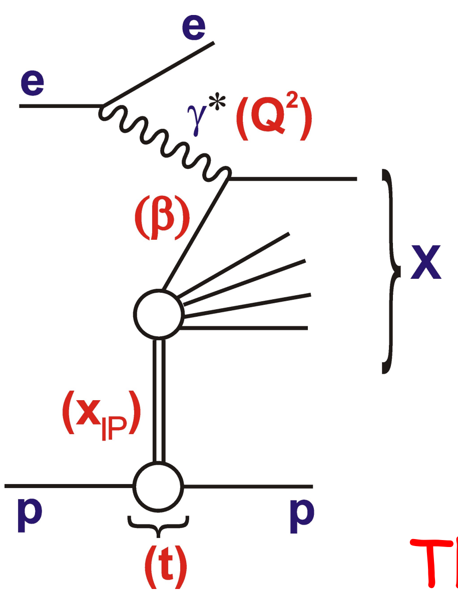
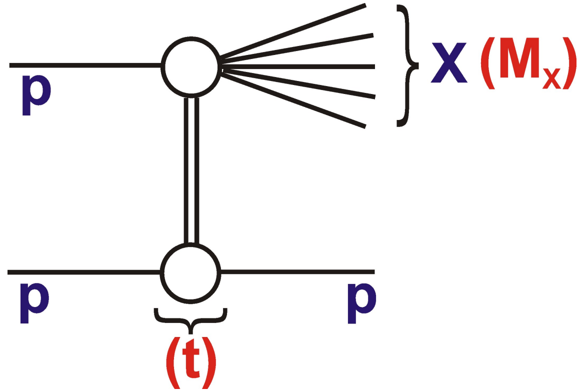
Diffraction from HERA to the LHC

Paul Newman (University of Birmingham)



Diffraction'10
11 September 2010



Thanks to IPPP, Durham for support

→ Defining diffractive cross sections
→ Modelling the Pomeron Flux Factor
→ Modelling soft diffractive cross sections
→ Modelling hard diffractive cross sections
→ Modelling diffractive particle production

HERA & Diffraction

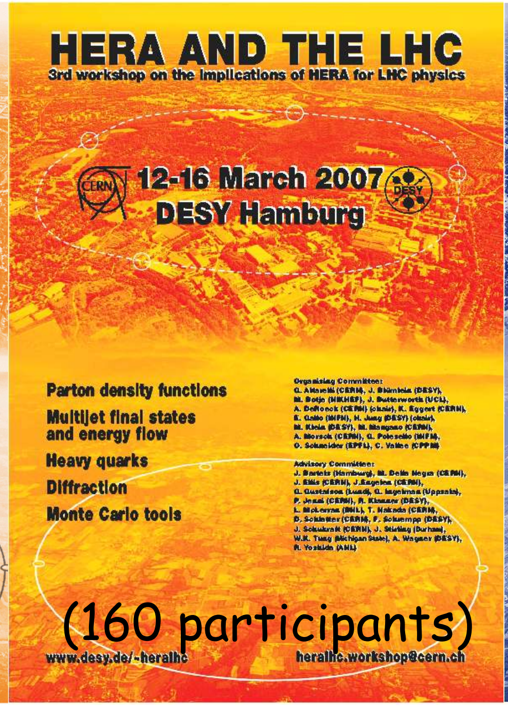
ep / $\gamma^{(*)}$p collisions
at sqrt(s) ~ 300 GeV
1992-2007

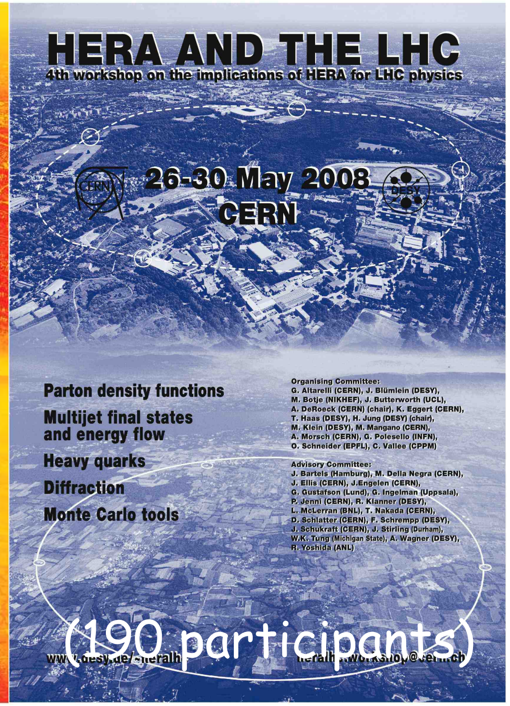
~ 0.5 fb^{-1} per expt.

e.g. H1 publications on diffraction (similar numbers in ZEUS):

- Diffractive cross sections (SD,DD): 11 papers
- Diffractive final states: 14 papers
- Quasi-elastic cross sections: 20 papers
- Total cross sections / decomposition: 2 papers

HERA-LHC Workshop 2004-2008





Workshops on the implications of HERA for the LHC

(including many contributions on diffraction …)

Procedings available from http://www.desy.de/~heralhc

807 pages! (March 2009)

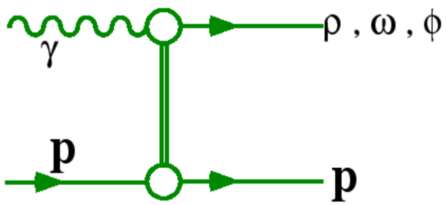
Impressum

Proceedings of the workshop
HERA and the LHC
2nd workshop on the implications of HERA for LHC physics
2006 - 2008, Hamburg - Geneva

Conference homepage
http://www.desy.de/~heralhc

Online proceedings at
http://www.desy.de/~heralhc/proceedings-2008/proceedings.html

Colour singlet exchange processes at HERA

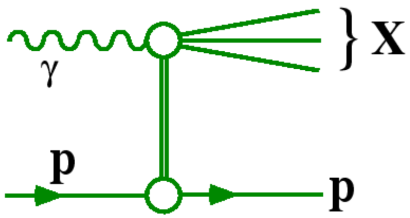


QUASI ELASTIC VECTOR MESON PRODUCTION

(EL)

$\gamma p \longrightarrow Vp$

LHC analogue is pp→pp

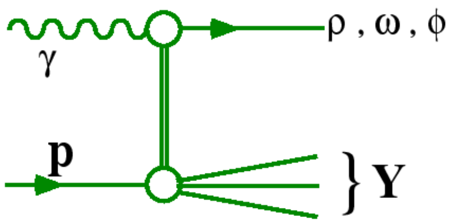


SINGLE PHOTON DISSOCIATION

(GD)

$\gamma p \longrightarrow Xp$

LHC analogue is pp→Xp

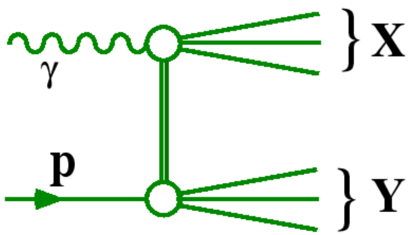


SINGLE PROTON DISSOCIATION

(PD)

$\gamma p \longrightarrow VY$

LHC analogue is pp→pX



DOUBLE DISSOCIATION

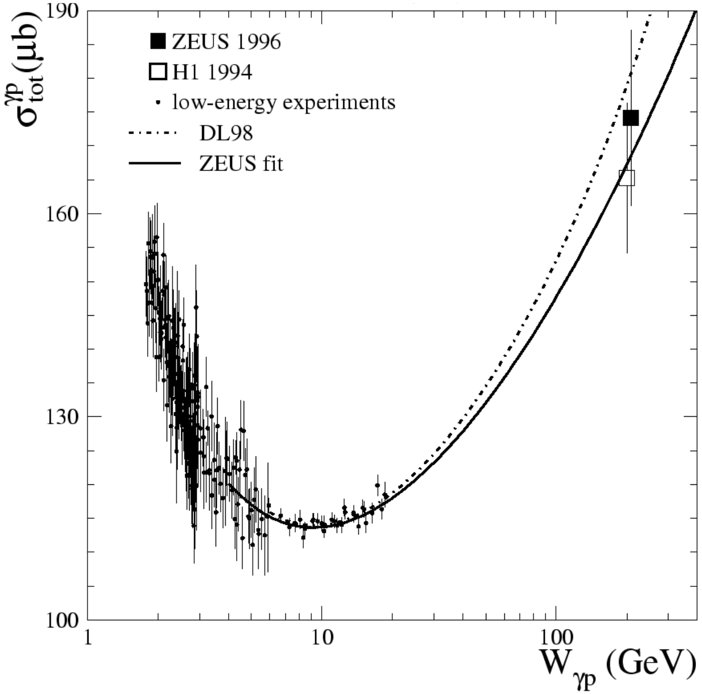
(DD)

