Diffraction at the LHC: a theoretical review

Soft diffraction

Predictions for
$$\sigma_{\text{tot}}, \frac{d\sigma_{\text{el}}}{dt}, \frac{d\sigma_{\text{SD}}}{dt dM^2} (pp \to pX) , \dots$$

Hard diffraction

especially $pp \rightarrow p + A + p$ with $A = H(bb_{bar})$



Alan Martin (Durham), Physics at the LHC, Split, Sept-October 2008



diagonal in b $SS^{\dagger} = I$ with $S = I + iT \rightarrow T - T^{\dagger} = iT^{\dagger}T$ elastic unitarity \rightarrow 2 Im $T_{el}(s,b) = |T_{el}(s,b)|^2 + G_{inel}(s,b)$ $\begin{cases} \frac{d^2 6 \text{tot}}{d^2 b} = 2 \text{ Im } T_{el} = 2 \left(1 - e^{-\Omega/2} \right) \\ \frac{d 6}{d^2 b} = \left| T_{el} \right|^2 = \left(1 - e^{-\Omega/2} \right)^2 \\ \frac{d 6}{d^2 b} = 2 \text{ Im } T_{el} - \left| T_{el} \right|^2 = 1 - \left(e^{-\Omega/2} \right)^2 \end{cases}$ Opacity/Eikonal _2(5,b) > 0 e.g. black disc $T_{el} = 1$, b < R $\int G_{tot} = 2\pi R^2$ $T_{el} = 1$, b < R $\int G_{el} = G_{inel} = \pi R^2$ $S_{el}^2 = e^{-\Omega}$ is the probability of no inelastic interaction



Elastic amp.
$$T_{el}(s,b)$$
bare amp. $\Omega =$ $T_{el} = \int_{\infty} = 1 - e^{-\Omega/2} = \sum_{n=1}^{\infty} \qquad (20\%)$ Low-mass diffractive dissociation p^* introduce diff^{ve} estates ϕ_i , ϕ_k (comb^{ns} of p,p*,..) which only
undergo "elastic" scattering (Good-Walker)

$$T_{ik} = \prod_{k=1}^{i} = 1 - e^{-\Omega_{ik}/2} = \sum \prod_{k=1}^{i} \dots \Omega_{ik}$$
(40%)
(SD 80%)

include high-mass diffractive dissociation

$$\Omega_{ik} = \prod_{k=1}^{i} + \underbrace{\bigvee}_{k=1}^{i} M$$

triple-Regge analysis of $d\sigma/dtd\xi$, including screening

(includes compilation of SD data by Goulianos and Montanha)



New analysis of soft data

$$\sigma_{\rm tot}, \ \frac{d\sigma_{\rm el}}{dt}, \ \sigma_{\rm SD}(\text{low } M), \ \frac{d\sigma_{\rm SD}}{dt dM^2}$$

model:

 \bigcirc

 3-channel eikonal, ϕ_i with i=1,3



KMR

attempt to mimic BFKL diffusion in \bigcirc log q_t by including three components to approximate q_t distribution – possibility of seeing "soft \rightarrow hard" Pomeron transition



Parameters

multi-Pomeron coupling λ from $\xi d\sigma_{SD}/d\xi dt$ data ($\xi \sim 0.01$)

diffractive eigenstates from $\sigma_{SD}(\text{low M})$ –2mb at sqrt(s)–31 GeV, -- equi-spread in R², and t dep. from $d\sigma_{el}/dt$

Results All soft data well described $g_{3P}=\lambda g_N$ with $\lambda=0.25$ (compared to $\lambda=0.2$ in Luna et al.)

 $\Delta_{Pi} = 0.3$ (close to the BFKL NLL resummed value) $\alpha'_{P1} = 0.05 \text{ GeV}^{-2}$

These values of the bare Pomeron trajectory yield, after screening, the expected soft Pomeron behaviour ----"soft-hard" matching (since P₁ heavily screened,....P₃~bare)

 $\Delta_{R} = -0.4$ (as expected for secondary Reggeon) $\Delta = \alpha(0) - 1$

KMR 3-ch eikonal, multi-Regge analysis of available "soft" data









HERA finds that about 10% of these events are





$$Q^{2} \qquad \qquad DIS \quad F_{2}(x, Q^{2}) = \sum_{i=q,\bar{q},g} f_{i} \otimes C_{2,i}$$

$$x = \beta x_{IP} \qquad \qquad Same$$

$$Q^{2} \qquad Diffractive DIS \qquad \qquad Same$$

$$F_{2}^{D(3)}(x_{IP}, \beta, Q^{2}) = \sum_{i} f_{i}^{D} \otimes C_{2,i}$$

$$If \text{ then assume, Regge factorization:} \qquad x = \beta x_{IP}$$

$$f_{i}^{D}(x_{IP}, \beta, Q^{2}) = Flux(x_{IP}) f_{i}^{IP}(\beta, Q^{2}) \qquad x_{IP}$$



diffractive partons g^D, q^D can be used to predict diffractive processes with hard scale? Yes, but...





