Partonic description of soft high-energy pp interactions

- Alternative s- and t-channel definitions of diffraction

- Partonic description of “soft” high-energy pp interactions, including diffraction, in terms of QCD/hard/BFKL-like Pomeron

- “SHRiMPS” Monte Carlo

Alan Martin
Diffraction 2012
Lanzarote, Sept.10-15

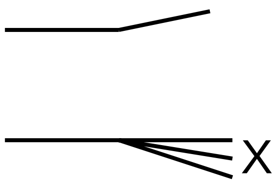
No unique definition of diffraction

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),

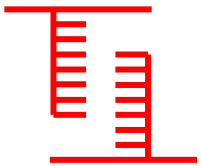
   pp→XX (both protons dissociate, DD)



q.no. of p

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.

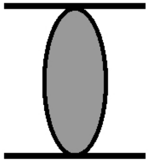
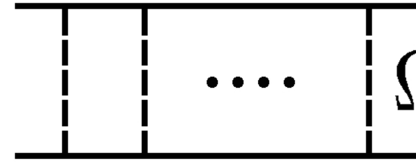
   (or, to be more precise, by the exchange corresponding to the rightmost singularity in the complex angular momentum plane with vacuum quantum numbers).

Only good for very LRG events – otherwise

Reggeon/fluctuation contaminations

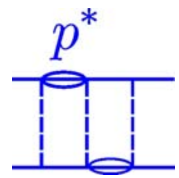
bare amp. $\Omega/2$ = 

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

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

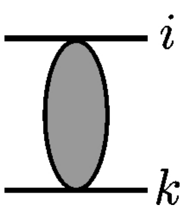
(s-ch unitarity)

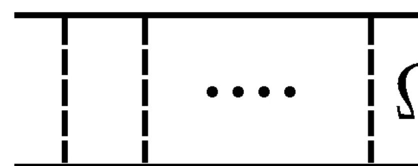
proton dissociation ?

Low-mass diffractive dissociation 

→multichannel eikonal

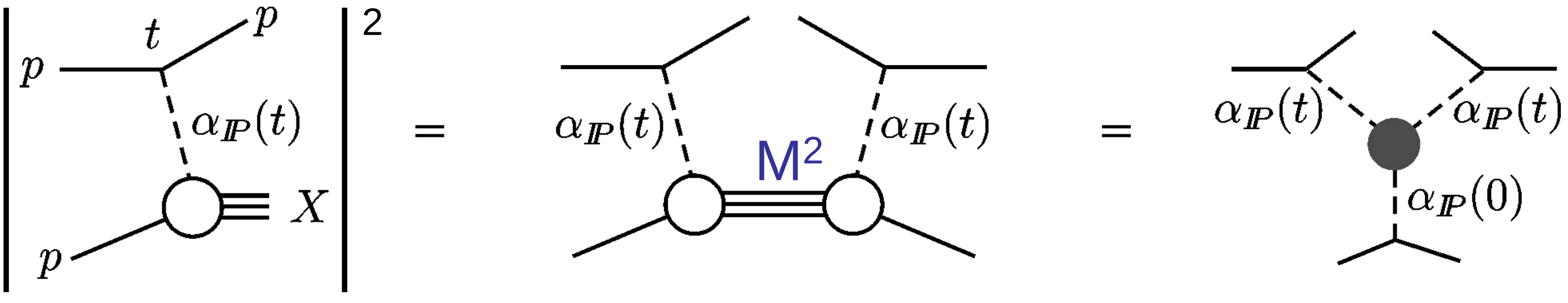
introduce diff[ve] estates ϕ_i, ϕ_k (comb[ns] of p,p*,..) which only undergo "elastic" scattering (Good-Walker)

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

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

what about high-mass diffractive dissociation ?

High-mass diffractive dissociation

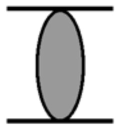
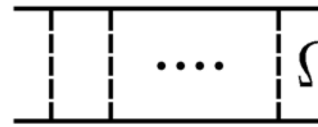


described by triple-Pomeron diagram, plus screening corrections

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

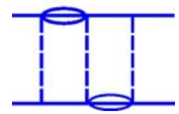
bare amp. $\Omega/2$ = 

(-20%)

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

(s-ch unitarity)

Low-mass diffractive dissociation



→multichannel eikonal

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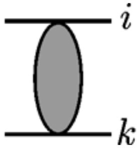
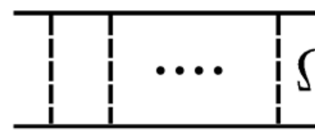
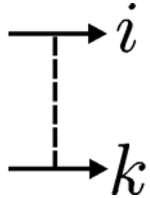
(-40%)

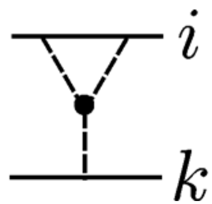
Im T_{ik} = 

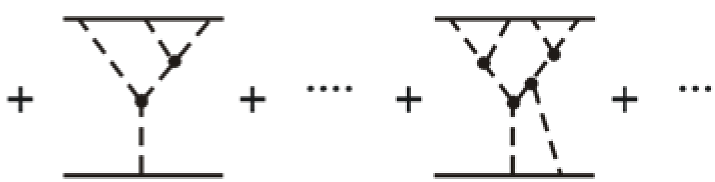
$= 1 - e^{-\Omega_{ik}/2} = \sum$  $\Omega_{ik}/2$

include high-mass diffractive dissociation

(SD -80%)

