XII. International Workshop on Deep-Inelastic Scattering and Related Subjects

DIS 2014

Search for QCD Instantons with the H1 experiment at HERA

Paweł Sopicki
IFJ PAN

On behalf of the H1 Collaboration

Warsaw 29.04.2014

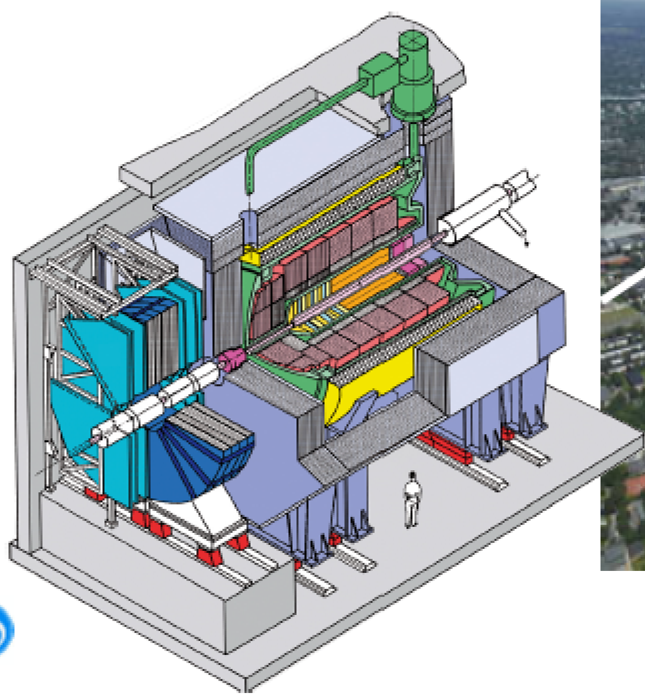
Outline

- Introduction
- Events Selection
- Analysis Strategy
- Observables and Multi Variate analysis
- Upper Limits Calculations
- Summary

HERA

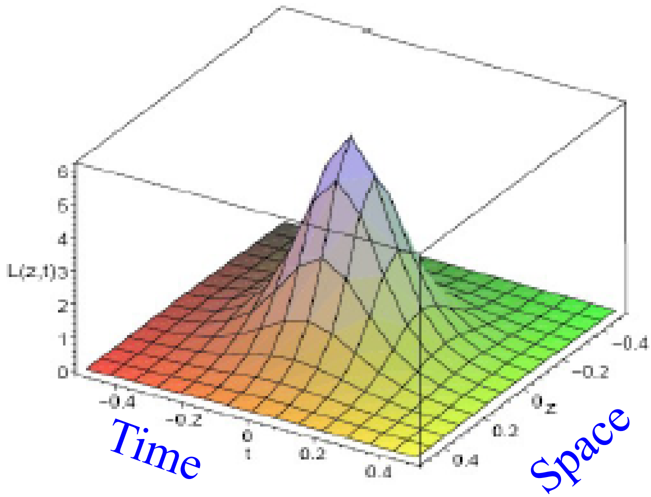
The HERA ep collider 1992-2007:

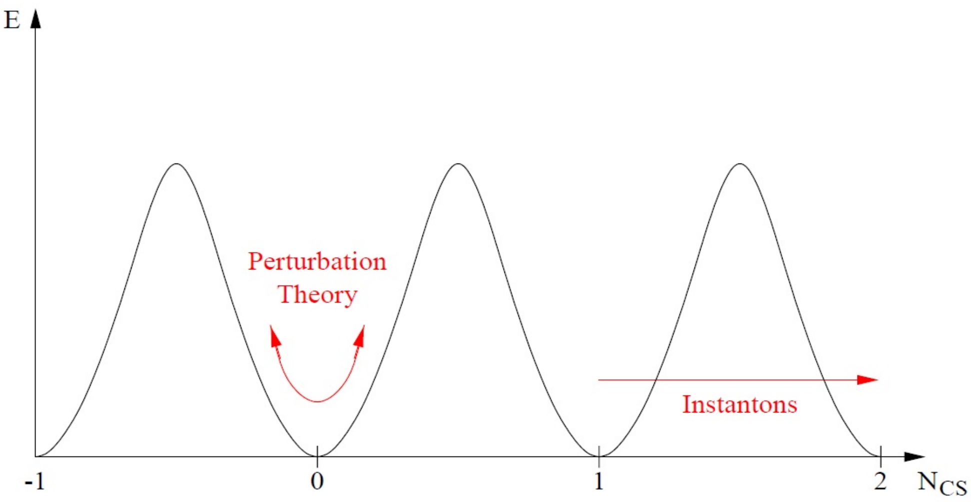
- $e^{\pm}$ energy: 27.6 GeV   and p energy: 920 GeV
- Center of mass energy: 319 GeV
- 2 collider experiments: H1 and ZEUS
- Integrated luminosity: ~0.5 fb^{-1} (per experiment)



Instantons

- Solution to Yang-Mills equation of motion in 4d Euclidean spacetime as a longrange fields A_μ with finite action $S(A_\mu) < \infty$
- Physical interpretations: pseudo-particle or tunneling process between topologicaly different vacuum states





- Lead to violations of baryon-lepton number (in EW) and chirality (QCD)
- Non-perturbative effect with cross section $\sim e^{-4\pi/\alpha}$ (α-coupling constant)

