Search for QCD Instanton-Induced Processes in DIS at HERA

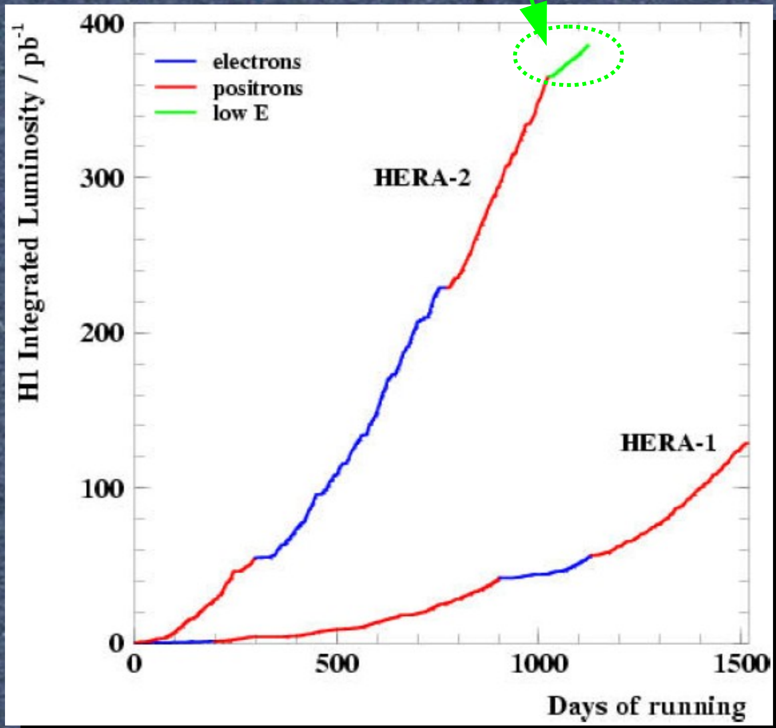
Hayk Pirumov
on behalf of the H1 Collaboration

ISMD 2015, Wildbad Kreuth, 06.10.2015

Introduction

HERA, worlds only *ep* collider, located at DESY, Hamburg

- HERA I: 1992 – 2000
- HERA II: 2003 – 2007
  - Low proton energy runs in the end of HERA operation



Two collider experiments H1 and ZEUS

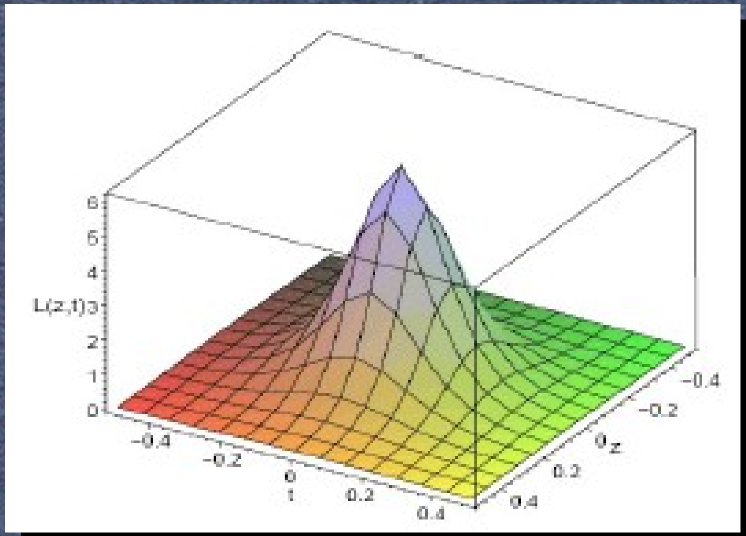
- Collected ~0.5 fb^{-1} of data per experiment

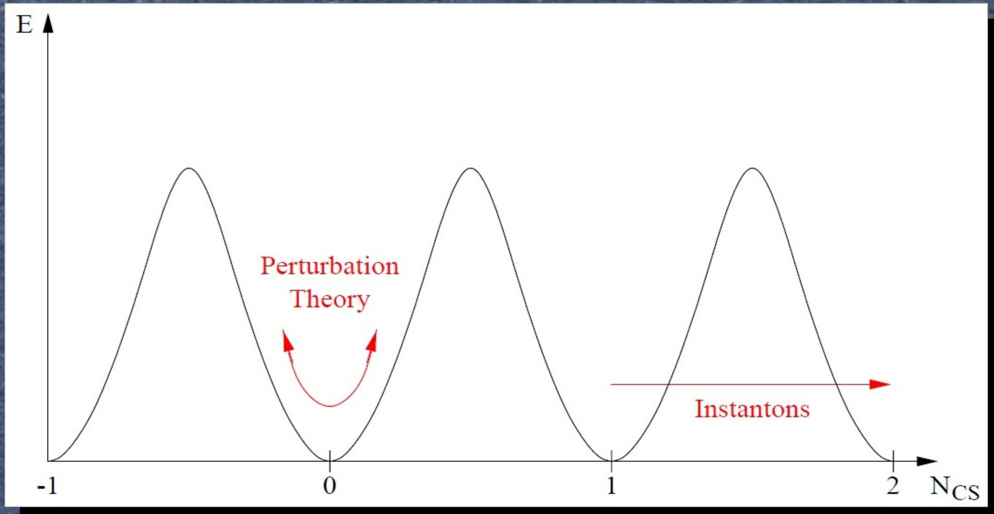
Presented analysis is based on HERA II data

