Soft Physics with a Proton Tag, Analysis report
LPCC Forward Physics, CERN

Tim Martin

University of Warwick

February 19, 2014

Introduction

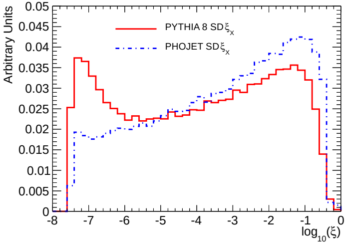
Look at some standard minimum bias analyses: Energy flow for $|\eta| < 4.8$, charged particle multiplicity spectra for $|\eta| < 2.5$ & diffractive gaps plus $\Sigma E \pm p_Z$.

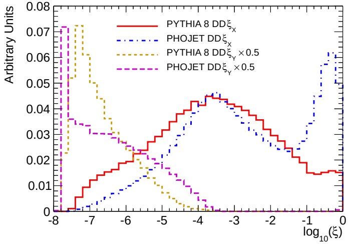
Add the requirement of a single proton tag from AFP at 210m or ALFA at 240m.

- Today I will go through comparisons of different generator predictions at $\sqrt{s} = 14$ TeV highlighting areas of greatest model uncertainty.
- These results are to highlight how preferential selection on *diffractive style* topologies with ultra-forward protons may be used as a handle on the modelling of the bulk of the diffractive cross section in Run-II.
- All variables shown are ones we know we can measure.

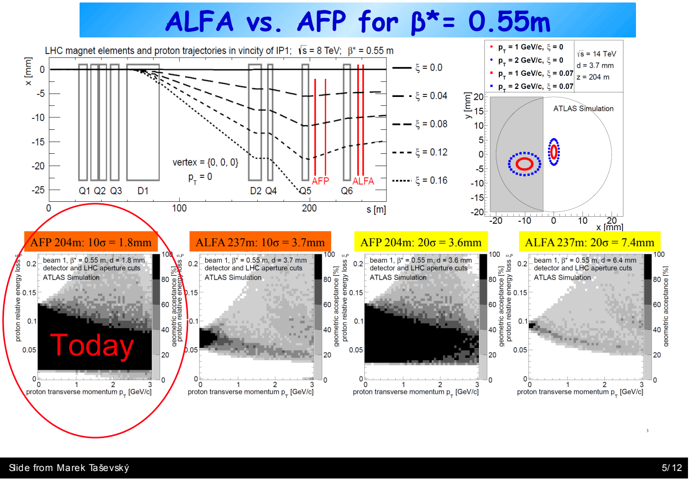
Diffractive Kinematics: Pomeron Flux

- Parametrised by ξ parameter. $\xi = M_X^2/s$ where M_X is the invariant mass of the larger diffractive system (c.f. M_Y).
- For a diffractivly scattered proton, ξ is equivalent to the fractional energy loss of the proton.
- Flux is $\approx$ flat in $\log(\xi)$ due to $1/M_X^2$ dependence on cross section from Regge theory.
- Different flux models & formalisms in different generators and tunes.

