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The Standard Model of particle physics

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Outline

- QED as a gauge theory
- Quantum Chromodynamics
- Breaking gauge symmetries:

  the Englert-Brout-Higgs-Guralnik-Hagen-Kibble mechanism
- Testing the Standard Model at the LHC
  - QCD at colliders
  - Higgs production and decay
  - Beyond the Standard Model?

The Standard Model Lagrangian is determined by symmetries

- space-time symmetry: global Poincaré-symmetry
- internal symmetries: local $SU(n)$ gauge symmetries

$$\begin{aligned}\mathcal{L}_{\rm SM} = \; & -\frac{1}{4}F^a_{\mu\nu}F^{a\mu\nu} + i\bar{\psi}\not{D}\psi && \text{gauge sector}\\ & + |D_\mu H|^2 - V(H) && \text{EWSB sector}\\ & + \psi_i\lambda_{ij}\psi_j H + \text{h.c.} && \text{flavour sector}\end{aligned}$$

...including only the operators of lowest dimension
and ignoring the strong CP-problem (see lectures by Andrew Cohen).

The Standard Model Lagrangian

$$\mathcal{L}_{\rm SM} = -\tfrac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \tfrac{1}{4} g_s^2 f^{abc} f^{ade} g^b_\mu g^c_\nu g^d_\mu g^e_\nu + \tfrac{1}{2} i g_s^2 (\bar{q}^\sigma_i \gamma^\mu q^\sigma_j) g^a_\mu + \bar{G}^a \partial^2 G^a +$$

$$g_s f^{abc}\partial_\mu \bar{G}^a G^b g^c_\mu - \partial_\nu W^+_\mu \partial_\nu W^-_\mu - M^2 W^+_\mu W^-_\mu - \tfrac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \tfrac{1}{2c_w^2} M^2 Z^0_\mu Z^0_\mu - \tfrac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu -$$

$$\tfrac{1}{2}\partial_\mu H \partial_\mu H - \tfrac{1}{2} m_h^2 H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - M^2 \phi^+ \phi^- - \tfrac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \tfrac{1}{2c_w^2} M \phi^0 \phi^0 - \beta_h[\tfrac{2M^2}{g^2} + \tfrac{2M}{g} H + \tfrac{1}{2}(H^2 +$$

$$\phi^0\phi^0 + 2\phi^+\phi^-)] + \tfrac{2M^4}{g^2}\alpha \ldots \partial_\nu W^+_\mu) + Z^0_\mu (W^+_\nu \partial_\nu W^-_\mu -$$

$$W^-_\nu \partial_\nu W^+_\mu)] - i g s_w [\partial_\nu A_\mu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu (W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + A_\mu (W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)] -$$

$$\tfrac{1}{2} g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \tfrac{1}{2} g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2 c_w^2 (Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) + g^2 s_w^2 (A_\mu W^+_\mu A_\nu W^-_\nu -$$

$$A_\mu A_\mu W^+_\nu W^-_\nu) + g^2 s_w c_w [A_\mu Z^0_\nu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - 2 A_\mu Z^0_\mu W^+_\nu W^-_\nu] - g\alpha [H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-] -$$

$$\tfrac{1}{8} g^2 \alpha_h [H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2 H^2] - g M W^+_\mu W^-_\mu H - \tfrac{1}{2} g \tfrac{M}{c_w^2} Z^0_\mu Z^0_\mu H -$$

$$\tfrac{1}{2} i g [W^+_\mu (\phi^0 \partial_\mu \phi^- - \phi^- \partial_\mu \phi^0) - W^-_\mu (\phi^0 \partial_\mu \phi^+ - \phi^+ \partial_\mu \phi^0)] + \tfrac{1}{2} g [W^+_\mu (H \partial_\mu \phi^- - \phi^- \partial_\mu H) - W^-_\mu (H \partial_\mu \phi^+ -$$

$$\phi^+ \partial_\mu H)] + \tfrac{1}{2} g \tfrac{1}{c_w} (Z^0_\mu (H \partial_\mu \phi^0 - \phi^0 \partial_\mu H) - i g \tfrac{s_w^2}{c_w} M Z^0_\mu (W^+_\mu \phi^- - W^-_\mu \phi^+) + i g s_w M A_\mu (W^+_\mu \phi^- - W^-_\mu \phi^+) -$$

