Search for QCD Instanton Induced Processes in Deep Inelastic Scattering at HERA

Krystyna Olkiewicz,
Institute
of Nuclear Physics,
Krakow, Poland

- Introduction
- Instanton search strategy
- Simulation of standard DIS and I- processes
- Event selection and reconstruction
- Instanton enhancement
- Determination of instanton induced events contribution
- Conclusions

ZEUS

DIS03 workshop
Sankt Petersburg, 23–27 April 2003

ZEUS

Introduction

Instantons

- Fluctuations of the gauge fields in non–abelian gauge theories;
- theoretically required by the Standard Model, but not yet experimentally observed.
- As developed theoretically and phenomenologically by A. Ringwald and F. Schrempp, instantons induce characteristic events in neutral current ep scattering
- and MC QCDINS simulates such events .

Expected contribution of I induced events in DIS sample : $\approx 0.65\%$
so there is a chance they are observed.

Strategy

- Event samples:
  - ZEUS DIS data,
  - MC QCDINS – instanton induced events;
  - MC – standard DIS events,
- identify the I region of the hadronic final state;
- find the observables which can be used to discriminate the I induced events from the standard DIS processes;
- enhance the sample with the I induced events by suitable cuts on the 'sensitive' variables or the linear combination of them;
- find the contribution of I induced events in the enhanced sample:
  - assuming standard DIS MC to be true, fit the instanton contribution f_I to the data: $P_{DATA} = (1 - f_I)P_{DIS} + f_I P_I$ where P is the probability distribution of the 'sensitive' variable (here sphericity);
  - obtain the conservative limit by assuming the standard DIS background to be 0.

Simulation

Standard DIS MC

- ARIADNE
  - event simulated using the color dipole model;
  - LUND string model of hadronization;
- RAPGAP – diffractive events;
- best agreement with the experimental sample :

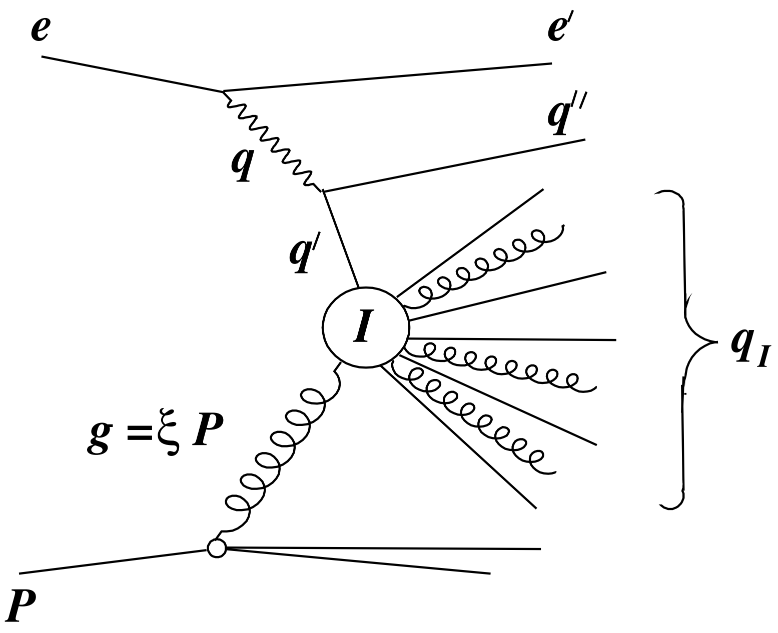
  ARIADNE + 12 % RAPGAP

interfaced with HERACLES using DJANGOH program.

- HERWIG (for comparison) :
  - matrix element and parton shower;
  - cluster hadronization model.

Simulation

- QCDINS (A. Ringwald and F. Schrempp, Comput.Phys.Commun. 132 (2000)):
  - simulation of the hard subprocess using instanton-perturbation theory;
  - fragmentation and hadronization done by HERWIG .