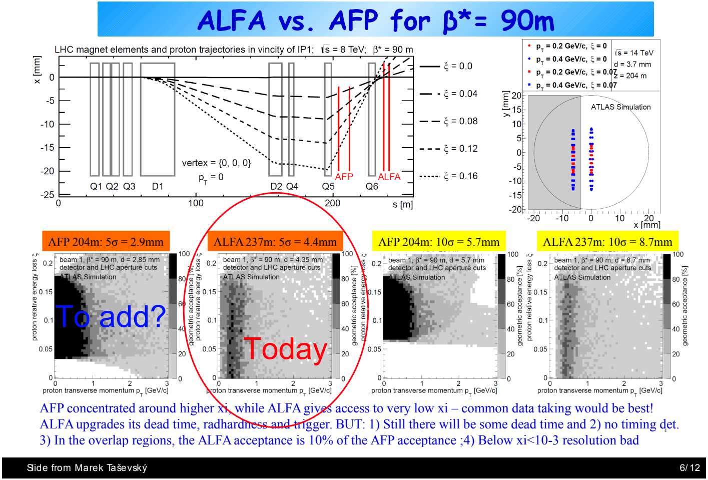




R. Staszewski, M. Taševský, M. Trzebiński



R. Staszewski, M. Taševský, M. Trzebiński

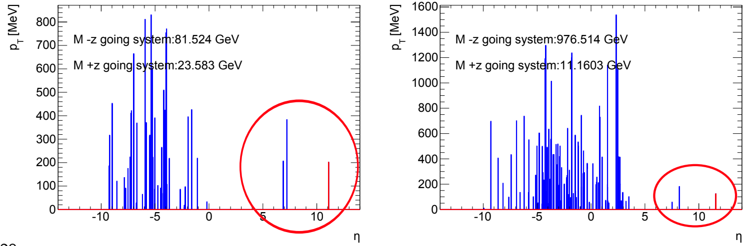


MC Choice and tunes

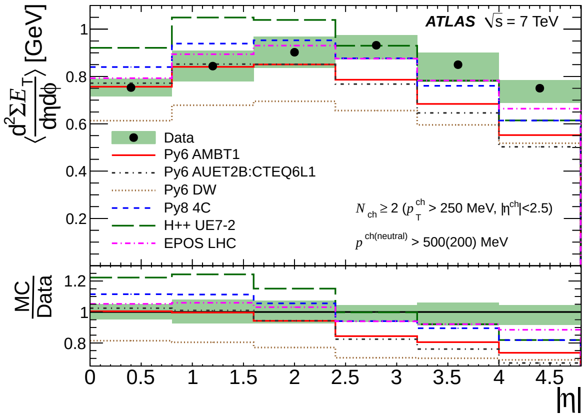
- Using three different generators to get a spread of predictions.
  - `PYTHIA 8 A2 MSTW2008LO` [ATL-PHYS-PUB-2012-003]
    - ATLAS tune of PYTHIA to 900 GeV and 7 TeV data, based on 4C but with x-dependent matter profile and without rapidity-ordered spacelike emissions. Past analyses [arXiv:1208.6256] have shown the dependence on the choice of PDF, this is not investigated as the effect is relativly small.
    - Explicit diffractive classifications.
  - `HERWIG++ UE-EE-4-CTEQ6L1`
    - https://herwig.hepforge.org/trac/wiki/MB_UE_tunes
    - With automatic evolution of minimum $p_{\mathrm{T}}^{\mathrm{min}}(s) = p_{\mathrm{T},0}^{\mathrm{min}}(\sqrt{s}/E_0)^b$ and cluster hadronisation.
  - `EPOS LHC` [Phys. Rev. C 83 (2011) 044915]
    - Parametrised approximation to hydrodynamic evolution of initial state using a parton based Gribov-Regge theory tuned to LHC data.

Soft Diffraction with p-tag.

- Forward acceptance for diffractivly scattered protons is a relatively high ξ, O(%) or $p_T \neq 0$, whereas diffractive physics at the LHC spans down to $\xi \approx 10^{-8}$.
- Dissociated systems at large ξ are harder to distinguish from non-diffractive interactions.
- **However, double-dissociative diffraction with a forward proton through a baryonic resonance may allow for lower, otherwise inaccessible diffractive masses to be enanced.**

