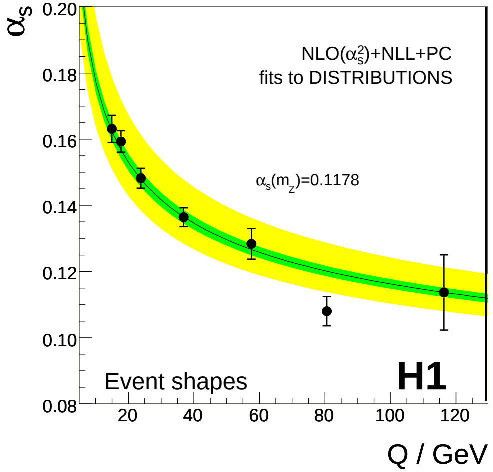
Moscow, Russia, July 26 - August 2, 2006

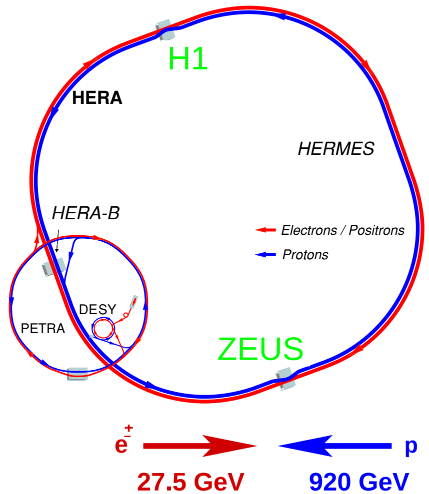


Azimuthal asymmetries, Subjets and Event shapes in DIS at HERA

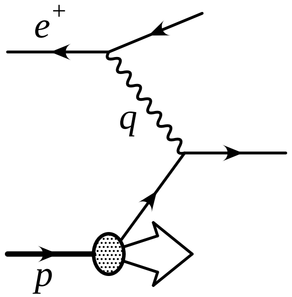
S. Levonian, DESY

on behalf of

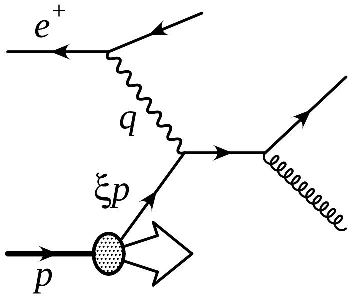
- Hadronic final states in NC DIS
- Azimuthal asymmetries and subjet distributions
- Event shape analysis
- Summary



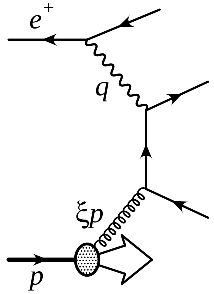
The hadronic final state in NC DIS



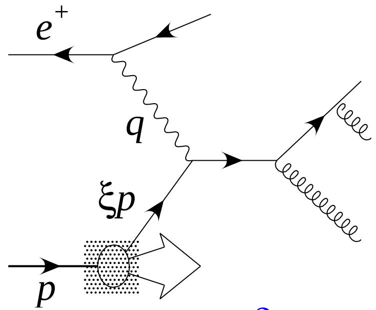
Born (α_s^0)



QCDC (α_s^1)

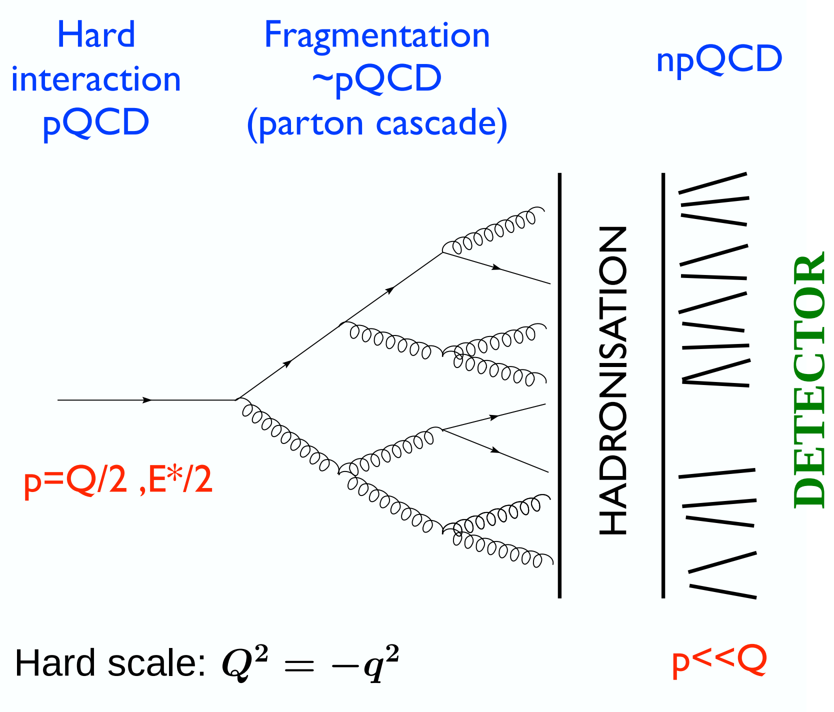


BGF (α_s^1)



$\mathcal{O}(\alpha_s^2)$

Rich final states which reflect underlying QCD dynamics



Particle spectra and E-flow

- high statistics, large hadronisation effects
- pQCD + phenomenological hadr.corr. (MC)

High E_T jets

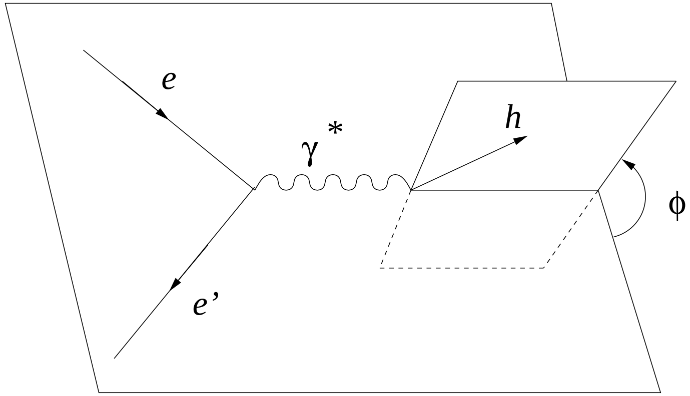
- limited statistics and phase space
- pQCD; hard.corr. are small

