Universiteit Antwerpen

Soft QCD from ATLAS and CMS

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(On behalf of both ATLAS & CMS Collaborations)

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Outline

The ATLAS & CMS detectors

Soft QCD

Results :

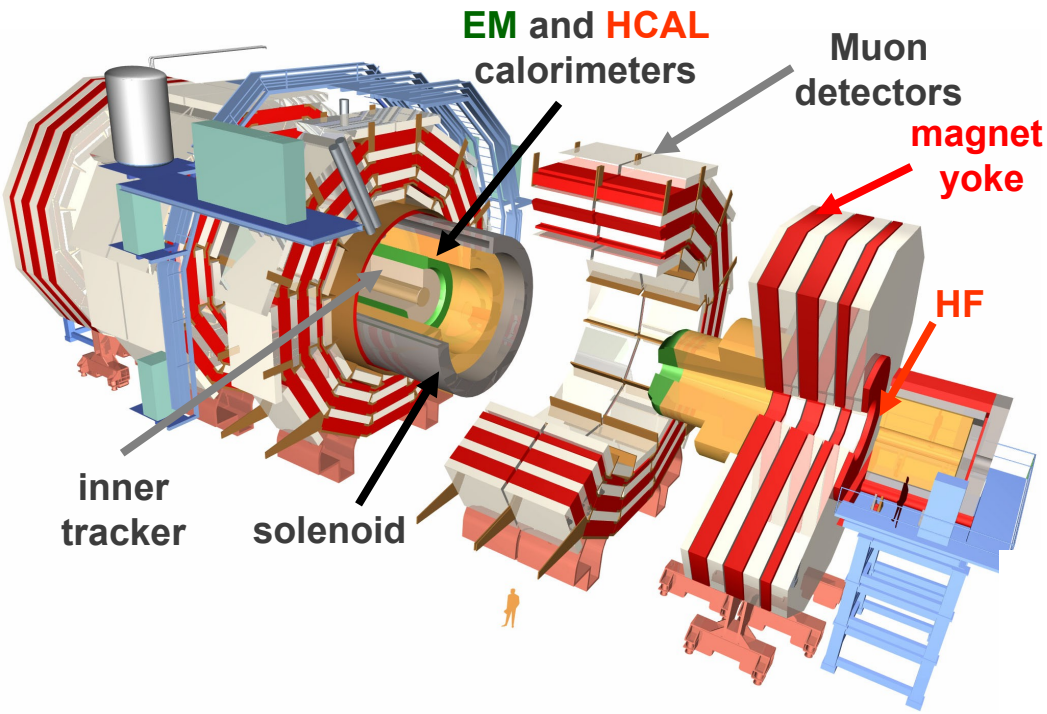
- Single charged particle spectra
- Multiplicities
- Strange particle production
- Inelastic cross-section / Gap cross-section
- Underlying Event:
  - leading track / trackjet
  - with Calorimeters / in Drell-Yan events
- Angular Correlations / 2-particle correlations / Ridge

MC tuning

Analysis Summary

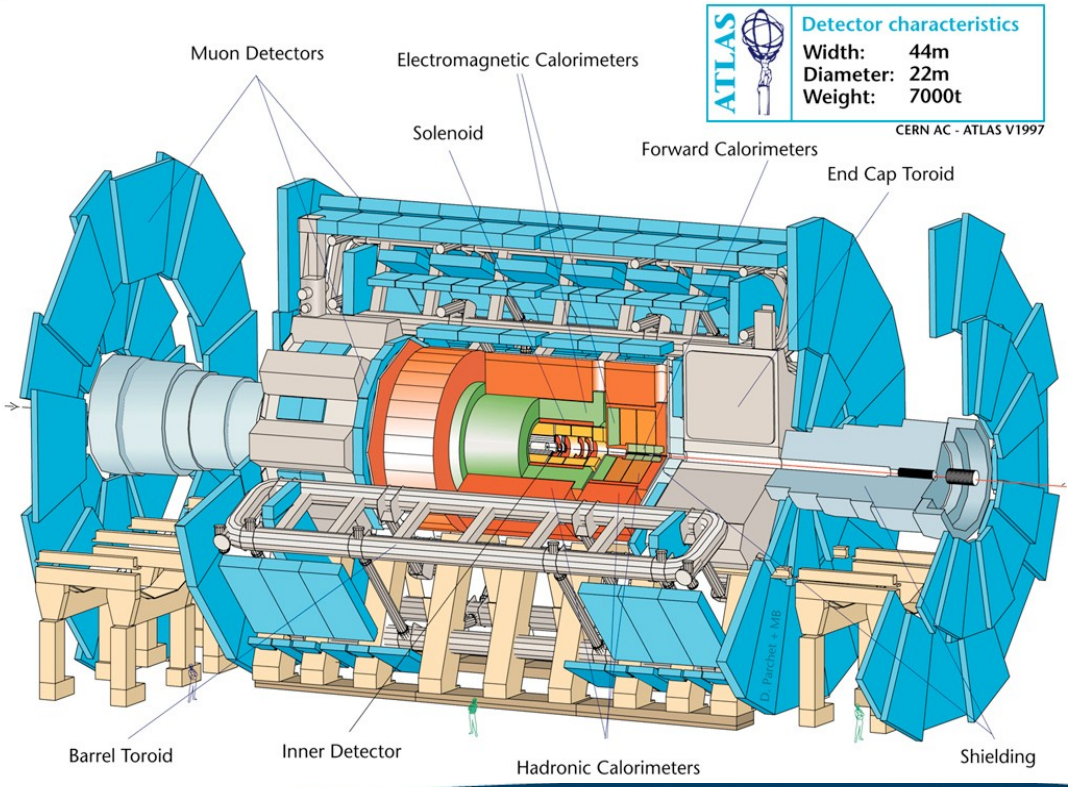
Conclusions

The ATLAS & CMS detectors



CMS η coverage:

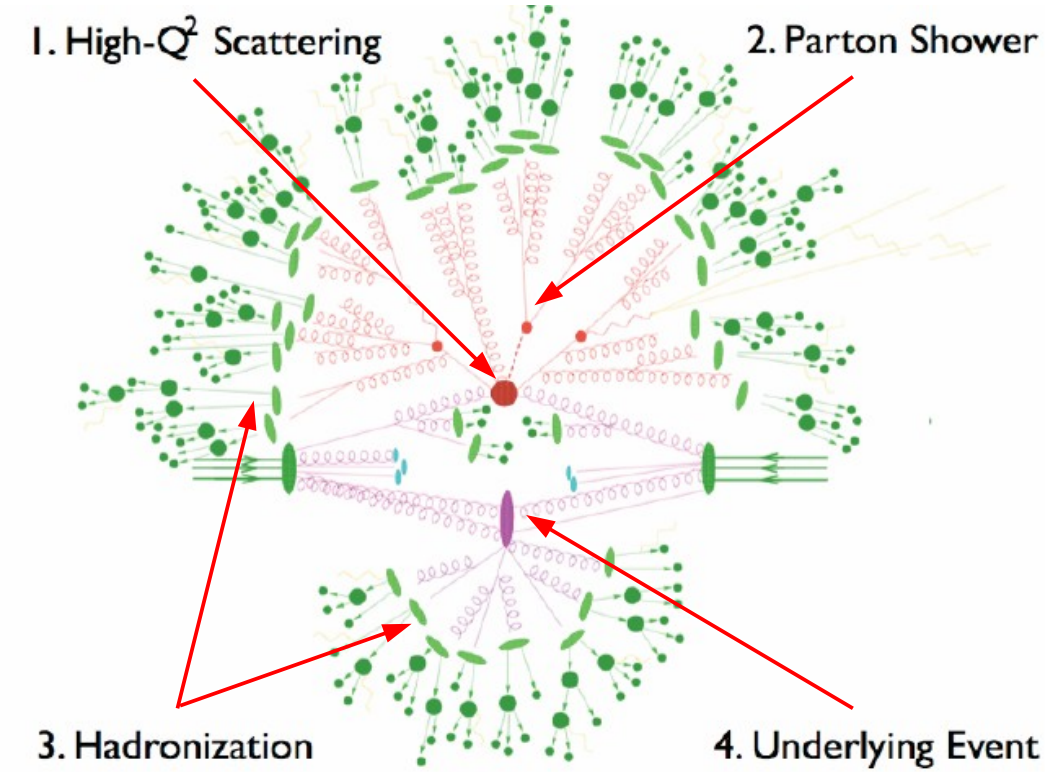
Tracker (Pixel + Strip)	$\|\eta\| < 2.4$
Calorimeters (EM+HCAL)	$\|\eta\| < 3.0$
HF Calorimeter	$3 < \|\eta\| < 5$
Muon Detectors	$\|\eta\| < 2.4$



Soft Interactions and Underlying Event

The majority of the pp collisions are soft
→ no "perturbative" predictions
→ need to model them phenomenologically

==> Use Monte-Carlo (MC) description to correct data:

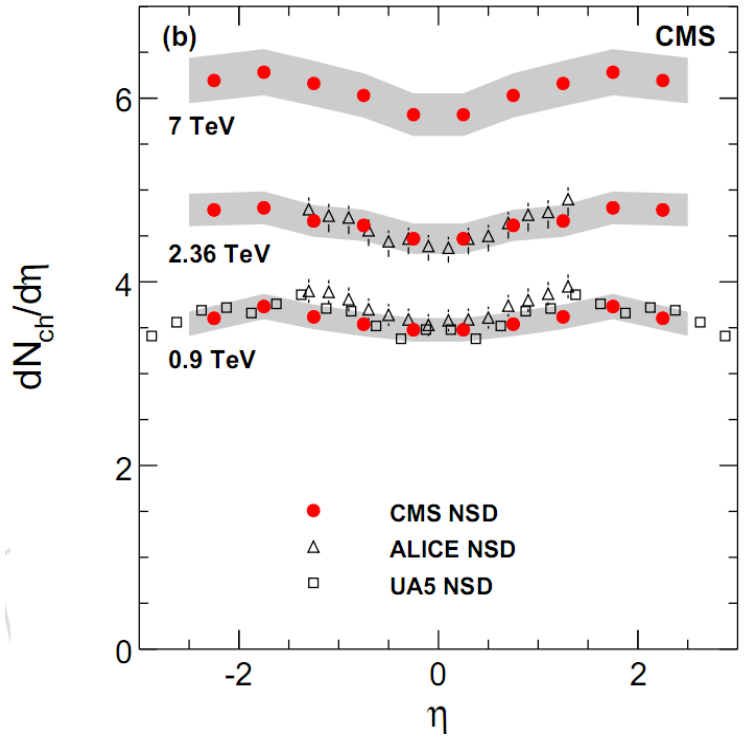


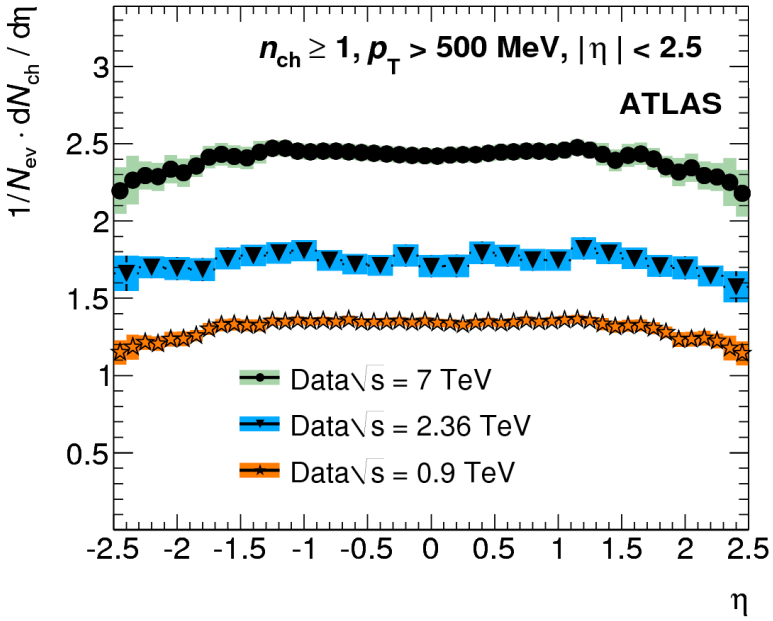
- PS, UE and hadronization models tuned on previous (low energy) data
- Different models available diverging at high energy prior to LHC

