Experimental View of Jets at an EIC

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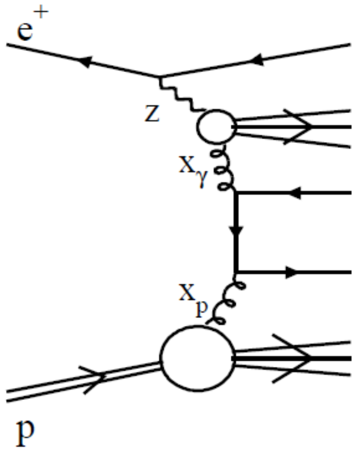
The battle for peace has begun.
Jets at an EIC
The Undiscovered Country
OPENS DECEMBER 6 AT THEATRES EVERYWHERE

Outline

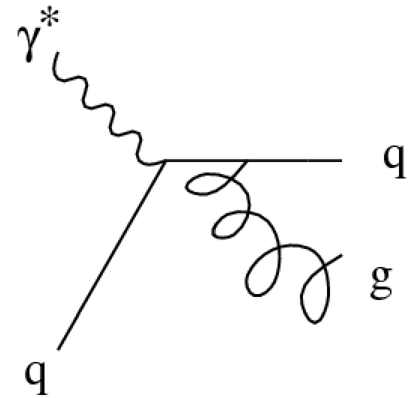
- Jet p_T and radius considerations
- Leading order Dijet A_{LL} measurement
- Substructure
- Detector effects

Relevant Subprocesses

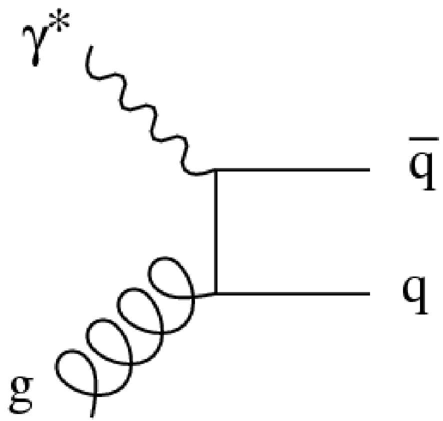
Resolved



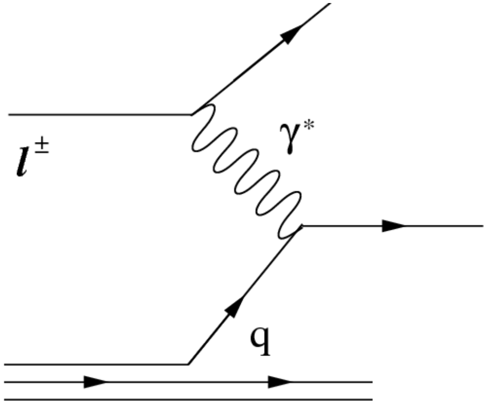
QCD-Compton (QCDC)



Photon-Gluon Fusion (PGF)

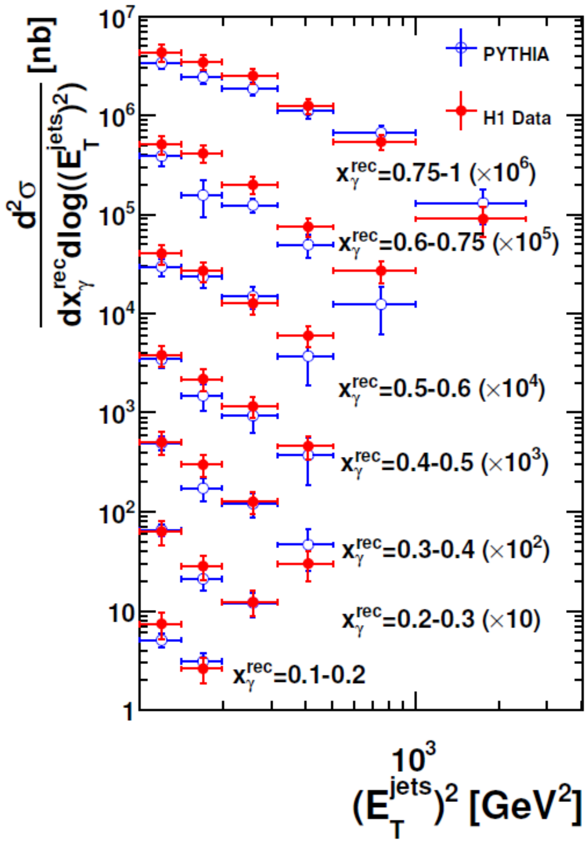


DIS



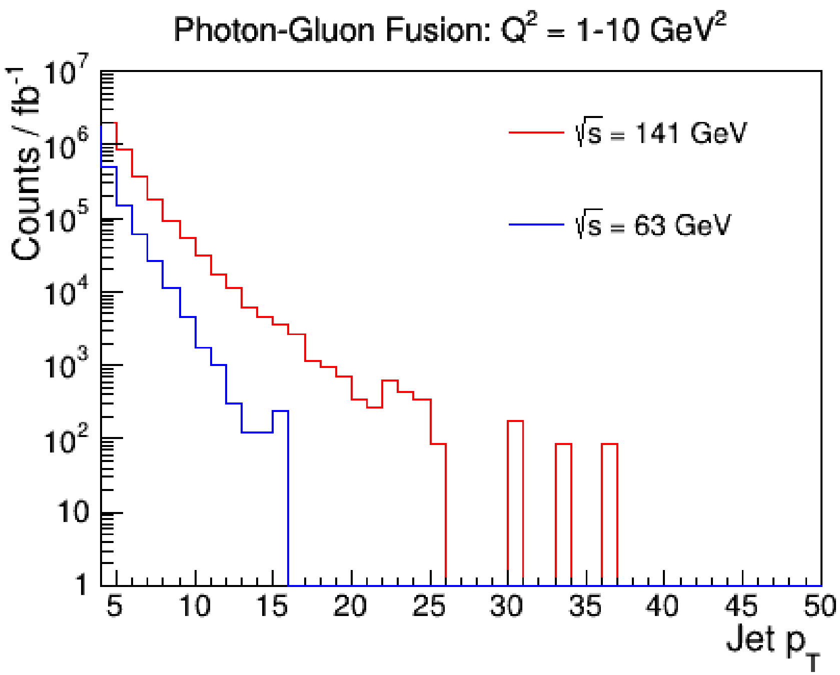
Simulation Details / Particle Cuts

- Electron – Proton events generated at √s = 141 GeV using PYTHIA (Full energy eRHIC design 20x250 GeV electron x proton)
- Cut on inelasticity: $0.01 \leq y \leq 0.95$
- Jet Algorithm: Anti_k_T (R = 1.0)
- Jets found in Breit frame
- Particles used in jet finding:
    - Stable
    - $p_T \geq 250$ MeV
    - $\eta \leq 4.5$
    - Parent cannot originate from scattered electron

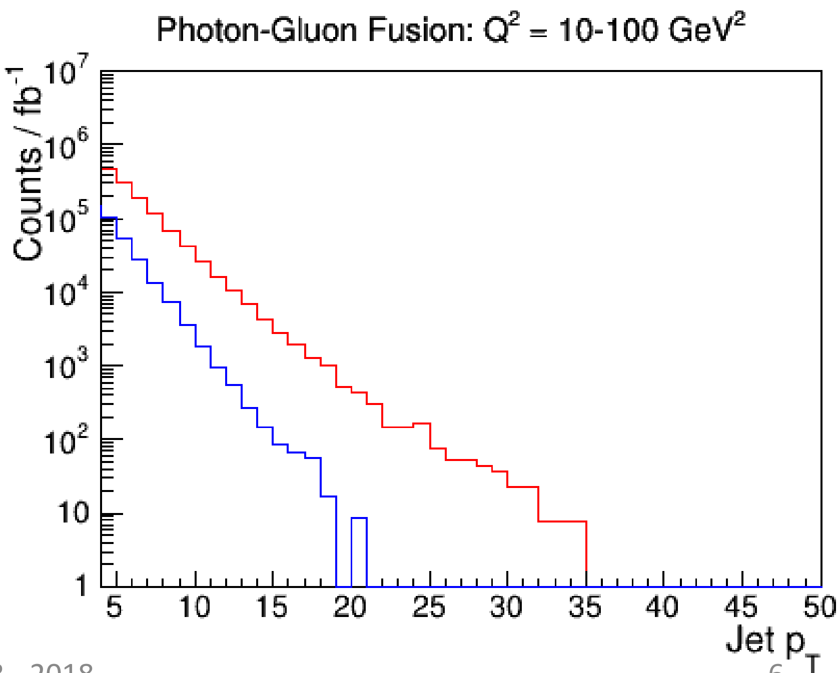


PRD 96, 074035 (2017)

Jet p_T: How Low is Too Low?

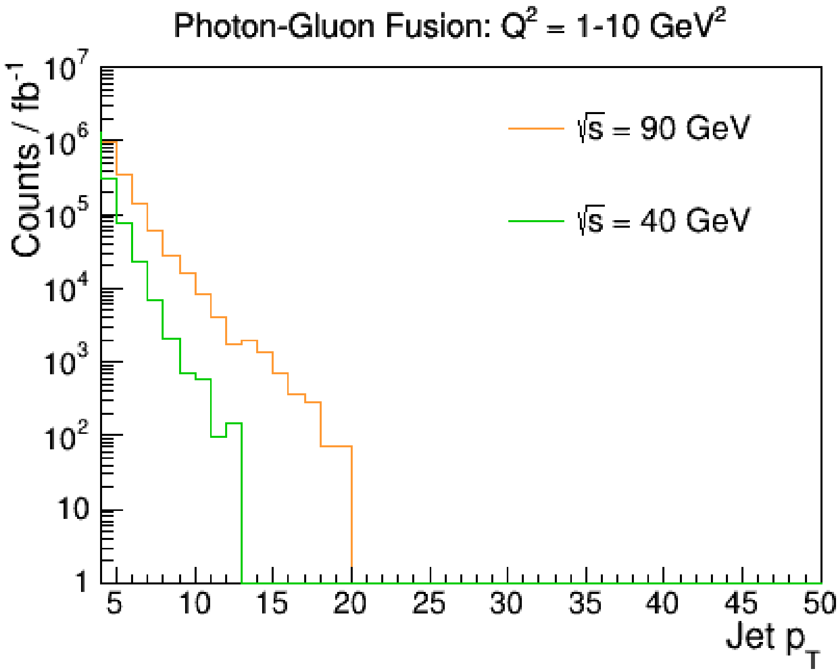


- Photon-gluon fusion jet p_T spectrum shown for two center of mass energies and two Q^2 ranges
- √s = 141 -> 20x250
- √s = 63 -> 10x100

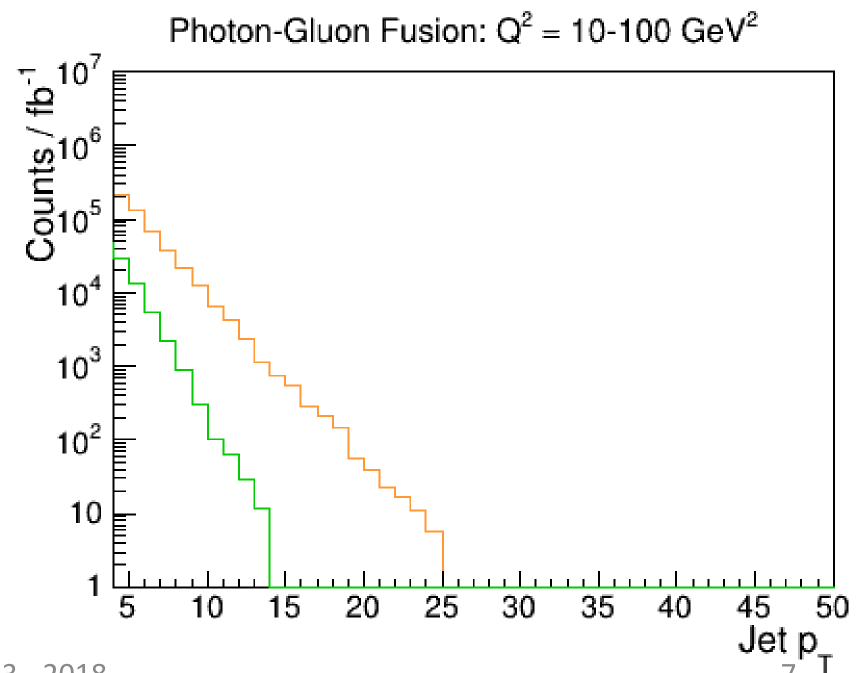


- In principle, can cluster particles and find 'jets' with very small p_T
- Where does theory break down?
- Would like to go as low as possible to get statistics

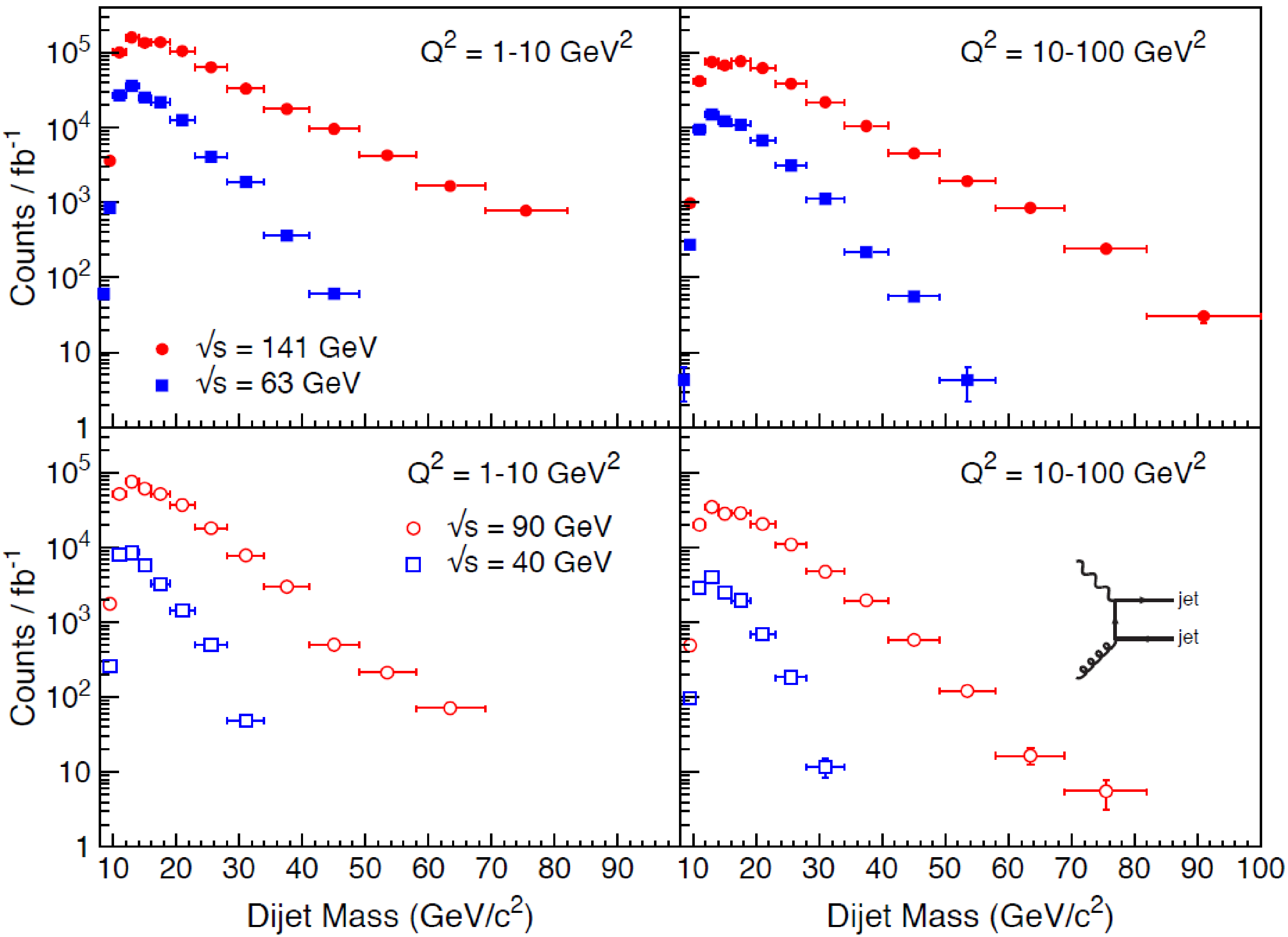
Jet p_T: How Low is Too Low?



