# Diffraction and Vector Meson Production

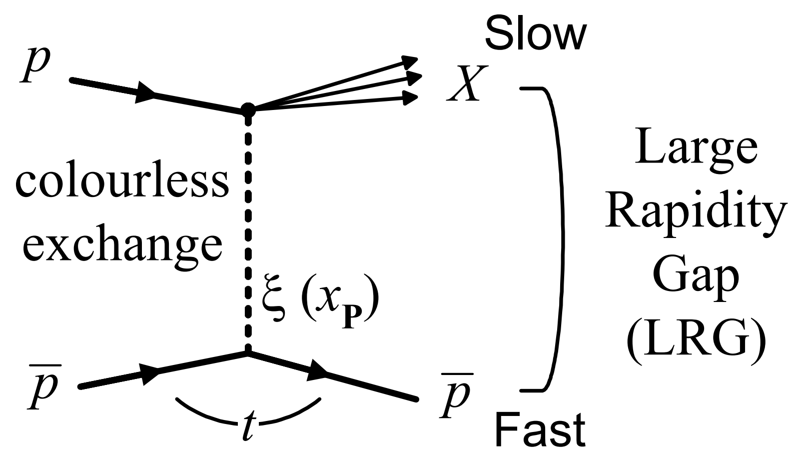
Yuji Yamazaki
KEK-IPNS / ZEUS collaboration

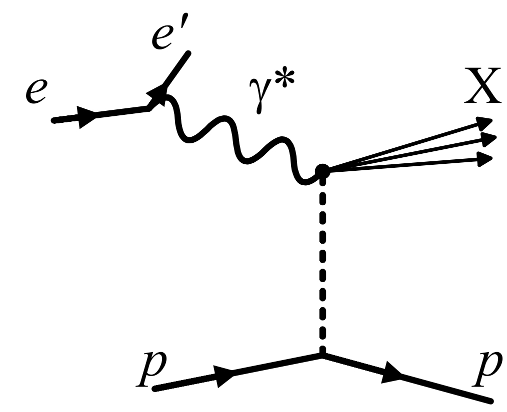
15 Aug 2003

The XXI International Symposium on
Lepton and Photon Interactions at High Energies

# Diffractive processes

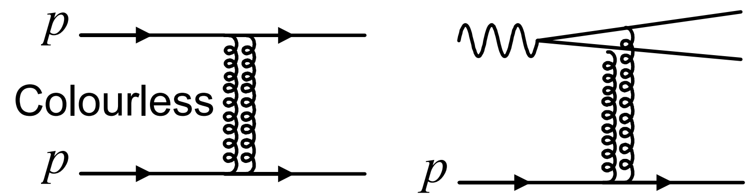
- $t$-channel exchange of the vacuum quantum numbers
  - Colourless exchange
  - Small momentum transfer
    - $t <<< s$
    - Longitudinal momentum fraction $\xi$ (= $x_{\mathrm{P}}$) < 0.05
    - Large Rapidity Gap (LRG)
- Historically described by an exchange Pomeron trajectory in the Regge theory

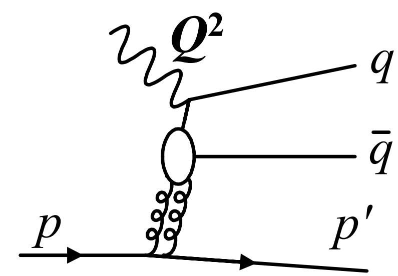


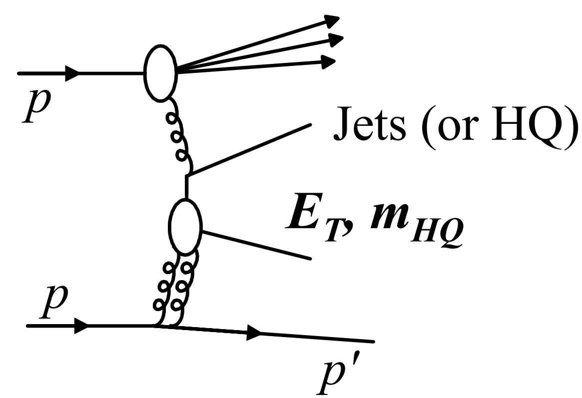



# Aim of studying diffraction

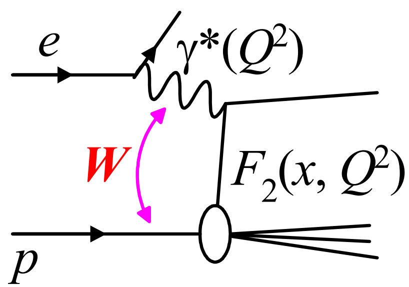
- … is to understand the exchange in terms of pQCD
  - 2-gluon exchange at LO
  - The exchange itself does not have hard scale: typically $t \approx \Lambda^2_{\mathrm{QCD}}$
    Need a scale to see partons
- Probing partonic structure by **hard diffraction** e.g.
  - DIS, jet / HQ production, large $t$

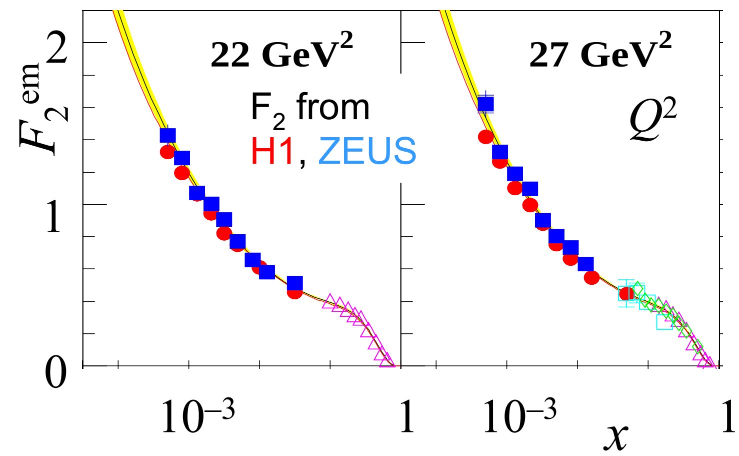


# The basic of hadron physics: $W^2 \propto 1/x_{Bj}$ dependence

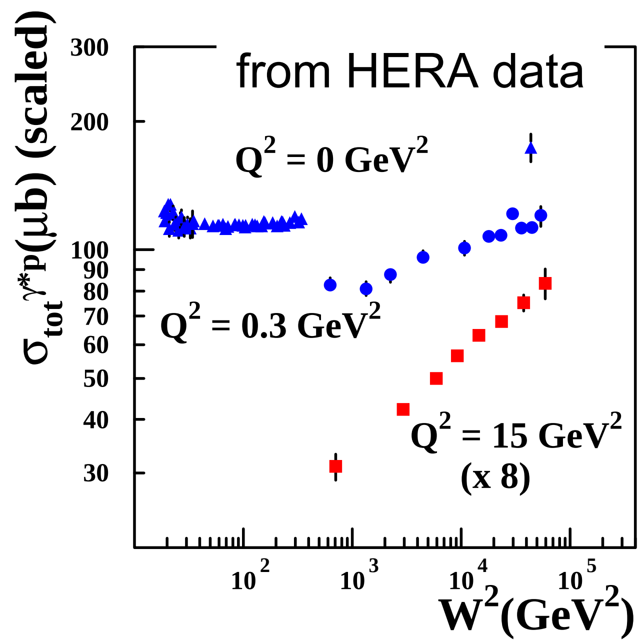



- $F_2$ rises steeply towards low-$x_{Bj}$
  - This means: the cross section steeply rises with $W$, the centre-of-mass energy of $\gamma^{(*)}$p system:

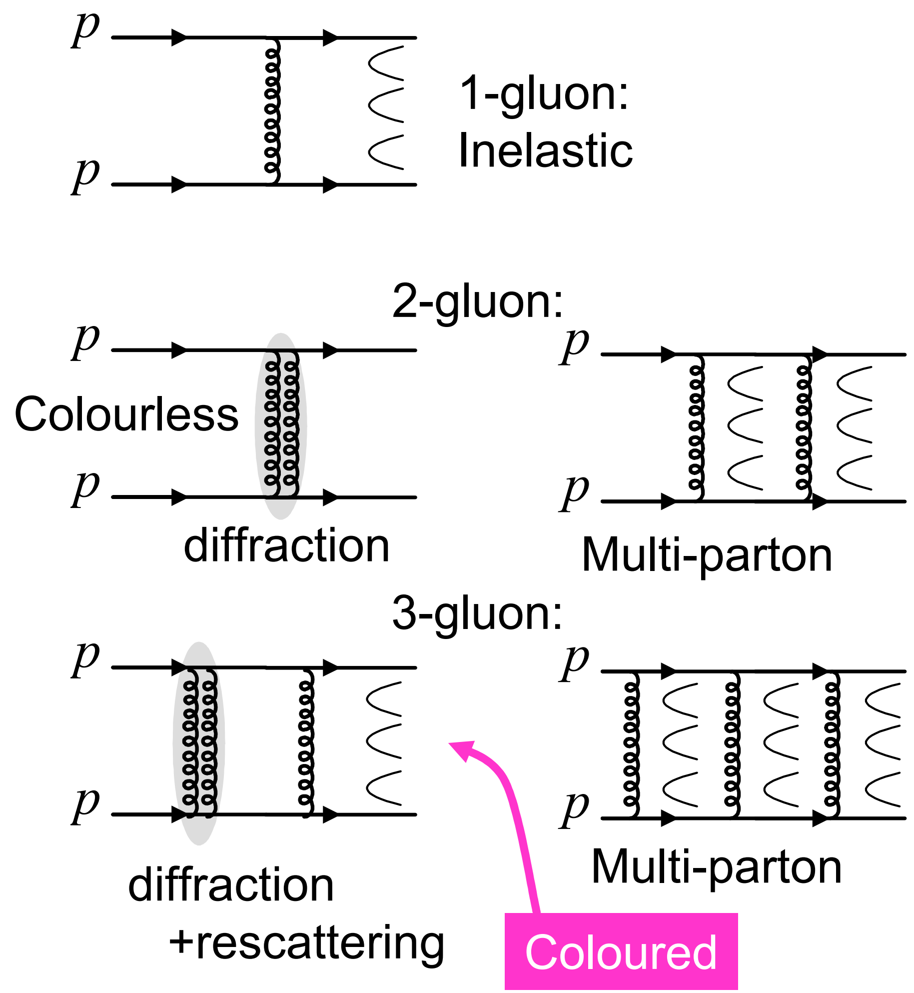
$$W^2 = \left(\frac{1}{x} - 1\right) Q^2 \approx \frac{Q^2}{x} \quad (x << 1)$$