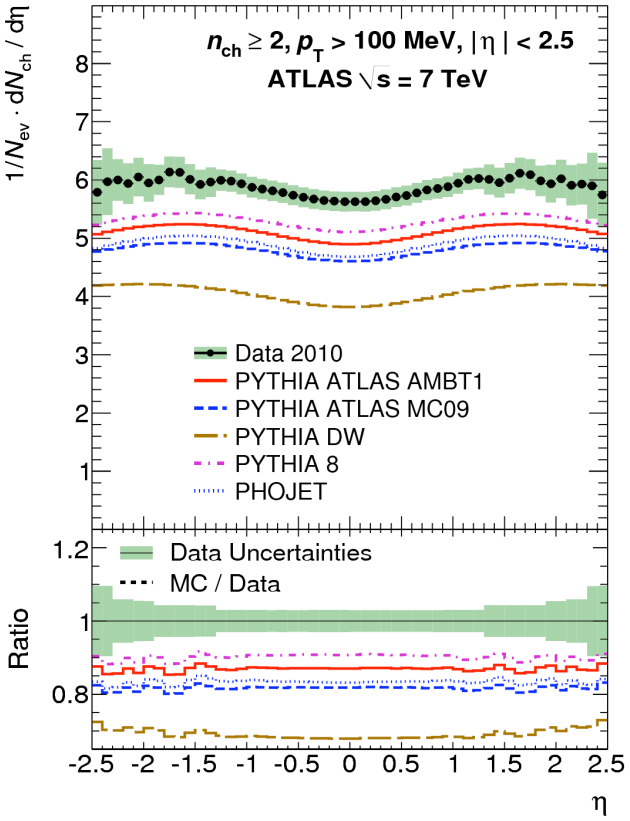
→ Early LHC data give us a unique chance to fill gaps in our knowledge on soft QCD

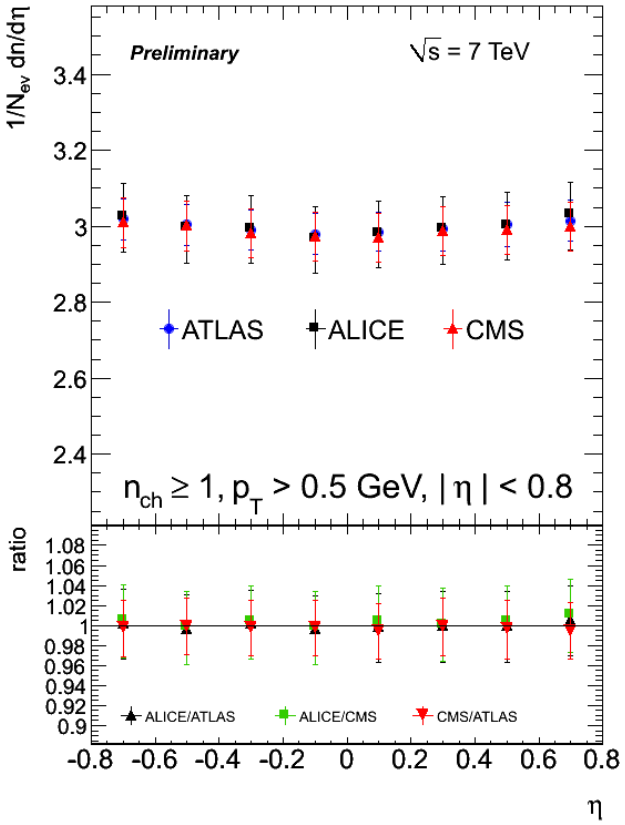
→ Reference for high energy pp collisions and heavy ions run

Single Particle Spectra – η



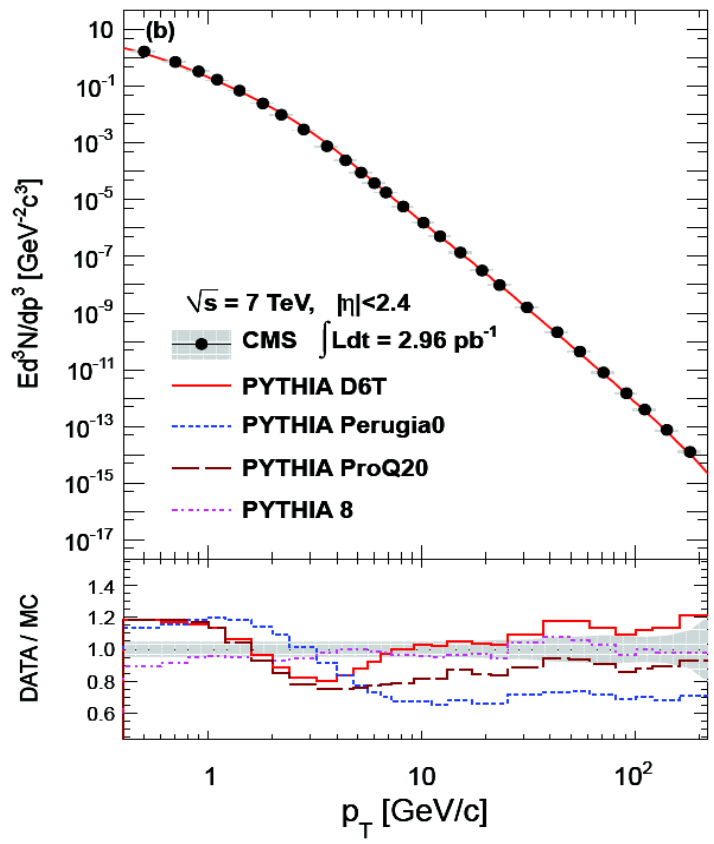


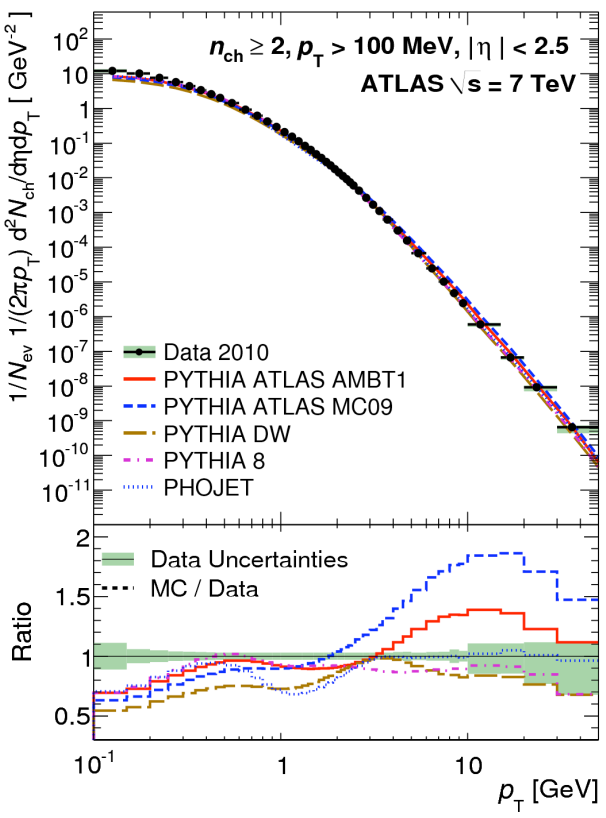


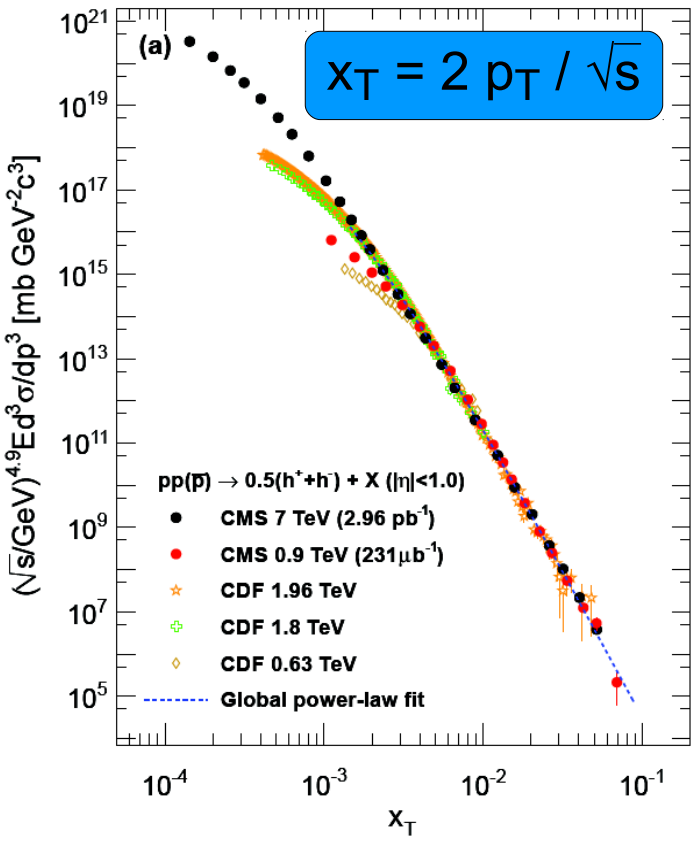


- Several event selections, pt/η acceptances, energies
- Very high particle production at increasing energy
- MC predictions are globally too low, specially pre-LHC tunes
- MBUEWG : common set of event Sel. + acceptance
  => excellent agreement between exp.
  => useful for tuning

