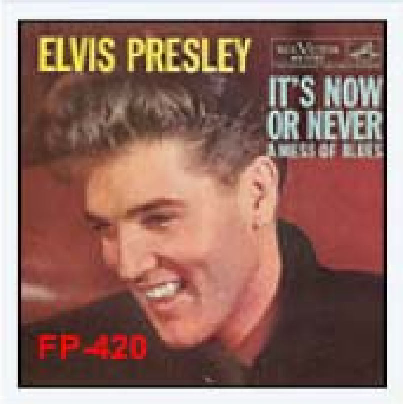
HERA and the LHC

A workshop on the implications of HERA for LHC physics

CERN - DESY Workshop 2006

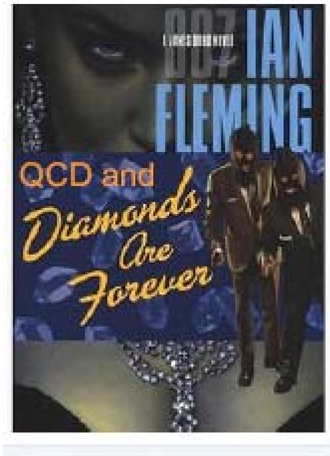


V. A. Khoze (IPPP, Durham)

Diffractve WG, p.2 (spiced with personal flavour)

Looking forward to Forward Physics at the LHC.

(11 talks & overlap with Paul)



Leading Neutron Energy and pT Distributions from ZEUS (20') (Slides)	(E)	Bill Schmidke (*MPI Munich*)
Information from Leading Neutrons at HERA (15') (Slides)	(T)	Alan Martin (*Durham*)
Central Exclusive Production of Long Lived Gluinos (20') (Slides)	(T)	Tim Coughlin (*Manchester*)
Odderon Searches in Exclusive Vector Meson Production in pp Collisions (10') (Slides)	(T)	Leszek Motyka (*Cracow*)
Factorisation Breaking in Diffractive Dijet Production (20') (Slides)	(T)	Michael Klasen (*Grenoble*)
Hard Rescattering Corrections to Exclusive Higgs Production at the LHC (20') (Slides)	(T)	Leszek Motyka (*Cracow*)
Issues Concerning Diffractive Higgs Production (20') (Slides)	(T)	Alan Martin (*Durham*)
Status and Plans for FP420 (20')	(T,E,MC)	Brian Cox (*Manchester*)
Simulations of Diffractive Higgs Production (20')	(E,T, MC)	Marek Tasevsky (*Prague*)
ExHuME Developments and SD Overlap to Exclusive Higgs (20') (Slides)	(T, MC)	Andrew Pilkington (*Manchester*)
Luminosity Determination and Forward Physics with ATLAS (20') (Slides)	(E)	Hasko Stenzel (*Giessen*)

Diffraction…..it is all about QCD…

Diffractive processes as a means to search for the New Physics & Phenomena.

Forward Proton Taggers as a gluonic Aladdin's Lamp

- Higgs Hunting in CED (A. Martin, M. Grothe, B. Cox, L. Motyka, M.Tasevsky, A. Pilkington).

- Photon-Photon, Photon - Hadron Physics (M. Grothe, L. Motyka, H. Stanzel)
- **'Threshold Scan':** 'Light' (split) SUSY ... (T. Coughlin)

- Various aspects of Diffractive Physics (*soft & hard*). (L. Motyka, A. Martin, V. Kundrat, A. Pilkington, H. Stanzel)

High intensity **Gluon Factory** *(underrated gluons)*
QCD test reactions, dijet P-luminosity monitor

- **pp**- luminometry (M. Grothe, H. Stenzel)
- Searches for new heavy gluophilic states (T.Coguhlin)

FPT

✷Would provide a unique additional tool to complement the conventional strategies at the LHC and ILC.

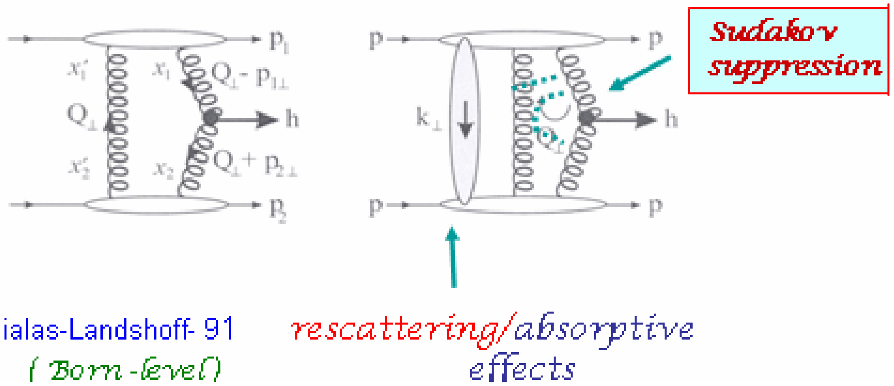
(>50% of the talks)

(L. Motyka, A. Matin)

The basic ingredients of Durham approach

Interplay between the soft and hard dynamics

RG signature for Higgs hunting (Dokshitzer, Khoze, Troyan, 1987). Elaborated by Bjorken (1992-93)



Main requirements:

•inelastically scattered protons remain intact

•active gluons do not radiate in the course of evolution up to the scale M

•$\langle Q_t \rangle \gg \Lambda_{QCD}$ in order to go by pQCD book

$$\sigma(\text{CDPE}) \sim 10^{-4} * \sigma \ (\text{incl})$$

High price to pay for such a clean environment:

σ (CEDP) ~ 10^{-4} σ(inclus.)

Rapidity Gaps should survive **hostile** hadronic *radiation damages* and *'partonic pile-up'*

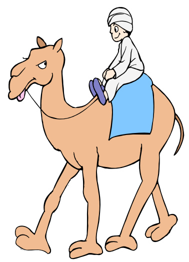
schematically : $W = S^2 T^2$

Colour charges of the 'digluon dipole' are screened only at $r_d \geq 1/(Q_t)_{ch}$

GAP Keepers (Survival Factors) , protecting RG against:

- the debris of QCD radiation with $1/Q_t \geq \lambda \geq 1/M$ **(T)**
- soft rescattering effects (necessitated by unitariy) **(S)**

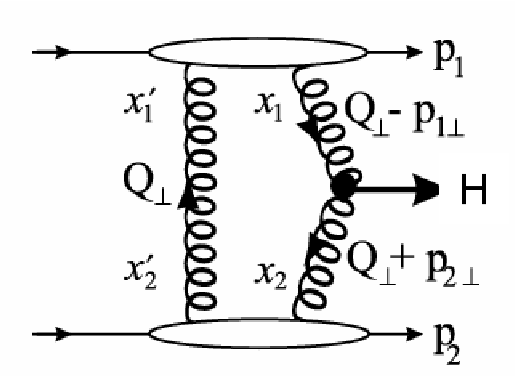
Forcing two (inflatable) camels to go through the eye of a needle



P **H** **P**

Reliability of pred^n of $\sigma(pp \rightarrow p + H + p)$ crucial

$$\sigma \sim \frac{\hat{S}^2}{b^2}\left| N \int \frac{dQ_t^2}{Q_t^4} f_g(x_1, x_1', Q_t^2, \mu^2) f_g(x_2, x_2', Q_t^2, \mu^2) \right|^2$$



contain Sudakov factor T_g which exponentially suppresses infrared Q_t region → pQCD

$$f_g(x, x', Q_t^2, \mu^2) = R_g \frac{\partial}{\partial \ln Q_t^2}\left[\sqrt{T_g(Q_t, \mu)}\, xg(x, Q_t^2)\right]$$

(High sens. to str. functs)

$\langle Q_t \rangle_{SP} \sim M/2 \exp(-1/\bar{\alpha}_s)$, $\bar{\alpha}_s = N_c/\pi\, \alpha_s\, C_\gamma$

SM Higgs, $\langle Q_t \rangle_{SP} \approx 2$ GeV $\gg \Lambda_{QCD}$

S^2 is the prob. that the rapidity gaps survive population by secondary hadrons
→ soft physics → S^2=0.026 (LHC) S^2=0.05 (Tevatron)