Event shapes

- large statistics and phase space
- pQCD + PC ($\mathcal{O}(1/Q)$)

(analytical approach to confinement from first principles)

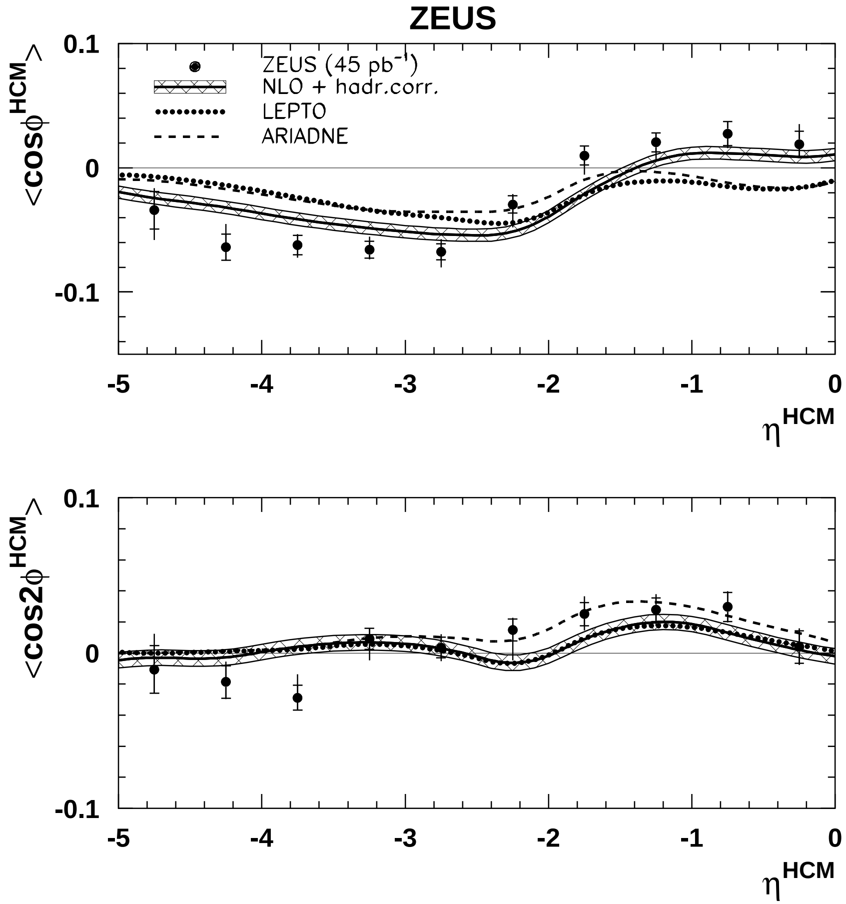
Asimuthal asymmetry in NC DIS



$\gamma^* p$ **HCM frame**

$$\frac{d\sigma}{d\phi} = 2A(\tfrac{1}{2} + B\cos\phi + C\cos 2\phi + D\sin\phi + E\sin 2\phi)$$

$$\langle\cos\phi\rangle = B/2A \qquad \langle\sin\phi\rangle = D/2A$$
$$\langle\cos 2\phi\rangle = C/2A \qquad \langle\sin 2\phi\rangle = E/2A$$



Data $\quad \mathcal{L} = 45\ \mathbf{pb}^{-1}$

$100 < Q^2 < 8000\ \mathbf{GeV}^2$

$0.2 < y < 0.8$

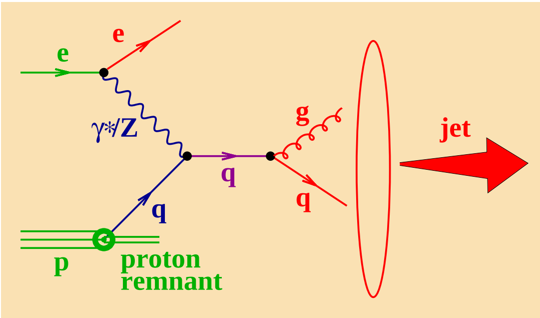
$0.01 < x < 0.1$

***E*-flow method is used:**

$$\langle F(n\phi)\rangle = \frac{\sum_i E_{T,i} F(n\phi)}{\sum_i E_{T,i}}$$

★ **The NLO is closer to the data as compared to LO Monte Carlo programs**

Subjet distributions

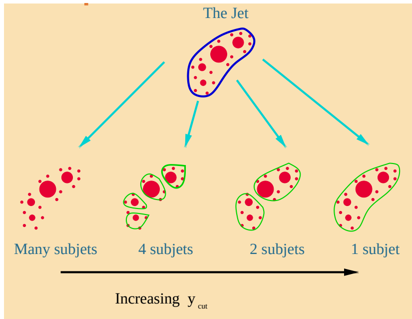


k_T **alg. in Lab frame**

$E_T^{jet} > 14$ GeV

$d_{cut} = y_{cut} \cdot (E_T^{jet})^2$

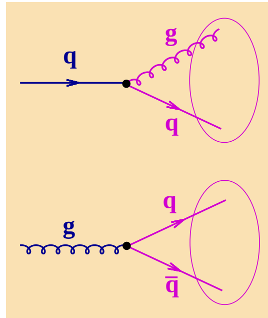
$y_{cut} = 0.05,\ n_{sj} = 2$



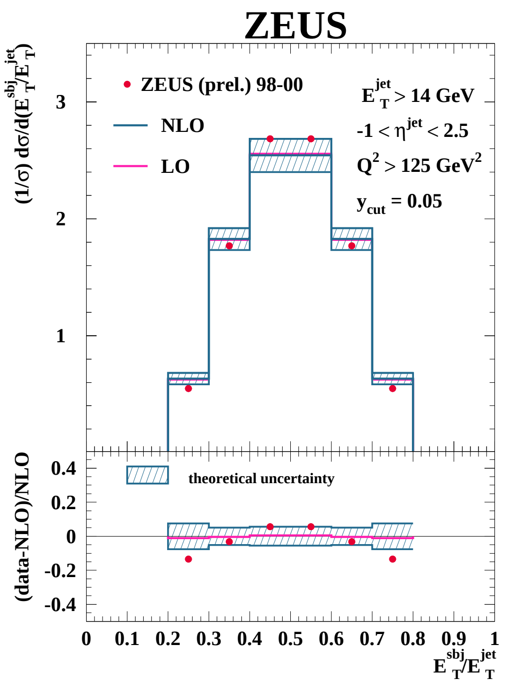
NLO:

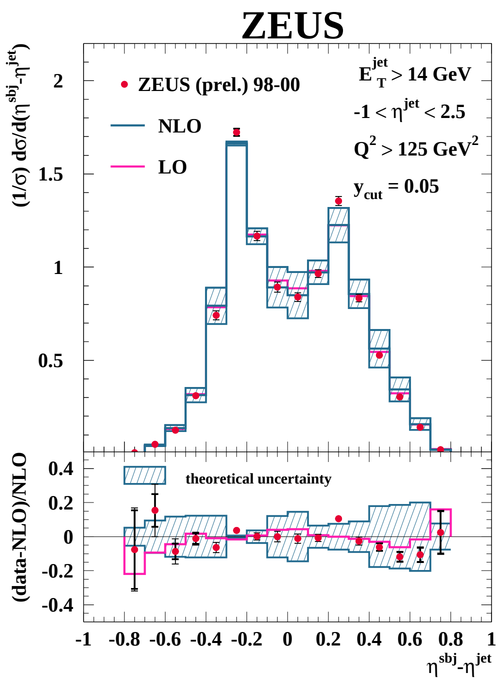
82%

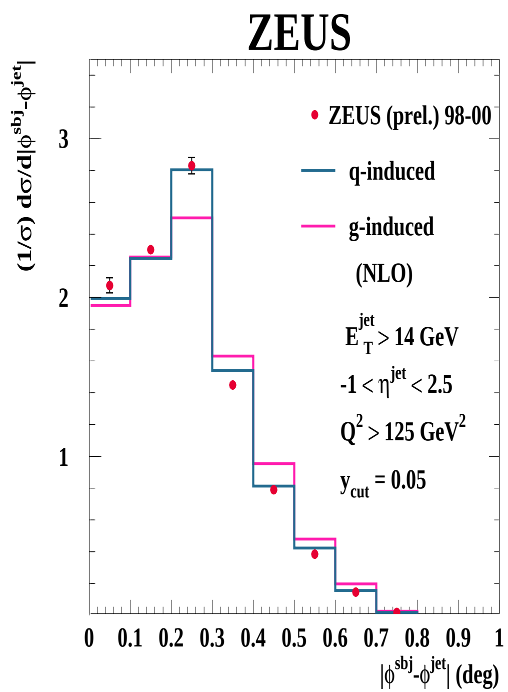
18%



Aim: study QCD parton radiation and transition from partons to jets of hadrons

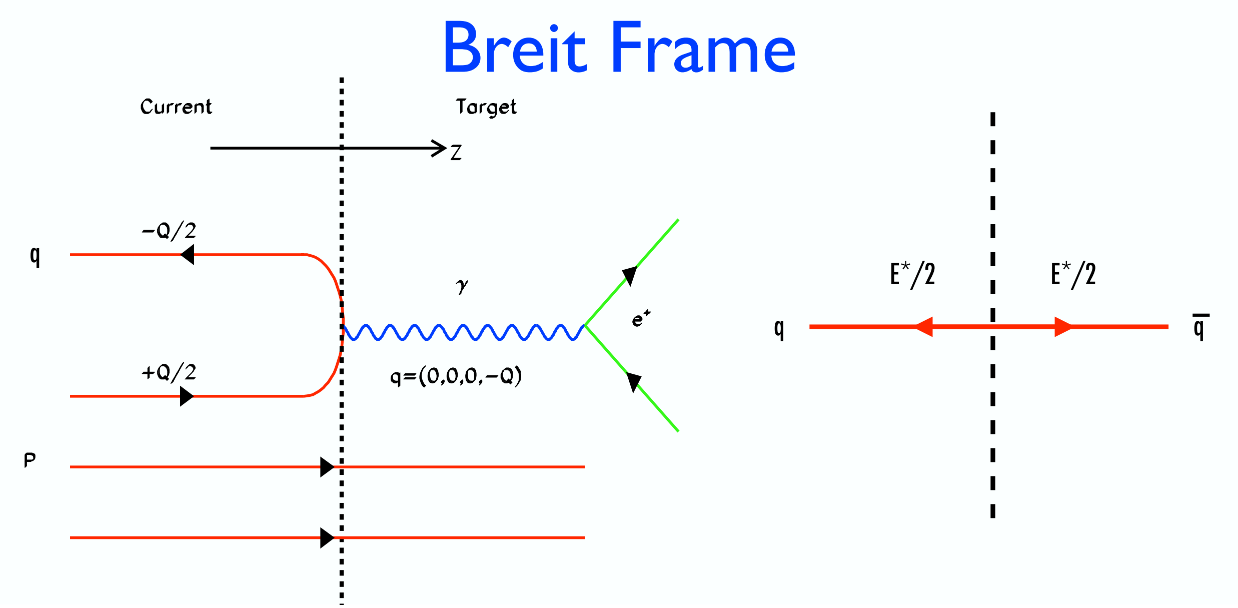






★ **NLO (DISENT) predictions describe all features of the data within** $\pm 10\%$

Event shape variables



- Inclusive jets in the Breit frame are $\mathcal{O}(\alpha\alpha_s)$ at lowest order (current quark has no E_T)
- Provides clearest separation between particles from hard scattering and p-remnant. Allows for easy comparison with e^+e^- data
- In this analysis sums extend over all particles in current hemisphere of the Breit frame (for K_{out} the region extended to $\eta < 3$)

Event shape variables, F

$\tau = 1 - T_\gamma$ with $T_\gamma = \frac{\sum_h |\vec{p}_{z,h}|}{\sum_h |\vec{p}_h|}$

$\tau_C = 1 - T_C$ - thrust along the axis maximising T (like in e^+e^-)

$B = \frac{\sum_h |\vec{p}_{t,h}|}{2\sum_h |\vec{p}_h|}$ – Jet Broadening

$\rho = \frac{(\sum_h E_h)^2 - (\sum_h \vec{p}_h)^2}{(2\sum_h |\vec{p}_h|)^2}$ – Jet inv. mass

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

$K_{out} = \sum_h |p_h^{\rm out}|$

$\chi = \sum_{h,i}(\pi\text{-}|\phi_h\text{-}\phi_i|)$

$(2+1)$ jet is minimal nontrivial confi guration

$F \longrightarrow 0$ for Born level,

$F > 0$ in case of multijets

Power correction approach

★ Introduce effective non-pert. coupling $\alpha_0 = \frac{1}{\mu_I}\int_0^{\mu_I} \alpha_{eff}(k)dk$ ($\alpha_0 = \alpha_s$ at $\mu_I = 2$GeV)
(theory predicts universal $\alpha_0 \simeq 0.5$)

