Jet Charge and Mass

By Taurean Zhang

Outline

- Introduction
  - What are jet charge and mass and why do we care
- Jet Charge and Mass Definitions
- Jet Charge Samples/Studies
  - Differentiation between jet types
- Jet Mass Samples/Studies
  - Comparison between different types of modeling software to experimental results

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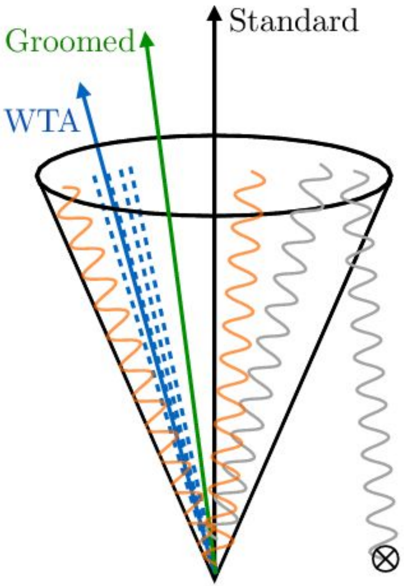
Why Do We Care

- Jet Charge
  - Can distinguish between particles within jets and between different types of jets
    - Up and down jets in dijet event
    - W+ vs W- bosons
- Jet Mass
  - Can plot mass distribution of jet
    - Allows one to identify the shape of the jet better
    - Can confirm accuracy of simulation software

Useful Notation



- P_{jet} is defined along the standard axis shown here
- $P^i_{||}$ is defined as the projection of the momentum of a particle along the standard axis

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Jet Charge and Mass Definitions

- $Q^{\kappa} = \frac{1}{(\mathrm{p_T^{jet}})^{\kappa}} \sum_i Q_i (\mathrm{p_T^i})^{\kappa}$
- $Q_L^{\kappa} = \sum_i Q_i \left(p_{\parallel}^i\right)^{\kappa} \Big/ \sum_i \left(p_{\parallel}^i\right)^{\kappa}$
  - $p_{\parallel}^i = \vec{p}^i \cdot \vec{p}_{jet} / |\vec{p}_{jet}|$
- κ parameter affects the contribution of low momenta particles to the jet charge

- $m^2 = \left(\sum_i p_i\right)^2$
- Mass found via summing the 4-momentum of the particles entering jet algorithm to describe jet momenta

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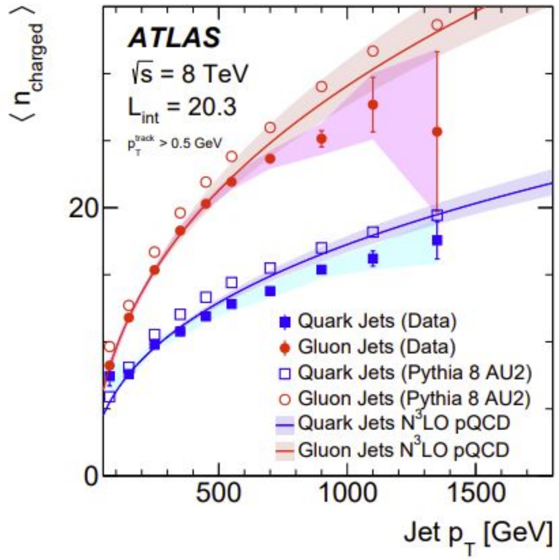
A Word on Jet Algorithms

- Jet algorithms can significantly alter results
  - For jet mass, low energy particles can be selectively removed
  - Type of algorithm used can give different values for the momentum of the original jet, which can be used in both jet mass and charge calculations
  - The papers looked at for this presentation used anti-kT or kT jet reconstruction algorithms

Properties of Jet Charge

- Relies on model dependence on parton showers (PS) and fragmentation
- Can be seen by comparing POWHEG + PYTHIA8 to POWHEG + HERWIG ++ simulations from Slide 8
- Can be used to identify quark (Z/γ + jets) vs gluon (dijet) jets



Distinguishing quark and gluon jets at the LHC

Giorgia Rauco[1] (on behalf of the ATLAS and CMS Collaborations)

