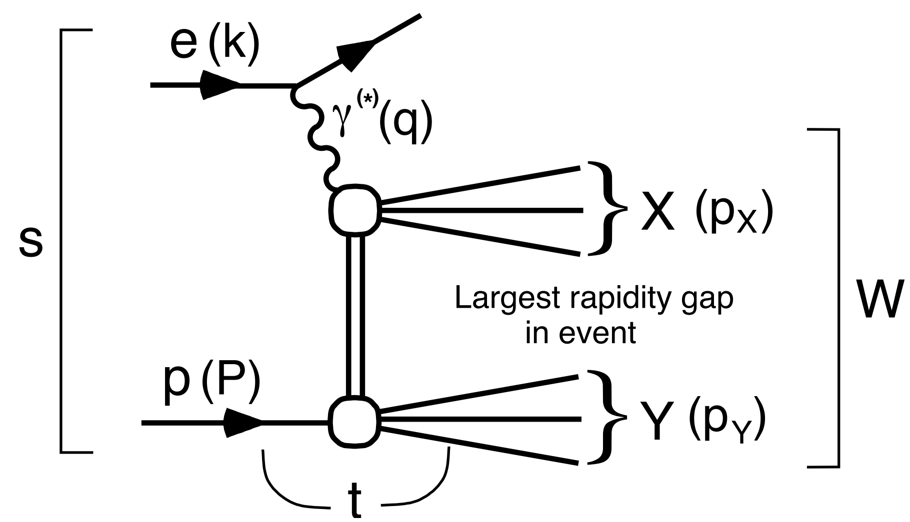
Diffractive factorisation and diffractive PDFs

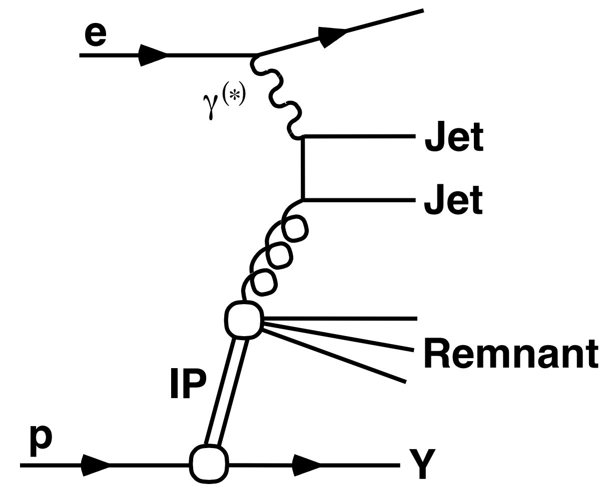
Roman Pasechnik
Lund U.

Diffractive factorisation scheme: diffractive di-jet

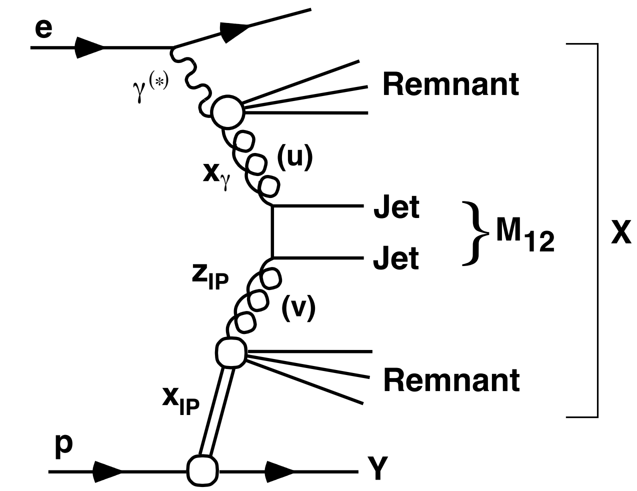
generic diffractive scattering at HERA



LO di-jet (photon-gluon)



LO di-jet (gluon-gluon)



Introduce a hard scale to probe "parton skeleton" of the Pomeron!

Access to gluon content of the Pomeron!

DIS kinematics

$$Q^2 \equiv -q^2 \,, \qquad y \equiv \frac{q \cdot P}{k \cdot P} \,, \qquad x \equiv \frac{Q^2}{2P \cdot q} \qquad Q^2 \approx sxy \qquad s \equiv (k+P)^2$$

$$W = \sqrt{(q+P)^2} \approx \sqrt{y\,s - Q^2} \qquad M_X^2 \equiv p_X^2 \,, \quad M_Y^2 \equiv p_Y^2 \,, \quad t \equiv (P - p_Y)^2 \,, \quad x_{I\!P} \equiv \frac{q \cdot (P - p_Y)}{q \cdot P}$$

factorisation formula

$$\boxed{\begin{aligned} d\sigma(ep \to e + 2\,\mathrm{jets} + X' + Y) \;&= \sum_{i,j} \int \mathrm{d}y\, f_{\gamma/e}(y) \int \mathrm{d}x_\gamma\, f_{j/\gamma}(x_\gamma, \mu_F^2) \;\times \\ &\times \int \mathrm{d}t \int \mathrm{d}x_{I\!P} \int \mathrm{d}z_{I\!P}\; d\hat{\sigma}(ij \to 2\,\mathrm{jets})\, f_i^D(z_{I\!P}, \mu_F^2, x_{I\!P}, t)\end{aligned}}$$

- ✓ **Diffractive PDFs are non-universal**
- ✓ **They can not be exported to describe other hard diffractive processes (e.g. in pp)**
- ✓ **We need to calculate the survival probability of the LRG's which is process-dependent**

Regge factorisation scheme

We have two different factorisations:

- diffractive fact.n: proven by Collins for a hard diffractive scattering (hep-ph/9709499)
- Regge fact.n: relates the power of $x_{\mathbb{P}}$ in diffractive DIS to the power of s in hadron-hadron elastic scattering and can be broken

Pomeron PDFs

DPDF $$f_i^D(z_{I\!P}, \mu_F^2, x_{I\!P}, t) = f_{I\!P}(x_{I\!P}, t)\; f_{i,I\!P}(z_{I\!P}, \mu_F^2)$$

soft and hard scales are separated!

Berera, Soper PRD'96

universal (soft) Pomeron flux in the proton (Regge theory)

DGLAP-evolved parton density in the Pomeron

At larger x subleading "Reggeon" is to be included

fit to inclusive diffraction data by H1 (2006) and ZEUS (2009)

$x_{I\!P} > 0.01$

$$\ldots + f_{IR}(x_{IP}, t) f_i^{IR}(z, Q^2)$$

Reggeon PDFs taken from pion (GRV)

Fit z and Q^2 dependence at fixed x_{IP} and t

Flux parametrisation

$$f(x_{IP}, t) = \frac{Ae^{Bt}}{x_{IP}^{2\alpha(t)-1}}$$

with $\alpha(t) = \alpha(0) + \alpha' t$

- ✓ DPDFs are extracted from global NLO fits of inclusive diffraction data at HERA
- ✓ Predictions based upon extracted DPDFs are fairly consistent with theoretical models
- ✓ Important tool for diffractive factorisation breaking studies (especially in had-had coll.)

Pomeron PDFs parameterization: HERA fits

starting scale parameterisation:

$$z f_k^{IP}(z, Q_0^2) = A_k \, z^{B_k} \, (1-z)^{C_k}$$ **with k=g,S at** $Q_0^2 = 1.8\,\mathrm{GeV}^2$

basic assumptions:

- for all flavors q=qbar
- d = u = s is assumed
- dynamical generation of heavy Q PDFs above thresholds (Thorne, Roberts)

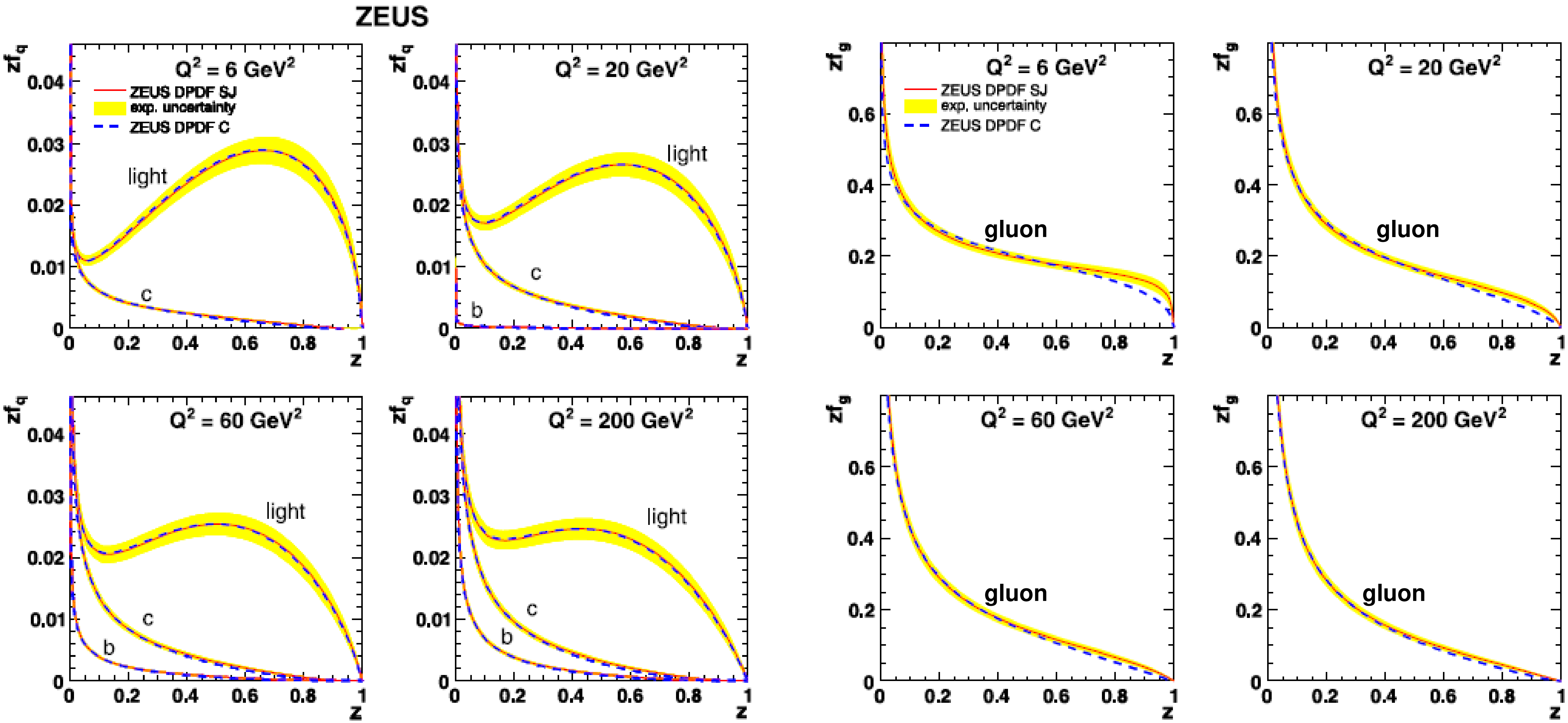
→ **in general, six free parameters** + $\alpha_{IP}(0),\ \alpha_{IR}(0),\ A_{IR}$

