

Probing the neutron skin thickness through jet charge in deep-inelastic scattering

Shan-Liang Zhang^{1,2,3,*}, Enke Wang^{2,4,†}, Xin-Nian Wang^{5,‡} and Hongxi Xing^{1,2,4,6,§}

¹Department of Physics, *Hubei University*, Wuhan 430062, China

²State Key Laboratory of Nuclear Physics and Technology, Institute of Quantum Matter,
South China Normal University, Guangzhou 510006, China

³Key Laboratory of Atomic and Subatomic Structure and Quantum Control (MOE),
Guangdong-Hong Kong Joint Laboratory of Quantum Matter, Guangzhou 510006, China

⁴Guangdong Basic Research Center of Excellence for Structure and Fundamental Interactions of Matter,
Guangdong Provincial Key Laboratory of Nuclear Science, Guangzhou 510006, China

⁵Key Laboratory of Quark and Lepton Physics (MOE) & Institute of Particle Physics,
Central China Normal University, Wuhan 430079, China

⁶Southern Center for Nuclear-Science Theory (SCNT), *Institute of Modern Physics*,
Chinese Academy of Sciences, Huizhou 516000, China

 (Received 16 July 2025; revised 26 August 2026; accepted 18 September 2026; published 20 October 2026)

The neutron-skin thickness in neutron-rich nuclei has traditionally been measured using low-energy hadronic and electronic scatterings at hadronic level. In this paper, we propose an alternative probe to the neutron-skin thickness through deep-inelastic scattering in high-energy electron-ion collisions, leveraging the intrinsic correlation between final-state jet charge distribution and initial-state partonic distributions in nucleons. Specifically, we demonstrate the sensitivity of jet charge distribution to the neutron skin-thickness and density profile in $e + \text{Pb}$ collisions with varying centralities as determined using Glauber model, and in isobar collisions of $e + \text{Ru}$ and $e + \text{Zr}$. We predict a strong suppression of positive jet charge distribution and an enhancement for negative jet charge distribution in peripheral electron-ion collisions, revealing the neutron-skin effect. Premised on the effective determination of centrality, this proposal can also be extended to photon and Z-boson tagged jet charge distribution in proton-nucleus collisions at the Large Hadron Collider, providing another similar access to neutron-skin structure.

DOI: [10.1103/zc6z-ss9j](https://doi.org/10.1103/zc6z-ss9j)

Introduction. Understanding the density distribution of protons and neutrons, particularly the neutron-skin thickness in nuclei, is crucial for constraining the fundamental properties of cold nuclear matter and the equation of state of neutron star [1–3]. The neutron-skin thickness $\Delta R_{np} = R_n - R_p$, defined as the difference in root-mean-square (rms) radii between neutrons (R_n) and protons (R_p) in nuclei, has been primarily studied using various channels including electroweak and hadronic probes at low-energy scales [4–8]. While proton radii have been accurately determined for many nuclei using electromagnetic probes since the 1970s [9], determining neutron density distribution is more challenge due to

nonperturbative uncertainties in hadronic probes and the low scattering rate for parity-violating electron scatterings.

Among various neutron-rich nuclei, the doubly magic nucleus ^{208}Pb is of particular interest due to its significant neutron excess. Recently, the PREX-II collaboration updated the measurement of neutron-skin thickness for ^{208}Pb , reporting $\Delta R_{np}^{\text{Pb}} = 0.283 \pm 0.071$ fm [10], significantly reducing the uncertainties compared to previous results $\Delta R_{np}^{\text{Pb}} = 0.33^{+0.16}_{-0.18}$ fm [11]. This measurement, derived from parity-violating asymmetries in polarized electron scattering, reveals some tension with *ab initio* calculations using chiral effective theory [12] and other measurements using hadronic probes and astrophysical observations [13]. For instance, coherent π photoproduction measurements reported $\Delta R_{np}^{\text{Pb}} = 0.15 \pm 0.03$ fm [6]. In addition to these measurements using low-energy facilities, new approaches have recently been proposed to extract ΔR_{np} from measurements in relativistic heavy-ion collisions [14–23]. In particular, through a global analysis of collective flow within the hydrodynamic model, $\Delta R_{np}^{\text{Pb}} = 0.217 \pm 0.058$ fm was obtained for ^{208}Pb [24], competitive with PREX-II measurement. Likewise, taking advantages of current programs at the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC), hard probes,

*Contact author: zhangshanl@hubu.edu.cn

†Contact author: wangek@scnu.edu.cn

‡Contact author: xnwang@ccnu.edu.cn

§Contact author: hxing@m.scnu.edu.cn

Published by the American Physical Society under the terms of the [Creative Commons Attribution 4.0 International](https://creativecommons.org/licenses/by/4.0/) license. Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI. Funded by SCOAP³.

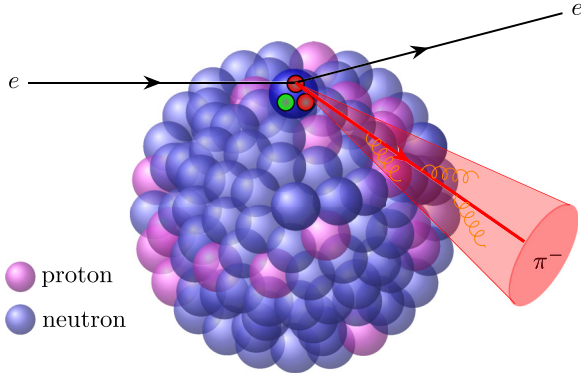


FIG. 1. An illustration depicting negative jet-charge production in eA collisions on a neutron-rich surface.

such as the ratio of W^+/W^- [25,26] and h^-/h^+ [27], as well as charged particles in isobar collisions [28], are also proposed to provide new insights into the nuclear structures.

