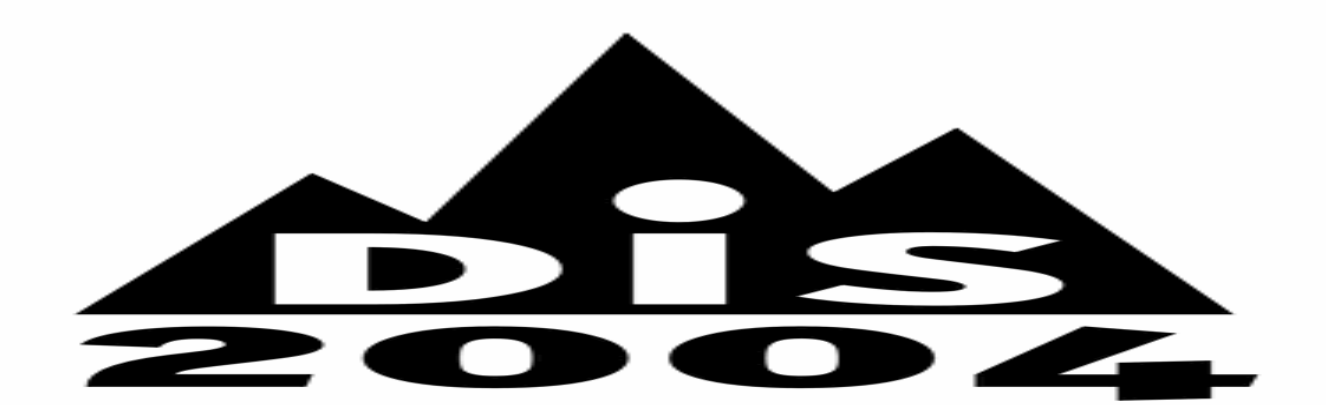



David Milstead
The University of Liverpool

## Working Group C: Hadronic Final States

27 experiment and 11 theory contributions

# Review of Experiments

# A few questions

Is perturbative QCD in good shape ?

- Current measurements of $\alpha_s$
- Jet rates at high $p_T$ and mass
- QCD dynamics at low x …

Progress in npQCD ?

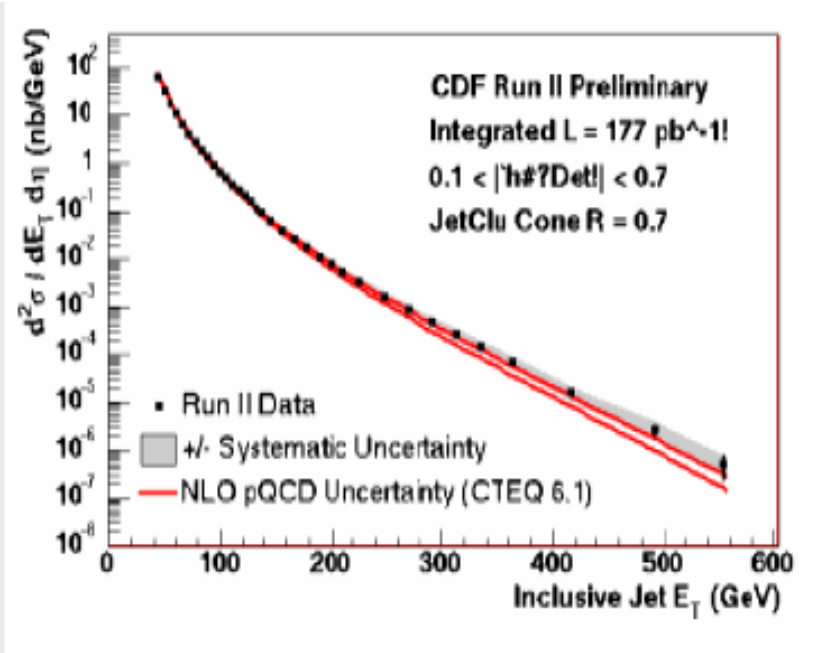
- Power corrections
- Pentaquarks
- Hadronisation universality
- Colour reconnections

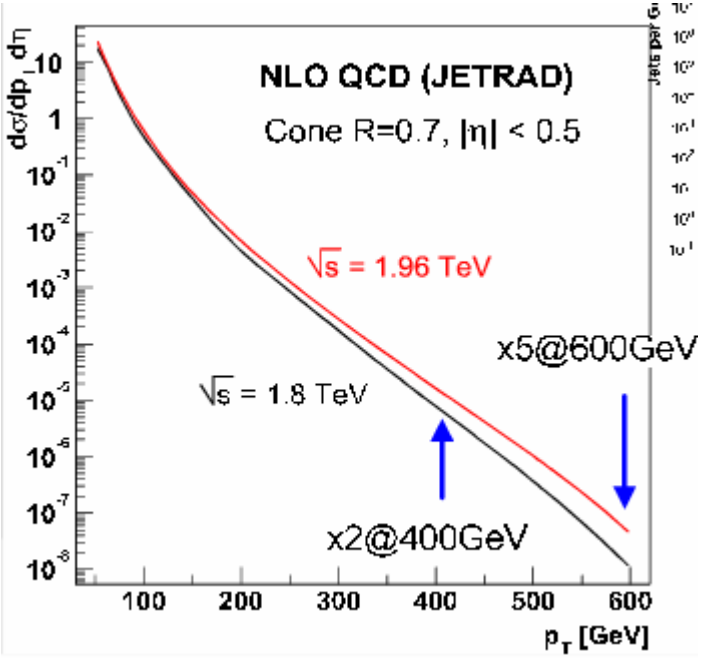
What does this mean for LHC ?

- QCD uncertainties

# Jet Production at CDF

## Increase in CM energy to 1.96 TeV extends high $p_T$ sensitivity



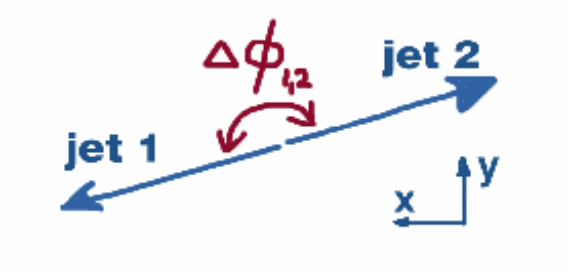



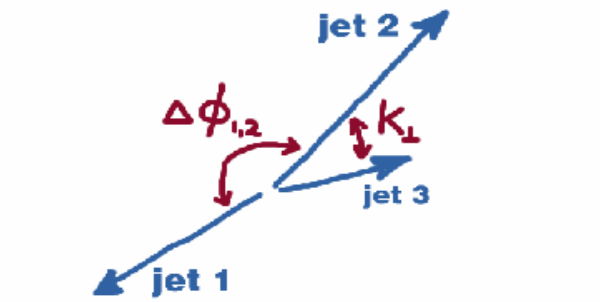

Next steps forward jet cross-sections and improved energy scale uncertainty (1%)

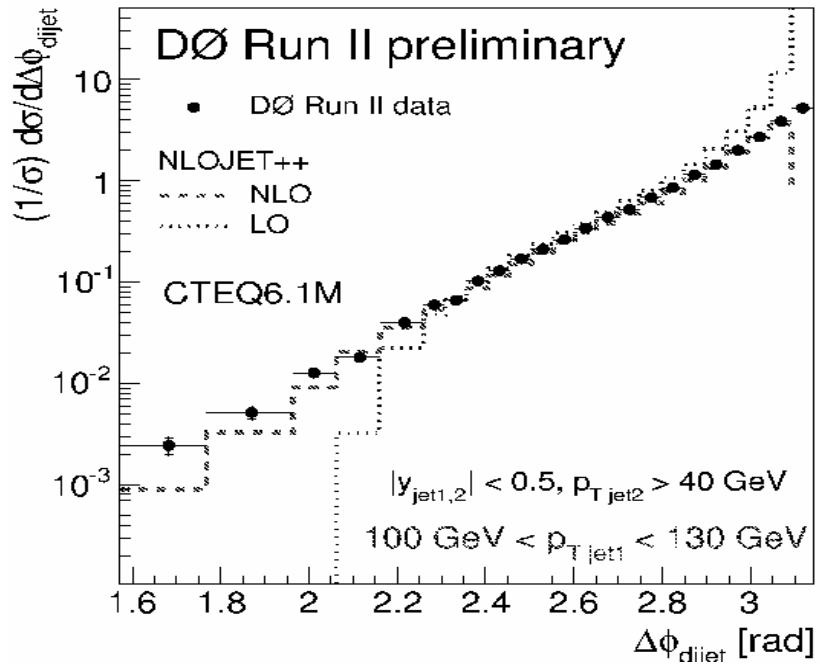
# Jet Production at D0

## Large energy scale uncertainty – under study

## Study angular correlations between jets to probe higher orders



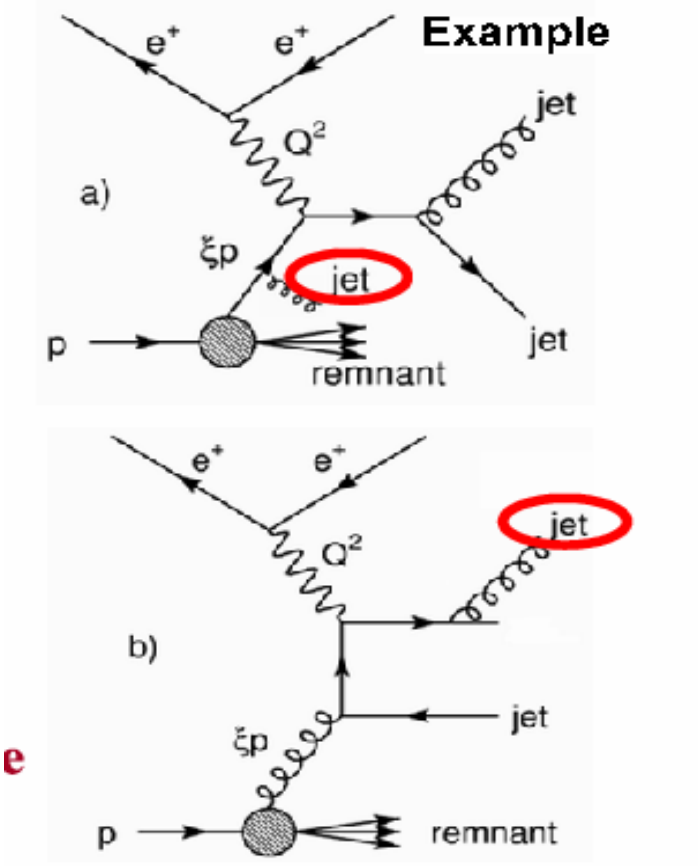

Good agreement by NLO except at extreme $\Delta\phi$ values

# Multi-jet Rates at HERA

Direct test of QCD at $O(\alpha_s^2)$

Measure ratio of 3-jets/2-jets and cancel correlated uncertainties

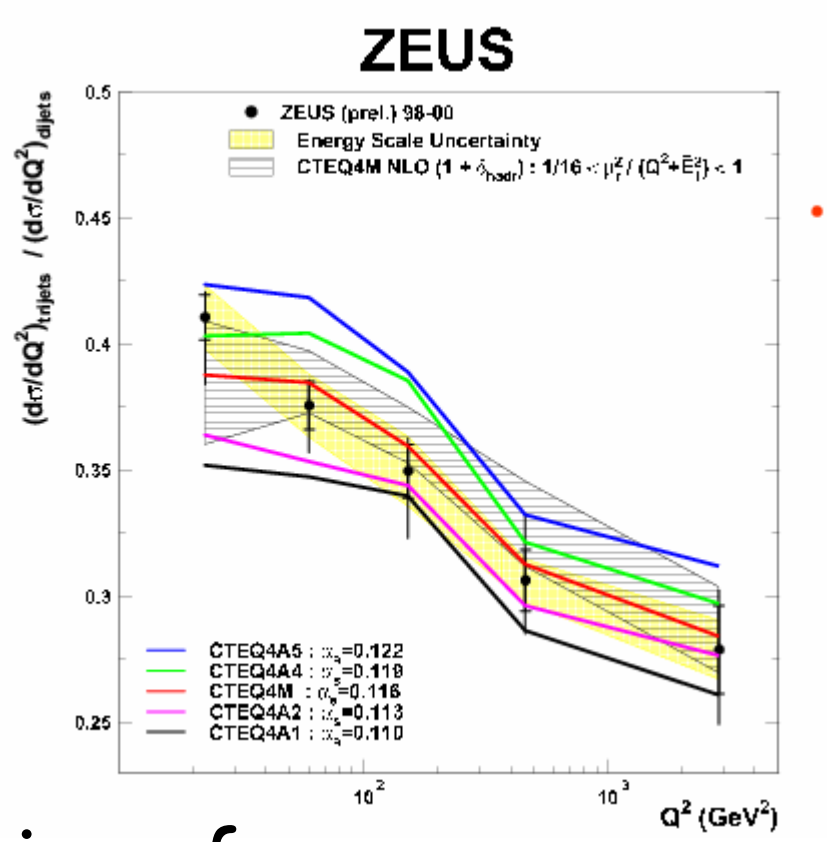
Multijet NLO calculations available (Phys. Rev. Lett.87:082001,2001)



