

Diffractive and QCD Processes in Experiment D0

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For D0 collaboration

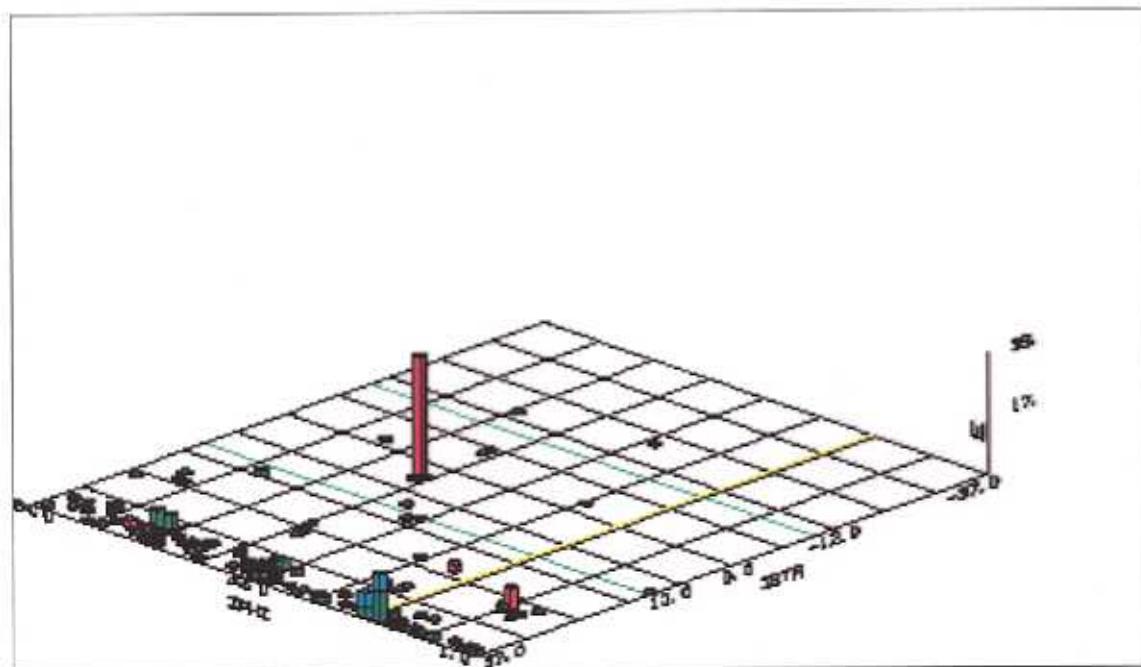
XXXII ISMD

Alushta Crimea
September 2002

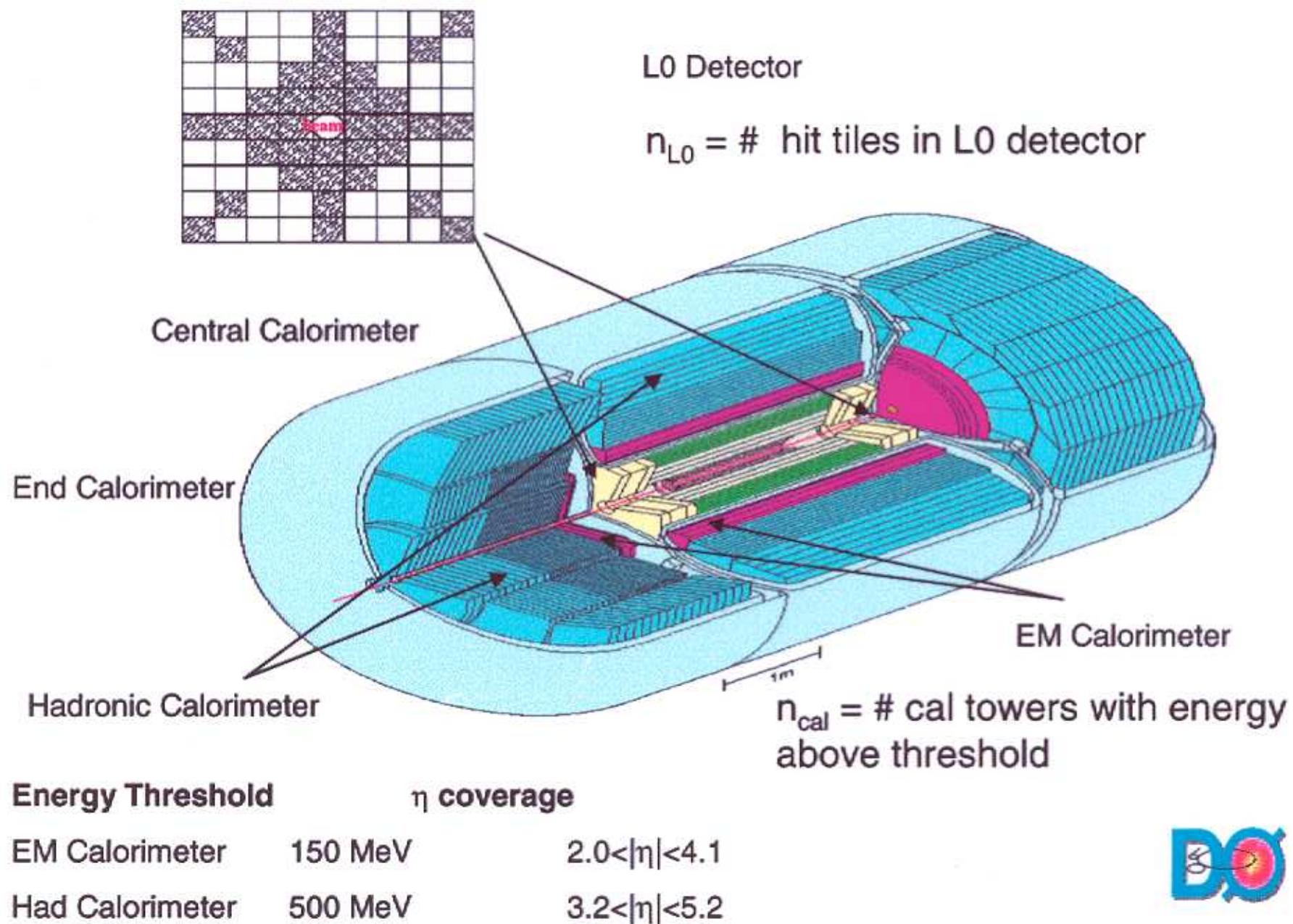


Outlines

- Topology of events and experiment D0
- Basic characteristics of interactions
- Multiplicities and jets in calorimeter
- W and Z production
- Some QCD-jets results
- Summary



D \emptyset Detector



Outline

$$p \bar{p} \rightarrow J1 (J2) + \text{anything}$$

- Inclusive Jet Cross Section :
 - at 1800 GeV
 - at 630 GeV
 - Ratio of Inclusive Jet Cross Sections

