Minimum Bias with SHRiMPS in SHERPA

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LIP Lisbon & CERN

Collective effects in small collision systems, CERN
15. 6. 2017

Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

Outline

Introduction

KMR model in a nutshell

SHRiMPS model: exclusive final states

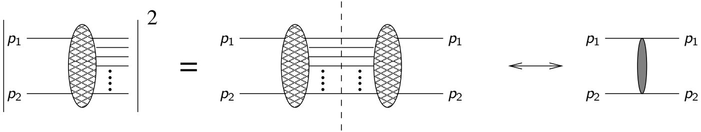
Comparison to data

Wrap-up

Introduction

- optical theorem

$$\sigma_{\text{tot}}(s) = \frac{1}{s}\,\text{Im}[\mathcal{A}_{\text{el}}(s, t=0)]$$

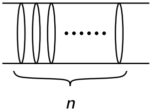


- grey blob: exchange of vacuum quantum numbers
- compute $\mathcal{A}_{\text{el}}$
  - Khoze-Martin-Ryskin (KMR) model
- cut to obtain differential total cross section
  - allows for MC event generation
  - SHRiMPS model

    Soft and Hard Reactions involving Multi-Pomeron Scattering

Eikonal models

- eikonal ansatz:

$$A(s,b) = i\left(1 - e^{-\Omega(s,b)/2}\right) = i\sum_{n=1}^{\infty}$$ 

- Good-Walker states (diffractive eigenstates):

$$|p\rangle = \sum_{i=1}^{N_{\mathrm{GW}}} a_i|\phi_i\rangle$$

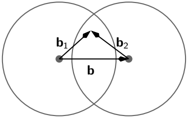
- allows for low mass diffractive excitations
- one single-channel eikonal Ω_{ik} per combination of Good-Walker states

$$\left(1 - e^{-\Omega(s,b)/2}\right) \to \sum_{i,k=1}^{N_{\mathrm{GW}}} |a_i|^2|a_k|^2\left(1 - e^{-\Omega_{ik}(s,b)/2}\right)$$

KMR approach

eikonal Ω_{ik}: product of two parton densities $\omega_{i(k)}$

$$\Omega_{ik}(s, \mathbf{b}) = \frac{1}{2\beta_0^2} \int d\mathbf{b}_1 d\mathbf{b}_2 \, \delta^2(\mathbf{b} - \mathbf{b}_1 + \mathbf{b}_2) \omega_{i(k)}(y, \mathbf{b}_1, \mathbf{b}_2) \omega_{(i)k}(y, \mathbf{b}_1, \mathbf{b}_2)$$



- $\omega_{i(k)}$: density of GW state i in presence of state k
- $\omega_{i(k)}$ obey evolution equation in rapidity
- boundary conditions: form factors

here: dipole form

KMR model: evolution equations

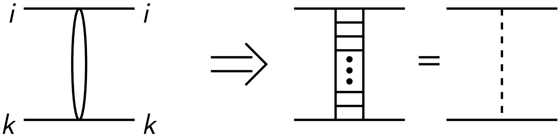
Bare Pomeron Contribution

- evolution equation for parton density

$$\frac{d\omega_{i(k)}(y)}{dy} = \Delta\omega_{i(k)}(y)$$
$$\frac{d\omega_{(i)k}(y)}{dy} = \Delta\omega_{(i)k}(y)$$

where $\Delta = \alpha_{\mathbb{P}}(0) - 1$

probability for emitting an additional gluon per unit rapidity



KMR model: evolution equations

Rescattering

- high density & strong coupling regime $\rightarrow$ rescattering

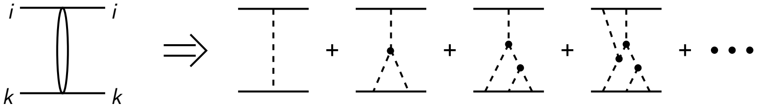
large triple pomeron vertex

- sum over rescattering/absorption diagrams on k and i

$$\frac{d\omega_{i(k)}(y)}{dy} = \Delta\omega_{i(k)}(y) \left[\frac{1-e^{-\lambda\omega_{i(k)}(y)/2}}{\lambda\omega_{i(k)}(y)/2}\right] \left[\frac{1-e^{-\lambda\omega_{(i)k}(y)/2}}{\lambda\omega_{(i)k}(y)/2}\right]$$