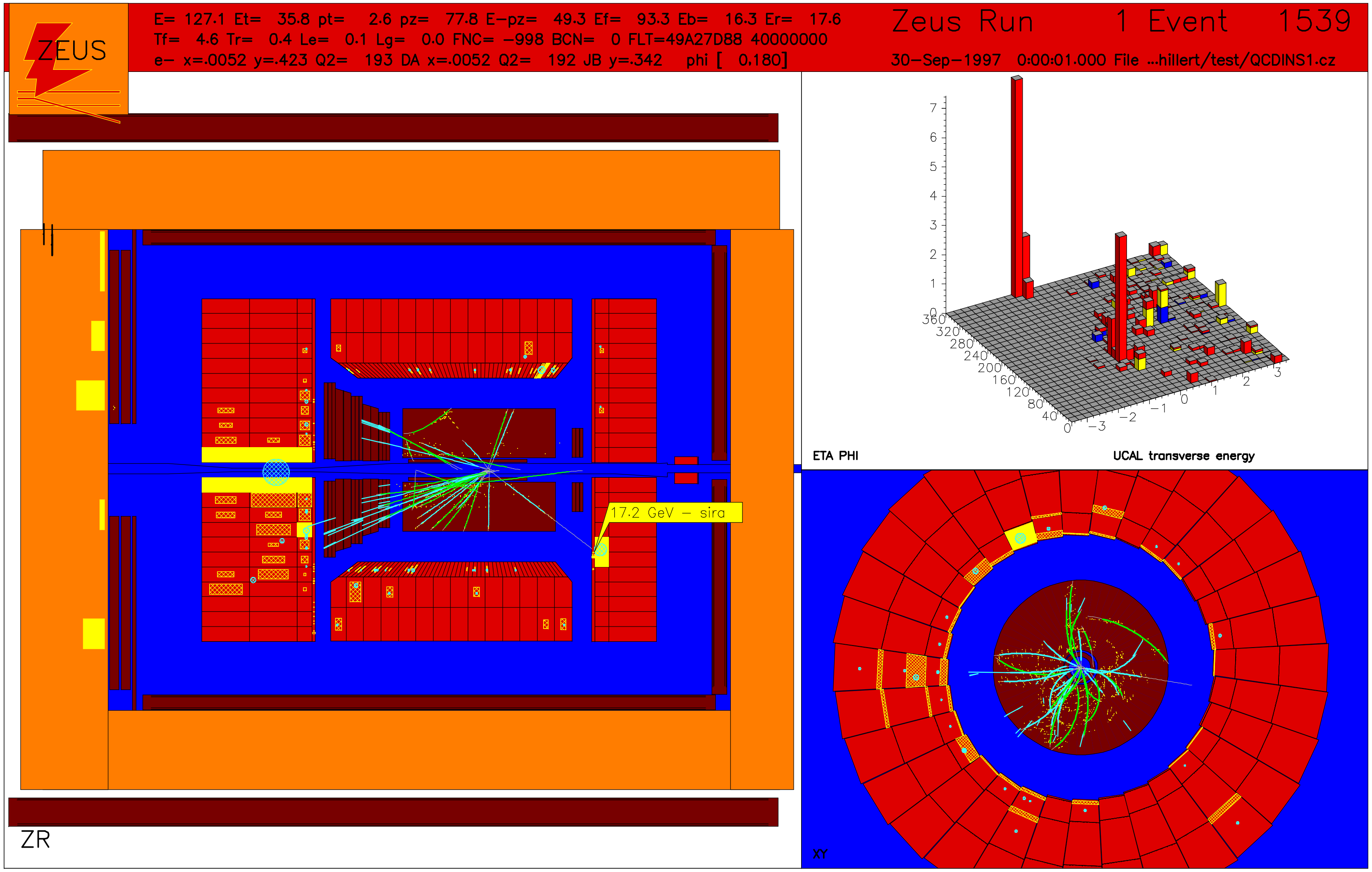


$Q'^2 = -q'^2$
$x' = Q'^2/(2g \cdot q')$
$Q' \geq \sqrt{113 GeV^2}$;
$Q \geq \sqrt{113 GeV^2}$;
$x' \geq 0.35$;

Signature:

- one current jet;
- large total E_T;
- large hadron multiplicity;
- u–d–s flavor democracy;
- isotropic particle production in I cm system.

Instanton portrait – MC



Event Selection

96-97 DATA , 38.2 pb^{-1}

kinematics:

- $Q^2 > 120 GeV^2$
- $x > 0.001$
- $y_{JB} > 0.05$
- usual cleaning cuts.

restriction to the fiducial region of the QCDINS MC:

- $Q'^2 \geq 140 GeV^2$ (QCDINS valid for $Q'^2 \geq 113 GeV^2$)

91846 events left

Event Reconstruction

- find all energy flow objects (efo's)
  - track and/or energy deposit;
- identify and remove scattered positron;
- identify current jet :
  - k_t cluster algorithm in its longitudinally invariant form in $hcms$ frame;
  - choose jet with the highest transverse energy satisfying the condition: $\eta_{jet}^{hcm} > \frac{\sum_{\text{efo}} E_T \eta}{\sum_{\text{efo}} E_T}$ as the current jet.
- assign all efos to the instanton, that are
  - not assigned to the current jet;
  - found in the hcm hemisphere opposite to the proton remnant.