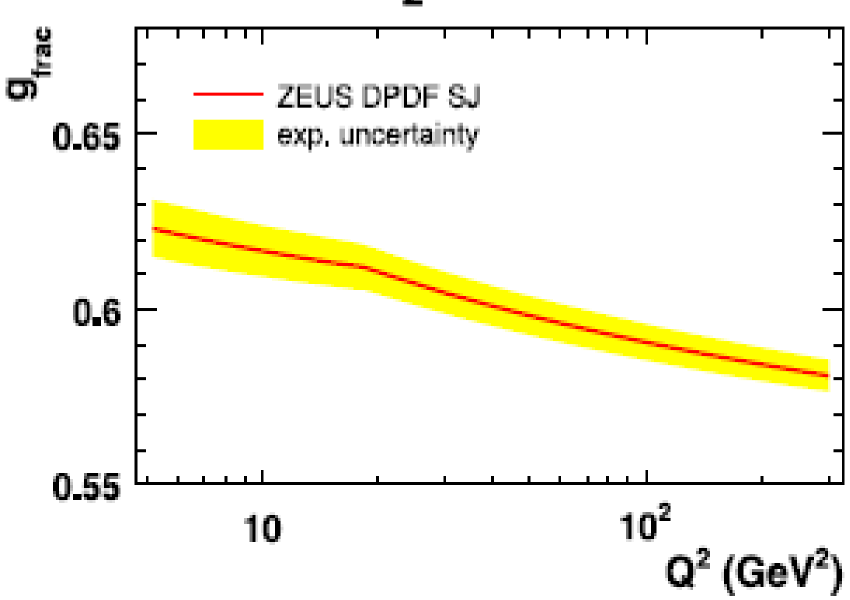
b and α' fixed by Regge fits to ep and pp data

- gluons are poorly constrained by inclusive data (log Q dependence)
- diffractive di-jets improved the fits for gluons
- two cases are considered: “Standard”: fit S with B_g and C_g free
  “Constant”: fit C with $B_g = C_g = 0$ H1 2006 fit B

fits have been performed separately by ZEUS and H1 Colls → **an agreement between different inclusive diffraction data, jets in DDIS and theory predictions**

Gluon fraction in diffractive PDFs

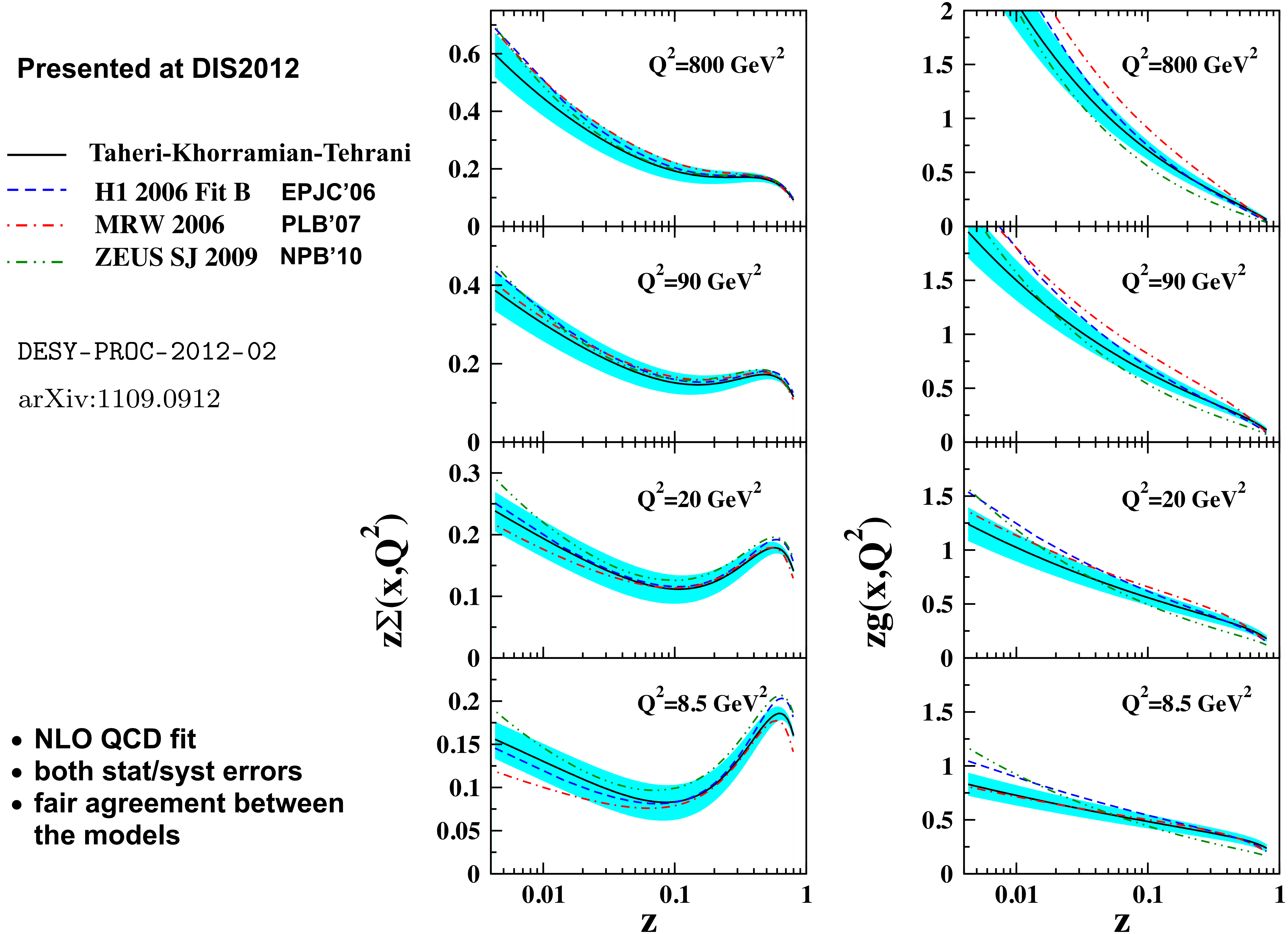




diffractive PDFs are gluon dominated (~60 %)!

Uncertainties in DPDFs

Presented at DIS2012



DESY-PROC-2012-02

arXiv:1109.0912

- NLO QCD fit
- both stat/syst errors
- fair agreement between the models

Diffractive factorisation tests at HERA

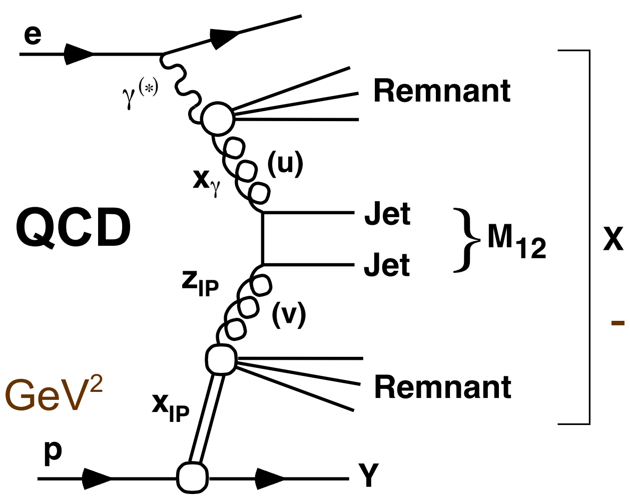
NLO pQCD with two-gluon exchange and gluon TMD ⟷ **predictions with DPDFs fitted to inclusive diffractive data**

Diffractive di-jet photoproduction

$Q^2 < 2$ GeV^2

LO QCD

$|t| < 0.6$ GeV^2

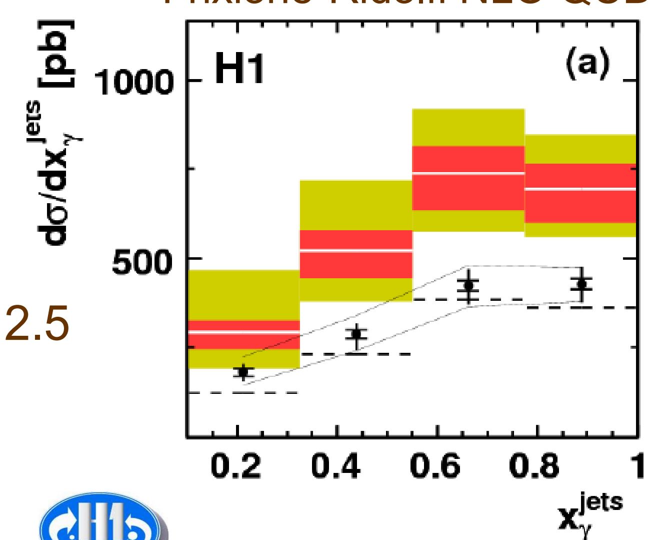


$-1 < \eta^{jet1(2)} < 2.5$

Eur. Phys. J. C68 (2010) 381

$E_T^{jet1(2)} > 5(4)$ GeV

Frixione-Ridolfi NLO QCD

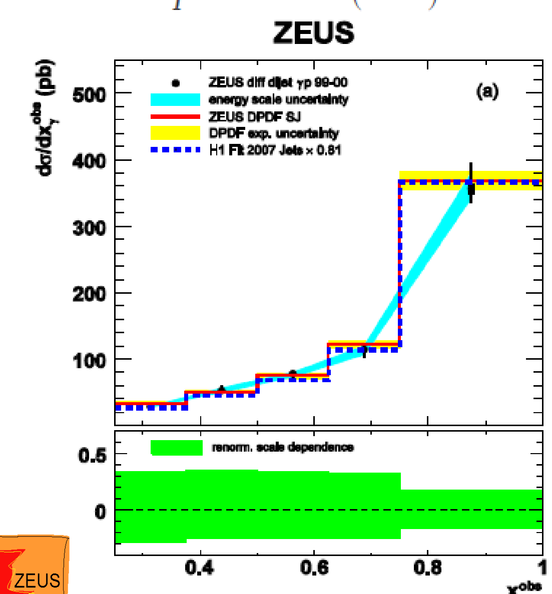


$\sigma_{data}^{H1}/\sigma_{NLO}^{H1} \approx 0.6$

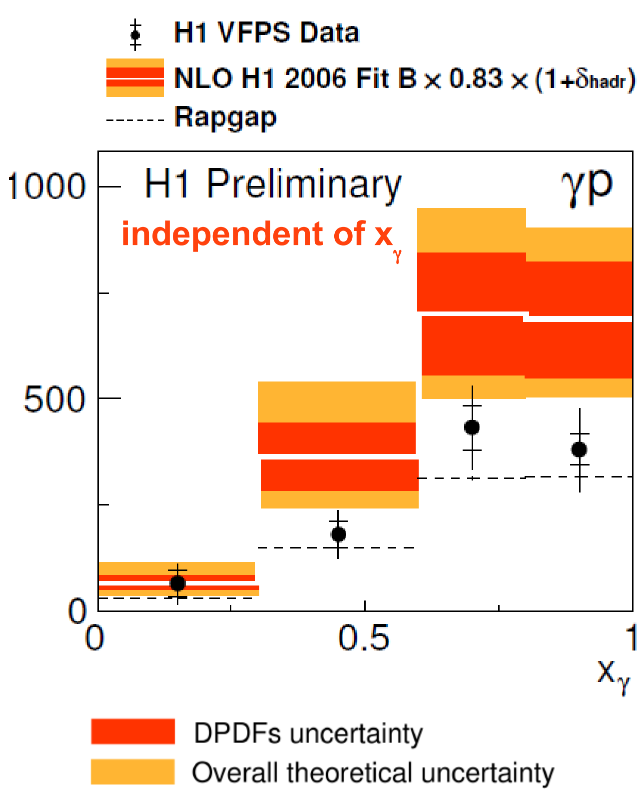
tension?

