

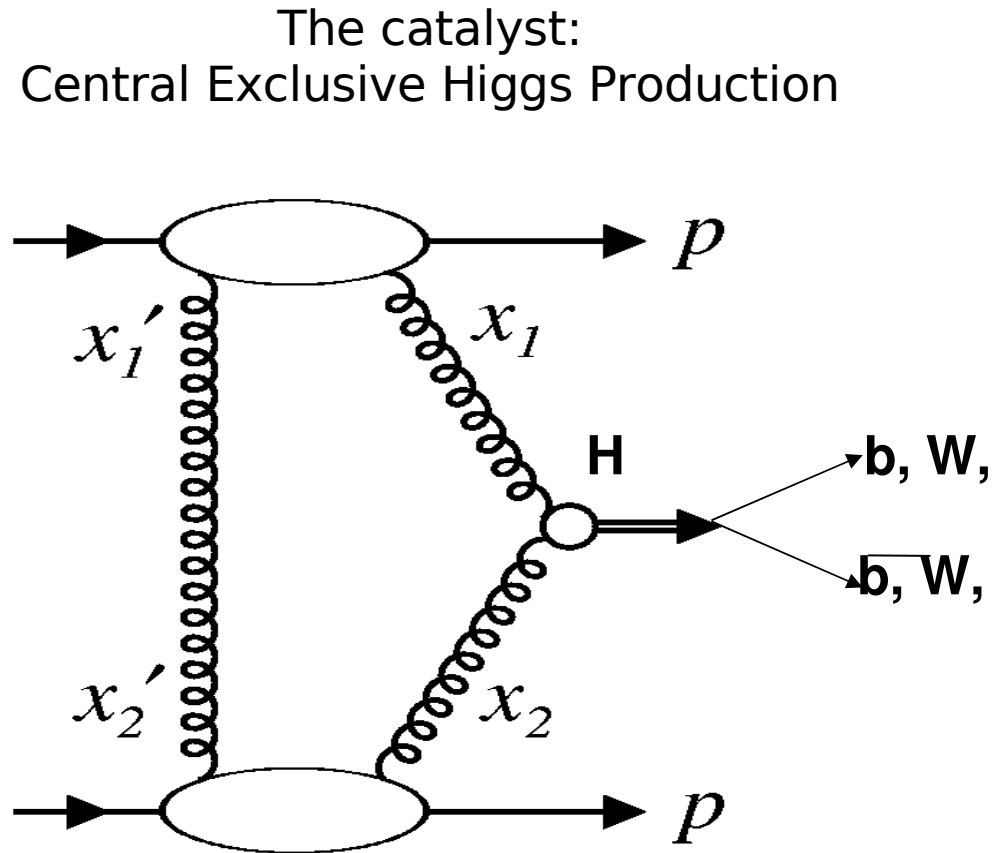
Experimental Results on Diffraction

Hadron Collider Physics Symposium
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Pierre Van Mechelen
Pierre.VanMechelen@ua.ac.be



- ▶ **Diffractive processes and kinematics**
- ▶ **Measuring diffractive parton density functions**
- ▶ **Survival probabilities**
- ▶ **Central exclusive production of dijets, diphotons and dileptons**
- ▶ **Forward look to the LHC**
- ▶ **Summary**



Apologies for not covering everything; no time for vector mesons, $\gamma\gamma$ collisions, ... !

Diffraction processes and kinematics

Kinematics of pp diffraction

▶ Single diffractive dissociation (SDD)

$$p \bar{p} \rightarrow [p' + \text{IP}] + p \rightarrow p' X$$

$$\xi = 1 - p'_L/p_L \quad \text{fractional longitudinal momentum loss of proton}$$

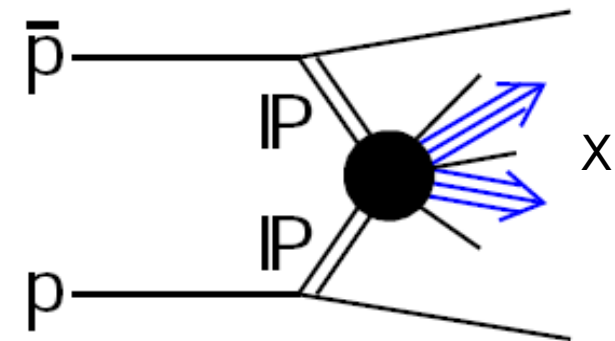
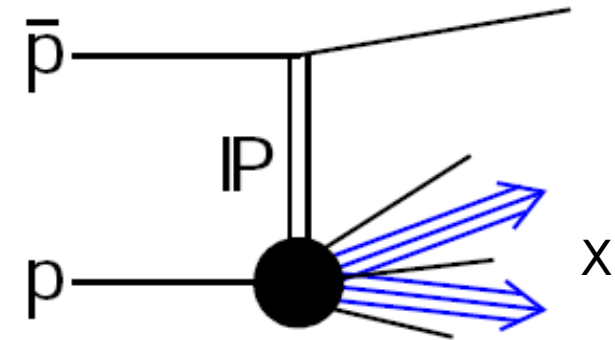
$$t = (p - p')^2 \quad \text{four-momentum transfer squared at proton vertex}$$

$$M_X = X^2 \quad \text{invariant mass of } X$$

▶ Double Pomeron exchange (DPE)

$$p_1 p_2 \rightarrow [p'_1 + \text{IP}] + [p'_2 + \text{IP}] \rightarrow p'_1 X p'_2$$

$$\xi_1, \xi_2, t_1, t_2, M_X$$



IP = colourless combination of gluons and quarks with vacuum quantum numbers

Kinematics of ep diffraction

▶ Diffractive deep-inelastic scattering (DDIS)

$$e p \rightarrow [e + \gamma^*] + [p' + IP] \rightarrow e X p'$$

$$Q^2 = -q^2 = (k - k')^2 \quad \text{photon virtuality}$$

$$x = Q^2 / 2q \cdot P \quad \text{Bjorken-}x$$

$$t = (P - P')^2 \quad \text{four-momentum transfer squared at proton vertex invariant mass of } X$$

$$M_X = X^2$$

$$x_{IP} = q \cdot (P - P') / q \cdot P \quad \text{fractional momentum loss of proton}$$

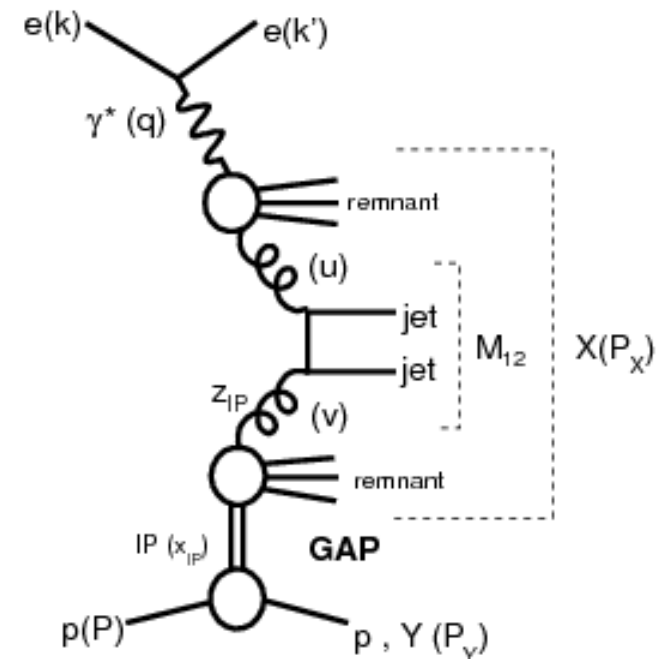
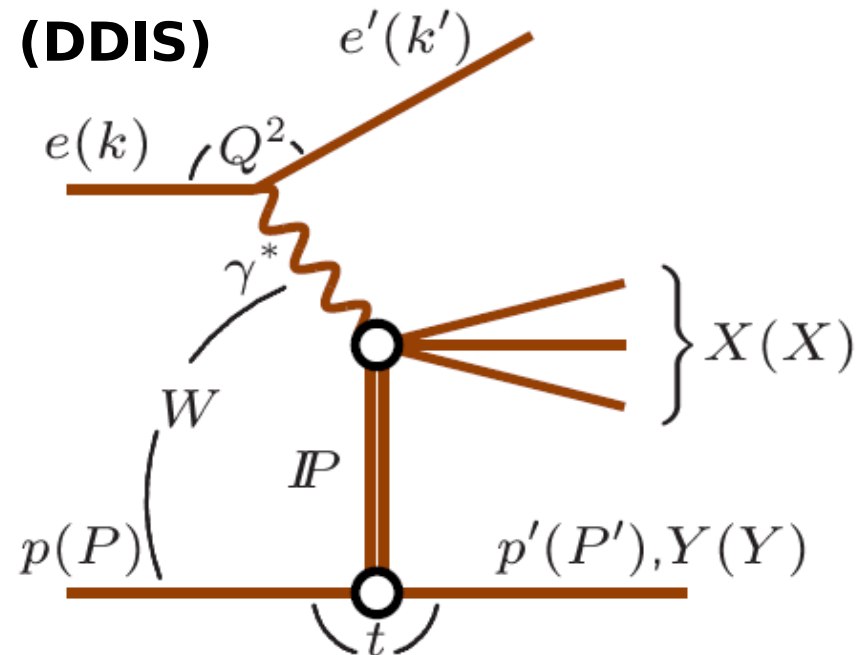
$$\beta = x / x_{IP} \quad \text{momentum fraction carried by quark out of pomeron}$$

▶ Diffractive photoproduction (DPHP)

$$e p \rightarrow [e + \gamma] + [p' + IP] \rightarrow e X p'$$

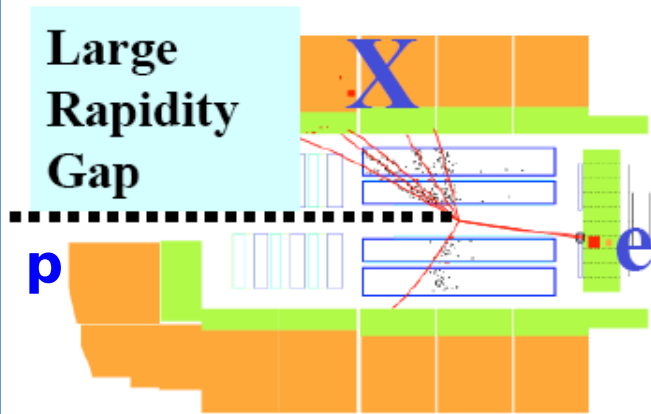
$$x_Y = P \cdot u / P \cdot q \quad \text{fractional momentum from photon to hard interaction}$$

$$z_{IP} = q \cdot v / q \cdot (P - P') \quad \text{fractional momentum from pomeron to hard interaction}$$



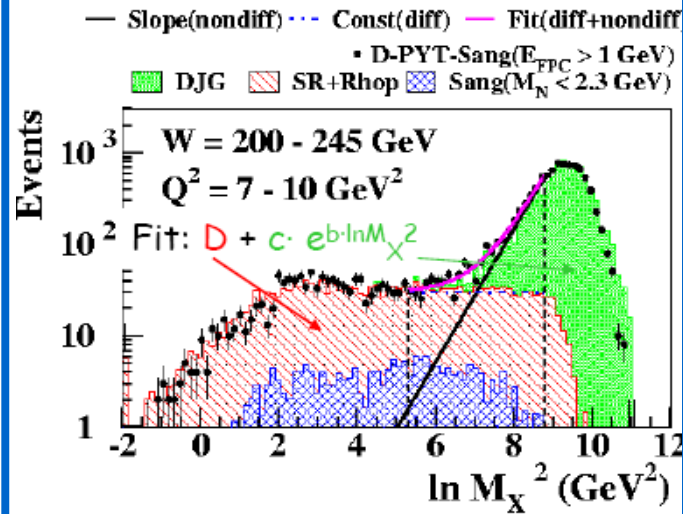
Measuring Diffractive Parton Density Functions at HERA

