XXIV International Symposium
on Lepton and Photon Interactions at High Energies

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Diffraction

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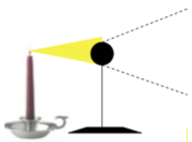
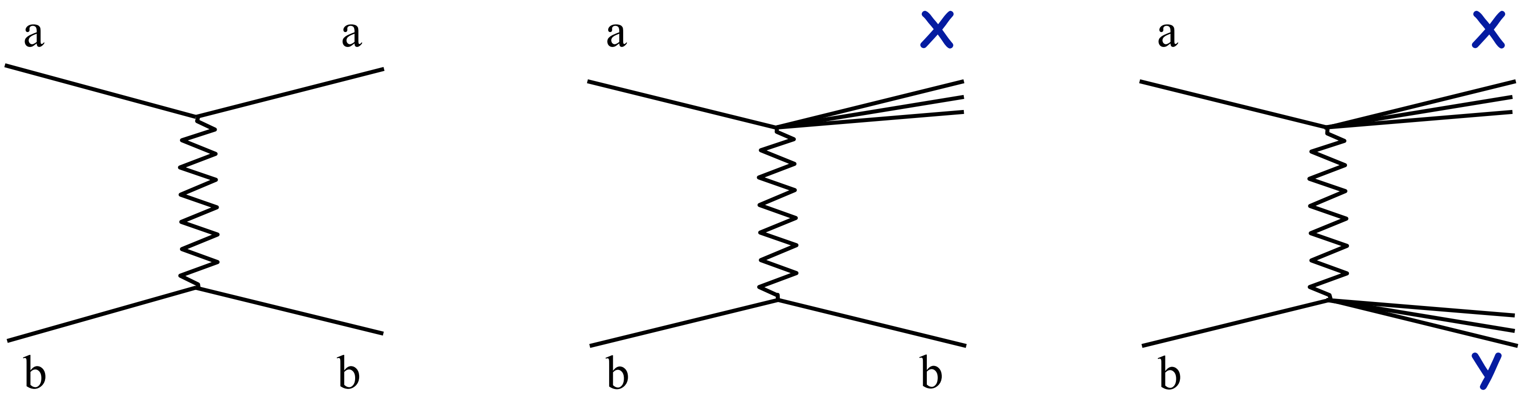


Look at hadrons/protons through a lens that filters out all parton combinations except those with the vacuum quantum numbers

What is diffraction in particle physics?

Feature of hadron-hadron interactions:



Elastic | Single Dissociation (SD) | Double Dissociation (DD)

Relevant feature!

- > 30% of σ_{tot}
- elastic part drives σ_{tot} through the optical theorem

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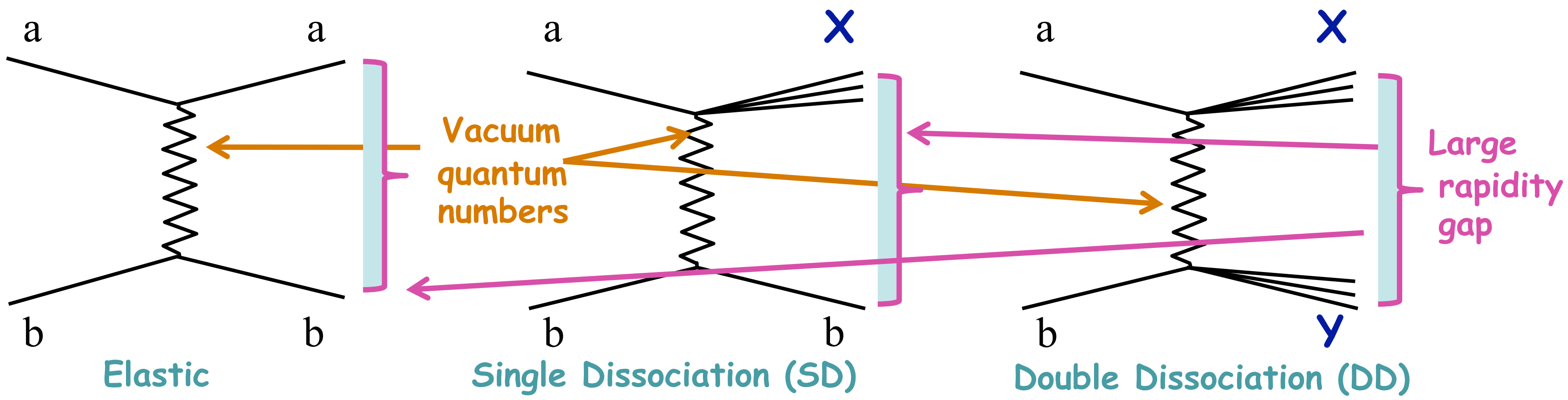

- Beam particles emerge intact or dissociated into low-mass states
  → **Energy ≈ beam energy (within a few %)**
- Final-state particles separated by large polar angle (or pseudorapidity, ln tg (θ/2))
  → Large Rapidity Gap (LRG)
- Interaction mediated by the exchange of vacuum quantum numbers, historically known as the Pomeron

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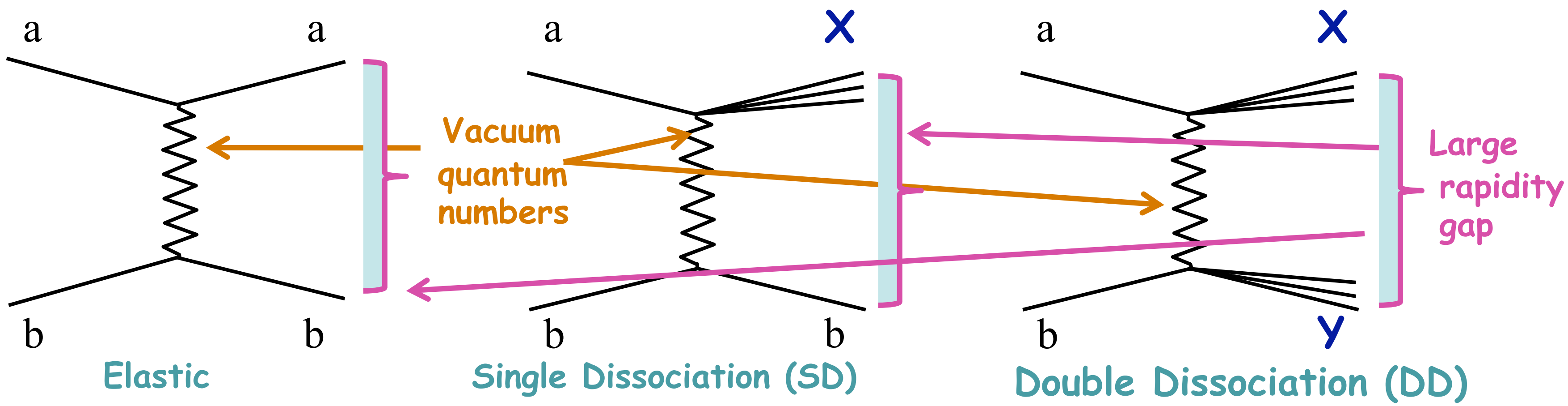


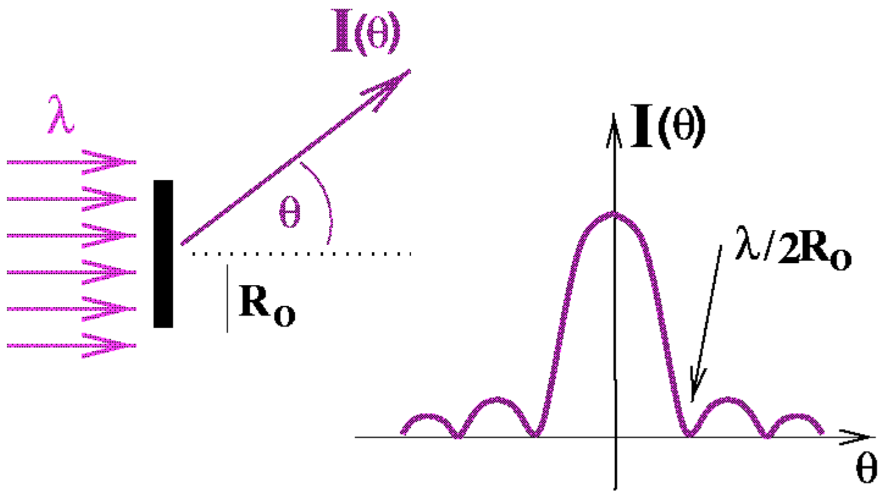
Good and Walker (1960): "*A phenomenon is predicted in which a high energy particle beam undergoing diffraction scattering from a nucleus will acquire components corresponding to various product of the virtual dissociations of the incident particle [...] These diffraction -produced systems would have a characteristic estremely narrow distribution in transverse momentum and would have the same quantum numbers of the initial particles.* "

Bjorken (1993): reactions with non- exponentially suppressed large rapidity gaps operationally termed diffractive

Selection tecniques: LRG requirement or hadron/proton tag

Why "Diffraction"

Term introduced in nuclear high-energy physics in the 50's, used in strict analogy with optics



$$\frac{I(\vartheta)}{I(\vartheta = 0)} \approx 1 - \frac{R_0^2}{4}(k\vartheta)^2 \qquad k = \frac{2\pi}{\lambda}$$

Forward peak for θ=0 (diffraction peak)

Diffraction pattern related to size of target and wavelength of beam

"Lume propagatur seu diffunditur non solum directe, refracte ac reflexe etiam quodam quarto modo diffracte
[Francesco Maria Grimaldi, XVII century]"

Why "Diffraction"

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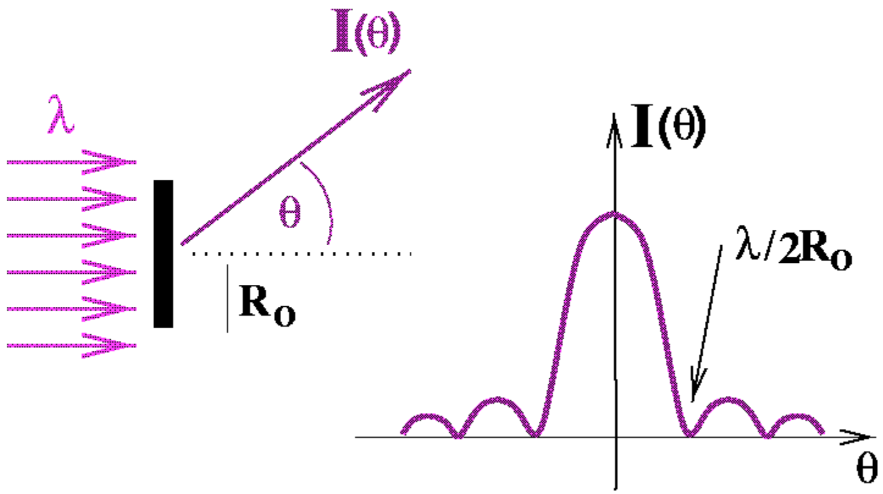

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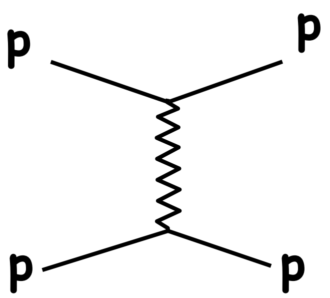
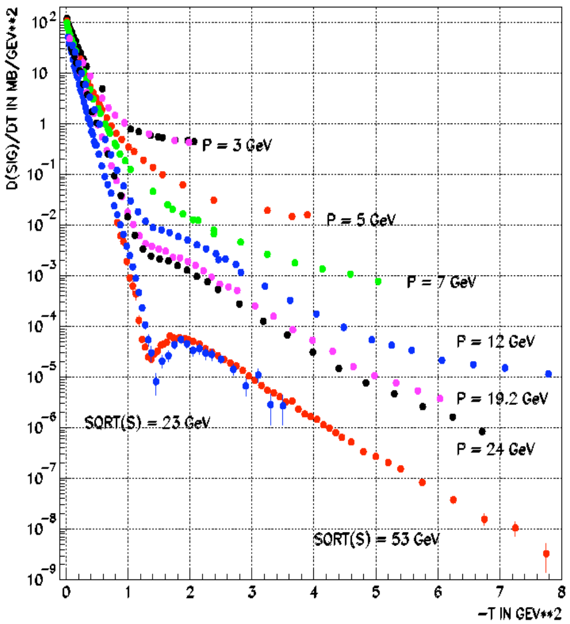
Diffraction pattern related to size of target and wavelength of beam

Propagation/interaction of a a hadron → absorption of its wave function





$$\frac{d\sigma/dt(t)}{d\sigma/dt(t=0)} \approx \exp(bt) \approx 1 - b(p\theta)^2$$

$|t| \approx (p\theta)^2$ 4-momentum transfer

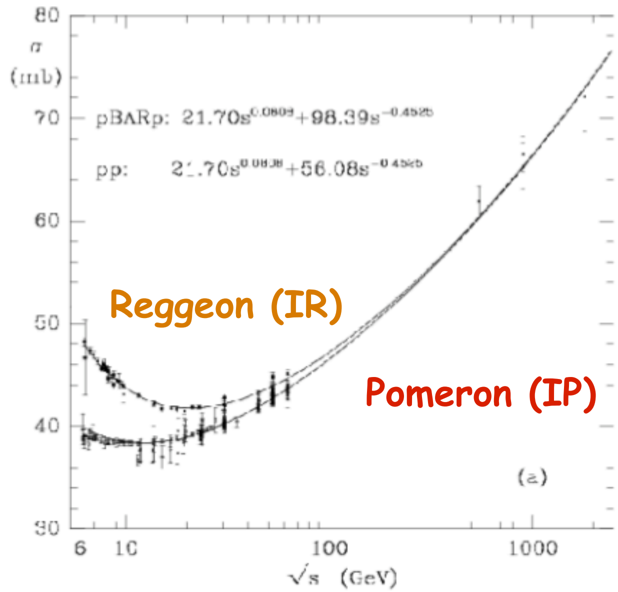
ϑ scattering angle

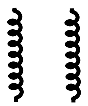
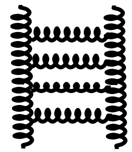
$b = R^2/4$

