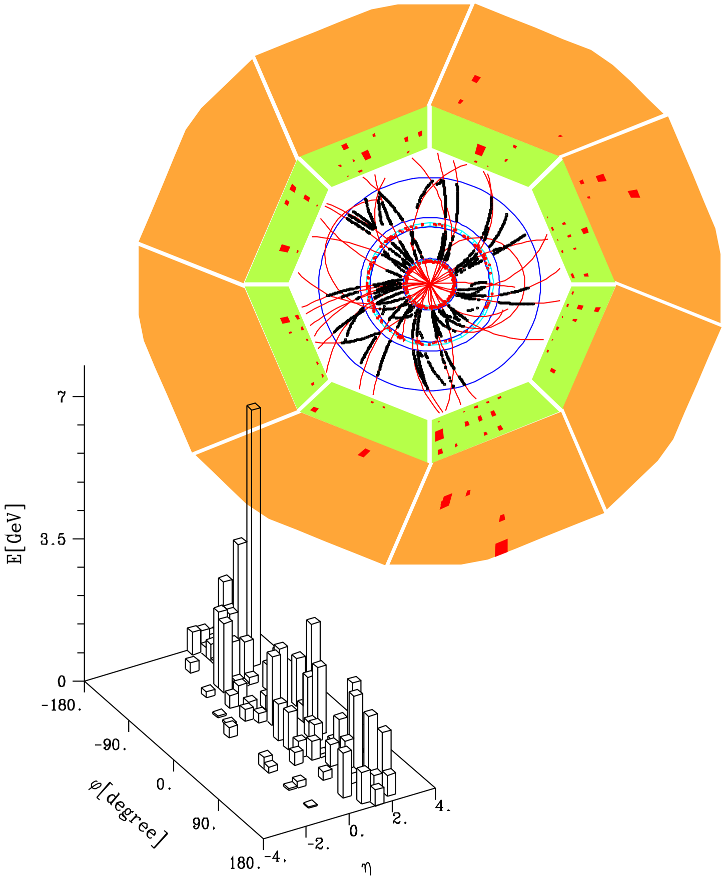
Search for QCD Instanton Induced Processes in DIS at HERA

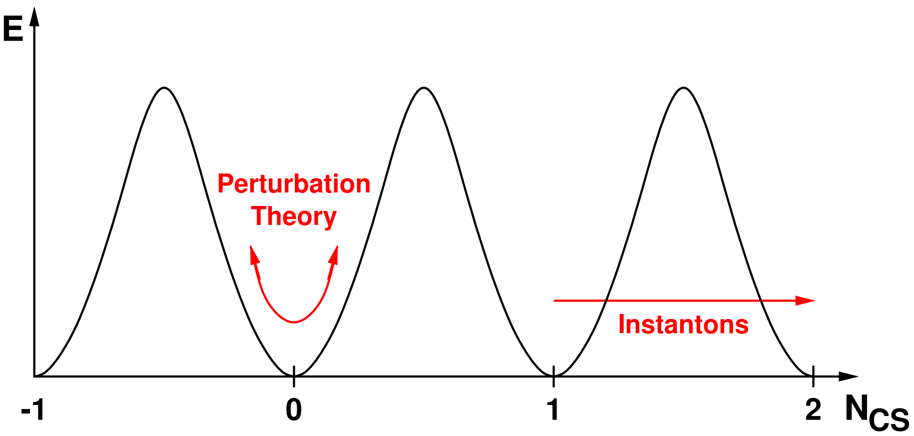
B. Koblitz for the H1-Collaboration



Overview:

- Instantons in DIS
- Experimental Signature
- Results of a Cut-Based Method
  (shown previously)
- Results Using a Discriminant
- Exclusion Limits
- Comparison with Lattice-Data
- Conclusions

What are Instantons?



Instantons are...

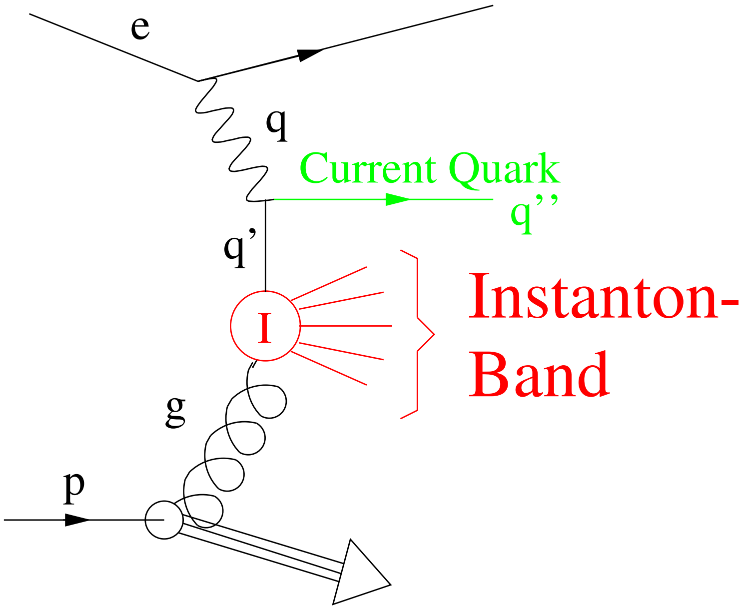
- Tunneling transitions between different topological ground-states in non-abelian gauge theories.
- exponentially suppressed: $\sim e^{-\frac{2\pi}{\alpha}}$
- processes which violate quantum numbers (in QCD: Chirality, in QFD: $B+L$)
- forbidden in perturbation theory
- part of Standard Model

I-density in the vacuum given by I-size ρ and $I\bar{I}$-distance R.

Experimental discovery would be a new non-perturbative manifestation of non-Abelian gauge theories at high energies.

QCD Instantons in DIS

Dominant process in DIS is quark-gluon-fusion:



Variables of I-subprocess:

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

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

I-Variables (x', Q'^2) conjugate to R, ρ.

Theory and phenomenology worked out by
A. Ringwald & F. Schrempp in I-perturbation theory.

