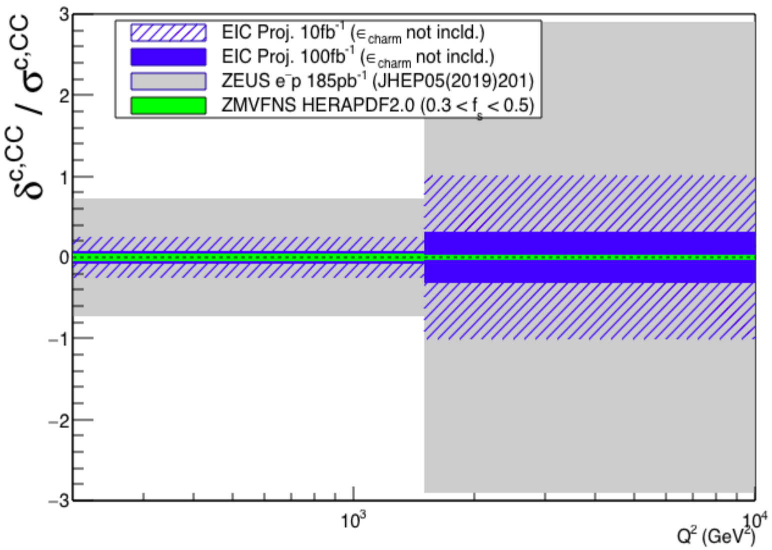
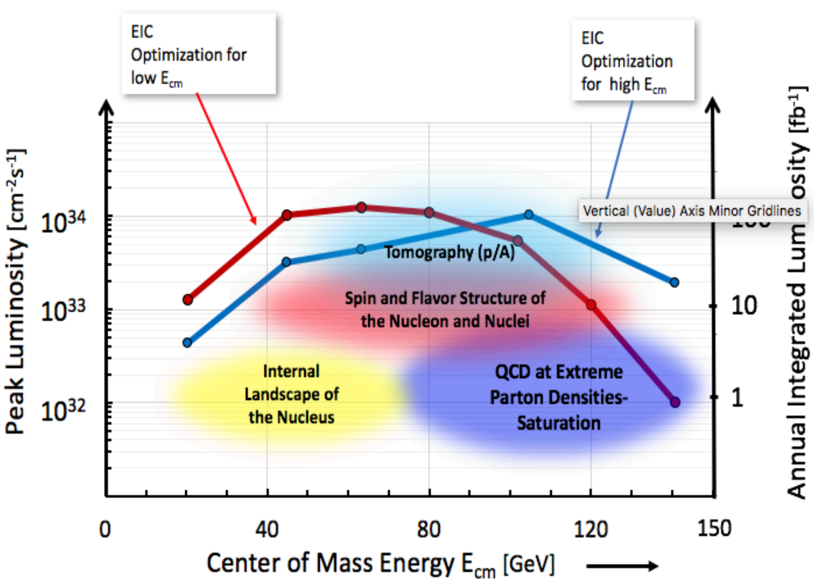
Charm production in CCDIS at EIC
(with secondary vertices)

Jae D. Nam Bernd Surrow Stephen Sekula Jared Burleson Miguel Arriatia
Yulia Furletova Tim Hobbs Olek Kusina Pavel Nadolsky Fred Olness

Review





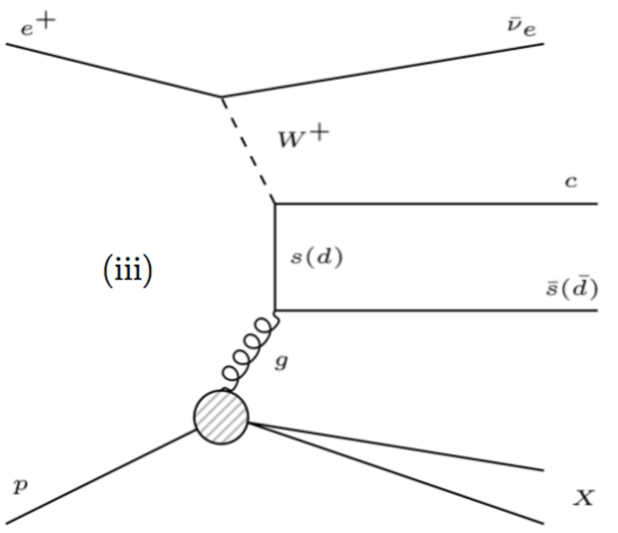
- Charm signal resolution has been studied based on DJANGOH at the DIS-level.
  - At the highest EIC energy mode ($\sqrt{s} = 141\ GeV$) with $\int dtL = 10fb^{-1}$, requires <10 times higher charm tagging efficiency to contribute to the investigation(strangeness in the proton).
  - Further study requires reconstruction of secondary vertices.

