Soft and diffractive scattering in Herwig

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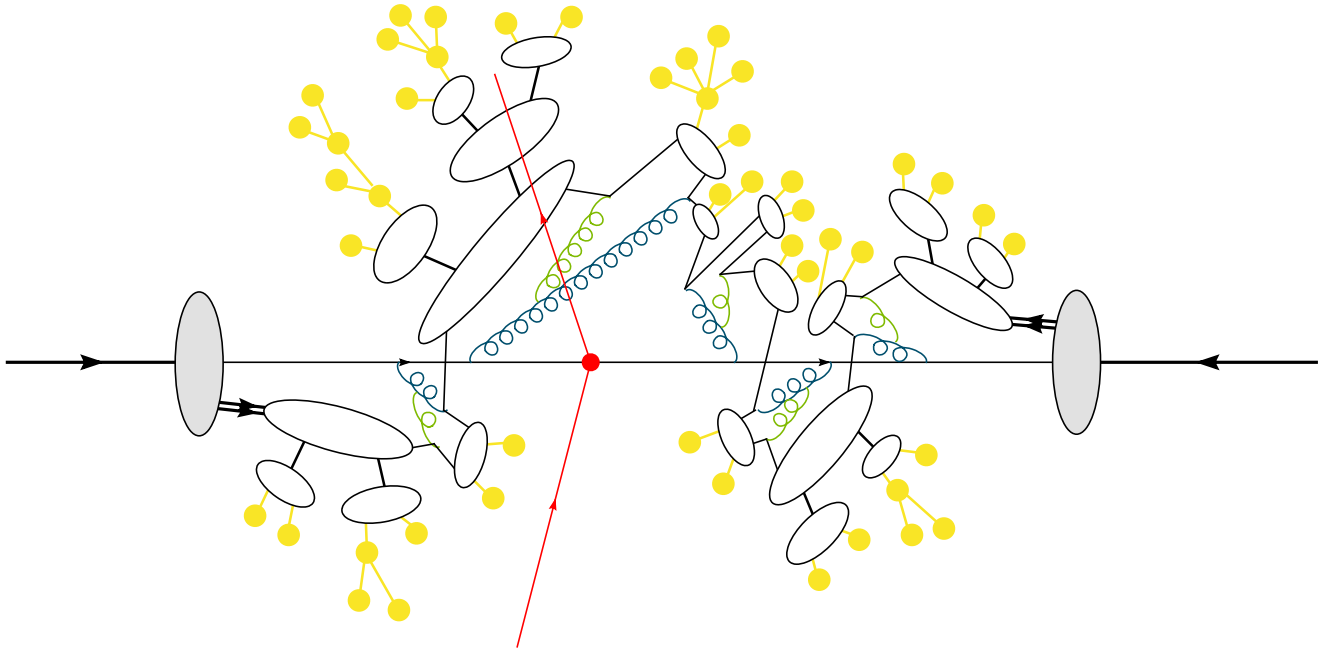
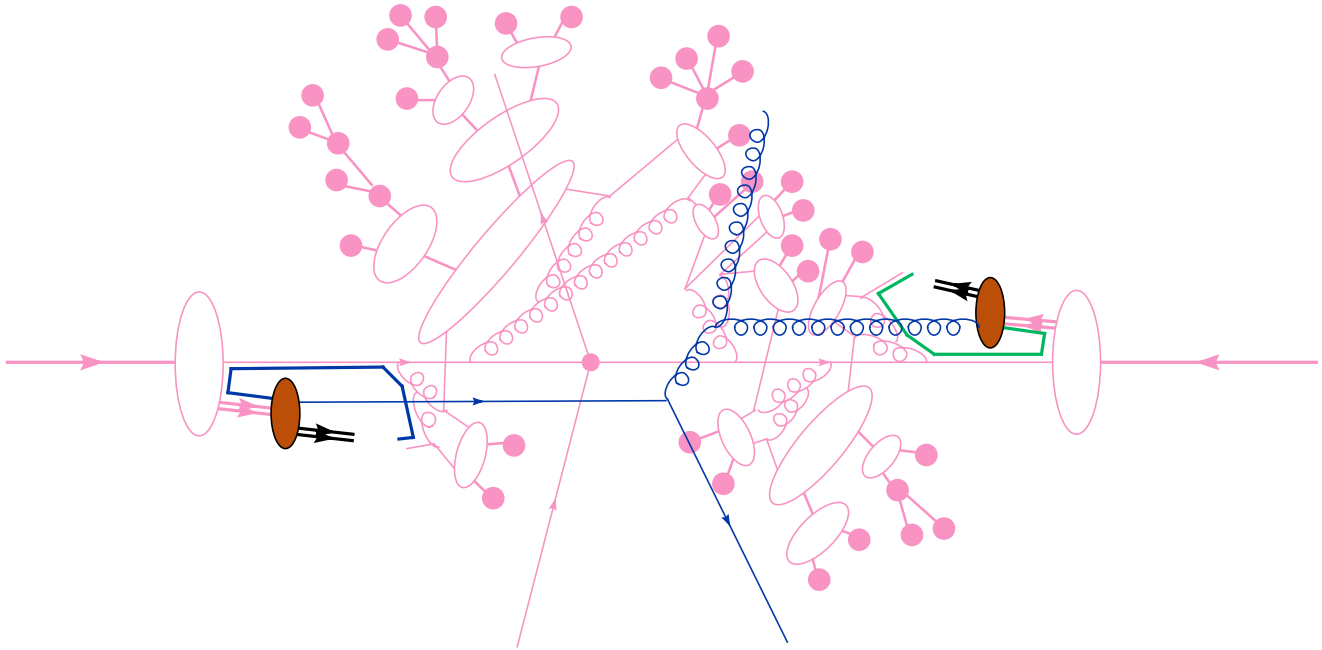
(with Stefan Gieseke and Frashër Loshaj)

based on [Gieseke, PK, Loshaj, Eur. Phys. J. C (2017)]