Large Rapidity Gap selection



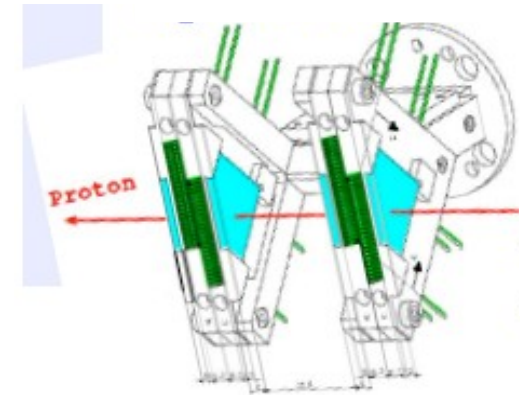
- require large rapidity gap (LRG) spanning at least $3.3 < \eta < 7.5$
- kinematics is measured from X system; integrate over $|t| < 1 \text{ GeV}^2$ and $M_Y < 1.6 \text{ GeV}$

Fit of M_X distribution



- extract diffractive sample from fit of $D + C \exp(b \ln M_X^2)$ to M_X distribution
- kinematics is measured from X; integrate over $|t|$ and $M_Y < 2.3 \text{ GeV}$

Proton tagging

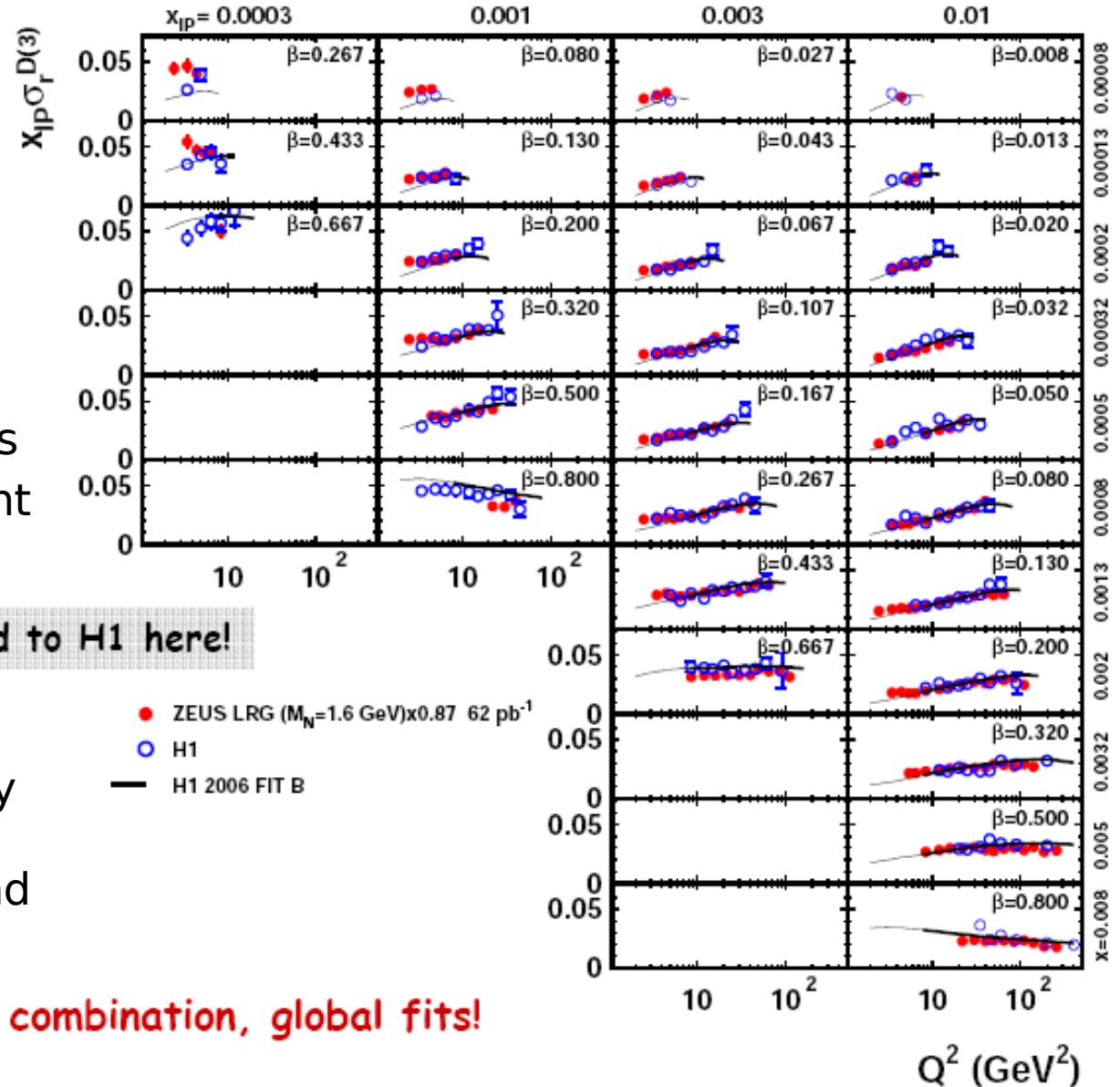


- Detect forward proton \rightarrow no proton dissociation
- Kinematics from proton momentum \rightarrow direct measurement of t

Different systematics \rightarrow non-trivial to compare!

$\sigma_r^{D(3)}$ LRG ZEUS vs H1

ZEUS

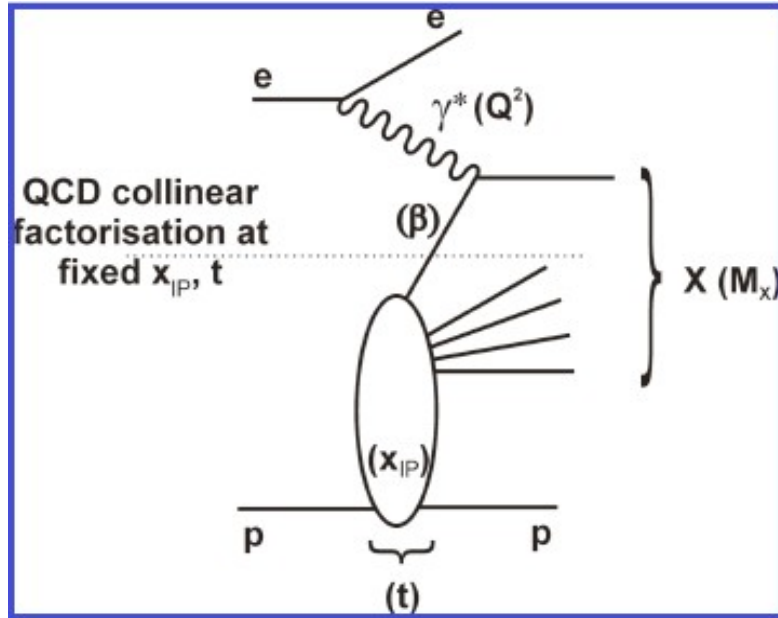


▶ LRG, M_x and LPS measurements from H1 and ZEUS all consistent within uncertainties

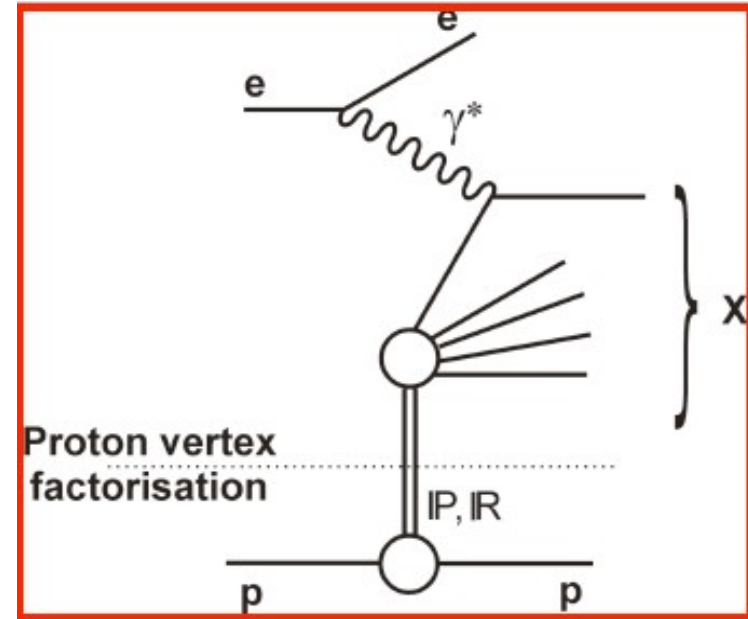
▶ Remaining normalisation difference of 13% is covered by the uncertainty on the proton dissociation correction (8%) and the relative normalisation uncertainty (7%)

Time for data combination, global fits!

► **QCD hard scattering collinear factorisation (Collins)**



► **Proton vertex factorisation (Regge)**



$$d\sigma^{ep \rightarrow eXY} = f_i^D(x, Q^2, x_{IP}, t) \otimes d\sigma^{ei}(x, Q^2)$$

Diffractive Parton Density Function (DPDF)

→ exact in DDIS

$$f_i^D(x, Q^2, x_{IP}, t) = f_{IP/p}(x_{IP}, t) \cdot f_i^{IP}(\beta = \frac{x}{x_{IP}}, Q^2) + n_{IR} f_{IR/p}(x_{IP}, t) \cdot f_i^{IR}(\beta = \frac{x}{x_{IP}}, Q^2)$$

→ approximation inspired by Regge theory

From cross sections to DPDFs

► H1 2006 DPDF fit

NLO QCD fit of $\alpha_{\text{IP}}(0)$, n_{IR} +
polynomials for DPDF at Q_0^2
(reggeon flux and pdf is fixed)

