Jet Substructure Measurements at ATLAS

Deepak Kar
On behalf of ATLAS collaboration

International Conference on High Energy Physics, Seoul, July 2018

Jet Substructure

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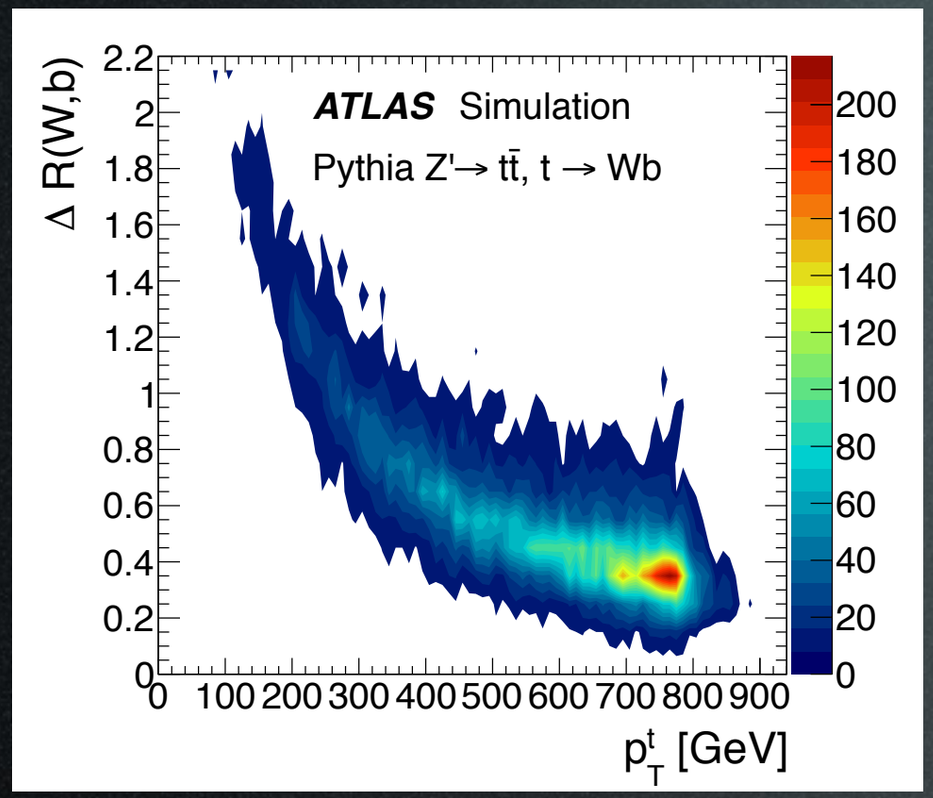
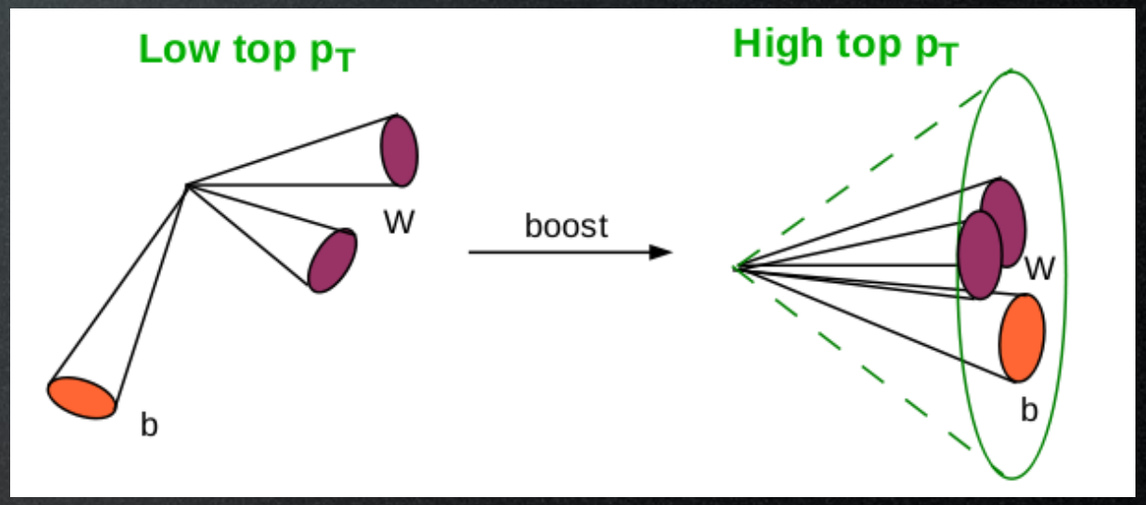


A large radius jet of $R = 2m/p_T$ can contain all decay products

Hadronically decaying top quark, Higgs/W/Z bosons, new heavy particles ...

Exploit the internal structure of the large radius jet coming from signal to distinguish them from large radius jet coming from background (light quark, gluon, lepton)



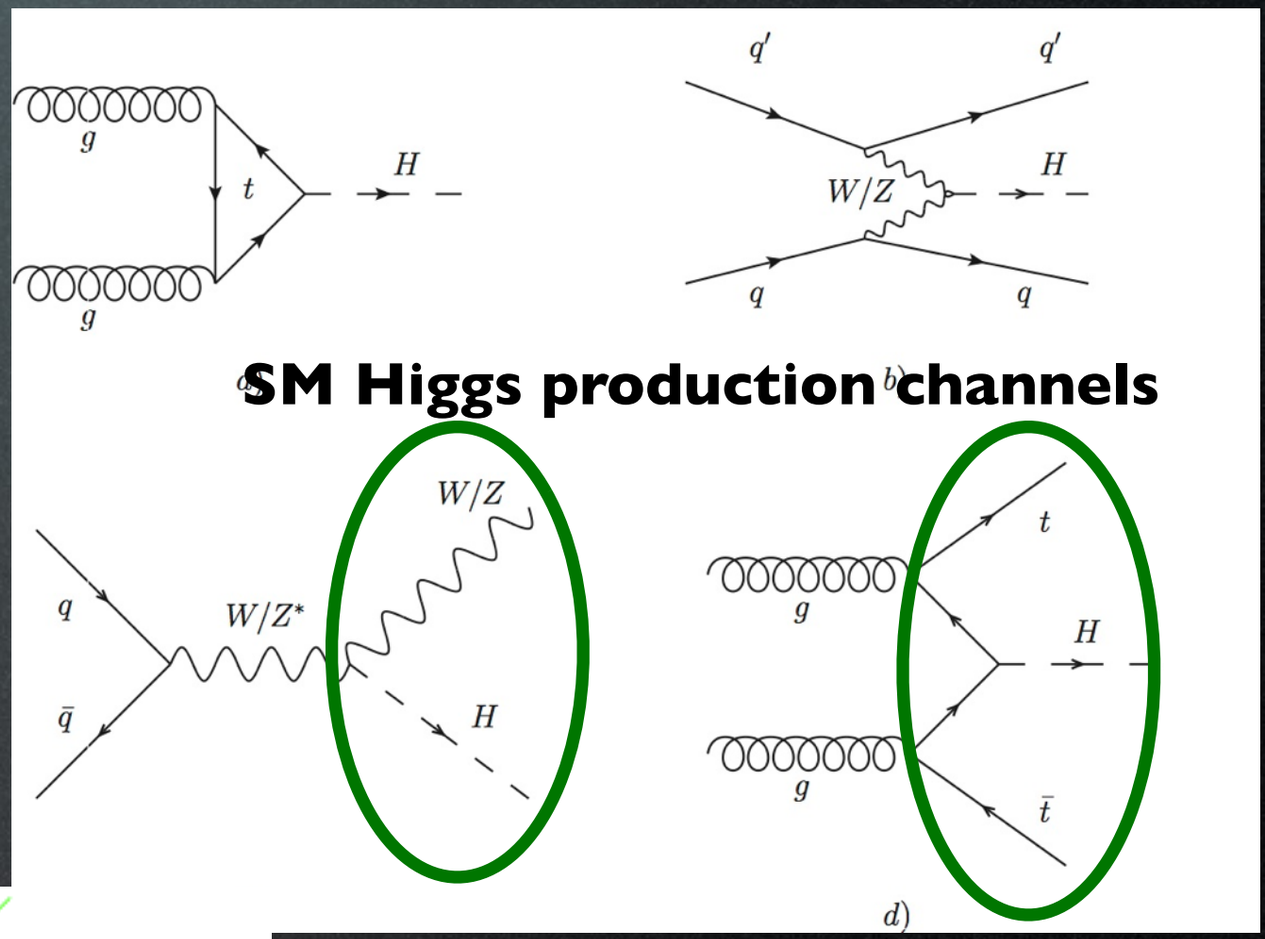
Preferred jet algorithms are k_t or CA, as they preserve clustering order, but anti-k_t is used to construct the large-radius jet

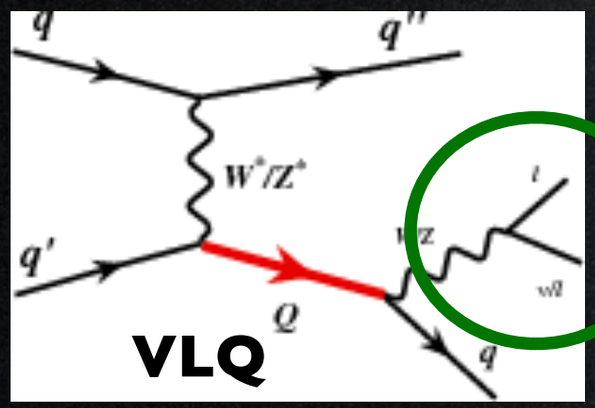

I'M NOT FAT
271516
15-07-13 09:38:38 CEST
ATLAS
EXPERIMENT
I'M JUST BIG CONED
made on imgur

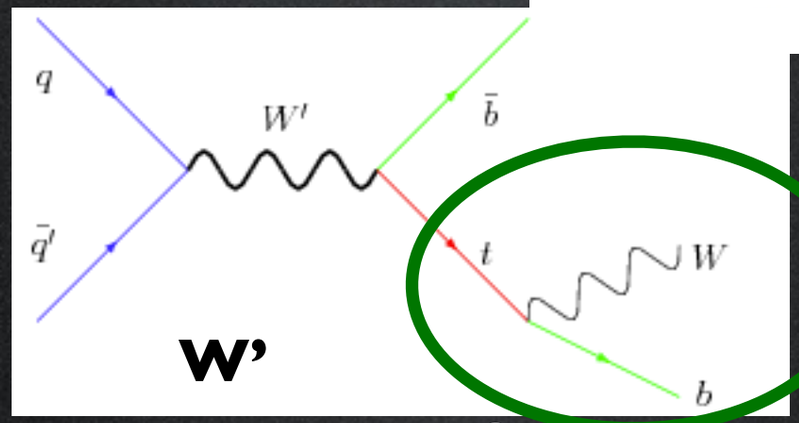
Why Jet Substructure

Searches for New Physics

- Deviation from SM predictions in Higgs coupling
- New heavy bosons
- Top partners/vector like quarks
- ...





