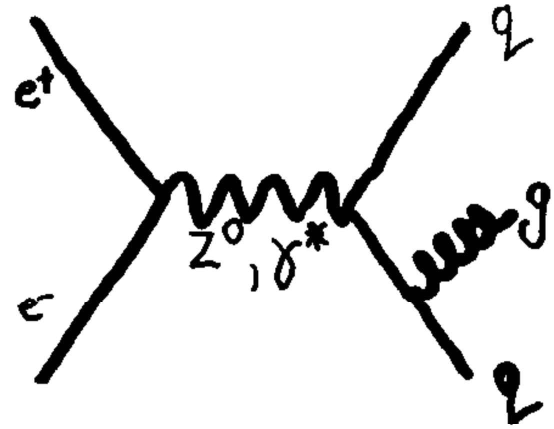
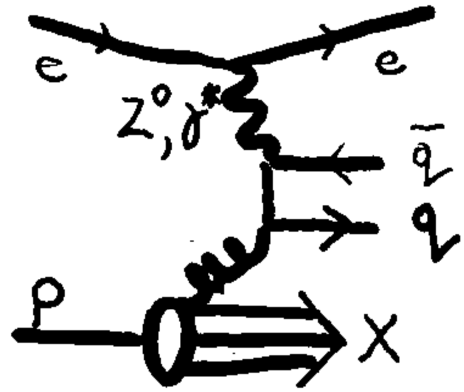
Outline : General Themes

"~ SOFT
→ ~ HARD"

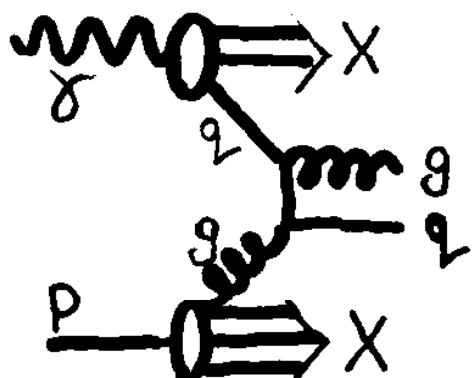
1. Multiple Scattering	J. Lamoureux (CDF) T. Ebert (H1) R. Saunders (ZEUS)
2. Fragmentation	R. Hemingway (OPAL) A. De Roeck (H1) J. Bromley (ZEUS) A. Baretvas (CDF) M. Charlet (H1)
3. Theory And Models	H. Kharraziha (Lund) A. Ringwald T. Carli
4. Event Shapes	M. Dasgupta K. Rabbertz (H1)
5. Jet Shapes	M. Martinez (ZEUS) A. Baretvas (CDF)D
6. Dijets At HERA (DIS)	D. Zeppenfeld M. Wobisch (H1) M. Weber (H1) F. Zomer (H1) D. Mikunas (ZEUS)
7. Jets At The Tevatron	R. Hirosky (DØ) W. Giele J. Huston
8. BFKL-Motivated Measurements	D. Zeppenfeld S.Y. Jun (DØ) M. Wobisch (H1) S. Wolfle (ZEUS)
9. W + Jet Production	T. Joffe-Minor (D

Hadronic Final States
QCD Effects

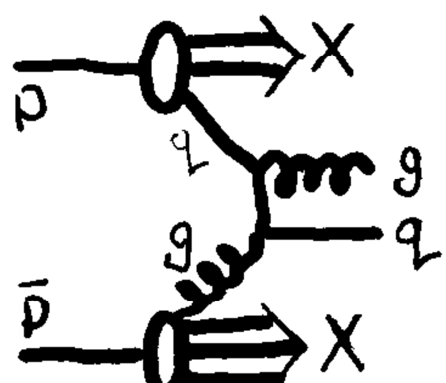




Common Themes And Highlights From Working Group 3.



DIS97



Tony Doyle,
University Of Glasgow.

MULTIPLE SCATTERING

'DOUBLE PARTON SCATTERIN'
'MULTIPLE INTERACTIONS'

- NEW RESULT FROM CDF (JODI LAMOREUX)
  - FIRST SIGNIFICANT MEASUREMENT

$$\sigma_{EFF} = 14.5 \pm 1.7 {}^{+1.7}_{-2.3} \text{ mb}$$

⇒ PROVIDES EXPERIMENTAL CONSTRAINT ON MODELS.

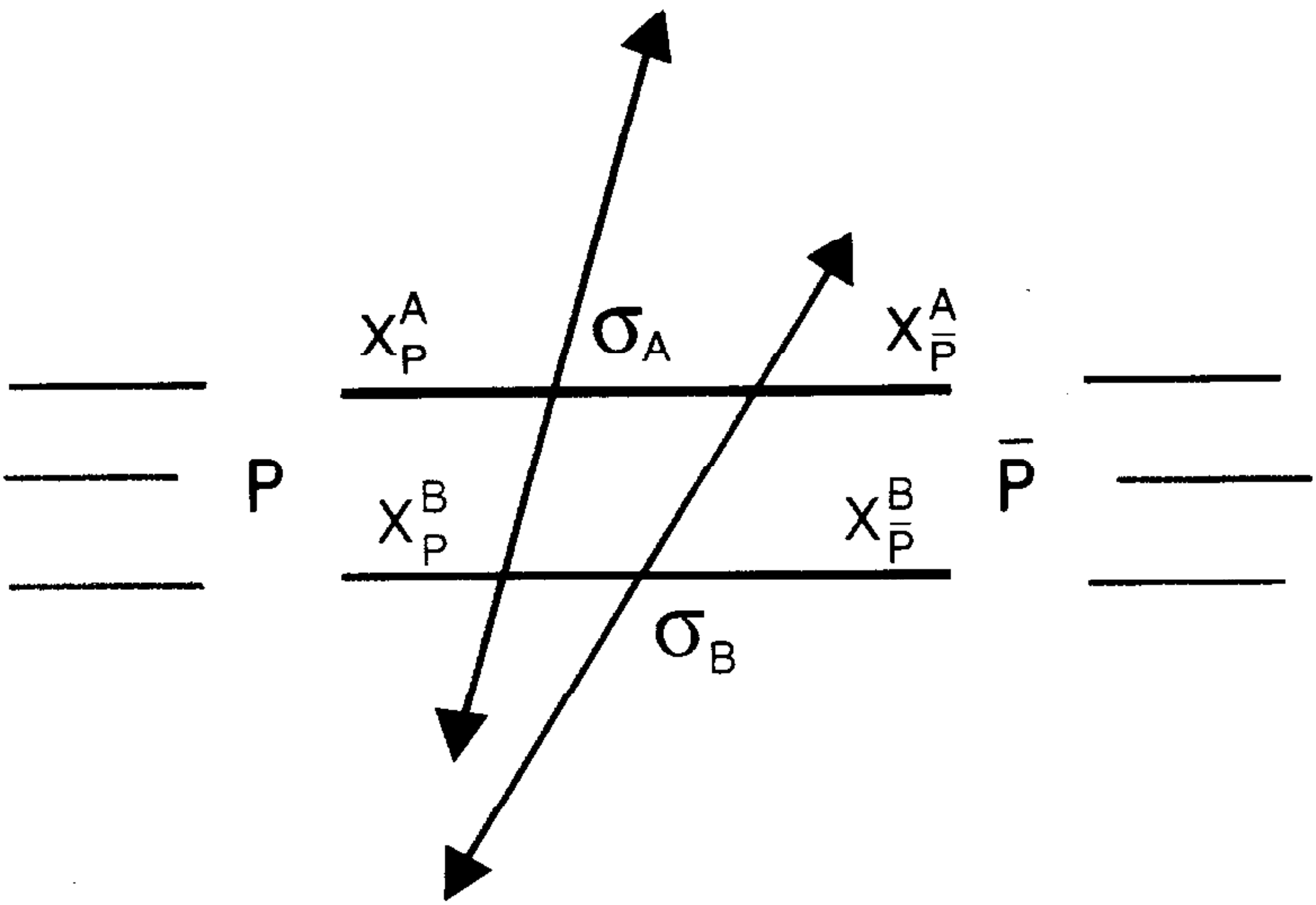
- OBSERVATIONS FROM H1 AND ZEUS IN PHOTOPRODUCTION DATA (TANIA EBERT)

⇒ CONSTRAINTS REQUIRED AT LOW x_γ IN ORDER TO DISENTANGL GLUON IN PHOTON - DIFFICULT....

LARGER E_T REQ$^{\underline{D}}$?

Double Parton Scattering

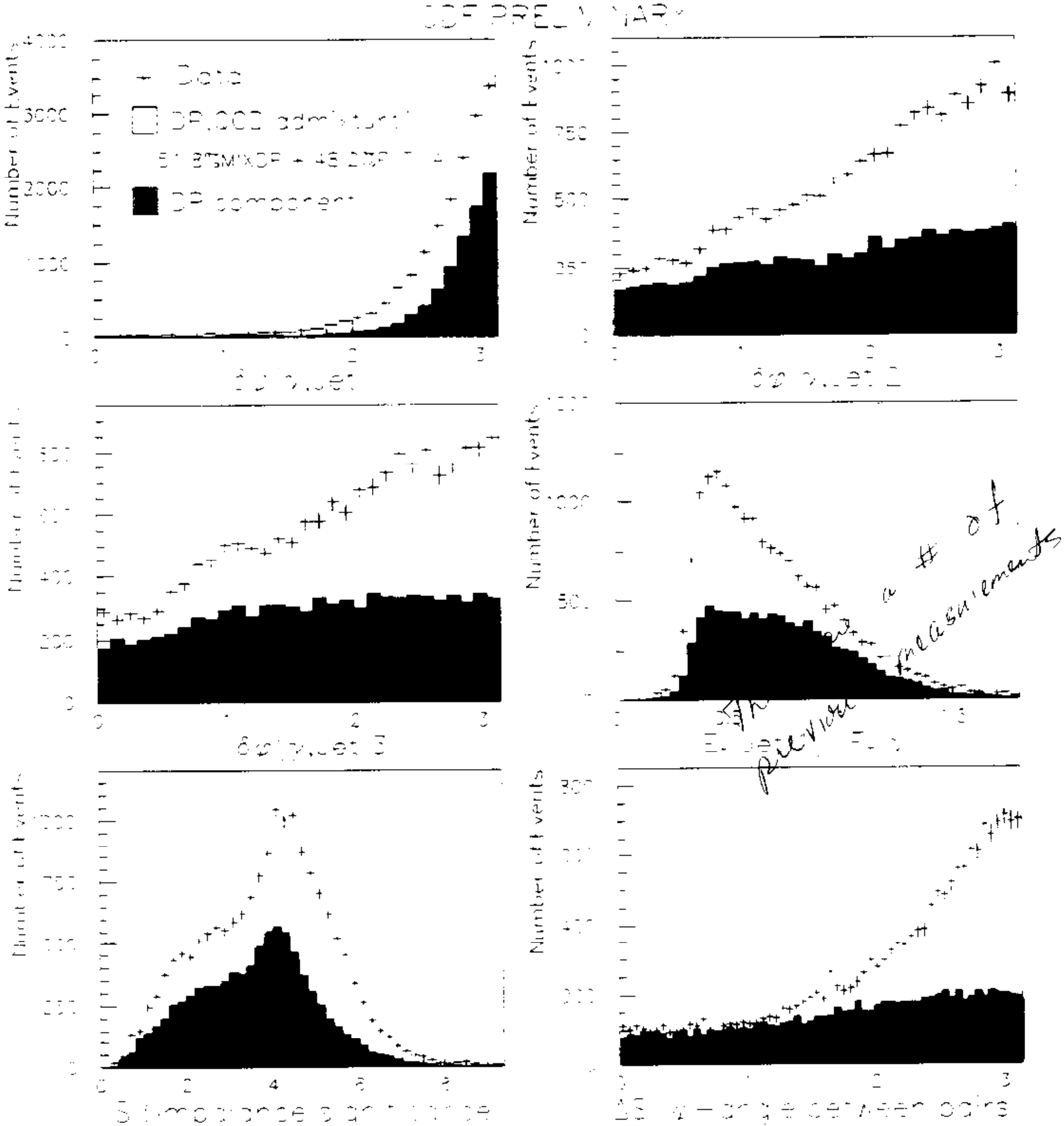
Jodi Lamoureux
Brandeis University



$$\sigma_{DP} = m \frac{\sigma_A \, \sigma_B}{2 \, \sigma_{eff}}$$

m = 2 if A and B are distinguishable
1 if A and B are indistinguishable

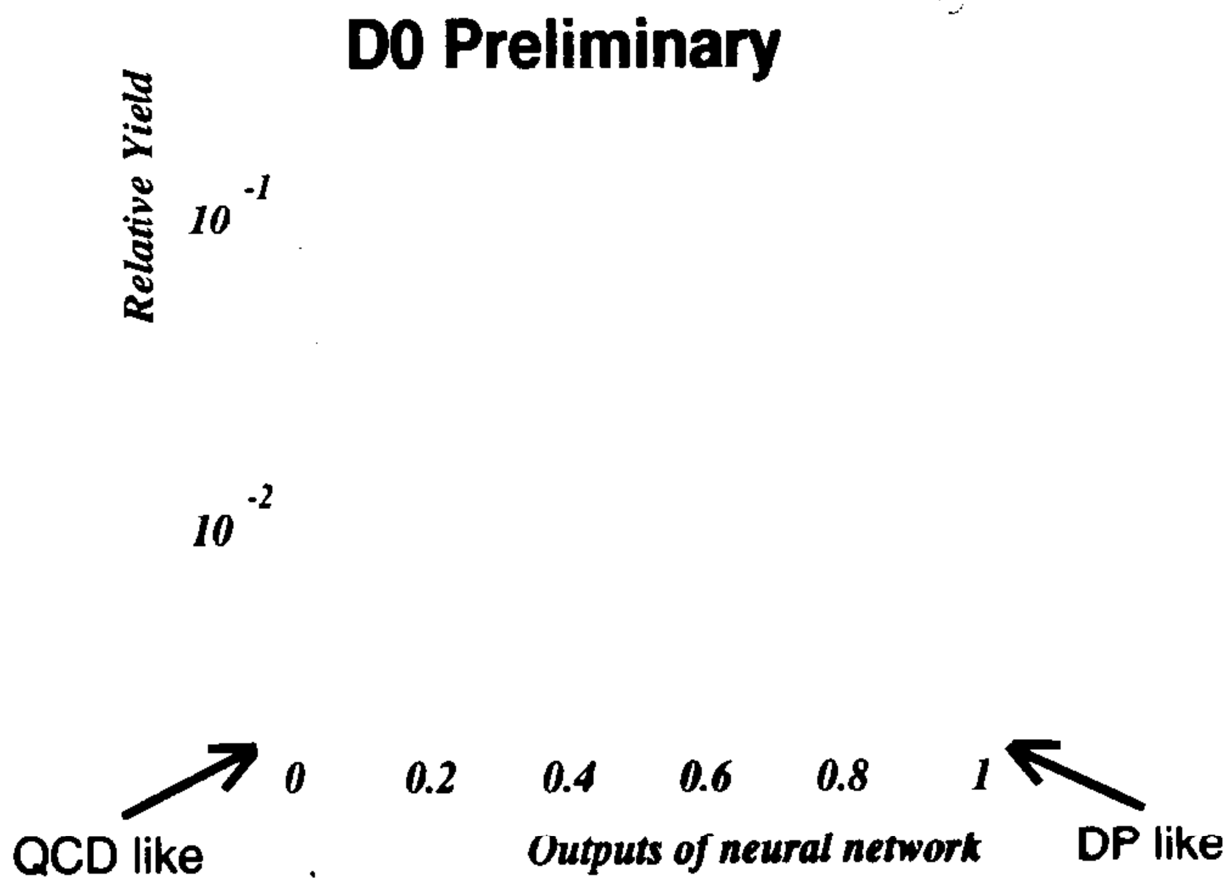
Six Sensitive Variables:



Previous measurements of σ_{eff}

Each used a 4 jet data sample and searched for the presence of uncorrelated dijets.