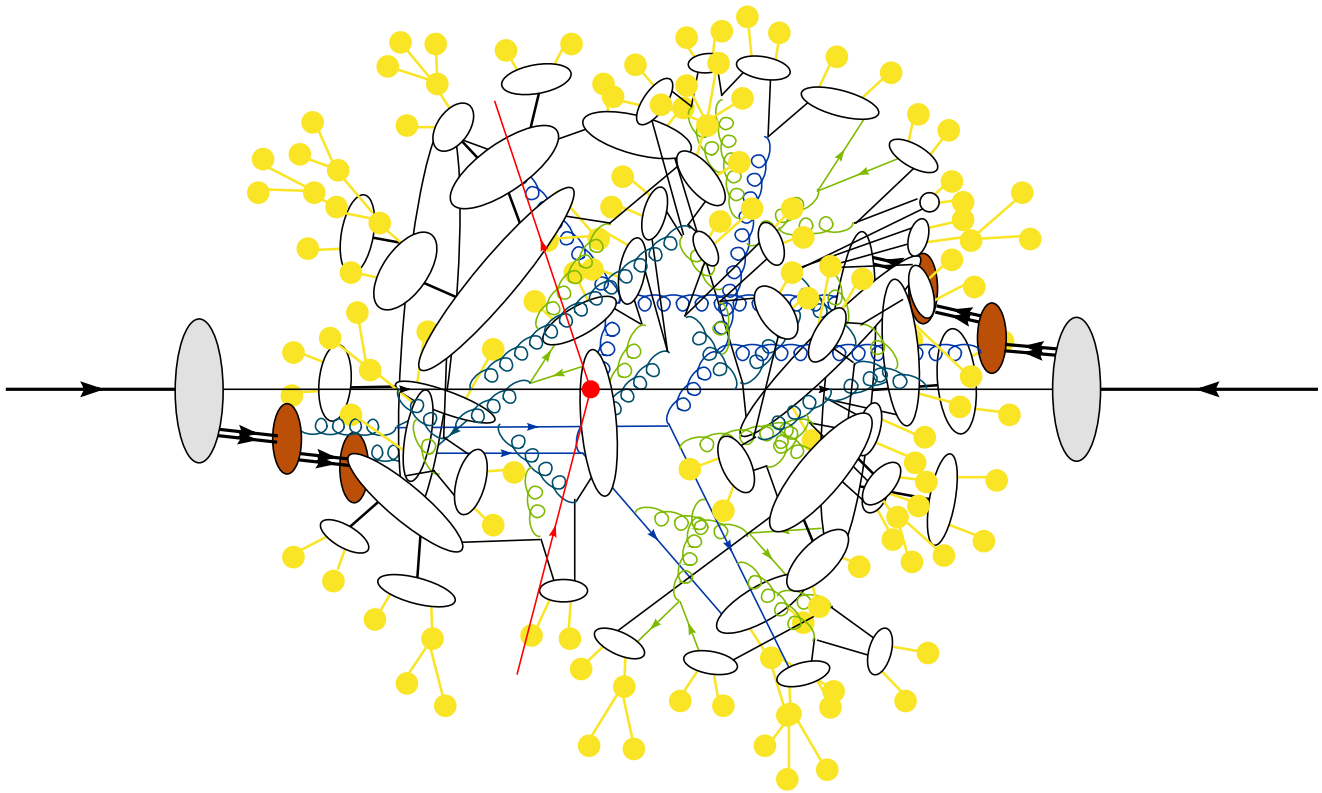
PP collision from Herwigs point of view



PP collision from Herwigs point of view



PP collision from Herwigs point of view



Simulation of Multiple parton interactions in Herwig

- Simulation of MPI $\rightarrow$ UE and MB
  - Background for searches
  - Interactions at low $p_\perp$ $\rightarrow$ interesting
  - MB for Cosmic ray physics
  - many more...
- Incorporation into Event-Generator tool chain
  - Simulate several uncorrelated partonic interactions
  - Apply known machinery like parton shower, colour reconnections
  - Hadronize with a hadronization model
  - hope for the best (many dofs in hadronization)

Multiple parton interactions in Herwig++

- Default from Herwig++ 2.1
- Differentiate between the perturbative and non-perturbative regime with a parameter $p_\perp^{\min}$ (tunable)

Interactions with $p_\perp > p_\perp^{\min}$:

- Simulated as gluonic QCD $2 \to 2$ processes (*semi-hard* interactions) [Bähr, Gieseke, Seymour, JHEP 0807:076]
- Good description of "harder" underlying event measurements

Multiple parton interactions in Herwig++

- Default from Herwig++ 2.1
- Differentiate between the perturbative and non-perturbative regime with a parameter $p_\perp^{\min}$ (tunable)

Interactions with $p_\perp < p_\perp^{\min}$:

- Simplest choice $\rightarrow$ elastic scattering among gluons [Bähr, Butterworth, Seymour, JHEP 0901:065] [Bähr, Butterworth, Gieseke, Seymour, 0905.4671]
- Gave good description of some soft UE observables
- Since Herwig 7.1 (May 2017): New default model for *soft* interactions based on multiperipheral kinematics

Multiple parton interactions

- In Herwig based on the eikonal model

$$\mathcal{P}_{h,s} = \frac{2\chi_{\text{hard}}(\vec{b},s)^h}{h!}\frac{2\chi_{\text{soft}}(\vec{b},s)^n}{n!}e^{-2\chi_{\text{tot}}(\vec{b},s)}$$

$$\chi_{\text{tot}}(b,s) = \frac{1}{2}(A(\vec{b},\mu)\sigma^{\text{inc}}_{\text{hard}}(s,p^{\text{min}}_{\perp}) + A(\vec{b},\mu_{\text{soft}})\sigma^{\text{inc}}_{\text{soft}})$$

- Parameters of the soft model fixed to describe σ_{tot} and b_{el}

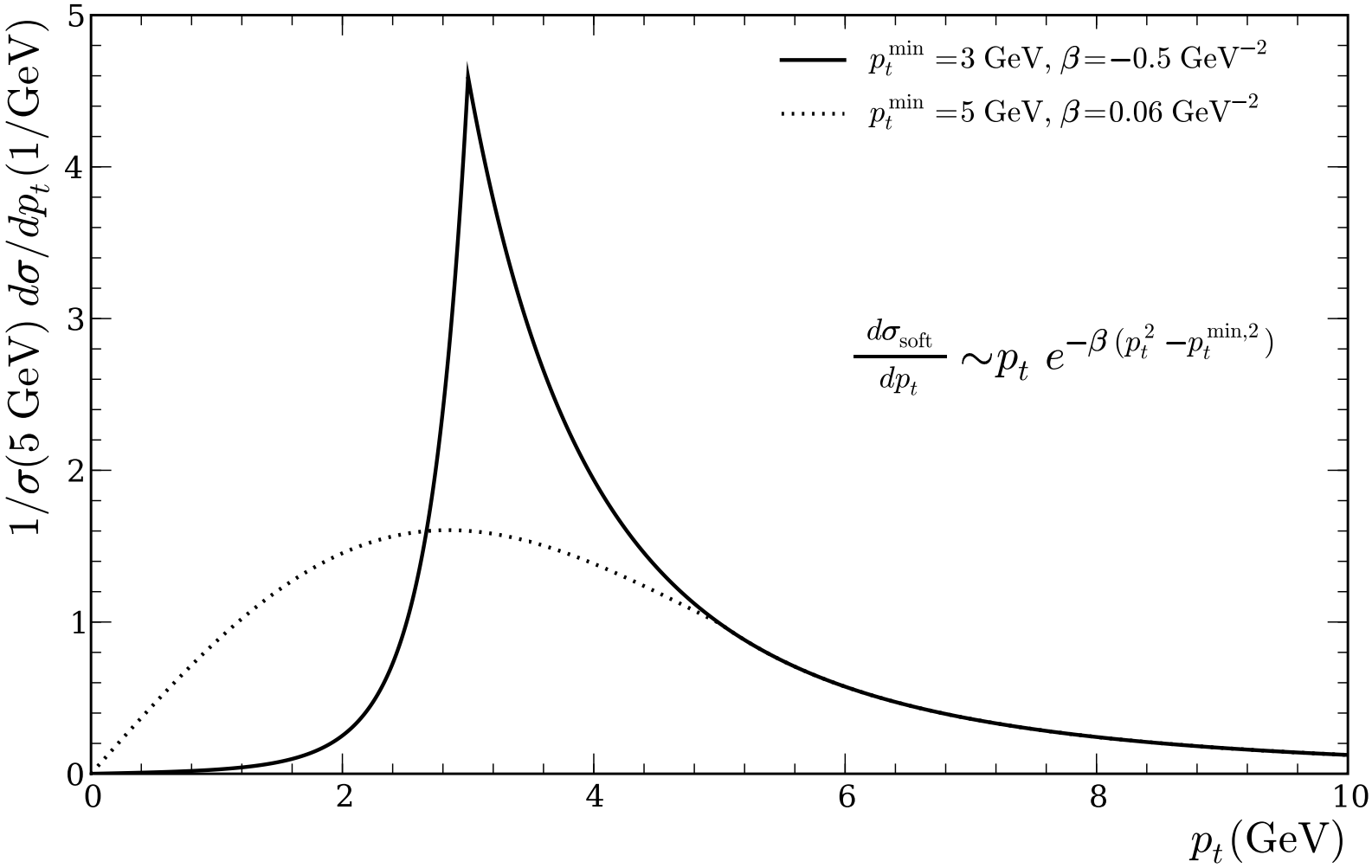
$$\sigma_{\text{tot}}(s) \stackrel{!}{=} 2\int \mathrm{d}^2\vec{b}\left(1 - e^{-\chi_{\text{tot}}(\vec{b},s)}\right)$$

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

- Simulate h semi-hard interactions and n soft interactions

Sampling of transverse momentum

- Extension of the differential cross section into the soft region $p_t < p_t^{min}$



Soft interactions

- N_{soft} from eikonal approximation s.t.

