Search for QCD Instanton-induced Processes in DIS at HERA

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for the H1 Collaboration

- ❏ Instantons in QCD and DIS
- ❏ Search Strategy
- ❏ Results
- ❏ Summary

ICHEP2000, Osaka July 27–August 2, 2000

Further reading

Instanton-Perturbation Theory in DIS

A. Ringwald and F. Schrempp,
Nucl. Phys. B 507 (1997) 134
A. Ringwald and F. Schrempp,
Phys. Lett. B 438 (1998) 217
A. Ringwald and F. Schrempp,
Phys. Lett. B 459 (1999) 249
Update: papers 250, 251, 252, 254, 255 ICHEP2000
...and more !

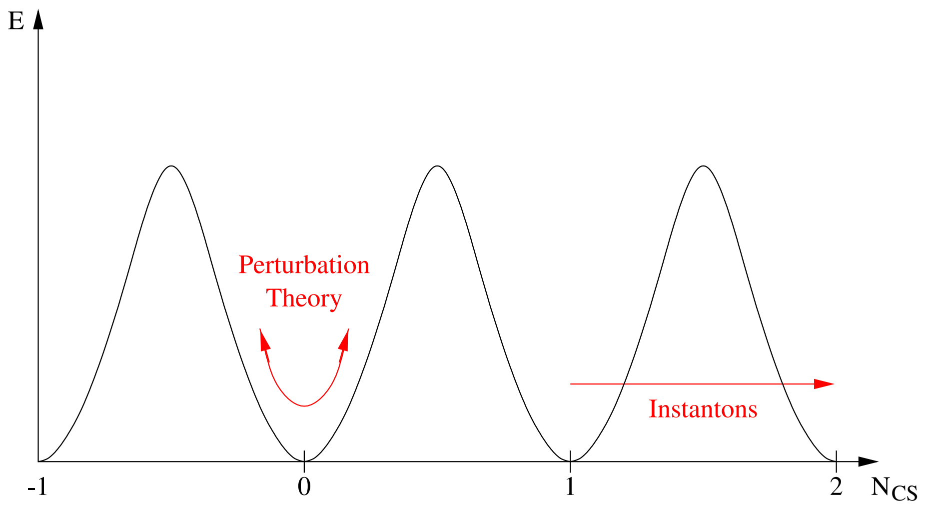
Experimental searches and strategies

T. Carli and M. Kuhlen,
Nucl.Phys. B511 (1998) 85
T. Carli, J. Gerigk, A. Ringwald and F. Schrempp,
hep-ph/9906441

See also A. Ringwald and F. Schrempp

http://www.desy.de/∼ringwald
http://www.desy.de/∼t00fri/talks/talks.html
http://www.desy.de/∼t00fri/instanton.html

What are Instantons?



• Tunneling transitions between topological inequivalent ground-states (feature of non-abelian theories)

• exponentially suppressed $\sim e^{-4\pi/\alpha}$

• may become observable at high energies via production of additional gauge bosons (Ringwald, Espinosa 90)

• processes which violate quantum number conservation. In QCD: Chirality: $\#(q_R) - \#(q_L)$ is normally conserved

• not present in conventional perturbation theory

• but... part of standard model

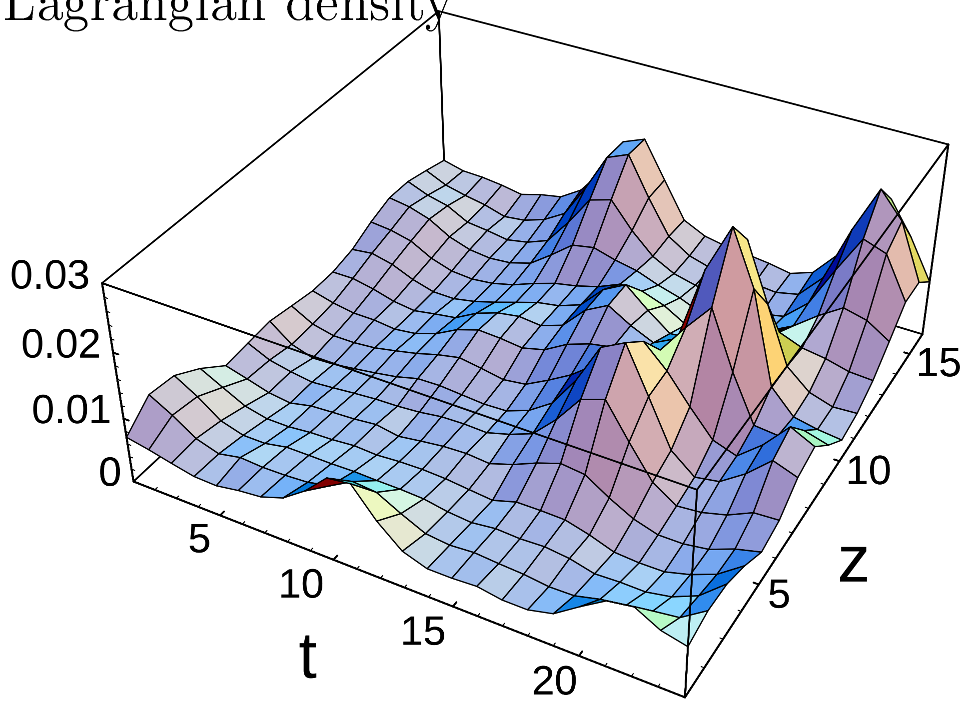
Experimental discovery would be novel non-perturbative evidence for non-Abelian gauge theories.

