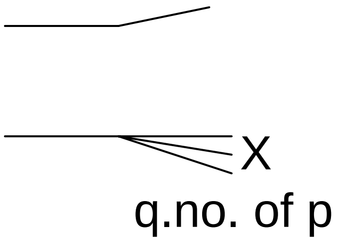
No unique definition of diffraction

1. Diffraction is elastic (or quasi-elastic) scattering caused, via s-channel unitarity, by the absorption of components of the wave functions of the incoming particles

   e.g. pp→pp,

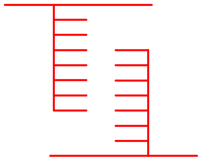
   pp→pX (single proton dissociation, SD),

   pp→XX (both protons dissociate, DD)



Good for quasi-elastic proc.

– but not high-mass dissoc^{n}



2. A diffractive process is characterized by a large rapidity gap (LRG), which is caused by t-channel Pomeron exch. (or, to be more precise, by the exchange corresponding to the rightmost singularity in the complex angular momentum plane with vacuum quantum numbers).

Only good for very LRG events – otherwise Reggeon/fluctuation contaminations

Why study diffraction ?

Intrinsic interest. The LHC should reach, for the first time, sufficiently HE to distinguish between the different theoretical asymptotic scenarios for HE interactions.

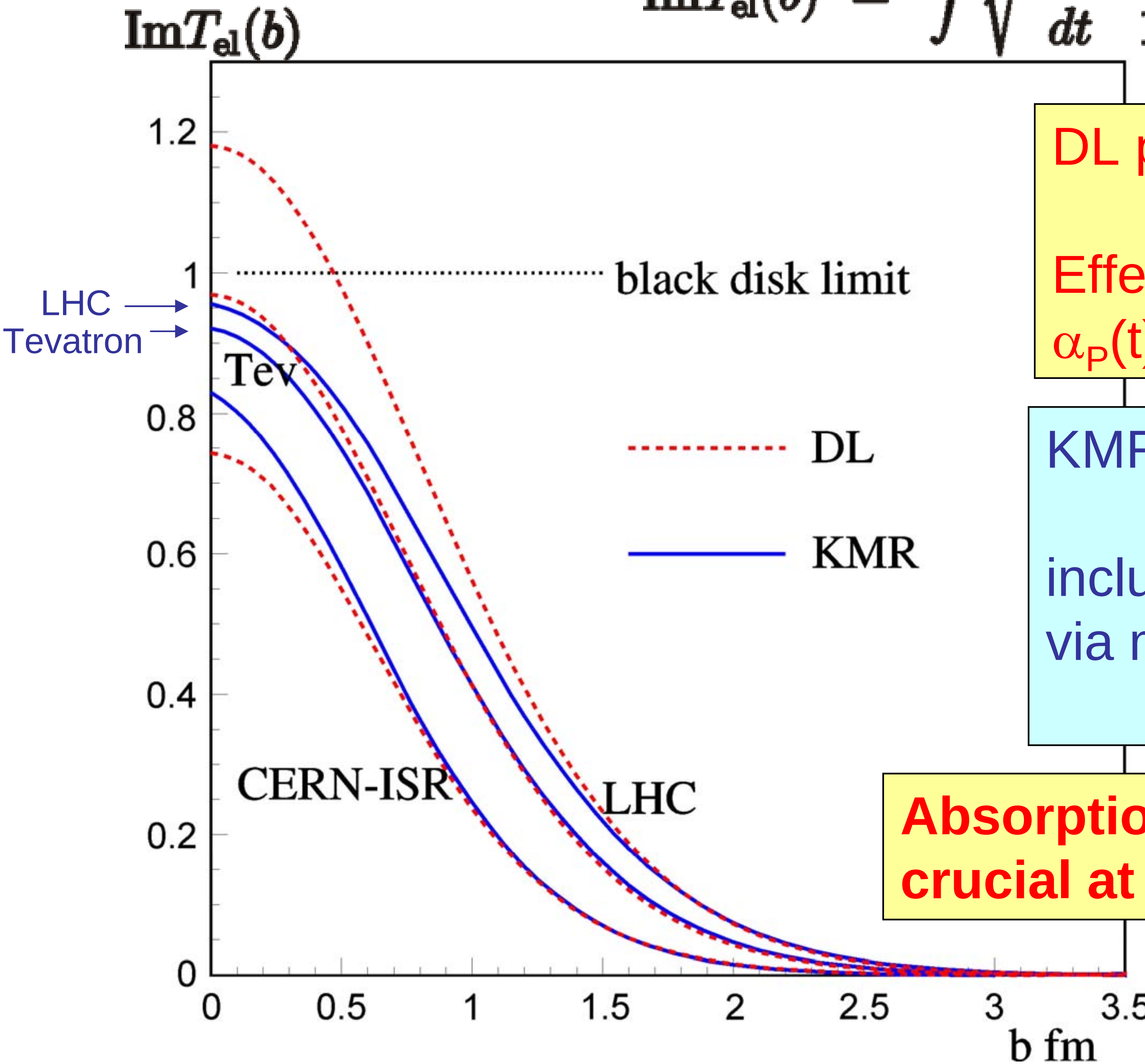
In HE pp collisions about 40% of σ_{tot} comes from diffractive processes, like elastic scatt., SD, DD. Need to study diffraction to understand the structure of σ_{tot} and the nature of the underlying events which accompany the sought-after rare hard subprocesses. (Note LHC detectors do not have 4π geometry and do not cover the whole rapidity interval. So minimum-bias events account for only part of total $\sigma_{inelastic}$.)