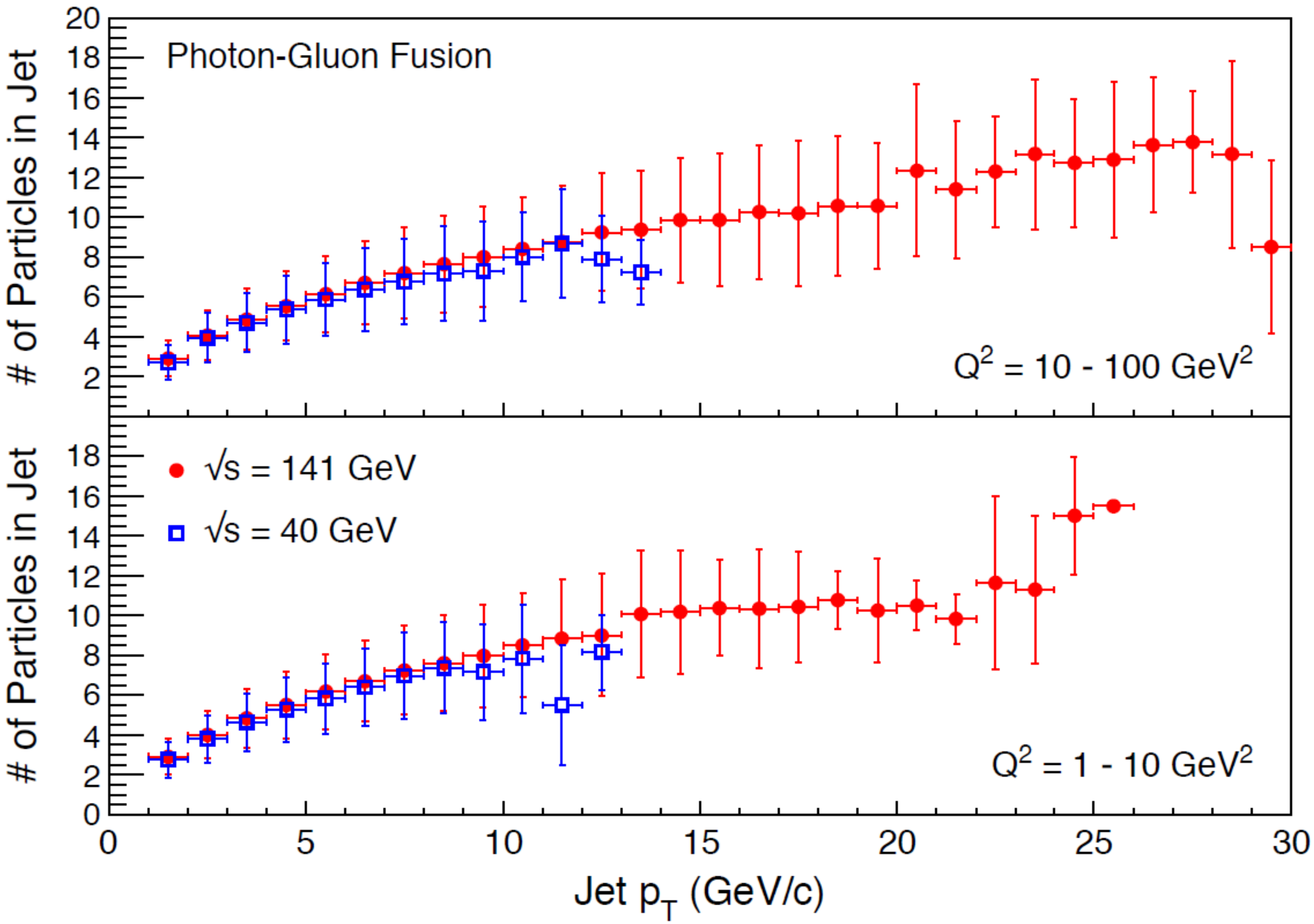
- √s = 90 -> 20x100
- √s = 40 -> 10x40



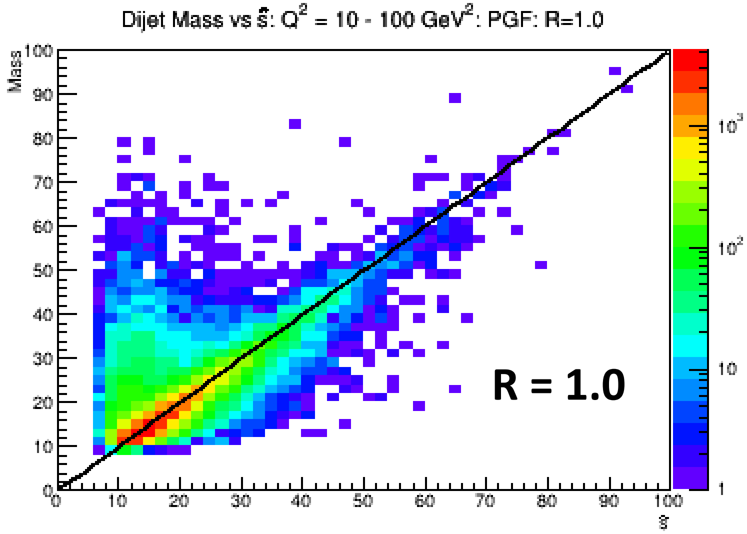
Dijet Mass Spectra

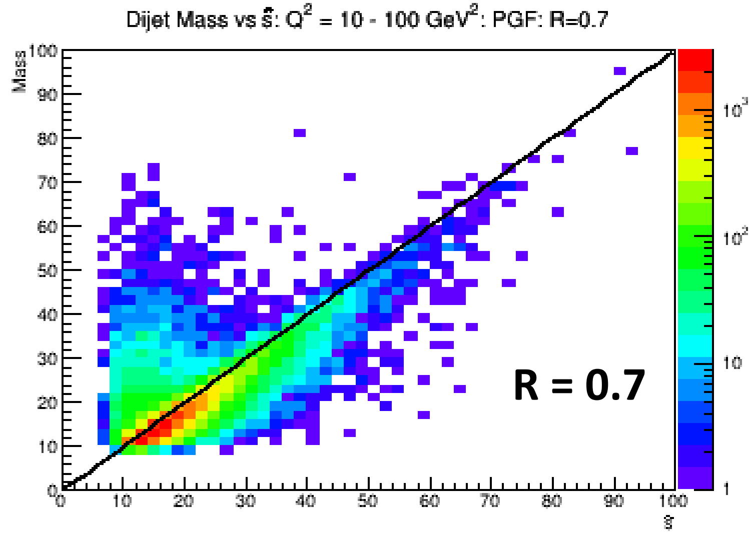


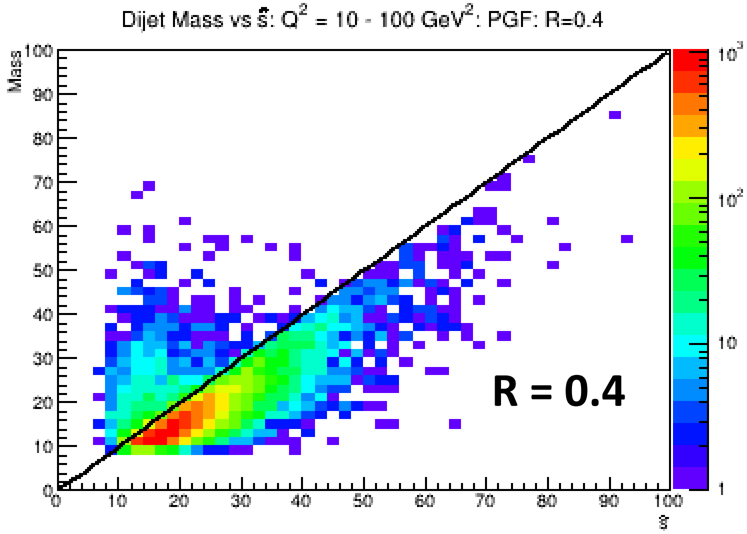
Jet Particle Content



Jet Radius Considerations







- What size radius is optimal?
- Dijet mass reproduces partonic s-hat better with larger radius
- Other analyses may benefit from smaller radii

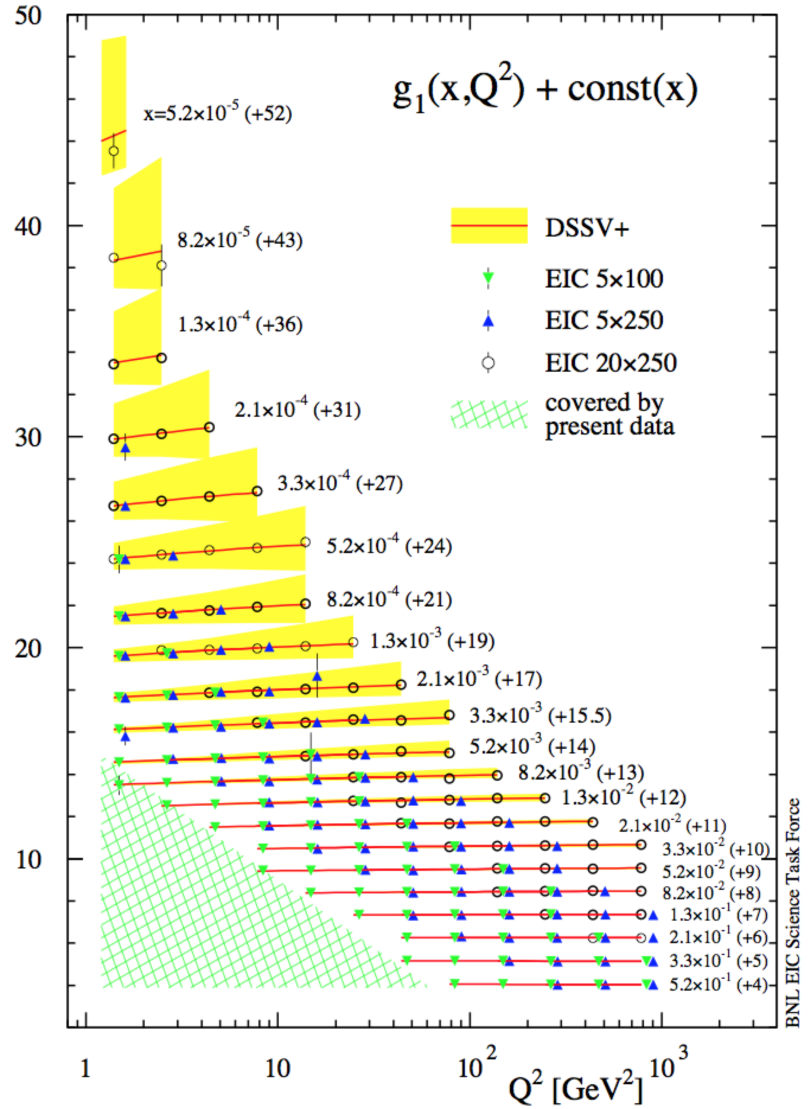
Accessing ΔG in DIS

- Several observables are sensitive to ΔG in DIS but golden measurement at an EIC would be scaling violation of $g_1(x,Q^2)$

$$\frac{dg_1(x,Q^2)}{dln(Q^2)} \approx -\Delta g(x,Q^2)$$

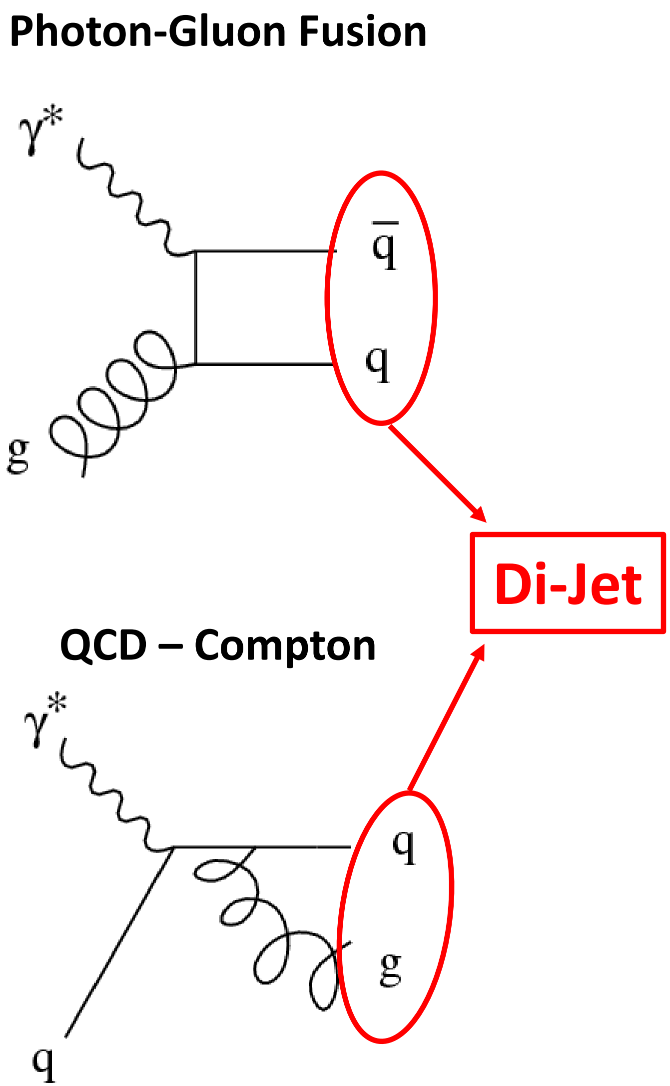
- Current DIS constraints on ΔG hampered by limited x & Q^2 coverage

- EIC would greatly expand kinematic reach and precision of $g_1(x,Q^2)$ measurements!



