Jets at an EIC

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Outline

- Introduction
- Jet Basics:
  - Algorithms
  - Radii
- Jet / Particle Multiplicities
- Jet Kinematics
- Di-jets
  - Definition
  - Frame Dependence
  - Applications

Subprocess Codes

11: $f_i\ f_j$ -> $f_i\ f_j$
12: $f_i\ f_i$_bar -> $f_k\ f_k$_bar
13: $f_i\ f_i$_bar -> g g
28: f_i g -> f_i g
53: g g -> $f_k\ f_k$_bar
68: g g -> g g

} Resolved

91: Elastic
92: Single Diffraction (xB)
93: Single Diffraction (Ax)
94: Double Diffraction
95: Low-p_T Production

} Elastic / Soft

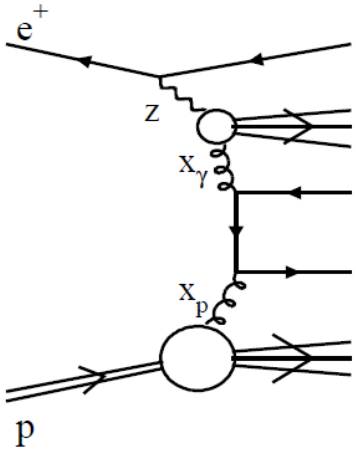
131: $f_i\ \gamma_T^*$ -> f_i g
132: $f_i\ \gamma_L^*$ -> f_i g
135: g γ_T^* -> $f_i\ f_i$_bar
136: g γ_L^* -> $f_i\ f_i$_bar

} PGF / QCDC

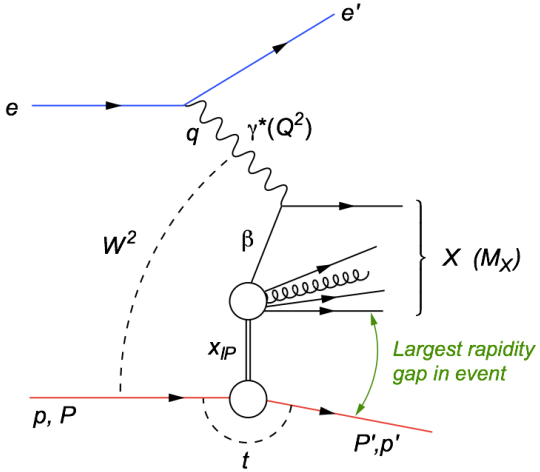
99: $\gamma^* q$ -> q } DIS

Subprocess Codes

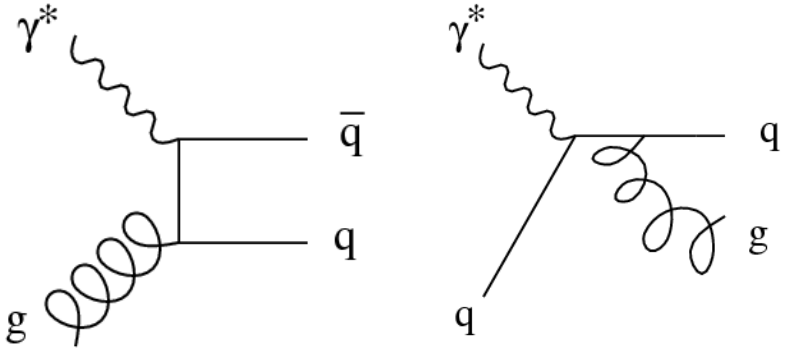
Resolved



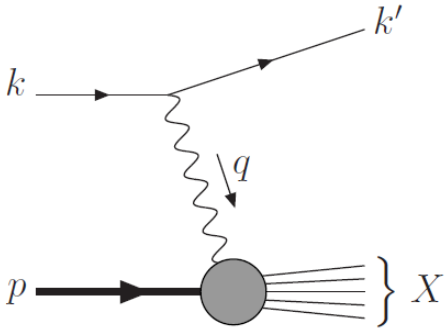
Diffractive



Photon-Gluon Fusion & QCD-Compton



DIS



Simulation Details / Particle Cuts

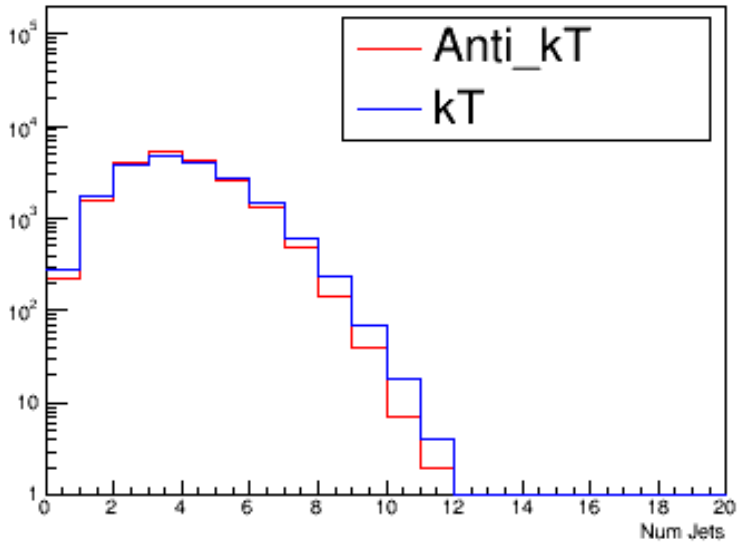
- Electron – Proton events generated using PYTHIA
- Full energy eRHIC: 20 x 250 GeV ($\sqrt{s}$ = 141 GeV)
- Cut on inelasticity: $0.01 \leq y \leq 0.95$
- Particles used in jet finding:
  - Stable
  - $p_T \geq 250$ MeV
  - $\eta \leq 4.5$
  - Parent cannot originate from scattered electron

Jet Basics: Frames

- Can define several useful frames:
  - Lab
  - Hadron-Boson: Beam hadron is at rest, z-direction chosen along virtual photon momentum vector
  - Breit: Virtual photon moves in -z direction and boost such that it has zero energy. Separation into target and remnant regions
  - Center of Mass: Virtual photon and struck parton have equal and opposite momenta. Can define Feynman-x

Jet Basics: Algorithm

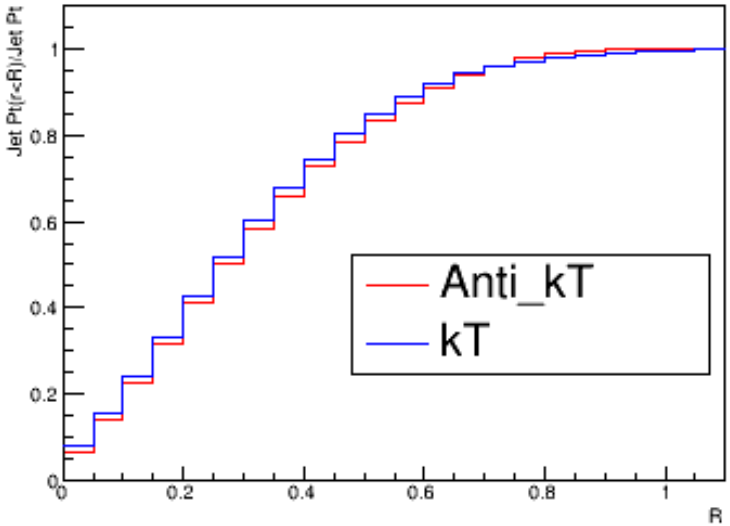
Number of Jets



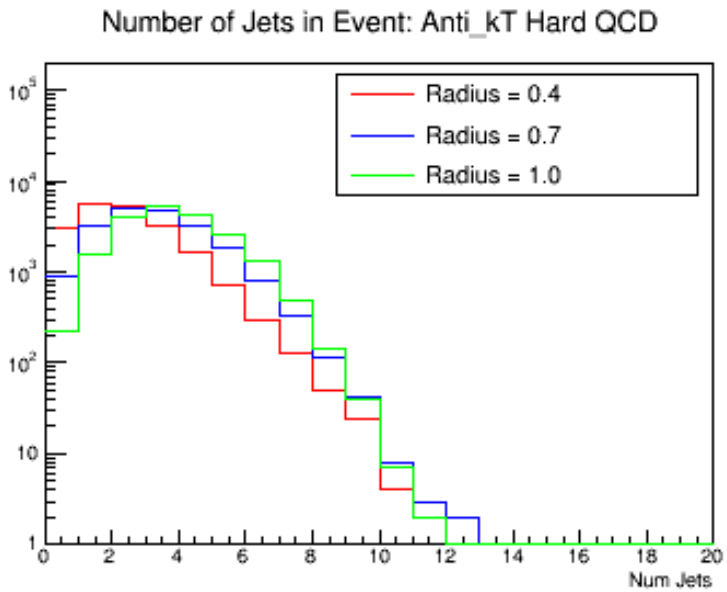
- Many jet clustering algorithms available
- Compare k_T and anti-k_T (widely used at hadron colliders)
- Infrared and collinear safe at all orders

- Parameters: Radius = 1, Min p_T = 1.0 GeV, Resolved Processes
- Look at number of jets in event and jet profile (amount of jet p_T in certain radius)
- k_T and anti-k_T show very similar behavior

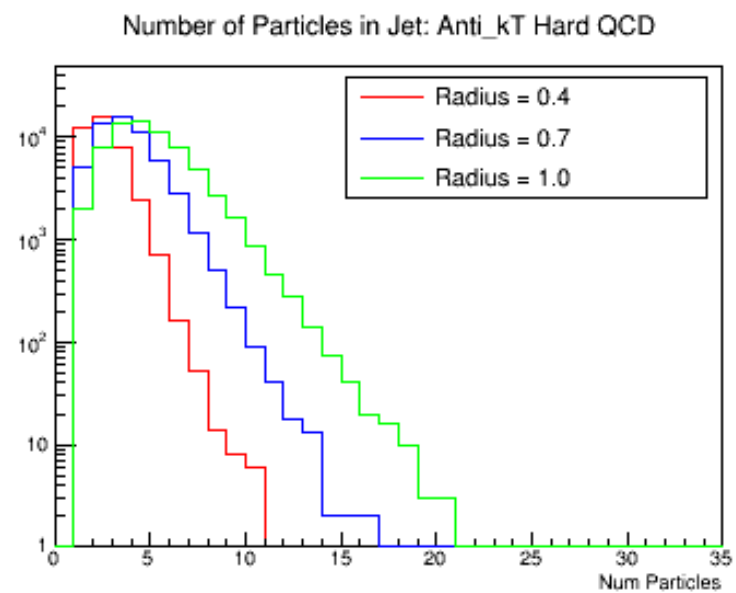
Jet Profile



Jet Basics: Radius



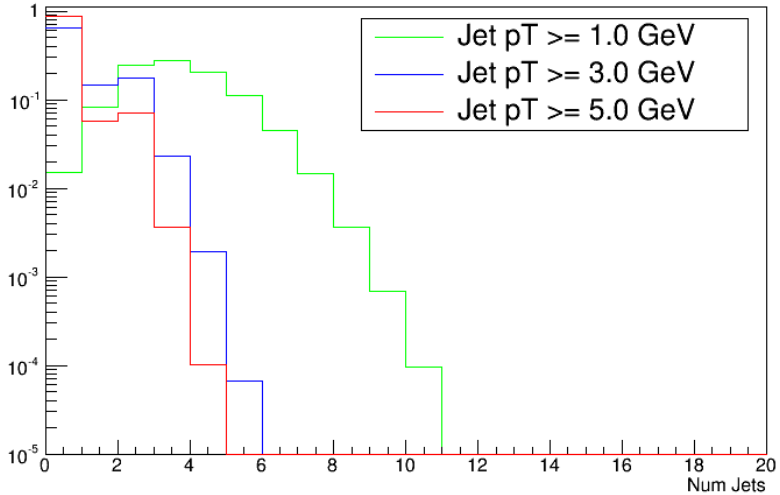
- For anti-k_T algorithm the radius parameter determines the distance at which particles can be grouped together
- Sets the effective size of the jet