$\sigma(pp \rightarrow p + H + p) \sim 3$ fb at LHC for SM 120 GeV Higgs

Implementation in ExHume MC (A. Pilkington) (rechecked by J.Forshaw (HERA-LHC) & BBKM)

$pp \rightarrow p + H + p$

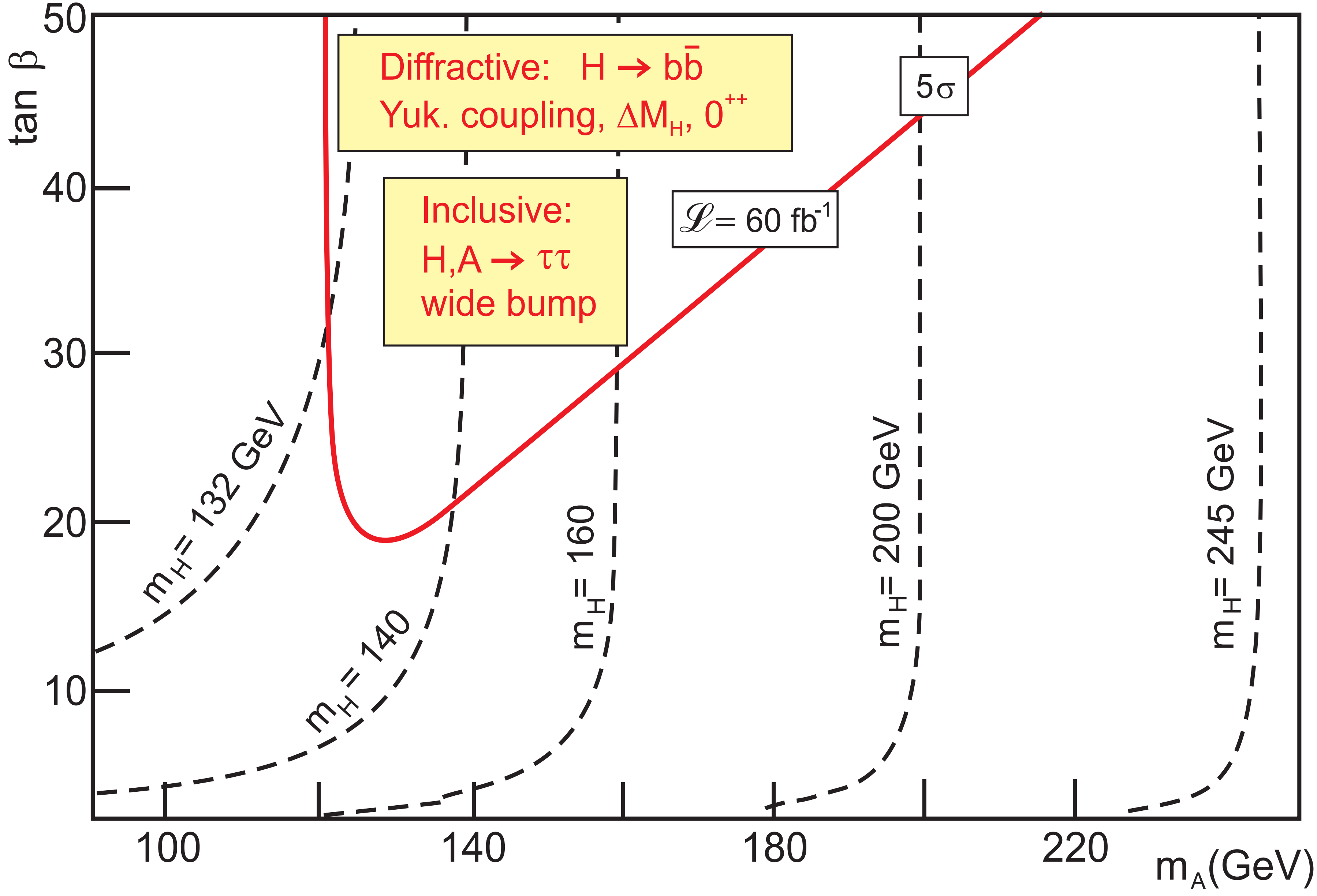
(A. Martin)

- If outgoing protons are tagged far from IP then $\sigma(M) = 1$ GeV (mass also from H decay products)
- Very clean environment
- $H \rightarrow b\bar{b}$: QCD $b\bar{b}$ bkgd suppressed by $J_z=0$ selection rule, and by colour and spin factors

  S/B~1 for SM Higgs M < 140 GeV

  Λ(LHC)~60 fb^{-1} ~10 observable evts after cuts+effic
- Also $H \rightarrow WW$ (L1 trigger OK) and $H \rightarrow \tau\tau$ promising
- SUSY Higgs: parameter regions with larger signal S/B~10, even regions where conv. signal is challenging and diffractive signal enhanced----h, H both observable
- Azimuth angular distribution of tagged p's $\rightarrow$ spin-parity 0^{++}

Studies of the MSSM Higgs sector are especially FPT –friendly (M. Tasevsky)



Adapted from a preliminary plot of Tasevsky et al.

(M. Tasevsky)

Major issues in selecting diffractive events with CMS+TOTEM+FP420

1. Background from non-diffractive events that are overlaid with diffractive pile-up events (1/5 of pile-up events are diffractive)

Talks by M. Tasevsky and A. Pilkington

2. Trigger is a major limiting factor for selecting diffractive events

The CMS trigger menus now foresee 1% of the trigger bandwidth on L1 and HLT for a dedicated diffractive trigger stream
where the combination of forward detector information with the standard CMS trigger conditions (jets, muons) makes it possible to lower the jet/muon thresholds substantially and still stay within the CMS bandwidth limits

This is the completion of the trigger studies presented in the proceedings of the HERA-LHC workshop of 2004/2005
Now available as CMS note 2006/054 and TOTEM note 2006/01:
"Triggering on fwd physics", M.Grothe et al.

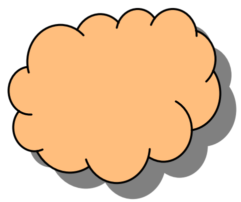
- How reliable are the calculations ?
- Are they well tested experimentally ?

- How well we understand/model soft physics ?
- How well we understand hard diffraction ?

✵ What else could/should be done at HERA in order to improve the accuracy of the calculations ?

☺ So far the Tevatron diffractive data have been Durham-friendly (K. Terashi)

clouds on the horizon ?



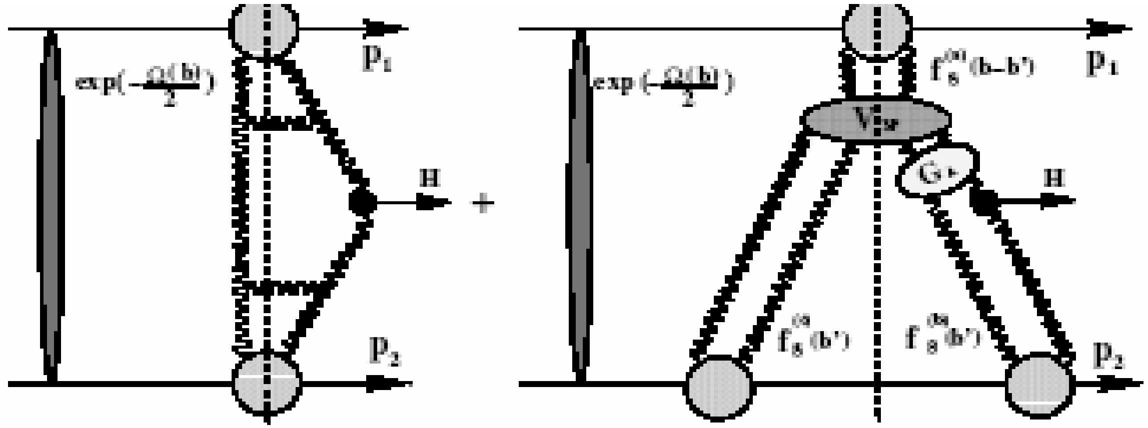
OR

Theory side -Hard rescattering corrections to CDEP (L. Motyka, A. Martin)

