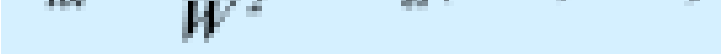
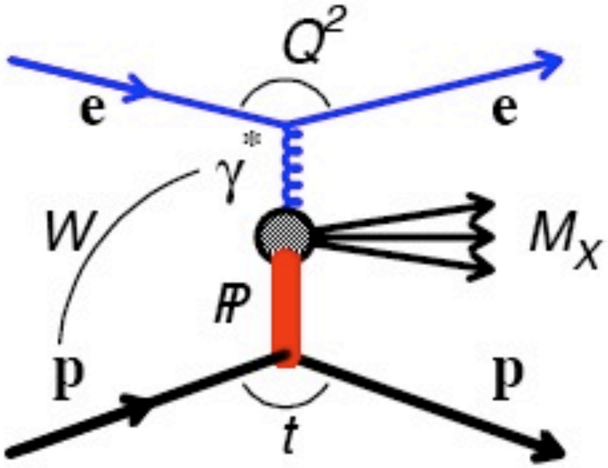


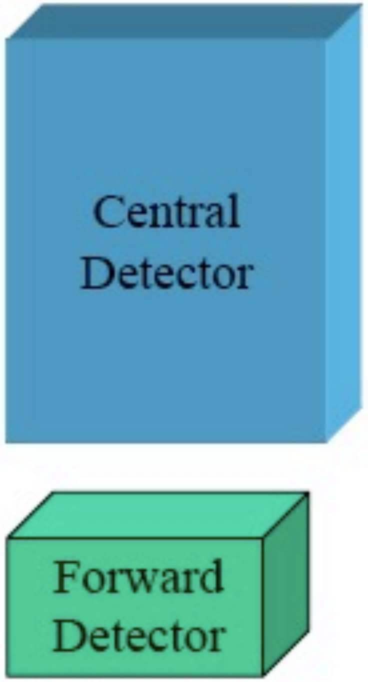
Diffractive measurements at HERA
Day one and later

Henri Kowalski

EDS'09

30 of June 2009 Geneva





Pseudo-Rapidity or Rapidity Gaps --
$\Delta Y = \ln(W^2/M^2_X)$
----- this talk -------

Forward Protons with > 95% of the incoming-momentum

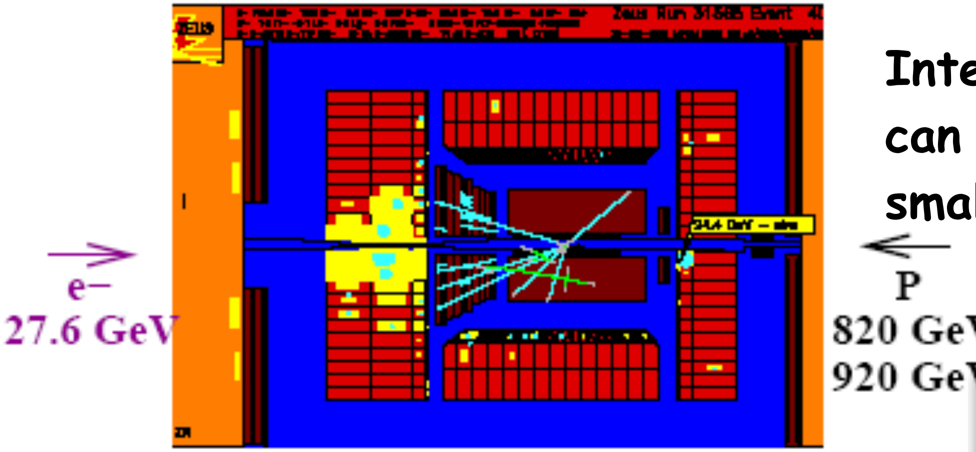
Q^2 - virtuality of the incoming photon
W - CMS energy of the incoming photon-proton system

M_X - invariant mass of all particles seen in the central detector
t - momentum transfer to the diffractively scattered proton

$\beta = Q^2/(Q^2+M^2)$ $x_{IP} = (Q^2+M^2)/(W^2+M^2)$

In the first month of HERA data taking the analysis trigger killed the diffractive signal with 100% efficiency

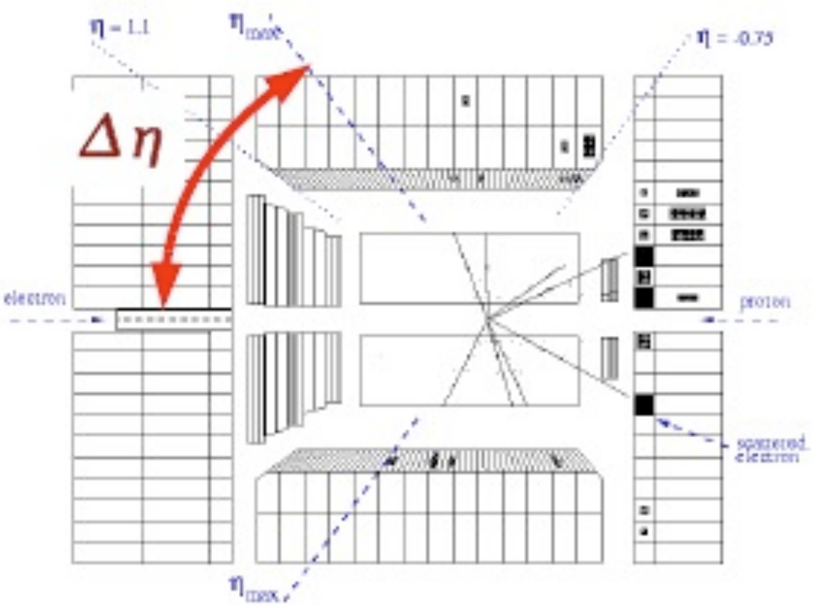
In ZEUS the analysis trigger required energy depositions in forward AND backward calorimeters (to measure vertex timing)



Interesting diffraction can be seen with small lumi, ~ 10 μb^{-1}

➥Watch the trigger and the cuts

Rapidity Gap Selection

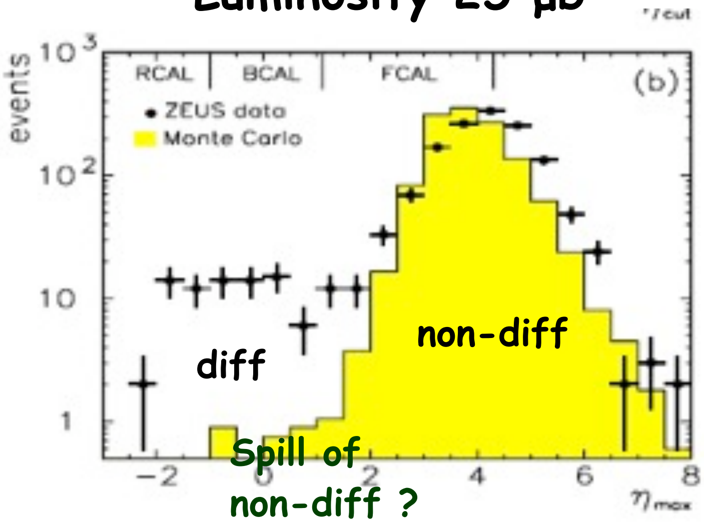


Select diffractive events by requirement:
No energy deposition in some area of the detector
- η_{max} cut

no energy means no cluster with > 400 MeV
note: noise O(100) MeV per cell

ZEUS Collaboration; M.Derrick et al.
Observation of Events with a Large Rapidity Gap in Deep Inelastic Scattering at HERA
DESY 93-093 (July 1993)
Physics Letters B 315 (1993) 481-493