# 3-jet/2-jet Ratio at HERA

Invariant $k_T$ jet algorithm

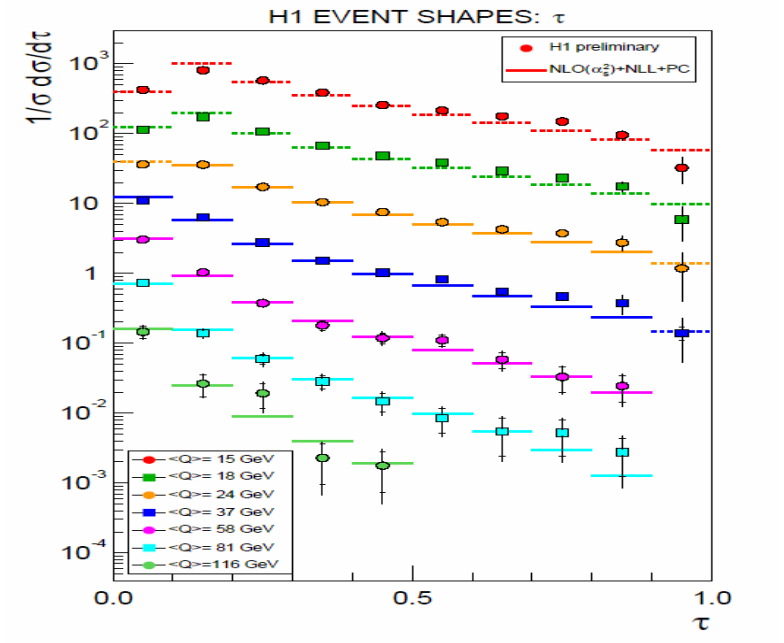
$E_{Tjet} > 5$ GeV
$-1 < \eta < 2.5$
$Mass_{2,3jet} > 25$ GeV

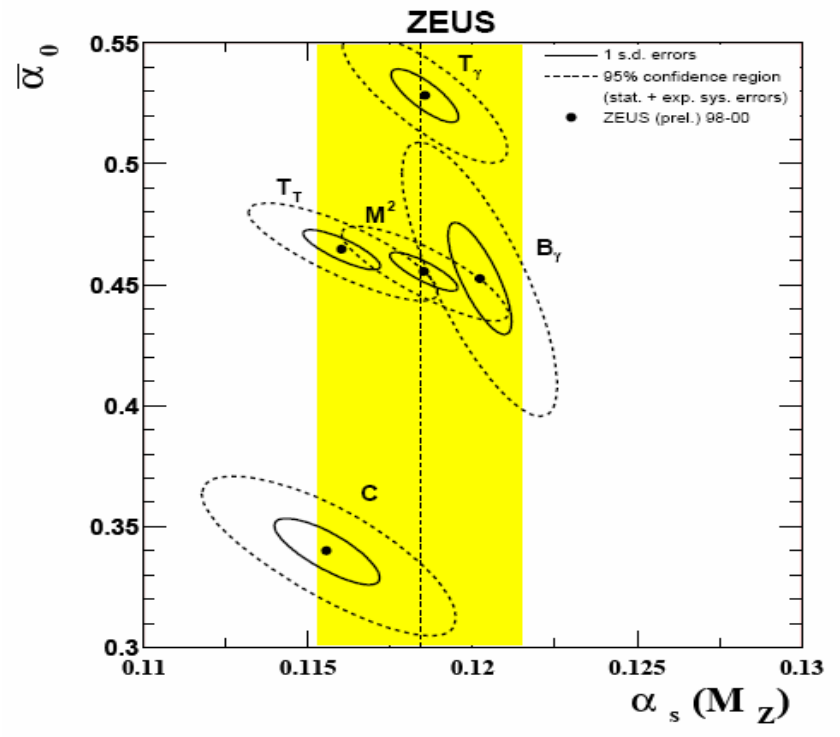



Towards an extraction of $\alpha_s$ .....

# Event shapes

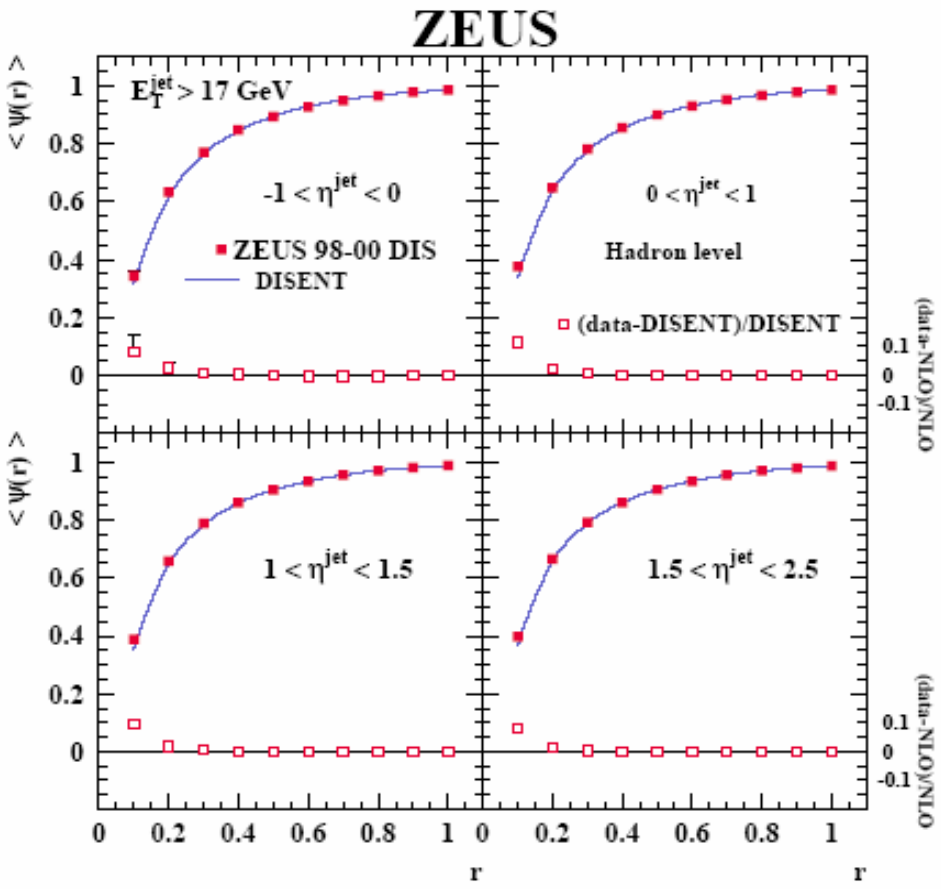
## Fit $\bar{\alpha}_0$ and $\alpha_s$ with NLO+NLL+PC

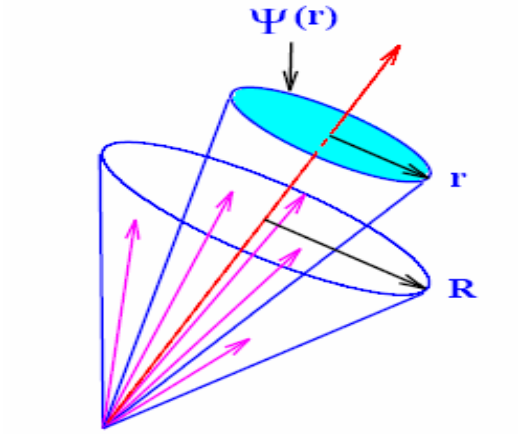


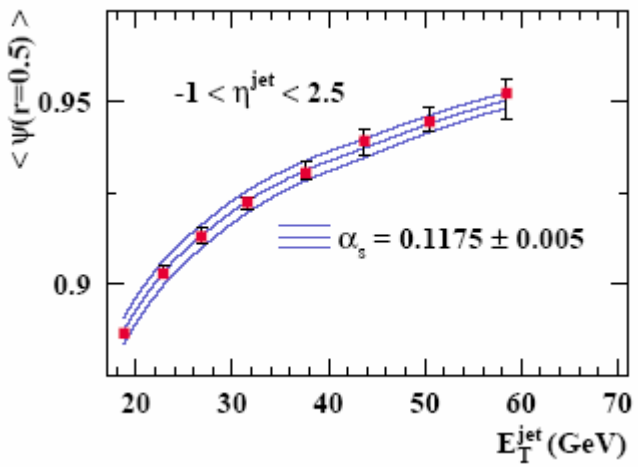




Resummed calculations (see Dasgupta talk) lead to improved consistency for both experiments