- about 0.4 fb^{-1}

Instantons

- Instantons: non-perturbative fluctuation of the gauge fields
- Physical interpretation: pseudo-particle or tunneling process between topologically different vacuum states



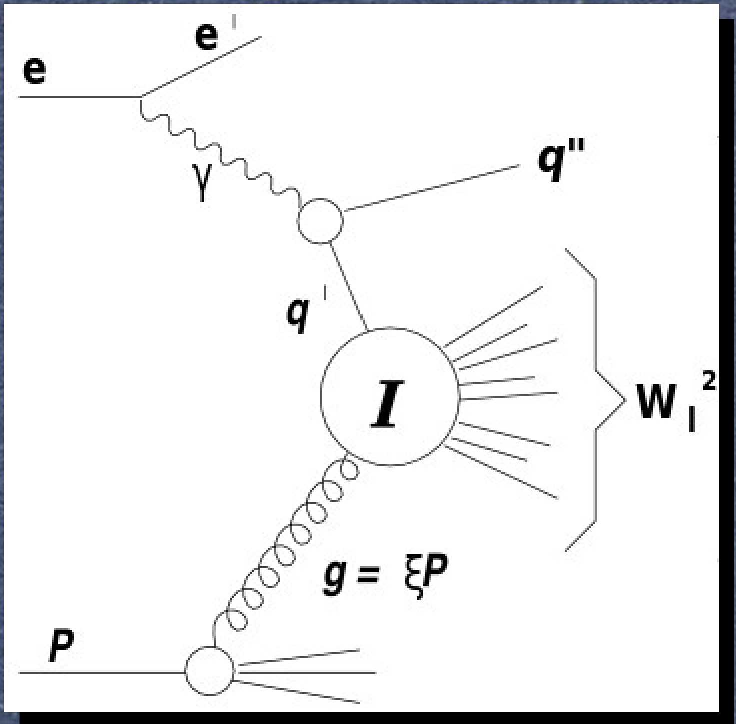


- In Standard Model, instantons induce anomalous processes violating conservation of baryon and lepton number in EW and chirality in QCD
- Cross-section for instanton induced processes $\sim e^{-4\pi/\alpha}$ (α-coupling constant)

QCD Instantons in DIS at HERA

- Instanton-induced events produced in quark-gluon fusion
- Theory and phenomenology workout out by A.Ringwald and F.Schrempp
- QCDINS Monte Carlo generator makes full event topology available
- Sizable cross section in part of the phase space where perturbative calculations are expected to hold:

$$\boxed{\begin{array}{c} 0.1 \leqslant y_{Bj} \leqslant 0.9, \quad x_{Bj} \geqslant 10^{-3} \\ Q^2 > Q'^2_{min} \approx 113\,\mathrm{GeV}^2, \quad x' > 0.35 \end{array}}$$



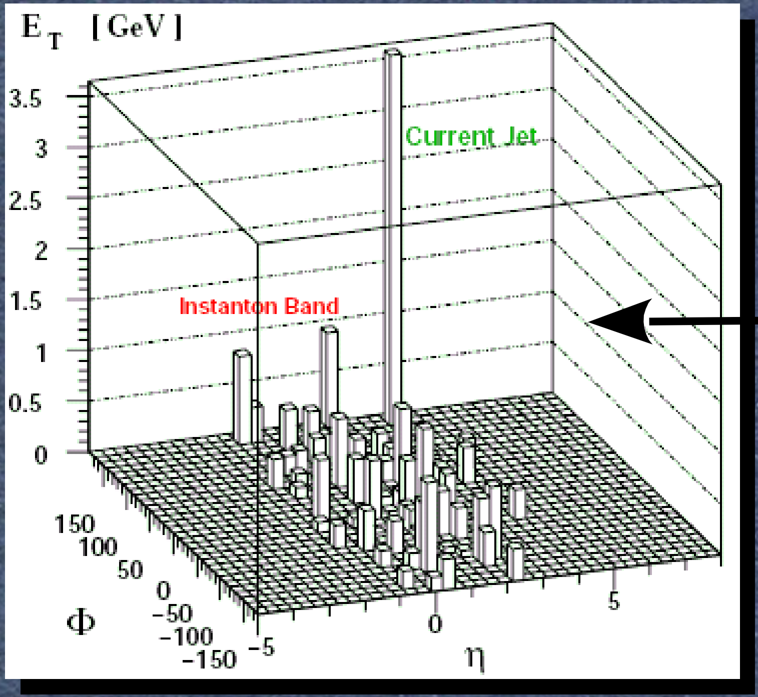
Variables of instanton subprocess:

