The underlying event in Herwig++

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Status

- Fully working model included from `Herwig++ 2.1` onwards. It allows for the simulation of multiple partonic interactions (MPI) to describe the underlying event (UE). Same functionality and physics than `JIMMY`.
- Overview available in *Herwig++ Physics and Manual* [arXiv:0803.0883]
- A more detailed description including tuning results: [arXiv:0803.3633, MB, S. Gieseke and M. H. Seymour]

Outline

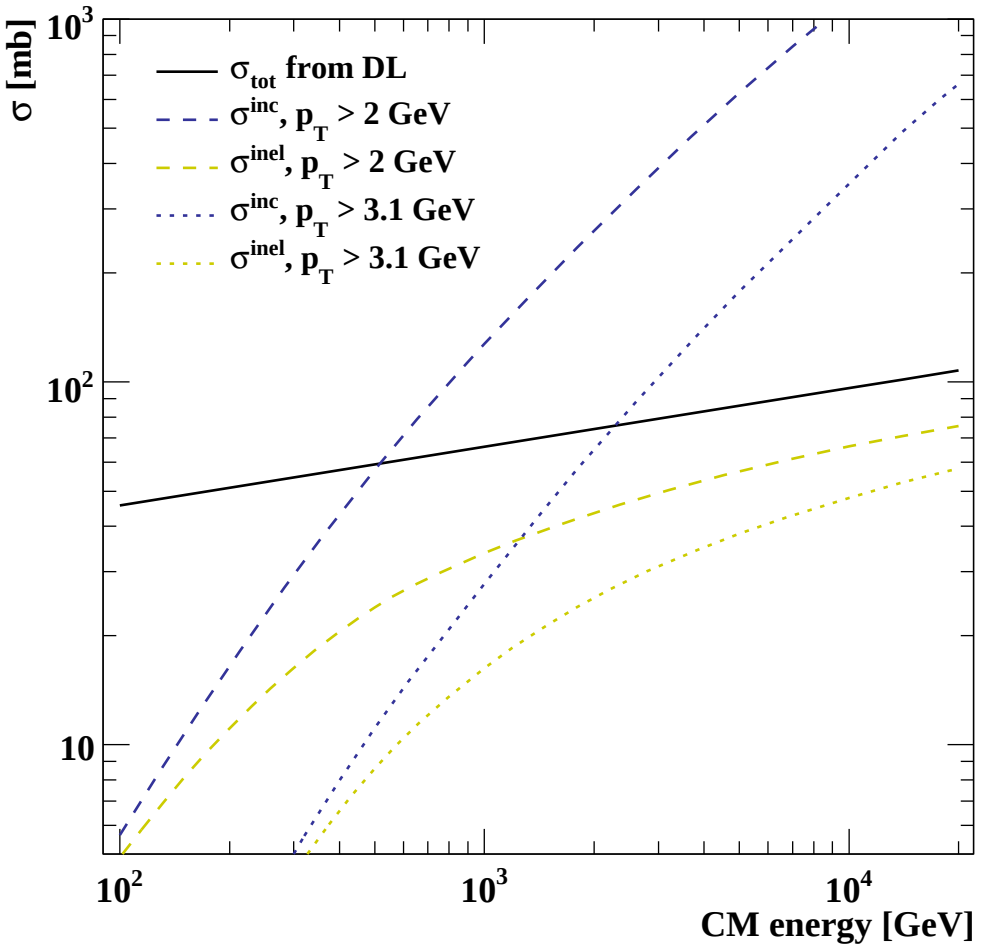
Model details

based on [Butterworth, Forshaw, Seymour '96]

- Starting point: The inclusive cross section $pp \to jj$ with $p_T > p_T^{\min}$ ($\sigma^{\rm inc}$) may exceed $\sigma_{\rm total}$

  $\sigma^{\rm inc} = \int dx_1 dx_2 dp_T^2 \; f(x_1) f(x_2) \frac{d\hat{\sigma}}{dp_T^2}$

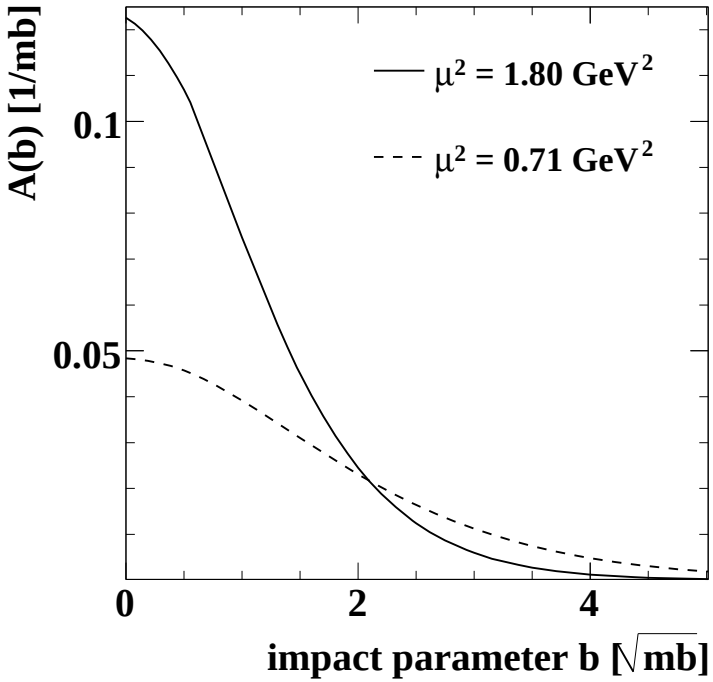
- Source: Proliferation of low x partons, which increases the probability of more than one partonic collision
- Unitarization of $\sigma^{\rm inc}$



$$\sigma_{inel} = \int d^2b \sum_{m=1}^{\infty} \frac{(A(b)\sigma^{\rm inc})^m}{m!} e^{-A(b)\sigma^{\rm inc}} = \int d^2b (1 - e^{-A(b)\sigma^{\rm inc}})$$

Model details contd.

- $A(b)$ is the overlap function of the two colliding particles
- Convolution of individual spatial parton distributions: $G_h(\mathbf{b})$
- Individual distributions are proportional to EM form-factors. But μ is not fixed to the radius measured there (0.71 GeV^2)!



$$A(b = |\mathbf{b}|) = \int d^2\mathbf{b}' G_{h_1}(\mathbf{b}')\ G_{h_2}(\mathbf{b} - \mathbf{b}')$$

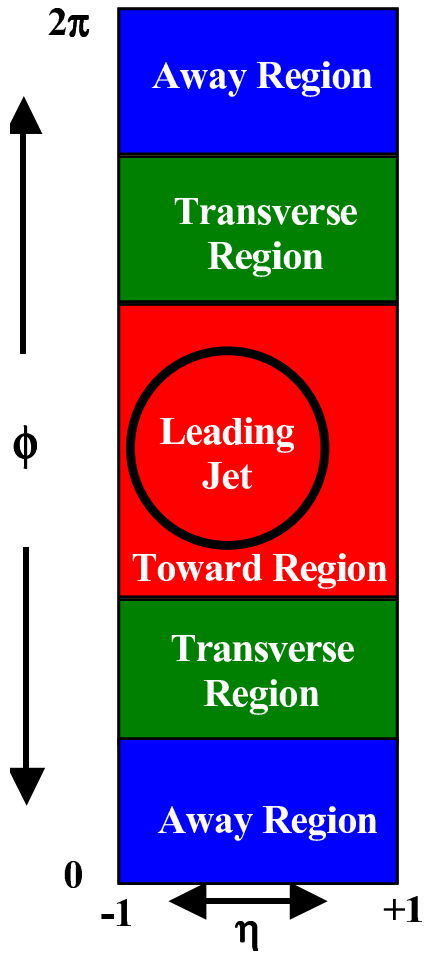
$$G_{\bar{p}}(\mathbf{b}) = G_p(\mathbf{b}) = \int \frac{d^2\mathbf{k}}{2\pi}\ \frac{e^{i\mathbf{k}\cdot\mathbf{b}}}{(1 + \mathbf{k}^2/\mu^2)^2}$$

