Measurement of azimuthal decorrelation angle between the leading jet and the scattered lepton in deep inelastic scattering at HERA (first preliminary presentation)

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1. Introduction
2. Event selection
3. Acceptance and efficiency
4. Systematics
5. Summary
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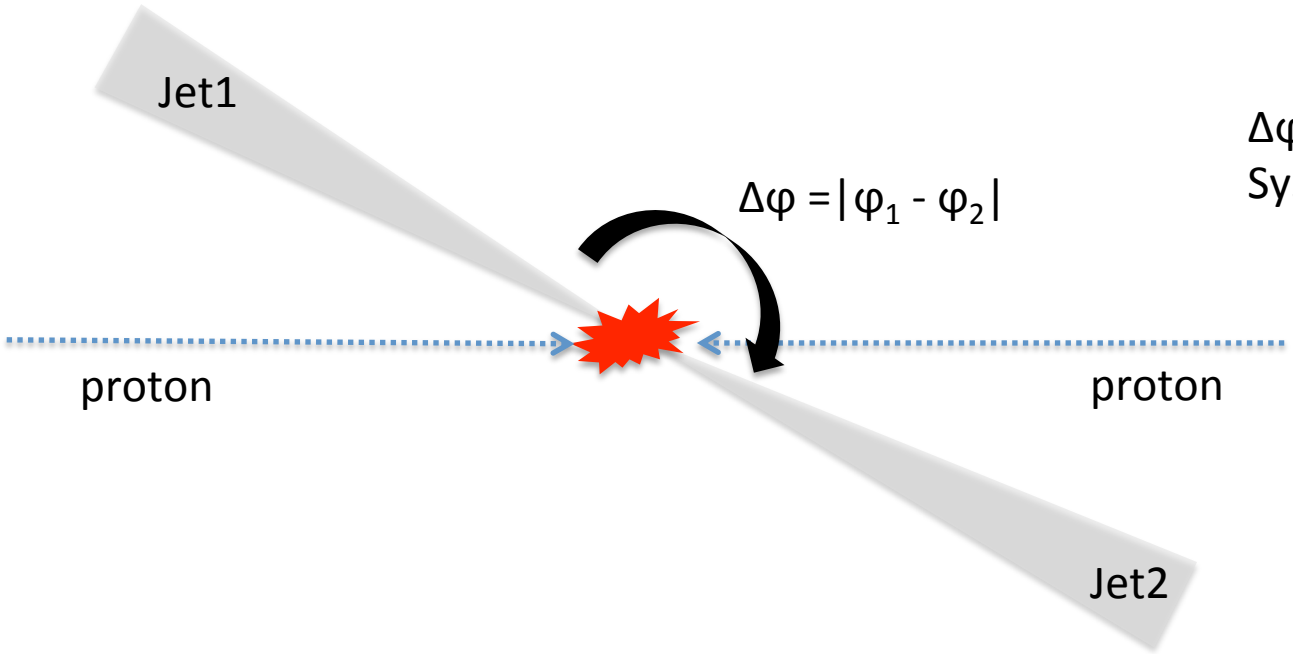
7. Backup

We present measurements of the azimuthal decorrelation angle between the leading jet and scattered lepton in deep inelastic scattering. Azimuthal angular decorrelation has been proposed to study the Q^2 dependence of the evolution of the transverse momentum distributions (TMDs) and understand the small x region, providing unique insight to nucleon structure with an electron-ion collider. Previous decorrelation measurements of two jets have been performed in proton-proton collisions at very high transverse momentum; these measurements are well described by perturbative QCD at next-to-leading order. The kinematic region covered with the HERA collider has never been studied before, where perturbative estimations might not apply. These measurements were obtained by the ZEUS experiment during the HERA II data-taking period. The analysis uses e^-p and e^+p data corresponding to integrated luminosities of 189 pb^{-1} and 143 pb^{-1}, respectively. The measurements will be compared to predictions from QCD calculations.

Introduction

Azimuthal angular decorrelation angle ($\Delta\varphi$) of two jets, have been studies in hadron collisions [1-3].

- Study parton radiation effects.
- Test pQCD and MC generators.
- Search for new physics.



$\Delta\varphi = \pi \rightarrow p_{T1} = p_{T2}$
System is balance

Warning: LO pQCD calculations,
$\Delta\varphi = \pi$ gives a delta function

Introduction

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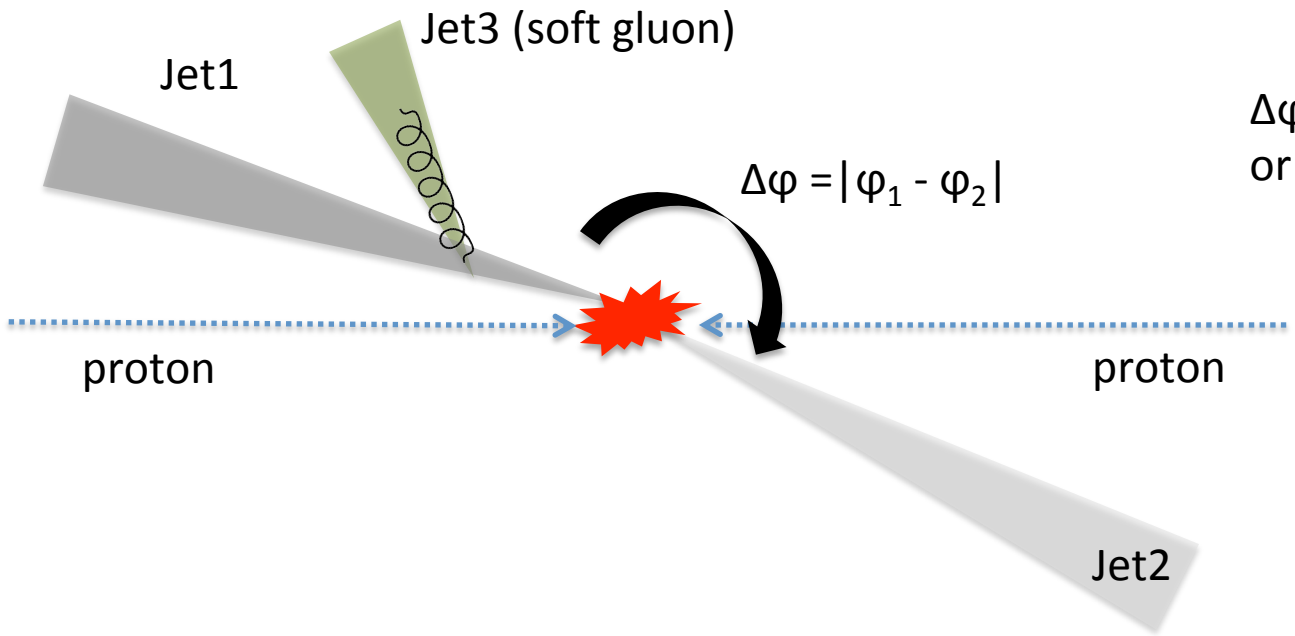
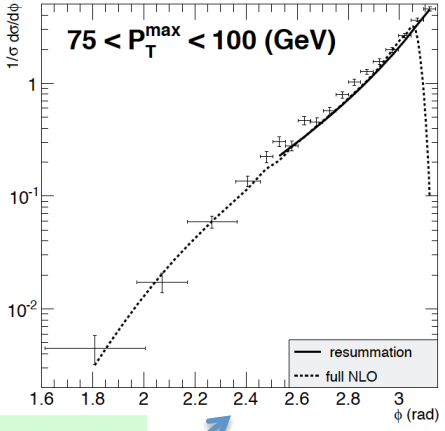


Δφ < π: soft gluon emission or multiple jets event.



Singularity persist at Δφ = π with one or more gluon radiation

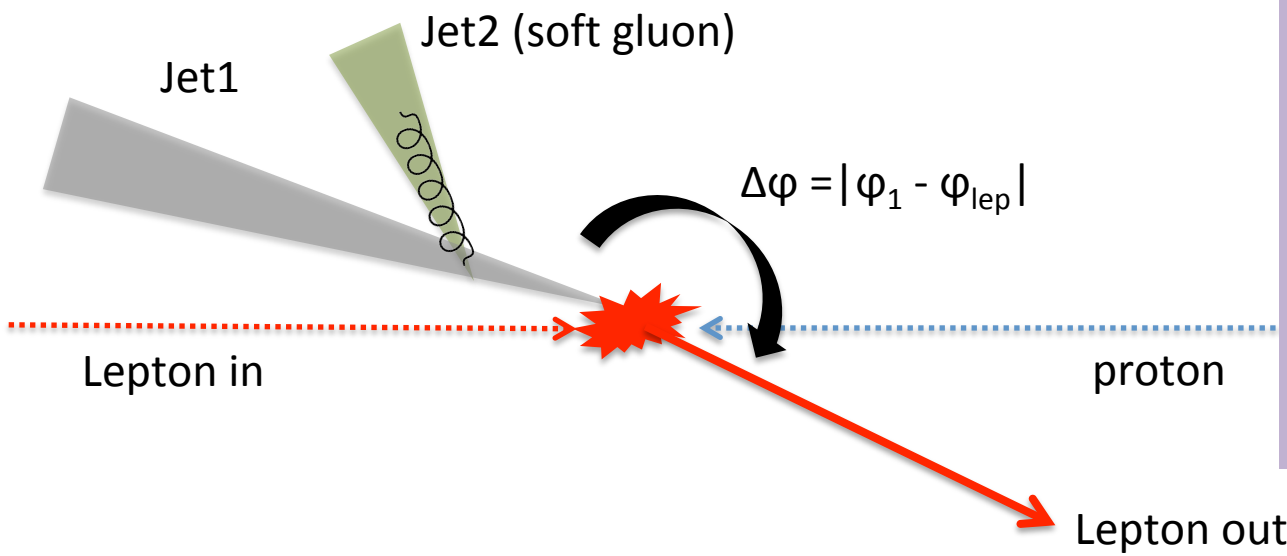
Resummation method [5], divergences cancel out.

Motivation

Azimuthal angular decorrelation angle ($\Delta\varphi$) of [illegible] have been studied in hadron collisions [1-3].

Never done for ep collisions

- Study parton radiation effects.
- Test pQCD and MC generators.
- Search for new physics.



-Start procedure for **EIC** (i.e. pt range, systematics, correction, etc.)
-Study **small-x** (HERA kinematic region).
Study **Q^2 dependence** on TMD evolution.
- **Low p_T** will probe the non-perturbative region.

