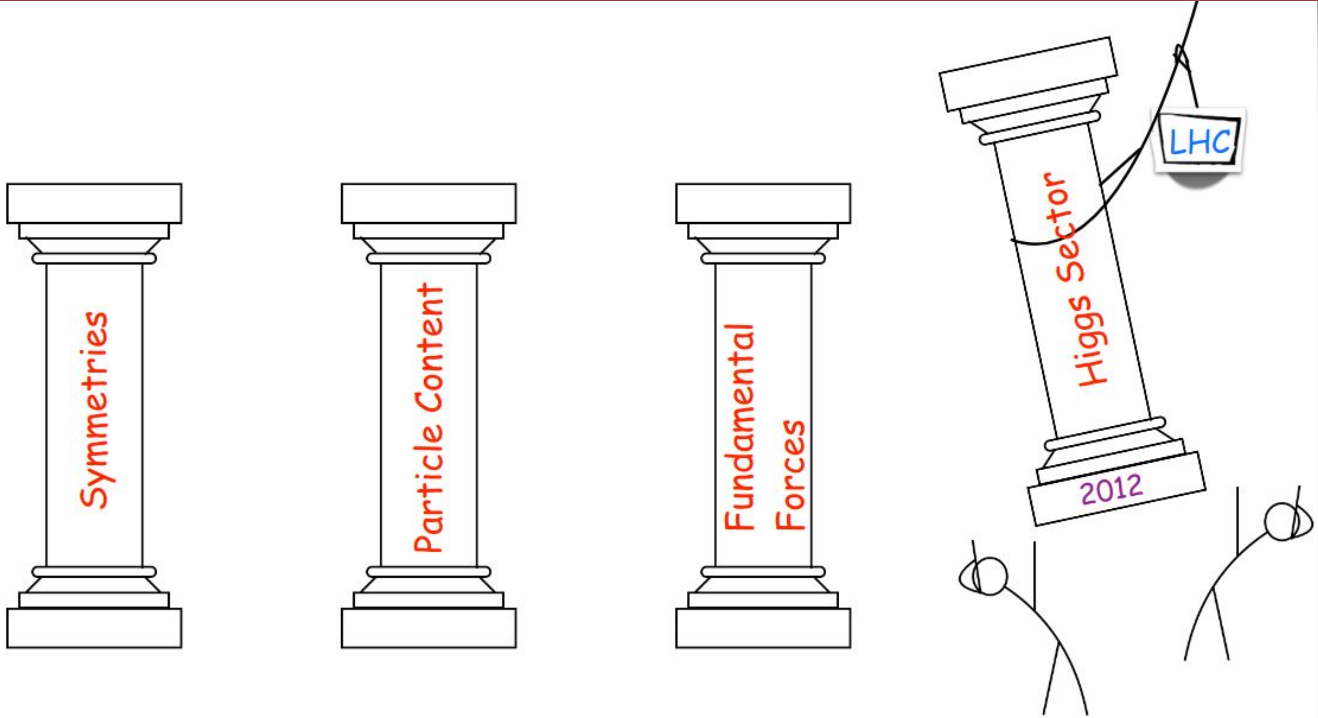
Nuclear Science Program internship at CERN:

Photo taken @ 1st August 2013

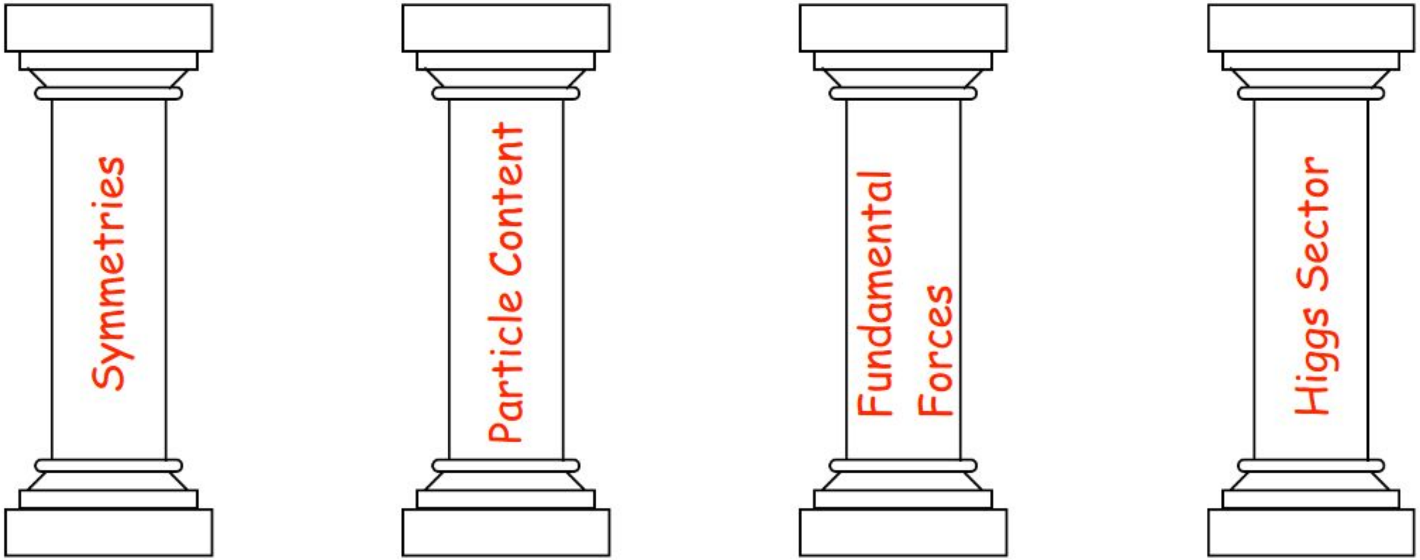
Thought I miss out all the fun on Higgs physics, but NOT REALLY!!

The coming decade is to elucidate rare Higgs decay channels and Higgs properties studies.

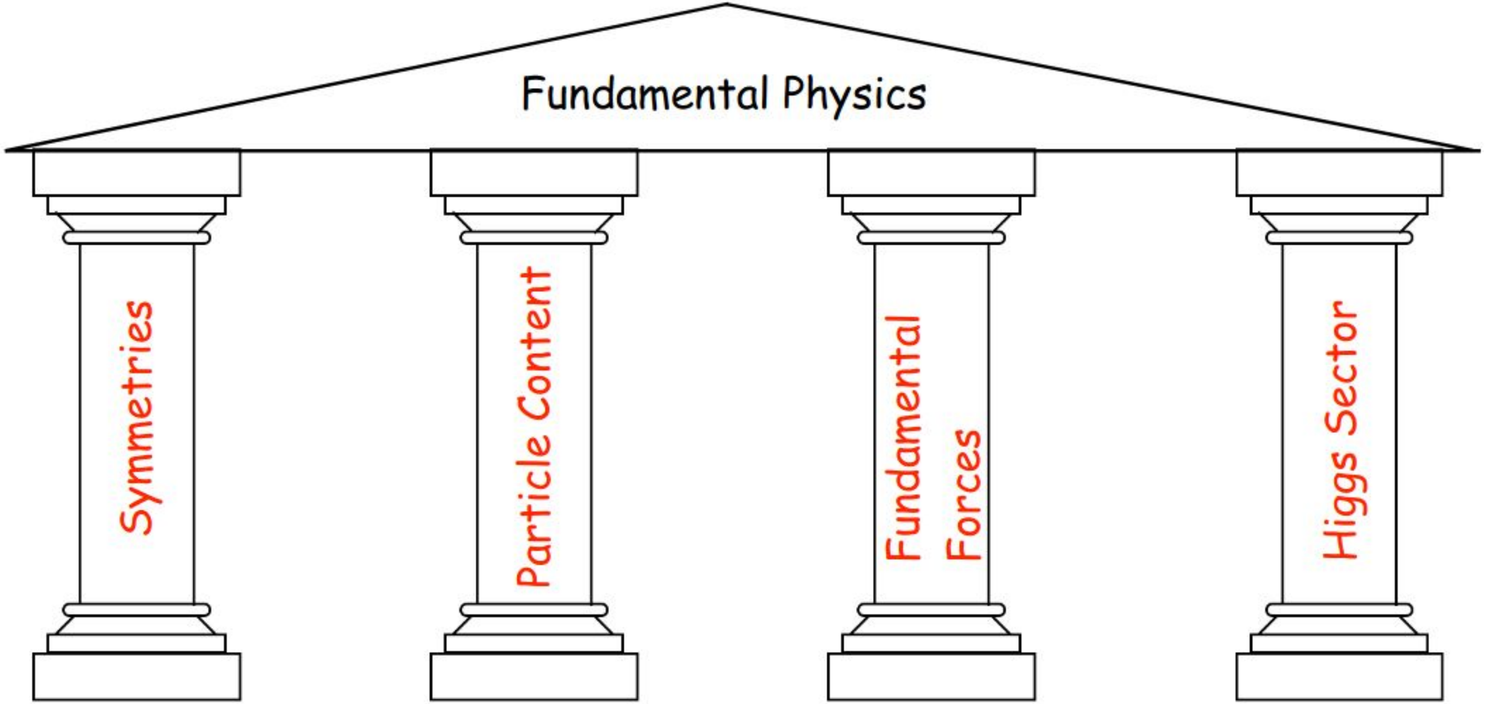
Four pillars of the Standard Model



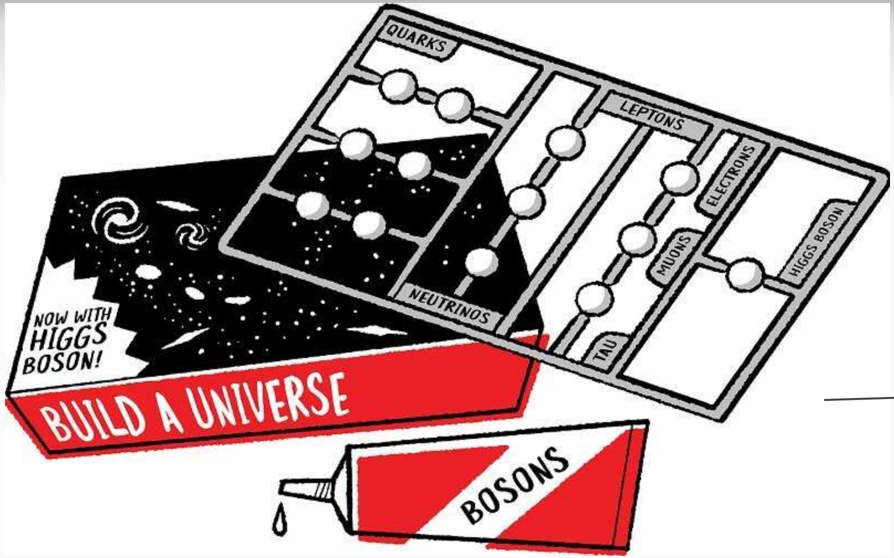
Four pillars of the Standard Model



Four pillars of the Standard Model



How do we study Particle Physics?

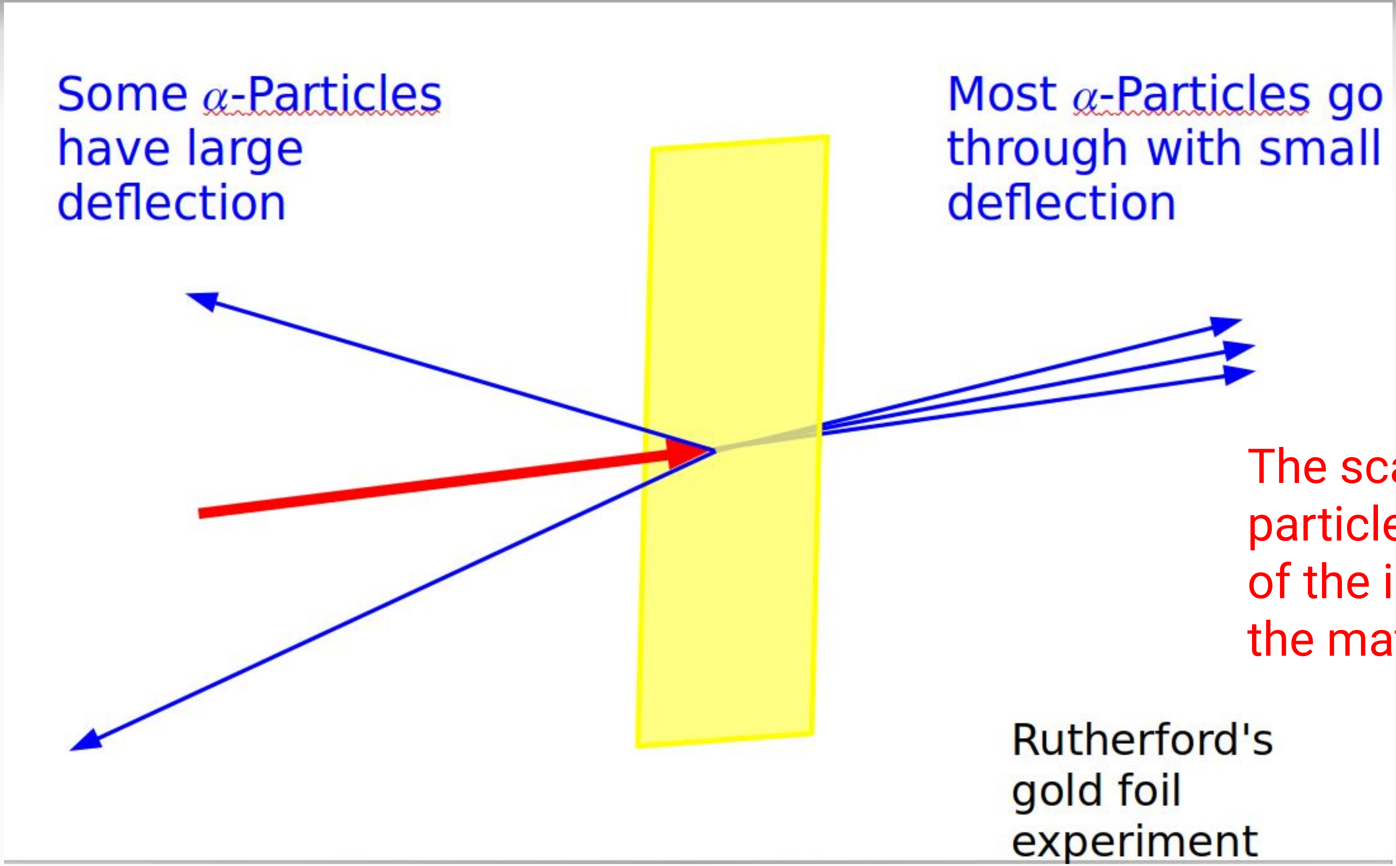


?????

We know the ingredients of the universe (effectively), how do we experimentally study or disprove them? We need to produce them!

Physics = Accelerator(s) + Collider(s) + Detector(s) + Computer(s)

Why Collision?

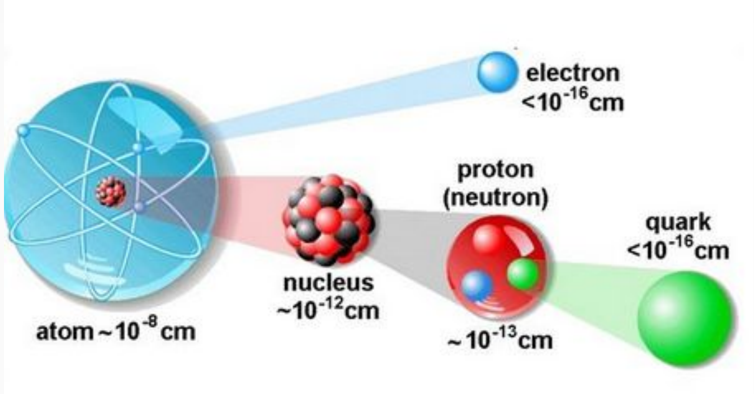


The scattered/unscattered particles “paint” the picture of the internal structure of the material/particle

Interaction Scale

- Studying the inner structure of matter with scattering experiments.
- The wavelength of the probe radiation needs to be smaller than the object to resolve the inner details.

$$\boxed{\lambda = \frac{hc}{E}}$$



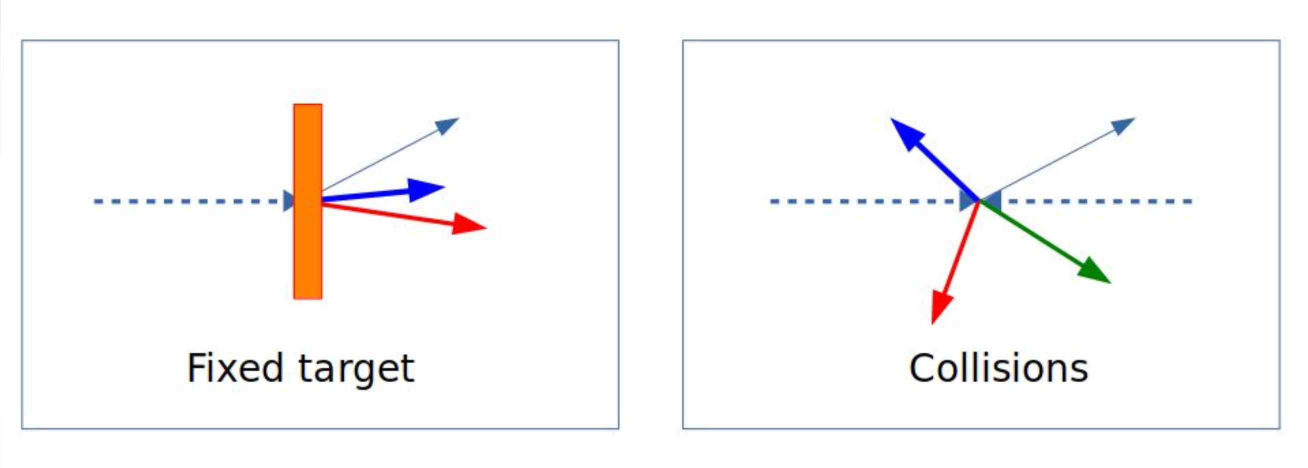
- Energy unit = 1 eV = 1.6e-19 Joule.
- hc = 1.24 eV.µm.
- Typical energy of α particle is 5 MeV, we can probe $\sim$ 250 fm.
- Proton is ~ 1 fm, we need energy of $\sim$ 1.24 GeV to “peek inside” a proton.
- A Higgs boson has a mass of 125 GeV, to produce it we would need collisions at C.O.M energy of at least 125 GeV.