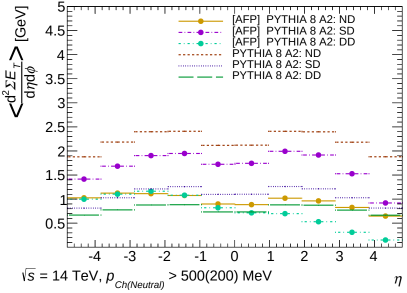


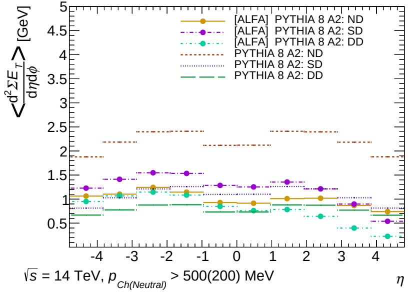
Energy Flow


ATLAS $\sqrt{s}$ = 7 TeV
$\langle \frac{d^2\Sigma E_T}{d\eta d\phi} \rangle$ [GeV]
Data
Py6 AMBT1
Py6 AUET2B:CTEQ6L1
Py6 DW
Py8 4C
H++ UE7-2
EPOS LHC
$N_{ch} \geq 2$ (p_T^{ch} > 250 MeV, $|\eta^{ch}|$<2.5)
$p^{ch(neutral)}$ > 500(200) MeV
MC/Data
|η|

Energy Flow ND/SD/DD

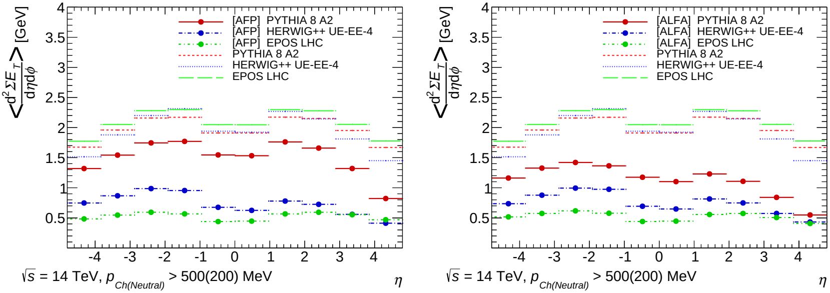
- Charged and neutral energy flow for $p_{\mathrm{ch(neutral)}} > 500(200)$ MeV in events $N_{\mathrm{Ch}} \geq 2(p_{\mathrm{T}} > 250$ MeV, $|\eta| < 2.5)$. Proton tag at $+$ve z.
- PYTHIA asymmetry in energy flow driven by double-dissociation.
- Only magnitude of single dissociative component strongly affected by acceptance of AFP vs. ALFA.





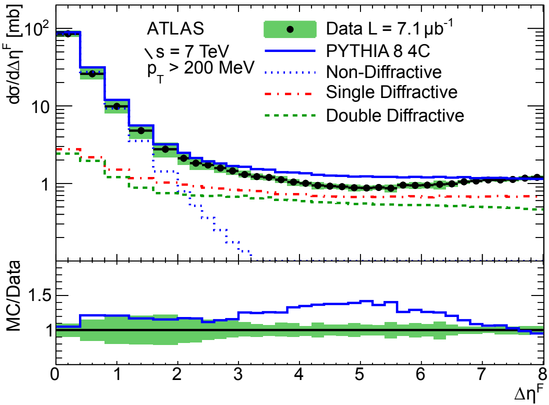
Energy Flow PY8/H++/EPSO

- Forward tag greatly enhances spread of model predictions.
- EPOS plus proton tag does not predict a notable asymmetry between the tag (+ve) and away (-ve) sides. The others do, notably PYTHIA 8.
- PYTHIA 8 exhibits a much greater sensitivity to the differences in acceptance between AFP and ALFA.



