Low-x Meeting 2015

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Search for QCD Instantons at HERA

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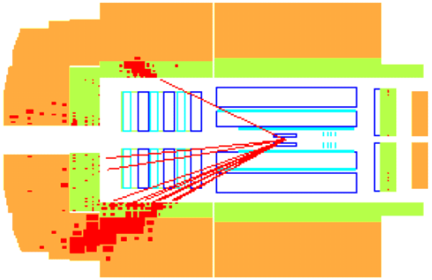
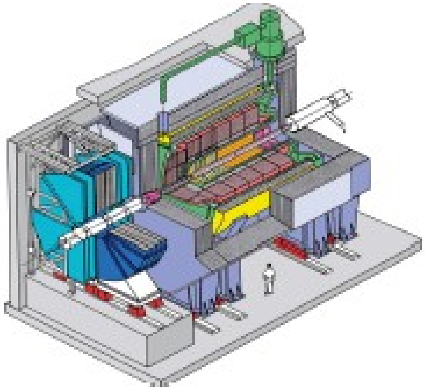
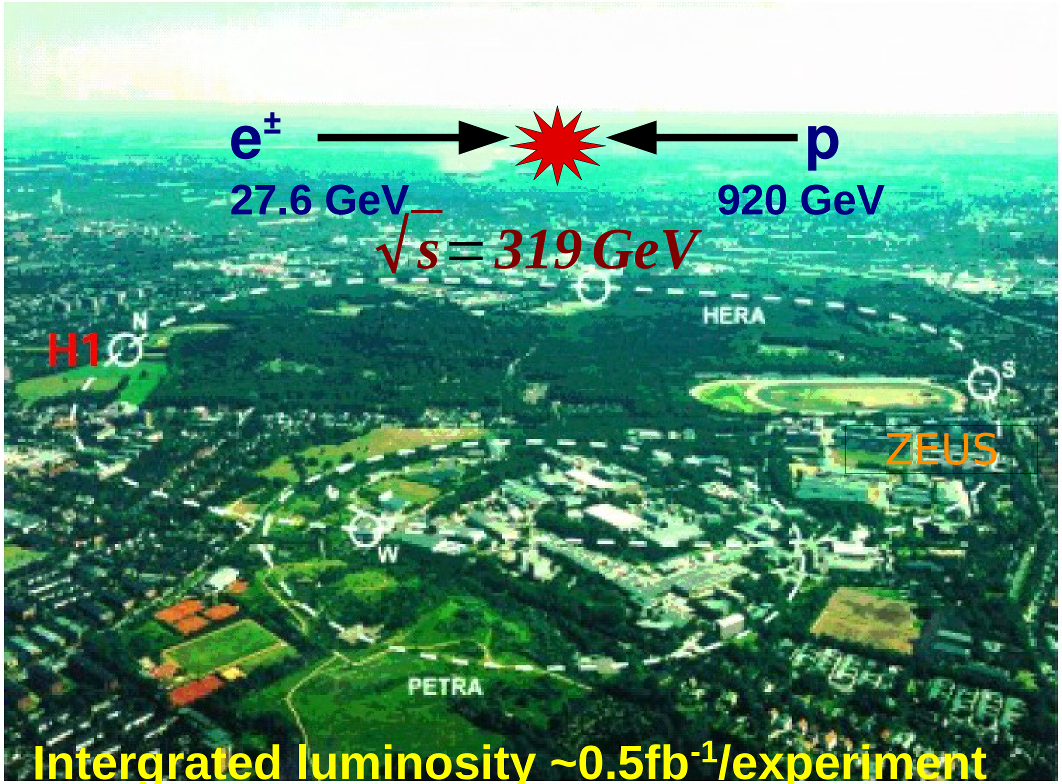
on behalf of the H1 Collaboration

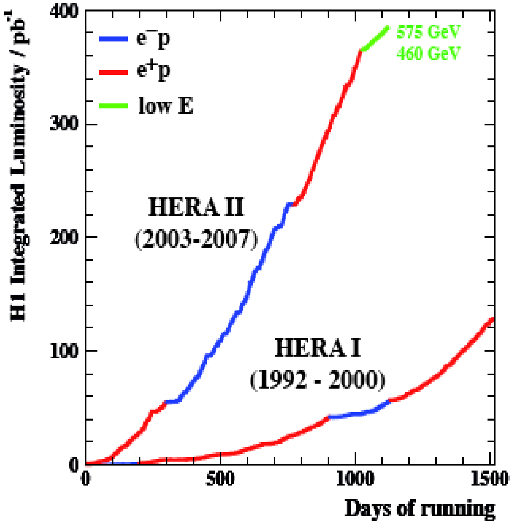
The H1 Experiment at HERA







HERA operation



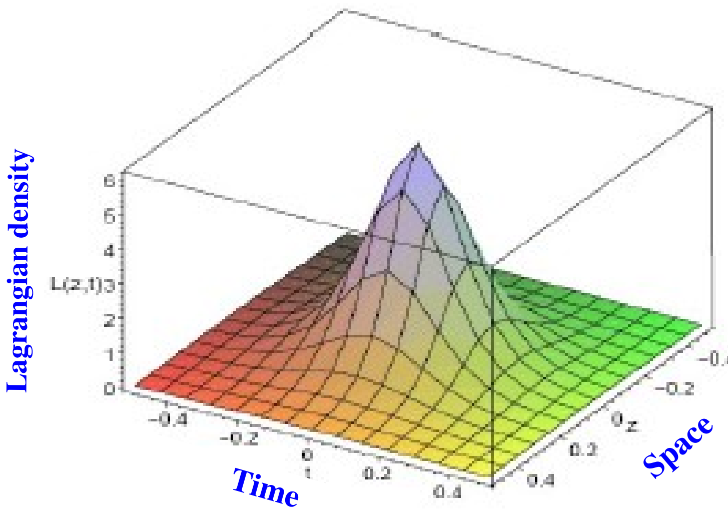
- Unique ep collider 1992-2007
- Two collider experiments H1 and ZEUS
- Collected data