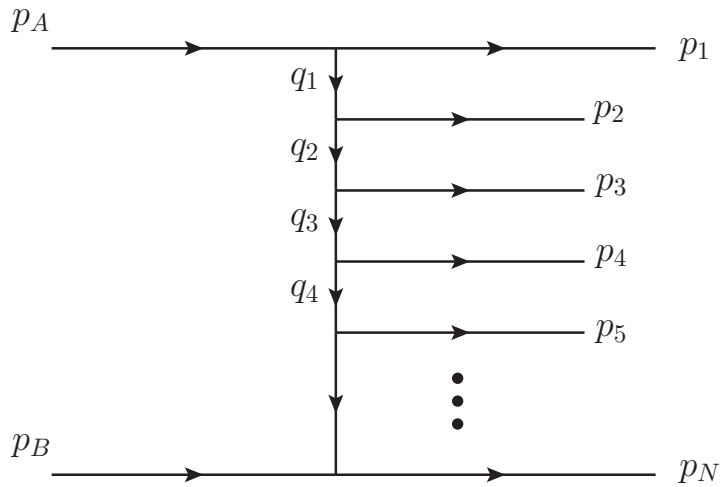
$$\sigma_{\text{tot}}(s) = \sigma_{\text{soft}}(s) + \sigma_{\text{semi}-\text{hard}}(s)$$

  where $\sigma_{\text{tot}}(s)$ is given by D-L parametrization and $\sigma_{\text{semi}-\text{hard}}$ is calculable

- Implemented model motivated by properties of “cut Pomerons”

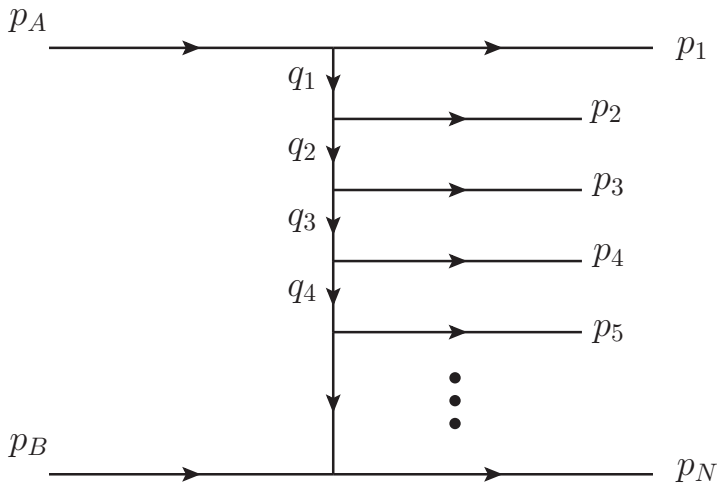
  [Baker, Ter-Martirosyan, Phys.Rept. 28 (1976) 1-143]

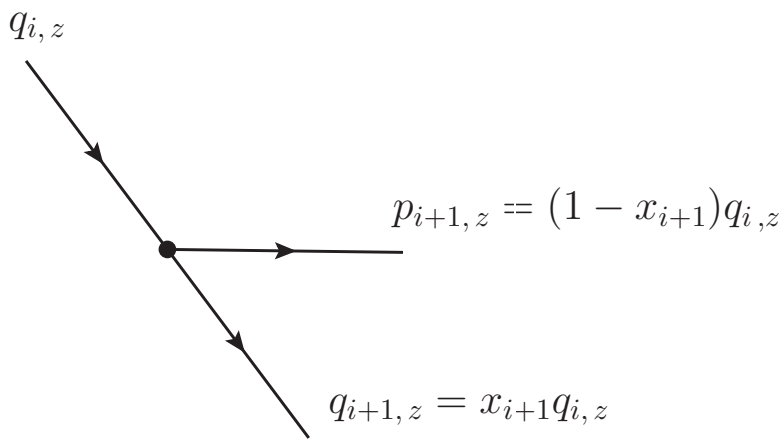
- Idea: Number of soft interactions from MPI model = cut pomerons = particle ladders with multiperipheral kinematics



Kinematics of the multiperipheral ladder

- Kinematics generated as a splitting process of the proton remnant





$$\langle N \rangle \simeq N_{ladder} \times \ln \frac{s}{m^2} \qquad \Delta y \sim \ln \frac{1}{x}$$

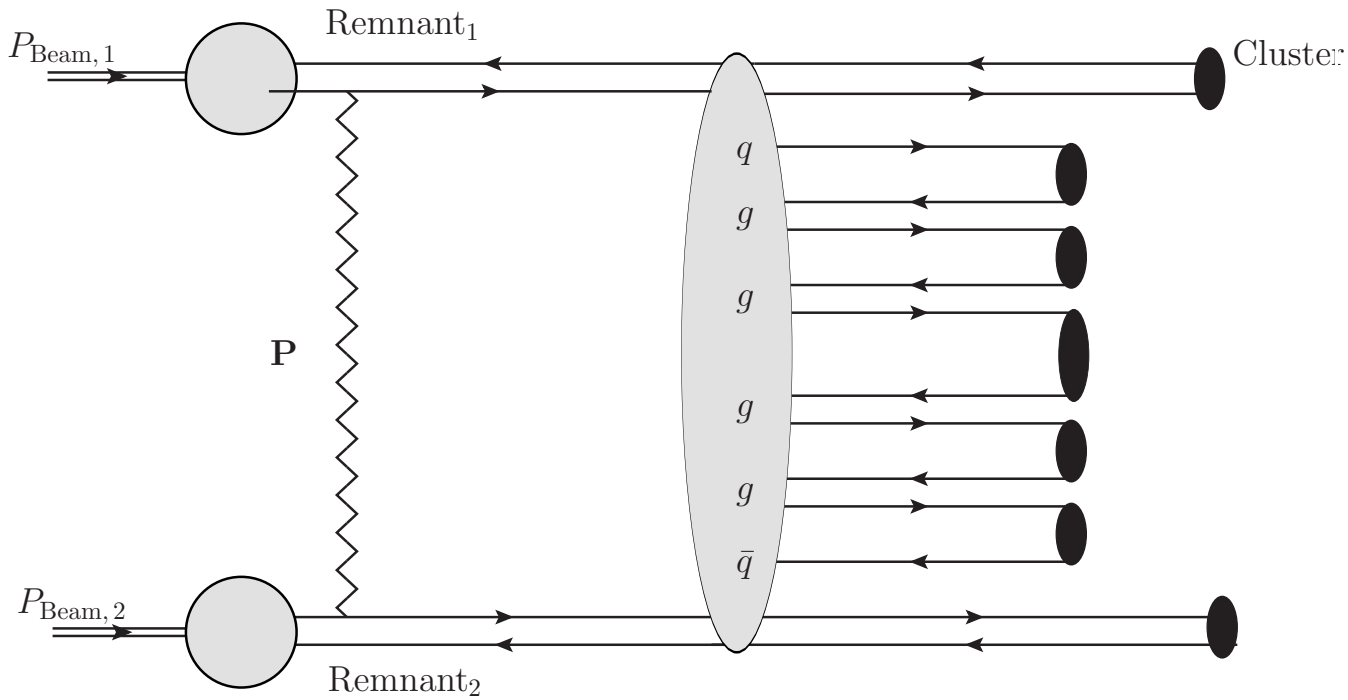
- $x_i \simeq x$ such that it gives uniform distribution in rapidity
- $N_{ladder} = N_0(\frac{s}{\mathrm{TeV}^2})^{-0.08}$ can be parametrized to follow power law ($N_0 \approx 1$)

Soft interactions

- Two guidelines:

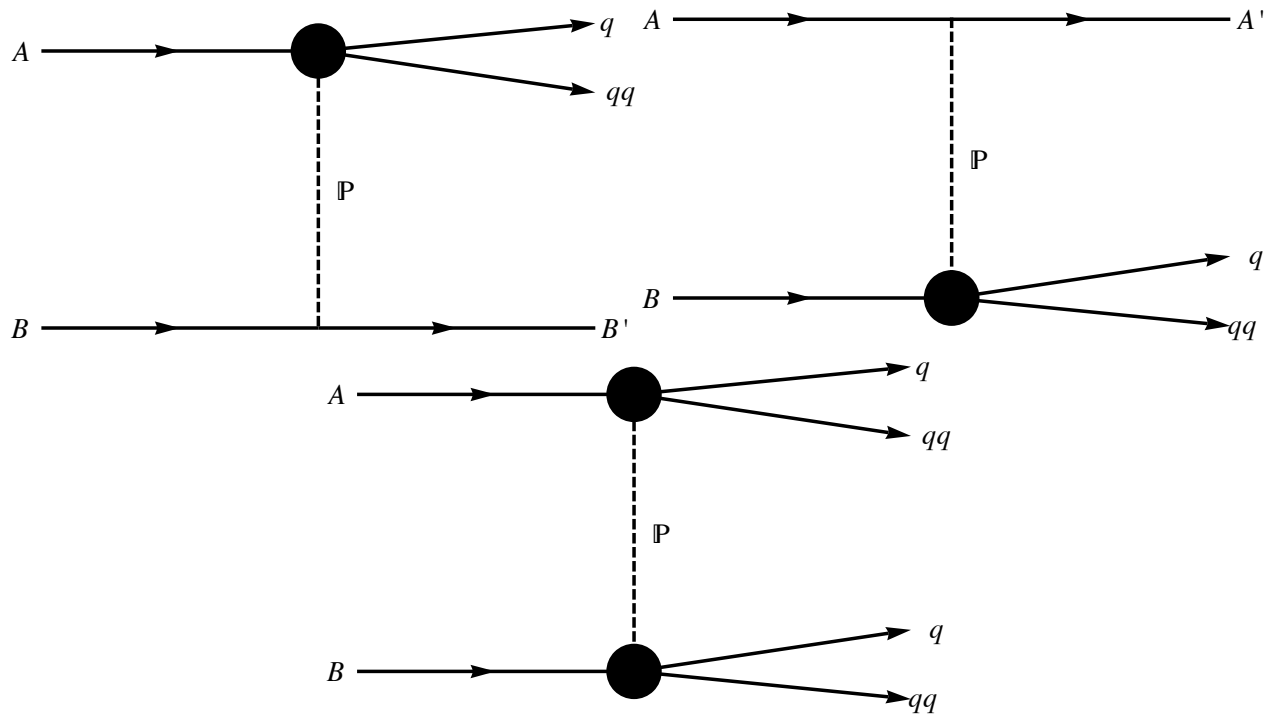
  i) Distribution of ladder particls approximately uniform in rapidity and with low $p_\perp$ $\mathcal{O}$(GeV)

  ii) Non-diffractive part of the cross section $\sim e^{-a\Delta\eta}$
- Particles within the ladder modeled as gluons
- Emit one $q\bar{q}$ pair in order to get the correct colour connections between the neighbours



Model for soft diffraction

- Implemented for soft diffraction (small $p_\perp$) in Herwig by modelling it with the following matrix elements



- Final state treated fully non-perturbatively - Quark (q) and diquark (qq) form a cluster with diffractive mass M and stretched along the direction of the dissociated proton $\rightarrow$ No crosstalk!

Model for soft diffraction

- Low mass diffraction with a tail towards high masses
- For very low masses of the dissociated system use Δ-resonance instead of clusters
- $p + p \to p' + \Delta$
- $p + p \to \Delta + \Delta$

Incorporation of soft diffraction into Herwig

- Simplest approach: Implementation into the existing MPI model
- In the simulation every event is either diffractive or non-diffractive
- Combine existing MPI model with diffraction, total cross section has to be altered by: $x\sigma_{\text{tot}}(s)$, where

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

and

$$x \approx 1 - \frac{\sigma_{\text{diff}}}{\sigma_{\text{tot}}}$$

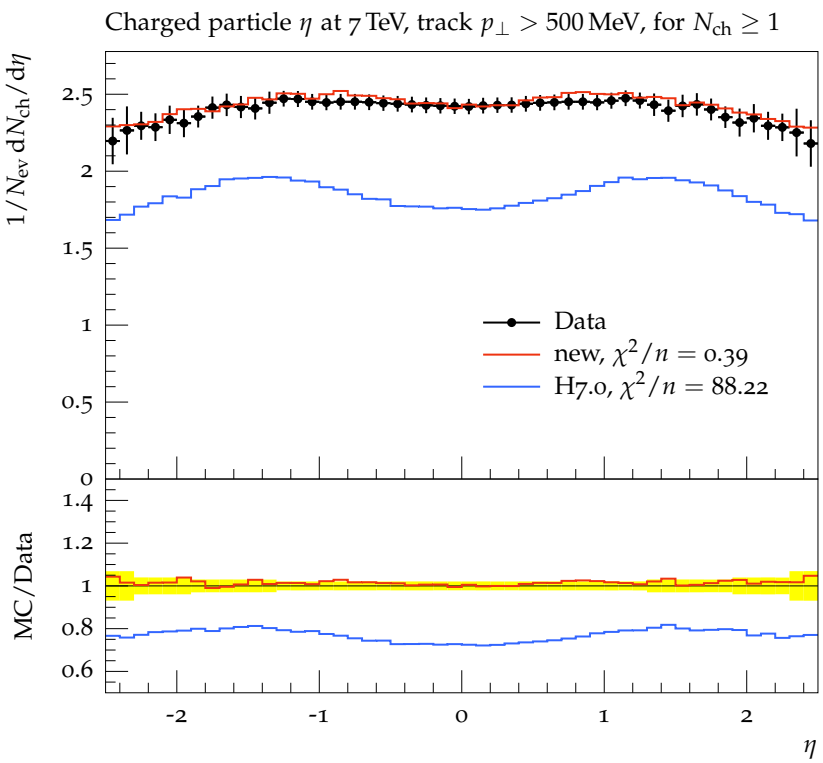
- x usually in the range $50 - 70\%$, get value from data

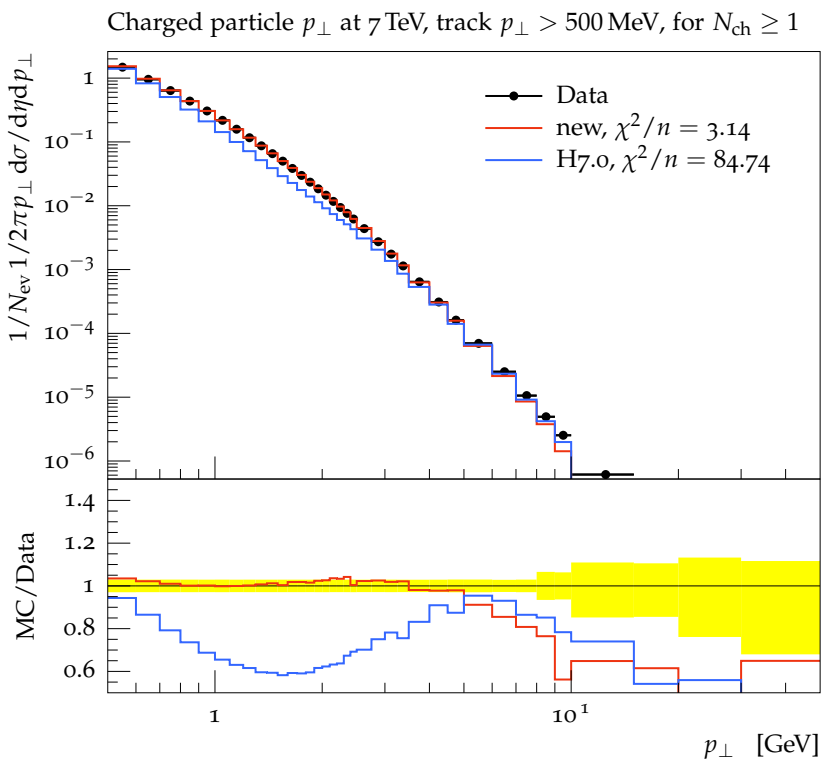
Tuning of free parameters

- Goal: energy independent description of all (LHC) energies available (900GeV, 7TeV, 13TeV) MB data/UE data.
- Free parameters of the model tuned with MC tuning framework PROFESSOR [Buckley, A., Hoeth, H., Lacker, H. et al. Eur. Phys. J. C (2010) 65: 331.] to MB data
- New “soft tune” comes with the default version of Herwig 7.1
- Ongoing tuning attempts to 13 TeV CMS UE data by CMS