- Parameters: Min p_T = 1.0 GeV, Resolved processes
- Larger radii result in more found jets as well as more particles in jet

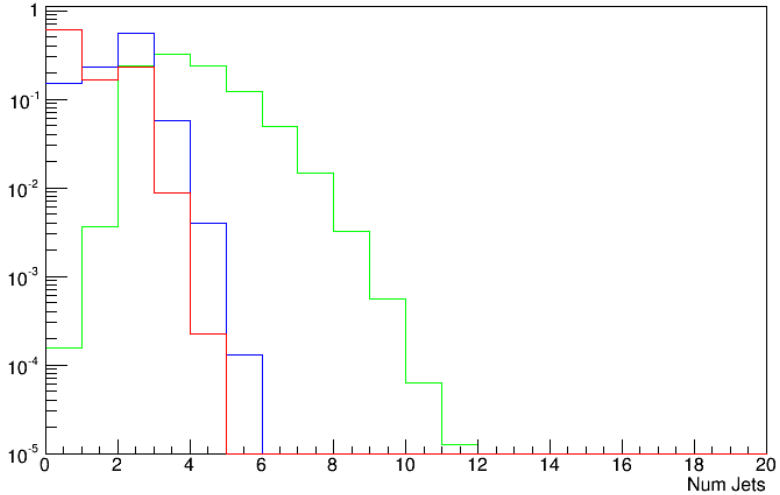
Jet Multiplicity: $Q^2 = 10 – 100\ GeV^2$

Jets: Resolved Processes

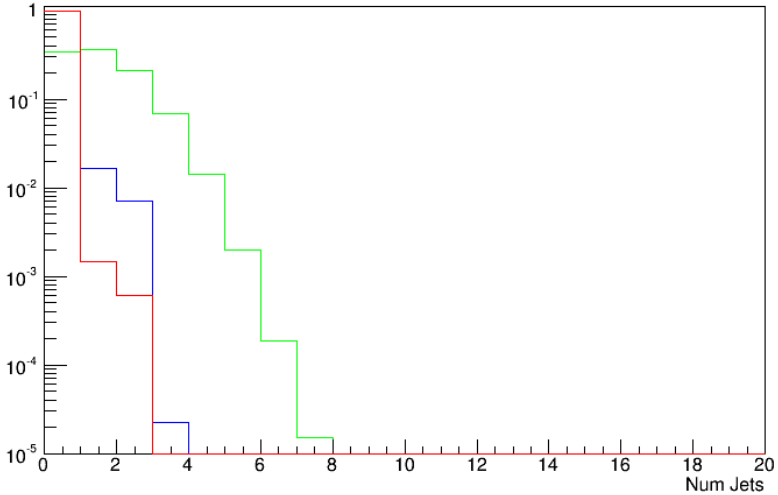


- Percentage of events with a certain number of found jets for different minimum allowed jet p_Ts
- See a decrease in number of jets with increasing minimum jet p_T
- Jet p_T of 1 GeV may not be well described theoretically
- Each curve normalized to unity

Jets: PGF / QCDC

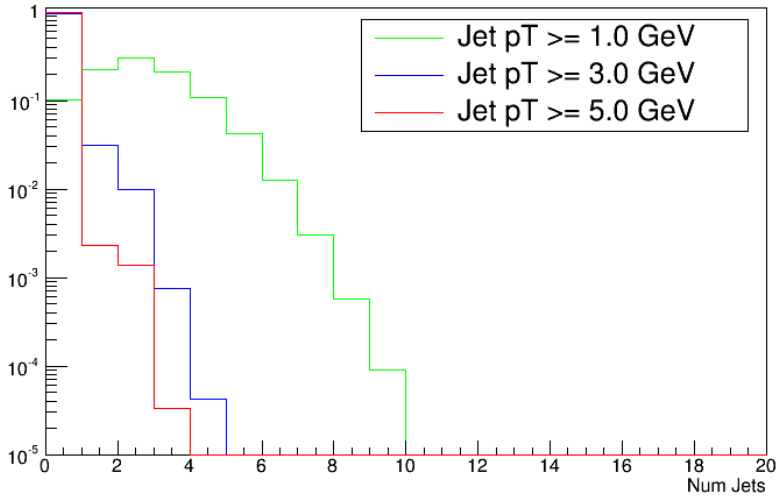


Jets: L.O. DIS



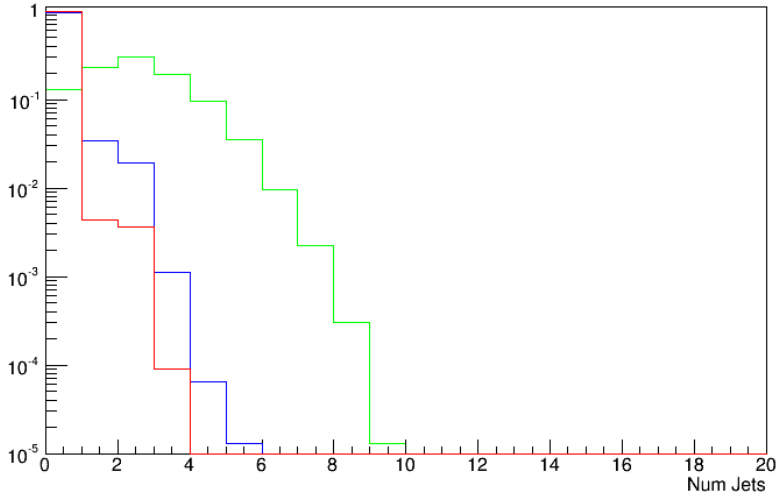
Jet Multiplicity: $Q^2 = 10^{-5} – 10^{-4}$ GeV^2

Jets: Resolved Processes

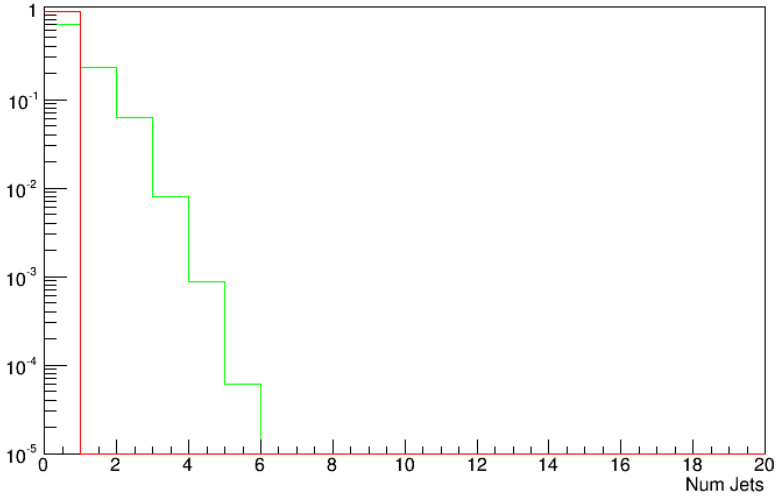


- Same as above for lower Q^2 range
- Note the decrease in percentage of events containing jets

Jets: PGF / QCDC

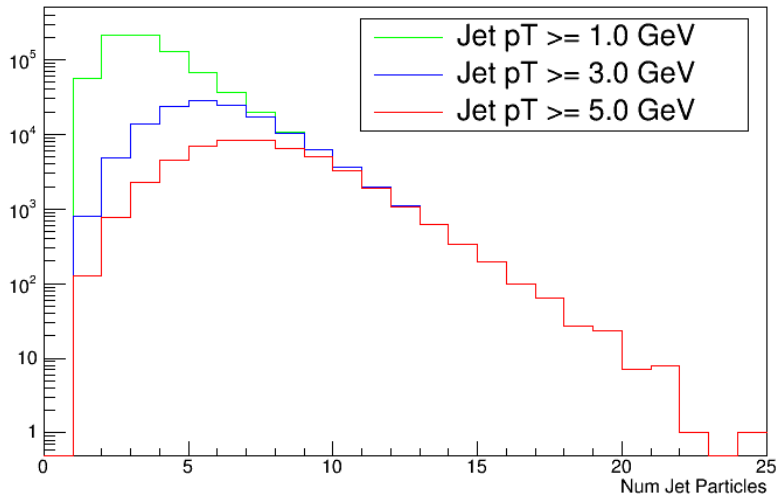


Jets: L.O. DIS



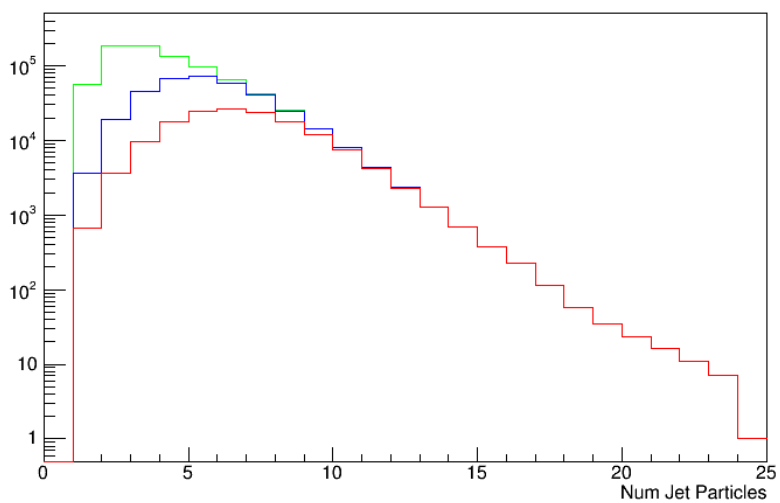
Jet Particle Mult: $Q^2 = 10 – 100\ GeV^2$

