Simulation of multiple partonic interactions in Herwig++

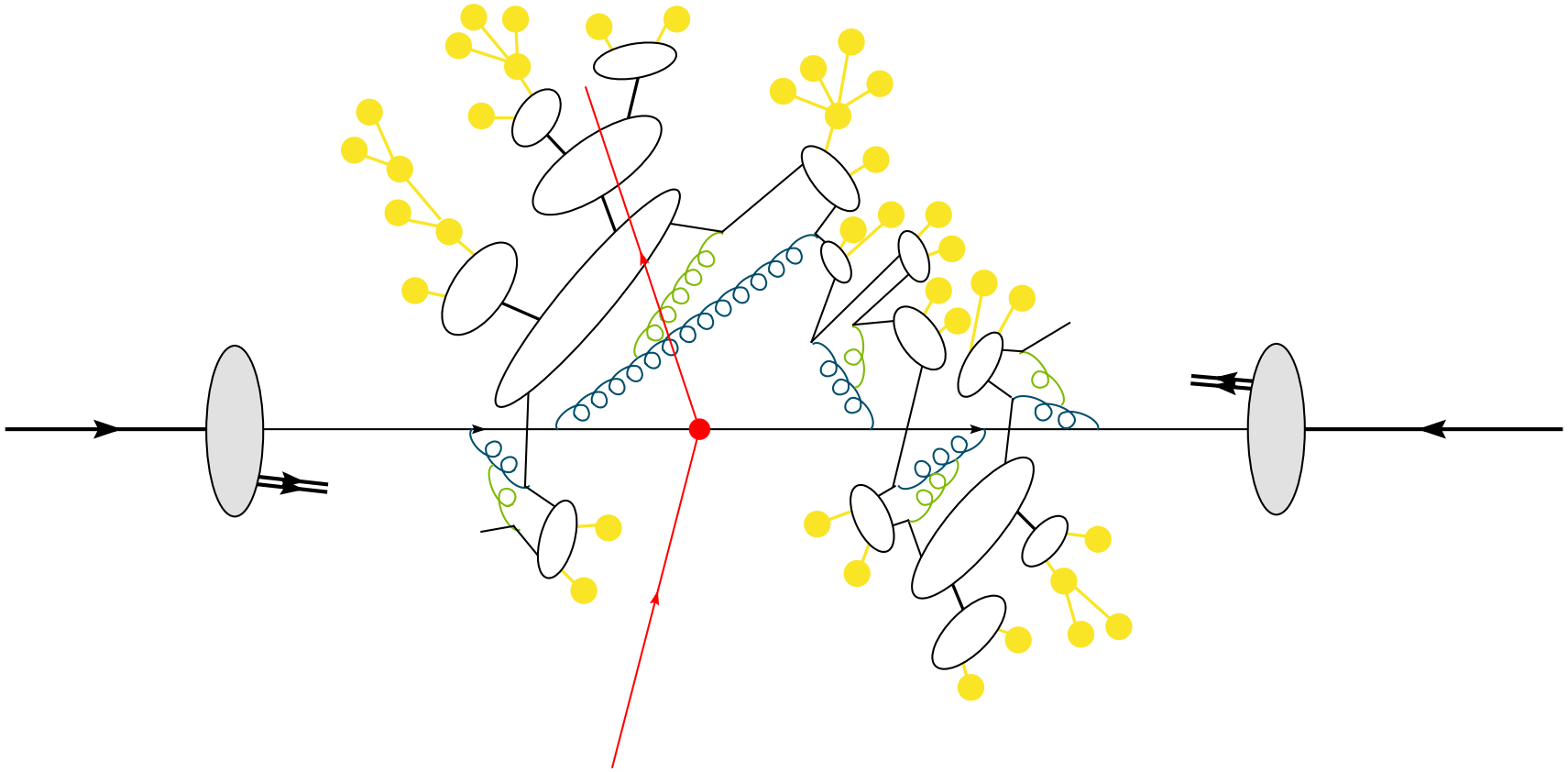
Andrzej Siódmok
in collaboration with
Manuel Bähr, Stefan Gieseke, Christian Röhr, Mike Seymour
on behalf of Herwig++ group

Institut für Theoretische Physik
KIT

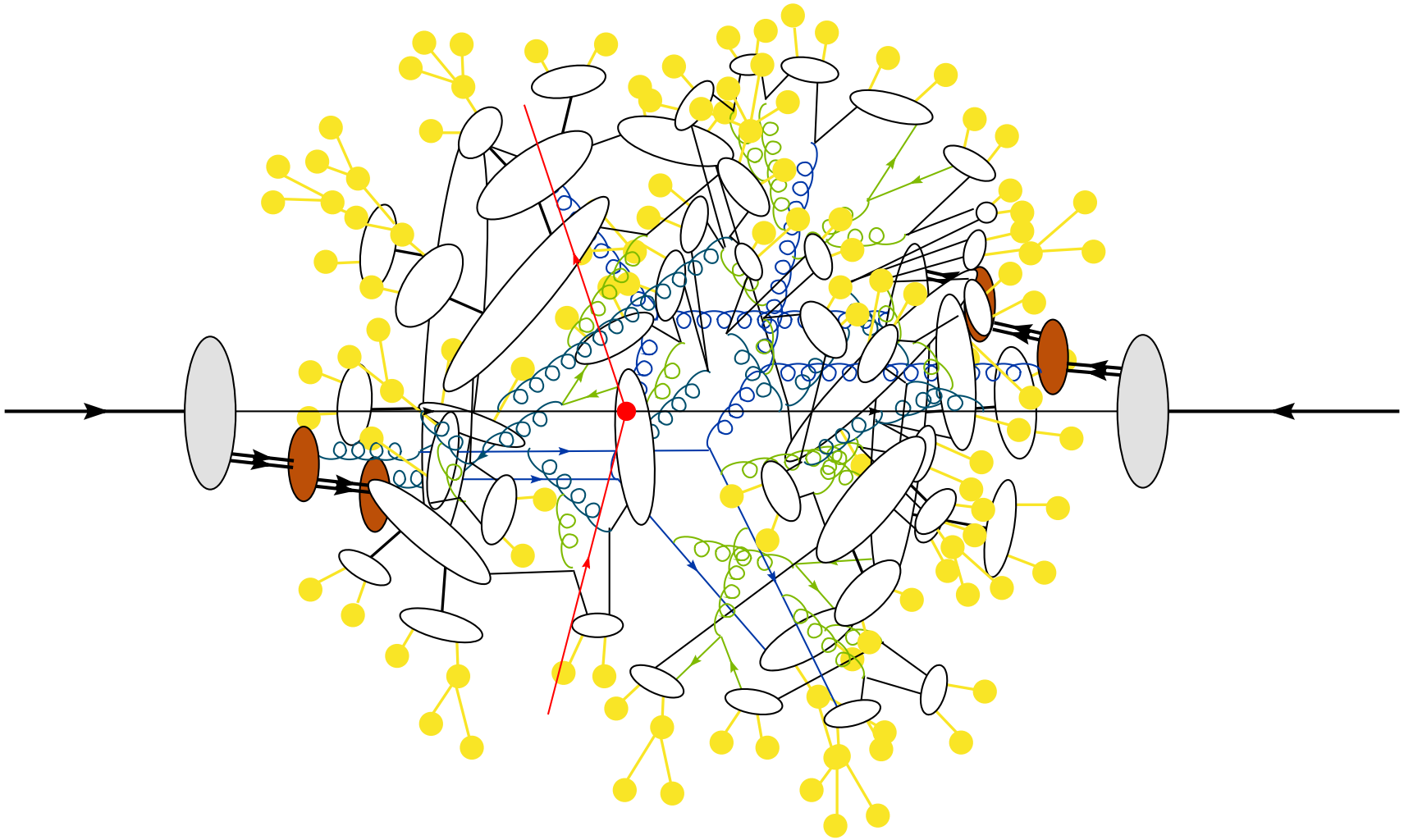
Winter Workshop on Recent QCD Advances at the LHC

University of Oregon, 7th March 2011

pp Event Generator



pp Event Generator



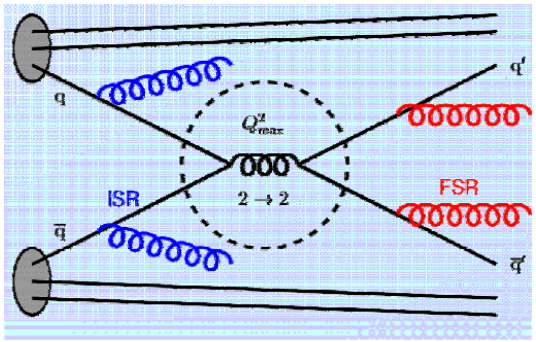
Outline

This talk:

- Philosophy
- Introduction - Evolution of MPI model in Herwig++
- MPI model in Herwig++
- Colour structure
- Comparison with ATLAS results: MB and UE @ 900 GeV and @ 7 TeV
- Outlook

From Peter Skands, slide from Eugene Workshop 2009

Monte Carlo Philosophy



► Calculate Everything: **solve QCD** → requires compromise

- Improve Born-level perturbation theory, by including the 'most significant' corrections → complete events → any observable you want

1. *Parton Showers*		1. *Soft/Collinear Logarithms*
2. *Matching*	roughly	2. *Finite Terms, "K"-factors*
3. *Hadronisation*		3. *Power Corrections (more if not IR safe)*
4. *The Underlying Event*		4. *?*

(+ many other ingredients: resonance decays, beam remnants, Bose-Einstein, …)

Asking for complete events is a tall order …

"Entities must not be multiplied beyond necessity"
(Entia non sunt multiplicanda praeter necessitatem)
[William of Ockham (d'Okham)]

Occam's razor (...) is a principle that generally recommends **selecting the competing hypothesis that makes the fewest new assumptions**, when the hypotheses are equal in other respects. For instance, **they must both sufficiently explain available data in the first place**. (...) That is, the razor is a principle that suggests **we should tend towards simpler theories until we can trade some simplicity for increased explanatory power**.

[Wikipedia]

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

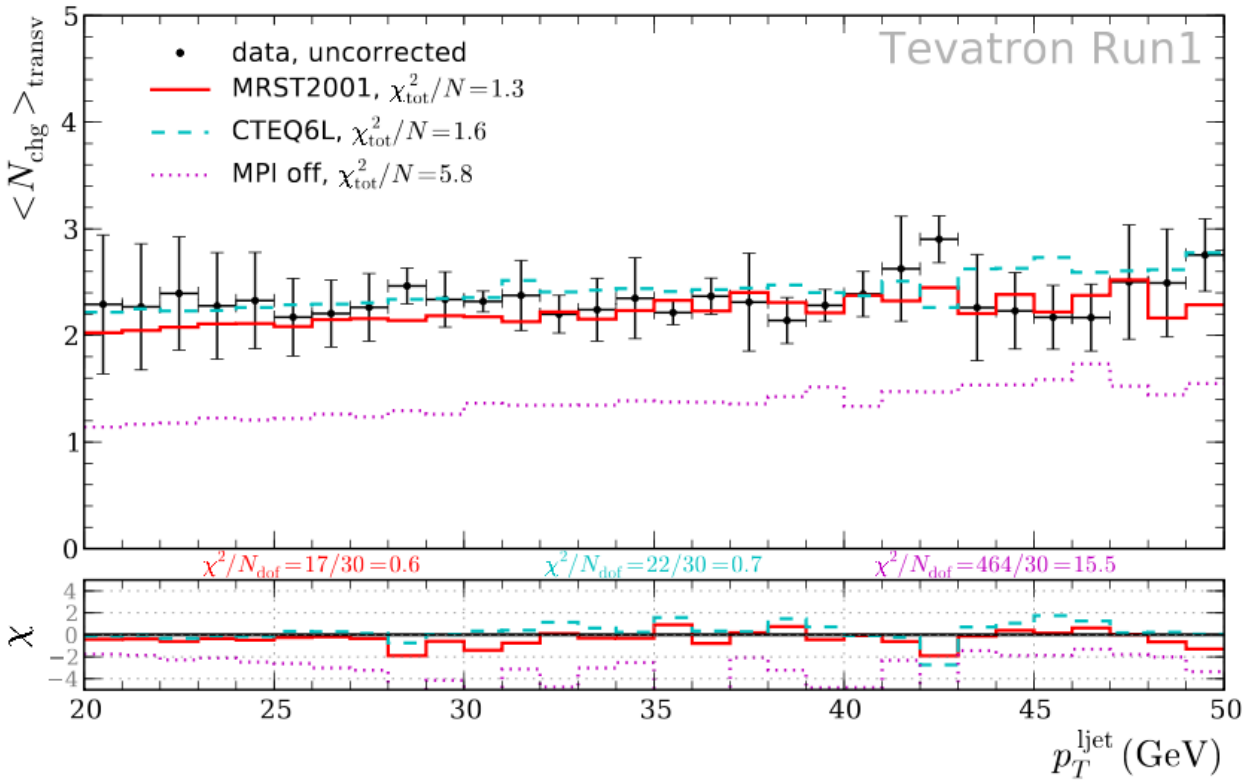
[JM Butterworth, JR Forshaw, MH Seymour, ZP C72 637 (1996)]

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 Run I UE data (Jet20).

Semihard UE

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



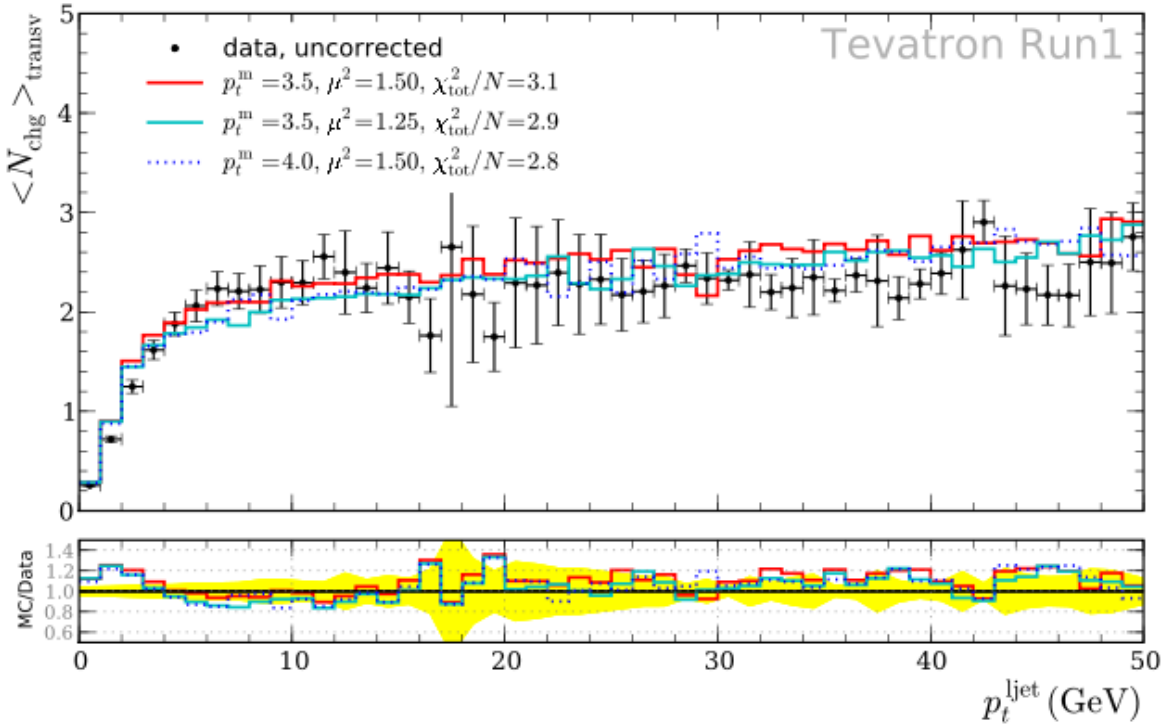
Only $p_T^{ljet} > 20\,\text{GeV}$.

Evolution of MPI model in Herwig++

Semihard+Soft UE

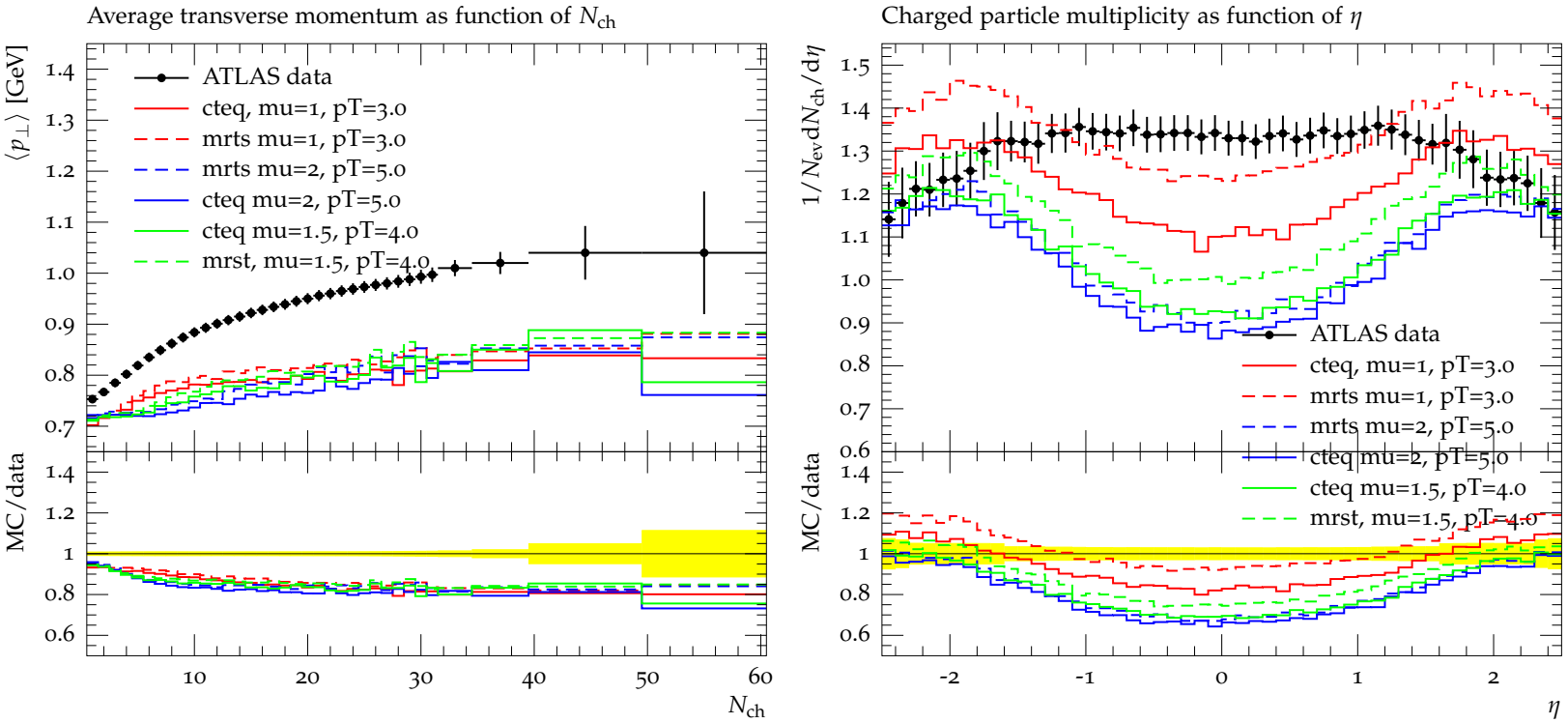
- Default from Herwig++ 2.3. [Herwig++, 0812.0529]
- Extension to soft interactions, $p_t \leqslant p_t^{\min}$ [Bähr, Gieseke, Seymour, JHEP 0807:076]
- Theoretical work with simplest possible extension. [Bähr, Butterworth, Seymour, JHEP 0901:065]
- "Hot Spot" model. [Bähr, Butterworth, Gieseke, Seymour,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

Semihard+Soft UE



Comparison with MinBias ATLAS data (900 GeV)

- ATLAS charged particles in Min Bias ($N_{ch} \geq 1,\ p_T > 500MeV,\ |\eta| < 2.5$)
- Convenient as the analysis was quickly available in `RIVET`.