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

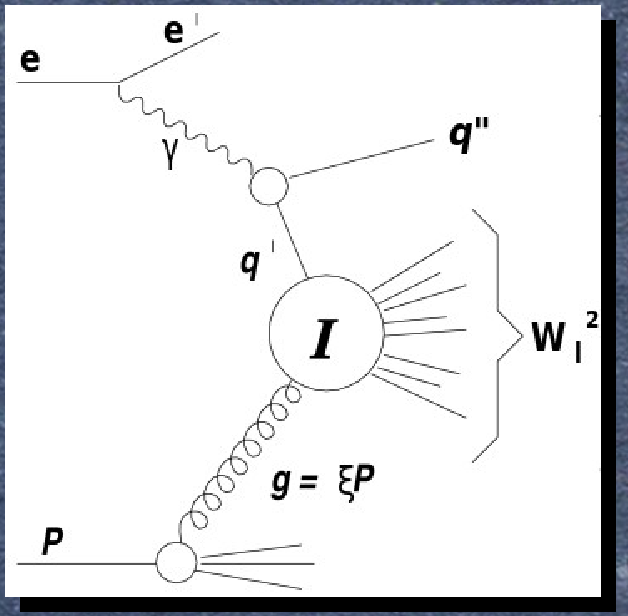
S. Moch, A. Ringwald, F. Schrempp, Nucl Phys. B 507 (1997) 134 [hep-ph/9609445],
A. Ringwald, F. Schrempp, Phys. Lett. B 438 (1998) 217 [hep-ph/9806528],
A. Ringwald, F. Schrempp, Phys. Lett. B 459 (1999) 249 [hep-ph/9903039].

Expected experimental signature

- Hard "current" jet
- Densely populated narrow I-band, flat in phi from isotropic parton decay in instanton rest frame
- Large total E_T
- Large particle multiplicities



"Typical event"
(η – Φ) plane, hadronic cms



Variables of instanton subprocess:

$$Q'^2 \equiv -q'^2 = -(\gamma - q'')^2$$

$$x' \equiv Q'^2 \;/\; (2\, g \cdot q')$$

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

Event Selection

DIS selection

- $150 < Q^2 < 15000$ GeV^2,
- $0.2 < y < 0.7$

Tracks Selection

- $P_T > 0.12$ GeV,
- $20° < \theta < 160°$

Jet Selection

- Inclusive kT algorithm in HCMS frame
- $P_T > 3$ GeV
- Jets boosted to LAB:
  - $P_{T,\,jet} > 2.5$ GeV
  - $-1 < \eta < 2.5$

Selected data sample:

- **~358 pb^{-1}**

Monte Carlos used

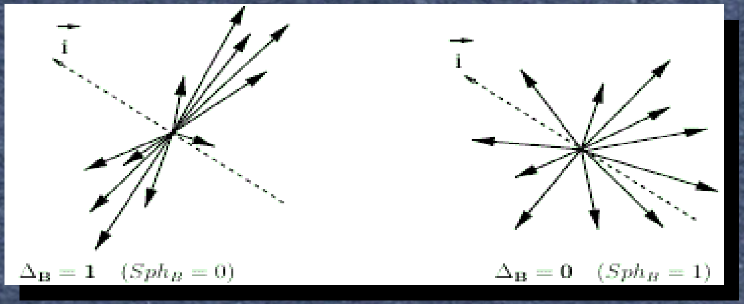
- Background: **Djangoh** and **Rapgap**
- Signal: **QCDINS**

A. Ringwald, F. Schrempp,[hep-ph/9911516], Comput. Phys. Commun. ***132*** *(2000) 267*
http://www.desy.de/t00fri/qcdins/qcdins.html

Observables and Analysis Strategy

- To separate signal from background a root package: Toolkit for MultiVariate Analysis (TMVA) is used.
- A set of five observables ($E_{T,\,jet}$, n_B, Δ_B, E_{IN}, x') is selected with good S/B separation and relatively good discriminator's background region description. Observables:
  - Transverse energy of the jet $E_{T,jet}$
  - n_B number of charged particles in band
  - Topological observables: E_{in}, E_{out}, isotropy Δ_B

