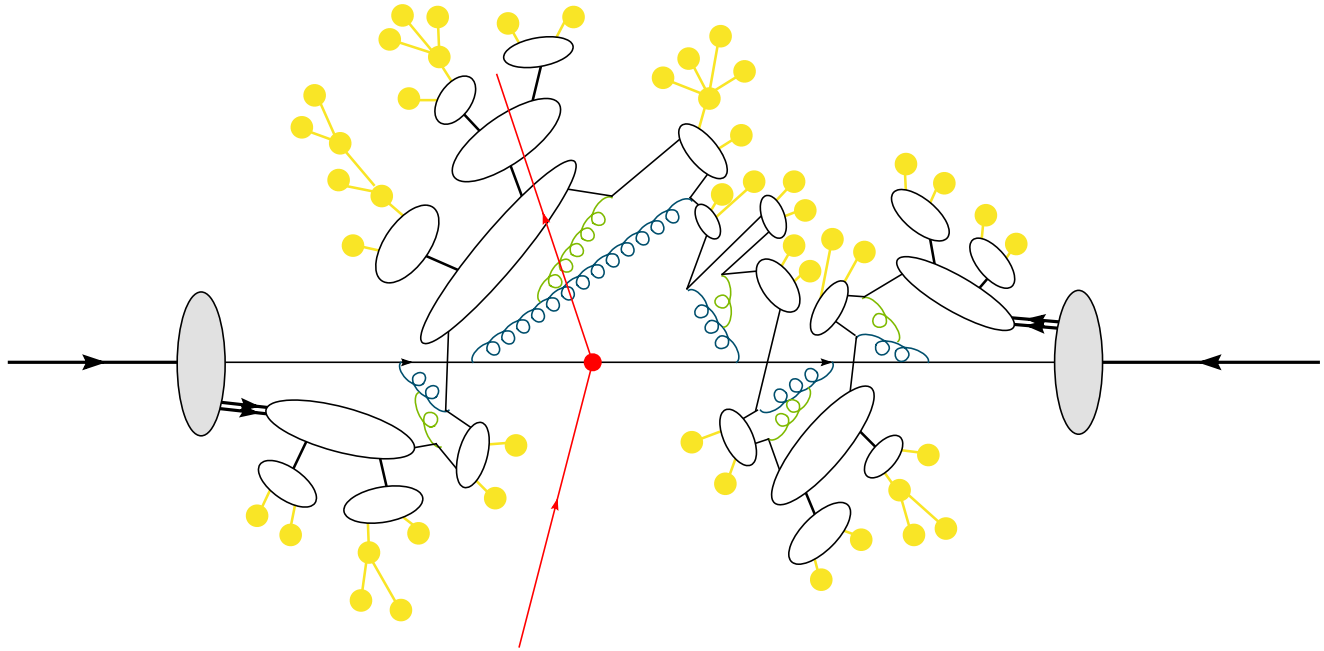
A new model for soft interactions in Herwig

Patrick Kirchgaeßer
(with Stefan Gieseke and Frashër Loshaj)

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

A typical pp collision from Herwigs point of view



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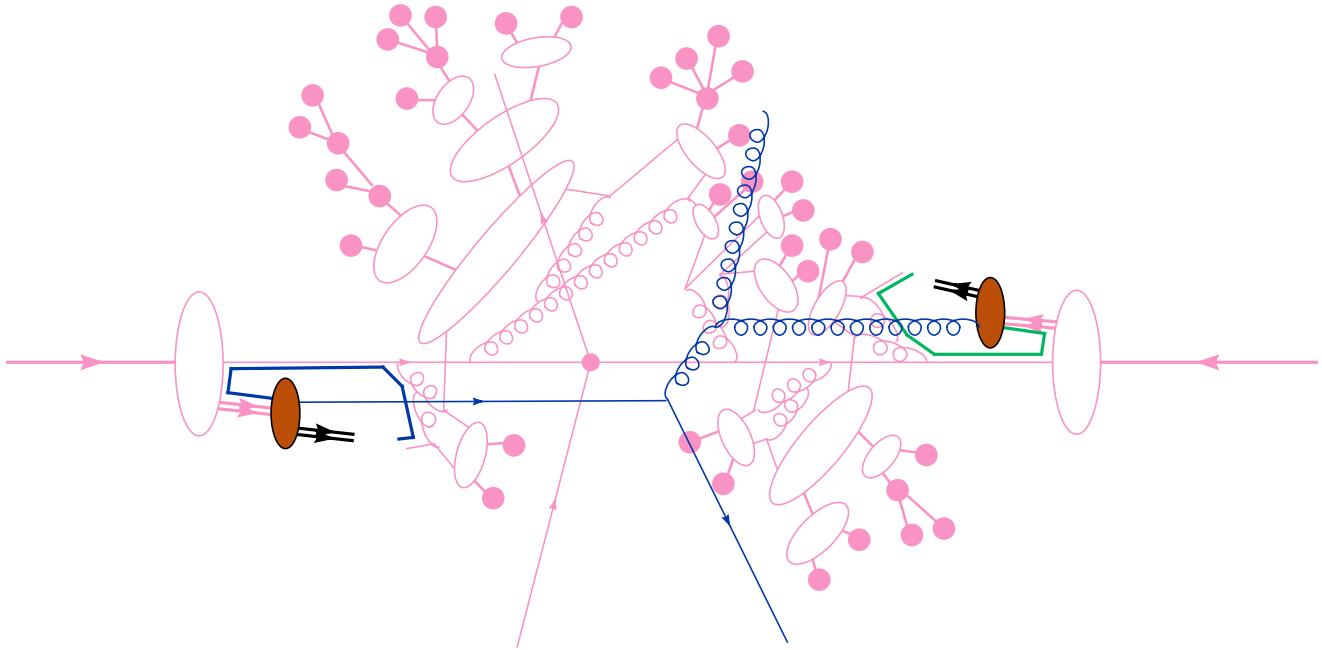

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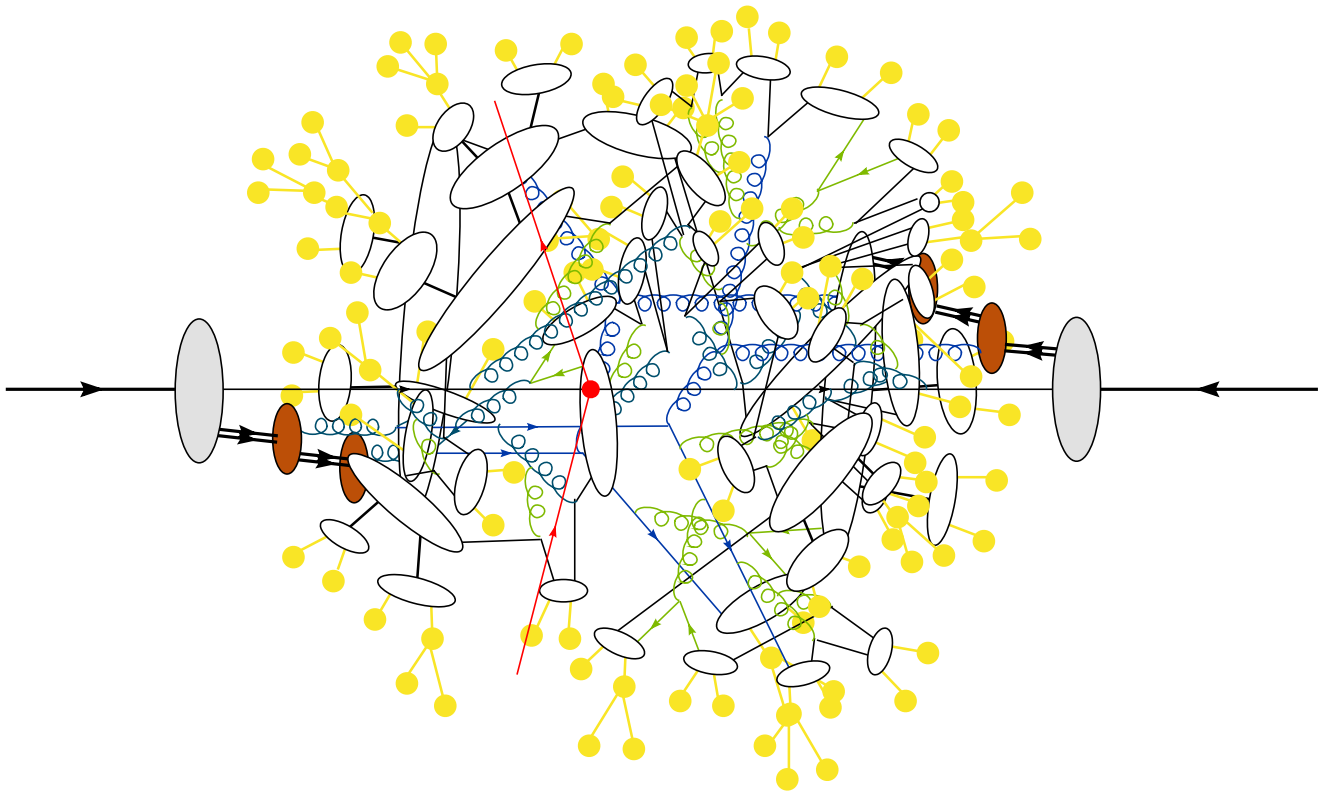