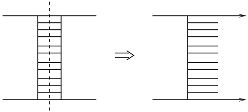
$$\frac{d\omega_{(i)k}(y)}{dy} = \Delta\omega_{(i)k}(y) \left[\frac{1-e^{-\lambda\omega_{i(k)}(y)/2}}{\lambda\omega_{i(k)}(y)/2}\right] \left[\frac{1-e^{-\lambda\omega_{(i)k}(y)/2}}{\lambda\omega_{(i)k}(y)/2}\right]$$

with $\lambda = g_{3\mathbb{P}}/g_{\mathbb{P}N}$



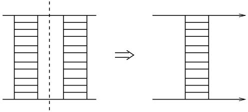
SHRiMPS model

- cutting a simple diagram:



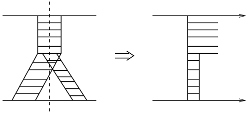
- inelastic scattering

- a even simpler diagram:

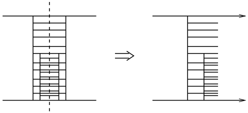


- elastic scattering

- cutting a triple-pomeron vertex:



- colour singlet exchange
- high mass diffraction



- rescattering

Global event properties

select elastic, low-mass diffractive or inelastic mode

according to cross sections

Elastic and low-mass diffractive

- fairly straight forward

Inelastic

- fix combination of colliding GW states

  according to contribution to inelastic cross section

- fix impact parameter
- assume ladders to be independent
- number of ladders: Poissonian with parameter Ω_{ik}
- for each ladder fix transverse position $\mathbf{b}_{1,2}$

Generating Ladders

- decompose protons using infra-red continued pdf's
- generate emissions using pseudo Sudakov form factor

$$\mathcal{S}(y_0, y_1) = \exp\left\{-\int_{y_0}^{y_1} \mathrm{d}y \int \mathrm{d}k_\perp^2 \, \frac{C_A \alpha_s(k_\perp^2)}{\pi k_\perp^2} \times \left(\frac{q_\perp^2}{Q_0^2}\right)^{\frac{C_A}{\pi}\alpha_s(q_\perp^2)\Delta y} \times \left(\frac{1 - e^{\lambda\omega_{i(k)}(y)/2}}{\lambda\omega_{i(k)}(y)/2}\right)\left(\frac{1 - e^{\lambda\omega_{(i)k}(y)/2}}{\lambda\omega_{(i)k}(y)/2}\right)\right\}$$

QCD; Regge weight; rescattering weight

- infra-red continuation
- t-channel propagators can be colour singlets or octets

probabilities for these depend on parton densities and λ

Generating Ladders

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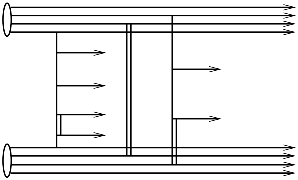
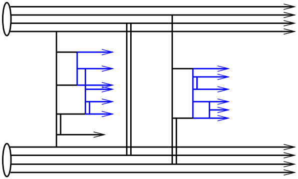


Rescattering & Hadronisation

Rescattering

- partons may exchange rescatter ladders
- rescatters of rescatters of rescatters. . .
- only local rescattering allowed