Study needed to estimate the survival probabilities of LRG to soft rescattering.
Recall “hard” exclusive diffractive processes (e.g., pp $\rightarrow$ p + Higgs + p) are an excellent means of suppressing the background for New Physics signals

Needed so as to understand the structure of HE cosmic ray phenomena (e.g. Auger experiment).

Finally, the hope is that a study of diffraction may allow the construction of a MC which merges “soft” and “hard” HE hadron interactions in a reliable and consistent way.

$$\mathrm{Im}T_{\mathrm{el}}(b) = \int \sqrt{\frac{d\sigma_{\mathrm{el}}}{dt}\,\frac{16\pi}{1+\rho^2}}\; J_0(qb)\,\frac{q\,dq}{2\pi}$$



DL parametrization:

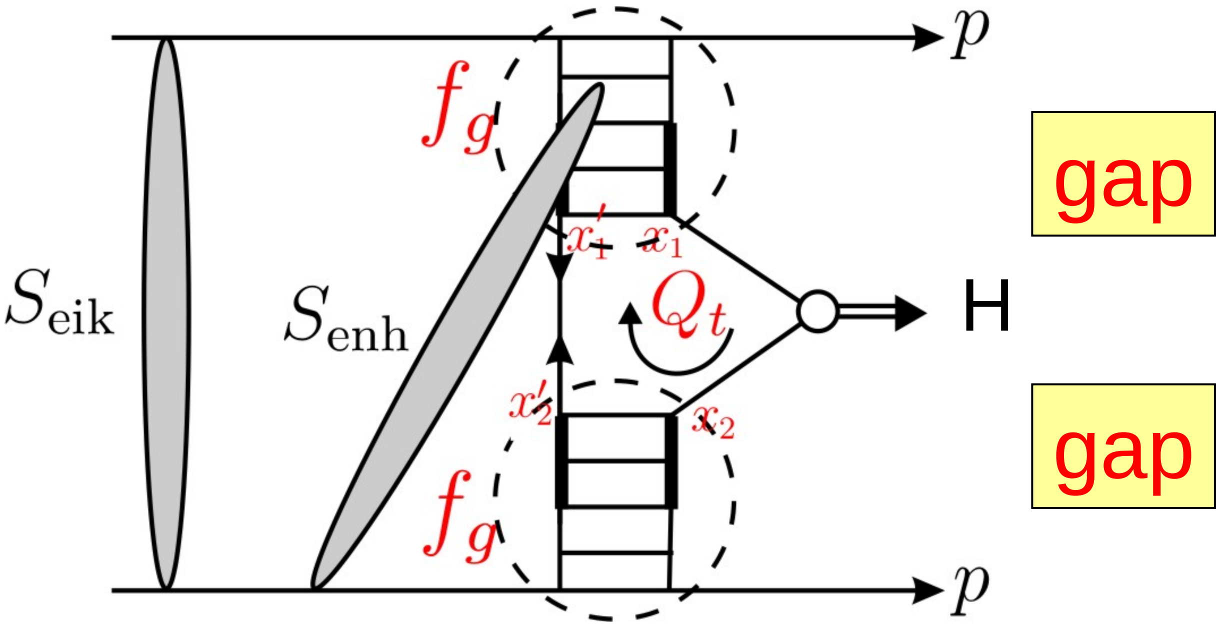
Effective Pom. pole
$\alpha_P(t) = 1.08+0.25t$