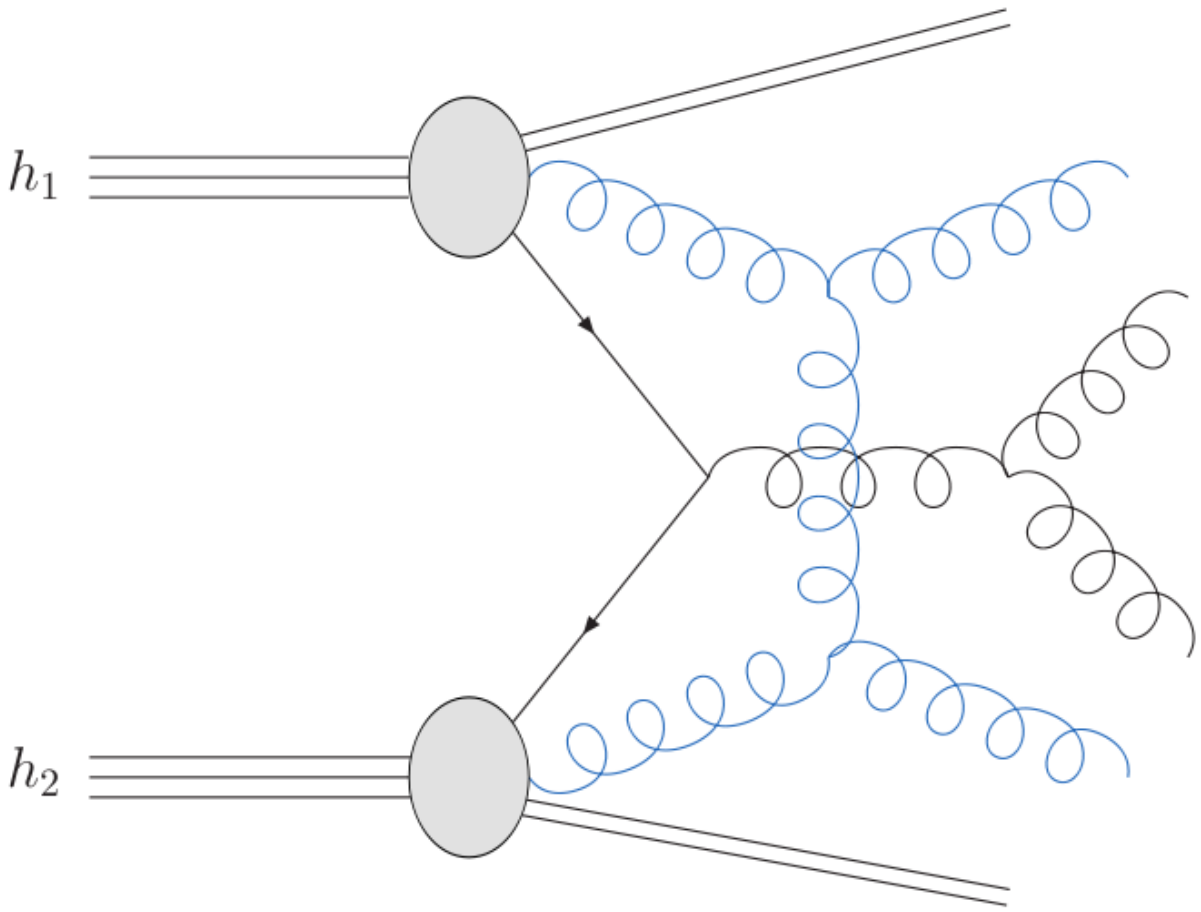


- Choice of PDF set (CTEQ6l1 vs MSTW LO**)

Colour Structure of the Underlying Event

- Colour Reconnection (parameter p_{reco}) - Included from Herwig++ 2.5
- Colour Disruption - only Soft UE (parameter p_{CD})
- Retuning to LEP data needed.
- Tests of Colour Reconnection model.

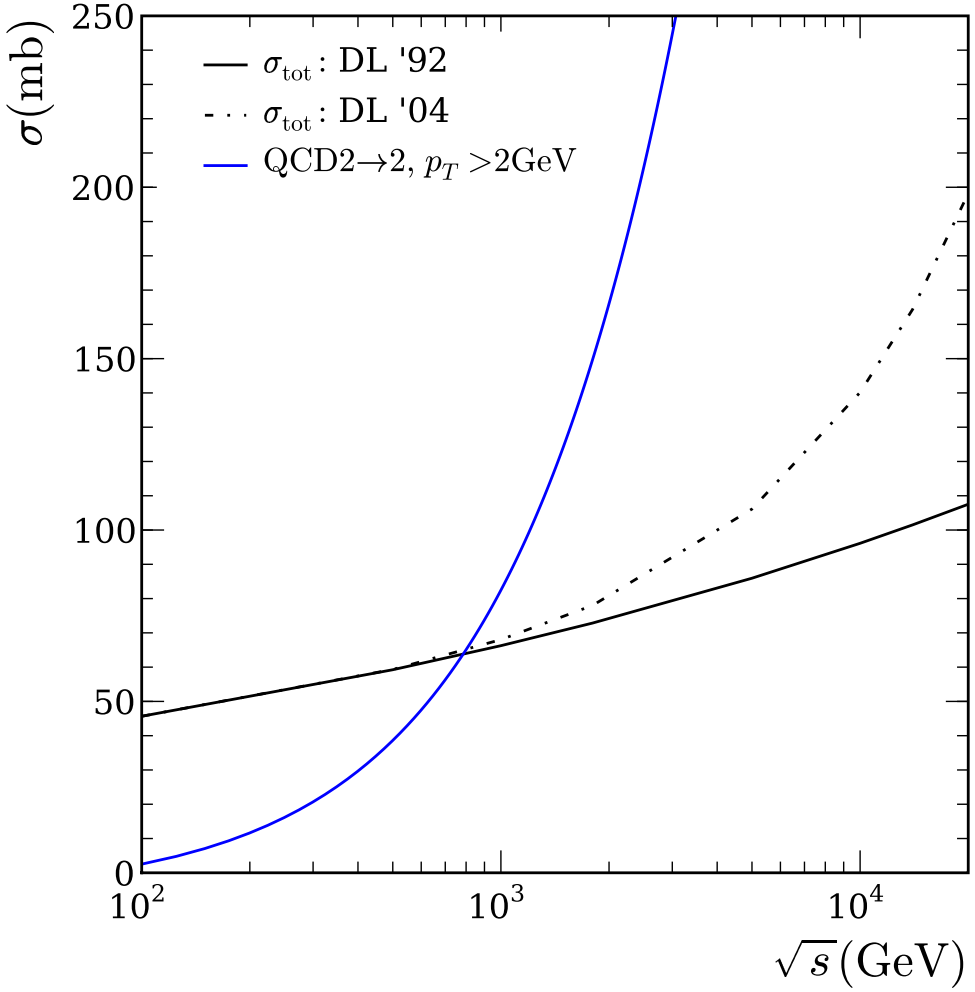
Mulitple hard interactions



Starting point: hard inclusive jet cross section.

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

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


$\sigma_{\rm tot}$: DL '92
$\sigma_{\rm tot}$: DL '04
QCD2→2, p_T >2GeV
σ(mb)
250
200
150
100
50
0
10^2
10^3
10^4
$\sqrt{s}$(GeV)

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^{min}).

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

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

Also measurement of momentum imbalance in multijet events at CERN ISR, $\gamma + 3$ jet at TVT.

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 σ_{inel}:

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

Eikonal model basics

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 σ_{inel}:

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

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

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

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

Calculation of $\bar{n}(\vec{b}, s)$ from parton model assumptions:

$$\begin{aligned}\bar{n}(\vec{b}, s) &= L_{\text{partons}}(x_1, x_2, \vec{b}) \otimes \sum_{ij} \int \mathrm{d}p_t^2 \frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}p_t^2} \\ &= \sum_{ij} \frac{1}{1+\delta_{ij}} \int \mathrm{d}x_1 \mathrm{d}x_2 \int \mathrm{d}^2\vec{b}' \int \mathrm{d}p_t^2 \frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}p_t^2} \\ &\quad \times D_{i/A}(x_1, p_t^2, |\vec{b}'|) D_{j/B}(x_2, p_t^2, |\vec{b} - \vec{b}'|)\end{aligned}$$

Calculation of $\bar{n}(\vec{b}, s)$ from parton model assumptions:

$$
\begin{aligned}
\bar{n}(\vec{b}, s) &= L_{\text{partons}}(x_1, x_2, \vec{b}) \otimes \sum_{ij} \int \mathrm{d}p_t^2 \frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}p_t^2} \\
&= \sum_{ij} \frac{1}{1+\delta_{ij}} \int \mathrm{d}x_1 \mathrm{d}x_2 \int \mathrm{d}^2\vec{b}' \int \mathrm{d}p_t^2 \frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}p_t^2} \\
&\qquad \times D_{i/A}(x_1, p_t^2, |\vec{b}'|) D_{j/B}(x_2, p_t^2, |\vec{b} - \vec{b}'|) \\
&= \sum_{ij} \frac{1}{1+\delta_{ij}} \int \mathrm{d}x_1 \mathrm{d}x_2 \int \mathrm{d}^2\vec{b}' \int \mathrm{d}p_t^2 \frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}p_t^2} \\
&\qquad \times f_{i/A}(x_1, p_t^2) G_A(|\vec{b}'|) f_{j/B}(x_2, p_t^2) G_B(|\vec{b} - \vec{b}'|) \\
&= A(\vec{b}) \sigma^{\text{inc}}(s; p_t^{\text{min}}) \ .
\end{aligned}
$$

Calculation of $\bar{n}(\vec{b}, s)$ from parton model assumptions:

$$\begin{aligned}
\bar{n}(\vec{b}, s) &= L_{\text{partons}}(x_1, x_2, \vec{b}) \otimes \sum_{ij} \int \mathrm{d}p_t^2 \frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}p_t^2} \\
&= \sum_{ij} \frac{1}{1+\delta_{ij}} \int \mathrm{d}x_1 \mathrm{d}x_2 \int \mathrm{d}^2\vec{b}' \int \mathrm{d}p_t^2 \frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}p_t^2} \\
&\qquad \times D_{i/A}(x_1, p_t^2, |\vec{b}'|) D_{j/B}(x_2, p_t^2, |\vec{b} - \vec{b}'|) \\
&= \sum_{ij} \frac{1}{1+\delta_{ij}} \int \mathrm{d}x_1 \mathrm{d}x_2 \int \mathrm{d}^2\vec{b}' \int \mathrm{d}p_t^2 \frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}p_t^2} \\
&\qquad \times f_{i/A}(x_1, p_t^2) G_A(|\vec{b}'|) f_{j/B}(x_2, p_t^2) G_B(|\vec{b} - \vec{b}'|) \\
&= A(\vec{b}) \sigma^{\text{inc}}(s; p_t^{\min}) \,.
\end{aligned}$$

$$\Rightarrow \quad \chi(\vec{b}, s) = \tfrac{1}{2}\bar{n}(\vec{b}, s) = \tfrac{1}{2} A(\vec{b}) \sigma^{\text{inc}}(s; p_t^{\min}) \,.$$

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

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

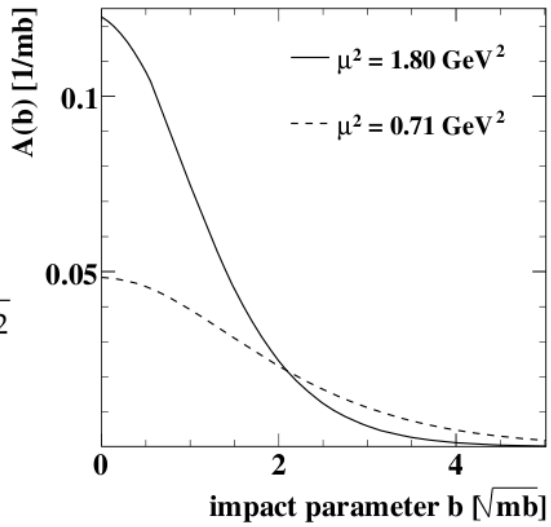
where $A(b)$ is the partonic overlap function of the colliding hadrons

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

$G(\vec{b})$ 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 μ^2 *not fixed* to the *electromagnetic* 0.71 GeV^2.
Free for colour charges.



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

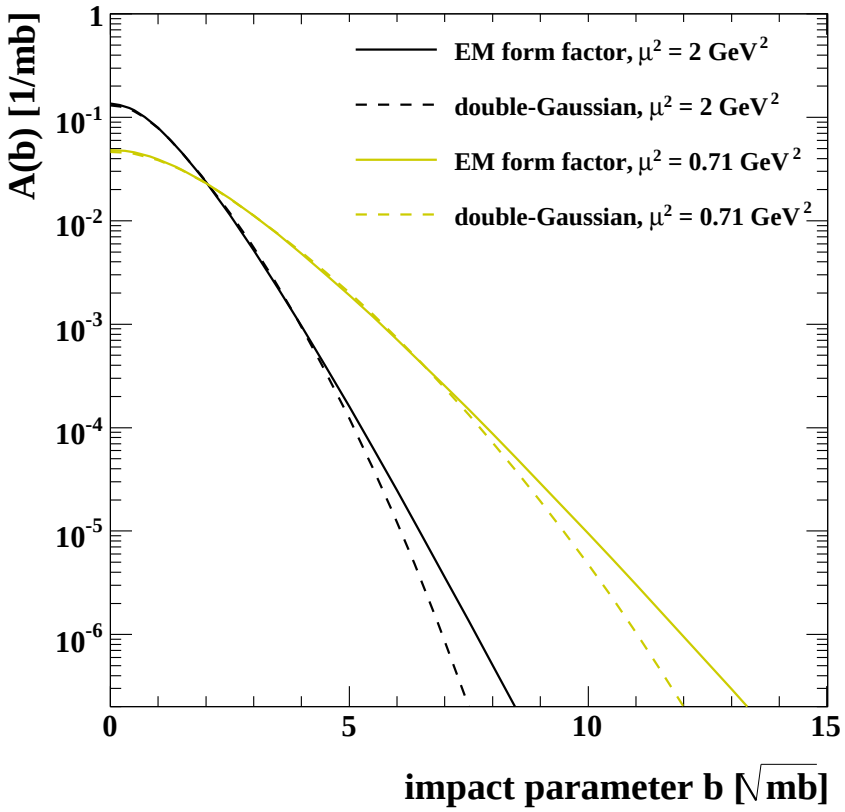
Overlap function

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

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

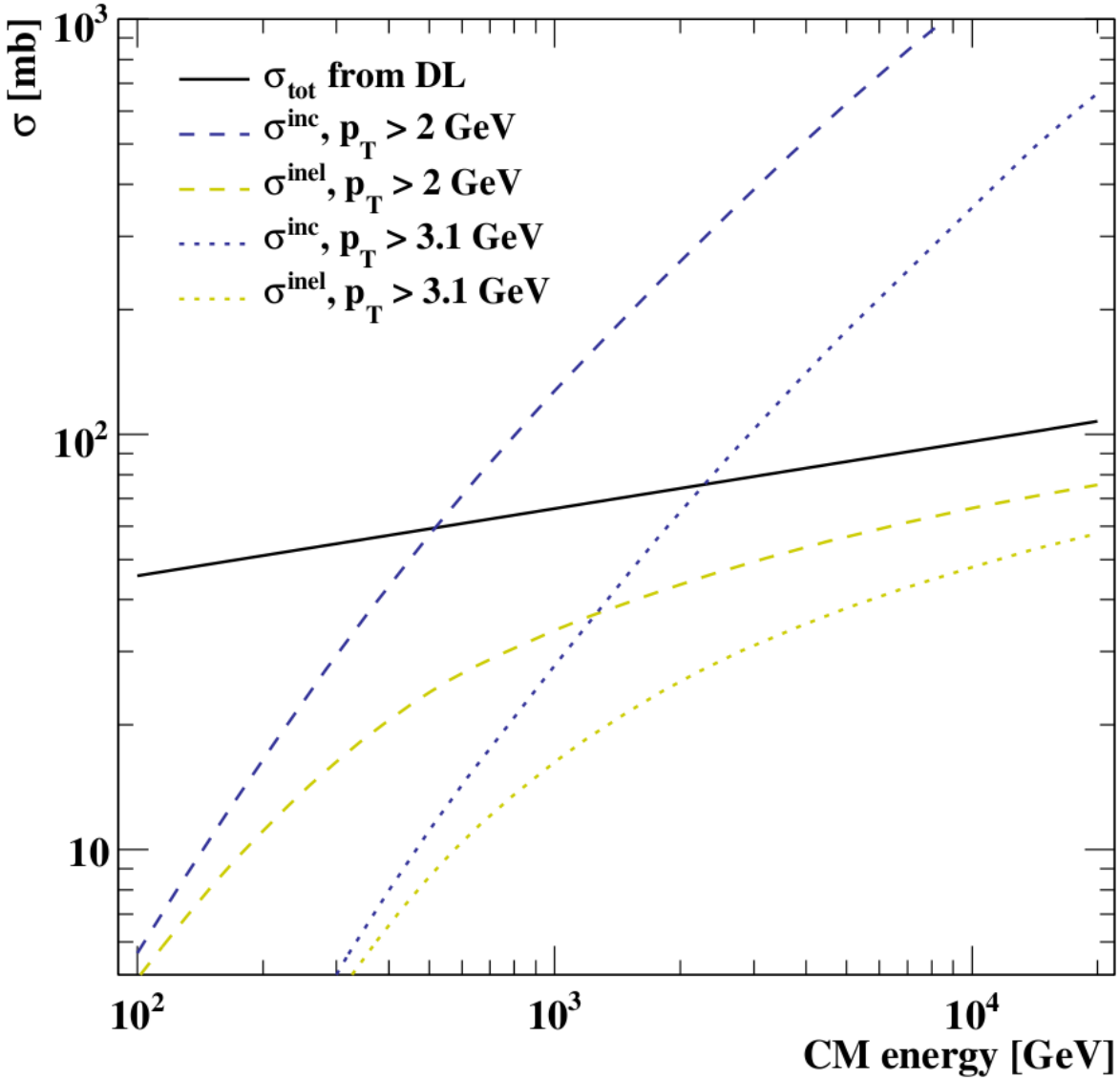
$$G_p(\vec{b}) = G_{\bar{p}}(\vec{b}) = \int \frac{\mathrm{d}^2\vec{k}}{(2\pi)^2} \frac{\mathrm{e}^{i\vec{k}\cdot\vec{b}}}{(1 + \vec{k}^2/\mu^2)^2}$$

But μ^2 *not fixed* to the *electromagnetic* $0.71\,\mathrm{GeV}^2$.
Free for colour charges.