Luminosity 25 μb^{-1}



diff

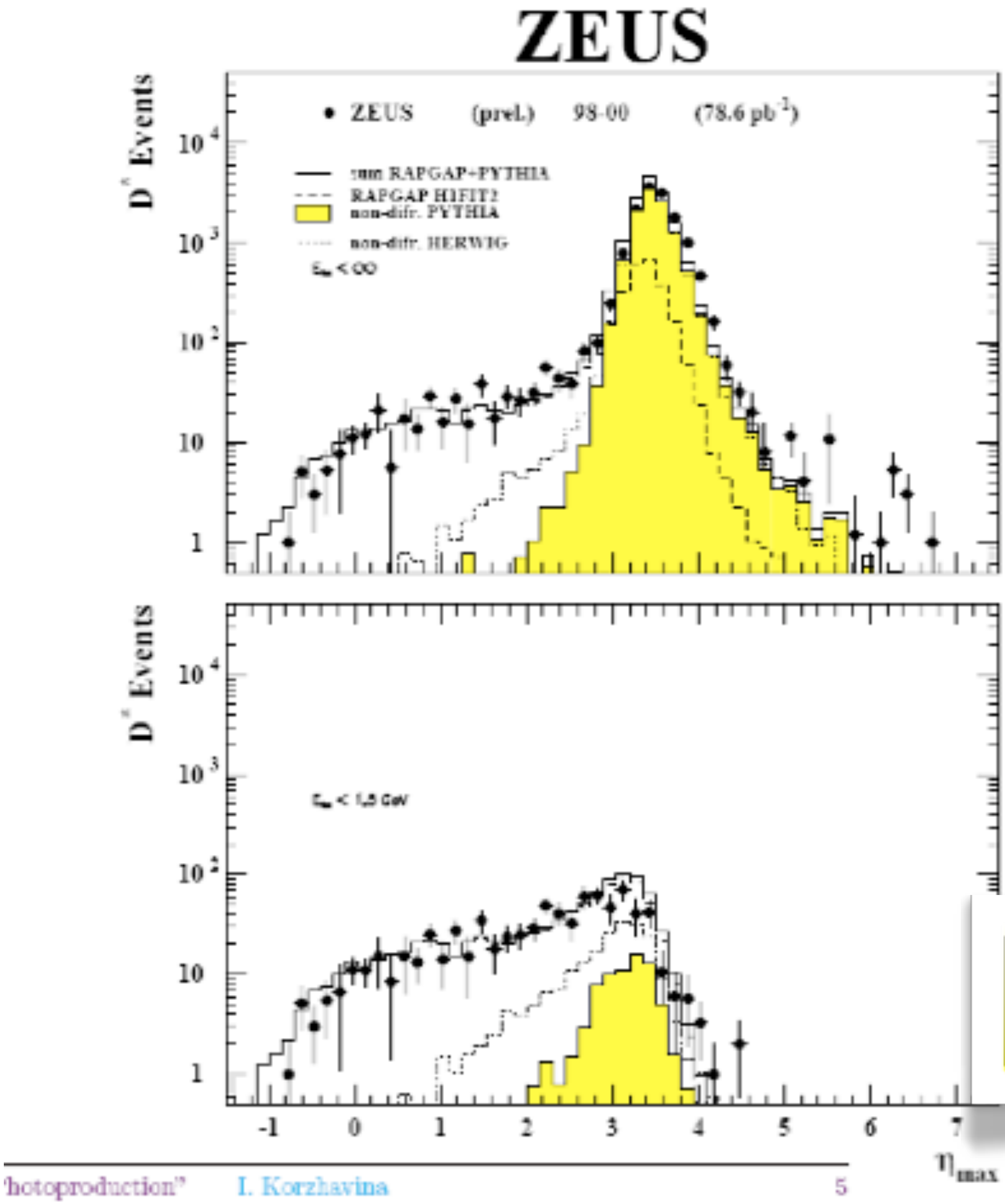
non-diff

Spill of
non-diff ?

Shape of MC ?
Shifts of MC ?

First diffractive signal seen in DIS

$D^*(2010)$ Signal Plots



➥Watch
the Monte Carlos

ZEUS Collaboration; J.Breitweg et al.
Measurement of the Diffractive Cross Section in Deep Inelastic Scattering using ZEUS 1994 Data
DESY 98-084 (July 1998)

The European Physical Journal C6 (1999) 43-66

as a function of W and M_X

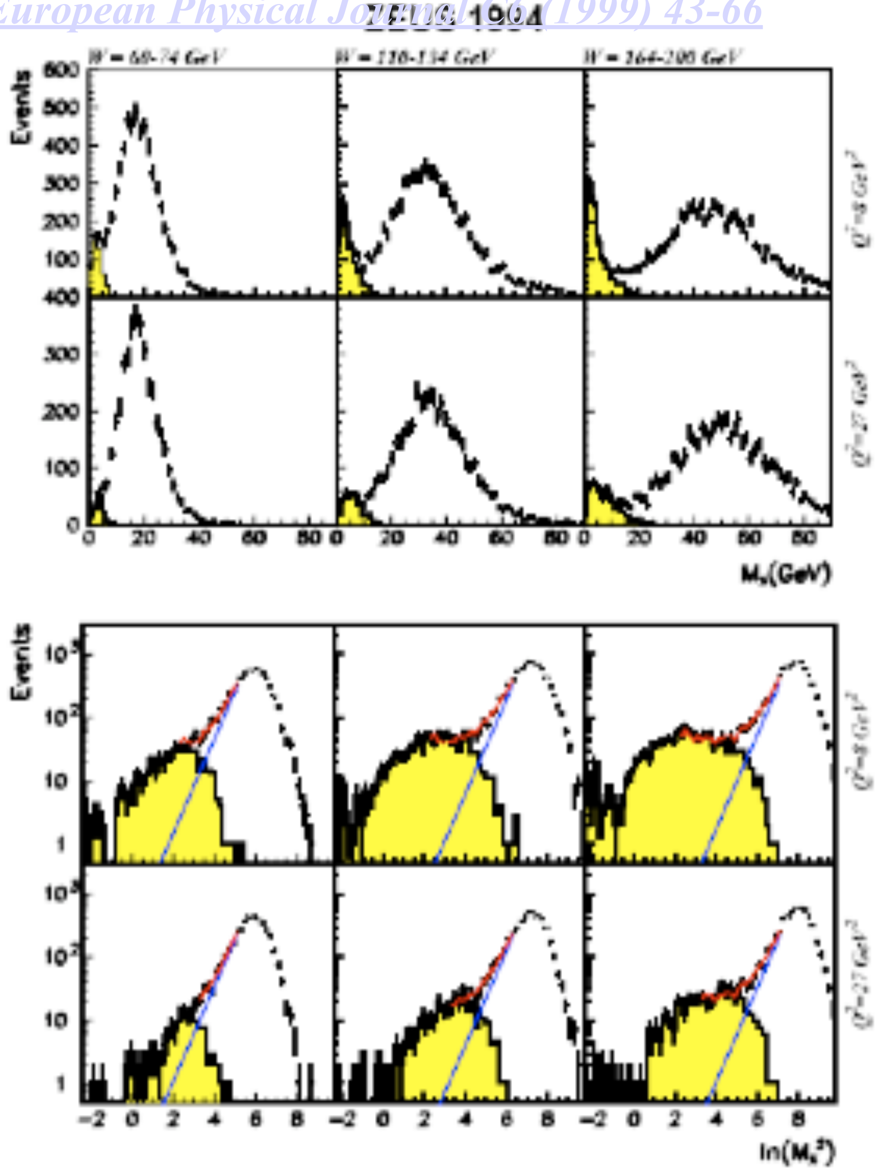


Fig. 1. Reaction $\gamma^* p \rightarrow X + anything$, where X is the system observed in the detector. *Top:* Distributions of M_X, the corrected mass of the system X. The distributions are not corrected for acceptance effects. The shaded histograms show the distributions of events with $\eta_{max} < 1.5$. *Bottom:* Same distributions as above presented in terms of $\ln M_X^2$. The straight lines give the nondiffractive contributions as obtained from the fits. The upper curves show the fit results for the sum of the diffractive and nondiffractive contributions