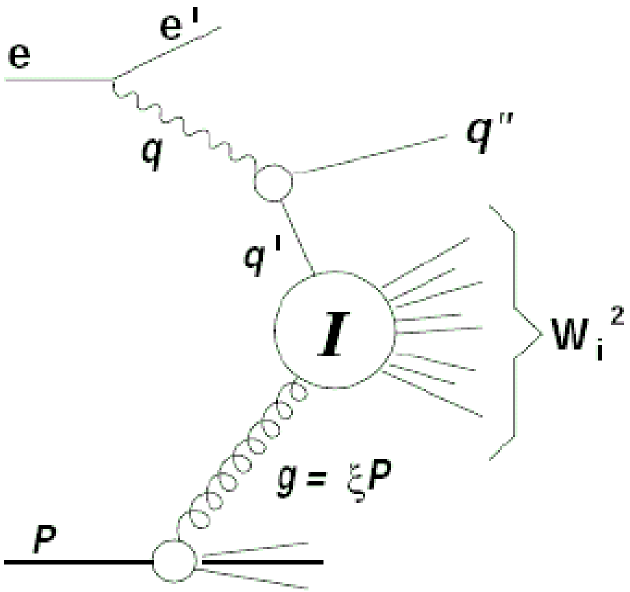
QCD Instantons
& HERA

QCD Instantons

- Instanton-induced events produced in quark-gluon fusion
- Theory and phenomenology worked out by A. Ringwald and F. Schrempp
- QCDINS Monte Carlo generator makes full event topology available
- Suggested phase space:

$$x_{Bj} \geqslant 10^{-3}, \quad 0.1 \leqslant y_{Bj} \leqslant 0.9$$

$$Q^2 > Q'^2_{min} \approx 113\, GeV^2, \quad x' > 0.35$$



Variables of I-subprocess:

$$Q'^2 = -q'^2 = -(q - q'')^2$$

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

$$W_i^2 = Q'^2\; (1 - x'\;)/x'$$

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
& HERA

Selected QCD Instantons

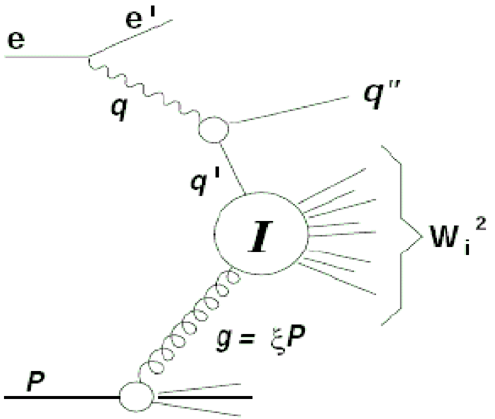
Signatures

Variables of I-subprocess:

$$Q'^2 = -q'^2 = -(q - q'')^2$$

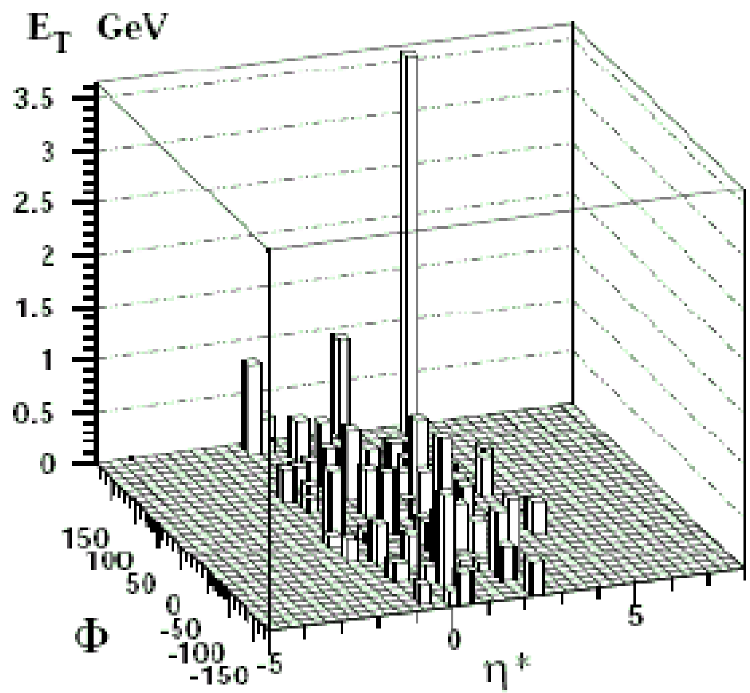
$$x' = Q'^2 \;/\; (2\, g \cdot q')$$

$$W_i^2 = Q'^2\;(1 - x'\;)/x'$$



- Hard Jet
- Densely populated narrow band, flat in phi from isotropic parton decay in Instanton-rest system
- Large total E_t
- Large particle multiplicities

'Typical event'
(η, ϕ) – plane: hadronic CMS



Events Selection

DIS selection

$150 < Q^2 < 15000\ \mathrm{GeV}^2$

$0.2 < y < 0.7$

Tracks Selection

$P_T > 0.12$ GeV

$20^o < \theta < 160^o$

Selected sample: *~358 pb^{-1}*

Jet Selection

Inclusive kT algorithm in HCMS frame

$P_T > 3$ GeV

Jets boosted to LAB:

$P_{T,\,jet} > 2.5$ GeV

$-1 < \eta_{jet} < 2.5$

Monte Carlos used

Background:

Djangoh (*CDM*) and
Rapgap[*DGLAP(MEPS)*]

