Exclusive Quark and Gluon Jet Properties

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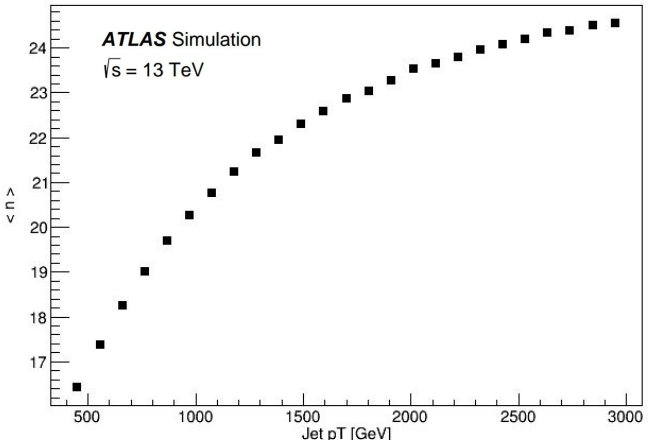
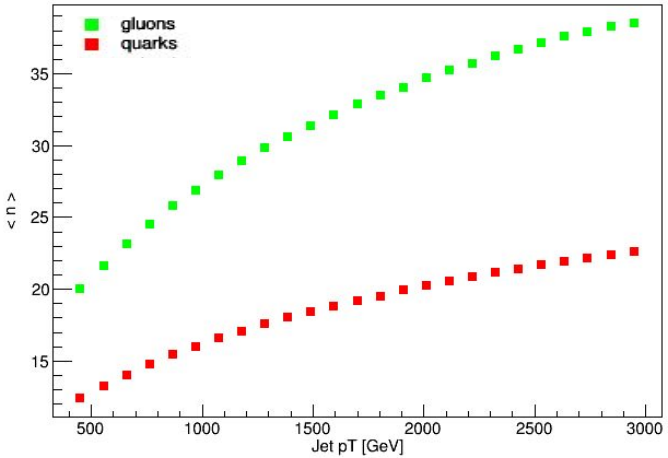
Motivation

- Quark and gluon jet properties differ because of their quantum properties (electric charge, color charge, spin).
- However, we cannot directly observe quark and gluon jets (we always get a mixture).
- We can exploit variations in the quark/gluon fraction with rapidity to extract exclusive distributions from the data.

Observables

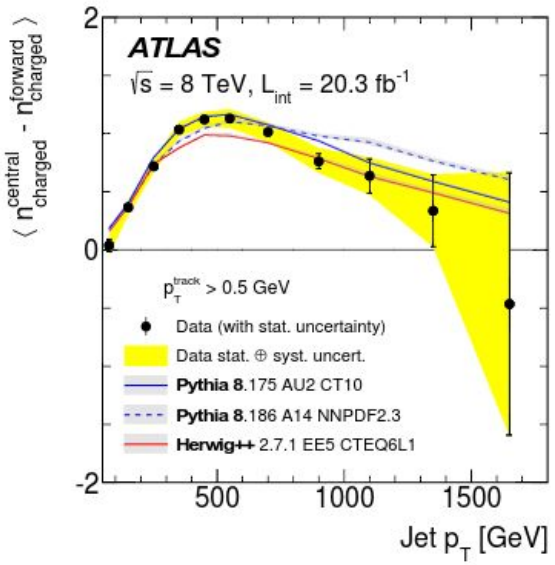
- There are many observable we can use for our distributions - let's use as an example the simplest: (charged) multiplicity
- Constituent multiplicity increases with p_T and is about twice as high for gluon jets as it is for quark jets.

