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Jet production and QCD measurements at HERA

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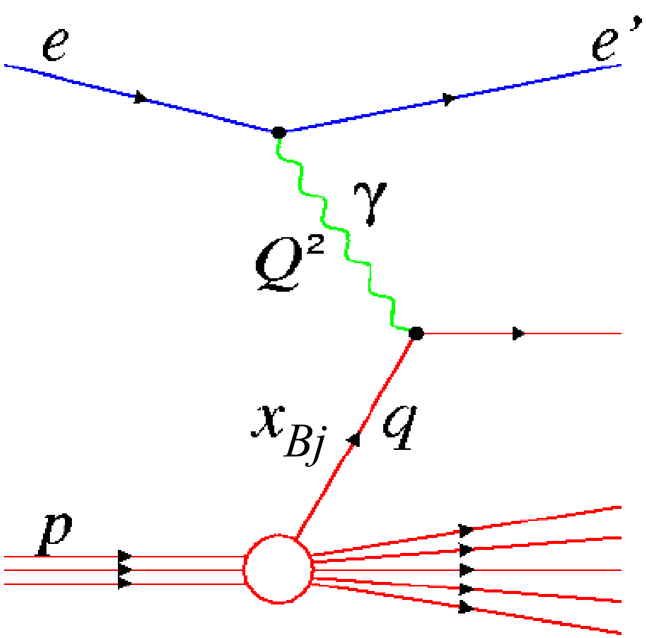
HERA

The HERA $e^{\pm}p$ collider 1992-2007:

- **$E_{e\pm}$ = 27.6 GeV**
- **E_p = 920 GeV**
- **$\sqrt{s}$ = 319 GeV**
- **Integrated luminosity: ~0.5 fb^{-1} (per experiment)**



Standard DIS variables

Q^2	**virtuality of the exchanged boson**
x_{Bj}	**in QPM fraction of proton momentum carried by struck quark**
y	**= Q^2/xs inelasticity**

Jet production at HERA

Jet production and determination of strong coupling constant

- **H1 jet production at high Q^2 and determination of α_s**

High Q^2 measurements with inclusive jets, dijet and trijet events ***arXiv:1406.4709***
Subm to EPJC

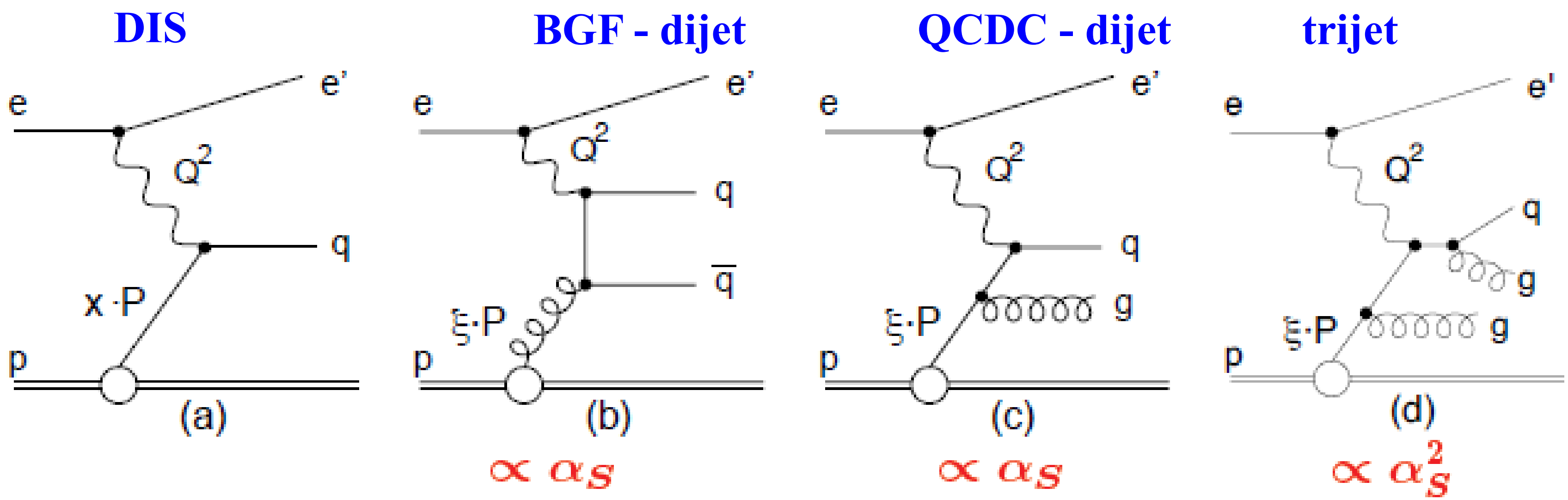
- **ZEUS jet production and determination of α_s**

High Q^2 measurements with trijet events ***ZEUS-prel-14-008***

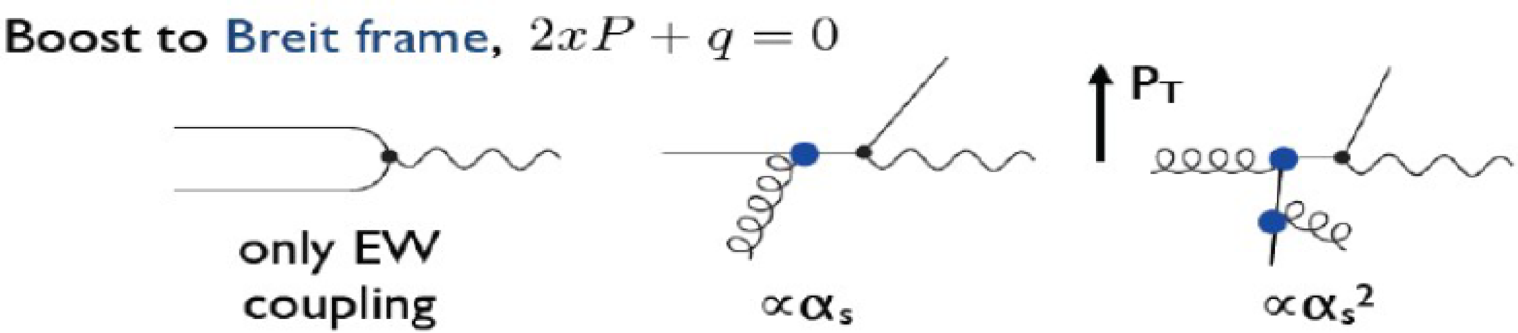
QCD measurements

- **H1 QCD Instantons searches at high Q^2** ***H1-prel-14-031***

Jet production in NC DIS



The fraction of the proton momentum carried by the parton that enters the hard subprocess: $\xi = x_{Bj} (1+ M_{jjj}^2/Q^2)$



In Breit frame only hard QCD process can generate significant P_T.