Test Resummation method [5] for lepton-jet decorrelation

→

Much simpler kinematics
NEW theory paper [6]

Event selection

Data:
040506e ~**189** pb^{-1}, 0607p ~**143** pb^{-1}

MC:
Ariadne_Low_Q2_NC_DIS_05e
Ariadne_Low_Q2_NC_DIS_06e
Ariadne_Low_Q2_NC_DIS_0607p

Phase Space:
$10 < Q^2 < 350\ GeV^2$
$y_{el} < 0.95$ && $y_{jb} > 0.04$

Cleaning cuts:
-40 < Zvtx/cm < 40
35 GeV < $E - p_z$ < 65 GeV (both Cal and Zufo)
Cal_pt / sqrt(Cal_et) < 2.5

Electron cuts:
10 GeV < Energy (Siecorr) < 25 GeV
140^o < Theta < 180^o
Electron position sqrt($x^2 + y^2$) > 20.0
Sienin[0] > 0.1*(Siein[0] +Sienin[0]) (energy in cone*)
Chimney cut *
Siprob[0], the lepton with highest prob (> 0.9)*

Triggers:
SPP02 (Tltw[2] & (1 << 1)) for 0405e
SPP09 (Tltw[2] & (1 << 8)) for 06e and 0607p

Jet selection:
$E_T > 2.5$ GeV && $P_T < 30$
|eta| < 1.0
Using "Kt_etjet_b[0]" (massive), the leading jet only

*Some cuts from: https://zeusdp.desy.de/ZEUS_ONLY/analysis/primer/DIS/index.html , and most cuts similar to slide 5 of: https://www-zeus.desy.de/ZEUS_ONLY/meetings/zems/group30/meet276/sess2812/pres12368/01_pr_photons_jets_04_05_2.pdf

Control plots

Total number of events:

040506e: 4 275 325

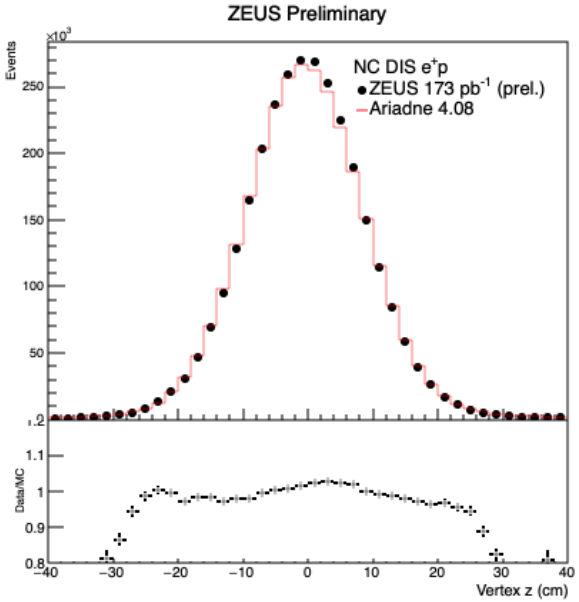
0607p: 3 021 148

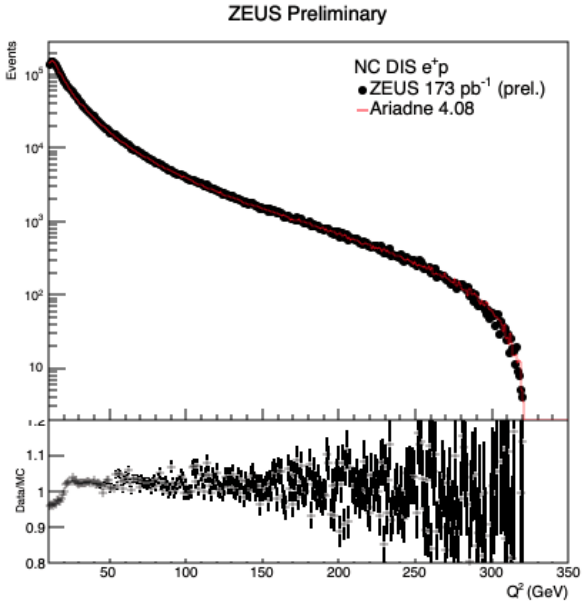
electron

positron

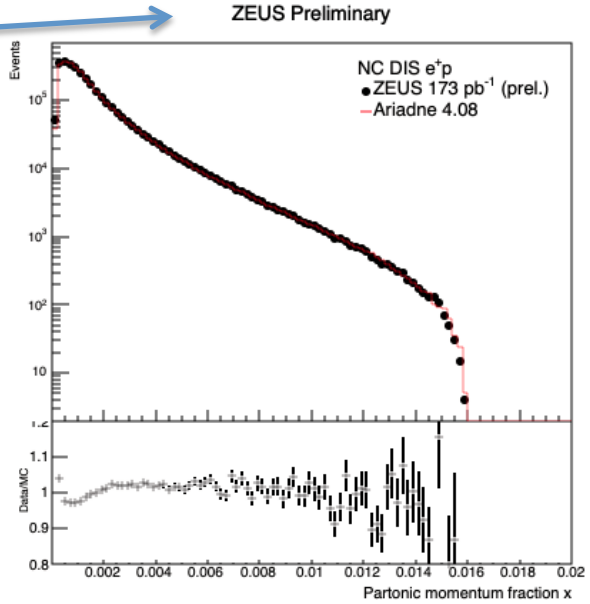
MC sample is not weighted by luminosity but normalized to the number of entries of the data.

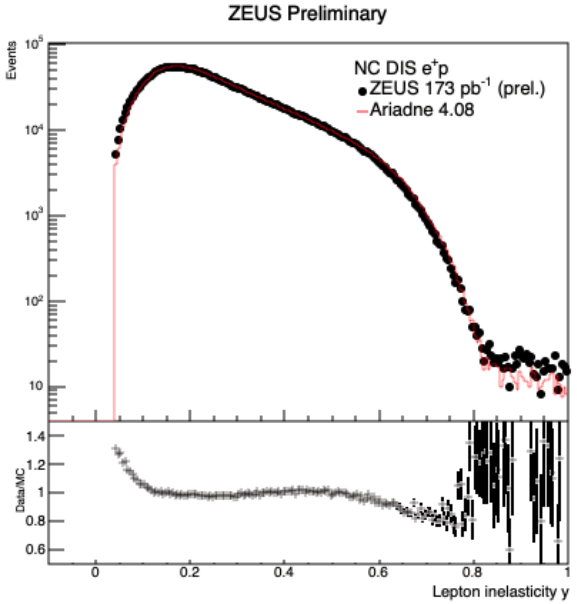
positron



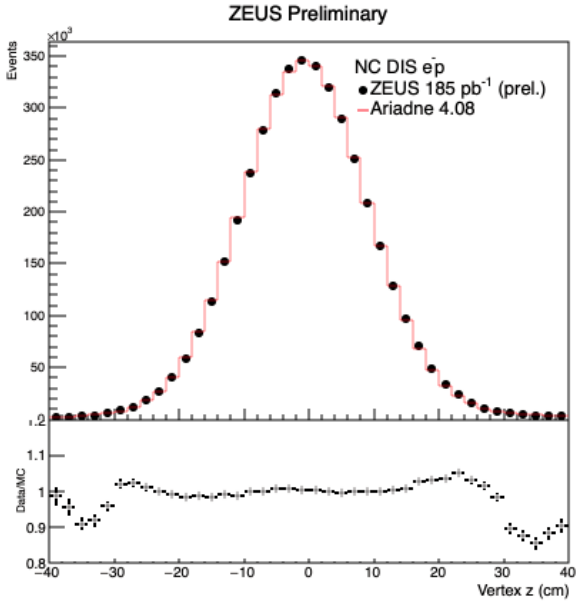


Request preliminary for figures with this tittle





electron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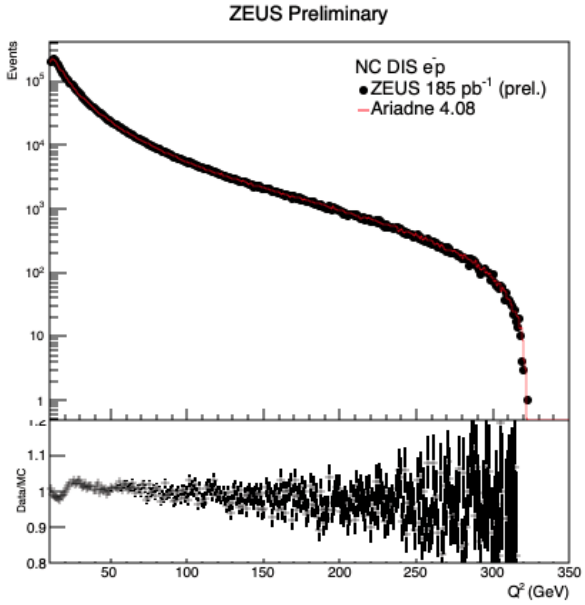
NC DIS e⁻p
ZEUS 185 pb⁻¹ (prel.)
Ariadne 4.08
Events
Data/MC
Vertex z (cm)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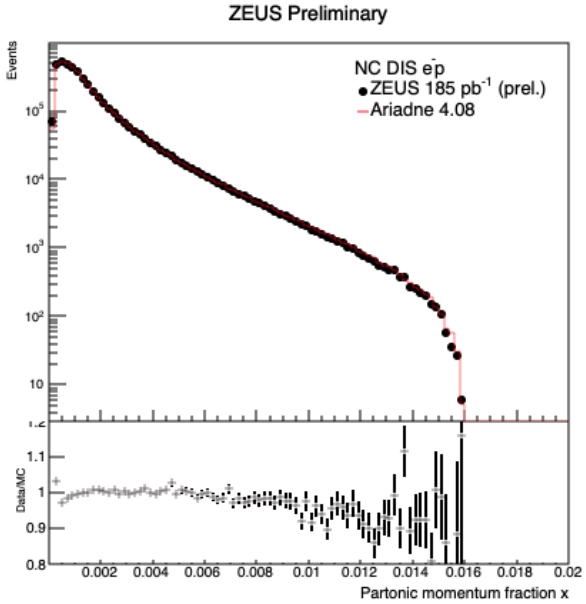
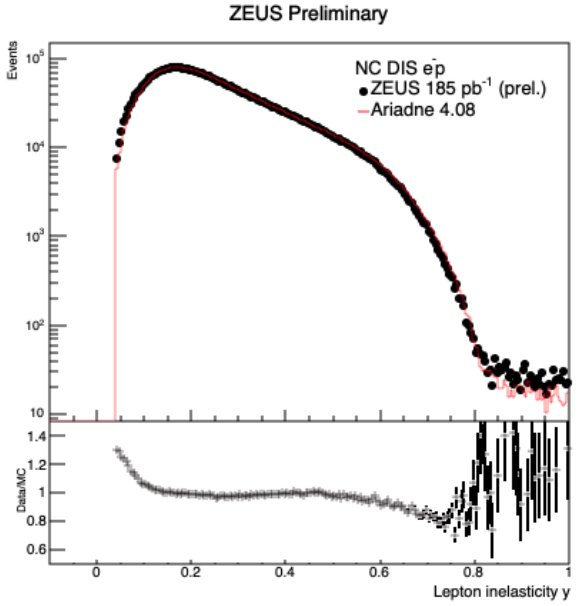
Ariadne 4.08
Events
Data/MC
Q² (GeV)


