Event shapes in Deep Inelastic Scattering

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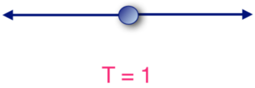
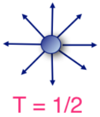
[T. Gehrmann, A. Huss, JM, J. Niehues, 1909.02760]

Event shapes

- Observables depending on final state hadrons momenta
- Describe structure of hadronic events
- Canonical example: thrust

$$\tau = 1 - T, \quad T = \max_{\vec{n}_T} \frac{\sum_i |\vec{p}_i \cdot \vec{n}_T|}{\sum_i |\vec{p}_i|}$$





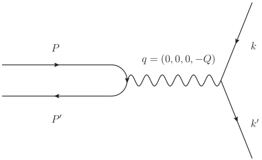
- Interesting for:
  - Studying hadronisation models
  - α_s extraction
  - Tuning of Monte Carlo event generators

Event shapes in DIS

- Originally defined for e^+e^- collisions, here we consider *ep* DIS
- DIS variables

$$s = (P+k)^2, \qquad Q^2 = -q^2$$

$$x = \frac{Q^2}{2q \cdot P}, \qquad y = \frac{q \cdot P}{k \cdot P} = \frac{Q^2}{xs}$$



- Breit frame: $2x\vec{P} + \vec{q} = 0$
  - Remnant hemisphere H_R
  - Current hemisphere H_C

Definitions DIS event shapes

- Thrust

$$\tau_{\gamma,T} = 1 - T_{\gamma,T}, \quad \text{with} \quad T_{\gamma,T} = \max_{\vec{n}_T} \frac{\sum_h |\vec{p}_h \cdot \vec{n}_{\gamma,T}|}{\sum_h |\vec{p}_h|}$$

- Jet mass

$$\rho = \frac{(\sum_h p_h)^2}{(2\sum_h E_h)^2}$$

- Jet broadening

$$B_{\gamma,T} = \frac{\sum_h |\vec{p}_h \times \vec{n}_{\gamma,T}|}{2\sum_h |\vec{p}_h|}$$

- C-parameter

$$C = \frac{3}{2} \frac{\sum_{h,h'} |\vec{p}_h||\vec{p}_{h'}| \sin^2\theta_{hh'}}{(\sum_h |\vec{p}_h|)^2}$$

Observables

- IRC-safe
- $F \in [0,1]$
  $F \to 0 \Rightarrow$ Born limit
  $F \to 1 \Rightarrow$ Multi-jet limit
- Distribution of the event shapes $\frac{1}{\sigma_H}\frac{d\sigma}{dF}$
- Moments
$$\langle F^n \rangle = \frac{1}{\sigma_H} \int_0^{F_{\max}} F^n \frac{d\sigma}{dF} dF$$
- First moment is mean value

H1 and ZEUS analyses

- Follow study of H1 [A. Aktas et al., 0512014] and ZEUS [S. Chekanov et al., 0604032] measurements at HERA
  - H1 kinematic ranges:

$$\sqrt{s} = 319\,\mathrm{GeV}$$
$$0.1 < y < 0.7$$
$$196\,\mathrm{GeV}^2 < Q^2 < 40000\,\mathrm{GeV}^2$$

  - ZEUS kinematic ranges:

$$\sqrt{s} = 319\,\mathrm{GeV}$$
$$0.0024 < x < 0.6$$
$$0.04 < y < 0.9$$
$$80\,\mathrm{GeV}^2 < Q^2 < 20480\,\mathrm{GeV}^2$$

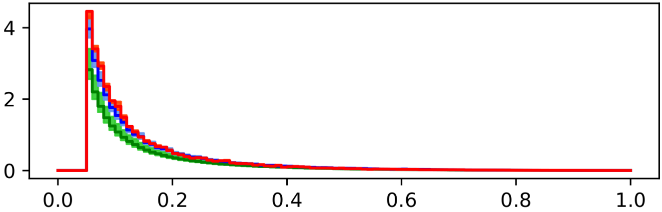
FO calculation with NNLOJET

- LO, NLO and NNLO FO QCD corrections calculated with NNLOJET
- DIS matrix elements producing 4 partons, 3 partons 1-loop, 2 partons 2-loop
- Antenna subtraction for isolation and recombining IR singular terms
- Integration over phase space
- Calculation details

$$\begin{aligned}\sqrt{s} &= 319\,\mathrm{GeV}, \quad \alpha_s(M_Z) = 0.118, \quad N_F = 5\,(\mathrm{massless}) \\ \mu_F &= \mu_R = Q, \quad 7-\mathrm{pt.} \quad \mathrm{PDF:NNPDF3.1}\end{aligned}$$

FO distribution shape

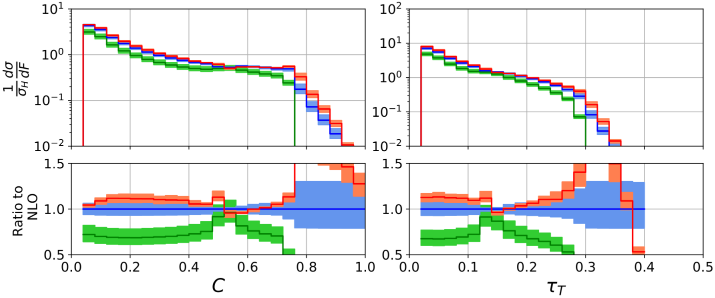
- Typical FO shape of event shape distribution