Results - minimum bias

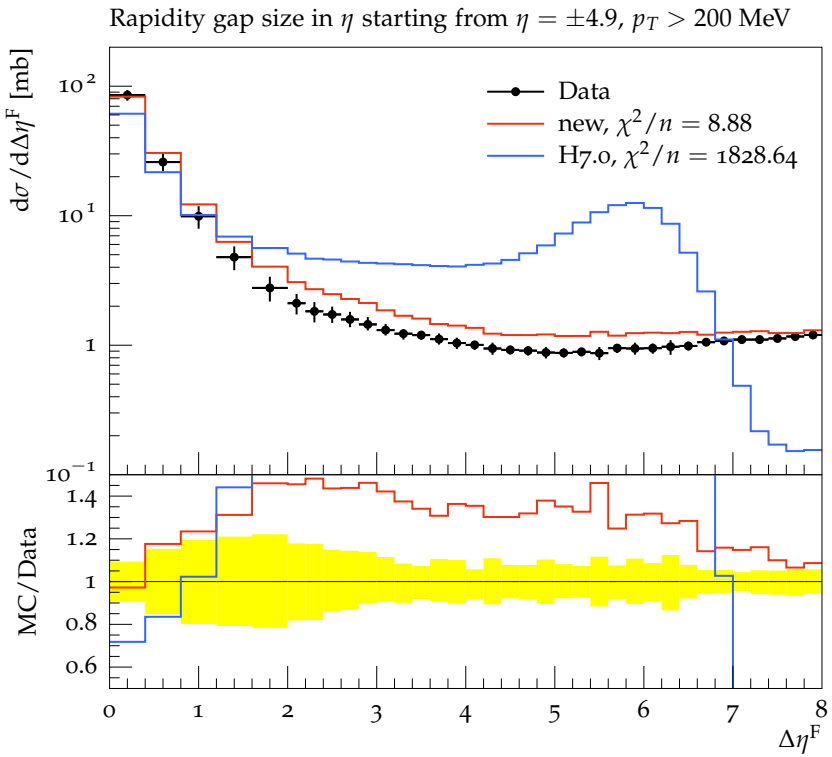
- New model for soft mpi + modeling of diffraction
  $\rightarrow$ able to cover a lot of aspects of MB analyses



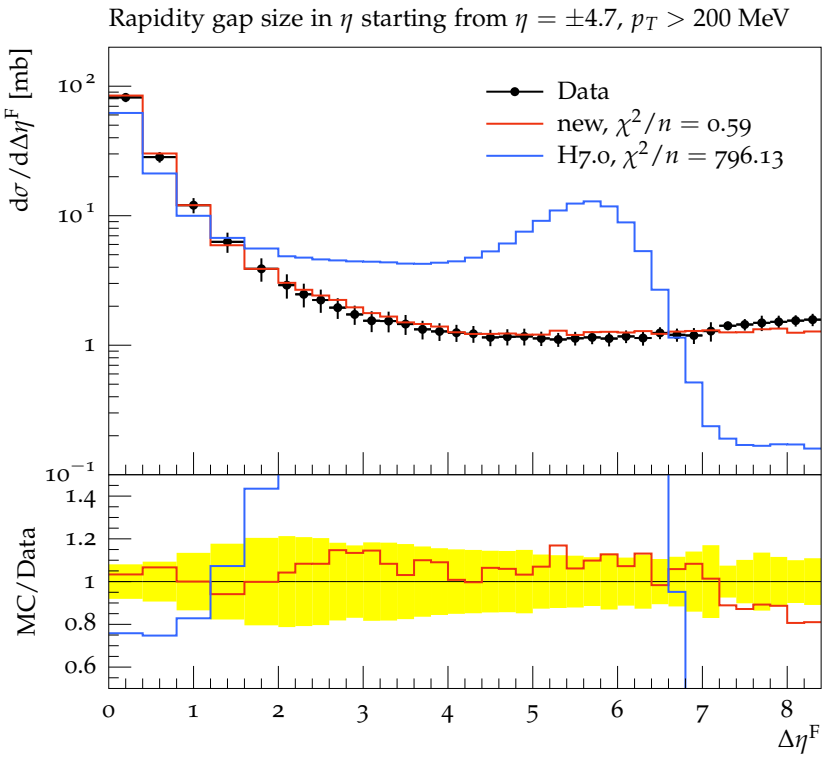


Results - rapidity gap

- Satisfying description of ATLAS and CMS data
- No model for diffraction in Herwig 7.0!



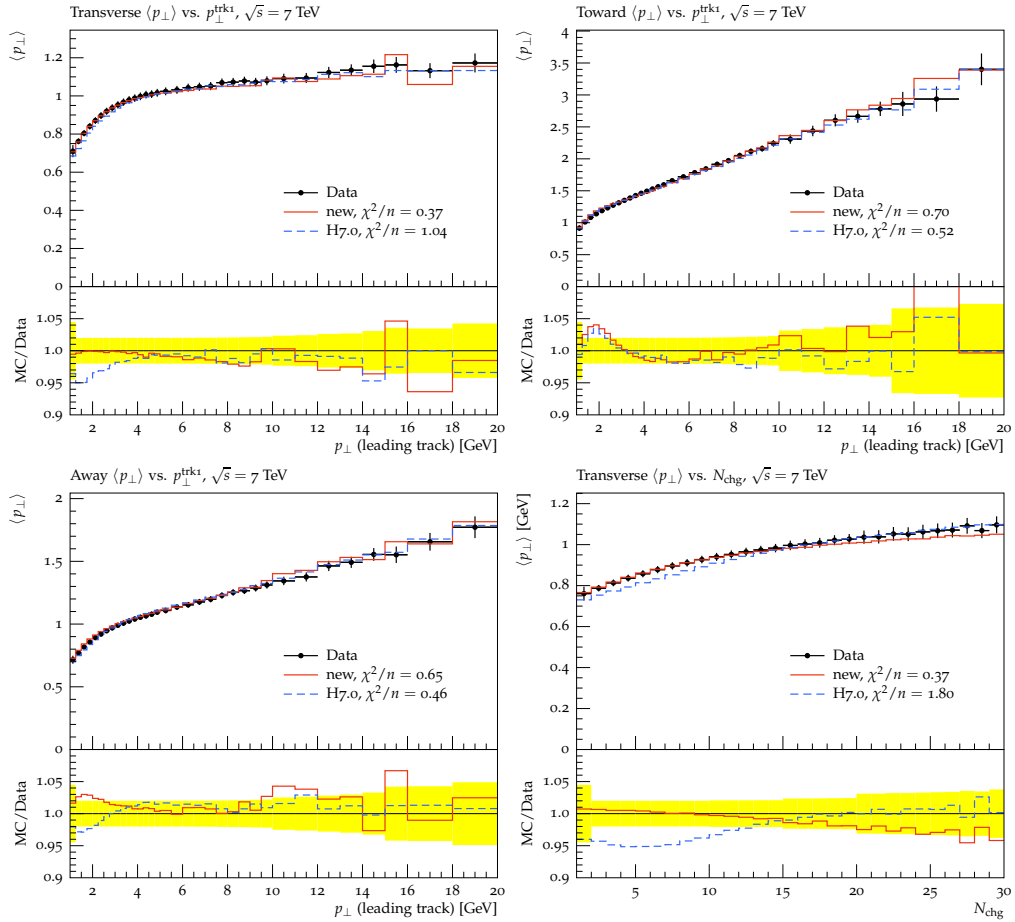
ATLAS [Eur.Phys.J. C72 (2012) 1926]



CMS [Phys.Rev. D92 (2015) no.1, 012003]