- Overview
  - Now also consider on EIC high luminosity sample at $\sqrt{s} = 101\ GeV$ w/ $\int dtL = 100\ fb^{-1}$.
  - A "first principle" type of reconstruction scheme used for today's update.

Delphes and Pythia8

- Event generator and detector implementation
  - Delphes: a fast detector response simulator.
  - Pythia8 interfaced in Delphes as implemented by Arriatia.
    - Details can be found in Sekula's presentation in Pavia.
    - https://indico.bnl.gov/event/8231/contributions/37698/
- Simulation samples
  - Internal PDF sets in Pythia8
  - Unpolarized high-$Q^2(> 200\ GeV^2)$ CCDIS
  - Assume high-E_{cm} optimization for EIC.
  - No NLO (BGF) contribution
  - ~100,000 events per sample

(iii)

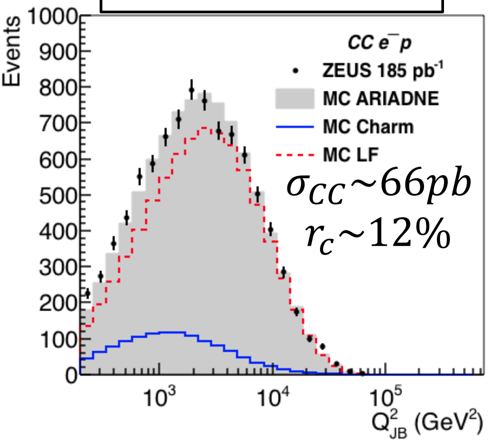


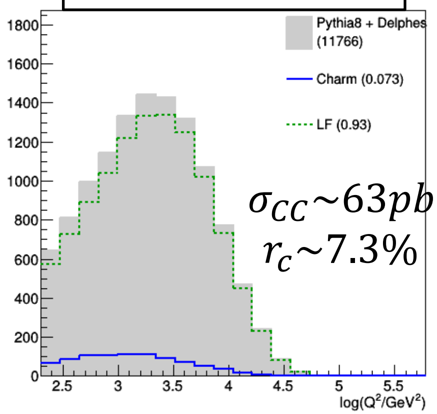
Sample	$\sqrt{s}$ (GeV)	(Expected) luminosity (pb^{-1})
HERA	318	~180
EIC (high energy)	141	~10,000
EIC (nominal)	104	~100,000

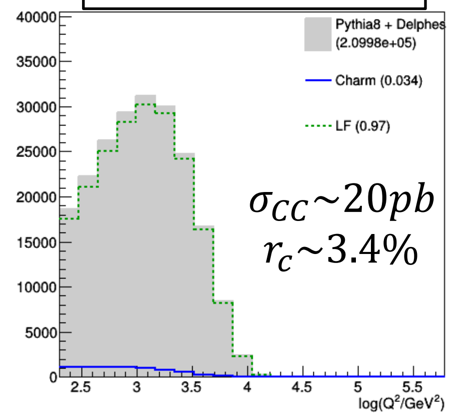
DIS

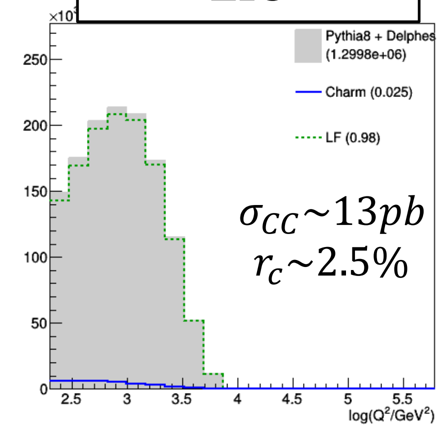
Pythia

ZEUS exp. | **HERA** | **EIC (HE)** | **EIC**









- Charm yield

Sample	σ_{CC} (pb)	r_c	Relative yield
ZEUS exp.	66	0.12	
HERA	63	0.073	1.00
EIC (HE)	21	0.034	0.15
EIC	13	0.025	0.07

- Good description of ZEUS experiment by Pythia.
  - ~ 20% overestimated DIS possibly due to missing DIS selection cuts.
- ~50% lower charm yield in Pythia due to missing BGF contribution.
- ~10% charm production rate in EIC compared to HERA.
  - Consistent with previous study with DJANGOH.

