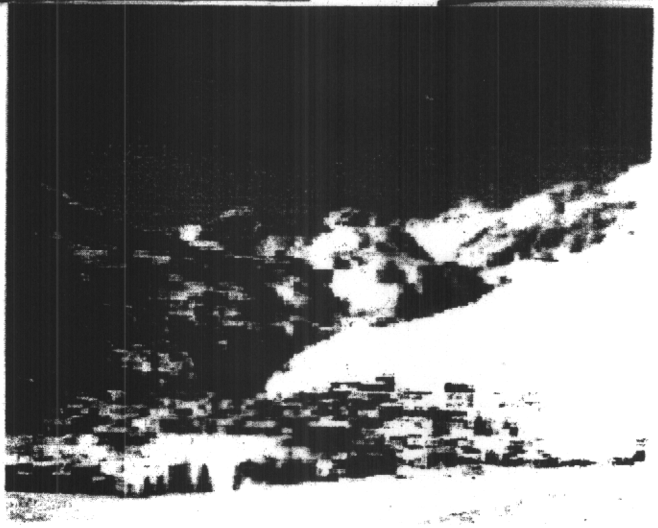
Les Rencontres de Physique de la Vallée d'Aoste

La Thuile, Aosta Valley March 4-10, 2001



Higgs and Dijet Production in Double Diffractive Processes

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(In collaboration with A. Martin and M. Ryskin)

PLAN

- Sweet dreams of the Higgs-hunters
- Is Rapidity Gap Signature an Advantageous Investment?
- 'Pomeron-Pomeron' luminometry.
- CDF testify ...

the Higgs

- is still elusive

LEP is no longer available for H-hunting

- searching for a good signal/friendly environment at hadron colliders

($(H \to b\bar{b})_{incl} \to$ small S/B ratio)

- looks quite appealing

$$p\overset{(-)}{p} \to p + H + \overset{(-)}{p}$$

$$X + M + Y$$

$(+) \equiv RG$

spectacular signature : RG – <u>hadron free zones</u> <u>(no-fly)</u>

- CDF proposal for Run–II (hep-ph/0009336)

($1 - x_p \lesssim 0.1$, $\Delta M \simeq 250$ MeV, $M \lesssim 200$ GeV)

- microstations proposed for an extension of ATLAS
- <u>Specialize to $H \to b\bar{b}$</u> (Int. mass Higgs)

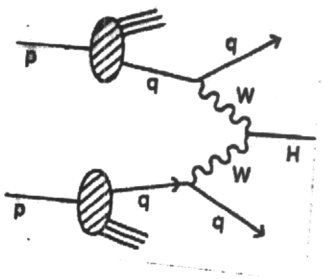
<u>MAIN QUESTIONS:</u>

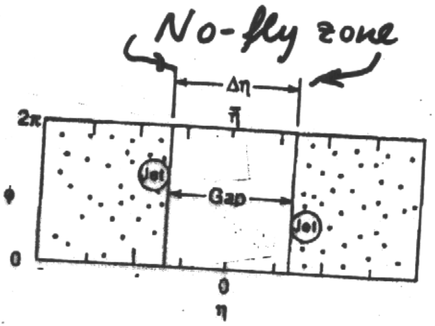
- How significant is an enhancement of the $S/B_{b\bar{b}}$ ratio ?
- Is the rate for RG Higgs production large enough ?
- Can we overcome the theoretical uncertainties ?

(predictions vary by many orders of magnitude)

Long (and checked) history

["squeezed" chronicle]



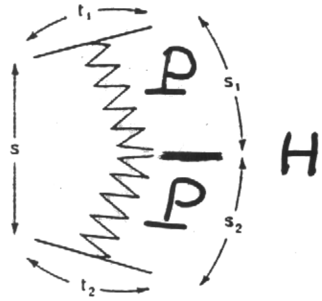


Lego plot

1987 – Yu. Dokshitzer, V. Khoze, S. Troyan

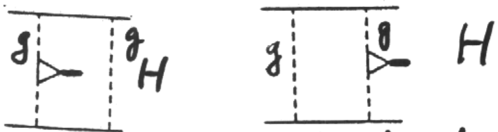
RG – footprints of the point-like colourless t-channel exchanges (EW, ...)

