First Study of Particle Production and Correlation at 13 TeV with CMS

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LHC Physics Discussion

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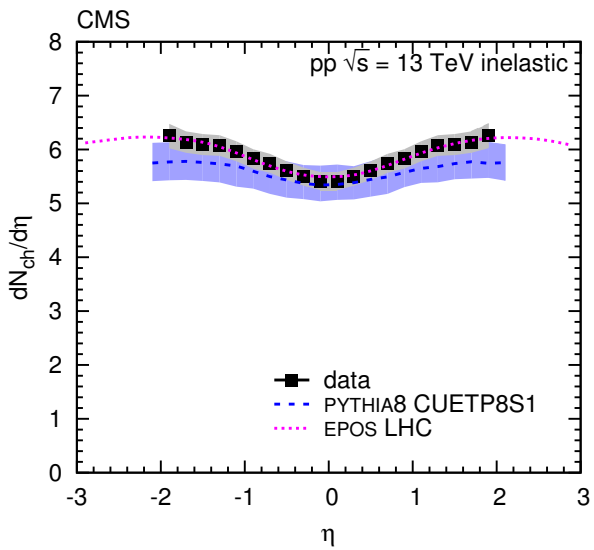
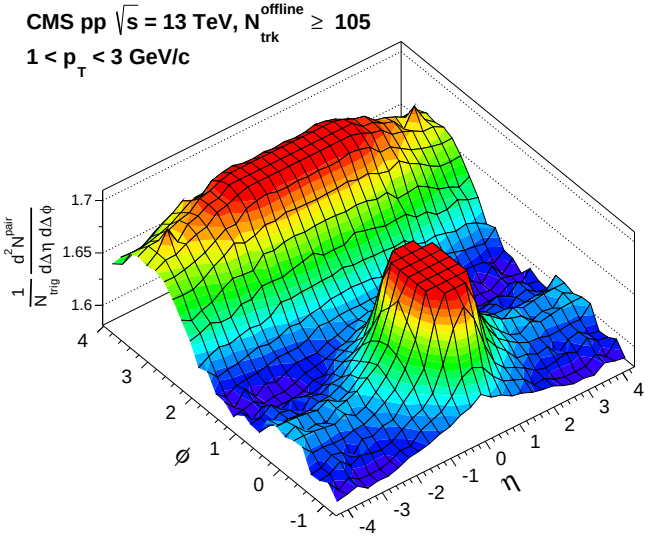
DESY, Hamburg

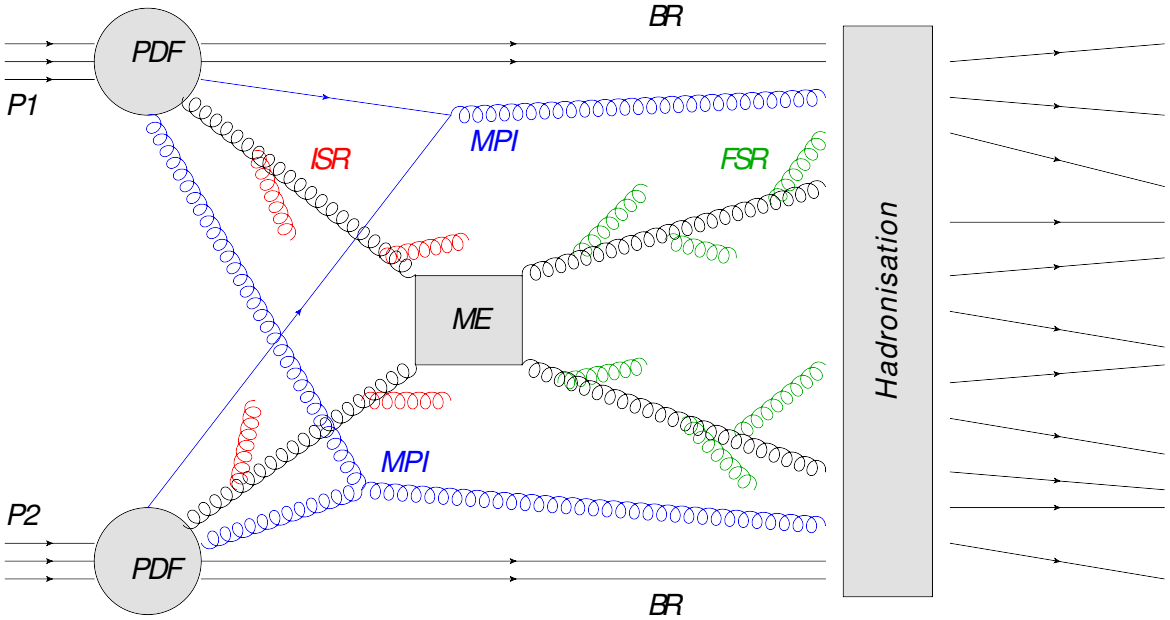
Outline

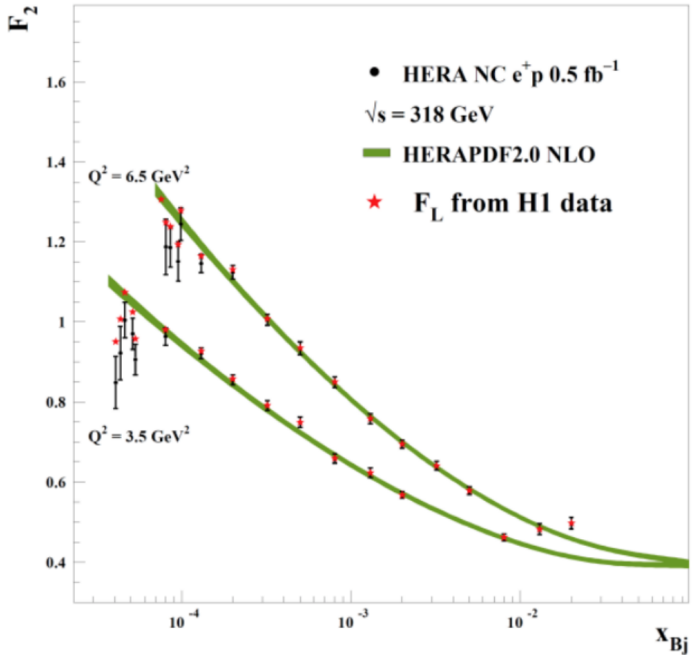
- **We want to probe**
  - The different components of hadrons production
  - The transition from the perturbative to the non-perturbative region
  - The behaviour of QCD at small-x
- **With inclusive observables as a first step**
  - Pseudorapidity distribution of charged hadrons
  - Two-particle correlations & Long-range near-side structure





Description of the hadron production

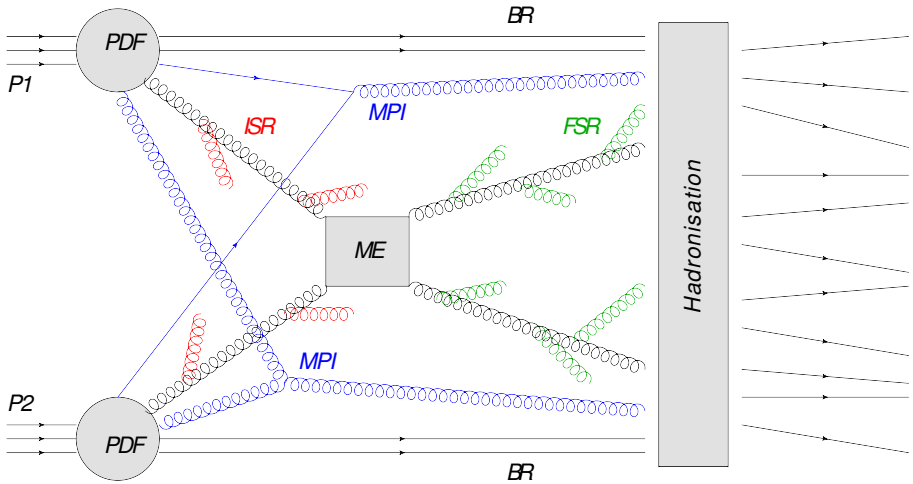




- Parton densities **at small x and small scale**
- Hard Scattering
  $\rightarrow$ described by pQCD at fixed order
- Initial-State Radiation and Final-State Radiation
  $\rightarrow$ account for higher order emissions
  $\rightarrow$ described by QCD-evolution-inspired Parton Shower
- Beam Remnants
- Multiple Parton Interactions (with its own ISR and FSR)
- Hadronisation