KMR parametrization

includes absorption
via multi-Pomeron
effects

Absorption/ s-ch unitarity crucial at small b at LHC

… “soft” scatt. can easily destroy the gaps



soft-hard factoriz^n

eikonal rescatt: between protons ← conserved

enhanced rescatt: involving intermediate partons ← broken

→ need a model for soft physics at HE, see later..

Recall the 2nd definition of diffraction

Diffraction is any process caused by Pomeron exchange.

(Old convention was any event with LRG of size $\delta\eta>3$, since Pomeron exchange gives the major contribution)

However LRG in the distribution of secondaries can also arise from

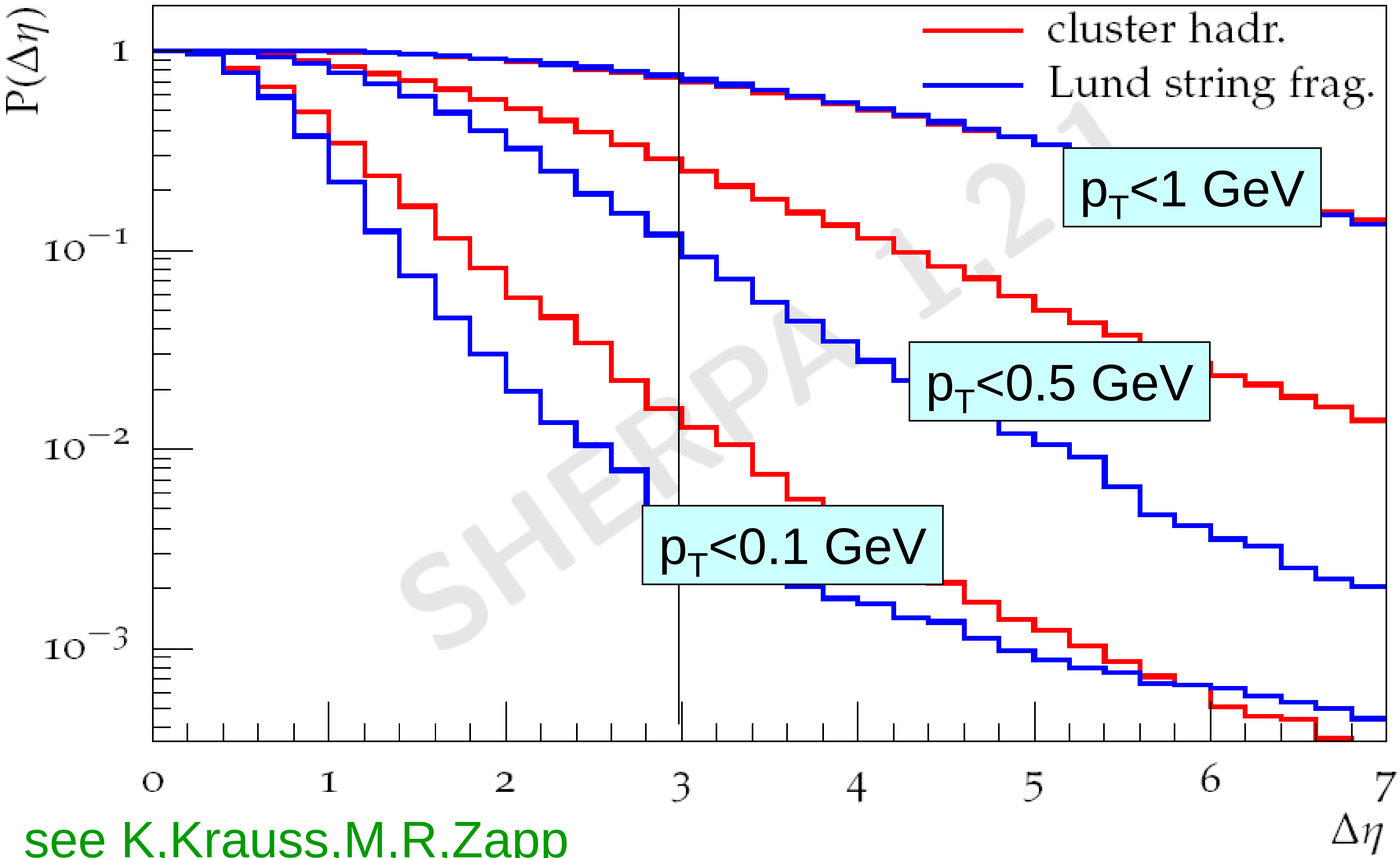
(a) Reggeon exchange

(b) fluctuations during the hadronization process

Indeed, at LHC energies LRG of size $\delta\eta>3$ do not unambiguously select diffractive events.

Prob. of finding gap larger than $\Delta\eta$ in inclusive event at 7 TeV due to fluctuations in hadronization

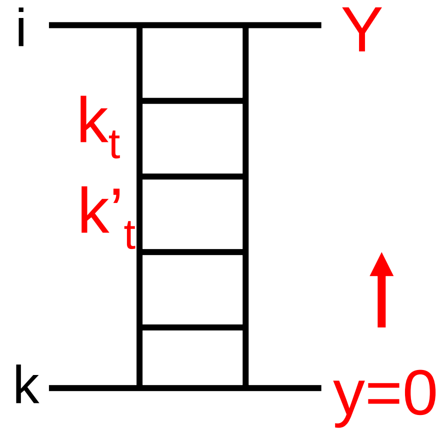