Instantons in QCD

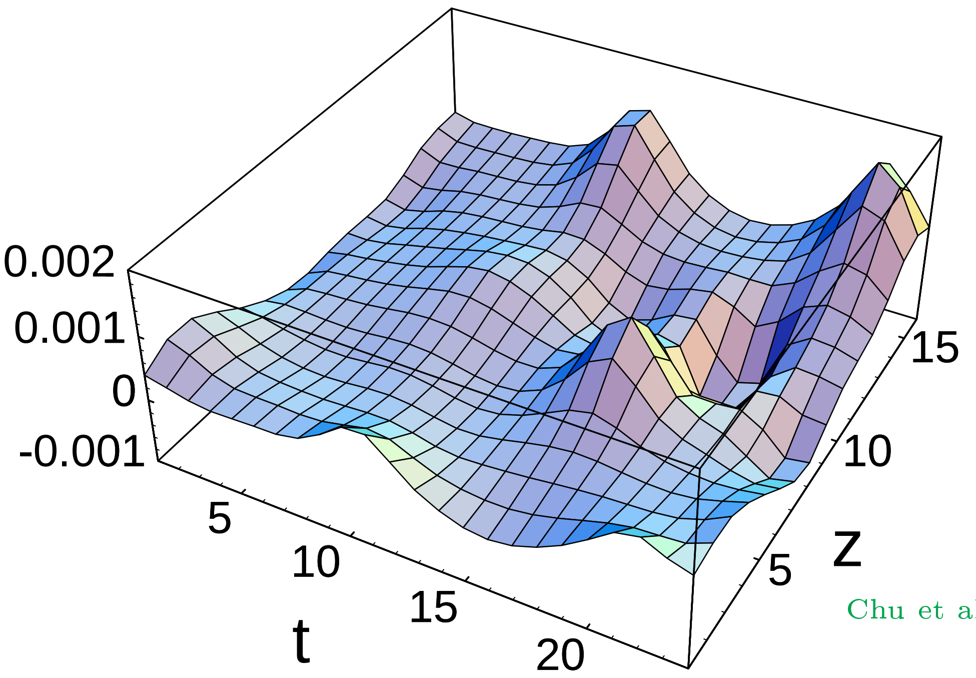
Non-perturbative topological fluctuations of gauge fields in time and space

Snapshot of the QCD vacuum

Lagrangian density



Topological Charge: $Q = \frac{\alpha_S}{2\pi} \int d^4x\, \frac{1}{2}\mathrm{tr}(F_{\mu\nu}\tilde{F}_{\mu\nu}) = \pm 1, \pm 2, \ldots$



Chu et al. PRD 49 (1994) 6039

Comparison to Lattice calculations

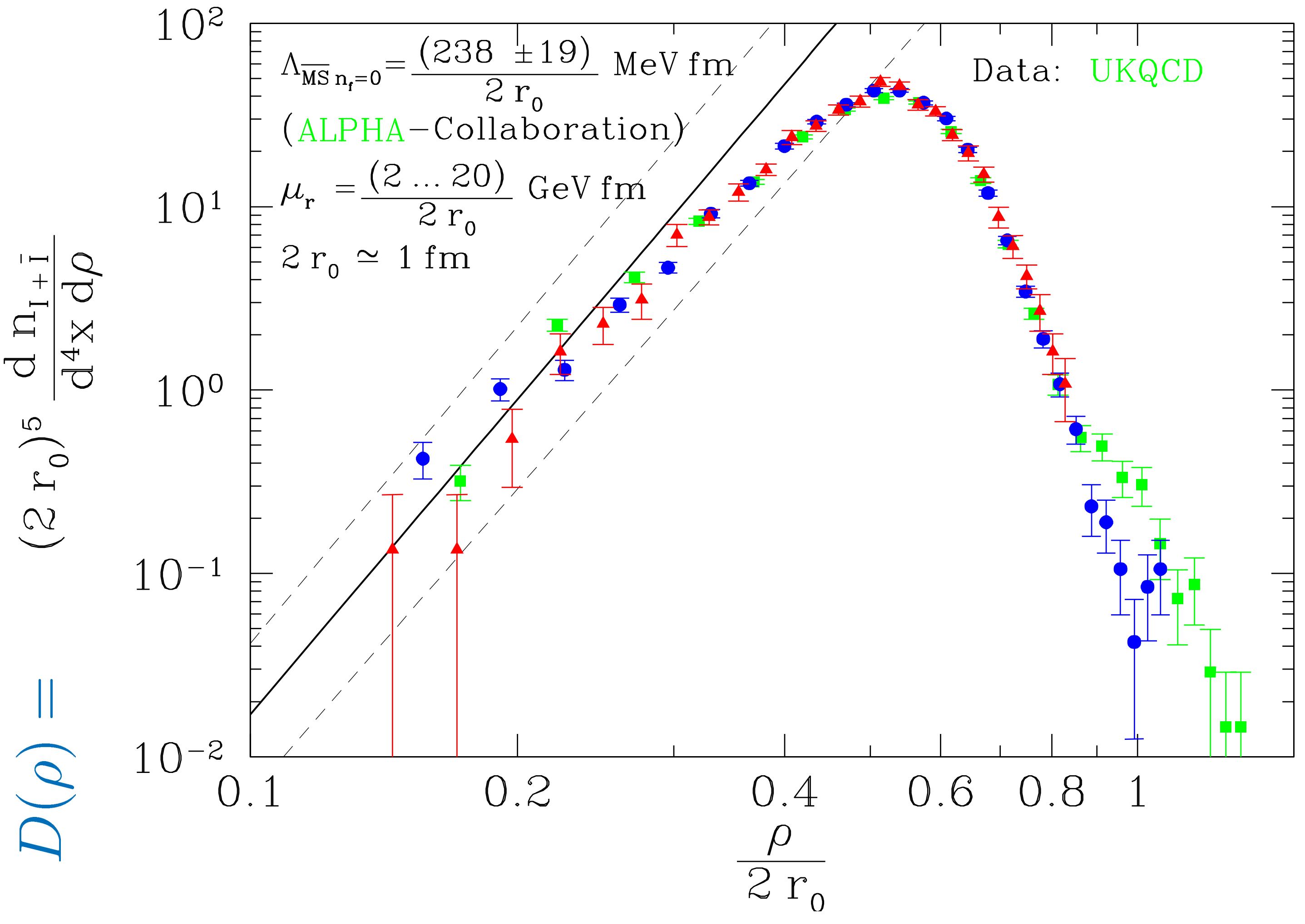
See Ringwald&Schrempp, paper #255 this conf.

