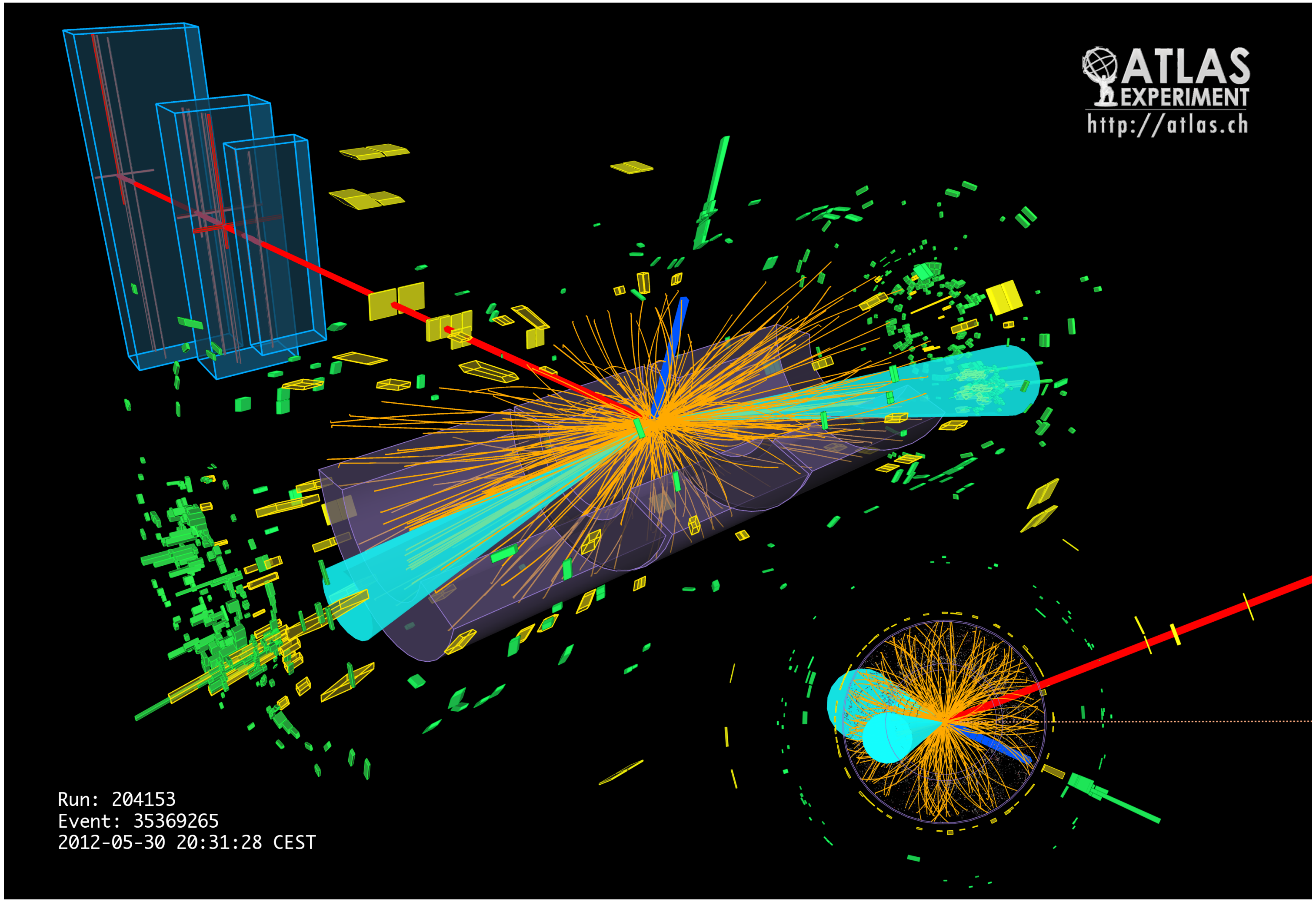
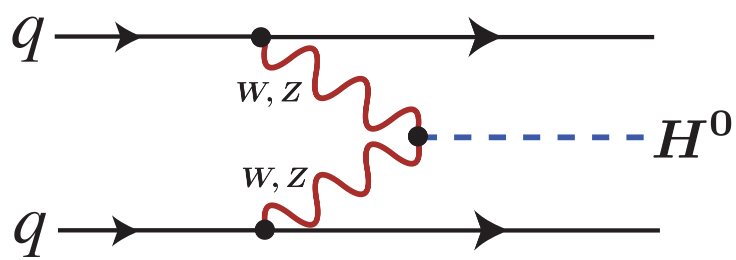
2012: the LHC finds the Higgs Boson!