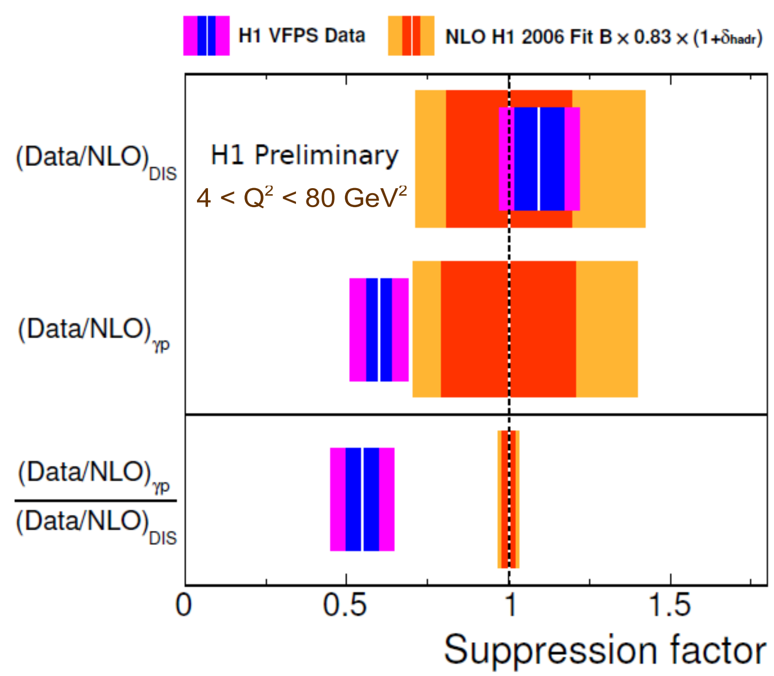
Nucl. Phys. B381 (2010)

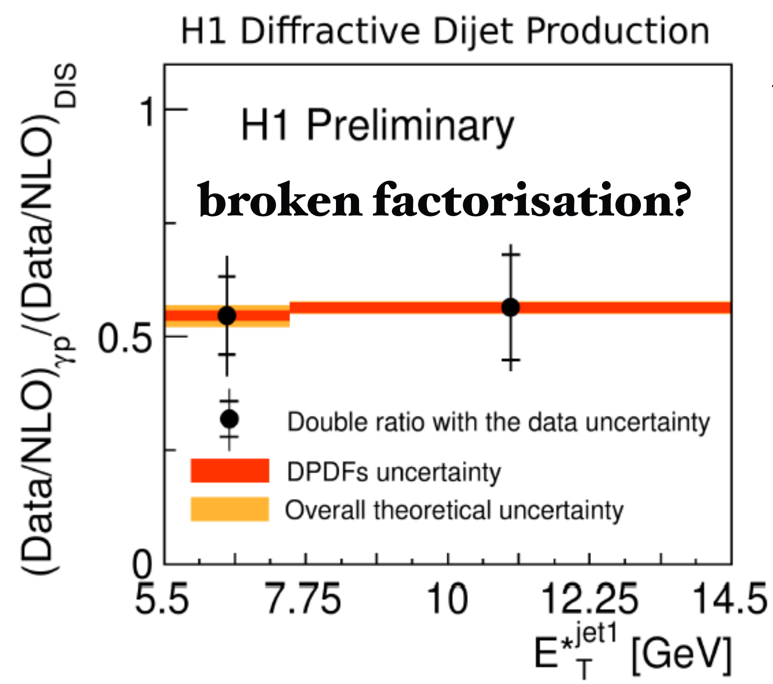
$E_T^{jet1(2)} > 7.5(6.5)$ GeV



$\sigma_{data}^{ZEUS}/\sigma_{NLO}^{ZEUS} \approx 1.0$







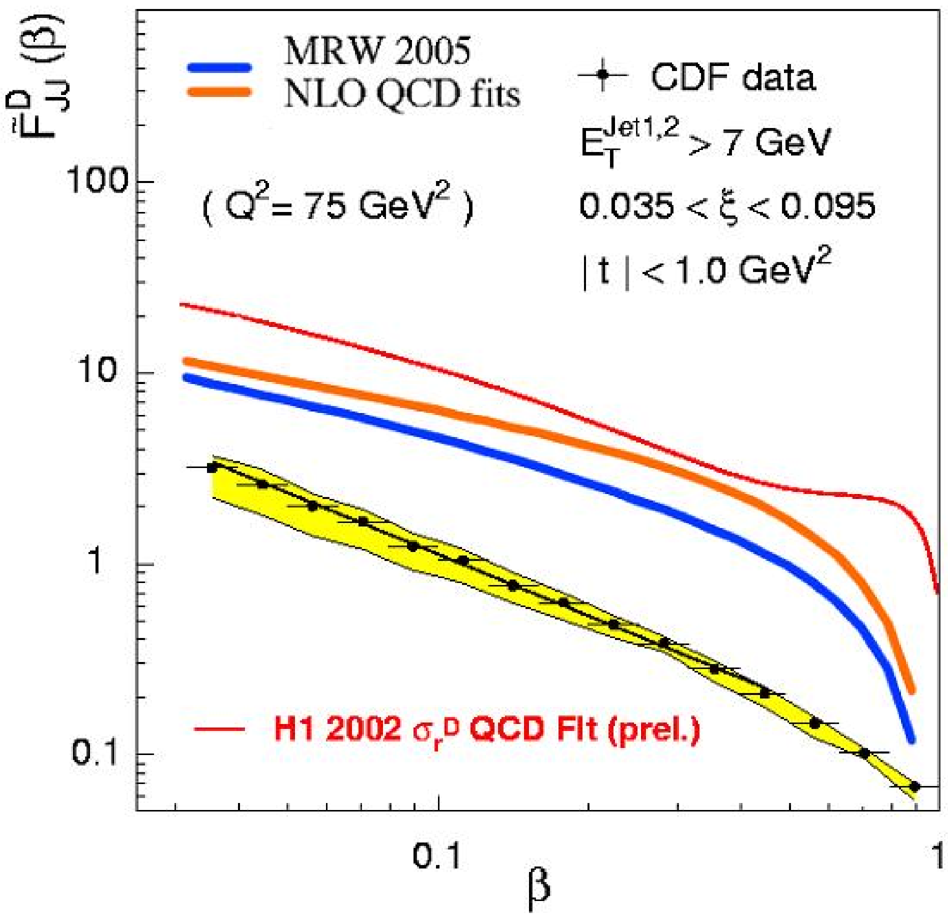
broken factorisation?

updated H1 analysis does not explain the discrepancy!

more in talk by Ewelina...

Diffractive factorisation breaking in pp collisions

Incoming hadrons are not elementary — experience soft interactions dissolving them leaving much fewer rapidity gap events than in ep scattering



Sources of Regge factorisation breaking:

- ✓ soft survival (=absorptive) effects (Khoze-Martin-Ryskin and Gotsman-Levin-Maor) affecting e.g. the Pomeron flux (Goulianos)
- ✓ interplay of hard and soft fluctuations in incoming hadron wave function
- ✓ saturated shape of the universal dipole cross section for large dipole sizes

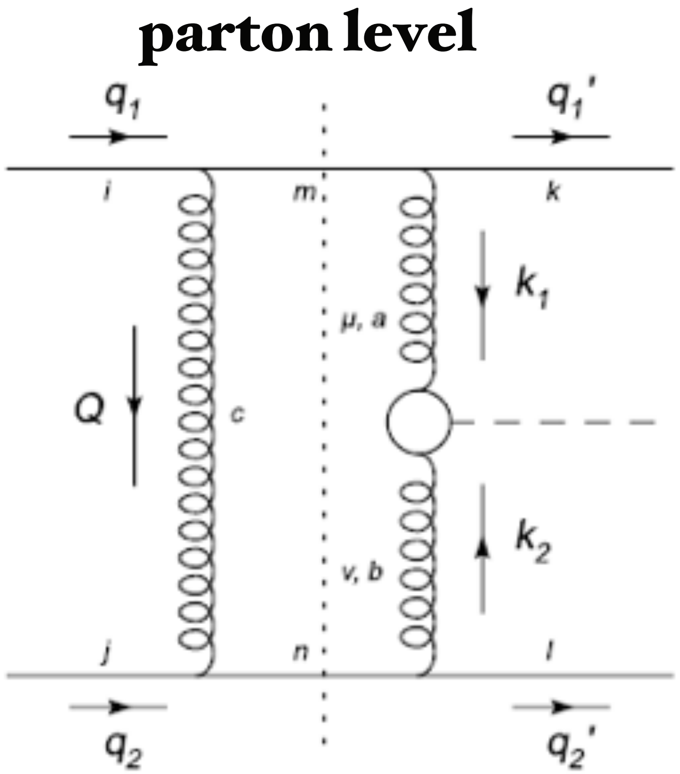
Two distinct approaches treating the above effects:

- ✓ **Regge-corrected (KMR) approach** — the first source of Regge factorisation breaking is accounted at the cross section level by "dressing" QCD factorisation formula by soft Pomeron exchanges
- ✓ **Color dipole approach** — the universal way of inclusive/diffractive scattering treatment, accounts for all the sources of Regge factorisation breaking at the amplitude level (Kopeliovich, RP et al)

Central exclusive Higgs... etc production

The Durham (KMR) model

implemented in ExHuME MC

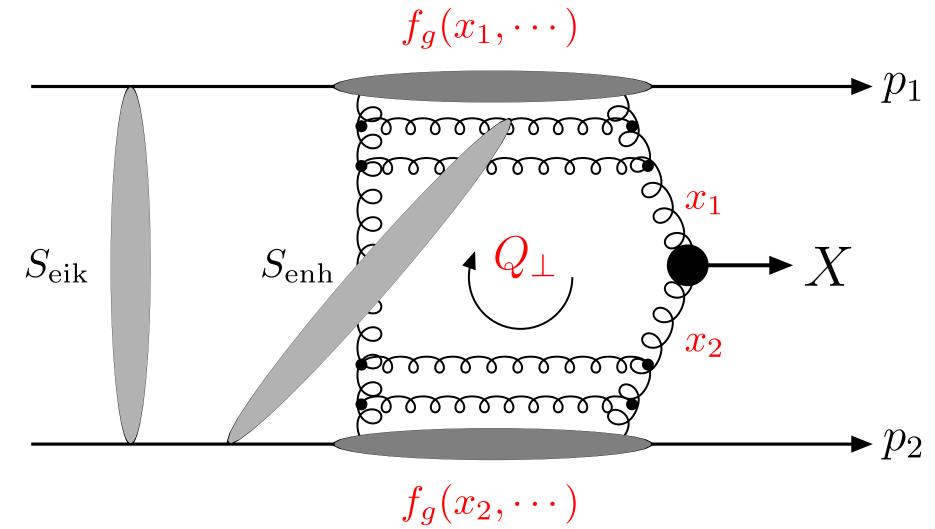


In the forward limit

$$\epsilon_i \sim k_{it}$$

$$Q_t = -k_{1t} = k_{2t}$$

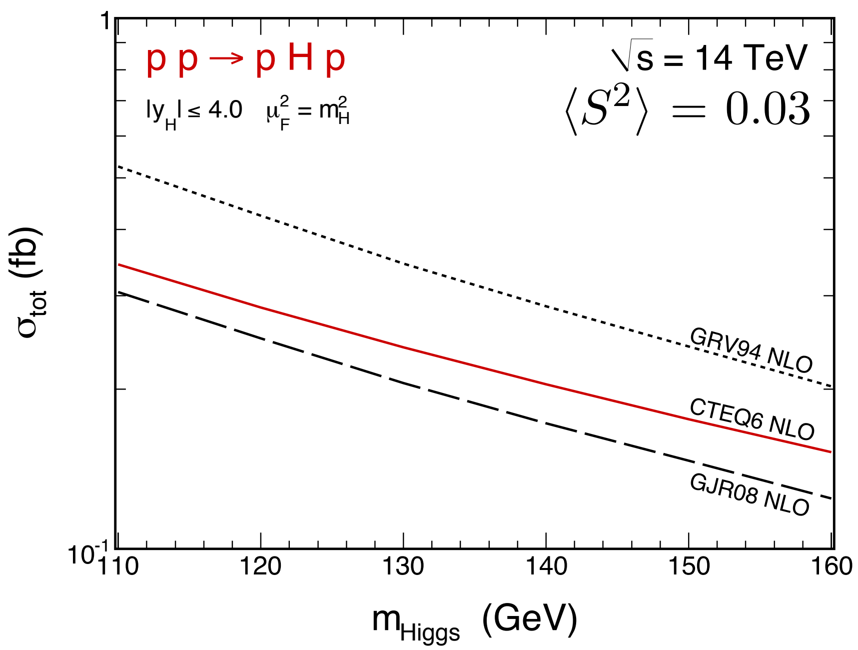
Spin-parity analyser!