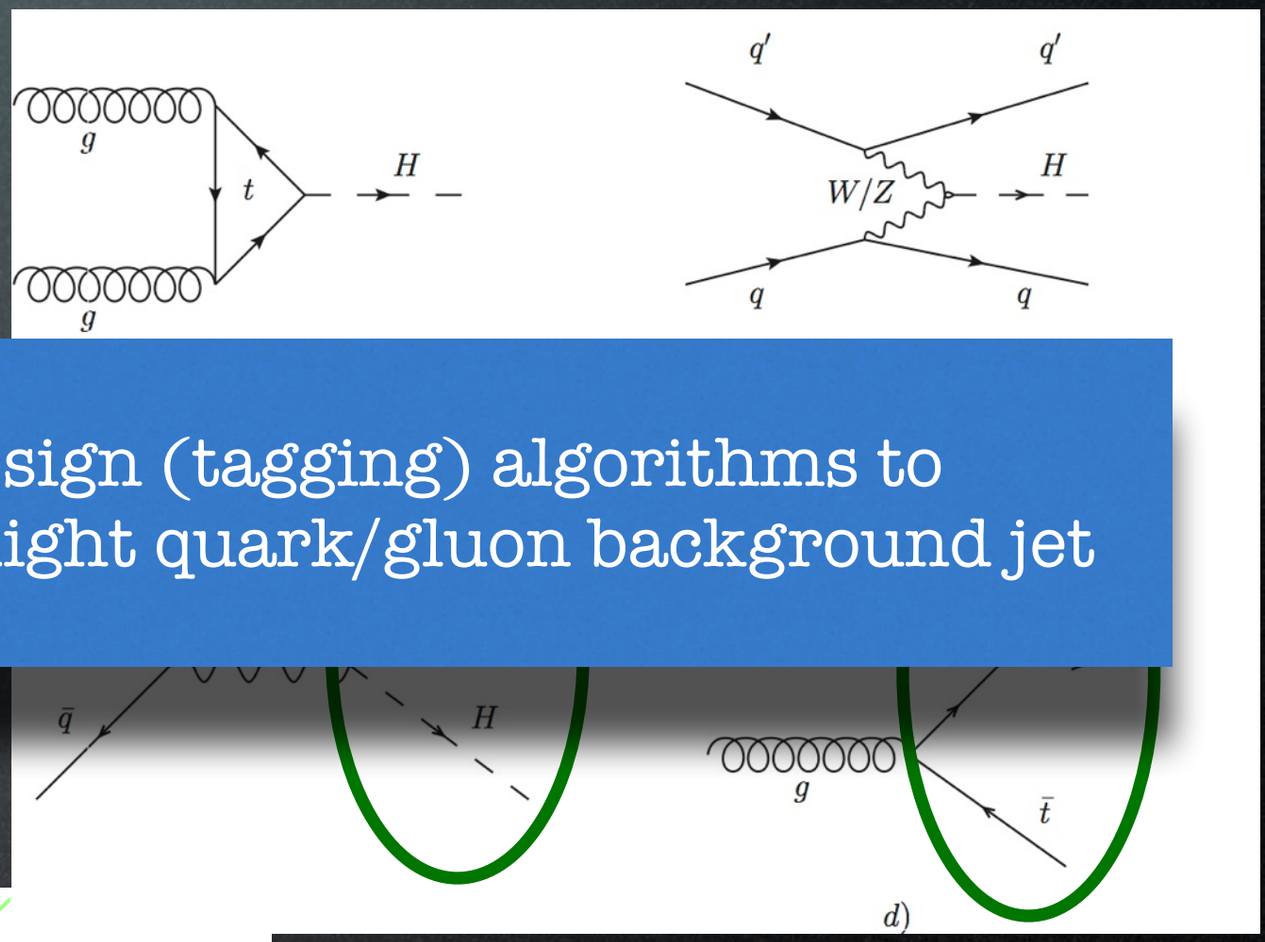


Substructure techniques help!
Reduces combinatorics in busy final states.

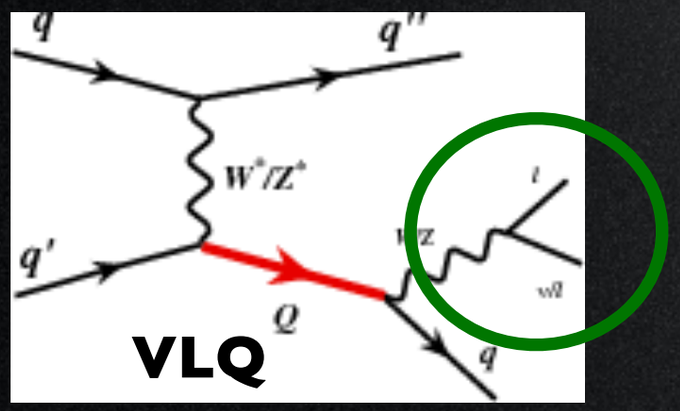
Why Jet Substructure

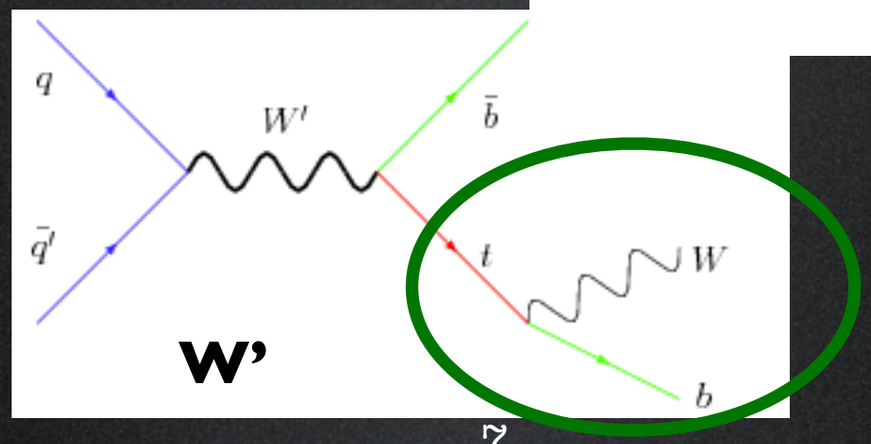
Searches for New Physics

- Deviation from SM predictions in Higgs coupling



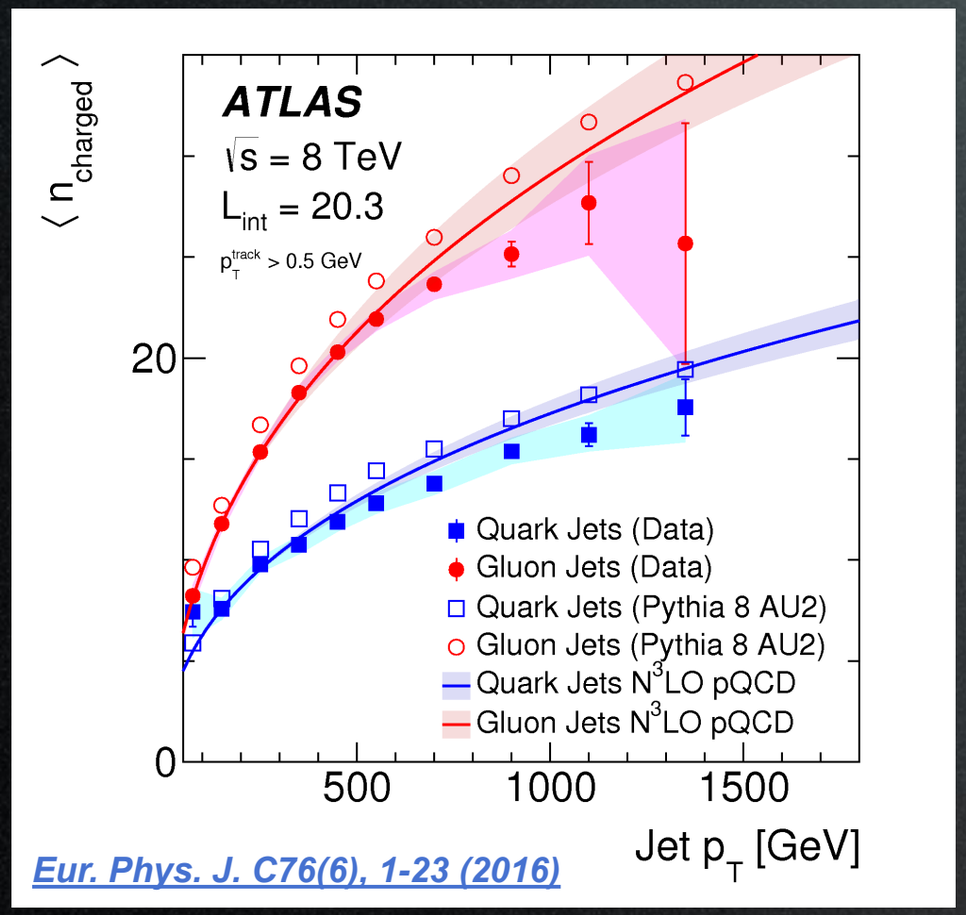
Most new developments to design (tagging) algorithms to discriminate signal(fat)jets from light quark/gluon background jet





Substructure techniques help!
Reduces combinatorics in busy final states.

Why Measurement?