2015-2018: Run II

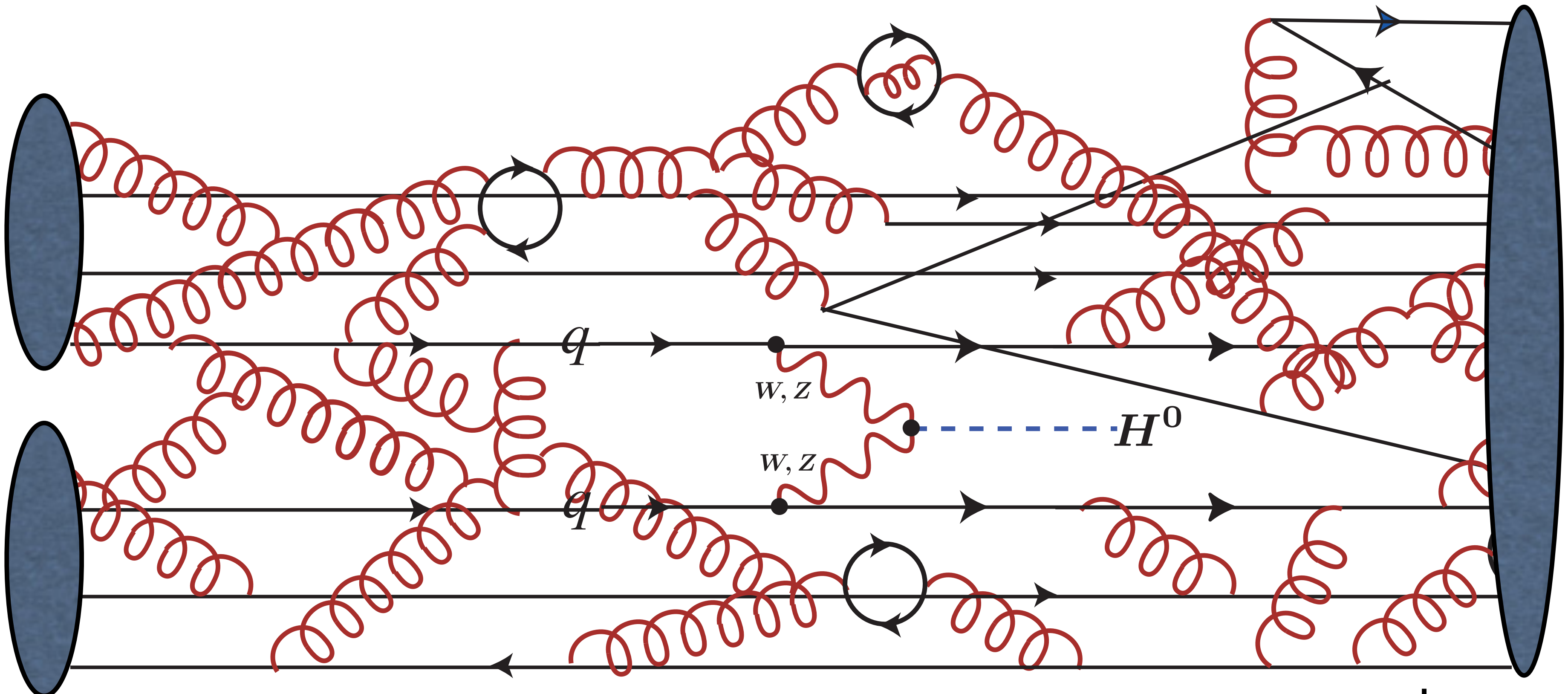


but ... how do we learn anything by scattering protons in the first place?

Scattering quarks (or gluons) is simple ...



