Towards a new model for Minimum Bias and the Underlying Event in Sherpa

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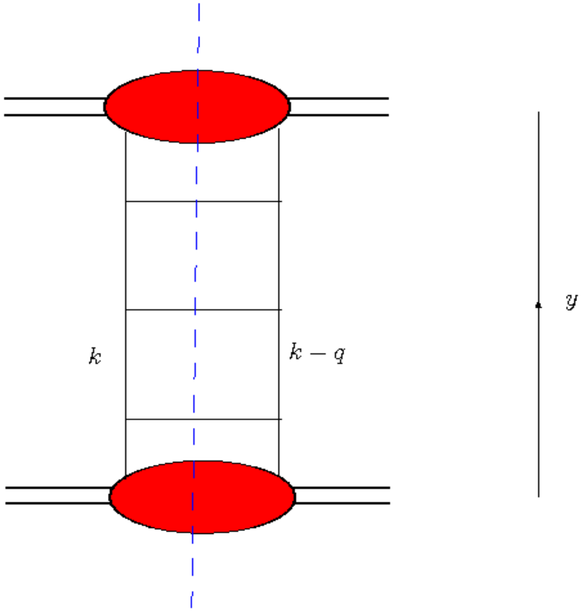
Partonic picture

- Basic idea: Regge physics rules!
  - define amplitudes/eikonals through pomeron exchange
  - must sum over all possible exchanges and topologies – hard to do in a MC, only approximate solutions will be possible (see Bartels' talk)
  - Simplified picture: start from a simple ladder
  - Treat as amplitude for the production of N particles, homogeneously distributed in rapidity in [-Y/s, Y/s], where Y = log s/m_p^s
  - $\sigma_{2\to N} = |A_{2\to N}|^2$
  - Will connect to pomeron on next slide



Ladders and pomerons

- The amplitude (scalar particles) then reads

$$A(Y) = \sum_n \frac{1}{n!} \prod_{i=1}^{N} \int_{-Y/2}^{Y/2} \mathrm{d}y_i \alpha = \sum_n \frac{(\alpha Y)^n}{n!} = e^{\alpha Y} = s^{\alpha}$$

- where the kernel is given by something like

$$\alpha(q_\perp^2) = \frac{\bar{g}^2}{16\pi^2} \int \frac{\mathrm{d}^2 k_\perp}{[k_\perp^2 - m^2][(k_\perp - q_\perp)^2 - m^2]}$$

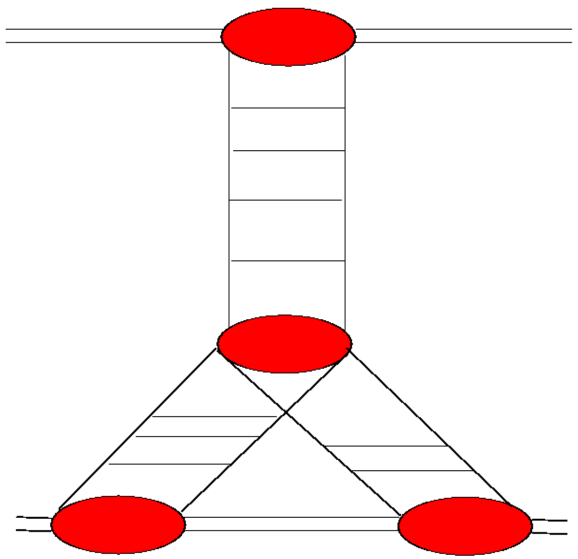
- This allows to rewrite the amplitude as evolution equation,

$$\frac{\mathrm{d}A(y)}{\mathrm{d}y} = \alpha A(y)$$

- write, as before, $\alpha_P = 1 + \Delta$, with the perturbative pomeron intercept $\Delta = 0.3\text{-}0.5$
- Note: also understood as evolution equation for parton densities f(y).

Rescattering

- In high-density, strong-coupling regime rescattering becomes important
- In Regge language this is driven by the triple-pomeron vertex.
- Visible physical effect: high-mass dissociation
- Also: softening of total cross section (rescattering as "fusion" of two partons)
- Note: also more complicated cuts than example
- Can resum "fan" diagrams (Schwimmer model):



$$\frac{\mathrm{d}f(y)}{\mathrm{d}y} = \Delta f(y) - g_{3P} f(y)$$

- But total cross section becomes too low, must resum all fans

$$\frac{\mathrm{d}f(y)}{\mathrm{d}y} = \exp[-\lambda f(y)]\Delta f(y)$$

Khoze-Martin-Ryskin model

- Eikonal as convolution of two" parton densities"

$$\Omega(\vec{b}_\perp) = \frac{1}{2\beta_0^2}\int \mathrm{d}^2 b_\perp^{(1)} \mathrm{d}^2 b_\perp^{(2)} \delta^2(\vec{b}_\perp - \vec{b}_\perp^{(1)} - \vec{b}_\perp^{(2)}) \cdot \Omega_{i(k)}(\vec{b}_\perp^{(1)}, \vec{b}_\perp^{(2)}, y) \Omega_{(i)k}(\vec{b}_\perp^{(1)}, \vec{b}_\perp^{(2)}, y)$$