- AFS $\sigma_{eff} \sim 5$ mb [Z. Phys. C34, 163 (1987)]
- UA2 $\sigma_{eff} > 8.3$ mb [Phys. Lett. B268, 145 (1991).]
- CDF $\sigma_{eff} = 12.1^{+10.7}_{-5.4}$ mb [Phys Rev D68, 4857 (1993
- Prediction - hard sphere proton 11 mb
- D0 preliminary - Et > 25 GeV, 1 vertex
  Use 10 input variables to tune neural net
  $\Delta\phi$ between jets, energy balance of jet pairs, S, ΔS
  Tune on PYTHIA's QCD prediction of 4 jets
  and a model derived from combining 2 dijet
  events. [FERMILAB-CONF-96/304-E]



Double Parton Result:

$$\sigma_{eff} = \frac{N_{DI} \; N_{cross}(1) \qquad A_{DP}}{N_{DP} \;\; 2\, N_{cross}(2) \;\; A_{DI}} \; \sigma_{NDS}$$

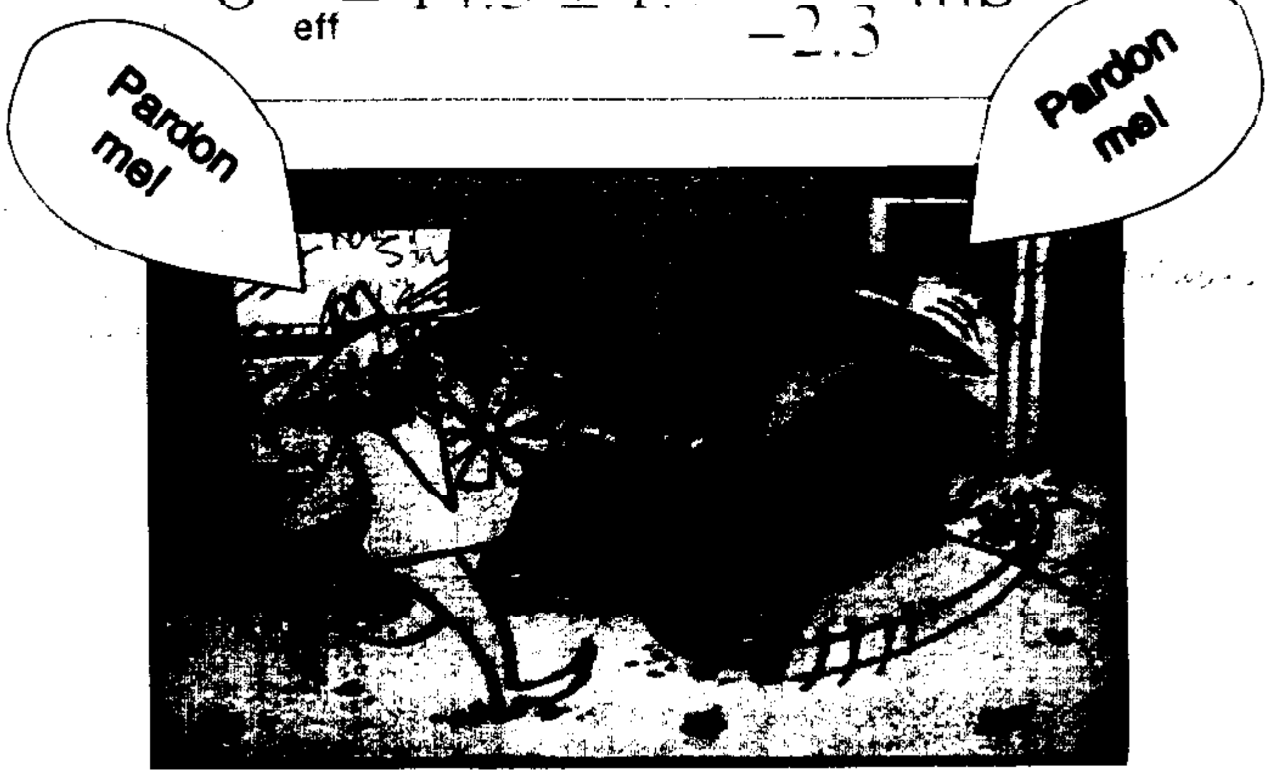
$$N_{DP} = 7{,}360 \pm 360 \,{}^{+720}_{-380} \qquad \text{(52.6\% 1 vertex)}$$

$$N_{DI} = 1060 \pm 110 \pm 110 \qquad \text{(17.7\% 2 vertex)}$$

$$\frac{N_{cross}(1)}{N_{cross}(2)} = 2.06 \pm 0.02 \,{}^{-0.01}_{-0.13} \qquad \frac{A_{DP}}{A_{DI}} = 0.958$$

$$\sigma_{NDS} = 50.9 \pm 1.5 \text{ mb}$$

$$\sigma_{eff} = 14.5 \pm 1.7 \,{}^{+1.7}_{-2.3} \text{ mb}$$



Conclusions:

First observation of a statistically significan
double parton signal.

$$\sigma_{eff} = 14.5 \pm 1.7 \, {}^{+1.7}_{-2.3} \text{ mb}$$

In agreement with the hard sphere prediction of 11 mb.

The radius of the proton is 0.73 ± 0.07 fm assuming a constant density spherical proton.

No x dependence to σ_{eff} is apparent.

No correlations in pt, pz or mass have been observed.

This represents a milestone in the study of double parton production.

PHOTOPRODUCTION JET RESULTS

(TANIA EBERT - H1
ROB SAUNDERS - ZE

DIJET CROSS SECTIONS

$$\frac{d^2\sigma}{dx_\gamma \, dE_T}$$

H1 - CONE

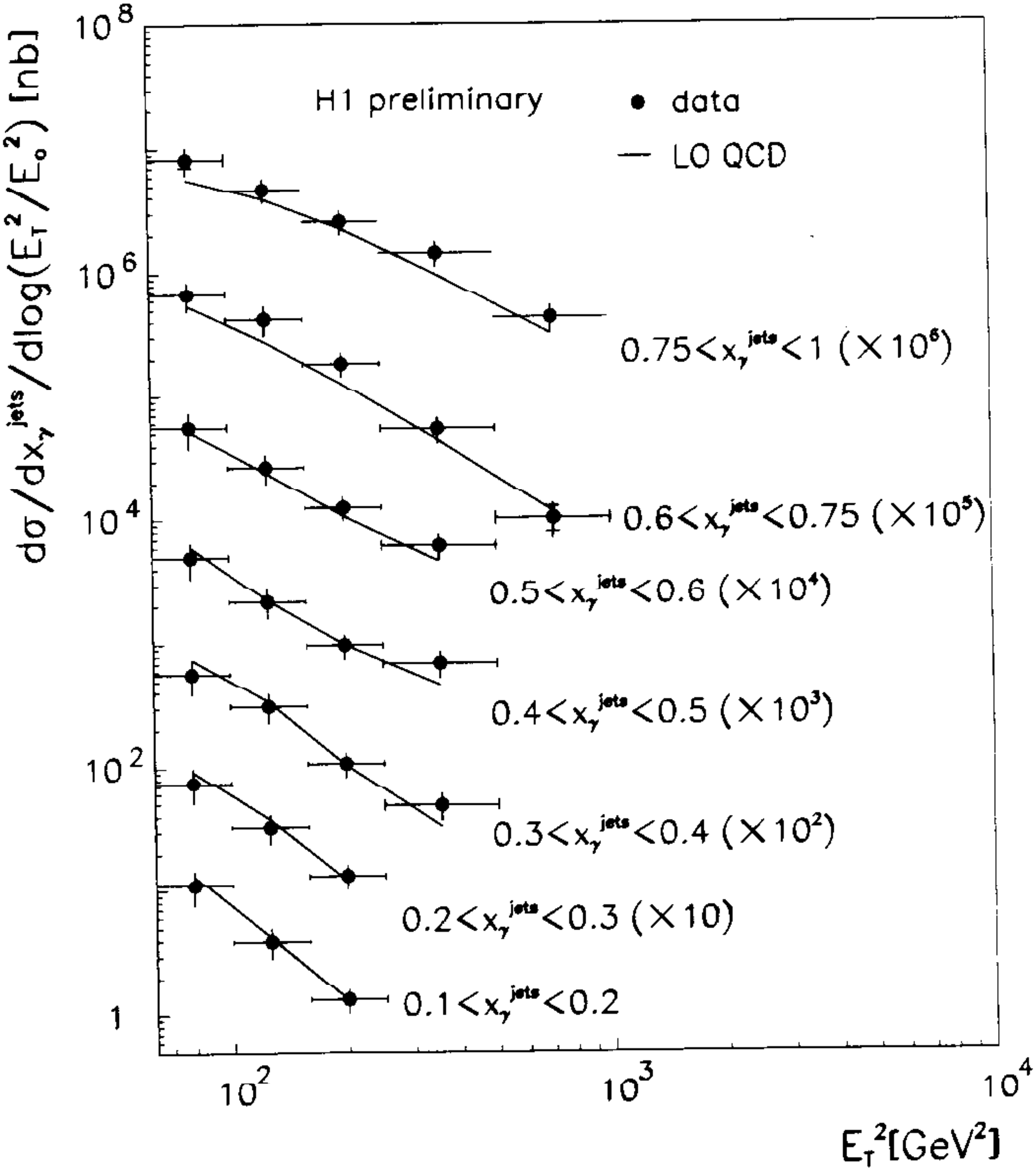
ZEUS - CONE, K_T

- GENERAL AGREEMENT DOWN TO RELATIVELY LOW E_T.
- HOWEVER, ZEUS COMPARISON INDICATES SIGNIFICANT EXCESS AT LOWER x_γ FOR E_T RANGE $6 < E_T < 11$ GeV, COMPARED TO NLO CALC$^{\underline{N}}$S.

[$0.3 < x_\gamma < 0.75$ - NOT SO LOW]

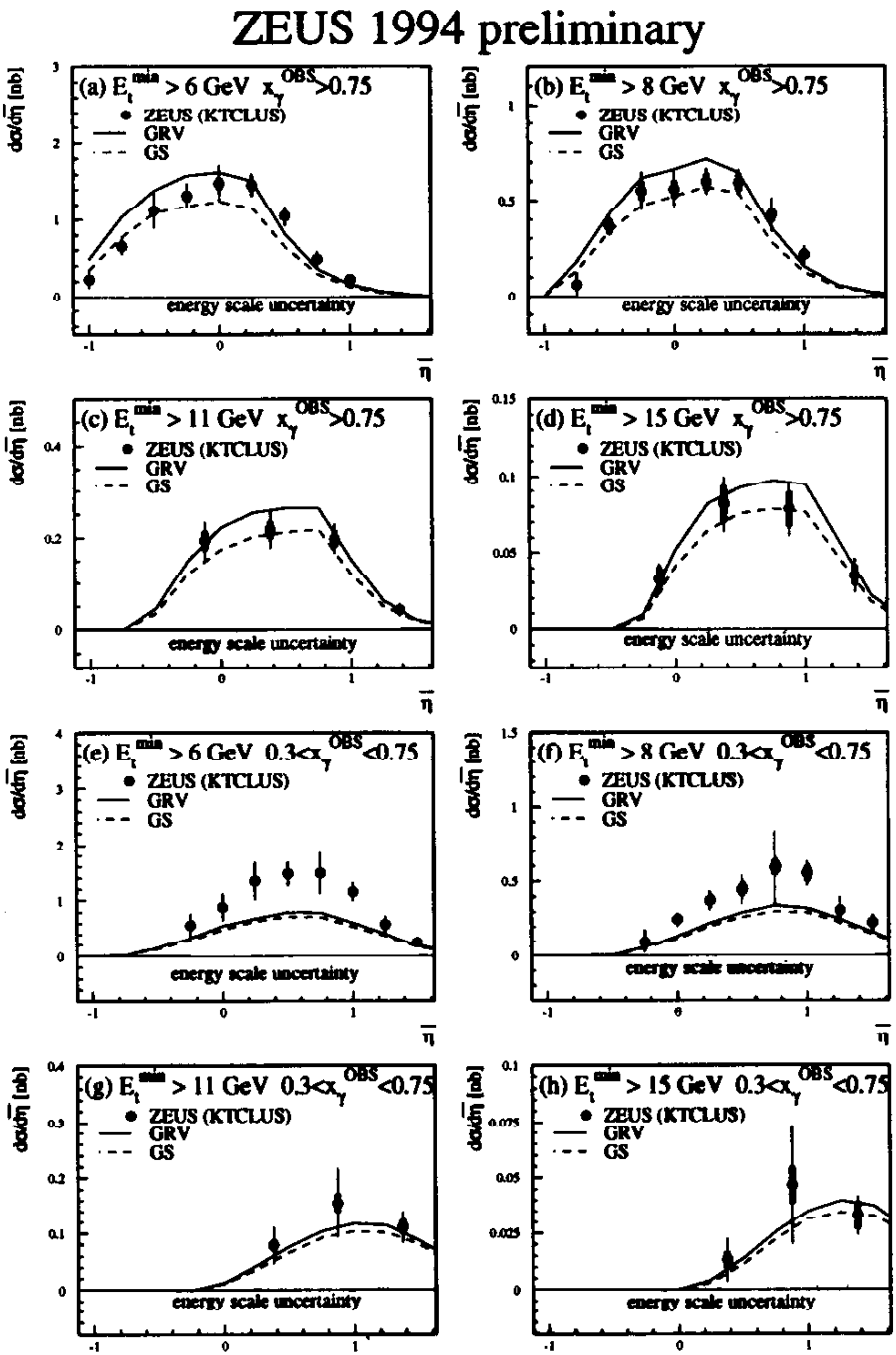
EXCESS DUE TO MULTIPLE INT$^{\underline{N}}$S ?

