Underlying Event Properties

Deepak Kar
University of Glasgow

Workshop on multi partonic interactions at LHC
Tel Aviv, Israel, October 2012

NEW PREDICTIONS (10 years)

1. QCD tests & applications will greatly improve, incorporating NLO, NNLO,...and a theory of fragmentation and hadronization.
2. Atlas and CMS will discover a candidate Higgs particle.
3. There will be convincing evidence for Susy particles.
4. Plans will be underway to build a LC (at Cern) to explore the superworld and the US will join CERN.
5. There will be direct detection of the Dark Matter wind.
6. Alice will see a crossover to the perturbative quark-gluon plasma.
7. Some new Z mesons will be discovered.
8. Gravitational waves and B modes will be observed.
9. String theory will start to be a **theory** with predictions.
10. We will have a plausible explanation of why Λ is so small.

David Gross: EPS 2012

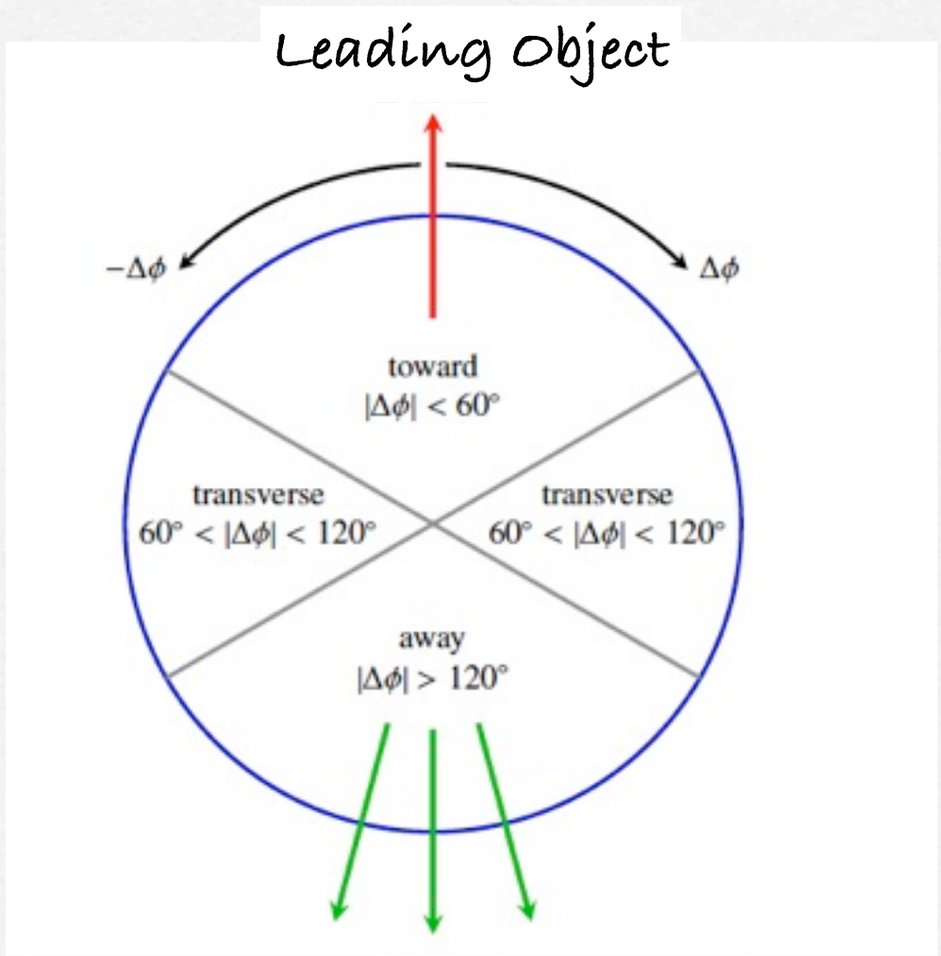
Outline:

- Looking back at the CDF results.
- Early LHC results, what they told us?
- Tuning MPI parameters in MC (and the dependence on PDF) from UE results.
- Newer LHC results.
- Wrapup.

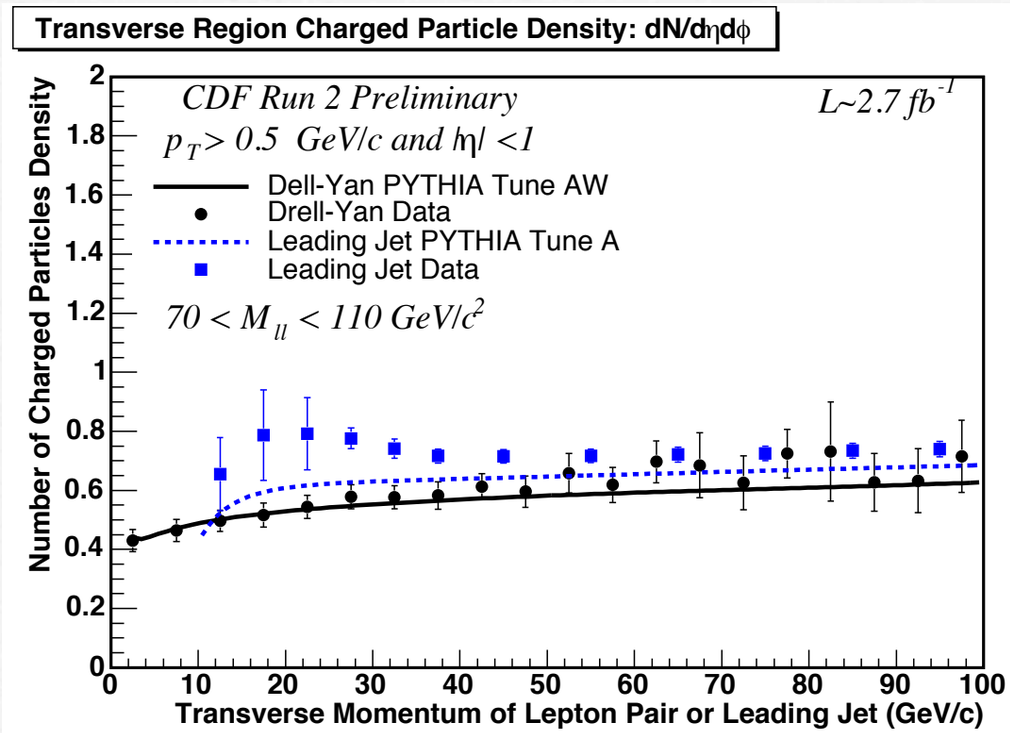
Underlying Event?

The usual "Rick Field" approach

- Divide the η-Φ space according to the direction of the leading object.
- Transverse regions are most sensitive to UE, but for Z-boson events, toward is also "clean".

