Model to merge ‘soft’ and ‘hard’ HE hadron interactions

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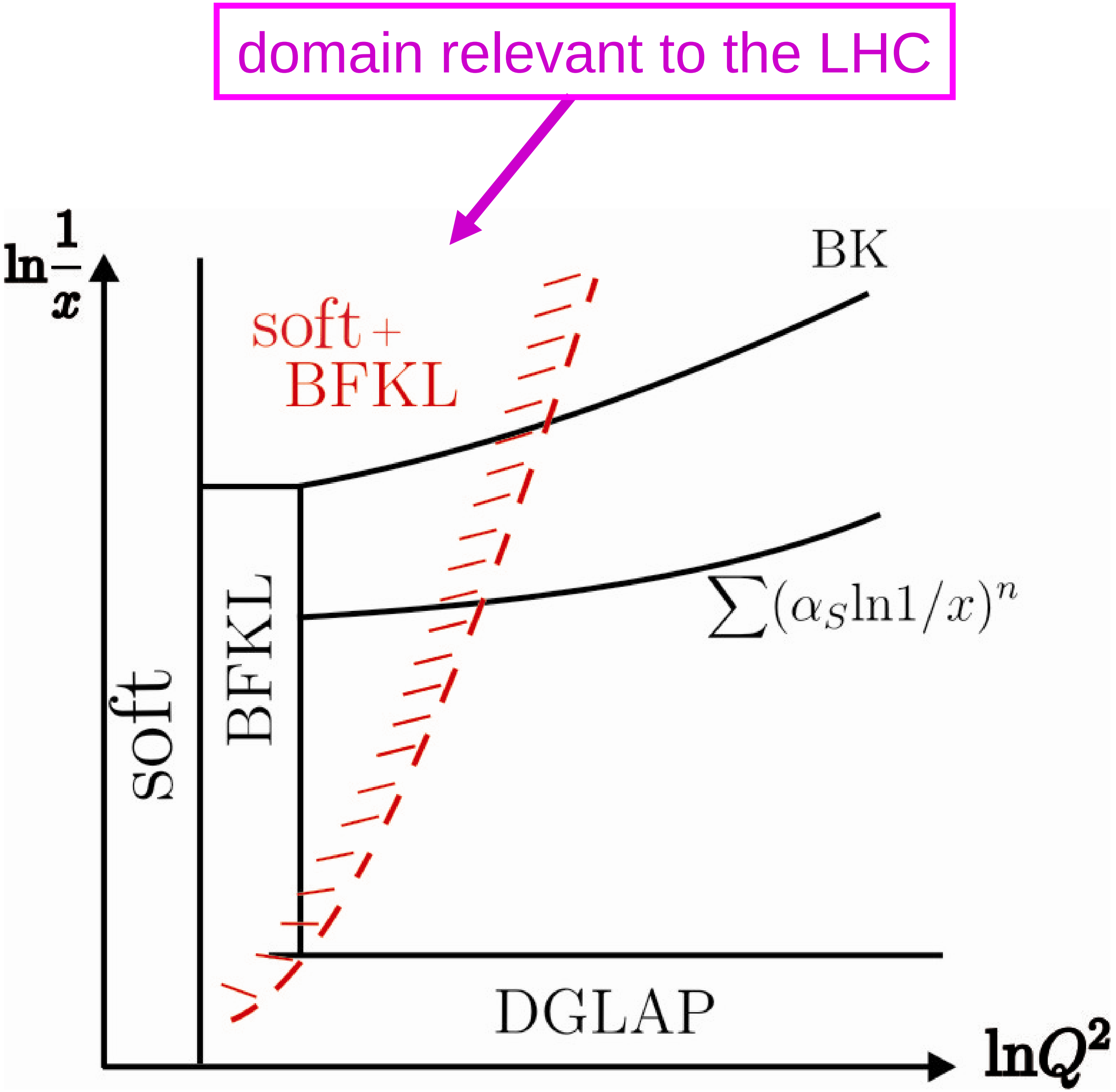
- Up to now no complete model (Monte Carlo) including all facets
  --- elastic scattering, diffractive events, hard jets, etc. ---
  on the same footing. Important for the LHC
- We seek a model that not only describes pure soft HE low k_t data, (via Pomeron exchange and Reggeon FT), but which also extends into the large k_t pQCD domain
- To do this we need to introduce the partonic structure of the Pomeron:
  “soft” → “hard” Pomeron


domain relevant to the LHC
$\ln\frac{1}{x}$
soft
BFKL
soft + BFKL
BK
$\sum(\alpha_S \ln 1/x)^n$
DGLAP
$\ln Q^2$

