Experimental Diffraction from HERA to the LHC

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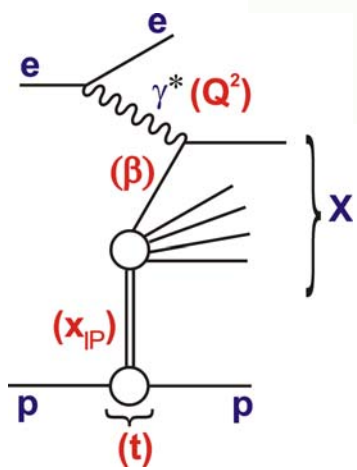
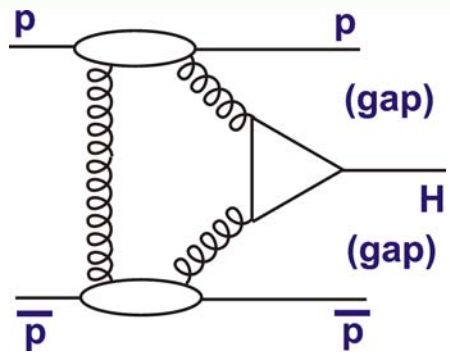
Diffractive Summary at IVth HERA-LHC Workshop

30 May 2008

- Forward Physics projects at the LHC
- Diffractive Parton Densities
- Absorption and Gap Survival
- Unintegrated gluon density
- Closing in on Central Exclusive Production





List of Experimental Talks

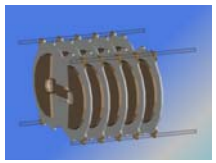
Review of Inclusive Diffraction at HERA	Marta Ruspa
Review of Diffractive Dijets at HERA	Alice Valkarova
Review of Leading Baryons at HERA	Bill Schmidke
Review of HERA Vector Meson and DVCS Data	Pierre Marage
Exclusive Di-lepton and Di-photon Production at CDF-II	Jim Pinfold
Diffractive and Exclusive Dijets and W/Z at CDF	Dino Goulianos
Forward Physics at the LHC	Peter Bussey
Forward Physics with CMS	Samim Ehran
Diffractive and Forward Physics with Totem	Ken Oesterberg
Update on the AFP Project in ATLAS	Christophe Royon
The ALFA Detector: Status and Physics Programme	Karl-Heinz Hiller
CASTOR Calorimeter: Physics and Status	Kerstin Borras
Diffractive Physics in ALICE	Rainer Schicker
Exclusive Dilepton Production at CMS	Jonathan Hollar
Single Diffractive W Production at CMS	Antonio Vilela-Pereira

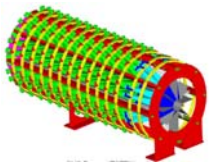
- Short & limited summary … apologies for the many omissions
- Focus on developments in last year and open points

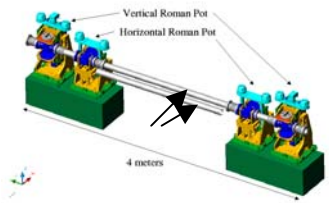
LHC Forward Instrumentation

(many talks)

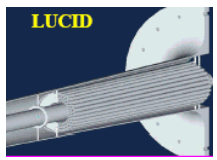
IP5

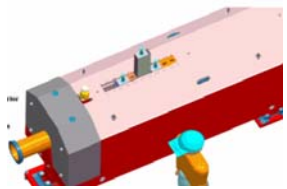


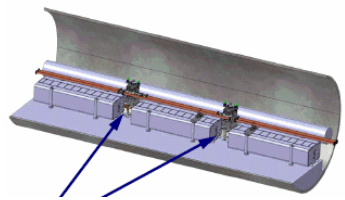




TOTEM-T2	CASTOR	ZDC/FwdCal	TOTEM-RP	FP420
14m	16m	140m	147-(180)-220m	420m
	LUCID	ZDC	ALFA/FP220	FP420







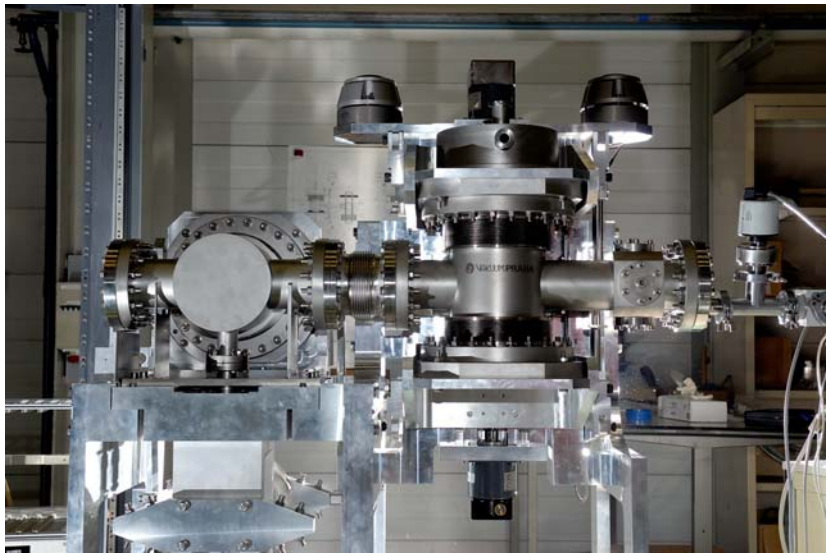
ATLAS

IP1

Impressive array of forward physics projects, providing high rapidity tracking / calorimetry and proton spectroscopy …

… the best instrumented forward beam-lines ever!

LHC Proton Spectrometry



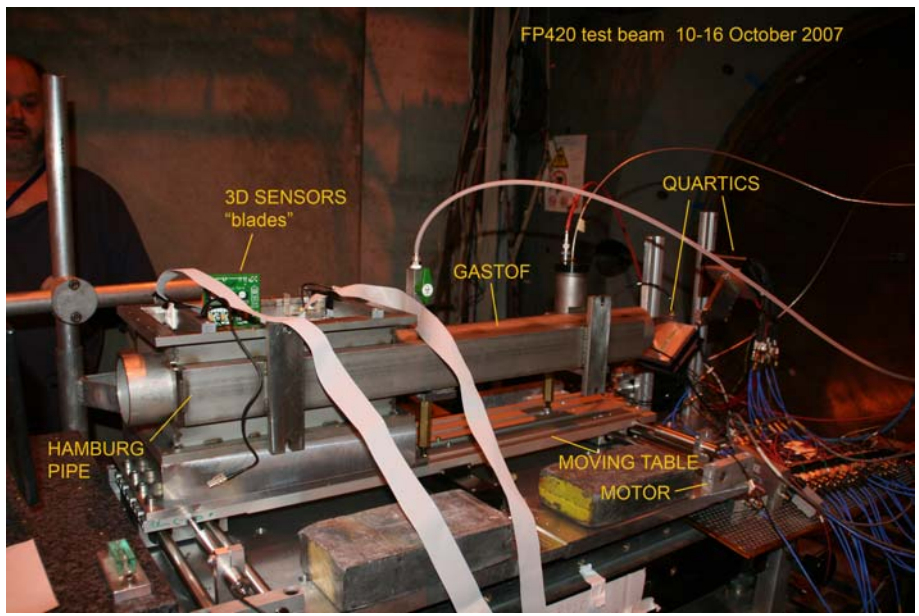
Pots up to 220m

TOTEM pots at 150m and 220m fully in place for 2009

FP220 proposed for installation in ATLAS >2009.

Pots at 420m

FP420 for ATLAS or CMS (installation >2009 if approved)

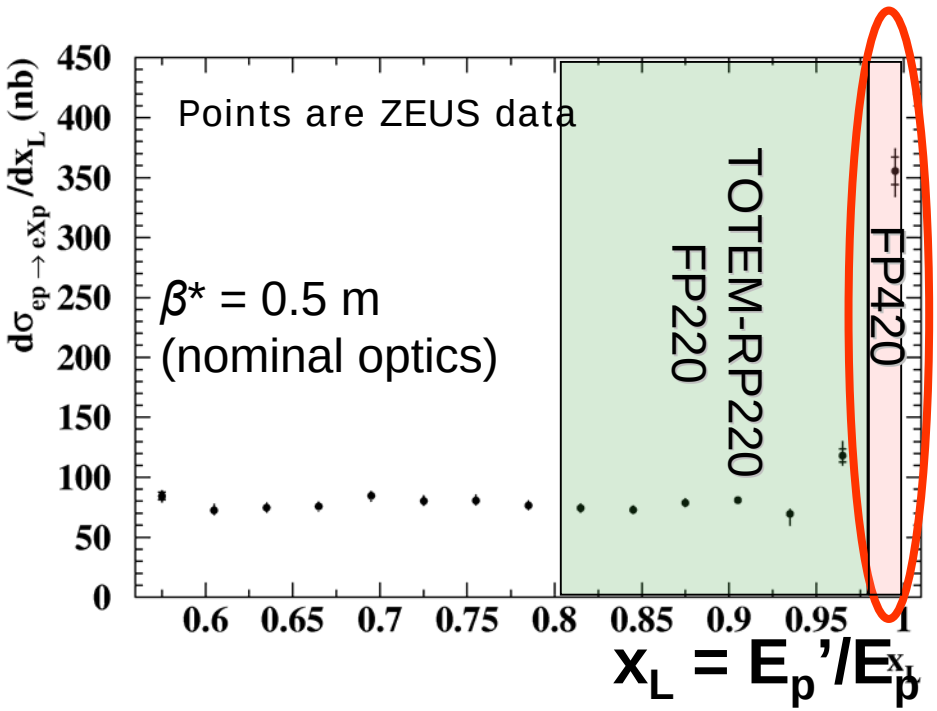


Proton Acceptance @ CMS / Totem

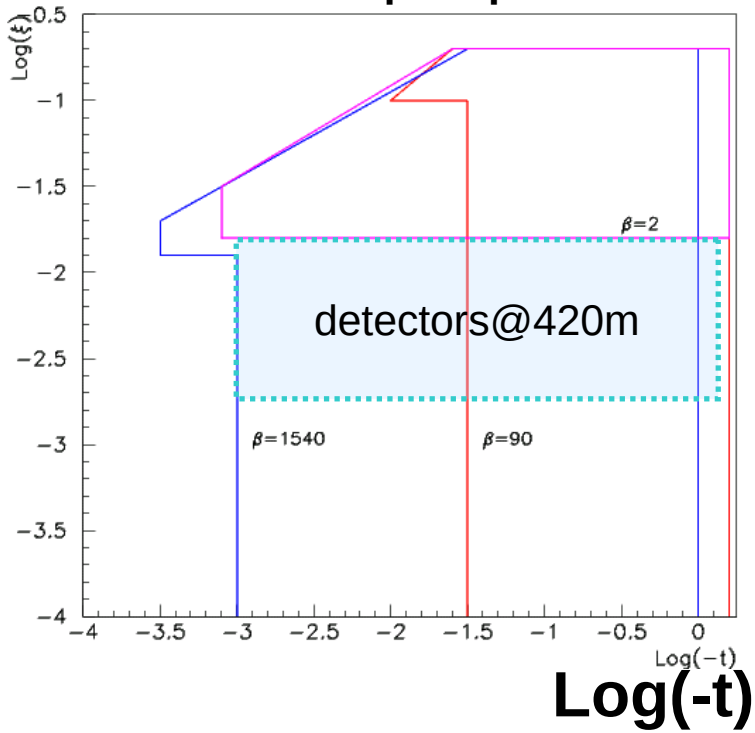
150m + 220m Pots

0.02 < ξ < 0.2 at β* = 0.5m
(high lumi optics)

Reaches lower ξ at
β* = 90 or 1540 m (lower lumi)



Logξ=Log(1-E_p'/E_p)

