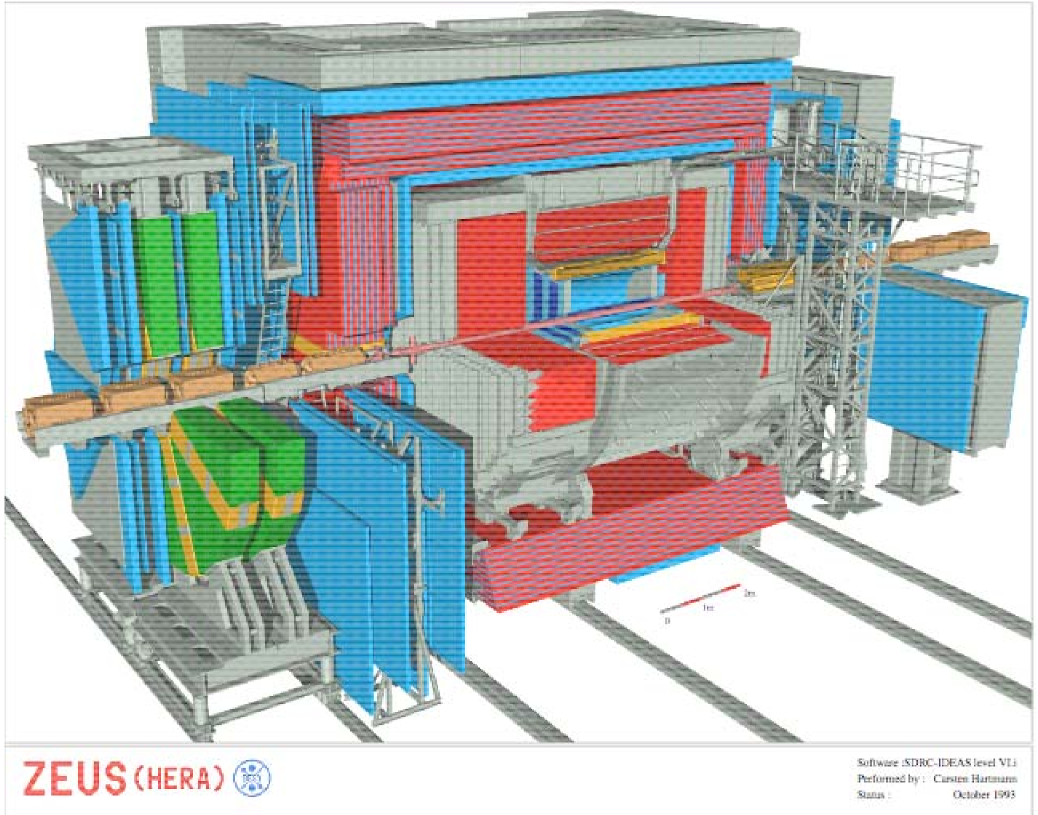
ICHEP'04 QCD soft interaction

Search for QCD Instanton Induced Processes in DIS at HERA

On Behalf of ZEUS-Collaboration

Z.Ren Columbia Univ.

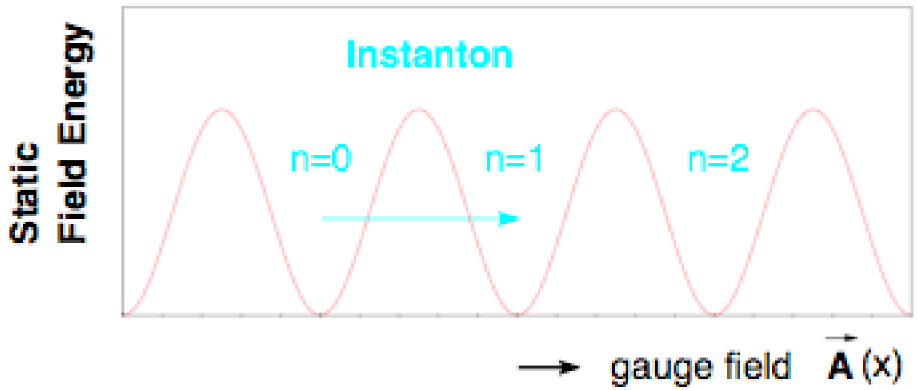


Overview:

- Instantons in DIS
- Event Signature
- Data Selection
- Signal Enhancement
- Result
- Conclusion

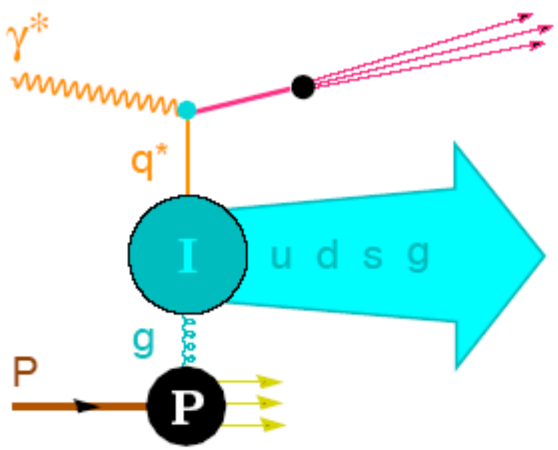
What is an Instanton?