More on Multiple Parton Interactions

- **Multiple Parton Interactions MPI**
  - → Soft to semi-hard interactions
  - → Phenomenological models
  - → Tuning of the model parameters based on experimental data



- **New default CMS tunes developed by the DESY QCD group**
  - → Simultaneous fits to CDF UE data at 0.3, 0.9 and 1.96 TeV, and CMS UE data at 7 TeV
  - → **Energy dependence** of the MPI parameters
  - → Different parton densities
  - → **Theoretical uncertainties** from allowed parameter space

- **MPI needed to explain the increase of hadron production in the DGLAP framework**
  - → collinear factorization and collinear parton densities
  - → no explicit k_T dependence
  - → **would a framework based on k_T-factorization require (the same amout of) MPI?**

Pseudorapidity distribution of charged hadrons at 13 TeV

CMS operated at 0 T $\rightarrow$ no transverse momentum measurement

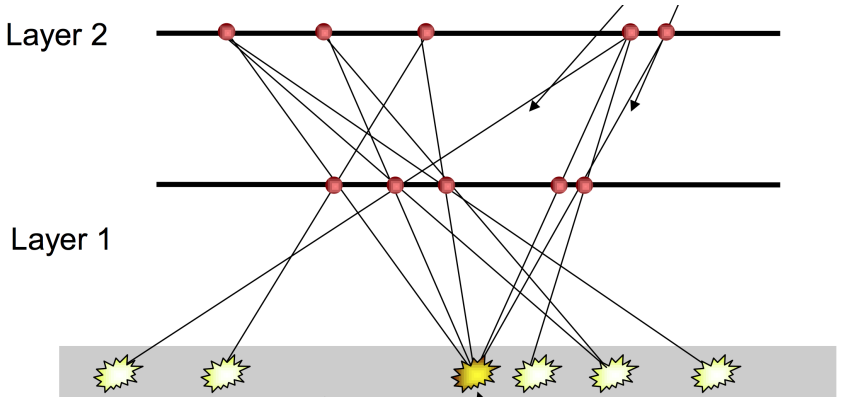
Two different reconstruction techniques: tracklets and tracks

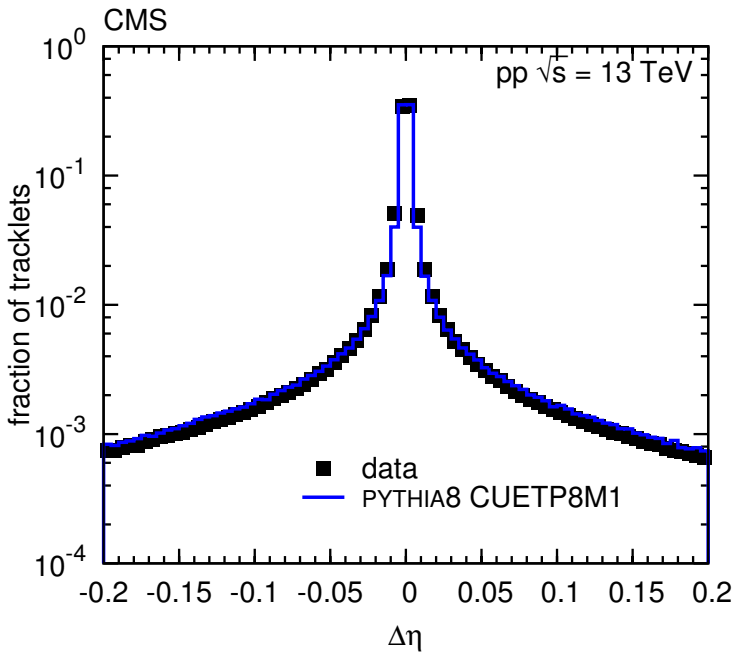
Zero Bias trigger $\rightarrow$ distributions for inelastic events

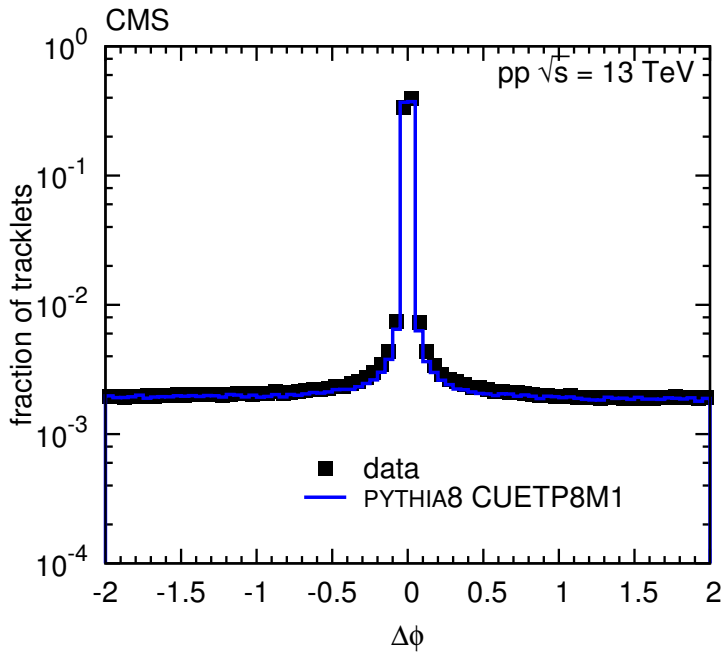
Final results corrected to primary charged long-lived hadrons
(strange baryons included $\rightarrow$ different from ATLAS definition)

Tracklet reconstruction

- Use pairs of hits from the barrel pixel layers
- $|\eta| < 2$ - p_T down to 40 MeV
- Vertex z resolution $\sim 0.02 - 0.1$ cm
- Only events with one primary vertex
- Few sensitivity to alignment