Multiple parton interactions - a bit of history

- Default from Herwig++ 2.1
- Differenciate between perturbative and non-perturbative regime with a parameter $p_\perp^{\min}$ (tunable)
- Interactions above $p_\perp^{\min}$ simulated as QCD $2 \to 2$ processes (*semi-hard* interactions). [Bähr, Gieseke, Seymour, JHEP 0807:076]
- Interactions below $p_\perp^{\min}$ modelled as an elastic scattering among gluons (*soft* interactions).[Bähr, Butterworth, Seymour, JHEP 0901:065] [Bähr, Butterworth, Gieseke, Seymour, 0905.4671]
- Achieved good description of underlying event measurements
- Not meant to describe full minimum bias (no model for diffraction)

Multiple parton interactions

- In Herwig based on the eikonal model

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

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

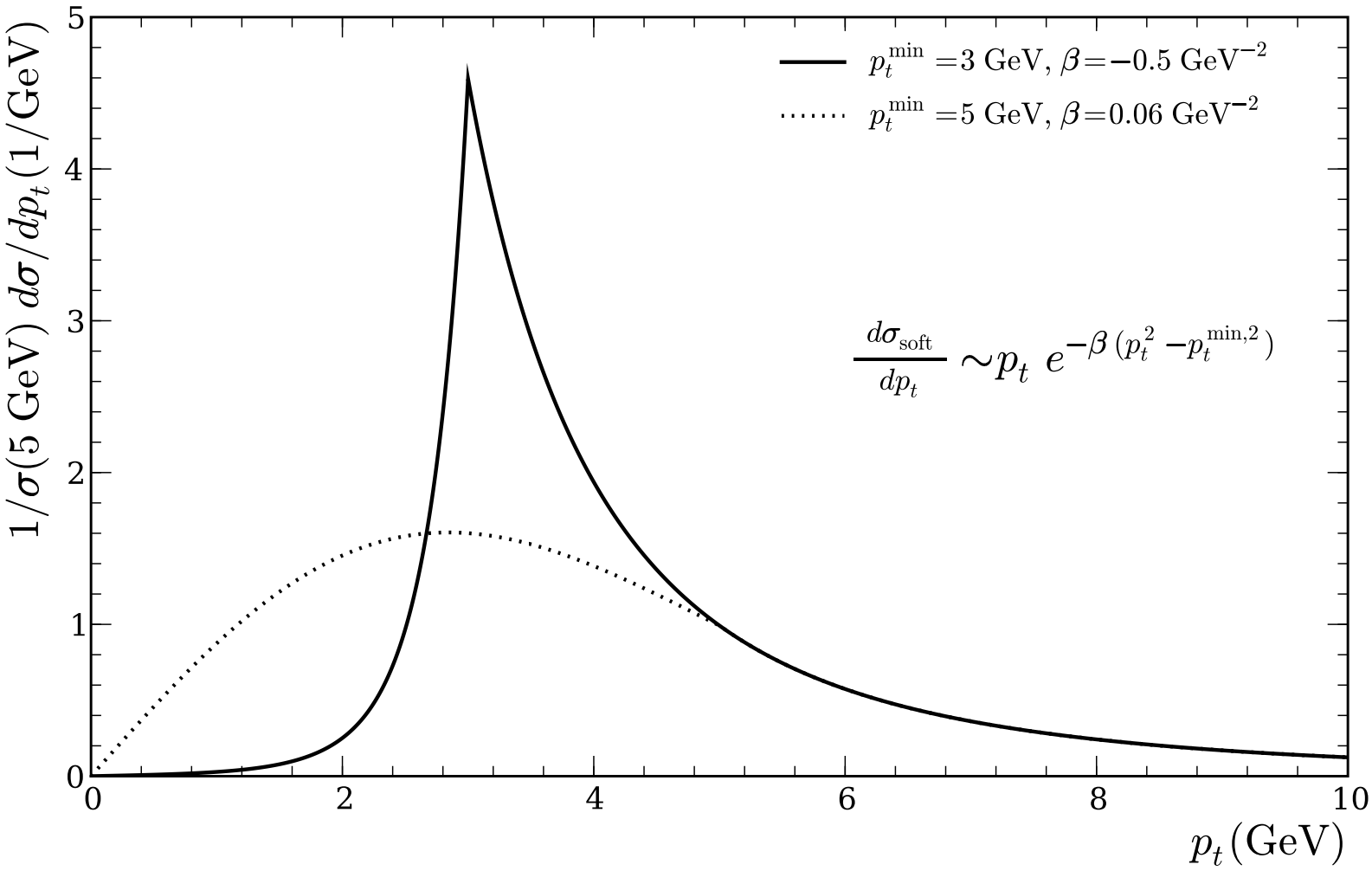
- Parameters of the soft model fixed to describe σ_{tot} and b_{el}
- $p_\perp$ sampled from a distribution that is parametrized with a Gaussian distribution

$$\frac{\mathrm{d}\sigma^{\text{inc}}_{\text{soft}}}{\mathrm{d}p_\perp} = Ae^{-\beta p^2_\perp}$$

- Then simulate h semi-hard interactions and n soft interactions

Sampling of transverse momentum

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

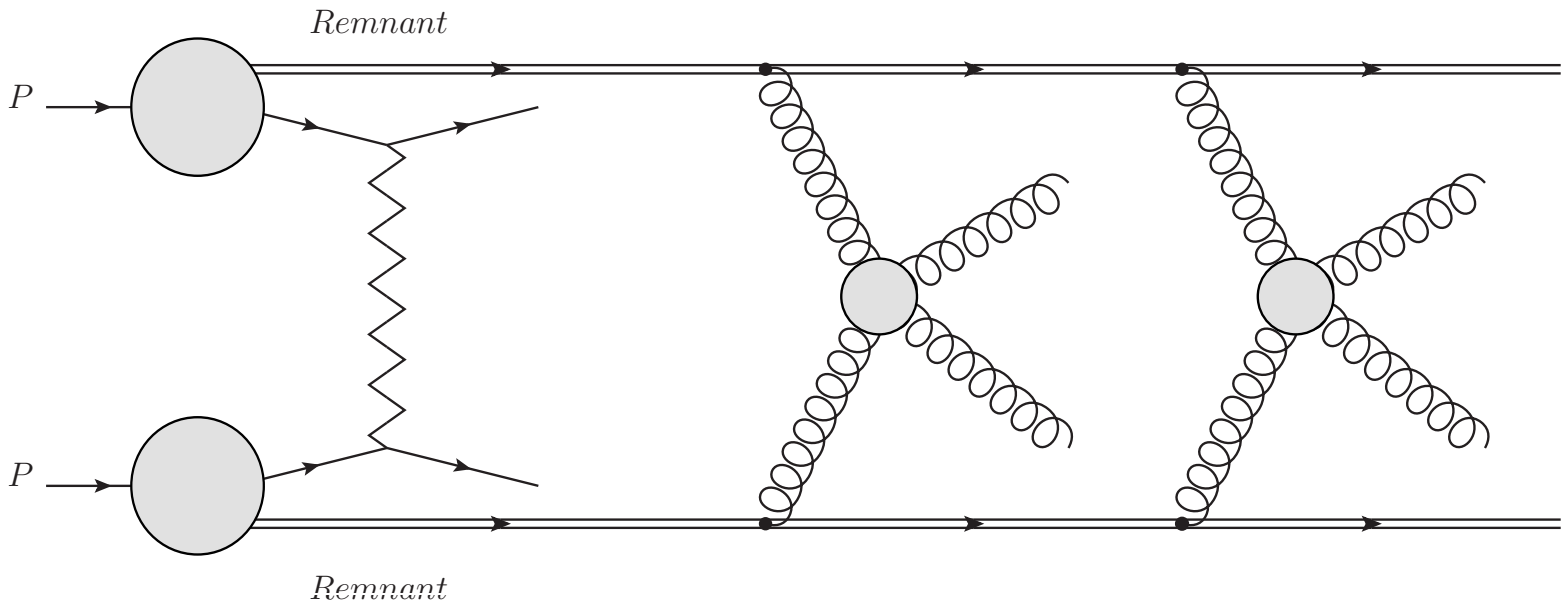


Soft interactions (old model)

- Number of soft interactions, N_{soft}, calculated in order to describe

$$\sigma_{\text{tot}} = \sigma_{\text{hard}} + \sigma_{\text{soft}} + (\sigma_{\text{diffraction}})$$

- Modelled as elastic $2 \to 2$ gluon scattering with $p_\perp < p_\perp^{\text{min}}$