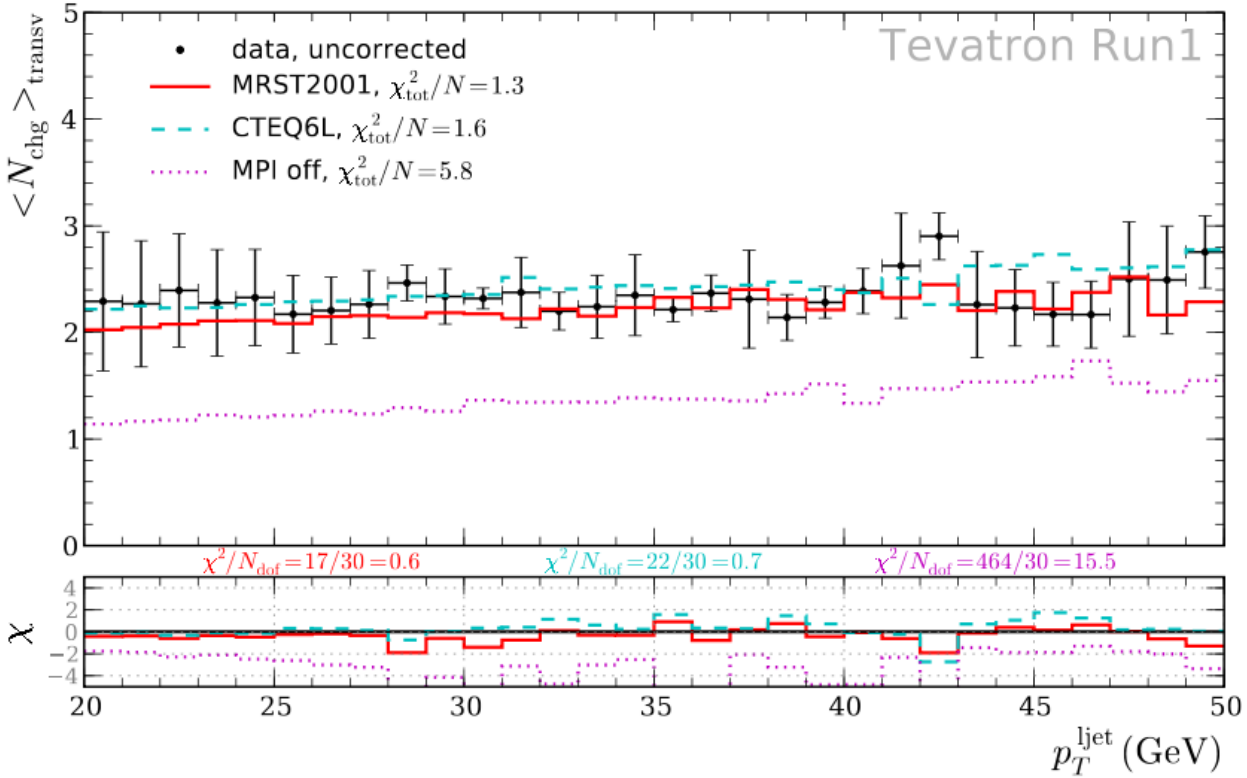


$\Rightarrow$ Two main parameters: $\mu^2, p_t^{\min}$.

Unitarized cross sections



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



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

Soft eikonal

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

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

Similar structures of eikonal functions:

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

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

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

Similar structures of eikonal functions:

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

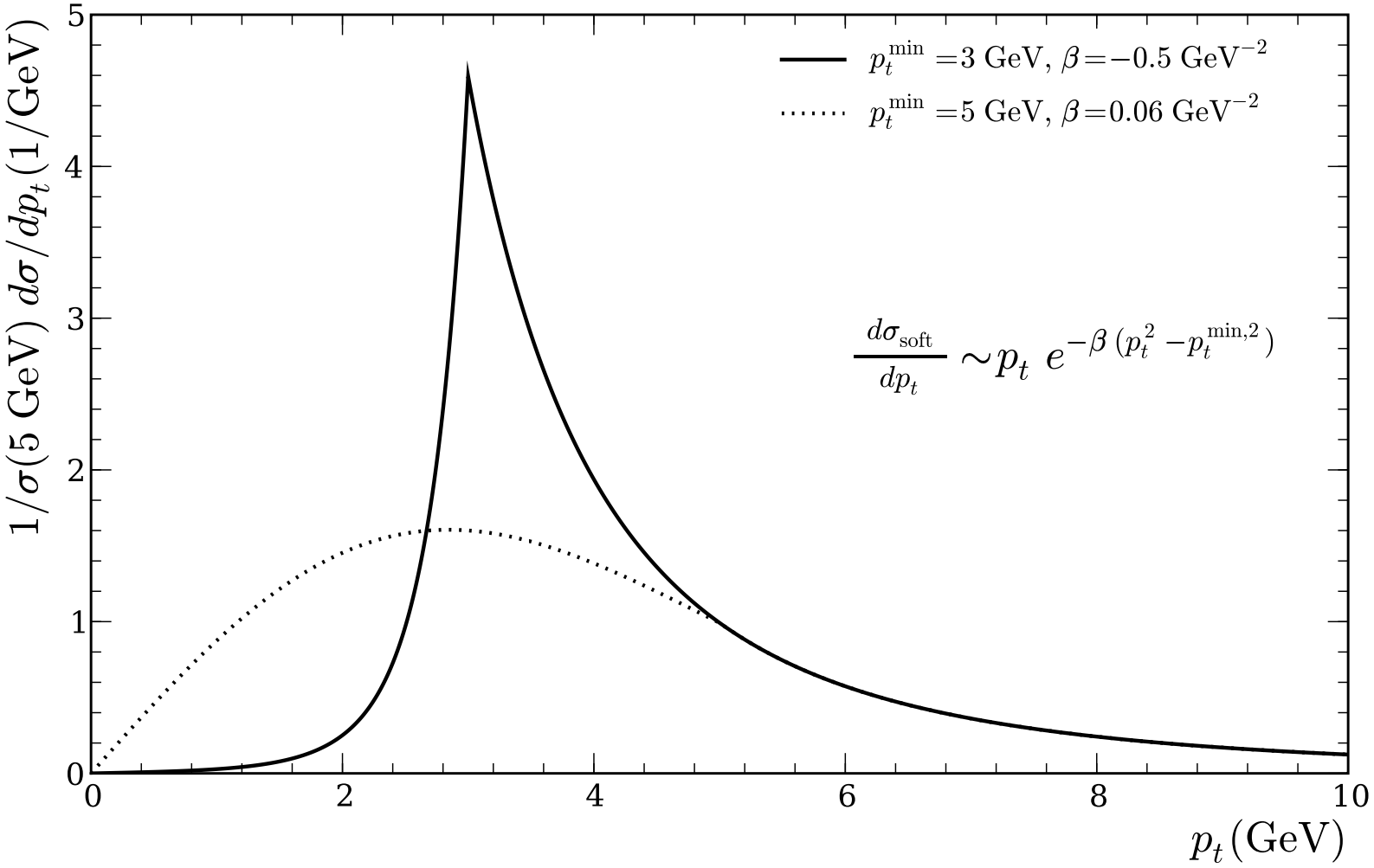
Simplest possible choice:
$A_{\text{soft}}(\vec{b};\mu) = A_{\text{hard}}(\vec{b};\mu) = A(\vec{b};\mu)$.
Then

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

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

Extending into the soft region

Continuation of the differential cross section into the soft region $p_t < p_t^{\min}$ (here: p_t integral kept fixed)



Fixing $\sigma_{\text{soft}}^{\text{inc}}$

Exploit knowledge of σ_{tot} in eikonal model:

$$\sigma_{\text{tot}} = 2 \int \mathrm{d}^2\vec{b} \left(1 - \mathrm{e}^{-\chi_{\text{tot}}(\vec{b},s)}\right)$$
$$= 2 \int \mathrm{d}^2\vec{b} \left(1 - \mathrm{e}^{-\frac{A(\vec{b};\mu)}{2}(\sigma_{\text{hard}}^{\text{inc}} + \sigma_{\text{soft}}^{\text{inc}})}\right)$$

σ_{tot} well measured. Fixes $\sigma_{\text{soft}}^{\text{inc}}$.

Energy extrapolation from Donnachie–Landshoff

- DL '92 [D&L, PLB296, 227 (1992)]
- DL '92 normalized at TVT
- DL '04 [D&L, PLB595, 393 (2004)]

Constraints at the Tevatron

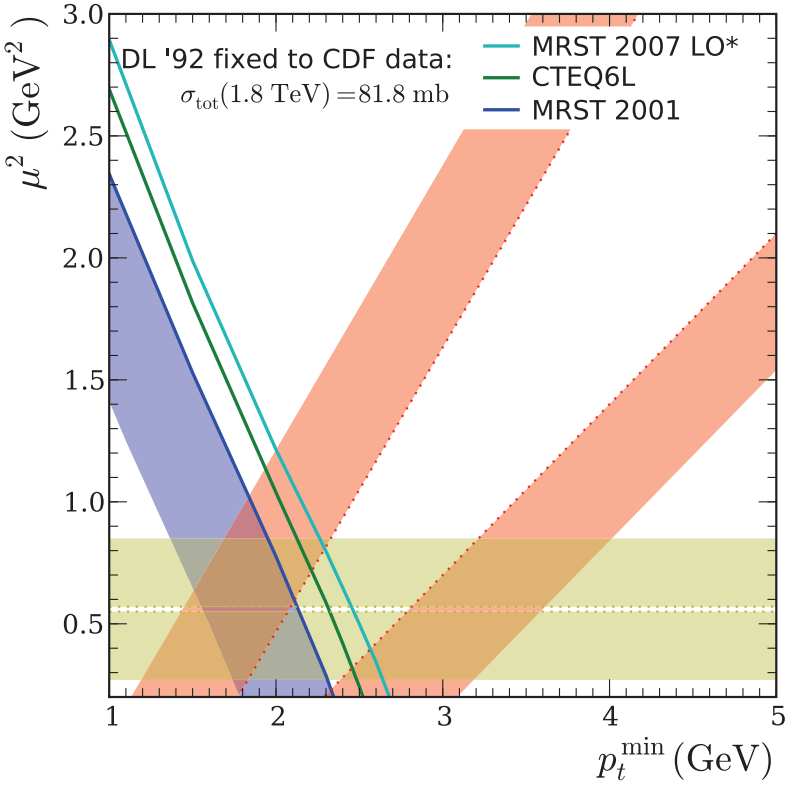
- Find constraints on $(p_t^{\min}, \mu)$.
- Require $\sigma_{\text{soft}}^{\text{inc}} > 0$ mb, while describing σ_{tot}.
- Require elastic t-slope,

$$b_{\text{el}}(s) = \left[\frac{\mathrm{d}}{\mathrm{d}t}\left(\ln \frac{\mathrm{d}\sigma_{\text{el}}}{\mathrm{d}t}\right)\right]_{t=0},$$

to be correctly described

$$b_{\text{el}}(s) = \int \mathrm{d}^2\vec{b}\,\frac{b^2}{\sigma_{\text{tot}}}\left[1 - \mathrm{e}^{-\chi_{\text{tot}}}\right] .$$

- Final state tune of **semi-hard** MPI (MRST2001)

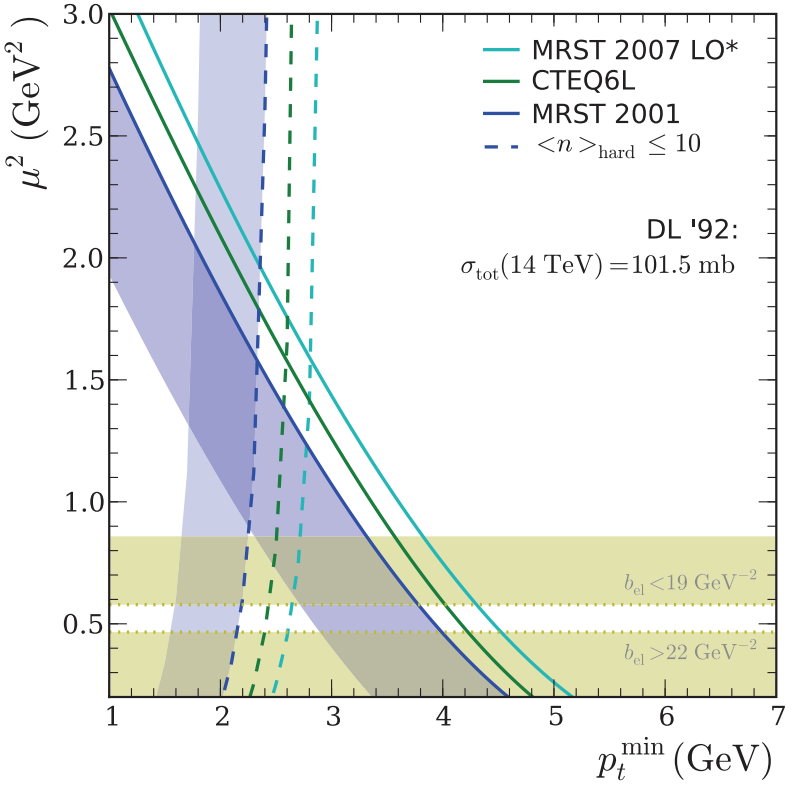


Constraints at the LHC

- What to expect at 14 TeV?
- $\sigma_{\text{soft}}^{\text{inc}} > 0$ mb. σ_{tot} from Regge fit
- Require $\bar{n}_{\text{hard}} < 10$
- Require elastic t-slope to be correctly described.
  Get range of possible measurements from DL '92 and predictions for b_{el}

[Khoze, Martin, Ryskin, 0710.2494]

[Gotsman, Levin, Maor, 0708.1506]



Observations

- $\sigma_{\text{soft}}^{\text{inc}}$ rises artificially fast (expect $\sim s^{0.08}$).
- Forced to have energy dependent parameters
  (would like to have the choice, i.e. let measurements decide).
- Measurement of b_{el} fixes μ^2 at Tevatron:

$$\mu^2 = 0.56 \pm 0.01\,\text{GeV}^2$$

$\sigma_{\text{eff}} = (\int \mathrm{d}^2\vec{b} A^2(b))^{-1}$ as measured by CDF in $\gamma + 3j$:

$$\mu^2 = 3.0 \pm 0.5\text{GeV}^2\ .$$

Observations

- $\sigma_{\text{soft}}^{\text{inc}}$ rises artificially fast (expect $\sim s^{0.08}$).
- Forced to have energy dependent parameters
  (would like to have the choice, i.e. let measurements decide).
- Measurement of b_{el} fixes μ^2 at Tevatron:

$$\mu^2 = 0.56 \pm 0.01\,\text{GeV}^2$$

$\sigma_{\text{eff}} = (\int \mathrm{d}^2\vec{b} A^2(b))^{-1}$ as measured by CDF in $\gamma + 3j$:

$$\mu^2 = 3.0 \pm 0.5\text{GeV}^2\ .$$

$\rightarrow$ Relax the constraint of identical overlap

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

If $\mu > \mu_{\text{soft}}$: Hot Spots functions:

Hot Spot model

Fix the two parameters μ_{soft} and $\sigma_{\text{soft}}^{\text{inc}}$ in

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

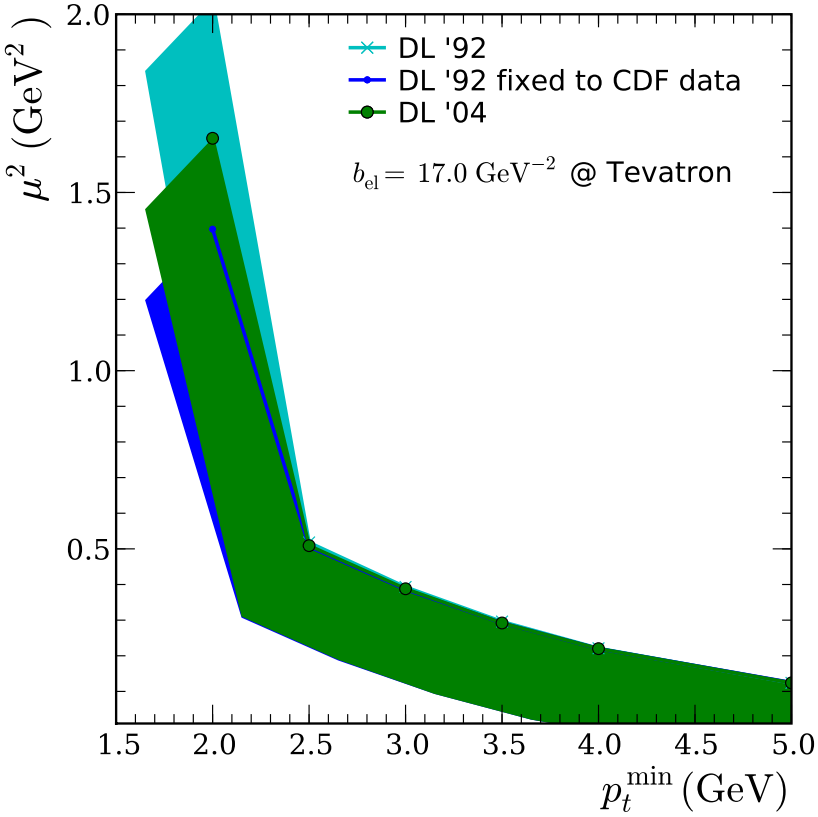
from two constraints. Require simultaneous description of σ_{tot} and b_{el} (measured/well predicted),

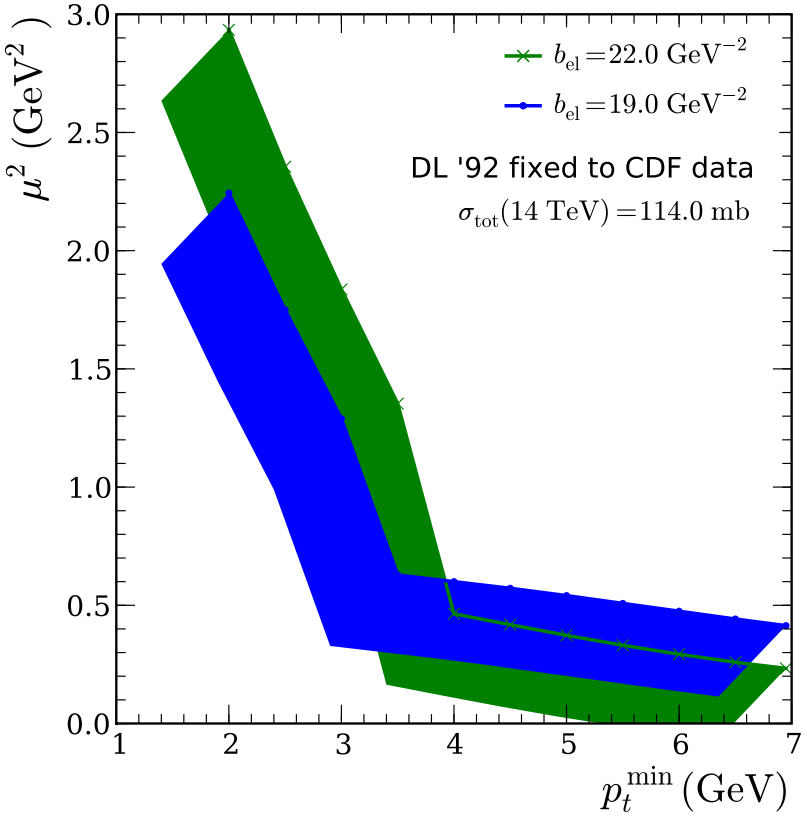
$$\sigma_{\text{tot}}(s) \stackrel{!}{=} 2\int \mathrm{d}^2\vec{b}\left(1 - \mathrm{e}^{-\chi_{\text{tot}}(\vec{b},s)}\right) ,$$

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

TVT and LHC parameter space

Constraint: describe σ_{tot} and b_{el}. TVT (left), LHC 14 TeV (right)



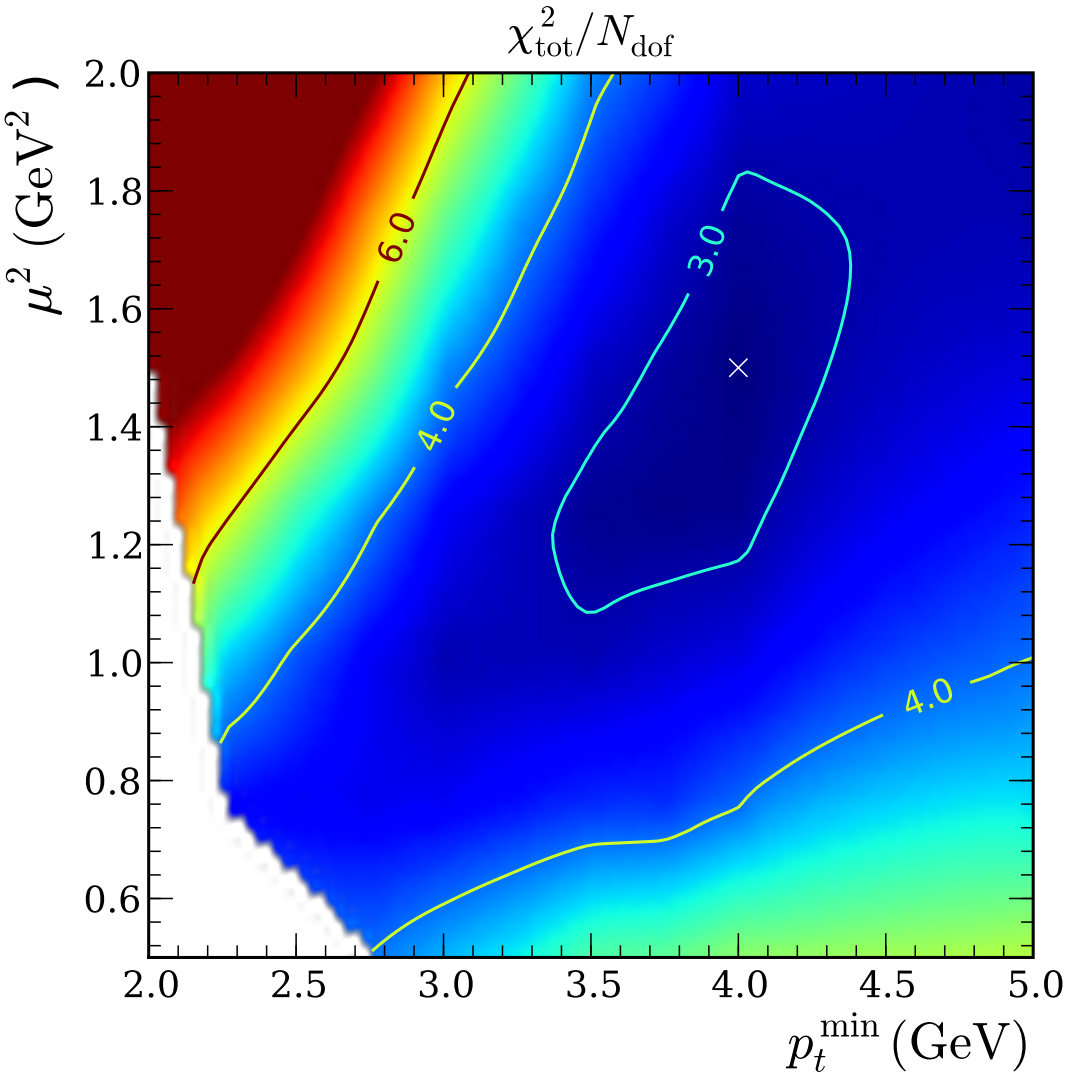


Tevatron Run I final states

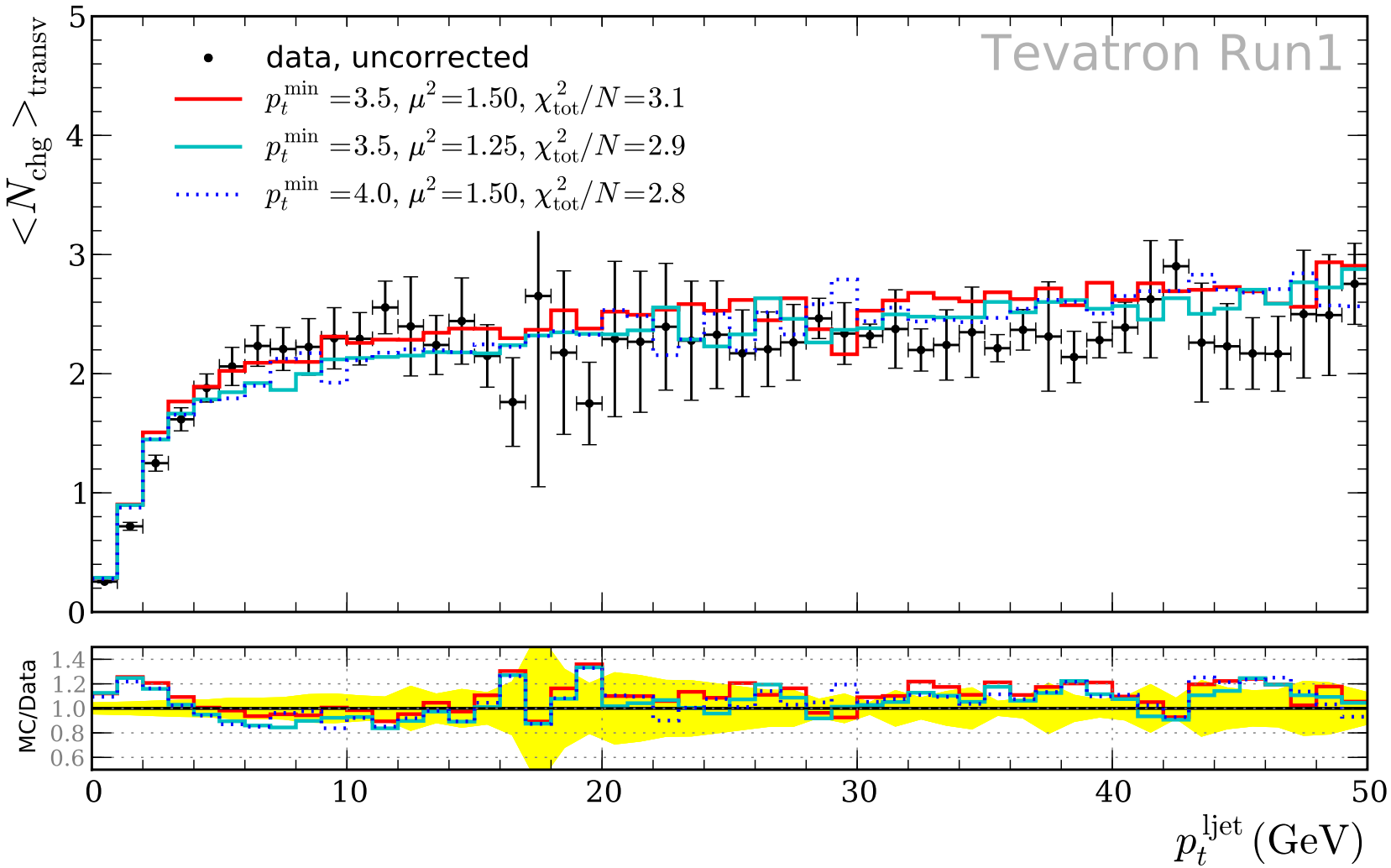
- So far: only indirect constraints from σ_{tot} and σ_{el}.
- Now use model in Herwig++ with $\bar{n}(\vec{b}, s)$ as input for MPI.
- Remaining free parameters $(p_t^{\min}, \mu^2)$.
- Look at χ^2/dof for Tevatron Run I data in the $(p_t^{\min}, \mu^2)$ plane.

Parameter space at Tevatron

- χ^2 for Rick's Run1 Jet analysis for **all** regions



Detailed look at observables: Transverse Region



What we have so far:

- Unitarized jet cross sections
- Fulfil constaints from σ_{tot} and σ_{el}.
- Simple model with similar overlap functions.
- No additional (explicit) energy dependence.
- Left with freedom in parameter space.

What we have so far:

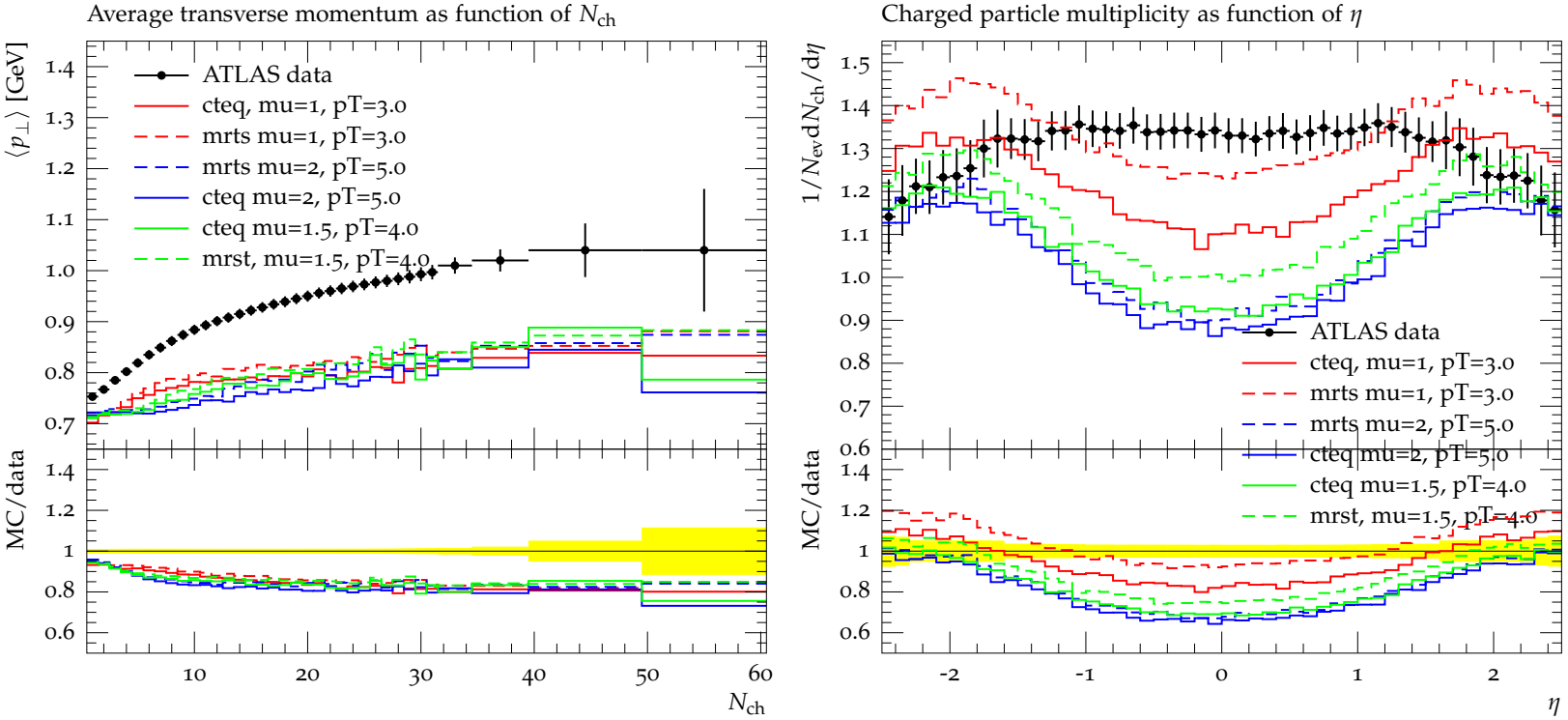
- Unitarized jet cross sections
- Fulfil constaints from σ_{tot} and σ_{el}.
- Simple model with similar overlap functions.
- No additional (explicit) energy dependence.
- Left with freedom in parameter space.

$\Longrightarrow$ *Look at LHC results (900 GeV).*

- ATLAS charged particles in Min Bias.
- Convenient as the analysis was quickly available in RIVET ;-)
- Three points from 'valley'
  $(p_t^{\min}/\text{GeV}, \mu^2/\text{GeV}^2) = (3.0, 1.0); (4.0, 1.5); (5.0, 2.0)$

Look at LHC results (900 GeV)

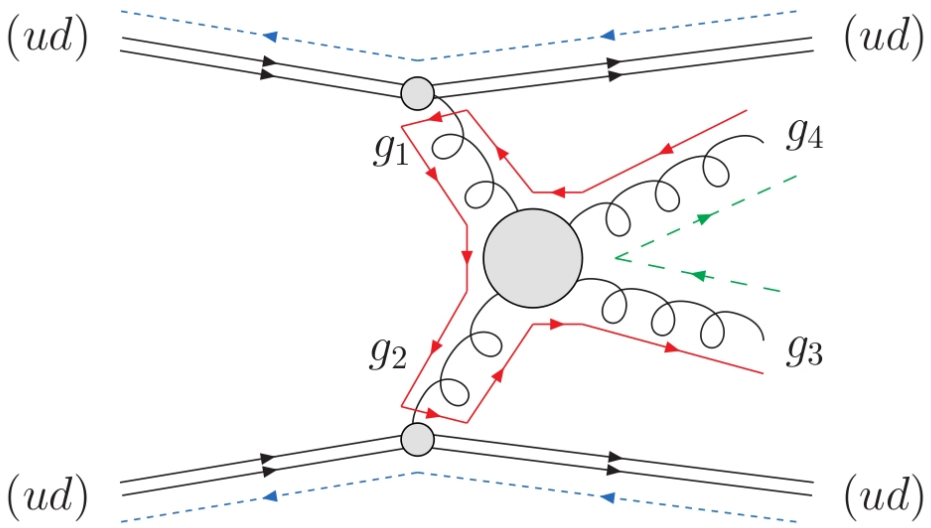
- ATLAS charged particles in Min Bias ($N_{ch} \geq 1,\ p_T > 500MeV,\ |\eta| < 2.5$)
- Convenient as the analysis was quickly available in `RIVET`.