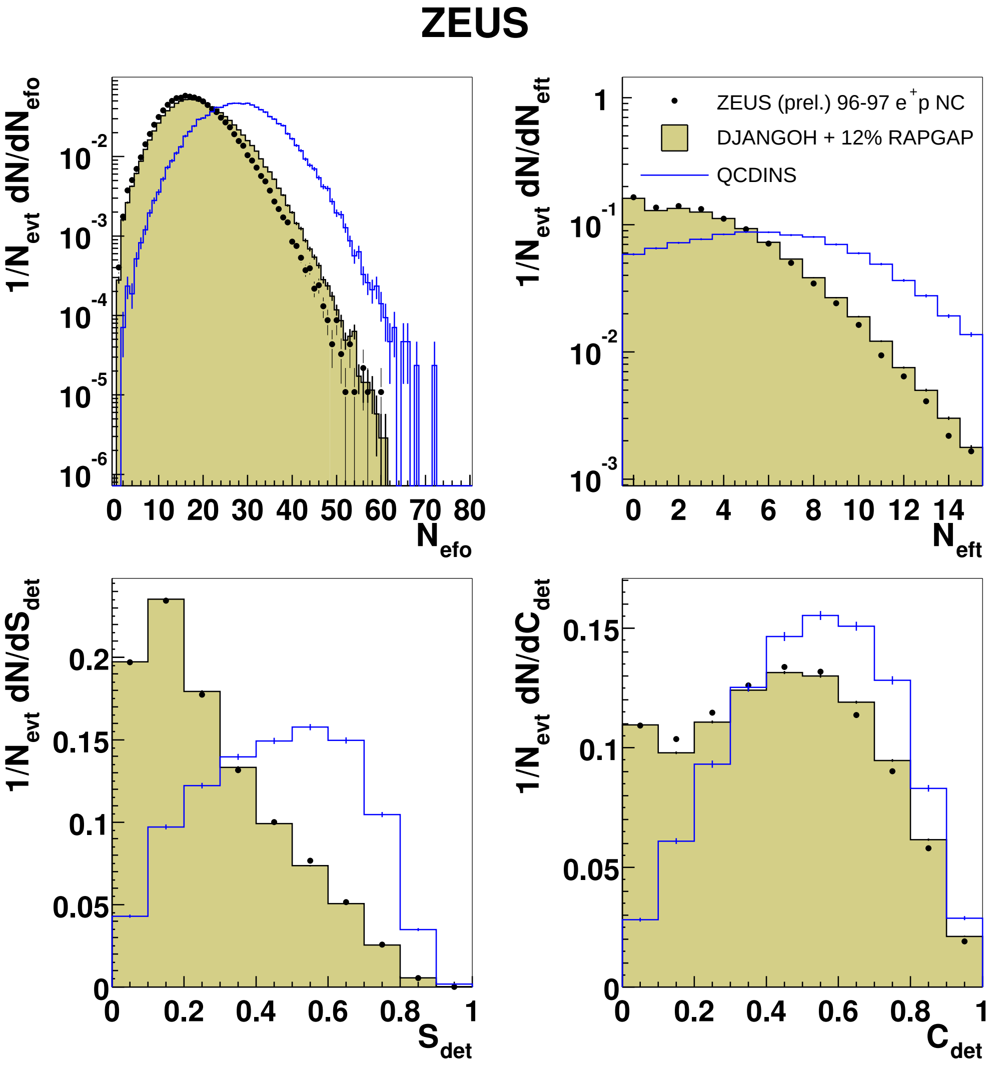
Instanton enhancement

Instanton induced final state is distinguished by its characteristic topology.

A. Ringwald and F. Schrempp – sensitive, discriminating observables are :

- transverse momentum of the current jet: p_T^{Jet};
- multiplicities of energy flow objects (efos) in I region – N_{efo} and of tracks used to construct these efos, N_{eft};
- variables measuring isotropy:
  - in 3 dimensions: sphericity S of efos from I region in I cms;
  - in 2 dimensions: circularity C of efos from I region in hadronic cms;
- η density of particles in I region (estimated by the event shape variable ϵ') .