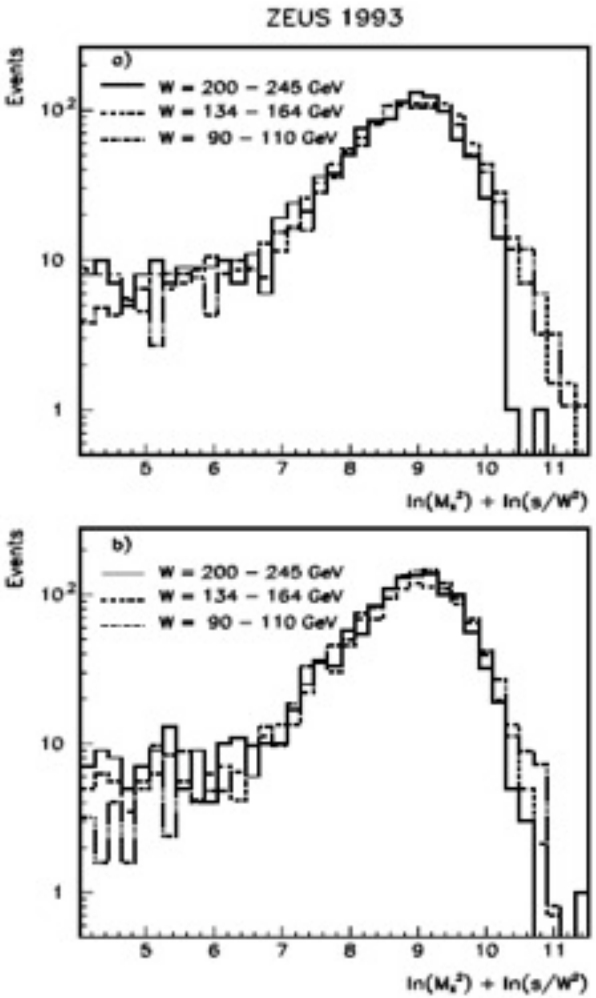


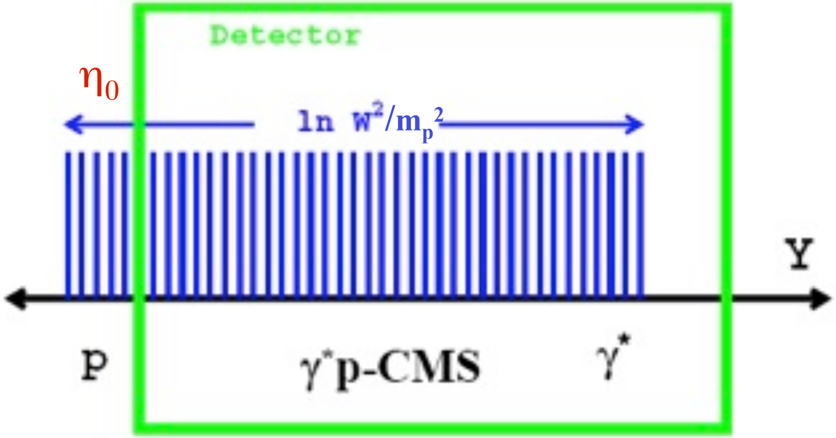
Figure 8: Distributions of $\ln M_X^2 + \ln(s/W^2)$ for the W intervals 90 - 110 GeV (dotted), 134 - 164 GeV (dashed), 200 - 245 GeV (solid) ($\ln W^2$ = 9.0 - 9.4, 9.8 -10.2, 10.6 - 11.0) at a) Q^2 =14 GeV^2 and b) 31 GeV^2. Here M_X is the corrected mass; the distributions are the measured ones, not corrected for acceptance effects. For each Q^2 the three distributions were normalized to the same number of events.

W - the CMS energy

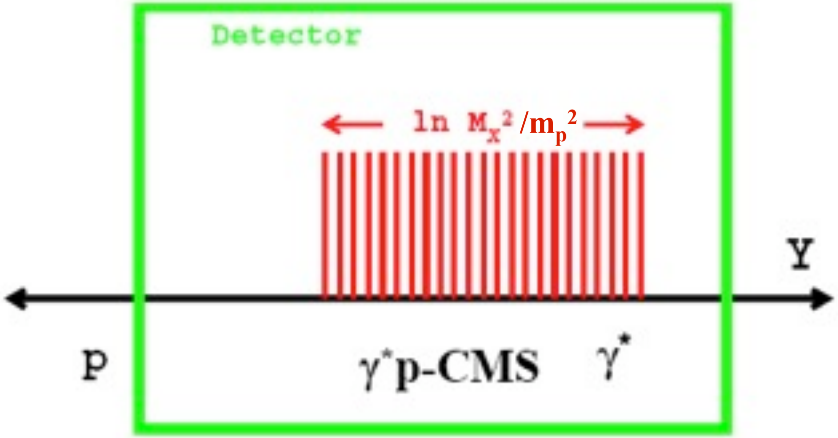
$\Delta Y = \ln(W/M_X)^2$ length of the rap-gap in the event

$\Delta Y = \ln(W/M_X)^2 - \eta_0$ length of the rap-gap seen in the detector

Non-Diffractive Event



Diffractive Event



non-diff events are characterized by uniform, uncorrelated particle emission along the whole rapidity axis => probability to see a gap ΔY is

$\sim \exp(-\lambda \Delta Y)$ --- Poisson $P(0, \Delta Y)$

λ – Gap Suppression Coefficient
(average multiplicity per unit of Y)

Examples of probabilities to see a gap ΔY in an non-diff event - $\exp(-1.7\,\Delta Y)$

P(1) = 18% P(2) = 3.3%
P(3) = 0.6%

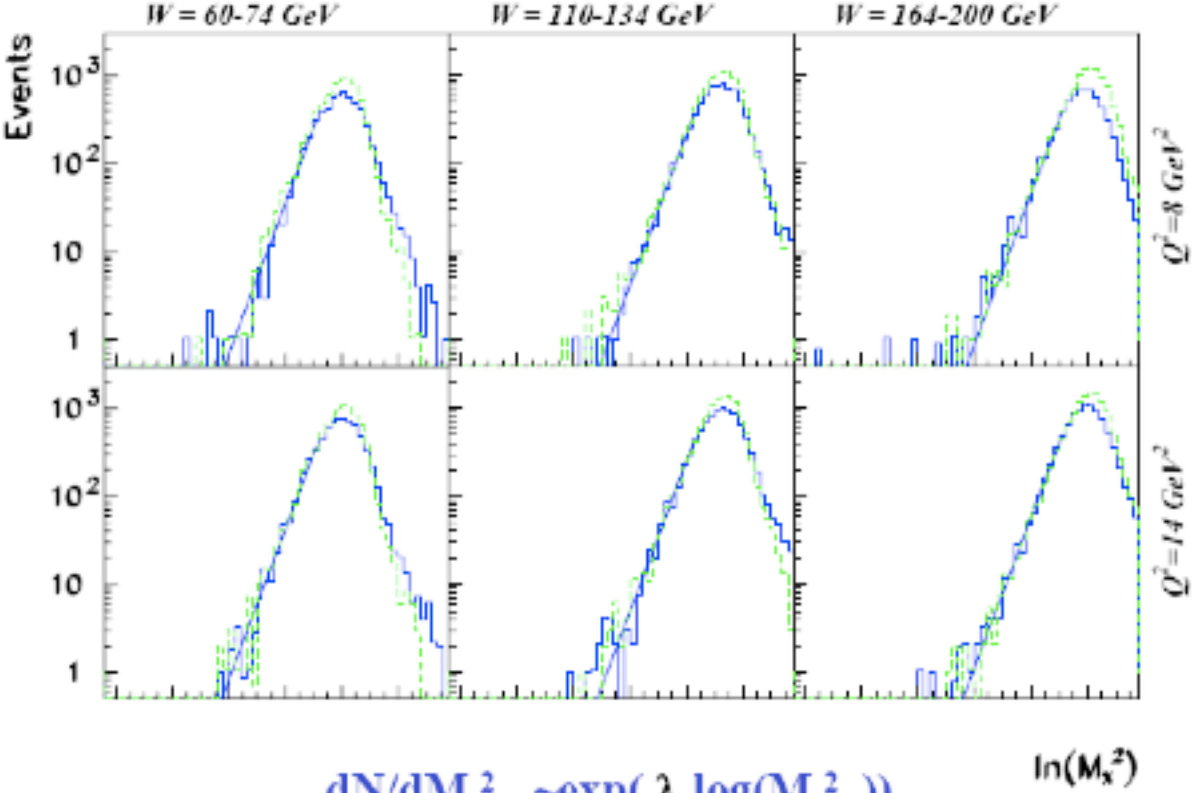
Non-Diff Color Dipole MC

$\Delta Y = \ln(W/M_X)^2$

$\Delta Y = \ln(1/x_{IP})$?