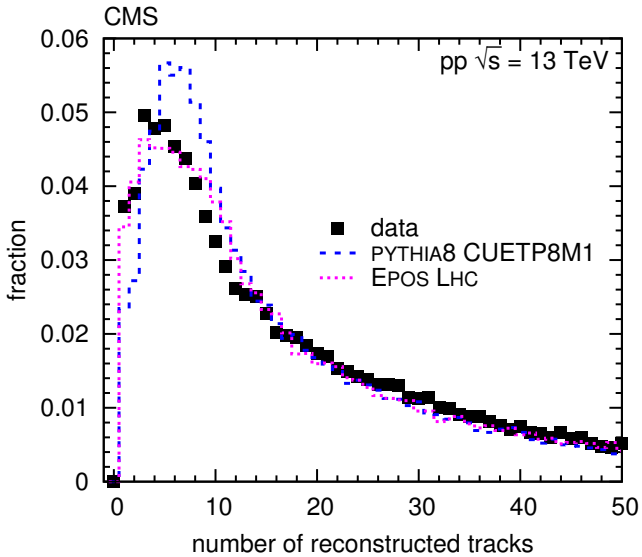


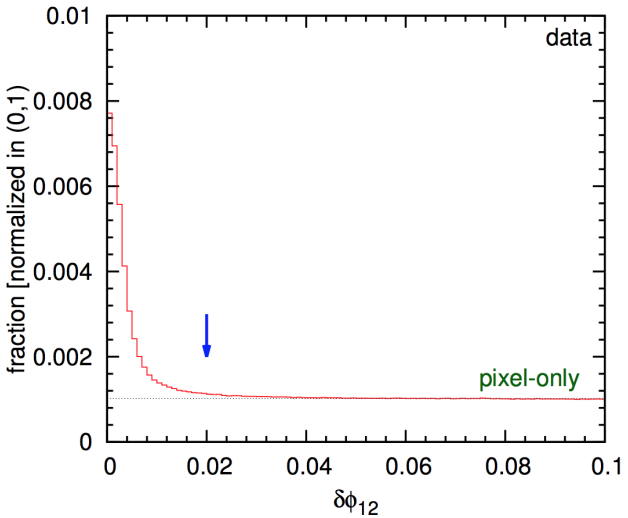


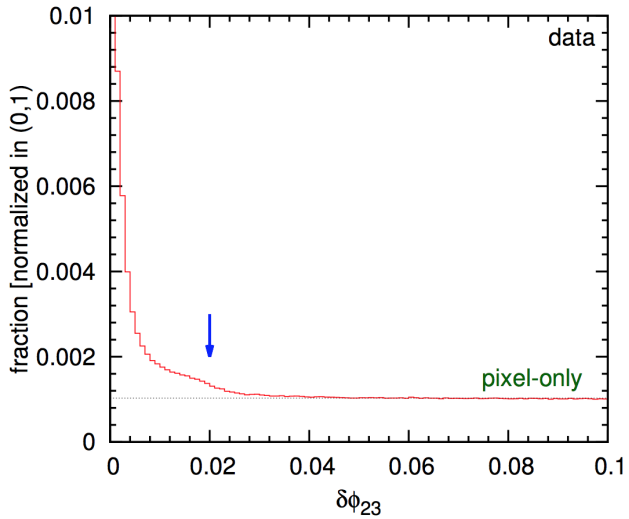
- Tracklets originating from primary vertex have sharp peak at $\Delta\varphi = 0$ (no magnetic field)
- Background suppressed with $\Delta\eta < 0.1$ and $\Delta\varphi < 1$ and subtracted using side band region

Track reconstruction - line tracking

- Use triplets of hits from the barrel pixel layers
- $|\eta| < 1.8$ - p_T down to 50 MeV
- Vertex z resolution ~ 250 μm
- No cut on vertex multiplicity
- More sensitivity to alignment

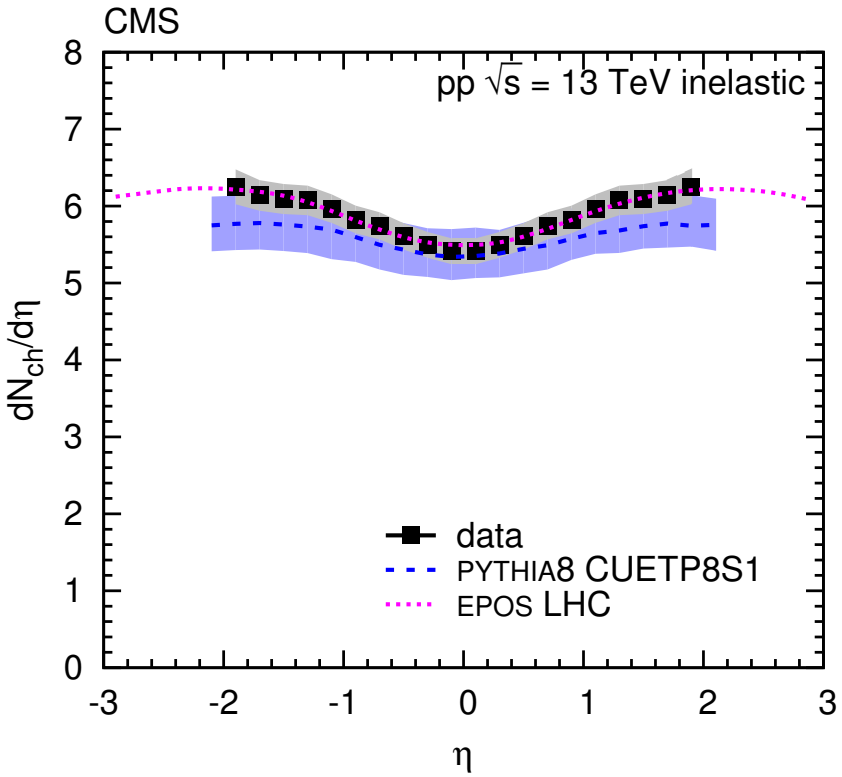


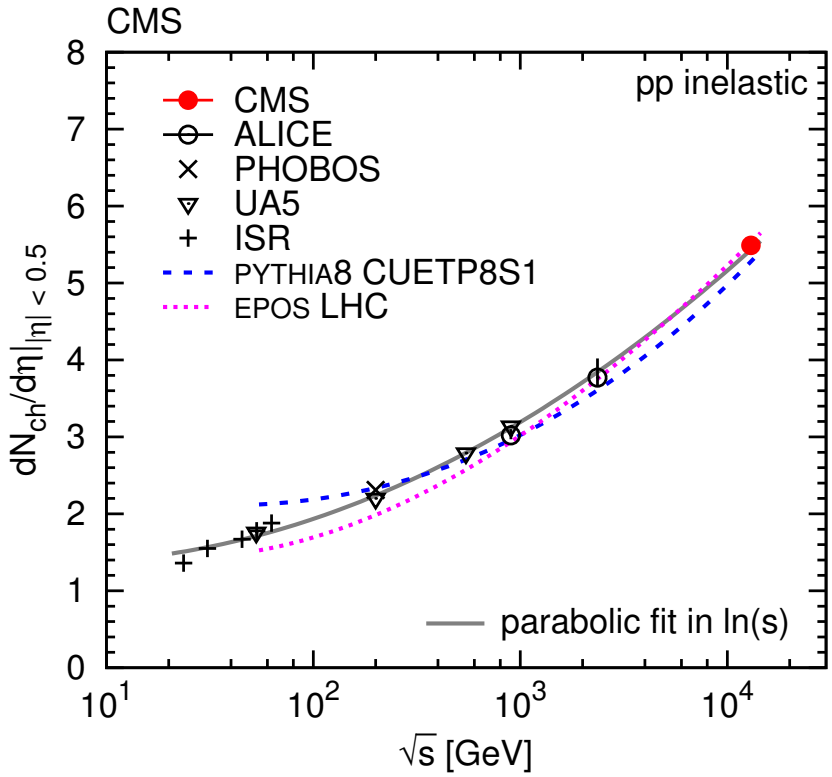




- Azimuthal correlation for the first and second pairs of hits
- Background suppressed with $\delta\varphi_{12} < 0.02$ and $\delta\varphi_{23} < 0.02$