QCD lattice vacuum fluctuations calculated in Euclidean $(\vec{x}, t)$, $n_f = 0$

Extract fiducial region (ρ, R) or $({Q'}^2\ , x')$ where I-perturb. theory is valid

(ρ=size,$R = I, \overline{I}$ distance)

$D(\rho) =$



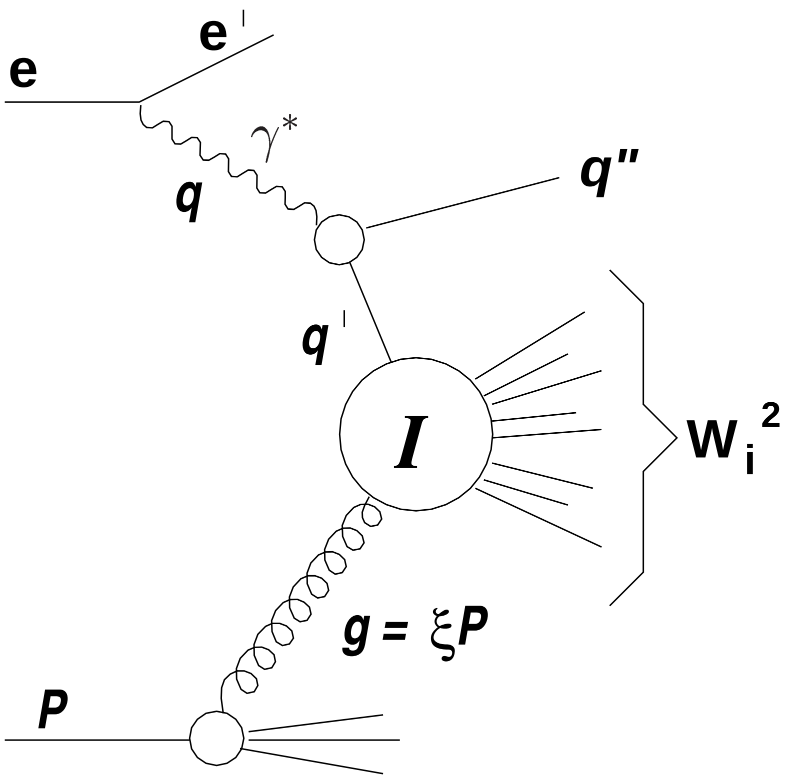
Agreement in shape and normalisation (!) for $\frac{\rho}{2\, r_0} \lesssim 0.35$

Error band due to uncertainty in $\Lambda_{\bar{MS}}^{(n_f=0)}$

$$\boxed{\begin{array}{lcl} \rho\Lambda_{\bar{MS}}^{(n_f=0)} \leq 0.42 & \leftrightarrow & Q'\ /\Lambda_{\bar{MS}}^{(n_f)} \geq 30.8 \\ R/\rho \geq 1 & \leftrightarrow & x' \geq 0.35 \end{array}}$$

For $Q^2 > 113\ \ \mathrm{GeV}^2, 0.1 < y < 0.9$: $\sigma_{HERA}^{(I)} = 29^{+10}_{-7.5}$ pb

Instantons in DIS



Variables of I-subprocess:

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

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

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

experimentally:
difficult or impossible
to reconstruct/cut

Instanton-induced events produced in quark-gluon fusion

Theory and phenomenology $\longrightarrow$ Ringwald&Schrempp

DIS: large Q'^2 selects small-size I's $\rightarrow$ I-pert.theory valid

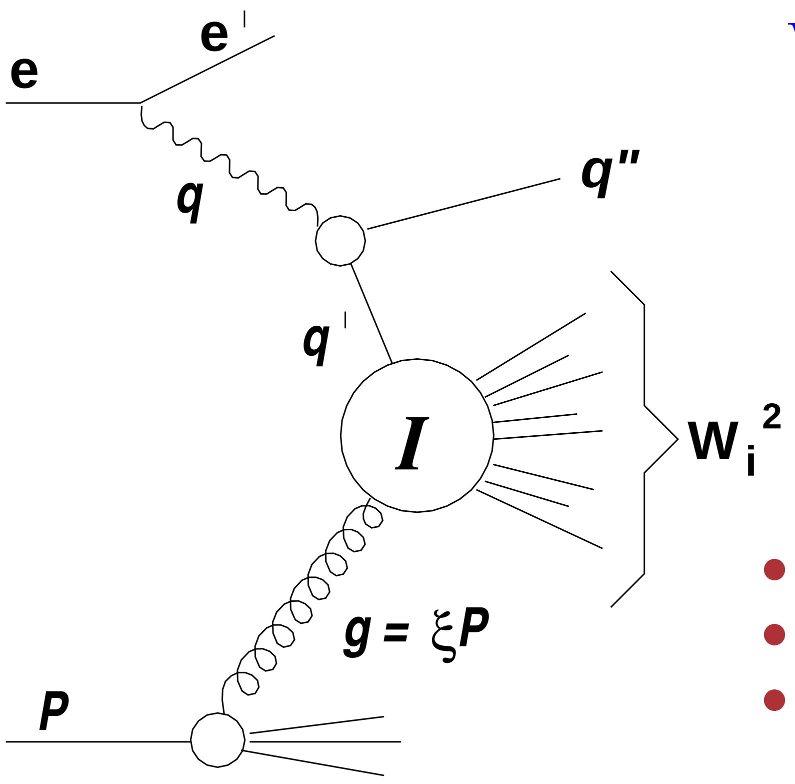
Implemented in QCDINS Monte Carlo (R&S, paper#251, this conf.)