Energy Comparison

Energy	Remarks
40 meV	Average kinetic energy for one air molecule in room temp.
$<$ 120 meV	Rest energy of neutrinos (sum of 3 flavors)
1.6 eV - 3.4 eV	The photon energy of visible light
2 MeV	E released in nuclear fission neutron from one U^{235}
125.1 GeV	Mass of a Higgs Boson
1 TeV	Kinetic energy of a flying mosquito
14 TeV	Designed centre of mass energy for Large Hadron Collider
2 PeV	Energetic neutrino detected in IceCube to date
624 EeV	E consumed by a 100-watt light bulb in one second
10 YeV (10^{25} eV)	approximate grand unification energy
1.22×10^{28} eV	Planck Energy

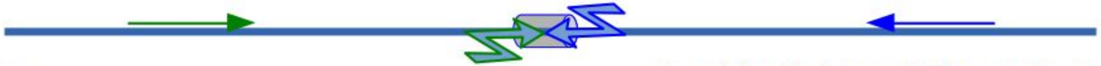
https://en.wikipedia.org/wiki/Electronvolt

The Collision



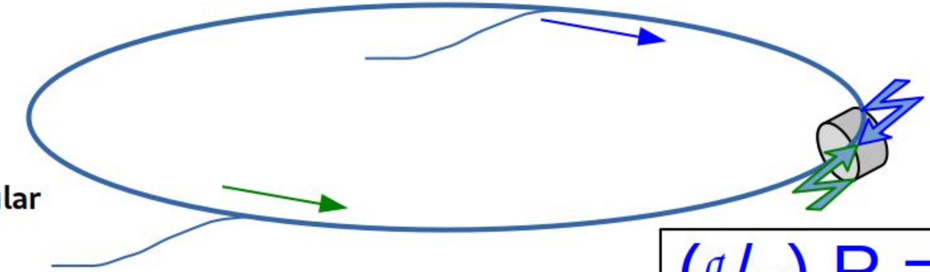
- What particle should I collide? Are they easily available?
- Most experiments start from proton and electron.
- What particles will be ejected? How do I identify them? What are their properties and how do I measure them?
- Can i manipulate them readily?

Colliders



Linear

Good for light particles such as electrons



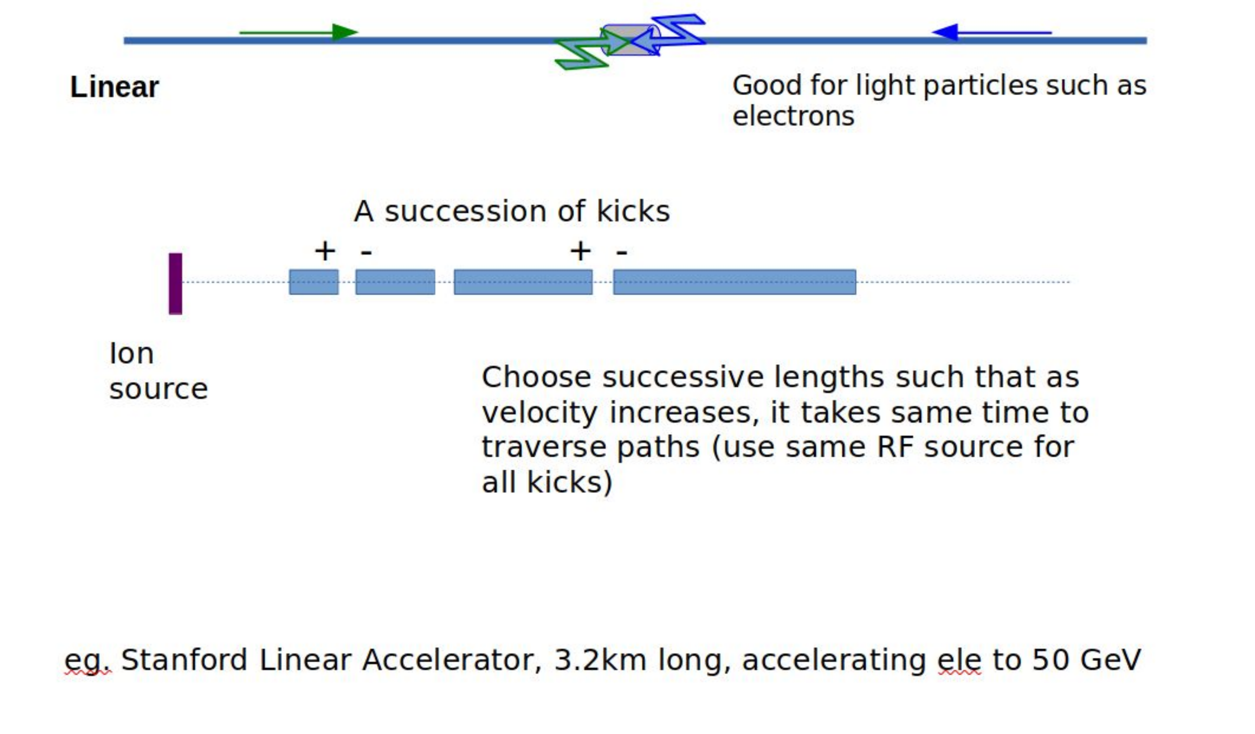
Circular

Use magnets to bend beams

$$\boxed{(q/m)\,R = v/B}$$

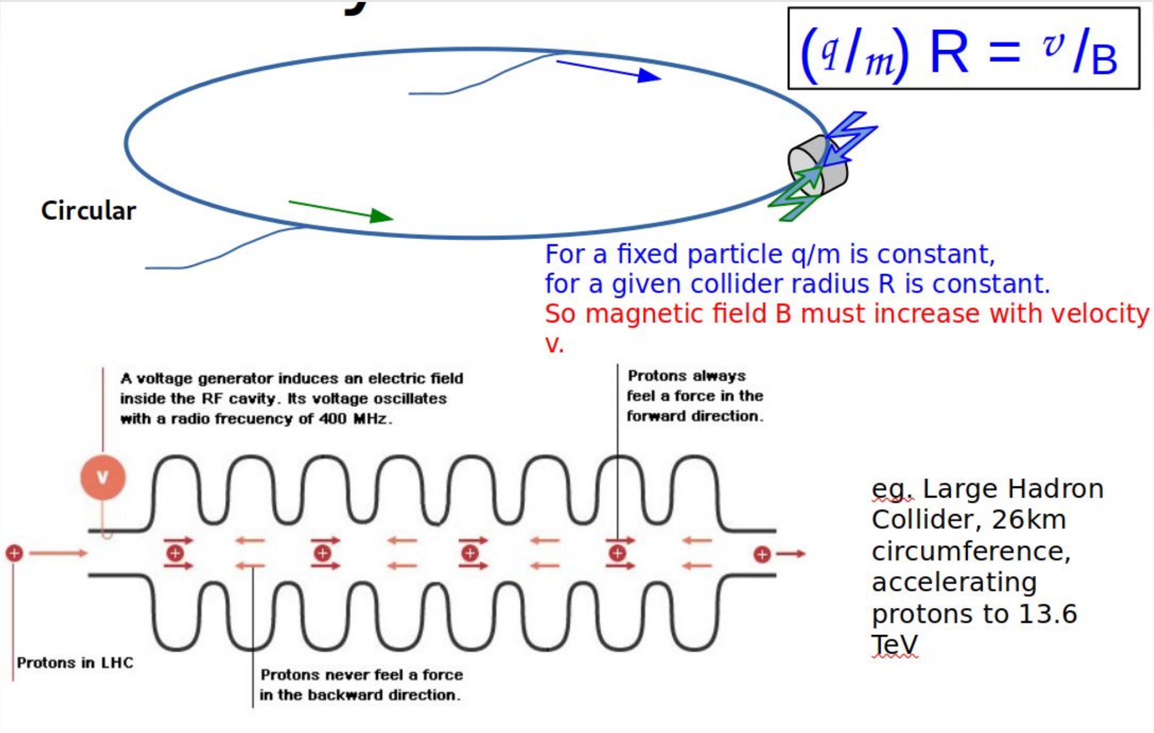
For a fixed particle q/m is constant,
for a given collider radius R is constant.
So magnetic field B must increase with velocity v.

Linear Accelerator



- Pro:
  - No synchrotron radiation.
  - Produce reliable beam (no bending).
- Con:
  - Consists of chain of many successive gaps.
  - Particle pass the accelerator only ONCE.
  - Final energy limited by length.

Synchrotron



- Pro:
  - Can accelerate to higher energies.
  - Can Reuse beam
  - Can have multiple collision
- Con:
  - Charged particles can radiate energies in circular motion. (Need bigger ring or heavy particles)
  - Expensive superconducting magnets (maintenance)

Collider Parameters

Hadron	HERA (DESY)	TEVATRON* (Fermilab)	RHIC Brookhaven	LHC (CERN)		
Physics start date	1992	1987	2001	2009	2015	2026 (HL-LHC)
Physics end date	2007	2011	—	—		
Particles collided	ep	$p\bar{p}$	pp (polarized)	pp		
Maximum beam energy (TeV)	e: 0.030 p: 0.92	0.980	0.255 55% polarization	4.0	6.5	7.0
Max. delivered integrated luminosity per exp. (fb^{-1})	0.8	12	0.38 at 100 GeV 1.3 at 250/255 GeV	23.3 at 4.0 TeV 6.1 at 3.5 TeV	160	250/y

Running!! → RUN3

e^+e^-	CESR (Cornell)	CESR-C (Cornell)	LEP (CERN)	SLC (SLAC)
Physics start date	1979	2002	1989	1989
Physics end date	2002	2008	2000	1998
Maximum beam energy (GeV)	6	6	100 - 104.6	50
Delivered integrated luminosity per experiment (fb^{-1})	41.5	2.0	0.221 at Z peak 0.501 at 65 – 100 GeV 0.275 at >100 GeV	0.022

Heavy Ions	RHIC (Brookhaven)		LHC (CERN)			
Physics start date	2000	2012 / 2018 / 2018 / 2012 / 2004 2014 / 2002 / 2015 / 2015	2010	2012	2017	$\geq$ 2021 (high lum.)*
Physics end date	—		—			
Particles collided	Au Au	U U / Zr Zr / Ru Ru / Cu Au Cu Cu / h Au d Au / p Au / p Al	Pb Pb	p Pb	Xe Xe	Pb Pb
Max. beam energy (TeV/n)	0.1	0.1	2.51	p:6.5 Pb:2.56	2.72	2.76
$\sqrt{s_{NN}}$ (TeV)	0.2	0.2	5.02	8.16	5.44	5.5
Max. delivered int. nucleon-pair lumin. per exp. (pb^{-1})	2639 (at 100 GeV/n)	21 / 36 / 36.9 / 167 / 60 43 / 169 / 124 / 63 (all at 100 GeV/n)	77.8	194	0.05	$\approx$ 121/y

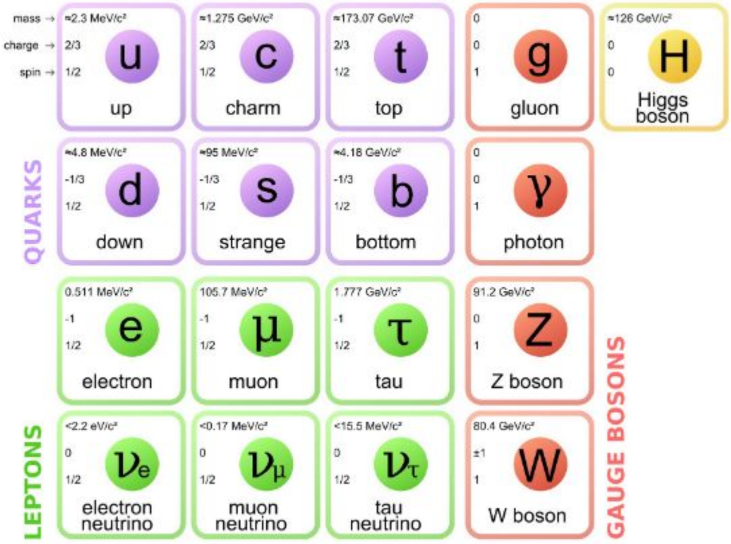
https://pdg.lbl.gov/2021/reviews/rpp2021-rev-accel-phys-colliders.pdf

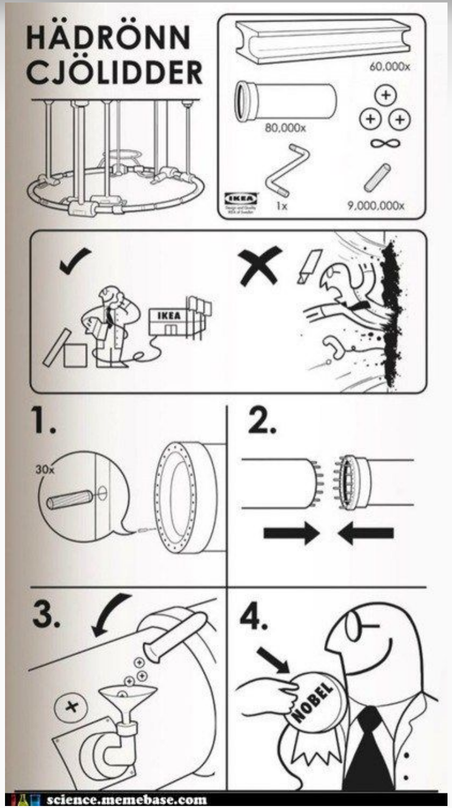
Collider as a discovery machine

Timeline of discoveries:

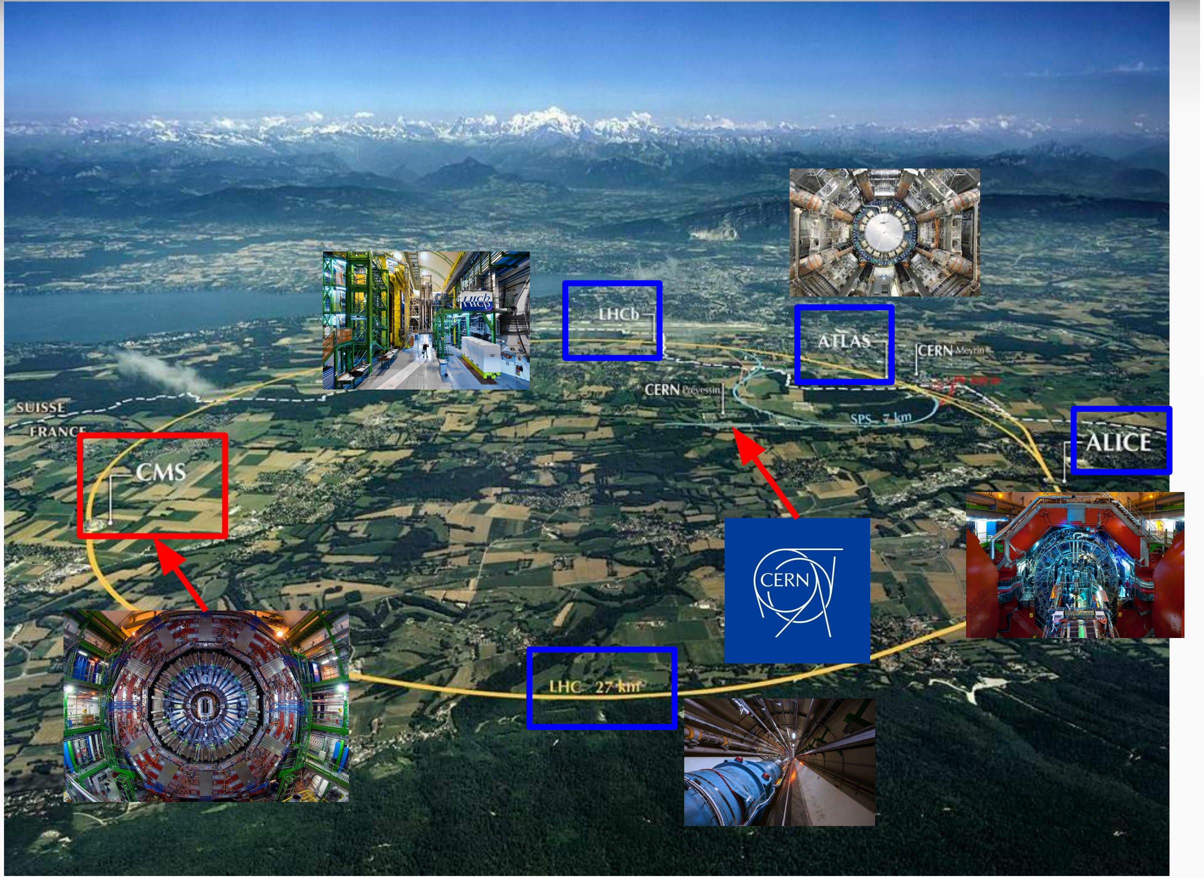
1897 : Electron – Cathode ray
1932 : Positron – Cloud chamber
1937 : Muon – Cloud chamber
1956 : Electron neutrino – Scintillator
1962 : Muon neutrino
1968 : u, d, s quarks – SLAC
1974 : c quark - SLAC
1975 : Tau – SLAC, LBNL
1977 : b quark – Fermilab
1979 : gluons - DESY
1983 : W and Z – UA1, UA2 (CERN)
1995 : t quark - Fermilab
2000 : Tau neutrino – DONUT collaboration