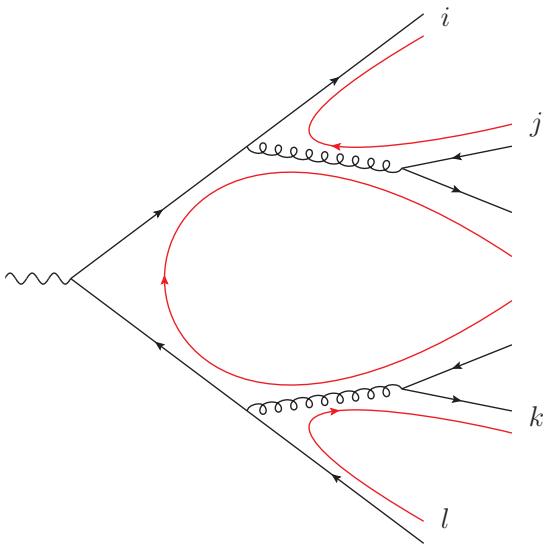
- oops, not so nice...
- despite very good agreement with Rick Field's CDF UE analysis.
- choice of PDF set (CTEQ6l1 vs MSTW LO** (our default))
- Failure of a physically motivated model usually points to more, interesting physics ... colour structure?

Colour structure

- 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.



Colour reconnection (CR) in Herwig++

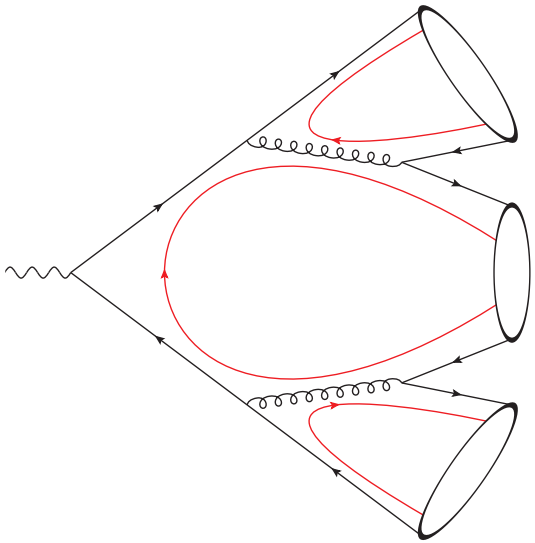


Extending the hadronization model in Herwig(++):

- QCD parton showers provide *pre-confinement* $\Rightarrow$ colour-anticolour pairs form highly excited hadronic states, the *clusters*

[1] For details look at Christians Röhr's Diploma thesis

Colour reconnection (CR) in Herwig++

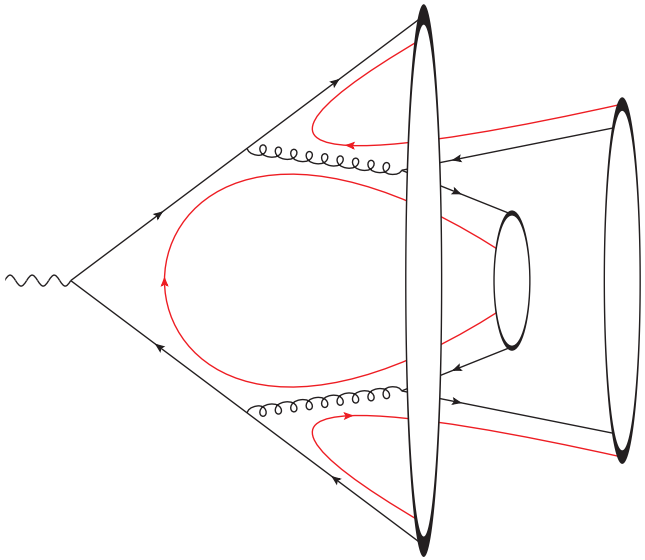


Extending the hadronization model in Herwig(++):

- QCD parton showers provide *pre-confinement* $\Rightarrow$ colour-anticolour pairs form highly excited hadronic states, the *clusters*

[1] For details look at Christians Röhr's Diploma thesis

Colour reconnection (CR) in Herwig++

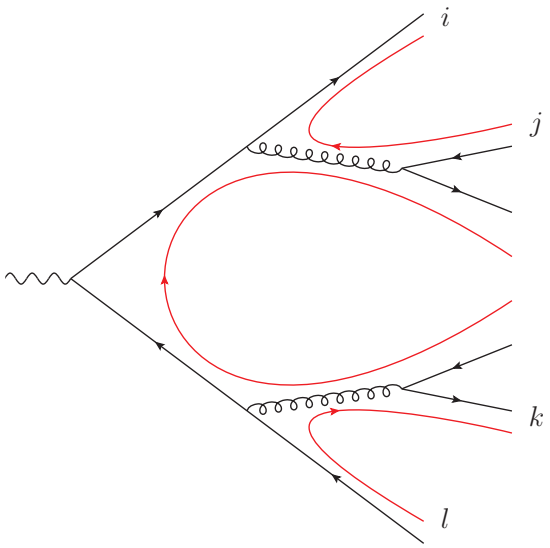


Extending the hadronization model in Herwig(++):

- QCD parton showers provide *pre-confinement* $\Rightarrow$ colour-anticolour pairs form highly excited hadronic states, the *clusters*
- CR in the cluster hadronization model: allow *reformation* of clusters, *e.g.* $(il) + (jk)$
- Physical motivation: exchange of soft gluons during non-perturbative hadronization phase

[1] For details look at Christians Röhr's Diploma thesis

Colour reconnection (CR) in Herwig++



Extending the hadronization model in Herwig(++):

- QCD parton showers provide *pre-confinement* $\Rightarrow$ colour-anticolour pairs form highly excited hadronic states, the *clusters*
- CR in the cluster hadronization model: allow *reformation* of clusters, *e.g.* $(il) + (jk)$
- Physical motivation: exchange of soft gluons during non-perturbative hadronization phase

Implementation[1]

- Allow CR if the cluster mass decreases,

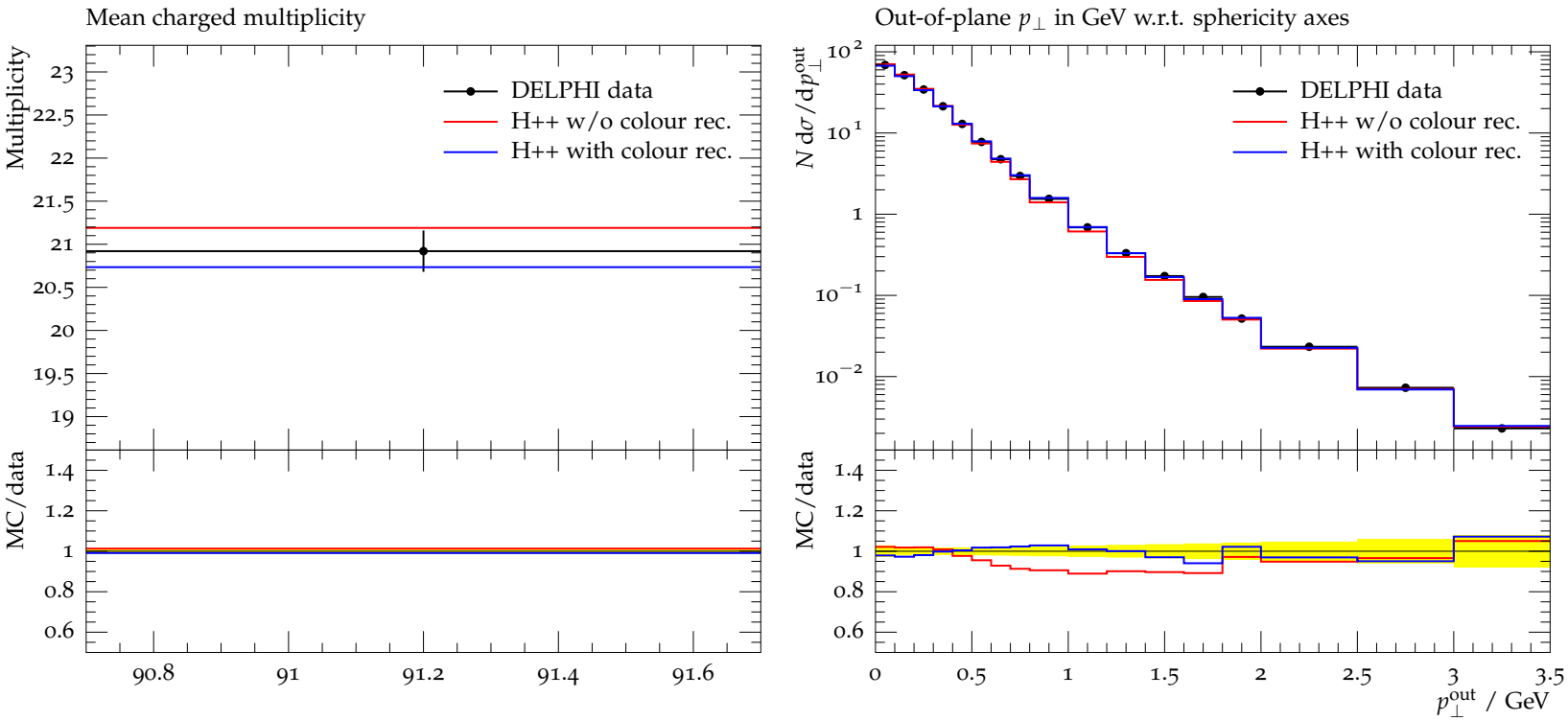
$$M_{il} + M_{kj} < M_{ij} + M_{kl},$$

  where $M_{ab}^2 = (p_a + p_b)^2$ is the (squared) cluster mass
- Accept alternative clustering with probability p_{reco} (model parameter) $\Rightarrow$ this allows to switch on CR smoothly

[1] For details look at Christians Röhr's Diploma thesis

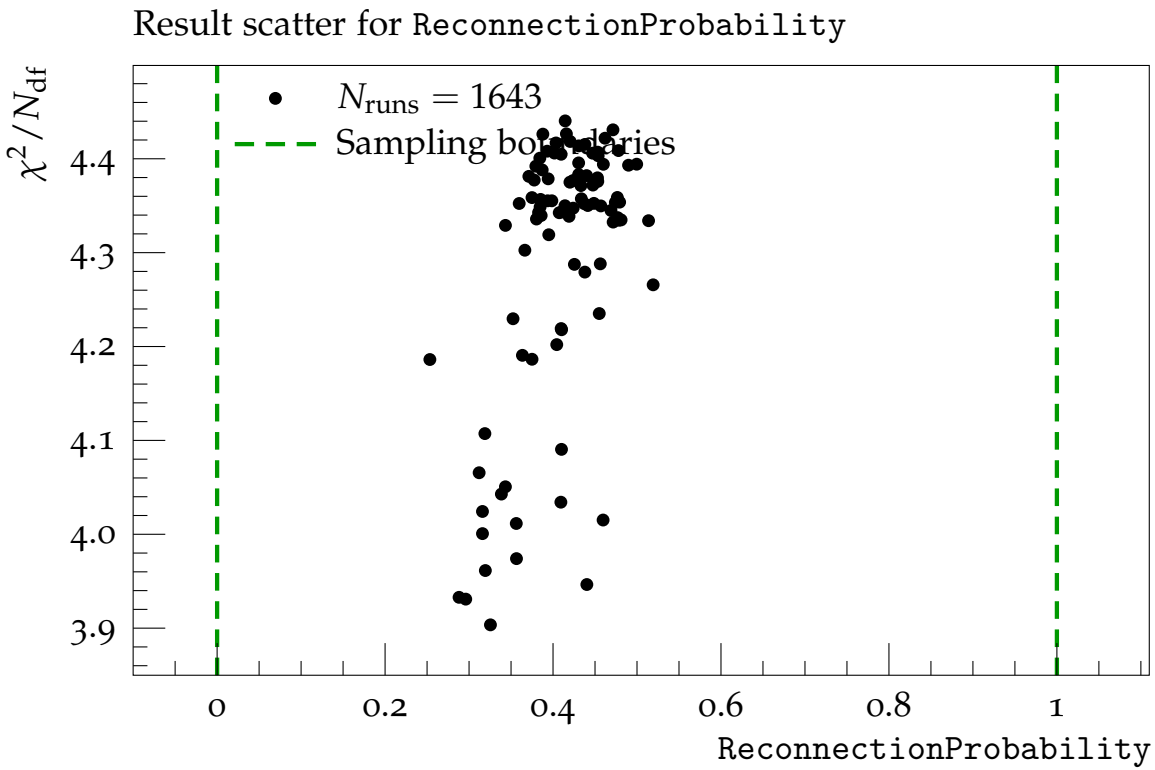
LEP tune

- Hadronization sensitive to CR model.
- Proper study requires re-tune to LEP data.
- Many thanks to the Professor team for help and hints how to use their program!



Agreement on same level as w/o CR model.

- Hadronization sensitive to CR model.
- Proper study requires re- tune to LEP data.
- Many thanks to the Professor team for help and hints how to use their program!



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

Colour Reconnection model tests

We used two LEP analyses (sensitive to color reconnection) to test the new model:

- OPAL Collaboration arXiv:hep-ex/0306021v1:
  "Tests of models of color reconnection and a search for glueballs using gluon jets with a rapidity gap"
- DELPHI Collaboration, Eur. Phys. J. C51 (2007) 249-269], particles flow in $WW \to 4j$ at LEP

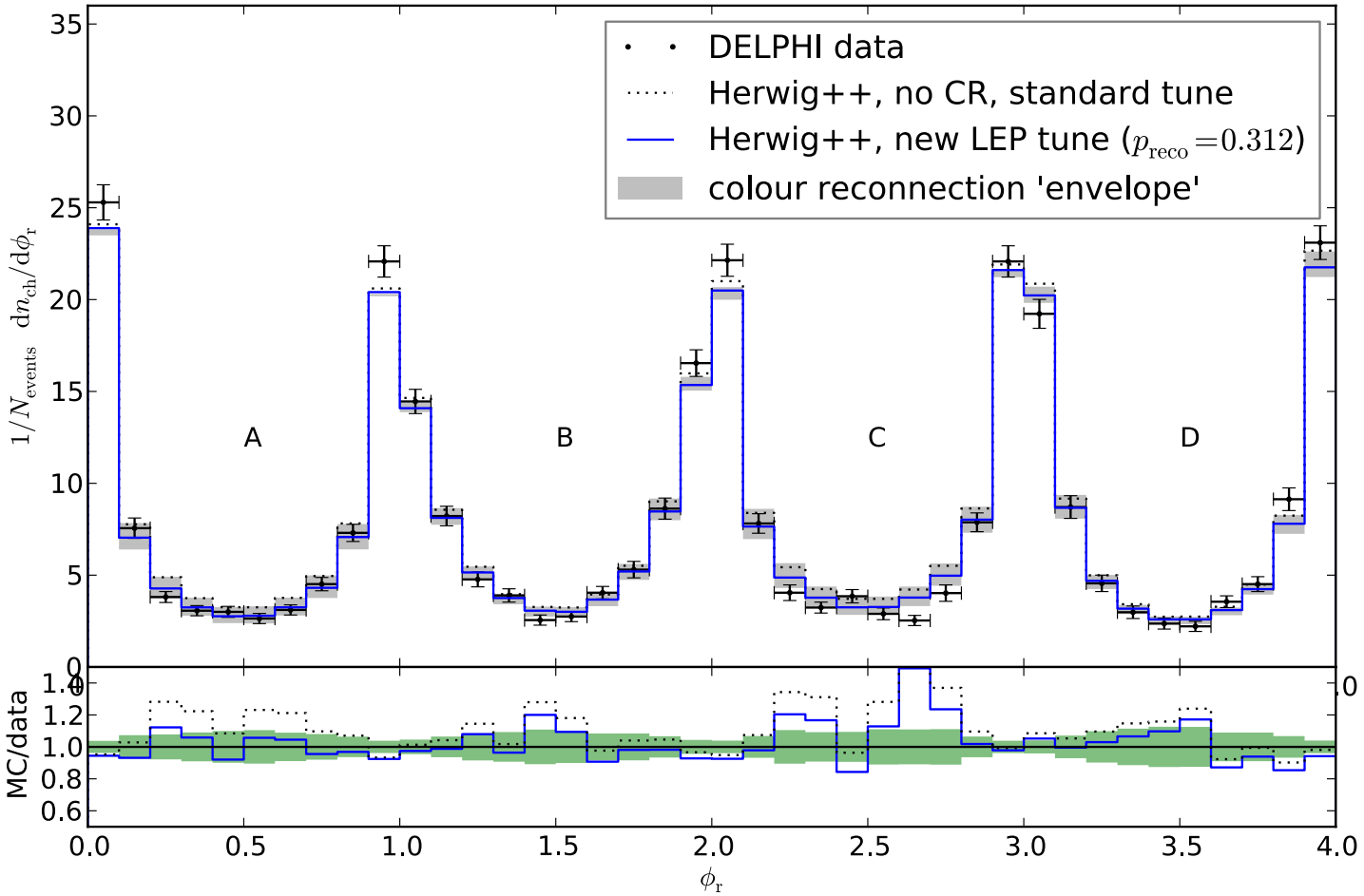
Result:

- Herwig++ with and w/o colour rec. seems to describe these data at the same level.

News:

- Work on new colour reconnection algorithms is ongoing.