Single Particle Spectra – p_T





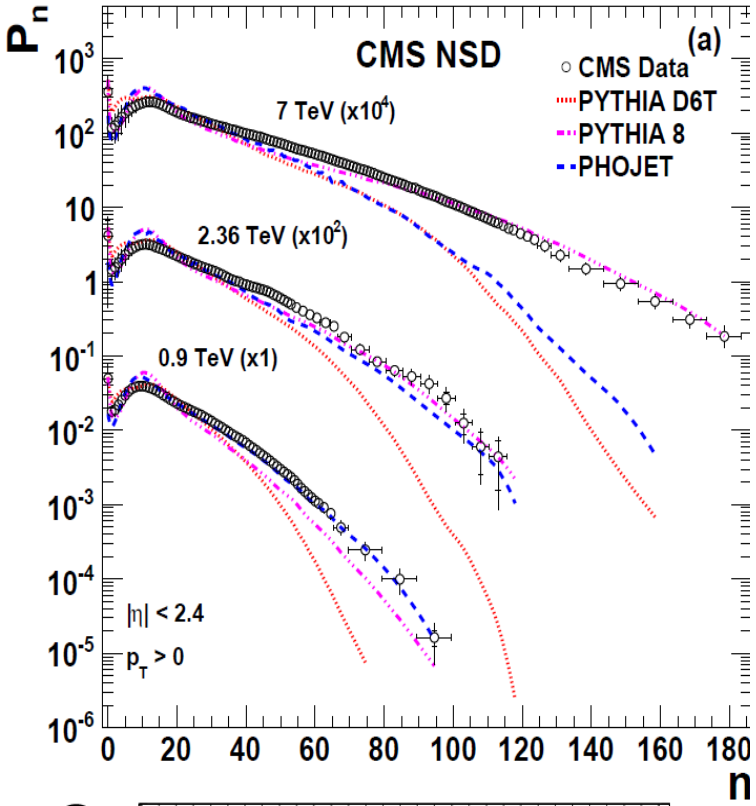


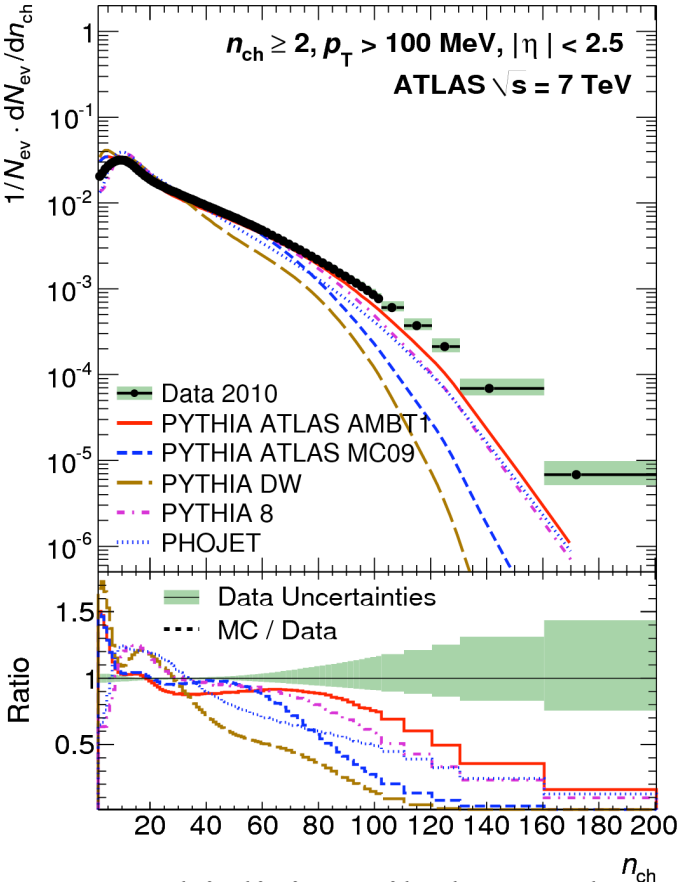
- Again, several event selections, p_T/η acceptances, energies

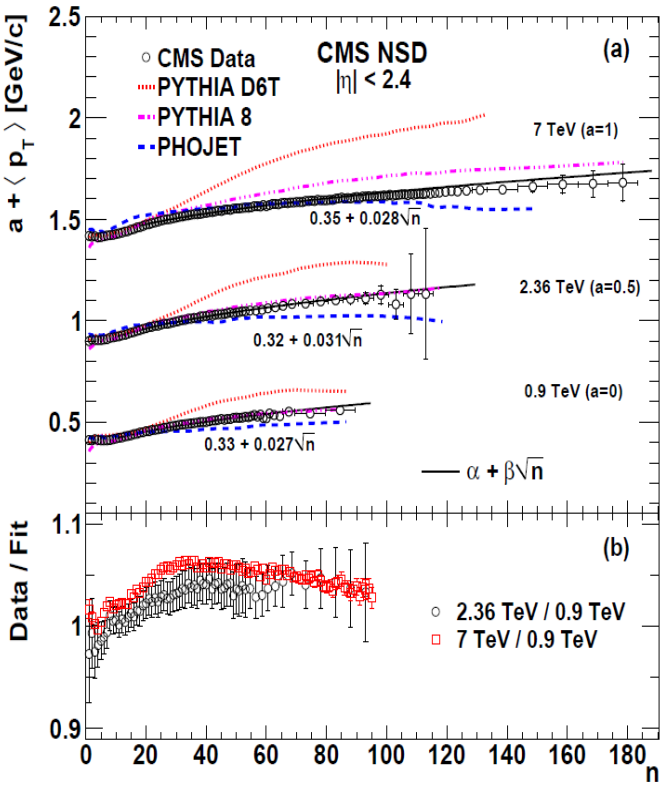
- Pre-LHC tunes tend to predict too strong events

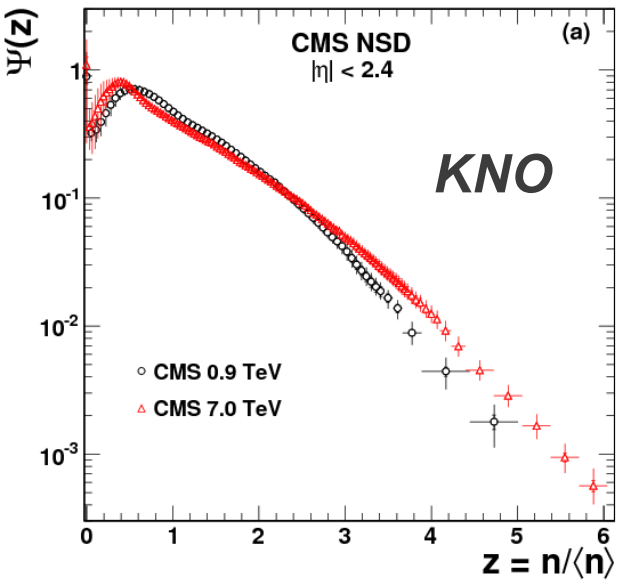
- Simple x_T scaling allows to derive p_T spectrum at 2.76TeV, useful for HI analysis, like jet quenching

Multiplicities



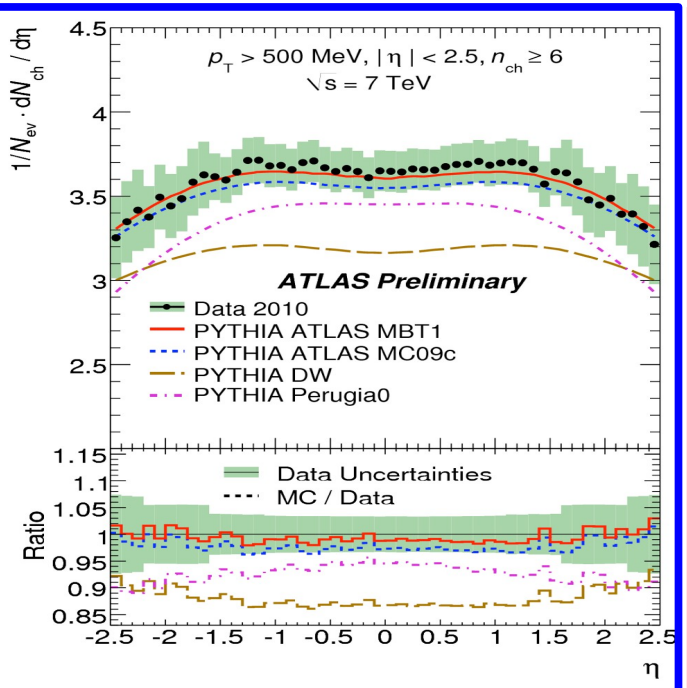


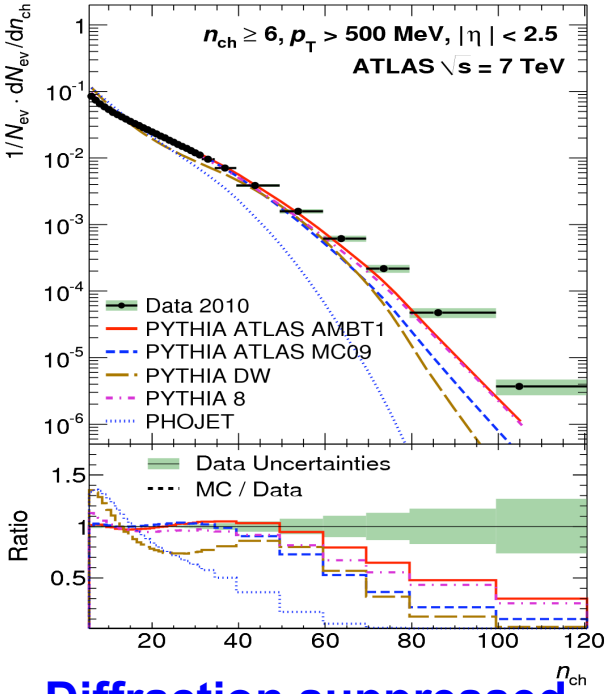




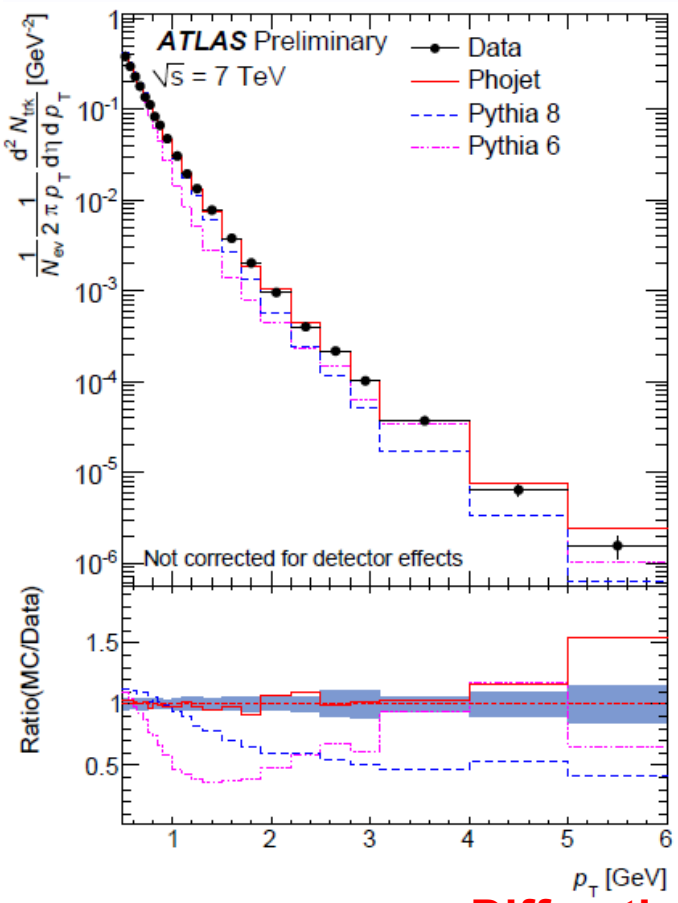
- Large multiplicity tail observed at 7 TeV (cf. dN/dη)
- Presence of second NBD, sign of MPI ?
- $\langle p_T \rangle$ vs n scales with energy
- MCs can't describe all multiplicities at all energies
- Most MC/tunes can not describe simultaneously the multiplicity and the p_T dependence
- KNO scaling violation for large η acceptance, confirmed by C_q moments analysis. Holds for small η.