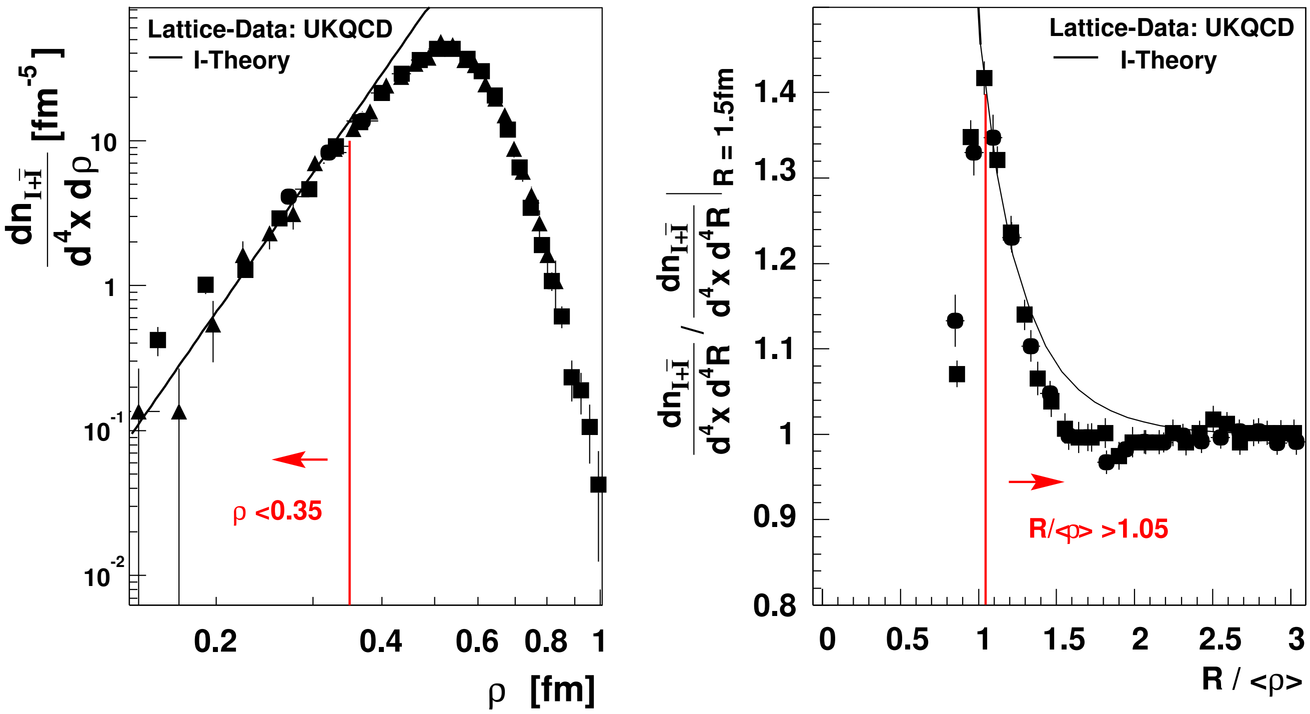
Cross-section in DIS integrates over I-density:

$$D(\rho) \sim \rho^6$$

$\Rightarrow$ Need to find (x', Q'^2) region of validity.

$\Rightarrow$ Comparison with Lattice Simulations.

Comparison to Lattice-Simulations



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

Most recent cross section prediction in this range (A. Ringwald & F. Schrempp) and for

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

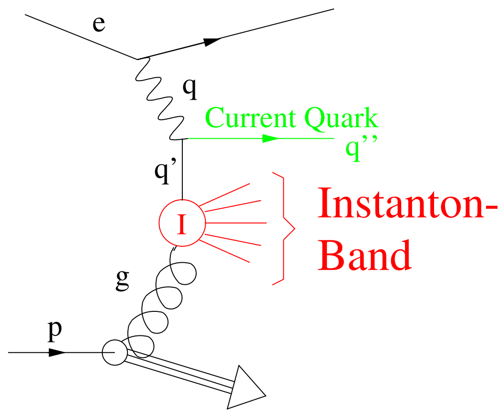
$$\sigma^{(I)}_{\mathrm{HERA}} \approx 10 - 100\,\mathrm{pb}$$

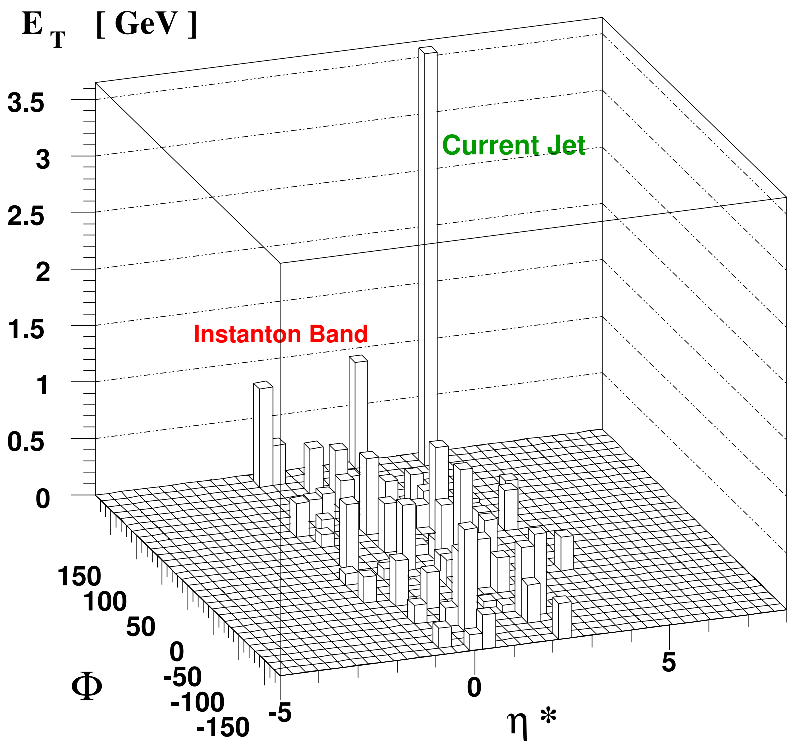
$\Rightarrow$ sizable number of events on tape expected,
but high (factor 100–1000) background

QCDINS Monte-Carlo generator provides full topology

Properties of I-induced Events

E_T-map of a ‘nice’ QCDINS generated event in hadronic CMS $(\vec{q}+\vec{p}=0)$:





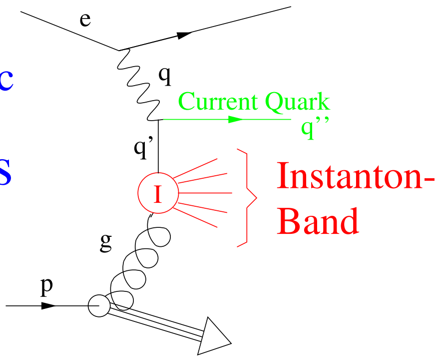
Characteristics used:

- Hard jet ($\rightarrow Q'^2_{\rm rec}$)
- Densely populated band in η, many charged and neutral particles with high E_T, isotropic in I rest frame ($\rightarrow$ Shape-variables)

I-Observables

Reconstruction of Kinematics:

1. Find the current jet:
   Highest E_T-jet in hCMS using cone algorithm with $R = 0.5$, right in $\approx 70\%$ of cases $\Rightarrow Q'^2_{\rm rec}$



2. Remove jet from had. final state objects
3. Reconstruct I-band of $\bar{\eta} \pm 1.1$
4. Boost to $q' + zP = 0$, $z = 0.076$ (QCDINS prediction)
   (approximated I rest system) $\Rightarrow$ Shape Variables

Definition of Observables:

1. Virtuality of quark entering I-subprocess: $Q'^2_{\rm rec}$
2. Number of charged particles in band: $n_{\rm B}$
3. Sphericity of the band $\mathrm{Sph_B}$

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4. $E_{\rm t,Jet}$ of current jet
5. Total transverse energy of band $E_{\rm t,B}$
6. Isotropy of band $\Delta_{\rm B}$

All observables in hCMS except $\Delta_{\rm B}$ and $\mathrm{Sph_B}$.