1990 – A. Schäfer, O. Nachtmann, R. Schöpf



1991 – A. Bialas, P. Landshoff

Non-perturbative two-gluon exchange picture of the Pomeron (widely used)



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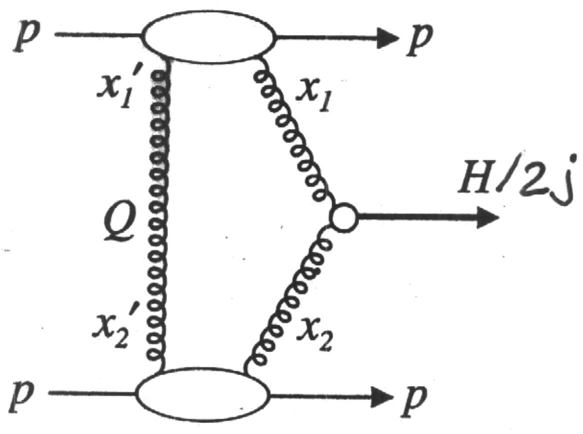
1997–2001 V. Khoze, A. Martin, M. Ryskin

SL-improved perturbative calculations using realistic unintegrated gluon densities with particular attention to the survival probabilities of RG's.

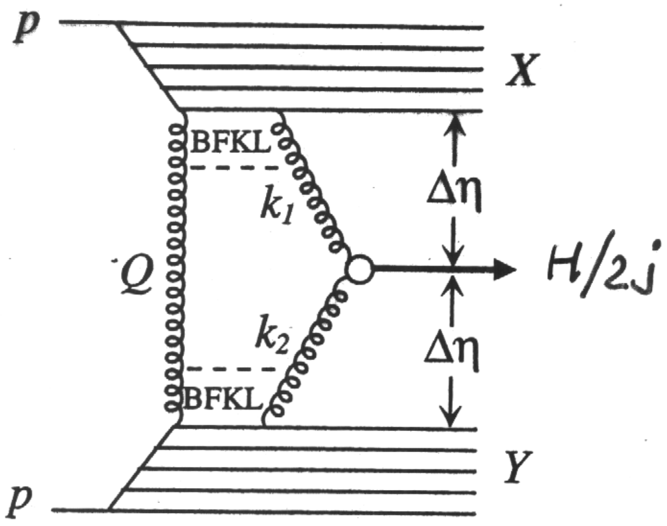
No consensus within the QCD-community:

$$\frac{\sigma_{RG}(gg\to H)}{\sigma_{incl}(gg\to H)} \propto 10^{-1} - 10^{-12} \qquad \left(\underset{BL}{10^{-1}} \sim \underset{KMR}{10^{-4}}\right)$$

(a) Exclusive production

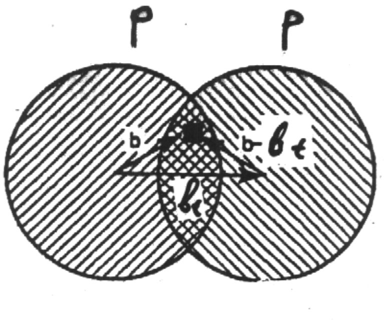


(b) Inclusive production



RG – very **promising**, but quite a **fragile** tool

May be easily filled by secondaries from:



Convolution of parton densities in impact plane.