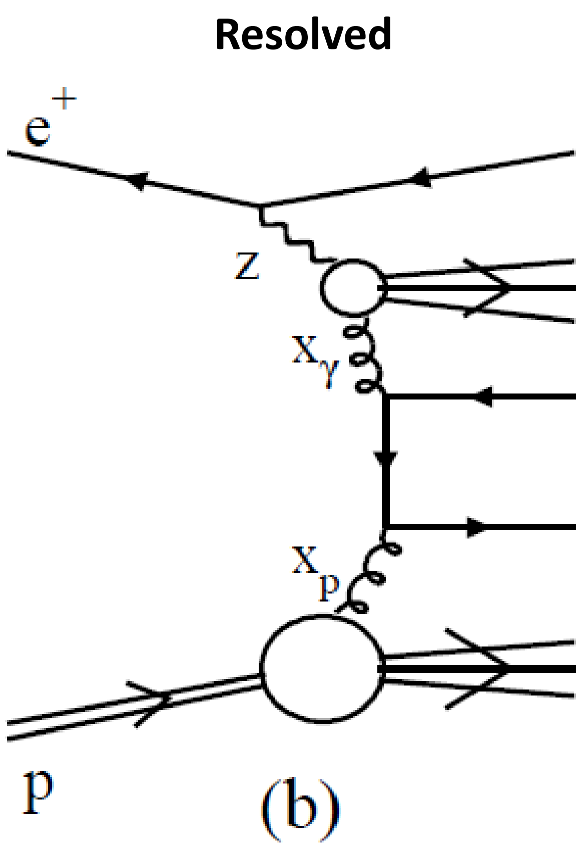
arXiv:1206.6014

Gluon Polarization with Di-jets



- Gluons can be also be probed in DIS via the higher-order photon gluon fusion process
- Also have the QCD – Compton process which probes quarks at the same order
- Both processes produce 2 angularly separated hard partons -> Di-jet

Gluon Polarization with Di-jets



- Gluons can be also be probed in DIS via the higher-order photon gluon fusion process
- Also have the QCD – Compton process which probes quarks at the same order
- Both processes produce 2 angularly separated hard partons -> Di-jet
- At lower Q2, resolved processes in which the photon assumes a hadronic structure begin to dominate
- Asymmetry is a convolution of polarized PDF from the proton and polarized photon structure – which is completely unconstrained
- Would like to suppress the resolved component

Proton Partonic Kinematics

$$X_P = x_B\left(1 + \frac{M^2}{Q^2}\right)$$

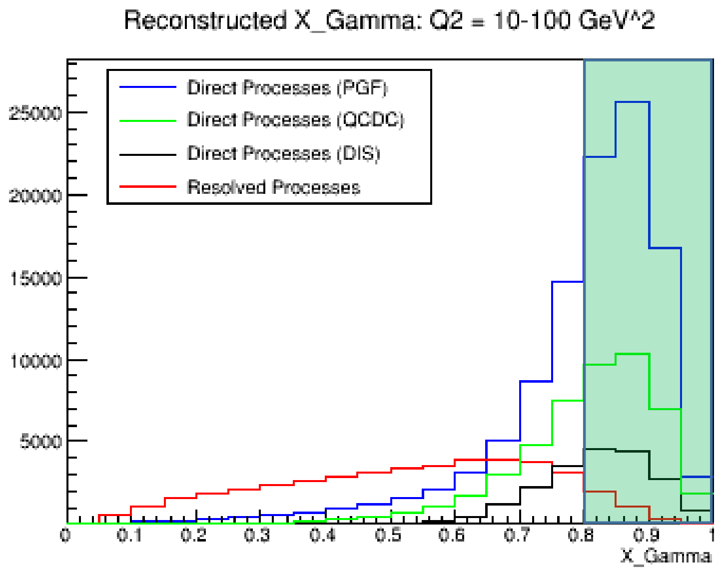
$$Q^2 = syx_B$$

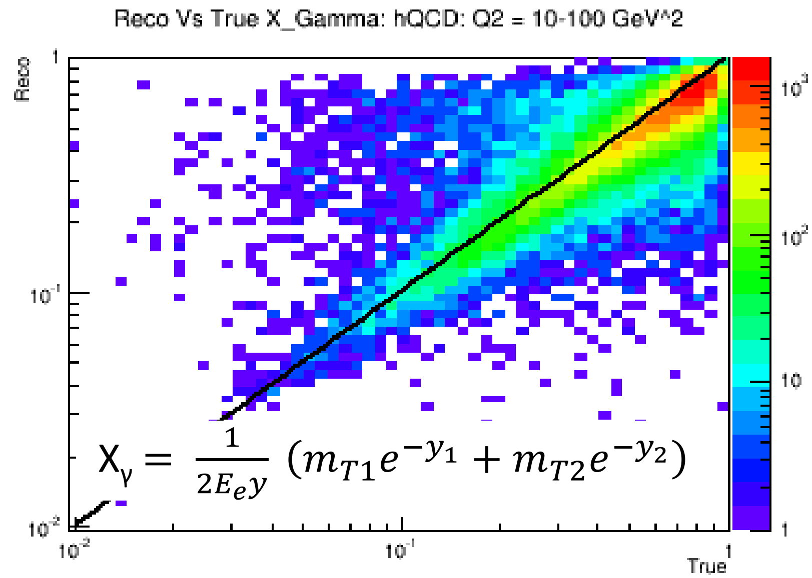
$$X_P = x_B + \frac{M^2}{sy}$$

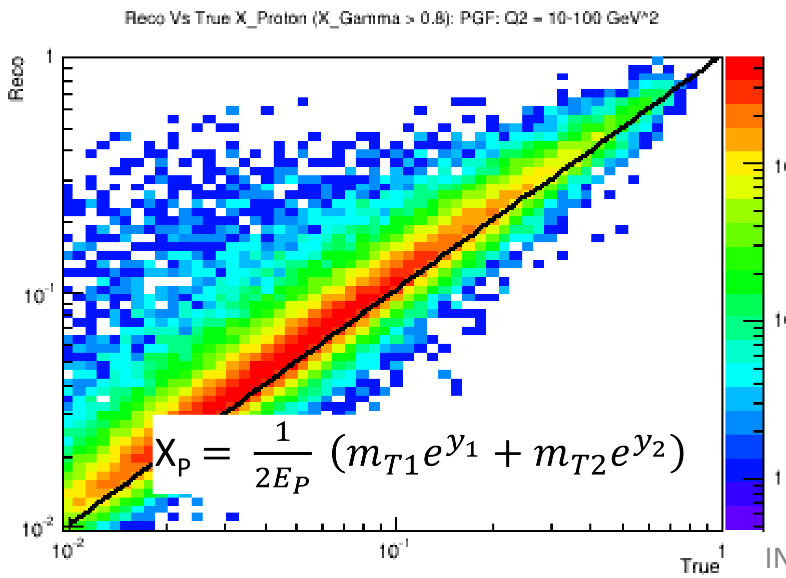
$$\approx \frac{100}{(20000\ x\ 0.95)} \approx 0.005$$

- To measure ΔG, need to probe the parton coming from the proton
- Momentum fraction of the parton from proton is well reconstructed
- X_P is related to Bjorken-x and Q^2 at leading order
- Q^2 and Bjorken-x are also related via the collision energy and inelasticity
- Accessible X_P range basically determined by beam energies
- Lowest X_P we can probe is about 0.005

Gluon Polarization with Di-jets





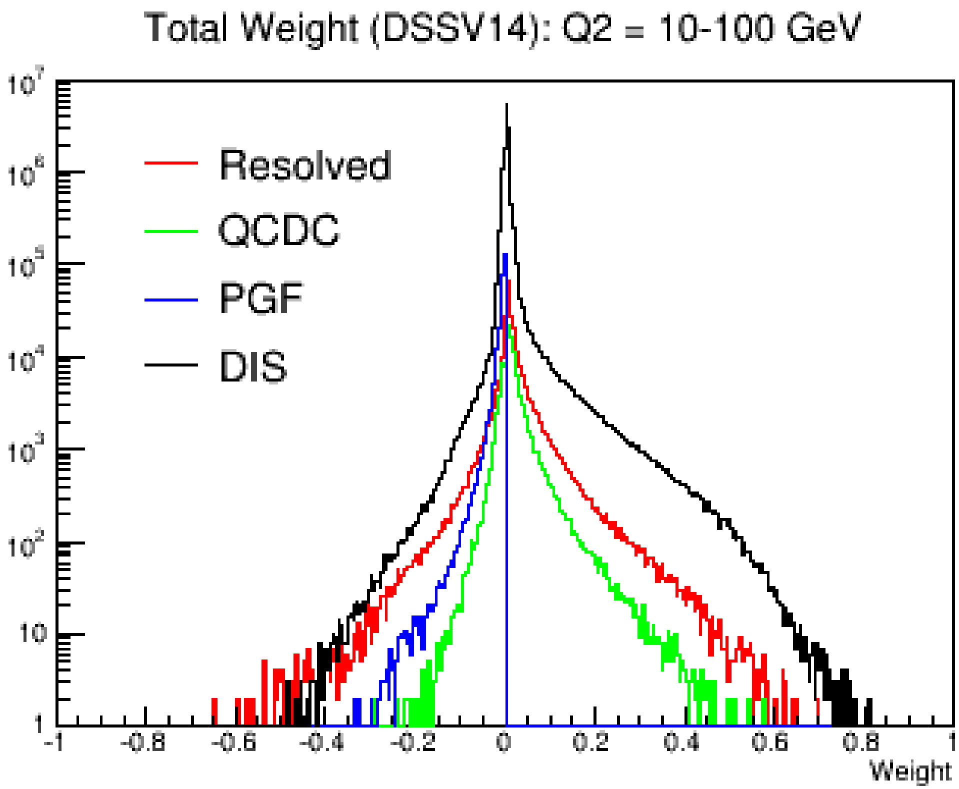


INT W

- Reconstruct virtual photon momentum fraction x_γ; direct processes concentrate toward 1 with resolved processes at lower values
- Cut of $x_\gamma > 0.8$ enhances the direct fraction
- Can also reconstruct momentum fraction of parton from the proton, x_P
- Both x_γ and x_P accurately reconstructed

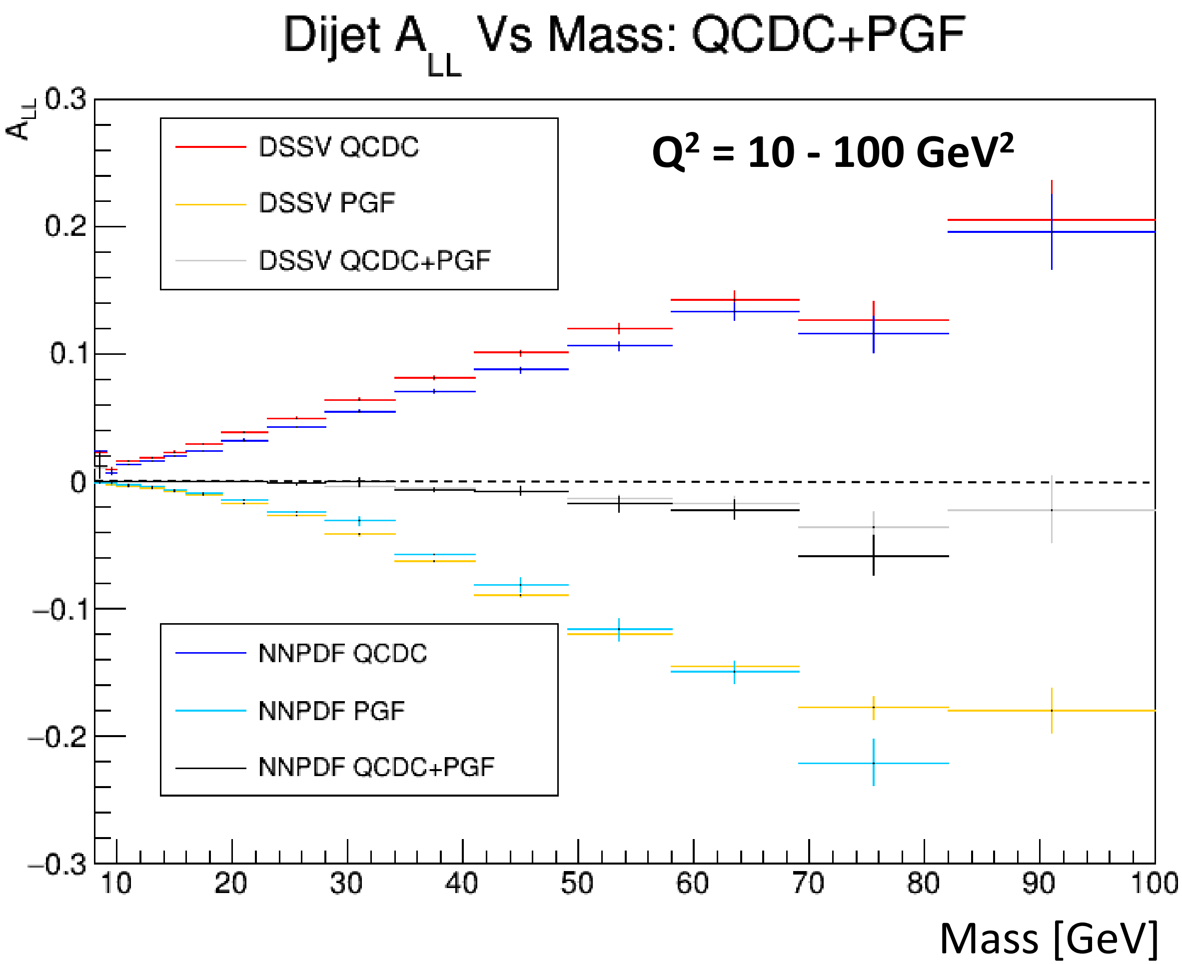
Weighting PYTHIA

$$w = \hat{a}(\hat{s},\hat{t},\mu^2,Q^2) \bullet \frac{\Delta f_a^{\gamma^*}(x_a,\mu^2)}{f_a^{\gamma^*}(x_a,\mu^2)} \bullet \frac{\Delta f_b^{N}(x_b,\mu^2)}{f_b^{N}(x_b,\mu^2)}$$



- PYTHIA does not include parton polarization effects, but an asymmetry can be formed by assigning each event a weight depending on the hard-scattering asymmetry and (un)polarized photon and proton PDFs
- Expected asymmetry is then the average over weights
- Weights are sharply spiked near zero -> expect small asymmetries