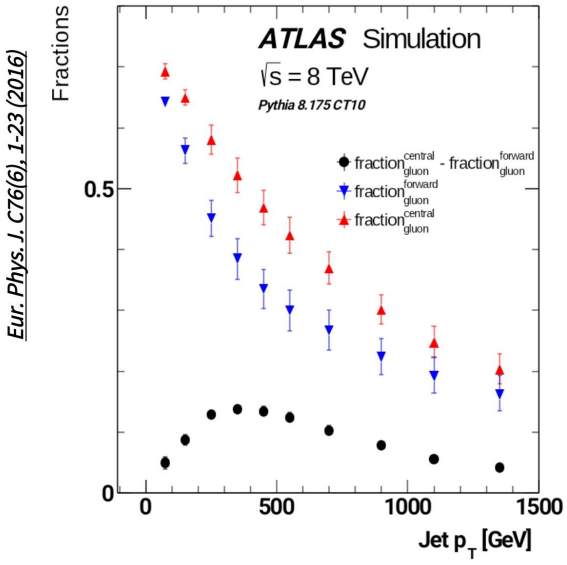




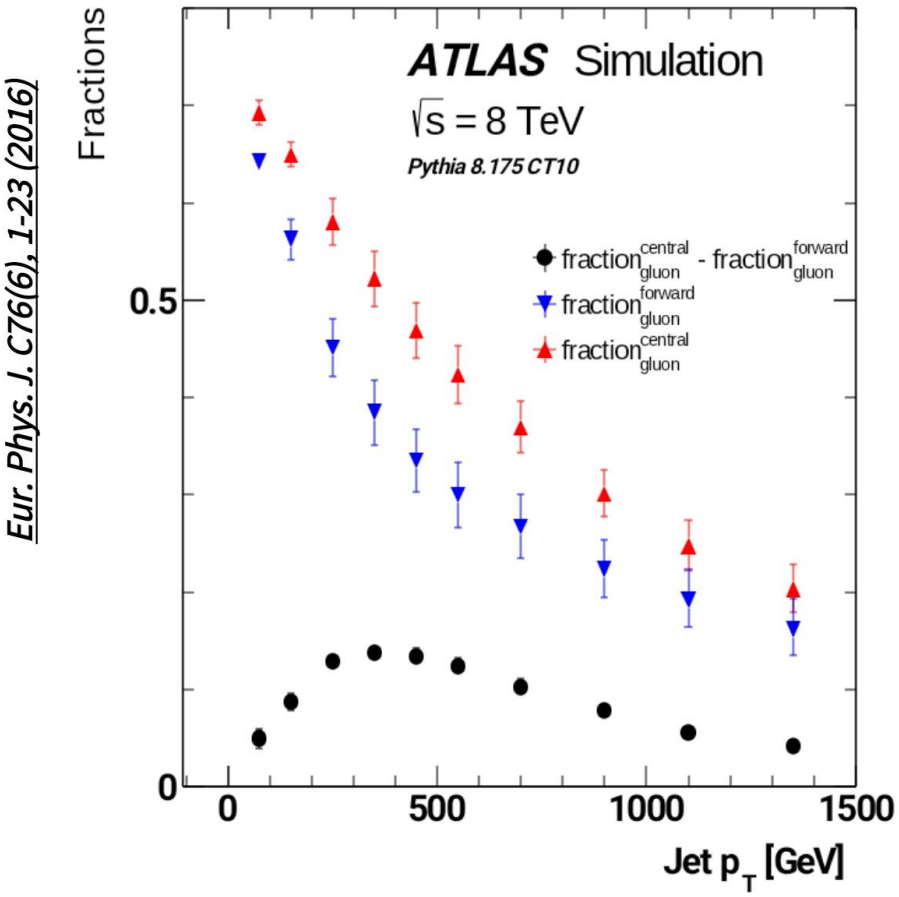
Quark/Gluon Fractions

- For a dijet event, we can measure the charged particle multiplicity for both the more forward and more central of the dijets.
- We know the quark/gluon fractions for the forward/central jets with low uncertainty.
- How these fraction change with p_T tells us about the quark/gluon composition of these jets.
- Quark/gluon differences are directly observable in the data.





- Gluons dominate at low p_T and quarks dominate at high p_T. At intermediate p_T they both contribute about the same.
- Simple observation: In dijet events, the more forward jet is more likely a quark jet.
- This is because for a fixed p_T, the more forward jet has a higher energy and thus higher momentum fraction, and is therefore more likely from the valence quark.



Exclusive Extraction

- The dependence of the averaged charged particle multiplicity of the forward and central jets can be expressed as a set of linear equations in the average charged particle multiplicity of quark and gluon jets, with the quark/gluon fractions as coefficients.

measured **extracted** **extracted**

$$\langle n^{f}_{\text{charged}} \rangle = f^{f}_{q} \langle n^{q}_{\text{charged}} \rangle + f^{f}_{g} \langle n^{g}_{\text{charged}} \rangle$$