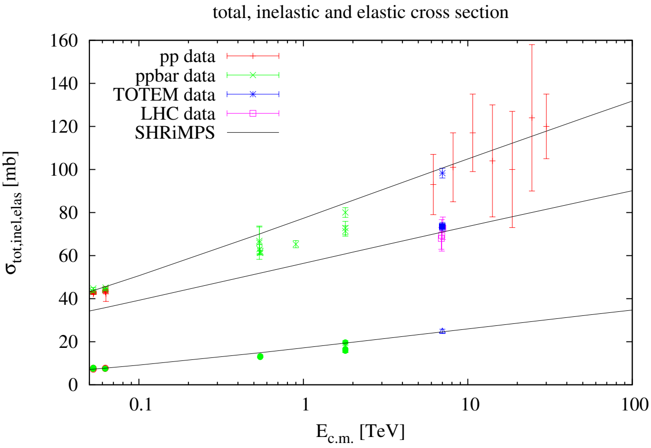
Hadronisation

- colour reconnections
- probability for colour swap decreases with distance

similar to PYTHIA model

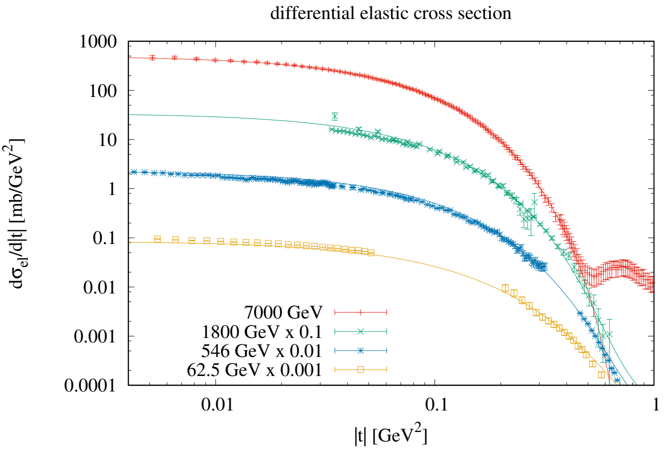
- hadronisation with SHERPA's cluster hadronisation