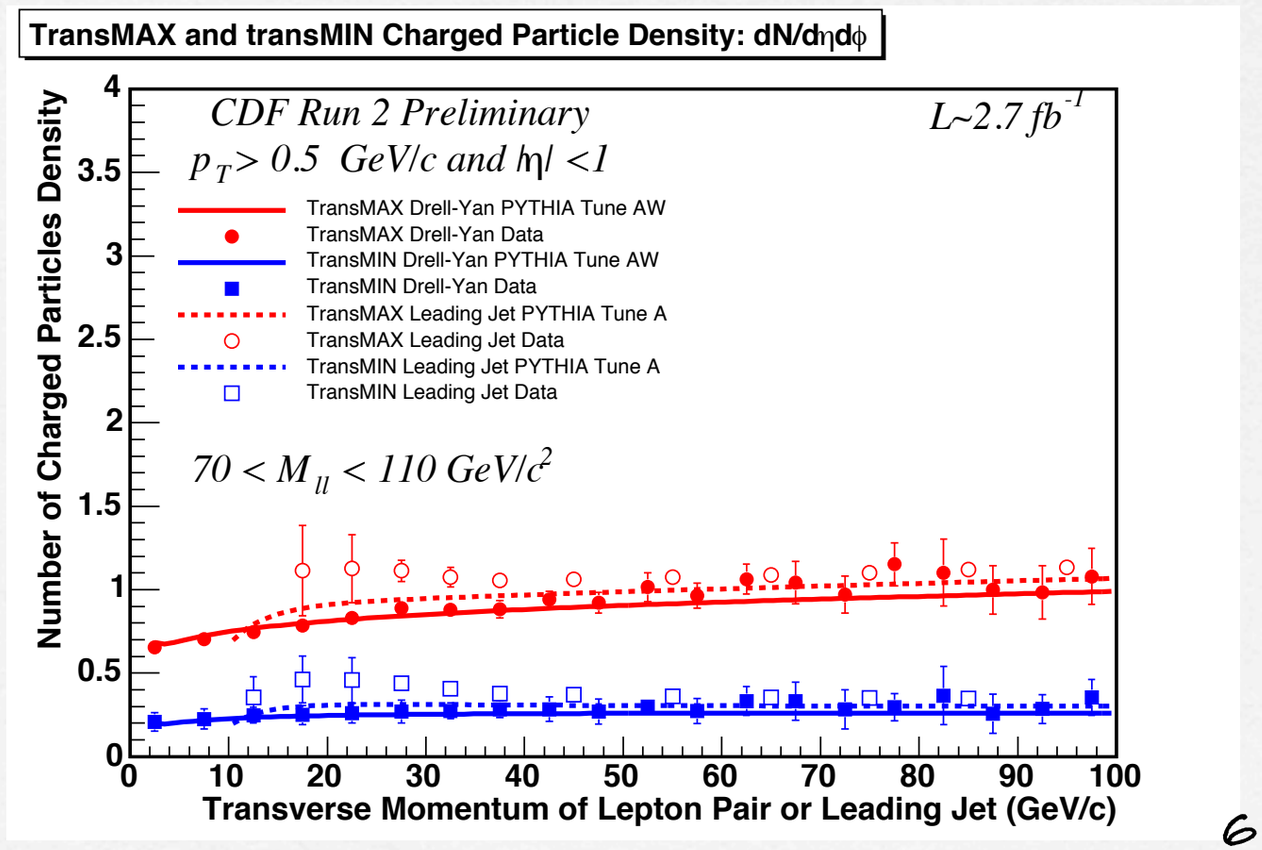


CDF Results

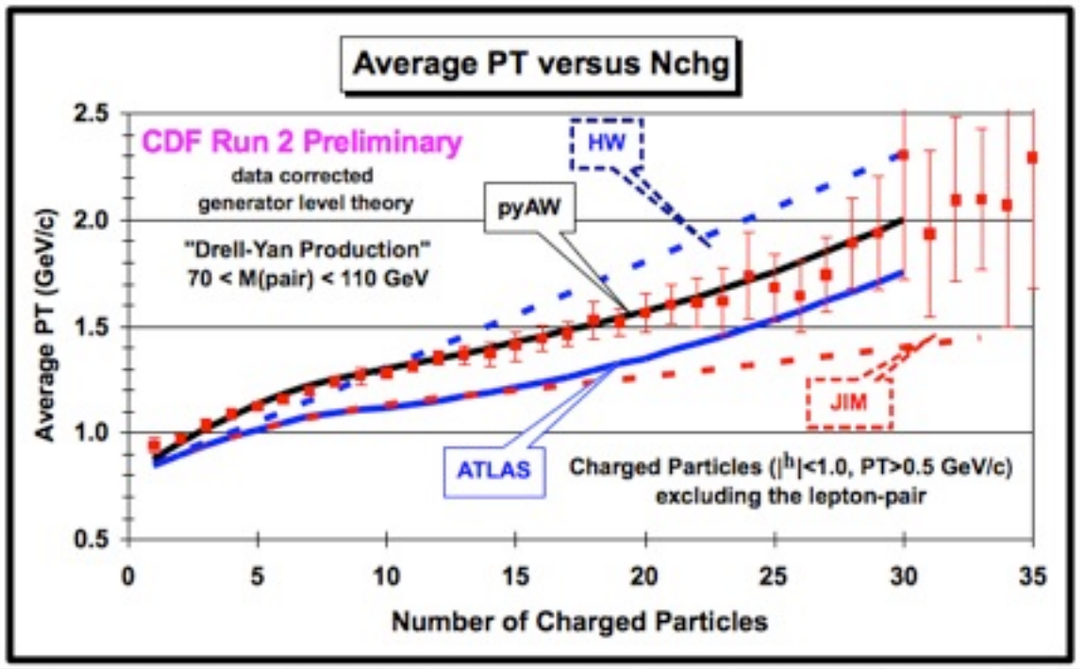


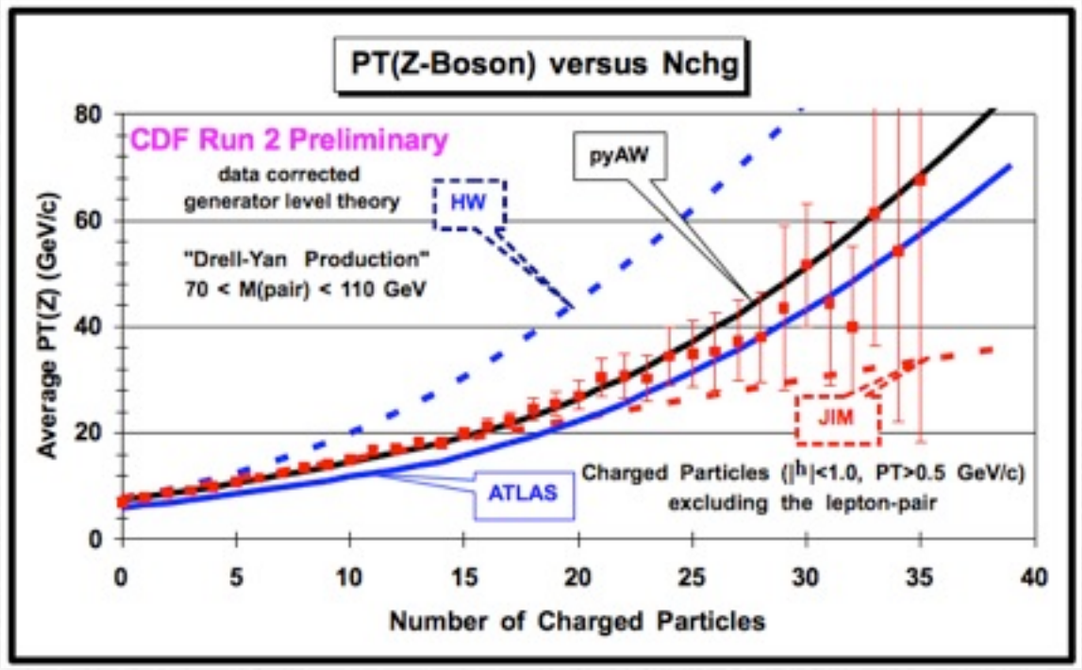
UE activity similar in leading jet and Z-boson events: coincidence?

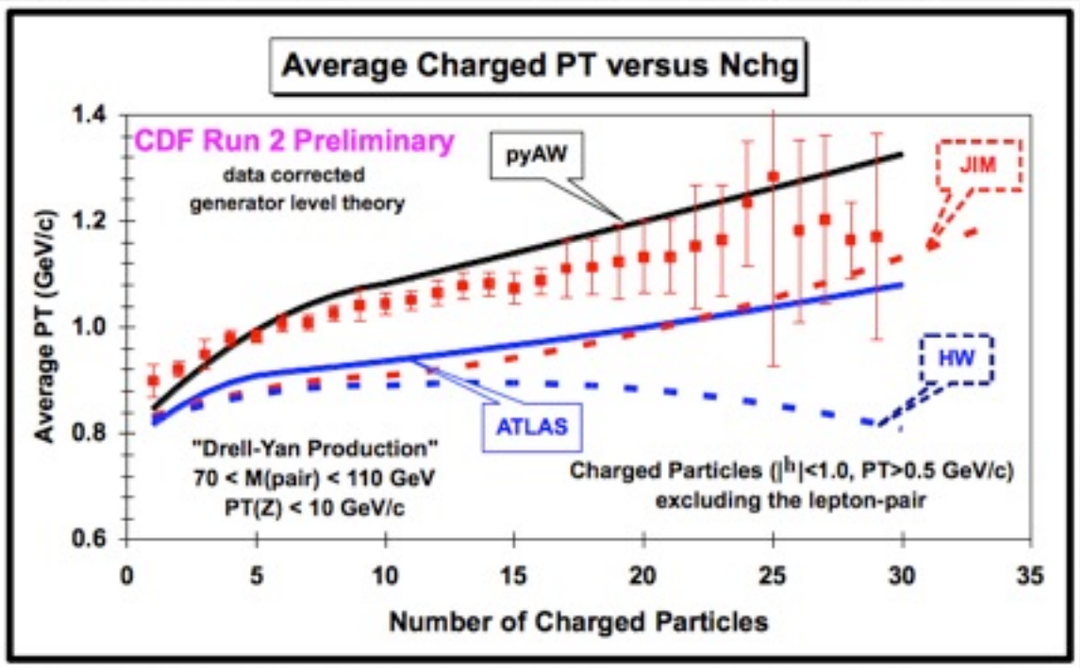
Transmax and transmin both flattens out, described well by MC. Same at the LHC?