$\gamma p \longrightarrow XY$

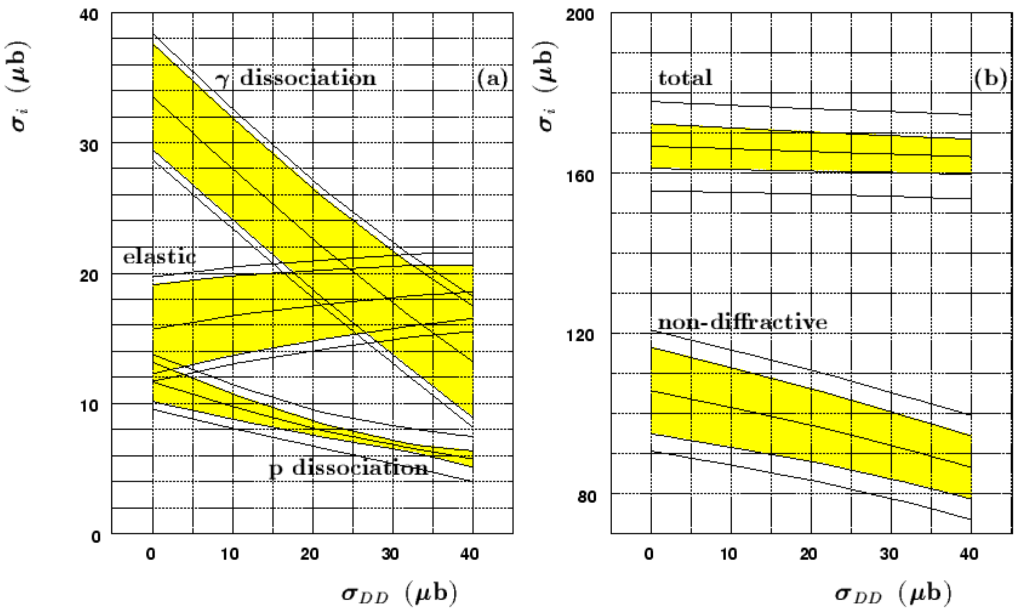
LHC analogue is pp→XY

Favourable kinematics to study X system (photon dissociation)

Diffraction as a Dominant Uncertainty in Minimum Bias Analyses



e.g. uncertainties on total cross section measurements dominated by modelling of diffractive contributions not observed in central detectors



- SD and DD cross sections strongly anti-correlated in this H1 analysis

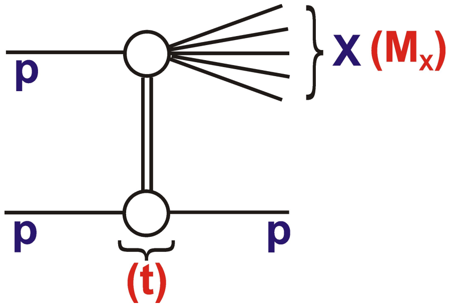
- Impossible to uniquely define ND, DD, SD …

… operational definitions e.g. $M_X^2/s < 0.05$ … ND is what's left

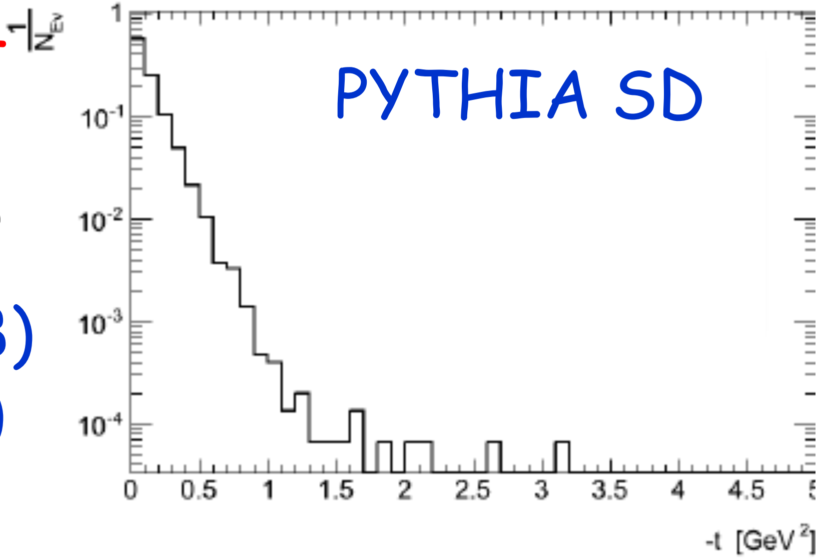
Processes and Kinematic Variables

HERA data are most relevant to low t processes at the LHC:

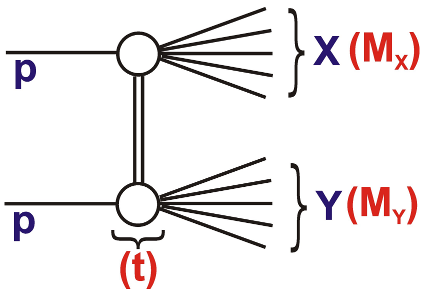
- Single diffractive (SD), pp → Xp



σ = 14mb (PYTHIA8)
σ = 10mb (PHOJET)



- Double diffractive (DD), pp → XY



σ = 9mb (PYTHIA8)
σ = 4mb (PHOJET)

Useful variable ...

$$\xi = M_X^2/s$$

For DD ...

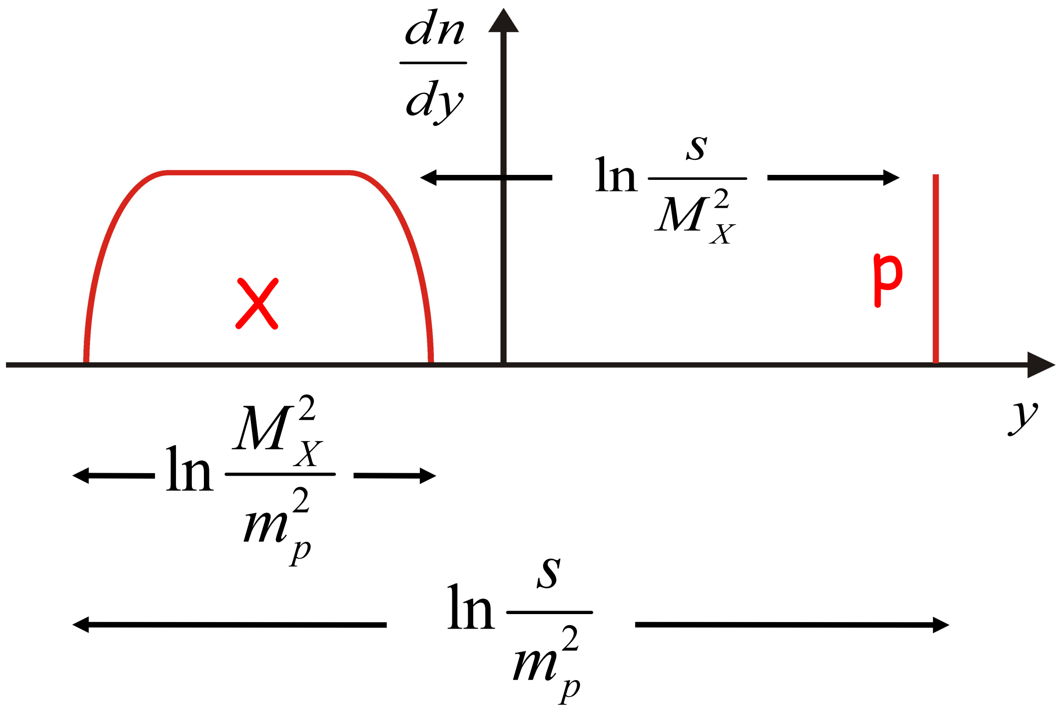
$$\xi_Y = M_Y^2/s$$

-At LHC energies, M_X, M_Y can range from $m_p + m_\pi$ → ~1 TeV

- HERA advises us how to model cross sections and soft/hard particle production in the X, Y systems

Final State Particle Production

Once generator has decided to produce an SD event with a given ξ, details of particle production within X system follow same models as non-diffractive processes, but at reduced energy: sqrt(s) → M_X

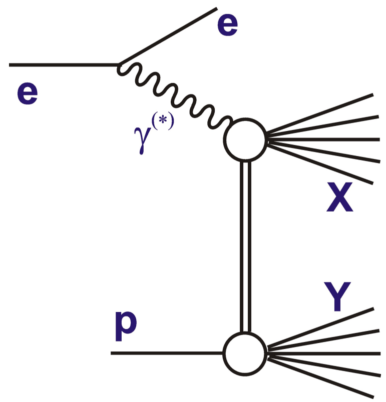


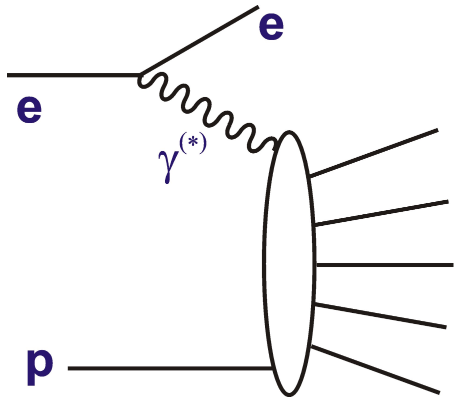
In hard diffraction at HERA, this approach was highly successful, provided the chosen DPDFs are accurate

Lots of experimental support … >20 HERA papers

Definition of Diffraction?