Instanton is a chunk of energy tunneling between different QCD vacuum states

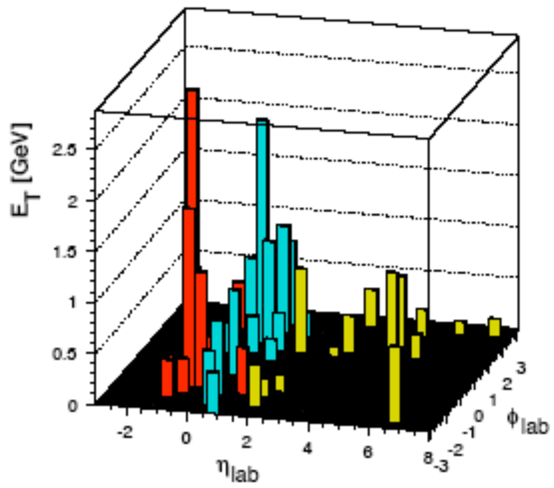


- Vacuum is defined as state with lowest energy, but it can not be “zero energy” because of Heisenberg’s Uncertainty Principle. E.g. the “Casimir-Effect” in electromagnetism.
- QCD should have an infinity number of vacuum states separated by potential walls because it is a non-Abelian gauge theory.

Instantons in DIS: Event Signature



- current jet
- "band"-region: $\Leftrightarrow$



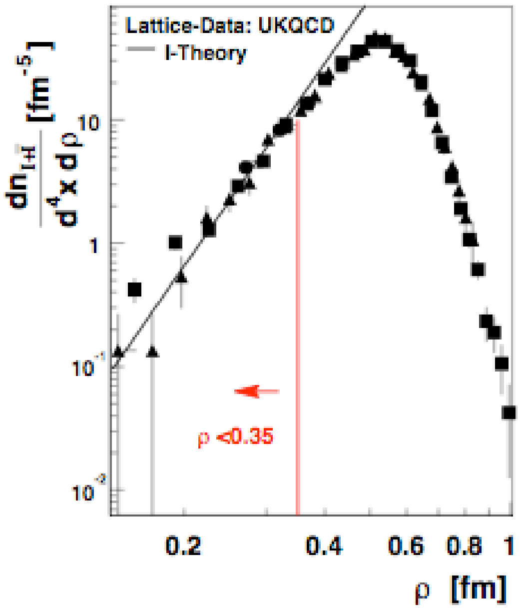
In I-rest system: **"Fireball"** decaying **isotropically** into

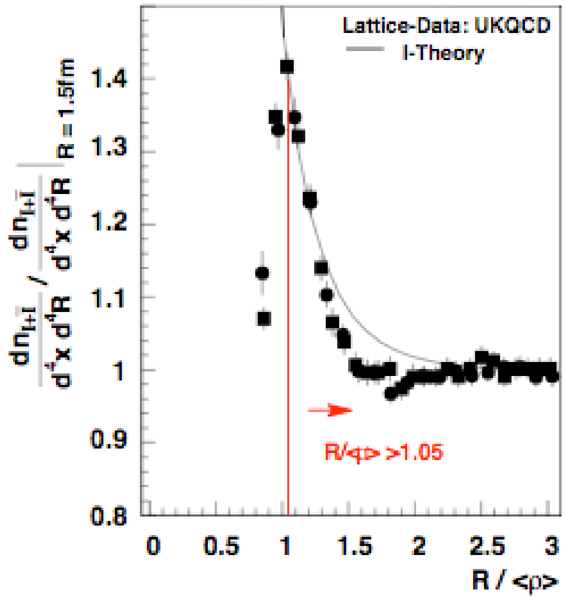
$n_f \cdot q + n_f \cdot \bar{q} + \mathcal{O}(\frac{1}{\alpha_s}) \cdot g =$

$\mathcal{O}(10)$ **partons!**

- ◇ Large total E_t
- ◇ "u, d, s flavour democracy": **Strangeness** $\Rightarrow K's, \Lambda's$
- ◇ Large multiplicity
- ◇ No further jets

Comparing Perturbation Theory with Lattice Calculation



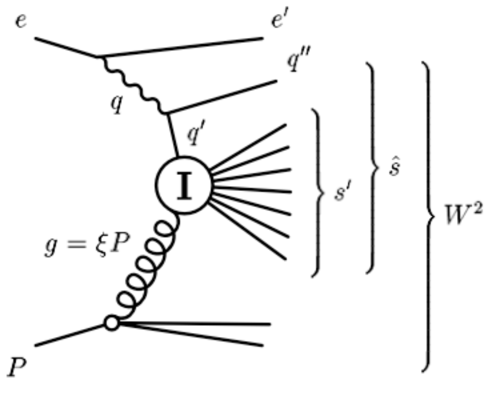


$$\left.\begin{array}{ll} \rho \lesssim \rho_{max} & \approx 0.35\,\mathrm{fm} \\ \frac{R}{\rho} \gtrsim \left(\frac{R}{\rho}\right)_{min} & \approx 1.05 \end{array}\right\} \Rightarrow \left\{\begin{array}{ll} Q'^2 \gtrsim & 113\,\mathrm{GeV}^2 \\ x' \gtrsim & 0.35 \end{array}\right.$$