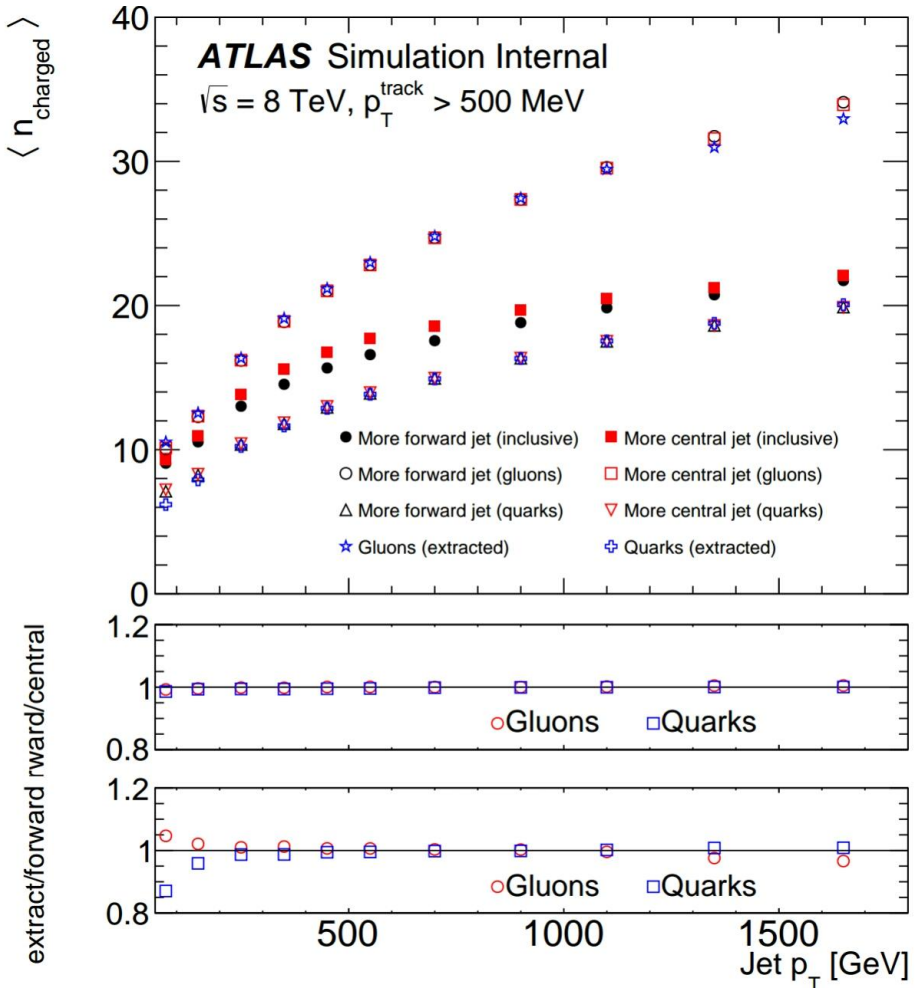
$$\langle n^{c}_{\text{charged}} \rangle = f^{c}_{q} \langle n^{q}_{\text{charged}} \rangle + f^{c}_{g} \langle n^{g}_{\text{charged}} \rangle .$$

f = forward, c = central
q = quark, g = gluon

input from simulation

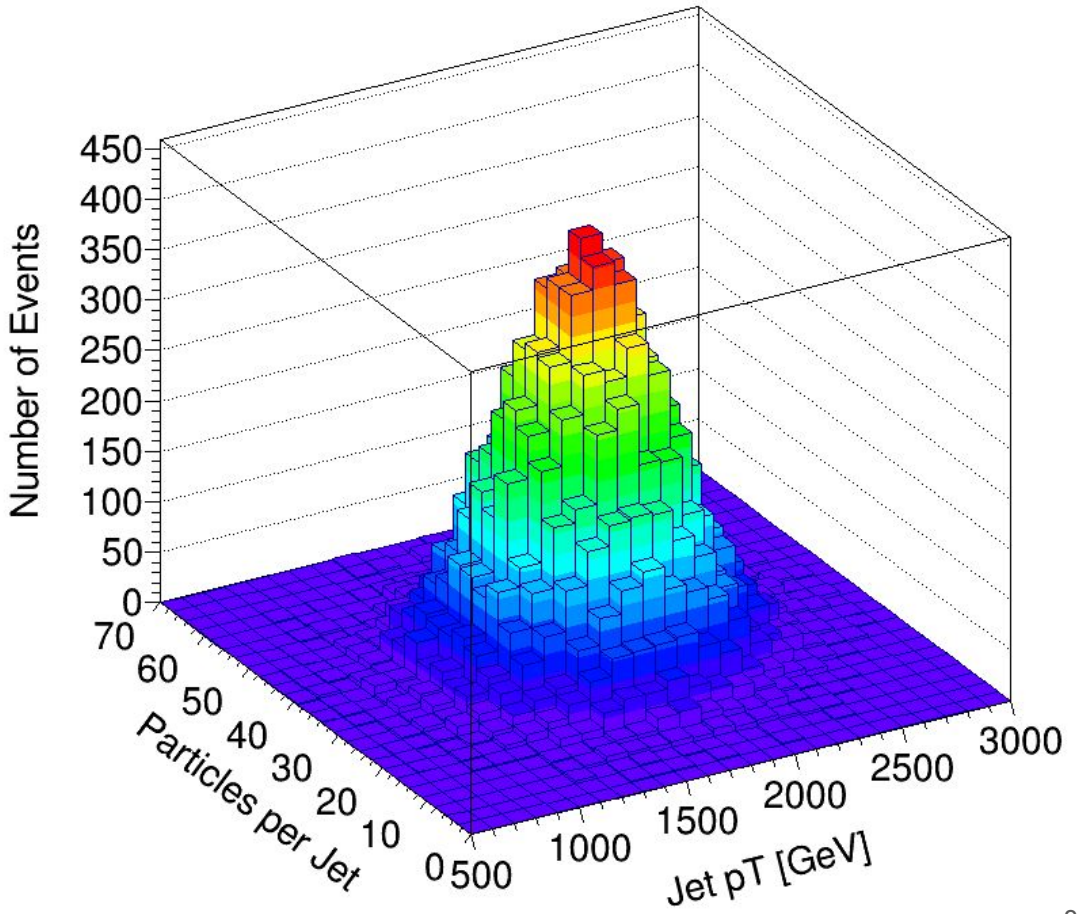
uncertainties fairly small – depend only on relative Parton Distribution Function for forward and central jet

- From that system of equations we are able to extract the average charged particle multiplicity for quark and gluon jets.
- This method has excellent closure for this observable over a wide range of p_T.
- Residual non-closure is possibly a statistical effect.
- However, this method only provided us information on the *average* charged multiplicity.