Signal: QCDINS

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

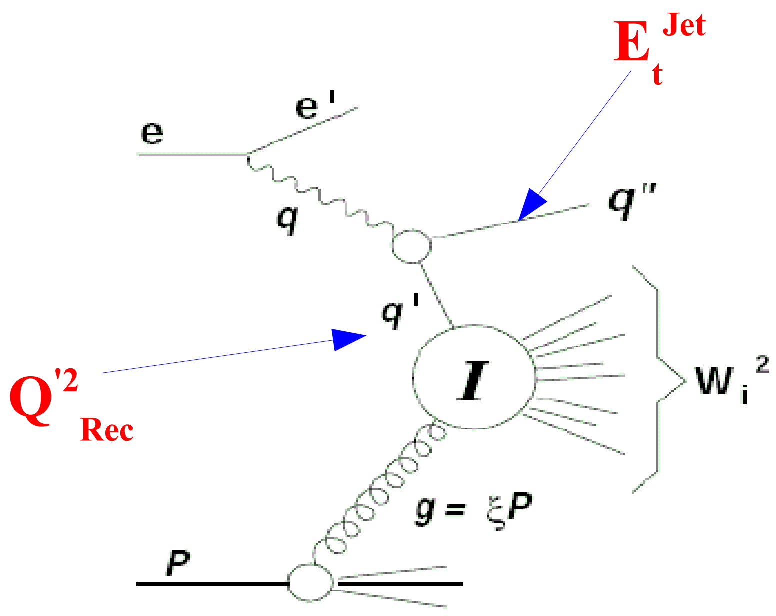
Analysis strategy

I. DIS Selection

II. Jet level

- Jet selection
- HCMS: find current jet (**E_t^{Jet}**, **Q'^2_{Rec}**) and remove its objects from HFS

  current jet requirements:
  - Maximal E_t and E_t > 4GeV
- Calculate **<η>** of HFS and define „instanton band" as objects within <η> +/- 1.1



Analysis strategy

I. DIS Selection

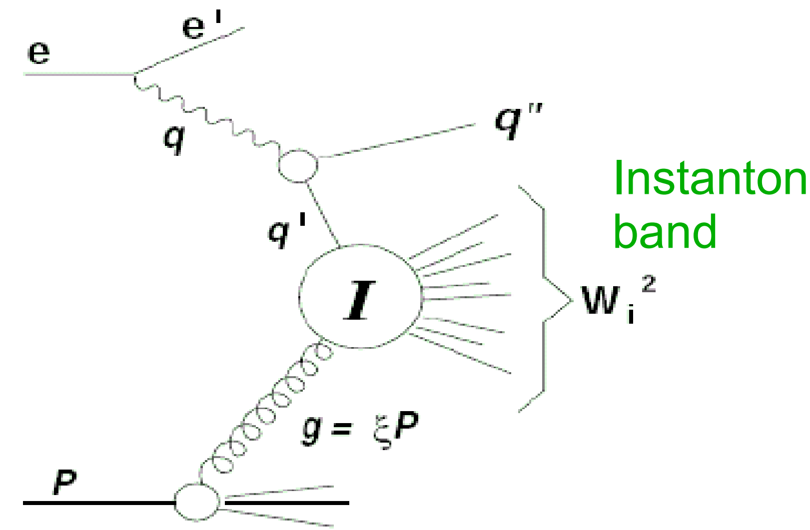
II. Jet level

III. Instanton level

- Boost HFS objects from „instanton band" to „instanton rest frame"

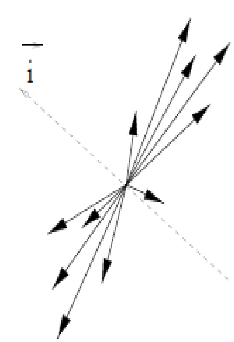
$$q' + \xi P = 0 \,,\ \xi = \langle \xi \rangle = 0.076$$

- Calculate observables
  - Transverse energy of the band $E_{T,B}$
  - n_B – number of charged particles in band
  - Topological observables: **Sphericity**, **Fox-Wolfram moments (H_{10}, ...)**, E_{In}, E_{out}, isotropy Δ_B

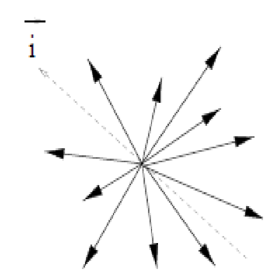


$$\Delta_b = (E'_{in,B} - E'_{out,B}) \,/\, E'_{in,B}$$

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



$\Delta_b \approx 1$



$\Delta_b \approx 0$

Observables and Multi Variate analysis

To separate signal from background a root package: Toolkit for MultiVariate Analysis (TMVA) has been used.