Cross section in this range predicted by A.Ringwald & F.Schrempp and for

$$0.1 < y < 0.9, x > 10^{-3}$$

$$\sigma_{HERA} \approx 10 - 100\,pb$$



DIS variables:
$Q^2 = -q^2 = -(e - e')^2$
$x = Q^2/(2P \cdot q)$
$W^2 = (q + P)^2 = Q^2(1 - x)/x$
$\hat{s} = (q + g)^2$
$\xi = x(1 + \hat{s}/Q^2)$

Variables of the instanton subprocess:
$Q'^2 = -q'^2$
$x' = Q'^2/(2g \cdot q')$
$s' = (q' + g)^2 = Q'^2(1 - x')/x'$

Sizable number of events on tape expected, but high (factor 100-1000) background

QCDINS Monte-Carlo generator provides full topology

Neutral Current DIS Data Selection

Clean neutral current data from 96-97 ZEUS run period with e^+P colliding beam at HERA

$$E_{e^+} = 27.5 GeV$$
$$E_P = 820 GeV$$

$$38.2 pb^{-1}$$

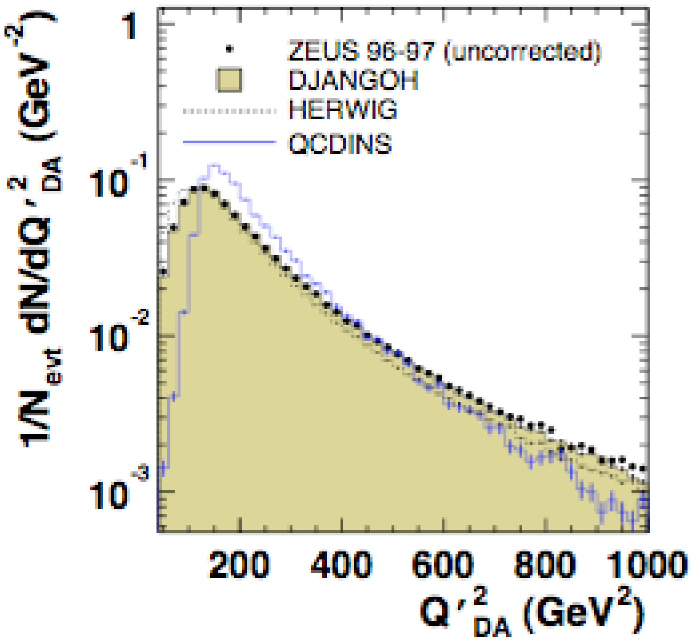
$$Q^2 > 120 GeV^2$$
$$x > 10^{-3}$$
$$y > 0.05$$
$$Q'^2 > 140 GeV^2$$

Data	DJANGOH	HERWIG	QCDINS
91846	88300	76400	578

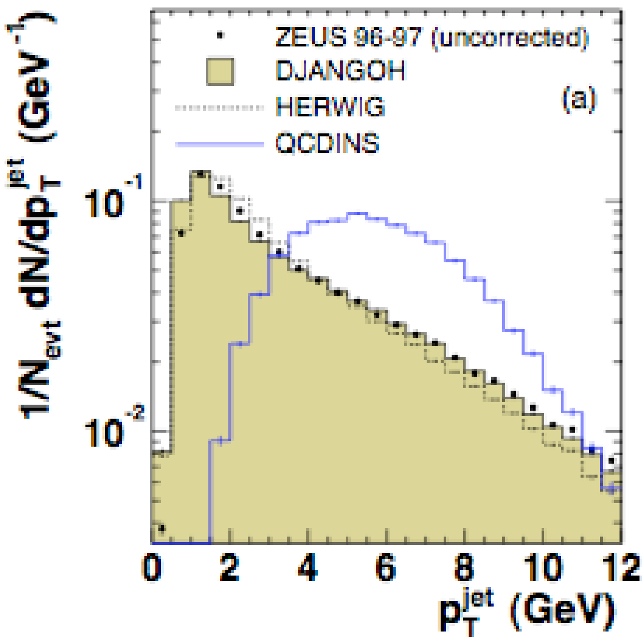
- Predicted instanton cross section 8.9pb
- Instantons only contribute ~0.7%
- Difference between DJANGOH and HERWIG mainly comes from Q'^2 cut