# Measurements of Jet Substructure



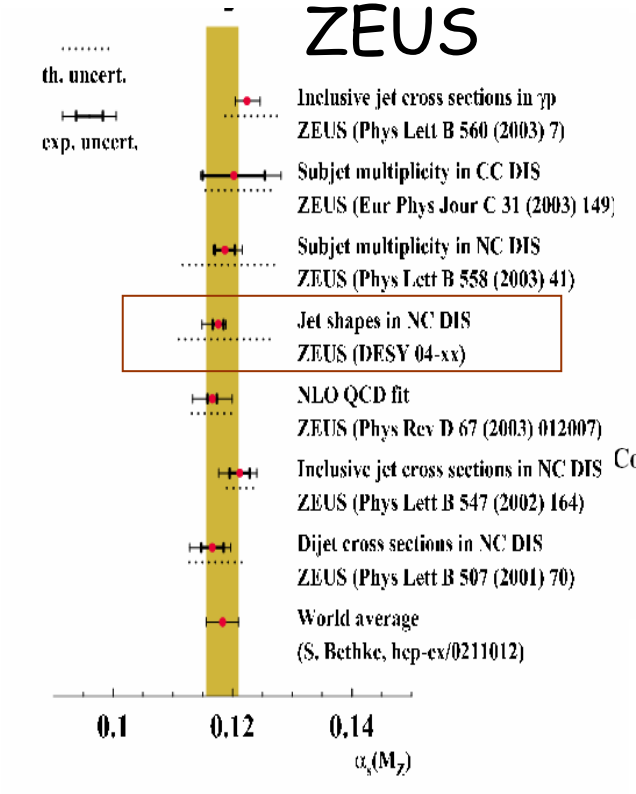




Extract $\alpha_s$ and separate quark/gluon jets

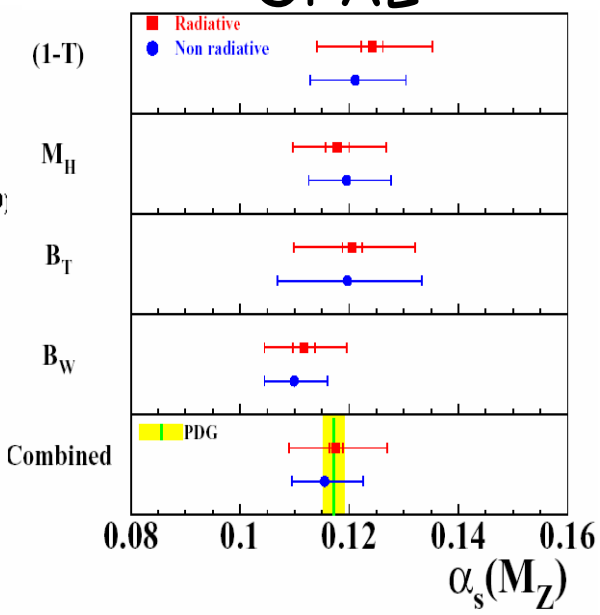
# Perturbative QCD is in good shape

## Selected $\alpha_s$ measurements presented this week

ZEUS

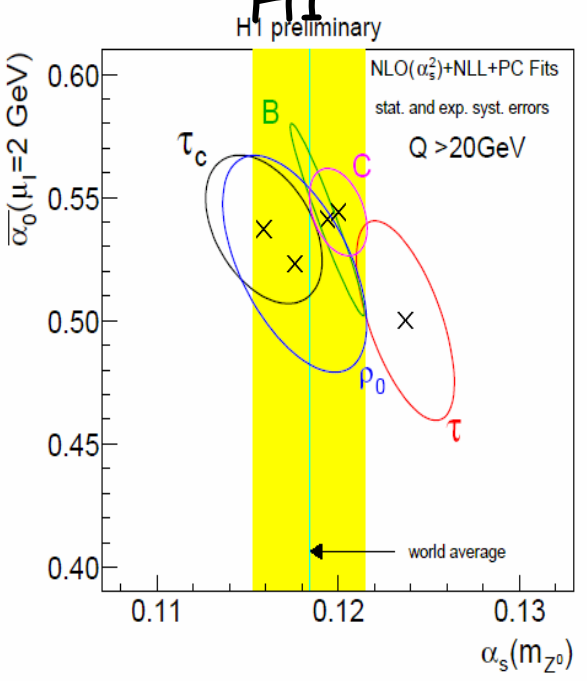



OPAL




Event shapes in radiative/non-radiative e+e-

H1



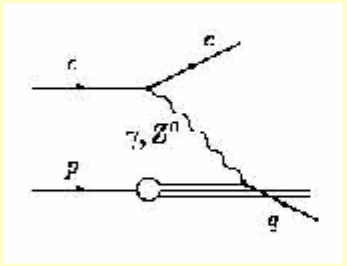

Event shapes in DIS

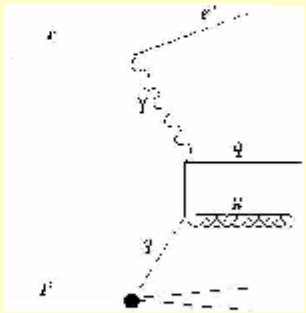
# Azimuthal Asymmetries at HERA

$$\frac{d\sigma^{ep \to ehX}}{d\phi} = 2A\left(\frac{1}{2} + B\cos(\phi) + C\cos(2\phi) + D\sin(\phi) + E\sin(2\phi)\right)$$

QCDC

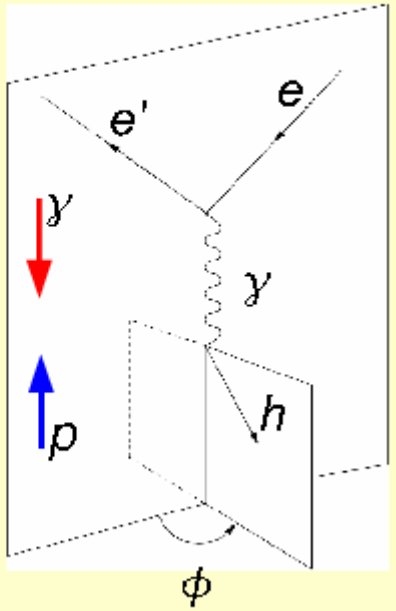
BGF





Zeroth order QCD process (Simple DIS, QPM)

First order QCD processes

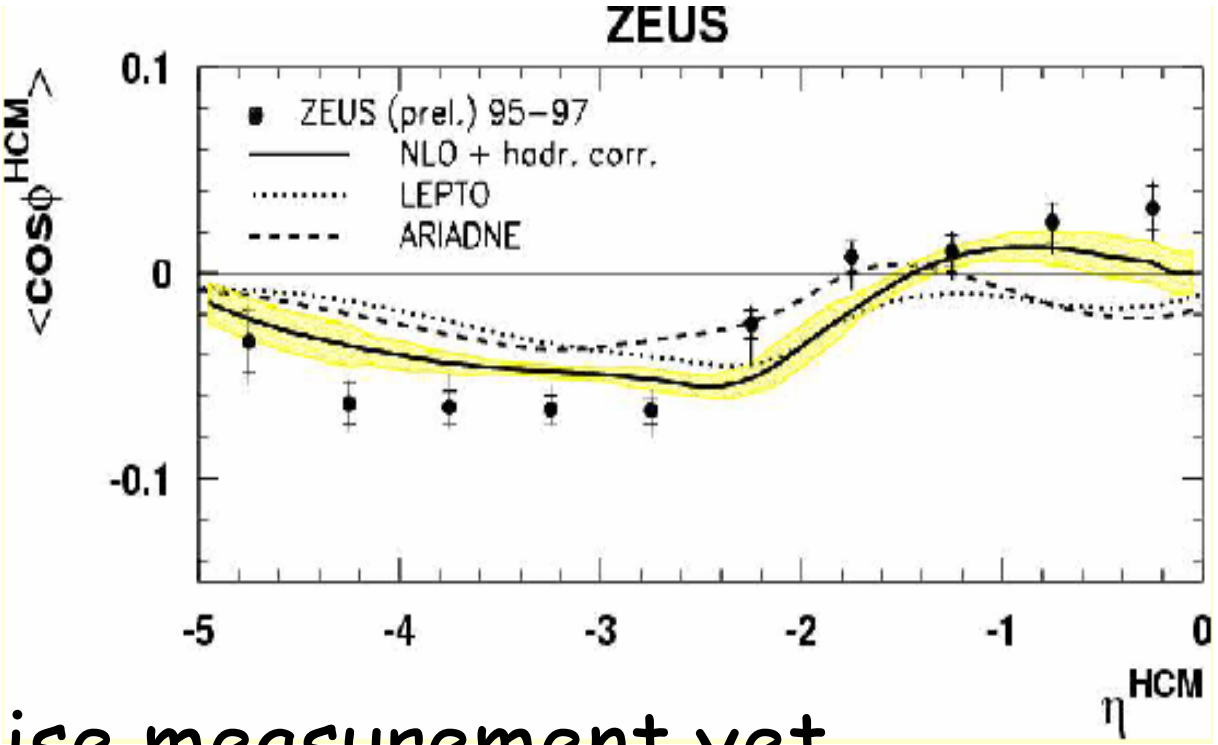



$\gamma^* p$ HCM frame

Use energy flow to measure over a wider phase space with reduced systematic errors

