# Herwig++ and the new ATLAS MB/UE results

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on behalf of Herwig++ group

Karlsruhe Institute of Technology

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**This talk:**

- Introduction - Underlying event in Herwig++
- New data! MinBias ATLAS @ 900 GeV and @ 7 TeV
- Colour structure
- First glance at the ATLAS UE @ 7 TeV results.
- Outlook

**UA5 model (deprecated, only for reference)**

- Included from Herwig++ 2.0. [Herwig++, hep-ph/0609306]
- Little predictive power.
- Was default in fHerwig. Superseded by JIMMY [JM Butterworth, JR Forshaw, MH Seymour, ZP C72 637 (1996)]

**Semihard UE**

- Default from Herwig++ 2.1. [Herwig++, 0711.3137]
- Multiple hard interactions, $p_t \geqslant p_t^{min}$ [Bähr, Gieseke, Seymour, JHEP 0807:076]
- Similar to JIMMY
- Good description of harder TVT Run I UE data (Jet20).

**Semihard+Soft UE**

- Default from Herwig++ 2.3. [Herwig++, 0812.0529]
- Extension to soft interactions, $p_t \leqslant p_t^{min}$ [Bähr, Gieseke, Seymour, JHEP 0807:076]
- Theoretical work with simplest possible extension. [Bähr, Butterworth, Seymour, JHEP 0901:065]
- "Hot Spot" model. [Bähr, Butterworth, Gieseke, Seymour, 0905.4671]

Starting point: hard inclusive jet cross section.

$$\sigma^{\text{inc}}(s;p_t^{\text{min}}) = \sum_{i,j} \int_{p_t^{\text{min}2}} \mathrm{d}p_t^2 f_{i/h_1}(x_1,\mu^2) \otimes \frac{\mathrm{d}\hat{\sigma}_{i,j}}{\mathrm{d}p_t^2} \otimes f_{j/h_2}(x_2,\mu^2)\,,$$

$\sigma^{\text{inc}} > \sigma_{\text{tot}}$ eventually (for moderately small $p_t^{\text{min}}$).

Interpretation: $\sigma^{\text{inc}}$ counts *all* partonic scatters that happen during a single *pp* collision $\Rightarrow$ more than a single interaction.

$$\sigma^{\text{inc}} = \bar{n}\sigma_{\text{inel}}.$$

Use eikonal approximation (= independent scatters). Leads to Poisson distribution of number $m$ of additional scatters,

$$P_m(\vec{b},s) = \frac{\bar{n}(\vec{b},s)^m}{m!} \mathrm{e}^{-\bar{n}(\vec{b},s)} \ .$$

Then we get $\sigma_{\mathrm{inel}}$:

$$\sigma_{\mathrm{inel}} = \int \mathrm{d}^2\vec{b} \sum_{n=1}^{\infty} P_m(\vec{b},s) = \int \mathrm{d}^2\vec{b} \left(1 - \mathrm{e}^{-\bar{n}(\vec{b},s)}\right) \ .$$

Cf. $\sigma_{\mathrm{inel}}$ from scattering theory in eikonal approx. with scattering amplitude $a(\vec{b},s) = \frac{1}{2i}(\mathrm{e}^{-\chi(\vec{b},s)} - 1)$

$$\sigma_{\mathrm{inel}} = \int \mathrm{d}^2\vec{b} \left(1 - \mathrm{e}^{-2\chi(\vec{b},s)}\right) \qquad \Rightarrow \qquad \chi(\vec{b},s) = \tfrac{1}{2}\bar{n}(\vec{b},s) \ .$$

$\chi(\vec{b},s)$ is called *eikonal* function.