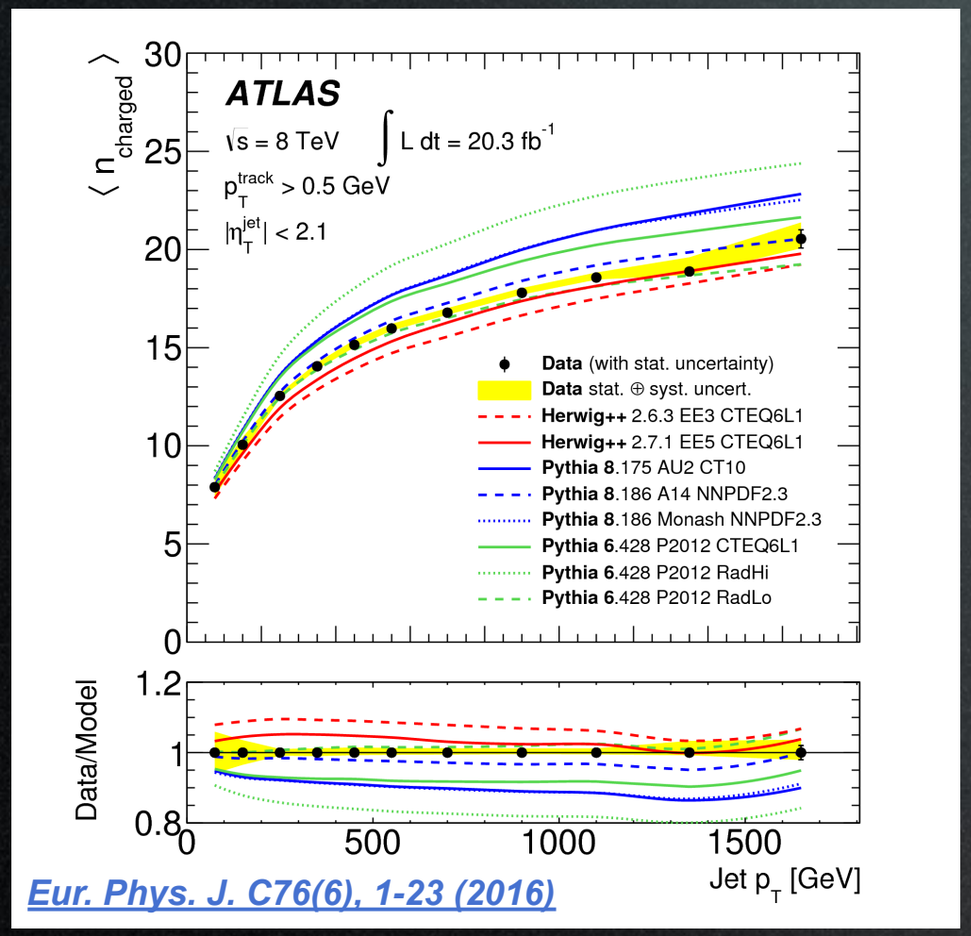
Eur. Phys. J. C76(6), 1-23 (2016)

Bulk properties of large-radius jets depend on pQCD modelling.

Non negligible differences from data are observed in MC predictions

Soft-drop is insensitive to non-global logarithmic terms, leading to precision analytic calculation of substructure variables

Why Measurement?



Eur. Phys. J. C76(6), 1-23 (2016)

Jet (sub)structure is mostly dependent on Parton Shower models

Non negligible differences from data are observed in MC predictions

(Unfortunately) Grooming to get rid of uncorrelated radiation also throws away the soft part we wish to tune to!

"Your garbage is my treasure"

Attributed to Stefan Prestel

Why Measurement?

Sensitive to both perturbative and non-perturbative QCD ("precision substructure")

Input to tune/improvement models and analytic calculations

Helps in tagging algorithm development.

Larkoski, Marzani, Soyez,Thaler, 2014

Soft Drop

Start with a jet j and it is split into last two subjets

If:

$$\frac{min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{cut} \left(\frac{\Delta R_{12}}{R_0} \right)^{\beta}$$

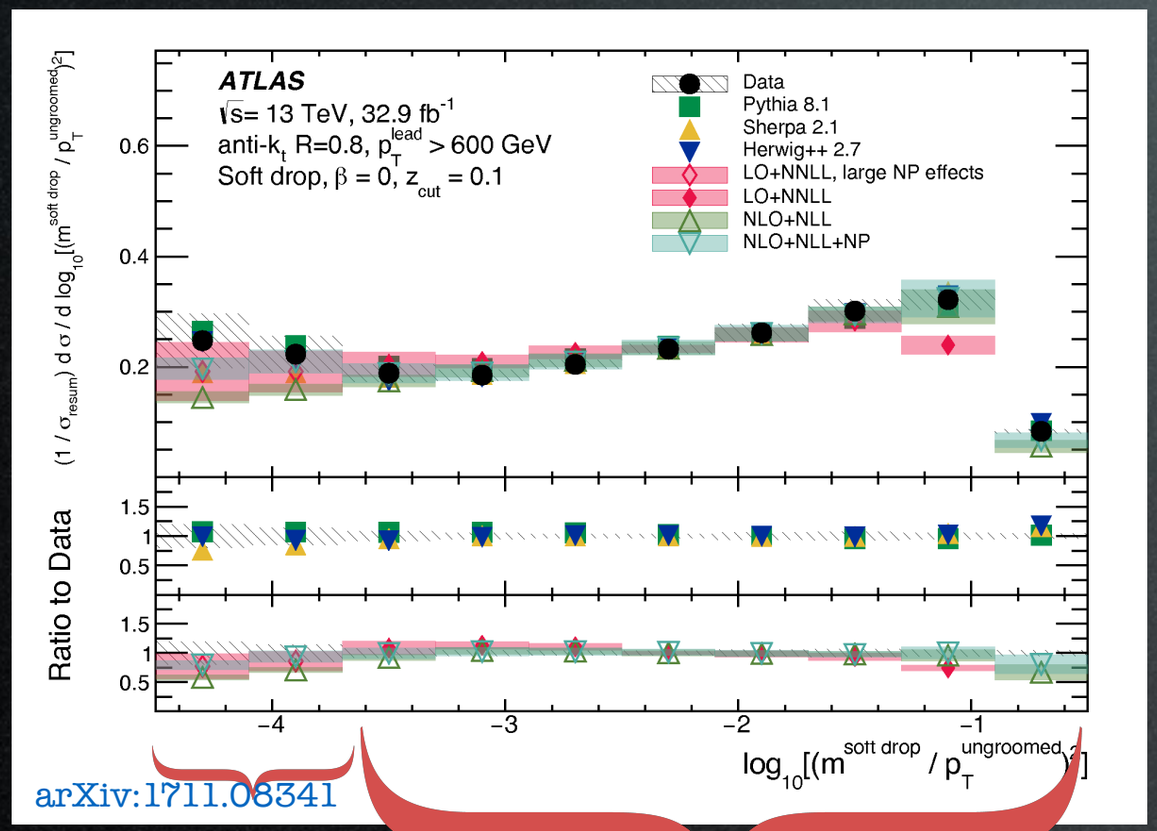
Then j is the final soft drop jet.

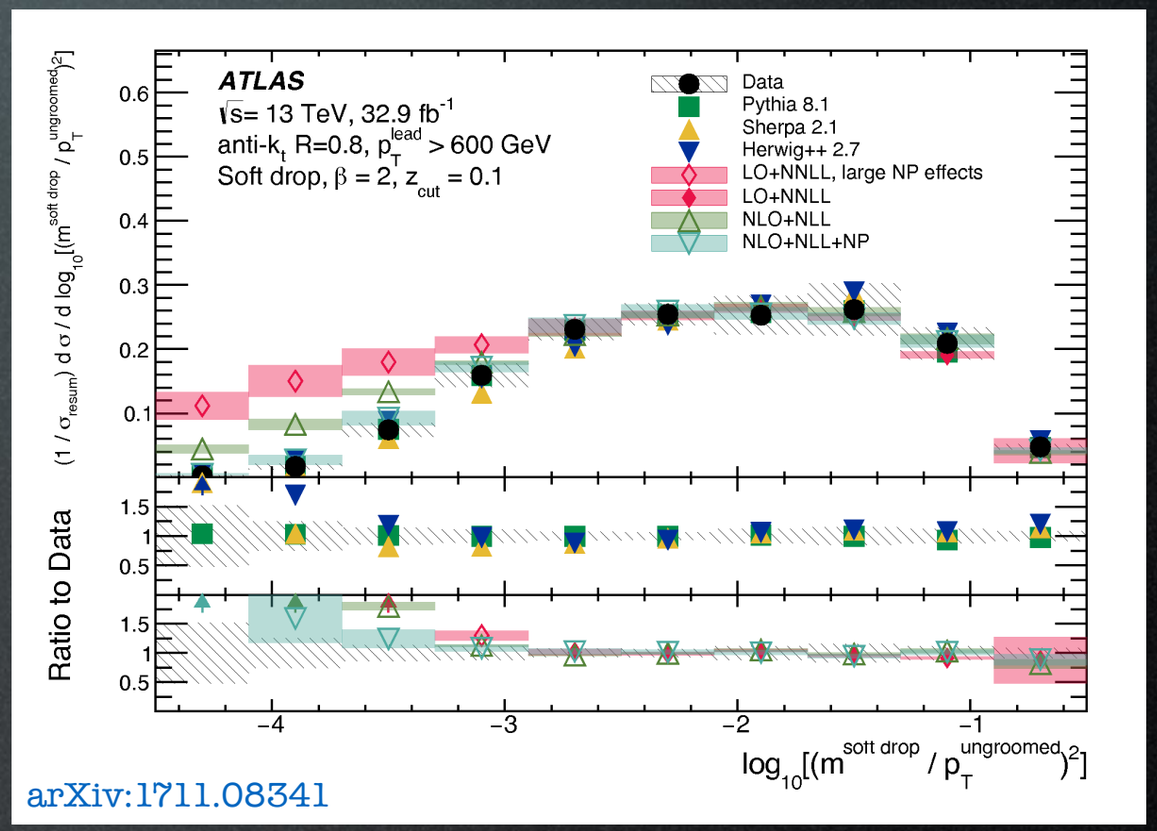
Otherwise the higher p_T subjet is taken as j, and iterated ...

