Experimental jet studies on photon structure at EIC

Xiaoxuan Chu

Brookhaven National Lab

xchu@mails.ccnu.edu.cn
Collaborators: Elke-Caroline Aschenauer,
Jeong-Hun Lee, Liang Zheng

EIC Users' meeting 2018

July 31, 2018

Outline

Experimental
jet studies on
photon
structure at
EIC

Xiaoxuan Chu

Photon
structure
studied at EIC
Introduction and
Motivation
Monte Carlo set
up
Unpolarized
photon structure
Possibility of
quark/gluon jet
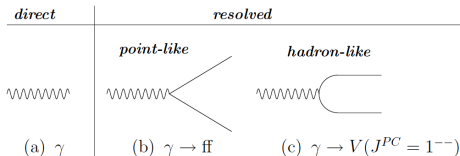discrimination
Polarized photon
structure

Calculation of
the underlying
events effect
Region method
Off-axis method

Summary and
outlook

1 Photon structure studied at EIC
- Introduction and Motivation
- Monte Carlo set up
- Unpolarized photon structure
- Possibility of quark/gluon jet discrimination
- Polarized photon structure

2 Calculation of the underlying events effect
- Region method
- Off-axis method

3 Summary and outlook

Photon structure studied at EIC: Introduction
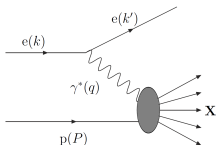
- Behavior of the exchanged photon: direct photon stat, resolved photon state
- The internal structure of photons is a manifestation of quantum fluctuations: photon splits into parton content
- Photoproduction: low Q^2
- Parton Distribution Functions(PDFs) of Photon: $q(x, Q^2)$, $g(x, Q^2)$

(a) γ — direct

(b) $\gamma \rightarrow f\bar{f}$ — resolved, point-like

(c) $\gamma \rightarrow V(J^{PC} = 1^{--})$ — resolved, hadron-like

$$\frac{d^2\sigma}{dxdQ^2} = \frac{2\pi\alpha^2 Y_\pm}{xQ^2}(F_2 - \frac{y^2}{Y_+}F_L \pm \frac{Y_-}{Y_+}xF_3), \ F_2 : q(x) - \bar{q}(x), F_L : g(x), F_3 : q(x) + \bar{q}(x)$$

Low Q^2 tagger

Experimental jet studies on photon structure at EIC

Xiaoxuan Chu

Photon structure studied at EIC
Introduction and Motivation
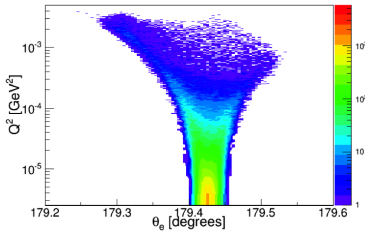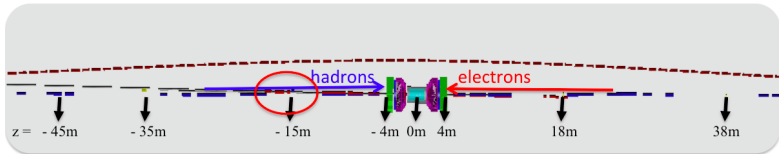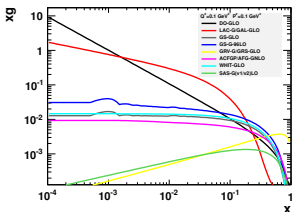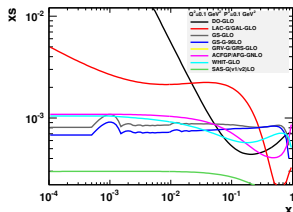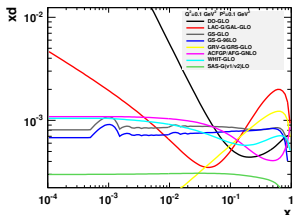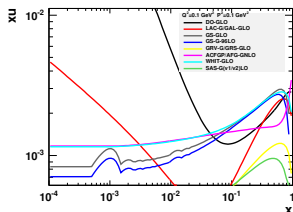Monte Carlo set up
Unpolarized photon structure
Possibility of quark/gluon jet discrimination
Polarized photon structure