$\longrightarrow$ main parameters: $p_T^{\min}, \mu^2$

Exp. analysis

R. Field's TVT analysis; PRD65,092002

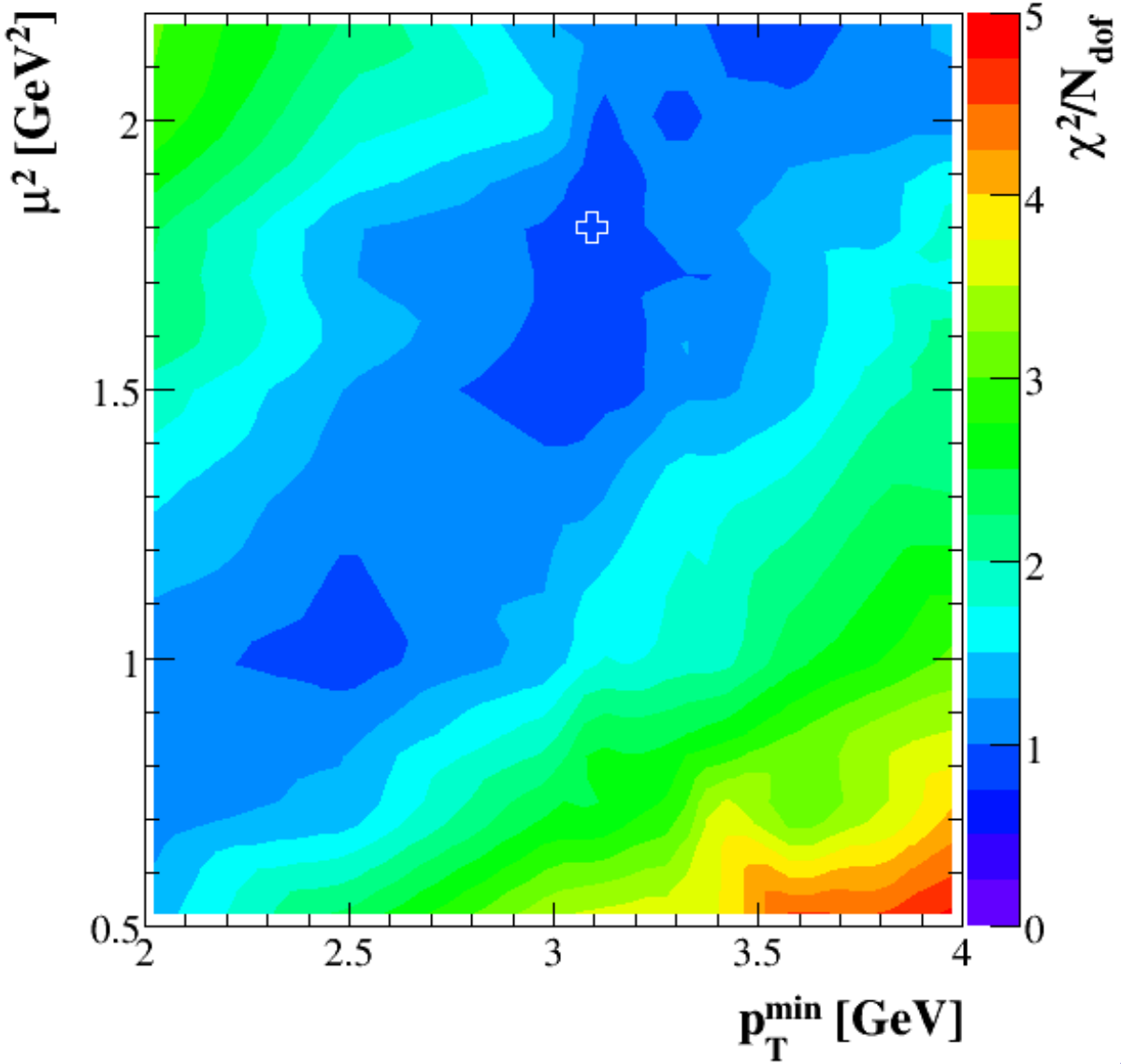
- non standard jet algorithm used to reconstruct the jet with the largest scalar ptsum from charged particle tracks: leading jet
- define 3 regions with respect to ϕ of the leading jet: towards, transverse, away
- plot $\langle N^{chg} \rangle$ and $\langle p_{T,sum}^{chg} \rangle$ for each of these regions
- comparison of `Herwig++ 2.1.3` to detector level data by applying 92% track efficiency (like the original experimental analysis)



Outline

Parameter Scan
all regions

- 120 points with 1M fully generated events each
- $\chi^2 = 4 \;\hat{=}\; 2\sigma$ contour
- correlation between μ^2 and $p_T^{\min}$ as it should be:
  $p_T^{\min} \uparrow \rightarrow \; \sigma^{\text{inc}} \downarrow \rightarrow \; \langle n \rangle \downarrow$
  $\mu^2 \uparrow \rightarrow \; \langle n \rangle \uparrow$
- favoured region around $p_T^{\min} \approx 3$ GeV