$$i g \tfrac{1-2c_w^2}{2c_w} Z^0_\mu (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) + i g s_w A_\mu (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) - \tfrac{1}{4} g^2 W^+_\mu W^-_\mu [H^2 + (\phi^0)^2 + 2\phi^+\phi^-] -$$

$$\tfrac{1}{4} g^2 \tfrac{1}{c_w^2} Z^0_\mu Z^0_\mu [H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2 \phi^+\phi^-] - \tfrac{1}{2} g^2 \tfrac{s_w^2}{c_w} Z^0_\mu \phi^0 (W^+_\mu \phi^- + W^-_\mu \phi^+) - \tfrac{1}{2} i g^2 \tfrac{s_w^2}{c_w} Z^0_\mu H (W^+_\mu \phi^- -$$

$$W^-_\mu \phi^+) + \tfrac{1}{2} g^2 s_w A_\mu \phi^0 (W^+_\mu \phi^- + W^-_\mu \phi^+) + \tfrac{1}{2} i g^2 s_w A_\mu H (W^+_\mu \phi^- - W^-_\mu \phi^+) - g^2 \tfrac{s_w}{c_w} (2c_w^2 - 1) Z^0_\mu A_\mu \phi^+ \phi^- -$$

$$g^1 s_w^2 A_\mu A_\mu \phi^+ \phi^- - \bar{e}^\lambda (\gamma\partial + m_e^\lambda) e^\lambda - \bar{\nu}^\lambda \gamma\partial \nu^\lambda - \bar{u}^\lambda_j (\gamma\partial + m_u^\lambda) u^\lambda_j - \bar{d}^\lambda_j (\gamma\partial + m_d^\lambda) d^\lambda_j + i g s_w A_\mu [-(\bar{e}^\lambda \gamma^\mu e^\lambda) +$$

$$\tfrac{2}{3} (\bar{u}^\lambda_j \gamma^\mu u^\lambda_j) - \tfrac{1}{3} (\bar{d}^\lambda_j \gamma^\mu d^\lambda_j)] + \tfrac{ig}{4c_w} Z^0_\mu [(\bar{\nu}^\lambda \gamma^\mu (1+\gamma^5) \nu^\lambda) + (\bar{e}^\lambda \gamma^\mu (4s_w^2 - 1 - \gamma^5) e^\lambda) + (\bar{u}^\lambda_j \gamma^\mu (\tfrac{4}{3} s_w^2 - 1 - \gamma^5) u^\lambda_j) +$$

$$(\bar{d}^\lambda_j \gamma^\mu (1 - \tfrac{8}{3} s_w^2 - \gamma^5) d^\lambda_j)] + \tfrac{ig}{2\sqrt{2}} W^+_\mu [(\bar{\nu}^\lambda \gamma^\mu (1+\gamma^5) e^\lambda) + (\bar{u}^\lambda_j \gamma^\mu (1+\gamma^5) C_{\lambda\kappa} d^\kappa_j)] + \tfrac{ig}{2\sqrt{2}} W^-_\mu [(\bar{e}^\lambda \gamma^\mu (1+\gamma^5) \nu^\lambda) +$$

$$(\bar{d}^\kappa_j C^\dagger_{\lambda\kappa} \gamma^\mu (1+\gamma^5) u^\lambda_j)] + \tfrac{ig}{2\sqrt{2}} \tfrac{m_e^\lambda}{M} [-\phi^+ (\bar{\nu}^\lambda (1-\gamma^5) e^\lambda) + \phi^- (\bar{e}^\lambda (1+\gamma^5) \nu^\lambda)] - \tfrac{g}{2} \tfrac{m_e^\lambda}{M} [H (\bar{e}^\lambda e^\lambda) + i\phi^0 (\bar{e}^\lambda \gamma^5 e^\lambda)] +$$

$$\tfrac{ig}{2M\sqrt{2}} \phi^+ [-m_d^\kappa (\bar{u}^\lambda_j C_{\lambda\kappa} (1-\gamma^5) d^\kappa_j) + m_u^\lambda (\bar{u}^\lambda_j C_{\lambda\kappa} (1+\gamma^5) d^\kappa_j] + \tfrac{ig}{2M\sqrt{2}} \phi^- [m_d^\lambda (\bar{d}^\lambda_j C^\dagger_{\lambda\kappa} (1+\gamma^5) u^\kappa_j) -$$