ZEUS Preliminary
NC DIS e⁻p
ZEUS 185 pb⁻¹ (prel.)
Ariadne 4.08
Events
Data/MC
Partonic momentum fraction x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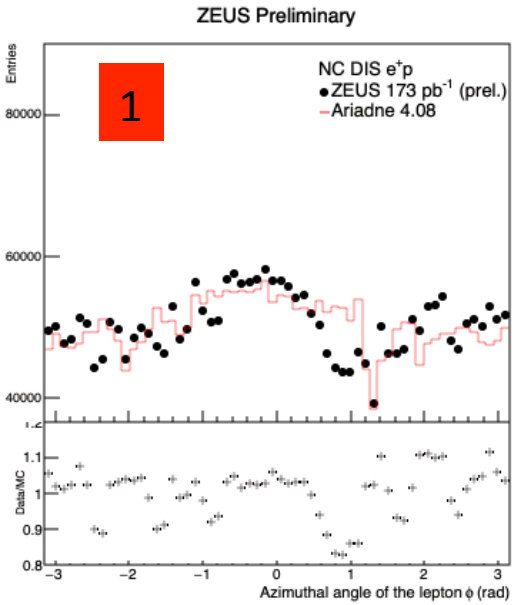
ZEUS 185 pb⁻¹ (prel.)
Ariadne 4.08
Events
Data/MC
Lepton inelasticity y

positron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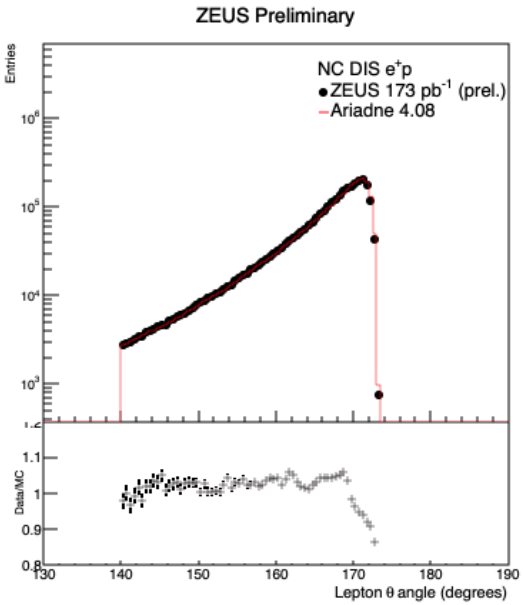
1
NC DIS e+p
ZEUS 173 pb-1 (prel.)
Ariadne 4.08
Entries
Data/MC
Azimuthal angle of the lepton φ (rad)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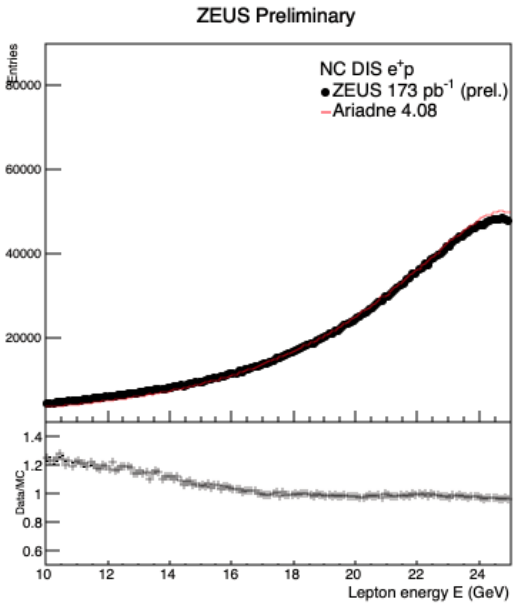
ZEUS 173 pb-1 (prel.)
Ariadne 4.08
Entries
Data/MC
Lepton θ angle (degrees)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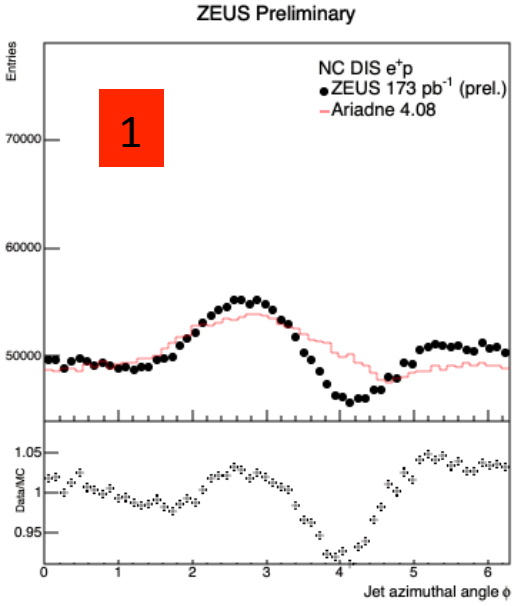
NC DIS e+p
ZEUS 173 pb-1 (prel.)
Ariadne 4.08
Entries
Data/MC
Lepton energy E (GeV)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1
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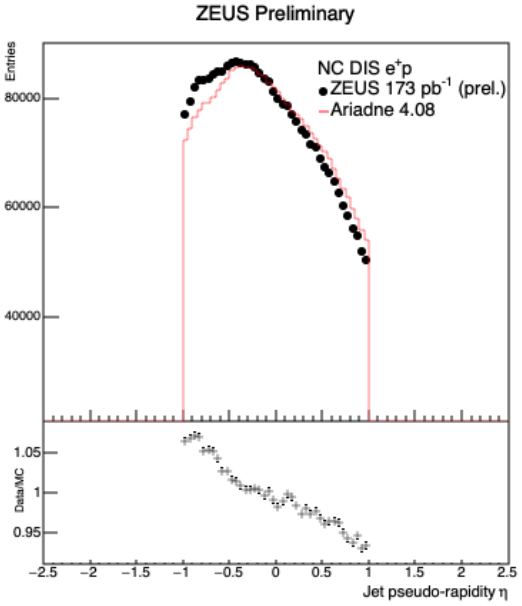
Entries
Data/MC
Jet azimuthal angle φ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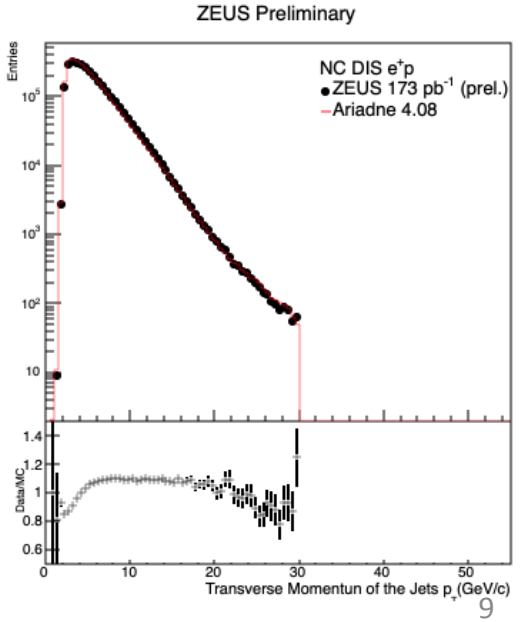
Entries
Data/MC
Jet pseudo-rapidity η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ZEUS 173 pb-1 (prel.)
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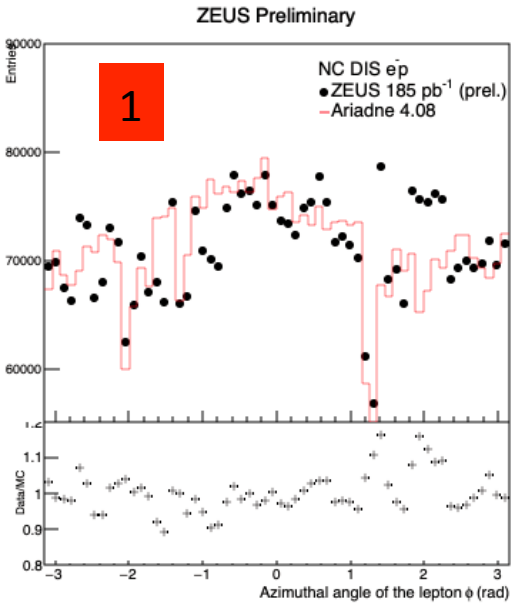
Entries
Data/MC
Transverse Momentun of the Jets pT (GeV/c)