Discriminating Variables from Kinematics

$$Q'^2$$



$$P_t^{current\ \ jet}$$



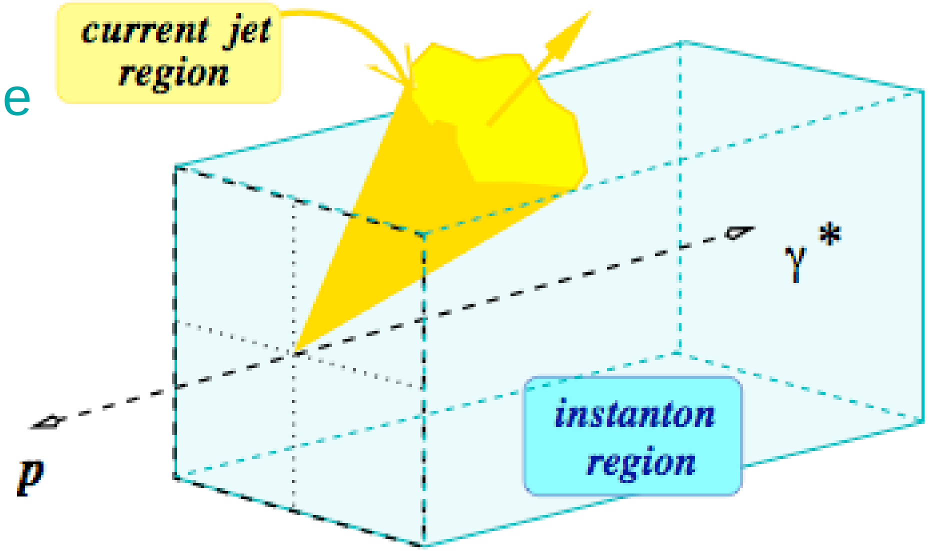
Data qualitatively agrees with DJANGOH and HERWIG, but QCDINS shows different distributions

Discriminating Variables from Shape of Instanton Region

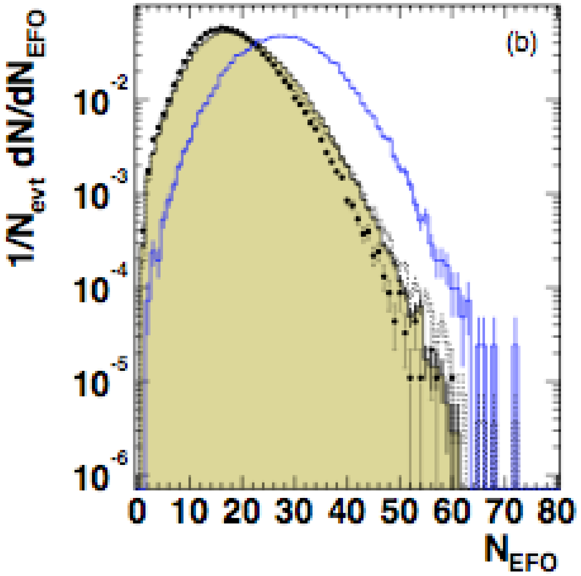
- N_{EFO}
  - Multiplicity of EFOs
- N_{EFT}
  - Multiplicity of tracks in reconstructing EFOs

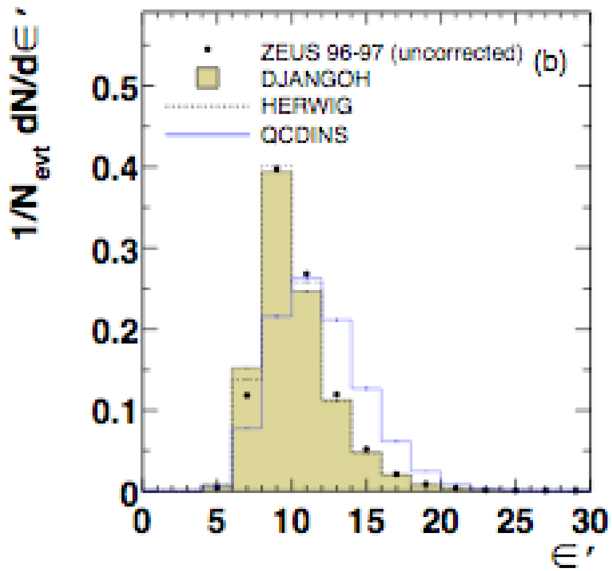
EFO: energy-flow objects measured by Calorimeter

