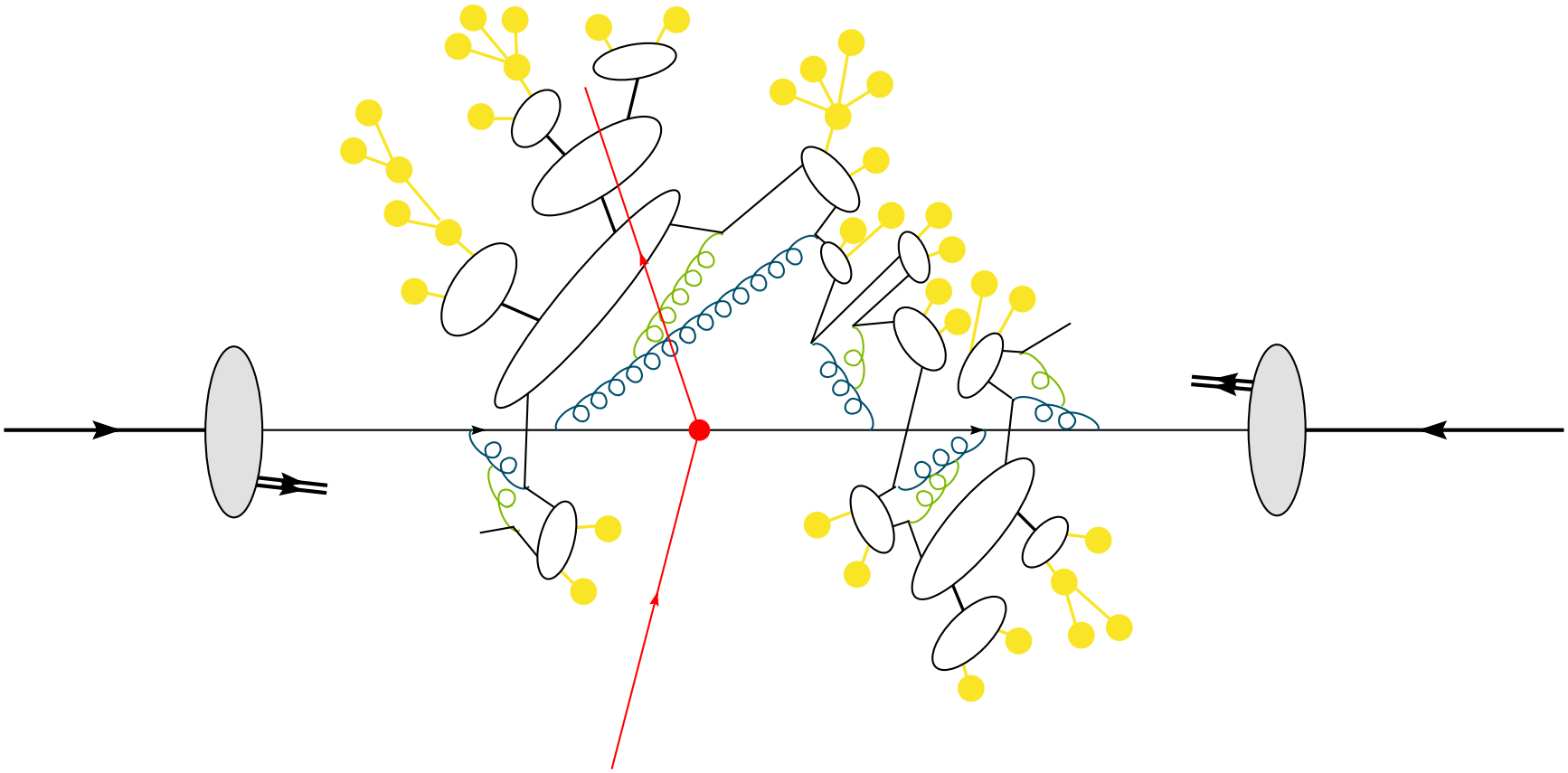
Underlying Event Extrapolation to 100 TeV