- Fit A

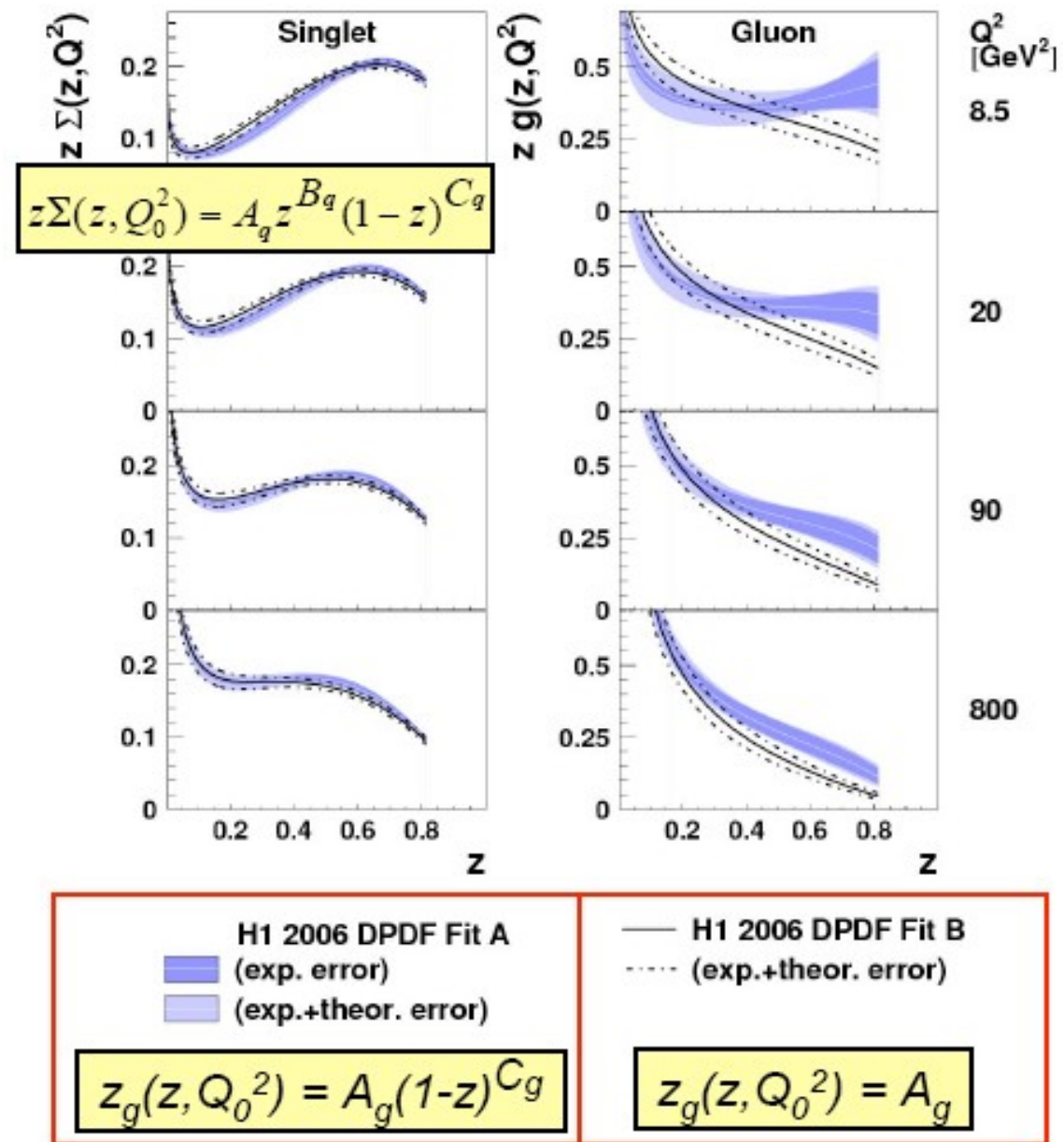
$$\chi^2 = 158 / 183 \text{ d.o.f.}$$

- Fit B

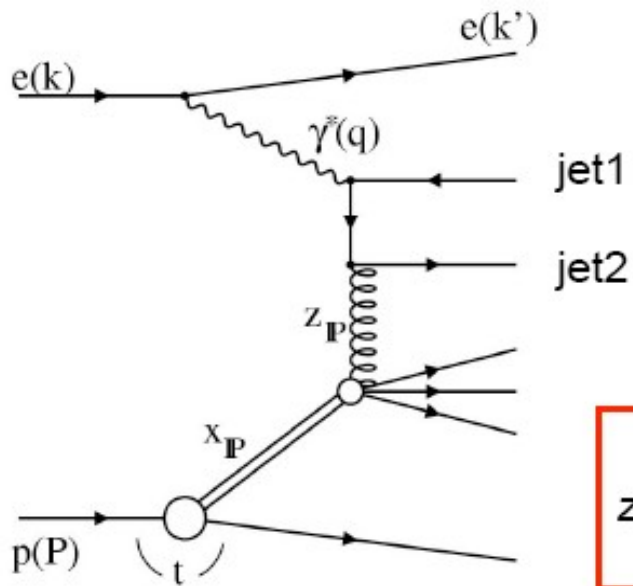
$$\chi^2 = 164 / 184 \text{ d.o.f.}$$

→ Quarks very stable

→ Gluons stable a low z , but no
sensitivity at high z



Comparison to DDIS dijets



Fit A in good agreement with data at low z , overshooting at high z

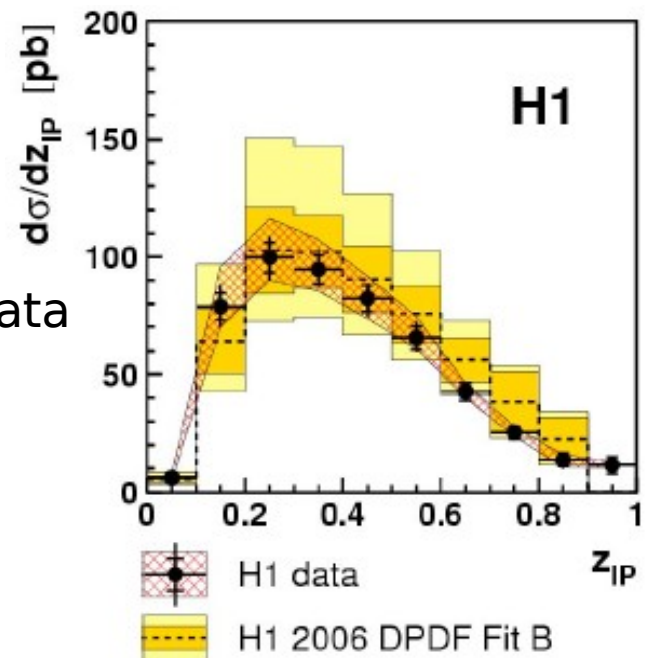
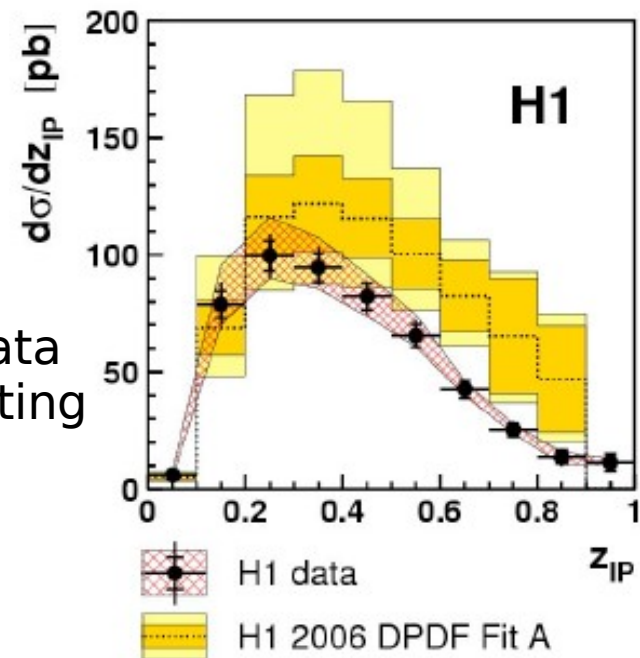
$$z_{IP} = \frac{M_{12}^2 + Q^2}{M_X^2 + Q^2}$$

sensitive to gluon at high z !

Fit B in good agreement with data at all z

→ QCD factorisation holds in DDIS

→ Fit B preferred by DDIS dijets

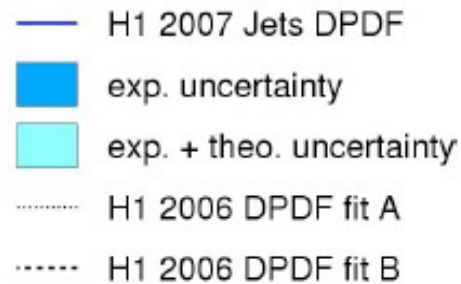




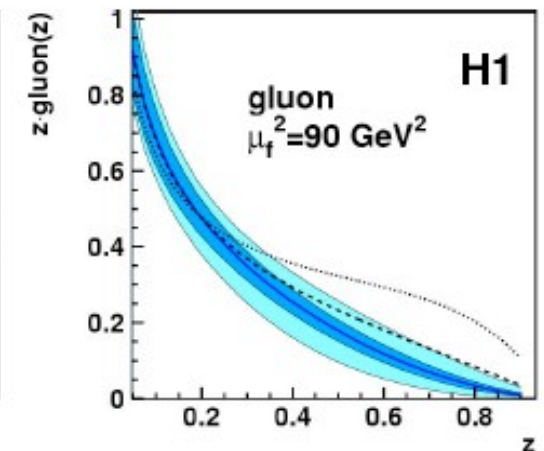
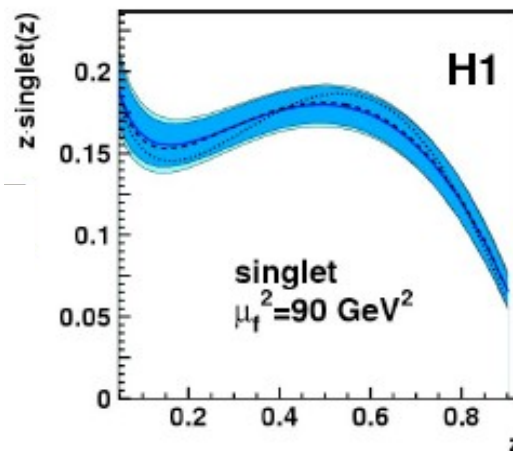
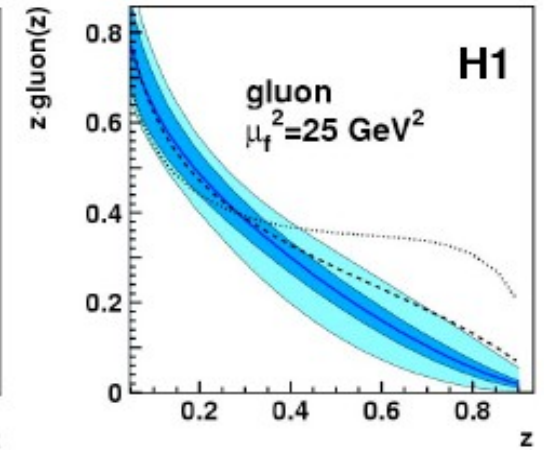
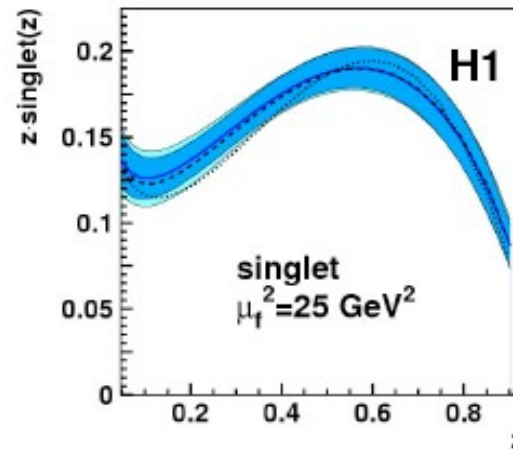
Combined fit

▶ H1 Jets 2007 DPDF fit

use DDIS dijet data as additional constraint in a NLO QCD fit



$$\chi^2 = 196 / 218 \text{ d.o.f.}$$



→ Combined inclusive + dijet fit constrain both quark and gluon DPDFs to similar good precision

→ H1 Jets 2007 fit yields most precise DPDFs to date

$$z\Sigma(z, Q_0^2) = A_q z^{B_q} (1-z)^{C_q}$$

$$z_g(z, Q_0^2) = A_g z^{B_g} (1-z)^{C_g}$$

Survival Probabilities

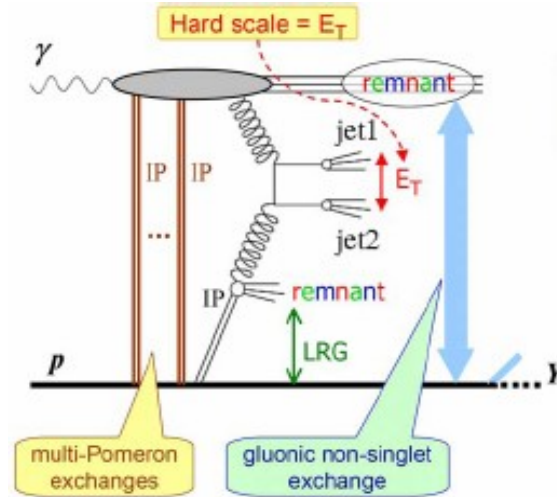
QCD factorisation breaking

▶ DPDF fits fail to predict TEVATRON data
 QCD factorisation not expected to hold in pp diffraction!

