A partonic description of “soft” interactions at the LHC

Alexei Kaidalov
(1940 – 2010)

Alan Martin (IPPP, Durham)
International Workshop on Particle Phys.Phenomenology in memory of Alexei Kaidalov
Moscow, 21-25 July 2013

Aliosha made many pioneering contributions to the understanding of diffractive processes in high-energy hadron interactions:

He was the first to evaluate the effects low mass (N*) diffractive dissociation (1971)

Kaidalov et al. performed the first triple-Regge analysis (1973)

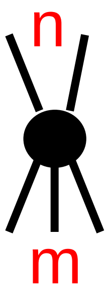
Pioneering model for soft high-energy hadron interactions

A.B. Kaidalov, L.A. Ponomarev, K.A. Ter-Martirosyan

Sov. J. Nucl. Phys. 44 (1986)

included multi-Pomeron diagrams in global description, for first time, with vertices

$$g(nP \rightarrow mP) = g_N \lambda^{n+m-2}$$



Basis of models of soft interactions, used to this day:

- Durham model (Khoze-Martin-Ryskin)
- Tel-Aviv model (Gotsman-Levin-Maor)
- Ostapchenko
- M. Poghosyan, A.B. Kaidalov 2007-2010 (ALICE coll$^{\text{bn}}$)

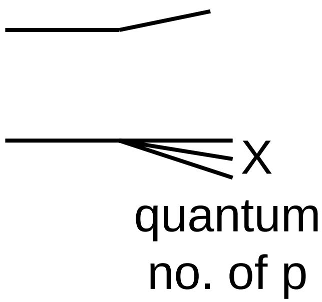
No unique definition of diffraction

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,

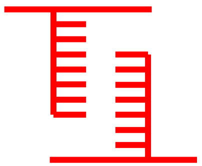
   pp→pX (single proton dissociation, SD),

   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

TOTEM data

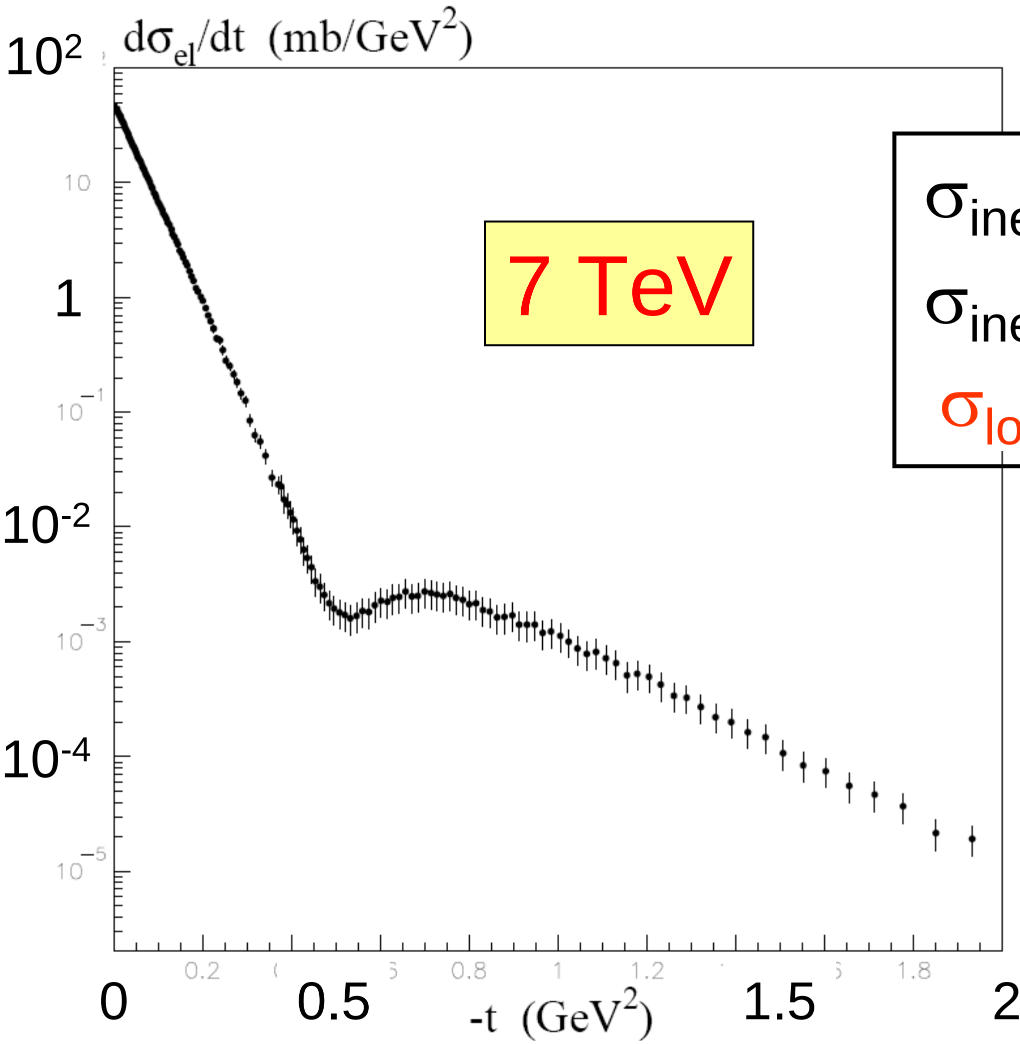
σ_{tot} = 98.6 +/- 2.2 mb

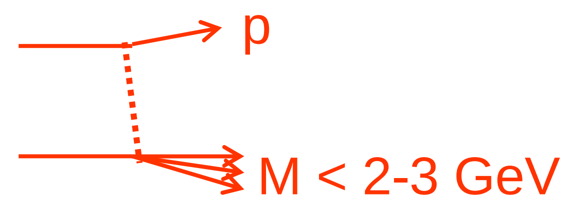
σ_{el} = 25.4 +/- 1.1 mb

σ_{inel} = 73.1 +/- 1.3 mb

$\sigma_{inel(|\eta|<6.5)}$ = 70.5 +/- 2.9 mb

$\sigma_{low\ M\ dissn.}$ = 2.6 +/- 2.2 mb

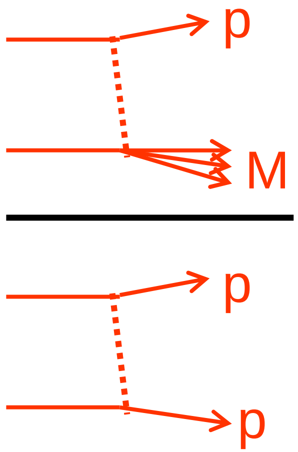




Only one other estimate of $\sigma_{\text{low M}}$

CERN-ISR 62.5 GeV

TOTEM 7 TeV



$$\frac{\sigma_{\text{low M}}}{\sigma_{\text{elastic}}} = \frac{\text{2-3 mb}}{\text{7 mb}} \stackrel{?}{=} \frac{\text{2.6 mb}}{\text{25.4 mb}}$$

Unexpectedly small

Before TOTEM, models predicted $\sigma_{\text{low M}} \sim$ 6-10 mb

Can we describe all “soft” HE data

σ_{tot}, $d\sigma_{el}/dt$, $\sigma_{low\ M}$, $(+\ \sigma_{high\ M})$

from CERN-ISR → Tevatron → LHC

in terms of a single “effective” pomeron ?

Low-mass dissociation is a consequence of the internal structure of proton. A constituent can scatter & destroy coherence of $|p\rangle$

Good-Walker: $|p\rangle = \sum a_i |\varphi_i\rangle$

where φ_i diagonalize T -- have only “elastic-type” scatt

Usually GW eigenstates assumed independent of t & s

KMR (2013) parametrize form factor $F_i(t)$ for each $\varphi_{i=1,2}$

- Allows for $B_{el} \sim 10\ \mathrm{GeV}^{-2}$ at CERN-ISR
  $B_{el} \sim 20\ \mathrm{GeV}^{-2}$ at LHC (7 TeV)

  as well as diff^ve dip

→ smaller |t| at LHC, |p⟩ less distorted, so $\sigma_{low\ M}$ smaller

model 1

- Pomeron is a (BFKL) cut, not a pole

← low k_t ● high k_t → diffusion in log k_t

abs. corr^ns between intermediate parton-parton inter^ns

$\sigma_{abs} \sim 1/k_t^2$, suppress low k_t → mean k_t increases with s

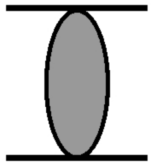
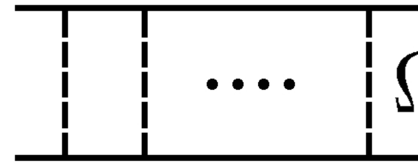
$$k_{min}^2 \sim s^{0.12}$$

model 2

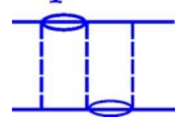
(enhanced multi-pom effects introduce dynamical infrared cutoff)

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

bare amp. $\Omega/2$ = 

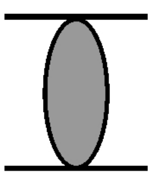
$\mathrm{Im}\, T_{\mathrm{el}} =$  $= 1 - e^{-\Omega/2} = \sum_{n=1}^{\infty}$  $\Omega/2$

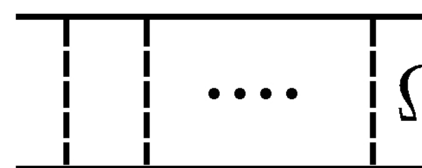
(s-ch unitarity)