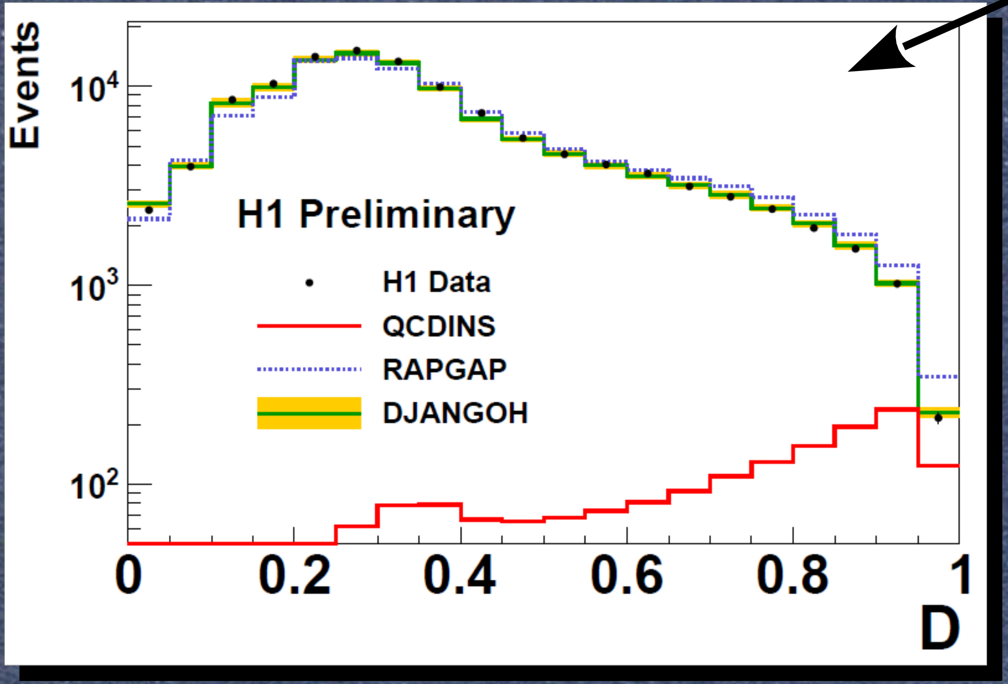
$$\boxed{\begin{gathered} E_{IN} = \sum_h |\vec{p}_h \cdot \vec{i}_{max}| \\ E_{OUT} = \sum_h |\vec{p}_h \cdot \vec{i}_{min}| \\ \Delta_B = (E_{IN} - E_{OUT}) / E_{OUT} \end{gathered}}$$

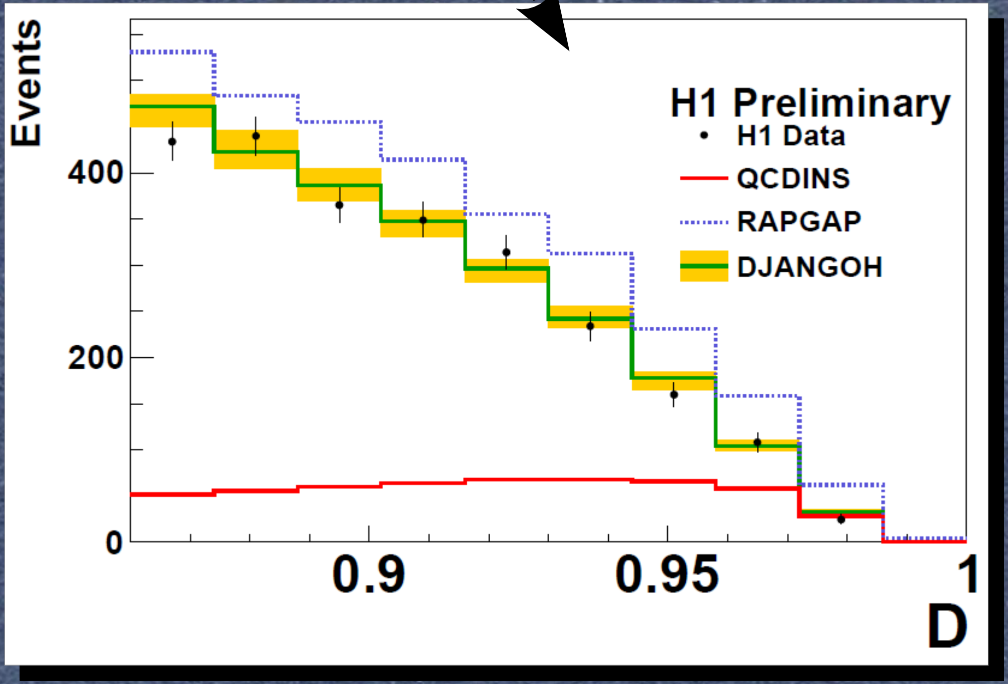


- A PDERS method (probability density estimator with range search) is selected.
- Training was done for both background MCs separately but for further analysis only Djangoh is used.