  - Or: rise in $s$ for hadron-hadron
- Fast rise in $W$: partons = pQCD
- Slow rise: soft collisions



# Why diffraction ? a simple view

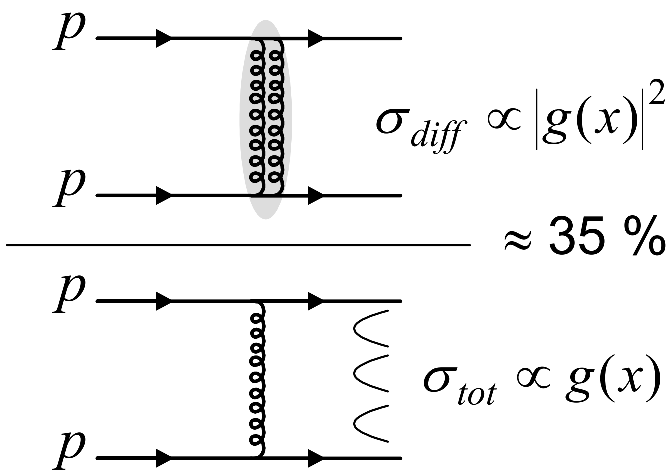
- Plenty of partons at low-$x$
  - 1-parton exchange
    - Hard scattering
  - 2-parton exchange
    - Multi-parton scattering – incoherent
    - Diffraction – coherent
  - 3 or more could occur as well
- These phenomena should be explained uniformly
  - Cannot be ignored at high energy



# Diffraction is a good part of $\sigma_{tot}^{hh}$

- Diffraction expected to be dominant in high-energy hadron-hadron collisions
  - Elastic + diffraction: already ~ 35 %
  - $\sigma_{tot} \propto g(x),\ \sigma_{diff} \propto |g(x)|^2$

    $\therefore \sigma_{diff} / \sigma_{tot} \propto g(x)$, **rising with $s$**
- Important component for understanding the asymptotic behaviour of hadron-hadron scattering at high energies



# Outline of the talk

- Hard diffraction and its partonic structure at HERA
- Vector meson production at HERA
- Diffraction at Tevatron

**The first subject:**
**Hard diffraction and**
**its partonic structure at HERA**

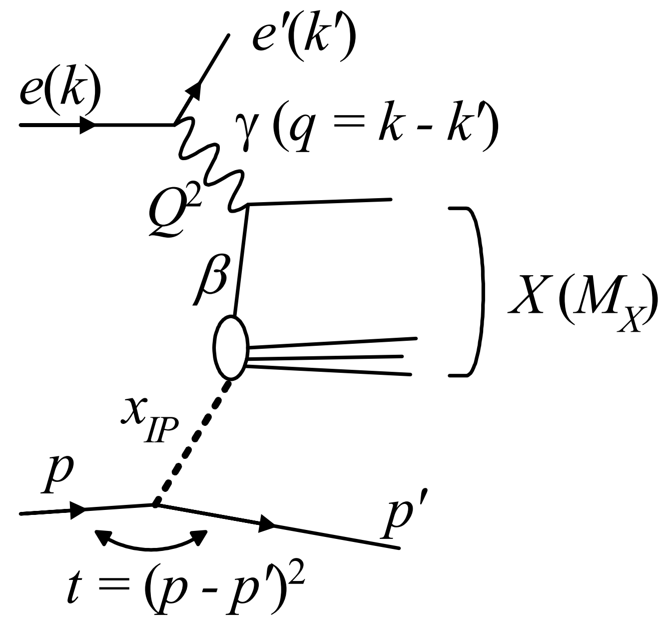
# Diffractive DIS (DDIS)

- $Q^2$ provides a hard scale
  - probing partonic structure
- Main task: $F_2^{D(3)}(\beta, Q^2, x_{\mathbf{P}})$
  - Structure function for diffractive processes

$$\int dt \frac{d^4\sigma_{diff}^{ep}}{d\beta dQ^2 dx_{\mathbf{P}} dt}$$

$$\cong \frac{4\pi\alpha^2}{\beta Q^4}\left(1 - y - \frac{y^2}{2}\right) F_2^{D(3)}(\beta, Q^2, x_{\mathbf{P}})$$

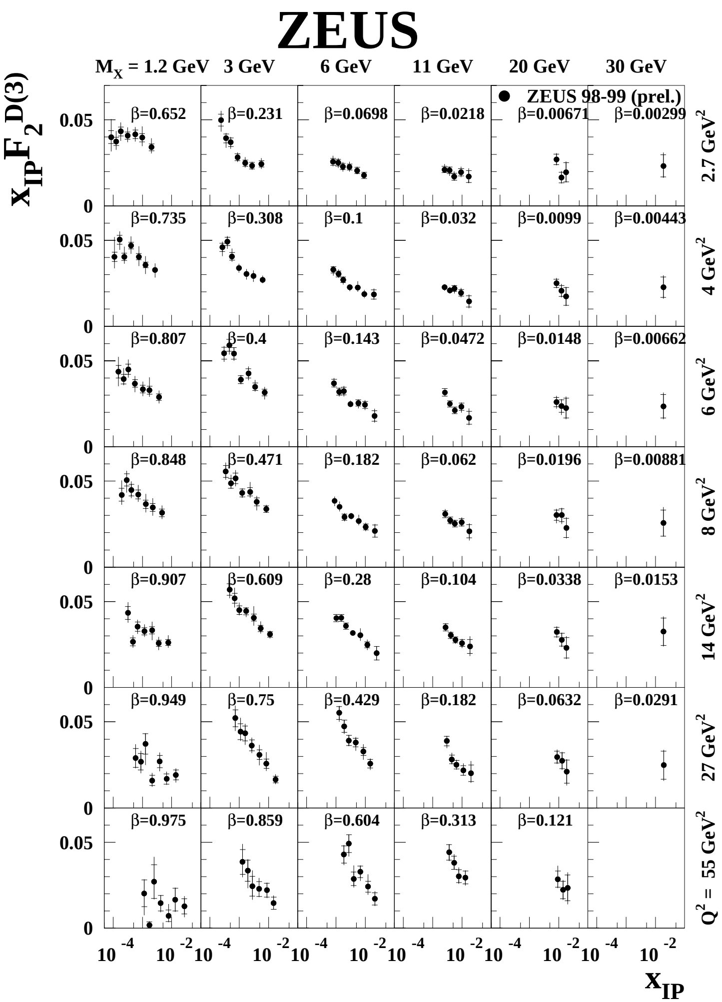
  - Sensitive to quarks
- Gluons are "measured" by
  - Jet and HQ production
  - Scaling violation of DDIS using DGLAP eq.