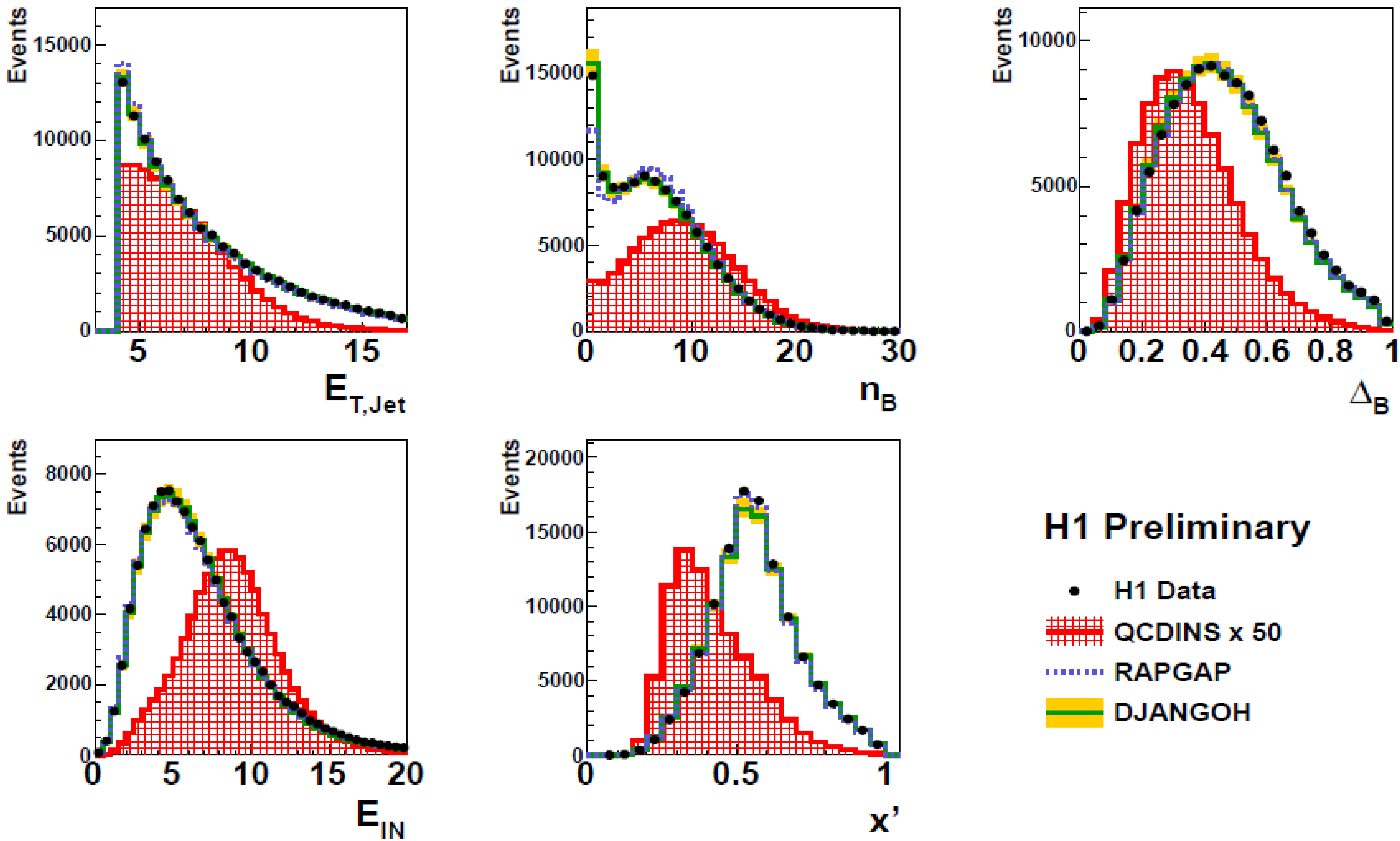
A set of five observables ($E_{T,jet}$, n_B, Δ_B, E_{IN}, x') has been selected with good S/B separation and relatively good discriminator's background region description

A PDERS method (probability density estimator with range search) has been selected and cross-checked with three other methods

Training was done for both background MCs separately but for further analysis only Djangoh has been used

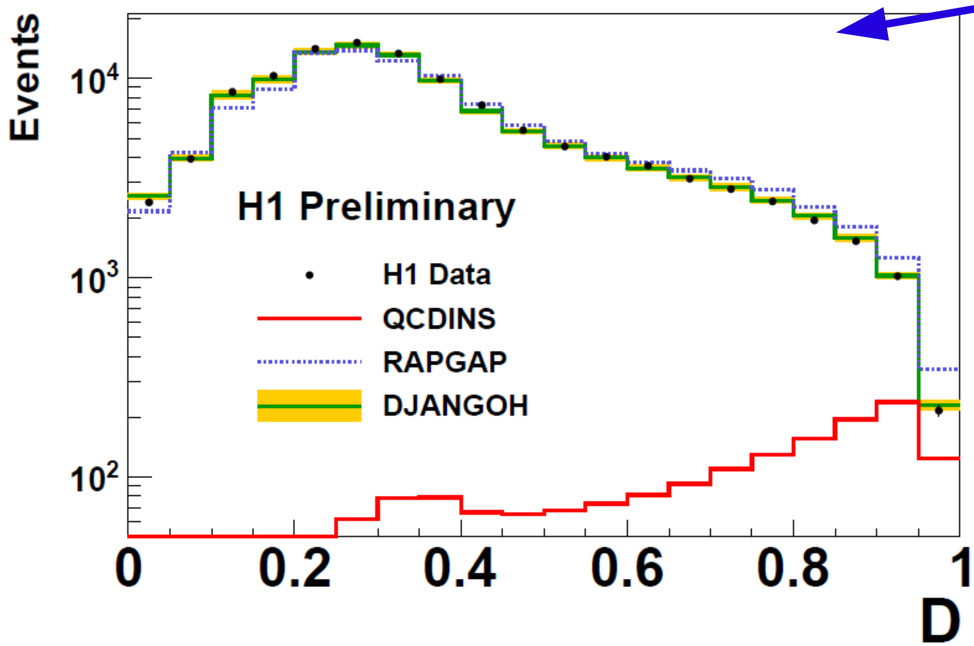
Observables

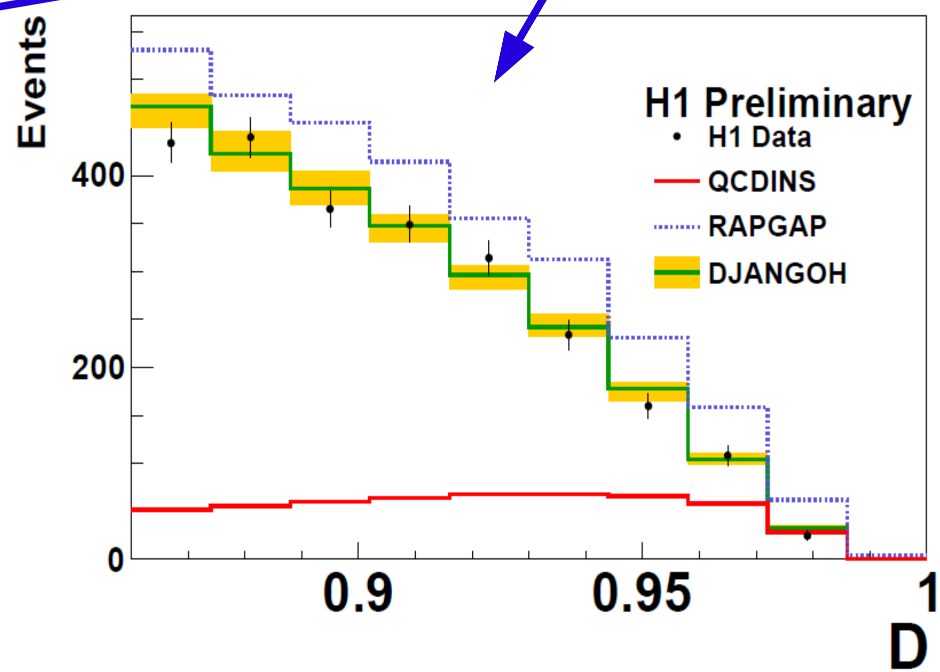
Distributions of observables selected for the TMVA training