Multi Variate Analysis

Distributions of the PDERS discriminator in its full and signal region



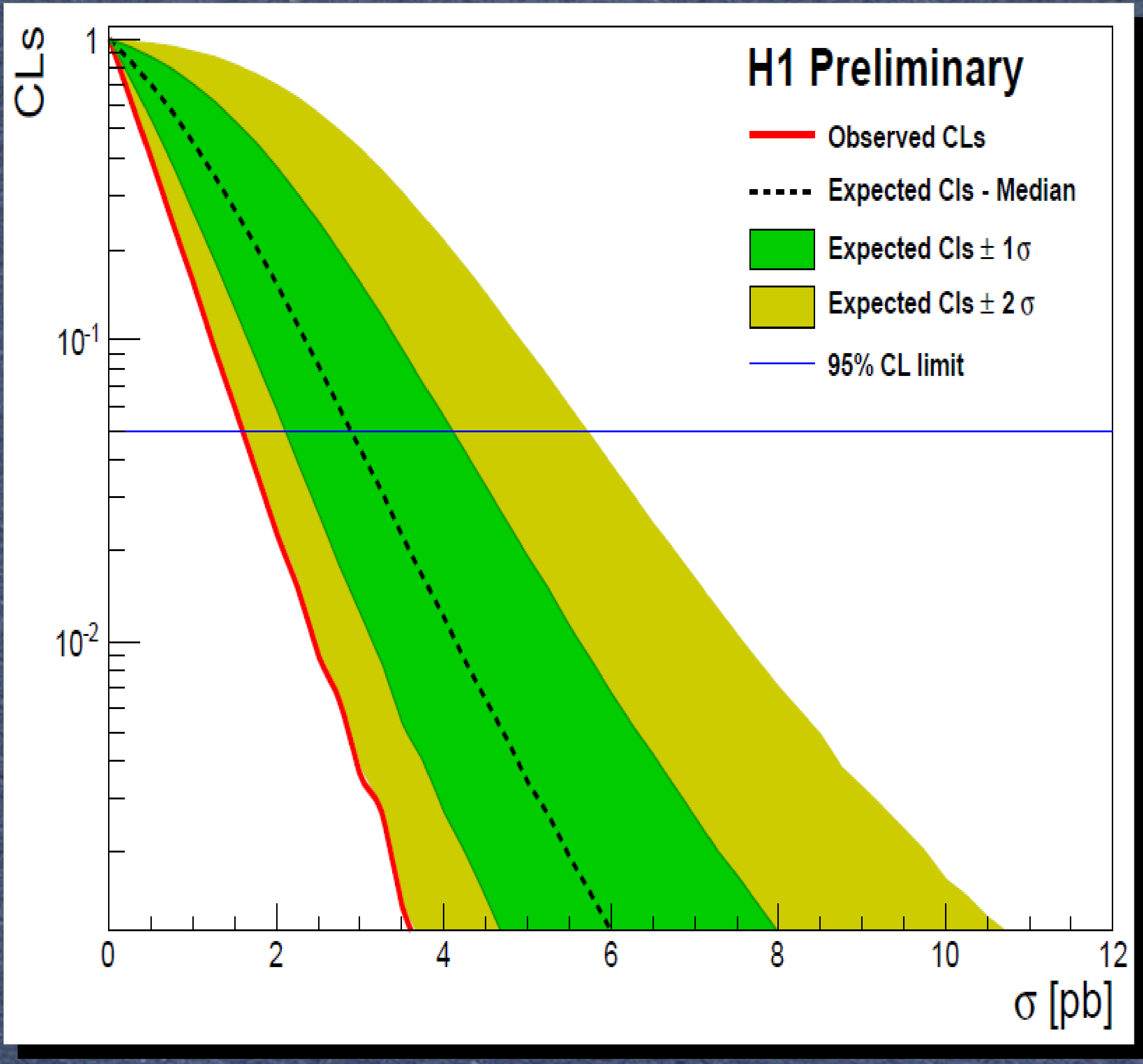


- Good description of data by DJANGOH in backgroundand signal regions
- RAPGAP systematically above data in the signal region $D > 0.86$