# Azimuthal Asymmetries at HERA

$100 < Q^2 < 8000\ GeV^2$
$0.2 < y < 0.8$
$0.01 < x < 0.01$

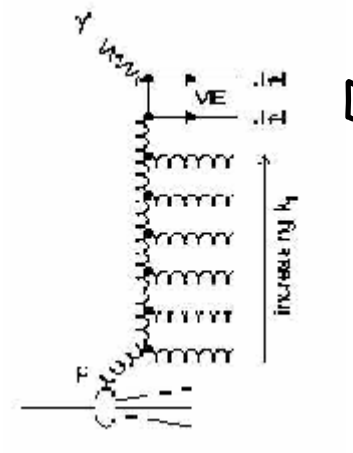



Most precise measurement yet

NLO fails to describe data

# Parton Dynamics at low x

- High precision measurements of forward jets
- Sensitive to QCD evolution



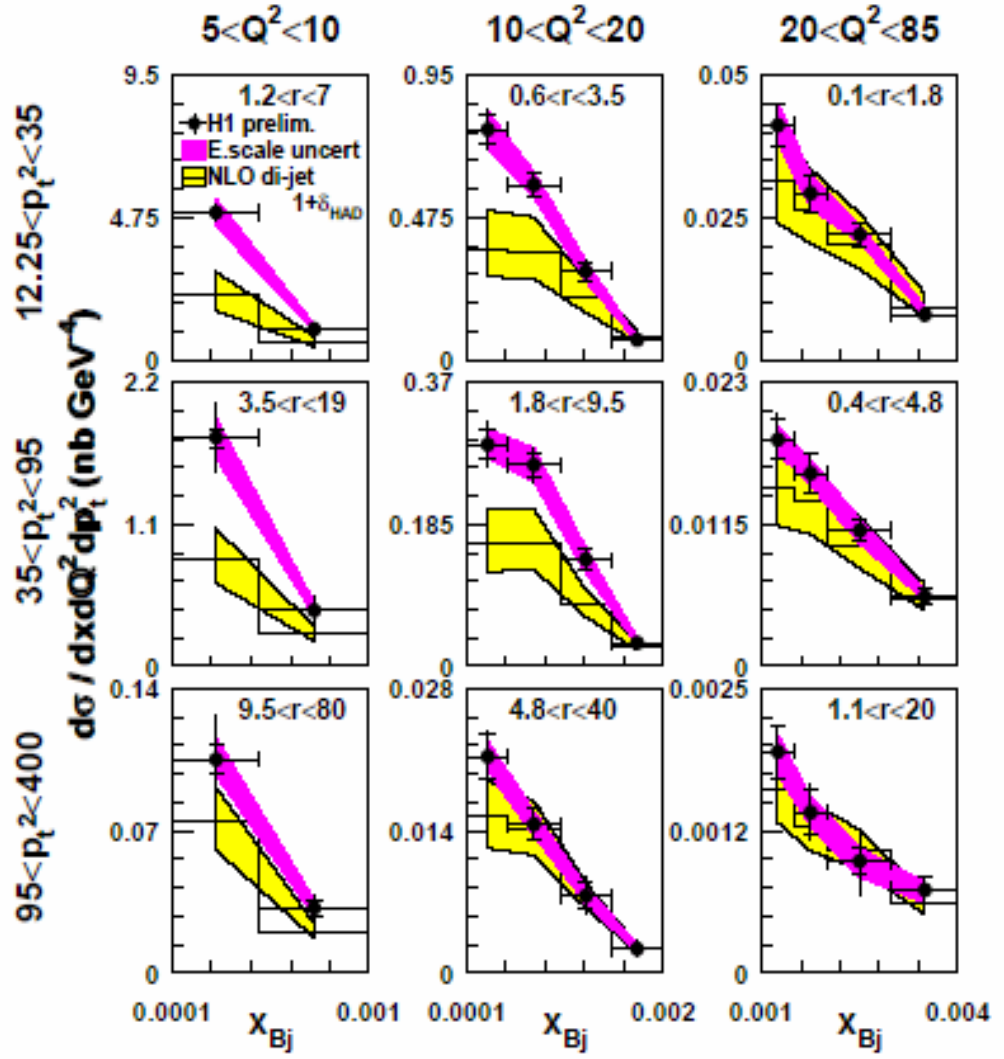
DGLAP $k_{Tn} \gg k_{Tn-1}$

$\updownarrow$

CCFM

$\updownarrow$

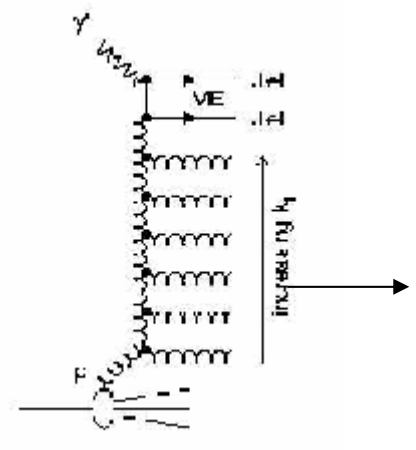
BFKL $x_n \gg x_{n-1}$



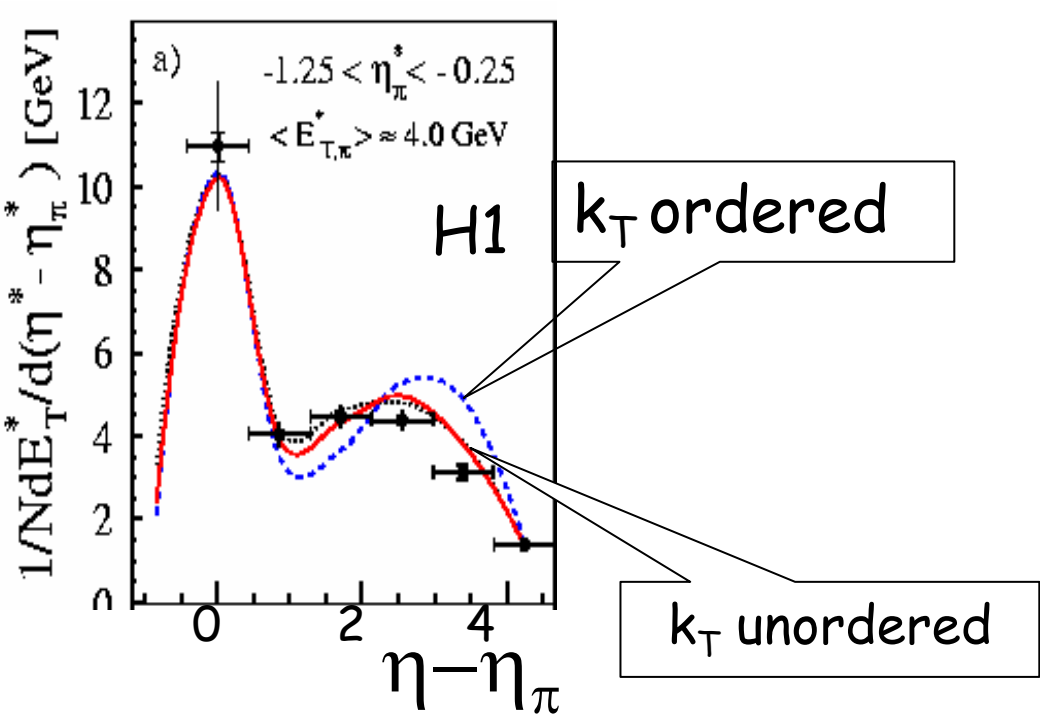

Failure of NLO calculations fail away from DGLAP region

# $k_T$ unordering at low x ?

Trigger low x events with hard forward $\pi^0$



$\pi^0$



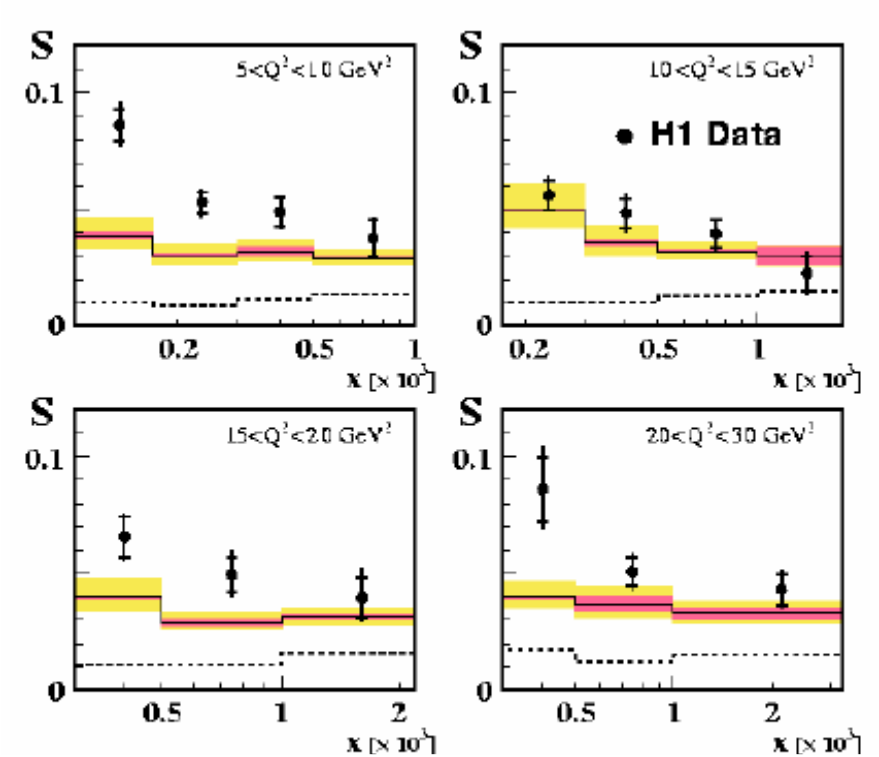

Shorter range transverse momentum compensation than predicted by DGLAP

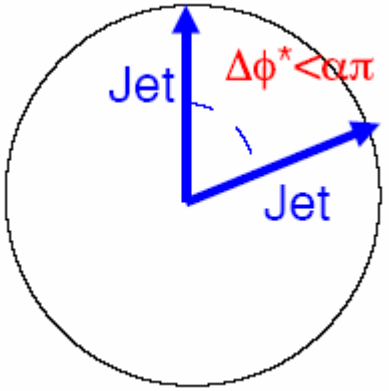
Looking forward to HERA-2 and improved forward acceptance

# Dijet Production in DIS

## Look for jets with $\Delta\Phi < 120^{o}$

Sensitive to incoming parton virtuality, Unintegrated gluon density, higher orders…




$$S(x, Q^2, \Delta\phi^*) = \frac{\int_0^{\alpha\pi} w(\Delta\phi^*, x, Q^2)}{\int_0^{\pi} w(\Delta\phi^*, x, Q^2)}$$

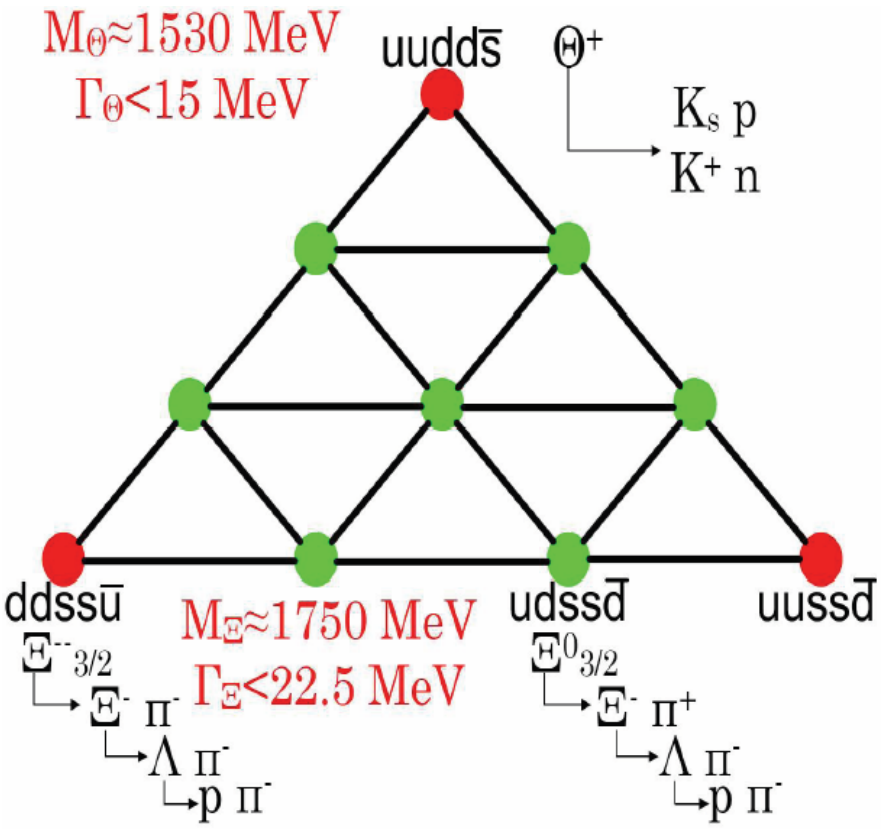
Significant difference between data and NLO at low x