To achieve a consensus on the quantitative constraints of ΔR_{np} , it is crucial to employ alternative probes with improvable theoretical and experimental control. In this paper, we propose to probe the neutron skin through deep-inelastic scattering (DIS) in high-energy electron-ion collisions. Unlike the conventional approach using hadronic or electroweak probes at low energies, where the nucleus remains intact, the virtual photon in DIS possesses sufficient energy to resolve the nucleons at the quark and gluon level. This mechanism effectively places proton and neutron on an equal footing for electromagnetic probes. This provides an alternative channel to detect the neutron density in nuclei using purely electromagnetic probes, which can be precisely measured in experiments and controlled via theoretical perturbative calculations. In terms of partonic structure, the primary difference between proton and neutron lies in the distribution of u -quark and d -quark within them, which is highly correlated with the final-state flavor distributions in neutral-current DIS process. This intrinsic correlation between the final-state flavor tagging and the initial-state u - and d -quark distributions, in turn, reveals the proton and neutron density distributions in nuclei, see Fig. 1.

We propose using the jet charge distribution as a proxy to u - and d -quark initiated jet, which has been shown to be a useful probe for nucleon structure [29] and extensively studied at RHIC and the LHC [30–33]. We demonstrate for the first time the sensitivity of this observable to the neutron skin of the nucleus at the upcoming Electron-Ion Collider (EIC) [34] with varying centralities as determined using Glauber model. Our findings indicate that the neutron-skin results in the increase of negatively charged jets and decrease of positively charged jets in the final state, particularly in peripheral collisions. Premised on the effective determination of centrality in EIC collisions, this approach enhances the capacity to study nucleon-level nuclear structure, connecting physical phenomena across distinct energy scales.

Jet charge and neutron skin. The concept of jet electric charge was initially proposed by Feynman and Field [35]. It

can be constructed from the definition [36,37]

$$Q_J = \sum_{h \in \text{jet}} \left(\frac{p_T^h}{p_T^J} \right)^\kappa Q_h, \quad (1)$$

where p_T^h and Q_h are the transverse momentum and electric charge, respectively, of the identified hadron within the jet with transverse momentum p_T^J , and κ is a free parameter that controls the shapes of the jet charge distribution.

In the center-of-mass frame of electron-nucleus (eA) DIS, $e + A \rightarrow e + \text{jet} + X$, the jet charge distribution in the back-to-back region of the outgoing electron jet can be derived within the transverse momentum-dependent (TMD) QCD factorization [29,38]

$$\frac{d\sigma}{dQ_J} = \sum_i e_i^2 \mathcal{F} \cdot \mathcal{T} \cdot \{ \tilde{f}_{i/A}(x, b_T) S_J(b_T, R) \times H_{ei \rightarrow ei}(Q) \mathcal{G}_i(Q_J, p_T^J R) \}, \quad (2)$$

where $\mathcal{F} \cdot \mathcal{T}$ stands for the Fourier transform from coordinate space to momentum space, $\tilde{f}_{i/A}(x, b_T)$ is the nuclear TMD distribution function [39,40], S_J is the soft function, and H is the hard factor with Q representing the invariant mass of the virtual photon in neutral-current DIS process. $\mathcal{G}_i$ is the fragmenting jet function with identified jet electric charge Q_J . The scale dependence in these functions is implicit.

As shown in Eq. (2), the initial parton i from the incident nucleus involved in the hard interaction is correlated with the flavor of final observed jet, making the jet flavor tagging an excellent probe of nuclear partonic structure. Noticing the primary difference in the flavor structure between proton and neutron lies in the distribution of u quark and d quark. Therefore, identifying u -quark and d -quark tagged jets in the final state can reveal the proton and neutron density distributions within the nucleus. We will utilize PYTHIA event generator, which has been shown to be consistent with the TMD factorization results [29], to simulate the jet charge distribution in DIS and demonstrate this correlation.

In our simulations, we investigate the neutron-skin effect by examining the centrality-dependent jet charge distribution in eA collisions,

$$\frac{d\sigma}{dQ_J} = 2\pi \sum_i \int_{b_{\min}}^{b_{\max}} db b f_{i/A}(x, \mu; b) \otimes \frac{d\sigma^i}{dQ_J}, \quad (3)$$

where b is the impact parameter, and the centrality class is determined by $b_{\min}$ and $b_{\max}$ [41]. In our calculation, the centrality is encoded in the impact parameter determined by the optimized Glauber model [41] as in Eq. (3). We notice that the event centrality in eA collisions is proposed to be correlated with the impact parameter b , and can be determined without relying on final-state hadron multiplicity. This can be achieved by measuring the evaporated neutrons from forward nuclear fragmentation in zero-degree calorimeters [42,43], or by analyzing the transverse momentum broadening of final-state particles [44]. A systematic investigation into the model dependence of centrality determination at the EIC is reserved for a dedicated future study.

In our calculation, the centrality dependence is encoded into the impact-parameter-dependent nuclear parton

distribution functions (nPDFs),

$$f_{i/A}(x, \mu; b) = \frac{T_A^p(b)}{T_A(b)} f_i^{p/A}(x, \mu) + \frac{T_A^n(b)}{T_A(b)} f_i^{n/A}(x, \mu), \quad (4)$$

where $T_A(b) = \int dz \rho_A(r)$ is the thickness function of nucleus A , and $T_A^p(b)$ and $T_A^n(b)$ are the corresponding thickness functions for proton and neutron, respectively.