CERN, Theory Division & IFJ, Cracow

Introduction - event generation in Herwig++



taken from Stefan Gieseke©

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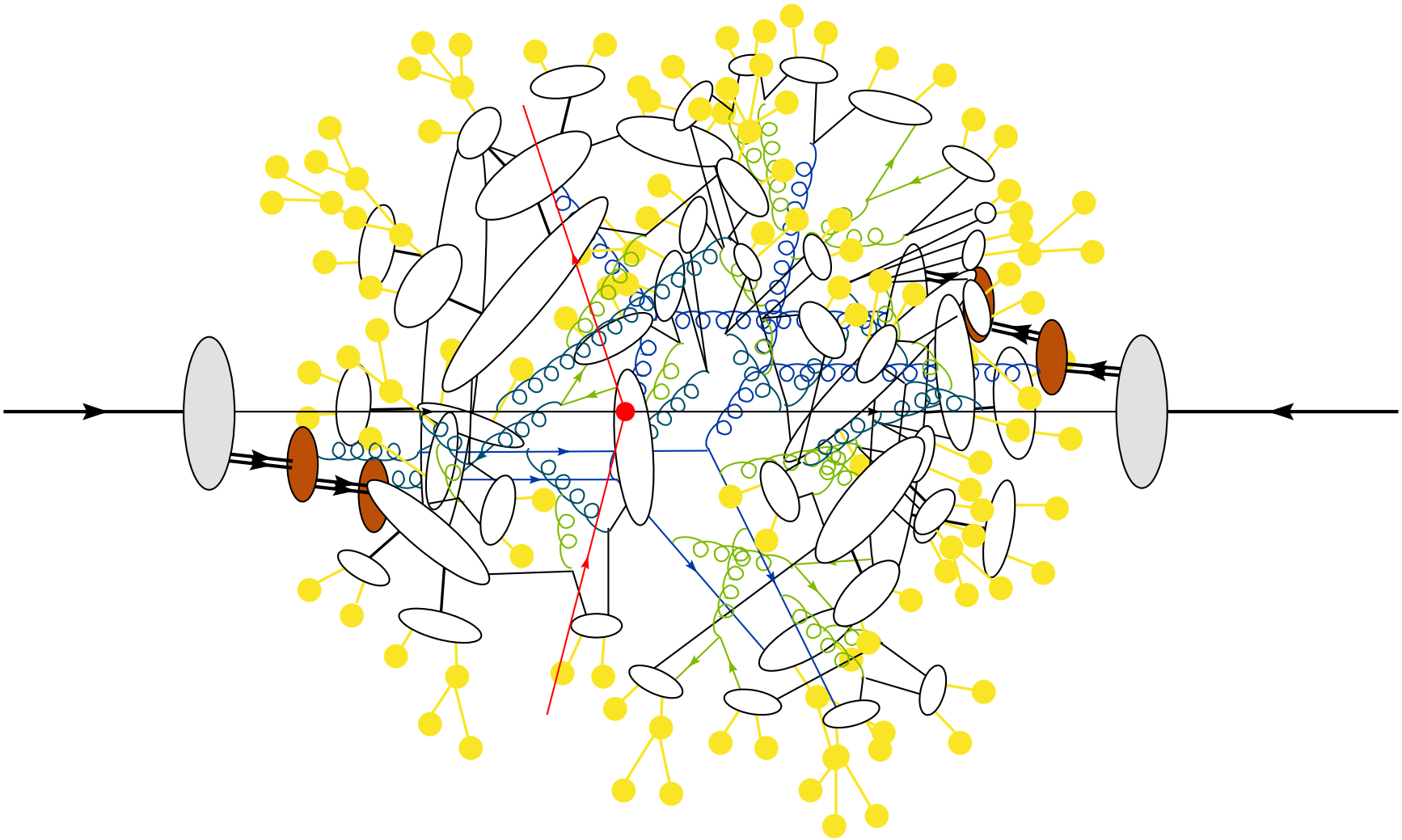

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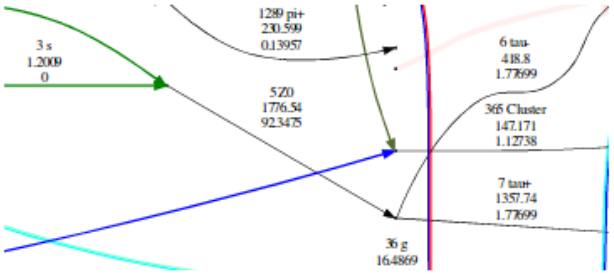
HERWIG++/Herwig 7 @ 100 TeV

Both HERWIG++/Herwig 7 run @ 100 TeV!

Global event structure @ 100 TeV



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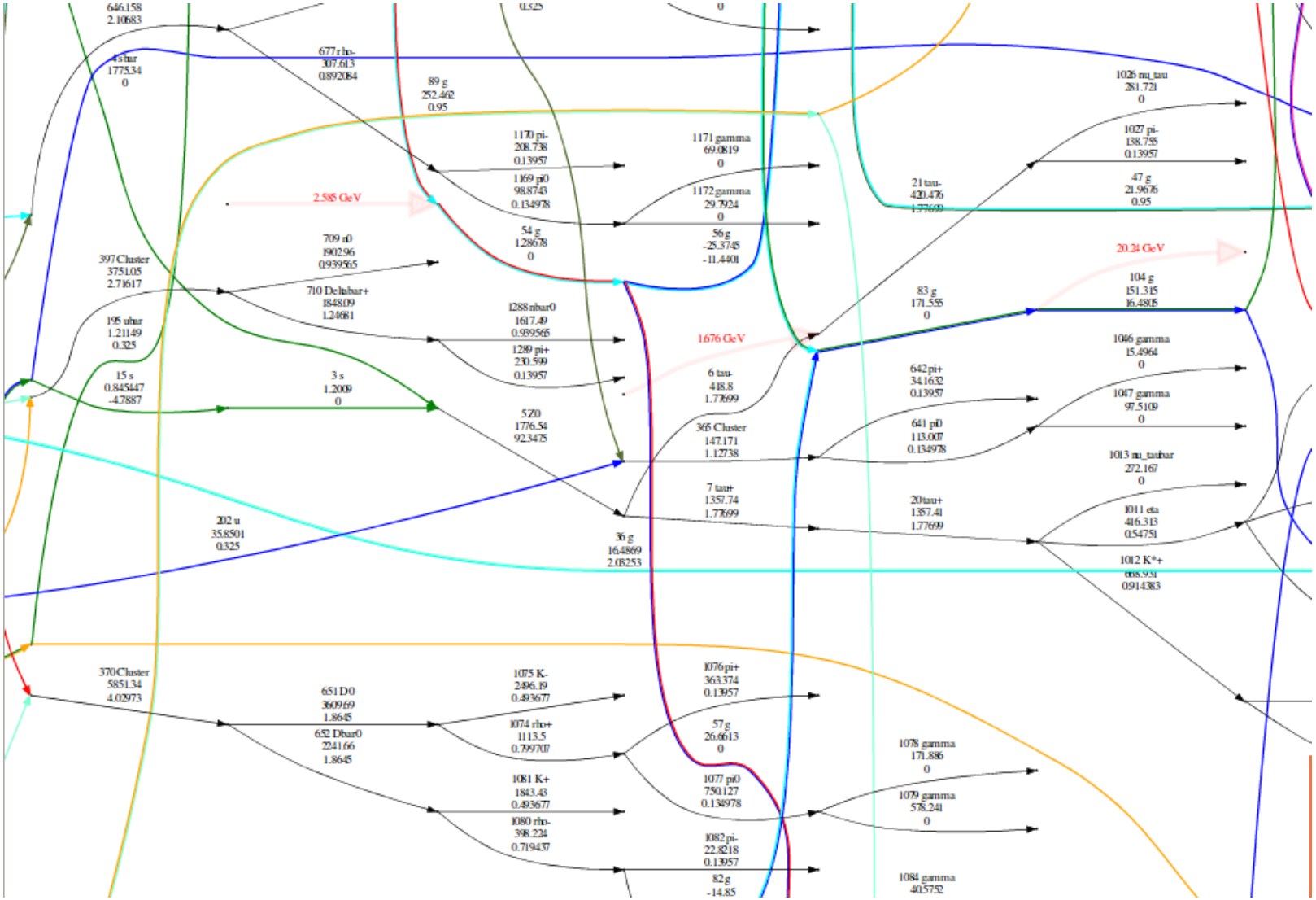