No signal observed

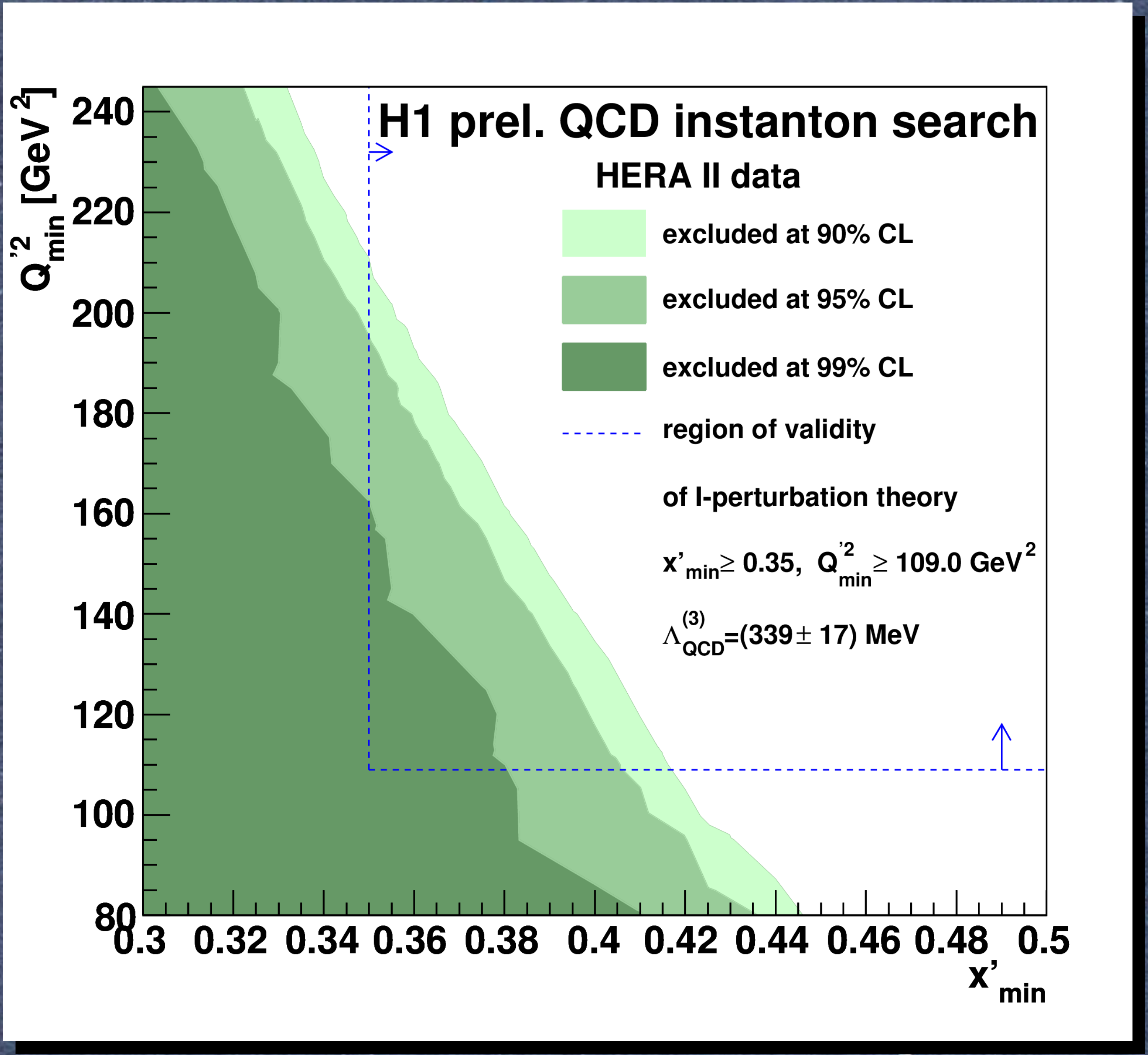
Upper Limits

- QCDINS predicted cross sections in the analysis phase space: *10±2* pb
- CL_S method used to calculate upper limit
- Full range discriminator distribution is used
- Difference between background MCs considered as model uncertainty
- 20% uncertainty of predicted signal cross section due to Λ_{QCD} uncertainty