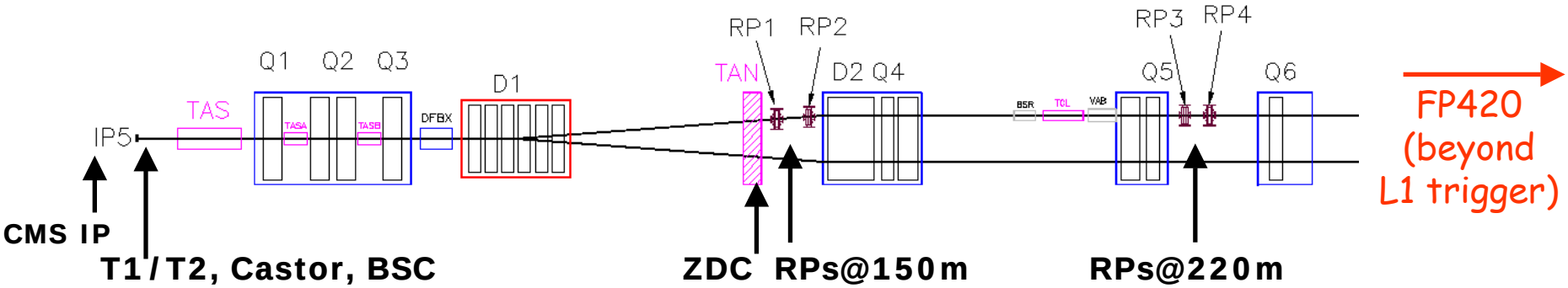


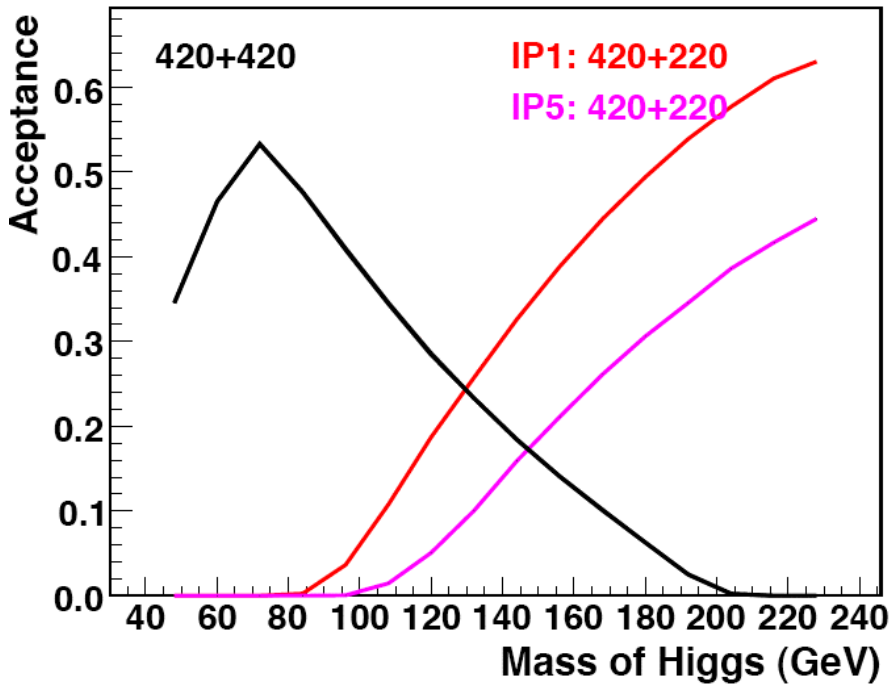
Log(-t)

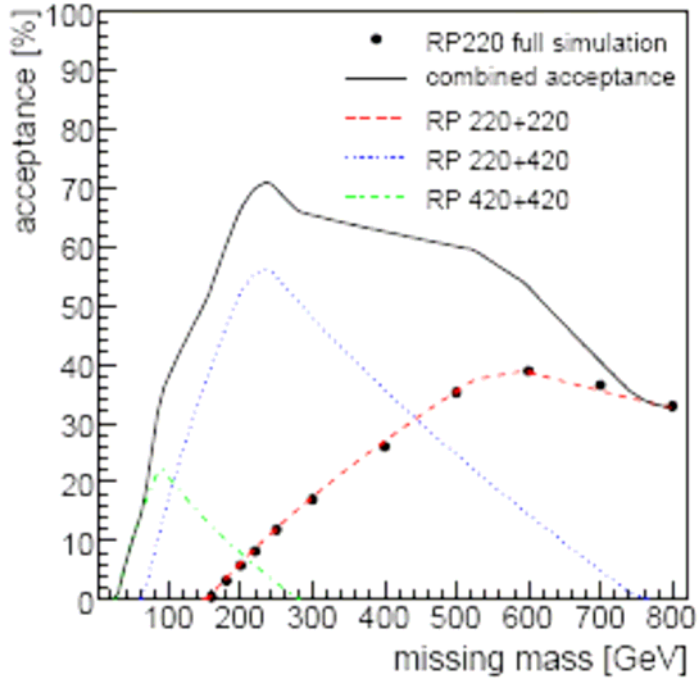
420m Pots

0.002 < ξ < 0.02
(high lumi optics)

Higgs / 0^+ Resonance Acceptance







Comprehensive coverage with 220m, 420m combined …

Higgs Mass resolution ~ 2-4 GeV over wide m_H range (Bussey)

Example Strategy: CMS + Totem + FP420

Totem (tracking + pots) and CMS are highly complementary
… greater than the sum of their parts …
essential to continue working together …

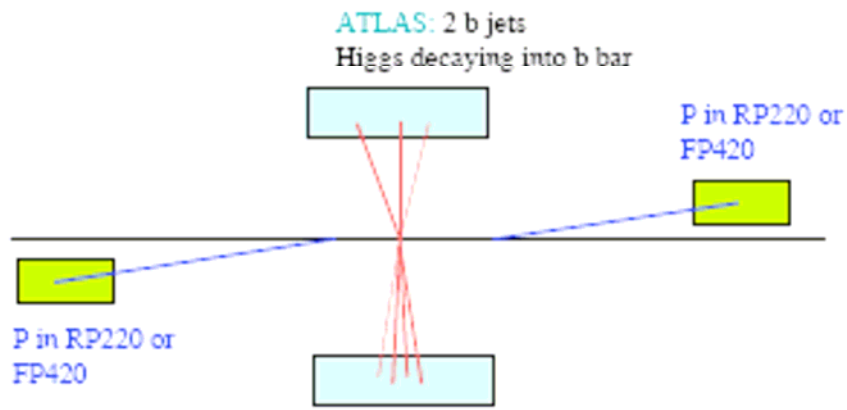
"Prospects for diffractive and forward physics at the LHC"

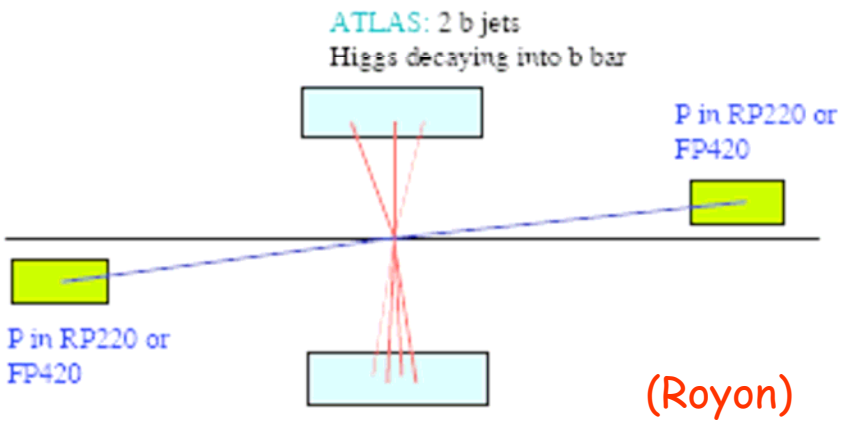
CERN/LHCC 2006-039/G-124, CMS Note 2007/002, TOTEM Note 06-5, Dec 2006

Low lumi: Large rapidity gap selection possible
Proton tagging optional
… Soft diffraction, σ_{tot}, σ_{el} …
… Some Hard diffraction / DPDFs
… Understanding pile-up
… $\gamma\gamma$ physics

High lumi: Pile-up ruins rapidity gap selection
Proton tagging essential (220 & 420 m)
… Diffractive Higgs and other exotica
… More hard diffraction / DPDFs
… $\gamma\gamma$ physics

Overcoming pile-up with Timing





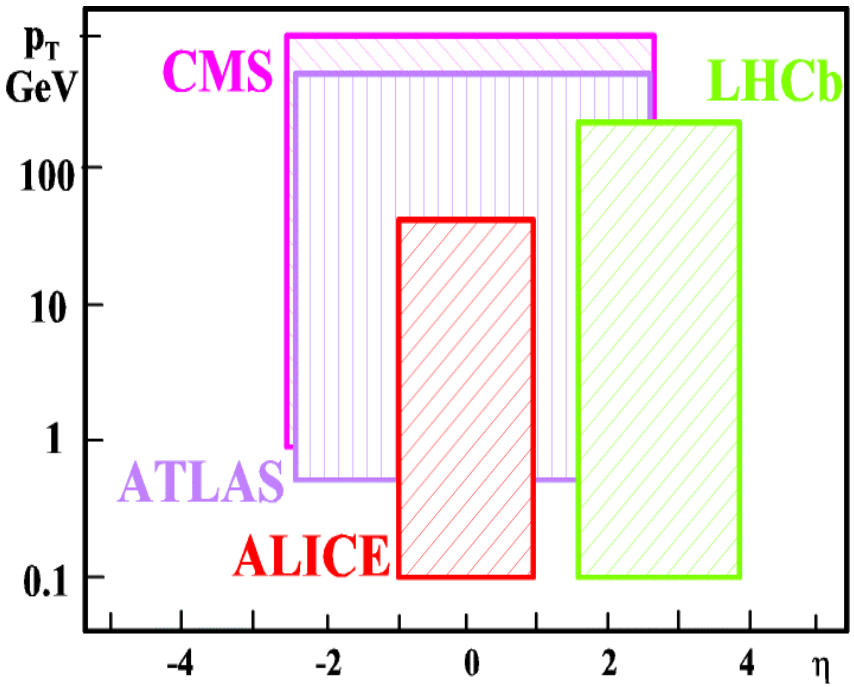
(Royon)

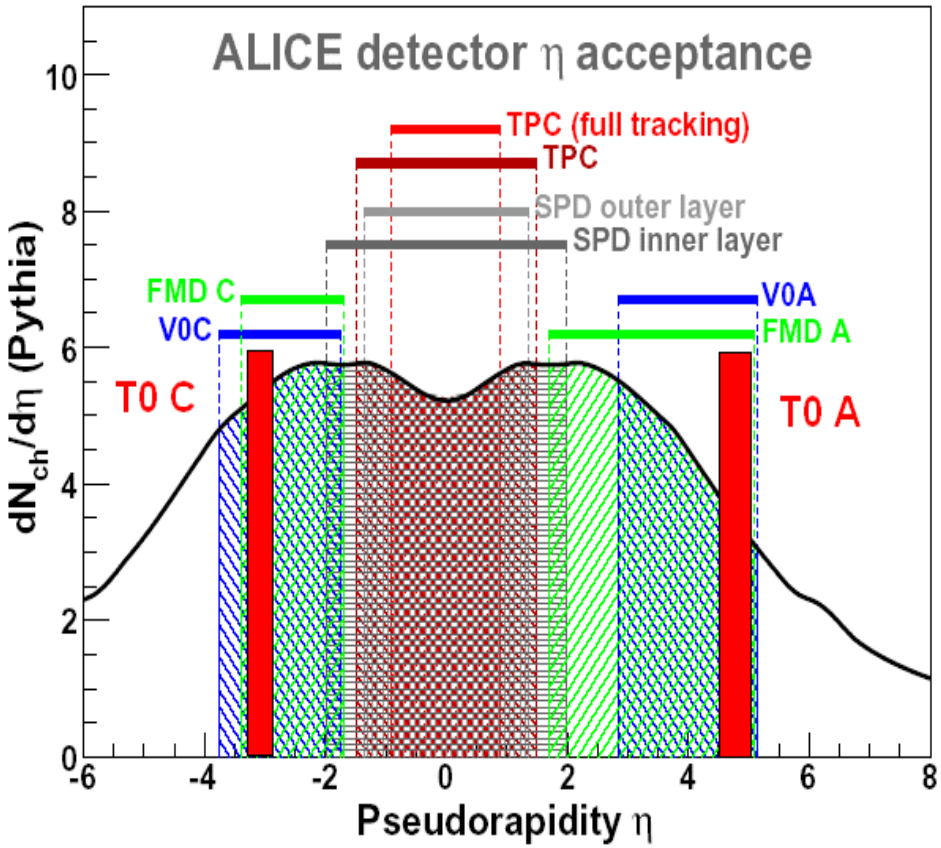
Proton spectrometer design incorporating precise (few ps) timing measurements, from which z position of vertex can be reconstructed to a few mm.