Di-jet Cross-Section

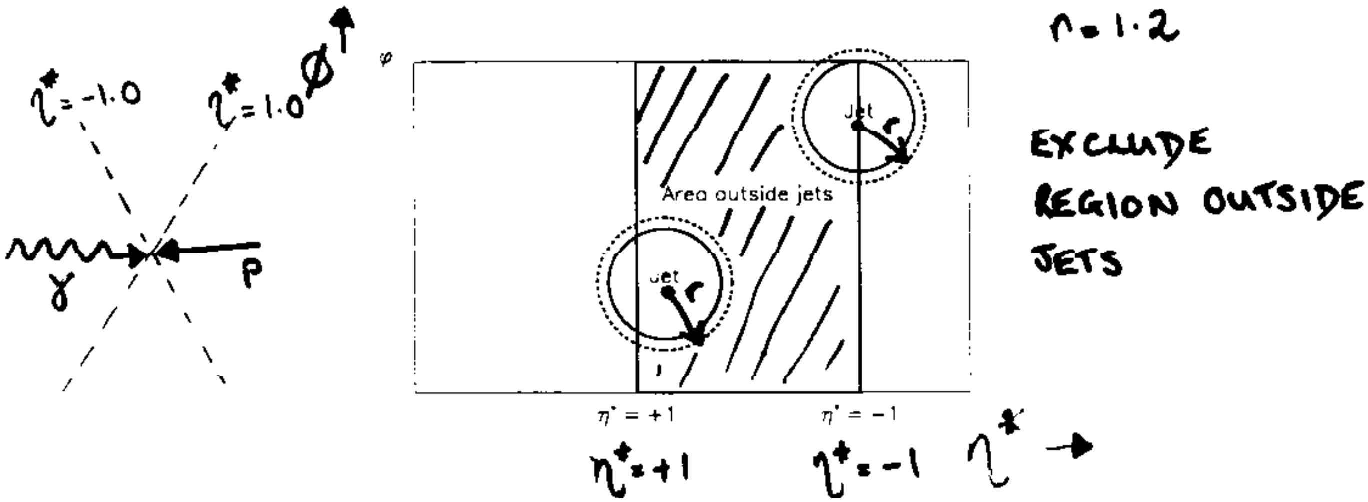


Comparison with NLO calculations

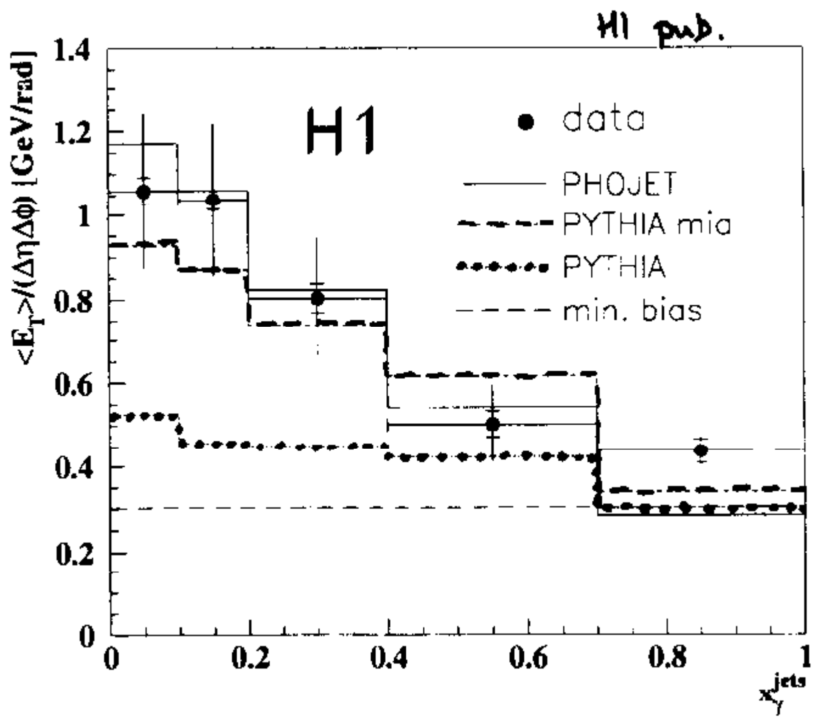
(Klasen, Kramer)



Evidence for Multiple Interactions



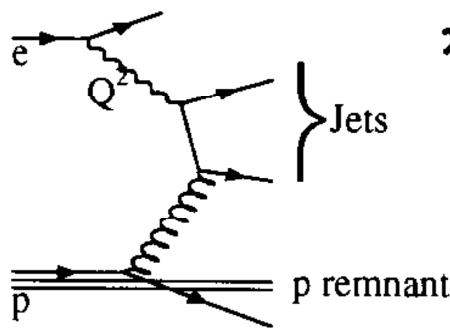
- $\sum E_t$/Area outside jets in region $-1.0 < \eta^* < 1.0$ in γp centre of mass frame.



Introduction

- Photoproduction of high p_t jets is sensitive to photon and proton structure.

DIRECT

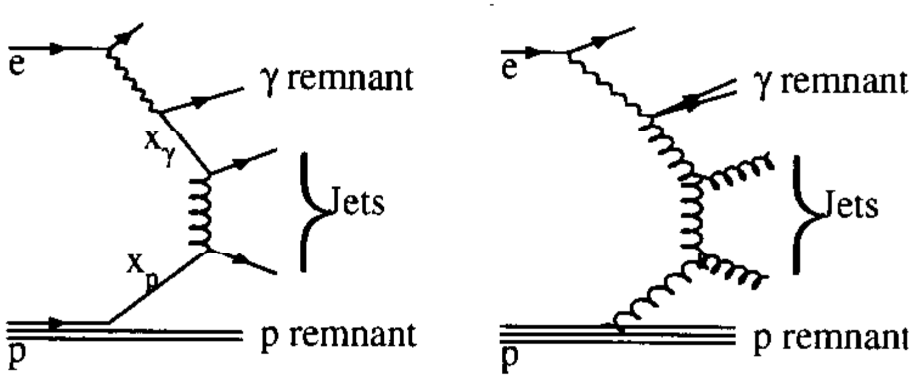


$x_\gamma = 1$

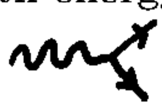
$$x_\gamma^{jets} = \frac{E_T^{j1} e^{-\eta^{j1}} + E_T^{j2} e^{-\eta^{j2}}}{2 y E_e}$$

RESOLVED

$x_\gamma < 1$



- Probability of finding quark with energy fraction x_γ in photon predicted by pQCD:



ANOMALOUS COMPONENT OF PHOTON.

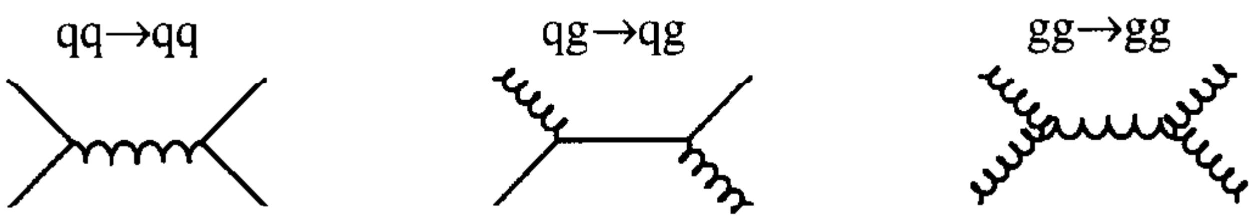
* $f_{q/\gamma} \sim \ln \mu_F^2$ *

$$f_{q/\gamma} = e_q^2 \frac{\alpha}{\pi} \ln \frac{\mu_f^2}{\Lambda_{QCD}^2} (x_\gamma^2 + (1 - x_\gamma)^2)$$

Single Effective Subprocess Approximation

((CAMBRIDGE + MAXWELL, 1983).

- Dominant contributions to dijet cross-section:



- Shape of these matrix elements is similar:

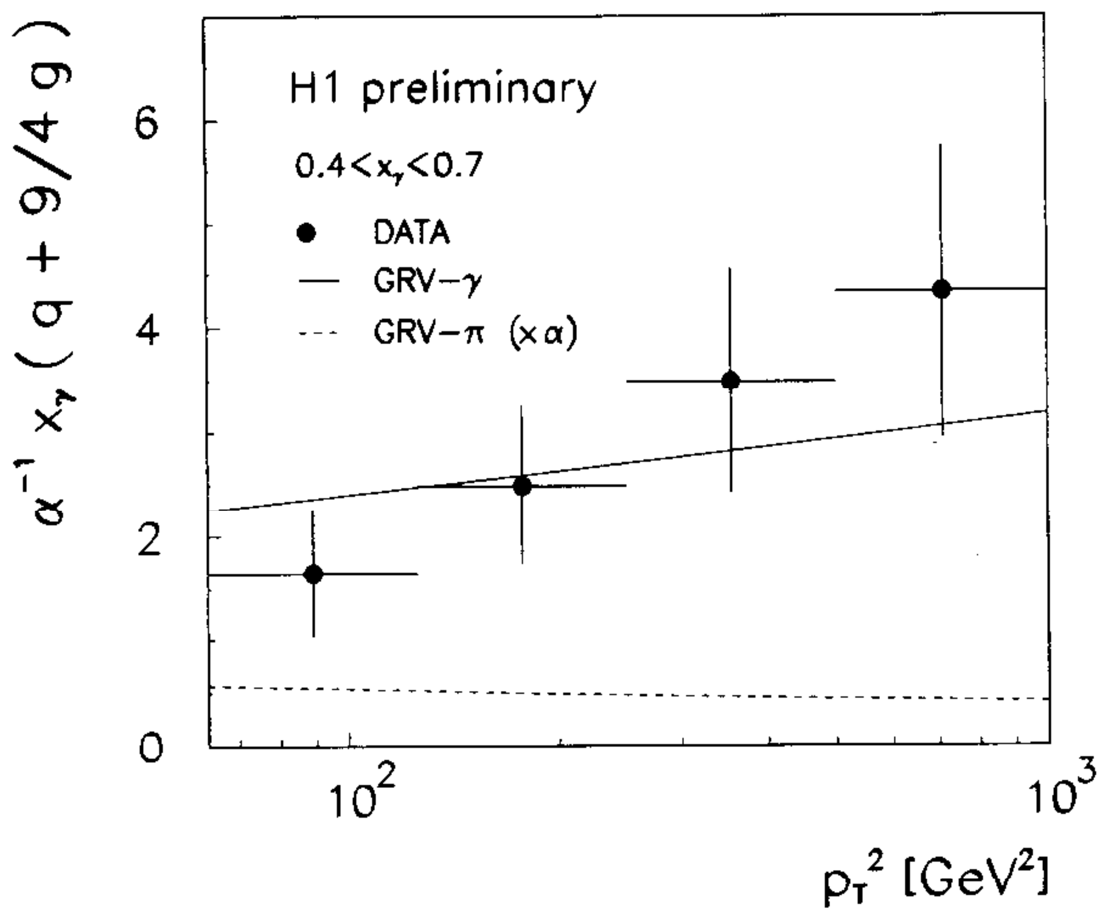
$$| M_{qq} |^2 : | M_{qg} |^2 : | M_{gg} |^2 \approx 1 : \frac{9}{4} : (\frac{9}{4})^2$$