Model for “soft” high-energy interactions

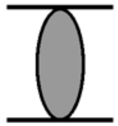
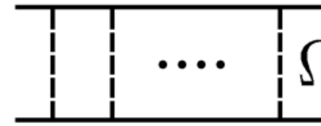
needed to ---- understand asymptotics, intrinsic interest
---- describe “min. bias/underlying” events
---- calc. rap.gap survival prob. S^2 for diff. processes
---- devise “all-purpose” Monte Carlo

Model should:

1. be self-consistent theoretically --- satisfy unitarity
   → importance of absorptive corrections
   → importance of multi-Pomeron interactions
2. agree with available soft data CERN-ISR to Tevatron range $\sigma_{\rm tot}, \ \frac{d\sigma_{\rm el}}{dt}, \ \frac{d\sigma_{\rm SD}}{dt dM^2}(pp \to pX)$
3. include b dependence of the Pomeron to study effects of absorption
4. be suitable for “all-purpose” MC --- partonic approach

Elastic amp. $T_{el}(s,b)$

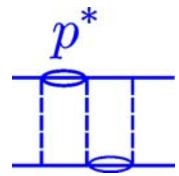
bare amp. $\Omega =$ 

Im $T_{el} =$  $= 1 - e^{-\Omega/2} = \sum_{n=1}^{\infty}$  Ω

(s-ch unitarity)

(-20%)

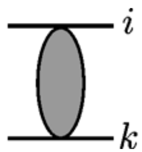
Low-mass diffractive dissociation

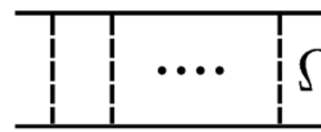


→multichannel eikonal

introduce diff^ve estates ϕ_i, ϕ_k (comb^ns of p,p*,..) which only undergo "elastic" scattering (Good-Walker)

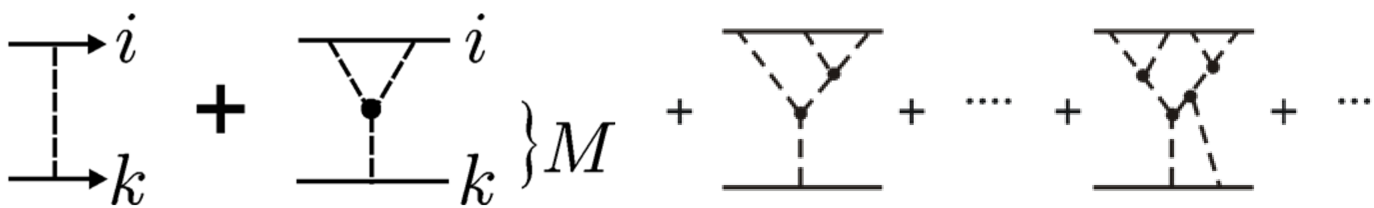
(-40%)