→Correlating leading protons with hard interaction in central detector in presence of (many) soft interactions

Diffraction at ALICE

(Schicker)

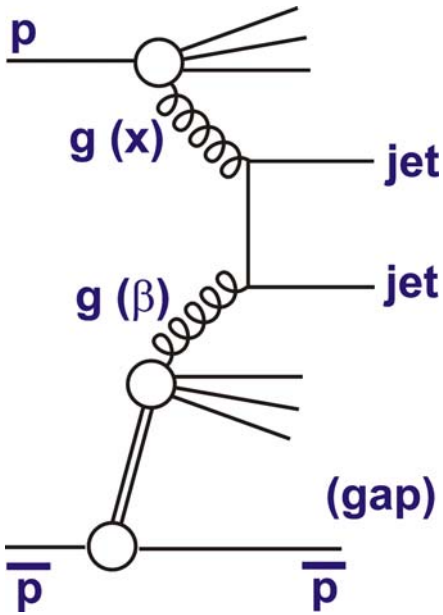


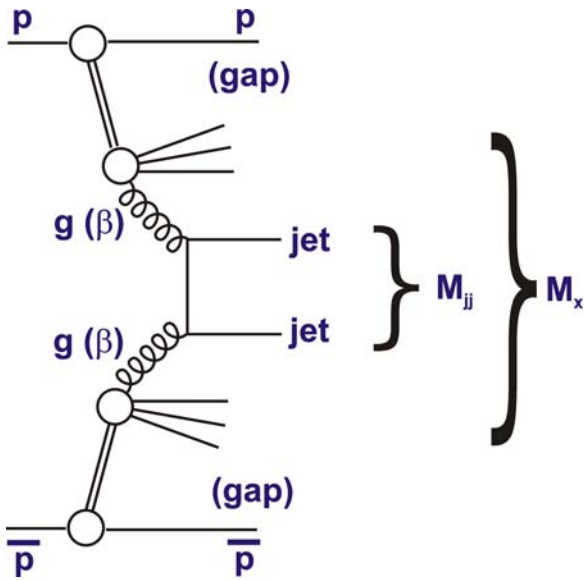


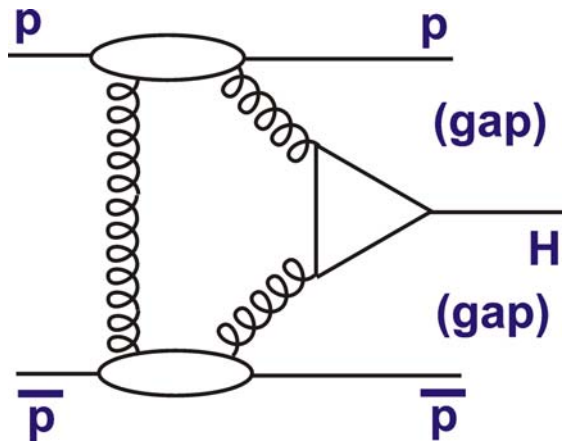
- (Uniquely?) capable of triggering on and detecting central tracks at very low pt.
- Together with 1st level `gap' trigger using scintilators and silicon, sensitive to `soft' and low p_t diffractive processes

… e.g. γ+odderon → J/Ψ searches

Diffraction at the LHC







Opportunity to study Single and Double Diffraction with and without hard scales (jet, heavy flavours, W, Z).

→ Depend on DPDFs from HERA

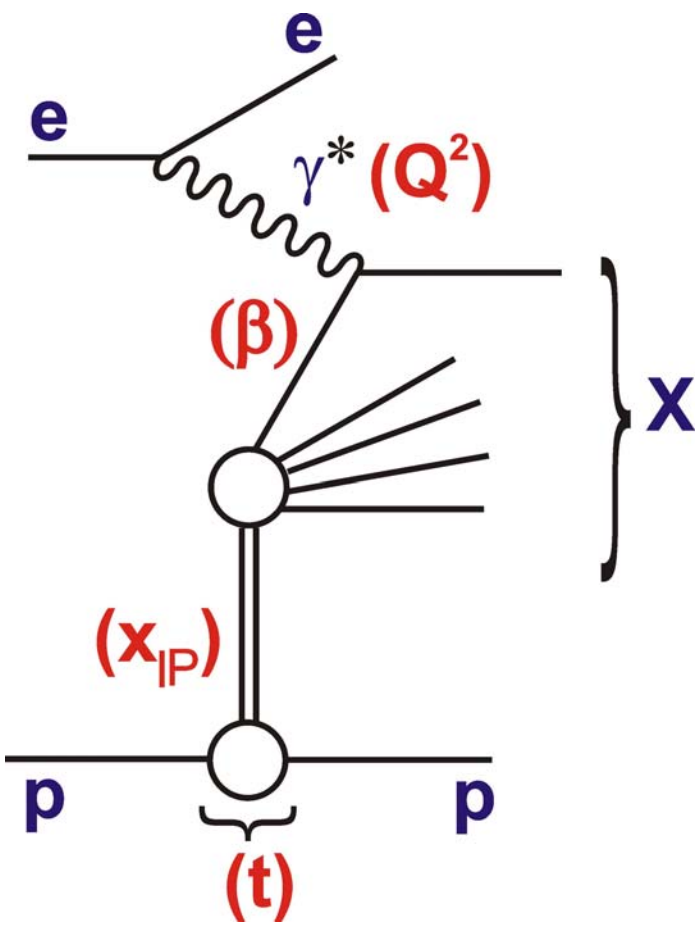
→ Also on gap survival factors!

'Central Exclusive Production'

- DPDFs for backgd
- Unintegrated gluon → J/Ψ / Υ
- Gap survival models (KKMR, GLM …)

… lots of possible input from HERA!

Inclusive ep Diffraction



Senisitive to Difffractive Parton Densities (DPDFs) and t dependences

(See also Fracture Functions)

(Ceccopieri, Trentadue)

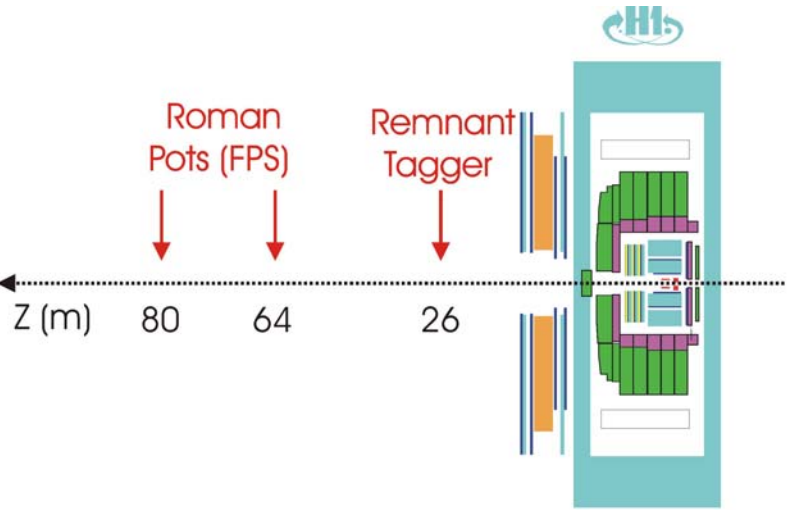
ZEUS and H1 both published highest precision measurements of 3 (or 4)-fold differential cross sections in past 2-3 years:

$\sigma_r^D(x_{IP}, \beta, Q^2)$

Work in HERA-LHC framework on level of agreement between collaborations and between different selection methods

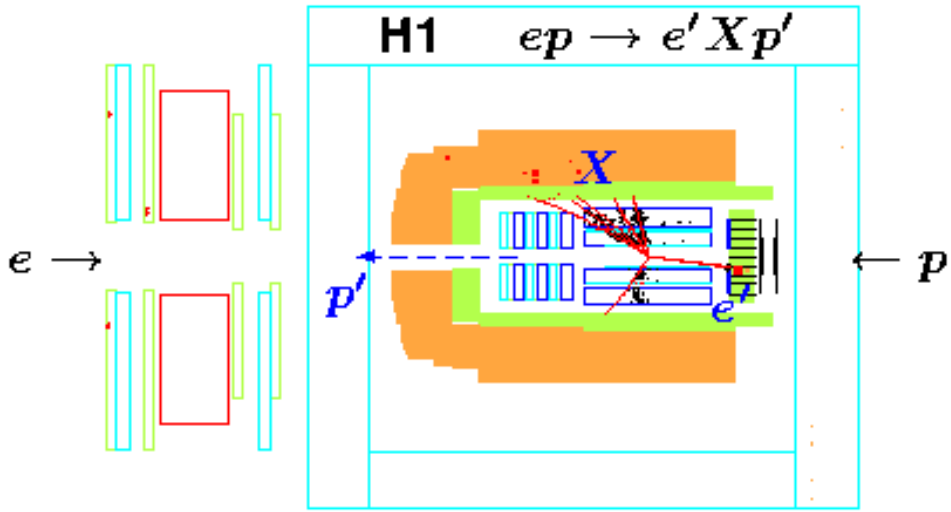
Selection Methods

Direct measurement of scattered proton in ZEUS LPS or H1 (V)FPS



Limited by statistics (at HERA-I) and proton tagging systematics

`Large Rapidity Gap' method (empty detectors) adjacent to outgoing (untagged) proton

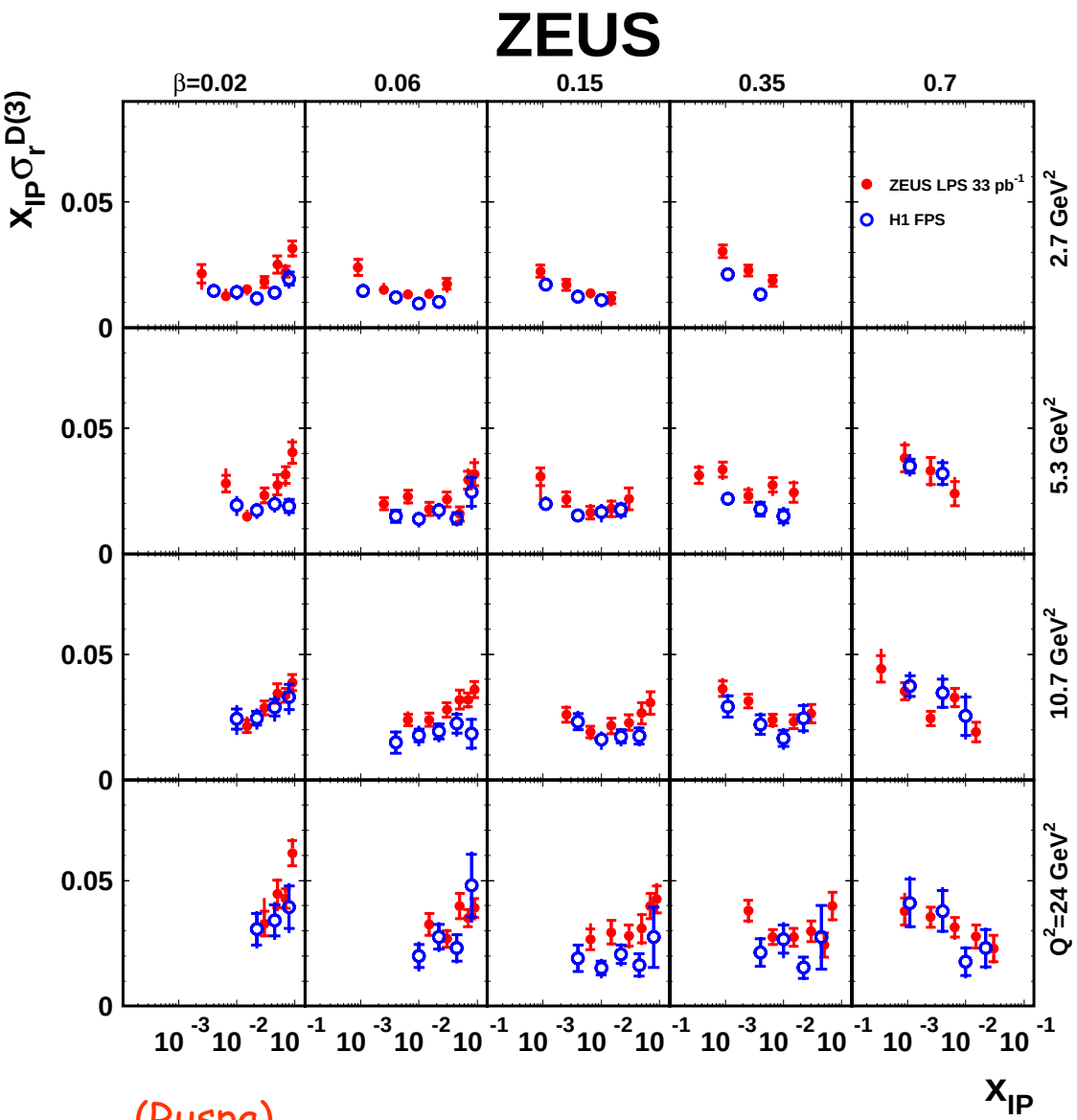


Limited by systematics associated with missing proton

The 2 methods have very different systematics!