CDF Results "Proving" MPI



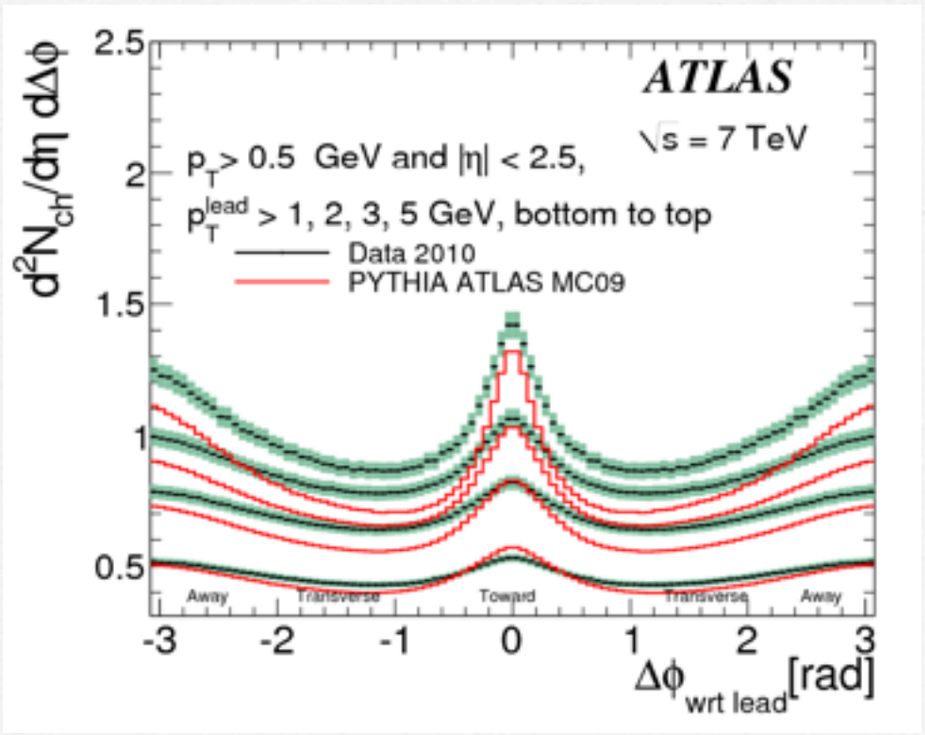


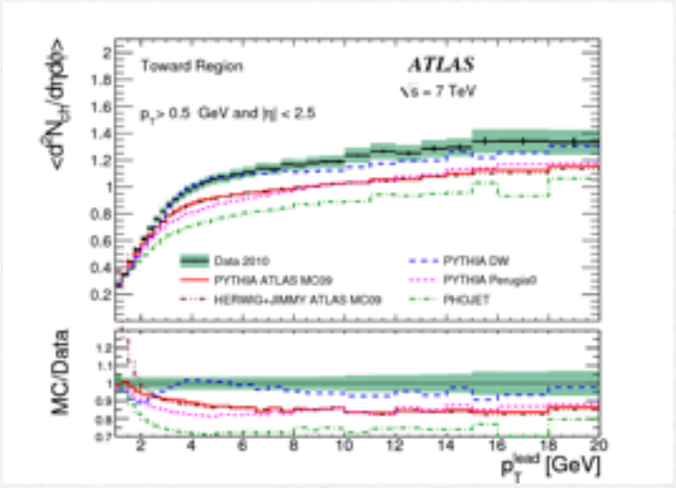


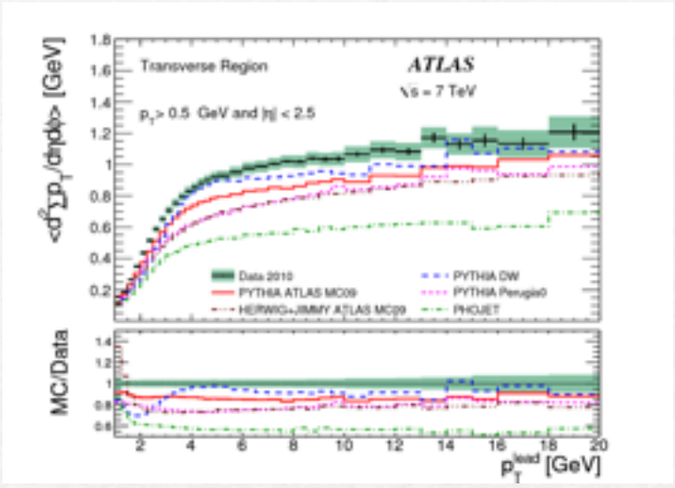
High multiplicity has to come from MPI

← $Z\ p_T < 10$ GeV

Early ATLAS Results



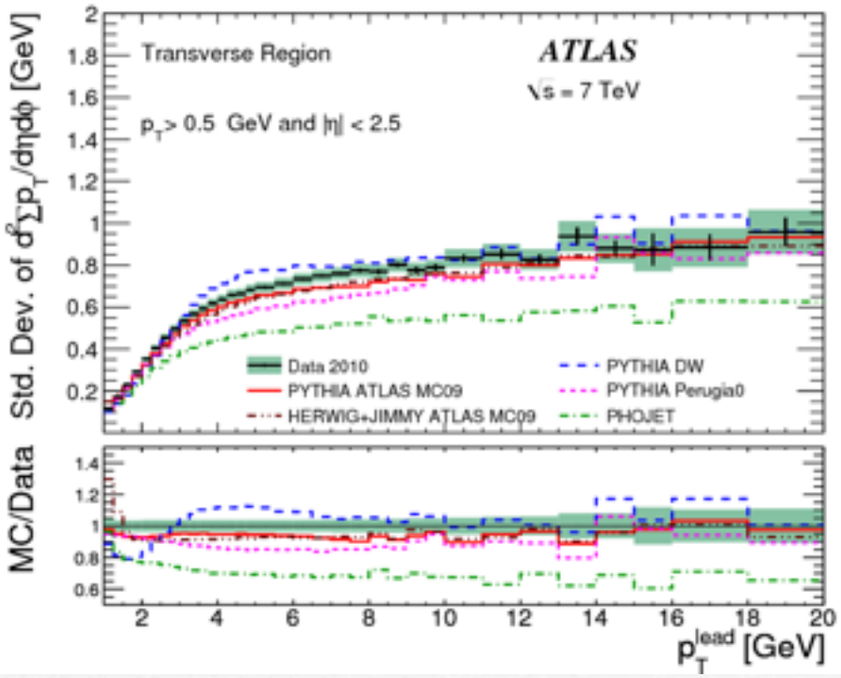




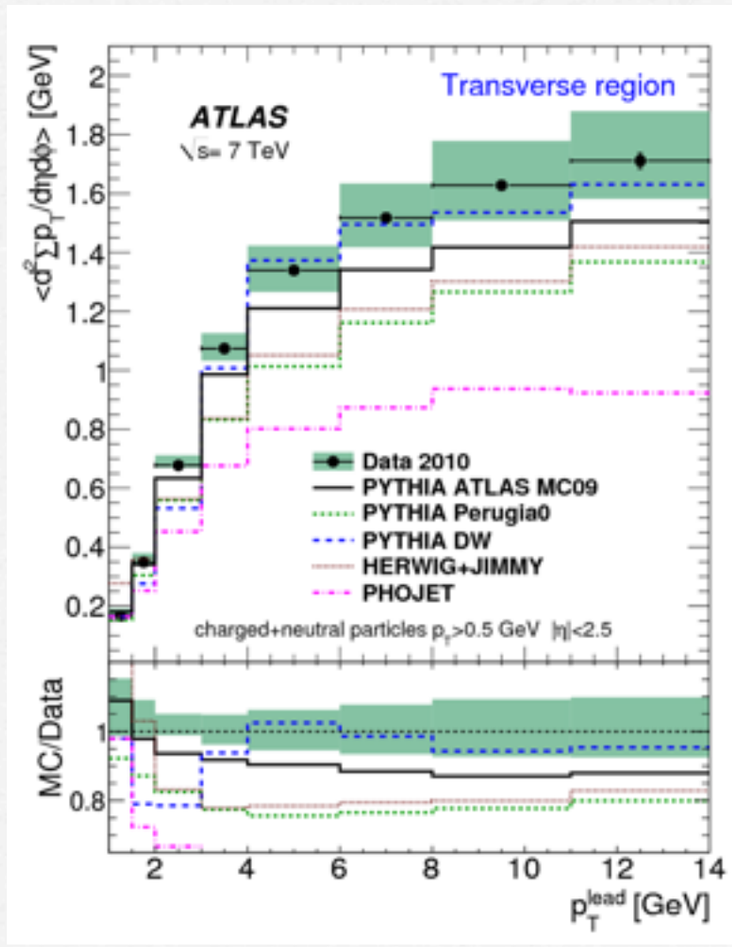
The pre-LHC models were not describing the LHC data at all!

An elaborate MC retuning program happened using these and other results

"New" from ATLAS



Using both charged and neutral particles



Std dev of UE variables: shows event-by-event correlation.

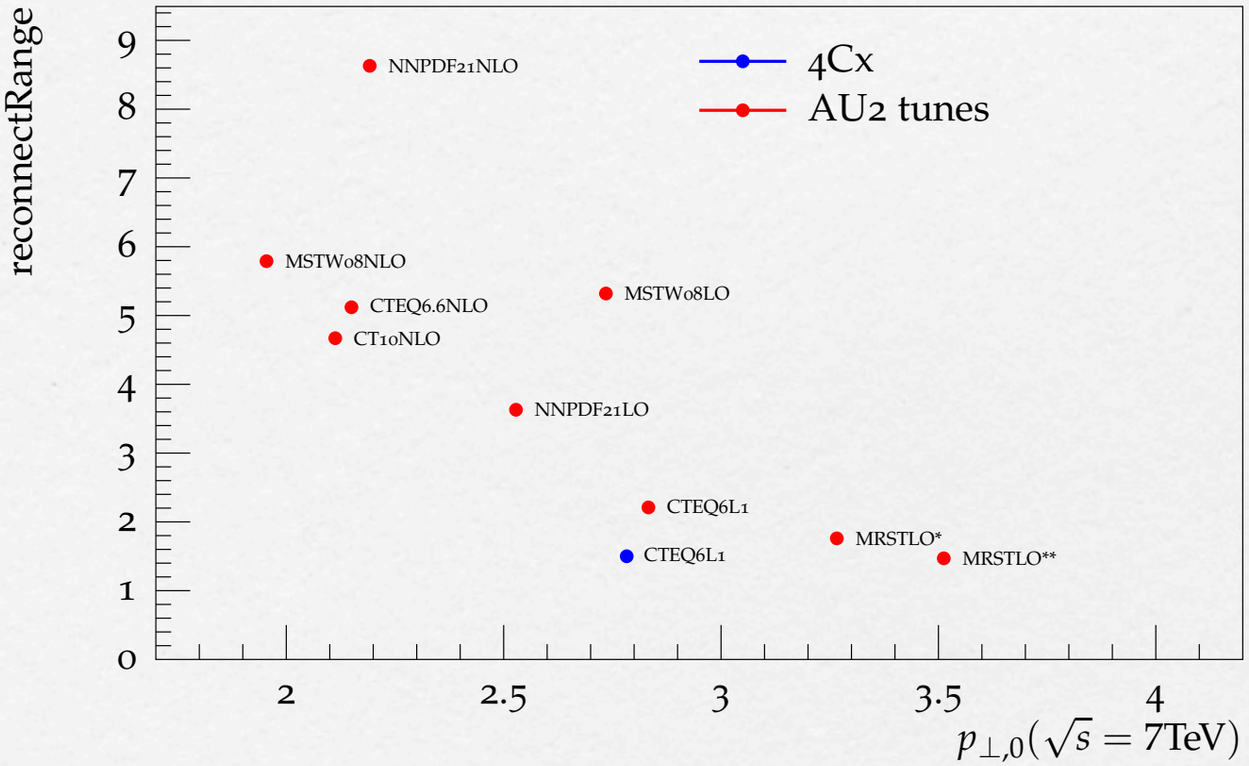
MPI Tuning Using These Results

- "CDF"-tunes failed to describe not only 7 TeV data, but also 900 GeV data.
- Tuning simultaneously to three c.m energies proved impossible.
- Describing MB and UE by the same tune proved equally challenging, and ATLAS moved to using separate tunes.
- Observed strong PDF dependence of the tunes.

PDF Dependence

- MB tunes prefer slightly higher values of MPI p_T cutoff (and hence less MPI activity) than in the corresponding UE tunes, but this effect is small compared to that due to the variation between PDFs.

- NLO PDF tunes seem to demand a stronger color reconnection strength but somewhat lower MPI p_T cutoff and energy exponent than LO/mLO PDFs.



Similar behaviour also seen during earlier Herwig+Jimmy tuning

Color Weighted Parton Flux

For each PDF at $Q^2 = (3\ \text{GeV})^2$:

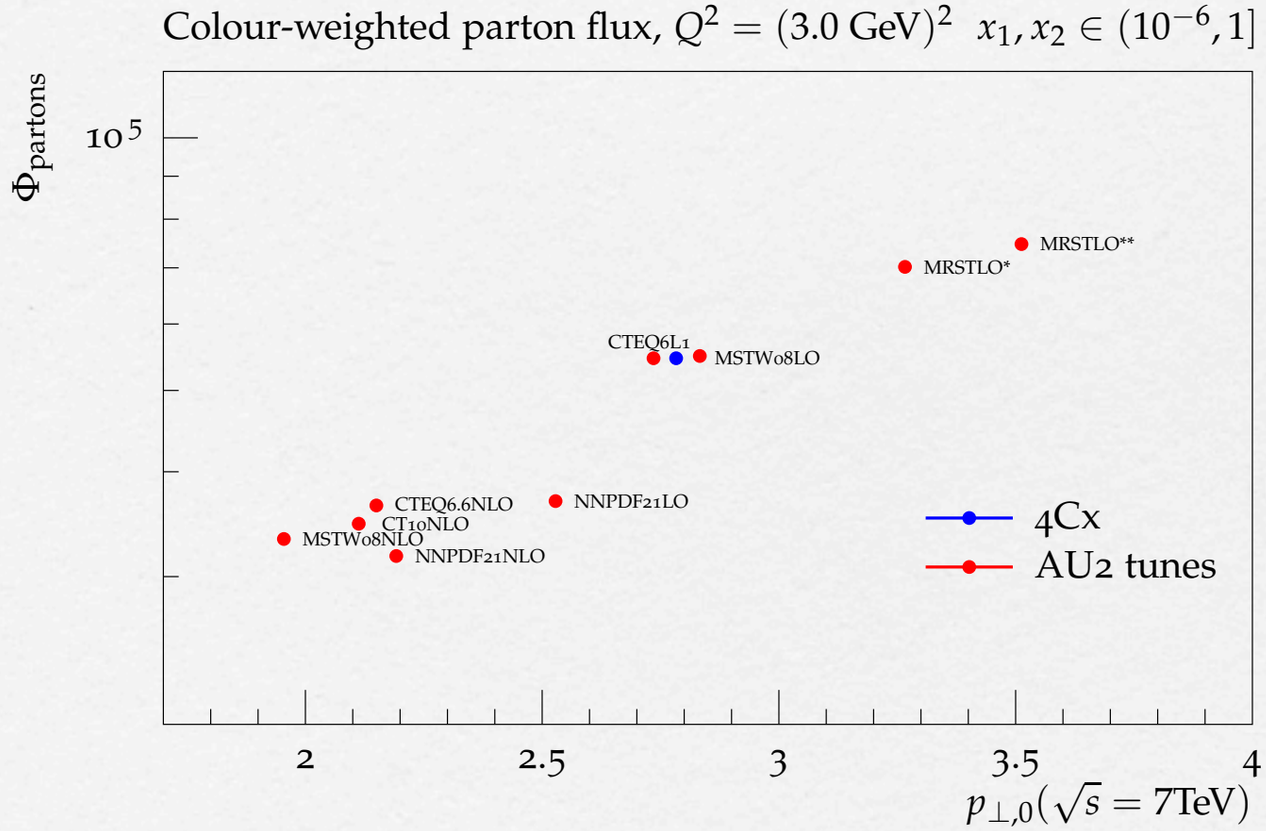
$$\Phi_{\text{partons}} = \iint_{x_1 x_2 > \tau_{\min}} \mathrm{d}x_1 \mathrm{d}x_2 N(x_1, Q^2) \cdot N(x_2, Q^2)$$

with x_1, x_2: parton momentum frac,

t_{min}: lower cutoff reqd by kinematics.