R transverse distance projectile-target

From the Pomeron to nowadays

- Pomeron goes back to the 60's and to Regge phenomenology:
  - Regge trajectory, ie a moving pole in complex angular momentum plane
    $\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha' t$
  - dominant singularity at high energy
    $\sigma_{tot} \sim s^{\alpha IP(0) - 1}$



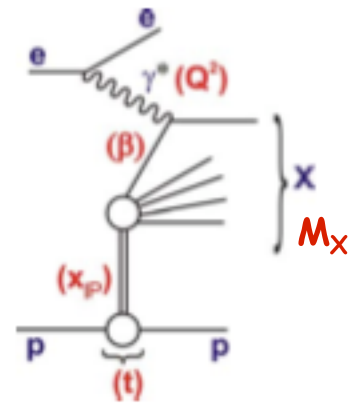
- In terms of QCD:
  - 2-gluon exchange at LO  , a gluon ladder at higher orders  ('BFKL Pomeron')
  - The exchange itself does not have a hard scale
    → **need a hard scale to see the partons! Pioneers:**
    UA8: jet production in diffractive ppbar collisions
    1993-1994: first LRG events @HERA
    1995-1996: first events with LRG between two jets @TEVATRON

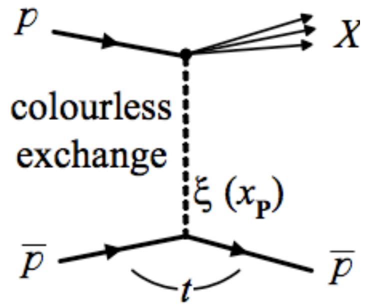
- In the last 10-15 years learned a lot at HERA and Tevatron → **" New" diffraction bridging the gap between the hard and soft regimes of strong interactions**

Outline

Will mainly concentrate on HERA and Tevatron results

- Diffractive Parton Distribution Functions (DPDFs)
- Mechanisms of factorisation breaking in hadron-hadron collisions - do they show up at HERA?
- Generalised Parton Distribution Functions (GPDs): a 3d picture of the proton
- Vector meson production at HERA : a window on the soft-hard transition
- Exclusive production at Tevatron
- A glance at the LHC



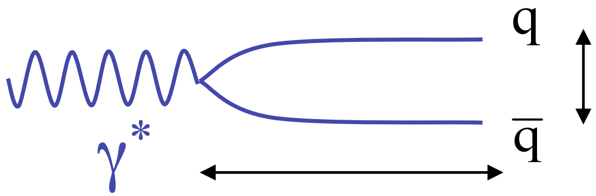


Will first look at the proton inclusively (X=anything), then exclusively (X=something specific)

An experimentalist+personal view…

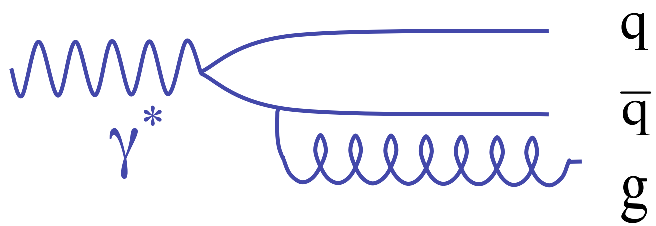
Diffraction in ep scattering?!

In p-rest frame, virtual photon fluctuates to qqbar, qqbarg states (color dipoles)



$$\propto \frac{1}{\sqrt{Q^2 + M_{q\bar{q}}^2}}$$

$$\propto E_\gamma \sim W^2 \sim 1/x$$



- Lifetime of dipole (hadron!) long because of large Lorentz boost
- Dipole interacts hadronically with the proton
- Transverse size proportional to $1/\sqrt{(Q^2+M_{qq}^2)}$

If dipole size small, its interaction with the proton can be treated perturbatively

Dipole models

(Nikolaev, Zakharov, Mueller, Golec-Biernat, Wuesthoff, Forshaw, Shaw, Watt, Kowalski,...)

- **Describe variety of ep processes at low x**
  - inclusive (F_2, F_L, F_2^{ccbar},F_2^{bbar})
  - exclusive (Deeply Virtual Compton Scattering and vector meson production)
  - inclusive diffraction (F_2^D, $F_2^{D(ccbar)}$)

- **Alternatively to collinear factorisation:**

  $\sigma^{\gamma p}$ ~ (dipole formation) x (dipole proton interaction $\sigma_{dip}(r,x)$)

  $\sigma_{dip}(r,x)$ parameterised

- **Allow incorporation of saturation dynamics**

Diffraction in ep scattering?!

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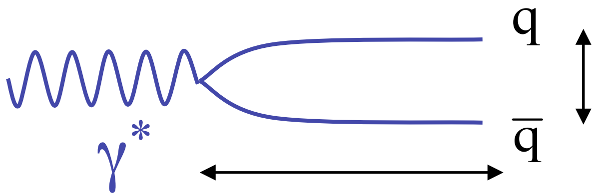

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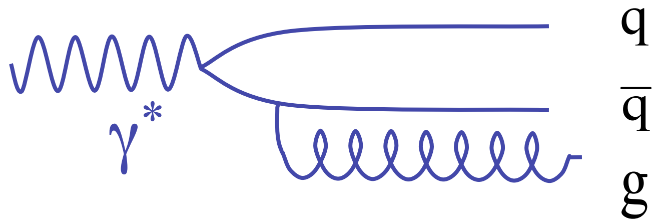

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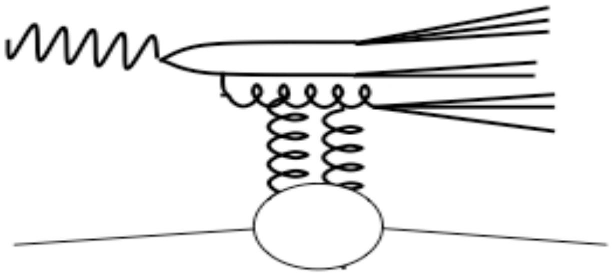
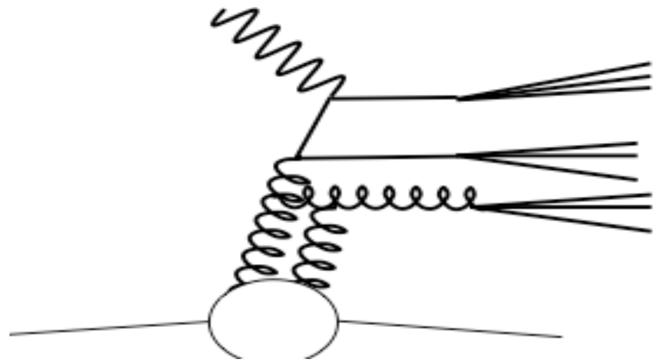
Two alternative pictures:



Proton rest frame
→ Dipole models



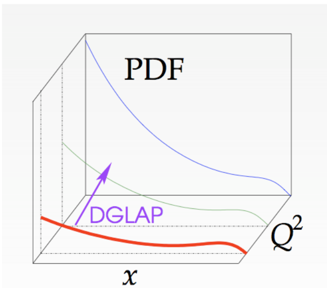
Breit frame (proton very fast)
DIS on the exchanged object
→ Collinear factorisation

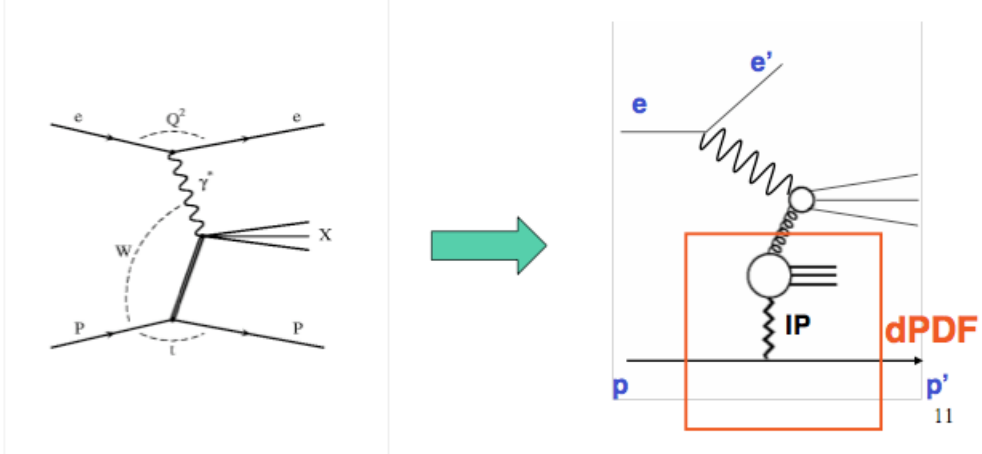
Diffractive parton distribution functions (DPDFs)

- **QCD collinear factorisation theorem proven also for diff DIS** (Collins,1998):

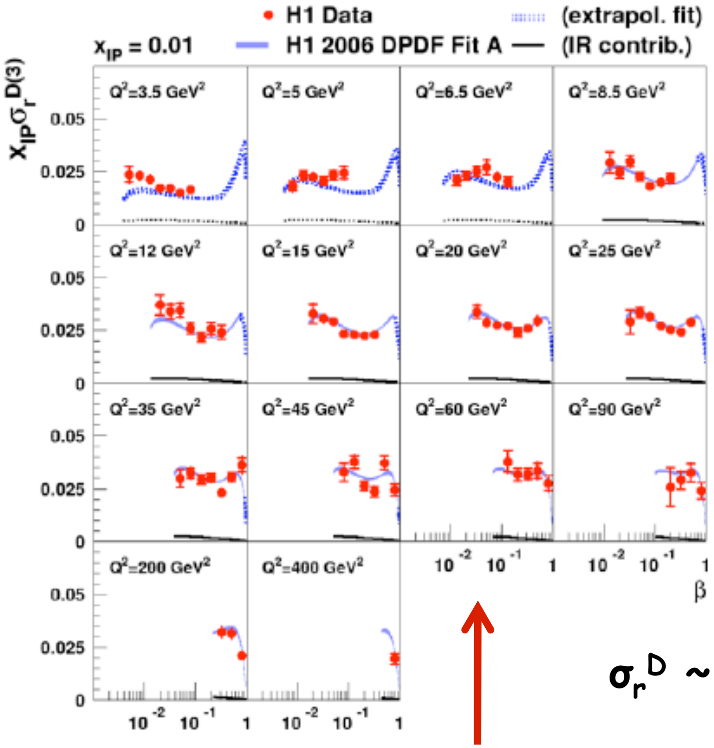
  $\sigma_{diff} \sim \sigma$(hard scatter) x (diffractive PDFs)

- **DPDFs**
  - universal (in DIS) parton proton conditional probabilities, apply when vacuum quantum numbers are exchanged
  - evolve according to DGLAP
  - extracted with NLO QCD fits as in standard PDF analyses