Also `Mx method' via decomposition of diffractive mass distn

Comparison of ZEUS v H1 Proton Tagged Data



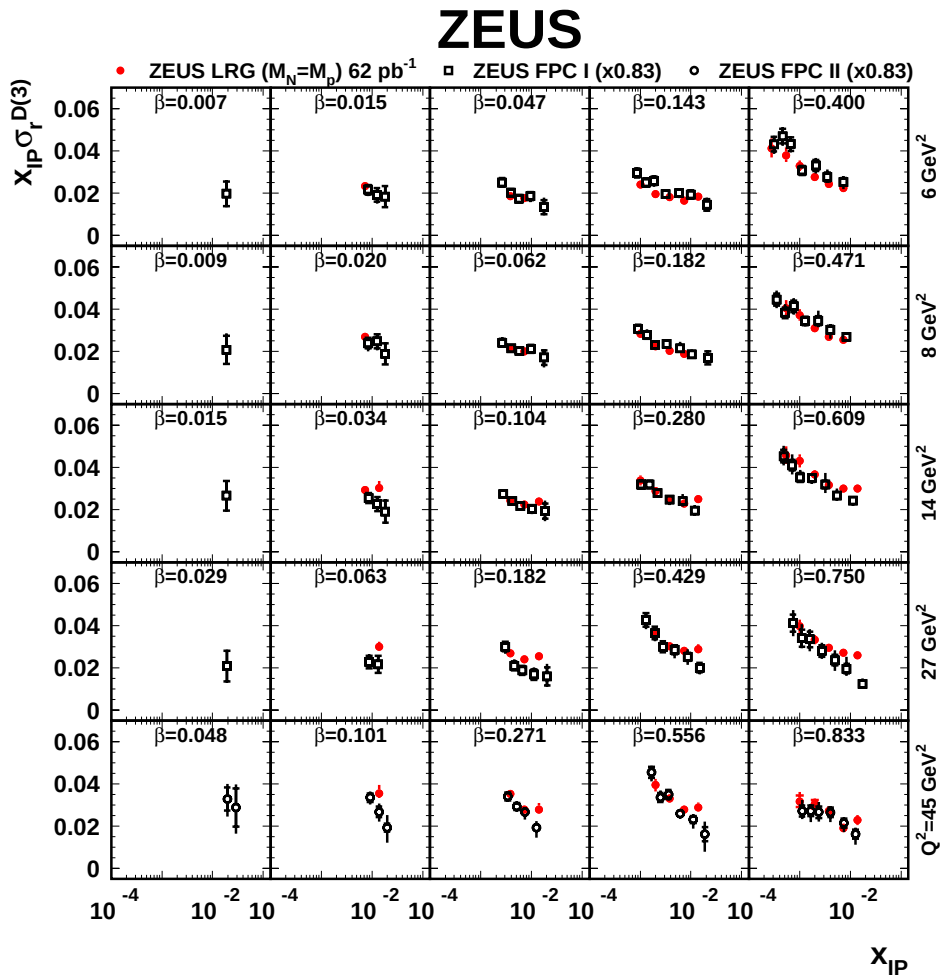
(Ruspa)

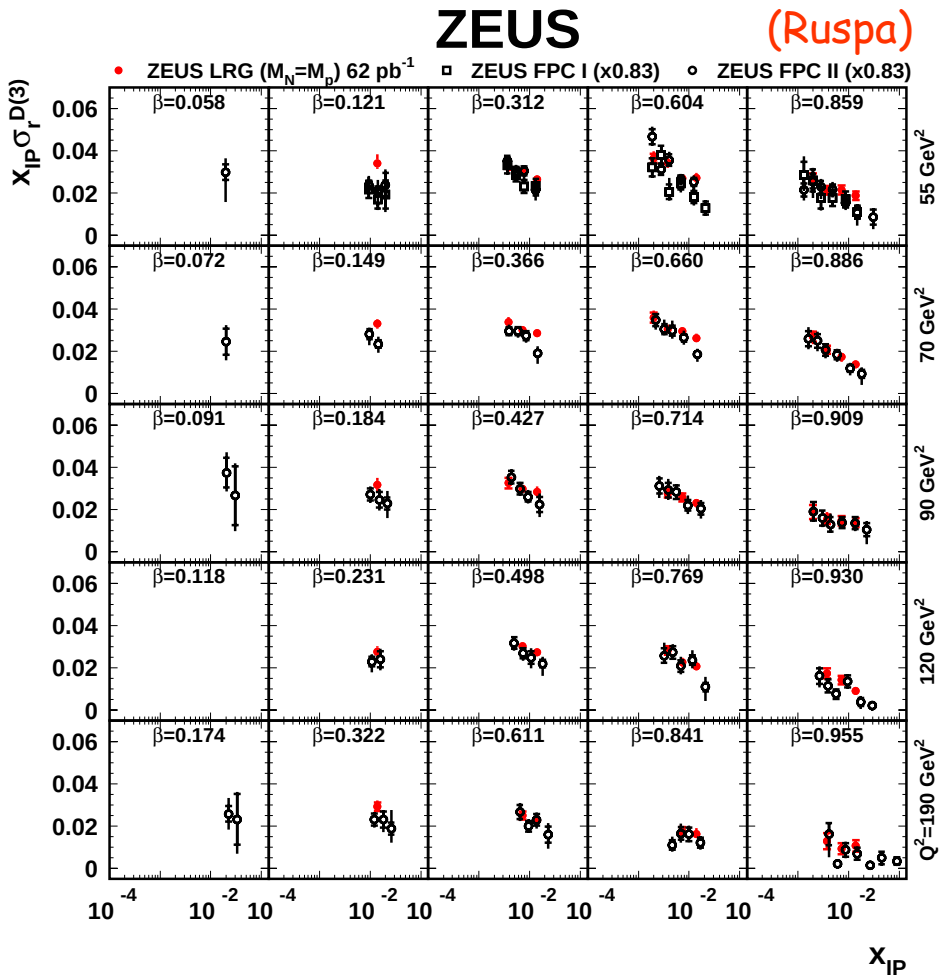
The cleanest possible comparison in principle….

… good agreement within (large) normalisation uncertainties (~ 10% for each experiment)

Also very good agreement on low mass proton diss'n e.g. from LRG / FPS

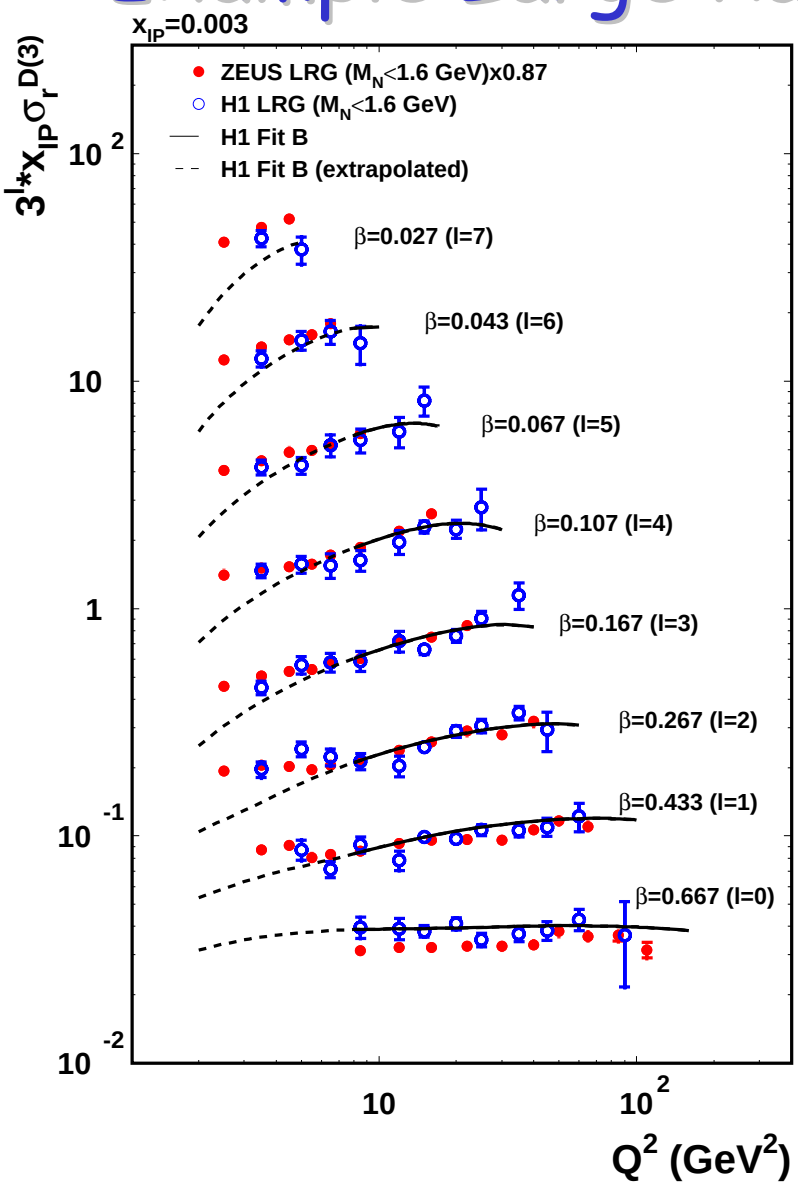
Comparison of ZEUS LRG v Mx Data

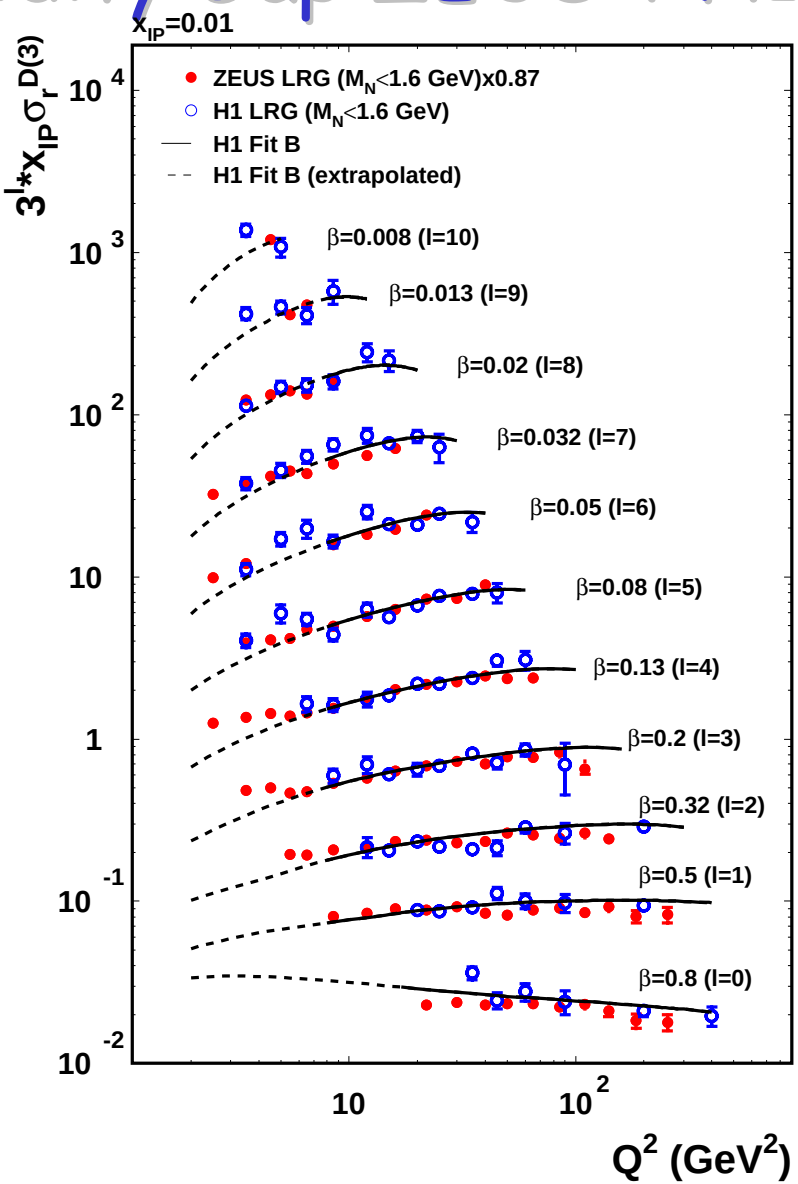




Good agreement again (except at high x_{IP}, where measured observables are differently defined)

Example Large Rapidity Gap ZEUS v H1





(Ruspa)