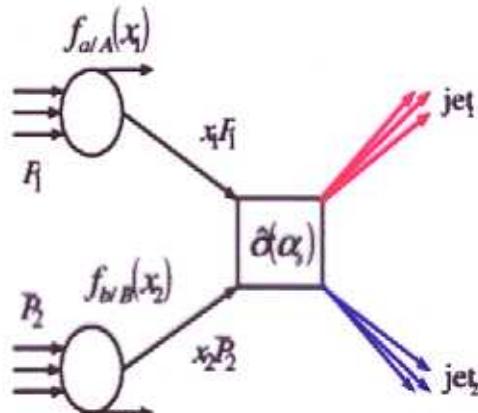
$$\frac{d^2\sigma}{dE_T d\eta}$$

- Dijet Triple Differential Cross Section

$$\frac{d^3\sigma}{dE_T d\eta_1 d\eta_2}$$

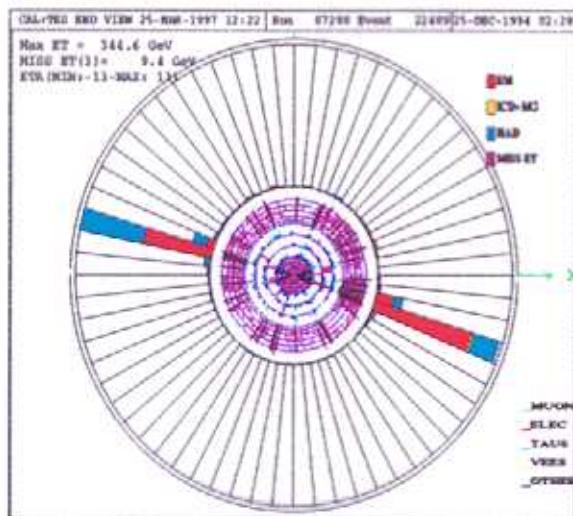
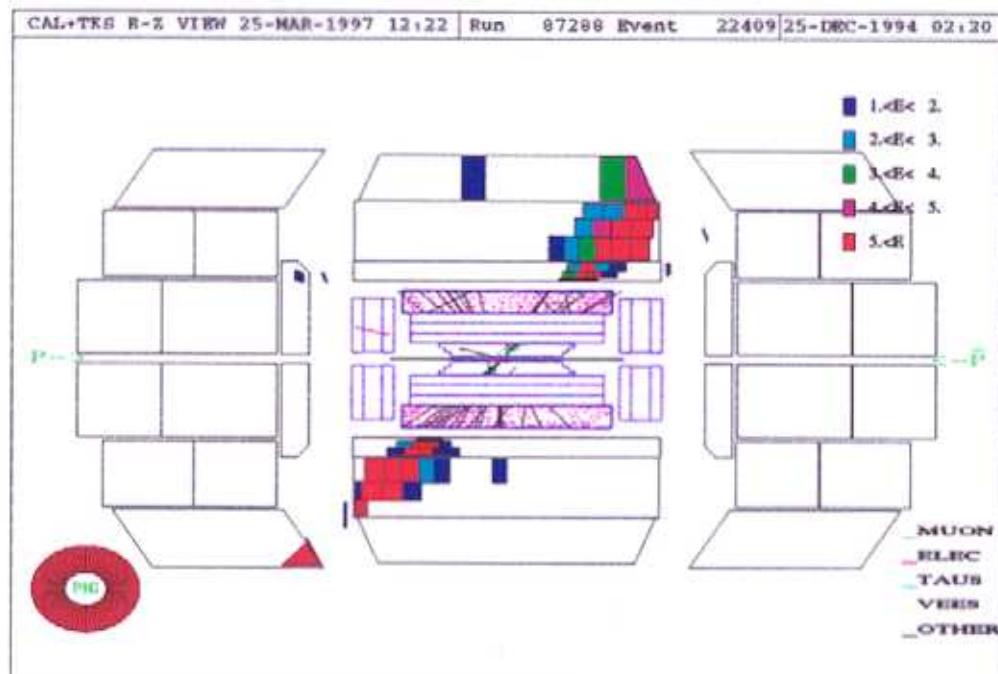
- Dijet Mass Spectrum

All theoretical
comparisons done
with JETRAD



$$\begin{aligned}\sigma(p_1 \bar{p}_2 \rightarrow 2 \text{ jets}) &= \\ \sum_{abcd} \int dx_1 dx_2 f_{a/A}(x_1) f_{b/B}(x_2) \hat{\sigma}(ab \rightarrow cd) &\end{aligned}$$

“Typical DØ Dijet Event”



$$M_{JJ} = 1.18 \text{ TeV}$$

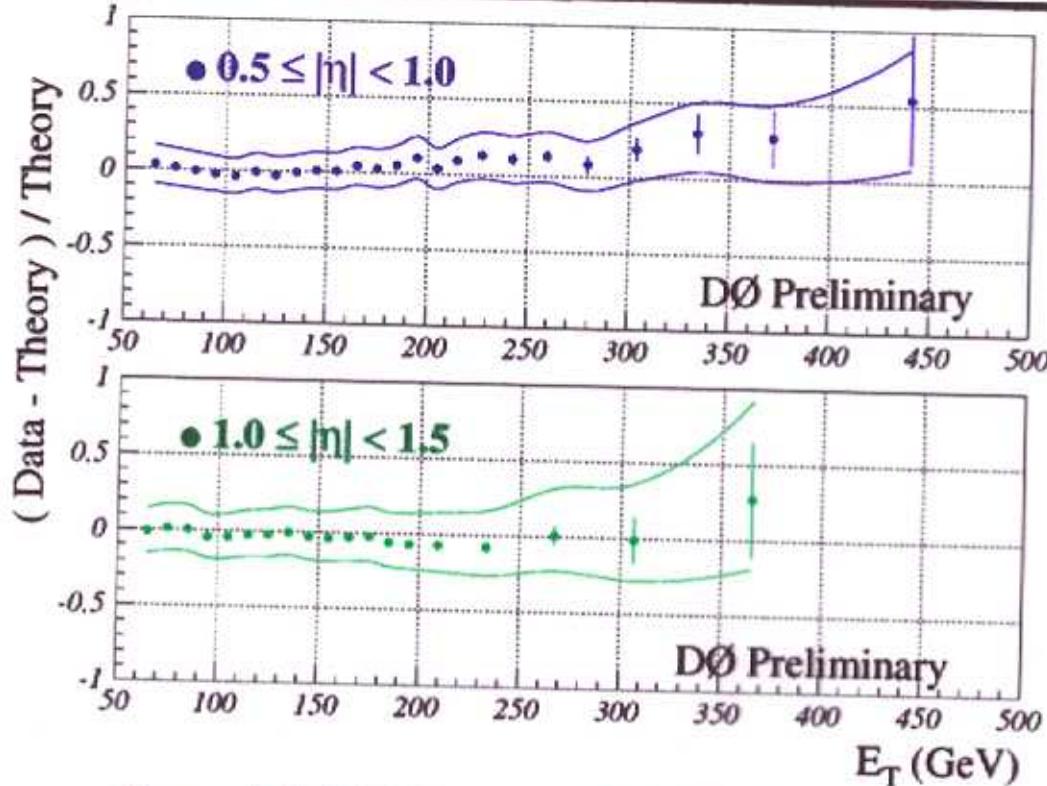
$$Q^2 = E_{T,1} \times E_{T,2} = 2.2 \times 10^5 \text{ GeV}^2$$