- Rescattering of spectator partons caused by the transverse overlap of the two incoming protons

$$S^2 = \frac{\int |M(s, b_t)|^2 e^{-\Omega(b_t)} d^2 b_t}{\int |M(s, b_t)|^2 d^2 b_t}$$

$\Omega(b_t)$ – 'optical density' of the interaction

Model dependence – the "Achilles heel"

Depend on : the nature of the colour-singlet exchange, spatial distribution of partons inside the proton, type of the process (SD, DD, CD)

First in the Higgs context:

Yu. Dokshitzer, V. Khoze, T. Sjöstrand – 1992

Bj – 1992 – SURVIVAL probability

- 'eikonal approach'

E. Gotsman, E. Levin, U. Maor 1995–2000
KMR – 1997–2001 – peaceful coexistence

- 'MC-approach'

OFTEN OVERLOOKED

(I)

(single-channel) traditional eikonal

$$\Omega(b_t) = \frac{\sigma_{pp}(s)}{4\pi B_P} e^{-b_t^2/4B_P}$$

- QCD-radiation induced by the 'active partons'

RECOGNIZED

Sudakov suppression phenomena — T^2

- QCD-radiation off the t-channel 'dipoles' ($\mathbb{P}$ - colour singlet digluon)

PRACTICALLY ALWAYS NEGLECTED

Symbolically

$$W = S^2 T^2$$

PROBABILITY for the RG's to survive in the hostile QCD-environtment

- HIGH price to pay for the RADIATION DAMAGES

3 major differences in theoretical approaches

- The specification of the exchanged gluons (BL - non-perturbative, KMR - perturbative)
- The value of the soft survival factor S^2 (BL $\simeq 1$, $KMR_{-LHC} \simeq 0.02$)
- The 'bremsstrahlung fee' - T^2.

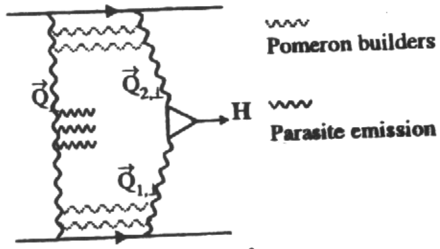
"Yesterday's orthodoxy is today's heresy"

B. Moore

REVIVAL
"conversion"

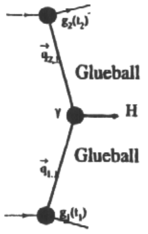
[Double Pomeron Higgs production is a "soft" process !!!

E. M. Levin (hep-ph/9912403)



D. Kharzeev, E. Levin (hep-ph/0005311)

use of QCD scale anomaly



belief, that there is

$$M(q+q \to q+H+q) \propto \int \frac{d^2Q_\perp}{Q_\perp^4}.$$

(2 dipoles $R_d^2 \sim 1/Q_\perp^2$)

an infrared divergence which is regularized by the size of the colliding hadrons

- ~ qualitative agreement with KMR on S^2
- clear difference in the gluon specification the bremsstrahlung fee T^2 and the size of the

·Model for soft diffraction

S^2 = Probability that no other interactions occur except the hard collision of interest (H-production)

Model description of soft diffraction in high energy pp (or $p\bar{p}$) collisions which embodies :

(i) *pion-loop* insertions in the bare Pomeron pole, which represent the nearest singularity generated by t-channel unitarity,