Low-mass diffractive dissociation 

→multichannel eikonal

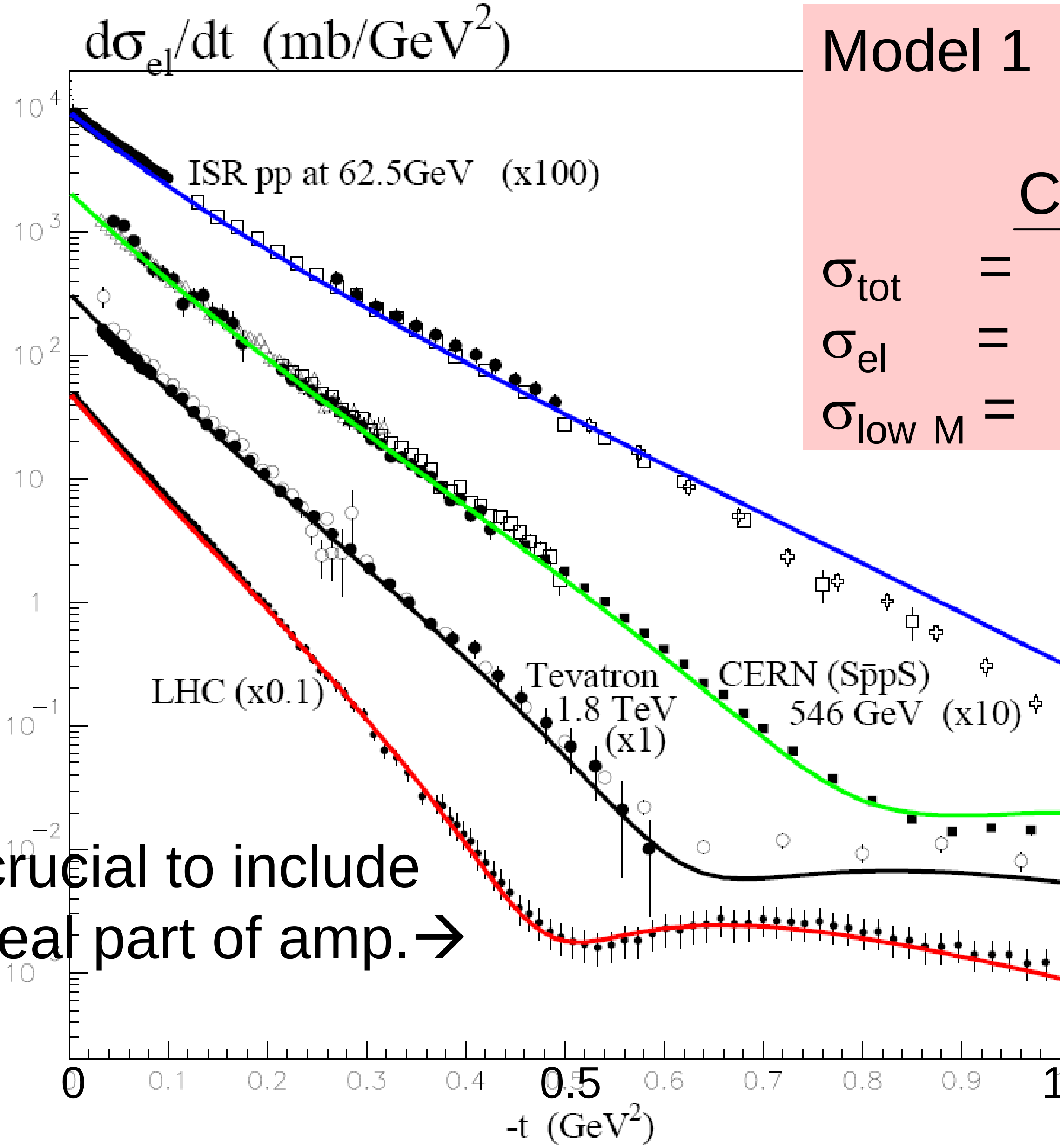
introduce diff[ve] estates ϕ_i, ϕ_k (comb[ns] of p,p*,..) which only undergo "elastic" scattering (Good-Walker)

$\mathrm{Im} T_{ik} =$ 

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

Model 1 (GW indep. of s)

	C-ISR	→	LHC
σ_{tot} =	42	→	97 mb
σ_{el} =	7	→	23 mb
$\sigma_{low\ M}$ =	2	→	5 mb



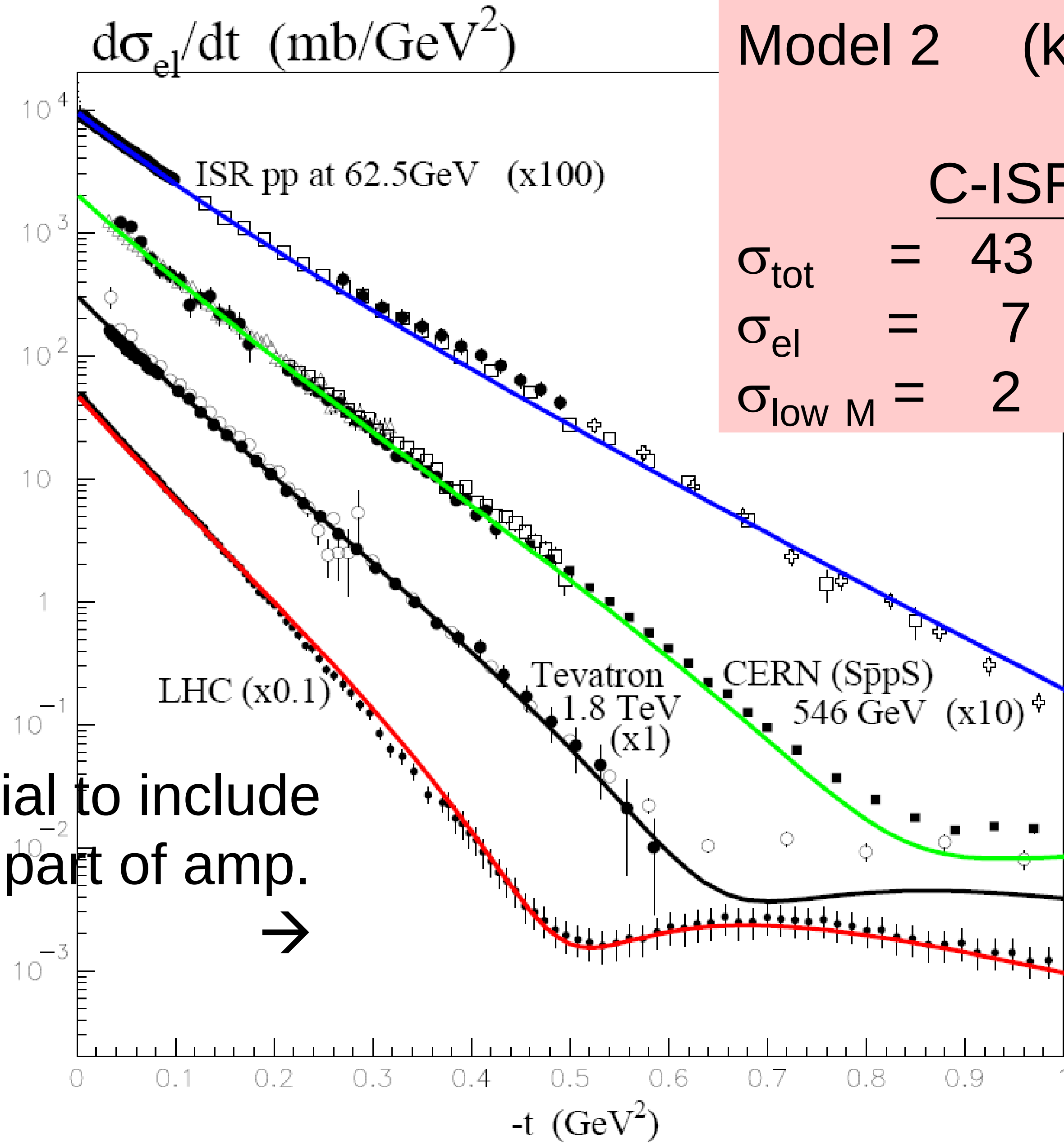
crucial to include real part of amp.→

better, data 2.6 +/- 2.2

A description with $\sigma_{low\ M}$ = 1 → 3 mb is possible (secondary reggeon at ISR→1mb?)

Model 2 ($k_{min} \sim s^{0.12}$)

	C-ISR → LHC
σ_{tot} =	43 → 96.4 mb
σ_{el} =	7 → 24 mb
$\sigma_{low\ M}$ =	2 → 3.2 mb



crucial to include real part of amp.

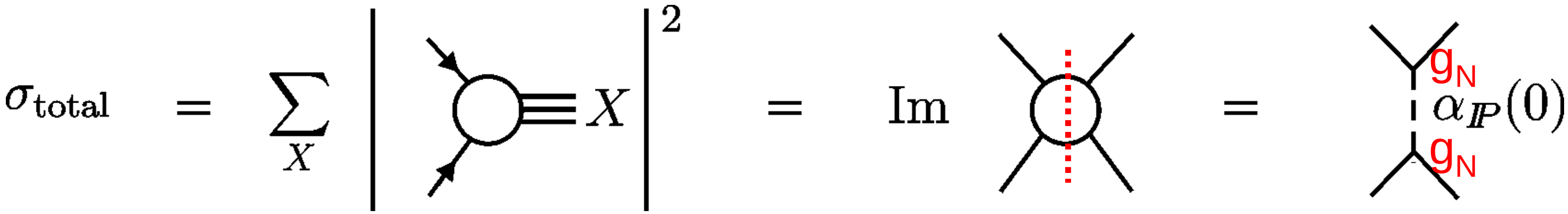
→

high-mass dissociation

→

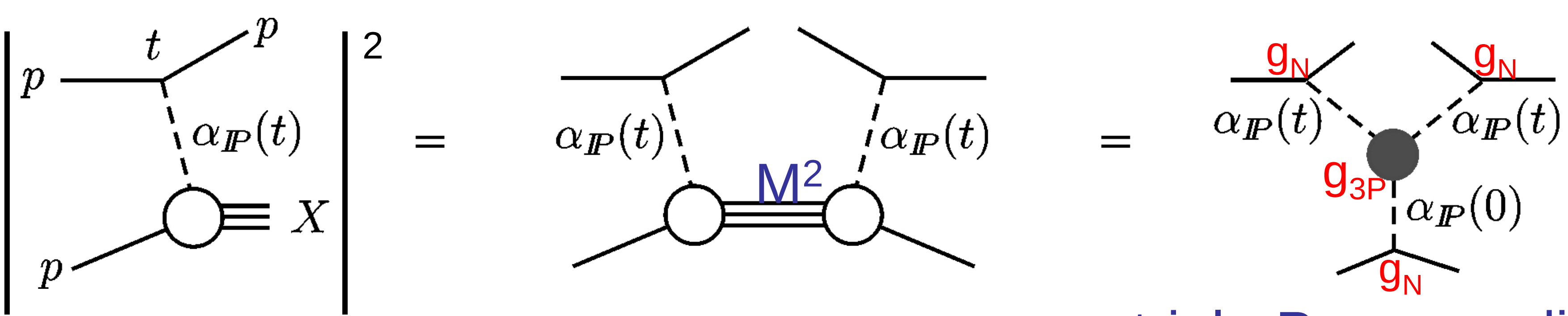
Optical theorems

at high energy
use Regge



$$g_N^2 \left(\frac{s}{s_0}\right)^{\alpha_{I\!P}(0)-1}$$

High-mass diffractive dissociation

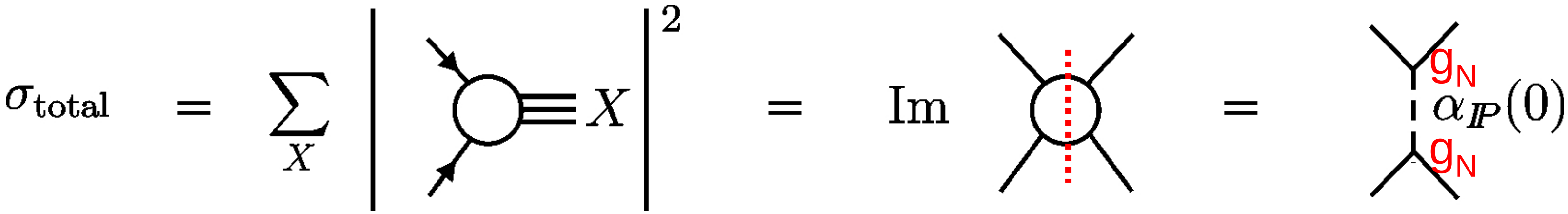


triple-Pomeron diag

$$g_N^3 g_{3P} \left(\frac{M^2}{s_0}\right)^{\alpha_{I\!P}(0)-1} \left(\frac{s}{M^2}\right)^{2\alpha_{I\!P}(t)-2}$$