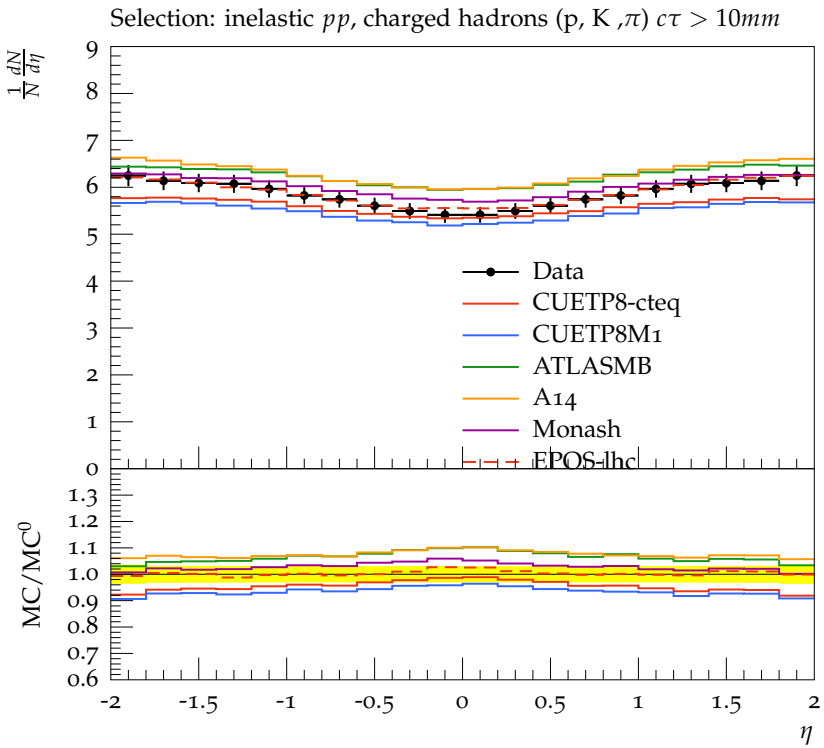
Charged hadron density - results

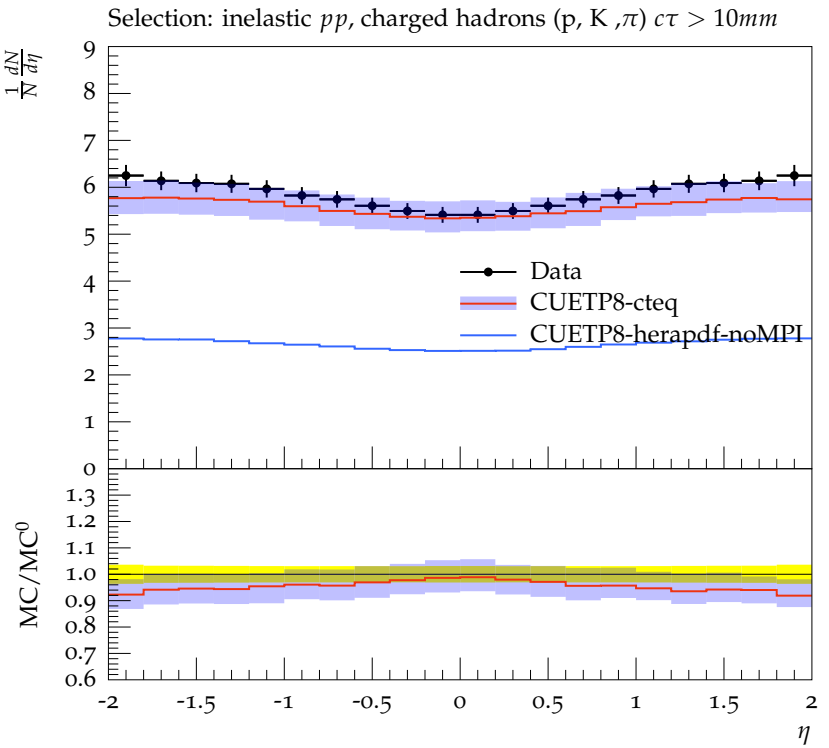




- Both reconstruction methods have a total systematic uncertainty $\sim$ 3 - 4 %
- Results of both analyses averaged and symmetrized in the range $|\eta| < 1.8$
- PYTHIA8 (CUETP8M1 and CUETP8S1) and EPOS LHC agree with the central value
- Density better described by EPOS LHC over the full η range
- $\sqrt{s}$ dependence fitted by a second order polynomial in ln(s)

Charged hadron density - more theoretical comparisons





- All theoretical predictions are in reasonable agreement with the data
- Need measurements for different event classes to be able to really constrain the models
- Theoretical predictions without MPI underestimate the density by a factor ~ 2
- Crucial need for MPI in the collinear factorization framework

Two-particle correlations and Long-range near-side structure at 13 TeV

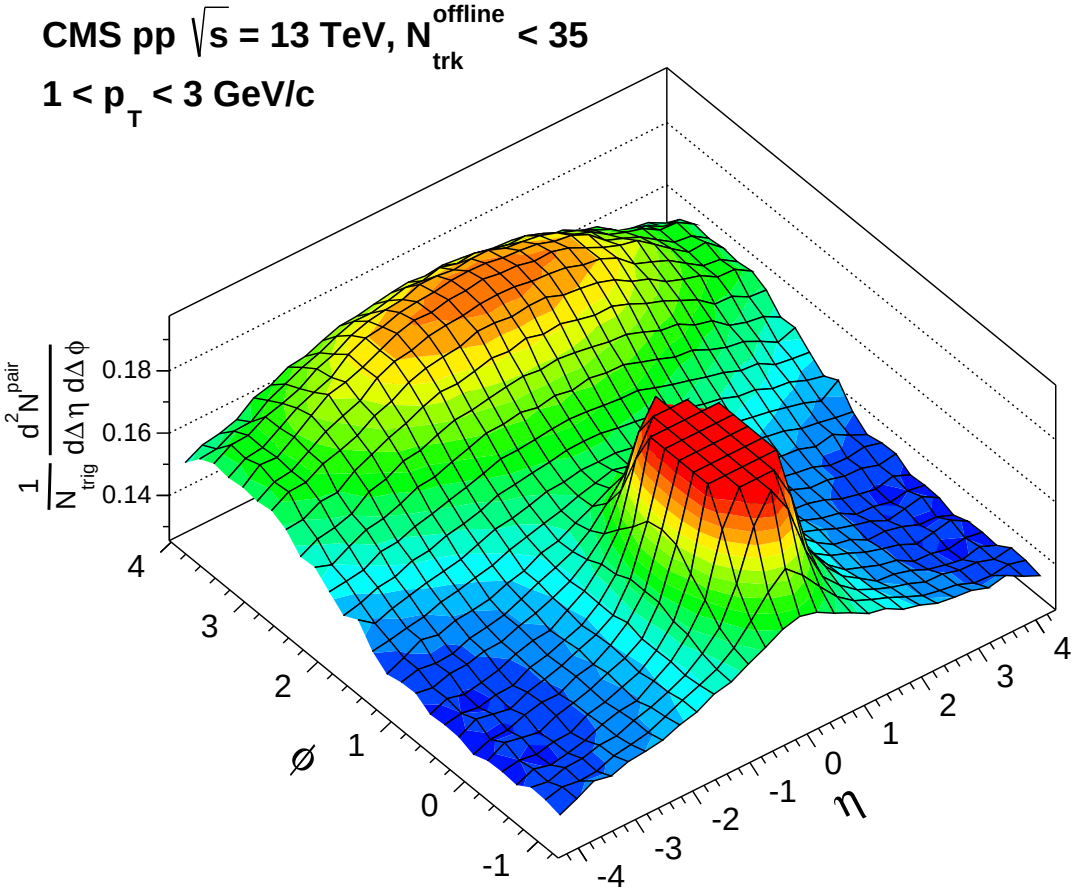
CMS operated at 3.8 T $\rightarrow$ transverse momentum measurement

Dedicated high multiplicity triggers - Only events with one primary vertex

$\eta - \varphi$ correlation for primary tracks with $|\eta| < 2.4$ and $p_T > 400$ MeV

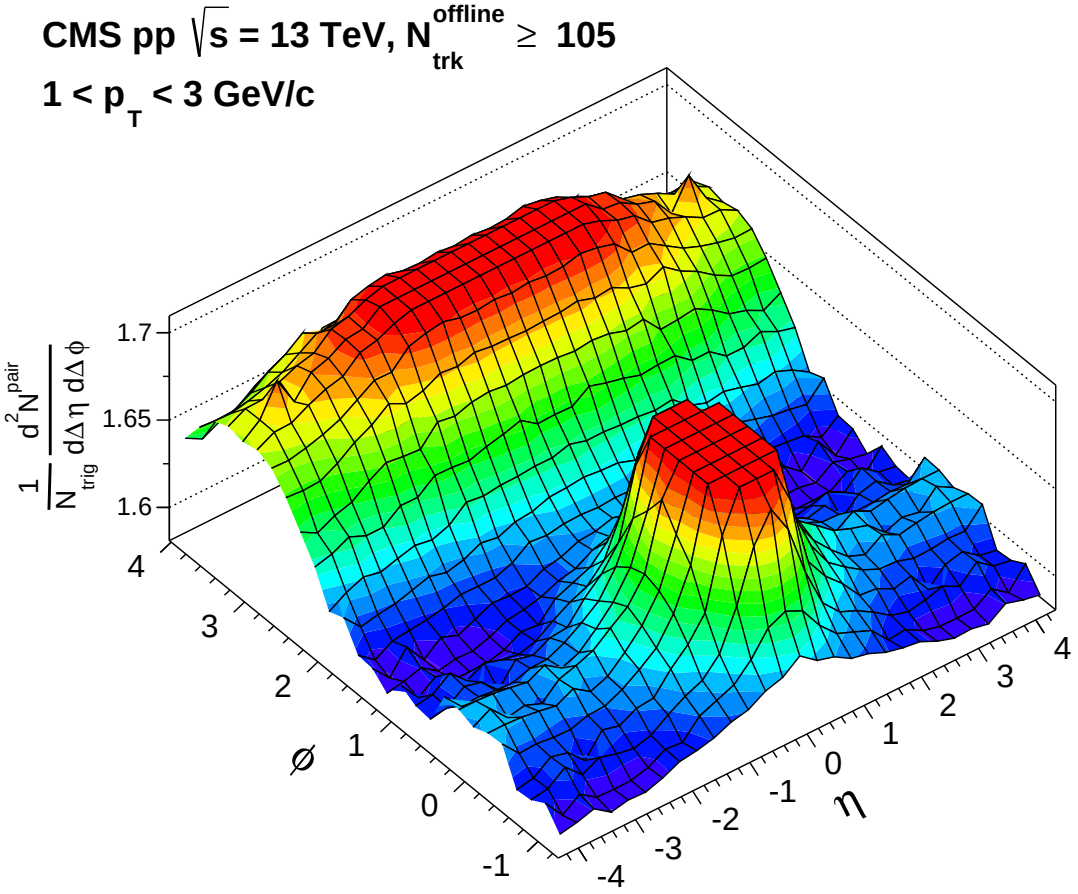
Correlation behaviour with p_T, track multiplicity, $\sqrt{s}$