Experim. Side – Diffract. Dijet Photoproduction (R. Wolf, A. Bonato, M. Klasen)

L. Motyka' talk

Based on recent work done with J. Bartels, S. Bondarenko and K. Kutak



$$\mathrm{Im}\,\tilde{M}_{corr}(y,\boldsymbol{b},\boldsymbol{b}_1) = -\Big\{ \frac{9}{8}\,16\pi^2\,(2\pi^3 A) \int_{x_a}^{x_b} \frac{dx_4}{x_4} \int \frac{d^2k_2}{2\pi k_2^4} \int \frac{d^2k_3}{2\pi k_3^4} \int \frac{d^2k_4}{2\pi k_4^4}$$

$$\times\, [V_{3P} \otimes \tilde{f}_g^{(a)}(x_1,\boldsymbol{b}-\boldsymbol{b}_1)](\boldsymbol{k}_2,\,\boldsymbol{k}_4)\; G_{\mathrm{A}}(\boldsymbol{k}_2,\boldsymbol{k}_3;x_1,x_2;M_H/2)$$

$$\times\, \tilde{f}_g^{(b)}(x_3,k_3^2,\boldsymbol{b}_1;M_H/2)\; \tilde{f}_g^{(c)}(x_4,k_4^2,\boldsymbol{b}_1)\Big\} \;-\; \{y\to -y\}$$

$$\frac{d\sigma^{(0+1),\Omega}_{pp\to pHp}(y)}{dy} = \frac{1}{16\pi}\int d^2b \int d^2b_1\, |S(\boldsymbol{b}_1)S(\boldsymbol{b}-\boldsymbol{b}_1)M_0(y) + M_{corr}(y,\boldsymbol{b},\boldsymbol{b}_1)|^2\, \exp(-\Omega(s,\,\boldsymbol{b})$$

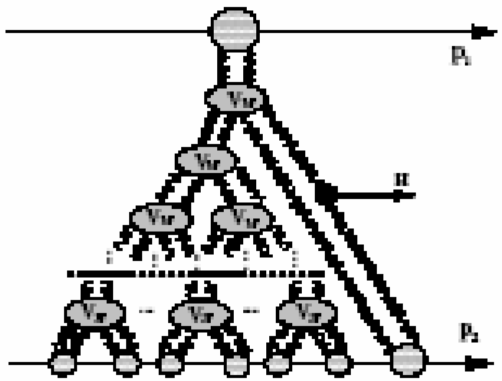
perturbative triple-Pom calculations, based on Bartels et al results

Discussion

The relative magnitude of the correction is large and the sign is negative

Factorisation between hard production amplitude and rescattering is strongly broken

- The magnitude of the higher order unitarity corrections in expected to be large as well
- Theoretical uncertainty of $\sigma_{excl}(pp \to pHp)$ is higher than expected
- Suppression or enhancement?
- Tests of the framework needed



Key ingredients:

- Large rapidity available for the screening pomeron $Y \sim 15 - 20$
- Perturbative momenta and large mass of the rescattering state
- Partial resummation of unitarity corrections

(L. Motyka)

Conclusions

- The hard rescattering correction to the exclusive Higgs boson production was evaluated and found to be large and clearly separated from soft rescattering
- Factorisation of the hard production process from the soft rescattering was found to be broken
- Theoretical uncertainty of the cross section for exclusive Higgs production was broadened
- Resummation of higher order unitarity corrections is necessary
- Practical goal – we want to have better theoretical controll of the exclusive Higgs production
- Theoretical goal – to understand the dynamics of dense gluonic systems and multiple scattering in pp collisions

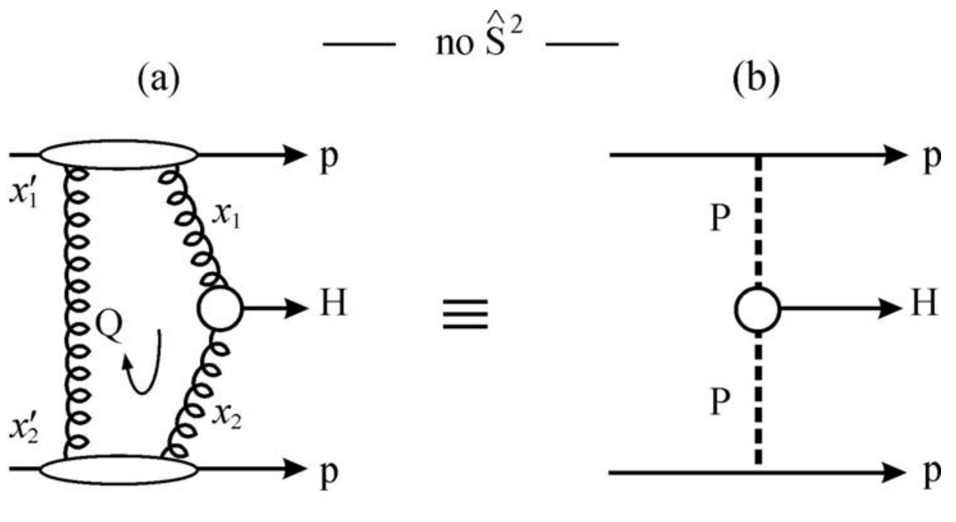
My personal view: there are (at least) 3 good news :

.
- confirmation of KMR appr. (within its framework), both **S** and **T**;
- step in the right theoretical direction;
- opens a window for many theory papers to come.

BBKM-KKMR –agreeable disagreement

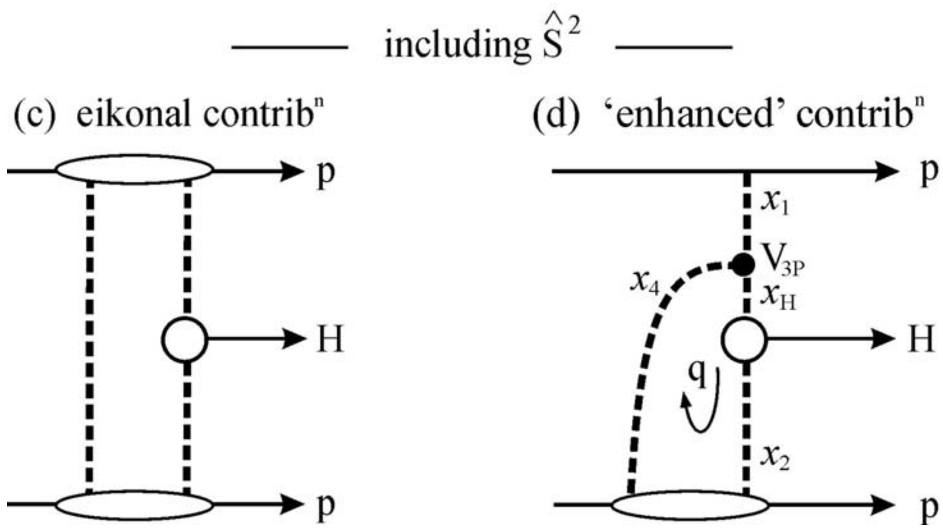
“enhanced” correction to σ_H(excl)?

(A. Martin)



eikonal

S^2 =0.026



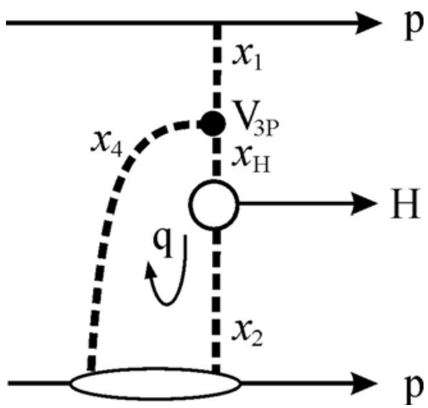
enhanced

KMR: using 2-channel eikonal
Gotsman,Levin,Maor..
Lonnblad, Sjodahl,
Bartels,Bondarenko,Kutak,Motyka

BBKM → use pert.thy. → corr^n could be large and -ve, → σ_H(excl) reduced ?
KMR → pQCD invalid → strong coup regime → small effect

(A.Martin)

BBKM use pQCD to calculate enhanced diagram



$$M_1 \sim \int \frac{dx_4}{x_4} \int \frac{d^2 q_t}{2\pi^2} \int \frac{d^2 k_{t,4}}{k_{t,4}^4} f_g(x_4, k_{t,4}^2, \ldots)\ V_{3P}\ M_0$$

(x_4 can be v.small, 10^{-5})

BK eq.