Ω_{ik} = 

+ 

$\}M$ + 

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

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

up to Tevatron energies

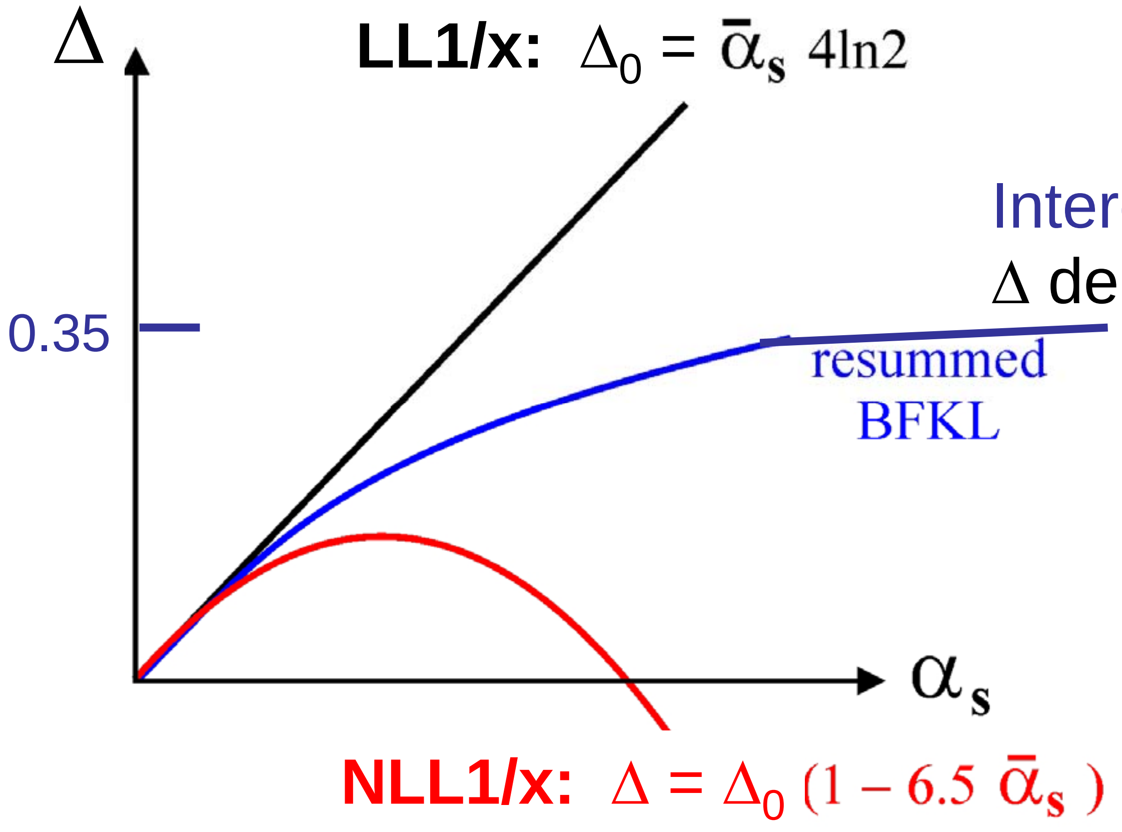
with absorptive
(multi-Pomeron) effects

$\alpha_P^{bare} \sim 1.35 + 0\ t$

small

BFKL stabilized

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



Intercept $\Delta = \alpha_P(0) - 1 \sim 0.35$

Δ depends weakly on k_t for low k_t

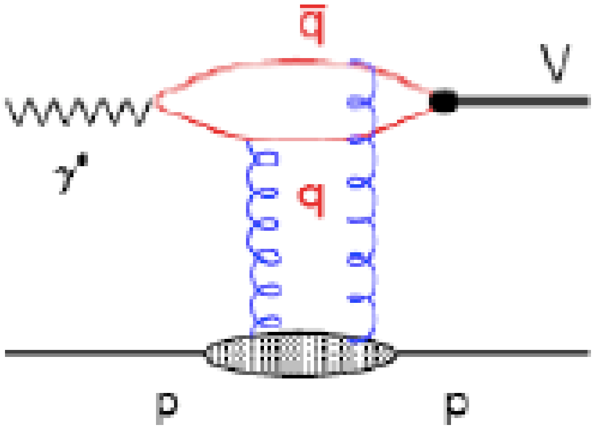
DGLAP: $\alpha_s \ln Q^2$
BFKL: $\alpha_s \ln 1/x$

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

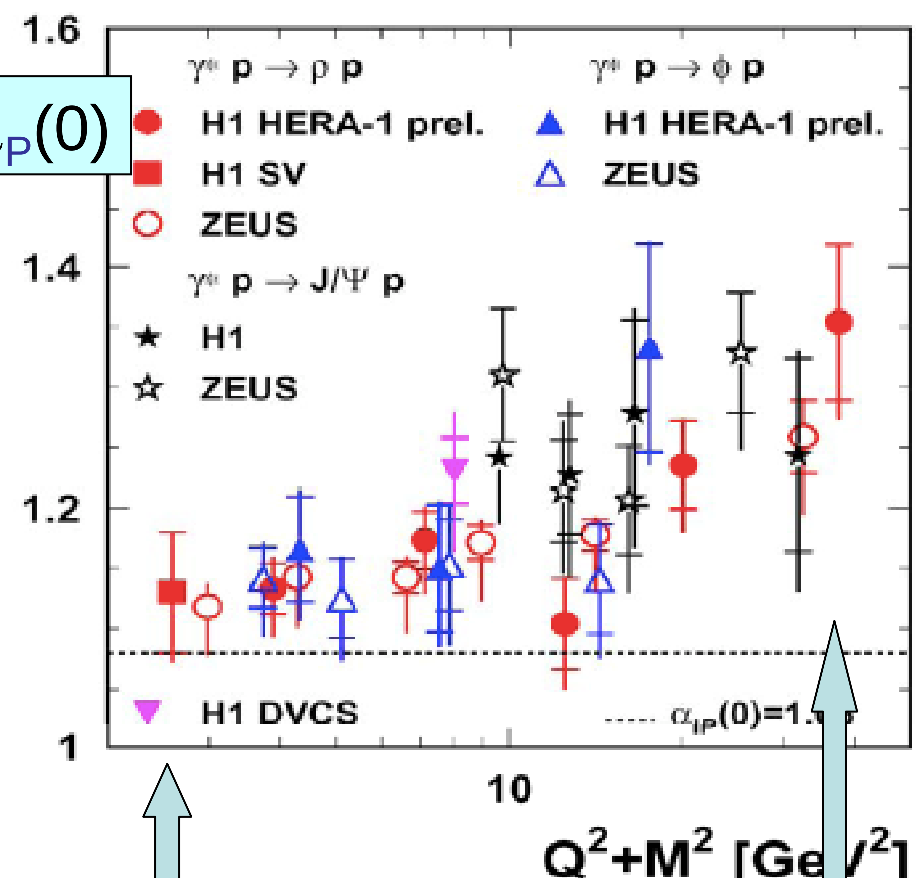
Vector meson prod^{n} at HERA
~ bare QCD Pom. at high Q^2
~ no absorption