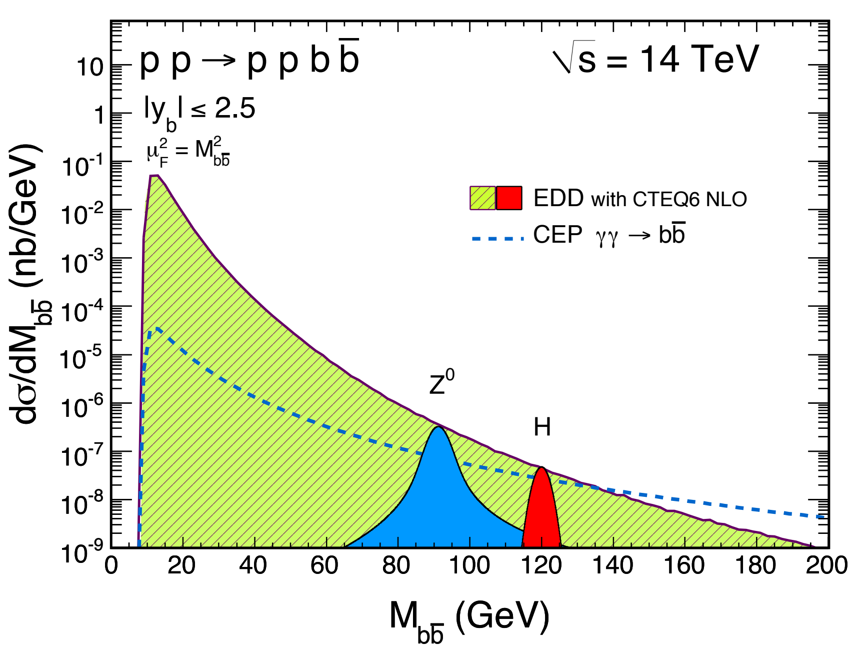


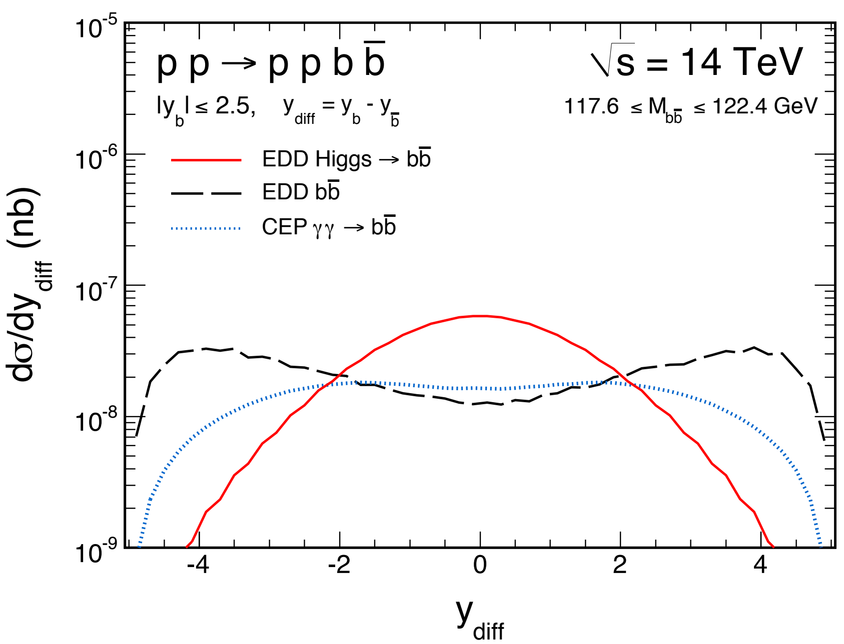
- Correct inclusion of Sudakov factor — JHEP 1001 (2010) 121
- Consistent treatment of 'skewed' gluon PDFs — Phys. Rev. D88 (2013) 034029
- Latest model of soft survival effects — Eur.Phys.J. C73 (2013) 2503

Small CS/large uncertainties

Large irreducible backgrounds



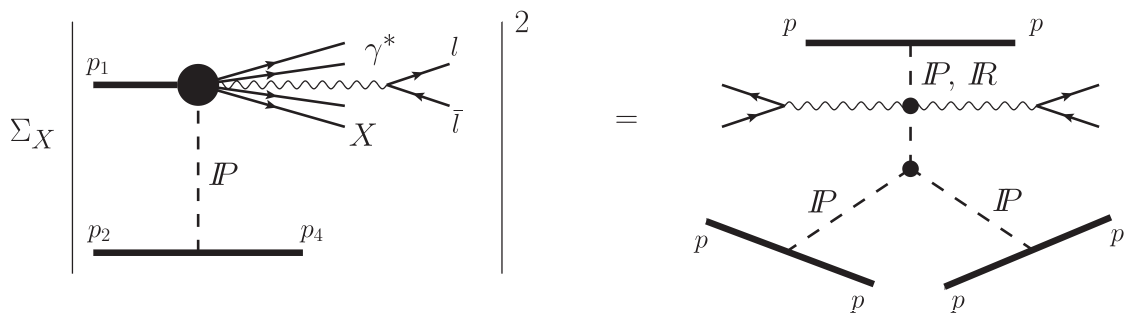




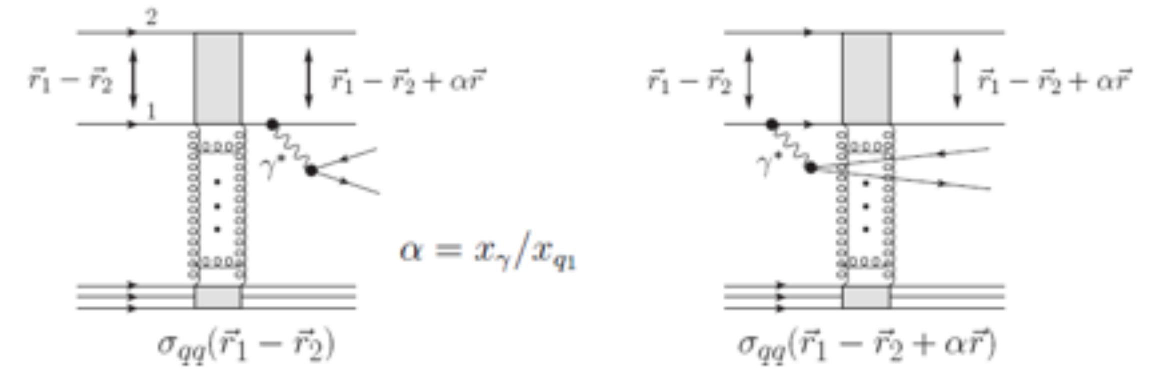
RP + Krakow group

Higgs CEP was proven to be hardly feasible at the LHC...

Hadronic diffraction via dipoles: diffractive Drell-Yan



Diffractive Drell Yan (semi-hard)



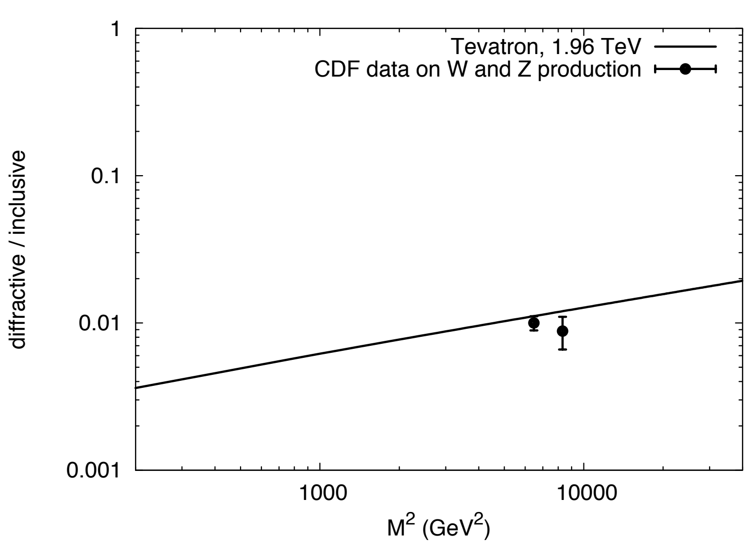
interplay between hard and soft fluctuations is pronounced!

superposition has a Good-Walker structure

$$\propto \sigma(\vec{R}) - \sigma(\vec{R} - \alpha\vec{r}) = \frac{2\alpha\,\sigma_0}{R_0^2(x_2)}\, e^{-R^2/R_0^2(x_2)} \left(\vec{r}\cdot\vec{R}\right) + O(r^2)$$

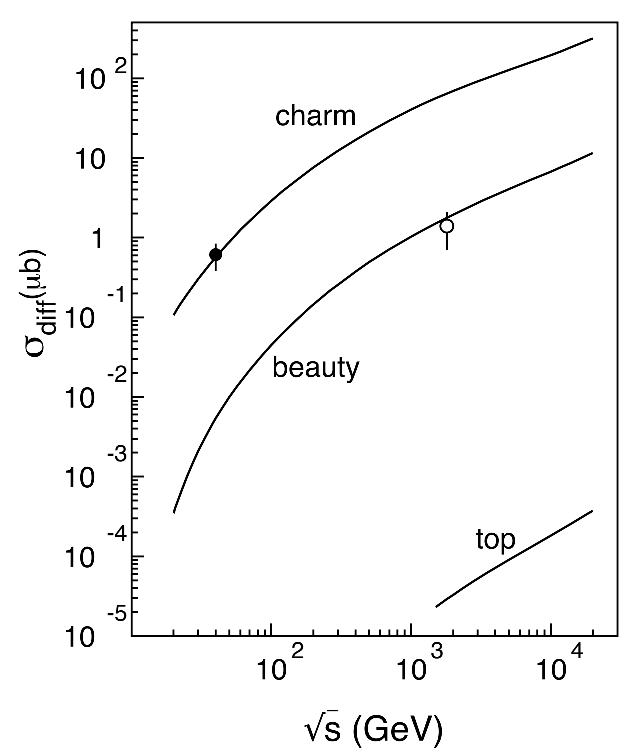
Diffractive DIS $\propto r^4 \propto 1/M^4$ vs diffractive DY $\propto r^2 \propto 1/M^2$