- Two channel eikonal, with two evolution equations

$$\frac{\mathrm{d} \ln \Omega_{i(k)}(y)}{\mathrm{d}y} = +\exp\left\{-\frac{\lambda}{2}\left[\Omega_{i(k)}(y) + \Omega_{(i)k}(y)\right]\right\}\Delta$$

$$\frac{\mathrm{d} \ln \Omega_{(i)k}(y)}{\mathrm{d}y} = -\exp\left\{-\frac{\lambda}{2}\left[\Omega_{i(k)}(y) + \Omega_{(i)k}(y)\right]\right\}\Delta$$

Khoze-Martin-Ryskin model (cont'd)

- Boundary conditions involve form factors

$$\Omega_{i(k)}(\vec{b}_\perp^{(1)}, \vec{b}_\perp^{(2)}, -Y/2) = F_i(b_\perp(1)^2)$$

$$\Omega_{(i)k}(\vec{b}_\perp^{(1)}, \vec{b}_\perp^{(2)}, +Y/2) = F_k(b_\perp(2)^2)$$

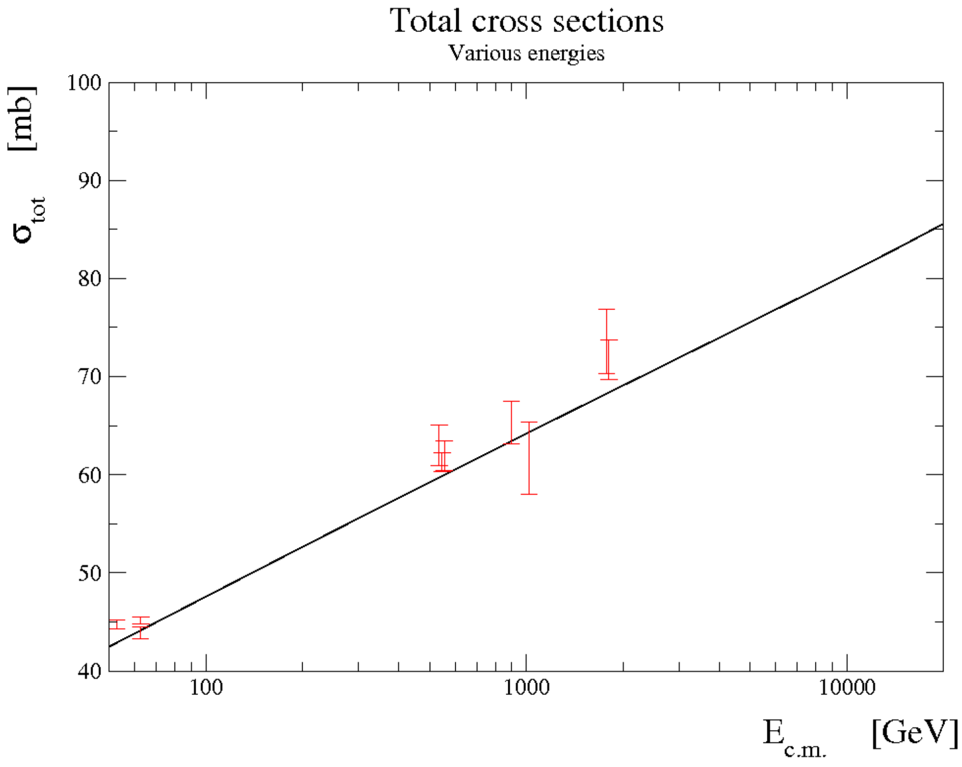
- Form factor as Fourier transforms of (dipole form with extra dampening)

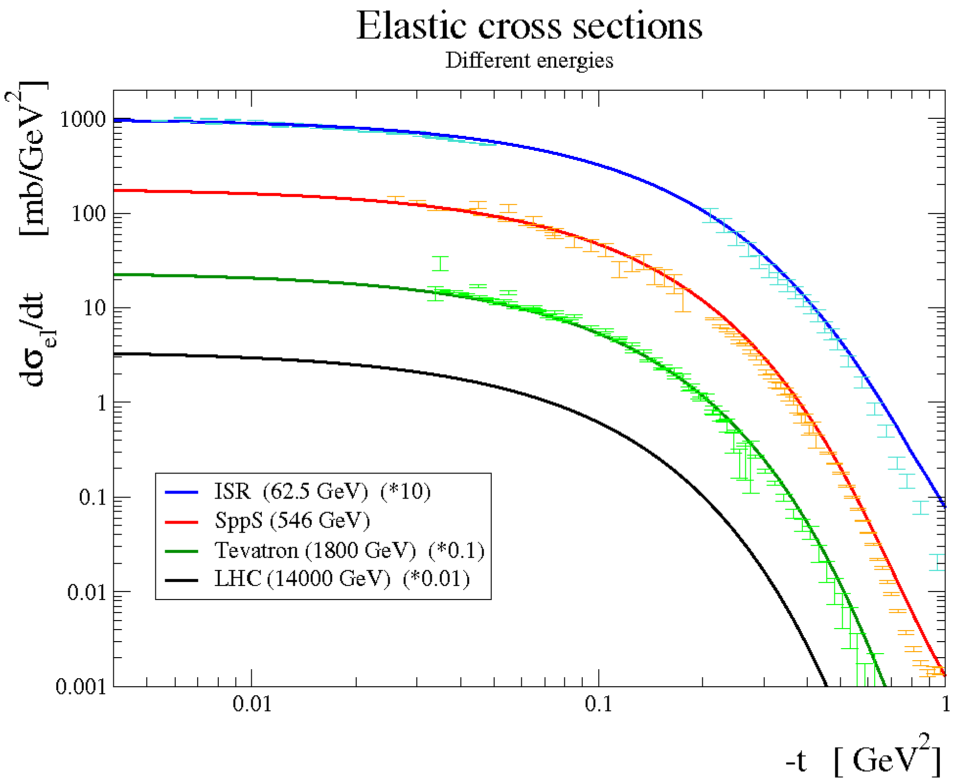
$$F_{1,2}(q_\perp) = \beta_0^2(1 \pm \kappa)\frac{\exp\left[-\frac{(1\pm\kappa)\xi q_\perp^2}{\Lambda^2}\right]}{\left[1 + \frac{(1\pm\kappa)q_\perp^2}{\Lambda^2}\right]^2}$$