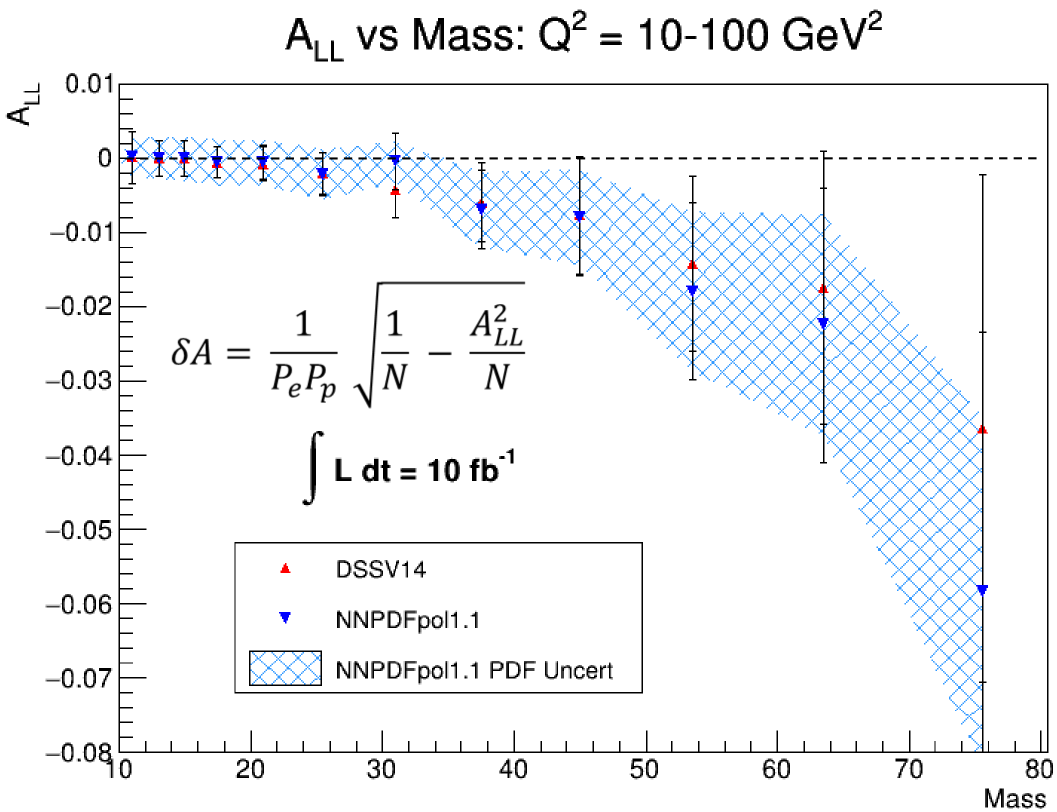
A_{LL} Vs Di-jet Mass

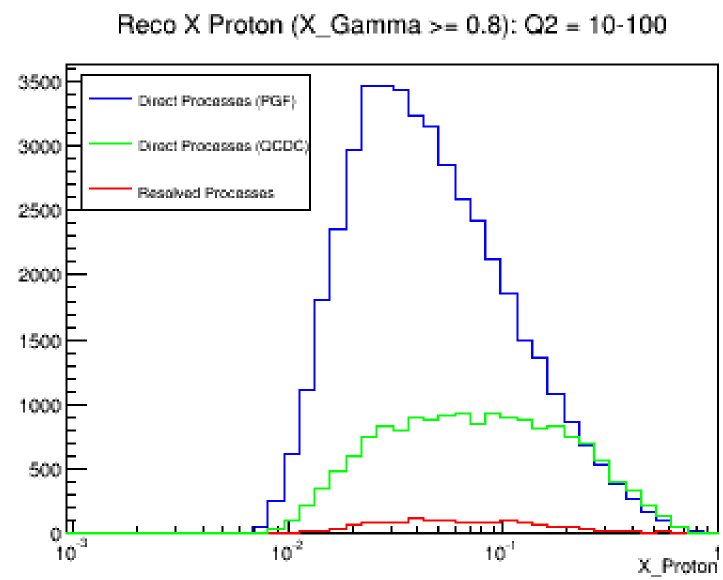


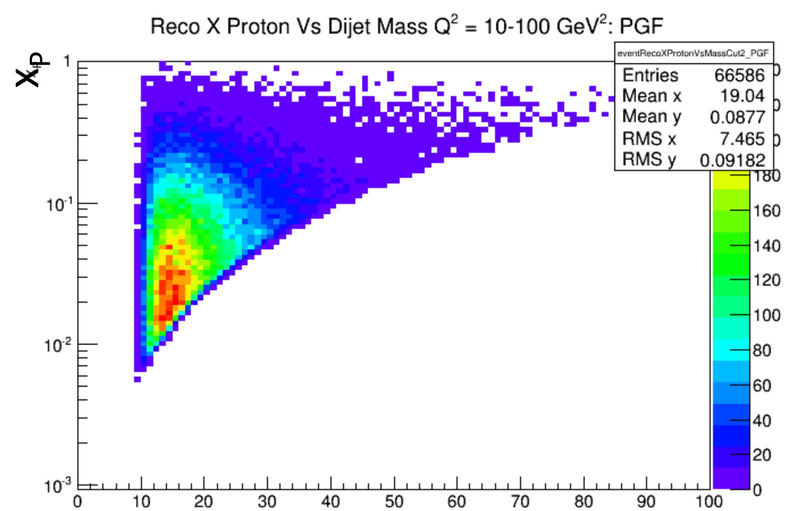
$$w = \hat{a}(\hat{s},\hat{t},\mu^2,Q^2) \bullet \frac{\Delta f_a^{\gamma^*}(x_a,\mu^2)}{f_a^{\gamma^*}(x_a,\mu^2)} \bullet \frac{\Delta f_b^N(x_b,\mu^2)}{f_b^N(x_b,\mu^2)}$$

- Weight simulated events by product of the partonic asymmetry and the ratios of the polarized over unpolarized photon and proton PDFs to obtain realistic estimate of A_{LL}
- Plot the expected A_{LL} as a function of di-jet invariant mass for each sub-process separately as well as the combined sample
- PGF asymmetry is nearly canceled out by QCDC asymmetry with opposite sign – would like to reduce QCDC contribution

A_{LL} Vs Di-jet Mass: x_P Cuts



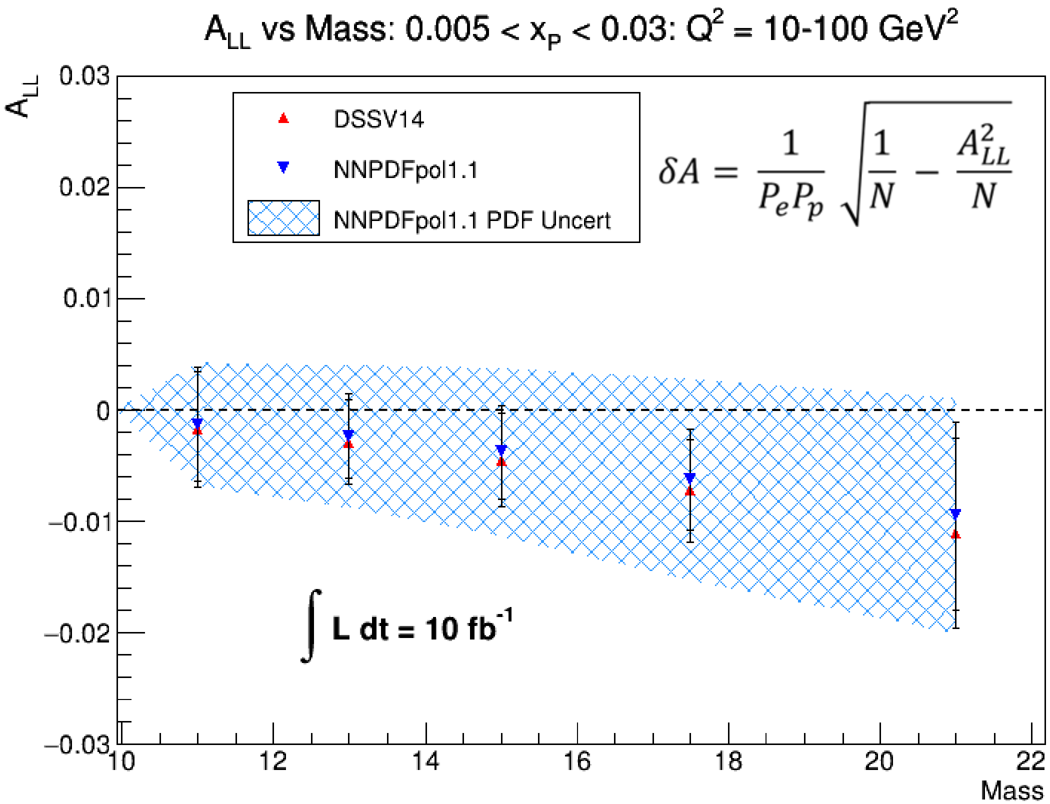


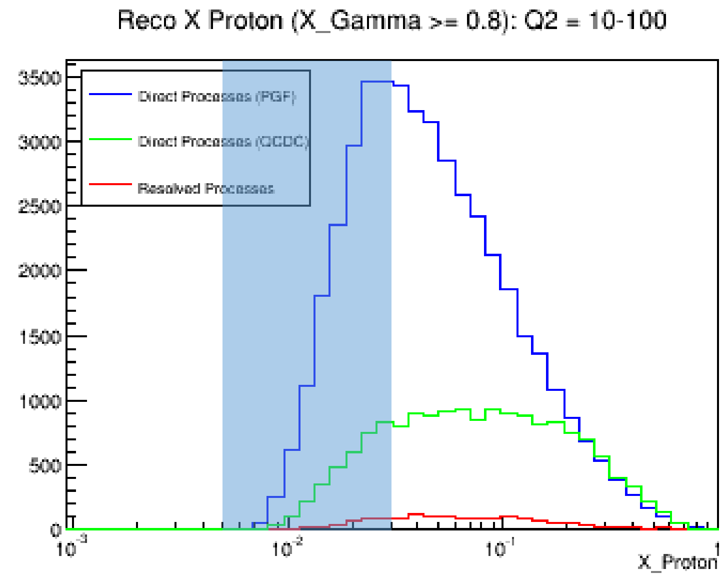


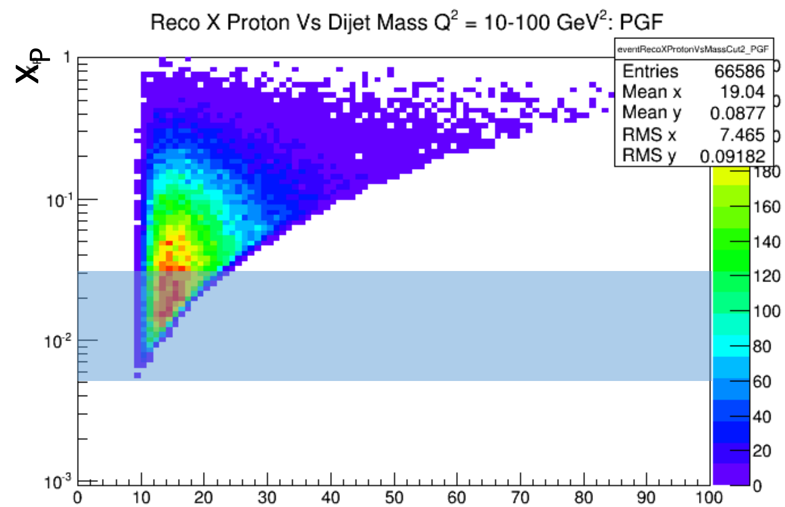
Dijet Mass

- QCDC and PGF asymmetries largely cancel out making overall asymmetry small
- Want to enhance PGF subprocess w.r.t. QCDC
- PGF events peaked to lower x_P values

A_{LL} Vs Di-jet Mass: x_P Cuts



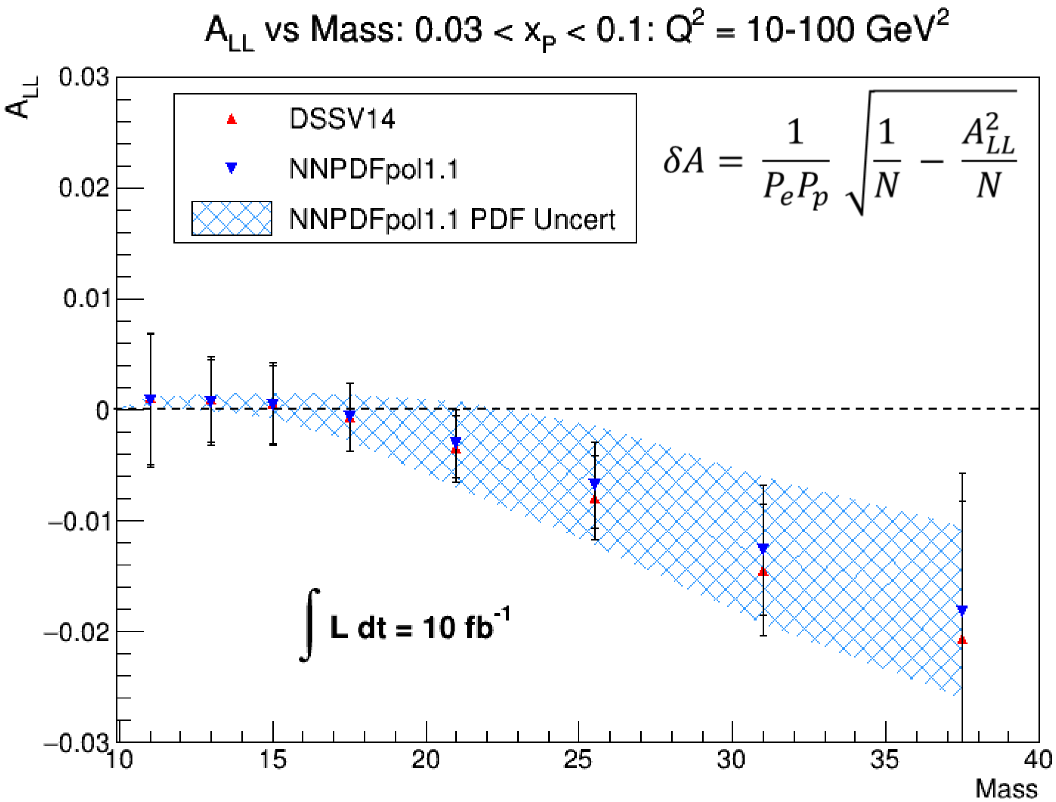


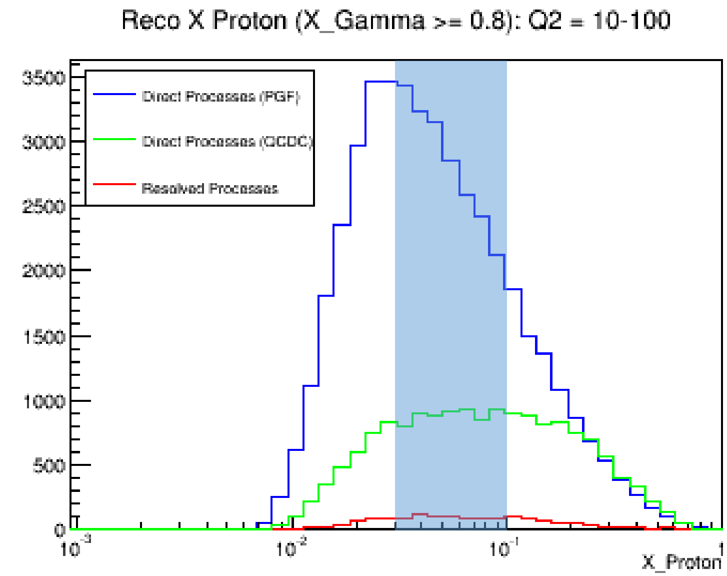


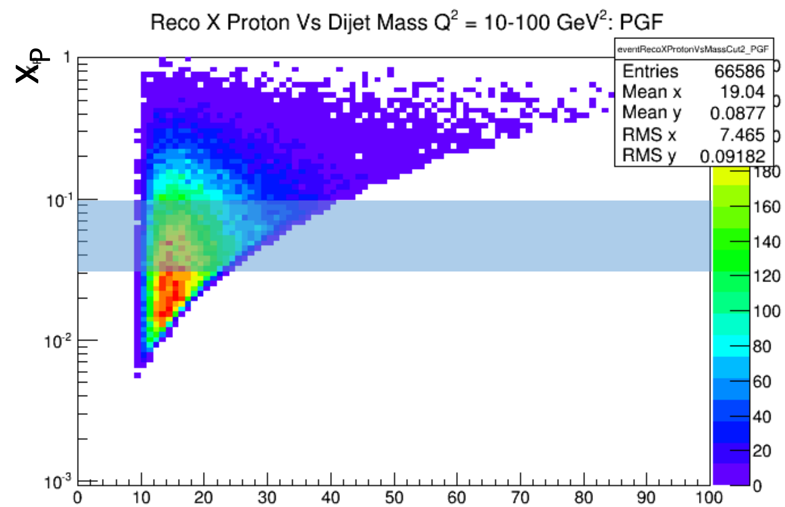
Dijet Mass

- Selecting events with $0.005 < x_P < 0.03$ enhances PGF asymmetry but restricts mass range