Advantage: can be compared directly to analytic calculations, factorises non-perturbative effects

Soft-dropped Jet Mass

Ratio of the soft-drop mass to the ungroomed jet transverse momentum





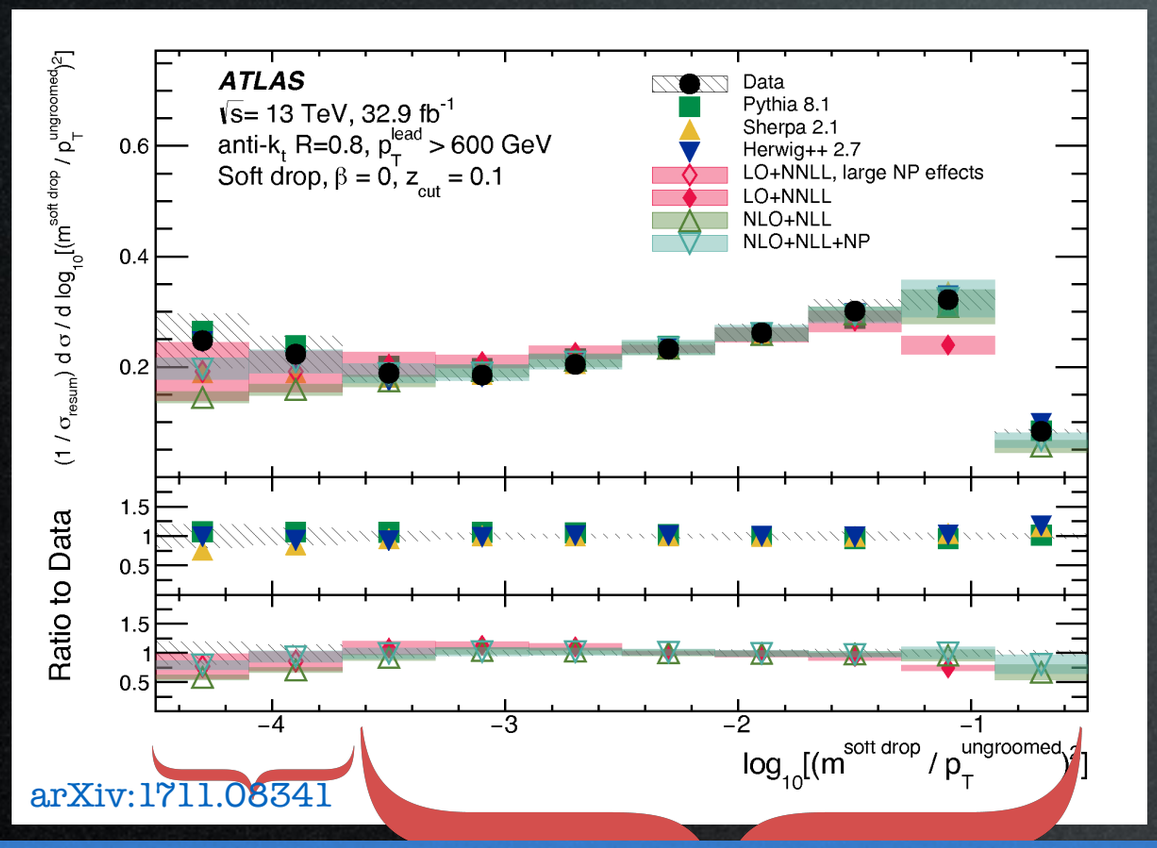
Collinear emission region

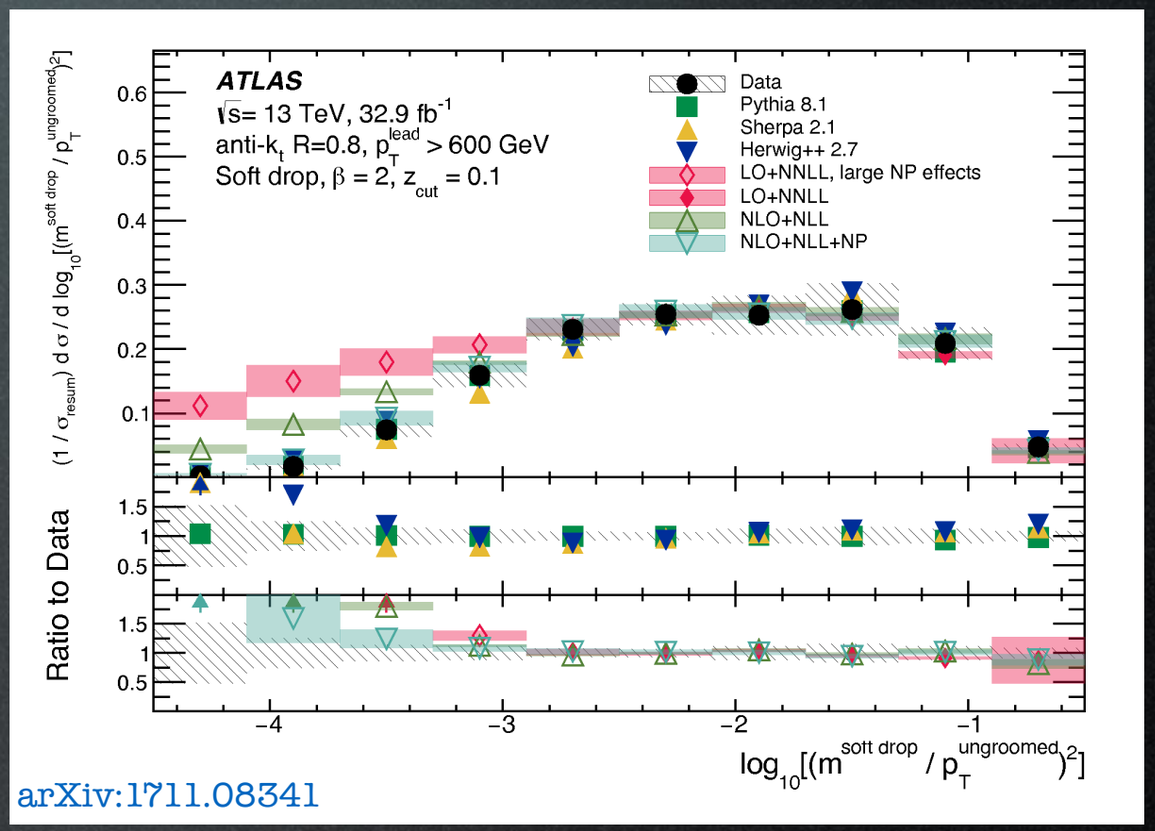
Resummation region

Higher beta
(smaller fraction of soft energy removed)

Soft-dropped Jet Mass

Ratio of the soft-drop mass to the ungroomed jet transverse momentum



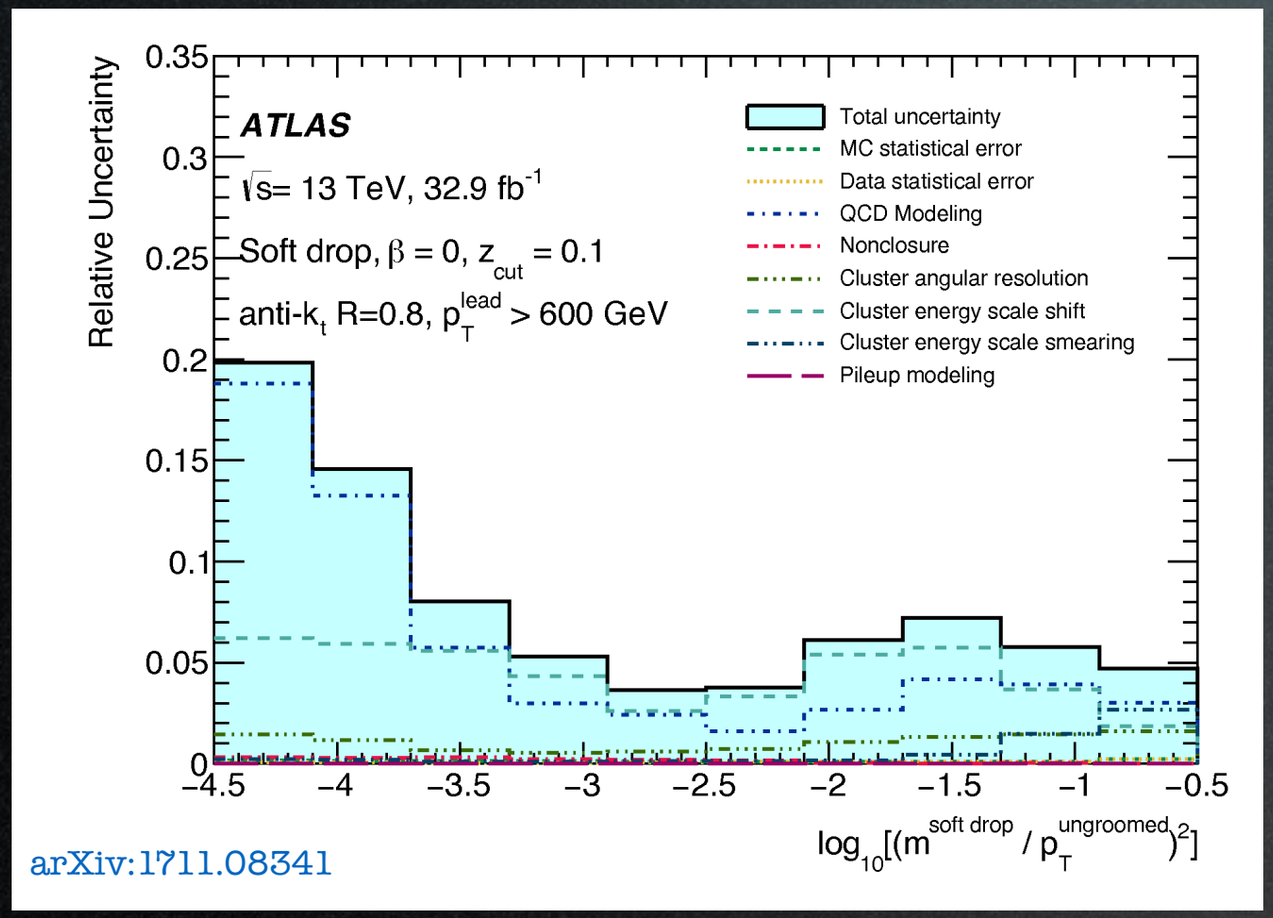


Largest difference between MC and analytic calculation in NP region

NLO+NLL+NP better at low logρ

Good agreement at resummation region for both MC and calculations

Uncertainty for JSS measurements



Leading experimental uncertainty from calorimeter cell-cluster energy, resolution, efficiency etc.