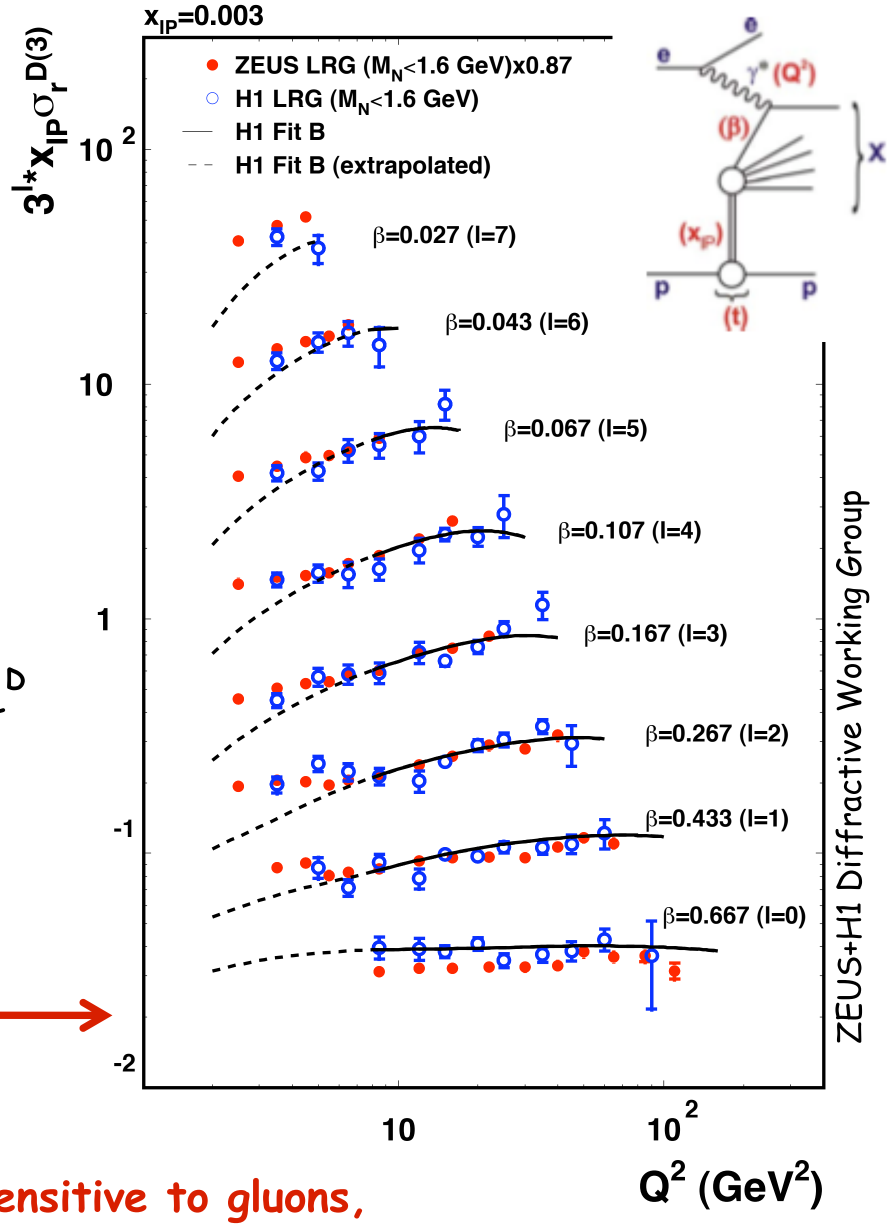
DPDFs extraction



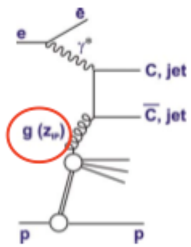
H1 Collab., EPJ C48 (2006), 715

$$\sigma_r^D \sim F_2^D - F_L^D$$

Quark densities constrained by reduced cross section



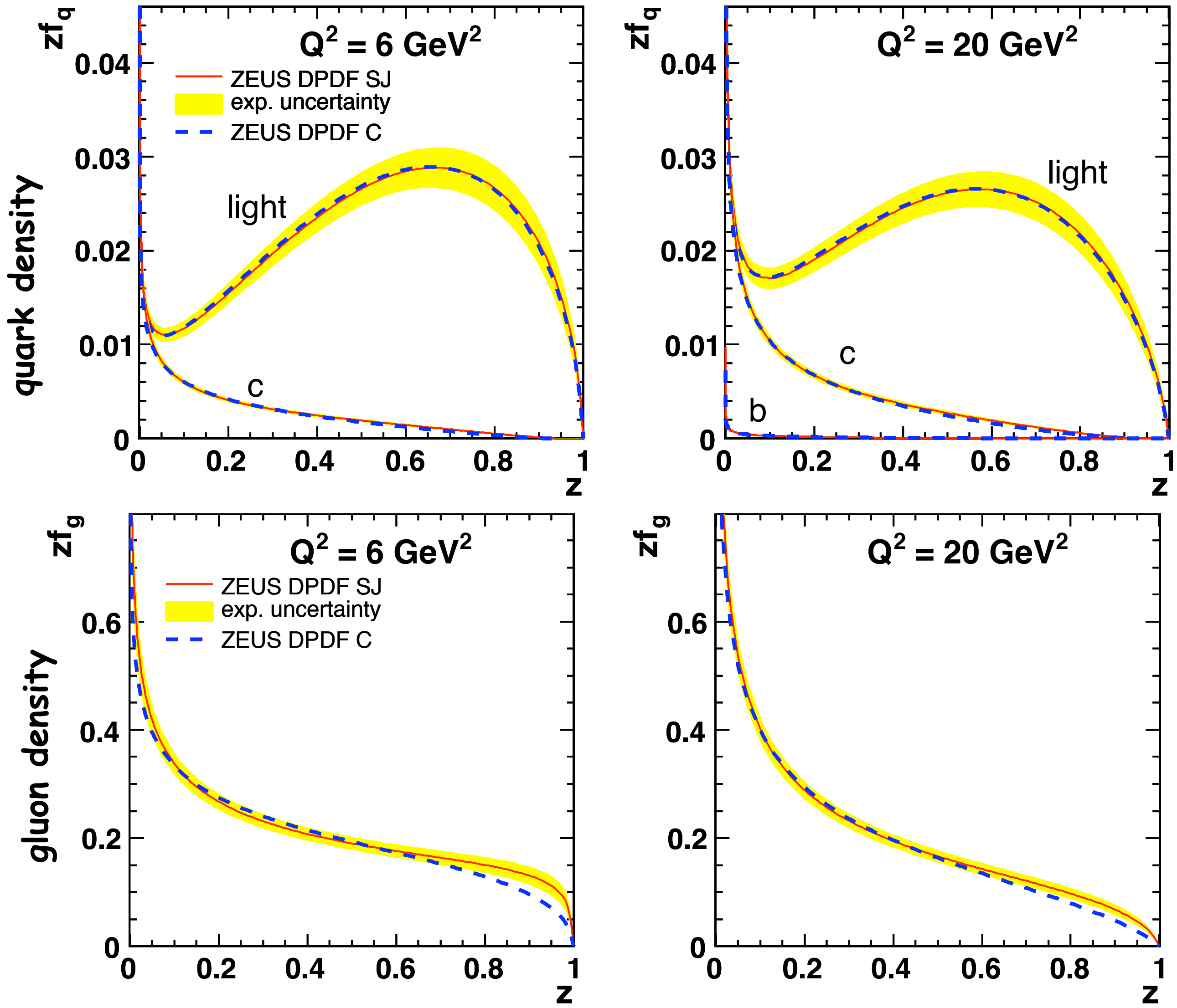
Gluon density constrained indirectly by scaling violations



Diff dijet data, directly sensitive to gluons, constrains the gluon density @high z

DPDFs

Note different scales!

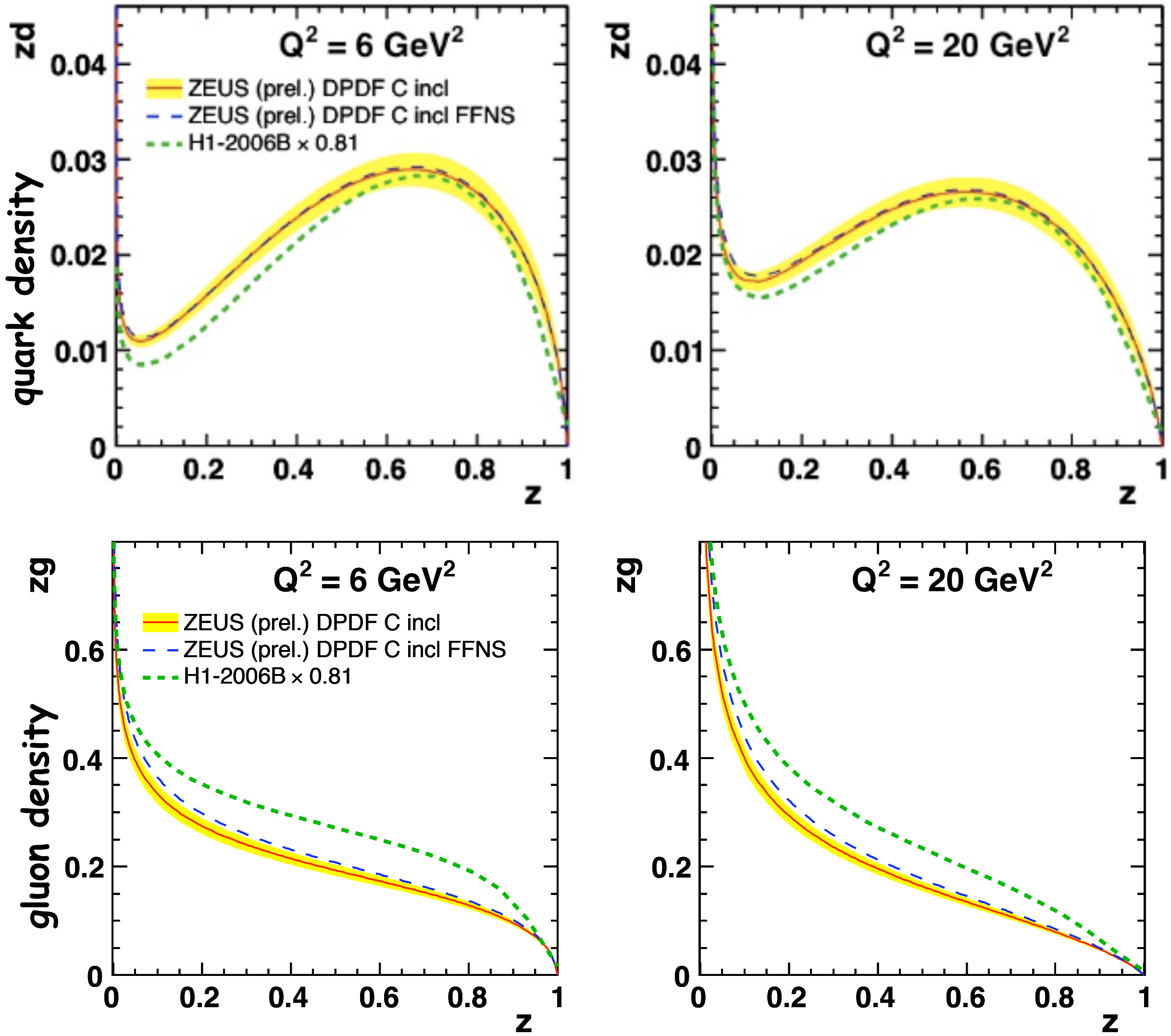


ZEUS Collab., to be published

Several DPDF fits from H1 as well
(and from theorists: MRW, Royon et al.**)**

Towards HERA DPDFs

ZEUS-prel-09-004

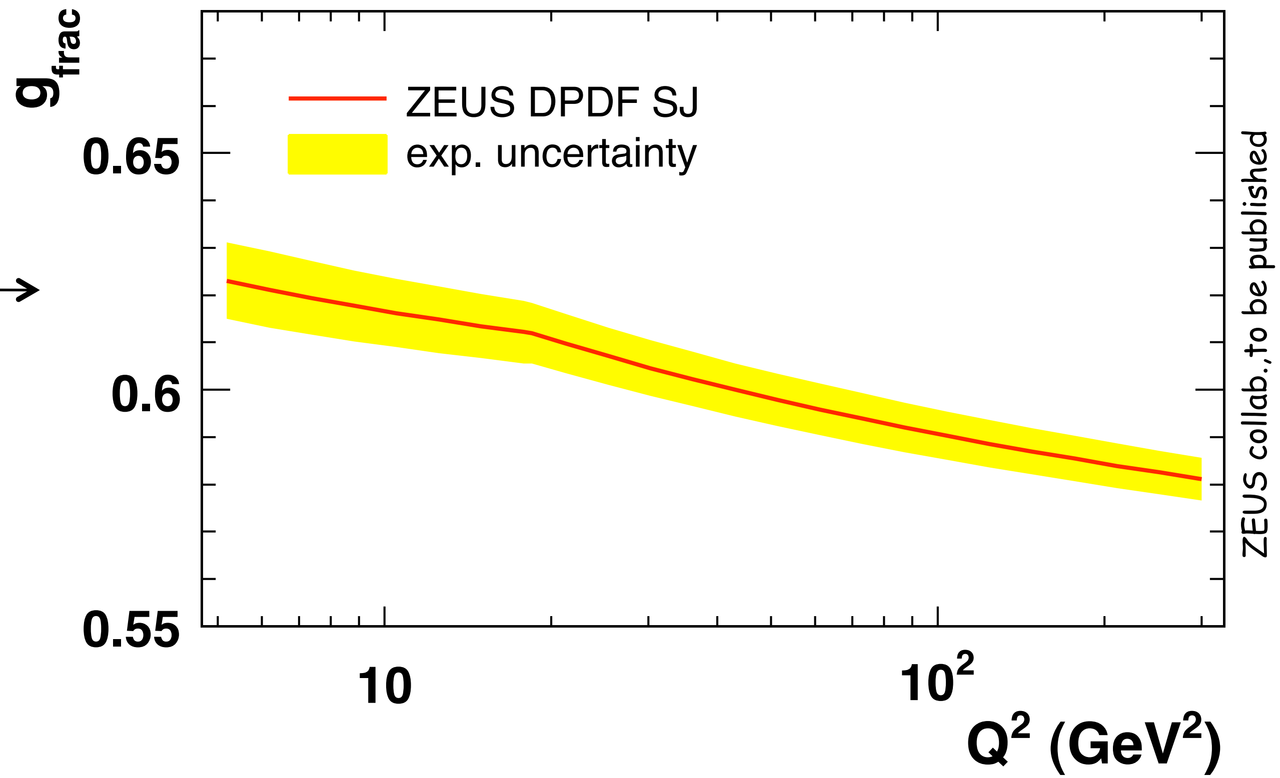


ZEUS DPDF C vs H1 DPDF Fit B

Plan to extract HERA DPDFs from H1+ZEUS final data combination (H1 data not final yet)

Lots of gluons in diffraction!

Fractional momentum carried by gluons →

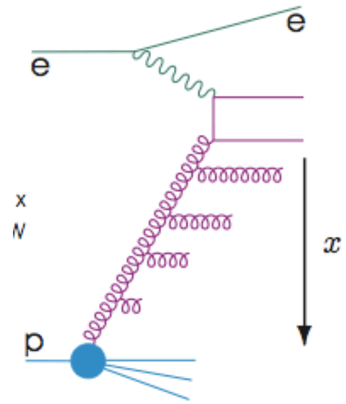


Not surprising: involved partons have **momentum fraction $x = \beta x_{IP}$, with x_{IP} < 0.01**

→ ***A window on low x physics***

Low x is..