# Eikonal model basics

From assumptions:

- at fixed impact parameter b, individual scatterings are independent,
- the distribution of partons in hadrons factorizes with respect to the b and x dependence.

we get the average number of partonic collisions at a given b value is

$$\bar{n}(b,s) = A(b)\sigma^{inc}(s; p_t^{min}) = 2\chi(b,s)$$

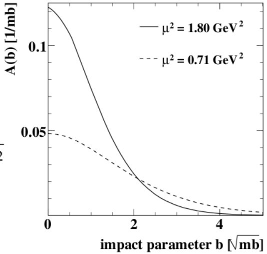
where $A(b)$ is the partonic overlap function of the colliding hadrons

$$A(b) = \int d^2\vec{b}' G_A(|\vec{b}'|) G_B(|\vec{b} - \vec{b}'|)$$

$G(\vec{b})$ from electromagnetic FF:

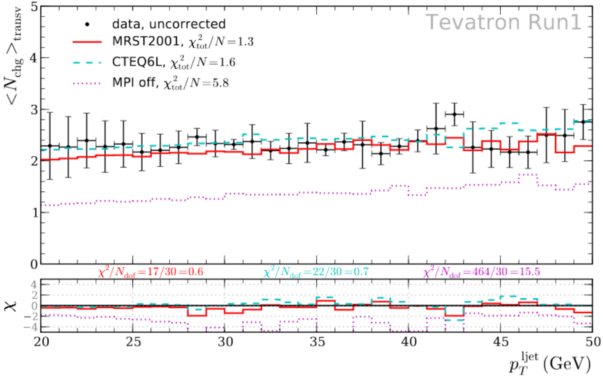
$$G_p(\vec{b}) = G_{\bar{p}}(\vec{b}) = \int \frac{d^2\vec{k}}{(2\pi)^2} \frac{e^{i\vec{k}\cdot\vec{b}}}{(1+\vec{k}^2/\mu^2)^2}$$

But $\mu^2$ *not fixed* to the *electromagnetic* 0.71 GeV$^2$. Free for colour charges.




$\Rightarrow$ Two main parameters: $\mu^2, p_t^{\min}$.

Good description of Run I Underlying event data ($\chi^2 = 1.3$).




Only $p_T^{\rm ljet} > 20\,{\rm GeV}$.

So far only hard MPI.
Now extend to soft interactions with

$$\chi_{\rm tot} = \chi_{QCD} + \chi_{\rm soft}.$$

Similar structures of eikonal functions:

$$\chi_{\rm soft} = \frac{1}{2} A_{\rm soft}(\vec{b}) \sigma_{\rm soft}^{\rm inc}$$

Simplest possible choice: $A_{\rm soft}(\vec{b};\mu) = A_{\rm hard}(\vec{b};\mu) = A(\vec{b};\mu)$.
Then

$$\chi_{\rm tot} = \frac{A(\vec{b};\mu)}{2} \left(\sigma_{\rm hard}^{\rm inc} + \sigma_{\rm soft}^{\rm inc}\right) \ .$$

One new parameter $\sigma_{\rm soft}^{\rm inc}$.

Taking the Tevatron data together with the wide range of possible values of $\sigma_{tot}$ considered at LHC, we see that this model is to simple.

Extension: Relax the constraint of identical overlap functions:

$$A_{soft}(b) = A(b, \mu_{soft})$$

Fix the two parameters $\mu_{\rm soft}$ and $\sigma^{\rm inc}_{\rm soft}$ in

$$\chi_{\rm tot}(\vec{b},s) = \frac{1}{2}\left(A(\vec{b};\mu)\sigma^{\rm inc}{\rm hard}(s;p_t^{\rm min}) + A(\vec{b};\mu_{\rm soft})\sigma^{\rm inc}_{\rm soft}\right)$$