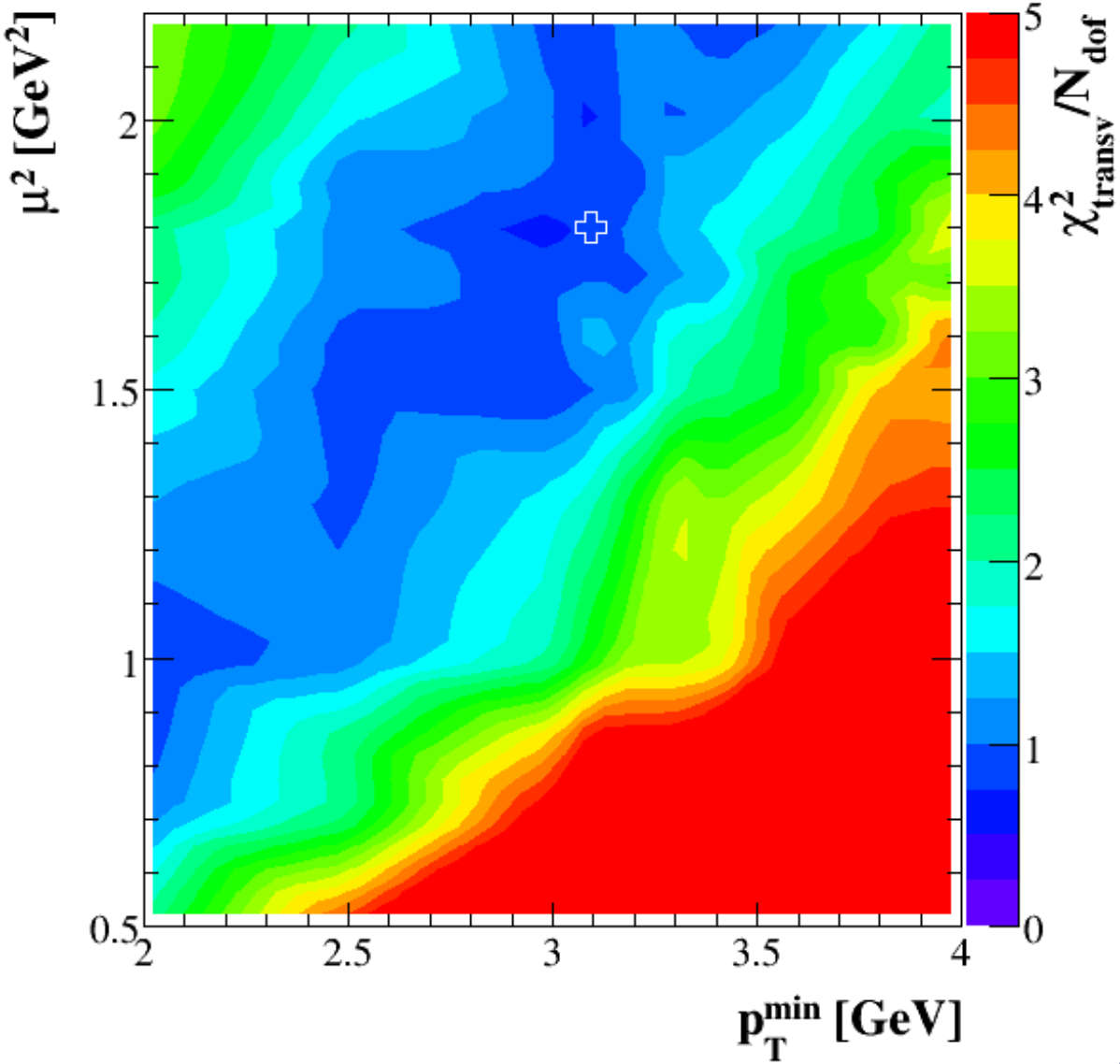
Parameter Scan

only transverse region

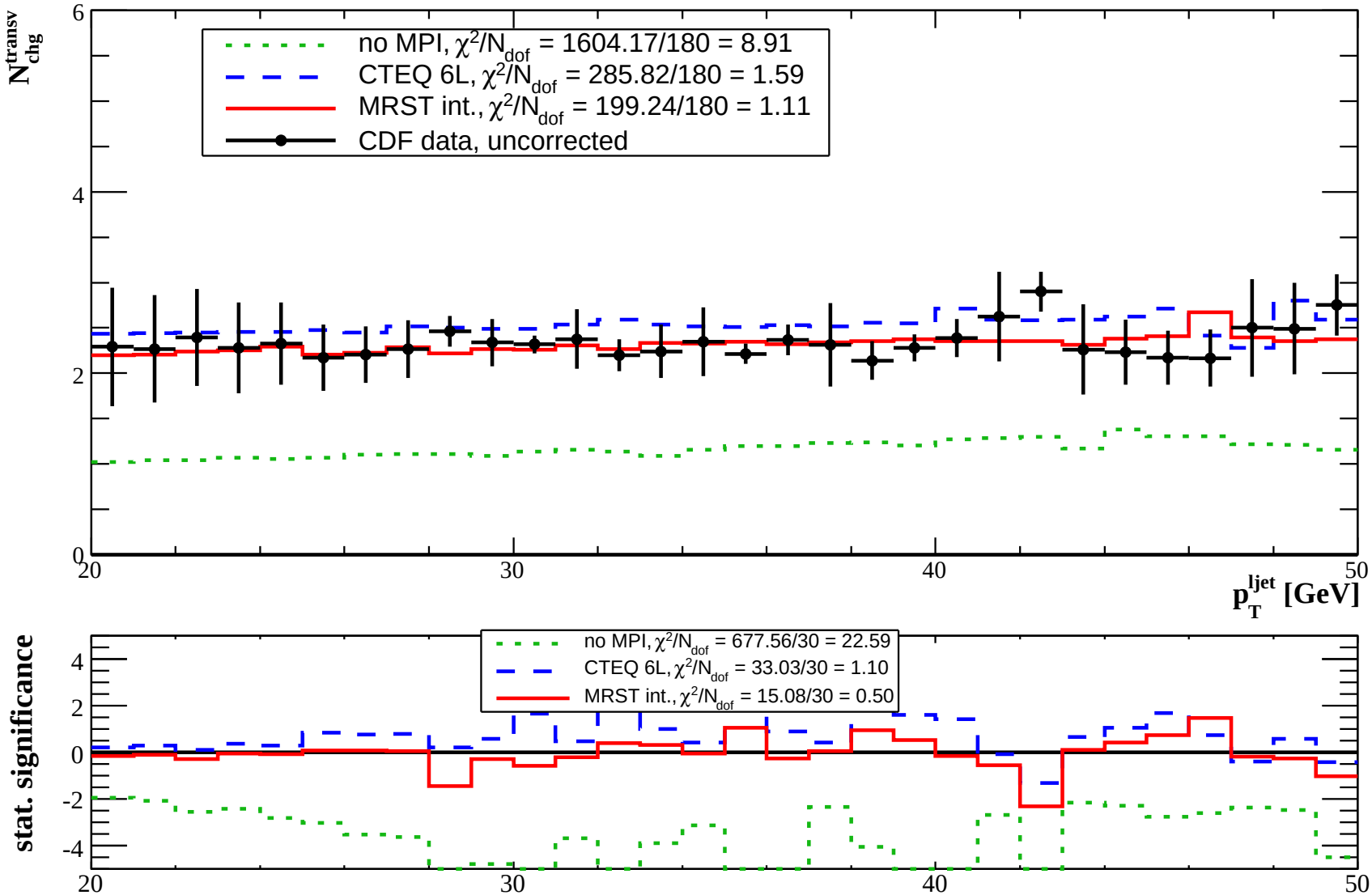
- MPI are isotropic
- *transverse* region receives the least contribution from the hard matrix element and parton showers

→ well suited to study MPI

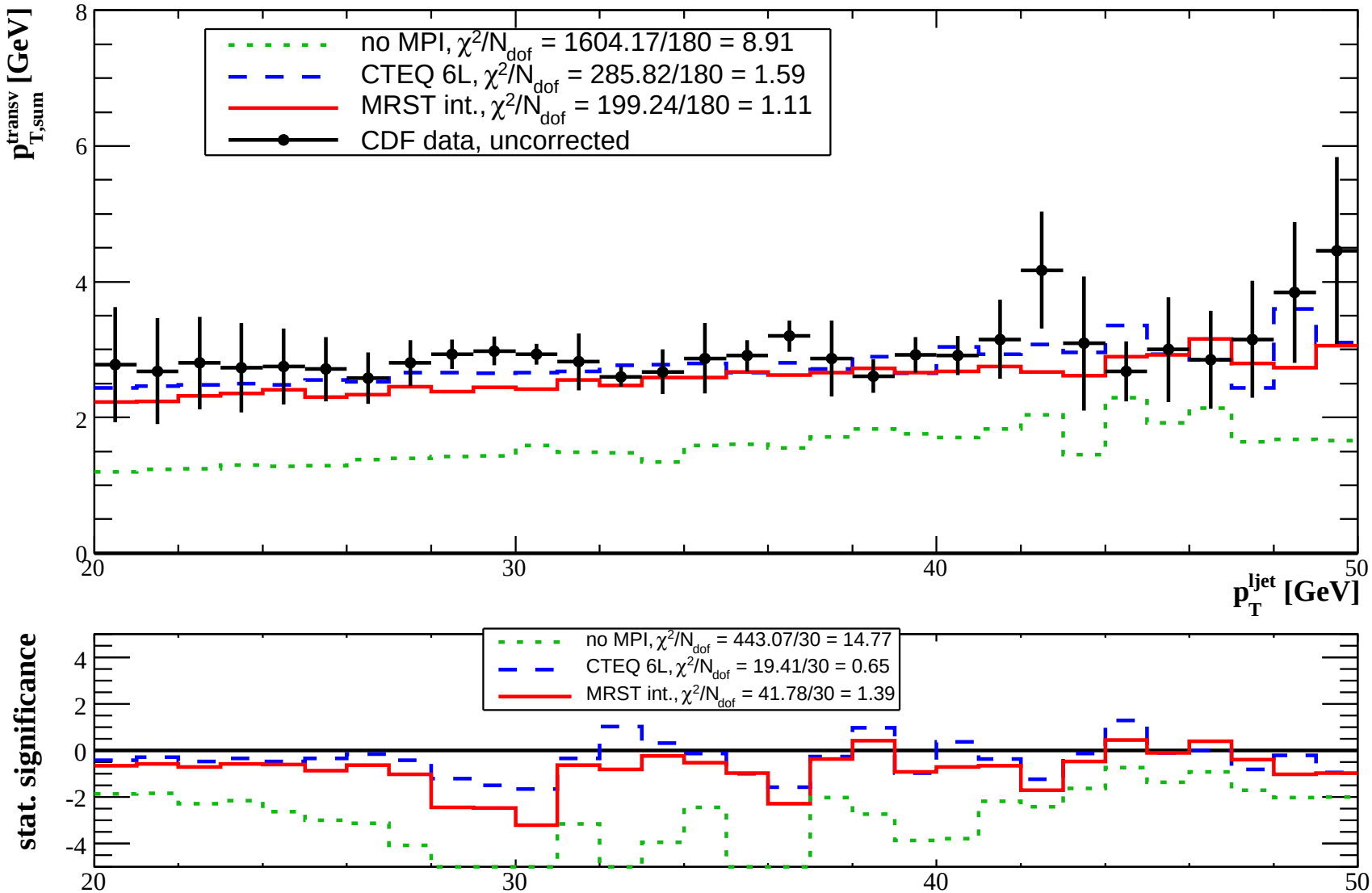
- minimum is confirmed → use $p_T^{\min} = 3.1$ GeV and $\mu^2 = 1.8$ GeV^2 as default tune.