- Use a single effective subprocess (SES) where $| M_{SES} |^2 \approx | M_{qq} |^2$ and define effective parton distribution functions:

$$\tilde{f}(x) = \sum_q (q(x) + \bar{q}(x)) + \frac{9}{4} g(x)$$

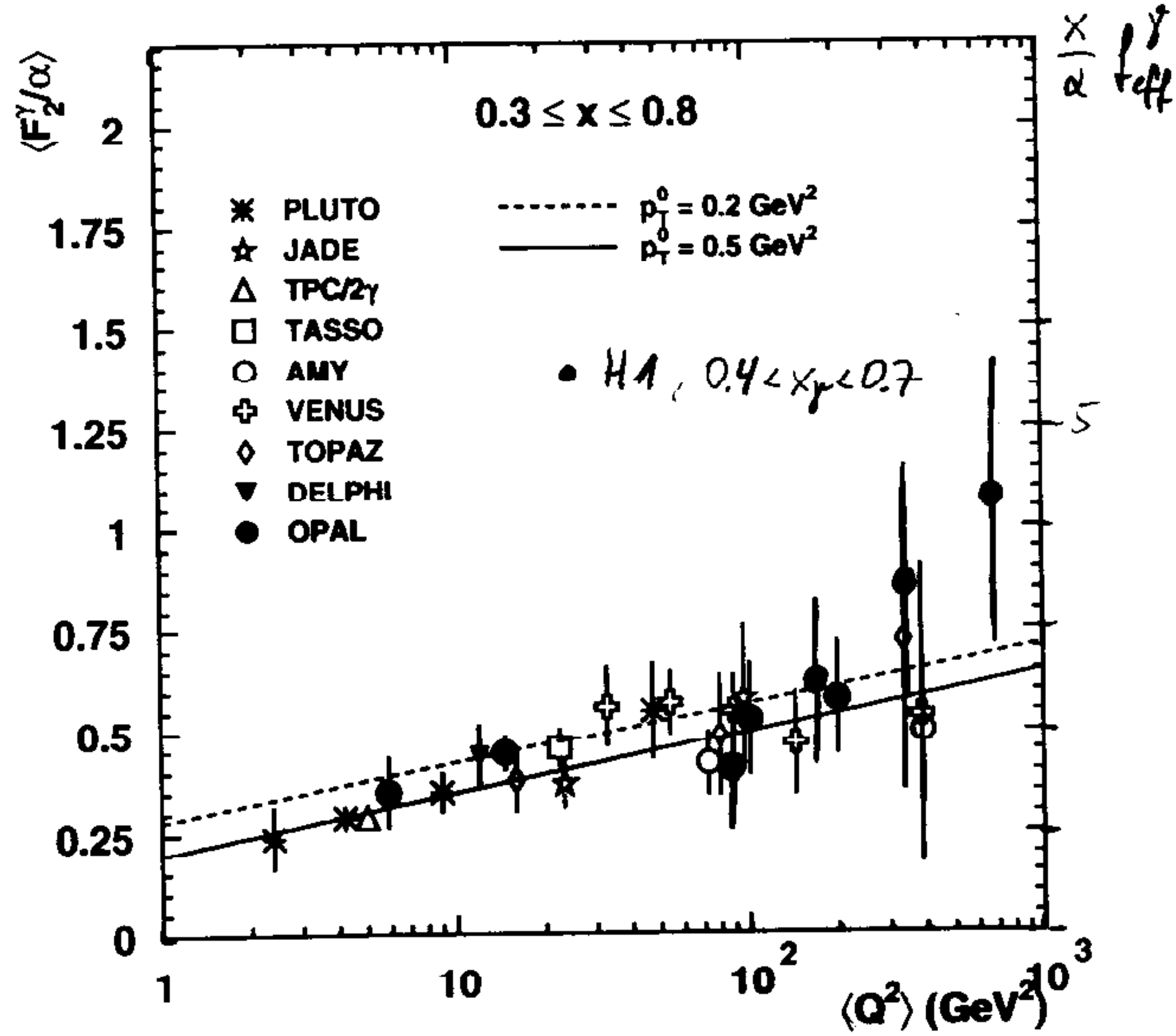
- Differential di-jet cross-section becomes:

$$\frac{d^4\sigma}{dy\,dx_\gamma\,dx_p\,d\cos\theta^*} \sim \frac{f_{\gamma/e}}{y} \frac{\tilde{f}_\gamma}{x_\gamma} \frac{\tilde{f}_p}{x_p} | M_{SES}(\cos\theta^*) |^2$$



- Data shows increase with p_t^2 compatible to the logarithmic increase predicted by pQCD from the anomalous component of the photon. (c.f $f_{q/\gamma} \sim \ln \mu_F^2$)
- Different to behaviour of other hadrons eg π.
- In GRV parameterisation, quark contribution to the effective photon pdf is 80% for $0.4 < x_\gamma < 0.7$.

$F_2^\gamma(Q^2)$, measured at e^+e^- experiments



Electromagnetic pointlike ("anomalous") coupling of the photon to $q\bar{q}$ pairs causes the photon structure function to rise with Q^2

⇒ Photon is not (only) a hadron.

Jet Definitions

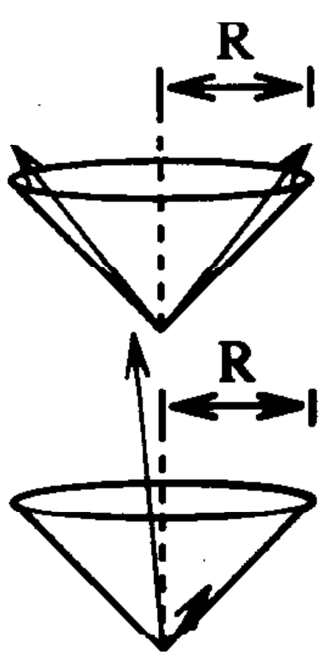
Standard in Hadron Physics: 'Snowmass' cone algorithms

We compare two algorithms using a cone radius $R = 1$:
PUCELL CDF type cone algorithm
EUCELL another cone algorithm used by ZEUS
Differences: seed finding and cone merging
(but both are in agreement with the Snowmass convention)

A new approach for Hadron Physics: cluster algorithm

KTCLUS (by M. Seymour)
using distance $d_{ij} = min({E_{ti}}^2, {E_{tj}}^2)[\Delta\eta_{ij}^2 + \Delta\phi_{ij}^2]$
There are no ambiguities in seed finding and merging.

Comparison with NLO Theory



→two or three parton final state
(no overlapping jets)

two partons are combined if

$$\Delta \equiv \sqrt{\Delta\eta_{ij}^2 + \Delta\phi_{ij}^2} < \frac{E_t^1 + E_t^2}{max\{E_t^1, E_t^2\}} R$$

with R_{sep} parameter (Ellis,Kunszt,Soper)

$$\Delta < min\left\{\frac{E_t^1 + E_t^2}{max\{E_t^1, E_t^2\}} R, R_{sep}\right\}$$

PUCELL$\longleftrightarrow R_{sep} = 1\ R$
EUCELL$\longleftrightarrow R_{sep} \approx 1.5 \ldots 2.0\ R$
KTCLUS$\longleftrightarrow R_{sep} = 1.$

$k_\perp$ Algorithm

Arbitrary parameter D

- 1a $\quad d_{i,j} = \min(E^2_{\perp,i}, E^2_{\perp,j}) \, \frac{(\Delta\eta)^2 + (\Delta\phi)^2}{D^2}$
- 1b $\quad d_i = E^2_{\perp,i}$
- 2 $\quad$ find minimum of $d_{i,j}$ and d_i
- 3a $\quad$ if minimum is $d_{i,j}$
  form a new pseudo-particle k
  i and j removed from the list of particles
- 3b $\quad$ if d_i is the min
  the particle is not "mergable"
  particle forms a jet
- go to step 1

Use 4 momentum scheme to combine particles

Use y(cut) to set scale for merging

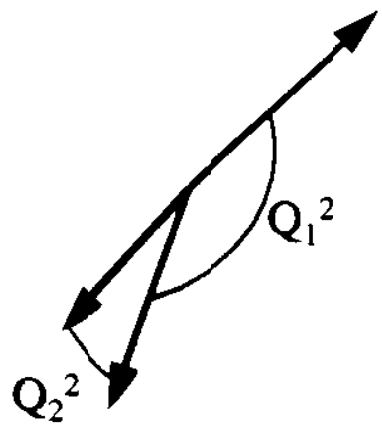
$d_{i,j}/E^2_{\perp,Jet}$

y(cut) = 1 no subjets

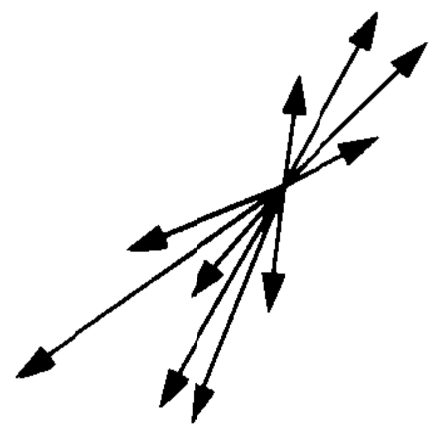
y(cut) $\rightarrow$ 0 each particle is a subjet

Case 2

Partons



Particles



Softer (lower Q^2) physics or
multi-scale physics
Moderately well separated partons
Not all jets equally resolvable

Cone algorithms do not perform well in such circumstances

Note: 'Split & Merge' is a trivialization of important underlying physics.

Radius of the Proton:

Model for density	Form of density, dN/d^3r	Predictions RMS r	σ_{eff}	Measurements scale (fm)	RMS r (fm)	n
Uniform Sphere	Constant, $r < r_p$	$\sqrt{3/5}r_p$	$4\pi r_p^2/4.6$	r_p=0.73	0.56	0.87
Gaussian	$e^{-r^2/2\Sigma^2}$	$\sqrt{3}\Sigma$	$4\pi\Sigma^2$	Σ=0.34	0.59	1.9
Exponential	$e^{-r/\lambda}$	$\sqrt{12}\lambda$	$35.5\lambda^2$	λ=0.20	0.70	3.2
Fermi, $\lambda/r_0 = 0.2$	$(e^{(r-r_0)/\lambda}+1)^{-1}$	$1.07r_0$	$4.6r_0^2$	r_0=0.56	0.60	1.1
Fermi, $\lambda/r_0 = 0.5$	" "	$2.01r_0$	$14.5r_0^2$	r_0=0.32	0.63	2.0
Fermi, $\lambda/r_0 = 0.8$	" "	$3.05r_0$	$32.8r_0^2$	r_0=0.21	0.64	3.0

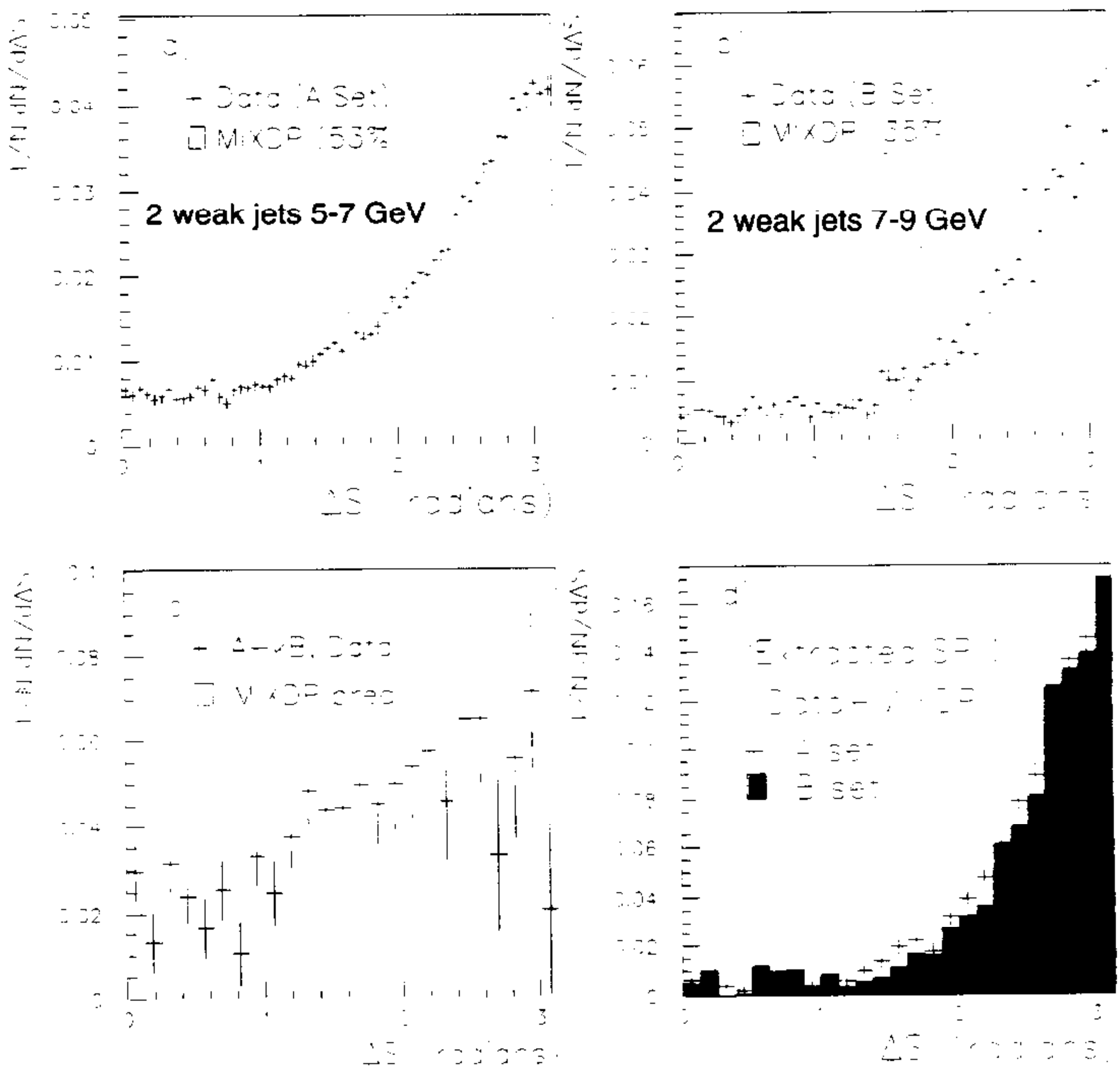
RMS radius varies by 20%.

Compares well with RMS radius = 0.77 ± 0.10 fm measured in ep scattering at Q^2 of order 0.1 GeV^2.
R. Hofstadter Rev. Mod. Phys. 28, 214 (1956).

S is the significance away from pairwise momentum balance

$$S = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{|\vec{p}_T(\gamma J)|}{\delta p_T(\gamma J)}\right)^2 + \left(\frac{|\vec{p}_T(JJ)|}{\delta p_T(JJ)}\right)^2}$$

ΔS is the $\Delta\phi$ angle between the pt vectors of the pairs which have the best momentum balance.



CDF "Photon" + 3 Jet DP search

KONIGSBERG (DOS)

PRL preprint FERMILAB-PUB-97-083-E

PRD preprint posted April 15.

Printed on April 14, 1997 at 9:11 PM

16 pb^{-1} of data collected in 1992-93.