Cross section prediction order $10 - 100$ pb

Expect sizeable number of events

but background O(100-1000) larger

Experimental Signature

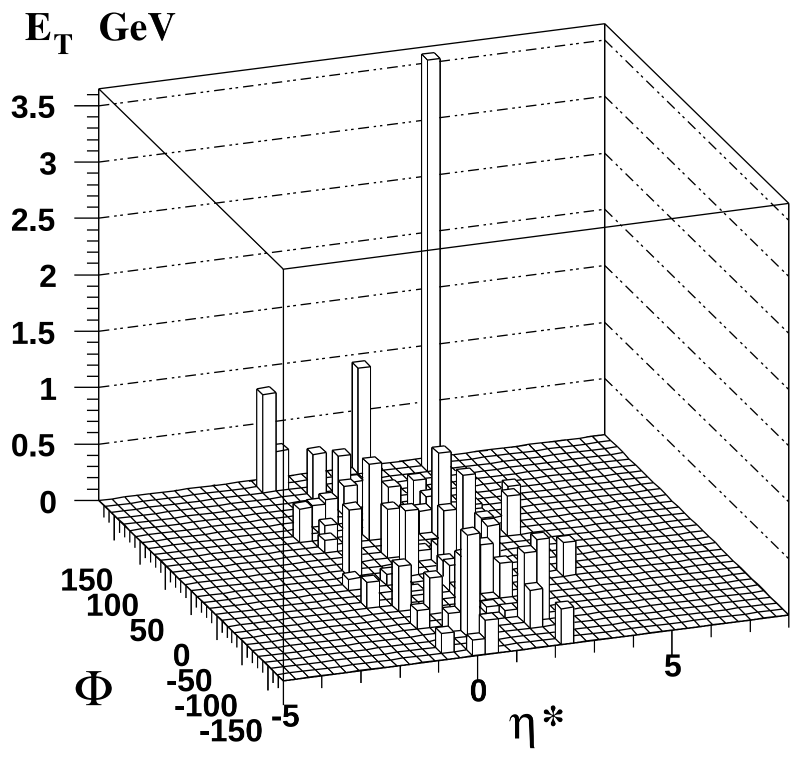


Variables of I-subprocess:

$$Q'^2 = -q'^2$$
$$x' = Q'^2 \ / \ (2\ g \cdot q')$$
$$W_i^2 = Q'^2 \ (1 - x' \ )/x'$$

- hard jet
- Q'^2 poorly reconstructed
- x' reconstr. impossible

'Typical event'
$(\eta, \phi)-$plane: hadronic CMS



- Densily populated narrow band flat in Φ from isotropic decay in $I-$rest system (central part of detector)

- Large total Et
- Large Multiplicity
- All kinds of flavours e.g. $K^{\pm}$, Λ → flavour tagging now under study

DIS Event Selection

H1 data 1997: $\int \mathcal{L} = 15.78\ \mathrm{pb}^{-1}$

- Phase space cuts:

$\theta_{el} > 156°, \quad 0.1 < y_{el} < 0.6, \quad x_{el} > 10^{-3}$

- Technical cuts:

Scattered electron in H1 backward calorimeter
with $E_{el} > 10$ GeV,
-30 cm $< z_{vtx} < 30$ cm
$35 < \sum E - P_z < 70$ GeV

- Hadronic Final State Objects:

Presence of charged particles in region of acceptance of Central Track Chambers:
$20° < \theta < 155°$, $p_T > 0.15$ GeV
and
combination of Tracks and Calorimeter clusters to measure particle-energy flow

- Data sample $\sim$ 275k events

Six Observables

Find highest E_T jet ("current jet"): cone algorithm, $R = 0.5$

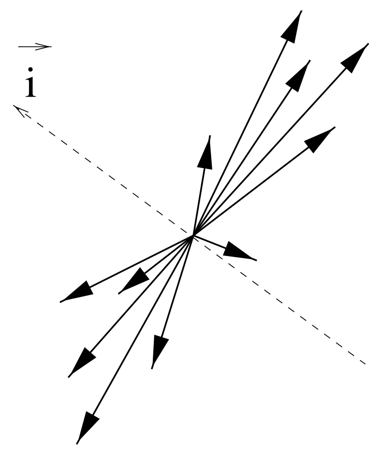
- ❑ Transverse energy of jet: Et_{jet} in hCMS
- ❑ Virtuality of quark entering I-subprocess: Q'^2

Remove particles in current jet to define band in η:

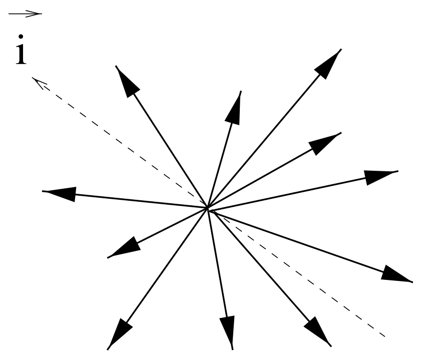
With $\bar{\eta} = \sum_h Et_h\, \eta_h / \sum_h Et_h$: define band as $\bar{\eta} \pm 1.1$

- ❑ n_b: Charged particle multiplicity in band
- ❑ Et_b: Total transverse energy
- ❑ Sph: Sphericity in rest-frame particles not in current jet.
- ❑ $\Delta_b = (E'_{in,b} - E'_{out,b}) \,/\, E'_{in,b}$