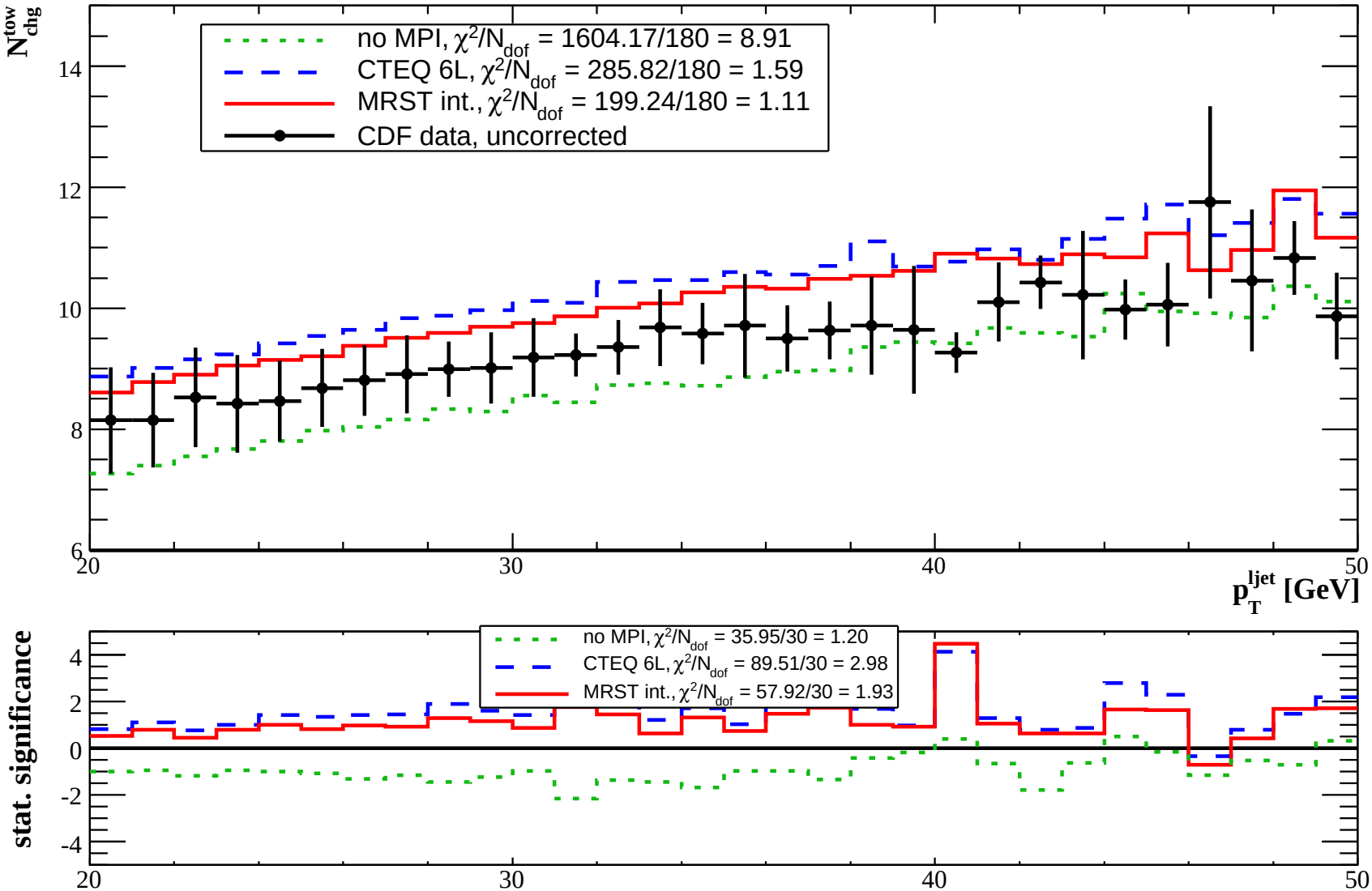
Best fit: N^{chg}_{transv}



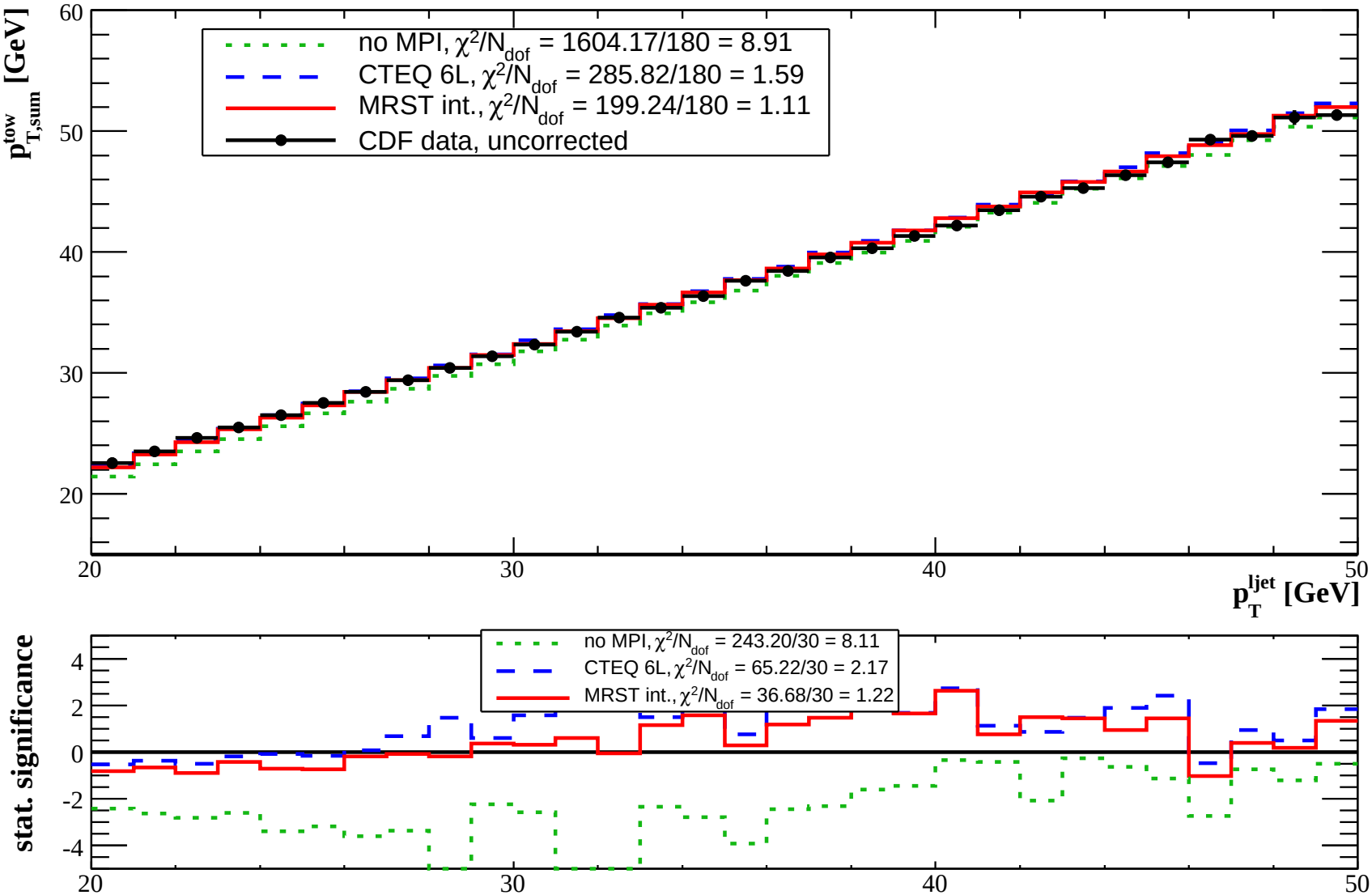
Best fit: $p_{T,sum}^{transv}$



Best fit: N_{tow}^{chg}



Best fit: $p_{T,sum}^{tow}$



Outline

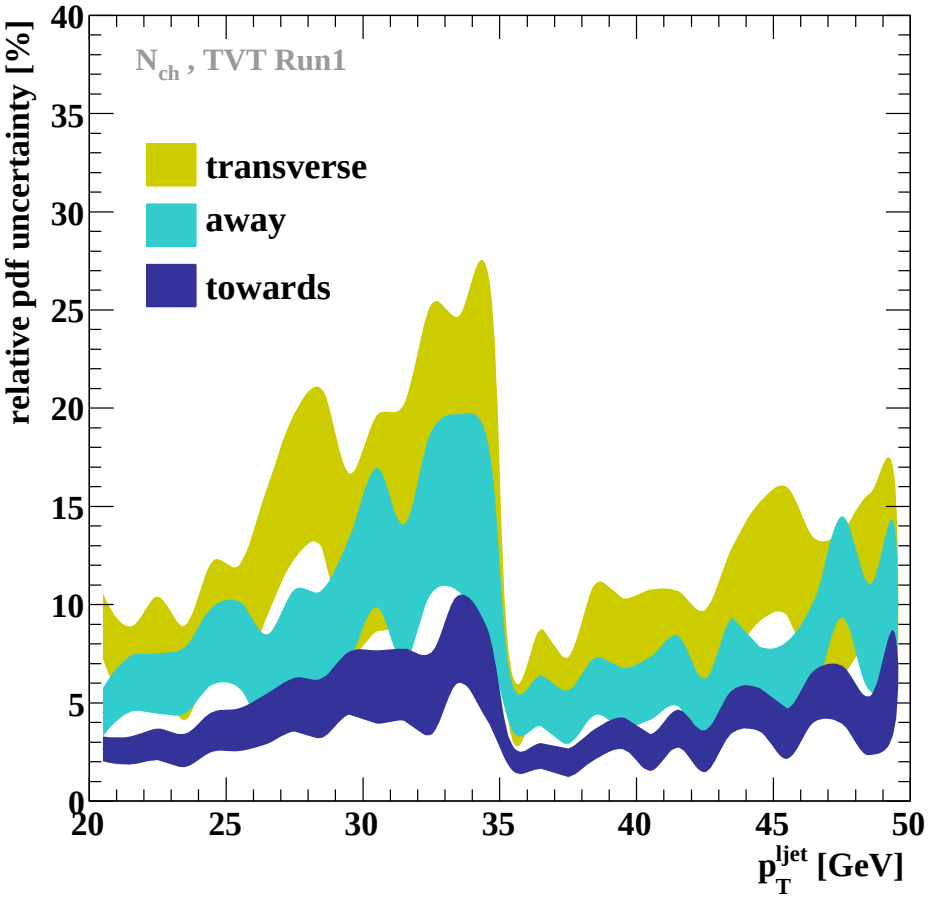
PDF uncertainties on the final state

- PDF influence enters exclusive final state via UE model. Cross section reweighting may not be enough.