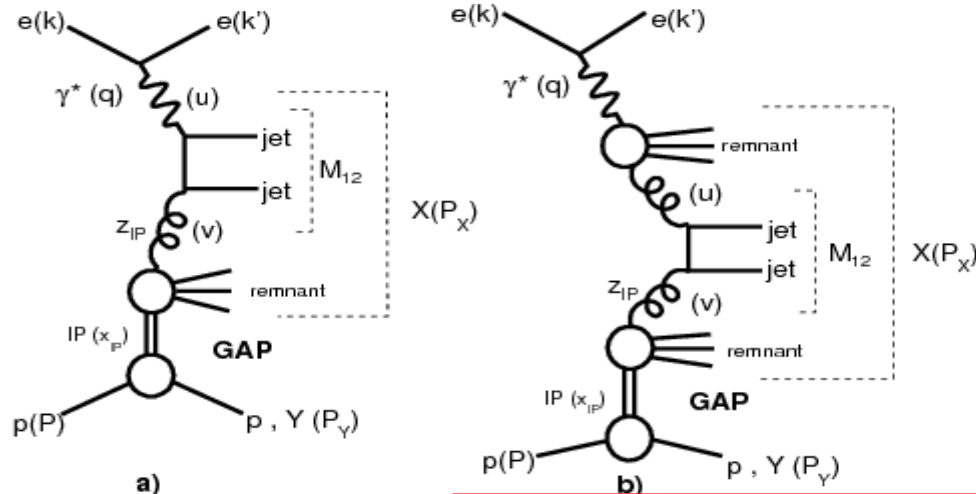
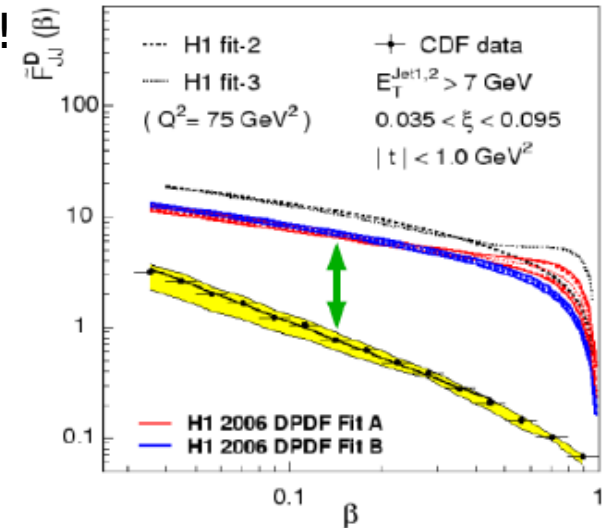
- multi-pomeron exchanges
- remnant interactions
- Screening

→ gap survival probability

▶ Look at DPHP dijets



H1 fits vs. Tevatron



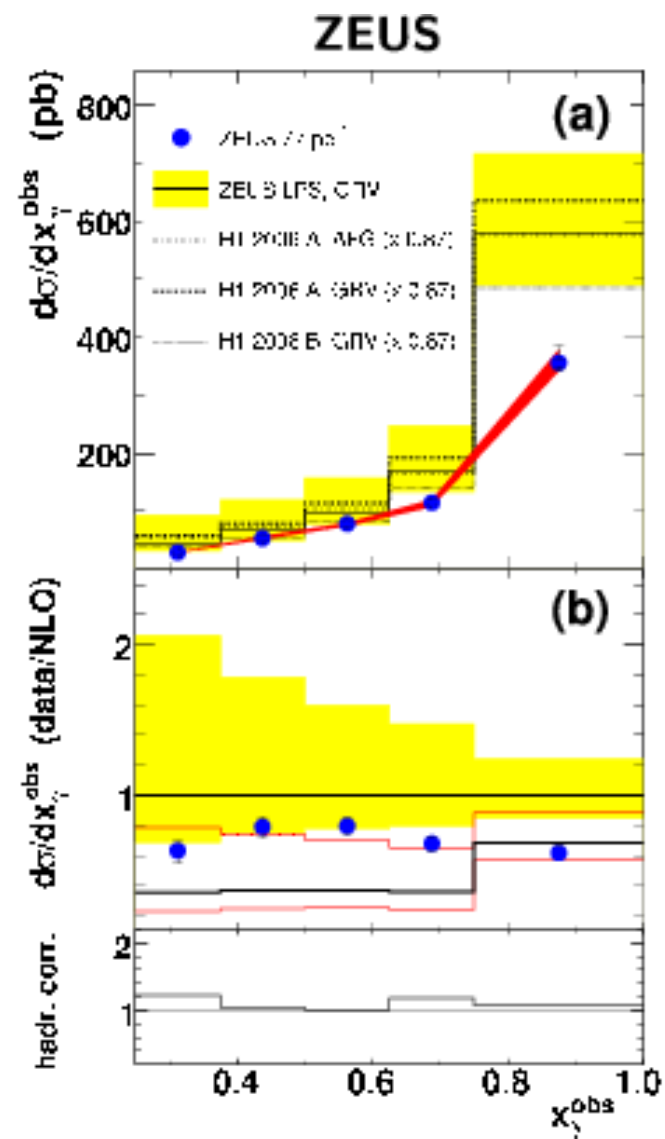
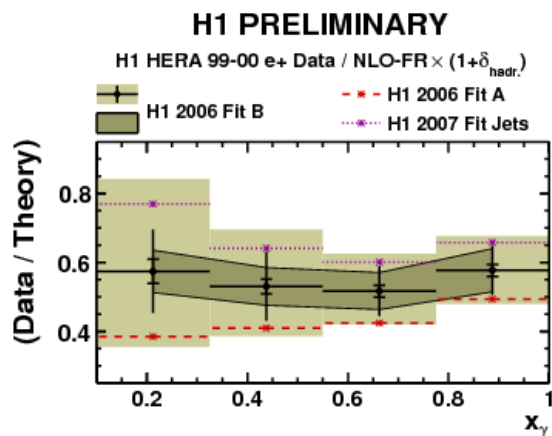
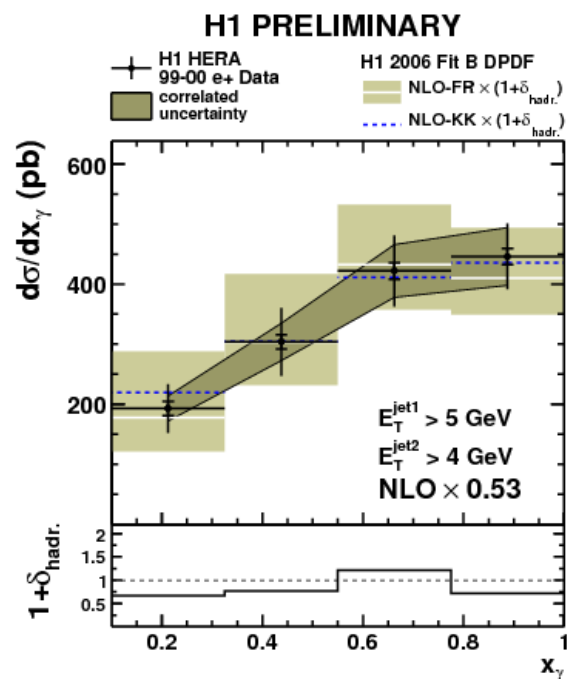
Direct photon ($x_Y = 1$)
 → factorisation should hold

Resolved photon ($x_Y < 1$)
 → suppression is expected

Note: separation between direct and resolved only possible at fixed order!



Survival probability from H1 and ZEUS

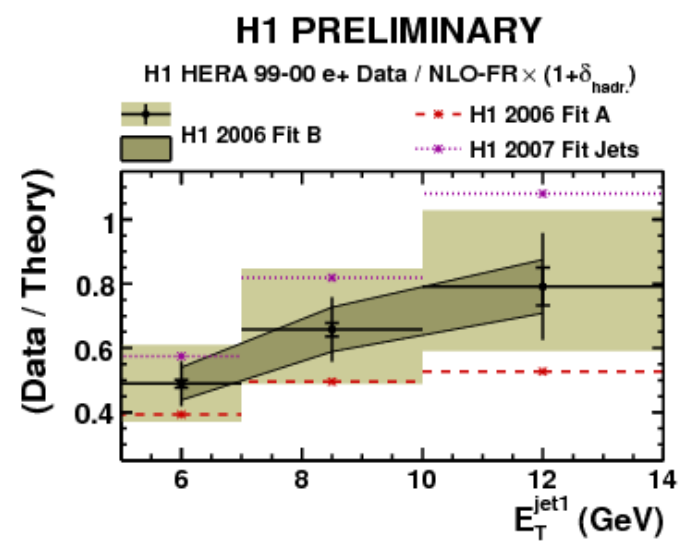
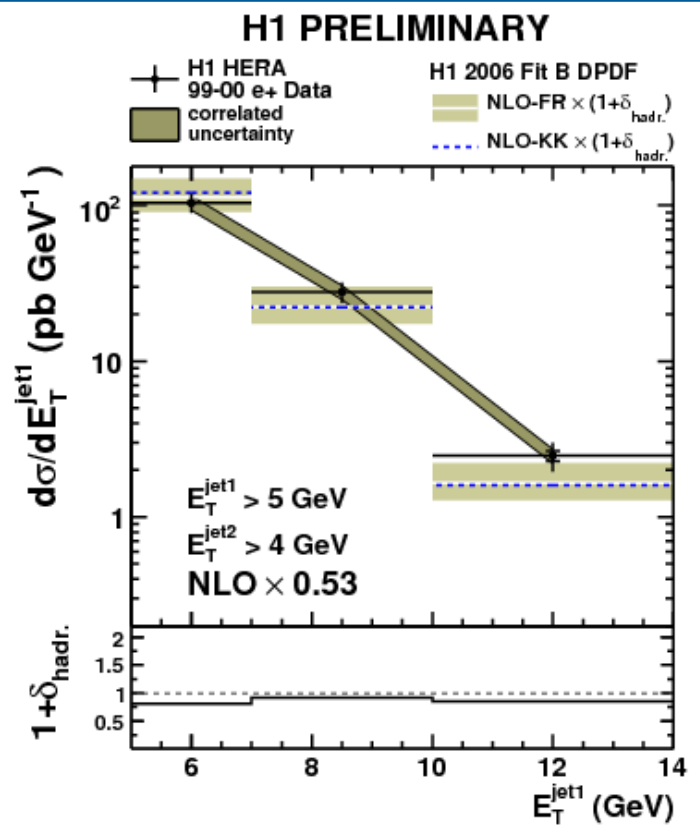