Nature provides a smooth transition between DD and ND processes, so how do we specify what is 'diffraction'?





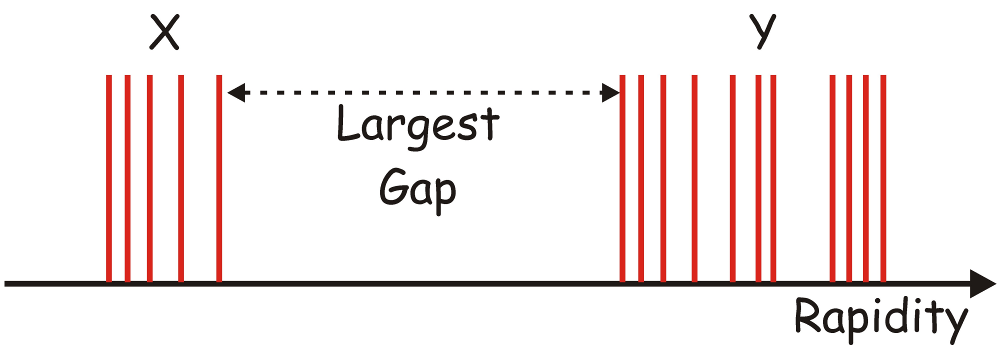
Definition of Diffraction?

Nature provides a smooth transition between DD and ND processes, so how do we specify what is 'diffraction'?

Definitions in terms of hadron-level observables rather than particular processes!...

- For SD ($\gamma p \rightarrow Xp$), can be done in terms of a leading proton

- More general definition to accommodate DD ($\gamma p \rightarrow XY$)
  ...can be applied to any diff or non-diff final state ...
  - Order all final state particles in rapidity
  - Define two systems, X and Y, separated by the largest rapidity gap between neighbouring particles.

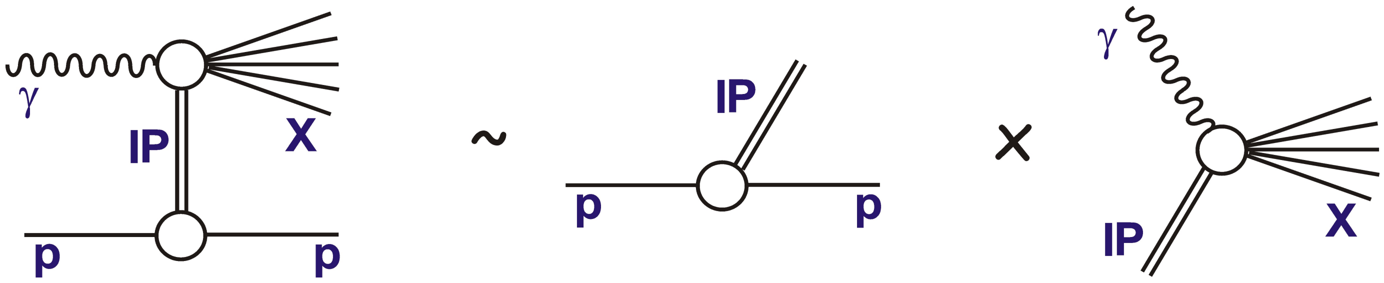


Many tests at HERA show leading proton & gap defs equivalent

Single Diffractive Photon Dissociation

Basic `proton vertex' factorisation hypothesis

… withstood many HERA tests

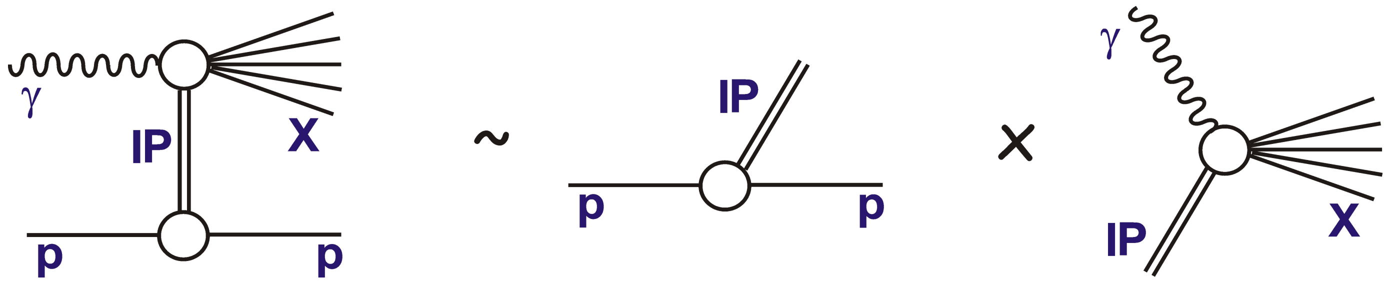


$f_{IP/p}(x_{IP}, t)$ $\sigma_{tot}(IP+\gamma \to X)$

• Lots of analyses extracted pomeron flux $f_{IP/p}$ from (quasi)-elastic and single diffractive cross sections … directly related to same vertex in pp scattering

• Total cross section σ_{tot} (IP + γ → X) described by:
  - Triple Regge phenomenology for soft processes
  - Diffractive parton densities (DPDFs) for hard processes

Pomeron Flux Factor from Single Diffraction



$f_{IP/p}(x_{IP}, t)$ $\quad$ $\sigma_{tot}(IP + \gamma \rightarrow X)$

All x_{IP} and t dependence contained in flux factor.
Standard parameterisation based on Regge theory …

$$f_{IP/p}(x_{IP}, t) = \frac{e^{B_{IP}t}}{x_{IP}^{2\alpha_{IP}(t)-1}} \qquad \alpha_{IP}(t) = \alpha_{IP}(0) + \alpha'_{IP}t$$

e.g. H1 LPS Diffractive DIS:

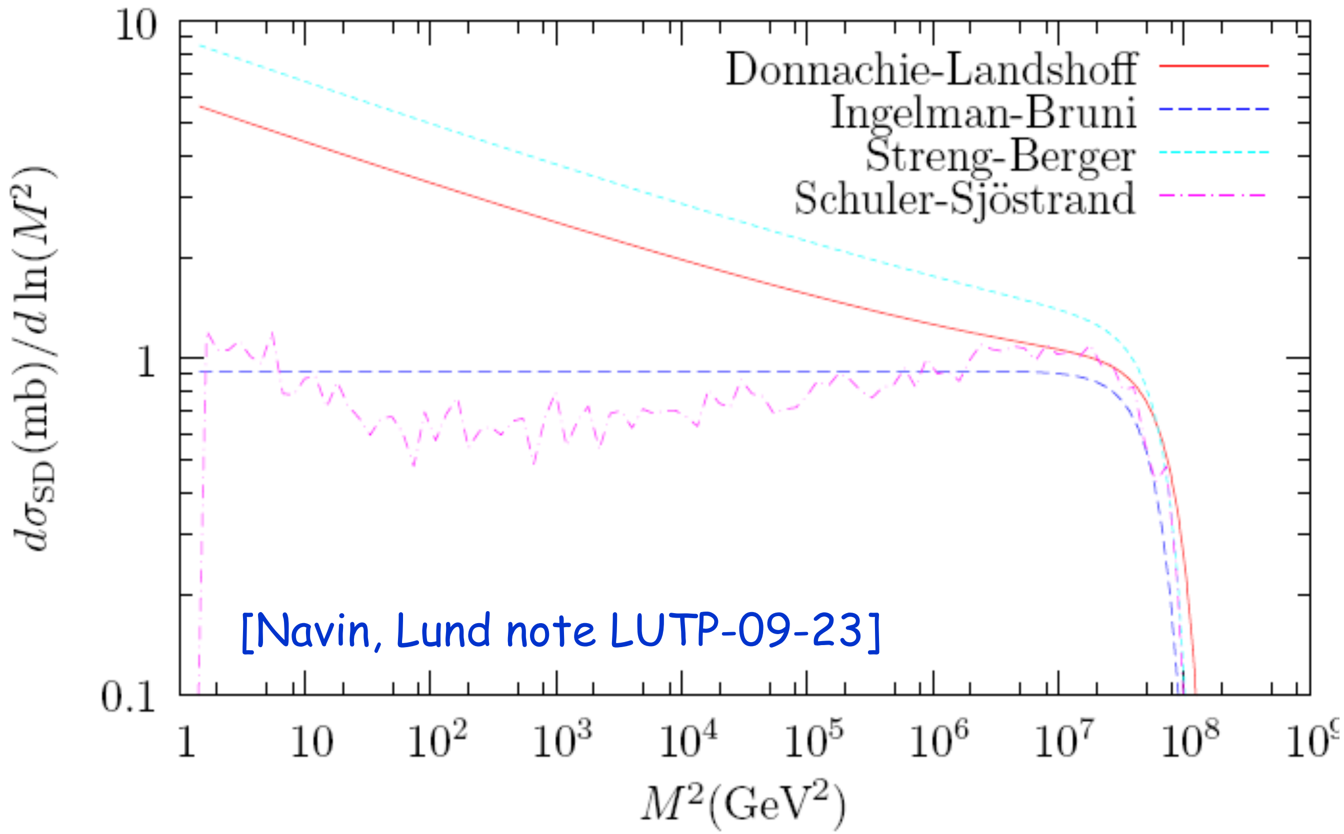
$\alpha_{IP}(0) = 1.12 \pm 0.01(\text{exp.}) \pm 0.02(\text{model})$