Multi Variate Analysis

Distributions of the PDERS discriminator in its full and signal region



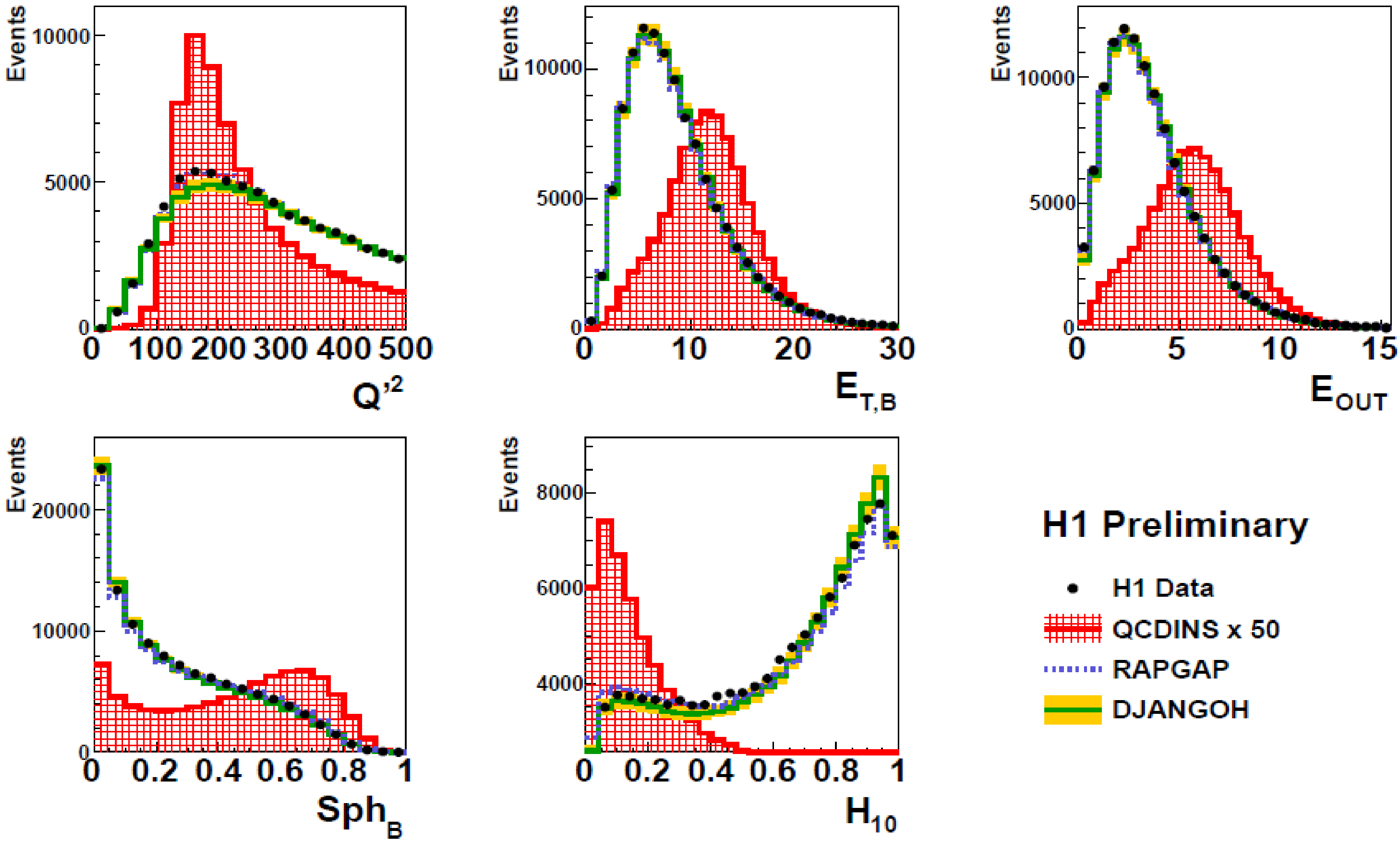


Quite good description of PDERS discriminator in the background region (5-10%)
Djangoh describes the signal region within 10%. Rapgap systematically above the data in the signal region.

Presented distributions are based on traning with Djangoh(CDM). Training with Rapgap leads to similar results.