- FO at left end diverges due to $\log(F)$ terms
- Would need resummation here
- Applied cuts F_{cut} on minimum value allowed
- First moment is regulated by F

Non-smoothness

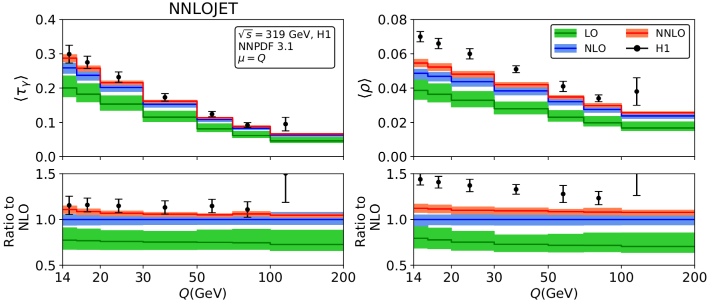
- Some subtle differences between e^+e^- and DIS shapes
- Non-smooth features in distribution



FO vs data

Large discrepancy between FO calculation and experimental data

Mean of thrust and jet mass at parton level (H1 kin.)

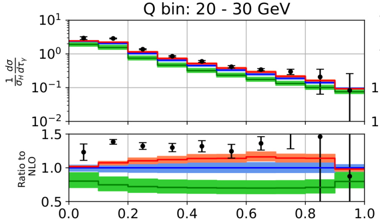


Experimental data is considerably above the FO predictions

FO vs data

Same for the differential distributions

Differential distribution of thrust at parton level (H1 kin.)



Need to include correction to hadron level

Hadronisation effects

- Need to account for parton $\rightarrow$ hadron
- Non-perturbative process
- Effects are power suppressed $\frac{1}{Q}$
- Dispersive model
  - IR finite effective coupling
  - Single parameter $\alpha_0 = 0.5$
  - $P(\alpha_0) = \alpha_s(\dots) + \alpha_s^2(\dots) + \dots$
- Effect on mean

$$\langle F \rangle = \langle F \rangle^{\text{pert.}} + a_F\, P$$

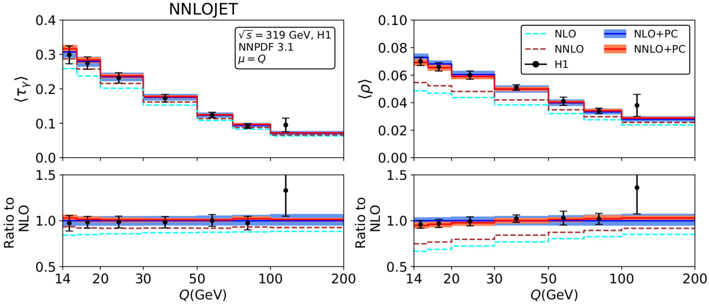
- Effect on distribution

$$\frac{\mathrm{d}\sigma^{\text{hadron}}(F)}{\mathrm{d}F} = \frac{\mathrm{d}\sigma^{\text{parton}}(F - a_F P)}{\mathrm{d}F}$$

FO+PC vs data

Fixed Order + Power Corrections

Mean of thrust and jet mass at hadron level

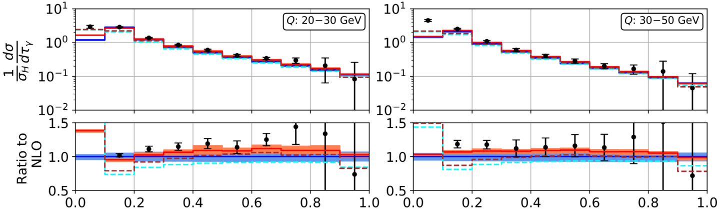


Very good agreement now

FO+PC vs data

Fixed Order + Power Corrections

Differential distribution of thrust at hadron level (H1 kin.)

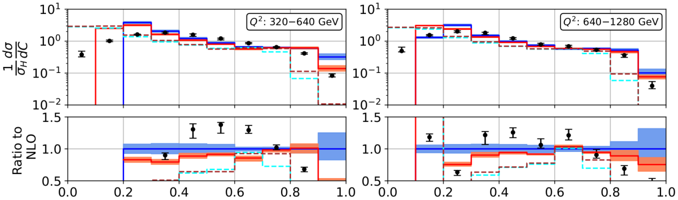


Flat shifted distribution

FO+PC vs data

In general, shift can also depend on the value of F

Differential distribution of C at hadron level (ZEUS kin.)



Conclusion

- The NNLO QCD corrections improve the theory description
- Smaller uncertainties
- Better overlap with previous order uncertainty bands
- Very good agreement for the mean values at NNLO
- Differential distributions has moderate agreement
    - Flat shift is too simplistic