In this study, the incoming nuclear beams are treated as consisting entirely of ground-state nuclei, which has been justified for high-energy collisions [45]. We implement the flavor-dependent nuclear distribution using the deformed Woods-Saxon (WS) distribution

$$\rho_{n,p}(r) = \frac{\rho_{n,p}^0}{1 + \exp\left(\frac{r - c_{n,p}}{a_{n,p}}\right)}, \quad (5)$$

where $\rho_{n,p}^0$ are the saturation densities, and $c_{n,p}$ and $a_{n,p}$ represent the half-density radius and surface diffuseness parameter, respectively. We neglect nucleon-nucleon correlation and nuclear deformation in our calculation as in Ref. [14]. We fix the WS parameters for the proton as $c_p = 6.680$ fm and $a_p = 0.448$ fm, corresponding to an rms proton radius in Pb $R_p = 5.436$ fm. PREX data [10] support a similar neutron diffuseness parameter a_n to that of proton a_p , while earlier measurements using hadronic probes [6,46] typically interpret the neutron skin as an increase in the neutron diffuseness parameter a_n rather than the half-density radius c_n . In our calculation, the parameters for neutron distribution were determined from different values of ΔR_{np} from the relation $R_n^2 \approx \frac{3}{5}c_n^2 + \frac{7}{5}\pi^2 a_n^2$ [46,47], assuming either $c_n = c_p$ (halo-type) or $a_n = a_p$ (skin-type).

Phenomenological results. We now present phenomenological results to demonstrate the sensitivity of nuclear skin on jet charge distribution at the EIC. We use the PYTHIA 8.3 [48], with default CT14nlo [49] and EPPS21 [50] parametrization for nPDFs in the following unless otherwise specified, to simulate jet charge distribution for eA collisions at $\sqrt{s} = 105$ GeV. DIS events are selected by requiring the invariant mass of the exchanged virtual photon $Q^2 \geq 10$ GeV². Both the electron's and jet's transverse momentum are selected within the phase space $p_T^{e,j} \geq 10$ GeV and rapidity $|\eta^{e,j}| \leq 2$. Jets are reconstructed with the FASTJET anti- k_t jet algorithm [51,52], with a radius parameter $R = 1.0$. We chose $\kappa = 0.3$ for jet charge distribution for effective jet flavor identification [29,53,54]. For the simplicity of illustration, we consider $\pi^\pm$ distribution in jet, as they play a dominant role in jet charge distribution. Besides, considering the fact that the contribution from strange quarks to the jet cross section is smaller than 6% and their negligible contribution to the jet charge asymmetry, we ignore the strange quark contributions in our analysis.

To illustrate the discriminative power of the jet charge distribution on u - and d -quark jet, we plot in Fig. 2 the u -quark (hollow) and d -quark (filled) initiated-jet distribution as a function of jet charge Q_J , normalized by the corresponding total jet cross section. The contributions from the bounded proton [denoted as “ $ep(A)$ ”] and neutron [denoted as “ $en(A)$ ”] in Pb are represented, respectively, by triangle and star markers, while the total contribution from $e + \text{Pb}$ collisions are

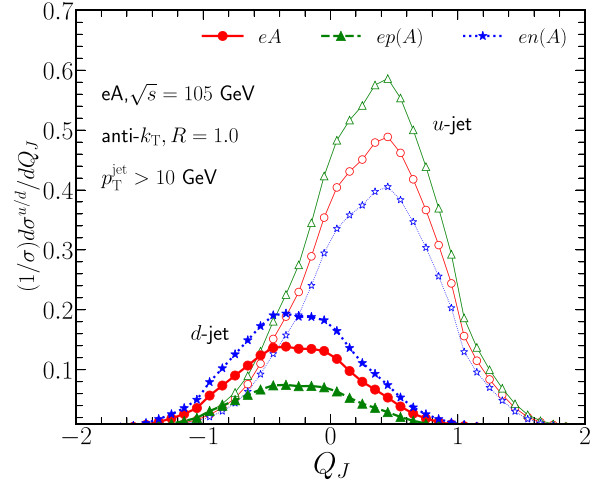


FIG. 2. Jet charge distribution of u - (hollow) and d -quark (filled) initiated-jet in $ep(A)$ (triangle), $en(A)$ (star), and eA (circle) collisions, normalized by the total jet cross section.

shown in circle marker. In this illustration, the neutron-skin thickness is set to 0, and the flavor of the final jet is tagged by the parton produced from the electron-parton hard scattering. As we expected, the positive jet charge is dominated by the u -quark channel, while d -quark channel mainly contributes in the negative jet charge region. These results indicate that the u -quark and d -quark jet can be well separated within different jet charge regions. It is important to note that u -quark jets play a major role across a wide range of Q_J , primarily due to the factor of four stronger electromagnetic coupling strength between the virtual photon and the u quark comparing to that for the d quark. This dominant role of u quark is even more pronounced for the contribution from protons bounded in Pb as shown by the green lines.

According to the above illustration, one would expect significant reduction in the positive jet charge distribution if the virtual photon interacts with the neutron-skin region, due to the relatively lower u -quark compositions in neutrons compared to protons. This phenomenon can be effectively examined as a function of centrality in eA collisions, which serves as a proxy for the spatial position of the struck nucleon within the nucleus. To quantify the correlation between nuclear skin and the jet charge distribution as a function of centrality, we propose measuring the centrality-dependent nuclear modification factor R^C . This factor is defined as the ratio of the jet charge distribution in a given centrality to that in minimum-bias (MB) events,

$$R^C(x, Q_J) = \frac{d\sigma^C/dxdQ_J}{d\sigma^{\text{MB}}/dxdQ_J}, \quad (6)$$

where x is the momentum fraction of parton i in nucleus per nucleon at leading order kinematics, defined as $x = \frac{e^{\eta^J} p_T^J}{E_e - e^{-\eta^J} p_T^J}$ [55], with E_e being the incoming electron energy in the center-of-mass frame.