... but scattering protons is an incalculable mess.



protons

huge mess of particles

This keeps theorists employed.

This keeps theorists employed.

Thinking about this kind of problem has given us **new and deeper ways to think about Quantum Field Theory** - in terms of distance and time scales, not particles and Feynman diagrams.

We are **developing new tools** which allow us to **pull apart complex processes like this in increasingly sophisticated ways**. Some of these pieces can be calculated analytically, some numerically, some extracted from experiment, some modelled - we can then stick the pieces back together.

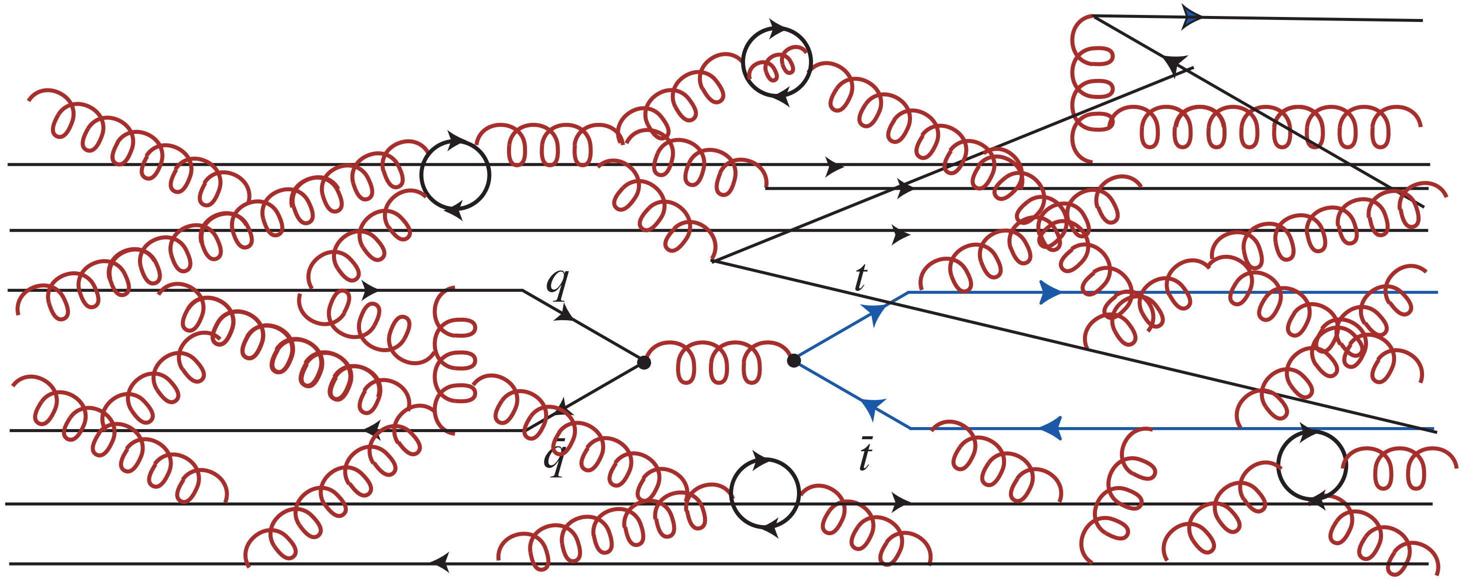
“Effective Field Theory”

classic example: pp scattering

$$\sigma(p(P_1) + p(P_2) \rightarrow t\bar{t} + X)$$

$$= \int_0^1 dx_1 dx_2 \sum_f f_f(x_1) f_{\bar{f}}(x_2) \cdot \sigma(q_f(x_1 P) + \bar{q}_f(x_2 P) \rightarrow t\bar{t})$$