LL

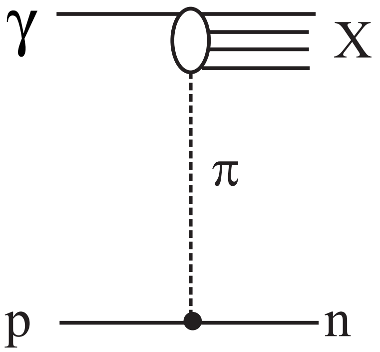
Various phenomenological and theor. contr-arguments

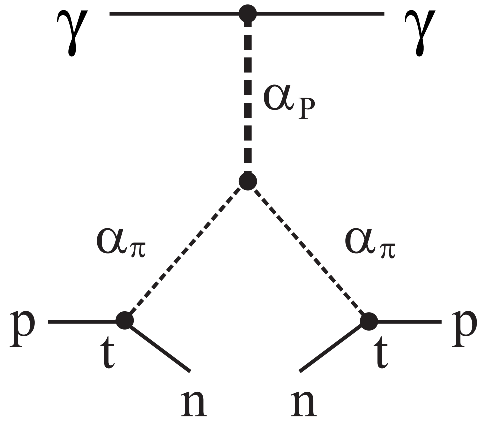
Infrared stability only provided by saturation momentum, $Q_S(x_4)$.
Hope is that at v.low x_4, Q_S allows use of pQCD.
Gluon density is unknown in this region!

BUT multi-(interacting)-gluon Pomeron graphs become important.
These can strongly decrease the effective triple-Pomeron vertex V_{3P} .

True expansion is not in α_S, but in prob. P of additional interaction.
Pert.theory → saturation regime where P=1, dominated by rescattering of low k_t partons, but already included in **phenomenological** soft pp amp.

New ZEUS data (B. Schmidke)



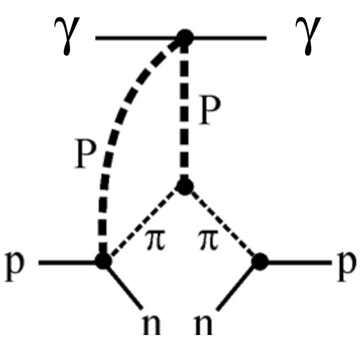


- **Leading neutron prod. at HERA**

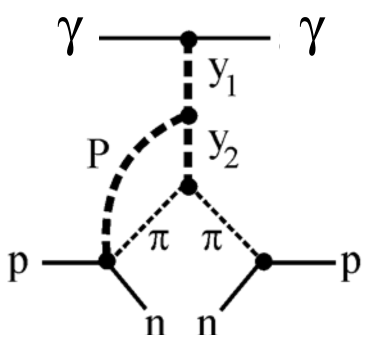
KKMR '06

gap due to π exchange
~ exclusive Higgs

eikonal



enhanced



$y_i > 2 - 3$

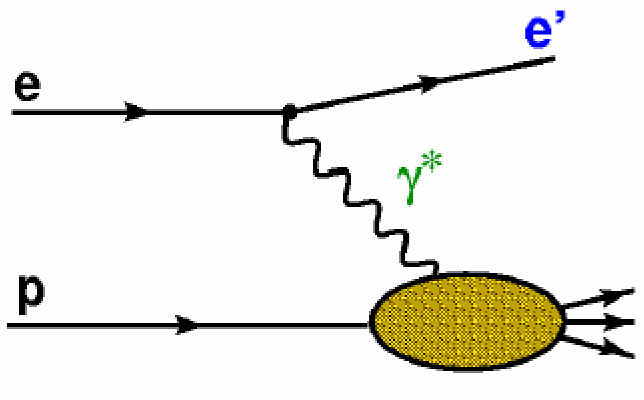
correction prop. to rap. interval
prop. to γ energy
(negative)

Prob. to observe leading neutron must decrease with γ energy
But expt. → flat
→ small enhanced correction

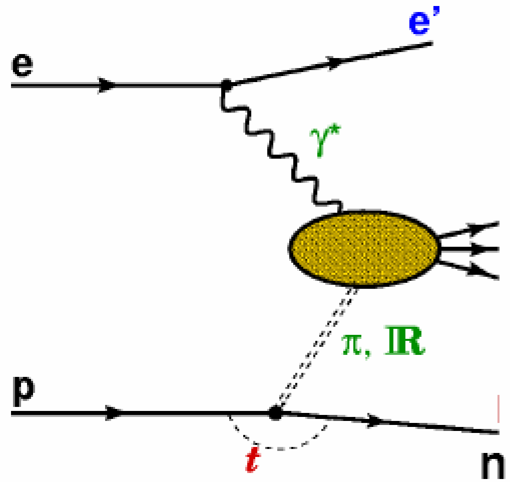
σ_{SD} may change (flat) behaviour at the LHC if enh . contr. is large

(B. Schmidke)

Motivations: LN production, OPE



$x_L = E_n/E_p$



LN can come from 'standard' fragmentation
(baryon # has to go somewhere)
Can compare to 'standard' MC gens.: x_L, p_T^2 distributions

- LN can be produced via isovector exchange: One Pion Exchange (OPE)
- Parameterizations from low energy hadronic scattering data. Can compare x_L, p_T^2 distributions

(B. Schmidke)

Data Sets

Inclusive data (i.e. no LN tag):

- DIS: $Q^2 > 2$ GeV^2, $\langle Q^2 \rangle \approx 14$ GeV^2
- γp: $Q^2 < 0.02$ GeV^2, e^+ tagged $\Rightarrow$ $180 < W_{\gamma p} < 255$ GeV

LN measurement: Forward Neutron Calorimeter (FNC) & Tracker (FNT)

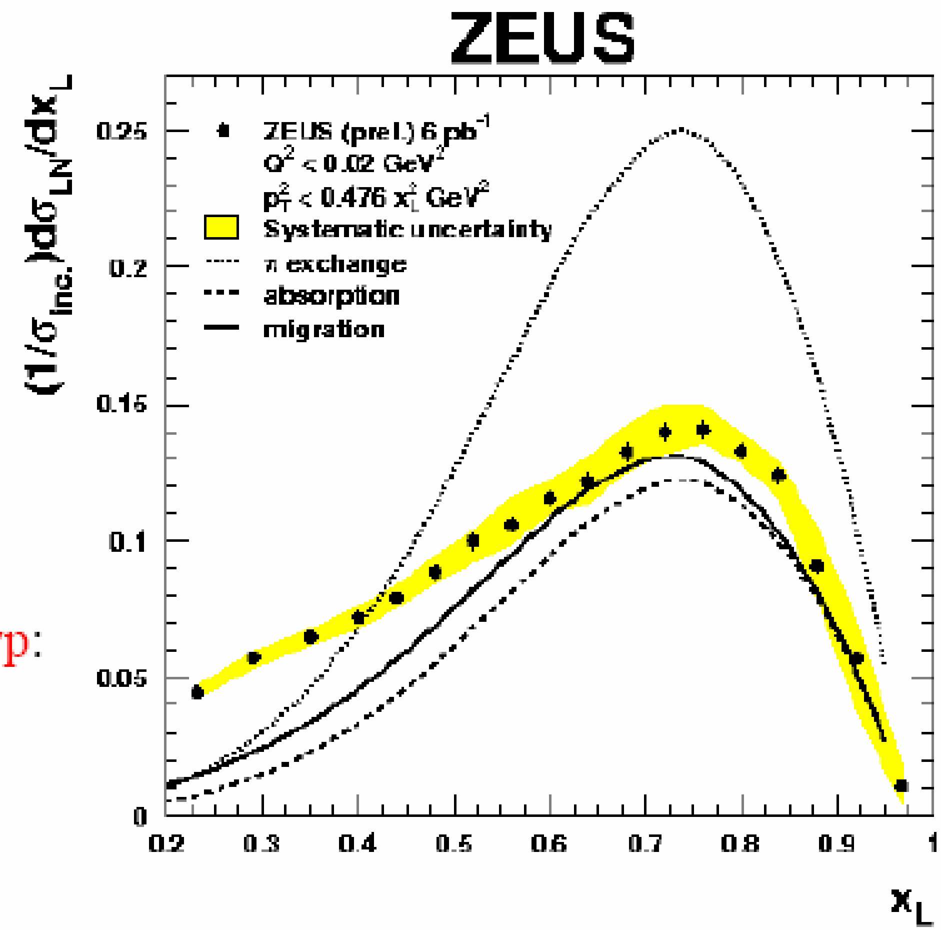
- 10.2 λ_I Pb-scint. calorimeter 105m from I.P.
- Scintillator hodoscope 1 λ_I into calorimeter for position detection
- Energy resolution $\sigma_E/E \approx 0.7/\sqrt{E}$
- p_T resolution dominated by proton beam p_T spread ~50-100 MeV
- Magnet apertures limit $\Theta_n < 0.75$ mrad $\Rightarrow$ $p_T^2 < 0.476\, x_L^2$ GeV^2