Calculation of the underlying events effect
Region method
Off-axis method

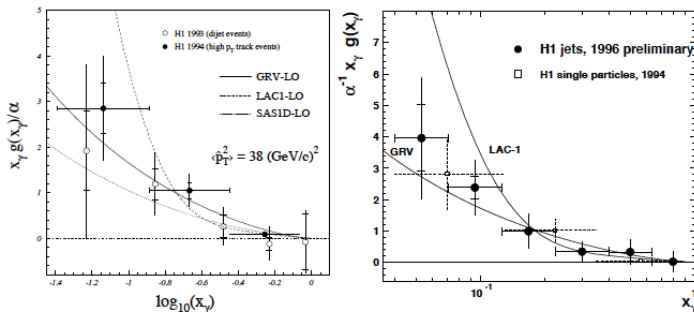Summary and outlook

- Outgoing electrons are reconstructed in the tagger
- Acceptance for electrons is down to 10^{-5} GeV^2

x is the momentum fraction of the parton from the photon, in the following section, it is marked with x_γ

[arXiv:9504004, arXiv:9710018, Eur. Phys. J. C 10, 363-372 (1999), DESY 97-164]


- Lack of statistic, especially in the small x_γ region which is important for the constrain of photon PDFs.
- Results from jet and charged particle measurements show that the best fit are GRV and SAS
- The nature of e^+e^- collisions is two photon physics, the photon structure is very important for ILC $\gamma\gamma$ option.
- Polarized photon PDFs are never measured before.

Di-jet measurment

Resolved process
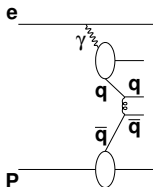
Direct process
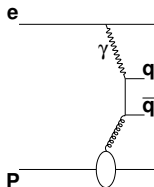
- How to separate: Resolved: $x_\gamma < 1$; direct: $x_\gamma = 1$.
 $x_\gamma^{\rm rec} = \frac{1}{2E_e y}(p_{T1} e^{-\eta_1} + p_{T2} e^{\eta_2})$, $y = \frac{E_\gamma}{E_e}$.

- Parton densities can be extracted by measuring di-jet cross section:
  $\frac{d^2\sigma}{dx_\gamma \, dQ^2} = \gamma_{flux} \otimes f_\gamma(x_\gamma, Q^2, \mu) \otimes f_p(x_p, \mu) \otimes \sigma_{ij}$,
  γ_{flux} is calculable in QED, f_p is the PDF of the proton, σ_{ij} is the cross section of the hard process, which is calculable in pQCD
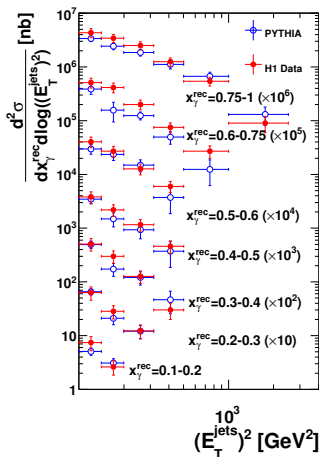
Reproduce HERA data

Reproduce the inclusive cross section, photon PDF set is SAS, proton PDF is CTEQ5m, 10^{-5}GeV$^2 < Q^2 <$1GeV^2, $L = $ 1fb^{-1}.
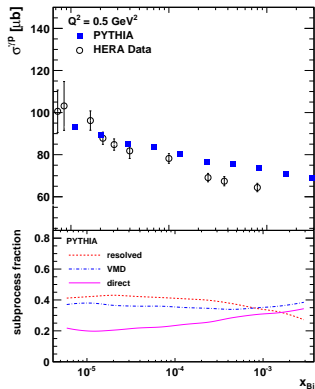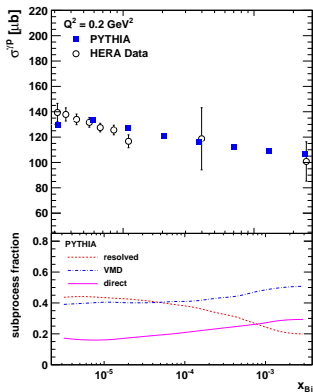
[HERA Data: Phys. Rev. D 96 014001(2017)]