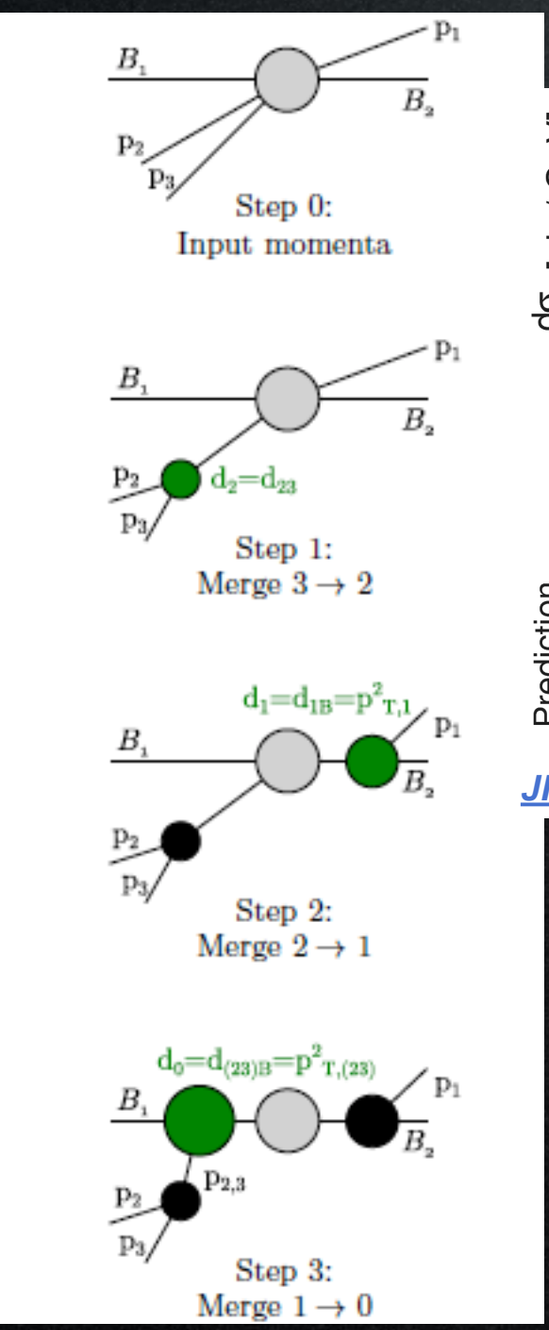
Cluster energy scale and resolution uncertainties estimated by track to cluster E/p ratio, angular resolution uncertainty by relative position shift

Reconstruction efficiency from unmatched tracks to clusters

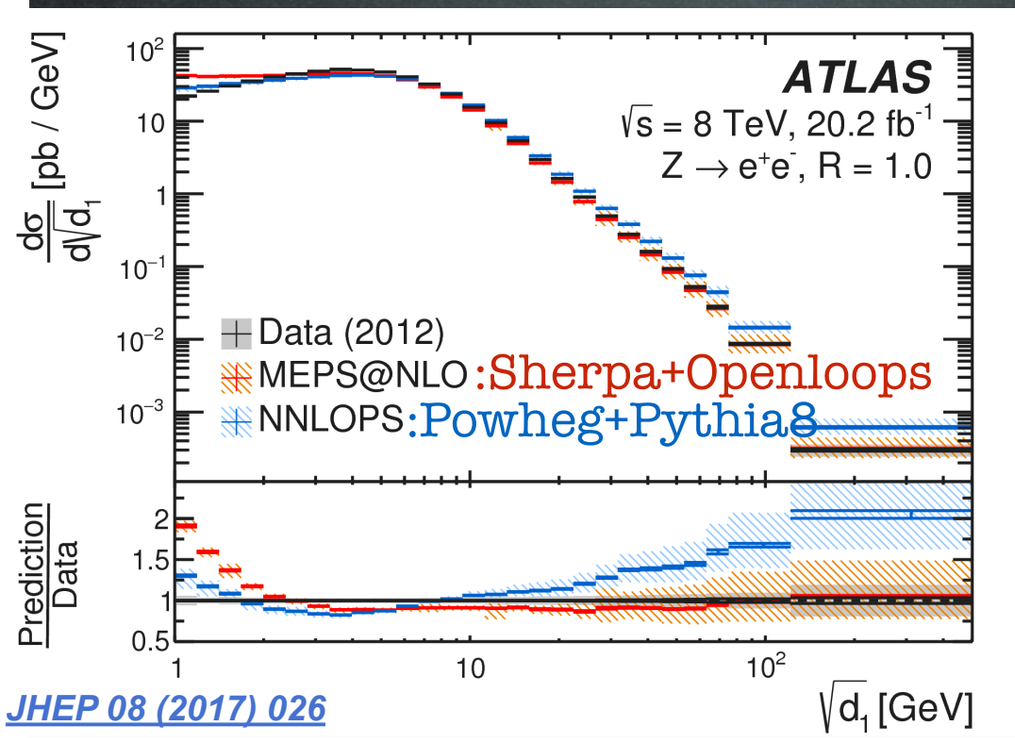
k_t Splitting Scale

$$\sqrt{d_{ij}} = \min(p_{\mathrm{T}i}, p_{\mathrm{T}j}) \times \Delta R_{ij}$$

When combining two subjets with k_t algorithm:



Using charged particles in Z-boson events



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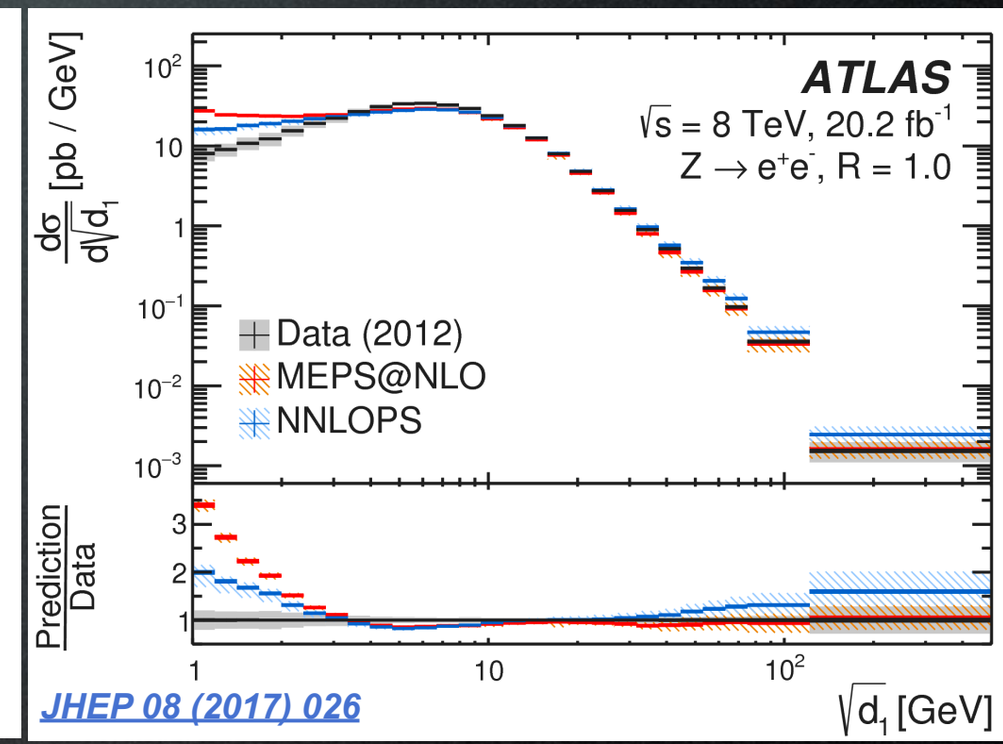

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More inclusive

Small values: soft splitting,
Larger values: hard splitting

k_t Splitting Scale

$$\sqrt{d_{ij}} = \min(p_{Ti}, p_{Tj}) \times \Delta R_{ij}$$

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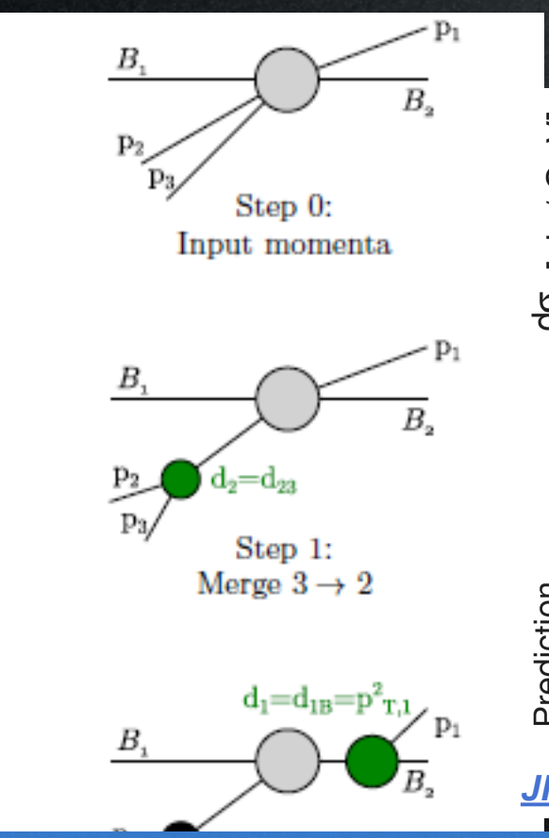