hard energy dependences

Q^2



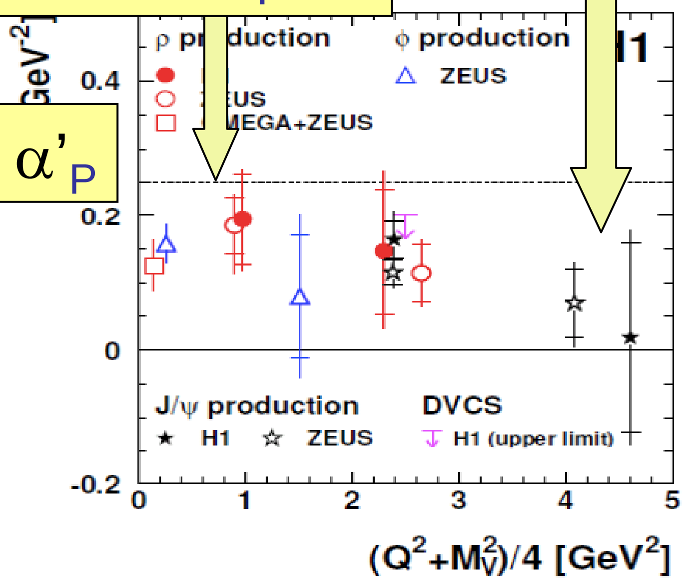
$\alpha_P(0)$



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

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

α'_P

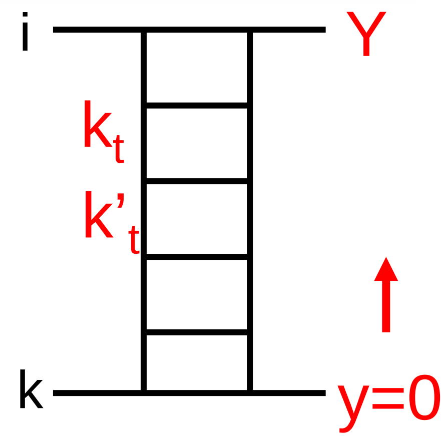


$\alpha_P(0) \sim 1.1$
after absorption

$\alpha_P^{bare}(0) \sim 1.35$

Partonic structure of "bare" Pomeron

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



BFKL evol^n in rapidity generates ladder

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

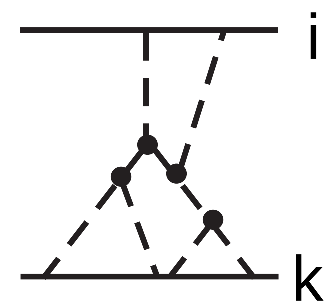
- At each step k_t and b of parton can be be changed – so, in principle, we have 3-variable integro-diff. eq. to solve

Khoze,Martin,Ryskin

- **Inclusion of k_t crucial to match soft and hard domains. Moreover, embodies less screening at larger k_t .**
- KMR model uses simplified form of the kernel K with the main features of BFKL – diffusion in log k_t^2, $\Delta = \alpha_P(0) - 1 \sim 0.35$
- 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 $\Longrightarrow$ $\boxed{\Omega = \Omega_{ik}(y, k_t, b)}$

Multi-Pomeron contributions

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

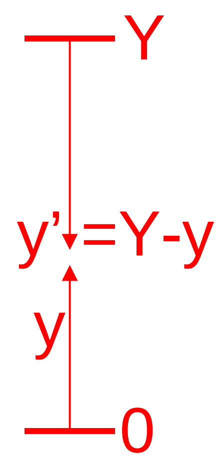


evolve up from y=0

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

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~0.3

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
- 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:

Gotsman,Levin,Maor have similar multi-Pomeron model as KMR, except that they do not include the k_T dependence (the internal structure) of the Pomeron.

Status report on "SHRiMPS" Monte Carlo

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.

Incorporate the KMR model in SHERPA MC framework

Krauss, Hoeth, Zapp + KMR

KMR model is based on bare QCD Pomeron, with
absorptive multi-Pomeron rescattering corrections →
"SHRiMPS" MC
= **S**oft-**H**ard **R**eactions **i**nvolving **M**ulti-**P**omeron **S**catt.

Special properties of “SHRiMPS” Monte Carlo

- Based on partonic model of Pomeron, which enables **BFKL-like** structure to be continued into soft domain, increasingly subject to absorptive corrections

- Stronger absorption of low k_T partons automatically gives effective infrared cutoff k_{min} which increases with collider energy
  (Existing general purpose **DGLAP-based** MCs have external parameter giving an energy dependent cutoff.
  “BFKL-like diffusion in lnk_T + absorption of low k_T”
  can be approximately mimicked by DGLAP)

- Consistently includes low-mass diffraction, via 2-channel eikonal.