Taking a moderate neutron-skin thickness as an example, i.e., $\Delta R_{np}^{\text{Pb}} = 0.15 \pm 0.03$ fm, we show in Fig. 3 the numerical results for R^C in 0–60%, 60–80% and 80–100% centrality

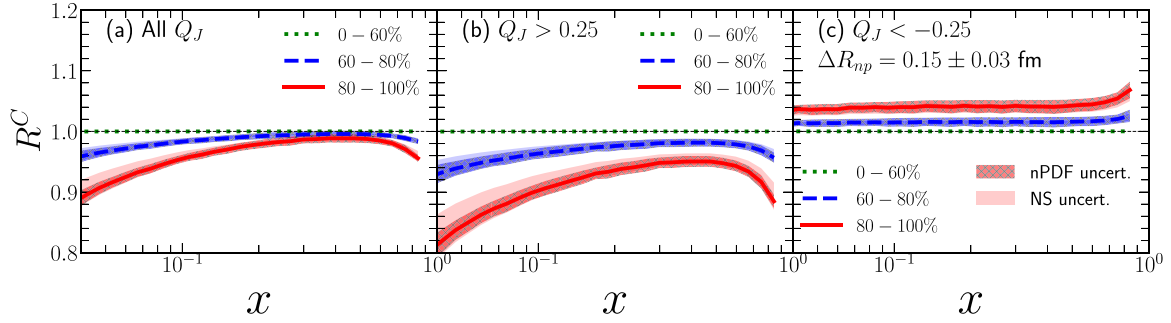


FIG. 3. The nuclear modification factor R^C in 0–60%, 60–80% and 80–100% centrality intervals with (a) all jet charge Q_J , (b) $Q_J > 0.25$, (c) $Q_J < -0.25$. The model uncertainties from EPPS21 nPDF set [50] are shown by dark color band around lines., while the light color band are calculated with the uncertainties of the extracted ΔR_{np} .

intervals with (a) all jet charge Q_J , (b) $Q_J > 0.25$, (c) $Q_J < -0.25$. As can be seen, even without specific jet charge selection, R^C exhibits a moderate sensitivity to centralities, which is caused by the dominance of u -quark jets in DIS as shown in Fig. 2. The suppression of R^C reveals the reduction of initial u -quark contribution in the presence of neutron skin in peripheral collisions, while such suppression is negligible in central collisions due to the absence of neutron-skin effect in the center of the nucleus. This sensitivity is further enhanced when a selection cut $Q_J > 0.25$ is applied, as the role of u -quark jet becomes more significant in this region. On the contrary, the increase of d -quark jets and suppression of u -quark jets in $Q_J < -0.25$ region lead to the enhancements of R^C with increasing centralities. Crucially, the theoretical uncertainty originating from the EPPS21 nPDF set [50] (dark color bands) is generally smaller than the uncertainty from current neutron-skin constraints (light color bands). Furthermore, we expect that more accurate nPDFs will be determined from the current proton-nucleus program at the LHC and the future EIC [34,56].

According to the above illustration, we propose measuring the following double ratio to enhance the sensitivity of jet charge distribution on ΔR_{np} :

$$\mathbb{R} \equiv \frac{R^C(x, Q_J \leq -Q_c)}{R^C(x, Q_J \geq Q_c)} = \frac{d\sigma^C/dxdQ_J|_{Q_J \leq -Q_c}}{d\sigma^C/dxdQ_J|_{Q_J \geq Q_c}} \frac{d\sigma^{\text{MB}}/dxdQ_J|_{Q_J \geq Q_c}}{d\sigma^{\text{MB}}/dxdQ_J|_{Q_J \leq -Q_c}}, \quad (7)$$

where Q_c is a parameter for specific selection of jet charge regions and set to 0.25 in our simulations. We expect that this double ratio could mitigate the model uncertainties of centrality definition and other cold nuclear-matter effects. One possible contamination of cold nuclear-matter effect is the effect of final-state multiple scattering, such as the transverse momentum broadening [57–60] and parton energy loss [61–63] in cold nuclear matter. However, such an effect is driven by the strong interaction of QCD and is blind to the electric charge. Therefore, it is expected that these final-state effects are similar for u -quark and d -quark jets and will also be significantly canceled in the double ratio $\mathbb{R}$.

Shown in the upper panel of Fig. 4 are the results for $\mathbb{R}$, as a function of centrality, evaluated at $x = 0.05$ with $\Delta R_{np} = 0$ fm, $\Delta R_{np} = 0.15 \pm 0.03$ fm, and $\Delta R_{np} = 0.28 \pm 0.071$ fm.

The solid lines represent the “skin-type” model by varying c_n and fixing $a_n = 0.448$ fm. The dashed lines represent the “halo-type” model by varying a_n as shown in Table I. One can clearly see larger ΔR_{np} for Pb yield a qualitatively similar increasing trend for $\mathbb{R}$ toward more peripheral collisions in both models. However, we also note distinct quantitative differences: the slope of the dashed curves from the “halo-type” model is steeper in peripheral collisions, whereas in the 40–60% centrality range, the “skin-type” leads to more pronounced effect on $\mathbb{R}$. In our calculation, we find out that the slope of the centrality-dependent $\mathbb{R}$ is mainly sensitive to surface-diffuseness parameter a_n , which controls the neutron density profile in nuclei. The magnitude of $\mathbb{R}$ in a given centrality can be used to determine the parameter c_n . Therefore, these distinct features further demonstrate the high sensitivity of our proposed observable not only to the magnitude of the neutron skin, but also to the underlying shape of