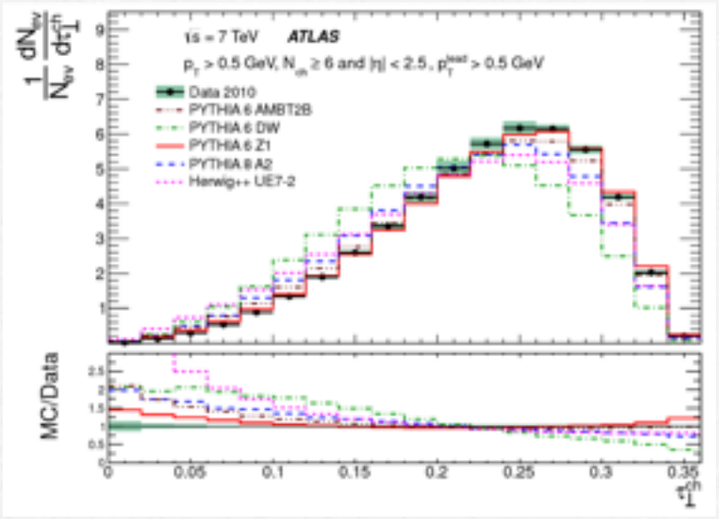
$$N(x, Q^2) = \sum_{\text{quarks}} (q(x, Q^2) + \bar{q}(x, Q^2)) + \frac{9}{4} g(x, Q^2)$$

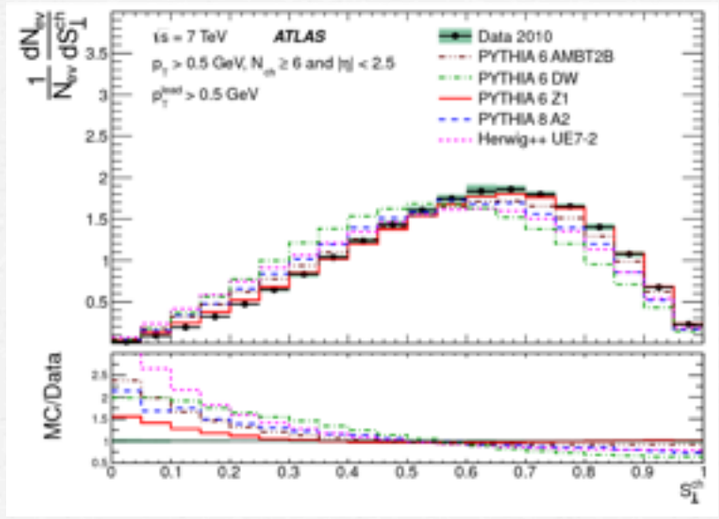
takes contributing quark and gluon distributions into acct.

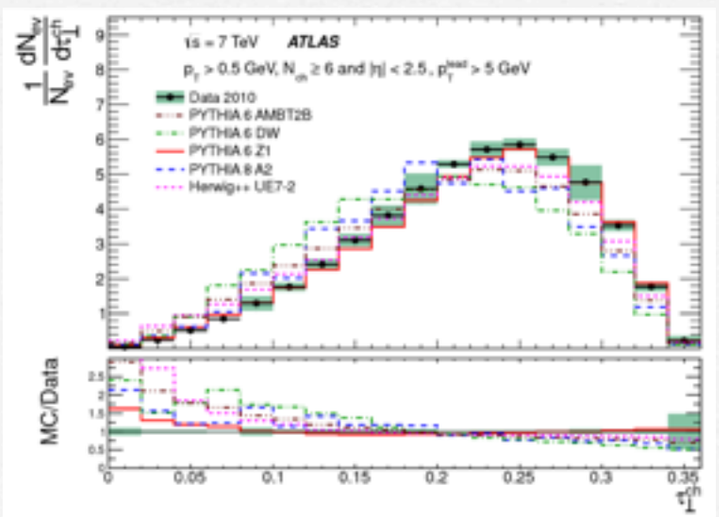


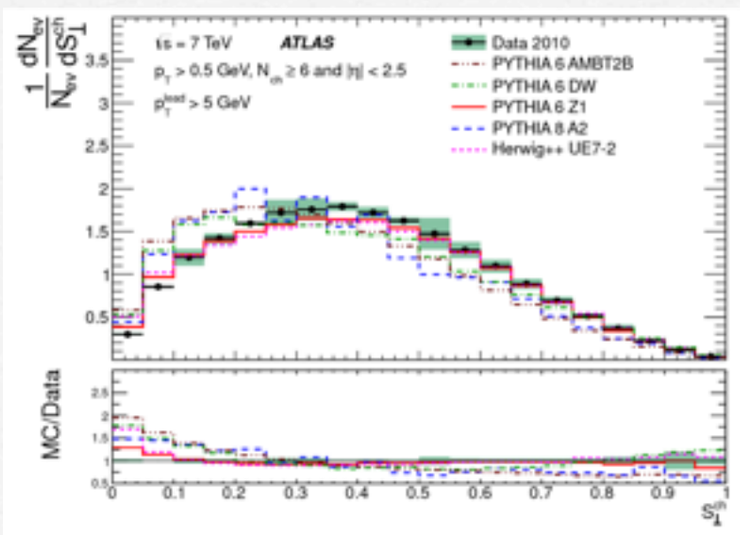
Shows the correlation of Φ_{partons} with $p_{T,0}$

Non-UE Results Showing the Importance of MPI Tuning





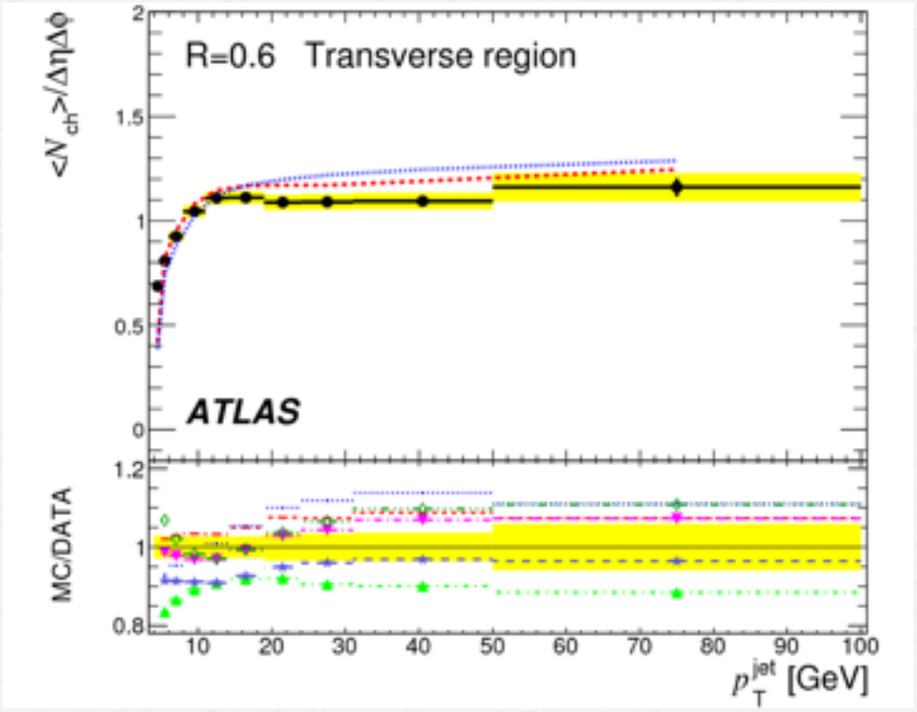


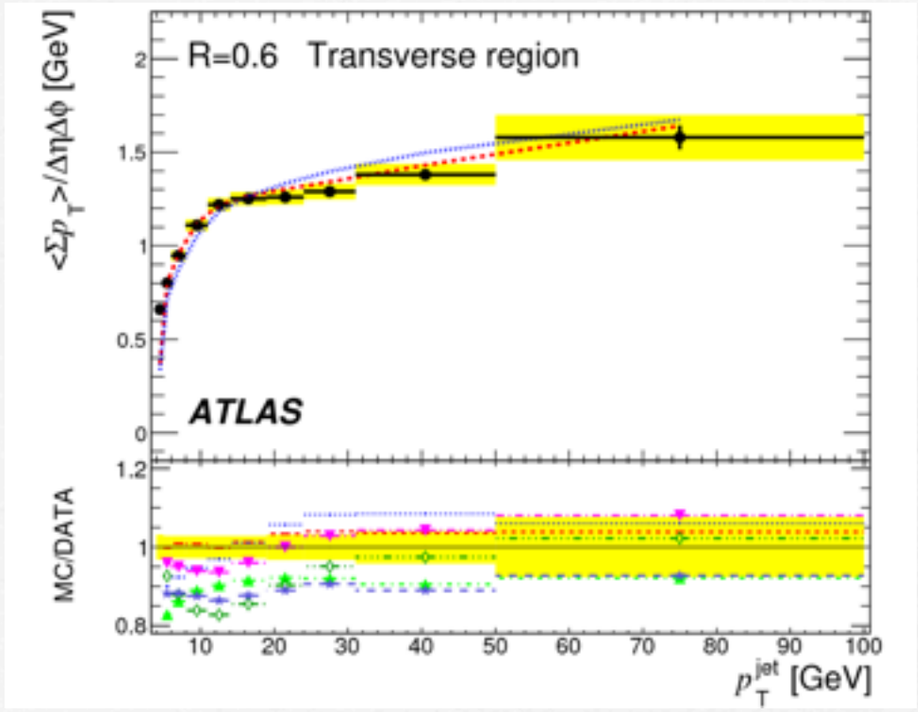


Sphericity moves to more "jet-like" events, but not thrust.

UE-tunes describe the data better!