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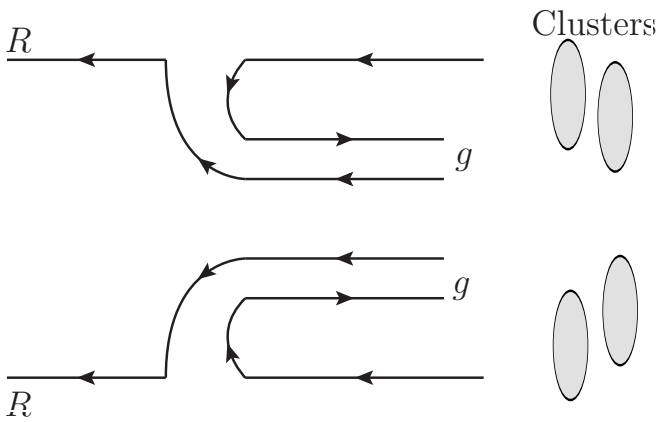
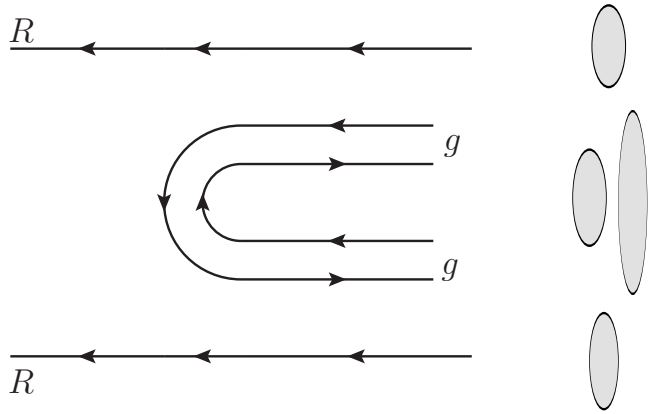
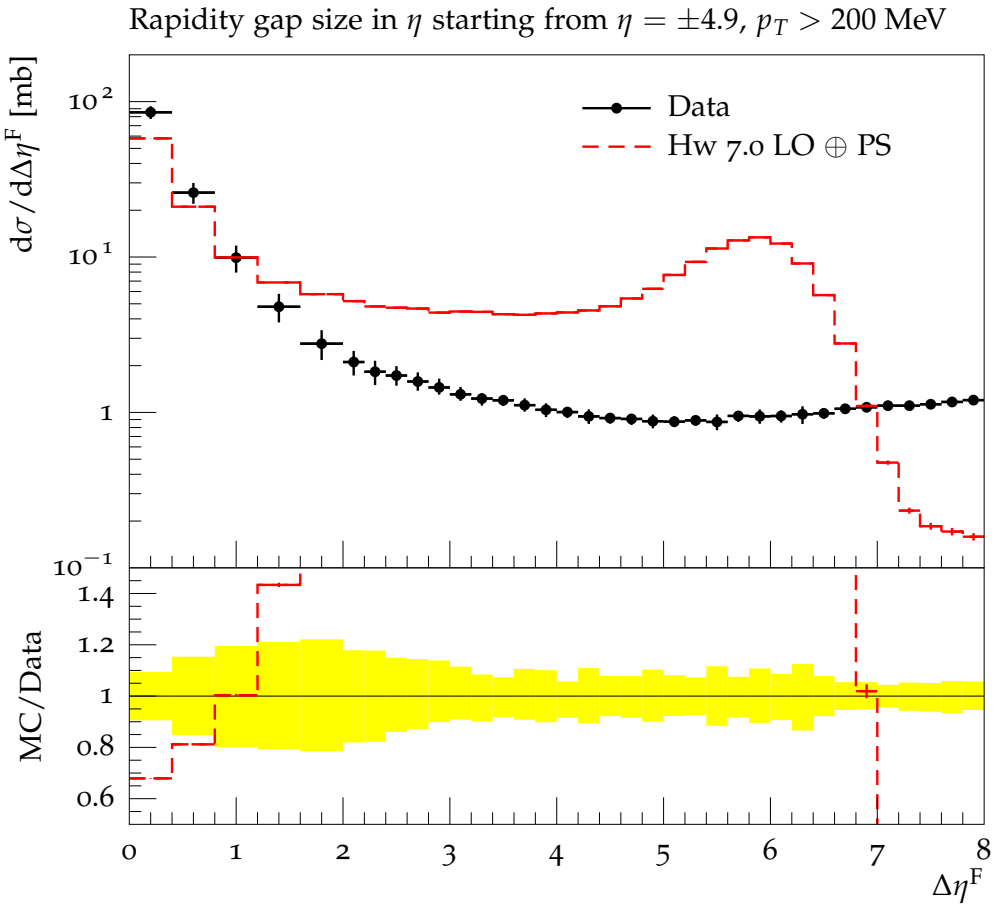
- Arbitrary colour connections between the gluons and the remnants $\to$ artificial events with large rapidity gaps





The “Bump” problem

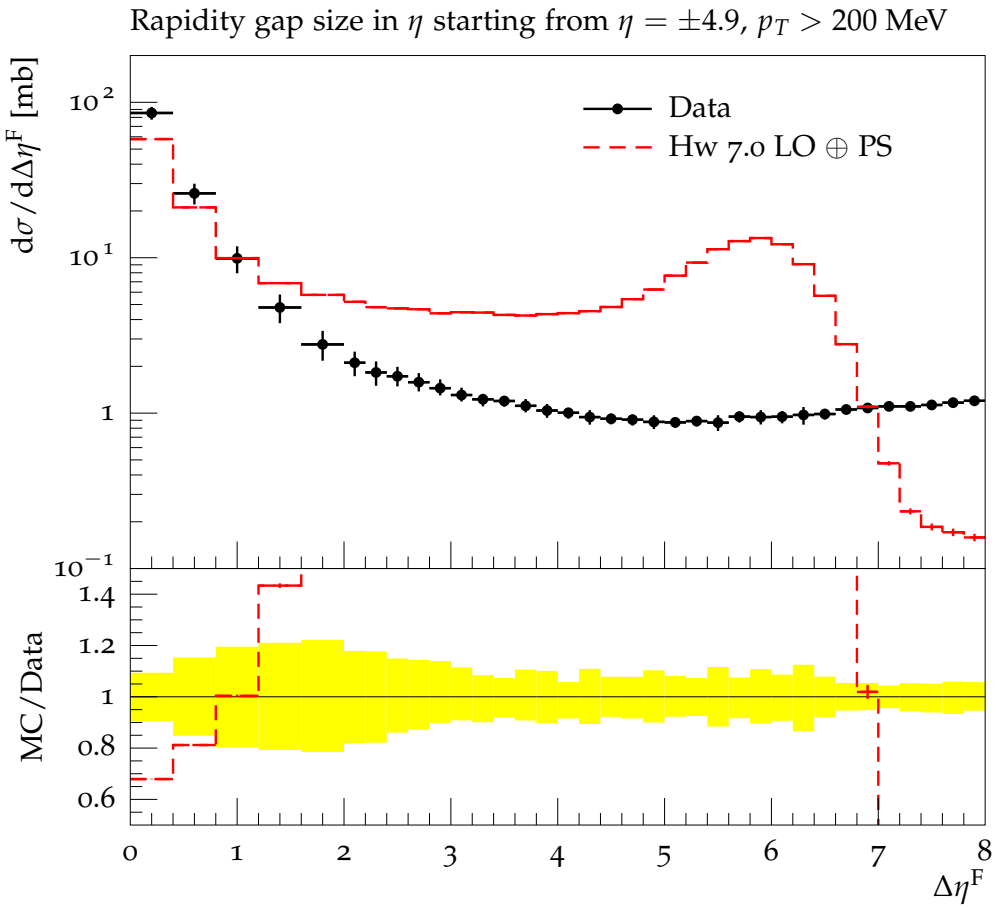
- Rapidity gap: $\Delta\eta^F$ is defined as the larger of two pseudorapidity regions without any hadronic activity
- Without diffraction: expect $\sim exp(-a\Delta\eta^F)$, extreme sensitive to colour connections in the soft model