Jet Particles: Resolved Processes

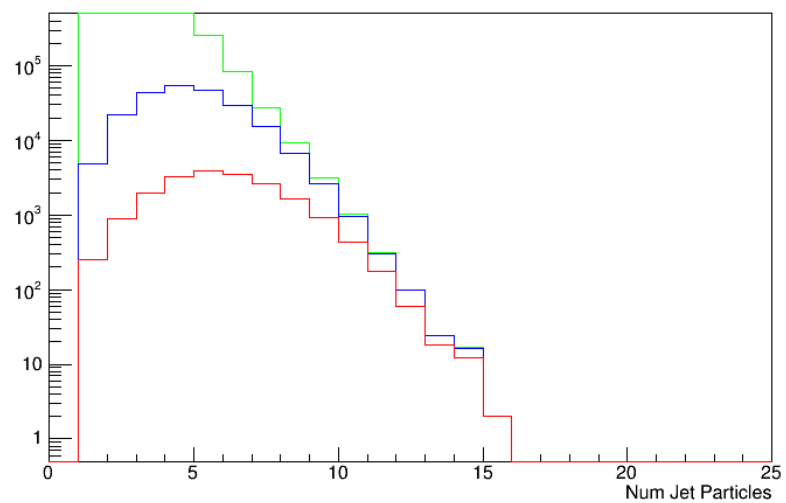


- Number of particles in a jet for 3 minimum jet p_T values
- Increase in minimum jet p_T leads to increase in average number of particles in jet
- Higher p_T jets -> more “jet like” than “single particle like”

Jet Particles: PGF / QCDC

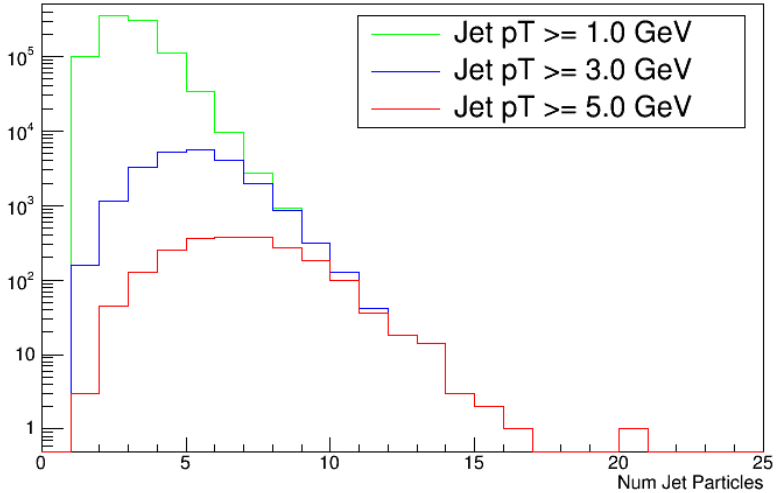


Jet Particles: L.O. DIS



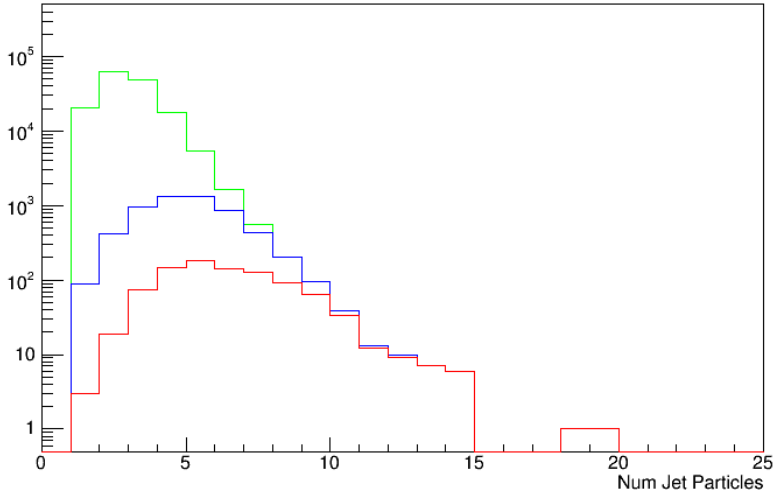
Jet Particle Mult: $Q^2 = 10^{-5} – 10^{-4}$ GeV^2

Jet Particles: Resolved Processes

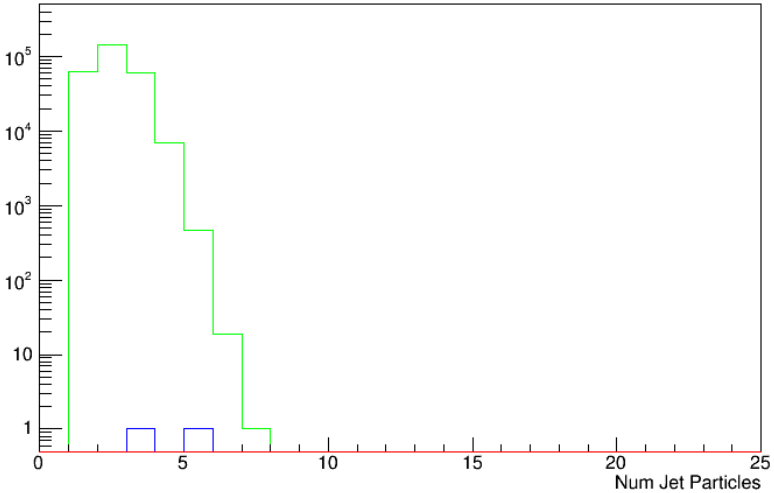


- Same as previous slide but for lower Q^2 range
- Median numbers of particles stay roughly the same as higher Q^2 case but frequency of jets with high number of particles down sharply

Jet Particles: PGF / QCDC

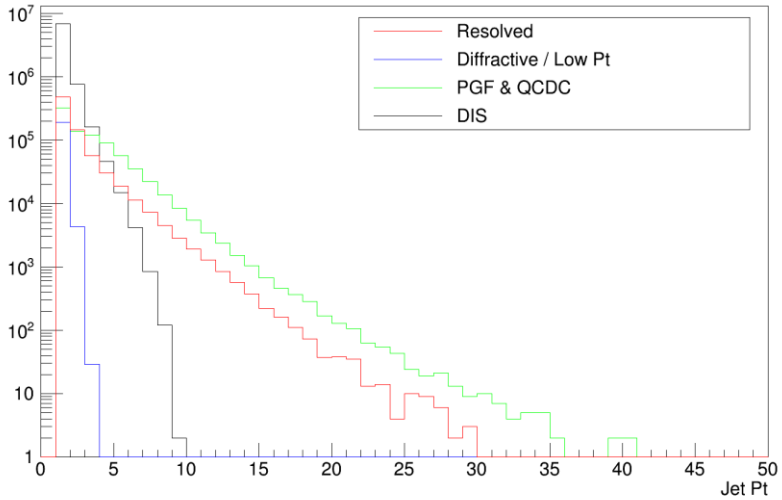


Jet Particles: L.O. DIS



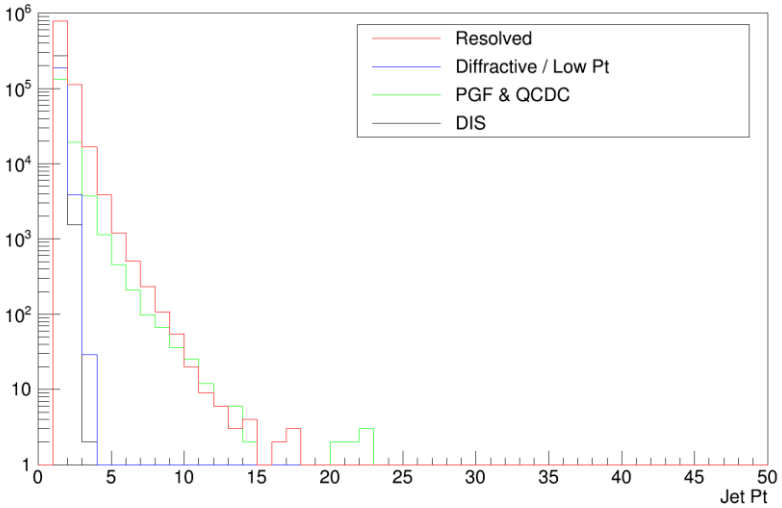
Jet p_T: Process and Q^2 Dependence

Inclusive Jet p_T: Q^2 = 10-100 GeV^2



- Jet p_T spectra for different sub-processes and Q^2 ranges
- Jets found in Breit frame

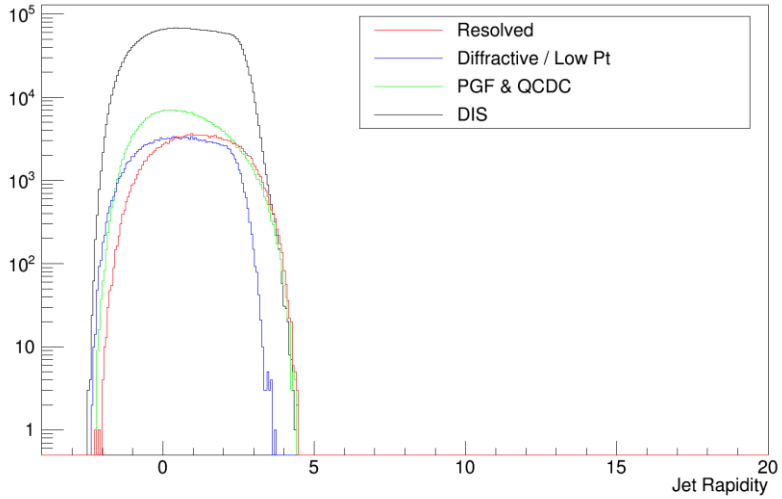
Inclusive Jet p_T: Q^2 = 10^{-5}-10^{-4} GeV^2



- Larger Q^2 leads to larger jet p_T for all sub-processes
- Corresponds to behavior seen in particle multiplicities