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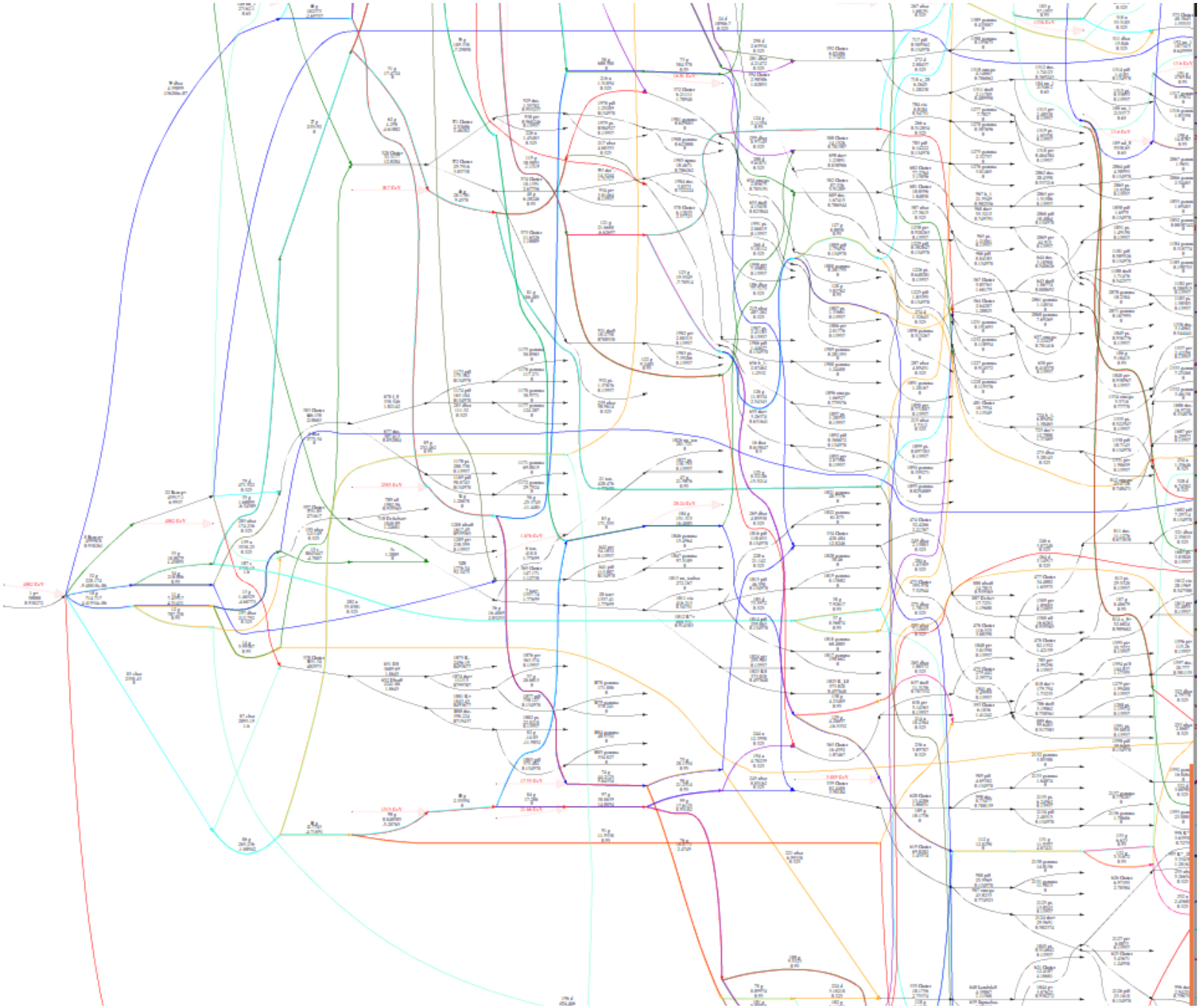