DIS Event Selection

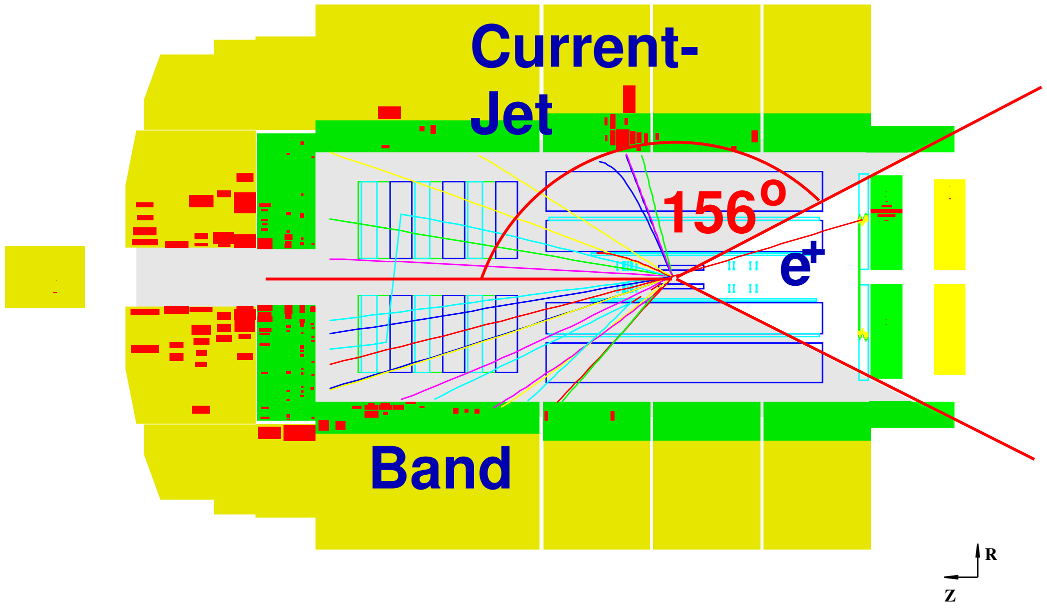
Using data taken in 96/97 $\mathcal{L} = 21.1\,\mathrm{pb}^{-1}$

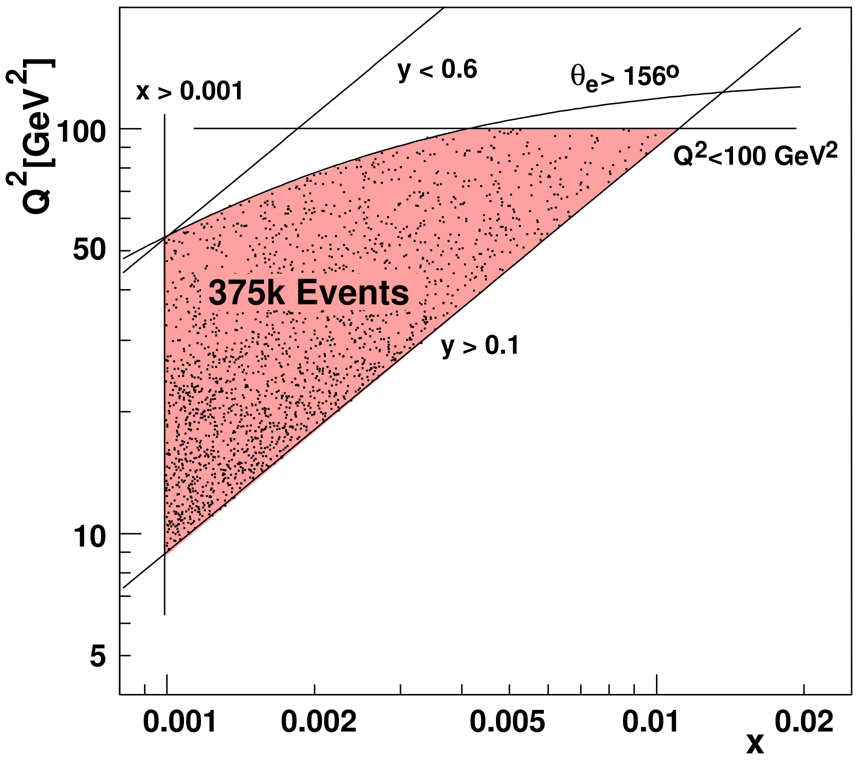
Phase space:

$\theta_{\mathrm{el}} > 156^\circ$,

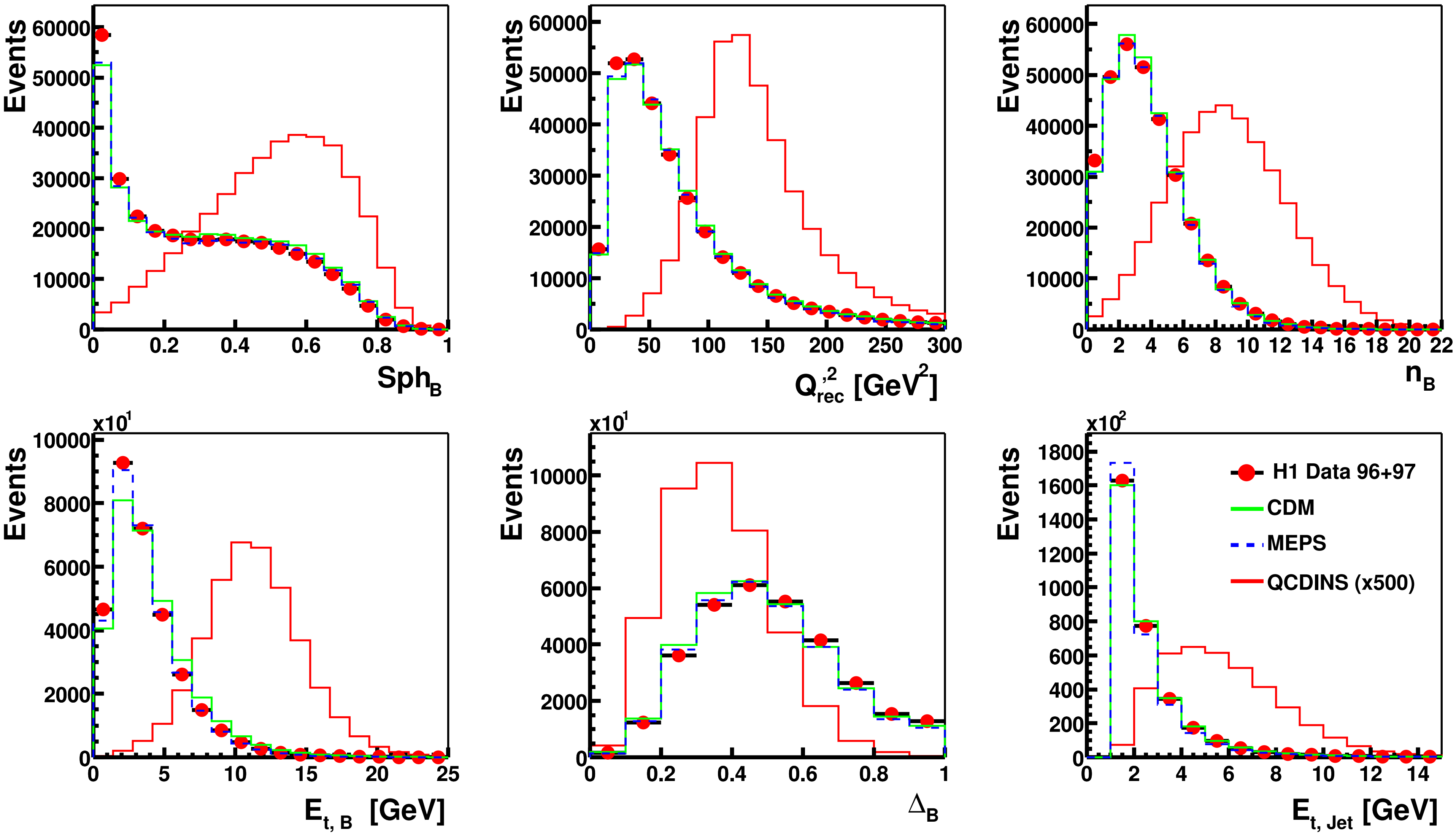
$0.1 < y_{\mathrm{el}} < 0.6, \quad x_{\mathrm{bj}} > 10^{-3}$