Reproduce HERA data

Reproduce the di-jet cross section, photon PDF set is SAS, proton PDF is CTEQ5m, $10^{-5}\text{GeV}^2 < Q^2 < 1\text{GeV}^2$.

- Kinematics cuts from HERA: 27.5GeV×820GeV, $0.2 < y < 0.83$, $|\Delta\eta^{\text{jets}}| < 1$, $0 < \eta^{\text{jet1}} + \eta^{\text{jet2}} < 4$, $E_T^{\text{jet1}}, E_T^{\text{jet2}} > 7.5\text{GeV}$, $E_T^{\text{jet1}} + E_T^{\text{jet2}} > 20\text{GeV}$, $|E_T^{\text{jet1}} - E_T^{\text{jet2}}|/(E_T^{\text{jet1}} + E_T^{\text{jet2}}) < 0.25$

- Our simulation can match the existing data

Unpolarized photon structure at EIC

20GeV×250GeV, $0.01 < y < 0.95$, two highest p_T jets, $p_T^{\mathrm{jet1}} > 5\mathrm{GeV}$, $p_T^{\mathrm{jet1}} > p_T^{\mathrm{jet2}} > 4.5\,GeV$, $|\eta^{\mathrm{jets}}| < 4.5$, stable particle $p_T > 250\mathrm{MeV}$.
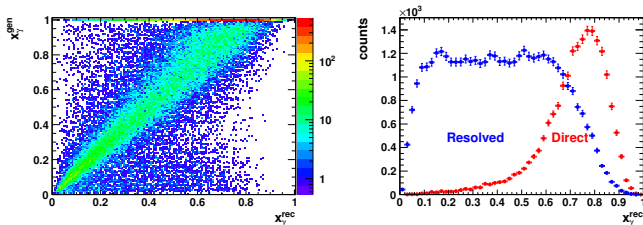
Di-jet method provides a good way to reconstruct x_γ, we can separate resolved/direct process($x_\gamma^{\mathrm{rec}} < 0.6$).

Unpolarized photon structure at EIC

20GeV×250GeV, $0.01 < y < 0.95$, two highest p_T jets, $p_T^{\text{jet1}} > 5$GeV,
$p_T^{\text{jet1}} > p_T^{\text{jet2}} > 4.5\,GeV$, $|\eta^{\text{jets}}| < 4.5$, stable particle $p_T > 250$MeV.
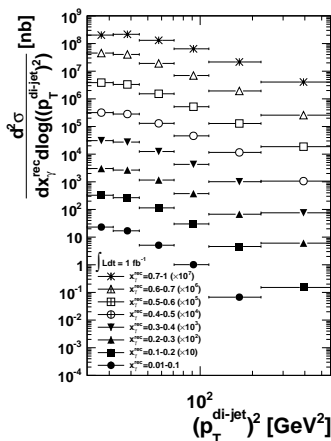
The simulation shows the capability to measure the cross section for di-jet production at $\int L = 1$fb^{-1} (10fb^{-1}/month), with high accuracy in a wide kinematic range at EIC and extract the unpolarized photon PDFs from a global fit.