$$+ O\left(\frac{\Lambda_{\rm QCD}}{2m_t}\right)$$



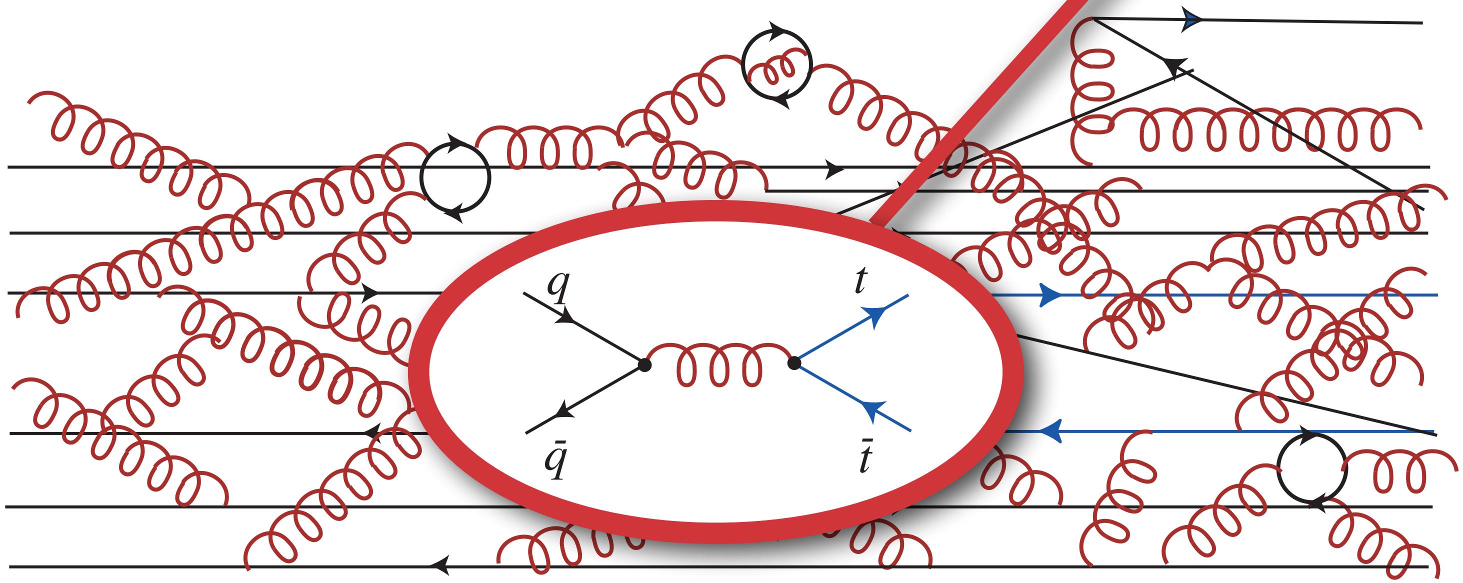
(Feynman, Bjorken)

classic example: pp scattering

$$\sigma(p(P_1) + p(P_2) \to t\bar{t} + X)$$

calculable

$$= \int_0^1 dx_1 dx_2 \sum_f f_f(x_1) f_{\bar{f}}(x_2) \cdot \sigma(q_f(x_1 P) + \bar{q}_f(x_2 P) \to t\bar{t}) + O\left(\frac{\Lambda_{\mathrm{QCD}}}{2m_t}\right)$$