Im $T_{ik} =$ 

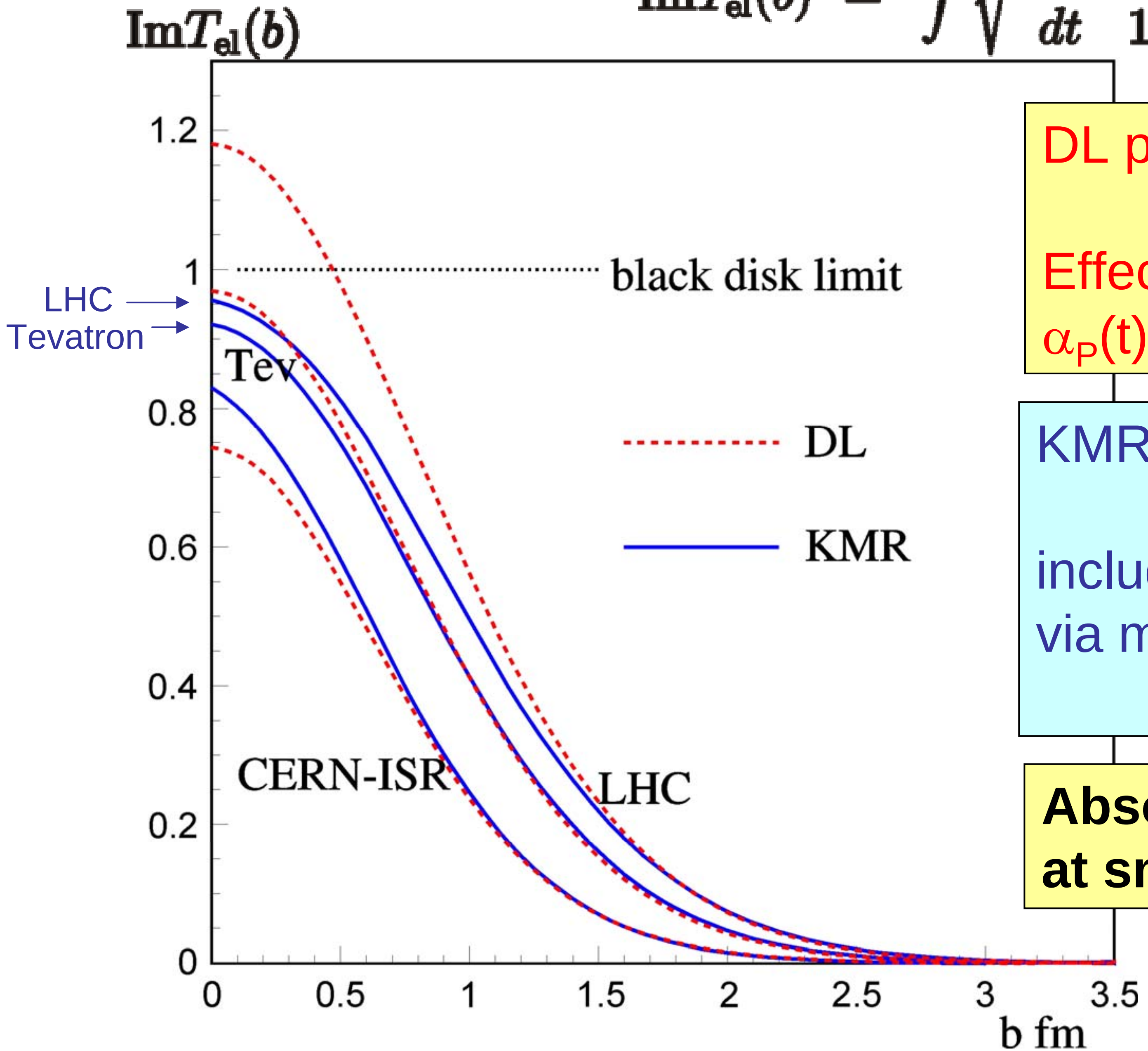
$= 1 - e^{-\Omega_{ik}/2} = \sum$  Ω_{ik}

include high-mass diffractive dissociation

(SD -80%)

$\Omega_{ik} =$ 

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



DL parametrization:

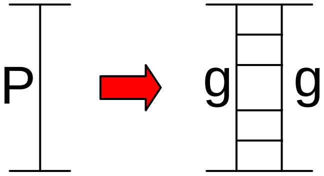
Effective Pom. pole
$\alpha_P(t) = 1.08+0.25t$

KMR parametrization

includes absorption via multi-Pomeron effects

Absorption crucial at small b

Smooth transition from "soft" to "hard" Pomeron?



- No irregularity in HERA data in $Q^2 = 0.3 - 2$ GeV^2 region

- Global analysis of "soft" data (incl. absorptive/multi-P effects)

  see below

  give "bare" slope $\alpha' < 0.05$ GeV^{-2}
  ($\alpha' \sim 1/\langle k_t^2 \rangle$ --- typical k_t in ladder in perturbative region)