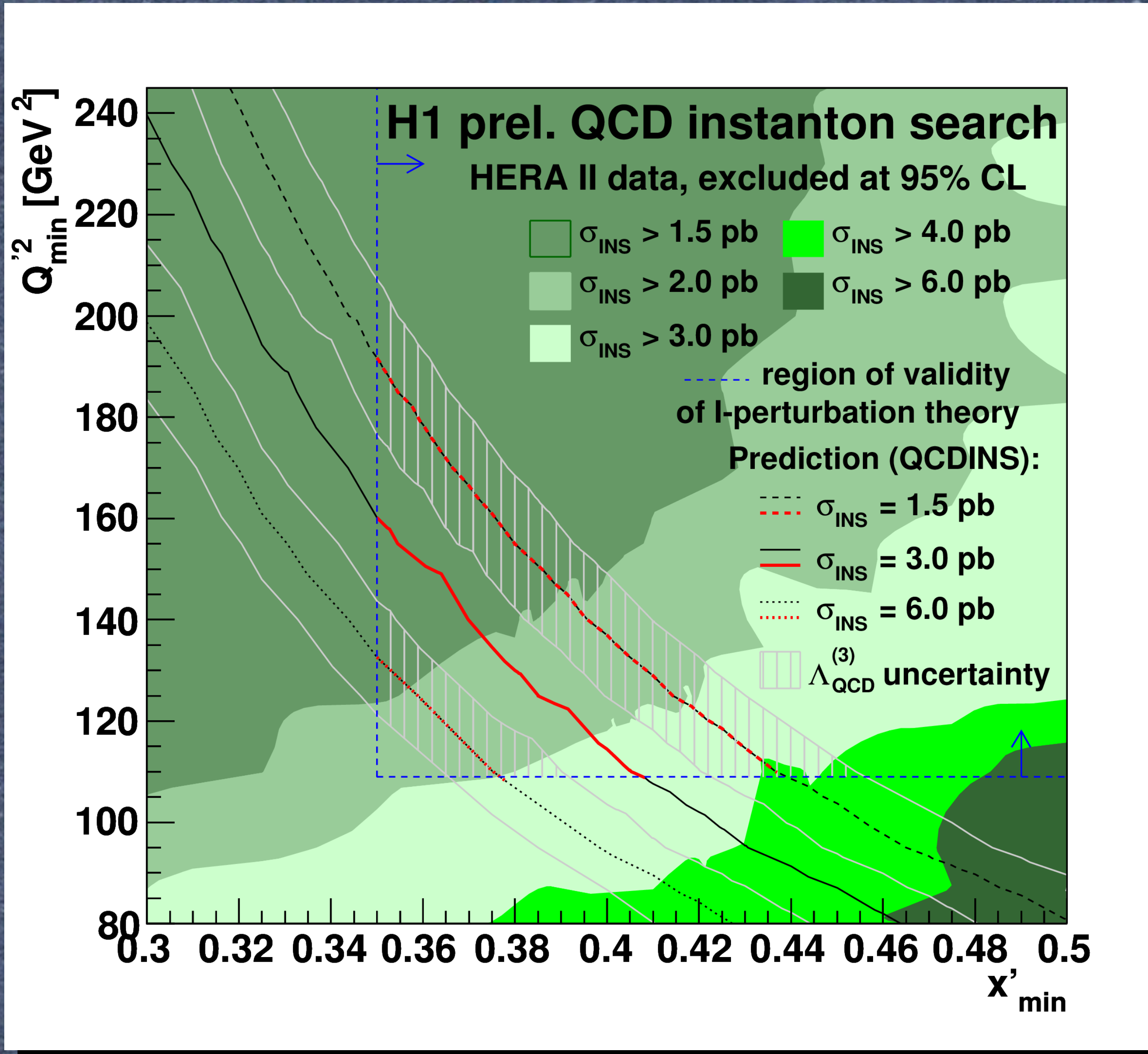
Observed Upper Limit: 2 pb at 95% CL

Exclusion Limits



- Instanton production exclusion limits as a function of parameters Q'^2_{min} and x'_{min}

Upper limits on Instanton Cross Section at 95% CL



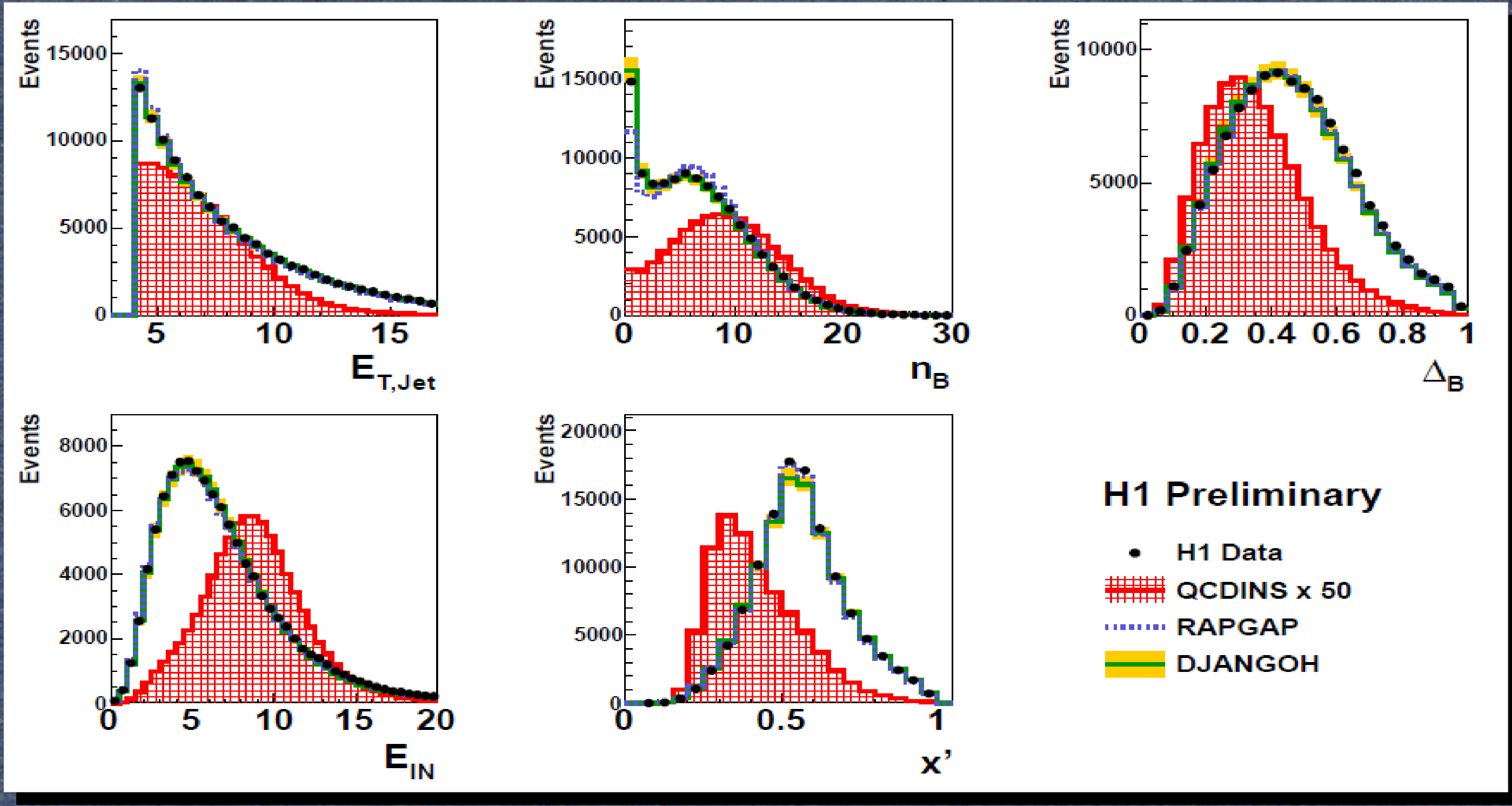
- Upper limits on instanton production cross section at *95%* CL. are set as function of parameters Q'^2_{min} and x'_{min}.
- Fixed predicted instanton cross-section and the effects of varying the QCD scale by its uncertainty are presented by lines.
- Most stringent exclusion limits σ_{lim}~1.5 pb observed for large Q'^2_{min} and small x'_{min}
- For increasing x'_{min} limits become weaker