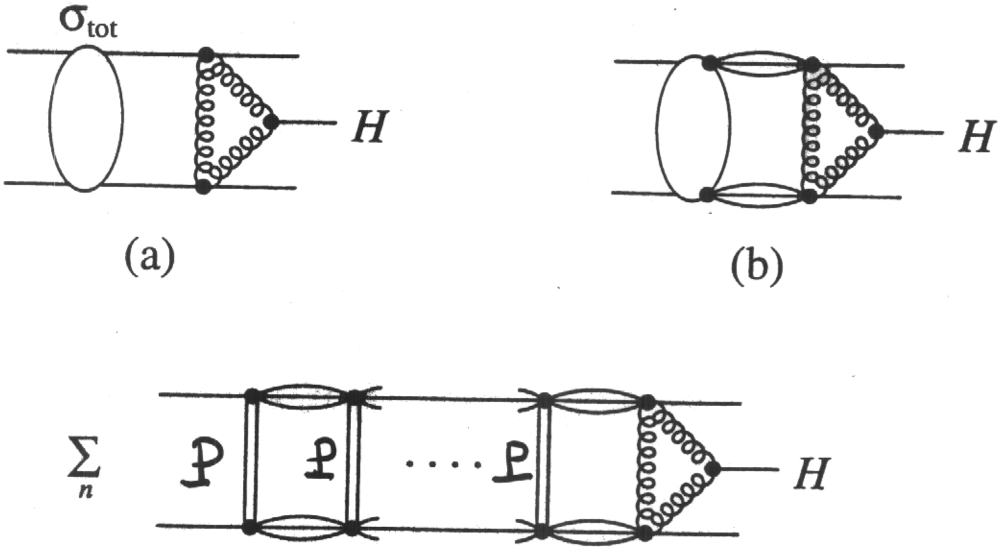
(ii) a *two-channel eikonal* which incorporates the Pomeron cuts generated by elastic and quasi-elastic (with N^* intermediate states) s-channel unitarity, $(1 \pm \gamma)$

(iii) high-mass *diffractive dissociation*.

$\gamma, \sigma_{pp}, B_{\mathbb{P}}, \Delta, \alpha'_{\mathbb{P}}$ – tuned to describe $pp/p\bar{p}$ data ISR-Tevatron

Classic (but unfortunately low priority) minimum-bias physics

bj
FAD
FELIX



(a) (b)

(c) two-channel eikonal representation

Diagram (a) illustrates the absorptive correction to exclusive Higgs production, assuming that only elastic pp rescattering occurs, with an amplitude $\mathrm{Im}A = s\sigma_{\mathrm{tot}}$. Diagram (b) includes both elastic and inelastic intermediate states. Diagram (c) is an eikonal representation of (b), where the double line denotes Pomeron exchange.

For $(\mathbb{P}\mathbb{P} \to H)_{excl}$, $S^2_{Tevatron} = 0.05$

$S^2_{LHC} = 0.02$

$$1 \simeq S^2(\gamma\gamma \to H) > S^2(WW \to H) > S^2(\mathbb{P}\mathbb{P} \to H)$$

0.15 (0.25) 0.02

A.B. Kaidalov + KMR (in progress)

A FREQUENT DILUSION:

- NO "charge" transfer ≠ NO accompanying radiation

$R_{hadr} \gg \frac{1}{Q_\perp}$ - characteristic $\perp_{gg}$ size at which the colour charge flow is screened (colour dipole radiation)

- a probability of radiation with

$$\frac{1}{Q_\perp} > \lambda \gtrsim \frac{1}{M_H}$$

... forcing two camels to go through the eye of a needle ..

To DLA

$$T(Q_\perp^2, M_H^2) = \exp\left(-\int_{Q_\perp^2}^{M_H^2/4} \frac{C_A \alpha_s(p_\perp^2)}{\pi} \frac{dE}{E} \frac{dp_\perp^2}{p_\perp^2}\right) =$$

$$= \exp\left(-\tilde{S}(Q_\perp^2, M_H^2)\right)$$

$$\left(\text{to SLA} \quad T(Q_\perp^2, \mu^2) = \frac{\alpha_s(Q_\perp^2)}{\alpha_s(\mu^2)} e^{-S}\right)$$

- Double role of the Sudakov-like form factor T

T strongly suppresses the infrared divergence in $M(qq \to q + H + q)$

$$M \sim \int \frac{d^2 Q_\perp}{Q_\perp^4} e^{-\tilde{S}}$$

(additional suppressi[on] $(Q_T^2)^\gamma$

a bit of formalism

to SL accuracy

$$M(pp \to p + H + p) = A\pi^3 \int \frac{dQ_T^2}{Q_T^4} f_g(x_1, x_1', Q_T^2, M_H^2/4) \otimes$$

$$\otimes f_g(x_2, x_2', Q_T^2, M_H^2/4)$$

$$A = (\sqrt{2} G_F)^{1/2} \alpha_s(M_H^2)/3\pi$$

$f_g(x, x', Q_T^2, \frac{M_H^2}{4})$ – skewed unintegrated gluon density

Skewed effect: the screening gluon carries a momentum fraction $x_i' \ll x_i$.