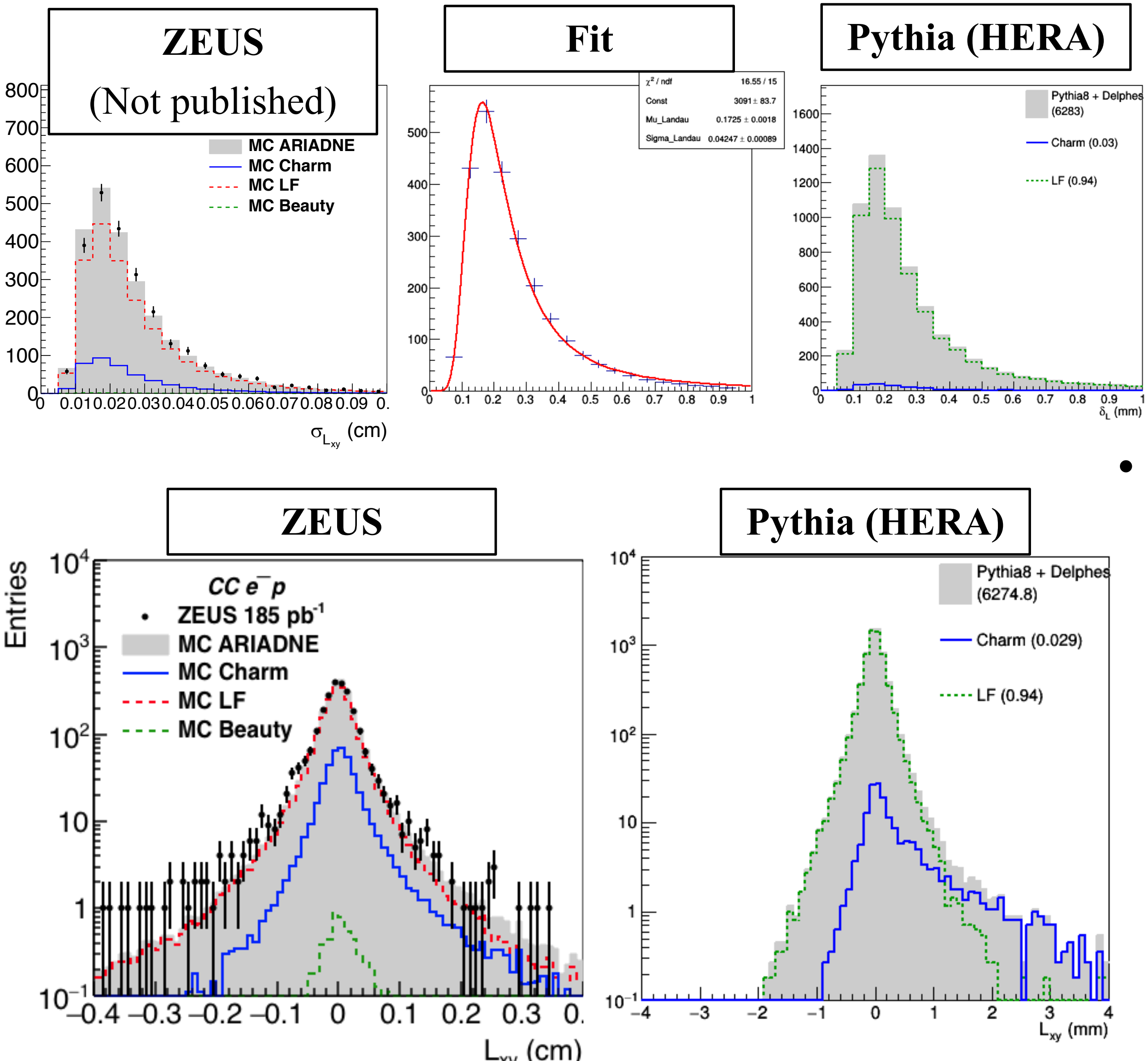
Secondary vertex

- Reconstruction of decay vertices
  - Full treatment: G4 framework F4A, G4E… → Detector level info (hit) → Vertexing
  - YR-goal: Truth-level info Pythia → Fast simulator (Delphes) → Vertexing
  - Current status: Truth-level info Pythia → Vertexing → Smearing