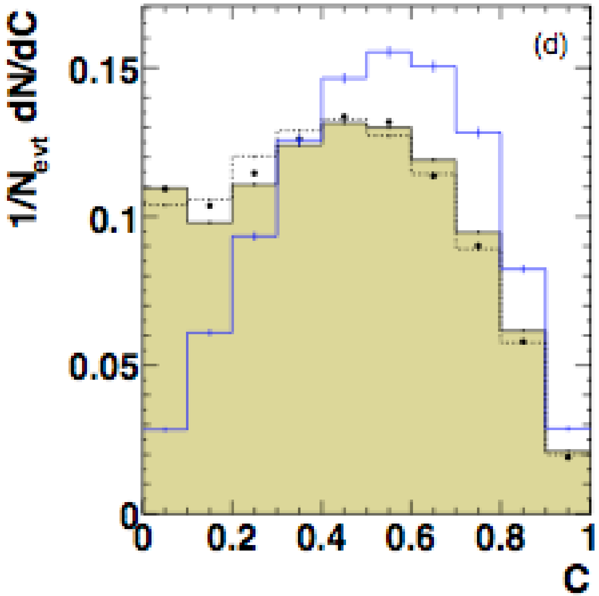
- C
  - 2D isotropy of EFOs in XY plane
- S
  - 3D isotropy of EFOs
- ε'
  - Density of η of EFOs