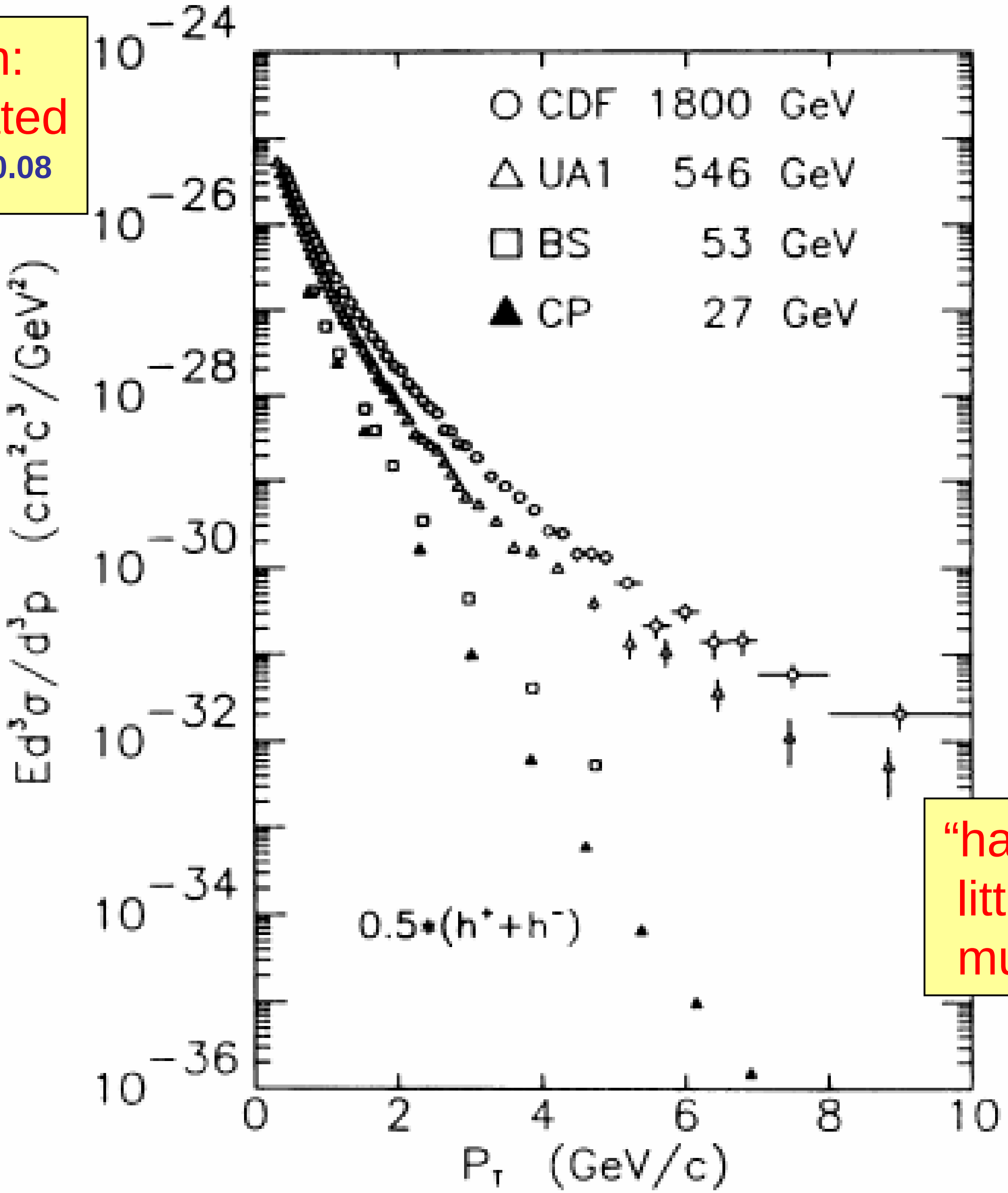
  give "bare" intercept $\Delta = \alpha_P(0) - 1 \sim 0.3$
  (close to intercept of QCD BFKL Pomeron after NLL corrections are resummed)

- The absorptive effects increase as we go to low k_t:

  $\rightarrow$ $\alpha_P^{\text{effective}} \sim 1.08 + 0.25\, t$ (t in GeV^2)

  (up to Tevatron energies)

“soft” Pomeron:
partons saturated
little growth $s^{0.08}$

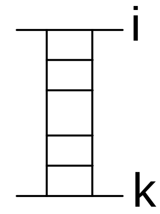


“hard” Pomeron:
little screening
much growth $s^{0.3}$

Partonic structure of Pomeron

"bare" Pomeron pole

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



new development:
k_t dependence included in integral form

BFKL kernel

$$\frac{\partial \Omega(y,k_t)}{\partial y} = \bar{\alpha}_s \int d^2k_t' \, K(k_t,k_t') \, \Omega(y,k_t') \qquad \left(\bar{\alpha}_s \equiv \frac{3\alpha_s}{\pi}\right)$$