Very good agreement through most of phase space …

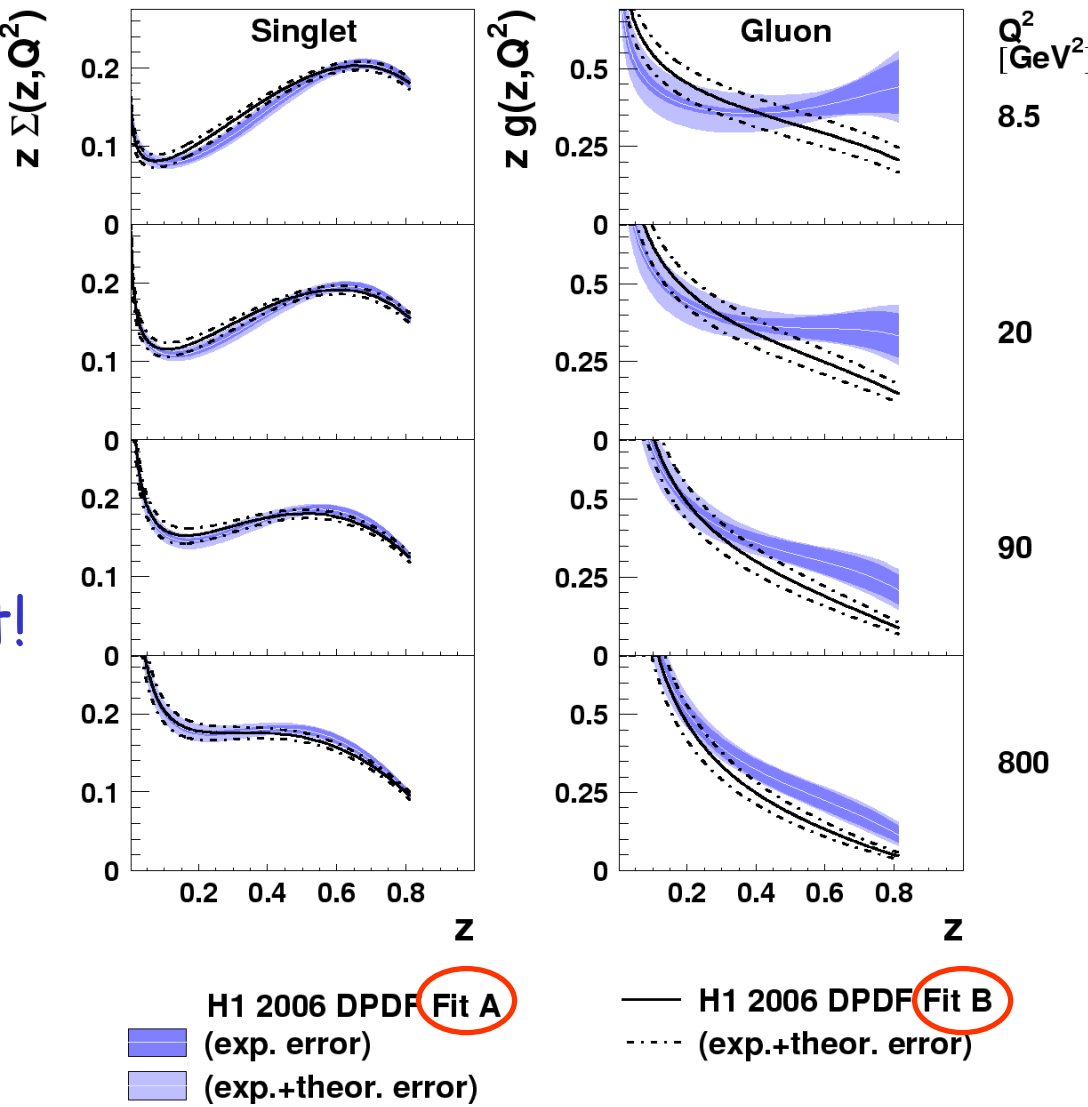
Diffractive Parton Densities from σ_r^D

- σ_r^D gives quark density to ~5%, gluon to ~15% at low z, increasing rapidly as $z \to 1$.

- Well tested in DIS final states (jets / charm)

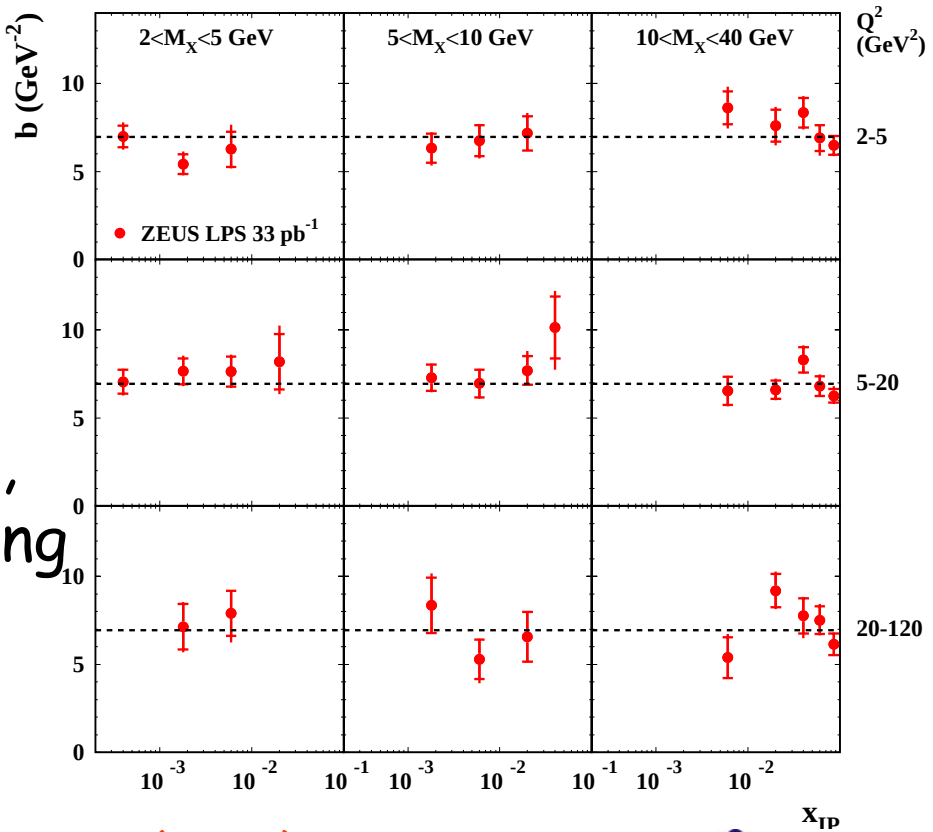
… but high z very important!
  - Background to CEP!
  - `Direct' IP (eg MRW)

- Including jet and charm data much improves high z



Next steps: Similar ZEUS fit
: More data comparisons and joint (`global'?) fit

t Dependence of σ_r^D from LPS / FPS



(Ruspa)

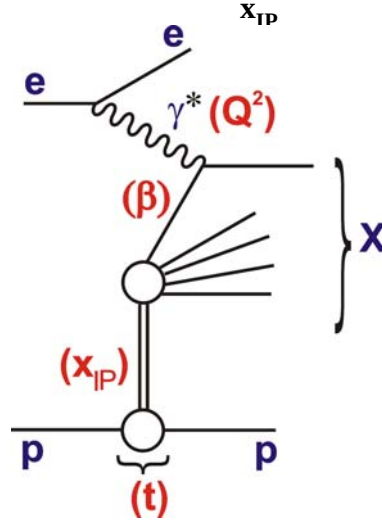
Fitting to e^{bt} yields b=6-7 GeV^{-2}, independently of β, Q^2, supporting proton vertex factorisation.

Also very little x_{IP} dependence

Very good ZEUS v H1 agreement on effective pomeron trajectory:

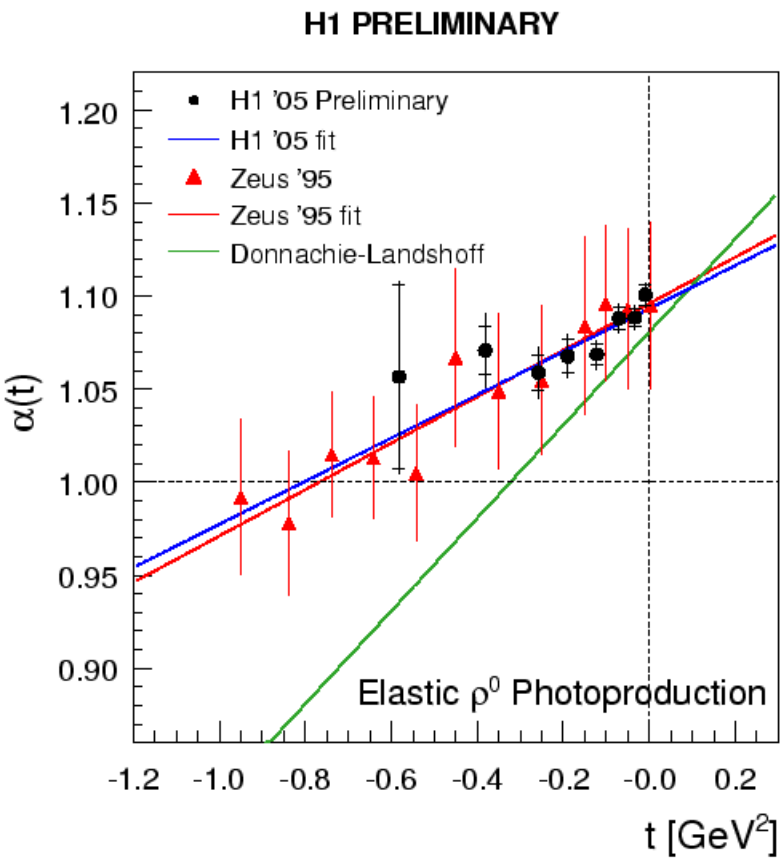
$\alpha_{IP}(0) = 1.11 - 1.12$ (various extractions)

α'_{IP} = -0.01 ± 0.06(stat)+0.04 -0.08(syst) GeV^{-2} (ZEUS LPS)



… not soft IP → multi-IP exchange / absorption in the game!

What is a soft pomeron anyway?



The `soft' pomeron in photoproduction at HERA is not as soft as we expected from pp

From $\gamma p \rightarrow \rho p$ (ZEUS ϕ similar) (Marage)

There is NO universal IP even in soft physics!

H1 $\alpha_{IP}(t) = [1.093 \pm 0.008] + [0.116 \pm 0.049]t$

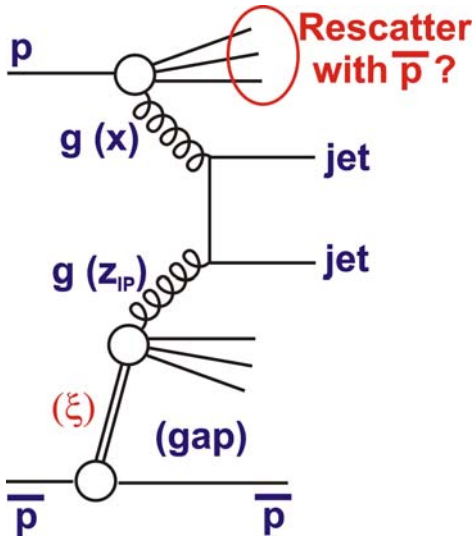
ZEUS $\alpha_{IP}(t) = [1.096 \pm 0.021] + [0.125 \pm 0.038]t$

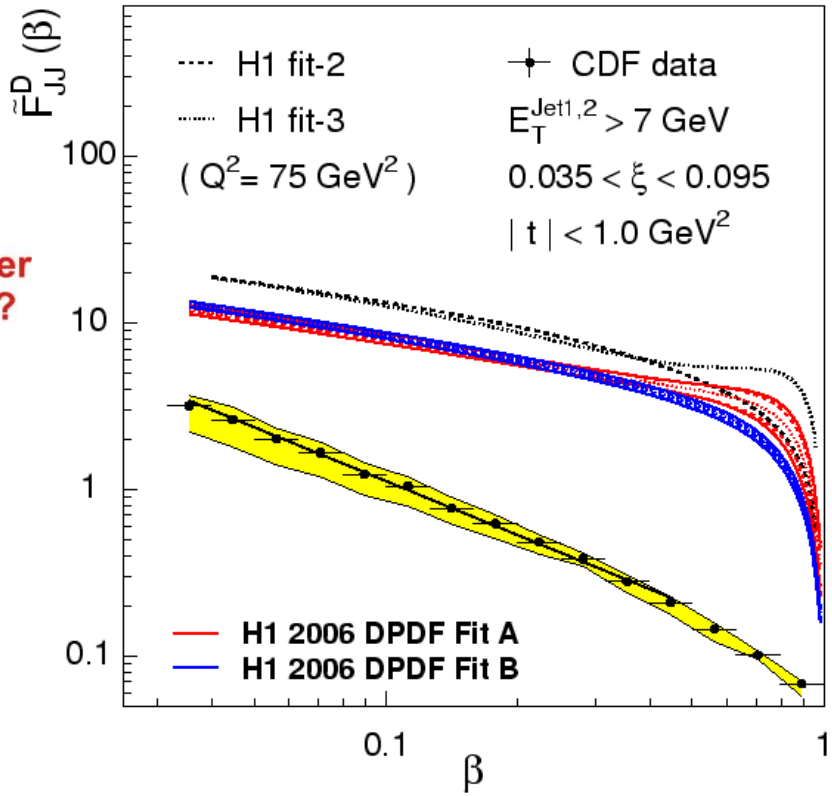
`Soft' $\alpha_{IP}(t) = [1.085] + [0.25]t$

Can be explained by different absorptive corrections?