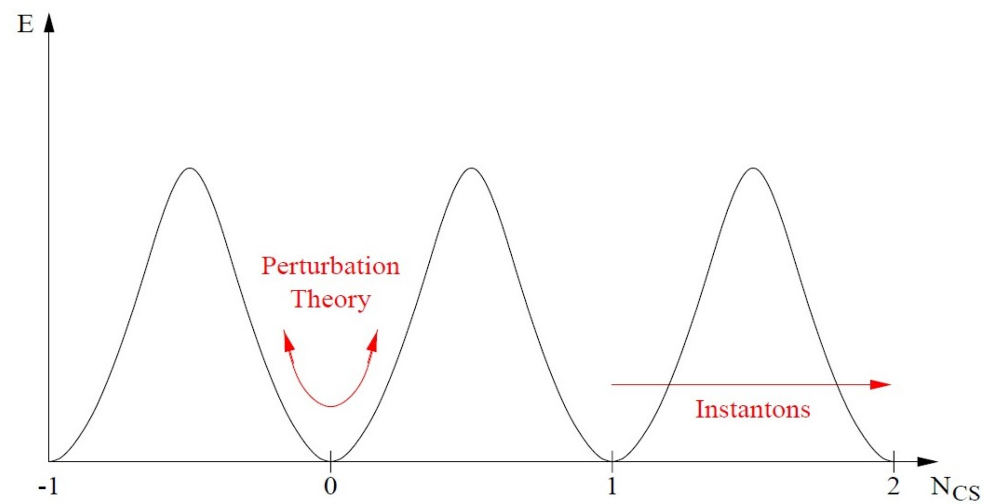
  ~100 pb^{-1} (HERA-I)

  ~400 pb^{-1} (HERA-II)
- This analysis: HERA-II data

Instantons

- **Instantons: non-perturbative fluctuation of the gauge fields**
- **In Standard Model, istantons induce anomalous processes violating conservation of baryon and lepton number in EW and chirality in QCD**
- **Instanton interpretations:**
  - **- localized *pseudoparticle* in space and time (euclidean space) or as**
  - **- tunnelling (Minkowski space) *process* between topologically non-equivalent vacua**



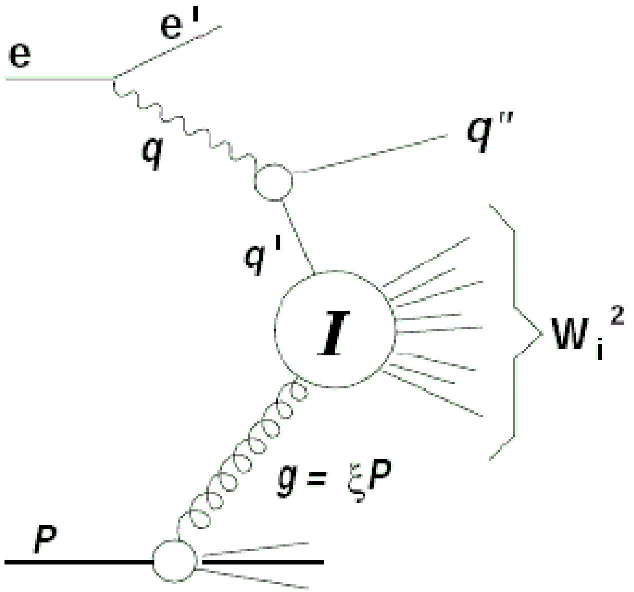


Cross-section for instanton induced processes exponentially suppressed

$\sigma \sim e^{-4\pi/\alpha}$ (α-coupling constant)

QCD Instanton in DIS at HERA

- **Instanton-induced events produced in quark-gluon fusion**
- **Theory and fenomenology workout out by A.Ringwald and F.Schrempp**
- **Implementation in QCDINS Monte Carlo generator makes full event topology available**



Sizeable cross section in recommended phase space:

$$0.1 < y < 0.9\,,\quad Q^2 > Q'^2_{min} \approx 113\,\mathrm{GeV}^2\,,\quad x' > 0.35$$

$$\textbf{Prediction}:\ \sigma^{(I)} \approx 25 - 30\,\mathrm{pb}$$

Variables of I-subprocess:

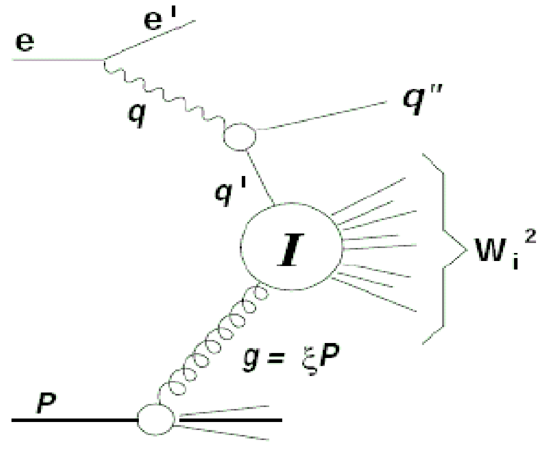
$$Q'^2 = -q'^2 = -(q - q'')^2$$

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

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

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].
http://www.desy.de/~t00fri/instanton.html

QCD Instanton at HERA : Expected Signature



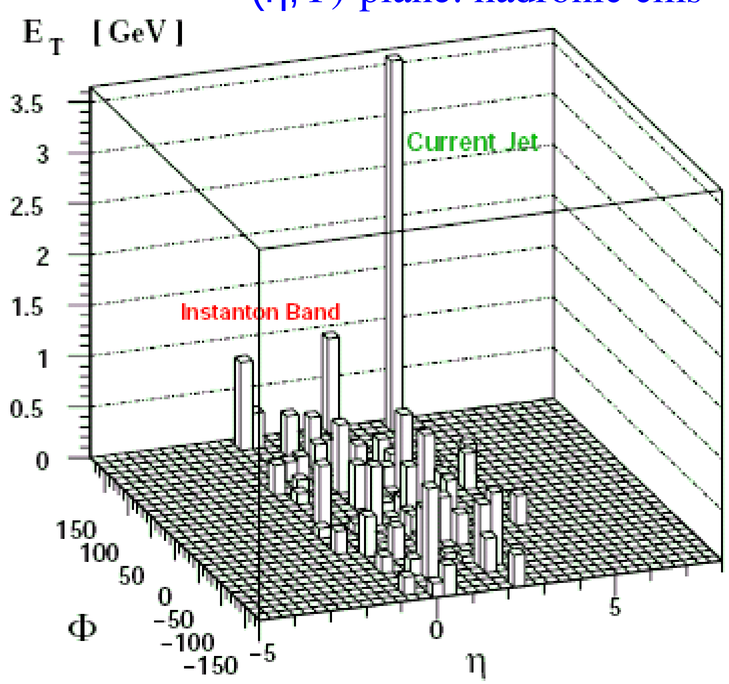
- **Hard "current" jet**
- **Densely populated narrow I-band**
- **Isotropy in instanton rest frame**
- **High multiplicity**
- **Large total Et**

not expoloited in this analysis:

- ***chirality violation***
- ***flavour "democracy"***

"Typical event"

(η,Φ)-plane: hadronic cms



H1 and ZEUS searches

- **early HERA-I data**
- **No signal observed and upper limits set**
- **Upper limits above theory prediction**

H1: hep-ex/0205078

ZEUS: hep-ex/0312048

This analysis: H1 prelim-15-031

H1 prelim-14-031

Events Selection

DIS selection

$150 < Q^2 < 15000$ GeV^2

$0.2 < y < 0.7$

Tracks Selection

$P_T > 0.12$ GeV

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

Data 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

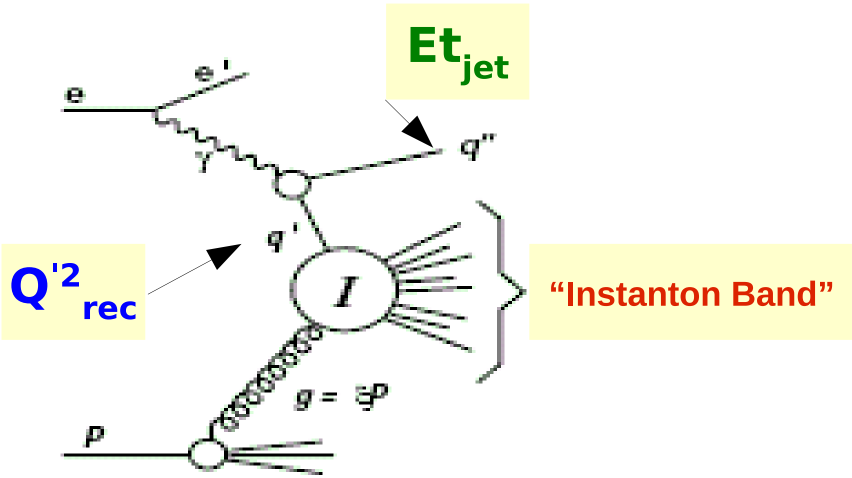
Background:

- **DJANGOH(*CDM*)**
- **RAPGAP[*DGLAP(MEPS)]***

Signal: QCDINS

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

Strategy and Observables



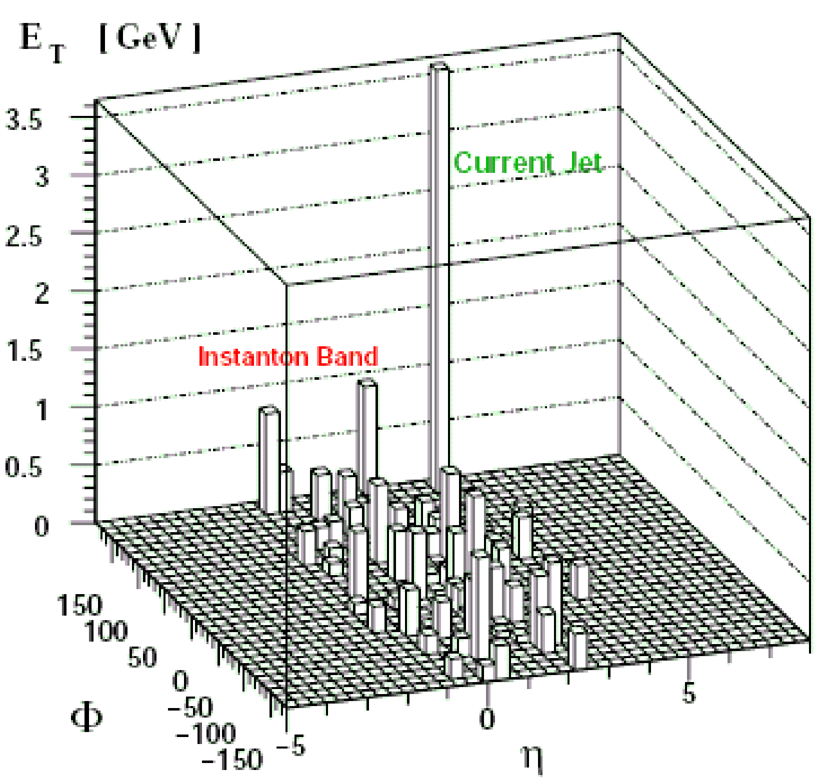
1. DIS selection
2. In hcms (γ+P=0)
   - Find jet → Et_{jet} and Q'^2_{rec}
   - Remove HFS objects found by jet algorithm
   - Find "instanton band" = <η>±1.1

   -> x'_{rec}

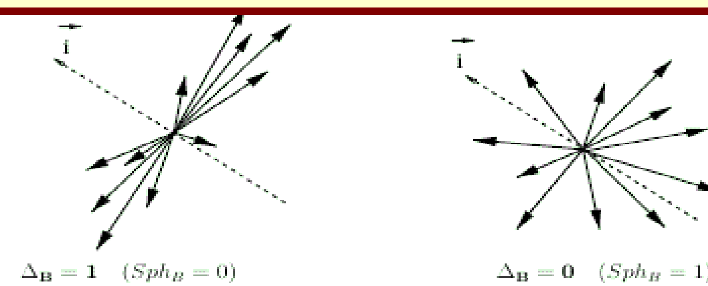
3. Boost HFS objects within "instanton band" into "instanton rest " frame

   $$q'+\xi P=0\ ,\ \xi = <\xi> = 0.076$$

4. For objects in "instanton band " find observables:
   - n_B - number of charged particles
   - Et_B - transverse energy of the band
   - Topological observables:
     - Sphericity, Fox-Wolfram moments,
     - Δ_B, E_{in}, E_{out}