New ATLAS UE Results





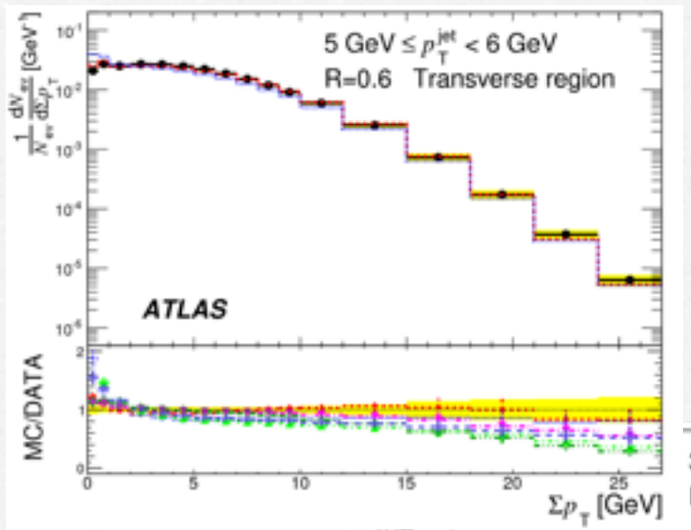
DATA 2010 $\sqrt{s}$ = 7 TeV
PYTHIA (Z1)
PYTHIA (AUET2B)
HERWIG++ (UE7-2)
PYTHIA (Perugia2011)
PYTHIA (Perugia2011 NOCR)
PYTHIA 8.145 (4C)

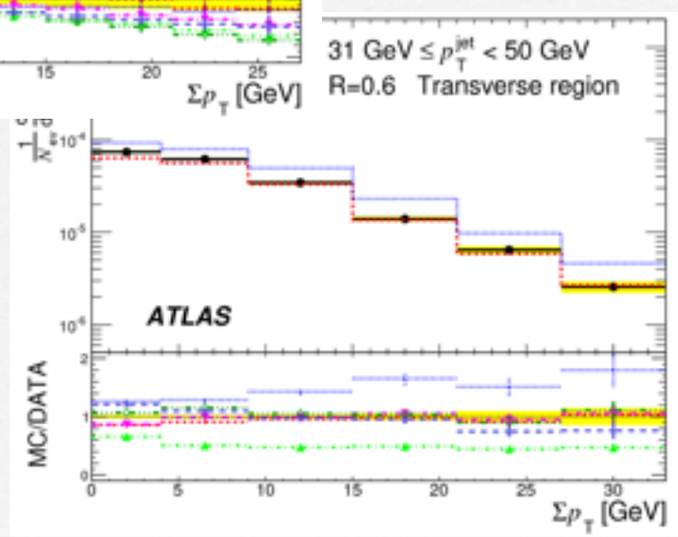
$p_T^{track} \geq 0.5$ GeV $|\eta^{track}| \leq 1.5$
anti-k_t jets: $|\eta^{jet}| \leq 1.5$ $\int L dt = 800\ \mu b^{-1}$

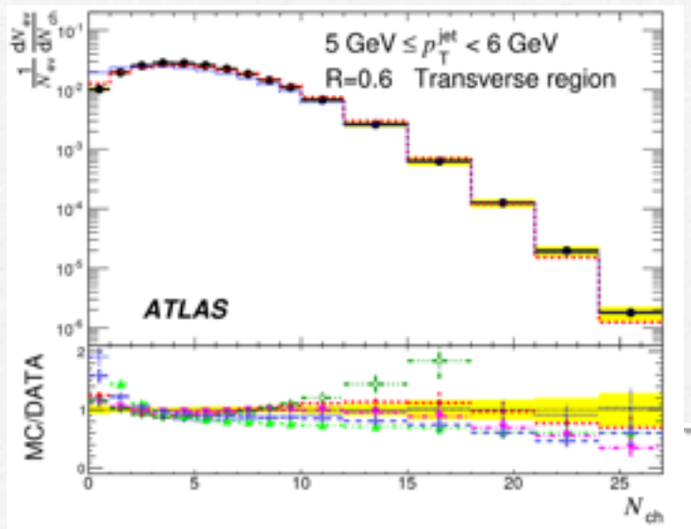
trackjet with (anti-kt) radius 0.6 (for other radii too)

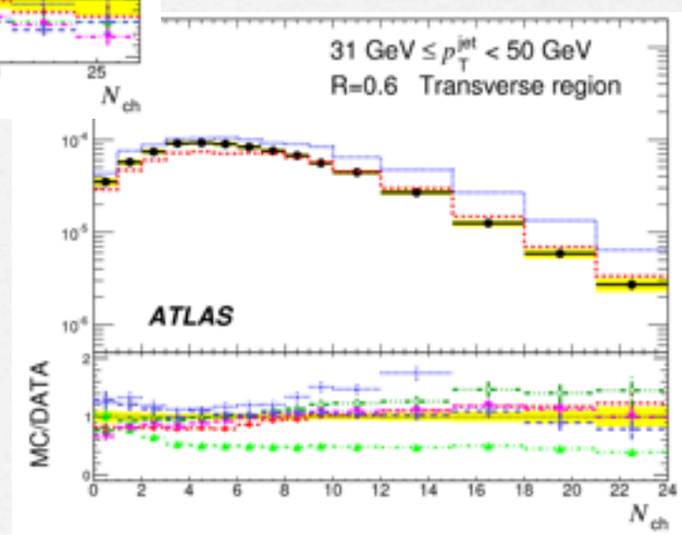
Post-LHC tunes are better, but not perfect agreement yet.

New ATLAS UE Results



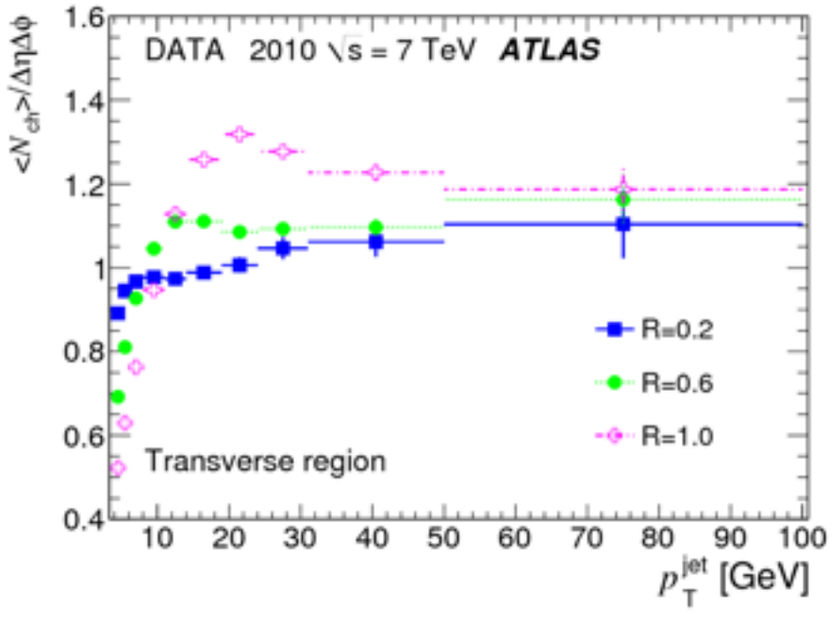


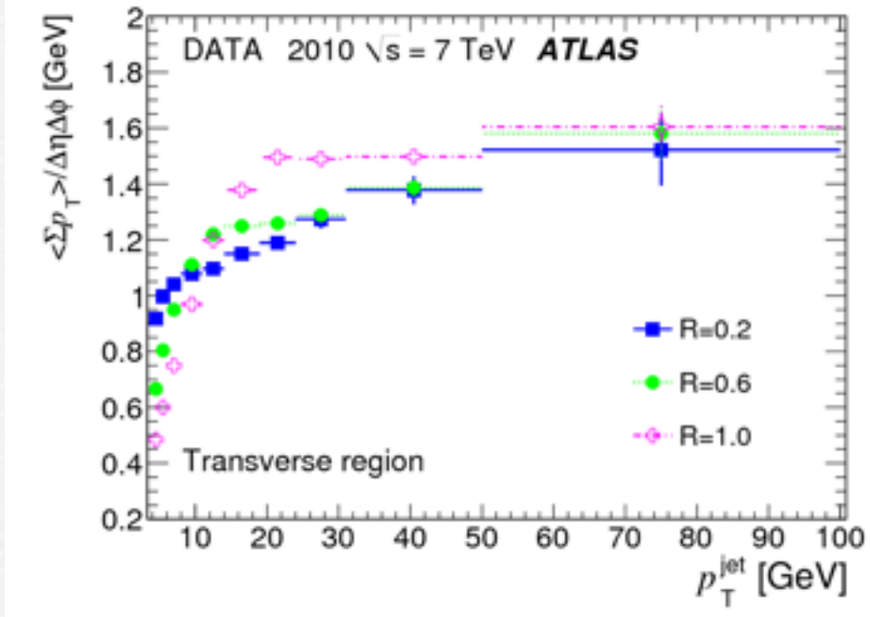


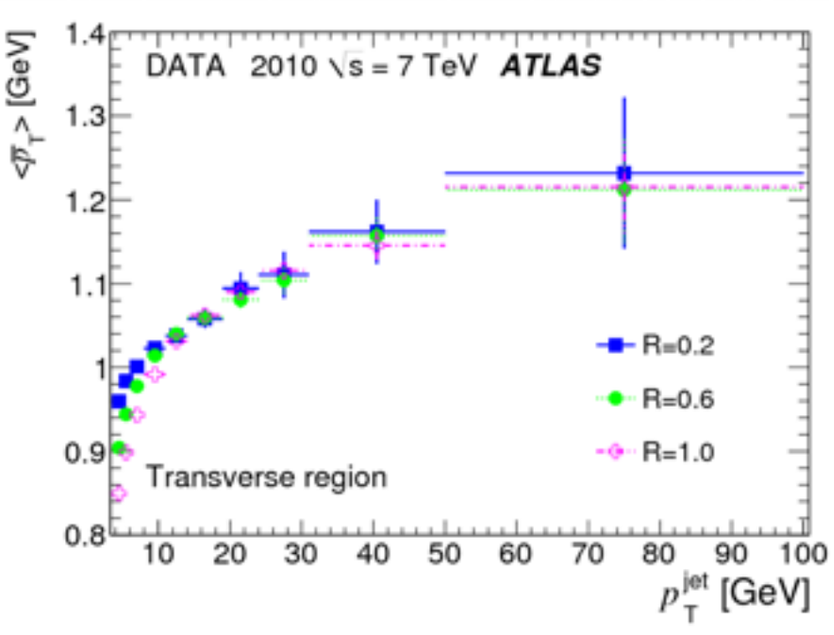


Distributions of UE observables in different jet p_T slices.
Different MC behaviour in different slices.

Big Surprise!