Simulated I-event:

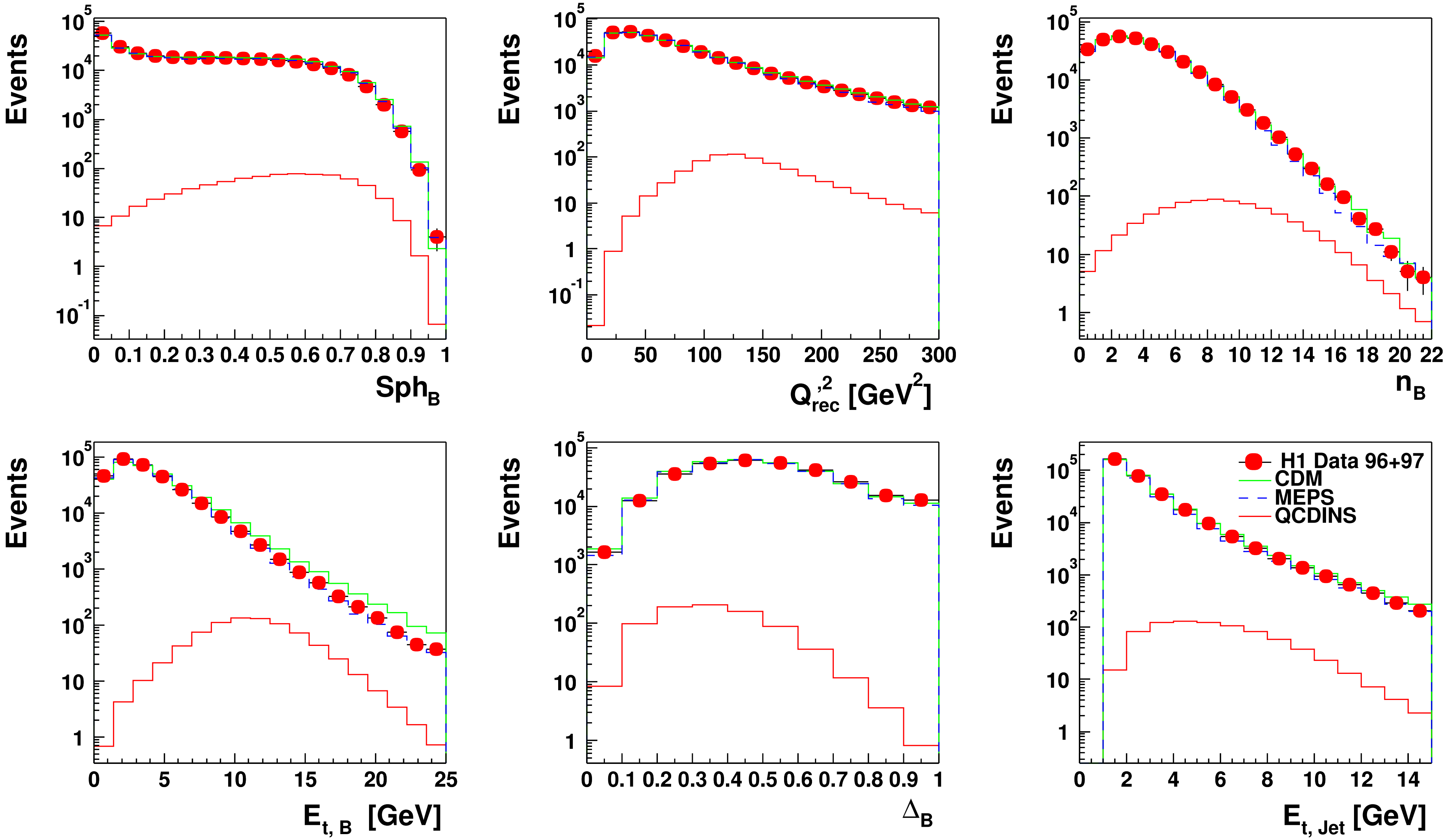




Observables Before Cuts



Observables on Log Scale



Search Strategy

Optimize separation power

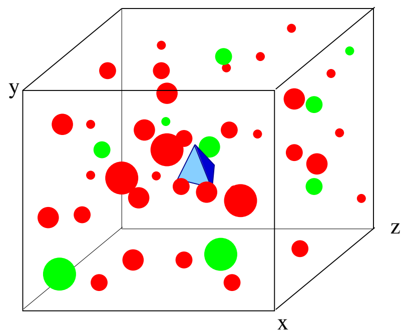
$$S = \frac{\varepsilon_{\mathrm{INS}}}{\varepsilon_{\mathrm{sDIS}}} \quad \text{at } \varepsilon_{\mathrm{INS}} > 10\%$$

using only MC simulations of signal and sDIS Background

Optimized cuts method shown before (S. Mikocki, DIS 2000).

Now: Multivariate Discriminant Method:

Idea: Directly classify events by counting MC-generated Instanton and DIS events in its vicinity.



$$\ell = \frac{\rho(\mathrm{I})}{\rho(\mathrm{nDIS})} = \frac{\#I(V)}{\#nDIS(V)}$$

Discriminant: $D = \frac{\ell}{1+\ell}$

How to find all events in vicinity in reasonable time?