Optical theorems

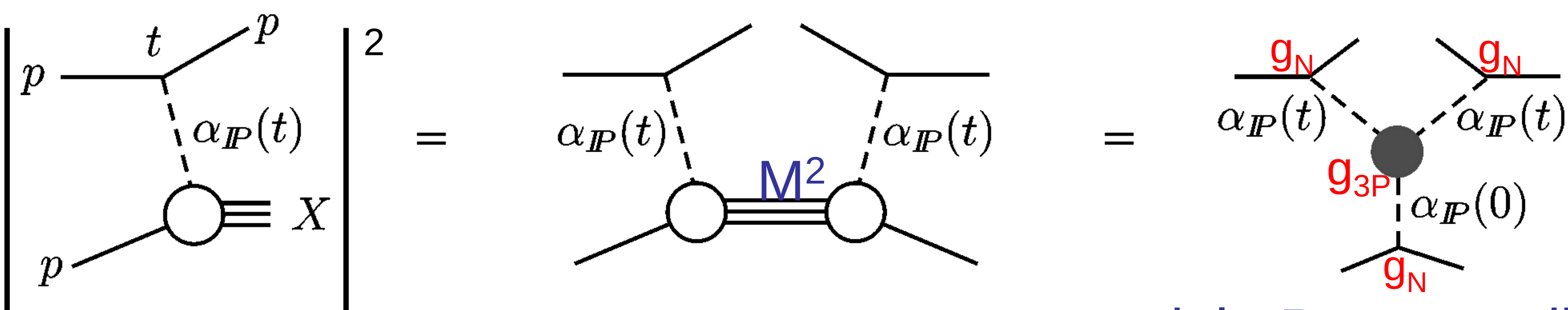
at high energy
use Regge



but screening/s-ch unitarity important so σ_{total} suppressed

$$g_N^{\,2} \left(\frac{s}{s_0} \right)^{\alpha_{I\!P}(0)-1}$$

High-mass diffractive dissociation



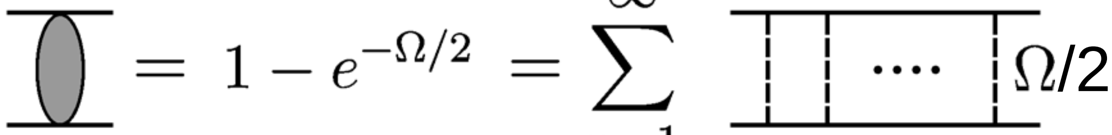
triple-Pomeron diag

$$g_N^{\,3} g_{3P} \left(\frac{M^2}{s_0} \right)^{\alpha_{I\!P}(0)-1} \left(\frac{s}{M^2} \right)^{2\alpha_{I\!P}(t)-2}$$

but screening even more important

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

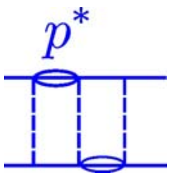
bare amp. $\Omega/2$ =

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

(s-ch unitarity)

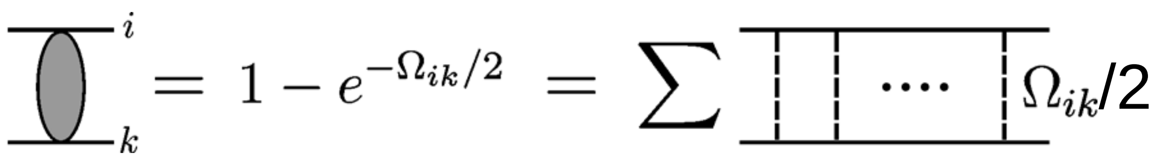
(-20%)

Low-mass diffractive dissociation



→multichannel eikonal

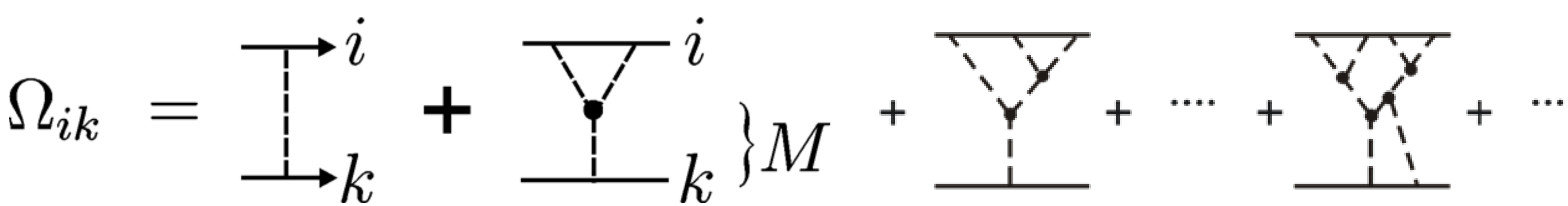
introduce diff^{ve} estates ϕ_i, ϕ_k (comb^{ns} of p,p*,..) which only undergo "elastic" scattering (Good-Walker)

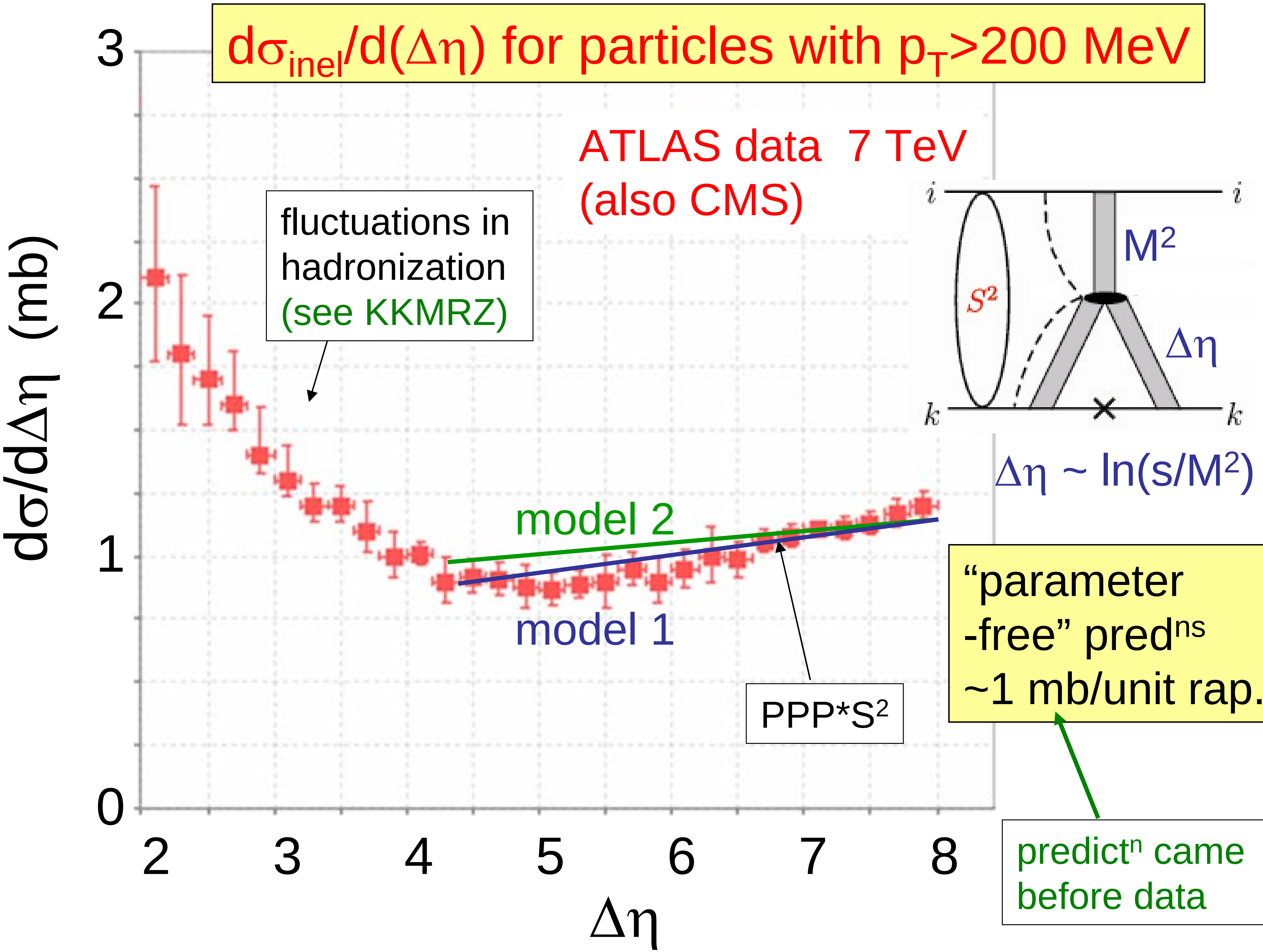
Im T_{ik} =  $= 1 - e^{-\Omega_{ik}/2} = \sum$ ... $\Omega_{ik}/2$

(-40%)

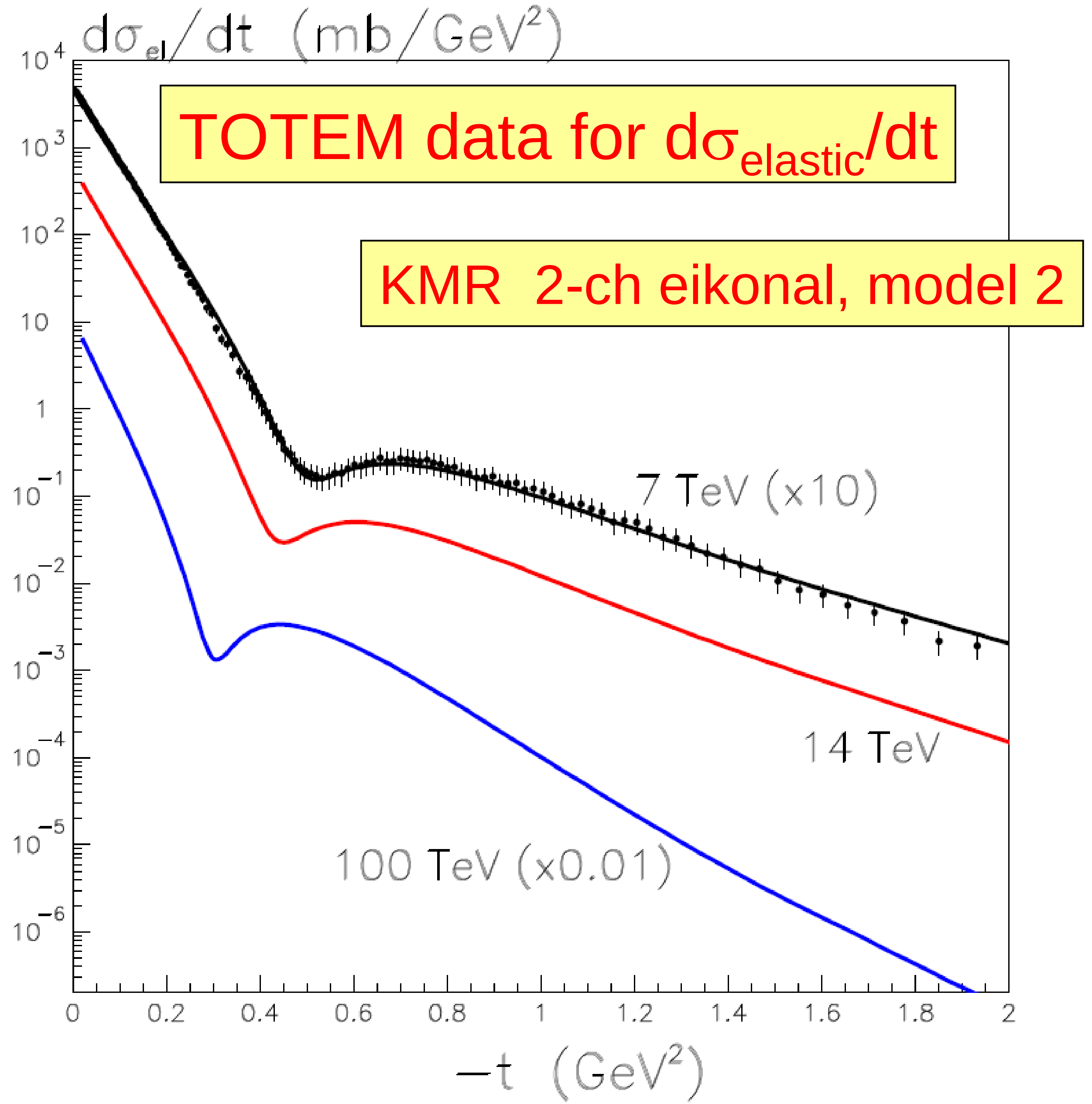
include high-mass diffractive dissociation