Photons candidates (isolated Em clusters)

Et > 16 Gev, $|\eta| < 0.9$

3 Jets

Et > 5 GeV

ΔR between photon and jet pairs > 0.8

Lowest two jets Et < 7 GeV

No 4th Jet with Et > 5 GeV

Two data sub-samples were constructed

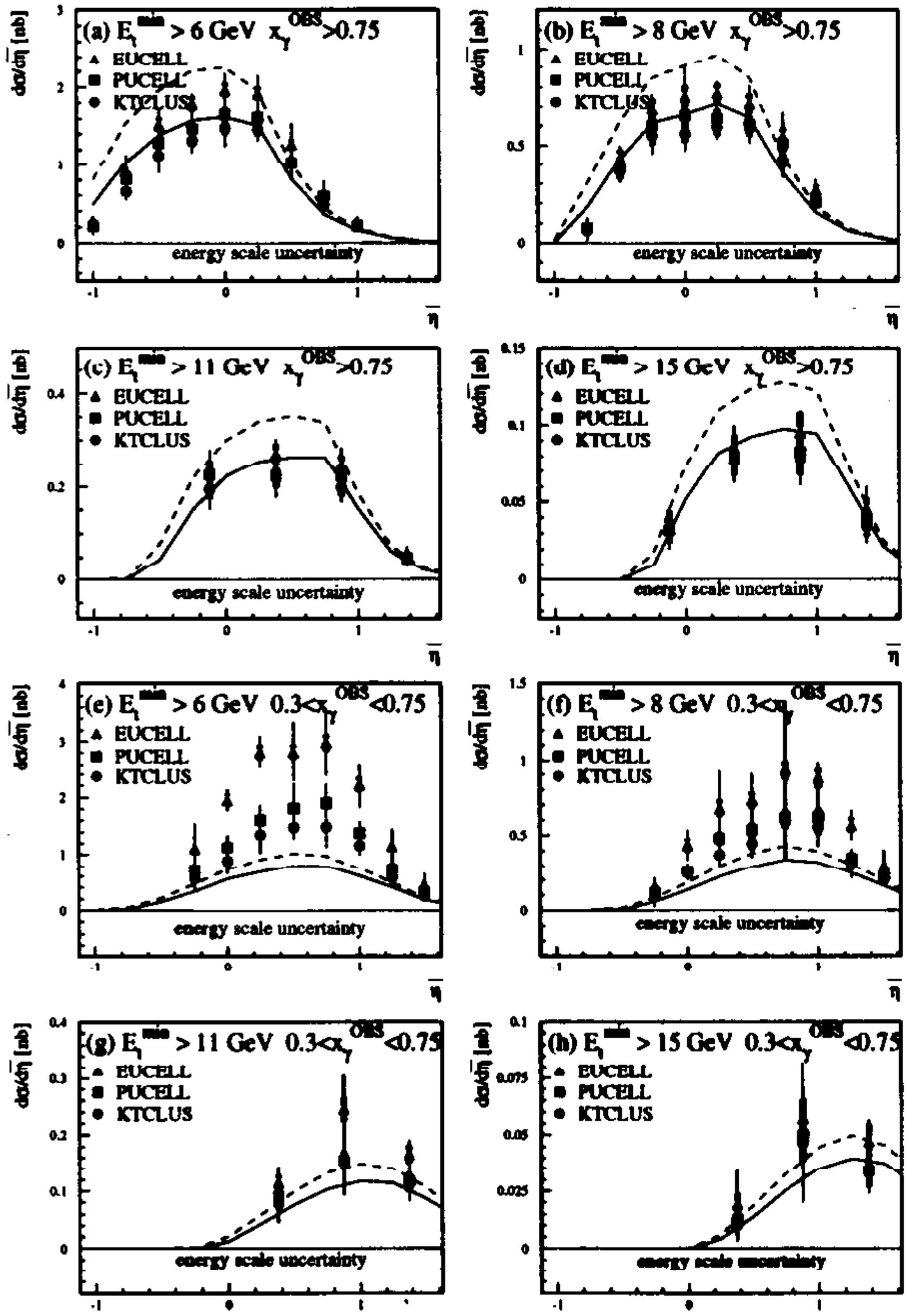
1 vertex events: double parton rate

2 vertex events: double interaction rate

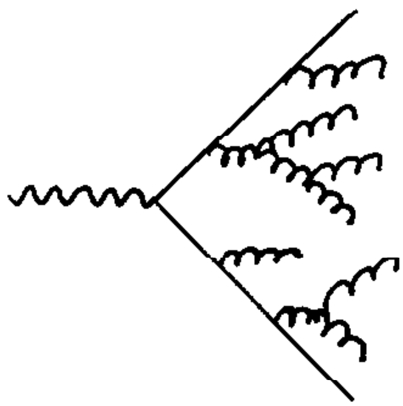
Comparison of Different Jet Algorithms With NLO Calculations

(Klasen, Kramer)

ZEUS 1994 Preliminary



BEYOND JETS AND EVENT SHAPES



PARTON CASCADES

CAN pQCD DESCRIBE BASIC QUANTITIE
OF HADRON PRODUCTION ?
e.g. MEAN HADRON MULTIPLICITY
BULK ENERGY DEPENDENCE

MODIFIED LEADING LOG. APPROXIMATION

INGREDIENTS :

1. RUNNING COUPLING CONSTANT AS VIRTUALITY DECREASES (Λ_{EFF})
2. COHERENCE : DESTRUCTIVE INTERFERENCE OF LARGE ANGLE GLUON EMISSION.
   QUANTUM MECHANICAL EFFECT ⇒ REDUCTION OF PHASE SPACE.
3. LOCAL PARTON - HADRON DUALITY
   PARTON CALCULATION DESCRIBES HADRON PRODUCTION
   PROPORTIONALITY CONSTANT , K.

[4. HEAVY QUARK EFFECTS ($m_b > m_c > \Lambda$)]

Selected Topics in Hadron Production in e^+e^- Collisions

Richard Hemingway

Carleton University

16 April 1997

- Introduction
- Inclusive hadron production at LEP1
- Inclusive hadron production at LEP1.5-2
- Production of identified hadrons at LEP1
- Aspects of hadronisation:
  - Flavour separation
  - Leading particle effects
  - Quark-Gluon differences
  - Spin effects (polarisation,helicity)
  - Correlations in the di-baryon system
- Comparison with models
- Conclusions

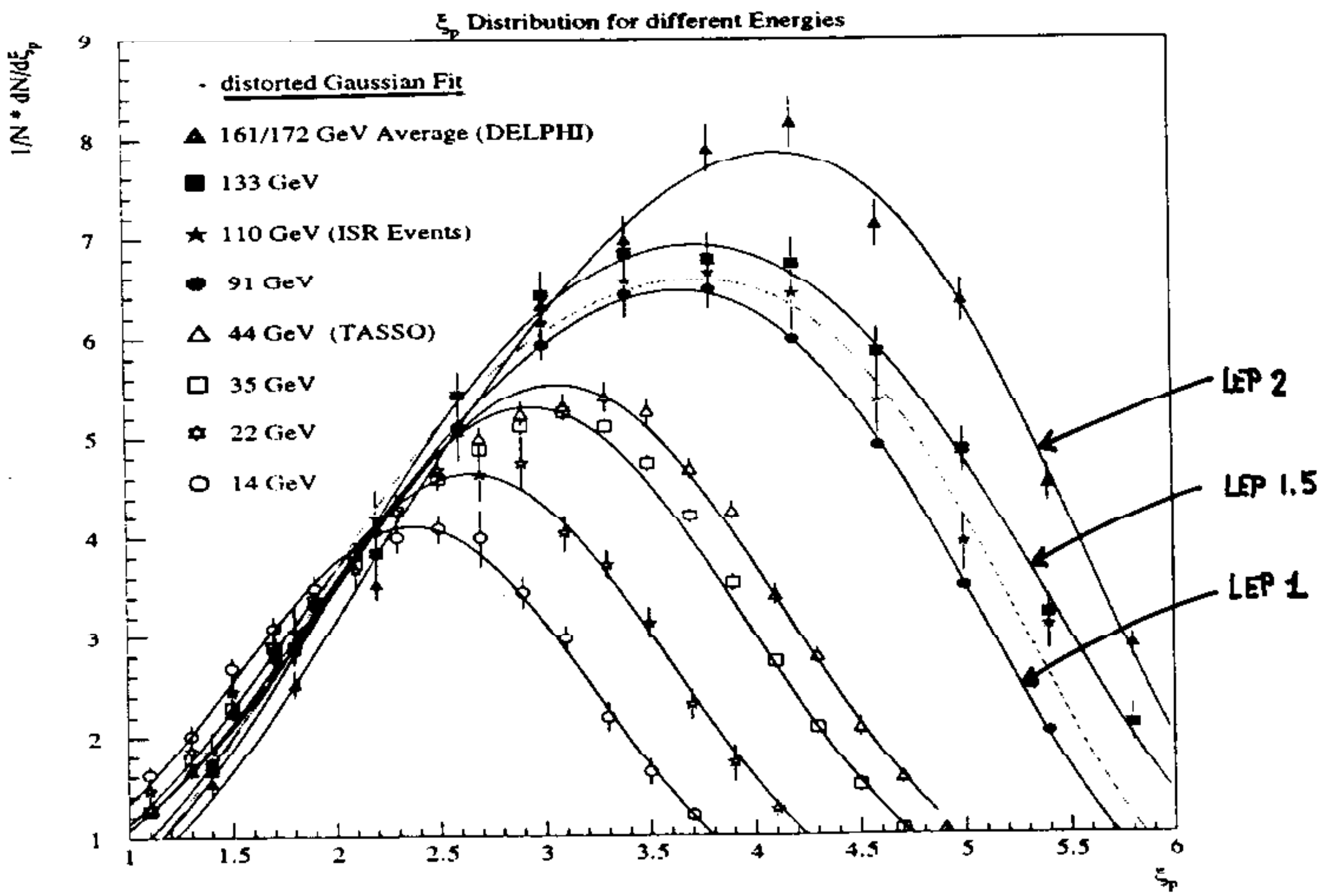
QCD TESTS AT LEP1.5 and LEP2

- See if QCD-based models/calculations give a good description of data
  - [1] EVENT SHAPES, JET RATES – evolution with $\sqrt{s} \rightarrow \alpha_s$ (not discussed here)
  - [2] CHARGED PARTICLES (a) Frag. F^{n} $\frac{1}{\sigma}\frac{d\sigma^h}{d\xi}$ $\xi = \ln(1/x)$
    - (b) Multiplicity Distrib^{n}

- LLA in QCD predicts
  - shape of ξ distrib^{n} [distorted Gaussian, peak ξ_0]
  - variation of ξ_0 with $\sqrt{s}$
  - variation of $\bar{n}_{ch}$ with $\sqrt{s}$