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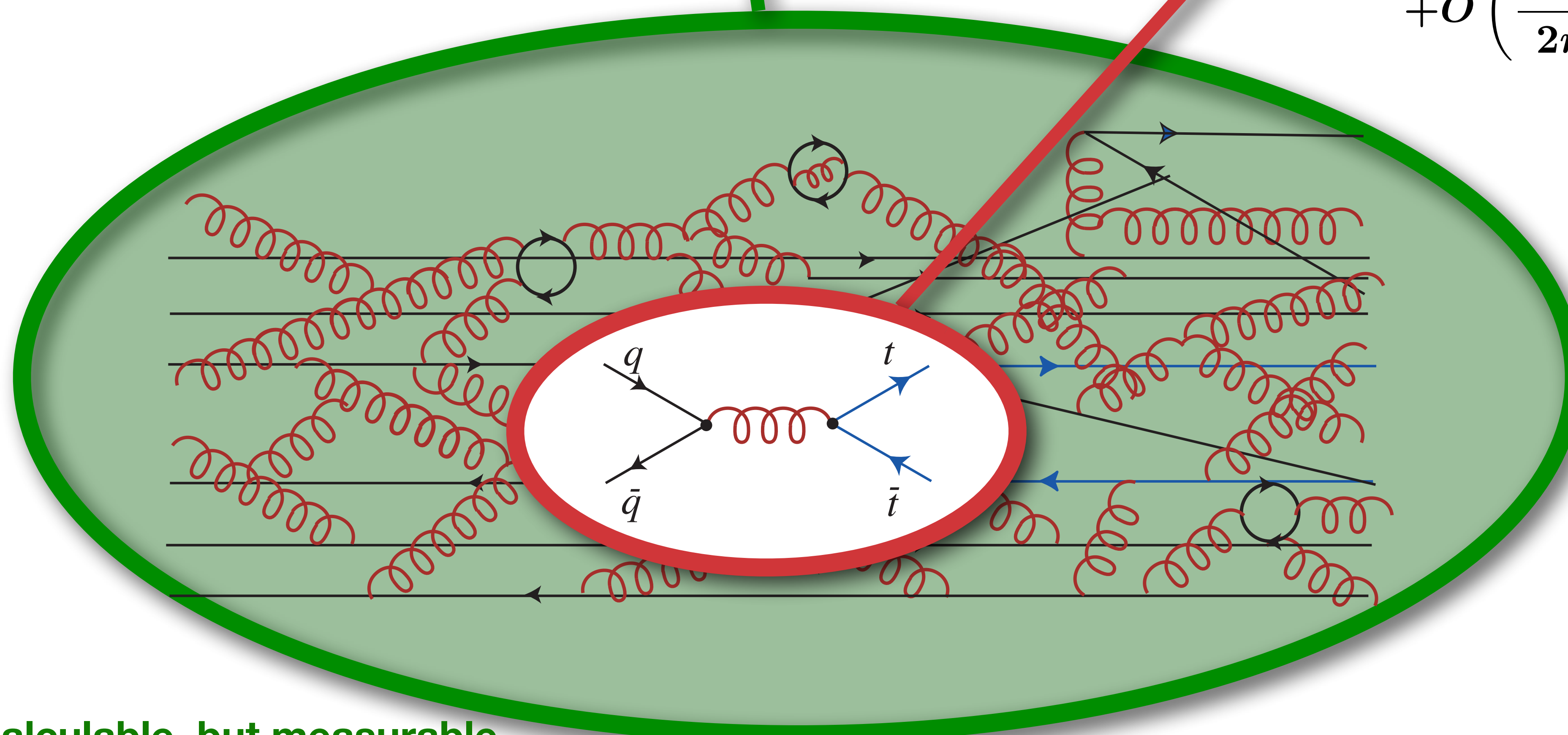
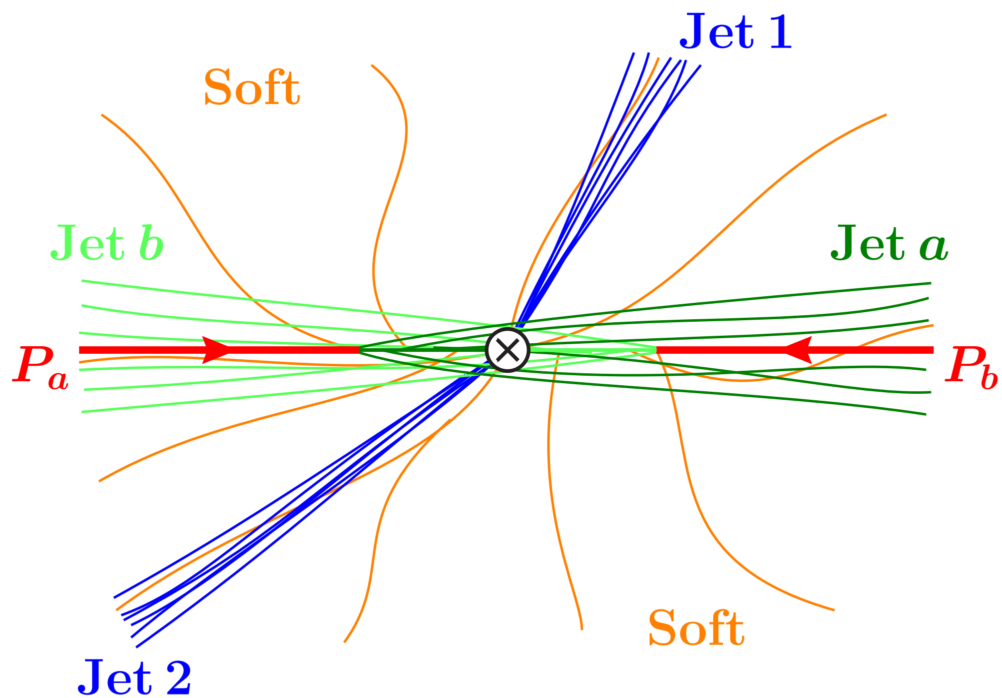