(SD -80%)





dσ_inel/d(Δη) for particles with p_T>200 MeV
ATLAS data 7 TeV
(also CMS)
fluctuations in
hadronization
(see KKMRZ)
model 2
model 1
PPP*S²
S²
M²
Δη
i
i
k
k
Δη ~ ln(s/M²)
"parameter
-free" predⁿˢ
~1 mb/unit rap.
predictⁿ came
before data
dσ/dΔη (mb)
Δη
0
1
2
3
2
3
4
5
6
7
8



TOTEM data for $d\sigma_{elastic}/dt$
KMR 2-ch eikonal, model 2
$d\sigma_{el}/dt$ (mb/GeV^2)
7 TeV (x10)
14 TeV
100 TeV (x0.01)
$-t$ (GeV^2)
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

Yes, it is possible to describe all “soft” HE data

σ_{tot}, $d\sigma_{el}/dt$, $\sigma_{low\ M}$, (+ $\sigma_{high\ M}$)

from CERN-ISR → Tevatron → LHC

in terms of a single “effective” pomeron ?

Energy dep. of σ_{el}, σ_{tot} controlled by intercept and slope of “effective” pomeron trajectory

Diffractive dip and $\sigma_{low\ M}$ controlled by properties of GW eigenstates

High-mass diss^{n} driven by multi-pomeron effects

Can we go further and consider

a partonic model of the pomeron ?

Could this be the basis of a Monte Carlo

which describes “soft” (as well as “hard”)

high energy pp interactions ?

High-energy pp interactions

soft

hard

Reggeon Field Theory
with phenomenological
soft Pomeron

← pQCD
partonic approach

smooth transition using
QCD / “BFKL” / hard Pomeron

There exists only one Pomeron, which makes
a smooth transition from the hard to the soft regime

Can this be the basis of a unified partonic model for
both soft and hard interactions ??

"Soft" and "Hard" Pomerons ?

A vacuum-exchange object drives soft HE interactions. Not a simple pole, but an enigmatic non-local object. Rising σ_{tot} means multi-Pom diags (with Regge cuts) are necessary to restore unitarity. σ_{tot}, $d\sigma_{el}/dt$ data, described, in a limited energy range, by eff. pole $\alpha_P^{eff} = 1.08 + 0.25t$

Sum of ladders of Reggeized gluons with, in LLx BFKL, a singularity which is a cut and not a pole. When HO are included the intercept of the BFKL/hard Pomeron is $\alpha_P^{bare}(0) \sim 1.3$

$\mathbf{\Delta = \alpha_P(0) -1 \sim 0.3}$

$\alpha_P^{eff} \sim 1.08 + 0.25\ t$

up to Tevatron energies

$(\sigma_{tot} \sim s^{\Delta})$

$\alpha_P^{bare} \sim 1.3 + 0\ t$

← with absorptive (multi-Pomeron) effects

Aside: absorption needed at LHC

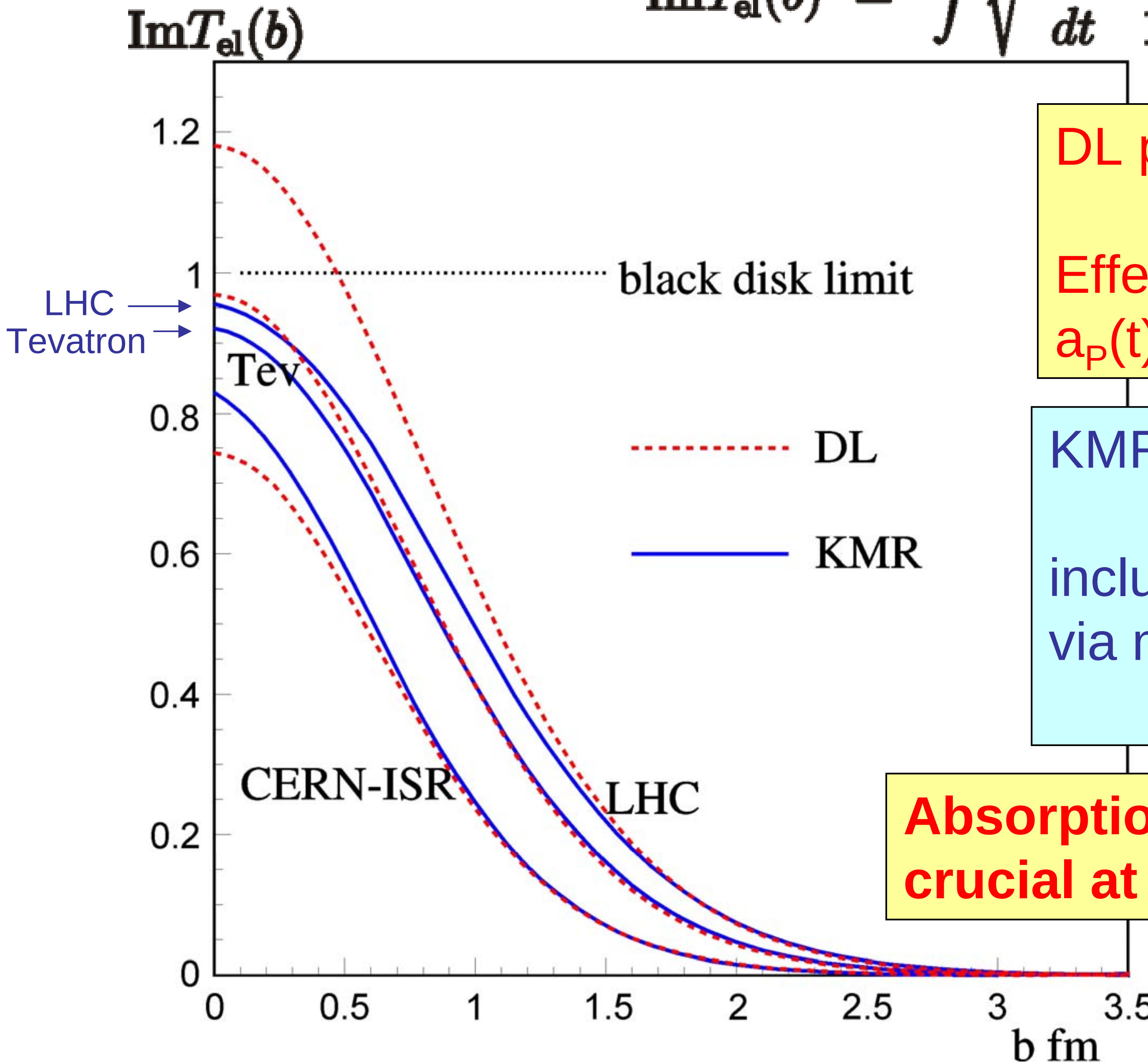
$ds_{el}/dt \sim |\ \mathrm{Im}T_{el}(s,t)\ |^2$ (r=|Re/Im|<<1)

so can get impact parameter profile $\mathrm{Im}T_{el}(s,b)$, via a Fourier transform q → b space ($t=q^2$), “direct” from data for elastic diff. x-sect:

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

data

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



DL parametrization:

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

KMR parametrization

includes absorption
via multi-Pomeron
effects

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

"Soft" and "Hard" Pomerons ?

A vacuum-exchange object drives soft HE interactions. Not a simple pole, but an enigmatic non-local object. Rising σ_{tot} means multi-Pom diags (with Regge cuts) are necessary to restore unitarity. σ_{tot}, $d\sigma_{el}/dt$ data, described, in a limited energy range, by eff. pole $\alpha_P^{eff} = 1.08 + 0.25t$

Sum of ladders of Reggeized gluons with, in LLx BFKL, a singularity which is a cut and not a pole. When HO are included the intercept of the BFKL/hard Pomeron is $\alpha_P^{bare}(0) \sim 1.3$

$\mathbf{\Delta = \alpha_P(0) - 1 \sim 0.3}$

$\alpha_P^{eff} \sim 1.08 + 0.25\ t$ up to Tevatron energies

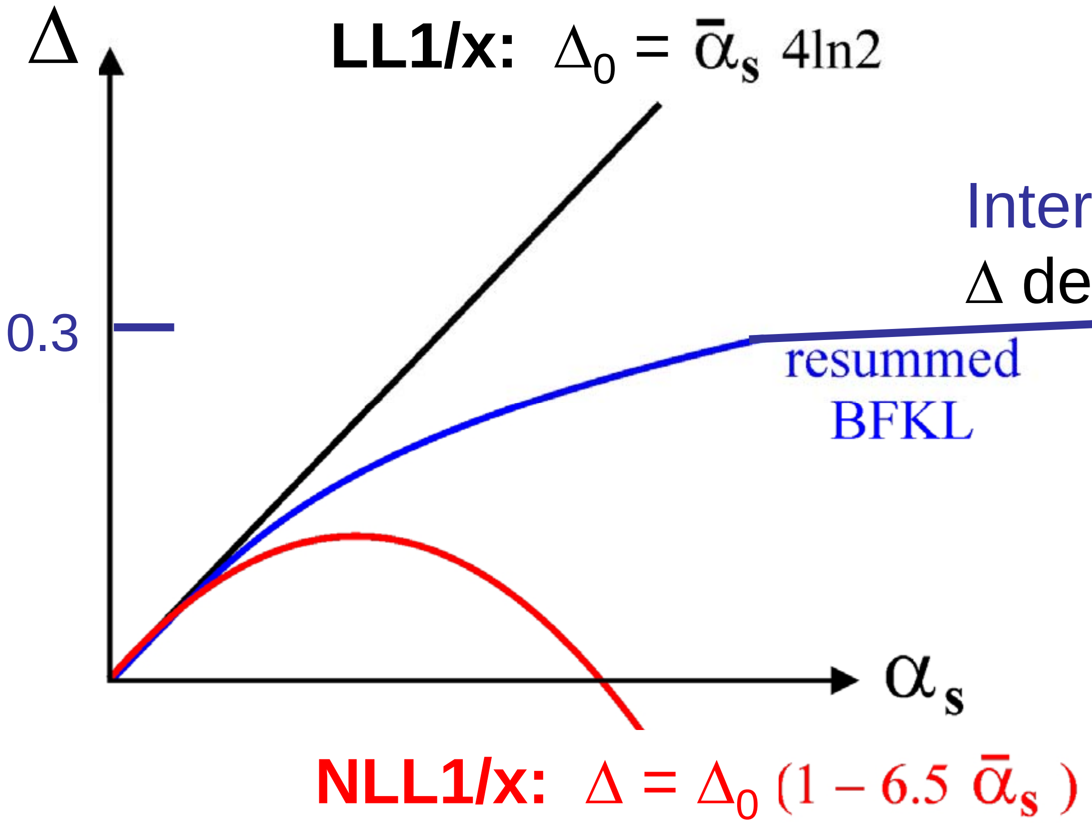
($\sigma_{tot} \sim s^{\Delta}$)