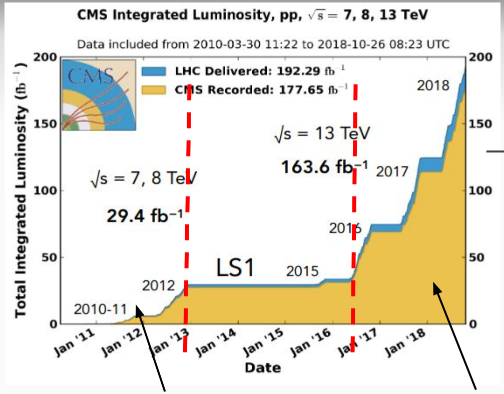
2012 : Higgs boson – LHC (CERN)





The Large Hadron Collider

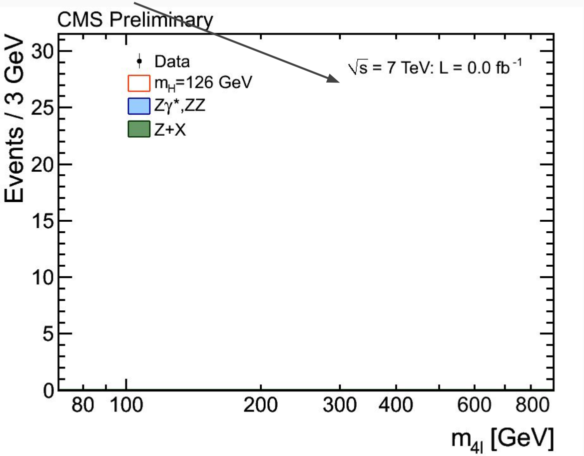




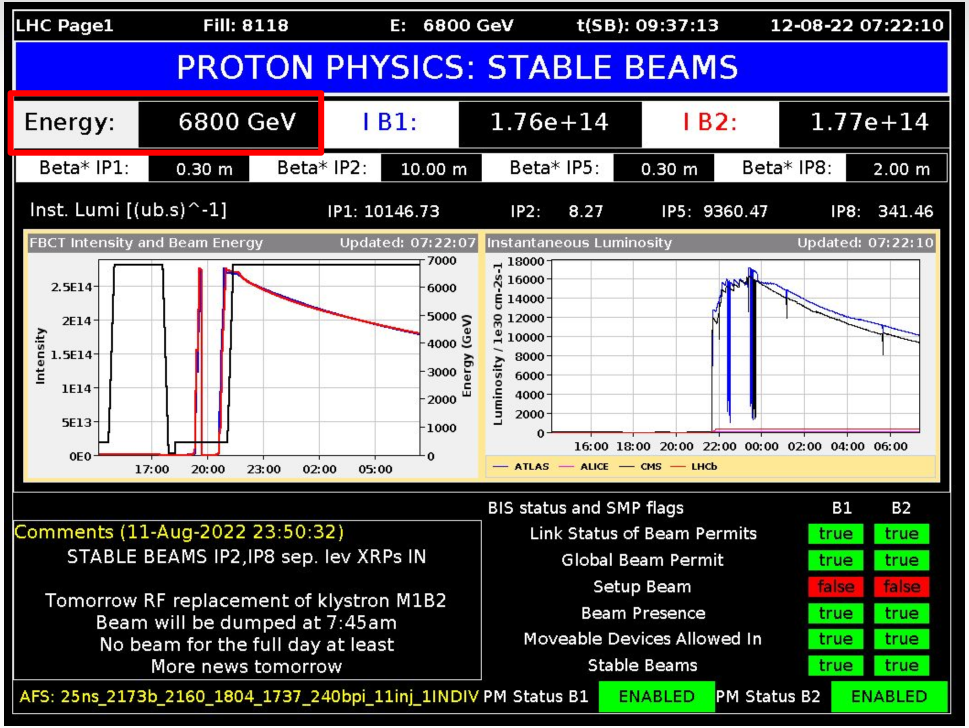
Run-III data-taking

Run-I Dataset

Run-II Dataset



Run-3 Begins on July 2022

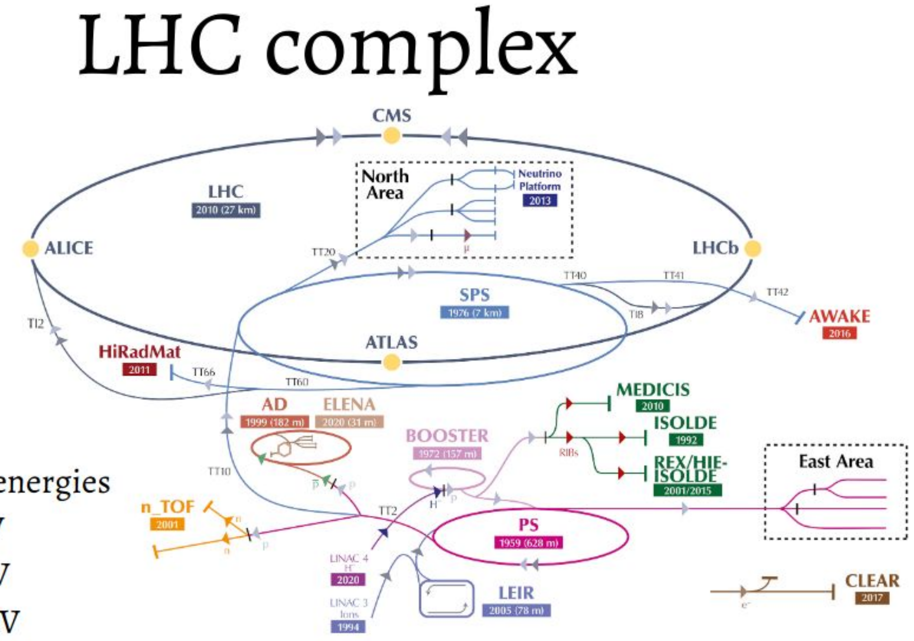


13.6 TeV

“Trailers” : ->
https://home.cern/press/2022/run-3

https://op-webtools.web.cern.ch/vistar/vistars.php

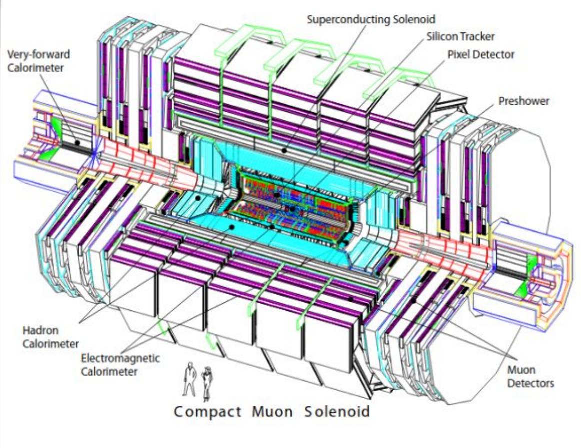
Accelerator and Detector

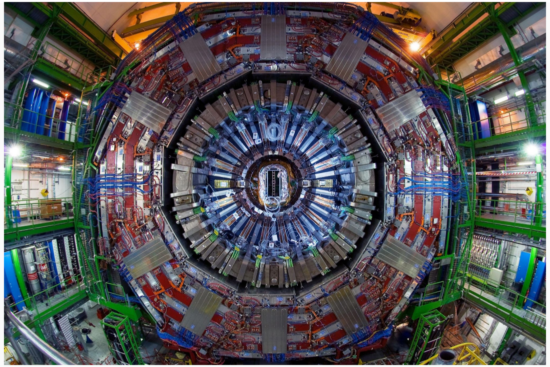


LHC operating energies

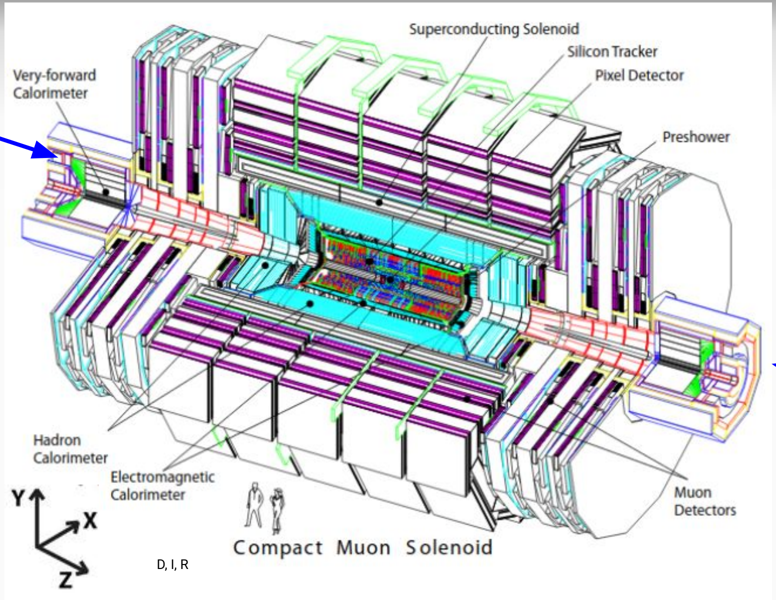
2010+2011	7 TeV
2012	8 TeV
2015-2018	13 TeV
2022-....	13.6 TeV

LINAC →	BOOSTER →	PS →	SPS →	LHC
50 MeV	1.4 GeV	26 GeV	400 GeV	7 TeV

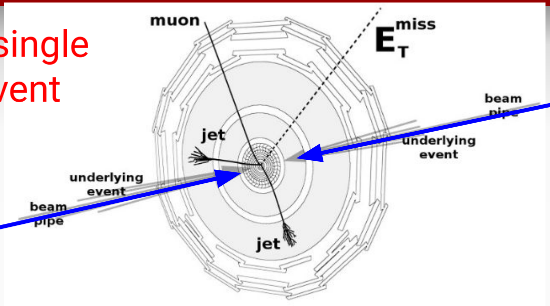


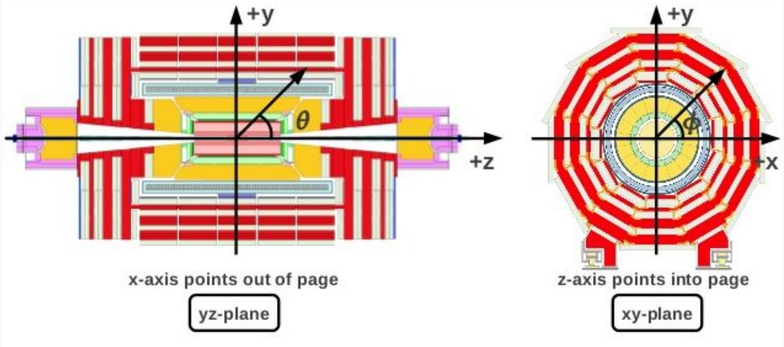


CMS Detector



Example of single collision event





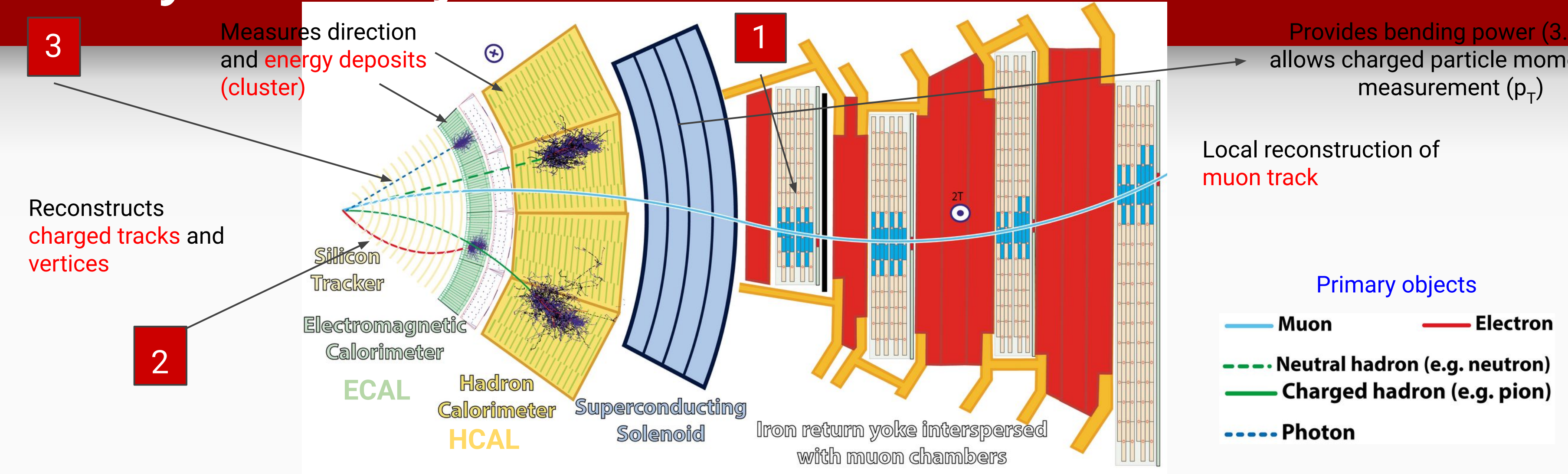
- Basic information:
  - Multi-purpose detector
  - Length: 21.6 m
  - Diameter: 15 m
  - Weight: ~ 14,000 tons

Pseudorapidity: $\eta = -\ln\left(\tan(\theta/2)\right)$

Transverse momentum: $p_T = \sqrt{p_x^2 + p_y^2}$

Distance between physics objects: $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$

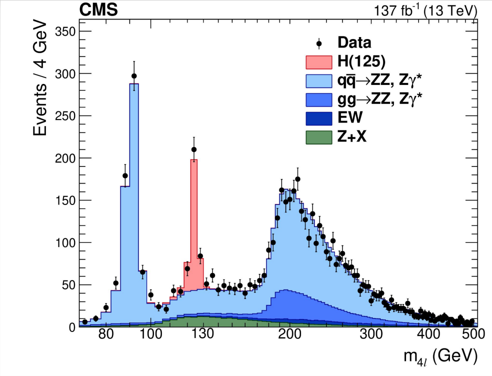
Physics Object Reconstruction



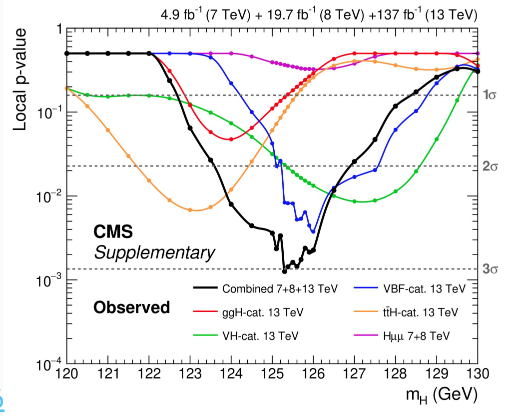
- Particle Flow (PF) algorithm uses basic elements from various sub-detectors to provide best reconstruction of the primary objects:
  1. Muon tracks are matched to tracks in inner tracker.
  2. Remaining inner tracker's tracks associated with energy deposits in ECAL (electron) and HCAL (charged hadrons).
  3. Remaining energy deposits are likely from neutral sources, ECAL (photons) and HCAL (neutral hadrons).