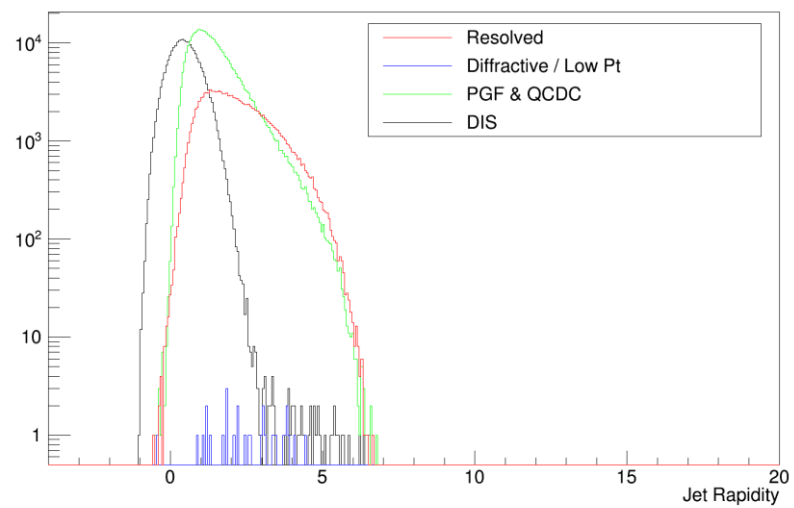
Jet Rapidity

Jet Rapidity Spectrum: Lab Frame



- Jet rapidity spectra for different sub-processes and frames
- Q^2 bin: 10 – 100 GeV^2
- Minimum jet p_T = 3 GeV

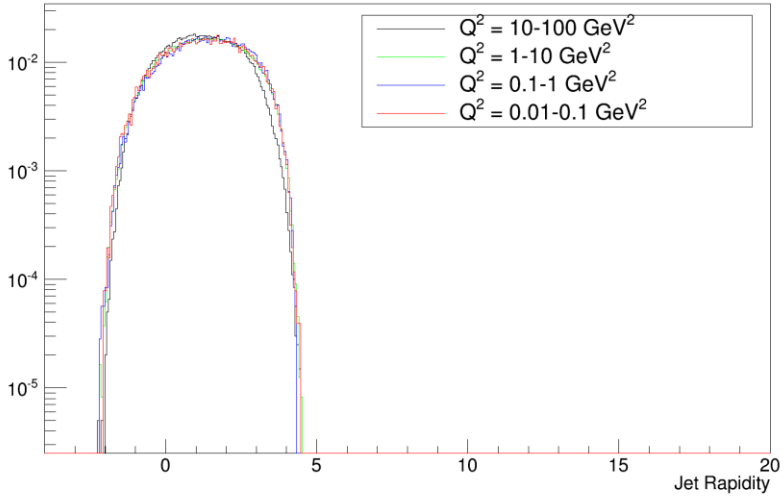
Jet Rapidity Spectrum: Breit Frame



- All sub-processes occupy the same rapidity region in lab frame, but show separation in Breit frame
- Note the large decrease in DIS and Diffractive / Low p_T jets in Breit frame

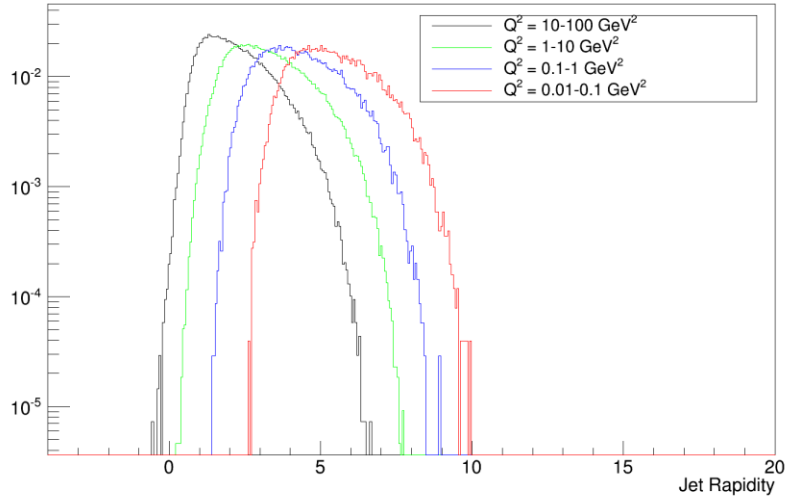
Jet Rapidity: Q^2 Dependence

Jet Rapidity Spectrum: Lab Frame



- Jet rapidity spectra for different Q^2 bins and frames
- Jets from resolved sub-process with a minimum p_T of 3 GeV
- All curves normalized to unity

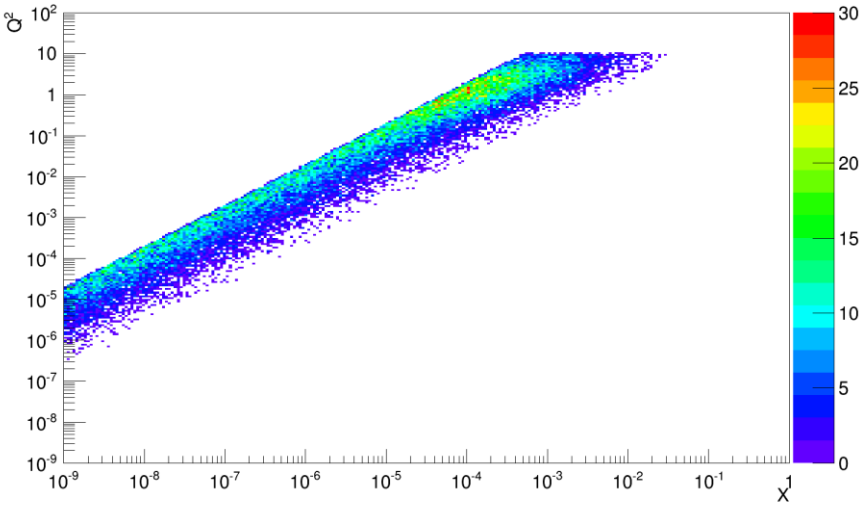
Jet Rapidity Spectrum: Breit Frame



- All Q^2 bins occupy the same rapidity region in lab frame but show separation in Breit frame
- Jets at lower Q^2 show up at higher rapidity in Breit frame

Di-jet Basics

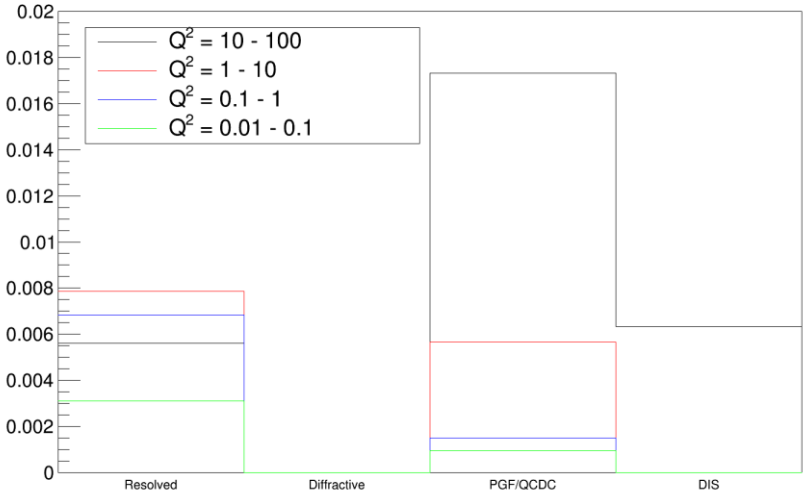
Di-jet Q^2 Vs X: Resolved Processes



- Two highest p_T jets form di-jet
- Both jets must have $p_T \geq 3$ GeV
- $\Delta\phi$ between jets must be $\geq 120^o$

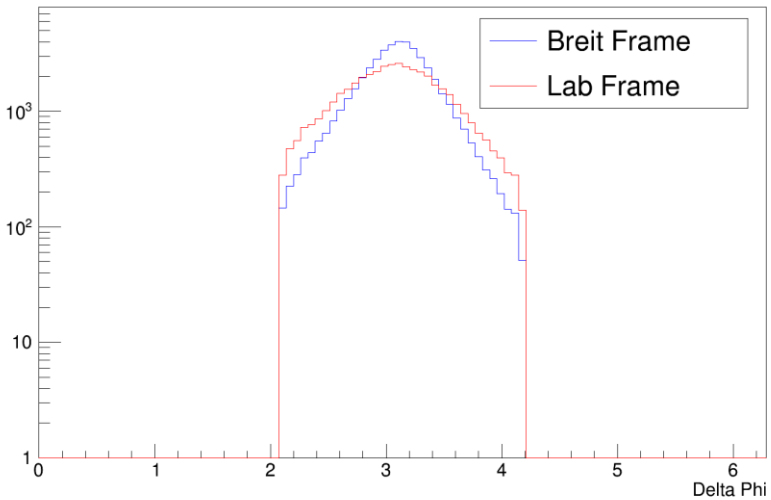
- Sample of di-jet coverage in Q^2 vs X space for resolved processes
- Fraction of events which contain di-jets from each sub-process for several Q^2 values
- Di-jets will be a rare probe compared to hadron colliders

Di-jets Per Event (Breit Frame)

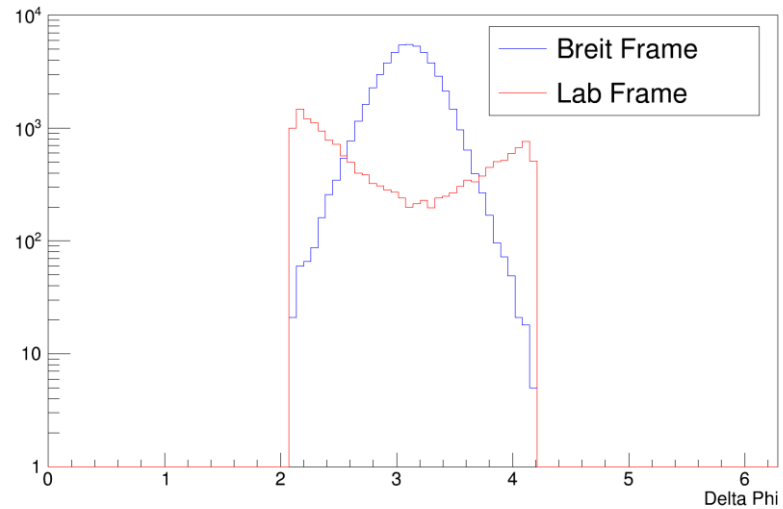


Di-jets: Frames Matter

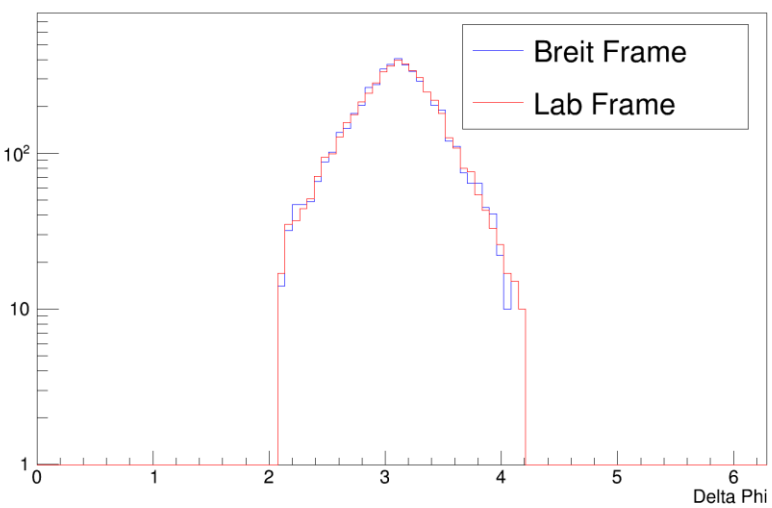
Di-jet Δϕ: Resolved (Q^2 = 10-100)