Extend to forward region with HERA-2

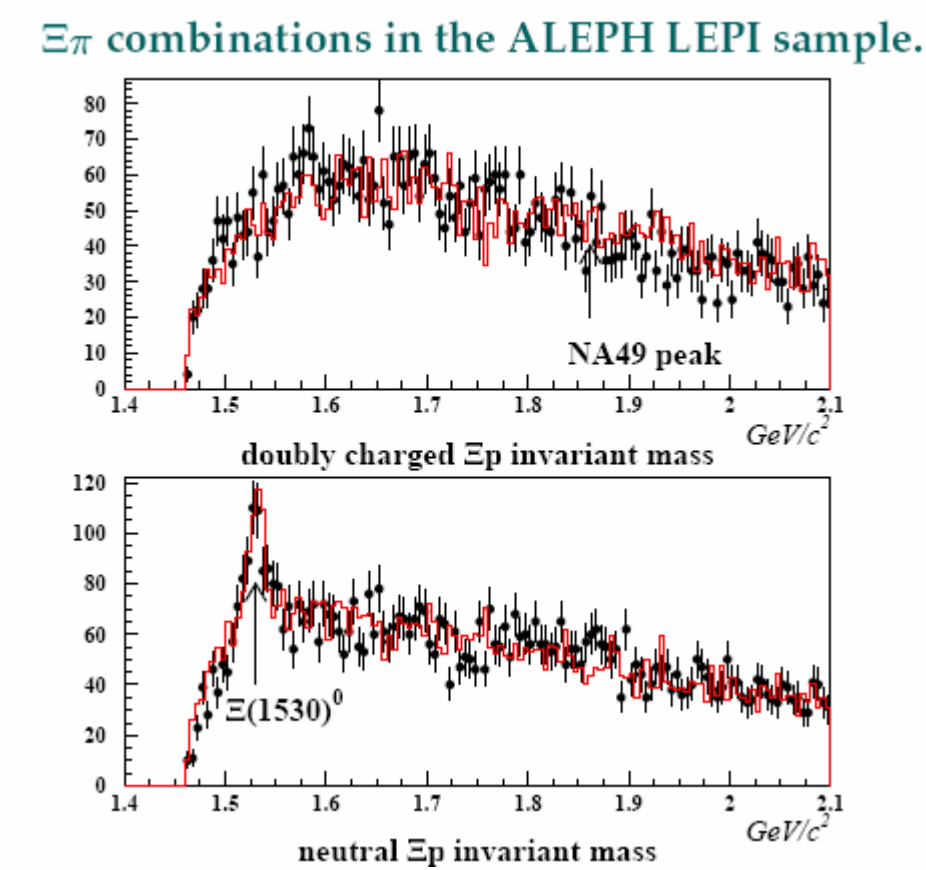
# Strange Pentaquarks

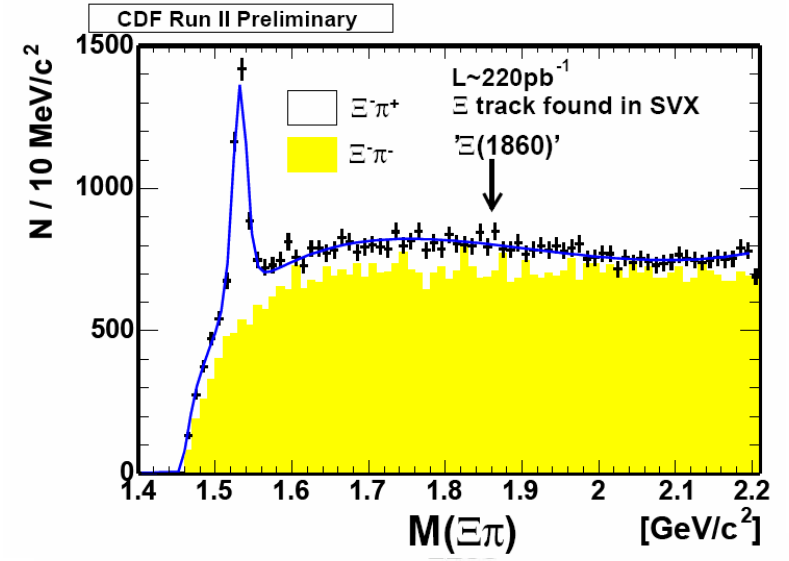
**Results from**

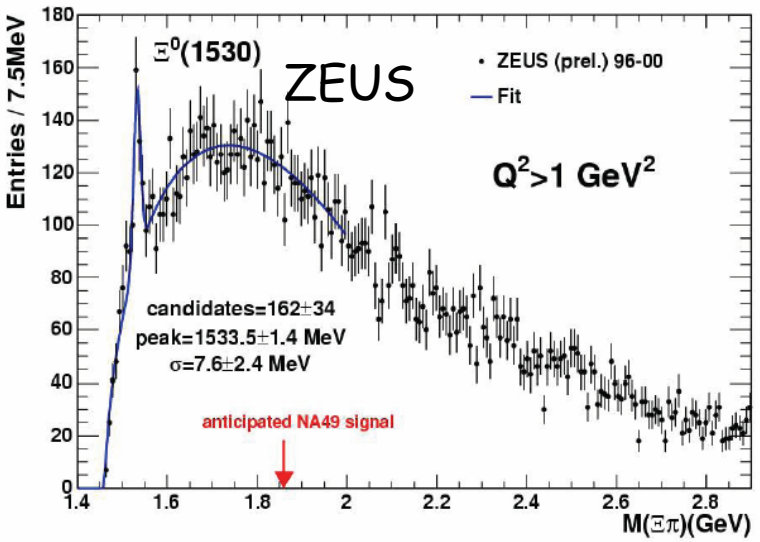
**ZEUS**
**HERMES**
**CDF**
**ALEPH**



# Searching for $\Xi_{3/2}^{--}$ and $\Xi^{0}_{3/2}$



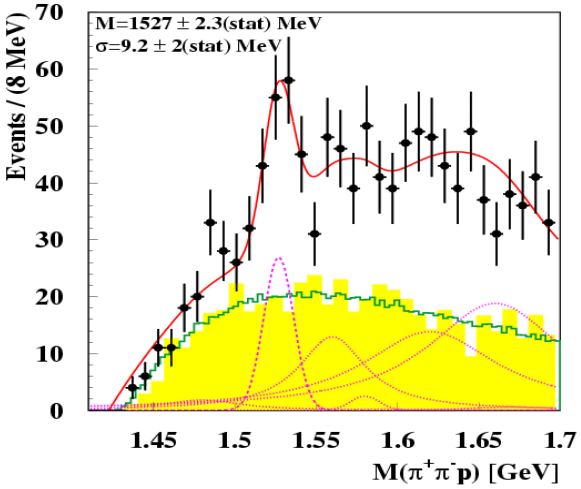

No sign of cascade pentaquark

Large statistics for Ξ(1530)

NA49 measurement in forward region

# New Results on the $\Theta_s$

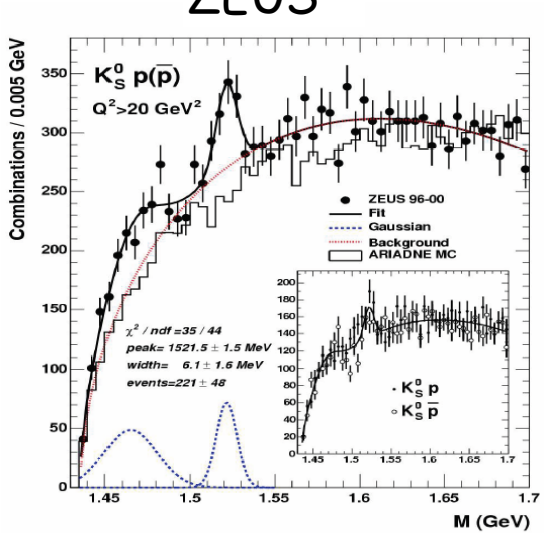
HERMES




1527 ± 2.3 MeV

σ= 9.2 ± 2 MeV

ZEUS



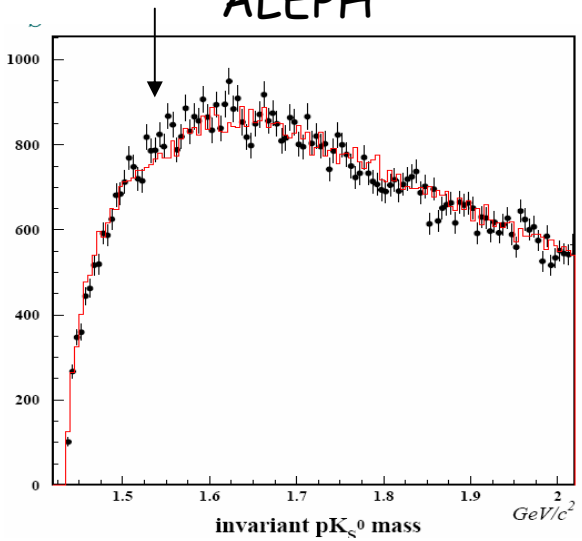

1521.5±1.5 $^{+2.8}_{-1.7}$ MeV

σ= 9.2 ± 2 MeV

Evidence for

antipentaquark

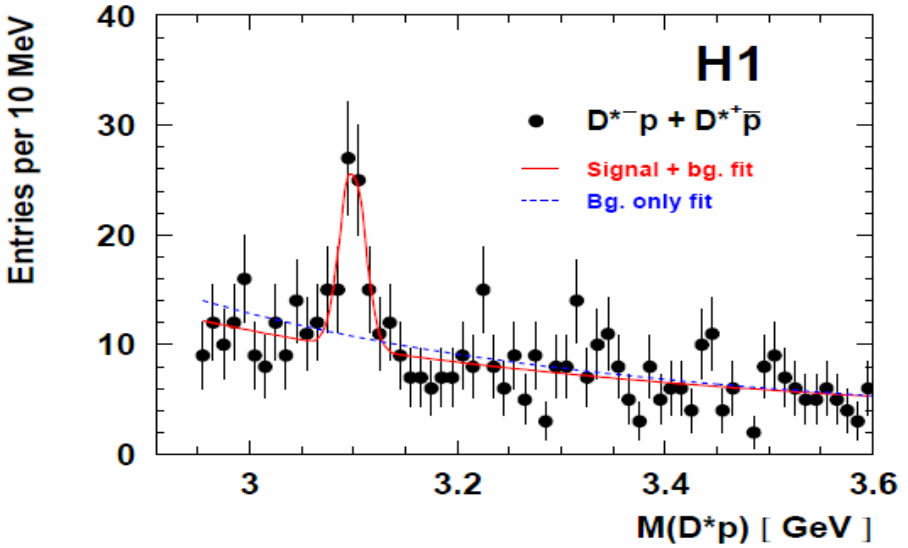
ALEPH

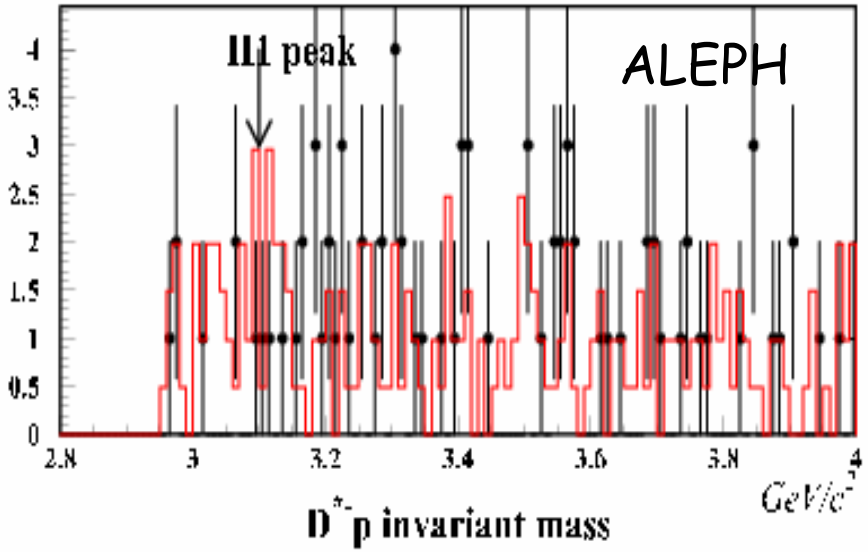



Nothing seen…
Fundamentally
different in e+e?

# ALEPH Charmed Pentaquark Search

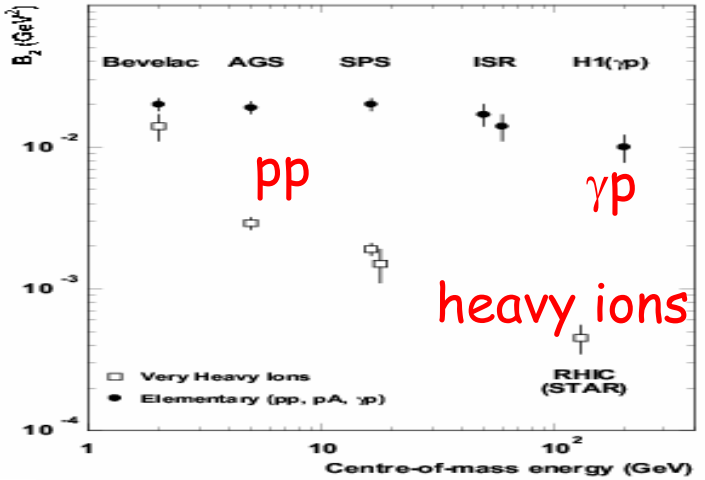
- LEP1 Data at Z-pole
- 1991-1995
- 4.6 M hadronic $Z^0$
- No resonance observed
- Upper limit of $6 \times 10^{-4}$ pq/had.$Z^0$



# Anti-Deuterons at High Energy

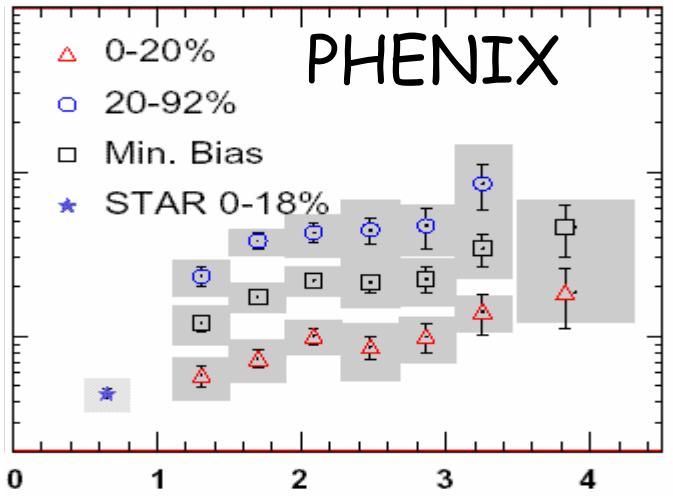
$\bar{D}$ cross-section presented by H1 and PHENIX




Fit to coalescence model

$B_2$

$$E_{\bar{d}}\frac{d^3\sigma(\bar{d})}{\sigma_{tot}d^3p_{\bar{d}}} = B_2\left(E_{\bar{p}}\frac{d^3\sigma(\bar{p})}{\sigma_{tot}d^3p_{\bar{p}}}\right)^2$$




$B_2$ -> interaction size

$p_T$/GeV

Structure dependence at the highest energies

# Workshop work (T. Sloan)
# H1 pentaquark vs ALEPH limit

EPILOGUE:-

ANTI-DEUTERONS AT LEP:-

OPAL HAVE REPORTED 1 ANTI-DEUTERON

$\therefore$ RATIO $\frac{N_{\bar{d}}}{N_Z} \sim \frac{1}{10^6} \sim 10^{-6}$

COMPARED TO $5.0 \times 10^{-4}$ OBSERVED IN $\gamma p$, $pp$, Au-Au COLLISIONS.