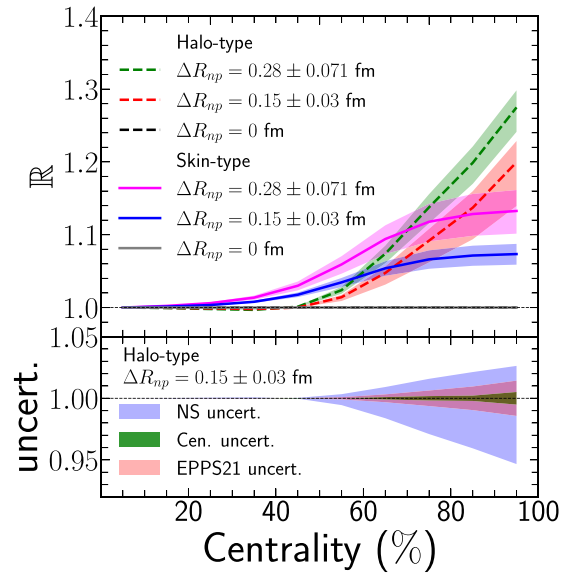


FIG. 4. Upper: The double ratio $\mathbb{R}$ at $x = 0.05$ in $e + \text{Pb}$ collisions with “halo-type” (dashed lines) and “skin-type” (solid lines) neutron-skin thickness. Bottom: Uncertainties for $\mathbb{R}$ calculated from centrality-selection effects (change the centrality class by 10% within Glauber model, and designated as “Cen. uncert.”), nPDF from EPPS21, and NS effect.

TABLE I. WS parameters and neutron-skin thickness for $^{208}_{82}\text{Pb}$, $^{96}_{44}\text{Ru}$, and $^{96}_{40}\text{Zr}$ used in our numerical calculations.

Nucleus	c_p [fm]	a_p [fm]	c_n [fm]	a_n [fm]	ΔR_{np}
$^{208}_{82}\text{Pb}$ [6]	6.68	0.448	6.69	0.448	0
$^{208}_{82}\text{Pb}$ [6]	6.68	0.448	6.69	$0.566^{+0.028}_{-0.045}$	0.15 ± 0.03
$^{208}_{82}\text{Pb}$ [10]	6.68	0.448	6.69	$0.654^{+0.044}_{-0.046}$	0.28 ± 0.071
$^{96}_{44}\text{Ru}$ [21]	5.06	0.493	5.075	0.505	0.03
$^{96}_{40}\text{Zr}$ [21]	4.915	0.521	5.015	0.574	0.16

the neutron density profile. Considering the high luminosity design and high statistics of the EIC [34], the uncertainties from systematic and statistical errors are expected to be much smaller than the bands shown in Fig. 4, providing a promising determination of ΔR_{np} in the future EIC.

The primary challenge in applying our proposal to realistic measurements lies in the determination of centrality. To simulate centrality-selection effects, we vary the centrality class by 10% within our optimized Glauber model. The results of this centrality-selection effect on the double ratio $\mathbb{R}$ is shown in the bottom panel of Fig. 4. The green band (designated by Cen. uncert.) shows the relative uncertainty, which is an order of magnitude smaller than that from neutron-skin effect (purple band). Within such an estimated centrality-selection uncertainty, the double ratio can still be well separated between different neutron-skin scenarios, as shown in the top panel.

To further investigate how our results depend on the choice of different nPDF sets, we present our results with three different nPDF sets (EPPSS21 [50], nNNPDF3.0 [64], and nCTEQ15 [65]) as shown in Fig. 5. The results for $\mathbb{R}$ from three nPDFs are qualitatively consistent. Quantitatively, EPPSS21 is consistent with that from nNNPDF3.0, but is larger than that from nCTEQ15. This difference arises from the fact that the extracted nuclear modification ratios R_A for both u and d quark at $x = 0.05$ from nCTEQ15 are smaller than the results from EPPSS21 and nNNPDF3.0. These dif-

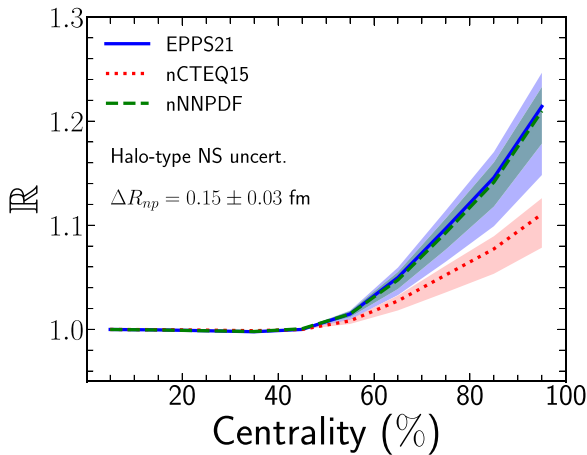


FIG. 5. The double ratio $\mathbb{R}$ calculated at $x = 0.05$ in $e + \text{Pb}$ collisions from EPPSS21, nCTEQ, nNNPDF nPDF set with halo-type neutron-skin thickness.