- Parameters: $\Delta = 0.3$, $\lambda = 0.25$, $\beta_0^2 = 30$ mb, $\kappa = 0.5$, $\Lambda^2 = 1.5$ GeV^2, $\xi = 0.225$

Inclusive results

- Total and elastic cross sections vs. data at various energies





Selecting the mode

- Select the mode according to cross sections:

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

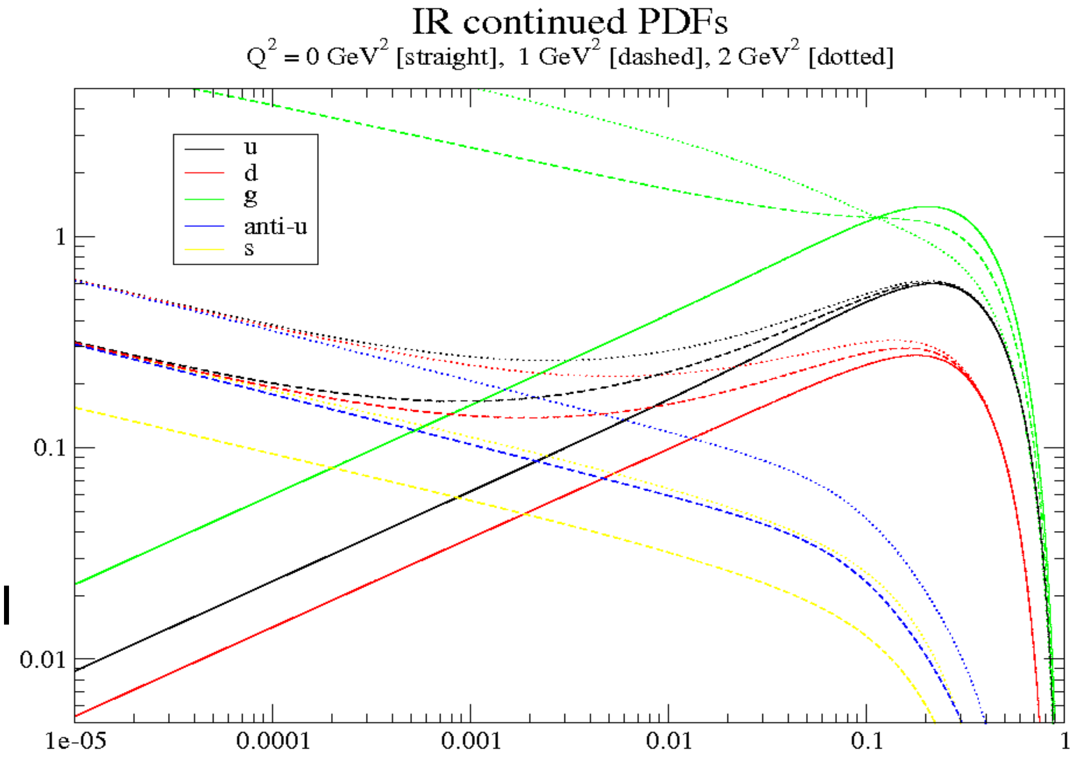
$$\sigma_{\rm inel}^{pp} = \int {\rm d}^2 b_\perp \sum_{i,k=1}^{S} \left\{ |a_i|^2 |a_k|^2 \left[1 - e^{-2\Omega_{ik}(b_\perp)}\right] \right\}$$

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

- Formula for single/double diffractive modes (low mass) pretty similar, will yield N(1440) in the final state(s) + subsequent decays.
- If elastic is chosen, select momentum transfer according to FT
- If inelastic is chosen, select Good-Walker states i and k and impact parameter according to contributions in integrand.