Δ_B, E_{in}, E_{out}



$$\Delta_B = (E_{IN} - E_{OUT}) / E_{IN}$$

$$E_{IN} = \sum_h |\vec{p}_h \cdot \vec{i}_{max}|$$

$$E_{OUT} = \sum_h |\vec{p}_h \cdot \vec{i}_{min}|$$

Observables and MultiVariate Analysis (MVA)

Multivariate discrimination technique was used
to reduce "standard" DIS Background and extract expected signal

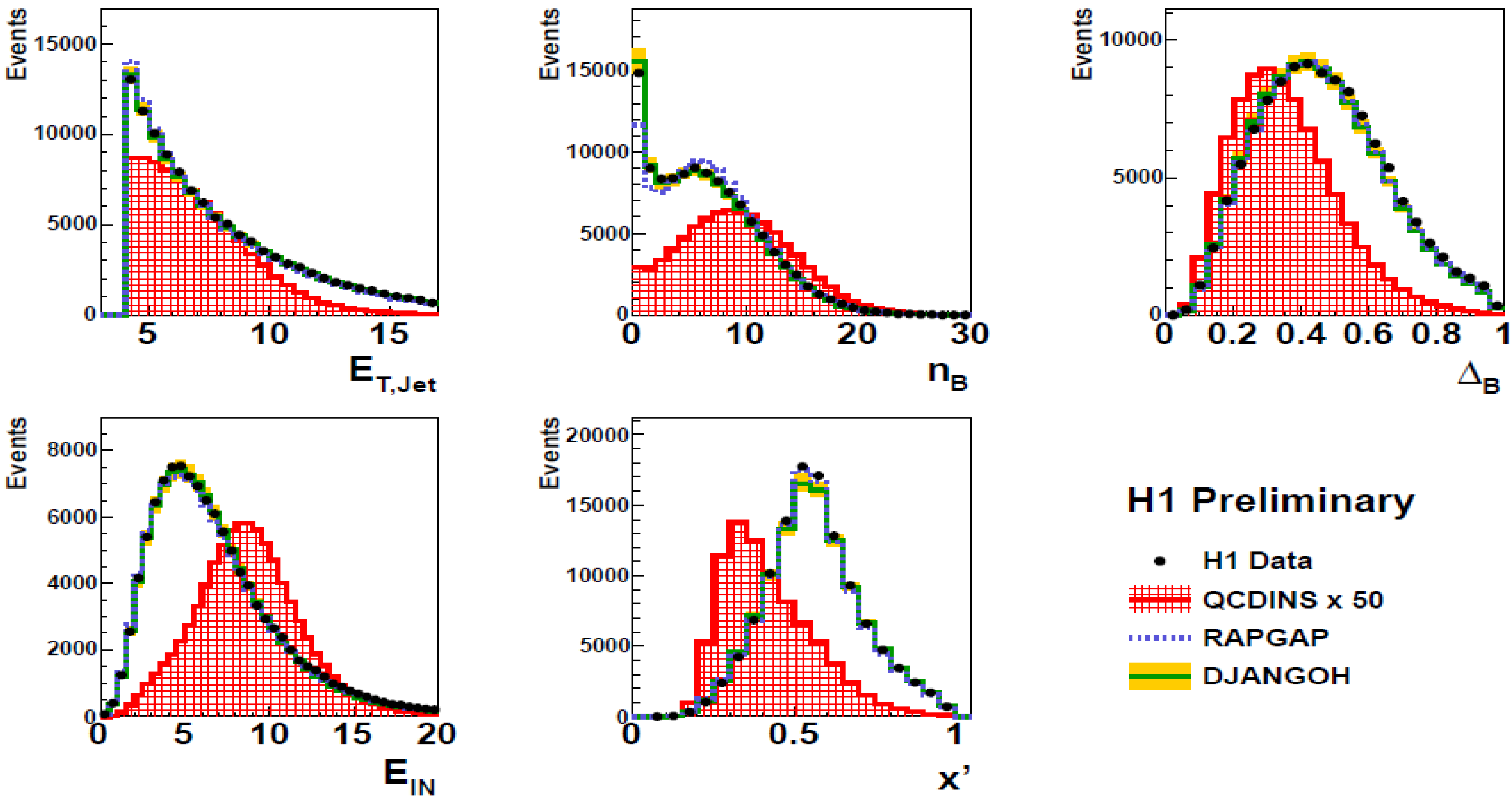
Five observables selected:
$E_{T,Jet}$, n_B , Δ_B , E_{IN} , x'

- **good signal to backgroud separation with good discription by MCs**
- **resulted discriminator distribution is well discribed in background dominated region**

PDERS method was used
(P*robability Density Estimator with Range Search,ROOT TMVA package*)