---- Generator Level

---- Detector Level



$dN/dM^2_X \sim \exp(\lambda \log(M^2_X))$

In MC λ independent of Q^2 and W^2

$\lambda \sim 2$ in MC

$\lambda \sim 1.7$ in data

➥Watch the Monte Carlos

Probability to see a gap ΔY in an non-diff event - $\exp(-\lambda\Delta Y)$

Physical interpretation of the Gap Suppression Coef. $\lambda \sim 1.7$

Feynman (~1970): λ depends on the quantum numbers carried by the gap

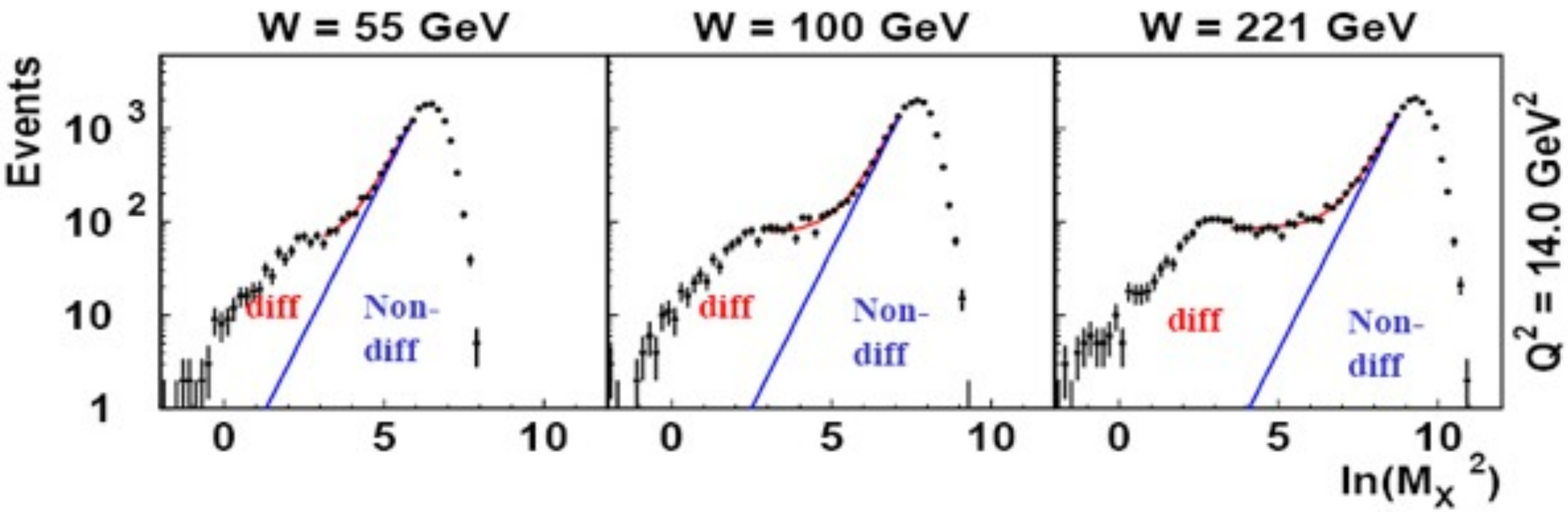
Photon – Hadron Interactions, lecture 52

λ = 2 for the exchange of pion q.n.
= 1 for the exchange of rho q.n.
= 0 for the exchange of pomeron q.n.

In the Longitudinal Phase Space Model

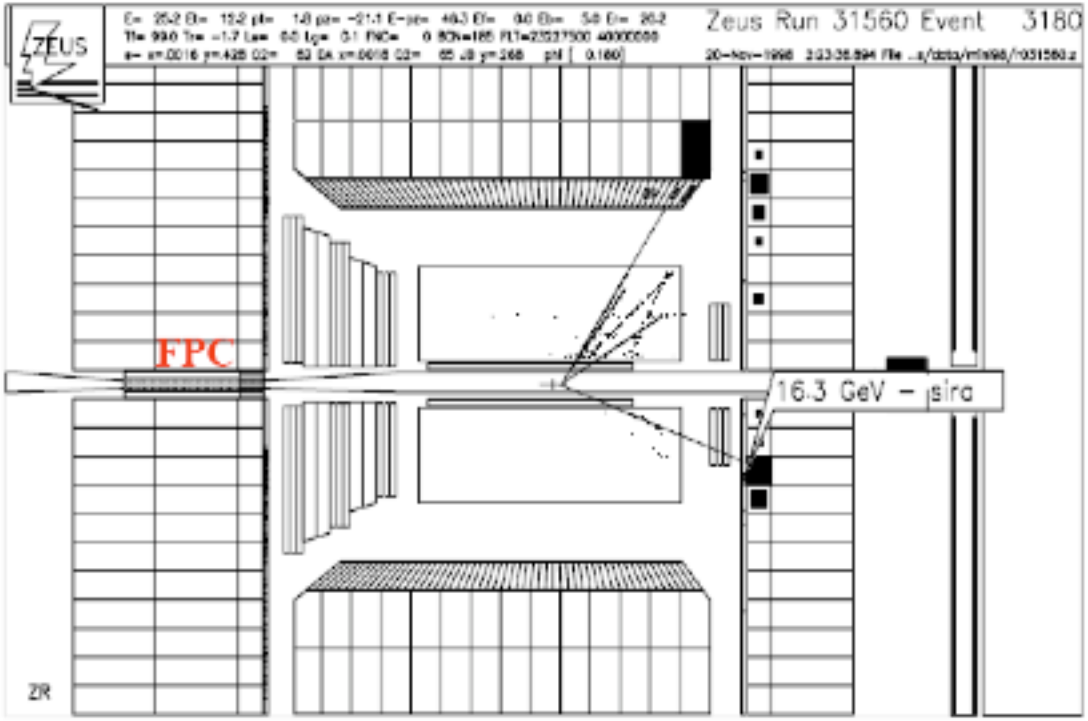
λ – particle multiplicity per unit of rapidity
cluster

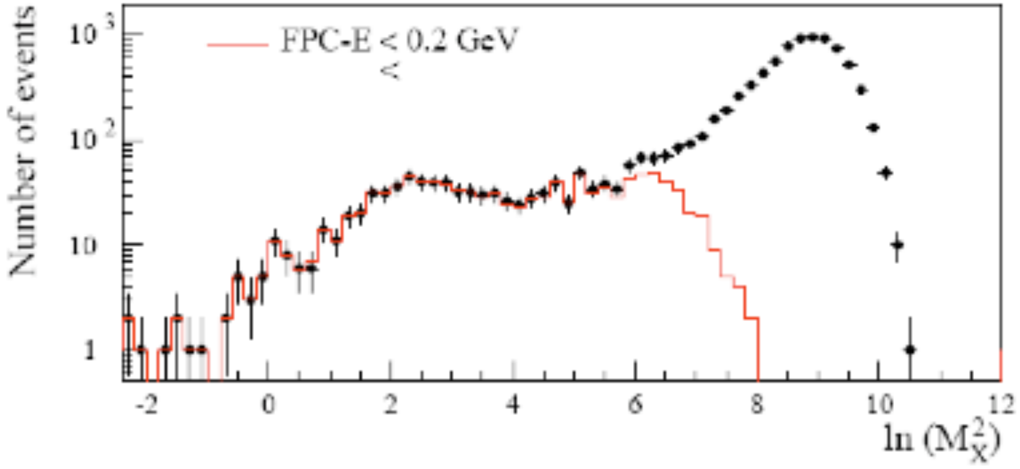
M_X Method


W = 55 GeV
W = 100 GeV
W = 221 GeV
Events
1
10
10 2
10 3
0
5
10
ln(M_X 2)
Q2 = 14.0 GeV2
diff
Non-
diff