electron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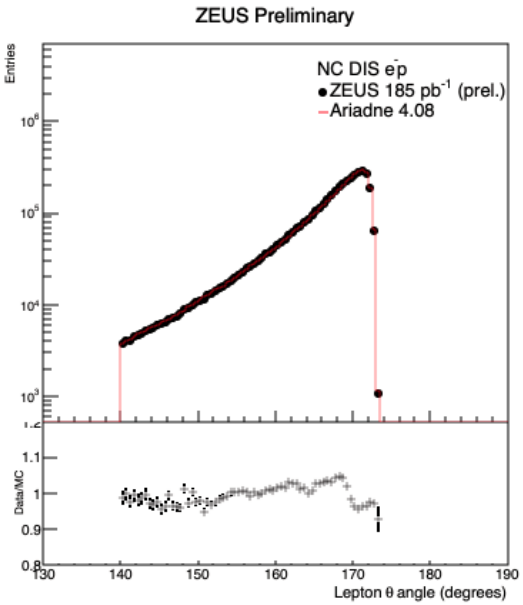
ZEUS 185 pb⁻¹ (prel.)
Ariadne 4.08
Entries
Data/MC
Azimuthal angle of the lepton φ (rad)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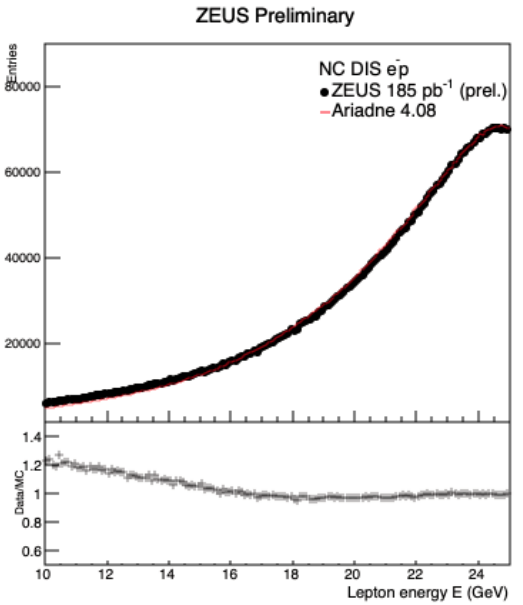
Ariadne 4.08
Entries
Data/MC
Lepton θ angle (degrees)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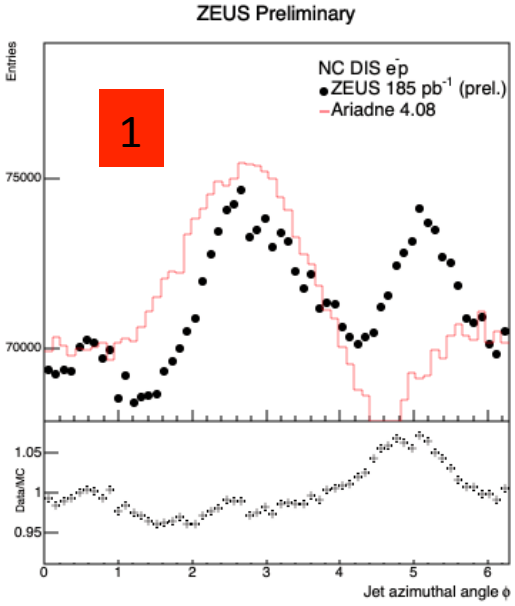
Ariadne 4.08
Entries
Data/MC
Lepton energy E (GeV)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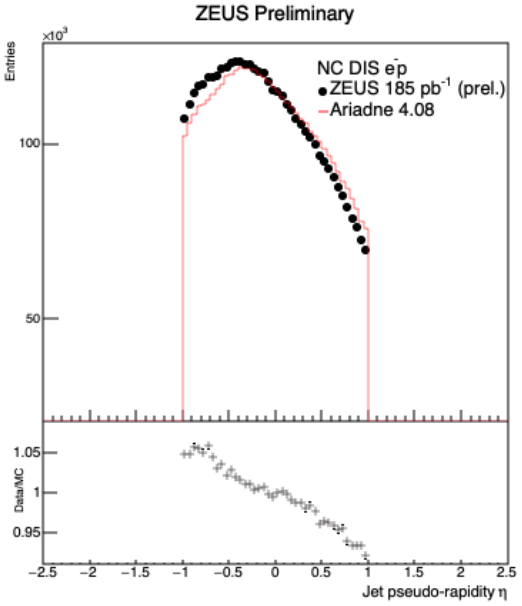
Ariadne 4.08
Entries
Data/MC
Jet azimuthal angle φ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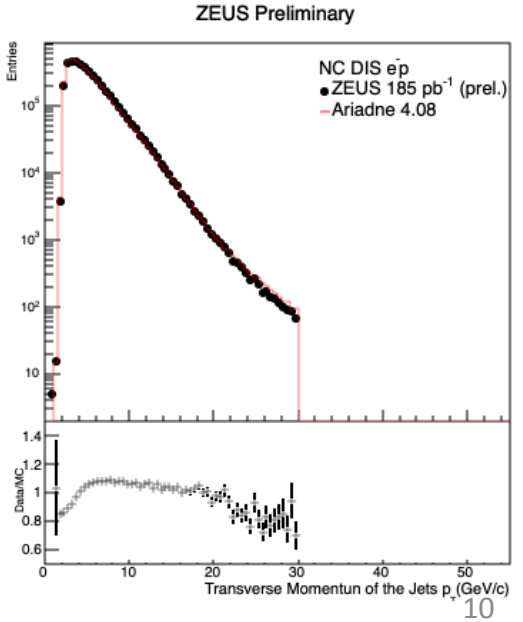
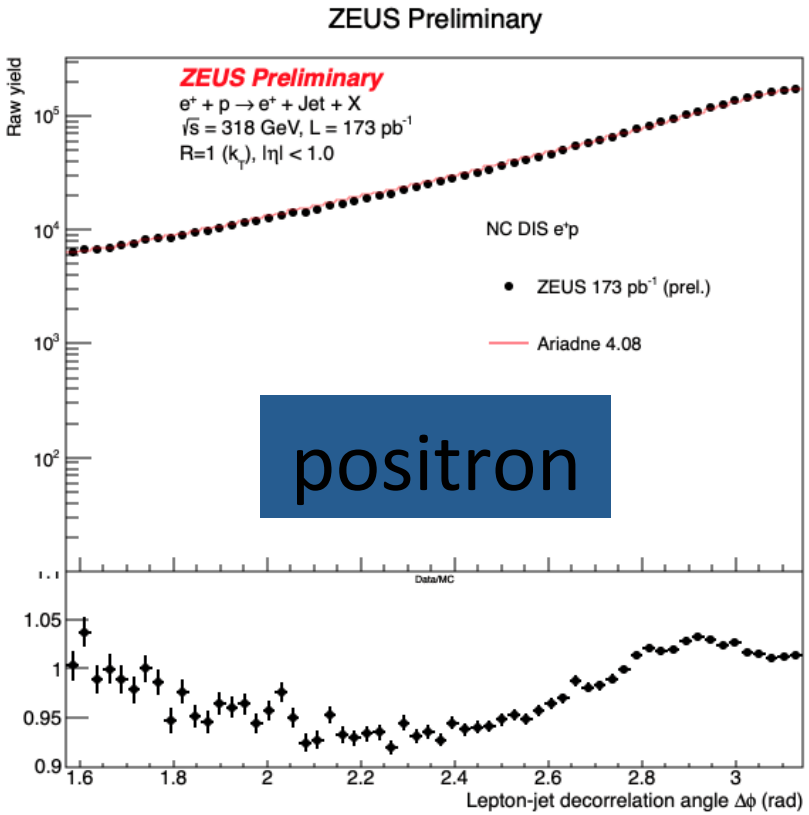
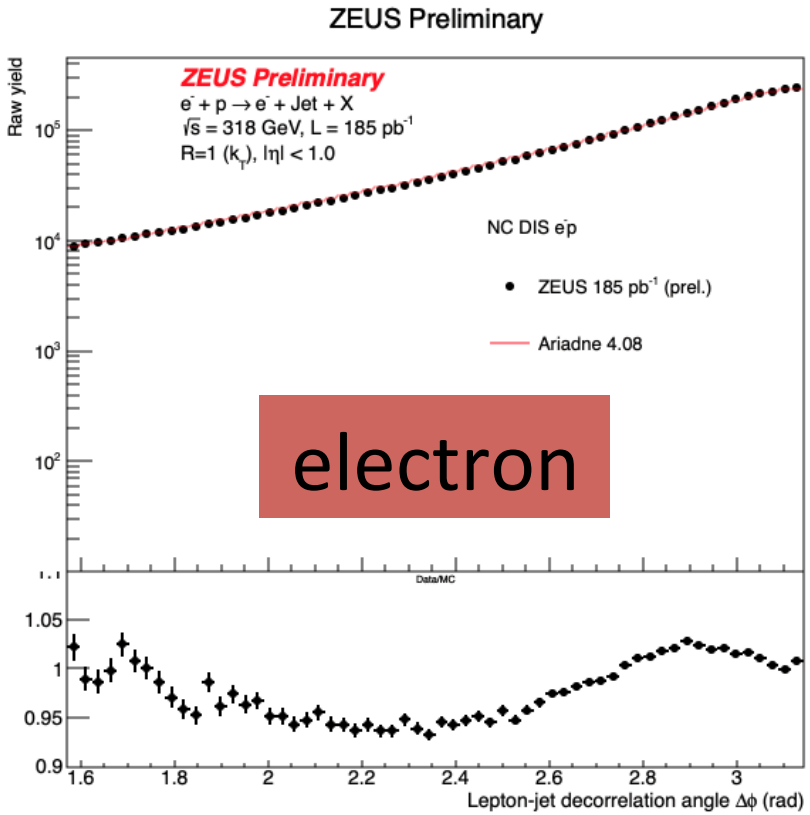
Ariadne 4.08
Entries
Data/MC
Jet pseudo-rapidity η


ZEUS Preliminary
NC DIS e⁻p
ZEUS 185 pb⁻¹ (prel.)
Ariadne 4.08
Entries
Data/MC
Transverse Momentun of the Jets p_T (GeV/c)

Decorrelation angle





Jet: $0 < \phi_{jet} < 2\pi$

Lepton: $-\pi < \phi_{lep} < \pi$

➔ $\Phi_{lep} = \phi_{lep}$ if $\phi_{lep} > 0$

$= 2\pi + \phi_{lep}$ if $\phi_{lep} < 0$

Decorrelation angle:

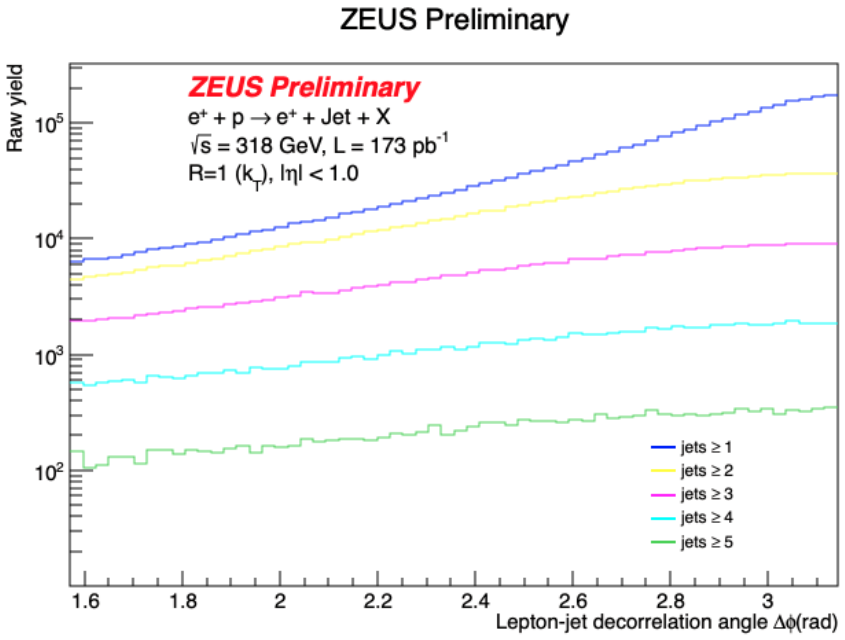
$\Delta\phi = |\phi_{jet} - \phi_{lep}|$ if $< \pi$