LN yields:

- DIS, γp have very different inclusive cross sections $\sigma_{inc.}$
- For sensible comparisons look at LN yields: $\sigma_{LN} / \sigma_{inc}$
- Additional benefit: systematic uncertainties of central ZEUS cancel; only have LN systematic uncertainties

Comparison: OPE w/ absorption

- Recent work of Kaidalov, Khoze, Martin & Ryskin:
  - start with pure OPE
  - some *n* rescatter on γ
  - rescattered *n* migrate in (x_L,p_T)
- Very nice agreement with LN in γp:
- Much more next speaker ➘



(B. Schmidke)

Summary

- Best measured LN x_L, p_T distributions in DIS, γp
- Comparison DIS$\leftrightarrow\gamma p$: evidence for absorption of n in large γ
- Pure OPE does not fully describe data
- More refined calculations: OPE+absorption+migration

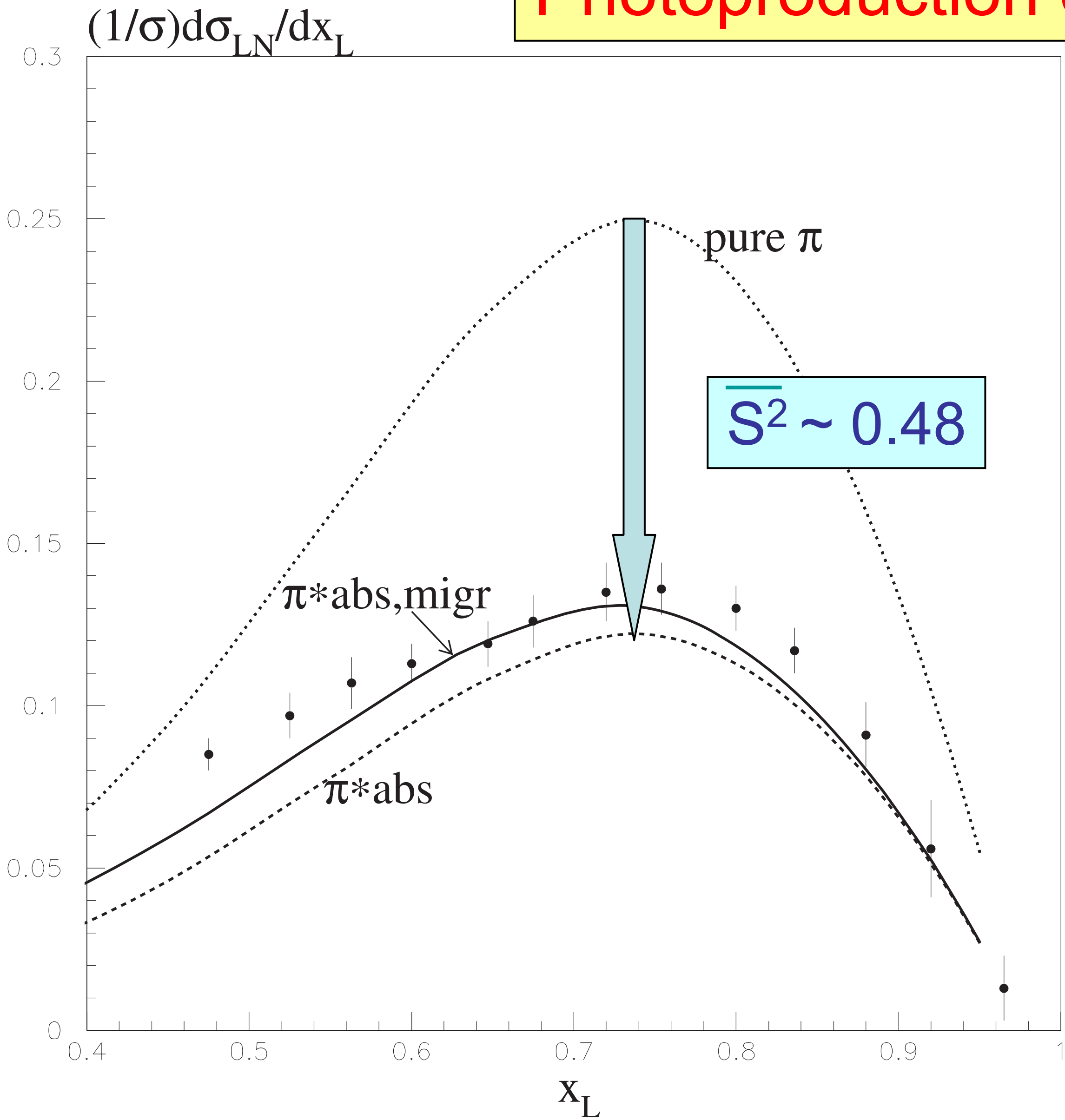
  $\Rightarrow$ very promising agreement with data (next speaker ↘)
- MC models with 'standard' fragmentation do not

  describe the data (LEPTO has some promise)

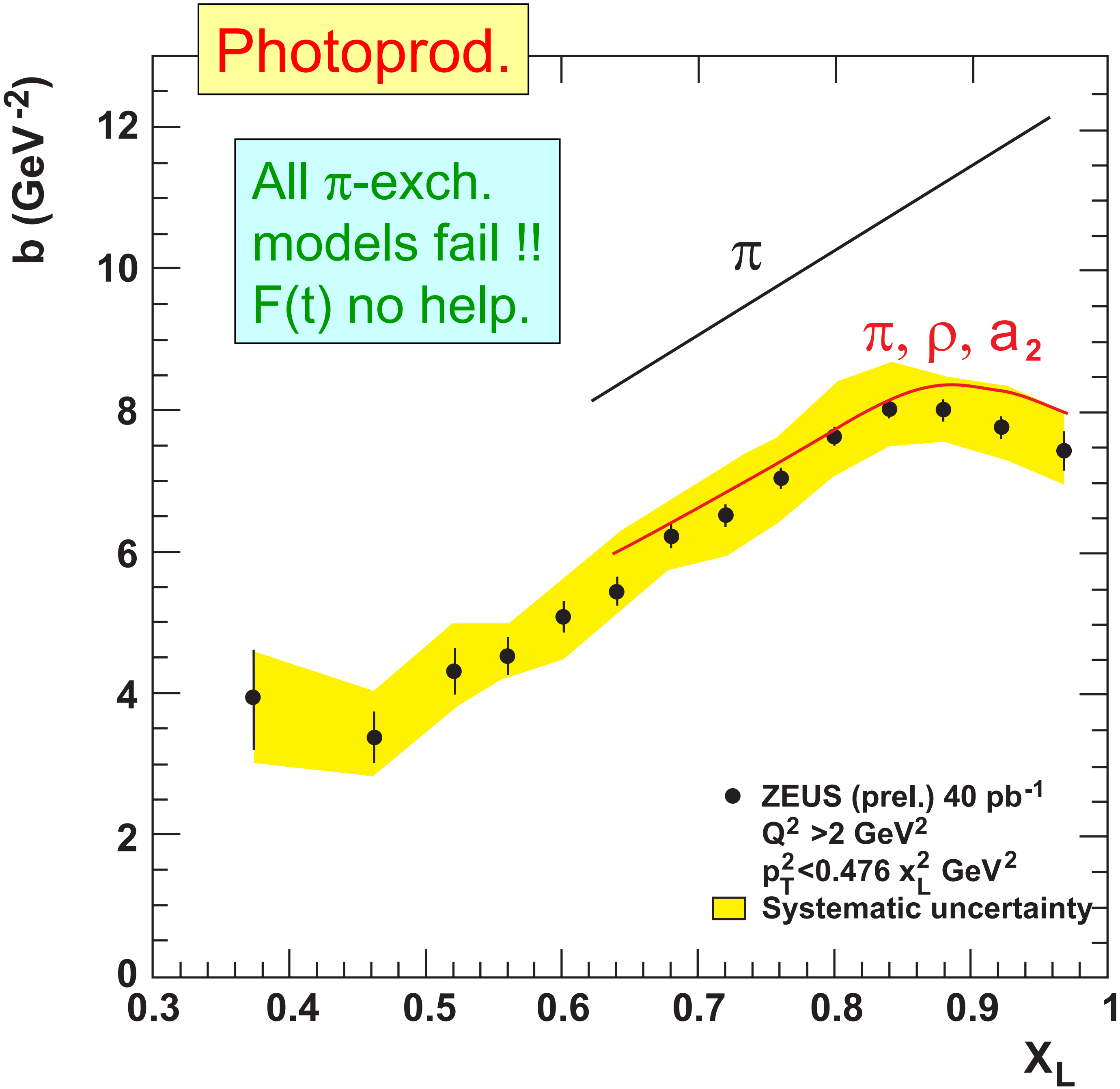
Now…ZEUS LN data as seen from Durham….