$$f_g(x, x', Q_T^2, M_H^2/4) = R_g \frac{\partial}{\partial \ln Q_T^2} \left[\sqrt{T(Q_T, M_H/2)} \times g(x, Q_T^2) \right]$$

$g(x, Q_T^2)$ – conventional integrated gluon density

$T(Q_T, \mu)$ – the survival probability that the gluon with $x = x'$ remains untouched in the evolution up to the scale μ $(= M_H/2)$

M. Kimber, A.D. Martin, M. Ryskin (1999)

Resumming the virtual contributions in DGLAP

$$T(Q_T, \mu) = \exp\left(- \int_{Q_T^2}^{\mu^2} \frac{\alpha_s(k_t^2)}{2\pi} \frac{dk_t^2}{k_t^2} \int \left[z P_{gg}(z) + \sum_q P_{qg} \right] dz \right).$$

$$T(Q_T,\mu) = \frac{\alpha_s(Q_T^2)}{\alpha_s(\mu^2)} e^{-\tilde{S}}$$

$$\tilde{S}(Q_T^2, M_H^2) = \int_{Q_T^2}^{M_H^2/4} \frac{C_A \alpha_s(P_T^2)}{\pi} \frac{dE}{E} \frac{dP_T^2}{P_T^2}$$

E, P_T – energy, transverse momentum of an emitted gluon

Sudakov form factor – probability not to have bremsstrahlung

Improvements : KMR-200

- inclusion of $\partial T / \partial \ln Q_T^2$

- R_g factor (SL part of the skewed effe

Enhancement of the $pp \to p + H + p$ exclusive ra

($R_g^4 \simeq 2(4)$ at LHC (Tevatron) energies)

Saddle points : $Q_\perp^2 = 3,2\ (1,5)\ GeV^2$ at LHC (Tevatron)

$$pp \to X + gap + H + gap + Y$$

(no form factor limitation → weaker Sudakov suppression)

(BFKL-type) non-forward amplitude

Essentially the DL result

Signal-to-background ratio

(Surprisingly, has never been addressed in the literature) (KMR-2000)

$$S/B_{gg} = (4.3 \cdot 10^{-3})\, Br(H \to b\bar{b}) \left(\frac{M}{100\,\text{GeV}}\right)^3 \left(\frac{250\,\text{MeV}}{\Delta M}\right)$$

$M_H = 120$ GeV, $\quad \frac{S}{B_{gg}} = 5 \cdot 10^{-3} \left(\frac{250\,\text{MeV}}{\Delta M}\right)$ $\theta > 60°$

- Does not depend on the uncertainty in the soft survival factor S^2

- we have to identify the b and $\bar{b}$-jets ($\sim 10^4$)

- May true $b\bar{b}$ background pose a problem?

(H → $b\bar{b}$ signal)/($b\bar{b}$ background) is strongly enhanced

  - Colour factors
  - Polarization structure of DD

$b\bar{b}$ production (Exclusive case only) (~20-30)

($J_z = 0$ selection rule in $\gamma\gamma \to q\bar{q}$, "polarized gluons for free") (Durham group - 1997) BKSO

$M_H = 120$ GeV, $\theta > 60°$

$$S/B_{b\bar{b}} \gtrsim 4 \left(\frac{1\,\text{GeV}}{\Delta M}\right)$$ Exclusive case

! $b\bar{b}$-background should not be a problem.

Is the production rate for RG events large enough?