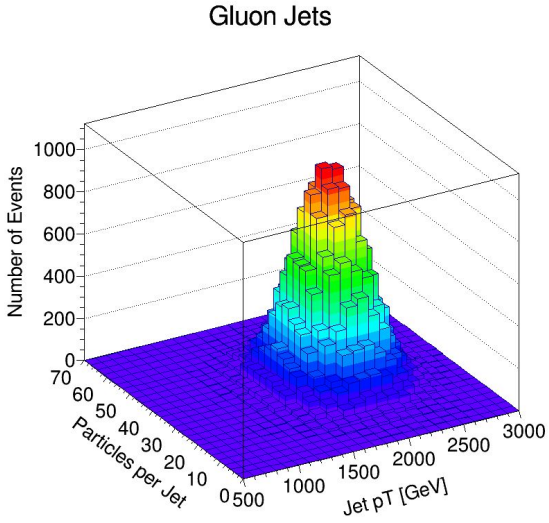


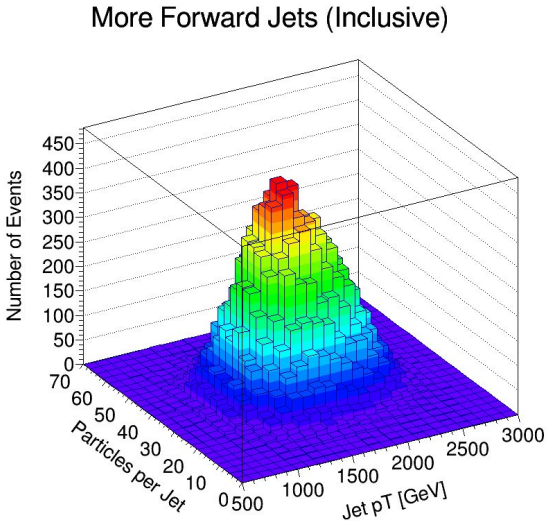
New Idea - Entire Distributions

- Rather than only looking at how average charged particle multiplicity changes with p_T, let's look at the distribution of events over both p_T and charged particle multiplicity.
- Goal: Given these distributions for the more forward and more central jets, we want to extract the distributions of the quark and gluon jets.
- The math is similar to before, but this time with quark/gluon fractions for whole rows of fixed p_T, rather than for individual points.

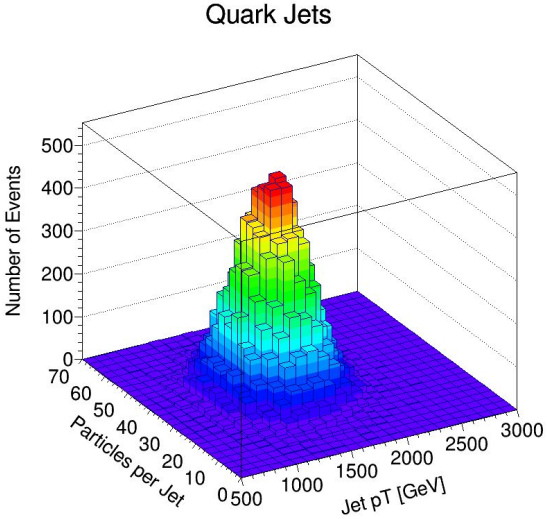


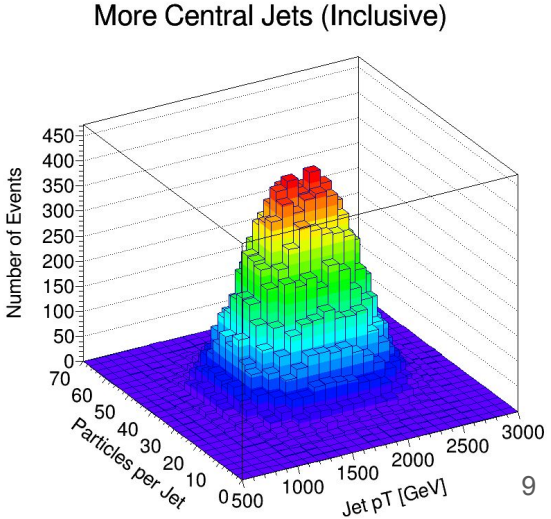
Visualization of Process





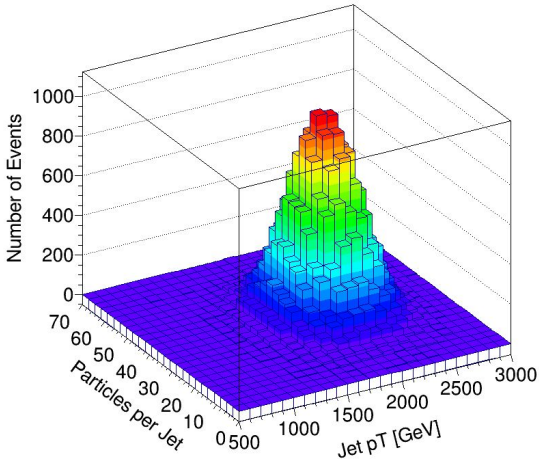
Quark/gluon jets mix into forward/central jets according to their respective fractions