$$m_u^\kappa (\bar{d}^\lambda_j C^\dagger_{\lambda\kappa} (1-\gamma^5) u^\kappa_j] - \tfrac{g}{2} \tfrac{m_u^\lambda}{M} H (\bar{u}^\lambda_j u^\lambda_j) - \tfrac{g}{2} \tfrac{m_d^\lambda}{M} H (\bar{d}^\lambda_j d^\lambda_j) + \tfrac{ig}{2} \tfrac{m_u^\lambda}{M} \phi^0 (\bar{u}^\lambda_j \gamma^5 u^\lambda_j) - \tfrac{ig}{2} \tfrac{m_d^\lambda}{M} \phi^0 (\bar{d}^\lambda_j \gamma^5 d^\lambda_j) + \bar{X}^+ (\partial^2 -$$

$$M^2) X^+ + \bar{X}^- (\partial^2 - M^2) X^- + \bar{X}^0 (\partial^2 - \tfrac{M^2}{c_w^2}) X^0 + \bar{Y} \partial^2 Y + i g c_w W^+_\mu (\partial_\mu \bar{X}^0 X^- - \partial_\mu \bar{X}^+ X^0) + i g s_w W^+_\mu (\partial_\mu \bar{Y} X^- -$$

$$\partial_\mu \bar{X}^+ Y) + i g c_w W^-_\mu (\partial_\mu \bar{X}^- X^0 - \partial_\mu \bar{X}^0 X^+) + i g s_w W^-_\mu (\partial_\mu \bar{X}^- Y - \partial_\mu \bar{Y} X^+) + i g c_w Z^0_\mu (\partial_\mu \bar{X}^+ X^+ - \partial_\mu \bar{X}^- X^-) +$$

$$i g s_w A_\mu (\partial_\mu \bar{X}^+ X^+ - \partial_\mu \bar{X}^- X^-) - \tfrac{1}{2} g M [\bar{X}^+ X^+ H + \bar{X}^- X^- H + \tfrac{1}{c_w^2} \bar{X}^0 X^0 H] + \tfrac{1-2c_w^2}{2c_w} i g M [\bar{X}^+ X^0 \phi^+ - \bar{X}^- X^0 \phi^-] +$$

$$\tfrac{1}{2c_w} i g M [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + i g M s_w [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + \tfrac{1}{2} i g M [\bar{X}^+ X^+ \phi^0 - \bar{X}^- X^- \phi^0]$$

The Standard Model Lagrangian

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$$\ldots \nu W^+_\mu) + Z^0_\mu(W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)] - igs_w[\partial_\nu A_\mu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu(W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + A_\mu(W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)] - \frac{1}{2}g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \frac{1}{2}g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2 c_w^2(Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) + g^2 s_w^2(A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2 s_w c_w[A_\mu Z^0_\nu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu] - g\alpha[H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-] - \frac{1}{8}g^2\alpha_h[H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2H^2] - gMW^+_\mu W^-_\mu H - \frac{1}{2}g\frac{M}{c_w^2}Z^0_\mu Z^0_\mu H - \ldots$$

- What are the free parameters?
- How can we make predictions for the LHC? ← QCD
- How can we test the Higgs mechanism?
- Why do we expect physics beyond the Standard Model?

$$\ldots + \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)] - \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 - \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]$$

Classifying the free parameters of the Standard Model

The free parameters in the electroweak Standard Model for one generation are

- the two gauge couplings g, g' for the $SU(2)_L$ and $U(1)_Y$ gauge groups;
- the two parameters μ and λ in the potential $V(\Phi)$;
- the Yukawa couplings Y_u, Y_d, Y_e and Y_ν.

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Adding the QCD sector and two more generations of quarks and leptons, the Standard Model contains at least 26 free parameters:

- 3 gauge couplings
- 6 quark masses
- 6 lepton masses
- 3+3 mixing angles
- 1+1 CP-violating phases
- 1 W or Z mass
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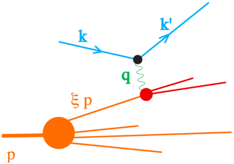
Having determined this finite number of parameters from experiment, we can – in principle – make predictions for any Standard Model observable to any desired accuracy.