$M_H = 120$ GeV

$\sigma_H \simeq 0.06\,fb \left(\frac{S^2}{0.05}\right)$ $\sqrt{s} = 2$ TeV

$\sigma_H \simeq 2.2\,fb \left(\frac{S^2}{0.02}\right)$ $\sqrt{s} = 14$ TeV

- Run II of the Tevatron at $\mathcal{L}_{int} = 15\,fb^{-1}$
  $\Rightarrow < 1$ event
  Too high price to be paid for improving $\frac{S}{B_{b\bar{b}}}$

- a real chance to observe DD exclusive Higgs production at the LHC
  $\mathcal{L}_{pp}(LHC) / \mathcal{L}_{p\bar{p}}(\text{Tevatron}) \simeq 40$

- $(\sigma_H)_{incl} = 40\,fb$ $\Delta\eta = 2$ LHC
  $4\,fb$ $\Delta\eta = 3$

- High event rate and the remarkable purity of the di-gluon system in the exclusive DD events $\Rightarrow$ a 'gluon factory'
  pure gluon jets on the level 3000:1 or even better

DRG dijet production as a
pp Luminosity Monitor

$pp \to p + (jj) + p$ (or $p\bar{p}$)

$pp \to X + (jj) + Y$

$pp \to X + Z^0 + Y$ } H. Chehime, D. Zeppenfeld-93

Luminometer for WWH

- Uncertainty due to the lack of knowledge of S^2.

Dijets ($E_T \sim M_H/2$) - Luminometer

- ~the same S^2 factor in the same kinematic region, (T^2 controllable)
  ($gg \to H \Longrightarrow gg \to$ dijet)
  ($WW \to H \Longrightarrow WW \to Z$ —)
- accessible at the Tevatron and the LHC

LHC ($E_T = 50$ GeV, $\delta E_T = 10$ GeV
$\delta(\eta_1 - \eta_2) = 1$, $(\eta_{min}, \eta_{max}) = (2, 4)$)

$d\sigma_{excl}/d\eta|_0 \simeq 40$ pb, $\frac{d\sigma_{incl}}{d\eta}\Big|_0 \simeq 250$ pb

$\otimes S^2/0.1$

Tevatron ($E_T = 30$ GeV)

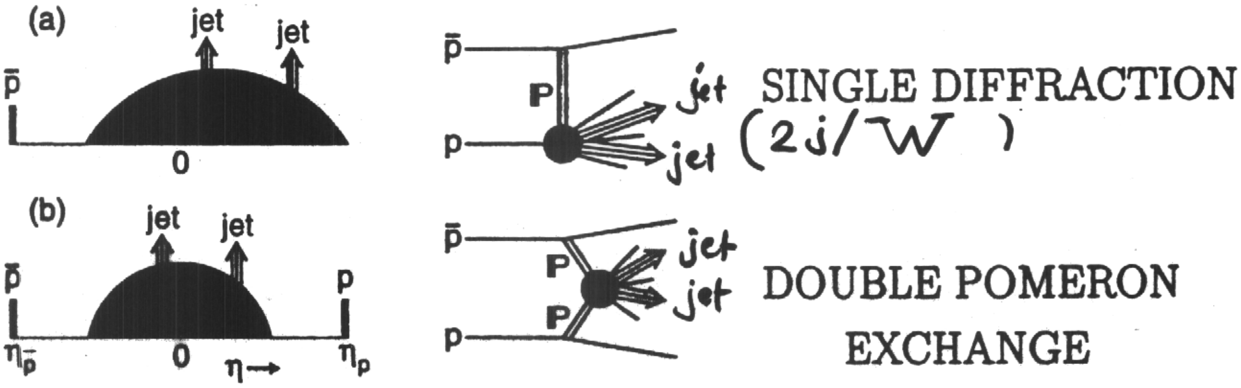
$d\sigma_{excl}/d\eta|_0 \simeq 17$ pb, $\frac{d\sigma_{incl}}{d\eta}\Big|_0 \simeq 150$ pb

Witnesses from CDF Testify ...