Cross Sections

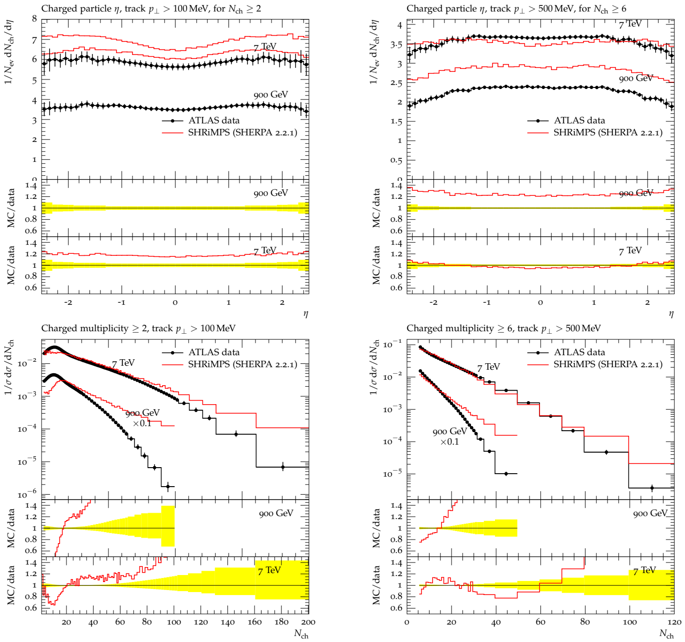


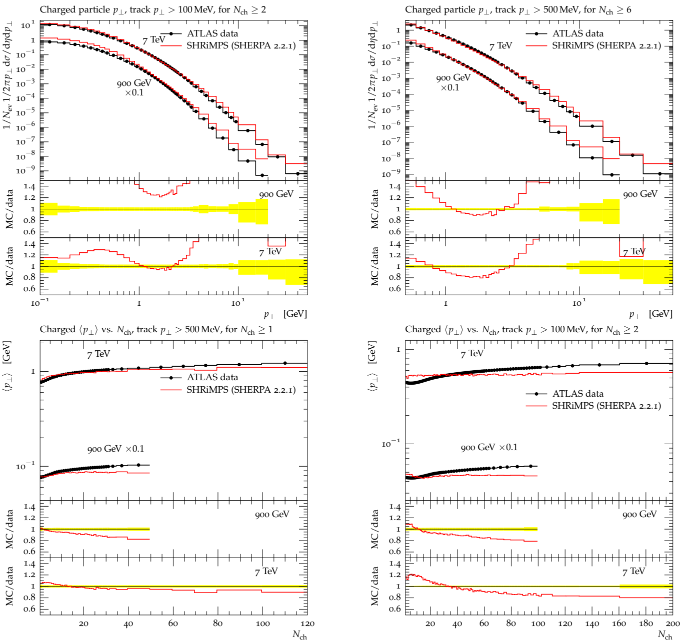
$$\Delta = 0.31,\ \ \lambda = 0.22,\ \ \beta_0^2 = 19\,\text{mb}$$

Differential Elastic Cross Section

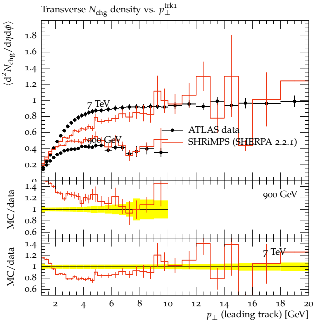


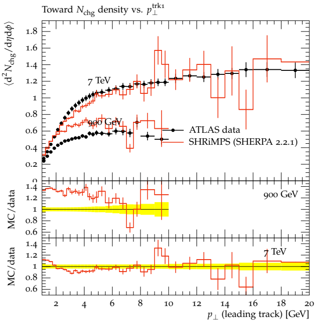
Minimum Bias @900 GeV & 7 TeV

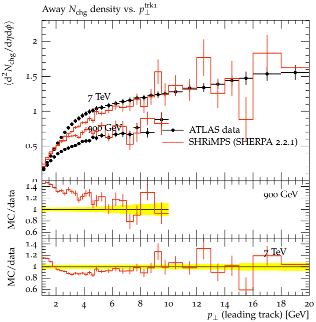



Charged particle $p_\perp$, track $p_\perp > 100$ MeV, for $N_{ch} \geq 2$
ATLAS data
SHRiMPS (SHERPA 2.2.1)
7 TeV
900 GeV
×0.1
$1/N_{ev}\ 1/2\pi p_\perp\ d\sigma/d\eta dp_\perp$
MC/data
900 GeV
7 TeV
$p_\perp$ [GeV]
Charged particle $p_\perp$, track $p_\perp > 500$ MeV, for $N_{ch} \geq 6$
ATLAS data
SHRiMPS (SHERPA 2.2.1)
7 TeV
900 GeV
×0.1
$1/N_{ev}\ 1/2\pi p_\perp\ d\sigma/d\eta dp_\perp$
MC/data
900 GeV
7 TeV
$p_\perp$ [GeV]
Charged $\langle p_\perp \rangle$ vs. N_{ch}, track $p_\perp > 500$ MeV, for $N_{ch} \geq 1$
7 TeV
ATLAS data
SHRiMPS (SHERPA 2.2.1)
900 GeV ×0.1
$\langle p_\perp \rangle$ [GeV]
MC/data
900 GeV
7 TeV
N_{ch}
Charged $\langle p_\perp \rangle$ vs. N_{ch}, track $p_\perp > 100$ MeV, for $N_{ch} \geq 2$
7 TeV
ATLAS data
SHRiMPS (SHERPA 2.2.1)
900 GeV ×0.1
$\langle p_\perp \rangle$ [GeV]
MC/data
900 GeV
7 TeV
N_{ch}