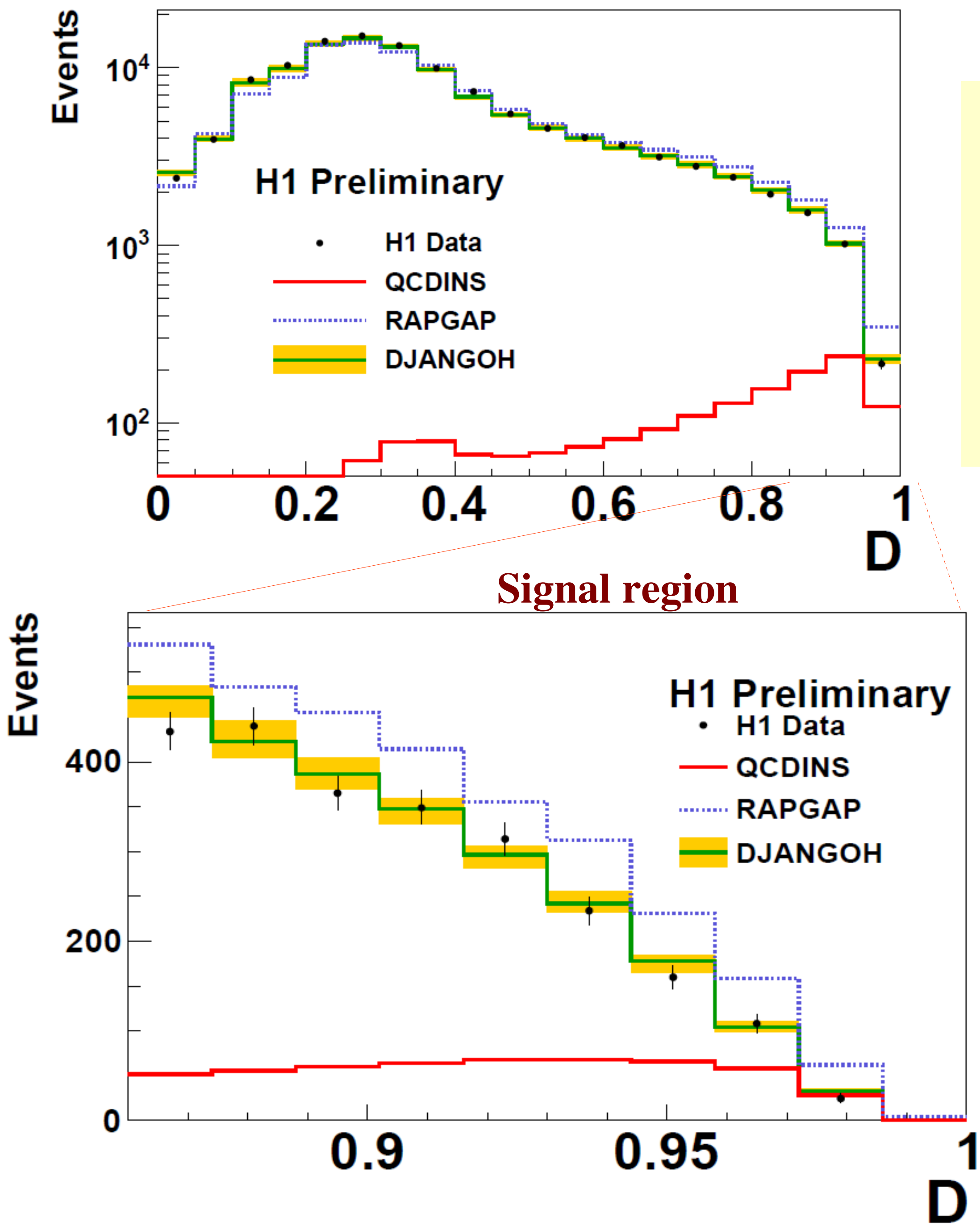
Trainning was done with
-QCDINS (signal)
-DJANGOH/RAPGAP (background)
(in the further analysis- only DJANGOH used)

Distributions of Selected Observables for TMVA training



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

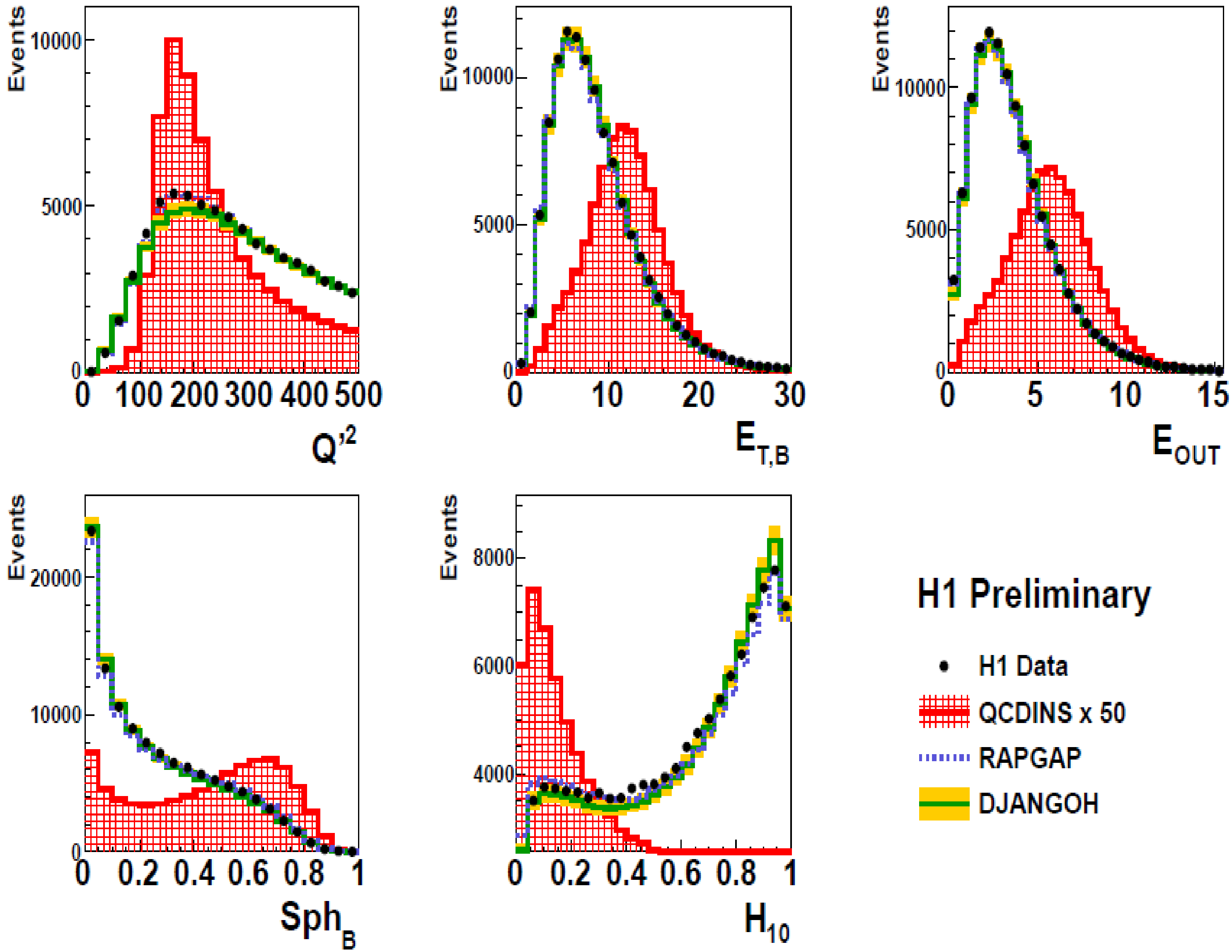
PDERS Discriminator Distribution



- Good discription of data by DJANGOH in background- and signal regions
- RAPGAP sytematically above data in signal region D>0.86