(A.Martin)

Photoproduction of leading n



Prelim. ZEUS data (DIS2006)

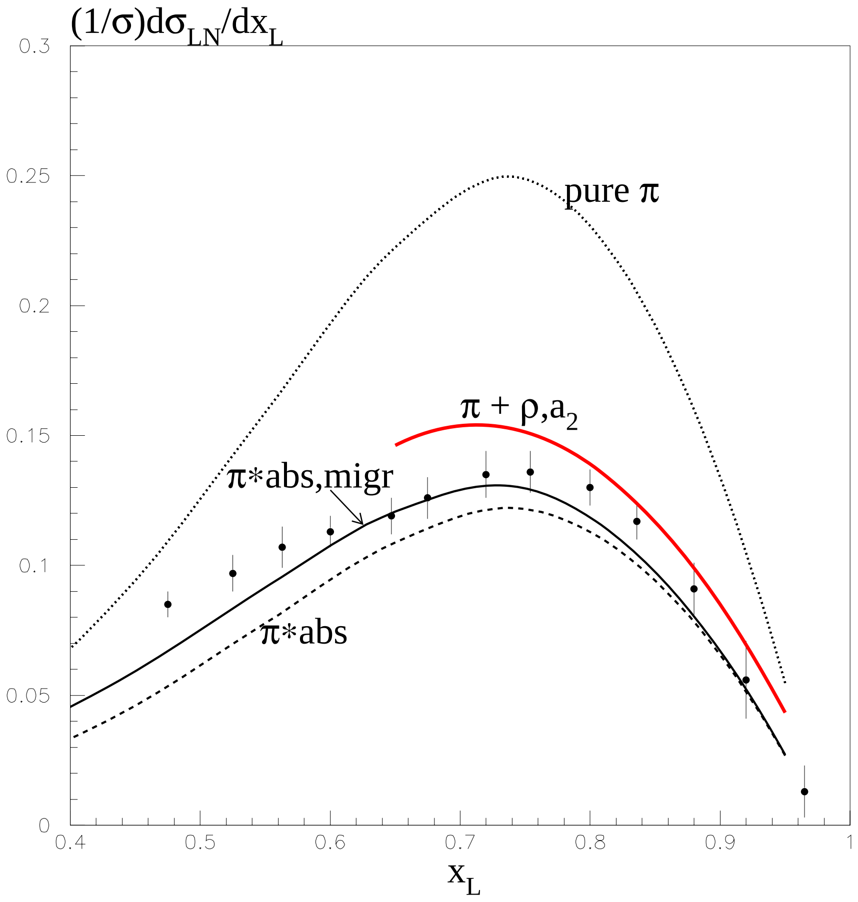


p_t^2 dep.