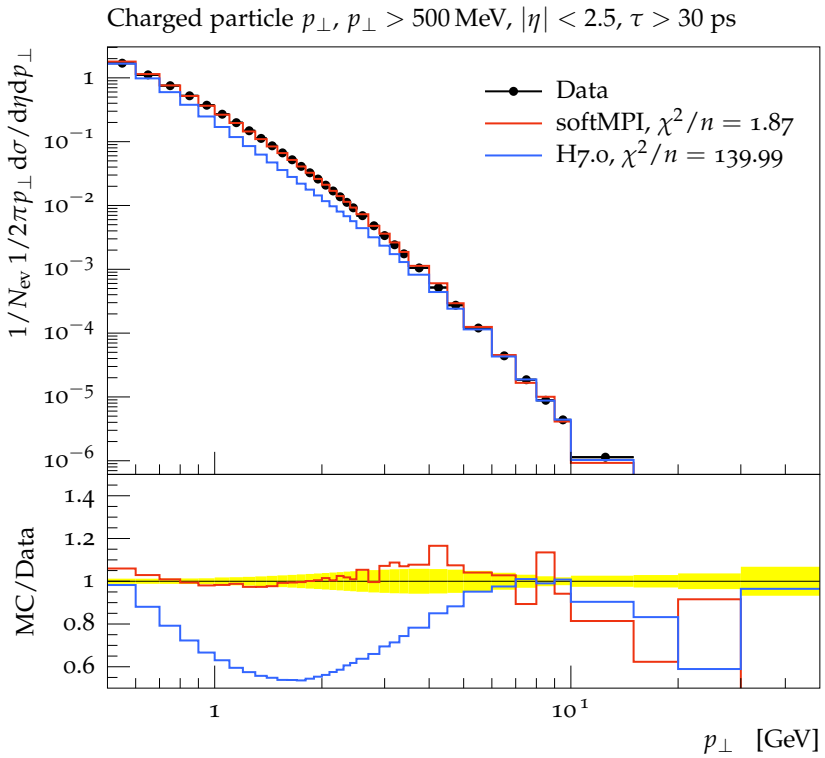
Underlying event

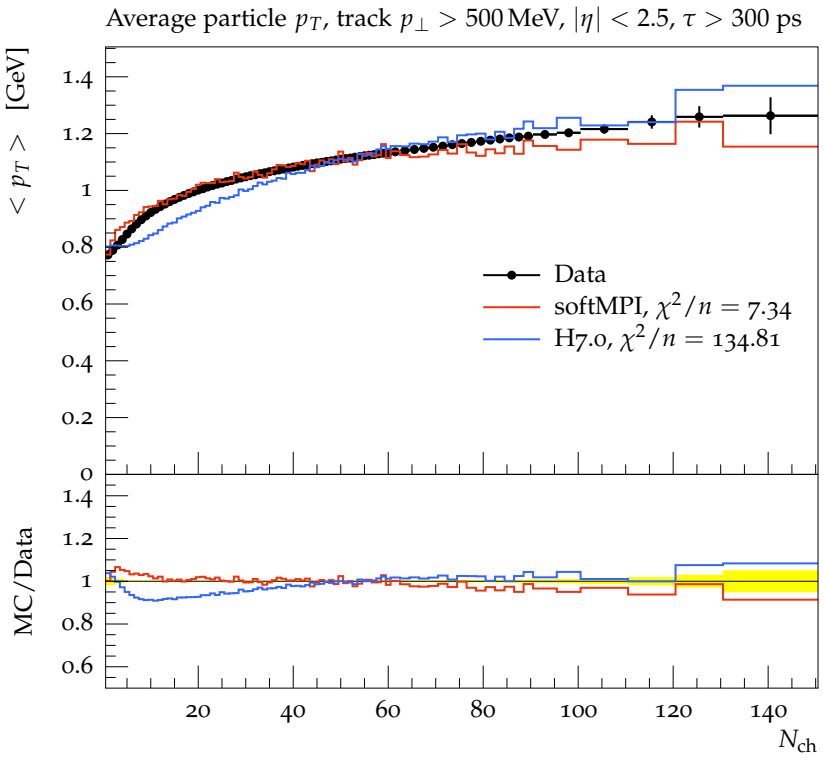
- Look at activity in transverse, toward and away region



Observables at 13 TeV

- ATLAS: [Physics Letters B (2016), Vol. 758, pp. 67-88]

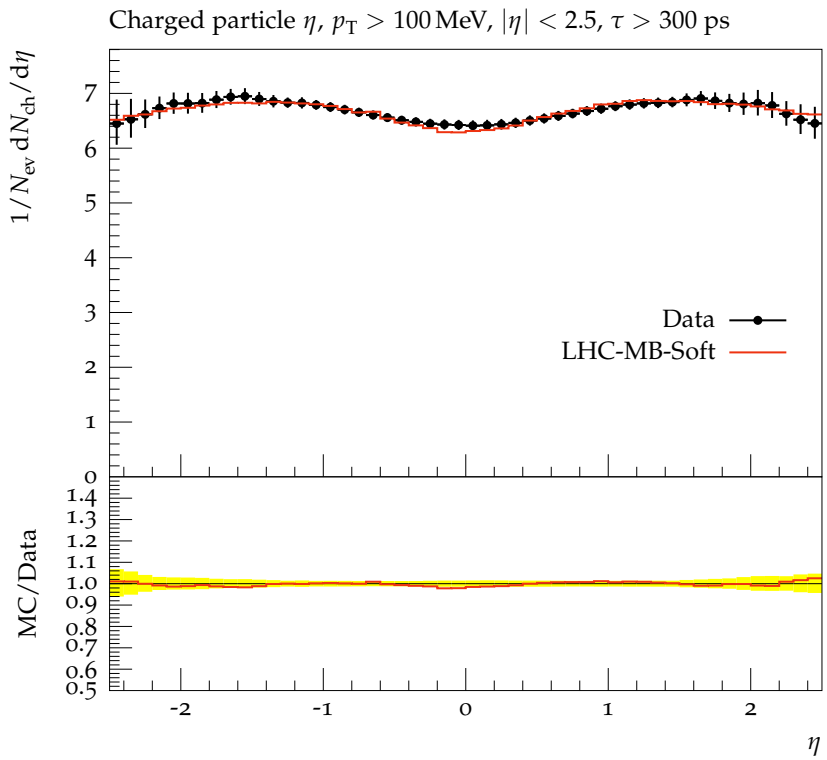


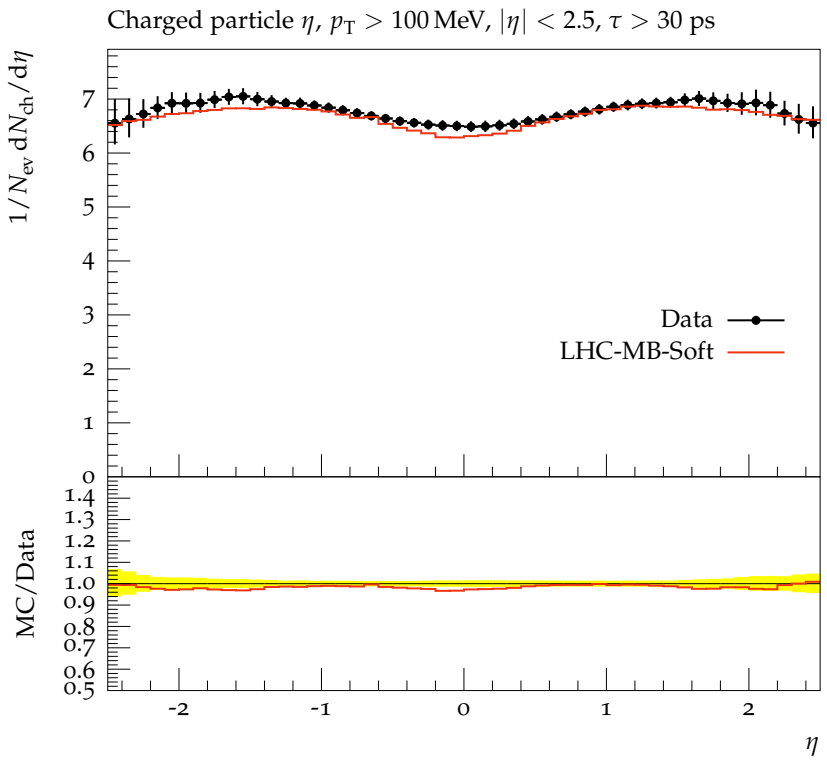


- Need more 13 TeV MB/UE analyses!
- Energy independent description reasonable?

