A new model for Minimum Bias and the Underlying Event in Sherpa

Korinna Zapp
(with F. Krauss, M. Ryskin, V. Khoze, A. Martin, H. Hoeth)

Institute for Particle Physics Phenomenology
Durham University

CERN 14. 01. 2010

Outline

Motivation

- minimum bias and diffractive physics interesting in its own right (most complete view of physics)
- first day physics at LHC
- intimiate connection to underlying event
- many search strategies (Higgs, ...) at LHC largely rely on event topologies with rapidity gaps $\longrightarrow$ can be filled by underlying event

$\Rightarrow$ important to have model embedding hard and semi-hard QCD, diffraction, elastic scattering

- so far, no such a model has never been directly implemented in a standard MC like
- convincing model for inclusive properties by KMR, started implementing this into SHERPA

s-Channel Unitarity and Cross Sections

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

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

- 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

- in eikonal model elasic amplitude given by sum of all Regge exchange diagrams:

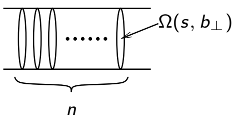
$$A(s,b) = i\left(1 - e^{-\Omega(s,b)/2}\right)$$

- $\Omega(s,b)$ is called eikonal or opacity
- eikonal is Fourier transform of two-particle irreducible amplitude $a(s,q_\perp)$

$$\Omega(s,b) = \frac{-i}{4\pi^2}\int d\mathbf{q}_\perp\, e^{i\mathbf{q}_\perp\cdot\mathbf{b}_\perp}\, a(s,q_\perp)$$

- pictorially:

$$\mathrm{Im}A(s,b) = \sum_{n=1}^{\infty}$$



Multi-Channel Eikonals

Motivation

- impossible to describe "diffractive excitation" (like e.g. $p \longrightarrow N(1440)$) with one eikonal only: such processes are a consequence of the internal structure of the colliding hadrons
- for description employ high-energy limit:
  in this limit the Fock states of the hadrons "frozen",

  (lifetime of fluctuations $\tau = E/m^2$ large)

  and each component can interact separately, destroying coherence of the colliding hadrons

Multi-Channel Eikonals

Good-Walker states

- introduce Good-Walker states (diffractive eigenstates):

$$|p\rangle = \sum_i a_i|\phi_i\rangle, \text{ where } \langle\phi_i|\phi_k\rangle = \delta_{ik} \text{ and } \sum_i |a_i|^2 = 1$$

- these states diagonalise the $\mathcal{T}$-matrix:

$$\langle\phi_i|\mathrm{Im}\mathcal{T}|\phi_k\rangle = T_k^D\delta_{ik}$$

- therefore only "elastic scattering" of these states
- N.B.: use two states (more later),

$$|p,\, N^*\rangle = \frac{1}{\sqrt{2}}\left[|\phi_1\rangle \pm |\phi_2\rangle\right],$$

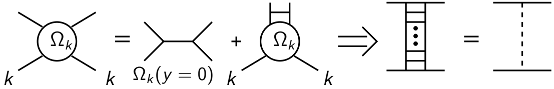
Khoze-Martin-Ryskin Model

Bare Pomeron Contribution

- evolution equation for elastic bare Pomeron exchange amplitude

$$\frac{d\Omega_k(y)}{dy} = \Delta\Omega_k(y)$$

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



- can be interpreted as evolution of parton density of "hadron" k with Δ being probability for emitting an additional gluon per unit rapidity

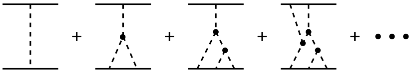
Khoze-Martin-Ryskin Model

Rescattering

- high density & strong coupling regime $\rightarrow$ rescattering important ($\Longleftrightarrow$ large triple pomeron vertex)
- sum over rescattering/absorption diagrams on k and i

$$\frac{d\Omega_k(y)}{dy} = \Delta\Omega_k(y) e^{-\lambda[\Omega_k(y)+\Omega_i(y)]/2}$$

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



- multi-pomeron diagrams give rise to high mass dissociation

Khoze-Martin-Ryskin Model

Eikonal

eikonal given by overlap of parton densities

$$\Omega_{ik}(\mathbf{b}) = \frac{1}{2\beta_0^2}\int \mathrm{d}\mathbf{b}_1\mathrm{d}\mathbf{b}_2\,\delta^2(\mathbf{b}-\mathbf{b}_1-\mathbf{b}_2)\Omega_i(\mathbf{b}_1,\mathbf{b}_2,y)\Omega_k(\mathbf{b}_1,\mathbf{b}_2,y)$$

Cross Sections

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

$$\sigma_{\rm inel}^{pp} = \int \mathrm{d}\mathbf{b}\sum_{i,k=1}^{S}\left\{|a_i|^2|a_k|^2\left[1-e^{-\Omega_{ik}(b)}\right]\right\}$$

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

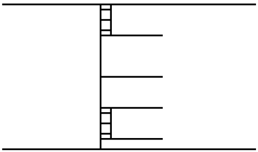
Event Generation

Elastic Scattering

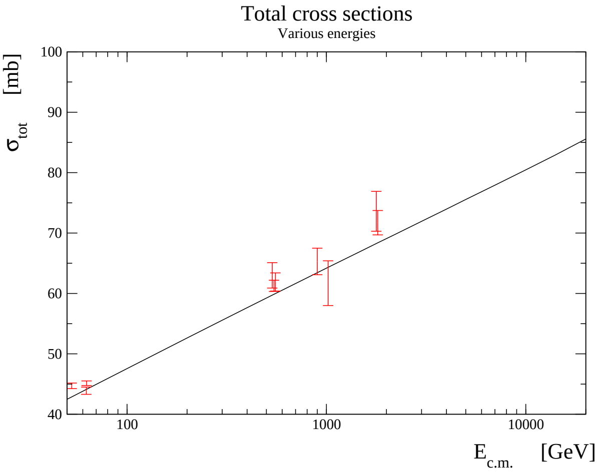
obvious...