A_{LL} Vs Di-jet Mass: x_P Cuts







Dijet Mass

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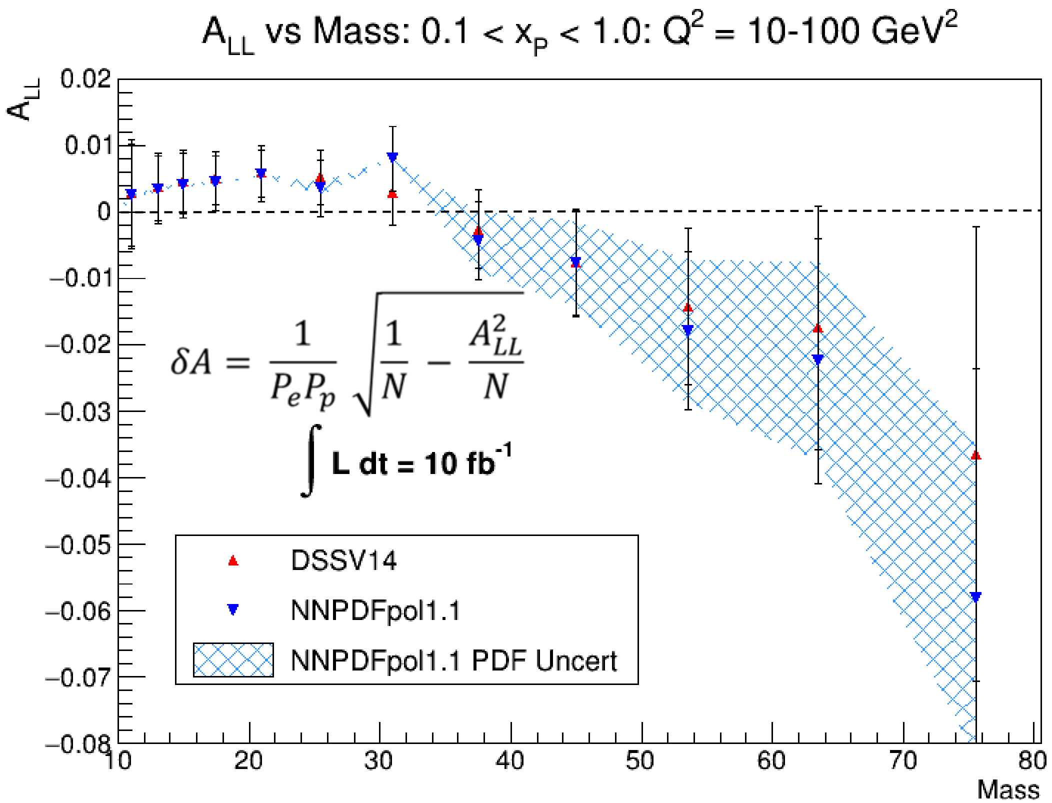
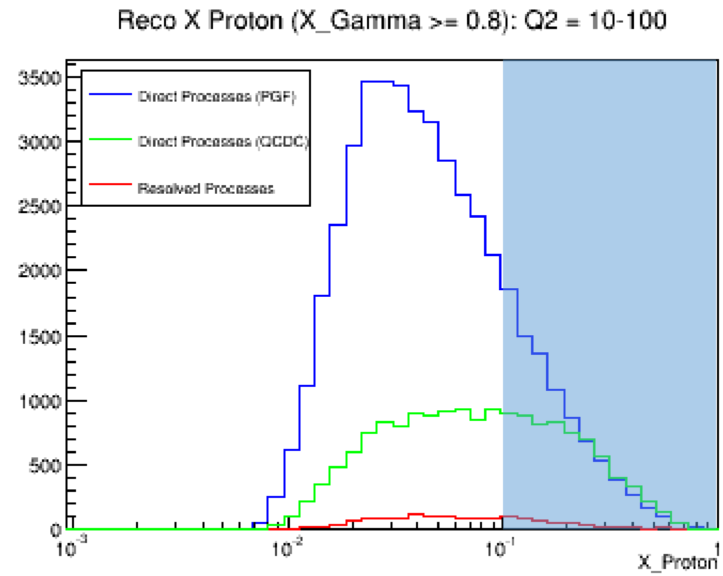
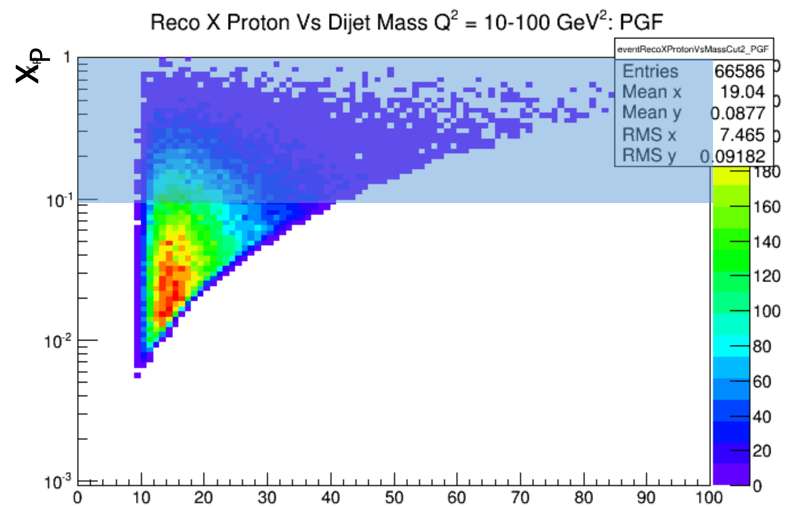
- Intermediate x_P values get more QCDC contribution

A_{LL} Vs Di-jet Mass: x_P Cuts

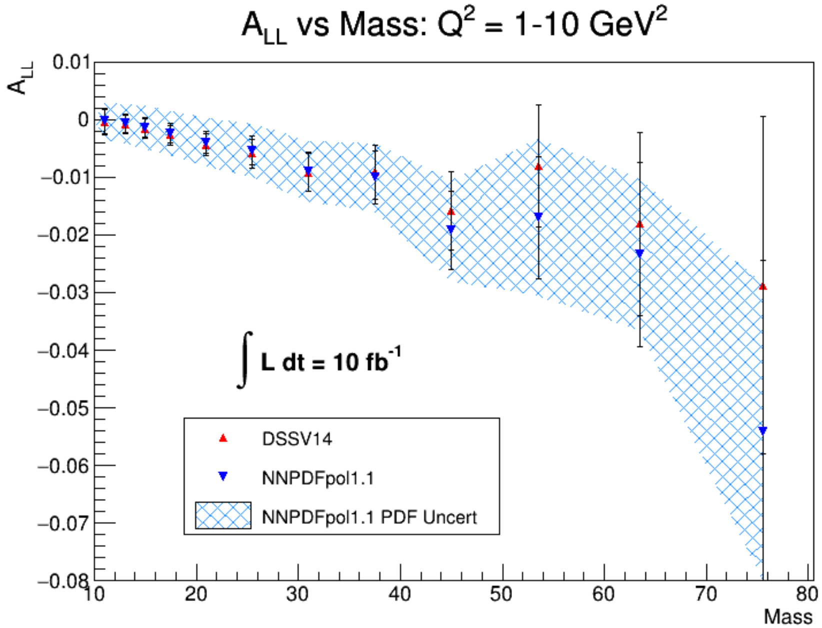


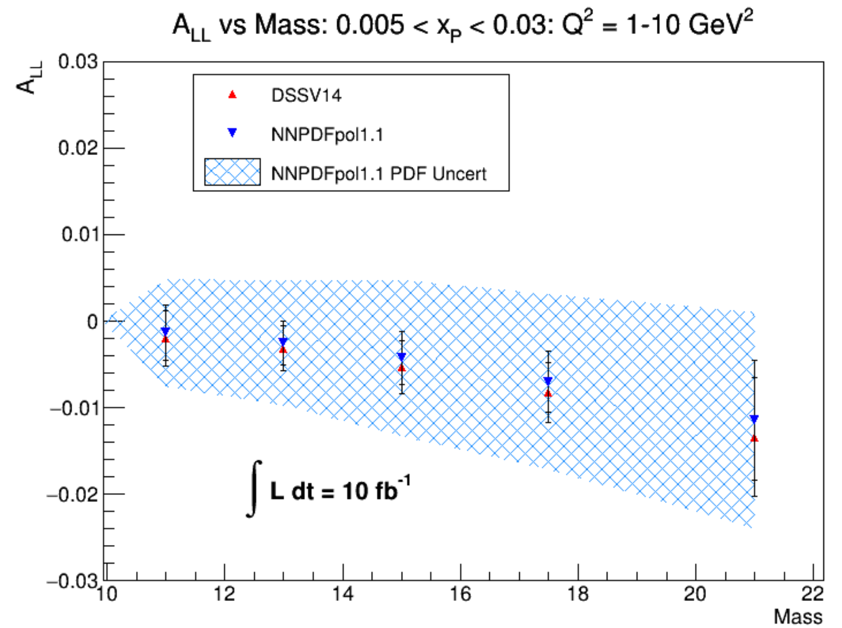


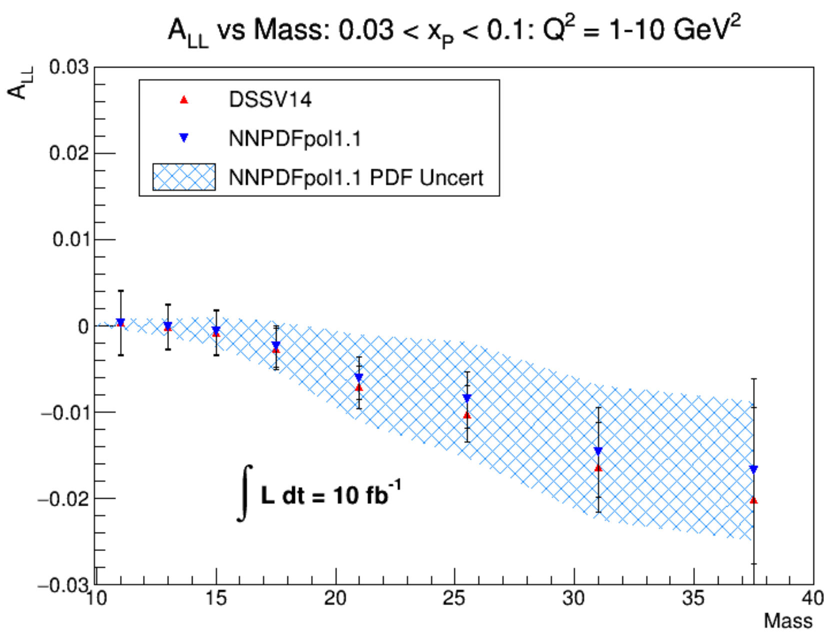


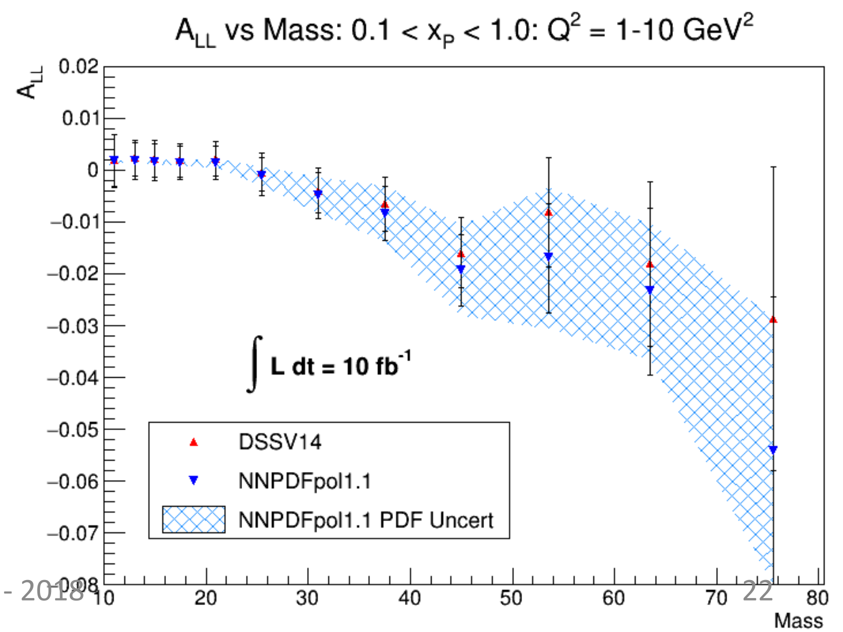
- Selecting events with $0.005 < x_P < 0.03$ enhances PGF asymmetry but restricts mass range
- Intermediate x_P values get more QCDC contribution
- Largest x_P values have roughly equal amounts of PGF and QCDC