- CTEQ6M and its 40 error sets with

$$\Delta X = \frac{1}{2}\left(\sum_{i=1}^{N_p}\left[X(S_i^+) - X(S_i^-)\right]^2\right)^{1/2}$$

used to quantify it. y-axis in the plot is $\Delta X / X(S_0)$

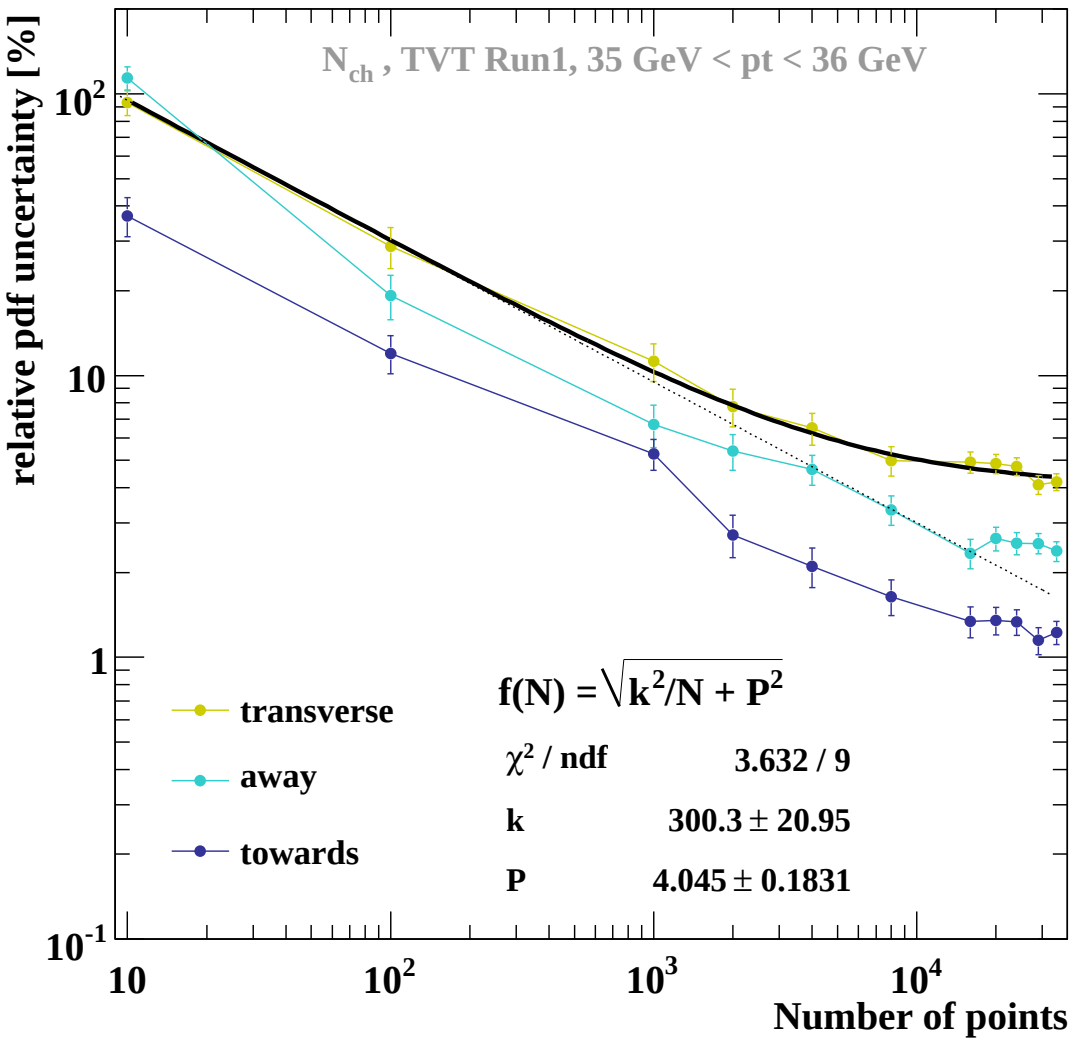
- large statistical uncertainties overlay the real PDF error



PDF uncertainties contd.