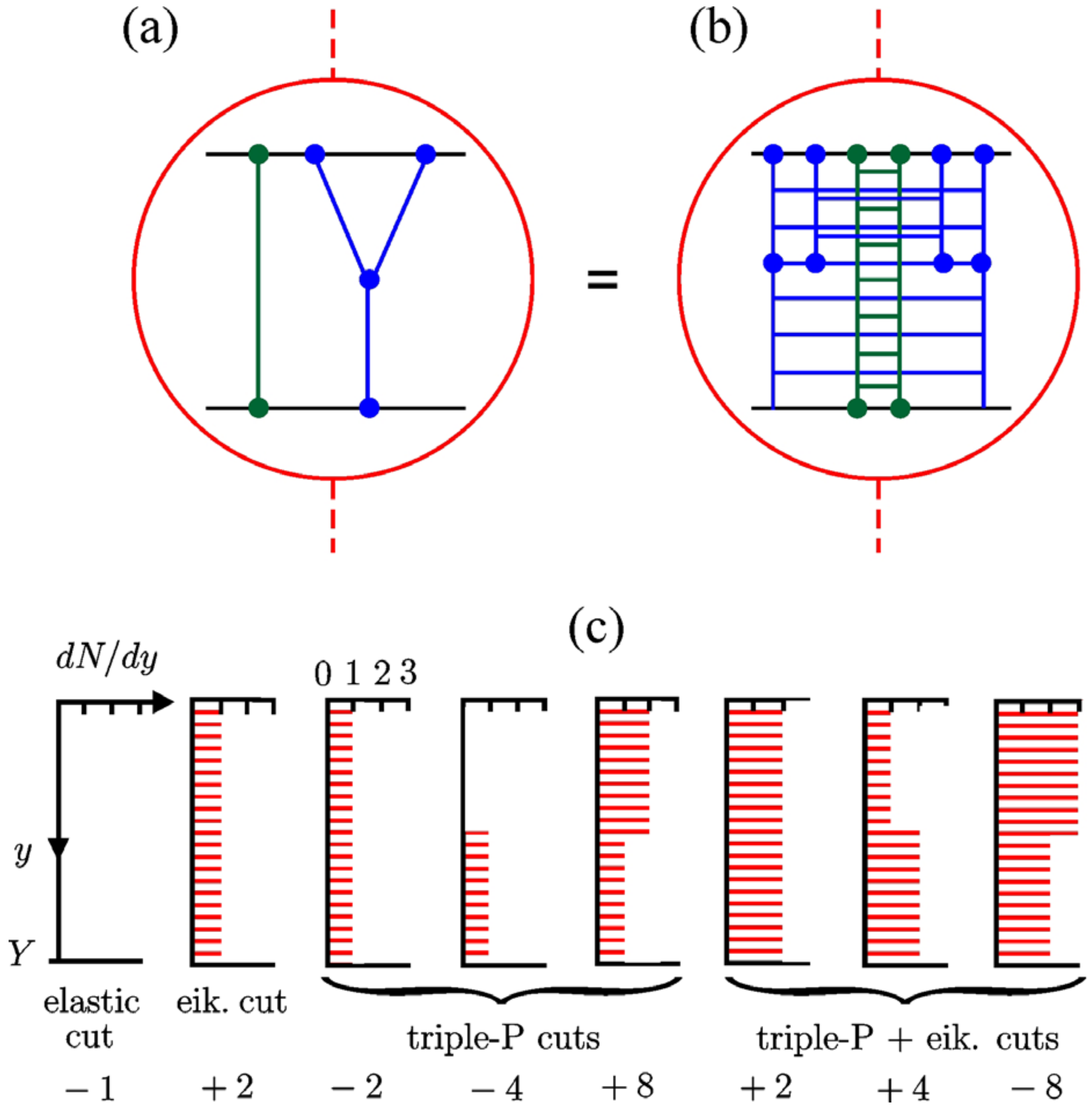
Special properties of "SHRiMPS" MC continued

- Consistent inclusion of (absorptive) multi-Pomeron effects.

  A multi-Pomeron diagram simultaneously describes several different processes depending on which Pomeron ladders are cut
  (i) multiparticle production results from "cut" ladders
  (ii) processes with rapidity gaps (no cut ladders in gap)

example →

Example: 8 ways to cut Pomeron ladders in this diagram



Special properties of "SHRiMPS" MC continued

- Consistent inclusion of (absorptive) multi-Pomeron effects. A multi-Pomeron diagram simultaneously describes several different processes depending on which Pomeron ladders are cut
  (i) multiparticle production results from "cut" ladders
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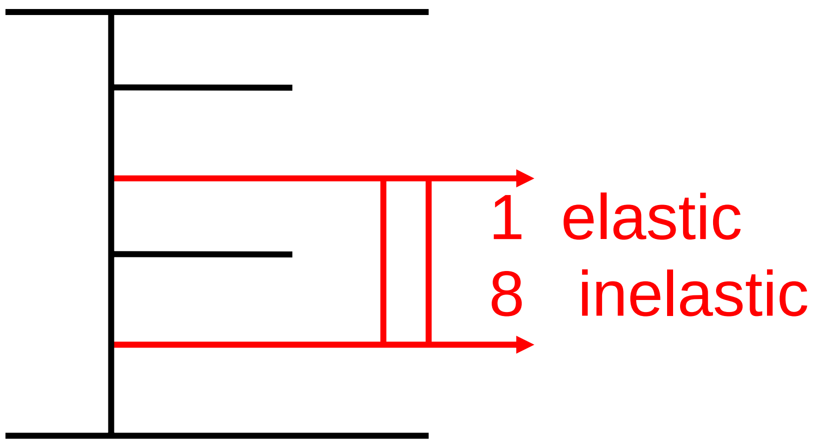
- Moreover, account not only for multiple interactions of incoming particles, but also the possibility of additional (elastic and inelastic rescattering) interactions of new partons produced by previous ladder.