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

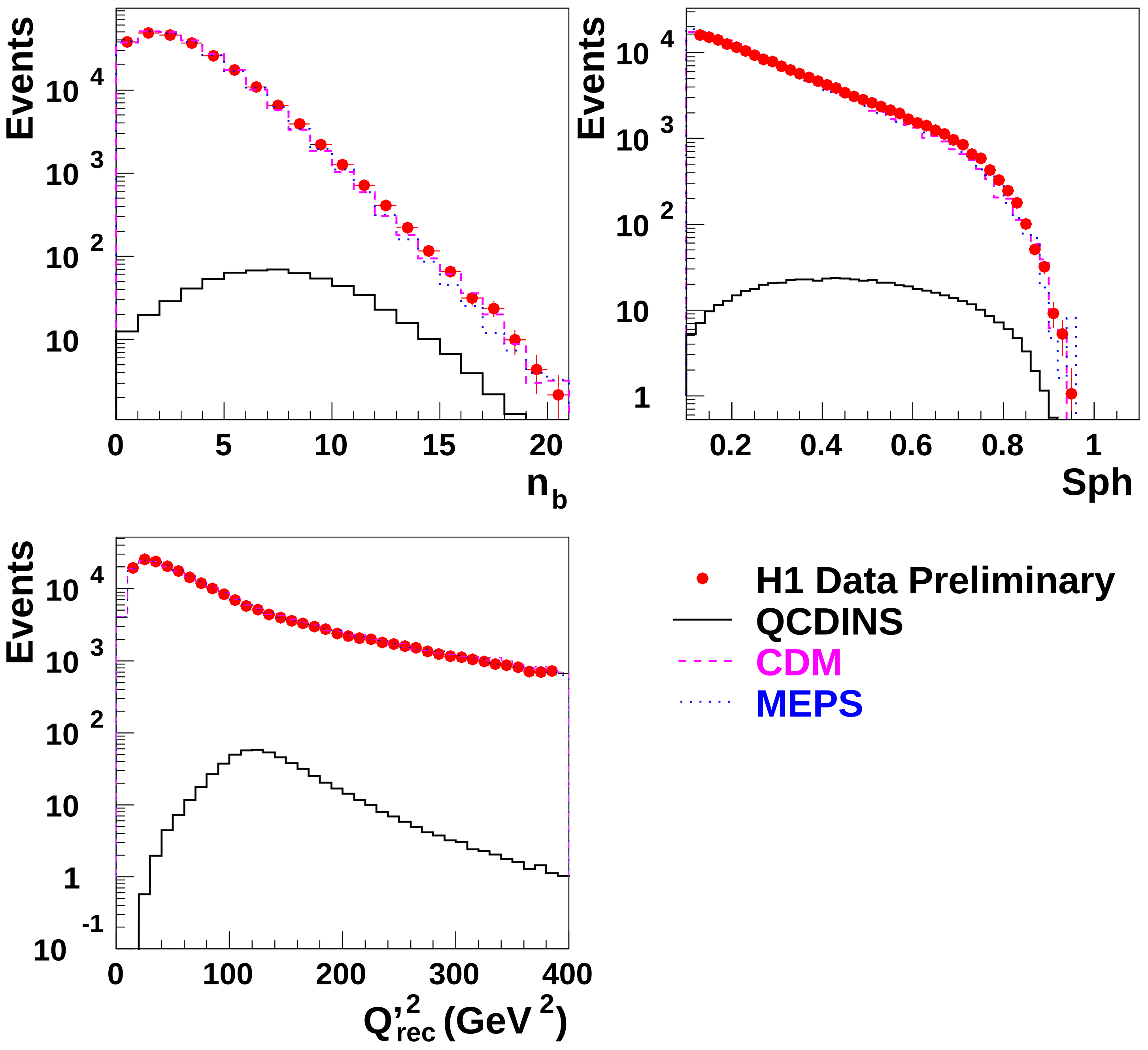


$\Delta_b \approx 1$



$\Delta_b \approx 0$

Distributions before Cuts



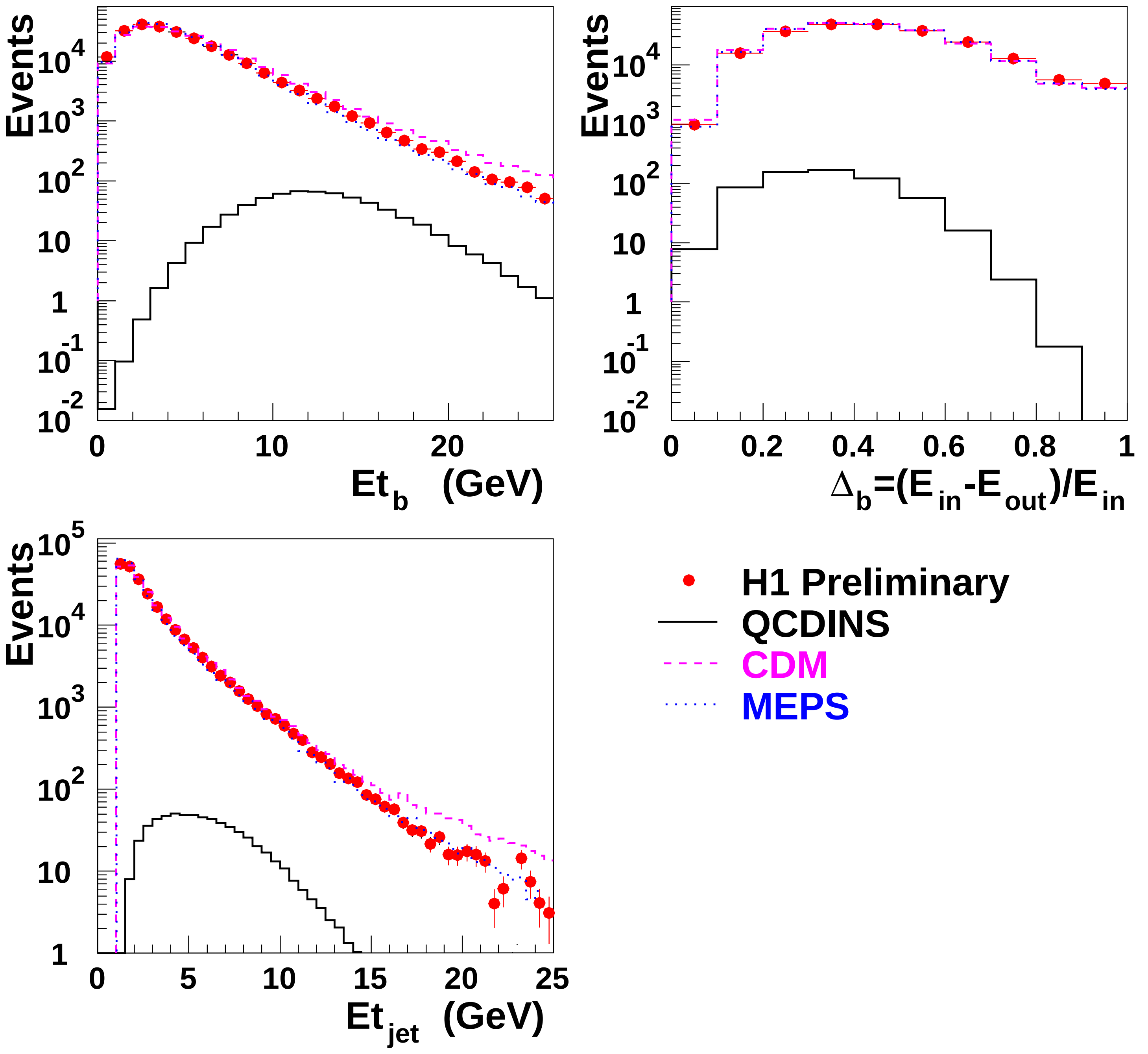
QCD Monte Carlo models describe data fairly well $(5-20\%)$