Initialising the (primary) ladders

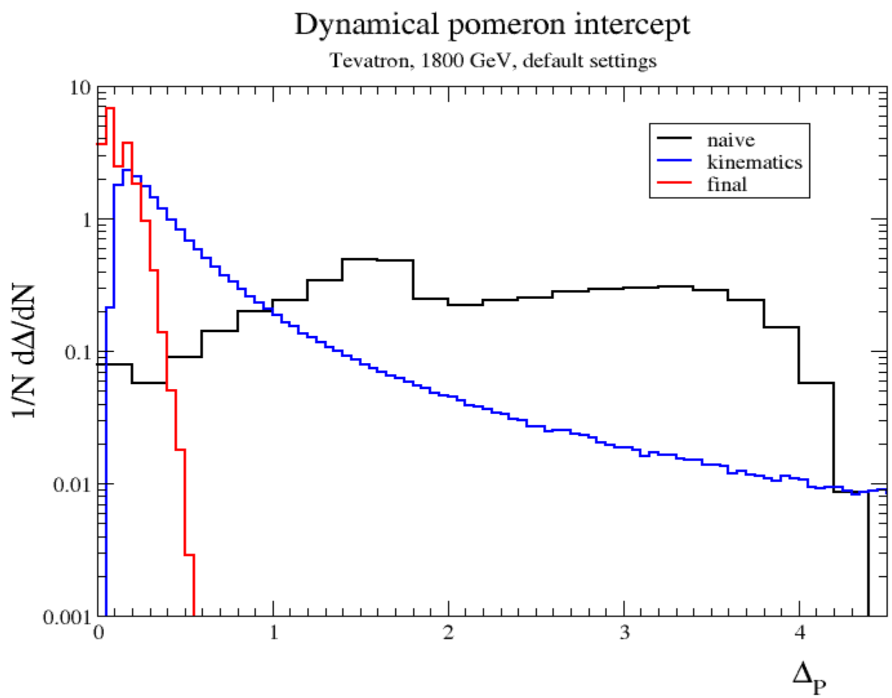
- Select flavours and (collinear) momenta according to IR-continued PDFs and Regge-motivated cross-section $(s/s_0)^{1+\eta}$, where
  - s_0 is fixed to reproduce inelastic cross section in this channel ik, $s>s_0$
  - Exponent $\eta = \Delta \exp[-\lambda/2(\Omega_{ik}(b,0)+\Omega_{ki}(b,0))]$ = "effective intercept"
- IR-continued PDFs:
  - assume f(x,0) = valence only
  - keep norm of valence quarks, renormalise "valence" gluons to satisfy momentum sum rule
  - switch off sea with Q
- Produce $N_{ladders}$ pairs of incoming partons (one valence quark, rest will be gluons)
- Weight for each pair given by Regge expression times the PDFs



Filling the ladders

- Generate emissions in between, according to “Sudakov form factor”

$$\mathcal{S}(y_0, y_1) = \exp\left\{ -\int_{y_0}^{y_1} \mathrm{d}y \int \mathrm{d}k_\perp^2 \frac{\alpha_s(k_\perp^2 + K_0^2)}{(k_\perp^2 + K_0^2)} \times \left[\frac{K_0^2}{q^2 + K_0^2}\right]^{\frac{3\alpha_s(q^2+K_0^2)}{\pi}|y-y_0|} \times \exp\left[-\frac{\lambda}{2}\left(\Omega_{i(k)}(y) + \Omega_{(i)k}(y)\right)\right] \right\}$$



- dynamical pomeron intercept
- Reweight ladder with ME ~ $1/t_{\text{hardest}}$ for hardest emission
- Note: At this point strictly t-channel, filling stops when either no more y can be “squeezed” in, or when “active” y-interval goes to singlet colour config.

Treatment of colours

($\rightarrow$ hard diffraction)

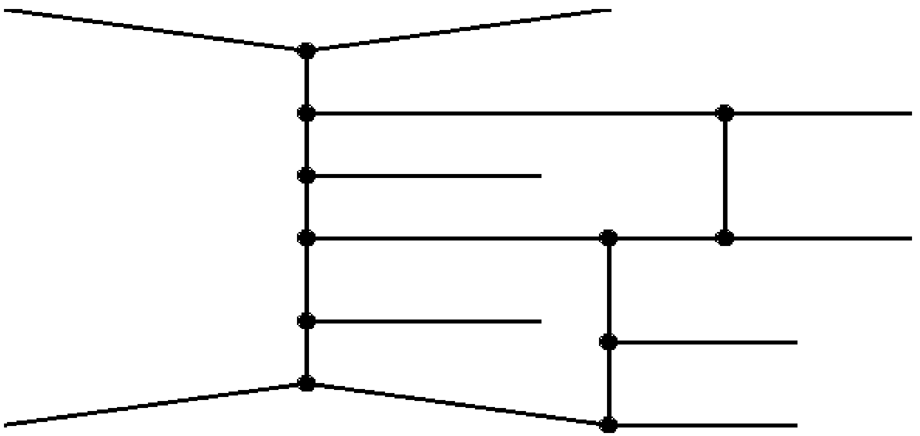
- In principle, BFKL equation resums “ladders in ladders”
- In as purely gluonic picture, this means that each t-channel propagator at LO is a (reggeised) gluon, but at all orders it is in a colour state given by something like C = [8] + [8]*[8] + [8]*[8]*[8] ...
- Take a look at the [8] * [8]: Its decomposition is something like