Instanton enhancement



- distributions of the sensitive variables for QCDINS (signal) and standard DIS (background).
- All distributions normalized to 1.

Instanton enhancement

The event shape variable ϵ'

calculated as:

- inverse of separation in η between efos in I region, ϵ_c:
- $\epsilon_c \equiv \epsilon_k = \frac{k}{N_{\text{efo}}-k} \sum_{i=1}^{N_{\text{efo}}-k} \frac{1}{\eta_{i+k}-\eta_i}$ with

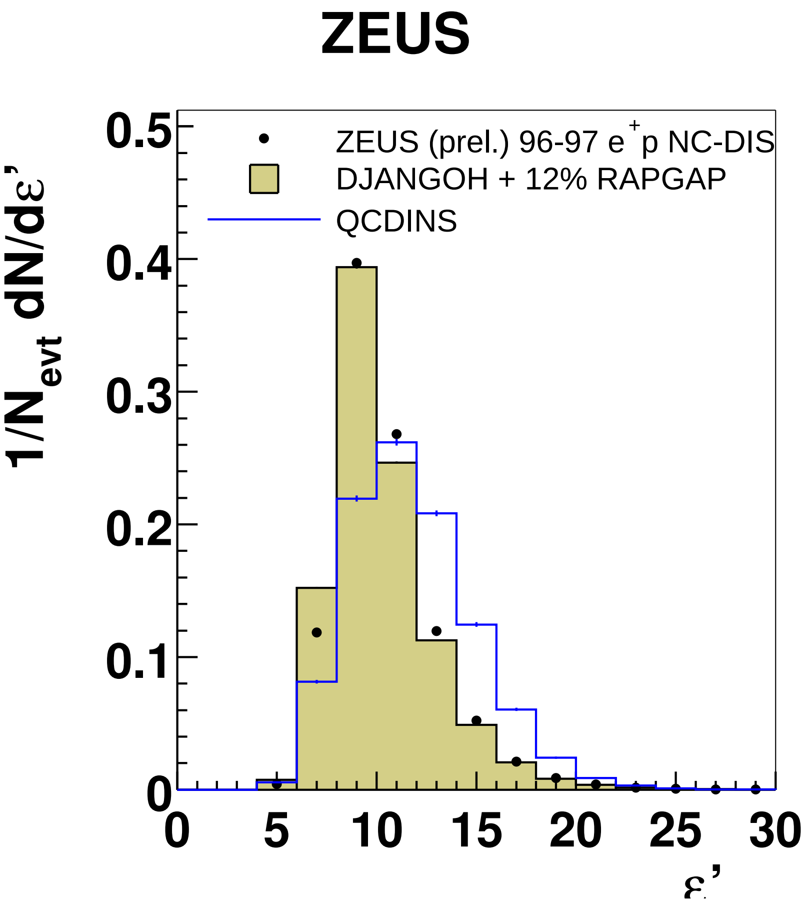
$$k = \begin{cases} N_{\text{efo}}/2 & \text{for } N_{\text{efo}} \text{ even,} \\ (N_{\text{efo}}+1)/2 & \text{for } N_{\text{efo}} \text{ odd} \end{cases}$$

- corrected for its correlation with the multiplicity in the I region of the event:

$$\epsilon' = \epsilon_c - b \cdot (N_{\text{efo}} - a)$$

where a and b come from the fit:

$$< \epsilon_c(N_{\text{efo}}) > = b \cdot (N_{\text{efo}} - a)$$



Instanton enhancement

To enhance DIS sample with instanton induced events –

- cuts on following variables:
  Q'^2_{DA}
  transverse momentum p_T^{Jet} in hcms
  $N_{\mathrm{efo}}, N_{\mathrm{eft}},\ S,\ C, \epsilon'$
- cuts on the optimized linear combination of them thus taking their correlations into account $\Longrightarrow$ **Fisher algorithm**.