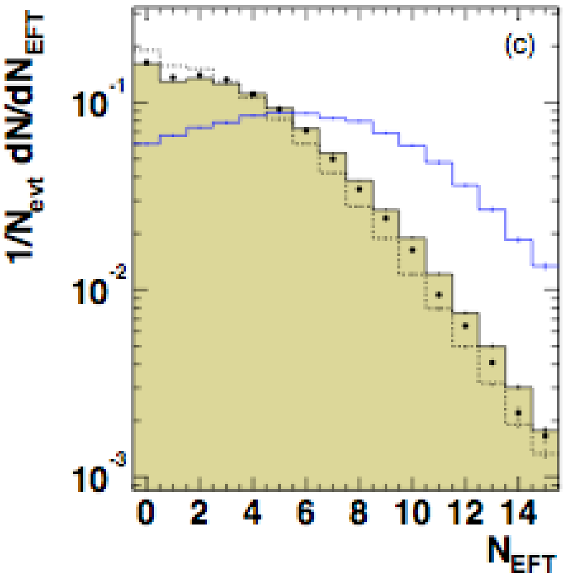


Instanton Shape Variables

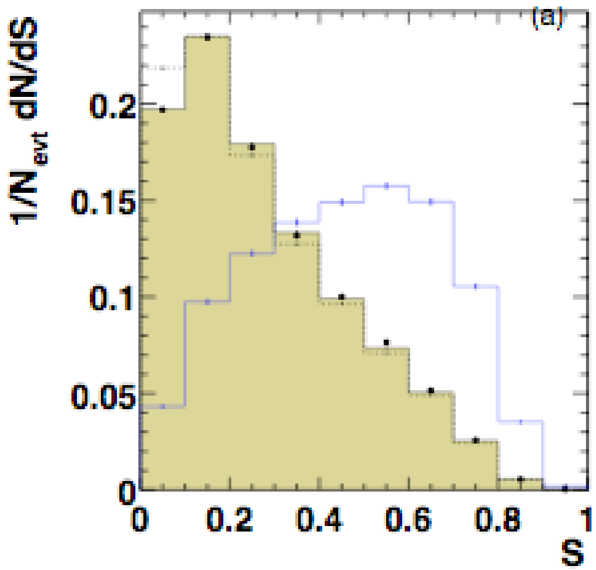




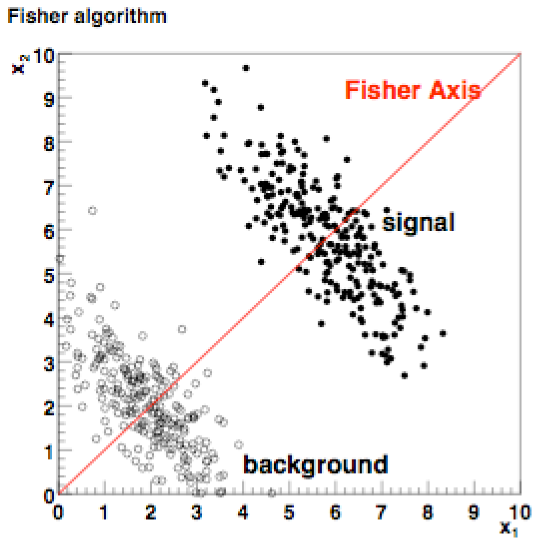




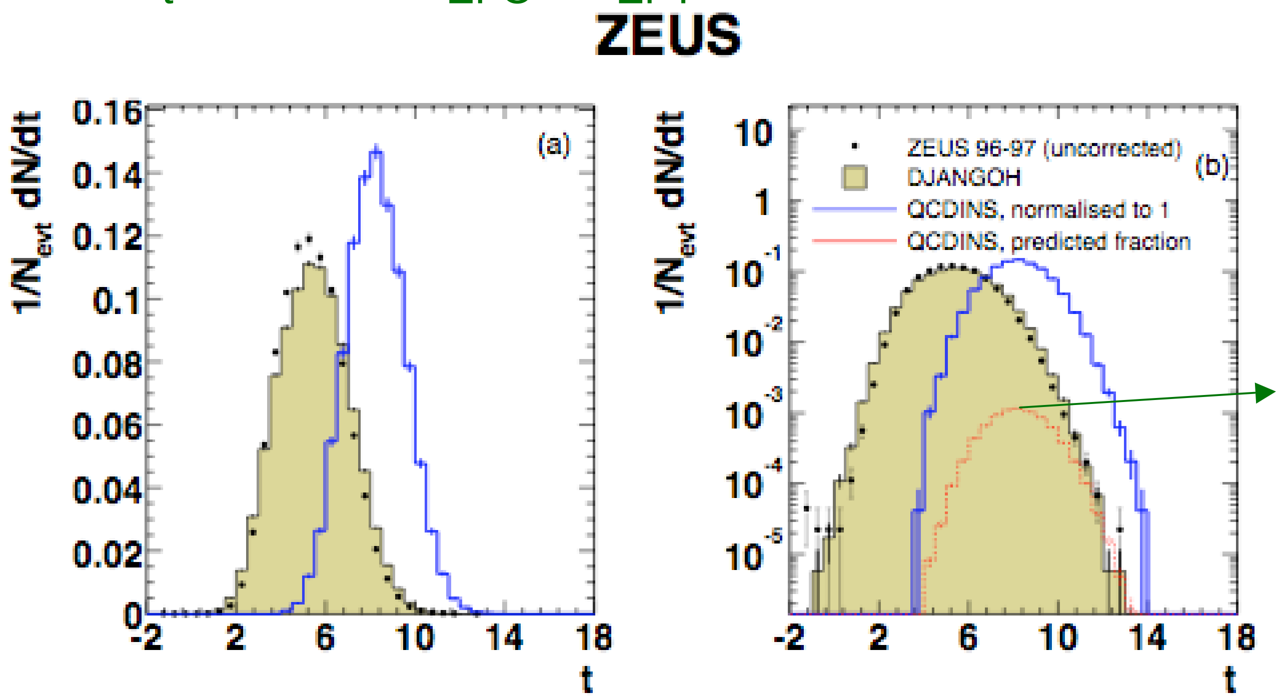
Data qualitatively agrees with DJANGOH and HERWIG, but QCDINS shows quite different distributions



Instanton Enhancement Fisher Algorithm



- Use correlations in n-dimensional phase space explicitly
- Discriminant t obtained from S, C, $P_t^{current\ jet}$, N_{EFO}, N_{EFT} and ε'



- Hard to get signal out
- Set a upper limit

Result: Limit Setting Method

- Background independent method, by applying hard cuts and assuming normal DIS background to be zero
  - Conservative upper limit

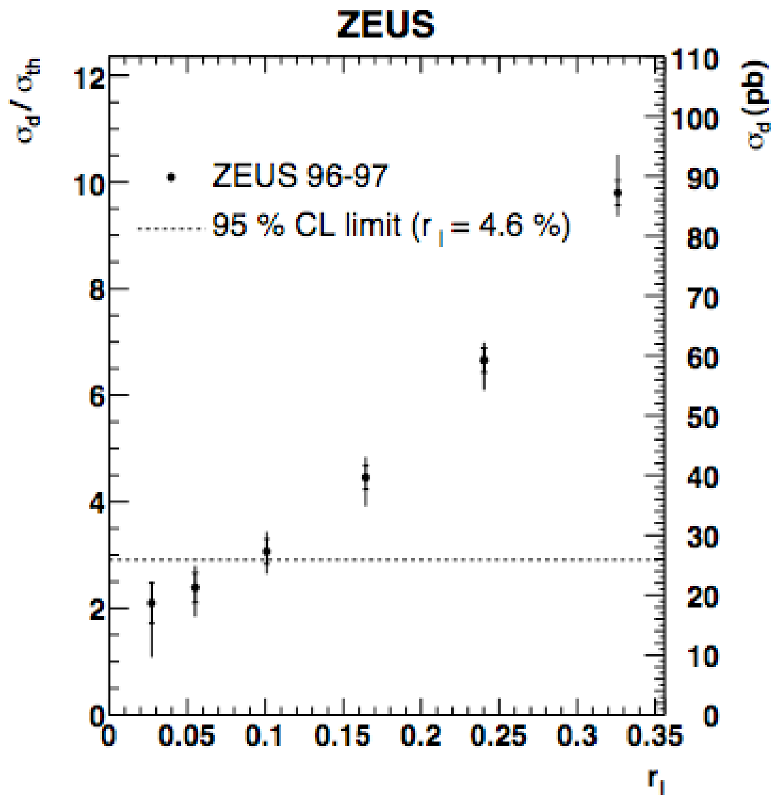
Cut: $Q'^2_{DA} < 250 GeV^2$

$t > t_0$

- r_I
  - Ratio of events left in QCDINS after instanton enhancement selection
- r_N
  - Ratio of events left in DJANGOH(HERWIG) after instanton enhancement selection
- P_S
  - r_I / r_N, describes the separation power