Rapidity Gap Selection ⟷ M_X Method

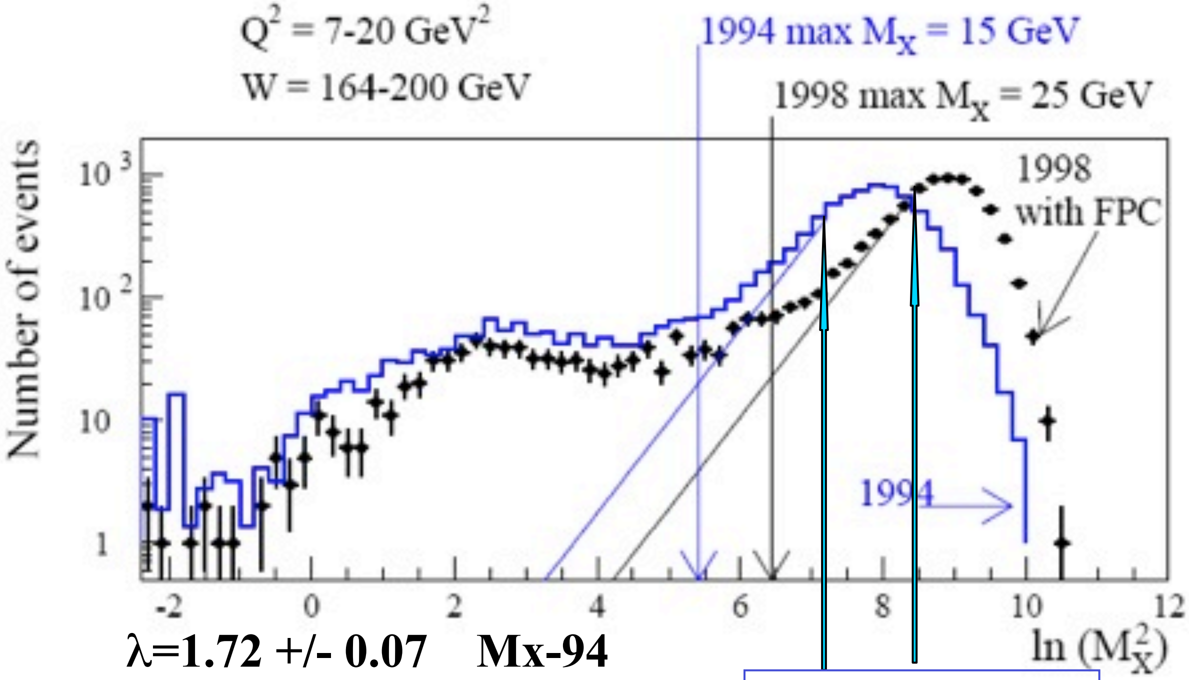
*





Effect of FPC on ZEUS Diffractive Measurement

FPC was added in 1998



λ=1.72 +/- 0.07 **Mx-94**

λ=1.63 +/- 0.07 **Mx-00**

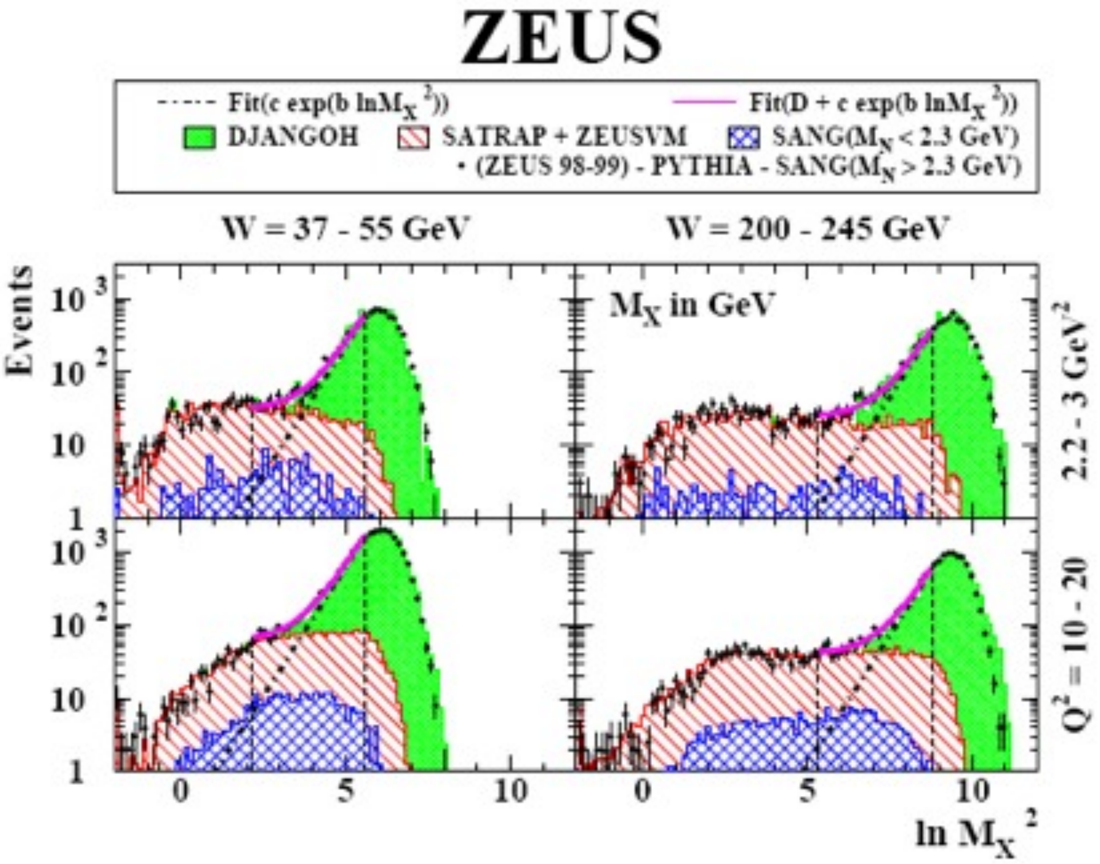
log W² – η_0

η_0 **= 3** **Mx-94**

η_0 = 2.2 **Mx-00**

FPC added
Mx-00

Larger W and M_X range
but
more proton dissociation

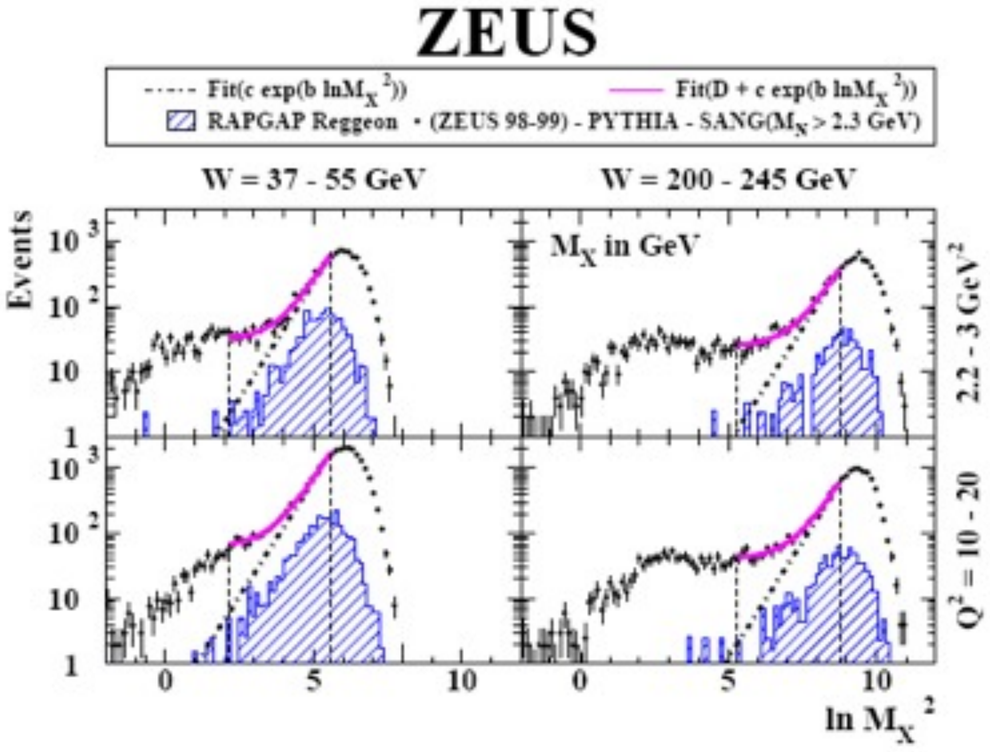


$\ln M_X^2 < \ln W^2 - \eta_0 - 2$

$\ln 46^2 = 7.7$ $M_X \sim$ 6 GeV

$\ln 222^2 = 10.8$ $M_X \sim$ 27 GeV

Reggeon Contribution

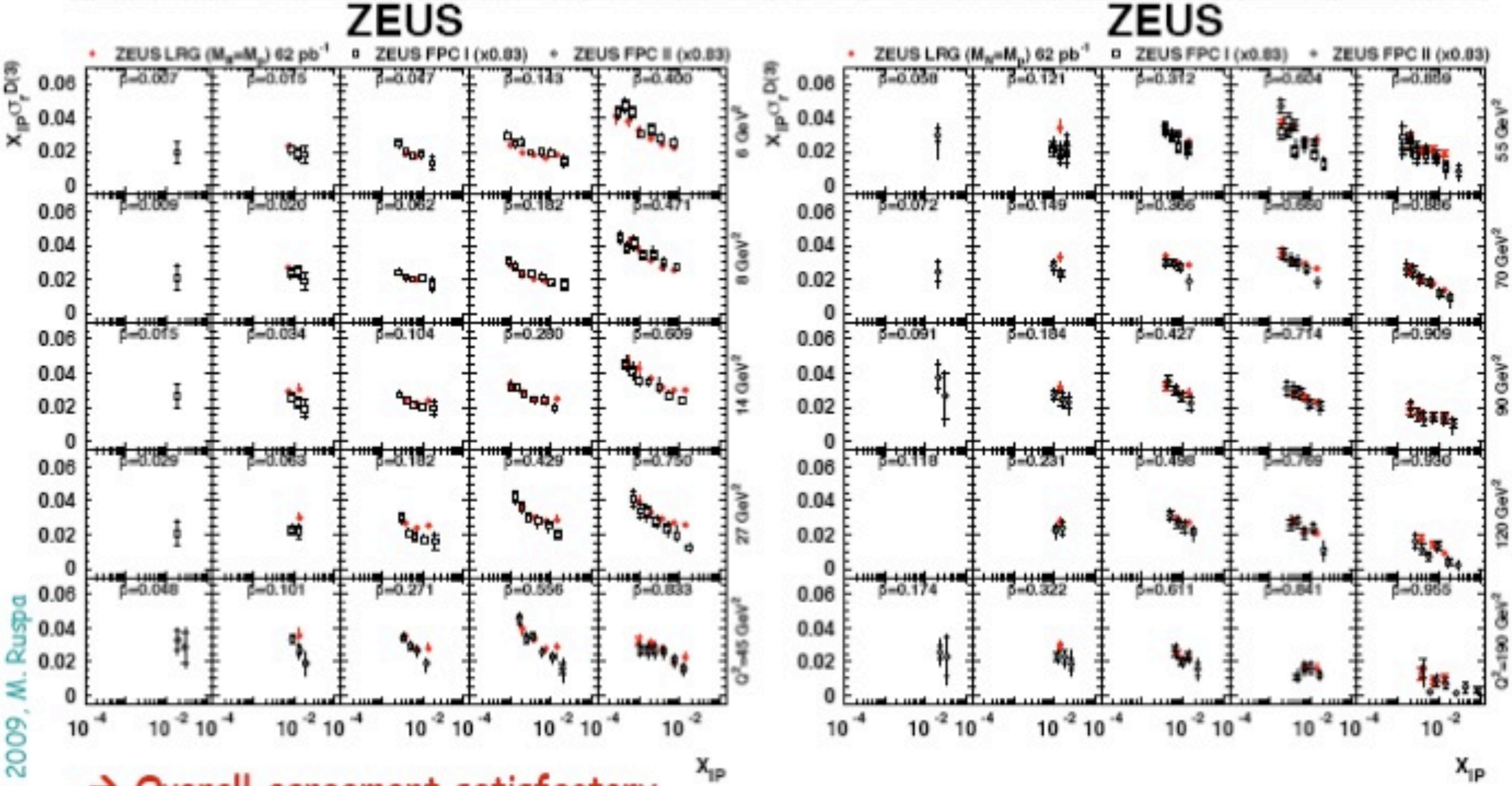


Reggeon MC reweighted to reproduce LPS data

Figure 6: *Distributions of* $\ln M_X^2$ *(*M_X *in units of* GeV*) at the detector level for different* (W, Q^2) *bins. The points with error bars show the data. The hatched histograms show the contributions predicted by the exchange of the* ρ*-Reggeon trajectory. The dash-dotted lines show the results for the non-diffractive contribution from fitting the sum of the diffractive and non-diffractive contributions in the* $\ln M_X^2$ *range delimited by the two vertical dashed lines.*

LRG vs M_x