$\alpha'_{IP} = 0.04 \pm 0.02\ (\text{exp.})\ \pm\ 0.03\ (\text{mod.})$

$B_{IP} = 5.7 \pm 0.3\ (\text{exp.})\ \pm\ 0.6\ (\text{mod.})$

Some or all of this should be instantly transportable to LHC, but not used in PYTHIA or PHOJET ☹

PYTHIA8 Pomeron Flux Models

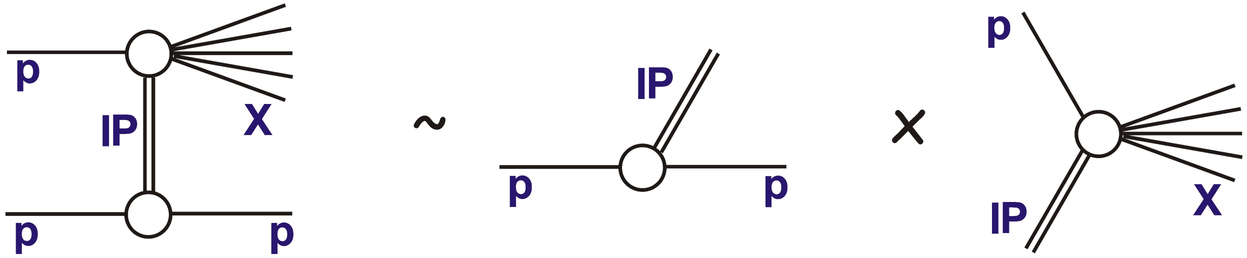


- Default Schuler & Sjostrand flux and more standard(?) Donnachie & Landshoff show significantly different ξ dependences when viewed over huge ξ range at LHC

- Not enough to vary σ(SD), σ(DD) when assessing diffractive cross section model uncertainties @ LHC

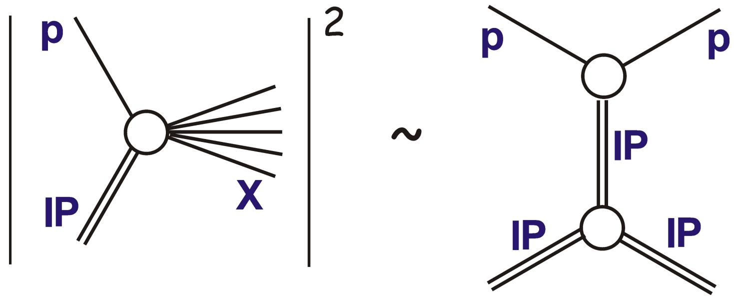
Soft Diffractive pp Cross Sections

1) Factorise SD into a pomeron (IP) flux and a total p+IP cross section

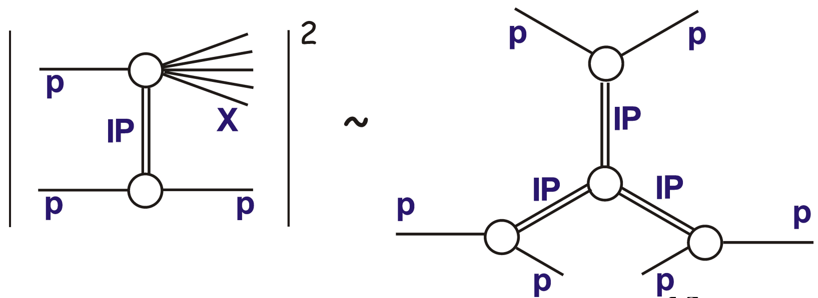


$$f_{IP/p}(\xi,t) \qquad \sigma_{tot}(IP+p\rightarrow X)$$

2) Similarly to total pp cross section, relate total p+IP cross section to forward elastic amplitude via optical theorem



3) Calculate SD cross sections from triple pomeron amplitudes

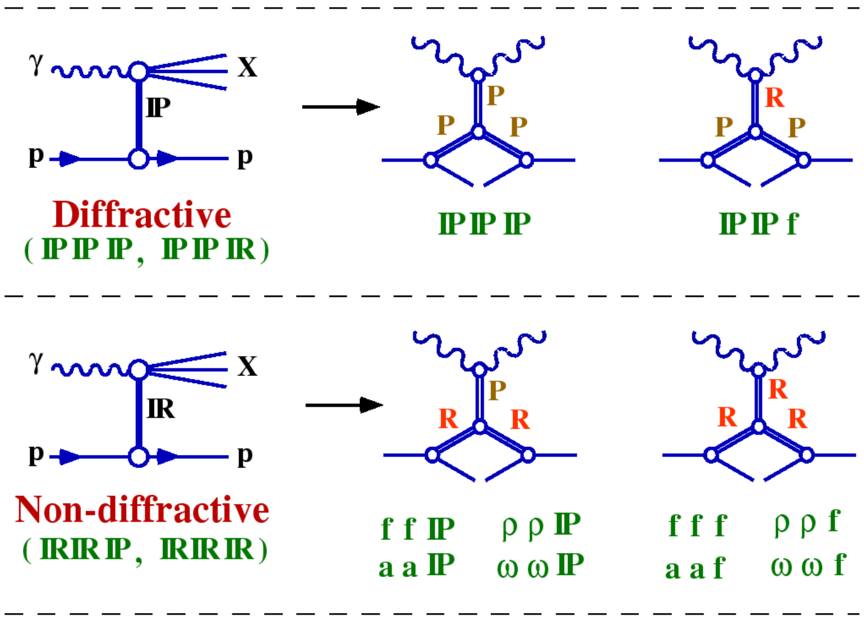


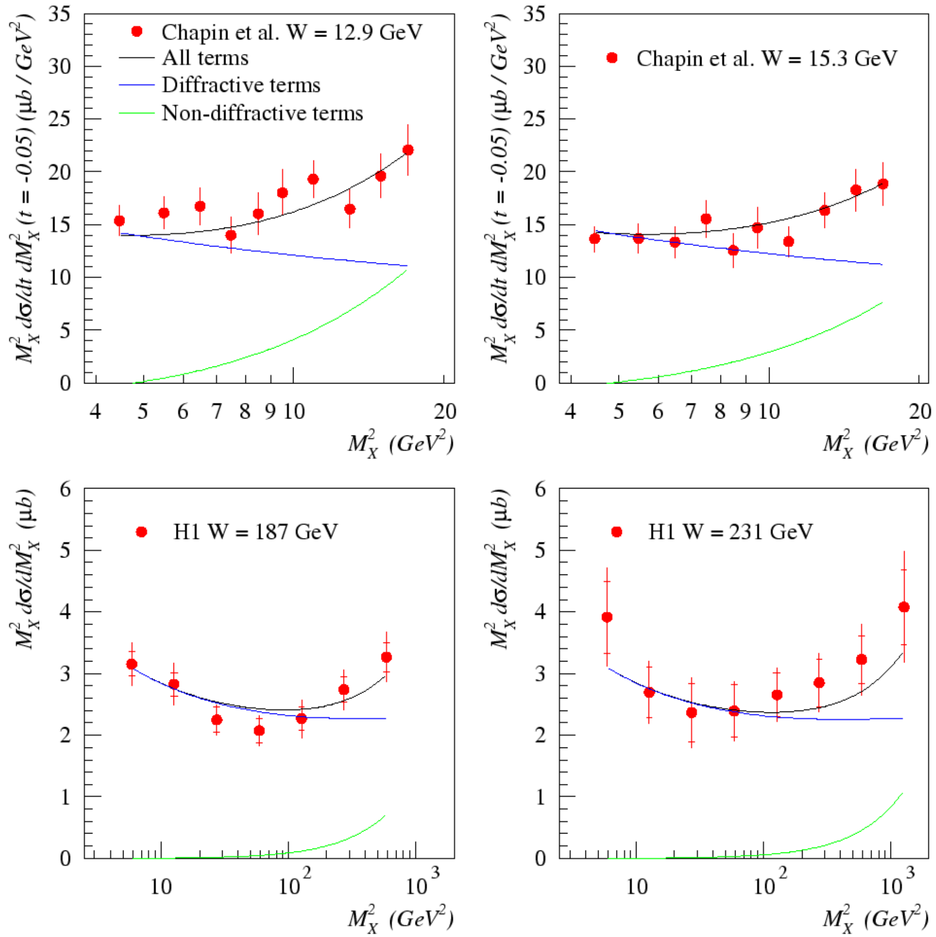
[similar treatment for DD]