iterate until kinematically forbidden

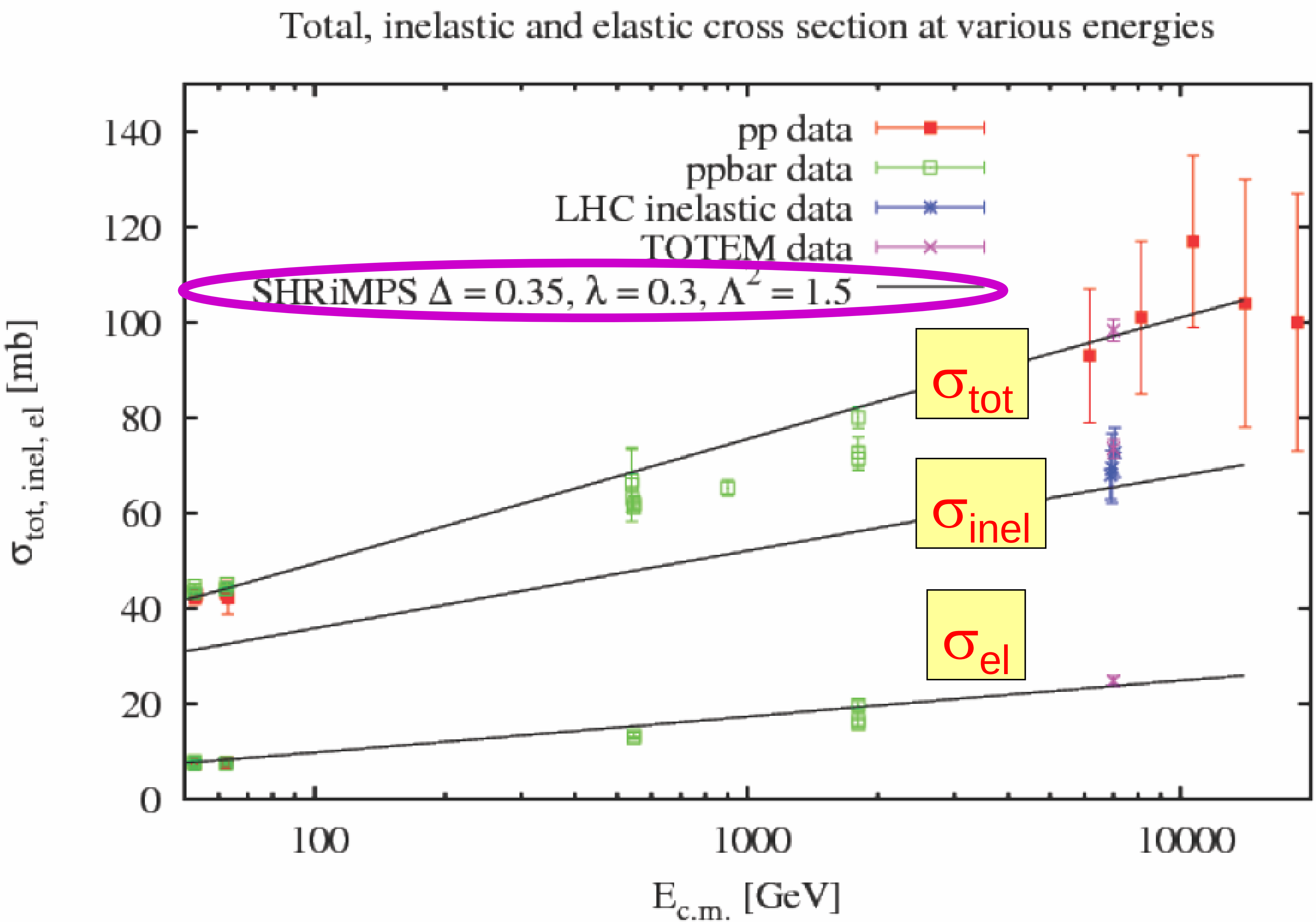
Special properties of "SHRiMPS" MC continued

- If we have hard interaction then multiplicity of secondaries enhanced by strong gluon emission during DGLAP evolution up to hard scale. Inelastic scattering of these additional partons produces new secondaries, which modify structure of underlying event

- Finally implement parton shower, plus hadronization, plus hadron decays, plus QED

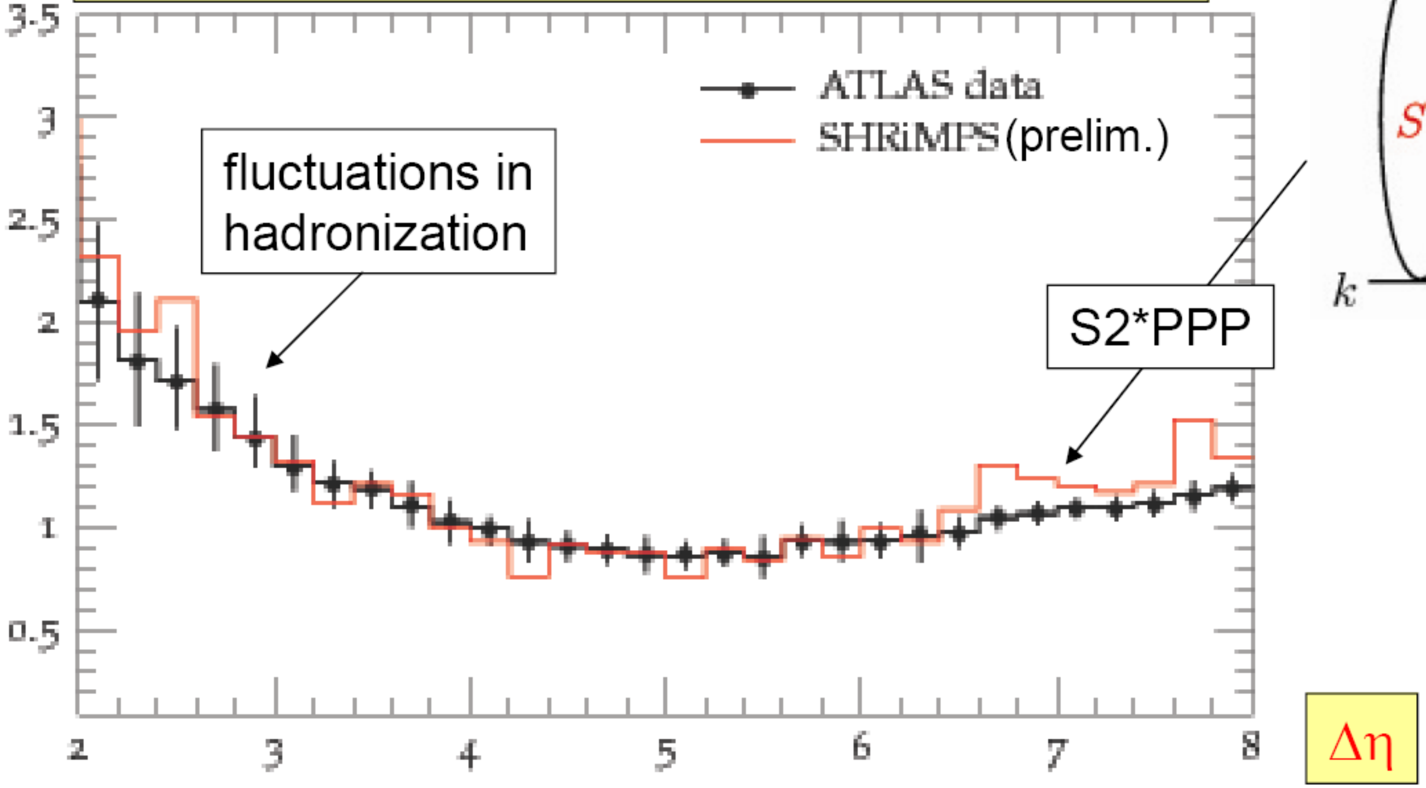
- At present, tuning MC to particle production at LHC, mainly rapidity gaps, minimum bias, and underlying event. Need correct energy dependence 900 GeV → 7 TeV, and interface of parton shower with hard m.e.,….