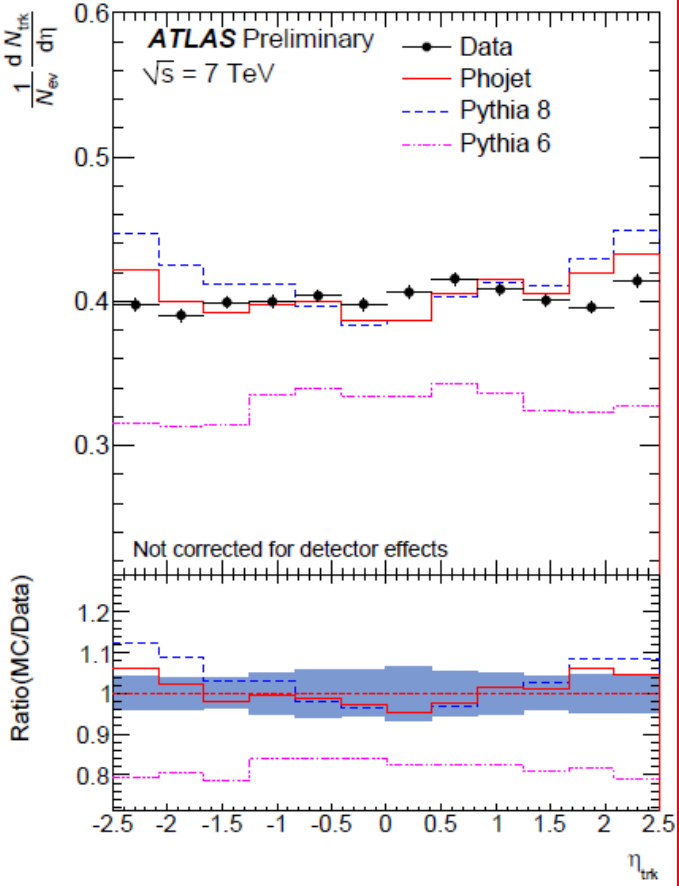
Single Particle Spectra – Diff. suppressed/enriched





Diffraction suppressed





Diffraction enriched

Diffraction suppressed:

- New tunes describe best the data, but there are still some discrepancies

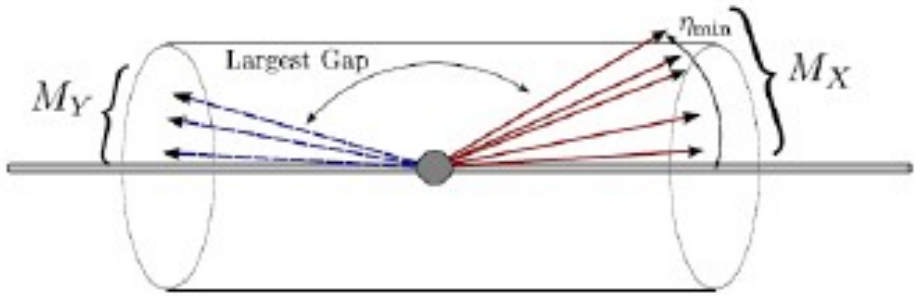
Diffraction enriched:

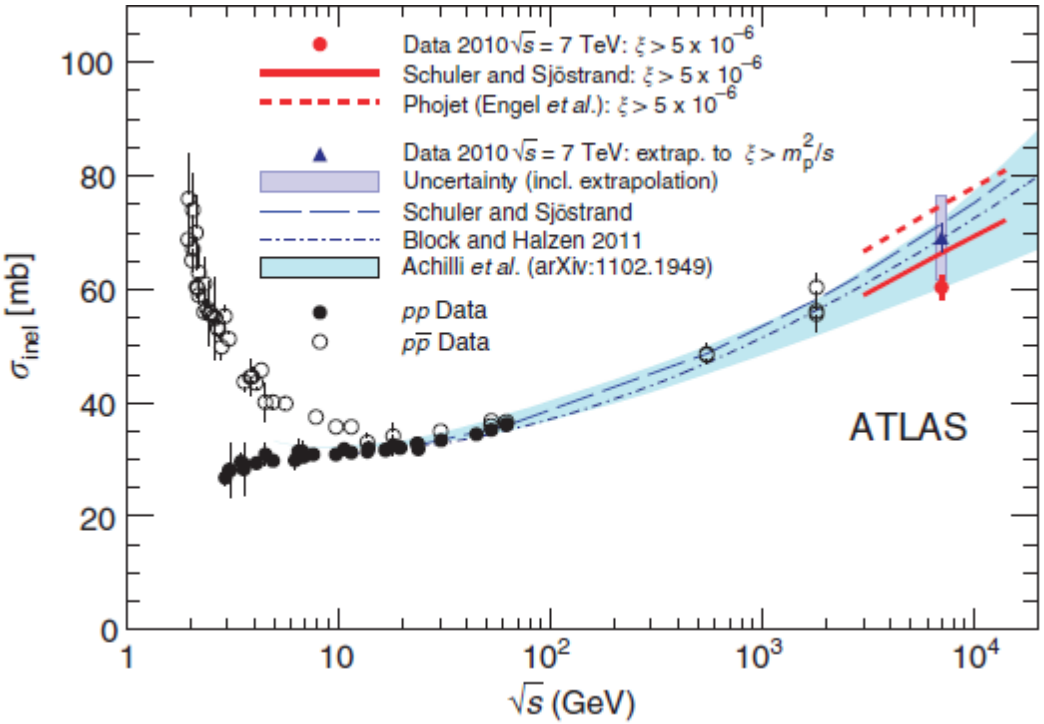
- Pythia8/Phojet have similar diffraction models, close to data, while Pythia6 is very different

Inelastic cross-section

Define $\xi = M_x^2 / s$ using largest rapidity gap

$$\sigma_{inel} = \frac{N_{evts} - N_{bckg}}{\epsilon \cdot L} \cdot \frac{1 - f_{\xi}}{\epsilon_{sel}}$$





$\sigma(\xi > 5\times10^{-6})$ (mb)	
ATLAS Data 2010	60.33±2.10(exp.)
Schuler and Sjöstrand	66.4
Phojet	74.2
Ryskin *et al.*	51.8–56.2

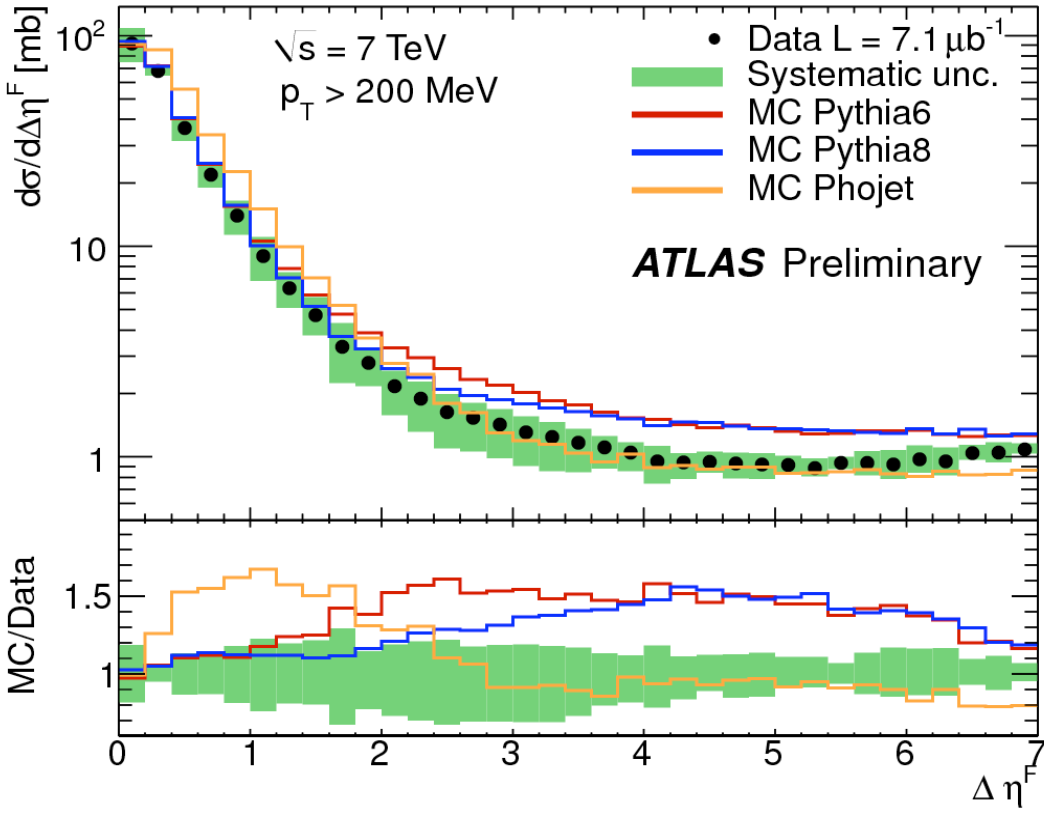
$\sigma(\xi > m_p^2/s)$ (mb)	
ATLAS Data 2010	69.1±2.4(exp)±6.9(extr.)
Schuler and Sjöstrand	71.5
Phojet	77.3
Block and Halzen	69.0±1.3
Ryskin *et al.*	65.2–67.1
Gotsman *et al.*	68
Achilli *et al.*	60–75

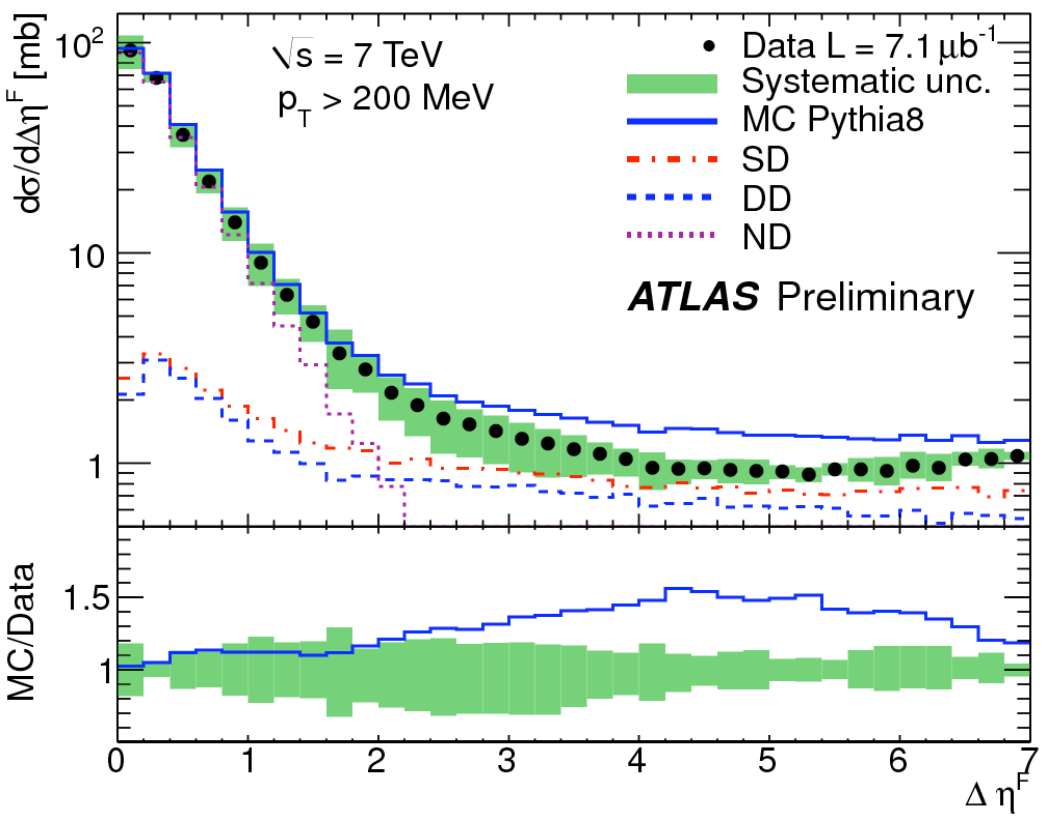
Measurement and theoretical predictions of the inelastic cross-section for the restricted kinematic range, $\xi > 5\times10^{-6}$, and for the full kinematic range, $\xi > m_p^2/s$. The experimental uncertainty (exp.) includes the statistical, systematic and luminosity uncertainties. The extrapolation uncertainty (extr.) only applies to the full kinematic range and is listed separately.