Di-jet Δϕ: DIS (Q^2 = 10-100)

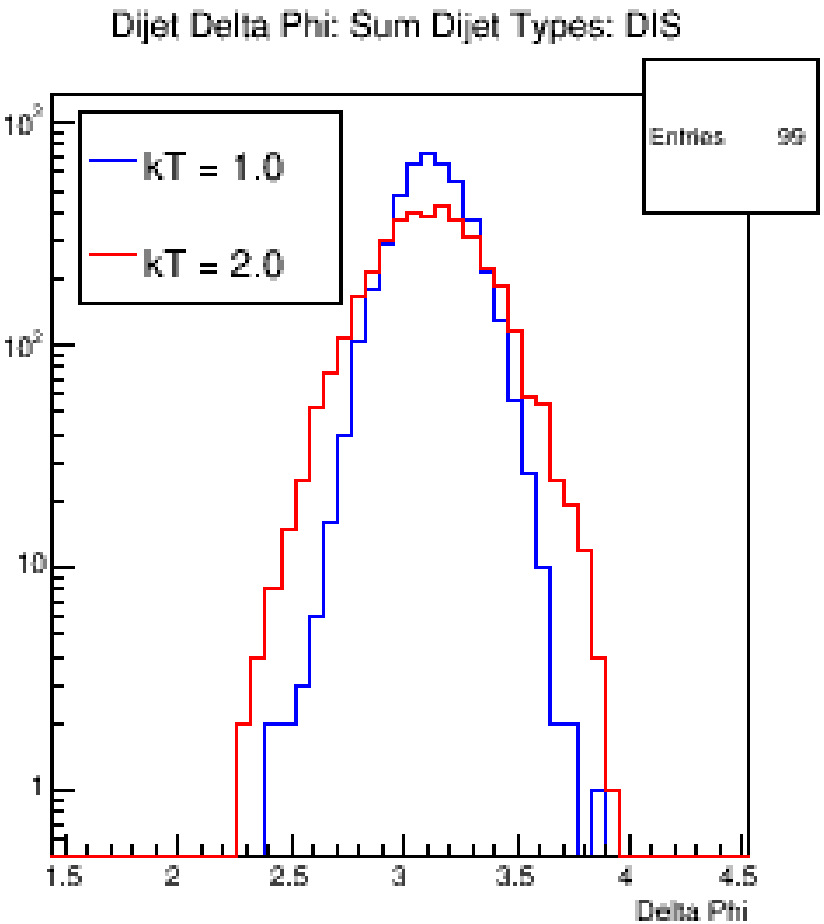


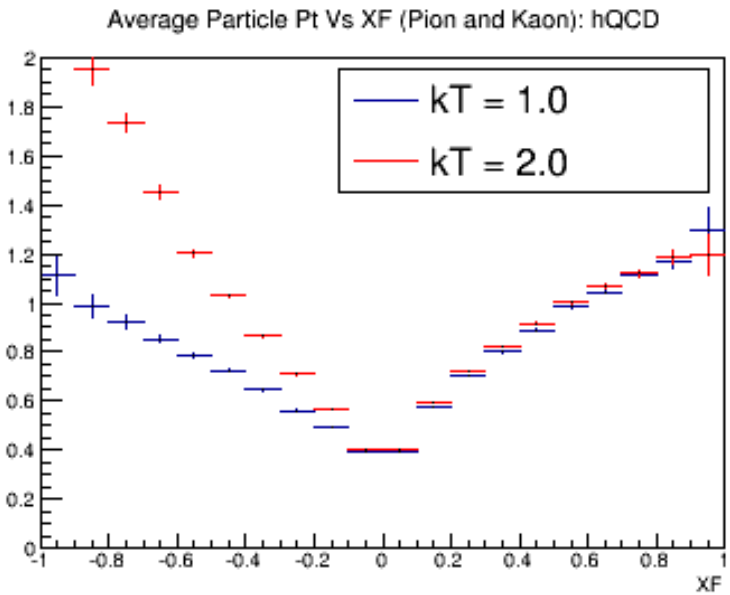
Di-jet Δϕ: Resolved ($Q^2 = 10^{-2}$-10^{-1})



- At high momentum transfers, can get some decorrelation between jets in lab frame
- This effect very prominent for the DIS process in which one jet arises from remnant
- Important to work in Breit frame at high Q^2 for di-jets

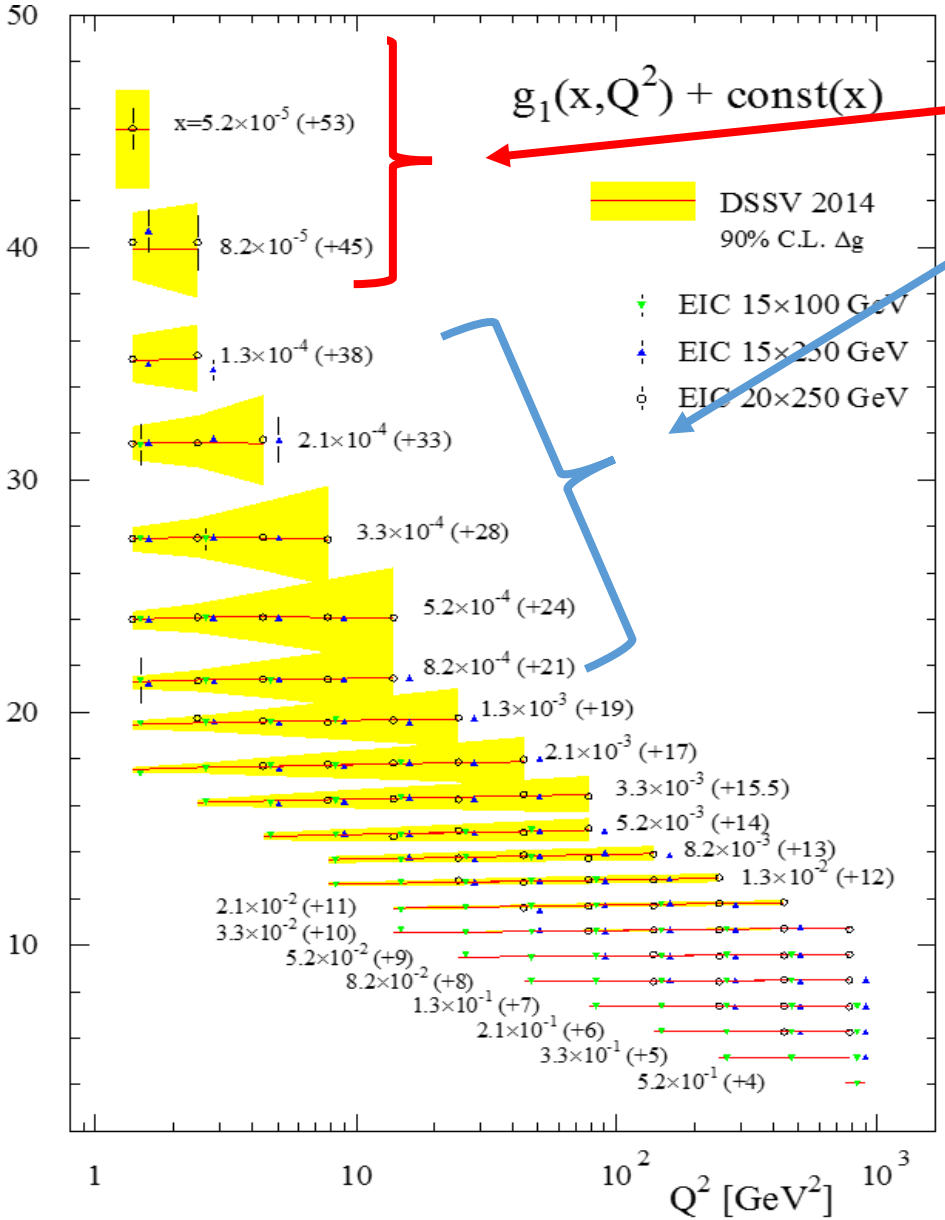
Di-jets: Probing Primordial k_T



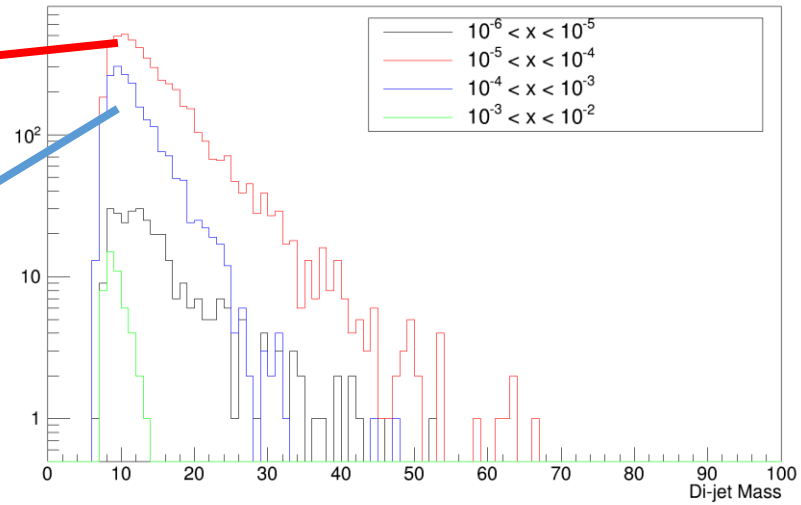


- Can access primordial k_T by looking at average particle p_T plotted vs xF
- Are di-jet phi correlations sensitive?
- $\Delta\phi$ shows some sensitivity, but statistics will be an issue
- See talk by Mark Baker for more discussion on measuring intrinsic k_T in DIS