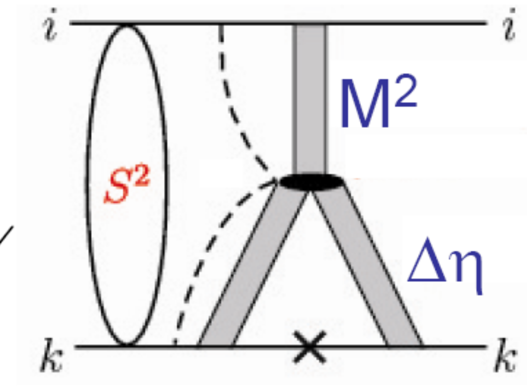
some preliminary plots →



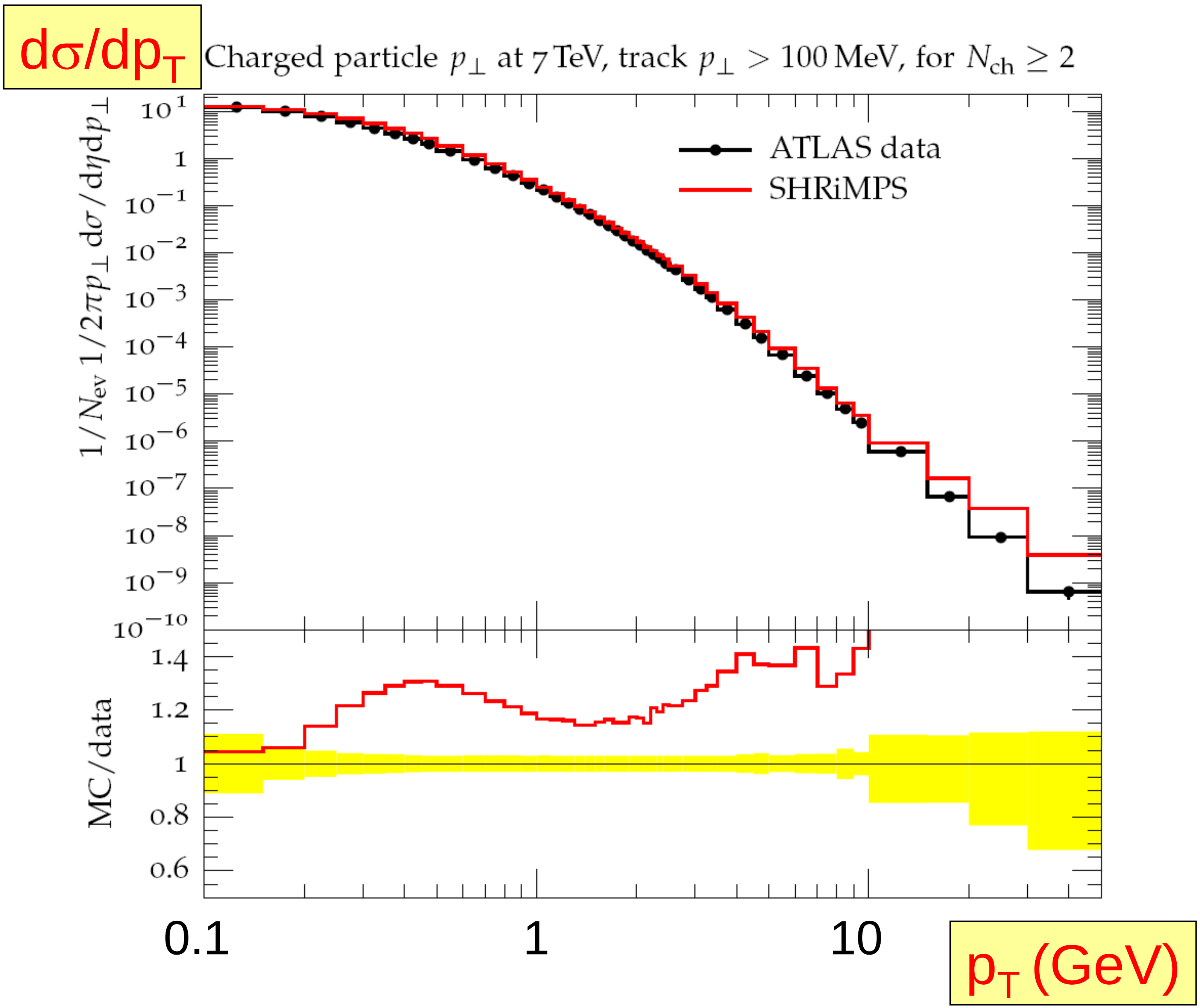
Total, inelastic and elastic cross section at various energies
pp data
ppbar data
LHC inelastic data
TOTEM data
SHRiMPS Δ = 0.35, λ = 0.3, Λ² = 1.5
σ_tot
σ_inel
σ_el
σ_tot, inel, el [mb]
E_c.m. [GeV]
0
20
40
60
80
100
120
140
100
1000
10000

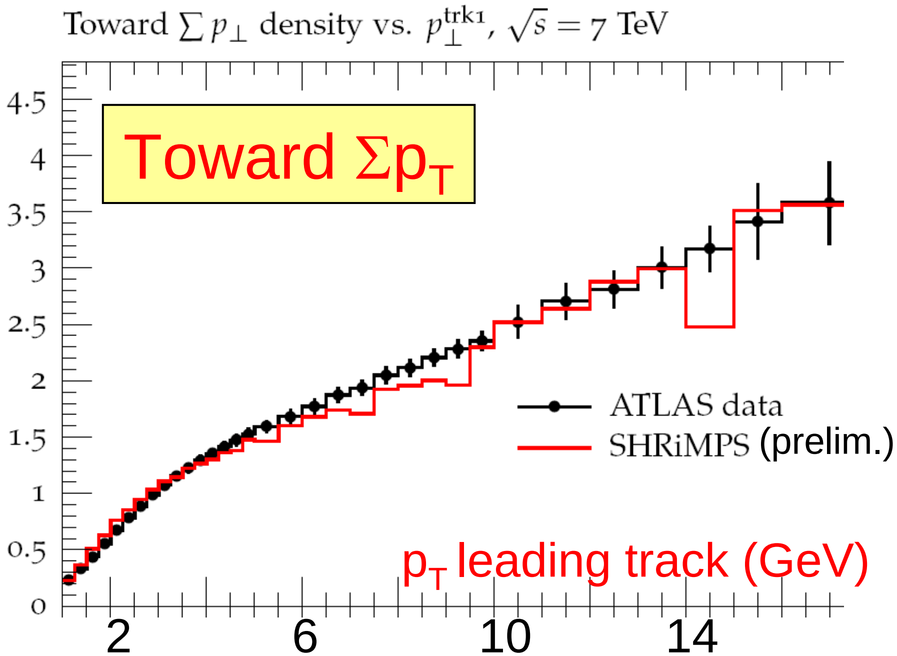
$(d\sigma_{inel}/d(\Delta\eta))$ for particles with p_T>200 MeV