  [8] * [8] = [27] + [10] + [10] + [8] + [8] + [1],

  i.e. containing a singlet state.
- Will treat anything else as octet. Decision of whether singlet or octet based on eikonals $\rightarrow$ singlet if elastic scattering between two rapidities y_1 and y_2.

$$P_{\mathrm{singlet}} = \{1-\exp[-\lambda\,(\Omega(y_1)-\Omega(y_2))/(2\Omega(y_1))]\}^2$$

Rescattering



- Consider configurations like
- Partons from ladder may rescatter
- Additional feature (not shown):

  FS parton shower attached to ladders …
- Question: How to decide if rescattering or not?
- Answer: Same as before
  - Iterate over all pairs of partons at some place in transverse plane
  - Construct rescattering probability for each pair as

$$P_{\text{rescatter}} = 1\text{-}\exp\{-\lambda/2\ [\Omega(y_1)-\Omega(y_2))/(\Omega(y_1)]\}$$

  - Check each pair (compare with random number)
  - Respect previously produced singlets (or not?)
- Open question: Is this consistent with AGK cutting rules?

Some example results @ 7 TeV

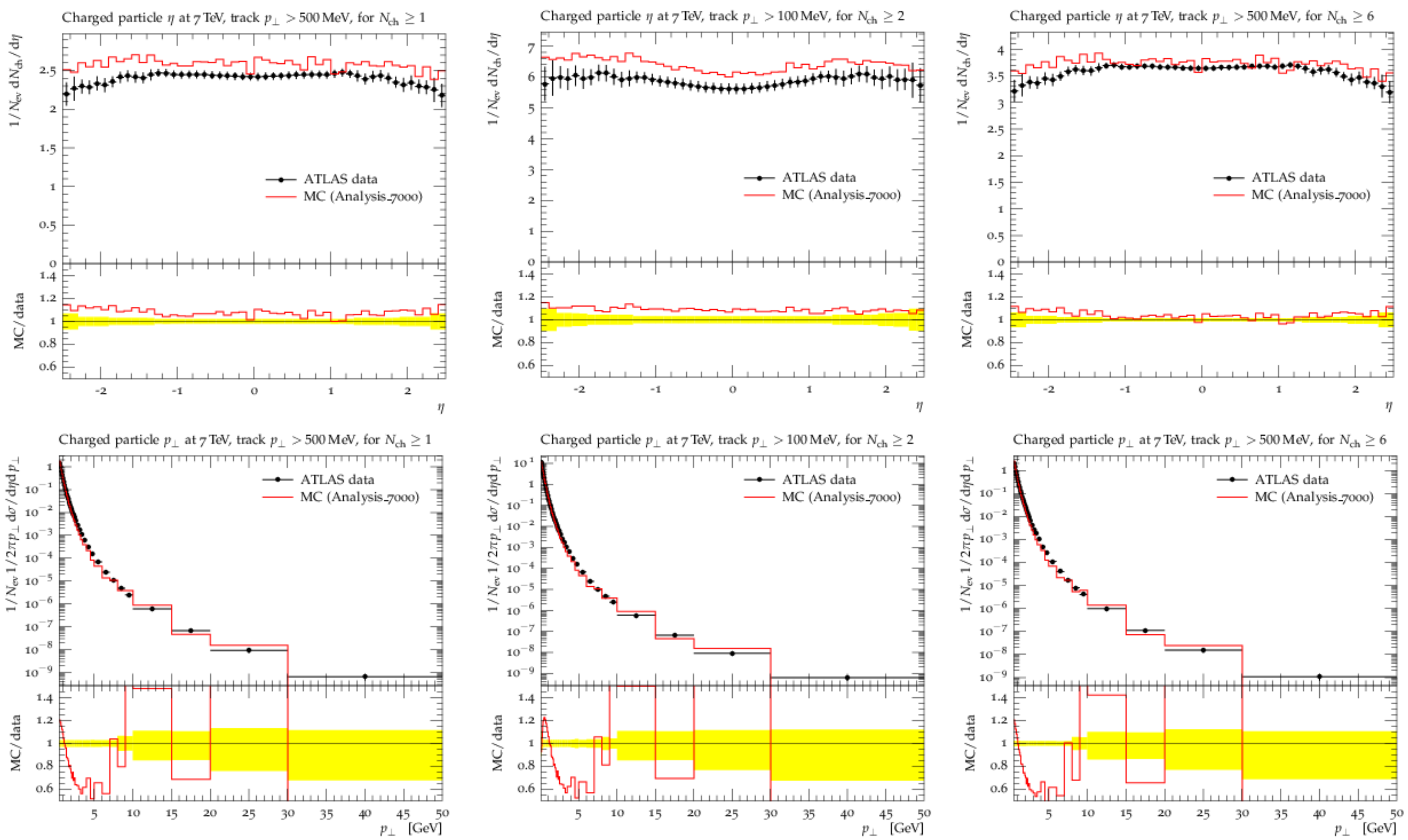
In the following:

- Untuned run (10 kEvents): Q_0 = 2 GeV, Δ = 0.4, λ = 0.5
  Λ = 1.5 GeV, ξ = 0.225, κ= 0.55