gap anywhere in $-5 < \eta < 5$, different threshold p_T



see K,Krauss,M,R,Zapp

Partonic structure of "bare" Pomeron

$$\Omega = \Omega_{ik}(y, k_t, b)$$



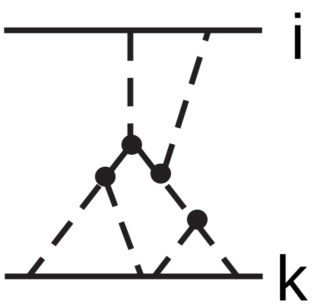
BFKL evol^n in rapidity generates ladder

$$\frac{\partial \Omega(y, k_t)}{\partial y} = \bar{\alpha}_s \int d^2 k'_t \; K(k_t, k'_t) \; \Omega(y, k'_t)$$

- At each step k_t and b of parton can be be changed – so, in principle, we have 3-variable integro-diff. eq. to solve
- **Inclusion of k_t crucial to match soft and hard domains. Moreover, embodies less screening for larger k_t comp^{ts}.**
- We use a simplified form of the kernel K with the main features of BFKL – diffusion in log k_t^2, $\Delta = \alpha_P(0) - 1 \sim 0.3$
- b dependence during the evolution is prop' to the Pomeron slope α', which is v.small ($\alpha' < 0.05$ GeV^{-2}) -- so ignore. Only b dependence comes from the starting evol^n distrib^n
- Evolution gives → $\Omega = \Omega_{ik}(y, k_t, b)$