Soft Photoproduction SD Cross Section

Triple pomeron → $$\frac{d\sigma}{dt\,dM_X^2} = \frac{1}{16\pi}\, g_{3IP}(t)\, \beta_{pIP}(t)^2\, \beta_{\gamma\, IP}(0)\, s^{2\alpha(t)-2}\, M_X^{2[\alpha(0)-2\alpha(t)]}$$

Complication: Triple Regge diagrams can have non-pomeron as well as pomeron contributions

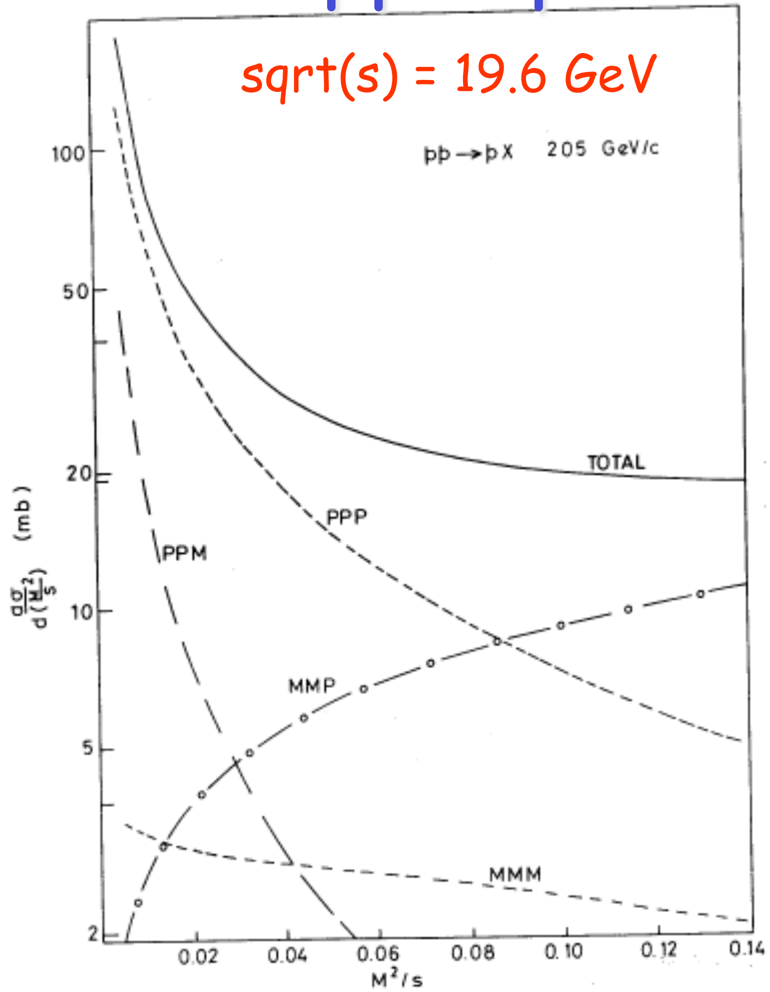




- Example fit to H1 and fixed target γp → Xp data shows non-diffractive contributions present at small s and large x_{IP}.

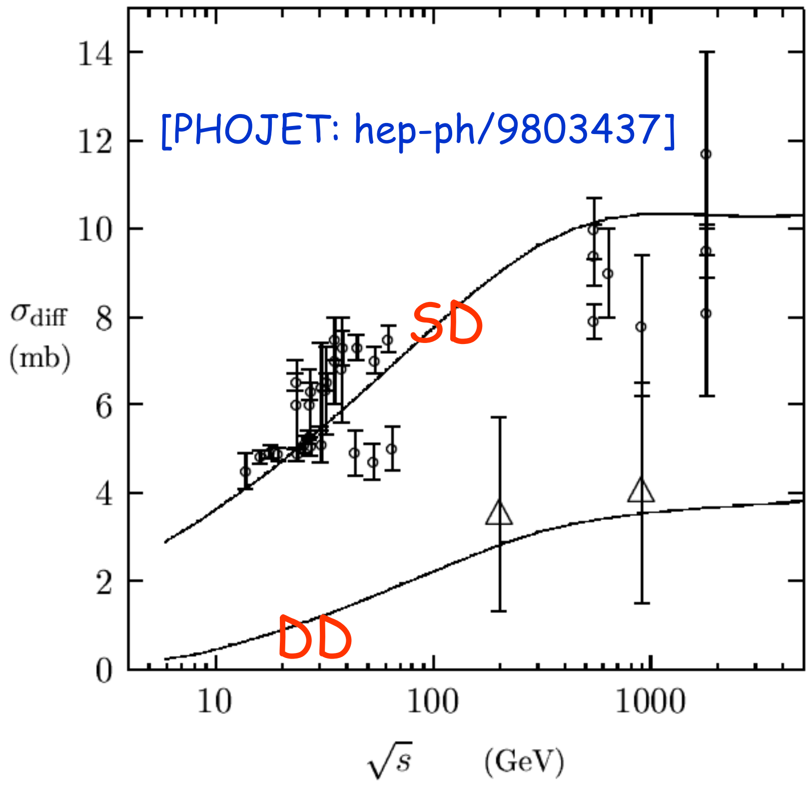
Sub-Leading Terms and pp→ pX

sqrt(s) = 19.6 GeV



Ancient (ISR) triple Regge phenomenology of pp → pX

Roberts & Roy: NP B77 (1974) 240
Field & Fox: NP B80 (1974) 367



- Sub-leading terms suppressed like 1/sqrt(s) or stronger … negligible at LHC,
- Perhaps influence assumed 3IP coupling in MC models?

PHOJET Implementation

- Cross section based on triple pomeron model with standard pomeron $\alpha(0) = 1.08$
- Sharp cut at steerable large ξ [default ~0.4?]
- No low ξ enhancement

PYTHIA Implementation

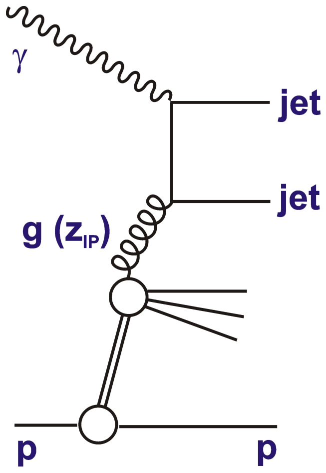
- Triple pomeron model. By default $\alpha(0) = 1$ (!)
- Fudge factors applied to suppress large ξ, give a low ξ enhancement and prevent X and Y systems overlapping in DD