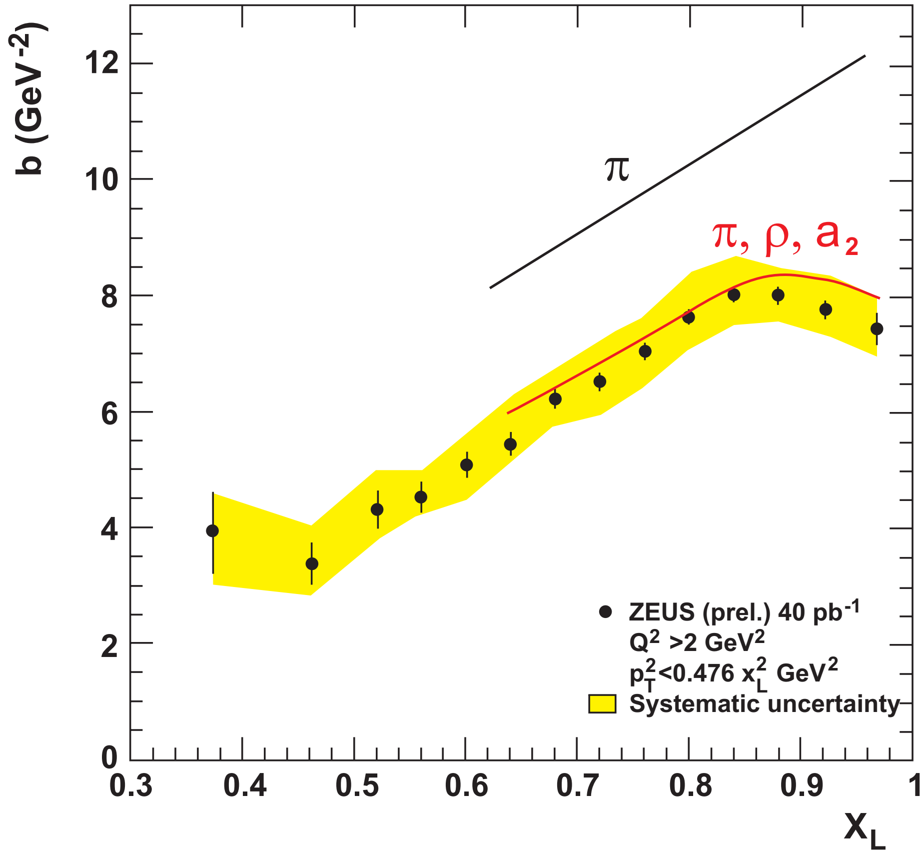
~ $\exp(-b p_t^2)$

led to include
ρ, a_2-exch. →

cross section



p_t^2 slope



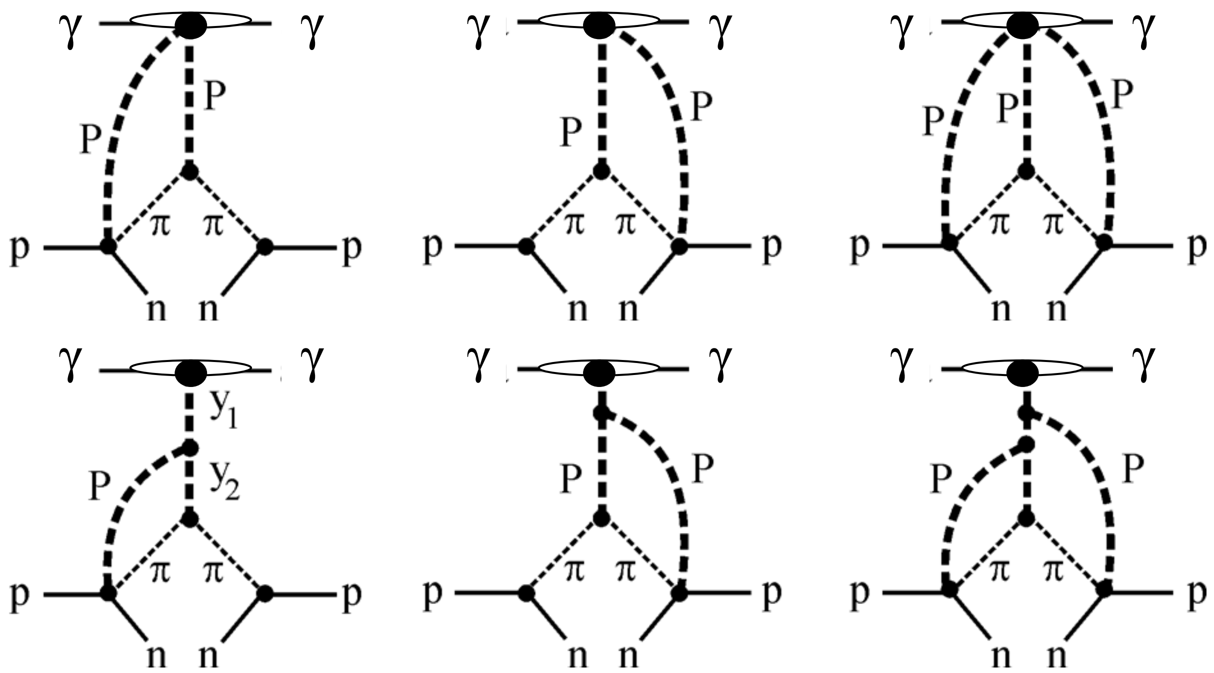
now $\overline{S^2}$ ~ 0.4, instead of 0.48

Recall :KKMR expected 0.34 for diffr.dijet photpr.
('resolved 'comp)

Calculation of survival factor, $S^2(x_L,p_t^2,Q^2)$

(a)

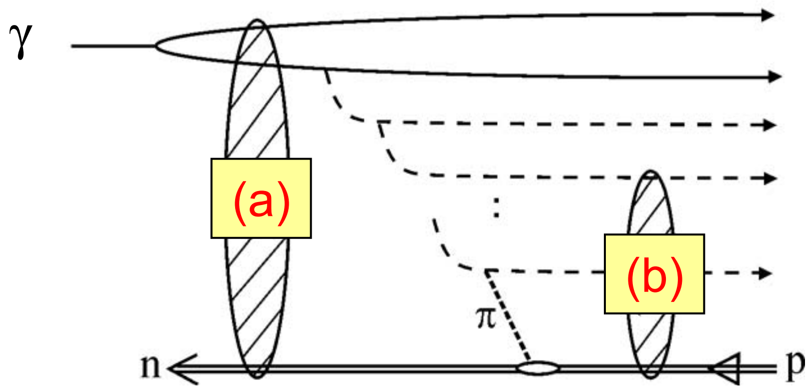
(b)



normal eikonal diagrams

enhanced diag. need y_i > 2-3: result ~ 15%

space-time picture



If enhanced diag were important, then n yield would be energy dep. Not seen in data.

Conclusions on leading neutrons at HERA

- Exploratory study of prelim. ZEUS data (Q^2, x_L, p_t, W) very informative

- π exch (with abs.) describes σ, but not p_t^2 slope b
  $\rightarrow$need also ρ, a_2 exchange

  turnover of slope as $x_L \rightarrow 1$ ($t_{min} \rightarrow 0$) may be used to determine ρ,a_2 versus π exchange contributions

- Absorptive corrections important $\bar{S}^2 \sim 0.4$
  Small contrib. from enhanced diagrams

  important for LHC

- Simultaneous description all data (Q^2, x_L, p_t dep.) difficult

- Precise data should determine $F_2^{\pi}(x,Q^2)$ and $S^2(x_L,p_t,Q^2)$

Possible problem: Dijets in diffractive PhP

(R. Wolf, A. Bonato, M.Klasen)

A.Bonato – HERA-LHC workshop 07/06/2006

Direct γ^* (small y^*) couples directly to parton
QCD factorisation is expected to hold

Resolved γ^* (large y^*) behaves like a hadron
QCD factorisation is expected to break

6

Apparent need for a global suppression of NLO prediction (both low and high x_γ)

Reservatins::
- high $x\gamma \neq$ small size component
- direct-resolved contr. are interconnected (gauge inv., M. Klasen's talk).
- using NLO at high $x\gamma$ may be risky (e.g. large Sudakov effects)
- hadronization corrections, M.Klassen.
- experiment. uncertainties

The same (Durham) 'machinery' should work/ be tested in diffr. PhP

Motivation

Hard diffraction:

→ Does factorization hold?

Deep inelastic scattering: Yes

→ Direct photoproduction

Hadroproduction: No

→ Resolved photoproduction

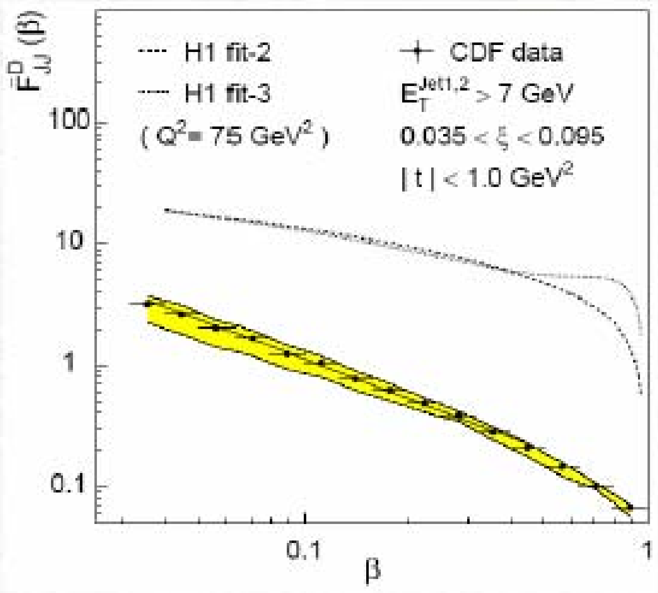
Why next-to-leading order?

→ $\sigma_{tot} = \sigma_{dir}(x_\gamma, M_\gamma) + \sigma_{res}(x_\gamma, M_\gamma)$

→ At LO $x_\gamma = 1$, but at NLO $x_\gamma \leq 1$

→ $\log(M_\gamma)$-dependence cancels

Diffr. hadroproduction of dijets:



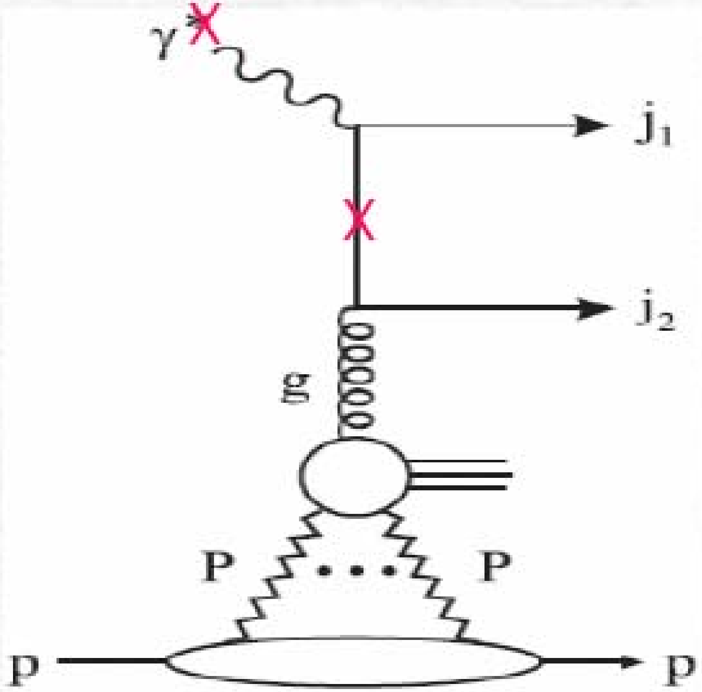
CDF Coll., PRL 84 (2000) 5043

KKMR-quantitat description(2001)

factorization scale/scheme dep. between dir. & resolv.