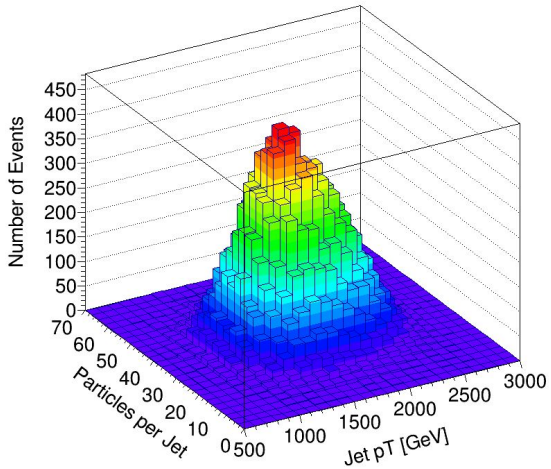


Visualization of Process

Gluon Jets (Extracted)

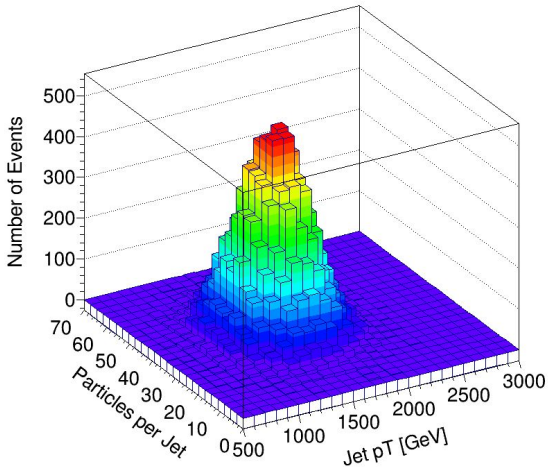


More Forward Jets (Inclusive)

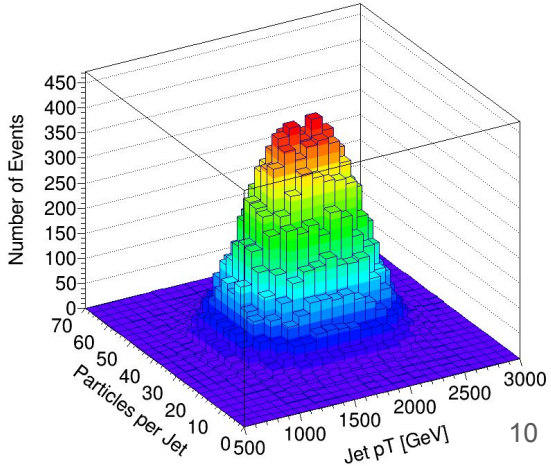


Extract quark/gluon jets from forward/central jets

Quark Jets (Extracted)