SD DY/gauge bosons



RP et al 2011,12

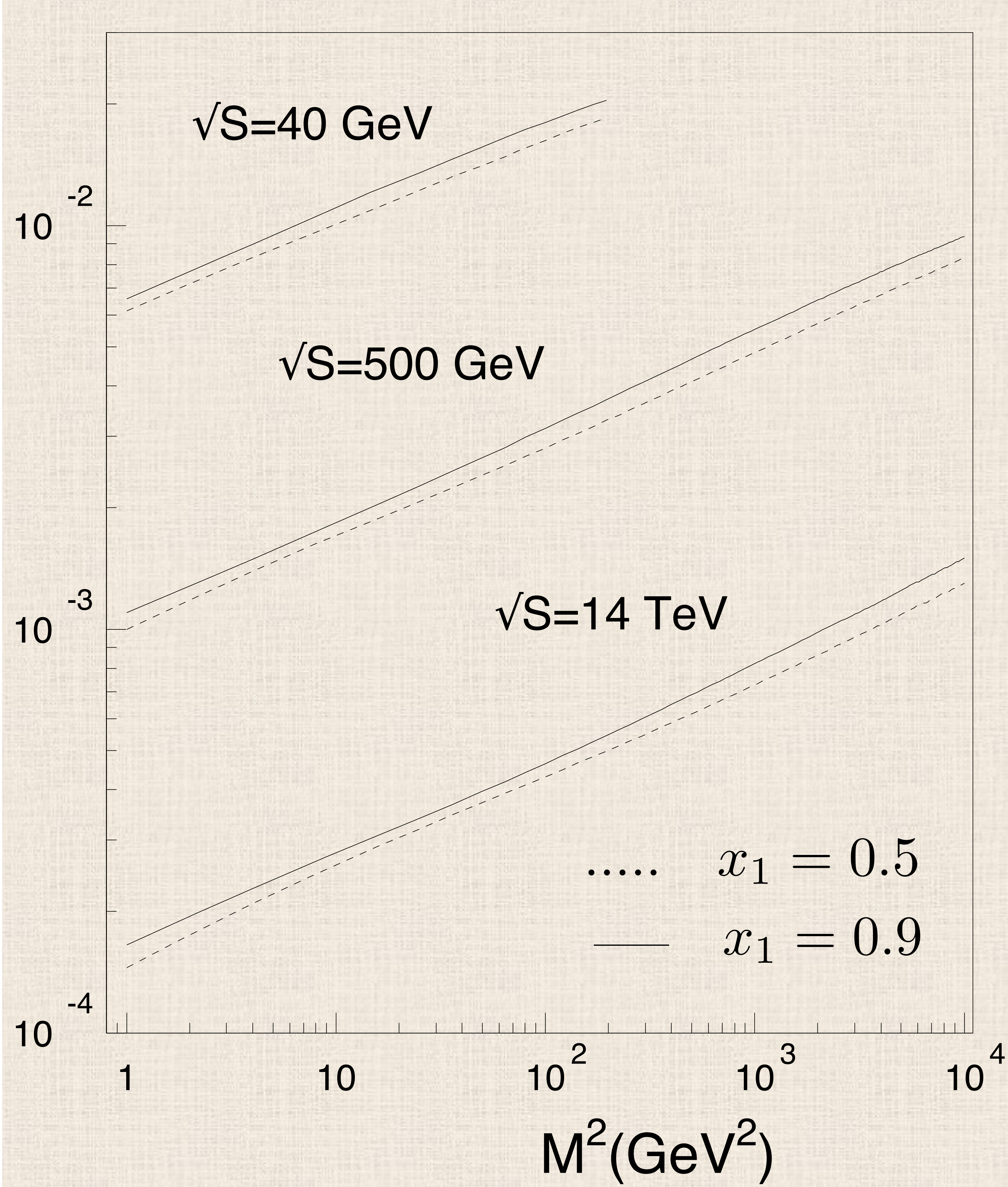
SD heavy quarks



Kopeliovich et al 2006

- ★ *diffractive factorisation is automatically broken*
- ★ *any SD reaction is a superposition of dipole amplitudes*
- ★ *gap survival is automatically included at the amplitude level on the same footing as dip. CS*
- ★ *works for a variety of data in terms of universal dip. CS*

Sophisticated dipole cascades are being put into MC: Lund Dipole Chain model (DIPSY)
Ref. G. Gustafson, and L. Lönnblad

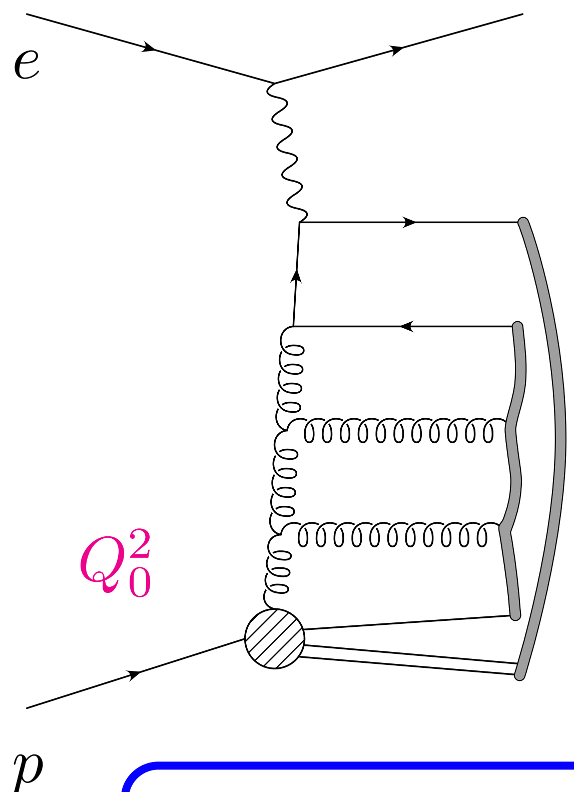

√S=40 GeV
√S=500 GeV
√S=14 TeV
10^{-2}
10^{-3}
10^{-4}
1
10
10^2
10^3
10^4
..... $x_1 = 0.5$
— $x_1 = 0.9$
$M^2(GeV^2)$

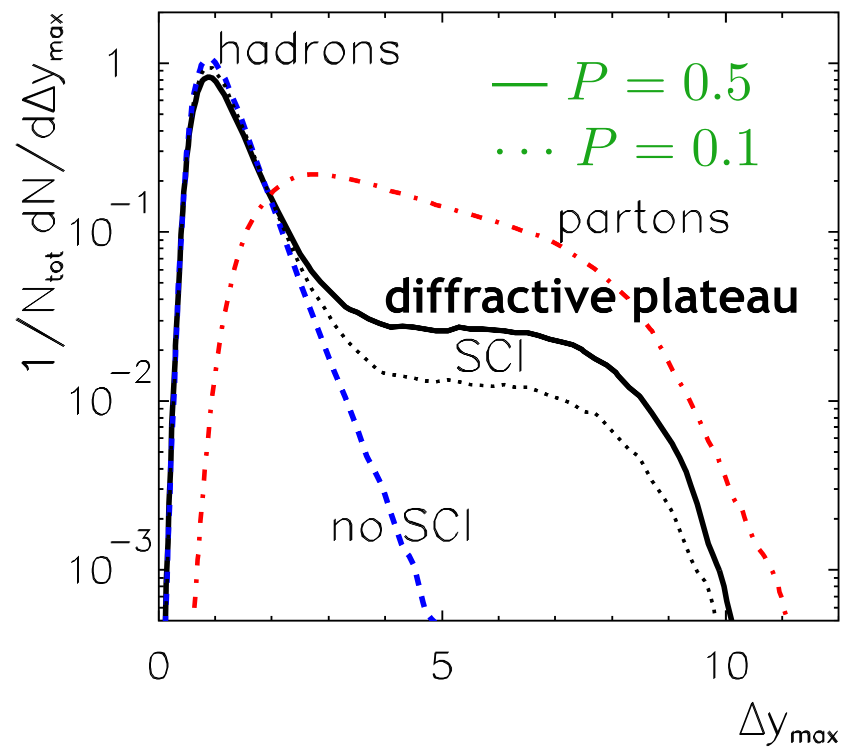
Sensitivity to the color string topology fluctuations

Edin, Ingelman, Rathsman

ME + DGLAP PS $> Q_0^2$ → SCI model → String hadronisation $\sim \Lambda$

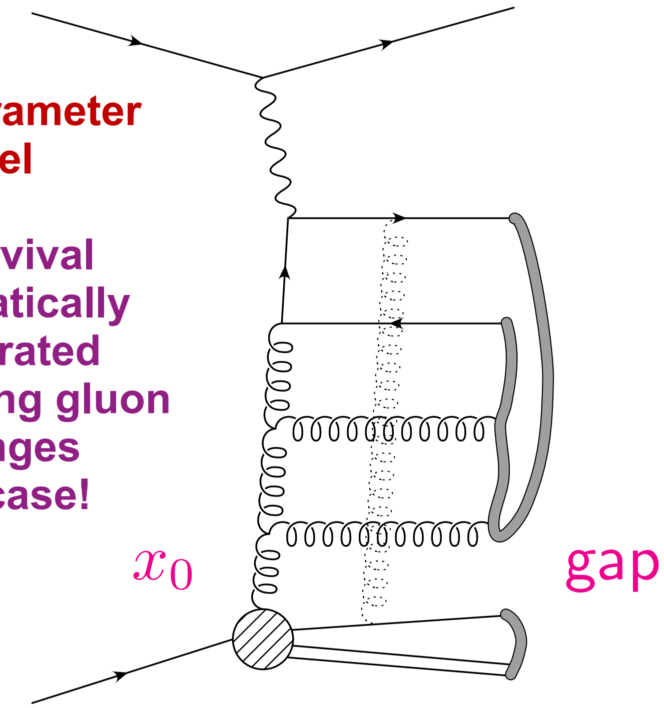
colour ordered parton state → rearranged colour order → modified final state





single parameter model

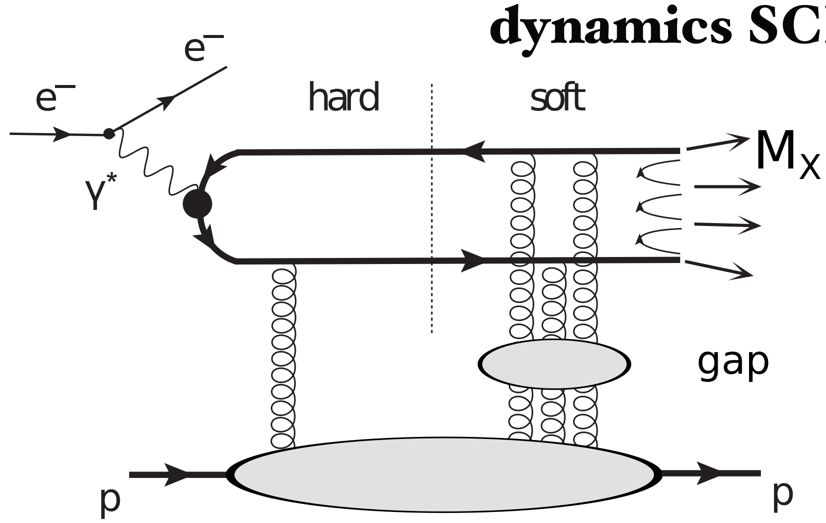
gap survival is automatically incorporated via screening gluon exchanges for pp case!



> Single model describing all final states: diffractive ↔ nondiffractive
> Gap events not 'special', but fluctuation in colour/hadronisation

diffractive events from fluctuations in color string topology!

dynamics SCI



Soft gluons can only change phase of propagating quark and it's color — should be resumed!

$$M(\delta) = \int d^2b \, \exp^{-i\delta \mathbf{b}} \, \hat{M}^{\mathrm{hard}}(b) \hat{M}^{\mathrm{soft}}(b)$$