Physics Program in CMS

- Higgs physics:
  - Precision measurement of Higgs Boson properties
  - Search for rare decay channel (Higgs → mu mu).
- Beyond Standard Model Searches:
  - Dark matter, SUSY, Extra Dimension, etc.
  - Model independent searches.
- Standard Model Measurement:
  - Top quark physics measurement
  - Measurement of Standard Model properties.
- B-physics (relatively new physics program):
  - CP-Violation
  - Beauty quark related measurement.
- Heavy Ion Physics



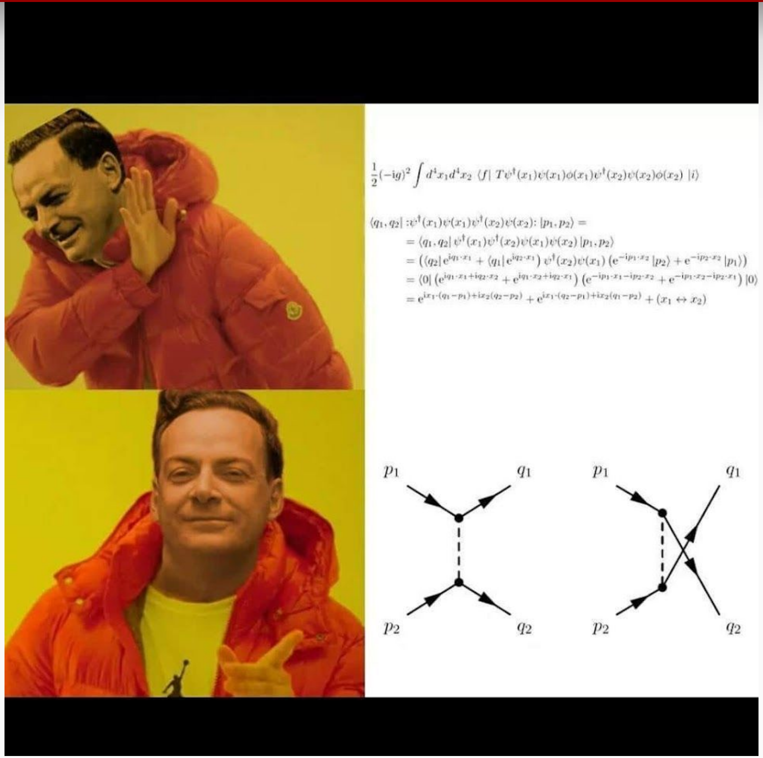
HIG-19-001

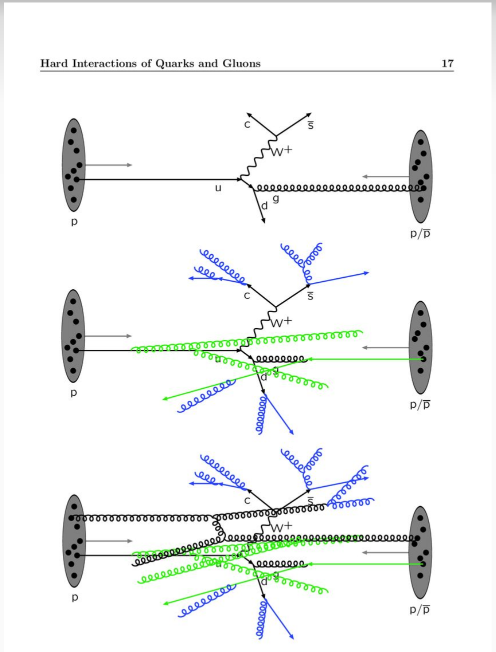


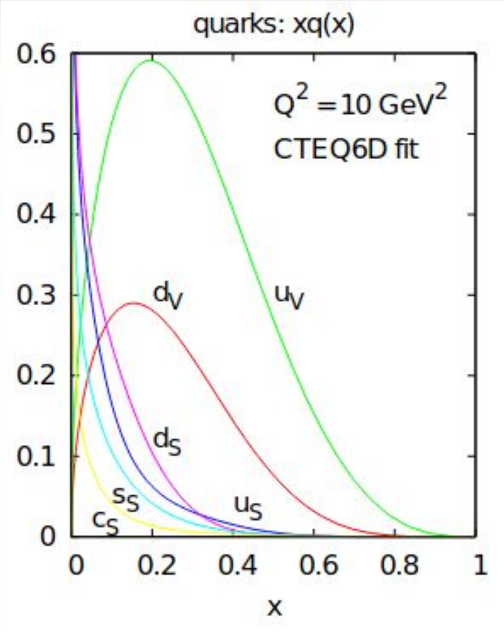
HIG-19-006

HEP Highlights

Feynman Diagrams and Parton Model







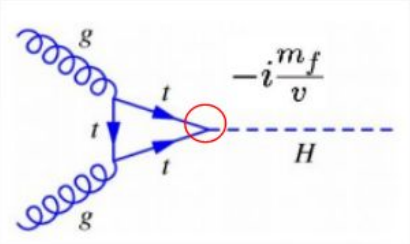
Parton distribution function (PDF) of a proton

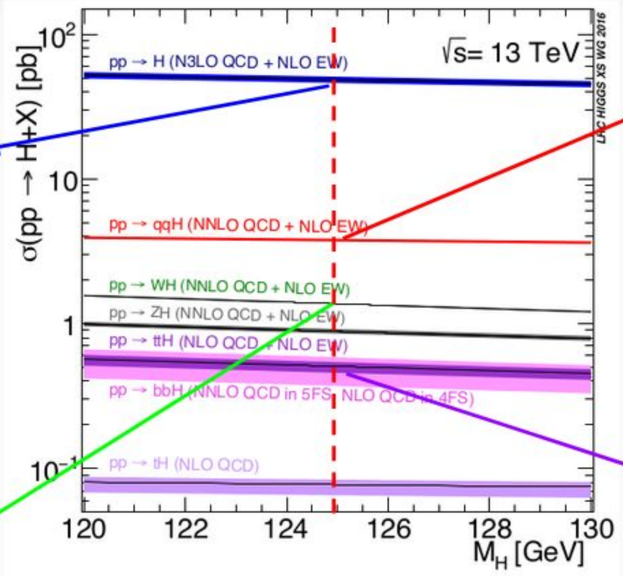
Feynman diagram is a pictorial representation of the mathematical expressions describing the behavior and interaction of subatomic particles

The constituents of proton involve in the interaction.

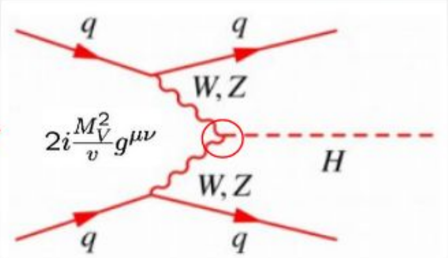
Higgs Production at LHC

Gluon fusion (ggH)

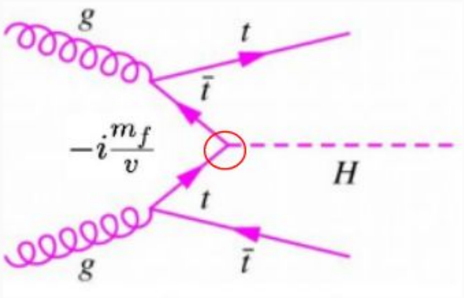




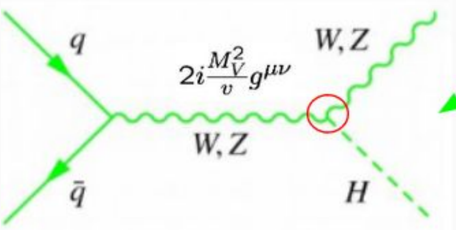
Vector boson fusion (VBF)



Top associated production (ttH)

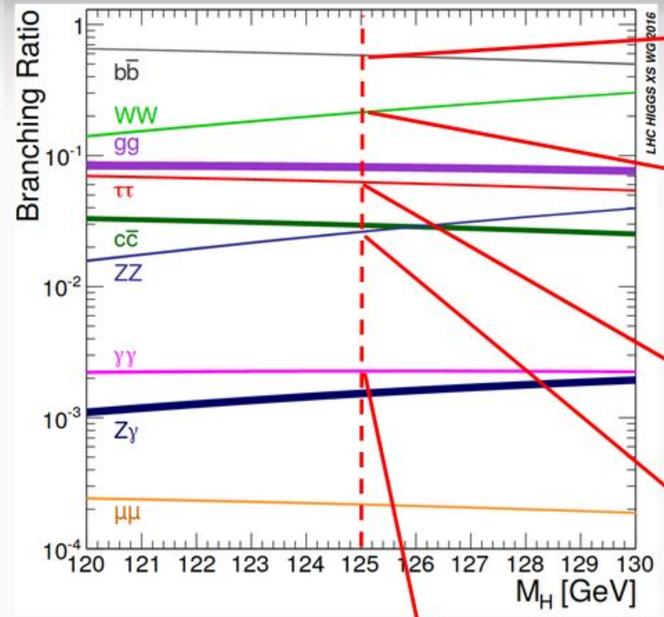


Vector boson associated production (VH)



M_{h} = 125.38 ± 0.14 GeV

Higgs decay at LHC



$H \rightarrow bb$ (~ 60%)

- Largest signal yield
- Large QCD background

$H \rightarrow WW^*$ (~ 22%)

- Large signal yield
- Clean experimental signature in $WW \rightarrow 2l2\nu$ final state.
- Poor Higgs mass resolution (~20%)

$H \rightarrow \tau\tau$ (~ 6%)

- Largest leptonic decay
- Reduced background compared to $H \rightarrow bb$

$H \rightarrow ZZ^*$ (~ 6%) [GOLDEN]

- Small backgrounds in the 4l final state
- Good Higgs mass resolution

$H \rightarrow \gamma\gamma$ (~0.1%) [GOLDEN]

- Substantial QCD backgrounds
- Good Higgs mass resolution

Summary of SM Higgs production and BR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Article | Open Access | Published: 04 July 2022

A portrait of the Higgs boson by the CMS experiment ten years after the discovery

The CMS Collaboration

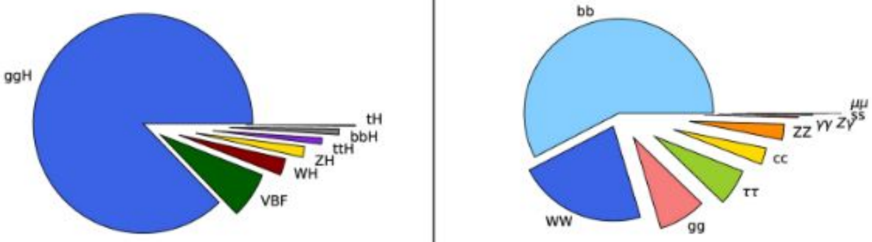
Nature **607**, 60–68 (2022) | Cite this article

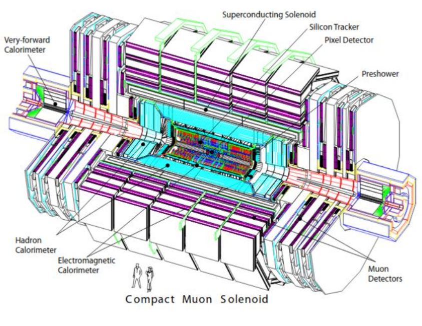
11k Accesses | **2** Citations | **406** Altmetric | Metrics

Results!

Extended Data Table 1 | The SM Higgs production cross-sections and branching fractions

Production mode	Cross section (pb)	Decay channel	Branching fraction (%)
ggH	48.31 ± 2.44	bb	57.63 ± 0.70
VBF	3.771 ± 0.807	WW	22.00 ± 0.33
WH	1.359 ± 0.028	gg	8.15 ± 0.42
ZH	0.877 ± 0.036	$\tau\tau$	6.21 ± 0.09
ttH	0.503 ± 0.035	cc	2.86 ± 0.09
bbH	0.482 ± 0.097	ZZ	2.71 ± 0.04
tH	0.092 ± 0.008	$\gamma\gamma$	0.227 ± 0.005
		$Z\gamma$	0.157 ± 0.009
		ss	0.025 ± 0.001
		$\mu\mu$	0.0216 ± 0.0004

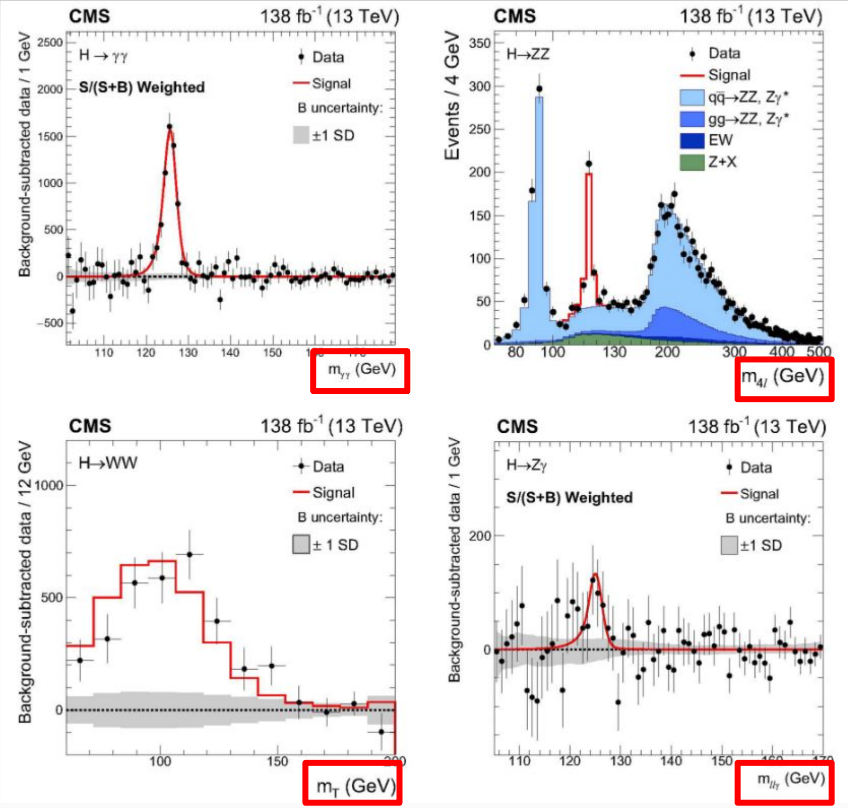


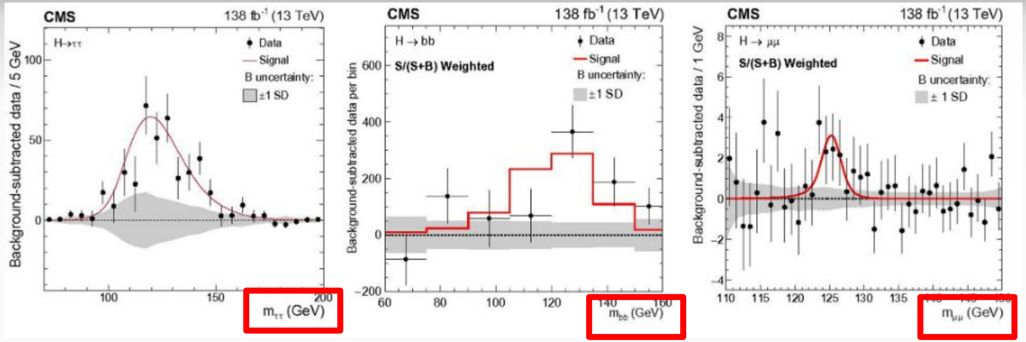


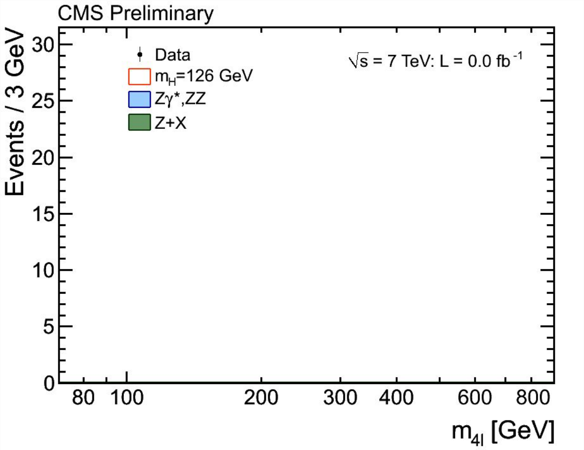
As a guide

Flexing its mighty muscle!

Bump Search

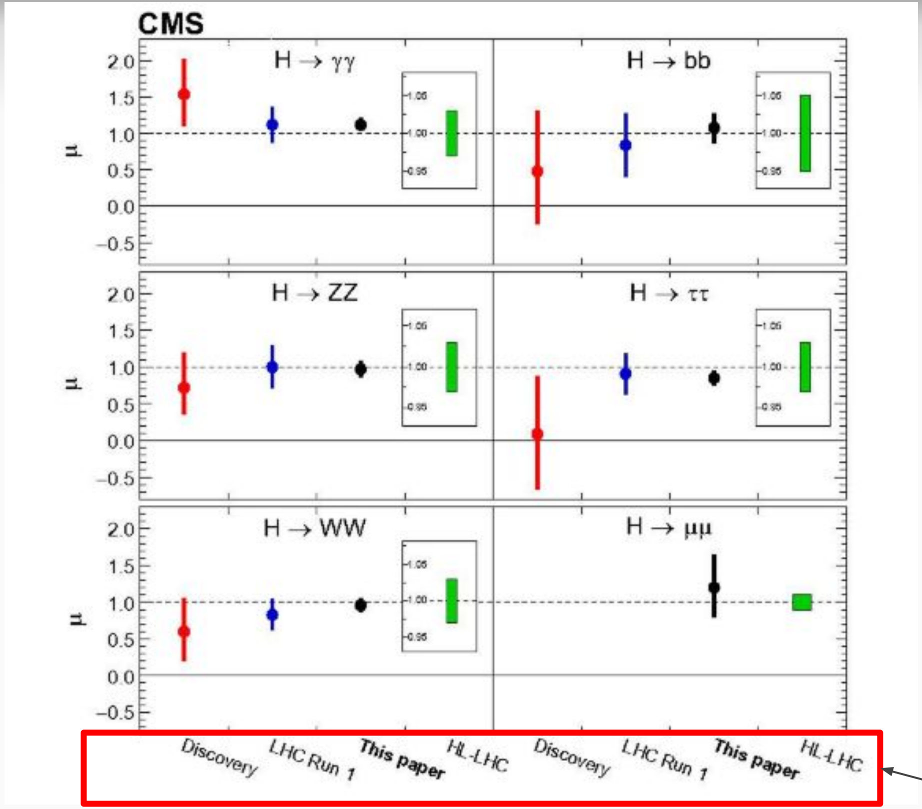


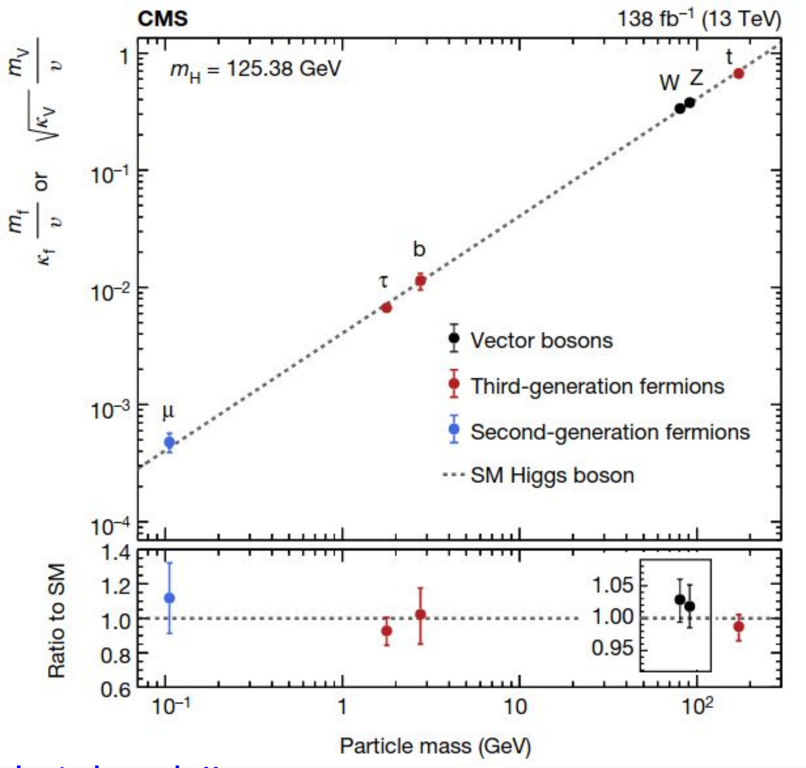




https://www.nature.com/articles/s41586-022-04892-x.pdf

Measurement





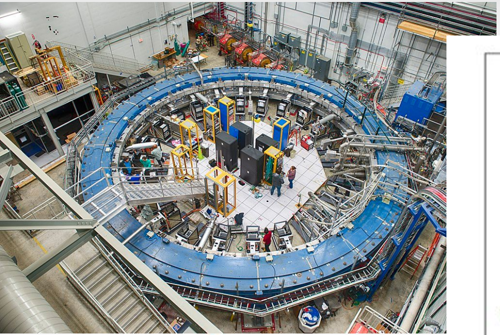
Exactly 1 decade!!