Advantages
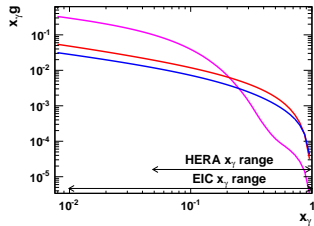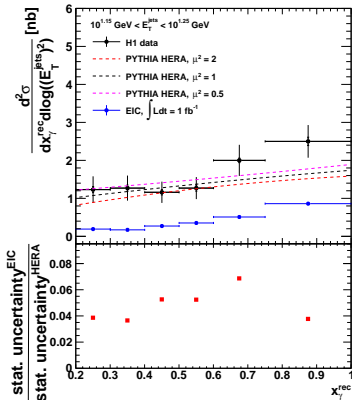
- High luminosity to define the uncertainty band
- Feasiblity to probe small x_γ region

Method of flavor tagging

- $\frac{d^2\sigma}{dx_\gamma \, dQ^2} = \gamma_{flux} \otimes f_\gamma(x_\gamma, Q^2, \mu) \otimes f_p(x_p, \mu) \otimes \sigma_{ij}$

- From measuring the di-jet cross section, we can extract the total PDFs of the photon.

- We search the possibility of q/g discrimination.

- We do flavor tagging to achieve the goal of separating the contribution from different flavor partons.
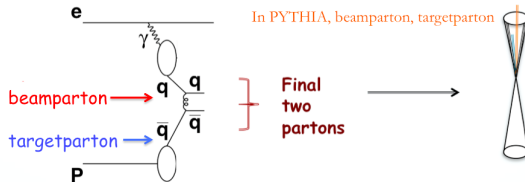
We will separate q/g jet first and select the jet from the parton which has the same flavor as the beamparton, which is marked with "jet from the photon side".

Multivariable-distribution of q/g jet
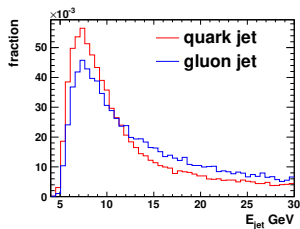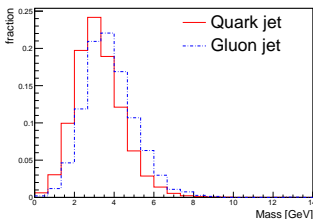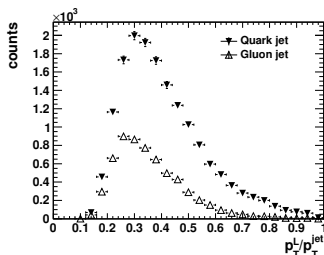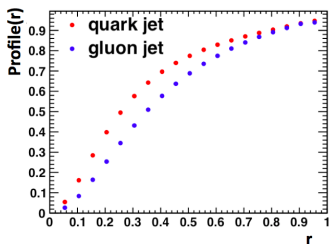
q/g jet discrimination
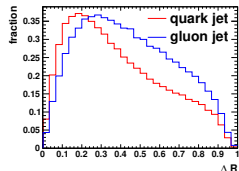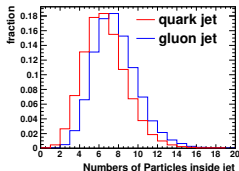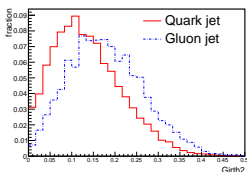
- **Some definitions**: p_T^L represents the highest p_T of the hadrons inside the jet; $\mathrm{Girth2} = \sum_{i \in \mathrm{cone}} \frac{p_T^i}{p_T^{\mathrm{jet}}} |R_i|^2$; ΔR is the distance between particle and jet axis
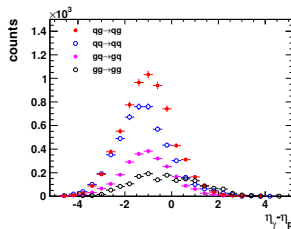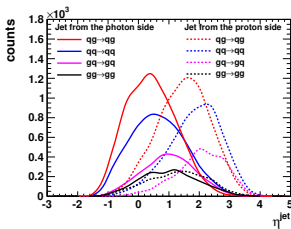
- **Conclusion**: Gluon jets are wider, with higher multiplicities, having a more uniform energy fragmentation, while quark jets are more likely to produce narrow jets with hard constituents that carry a significant fraction of the energy

