Forward Physics and Small-x QCD results from CMS Run II data

Hans Van Haevermaet (University of Antwerp)

Universiteit Antwerpen

fwo Research Foundation Flanders
Opening new horizons

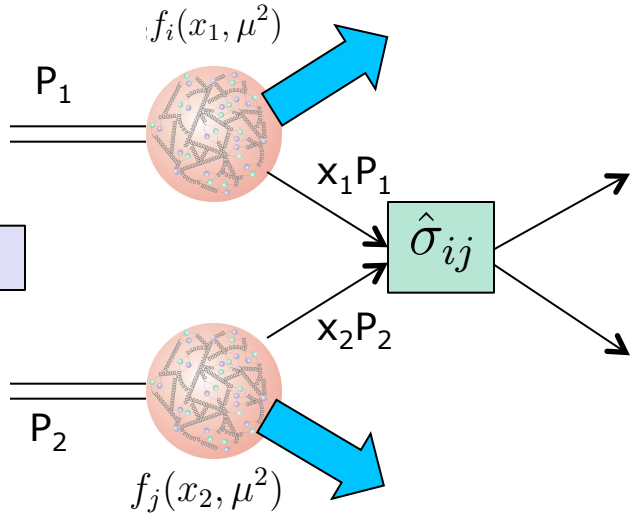
Meeting of the Belgian Inter-University Attraction Pole network on fundamental interactions – 18/12/15

Outline

- Introduction
- Pseudorapidity distribution of charged hadrons in pp collisions at 13 TeV
  [Phys.Lett. B751 (2015) 143-163]
- The underlying event at 13 TeV
  [CMS-PAS-FSQ-15-007]
- Measurement of long-range near-side two-particle correlations in pp collisions at 13 TeV
  [arXiv:1510.03068]
- Summary

Description of proton-proton collisions

- Factorise the cross section as: $\sigma(P_1, P_2) = \sum_{i,j} \int dx_1 dx_2 f_i(x_1, \mu^2) f_j(x_2, \mu^2) \hat{\sigma}_{ij}(p_1, p_2, \alpha_S(\mu^2), Q^2/\mu^2)$



Collinear factorisation

Hard scattering cross section:
process dependent, short distance (high energy) interaction with small coupling, calculated with fixed order perturbation theory

Process independent PDF's:
non-perturbative long distance interactions with high coupling

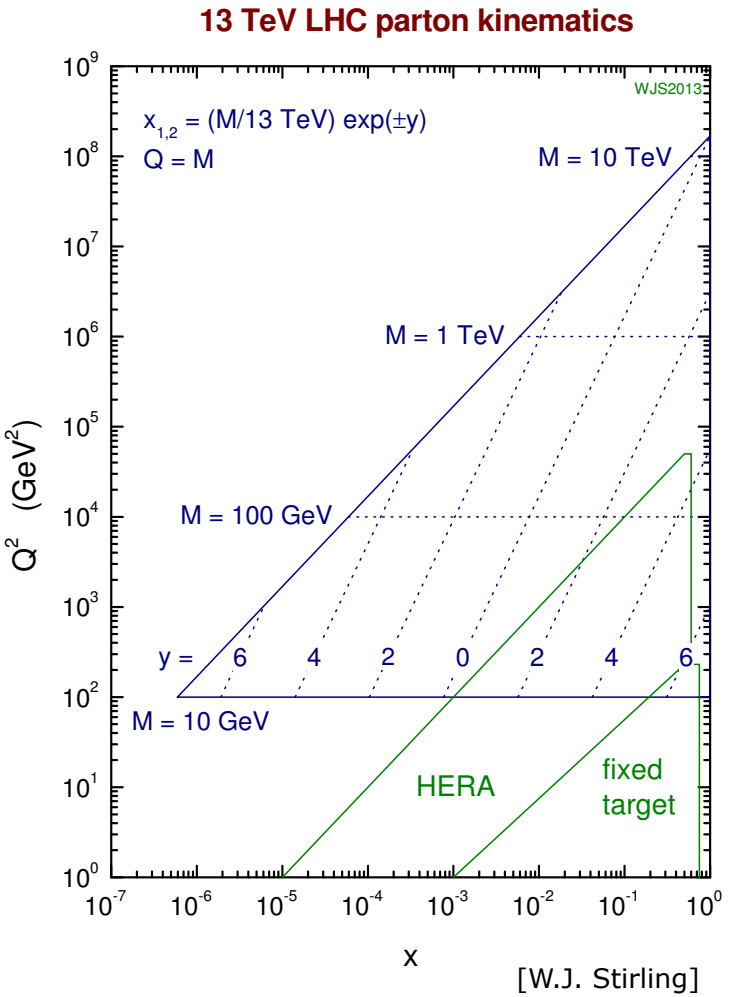
Evolution of PDF's driven by DGLAP equations:
$f(x,Q^2)$ determined by $f(x_0>x, Q_0^2<Q^2)$

- Successful in describing many inclusive processes
- However: ➔ Valid for one hard momentum scale and not too low x (dilute hadron)
  ➔ Treatment of initial transverse momenta of the partons neglected
- Complemented with phenomenological models that add initial and final state radiation, and allow for multiple parton interactions