Measurement on signal strength and yukawa coupling(s)

https://www.nature.com/articles/s41586-022-04892-x.pdf

Beyond Standard Model (BSM)

Muon g-2 anomaly



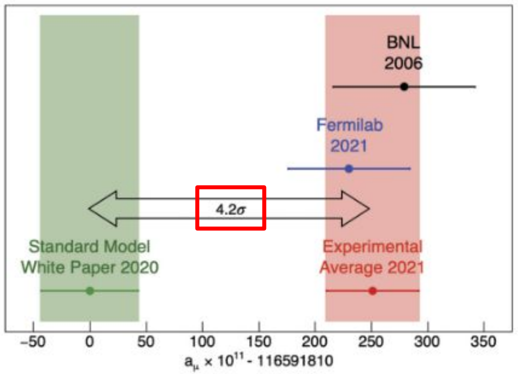


Fig. 2. Comparison between experimental values and theoretical prediction of a_μ

$$\vec{\mu} = g \frac{q}{2m} \vec{S}$$

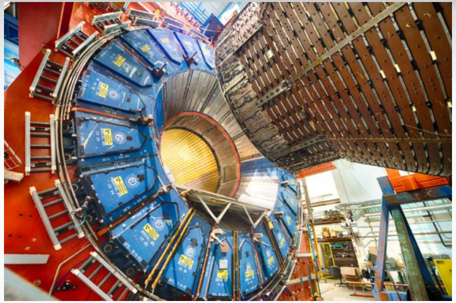
U = magnetic moment
g = gyromagnetic ratio
S = spin

$$a_l = (g_l - 2)/2$$

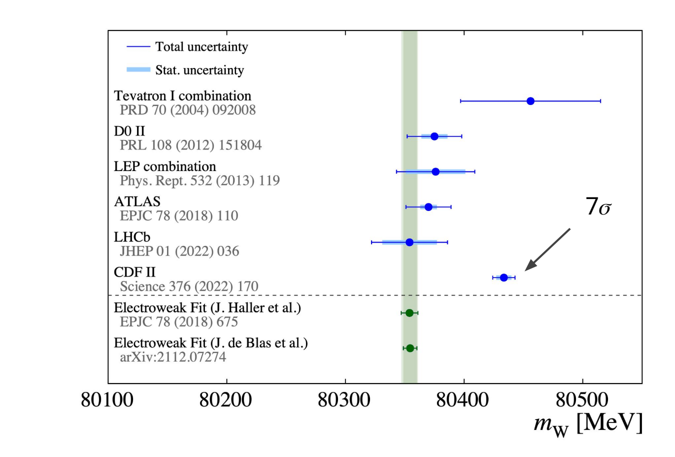
Radiative correction modifies g in relativistic limit.

Deviation implies BSM models that break lepton flavor universality.

https://www.sciencedirect.com/science/article/pii/S0550321322000268

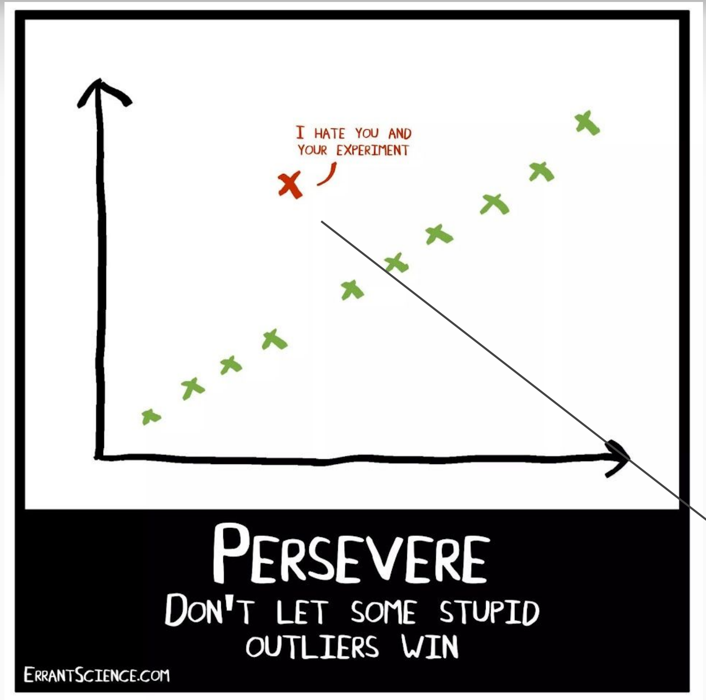


Precision measurement of W boson mass at CDF



https://www.youtube.com/watch?v=wRhAZ9M-lI8
https://cerncourier.com/a/cdf-sets-w-mass-against-the-standard-model/

Is Standard Model Broken??



Le Physicist

Hierarchy problem

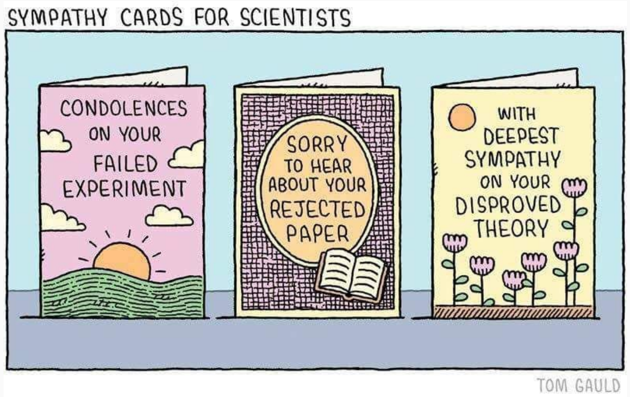
Why neutrino has mass?

Is there a graviton?

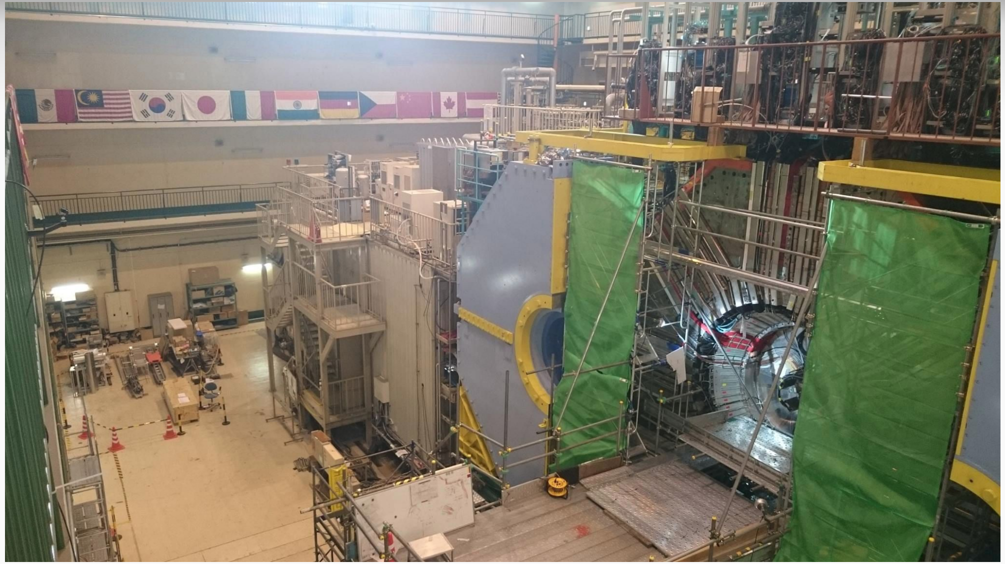
What is Dark Matter??

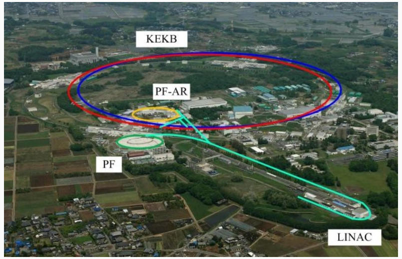
Why so much matter in the universe??

We LOVE IT!!!
Hints of Beyond Standard Model!!



HEP International Collaboration

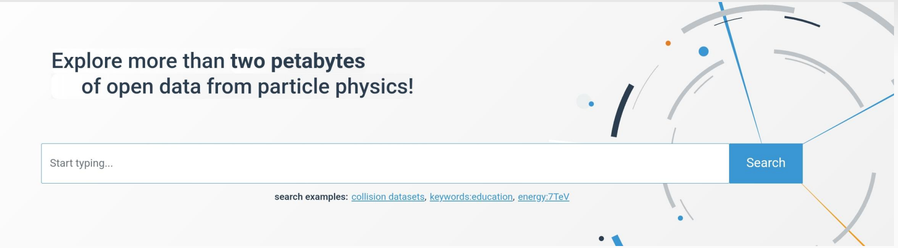




Frontier Research Powered by Open Science

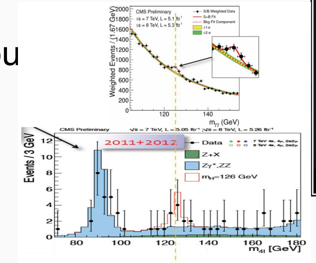
World Wide Web (WWW) invented at CERN

"An essential point was that the web should remain an open standard for all to use and that no-one should lock it up into a proprietary system."
– Berners-Lee, W3S, MIT



https://home.cern/news/press-release/knowledge-sharing/cern-announces-new-open-data-policy-support-open-science

"Open source is the only right way to do software"
– Torvalds Linus, Linux fou



Why open source solves the biggest problem

HEP Collaboration in Malaysia

CERN and Developing Countries

Malaysia is one country that is currently discussing a possible future collaboration with CERN. During a recent visit to Malaysia, Diether Blechschmidt (centre right), advisor to CERN's director-general, and his wife Britta Dezilli (left), attended an official dinner for CERN hosted by Datuk Abdul Rafie Bin Mahat (centre left), director-general of the Malaysian Ministry of Education. Also attending was Keith Lewin (right), director of the Centre for International Education at the University of Sussex, UK. The dinner offered an opportunity to establish first ties with Ministry officials, representatives of the Academy of Science of Malaysia and Malaysia's universities (standing).

What, then, are the main benefits for developing countries in collaborating with CERN? It certainly provides them with a way to participate in research at the cutting edge, just as it always has for physicists from smaller European countries. In general, these users spend limited periods at CERN, preparing experiments, taking data and meeting other scientists. Thanks to the Internet, and to CERN's World Wide Web in particular, particle physicists were the first to make remote collaboration commonplace, and this habit has spread to many other fields beyond the sciences. It is now relatively easy for scientists working on an experiment at CERN to maintain contact with their colleagues around the world, and they can even contribute to software development, data analysis and hardware construction from their home institute. The Web has enabled Indian experimentalists to access LEP data, and their theoretician colleagues to access the latest scientific papers from around the world, all while sitting at their home desks.

[Published on CERN courier on 30 June 2003]

Malaysia joining CMS Collaboration

CMS COLLABORATION

Faridah Mohamad Idris[1], **Wan Ahmad Tajuddin Wan Abdullah**[2], **Zainol Abidin Ibrahim**[2], **Zukhaimira Zolkapli**[2], **Afiq Aizuddin Anuar**[2], **Nurfikri Norjoharuddeen**[2], **Mohd Adli bin Md Ali**[2], **Abdul Aziz Mohamed**[2], **Roslan Ismail**[2], **Abdul Rahim Ahmad**[2]

[1]Malaysian Nuclear Agency, Bangi, 43000 Kajang, Selangor, Malaysia; [2]Physics Department, University of Malaya, 56003 Kuala Lumpur, Malaysia; [3]Universiti Tenaga Nasional (UNITEN), Kajang, Selangor, Malaysia

Corresponding email: faridah_idris@nuclearmalaysia.gov.my

Abstract. CMS Collaboration is an international scientific collaboration located at European Organization for Nuclear Research (CERN), Switzerland, dedicated in carried out research on experimental particle physics. Consisting of 182 institutions from 42 countries from all around the world, CMS Collaboration hosts a general purpose detector i.e. the Compact Muon Solenoid (CMS) for members in CMS Collaboration to conduct experiments from the collision of two proton beams accelerated to a speed of 8TeV in the LHC ring. In this paper, we described how the CMS detector is used by the scientists in CMS Collaboration to reconstruct the most basic building of matter..

INTRODUCTION. Malaysia was officially **accepted into the CMS Collaboration on 20 October 2013**, after a voting by the CMS Board Members in the CMS Meeting in Taiwan recently. The acceptance of Malaysia into the CMS Collaboration is under the umbrella **National Centre of Particle Physics (NCPP)**, which is jointly sponsored by **University of Malaya and Academy of Sciences Malaysia**. NCPP will coordinate the activities of Malaysia as member of CMS Collaboration. Malaysia is the 42nd country to join CMS Collaboration **at the frontier of research**.

Further reading: CERN, ASM

The CMS Collaboration

[The CMS Experiment](#)

3103	1031	269	241	54
PHYSICISTS (1050 STUDENTS)	ENGINEERS	TECHNICIANS	INSTITUTES	COUNTRIES & REGIONS

The Details

The CMS collaboration has around:

5494
ACTIVE PEOPLE
(PHYSICISTS, ENGINEERS, TECHNICAL, ADMINISTRATIVE, STUDENTS, ETC.)

Of these members there are about:

2053	1050	1031	978
PHD PHYSICISTS (1689 MEN, 364 WOMEN)	PHYSICS DOCTORAL STUDENTS (792 MEN, 258 WOMEN)	ENGINEERS (895 MEN, 136 WOMEN)	UNDERGRADUATES (708 MEN, 270 WOMEN)

* The above categories are, by definition, non-overlapping

** As of February 2022

[Further reading](#)

Malaysian Institution Participation in HEP

Notable mentioned

Dr. Imran yusuff
Dr. Hoh Siew Yan

As I have known of...

National Centre for Particle Physics (NCPP)

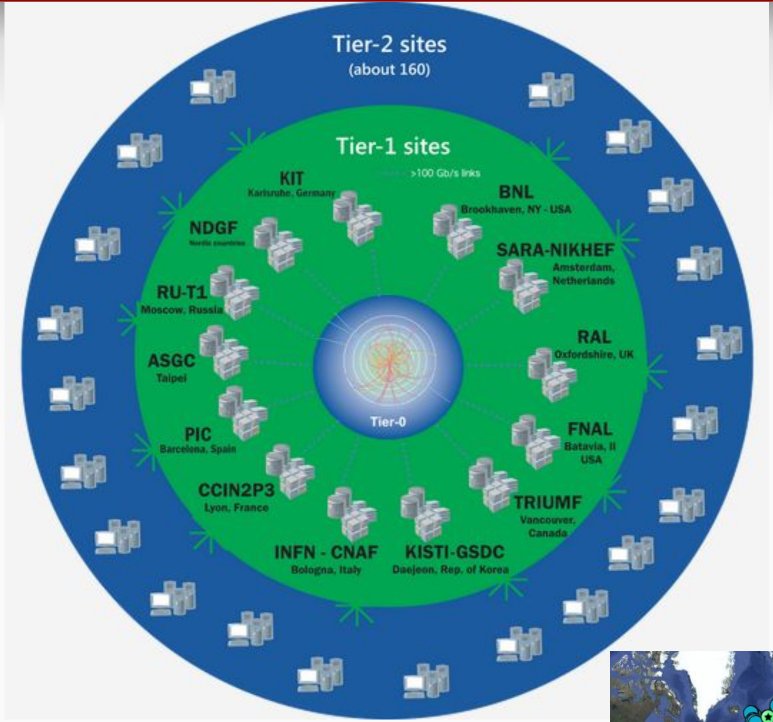
- NCPP is a consortium founded to centralize scientific collaboration between particle physics research groups within Malaysia:
  - UM, UKM, UTM
- Local particle physics researchers are allowed to utilise NCPP facilities and international network.