Direct sensitivity to α_s and gluon PDF

H1 High Q^2 Jet Production Analysis

Jets reconstruction

- **Overconstrained system in DIS**
- **Energy flow algorithm**
  - **Calibration using neural networks**
- **k_T and anti-k_T algorithm in the Breit frame**

Hadronic energy scale uncertainty 1%

Phase space and Jet samples

- **HERA II data, 351 pb^{-1}**
- **Inclusive jets: every jet in an event exceeding a min P_T contribute to a cross section σ_{jet}**
- **Dijets (Trijets): events with at least 2 (3) jets above a given PT contribute to a cross section $\sigma_{dijet\ (trijet)}$**
- **Normalised cross sections: σ_{jet} / $\sigma_{NC\ DIS}$**

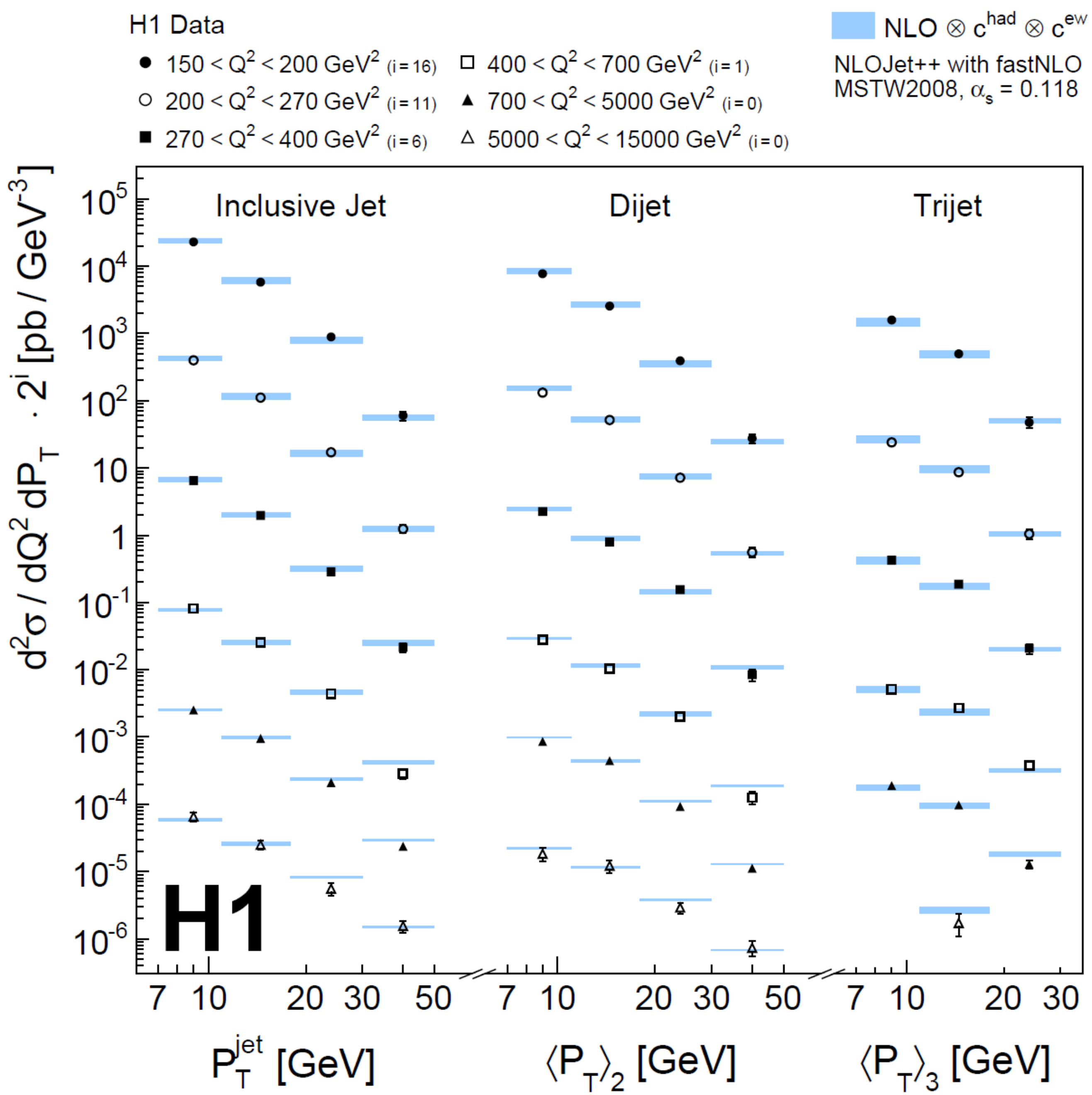
Measurement phase space for jet cross sections
$150 < Q^2 < 15\,000\ \mathrm{GeV}^2$ $0.2 < y < 0.7$
$-1.0 < \eta^{jet}_{lab} < 2.5$
$7 < P_T^{jet} < 50\ \mathrm{GeV}$
$5 < P_T^{jet} < 50\ \mathrm{GeV}$ $M_{12} > 16\ \mathrm{GeV}$

Unfolding

- **Regularized unfolding with TUnfold***
- **Multidimensional unfolding in Q^2, y, P_T**
- **Migrations of up to 7 observables and correlations between samples taken into account**