Naïve:

$$\frac{\partial \Omega}{\partial y} = \Delta \, \Omega \quad \text{where} \quad \Delta = \bar{\alpha}_s \langle K \rangle \qquad \left(y = \ln\frac{1}{x}\right)$$

$$\Rightarrow \quad \Omega = e^{\Delta y} = x^{-\Delta} \sim s^{\alpha(0)-1} \qquad (\text{so} \quad \Delta = \alpha(0) - 1)$$

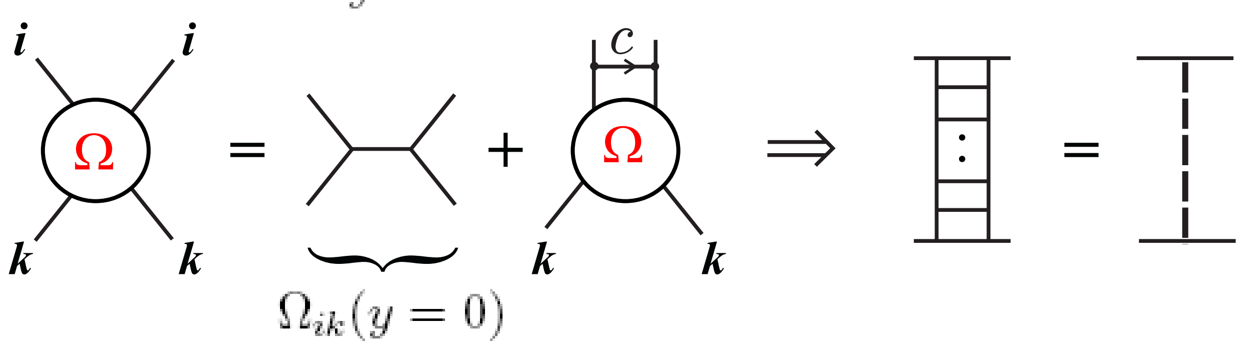
BFKL :

$$\text{LL}(1/x): \quad \Delta = 4\ln 2 \, \bar{\alpha}_S \quad \rightarrow \quad \Delta \sim 0.5$$

$$\text{NLL}(1/x): \quad \Delta = 4\ln 2 \, \bar{\alpha}_S(1 - 6\bar{\alpha}_S): \quad \text{resum all major HO} \rightarrow \boxed{\Delta \sim 0.3}$$

---

evolution in rapidity $\frac{\partial \Omega(y,k_t)}{\partial y} = \bar{\alpha}_s \int d^2k_t' \, K(k_t,k_t') \, \Omega(y,k_t')$, generates ladder



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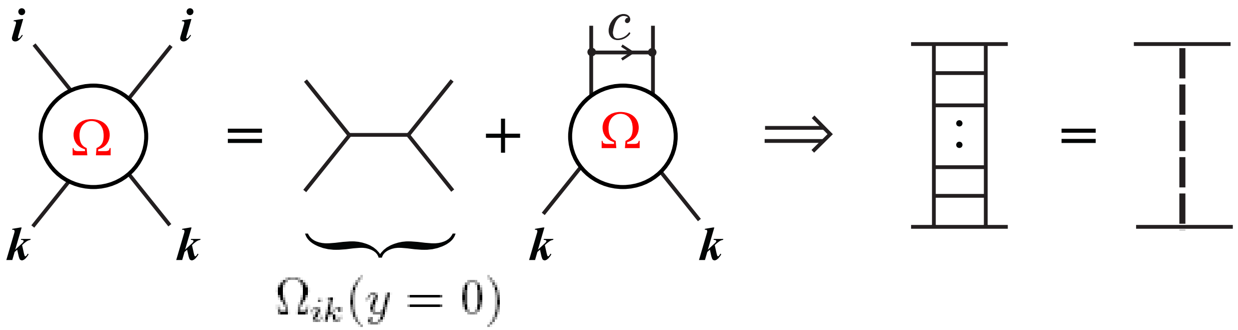


- At each step k_t and b of parton can be changed – so, in principle, we have 2-variable integro-differential eq. to solve

