Quantum Chromodynamics and Jets at the LHC

Herbstschule HEP

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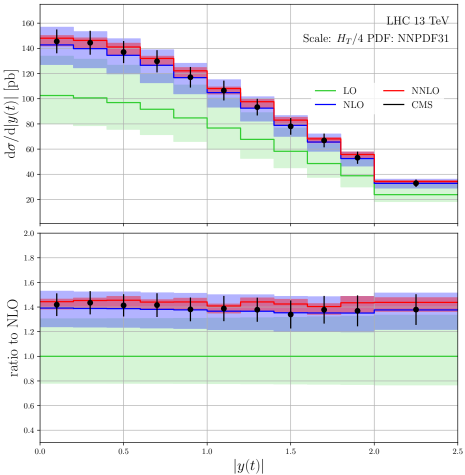
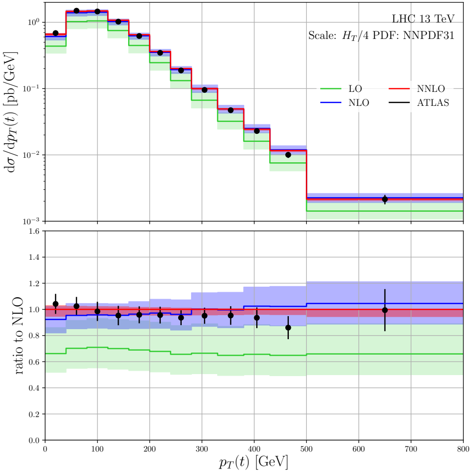
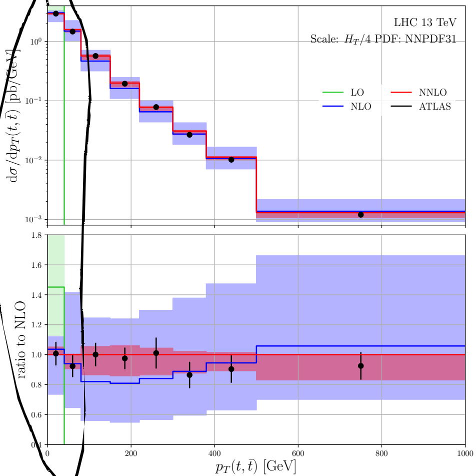
LHC top-quark pair at higher orders







$$\frac{d\sigma}{dq_T^2} \sim \frac{1}{q_T^2} \sum_{n=1}^{\infty} \left(\frac{\alpha_s}{2\pi}\right)^n \sum_{k=1}^{2n} c_{k,n} \ln^{k-1}\left(\frac{m_{t\bar t}}{q_T^2}\right)$$

$\hookrightarrow$ virtual $\delta(q_T^2)$

Resummation (Collin. Soper - Sterman)

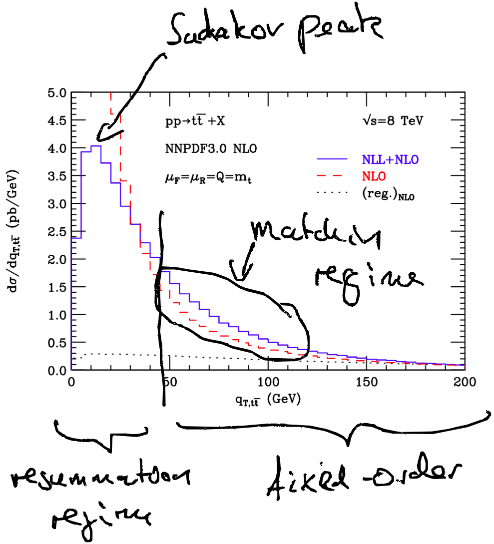
$$\frac{d\sigma}{dq_T\, dM^2\, dy\, d\Omega} = \frac{1}{(2\pi)^2} \int d^2b\, e^{i\vec{b}\,\vec{q}_T} \overbrace{\frac{d\sigma^{(res)}}{dM^2 dy\, d\Omega\, d^2b}}^{\text{resummation}}$$

$$+ \cancel{\text{finite}}$$

$$d\sigma^{(res)} = B\left(x_1, \frac{b_0}{b}\right) B\left(x_2, \frac{b_0}{b}\right) \underbrace{\exp\left(-S(b, M^2)\right)}_{\text{collinear resummation}}$$

$$\times \underbrace{\mathrm{Tr}\left[H\,\Delta\right]}_{\text{soft gluons}}$$

$$S(b, M^2) = \int_{b_0^2/b}^{M^2} \frac{d\mu^2}{\mu^2} \left[A(\alpha(\mu)) \ln\left(\frac{M^2}{\mu^2}\right) + B \right]$$