A_{LL}: $Q^2 = 1 – 10\ GeV^2$

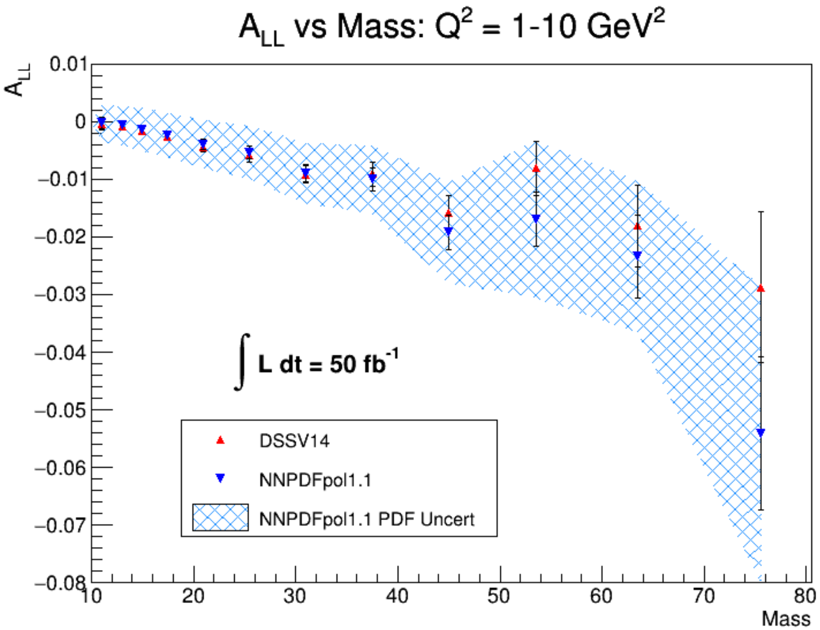


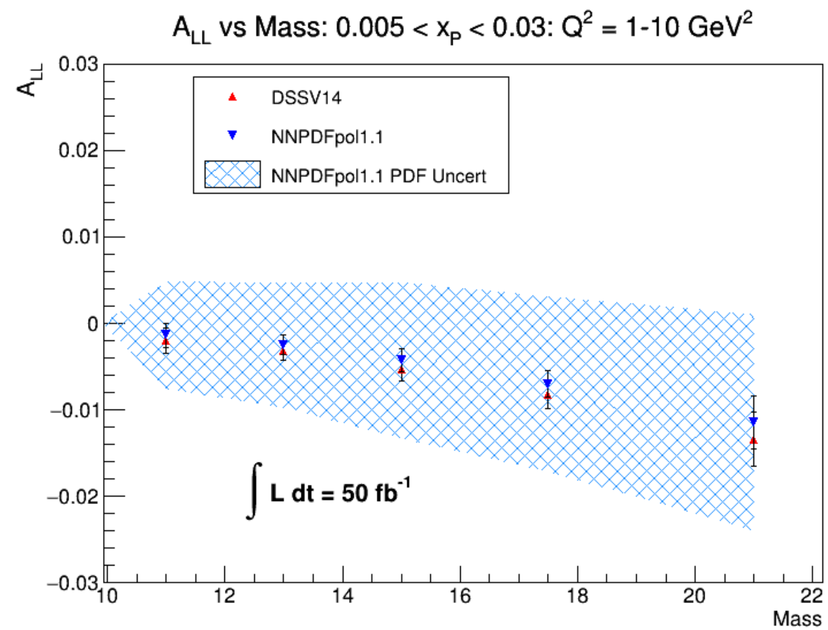


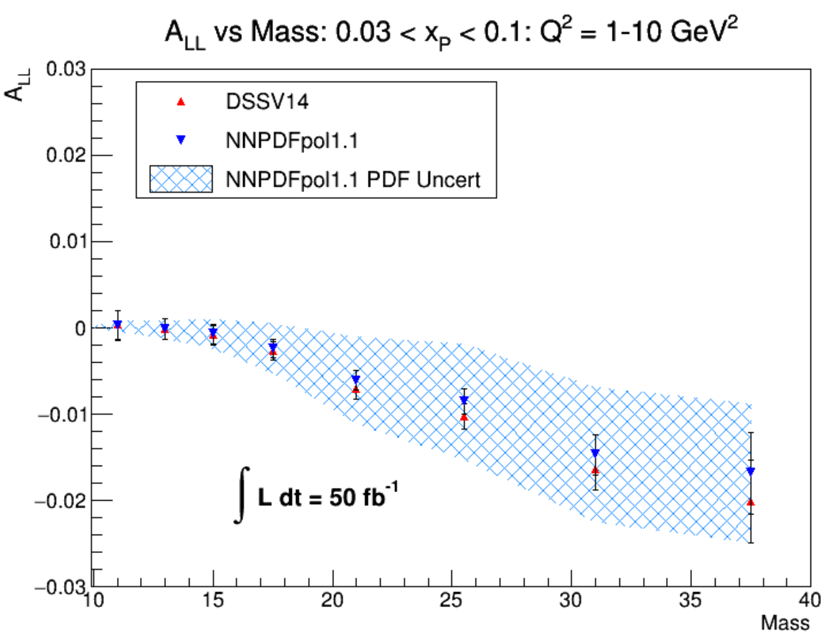


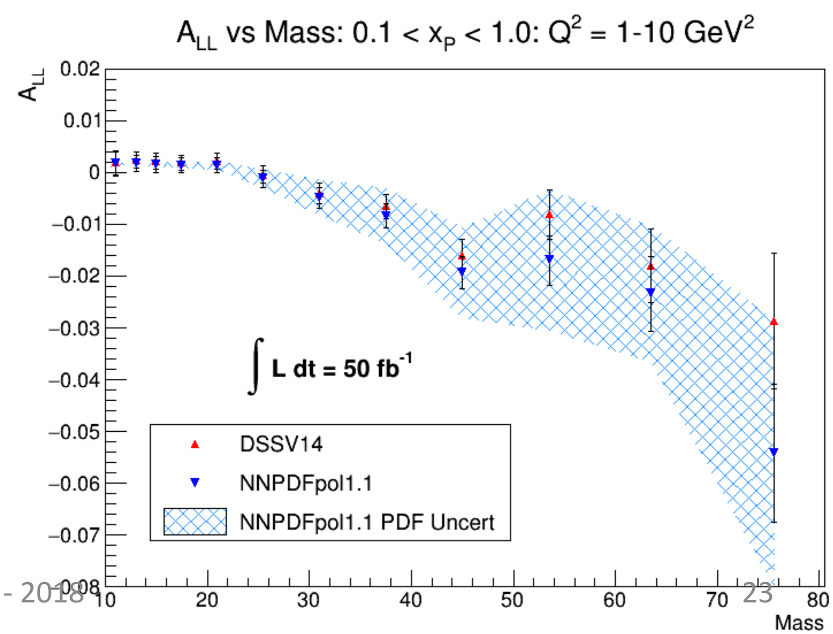


A_{LL}: Q^2 = 1 – 10 GeV^2 High Stats

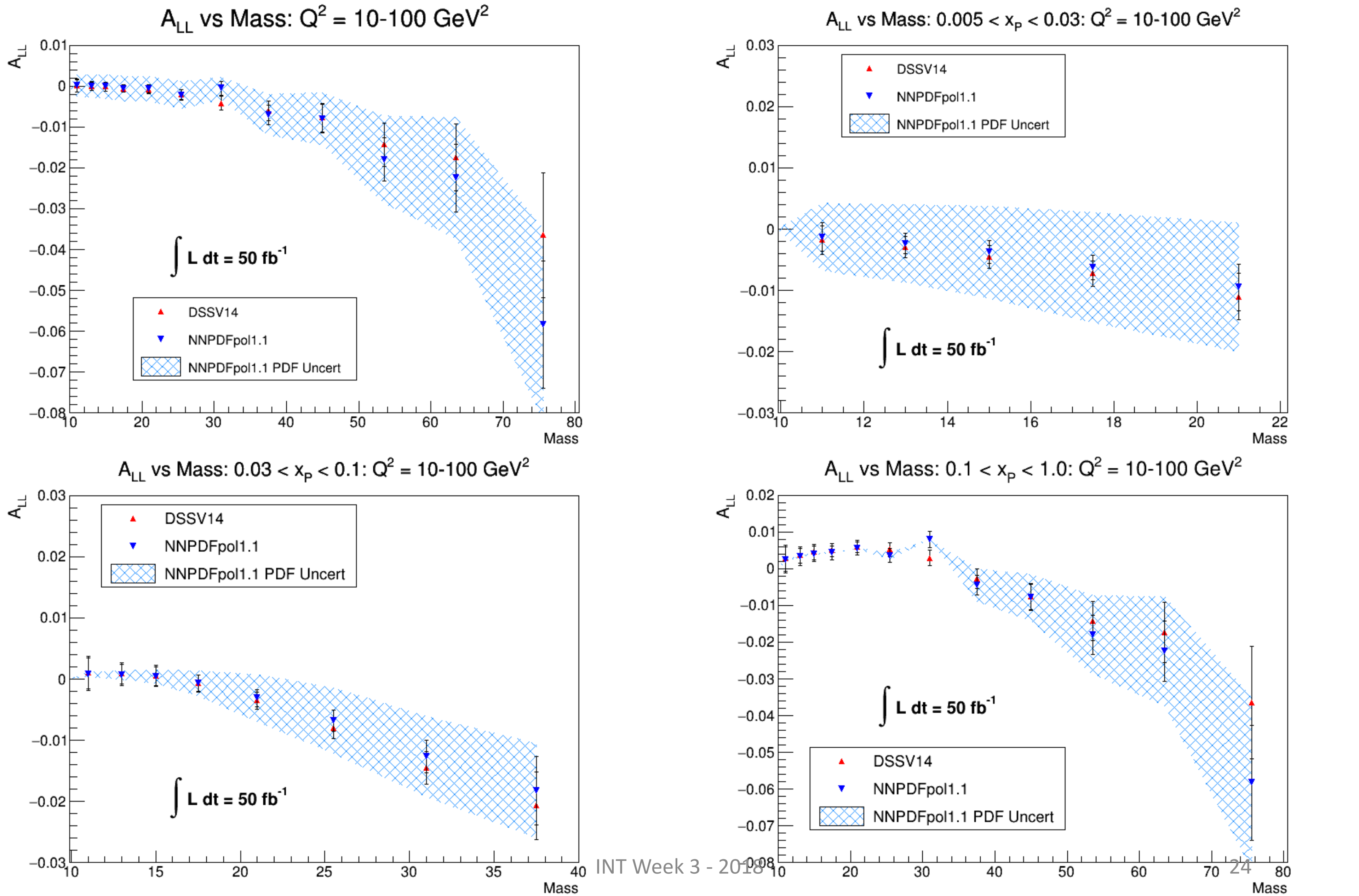




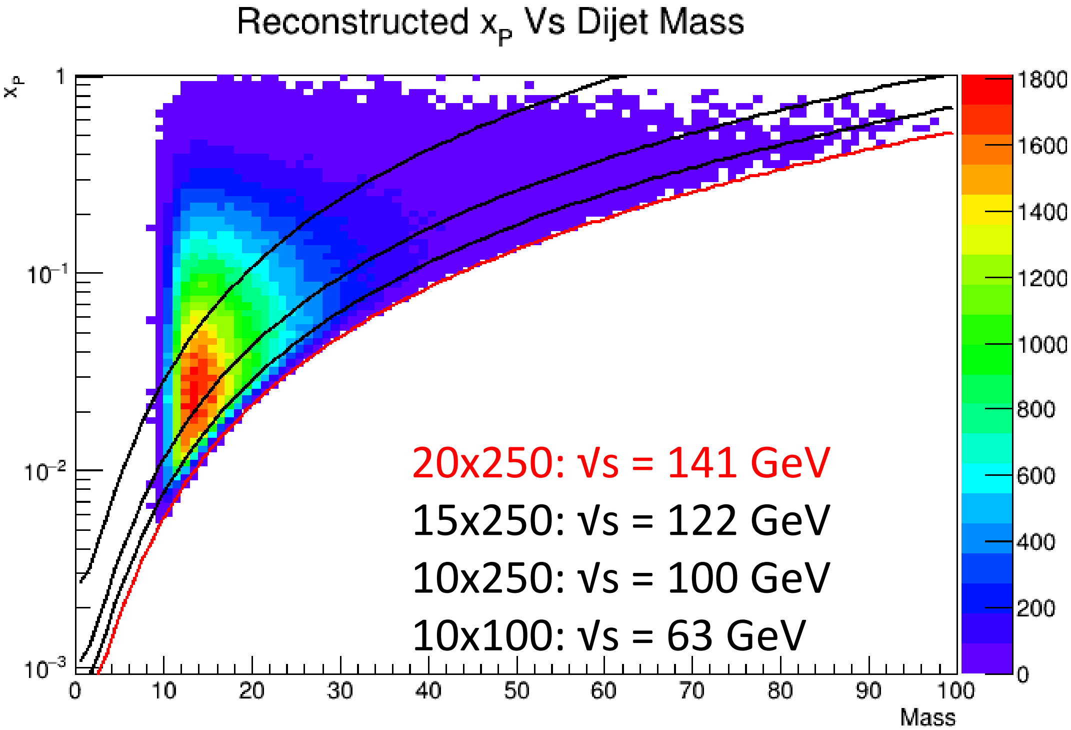




A_{LL}: Q^2 = 10 – 100 GeV^2 High Stats

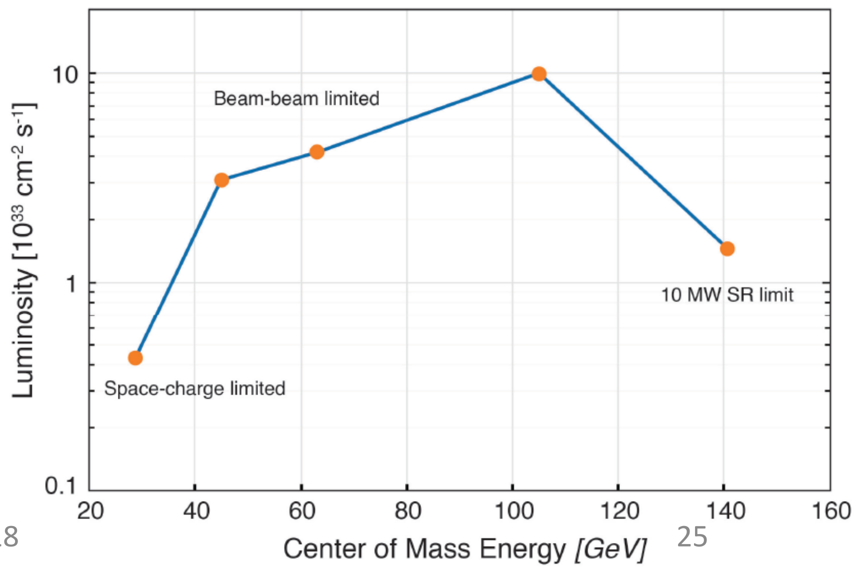


Alternate Energies

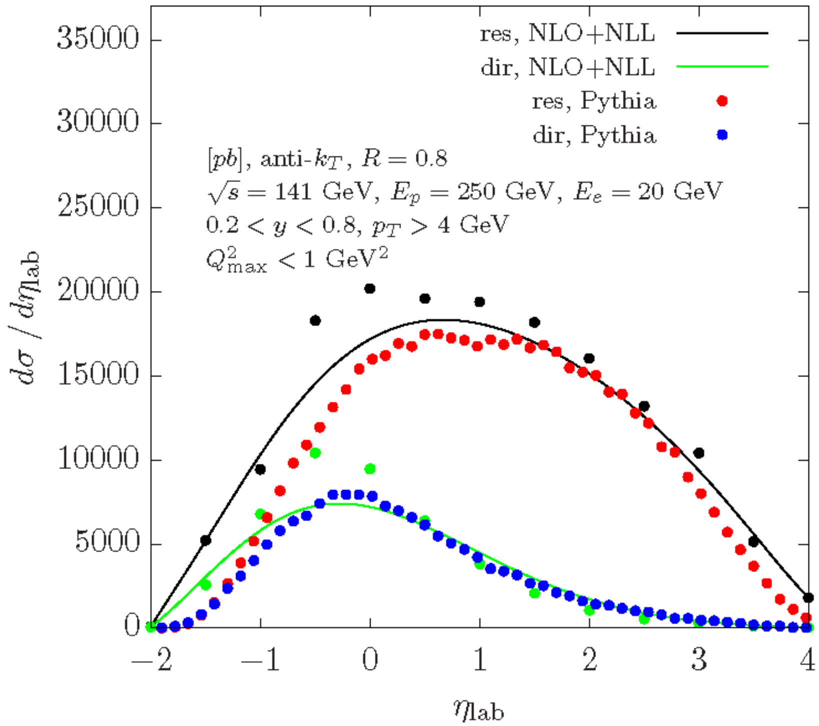


- Only showed asymmetries at highest beam energy configuration
- What happens if we lower the energy?

