Electroweak Tutorial

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Decay Width

- Near a resonance, the cross-section is described by a Breit-Wigner

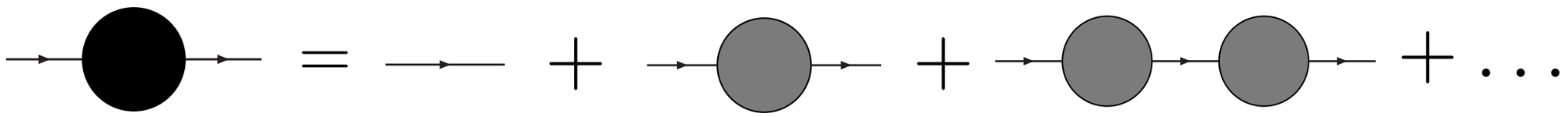
$$\sigma \sim \left| \frac{1}{p^2 - m^2 + im\Gamma} \right|^2$$

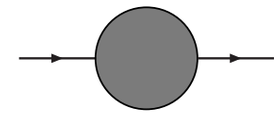
where Γ is the decay rate and *m* is the physical mass.

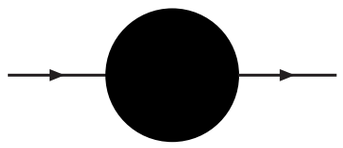
- How to calculate the decay rate from first principles?

Decay Width

- The complete propagator can be written



Where $-i\Pi(p^2) =$  denotes all 1PI (1-particle-irreducible) diagrams.



$$= \frac{i}{p^2 - m_0^2} + \frac{i}{p^2 - m_0^2}\left(-i\Pi(p^2)\right)\frac{i}{p^2 - m_0^2} +$$

$$+ \frac{i}{p^2 - m_0^2}\left(-i\Pi(p^2)\right)\frac{i}{p^2 - m_0^2}\left(-i\Pi(p^2)\right)\frac{i}{p^2 - m_0^2} + \ldots$$

$$= \frac{i}{p^2 - m_0^2}\sum_{n=0}^{\infty}\left(\frac{\Pi(p^2)}{p^2 - m_0^2}\right)^n$$

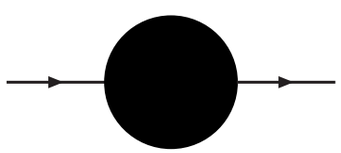
$$= \frac{i}{p^2 - m_0^2}\frac{1}{1 - \frac{\Pi(p^2)}{p^2 - m_0^2}} = \frac{i}{p^2 - m_0^2 - \Pi(p^2)}$$

Decay Width

- Renormalisation

$$m^2 = m_0^2 + \mathrm{Re}\,\Pi(p^2)$$

- Complete propagator after renormalisation



$$= \quad \frac{i}{p^2 - m^2 - i\mathrm{Im}\,\Pi(p^2)}$$

Decay Width

- Cross-section near a resonance

$$\sigma \sim \left| \frac{1}{p^2 - m^2 - i \mathrm{Im}\, \Pi(p^2)} \right|^2$$

- Breit-Wigner

$$\sigma \sim \left| \frac{1}{p^2 - m^2 + i m \Gamma} \right|^2$$

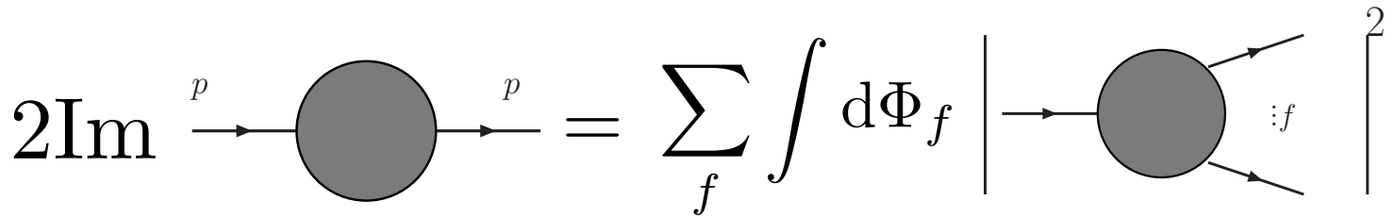
- Comparing the two

$$-m\Gamma = \mathrm{Im}\, \Pi(p^2)$$

Decay Width

- How to calculate this imaginary part?