Measured cross-section is lower than expected from models

Gap cross-section

Diffractive events have large rapidity gaps $\Delta\eta$
=> measure cross-section with respect to $\Delta\eta$

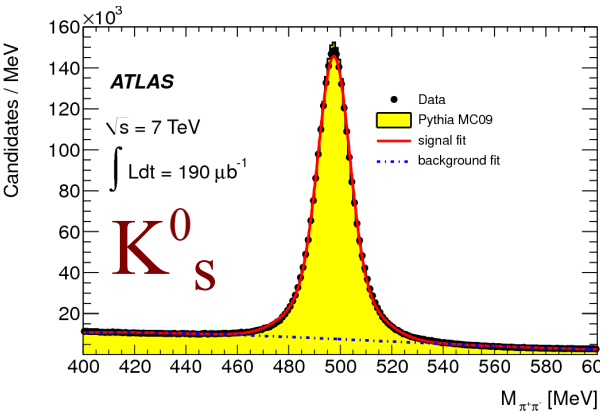


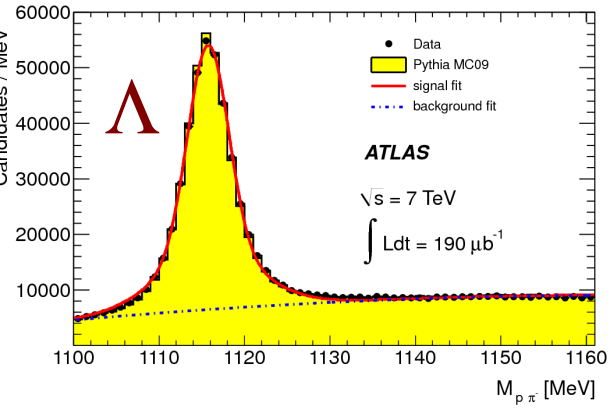


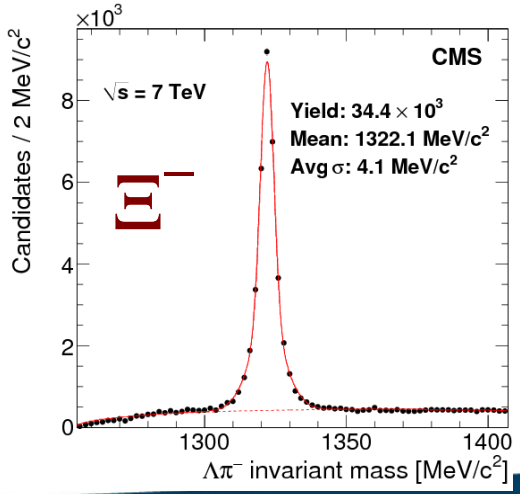
- MCs behave very differently, but they all overestimate diffractive fraction

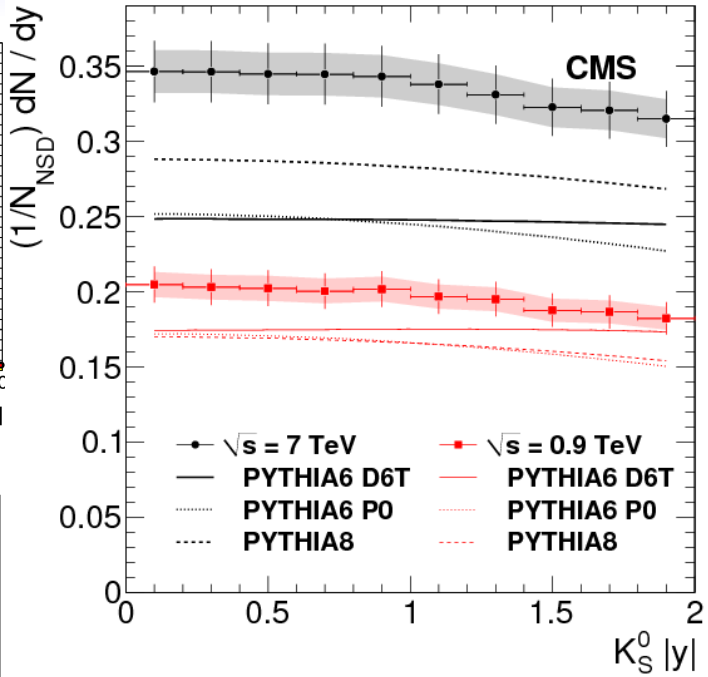
- None of them describe the data correctly

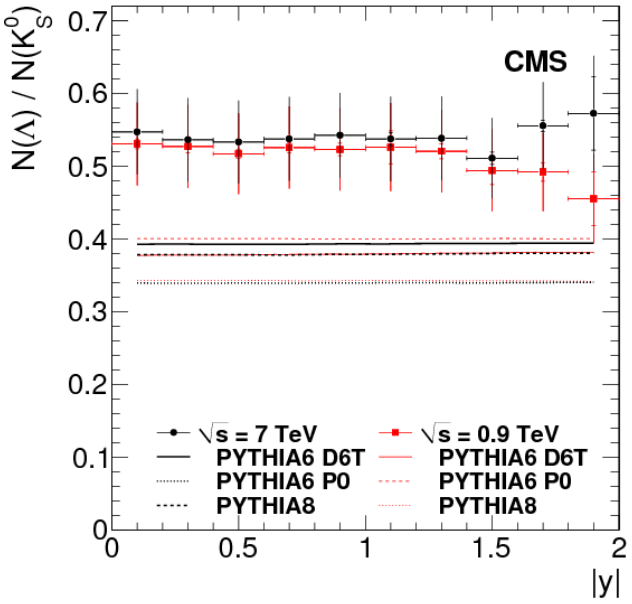
Strange particle production

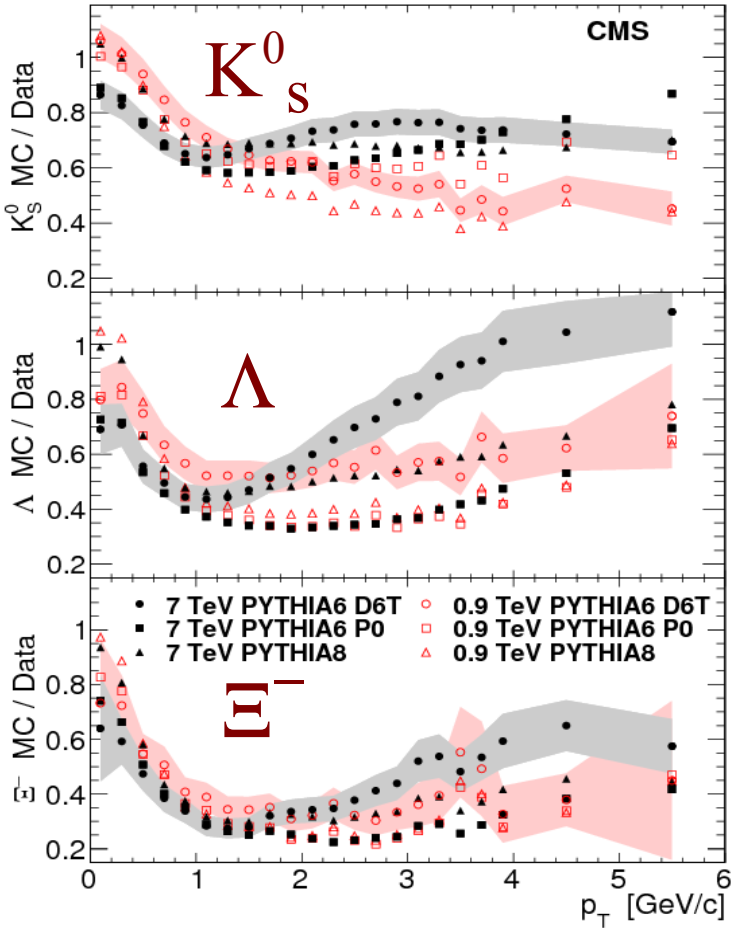








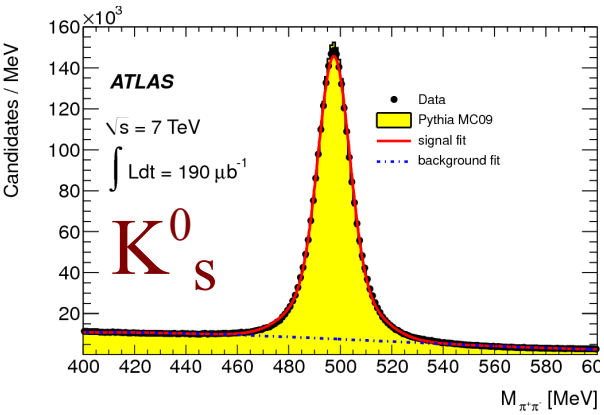


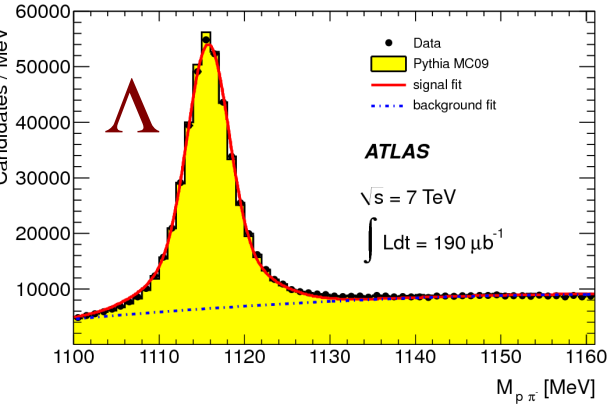


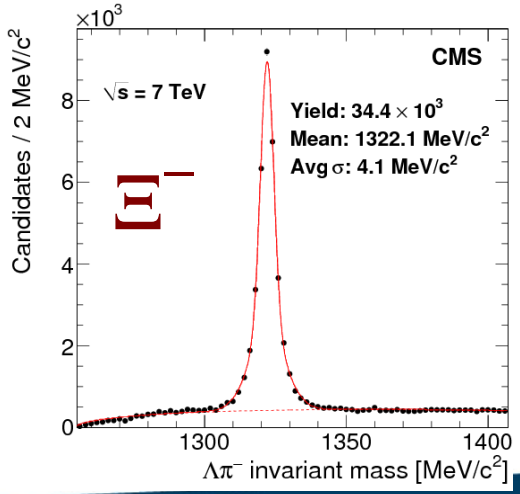
- Same behavior as ch. particles
- MCs can't reproduce distributions, mismatch increases with mass

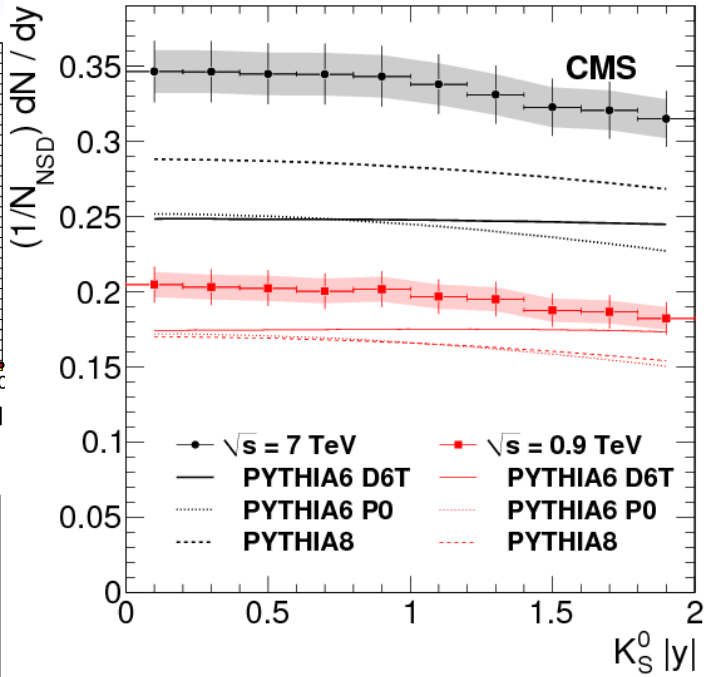
- production ratios seem energy-independent => no sign of QGP