Hadron scattering

Consider first the scattering of a high-energy charged lepton off a proton target.

In the parton model we imagine the proton, or any other hadron, to be made of point-like constituents, the partons. The photon scatters from a point-like quark with fraction ξ of the proton's momentum.



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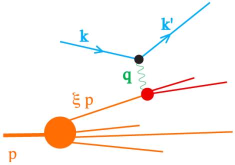
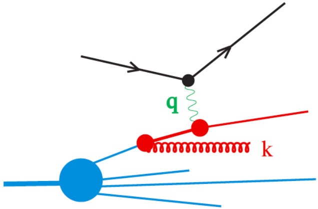


The parton model leads to an intuitive formula that relates the lepton-hadron cross section to the cross section for the electron-parton scattering:

$$\frac{d\sigma^{(lh)}}{dxdQ^2} = \sum_a \int_0^1 d\xi\, f_{a/h}(\xi)\, \frac{d\sigma^{(la)}}{dxdQ^2},$$

where $d\sigma^{(lh)}$ is the inclusive cross section for lepton-nucleon scattering, while $d\sigma^{(la)}$ is the parton-electron cross section, with the parton's momentum given by ξp, ξ between zero and one, and $f_{a/h}(\xi)$ is a parton distribution function.

In QCD, beyond the lowest order approximation, we have to include diagrams like



The integral over the transverse momentum of the emitted gluon is logarithmically divergent at small $|k_T|$.

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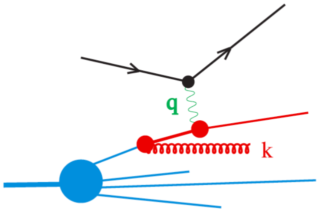

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The limit $k_T \to 0$ corresponds to a long-range part of QCD which is not calculable in perturbation theory. However, there is a factorisation theorem which states that the long-range contributions can be absorbed in the parton distribution functions.

Separating short- and long-distance physics requires the introduction of a factorisation scale μ_F.

The Dokshitzer-Gribov-Lipatov-Altarelli-Parisi equation

The parton distribution function can be defined in terms of quark and gluon field operators. They are universal, i.e. independent of the particular hard scattering process. Pdfs could, in principle, be calculated using lattice QCD, but currently they are determined from experiment.

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The dependence of the parton distribution function on the renormalisation scale μ_F is determined by the DGLAP equation:

$$\frac{d}{d\ln\mu_F} f_{a/h}(x,\mu_F) = \sum_b \int_x^1 \frac{d\xi}{\xi}\; P_{ab}(x/\xi,\alpha_s(\mu_F))\; f_{b/h}(\xi,\mu_F).$$

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The splitting function P_{ab} has a perturbative expansion

$$P_{ab}(x/\xi,\alpha_s(\mu_F)) = P_{ab}^{(1)}(x/\xi)\;\frac{\alpha_s(\mu_F)}{\pi} + P_{ab}^{(2)}(x/\xi)\;\left(\frac{\alpha_s(\mu_F)}{\pi}\right)^2 + \cdots .$$

and can be calculated order by order in perturbation theory.

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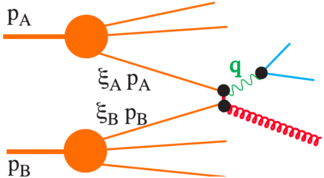
The DGLAP-equation is one of the most important equations in perturbative QCD.

Hadron-hadron collisions

In hadron-hadron scattering, constituent partons from each incoming hadron interact at short distance (large momentum transfer Q^2).