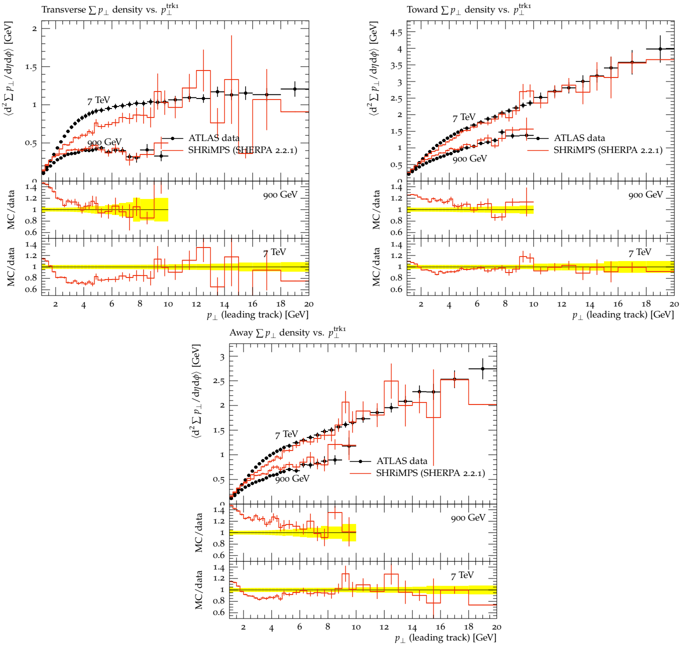
Underlying Event @900 GeV & 7 TeV



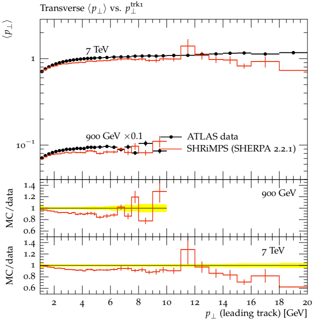


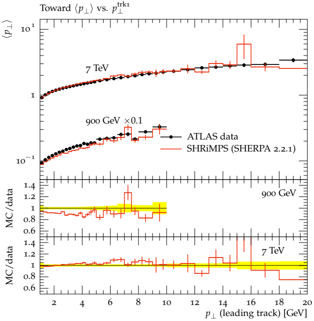


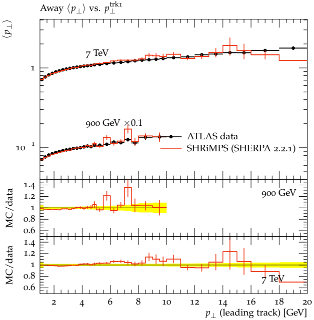
Underlying Event @900 GeV & 7 TeV



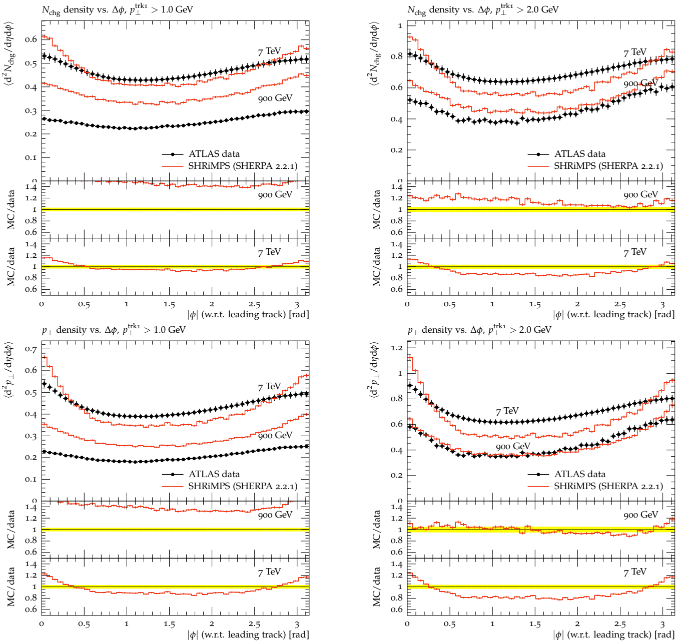
Underlying Event @900 GeV & 7 TeV



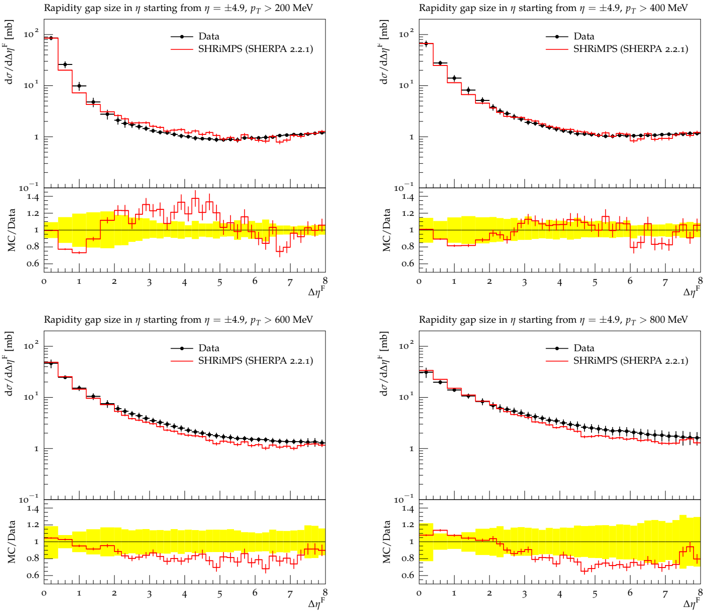




Underlying Event @900 GeV & 7 TeV



Rapidity Gap Cross Section @7 TeV



Status

- model for soft & semi-hard QCD based on KMR model
- complete picture including all interactions
  elastic, low & high mass diffractive, inelastic
- describes data reasonably well, but room for improvements/tuning
  so far only hand tune
- geometry-aware model

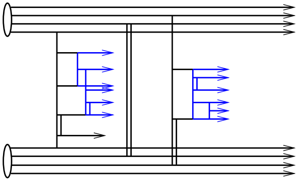
Outlook

- overhaul of exclusive model
- tune
- formulate as underlying event model
- include secondary Reggeons (quarks)
- other improvements

Can SHRiMPS fake signs of collectivity?

The (current) answer is no.

- strangeness enhancement: no quarks
- azimuthal anisotropy: absorption & rescattering local