Some more recent analyses

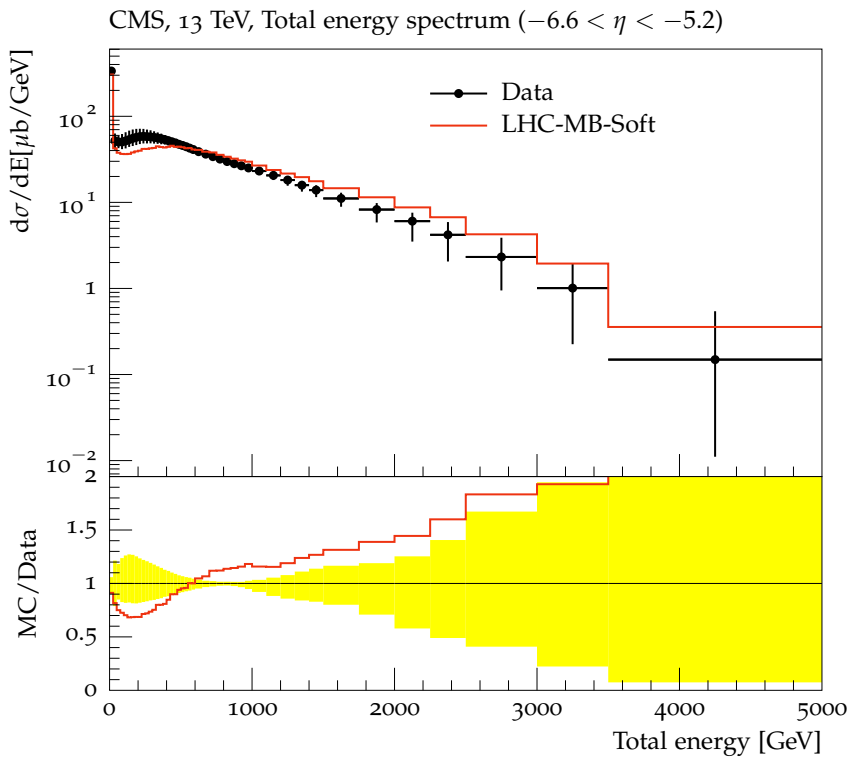
- ATLAS: [Eur.Phys.J. C76 (2016) no.9, 502]

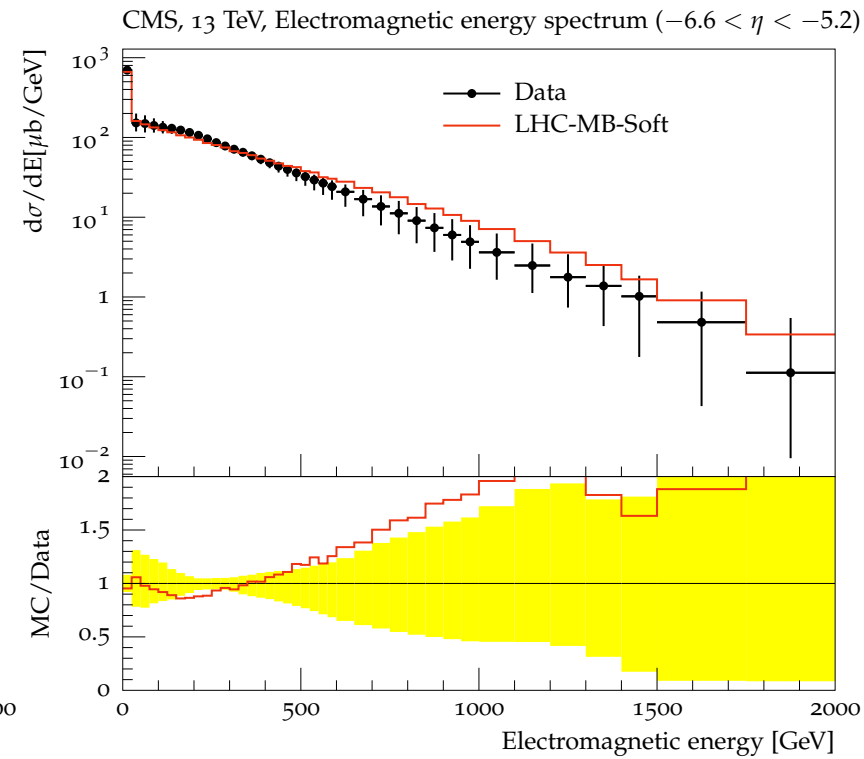




Some more recent analyses

- CMS/CASTOR: [1701.08695]



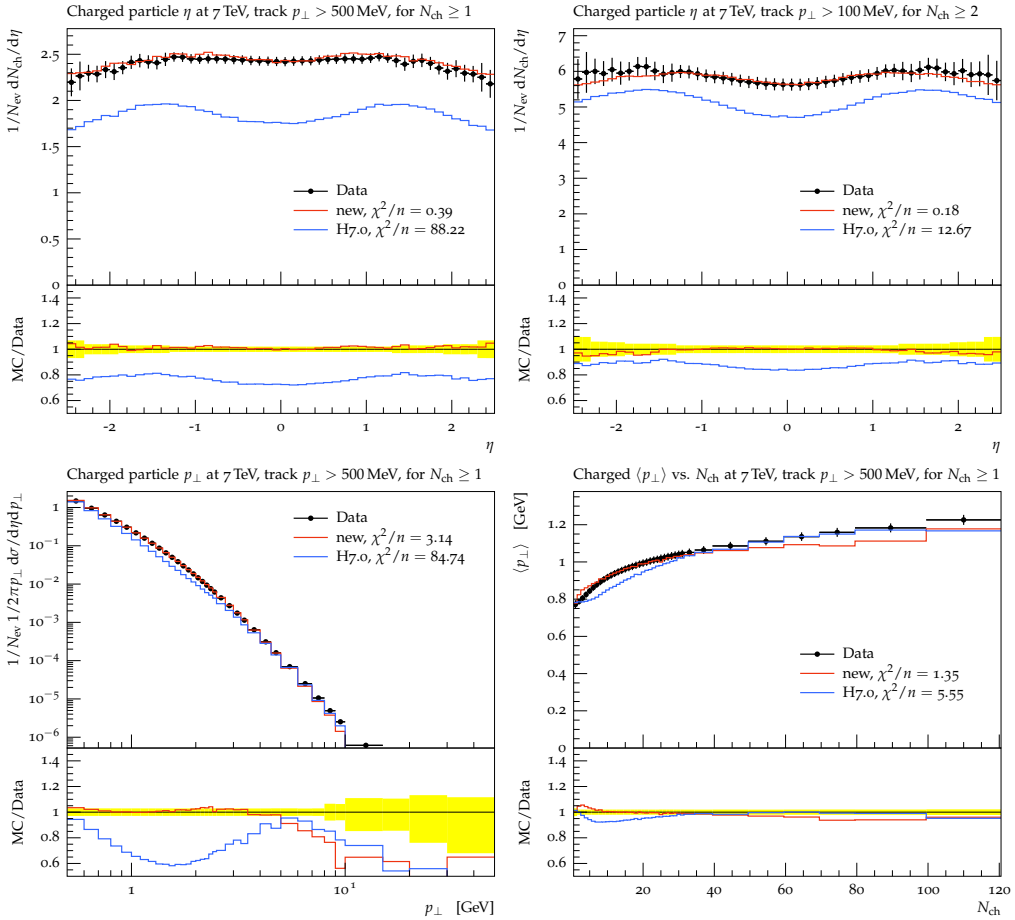


Summary and outlook

- New model for soft MPI and diffraction
- New default with Herwig 7.1 (was released in May)
  [Herwig 7.1 Release Note, J. Bellm. et al., 1705.06919]
- General improvement of all observables considered
- Just started development in this regime of physics
- Many construction sites (e.g central diffraction, more sophisticated ladder dynamics, no correlations inside the ladder, some observables not yet well described)
- Many todos $\rightarrow$ exciting next years
- More details in [Gieseke, PK, Loshaj Eur. Phys. J. C (2017)]