Inclusive Quantities:

- σ_{tot} = 99.2 mb, σ_{inel} = 68.5 mb, σ_{el} = 24.5 mb, σ_{SD} = 5.6 mb
- Δ_{naive} = 3.59, Δ_{kin} = 0.55, Δ_{fin} = 0.14
- 3.26 primary ladders/event, 5.2 in total (incl. Rescattering)
- 22% of ladders have singlet, out of which 45% are hardest
- Colour reconnections switched off (can enable some if necessary)

Some example results @ 7 TeV



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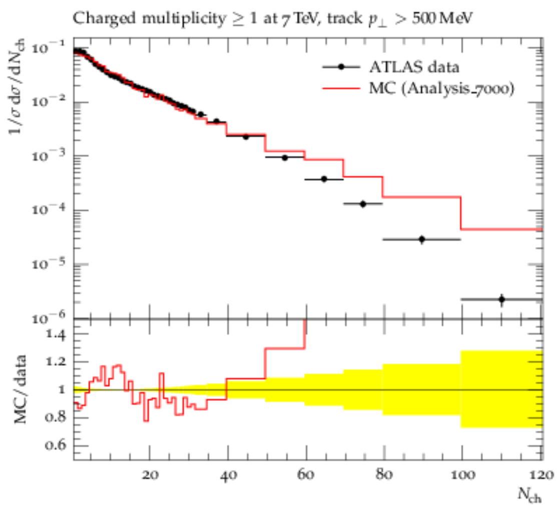