incalculable, but measurable

(Feynman, Bjorken)

modern example #1: pp scattering to final state jets

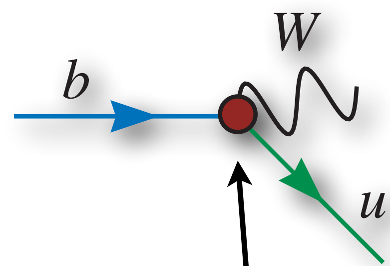
(one of the things we do)



$$
\begin{aligned}
\frac{1}{\sigma_0}\frac{d\sigma}{dY\,dq^2\,dB_a^+\,dB_b^-} = \sum_{ij} H_{ij}\left(q^2,\mu\right)\int dk_a^+\,dk_b^+ \\
\times\, q^2 B_i\left[\omega_a(B_a^+ - k_a^+, x_a, \mu\right] B_j\left[\omega_b(B_b^+ - k_b^+, x_b, \mu\right] \\
\times\, S_{\mathrm{ihemi}}(k_a^+, k_b^+, \mu)
\end{aligned}
$$

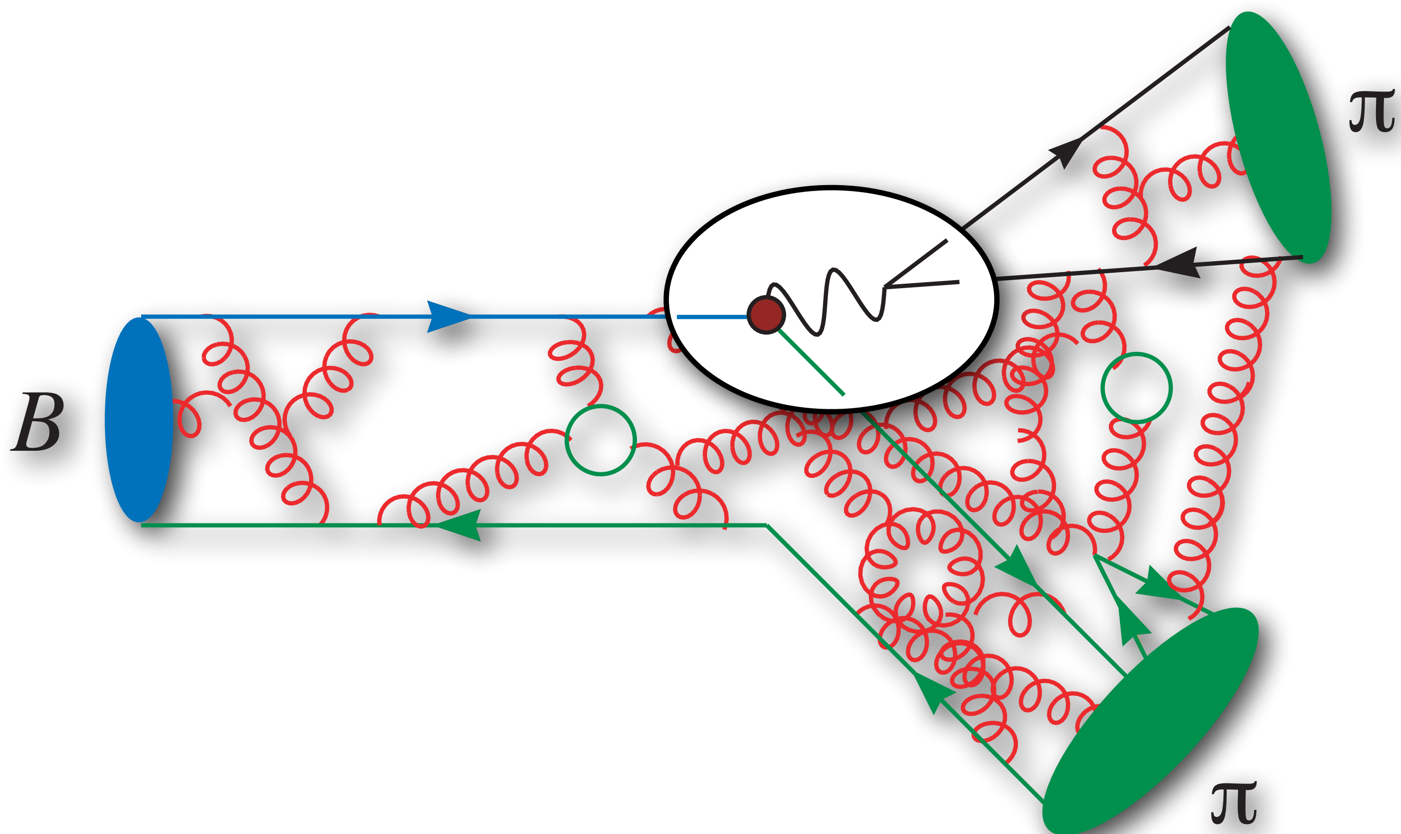
modern example #2: precision weak interaction physics