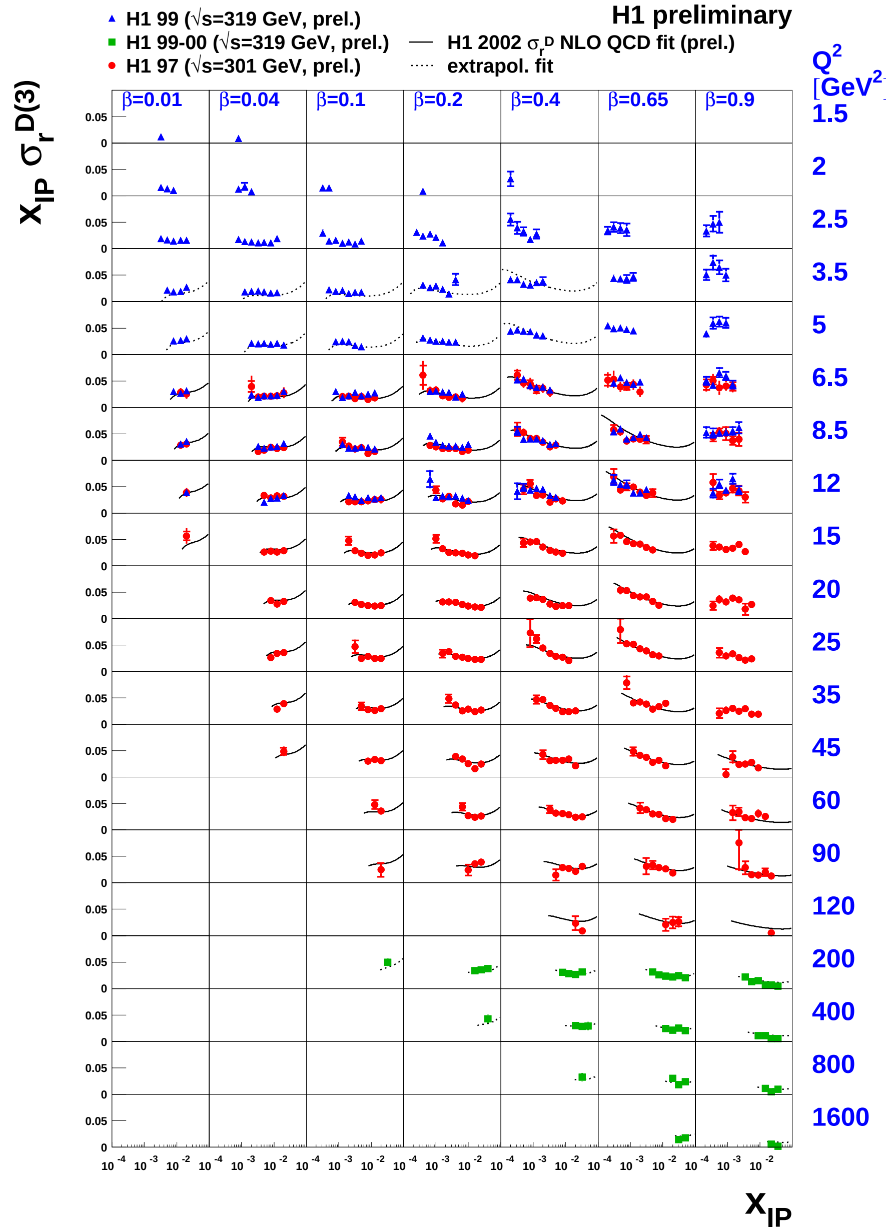



β: long. momentum fraction of the parton in the exchange

$x_{\mathbf{P}}$ : long. momentum fraction of the exchange in the proton

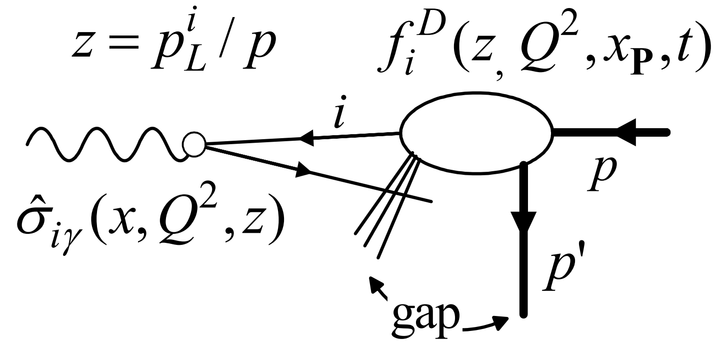
# $F_2^{D(3)}$ from H1, ZEUS




- 3 issues on $F_2^D$ , in this talk

# 1. Factorisation in DDIS




- In normal DIS or hard scattering

$$\sigma = \sum_i f_i(x, \mu^2) \otimes \hat{\sigma}_{i\gamma}(x, \mu^2)$$

  - □ **QCD factorisation**

- The factorisation theorem is also applicable for DDIS:

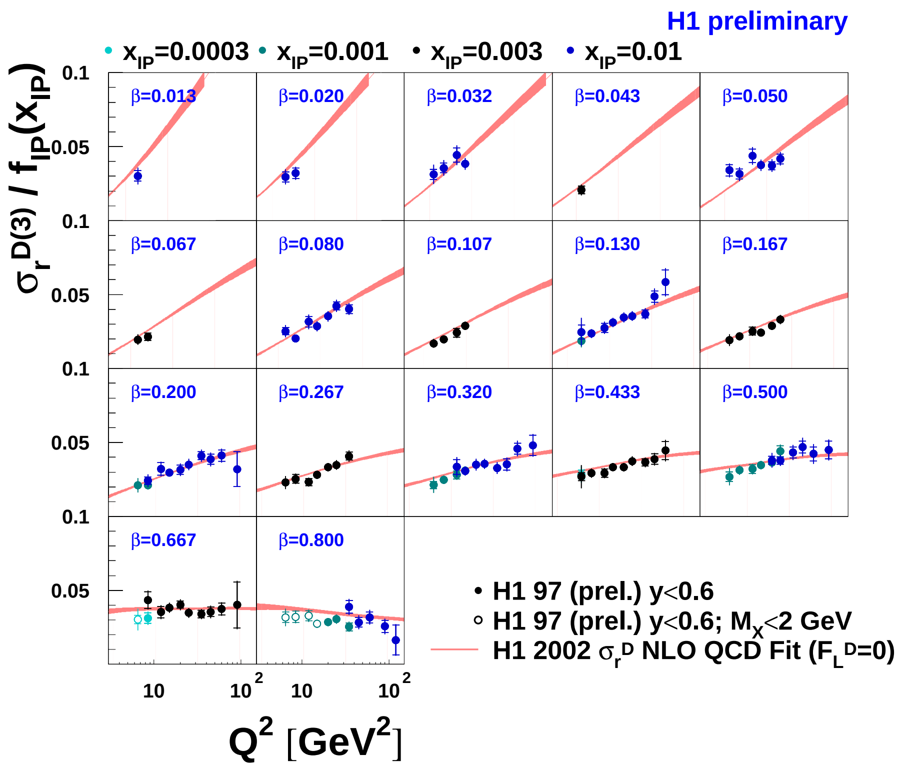
$$\frac{d\sigma(x, Q^2, x_{\mathbf{P}}, t)}{dx_{\mathbf{P}} dt} = \sum_i \int_x^{x_{\mathbf{P}}} [dz \hat{\sigma}^{i\gamma}(z, Q^2, x_{\mathbf{P}}) f_i^D(z, Q^2, x_{\mathbf{P}}, t)]$$

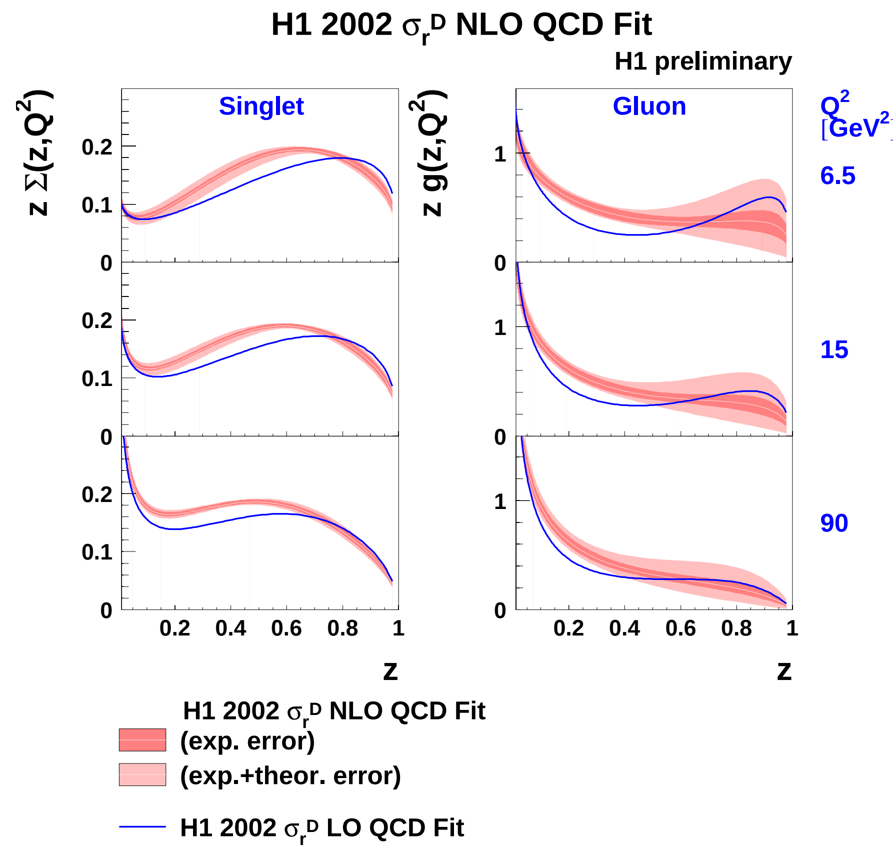
  - □ $f_i^D$ : pdfs with a diffractive exchange at $(x_{\mathbf{P}}, t)$
  - □ Q1: **Is the pdfs universal ?**

- How to test:
  - □ Diffractive pdfs extracted from DGLAP NLO fit of inclusive DIS
  - □ Data of Jet / HQ production cross section (sensitive to gluons!) compared to the calculation using THE pdfs

# Extraction of the diffractive pdfs

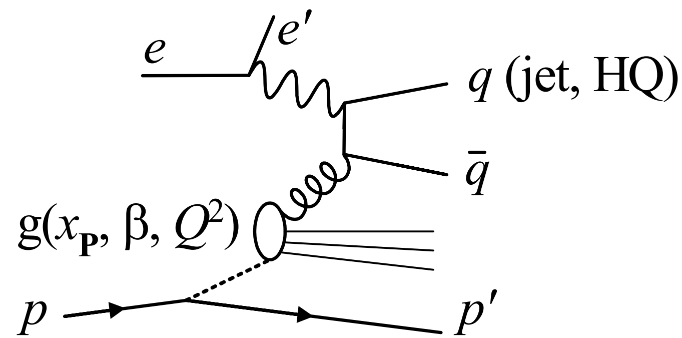
- NLO QCD fit performed to $F_2^{D(3)}$
  - Strong scaling violation up to high-β, origin from a boson (cf. $F_2^{\gamma}$) → the exchange contains more gluons than quarks