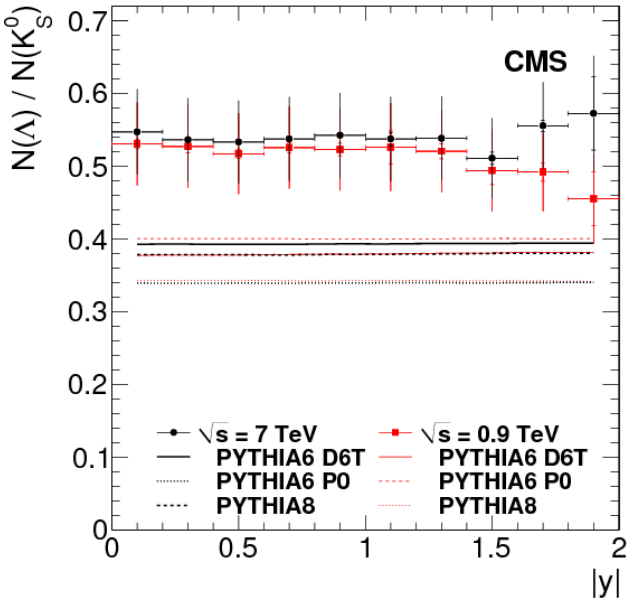
Strange particle production

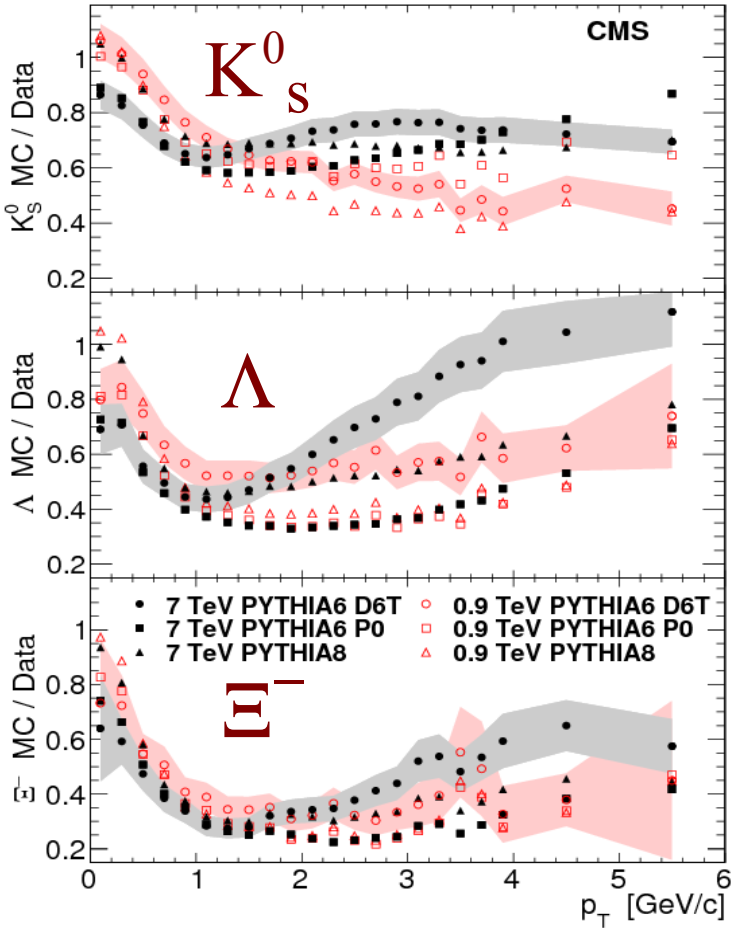












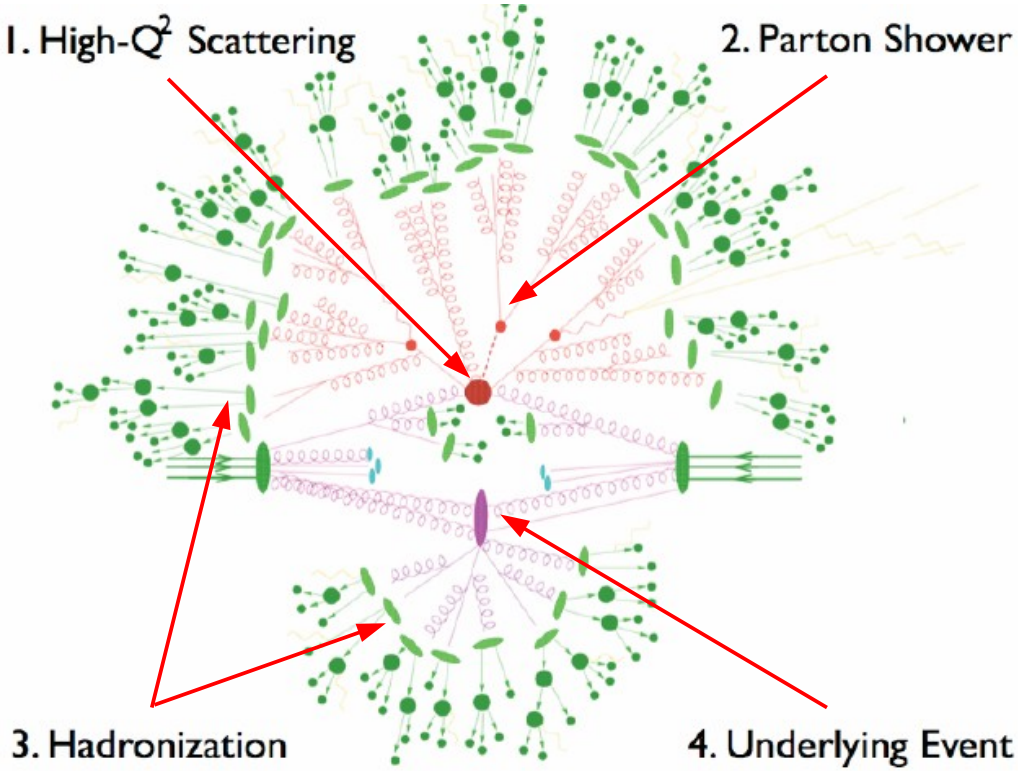
- Same behavior as ch. particles
- MCs can't reproduce distributions, mismatch increases with mass

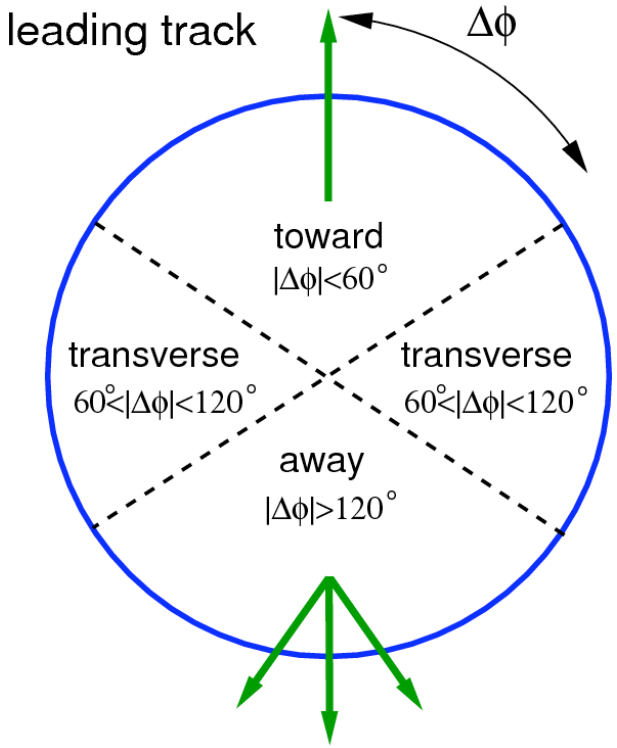
- production ratios seem energy-independent => no sign of QGP

Underlying Events - theory

- Take events with a hard probe

  => Look at everything but this hard probe





3 topological regions:

- **toward**: contains the hard scatter
- **away**: opposite side of the hard scatter
- **transverse**: interesting for UE study

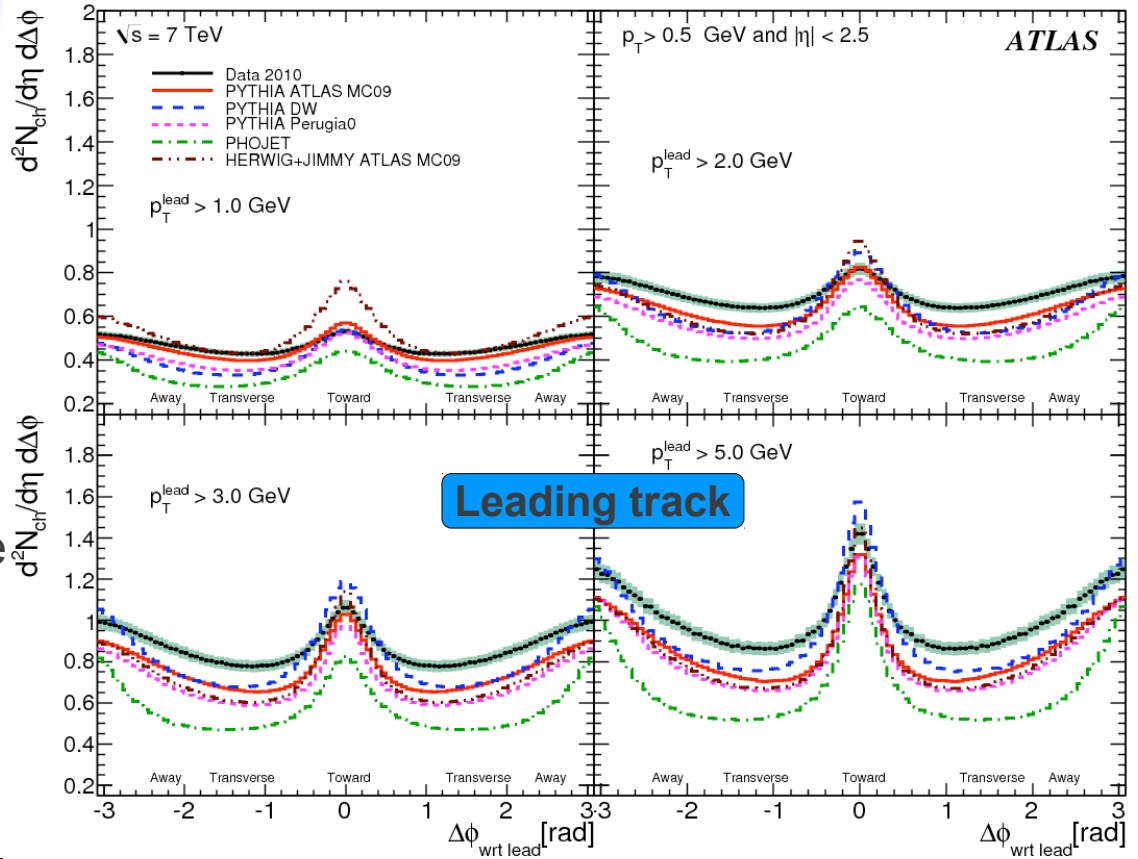
Underlying Event - tracks/trackjets approach