[1] Universität Zürich, Zürich, Switzerland

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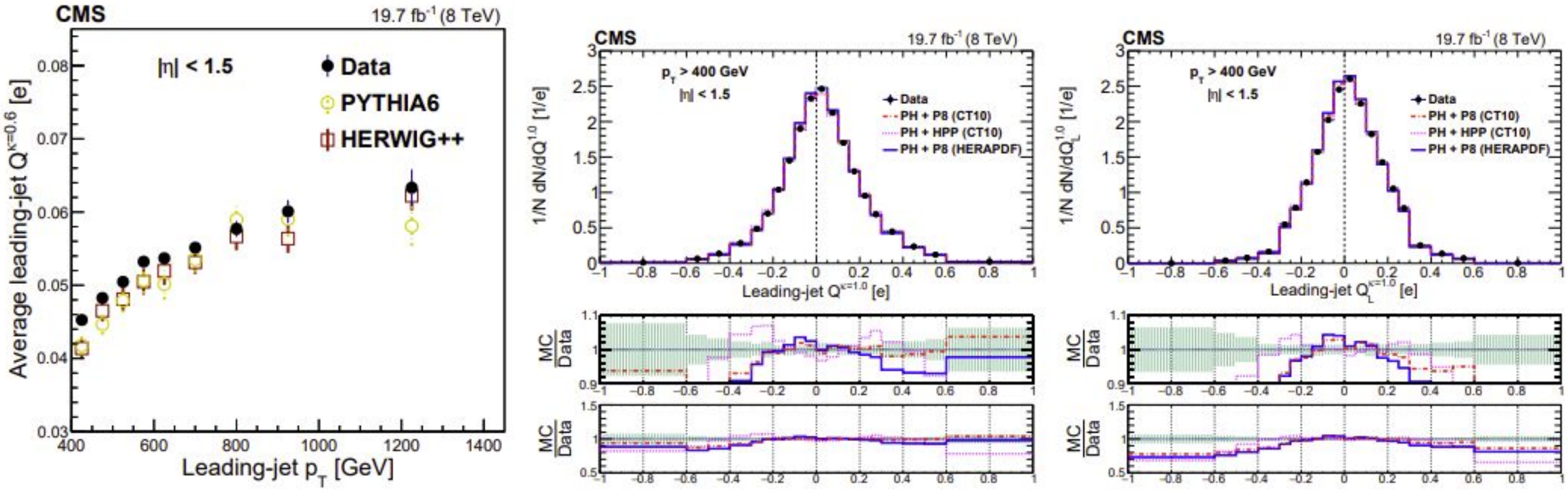
Jet Charge CMS Samples



- Jet charge from proton proton collisions in CMS
- Compares data result with simulation results from PYTHIA6/8 and HERWIG++

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Studies on Jet Charge

Jet charge determination at the LHC

Stano Tokar[1]

On behalf of the ATLAS and CMS Collaborations

$$\langle Q_\kappa^i \rangle = \int dz z^\kappa \sum_h Q_h \frac{1}{\sigma_{\text{jet}}} \frac{d\sigma_{h\in\text{jet}}}{dz} = \frac{1}{16\pi^3} \frac{\tilde{J}_{ii}(E,R,\kappa,\mu)}{J_i(E,R,\mu)} \sum_h Q_h \tilde{D}_i^h(\kappa,\mu)$$

soft-collinear effective theory (SCET)

- Study focuses on using jet charge to distinguish between various types of particles (pp collision focused)