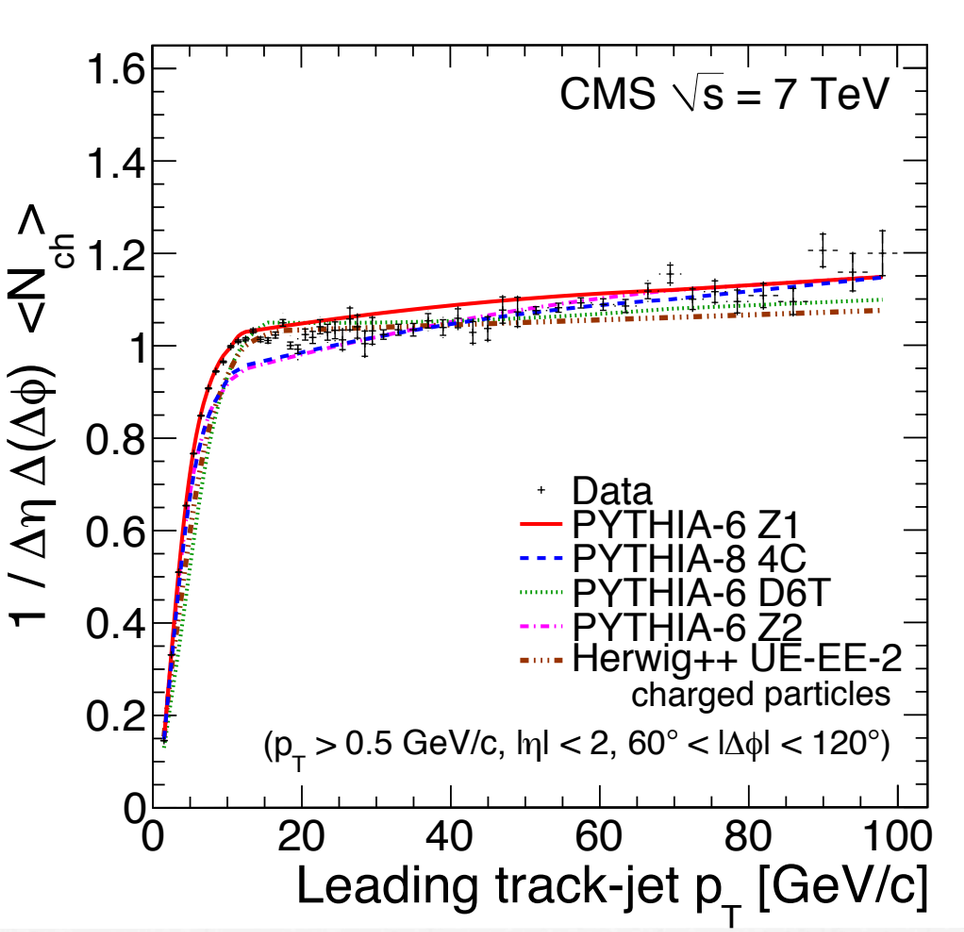


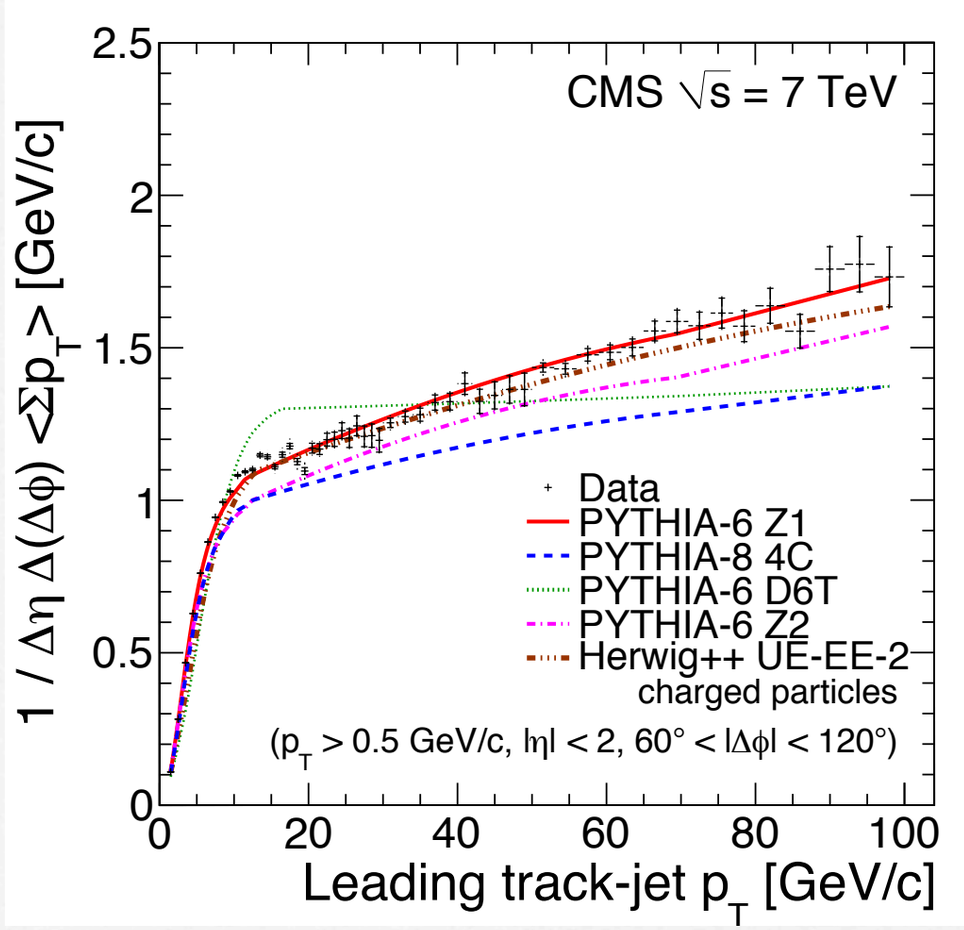




Dependence of UE on jet radius

CMS Trackjet UE Results

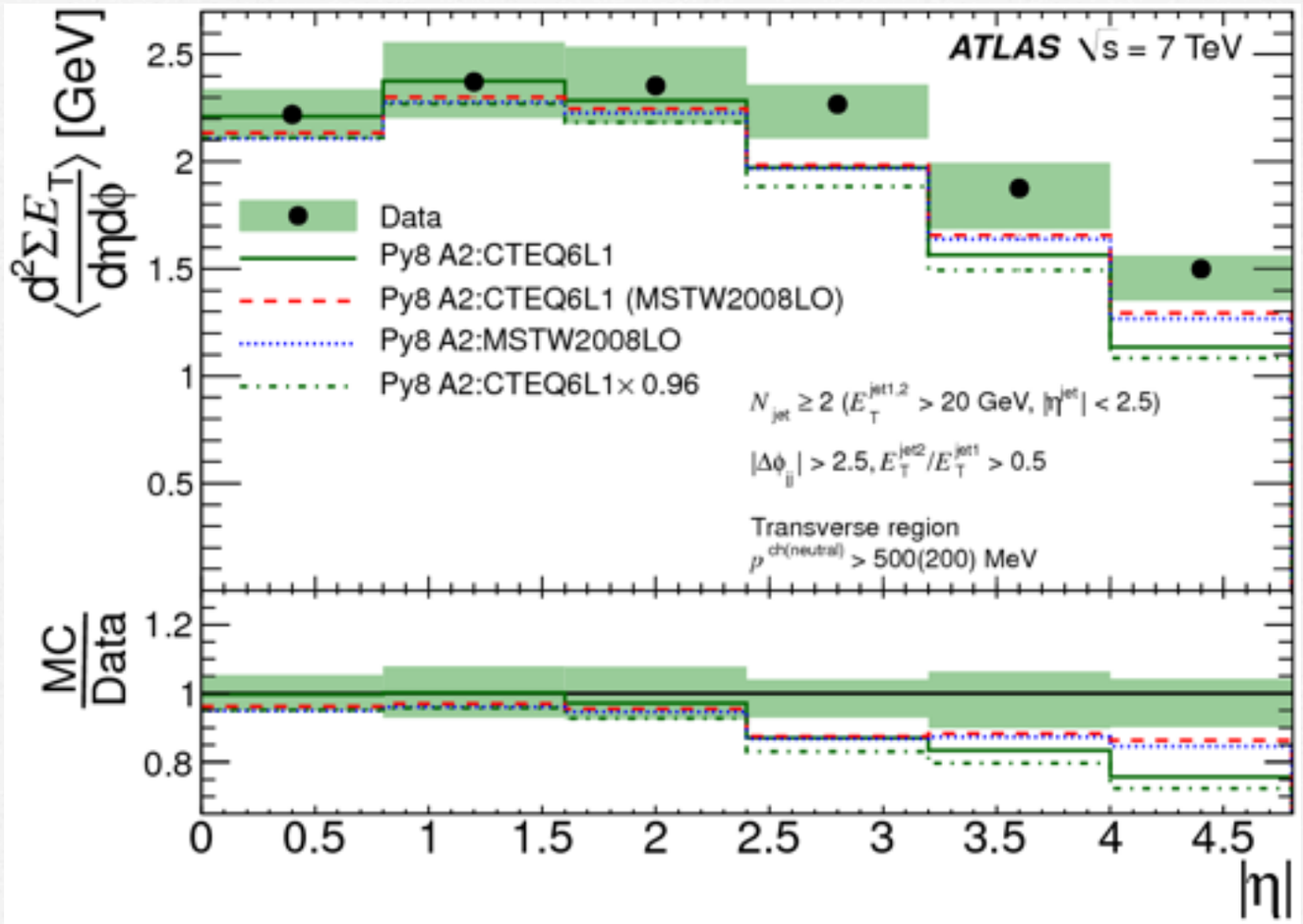


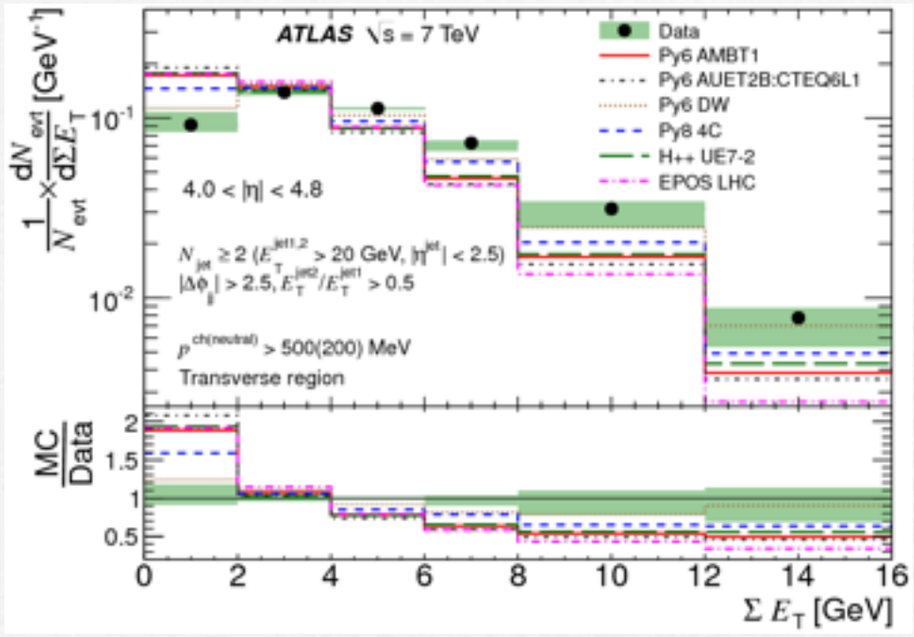


Similar conclusions; Z1 is probably the best tune*

*full disclosure: CMS trackjet results were earlier

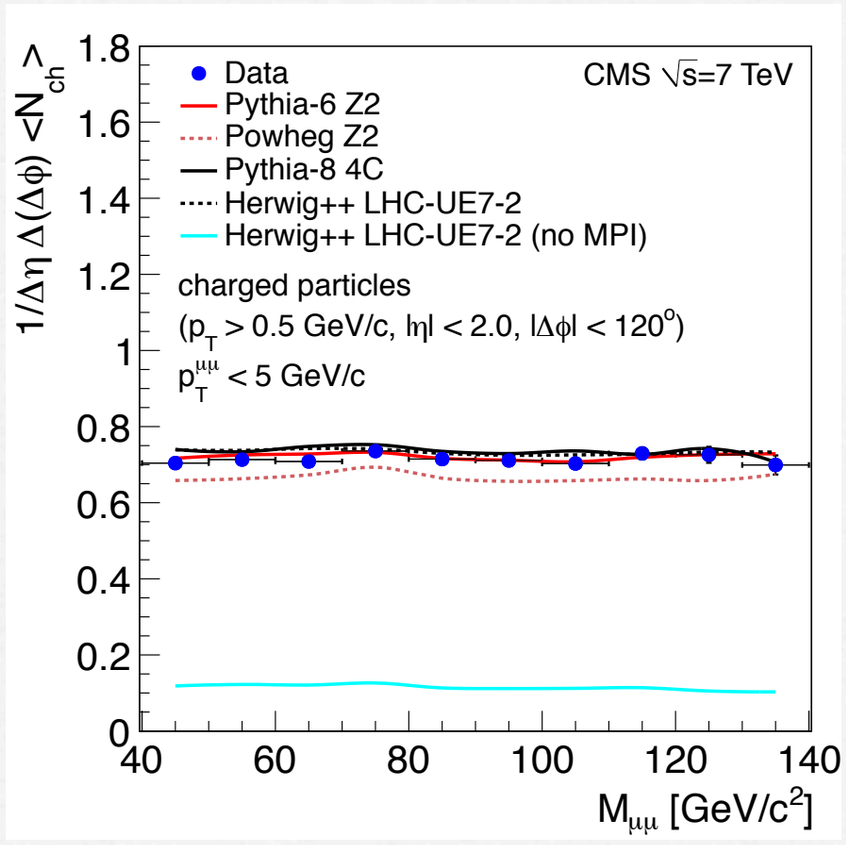