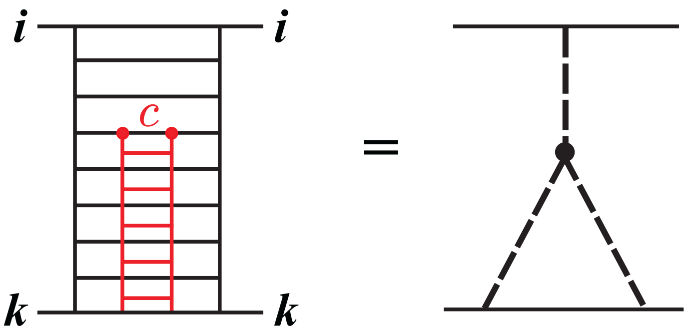
- We use a simplified form of the kernel K which incorporates the main features of BFKL – diffusion in log k_t^2, $\Delta \sim 0.3$-0.4

- 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

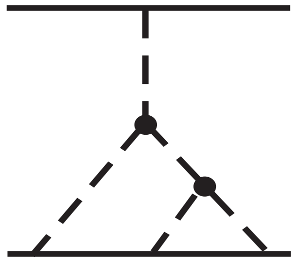
- Evolution gives ⟹ $\Omega = \Omega_{ik}(y, k_t, b)$

Multi-Pomeron contrib^ns

- e.g. triple-Pomeron diagram: parton c has extra scattering with "target" k



- Many rescatt: different no. of ladders between c and k



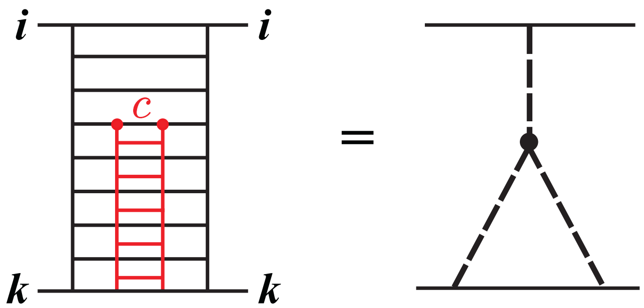
$$\frac{\partial \Omega_k(y)}{\partial y} = \bar{\alpha}_s \int d^2k_t' \, e^{-\lambda\Omega_k(y)/2} K(k_t, k_t') \, \Omega_k(y)$$

where $\lambda\Omega_k$ reflects the different opacity of "target" k felt by c, rather opacity Ω_k than felt by "beam" i

$\lambda \sim 0.25$

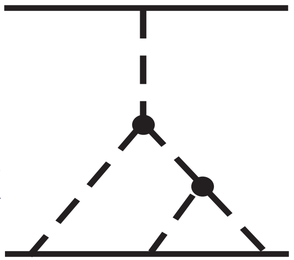
Multi-Pomeron contrib^{ns} continued

so far

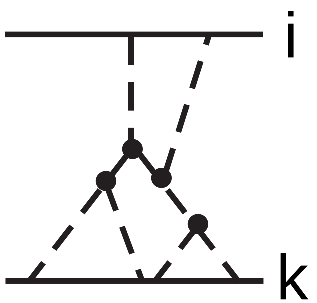


then we include a full set of fan diagrams for rescatt of c with k

$$e^{-\lambda\Omega_k(y)/2}$$



- Now include rescatt of c with "beam" i

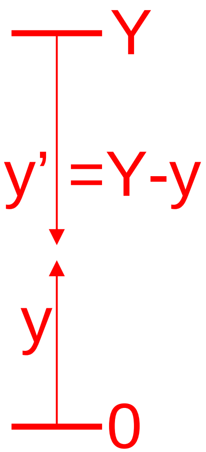


evolve up from y=0

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

evolve down from y'=Y-y=0

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



solve iteratively for $\Omega_{ik}(y,k_t,b)$

Aim is to study main features of data in terms of a realistic model with just a few physically motivated parameters:

- Δ and d which specify the simplified BFKL kernel
  d gives diffusion in log k_t^2, Δ controls s dependence

- β_0 specifies the Pomeron-proton coupling

- c_1 and c_2 specify proton form factor

- λ determines multi-Pomeron couplings, which are constrained by data on high-mass diffractive dissociation