M_x data (M_N < 2.3 GeV) normalised to LRG (M_N=m_p): factor 0.83 ± 0.04 determined via a global fit estimates residual p-diss. background in M_x sample

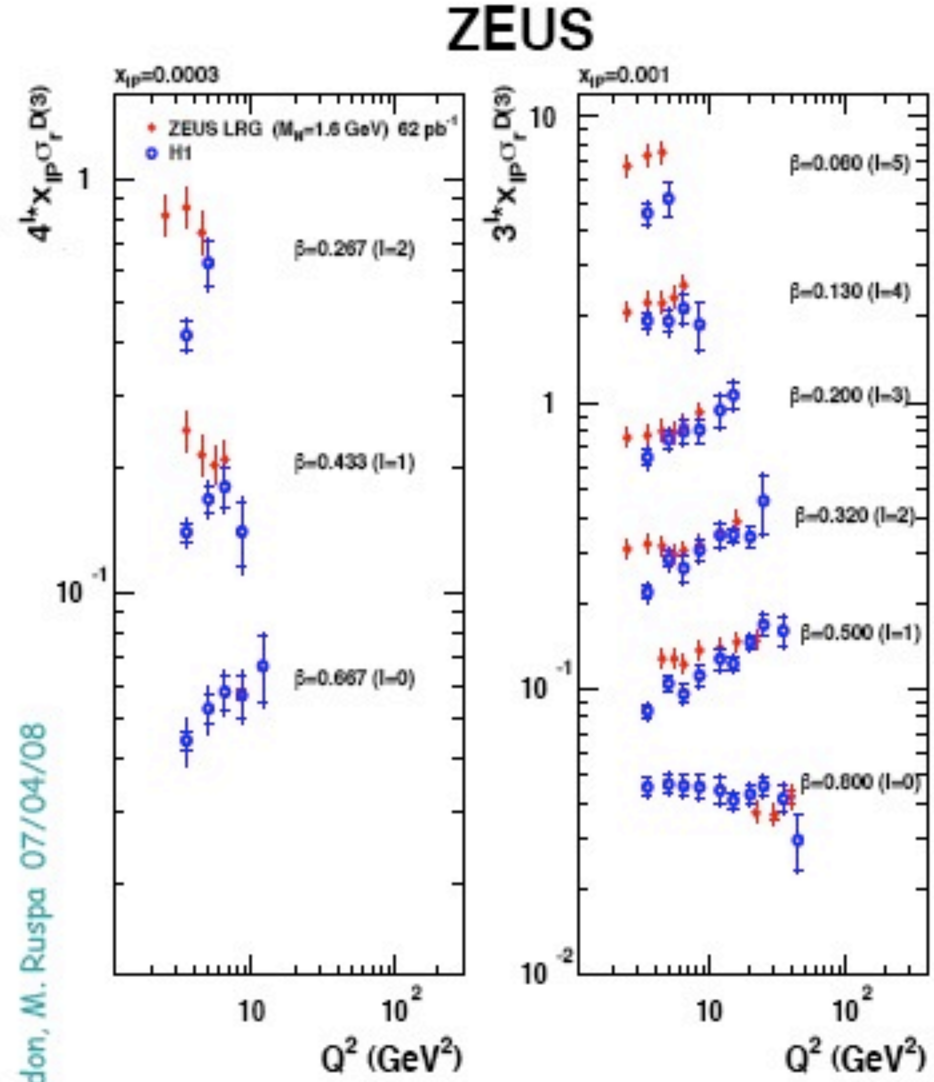


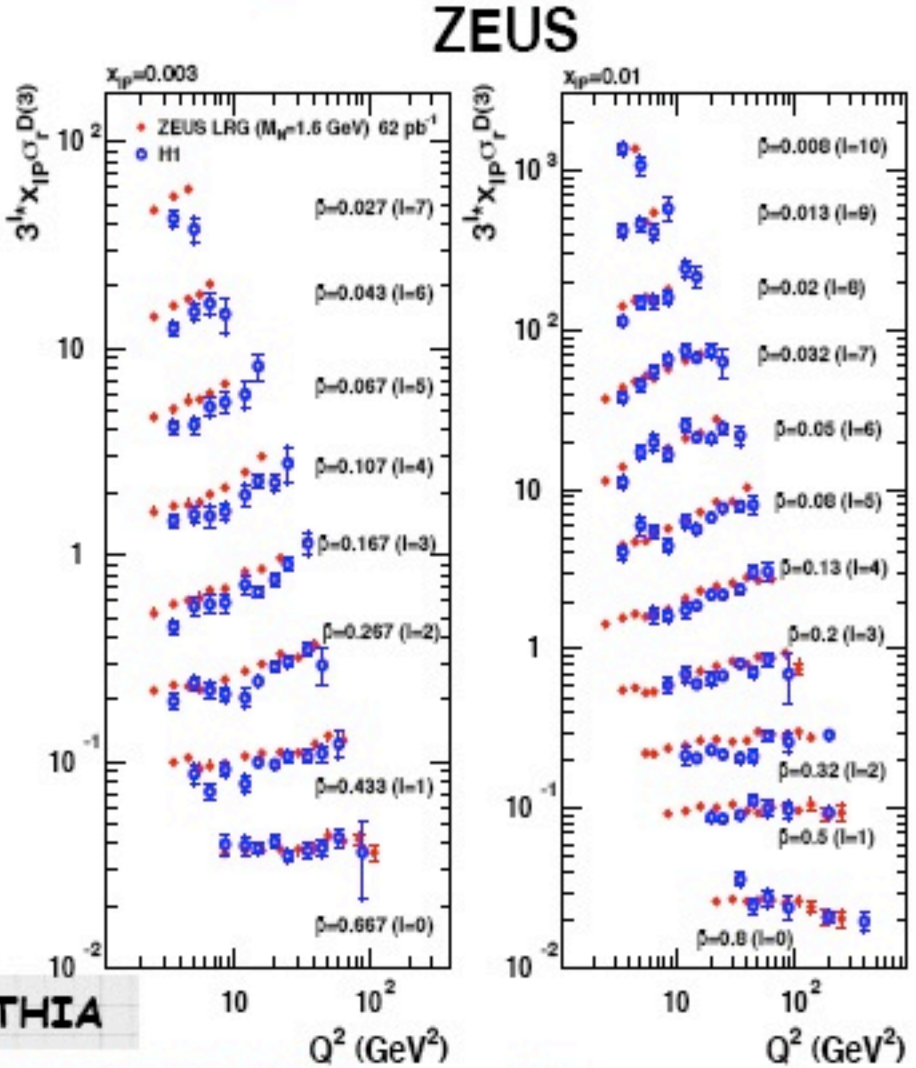
→ Overall agreement satisfactory

→ Different x_{IP} dependence ascribed to IR suppressed in M_x data

DIS 2009, M. Ruspa

ZEUS LRG vs H1 LRG





ZEUS corrected to M_N < 1.6 GeV with PYTHIA

→ Remaining normalisation difference of 13% (global fit) covered by uncertainty on p-diss. correction (8%) and relative normalisation uncertainty (7%)

→ Shape agreement ok except low Q^2

Conclusions I

ZEUS detector covers ~ 6.5 units of rapidity by high quality calorimetry

Rapidity Gap Selection & M_X Method used for Inclusive Diffractive Measurements

H1 detectors covers ~ 4.5 units by high quality calorimeter +
~ 3-4 units by particle detectors

Rapidity Gap Selection used only for Inclusive Diffractive Measurements

The agreement between H1 and ZEUS incl. diffractive measurements is fairly good although worst than for F_2 . Personal judgment: Main difficulty is due to the diffractive proton dissociation

Measurement of F_2^D is as fundamental as of F_2 . Combined effort using all methods (including forwards protons) necessary.