QCD at the LHC

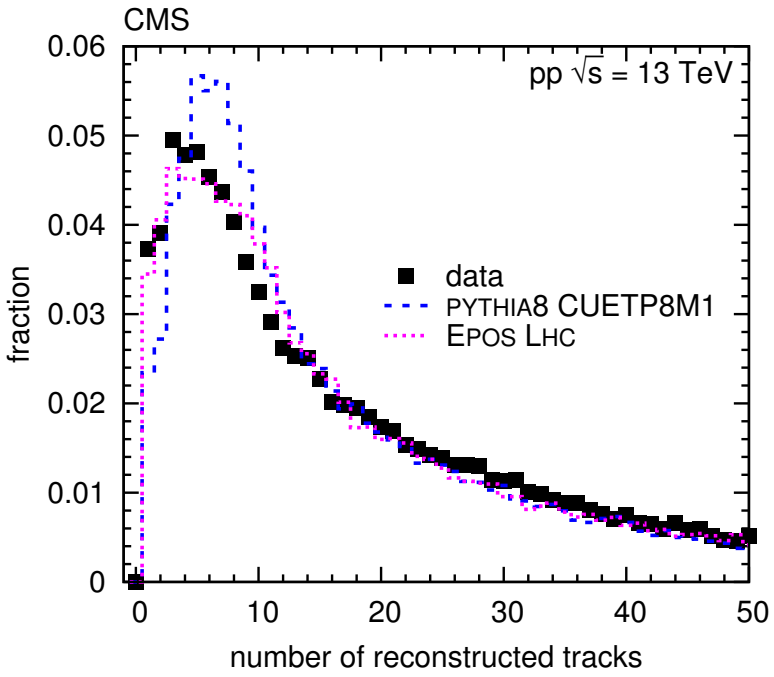
- What will happen at 13 TeV?
  Do the collinear approximations stay valid?
- Gluons dominate low-x region:
  saturation or recombination effects?
- Monte Carlo models tuned with data
  up until centre-of-mass energies of 7 TeV

  ➔ performance at 13 TeV?
- Need to measure fundamental properties
  of proton-proton collisions at 13 TeV



Pseudorapidity distribution of charged hadrons

- First measurement with proton-proton collisions at $\sqrt{s}$ = 13 TeV
- Inclusive production of charged hadrons driven by combination of perturbative and non-perturbative QCD phenomena
  (saturation of parton densities, MPI, hadronisation, soft diffractive scattering)
- Measurement necessary to tune the modeling of these contributions
- Important to control pile-up backgrounds



- Study yield of charged hadrons in $|\eta| < 2$ for inelastic events
- No minimum transverse momentum requirement (➔ B = 0 T data)
- Corrected to primary long-lived charged hadrons (no leptons)