…long parton cascades



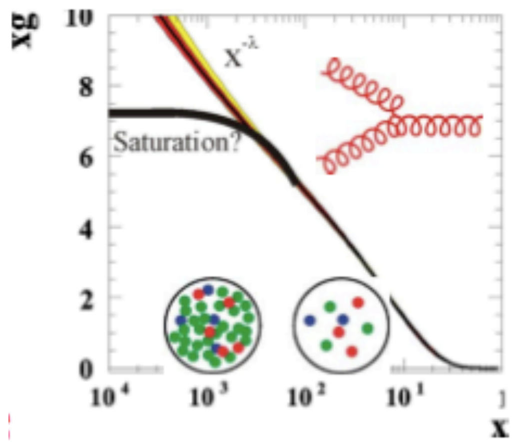
→ Breakdown of DGLAP approx?

Theoretically large ln(1/x)
terms expected (BFKL)

…very large gluon densities

→ Unitarity limit, gluon recombination?
Saturation?

→ Connection to high density QCD,
RHIC physics,…



QCD factorisation in diffractive DIS

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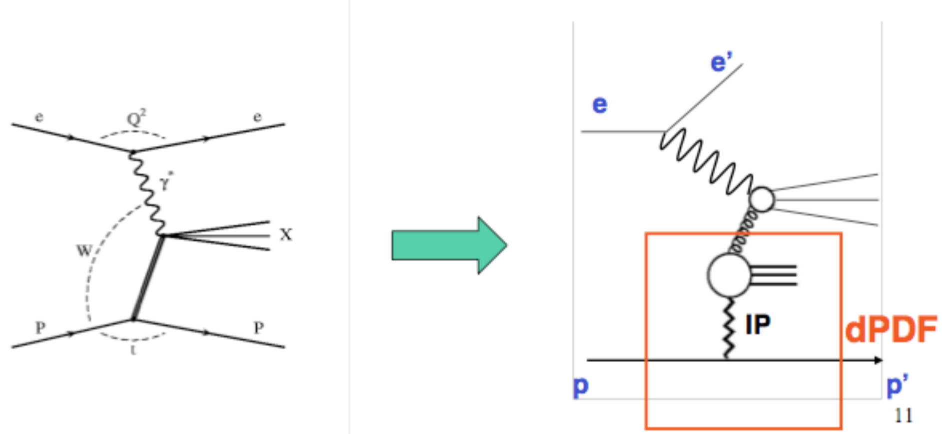

- Can use DPDFs to predict cross section for other processes in diff DIS
  → **shown to work, eg in diff charm and dijet production**

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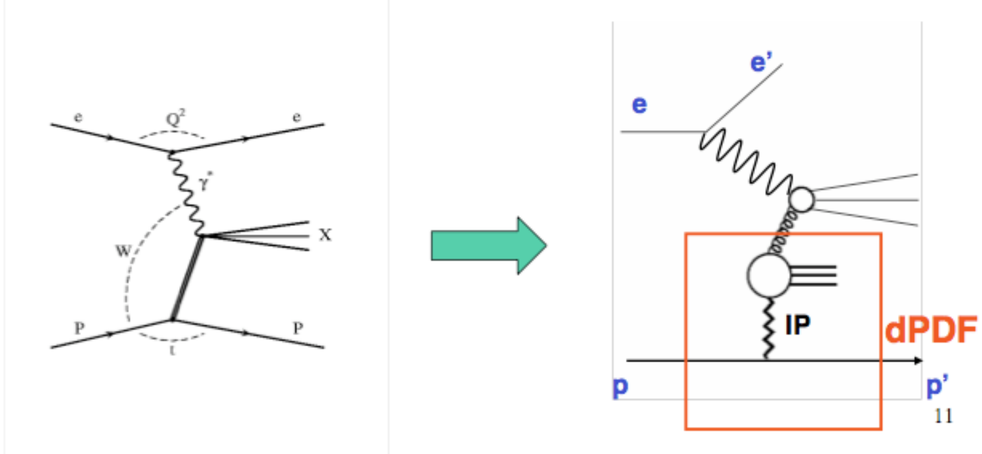

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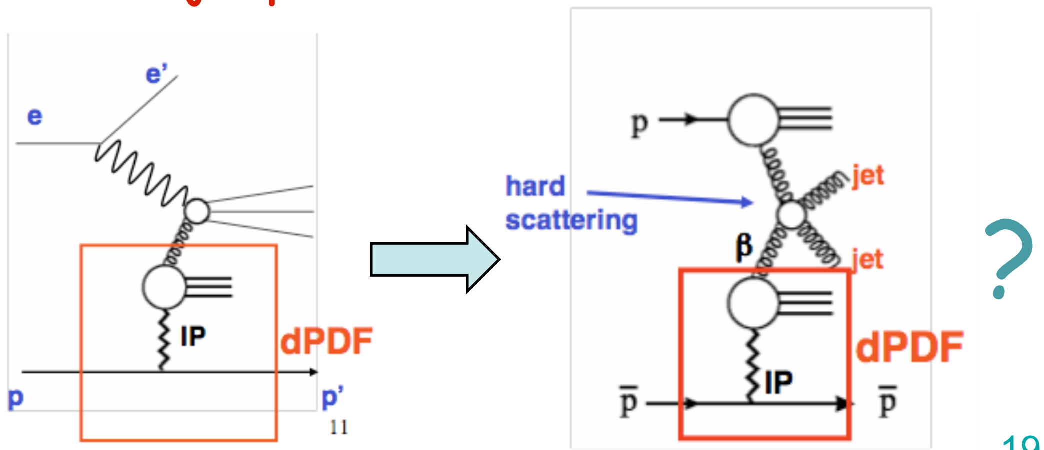
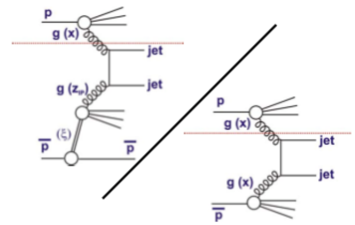
How about using HERA DPDFs to predict cross sections in hadron-hadron collisions?



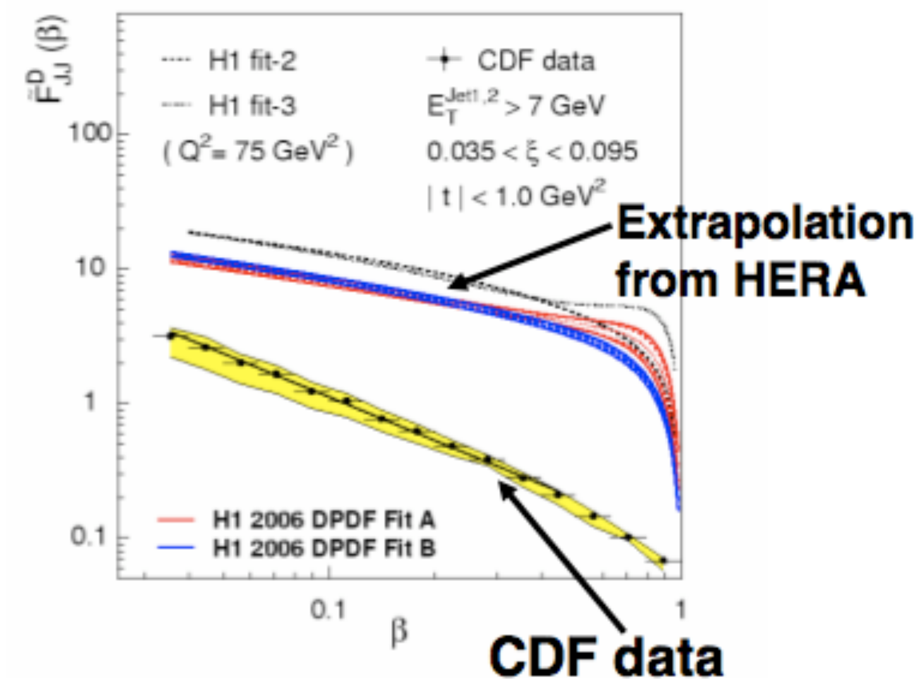
Factorisation breaking at Tevatron



QCD factorisation not expected to hold in ppbar, pp: indeed it does not!

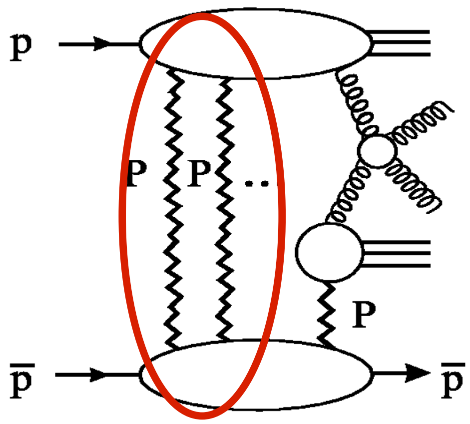
- **Factor 10 normalisation difference** between extrapolation from HERA data and CDF measurement

- Similarly, diffractive yields of W, Z (CDF, D0) and J/psi, b-mesons (CDF) **~1% vs ~10% expectations** based on HERA DPDFs



[PRL 84 (2000), 5043]

Rapidity gap survival probability factor, <|S²|>



- Factorisation breaking understood in terms of **(soft) interactions/rescatterings based on multi-Pomeron exchanges among spectator partons**
[Kaidalov, Khoze, Martin, Ryskin]

- Lots of different theoretical approaches
[Goulianos; Gotsman, Levin, Maor; Ingelman, Enberg; Cox, Forshaw, Lonnblad…]

- Quantified by **"rapidity gap survival probability", <|S|²>**
  - at Tevatron <|S|²> ~ 0.1 compared to HERA
  - at LHC <|S|²> ~ 0.15% (GLLM), 1.5% (KMR)

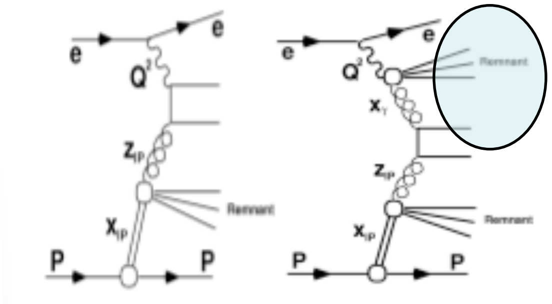
Intimately related with multiple parton interactions in hadron-hadron collisions

Of GREAT interest for LHC

Can we learn something from HERA DATA?

Rescattering effects at HERA?

- **Diffractive dijet photoproduction:**
  direct vs resolved events
  → switch photon remnant on/off:



$$x_\gamma = \frac{\sum_{jets} E - p_z}{\sum_{HFS} E - p_z}$$

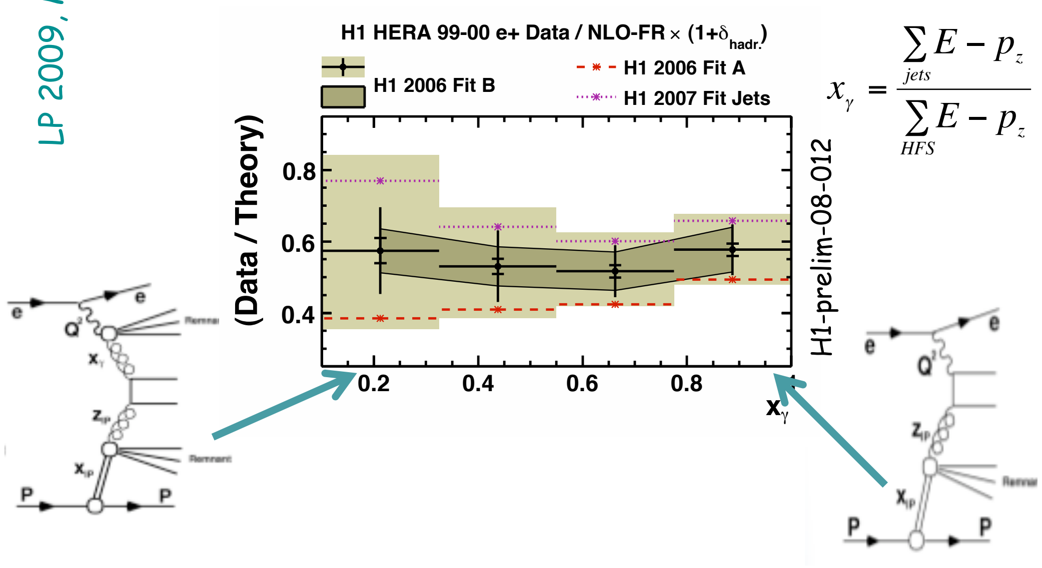
$x_\gamma < 0.75$

Rescatter

?

Rescattering effects at HERA?