Retrospective: particle flow in $WW \to 4j$ at LEP



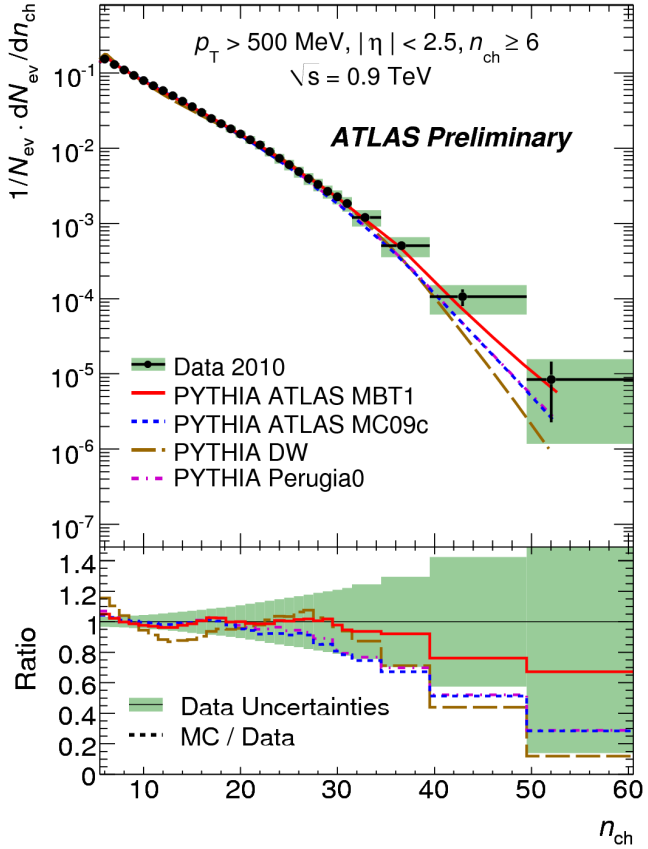
- small effects here
- marginal improvement (if at all)

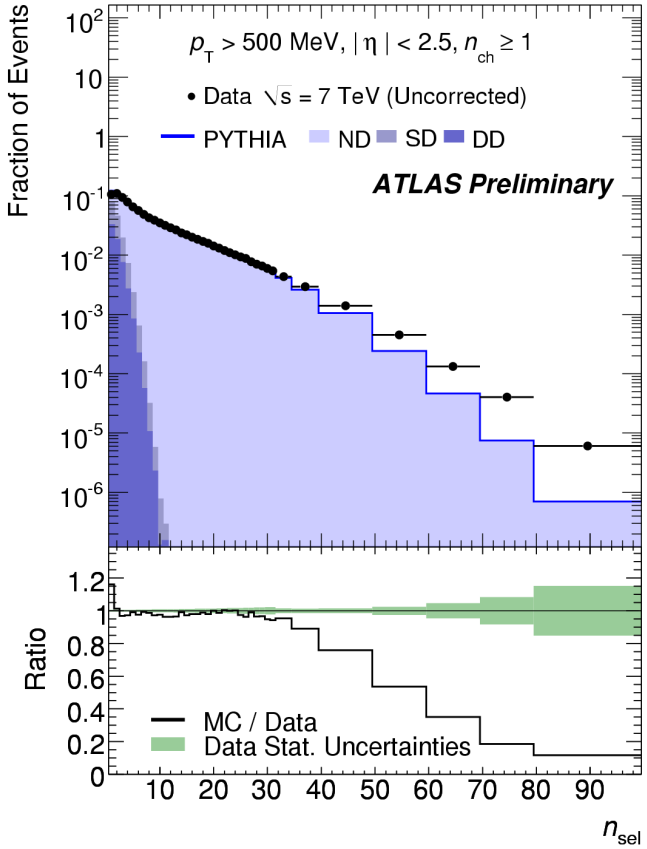
data from [DELPHI Collaboration, Eur. Phys. J. C51 (2007) 249-269]

Comparison with MinBias ATLAS data

Proper comparison: lack of diffraction in Herwig++!

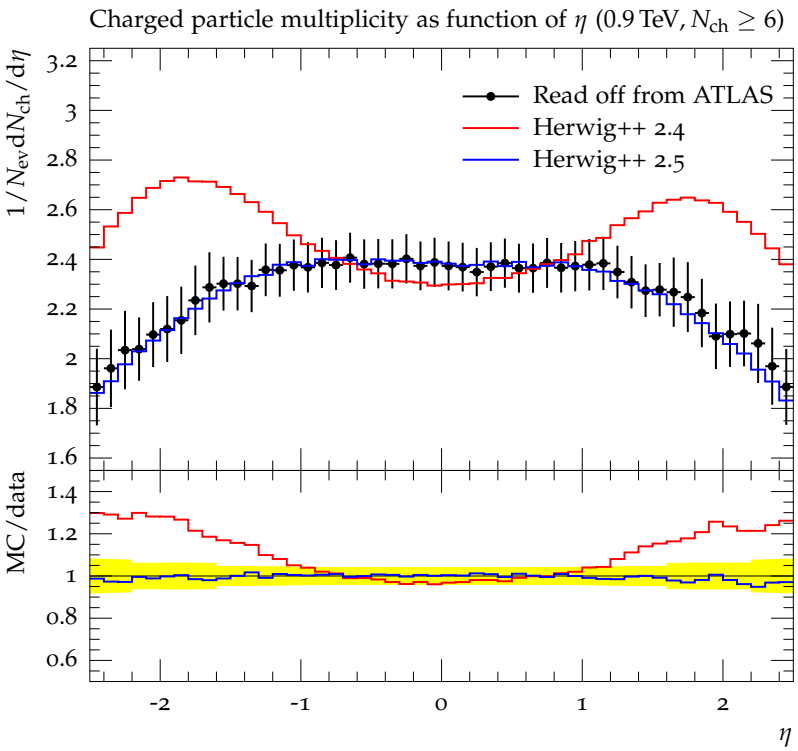
We used a diffractive suppressed sample with cut: $N_{ch} \geqslant 6$

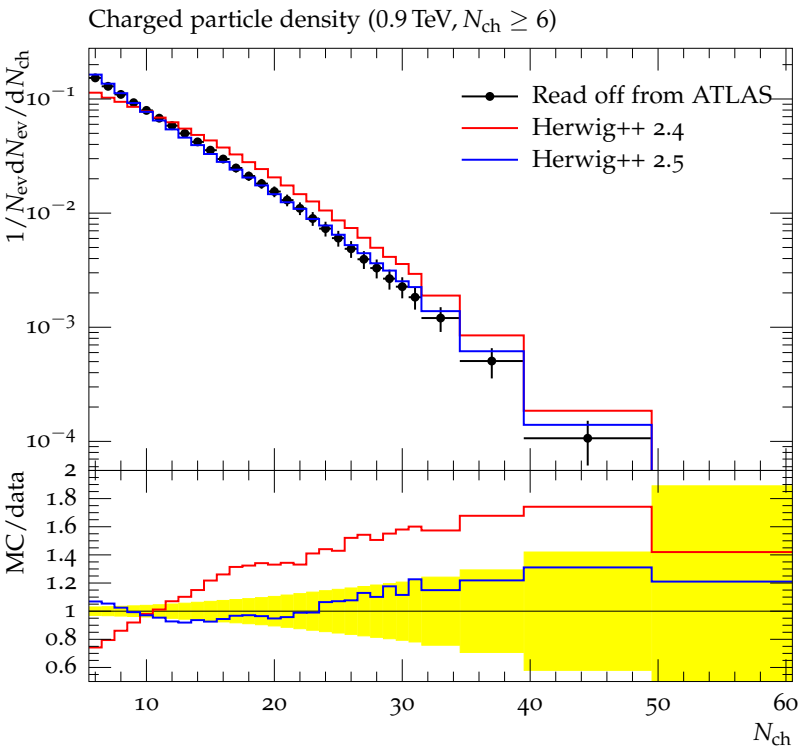




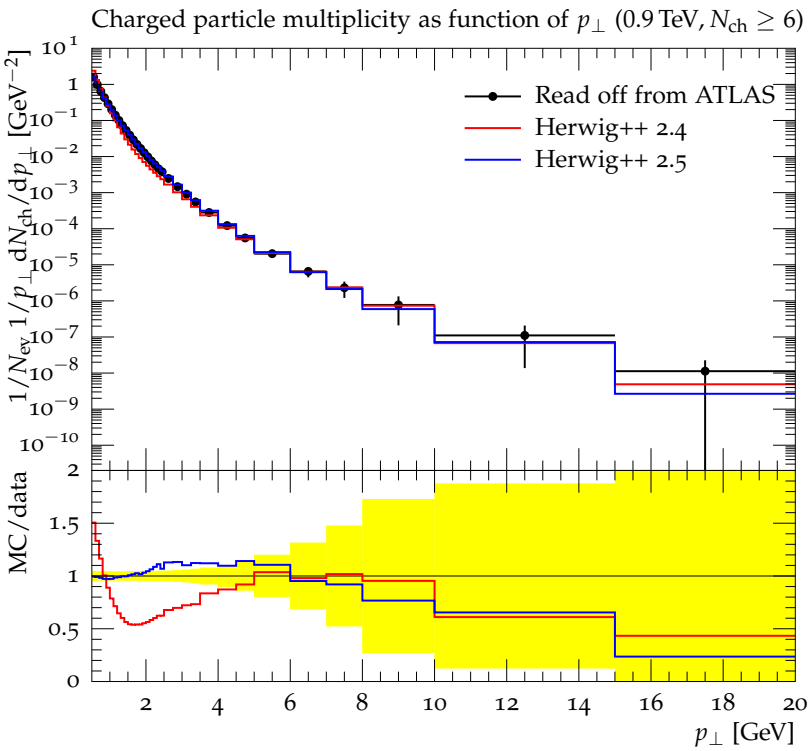
6

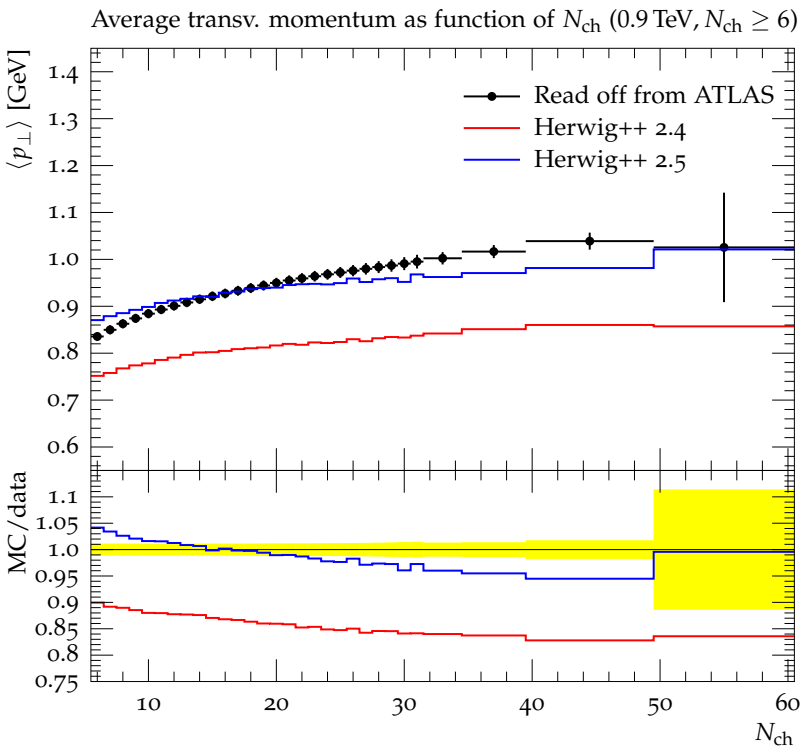
MinBias ATLAS 900 GeV



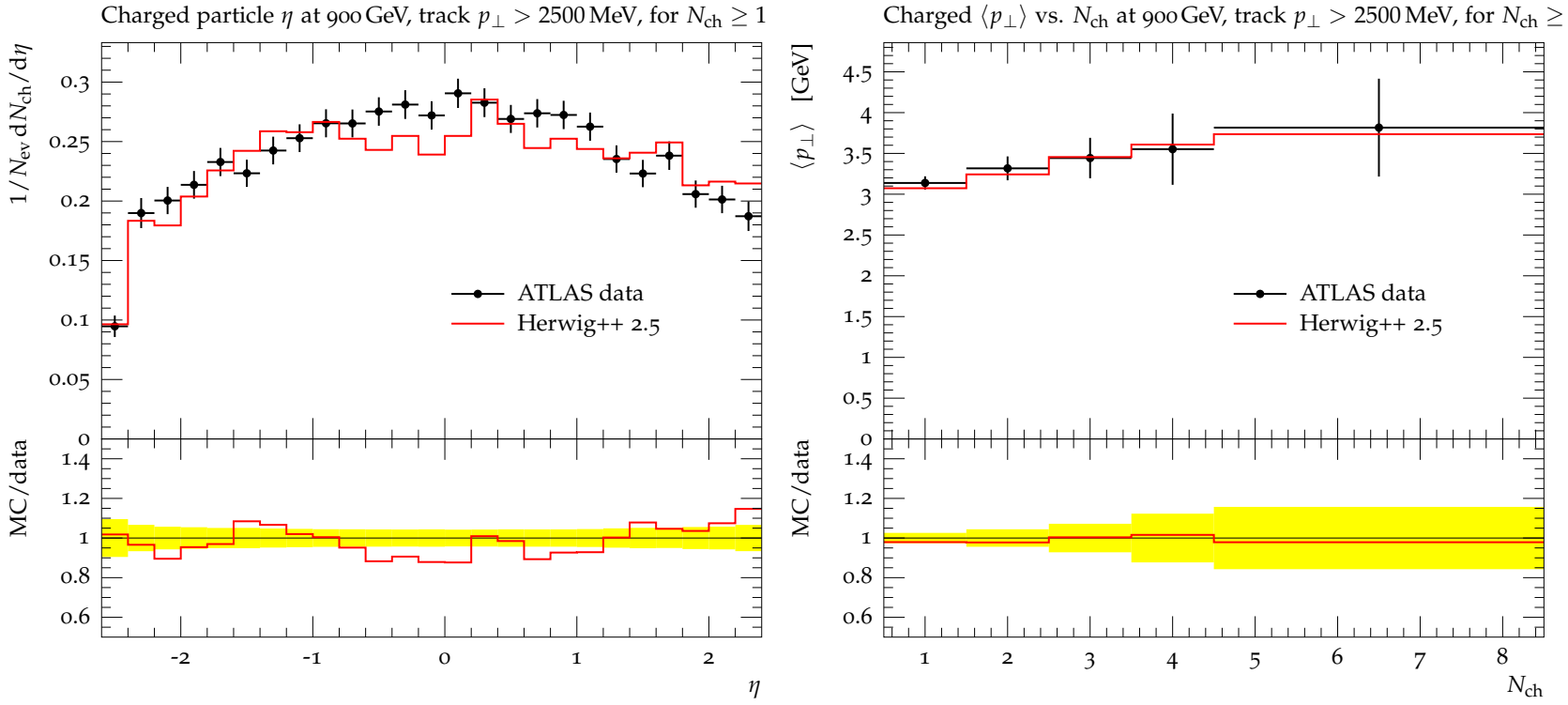


MinBias ATLAS 900 GeV





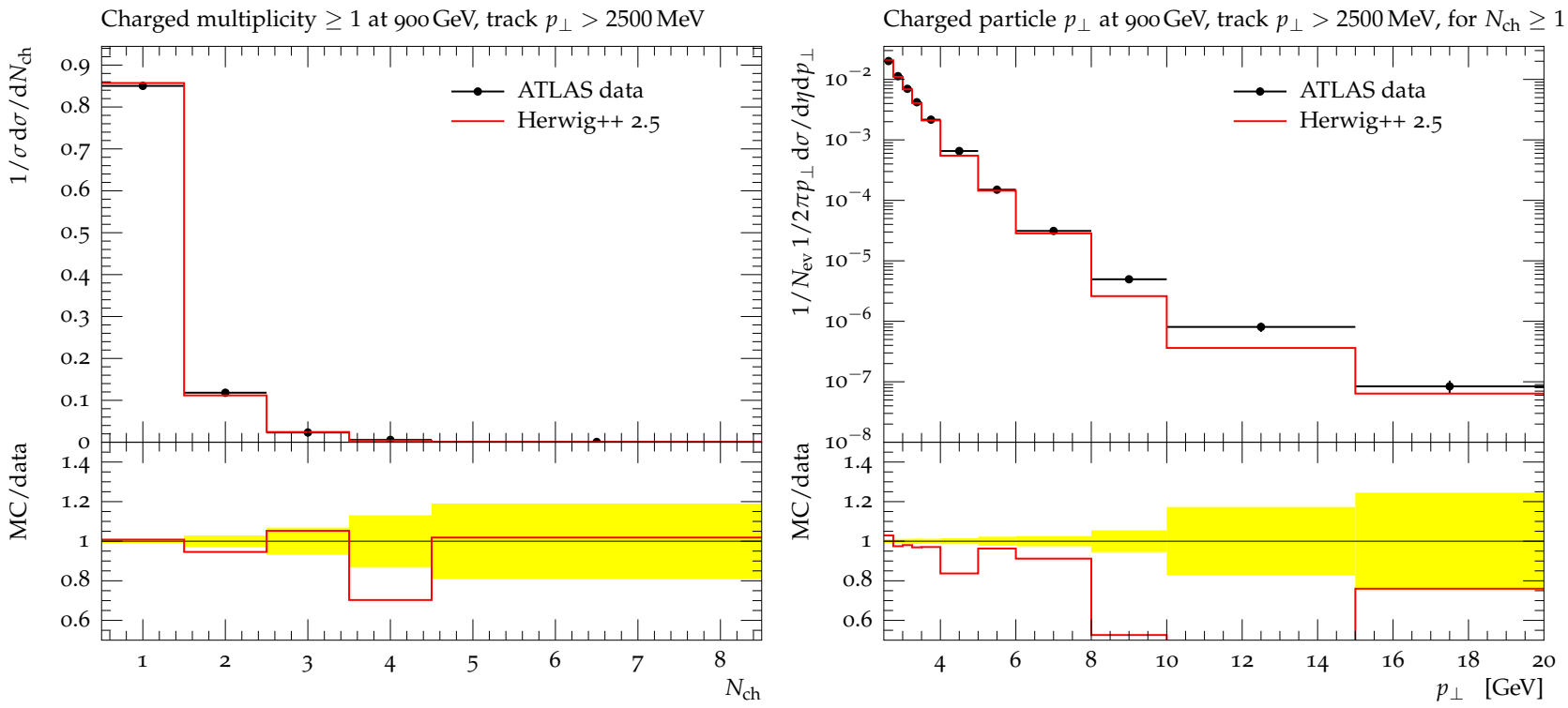
2nd MB ATLAS publication [arXiv 1012.5104], more phase spaces.
$N_{ch} \geq 1,\ p_T > 2500\ MeV,\ |\eta| < 2.5$



This was not tuned! We used tune to ATLAS MB data for $N_{ch} \geq 6,\ p_T > 500\ MeV$ presented in MB&UE WG in September 2010