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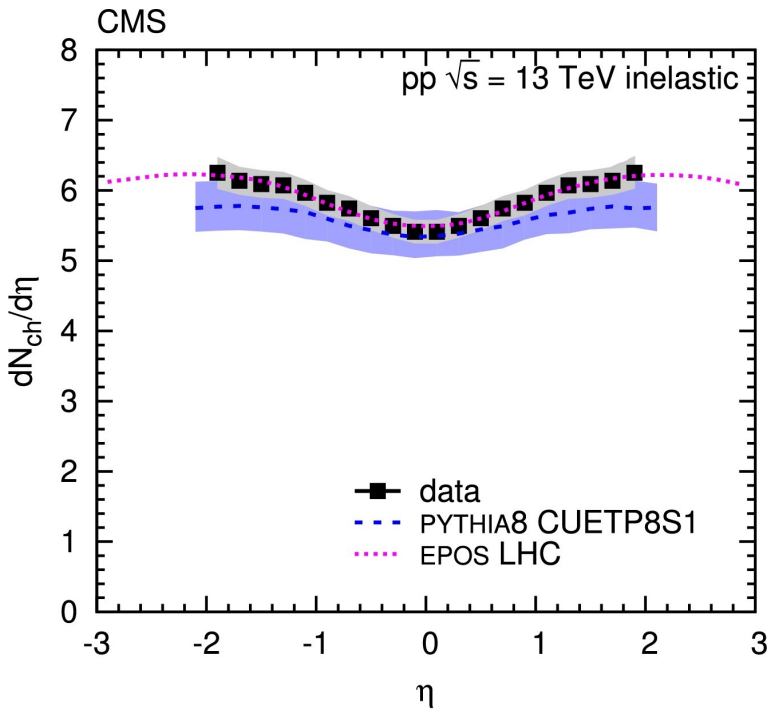
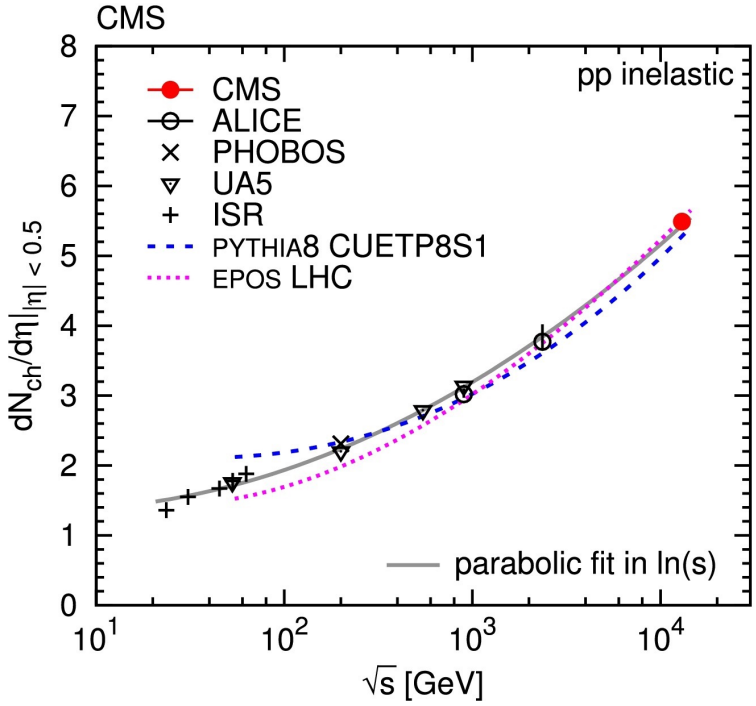
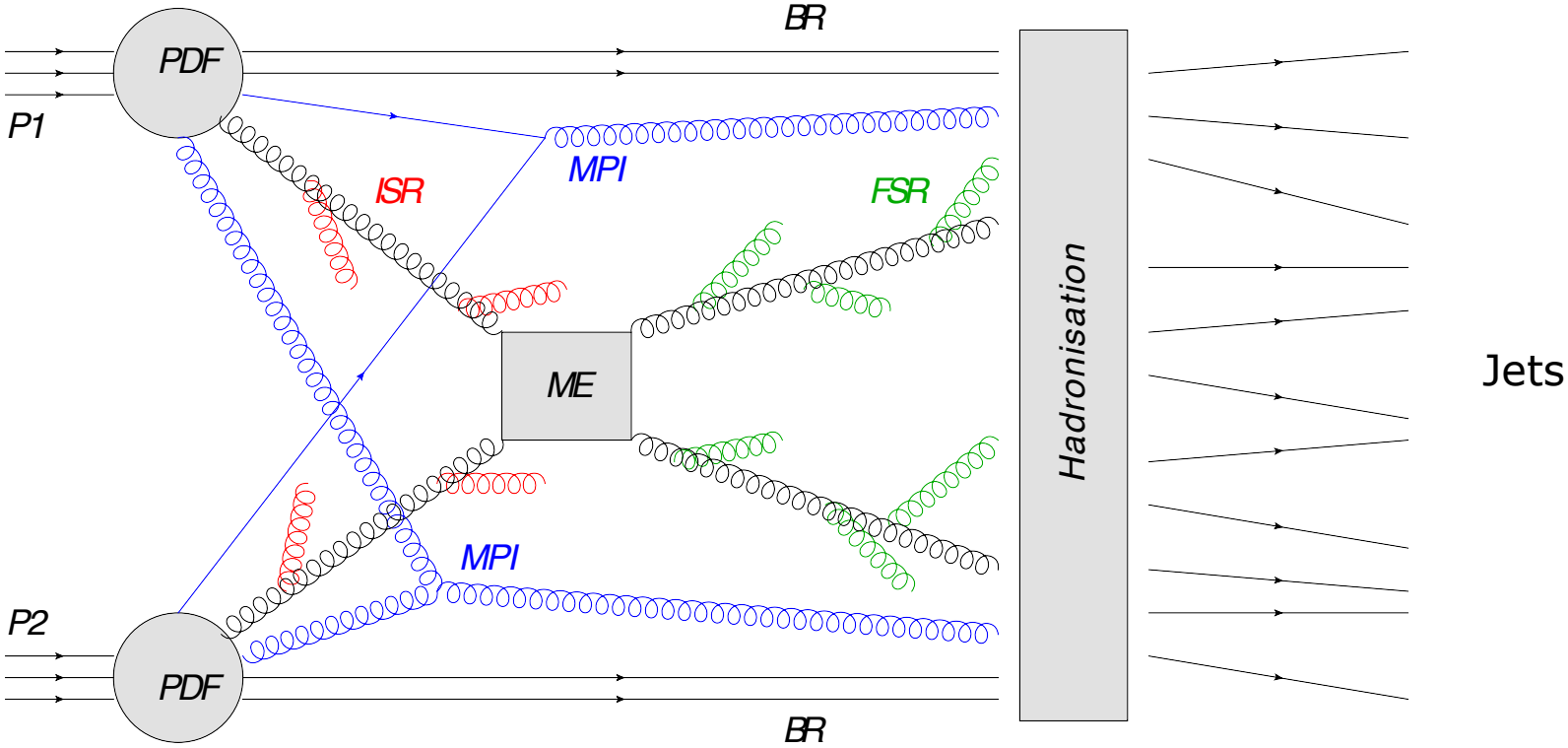




- For $|\eta| < 0.5$: $dN_{ch}/d\eta = 5.49 \pm 0.01\ (stat) \pm 0.17\ (syst)$

The underlying event at √s = 13 TeV

- The underlying event (UE) is everything except the hard scattering (ME)

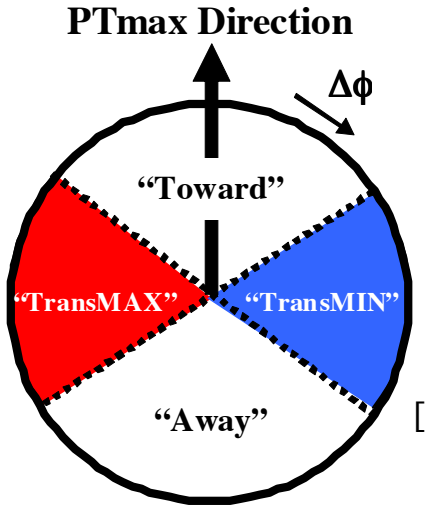


- Understanding the UE is crucial for precision measurements of the SM and for the search for new physics, but its dynamics are not well understood
  ➔ soft & semi-hard interactions can not be fully described with perturbative QCD
  ➔ phenomenological models involve parameters that **must be tuned to data**

The underlying event at √s = 13 TeV

- Study the UE activity in proton-proton collisions as a function of the hard scale of the event, and at different centre-of-mass energies (√s)