Advantages of $pp \rightarrow p + (H \rightarrow bb) + p$

- accurate determination of M_H using tagged protons, M_H=M_{missing}
- -- $M_H = M_{decay}$ must match $M_H = M_{missing}$



- -- bb_{bar} QCD background suppressed by J_z =0 selection rule
- -- can determine J^{PC}. Selection rule favours 0⁺⁺ production
- -- S/B ~ O(1) for SM 120 GeV Higgs (...but σ ~ few fb)
- -- $\sigma \ge 10$ for some SUSY Higgs scenarios e.g. $M_A > 140$ GeV: then $h \rightarrow h_{SM}$ H, A decouple from gauge bosons H, A \rightarrow bb_{bar}, $\tau\tau$ enhanced by tan β

Kaidalov+KMR Heinemeyer,Khoze et al Cox,Loebinger,Pilkington Survival Probability of gaps for pp \rightarrow p + H +p



 $\overline{S^2} \sim 0.02$ for 120 GeV Higgs at the LHC

bb_{bar} background to $pp \rightarrow p + (H \rightarrow bb_{bar}) + p$ signal

- -- irreducible QCD $gg^{PP} \rightarrow bb_{bar}$ events
- -- gluons mimicing b jets
- -- $J_z=2$ contribution

New results: NLO calculation of $gg^{PP} \rightarrow bb_{bar}$ reduces irreducible background by factor of 2 or more

Shuvaev et al

Also, experimentally, there has been a reduction in the chance that gluons mimic b jets.

Experimental checks of calculation of $\sigma(pp \rightarrow p + A + p)$

KMR cross section predictions are consistent with the recent observed rates of three exclusive processes at the Tevatron: CDF

$$pp_{bar} \rightarrow p + \gamma \gamma + p_{bar}$$

$$pp_{bar} \rightarrow p + dijet + p_{bar}$$

$$pp_{bar} \rightarrow p + \chi_{c} + p_{bar} \qquad (68 \quad \chi_{c}^{0} \rightarrow J/\psi + \gamma \text{ events})$$

Early LHC runs can give detailed checks of all of the ingredients of the calculation of $\sigma(pp \rightarrow p + A + p)$, even without proton taggers





Bank (1978) Fact HillS Bank (pr. DATA 106 per USLE), 9, 233 Perc USLE 2



3 events observed (one due to $\pi^0 \rightarrow \gamma \gamma$)

 $\sigma(\text{excl }\gamma\gamma)_{\text{measured}} \sim 0.09 \text{pb}$

 $\sigma(\text{excl }\gamma\gamma)_{\text{predicted}} \sim 0.04\text{pb}$



for E_T^{γ} >14 GeV at LHC





S²_{en} = gap survival to rescattering on intermediate partons

There is controversy about its size.

Evidence is that $S^2_{en} \sim 1$ for pp \rightarrow p + H + p

-- explicit calc. using soft model



- -- kinematic suppression, need $\Delta y > 2.3$ to establish Pomeron exchange
- -- HERA leading neutron data, no energy dep. in n yield
- -- after including S^2_{eik} we are left with b > 0.6 fm, where $Q^2_{saturation} < 0.3 \text{ GeV}^2$ (Watt et al), so $S^2_{en} \sim 1$

Early LHC probe of $S^{2}_{en} \rightarrow$



Possibility for LHC to probe S²_{enhanced}



rough estimates of enhanced absorption S²_{en}

Exclusive Y production as probe of odderon and f_g



Conclusions – soft diffraction

-- screening/unitarity/absorptive corrections are vital -- Triple-Regge analysis with screening \rightarrow g_{3P} increased by ~3 \rightarrow importance of multi-Pomeron diagrams -- Latest analysis of all available "soft" data: multi-ch eikonal + multi-Regge + compts of Pom. to mimic BFKL (showed some LHC predictions $\sigma_{total} \sim 90$ mb) soft-hard Pomeron transition emerges "soft" compt. --- heavily screened --- little growth with s "intermediate" compt. --- some screening "hard" compt. --- little screening --- large growth (~pQCD) -- LHC can explore multigap events \rightarrow probe multi-Pomeron

structure



LHC is a powerful probe of models of soft processes

Conclusions – hard diffraction

soft analysis allows rapidity gap survival factors to be calculated for any hard diffractive process

Exclusive central diffractive production, $pp \rightarrow p+H+p$, at LHC has great advantages, S/B~O(1), but σ ~ few fb for SM Higgs. However, some SUSY-Higgs have signal enhanced by 10 or more. **Very exciting possibility, if proton taggers installed at 420 m**

Formalism consistent with CDF data for $pp(bar) \rightarrow p + A + p(bar)$ with A = dijet and A = $\gamma\gamma$ and A = χ_c More checks with higher M_A valuable.

Processes which can probe all features of the formalism used to calculate $\sigma(pp \rightarrow p+A+p)$, may be observed in the early LHC runs, even without proton taggers