MinBias ATLAS 900 GeV

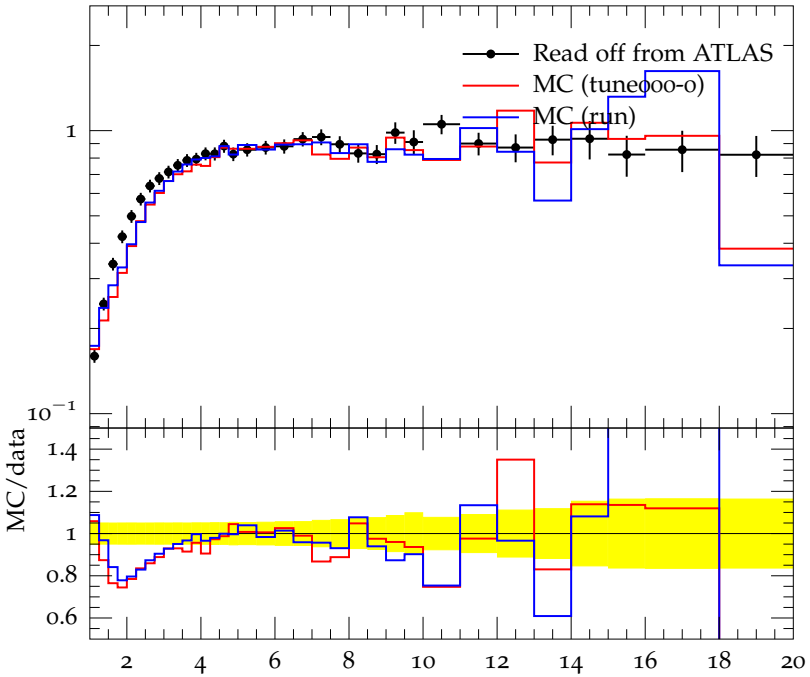
2nd MB ATLAS publication [arXiv 1012.5104], more phase spaces.
$N_{ch} \geq 1,\ p_T > 2500\ MeV,\ |\eta| < 2.5$

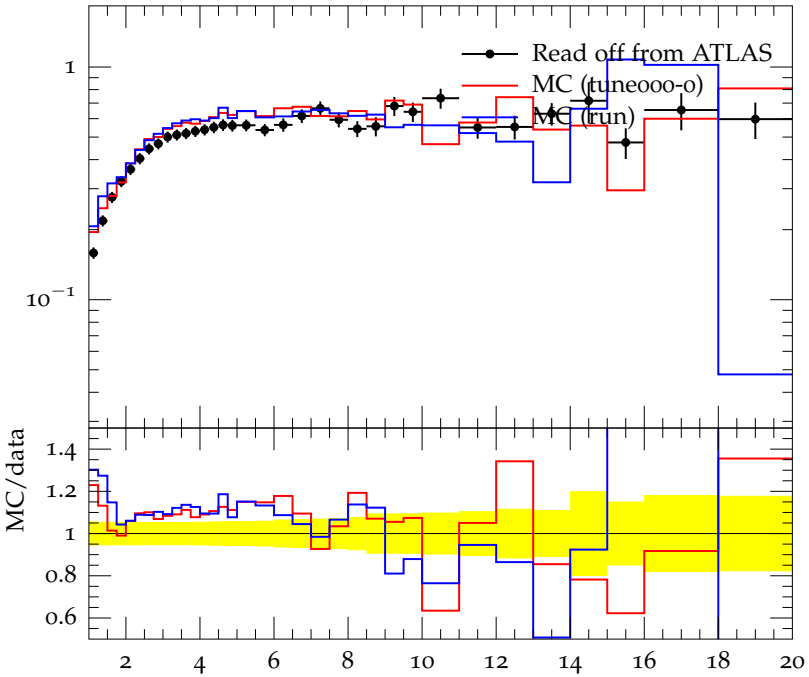


This was not tuned! We used tune to ATLAS MB data for $N_{ch} \geq 6,\ p_T > 500\ MeV$ presented in MB&UE WG in September 2010

Underlying Event 7000 GeV (ATLAS-CONF-2010-029)

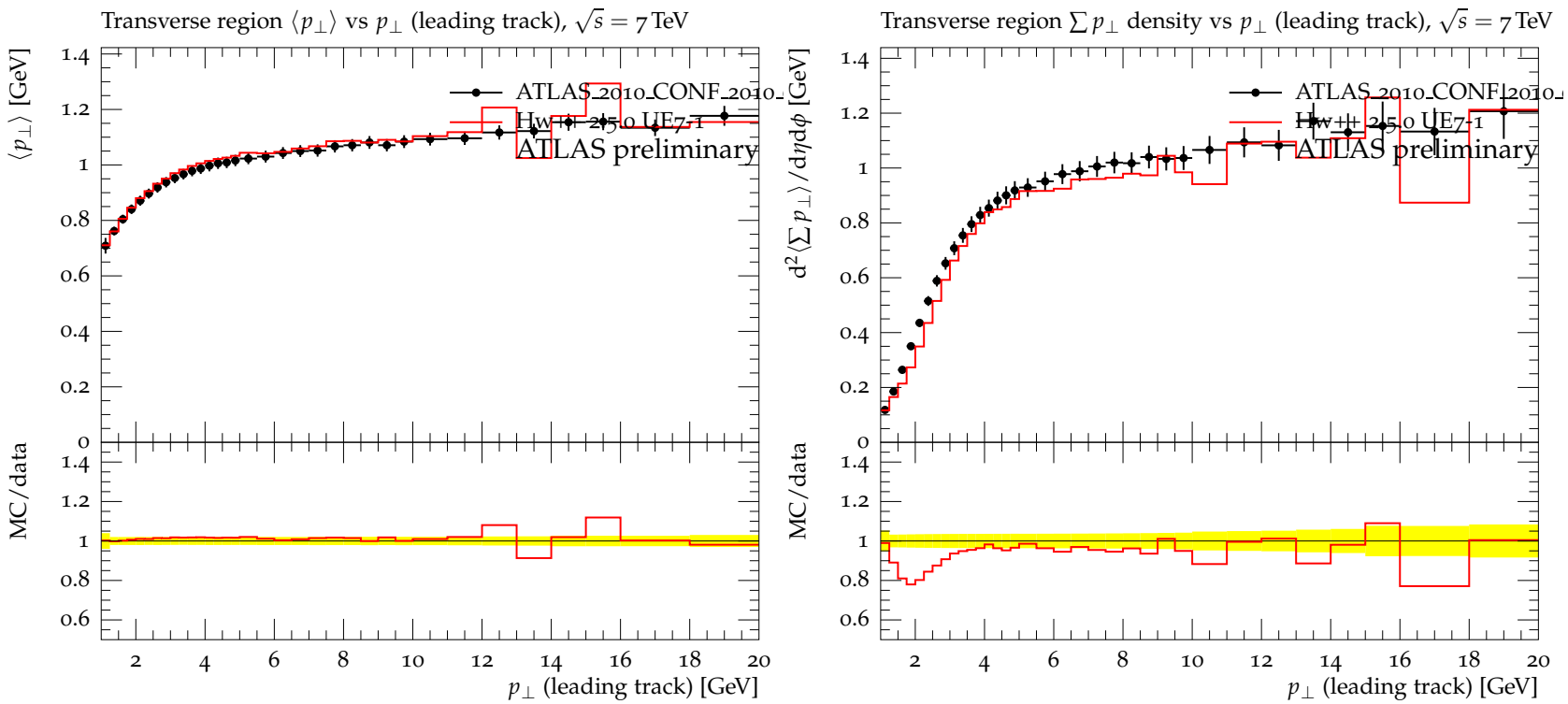
N_{ch}/StdDev transverse vs p_t^{lead}/GeV





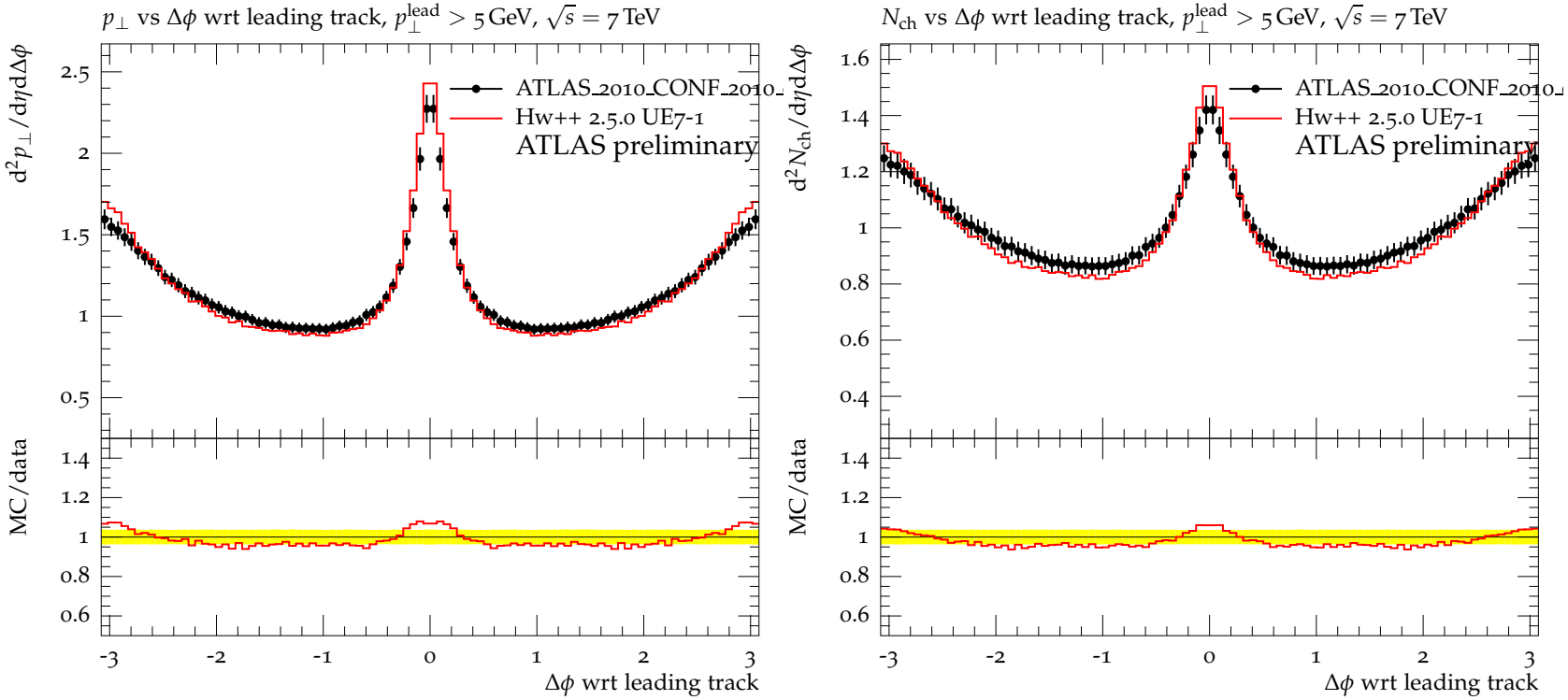
Slide from MPI@LHC 2010 in Glasgow

$p_t^{\min} = 3.2\,GeV\,, \quad \mu^2 = 0.81\,GeV^2, \quad p_{\text{reco}} = 0.61, \quad p_{\text{disrupt}} = 0.34$

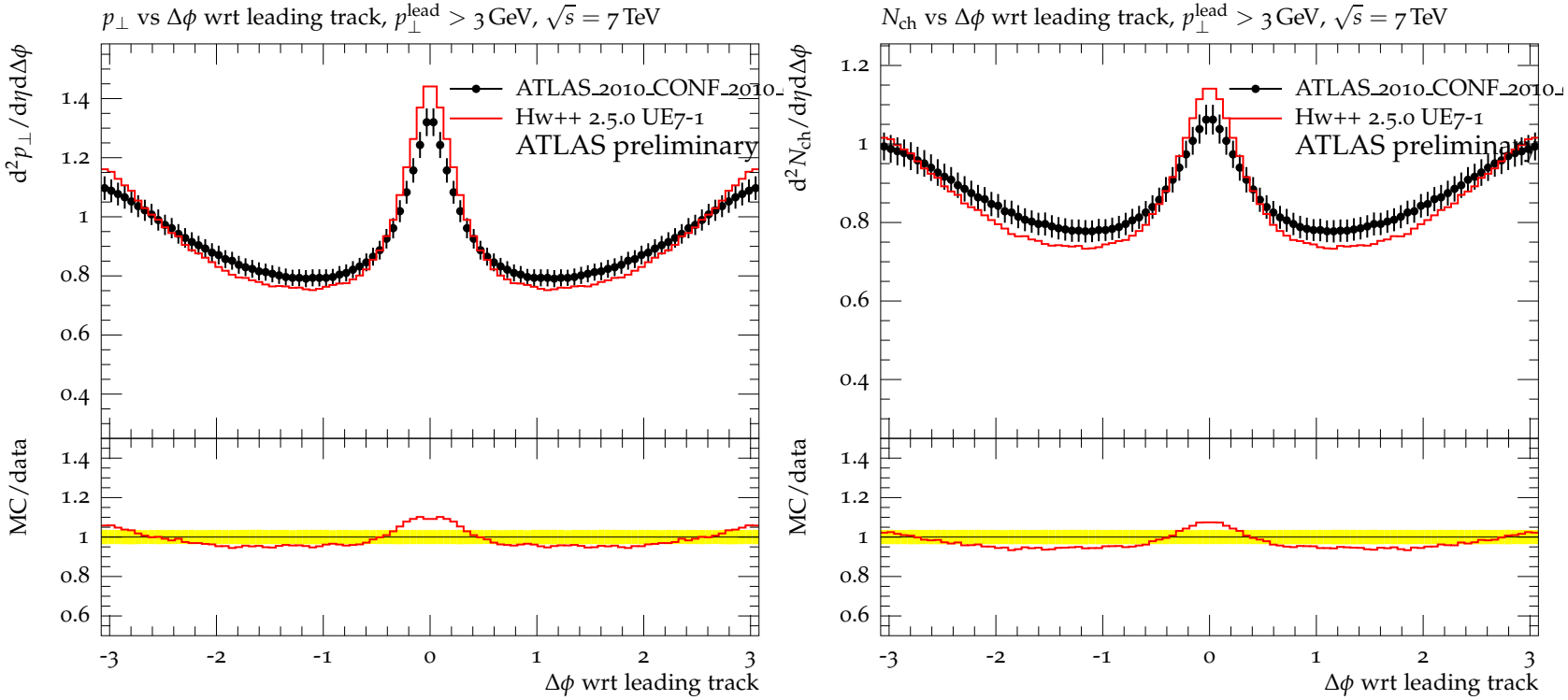


Those observables (in transverse region) were used for the tuning.

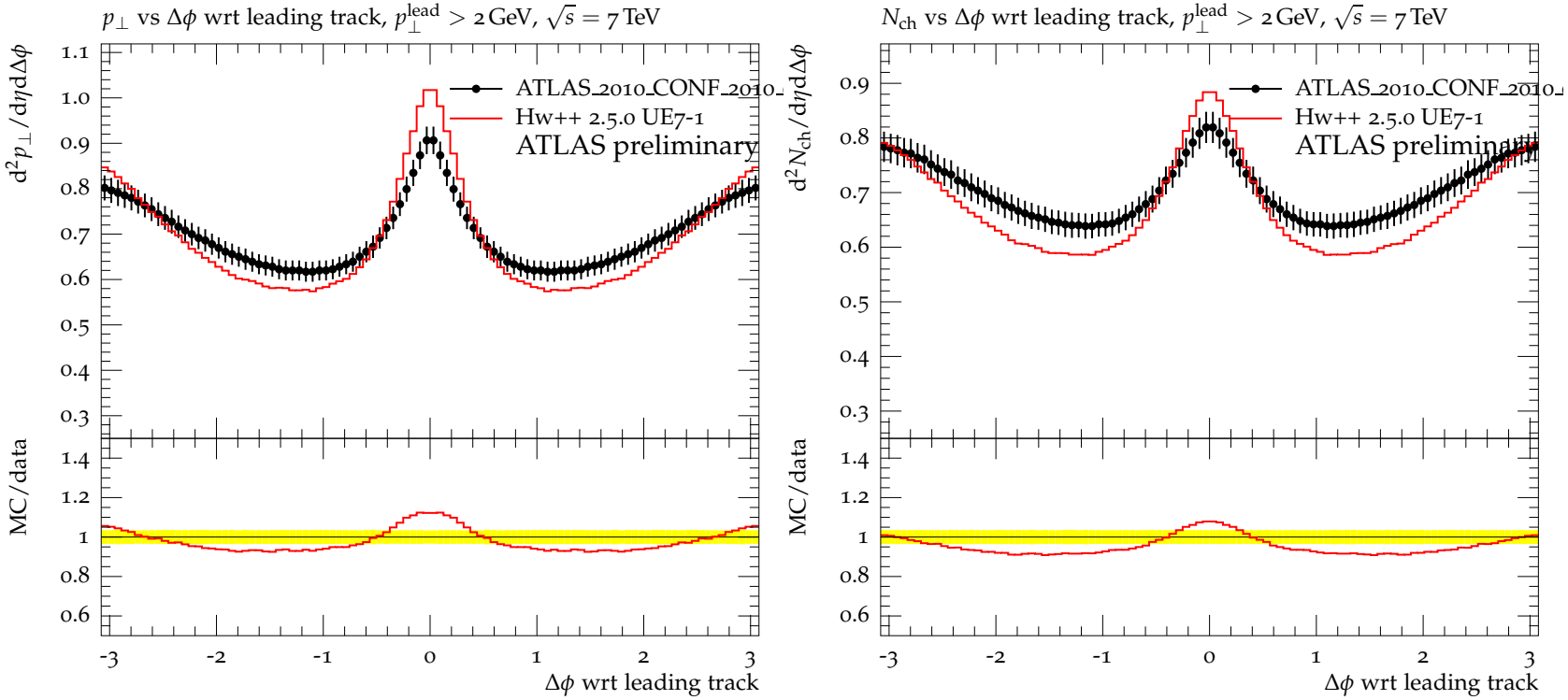
This was not tuned! We used tune to ATLAS UE presented during MPI@LHC 2010 on 1 December 2010 in Glasgow