★ PC (Dokshitzer at al.): non-pert. corrections (suppressed by powers of $1/Q$) obtained from first principles

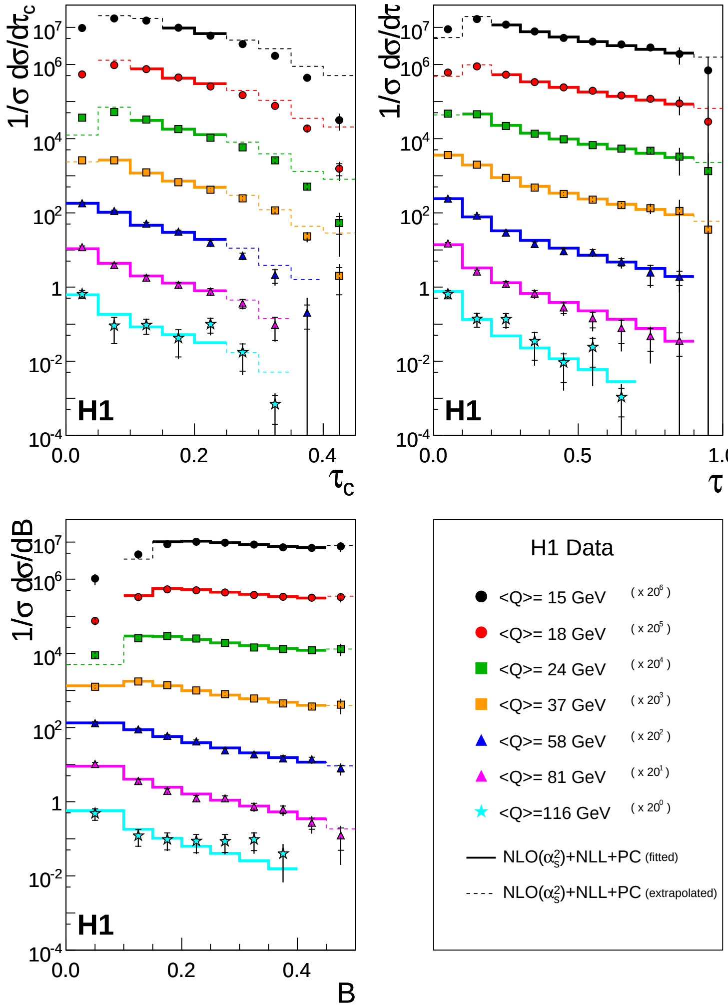
- for distributions $\frac{1}{\sigma}\frac{d\sigma(F)}{dF} = \frac{1}{\sigma}\frac{d\sigma^{\mathrm{pQCD}}(F-a_F\mathcal{P})}{dF}$ New
- for mean values $\langle F\rangle = \langle F\rangle^{\mathrm{pQCD}} + a_F\mathcal{P}$ (with universal PC term $\mathcal{P}$)

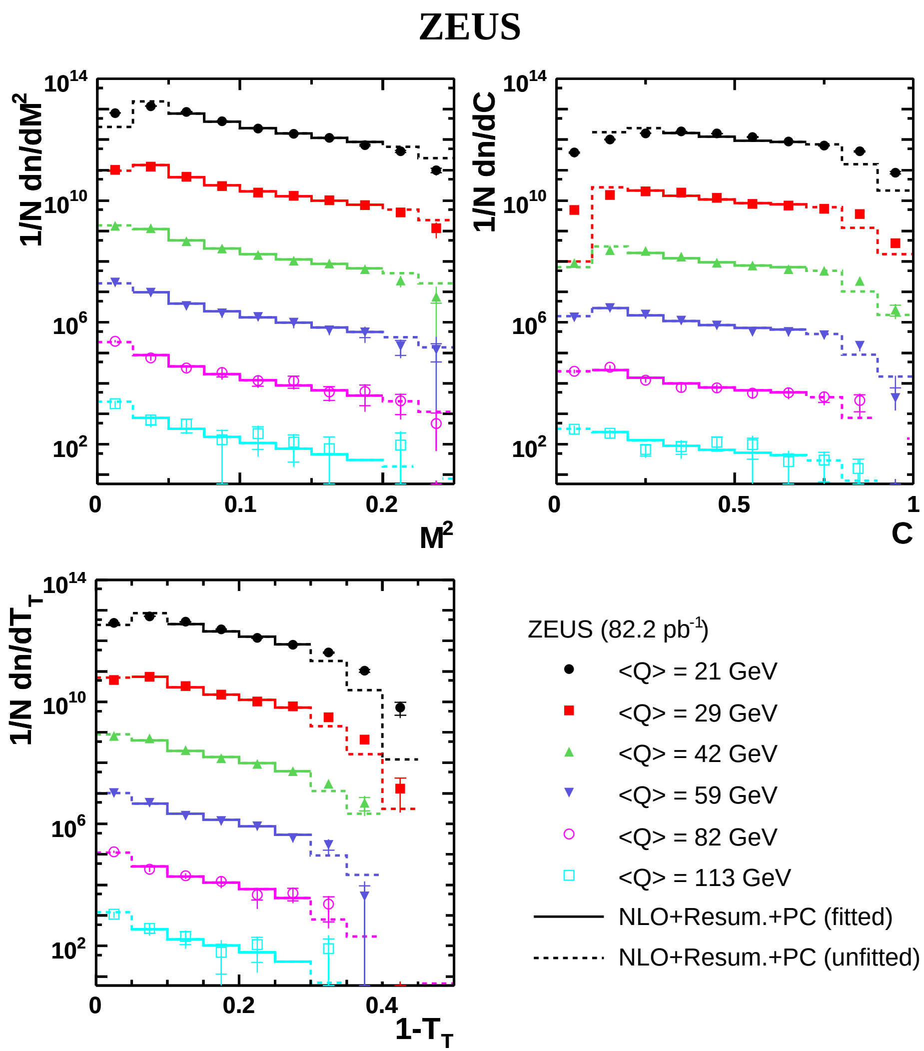
★ Complete description for F: NLO+NLL+PC
Recent progress in theory (as compared to previous round of event shape analyses in DIS) – resummation of large log terms and matching it to fixed order NLO (DISRESUM package by Dasgupta and Salam, 2002)

★ Limitations: very low F ($F \leq a_F\mathcal{P} \sim \mu_I/Q$) and very high F (substantial HO corr.)