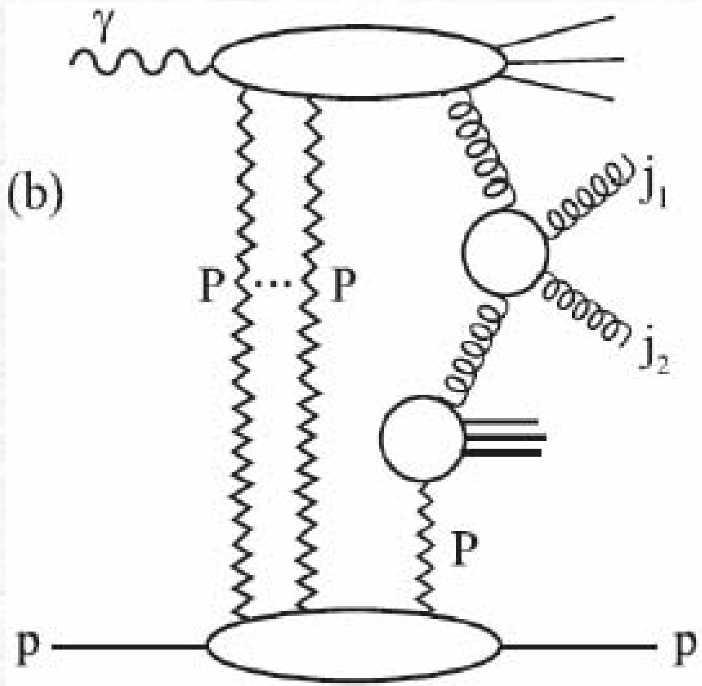
Multipomeron Exchanges

Direct photoproduction:



→ Modify the Regge trajectory

Resolved photoproduction:



→ Factorization breaking

Survival probability:

$R \equiv |S|^2 \approx 0.34$

Kaidalov et al., PLB 567 (2003) 61

Interconnect. drect- resolved, collinear. sigularities, scale depend.

Conclusions

Hard diffraction: Factorizable or not?

- Deep inelastic scattering: Yes $\rightarrow$ Diffractive parton densities
- Hadronic scattering: No $\rightarrow$ Multipomeron exchanges
- Important application: Diffractive Higgs production at LHC

Diffractive photoproduction of dijets: Initial state singularity at NLO

- Direct / resolved photoproduction: x_γ and M_γ dependence
- (Non-) factorizable multipomeron exchanges

Two-channel eikonal model:

- Generalized vector meson dominance: $\gamma \rightarrow \rho, \omega, \ldots$
- Rapidity gap survival probability: $R = 0.34$

Related process:

- Leading neutron with π-exchange (NB: $f_{q/\pi}$, not $f_{g/IP}$!)

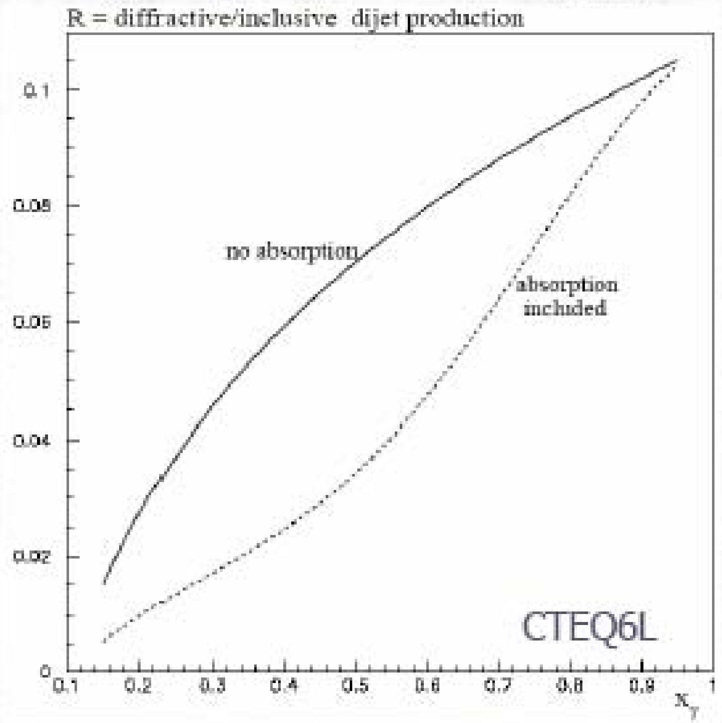
June 7, 2006 Michael Klasen, LPSC Grenoble 26

a guage invariant. recipe on how to deal with the long-distance comp. of the ‘direct’ contribn. Important feature: scale/ scheme dependence cancel.

Diffractive / Inclusive Production

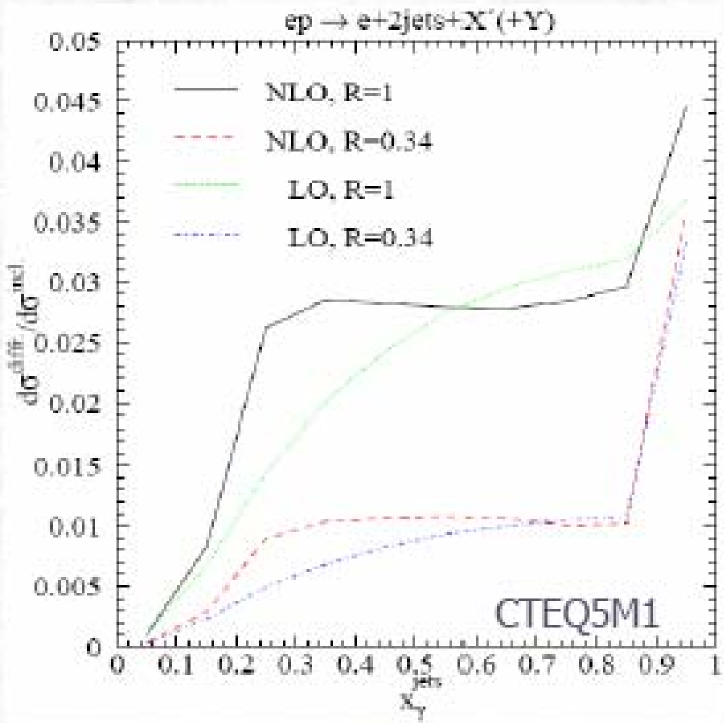
Some uncert. cancel

$R = f_{g/IP} \otimes f_{IP/p} / f_{g/p}$ with $M_{12} = x_\gamma z_{IP} x_{IP} W$:



A. Kaidalov et al., PLB 567 (2003) 61

$R = \sigma^{diffr.} / \sigma^{incl.}$ with full kinematics:



MK, G. Kramer, EPJC 38 (2004) 39

still may be done at HERA

Something Exotic

Central exclusive production of long lived gluinos at the LHC

Tim Coughlin
- In collaboration with J. Forshaw, A. Pilkington and P. Bussey

- Gluinos can form colourless bound states with gluons ($\tilde{g}g$), as well as 'R-mesons' ($\tilde{g}q\bar{q}$) and 'R-Baryons' ($\tilde{g}qqq$).
- Expected that hadronic interactions in the detector will convert R-mesons $\rightarrow$ R-Baryons, but not visa versa. Therefore, most reach muon chambers as R-Baryons.
- Charged R-hadrons will look like a muon within a jet, though much slower and more isolated.

- Given the small backgrounds we only need a few events.
- Expect at least 10 events over 3 year high luminosity running (100 fb^{-1} per year) for gluino masses up to 350 GeV.
- This is sufficient for a mass measurement of better than 1%!
- Mass measurement is complementary to inclusive production in this mass region (Kilian et. al. hep-ph/0408088), as we avoid systematic uncertainties due to modeling the energy loss in the detector.

To do list for the LHC community

o) Most recent input from HERA (dPDFs, leading baryon spectra etc) should be included in all studies

o) Need to finalise studies on the potential of LHC for (hard) diffraction/forward physics including all experimental details: pile-up, full detector simulation, trigger etc