from talk by Emile Schyns/DELPHI at MORIOND-QCD 1997

Inclusive Charged Particle Production



ALEPH, CERN-PPE/96-43

DELPHI, CERN-PPE/96-05, CERN-PPE/96-130

OPAL-PN281, CERN-PPE/97-15, CERN-PPE/96-47

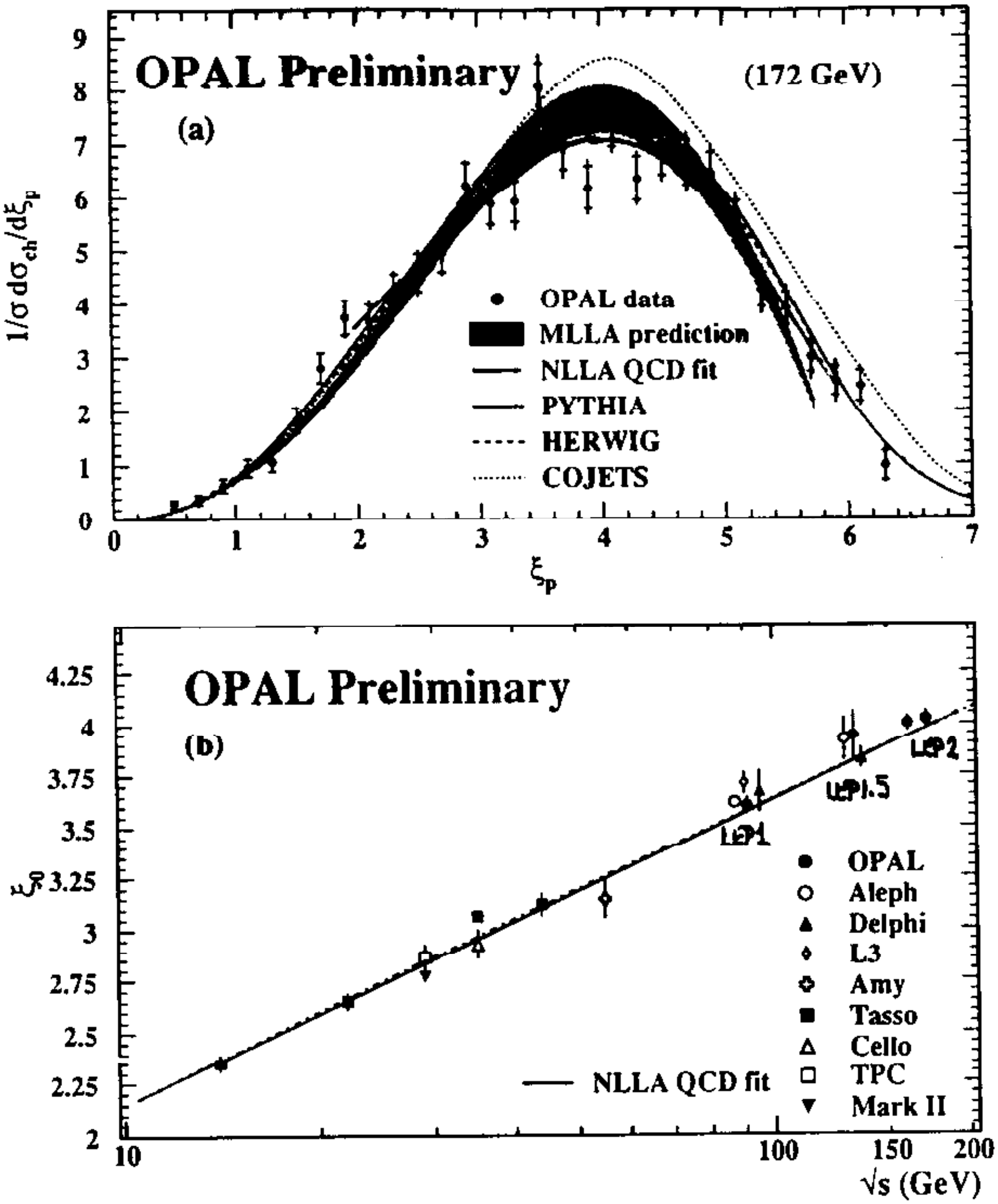
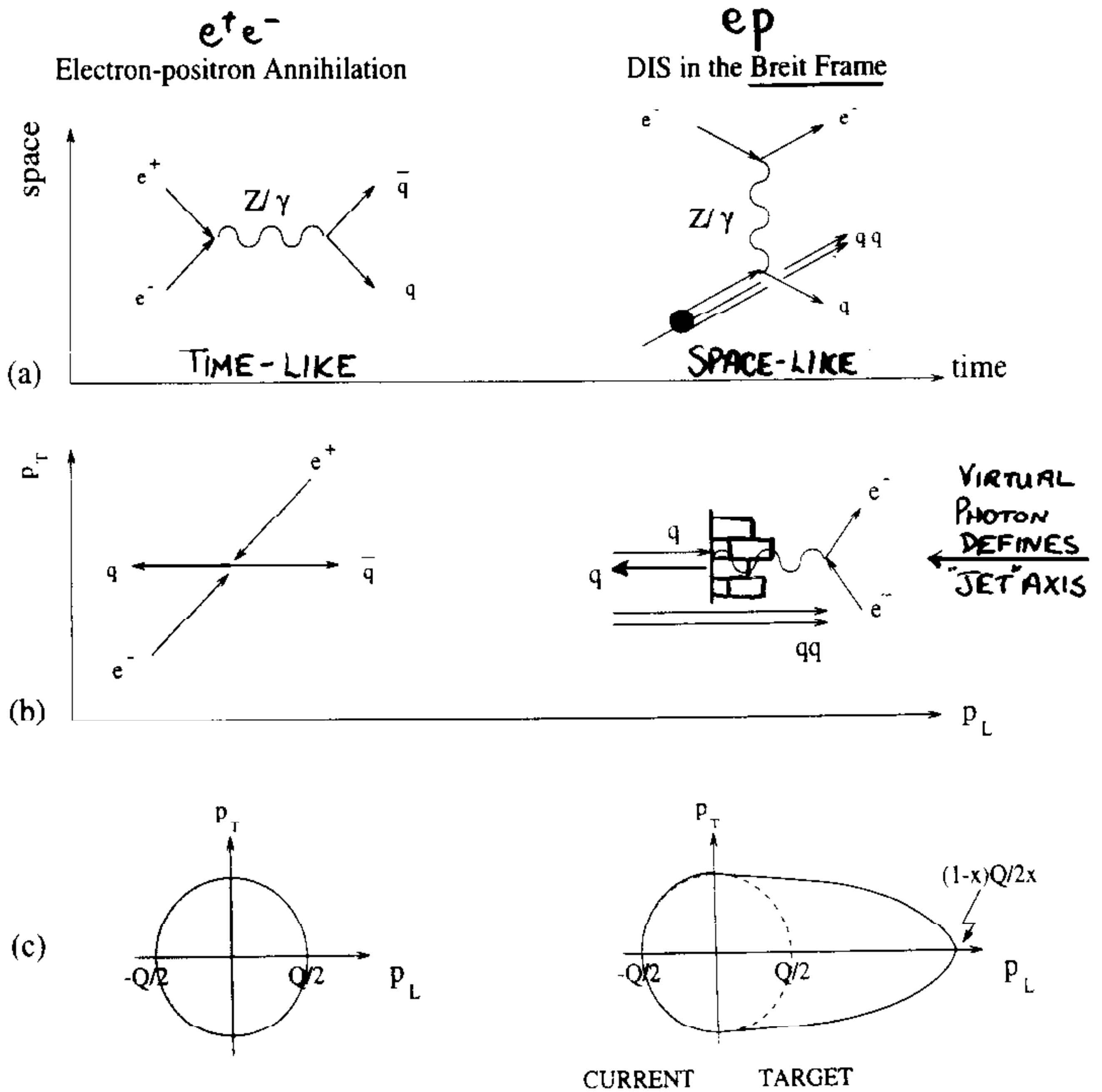


Figure 13: (a) Distribution of $\xi_p = \ln(1/x_p)$ for charged particles. Also shown are a fit of the NLLA QCD prediction, and predictions from MLLA QCD and PYTHIA, HERWIG and COJETS. The curve for the ARIADNE prediction is almost indistinguishable from the PYTHIA prediction and is omitted. (b) Evolution of the position of the peak of the ξ_p distribution, ξ_0, with the c.m. energy $\sqrt{s}$, compared with a fit of the NLLA QCD prediction up to and including the data at 161 GeV.

UNIVERSALITY OF FRAGMENTATION!

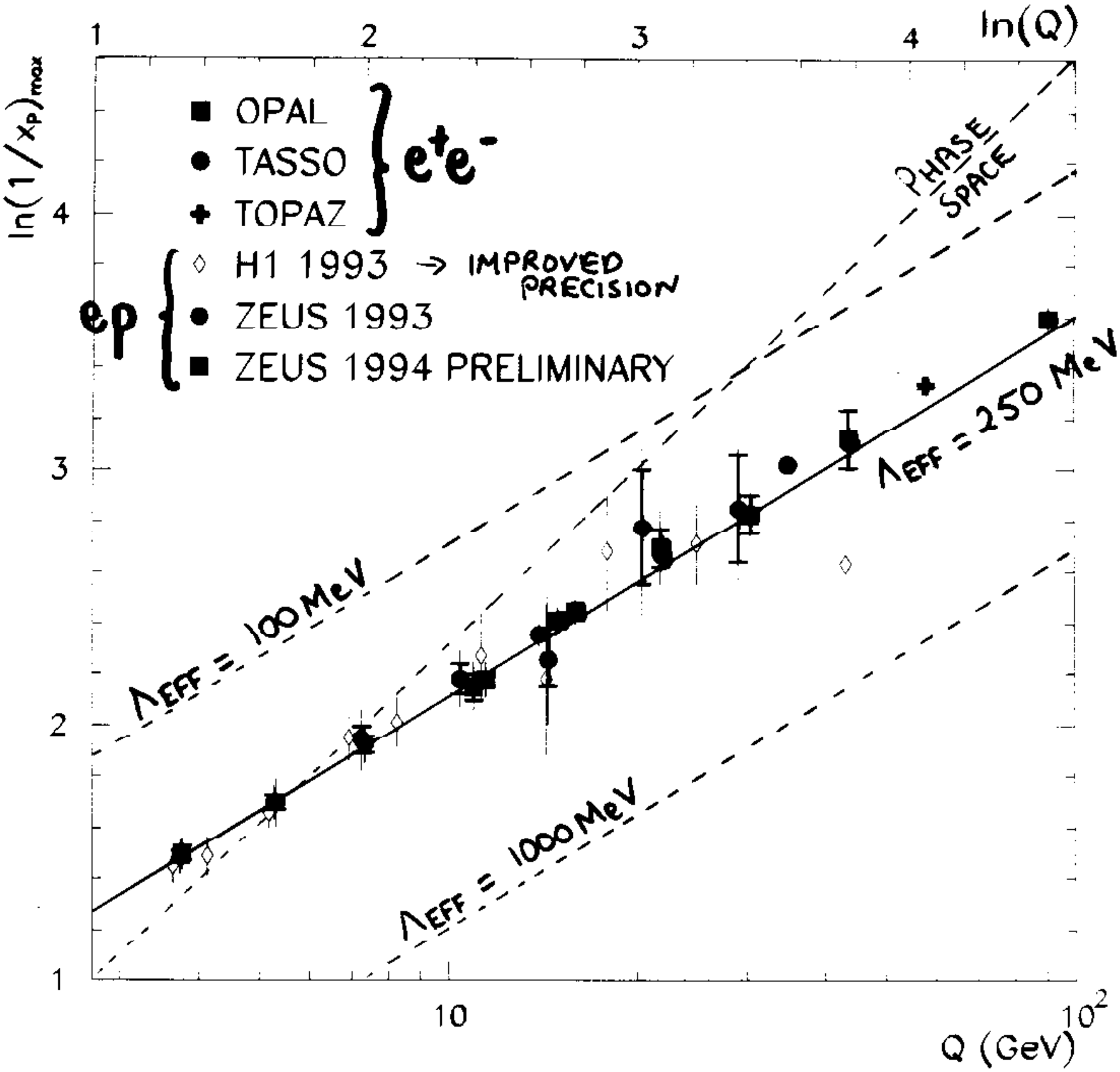
KINEMATICS:

THE BREIT FRAME
('BRICKWALL' FRAME)



⇒ COMPARE HEMISPHERE OF e^+e^- WITH CURRENT REGION OF ep COLLISIONS

$e^+e^- \equiv ep$

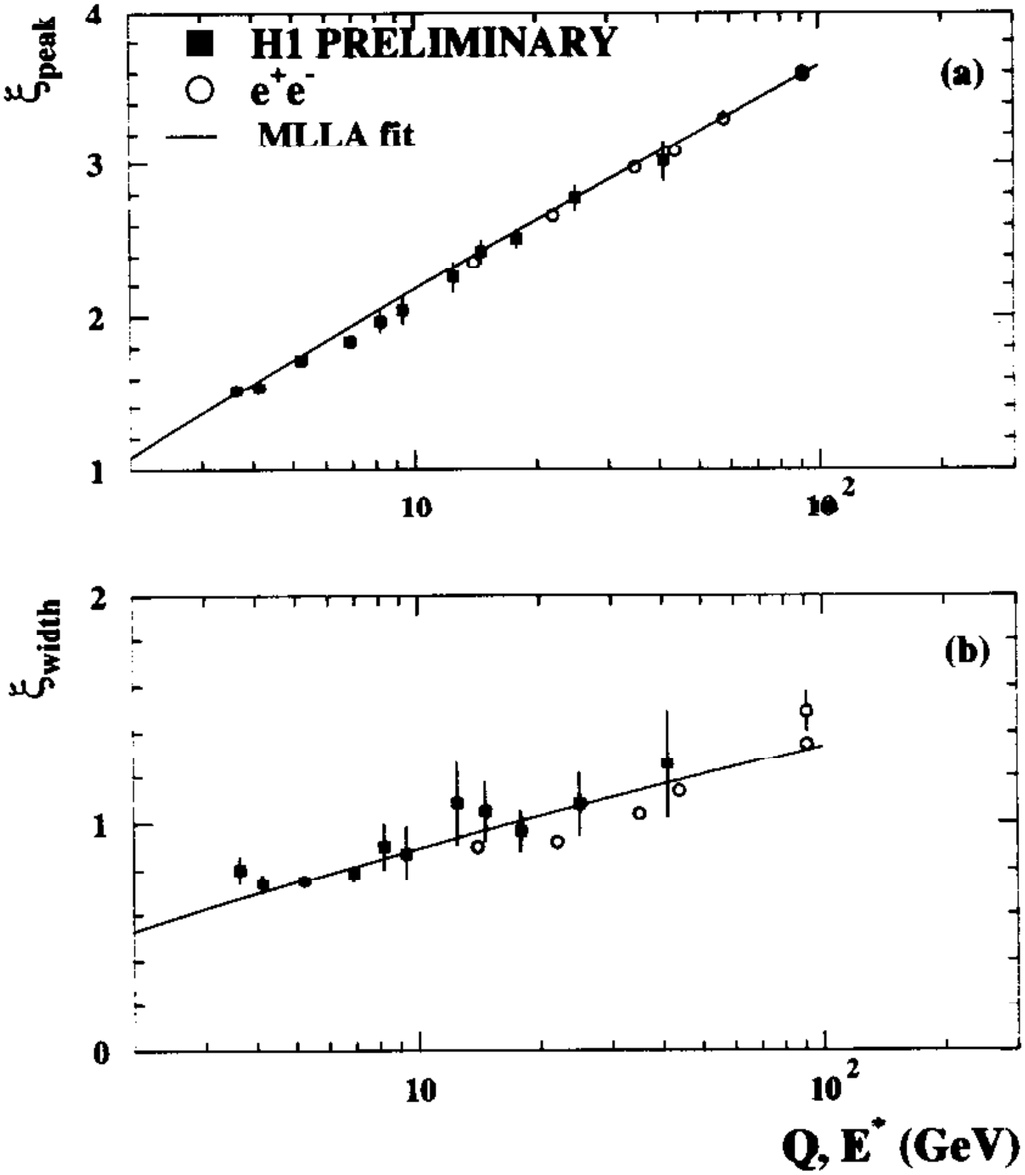


PHASE SPACE = NO COHERENCE [SLOPE = 1]
DOES NOT DESCRIBE DATA

pQCD DESCRIBES DATA (EVEN AT
LOW Q ≃ 4 GeV)

Evolution of the Peak and Width of D(ξ)