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

The “Bump” problem

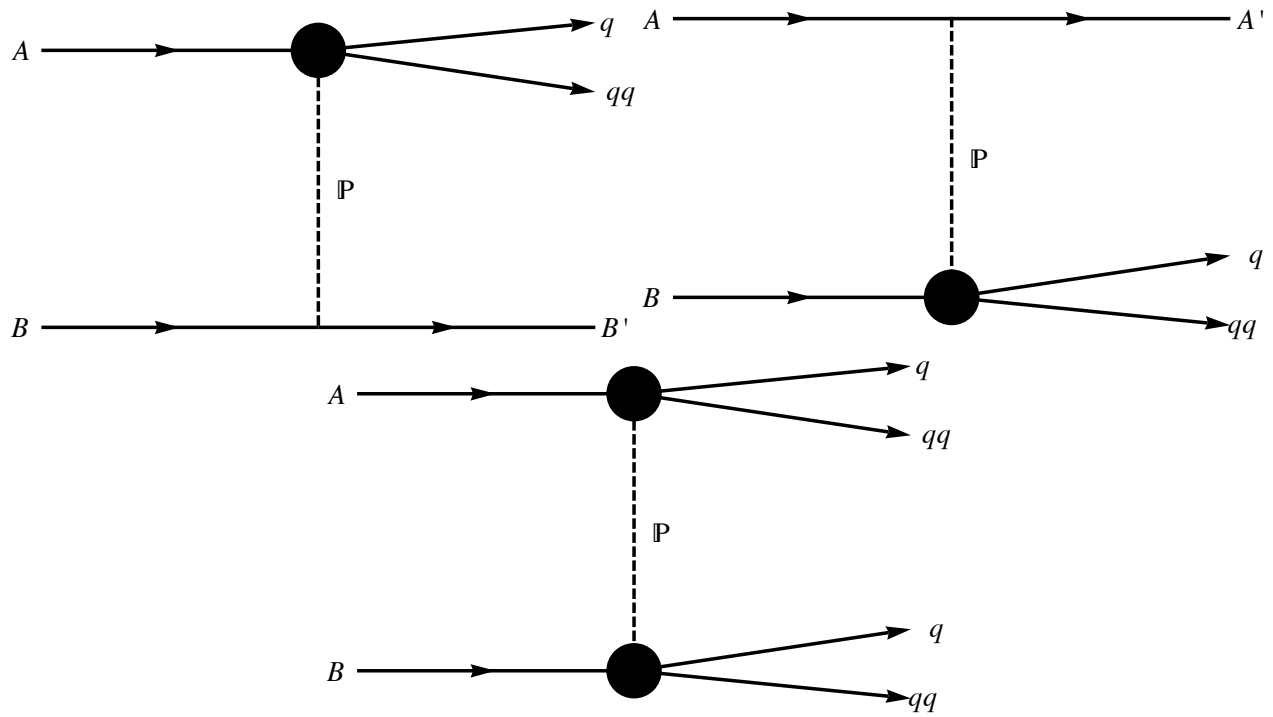
- Need model for diffractive events!
- Revised model for soft interactions!



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

Model for soft diffraction

- Implemented for soft diffraction 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!

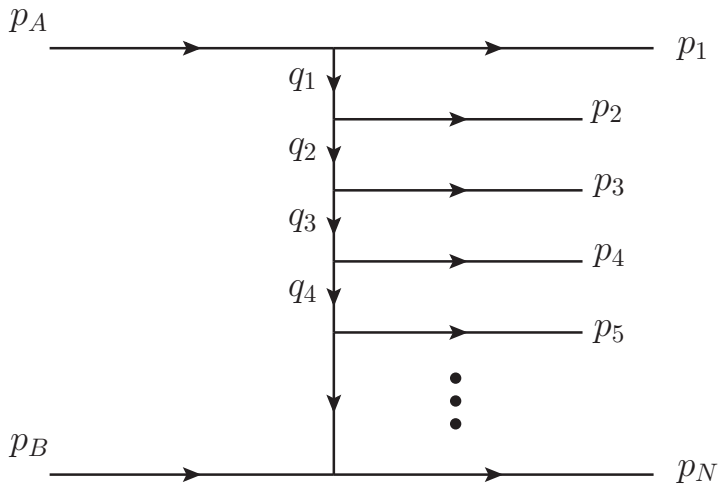
New model for soft interactions

- Two constraints:

  i) From MB data: Distribution should be approximately uniform in rapidity

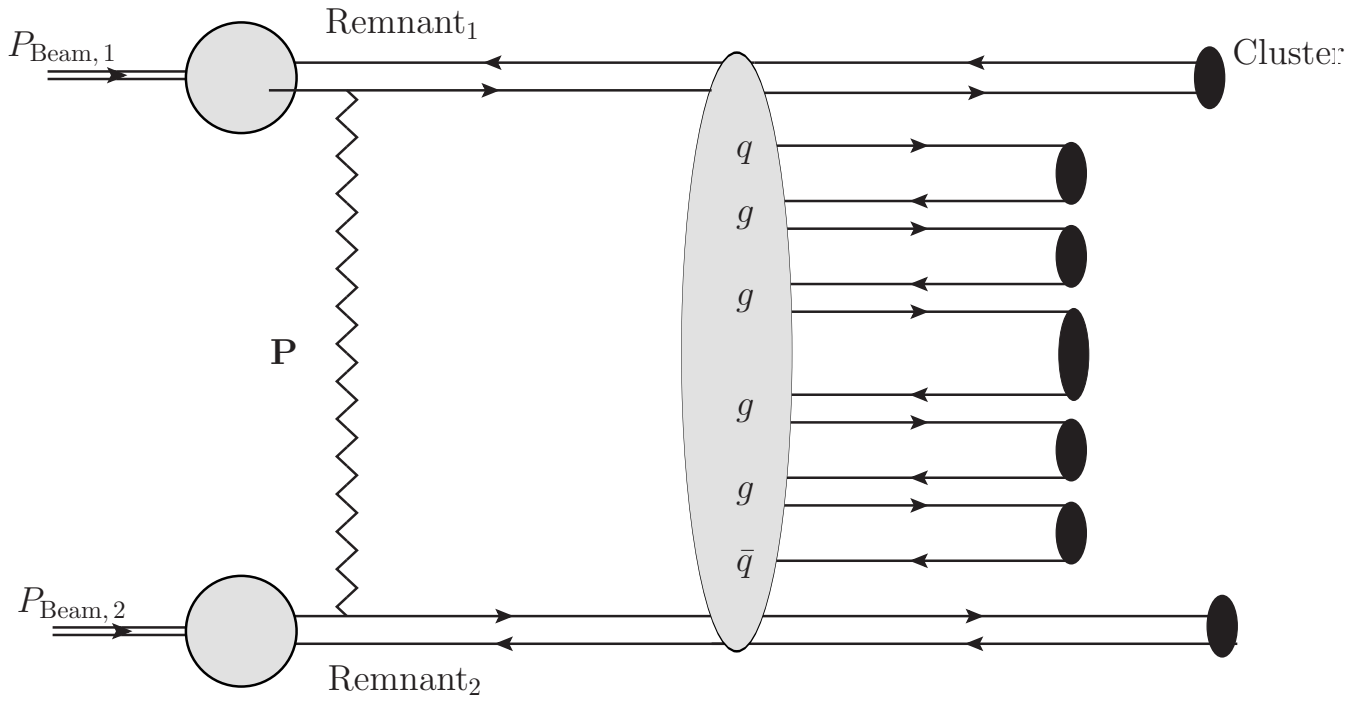
  ii) Non-diffractive part of the cross section $\sim e^{-a\Delta\eta}$
- Implemented model motivated by properties of “cut Pomerons“

  [Baker, Ter-Martirosyan, Phys.Rept. 28 (1976) 1-143]
- Idea: Number of soft interactions from MPI model = cut pomerons = particle ladders



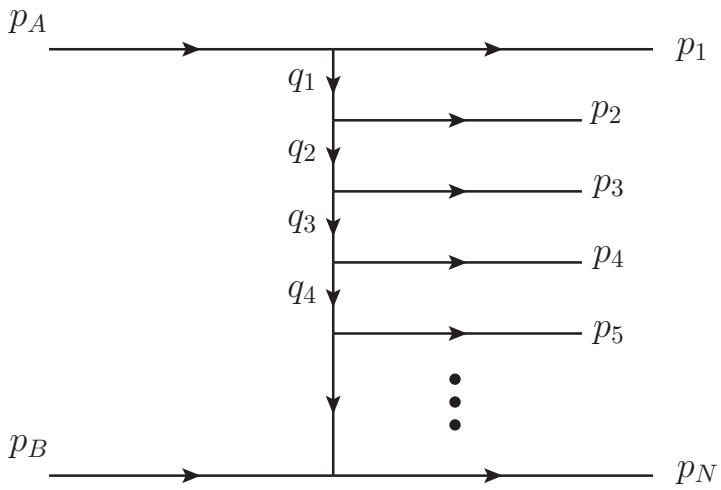
Colour connections

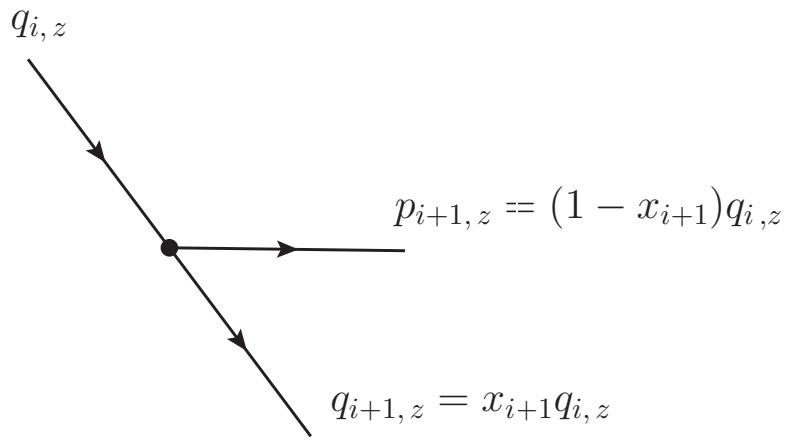
- Particles in the ladder modelled as gluons
- Emit one $q\bar{q}$ pair in order to get the correct colour connections between the neighbours