No signal observed in data

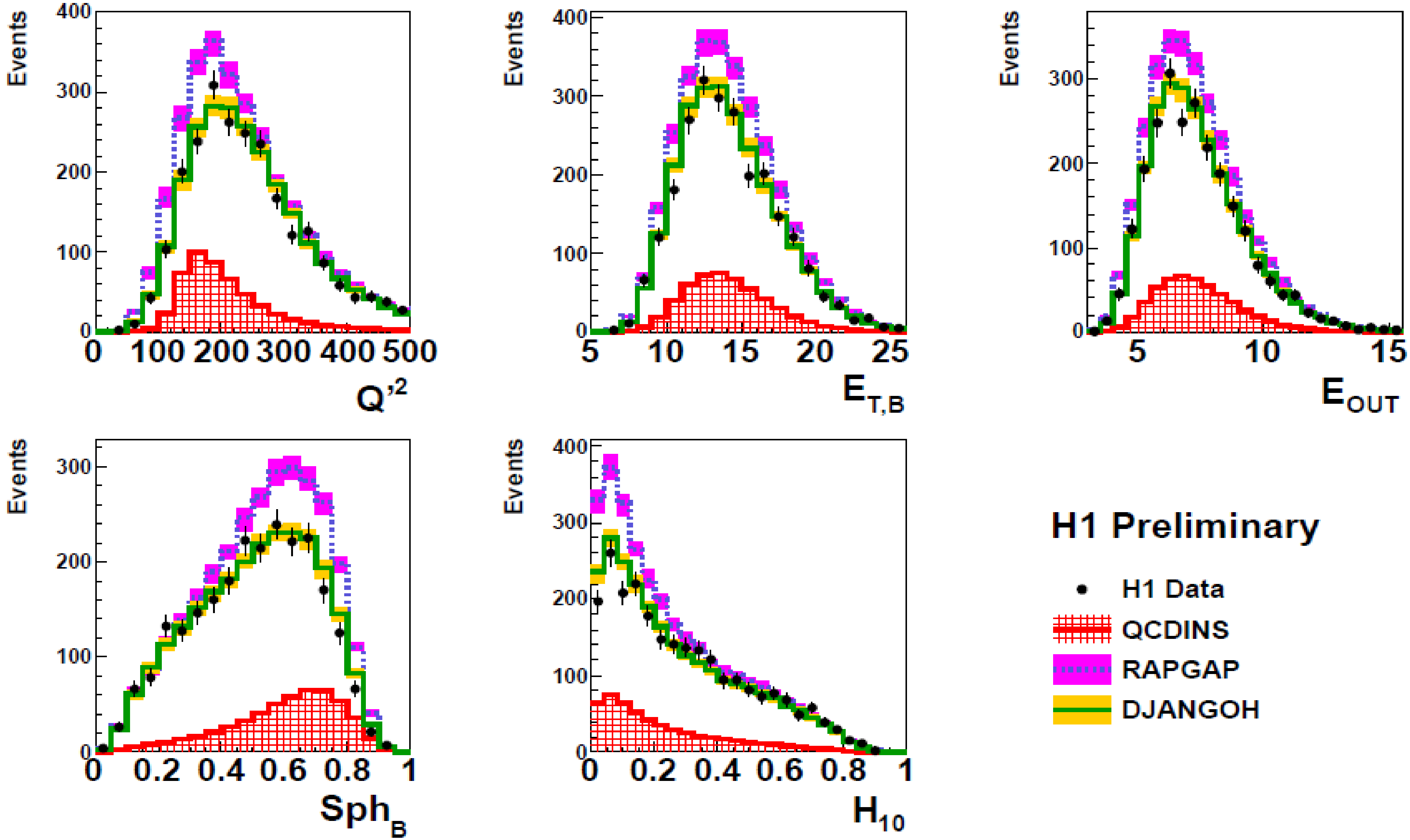
Distributions of Selected Observables NOT used in training



Also other observables were checked on whether the signal is observed

➡ **see next slide**

Distributions of Selected Observables NOT used in training
Signal region D>0.86



Data are discribed by DJANGOH, No excess of events observed

Upper Limit

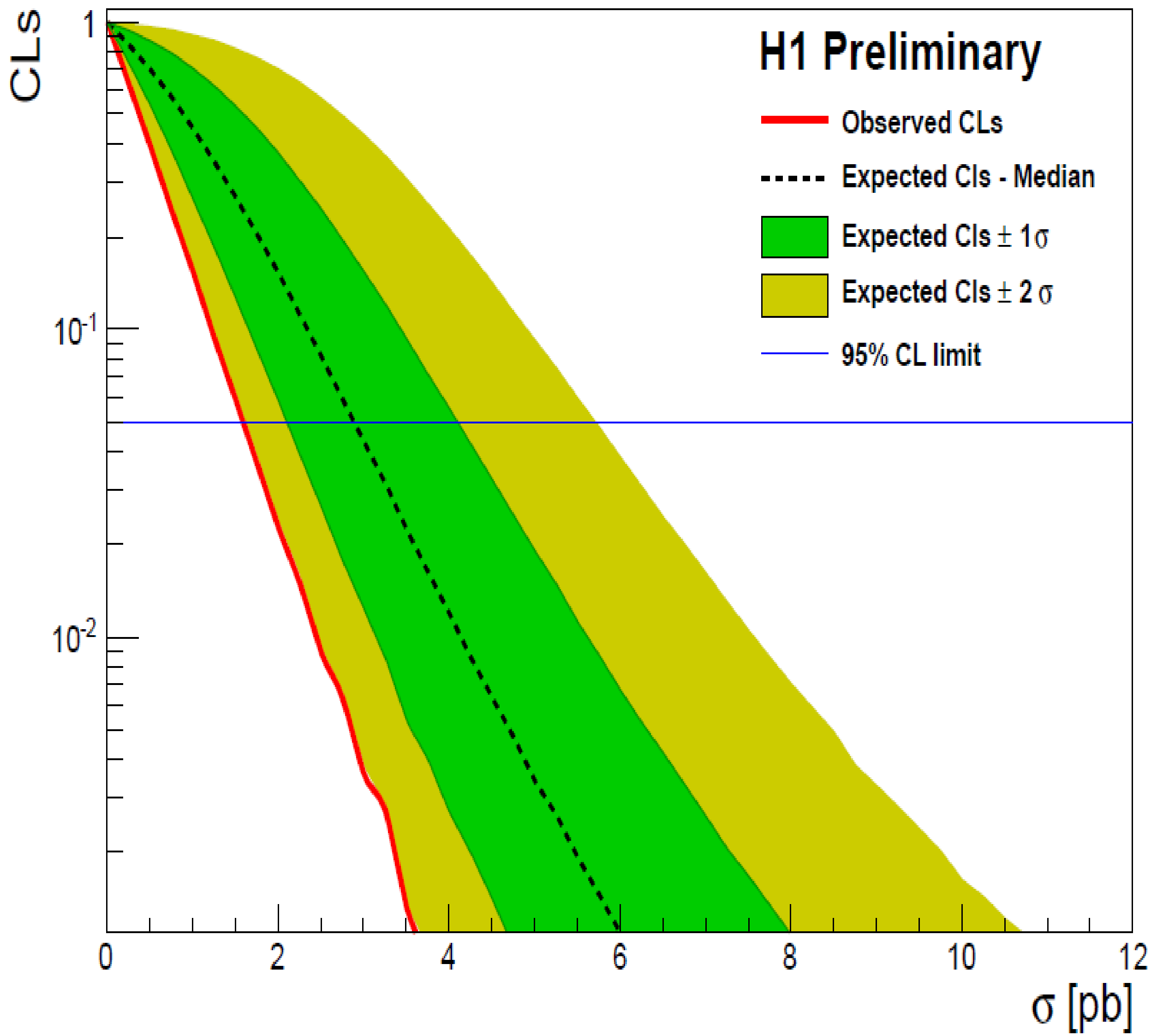
- **Cls method**
- **Using full range discriminator**
- **Background:DJANGOH**