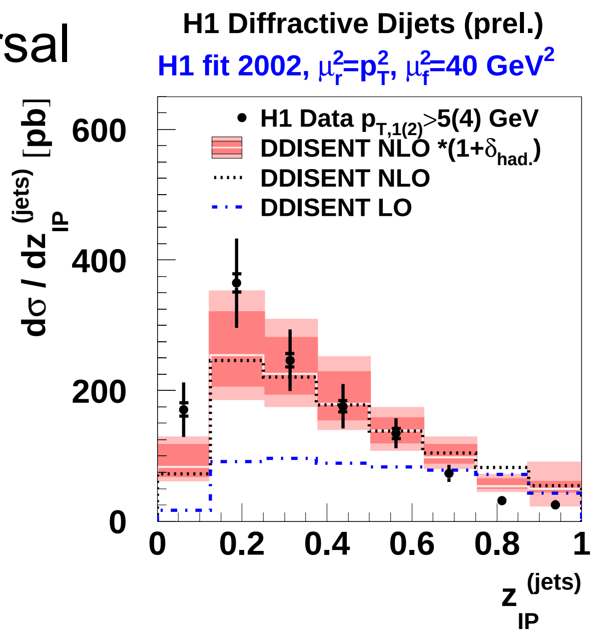


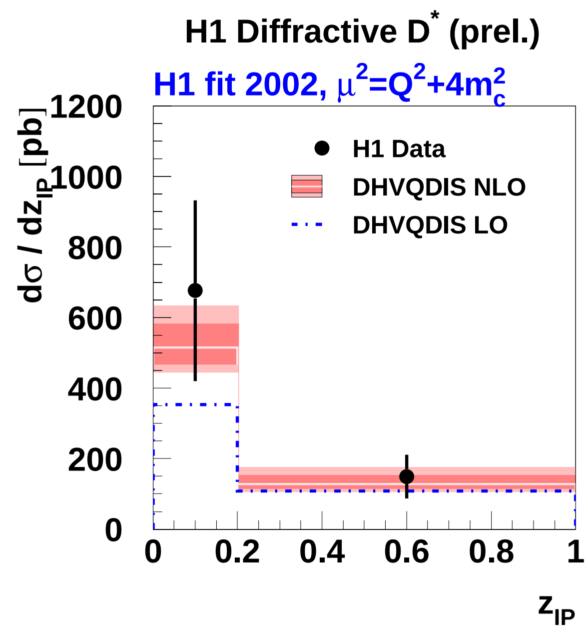



# Comparison with Jets and D* production

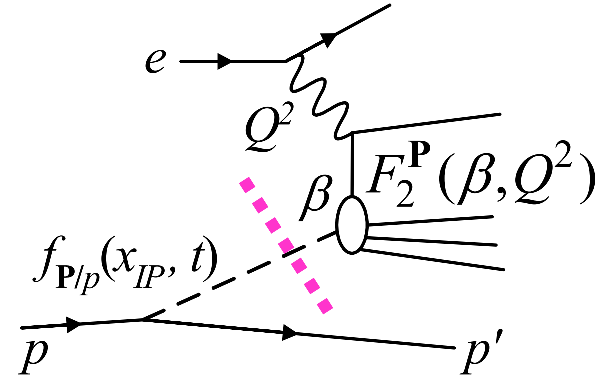
- Jets and D*: sensitive to gluons
- Both jets and D* agrees well with NLO
- **A1. QCD factorisation holds in DDIS**
  - PDFs are universal within DDIS



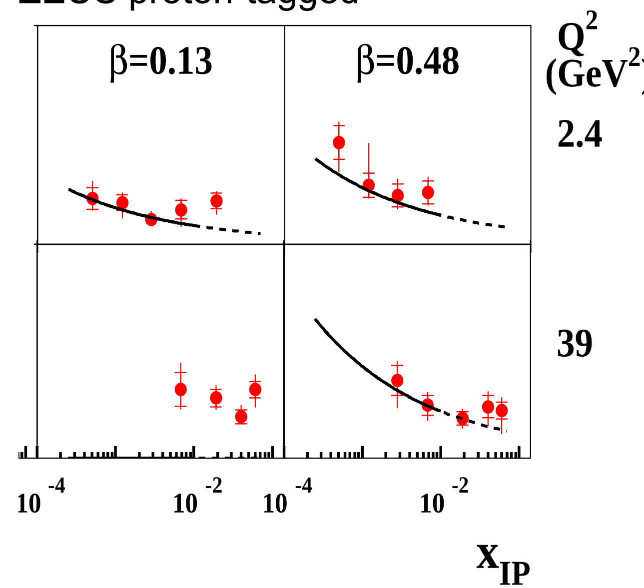



# 2. Test of the resolved Pomeron model




- If the exchange is a pseudo-particle
  - σ = (flux of **P**omeron) ⊗ ($F_2$ of **P**)
    $F_2^D \propto f_{\mathbf{P}/p}(x_{\mathbf{P}},t)\cdot F_2^{\mathbf{P}}(\beta,Q^2)$
  - Q2: **Does the "resolved Pomeron" model describe data ?**

ZEUS proton-tagged




- This means
  - The $x_{\mathbf{P}}$ shape is independent of (β, $Q^2$) values ("Pomeron flux" shape)
- Flux fit: $x_{\mathbf{P}}$ or $W$ dependence

$$F_2^D \propto \frac{1}{x_{\mathbf{P}}^{a/2}}\cdot b(\beta,Q^2)$$

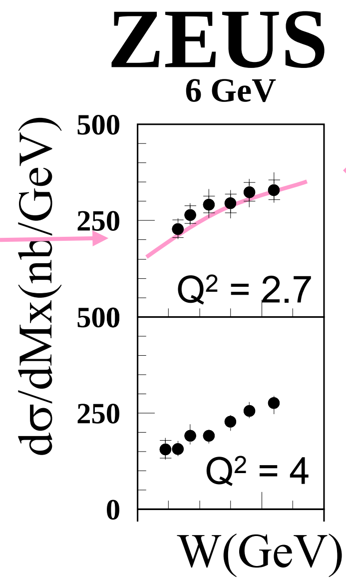
$$= W^a \cdot \left(\frac{\beta}{Q^2}\right)^{a/2} b(\beta,Q^2) \quad \because W^2 \simeq \frac{Q^2}{\beta\, x_{\mathbf{P}}}$$

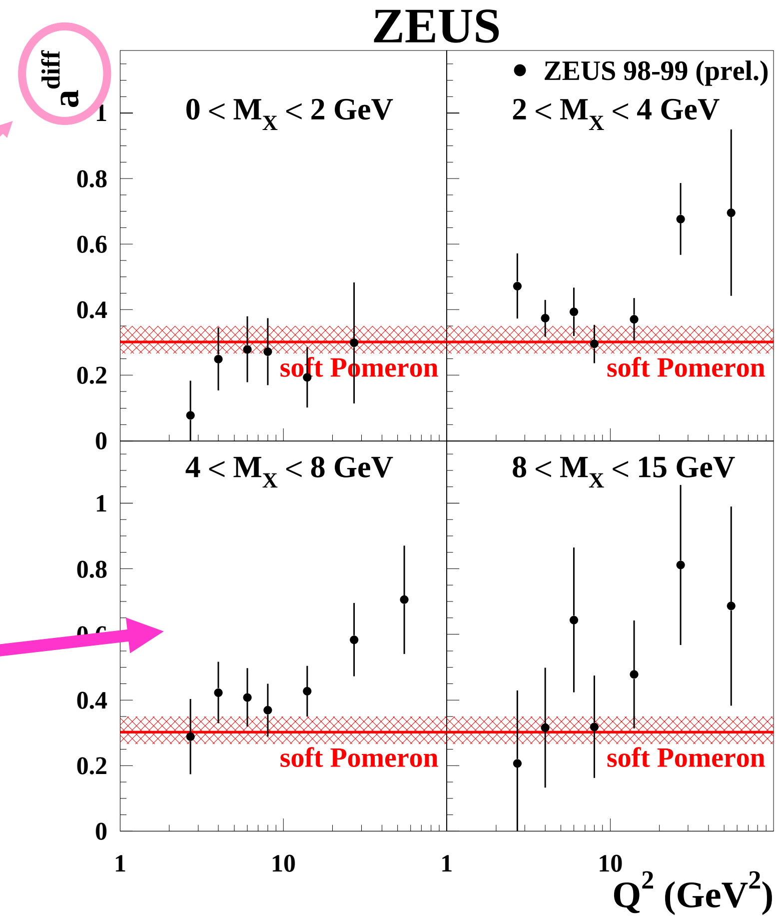
# W slope of the diffraction

$$F_2^D \propto \frac{1}{x_{\mathrm{P}}^{a/2}} \cdot b(\beta, Q^2)$$

$$= W^{a} \cdot \left(\frac{\beta}{Q^2}\right)^{a/2} b(\beta, Q^2)$$

$$\because W^2 \cong \frac{Q^2}{\beta\, x_{\mathrm{P}}}$$




- An indication of the slope rising with $Q^2$
- Shape of the flux differs in $Q^2$

  **A2. The exchange is not single pseudo-particle state**

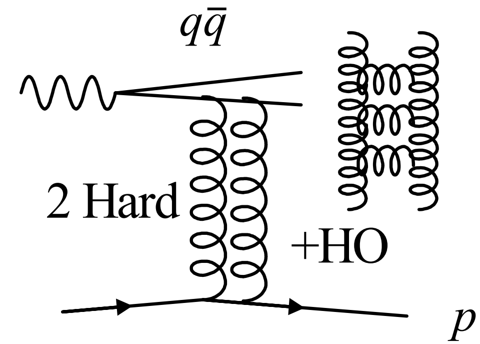
# 3. pQCD models and W dependence

- Colourless exchange of a $\bar{q}q$ dipole and proton: how ?
  - Two perturbative gluons (+HO)

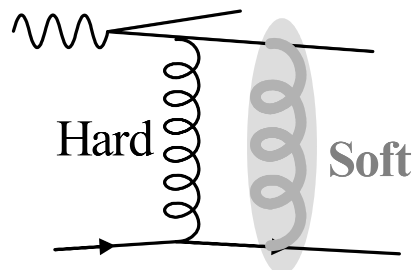
    $\sigma_{\rm inel} \propto g(x), \ \sigma_{\rm diff} \propto |g(x)|^2$

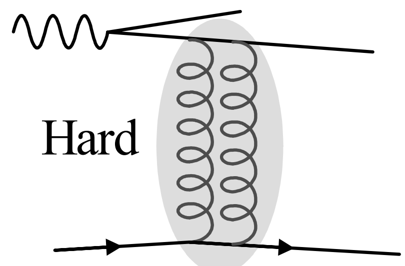
    i.e. $\sigma_{\rm inel} \propto W^a \Rightarrow$ $\boldsymbol{\sigma_{\rm diff} \propto W^{2a}}$
  - If softer gluons are exchanged e.g.
    - Soft-colour interaction (SCI) model = 1 hard + 1 soft
    - Saturation model: two gluons, but somewhat softer

  $\rightarrow \sigma_{\rm diff}$ rises **less steep** than $|g(x)|^2$ or $W^{2a}$
  - Q3: **how fast is the rise in W ?**




SCI etc.

