Lecture 7.

QFT 3: The Standard Model & Electroweak Theory

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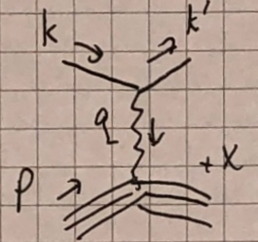
Today: Bjorken scaling

SM Particles and their evolution as detector objects

Recap Bjorken scaling: Consider $\bar{e}p$ scattering, t channel with photon

Schwartz, 32.1



θ = angle between $\vec{k}$ & $\vec{k}'$, so $\theta = 0$ is forward scattering.

$$\left(\frac{d\sigma}{d\Omega dE'}\right)_{lab} = \frac{\alpha_e^2}{4\pi m_p q^4} \frac{E'}{E} L^{\mu\nu} W_{\mu\nu}$$

For unpolarized scattering,

leptonic tensor $L_{\mu\nu} = \frac{1}{2} \mathrm{Tr}[\not{k}' \gamma^\mu \not{k} \gamma^\nu] = 2(k'^\mu k^\nu + k'^\nu k^\mu - k\cdot k' g^{\mu\nu})$

avg. spins init.

hadronic tensor $W_{\mu\nu} = W_1\left(-g^{\mu\nu} + \frac{q^\mu q^\nu}{q^2}\right) + W_2\left(P^\mu - \frac{P\cdot q}{q^2} q^\mu\right)\left(P^\nu - \frac{P\cdot q}{q^2} q^\nu\right)$

parametrization from

1. Must depend only on P^μ & q^μ since final states are integrated over.
2. Ward identity. $q_\mu W^{\mu\nu} = 0$
3. Unpolarized scattering, $W^{\mu\nu} = W^{\nu\mu}$.

W_1 & W_2 are Lorentz scalars & can depend on $P^2 = m_p^2$, q^2, $P\cdot q$. Naturally use $Q \equiv \sqrt{-q^2} > 0$, energy transfer.

$\nu \equiv \frac{P\cdot q}{m_p} = (E - E')_{lab}$; in proton rest frame, is energy lost by electron

Alternately, use Bjorken $x \equiv \frac{Q^2}{2P\cdot q}$, dimensionless.

After contracting $L_{\mu\nu}$ + $W_{\mu\nu}$,

$$\left(\frac{d\sigma}{d\Omega\, dE'}\right)_{lab} = \frac{\alpha_e^2}{8\pi E^2 \sin^4\frac{\theta}{2}}\left[\frac{m_p}{2} W_2(x,Q)\cos^2\frac{\theta}{2} + \frac{1}{m_p} W_1(x,\theta)\sin^2\frac{\theta}{2}\right]$$

W_1 & W_2 can be determined by energy & angular dependence of outgoing electron.

For partonic interactions within proton,

$$p_i^\mu + q^\mu = p_f^\mu$$

$$\Rightarrow m_q^2 + 2p_i\cdot q + q^2 = m_q^2$$

$$\Rightarrow 2p_i\cdot q = Q^2$$

$$\Rightarrow \frac{Q^2}{2p_i\cdot q} = 1$$

Use PDF notation, so $p_i^\mu = \xi P^\mu \Rightarrow x = \frac{Q^2}{2P\cdot q} = \frac{\xi Q^2}{2p_i q} = \xi$

Assuming partons are free other than photon interaction, the $e^- q \to e^- q$ scattering is exactly analogous to $e^-\mu \to e^-\mu\ (+\gamma)$ scattering in QED, where the form factors only get $\log Q^2$ dependence from vertex corrections at 1-loop, as long as we fix x (to fix the partonic momentum fraction). This is the origin of Bjorken scaling: cross section (+ form factors W_1 & W_2) only has $\log Q^2$ dependence at fixed x, so increasing Q^2 & keeping x fixed only shows $\log Q^2$ dependence in the cross section.

Particle signals in detectors.

Having discussed the hard interaction and how partons are modeled as parton distribution functions, we now turn to the decay and detection side of SM particle physics.

Basic detector physics:

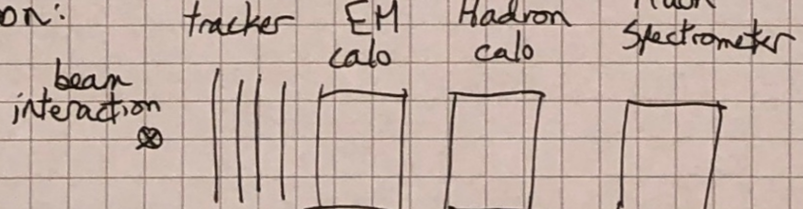
For a given particle, detector physics is always a compromise between measuring energy & momentum (direction).

Measuring energy: ideally, destroy/absorb particle and capture/stop it completely & measure energy deposition. This necessarily washes out any directional information.

Measuring direction: Ideally, charged particles are deflected by a magnetic field; uncharged particles can have very soft interactions. By registering many soft hits, we can map out a particle trajectory. This will generally cause a loss in particle energy. For a high resolution momentum measurement, need to "kick" particle a significant fraction of momenta.

Thus, the best detectors balance these competing principles, and most importantly, try to have as wide of a dynamic range as practical. This is also driven by the beam energies that power the entire appartus.

Cartoon:



Since colored particles are complicated by ~~hadronization~~ ~~and~~ fragmentation and hadronization, in addition to jet finding + jet algorithms, we start with the leptons + EW bosons + Higgs boson.

Key conversion: $1\ \text{GeV} = 1.52 \cdot 10^{24}\ \frac{1}{s}$

Quick + dirty estimates of lifetimes:

$$\Gamma_{\text{2-body}}(\text{tree}) \sim g^2 \cdot m_X$$

Ex. $\Gamma(W) = 2.085 \pm 0.042\ \text{GeV}$
$m_W = 80.379 \pm 0.012\ \text{GeV}$

$\Gamma(Z) = 2.4952 \pm 0.0023\ \text{GeV}$
$m_Z = 91.1876 \pm 0.0021\ \text{GeV}$

$\Gamma(h) = 4\ \text{MeV}$ (theory)
$m_h = 125.10 \pm 0.14\ \text{GeV}$

$\Gamma(t) = 1.42\ ^{+0.19}_{-0.15}\ \text{GeV}$
$m_t = 172.76 \pm 0.30\ \text{GeV}$