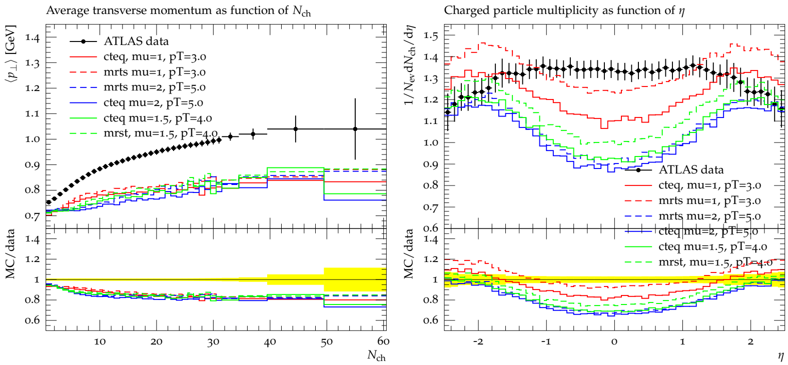
from two constraints. Require simultaneous description of $\sigma_{\rm tot}$ and $b_{\rm el}$ (measured/well predicted),

$$\sigma_{\rm tot}(s) \stackrel{!}{=} 2\int {\rm d}^2\vec{b}\left(1-{\rm e}^{-\chi_{\rm tot}(\vec{b},s)}\right) ,$$

$$b_{\rm el}(s) \stackrel{!}{=} \int {\rm d}^2\vec{b}\,\frac{b^2}{\sigma_{\rm tot}}\left(1-{\rm e}^{-\chi_{\rm tot}(\vec{b},s)}\right) .$$

# Comparison with MinBias ATLAS data

New data! The first comparison ...




- Ups, not so nice...
  Despite very good agreement with Rick Field's CDF UE analysis.

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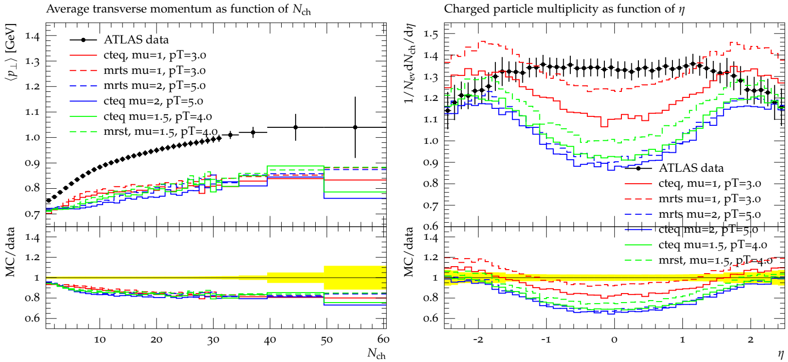
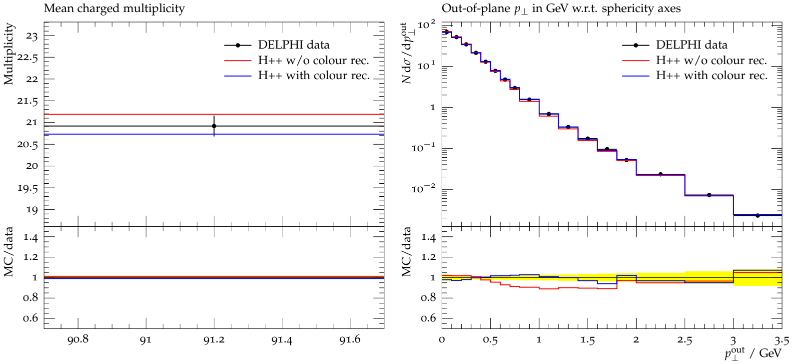



- Ups, not so nice...
  Despite very good agreement with Rick Field's CDF UE analysis.
- Colour structure?

# Colour structure - CR model - LEP tune

- Colour reconnection (CR) model - see Christian's talk.
  - One parameter of the CR model: $p_{\text{reco}}$
  - Validation against LEP data.

**Preliminary results**

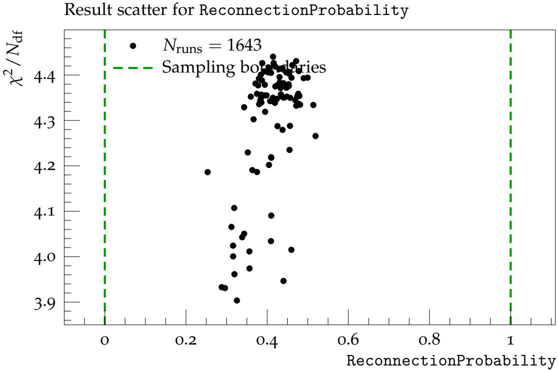



Agreement on same level as w/o CR model.