Optical theorem



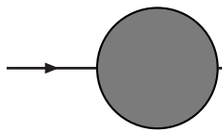
$$2\mathrm{Im}\,\mathcal{M}(p \to p) = \sum_f \int \mathrm{d}\Phi_f \, |\mathcal{M}(p \to f)|^2$$

where

$$\mathrm{d}\Phi_n = (2\pi)^4 \delta^{(4)} \left(P - \sum_f p_f \right) \prod_{i=1}^{n} \frac{\mathrm{d}^3 p_i}{(2\pi)^3} \frac{1}{2E_i}$$

Decay Width

$$i\mathcal{M}(p \to p) = \quad = -i\Pi(p^2)$$



$$2\mathrm{Im}\,\mathcal{M}(p \to p) = \sum_f \int \mathrm{d}\Phi_f \, |\mathcal{M}(p \to f)|^2$$

$$-m\Gamma = \mathrm{Im}\,\Pi(p^2)$$

Decay Width

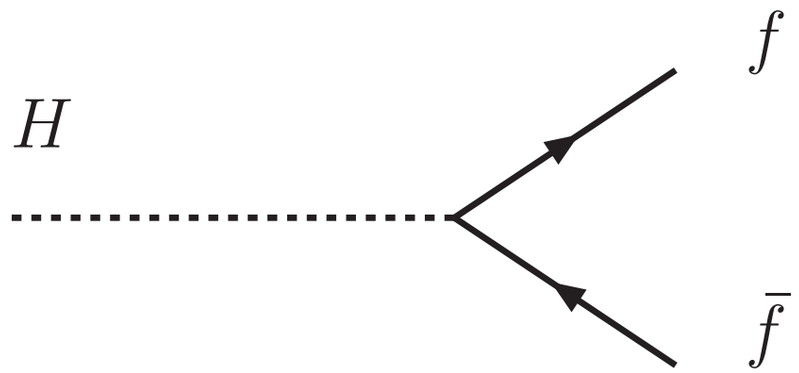
$$\Gamma = \frac{1}{2m} \sum_f \int \mathrm{d}\Phi_f \, |\mathcal{M}(p \to f)|^2$$

Higgs decays

- Higgs decays into fermions
- Higgs decays into vector Bosons (W, Z)

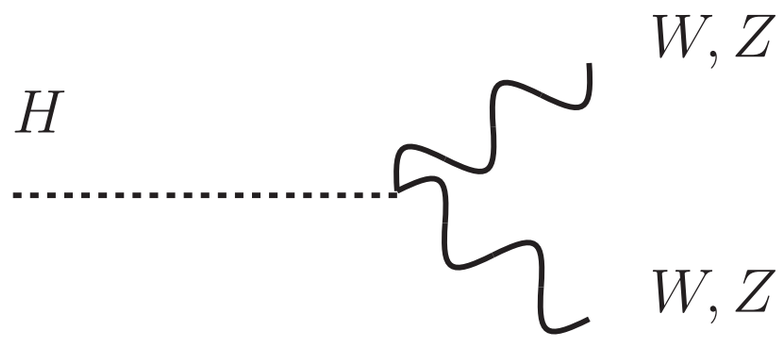
Higgs decays

- *Hff*-vertex $-i\frac{m_f}{v}$



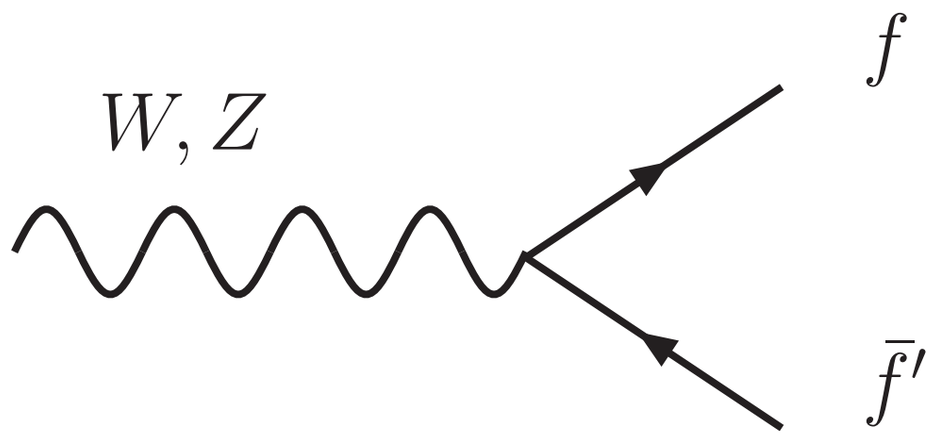
- *HZZ*-vertex $\frac{1}{2}i\frac{vg^2}{\cos^2\theta_W}g^{\mu\nu}$

- *HWW*-vertex $\frac{1}{2}ivg^2g^{\mu\nu}$



Vector boson decays

- *Wff*-vertex $\dfrac{-ig}{2\sqrt{2}}\gamma^\mu(1-\gamma^5)$

- *Zff*-vertex

$$\frac{-ie}{2\cos\theta_W \sin\theta_W}\left(\gamma^\mu(1-\gamma^5)(\epsilon\frac{1}{2}-Q\sin^2\theta_W)-Q\gamma^\mu(1+\gamma^5)\sin^2\theta_W\right)$$