➡ Main aim of the analysis: check the validity of PC concept and universality of α_0
By product: yet another method/observables to extract $\alpha_s(M_Z)$

Fits to distributions

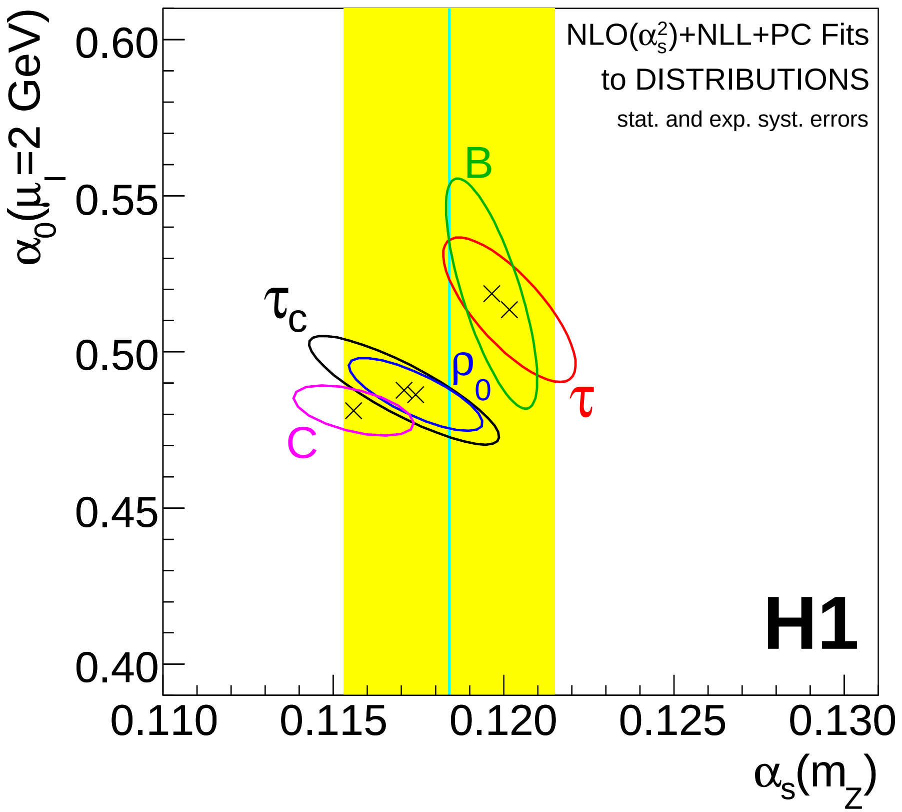


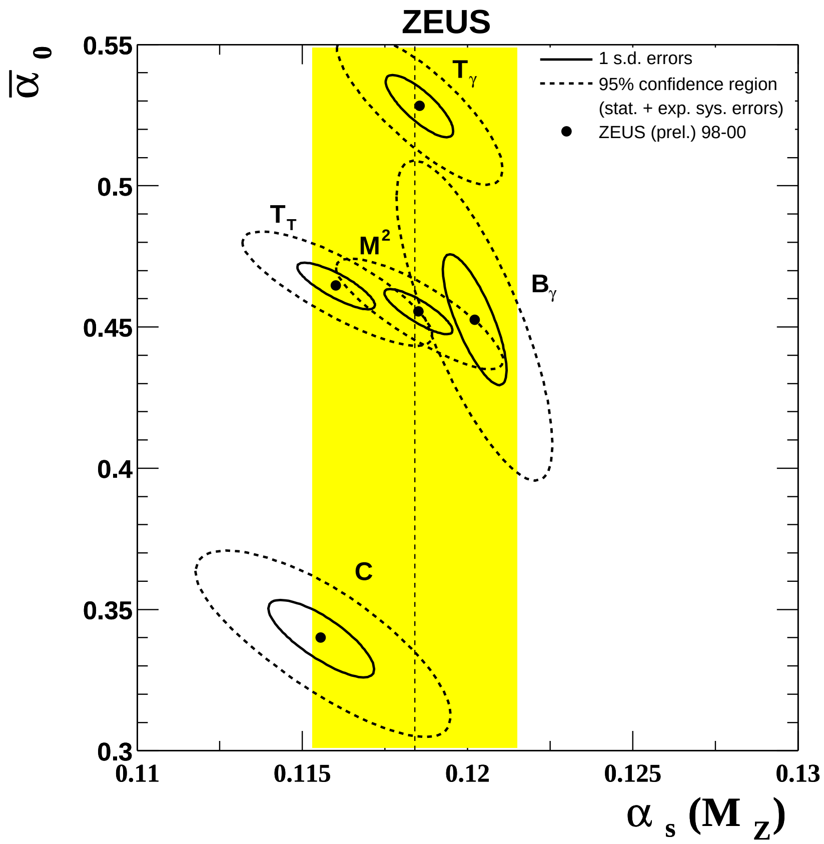


- H1 and ZEUS data are in agreement, but somewhat different fit range used
- Not all points are used in the NLO+NLL+PC fit: theory has limited range of applicability

α_s and α_0 from the fits to distributions

(1σ contours denote experimental errors alone; not shown are theoretical errors, $\sim 10\%$, which dominate)