DIFF DIJET PHOTOPRODUCTION



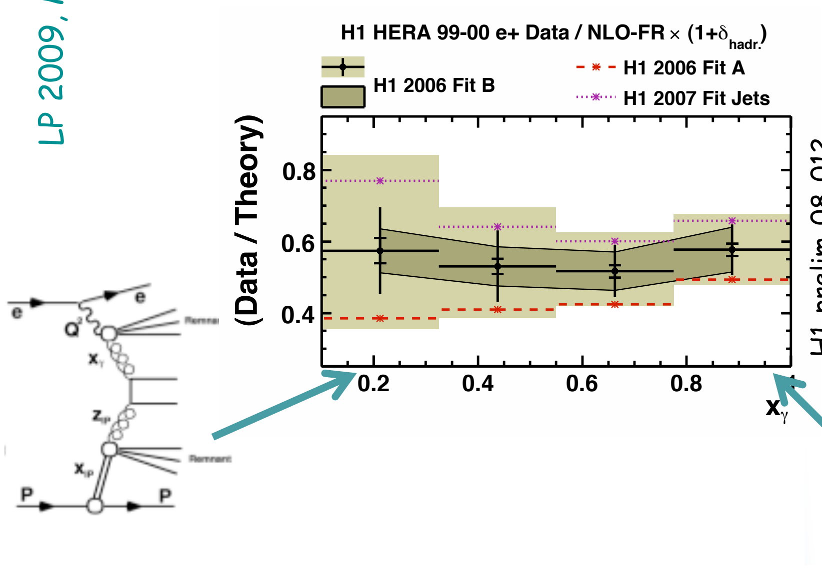
$$x_\gamma = \frac{\sum_{jets} E - p_z}{\sum_{HFS} E - p_z}$$

- **Suppression everywhere** though factor ~0.34 expected only for resolved component
  [Kaidalov et al., PL B 567 (2003), 61]
- $E_T^{jet1} > 5$ GeV
- **For higher E_T^{jet1}, <|S²|> compatible with unity (and with ZEUS)**

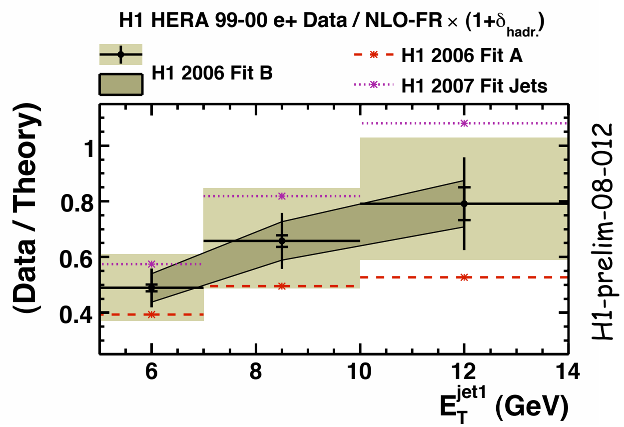
Could rescattering effects depend on E_T, not x_γ?

Rescattering effects at HERA?

DIFF DIJET PHOTOPRODUCTION



$$x_\gamma = \frac{\sum_{jets} E - p_z}{\sum_{HFS} E - p_z}$$



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- E_T^{jet1} > 5 GeV
- **For higher E_T^{jet1}, <|S²|> compatible with unity (and with ZEUS)**

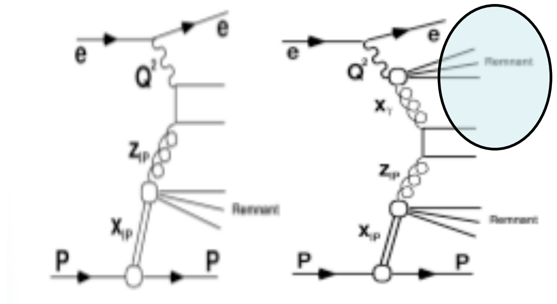
Could rescattering effects depend on E_T, not x_γ?

- Harder E_T^{jet1} dependence in data than in NLO
- Factorisation OK at large E_T?
- Beware: suppressing only the resolved component also ok if not better
  [Klasen and Kramer, DESY 08-074]

→ **Needs further understanding**

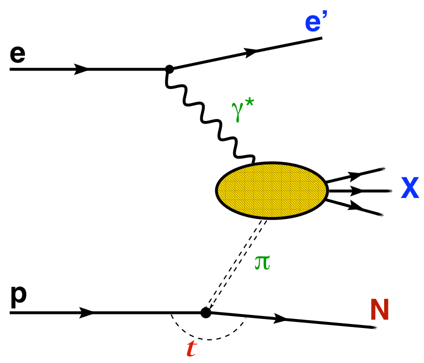
Rescattering effects at HERA?

- **Diffractive dijet photoproduction:**
  direct vs resolved events
  → switch photon remnant on/off:



- **Leading baryon production:**
  photoproduction vs DIS
  → change photon size

Secondary interaction can fill the gap associated with π exchange!

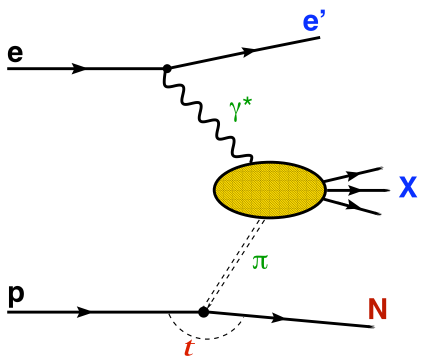


Rescatter

?

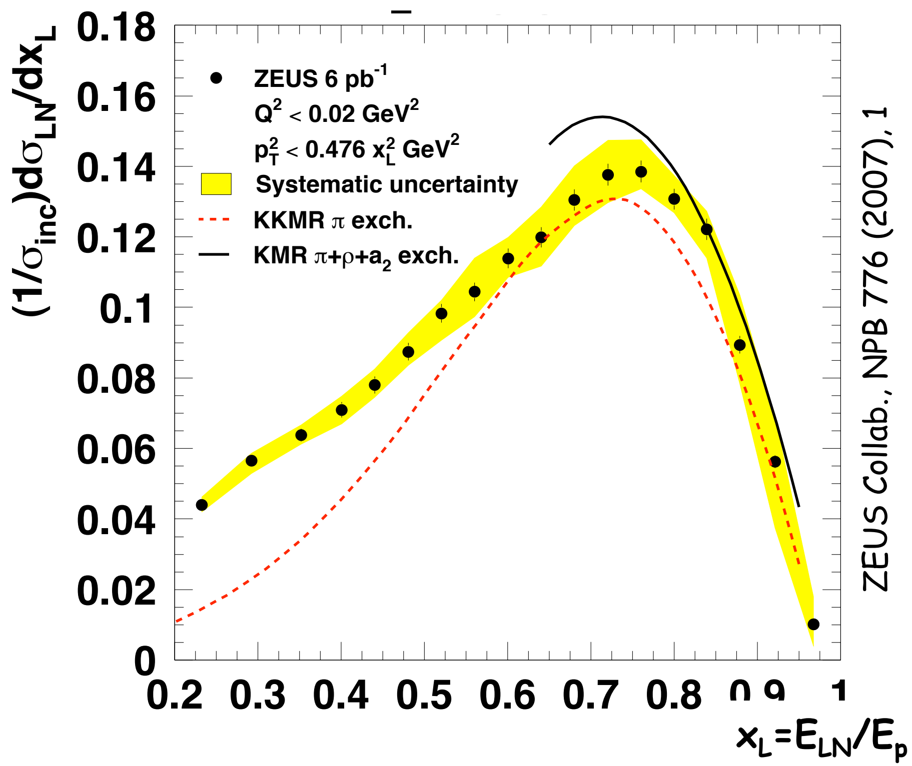
Rescattering effects at HERA?

LEADING NEUTRON PRODUCTION



Neutron yield in photoproduction consistent with rescattering:
[Kaidalov et al., EPJ C47 (2006), 385;
EPS C48 (2006), 797]

- Rescattering causes migration of LN to lower x_L, thus acting as absorption at high x_L

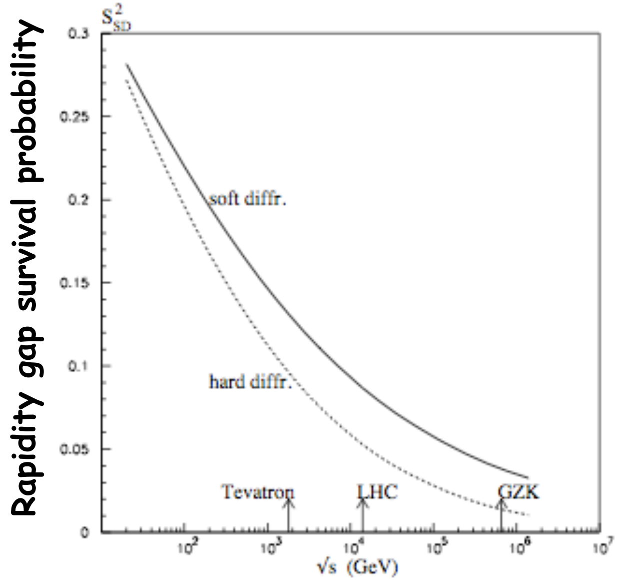


ZEUS Collab., NPB 776 (2007), 1

→ Extrapolations to LHC

"Practical" implications of <|S²|>

<|S²|> estrapolation to LHC not only crucial for predicting LHC physics – has important other implications, eg



arXiv: 0609312 [hep-ph]

- @LHC ~ half of the cross section will be elastic+diffractive

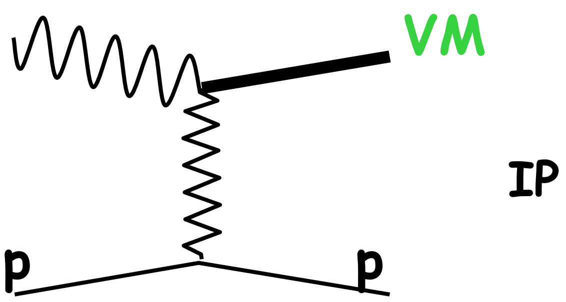
- @LHC ~30 multiple interactions per bunch crossing at full luminosity, of which ~ half are elastic+diffractive

  → soft **pile-up** diffractive processes **suppressed by <|S²|>**

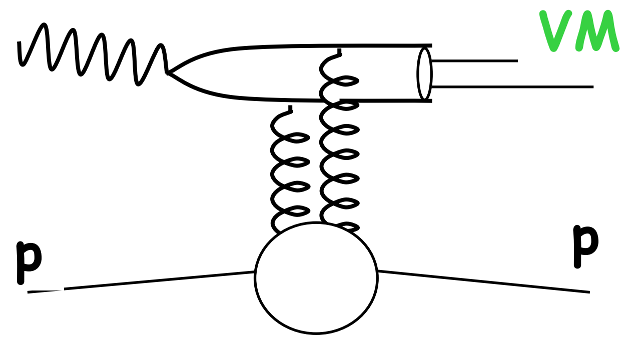
  - can overlap with non diffractive hard process observed in central detector and fake it
  - ingredient to backgrounds induced by collimators, machine elements

Exclusive processes at HERA

Soft - Regge

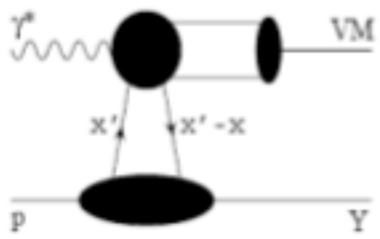


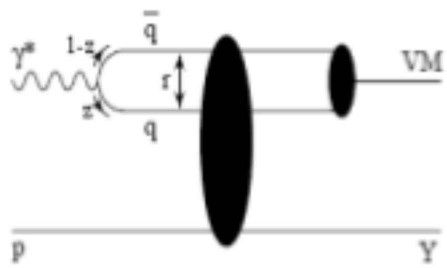
Hard - QCD



VM ($J^{PC}=1^{--}$): γ, ρ, ϕ, J/ψ, Υ,...

As in the inclusive case two alternative pictures

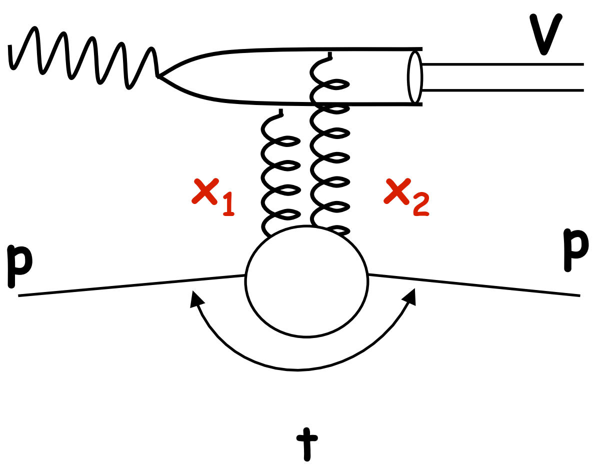




Breit frame (proton very fast)
→ Collinear factorisation

Proton rest frame
→ Dipole models

Generalised parton distribution functions



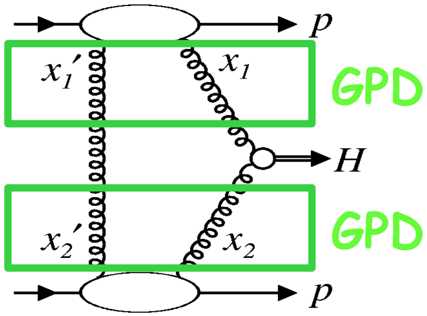
- In general, $x_1 \neq x_2$:

$$\sigma \propto [x\, g(x, Q^2)]^2$$

$$\sigma \propto [H(x_1, x_2, t, Q^2)]$$

- $H(x_1,x_2,t,Q^2)$, **generalised PDFs** (also termed "non-diagonal", "skewed"), take into account difference in momenta between emitted and reabsorbed parton:
  - sensitive **to parton-parton momenta correlations** in the proton !
  - t-dependence gives (via Fourier trasform) 2dim distribution of partons in the tranverse plane → **tomography**