Managerial Position

- NCPP:
    - Malaysia CMS team leader : Dr. Nurfikri (UM)
    - Malaysia CMS deputy team leader : Dr. Imran (UKM)
    - NCPP Fellow: Dr. Izyan, Dr. Hoh, Dr. Anuar
- Responsibilities in the collaboration:
    - Jet-Met reconstruction algorithm Level-3 Co-convener : Dr. Nurfikri (UM)
    - Very Heavy Fermions (VHF) Level-3 (Former) Co-convener: Dr. Nurfikri (UM)
    - Generator integration Level-3 Convener : Dr. Hoh (UKM)
    - Representative of NCPP for HGCAL institution board : Dr. Imran (UKM)
    - CMS HGCAL shifter: Dr. Imran (UKM)
    - Spokesperson for MuCID and COMET-MY collaboration: Dr. Izyan (UTM)

Color code:
Local researchers involvement → UM ; UKM ; UTM

Malaysia participation in WLGC



- WLCG (WorldWide LHC Computing Grid) is made up of four layers, or "tiers"; 0, 1, 2 and 3. Each tier provides a specific set of services.
- Malaysia contributes Tier 2s.
- The Tier 2s are typically **universities and other scientific institutes**, which can store sufficient data and provide adequate computing power for specific analysis tasks. They handle analysis requirements and proportional share of simulated event production and reconstruction.

World Wide Web is invented at CERN

Data Intensive Computing Centre (DICC)

Data-Intensive Computing Centre (a.k.a. DICC/HPC Service Unit, IPPP)

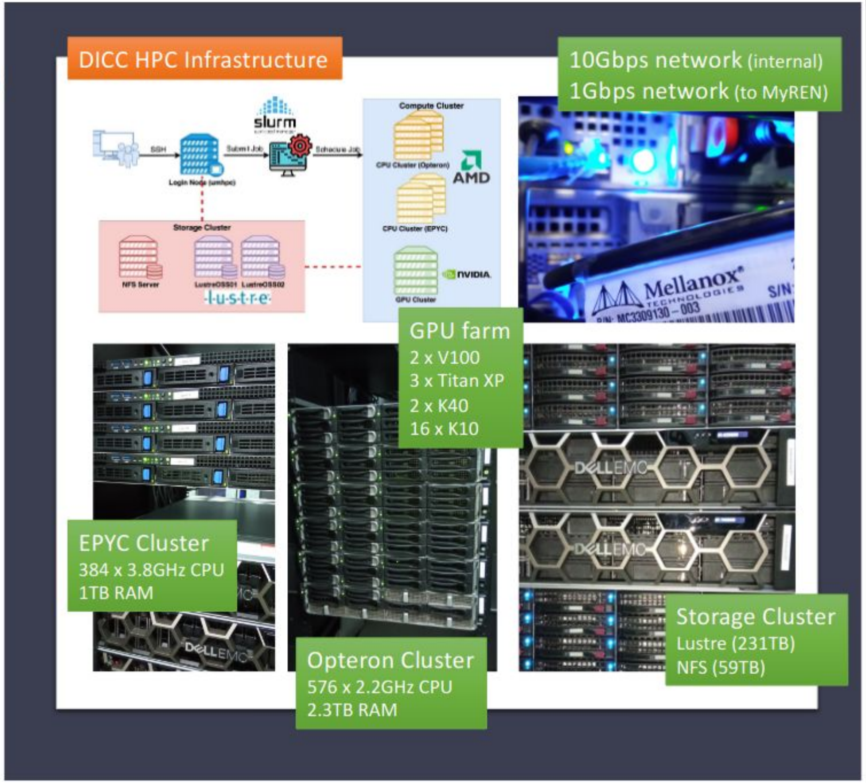
Our mission is to **enable scientific discoveries** through the **exploitation of advanced computing technologies**, by:

i) providing research communities with excellent IT service and support in addressing research computing challenges, and

ii) actively engaging data- and compute-intensive research in solving the domain science problems.

DICC

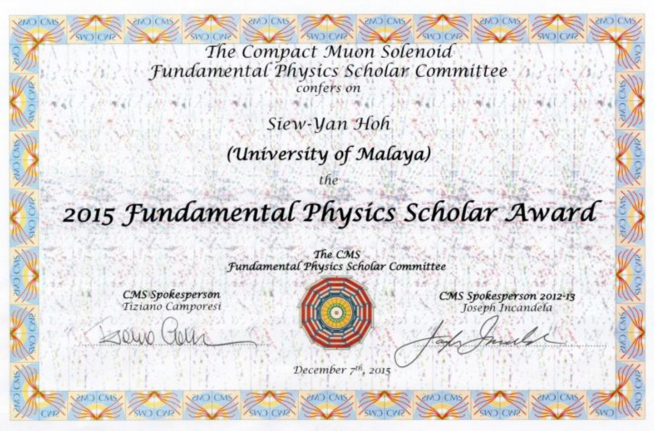
www.dicc.um.edu.my

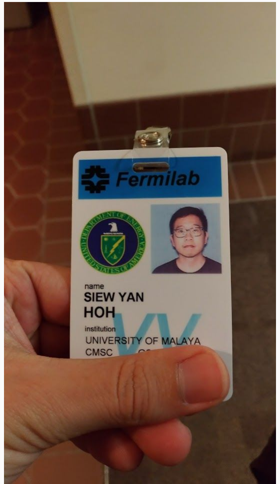


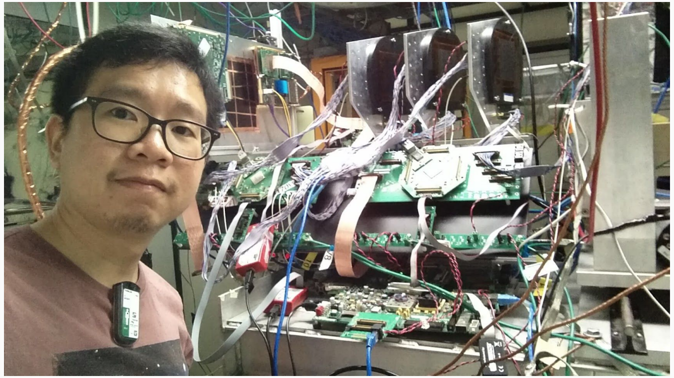
- Network bottleneck and power line instability causes the server room backout.
- The HPC is moved to PTM-UM.
- The HPC is under DICC maintenance and care.
- All discipline from UM and collaborators are using the HPC service.

NCPP Achievement

- NCPP produced 5 master students:
  - One DESY affiliated post-doctorate working at DESY (On-going).
  - One DESY affiliated post-doctorate working at CERN (On-going).
  - Two faculty members in UM and UKM, affiliated with FERMILAB (me).
- NCPP produced master student, awarded with Fundamental Physics Scholarship (FPS) 2016 and LPC Guest and visiting program 2017.



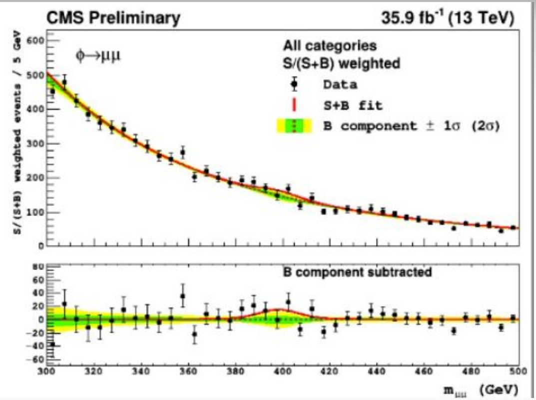


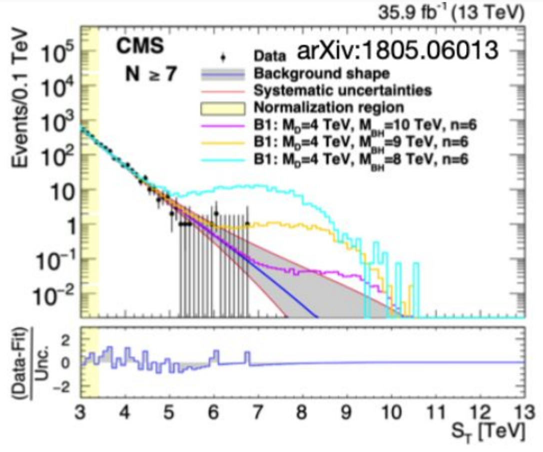


2-strip module prototype

NCPP Research Activities

- Active research in NCPP:
  - Search for Heavy Higgs Boson. (CMS)
  - Measurement of Vector Boson Scattering in the semi-leptonic final state. (CMS)
  - Dark Higgs searches. (FERMILAB-CMS)
  - Top quark pair production measurement using bottom-quark parked dataset. (CMS)
  - Proton decay searches (DUNE)
  - Neutrinoless muon decay into electron (COMET)
  - Development work on HGCAL, phase-II upgrade. (CMS)
  - String theory and loop quantum gravity (UKM)
  - Search for Micro Black Hole



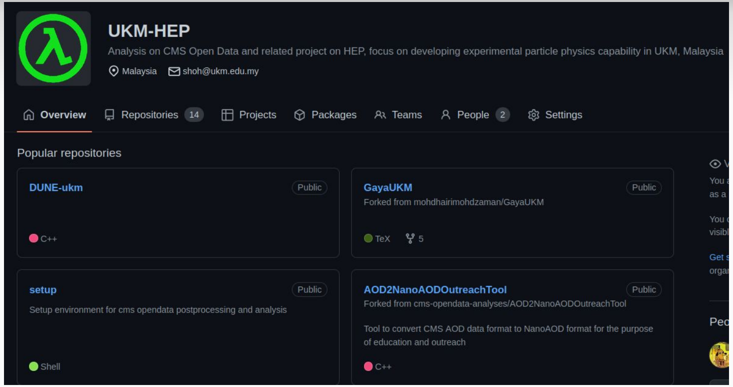


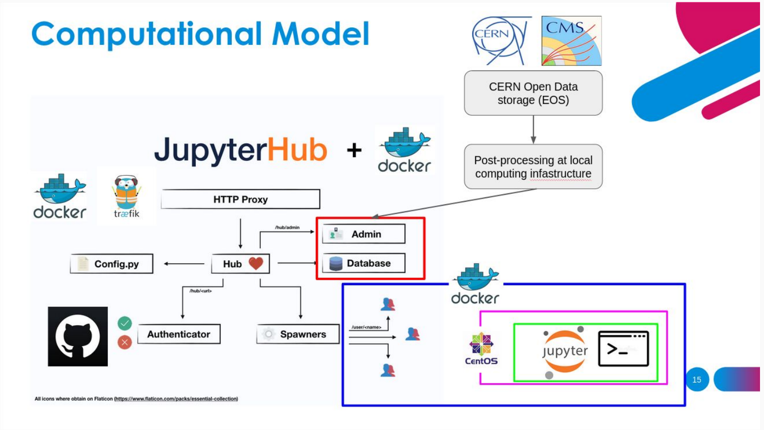
Color code:
Local researchers involvement → UM ; UKM ; UKM-UM ; UKM-UTM

HEP-UKM

HEP-UKM

- Redefine pedagogical structure for HEP in UKM, adding basic Standard Model physics, experimental hand-on exercises. (with Dr. Imran).
- Establishing local fundamental particle physics research group, focusing on experimental collider physics.
- 5 bachelors students under my supervision, working on HEP subjects (CMS Open Data).





https://github.com/UKM-HEP
https://github.com/UKM-HEP/jupyterhub-docker

Jupyter notebook server hosted in one node.

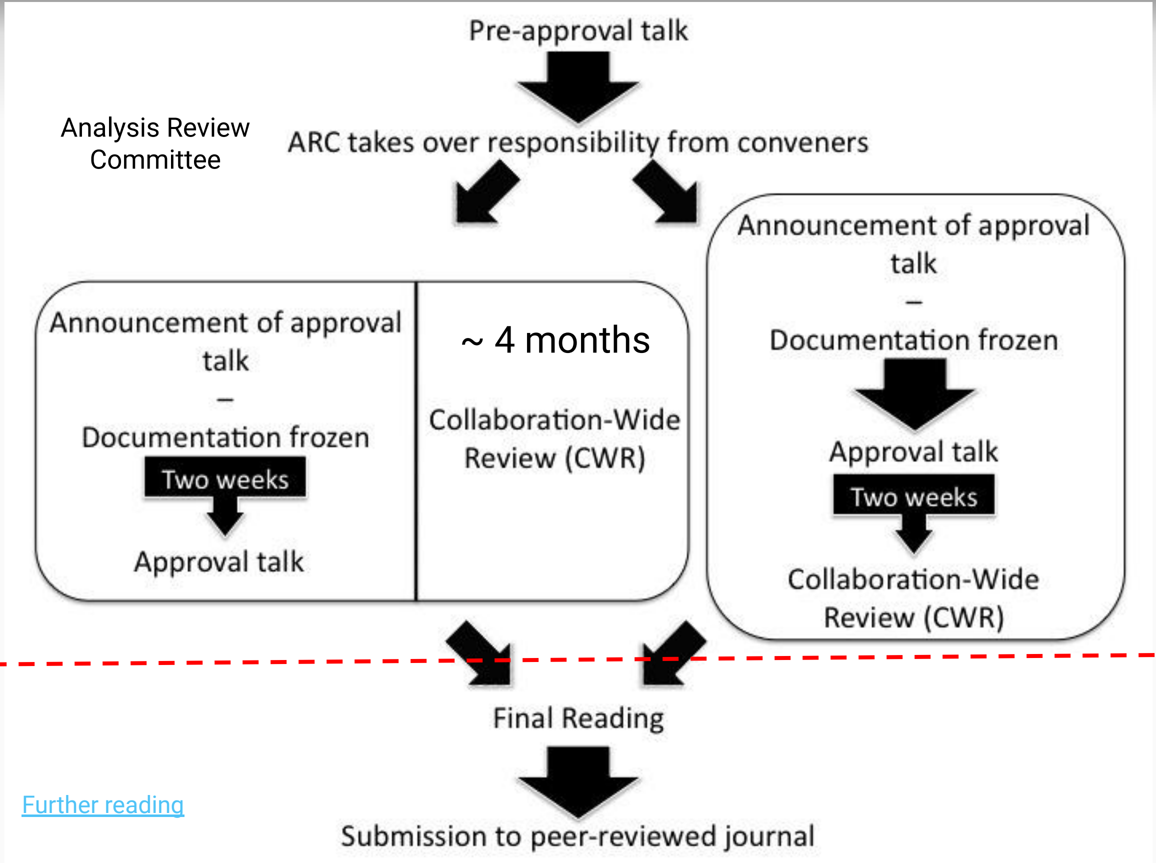
Conclusion

Conclusion

- The Standard Model (SM) of Particle Physics is a theoretical framework used to describe the particle properties and fundamental interactions.
- High Energy Physics (HEP) studies the inner structure of the particle, based on the theory of Standard Model.
- HEP research is done in a collaborative framework, coupled with open source philosophy (science for everyone!).
- The Higgs physics is an active ongoing research, so as the other long standing open questions such as the g-muon and W mass measurements, etc.
- NCPP caters several HEP experiments, connecting local researchers to collaborative research activities.
- HEP-UKM efforts are briefly discussed.