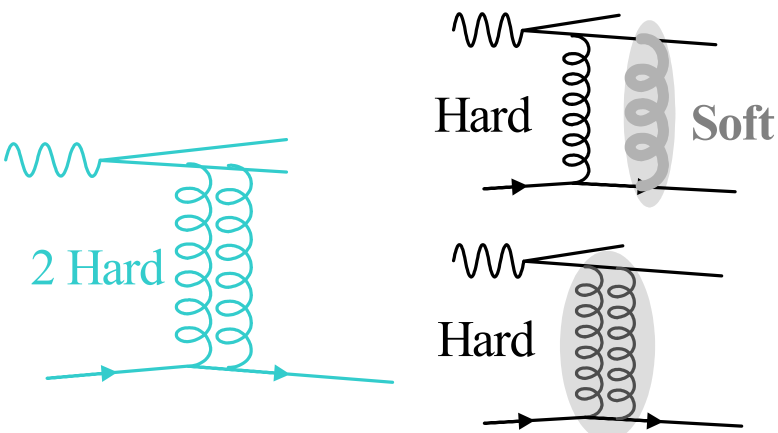


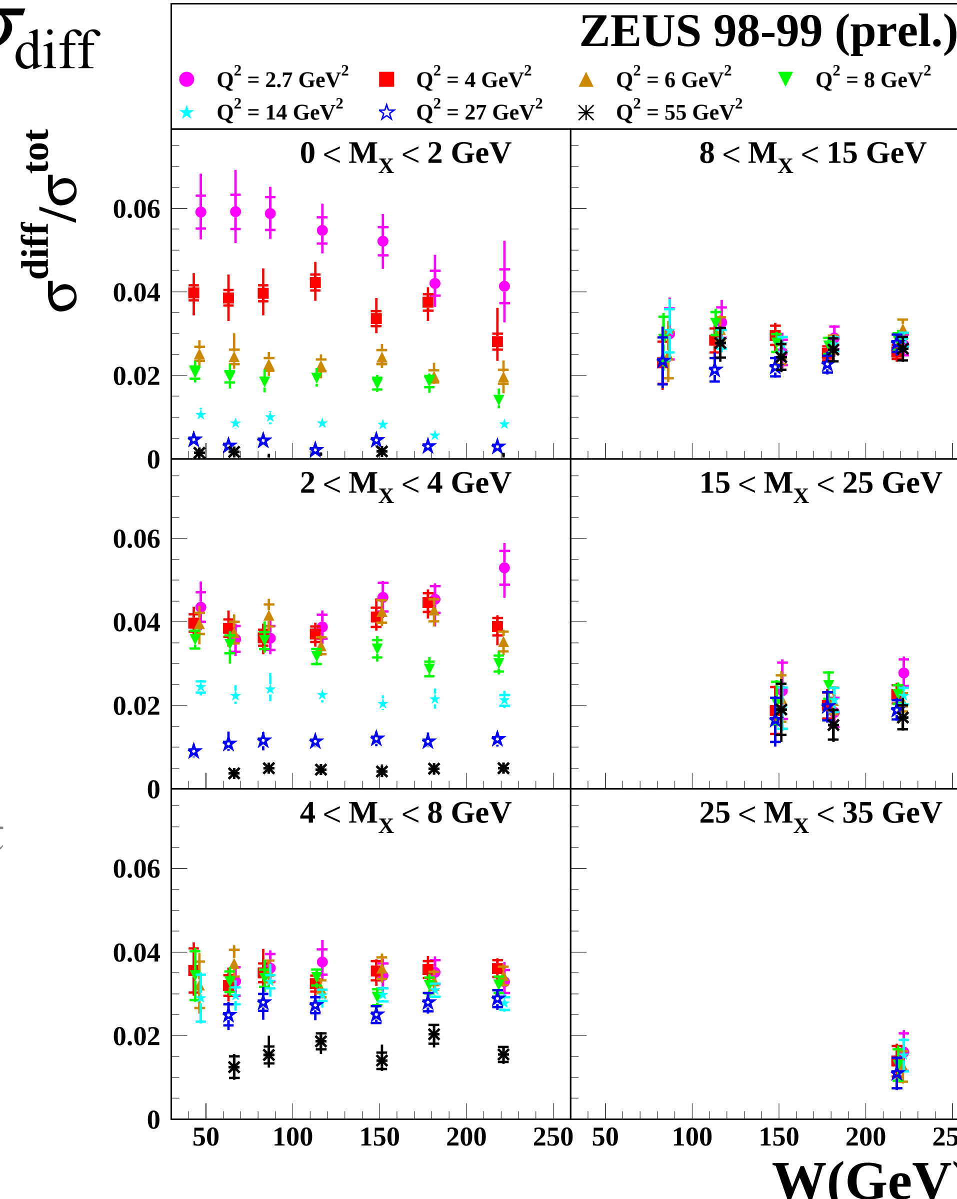




Saturation model etc.

# W slopes: $\sigma_{tot}$ and $\sigma_{diff}$

- Result:
  $\sigma_{diff} / \sigma_{tot}$ flat in $W$
- **A3. Diffraction and inclusive has the same energy behaviour**
  - Not consistent with “two hard parton” model



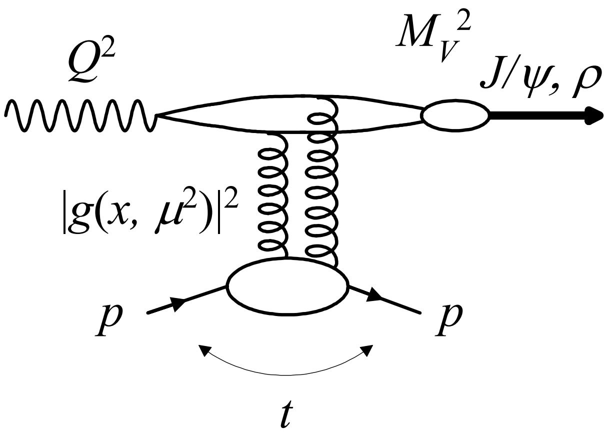



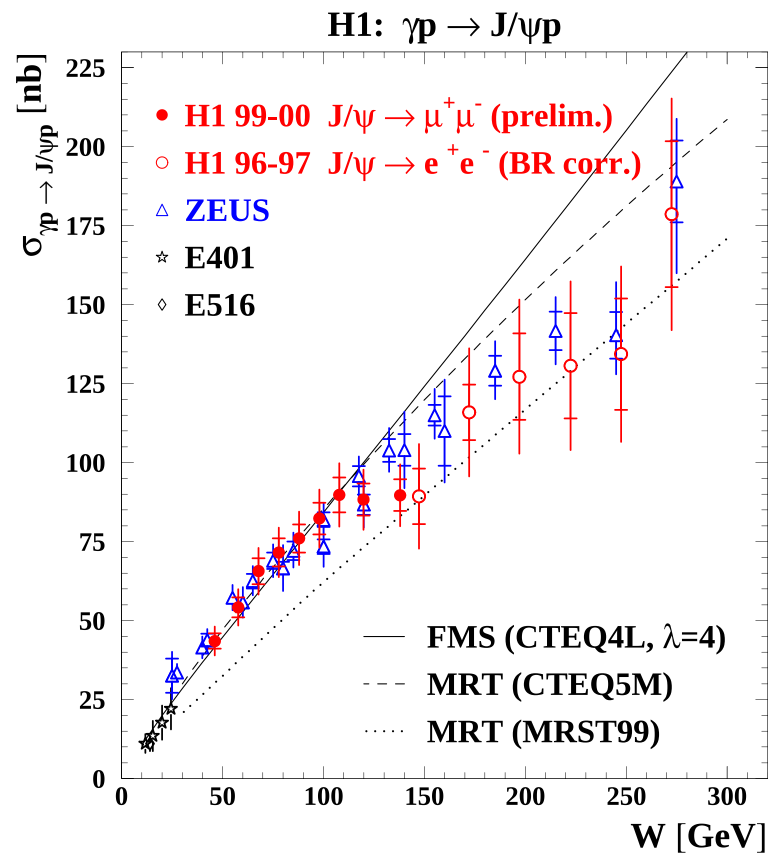
# Conclusions from DDIS at HERA

- Diffractive pdfs are universal within DIS
  - QCD factorisation holds
- Diffractive exchange is not single pseudo-particle state
  - The "flux" depend on $Q^2$: onset of pQCD
- $\sigma_{\mathrm{diff}} / \sigma_{\mathrm{tot}}$ is flat in $W$
  - Softer than pure 2-gluon exchange

**Next:**
**Vector meson (VM) production at HERA**

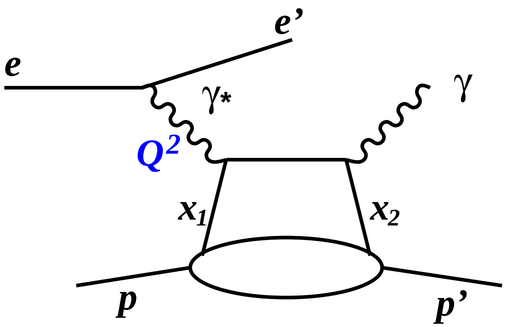
# pQCD framework of the VM production




- Hard scale given by
  - $Q^2$, $M_V^2$, or $t$
- 2-gluon exchange
  - $\sigma_L \sim |g(x)|^2$ i.e. steep rise in $W$
- The concept works !
  - J/ψ photoproduction:
    steep rise in W, agree with pQCD predictions

# Another example: DVCS
## (Deeply virtual Compton Scattering)

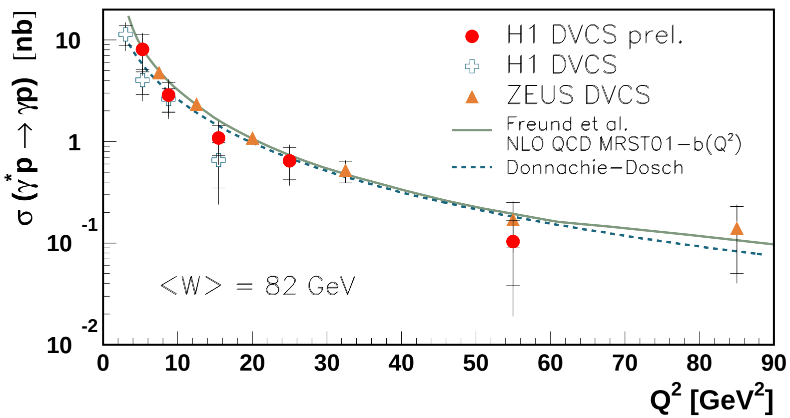


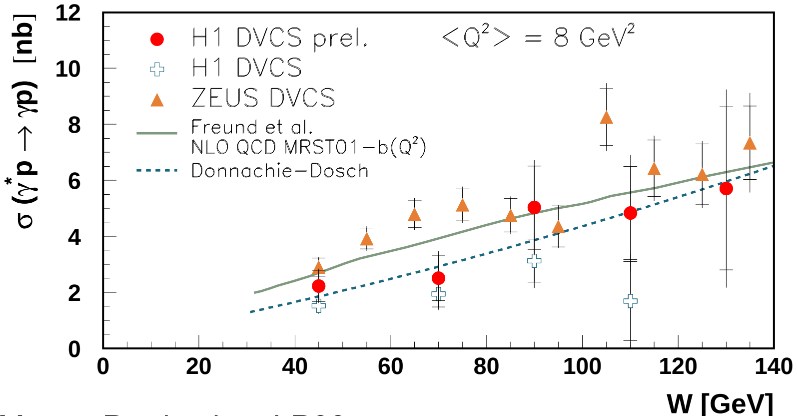

- Elastic process in $\gamma^* p$
  - No uncertainty in the VM wave function
- Steep rise in W
  - $\sigma \propto W^\delta$