- Restrict analysis to the first unbiased bin (number of events in this bin: N)
- Statistical error should scale like $1/\sqrt{N}$
- use the assumption of a constant PDF induced error (P) to fit the points.
- 20M events/PDFset:

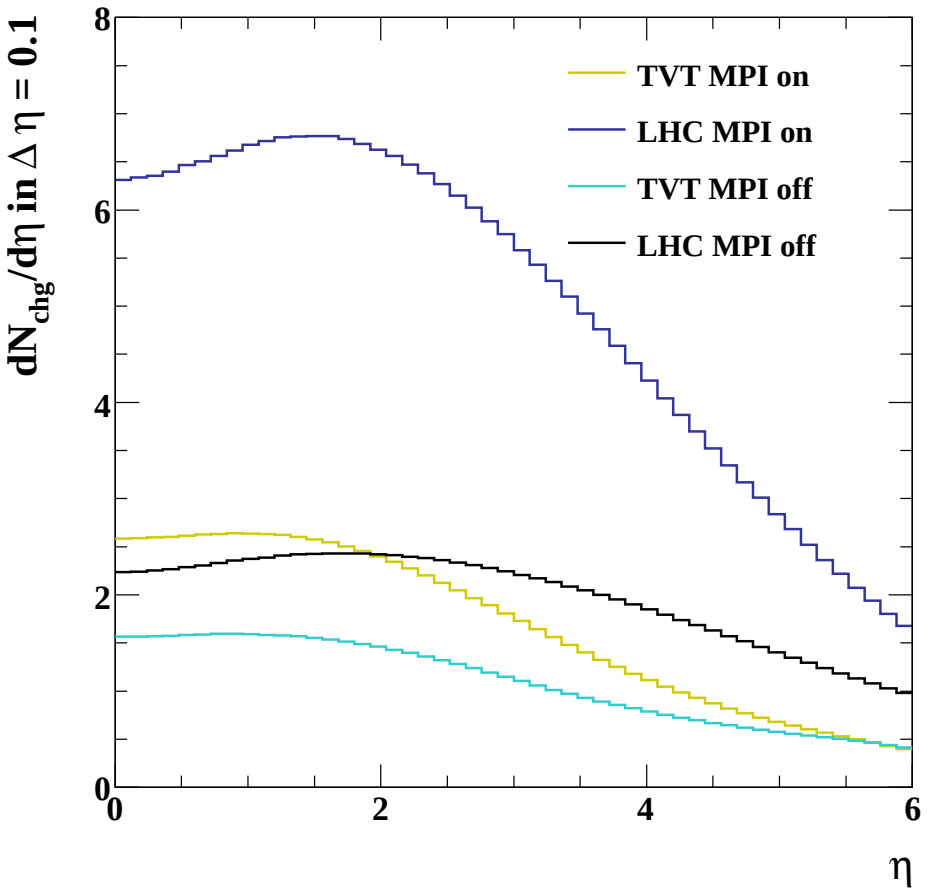
observable	P
$\langle N_{chg} \rangle_{transv}$	4.0 %
$\langle p_T^{sum} \rangle_{transv}$	4.5 %



Outline

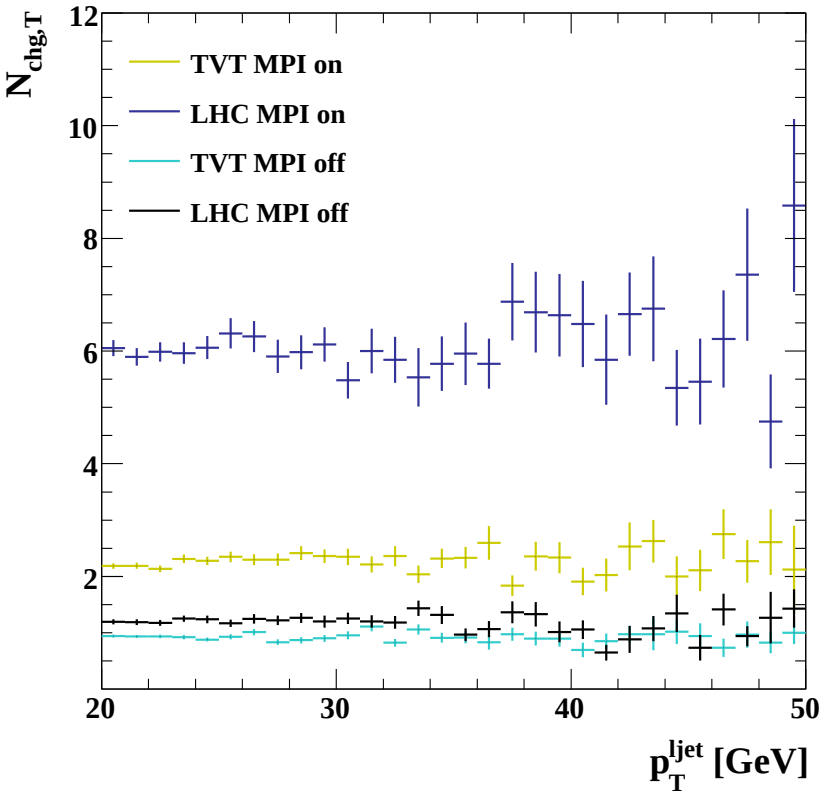
LHC extrapolation

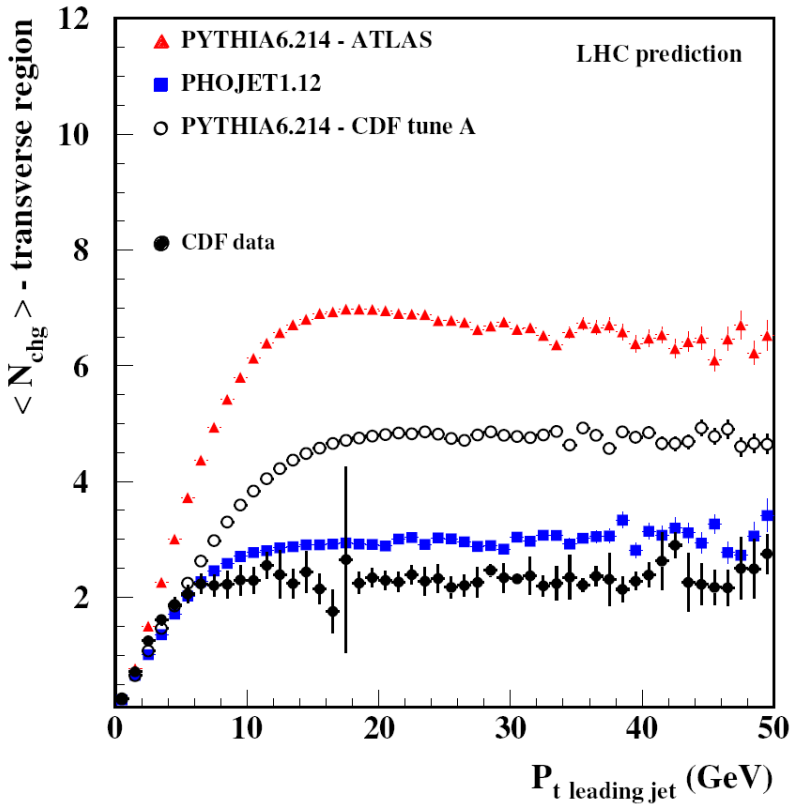
- All parameters left on their values obtained from the fit to Tevatron data
- Factor of 3 activity increase in the central region
- comparison to other generators...



LHC extrapolation contd.

Use transverse region as benchmark.





extracted from: *Hera and the LHC* proceedings [Alekhin et al. 2005]

Outline

Idea

Ongoing work with Jon Butterworth and Mike Seymour. Inspired by [hep-ph/0207283, I. Borozan and M. H. Seymour]

- Eikonal model allows the calculation of the total pp cross section at high energies
- Use the total cross section to fix the amount of scatters (cross section) below $p_T^{\min}$. σ_{tot} =Donnachie & Landshoff
- Model consistency at LHC implies constraints on the parameter space $(p_T^{\min}, \mu^2)$

Details

- Total cross section is

$$\sigma_{\rm tot} = 2 \int {\rm d}^2 b \, \left[1 - \, e^{-\chi(b,s)} \right] \tag{1}$$

- Intrinsic p_T cutoff ($p_T^{\rm min}$):

$$\chi(b,s) = \frac{1}{2} A(b) \cdot \sigma_{\rm hard}^{\rm inc}(s; p_T^{\rm min}) \tag{2}$$

