Total and Diffractive Cross Sections in Photon-Proton Collisions at HERA

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Pomeron and Odderon in Theory and Experiment

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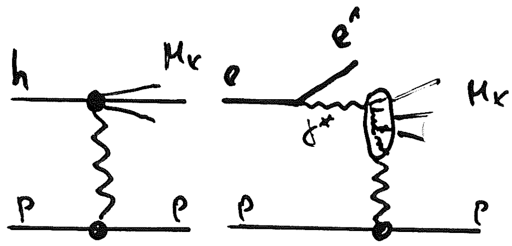
Outline of the talk

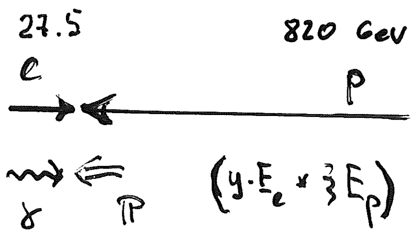
- Introductory remarks
- Real Photon case
- Virtual Photon case
- Summary and Outlook

Motivation

- **Soft DD and Unitarity**
  - $\sigma_{tot} \propto s^{\epsilon}$ $\rightarrow$ Froissart boundary ?
  - $\sigma_{el/diff} \propto s^{2\epsilon}$ $\rightarrow$ $\sigma_D/\sigma_{tot} \propto s^{\epsilon}$ (Pumplin limit?)
  - Do we see this at present energies ?
  - How to restore unitarity ? (RFT, eikonalisation,...)
- **Hard DD** (high Q^2 DIS ?)
  - do wee see 'hard' (pQCD) Pomeron ?
- **Transition regime**
  - how to combine in a common picture soft and hard interactions, **RFT** and **pQCD** ?
- **HERA specifics**



  - $\gamma^*(Q^2)$ provides additional resolving power ($10^{-8} < Q^2 < 10^5$ GeV^2)
  - $x/Q^2 \geq 10^{-5}$ GeV^{-2} $\rightarrow$ low x regime $\rightarrow$ high parton densities

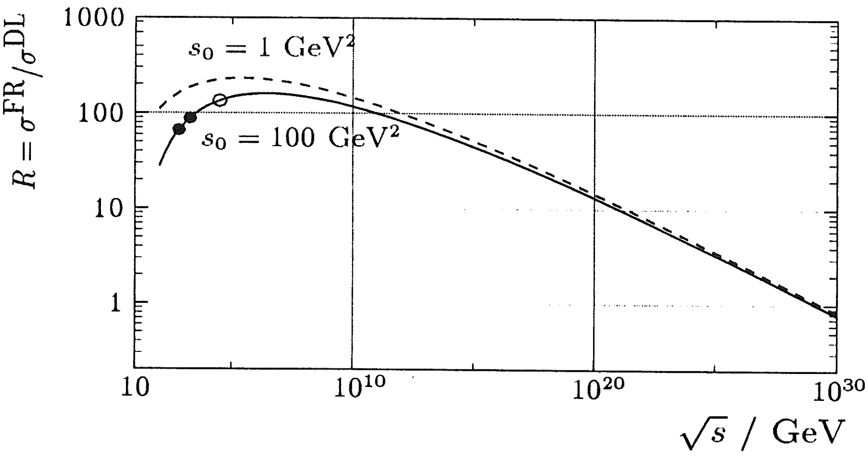


  - large energy range ($40 \leq W_{\gamma p} \leq 300$ GeV)
  - asymmetric beam configuration $\rightarrow$ excellent acceptance for γ^* DD system

$\Rightarrow$ **a unique facility to probe partonic content of diffractive exchange ($I\!P$) and to study the transition from soft to hard regime**

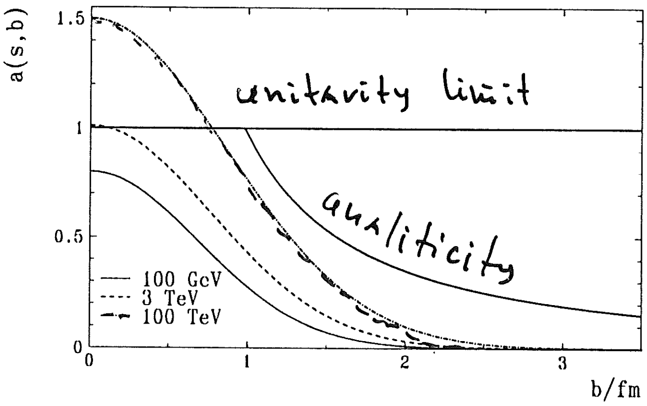
S-channel Unitarity

$$\sigma_{tot} \leq \sigma^{\rm FR} = \frac{\pi}{m_\pi^2} \ln^2\left(\frac{s}{s_0}\right)$$