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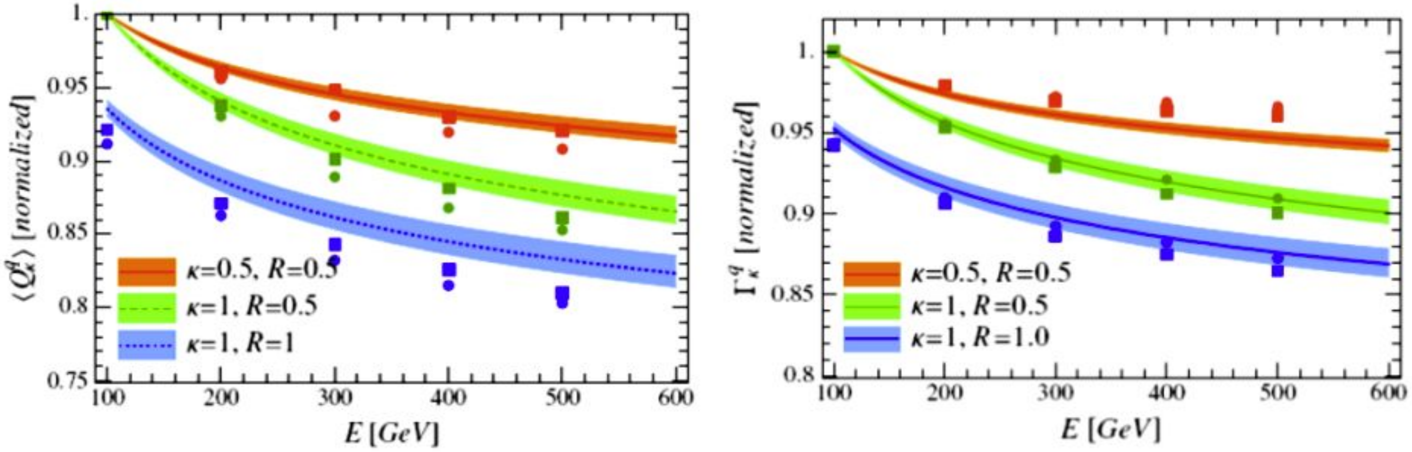
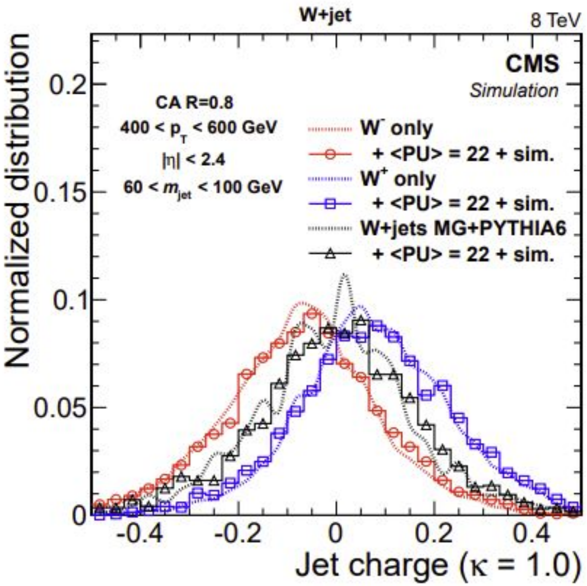
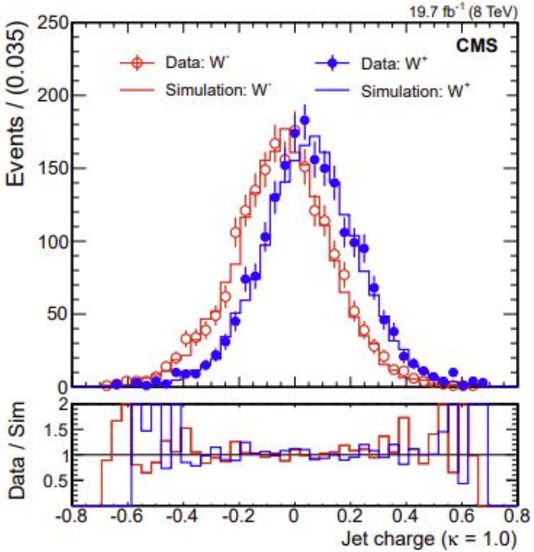
Studies on Jet Charge



- Left figure depicts average jet charge, right figure jet charge width
- Compares measured data to PYTHIA8 simulation