- **Experimental syst uncertainties**
- **Difference DJAMGOH-RAPGAP as background model uncertainty**
- **20% uncertainty of predicted signal cross section due to Λ_{QCD} uncertainty**

Observed Upper Limit:
1.6 pb at 95% CL

Predicted cross section:

$$150 < Q^2 < 15000\,\mathrm{GeV}^2,\quad 0.2 < y < 0.7$$
$$Q'^2 > 113\,\mathrm{GeV}^2,\quad x' > 0.35$$
$$\sigma^{(I)} = 10\,\mathrm{pb}$$



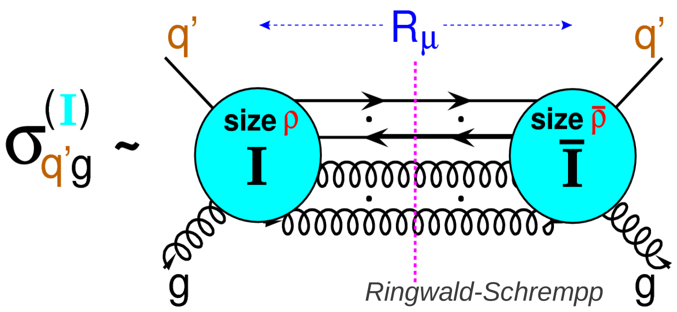
Exclusion limits on the plane Q'^2 vs x'

Calculation of instanton cross-section involes
I-size distribution (ρ) and
I-Ī-distance distribution (R/ρ)

<u>Key feature</u> : It is one-to-one relation between -variables in momentum space (Q',x') and space variables (ρ,R)

Large Q' ↔ small ρ

Large x' ↔ large R/ρ



Region of validity of I-perturbation theory in (Q',x') from Confrontation with lattice results for QCD(nf=0):

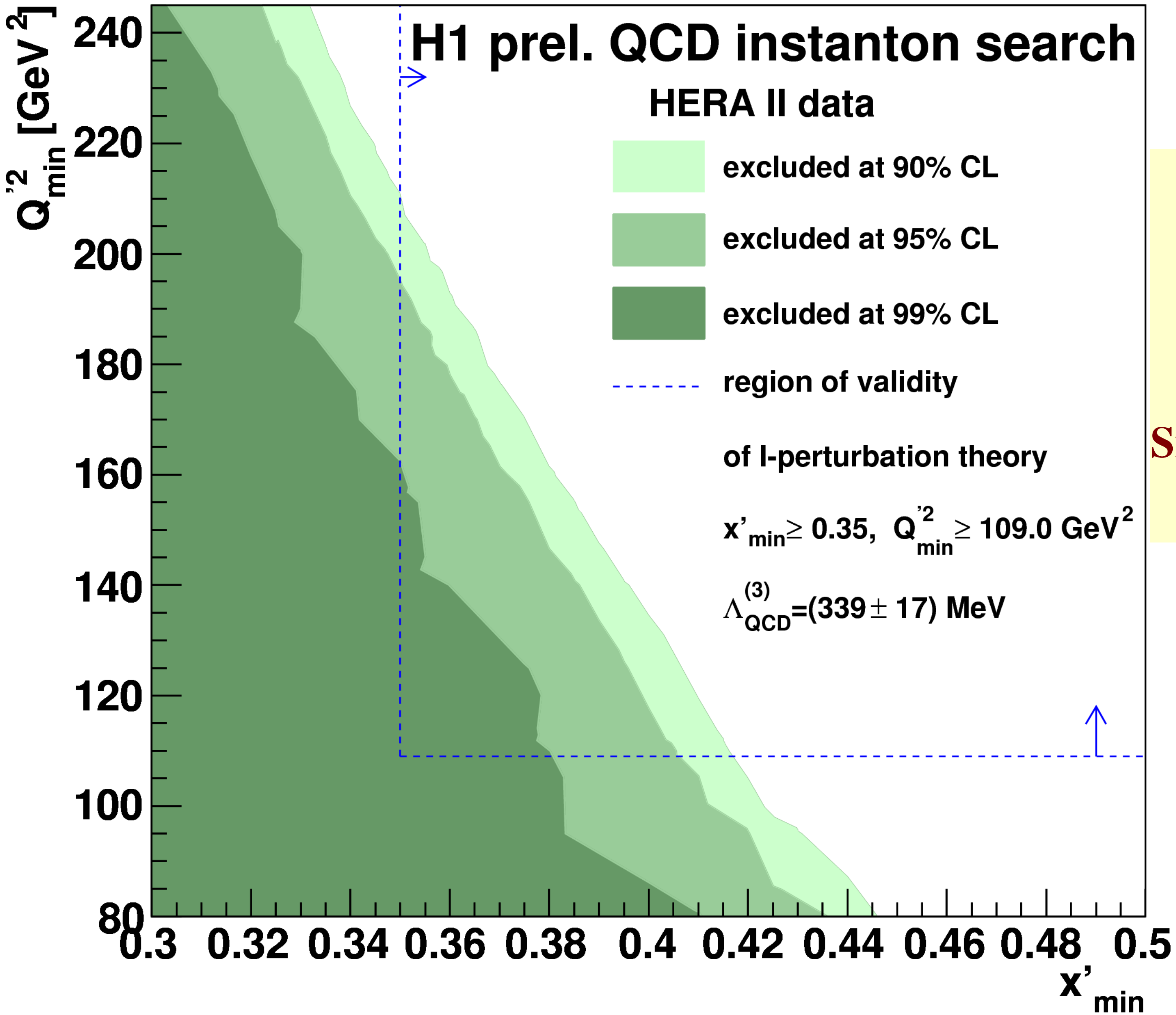
$$\left.\begin{array}{ll} \rho \lesssim \rho_{\max} & \approx 0.35 \text{ fm} \\ \frac{R}{\rho} \gtrsim \left(\frac{R}{\rho}\right)_{\min} & \approx 1.05 \end{array}\right\} \Rightarrow \left\{\begin{array}{lll} Q'^2 \geq \left(30.8\Lambda_{\overline{MS}}^{n_f=3}\right)^2 & \approx 113 \text{ GeV}^2 \\ x' \gtrsim & 0.35 \end{array}\right.$$