1. Only charged tracks within a jet cone ($R < 1.0$) are considered.
2. Vertex information for each track is taken from Pythia.
3. Vertex candidates are reconstructed based on the truth info, then smeared.***
4. The candidate that is farthest (2D, along the jet-axis) from the primary vertex is chosen for the jet.

	Selection cuts
Track	$p_T^{trk} > 0.5\ GeV$
Jet	$p_T^{jet} > 5\ GeV$ $\lvert\eta_{jet}\rvert > 2.5$
Vertex	$N_{trk}^{vtx} > 3$ $\lvert L_{xy}\rvert < 1\ cm$ $S = L_{xy}/\delta_{L_{xy}} > 2$

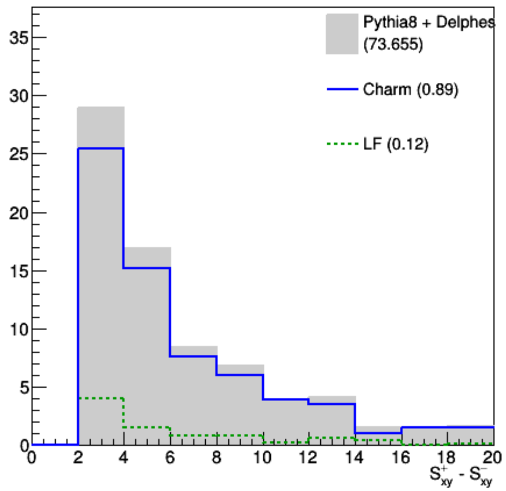
Secondary vertices



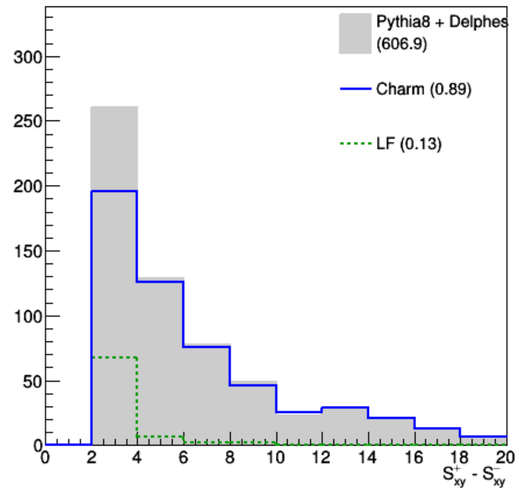
- Smearing
  - Uses analytical description (Landau) of $\delta_{L_{xy}}$ based on ZEUS exp.
  - Sharp cutoff $\sim 100\mu m$ from RMS beamspot size.
    - Improvement in vertexing algorithm may reduce the offset.
- Reconstructed vertices
  - ~50% fewer reconstructed charm vertices due to missing BGF.
  - ~ 4 times higher LF vertex acceptance.
  - Imperfect description of decaylength distribution.
  - These discrepancies may be artifacts of the current vertexing algorithm.