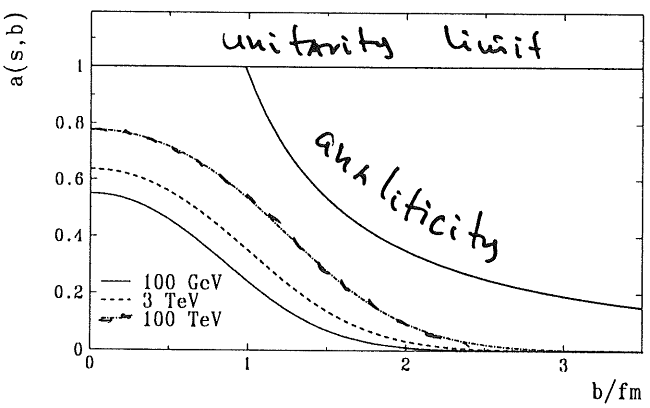


Problematic area – beyond the GUT scale → no practical importance

T-channel Unitarity and Screening Corrections

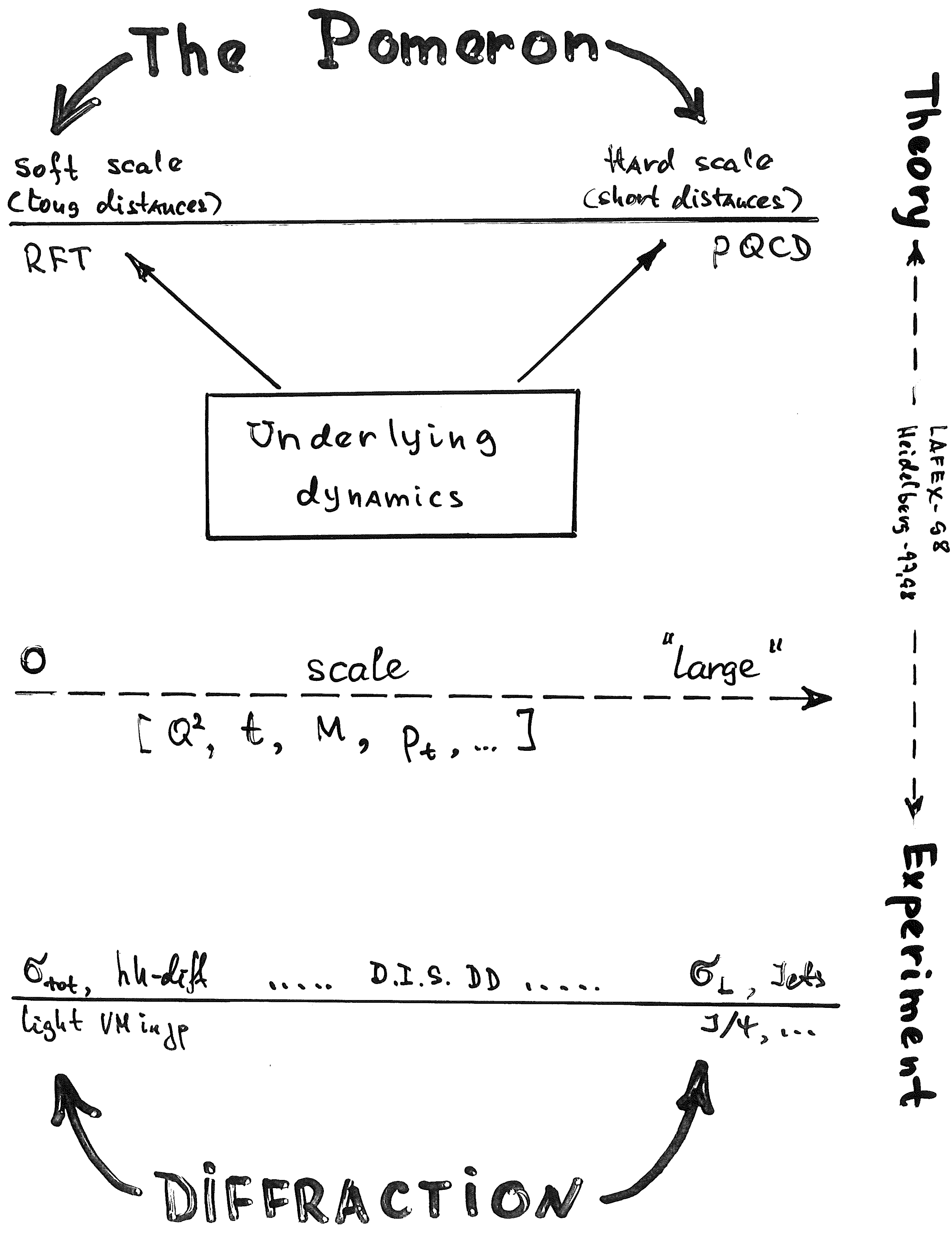


DL Pomeron violates unitarity at small values of impact parameter b already at few TeV !

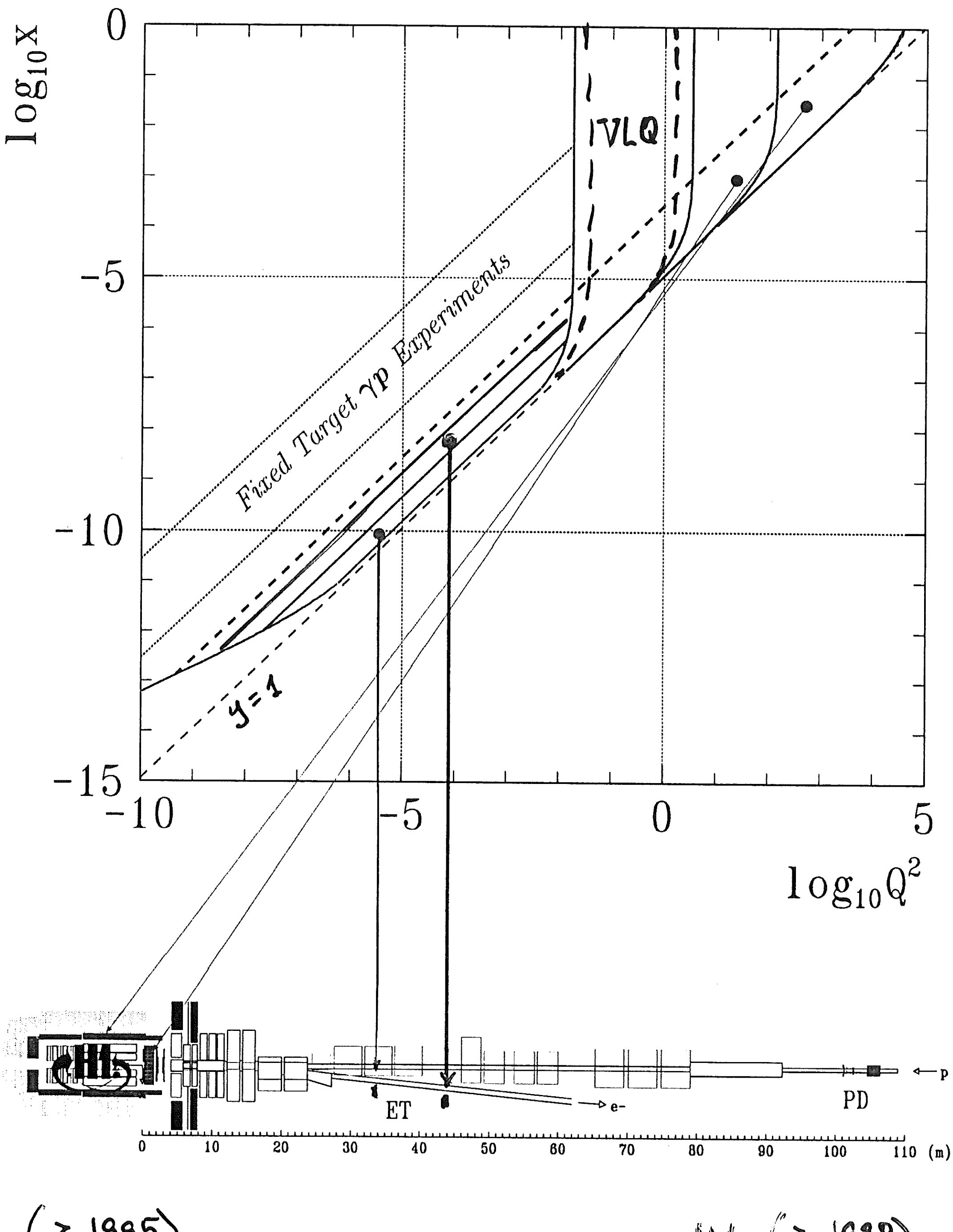


Unitarity can be restored e.g. by eikonalisation of scattering amplitude :

$$a(s,b) = i\left(1 - e^{-\Omega(s,b)}\right)$$

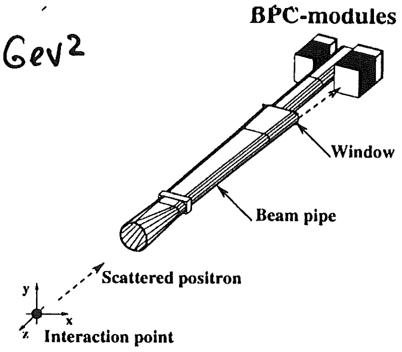

The Pomeron
soft scale
(long distances)
hard scale
(short distances)
RFT
pQCD
Underlying dynamics
Theory
LAFEX-98
Heidelberg-97,98
Experiment
0
scale
"large"
[Q², t, M, p_t, ...]
σ_tot, hh-diff ..... D.I.S. DD ..... σ_L, Jets
light VM in γp
J/ψ, ...
DIFFRACTION

Tagged electrons at HERA



ZEUS (≥ 1995)

$Q^2 \approx 0.15$ GeV^2



H1 (≥ 1998)

VLQ calorimeter

$0.02 \leq Q^2 \leq 1$ GeV^2

Important remarks

- **Direct comparisons of data are often difficult**
  - different treatment of non-diffractive background
  - $M_x/\sqrt{s} \ll 1$; cuts vary in $0.01 \div 0.1$ range

- **Multi-dimensional measurements are important**
  - e.g. at HERA essential variables are: M_X, t, W^2, Q^2
    $\rightarrow$ statistics limitations

- **Limited detection capabilities in rapidity space**
  - model dependencies in data corrections
  - losses of interesting and eventually novel physics

1. HERA Luminosity Upgrage is important! (Y-2000)
2. New improved experiments are desirable! (FELIX ?)

Real Photons: σ_{tot}

$$\frac{d^2\sigma^{ep}(s)}{dy\,dQ^2} = \sigma_{tot}^{\gamma p}(y \cdot s)\cdot(1+\delta_{RC})\cdot F(y, Q^2)$$