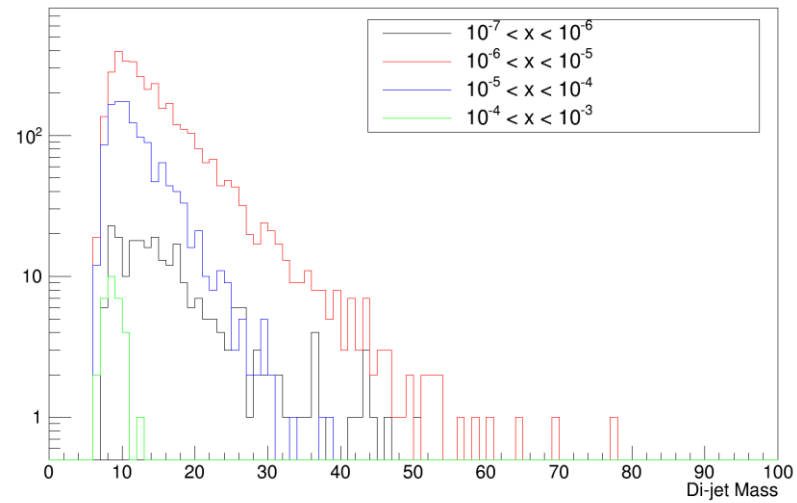
Di-jets: Extra Scale



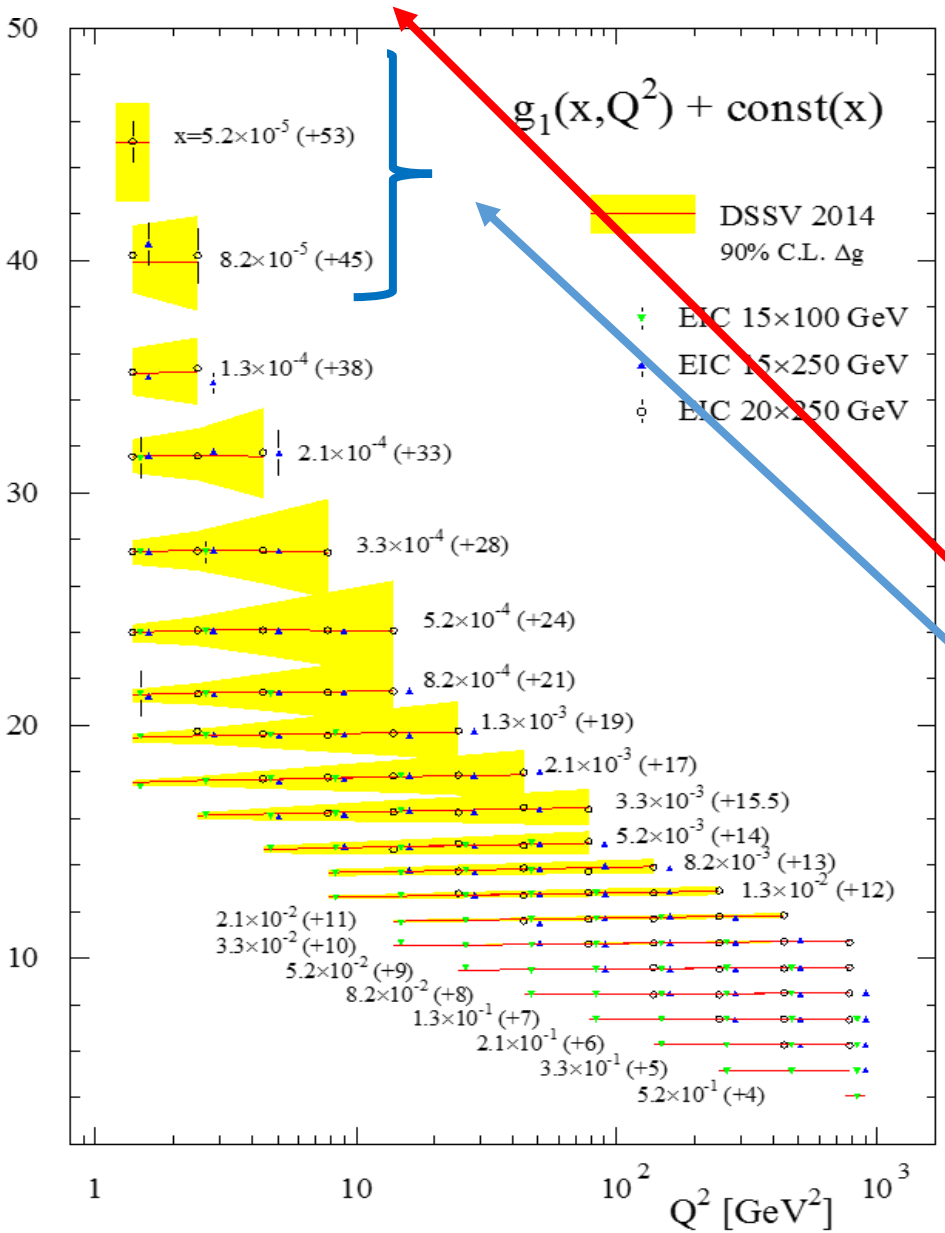
Resolved Di-jet Mass: Q^2 = 0.1 – 1.0



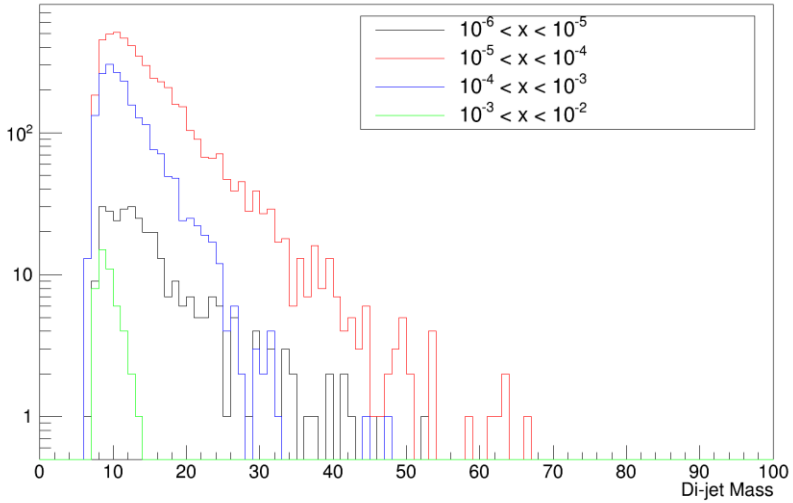
Resolved Di-jet Mass: Q^2 = 0.01 – 0.1



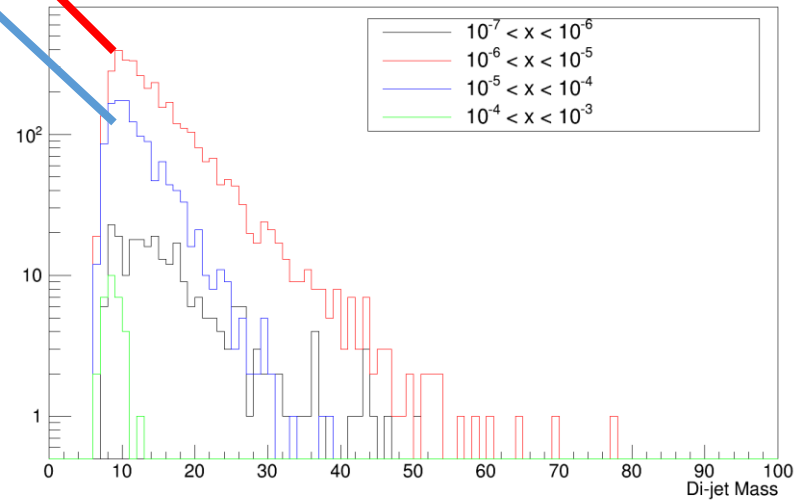
Di-jets: Extra Scale



Resolved Di-jet Mass: Q^2 = 0.1 – 1.0



Resolved Di-jet Mass: Q^2 = 0.01 – 0.1

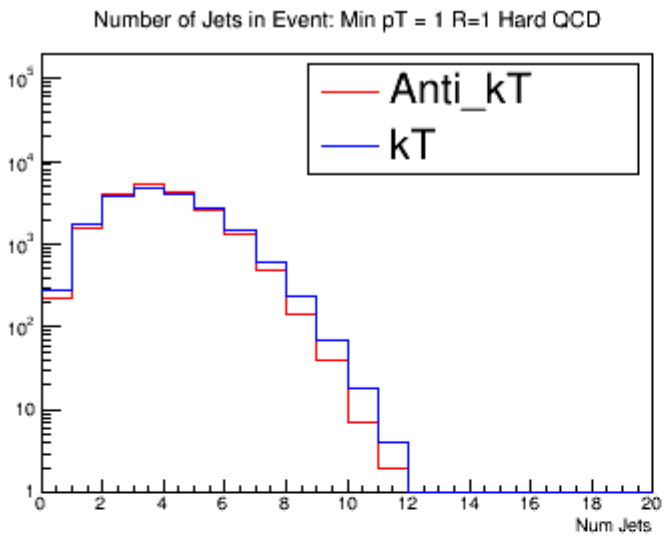


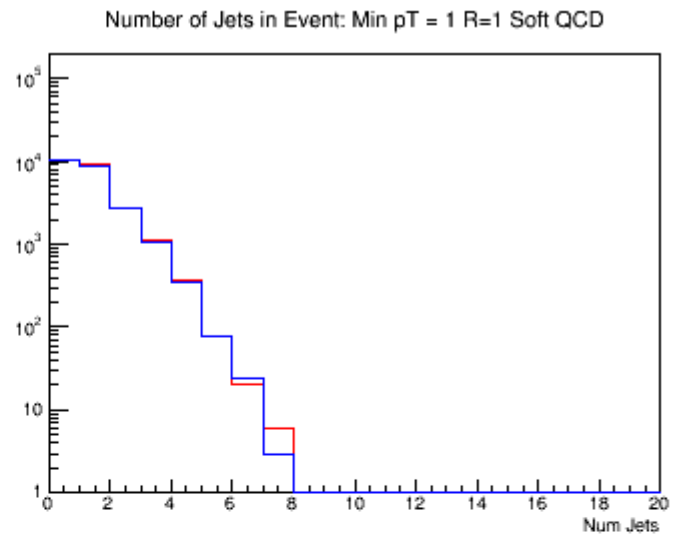
Summary

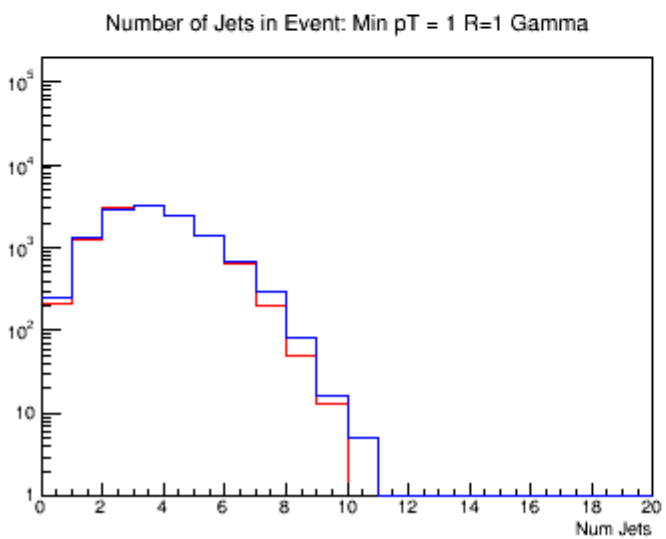
- Jet finding details for e-p well established: want IR safe algorithm (k_T / anti-k_T) with a large radius
- e-p environment is relatively quiet compared to p-p -> jet multiplicities will be low, especially as minimum p_T conditions are applied. Low $\sqrt{s}$ will also be an issue
- Jet multiplicities and kinematics depend strongly on event kinematics (Q^2 etc)
- Di-jets will have some sensitivity to intrinsic k_T and will allow an extra hard scale for extension of g_1 coverage
- Many applications where jets / di-jets will be powerful probes not discussed in this talk (see for example following talk by Xiaoxuan)