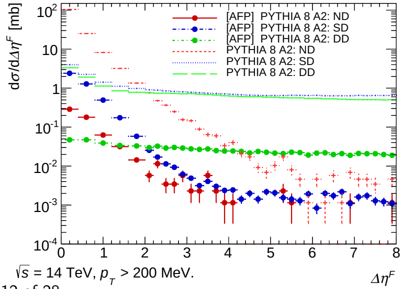
Eur. Phys. J. C72 (2012) 1926

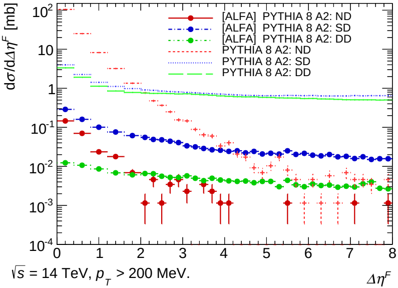
Diffractive Gaps & $\sum E \pm p_z$



Forward Diffractive Gaps ND/SD/DD

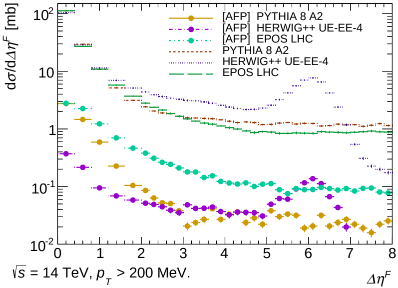
- $\Delta\eta^F$ is the largest pseudorapidity gap per event which starts at $\eta = \pm 4.9$ and contains no final state particles with $p_T > 200$ MeV.
- As expected, the large ξ required to tag a single diffractive p results in essentially no rapidity gap within main ATLAS acceptance.
- Specifically for PYTHIA 8 - AFP tag yields enriched double diffractive sample at large gaps (through forward resonance $\to p$), for ALFA - SD dominated, at larger $|t|$.

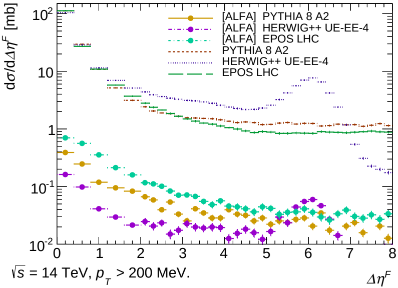




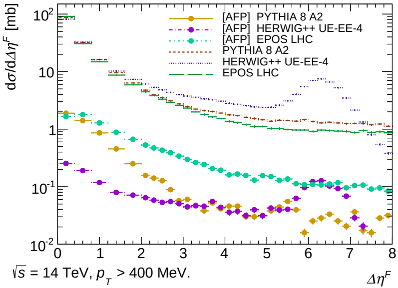
Forward Diffractive Gaps PY8/H++/EPOS

- The `HERWIG++` bump is known, due to clustering of beam remnants.
- All models continue to predict the existence of a flat tail with *p*-tag.
- Significant variation of the expected magnitude of this tail.





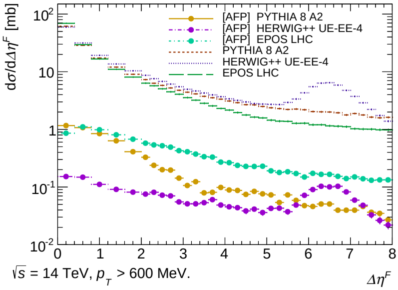
Forward Diffractive Gaps PY8/H++/EPOS

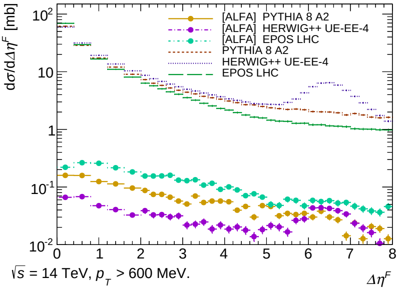


$p_T > 400$ MeV

- Increasing the threshold p_T cut defining the gap tends to enlarge gaps. Allows more SD at larger gap sizes.
- **Proton tag enlarges the discrimination possible between hadronisation models.**

Forward Diffractive Gaps PY8/H++/EPOS

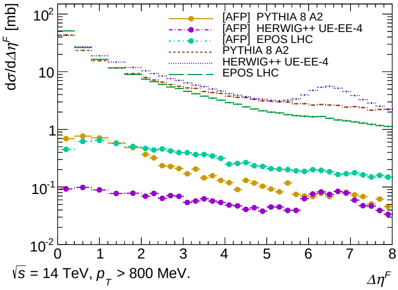


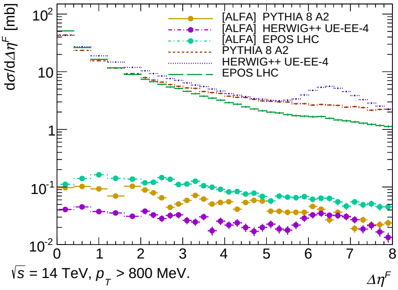


$p_T > 600$ MeV

- Increasing the threshold p_T cut defining the gap tends to enlarge gaps. Allows more SD at larger gap sizes.
- **Proton tag enlarges the discrimination possible between hadronisation models.**