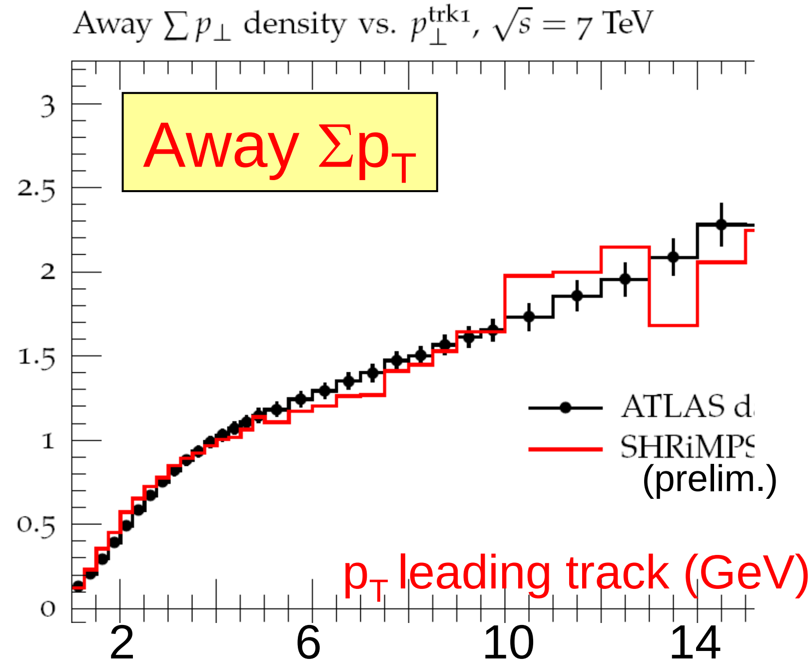


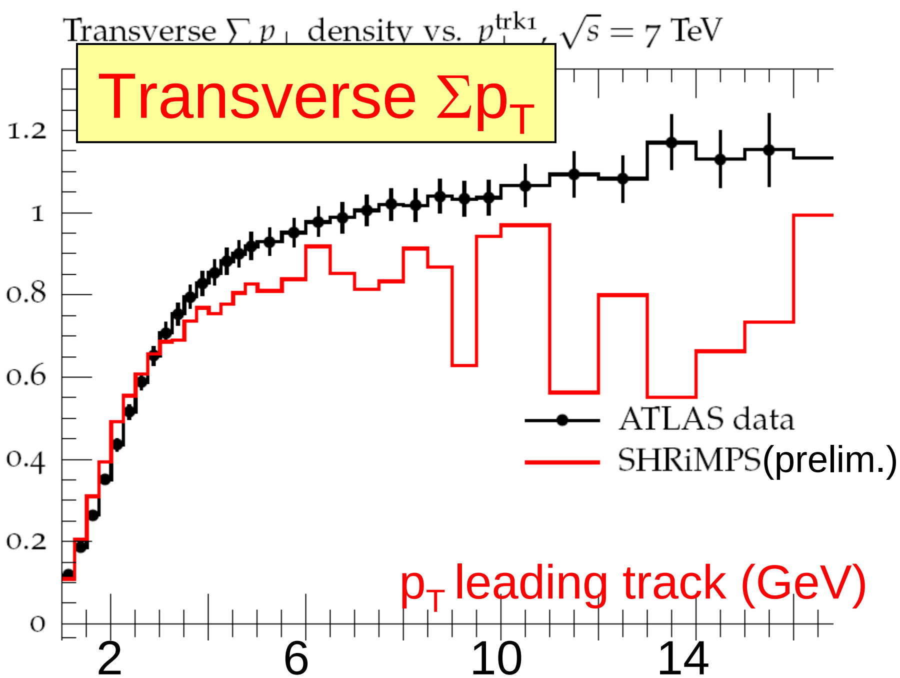


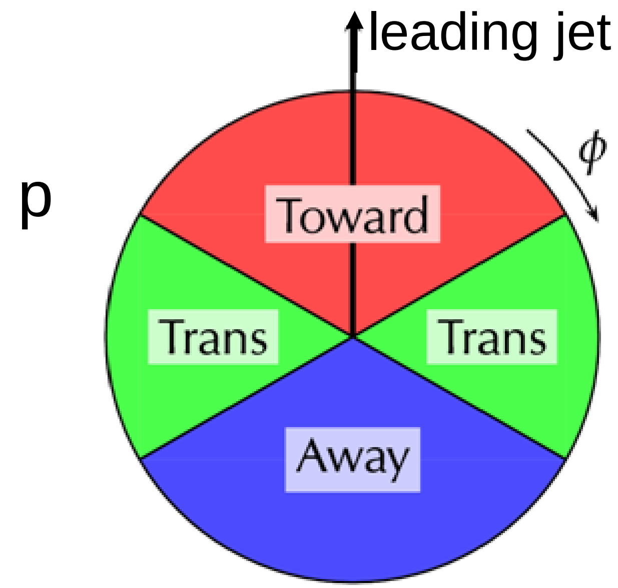
$\Delta\eta \sim \ln(s/M^2)$


dσ/dp_T
Charged particle p⊥ at 7 TeV, track p⊥ > 100 MeV, for N_ch ≥ 2
1/N_ev 1/2πp⊥ dσ/dηdp⊥
ATLAS data
SHRiMPS
MC/data
0.1
1
10
p_T (GeV)