$$E_{T,1} = 475 \text{ GeV}, \eta_1 = -0.69, x_1 = 0.66$$

$$E_{T,2} = 472 \text{ GeV}, \eta_2 = 0.69, x_2 = 0.66$$

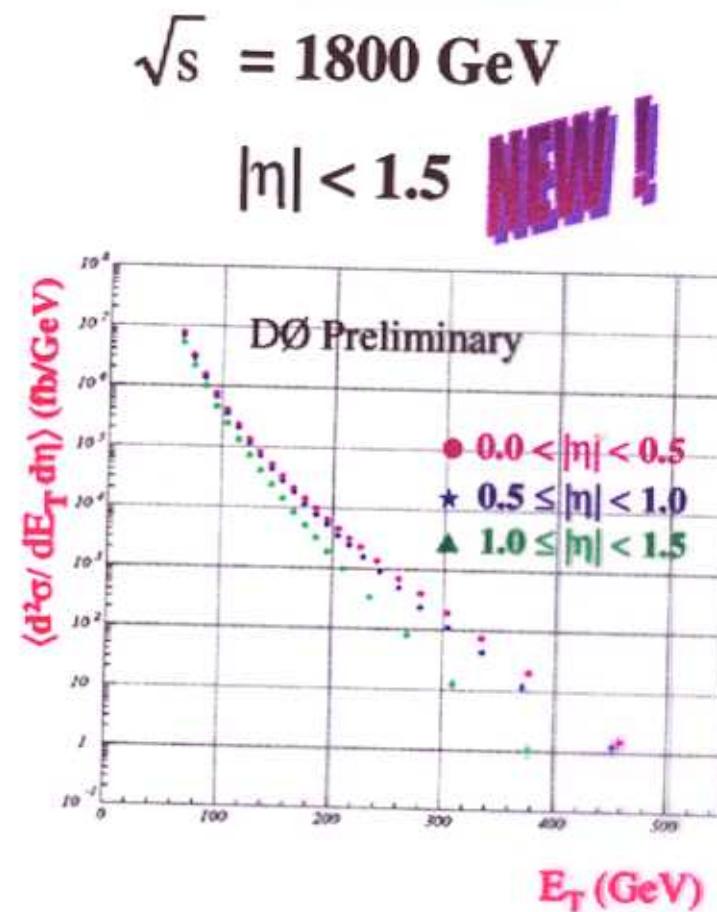
V. Simak

Rapidity Dependence of Inclusive Cross Section



Theory is JETRAD: $\mu = E_T^{\text{MAX}}/2$, $R_{\text{sep}} = 1.3$

pdf = CTEQ3M



Data and NLO QCD in good agreement

- Extend measurement to $|\eta| = 3$
- Error analysis

Compositeness Contact Predictions

QCD +

$$L = \frac{4\pi}{\Lambda^2} \left[\eta_{LL}^0 (\bar{q}_L \gamma^\mu q_L) (\bar{q}_L \gamma_\mu q_L) + \eta_{LR}^0 (\bar{q}_L \gamma^\mu q_L) (\bar{q}_R \gamma_\mu q_R) + \right. \\ \eta_{RL}^0 (\bar{q}_R \gamma^\mu q_R) (\bar{q}_L \gamma_\mu q_L) + \eta_{RR}^0 (\bar{q}_R \gamma^\mu q_R) (\bar{q}_R \gamma_\mu q_R) + \\ \eta_{LL}^1 \left(\bar{q}_L \gamma^\mu \frac{\lambda_a}{2} q_L \right) \left(\bar{q}_L \gamma_\mu \frac{\lambda_a}{2} q_L \right) + \\ \eta_{LR}^1 \left(\bar{q}_L \gamma^\mu \frac{\lambda_a}{2} q_L \right) \left(\bar{q}_R \gamma_\mu \frac{\lambda_a}{2} q_R \right) + \\ \eta_{RL}^1 \left(\bar{q}_R \gamma^\mu \frac{\lambda_a}{2} q_R \right) \left(\bar{q}_L \gamma_\mu \frac{\lambda_a}{2} q_L \right) + \\ \left. \eta_{RR}^1 \left(\bar{q}_R \gamma^\mu \frac{\lambda_a}{2} q_R \right) \left(\bar{q}_R \gamma_\mu \frac{\lambda_a}{2} q_R \right) \right]$$

η_{XX}^0 : singlet interactions

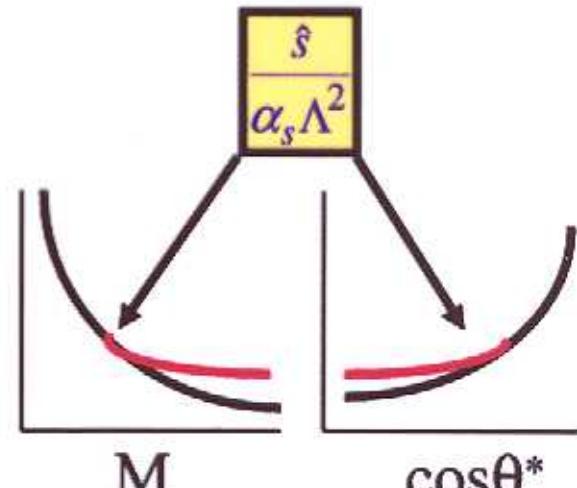
η_{XX}^1 : octet interactions

$\eta_{LL}^X = \eta_{RR}^X = \eta_{LR}^X = \eta_{RL}^X = \pm 1$:

Vector Λ_V

$\eta_{LL}^X = \eta_{RR}^X = -\eta_{LR}^X = -\eta_{RL}^X = \pm 1$:

Axial Λ_A



Compositeness Calculations

Eichten et al., Rev. Mod. Phys. 56, 579 (84)

Eichten et al., Phys. Rev. Lett 50, 811 (83)

Chivukula et al., Phys. Lett. B 380, 92 (96)

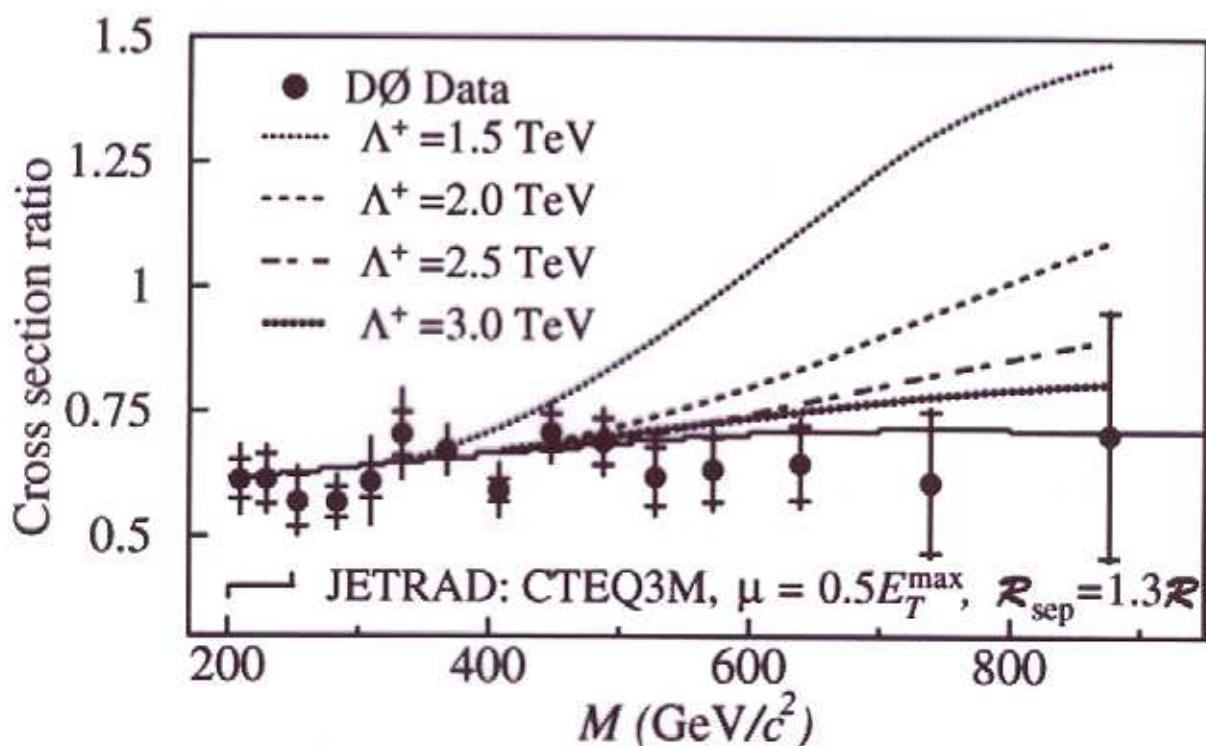
Lee, Phys. Rev. D 55, 2591 (97)

Lane, hep-ph/9605257 (96)

Suggested Scale: 1.6 TeV (LL)

PRL 77, 438(1996)

$$\frac{\sigma(\Lambda = X \text{ TeV})_{\text{LO}}}{\sigma(\Lambda = \infty \text{ TeV})_{\text{LO}}} \times \sigma(\Lambda = \infty \text{ TeV})_{\text{NLO}}$$