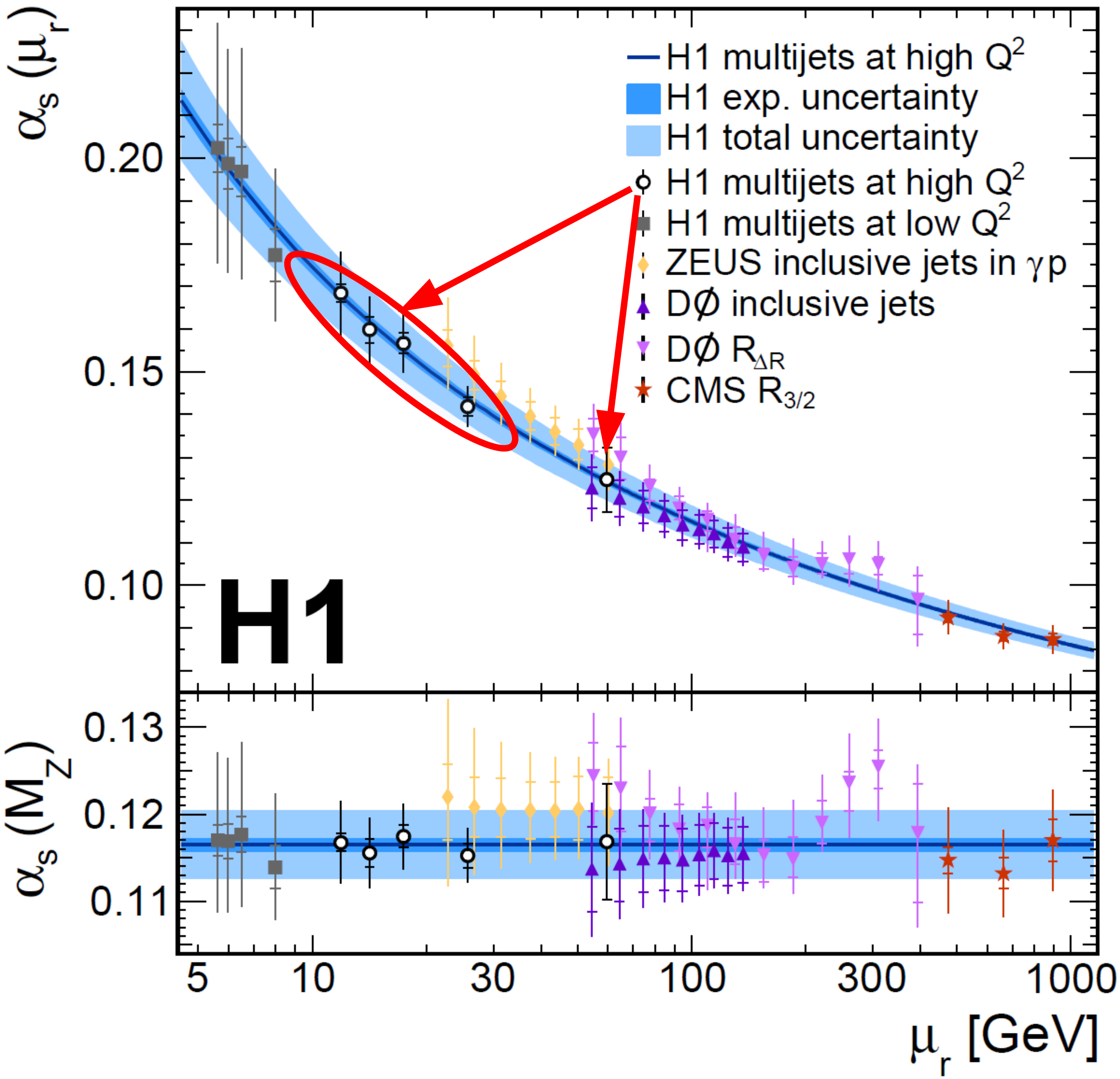
*** S.Schmitt, JINST 7 (2012) T1003, (arXiv:1205.6201)***

H1 high Q^2 Jets Results



NLO QCD predictions, corrected for hadronisation and electroweak effects, in good agreement with data within uncertainties

The determination and running of α_S



From normalised multijet:

$\alpha_s(M_Z)$= 0.1165 (8)$_{exp}$ (38)$_{pdf,theo}$

The most precise measurement from jet cross sections so far

The prediction for running using RGE and measured α_s agrees well with previous measurements at different scales

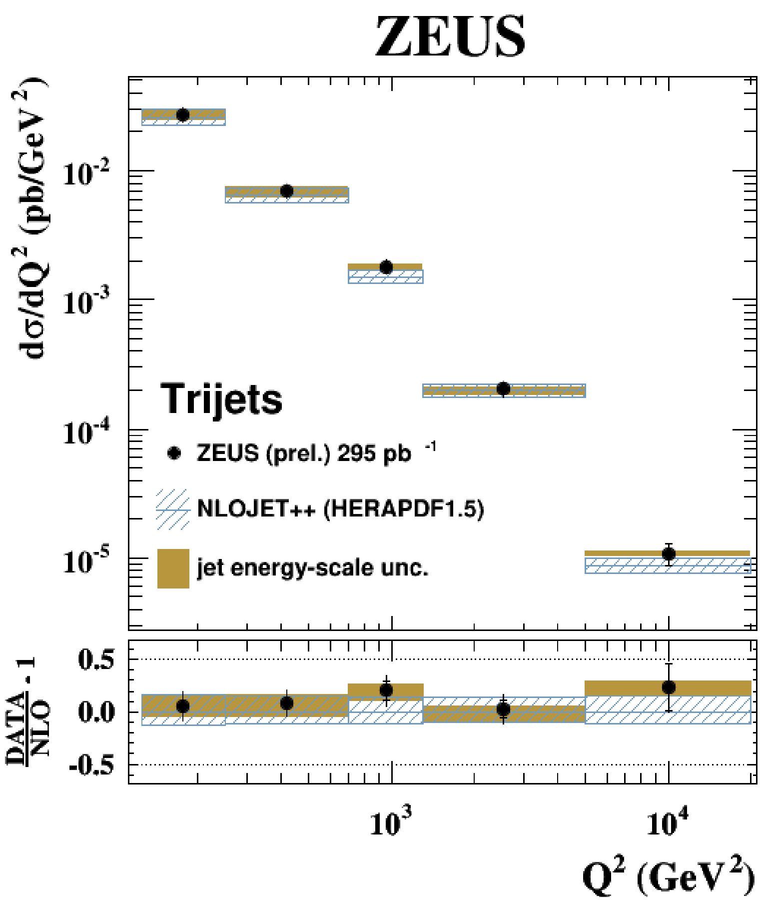
ZEUS trijet measurements

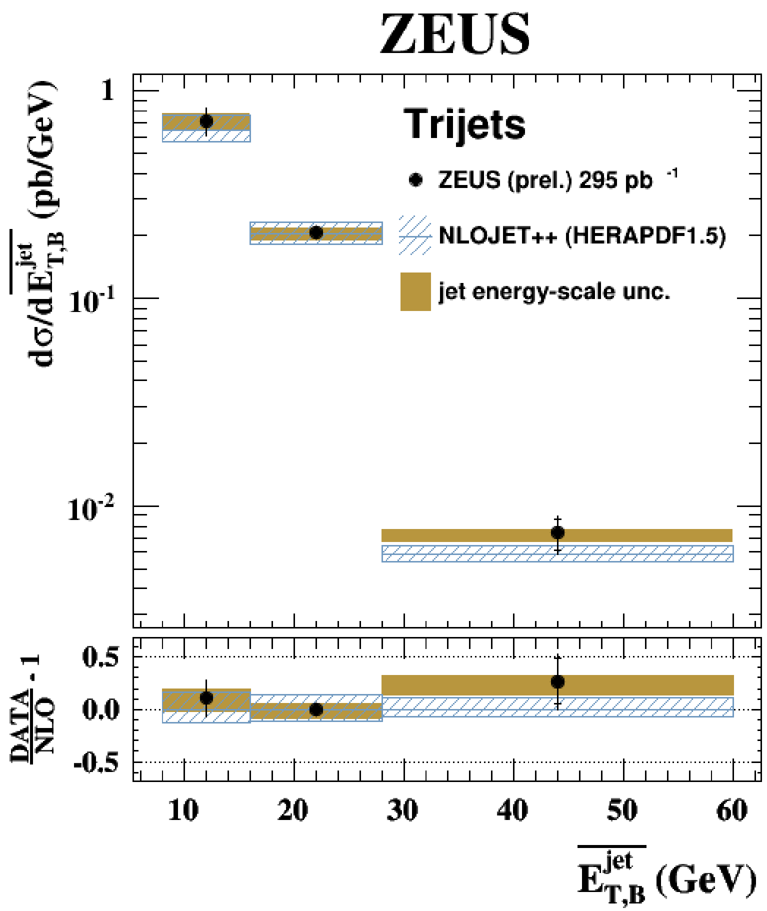
Phase space: $125 < Q^2 < 20000\ GeV^2$
$0.2 < y < 0.6$