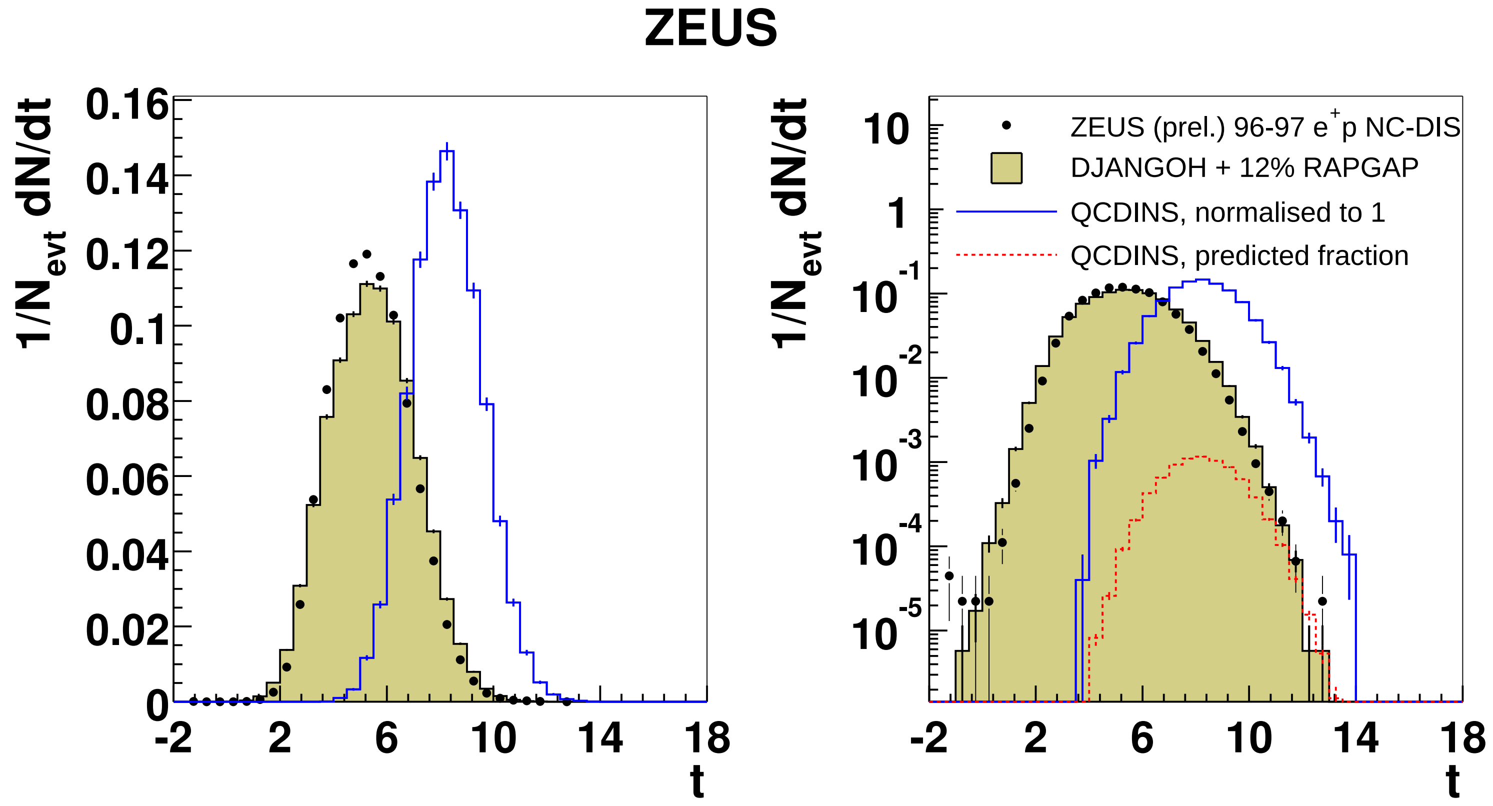
To obtain the best discriminating variable:

- for both samples (signal s and background b) described by a set of variables x_i calculate the averages: $\overline{x_i}^s$, $\overline{x_i}^b$ and covariance matrices: $V_{ik,s}\ V_{ik,b}$
- with $\overline{V}_{ik} = \frac{1}{2}(V_{ik,s} + V_{ik,b})$ find weights $w_i = \sum_k (\overline{V}^{-1})_{ik}(\overline{x_k}^b - \overline{x_k}^s)$
- Fisher discriminant $t = \sum_i w_i x_i$