    $\delta = 0.98 \pm 0.44$ (H1)

    $= 0.75 \pm 0.15^{+0.08}_{-0.06}$ (ZEUS)

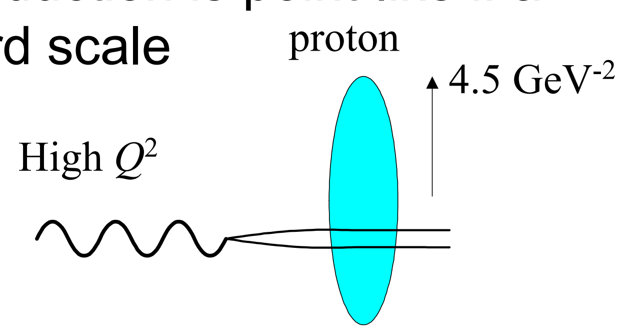
    Similar to $J/\psi$ value (~ 0.7)
    Larger than soft (~ 0.22)
- $Q^2$ dependence also described



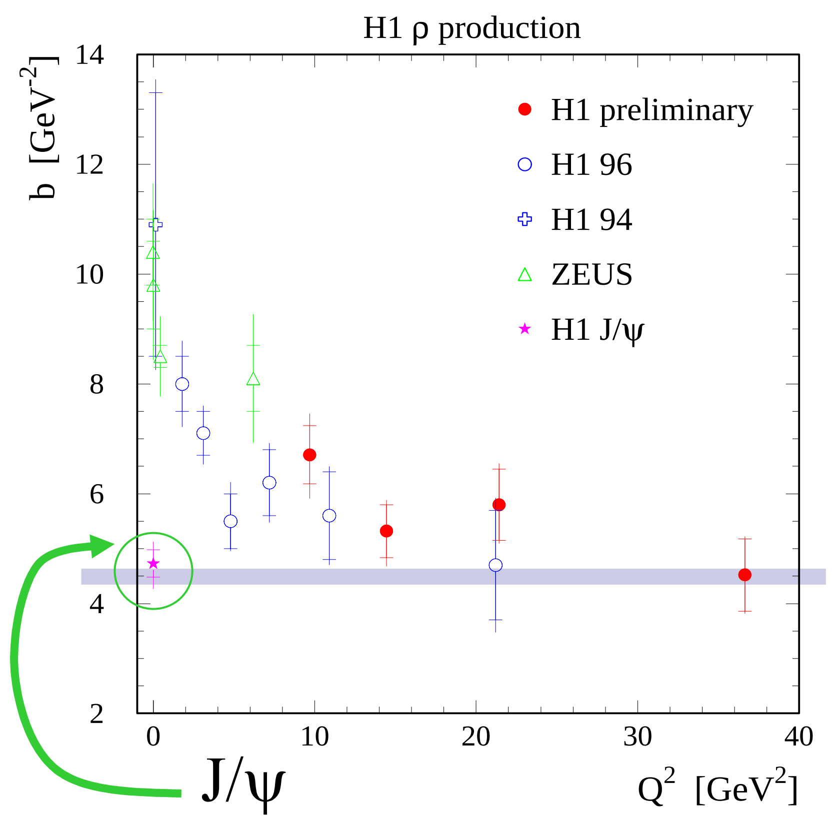



# Forward slope (*B*) for VMs

- Slope of the scattering angle of the proton $\equiv$ interaction size
  - $\sigma \propto \exp(Bt)$: $B$ is the size of the interaction
- B ~ 4.5 GeV$^{-2}$ at $\rho$ in high $Q^2$ and J/$\psi$
  - Similar to proton size → VM production is point-like if a hard scale




*B* in ρ production vs $Q^2$



# Conclusions from VM production

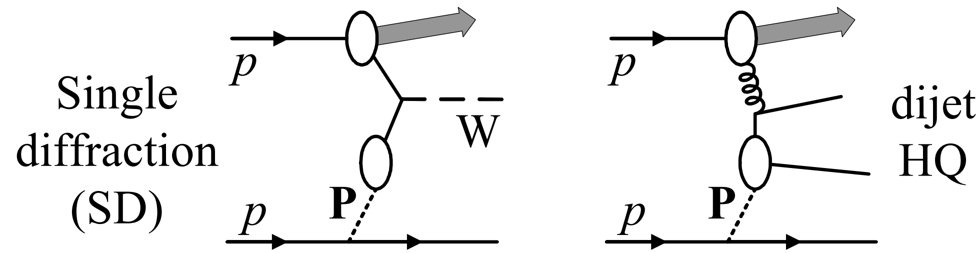
- Steep W dependence for VM and DVCS
  - Agrees with pQCD prediction
- B-slope ~ 4.5 $GeV^{-2}$
  - VM with a hard scale is point-like production

**Pure-pQCD approach is successful in VM, unlike in DDIS**

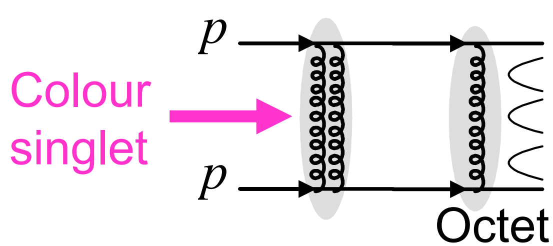
**Next:**
**Tevatron results**
**and comparison with HERA**

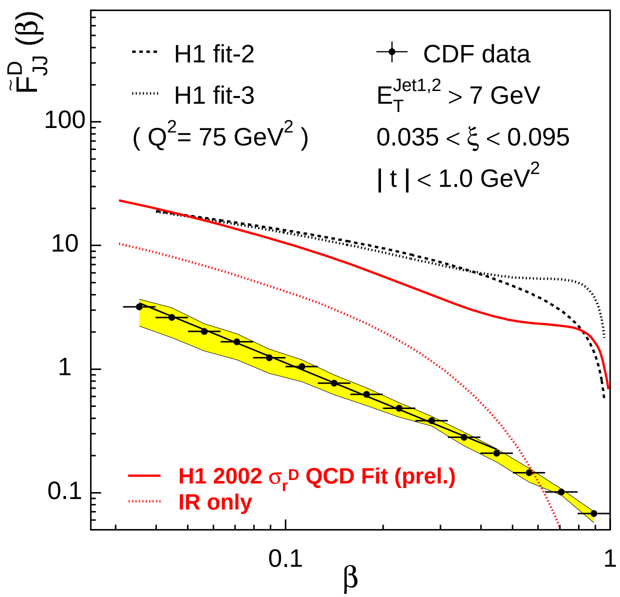
# Run 1 results: hard diffraction

- Extensive survey
  - W – sensitive to quarks
  - Dijet, b-quark, J/ψ – gluons




- Hard diffraction is suppressed w.r.t. the prediction using pdfs measured at HERA
  - by about factor 5-10 (depending on diffractive pdfs)
- Diffraction seems lost by re-scattering between two remnants
  - Gap survival probability $S^2$ is small

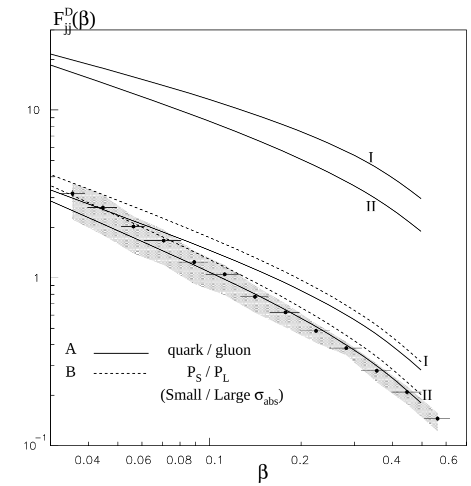


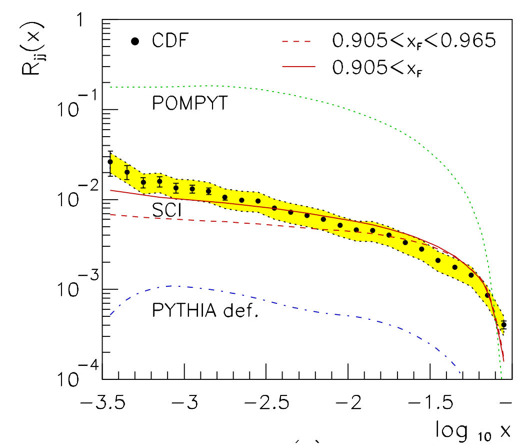

Tevatron data vs H1 fit

# Recent theoretical development on $S^2$

- Various approach for multi-exchange effect: Rapid progress in last several years
  - Renormalised Pomeron flux: Goulianos
  - Estimation from the soft hh cross sections:
    - Kaidalov, Khoze, Martin, Ryskin
    - Gotzman, Levin, Maor
    - Bialas, Peschanski
  - Soft colour interactions: Ingelman, Enberg et al.
  - Overlapping with hard multi-parton scattering: Cox, Forshaw, Lönnblad …
  - …(not complete)
- Which model is more universal ? (e.g. applicability to LHC) more data needed to check models