reconnection probability becomes dynamical

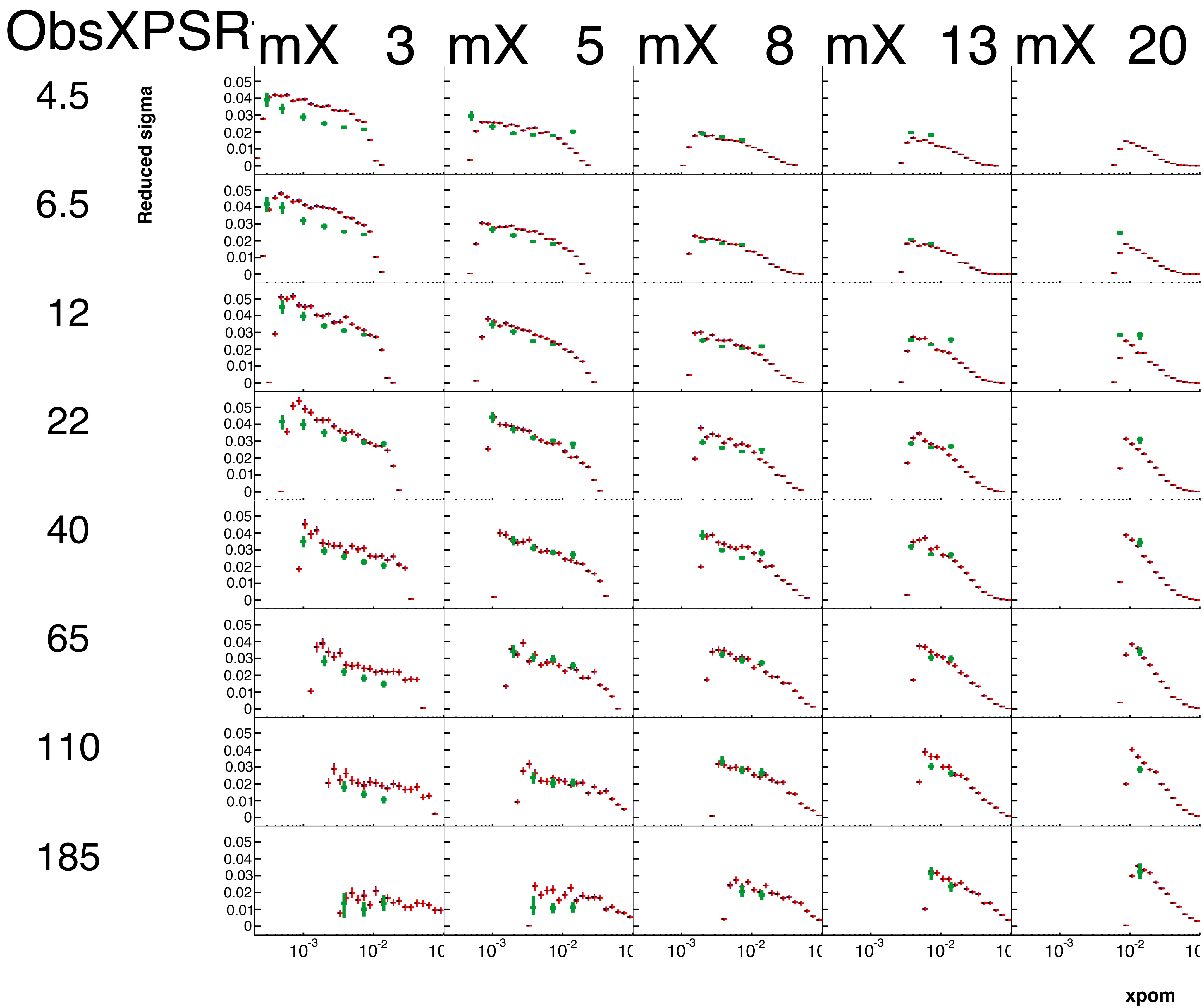
$$\hat{M}^{\mathrm{soft}}(\mathbf{b}, \mathbf{r}) \propto \left(1 - e^{A \ln \frac{|\mathbf{b}-\mathbf{r}|}{|\mathbf{b}|}}\right)$$

RP, Ingelman, Enberg

DynSCI Monte Carlo vs diffractive DIS

Werder, Ingelman, RP

Preliminary results!



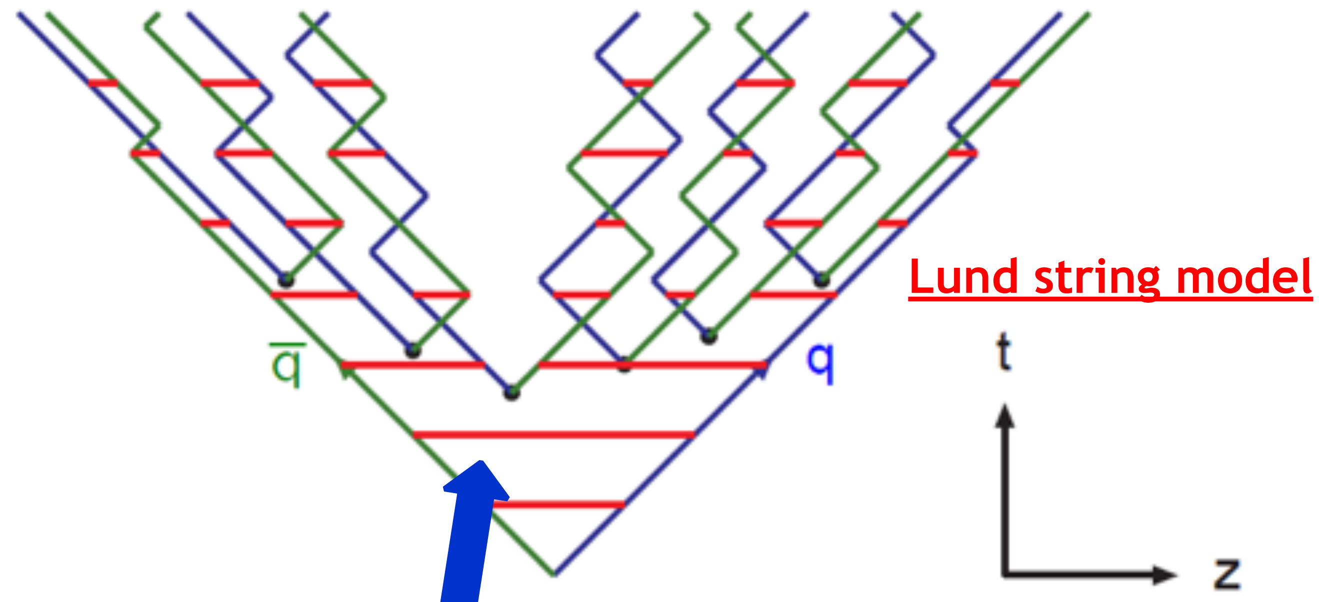
only physical parameters!

Dynamical color screening: Generalised Area Law model

Rathsman'99

dynamical string rearrangement

Motion of quarks and antiquarks in a $q\bar{q}$ system:



Area spanned by a string in momentum space

$$A(p_i, p_j) = 2(p_i \cdot p_j - m_i \cdot m_j)$$

Area difference between two string configurations

$$\Delta A = A^{\text{old}} - A^{\text{new}}$$

System prefers to turn to minimal area configuration!

GAL has been implemented to Pythia

Reconnection probability

$$\boxed{\begin{gathered} P_{\text{GAL}} = P_0 \left[1 - \exp(-b\Delta A)\right] \\ P_0 \sim 0.1 \end{gathered}}$$

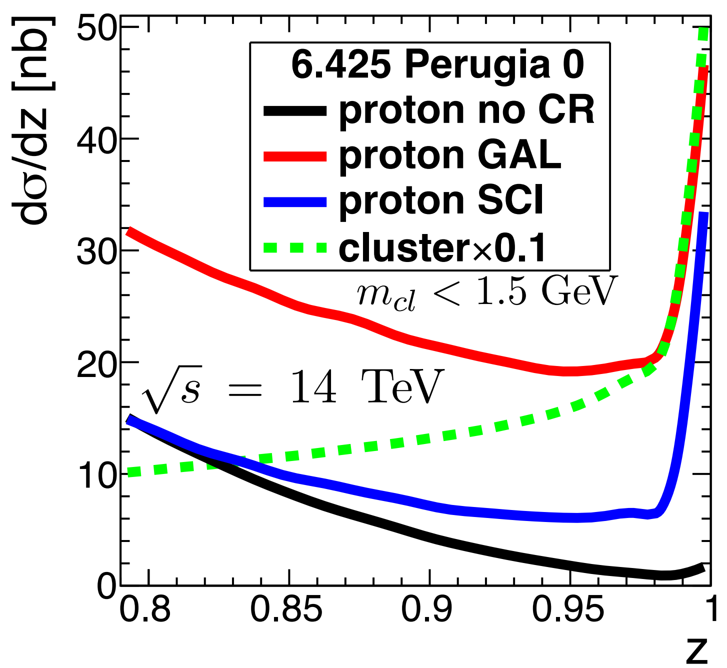
GAL has been successfully applied to inclusive and diffractive DIS

Diffractive W production in high-energy pp collisions

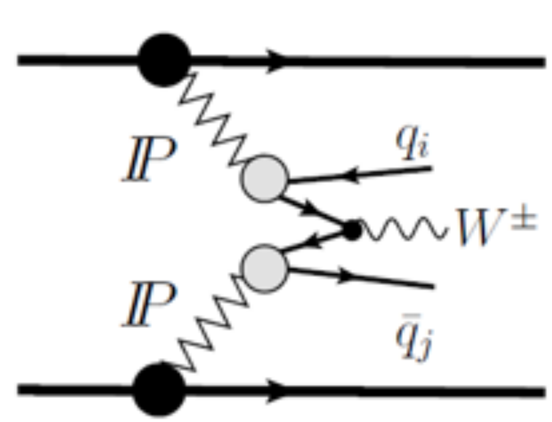
Features:

- ✓ clean environment (color singlet)
- ✓ well-defined hard scale (tests of QCD factorisation)
- ✓ high sensitivity to the production mechanism
- ✓ large enough cross section to be experimentally observed and tested

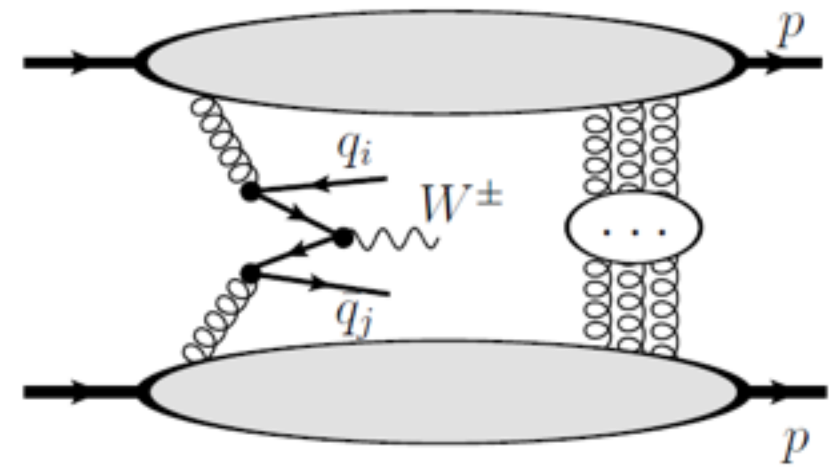
$$z = |p_z|/p_{\rm beam} \qquad pp \to p[W^{\pm}X]$$