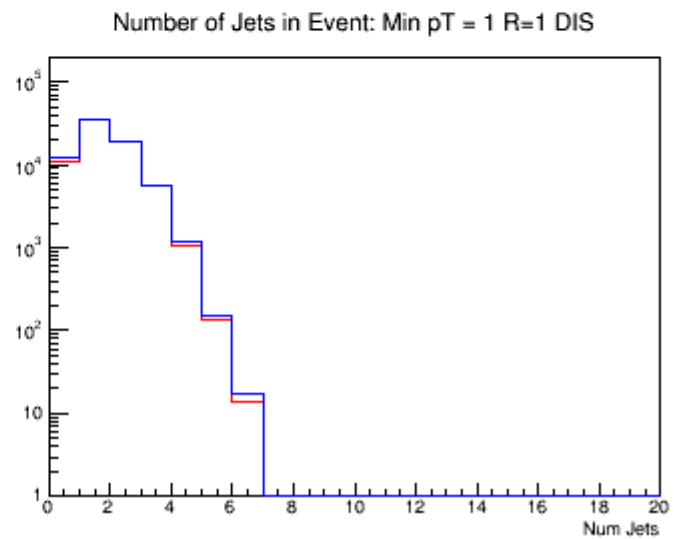
Backup

Jet Multiplicity: Algo: 20x250

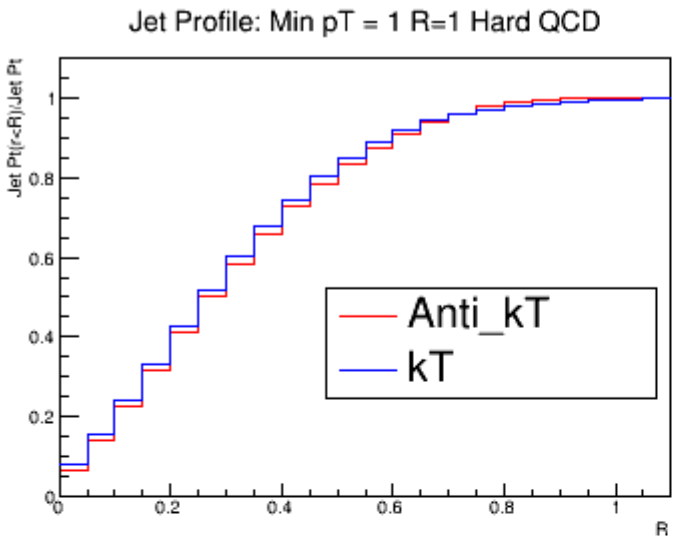


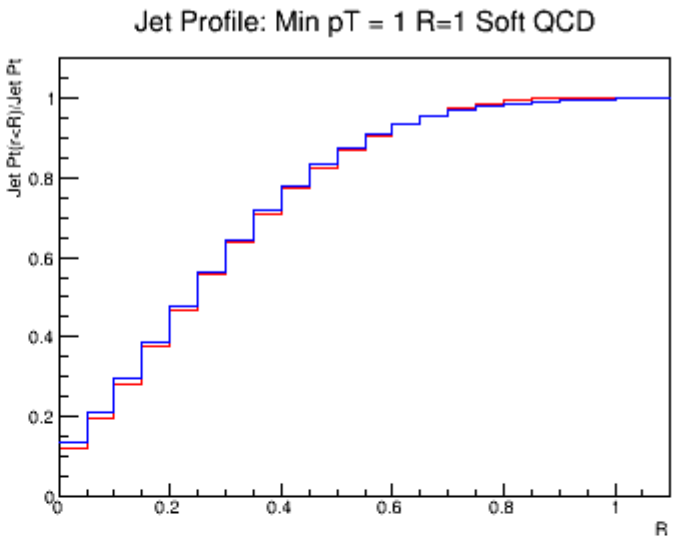


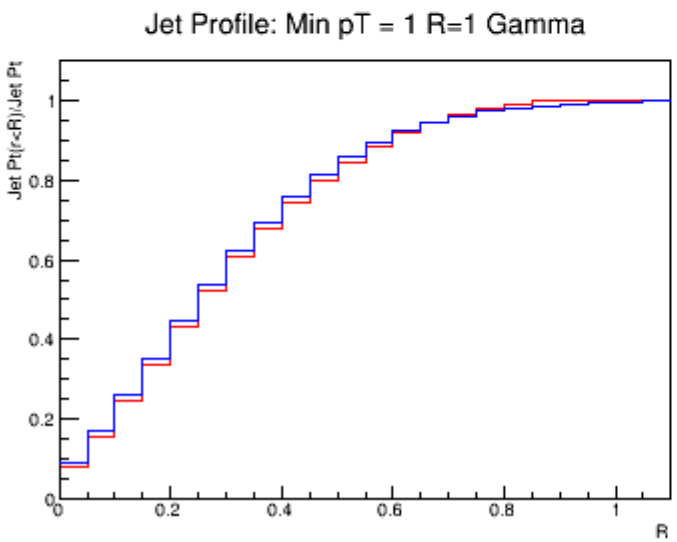


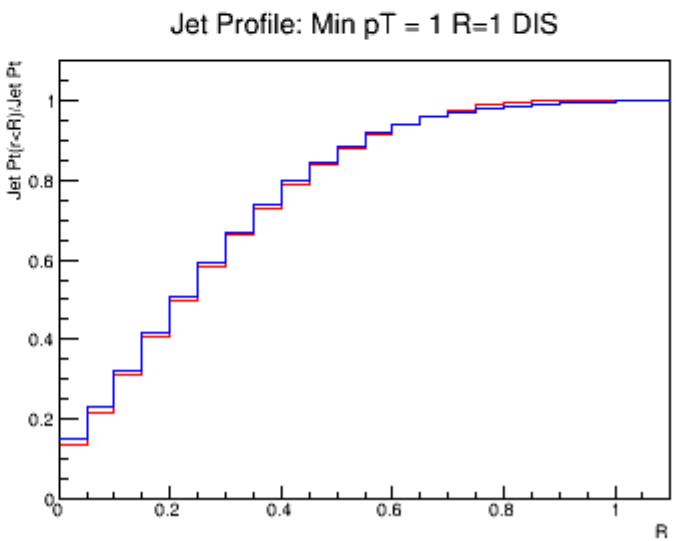


Jet Profile: Algo: 20x250

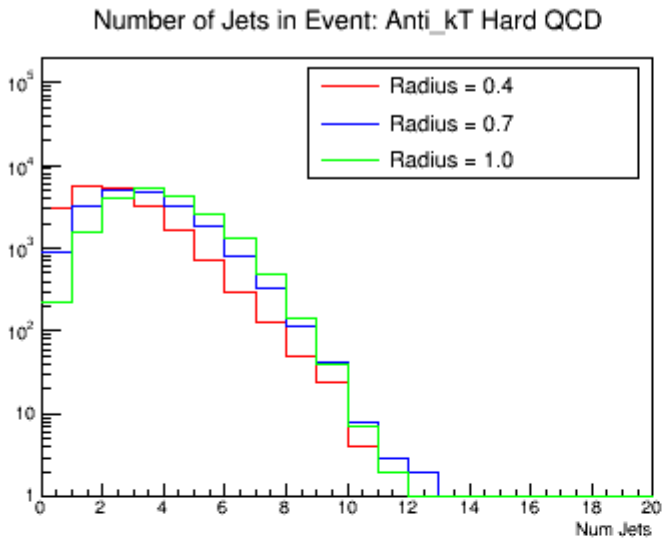


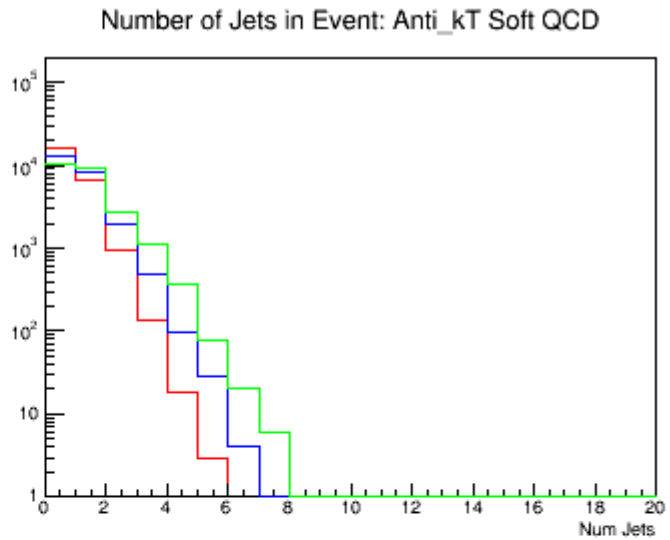


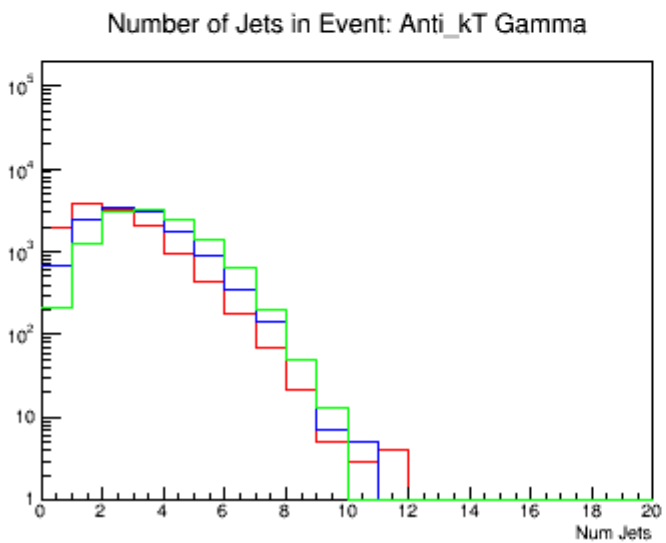


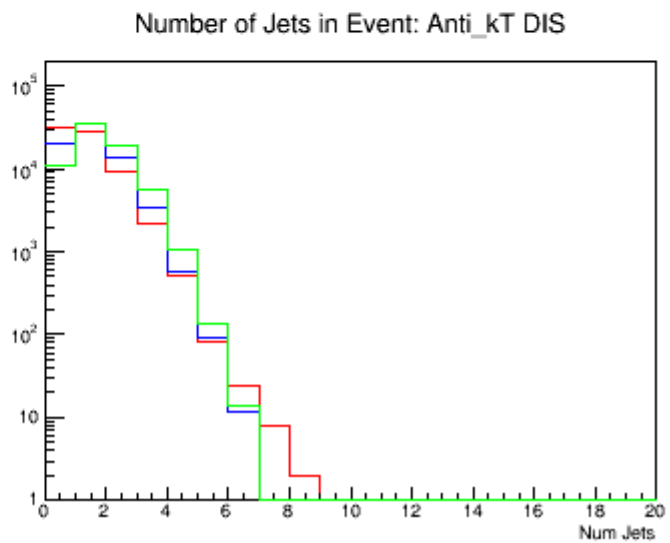


Jet Multiplicity: Radii: 20x250