Can SHRiMPS fake signs of collectivity?

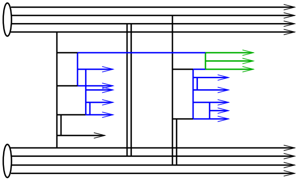
The (current) answer is no.

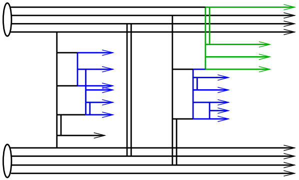
- strangeness enhancement: no quarks
- azimuthal anisotropy: absorption & rescattering local

And in future?

- quarks: are on ToDo list
- non-local absorption/rescattering: conceivable, but not included in KMR model

long term project





s-Channel Unitarity and Cross Sections

- optical theorem relates total cross section σ_{tot} to elastic forward scattering amplitude $\mathcal{A}(s,t)$ through

$$\sigma_{\mathrm{tot}}(s) = \frac{1}{s}\,\mathrm{Im}[\mathcal{A}(s,t=0)]$$

- rewrite $\mathcal{A}(s,t)$ as $A(s,b)$ in impact parameter space

$$\mathcal{A}(s,t=-\mathbf{q}_\perp^2) = 2s\int \mathrm{d}\mathbf{b}\, e^{i\mathbf{q}_\perp\cdot\mathbf{b}} A(s,b)$$

- cross sections

$$\begin{aligned}
\sigma_{\mathrm{tot}}(s) &= 2\int \mathrm{d}\mathbf{b}\,\mathrm{Im}[A(s,b)] \\
\sigma_{\mathrm{el}}(s) &= 2\int \mathrm{d}\mathbf{b}\,|A(s,b)|^2 \\
\sigma_{\mathrm{inel}}(s) &= \sigma_{\mathrm{tot}}(s) - \sigma_{\mathrm{el}}(s)
\end{aligned}$$