Correlation in low multiplicy events



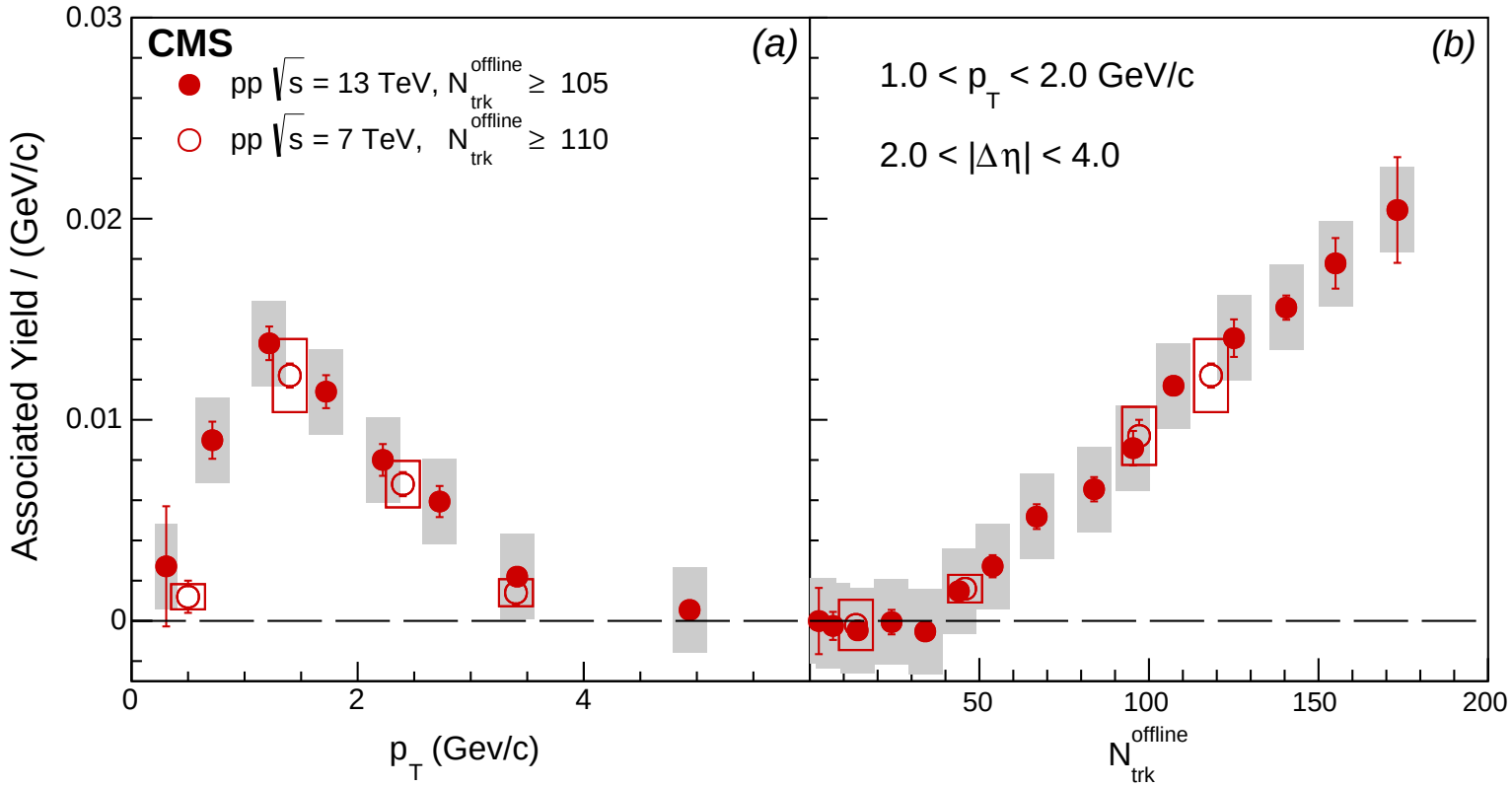
- Jet-like structure - Correlation from four-momentum conservation
- Pairs of particles from the same jet: peak at $(\Delta\eta, \Delta\varphi) \sim (0, 0)$
- Pairs of particles from back-to-back jets: long-range away-side correlation at $\Delta\varphi \sim \pi$

Correlation in high multiplicy events



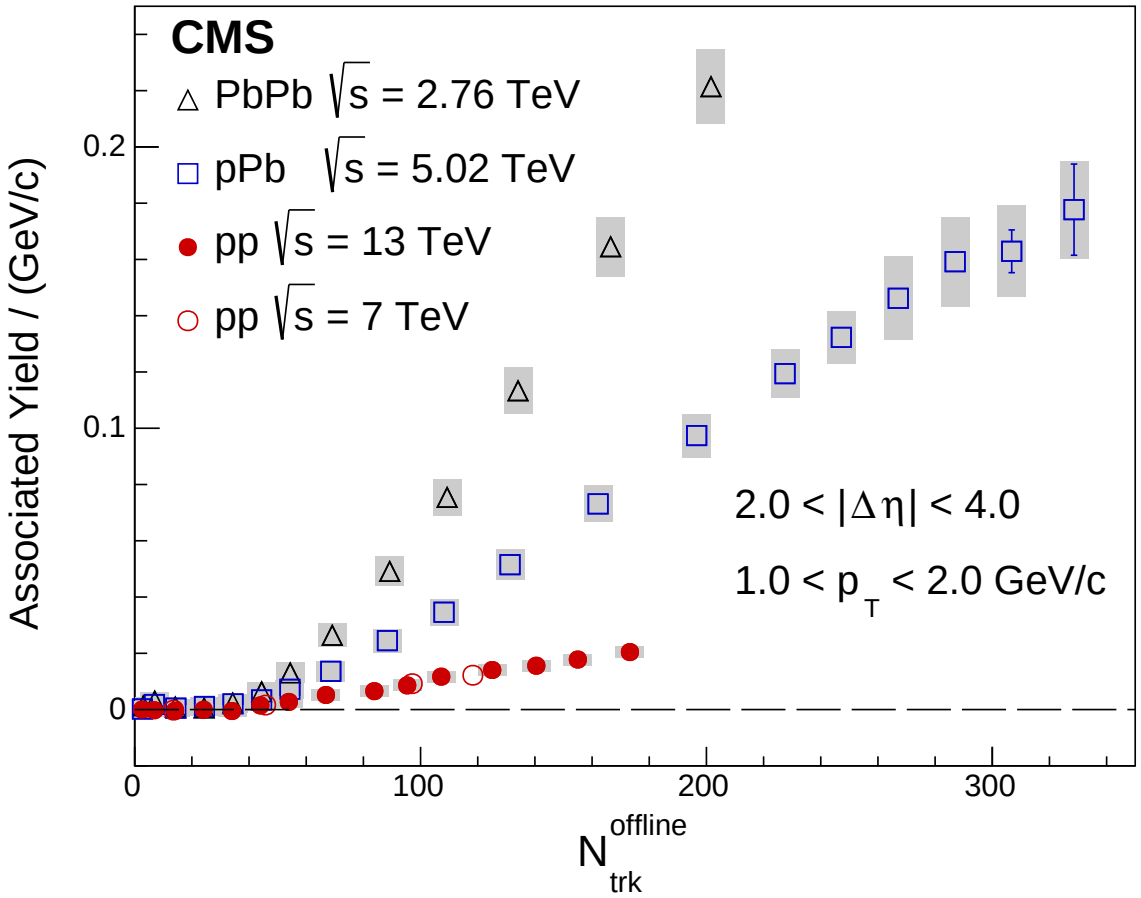
- Jet-like structure - Emergence of a ridge-like structure
- long-range same-side correlation at $\Delta\varphi \sim 0$ over a range of at least 4 units in $|\Delta\eta|$
- Qualitatively explained by gluon saturation and hydrodynamic models