Non-Elastic Scattering

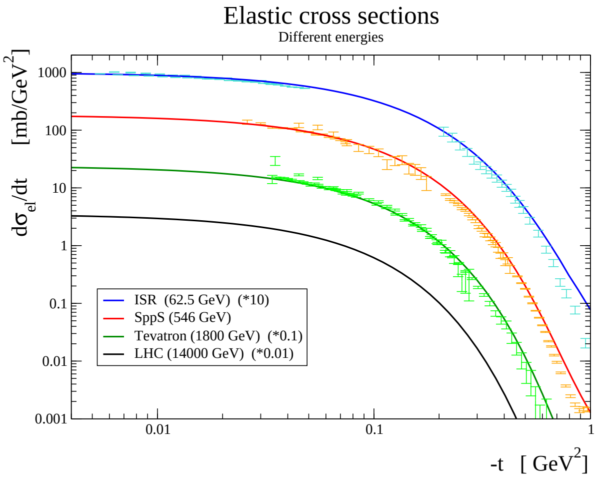
- number of (cut) ladders
- impact parameter of each ladder
- number of gluons per ladder, rapidities
- singlet/octet t-channel propagators (singlets give rise to rapidiy gaps)
- kinematics
- parton shower, hadronisation



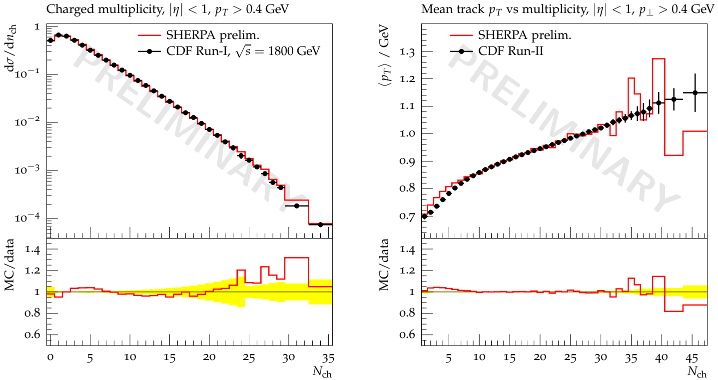
Total Cross Section



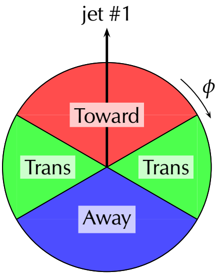
Elastic Cross Section

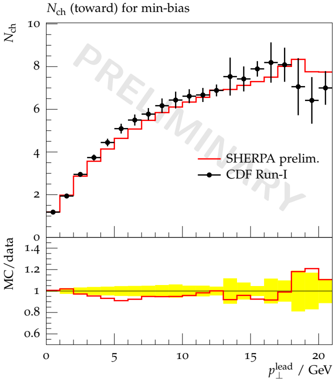


Minimum Bias from CDF ($p\bar{p}$ @1800 GeV)

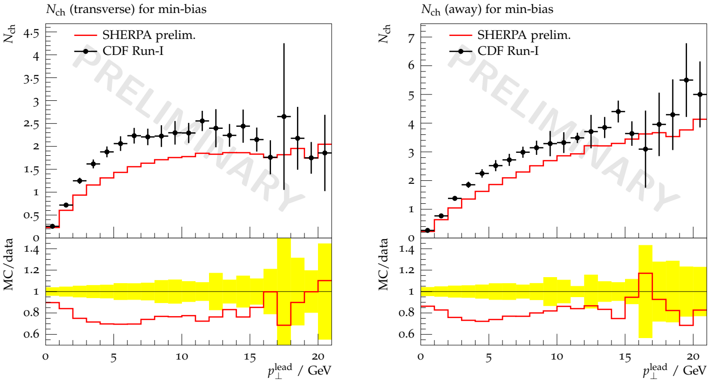


Minimum Bias from CDF ($p\bar{p}$ @1800 GeV)

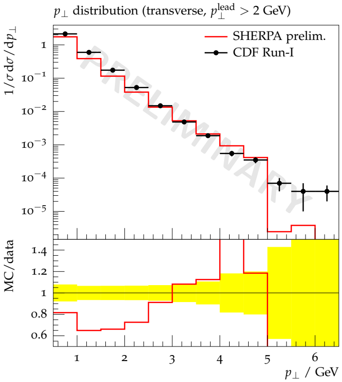




Minimum Bias from CDF ($p\bar{p}$ @1800 GeV)



Minimum Bias from CDF ($p\bar{p}$ @1800 GeV)



Outlook

- Next steps (short timescale):
  - improved colour treatment (larger rapidity gaps)
  - include single and double low-mass diffraction
  - formulate as underlying event model
  - validate the physics/tune the parameters & publish the module as part of SHERPA 1.3.
- Near future:
  - include secondary Reggeon (quarks!)
  - allow for open and closed heavy flavour production
  - include $k_\perp$ dependence into differential equations

Pion Spectrum and Jet cross section at STAR (pp @200 GeV)