CONCLUDE $\bar{d}$ FORMATION SUPPRESSED IN $e^+e^-$.

ALEPH PENTAQUARK LIMIT $< 6 \times 10^{-4} \frac{p\bar{q}+\bar{p}q}{N_Z}$ (HANDEN TALK)

BR $Z^0 \to D^{*\pm} X$ = 0.11 (PDG)
(.07 DIRECT FROM $c$)

$\therefore$ ALEPH $\frac{p\bar{q}+\bar{p}q}{D^*} < \frac{6 \times 10^{-4}}{0.11}$ (OR .07) $< .0056$ (0.01)

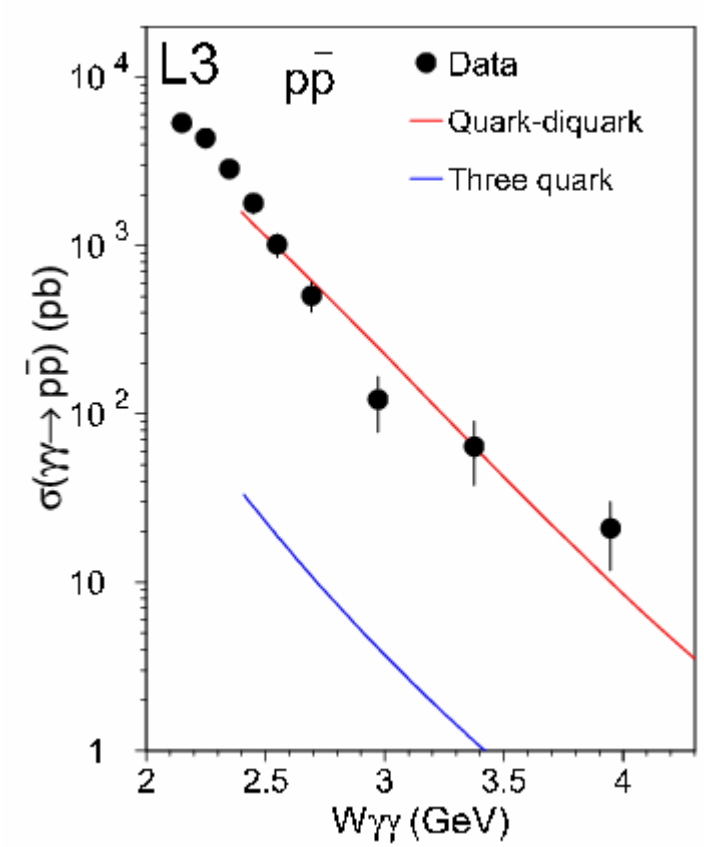
H1 SEES $\frac{p\bar{q}+\bar{p}q}{D^*} \sim 0.01$

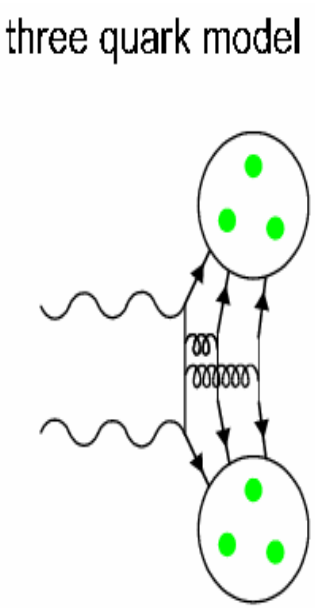
CONSISTENCY?

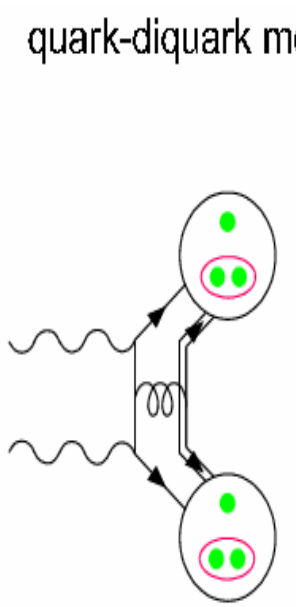
(1) $p\bar{q}$ MC EFFICIENCY UNCERTAINTY.

(2) (3) SUPPRESSION OF MULTIQUARK STATES IN $e^+e^-$ KINEMATIC RANGE.

# Two Proton Production in $\gamma\gamma$ Collisions



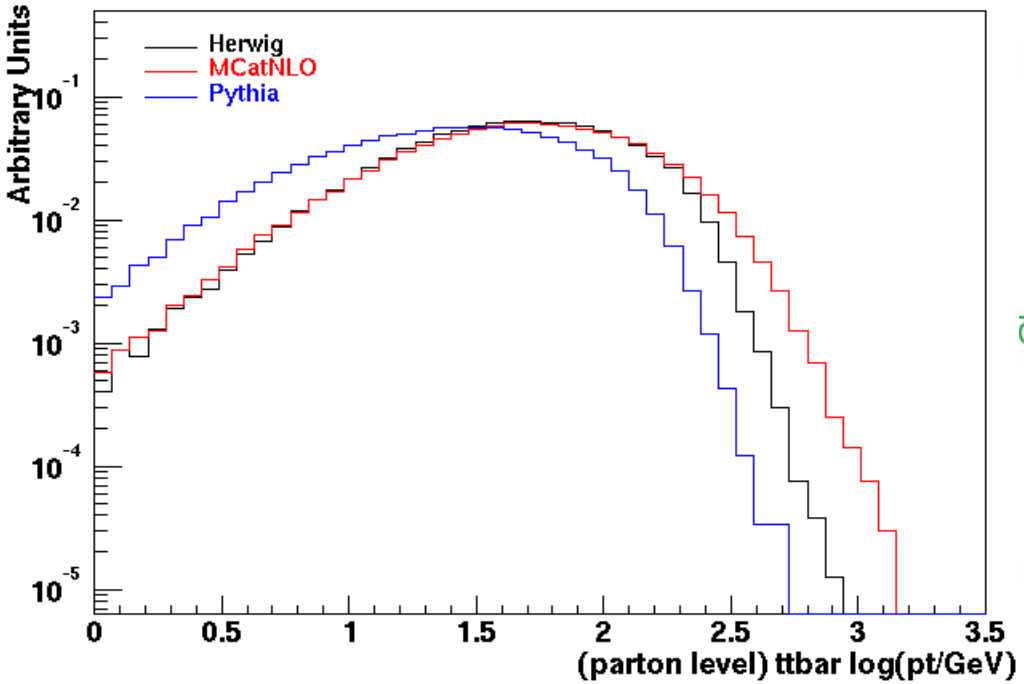



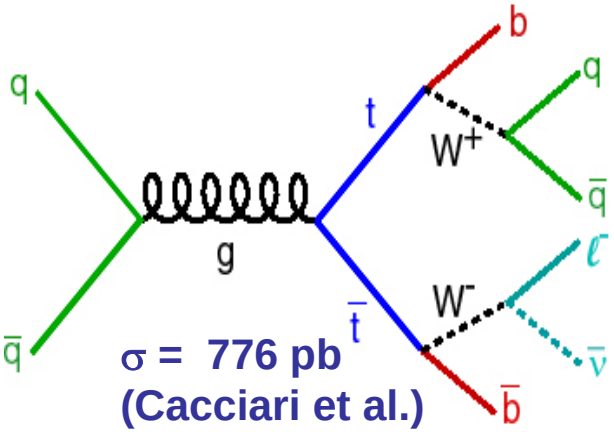




Extend range in W
Diquark model supported

# Looking ahead….

## Substantial QCD uncertainties at the LHC




σ = 776 pb
(Cacciari et al.)

Large phase space for QCD radiation

Appropriate modelling of ME+PS

Large theory disagreements

Health warning for current LHC studies

Much work ongoing by MC builders (see Dasgupta's talk)
Need close experimental/theory collaboration

# Summary

QCD studied in hadronic final states in pp,ep,e+e-,NN

Perturbative QCD in good shape

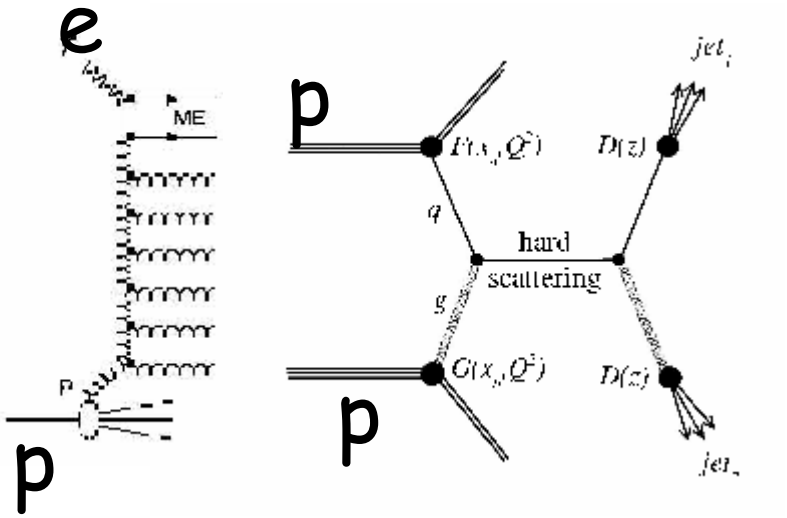
Higher orders needed for low x parton evolution and azimuthal asymmetries

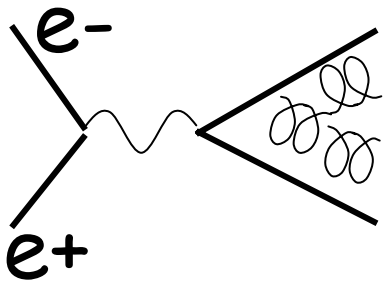
Non-pQCD probed by identified particle production

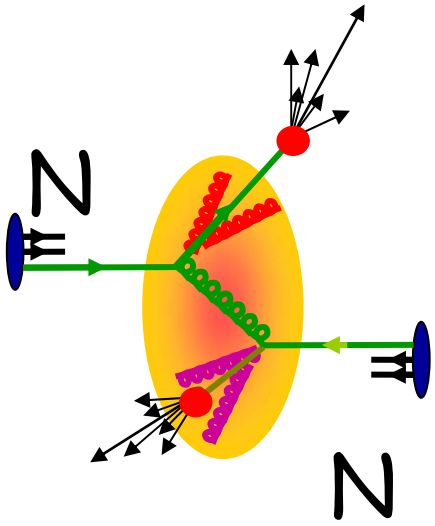
Pentaquarks, Deuterons challenge theorists and experimentalist

HERA-2 and Run II necessary to make progress

# Testin




pQCD tests with jets, event shapes..

Latest $\alpha_s$ low x dynamics…

Explore npQCD with pentaquarks, deuterons, power corrections..