Focus on the near-side



- Correlation on the near-side: associated yield averaged over $2 < |\Delta\eta| < 4$
- In the high multiplicity region: yield is maximum in the range $1 < p_T < 2$ GeV
- In the range $1 < p_T < 2$ GeV: linear increase of the yield with the track multiplicity
- Comparison between 7 TeV and 13 TeV results: no observation of $\sqrt{s}$ dependence

Size of the interacting systems



- Strong dependence on the size of the interacting systems
- At same track multiplicity: associated yield in p Pb $\sim$ 4 times higher, $\sim$ 20 times in Pb Pb

Conclusion

Charged hadron pseudorapidity density for inelastic events

- Important contributions from soft to semi-hard multiple parton interactions
- MPI are crucial in the collinear factorization framework
- Would a framework based on k_T-factorization require (the same amout of) MPI?
- All theoretical predictions are in reasonable agreement with the data
- Need measurements for different event classes to be able to really constrain the models

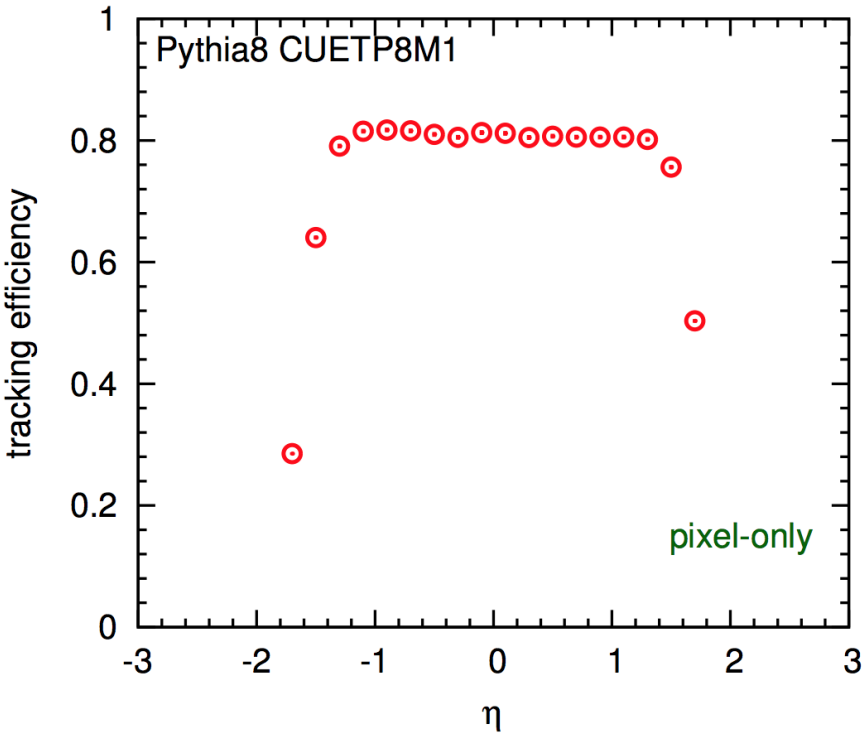
Charged hadron angular correlation

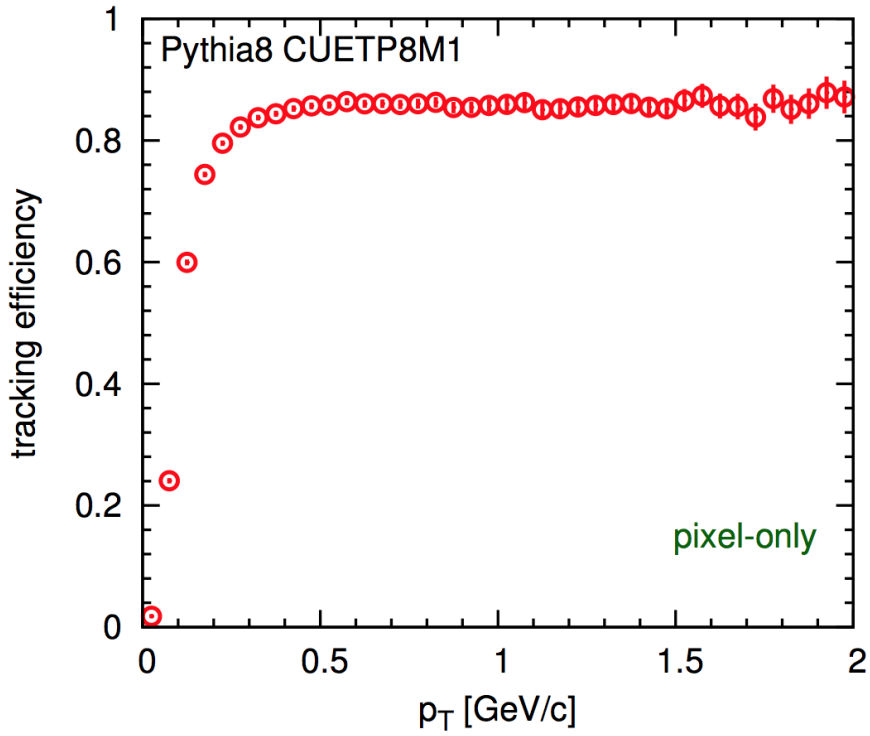
- Emergence of a long-range same-side correlation in high multiplicity events
- Correlation maximum in the range $1 < p_T < 2$ GeV - Linear increase with multiplicity
- No observation of $\sqrt{s}$ dependence - Strong dependence on the system size
- Qualitatively explained by gluon saturation and hydrodynamic models

Thanks for your attention!