← WWA-flux

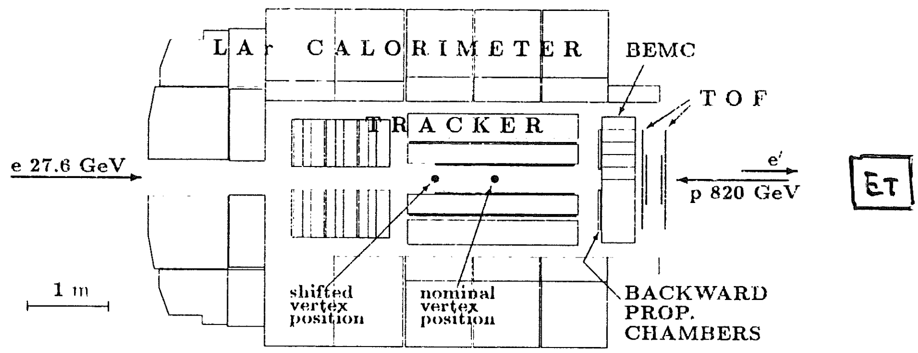
Ensure low $Q^2 \lesssim 10^{-2}\ GeV^2$ by tagging photons with ET of $\mathcal{L}$-system

Then:

$$\frac{dN}{dy\,dQ^2} = \mathcal{L}\cdot\varepsilon(y)\cdot A(y, Q^2)\,\frac{d^2\sigma^{ep}}{dy\,dQ^2}$$

ε: efficiency of the main detector to γp final states

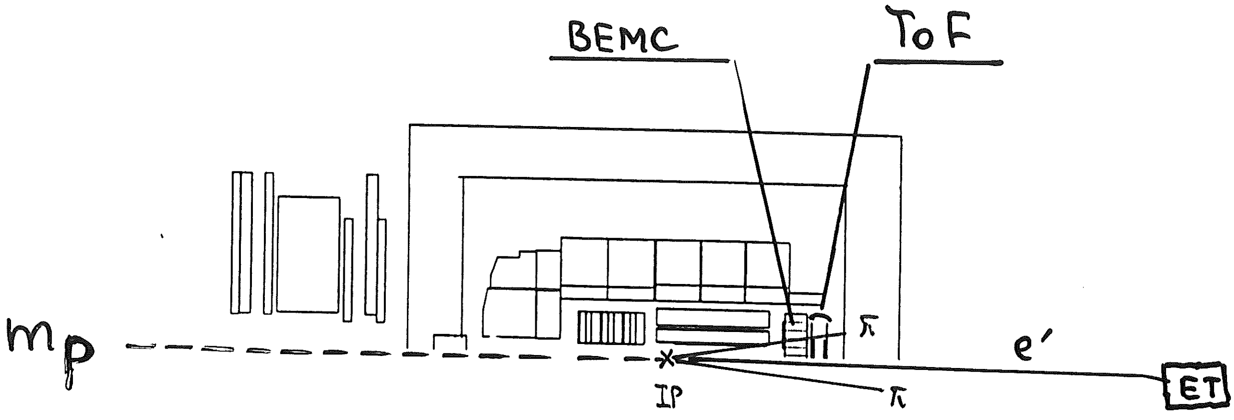
A: acceptance of the Electron Tagger



Experiment	ZEUS	H1
Data sample	1992	1994
$\mathcal{L}$ / nb^{-1}	~13.	25 + 25
Trigger	eTAG * CALO	eTAG * (TRACK / Sc. counter)
Kin. range	$Q^2 < 0.02$; $\bar{W} = 180$	$Q^2 < 0.01$; $\bar{W} = 200$

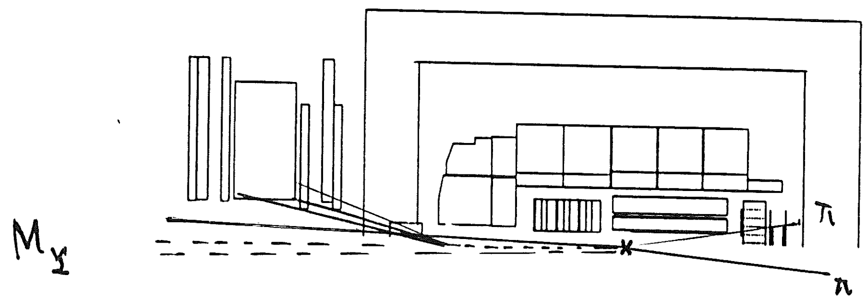
Diffractive event classes:

EL:



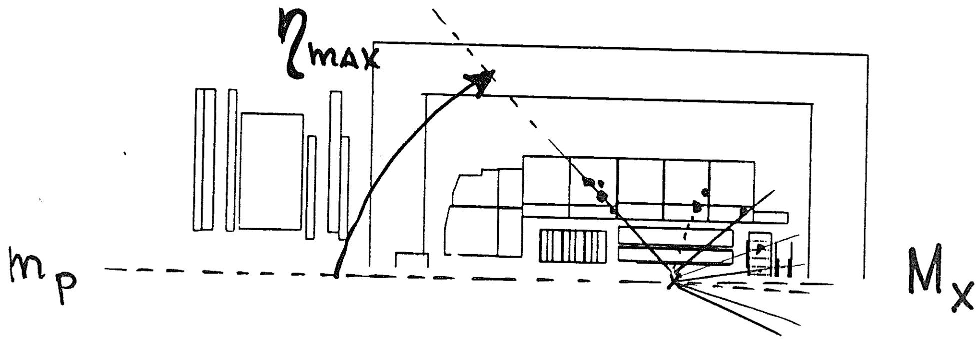
BETTER SEEN FROM IP = +70 cm

PD:

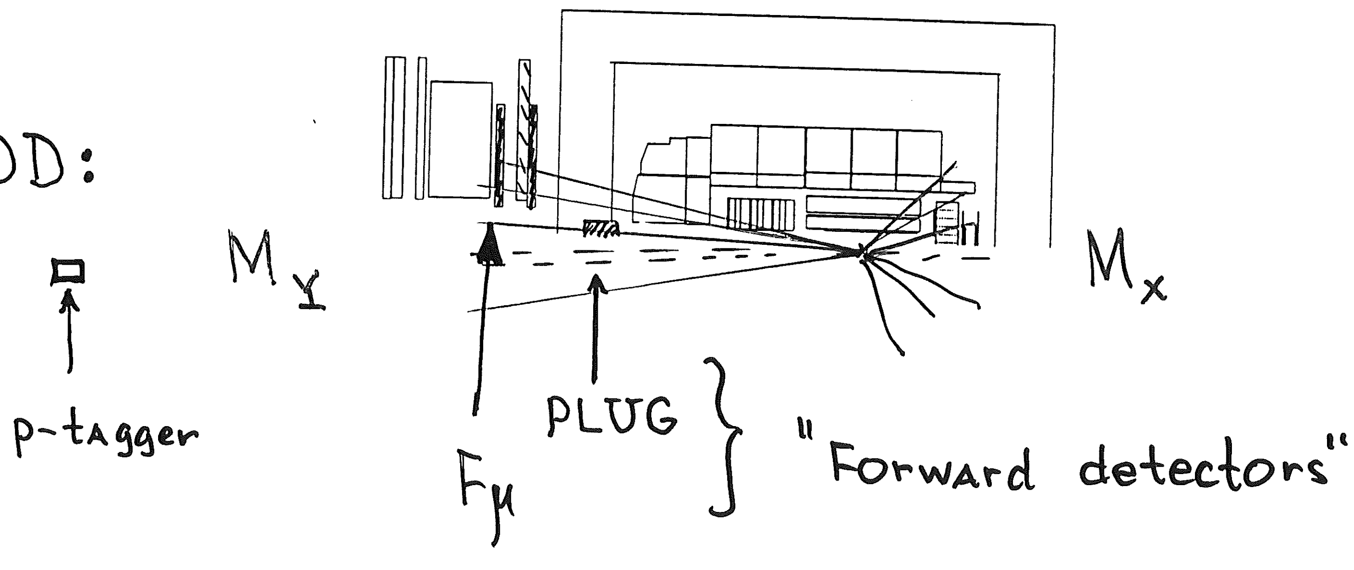


BETTER SEEN FROM NOMINAL IP = 0 cm

GD:



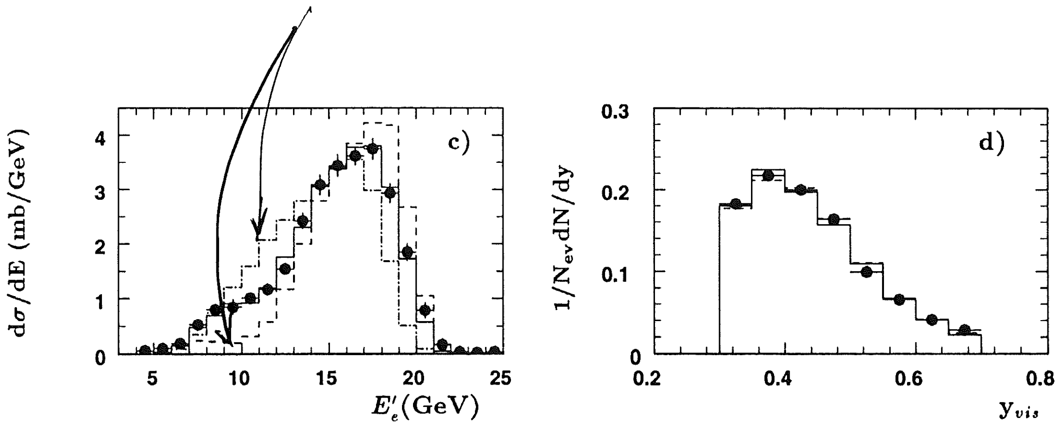
DD:



Real Photons: σ_{tot}

- Electron Tagger acceptance: very sensitive to the beam conditions (optics)

- Changes in the $A_{E_T}(y)$ originating from the ± 1 mm horizontal offset of the beam trajectory in IP



- **Solution:** controlled using real data ($ep \to ep\gamma$ events)

Important practical consequence:

Use preferentially short dedicated runs with stable beam conditions!

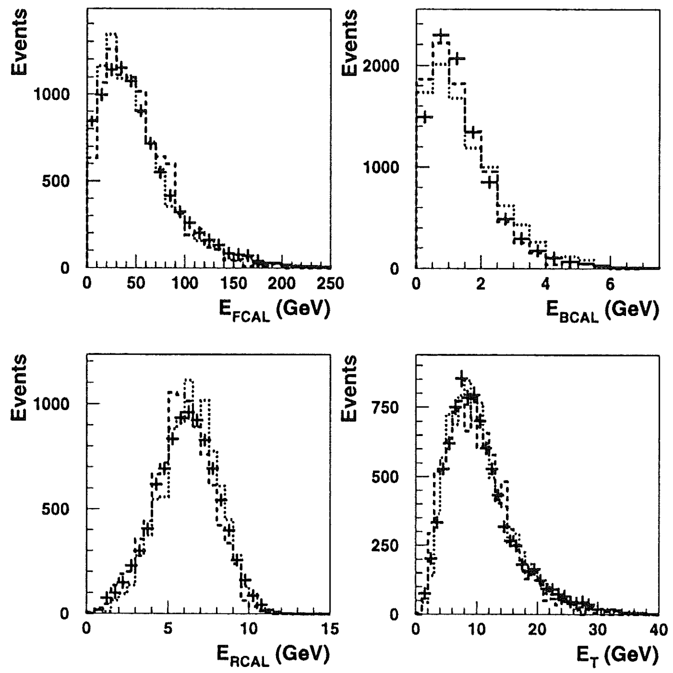
↳ **New round:**

ZEUS: 1995 (~1 week) → results expected soon

H1: 1997 (~2 weeks) → analysis started...

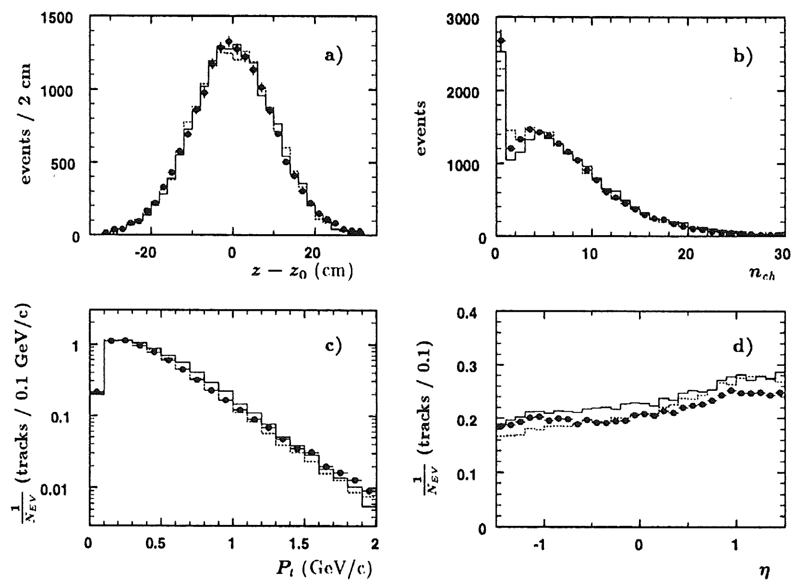
Real Photons: σ_{tot}

- **Main detector responce :**



Energy distributions in various parts of **ZEUS** calorimeter compared to min. bias γp MC simulation using PYTHIA and HERWIG models

Description of the **H1** tracking system responce by the PYTHIA and PHOJET MC models

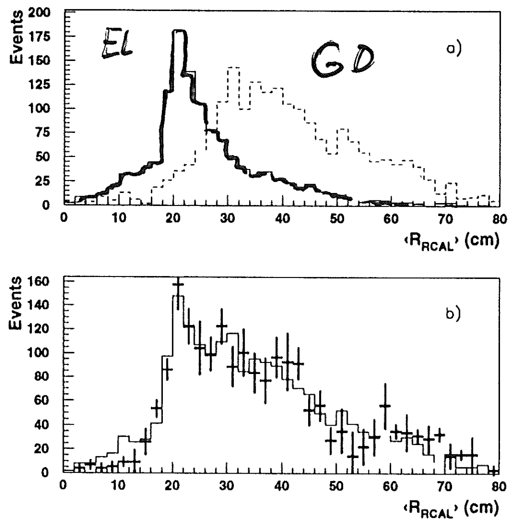


Real Photons: σ_{tot}

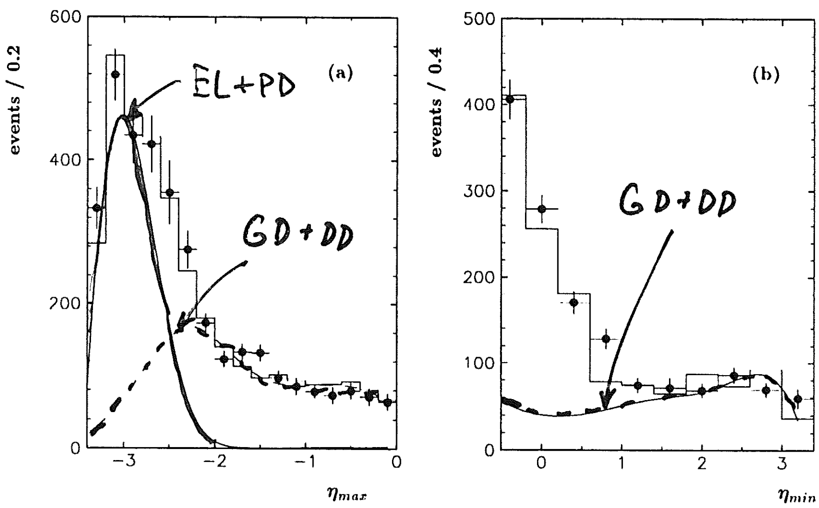
- Most sensitive distributions are used to fix the event class composition into $\sigma^{\gamma p}_{tot}$:

(EL): $\gamma p \to V p$ (GD): $\gamma p \to X p$ (PD): $\gamma p \to V Y$

(DD): $\gamma p \to X Y$ (ND): $\gamma p \to X$ (the rest)



ZEUS energy weighted Radius of the cluster in REAR calorimeter



H1 shifted IP sample

- All component can be fixed except DD (very similar to ND)