Target influence on hadronisation

# Evidence for light pentaquark

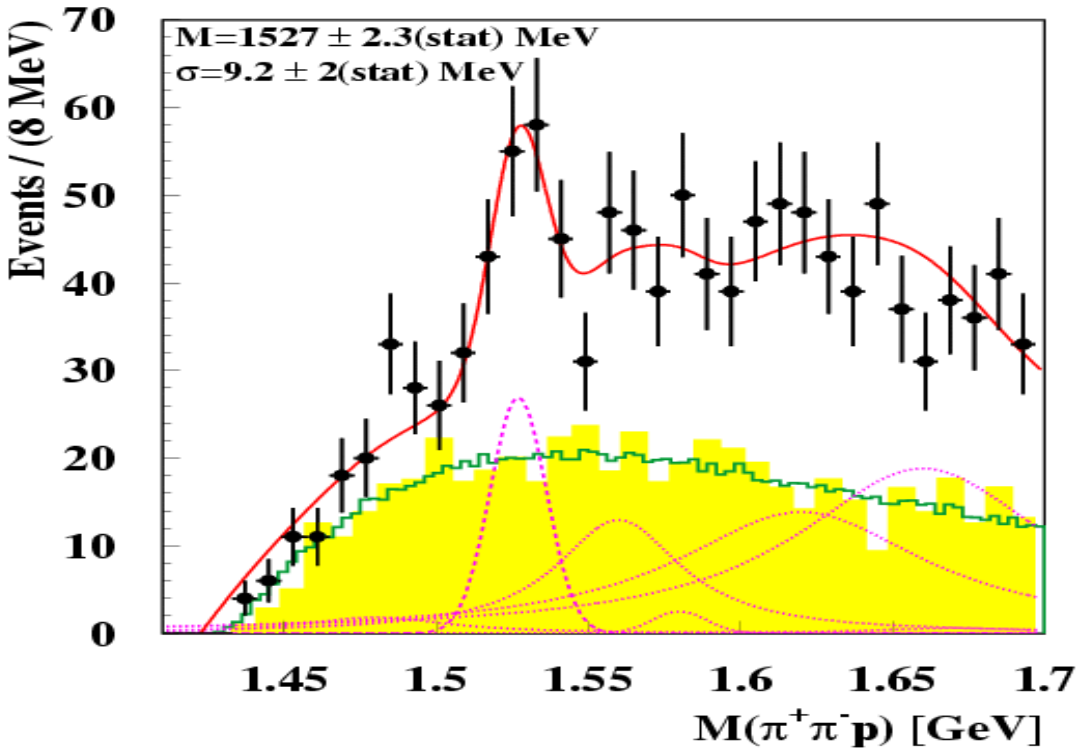
## HERMES

**Peak at:**

**1527 ± 2.3 MeV**

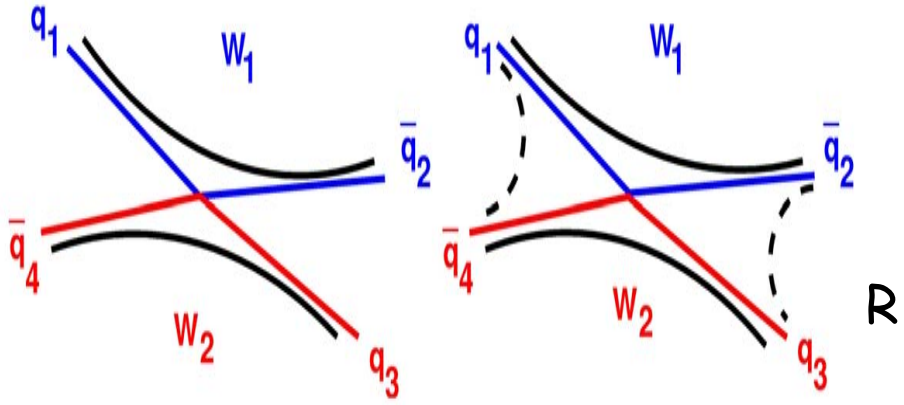
**σ= 9.2 ± 2 MeV**

**Significance: 4.3**



# Colour Reconnection in e+e-

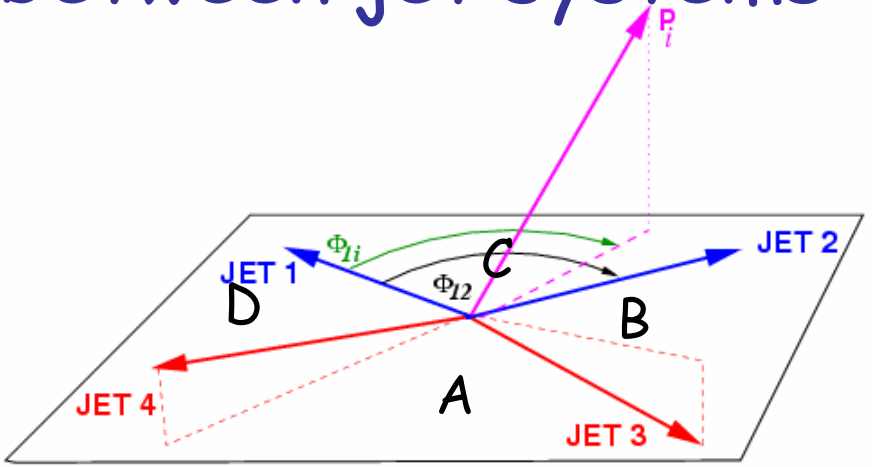
$$e^+e^- \rightarrow W^+W^- \rightarrow q\bar{q}'Q'\bar{Q}$$



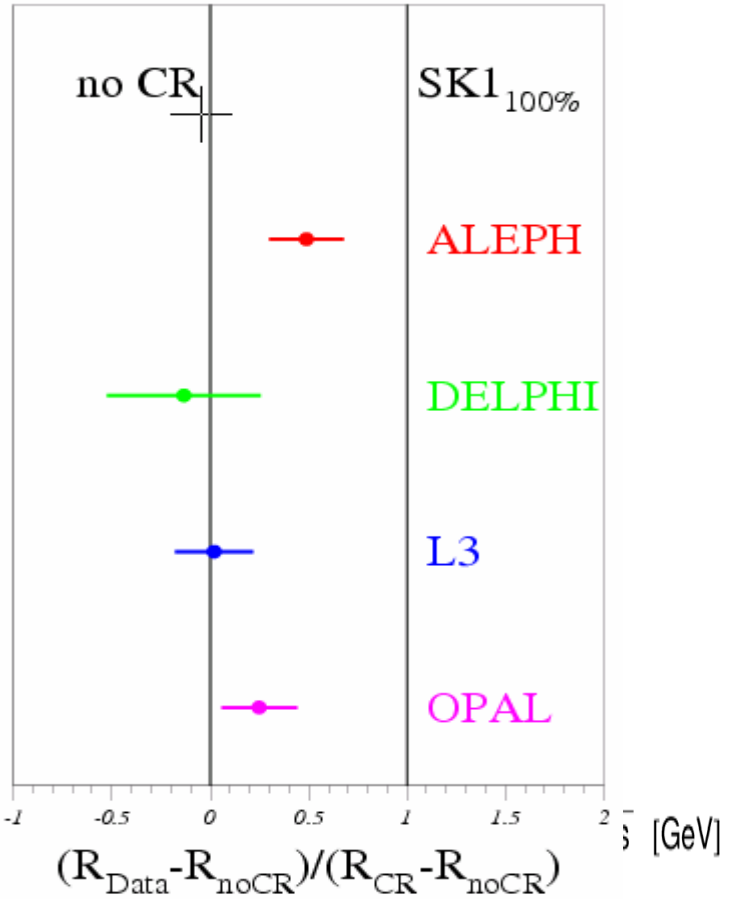

R

$$R = \frac{\int_{0.2}^{0.8} \frac{dn}{d\Phi_r} d\Phi_r \left(\text{regions A} + \text{C}\right)}{\int_{0.2}^{0.8} \frac{dn}{d\Phi_r} d\Phi_r \left(\text{regions B} + \text{D}\right)}$$