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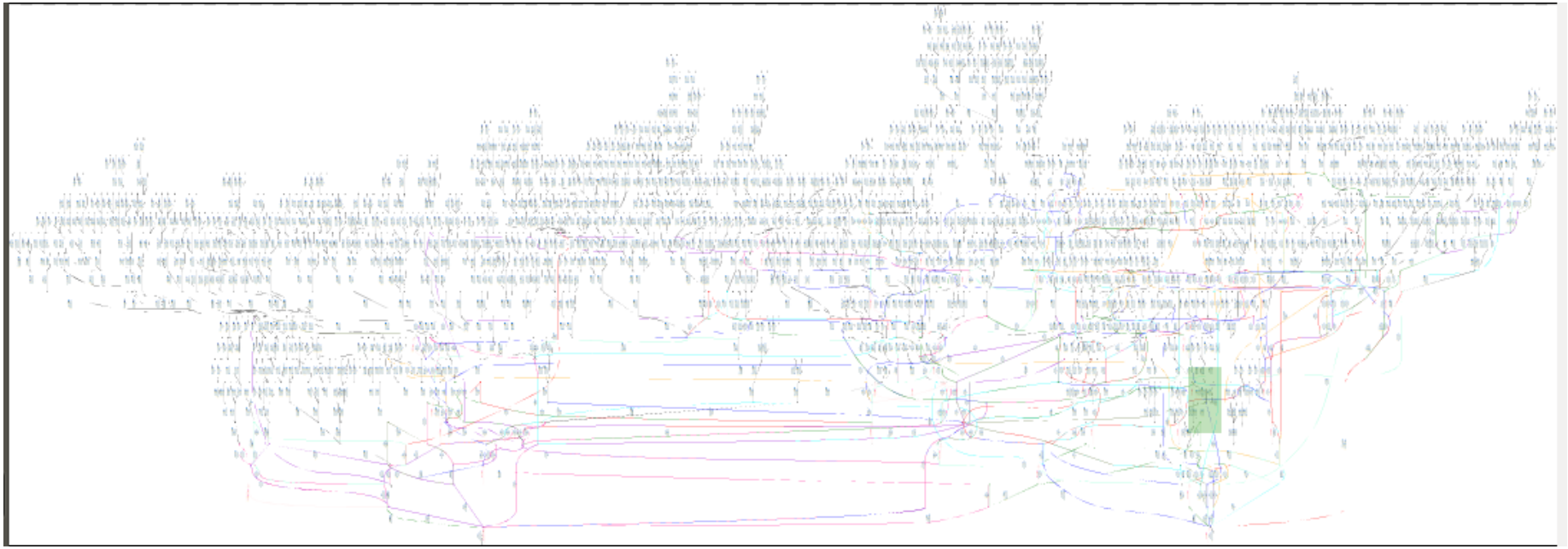

Quiz: HERWIG++/Herwig 7 @ 100 TeV

How many parameters of
HERWIG++/Herwig 7 need to be extrapolated
to 100 TeV?

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1

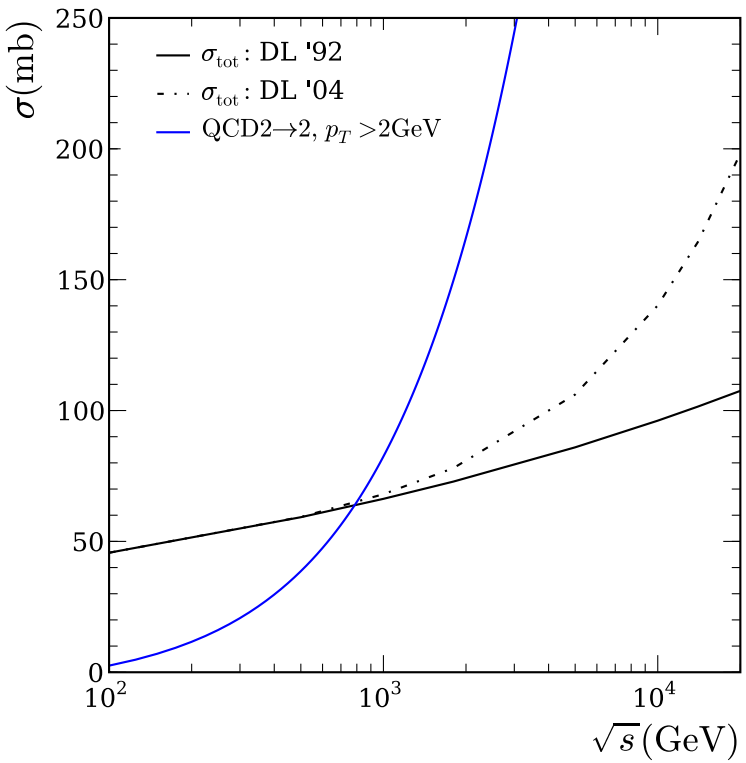
Multiple interaction model:

$p_t^{\min}$ - transition scale between soft MPI and hard MPI components

MPI model basics

Inclusive hard jet cross section in pQCD:

$$\sigma^{\text{inc}}(s, p_t^{\text{min}}) = \sum_{i,j} \int_{p_t^{\text{min}2}} \mathrm{d}p_t^2 \int \mathrm{d}x_1 \mathrm{d}x_2 \; f_i(x_1, Q^2)\, f_j(x_2, Q^2) \; \frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}p_t^2}$$