Studies on Jet Charge



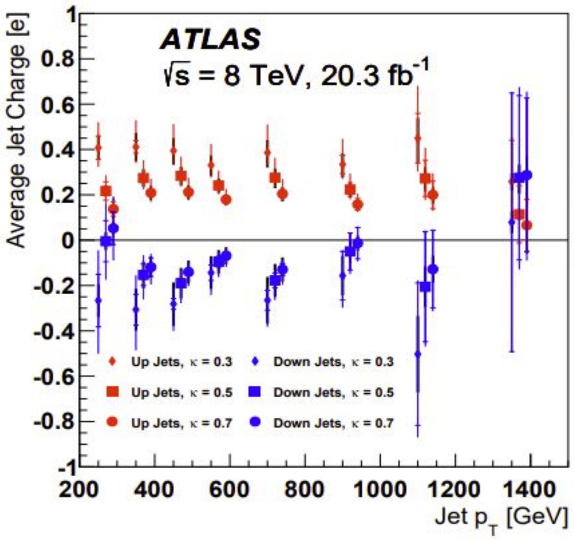


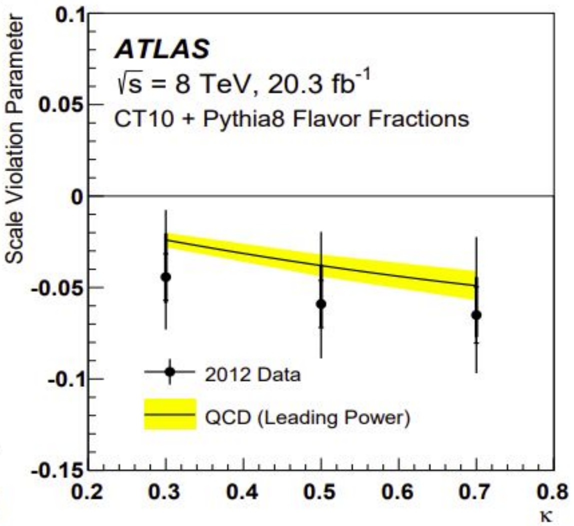
- Charge calculated using first formula on Slide 6

$$Q^{\kappa} = \frac{1}{(p_T^{jet})^{\kappa}} \sum_i Q_i (p_T^i)^{\kappa}$$

- W+ and W- distributions translated in jet charge

Studies on Jet Charge





- Can tell between individual jets produced during dijet events
- Up Jets have a considerable charge difference compared to down jets

Properties of Jet Mass

- Sensitive to modeling of PS
- Can be used to tune model parameters
- During calculation, can be groomed, where grooming means selectively removing low-energy particles from mass calculation
    - Grooming is done to lower uncertainties in the physics model and is done in various different manners

Studies on Jet Mass

First measurement of jet mass in Pb–Pb and p–Pb collisions at the LHC

ALICE Collaboration *

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ABSTRACT

This letter presents the first measurement of jet mass in Pb–Pb and p–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV and $\sqrt{s_{\rm NN}} = 5.02$ TeV, respectively. Both the jet energy and the jet mass are expected to be sensitive to jet quenching in the hot Quantum Chromodynamics (QCD) matter created in nuclear collisions at collider energies. Jets are reconstructed from charged particles using the anti-$k_{\rm T}$ jet algorithm and resolution parameter $R = 0.4$. The jets are measured in the pseudorapidity range $|\eta_{\rm jet}| < 0.5$ and in three intervals of transverse momentum between 60 GeV/c and 120 GeV/c. The measurement of the jet mass in central Pb–Pb collisions is compared to the jet mass as measured in p–Pb reference collisions, to vacuum event generators, and to models including jet quenching. It is observed that the jet mass in central Pb–Pb collisions is consistent within uncertainties with p–Pb reference measurements. Furthermore, the measured jet mass in Pb–Pb collisions is not reproduced by the quenching models considered in this letter and is found to be consistent with PYTHIA expectations within systematic uncertainties.

Studies on Jet Mass

- Used kT and anti-kT recombination jet algorithms
  - anti-kT used for the signal jets
  - kT used for clusters
- $$m_{\delta,k_{\mathrm{T}}^{\mathrm{cluster}}} = \sum_i \left(\sqrt{m_{\mathrm{j}}^2 + p_{\mathrm{T,j}}^2 c^2} - p_{\mathrm{T,j}} c\right)$$
  - Account for background influence on the reconstructed jet mass
- Background mass density is calculated by dividing the median value of the set of cluster masses divided by the area of the cluster
  - Subtracted later on to reduce effect of background events