$\Rightarrow$ Range Searching (details: hep-ph/0011224)

Method allows: $\Rightarrow$ Higher separation

$\Rightarrow$ Investigation of gradual transition from DIS-like to Instanton-like events with single variable

$D = f(n_{\mathrm{B}}, \mathrm{Sph}_{\mathrm{B}}, Q'^2_{\mathrm{rec}})$

Results after Cuts

1. Optimised Cuts Method: Selected cut:

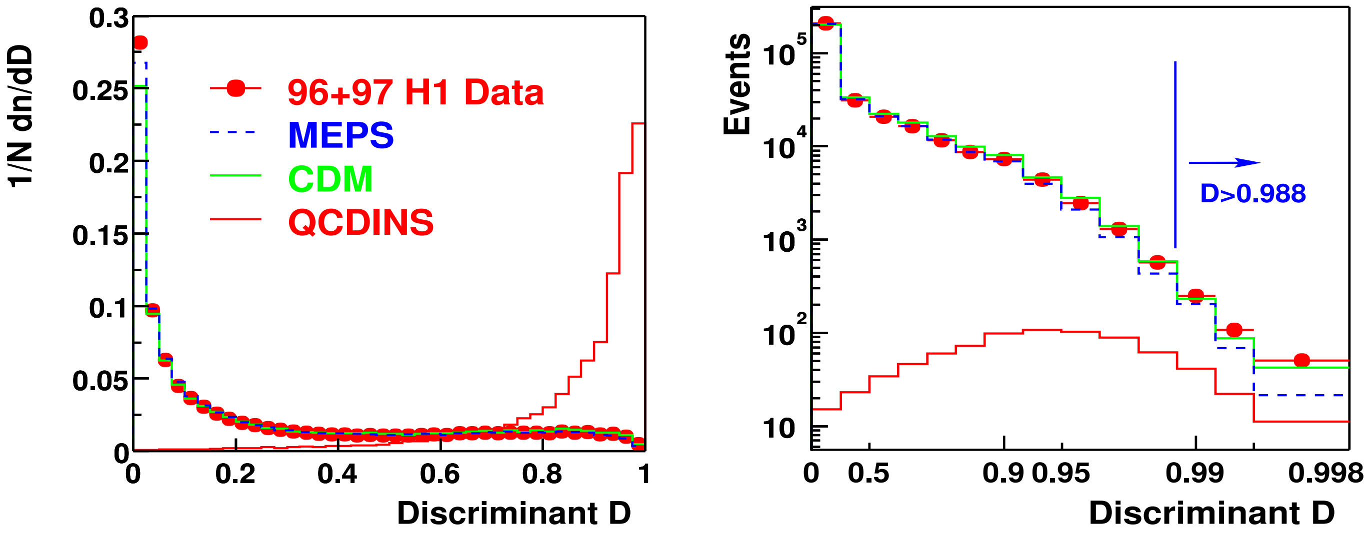
$$n_{\mathrm{B}} > 11, \quad 95 < Q'^2_{\mathrm{rec}} < 200\,\mathrm{GeV}^2, \quad \mathrm{Sph}_B > 0.4$$

Performance: $\varepsilon_{\mathrm{INS}} = 10.2\%$, $S_{\mathrm{CDM}} = 86$, $S_{\mathrm{MEPS}} = 125$

Events after cut:

DATA	CDM	MEPS
484	443^{+29}_{-35}	304^{+21}_{-25}

2. Discriminant Method:



Selected cut: $D > 0.988$

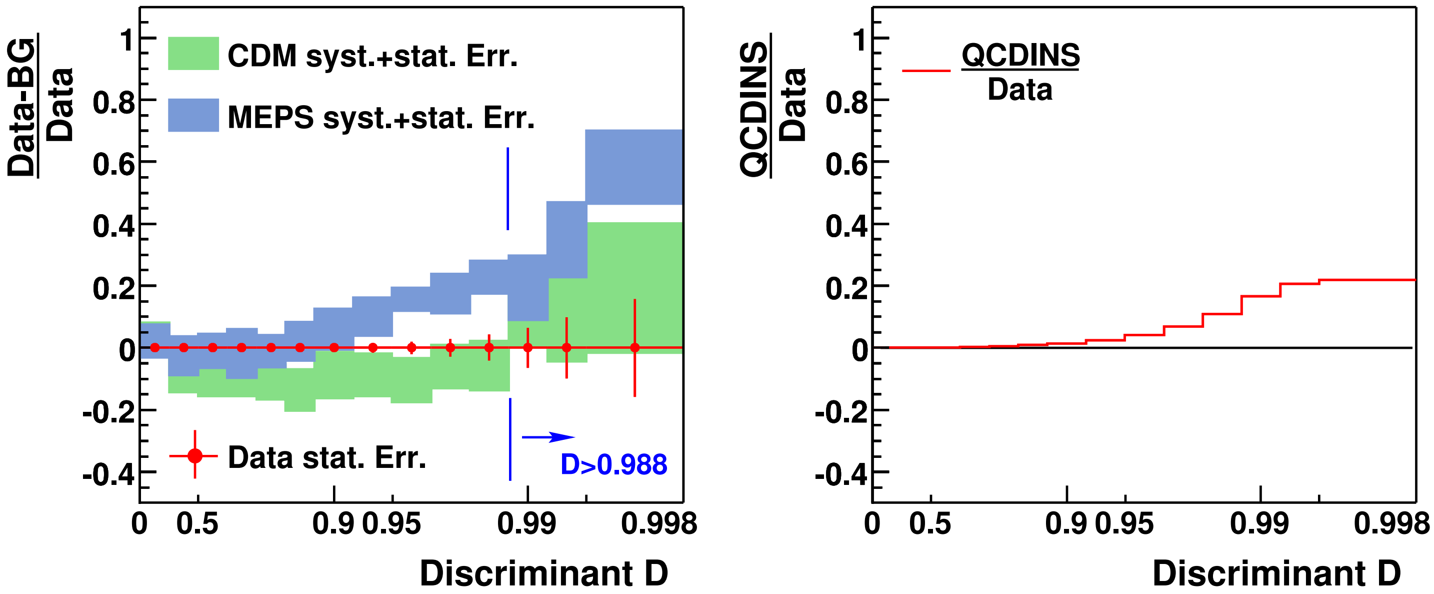
Performance: $\varepsilon_{\mathrm{INS}} = 10.0\%$, $S_{\mathrm{CDM}} = 106$, $S_{\mathrm{MEPS}} = 126$

Events after cut:

DATA	CDM	MEPS
410	354^{+40}_{-26}	299^{+25}_{-38}

Discriminant can show transition to I-region:

Close-Up of Discriminant



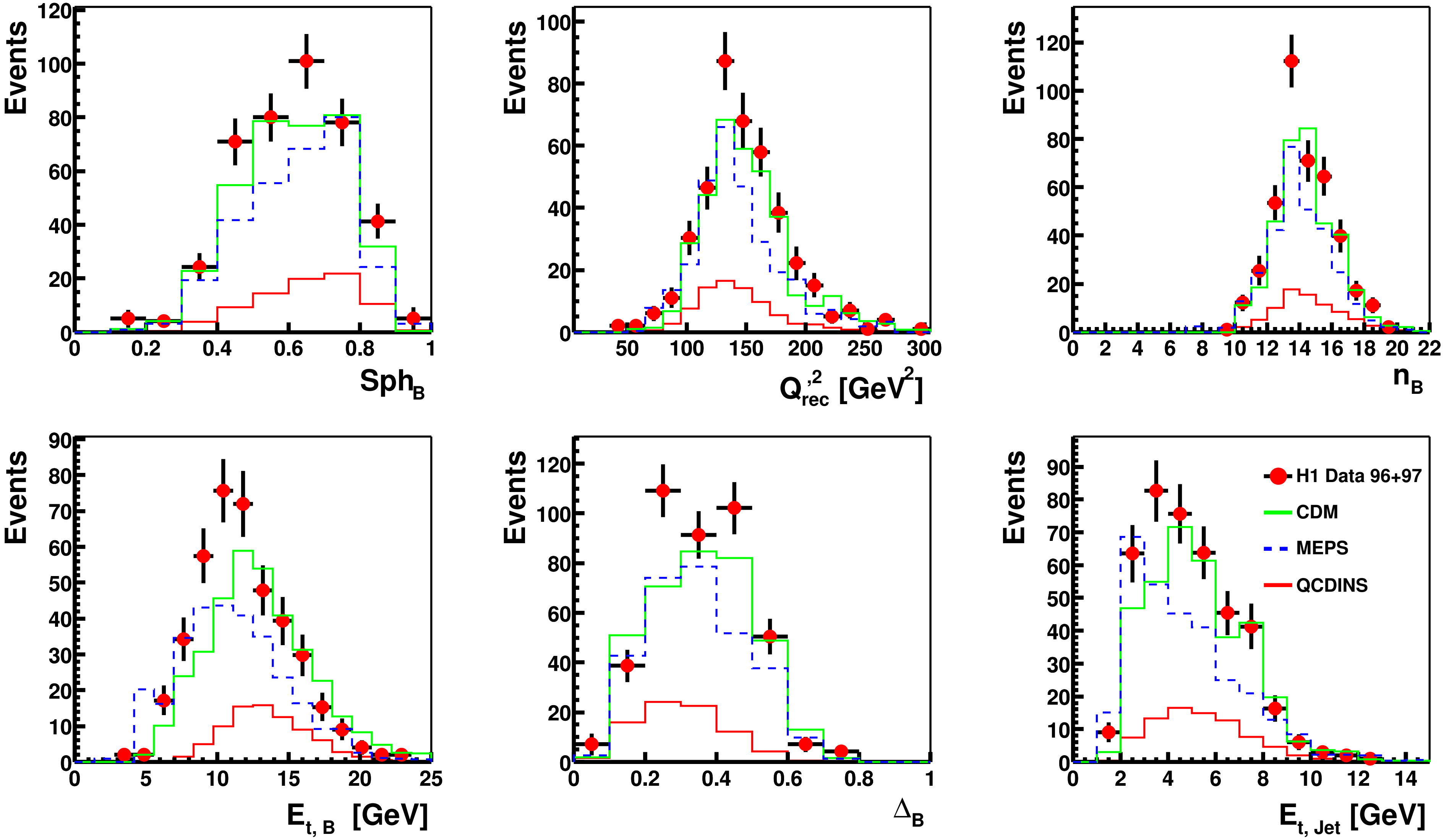
MEPS describes data for $D < 0.9$, but below data in I-Region, excess in qualitative agreement with I-prediction

CDM describes data at $D \approx 0$, but not for $0.2 < D < 0.9$, above $D > 0.95$ in agreement with data

Large uncertainty of background.

How do the observables look like after the cut?

Observables After Cut $D > 0.988$



Exclusion Limits

Background uncertainties too large to draw firm conclusions.

$\Rightarrow$ We set exclusion limits (95% CL):

In fiducial I-source region ($x' > 0.35, Q'^2 > 113\,\mathrm{GeV}^2$):

	CDM	MEPS	BG=0
Opt. Cuts	$\sigma_{\mathrm{lim}} = 47\,\mathrm{pb}$	$\sigma_{\mathrm{lim}} = 109\,\mathrm{pb}$	$\sigma_{\mathrm{lim}} = 255\,\mathrm{pb}$
Discriminant	$\sigma_{\mathrm{lim}} = 55\,\mathrm{pb}$	$\sigma_{\mathrm{lim}} = 80\,\mathrm{pb}$	$\sigma_{\mathrm{lim}} = 221\,\mathrm{pb}$

Model independent limit by setting background to zero (BG=0). Optimized cuts shown before (S. Mikocki, DIS 2000).

QCDINS predictions depend on x', Q'^2 distribution

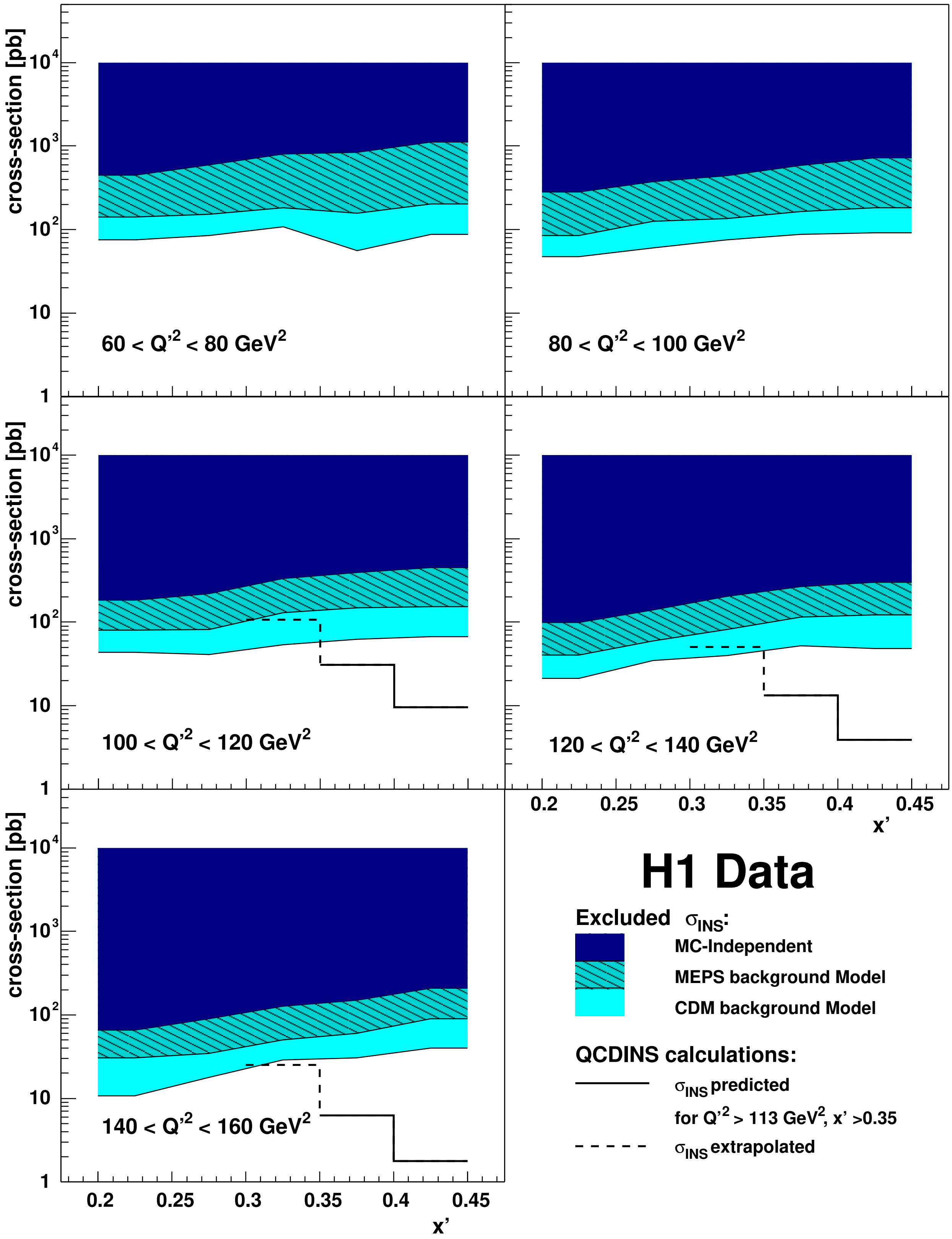
$\Rightarrow$ Work at fixed x', Q'^2 to set limits for Instantons with different size and distances