Result: Background Independent Limit

	r_I [%]	DATA	QCDINS	DJANGOH	P_S	HERWIG	P_S
$t > 8.0$	32.6	1847 ± 43	188.5 ± 1.7	2592 ± 26	12	2145 ± 27	14
$t > 8.5$	24.0	925 ± 30	139.0 ± 1.4	1338 ± 19	17	1091 ± 19	21
$t > 9.0$	16.4	424 ± 21	95.1 ± 1.2	630.2 ± 13	24	524.1 ± 13	29
$t > 9.5$	10.1	179 ± 13	58.4 ± 0.9	263.8 ± 8.3	36	229.5 ± 8.8	41
$t > 10.0$	5.5	76 ± 8.7	31.8 ± 0.7	105.6 ± 5.3	49	89.8 ± 5.5	58
$t > 10.5$	2.7	33 ± 5.7	15.7 ± 0.5	35.1 ± 3.0	73	35.1 ± 3.4	73

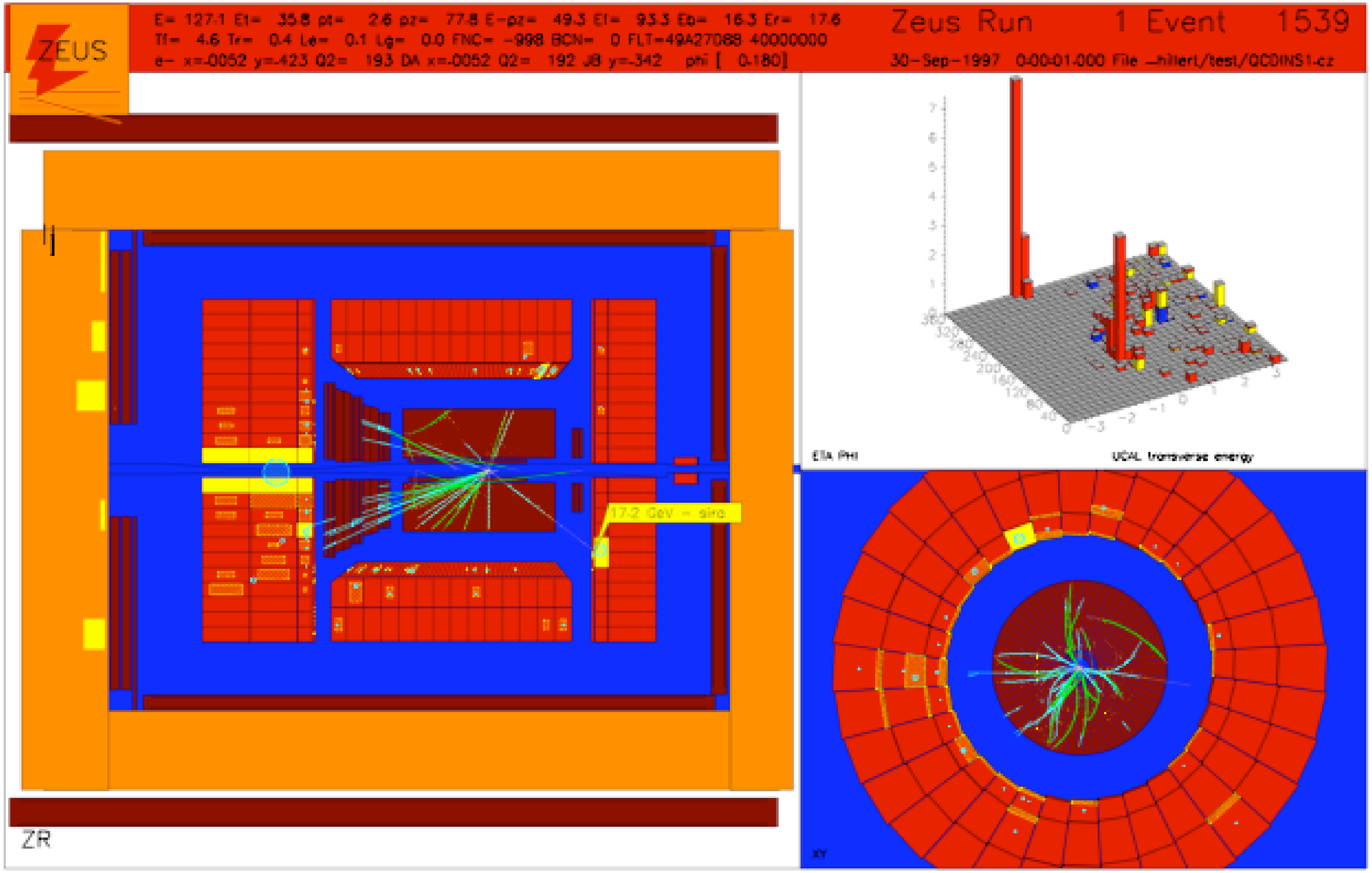


- An upper limit can be derived for any choice of r_I
- Without an explicit choice of r_I, at 95% c.l., an upper limit of 26pb ($r_I \approx 4.6$) is set, compared with theory predicted 8.9pb