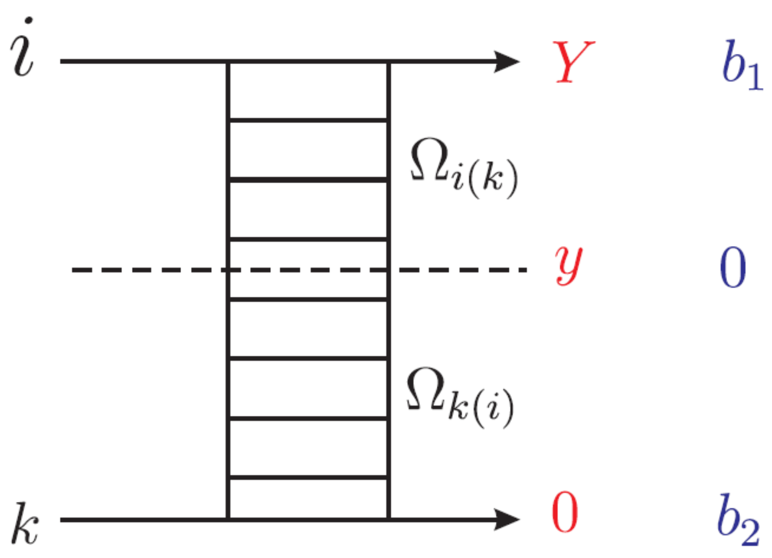
- γ specifies (Good-Walker) diffractive eigenstates, which is constrained by data on low-mass diffractive dissociation

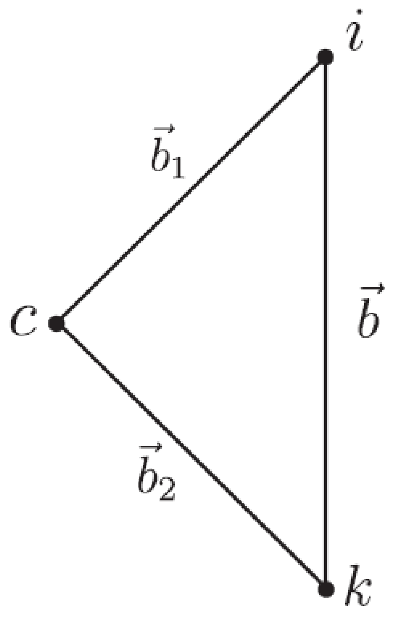
Observables from $\Omega_{ik}(k_t,b,y)$

example 1: total cross section

$$\Omega^{\rm eff}_{ik}(\vec{b},Y) = \int d^2k_t \int \Omega_i(\vec{k}_t,\vec{b}_1,\vec{b}_2,y)\,\Omega_k(\vec{k}_t,\vec{b}_1,\vec{b}_2,Y-y)\,d^2b_1 d^2b_2 \delta^{(2)}(\vec{b}_1-\vec{b}_2-\vec{b})$$

$$\sigma_{\rm tot} = 2\sum_{i,k}|a_i|^2|a_k|^2\int\left(1-e^{-\Omega^{\rm eff}/2}\right)d^2b$$

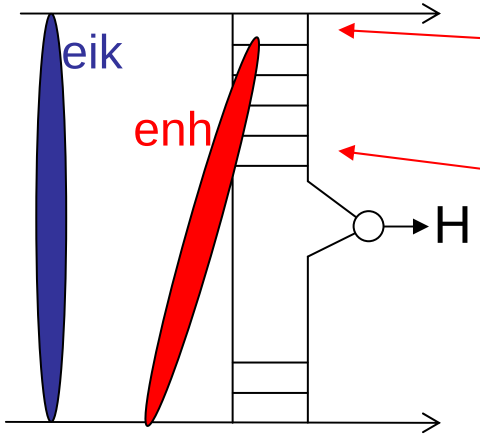




example 2: rapidity gap survival

to eikonal rescattering $$S^2_{ik}(\vec{b}) = \exp(-\Omega^{\text{eff}}_{ik}(\vec{b}))$$

to enhanced rescattering --- now need b, k_t correlation



rescatt. between low x, low k_t partons and "target" distorts input distrib^n -- violates soft-hard factoriz^n

large k_t partons -- rescatt. negligible

parton only survives eik. rescatt. on periphery, where parton density is small and prob. of enh. abs. small