- At least three jets with $E_{T,B}^{jet} > 8$ GeV and $-1 < \eta_{LAB}^{jet} < 2.5$
- $M_{jj} > 20$ GeV

Prediction: NLOJet++

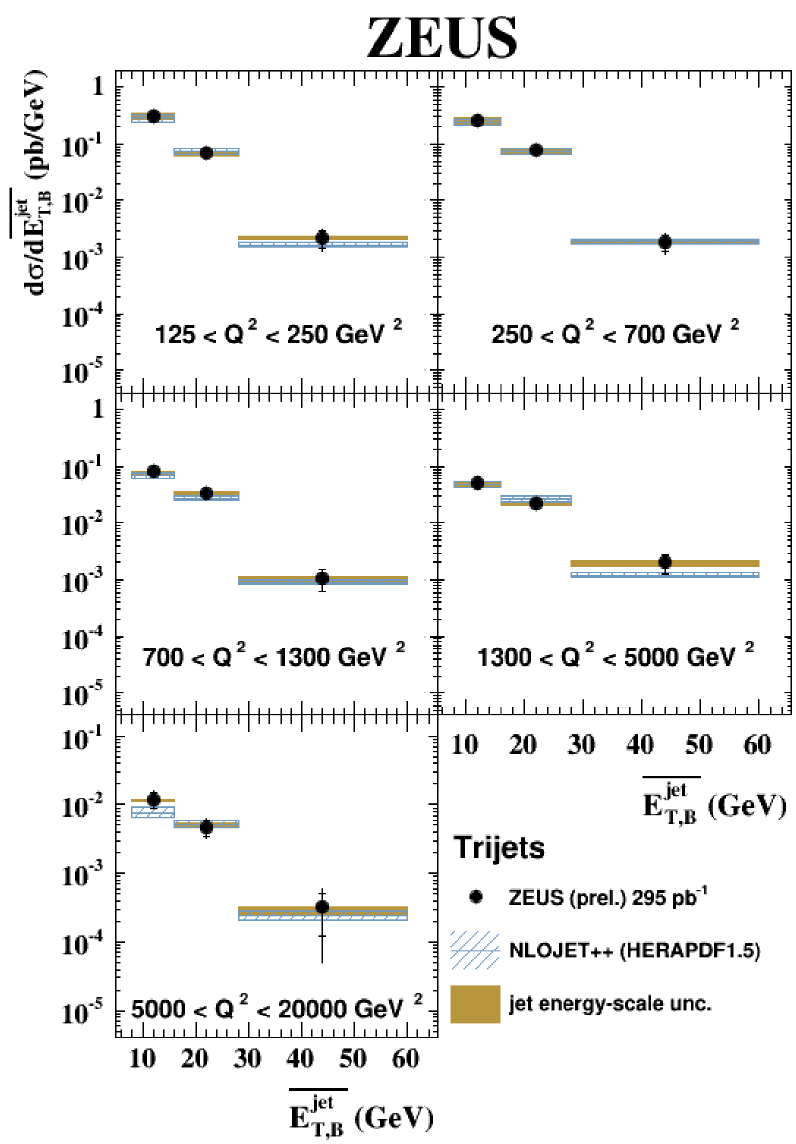
- pPDF: HERAPDF1.5
- $\mu_R^2 = Q^2 + \langle E_t^{jet} \rangle^2$
- $\mu_f^2 = Q^2$