Charm isolation

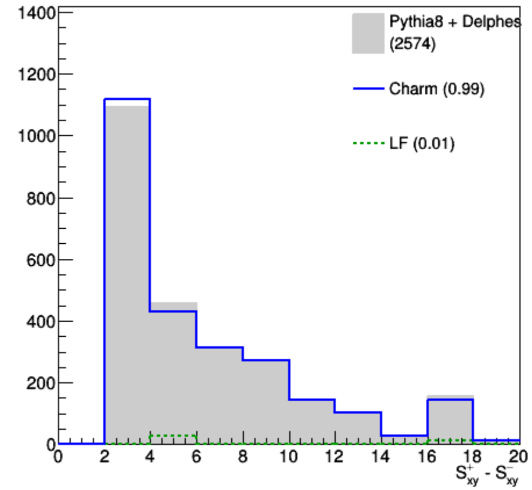
HERA

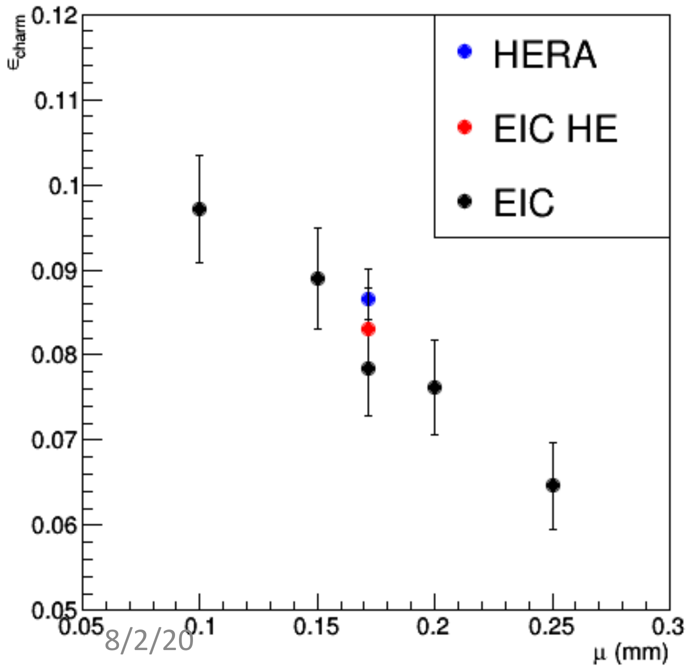


EIC (HE)