Global fit to soft data:
total, elastic, low- and high-mass diffraction

Cross sections (in mb) at various energies (in TeV)

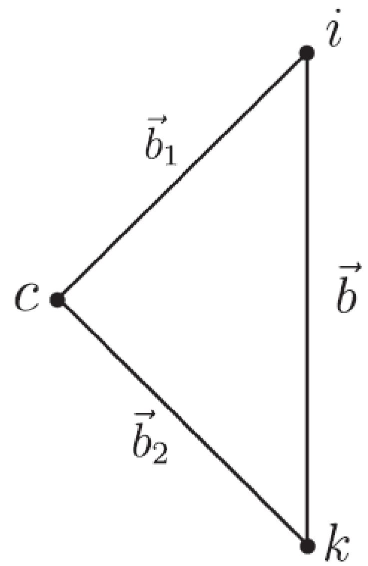
energy	$\sigma_{\rm tot}$	$\sigma_{\rm el}$	$\sigma_{\rm SD}^{{\rm low}M}$	$\sigma_{\rm SD}^{{\rm high}M}$	$\sigma_{\rm SD}^{\rm tot}$
1.8	72.1	15.9	4.05	5.97	10
14	90.4	21.4	5.1	10.5	15.6
100	107.3	26.4	6.1	15.7	21.8

preliminary

Implementation as MC algorithm (naive version)

- Solve simplified equations for $\Omega_{i(k)}$ (depend only on rapidity y and impact parameters; k_t imported via BFKL-inspired Sudakov factor).
- Select scattering mode (elastic vs. single-diffractive vs. inelastic) according to respective cross section.
- Elastic, low-mass SD trivial, must select t and diffractive objects (typically a nucleon resonance like N^*), then fix kinematics.
- Inelastic case: modelled as exchange of ladders, see below (add in parton showering, hadronization, hadron decays, QED radiation etc).

Inelastic scattering: generating ladders



- Assume no correlations between ladders
- Select (naive) number of ladders to be exchanged according to Poissonian:

$$\mathcal{P}_{n=N_{\mathrm{naive}}-1} = \frac{[2\Omega_{ik}(b)]^n}{n!} \exp[-2\Omega_{ik}(b)]$$

- For each ladder, fix $\vec{b}_{(1,2)}$ with $\vec{b} = \vec{b}_1 + \vec{b}_2$:

$$\Omega_{ik}(b) = \int \Omega_{i(k)}(\vec{b}_1, \vec{b}_2)\Omega_{(i)k}(\vec{b}_1, \vec{b}_2) d^2b_1 d^2b_2 \delta(\vec{b}_1 + \vec{b}_2 - \vec{b})$$

- After each ladder, check momentum of incoming hadrons if E_1 or E_2 exhausted terminate exchanging ladders therefore $N_{\mathrm{ladders}} \leq N_{\mathrm{naive}}$

Inelastic scattering: generating emissions

- Select initial $2 \to 2$ kinematics according to IR-continued PDF (at $Q^2 = 0$ only valence quarks and gluons).
- Order emissions in rapidity y, allowed interval initially given by two outgoing, elastically scattered partons, typically $Y_{2\to 2} = \log s_{pp}$.
- In "active" y-interval, select "emitter" and "spectator".
- Can write "next emission", with Sudakov-like form factor
$$\exp\left(-\int dy \int dk_t^2 \, \frac{\alpha_s(k_t^2+\mu^2)}{k_t^2+\mu^2}\right),$$
as ordering in y, reweight with absorption coefficient.
- Repeat until phase space exhausted.

First Monte Carlo results very encouraging

Conclusions

-- Obtained a fully consistent description of all high-energy soft interactions; new model based on both a multi-channel eikonal and multi-Pomeron interactions (with k_t dependence)

-- screening/unitarity/absorptive corrections are appreciable at LHC energies. (σ_{total} (14 TeV) ~ 90 mb)

-- soft-hard Pomeron transition emerges
"soft" compt. --- heavily screened --- little growth with s
"hard" compt. --- little screening --- large growth (~pQCD)

-- Model allows both eikonal and enhanced rescatt. corrections and gap survival prob. to be calculated for any diffractive proc.

-- Model has partonic interpretation, so can form basis of "all purpose" Monte Carlo. Model tuned to describe elastic, diffractive processes, but MC also gives description of multiparticle production. Preliminary results v.encouraging.