- Include scatters below $p_T^{\rm min}$, assuming

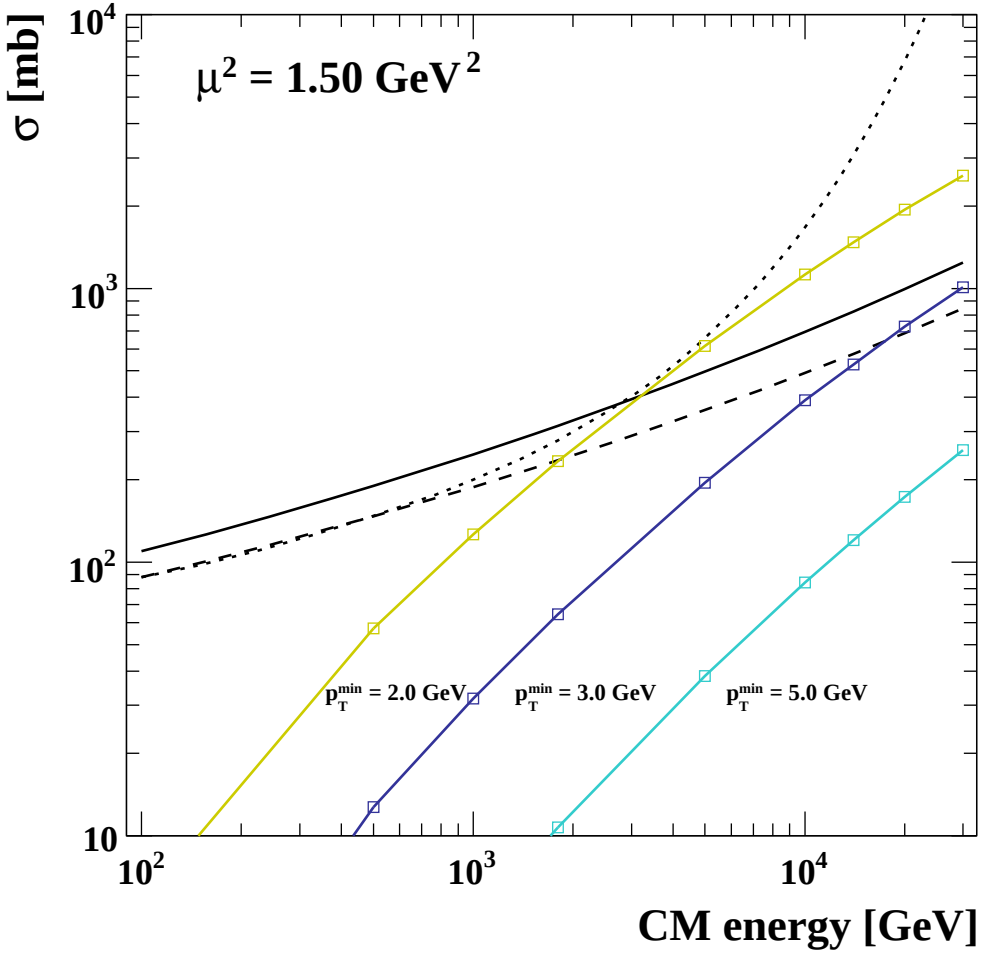
$$\chi(b,s) = \frac{1}{2} A(b) \cdot (\sigma_{\rm hard}^{\rm inc} + \sigma_{\rm soft}^{\rm inc}) \tag{3}$$

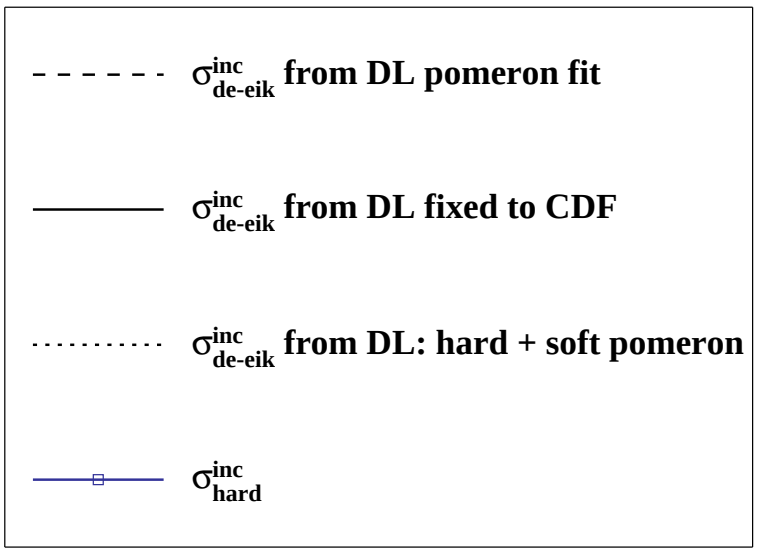
- $\sigma_{\rm tot}$ is a function of $\sigma_{\rm de-eik}^{\rm inc} = \sigma_{\rm hard}^{\rm inc} + \sigma_{\rm soft}^{\rm inc}$

Outline

De-eikonalized cross sections

$$\sigma_{\rm tot} = 2\int {\rm d}^2 b \left[1 - e^{-\frac{1}{2}A(b)\cdot(\sigma^{\rm inc}_{\rm hard}+\sigma^{\rm inc}_{\rm soft})}\right]$$