Kinematics of the multiperipheral ladder

- Kinematics generated as a splitting process of the proton remnant



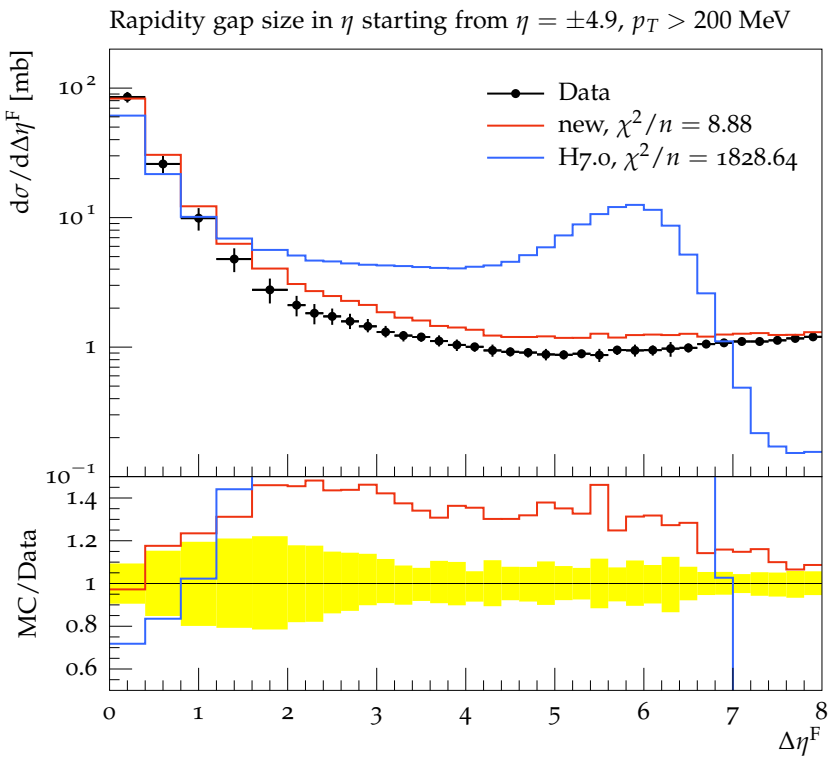


$$\langle N \rangle \simeq N_{ladder} \times \ln \frac{s}{m^2} \qquad \Delta y \sim \ln \frac{1}{x}$$

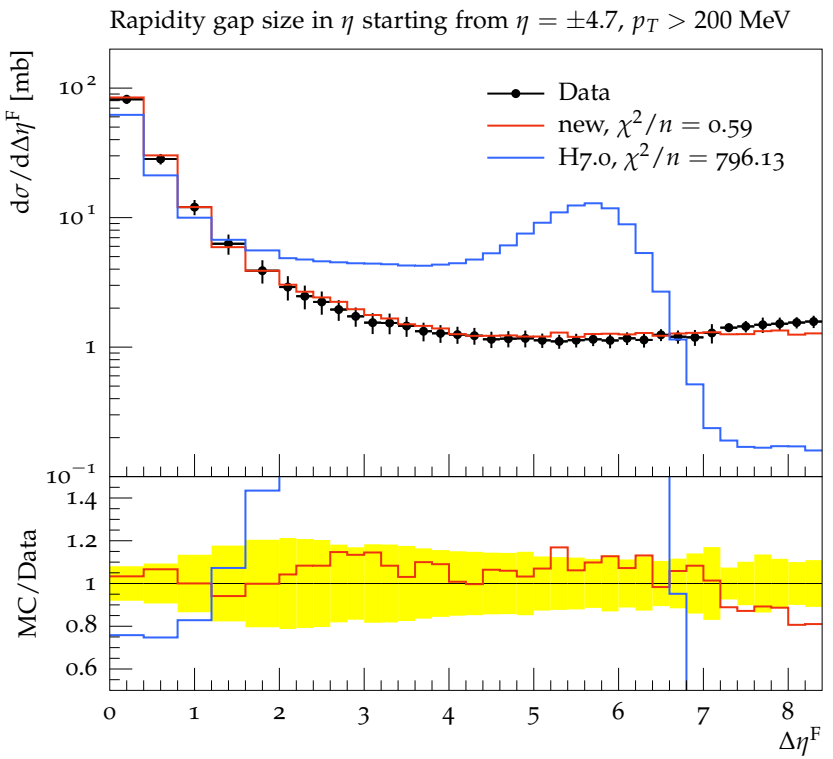
- $x_i \simeq x$ such that it gives uniform distribution in rapidity
- $N_{ladder} = N_0(\frac{s}{\mathrm{TeV}^2})^{-0.08}$ can be parametrized to follow interesting power law ($N_0 \approx 1$)

Results - rapidity gap

- Satisfying description of ATLAS and CMS data



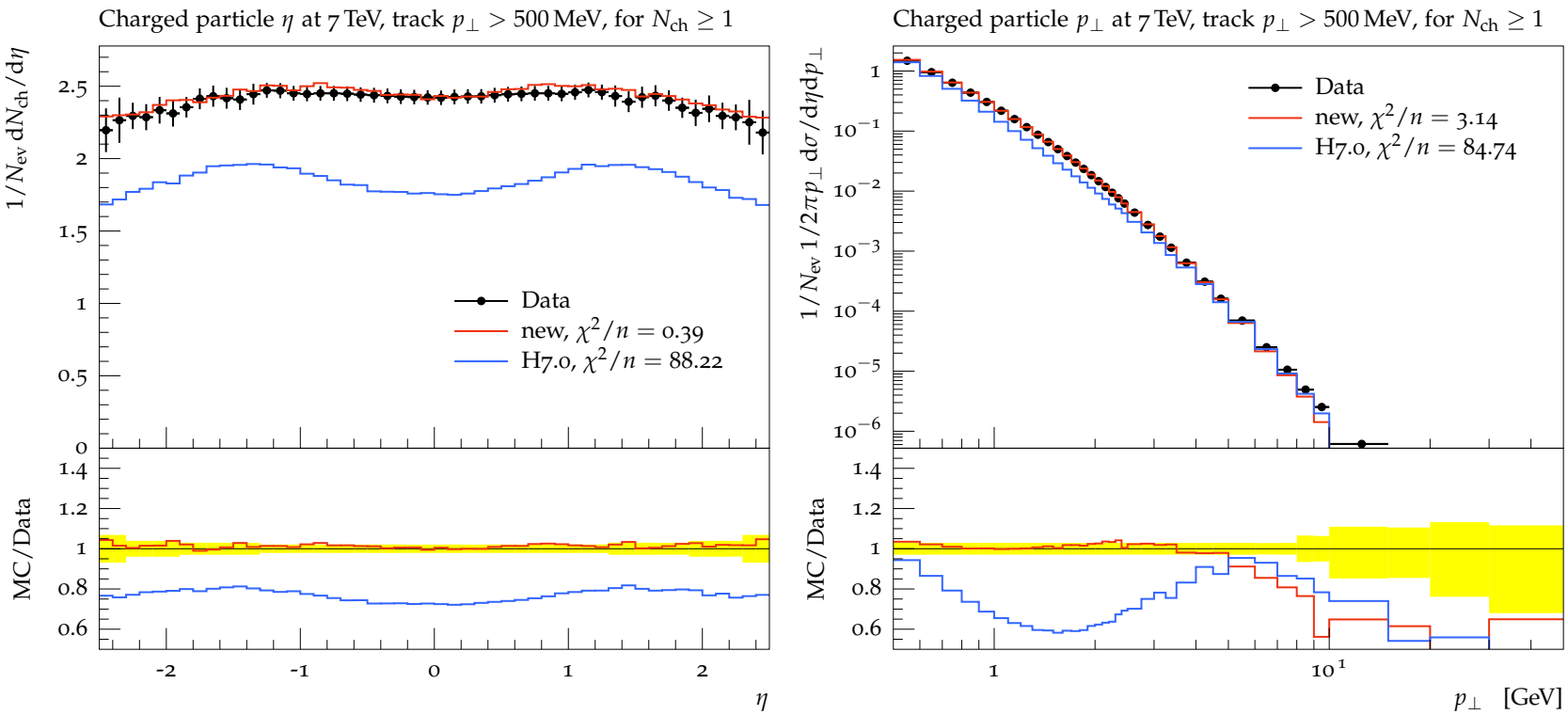
ATLAS [Eur.Phys.J. C72 (2012) 1926]