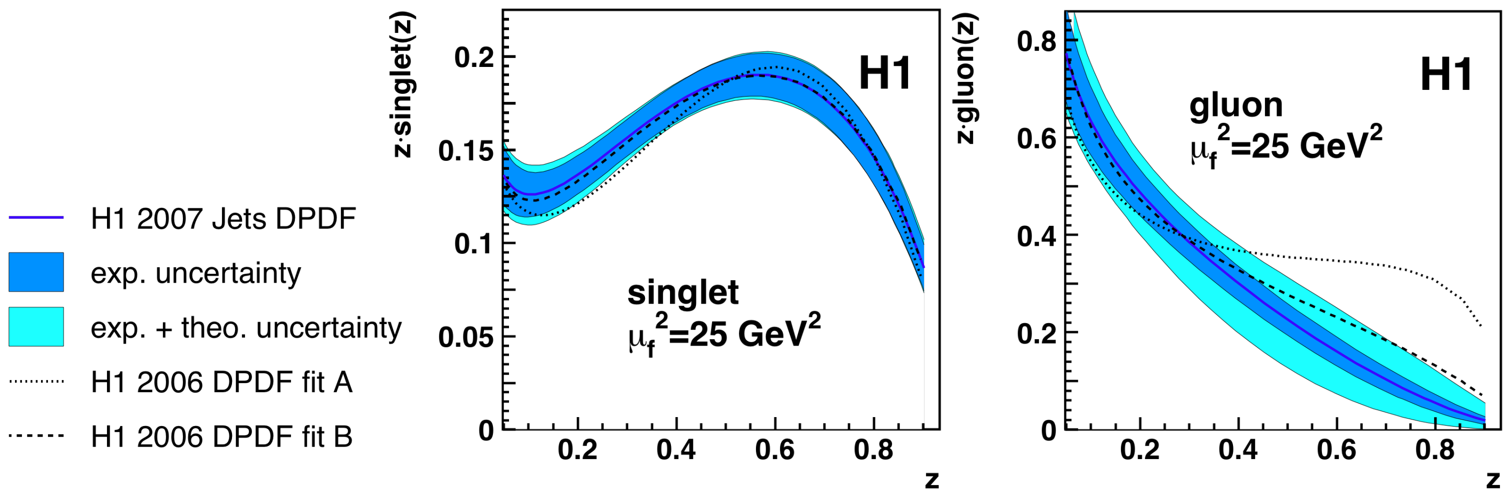
$$\frac{\mathrm{d}\sigma_{\mathrm{sd}(AX)}(s)}{\mathrm{d}t\,\mathrm{d}M^2} = \frac{g_{3\mathbb{P}}}{16\pi}\,\beta_{A\mathbb{P}}^2\,\beta_{B\mathbb{P}}\,\frac{1}{M^2}\,\exp(B_{\mathrm{sd}(AX)}t)\,F_{\mathrm{sd}}$$

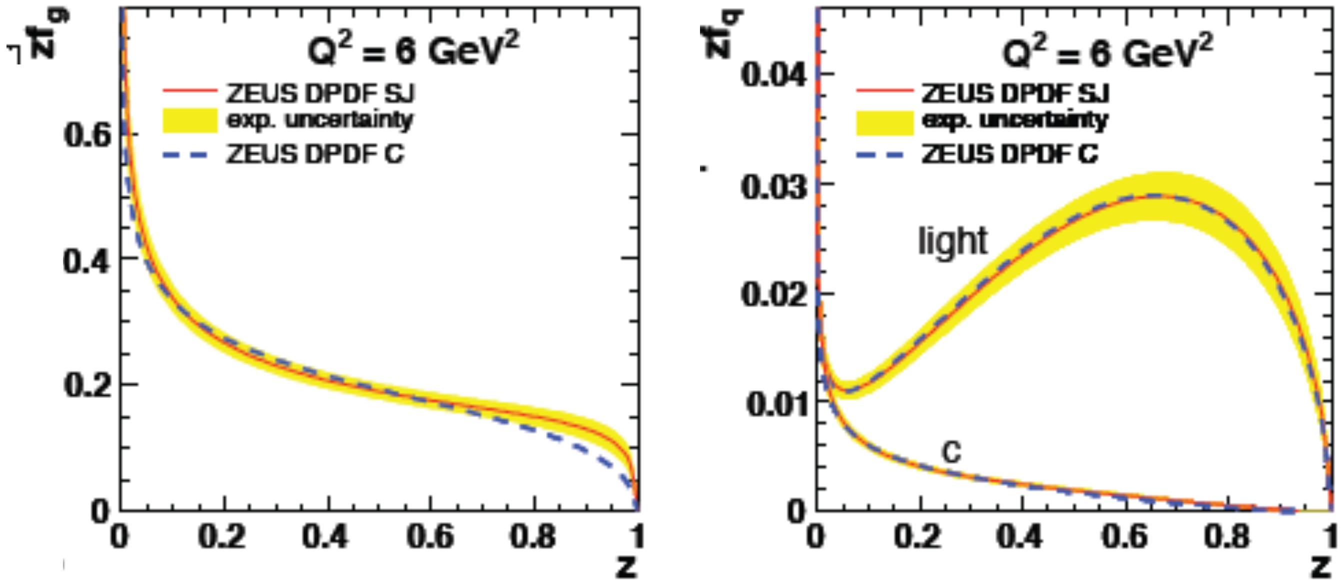
$$F_{\mathrm{sd}} = \left(1 - \frac{M^2}{s}\right)\left(1 + \frac{c_{\mathrm{res}}\,M_{\mathrm{res}}^2}{M_{\mathrm{res}}^2 + M^2}\right)$$

- Exactly the same default in PYTHIA8, but now with 3 other parameterisations available

Hard Processes: Diffractive PDFs



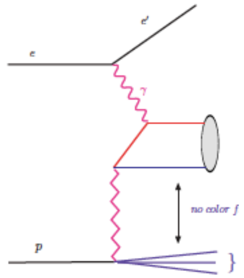




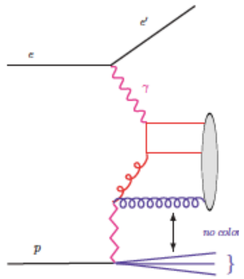
Lead to impressive descriptions of all hard diffractive DIS data

DPDFs dominated by a gluon density which extends to large z

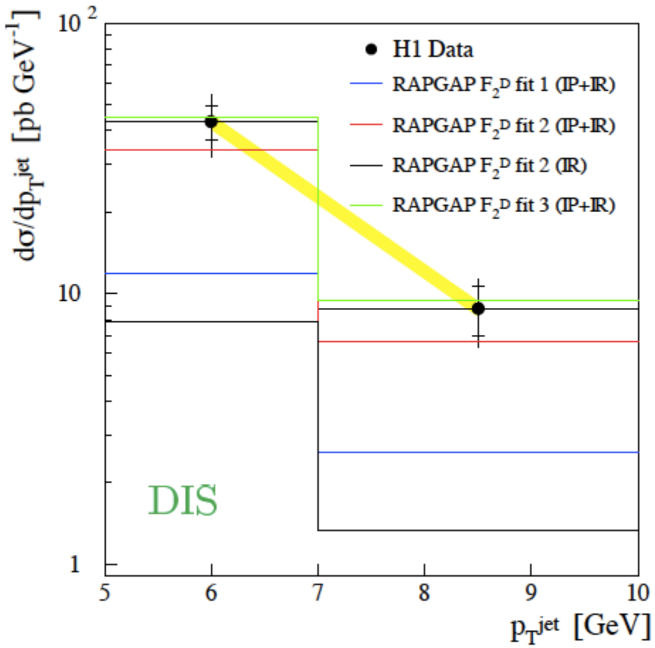
Good and Bad DPDFs

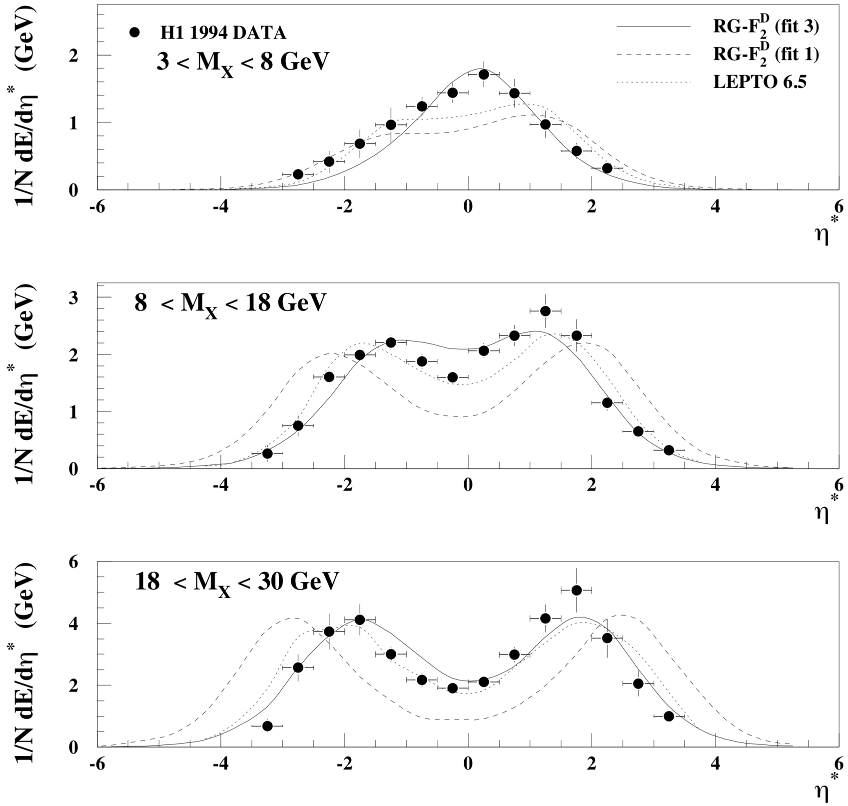


“Fit 1”