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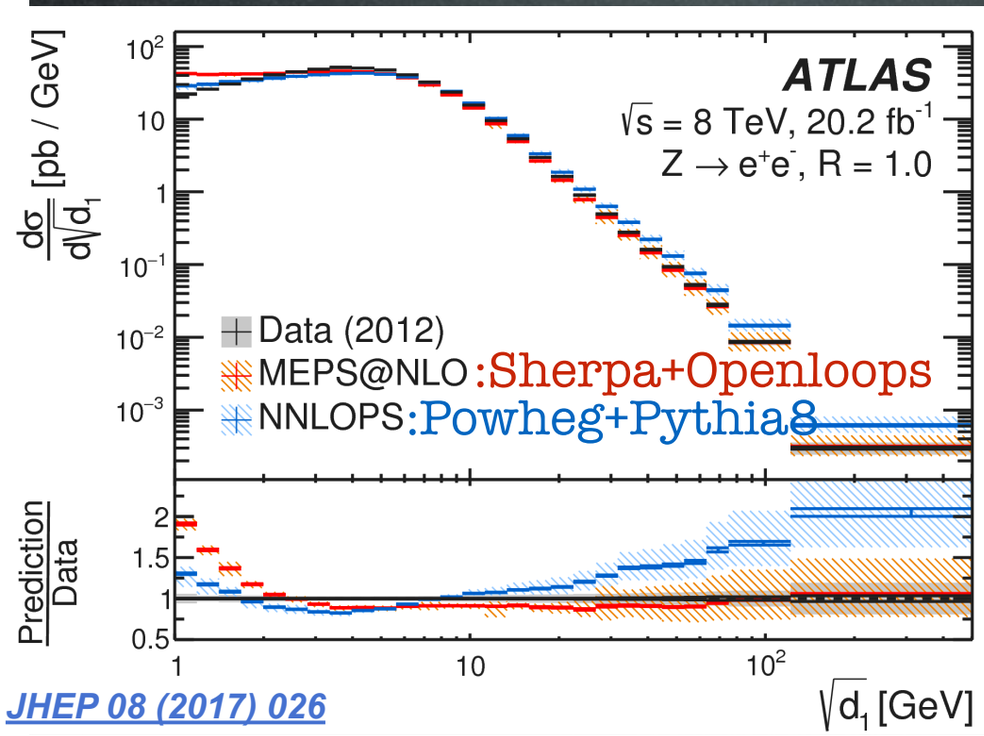

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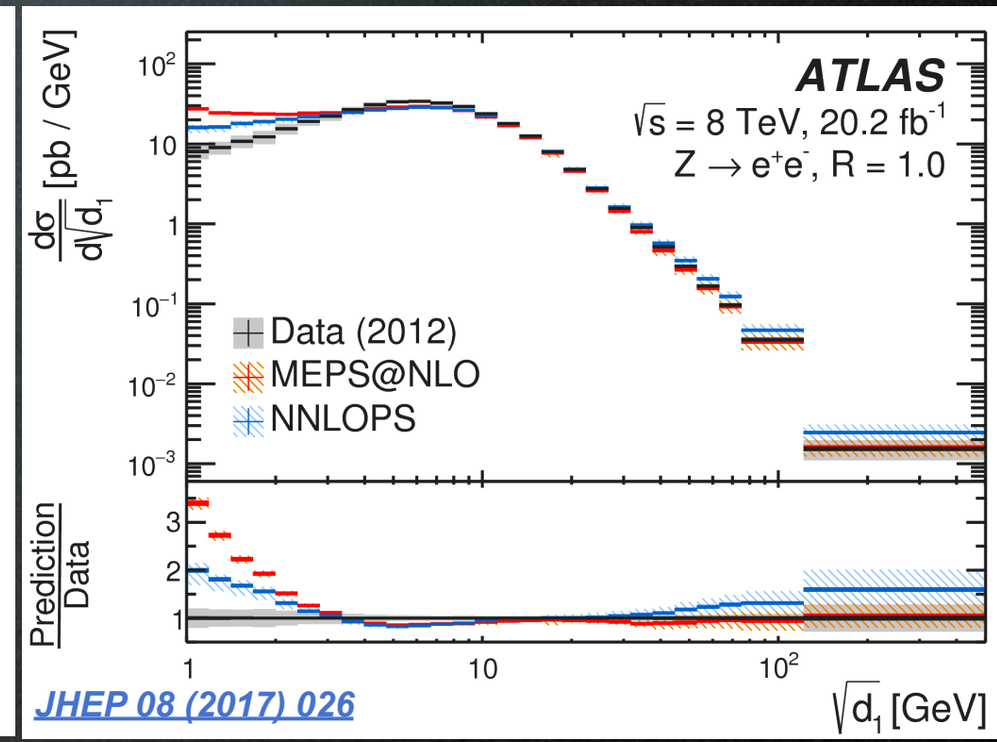

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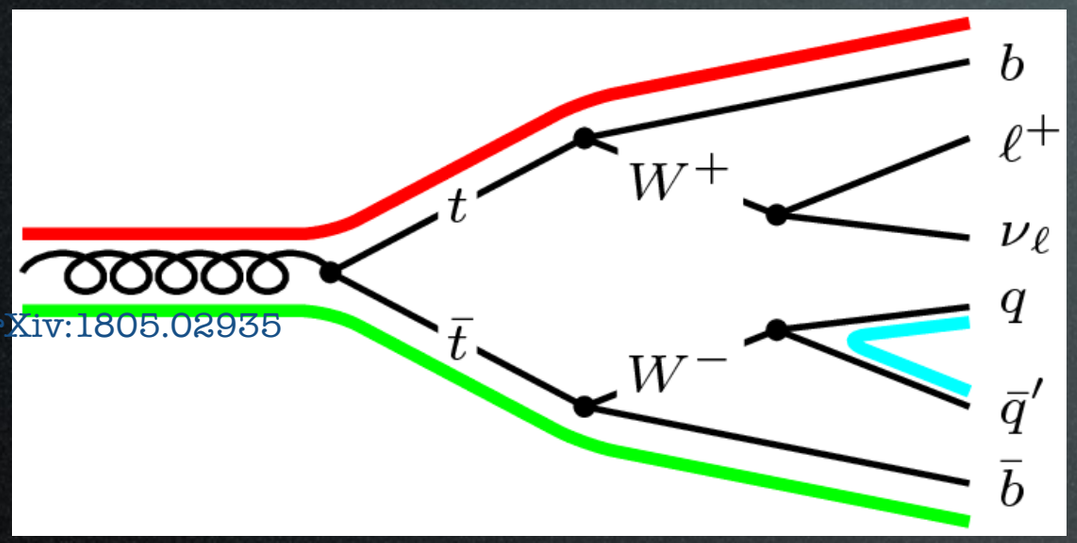
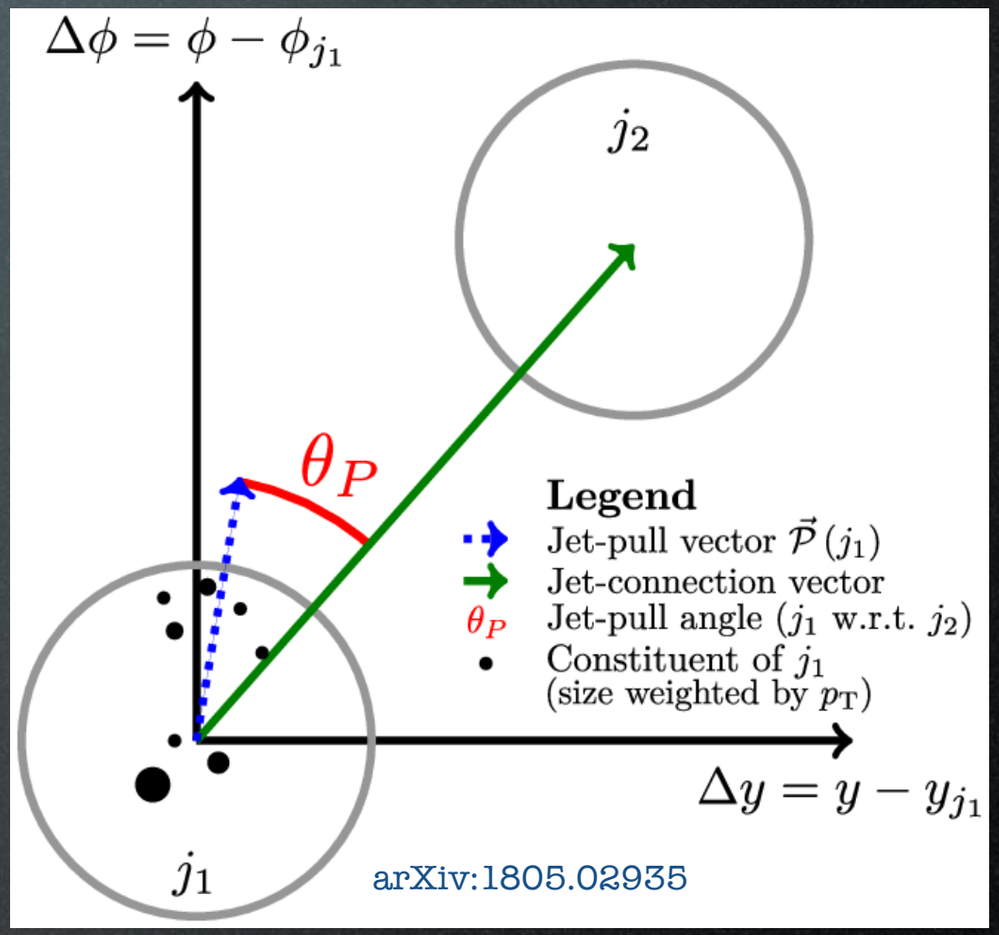
Large discrepancy at soft/collinear regime