$\alpha_P^{bare} \sim 1.3 + 0\ t$

with absorptive (multi-Pomeron) effects

BFKL stabilized

$\Delta = \alpha_P(0) - 1$



Intercept $\Delta = \alpha_P(0) - 1 \sim 0.3$

Δ depends weakly on k_t for low k_t

DGLAP: $\alpha_s \ln Q^2$

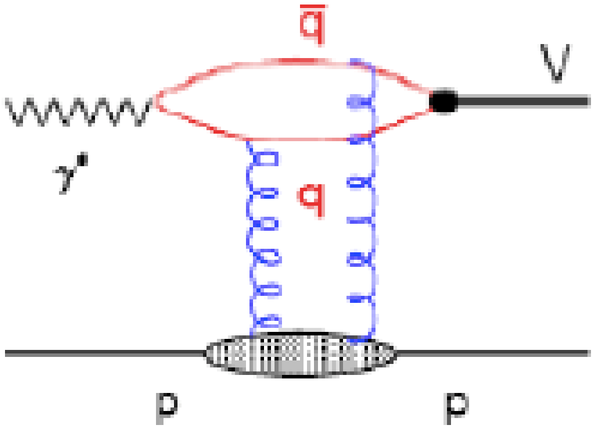
BFKL: $\alpha_s \ln 1/x$

Small-size “BFKL” Pomeron is natural object to continue from “hard” to “soft” domain

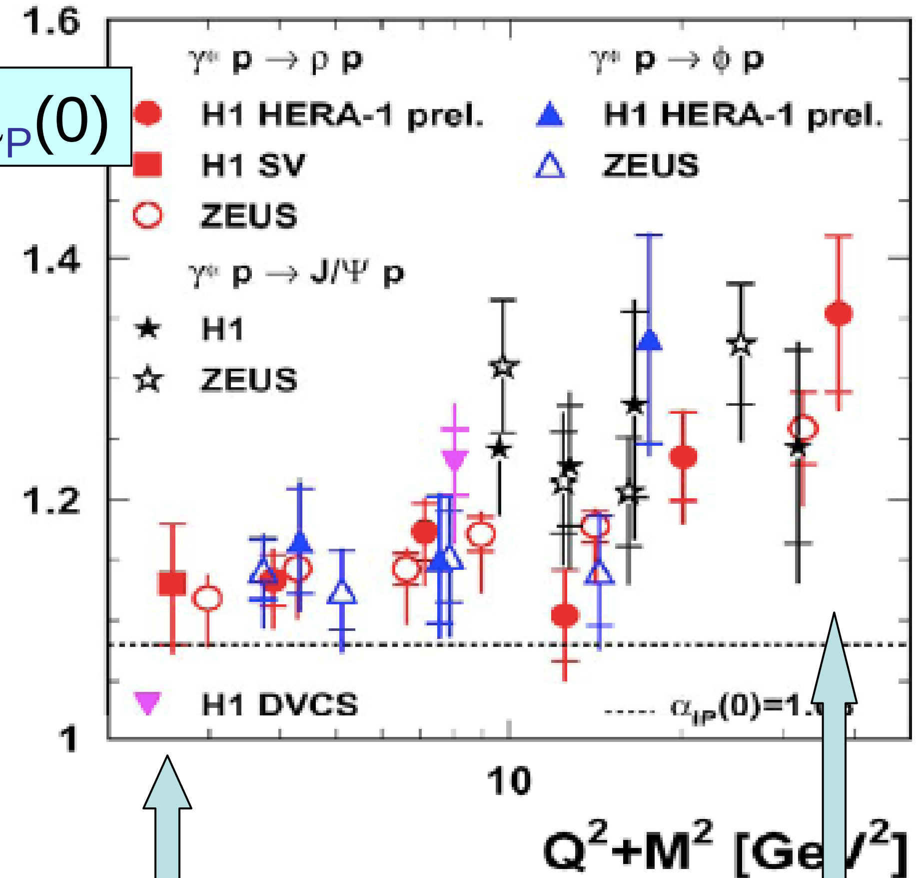
Vector meson prod^{n} at HERA
~ bare QCD Pom. at high Q^2
~ no absorption

hard energy dependences

Q^2



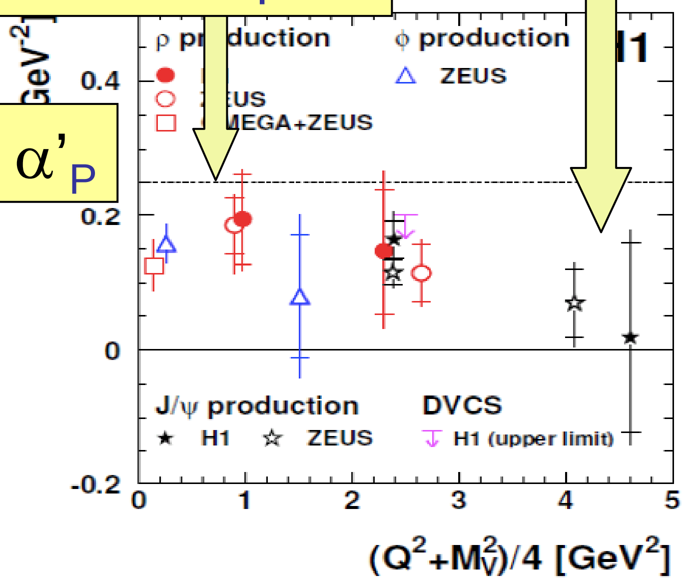
$\alpha_P(0)$



$\alpha'_P(0) \sim 0.25$
after absorption

$\alpha'^{bare}_P(0) \sim 0$

α'_P

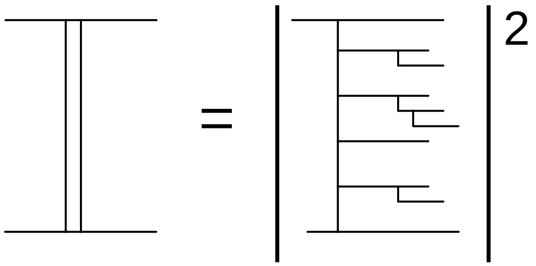


$\alpha_P(0) \sim 1.1$
after absorption

$\alpha_P^{bare}(0) \sim 1.3$

Phenomeno^{logical} hints that $R_{\text{bare Pom}} \ll R_{\text{proton}}$

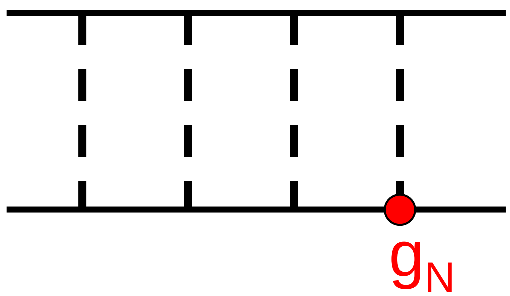
small slope $\alpha'_{\text{bare}} \sim 0$
success of Additive QM
small size of triple-Pomeron vertex
small size of BEC at low N_{ch}



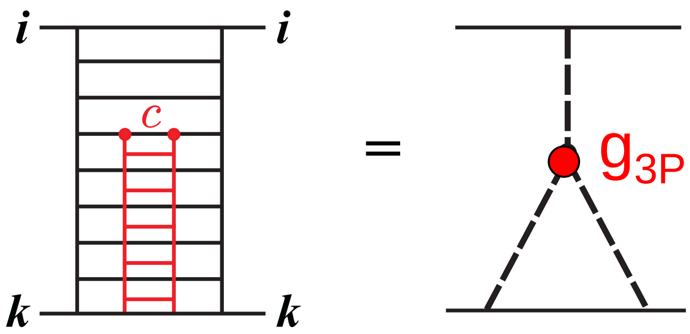
Pomeron is a parton cascade which develops in ln(1/x) space, and which is not strongly ordered in k_t.
However, above evidence indicates the cascade is compact in b space and so the parton k_t's are not too low. We may regard the cascade as a hot spot inside the two colliding protons

Multi-Pomeron contributions

eikonal: Pomerons well separated in b-plane



enhanced: interactions with partons in an individual cascade



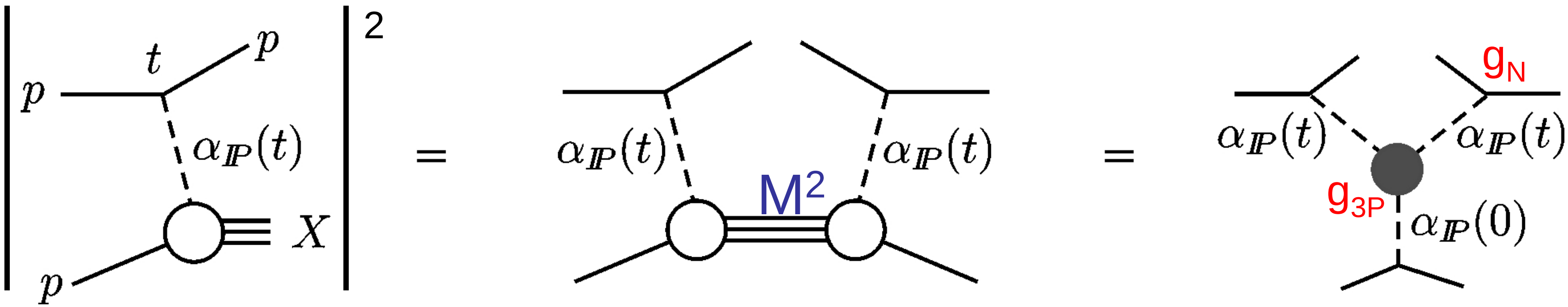
despite $g_{3P} \sim 0.2\ g_N$, enhanced by phase space, which grows with s

→ see next slide

$g_{3P}=\lambda\ g_N \qquad \lambda \sim 0.2$

← why is λ sufficently large, that enh. multi-Pom diagrams important at HE ?

naïve argument without absorptive effects:



$M^2 d\sigma_{SD}/dM^2 \sim g_N^3\ g_{3P} \sim \lambda\sigma_{el}$

$\ln s/M_0^2$

$(\sigma_{el} \sim g_N^4)$

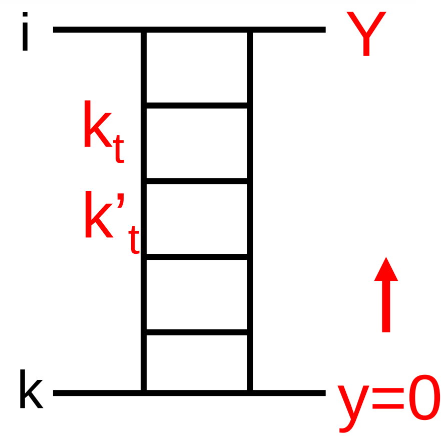
$$\sigma_{SD} = \int \frac{M^2 d\sigma_{SD}}{dM^2} \frac{dM^2}{M^2} \sim \lambda \ln(s/M_0^2)\ \sigma_{el}$$

so at HE collider energies $\sigma_{SD(\text{high mass})} \sim \sigma_{el}$

SD is “enhanced” by larger phase space available at HE.