Meanwhile in pp(bar) …

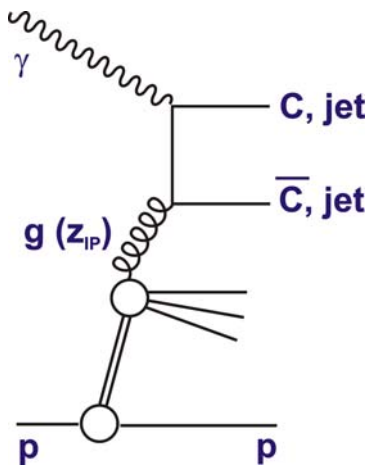
- Huge corrections when applying DPDFs:`Gap survival' factor~10

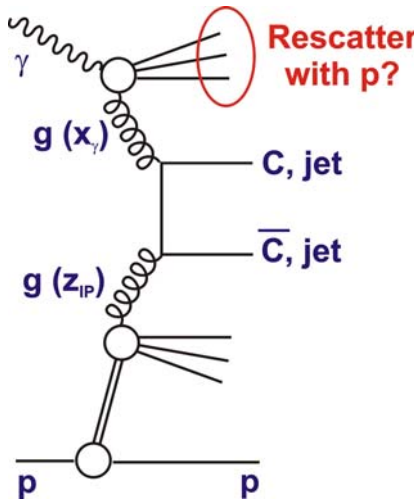




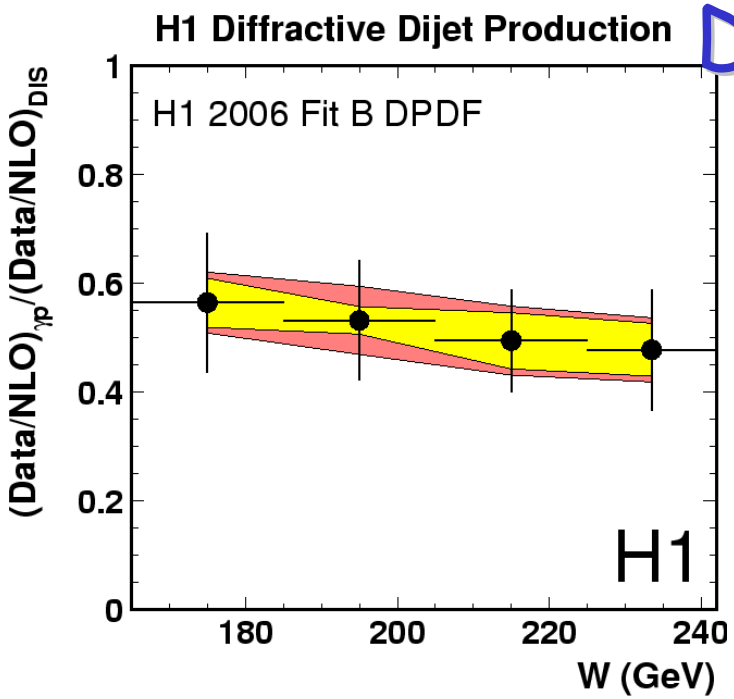
… γp as a Control Expt?

Most models predict gap survival probability …
= 1 (direct)
< 1 (resolved … e.g. Kaidalov, Khoze, Martin. Ryskin → ~0.34)





Dijet Photoprodcution: 2007

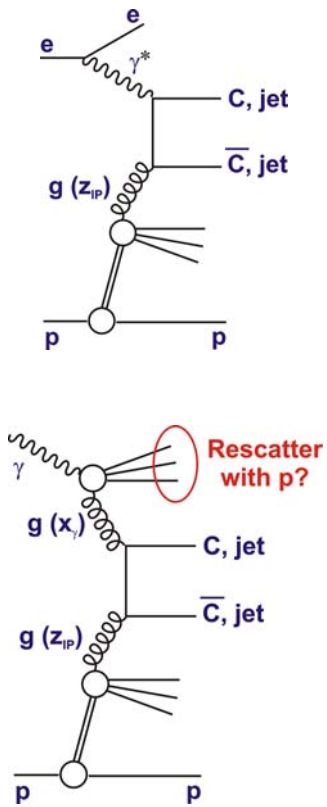


- H1 97: $E_t^{jet1} > 5$ GeV

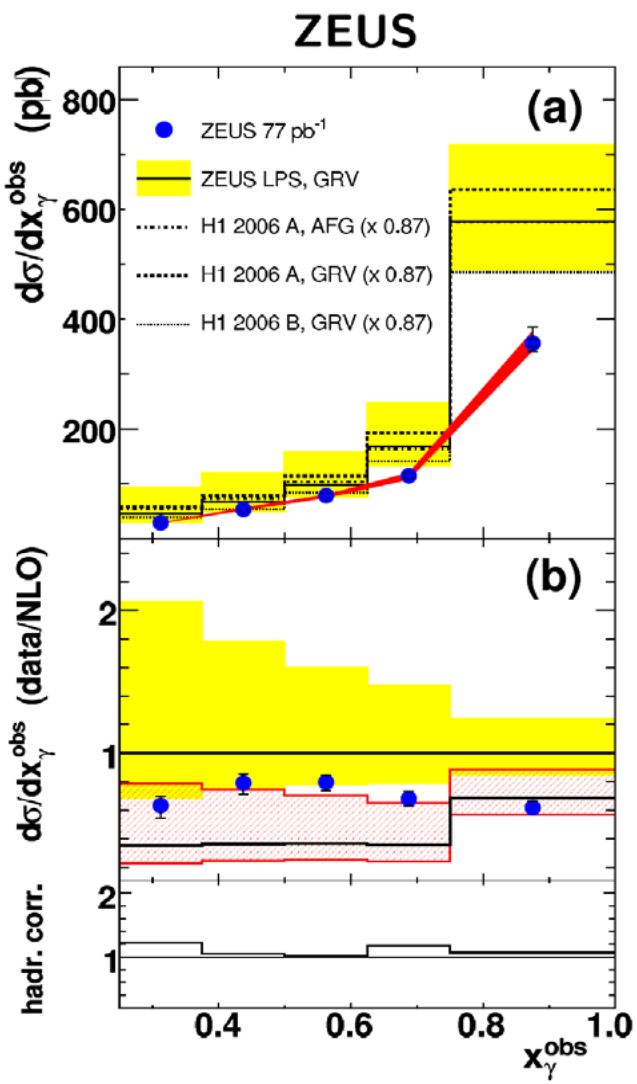
"Suppression by factor ~2"

- ZEUS 99-00: $E_t^{jet1} > 7.5$ GeV

"Weaker suppression"



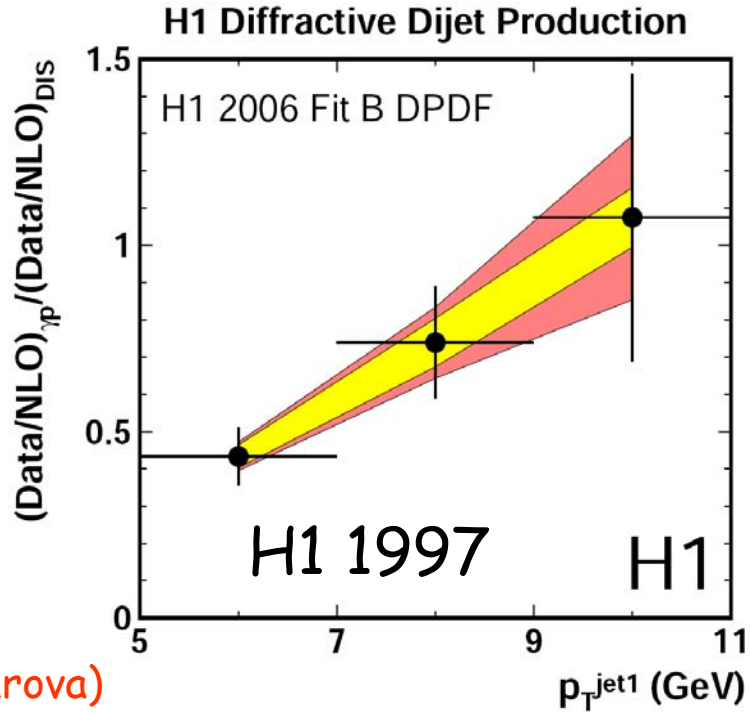
(Valkarova)



- Neither collaboration sees difference between resolved and direct regions, in contrast to theoretical expectations!

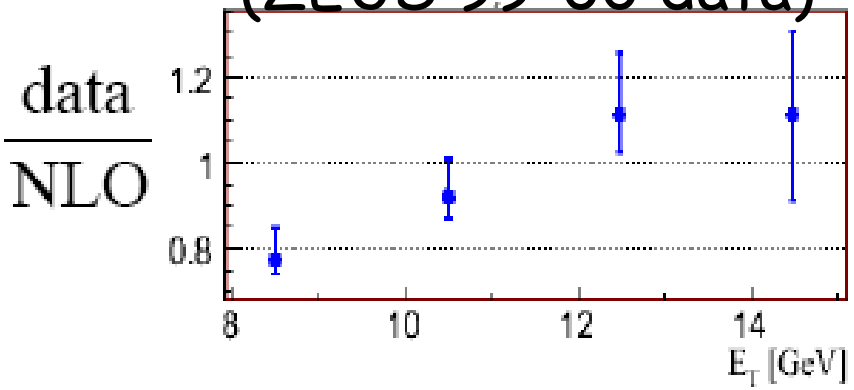
Recent Developments

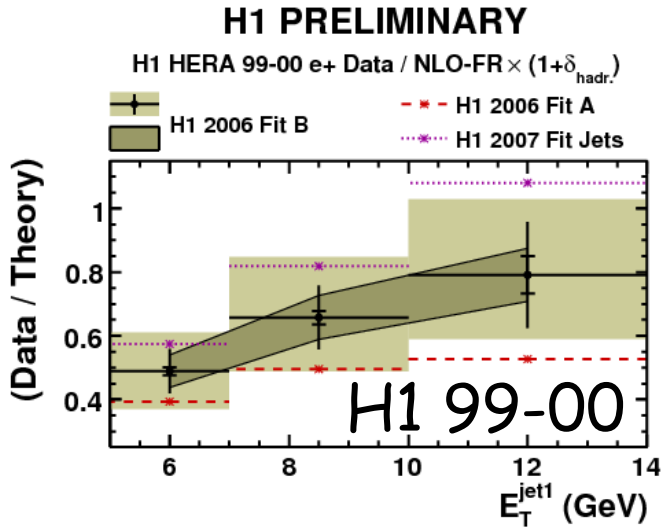
"H1 – ZEUS difference due to different E_T?" (DIS07, ZEUS)



(Valkarova)

(ZEUS 99-00 data)



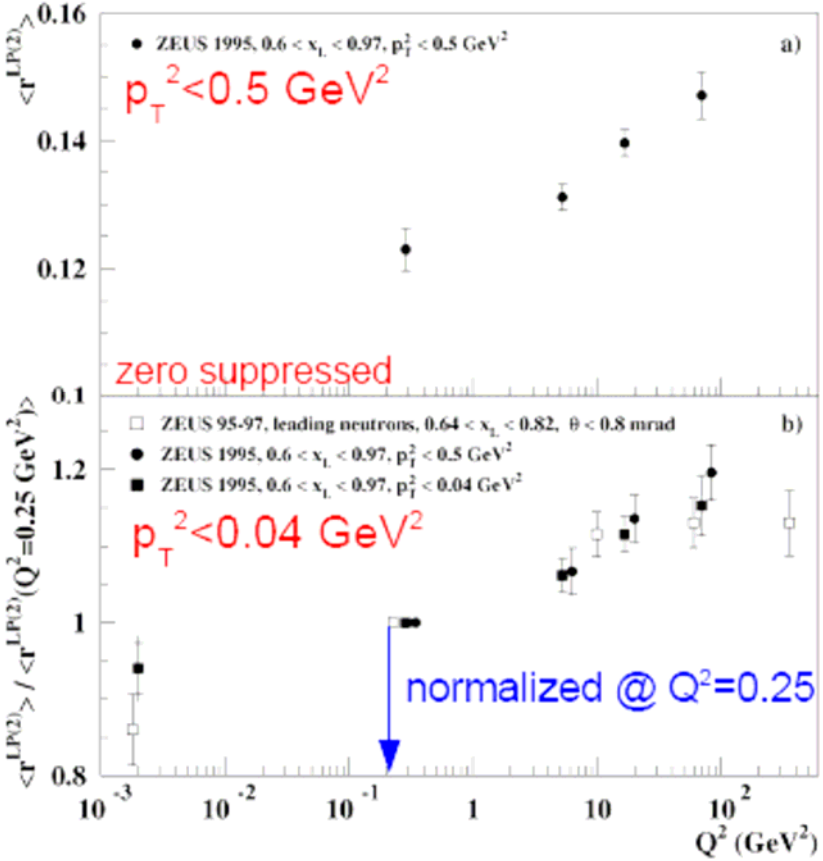


? Rescattering probability α Photon Size r α $1/E_T$?