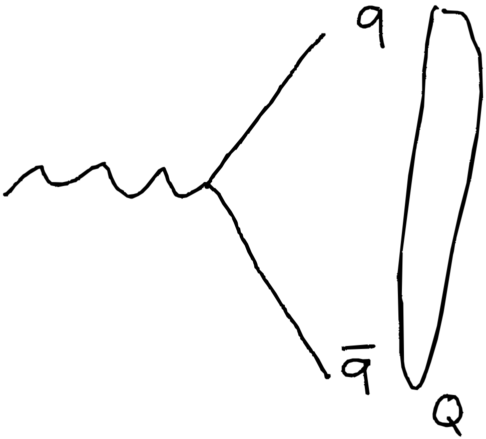
$$d\sigma^{\text{matched}} = d\sigma^{\text{res}} + \left(d\sigma^{\text{FO}} - d\sigma^{\text{res}}\big|_{\text{FO}}\right)$$

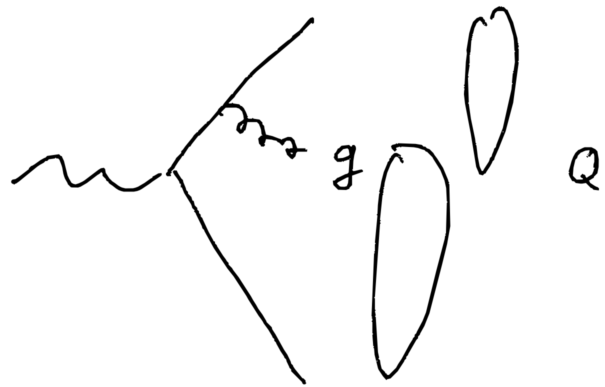
→ analytic control over logs

→ observable specific

→ does produce events

Parton-showers





$$Q > Q'$$

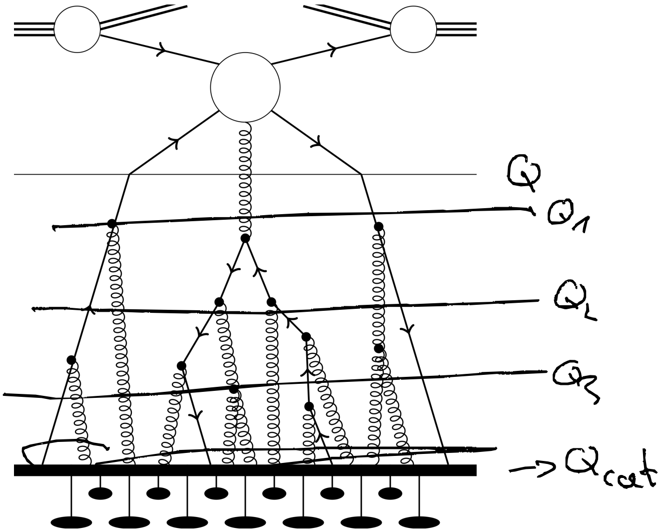
IR enhancement: $$\frac{|\mathcal{M}_{q\bar{q}g}|\, d\Phi_3}{|\mathcal{M}_{q\bar{q}}|\, d\Phi_2} \xrightarrow{\text{soft}} \frac{2\alpha_s C_F}{\pi} \underbrace{\frac{dE_g}{E_g}\frac{d\theta}{\theta}}\frac{d\phi}{2\pi}$$

Ordering variable: $\Theta_0 > \Theta_1 > \Theta_2 > \dots$

$$k_\perp \sim E_g \Theta$$

$$k_\perp^1 > k_\perp^2 > k_\perp^3 > \dots$$

Parton-shower



Formulate this as a Markov process:

Probability splitting

$$dP_a(t) = \frac{dt}{t}\,\frac{\alpha_s(t)}{2\pi}\sum_{b,c}\int_{z_{min}}^{z_{max}} dz\, P_{a\to bc}(z)$$

Let $\Delta_a(t_1, t_2)$ the probability for a evolution <u>without</u> splittin -> Sudakov form factor

Derive a DEQ: $\Delta_a(t_1, t - dt) = \Delta_a(t_1, t)(1 - dP_a(t))$

$$\Rightarrow \frac{d\Delta_a}{dt}(t_1, t) = \Delta_a(t_1, t)\frac{dP_a}{dt}$$

$$\Delta_a(t_1, t_1) = 1$$

$$\Rightarrow \Delta_a(t_1, t_2) = \exp\Big(-\underbrace{\int_{t_2}^{t_1} \frac{dt'}{t} \frac{\alpha_s(t')}{2\pi}}_{\to \text{logs}} \sum \int \hat{P}_a\Big)$$

$$d\sigma^0 = d\sigma^0 \underbrace{\big(\Delta_q(Q, Q_{cut}) + \sum \text{possibilities of emission}\big)}_{=1}$$

$$= \Delta_q(Q, Q_{cut})\, d\sigma^0$$

$$+ d\sigma^0 \int_{Q_{cut}}^{Q} \frac{dt}{t} \frac{\alpha_s(t)}{2\pi} \int_{z_{min}}^{z_{max}} dz\, P(z)\, \Delta(Q, t)$$