$\sigma^{\text{inc}} > \sigma_{\text{tot}}$ eventually

Interpretation:

- σ^{inc} counts all partonic scatters in a single pp collision
- more than a single interaction

$$\sigma^{\text{inc}} = \langle n_{\text{dijets}} \rangle \sigma_{\text{inel}}$$

MPI model basics (Herwig++)

Assumptions:

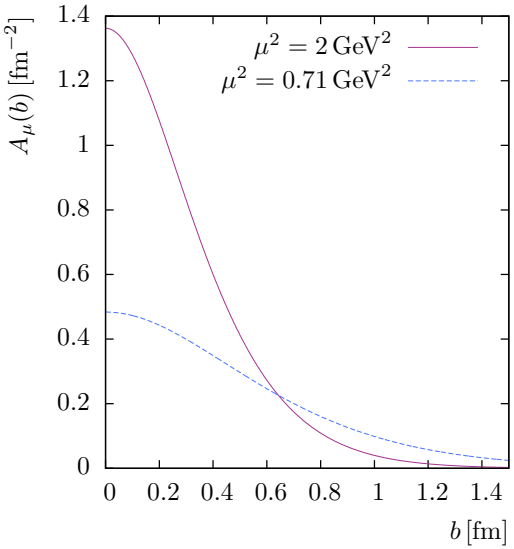
- the distribution of partons in hadrons factorizes with respect to the b and x dependence ⇒ average number of parton collisions:

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

- at fixed impact parameter b, individual scatterings are independent (leads to the Poisson distribution)

Underlying event in Herwig++ - key components

Matter distribution (μ^2)

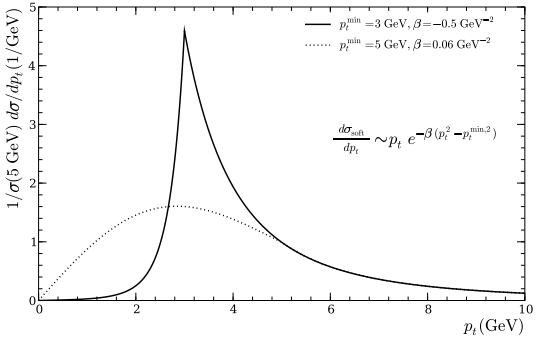


Based on electromagnetic form factor

(radius of the proton free parameter)

Extension to soft MPI

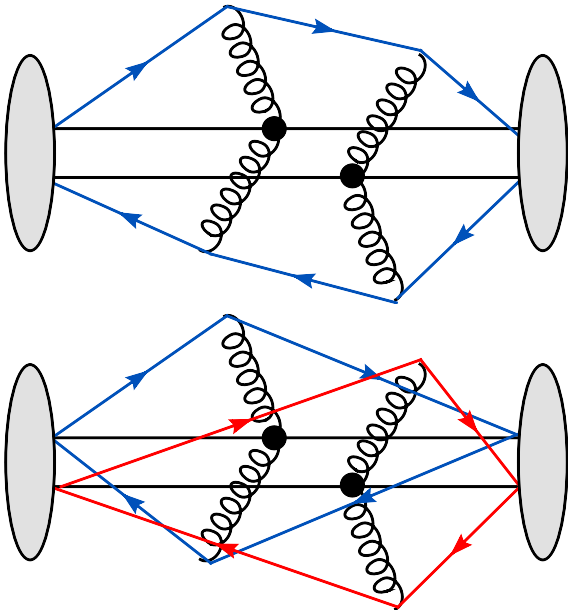
($p_t < p_t^{\min}$)



Gaussian extension below $p_t^{\min}$

Energy dependent $p_t^{\min}$

Colour structure (p_{reco}, p_{CD})



Possibility of change of color structure (color reconnection)

The least understood part of modeling

Main parameters:

- μ^2 - inverse hadron radius squared (parametrization of overlap function)
- $p_t^{\min}$ - transition scale between soft and hard components $\Rightarrow p_t^{\min} = p_{t,0}^{\min}\left(\frac{\sqrt{s}}{E_0}\right)^b$
- p_{reco} - colour reconnection
- p_{CD} - colour structure of the Soft UE