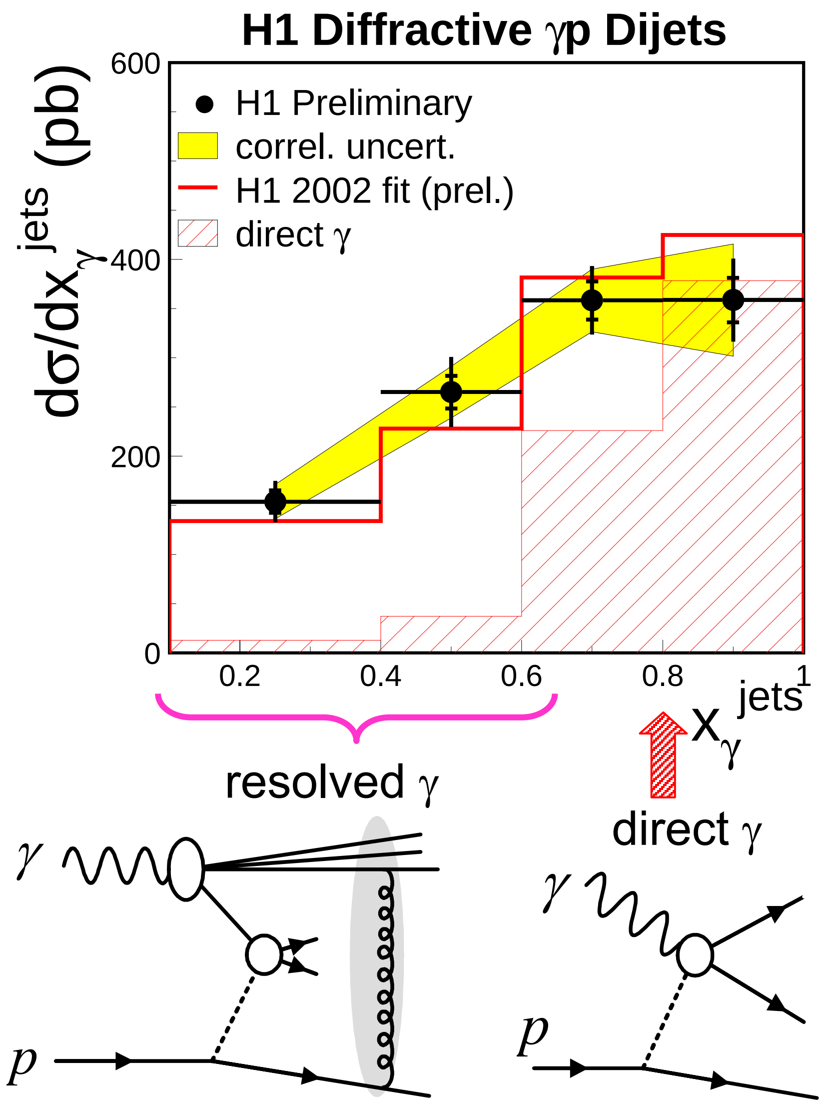

Kaidalov et al., Eur.Phys.J.C21 (2001) 521




Enberg et al., Phys. Rev. D 64 (2001) 114015

# Suppression within HERA ?

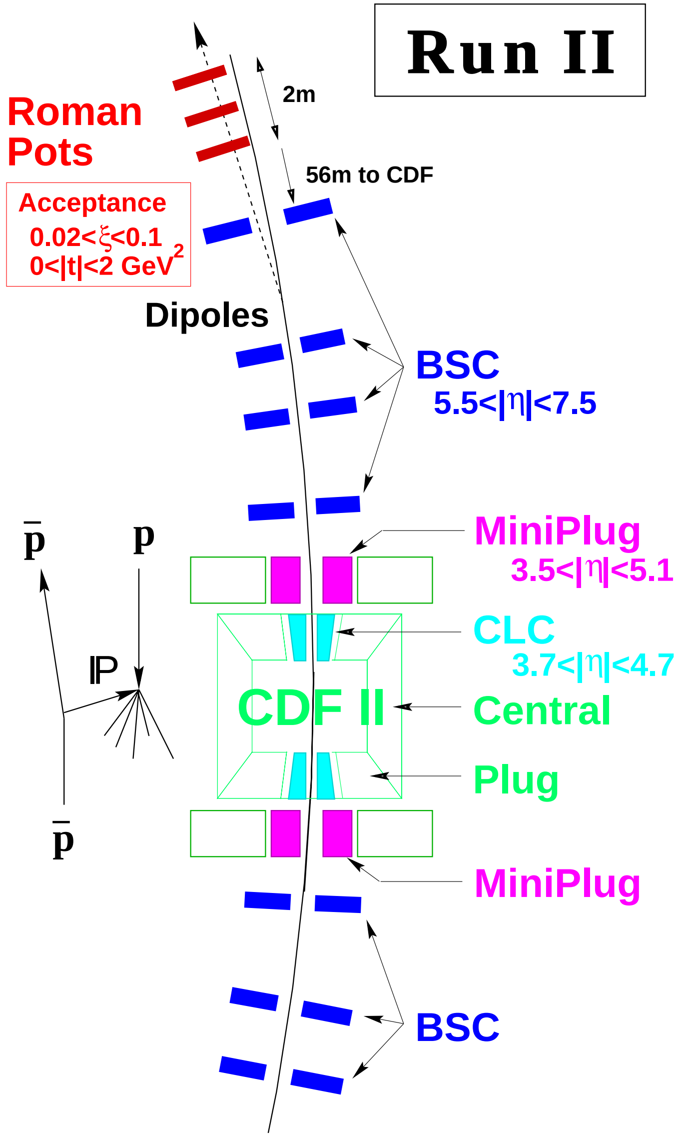
- Photoproduction: scatter of a real photon and the proton
  - Resolved photon can be regarded as a hadron ⇒ possible re-scattering between the photon and proton remnant
  - suppression for resolved ?
- Result:
  - The shape described by MC **No evidence of the suppression of resolved γ**
- No significant of factorisation breaking in photoproduction



# RunII results from CDF

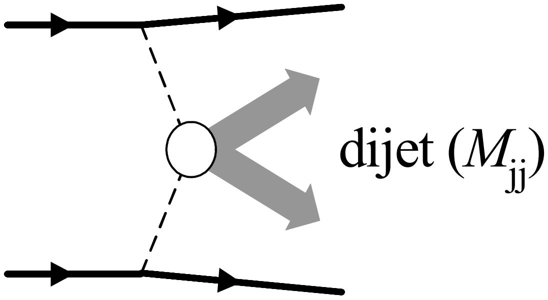
- Upgrade in CDF: forward detectors
  - new MiniPlugs
  - new Cerenkov LUMI Counters
  - new Beam Shower Counters
  - More coverage in large rapidity
    Better detection of rapidity gaps

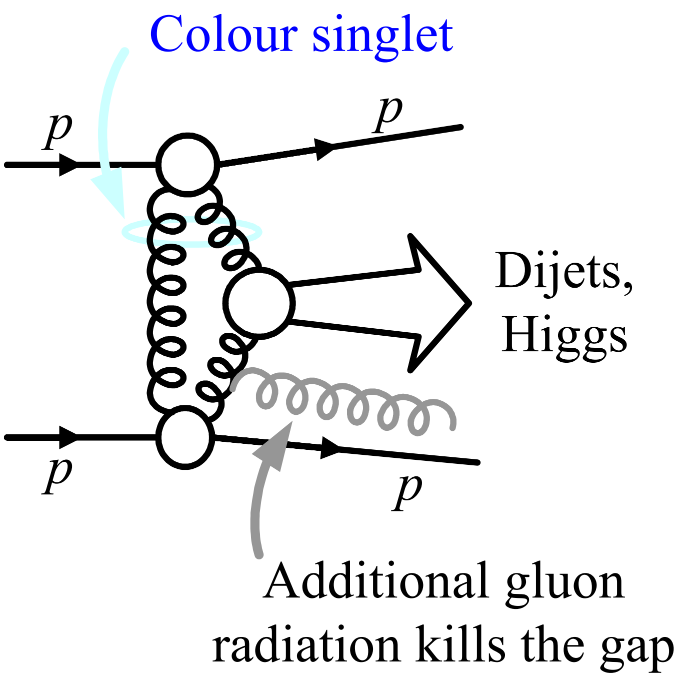
  - Already reproducing run1 results



# From CDF runII: exclusive dijet

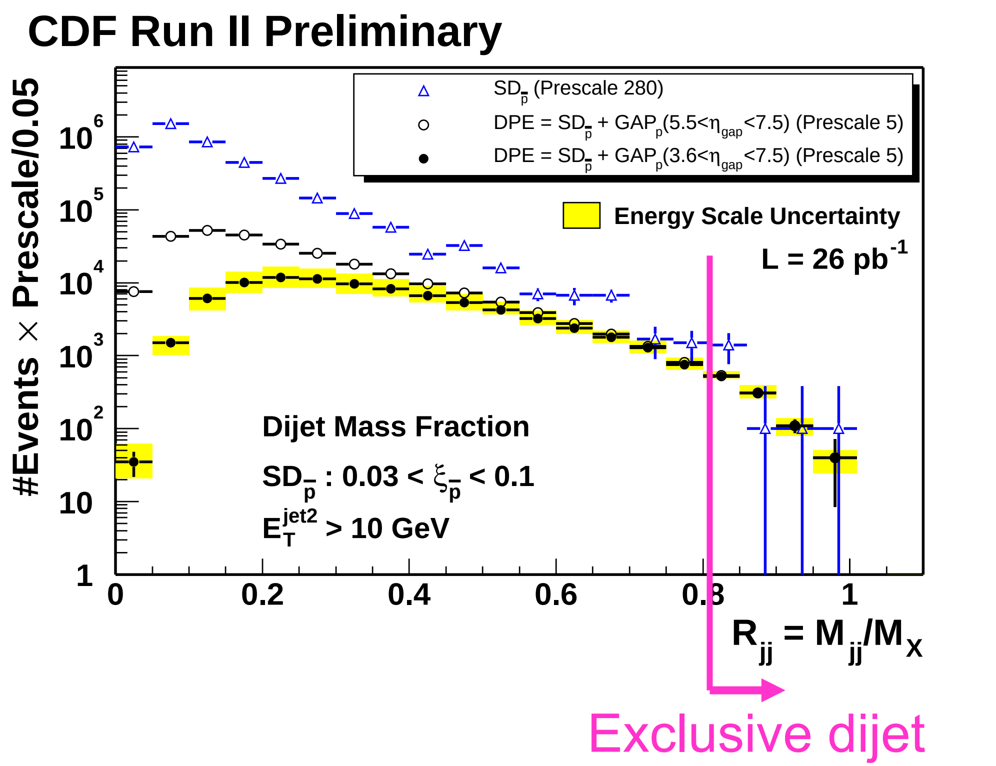
- Two colourless exchange fusion to dijet, nothing else
- Resonance in $M_{\mathrm{P\text{-}P}}$ can be detected by Roman pots
  - clean signal for diffractive Higgs production
- Cross section: difficult to calculate
  - Cannot use diffractive pdfs
  - QCD radiation to be estimated
  - Gap survival probability $S^2$ on top:
- The dijet measurement gives …
  - the normalisation of the calculation $\rightarrow$ better estim. for Higgs production