Sherpa better than Powheg+Pythia8 at high tails

Colour Flow in TTbar Events



arXiv:1805.02935



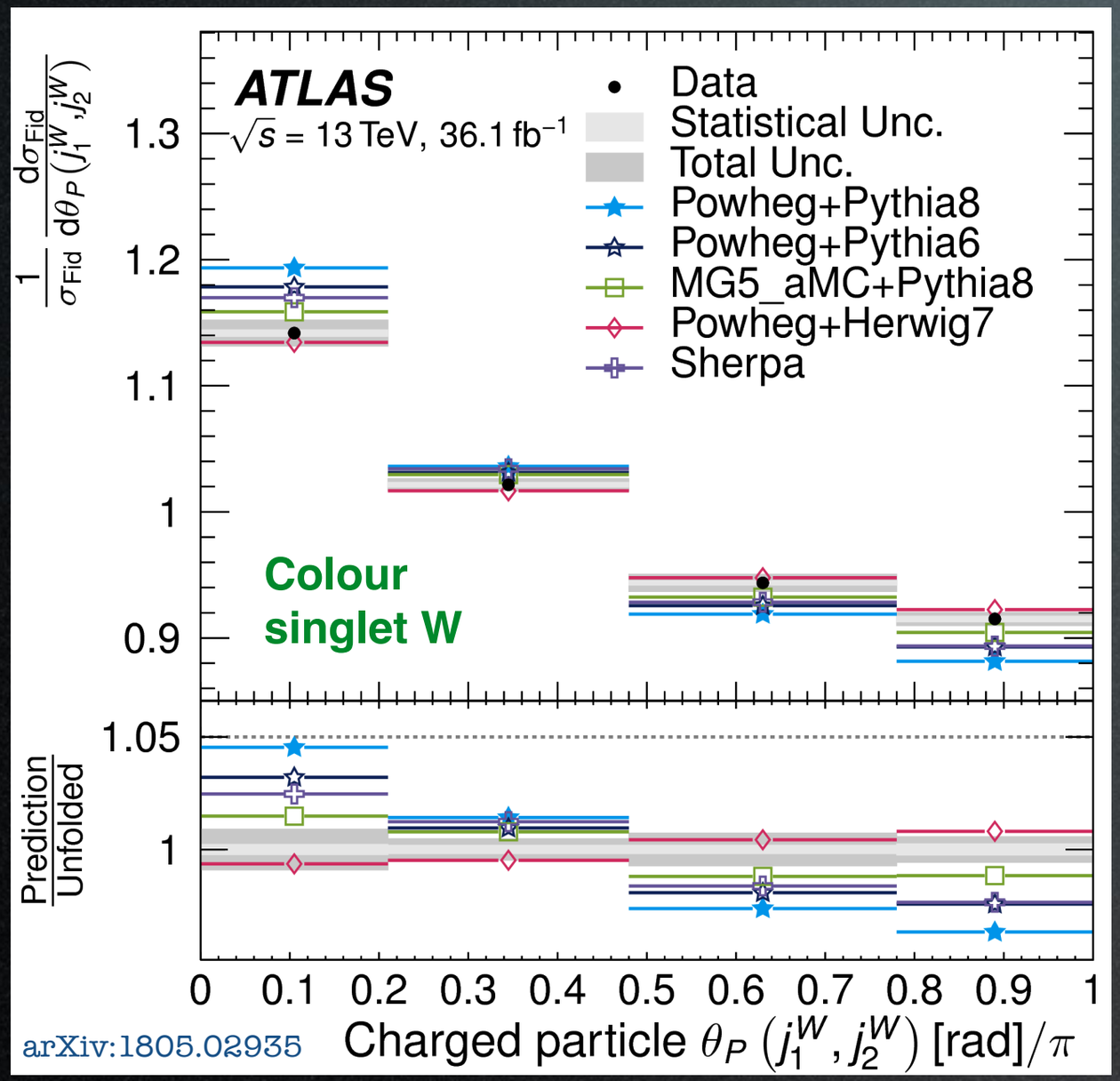
Colour flow modelling in MC generators is Poorly constrained by current measurements

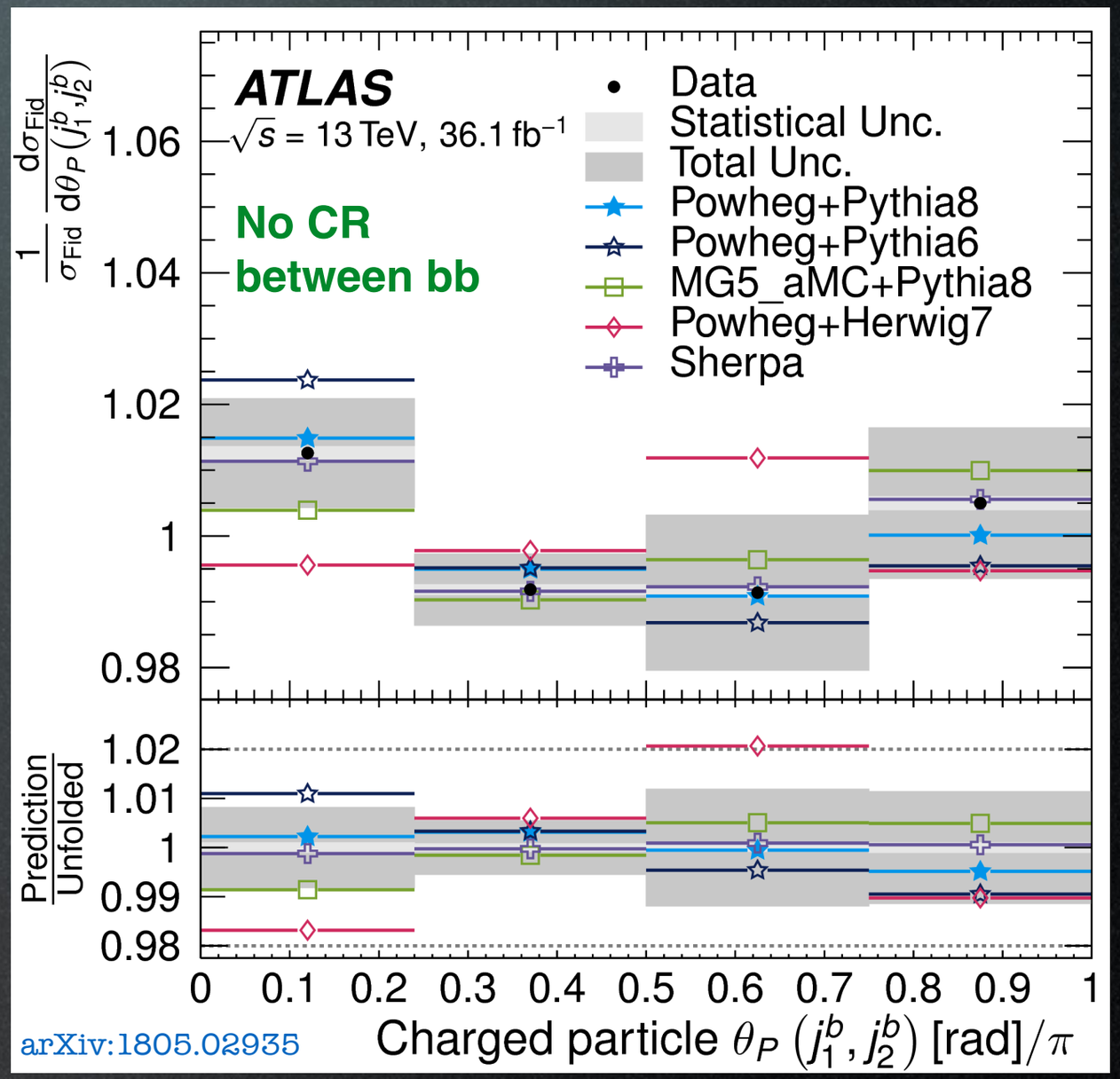
Weighted angular moments derived from jet constituents

$$\vec{\mathcal{P}}(j) = \sum_{i \in j} \frac{\left|\vec{\Delta r}_i\right| \cdot p_T^i}{p_T^j} \vec{\Delta r}_i$$