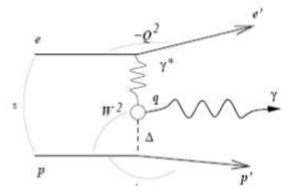
- **Ingredient for estimating central exclusive cross sections at LHC (see later in this talk)**



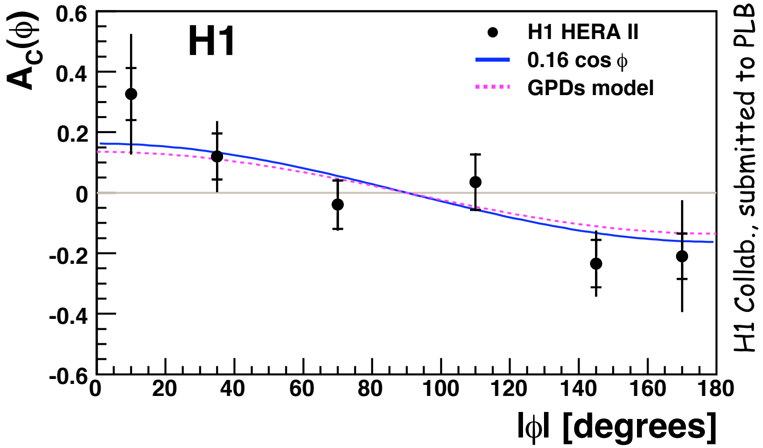
Generalised parton distribution functions

- **Sensitivity to GPDs modest at HERA – largest at larger x (JLab, HERMES, Compass…)**
- In VM production @HERA, GPDs can be approximated by standard PDFs, modulo a normalisation factor (2-3 in Υ case)
- **Evidence of GPDs in DVCS**

  Asymmetry amplitudes related to GPDs



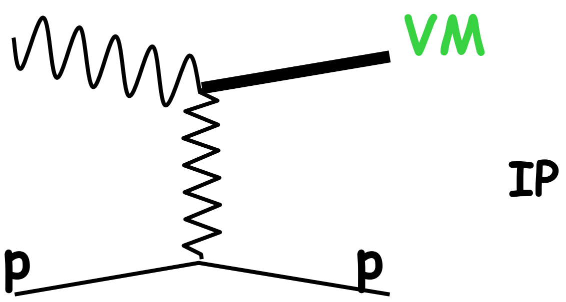
$$A_C = \frac{d\sigma^+/d\phi - d\sigma^-/d\phi}{d\sigma^+/d\phi + d\sigma^-/d\phi} = 2A_{BH}\frac{\mathrm{Re}A_{DVCS}}{|A_{DVCS}|^2 + |A_{BH}|^2}\cos\phi.$$



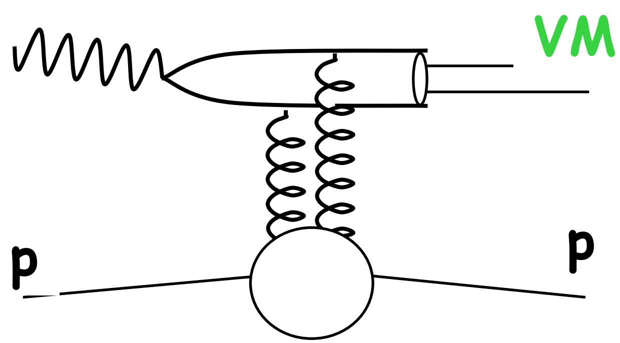
- By analysing DVCS on nuclear target HERMES can map partons in nuclear matter

Exclusive processes at HERA: soft → hard

Soft - Regge



Hard - QCD



VM ($J^{PC}=1^{--}$): γ, ρ, ϕ, J/ψ, Υ,...

With increasing scale (Q^2, M_{VM}, t)

$$\sigma(W) \propto W^{\delta}$$

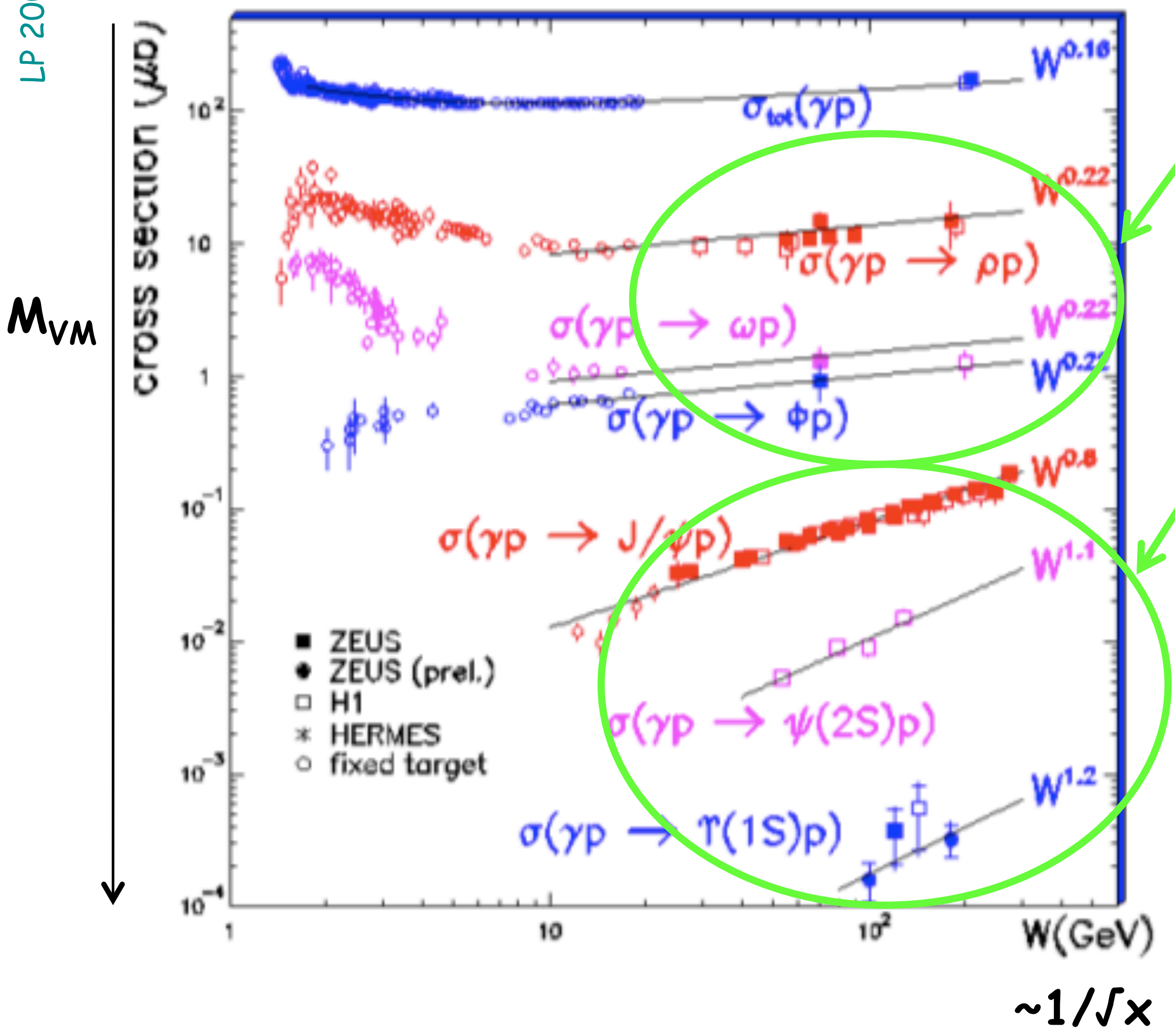
- Expect δ to increase from soft (~0.2, 'soft Pomeron' value) to hard (~0.8, reflecting large gluon density at low x)

$$\frac{d\sigma}{dt} \propto e^{-b|t|}$$

- Expect b to decrease from soft (~10 GeV^{-2}) to hard (~4-5 GeV^{-2})

Exclusive processes at HERA: soft → hard

Photoproduction, $Q^2 = 0$



small M_{VM} (~ 1 GeV²): transverse size of dipole ~ size of proton

large M_{VM} : small dipole size

→cross section much smaller (color screening)

→dipole resolves partons in the proton:

$\sigma \sim (xg)^2$ → large δ

VM data can help determine gluon density!

Here scale is M_{VM} – same observed when varying Q^2 for a given VM

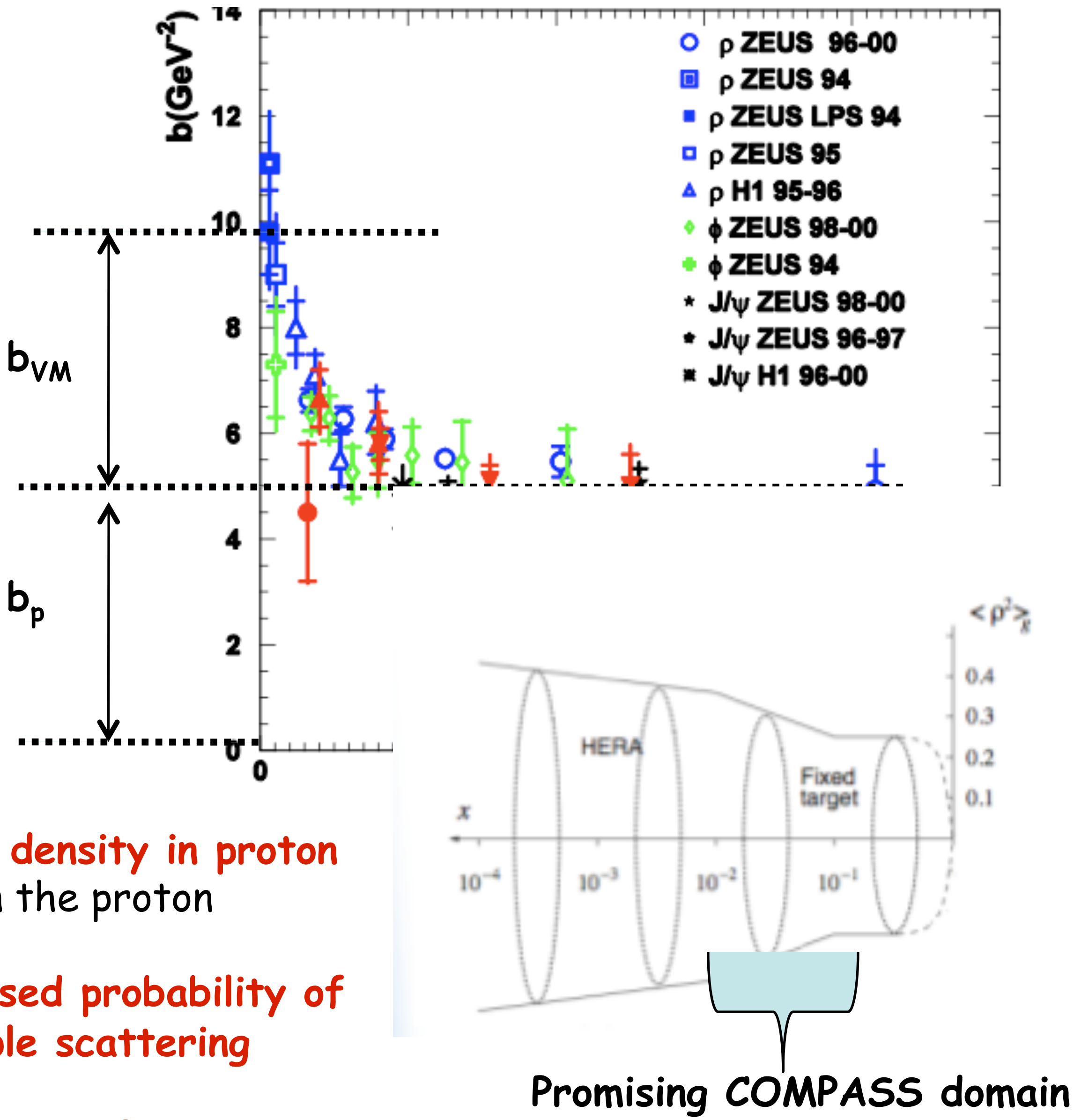
Exclusive processes at HERA: soft → hard

$$\frac{d\sigma}{dt} \propto e^{-b|t|}$$

Slope b smaller
as scale increases

As in optical diffraction,
size of diffractive cone
related to size of
interacting objects