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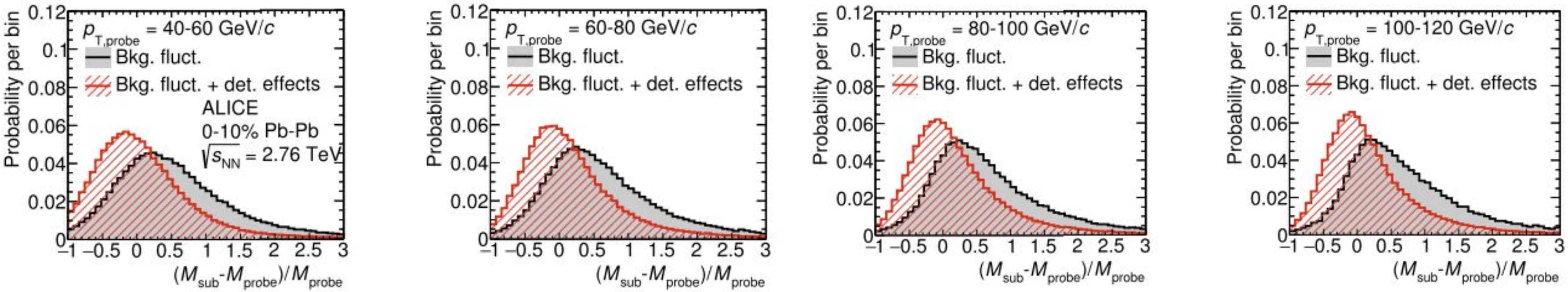
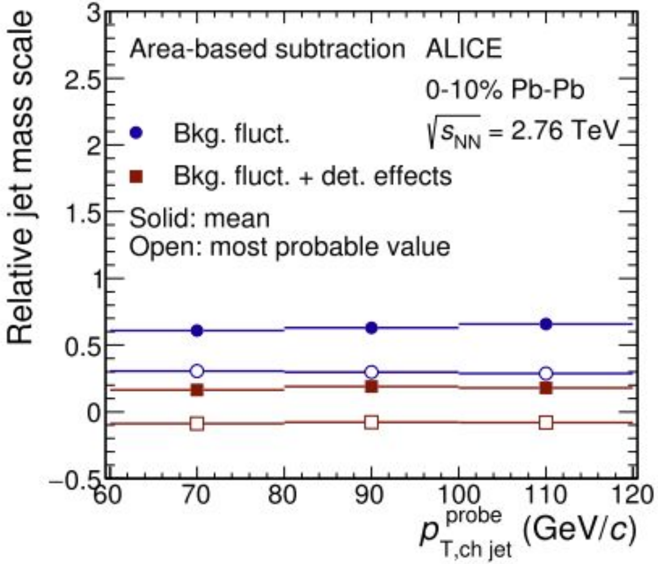
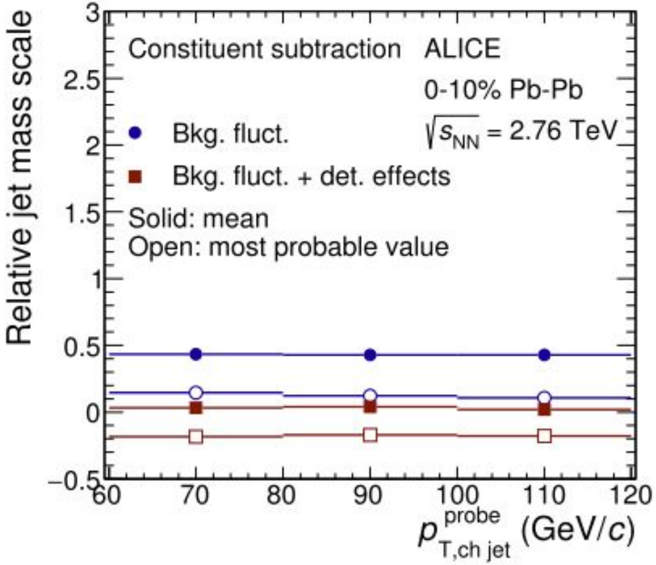
Studies on Jet Mass (LHC)



- Two ways to calculate background events
  - Area based subtraction - corrects on a jet-by-jet basis (shown in the above figure for varying transverse momentum densities)
  - Constituent subtraction - corrects on a particle level