CDF-2000

Double Pomeron Exchange

$E_T^j > 7$ GeV



- a search for DD dijet events

$(\sigma_{2j})^{exc}_{RG} < 3.7$ nb (95% c.l.), 10^3 smaller than the 'standard' calculations (A. Bereza)

KMR-2000 $(\sigma_{2j})^{exc}_{RG} \lesssim 1$ nb

Test of Factorization

- Compare the structure function on the proton side in DPE with the structure function of the antiproton in SD. within the CDF data

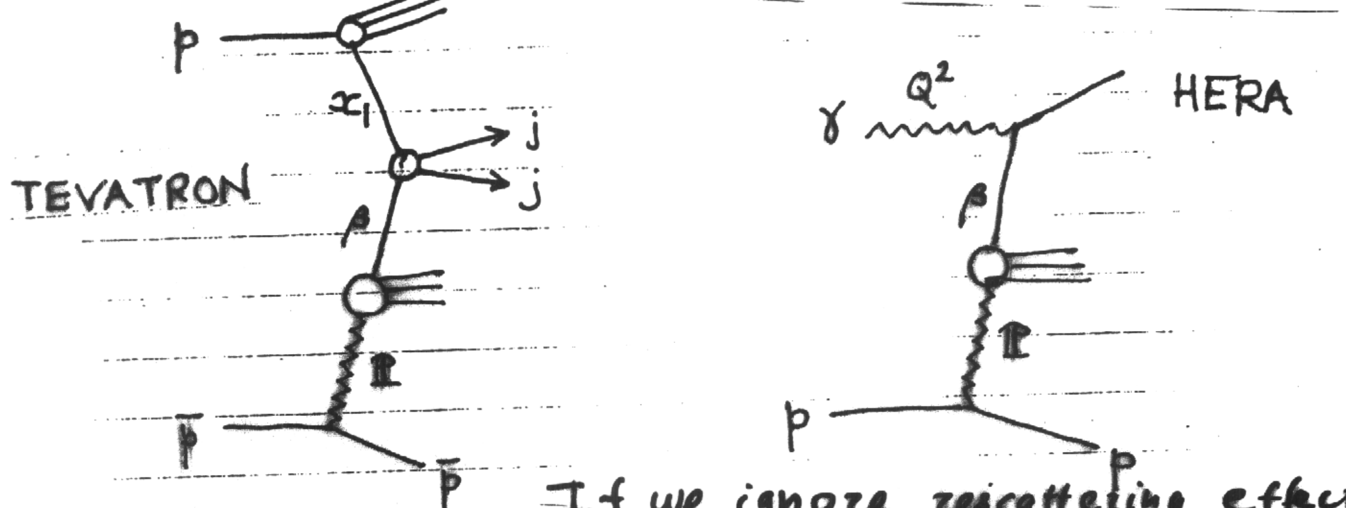
- Compatibility of diffractive dijet production at the Tevatron with Diffractive DIS ep-data at HERA

The 'breakdown' of factorization.