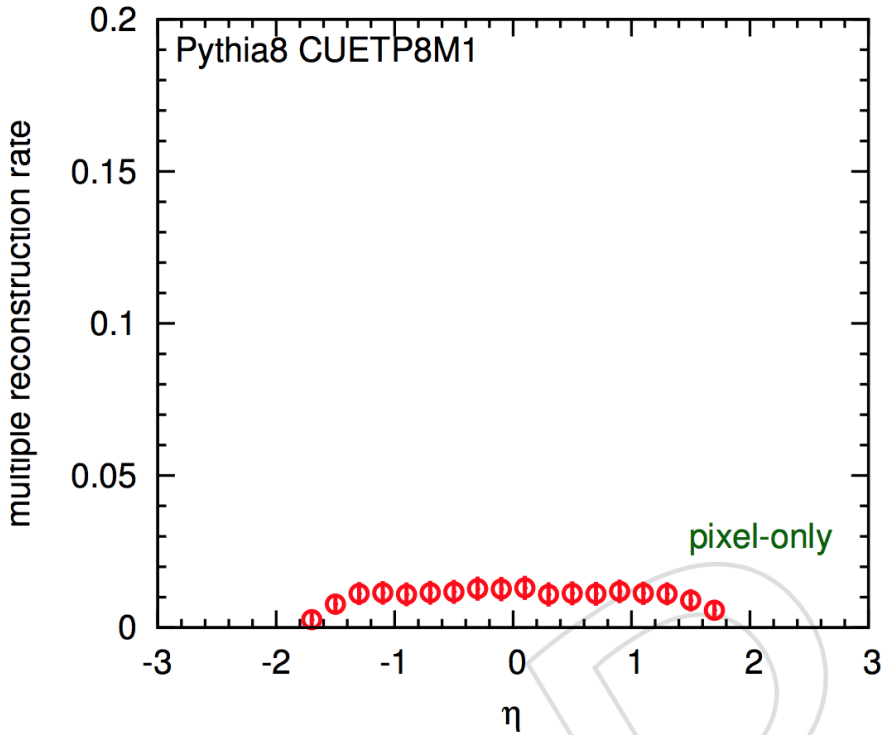
Back up

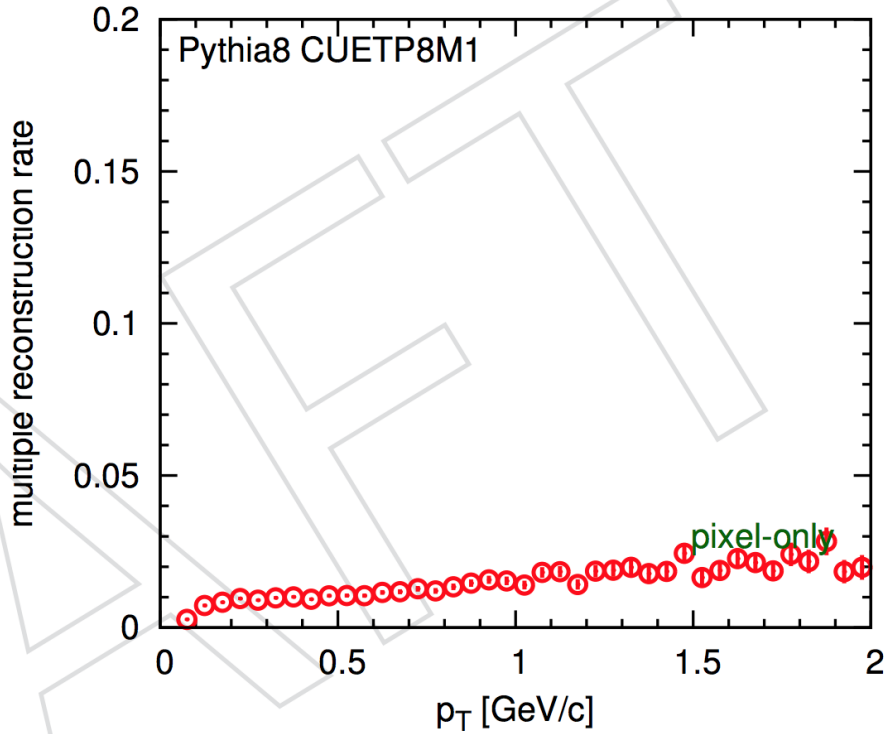
Efficiency line tracking



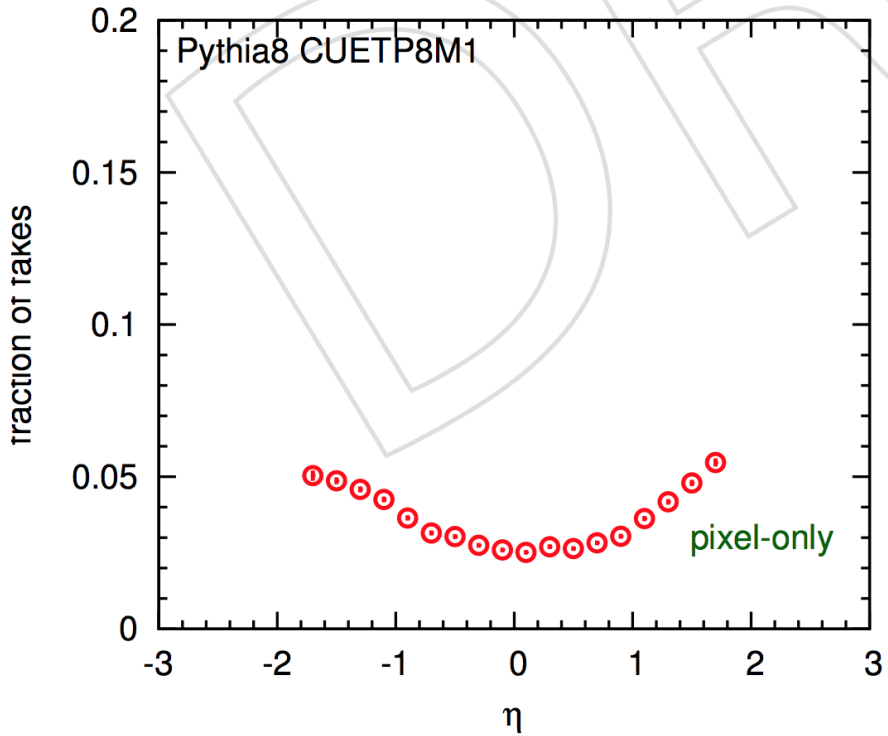


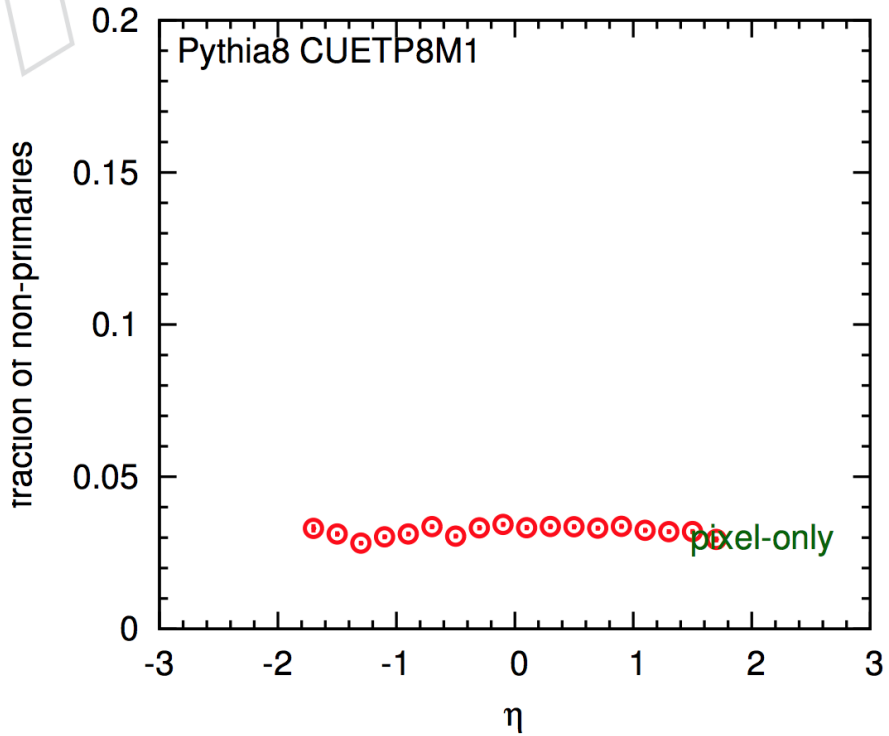
Multiple reconstruction line tracking





Fakes - non primaries line tracking





Phenomenology of the low-p_T region

- Total $2 \to 2$ **partonic cross section**: $\sigma(p_T) \propto \frac{1}{p_T^2}$

  is **divergent towards low** p_T and eventually becomes **larger than** σ_{inel}

- At LHC energies: $\sigma(p_T) > \sigma_{inel}$ already for $p_T \sim 5$ GeV
  $\to$ **Cross section needs to be tamed in the low** p_T **region**

- In PYTHIA: the rise of the $2 \to 2$ partonic cross section is controled by:

  - a regularization factor p_{T0} tuned to data:

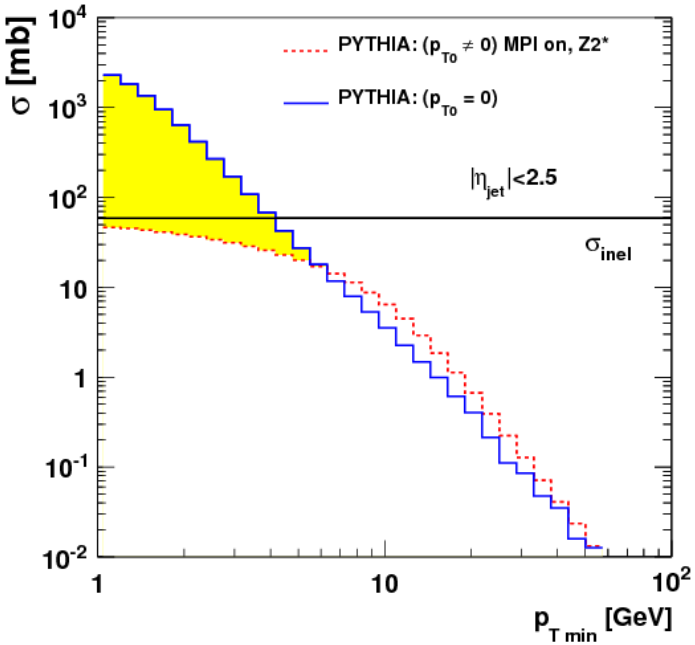
$$\sigma(p_T) \propto \frac{1}{p_T^2 + p_{T0}^2}$$