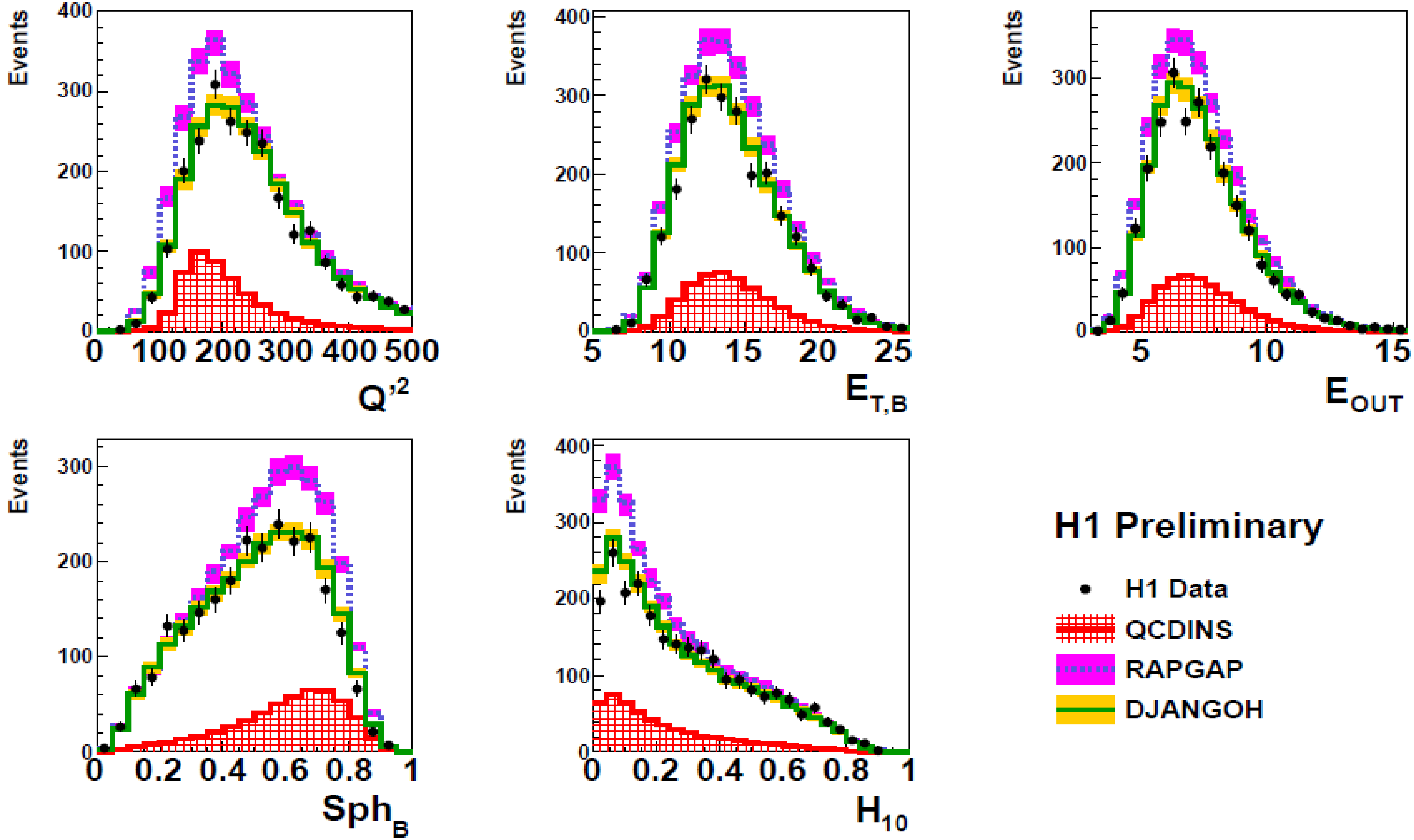
Observables not used in the TMVA training

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

Upper limits

QCDINS predicted cross section in the analysis phase space is:

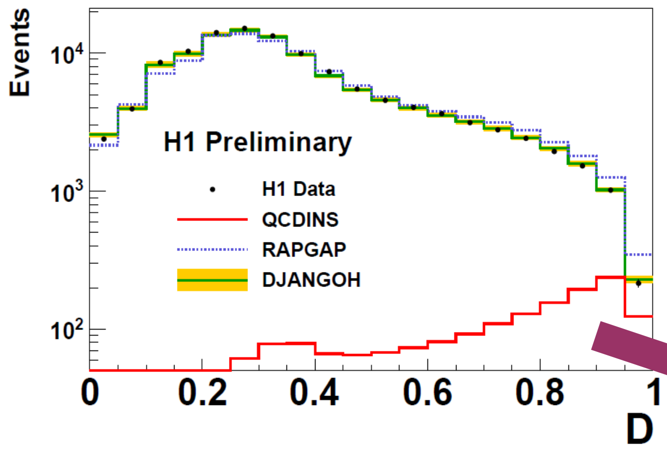
10 +/- 2 pb

For upper limit calculation a CL_s method has been used

For better CL_s method reliability full range discriminator distributions have been used