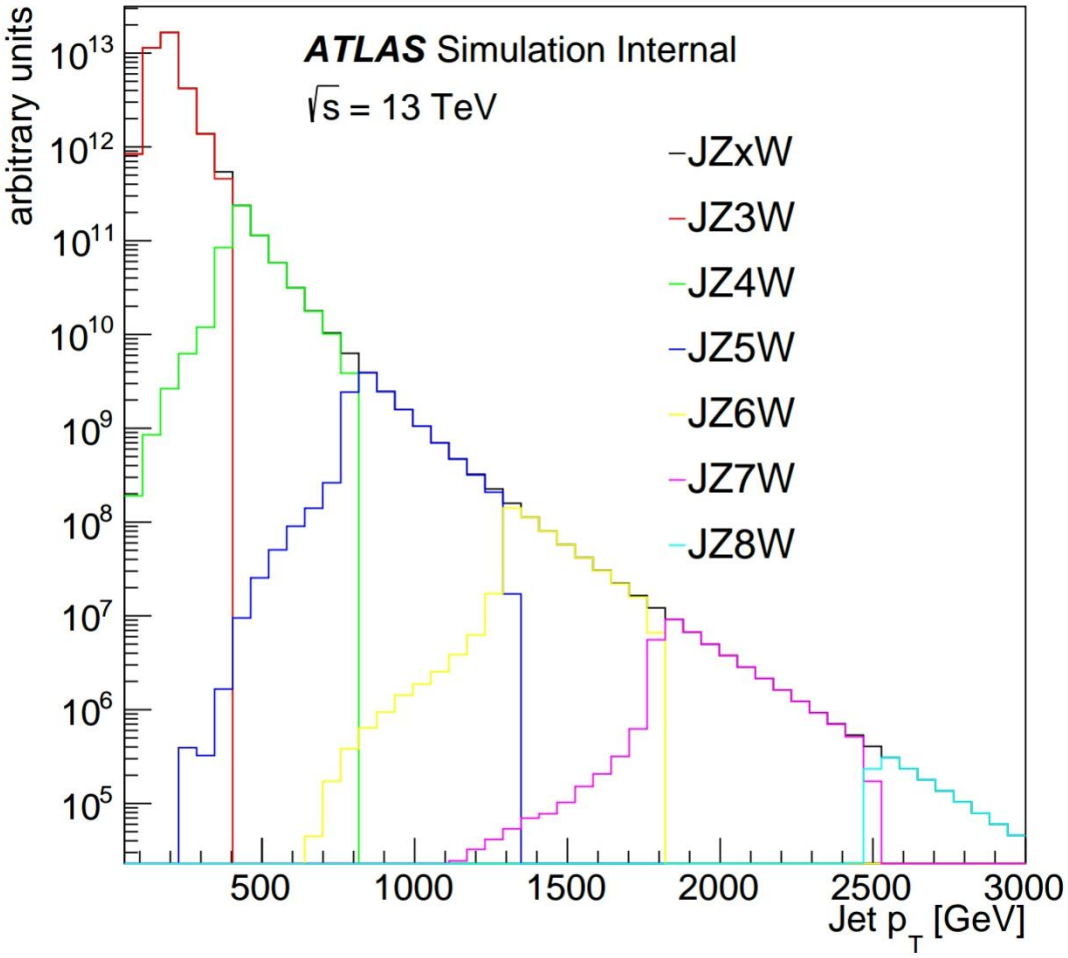


More Central Jets (Inclusive)



The Data

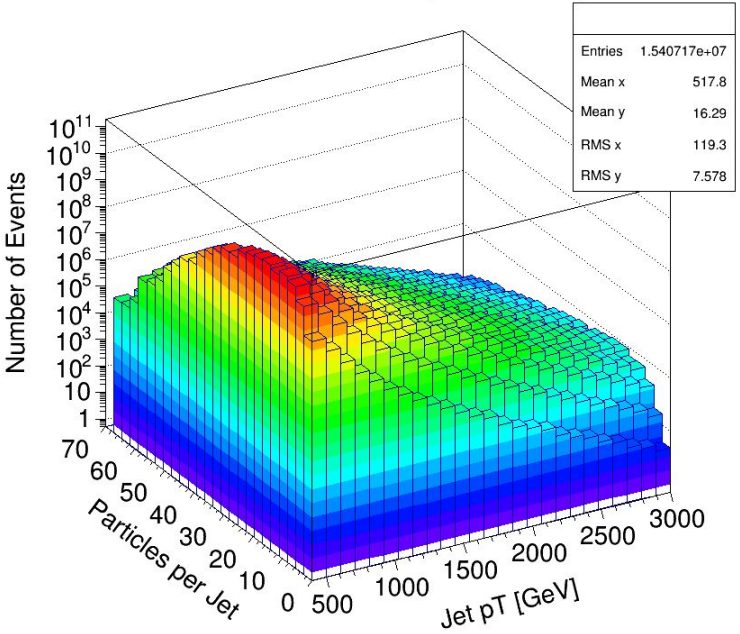
- We demonstrated the effectiveness of this method on the JZx data set, particle-level data simulated in Pythia with the ATLAS Monte Carlo.
- Contains over 15 million events with p_T ranging up to 3000 GeV, and with a center of mass energy of 13 TeV.



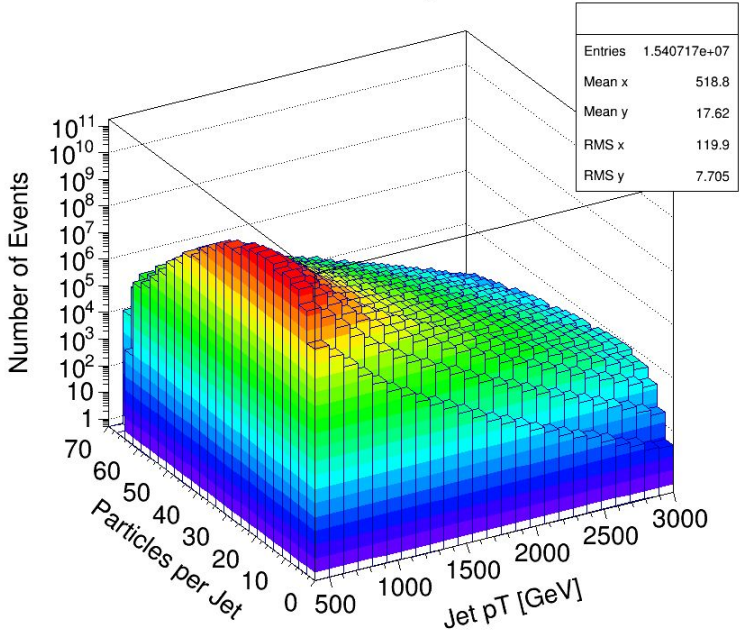
Forward/Central Jet Distributions

- The data had the following distributions for the more forward and more central jets.
- Note that these distributions are skewed towards lower p_T. Of the 15 million events in the sample, over 11 million were at less than 1500 GeV.