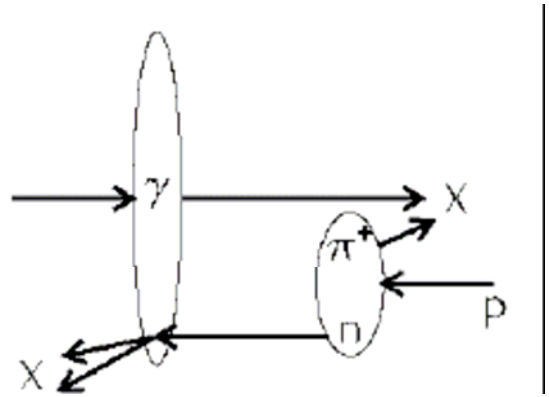
Understanding H1-ZEUS discrepancies is a success for the workshop, but probably tells us more about the high energy photon than it does about the LHC!

Absorptive Corrections in Leading Neutrons

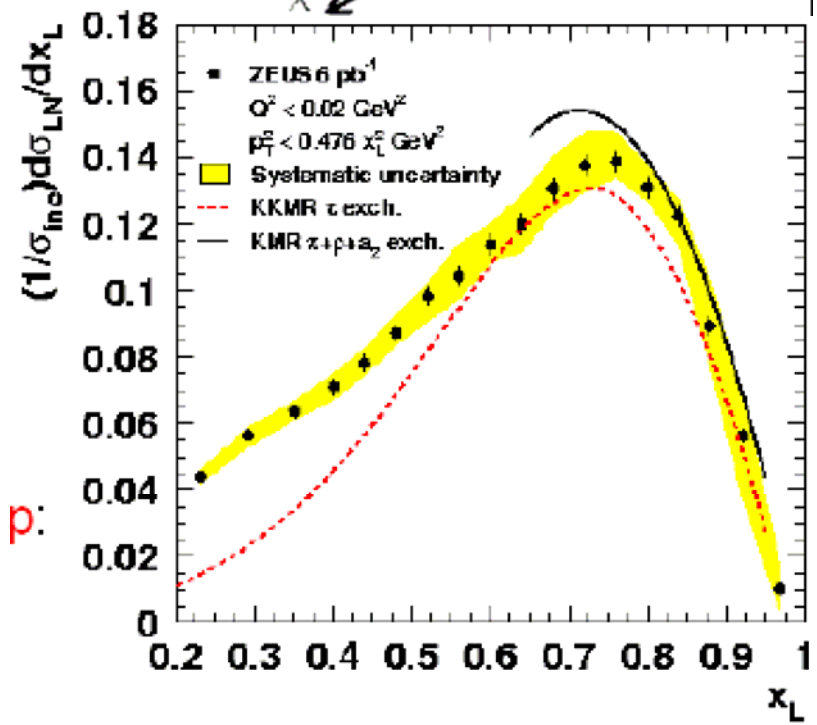
- Total yield $0.6<x_L<0.9$:



(Schmidke)



p:



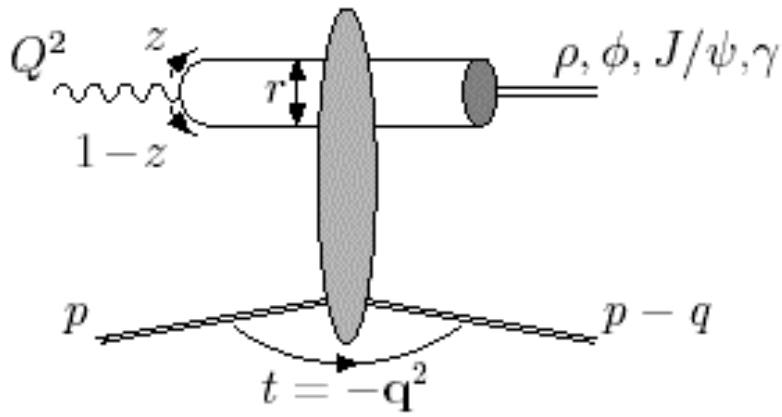
- Precise leading baryon data!
- LN yield decreases as Q^2 decreases, can be interpreted semi-quantitatively as absorptive effect. (Kaidalov et al)

Vector Mesons and DVCS at HERA

Wealth of data (33 H1 + ZEUS papers, many more theory)

-Tests many pictures of γ(*) p scattering …

- most commonly, scaterring colour dipoles from the proton



- Unique transverse / longitudinal γ* separation

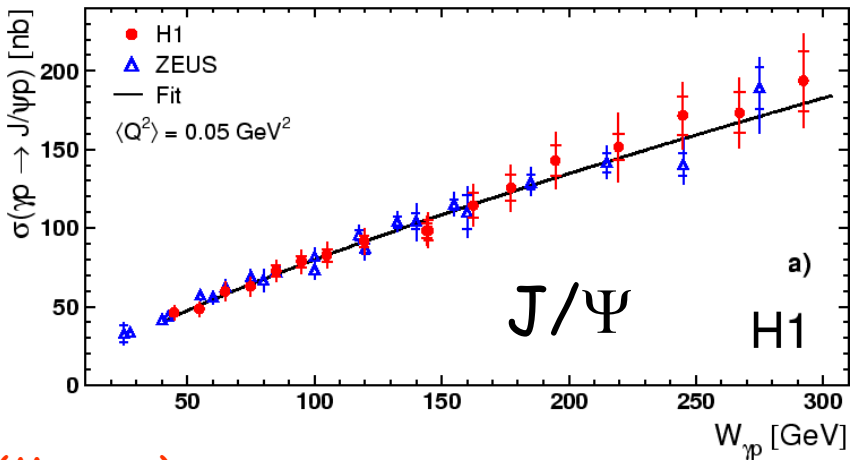
- Unique sensitivity to `soft → hard' transition

- t measurements → transverse picture of proton

- Proton vertex factorisation tests e.g. from PD / EL

- Constraints on generalised gluon density (best with heavy VM)

Heavy VMs → Generalised Gluon Density

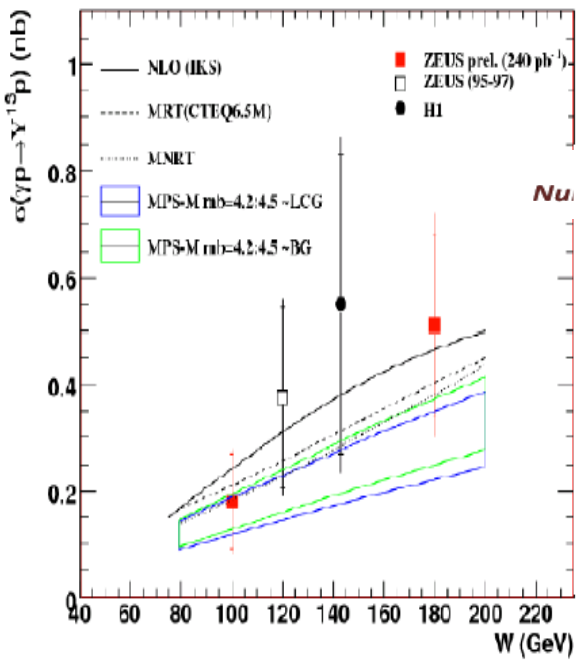


(Marage)

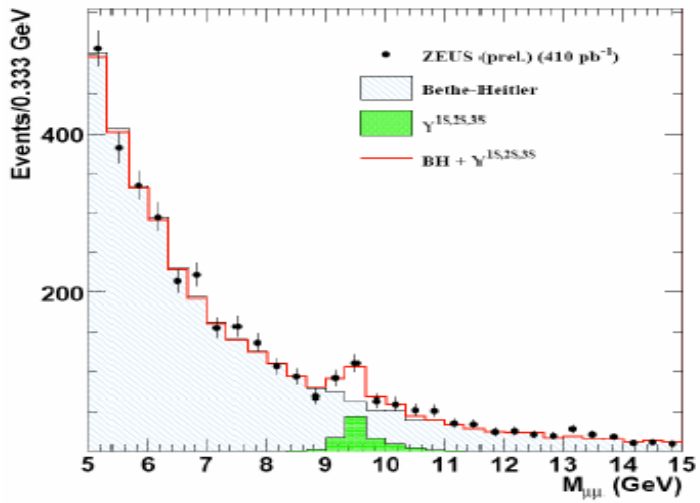
High precision J/Ψ data,
→ Gluon (see e.g. Teubner et al.)

… Still statistics limited in (double differential) places

… every reason to analyse full HERA-II data



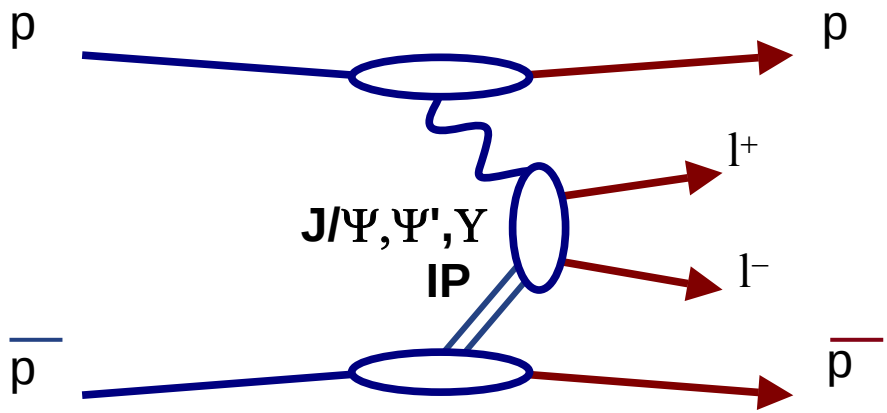
Even with HERA-II there will not be big Υ Yields At HERA



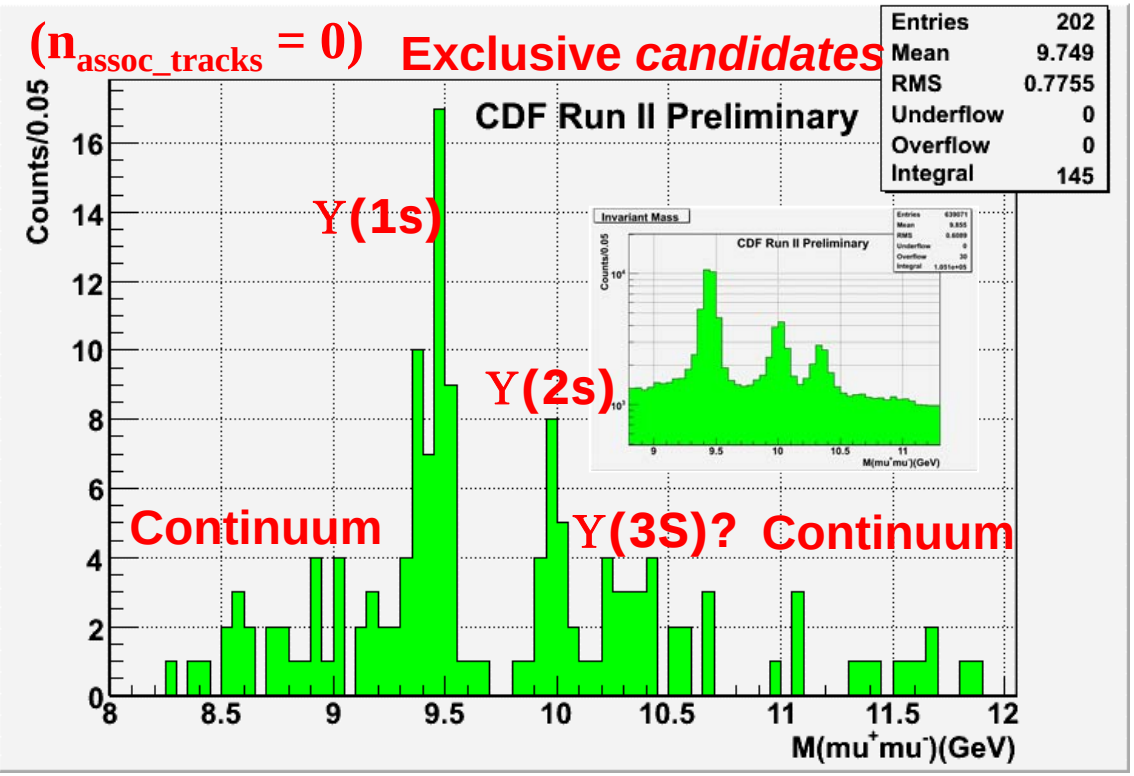
… but maybe Tevatron / LHC?