Direction of the leading object:
e.g. leading charged particle/jet



ISR/FSR + MPI/BR ➔ ➔ MPI/BR

[R. Field]

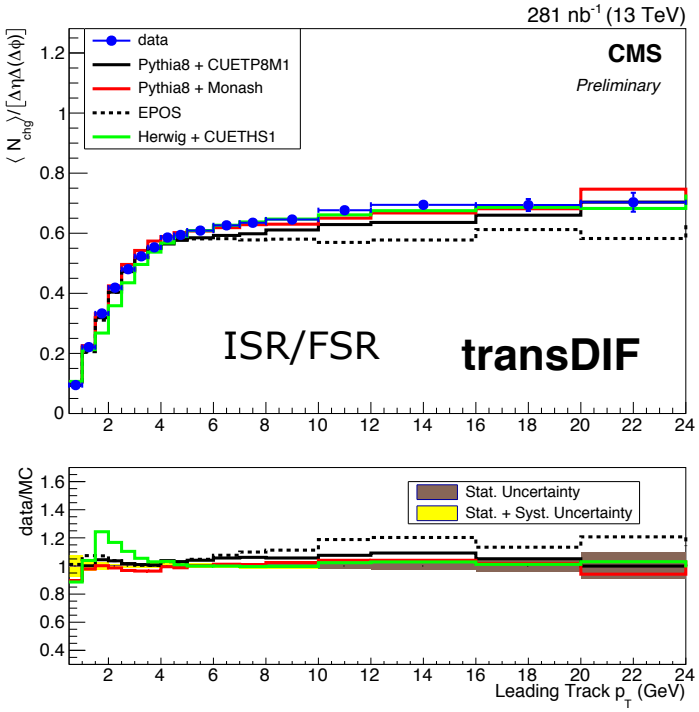
Towards region: $|\Delta\phi| < 60°$
Away region: $|\Delta\phi| > 120°$
Transverse region: $60° < |\Delta\phi| < 120°$

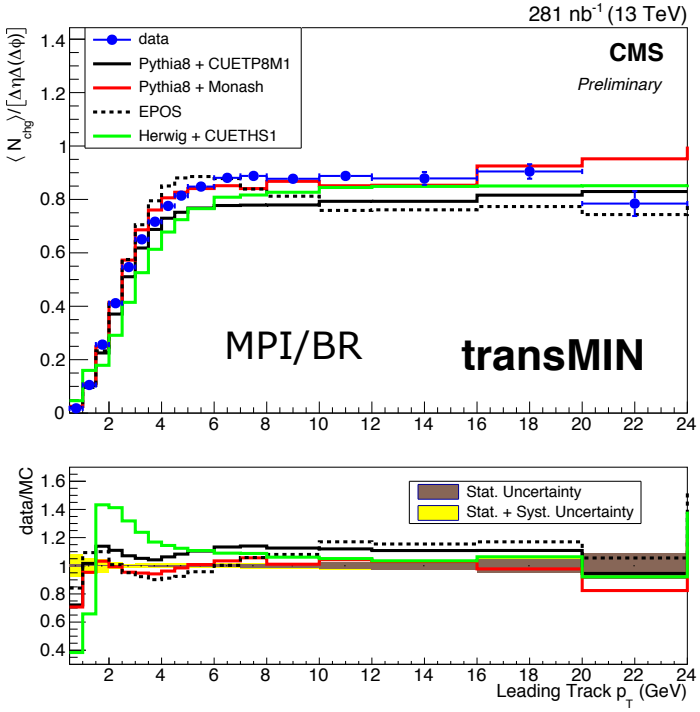
Observables: $\langle N_{ch} \rangle / [\Delta\eta\Delta(\Delta\phi)], \langle \Sigma p_T \rangle / [\Delta\eta\Delta(\Delta\phi)]$

TransMAX (TransMIN): side of transverse region with highest (lowest) activity
TransAVE: (TransMAX + TransMIN) / 2
TransDIF: TransMAX – TransMIN ➔ only sensitive to ISR/FSR

The underlying event at √s = 13 TeV

- $\langle N_{ch} \rangle$ as function of leading charged particle p_T (p_T > 1 GeV and |η| < 2)
- Sum particles in transverse region with p_T > 0.5 GeV and |η| < 2
- Data: B = 3.8T; pile-up ~1.3; ZeroBias trigger; exactly 1 good primary vertex