Partonic structure of “bare” Pomeron

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



BFKL evol^n in rapidity generates ladder

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

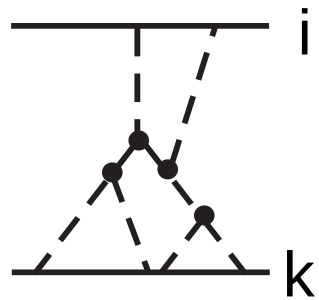
- At each step k_t and b of parton can be be changed – so, in principle, we have 3-variable integro-diff. eq. to solve

Khoze,Martin,Ryskin

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

How are Multi-Pomeron contrib^{ns} included?

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

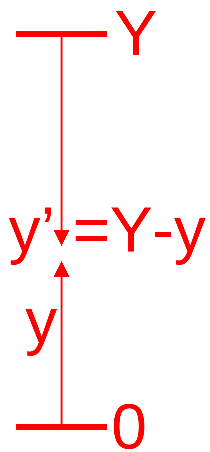


evolve up from y=0

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

evolve down from y'=Y-y=0

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



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 $\Omega_{ik}(y,k_t,b)$ (and hadronization) 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…

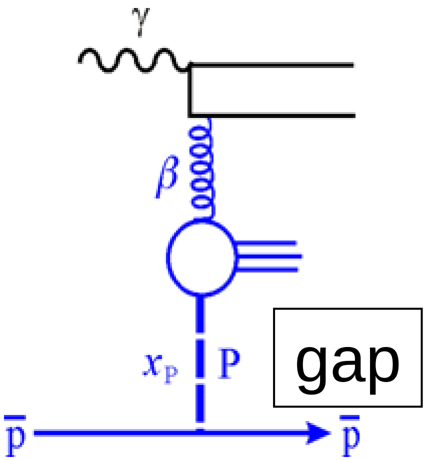
LRG survival factors S^2 (to both eikonal, enhanced rescatt)

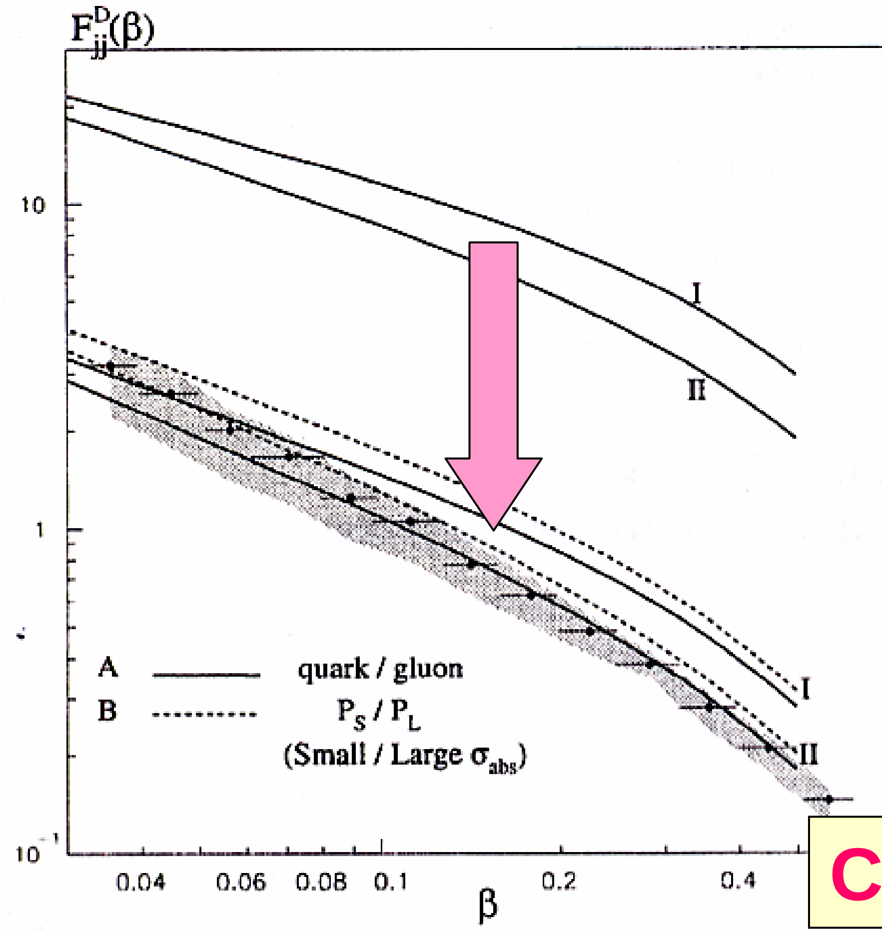
PDFs and diffractive PDFs at low x and low scales

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. (KMR, EPJ C71)

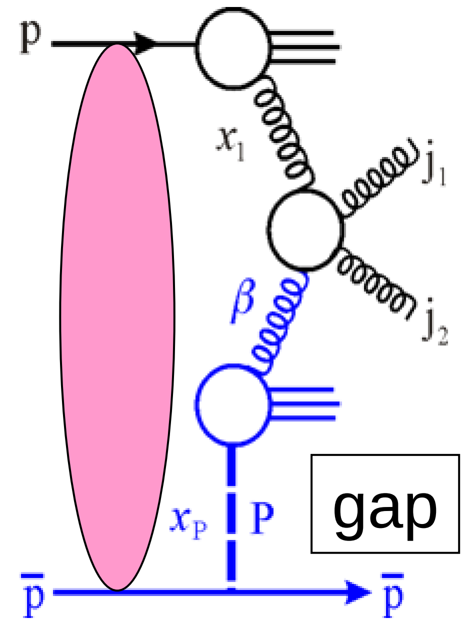
early work on survival factors →

Kaidalov + KMR   Durham (2001)





soft rescatt.



CDF diff^{ve} dijets

HERA→diff^{ve} PDFs

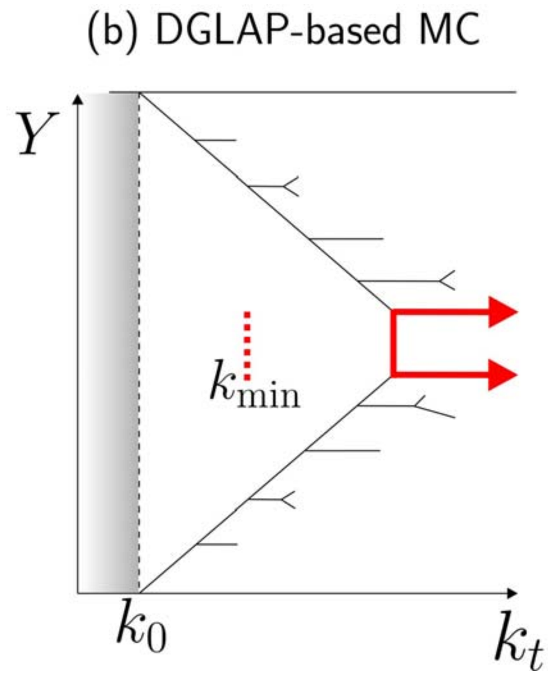
CDF data

$E_T^{Jet1,2} > 7$ GeV

$0.035 < \xi < 0.095$

$|t| < 1.0$ GeV^2

Paper also discussed possible β dependence, and emphasized enhanced rescatt. effects



Existing all-purpose MCs describe inclusive spectra with hard parton-parton interaction in central region, with secondaries from backward evol^{n}.

Infrared cutoff k_{min}~3 GeV at LHC(7 TeV) compared to cutoff k_{min}~2.15 GeV at Tevatron.

Understood in pQCD: in relevant low x region, prob of rescatt. large, corresponding abs^{ve} corr^{n}, σ_{abs}~$1/k_t^2$, suppress low k_t .

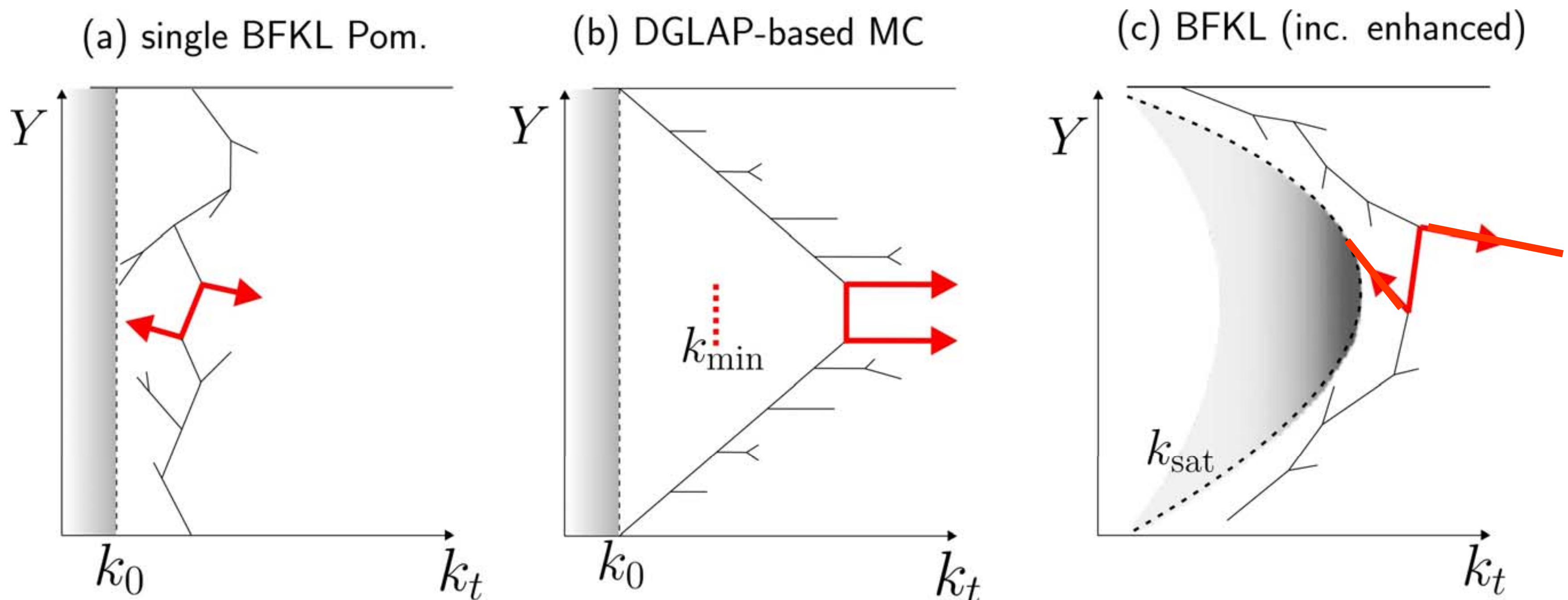
model → $d\sigma/dy \sim s^{0.2}$ like the LHC data for 0.9 to 7 TeV

LHC

DGLAP $\ln k_t^2$ evol^n interval << BFKL $\ln(1/x)$ evol^n interval

overestimates $\langle k_t \rangle$
underestimates growth dN/dy

not strongly-ordered in k_t
$dN/dy = n_P\,(dN_{1\text{-}Pom}/dh)$
n_P=no. of Poms. grows



$d\sigma_{subp}/dk_t^2 \sim 1/k_t^4$
→ tune cutoff to data
$k_{min} \sim s^a$, $a \sim 0.12$

Enh: $\sigma_{abs} \sim 1/k_t^2$
→ dyn. cutoff k_{sat}
→ besides SD, DD

Can conclude from the LHC data:

The $<p_T>$ of hadrons measured by ATLAS, CMS, ALICE is smaller than that expected from the **DGLAP-based** MC's (which have strong-ordering in k_T going from the protons to the central region).