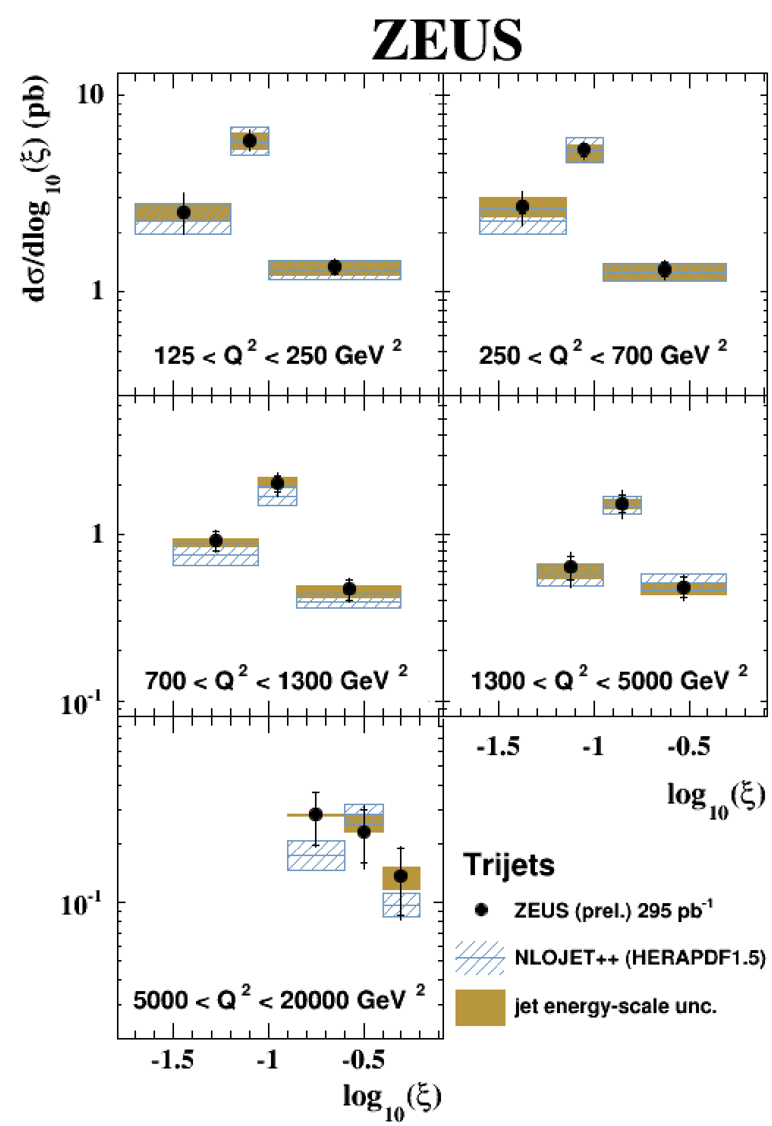




ZEUS trijet measurements

Double differential cross sections





Good agreement between data and NLO calculations

QCD Instantons

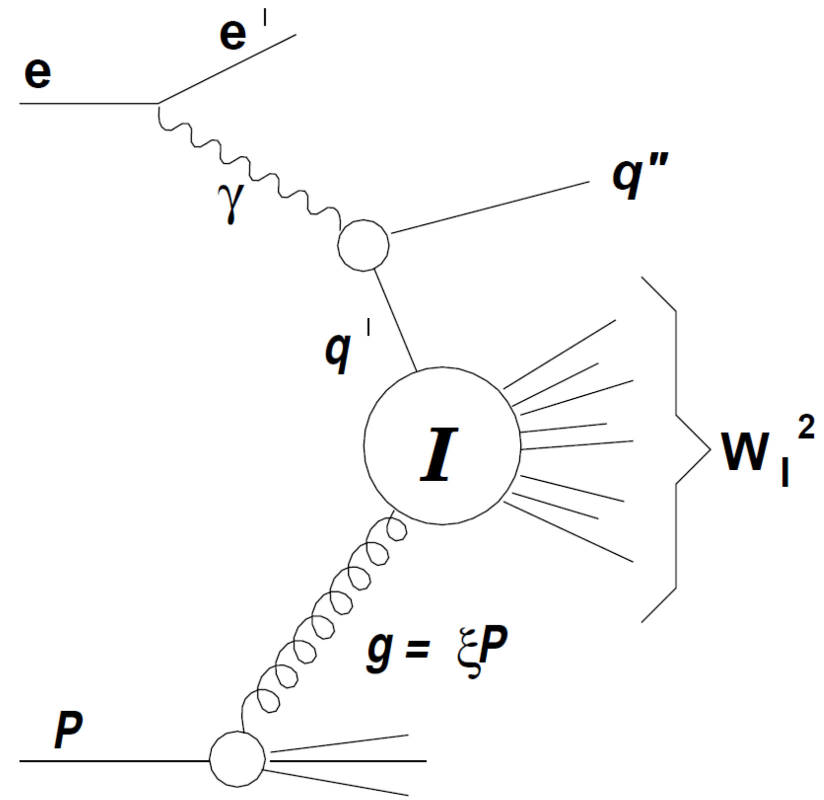
Instantons
- **Solutions to Yang-Mills equations of motion**
- **Physical interpretations:**
  pseudo particle **or** ***tunneling process between topologicaly different vacuum states***

QCD Instantons at HERA
- **Produced in quark-gluon fusion***
- **Analysis phase space:**

$$150 < Q^2 < 15000 \text{ GeV}^2$$
$$0.2 < y < 0.7$$

- **QCDINS Monte Carlo: access to full event topology**

Selected Signatures
- **One hard jet**
- **Densely populated eta band, flat in φ**
- **Large particles multiplicities**



Variables of I-subprocess:

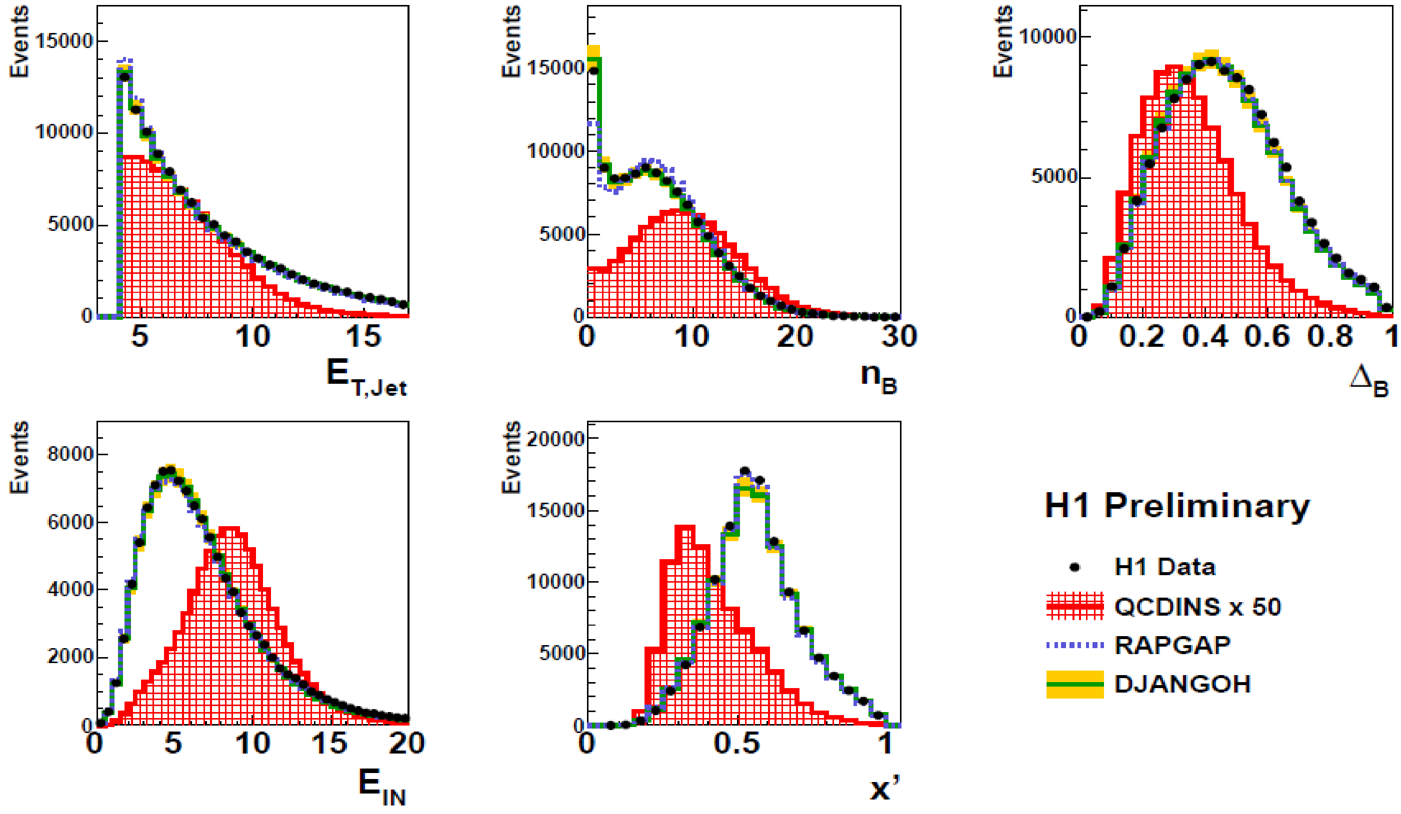
$$Q'^2 \equiv -q'^2 = -(\gamma - q'')^2$$
$$x' \equiv Q'^2 \,/\, (2\, g \cdot q')$$
$$W_I^2 \equiv (q' + g)^2 = Q'^2 \,(1 - x')/x'$$

*S. Moch, A. Ringwald, F. Schrempp, Nucl Phys. B 507 (1997) 134 [hep-ph/9609445],
A. Ringwald, F. Schrempp, Phys. Lett. B 438 (1998) 217 [hep-ph/9806528],
A. Ringwald, F. Schrempp, Phys. Lett. B 459 (1999) 249 [hep-ph/9903039].