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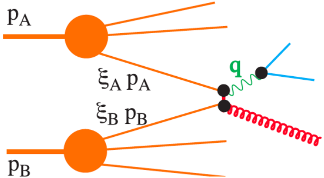
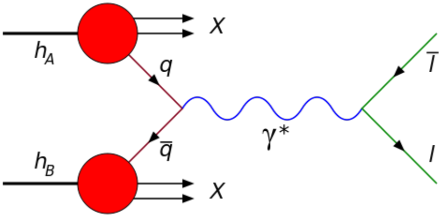


The cross section for a hard scattering process initiated by two hadrons with momenta p_A and p_B takes a factored form similar to that found for deeply inelastic scattering

$$d\sigma(p_A, p_B) = \sum_{a,b} \int d\xi_A d\xi_B \; f_{a/A}(\xi_A, \mu_F) \; f_{b/B}(\xi_B, \mu_F)$$
$$\times d\hat{\sigma}_{ab}(\xi_A p_A, \xi_B p_B, \mu_F).$$

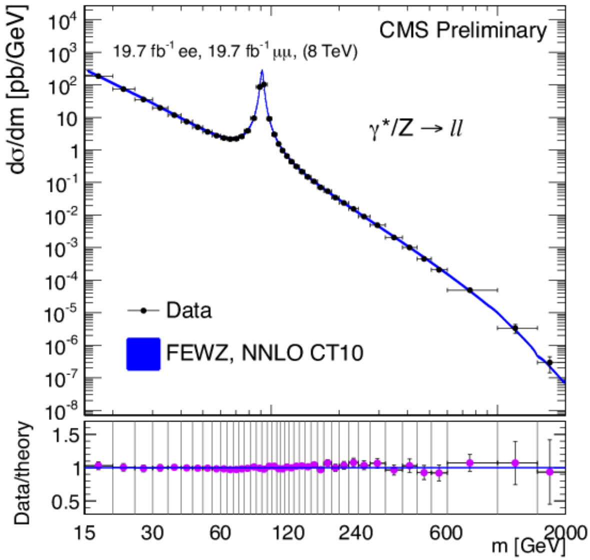
Hadron-hadron collisions

Historically, the most convincing evidence that the quark-parton-model provides the correct framework for high-energy processes in general came from its success in describing the Drell-Yan process (1971).



This was the birth of quantitative hadron collider phenomenology.

Hadron-hadron collisions



Higgs production and decay

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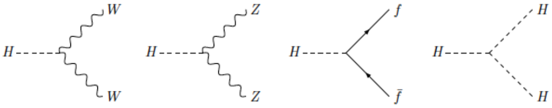
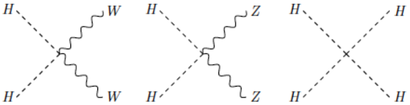
Recall that the strength of the interaction between the Higgs particle and the other Standard Model particles is proportional to the particle mass:

Three-point couplings with Higgs bosons



$= i g_W M_W g_{\mu\nu}$ $\quad = i \frac{g_W}{\cos^2\theta_W} M_W g_{\mu\nu}$ $\quad = -\frac{i g_W m_f}{2M_W}$ $\quad = -\frac{3 i g_W M_H^2}{2M_W}$

Four-point couplings with Higgs bosons



$= \frac{1}{2} i g_W^2 g_{\mu\nu}$ $\quad = \frac{i g_W^2}{2\cos^2\theta_W} g_{\mu\nu}$ $\quad = -\frac{3 i g_W M_H^2}{4M_W^2}$

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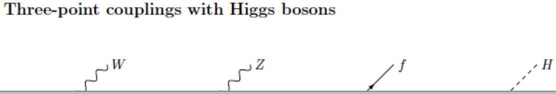
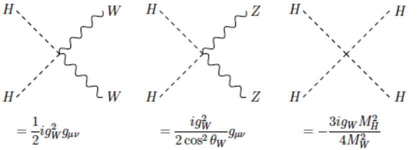
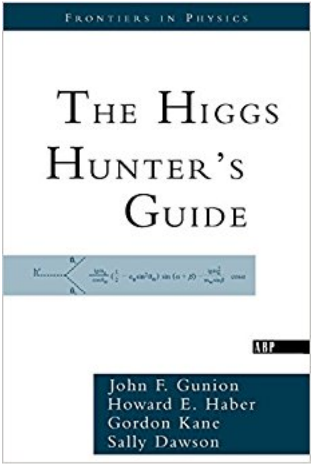