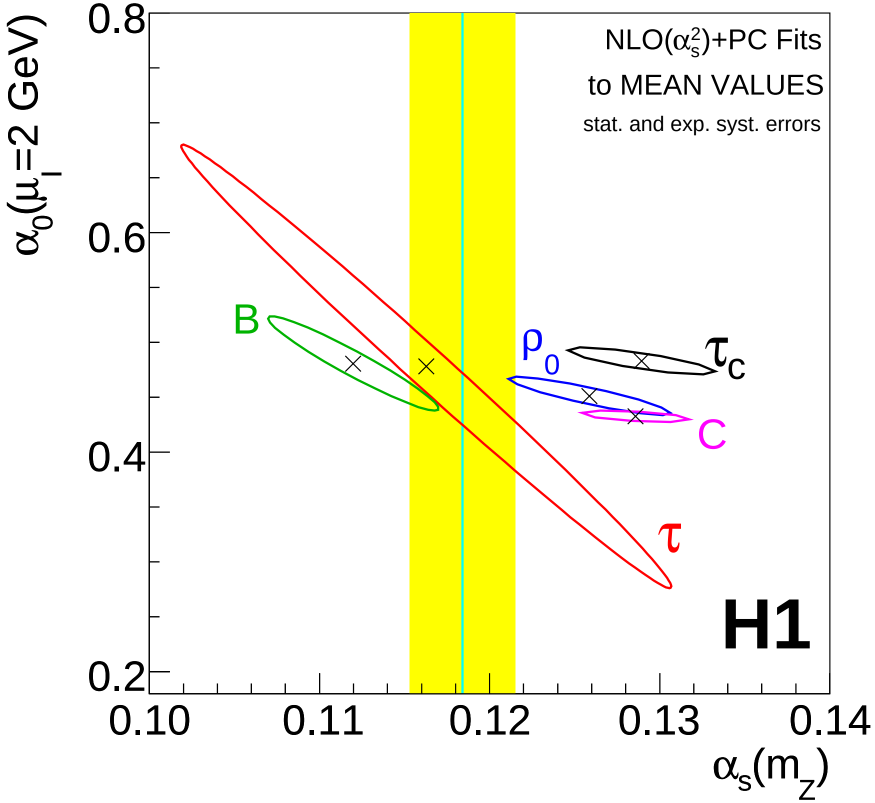
$$\alpha_s(M_Z) = 0.1198 \pm 0.0013(\text{exp})^{+0.0056}_{-0.0043}(\text{th})$$

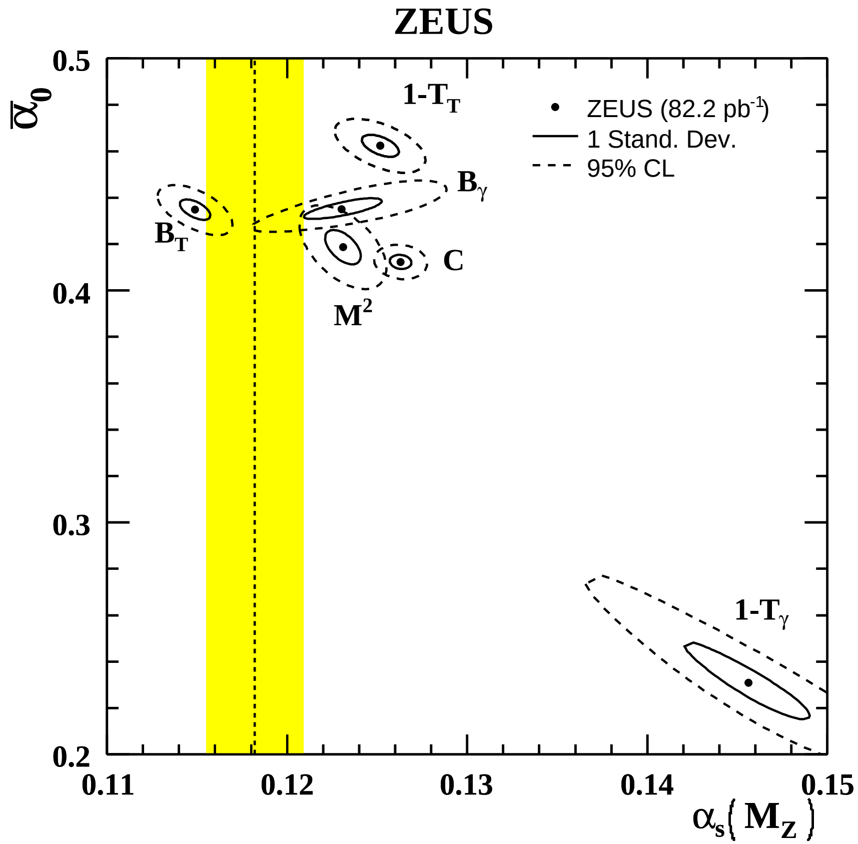
$$a_0 = 0.476 \pm 0.008(\text{exp})^{+0.018}_{-0.059}(\text{th})$$

- different error treatment in case of H1 and ZEUS
- extracted values of α_s are in good agreement with world average (shown by yellow band)

α_s and α_0 from the fits to mean values

(Note different scales in case of H1 and ZEUS plots)