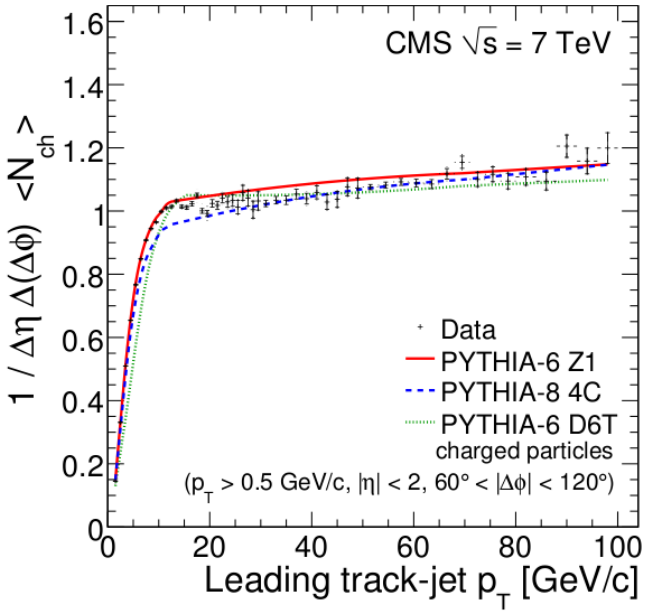
- MC underestimate activity, specially in transverse region, and even more at low-p_T

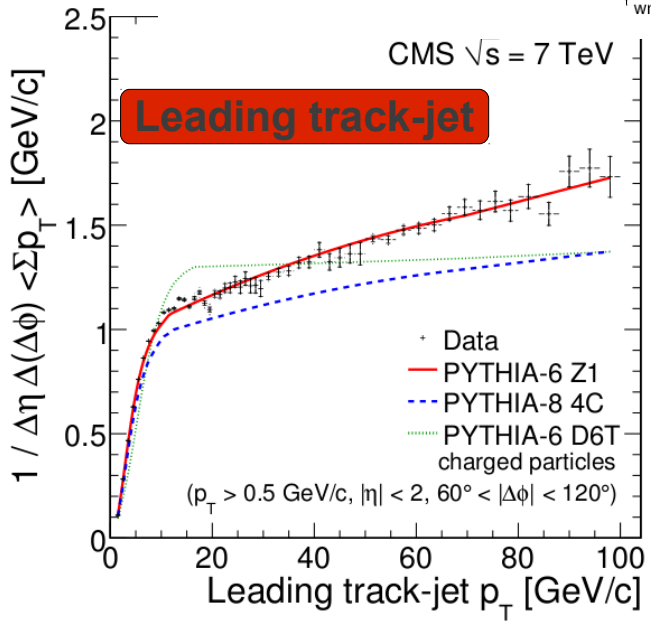
- For <N> & Σp_T VS leading object p_T, fast rise at low-pt due to increase in MPI activity, then reaches plateau

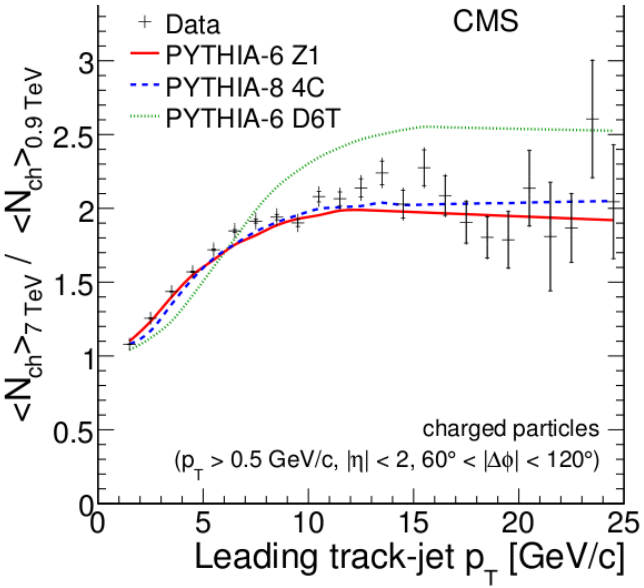
- Ratios 7TeV / 0.9TeV show strong increase of hadronic activity for same value of hard scatter p_T

- With results at 0.9TeV, used to tune MC

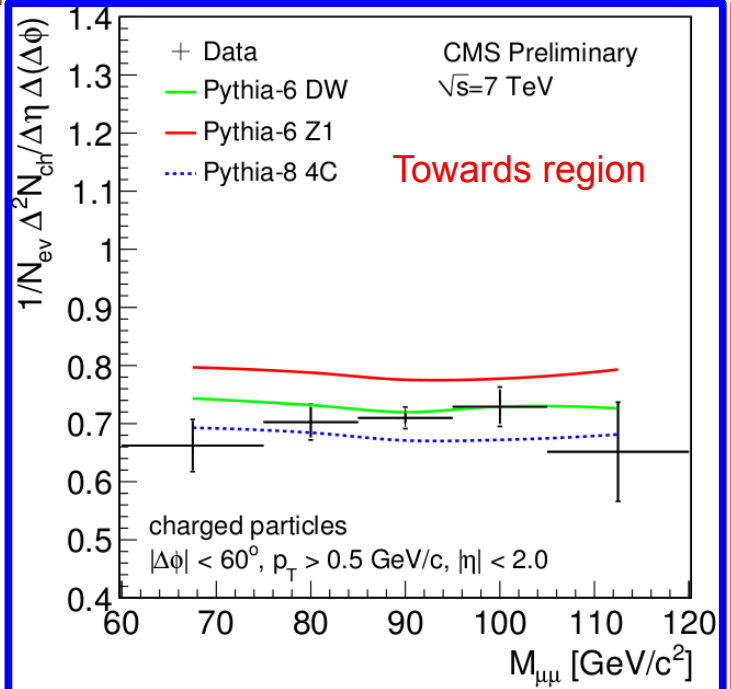


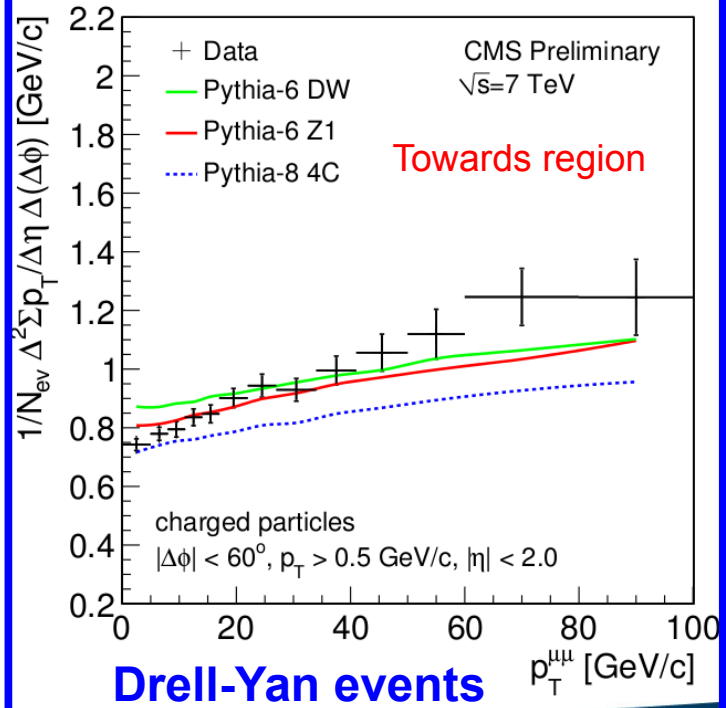




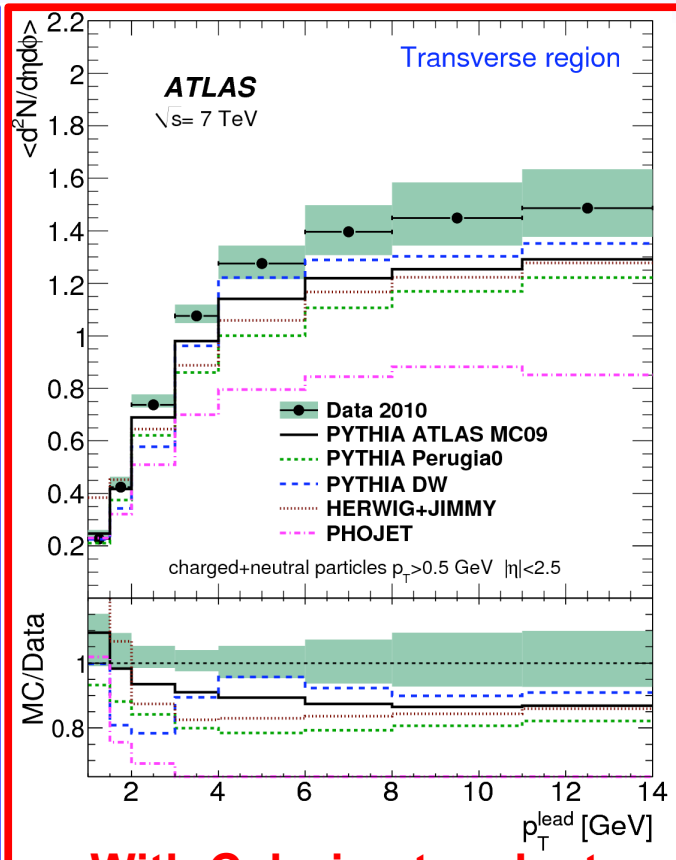


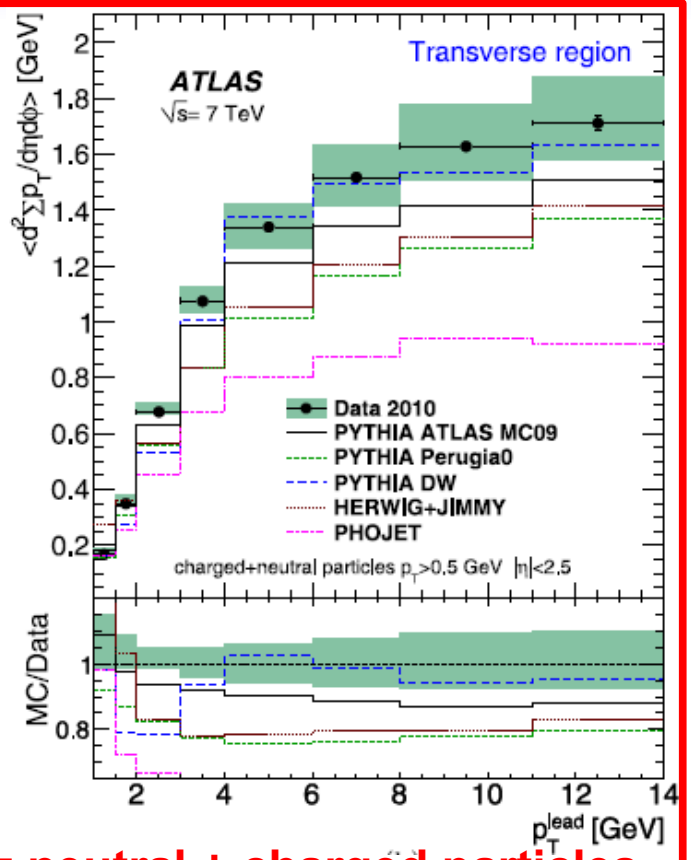
Underlying Event – Drell-Yan/Calorimeter