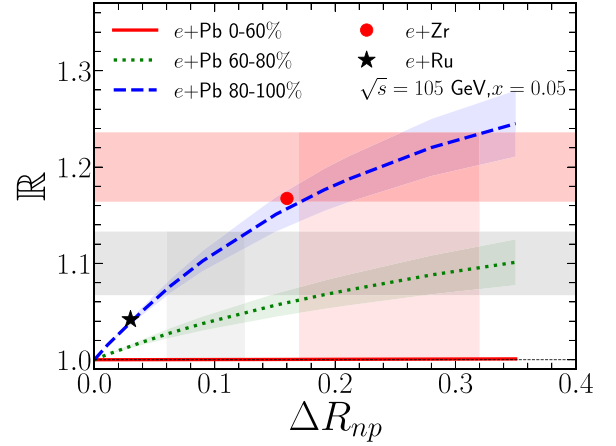


FIG. 6. The double ratio $\mathbb{R}$ evaluated as a function of ΔR_{np} in three centralities of $e + \text{Pb}$ (lines) collisions, 80–100% $e + \text{Ru}$ (solid circle), and $e + \text{Zr}$ (solid star) collisions. The vertical bands show the variation of $\mathbb{R}$ due to uncertainties of ΔR_{np} , while the horizontal bands represent the impact of 3% uncertainty of $\mathbb{R}$ on ΔR_{np} .

ferences are mainly driven by different experimental datasets selection in their fittings, which we believe will be converged considering world data from the current proton-nucleus programs at the LHC and the future EIC [34,56], and this will in turn reduce the model uncertainties in our proposal.

Shown in Fig. 6 are results for $\mathbb{R}$ as a function of ΔR_{np} of ^{208}Pb , ^{96}Ru , and ^{96}Zr . As we observe, $\mathbb{R}$ for $e + \text{Pb}$ with different centralities, shown by the curves, increases monotonically with ΔR_{np} , and the growth rate rises with centrality. The vertical bands show the variation of $\mathbb{R}$ due to uncertainties in the extracted ΔR_{np} , while the horizontal bands represent the impact of 3% experimental uncertainty (akin to LHC measurements [30–32]) of $\mathbb{R}$ on the extraction of ΔR_{np} . The predicted sensitivity to the relative differences in the small- ΔR_{np} region is particularly impactful for probing the differences between $^{96}_{44}\text{Ru}$ and $^{96}_{40}\text{Zr}$. For illustration, we use the WS parameters for $^{96}_{44}\text{Ru}$ and $^{96}_{40}\text{Zr}$ from Ref. [21], as listed in Table I. The small ΔR_{np} of $^{96}_{44}\text{Ru}$ results in small impact on the double ratio in peripheral collisions (80–100%) as shown by the black star marker, while $^{96}_{40}\text{Zr}$, shown by red circle point, result in a 17% change in the double ratio in peripheral collisions.

Summary and discussions. Taking full advantage of the intrinsic correlation between final-state jet-flavor information and initial-state nuclear partonic structure in high-energy deep-inelastic eA collisions, we propose using jet charge distribution as a novel hard probe to measure ΔR_{np} , differing from the traditional method of low-energy elastic scatterings. Taking $e + \text{Pb}$ collision as an example, we demonstrate the sensitivity of jet charge distributions in peripheral collisions to the neutron-skin effect at the EIC, based on the centrality determination using Glauber model. We calculated the peripheral to minimum-bias event ratio R^C and predicted strong suppression in positive jet charge region and enhancement in negative jet charge region, revealing the impact of ΔR_{np} on the u -quark and d -quark jet production in peripheral eA collisions. Furthermore, through the double ratio of $\mathbb{R}$, we ex-

pect improved sensitivity to ΔR_{np} and mitigation of bias from centrality classification, as well as final-state cold nuclear-matter effects. Specifically, considering the WS parameters from the state-of-art measurement of PREX-II, we observe up to 30% deviations from unity, representing non-neutron-skin effects, in the most peripheral 90–100% $e + \text{Pb}$ collisions. We also observe pronounced sensitivity to the relative differences in the small- ΔR_{np} region, leading to more than 10% change in the double ratio in peripheral collisions between $e + \text{Ru}$ and $e + \text{Zr}$ collisions. Our proposal extends the current programs of EIC, providing an alternative method to probe the neutron-skin effect. Premised on the effective determination of centrality, high luminosity, and statistics at the EIC, more accurate determination of the neutron skin will be feasible.

We emphasize that our proposal of using jet charge to probe ΔR_{np} is not limited to the EIC and can have broad applications. For example, the idea can be extended to jet charge distribution in $p + \text{Pb}$ program at the LHC. It has been show that prompt photon and Z-boson tagged jets are dominated by quark jets [66], providing another golden channel to access

the initial u -quark and d -quark distributions. This intrinsic correlation offers an alternative approach to measure ΔR_{np} . Detailed phenomenological investigations will be presented in a future publication. Furthermore, joint distribution of jet charge and particle multiplicity can carry more information for u - and d -quark jet discrimination [54] at the LHC, which can be implemented to further improve the sensitivity of jet charge on neutron-skin effect.

Acknowledgments. We thank Weiyao Ke, Xiaohui Liu, and Liang Zheng for useful discussions. This research is supported by the National Natural Science Foundation of China with Projects No. 12405152, No. 12525508, No. 12475139, and No. 11935007.

Data availability. The data that support the findings of this article are not publicly available upon publication because it is not technically feasible and/or the cost of preparing, depositing, and hosting the data would be prohibitive within the terms of this research project. The data are available from the authors upon reasonable request.