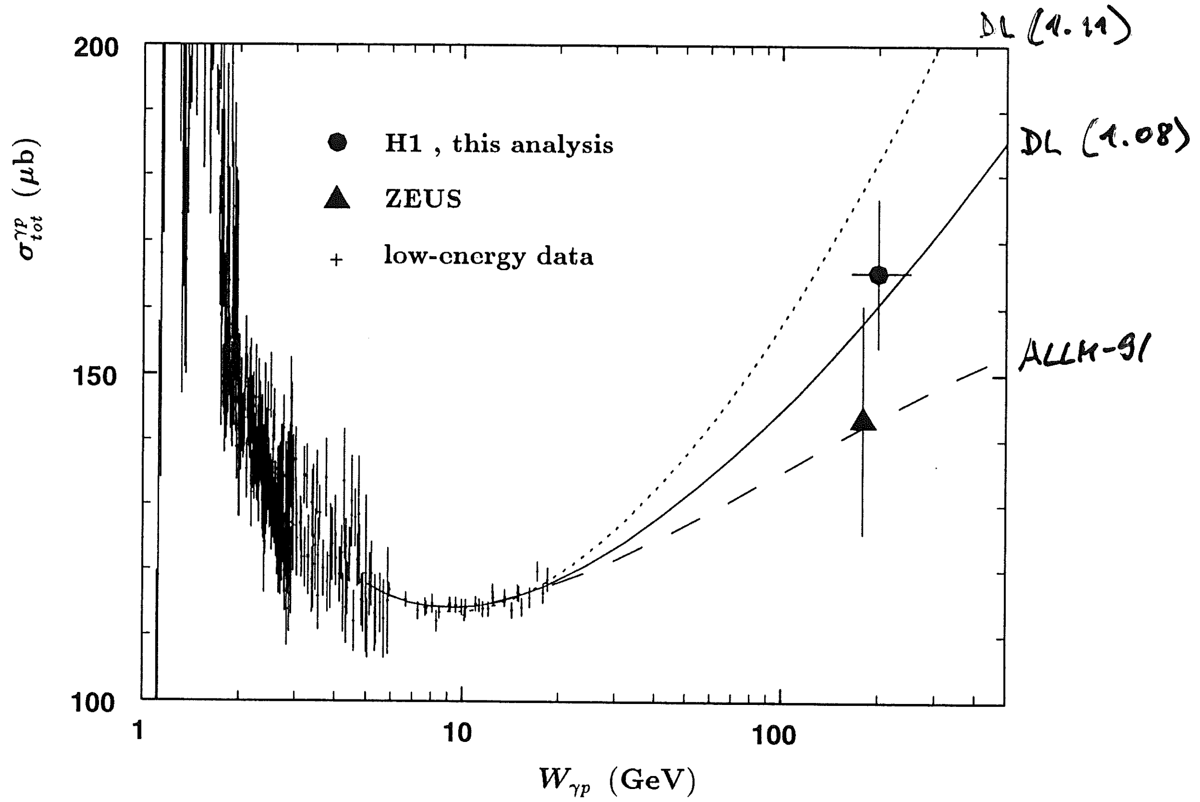
Efficiency table (%)

Event category	ZEUS	H1
EL	31 ± 4	53±3
GD	80 ± 5	75±2
PD	37 ± 4	69±2
DD+ND	88 ± 8	70±3

Real Photons: σ_{tot}

$\sigma_{tot}^{\gamma p}$ (ZEUS) = 143 ± 4 (stat) ± 17 (syst) μb

$\sigma_{tot}^{\gamma p}$ (H1) = 165.3 ± 2.3 (stat) ± 10.9 (syst) μb

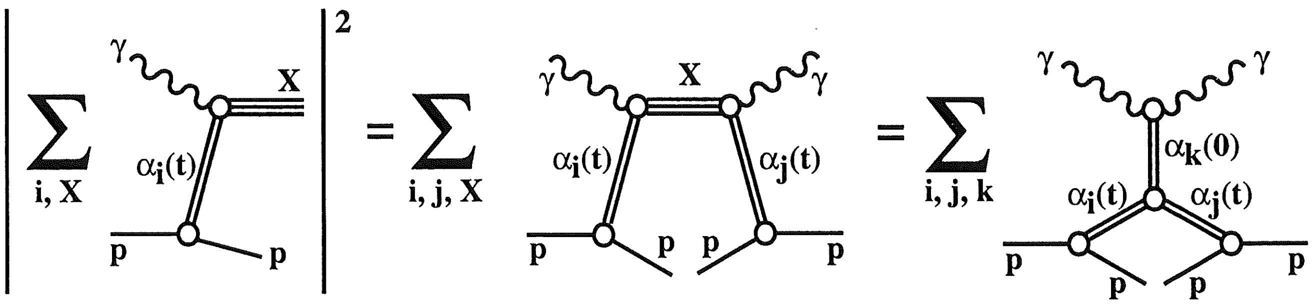


Main uncertainties (%)	ZEUS	H1	Aim
Tagging acceptance	9	5	3
Main det. eff. (MC models)	7	3	2
Luminosity error	4.3	1.6	1
Stat. error (bgr. subtr.)	2.5	1.2	—
Total error	~ 12%	~ 7%	< 4%

$$\gamma p \rightarrow M_x p$$

Analysis of the diffractive mass spectra in triple Regge approach by H1 and ZEUS collaborations:

$$\frac{d^2\sigma}{dt dM_X^2} = \left(\frac{1}{W^2}\right)^2 \sum_{ijk} G_{ijk}(t) \left(\frac{W^2}{M_X^2}\right)^{\alpha_i(t)+\alpha_j(t)} M_X^{2\alpha_k(0)}$$

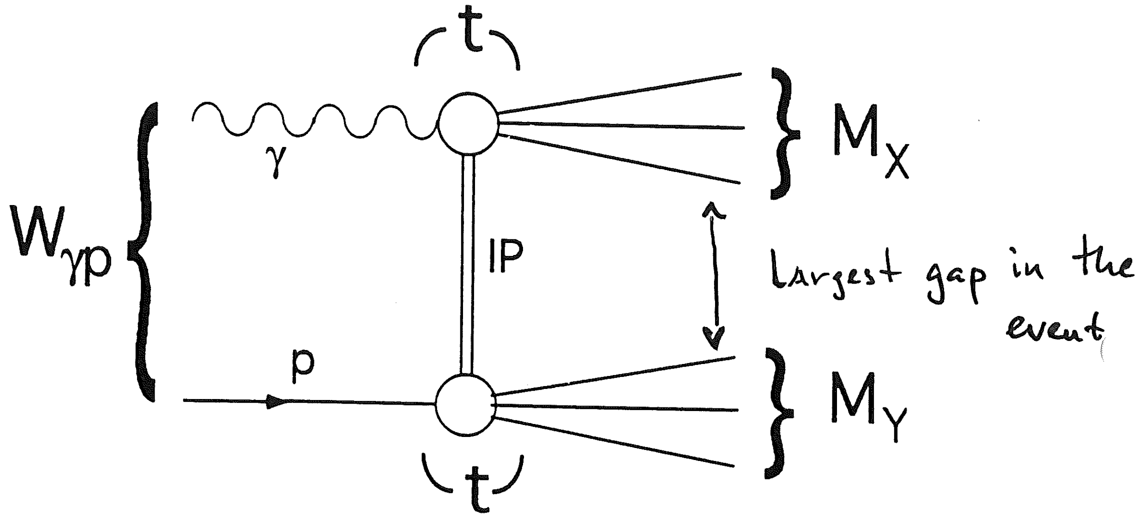


- This is an additional measurement compared to $\sigma_{tot}^{\gamma p}$ analyses (mass of the dissociative system is measured)

Q1: Do we see the same $\alpha_P(0)$ here, as in $\sigma_{tot}^{\gamma p}(W)$ behaviour?

Q2: Can we see a bigger absorbtive (screening) corrections as compared to σ_{tot} case (like in $p\bar{p}$ at Tevatron)?