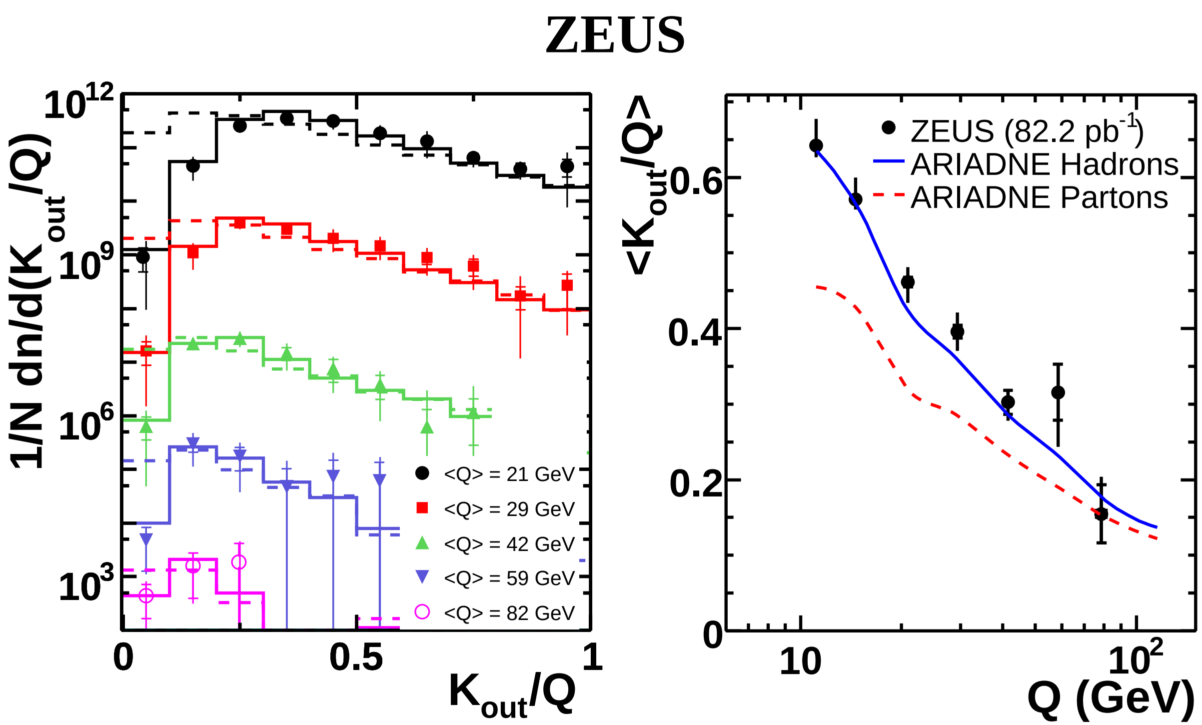


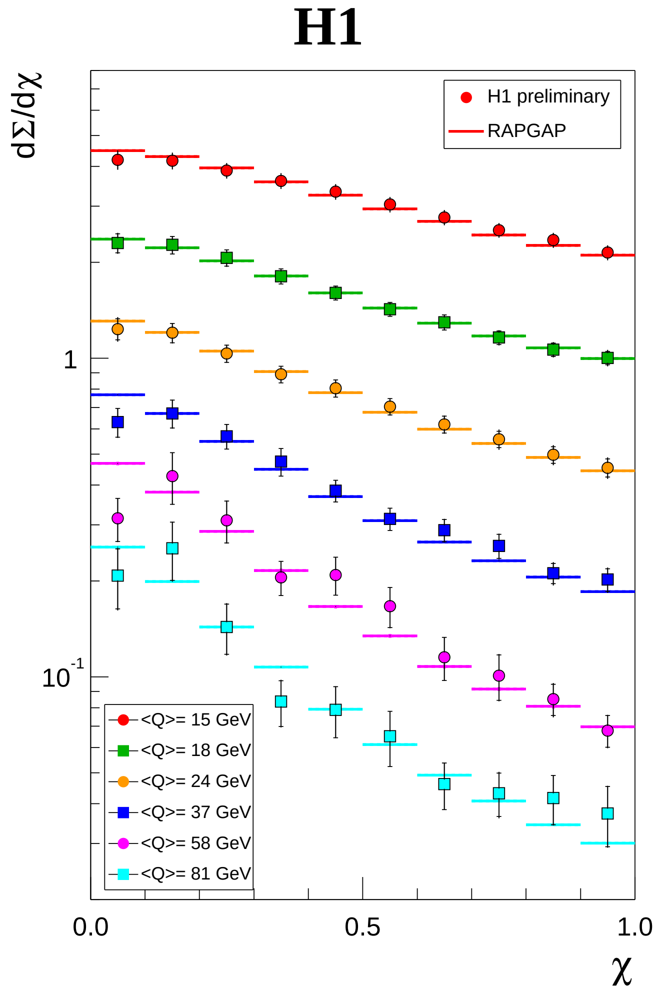
- Bigger spread in α_s as compared to fits to distributions $\Rightarrow$ indirect indication of the success of resummed theory
- With exception of thrust, H1 and ZEUS results display similar pattern: universal α_0 within $\pm 10\%$

3-jet event shape observables

$$K_{out} = \sum_h |p_h^{\mathrm{out}}| \qquad \chi = \sum_{h,i}(\pi - |\phi_h - \phi_i|)$$

In LO appear only due to non-perturbative effects, hence large sensitivity to NLO and to PC





★ **No complete theoretical calculations for these variables available yet**

★ **MC models give fair description in the bulk of the phase space**

Summary

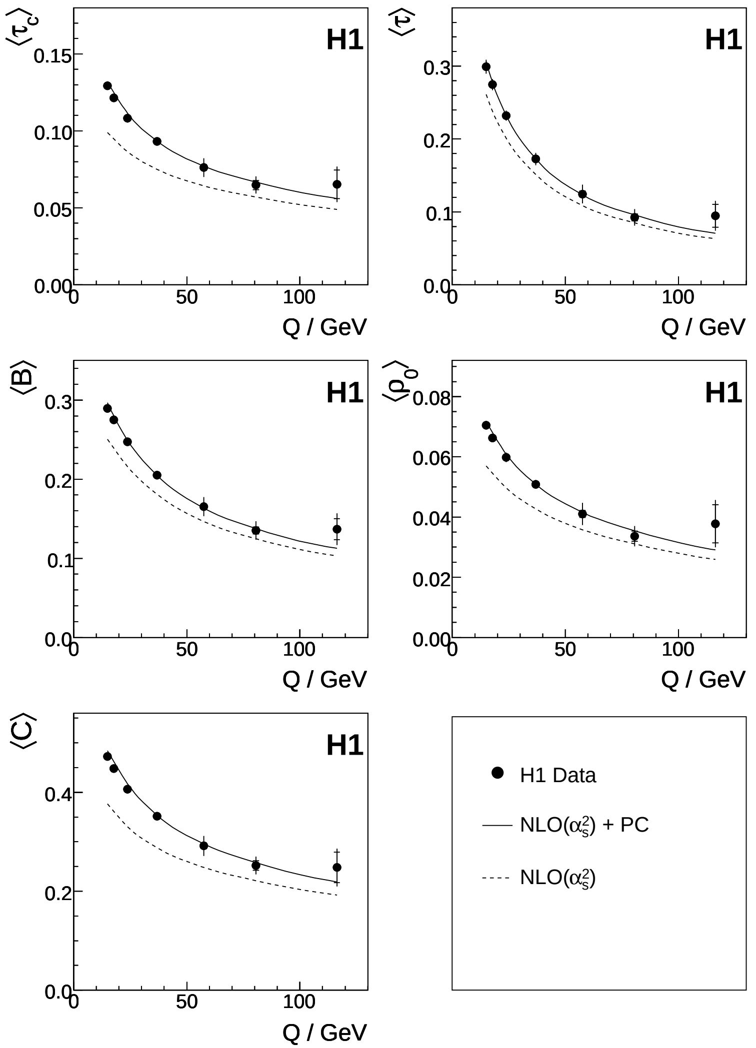
- High statistics HERA data on HFS in DIS provide stringent tests of pQCD.
  - In most of the observables NLO effects give sizeable contribution.
  - In many cases the dominant systematics comes from theory $\Rightarrow$ need for NNLO.