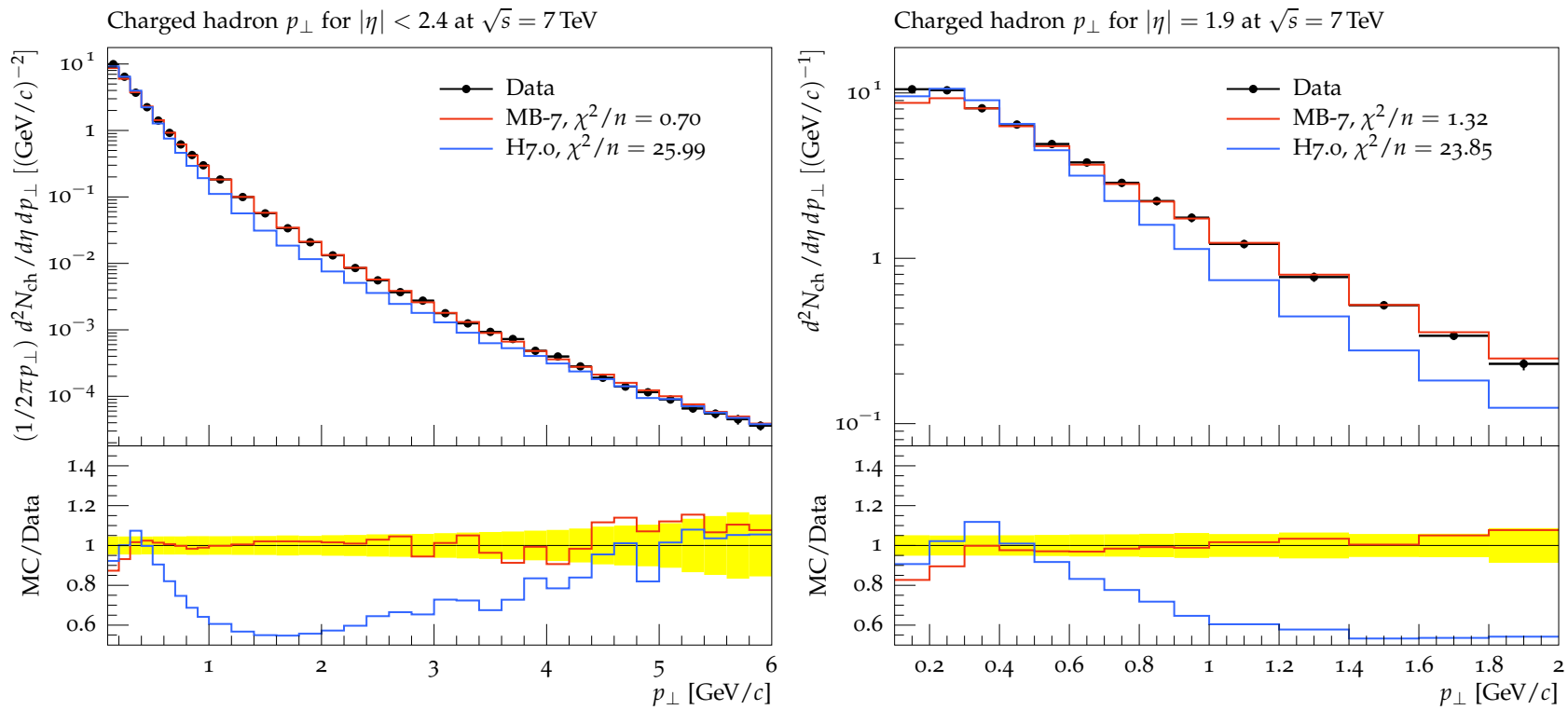
Backup

Minimum bias



Non-single-diffractive analyses

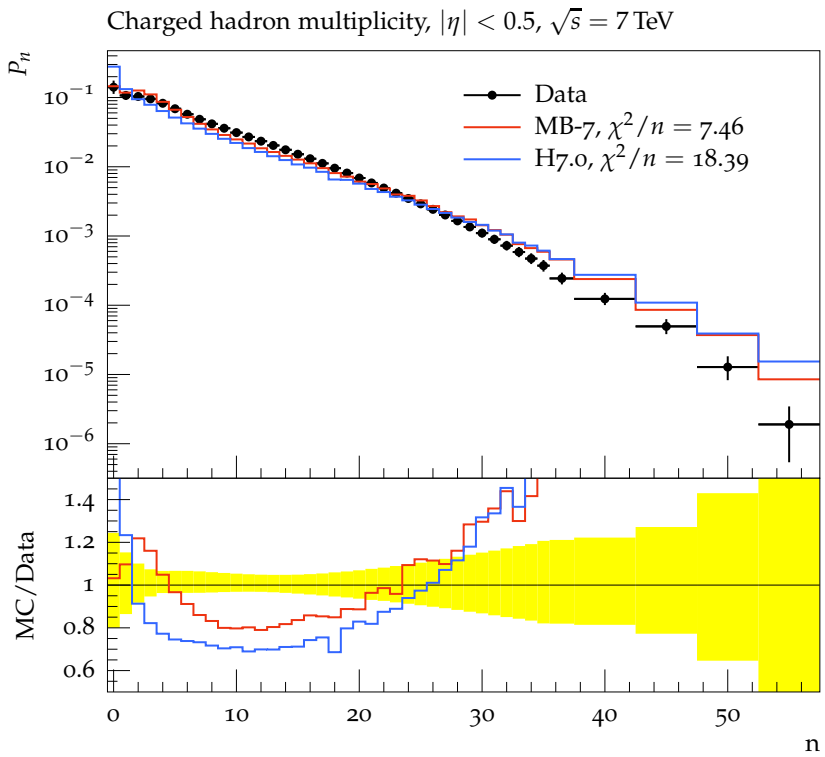
- CMS: [**Phys.Rev.Lett.105:022002,2010**]

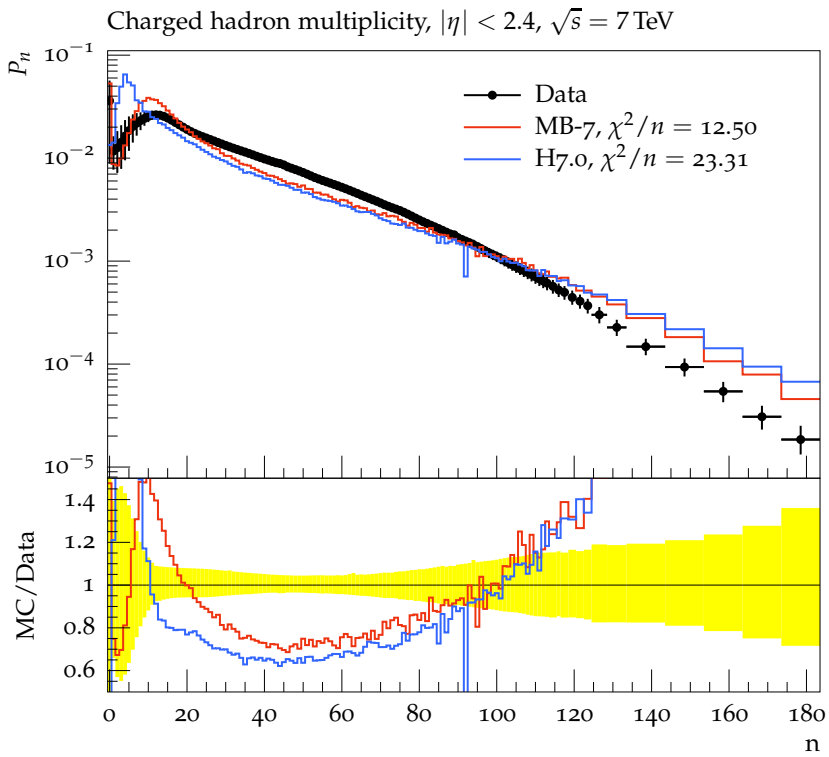


- Overall good description.
- For transverse momenta $p_\perp < 0.3\,\text{GeV}$ difficult

Non-single-diffractive analyses

- CMS: [**J. High Energy Phys. 01 (2011) 079**]





- Overestimation of the high *n* region

Backup