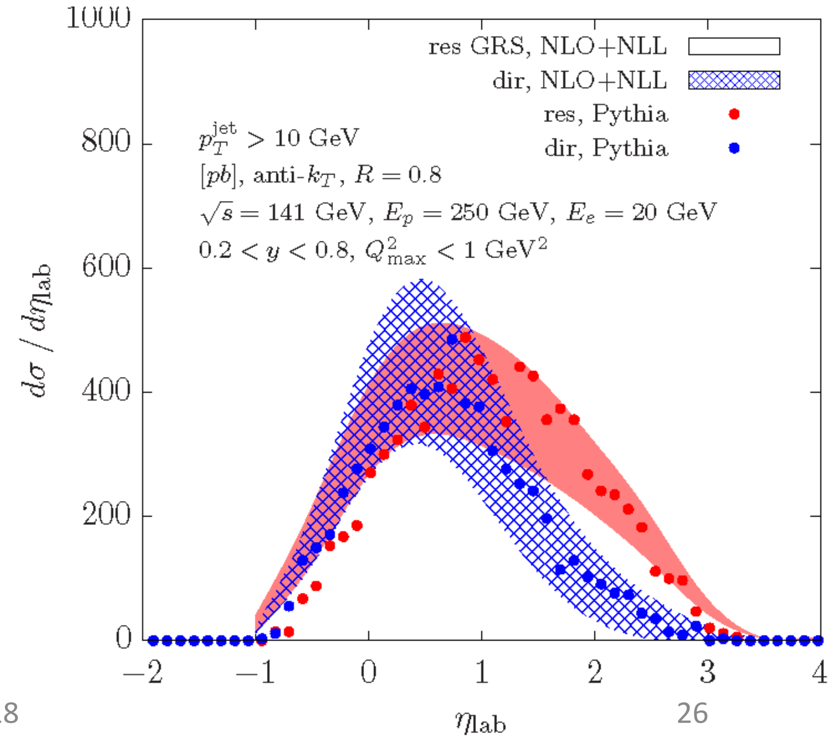
- In general, largest instantaneous luminosities will be achieved for center of mass energies somewhat below the max
- May need to trade some kinematic reach for improved statistics



Photoproduction Cross Section



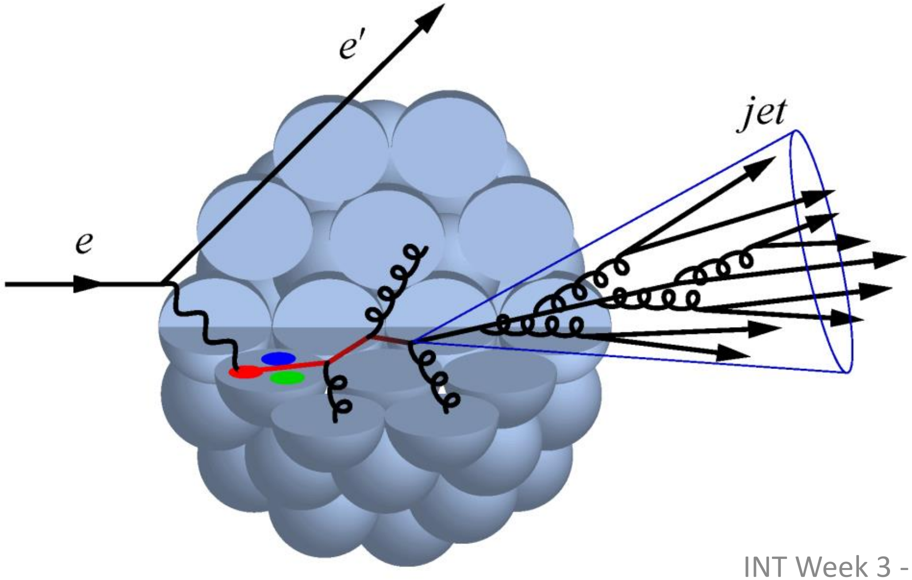
- Carry out angularity studies in photoproduction region ($10^{-5} < Q^2 < 1$)
- Resolved and direct cross sections from PYTHIA in good agreement with theoretical expectations (F. Ringer, K. Lee)



- Jet Radius = 0.8
- 0.2 < inelasticity < 0.8
- Lab Frame
- Cross sections shown for jet $p_T > 4$ and jet $p_T > 10$ GeV

Jet Substructure: Angularity

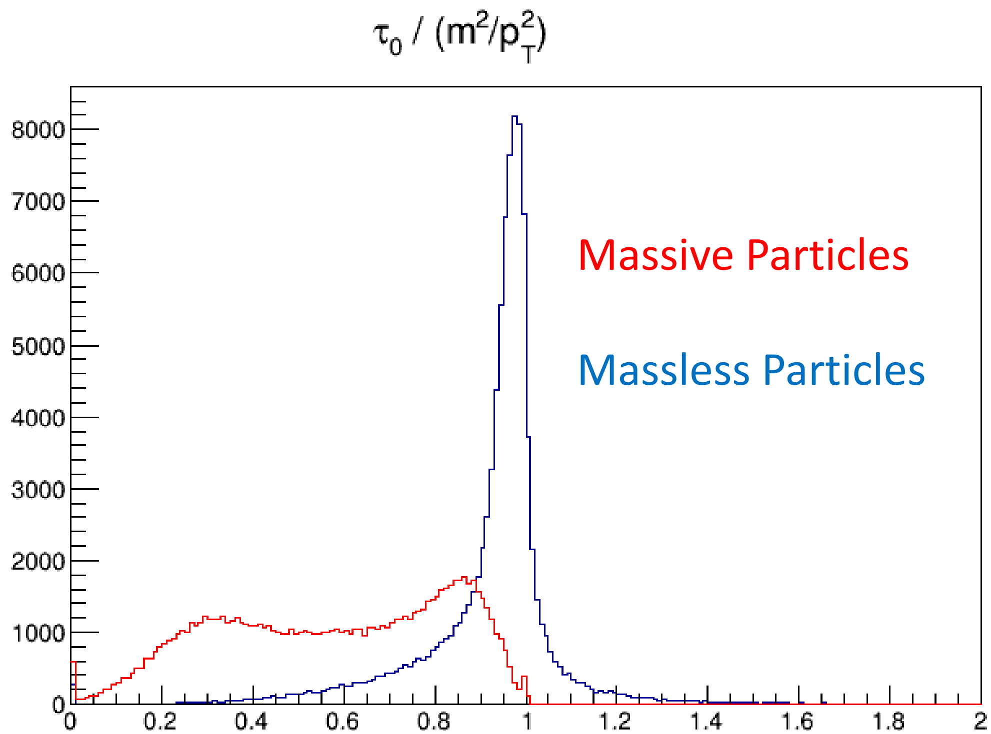
- One goal of the EIC will be the exploration of cold nuclear matter, as well as the hadronization process, via electron-nucleus collisions
- Substructure observables quantify how energy is distributed within the jet – modification of substructure in eA may be sensitive to details of hadronization in nuclear matter and possibly to certain properties of the matter
- First step: explore behavior of substructure observables at EIC energies – focus on angularity



$$\tau_a \equiv \frac{1}{p_T} \sum_{i \in J} p_T^i \left(\Delta \mathcal{R}_{iJ}\right)^{2-a}$$

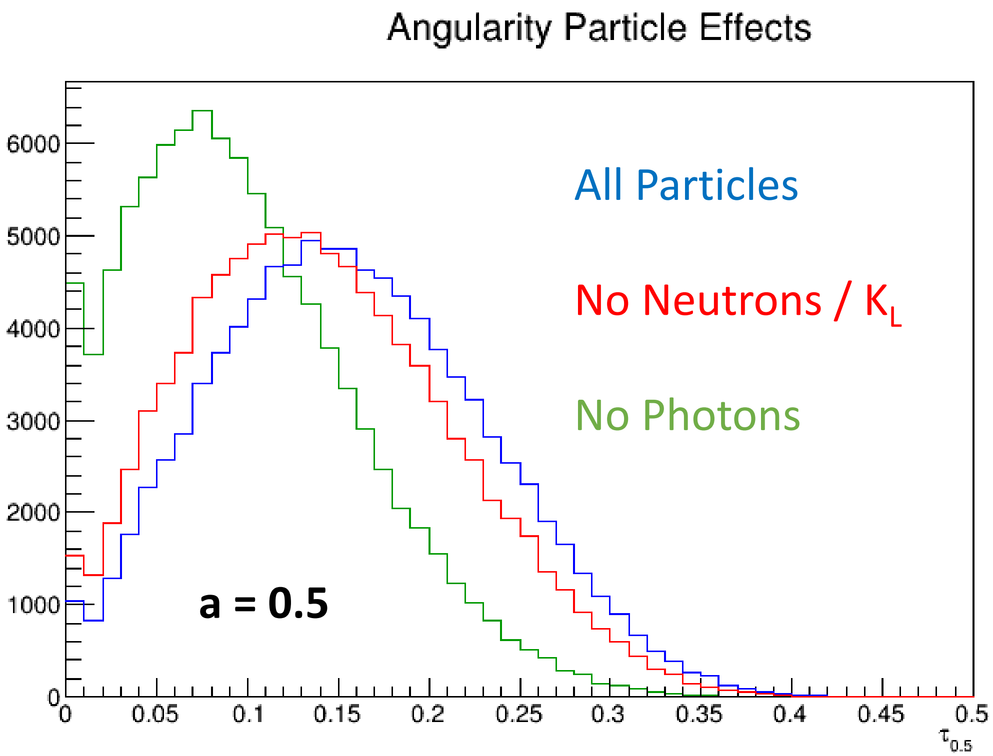
Relationship to Jet Mass

$$\tau_0 \sim \frac{m^2}{p_T^2}$$



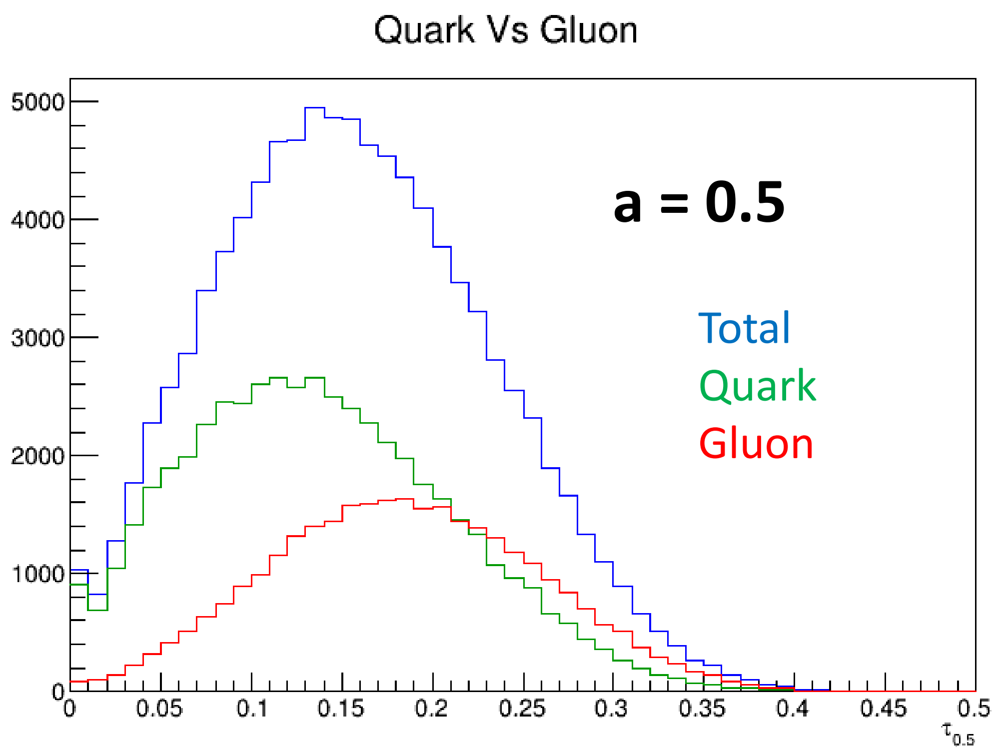
- Angularity with a = 0 is equal to the square of jet mass divided by the square of jet p_T (plus higher order terms)
- We find the validity of this relationship depends strongly on how the jet mass is constructed
- Adding full particle 4-vectors leads to discrepancy while good agreement seen for 'massless' particles
- Jet p_Ts are small at an EIC, individual particle masses can by a non-negligible contribution
- Look at relationship for high p_T jets