Instanton enhancement

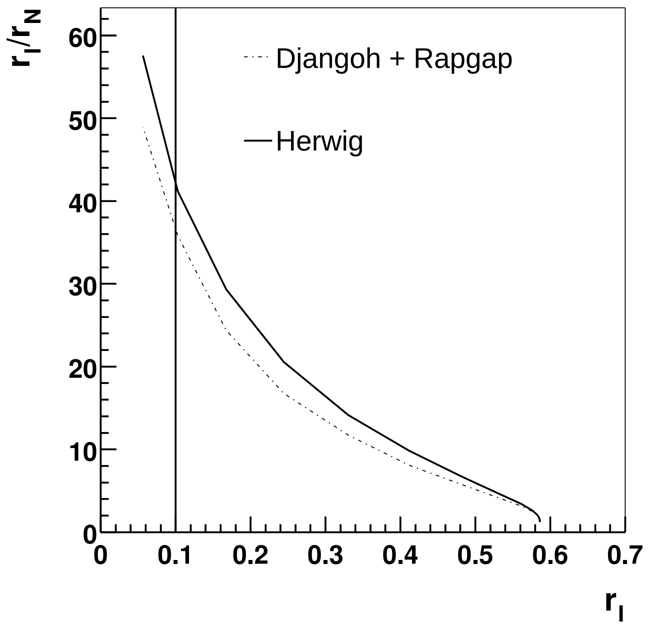
Fisher discriminant t calculated with variables:

S,C, p_T^{Jet}, N_{efo}, N_{eft}, ϵ'



Instanton enhancement

Efficiency of the enhancement:



- $N_0(I_0)$: number of standard DIS MC (QCDINS) events in the inclusive sample;
- $N_E(I_E)$: number of standard DIS MC (QCDINS) events in the enhanced sample;
- Efficiency of the enhancement: $r_I = \frac{I_E}{I_0}$, $r_N = \frac{N_E}{N_0}$ $P_s = \frac{r_I}{r_N}$ vs r_I for t cuts.

Results

Find the fraction of instanton induced events f_I by fitting sphericity distribution:

- minimize χ^2 for:
- $P_{DATA} = (1 - f_I)P_{\text{MCDIS}} + f_I P_{\text{QCDINS}}$
- for both standard DIS MC: ARIADNE and HERWIG.