$\Rightarrow$ Rely only on I-topology

$\Rightarrow$ Background independent limits for BG=0

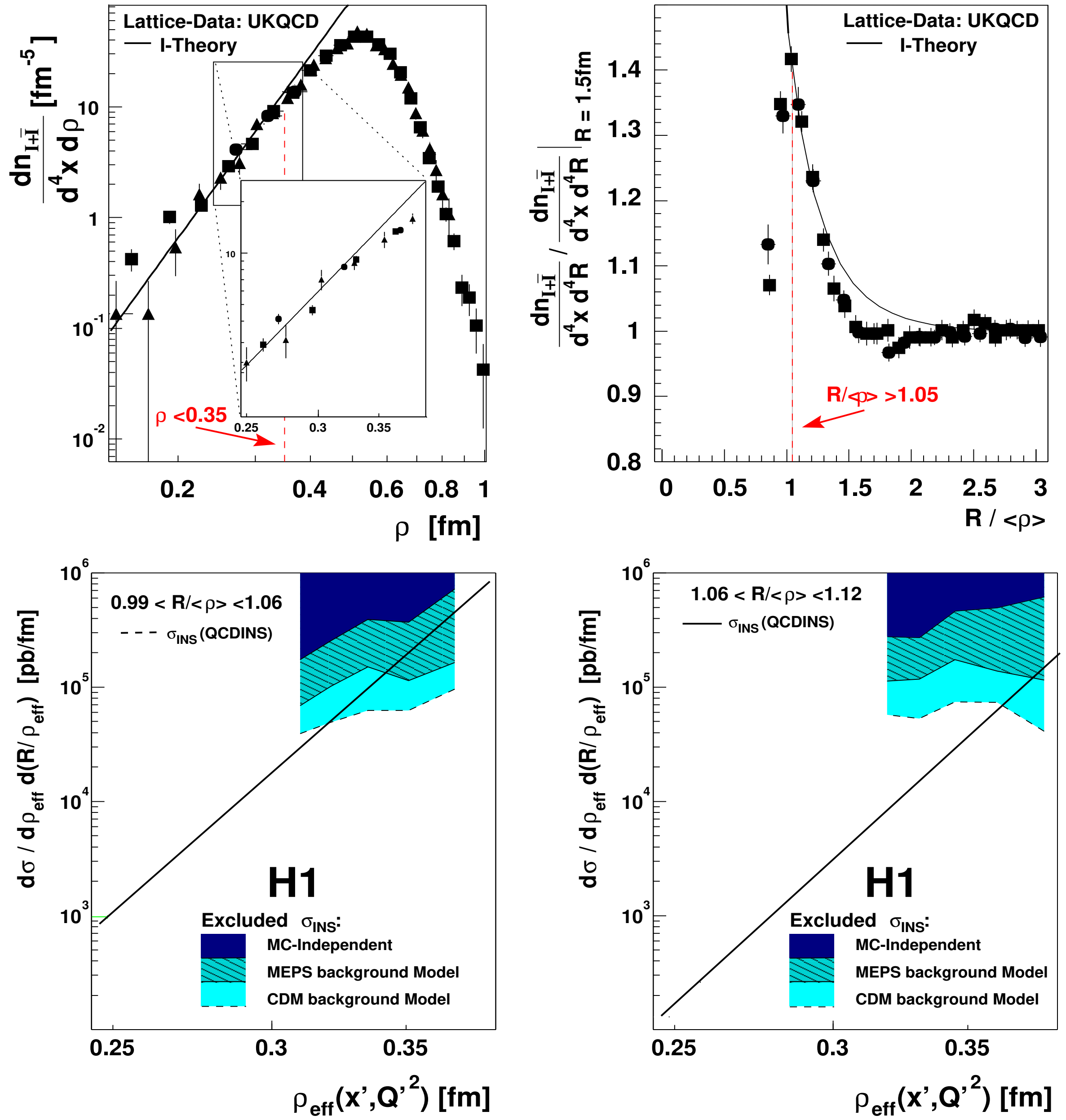
Limits depend only on I-topology and # events in data.

Exclusion Limits



Comparison with Lattice-Simulations

Perturbative theory only valid for small I-sizes $\rho < 0.35\,\mathrm{fm}$ and large $I\bar{I}$-distances $R/\langle\rho\rangle > 1.05$ ($\triangleq x' > 0.35$, $Q'^2 > 113\,\mathrm{GeV}^2$)



Start to exclude steep rise of pert. I-cross-section at large I-sizes. In agreement with lattice-simulations.

Better understanding of BG needed!

Conclusions & Outlook

Conclusions:

- First dedicated exp. search for QCD instanton-induced processes modelled by QCDINS conducted at
$$x > 10^{-3}, \quad 0.1 < y < 0.6, \quad \theta_e > 156^\circ$$
- More sensitive multivariate discriminant analysis agrees with previous H1 search, allows to study transition from BG to I-region.
- Discriminant based on 3 observables n_B, Sph_B and Q'^2_{rec} achieves background reduction of 1000 at $\varepsilon_{\mathrm{INS}} = 10\%$.
- After cut 410 events are observed while 354^{+40}_{-26} (CDM) and 299^{+25}_{-38} (MEPS) events are expected.
- H1 data starts to exclude steep rise in cross-section to large I-sizes predicted by extrapolation of I-pert. theory. This is in accordance with lattice data.