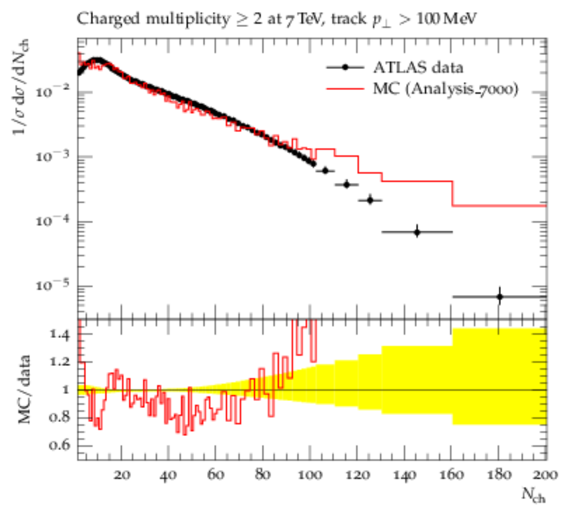

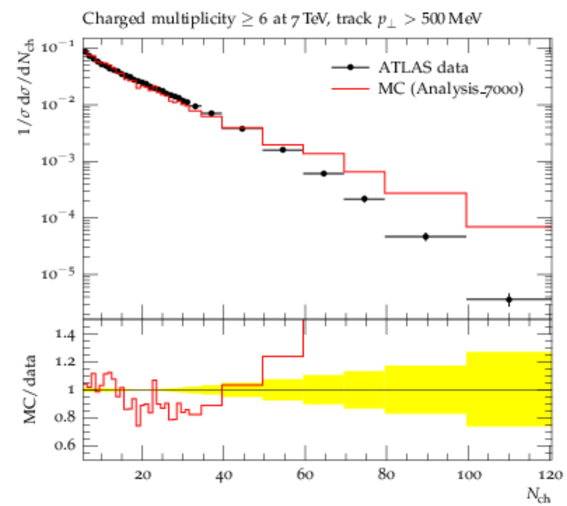

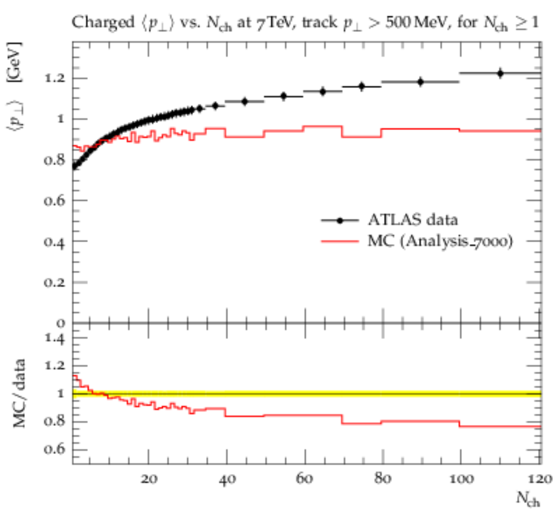

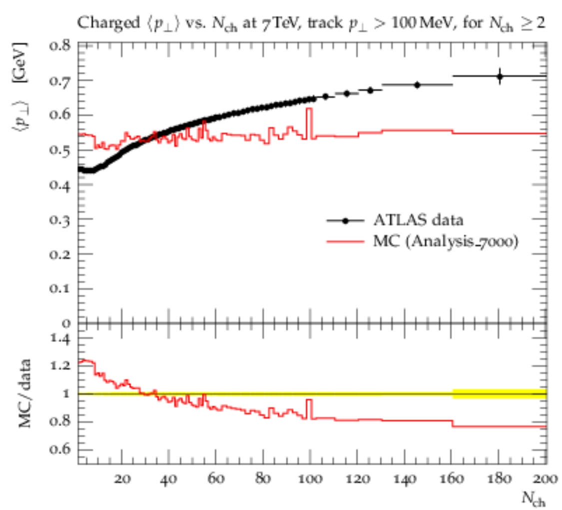

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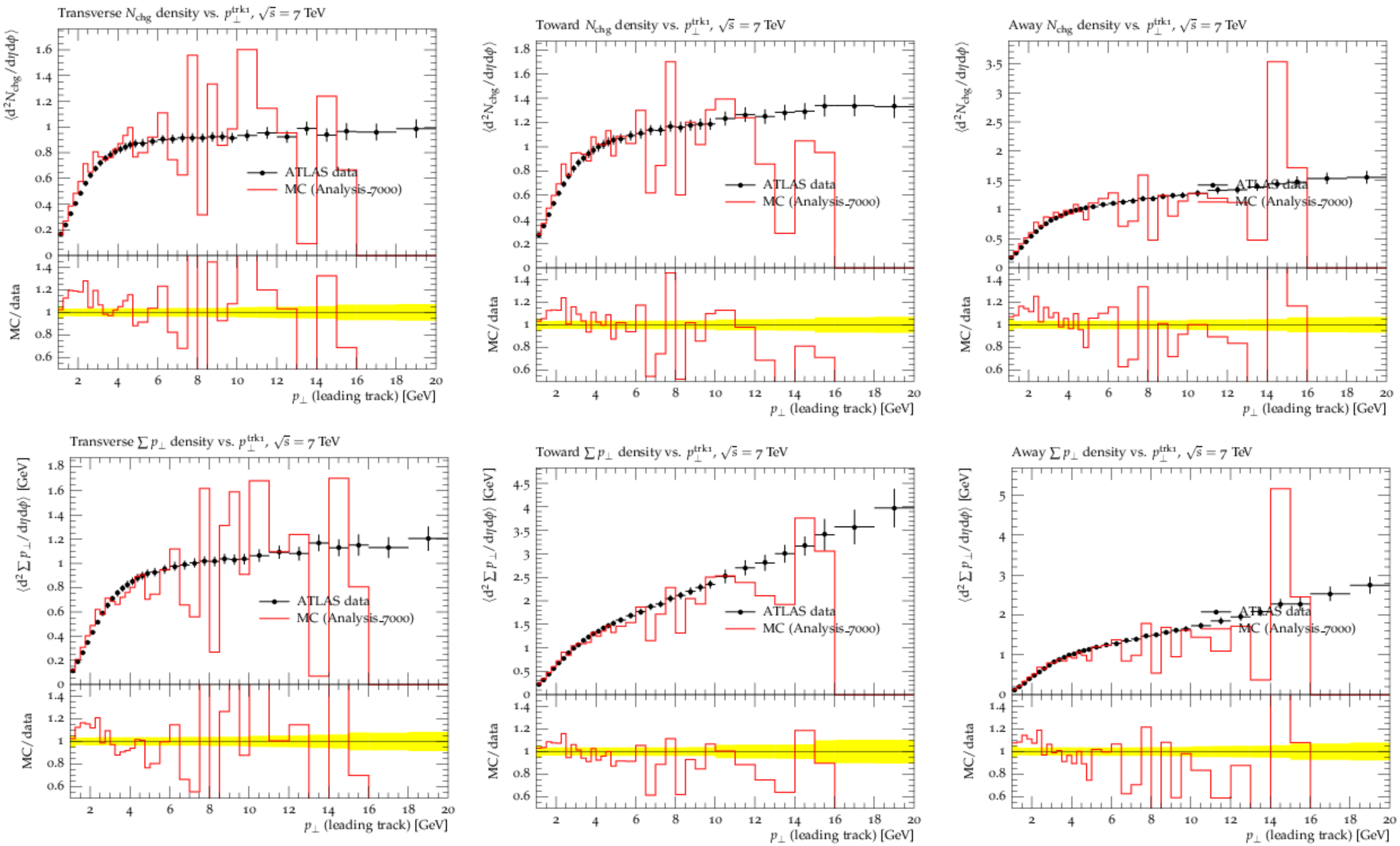

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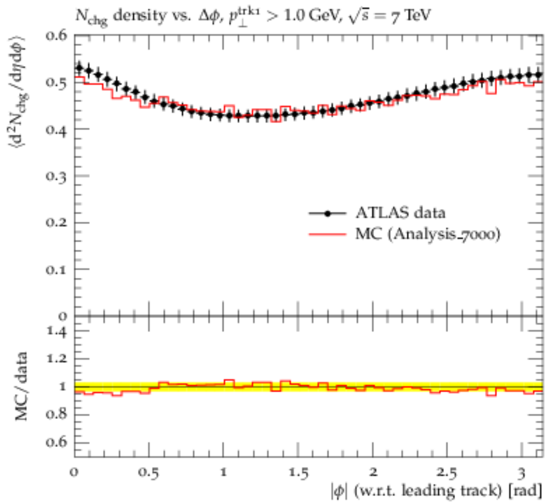