EIC

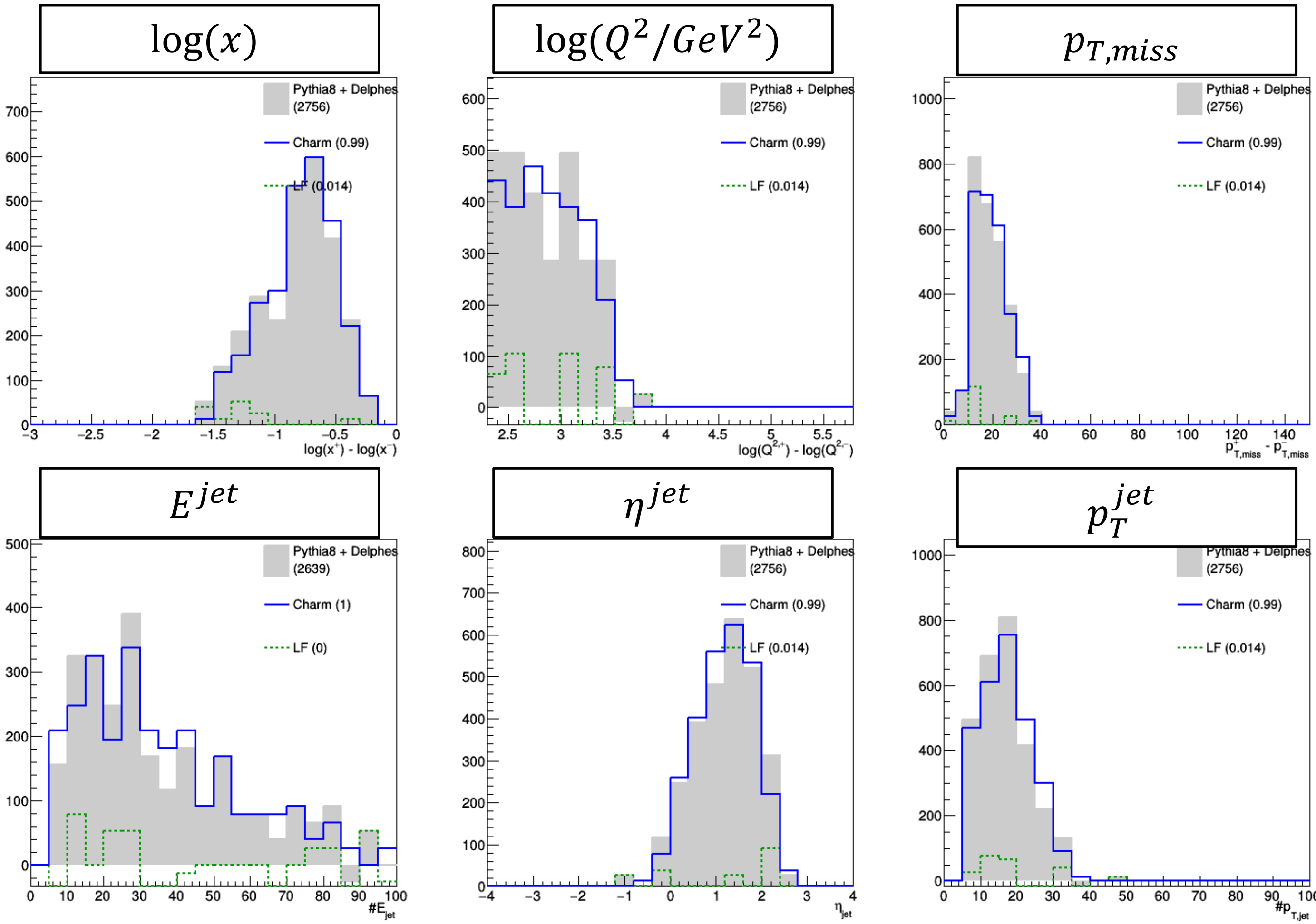




- Charm isolation
  - Charms are isolated by subtracting the negative vertex distribution from the positive.
  - Good charm isolation after the background subtraction.
- Charm tagging efficiency
  - HERA sample overestimates tagging efficiency by a factor of 4 (At ZEUS, was ~ 2%)
  - On the left records the variation in charm tagging efficiency while the μ value of the Landau fit was varied up to 40%.
  - Difficult to extract physical quantities, such as vertex resolution, from the analytical value μ.

Charm isolated quantities

- Charmed vertices method sensitive to the following kinematic regions:
  - $Q^2 < 3000\ GeV^2$
  - $0.03 < x < 0.5 \quad (\bar{x} \sim 0.15)$