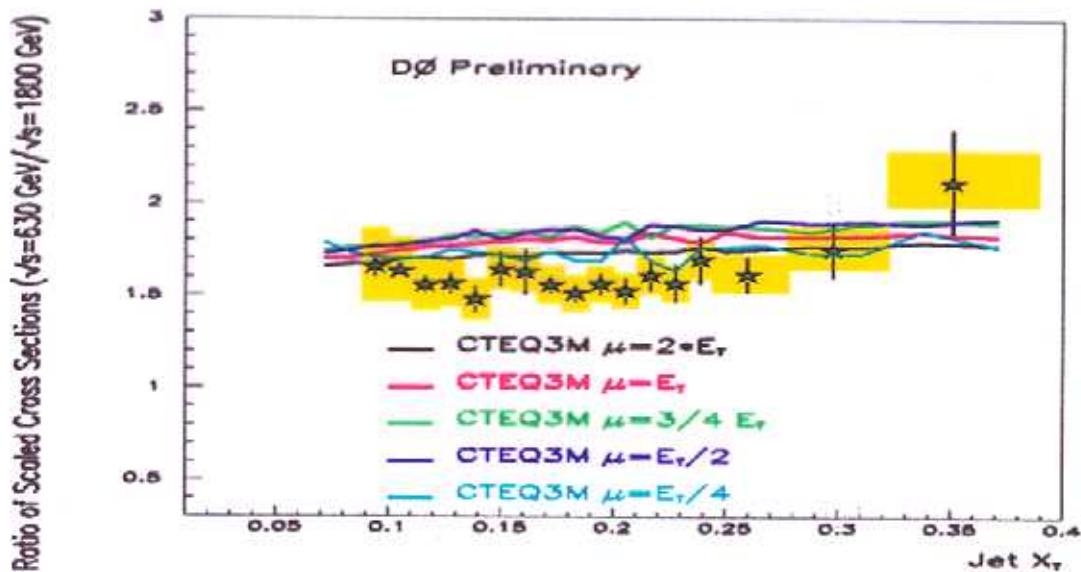
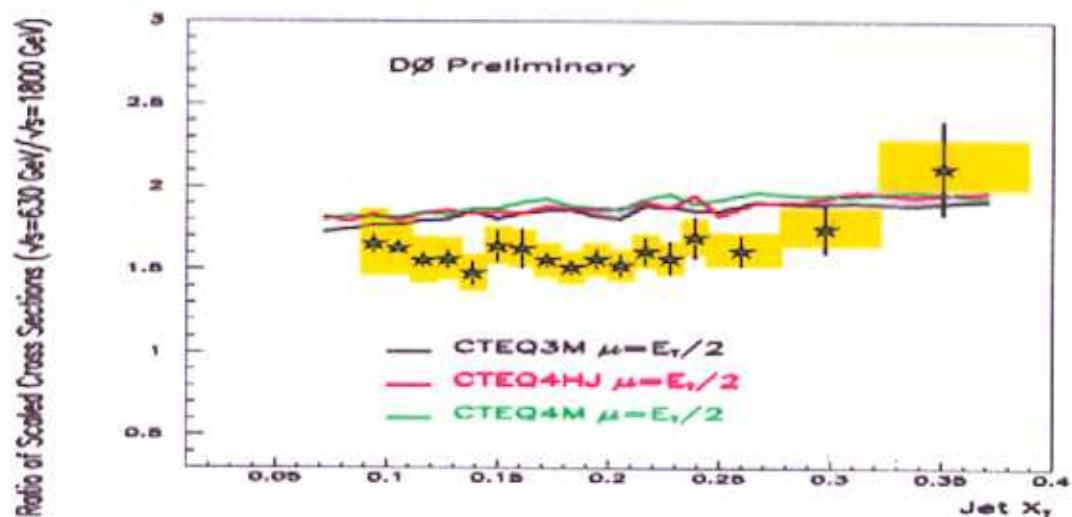


$$\Lambda^+ > 2.7 \text{ TeV} \quad \Lambda^- > 2.4 \text{ TeV}$$

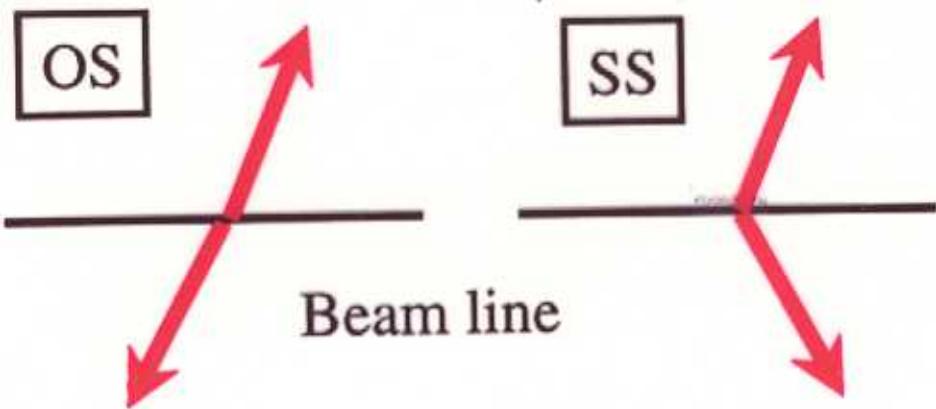
Ratio of Inclusive Jet Cross Sections (D \emptyset)

Four distributions: data for 1800 GeV and 630 GeV and theory for 1800 GeV and 630 GeV.

Ratio of 630 GeV cross section over 1800 GeV as a function of x_T



Dijet Triple Differential Cross Section ($D\emptyset$)



- Divide data sample into four eta bins:
 - $0.0 < |\eta| < 0.5$, $0.5 < |\eta| < 1.0$, $1.0 < |\eta| < 1.5$,
 $1.5 < |\eta| < 2.0$
- Divide each eta bin into two subsamples:
 - events with 2 jets on the Opposite Side (OS)
 - events with 2 jets on the Same Side (SS).
- E_T of both jets are measured so there are two entries per event into each of the eight cross sections.
- JETRAD using $\mu = E/2$
Note that the renormalization and factorization scale are chosen to be:
 - $\mu_f = \mu_r = E/2$ (max jet)