“Fit 2,3”



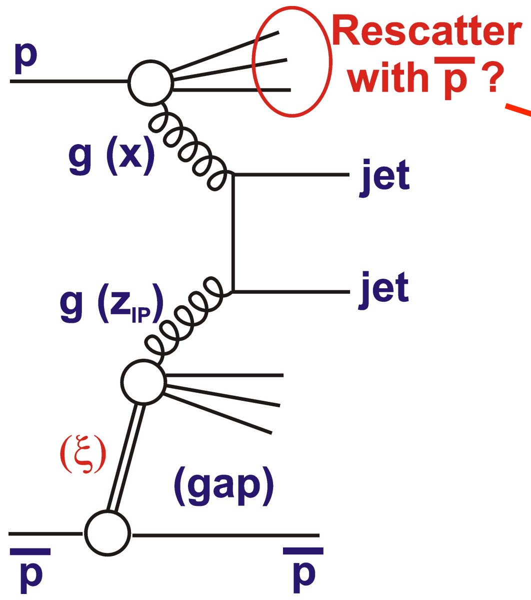


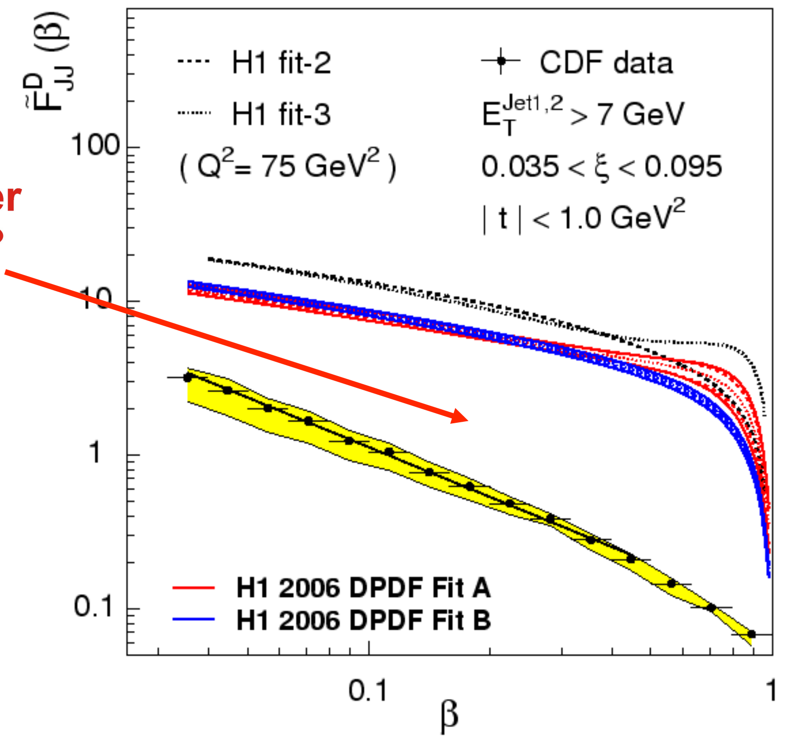
Using DPDFs with no gluons at starting scale:

- Particle flow & spectra wrong
- Jet cross sections factor ~5 too small
- ...

Predicting Tevatron Data

Tevatron effective DPDFs from dijets show strong factor^{n} breaking compared with HERA DPDFs … `gap survival' factor $S^2 \sim 0.1$



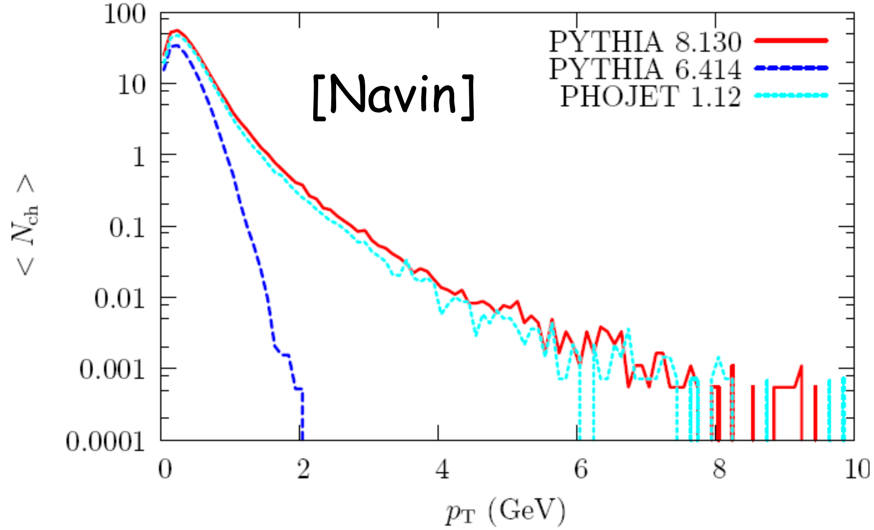


… usually explained by multiple interactions / absorption

- Rapidity gap survival probabilities / multiple interactions relevant not only to (short-distance) gaps between jets

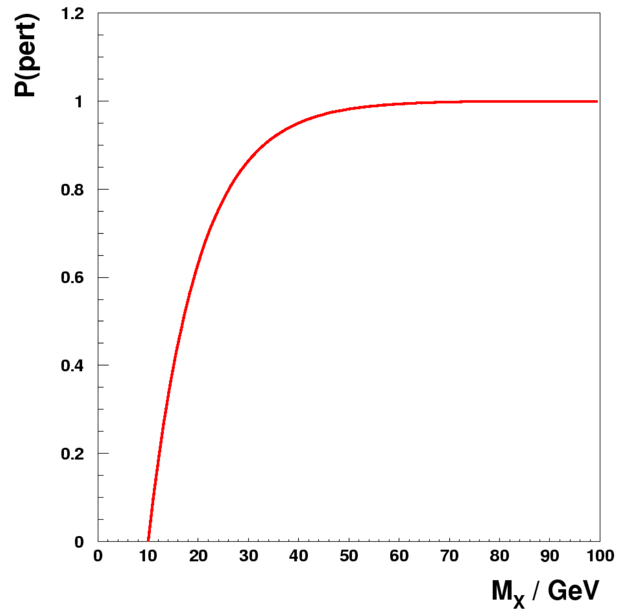
- Also relevant to partonic processes in pp→pX at low t (large impact parameter)

Hard Diffraction in MCs



PHOJET

- Fairly standard IP flux
- Two components (soft / hard)
- Divided at p_T = 3 GeV
- (Old) CKMT model of DPDFs



PYTHIA8

- Choice of (old) IP fluxes
- Two component (soft / hard)
- Divided according to smooth turn-on
- Hard component dominates at LHC
- Choice of modern DPDFs for hard part

RAPGAP / POMWIG

- Hard component only
- Consistent use of flux and DPDFs from fits to HERA data

None contain models of MI induced Rapidity Gap Destruction ☹

Summary

There are many areas where HERA experience and results provide potentially vital input to LHC modelling of soft and hard diffractive dissociation

- Cross Section Definitions
- Pomeron Flux modelling
- Diffractive Parton Densities
- Final state particle production

This information is not yet all implemented in MC models

Another missing ingredient – rapidity gap survival probability

HERA+Tevatron+LHC data considered together can teach us a lot about

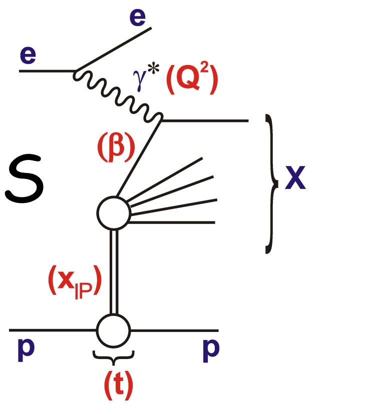
- Colour singlet exchange
- Multiple interactions …

Big opportunity while diffr^{n} is major current LHC topic!