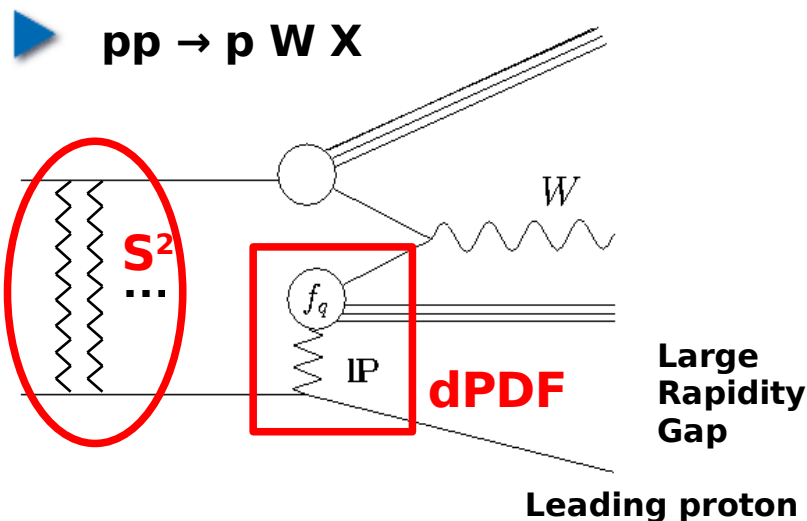
- Neither experiment observes a x_γ dependence
- H1 observes a larger suppression than ZEUS



E_T dependence of survival probability

- No evidence for any difference in survival probability for resolved and direct photons
- Harder E_T slope in data than in NLO theory
- H1 and ZEUS suppression factors are consistent





Motivation:

- Sensitive to quark component of diffractive PDF's
- Probe Rapidity Gap Survival Probability (S^2) – connection to multiple partonic interactions and soft rescattering effects

Selection uses additional fwd detectors of Run-II

(Miniplug calorimeter, Beam Shower Counters, RomanPot proton taggers)

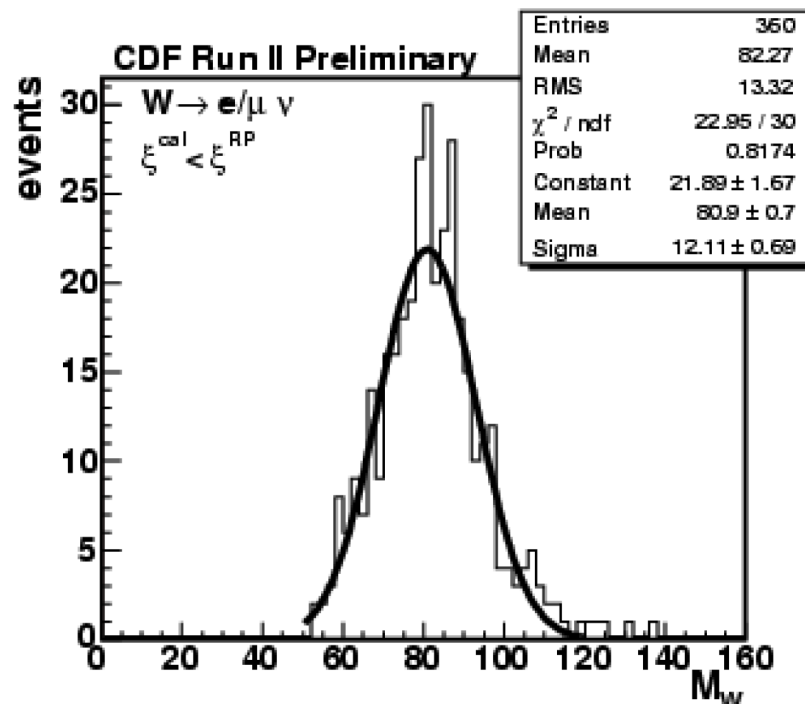
Diffractive W/Z results

$$R^W (0.03 < \xi < 0.10, |t| < 1) = [0.97 \pm 0.05(\text{stat}) \pm 0.11(\text{syst})]\%$$

Run I: $R^W = 1.15 \pm 0.55\%$ for $\xi < 0.1 \rightarrow$ estimate $0.97 \pm 0.47\%$ in $0.03 < \xi < 0.10$ & $|t| < 1$

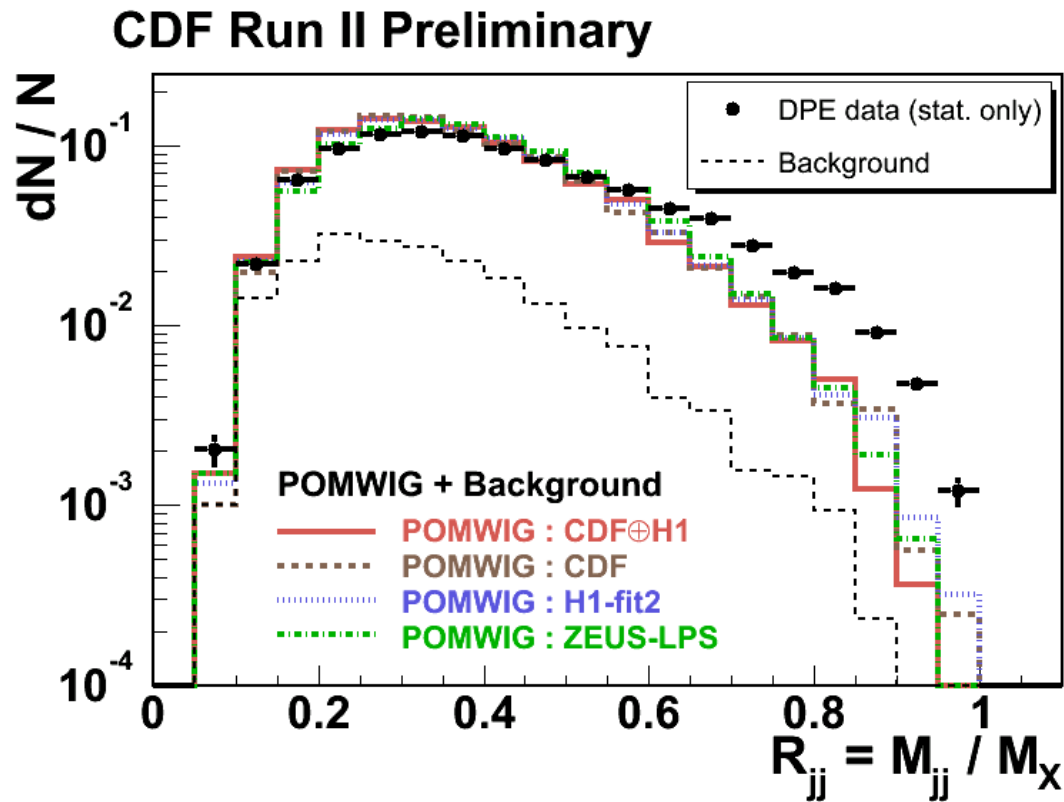
$$R^Z (0.03 < x < 0.10, |t| < 1) = [0.85 \pm 0.20(\text{stat}) \pm 0.11(\text{syst})]\%$$

In good agreement with rap gap acceptance corrected Run-I results of D0 and CDF



Central Exclusive Production at the TEVATRON

- Strategy: look for excess in dijet mass fraction $R_{jj} = M_{jj}/M_X$
 → expectation for CEP dijets $R_{jj} = 1$

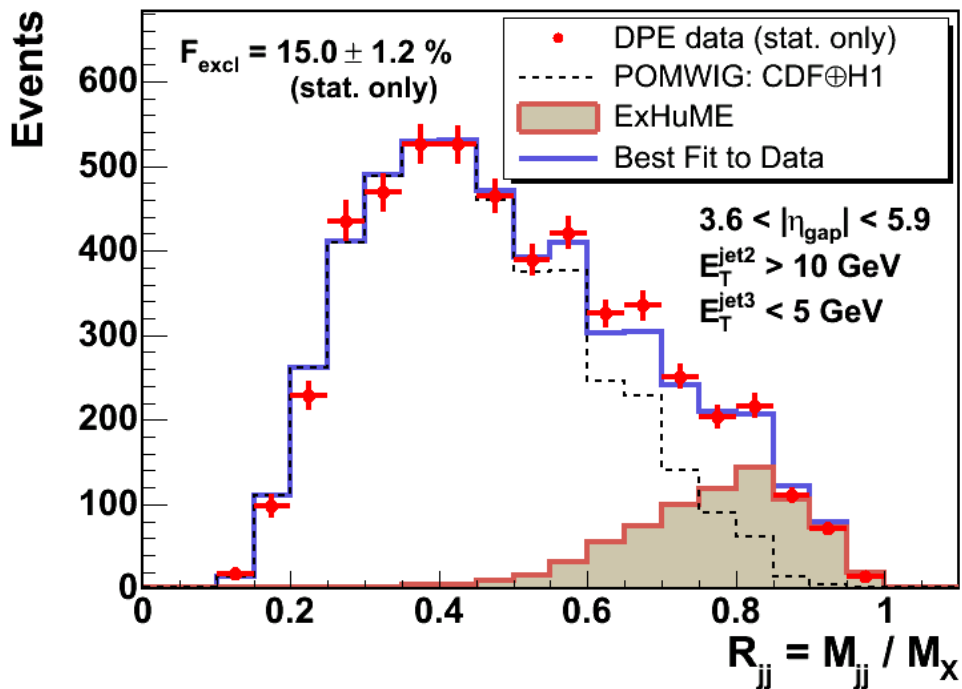


- Excess observed over POMWIG MC prediction at high R_{jj}
 (POMWIG does not include exclusive production)
- Excess is absent in exclusive b-tagged jets (expected due to $J_z = 0$ selection rule)