Detector Considerations



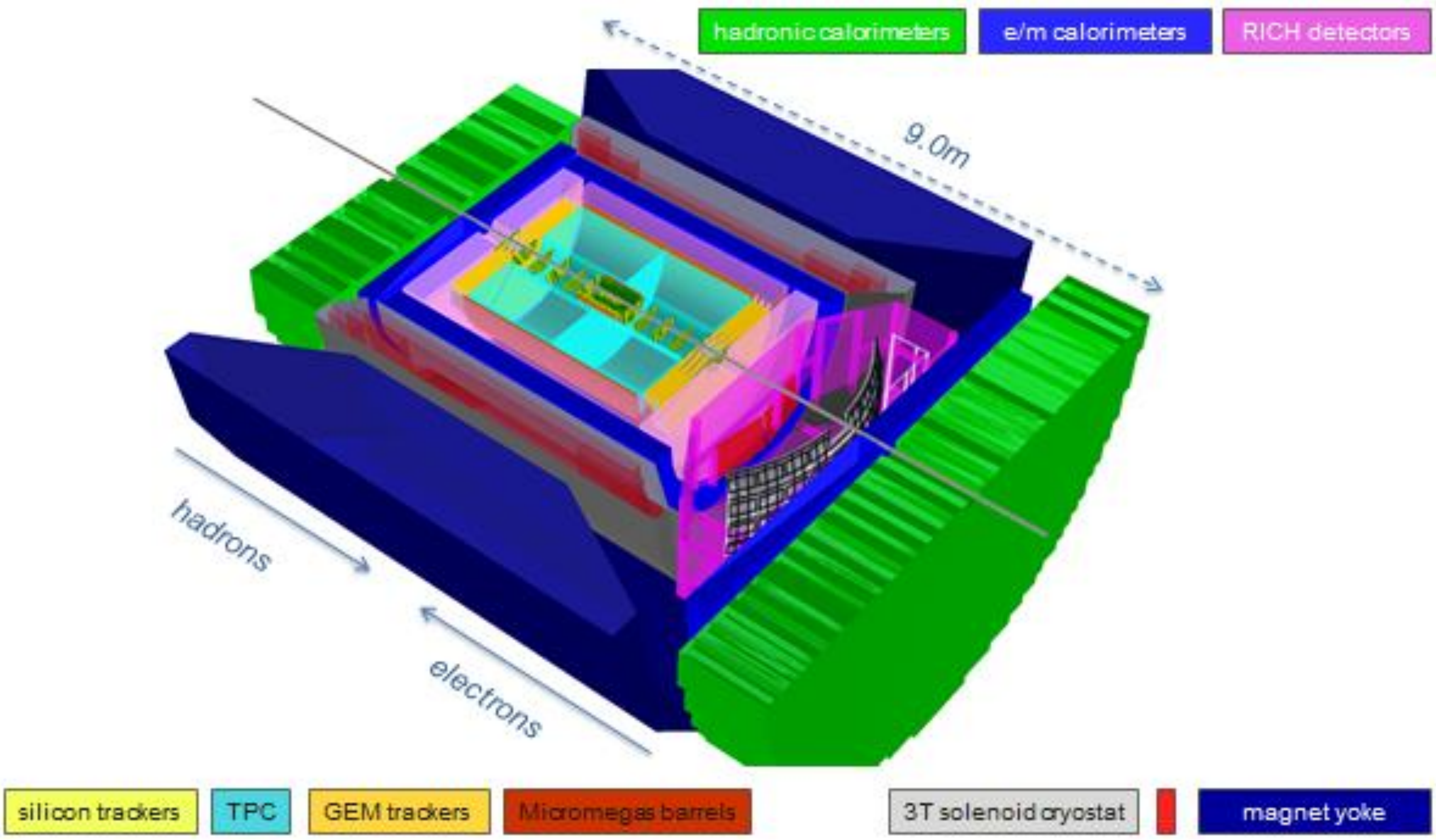
- In simulation, we can measure all particles exactly – what happens if some classes of particles are not measured or not measured well?
- Construct angularity excluding neutral hadrons (neutrons & K_L) and photons from pion decay
- Not measuring neutral hadrons results in a shift and slight shape change to angularity distribution
- Neglecting photons will significantly change distribution – electromagnetic calorimeter with good pointing resolution will be important

Quark / Gluon Discrimination

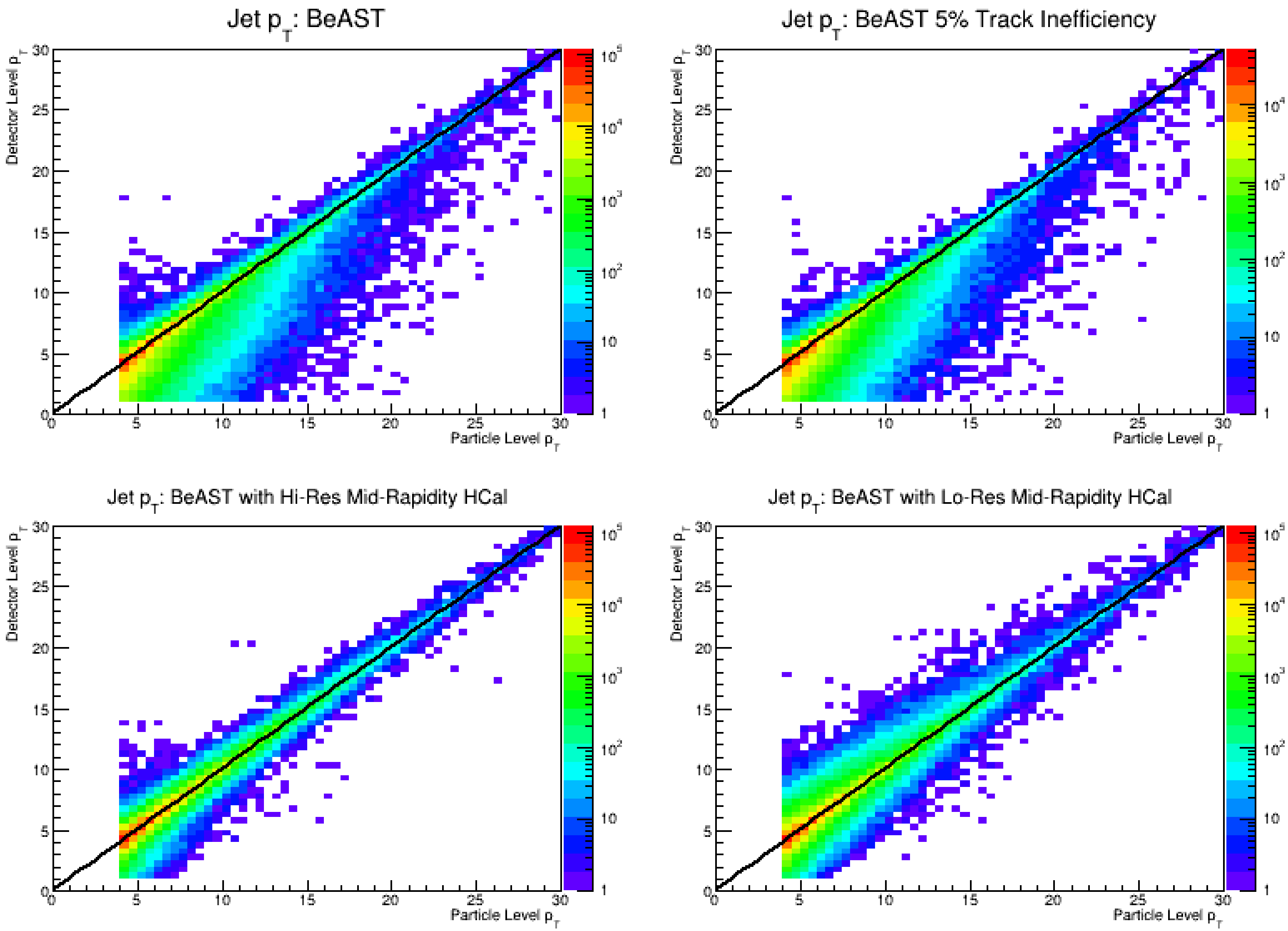


- Quarks and gluons are expected to shower in different ways with jets arising from gluons being 'fatter' than those from Quarks
- Can angularity differentiate between quark and gluon jets?
- See decent differentiation between light quarks and gluons for a = 0.5
- Next: explore correlations with other discriminating variables

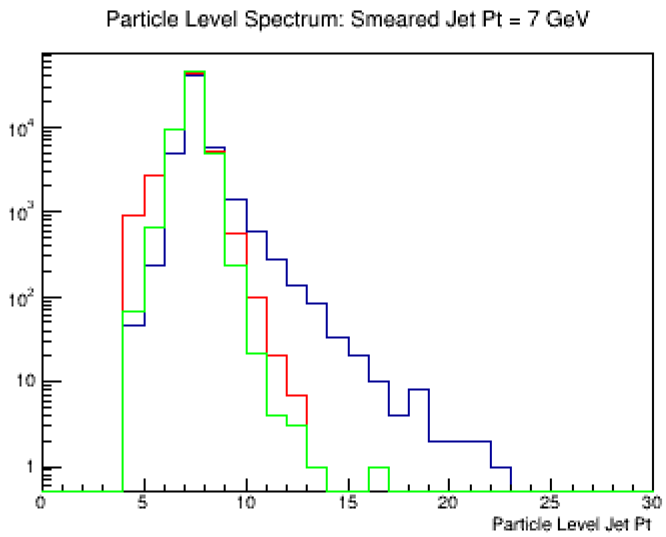
Detector Overview (BNL)

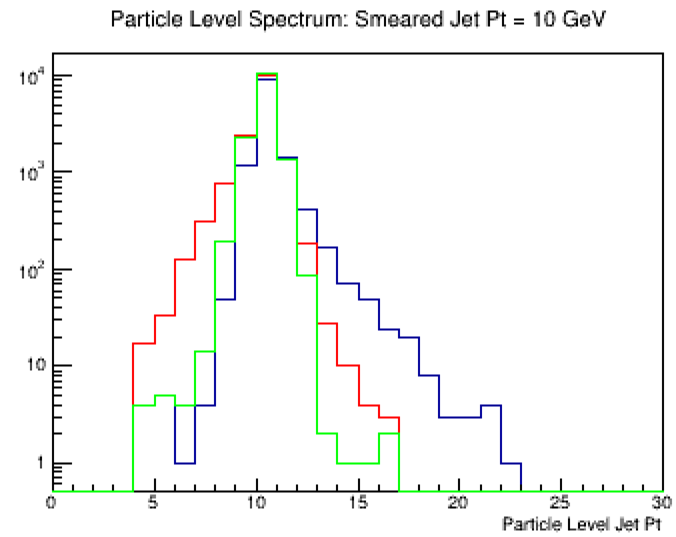


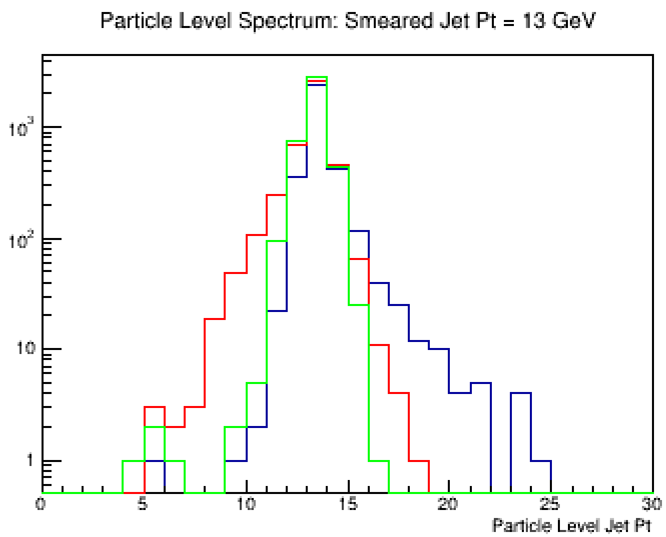
Jet p_T Reconstruction: HCal Options



Comparing Resolutions

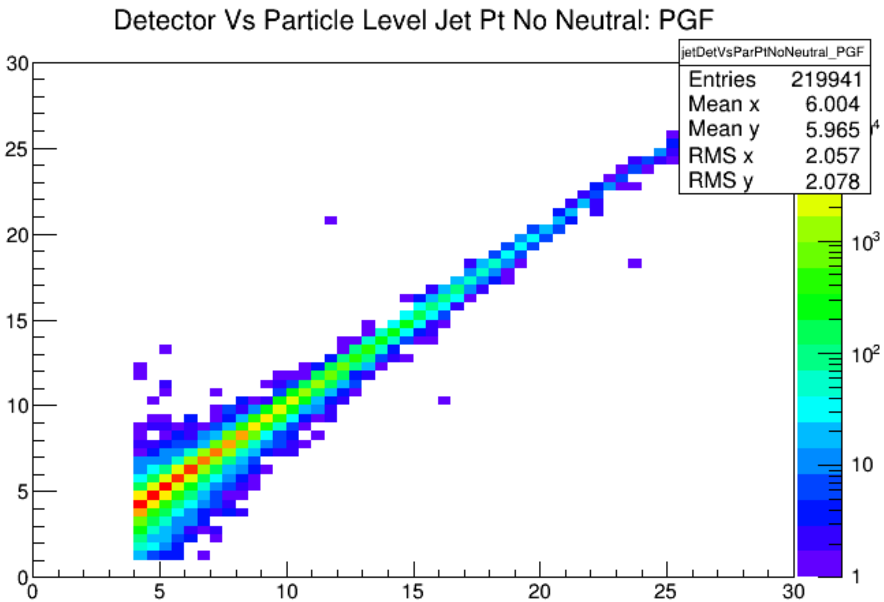


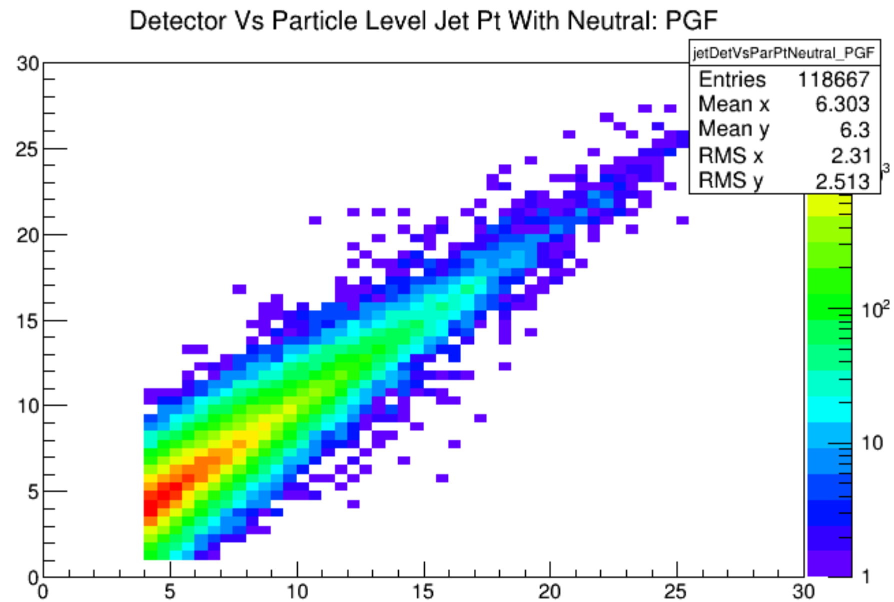




- Show particle level jet p_T spectrum for 3 specific reconstructed jet p_T values
- No mid-rapidity HCal
- Lo Res mid-rapidity HCal
- Hi Res mid-rapidity HCal

Neutral Hadron Veto





- Can use lo res HCal to select jets which contain a neutral hadron

- This subsample can be unfolded while leaving the larger jet sample which do not contain a neutral hadron alone

Summary

- Jet p_T spectrum at an EIC will be very soft – want to go as low as possible in p_T to ensure enough statistics
- Choice of jet radius will likely depend on specific analysis – larger R captures more accurate information on source parton
- Explored using dijets as a tag for photon-gluon fusion process to do a leading order analysis of ΔG – will be a statistically challenging measurement, but may be complimentary to g_1 due to differing systematics
- First look at cross sections and angularities in the photoproduction region presented
- Current detector designs should be adequate for measuring jets