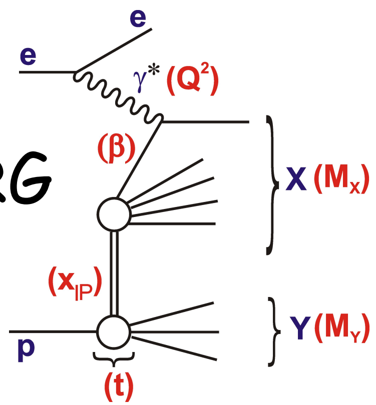
Back-ups

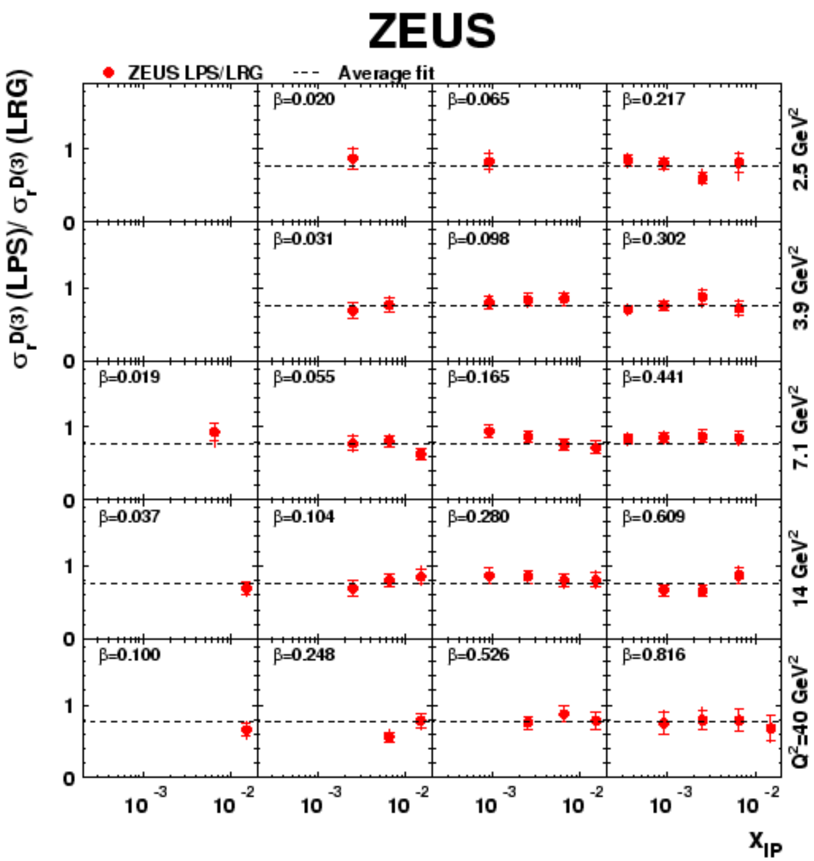
Comparisons between Methods

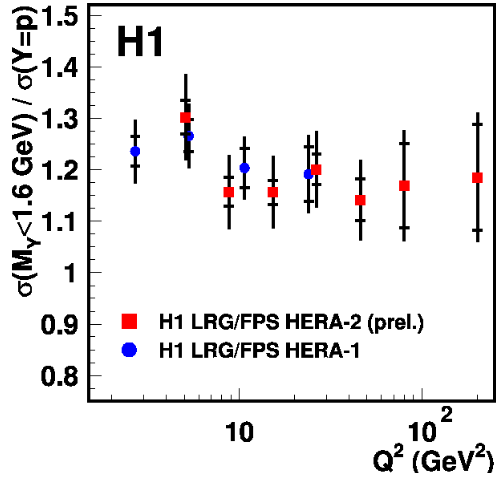
LPS

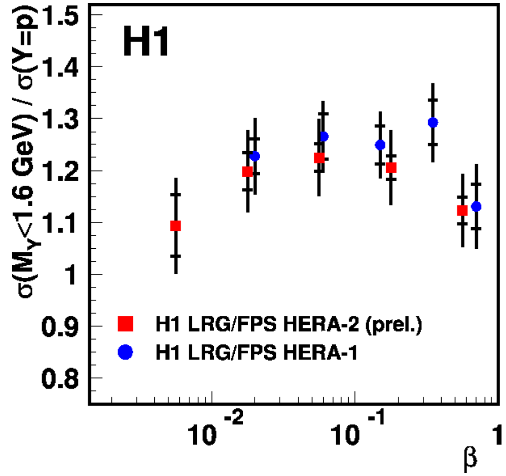


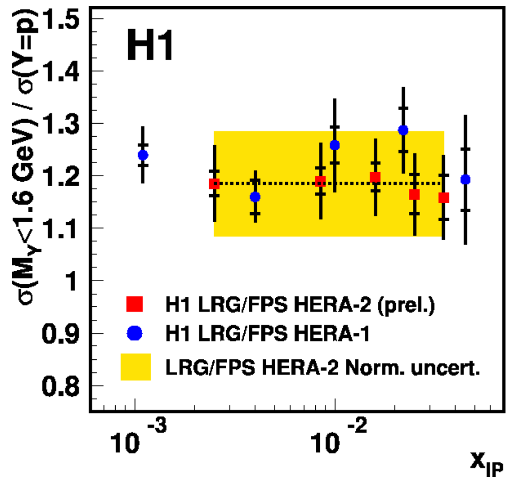
LRG







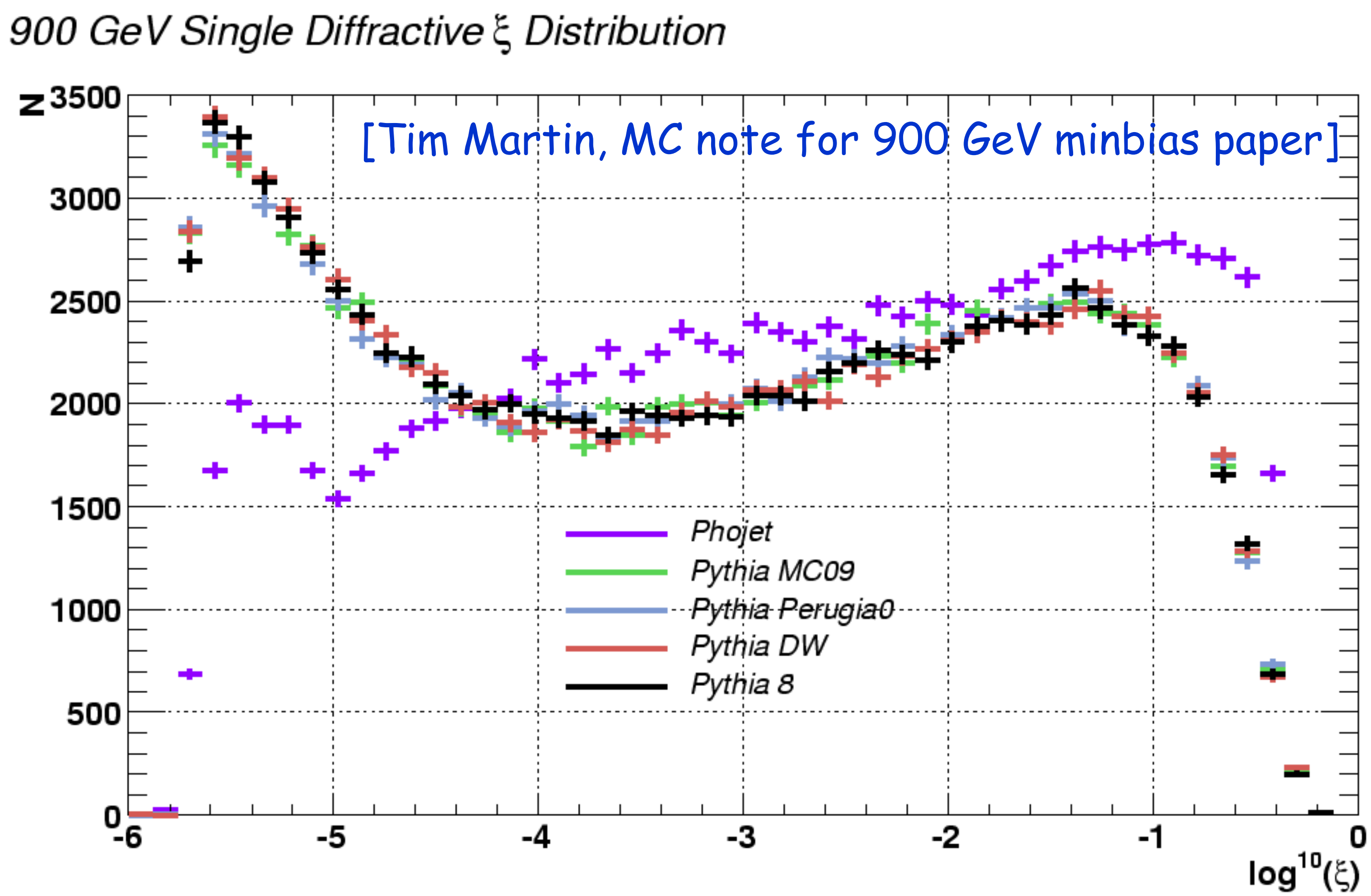




- LRG selections contain typically 20% p diss
- No significant dependence on any variable
- Similar compatibility with Mx method

… **well controlled, precise measurements**

Comparison between Cross Sections



- Big difference between PHOJET and PYTHIA cross sections at small and large ξ
- Different tunes of PYTHIA6 and PYTHIA8 are very similar