More Forward Jets (Inclusive)

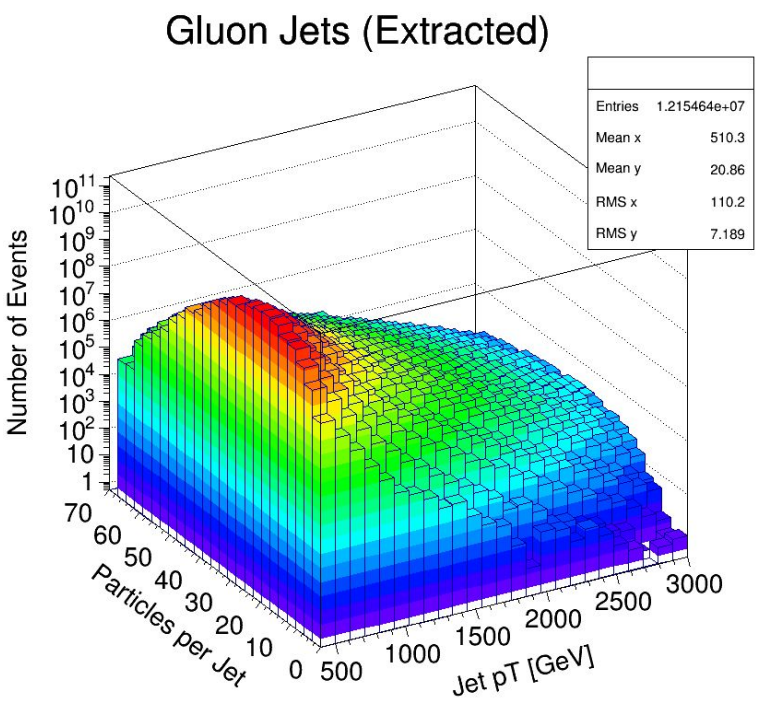


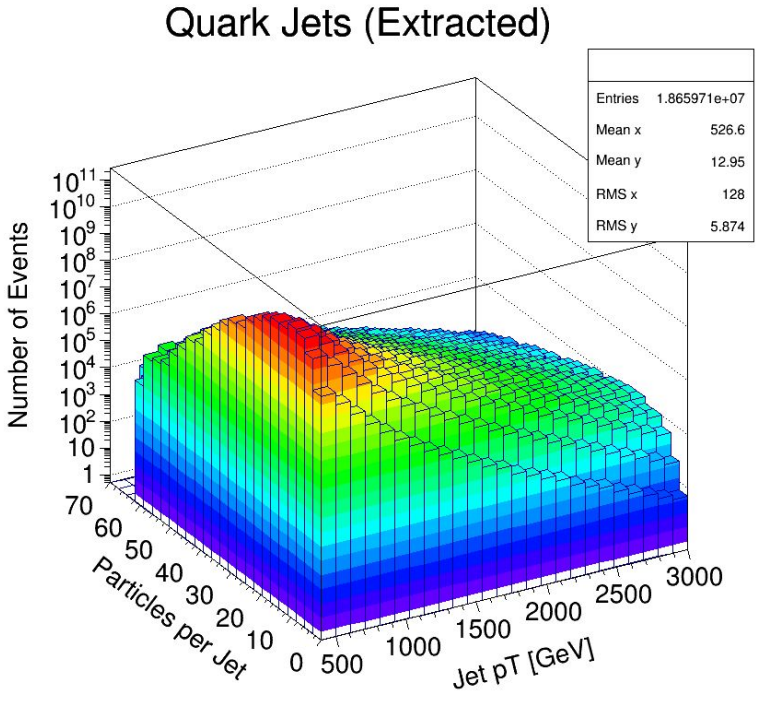
More Central Jets (Inclusive)