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

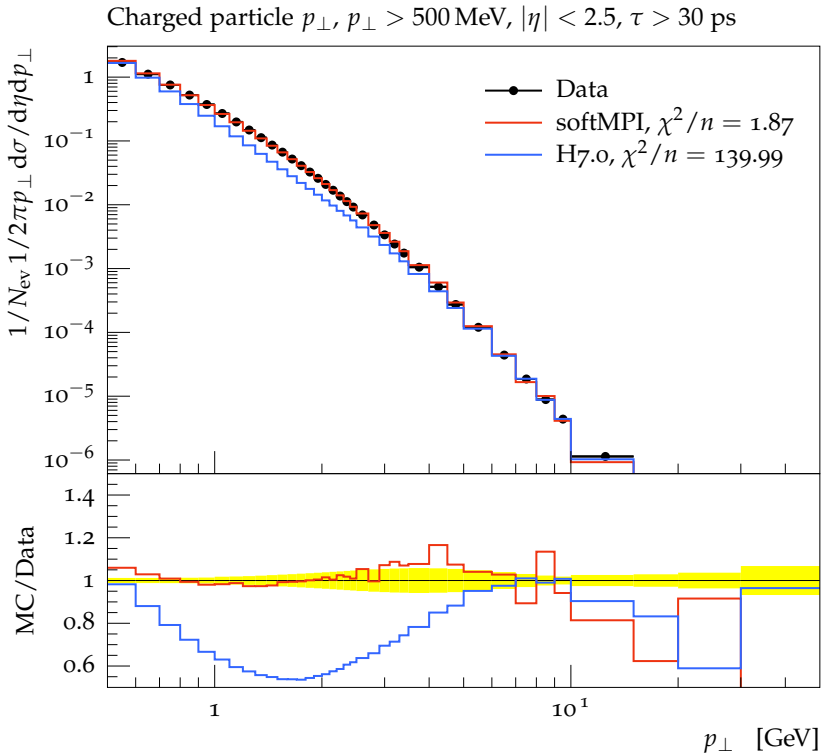
Results - minimum bias

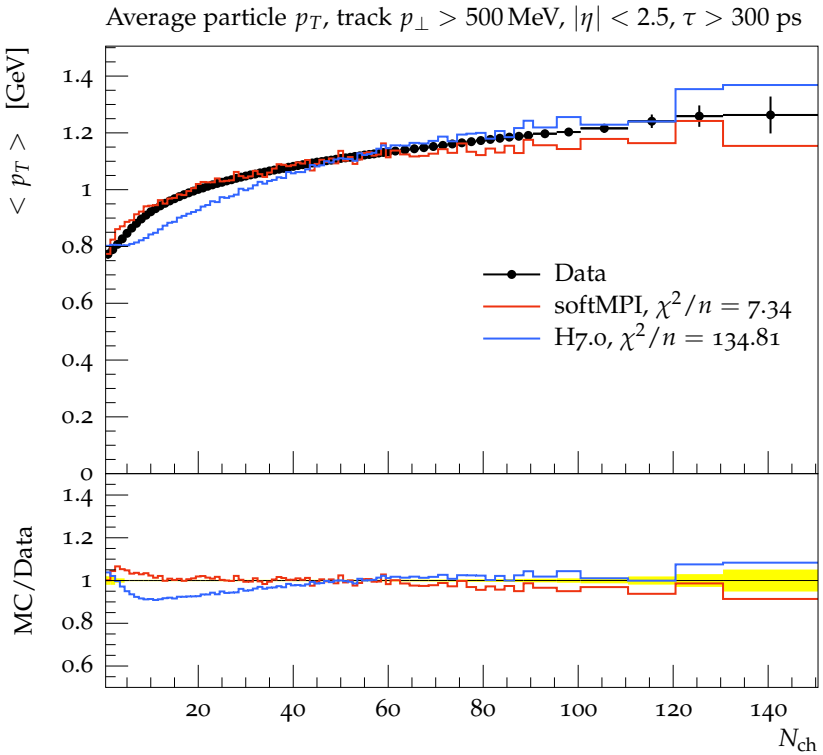
- Parameters tuned to minimum-bias (MB) data from ATLAS [New J.Phys.13:053033,2011] with PROFESSOR 2 [Eur.Phys.J. C65 (2010) 331-357]
- In combination with the model for diffraction Herwig is for the first time able to cover all aspects of MB analyses