-
- [1] P. Roy, R. Kanungo, E. Haettner, Y. Tanaka, S. Bagchi, T. Dickel, D. Kostyleva, J. Zhao, H. Geissel, C. Scheidenberger, and I. Tanihata (SuperFRS Collaboration), Neutron skin thickness in ^{208}Pb and its connection to nuclear equation of state, and neutron star structure, *DAE Symp. Nucl. Phys.* **67**, 23 (2024).
 - [2] F. Sammarruca, The neutron skin of ^{48}Ca and ^{208}Pb : A critical analysis, *Symmetry* **16**, 34 (2024).
 - [3] Y.-G. Ma and S. Zhang, in *Influence of Nuclear Structure in Relativistic Heavy-Ion Collisions*, edited by I. Tanihata, H. Toki, and T. Kajino, Handbook of Nuclear Physics (Springer, Singapore, 2022), pp. 1–30.
 - [4] B. C. Clark, L. J. Kerr, and S. Hama, Neutron densities from a global analysis of medium-energy proton-nucleus elastic scattering, *Phys. Rev. C* **67**, 054605 (2003).
 - [5] E. Friedman, Neutron skins of ^{208}Pb and ^{48}Ca from pionic probes, *Nucl. Phys. A* **896**, 46 (2012).
 - [6] C. M. Tarbert, D. P. Watts, D. I. Glazier, P. Aguar, J. Ahrens, J. R. M. Annand, H. J. Arends, R. Beck, V. Bekrenev, B. Boillat, A. Braghieri, D. Branford, W. J. Briscoe, J. Brudvik, S. Cherepnaya, R. Codling, E. J. Downie, K. Foehl, P. Grabmayr, R. Gregor, *et al.*, Neutron skin of ^{208}Pb from coherent pion photoproduction, *Phys. Rev. Lett.* **112**, 242502 (2014).
 - [7] B. Alex Brown, G. Shen, G. C. Hillhouse, J. Meng, and A. Trzcińska, Neutron skin deduced from antiprotonic atom data, *Phys. Rev. C* **76**, 034305 (2007).
 - [8] X. Roca-Maza, X. Viñas, M. Centelles, B. K. Agrawal, G. Colò, N. Paar, J. Piekarewicz, and D. Vretenar, Neutron skin thickness from the measured electric dipole polarizability in ^{68}Ni , ^{120}Sn , and ^{208}Pb , *Phys. Rev. C* **92**, 064304 (2015).
 - [9] B. Frois, J. B. Bellicard, J. M. Cavedon, M. Huet, P. Leconte, P. Ludeau, A. Nakada, P. Z. Hô, and I. Sick, High-momentum-transfer electron scattering from ^{208}Pb , *Phys. Rev. Lett.* **38**, 152 (1977).
 - [10] D. Adhikari, H. Alataineh, D. Androic, K. Aniol, D. S. Armstrong, T. Averett, C. Ayerbe Gayoso, S. Barcus, V. Bellini, R. S. Beminiwattha, J. F. Benesch, H. Bhatt, D. Bhatta Pathak, D. Bhetuwal, B. Blaikie, Q. Campagna, A. Camsonne, G. D. Cates, Y. Chen, C. Clarke, *et al.*, (PREX Collaboration), Accurate determination of the neutron skin thickness of ^{208}Pb through parity-violation in electron scattering, *Phys. Rev. Lett.* **126**, 172502 (2021).
 - [11] S. Abrahamyan, Z. Ahmed, H. Alataineh, K. Aniol, D. S. Armstrong, W. Armstrong, T. Averett, B. Babineau, A. Barbieri, V. Bellini, R. Beminiwattha, J. Benesch, F. Benmokhtar, T. Bielarski, W. Boeglin, A. Camsonne, M. Canan, P. Carter, G. D. Cates, C. Chen, *et al.*, Measurement of the neutron radius of ^{208}Pb through parity violation in electron scattering, *Phys. Rev. Lett.* **108**, 112502 (2012).
 - [12] B. Hu, W. Jiang, T. Miyagi, Z. Sun, A. Ekström, C. Forssén, G. Hagen, J. D. Holt, T. Papenbrock, S. Ragnar Stroberg, and I. Vernon, *Ab initio* predictions link the neutron skin of ^{208}Pb to nuclear forces, *Nat. Phys.* **18**, 1196 (2022).
 - [13] B. T. Reed, F. J. Fattoyev, C. J. Horowitz, and J. Piekarewicz, Implications of PREX-2 on the equation of state of neutron-rich matter, *Phys. Rev. Lett.* **126**, 172503 (2021).
 - [14] H. Li, H.-j. Xu, Y. Zhou, X. Wang, J. Zhao, L.-W. Chen, and F. Wang, Probing the neutron skin with ultrarelativistic isobaric collisions, *Phys. Rev. Lett.* **125**, 222301 (2020).
 - [15] Q. Liu, S. Zhao, H.-j. Xu, and H. Song, Determining the neutron skin thickness by relativistic semi-isobaric collisions, *Phys. Rev. C* **109**, 034912 (2024).
 - [16] W.-M. Guo, B.-A. Li, and G.-C. Yong, Interplay of effects of neutron skins in coordinate space and proton skins in momentum space on emission of hard photons in heavy-ion collisions near the Fermi energy, *Phys. Rev. C* **108**, 034617 (2023).
 - [17] L.-M. Liu, J. Xu, and G.-X. Peng, Measuring deformed neutron skin with free spectator nucleons in relativistic heavy-ion collisions, *Phys. Lett. B* **838**, 137701 (2023).
 - [18] Y.-L. Cheng, S. Shi, Y.-G. Ma, H. Stöcker, and K. Zhou, Examination of nucleon distribution with Bayesian imaging for isobar collisions, *Phys. Rev. C* **107**, 064909 (2023).