Expected I–signal $O(10^2 - 10^3)$ below "background"

- CDM: Color Dipole Model $\longrightarrow$ ARIADNE
- MEPS: Matrix Element + Parton Showers $\longrightarrow$ RAPGAP

Distributions before Cuts

Observables not used in cuts

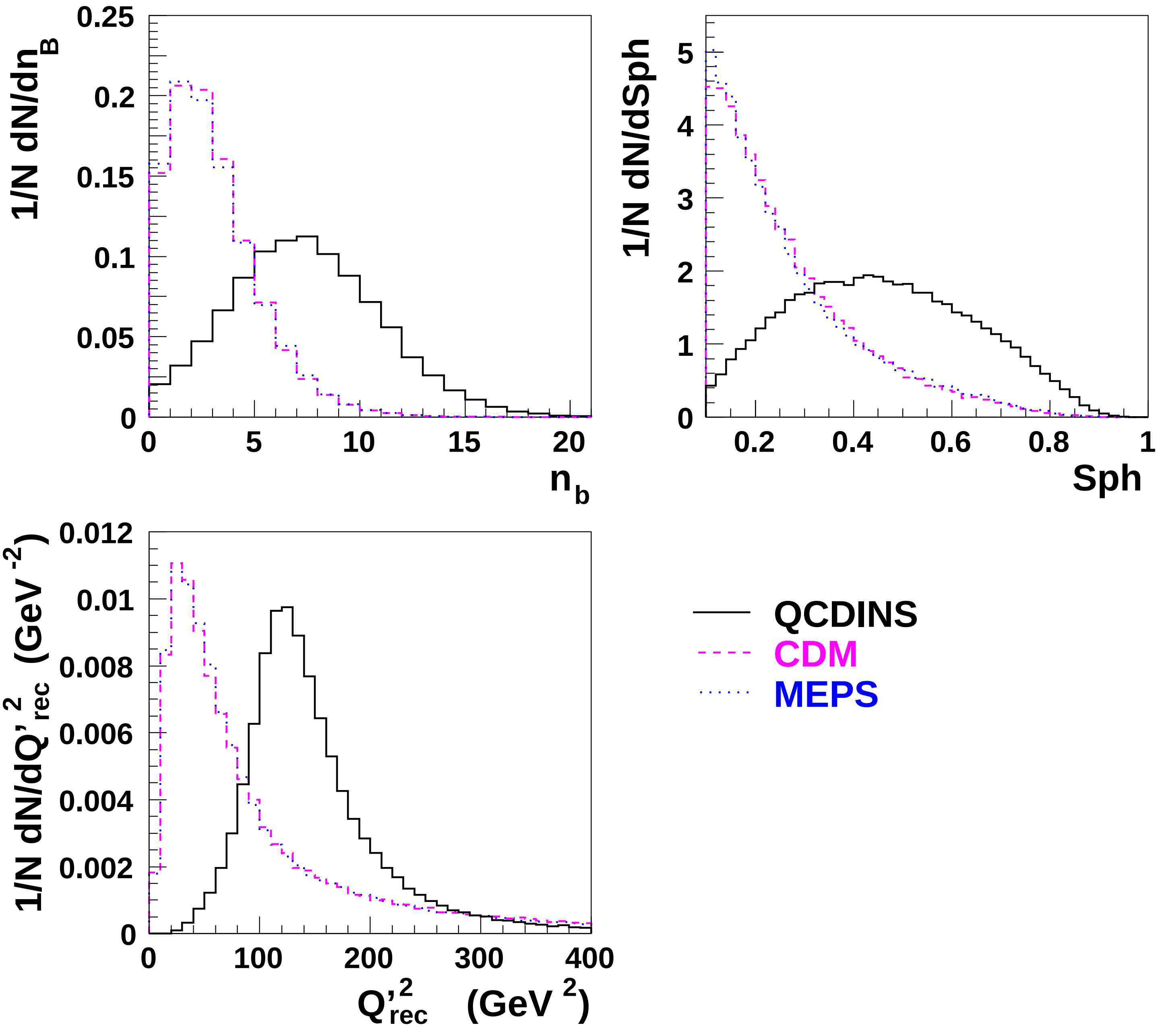


QCD Monte Carlo models describe data quite well $(5-20\%)$

Expected I–signal $O(10^2-10^3)$ smaller than "background"

Search Strategy

Shape-normalized distributions



Large differences “normal DIS” $\Leftrightarrow$ QCDINS used to find optimized selection cuts

Selection of Cut Scenario

Cut values:

$n_b \geq$ 5 6 7 8 9

Sph $\geq$ 0.4, 0.5, 0.55, 0.6, 0.65

95, 100, 105, 110, 115 $< Q'^2 <$ 200 GeV^2

in total 125 combinations !

Define cut-scenario on basis of instanton efficiency and separation power

Scenario	Cuts			ϵ_{ins}	$\frac{\epsilon_{ins}}{\epsilon_{DIS}}$	
	Q'^2 (GeV^2)	Sph	n_b		CDM	MEPS
A	95.0-200.0	0.40	5	32 %	35	34
B	105.0-200.0	0.40	7	21 %	56	52
C	105.0-200.0	0.50	8	11%	86	71

Scenario A: Highest instanton efficiency (ϵ_{ins})