After tuning the MC's to lower energy data, find smaller $<p_T>$ and larger particle density dN/dy at LHC.

This indicates the need for a **BFKL-based** MC (with multi-Pomeron absorptive corrections), where we have diffusion in log k_T and a growth of particle density as we go to large initial energy, that is smaller x.

Ostapchenko (based on Kaidalov and co-workers)
Lund dipole cascade model (Flensburg,Gustafson,Lonnblad)
SHRiMPS (SHERPA) based on KMR model

Existing “all purpose” (DGLAP) Monte Carlos split eikonal

$$\Omega(s,b) = \Omega_{soft} + \Omega_{hard(pQCD)}$$

Seek MC that describes all aspects of minimum bias
-- total, differential elastic Xsections, diffraction, jet prod...—
in a unified framework; capable of modelling exclusive
final states.

SHERPA Monte Carlo based on KMR framework

“SHRiMPS” MC
= **S**oft-**H**ard **R**eactions **i**nvolving **M**ulti-**P**omeron **S**catt.

Krauss, Hoeth, Zapp et al

OUTLINE of SHRiMPS:

Solve coupled evol eqs. in y to generate $\Omega(y,k_t,b)$, specifying boundary conditions of GW eigenstates. Eigenstates give elastic, quasi-elastic scatt.

Select no. of ladders exchanged (according to Poisson distribution with parameter $\Omega_{ik}(b)$) to simulate inelastic state

Incoming protons dissolved into val. q, diquark and gluons

A random pair chosen to exchange next ladder

Gluon emissions from ladder according to Markov chain, ordered in y, with pseudo Sudakov form factor

t-ch propagators are reggeized gluon in either colour singlets or octets. Prob(singlet) = $P_1 = (1-\exp(-\delta\Omega/2))^2$

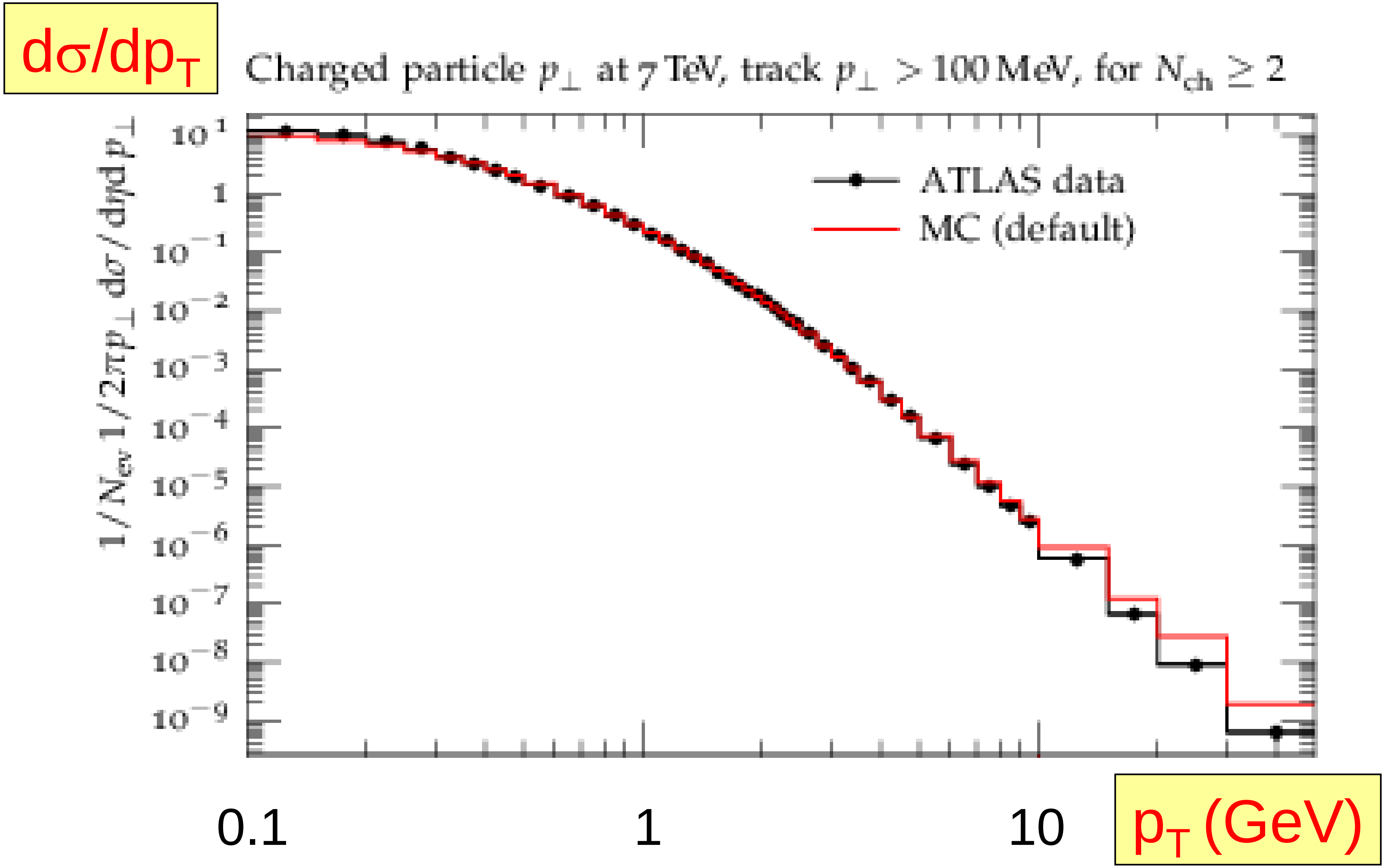
Each gluon emission leads to two new propagators---allowed combinations P_1P_8, P_8P_1, P_8P_8-----singlet propagators give rise to rapidity gaps associated with elastic scatt.

Also rescatt. can give inelastic interaction of secondaries, producing new ladders with Poisson prob. $\exp(-\delta\Omega)(\delta\Omega)^n/n!$

single gluon emission iterated until active interval is colour singlet or no further emissions are kinematically allowed in rapidity interval

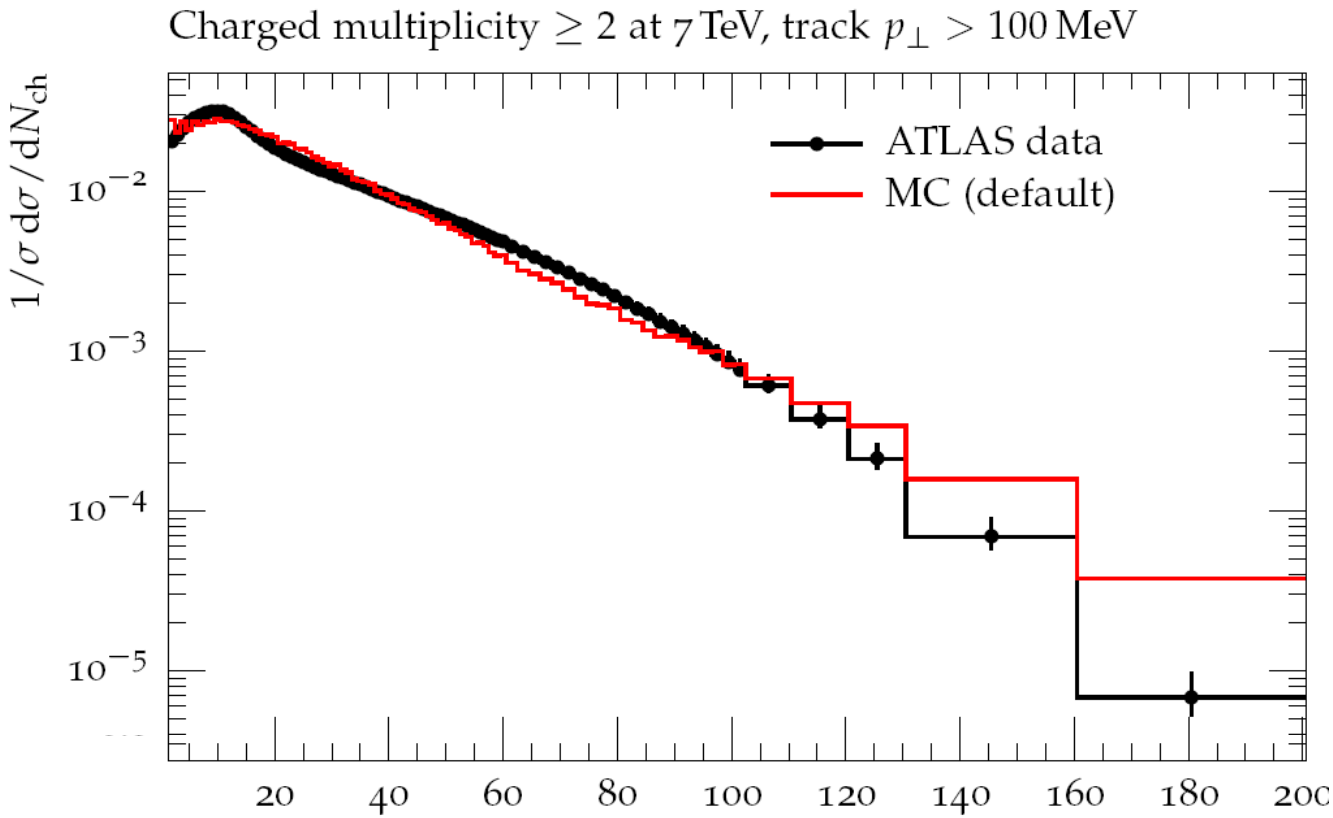
Finally usual hadronization, plus hadron decays, plus QED, to produce final scatter of observed particles.