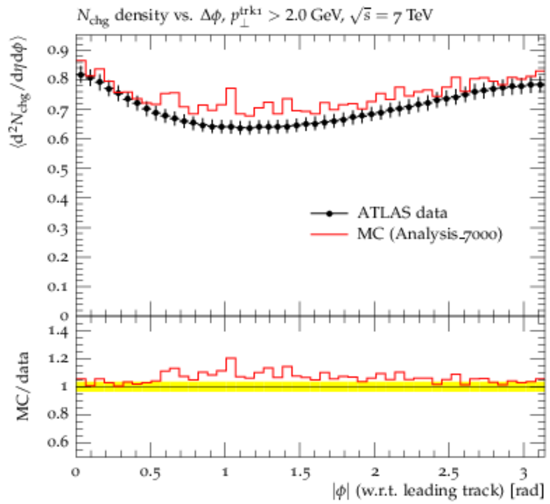

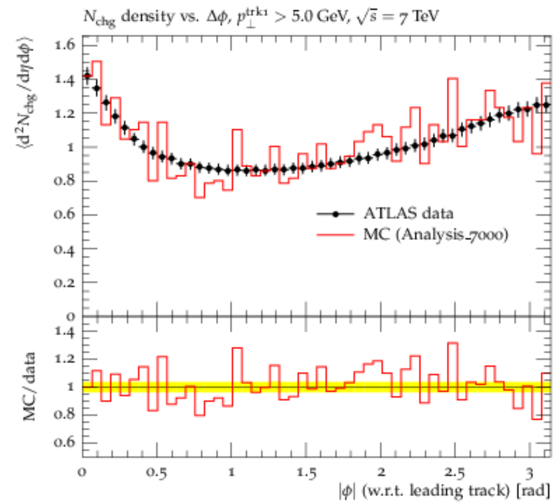

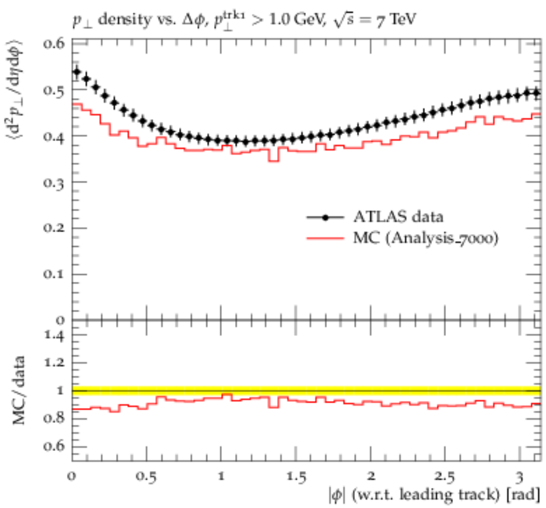

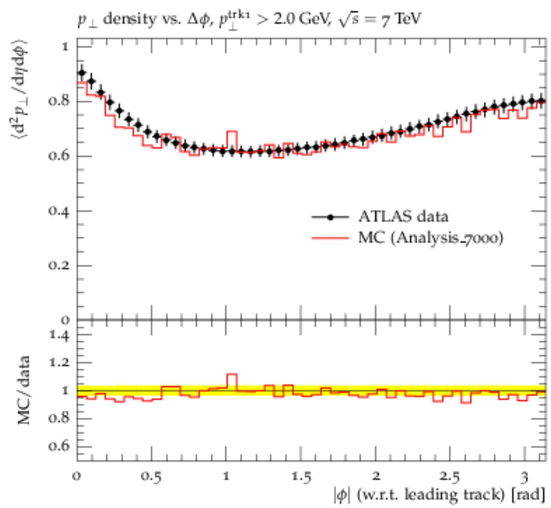

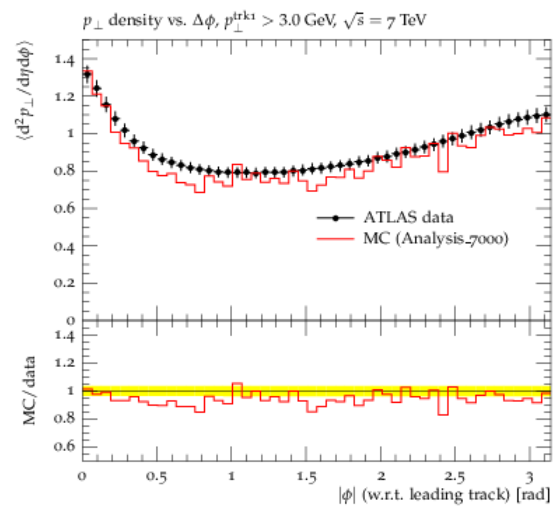

Conclusions & outlook

- Implementation of the KMR model

  (as 2 state model)

- Could add further states/reggeons

  (more important for low energies)

- Added dynamical picture of the gluon ladders

  (including rescattering, showering, …)

- By now we're halfway happy with the results
- Model needs tuning (2 steps)
- Still to come: quarks in ladders, photons, mesons (quarkonia)

  … framework for doing so is clear

- Still to do: transformation into UE model