ATLAS Forward E_T Flow

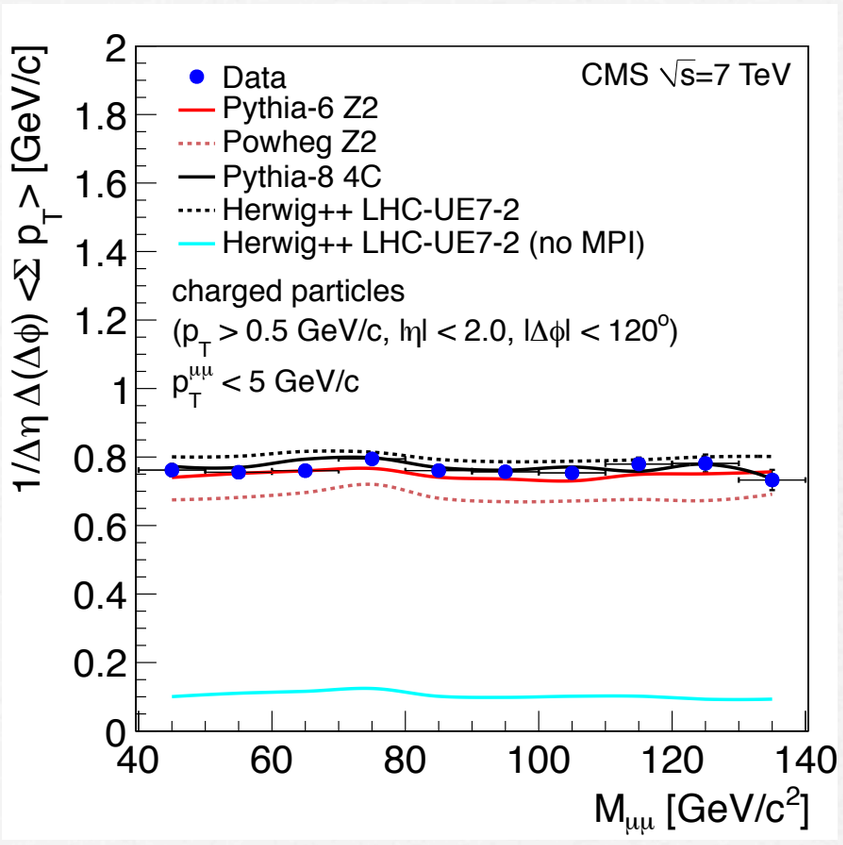




UE-like dijet topology: MC description worse in more forward region(s).

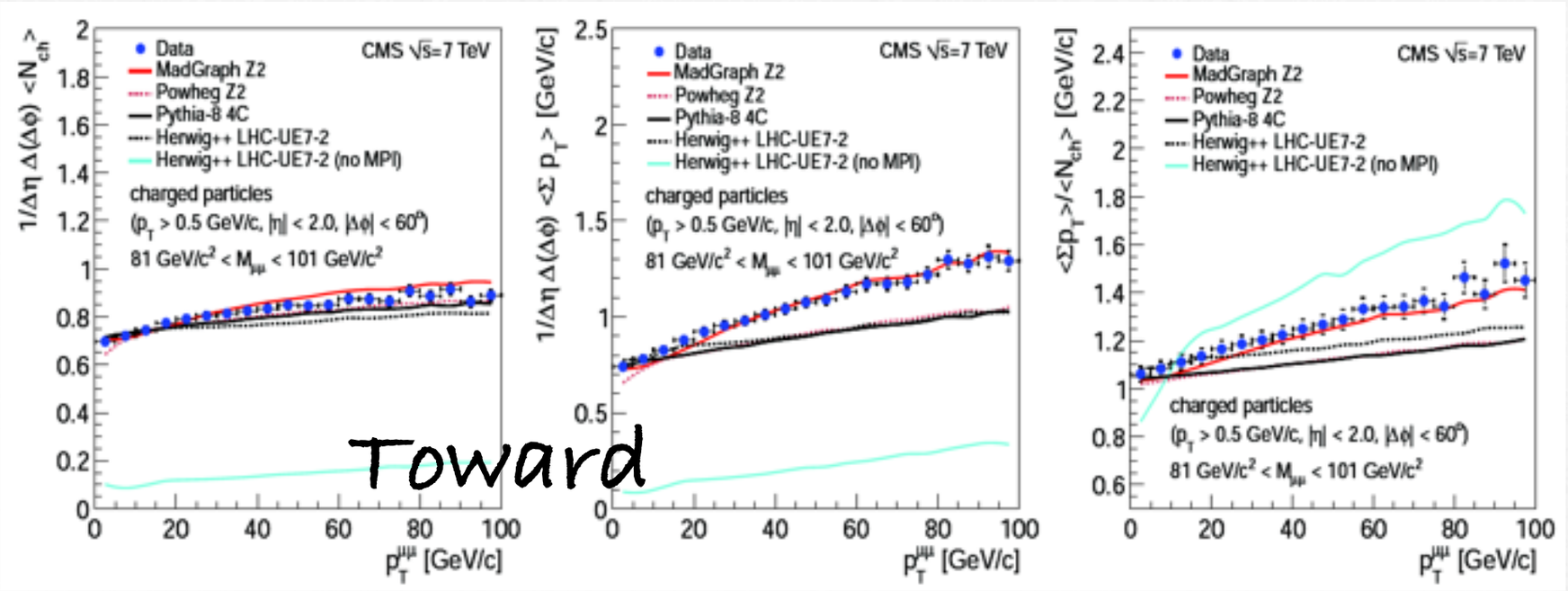
CMS UE Results: DY



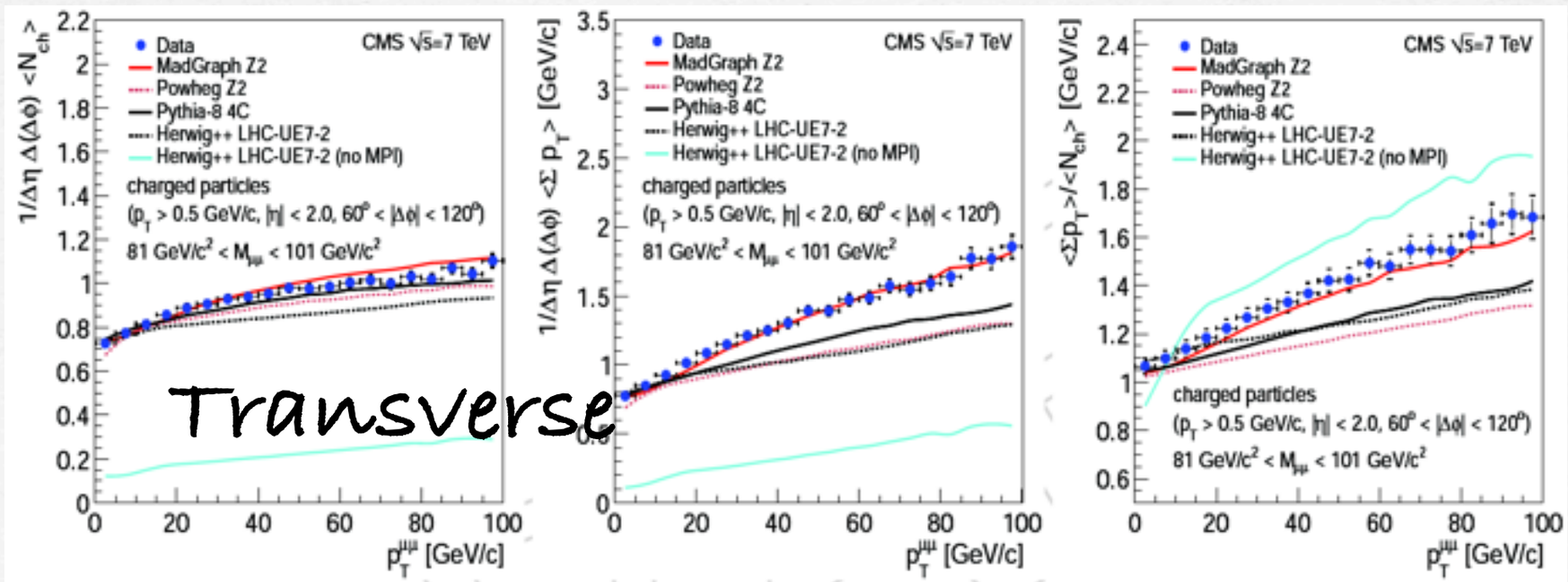


As a function of lepton pair invariant mass; essentially flat - indicating MPI saturation over the energy scale probed.