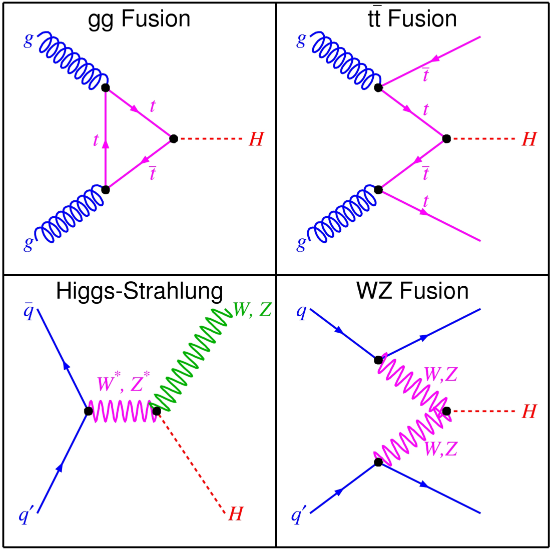
- The only free parameter was the Higgs mass
- Higgs production and decay can be predicted unambiguously
- The Higgs search can be planned



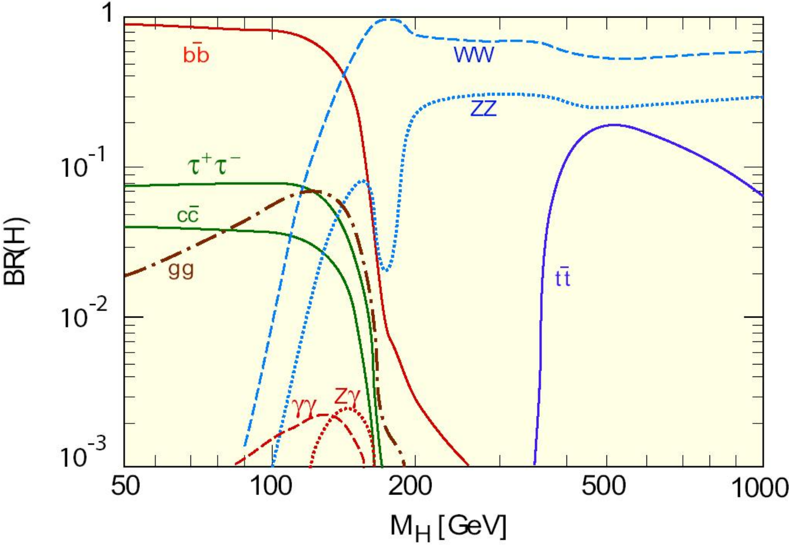
Higgs production and decay



The Higgs is produced through its interaction with heavy particles

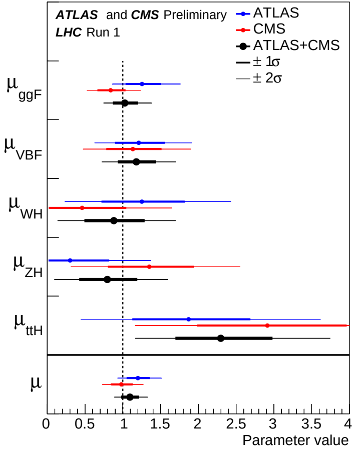


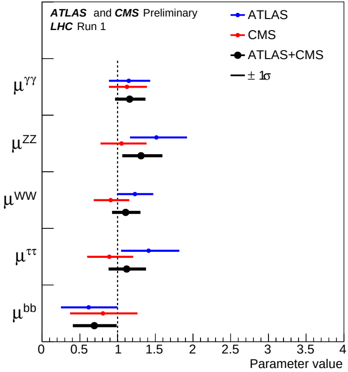
The Higgs likes to decay to heavy particles



Testing the Standard Model Higgs sector

So far, the Higgs particle looks like predicted by the Standard Model





Physics beyond the Standard Model?

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- The problem of mass:

  What is the origin of particle masses? Is it the SM Higgs field?

  What stabilizes the Higgs mass?