How to choose the jet from the photon side

$$\xrightarrow{\text{hadrons}, \eta_{\text{Lab}} > 0} \xleftarrow{\text{electrons}, \eta_{\text{Lab}} < 0}$$

- **Conclusion**: Influenced by the moving direction of the incoming electrons, the jets from the photon which is radiated from the electron, the pseudo-rapidity of jet from the photon is smaller than that of proton side jet
- **What we can do in the experiment**: take the jet with smaller η as the photon side jet
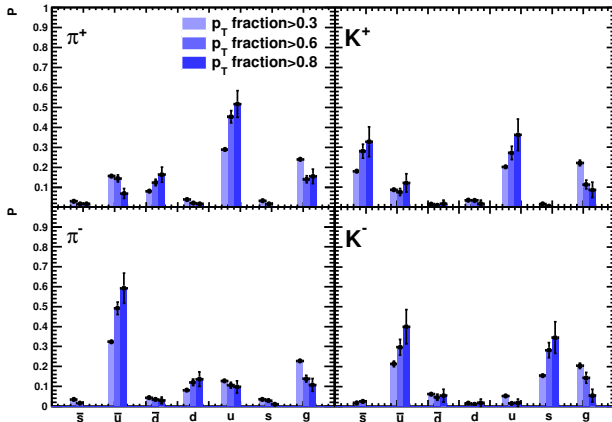
Flavor tagging

The correlation between the beamparton flavor and the type of
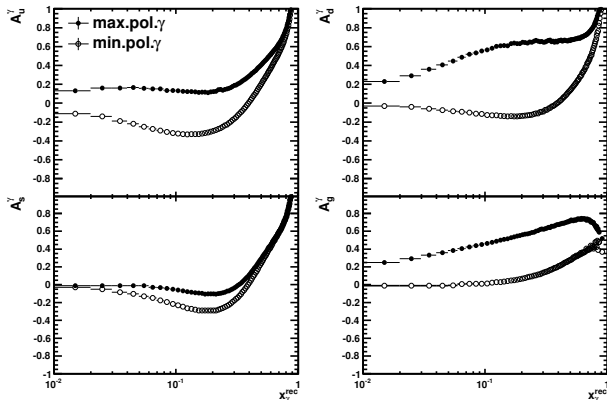the leading hadron inside photon side jet.
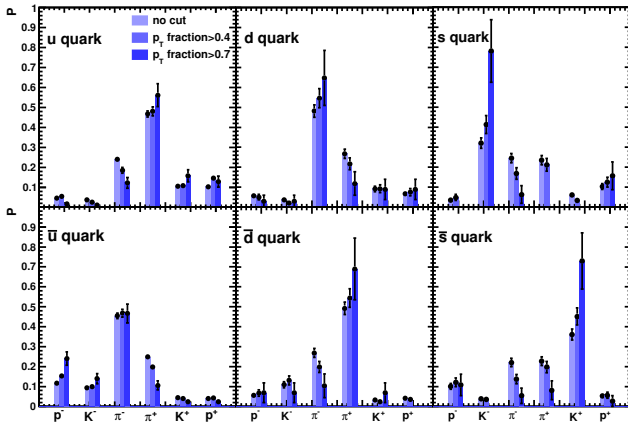
Flavor tagging

The correlation between the beamparton flavor and the type of
the leading hadron inside photon side jet.

Input for polarized ep collision

pol. photon PDFs	min: $\Delta f^{\gamma} = 0$; max: $\Delta f^{\gamma} = f^{\gamma}$
pol. proton PDF	DSSV