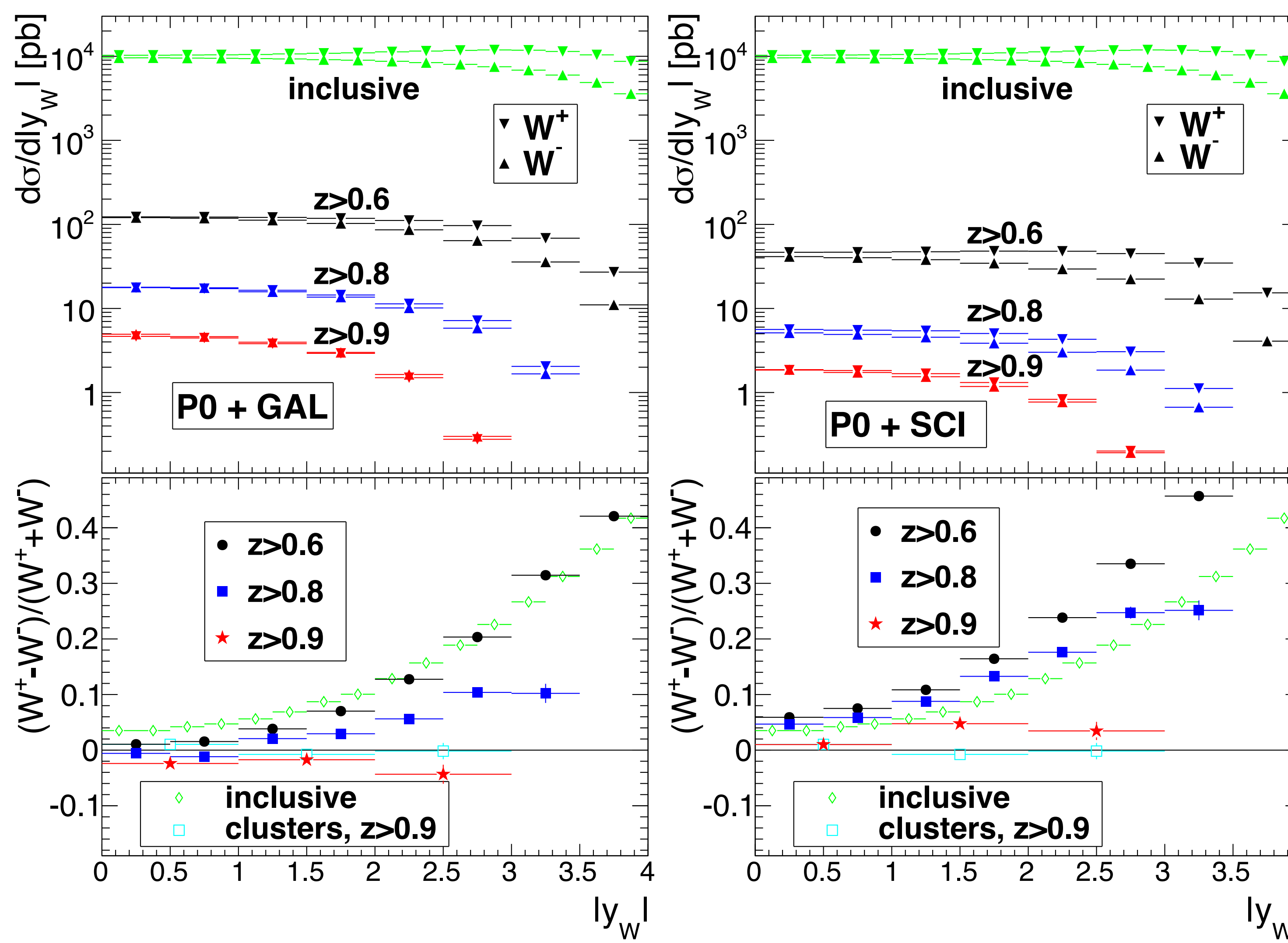
Regge models



QCD inspired models



Ingelman, RP, Rathsman, Werder



background for anomalous couplings studies with forward detectors see C. Royon

SD/ND ~ 1 % for SCI/GAL close to Tevatron data!

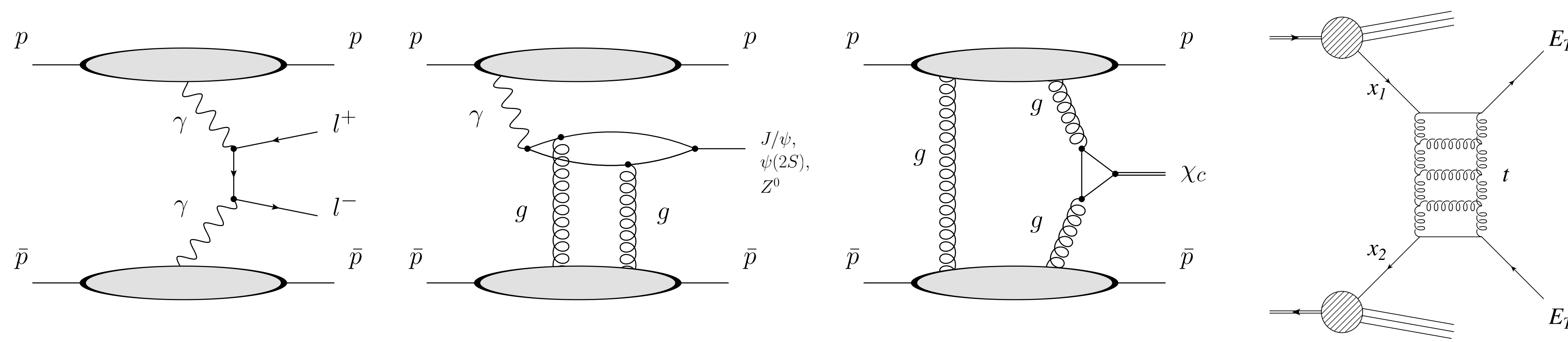
Mainly gluon-initiated diffraction at large Z!

More exclusive/diffractive reactions...

Examples of typical exclusive reactions studied so far...

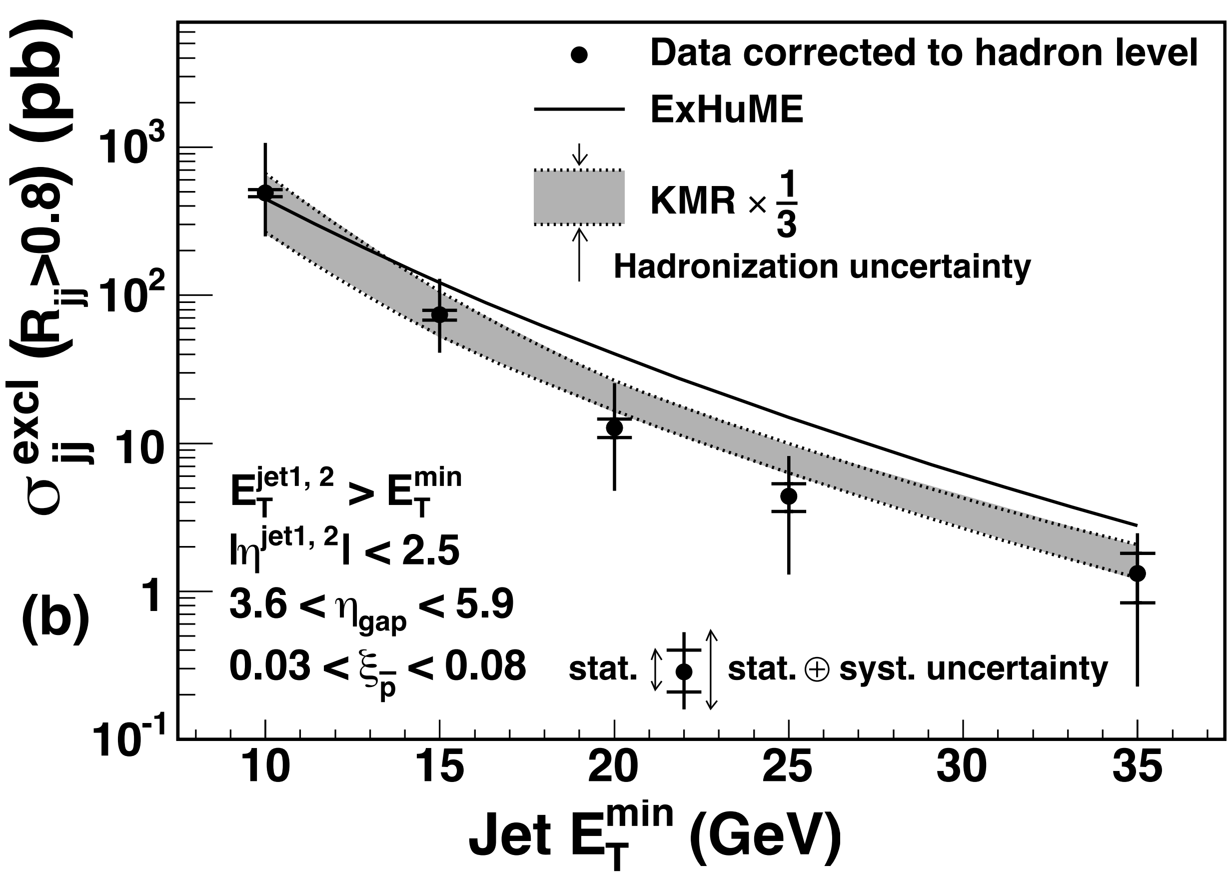
many covered in SuperChic/FPMC Monte Carlo

Laboratory of quarkonia, meson pair, exotics, gauge bosons, New Physics... production