Conclusion

- A search of instanton induced events has been performed at ZEUS in NC DIS data based on 38pb^{-1} in the kinematics range Q^2>120GeV^2, x>10^{-3}
- At 95% c.l., an upper limit of 26pb is set, compared with predicted 8.9pb
- Result still consistent with predictions by A.Ringward and F.Schrempp, but not so far away

Instanton Portrait in ZEUS Detector (MC)



Result: Limit Setting Methods

Limits obtained from two different ways:

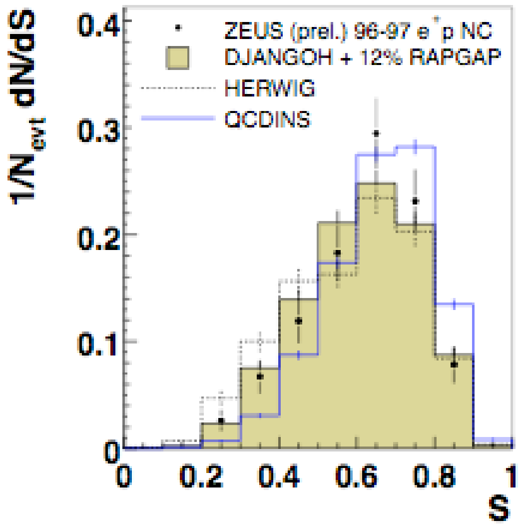
- Fit method, from fit of sphericity distribution in instanton enhanced samples
  - Use f_I, portion of instantons inside the data sample, as parameter, and define

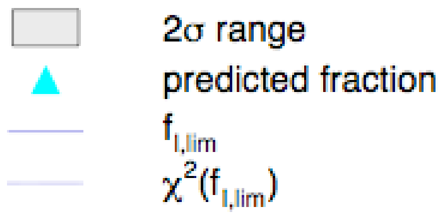
$$\chi^2(f_I) = \sum_{i=1}^{n_{\text{bins}}} \frac{\{n^*_{iD} - [f_I \cdot n^*_{iI} + (1-f_I)\cdot n^*_{iN}]\}^2}{{\sigma^*_{iD}}^2 + f_I^2 {\sigma^*_{iI}}^2 + (1-f_I)^2 {\sigma^*_{iN}}^2}$$

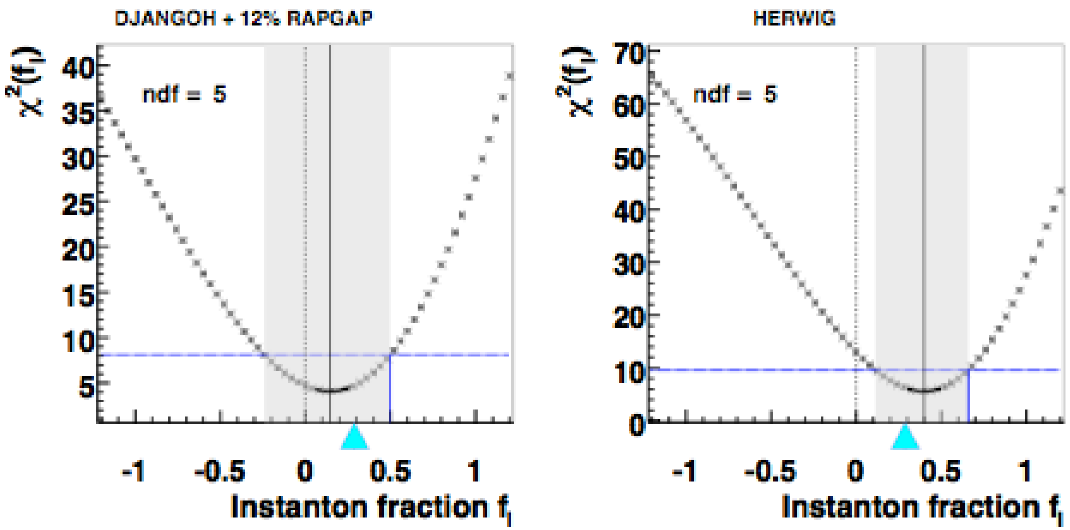
  - Set 2σ limit according to maximum likelihood method
  - Sensitive to exact description of the DIS background

- Background independent method, by applying hard cuts and assuming normal DIS background to be zero
  - Conservative upper limit

Result: Sphericity Fit Approach







cuts: $Q'^2_{\mathrm{DA}} < 250\ \mathrm{GeV}^2$, $t' > 8.0$

(t' calculated from S, C, p_T^{Jet}, N_{efo} and N_{eft}

Predicted		0.28
Fit Minimum	HERWIG	0.397
	DJANGOH	0.146
2σ upper Limit	HERWIG	0.657
	DJANGOH	0.499

- $f_I = 0$ can't be excluded
- Consistent with theoretical prediction