  - multiple partonic interactions (MPI):

$$< n_{MPI} >= \sigma(p_T)/\sigma_{inel}$$

- Energy dependence of the regularization factor:

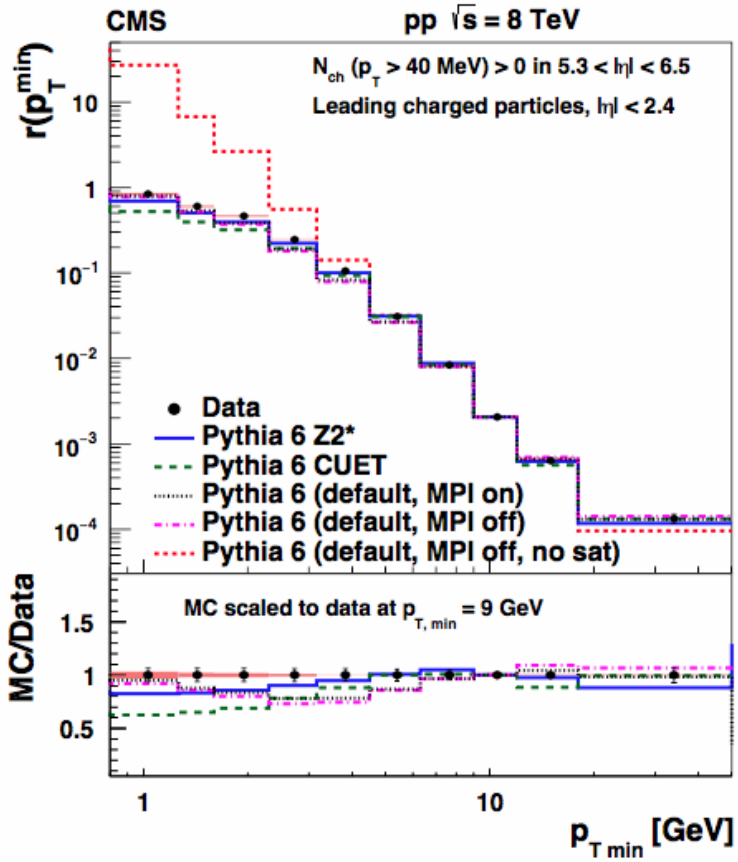
$$p_{T0}(\sqrt{s}) = p_{T0}(\sqrt{s_0}) \left(\frac{\sqrt{s}}{\sqrt{s_0}} \right)^{\alpha}$$



Phys. Rev. D 86 (2012) 117501

Integrated leading jet cross section at low p_T

arXiv 1507.00233 - submitted to PRD

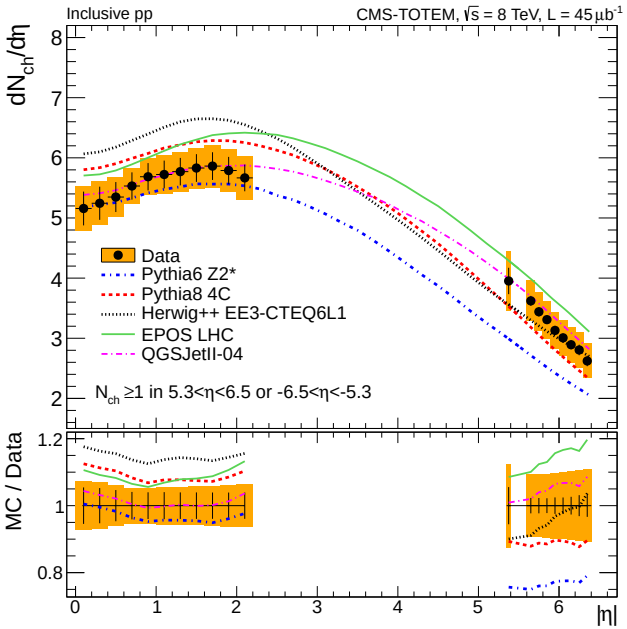


- **Saturation at low p_T observed experimentally**
- Event cross section $\rightarrow$ no sensitivity to jet multiplicities $\rightarrow$ no sensitivity to MPI
- Normalized cross section $\rightarrow$ converges to one at low p_T by construction
- **Global behavior reproduced by the MC - detailed description may be improved**

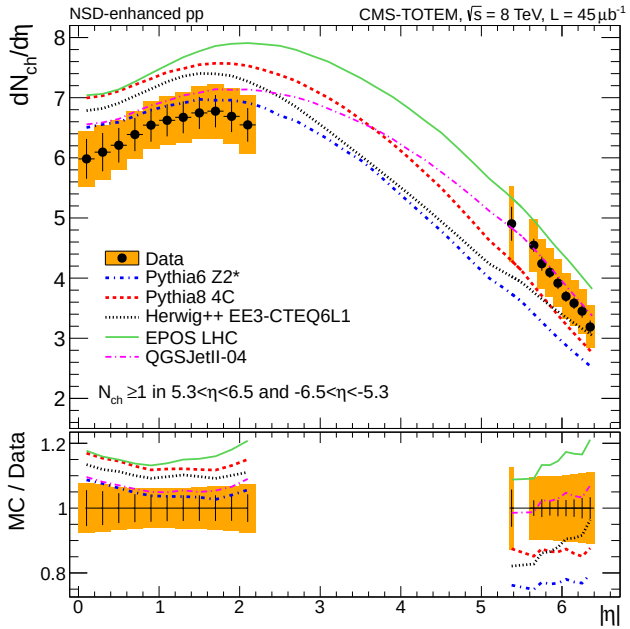
Pseudorapidity distributions of charged particles at 8 TeV

Eur. Phys. J. C 74 (2014) 10, 3053

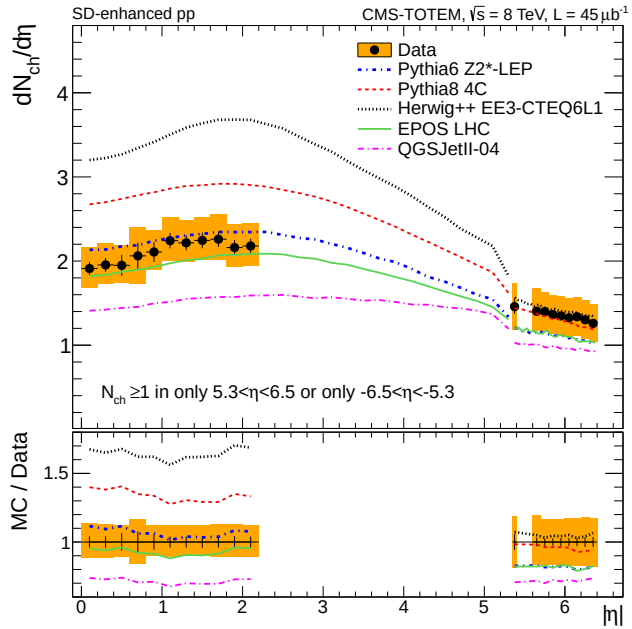
Inclusive



NSD-enhanced



SD-enhanced



- Bulk of particles produced in pp collisions from **semi-hard (multi)parton interactions** $\rightarrow$ Phenomenological models $\rightarrow$ Tuning based on experimental data
- NSD: sensitive to MPI - SD: sensitive to diffraction modeling
- **No consistent description** of the distributions over the full η range
- Up to 20 % (30 %) discrepancy in the central (forward) region $\rightarrow$ **valuable input for tuning**