Forward Diffractive Gaps PY8/H++/EPOS



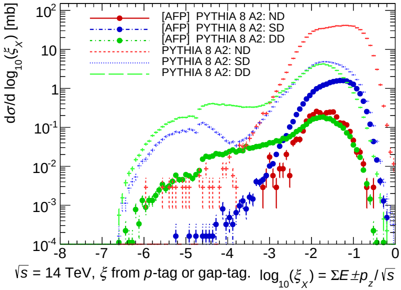


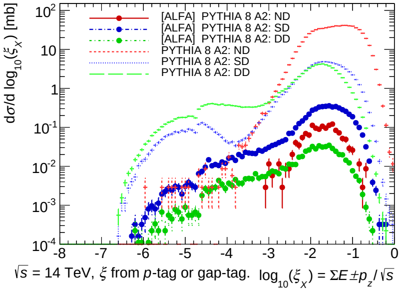
$p_T > 800$ MeV

- Increasing the threshold p_T cut defining the gap tends to enlarge gaps. Allows more SD at larger gap sizes.
- **Proton tag enlarges the discrimination possible between hadronisation models.**

Forward Diffractive Gaps ND/SD/DD

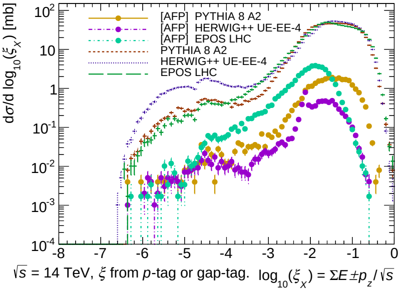
- The same story is seen when approximately reconstructing ξ using $p_{\text{ch(neutral)}} > 500(200)$ MeV particles within $|\eta| < 4.8$
- Opposite of proton tag used as direction of primary dissociative system and opposite largest forward gap for non-tagged sample.
- Bumps in inclusive distribution under investigation.

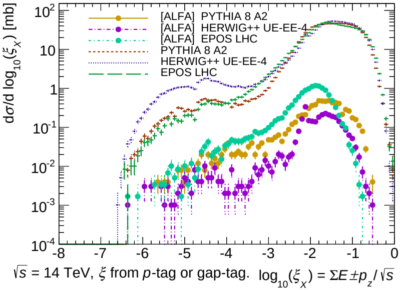




Forward Diffractive Gaps PY8/H++/EPOS

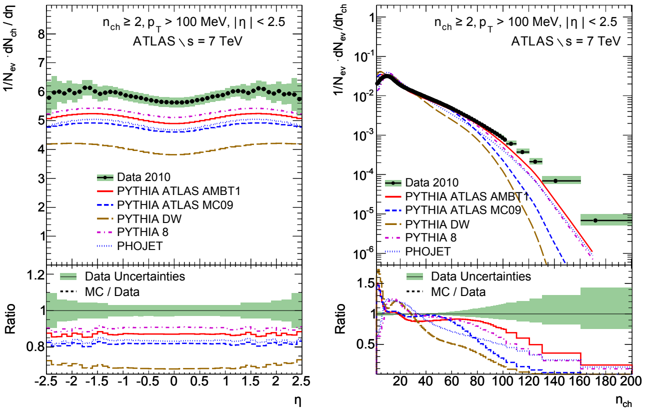
- The same story is seen when approximately reconstructing ξ using $p_{\mathrm{ch(neutral)}} > 500(200)$ MeV particles within $|\eta| < 4.8$
- Opposite of proton tag used as direction of primary dissociative system and opposite largest forward gap for non-tagged sample.
- Bumps in inclusive distribution under investigation.