Results of Simultaneous fit to H1 data ONLY — $\Lambda = 0.21 \pm 0.02$ GeV (*), $\kappa = -0.43 \pm 0.06$



e^+e^-

$\Lambda = 0.21 \pm 0.02$ GeV

$\kappa = -0.32 \pm 0.06$

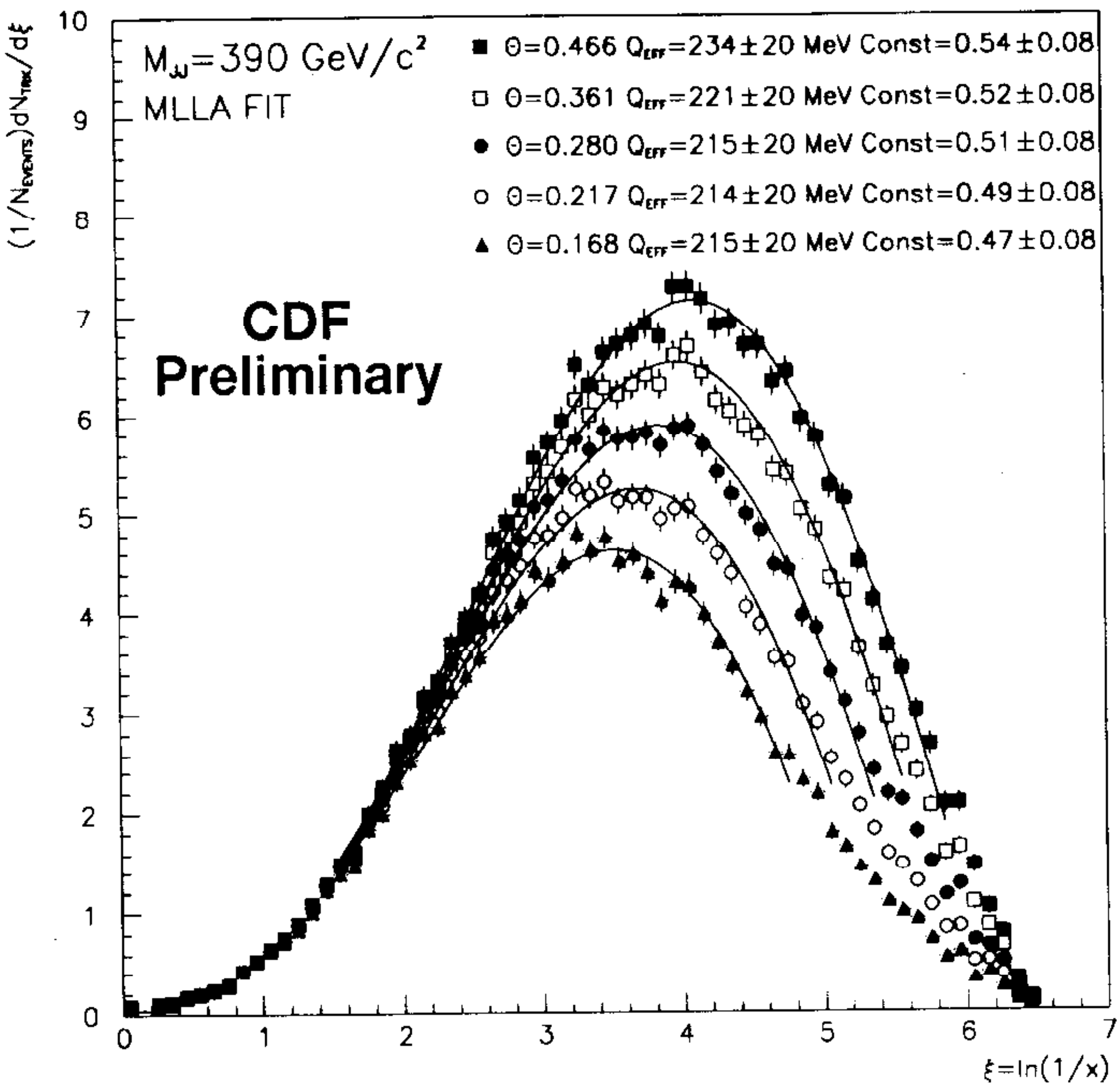
(*) MLLA/LPHD → $\xi_{PEAK} = 0.5\,Y + c_2\sqrt{Y} + \kappa$

$\xi_{WIDTH} = \sqrt{Y^{3/2}/2c_1}$

$Y = \ln(Q/\Lambda_{eff})$; c_1, c_2 CONSTANTS, DEPEND ON N_c, N_f

Jet Fragmentation Function compared with QCD Modified Leading Log (MLLA) Predictions

Fix two–jet mass (hence jet energy) and vary cone containing charged tracks:

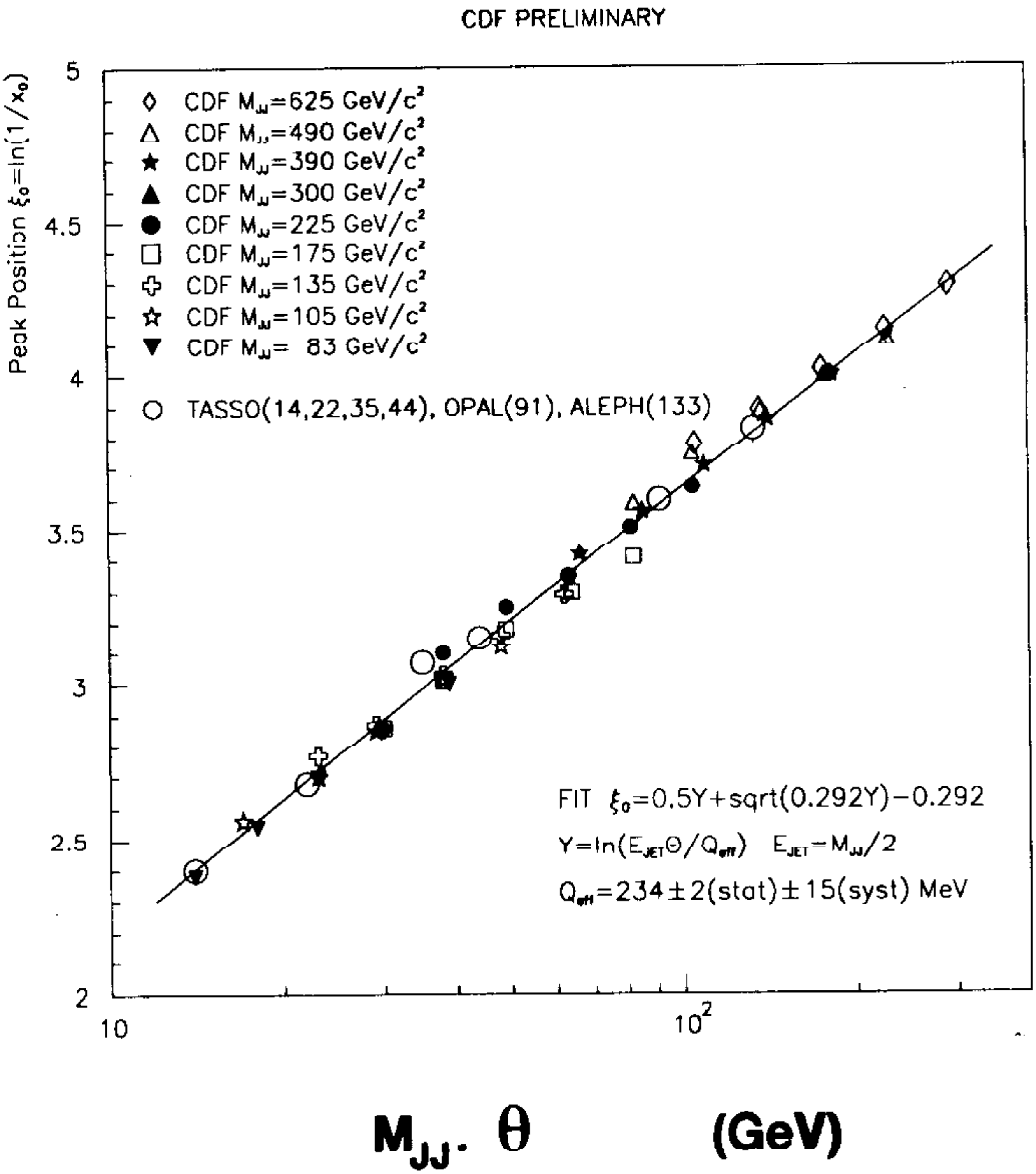


$$\xi = \mathrm{Ln}\,(E_{Jet} / P_{Track})$$

Note: MLLA –> 2 parameters:

Perturbative cutoff scale: Qeff
Normalization = number particles/parton: const

MLLA Scaling seems OK

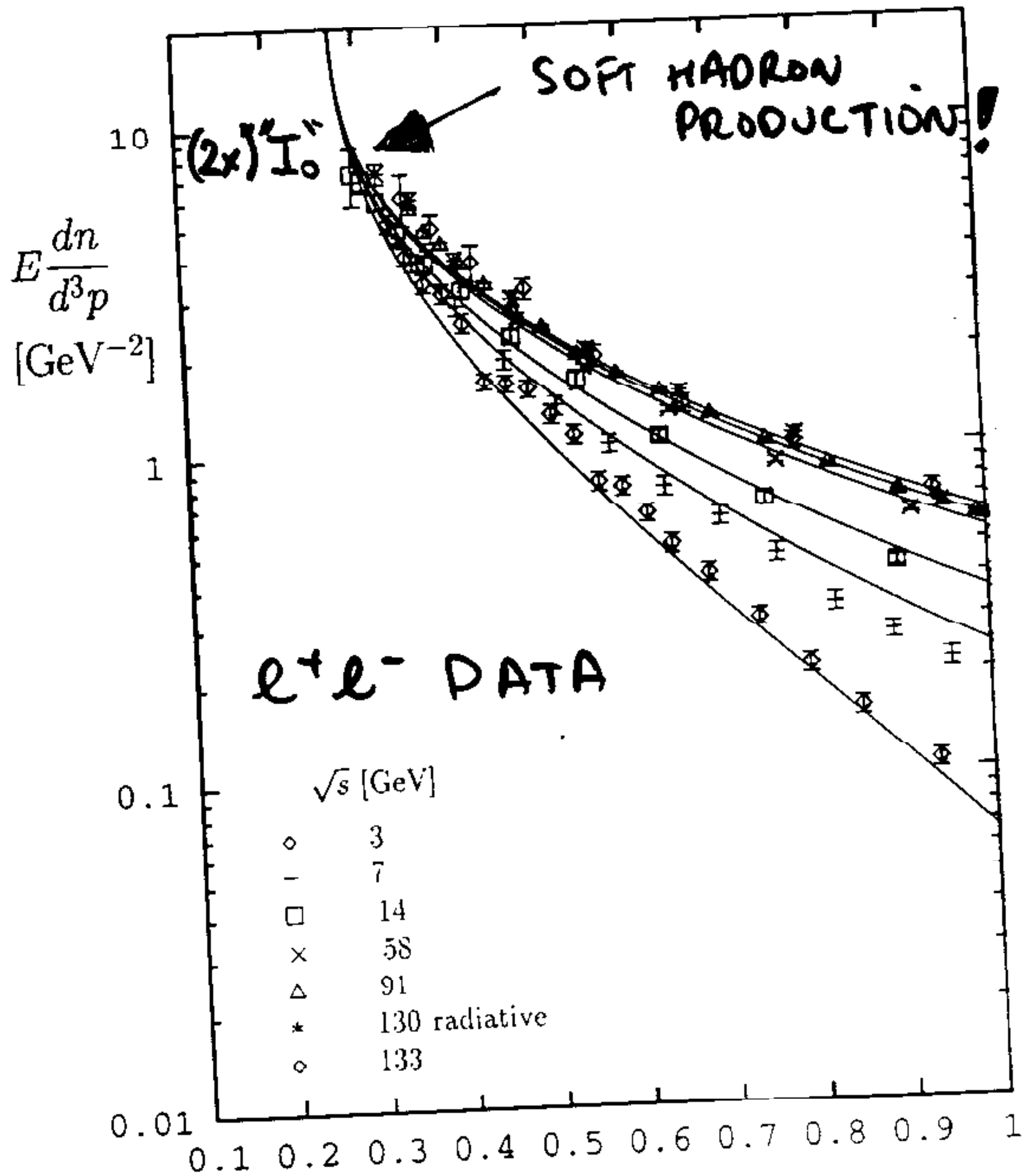


INVARIANT ENERGY SPECTRA

MEASURE $\frac{1}{N_{ev}} E \frac{dn}{d^3p}$ $I_0^{e^+e^-} = \frac{1}{2} \lim_{p \to 0} E \frac{dn}{d^3p}$

- { MLLA/LPHD SCALING EXPECTED AT SMALL p
  { COLOUR COHERENCE

V. KHOZE ET AL.
HEP/PH 9610204



$E[GeV] = \sqrt{Q_0^2 + p^2}$

$e^+e^- \to$ 270 MeV

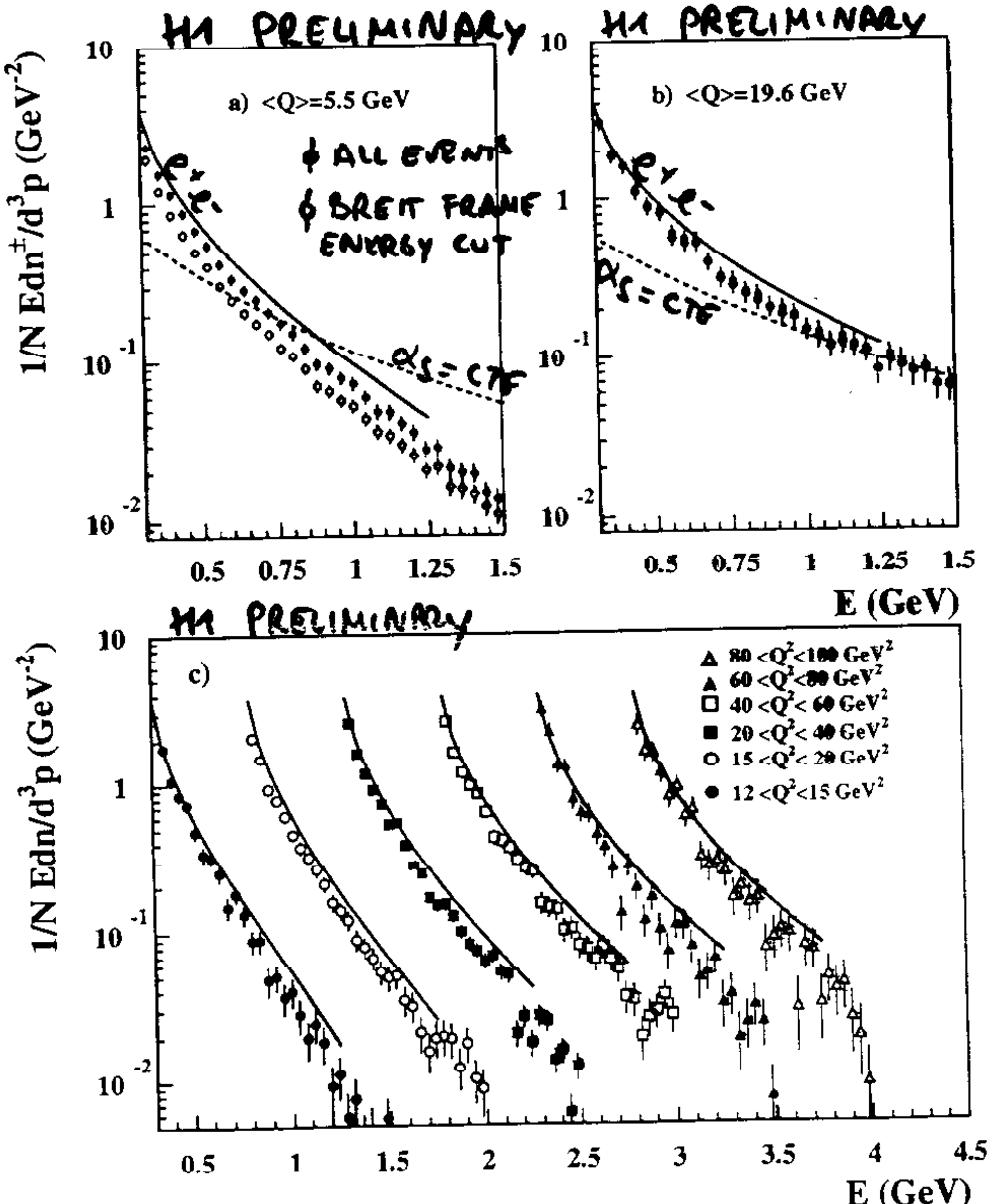
- "EFFECTIVE MASS SCALE"
- p_T^2 CUTOFF IN CASCADE

$I_0^{e^+e^-} \leftrightarrow I_0^{DIS}$?