$$+ \frac{1}{2}(2\,\text{emission}) + \dots$$

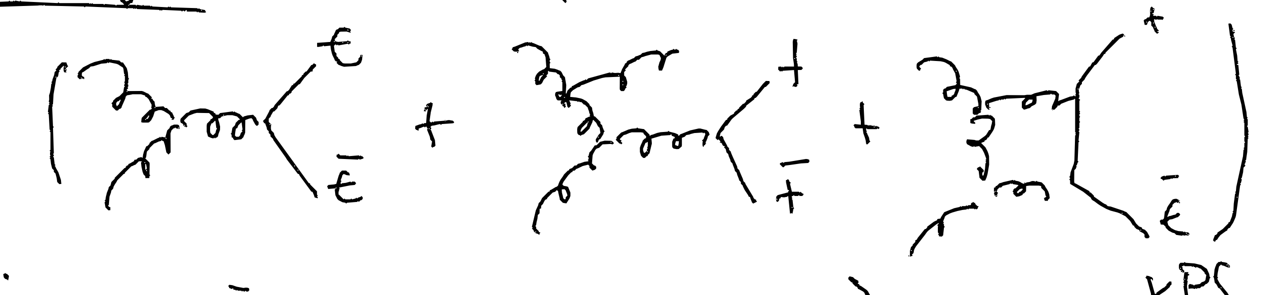
=> solved σ, Sudakov veto algorithm

-> (N)LL resummation

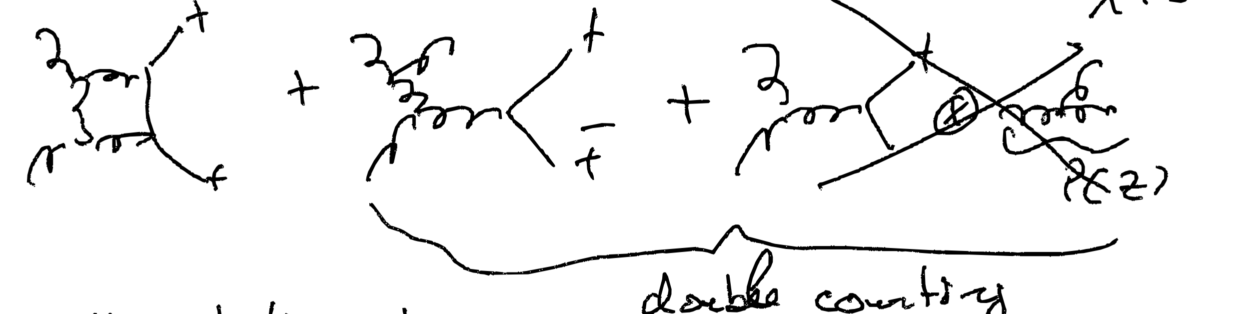
-> hot topic: workin toward NNLL showers !

<u>Matching Procedure</u>

NLO: real



reexpand: α_s^3



-> technically challenging

-> NLO + PS solved MC@NLO, Powheg

-> NNLO + PS only special case

-> colorsinglett & $t\bar{t}$ MiNNLOPS

Geneva,

Vincia

<u>Merging</u>

LO: $gg \to H$ LO: $gg \to Hg$ ~~N~~LO: $gg \to Hgg, \dots$

↳ cuts that the jet

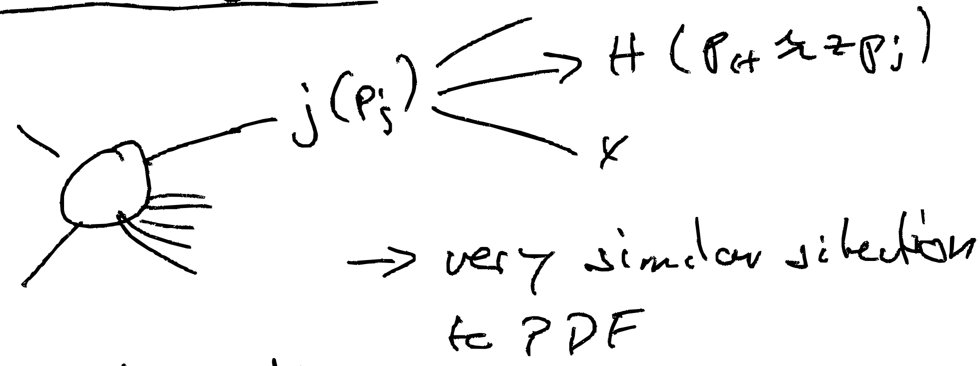
-> slice the phase space in jet multiplicities and fill up the gaps with PS

-> CKKW -> Sherpa, MLM scheme -> Madgraph

-> improve hard radiation description

<u>Fragmentation, Hadronization</u>

<u>Fragmentation</u>



-> very similar situation to PDF

=> collinear factorization

$$d\sigma_{AB \to H+X} = \sum_{a,b,j} f_a \otimes f_b \otimes d\hat{\sigma}_{ab \to j+X'}(x_1, x_2, z, \mu_{FR})$$

$$\otimes D_{j \to H}(z, \mu_{FF})$$

-> DGLAP?

-> fit non-perturbative information to data

-> only works for few identified hadrons

<u>Hadronization models</u>

-> quark-hadron duality $q \to H_q$

-> direction of quarks is direction of hadrons

-> Lund-string model, cluster model

Fragmentation