$b \sim b_{VM} + b_p$



$\langle r^2 \rangle = b(hc)^2$

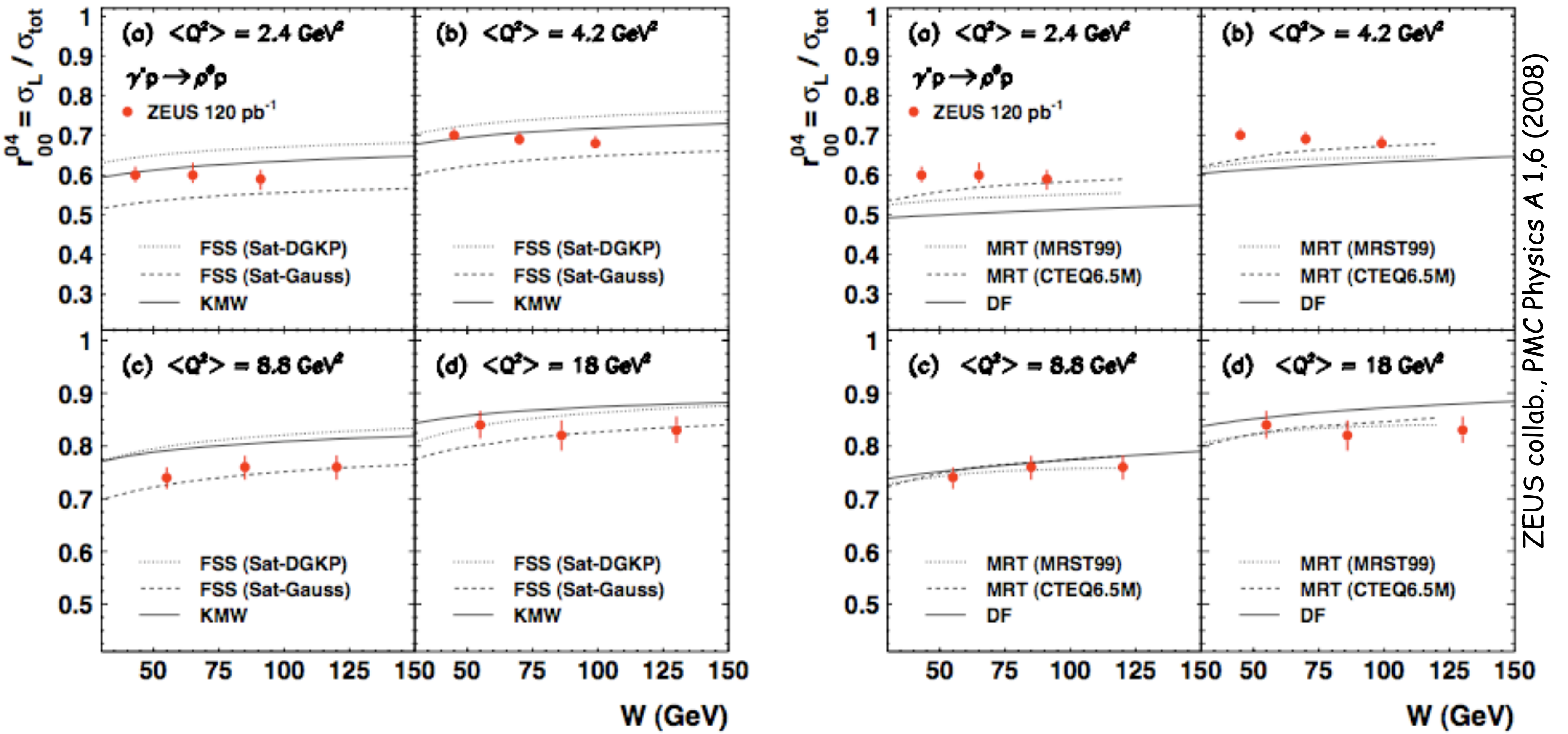
→ r_g ~0.6 fm, radius of gluon density in proton

r_p ~ 0.8 fm, charge density in the proton

Smaller x larger r_g → increased probability of multiple scattering

→ implications for LHC

Comparison with (dipole) models

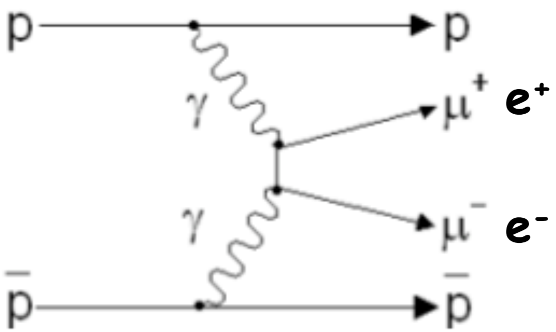


ZEUS collab., PMC Physics A 1,6 (2008)

Martin-Ryskin-Teubner (MRT) – Phys. Rev. D 62, 014022 (2000)
Forshaw-Sandapen-Shaw (FSS) – Phys. Rev. D 69, 094013 (2004)
Kowalski-Motyka-Watt (KMW) – Phys. Rev. D 74, 074016 (2006)
Dosch-Ferreira (DF) – Eur. Phys. J. C 51, 83 (2007)

None of the models describes in whole kinematic region these high precision data

Exclusive processes at CDF→LHC
DILEPTON PRODUCTION

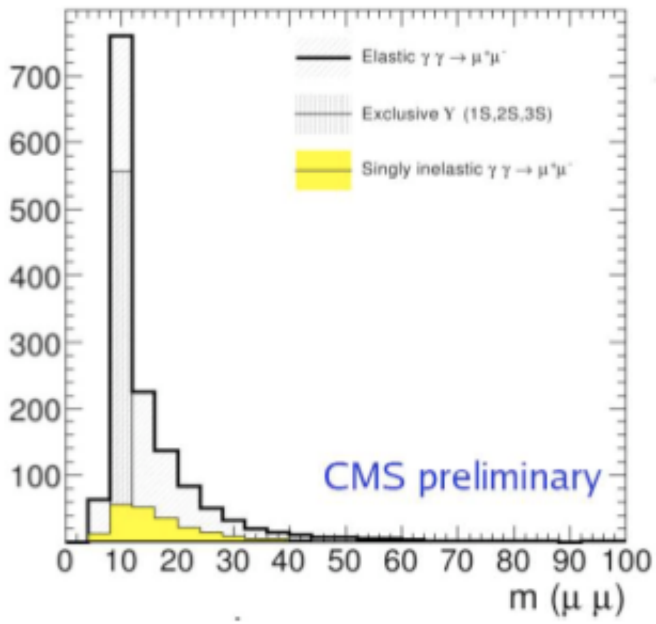


[PRL 98, 112001 (2007): PRL 102, 242001 (2009)]

QED known to 1% precision

@LHC can rely on this process for

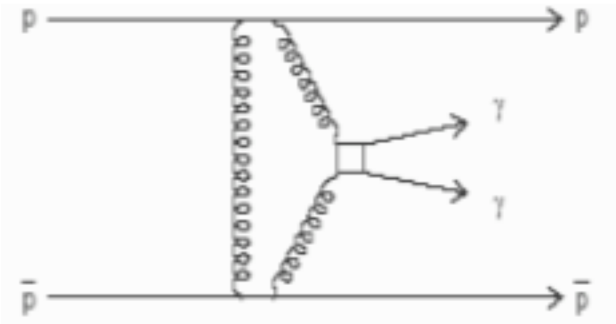
- lumi measurements
- forward spectrometers calibration
- control sample to less known exclusive processes



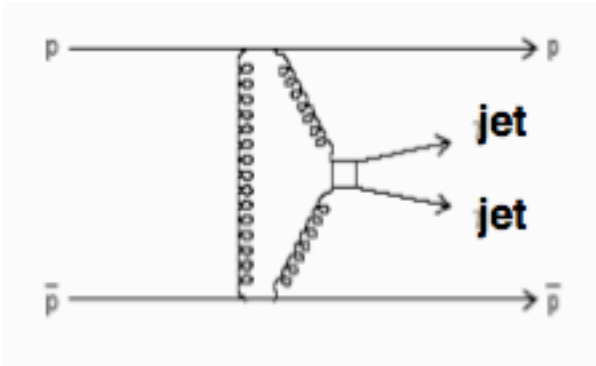
Absolute luminosity measurement with precision O(5%) in 100 pb^{-1} feasible [CMS PAS DIF-07-001]

Exclusive processes at CDF→LHC

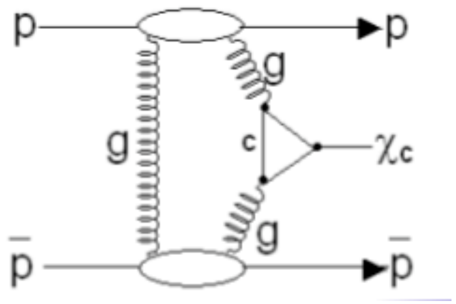
gg t-CHANNEL COLOR-SINGLET EXCHANGE



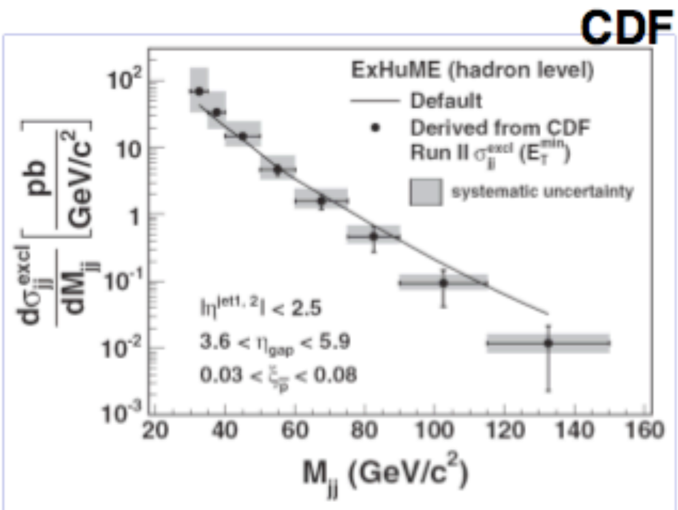
Exclusive γγ
[PRL 99, 242002 (2007)]



Exclusive dijet
[PR D77, 052004 (2008)]

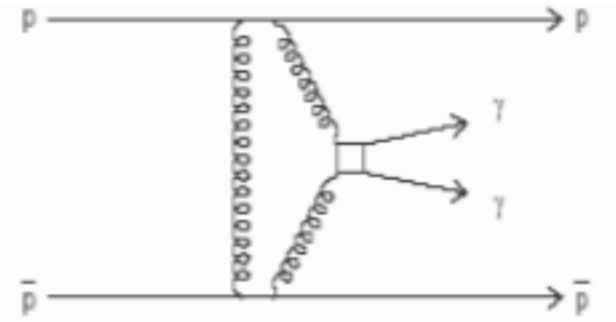


Exclusive χ_c
[PRL 102, 242001 (2009)]

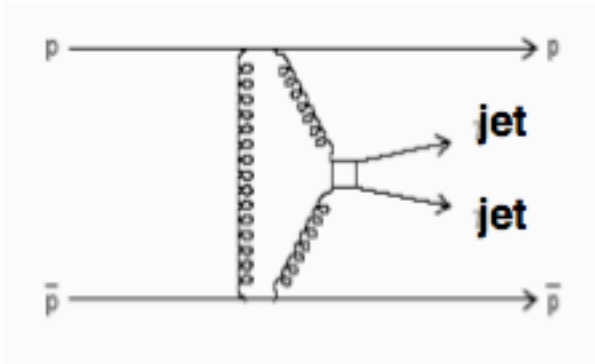


Exclusive processes at CDF→LHC

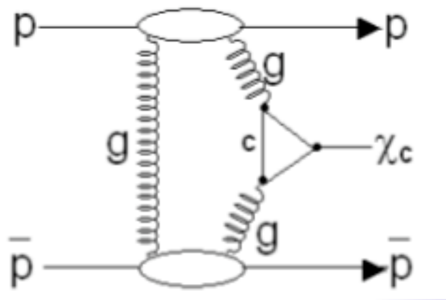
gg t-CHANNEL COLOR-SINGLET EXCHANGE



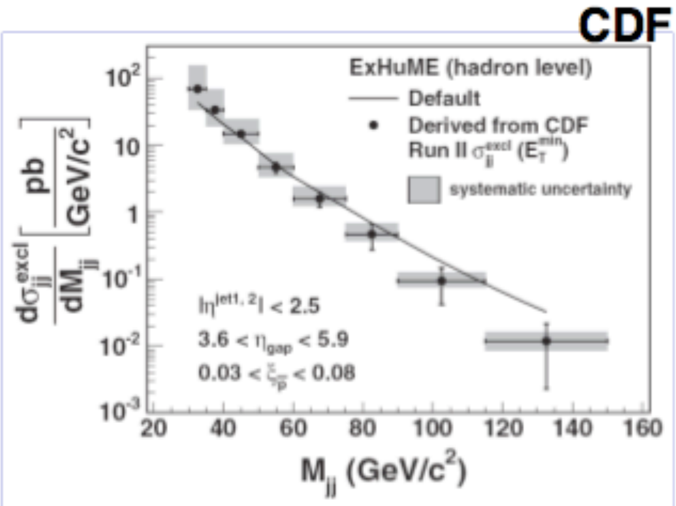
Exclusive $\gamma\gamma$
[PRL 99, 242002 (2007)]



Exclusive dijet
[PR D77, 052004 (2008)]



Exclusive χ_c
[PRL 102, 242001 (2009)]



Good agreement with theory lends support and helps test/calibrate predictions for Central Exclusive Production at the LHC

Main theory uncertainties:

- rapidity gap survival probability → could be pinned down with early LHC data, eg diff W production
  [CMS PAS DIF-07-002]
- proton PDFs

Same mechanism as central exclusive Higgs boson production!

http://focus.aps.org/story/v23/st21

Physical Review Focus

Focus Archive | PNU Index | Image Index | Focus Search

Previous Story / Next Story / Volume 23 archive

Phys. Rev. Lett. **102**, 242001
(issue of 19 June 2009)
Title and Authors

24 June 2009

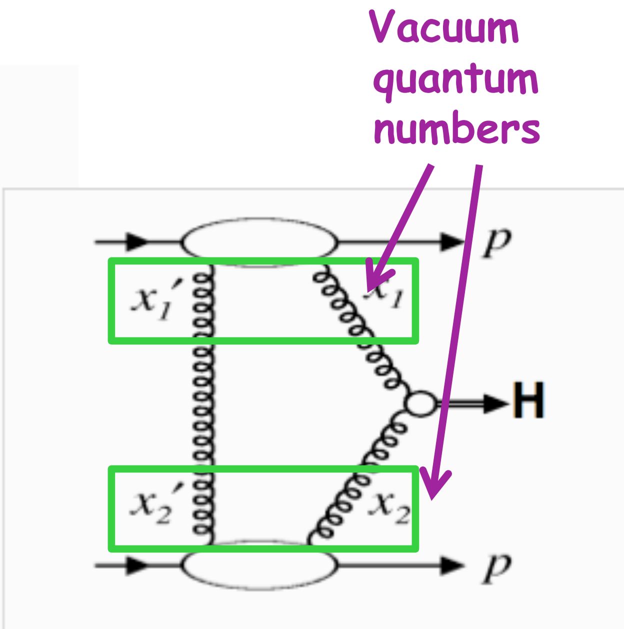
A Higgs Boson without the Mess

Particle physicists at CERN's Large Hadron Collider (LHC) hope to discover the Higgs boson amid the froth of particles born from proton-proton collisions. Results in the 19 June *Physical Review Letters* show that there may be a way to cut through some of that froth. An experiment at Fermilab's proton-antiproton collider in Illinois has identified a rare process that produces matter from the intense field of the strong nuclear force but leaves the proton and antiproton intact. There's a chance the same basic interaction could give LHC physicists a cleaner look at the Higgs.