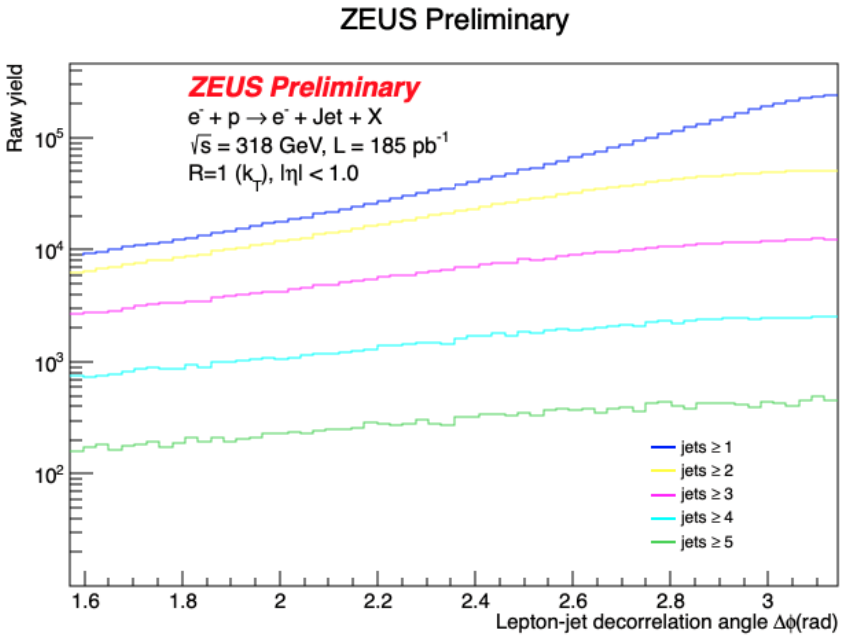
$2\pi - |\phi_{jet} - \phi_{lep}|$ if $> \pi$

Decorrelation angle

positron

electron





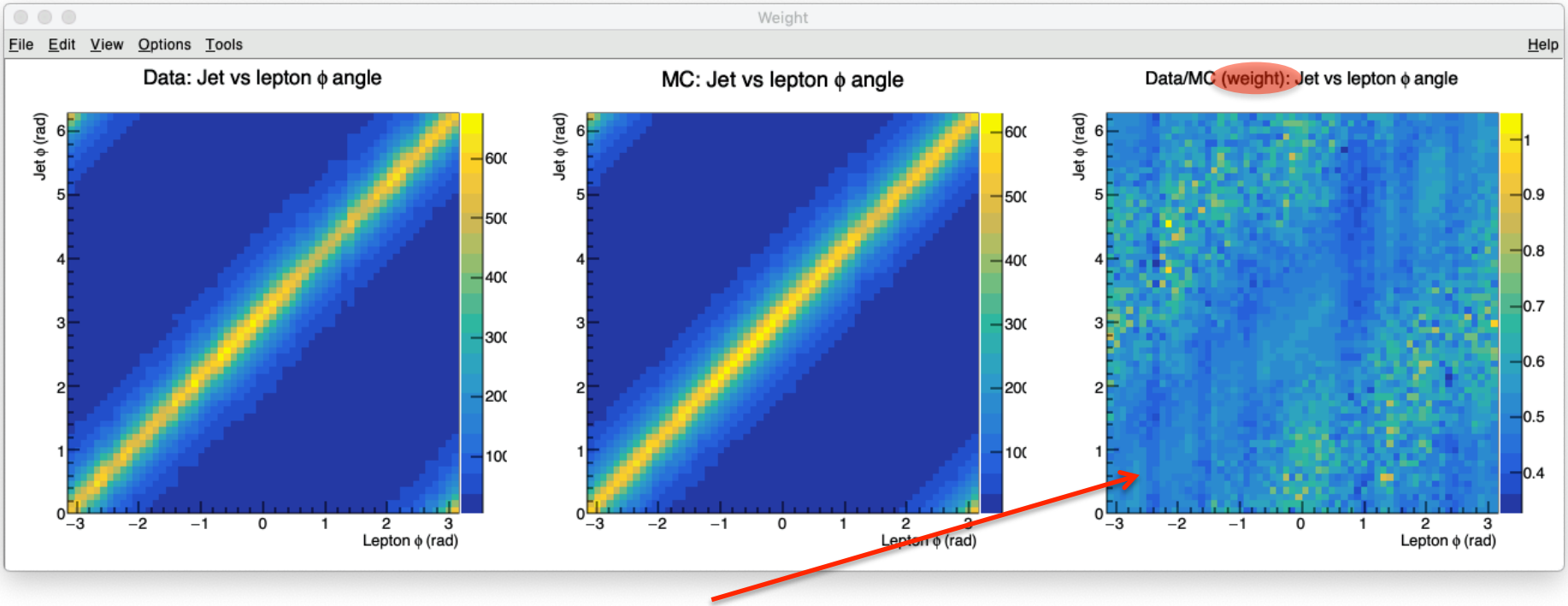
Similar behavior reported by ATLAS [3] and CMS [6].
High jet multiplicity events deviate from $\Delta\phi \sim \pi$.

positron

Acceptance and efficiency

1 Perform 2D reweighting correction (bin by bin) for both lepton and jet phi angles to improve the decorrelation data and MC matching.

- Apply these weights to all the variables in the control plots. No major changes for most of the variables. Apply same procedure for electron period.



Each bin is the weight depending of both lepton and jet phi, per event

positron

Acceptance and efficiency

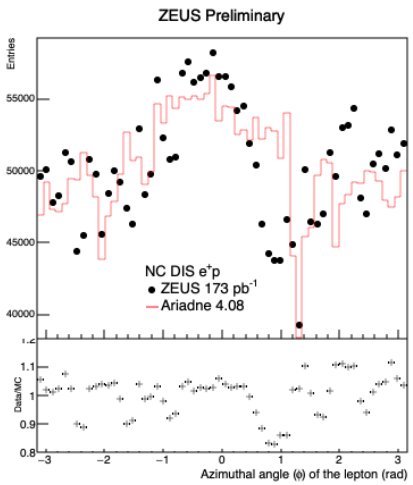
Reweight\phi

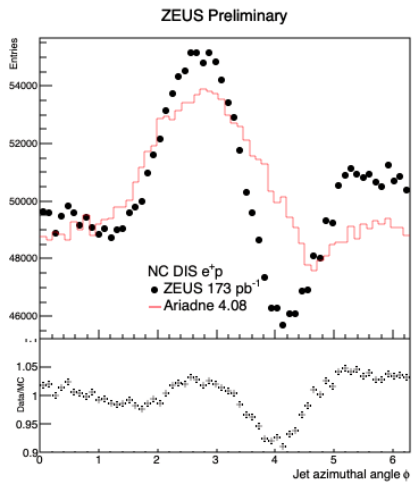
Jets

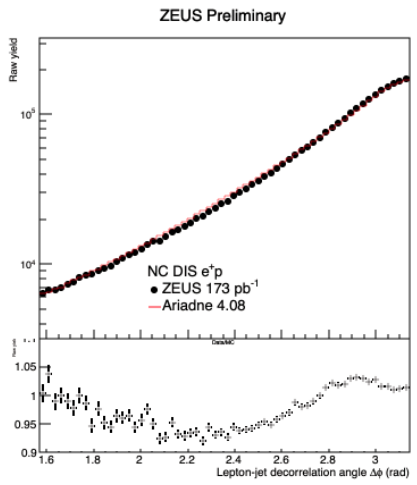
Lepton

Decorrelation

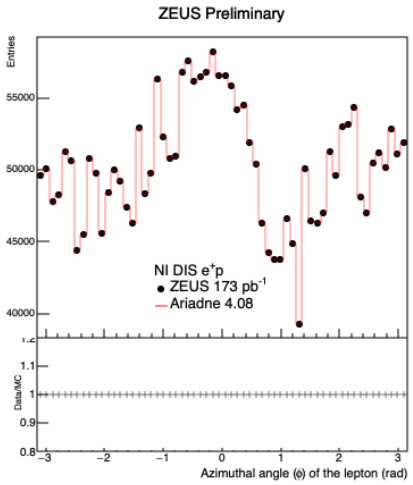
Before →

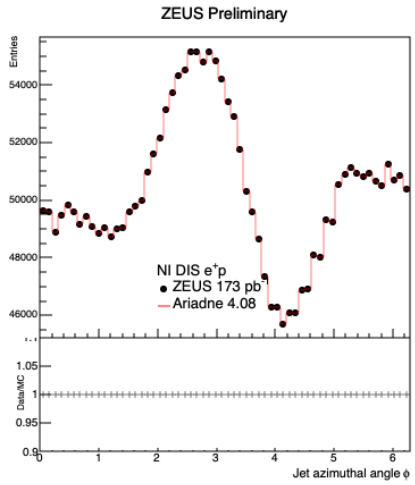


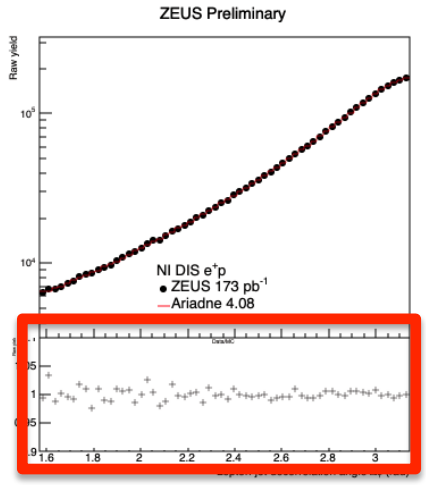




After→







Acceptance and efficiency

The observable: $\frac{1}{\sigma_{mes}}\frac{d\sigma_{mes}}{d\Delta\varphi}$

where σ_{mes} : the measured cross section

ε : efficiency correction

$\sigma = \sigma_{mes}/\varepsilon$: cross section at parton level

Use true level MC to estimate the efficiency:

ε = MC (detector level and after reweighting) / MC_true (parton level)

$$\Rightarrow \frac{1}{\sigma}\frac{d\sigma}{d\Delta\varphi} = \frac{\varepsilon}{N}\frac{d(N/\varepsilon)}{d\Delta\varphi}$$