$A^{\gamma} = \Delta f^{\gamma} / f^{\gamma}$

Polarized photon structure
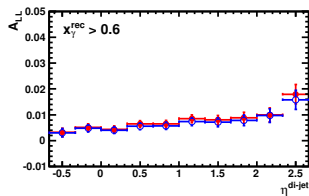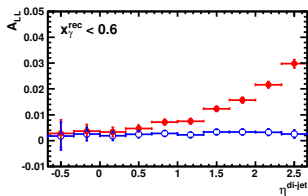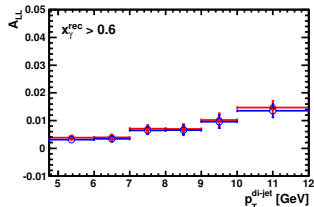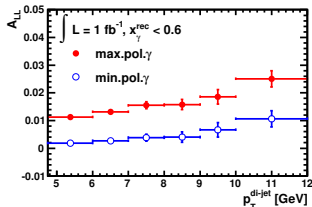
$$\frac{d^2\Delta\sigma}{dx_\gamma\,dQ^2} = \Delta\gamma_{flux} \otimes \Delta f_\gamma(x_\gamma, Q^2, \mu) \otimes \Delta f_p(x_p, \mu) \otimes \sigma_{ij}$$
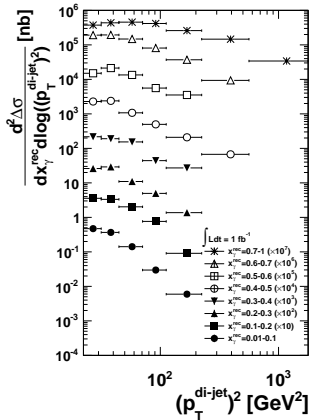
$$\Delta\sigma = \tfrac{1}{2}(\sigma^{++} - \sigma^{+-})$$

- The simulation shows the capability to measure the polarized cross section for di-jet production, with high accuracy in a wide kinematic range at EIC.

- First measurement of polarized photon PDFs with high precision.

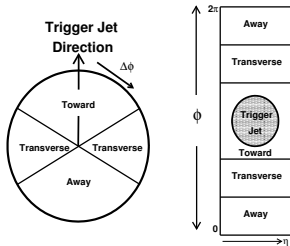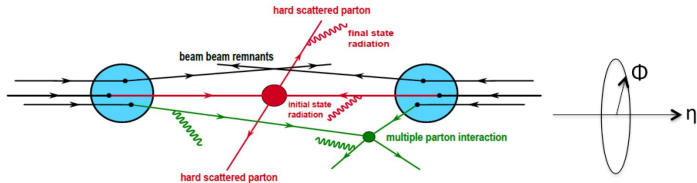- Flavor tagging can also be applied in polarized case.

A_{LL}

$A_{LL} = \Delta\sigma/\sigma$

The difference between max.pol. photon and min.pol. photon can be measured in experiment, the pol.photon PDFs can be constrained at EIC.

Underlying events: region method

Underlying events: everything except the particles fragmented from the hard scatted partons.

Three regions: ($\Delta\Phi = \Phi_{\text{part}} - \Phi_{\text{Jet1}}$)

- Toward: $|\Delta\Phi| < 60^\circ$
- Transverse: $60^\circ < |\Delta\Phi| < 120^\circ$
- Away: $|\Delta\Phi| > 120^\circ$

Measurments:

- Charged multiplicity density, sum pt density Versus $\Delta\Phi$
- Charged multiplicity density, sum pt density Versus p_T^{Jet1}

Results from region method
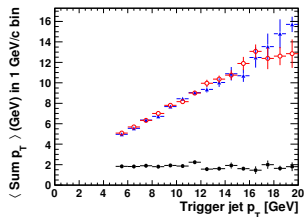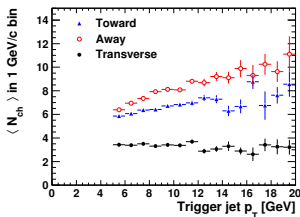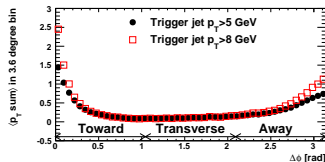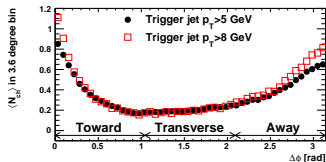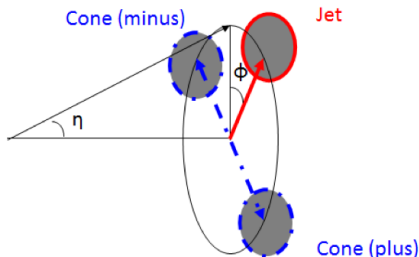
Off-axis method

- Look at jets with high momentum, jet by jet
- Two off-axis cones are centered at the same η as the jet but $\pm\pi$ away in Φ from the jet
- Take the particles inside the cones as from underlying events. By using this method, the dependence on η is considered.