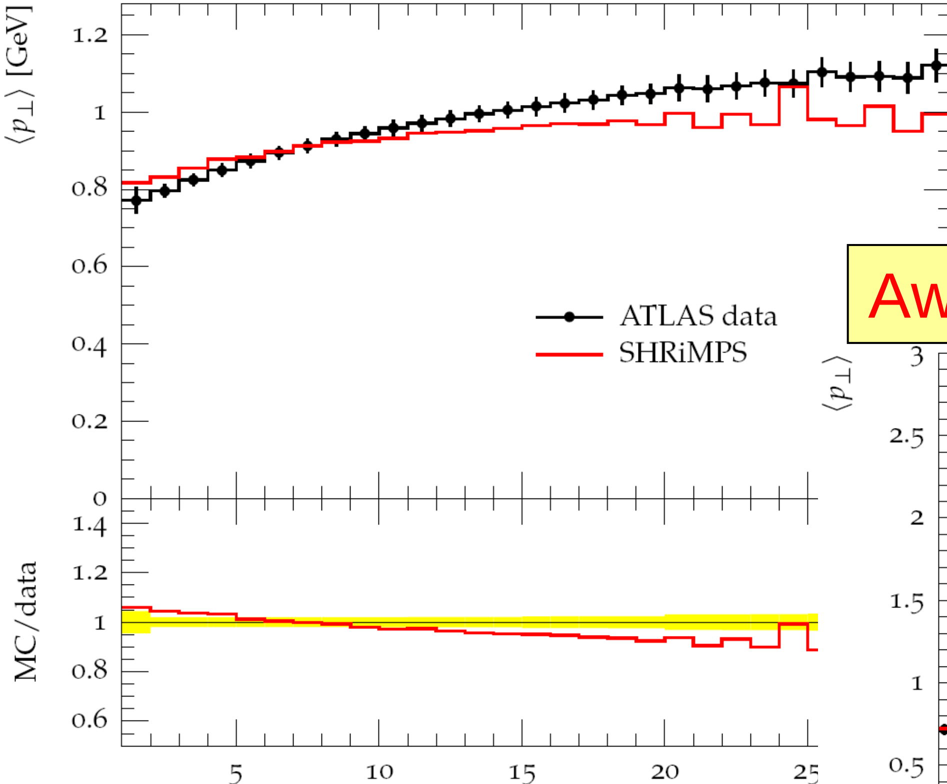

Toward $\sum p_\perp$ density vs. $p_\perp^{\mathrm{trk1}}$, $\sqrt{s} = 7$ TeV
Toward Σp_T
ATLAS data
SHRiMPS (prelim.)
p_T leading track (GeV)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
2
6
10
14


Away $\sum p_\perp$ density vs. $p_\perp^{\mathrm{trk1}}$, $\sqrt{s} = 7$ TeV
Away Σp_T
(prelim.)
p_T leading track (GeV)
0
0.5
1
1.5
2
2.5
3
2
6
10
14


Transverse Σp_T
ATLAS data
SHRiMPS(prelim.)
p_T leading track (GeV)
0
0.2
0.4
0.6
0.8
1
1.2
2
6
10
14

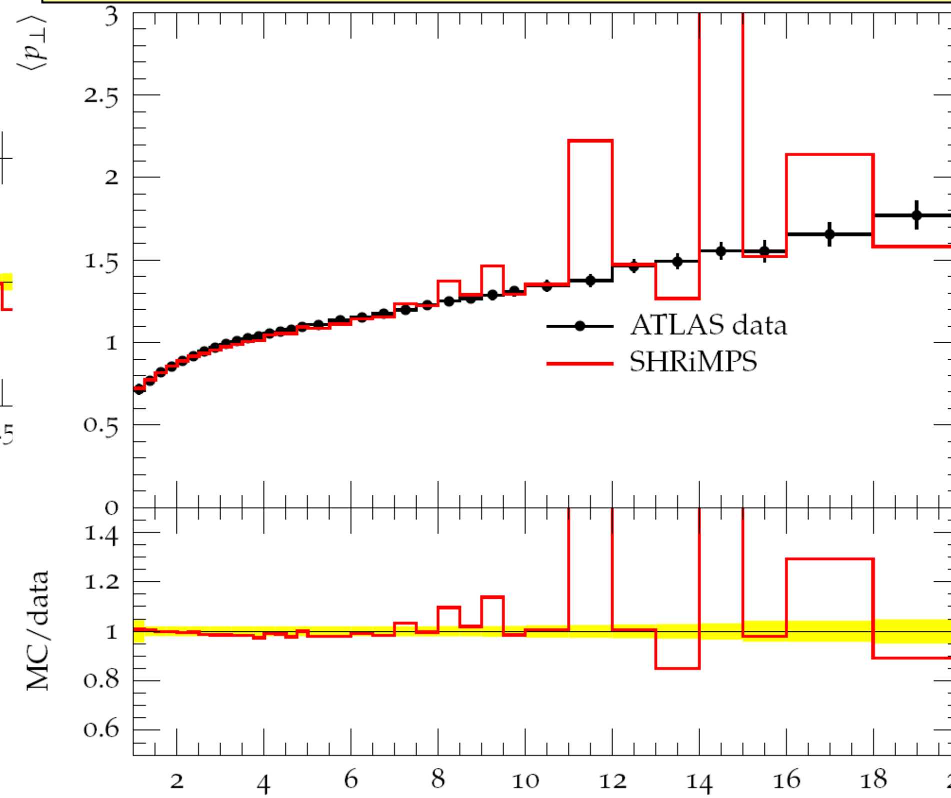

leading jet
ϕ
p
Toward
Trans
Trans
Away

Away $\langle p_T \rangle$ v N_{ch}



N_{ch}

Away $\langle p_T \rangle$ v p_T(leading track)



p_T(leading track) GeV

Conclusion

High-energy soft pp interactions may be described by the continuation of QCD/BFKL-like Pomeron into the low k_T domain, where it suffers increasingly from multi-Pomeron absorptive corrections, which automatically provides low k_T effective cutoff

Such a model forms the basis of an "all purpose" Monte Carlo -- SHRiMPS

3-ch eikonal description of elastic pp data