Tuning of MPI parameter in Herwig

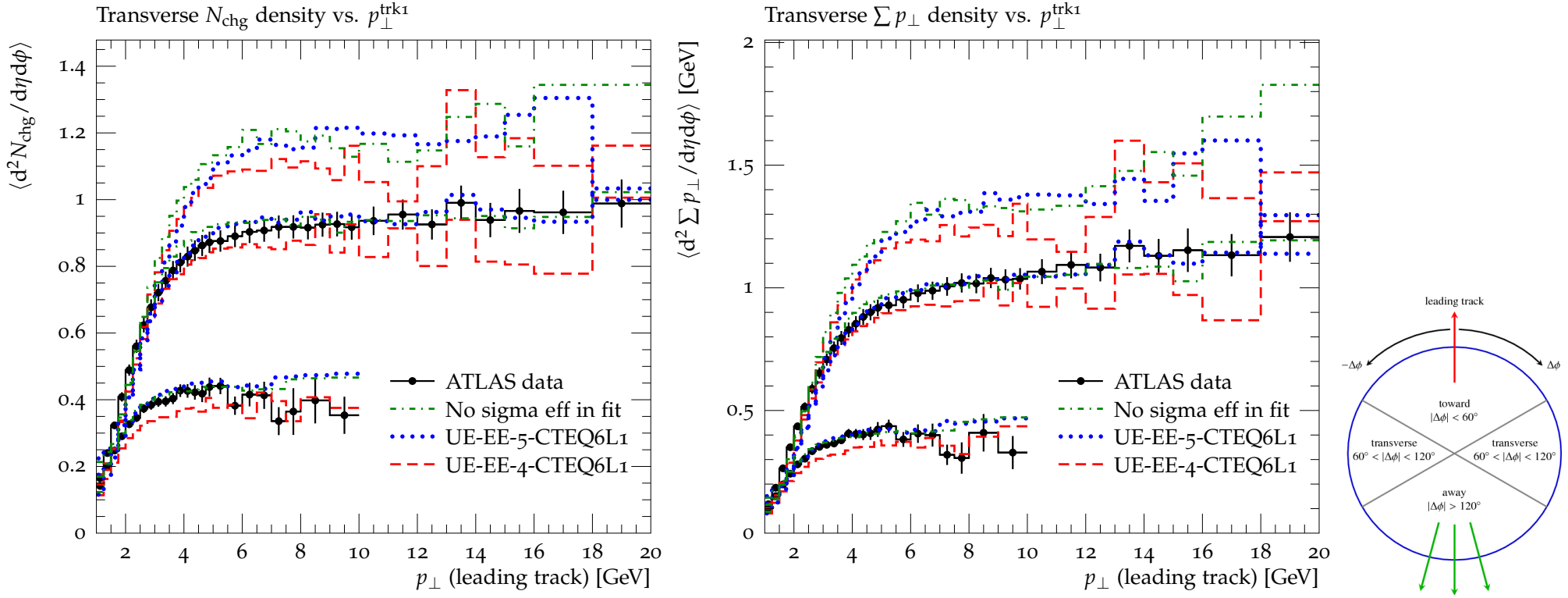
- We focused on the UE data (in transverse area which is sensitive to MPI)
- The UE experimental data used for the tune should be measured at a wide range of collider energies in similar phase-space regions and under not too different trigger conditions.
- These conditions are met by two UE observables:
  - mean number of stable charged particles per unit of η-ϕ: $\langle \mathrm{d}^2 N_{\mathrm{ch}}/\mathrm{d}\eta\,\mathrm{d}\phi \rangle$, in the tranverse region;
  - The mean scalar $p_\perp$ sum of stable particles: $\langle \mathrm{d}^2 \sum p_t/\mathrm{d}\eta\,\mathrm{d}\phi \rangle$, in the tranverse region.

Both are measured as a function of $p_\perp^{\mathrm{lead}}$ (with $p_\perp^{\mathrm{lead}} < 20$ GeV) by ATLAS at 900 GeV and 7 TeV (with $p_\perp > 500$ MeV and by CDF at 300 GeV, 900 GeV and 1960 GeV (with $p_\perp > 500$ MeV).

- Additionally most recent tunes (UE-EE-5) includes σ_{eff} data.