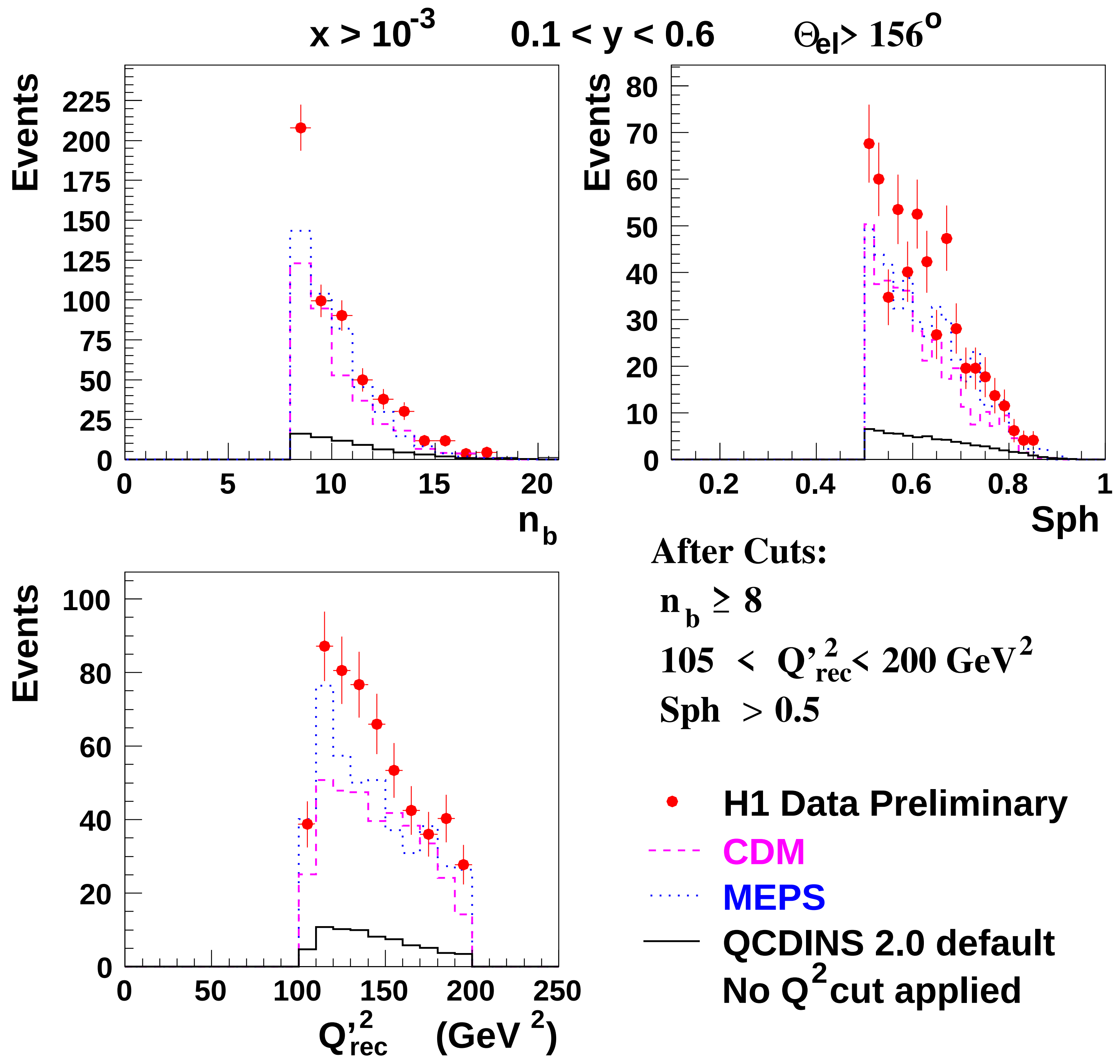
Scenario B: High ϵ_{ins} at reasonable separation power ($\frac{\epsilon_{ins}}{\epsilon_{DIS}}$)