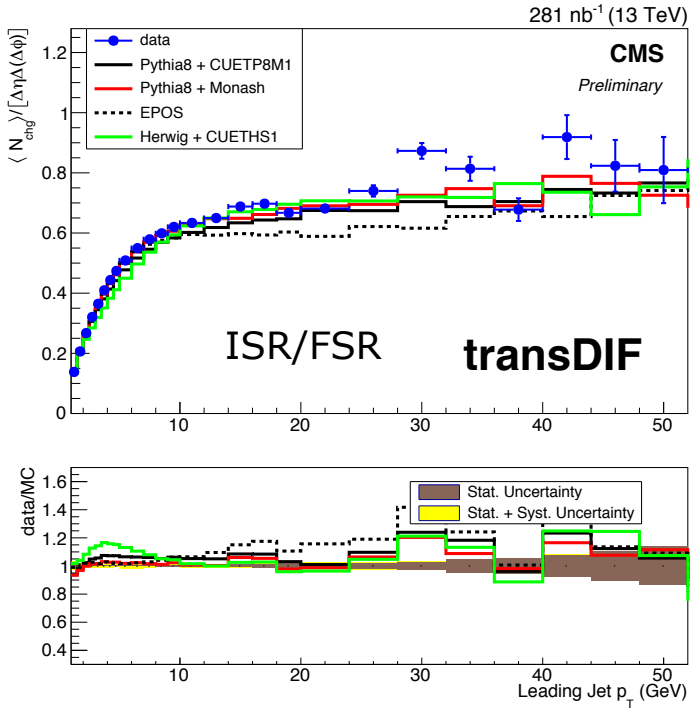


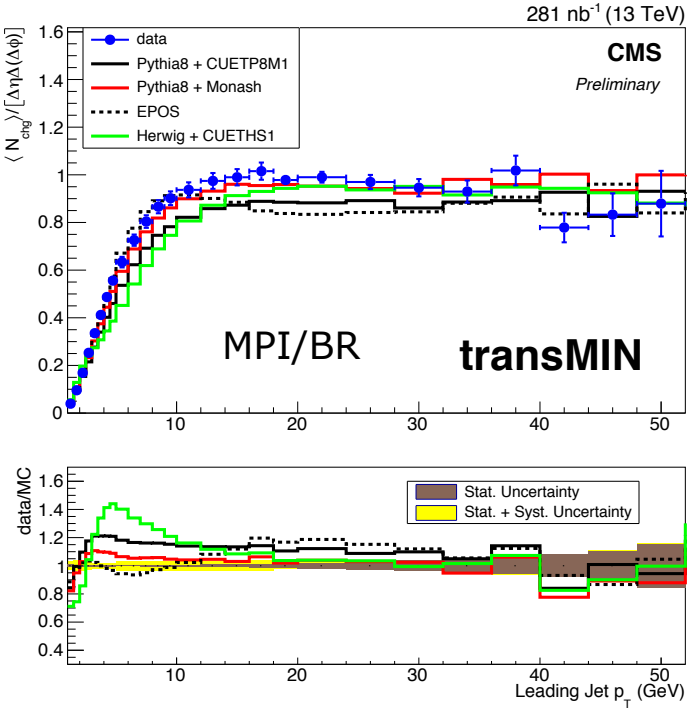


- Good description of existing tuned models
- Pythia8 Monash and CMS tune CUETP8M1 perform best

The underlying event at √s = 13 TeV

- $<N_{ch}>$ as function of leading charged-particle jet p_T (p_T > 1 GeV and |η| < 2; SisCone R = 0.5)
- Sum particles in transverse region with p_T > 0.5 GeV and |η| < 2
- Data: B = 3.8T; pile-up ~1.3; ZeroBias trigger; exactly 1 good primary vertex





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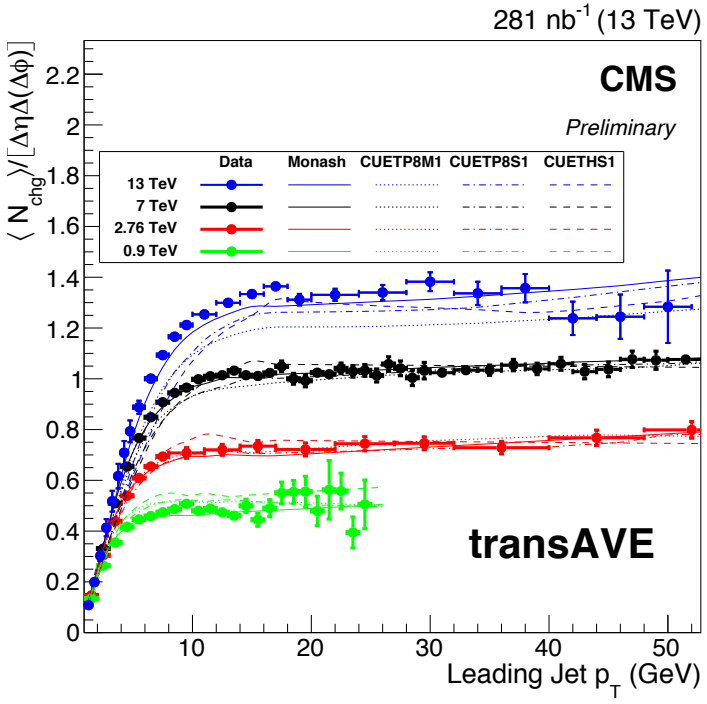
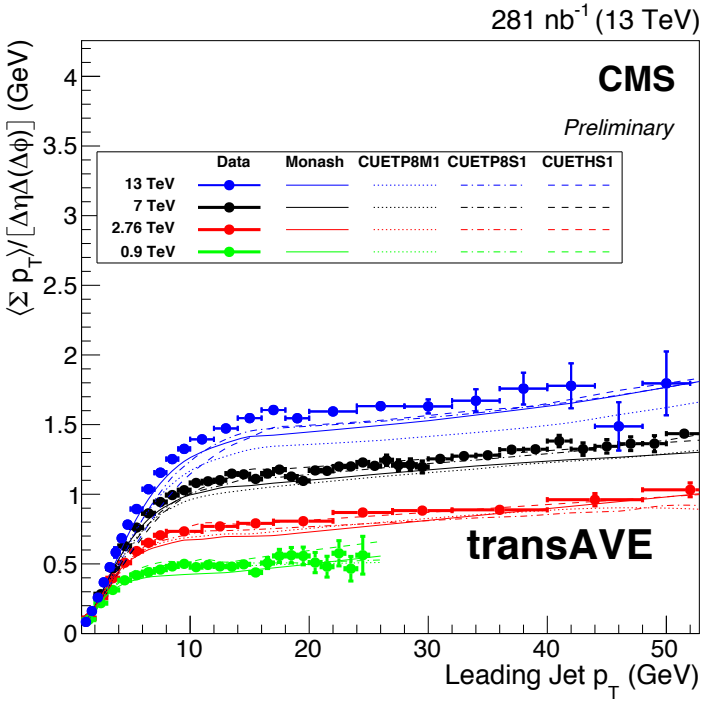
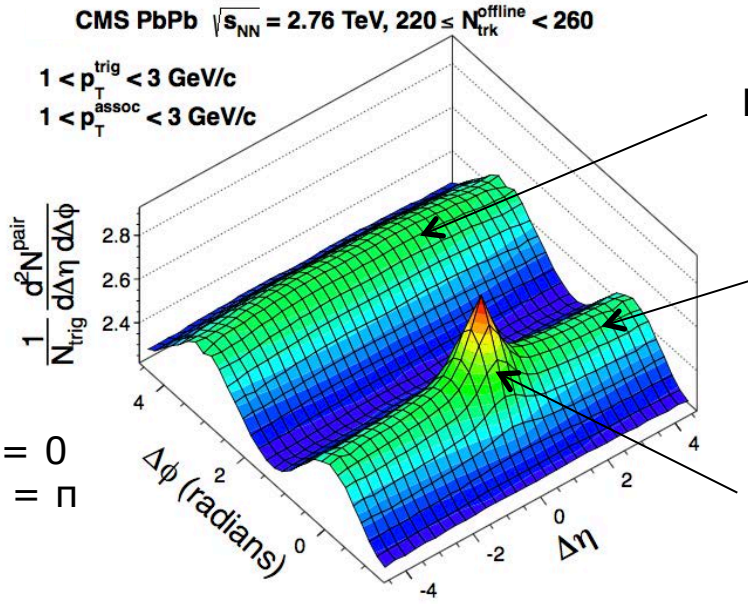