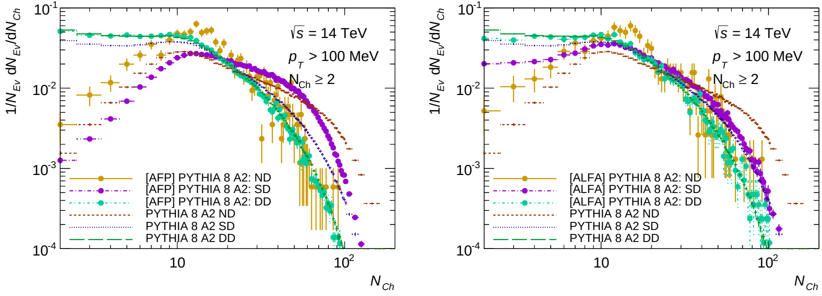
New J. Phys. 13 (2011) 053033

Charged Particle Spectra



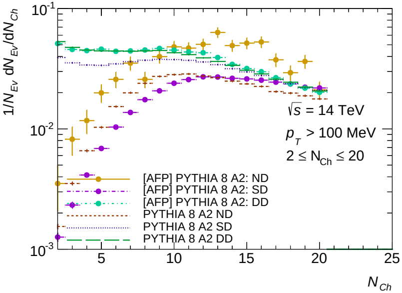
Charged Particle: N_{Ch} ND/SD/DD

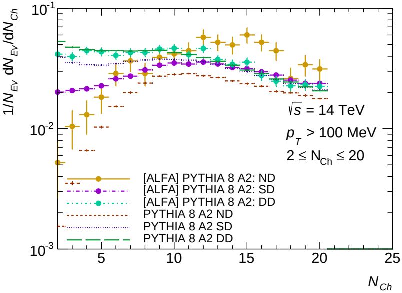
- The enhancement of double dissociation in AFP tagged events with `PYTHIA 8` is nicely contained at low overall charged particle multiplicity ($|\eta| < 2.5$).
- Also seen in AFLA, but to a lesser extent as more single diffraction is accessable.



Charged Particle: N_{Ch} ND/SD/DD

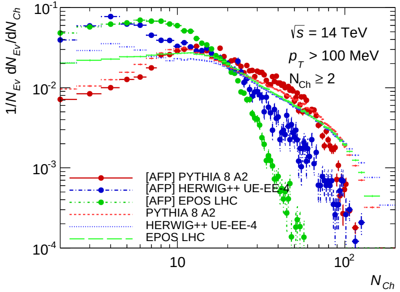
- On some following slides an explicit upper cut of 20 charged particles will be applied to observe the effects of this enrichment.

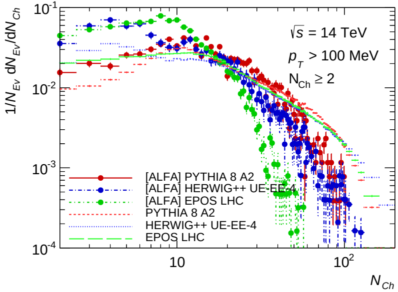




Charged Particle: N_{Ch} PY8/H++/EPOS

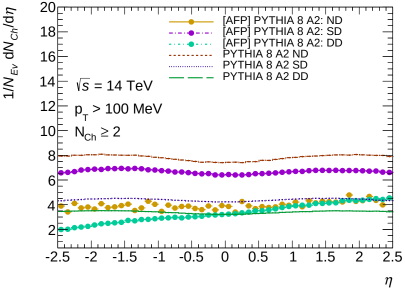
- When comparing between the generators, only `PYTHIA 8` is observed to have (overall) reduced activity at low N_{Ch} with a proton tag. `HERWIG++` and `EPOS` are both observed to rise.
- Similar stories for AFP and ALFA for this variable.