A few typical plots from SHRiMPS Monte Carlo (in SHERPA) →

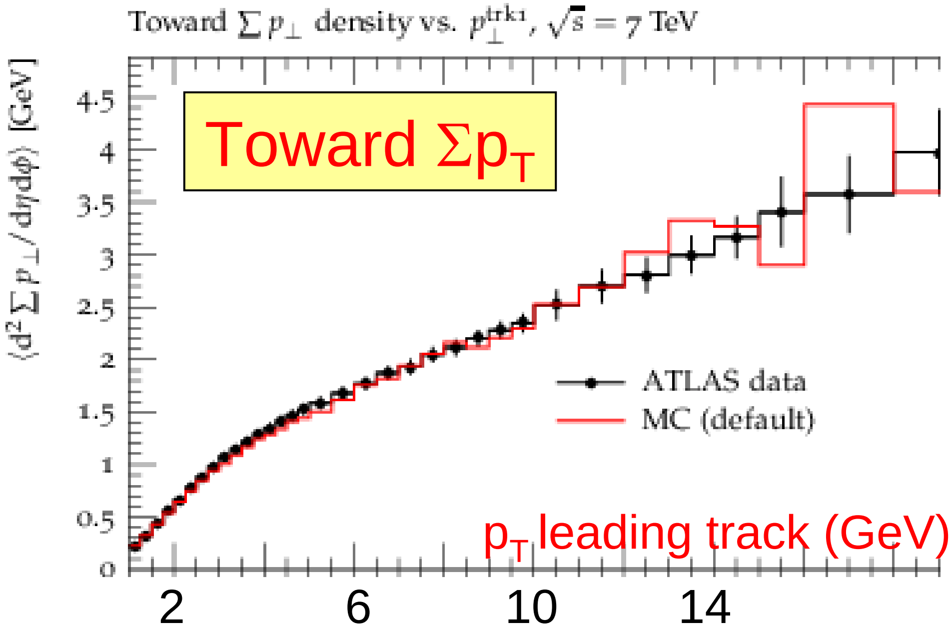


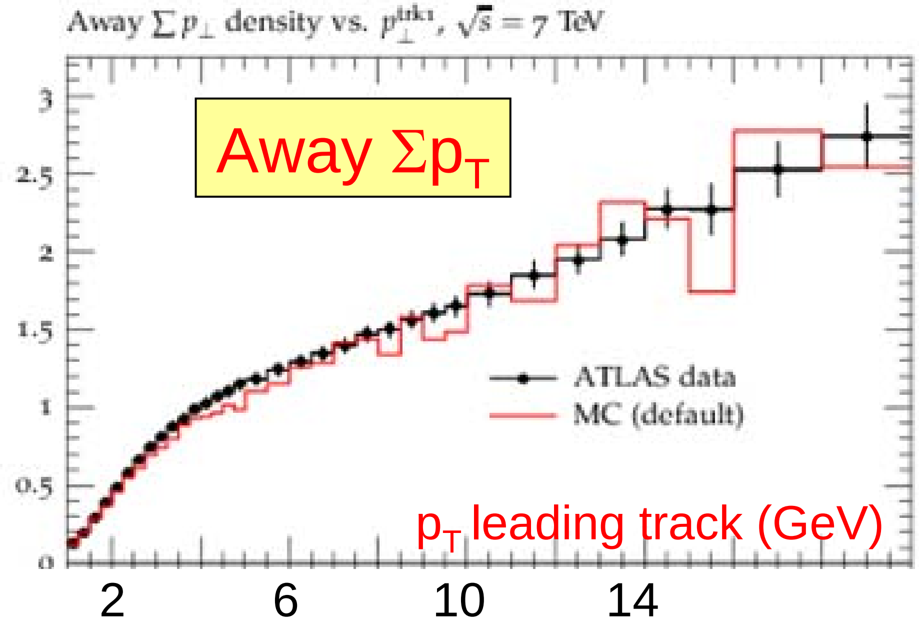
dσ/dp_T
Charged particle p⊥ at 7 TeV, track p⊥ > 100 MeV, for N_ch ≥ 2
1 / N_ev 1 / 2πp⊥ dσ / dηdp⊥
10^1
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
ATLAS data
MC (default)
0.1
1
10
p_T (GeV)

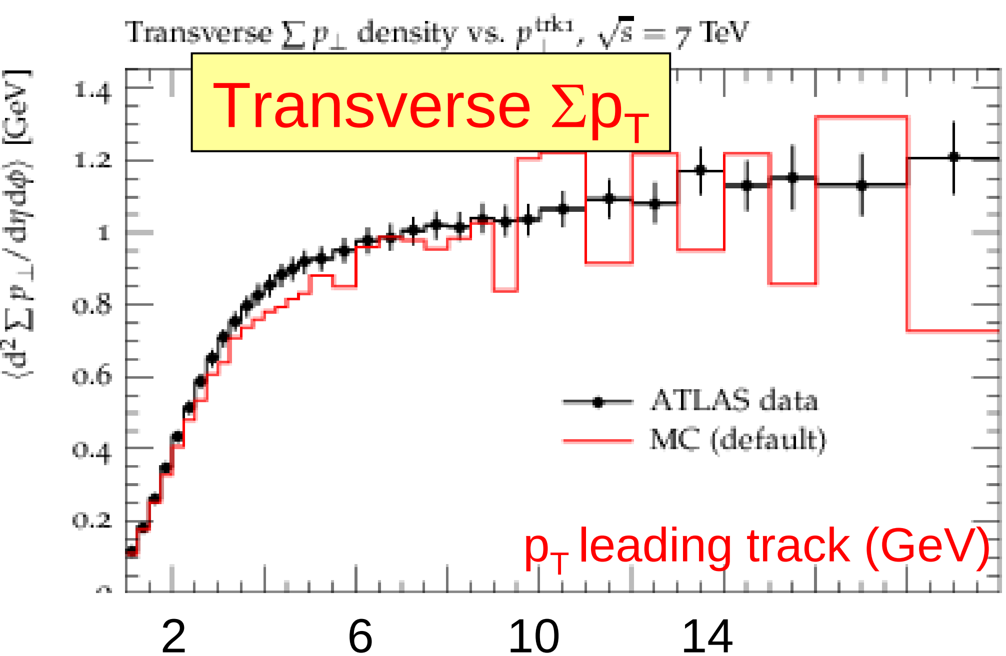
$1/\sigma \; d\sigma/dN_{ch}$

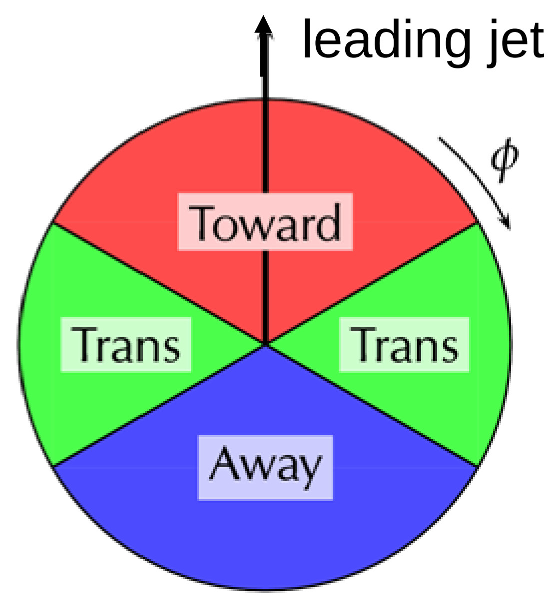


N_{ch}

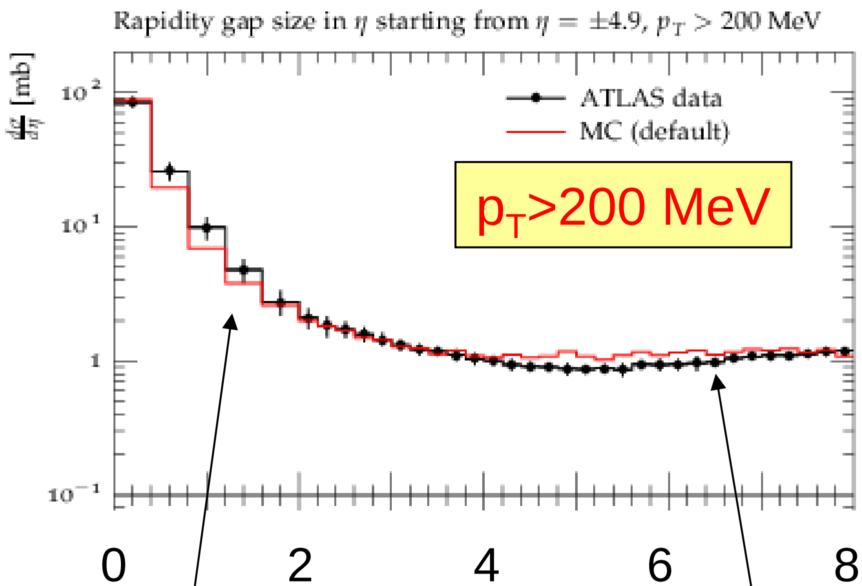

Toward ∑ $p_\perp$ density vs. $p_\perp^{trk1}$, $\sqrt{s}$ = 7 TeV
Toward Σp_T
$\langle d^2 \sum p_\perp / d\eta d\phi \rangle$ [GeV]
ATLAS data
MC (default)
p_T leading track (GeV)
2
6
10
14

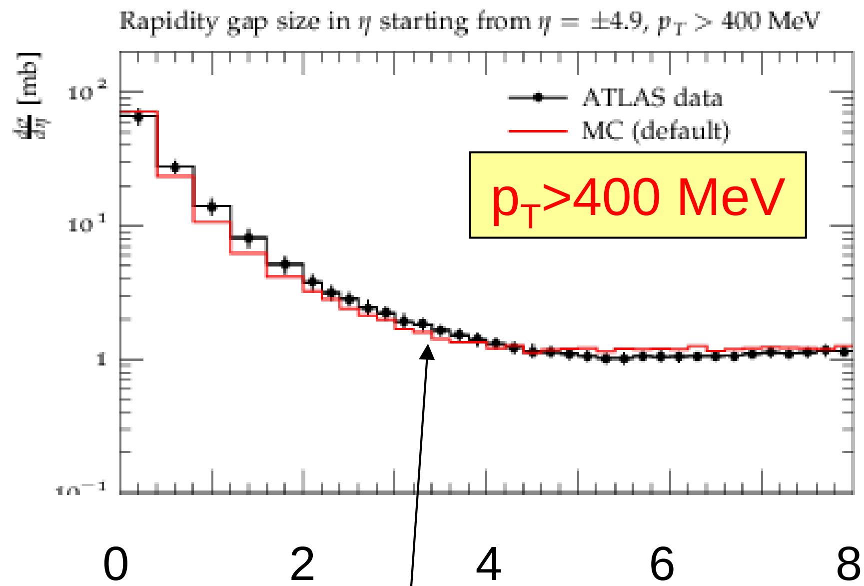

Away ∑ $p_\perp$ density vs. $p_\perp^{trk1}$, $\sqrt{s}$ = 7 TeV
Away Σp_T
ATLAS data
MC (default)
p_T leading track (GeV)
2
6
10
14


Transverse ∑ $p_\perp$ density vs. $p_\perp^{trk1}$, $\sqrt{s}$ = 7 TeV
Transverse Σp_T
$\langle d^2 \sum p_\perp / d\eta d\phi \rangle$ [GeV]
ATLAS data
MC (default)
p_T leading track (GeV)
2
6
10
14


leading jet
ϕ
Toward
Trans
Trans
Away

$d\sigma/d(\Delta\eta)$





fluctuations in hadronization

PPP*S^2

$\Delta\eta$

fluctuations extend to larger $\Delta\eta$

Conclusions on soft-hard high energy pp interactions

- s-ch unitarity is important for elastic, quasi-elastic scatt ; multi-Pomeron exchange diagrams restore unitarity:

- Altho' g_{3P}~$0.3g_N$, high-mass dissoc^n is enhanced: $\sigma_{highM} \sim \sigma_{el}$ at high energy

---

- Soft data can be described by single "effective" pomeron (bare QCD pomeron + multi-pomeron contributions that is, QCD/BFKL pomeron → framework for "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 - SHRiMPS - Krauss et al, which unifies description of particle prod. from soft/hard inter^{ns}

Gives excellent description of observable pts of soft HE inter^{ns}.