Backup

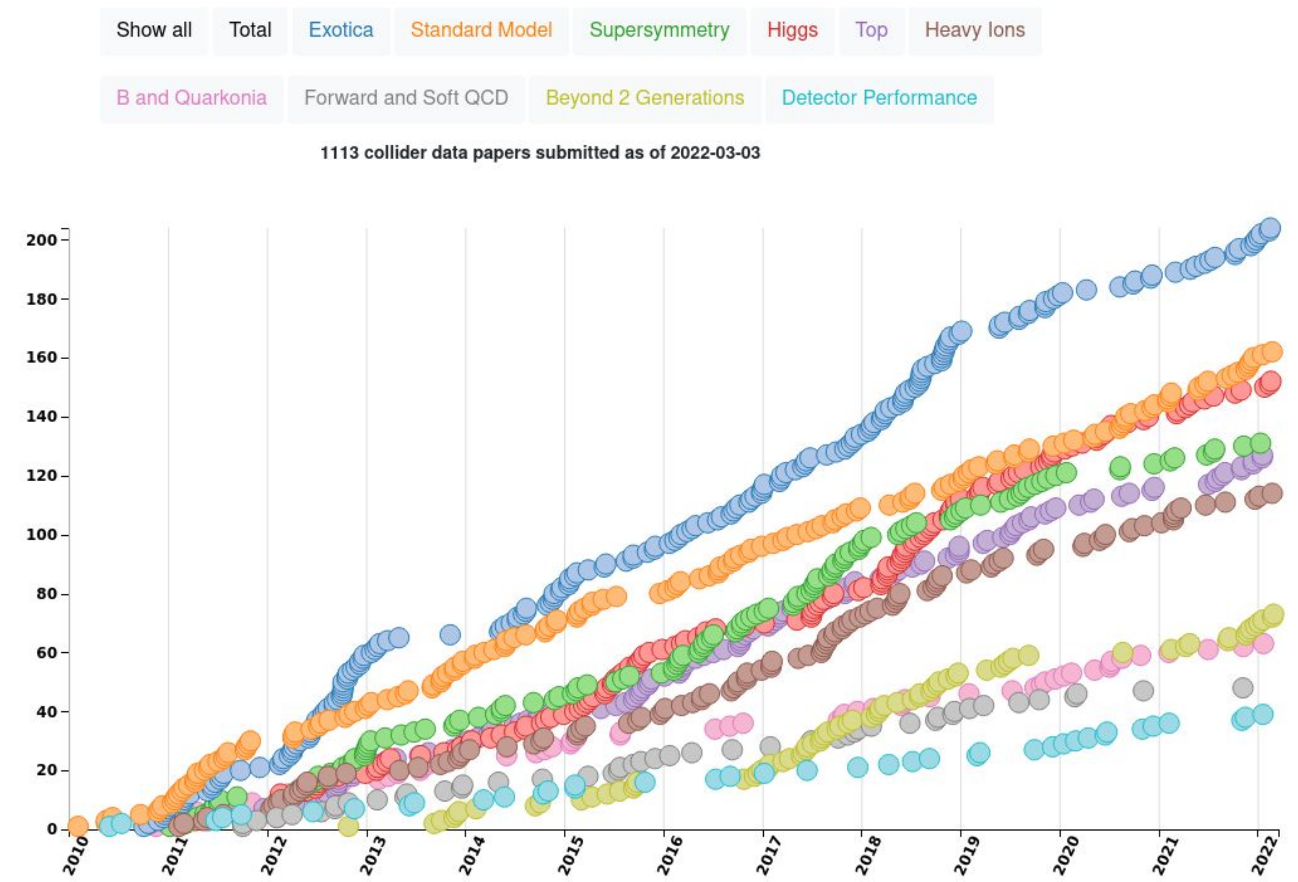
CMS Publication



[Further reading]()

"After approval of the physics, if the paper as a whole is not ready but CMS would like to present analysis to a conference, a Physics Analysis Summary (PAS) is made available for distribution outside the collaboration."
— CMS experiment

CMS Publication



The CMS collaboration has published more than 1000 papers in top-ranked Q1 & Q2 physics journals since the start of data taking in 2010

Two Higgs papers will be submitted to Nature journal in 2022!!

Interactive link

The Standard Model Higgs Boson

$$SU(3)_C \otimes \boxed{SU(2)_L \otimes U(1)_Y}$$

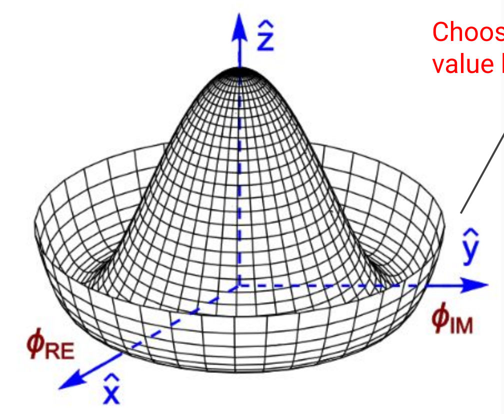
$$\mathscr{L}_{Higgs} = (D_\mu \Phi)^\dagger (D^\mu \Phi) - V(\Phi)$$

Minimizing the Higgs potential yields infinite possible minimum field values

$$\phi_{min} = \pm \frac{1}{\sqrt{2}} v e^{i\varphi}$$

$$\Phi_{min} = \begin{pmatrix} \phi^+_{min} \\ \phi^0_{min} \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix}$$

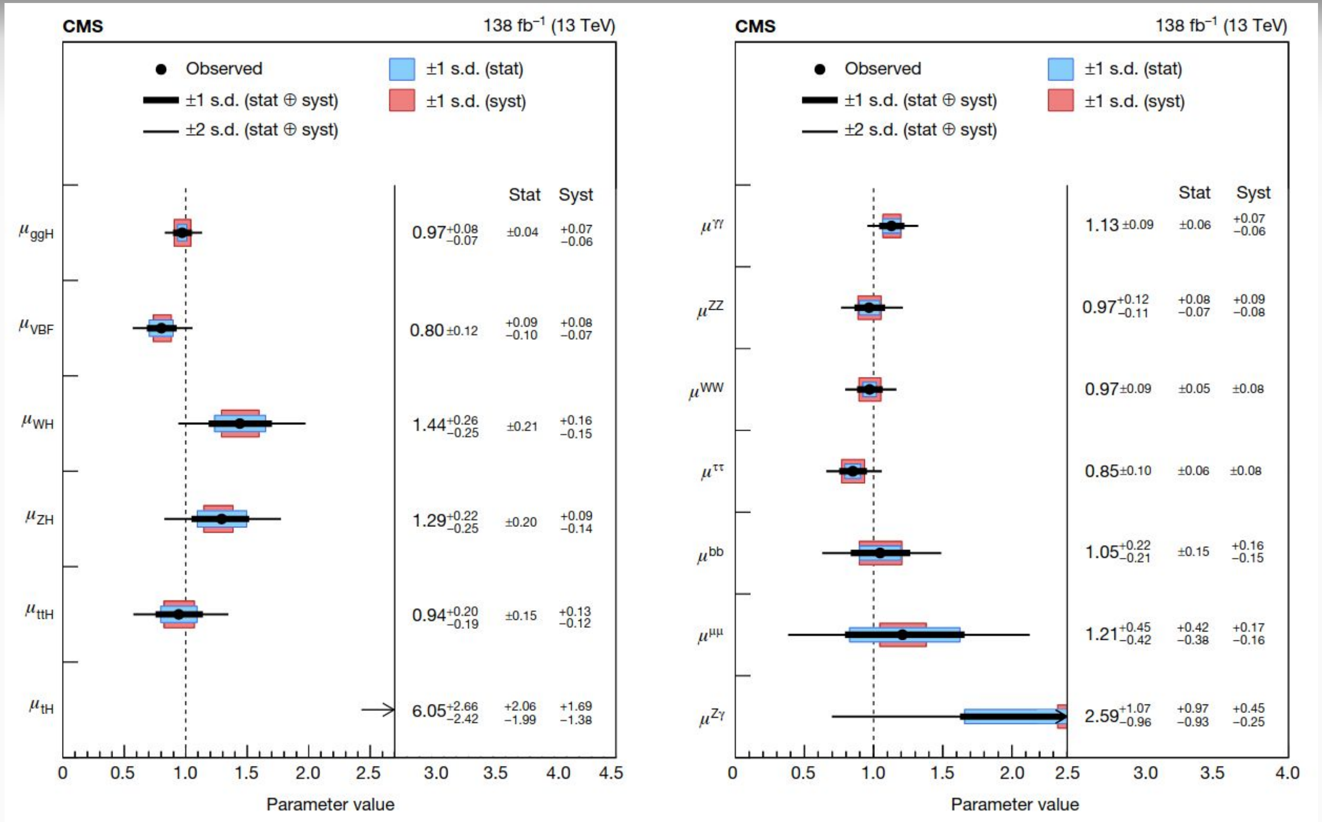
v = 246 GeV



Choosing one minimum value breaks the symmetry

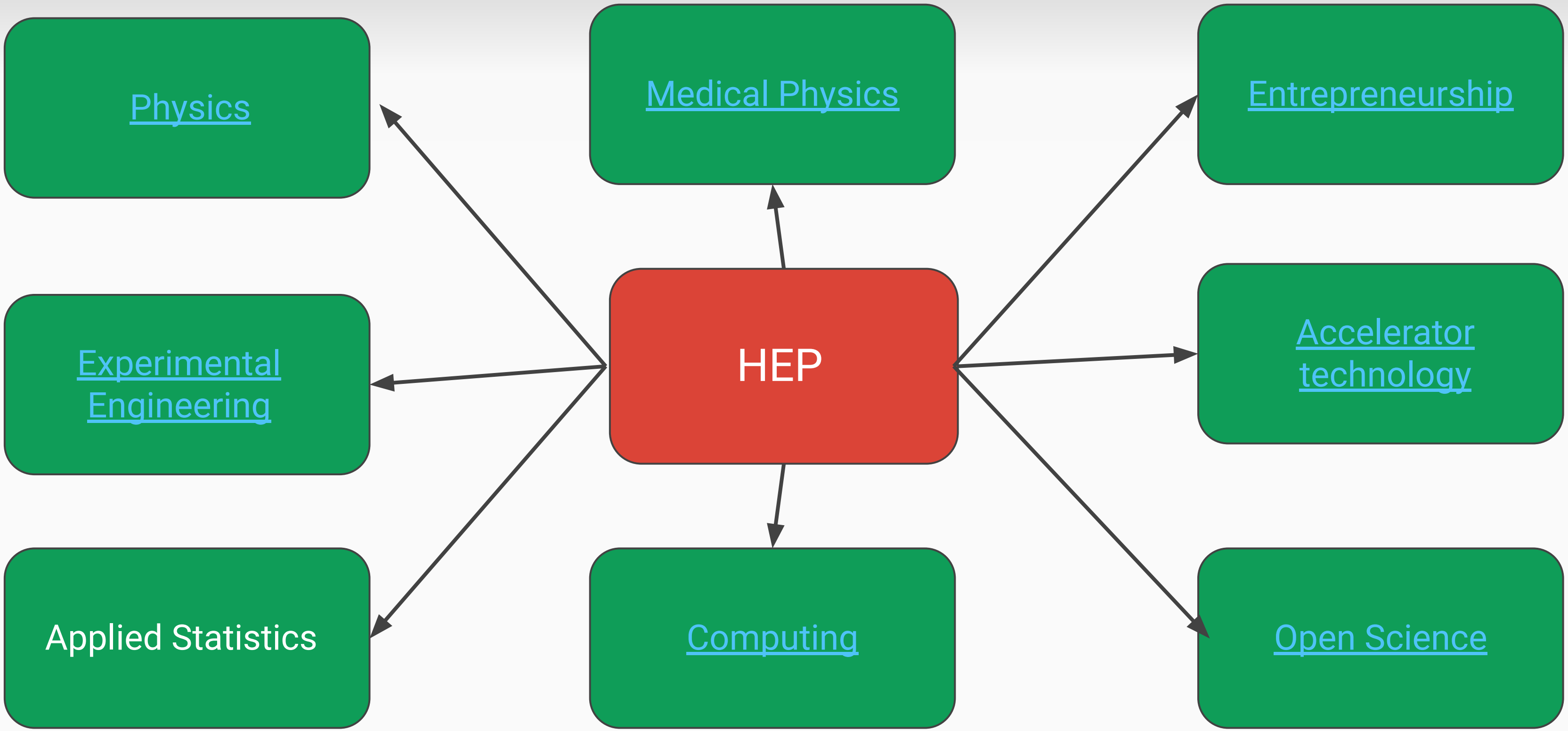
- Introducing a complex scalar doublet (the Higgs doublet) in the Lagrangian entails the presence of 4 Goldstone bosons: $$\Phi(x) = \frac{1}{\sqrt{2}} \begin{pmatrix} \phi_{1r}(x) + i\phi_{1c}(x) \\ v + \phi_{2r} + i\phi_{2c}(x) \end{pmatrix}$$
- After the electroweak symmetry breaking, 3 Goldstone bosons give mass to the $W^\pm$ and Z bosons: $$m_W = \left(\frac{g' v}{2}\right) \qquad m_Z = \frac{1}{2} v \sqrt{g^2 + g'^2} \qquad m_\gamma = 0$$
- The fourth Goldstone boson originates a new fundamental massive scalar particle, the Higgs boson, with mass: $$m_h = v\sqrt{2\lambda}$$
- The scalar field interacts with fermions, relating the masses of fermions to the Higgs couplings (h_f): $$m_f = \frac{h_f v}{\sqrt{2}}$$

Signal Modifier measurements for SM Higgs

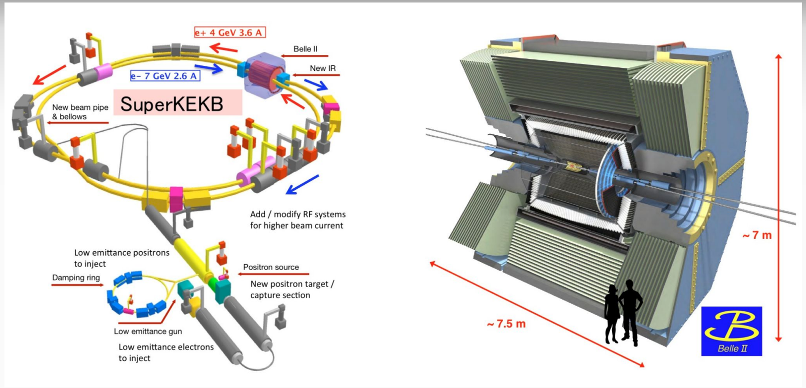


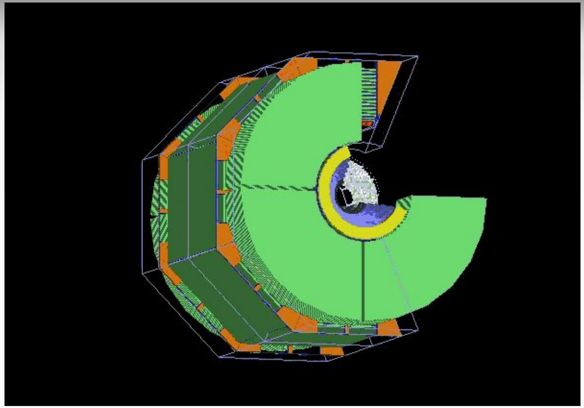
https://www.nature.com/articles/s41586-022-04892-x.pdf

HEP is Multi-Discipline

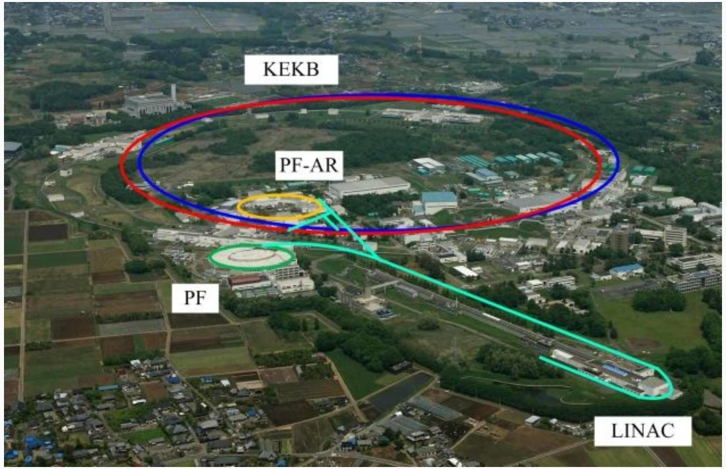


Belle-II Collaboration



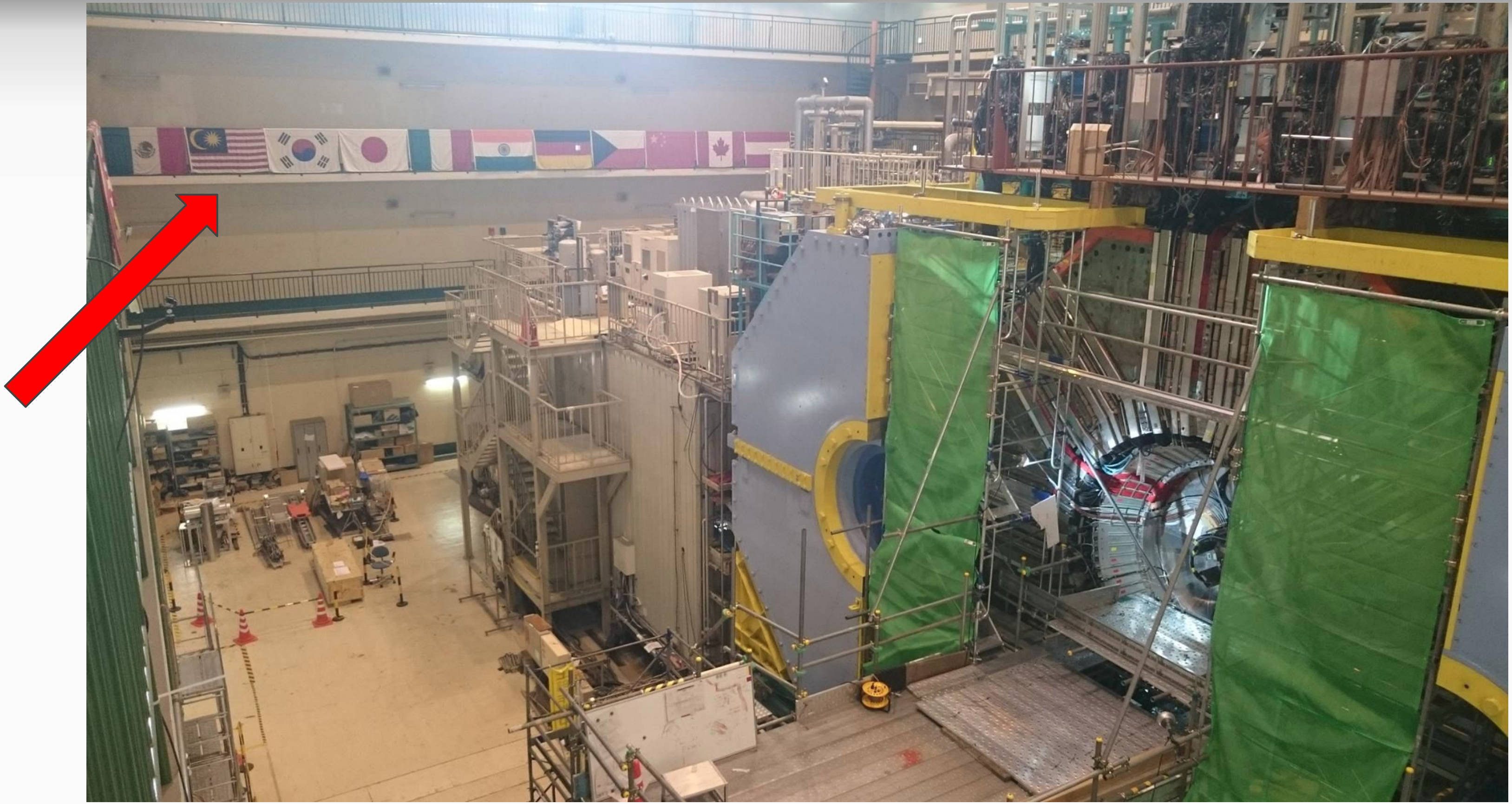


The Belle experiment precisely analysed the characteristics of pairs of B- and anti-B-mesons and confirmed the effect of CP-violation as described by the theory of Makoto Kobayashi and Toshihide Maskawa, who both were awarded the Nobel prize in physics in 2008.