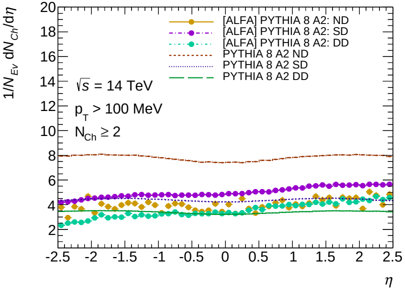




Charged Particle: η ND/SD/DD

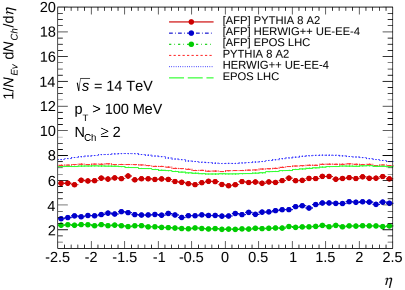
- As seen before, asymmetry in particle flow for `PYTHIA 8` with AFP tag driven by double diffractive component.
- For ALFA tag, the single diffracive plays a role too.

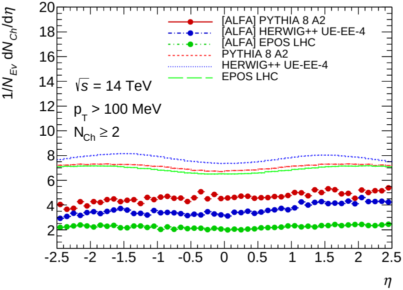




Charged Particle: η PY8/H++/EPOS

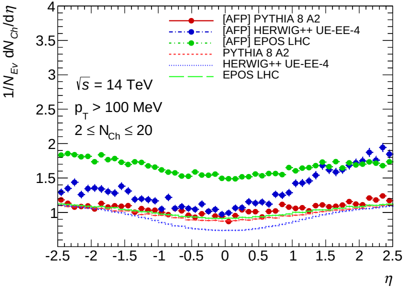
- Good degree of model separation observed when comparing the generators.
- Like with the energy flow, EPOS shows no sign of any asymmetry in flow.

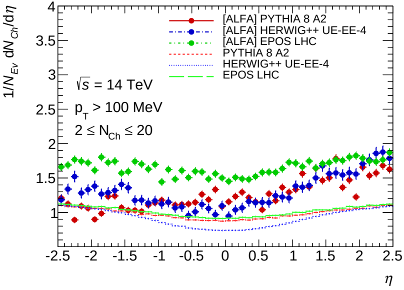




Charged Particle: η PY8/H++/EPOS

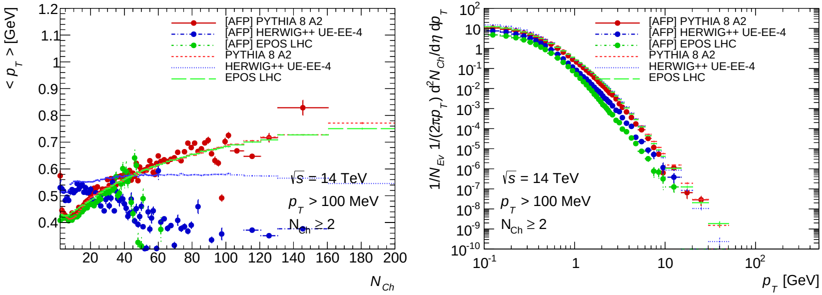
- By applying the upper multiplicity cut, these differences are nicely enhanced.
- AFP in particular shows good promise for model discrimination here.
- HERWIG++ has the largest asymmetry in this phase space.





Charged Particle: p_{T} PY8/H++/EPOS

- p_{T} based variables displayed less sensitivity to an explicit upper cut on charged particle multiplicity.
- The long, steeply falling tail of the inclusive charged particle p_{T} distribution could prove useful too in modelling these interactions.



Conclusion

Good descriptions of minimum bias pp interactions at $\sqrt{s} = 13$ or 14 TeV yields higher precision physics at the LHC through better modelling of the increasingly fierce pileup conditions.

Use of the forward detectors will allow for the soft diffractive component of the cross section to be enhanced in interesting phase spaces, yielding a greater handle on the physics of the $p - I\!P$ interaction.

ALFA is shown to select events of all ξ though at larger $|t|$, AFP selects events only at larger ξ but may also be sensitive to low mass diffractive systems through forward baryonic excitation and subsequent decay to a proton within AFP acceptance.