Comparison to CEP models

→ Fit R_{jj} distribution by POMWIG+CEP model with free normalisation

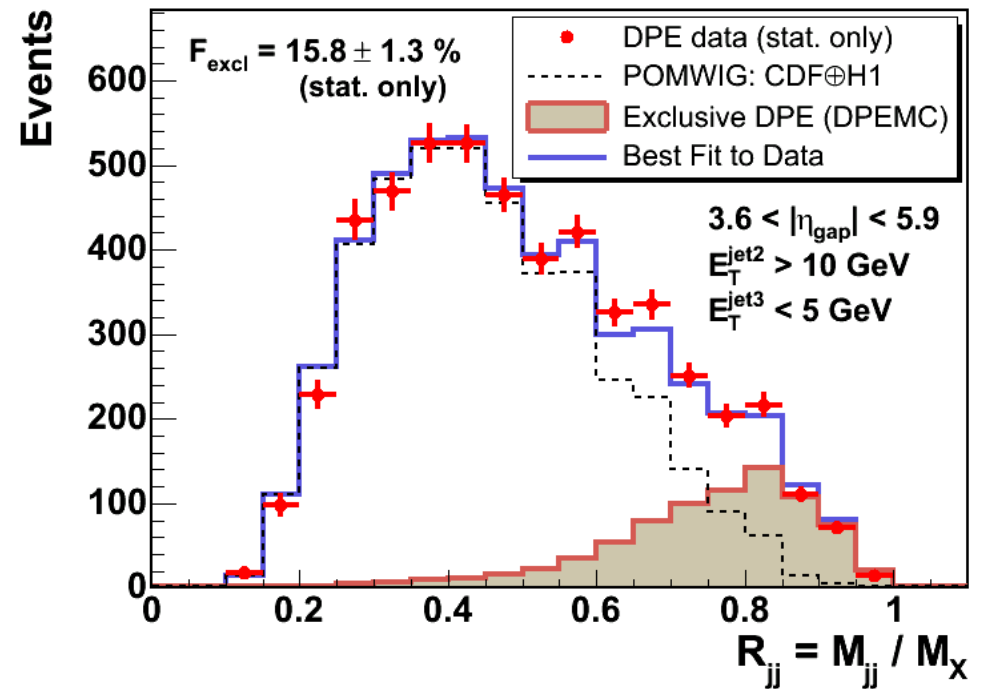
CDF Run II Preliminary



► **ExHuME:**

$gg \rightarrow gg$ process, based on LO pQCD calculation by Khoze-Martin-Ryskin

CDF Run II Preliminary



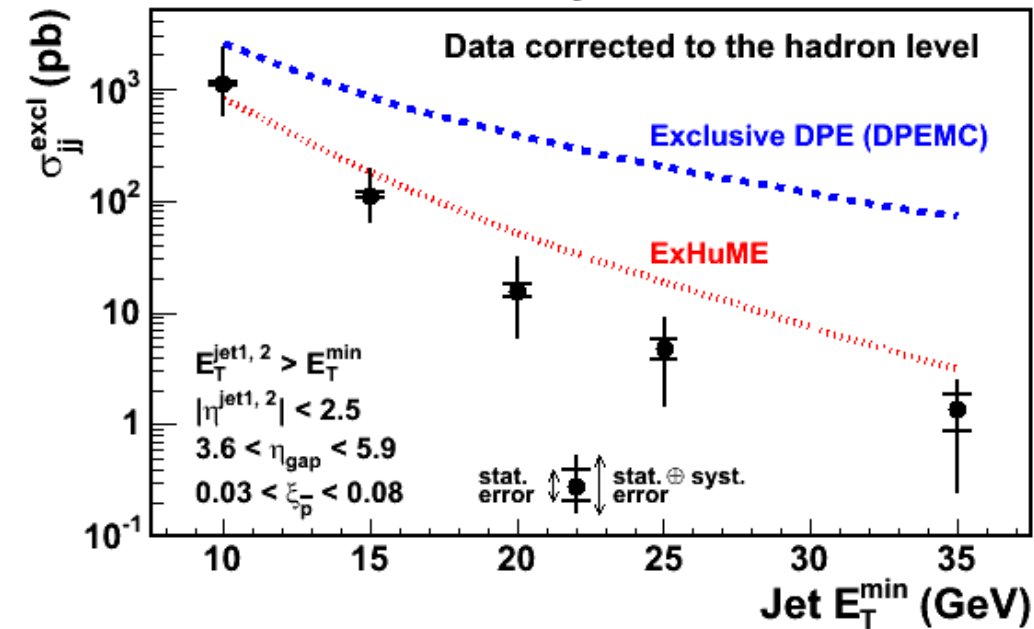
► **DPEMC:**

exclusive DPE MC based on Regge theory (Bialas-Landshoff model)

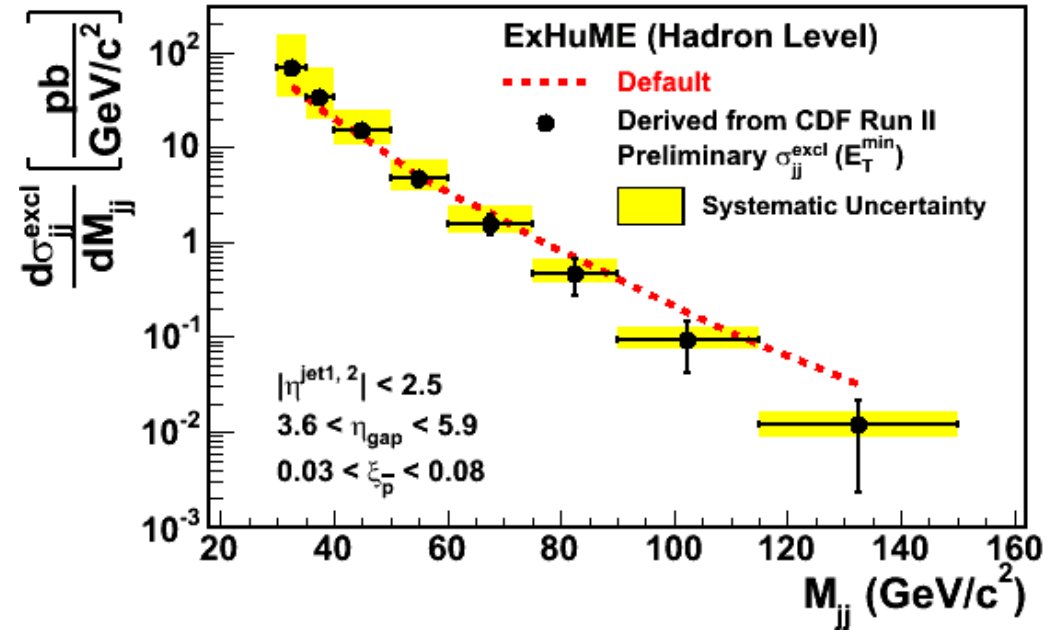
→ Both models describe excess of events at high R_{jj} well

Jet E_T and M_{jj} distributions

CDF Run II Preliminary



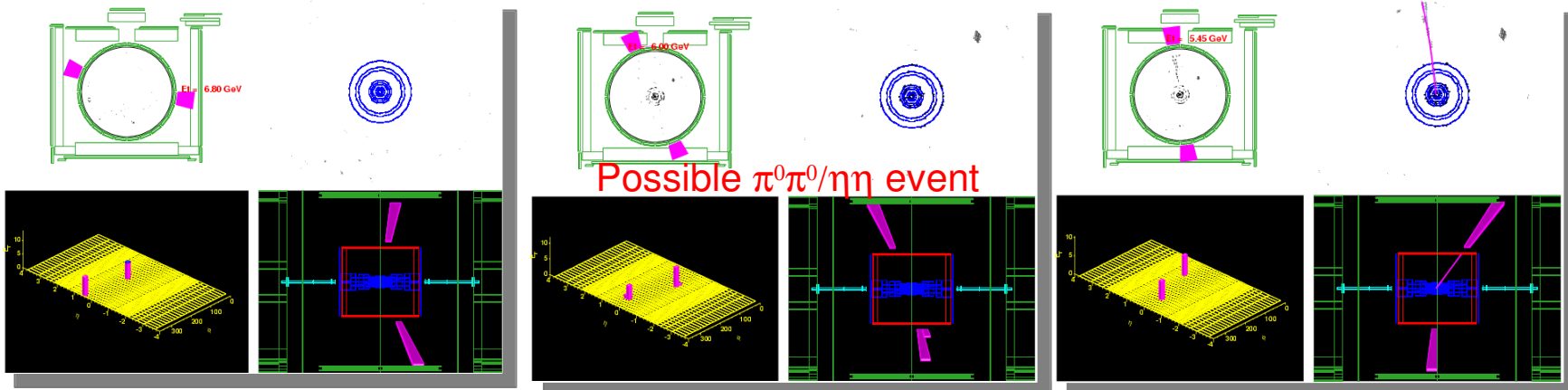
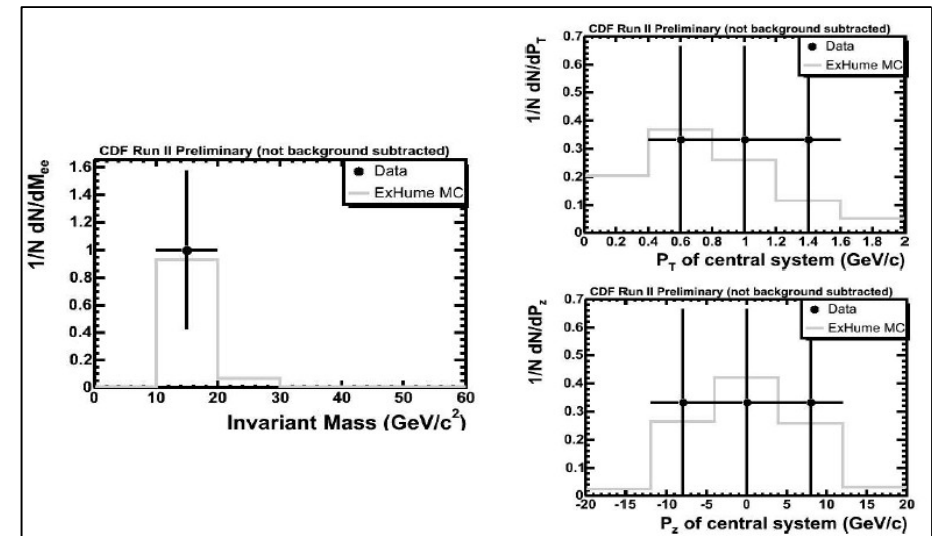
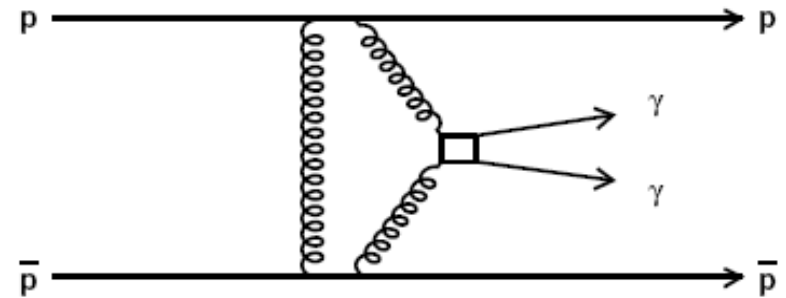
- Data favours ExHuME



- Good description of M_{jj} distribution by ExHuME (data fall slightly faster)

▶ $pp \rightarrow pp \gamma\gamma$

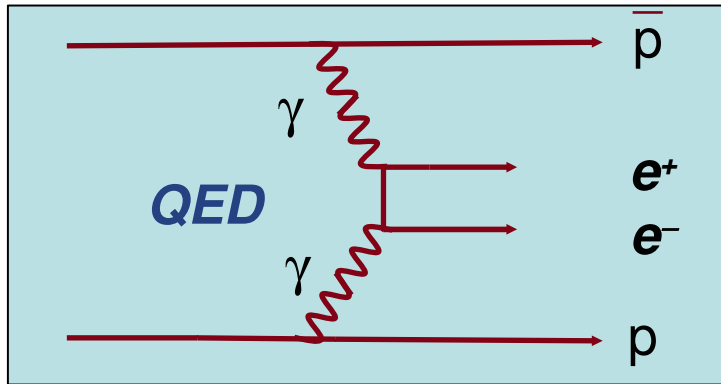
- 3 candidate events are found in 532 pb^{-1} of Run II data.
- Background 0.09 ± 0.04 events
- Good agreement on kinematics with ExHuME
- $0.8^{+1.6}_{-0.5}$ events predicted from ExHuME - 2 candidates are almost certainly $\gamma\gamma$ but the $\pi^0\pi^0/\eta\eta$ hypotheses cannot be excluded
- The upper limit of the cross-section $pp \rightarrow p \gamma\gamma p$ is set at 410 fb (95% CL)