QCD Instantons - strategy

Strategy I

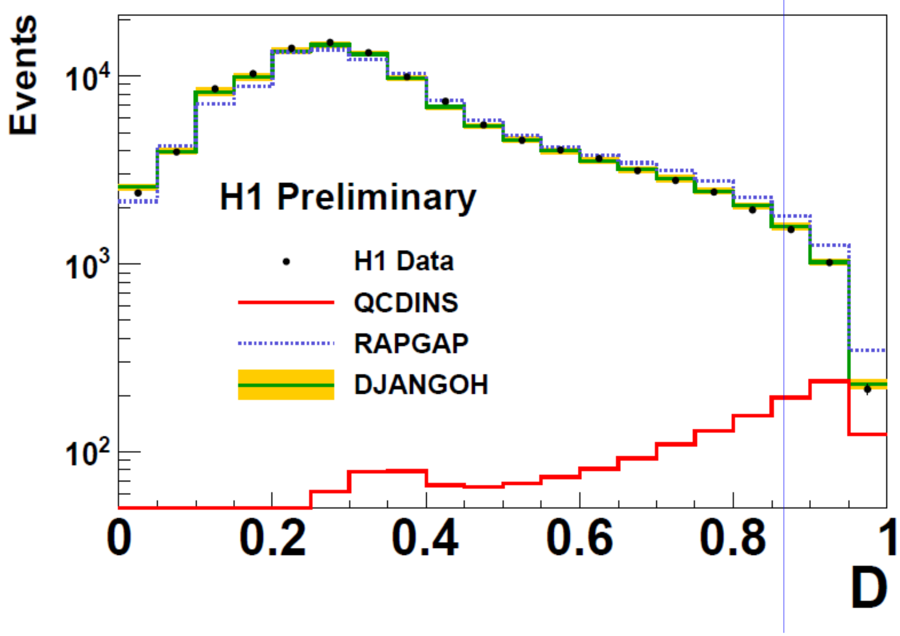
- **Find jets in hadronic center of mass frame**
  - **Remove hardest jet from objects of hadronic final state (HFS)**
- **Boost to instanton rest frame and define variables**
  - **Topological: sphericity, Fox-Wolfram moments, azimuthal isotropy (Δ_B), ...**
  - **Number of charged particles n_B**
  - **Transverse energy of the band...**
- **Variables are used as input to MVA**

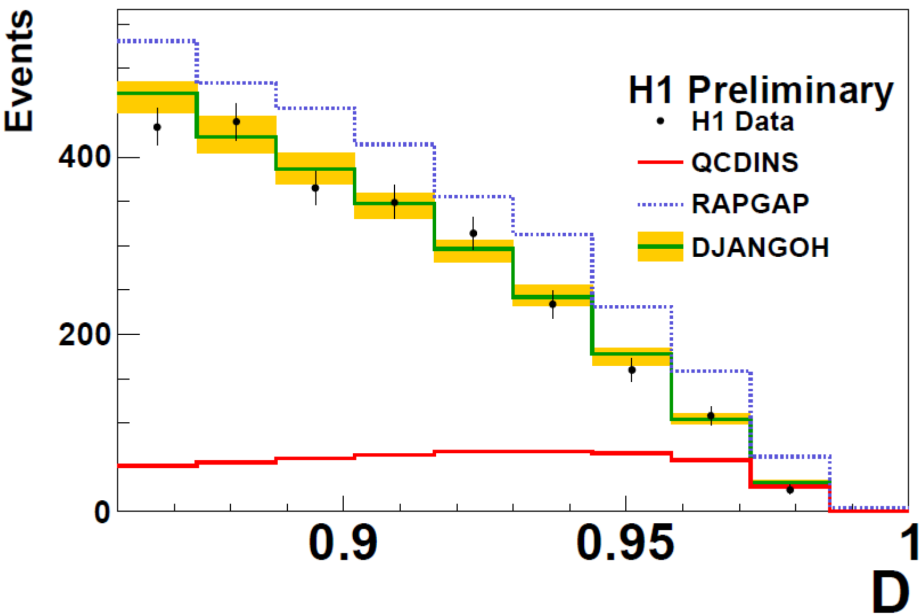


QCD Instantons - strategy

Multivariate Analysis

- **Probability density estimator with range search (PDERS)**
- **Training with Rapgap/Djangoh MC as background and QCDINS as signal MC**
- **Good discriminator description in the background region**
- **Signal region: D > 0.86**



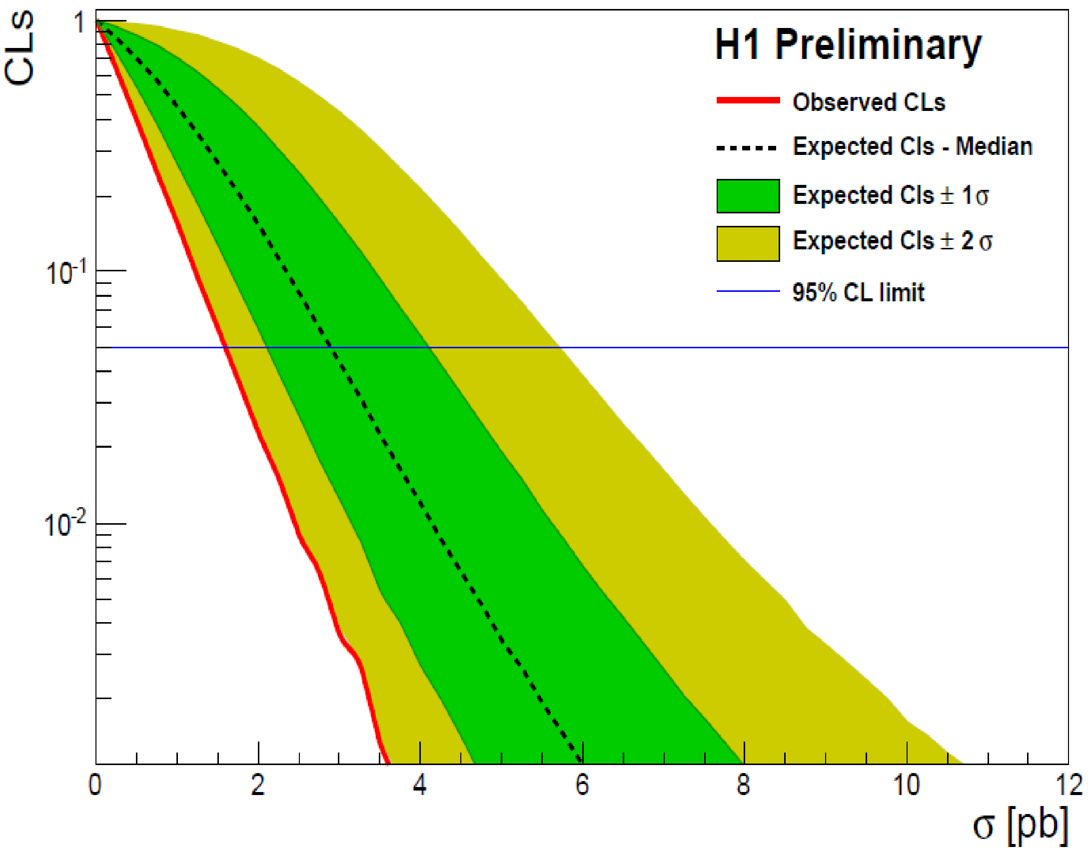


QCD Instantons - results

Data are *consistent with background*
No evidence for QCD Instantons

Limit calculations

- **CL_s method used**
- **Input for limit calculations:**
  QCD Instanton cross section
  Uncertainties: systematic and model
- **Full range of the PDERS discriminator for better method reliability**