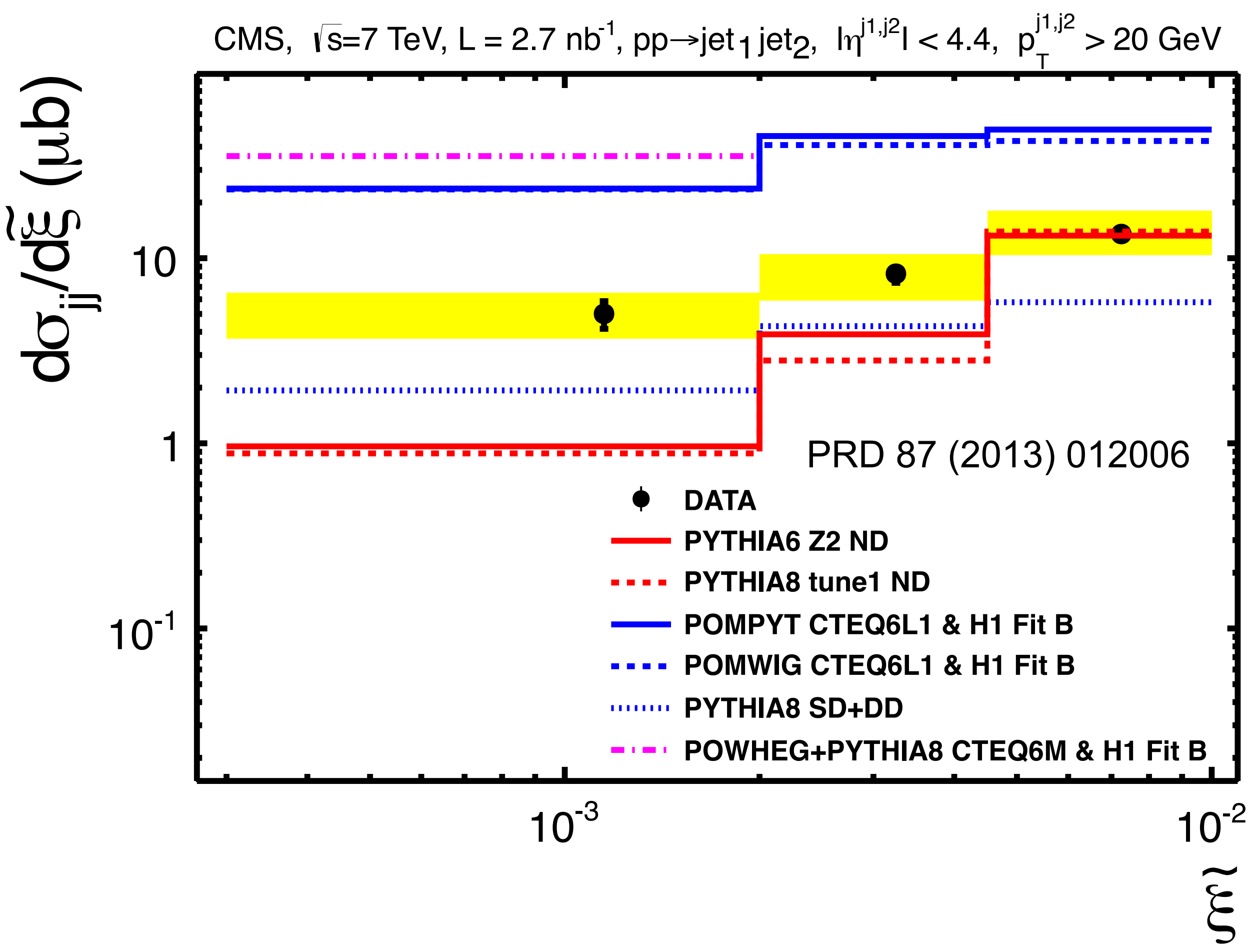


Diffractive di-jets at Tevatron

CDF Collab., Phys.Rev.D77:052004,2008

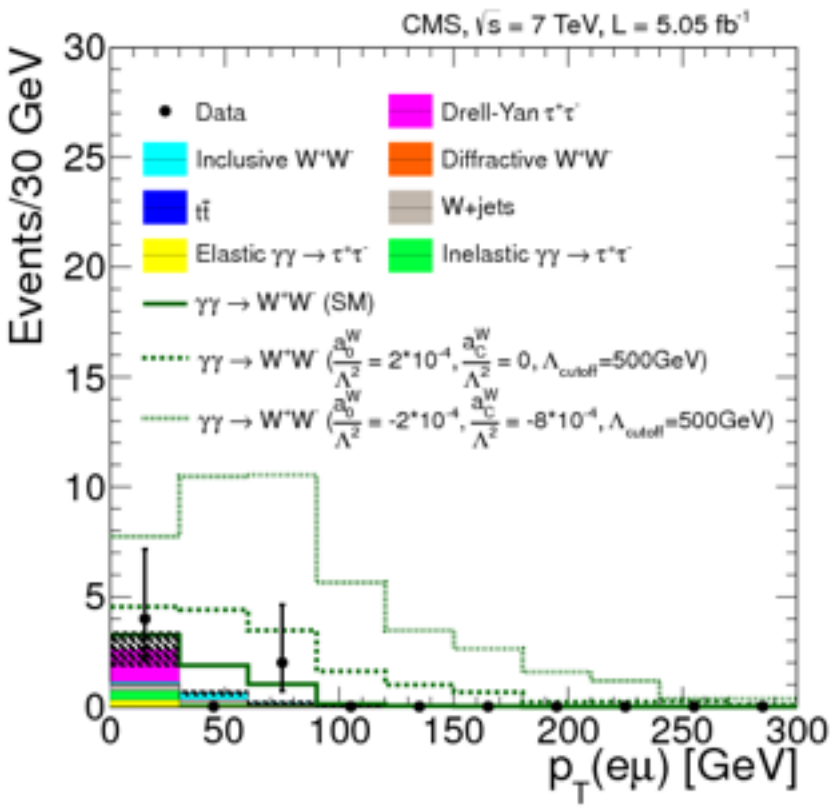


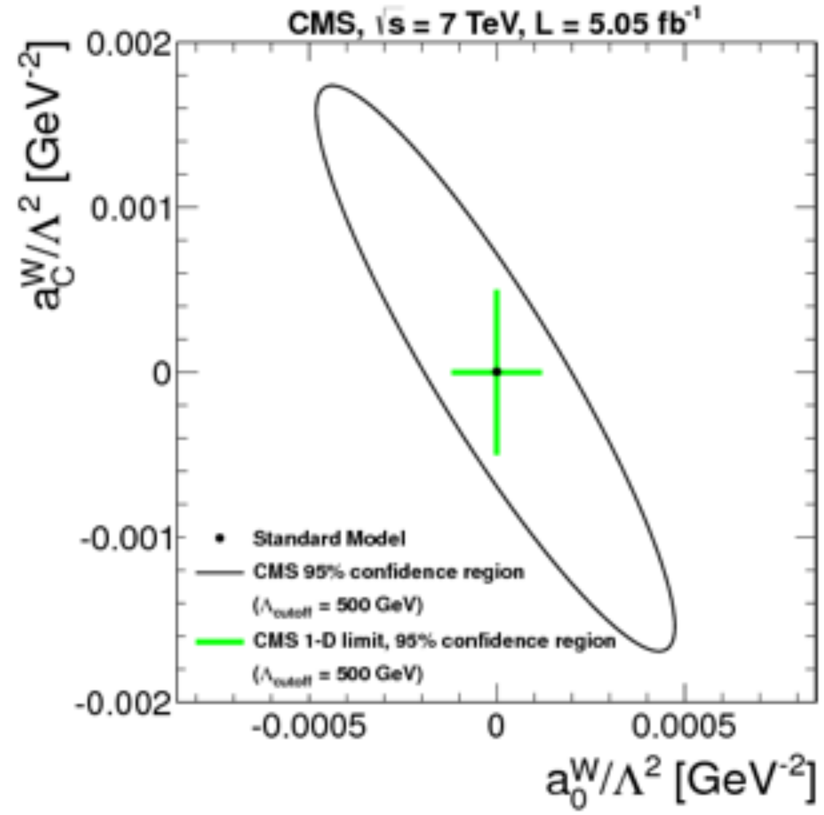
The first observation of diffractive di-jet at the LHC



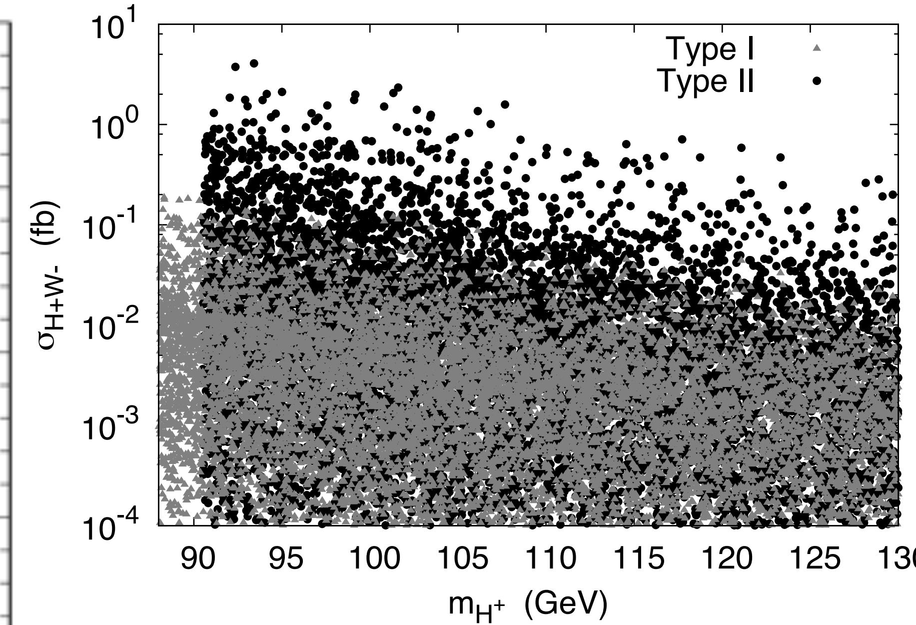
Why do we need high-precision diffraction?

anomalous couplings JHEP 1307 (2013) 116





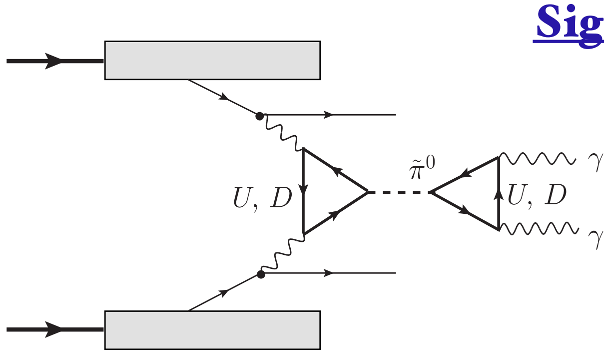
charged Higgs+W CEP

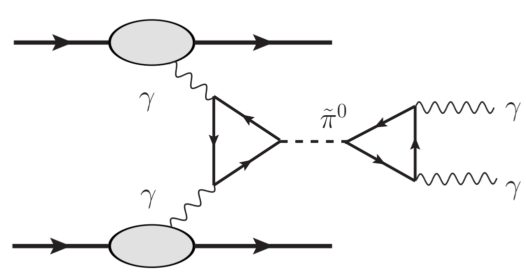


RP, R. Enberg PRD'11

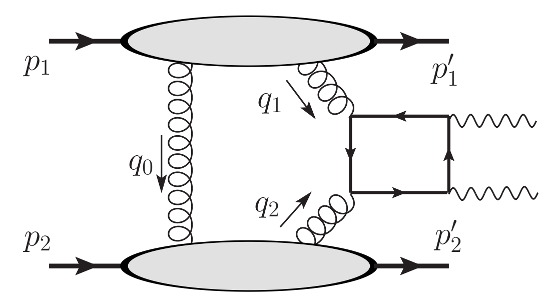
RP, Szczurek, Lebiedowicz, NP881, 288 (2014)

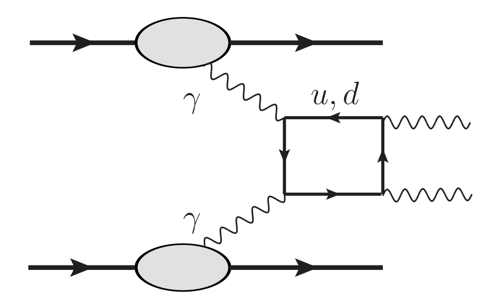
Signal

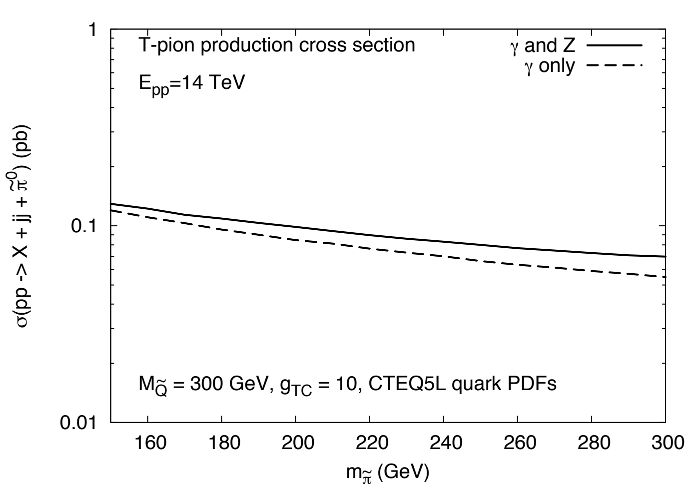


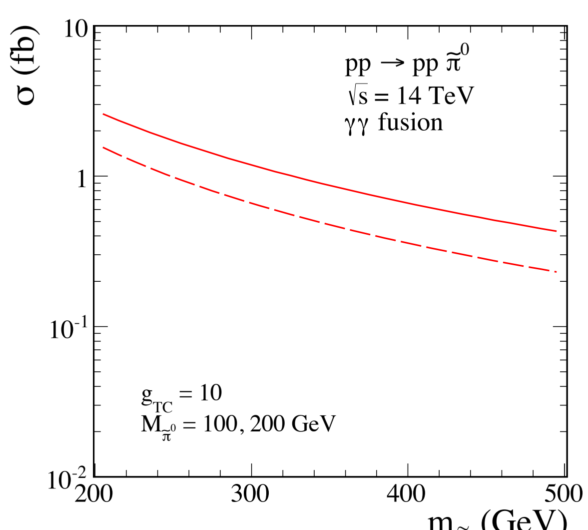


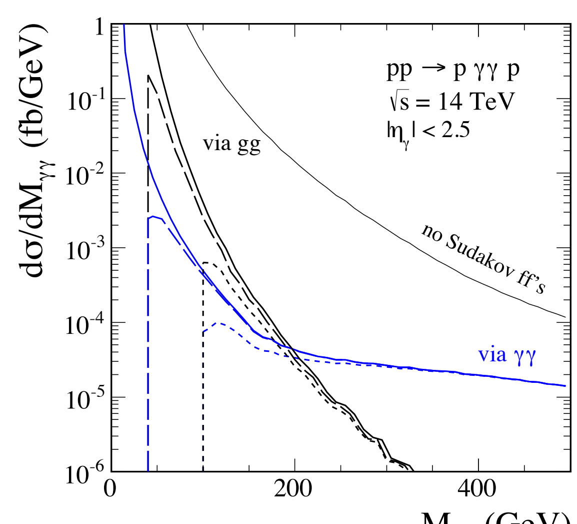
Background











see also Royon

Summary: Diffraction as a QCD laboratory

- ✓ Definition of diffraction is not unique but understood
- ✓ We have seen the Pomeron at work both in soft and hard regimes, as well as in the transition region — marginal agreement with data is achieved despite large uncertainties
- ✓ Matching between “soft” DL and “hard” BFKL Pomerons is a big challenge, but there is a progress
- ✓ Many theoretical developments in QCD-ish modelling of soft/hard Pomeron
- ✓ Diffraction is highly sensitive to small-x/long distance and multiple exchange physics
- ✓ Such effects as Regge/diffractive factorisation breaking, fluctuations in hadronisation, color screening need a proper universal treatment
- ✓ Further MC development/improvements and measurements are required
- ✓ Exclusive diffraction opens up new opportunities for New Physics searches due to reduced backgrounds

As long as QCD dynamics not understood, diffraction continues to be interesting