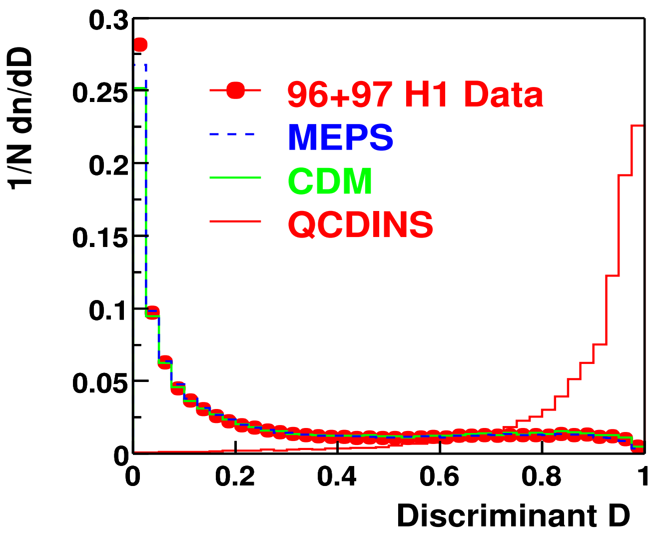
Outlook:

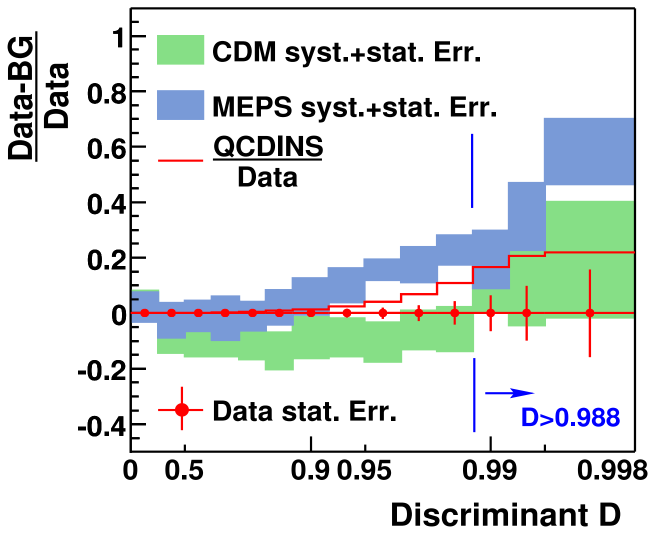
- Limited by BG uncertainties!
$\Rightarrow$ search at high Q^2.
- Exploit chirality violation and flavour tag.

Summary: Search for Instantons in DIS

QCD-Instantons are tunneling transisitions between topologically different QCD-vacua.
DIS offers unique opportunity to find instantons.

H1 used multivariate discrimination method based on char. hadr. final state observables to suppress standard DIS BG (update of S. Mikocki, DIS 2000):





Selected cut: $D > 0.988$

Events after cut:

DATA	CDM	MEPS
410	354^{+40}_{-26}	299^{+25}_{-38}

$$(x > 10^{-3}, \quad 0.1 < y < 0.6, \quad \theta_e > 156^\circ)$$

No significant excess seen in the data.

$\Rightarrow$ Limits are made for different I-sizes ρ and $I\bar{I}$ distances R.

Comparison with Lattice-Simulations

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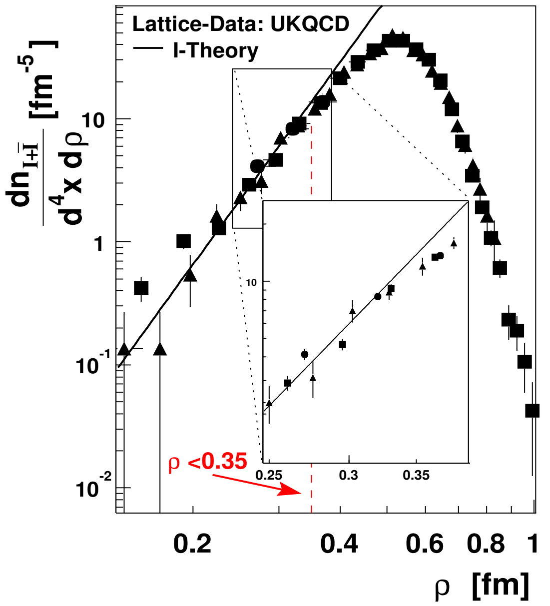

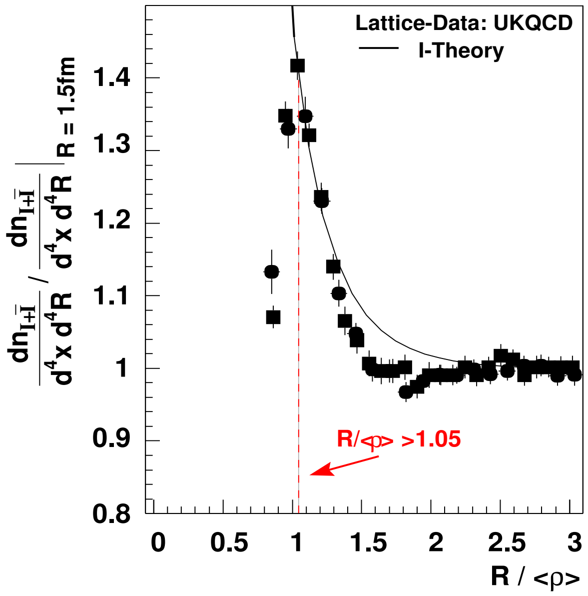

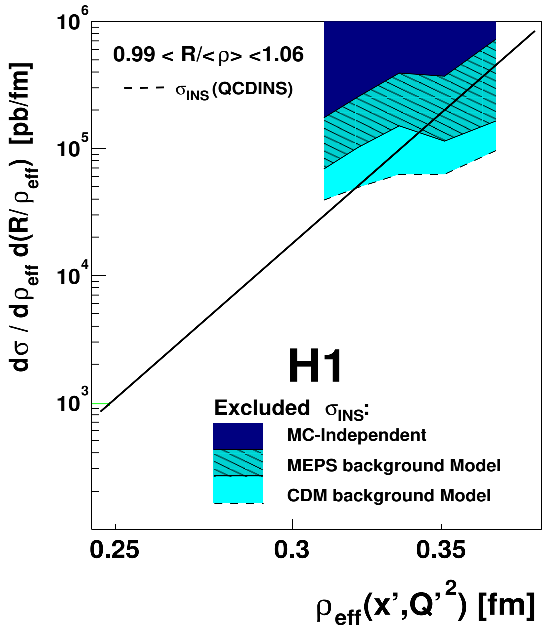

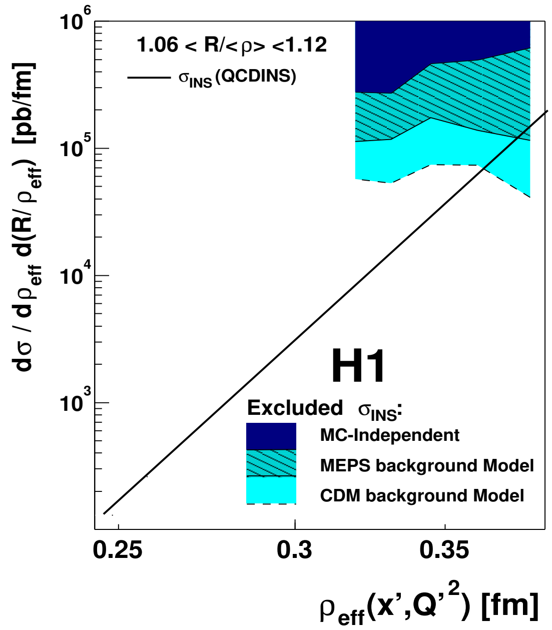

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