INVARIANT ENERGY SPECTRA

→ MEASURED FOR THE FIRST TIME

$$I_0^{e^+e^-} \sim I_0^{DIS}$$



* ALL Q^2 ~ COMMON LOW ENERGY LIMIT
* VERY SENSITIVE TO α_s

SCALING VIOLATIONS IN FRAGMENTATION FUNCTIONS

⇒ MEASUREMENT OF α_s

ALEPH
CERN-PPE/95-096

and

DELPHI
CERN-PPE/96-185

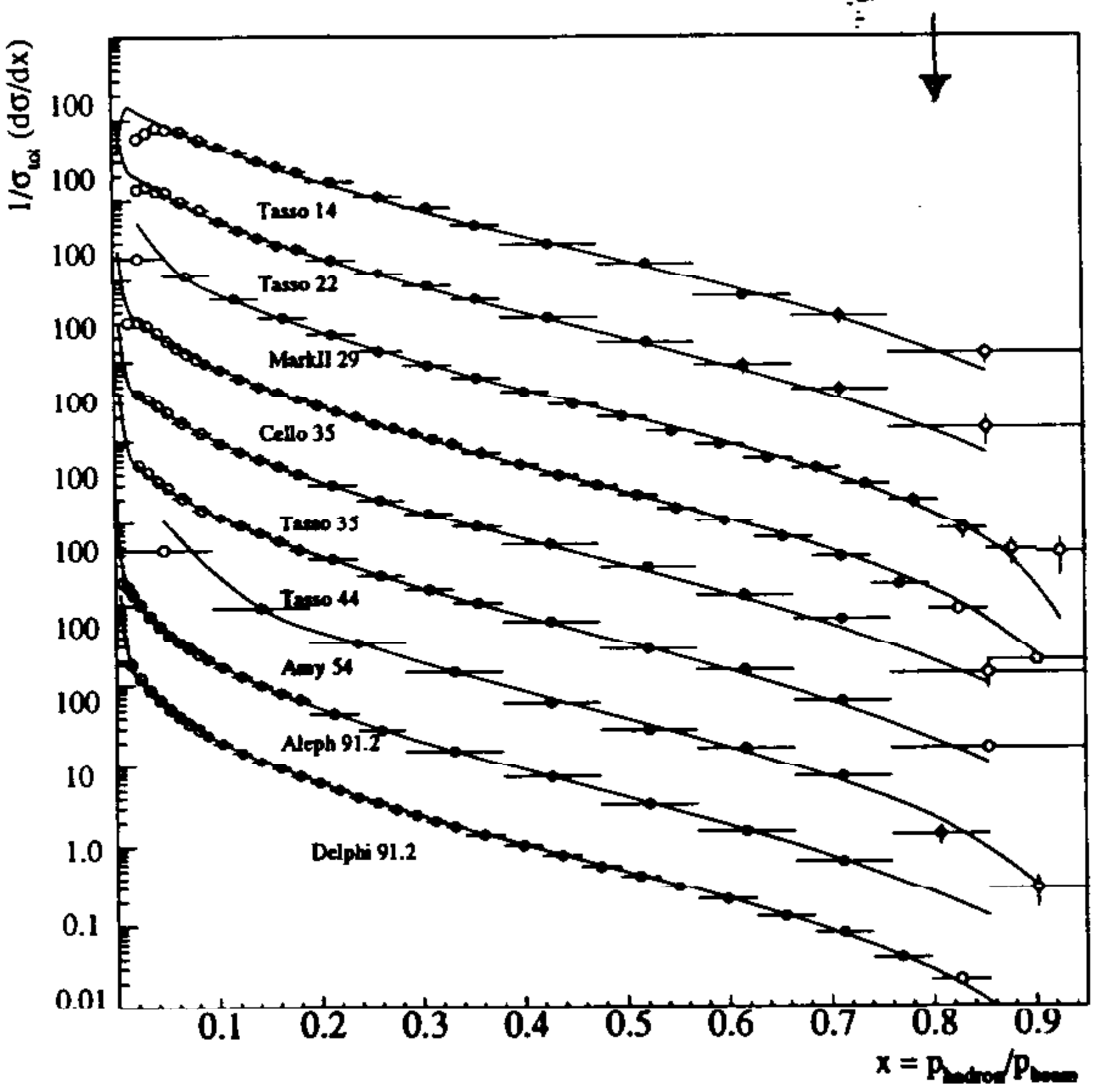
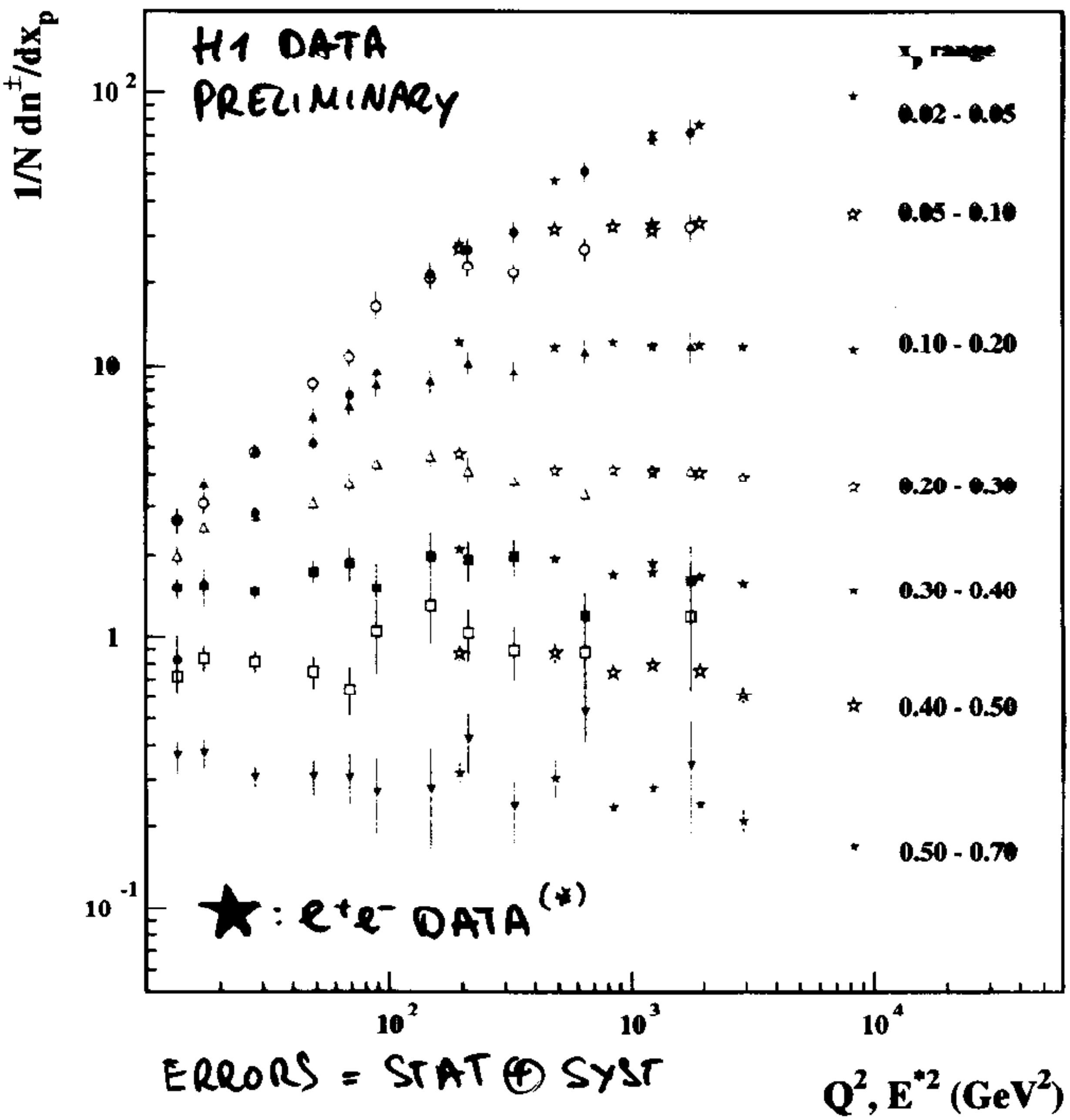


Figure 3: Inclusive scaled momentum distributions at centre-of-mass energies in the range between 14 GeV and 91.2 GeV. Only the full dots have been used in the fit.

$$\alpha_s(M_Z) = 0.124 {}^{+.006}_{-.007} \pm .009$$

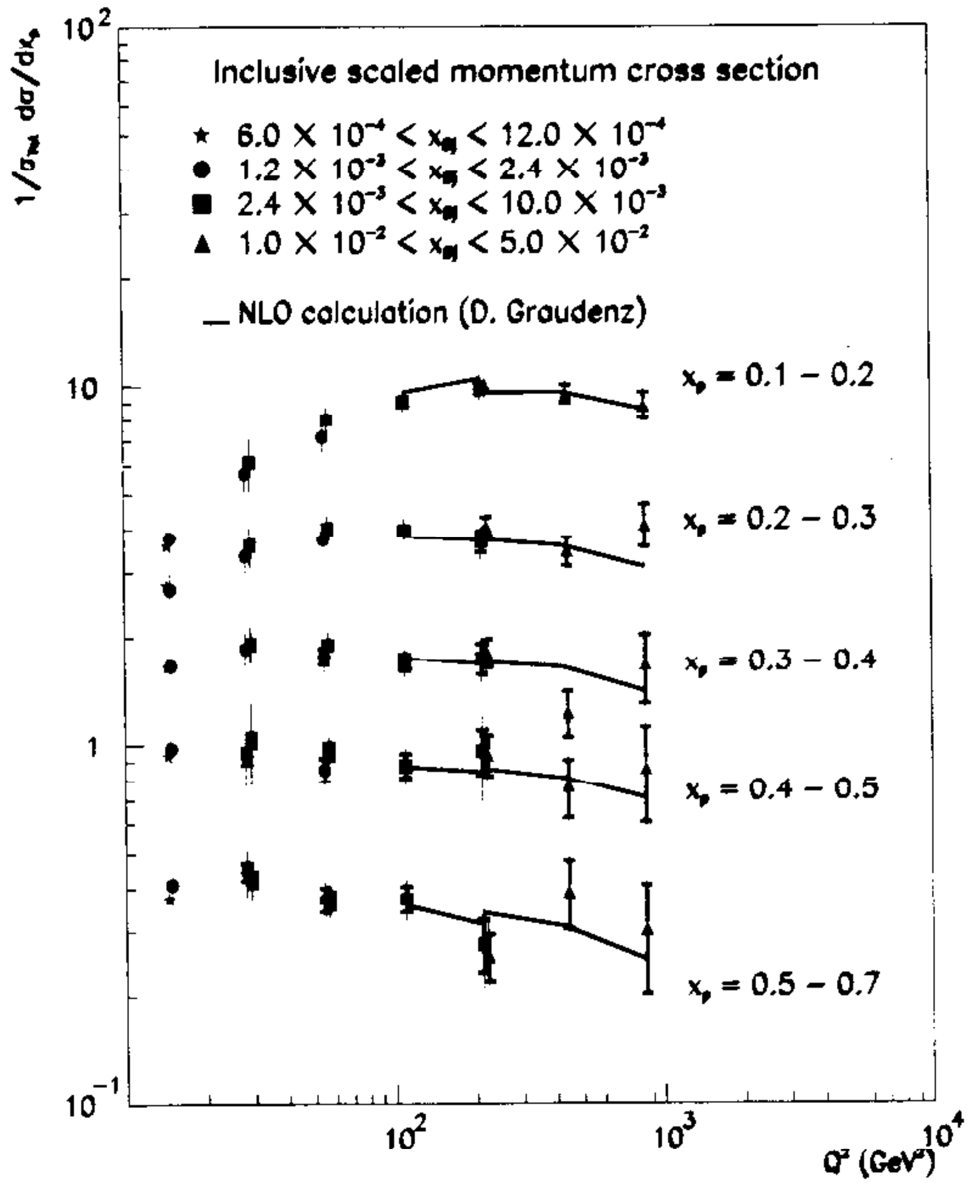
SCALING VIOLATIONS

Q2 dependence of D(x_p)



* SAME BEHAVIOUR AS IN e^+e^-
* EXTRACTION OF α_s IS BEING STUDIED

Comparing the Data with a Next-to-Leading Order Calculation (CYCLOPS)



NLO calculation with different input values of Λ_{QCD}