Summary

- The discovery of instantons would be the first evidence for topological fluctuations of a non-perturbative aspect of QCD
- H1 performed searches in high Q^2 regime for instanton-induced DIS processes predicted by A. Ringwald and F. Schrempp
- No evidence for QCD instanton induced processes is observed
- In nominal kinematic region $x' > x'_{min} = 0.35$ and $Q'^2 > Q'^2_{min} = 113$ GeV^2 upper limit 2 pb is set on instanton cross section at 95 % CL and corresponding predicted cross section 10 pb is excluded
- Exclusion limits on Q'^2-x' plane in terms $Q'^2 > Q'^2_{min}$, $x' > x'_{min}$ are calculated
  - Part of kinematic region is excluded
  - Upper limits on the cross section between 1.5 pb and 6 pb at 95% CL are set, depending on the kinematic domain

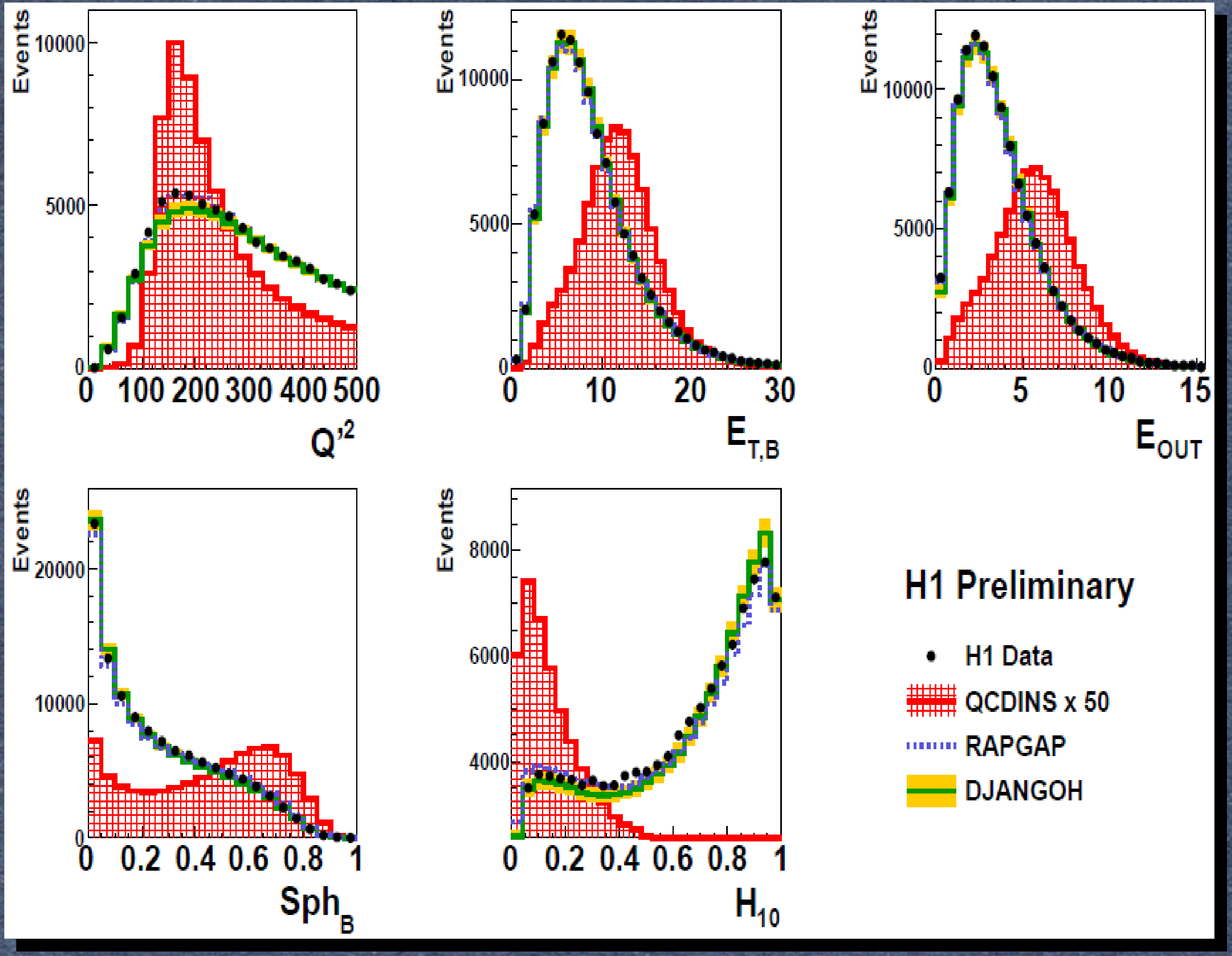
Backup

Observables used for TMVA training



Background models describe data within 5-10%
At very low and/or very large values the difference up to 20%.

Observables NOT used for TMVA training



Observables NOT used for TMVA training