Comparison of the two methods

- Results from two different method are consistent, the dependence on η is minor
- The underlying event effect from EIC is comparable with the results from $\sqrt{s} = 250$ GeV pp collisions at STAR

Summary and outlook

1. Photon PDFs can be extracted by reconstructing x_γ.
   - x_γ^{rec} is correlated with input x_γ
   - We can effectively access the underlying photon PDFs very high at EIC

2. Flavor tagging is firstly applied to identify the flavor of the parton from the photon.

3. Pol. Photon PDF is the first time been measured in the world.

Further steps: Machine learning can be applied in q/g jet discrimination; we can think about considering the detector response in the simulation...

Experimental
jet studies on
photon
structure at
EIC

Xiaoxuan Chu

Photon
structure
studied at EIC
Introduction and
Motivation
Monte Carlo set
up
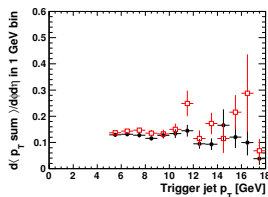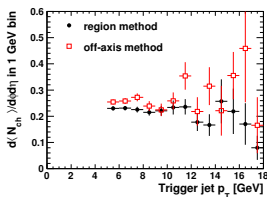Unpolarized
photon structure
Possibility of
quark/gluon jet
discrimination
Polarized photon
structure

Calculation of
the underlying
events effect
Region method
Off-axis method

Summary and
outlook

Plots from Brian Page:
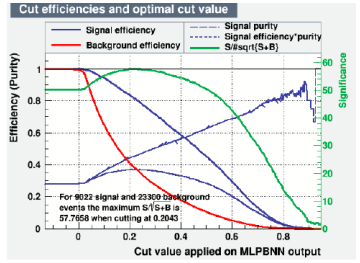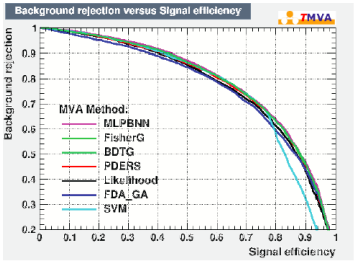
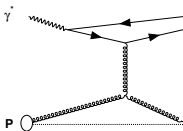Toolkit for Mulivariate Data Analysis with ROOT (TMVA): for current study, we place cut where signal purity = signal efficiency

Experimental
jet studies on
photon
structure at
EIC

Xiaoxuan Chu

Photon
structure
studied at EIC
Introduction and
Motivation
Monte Carlo set
up
Unpolarized
photon structure
Possibility of
quark/gluon jet
discrimination
Polarized photon
structure

Calculation of
the underlying
events effect
Region method
Off-axis method
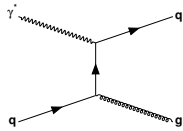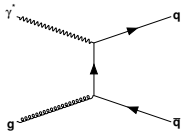
Summary and
outlook

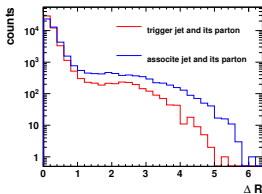# Thank you!

Back up: Di-jets at EIC from PYTHIA

Resolved   Photon gluon fusion(PGF)   QCD Compton(QCDC)

- The resolved, direct (PGF, QCDC) processes can produce di-jets.
- For each di-jet pair, we do geometry match in the simulation, then will know the jet is a quark/gluon jet.

- two output partons → di-jet match in each event, $\Delta R < 1.0$