Theoretical prediction in the analysis phase space: **10±2 pb**

Upper limit for the instanton cross seciotn at 95%CL: **1.6 pb**

Exclusion of the Ringwald-Schrempp's predictions for the QCD Instantons at HERA

Summary

New interesting QCD results from the HERA experiments

Jet production in *ep* collisions at HERA and determination of α_s

- **ZEUS and H1 measurements consistent with NLO calculations**
- **Most precise $\alpha_s(M_Z)$ is extracted from fit to the normalised multijet cross section, yielding**

$$\alpha_s(M_Z)|_{k_T} = 0.1165\ (8)_{\text{exp}}\ (38)_{\text{pdf,theo}}$$

- **The running of $\alpha_s(\mu_r)$ consistent with the RGE and with results from other jet data**
- **Precision of the measurement (H1)is better than that of NLO calculations**

Need NNLO

QCD Instantons searches

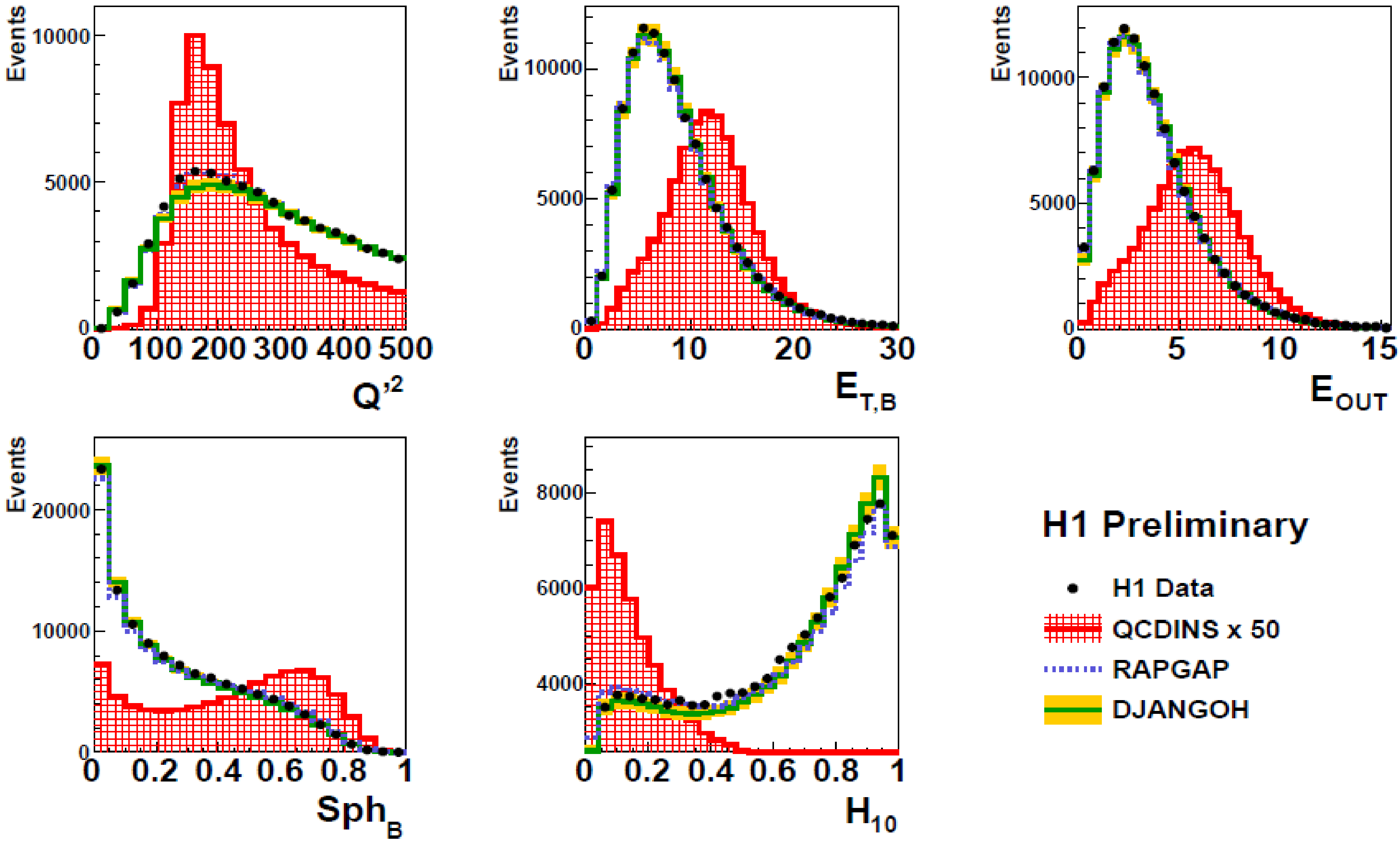
- **Ringwald-Schrempp's predictions for the QCD Instantons at HERA appears to be excluded**