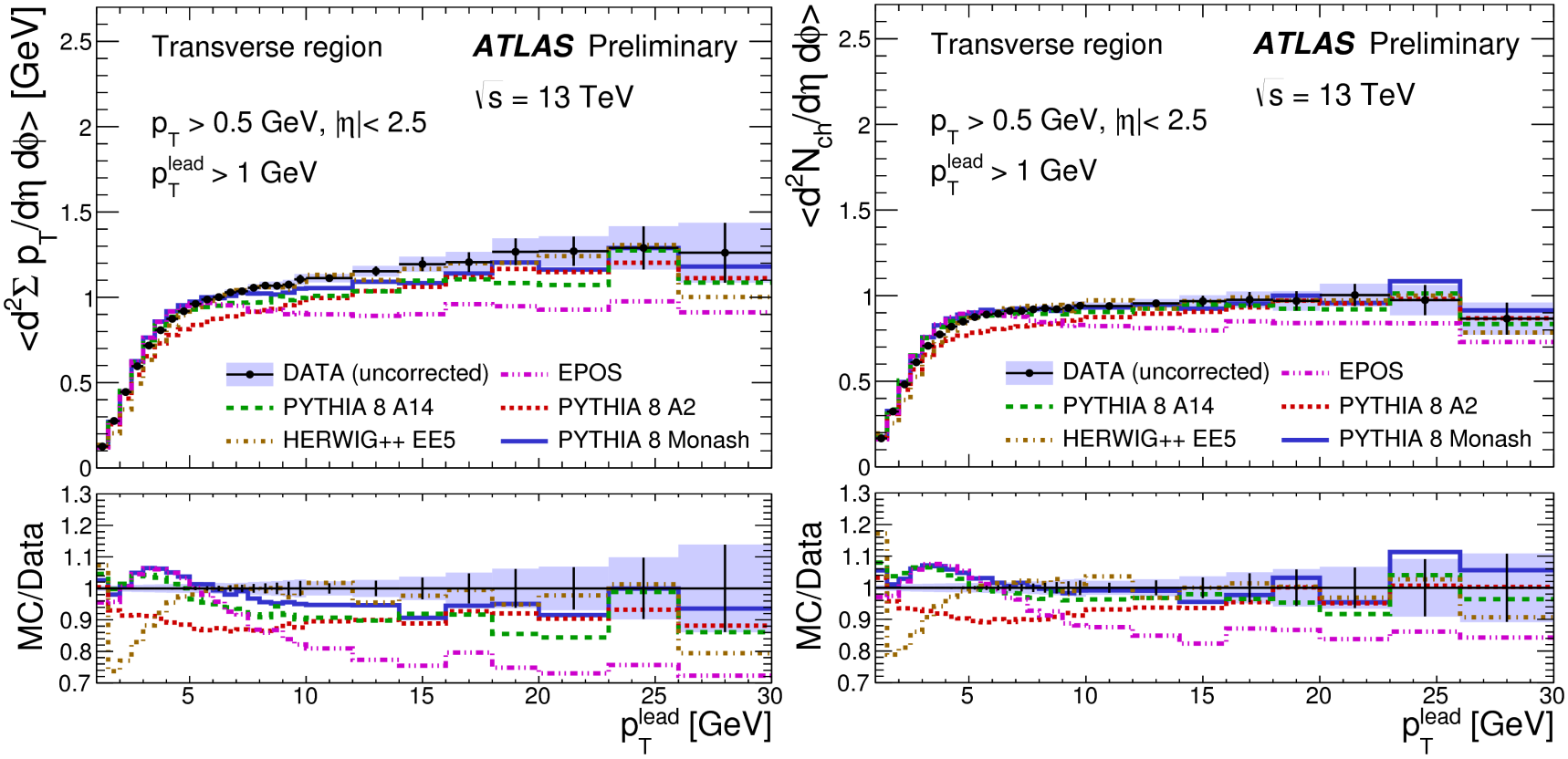
Tuning of MPI parameter in Herwig

ATLAS data at 900 GeV (lowest sets), 7 TeV (middle sets) and the predictions for 14 TeV (top sets).
The mean multiplicity density (left panel) and
mean scalar $p_\perp$ sum (right panel) in the "transverse" area as a function of $p_\perp^{\text{lead}}$.



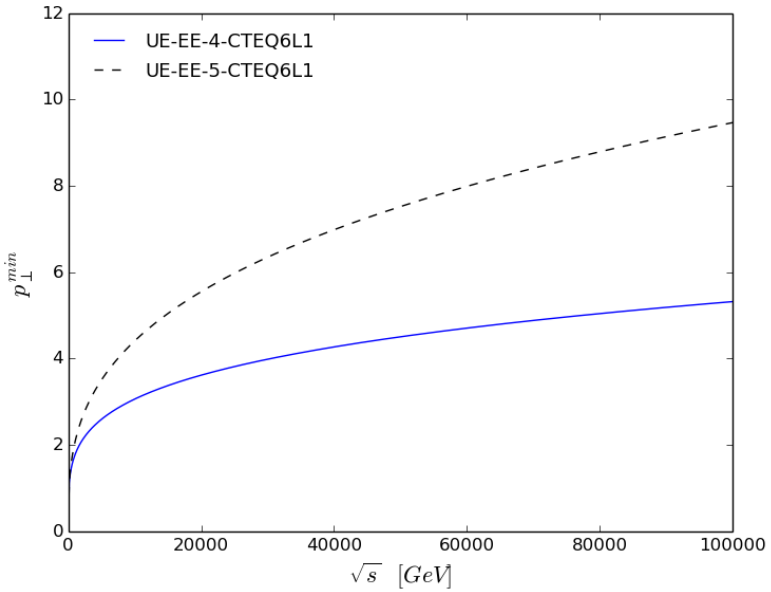
- Tunes describes data quite well over the range of energies.

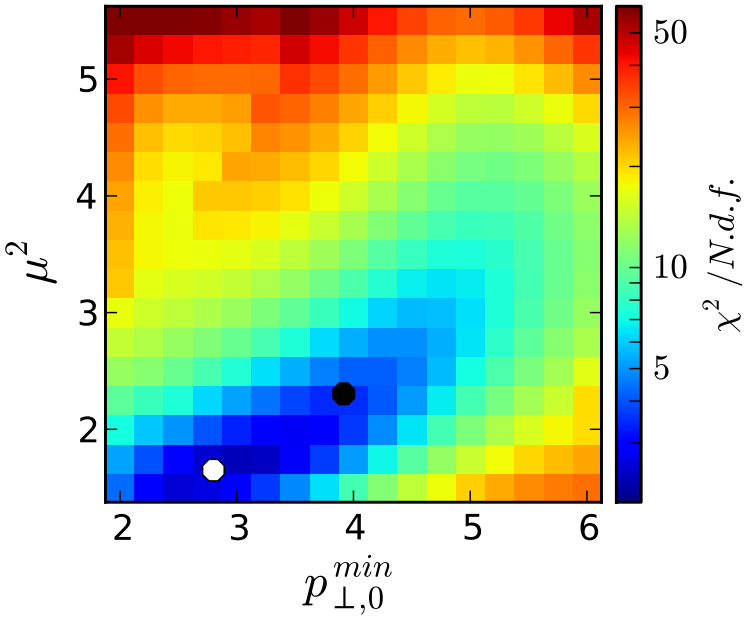
Run II results - UE [ATL-PHYS-PUB-2015-019]



- Many LHC UE observables (not tuned since not available) and well described!
- Promising for 100 TeV extrapolation...