Drell-Yan events





With Calorimeter clusters = neutral + charged particles

Both measurements independent from tracks => constrain model

Drell-Yan:

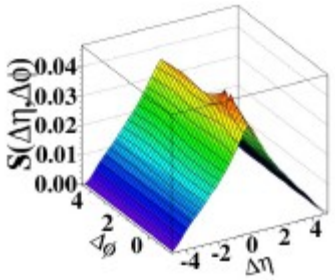
- densities are independent of Mμμ (saturation of MPI)
- growth with p_T attributed to ISR increase

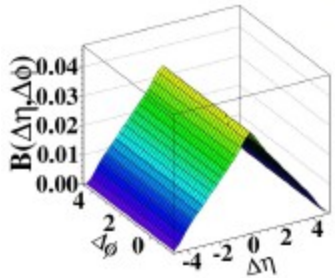
Calorimeters:

- Transverse activity is again underestimated in MC

2-particle correlations

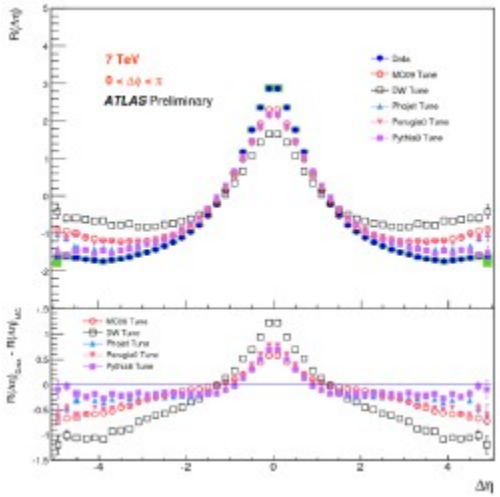
$$R(\Delta\eta,\Delta\phi)=\left\langle(\langle N\rangle-1)\left(\frac{S_N(\Delta\eta,\Delta\phi)}{B_N(\Delta\eta,\Delta\phi)}-1\right)\right\rangle_{bins}$$

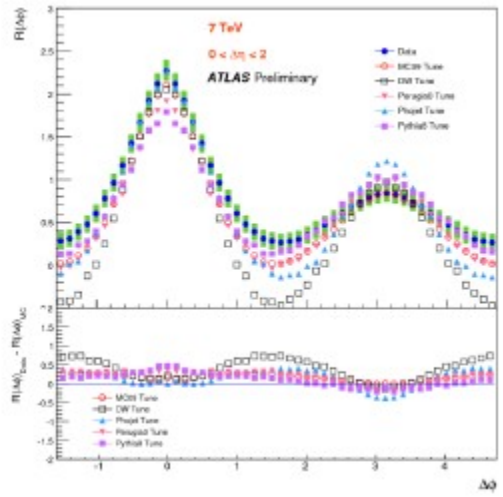


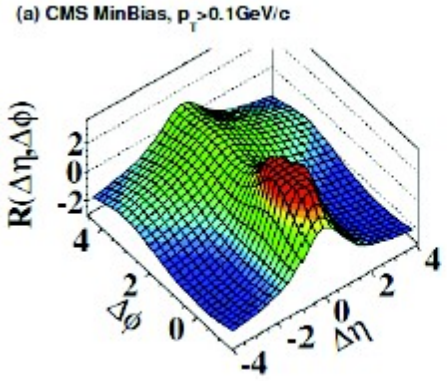


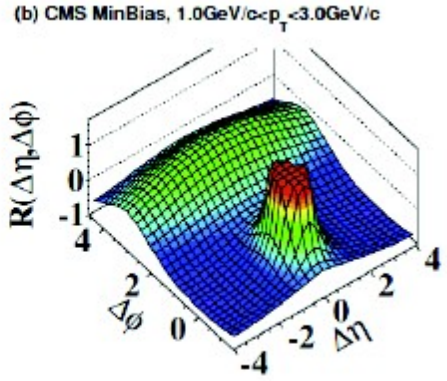
Correlated & uncorrelated pairs from same events
SIGNAL

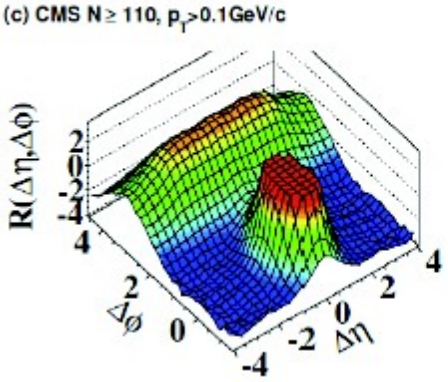
Uncorrelated pairs from different events
BACKGROUND

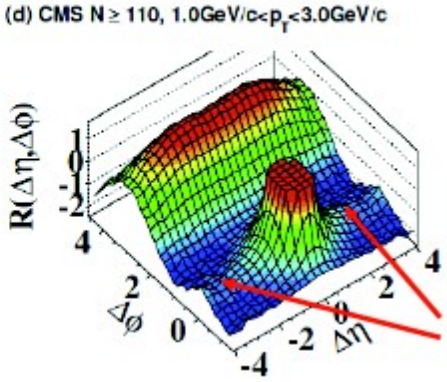






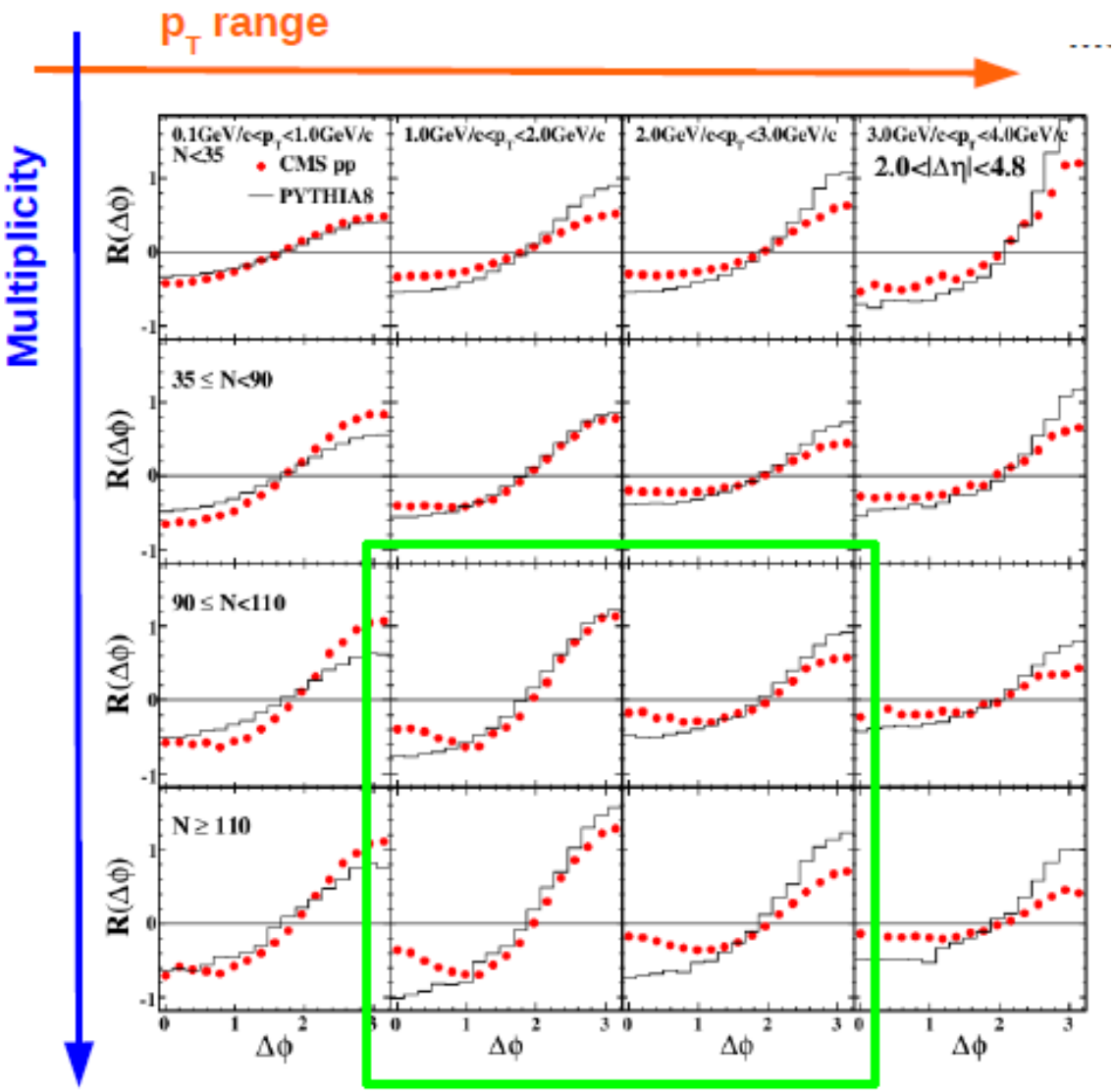


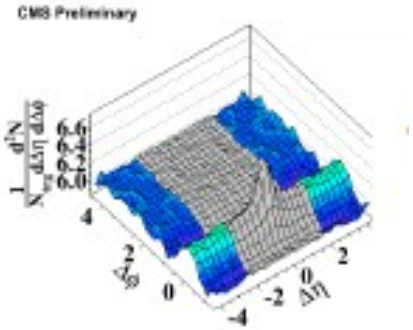




- Jet + away structures as expected
- MCs don't reproduce the correlation strength
- For N>110 & 1<p_T<3, a ridge structure appears (see next slide)

2-particle correlations – Ridge effect





- Look at $\Delta\phi$ distribution for η away from the jet structure

- Peak emerges at $\Delta\phi = 0$ for high nch events and intermediate pt range

- Not reproduced by MC !!

- A lot of different ideas trying to explain it's origins ...

Monte-Carlo tuning

Pre-LHC tunes don't predict correctly minbias distributions

=> MC need to be tuned on the new 7TeV results !

MBUEWG (slide 5) to get common plots, easier for tuning purposes

Used RIVET + Professor for tuning. A lot of analysis are implemented from both exp in RIVET, to be used by everyone

Both experiments have a series of new Pythia6 tunes, using different distributions for the tuning

ATLAS:

MC09: tuned on CDF UE results
AMBT1: used diffraction suppressed (nch>6)
AMBT2: tuned on MB results
AUET2: tuned on UE results

ATL-PHYS-PUB-2010-002
arXiv:1010.0893v1
ATL-PHYS-PUB-2011-008

CMS:

Z1: tuned on UE events
Z2: CTEQ6L pdfs + retuned to UE
Z1f & Z2f: also added forward results

- ==> It is hard to get both MB & UE right

ATLAS & CMS papers

ATLAS public page:

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults#Soft_QCD

6 papers published

4 CONF notes

CMS public page:

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsQCD#Results

10 papers published

3 PAS notes

==> Links to papers, figures, durham DB

Conclusion

- Understanding of soft QCD contributions is crucial for new physics searches and precision measurements of Standard Model processes
- Pre-LHC Monte Carlo tunes do not describe the data well in all aspects
  → Monte Carlo tuning effort ongoing
- Strangeness production has been investigated showing similar discrepancy
- Common efforts between the LHC experiments to provide well-defined plots is starting to show results
- Underlying events have been well studied with different hard probes
- Angular particle correlations show unexpected Ridge feature
- Many new results to come, for instance with 2.76TeV data.

THANKS