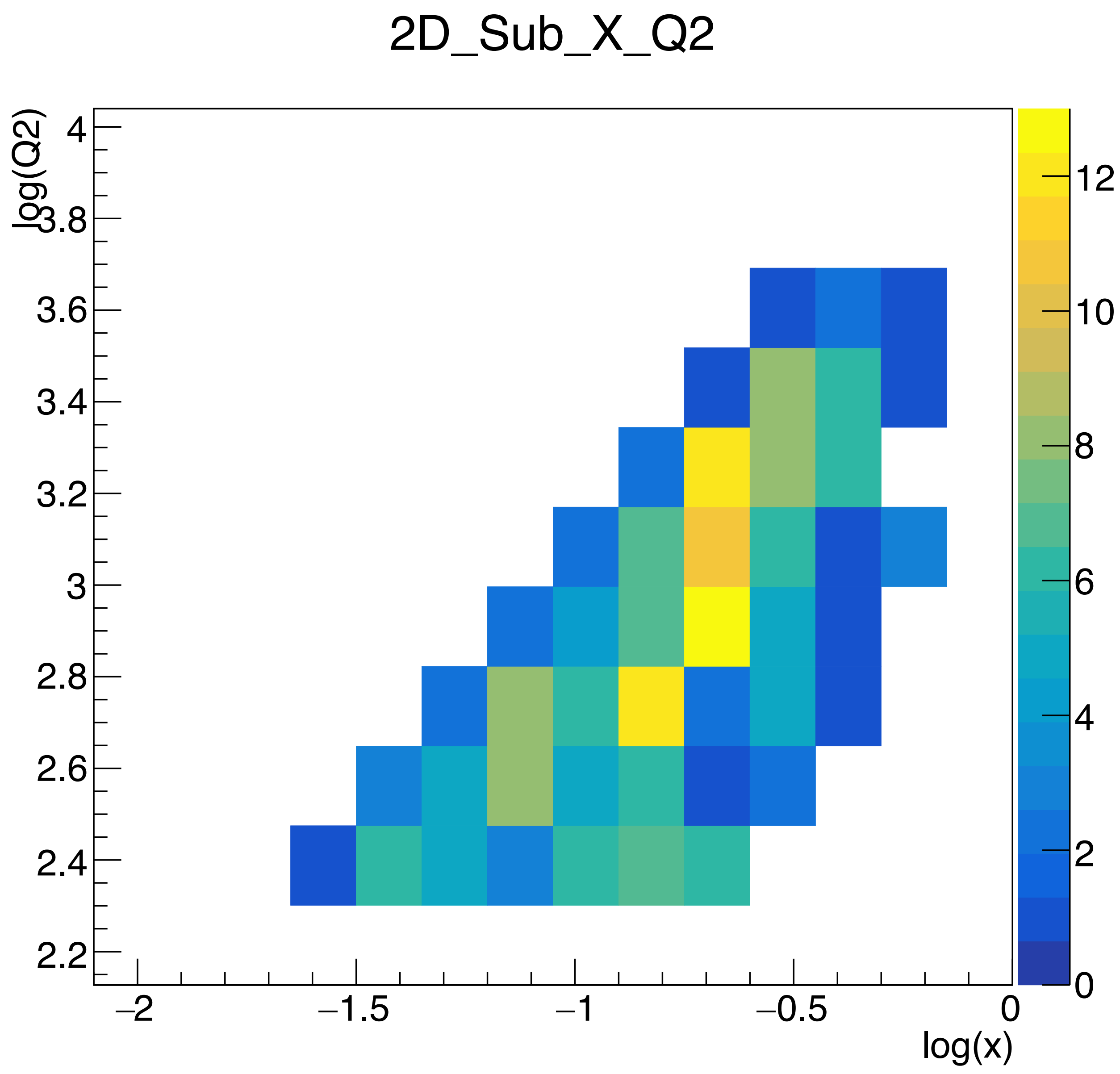
Summary

- Charm production in CCDIS at EIC with Delphes + Pythia8.
  - At DIS-level, good description of data by Pythia.
  - 50% lower charm yield than expected due to missing BGF contribution, a well-understood artifact of Pythia.
  - Charm production rate in EIC ~10% of HERA kinematics.

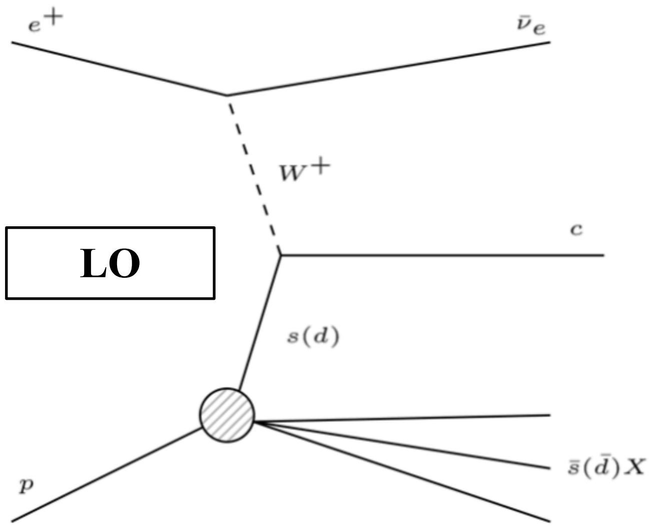
- Charm isolation with "first principle" secondary vertices.
  - Well-isolated charm signal has been observed in all HERA and EIC samples.
  - ~10% less charm tagging efficiency than in ZEUS, assuming no improvement in vertex resolution.
    - Small improvement in vertex resolution expected to help overcome this reduction.
  - Several issues with the current vertexing algorithm.
    - Imperfect description of decay length distribution.
    - ~4 times higher vertex acceptance for LF → higher uncertainty in charm signal in simulation.
    - ~4 times higher charm tagging efficiency in HERA sample than expected.
    - Difficulties with developing quantitative understanding of the effect of vertex resolution to charm tagging efficiency.

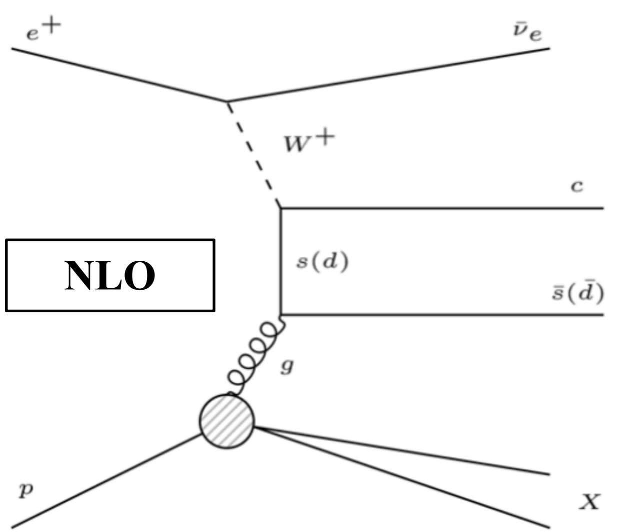
- Path forward
  - Improvement in vertexing algorithm.
  - Theoretical input on variation in charm cross-section/yield at EIC under different assumptions on the strange content.