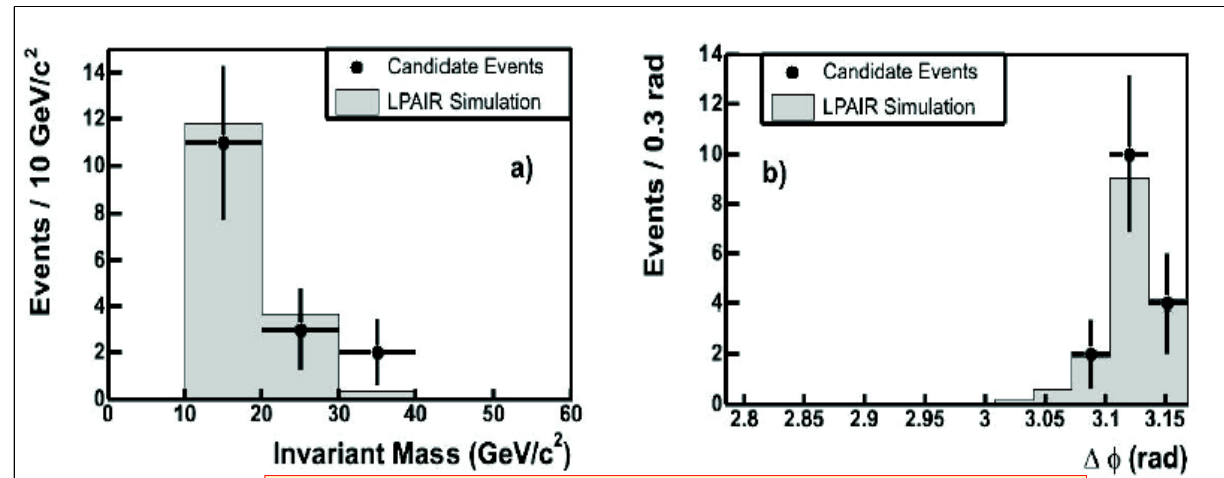


CEP Dileptons

▶ $pp \rightarrow pp e^+e^-$

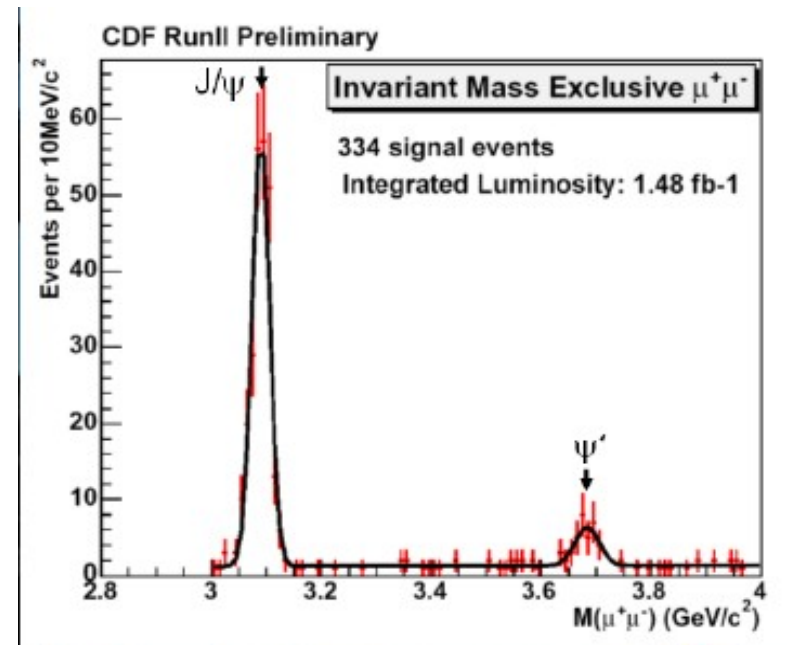
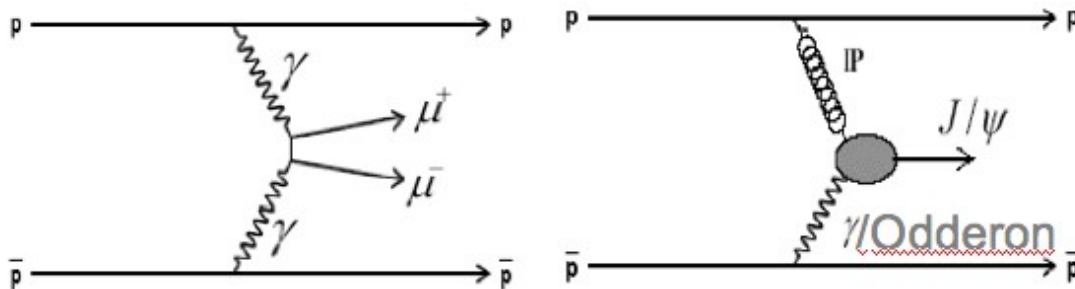


$$\sigma_{MEASURED} = 1.6^{+0.5}_{-0.3} (stat) \pm 0.3 (sys) pb$$



16 candidate e^+e^- events found
(expected background 1.9 ± 0.3)

▶ $pp \rightarrow pp \mu^+\mu^-$

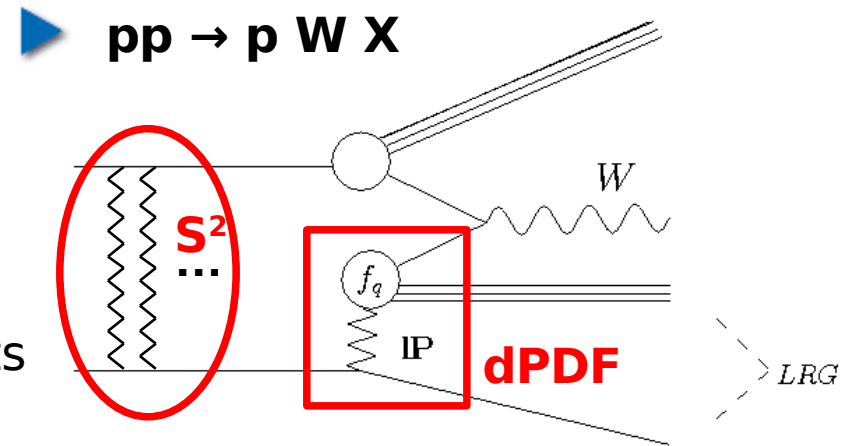


Forward look to LHC

Diffractive W production

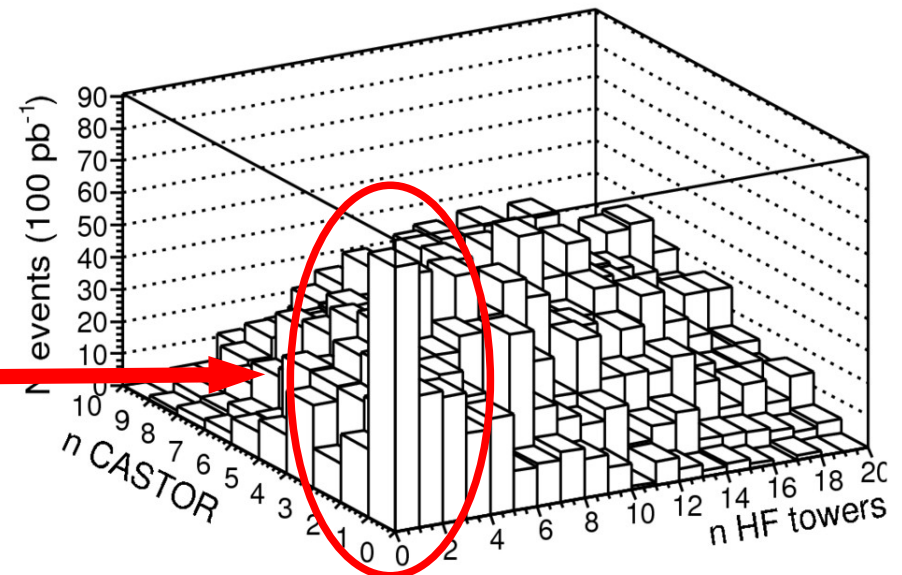
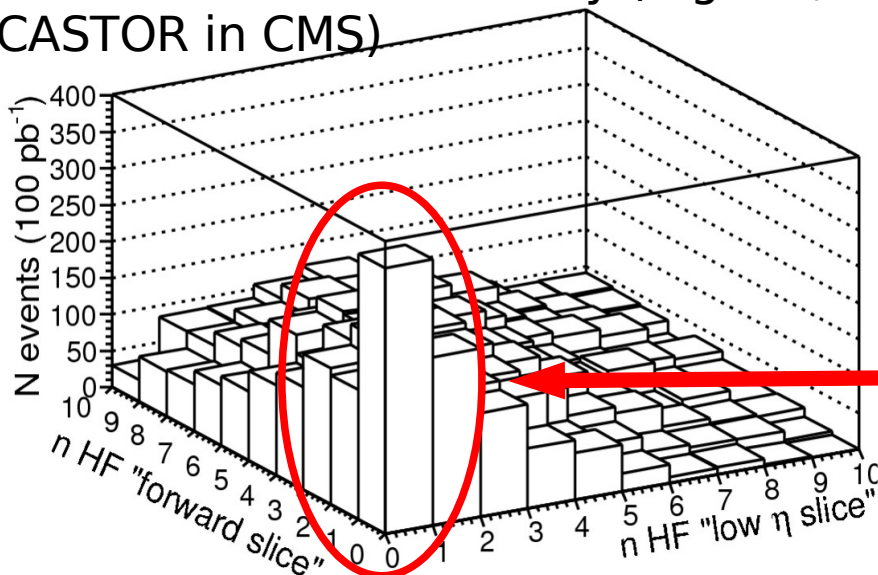
Motivation:

- Sensitive to quark component of diffractive PDF's
- Probe Rapidity Gap Survival Probability (S^2) – connection to multiple partonic interactions and soft rescattering effects



Rapidity gap selection:

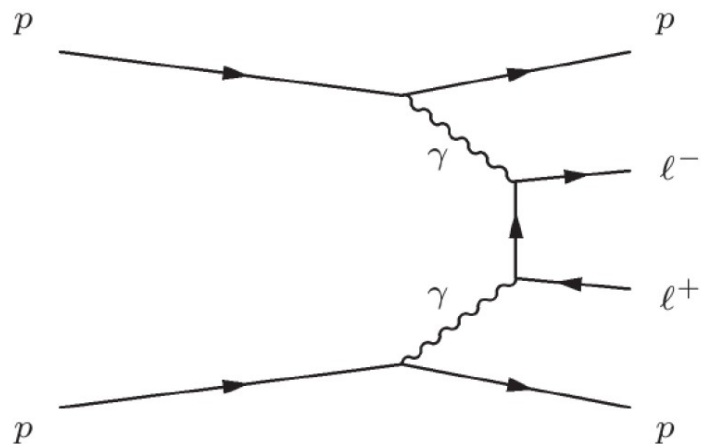
- Based on forward activity (e.g. HF, CASTOR in CMS)



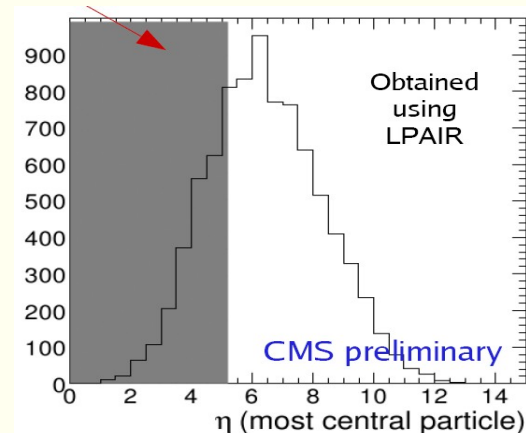
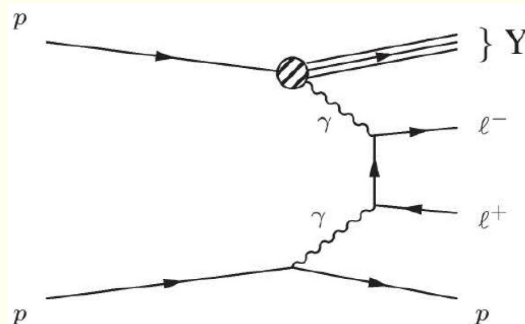
Much better rejection of non-diffractive background with CASTOR (S/B \rightarrow 20)
 ZDC reduces diffractive dissociation background by 50%