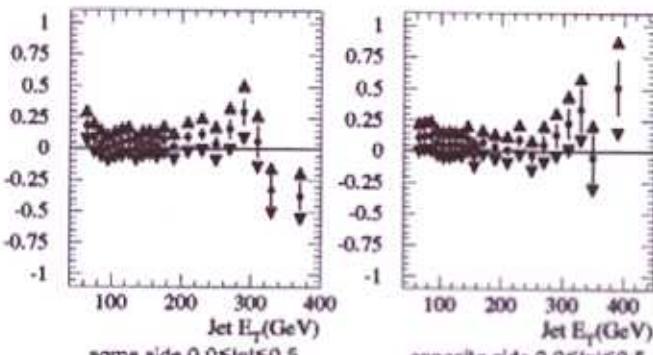
Data Theory Comparisons

Jetrad: CTEQ4M, $\mu=0.5E$

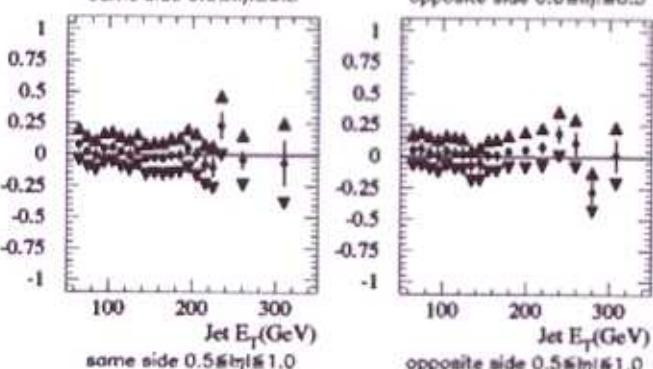
SS

OS

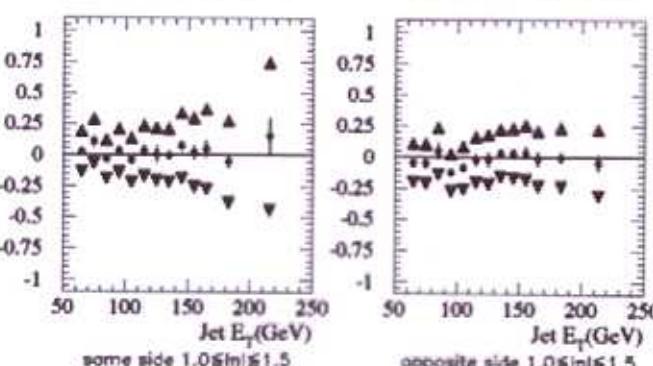
$0.0 < \eta < 0.5$



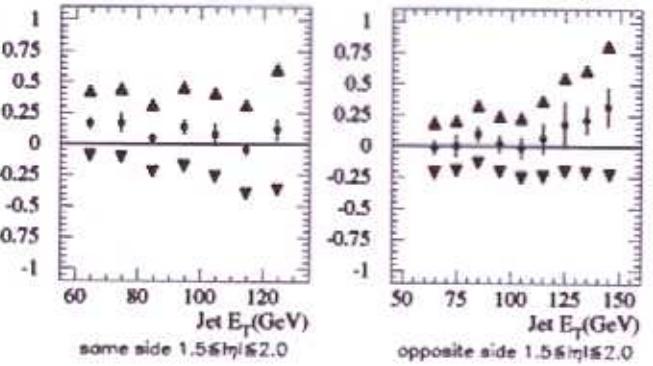
$0.5 < \eta < 1.0$



$1.0 < \eta < 1.5$

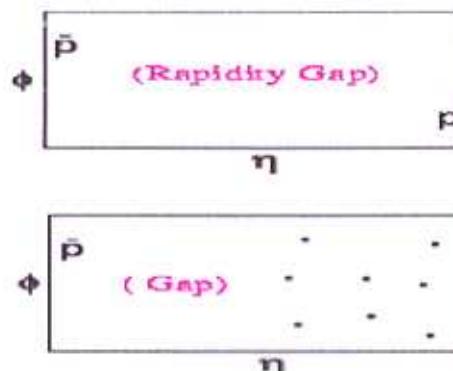
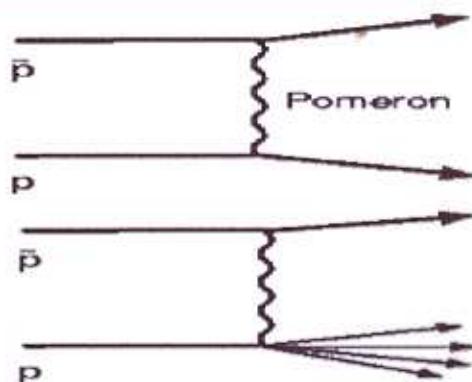


$1.5 < \eta < 2.0$



Diffraction

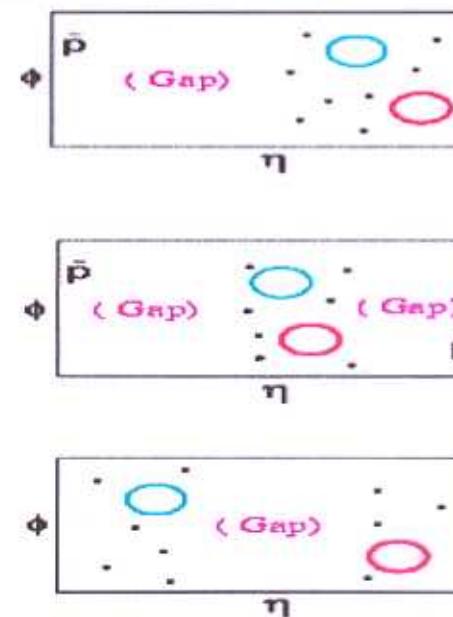
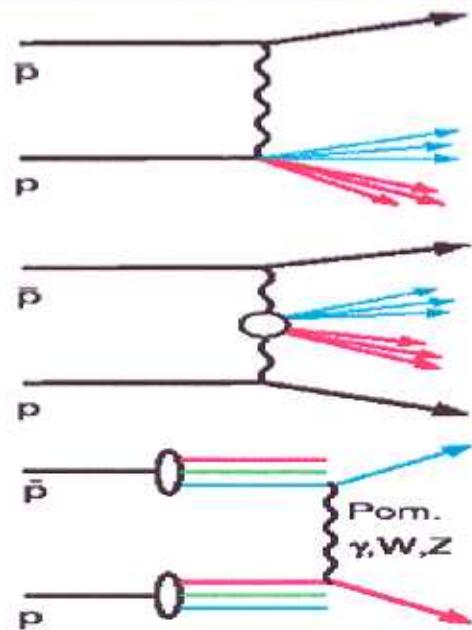
Soft Processes:



Elastic Scattering



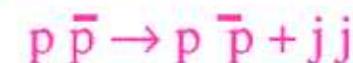
Hard Processes (jet production):