Measure particle flow between jet systems




DELPHI



# Evidence for light pentaquark

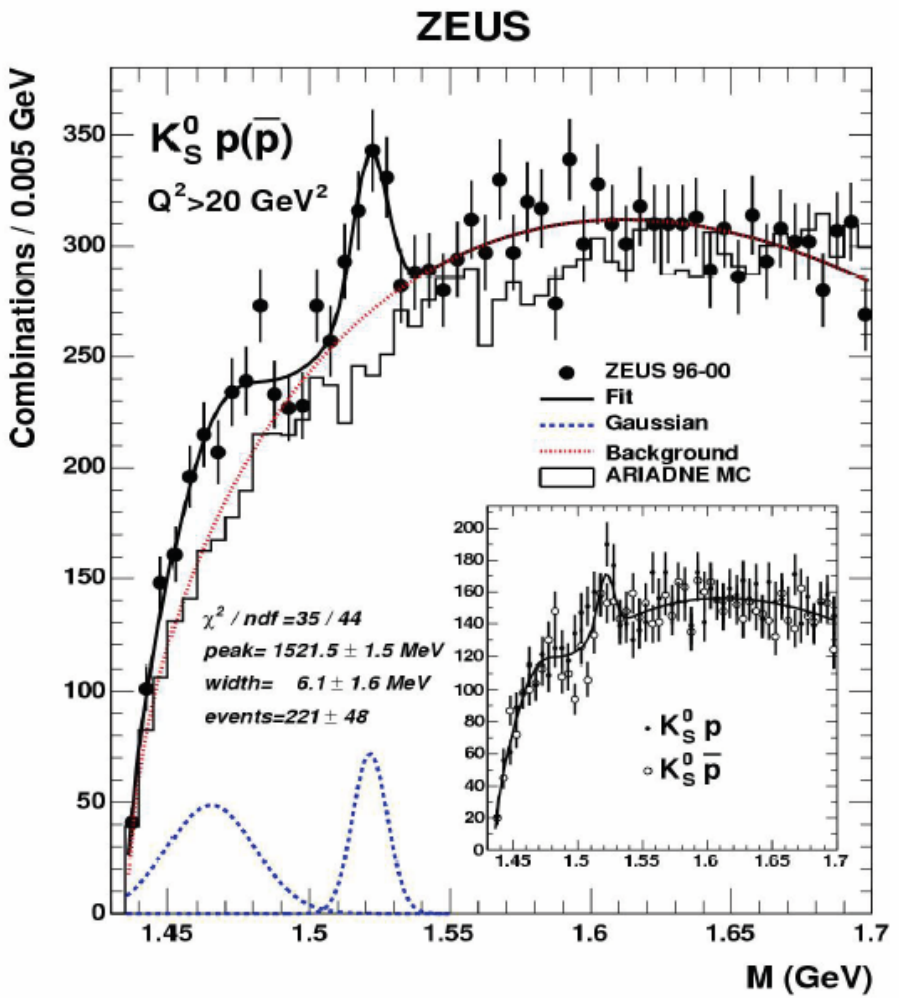
## ZEUS

First evidence from colliding experiment

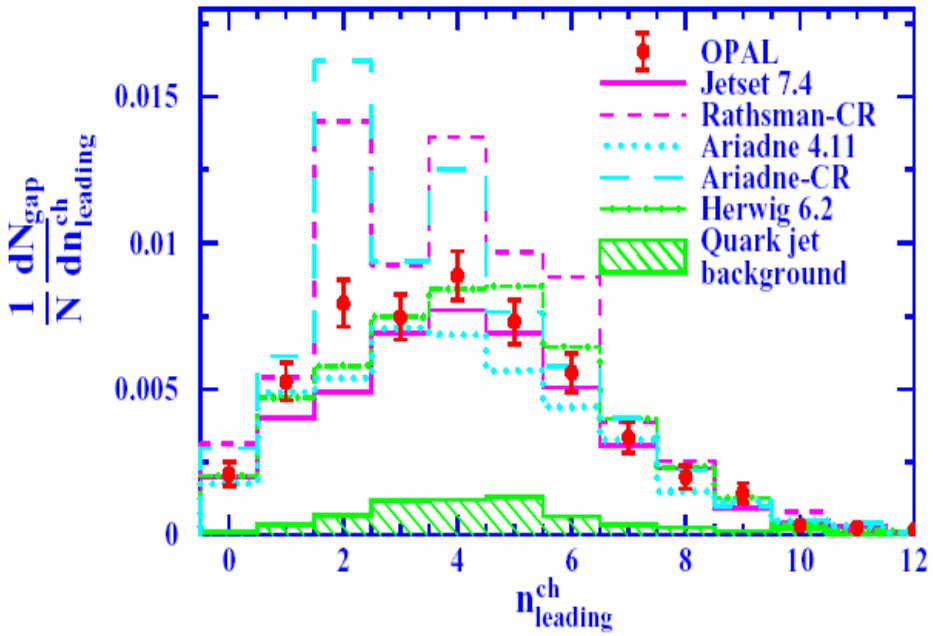
First evidence for antipentaquark

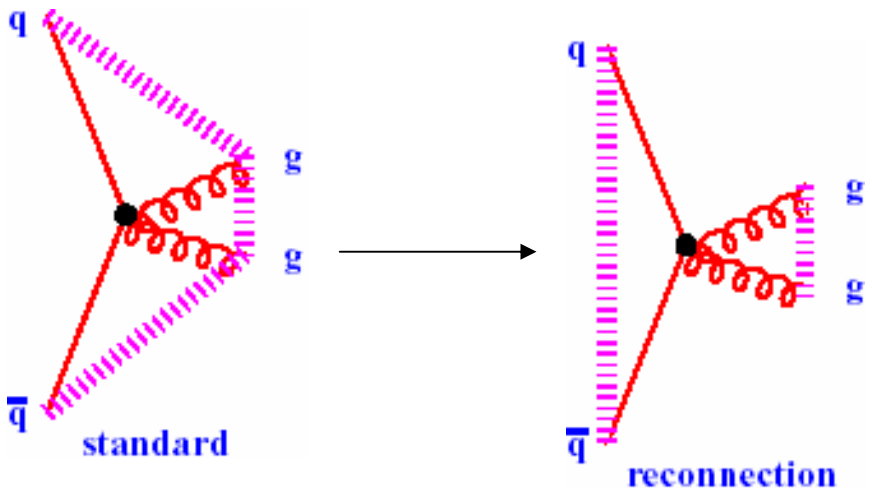
96±34

Measurement in the central fragmentation region

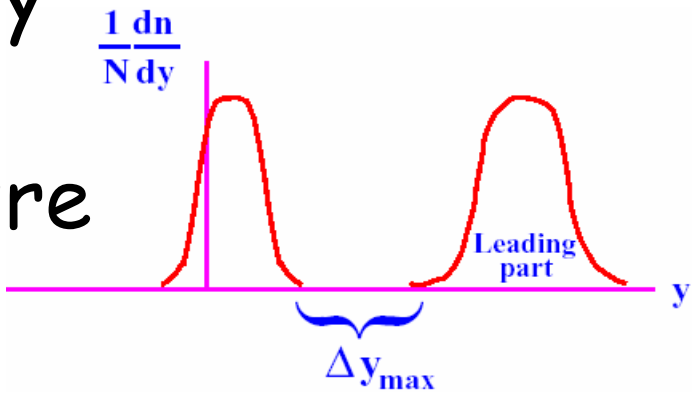


# Soft Colour Rearrangement in e+e-



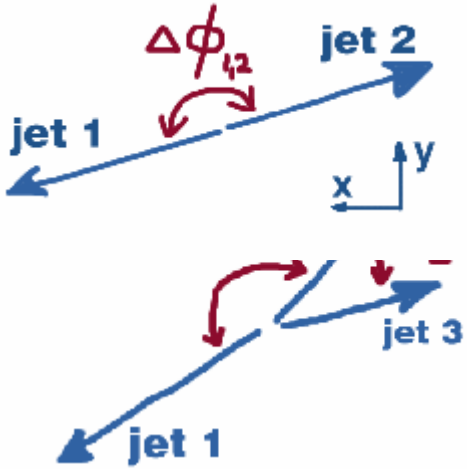

Rapidity gap signature

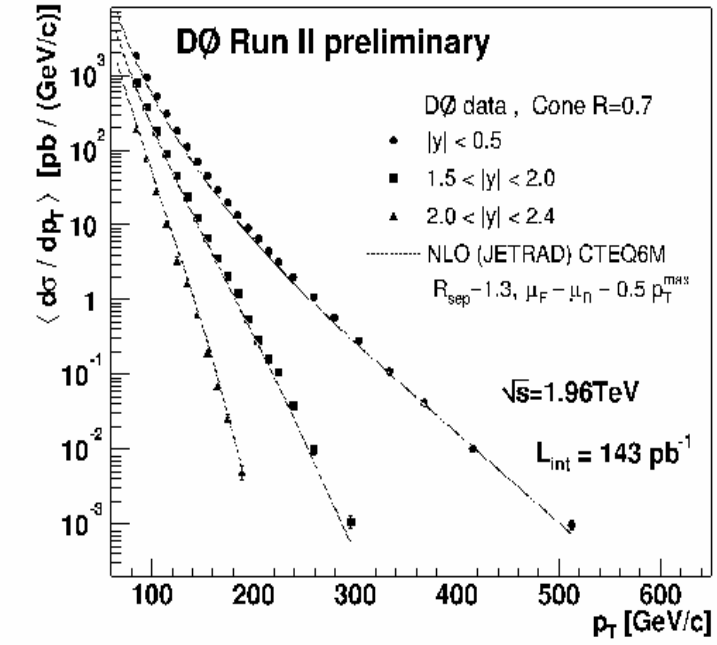



Failure of Colour Rearrangement Models

# Jet Production at D0

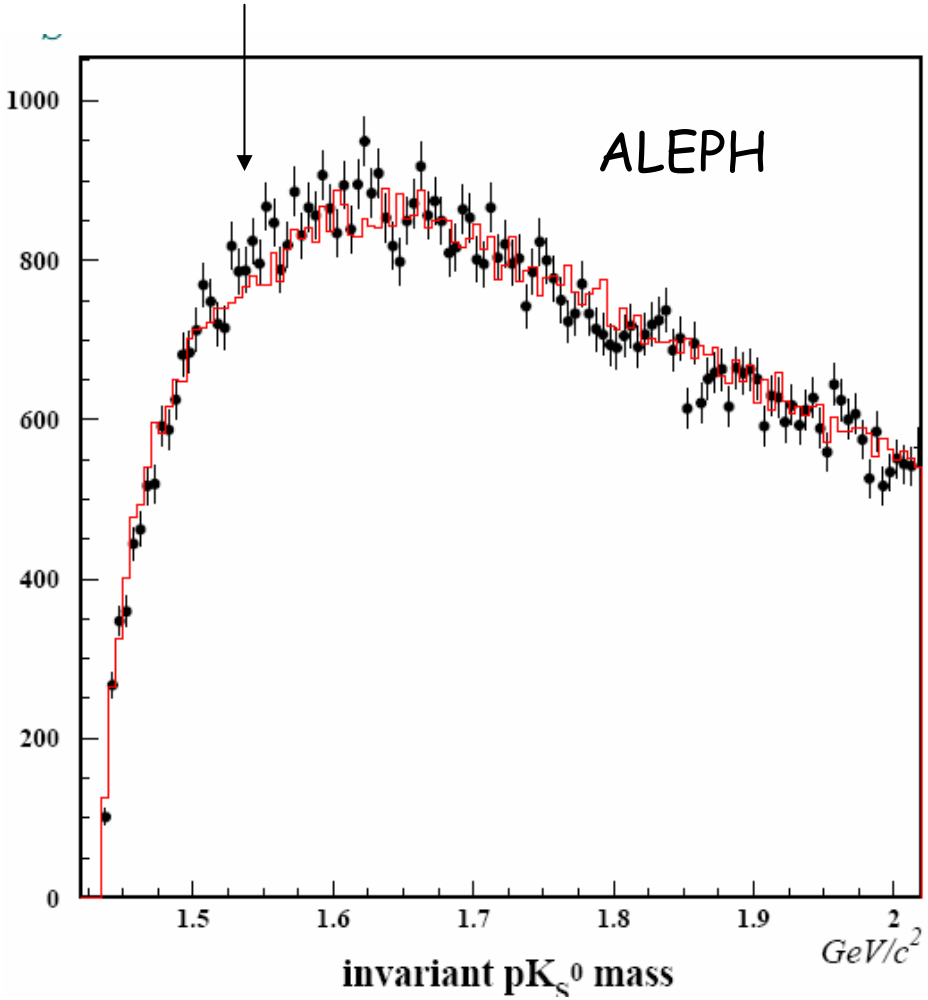
Jets measured over wide pseudorapidity region
but with large energy scale uncertainty
Angular correlations between jets allow
sensitive probe of QCD




Good agreement by
NLO except
at extreme $\Delta\phi$ values

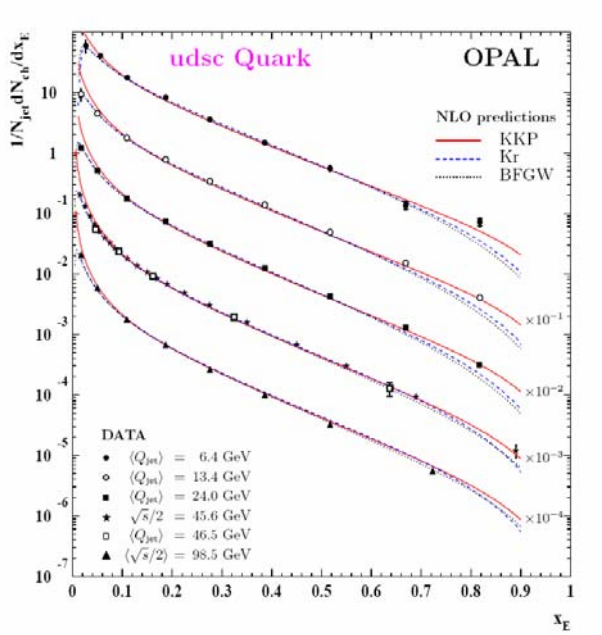
# … but no evidence for light pentaquark in ee

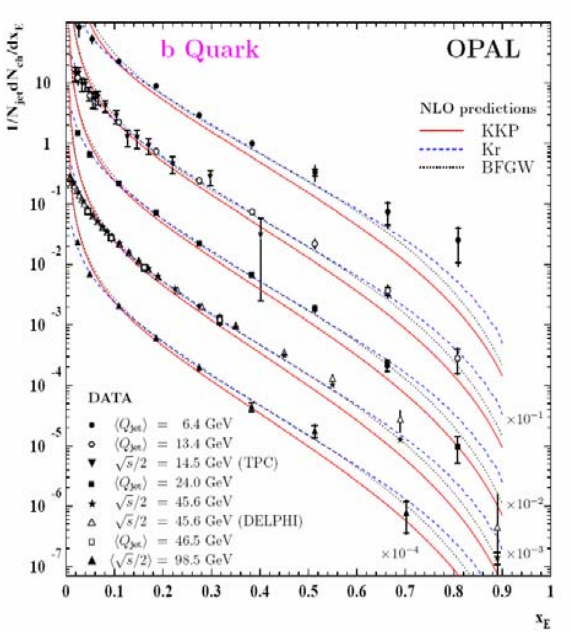


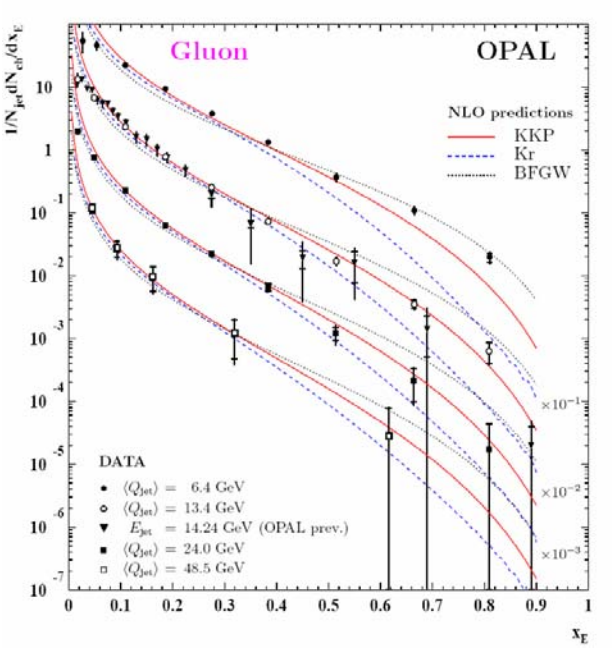

Something fundamentally different in baryon production

# Fragmentation functions in e+e-

## Use LEP1 and LEP2 data




## Good agreement with NLO