CERN

Higgs machine. If CERN's Large Hadron Collider (LHC) can create Higgs bosons, a handful may appear in rare "exclusive" reactions that don't destroy the colliding protons--similar to a reaction now observed at Fermilab. CERN's ATLAS and CMS teams are considering adding equipment to their detectors (CMS shown here) to look for such events (click image to enlarge).

A proton is always surrounded by a swarm of ghostly virtual photons and gluons associated with the fields of the electromagnetic and strong nuclear forces. Researchers have predicted that when two protons (or a proton and an antiproton) fly past one another at close range, within about a proton's diameter, these virtual particle clouds may occasionally interact to



[Khoze, Martin, Ryskin hep-ph/0002072]

- Missing mass from protons: excellent mass resolution (~GeV) irrespective of decay products of central system
- J_Z=0, C-even, P-even selection rule
- Any new particle produced exclusively with p-tags has known quantum numbers

Take a look very forward

The FP420 R&D Project: Higgs and New Physics with forward protons at the LHC

M. G. Albrow[1], R. B. Appleby[2], M. Arneodo[3], G. Atoian[4], R. Barlow[2], W. Beaumont[5], L. Bonnet[6], A. Brandt[7], P. Bussey[8], C. Buttar[8], J. M. Butterworth[9], M. Carter[10], B.E. Cox[2,*], D. Dattola[11], C. Da Via[12], J. de Favereau[6], D. d'Enterria[13], P. De Remigis[11], A. De Roeck[13,5,*], E.A. De Wolf[5], P. Duarte[7,†], J. R. Ellis[13], B. Florins[6], J. R. Forshaw[12], J. Freestone[12], K. Goulianos[14], J. Gronberg[15], M. Grothe[16], J. F. Gunion[17], J. Hasi[12], S. Heinemeyer[18], J. J. Hollar[15], S. Houston[8], V. Issakov[4], R. M. Jones[2], M. Kelly[12], C. Kenney[19], V.A. Khoze[28], S. Kolya[12], N. Konstantinidis[9], H. Kowalski[21], F. Lanni[22], H.E. Larsen[23], S.-L. Liu[24], A. Lyapine[9], F.K. Loebinger[12], R. Marshall[12], A. D. Martin[28], J. Monk[9], I. Nasteva[12], P. Nemegeer[6], M. M. Obertino[3], R. Orava[25], V. O'Shea[8], A. Pal[7], S. Parker[19], J. Pater[12], A.-L. Perrot[26], T. Pierzchala[6], A. D. Pilkington[12], J. Pinfold[24], K. Piotrzkowski[6], W. Plano[12], A. Poblaguev[4], V. Popov[27], K. M. Potter[2], V. Radeka[22], S. Rescia[22], F. Roncarolo[2], A. Rostovtsev[27], X. Rouby[6], M. Ruspa[3], M.G. Ryskin[28], A. Santoro[28], N. Schul[6], G. Sellers[2], A. Solano[23], S. Spivey[7], W.J. Stirling[28], D. Swoboda[26], M. Tasevsky[29], R. Thompson[12], T. Tsang[22], P. Van Mechelen[5], A. Vilela Pereira[23], S.J. Watts[12], M. R. M. Warren[9], G. Weiglein[20], T. Wengler[12], S.N. White[22], B. Winter[18], Y. Yao[24], D. Zaborov[27], A. Zampieri[11], M. Zeller[4], A. Zhokin[9,27]

FP420 R&D Collaboration

[1]Fermilab, [2]University of Manchester and the Cockcroft Institute, [3]Università del Piemonte Orientale, Novara, and INFN, Torino, [4]Yale University, [5]Universiteit Antwerpen, [6]Université Catholique de Louvain, [7]University of Texas at Arlington, [8]University of Glasgow, [9]University College London (UCL), [10]Mullard Space Science Laboratory (UCL), [11]INFN Torino, [12]University of Manchester, [13]CERN, PH Department, [14]Rockefeller University, NY, [15]Lawrence Livermore National Laboratory (LLNL), [16]University of Wisconsin, Madison, [17]UC Davis, [18]IFCA (CSIC-UC, Santander), [19]Molecular Biology Consortium, Stanford University, [20]Institute for Particle Physics Phenomenology, Durham, [21]DESY, [22]Brookhaven National Lab (BNL),

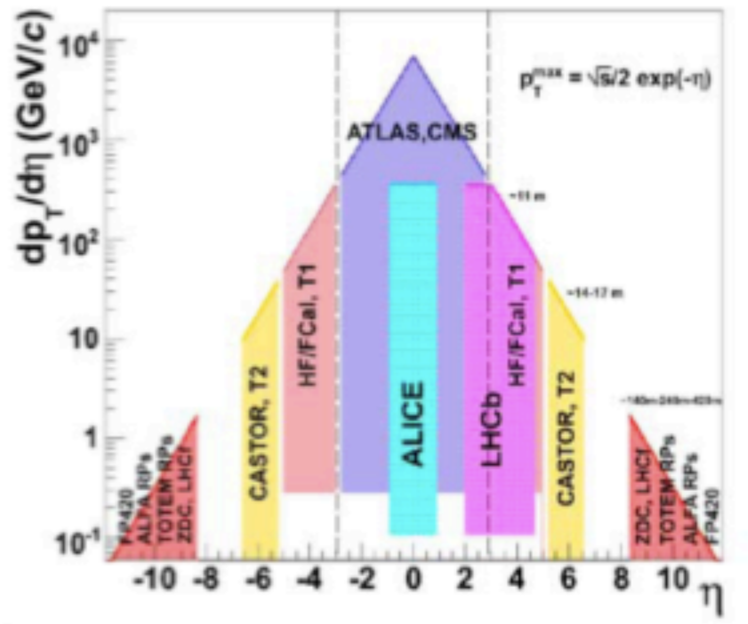
arXiv:0806.0302v1 [hep-ex] 2 Jun 2008

To be published in JINST

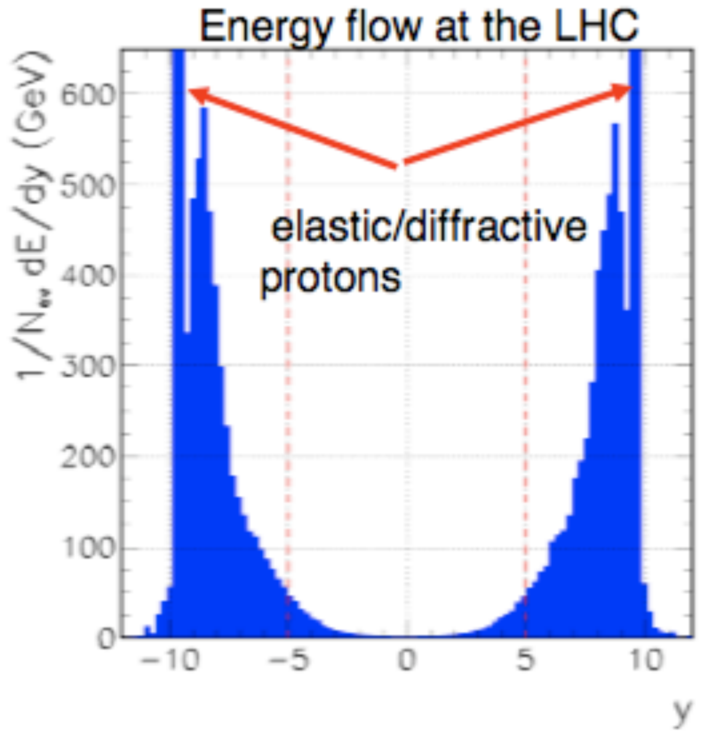
Under review in ATLAS/CMS

Detectors at 420 m from ATLAS/CMS IPs

Take a look forward



CMS+TOTEM ATLAS and ALICE instrumented for forward physics



- Early data taking (minimal pile-up, ie low luminosity):
  - low-x studies
  - photon mediated processes
  - hard diffraction 'a la Tevatron'
  - total cross section (TOTEM, special runs)
- @ high luminosity CMS and ATLAS will need proton taggers to cope with pile-up

In summary

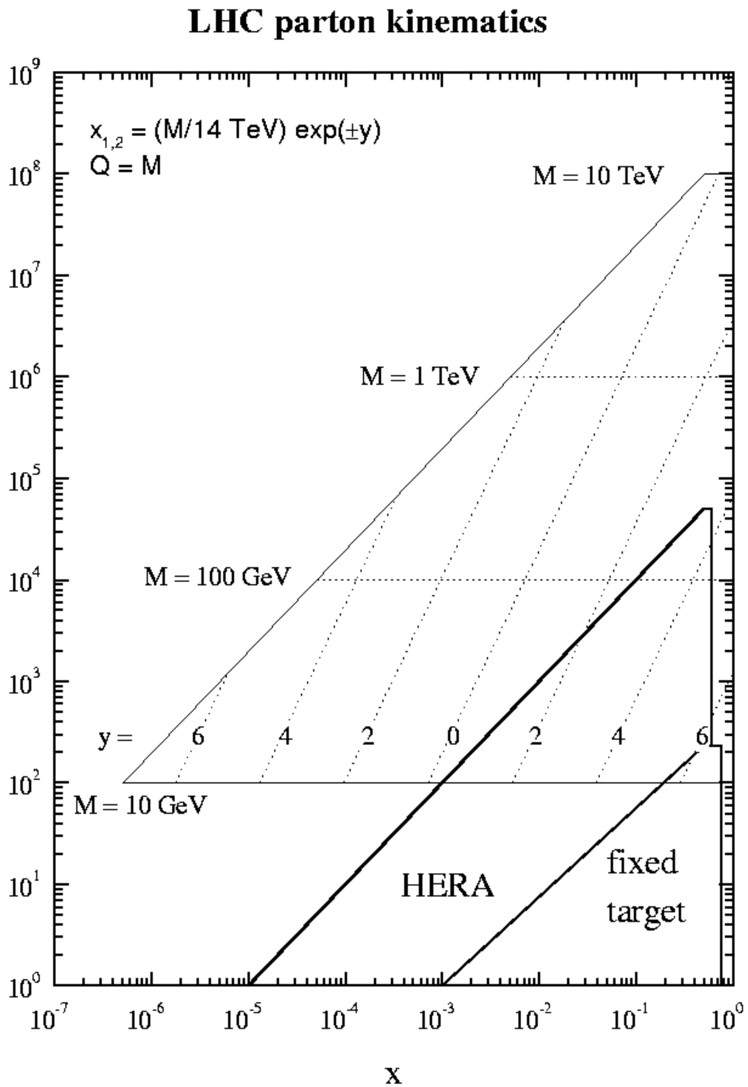
- **Diffraction received a great boost from HERA and Tevatron data in the last decade**
  - Many aspects of diffractive DIS can be described by pQCD if a hard scale is present
  - **Diffractive Parton Distribution Functions (DPDFs)** extracted from inclusive and diffractive final state (dijet) data : describe partonic content of proton probed diffractively, mainly gluons
  - Further input from hard vector meson production and DVCS, where precision measurements can constrain the gluon density and their sensitivity to **Generalised Parton Distribution Functions (GPDs)** allows access to parton momenta correlations and trasverse distribution of partons → **scanning the proton at different x** is a unique feature of diffraction!
- **Hard diffraction in hadron-hadron collisions more challenging due to rescattering effects between spectator partons**
  - Need to understand rescattering corrections in terms of QCD – **intimate relation with multiple scattering effects**, great interest in view of the LHC
  - Hint of such effects at HERA, more investigation needed
- **Recent evidence of central exclusive production at Tevatron → promising precision-measurement (if not discovery) tool at the LHC**

In summary

- **Fundamental links**
  - between the degrees of freedom prevailing in soft interaction - hadrons and Regge trajectories, and those of QCD – quarks and gluons
  - to low-x physics, saturation,…

A window on QCD dynamics in the regime of high parton densities

MANY THANKS TO THE MANY COLLEAGUES AND FRIENDS WITH WHOM I HAVE BEEN TALKING DIFFRACTION IN THE LAST YEARS


LHC parton kinematics
x1,2 = (M/14 TeV) exp(±y)
Q = M
M = 10 TeV
M = 1 TeV
M = 100 GeV
M = 10 GeV
y = 6 4 2 0 2 4 6
HERA
fixed target
x
10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9
10^-7 10^-6 10^-5 10^-4 10^-3 10^-2 10^-1 10^0