- **Results have additional meanning in terms of instantons size/distance (at least qualitatively)**

In addtion:

- **it takes into account effect of very steep behavior of x' and Q' distributions**

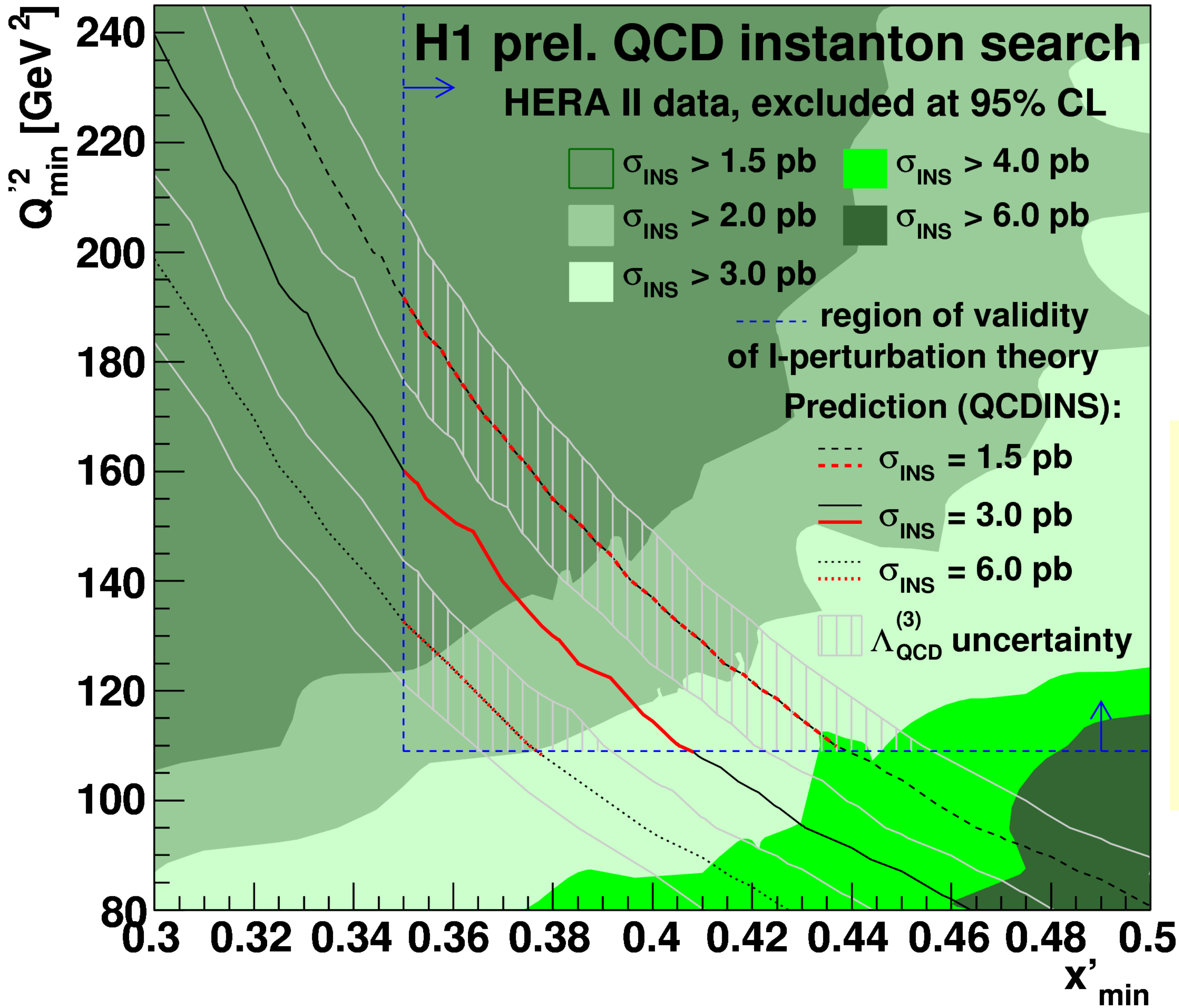
Exclusion Limits



Exclusion limits on Q'^2-x' plane as $Q'^2 > Q'^2_{min}$, $x' > x'_{min}$

Significant part is excluded

Upper limits on Instanton Production Cross Section at 95% CL



Upper limits on cross section
1.5 - 6 pb at 95%CL
are set depending on
kinematic domain

- Most strigent 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 1.6 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