Results

Using charged particles in semi-leptonic ttbar events

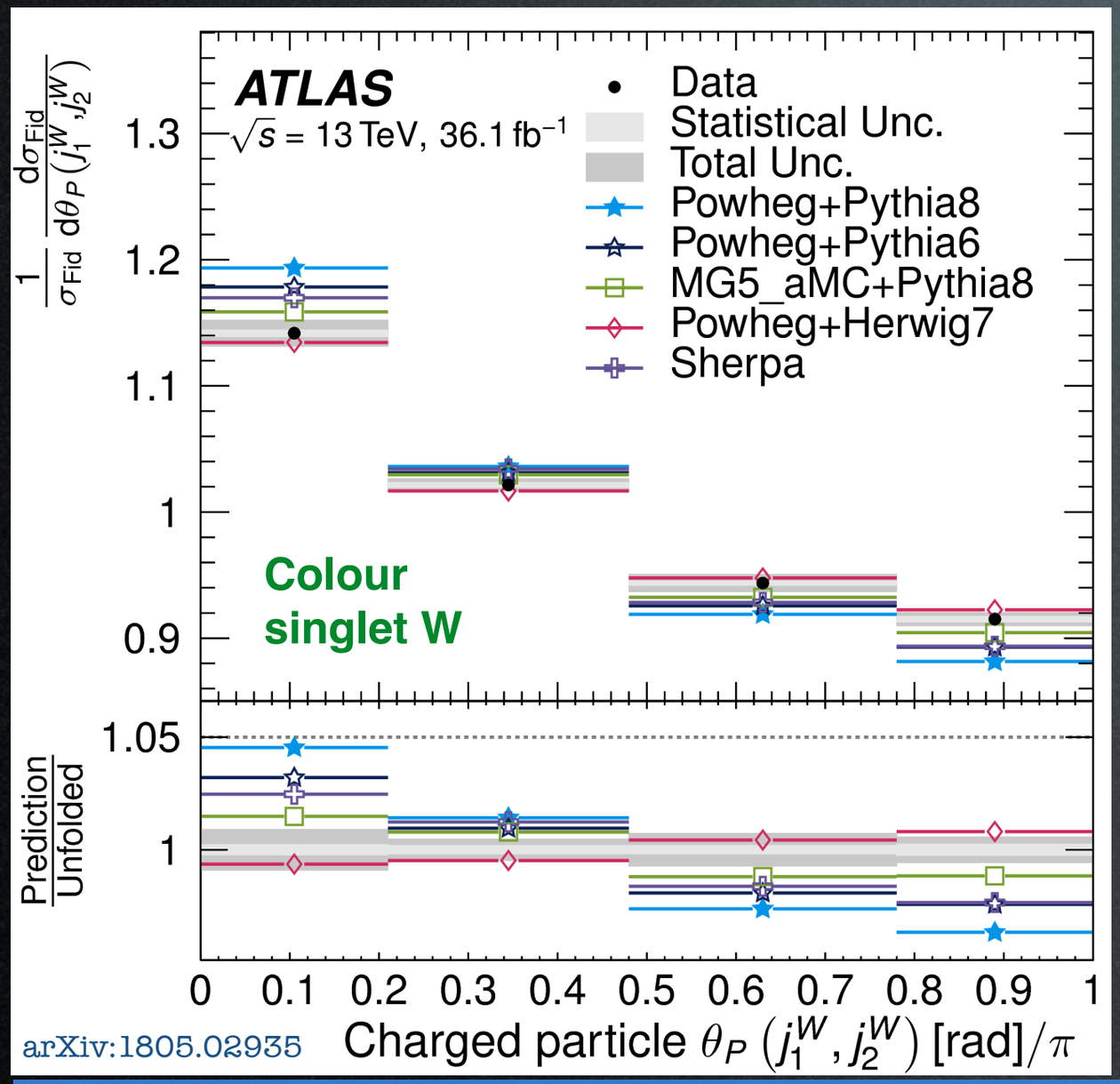


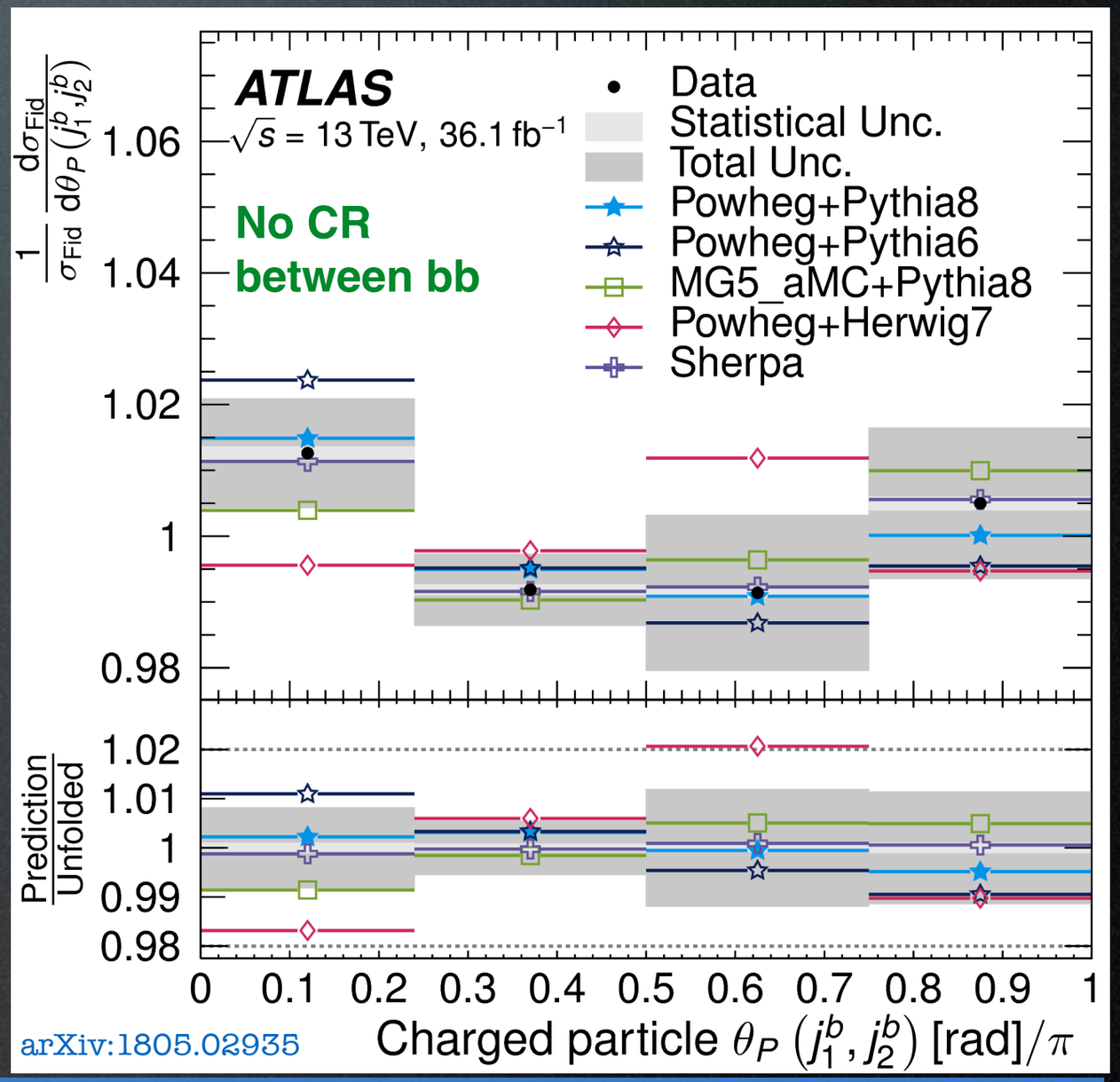


Close to zero for colour connected jets, uniform if no colour connection

Results

Using charged particles in semi-leptonic ttbar events

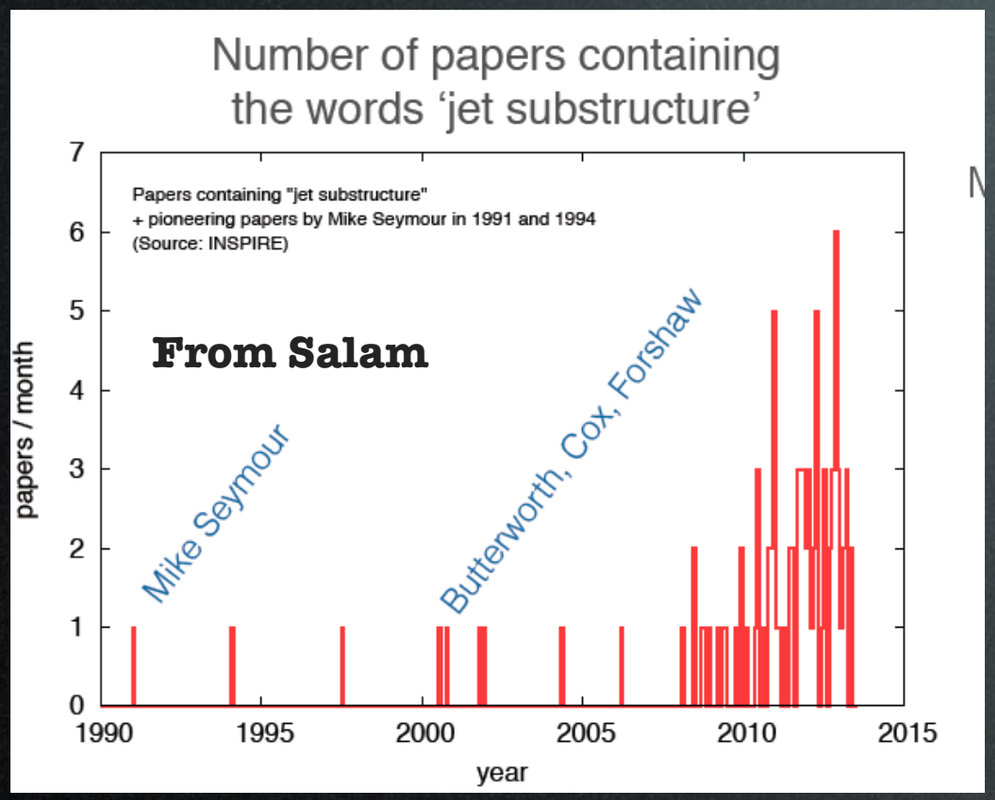


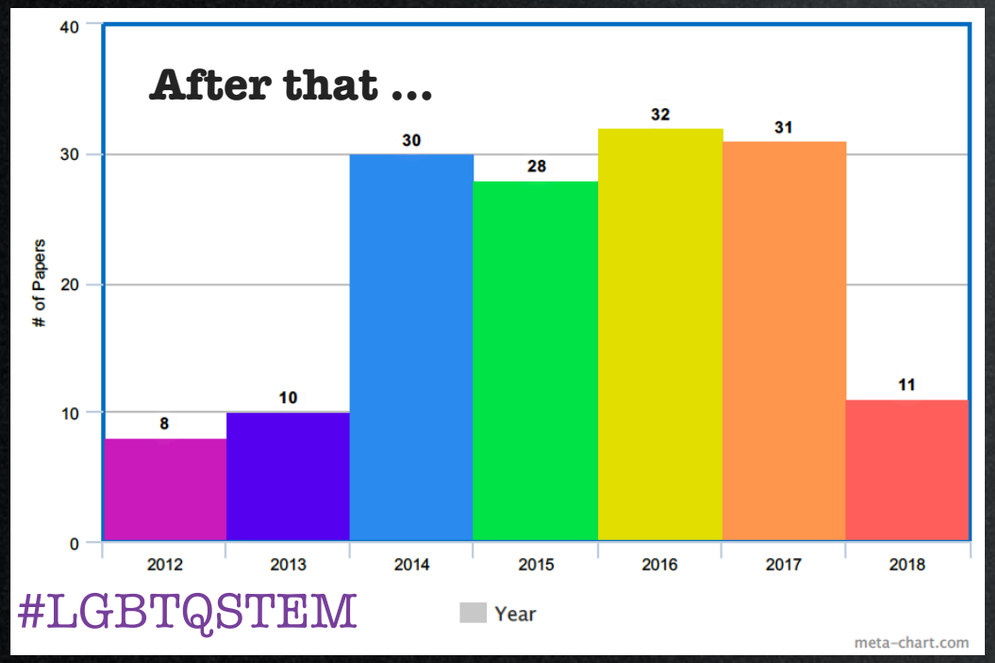


MCs predict stronger colour connection than data

Powheg+Herwig7 describes the data the best

Looking Forward





#LGBTQSTEM

- Jet substructure studies are essential for finding new physics in post-Higgs era in (HL) LHC and ILC.
- Need measurements, and best possible MC modelling
- Proper estimation of uncertainties, and robustness against pileup is critical