- Many thanks for help and hints how to use their program to the Professor team! (Especially to Holger Schulz and Eike von Seggern)

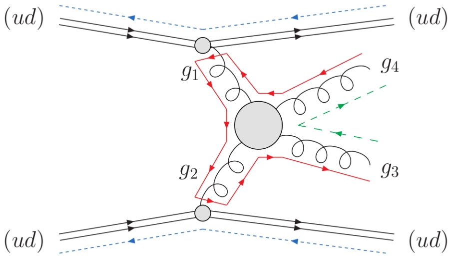
Can we still describe the LEP data similar to Herwig++ w/o colour reconnection?

# Preliminary results




Prefered by LEP data is: $0.2 \leq p_{\mathrm{reco}} \leq 0.6$

- Colour structure of the soft interactions, $p_t \leqslant p_t^{min}$
  Sensitivity to parameter:
  • `colourDisrupt` = P(disrupt colour lines) as opposed to hard QCD.
  • `colourDisrupt` = 1, completely disconnected.



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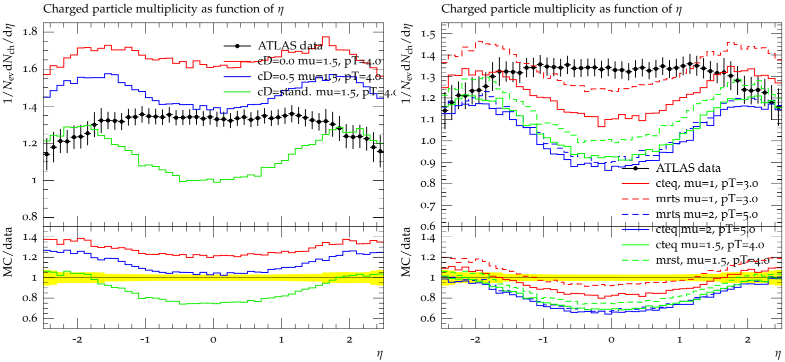
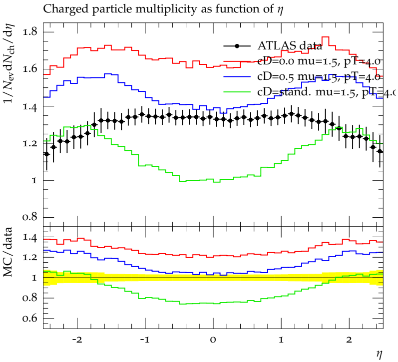
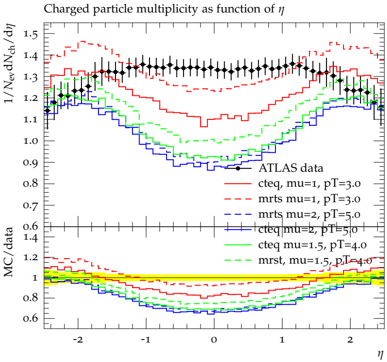



- Colour structure of the soft interactions, $p_t \leqslant p_t^{min}$

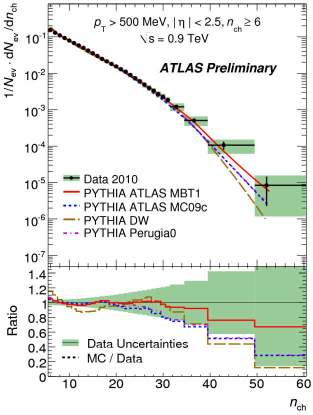
New data! The first comparison ...