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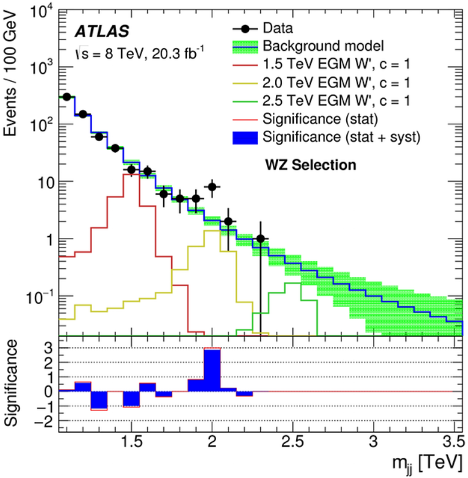
- Cosmological problems:

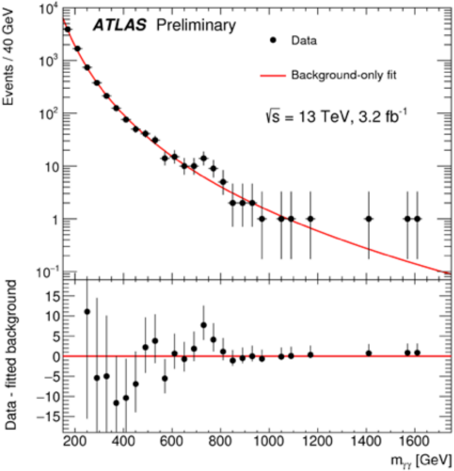
  What is the origin of the baryon-antibaryon asymmetry?
  What is the nature of dark matter and dark energy?

- The di-boson cross section (2015)



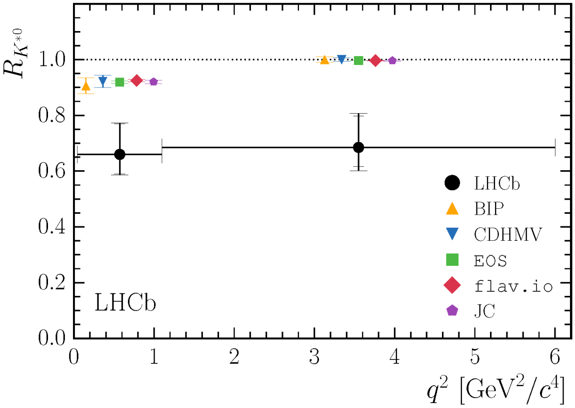
New discoveries?

- The di-photon cross section (2016)



New discoveries?

- Rare B-meson decays (2017)



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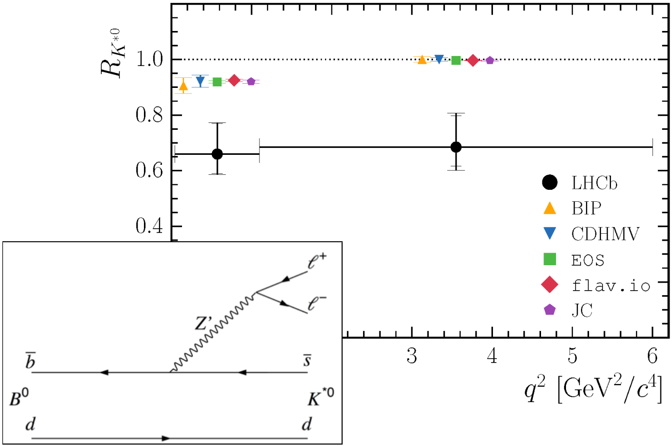

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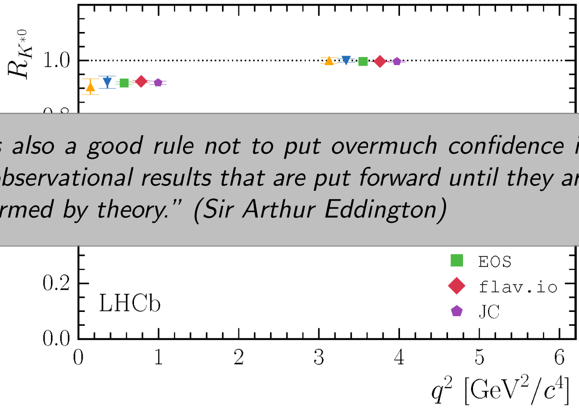

"It is also a good rule not to put overmuch confidence in the observational results that are put forward until they are confirmed by theory." (Sir Arthur Eddington)

Thanks
& enjoy the summer at CERN

Questions, suggestions etc.? Please get in touch!

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