DEFINITION OF TERMS



THE GENERIC DIAGRAM ABOVE DESCRIBES
ALL PROCESSES CONSIDERED

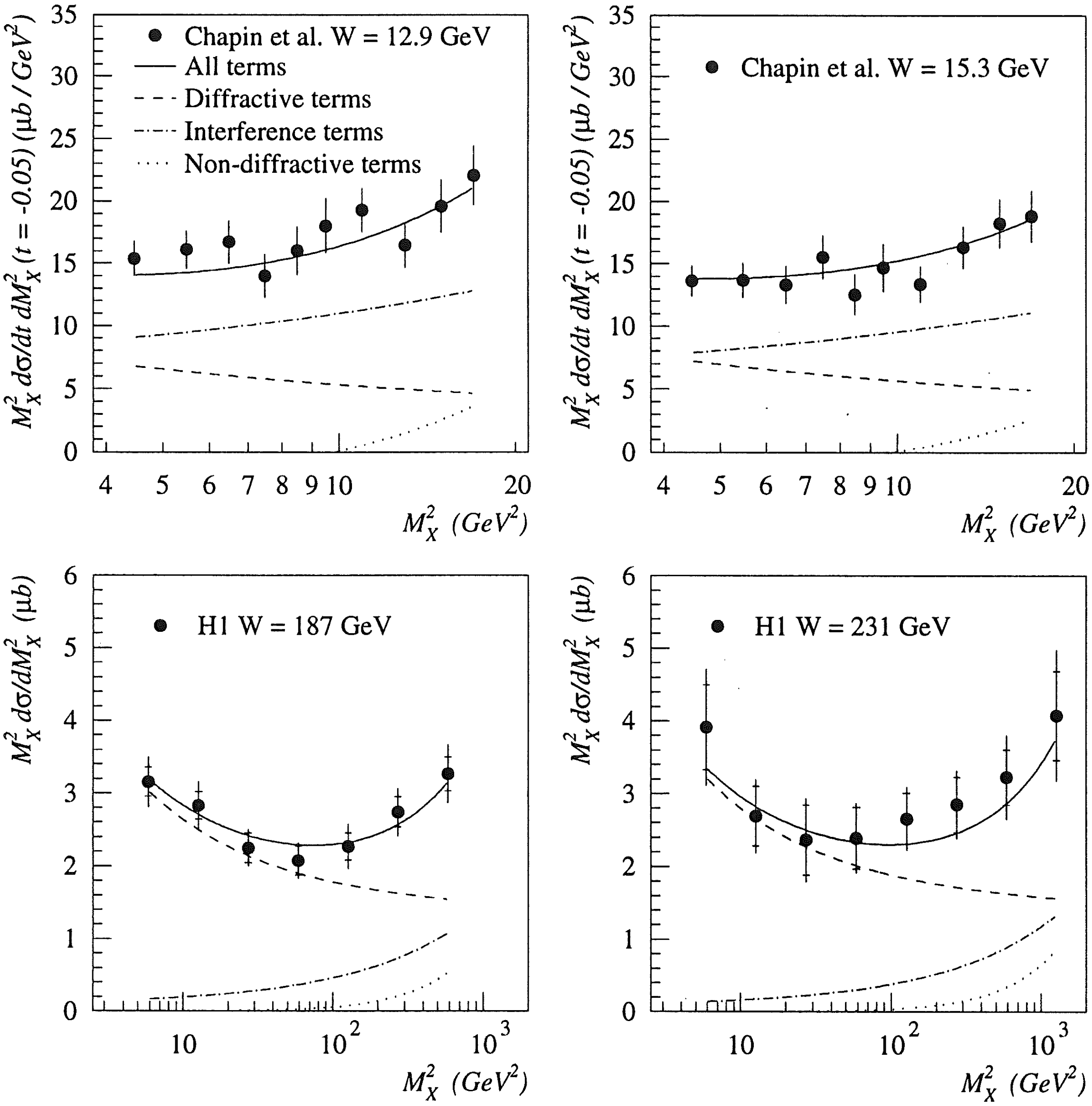
EL - QUASI ELASTIC VM PRODUCTION
$M_X = m_\rho \;/\; m_\omega \;/\; m_\phi \quad M_Y = m_p$

GD - SINGLE PHOTON DISSOCIATION
M_X continuum $M_Y = m_p$

PD - SINGLE PROTON DISSOCIATION
$M_X = m_\rho \;/\; m_\omega \;/\; m_\phi \quad M_Y$ continuum

DD - DOUBLE DISSOCIATION
$M_X \;\; M_Y$ continua

$$\boxed{\gamma p \to M_x p}$$



$$\alpha_{I\!P}(0) = 1.068 \pm 0.016 \pm 0.022 \pm 0.041 \text{ (H1)}$$
$$\alpha_{I\!P}(0) = 1.12 \pm 0.04 \pm 0.08 \text{ (ZEUS)}$$

Subleading trajectory is needed in the fit

No evidence for enhanced screening w.r.t. $\sigma_{tot}(\gamma p)$

(although $\sigma_D/\sigma_{tot} \simeq 40\%$ in photoproduction at HERA)

→ close to Pumplin limit (?)

$\gamma p \rightarrow M_x p$

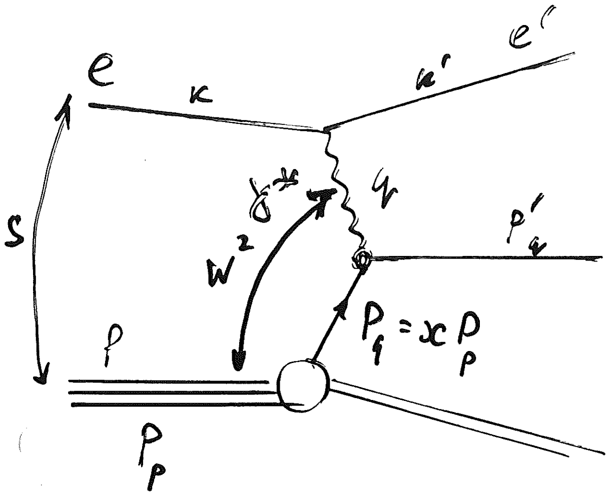
Value	ZEUS	H1
$\langle W_{\gamma p} \rangle$	200	187 ; 231
M_x / GeV	$3 \div 24$	$0.4 \div 30$
Analysis method	TR (DD)	TR(DD+ND+ Interf.)
$\alpha_{R}(0)$	1.12 ± 0.09	1.07 ± 0.05
σ_{GD}/σ_{tot}	$(13.3 \pm 3.6)\%$ $\langle 200 \rangle$	$(22.2 \pm 3.1)\%$ $\langle 187 \rangle$

Both: σ_{SD} > PPP prediction

ZEUS: 26 % contribution from PPR

H1: both subleading trajectories <u>and</u> interference term (DD vs ND) are necessary to describe the data