Studies on Jet Mass





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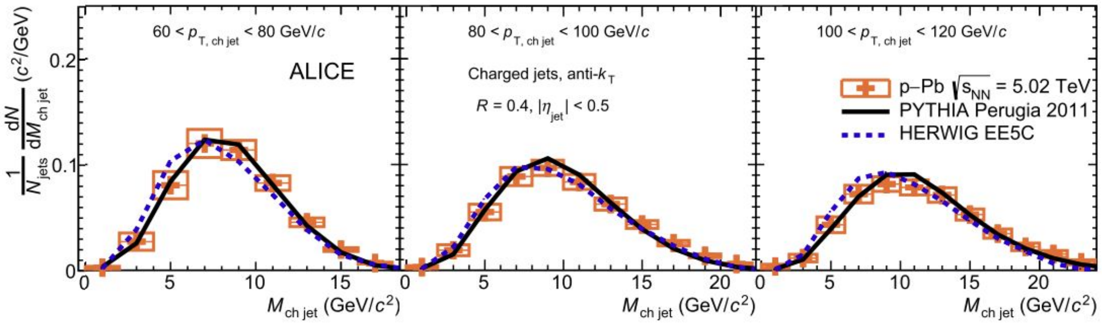
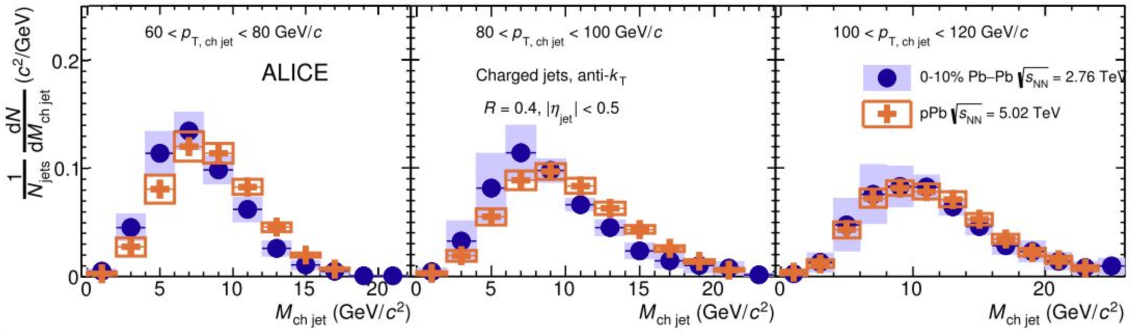
Studies on Jet Mass





- p-Pb collision data compared to PYTHIA and HERWIG simulations
- Confirms accuracy of simulation models

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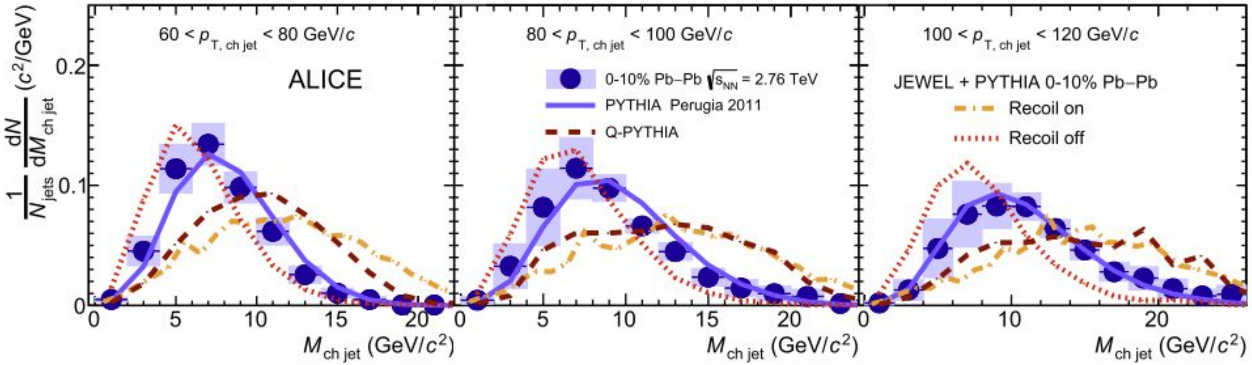
Studies on Jet Mass



- First Pb-Pb collision results
  - JEWEL “recoil on” overestimates jet mass and Q-PYTHIA also doesn’t model the situation well
  - PYTHIA and JEWEL “recoil off” match data with some systematic variation
    - Recoil setting determines whether to keep track of scattering centers post-collision

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Summary

- Jet charge is useful in determining what a jet is made out of
  - Can also show separate jets in a multi-jet event
  - Examples include distinguishing W+ vs W- bosons, up jets vs down jets in dijet events, etc.
- Multiple different ways to calculate it, each with varying results
  - Can be dependent on the jet algorithm used

Summary

- Jet mass helps determine model consistency
  - In the case of Pb-Pb collisions, it can be seen that some models (PYTHIA, JEWEL “recoil on”) are better than others
- Relies heavily on jet recombination algorithms