# Dijet spectrum in $R_{jj}$

- No peak in dijet mass observed
  - No evidence for the exclusive dijet
  - The measured cross section for $R_{jj} > 0.8$ gives upper limit of the exclusive cross section



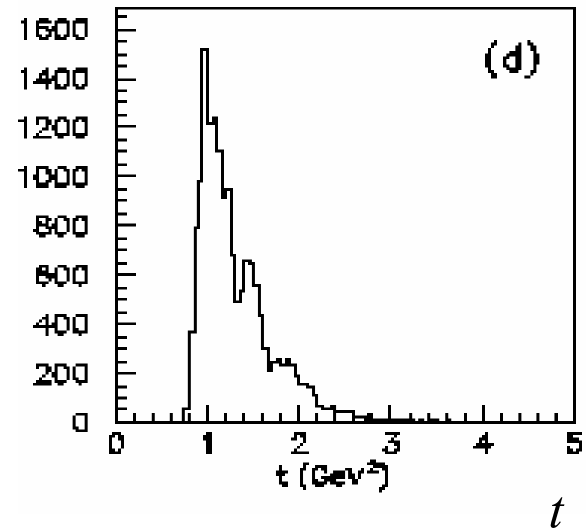

| Minimum $E_T^{\text{jet1}}$ | Cross section: $\sigma_{DPE}^{excl.dijet}(R_{jj} > 0.8)$ |
|---|---|
| 10 GeV | 970 ± 65(stat) ± 272(syst) pb |
| 25 GeV | 34 ± 5(stat) ± 10(syst) pb |

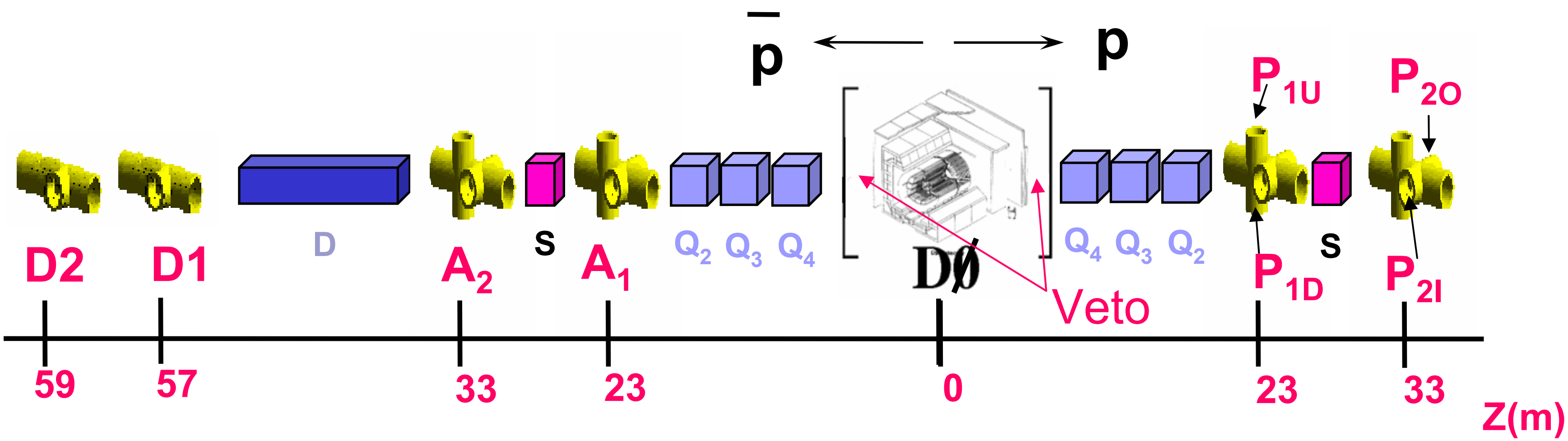
# Conclusions on Tevatron – HERA comparison

- Factorisation breaking Tevatron-HERA
  - Rapid development in the theoretical framework
- Factorisation test HERA photoproduction: no breaking
- RunII data + results coming
  - Further data from D∅ soon (next slide)

# Future direction (1): upgrade in D∅

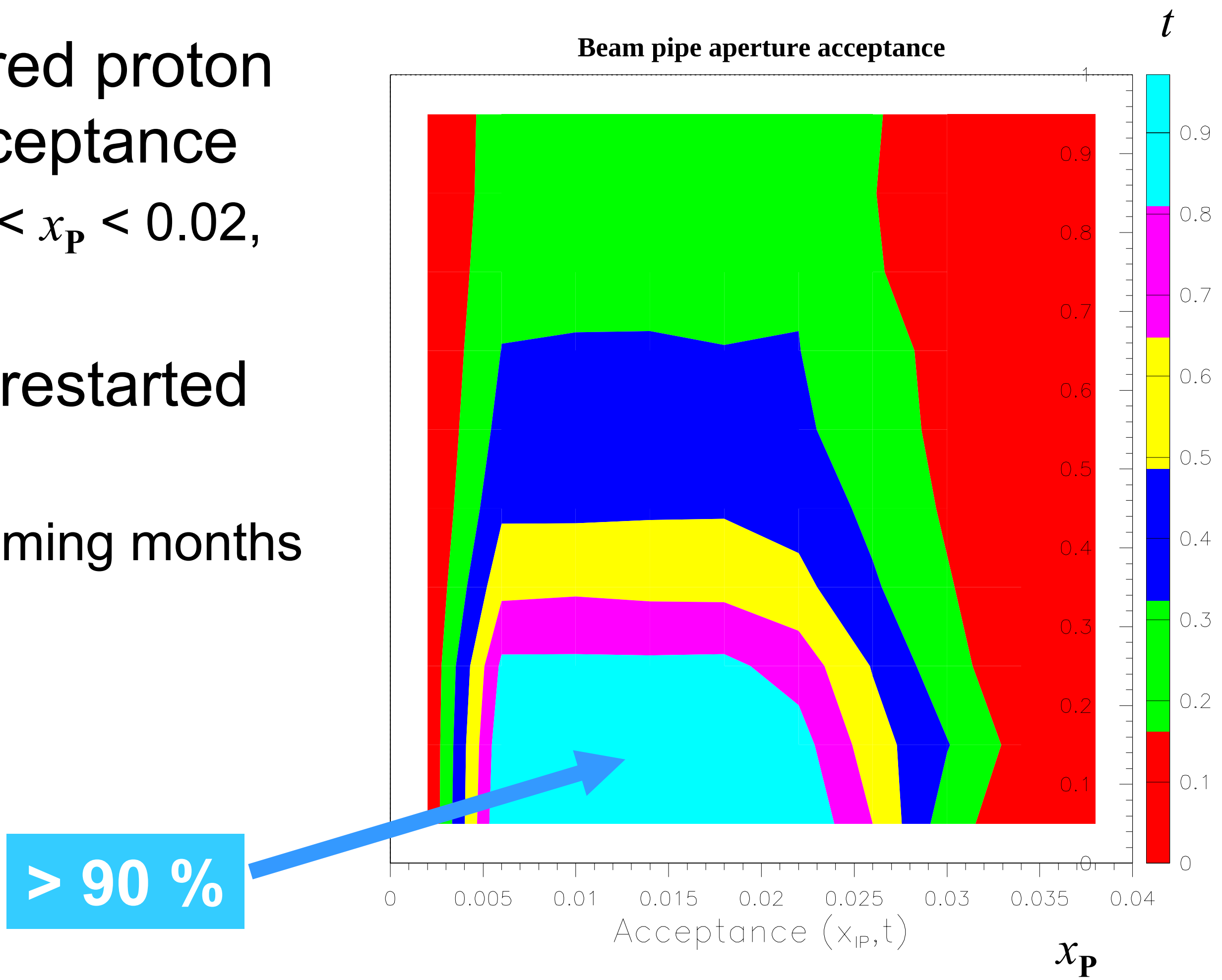
- New forward detectors
- New Roman pots
  - very large acceptance in $(\xi, t)$
- Status
  - alignment just finished
  - Observing right $t$-shape – results in coming months



# Future direction (2) H1 VFPS

- Tagging scattered proton at very high acceptance
  > 90 % for $0.005 < x_P < 0.02$, $|t| < 0.2$
- HERA has just restarted after shutdown
  - New data in coming months



# Summary

- The aim of studying diffraction was
  to understand the exchange **in terms of pQCD**
- Was it successful ?

  The answer is "Quite well, but some homework."
  - ✓ The exchange is not a pseudo-particle: we need pQCD
  - ✓ Diffractive pdfs is universal within HERA
  - ? Factorisation breaking at Tevatron – soft re-scattering
  - ? $\sigma_{\mathbf{diff}}$ / $\sigma_{\mathbf{tot}}$ flat in $W$ at HERA

    $\Rightarrow$ need non-perturbative phenomenology
- Huge effort in building the theoretical framework
  - Experiments should provide data to "distinguish" models