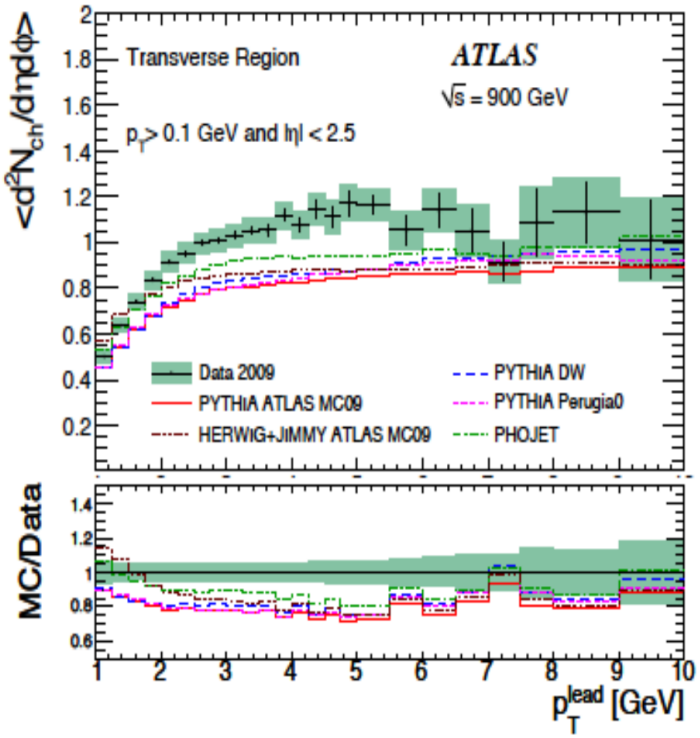
This was not tuned! We used tune to ATLAS UE presented during MPI@LHC 2010 on 1 December 2010 in Glasgow

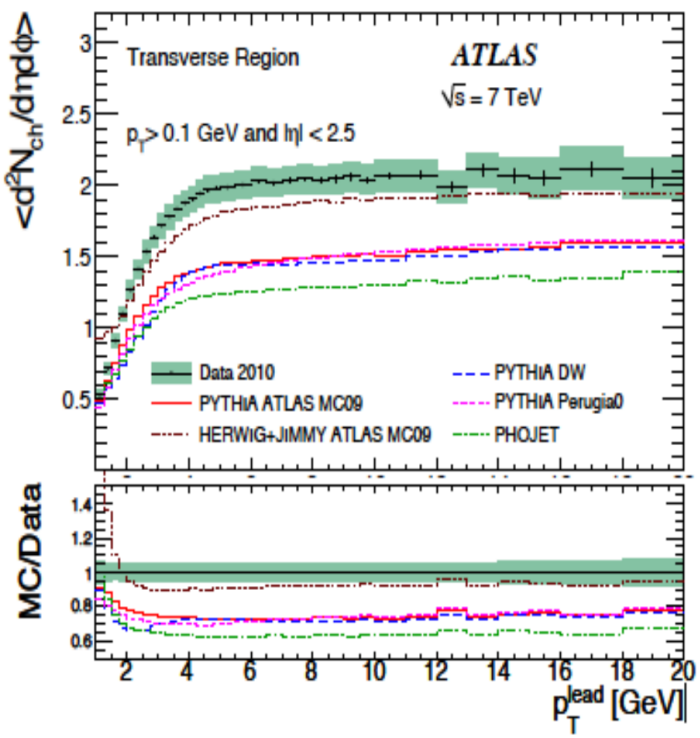


This was not tuned! We used tune to ATLAS UE presented during MPI@LHC 2010 on 1 December 2010 in Glasgow



Particle Density vs. P_T^{lead}

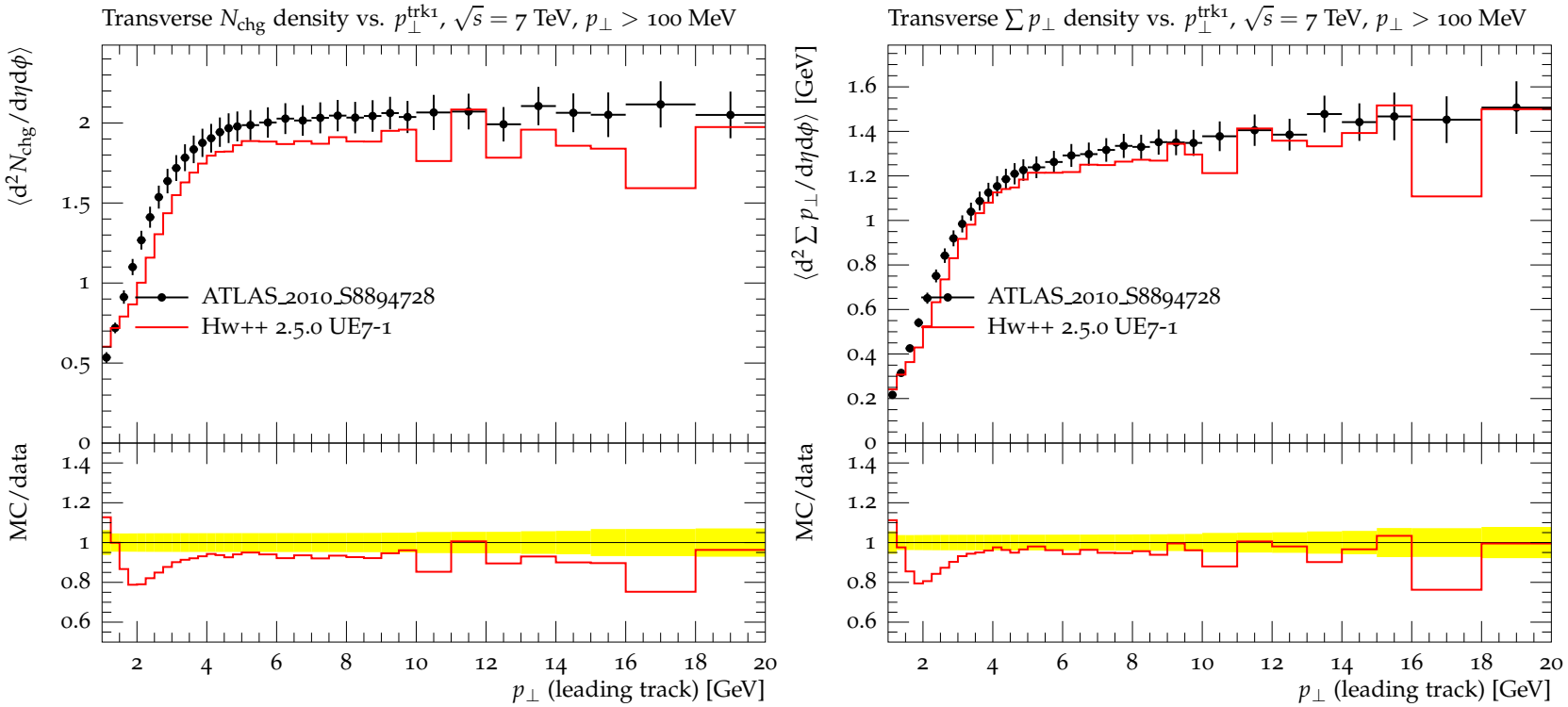




Particle density increases by a factor of ~2 but The conclusion is the same

Underlying Event 7000 GeV

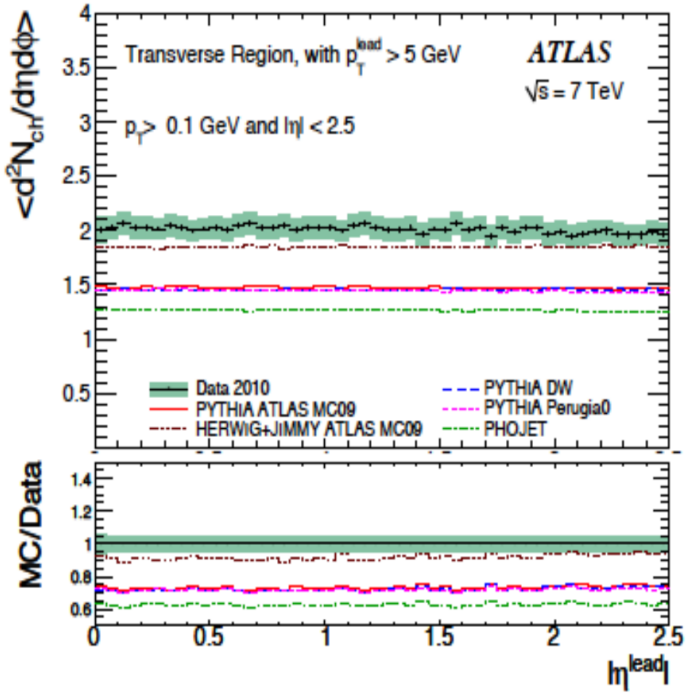
This was not tuned! We used tune to ATLAS UE presented during MPI@LHC 2010 on 1 December 2010 in Glasgow

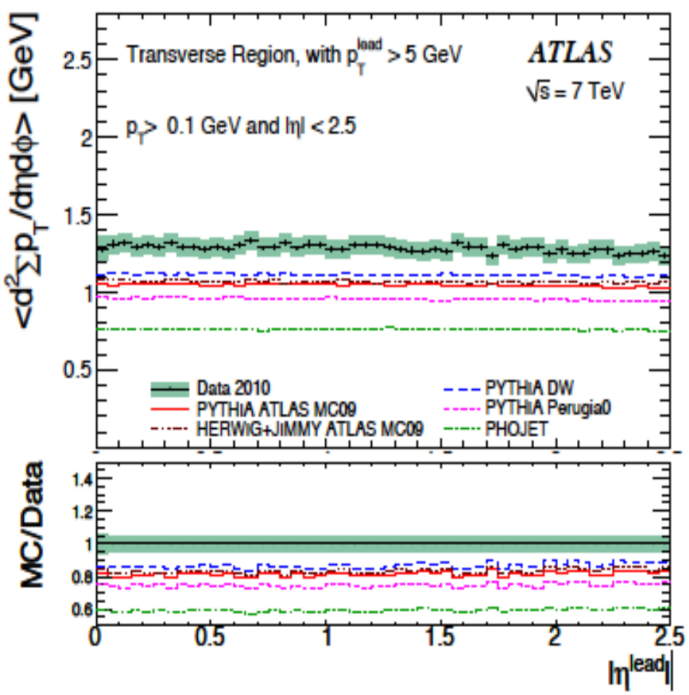


In Glasgow Arthur Moraes asked us how it would look like for $p_T = 100$ MeV

Tunes (input files, plots) are available at Herwig++ wiki page.

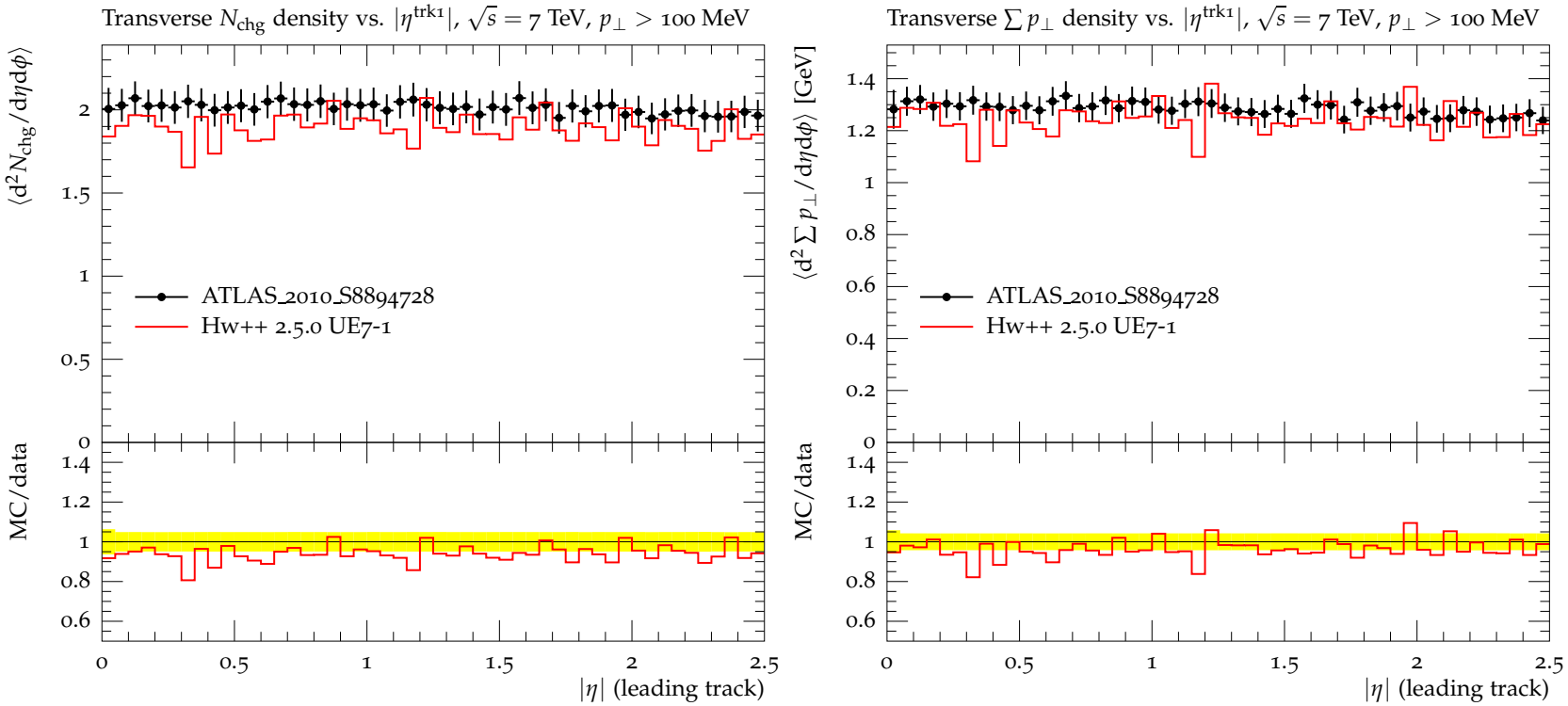
Particle Density, Scalar ΣP_T vs. η^{lead}





Lower particle activities in MC tunes
Particle density & scalar ΣP_T independent of η^{lead}

This was not tuned! We used tune to ATLAS UE presented during MPI@LHC 2010 on 1 December 2010 in Glasgow



In Glasgow Arthur Moraes asked us how it would look like for $p_T = 100$ MeV

Tunes (input files, plots) are available at Herwig++ wiki page.

New release: Herwig++ 2.5

Herwig++ 2.5

- POWHEG NLO parton shower matching scheme with:
  - Vector Boson Pair Production
  - $e^+e^- \longrightarrow q\bar{q}$
  - Higgs Decay
- MC@NLO program now can be use with Herwig++
- Colour Reconnection
- Diffractive and Photon Initiated Processes
- BSM Physics
  (ADD Model, Leptoquarks, NMSSM, Transplanckian Scattering)
- New Matrix Elements

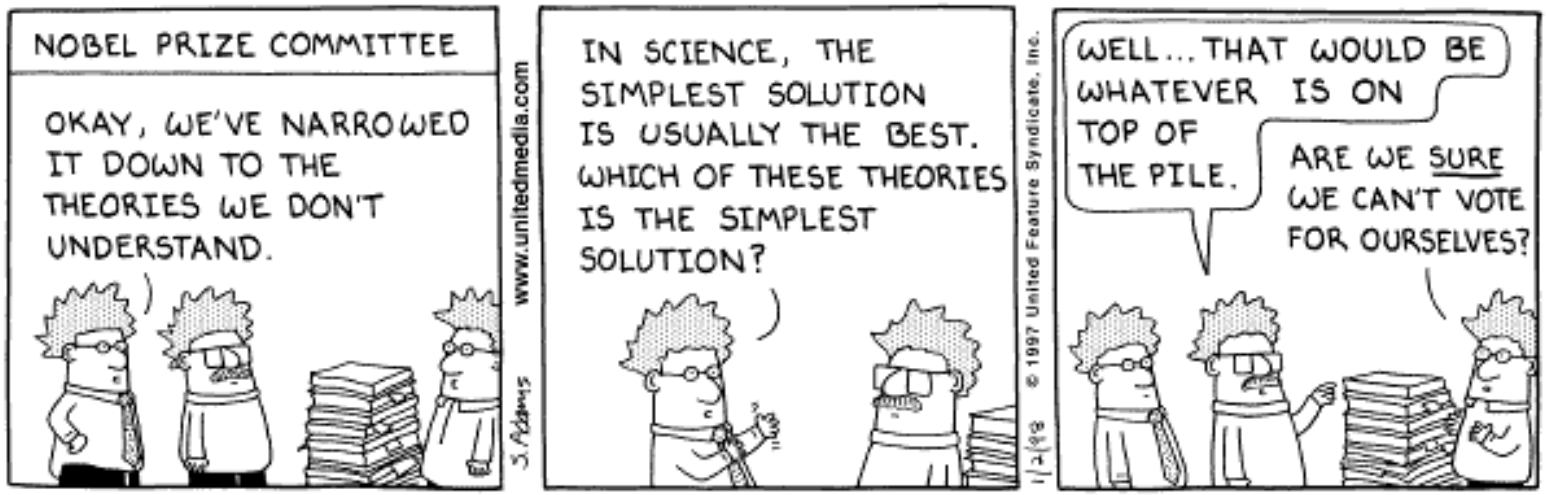
For details please look at release note.

Summary

- First look at LHC data.
- Need colour reconnection model.
- First tunes to 900 GeV and 7000 GeV Min Bias ($N_{ch} \geqslant 6$) give good results.
- Non-diffractive physics under good control
- So is this the end of the story?

Summary

- First look at LHC data.
- Need colour reconnection model.
- First tunes to 900 GeV and 7000 GeV Min Bias ($N_{ch} \geqslant 6$) give good results.
- Non-diffractive physics under good control
- So is this the end of the story? No! This is just the beginning...



- When we are happy with the description of existing data wa should ask more and more detailed questions (fb asymmetries, event shapes).
- Experiments provide more and more data (better statistics: Nch $\geq$ 20 , new observables: strange particle and proton production, LHC@2.8TeV ...)

Outlook

Open question:

- Energy dependent parameters?
- More involved overlap function (x-dependent)?
- Understanding of colour reconnection?
  (OPAL "rapidity gap analysis' - done, new CR algorithms - soon)
- Universal tune of UE parameters?
- New model of diffraction R&D
- Treatment of remnant pdfs too naive?
- Minimum bias/underlying event/diffraction under constant improvement!