A difference between background MCs taken as the model uncertainty

Upper limits

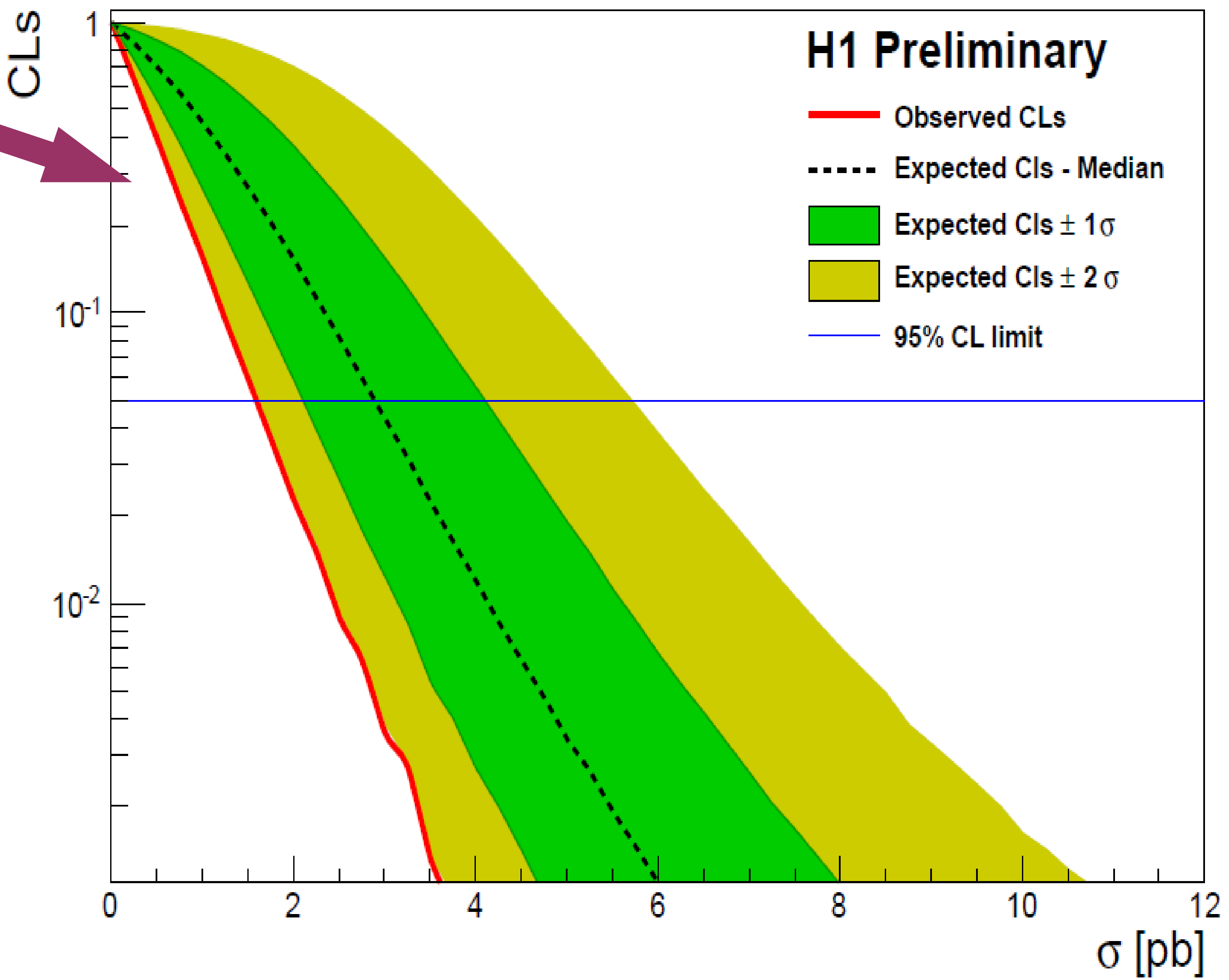


Confidence level distribution CLs

versus
upper limit on the instanton cross section

Upper limit on the instanton cross section at 95% CL :

1.6 pb



Summary

- A search for QCD instanton-induced processes in DIS events at HERA collider is presented

- In order to extract the expected signal a multivariate data analysis technique is used

- Data are consistent with background and no evidence for QCD Instantons is observed

- Observed upper limit on the HERA instanton-subprocess cross section of 1.6 pb at 95% CL.

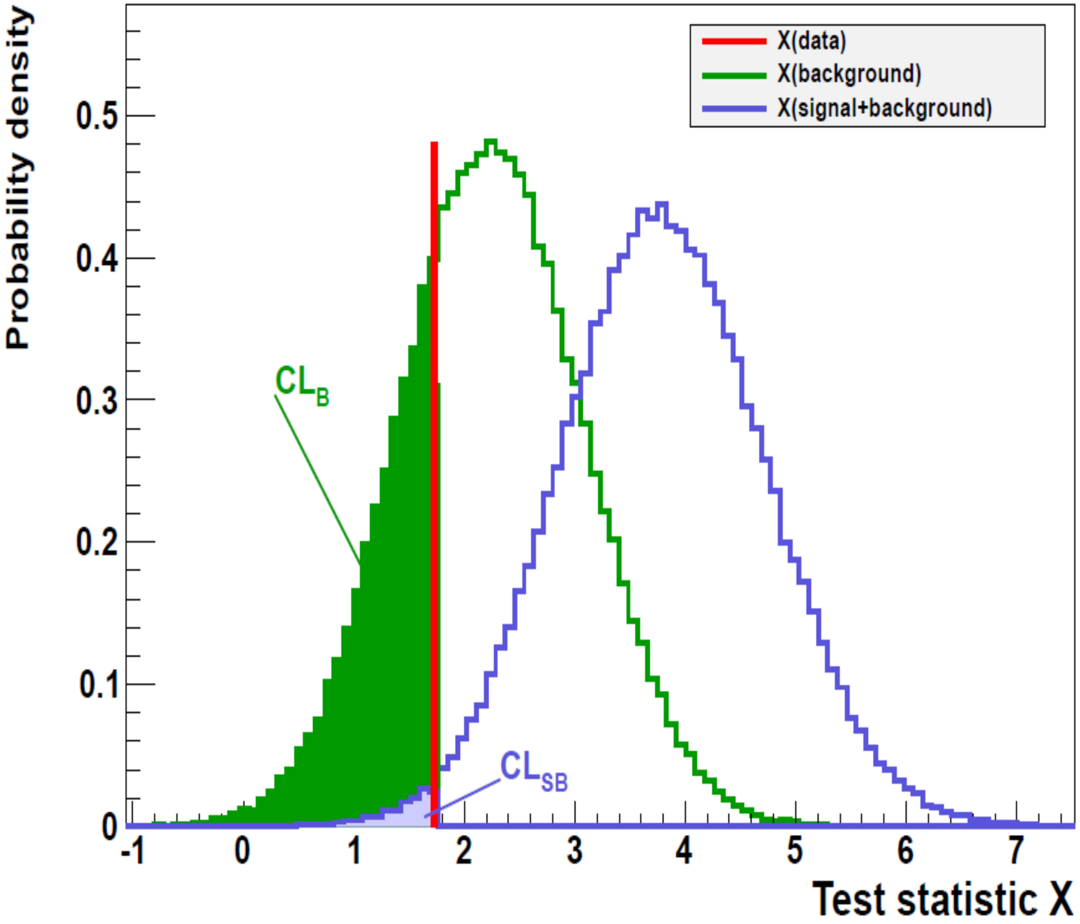
  Ringwald-Schrempp-Model excluded.