Virtual Photon: $\sigma^{tot}_{\gamma^* p}$



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

$$x = \frac{Q^2}{(2pq)}$$

$$y = \frac{p \cdot q}{(p \cdot k)}$$

$$W^2 = (p+q)^2 \approx \frac{Q^2}{x}$$

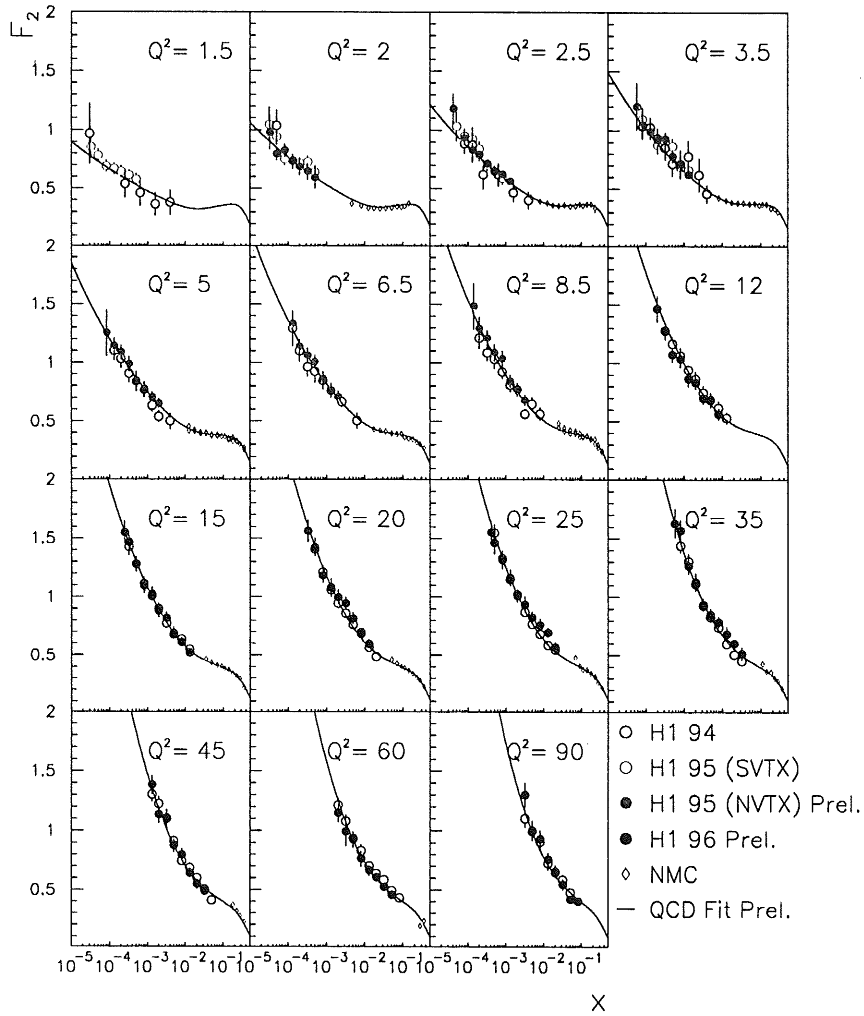
$$\sigma^{\gamma^* p}_{tot} = \sigma^{\gamma^* p}_{T} + \sigma^{\gamma^* p}_{L} \simeq \frac{4\pi^2 \alpha}{Q^2} F_2(x, Q^2)$$

$F_2(x, Q^2)$ or equivalently $\sigma^{\gamma^* p}_{tot}(W^2, Q^2)$

is well described by pQCD down to $Q^2 \approx 1.5\ GeV^2$

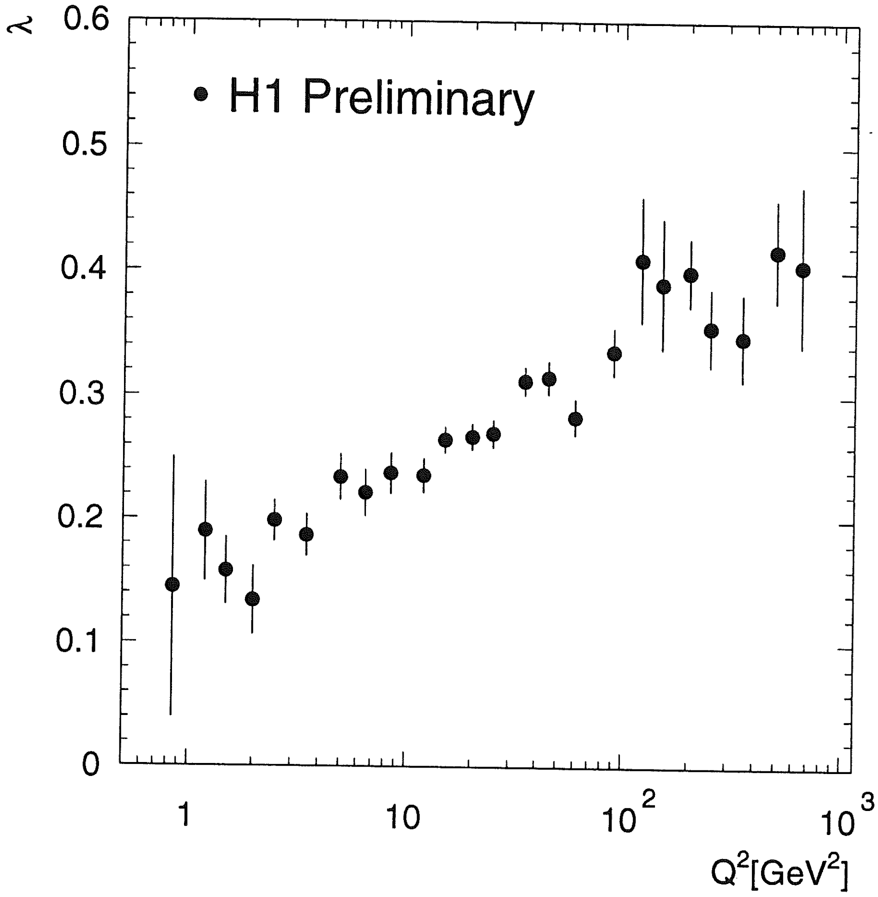
Then theoretical prediction starts to deviate from the data trend.

Virtual Photon: $\sigma^{tot}_{\gamma^* p}$



Very good description by pQCD

Virtual Photon: $\sigma^{tot}_{\gamma^* p}$



For fixed Q^2 $\qquad W^2 \sim \frac{1}{x} \Rightarrow \sigma_{tot}^{\gamma^* p} \sim W^{2\lambda}$

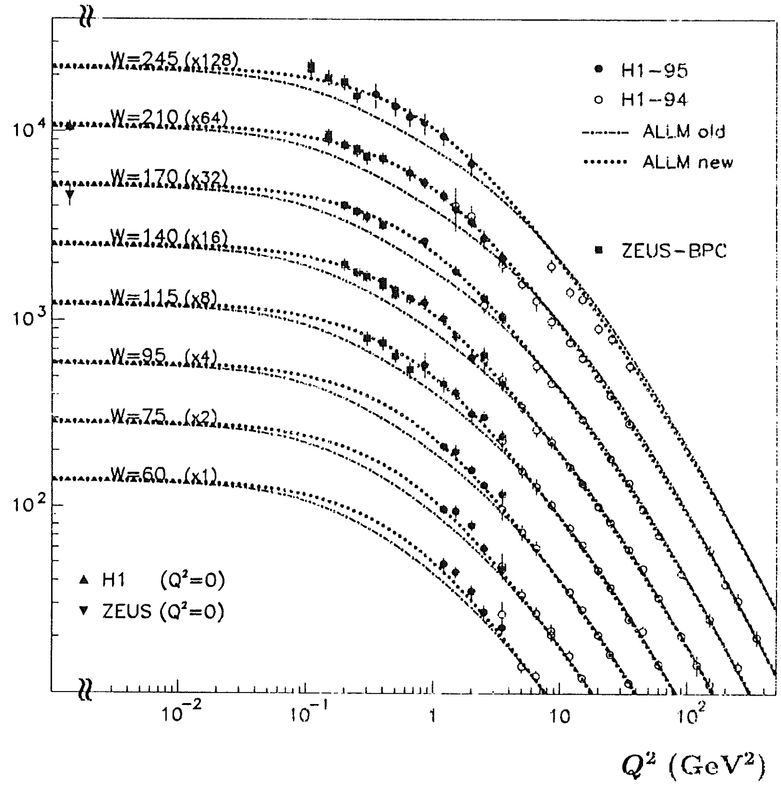
$\lambda_{eff} = \frac{\partial \ln F_2}{\partial \ln (\frac{1}{x})}$: fit the data and plot