Hard Single Diffraction



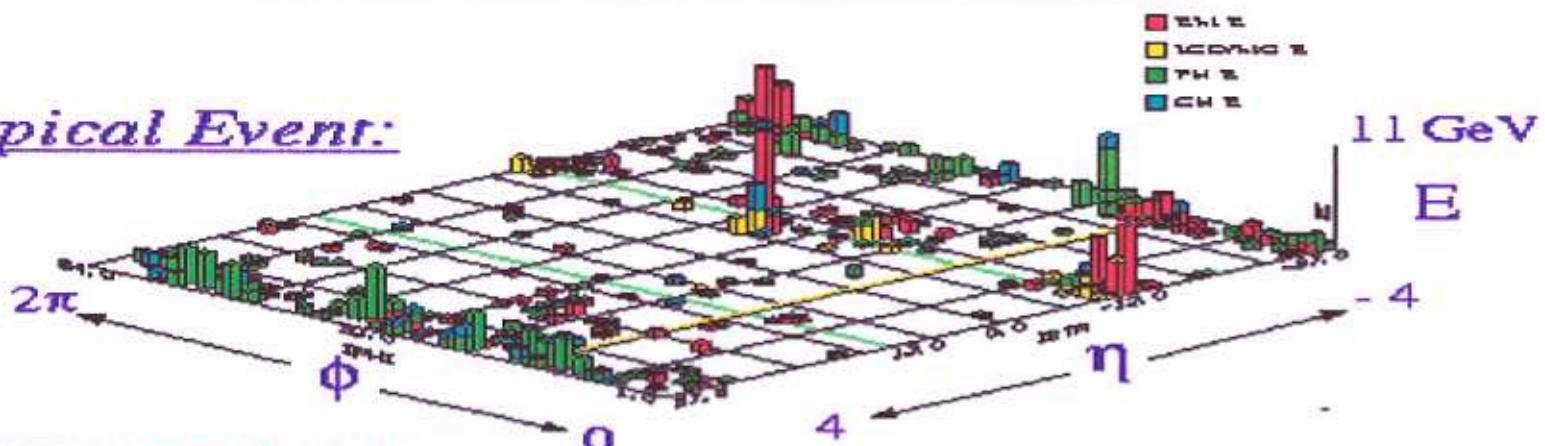
Hard Double Pomeron



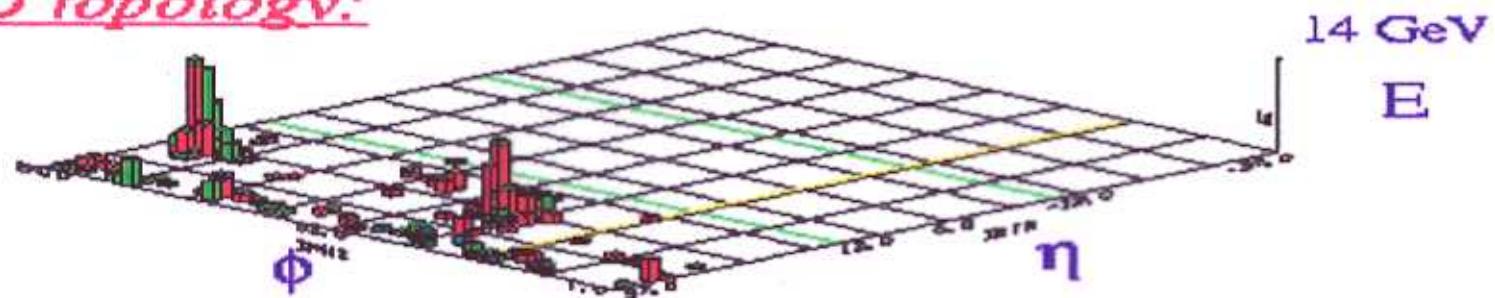
Hard Color-Singlet

DØ Dijet Events: η - ϕ Legos

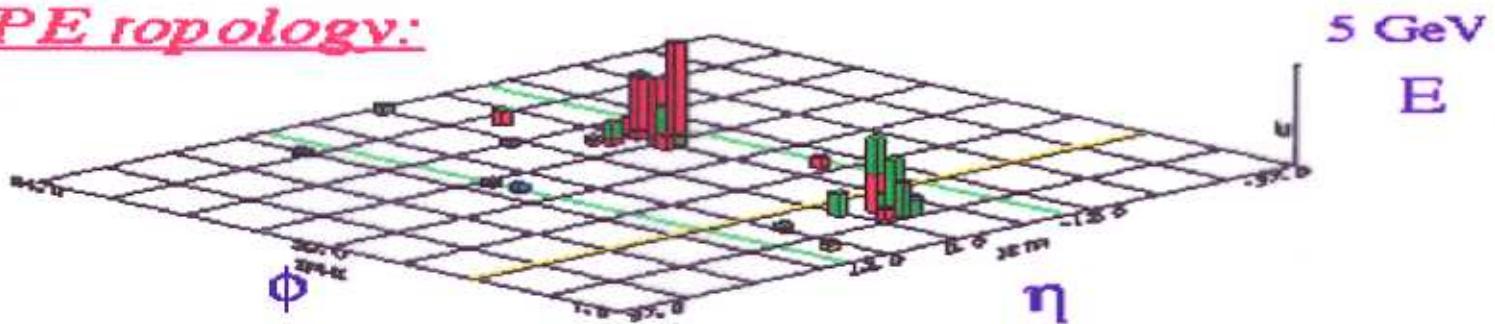
Typical Event:



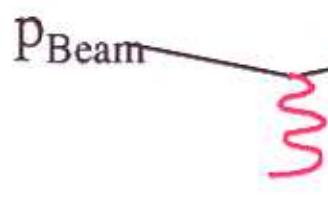
HSD topology:



HDPE topology:



Diffractive Variables



$$t = (P_{Beam} - P_F)^2$$

$$\xi = 1 - x_p = \frac{\Delta P}{P}$$

$$M_x = \sqrt{\xi} \sqrt{s}$$

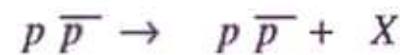
$$\sqrt{s} = 2 \text{ TeV}$$



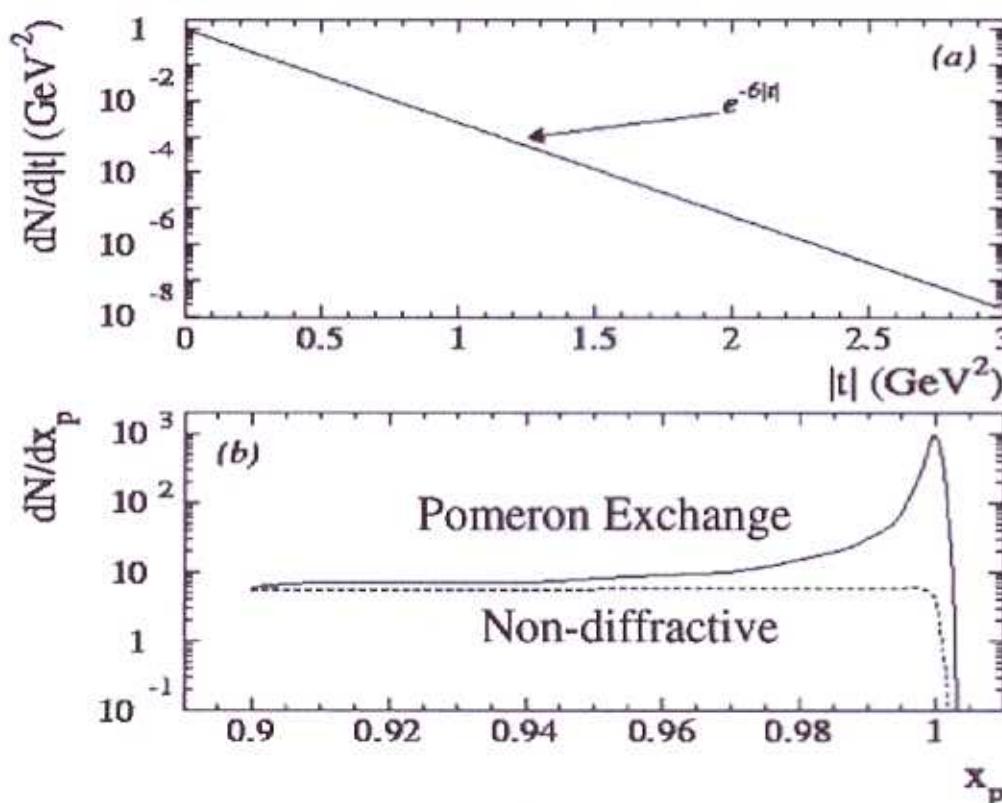
$$x_p = 0.95$$

$$(\xi = 0.05)$$

$$M_x = 450 \text{ GeV}$$



$$M_x = 100 \text{ GeV}$$



POMPYT Monte Carlo

$$p \bar{p} \rightarrow p (\text{or } \bar{p}) + j j$$

* Model pomeron exchange POMPYT26 (Bruni & Ingelman)

* based on PYTHIA

*define pomeron as beam particle



* Structure Functions:

1) Hard Gluon $xG(x) \sim x(1-x)$

2) Flat Gluon (flat in x)



3) Quark $xG(x) \sim x(1-x)$

$$\xi = 1 - x_p$$

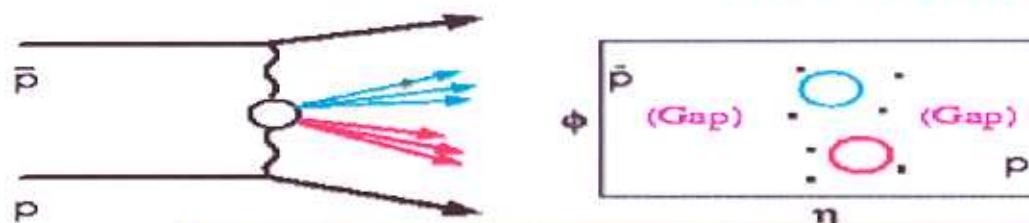
4) Soft Gluon $xG(x) \sim (1-x)^5$

ξ (momentum loss of proton)



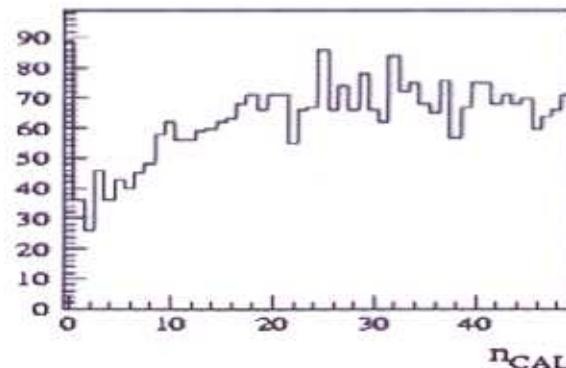
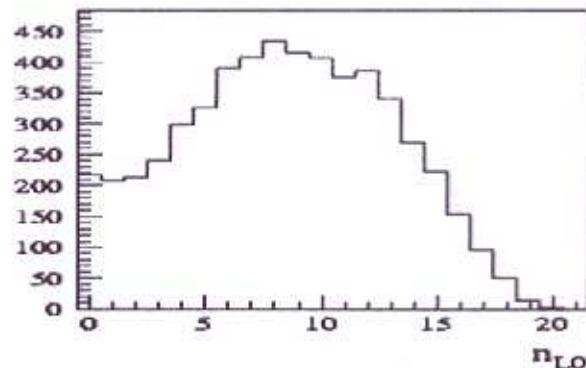
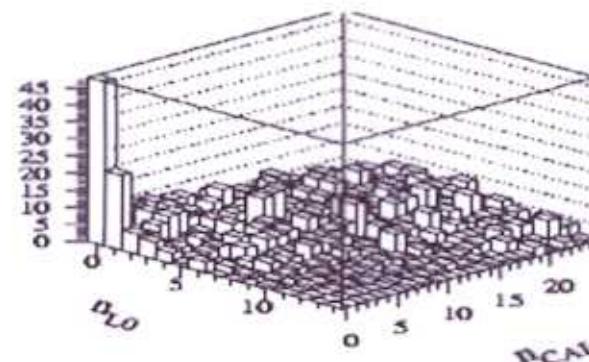
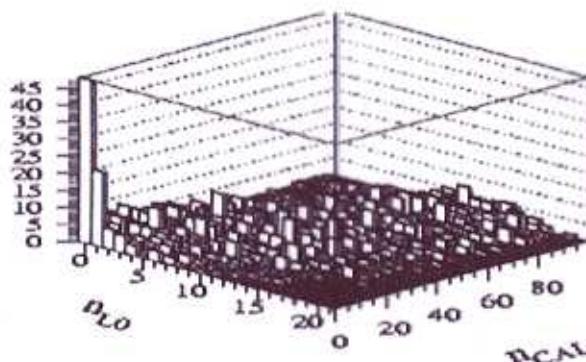
Double Gaps at 1800 GeV