Thank you for your attention

Backup slides

Test statistic distribution

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



$$CL_S = \frac{CL_{SB}}{Cl_B} \qquad \textit{Confidence Level}: CL = 1 - CL_S$$

Systematic uncertainties

Not drawn on discriminators plots but used for limit calculations:

- **luminosity uncertainty 2.3%**
- **Signal cross section 20%**
- **Model depandance |Dj-Rapgap|**

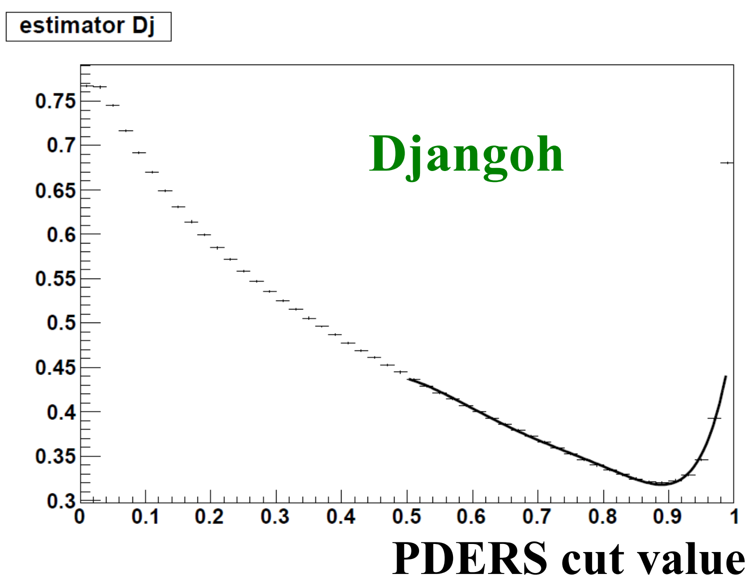
Varied	Shift
Electron Energy	0.5% / 1% $z_{impact} < 1m$ / $z_{impact} > 1m$
Electron Theta	1 mrad
Electron Identification	2% / 0.5% $Z_{impact} > 0$ / $z_{impact} < 0$
HadEnergy	1%
Tracks Efficiency	0.5%
Nuclear Interaction Correction	0.5%

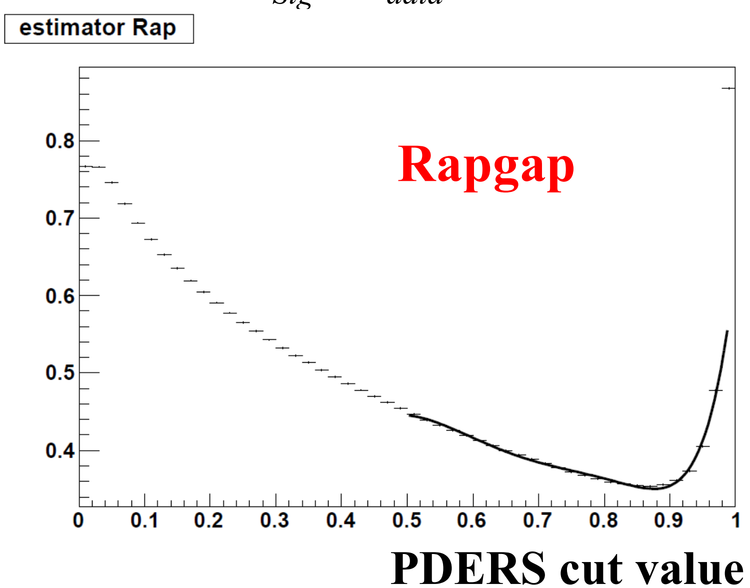
Multi Variate Analysis

Where to cut on discriminator?

One can use a method that estimates an error of signal cross section:

$$err(\sigma_{sig}) = \frac{\sqrt{N_{bckg} + \Delta^2_{model}}}{\epsilon * L_{data}} \longrightarrow \frac{\sqrt{N^{cut}_{Bckg}} * N^{total}_{Sig}}{N^{cut}_{Sig} * L_{data}}$$





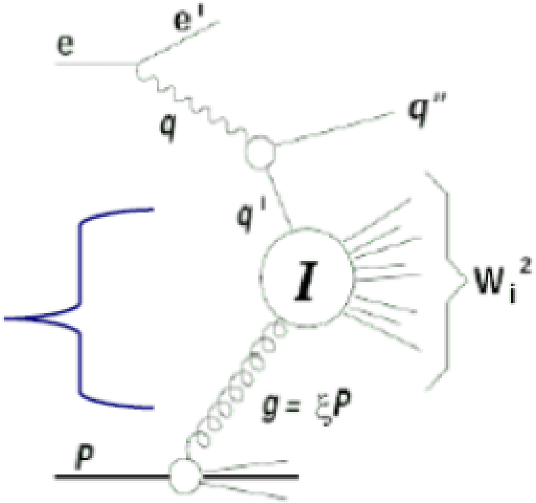
Using this method a cut on the discriminator
was set to **0.86**
This cut defines a **signal region**

Instanton cross section and alpha_S

The total I-production cross-section at HERA $\sigma^{(I)}_{HERA}$ is essentially determined by the cross-section of I-subprocess $\sigma^{(I)}_{q'g}$ which is calculated by Ringwald-Schrempp (*details see eg H1 Instanton publication*)

And qualitative behaviour :

$$\sigma^{(I)}_{q'g} \sim \left[\frac{2\pi}{\alpha_S}\right]^{12} e^{-\frac{4\pi}{\alpha_S}}$$



Instanton-induced cross section depend strongly on alpha_S (QCD scale Λ)