(another of the things we do)



measure the COMPLEX PHASE of this coupling (CP violation -> new physics, understanding early universe ...) ... two dedicated colliders (>$1B) were built to measure this kind of thing modern example #2: precision weak interaction physics

(another of the things we do)



Need to extract this from a complicated hadronic mess ...

- need new factorization theorems ...
- need to understand corrections, validity ... lots of interesting theory!

... there are a lot of interesting and subtle things to worry about for LHC physics ...

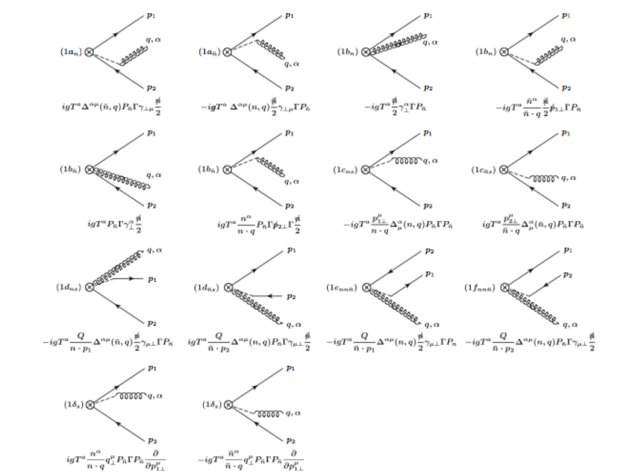


Figure 6: One-gluon Feynman rules for NLO dijet operators $O_2^{(1i)}$. The notation is the same as Fig. 2. The rule for $O_2^{(1b_n)}$ has been split into two diagrams, depending on whether the gluon is emitted from the vertex or the Wilson line.

Renormalization of dijet operators at order $1/Q^2$ in soft-collinear effective theory

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ABSTRACT: dijet event s
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Power Counting and Modes in SCET

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ABSTRACT: We present a formulation of soft-collinear effective theory (SCET) in the two-jet sector as a theory of decoupled sectors of QCD coupled to Wilson lines. The formulation is manifestly boost-invariant, does not require the introduction of ultrasoft modes at the hard matching scale Q, and has manifest power counting in inverse powers of Q. The spurious infrared divergences which arise in SCET when ultrasoft modes are not included in loops disappear when the overlap between the sectors is correctly subtracted, in a manner similar to the familiar zero-bin subtraction of SCET. We illustrate this approach by analyzing deep inelastic scattering in the endpoint region in SCET and comment on other applications.

Theoretical tools:

effective field theory
1/Q expansion
operator product expansion
chiral perturbation theory
perturbative QCD
...

students: Matt Inglis-Whalen, Aris Spourdalakis, Jyotirmoy Roy