Exclusive dilepton production

▶ $pp \rightarrow pp l^+l^-$



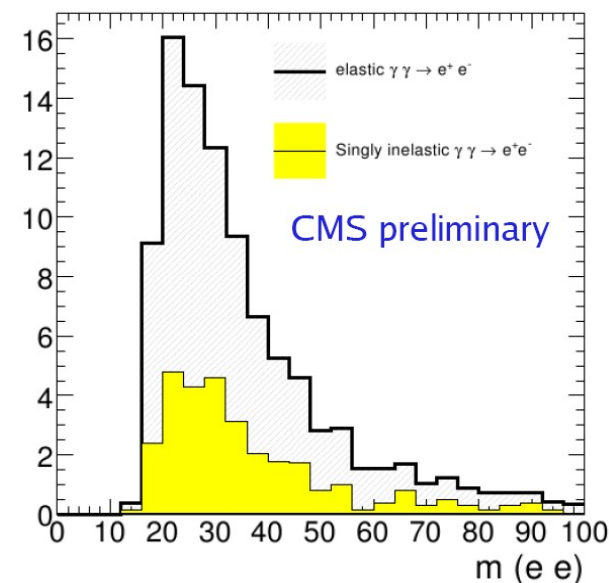
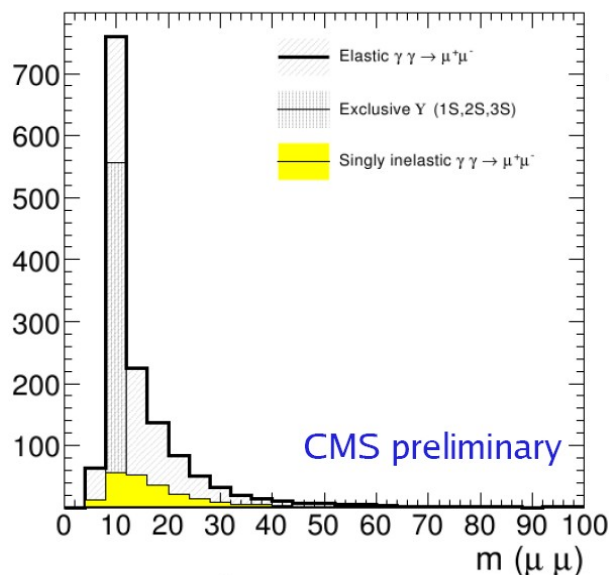
Inelastic background



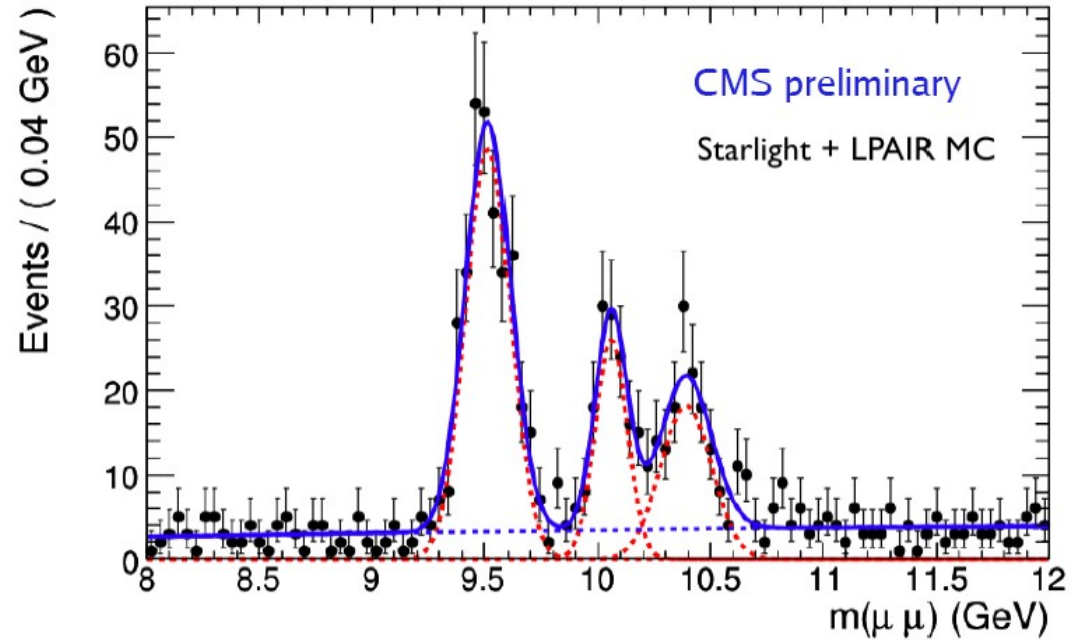
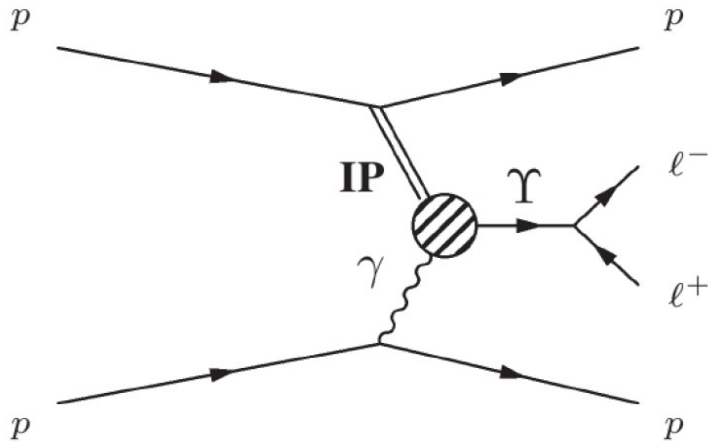
→ can be reduced using CASTOR/ZDC

Motivations:

- Nearly pure QED process
→ luminosity monitoring (precision of 4% is feasible)
- Study of lepton identification
- Calibration of forward proton detectors

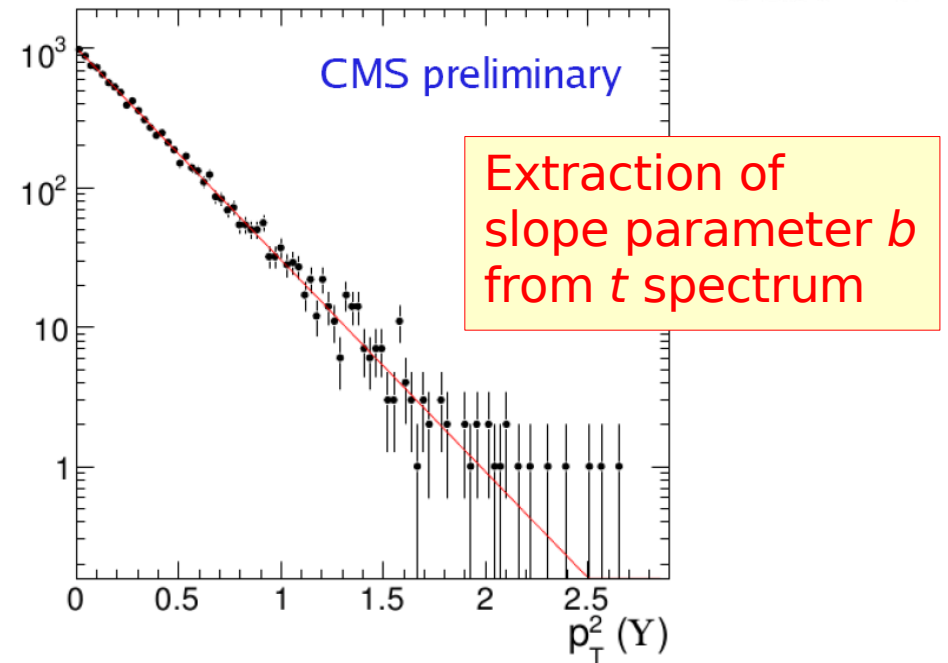


► $pp \rightarrow pp\Upsilon, \Upsilon \rightarrow l^+l^-$

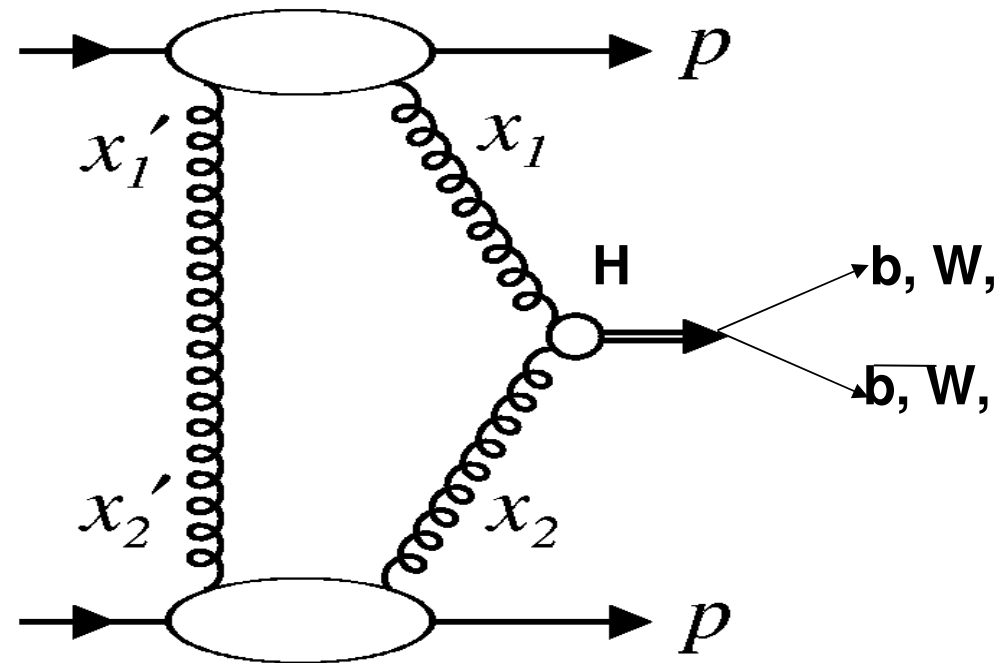


Motivations:

- Measure gluon distribution in proton at low x
- Constrain diffractive/QCD models
- Alignment of forward proton detectors



- Advantages of CEP Higgs channel
 - QCD $b\bar{b}$ background suppressed due to $J_z = 0$ selection rule
 - Determination of m_H through outgoing proton momentum measurement
 - Azimuthal angular correlations yield spin-parity of Higgs
- CEP of dijets, diphotons, χ_c can serve as standard candles to calibrate models
- KMR (supported by CDF CEP dijet measurement) predicts $\sigma(p p \rightarrow p H p) = 3 \text{ fb}$ for a SM Higgs at the LHC
- Discovery possibilities for MSSM, NMSSM Higgs scenarios...



Summary



Summary

- ▶ HERA measurements of inclusive DDIS give consistent results for all methods and experiments
- ▶ DPDFs are extracted; H1 Jets 2007 DPDF most precise
- ▶ No suppression observed in DPHP dijets for resolved photons; survival factor does seem to increase for higher E_T jets
- ▶ CEP dijet production is observed at the TEVATRON and can serve as “standard candle” process for CEP Higgs
- ▶ KMR model for CEP has been validated by data
- ▶ Plans to establish diffractive signals are being developed at the LHC
- ▶ CEP Higgs production has some advantage over inclusive channels and discovery potential in some MSSM and NMSSM Higgs scenarios

Thanks to Monika Grothe, Daniel Elvira, Sasha Pranko and the DIS08 summary speakers