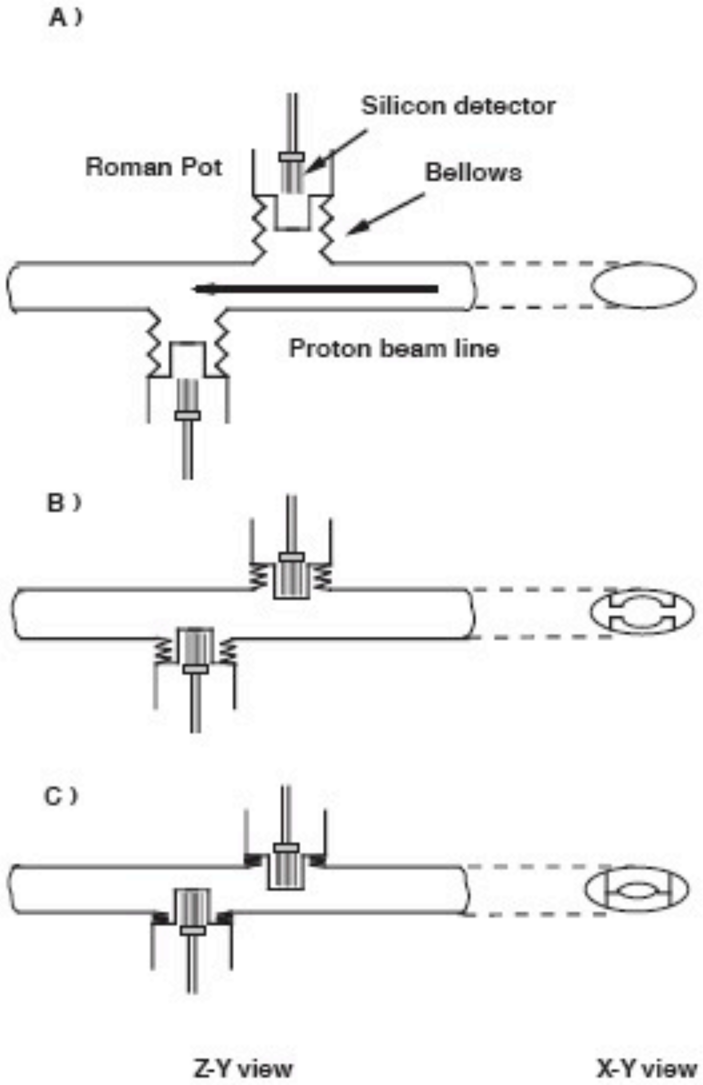
Lesson for LHC: Extend good calorimeter coverage, build as many forwards detectors as possible

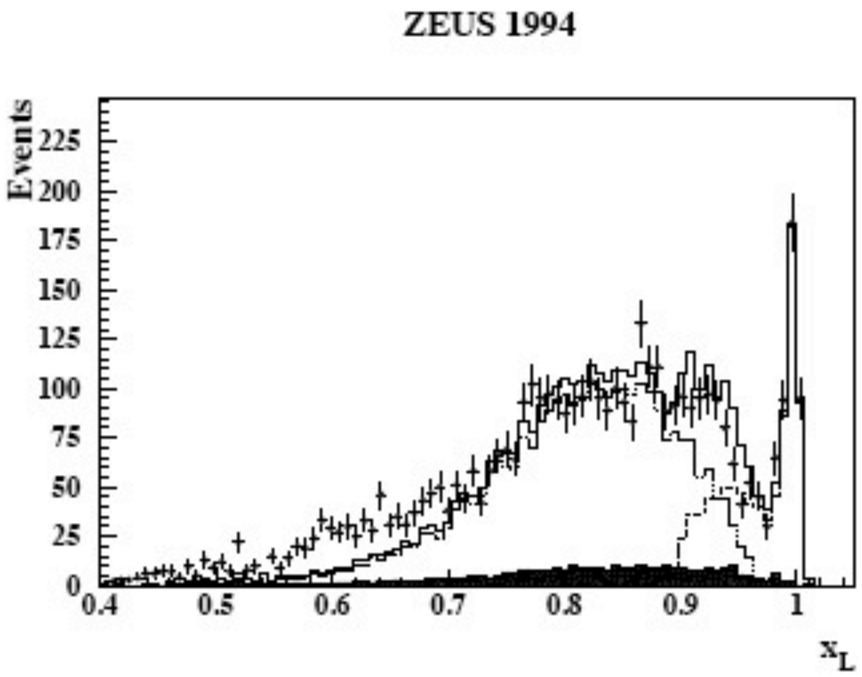
Leading Proton Spectrometer

Detector operation using Roman Pots

6 Ro-Pots equipped with micro-strip silicon detectors

pitch 115 micron
3 different strip orientations





Diffractive analysis using LPS detector allows :

Clean selection of the single diffraction processes (no proton dissociation)

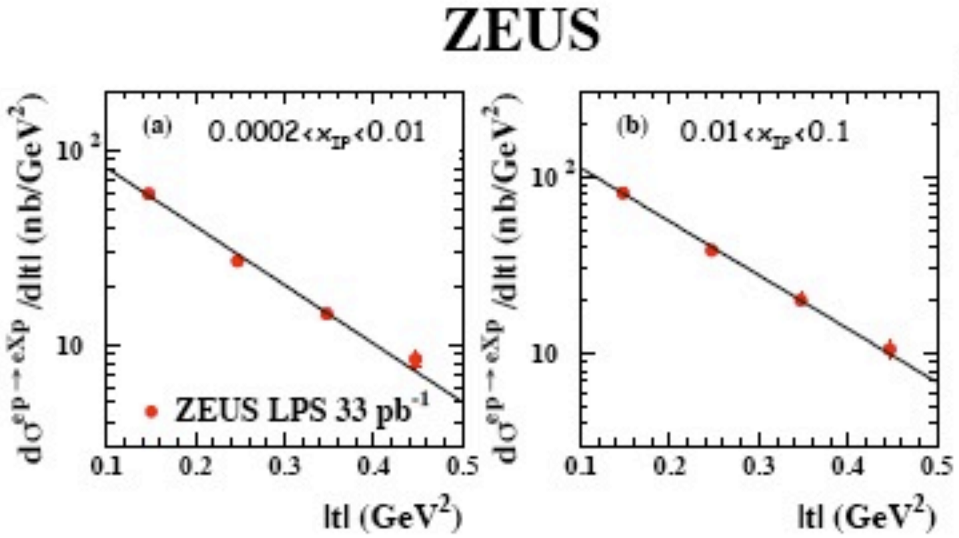
Measurement of *t* in diffractive reactions

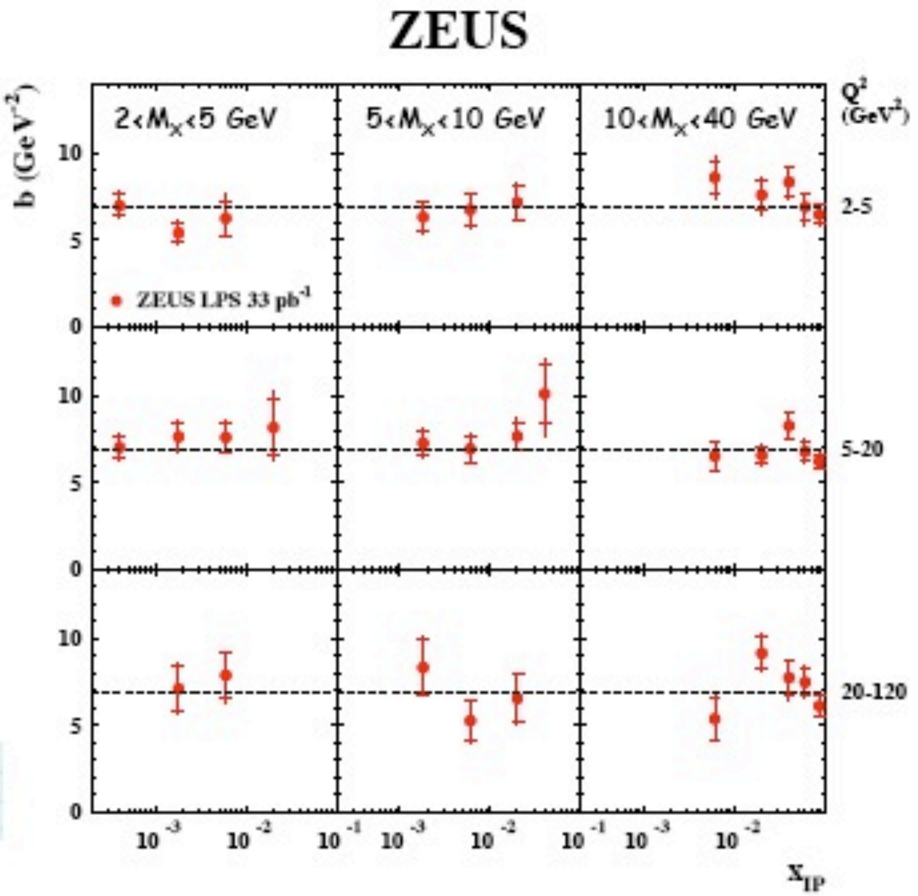
Good reconstruction of kinematical variables when combined with the central detector