Multi-Pomeron contributions

Now include rescatt of intermediate partons with the "beam" i and "target" k

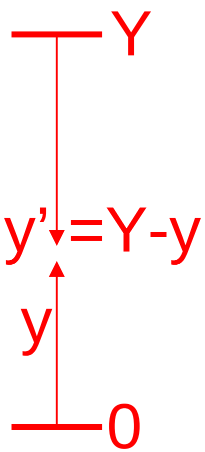


evolve up from y=0

$$\frac{\partial \Omega_k(y)}{\partial y} = \bar{\alpha}_s \int d^2k_t' \, \exp(-\lambda(\Omega_k(y) + \Omega_i(y'))/2) \, K(k_t, k_t') \, \Omega_k(y)$$

evolve down from y'=Y-y=0

$$\frac{\partial \Omega_i(y')}{\partial y'} = \bar{\alpha}_s \int d^2k_t' \, \exp(-\lambda(\Omega_i(y') + \Omega_k(y))/2) \, K(k_t, k_t') \, \Omega_i(y')$$



where $\lambda\Omega_{i,k}$ reflects the different opacity of protons felt by intermediate parton, rather the proton-proton opacity $\Omega_{i,k}$ λ~0.2

solve iteratively for $\Omega_{ik}(y,k_t,b)$ **inclusion of k_t crucial**

Note: data prefer $\exp(-\lambda\Omega)$ → $[1 - \exp(-\lambda\Omega)] / \lambda\Omega$

Form is consistent with generalisation of AGK cutting rules

In principle, knowledge of $\Omega_{ik}(y,k_t,b)$ allows the description of all soft, semi-hard pp high-energy data:

σ_{tot}, $d\sigma_{el}/dt$, $d\sigma_{SD}/dtdM^2$, DD, DPE…

LRG survival factors S^2 (to both eikonal, enhanced rescatt)

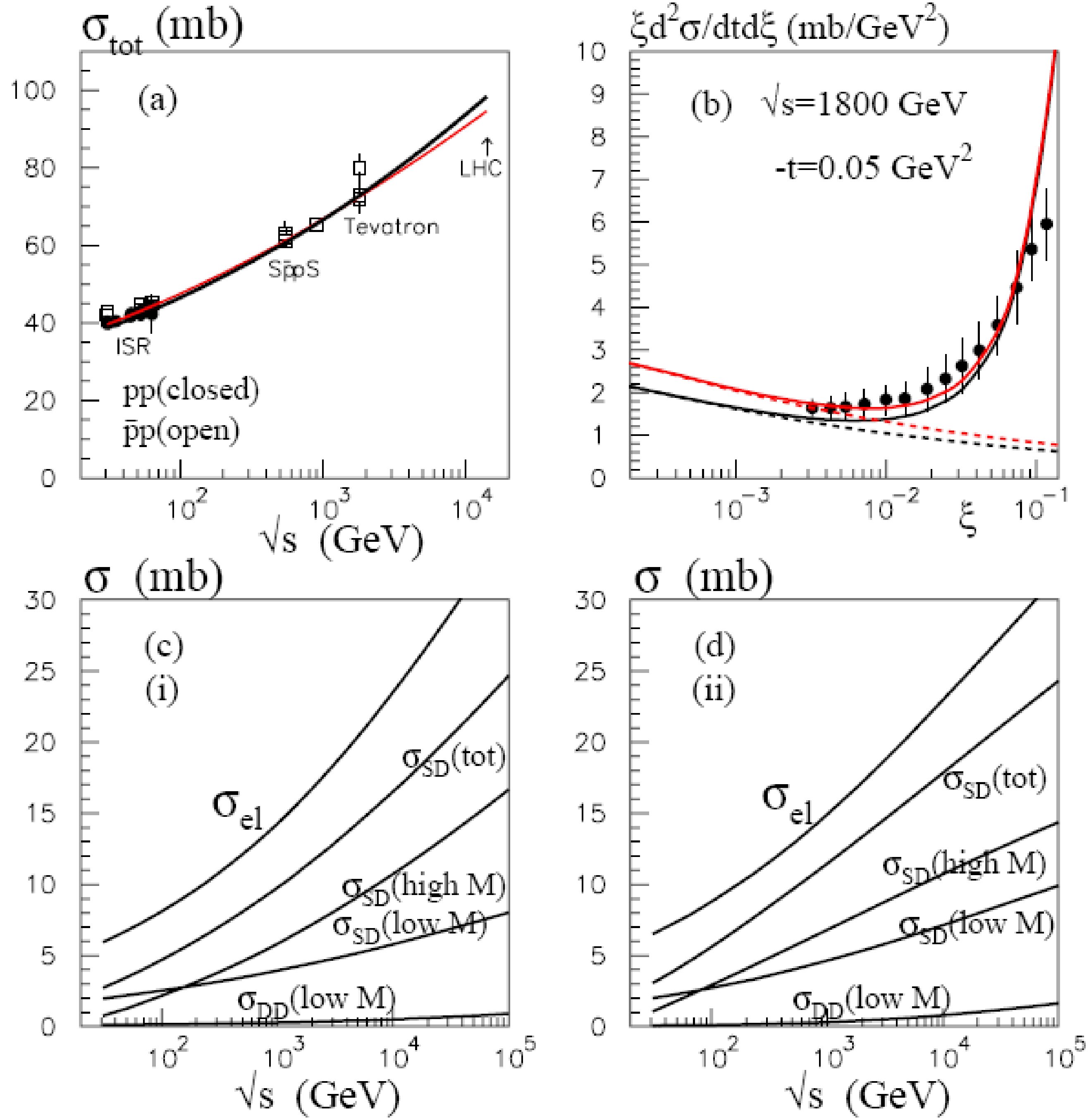
PDFs and diffractive PDFs at low x and low scales