Backup: Kinematic region



Backup

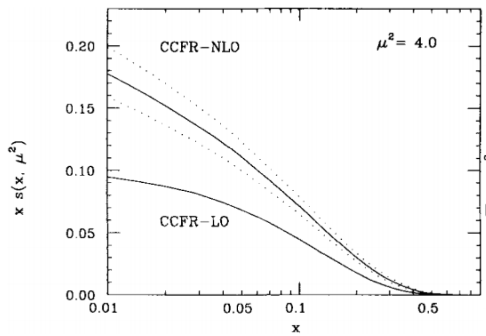


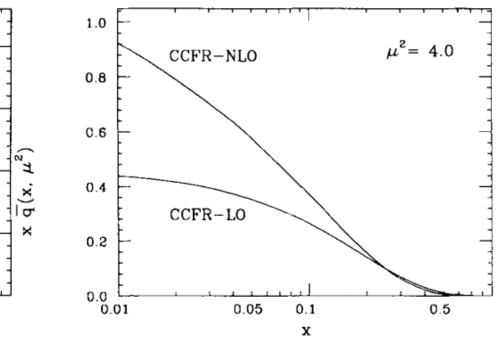


- Objective
  - Study the intrinsic strangeness of the proton via charm production in charged current DIS.
  - Use the decay vertex of charmed hadrons in order to distinguish charm from LF hadrons.
  - Extrapolate the charm yield & uncertainty from a previous ZEUS experiment (JHEP05(2019)201).
- Subprocesses
  - LO:
    - Sensitive to strange and down, while the latter is Cabbibo-suppressed.
  - NLO:
    - Boson-gluon fusion (BGF), sensitive to gluons.
    - Overcomes higher order due to large gluon content in low-x_{Bj}.
    - In ZEUS, found to contribute to ~50% of charm cross section.

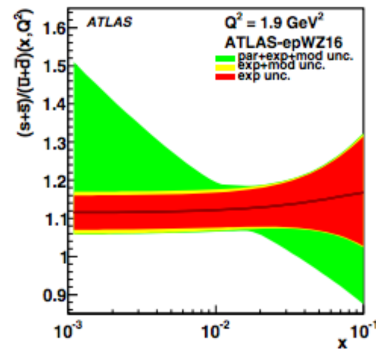
Back up

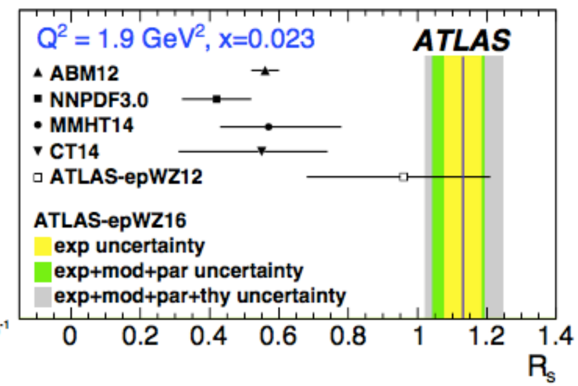
- Neutrino-scattering experiments
  - CCFR/NuTeV, NOMAD, CHORUS, etc.
  - Sensitive to high x_{Bj} (~ 0.1) region.
  - Mass suppressed strangeness, $\bar{s}/\bar{d} \sim 0.5$





- $p + p$ collision
  - ATLAS (W/Z measurement), CMS ($W + c$),etc
  - Sensitive to low x_{Bj} (~ 0.02) region.
  - Flavor symmetry conserved, $\bar{s}/\bar{d} \sim 1.0$





- $e + p$ DIS
  - HERA/ZEUS (Charm in CC, JHEP05(2019)201)
  - Tested various assumptions on the strangeness.
  - Found the feasibility of DIS in this investigation.
    - Different assumptions in strangeness result in ~20% variation in charm cross-section.
  - Statistically limited (requires ~2 orders of magnitude higher luminosity).