Extrapolation to 13 TeV

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

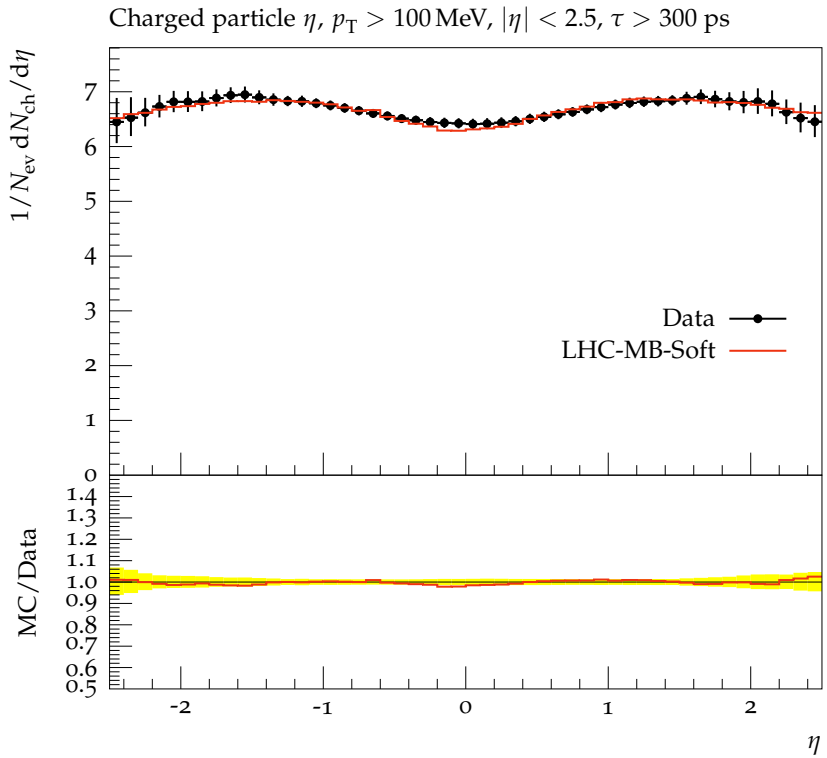


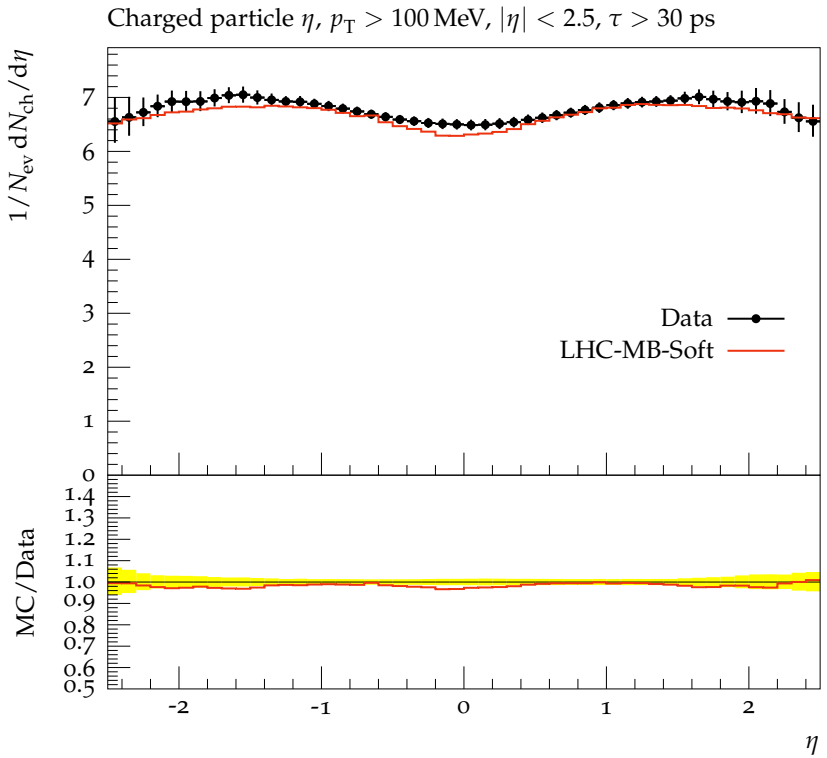


- Need more 13 TeV MB/UE analyses!
- Supports 7 TeV tune

Some more recent analyses

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



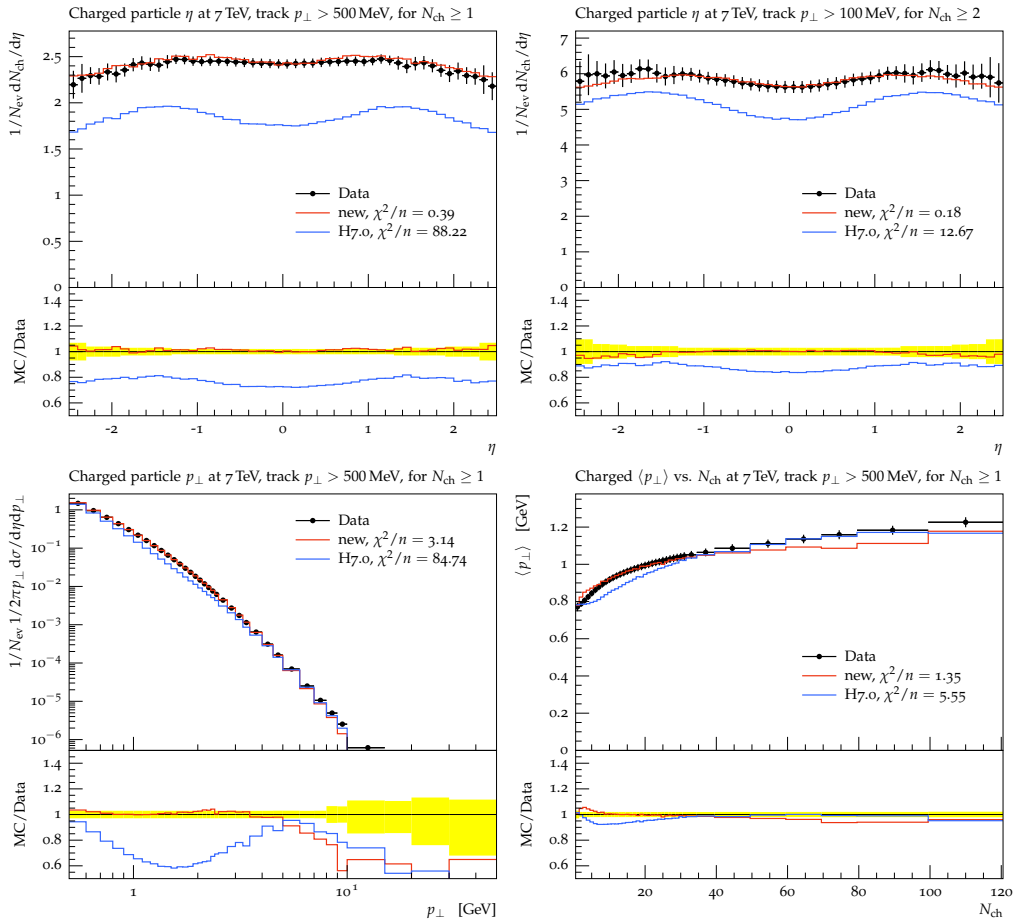


Summary and outlook

- Herwig has a new model for soft mpi and diffraction
- Default starting with the release of Herwig 7.1 (hopefully soon)
- Resolved the “bump“ problem
- General improvement of all observables considered
- Complementary to the other new features of Herwig 7.1 (see talk of Johannes Bellm)
- More details in **[Gieseke, PK, Loshaj Eur. Phys. J. C (2017)]**
- And in the release note/manual ...

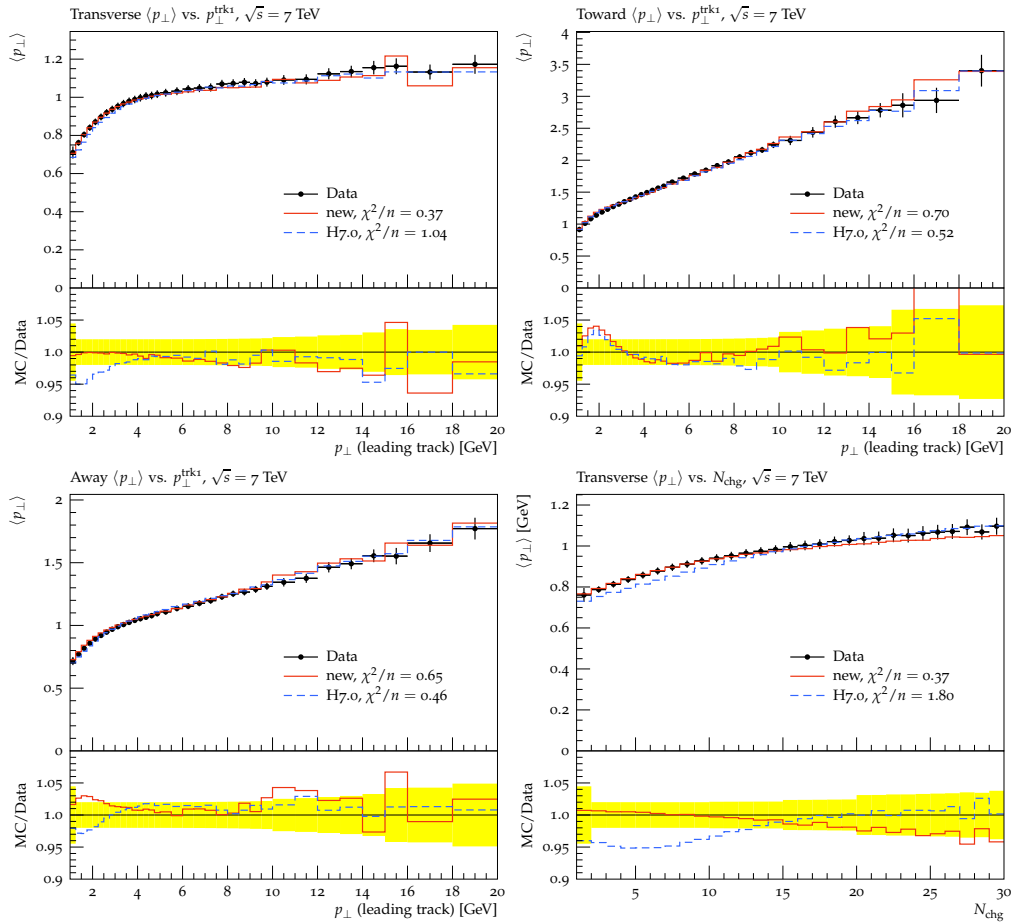
Backup

Minimum bias



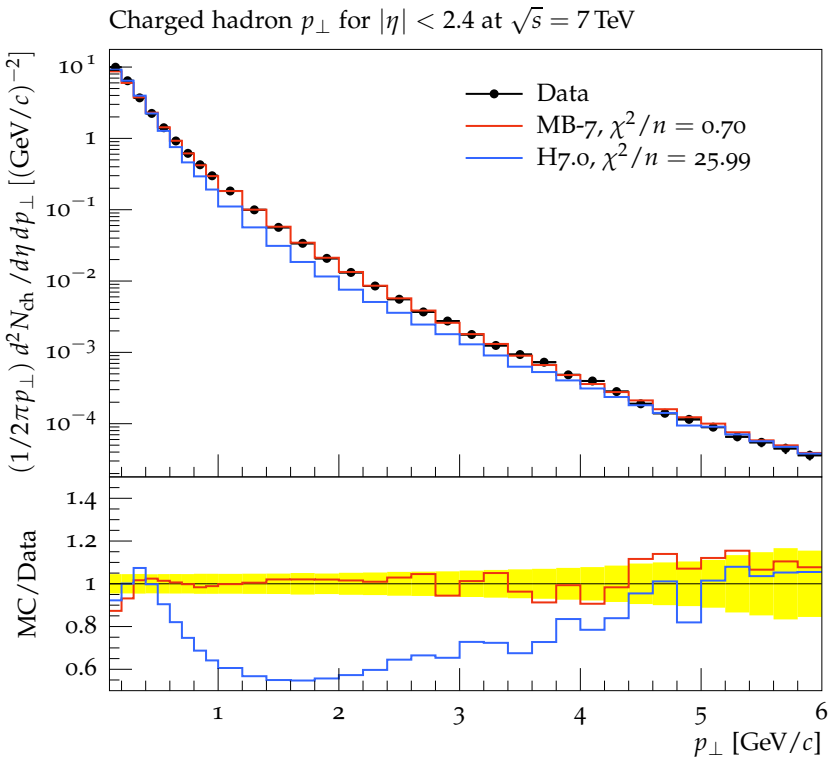
Underlying event

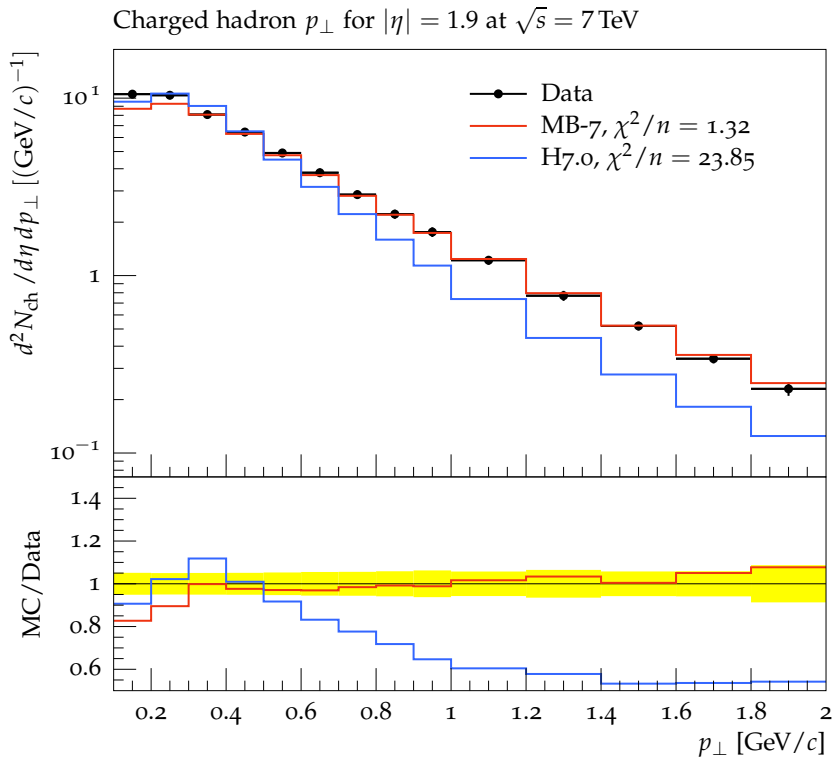
- Look at activity in transverse, toward and away region