Indeed, such a model can describe the main features of all the data, in a semi-quantitative way, with just a few physically motivated parameters.

energy	σ_{tot}	σ_{el}	$\sigma_{SD}^{\mathrm{low}M}$	$\sigma_{SD}^{\mathrm{high}M}$	$\sigma_{SD}^{\mathrm{tot}}$	$\sigma_{DD}^{\mathrm{low}M}$
1.8	72.8/72.5	16.3/16.8	4.4/5.2	8.3/11.1	12.7/16.3	0.8/1.7
7	89.0/86.8	21.9/21.6	5.5/6.7	12.0/14.4	17.5/21.1	1.4/2.8
14	98.3/94.6	25.1/24.2	6.1/7.5	14.0/15.9	20.1/23.4	1.8/3.6
100	127.1/117.4	35.2/31.8	8.0/9.9	20.6/20.0	28.6/29.9	3.4/6.2

$d\sigma/dy \sim s^{0.2}$ like the LHC data for 0.9 to 7 TeV

$S^2 = 0.010\text{-}0.016$ for gaps in pp → p + H + p (120GeV SM Higgs at 14TeV)



σ_tot (mb)
(a)
LHC
Tevotron
SppS
ISR
pp(closed)
p̄p(open)
√s (GeV)
ξd²σ/dtdξ (mb/GeV²)
(b) √s=1800 GeV
-t=0.05 GeV²
ξ
σ (mb)
(c)
(i)
σ_el
σ_SD(tot)
σ_SD(high M)
σ_SD(low M)
σ_DD(low M)
√s (GeV)
σ (mb)
(d)
(ii)
σ_el
σ_SD(tot)
σ_SD(high M)
σ_SD(low M)
σ_DD(low M)
√s (GeV)

Conclusions

- s-ch unitarity is important for quasi-elastic scatt or LRG events

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- Multi-Pomeron exchange diagrams restore unitarity:
  (i) eikonal pp rescatt. (ii) enhanced with intermediate partons

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- Altho' g_{3P}~$0.2g_N$, high-mass p dissoc^n is enhanced at the LHC

- Unitarity is restored for LRG by small survival prob. S^2 of gaps
  e.g. S^2 ~ 0.015 for pp → p + H + p (M_H=120 GeV at 14 TeV)

- LRG also from fluct^{ns} in had^n: study different p_T cuts and Δy
  also study long-range rapidity correlations at the LHC

- QCD/BFKL Pom. → Pomeron describing soft physics

- Partonic struct. of Pom, with multi-Pom contrib^{ns} can describe
  all soft ($\sigma_{tot,el,SD}$..) and semihard (PDFs, minijets..) physics-KMR

- Forms the basis of "all purpose" MC - Krauss, Hoeth, Zapp