N: the yield measured

This is a first approximation correction, due good agreement of data and MC.
Comparison of MC detector and parton level was done in:
https://indico.desy.de/indico/event/23125/contribution/3/material/slides/0.pdf

Event selection for true MC

~~**Data:**~~
~~040506e ~189 pb^{-1}, 0607p ~143 pb^{-1}~~

MC:
Ariadne_Low_Q2_NC_DIS_05e
Ariadne_Low_Q2_NC_DIS_06e
Ariadne_Low_Q2_NC_DIS_0607p

Phase Space:
$10 < Q^2 < 350\ GeV^2$
~~$y_{el} < 0.95$ && $y_{jb} > 0.04$~~ $0.04 < y < 0.95$

Cleaning cuts:
$-40 < Zvtx/cm < 40$
~~35 GeV < E − p_z < 65 GeV (both Cal and Zufo)~~
~~Cal_pt / sqrt(Cal_et) < 2.5~~

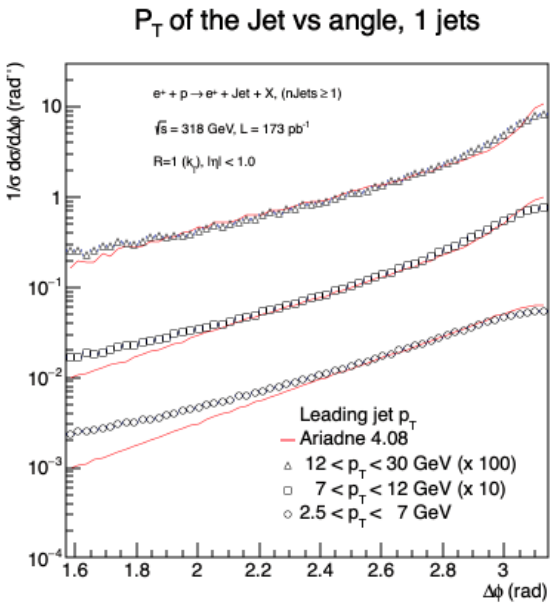
Electron cuts:
10 GeV < ~~Siecorr~~ Mc_pfsl[3]< 25 GeV
140^o < Theta < 180^o
~~Electron position sqrt($x^2 + y^2$) > 20.0~~
~~Sienin[0] > 0.1*(Siein[0] +Sienin[0]) *(energy in cone)~~
~~Chimney cut~~
~~Siprob[0], the lepton with highest prob (>0.9).~~

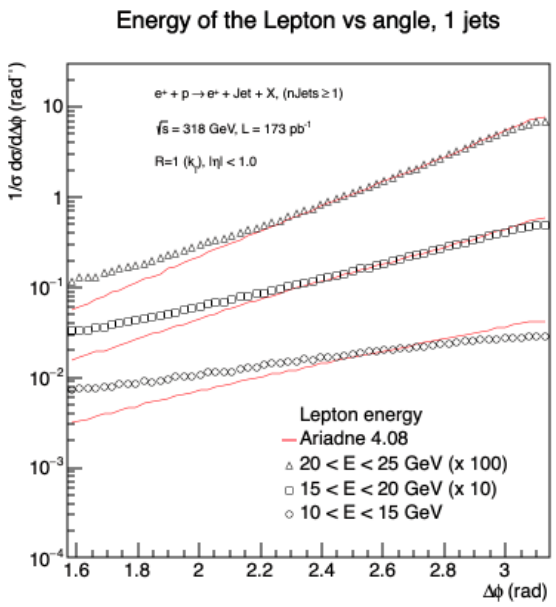
Triggers:
~~SPP02 (Tltw[2] & (1 << 1)) for 0405e~~
~~SPP09 (Tltw[2] & (1 << 8)) for 06e and 0607p~~

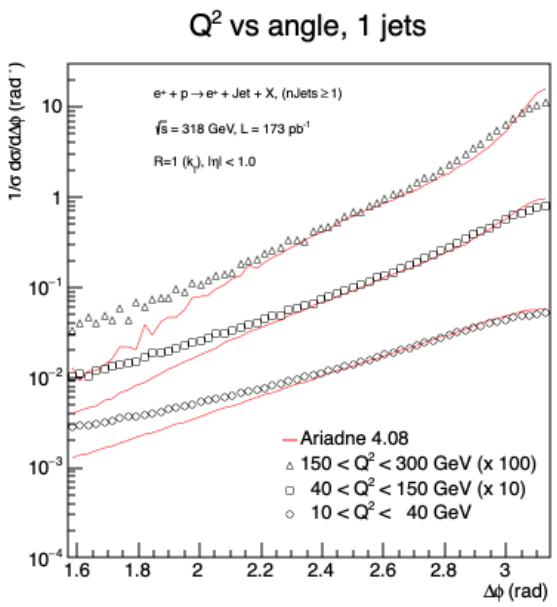
Jet selection:
$E_T > 2.5$ GeV && $P_T < 30$
|eta| < 1.0
Using “MCHMJets” (massive), the leading jet only

* Use all the true MC variables and remove all the detector dependences

positron







No correction

Systematic studies

Data:
040506e ~189 pb^{-1}, 0607p ~143 pb^{-1}

MC:
Ariadne_Low_Q2_NC_DIS_05e
Ariadne_Low_Q2_NC_DIS_06e
Ariadne_Low_Q2_NC_DIS_0607p

Phase Space:
$10 < Q^2 < 350\ GeV^2$
$y_{el} < 0.95$ && $y_{jb} > 0.04$

Cleaning cuts:
-40 < Zvtx/cm < 40
35 GeV < $E - p_z$ < 65 GeV (both Cal and Zufo)
Cal_pt / sqrt(Cal_et) < 2.5

Electron cuts:
10 GeV < Energy (Siecorr) < 25 GeV
140^o < Theta < 180^o
Electron position sqrt($x^2 + y^2$) > 20.0
Sienin[0] > 0.1*(Siein[0] +Sienin[0]) *(energy in cone)
Chimney cut *
Siprob[0], the lepton with highest prob (> 0.9)

Triggers:
SPP02 (Tltw[2] & (1 << 1)) for 0405e
SPP09 (Tltw[2] & (1 << 8)) for 06e and 0607p

Jet selection:
$E_T > 2.5$ GeV && $P_T < 30$
|eta| < 1.0
Using "Kt_etjet_b[0]" (massive), the leading jet only

Varied approximately ±5%, but effect produced a systematics variation less than 0.2%.

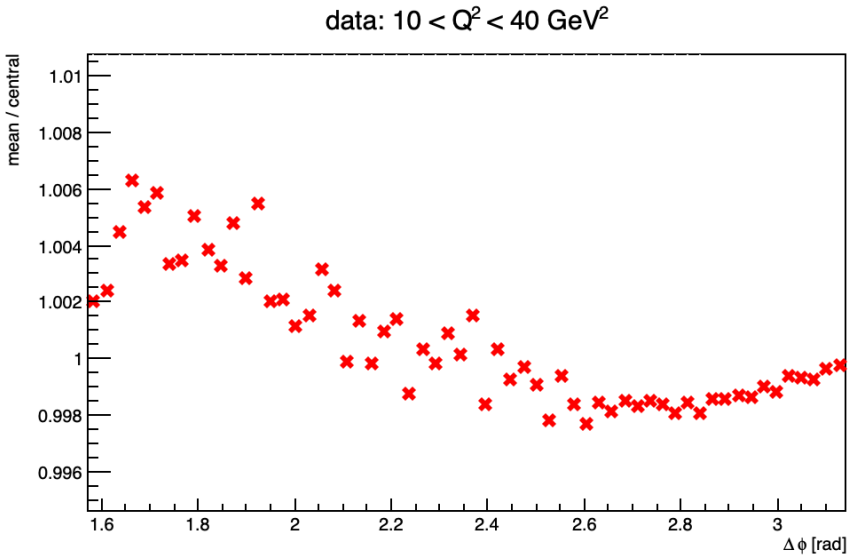
Systematic studies

cuts for systematics:
- lepton E (min): 10.03, 10.06, 10.9, **10.0**, 10.12, 9.88, 9.91, 9.94, 9,.97
- jet Et (min): 2.0, 2.42, 2.45, 2.48, **2.5**, 2.52, 2.55, 2.57, 3.0
- inelasticity (max): 0.92, 0.93, 0.94**, 0.95**, 9.96, 0.97, 0.98
- inelasticity (min): 0.0385, 0.038, 0.039, **0.04**, 0.0415, 0.041, 0.042

Showing the result from the varying E_T for $10 < Q^2 < 40$ bin.

The red points are the average of all the variations to the yield divided by the nominal yield.

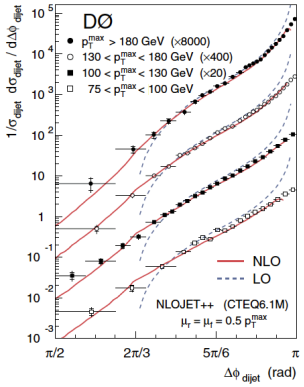
Root file “sys.root” with all values at ~quintera/public/Preliminary



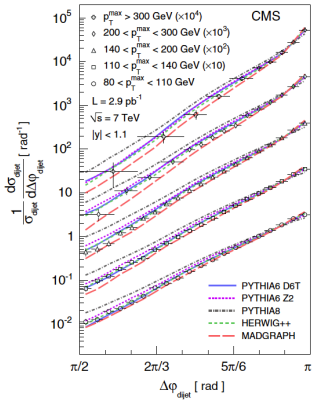
Systematics uncertainty of the variations are **~0.2%** in average for all decorrelation angle bins. The systematic uncertainties are not plotted for visualization purposes.