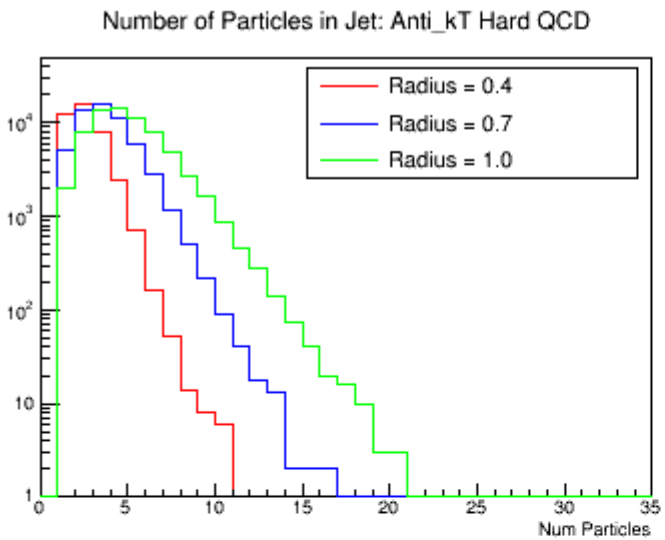


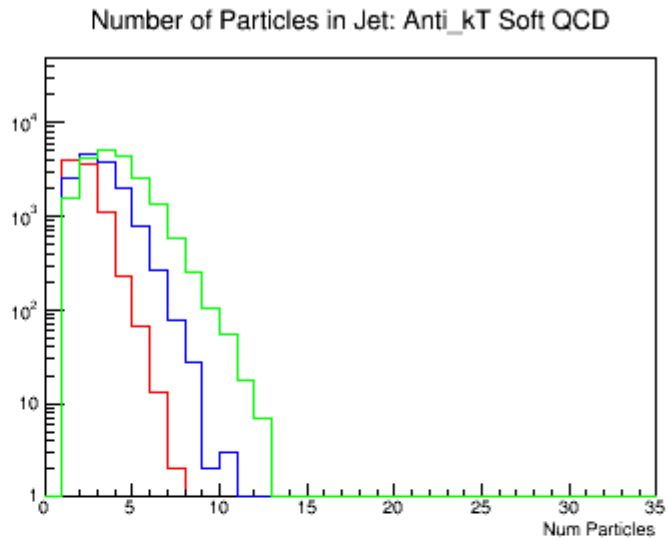


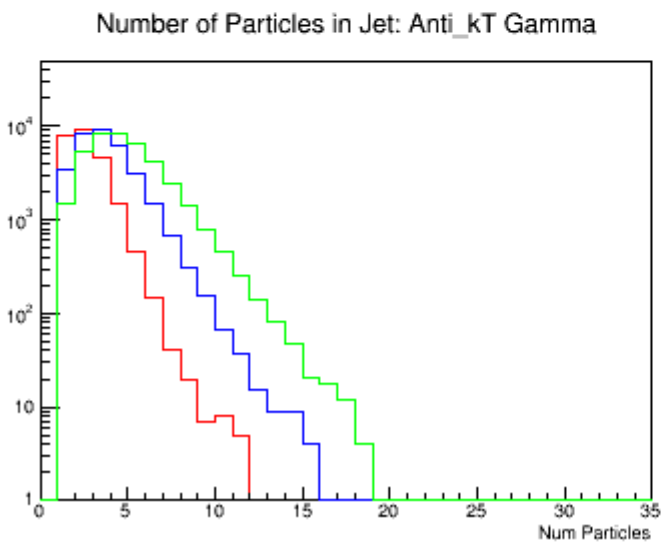


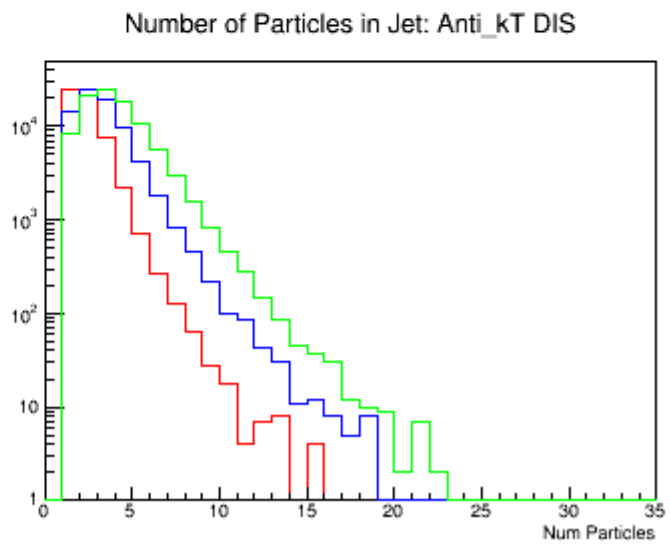


Part Multiplicity: Radii: 20x250



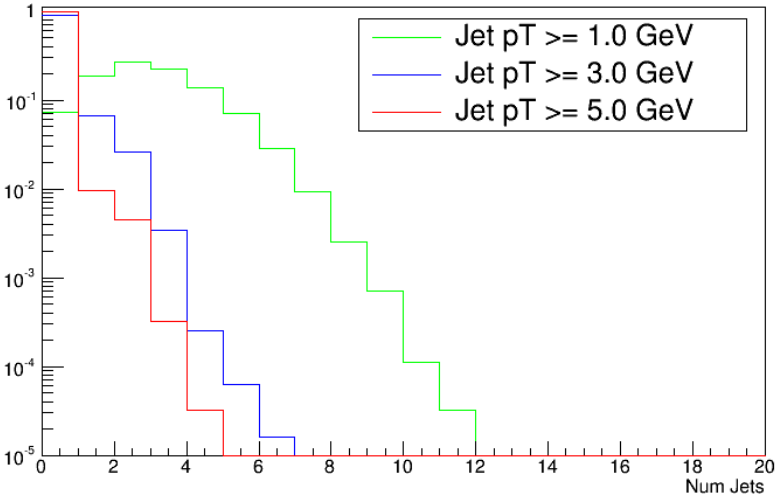






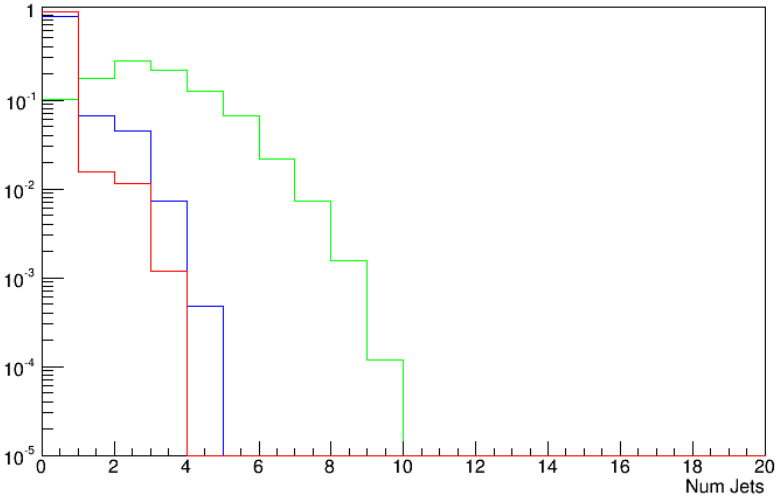
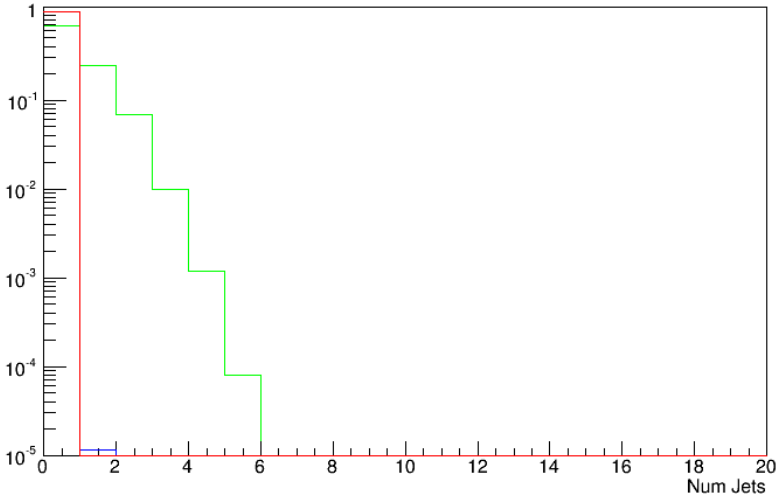
Jet Mult (HERA): $Q^2 = 10^{-5} – 10^{-4}$ GeV^2

Jets: Resolved Processes



- Same as previous slide, but now for HERA energies
- Electron beam =

Jets: PGF / QCDC



Jets: L.O. DIS