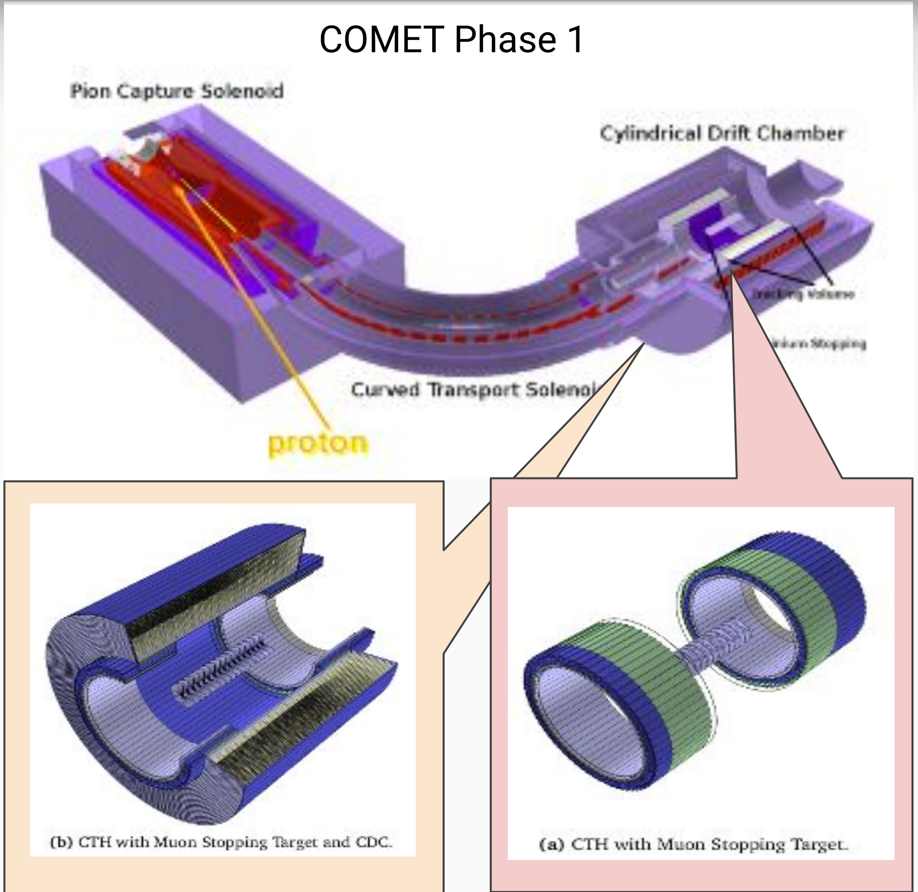


BELLE-II

Malaysia flag spotted!



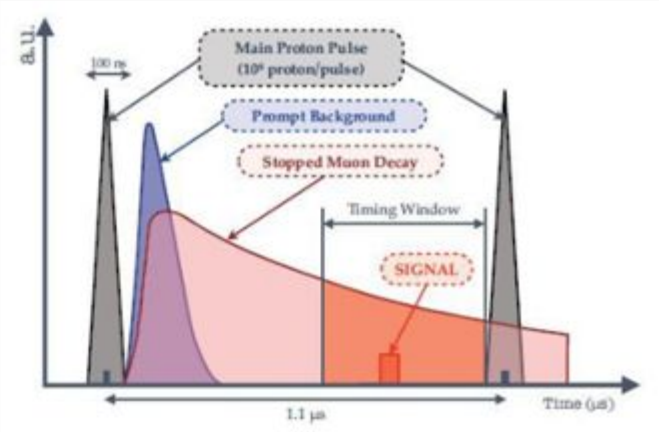
COMET



(b) CTH with Muon Stopping Target and CDC.

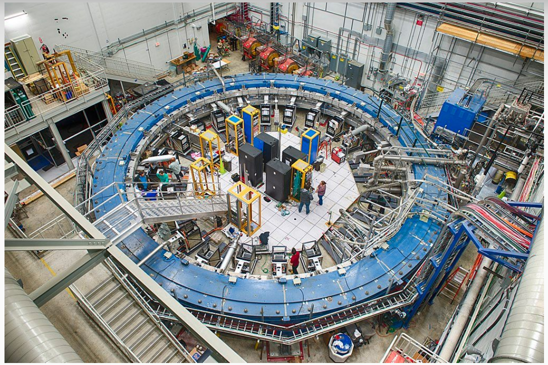
(a) CTH with Muon Stopping Target.

The COMET experiment is dedicated to the study of CLFV in a neutrinoless $\mu - e$ conversion signal down to the sensitivity 10^{-15}.



The goal of COMET experiment is aiming to set the new limit of sensitivity of $\mu - e$ conversion comparable to MEG and SINDRUM experiments. COMET phase II improvise sensitivities up to 10-^{17} from muon intensity of 10^{18}.

DUNE Experiment at FERMILAB

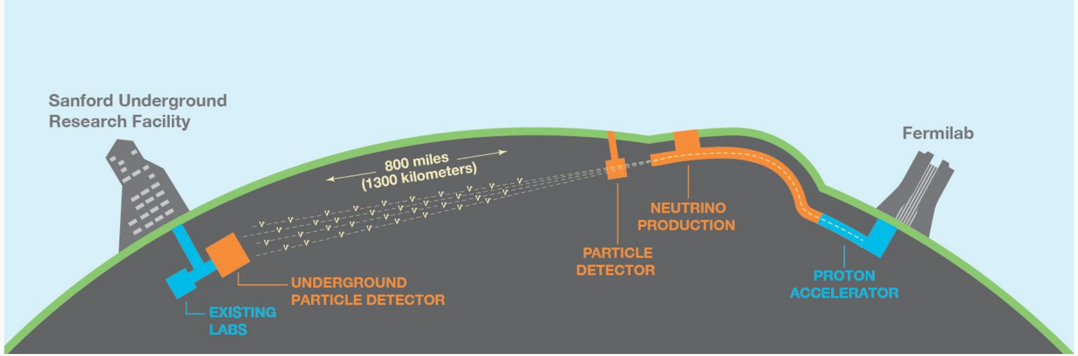


Notable experiments:

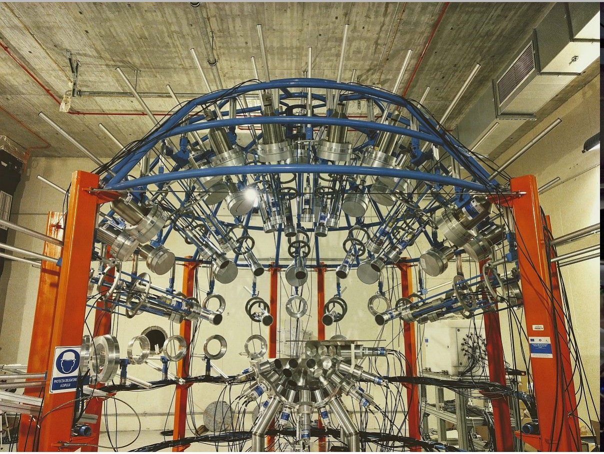
- DUNE
- CMS
- Muon g-2

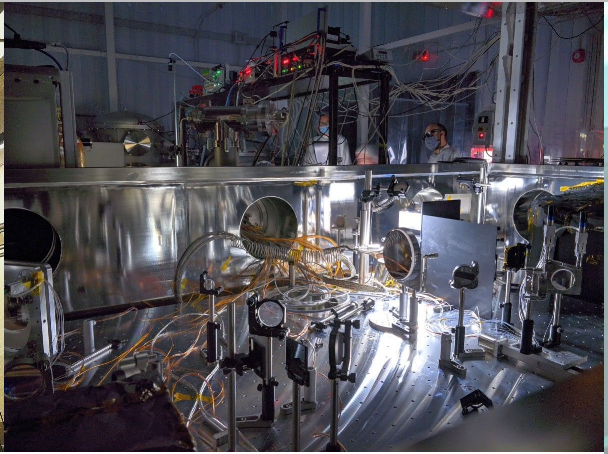
Further reading

Limited membership, in collaboration with Sheffield university.



ELI-NP





Research & Applications

Fundamental Research

- understanding laser-driven acceleration mechanism;
- exotic nuclei and photo-fission;
- vacuum properties and particle creation in laser-gamma beams interactions;
- nuclear structure and astrophysics studies.

Applied Research

- materials under extreme irradiation for space science;
- management of nuclear materials;
- industrial tomography;
- brilliant positron source for materials / processes characterization;
- radioisotopes for medical applications.

Our equipment

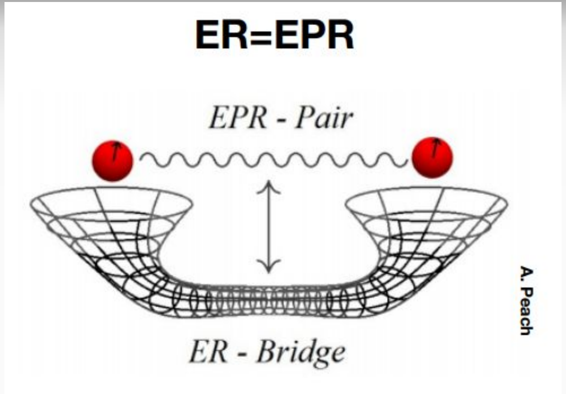
- HIGH-POWER LASER SYSTEM **2 x 10 PW ultra-short pulse laser arms** (Chirped Pulse Amplification method by Nobel Prize Winner **Gerard Mourou**)
- BRILLIANT ENERGY TUNABLE GAMMA-RAY BEAM SYSTEM

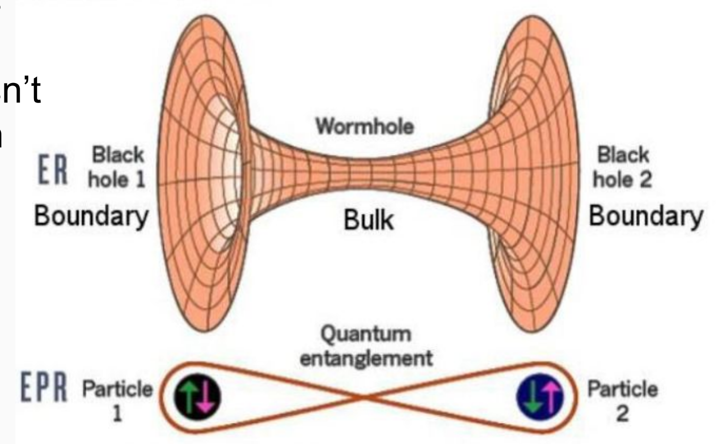
International collaboration | Interdisciplinarity | State-of-the-art technology | Ground-breaking science | Innovation | Regional development

"Table-top collider! An electron of energy up to 1 GeV is expected within 1 mm of acceleration length"

Einstein Rosen Bridge

“Standard model is still incomplete should gravitation is taken into consideration. The search for the constituent of gravitation is still on going. Among the top candidate to study the fundamental of gravitation is string theory and loop quantum gravity. The gravity as emergence model currently known as ER=EPR (Einstein Rosen bridge (subatomic wormhole) =Einstein Podolsky Rosen (EPR)). Up till now the evidence of supersymmetric pairs of subatomic particles as predicted by string theories haven’t been observed in particle accelerator experiments but via this ER-EPR conjecture which doesn’t necessarily require supersymmetry may infer links not only between general relativity and quantum mechanics but also between string theory and its rival the loop quantum gravity.”
— Dr. Anuar bin Alias, Senior Lecturer UKM





Notable Mention: Particle Fever

“When radio wave were discovered, they weren’t called radio wave as a sort of radiation; basic science for big breakthrough need to occur at the level where you are not asking the economic gain, we are asking what do we not know, and where can we make progress. So what is the economic gain for LHC? Could be nothing but just understanding of everything.”

– David E. Kaplan, Theoretical Physicist at Johns Hopkin University

https://youtu.be/5Lx109jdGCc?t=1180

HEP Collaboration in a nutshell

- HEP Collaboration needs committed sustainable funding.
- The institutional centre needs rigid structure to manage research finances and activities.
- Research activities involve only computing resources; do not need expensive and sophisticated experimental setup; no maintenance.
- Collaborative research is money-efficient, with PROMISING return (fundamental research paper published in high impact journal).
- Increases Malaysia talent's visibility via participation in a world-class international experimental collaboration. (knowledge transfer and crucial to development of IR4.0 culture).
- No patentship or commercialization activities involved. PURE KNOWLEDGE.

HEP Collaboration Perks

Recent Higgs boson measurements in the WW final state using CMS data

Parallel given at Pheno2020: Phenomenology 2020 Symposium, 4-6 May 2020, University of Pittsburgh, Pittsburgh, PA (United States) The talk is selected (cms speaker).

Abstract

The latest CMS results on the Higgs boson decays to a W boson pair are presented. The focus of the talk are the inclusive and differential cross section measurements performed using the full Run2 data collected by the CMS detector at LHC, as well as the constraints on the Higgs boson couplings to fermions and vector bosons arising from the simultaneous measurement of different production mechanisms. Recent constraints on BSM models arising from high mass resonance searches in the WW channel are also presented.

Speakers

Siew Yan Hoh (Univ. di Padova e Sez. dell'INFN)

Files

- SYH_HWW_measurement_Pheno_2020.pdf (8040.0 kB) Final Version ✖
- HWW_measurement_Phenom_2020.pdf (8045.9 kB) [Final draft approved by Paul Padley] ✖

Bibliography

- Measurements of properties of the Higgs boson decaying to a W boson pair in pp collisions at 13 TeV, CMS PAS HIG-16-042
- Search for a heavy Higgs boson decaying to a pair of W bosons in proton-proton collisions at, CMS PAS HIG-17-033
- Measurements of differential Higgs boson production cross sections in the leptonic WW decay mode at 13 TeV, CMS PAS HIG-19-002

Content Review

The content of this talk is related to the activities of one or more CMS groups listed below. The conveners or conference committee representatives of these groups have enhanced CINCO administrative rights. They will be informed by e-mail about any changes and updates to the presentation title, abstract or file upload.

- CMS: Higgs

Instructions

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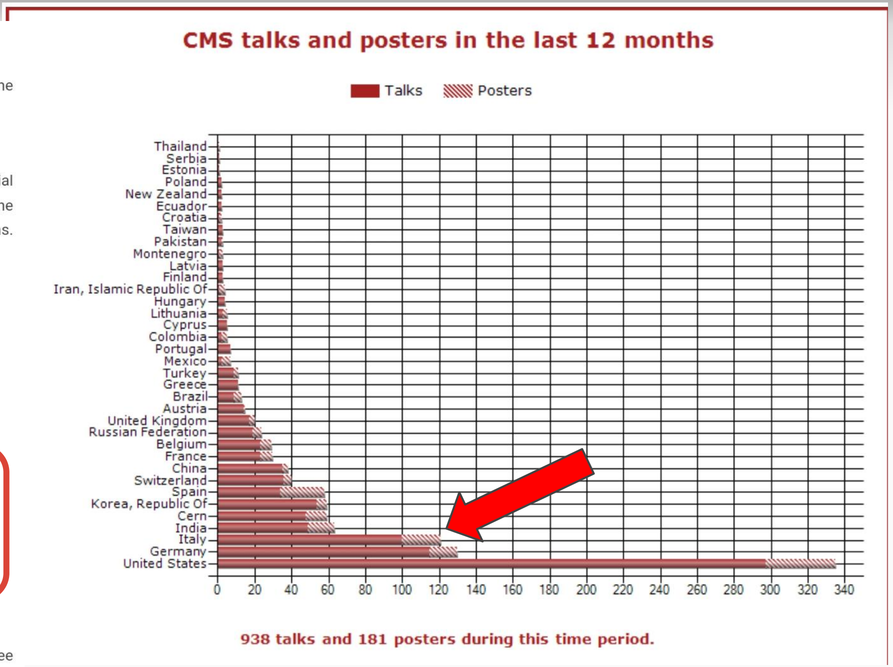

-> Conference make easy!
-> Peer reviewed!
-> Represent CMS Experiment!

Prerequisite for Sustainable Collaboration

- Long term sustainable funding for collaboration, realistically collaborator need to contribute some form of money to the experiment.
- Funding for travel (optional), stipend for master, PhD student, the main source of person-power.
- Well staffed and structure institutional centre.
- The CMS paper publication mechanism does not square well with Malaysia's higher education system:
    - Paper requirements for graduation (Master, PhD).
    - Patentship requirement for funding.
    - Funding for post-doctorate and student stipend.