Results

[1]



[2]



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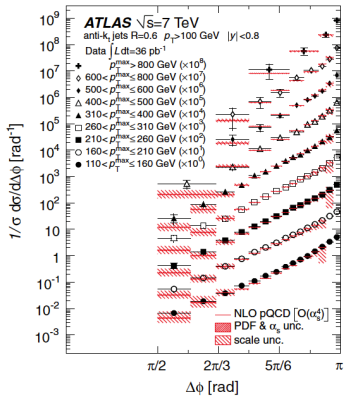

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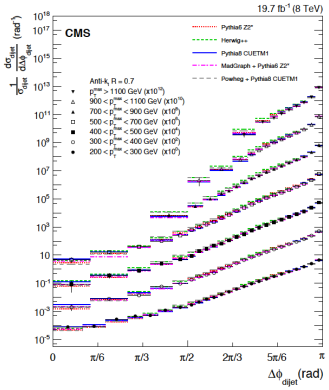

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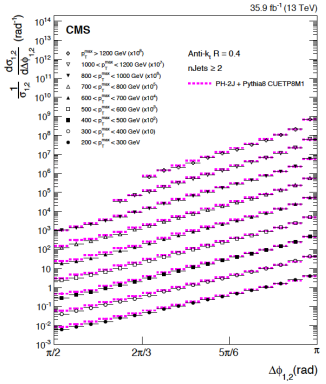
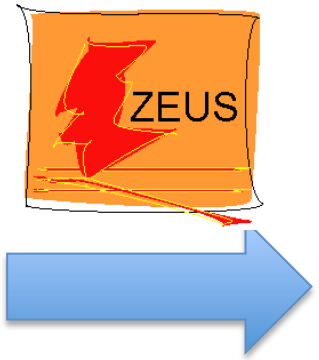
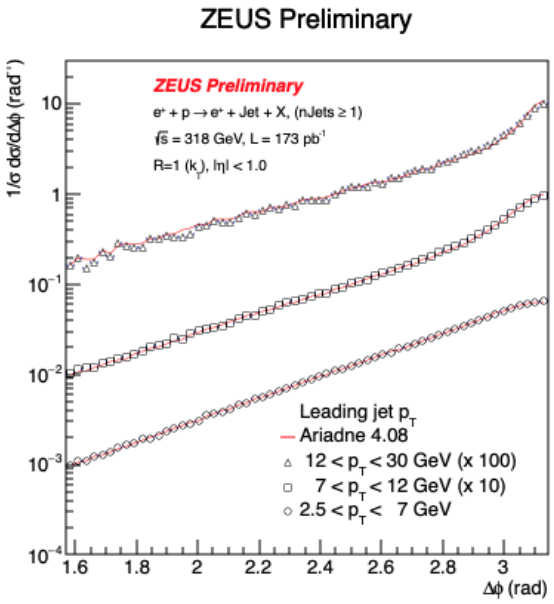
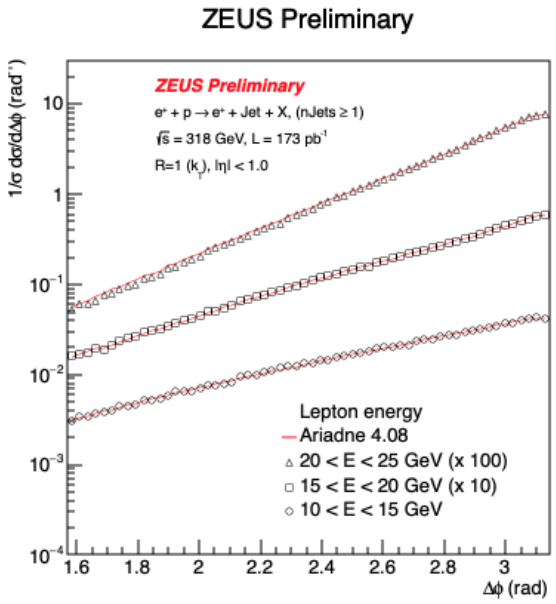


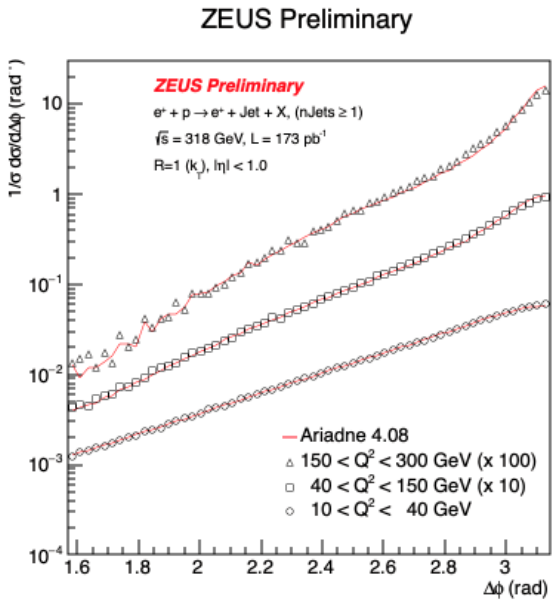


Both statistical and systematics uncertainties are very small. Not plotted for visualization purposes.

positron

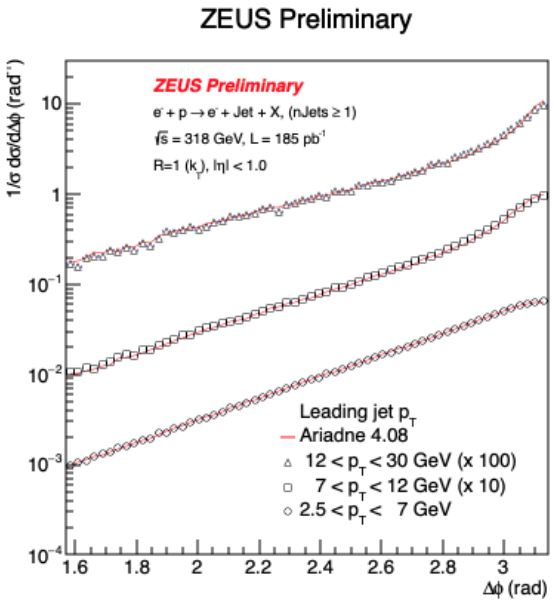


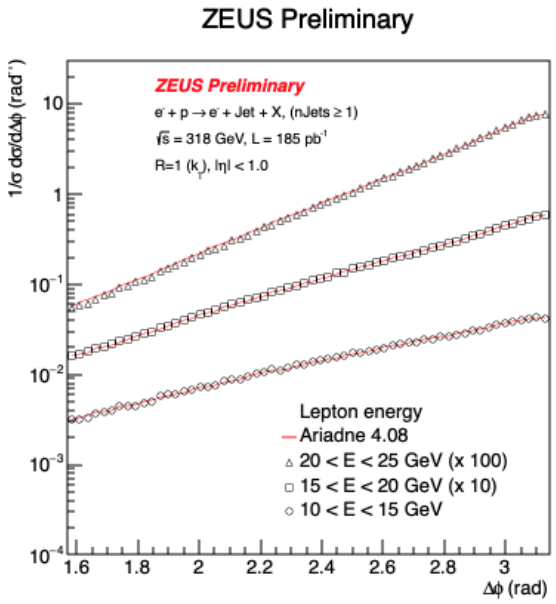


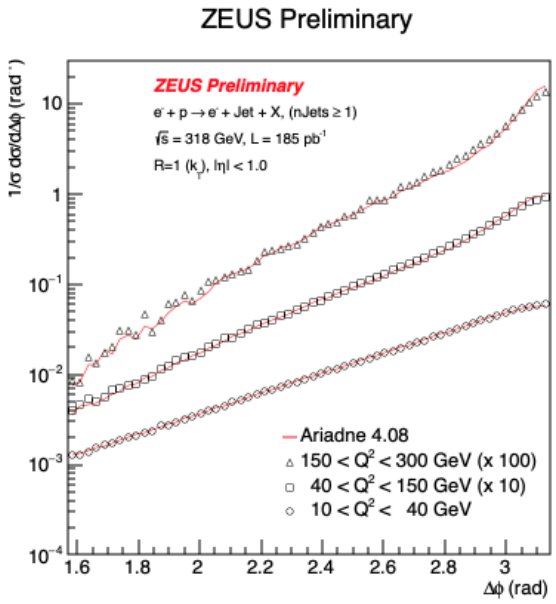


No considerable differences between electron and positron periods.
The theory curves matches the data (using slide 15).

electron

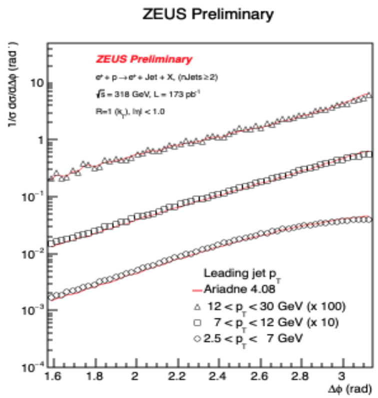


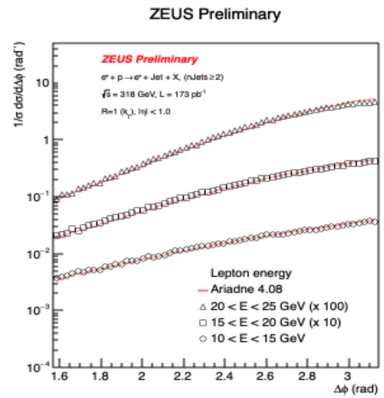




No considerable differences between electron and positron periods.
The theory curves matches the data (using slide 15).

positron


ZEUS Preliminary
ZEUS Preliminary
e+ + p → e+ + Jet + X, (nJets ≥ 2)
√s = 318 GeV, L = 173 pb⁻¹
R=1 (kT), |η| < 1.0
Leading jet pT
Ariadne 4.08
12 < pT < 30 GeV (x 100)
7 < pT < 12 GeV (x 10)
2.5 < pT < 7 GeV
1/σ dσ/dΔφ (rad⁻¹)
Δφ (rad)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ZEUS Preliminary
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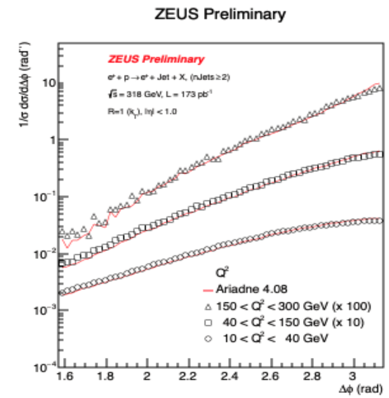
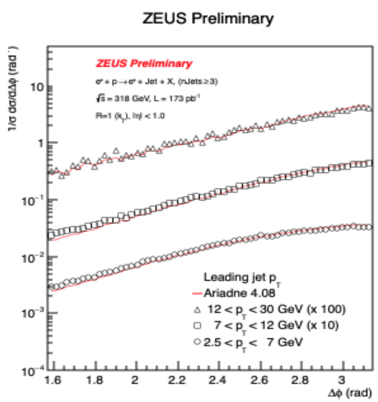
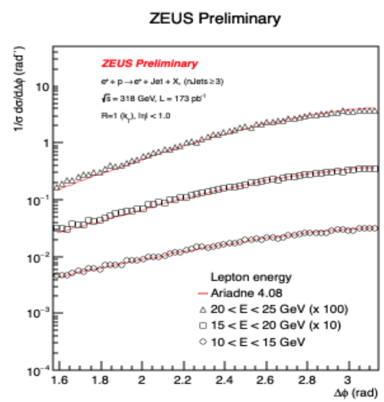
√s = 318 GeV, L = 173 pb⁻¹
R=1 (kT), |η| < 1.0
Lepton energy
Ariadne 4.08
20 < E < 25 GeV (x 100)
15 < E < 20 GeV (x 10)
10 < E < 15 GeV
1/σ dσ/dΔφ (rad⁻¹)
Δφ (rad)