Non-single-diffractive analyses

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

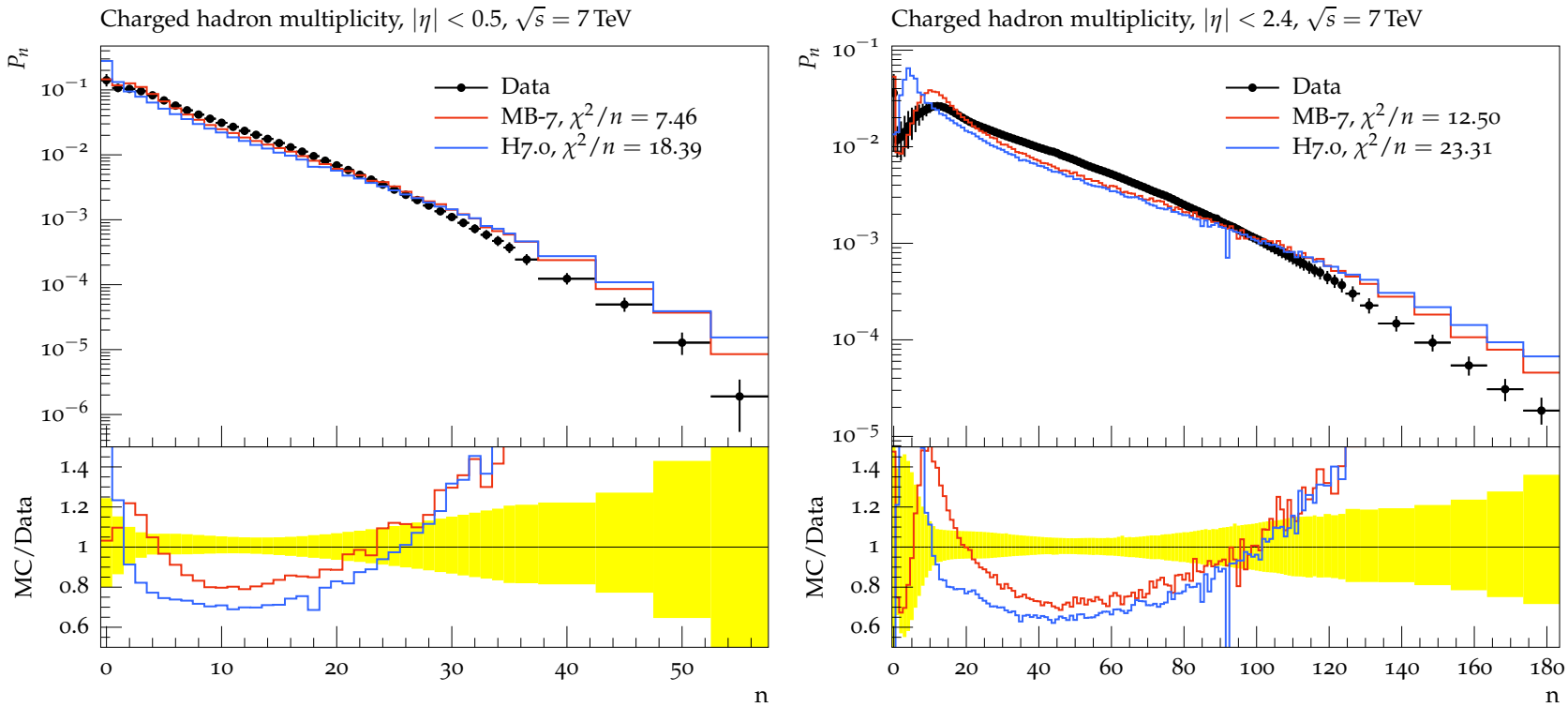




- Overall good description.
- For transverse momenta $p_\perp < 0.3\,\text{GeV}$ difficult

Non-single-diffractive analyses

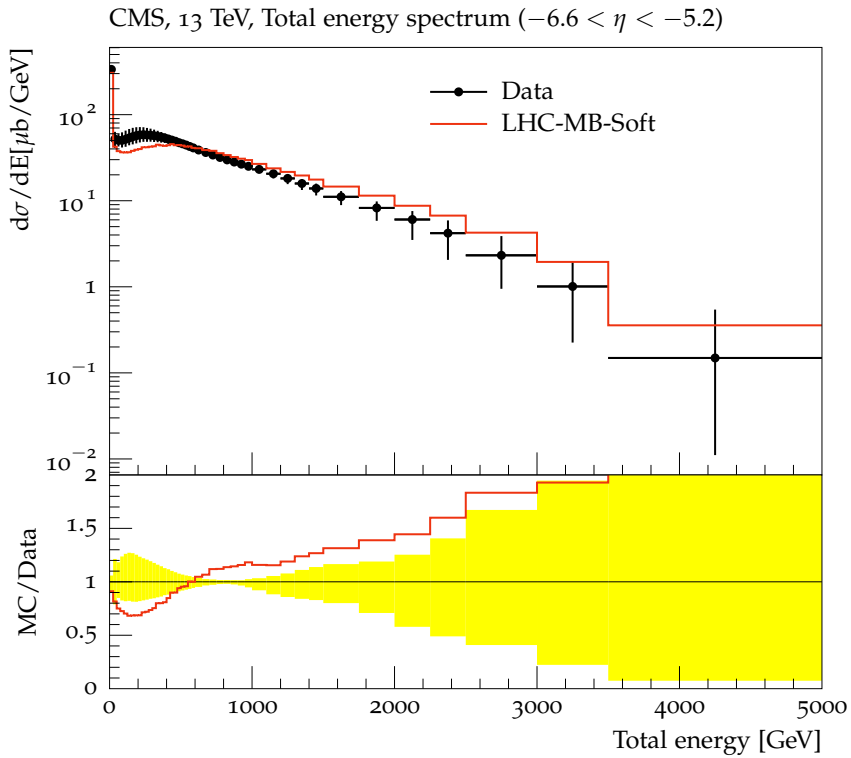
- CMS: [**J. High Energy Phys. 01 (2011) 079**]

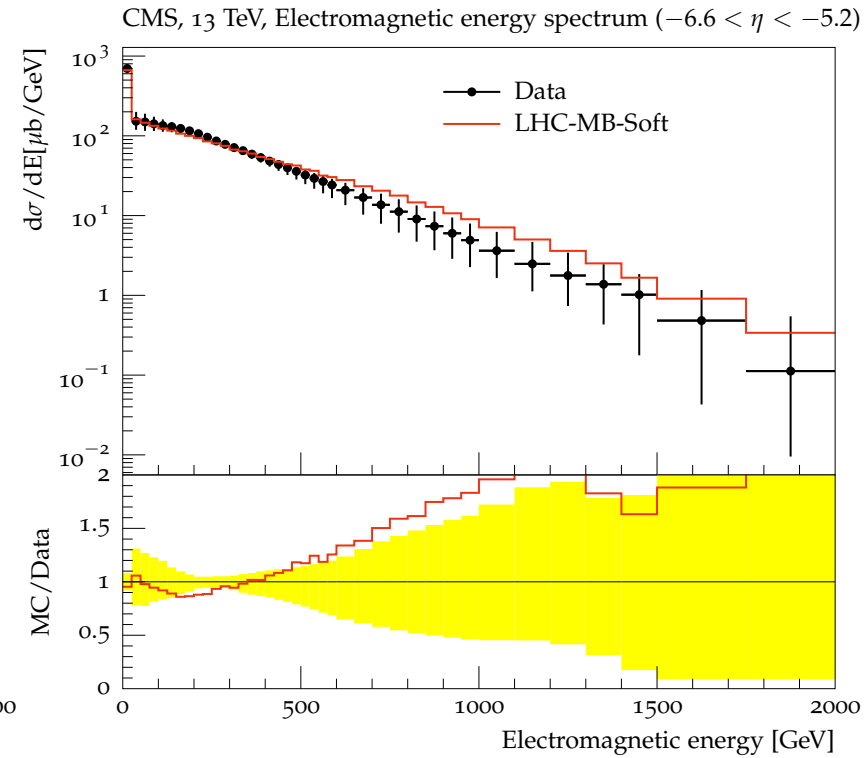


- Overestimation of the high n region $\rightarrow$ new model for CR

Some more recent analyses

- CMS/CASTOR: [1701.08695]





Outlook

- New model for CR with baryonic reconnection to handle high multiplicities $\rightarrow$ charged multiplicities still very difficult