$|\text{Jet } \eta| < 1.0, E_T > 15 \text{ GeV}$



Gap Region
 $2.5 < |\eta| < 5.2$

Demand gap on one side, measure multiplicity on opposite side



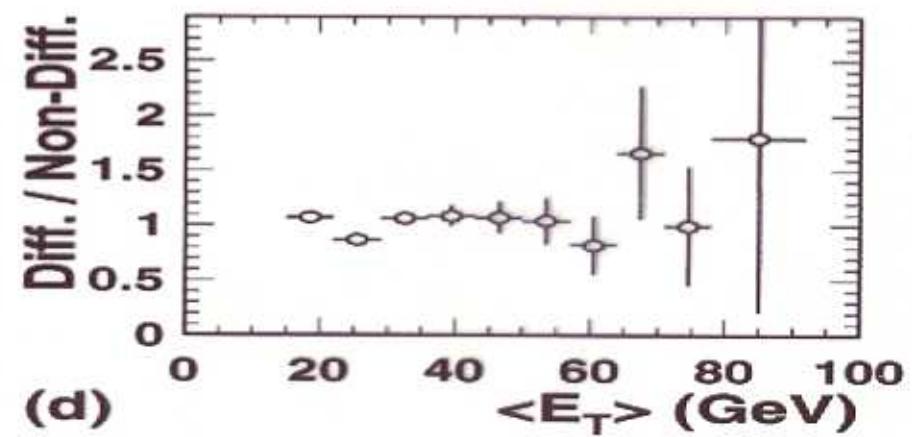
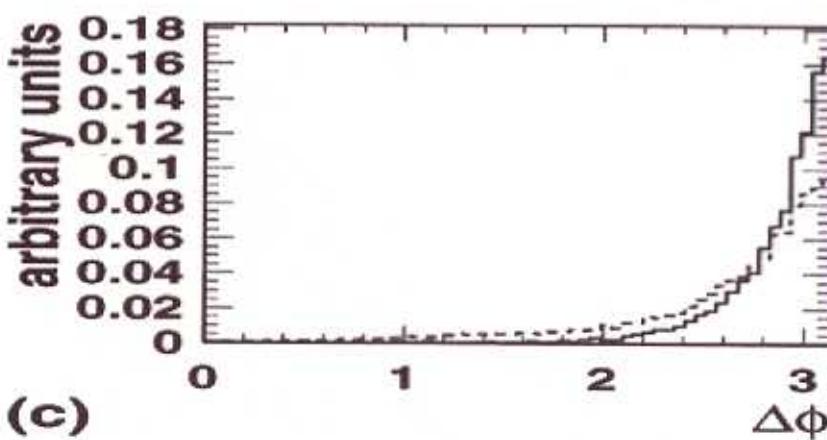
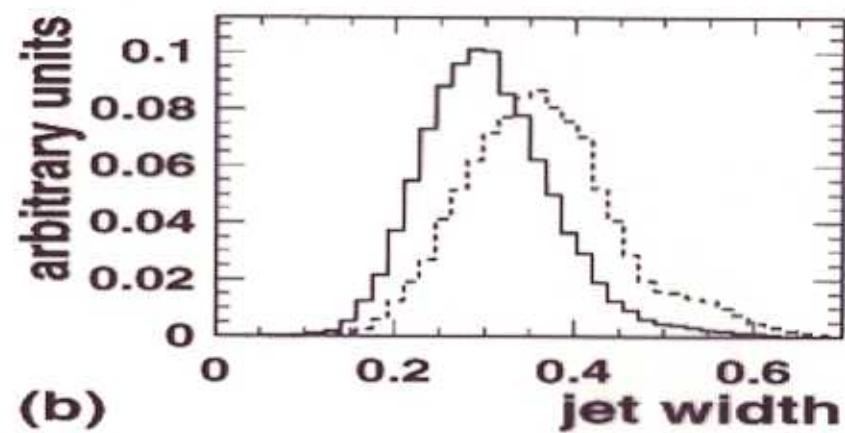
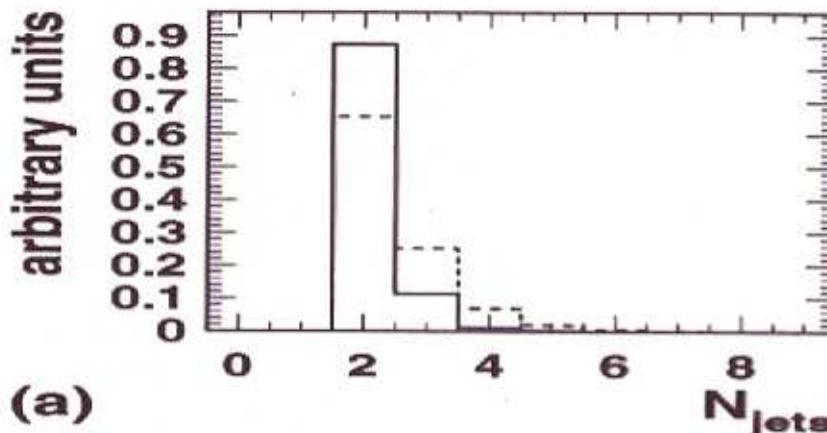
Event Characteristics(1800GeV)

$n_{L0} > 1$ and $n_{CAL} > 1$

$n_{L0} = n_{CAL} = 0$

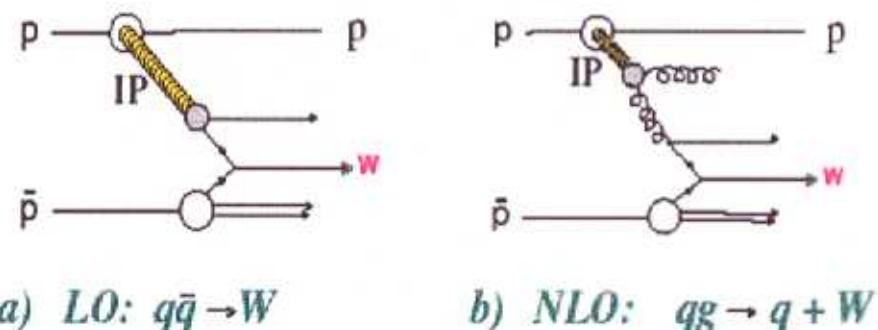
- Diffractive events have less radiation (a-c)

- Gap fraction has little dependence on $\langle E_T \rangle$ (d)



Why study the Diffractive W?

The pomeron (P) structure is not yet understood which motivates a study that will better clarify the quark/gluon composition involved. This is found in the diffractive W , which to leading order can only happen based on a quark component in the pomeron.¹



Diffractive process (a) probes the quark content of the pomeron.

¹(Bruni & Ingelman, Phys. Lett. B311(1993)318)

D $\bar{\Omega}$ Event Displays: $\eta - \phi$

Typical W Event:



Diff W topology:



MC - Find predicted rate POMPYT·2 / PYTHIA

*Factor of 2 since only antiproton allowed to diffract

*Apply same cuts as data

*Full detector simulation (error statistical)

Sample	Quark	Hard Gluon	Soft Gluon
Central W	$(20 \pm 1)\%$	$(0.45 \pm 0.02)\%$	$(0.10 \pm 0.01)\%$
Forward W	$(21 \pm 2)\%$	$(0.61 \pm 0.04)\%$	$(0.38 \pm 0.02)\%$
Z	$(17 \pm 1)\%$	$(0.45 \pm 0.02)\%$	$(0.13 \pm 0.01)\%$

(Pion exchange predicts diffractive fraction on the order of 10^{-31} for W and Z)

NOTE:

- *Quark pomeron model highest fraction
- *Soft gluon model smallest fraction
- *Pion exchange zero



W+Jet Rates

It is instructive to look at W+Jet rates for rapidity gap events compared to POMPYT Monte Carlo, since we expect a high fraction of jet events if the pomeron is dominated by the hard gluon NLO process.