CMS UE Results



Toward

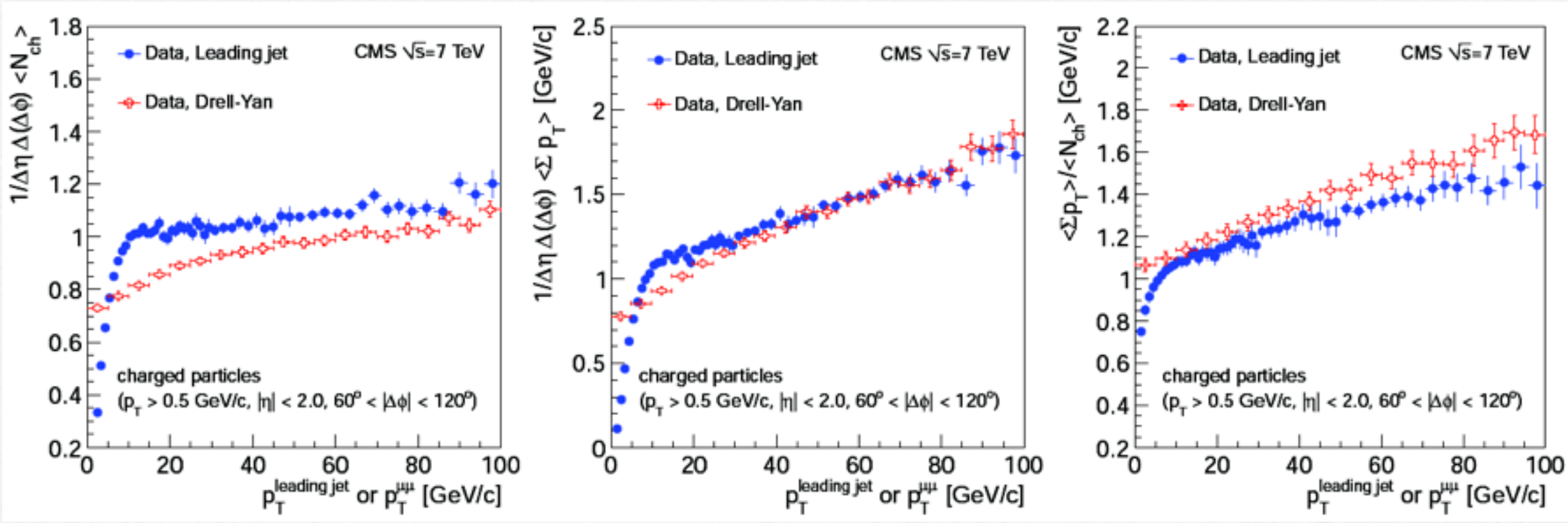


Transverse

Usual plots against Z-boson p_T.

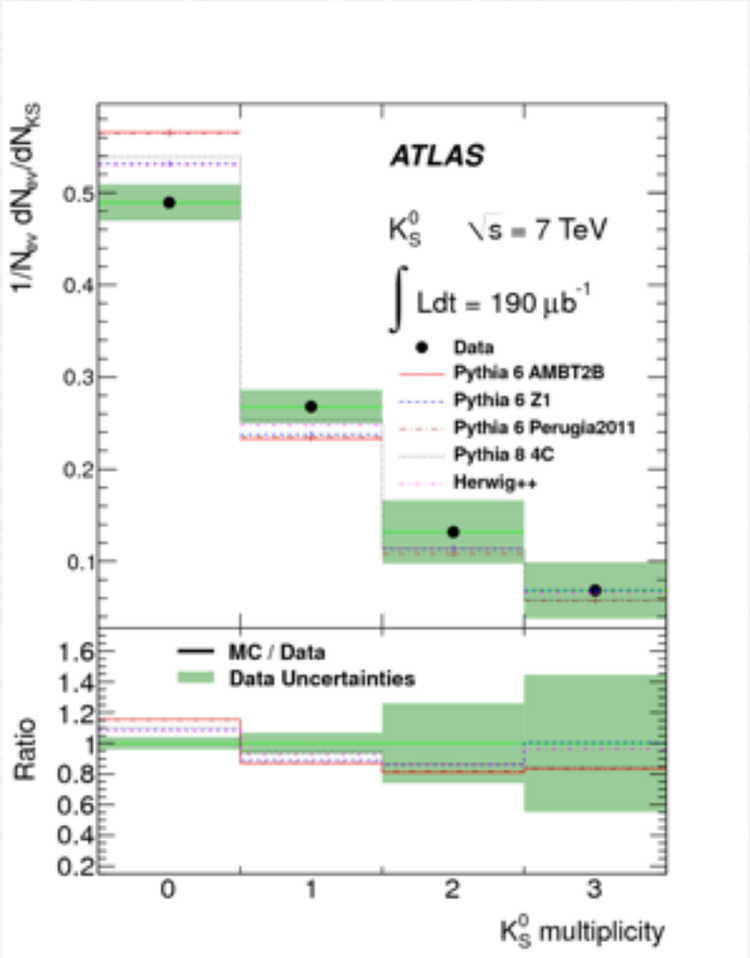
Madgraph+(?) agrees best with the data, most tunes/ models underestimate the UE activity compared to the data.

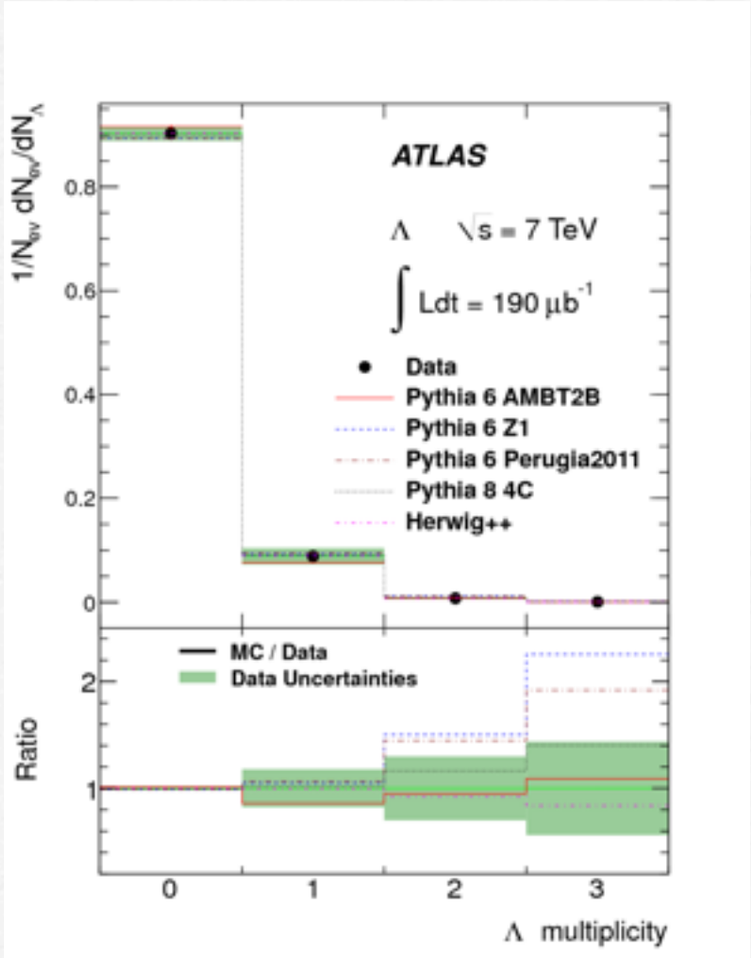
Revisiting the Old Question



Comparison of Z-boson and jet events;
more active UE in jet events, but softer spectra?

Identified Particle Production: Time to look at UE ...





ATLAS results in inclusive events; this part of MCs have not really been tuned from LHC data.

From Andrew Larkoski's talk at BOOST12

New Ideas?

Angular Correlation Function (ACF)

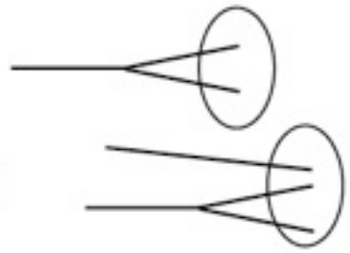
$$\mathcal{G}(R) \equiv \sum_{i \neq j} p_{\perp i} p_{\perp j} \Delta R_{ij}^2 \Theta[R - \Delta R_{ij}]$$

Introduce ensemble average ACF (analogous to jet shape)

$$\langle \mathcal{G}(R) \rangle = \frac{1}{N} \sum_{i=1}^{N} \mathcal{G}(R)_i$$

ACF ~ (Pert-Pert correlations) + (Pert-UE correlations)

- Red ~ p_T^2
- Blue ~ $p_T \Lambda_{UE}$

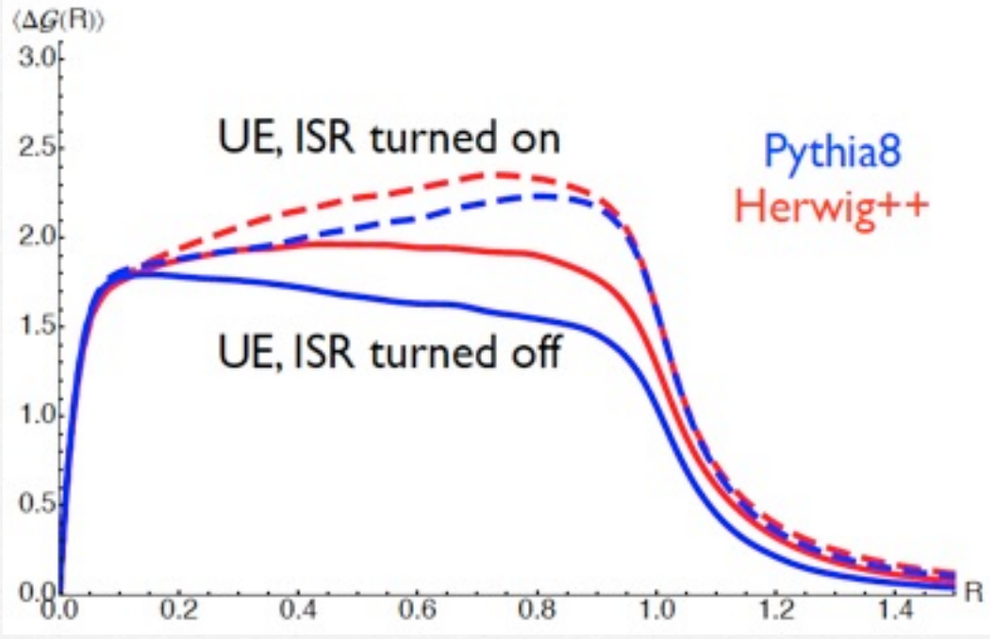


- ACF including UE ansatz:

$$\langle \mathcal{G}(R)_{\text{with UE}} \rangle = \langle \mathcal{G}(R)_{\text{no UE}} \rangle + \frac{\pi}{2} p_{\perp \text{jet}} \Lambda_{\text{UE}} R^4$$

~R^2, important at small angles

~R^4, important at large angles



Summary

- At the LHC, UE measurements affected by pileup and extra jets. The former adds challenges analysis-wise, while the latter stretches the UE definition.
- ATLAS results looking at transmax/min regions in jet/Z-boson events coming soon*, trying to probe effect of additional jets.
- 7 TeV UE measurements are on the way to completion, but will have to do this all over again for 13/14 TeV LHC running.