- Colour structure of the soft interactions, $p_t \leqslant p_t^{min}$
- Problem: diffraction $\Rightarrow$ diffractive suppressed data with cut: $N_{ch} \geqslant 6$

# Comparison with MinBias ATLAS data

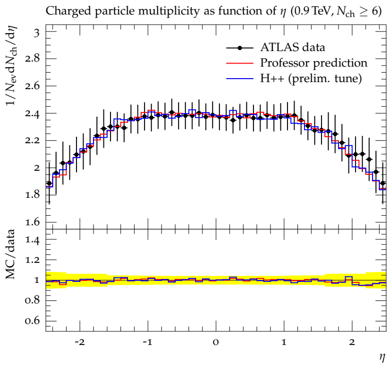


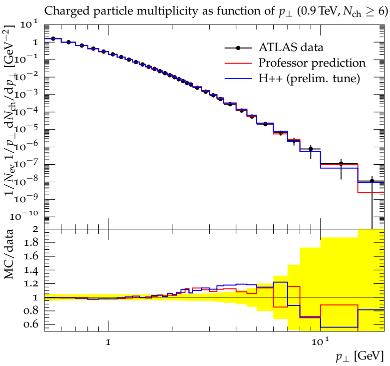

- We used a diffractive suppressed sample with cut: $N_{ch} \geqslant 6$
- **Attention:** The ATLAS graphs for $N_{ch} \geqslant 6$ are public, but the data points are not. We read the data points from the plots using:
  - **EasyNData** - Peter Uwer [arXiv:0710.2896]
  - **DataThief** - B. Tummers, http://datathief.org/
  - **g3data** - J. Frantz, http://www.frantz.fi/software/g3data.php
  - some other tricks ...
  - question to the collaboration: can we do something about this?

I am happy to provide data points with corresponding Rivet analyses if someones needs it.

# Preliminary results

(space for improvement)

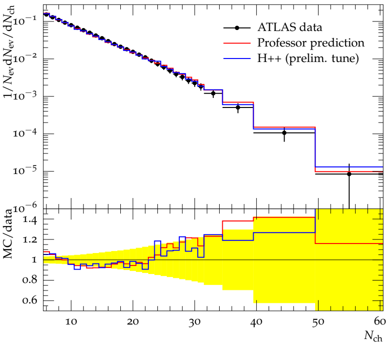


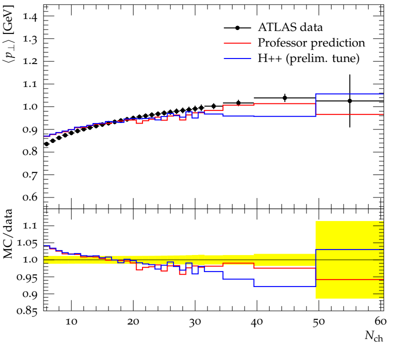




$p_t^{min} = 2.6$ GeV, $\mu^2 = 1.1$, $p_{\text{reco}} = 0.48$, $p_{\text{disrupt}} = 4.3$

# Preliminary results

(space for improvement)