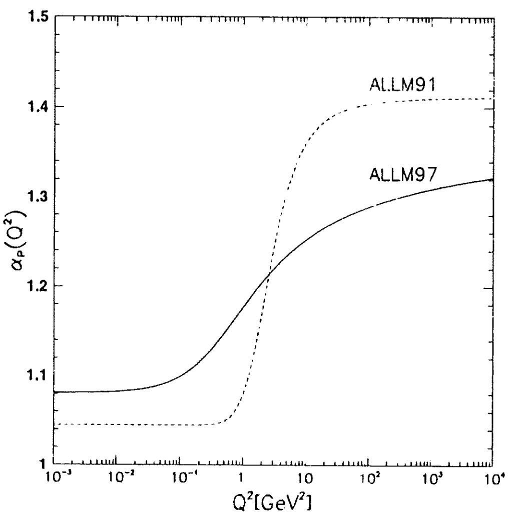
$\boxed{\lambda_{eff}\ (Q^2)}$

Transition regime – $\sigma^{tot}_{\gamma^* p}$

(H.Abramowitz and A.Levy, hep-ph/9712415)

[another more recent, but similar empirical approach interpolating between soft Regge and hard pQCD regimes : P. Desgrolard et al, hep-ph/9803286]



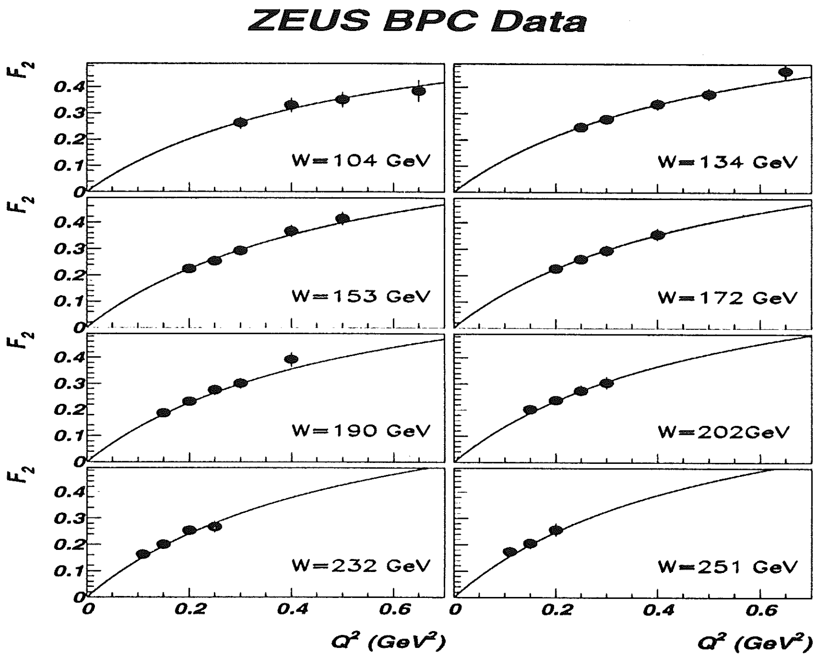


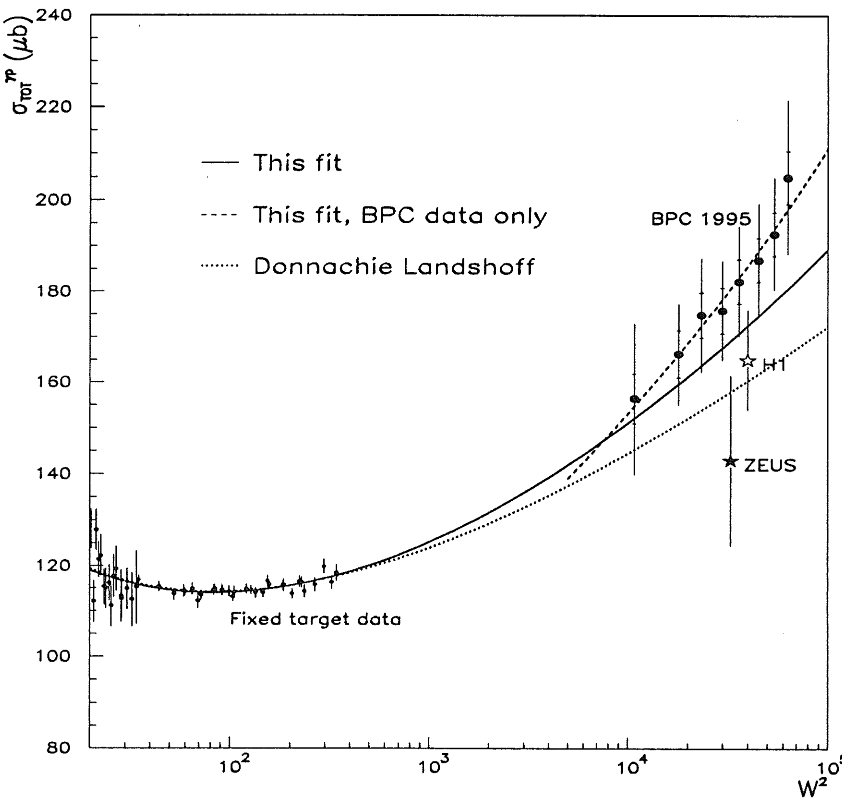
- Good description of data, but 23 (8) parameters !
- Transition is smooth, but what is the dynamics behind that ?
- $\alpha_P(Q^2)$ dependence is very similar to CKMT model picture

$$\alpha_P^{eff}(Q^2) = \alpha_{IP}^{bare} \cdot f\left(\frac{s}{Q^2}\right) = \alpha_P^0\left(1 + \frac{2Q_0^2}{d+Q_0^2}\right)$$

⟹ Screening corrections at work ??

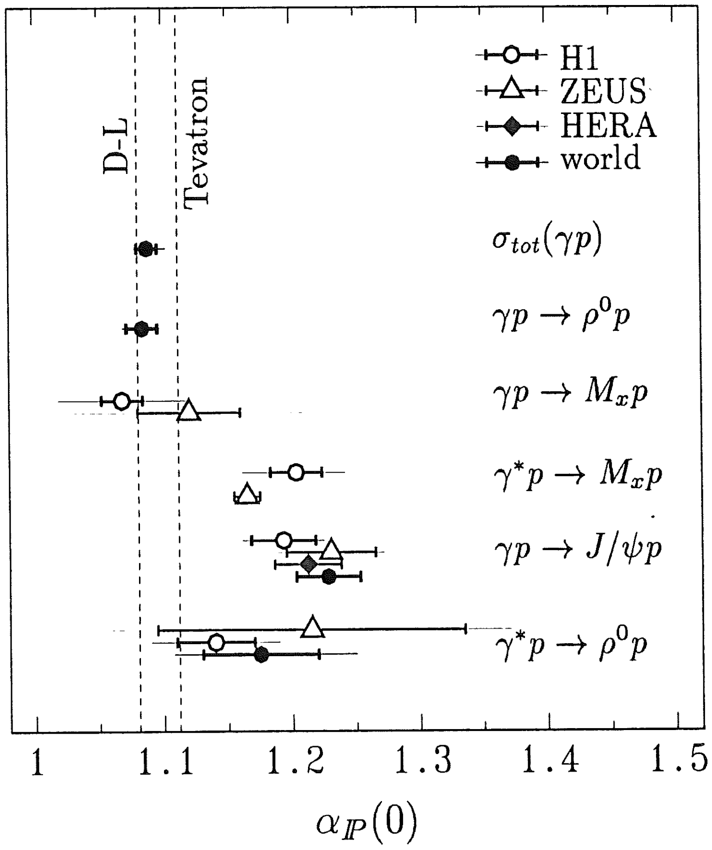
Transition regime





SUMMARY

Pomeron Intercept Measurements at HERA



The data clearly show the departure

from **'soft' Pomeron**

towards larger values of $\boldsymbol{\alpha_{I\!P}(0)}$

whenever a *hard scale* is present

SUMMARY

- Total photoproduction cross section at HERA as well as inclusive γp diffractive dissociation properties are in a perfect agreement with Regge model and universal DL Pomeron

- The behavior of virtual photon-proton cross sections (or F_2^p) is very well described by perturbative QCD based on DGLAP dynamics (at $Q^2 > 1\,GeV^2$)

- The transition region between these two extremes can be quite precisely described by several empirical fits ~~with~~ using significant number of free parameters ($8 \div 23$).

- The major task: to reveal underlying dynamics (non-perturbative QCD) still with us:

join the effort!