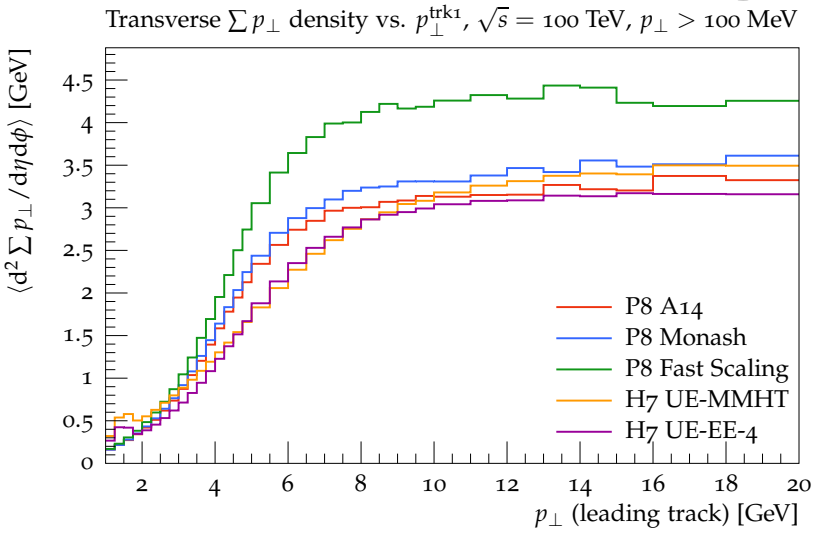
Energy extrapolation to 100 TeV

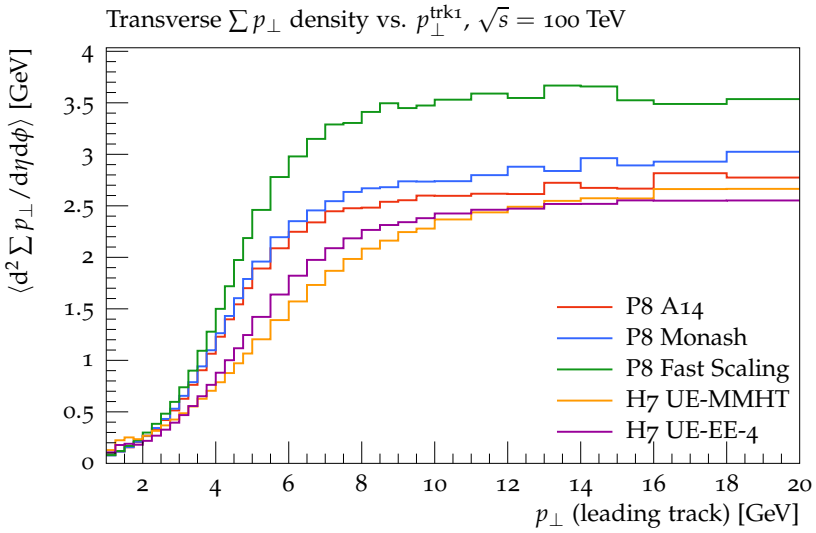




- Despite quite different extrapolation of different tunes we get quite similar description of the data.
- The reason for this is a strong correlation of μ^2 and $p_t^{\min}$

UE@100TeV





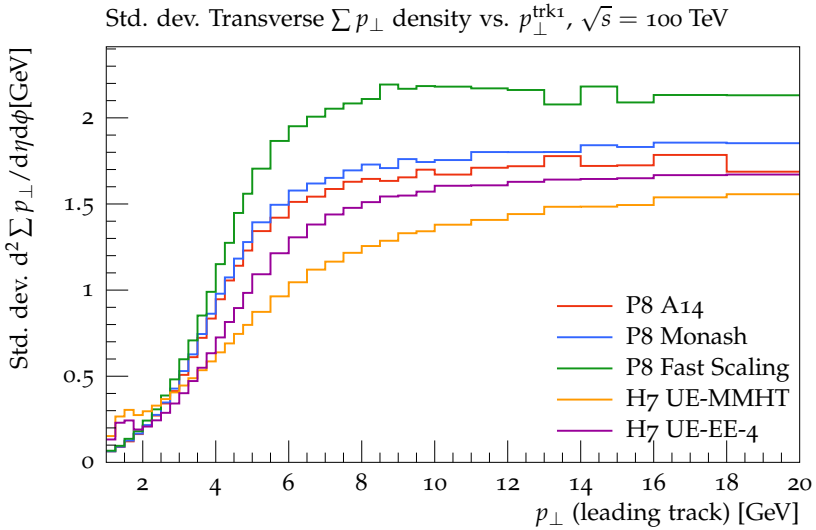


Fig. 7: pp collisions at 100 TeV. Predictions for the transverse-region charged-particle $\Sigma p_\perp$ density, with $\mathrm{p}_{\perp \mathrm{ch}} > 100$ MeV (top left) and $\mathrm{p}_{\perp \mathrm{ch}} > 500$ MeV (top right) cuts. The bottom right-hand plot shows the event-by-event fluctuations as measured by the standard deviation for the $\mathrm{p}_{\perp \mathrm{ch}} > 500$ MeV cut.

- Given the order-of-magnitude extrapolation in c.m. energy, there is a remarkable level of agreement between the central models (i.e., extreme Fast Scaling one)

Conclusions

- First look at the UE extrapolation to 100 TeV
- Useful for detector-design and jet energy calibration estimations
- Given the order-of-magnitude extrapolation in c.m. energy, there is a remarkable level of agreement between the central models