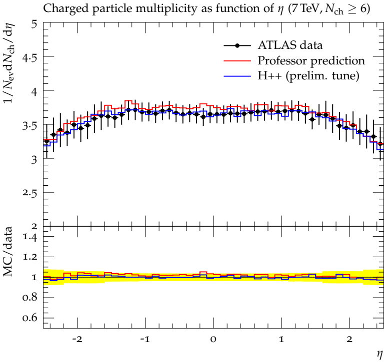


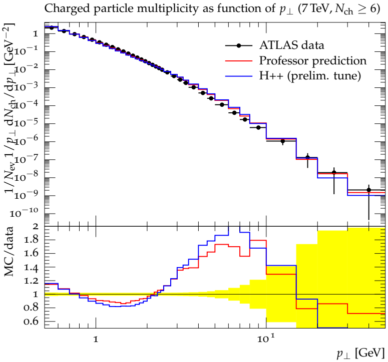




$p_t^{min} = 2.6$ GeV, $\mu^2 = 1.1$, $p_{reco} = 0.48$, $p_{disrupt} = 4.3$

# MinBias ATLAS 7000 GeV

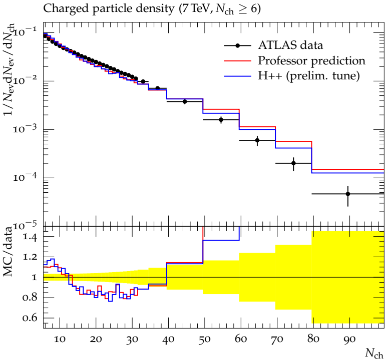
## Very preliminary results

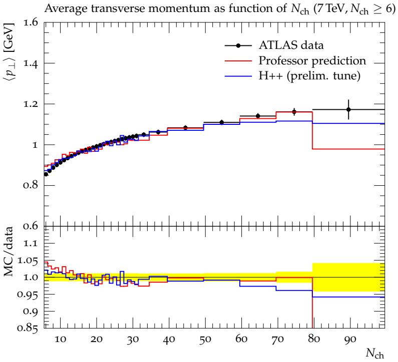



$p_t^{min} = 5.2\,GeV\,,\quad \mu^2 = 1.8\,GeV^2,\quad p_{\mathrm{reco}} = 0.55,\quad p_{\mathrm{disrupt}} = 0.68$

# Very preliminary results




$p_t^{min} = 5.2\,GeV$ ,   $\mu^2 = 1.8\,GeV^2$,   $p_{reco} = 0.55$,   $p_{disrupt} = 0.68$

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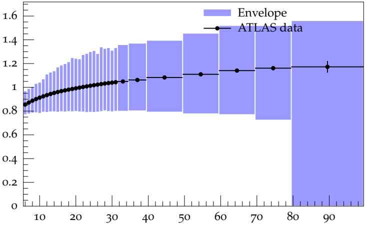
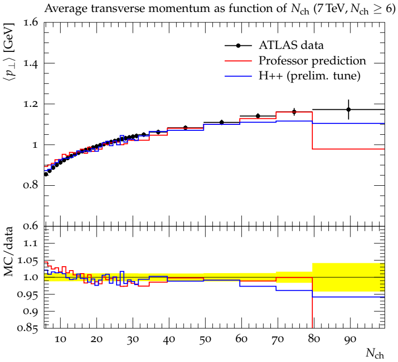
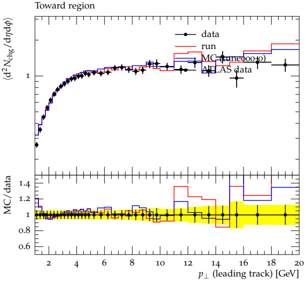


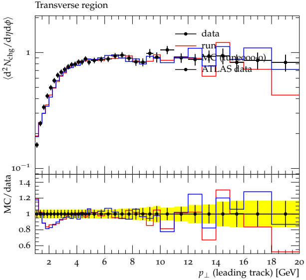



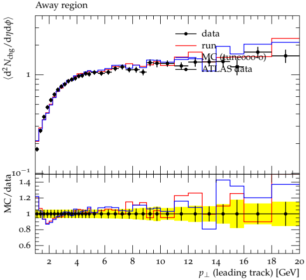

$p_t^{min} = 5.2\,GeV$ , $\mu^2 = 1.8\,GeV^2$, $p_{\text{reco}} = 0.55$, $p_{\text{disrupt}} = 0.68$

# First glance on the ATLAS UE @ 7 TeV results.

Very, very preliminary results (ATLAS-CONF-2010-029)



# Summary

- Need colour reconnection.
- First tunes to 900 GeV and 7 TeV Min Bias (Nch $\geq$ 6) data give good results.
- We start to look also at UE results.
- ATLAS 7TeV data will be investigated in more details soon.
- Still space for improvements: treatment of remnants pdf, more involved overlap function, energy dependent parameters, better understanding of colour structure, more universal tune ...
- Minimum bias/underlying event/diffraction under constant improvement!
- Stay tuned!