Extracted Distributions

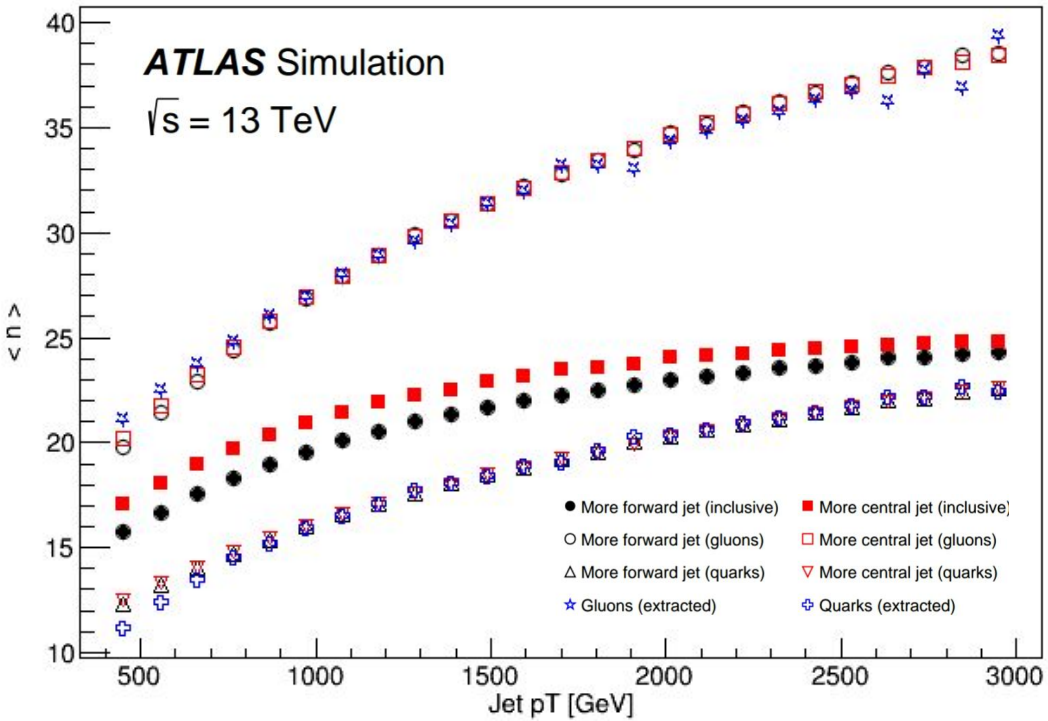
- From that we were able to extract the following distributions for the gluon and quark jets using the method described earlier.





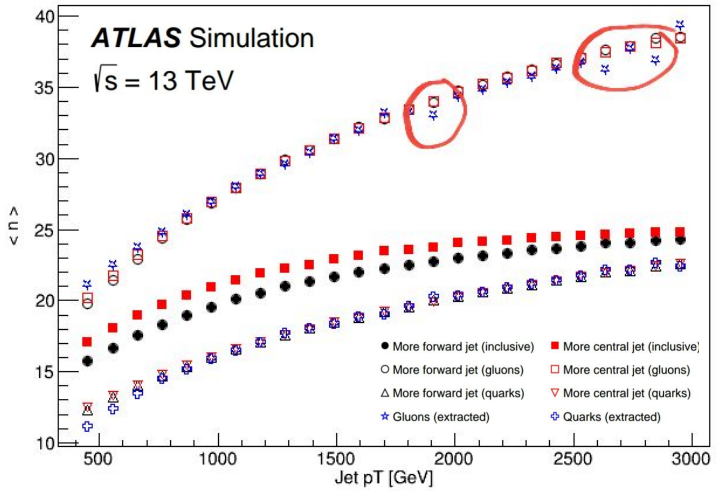
Closure of the Means

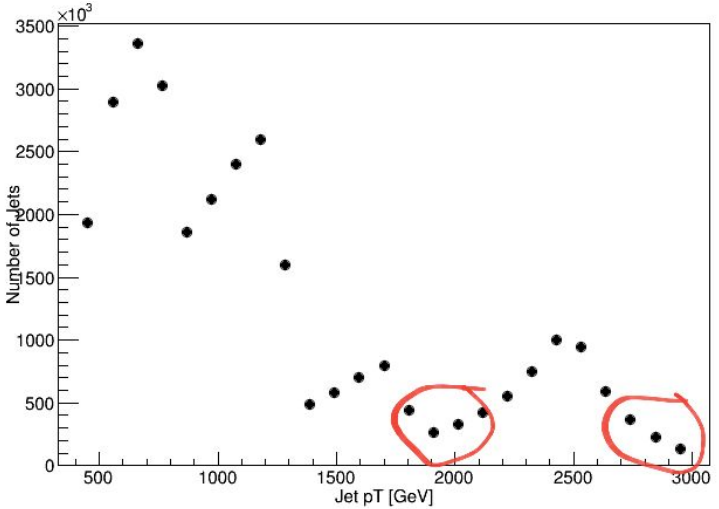
- Taking the means of these distributions for each p_T gives us the same result as when we just extracted the means. The method is consistent!
- As before, we have closure over a wide p_T range.
- Small non-closures are likely a statistical effect.



Statistical Uncertainty

- Uncertainties scale with the square root of the product of the difference in quark/gluon fraction and the number of events.
- Note that the largest non-closures occur where the number of events is lowest (such as around 2000 GeV and 3000 GeV).





Next Steps

- More observables:
  - Integrated momentum fraction - F(z)
  - Momentum transverse to the jet - $f(p_T^{rel})$
  - Particles in annuli rho (r, p_T)
  - Exclusive momentum fractions - $D^h(z)$ for low z using dE/dx
- Using unfolded data
- Systematic uncertainties

Conclusions

- We have developed a new technique for extracting the exclusive quark/gluon distributions.
- This procedure generalizes a technique from 8 TeV and can be used to carefully study the shapes of quark/gluon jet observables.