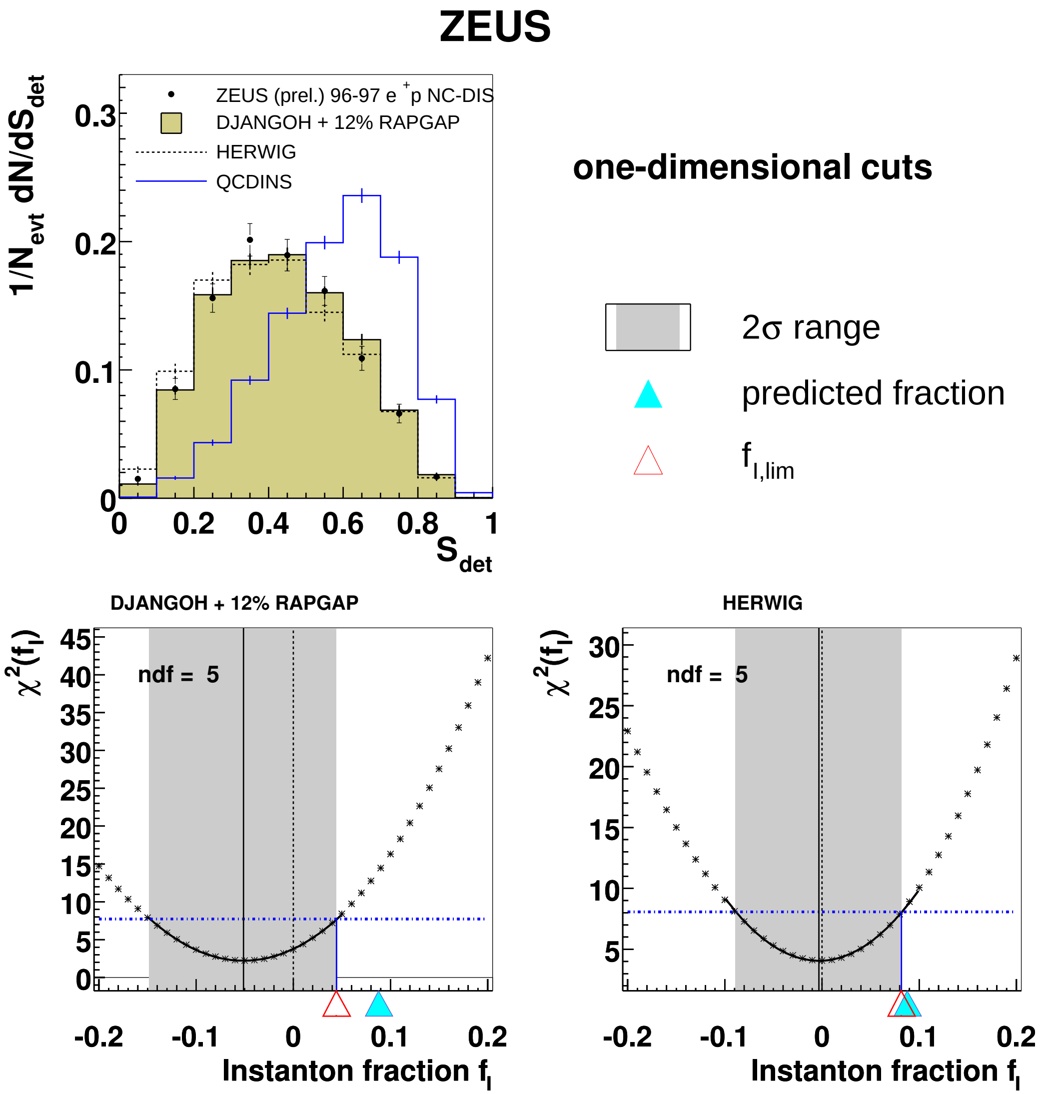
and compare with

- predicted fraction $f_{\text{I,th}}$ of instanton-induced events defined as:

$$f_{\text{I,th}} = \frac{\sigma_I}{\sigma_D} \qquad \text{where} \qquad \sigma_I = \frac{N_c}{N_g}\sigma_g \qquad \text{and} \qquad \sigma_D = \frac{N_D}{L}$$

  - σ_I: QCDINS cross section;
  - σ_D: data cross section; L: the luminosity;
  - N_c: number of QCDINS events within the cuts that constrain the sample;
  - N_g: number of events generated;
  - σ_g: QCDINS generated cross section.

Results



Sphericity fits for direct cuts (1D) on the 'sensitive' variables:

$p_T^{\text{Jet}} > 4$ GeV

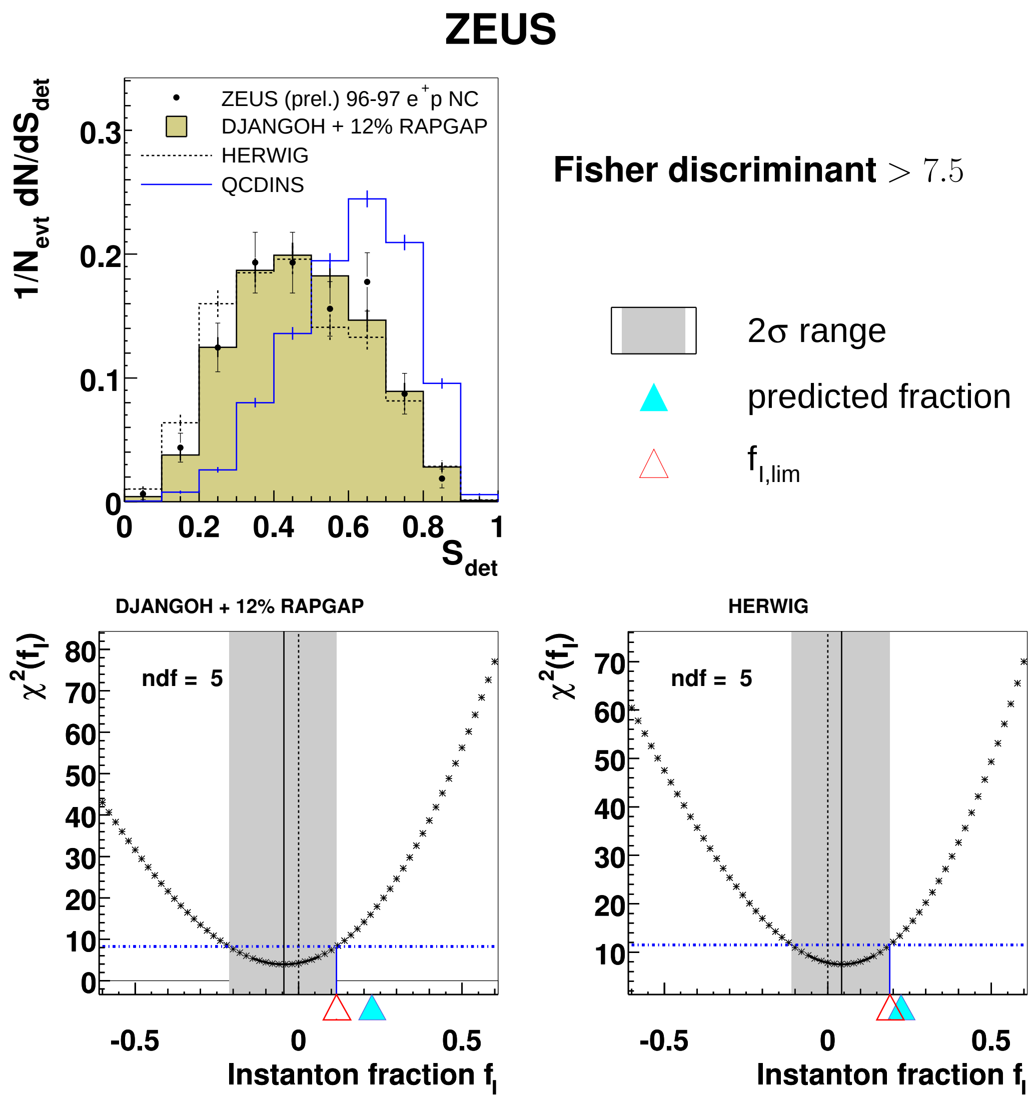
$Q'^2_{\text{DA}} < 250$ GeV^2

$N_{\text{eft}} > 7$

$C > 0.2,\ S > 0.2$

- $f_I = 0$ cannot be excluded: only upper limits can be set
- $\chi^2\left(f_{\text{I,lim}}\right) = \chi^2_{\text{min}} + 4$ or $\chi^2\left(f_{\text{I,lim}}\right) = \chi^2(f_I = 0) + 4$, if minimum χ^2 at $f_I < 0$

Results



Sphericity fits for
cut on the Fisher discriminant
and $Q'^2_{\rm DA}$:

$Q'^2_{\rm DA} < 250$ GeV^2

$t > 7.5$

t calculated from

C, $p_T^{\rm Jet}$, $N_{\rm efo}$, $N_{\rm eft}$

- The upper limit on the contribution of instanton induced events below prediction for both enhanced samples.

Results

Obtain the I cross section limits by:

- hard cuts and assuming standard DIS background to be 0.

	r_I [%]	DATA	QCDINS	DJA, RGP	P_S	HERWIG	P_S
1D	9.1	252 ± 16	54.6 ± 0.9	340.4 ± 9.4	24	184.6 ± 7.9	45
$t > 9.5$	10.3	179 ± 13	61.3 ± 0.9	261.4 ± 8.3	36	227.4 ± 8.7	41
$t > 10.0$	5.6	76 ± 8.7	33.5 ± 0.7	104.7 ± 5.2	49	89.0 ± 5.5	58
$t > 10.5$	2.8	33 ± 5.7	16.7 ± 0.5	34.8 ± 3.0	73	35.1 ± 3.4	73

For the cut on the Fisher discriminant at $r_I \approx 10\%$,
the 2σ limit of instanton induced events is $179 + 2\sqrt{179} = 206$ events.
Scaled to $Q^2 > 120\,\mathrm{GeV}^2$, $x > 10^{-3}$, $0.05 < y < 0.9$, $Q'^2 > 140\,\mathrm{GeV}^2$,
this number of events corresponds to the cross section 30 pb.

Conclusions

- A search for QCD–instanton–induced events has been performed in neutral current deep–inelastic ep scattering based on 38pb^{-1} in the kinematic range $Q^2 > 120\,\mathrm{GeV}^2$, $x > 10^{-3}$.
- Combination of one–dimensional cuts, and cuts on the Fisher discriminant have been used to obtain instanton–enhanced subsamples.
- Using these enhanced subsamples, a fit to the sphericity distribution for the fraction of instanton events is compatible with zero.
- Stringent upper limits close to the theoretically expected value for this fraction are obtained

Assuming the standard DIS background to be zero,
a most conservative 2σ limit has been set at 30 pb, a factor 3.4 above predicted cross section.