Scenario C: Highest separation power at $\epsilon_{ins} > 10\%$

Here: concentrate on Scenario C

Distributions after Cuts C

Observables used in cuts



Background reduction by factor $\sim 600 - 800$

In some regions excess of events compared to CDM/MEPS

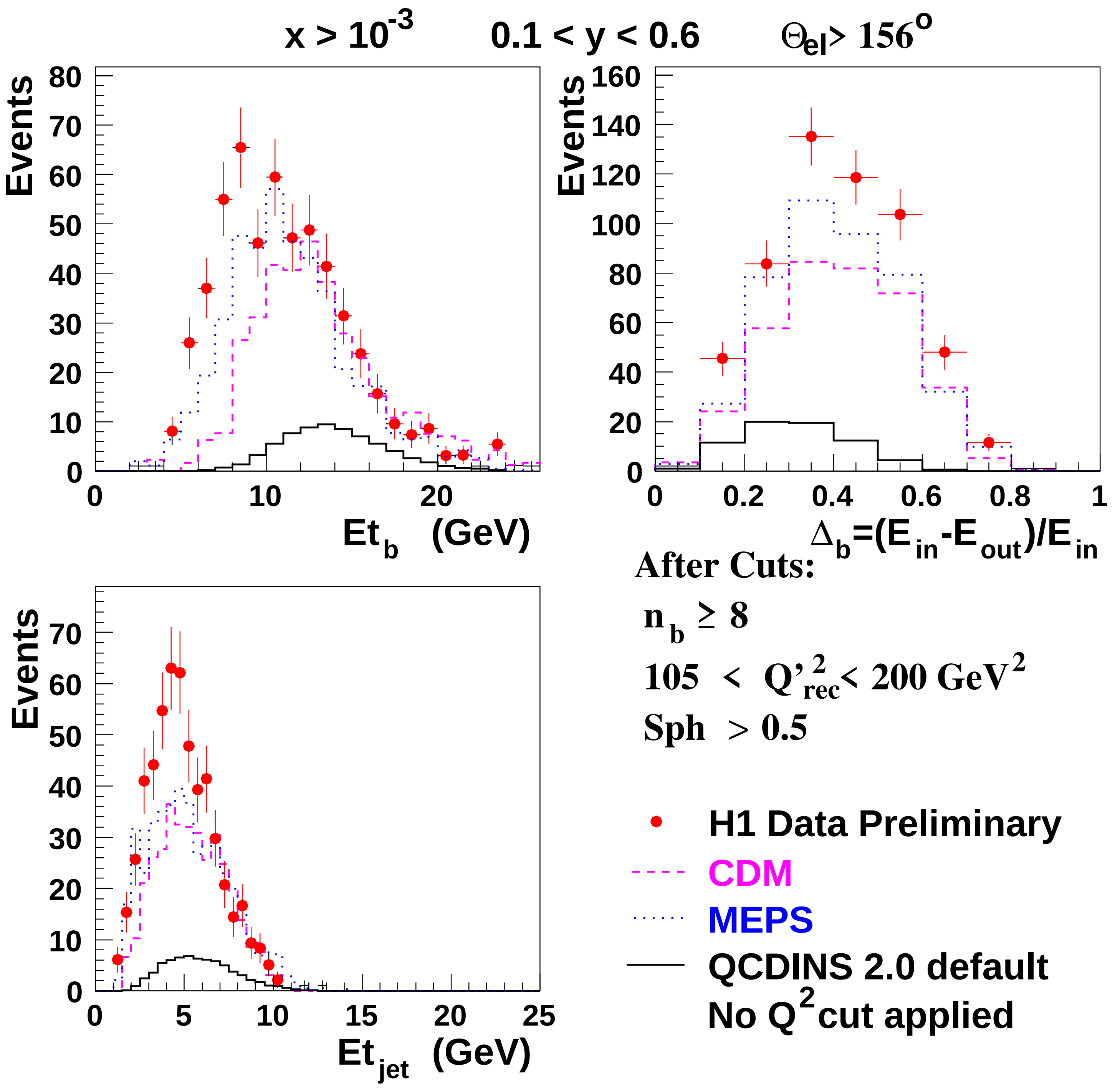
549 events measured

363^{+22}_{-26} (CDM) and 435^{+36}_{-22} (MEPS) expected

Expected instanton signal $\sim$ discrepancy data and CDM/MEPS

Distributions after Cuts C

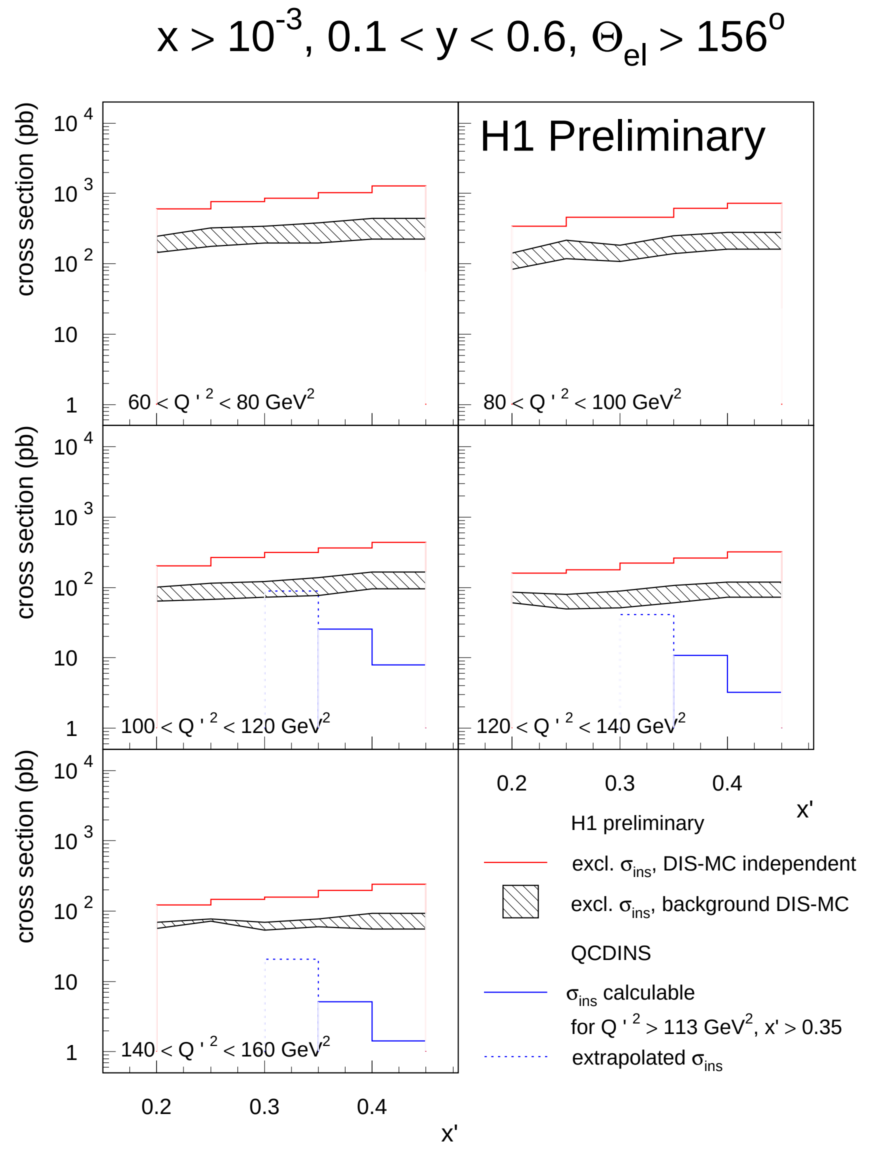
Observables not used in cuts



Shape of the spectra of observables not used to cut
is not well reproduced CDM and MEPS

Event excess in E_{t_b} not quite as expected from QCDINS, but …
QCDINS cannot be excluded given
the uncertainties in $\sigma^{(I)}$, I-hadronisation and DIS modelling

Cross Section Upper Limits



- Red Lines: Upper limit assuming standard-DIS $\sigma = 0$
- Bands: Upper limit from difference data and CDM/MEPS
- Exclude $\sigma^{(I)} \sim 100 - 1000$ pb

Summary

- H1 searched for I-induced DIS events predicted to be measureable at HERA (Ringwald&Schrempp).
- Search strategy optimised to exploit the characteristics of instanton-induced processes, (but) based on QCDINS Monte Carlo.
- For $n_b \geq 8$, $105 \leq Q'^2 \leq 200$ GeV^2, Sph ≥ 0.5:
  549 events found in the data,
  363^{+22}_{-26} (CDM) and 435^{+36}_{-22} (MEPS) are expected,
  Qualitative similarity between observed excess and shape predicted by QCDINS for 3 variables used in cuts.
- But... predicted instanton cross section is at the level of the difference between the pQCD models (CDM/MEPS)
- Shape of three other discriminating variables not used in cuts not well reproduced by CDM or MEPS

  Excess in data not really as expected from I-signal distribution but no definitive conclusions given uncertainties in theoretical $\sigma^{(I)}$ and in standard pQCD Monte-Carlo's.
- Experimental upper limits $(100 - 1000$ pb) exclude rapid rise of $\sigma^{(I)}$ with ρ as would follow from naive extrapolation of I-perturbation theory. **Consistent with lattice results!**
- Future: multidimensional analysis, flavour-tags, ...