Heavy VM Photoproduction at Tevatron

CDF Exclusive (γIP) Data



$$\Delta\phi > 120^0, \; p_T(\mu^+ + \mu^-) < 7 \text{ GeV/c}$$



… potential to add further statistics …

(Pinfold)

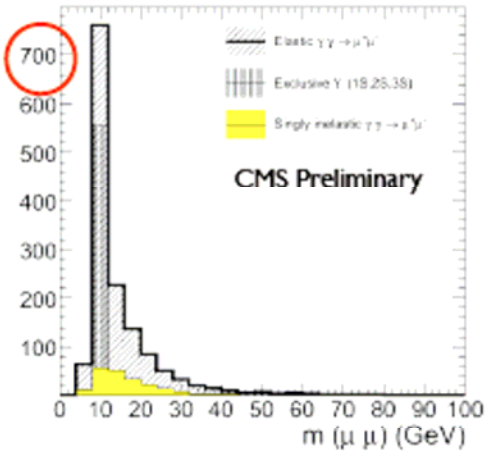
Similarly In CMS study of exclusives at low luminosity…

Final samples (100 pb^{-1})

- In MC, several hundred two-photon and Upsilon events pass the final selection in the dimuon channel

709 ± 27 (stat) elastic events
223 ± 15 (stat) ± 42 (model) singly inelastic events

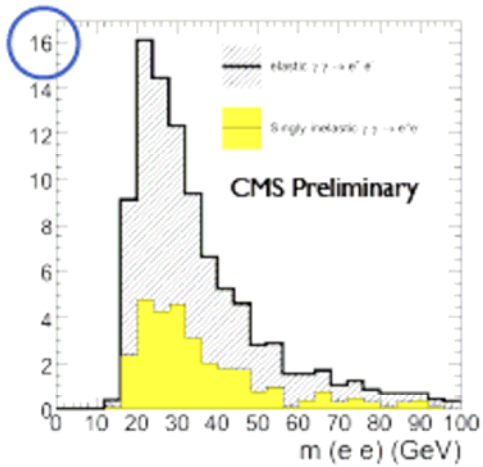
636 ± 25 (stat) ± 121 (model) singly inelastic events, no ZDC/Castor



- Electron sample a factor of ~10 smaller due to higher trigger threshold, efficiency for low E_T electron reconstruction
  - No sensitivity to Upsilon region

67 ± 8 (stat) elastic events
31 ± 6 (stat) ± 6 (model) singly inelastic events

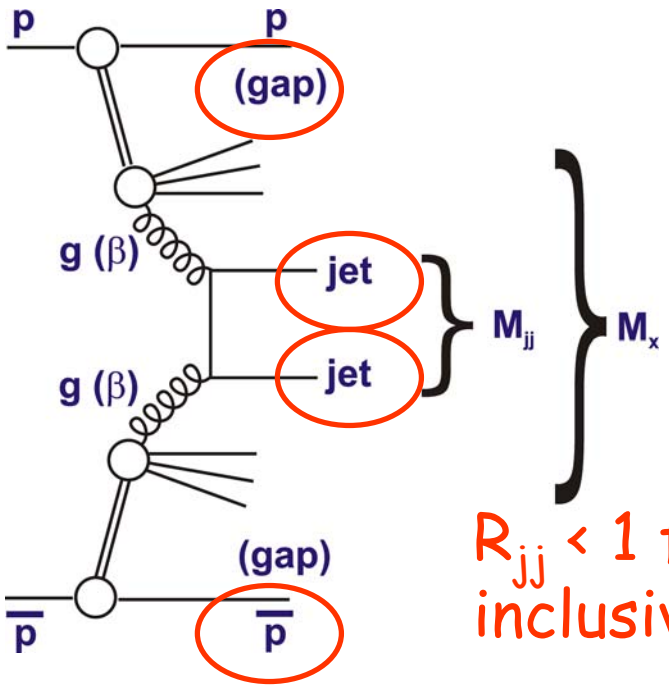
82 ± 9 (stat) ± 15 (model) singly inelastic events, no ZDC/Castor



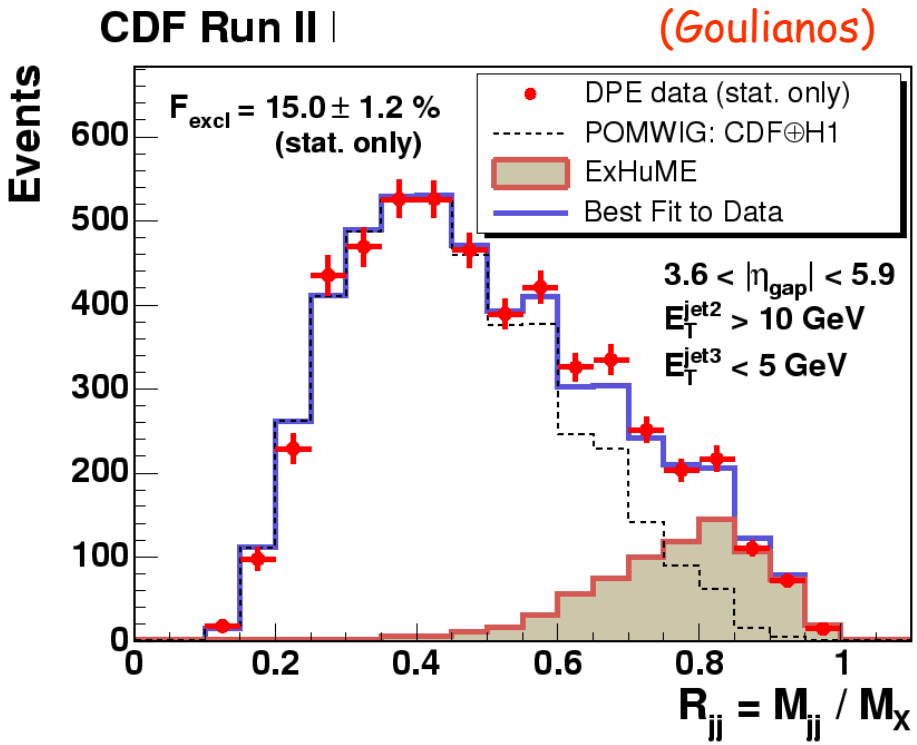
(Hollar)

Exclusive Dijet Production at the Tevatron?

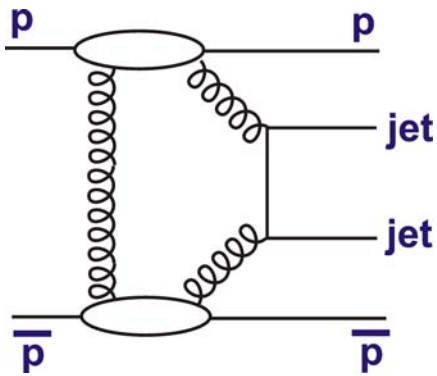
"DPE" dijets, plot $R_{jj}=M_{jj}/M_x$



R_{jj} < 1 for inclusive

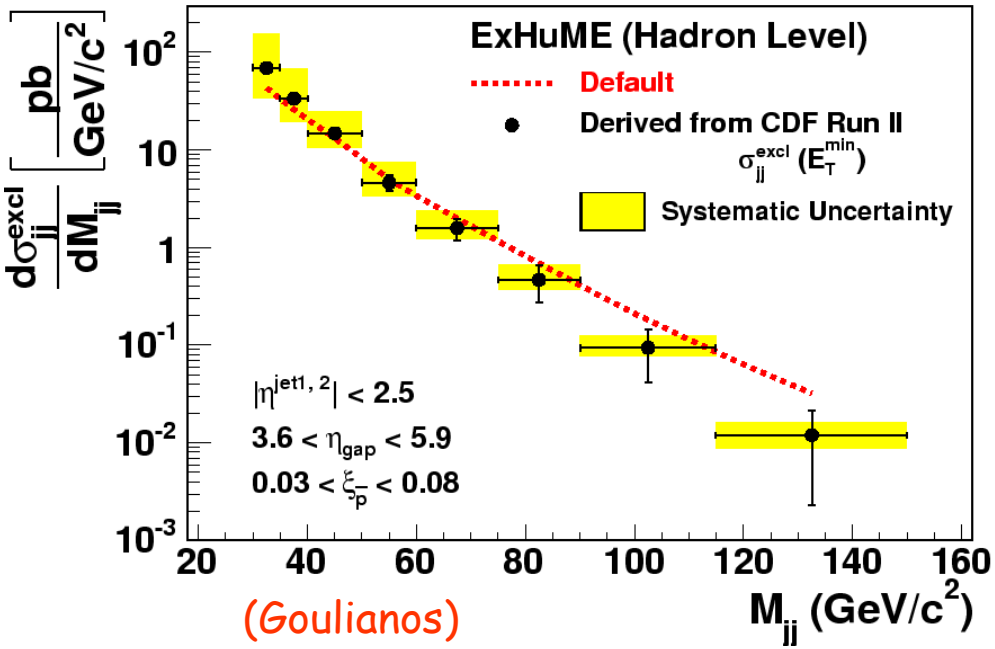


$R_{jj} \rightarrow 1$ for exclusive (complicated by hadronisⁿ, higher order QCD …)



Many comparisons with varying MC modelling and DPDFs …
…hard to get rid of signal!
Fit with free normalisation of inclusive, exclusive models to quantify exclusive part …

CDF Exclusive Dijet Cross Section

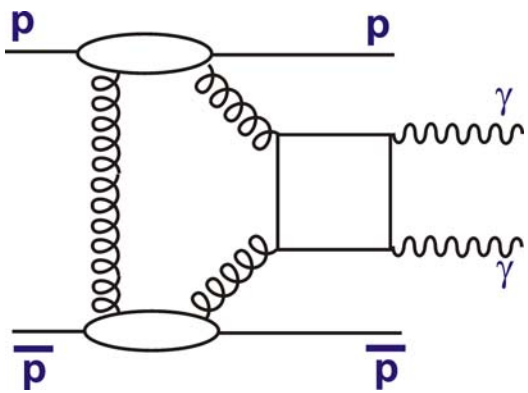


(Goulianos)

- ExHuME model based on KMR calculation …
  - 4.5% gap survival prob
  - "Uncertainty factor 2.5"

- Expressed in terms of M_{jj}, signal extends into possible Higgs discovery mass region!

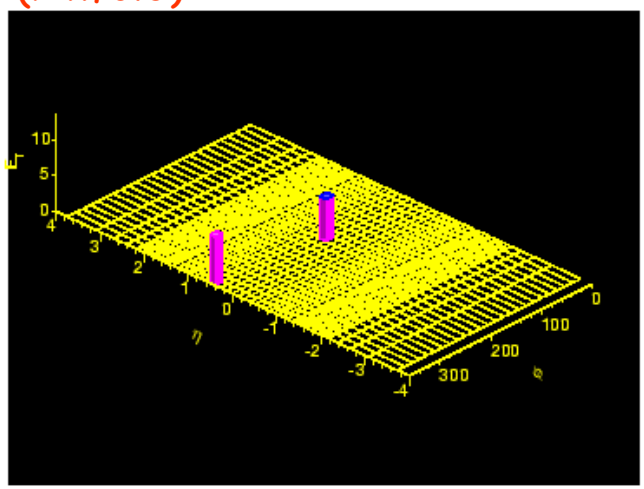
CDF Exclusive Di-photons



2/3 candidates with bkgrd 0.09 +/- 0.04

KMR predicts 0.8 events (big uncty.)

(Pinfold)



Some experimental successes of Workshop

Understanding the dynamics of diffraction in detail …

- H1 v ZEUS F_2^D in much better agreement → DPDFs
- Dijet γp → some understanding of S^2 for photons
- Connections between ep and pp via HERA-Tevatron
- New studies of γIP (and $\gamma\gamma$ and γp …)
- Theory / expt input to LHC detector development
- New diffractive LHC programmes (e.g. ALICE)

… which tests (non-trivial) ingredients of LHC predictions

THANKS TO - ALL EXPERIMENTAL SPEAKERS IN 2006-2008 WORKSHOPS
- CO-CONVENORS FOR GOOD (EDUCATIONAL!) COLLABORATION