ZEUS Preliminary
ZEUS Preliminary
e+ + p → e+ + Jet + X, (nJets ≥ 2)
√s = 318 GeV, L = 173 pb⁻¹
R=1 (kT), |η| < 1.0
Q²
Ariadne 4.08
150 < Q² < 300 GeV (x 100)
40 < Q² < 150 GeV (x 10)
10 < Q² < 40 GeV
1/σ dσ/dΔφ (rad⁻¹)
Δφ (rad)


ZEUS Preliminary
ZEUS Preliminary
e+ + p → e+ + Jet + X, (nJets ≥ 3)
√s = 318 GeV, L = 173 pb⁻¹
R=1 (kT), |η| < 1.0
Leading jet pT
Ariadne 4.08
12 < pT < 30 GeV (x 100)
7 < pT < 12 GeV (x 10)
2.5 < pT < 7 GeV
1/σ dσ/dΔφ (rad⁻¹)
Δφ (rad)


ZEUS Preliminary
ZEUS Preliminary
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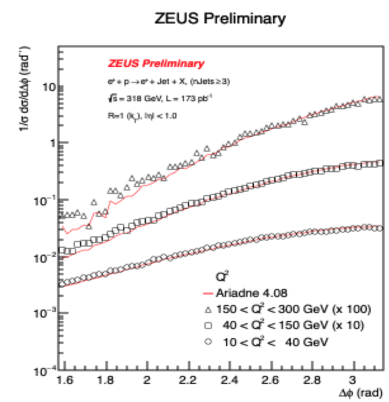
10 < E < 15 GeV
1/σ dσ/dΔφ (rad⁻¹)
Δφ (rad)


ZEUS Preliminary
ZEUS Preliminary
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√s = 318 GeV, L = 173 pb⁻¹
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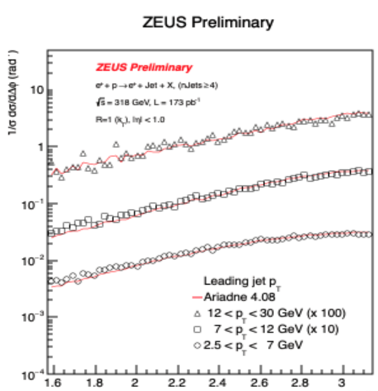
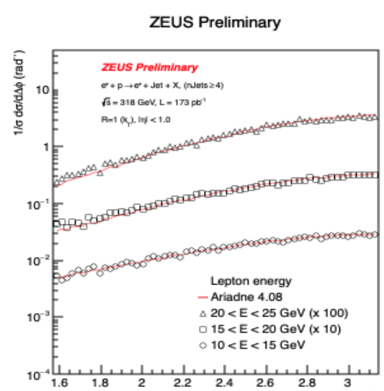
Ariadne 4.08
150 < Q² < 300 GeV (x 100)
40 < Q² < 150 GeV (x 10)
10 < Q² < 40 GeV
1/σ dσ/dΔφ (rad⁻¹)
Δφ (rad)


ZEUS Preliminary
ZEUS Preliminary
e+ + p → e+ + Jet + X, (nJets ≥ 4)
√s = 318 GeV, L = 173 pb⁻¹
R=1 (kT), |η| < 1.0
Leading jet pT
Ariadne 4.08
12 < pT < 30 GeV (x 100)
7 < pT < 12 GeV (x 10)
2.5 < pT < 7 GeV
1/σ dσ/dΔφ (rad⁻¹)
Δφ (rad)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Lepton energy
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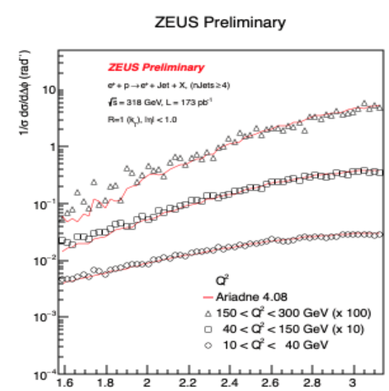
Δφ (rad)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ZEUS Preliminary
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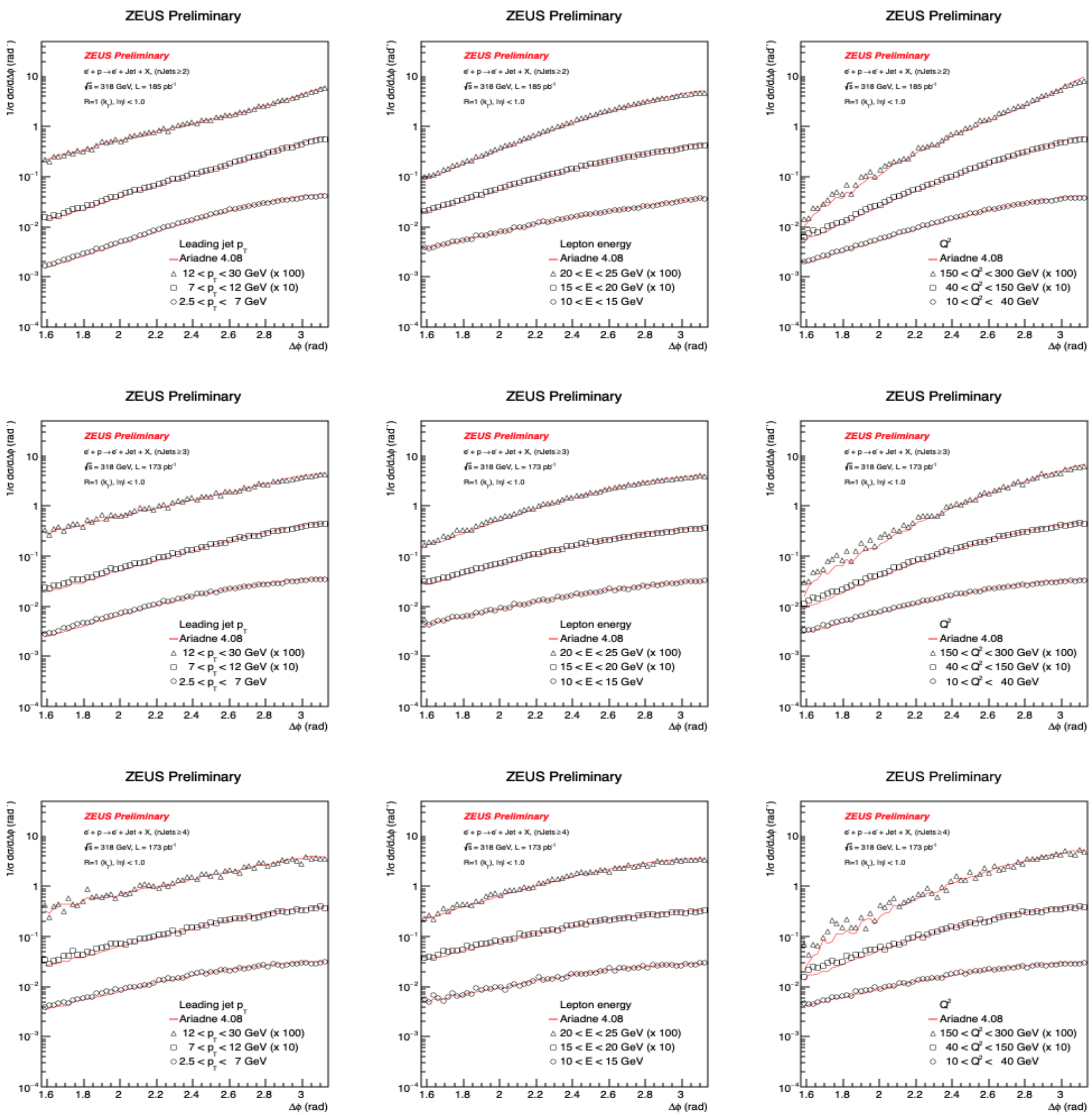
√s = 318 GeV, L = 173 pb⁻¹
R=1 (kT), |η| < 1.0
Q²
Ariadne 4.08
150 < Q² < 300 GeV (x 100)
40 < Q² < 150 GeV (x 10)
10 < Q² < 40 GeV
1/σ dσ/dΔφ (rad⁻¹)
Δφ (rad)

electron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ZEUS Preliminary
Leading jet p_T
Ariadne 4.08
12 < p_T < 30 GeV (x 100)
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2.5 < p_T < 7 GeV
Lepton energy
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15 < E < 20 GeV (x 10)
10 < E < 15 GeV
Q²
Ariadne 4.08
150 < Q² < 300 GeV (x 100)
40 < Q² < 150 GeV (x 10)
10 < Q² < 40 GeV
1/σ dσ/dΔφ (rad⁻¹)
Δφ (rad)

Summary

- Perform decorrelation measurements of DIS lepton with leading jet, similar to Tevatron, CMS and Atlas.
- Presented results for different jet multiplicity, showing similar behaviour as pp measurements.
- No considerable differences between electron and positron periods.
- Good matching between data and MC at parton level (simplified correction or unfolding method).
- Systematic uncertainties studied are small (~0.2%).
- Initial studies for futures EIC measurements.
- Intent to present a poster at EIC Users meeting July 2019 and a presentation at DNP in October 2019 (abstract deadline 1 July).

Backup

References

[1] Phys. Rev. Lett. **94**, 221801 (2005). D0

[2] Phys. Rev. Lett. 106, 122003 (2011). CMS

[3] Phys. Rev. Lett. 106, 172002 (2011). Atlas

[4] Phys. Rev. D 92, 094007 (2015). Feng Yuan

[5] Phys. Rev. Lett. 122, 192003 (2019). F. Yuan

[6] Eur. Phys. J. C 76:536 (2016). CMS

[7] Eur. Phys. J. C 78:566 (2018). CMS

Code

- Location: /afs/desy.de/user/q/quintera/public/Preliminary
- Macro: MakeHist_v6.C
- Script to run: > sh runInc.sh # (# is a number)
- To submit: > condor_submit QA.job

Change the path of the script and submit script.