- Pythia8 Monash tune predicts better centre-of-mass energy dependence

Long-range near-side two-particle correlations

- Well known in heavy ion collisions: used to probe hydrodynamics
- Two particle correlations produce double ridge structure in (Δη,Δϕ) plane

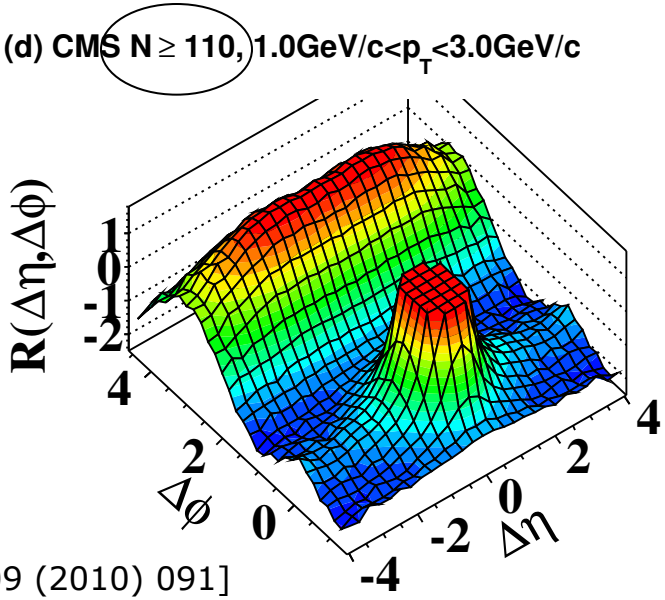


Near side at Δφ = 0
Away side at Δφ = π

- Long-range near-side ridge structure:
  ➔ reflects hydrodynamic properties of the medium

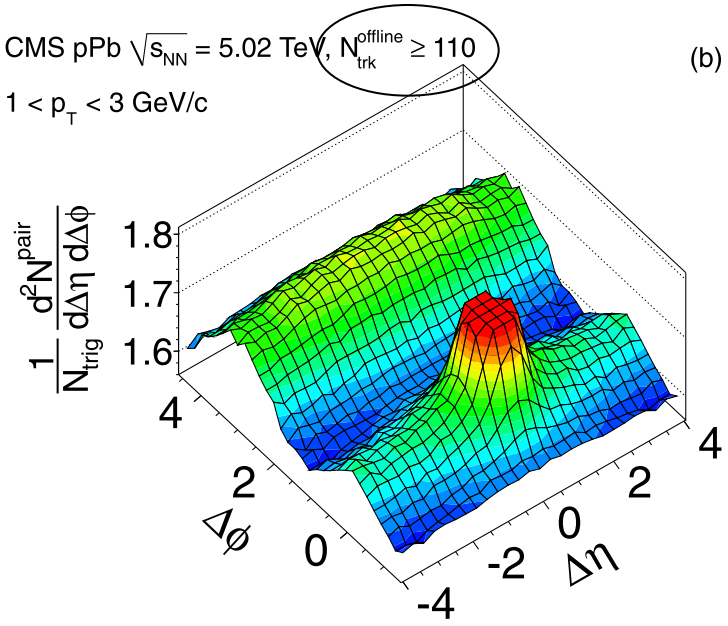
Long-range near-side two-particle correlations

- First observation by CMS of near-side long-range correlations in high multiplicity proton-proton collisions at √s = 7 TeV during LHC Run I



[JHEP 09 (2010) 091]

Later also seen in proton-lead collisions:

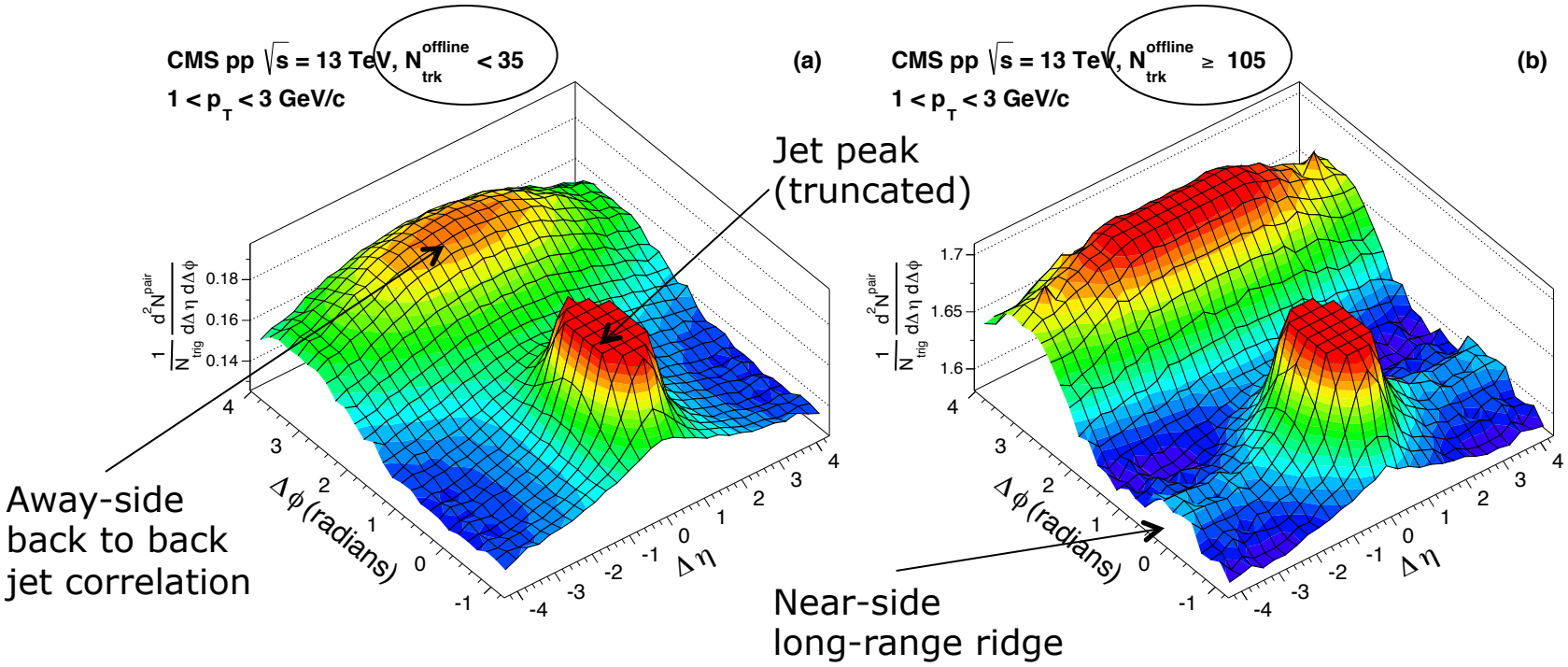


[PLB 718 (2013) 795-814]

- Unexpected in pp collisions
  ➔ origin remains unknown!
- P-Pb origin similar to Pb-Pb: hydrodynamics can describe data

Long-range near-side two-particle correlations

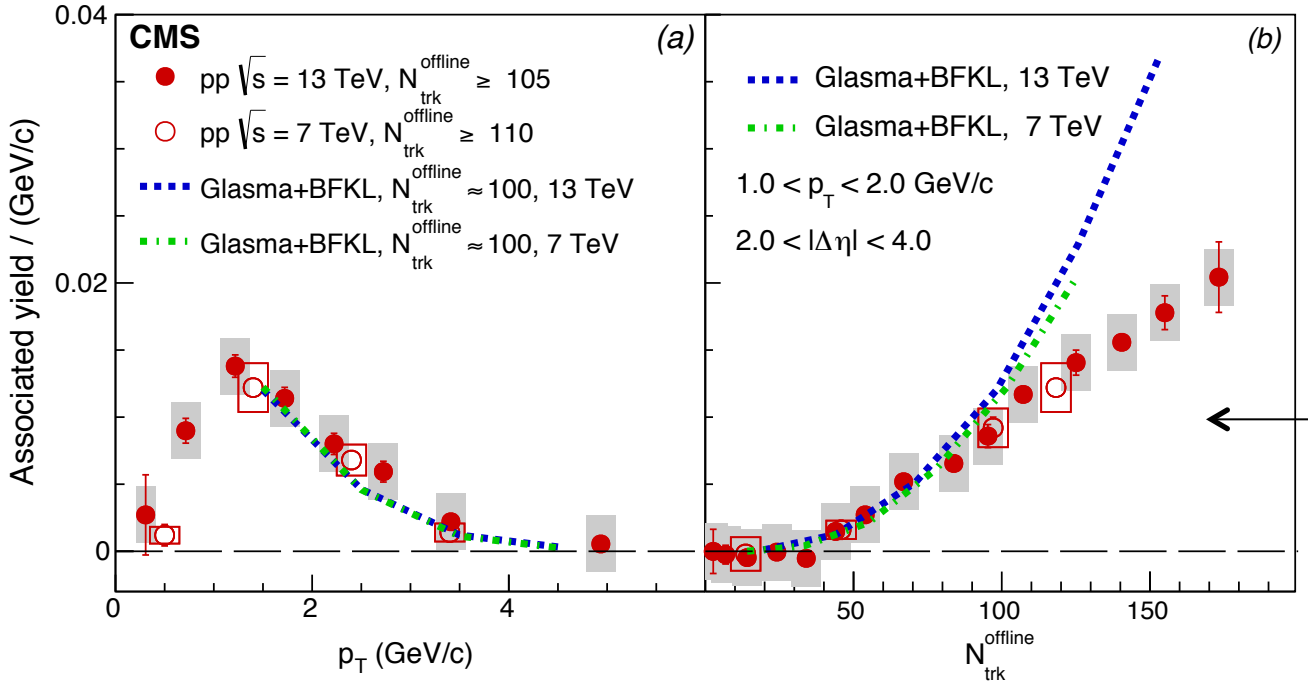
- Does the ridge magnitude depend on √s?
- Observation of long-range near-side correlations in high multiplicity proton-proton collisions at √s = 13 TeV during LHC Run II