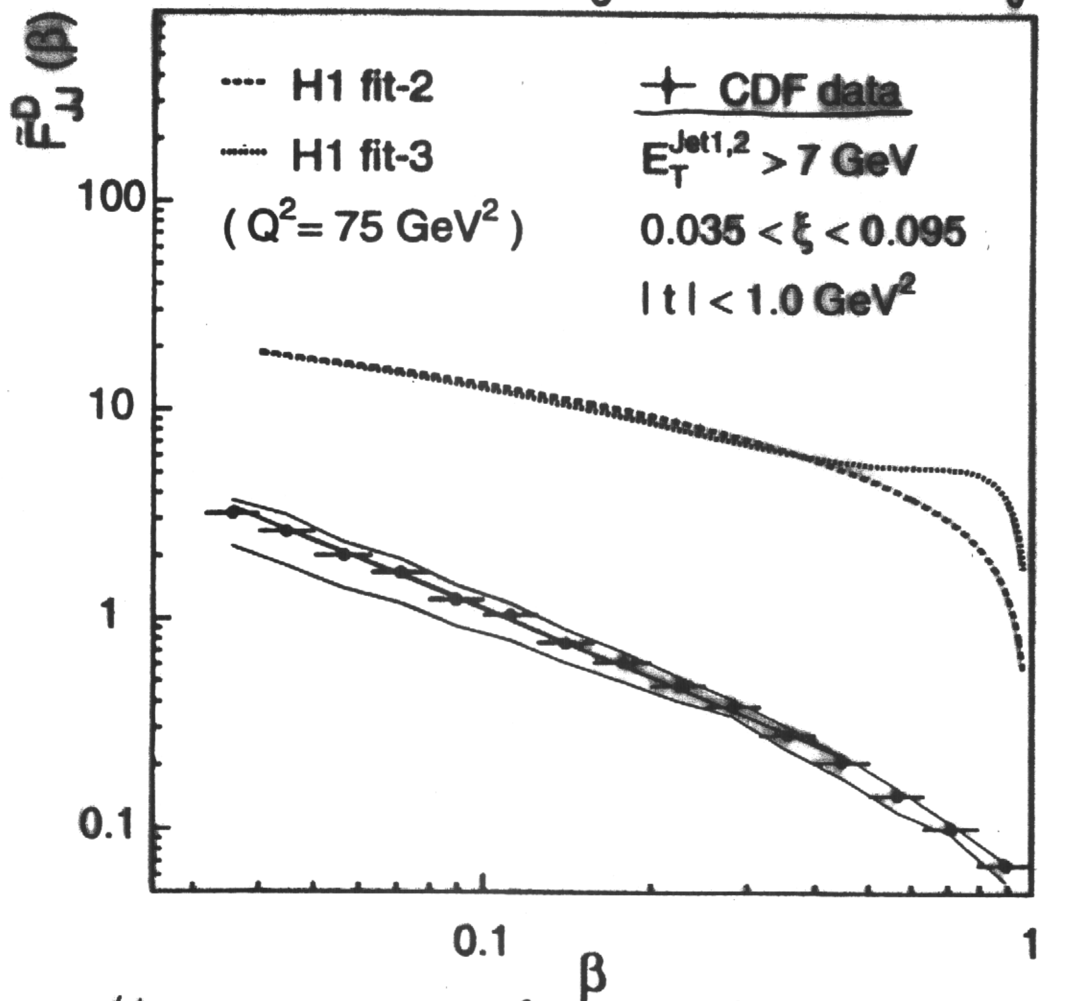
Predictions using parton densities of the Pomeron and of the proton are an order of magnitude larger than the data.

Factorization Test in Hard Diffraction

Compare the structure function measured in diffractive dijet production at the TEVATRON with expectations based on diffractive DIS measurements at HERA



If we ignore rescattering effects



$\beta \equiv x/\xi \Rightarrow$ momentum fraction of parton in Pomeron

$\tilde{F}^D_{jj}$ – the diffractive structure function of the $\bar{p}$

$$\frac{1}{(\xi_{max} - \xi_{min})} \int d\xi \, F_{IP}(\xi) \beta \left[f_g^{IP}(\beta, E_T^2) + 4/9 \, f_q^{IP}(\beta, E_T^2) \right]$$

+ secondary Reggeons

Summary

- Presented improved perturbative results for

$$pp(\bar{p}) \to p + (H \text{ or } jj) + p(\bar{p})$$

$$pp(\bar{p}) \to X + (H \text{ or } jj) + Y$$

$$(+) \equiv RG$$

- Developed a formalism for high energy soft processes, mediated by Pomerons

Description of ISR, $Sp\bar{p}S$, Tevatron data

Predictions for the LHC

- The major uncertainty comes from the soft survival factor
  - the 'Achilles heel' of the calculations

- Double Diffractive dijet production as
  - a Pomeron-Pomeron Luminometer
  - a unique gluon factory

- Remarkable agreement of the KKMR predictions with the CDF dijet data.

A clear evidence in favour of the low survival probability of the RG

(DD of large E_T-jets separated by RG).

The work continues... and so does the excitement!