Jet E _T	Data	Quark	Hard Gluon
>8GeV	(10 ± 3)%	14-20%	89 %
>15GeV	(9 ± 3)%	4-9 %	53 %
>25GeV	(8 ± 3)%	1-3 %	25 %

The W+Jet rates are consistent with a quark dominated pomeron and inconsistent with a hard gluon dominated one.

630 and 1800 GeV Ratios

Event Sample	Hard Glu	Flat Glu	Quark
630/1800 FWD	1.7 ± 0.4	1.4 ± 0.3	2.7 ± 0.6
630/1800 CEN	2.1 ± 0.4	1.8 ± 0.3	3.2 ± 0.5
1800 FWD/CEN	0.9 ± 0.2	0.6 ± 0.1	1.6 ± 0.3
630 FWD/CEN	0.8 ± 0.2	0.5 ± 0.1	1.4 ± 0.3

Event Sample	Soft Glu	DATA
630/1800 FWD	1.4 ± 0.3	1.8 ± 0.2
630/1800 CEN	3.1 ± 1.1	4.1 ± 0.9
1800 FWD/CEN	$30. \pm 8.$	3.0 ± 0.7
630 FWD/CEN	$13. \pm 4.$	1.3 ± 0.1

- Hard Gluon & Flat Gluon forward jet rate is lower than central jet rate -- and lower than observed in data

- * Quark rates and ratios are similar to observed

- * Combination of Soft Gluon and harder gluon structure is also possible for pomeron structure



*Valuable for measurement of the W and Z cross section ratio:

$$R = (\text{all W/all Z}) = 10.34 \pm 0.15 \pm 0.20 \pm 0.10$$

*Assumed that diffractive W and Z production of the same order

*No correction made regarding the presence of diffractive events in the data sample

*Measured (Diffractive W/All W) = (0.89 +0.20-0.19)%

(Diffractive Z/All Z) = (1.44 +0.62-0.54)%

$$\frac{\text{Diffractive W}}{\text{Diffractive Z}} = \frac{0.89}{1.44} \times 10.43 = 6.45 \pm 3.14 \\ 2.79$$

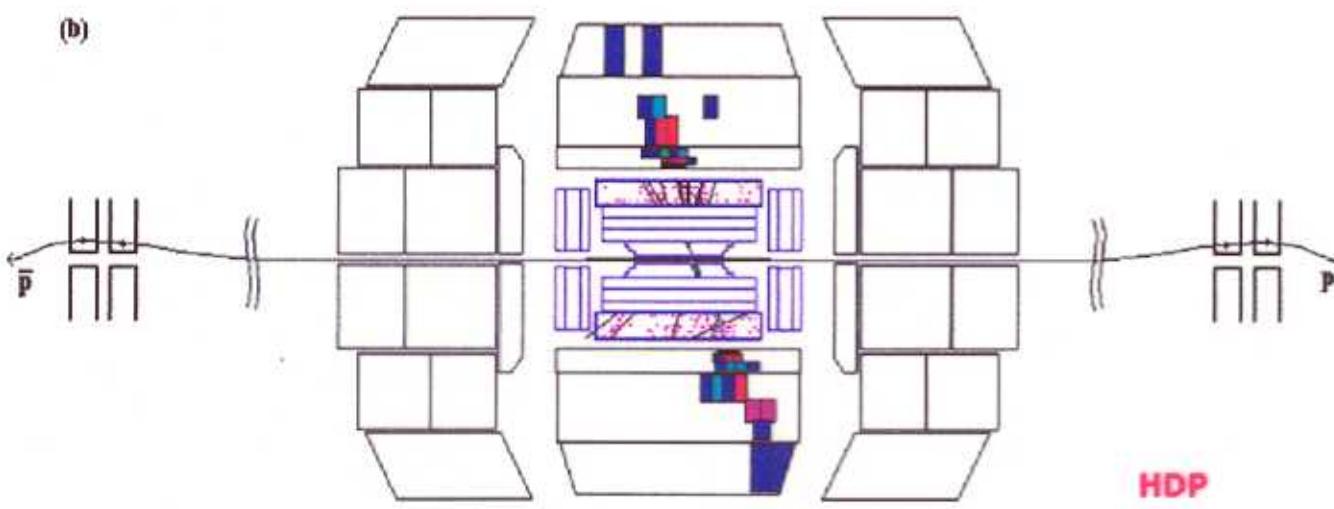
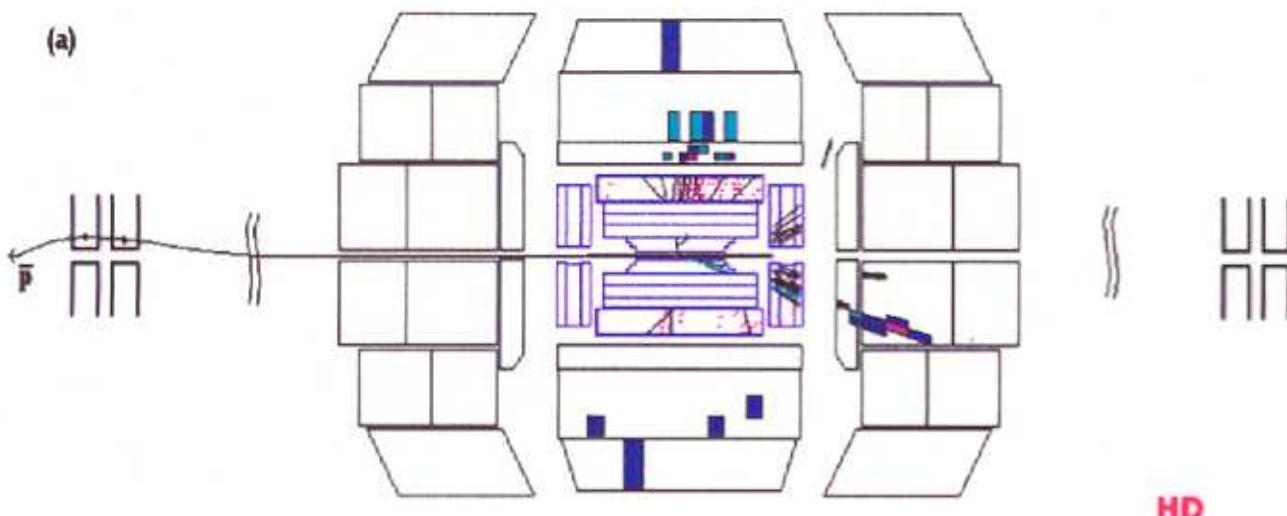


Summary

SD results: Physics Letters B531 52 (2002)

- New definitive observation of Diffractive W-boson signal: $R_W = (0.89 + 0.20 - 0.19)\%$
- Diffractive W as function of rapidity:
Central $1.08\% + 0.21\% - 0.19\%$
Forward $0.64\% + 0.19\% - 0.16\%$
- First observation of Diffractive Z-bosons:
 $R_Z = (1.44 + 0.62 - 0.54)\%$
- Diffractive W shows similar characteristics to non-diffractive ones.
- Ratio of $(W_{\text{diffractive}} / Z_{\text{Diffractive}}) = 6.45 + 3.14 - 2.79$
- Pomeron based MC does not predict magnitude or η dependence of results





- Read out Roman Pot detectors for all events
 - A few dedicated global triggers for diffractive jets, double pomeron, and elastic events
 - Use fiber tracker trigger board -- select ξ , $|t|$ ranges at L1, readout DØ standard
 - Reject fakes from multiple interactions (Ex. SD + dijet) using L0 timing, silicon tracker, longitudinal momentum conservation, and scintillation timing
 - Obtain large samples (for 1 fb^{-1}):
 - ~ 1K diffractive W bosons
 - ~ 3K hard double pomeron
 - ~ 500K diffractive dijets