De-eikonalized cross sections

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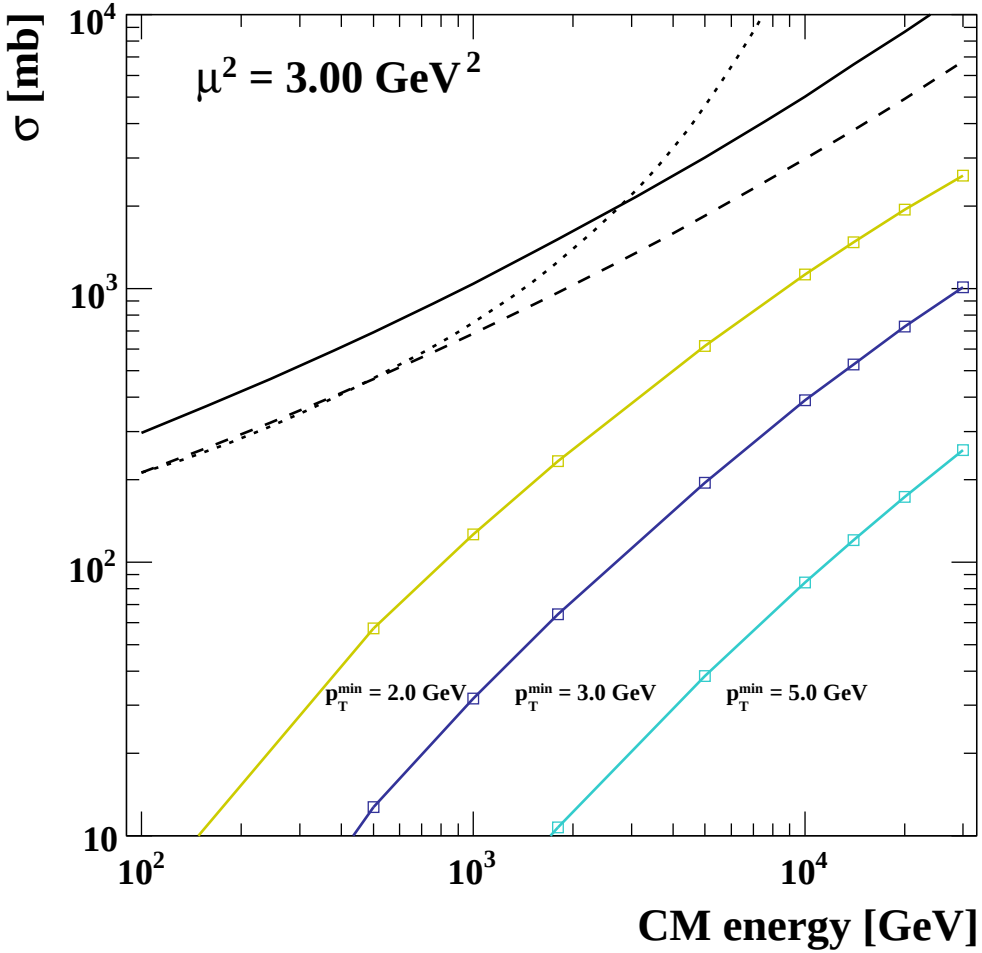
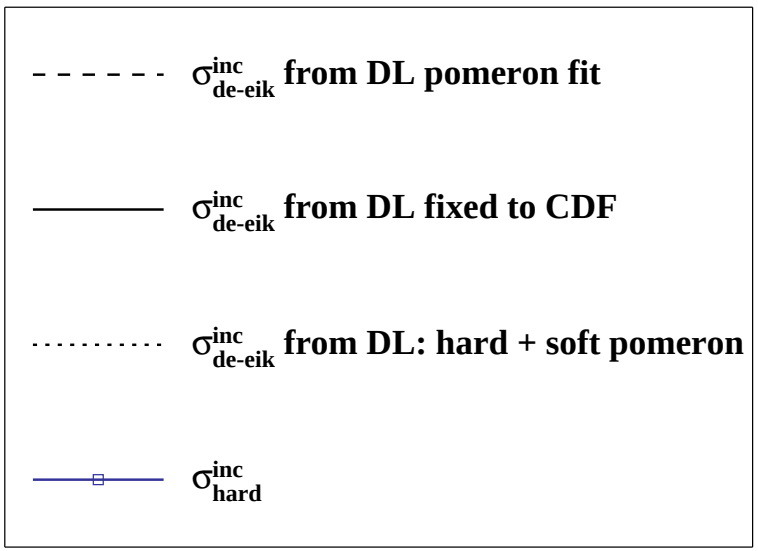
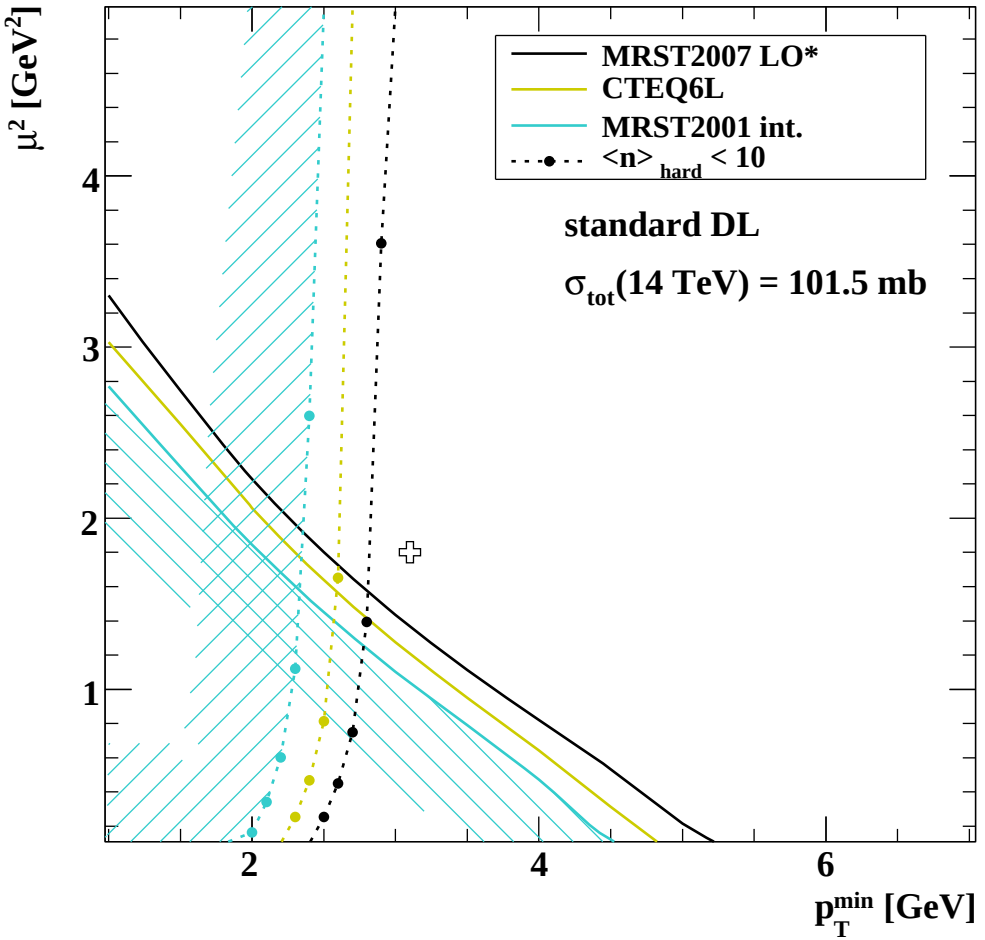




Parameter space

- Solid curves: Points where $\sigma_{\text{soft}}^{\text{inc}} = 0$ mb.
- Experience showed that $n_{int} \gtrsim 10$ is very hard to establish due to energy-momentum conservation.
- Cross shows the position of the Hw2.1.3 **TVT** tune using **MRST2001 int.**



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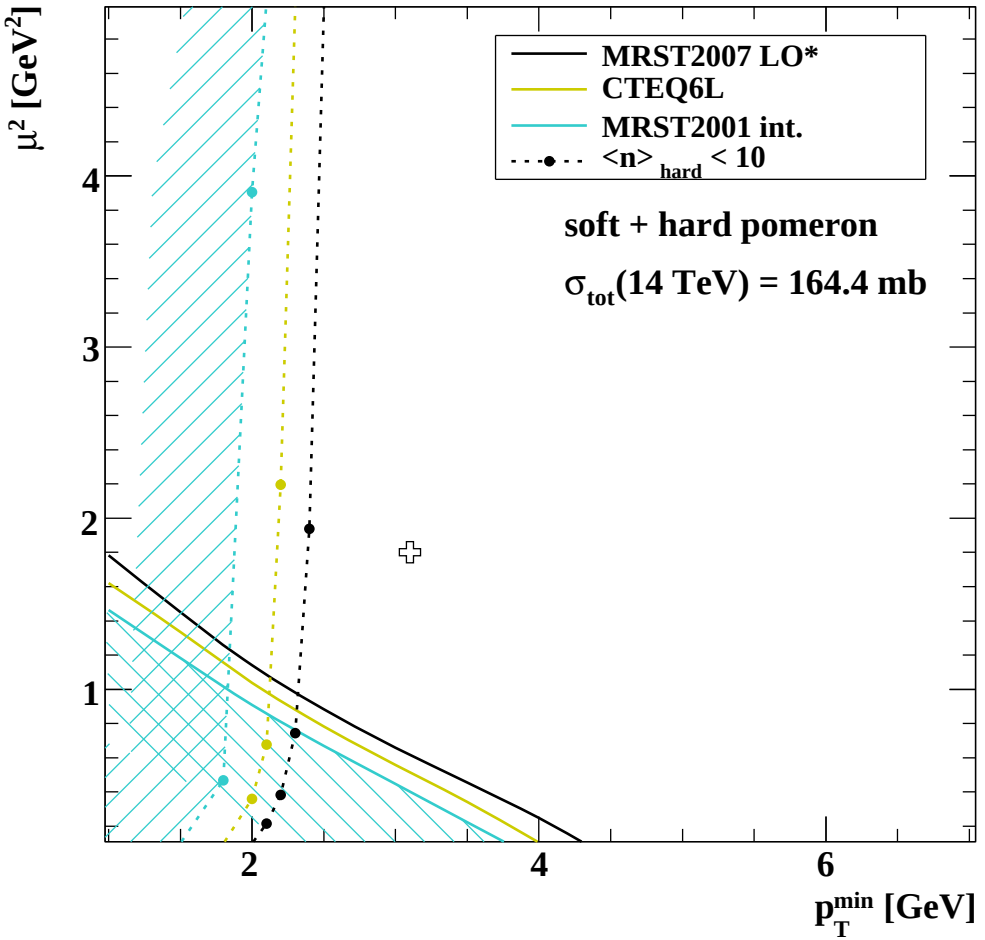

Conclusions

- The presented model describes the Tevatron data
- Our model gives similar results than PYTHIA with energy dependent parameters

Next steps:

- Modelling of the non perturbative scatters, i.e. $p_T \in (0, p_T^{min})$ to enable the simulation of minimum bias events.
  The parameters where this works fine are known now!
- PDF uncertainty for LHC final states (GRID)
- Double/multiple parton scattering (hard processes) + low p_T jets. (completed, not released yet)