Thank you for your attention

Backup slides

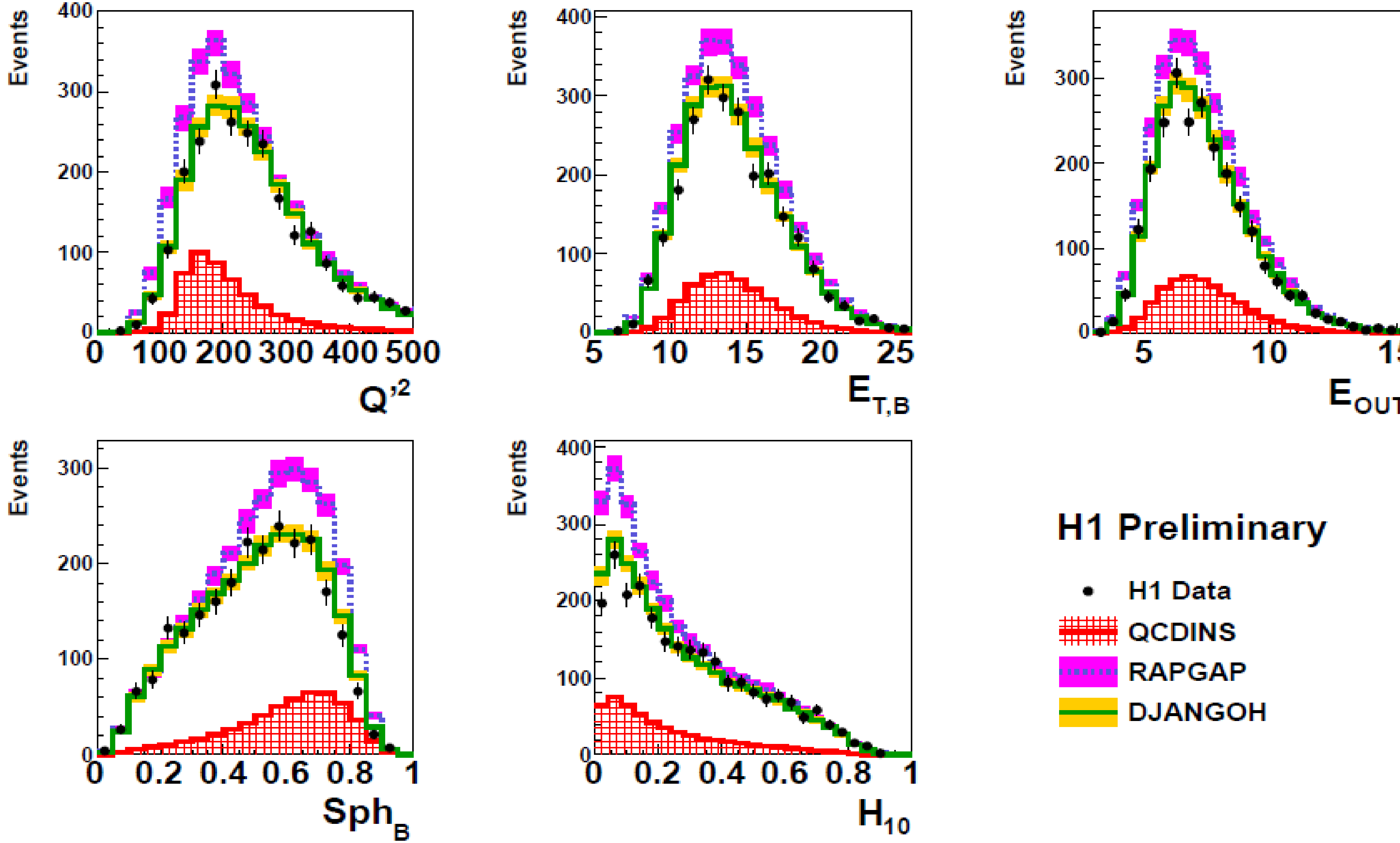
Observables not used in the TMVA training

Full range of the discriminator



Observables not used in the TMVA training

Signal range of the discriminator

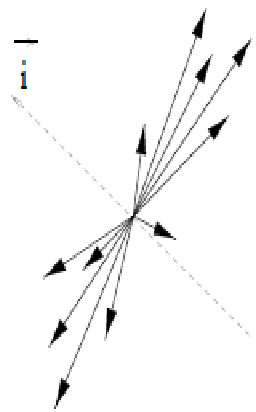


No excess of events in the signal region

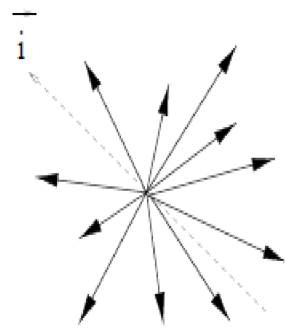
Azimuthal isotropy

$$\Delta_b = (E'_{in,B} - E'_{out,B}) \,/\, E'_{in,B}$$

$$E_{out} = \min \sum_{n\ Hadr.} |\, \vec{p_n} \cdot \vec{i}\, |$$
$$E_{in} = \max \sum_{n\ Hadr.} |\, \vec{p_n} \cdot \vec{i}\, |$$



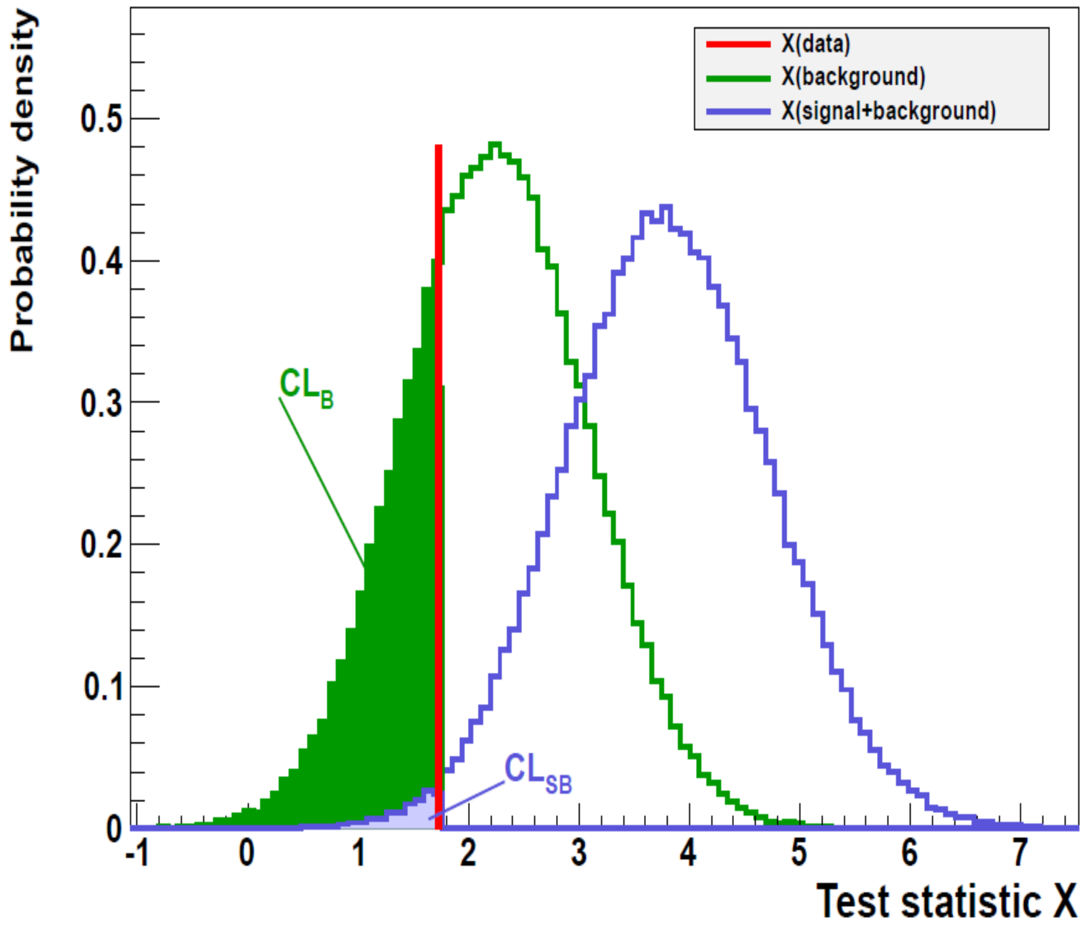
$\Delta_b \approx 1$



$\Delta_b \approx 0$

Test statistic distribution

Lets construct test statistics for Data, Background and Backgr+Signal



$$CL_S = \frac{CL_{SB}}{Cl_B}$$

$$\textit{Confidence Level}: CL = 1 - CL_S$$