- N.B.: real part of $A(s,b)$ vanishes

Single-Channel Eikonal Model

- cross sections in eikonal model

$$
\begin{aligned}
\sigma_{\text{tot}}(s) &= 2\int d\mathbf{b}\,\left(1 - e^{-\Omega(s,b)/2}\right) \\
\sigma_{\text{el}}(s) &= 2\int d\mathbf{b}\,\left(1 - e^{-\Omega(s,b)/2}\right)^2 \\
\sigma_{\text{inel}}(s) &= \int d\mathbf{b}\,\left(1 - e^{-\Omega(s,b)}\right)
\end{aligned}
$$

Multi-Channel Eikonals

Cross sections with Good-Walker states

- decompose incoming state $|j\rangle = a_{jk}|\phi_k\rangle$ and write
$$\langle j|\mathrm{Im}\mathcal{T}|j\rangle = \sum_k |a_{jk}|^2 T_k \equiv \langle T\rangle$$
- allows to write cross sections as

$$\begin{aligned}
\frac{\mathrm{d}\sigma_{\mathrm{tot}}}{\mathrm{d}\mathbf{b}} &= 2\mathrm{Im}\langle j|\mathcal{T}|j\rangle = 2\langle T\rangle \\
\frac{\mathrm{d}\sigma_{\mathrm{el}}}{\mathrm{d}\mathbf{b}} &= |\langle j|\mathcal{T}|j\rangle|^2 = \langle T\rangle^2 \\
\frac{\mathrm{d}\sigma_{\mathrm{el+SD}}}{\mathrm{d}\mathbf{b}} &= |\langle \phi_k|\mathcal{T}|j\rangle|^2 = \sum_k |a_{jk}|^2 T_k^2 = \langle T^2\rangle \\
\frac{\mathrm{d}\sigma_{\mathrm{SD}}}{\mathrm{d}\mathbf{b}} &= \langle T^2\rangle - \langle T\rangle^2
\end{aligned}$$

- single diffraction given by statistical dispersion of absorption probabilities of diffractive eigenstates

Selecting the Modes

- select elastic vs. inelastic processes according to

$$\sigma^{pp}_{\text{tot}} = 2\int d\mathbf{b} \sum_{i,k=1}^{S} |a_i|^2 |a_k|^2 \left(1 - e^{-\Omega_{ik}(b)/2}\right)$$

$$\sigma^{pp}_{\text{inel}} = \int d\mathbf{b} \sum_{i,k=1}^{S} |a_i|^2 |a_k|^2 \left(1 - e^{-\Omega_{ik}(b)}\right)$$

$$\sigma^{pp}_{\text{el}} = \int d\mathbf{b} \left\{ \sum_{i,k=1}^{S} \left[|a_i|^2 |a_k|^2 \left(1 - e^{-\Omega_{ik}(b)/2}\right)\right]\right\}^2$$

$$\sigma^{pp}_{\text{el+sd}} = \int d\mathbf{b} \sum_{i=1}^{S} |a_i|^2 \left\{ \sum_{k=1}^{S} |a_k|^2 \left(1 - e^{-\Omega_{ik}(b)/2}\right)\right\}^2$$

$$\sigma^{pp}_{\text{el+2sd+dd}} = \int d\mathbf{b} \sum_{i,k=1}^{S} |a_i|^2 |a_k|^2 \left\{\left(1 - e^{-\Omega_{ik}(b)/2}\right)\right\}^2$$

Aside: continued pdf's

- sea (anti)quarks: scale down to vanish as $Q^2 \to 0$
- valence quarks: transform to pure valence contribution as $Q^2 \to 0$
- same shape as valence quarks as $Q^2 \to 0$, scale to satisfy momentum sum rule