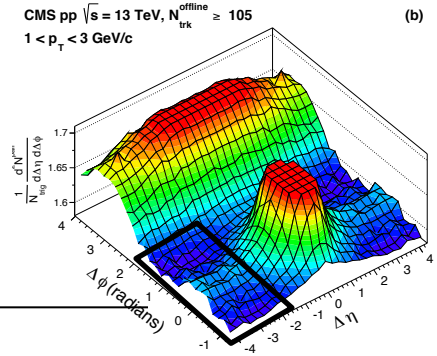


- Data collected at B = 3.8 T; L = 270 nb^{-1}; pile-up ~1.3

Long-range near-side two-particle correlations

- Calculation of associated yield as function of p_T and N_{trk}:

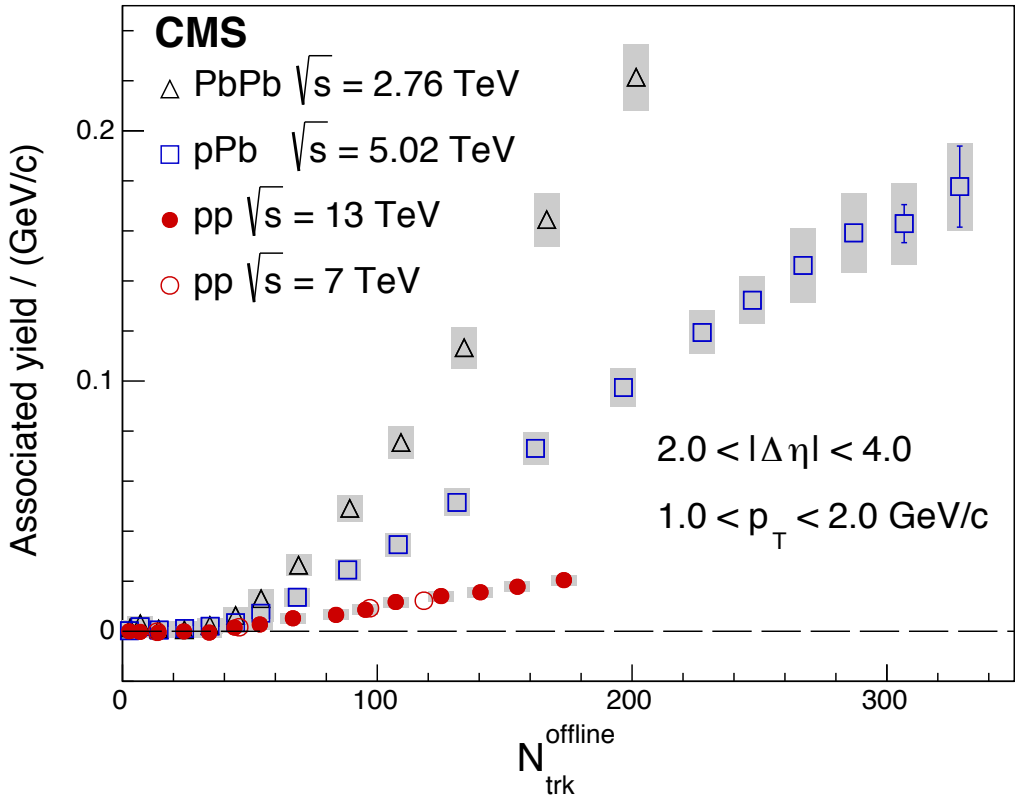




- Low multiplicity: no ridge-like correlations
- High multiplicity: ridge-like correlations with linear increase
  yield reaches maximum in p_T = 1 – 2 GeV/c range

Long-range near-side two-particle correlations

- Comparison of different systems:



- Ridge yield starts to increase linearly from N_{trk} ~ 40 in all 3 systems
- Strong system size dependence

Summary

- The CMS forward physics and small-x QCD program had a good start in LHC Run II, with low pile-up data available at B = 0T and 3.8T

- 3 measurements public, many more to come in the next months (inelastic cross section, $dE/d\eta$, dN/dp_T spectra, Bose-Einstein correlations,…)

- Pseudorapidity distribution of charged hadrons at $\sqrt{s}$ = 13 TeV:
  - ➔ first crucial test of our available phenomenological models
  - ➔ LHC tuned Monte Carlo generators can describe data well

- Underlying event measurements at $\sqrt{s}$ = 13 TeV:
  - ➔ important to understand contributions of MPI, ISR/FSR, BR
  - ➔ fundamental to constrain and tune existing models
  - ➔ LHC tuned Monte Carlo generators perform well

- Measurement of two particle correlations in pp collisions at $\sqrt{s}$ = 13 TeV:
  - ➔ observation of long-range near-side ridge structure in high multiplicity events
  - ➔ no centre-of-mass energy dependence observed
  - ➔ origin remains unknown