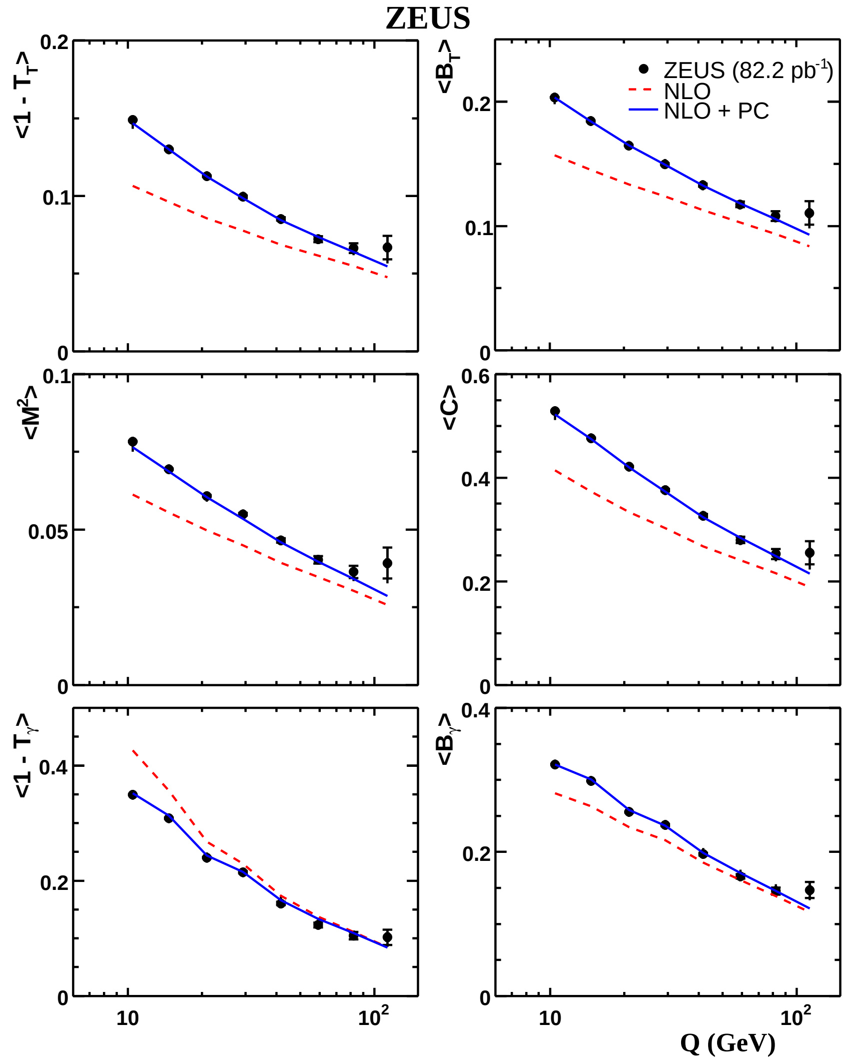
- Event shape means and distributions have been measured and analysed by both H1 and ZEUS collaborations.
  - The measurements themselves are in good agreement between the experiments
  - Obtained values of $\alpha_s(M_Z)$ are in agreement with world average
  - 3-jet event shapes, sensitive to higher orders and non-perturbative effects, have been measured as well and are waiting for theoretical calculation.

  ★ **The observed universality of α_O gives strong support for the concept of power corrections.**

BACKUP SLIDES...

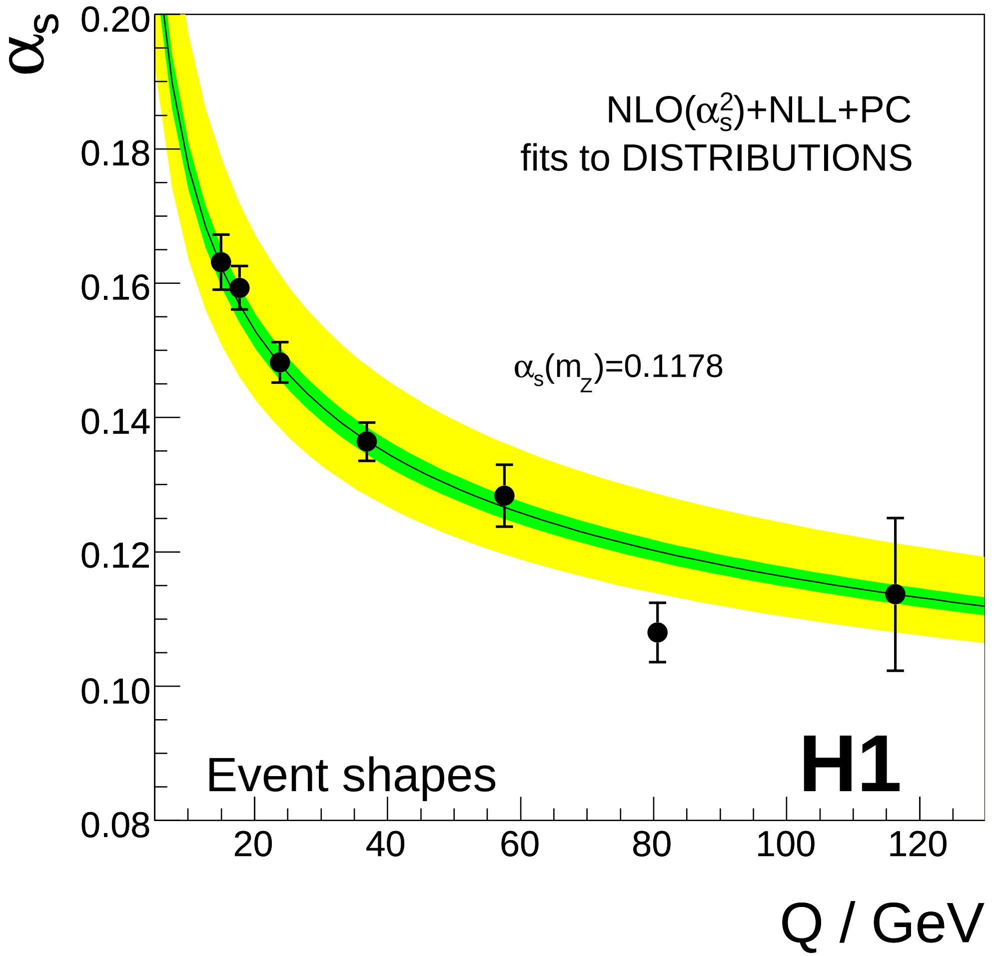
Fits to mean values





- Reminder: resummation is not applicable, as means contain ‘forbidden’ regions
- Significant positive PC values for all observables (except thrust along γ^* axis in case of ZEUS)

Running $\alpha_s(Q)$



$$\alpha_s(M_Z) = 0.1178 \pm 0.0015(\text{exp})^{+0.0081}_{-0.0061}(\text{theo})$$

(α_s, α_0) from fits to distributions in different matching schemes