Problem - limited statistics

t dependence

LPS data



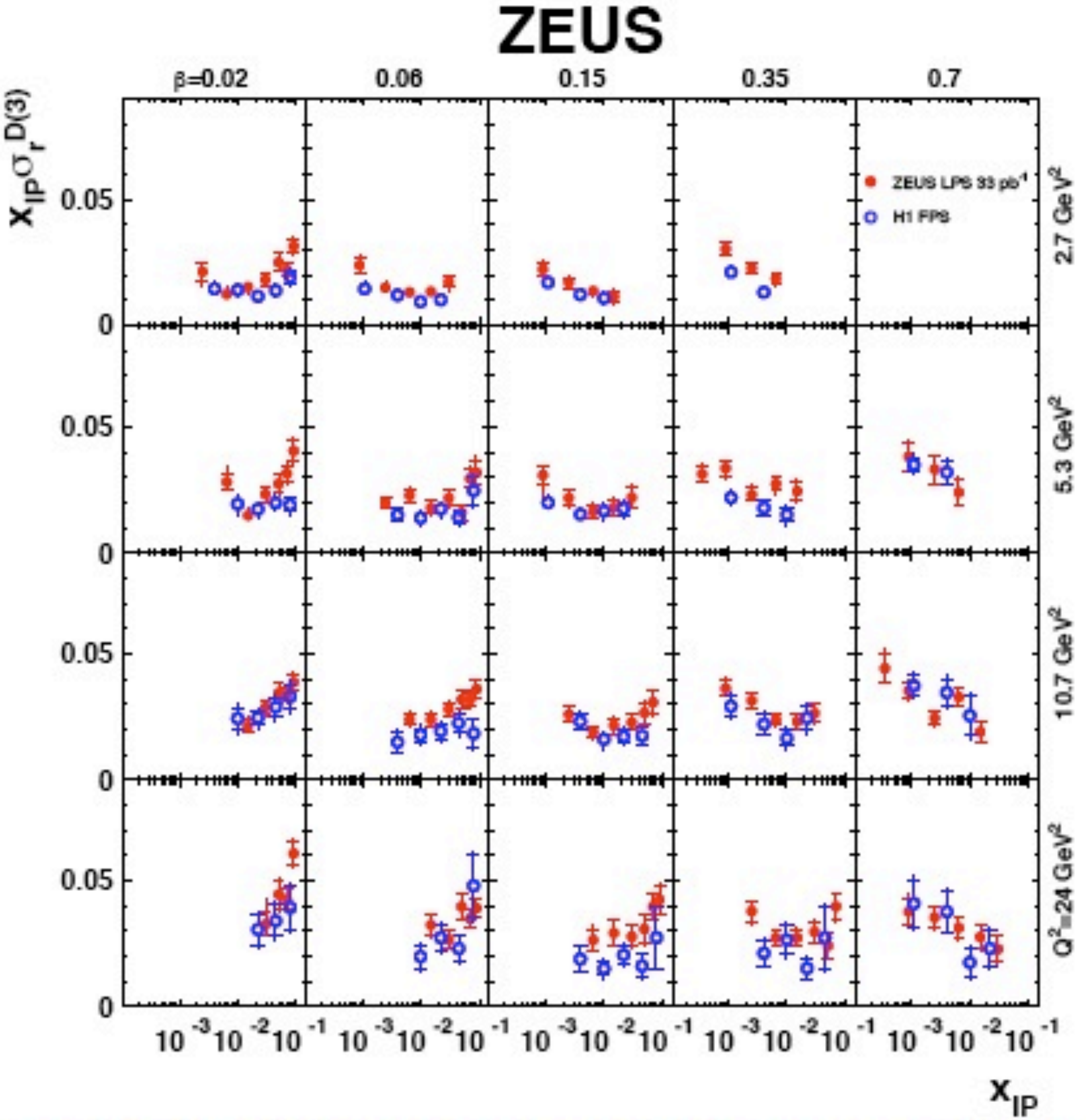


Fit to $e^{-b|t|}$ → b = 7.0 ± 0.4 GeV^{-2}

used in DPDF fits
see talk by W. Slominski

Lack of Q^2 dependence and b much larger than in vector meson production → features of a soft process

ZEUS LPS vs H1 FPS



The cleanest possible comparison in principle…

…but large normalisation uncertainties (LPS:+11-7%, FPS: +-10%)

New comparison plot available with HERA II FPS data!
see talk by M.Kapishin

→ ZEUS and H1 proton-tagged data agree within normalisation uncertainties

Conclusions

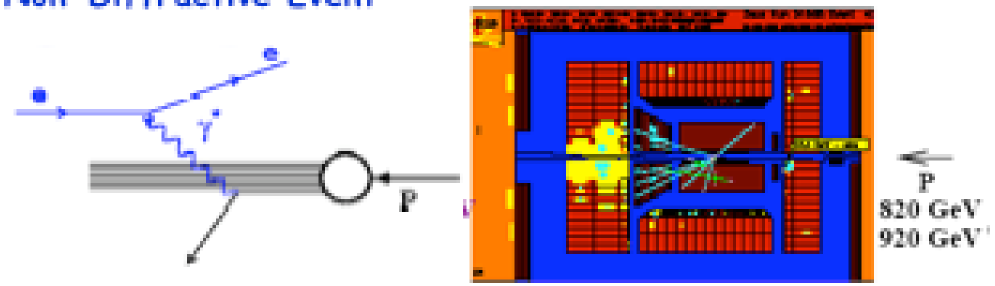
Diffractive measurements at HERA achieved an impressive agreement between the different methods

Surprise of HERA:
Diffractive processes are an important part of short distance physics

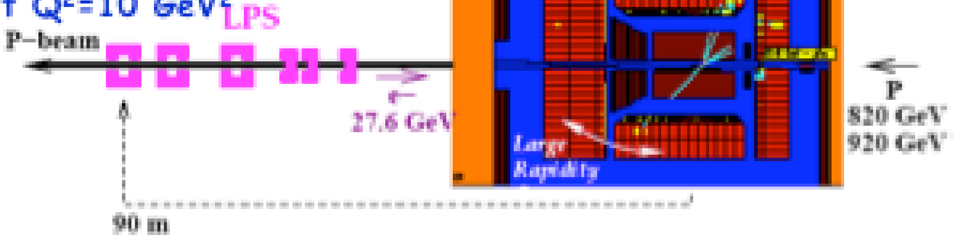
➥ implication on understanding of the QCD evolution
➥ implication on understanding of confinement and nuclear structure

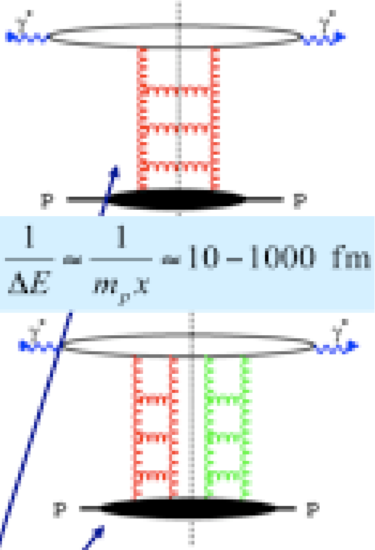
Hard Diffraction - the HERA surprise

Non-Diffractive Event



Diffractive Event
expected before HERA
<0,01%, seen over 10%
at Q^2=10 GeV²





$$\tau_{q\bar{q}} \approx \frac{1}{\Delta E} \approx \frac{1}{m_p x} \approx 10-1000\ \text{fm}$$

Diffraction at HERA is so large because it is a shadow of DIS (i.e. inelastic processes) ➔ dipole picture

$$\sigma_{tot}^{\gamma^* p} = \frac{1}{W^2}\, Im A_{el}(W^2, t = 0)$$