- [19] L.-M. Liu, C.-J. Zhang, J. Xu, J. Jia, and G.-X. Peng, Free spectator nucleons in ultracentral relativistic heavy-ion collisions as a probe of neutron skin, *Phys. Rev. C* **106**, 034913 (2022).
- [20] L.-M. Liu, C.-J. Zhang, J. Zhou, J. Xu, J. Jia, and G.-X. Peng, Probing neutron-skin thickness with free spectator neutrons in ultracentral high-energy isobaric collisions, *Phys. Lett. B* **834**, 137441 (2022).
- [21] H.-j. Xu, W. Zhao, H. Li, Y. Zhou, L.-W. Chen, and F. Wang, Probing nuclear structure with mean transverse momentum in relativistic isobar collisions, *Phys. Rev. C* **108**, L011902 (2023).
- [22] H.-j. Xu, H. Li, X. Wang, C. Shen, and F. Wang, Determine the neutron skin type by relativistic isobaric collisions, *Phys. Lett. B* **819**, 136453 (2021).
- [23] H. Zhang, A. Akridge, C. J. Horowitz, J. Liao, and H. Xing, Probing the neutron skin with extreme collision geometries in heavy-ion collisions, [arXiv:2510.07816](https://arxiv.org/abs/2510.07816).
- [24] G. Giacalone, G. Nijs, and W. van der Schee, Determination of the neutron skin of ^{208}Pb from ultrarelativistic nuclear collisions, *Phys. Rev. Lett.* **131**, 202302 (2023).
- [25] H. Paukkunen, Neutron skin and centrality classification in high-energy heavy-ion collisions at the LHC, *Phys. Lett. B* **745**, 73 (2015).
- [26] G. Aad, B. Abbott, D. C. Abbott, A. Abed Abud, K. Abeling, D. K. Abhayasinghe, S. H. Abidi, O. S. AbouZeid, N. L. Abraham, H. Abramowicz, H. Abreu, Y. Abulaiti, B. S. Acharya, B. Achkar, S. Adachi, L. Adam, C. Adam Bourdarios, L. Adamczyk, L. Adamek, J. Adelman, *et al.*, (ATLAS), Measurement of $W^\pm$ boson production in Pb+Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV with the ATLAS detector, *Eur. Phys. J. C* **79**, 935 (2019).
- [27] I. Helenius, H. Paukkunen, and K. J. Eskola, Neutron-skin effect in direct-photon and charged-hadron production in Pb+Pb collisions at the LHC, *Eur. Phys. J. C* **77**, 148 (2017).
- [28] W. van der Schee, Y.-J. Lee, G. Nijs, and Y. Chen, Hard probes in isobar collisions as a probe of the neutron skin, *Phys. Lett. B* **856**, 138953 (2024).
- [29] Z.-B. Kang, X. Liu, S. Mantry, and D. Y. Shao, Jet charge: A flavor prism for spin asymmetries at the electron-ion collider, *Phys. Rev. Lett.* **125**, 242003 (2020).
- [30] G. Aad, B. Abbott, J. Abdallah, O. Abidinov, R. Aben, M. Abolins, O. S. AbouZeid, H. Abramowicz, H. Abreu, R. Abreu, Y. Abulaiti, B. S. Acharya, L. Adamczyk, D. L. Adams, J. Adelman, S. Adomeit, T. Adye, A. A. Affolder, T. Agatonovic-Jovin, J. Agricola, *et al.* (ATLAS Collaboration), Measurement of jet charge in dijet events from $s = 8$ TeV pp collisions with the ATLAS detector, *Phys. Rev. D* **93**, 052003 (2016).
- [31] A. M. Sirunyan, A. Tumasyan, W. Adam, E. Asilar, T. Bergauer, J. Brandstetter, E. Brondolin, M. Dragicevic, J. Erö, M. Flechl, M. Friedl, R. Frühwirth, V. M. Ghete, C. Hartl, N. Hörmann, J. Hrubec, M. Jeitler, A. König, I. Krätschmer, D. Liko, *et al.*, (CMS Collaboration), Measurements of jet charge with dijet events in pp collisions at $\sqrt{s} = 8$ TeV, *J. High Energy Phys.* **10** (2017) 131.
- [32] A. M. Sirunyan *et al.*, (CMS Collaboration), Measurement of quark- and gluon-like jet fractions using jet charge in PbPb and pp collisions at 5.02 TeV, *J. High Energy Phys.* **07** (2020) 115.
- [33] B. E. Aboona, J. Adam, G. Agakishiev, I. Aggarwal, M. M. Aggarwal, Z. Ahammed, A. Aitbayev, I. Alekseev, E. Alpatov, A. K. Alshammri, A. Aparin, S. Aslam, J. Atchison, G. S. Averichev, V. Bairathi, X. Bao, K. Barish, S. Behera, P. Bhagat, A. Bhasin, *et al.*, (STAR Collaboration), Measurement of two-point energy correlators within jets in $p + p$ collisions at $s = 200$ GeV, *Phys. Rev. Lett.* **135**, 111901 (2025).
- [34] R. Abdul Khalek, A. Accardi, J. Adam, D. Adamiak, W. Akers, M. Albaladejo, A. Al-bataineh, M.G. Alexeev, F. Ameli, P. Antonioli, N. Armesto, W.R. Armstrong, M. Arratia, J. Arrington, A. Asaturyan, M. Asai, E.C. Aschenauer, S. Aune, H. Avagyan, C. Ayerbe Gayoso, *et al.*, Science requirements and detector concepts for the electron-ion collider, *Nucl. Phys. A* **1026**, 122447 (2022).
- [35] R. D. Field and R. P. Feynman, A parametrization of the properties of quark jets, *Nucl. Phys. B* **136**, 1 (1978).
- [36] D. Krohn, M. D. Schwartz, T. Lin, and W. J. Waalewijn, Jet charge at the LHC, *Phys. Rev. Lett.* **110**, 212001 (2013).
- [37] W. J. Waalewijn, Calculating the charge of a jet, *Phys. Rev. D* **86**, 094030 (2012).
- [38] X. Liu, F. Ringer, W. Vogelsang, and F. Yuan, Lepton-jet correlations in deep inelastic scattering at the electron-ion collider, *Phys. Rev. Lett.* **122**, 192003 (2019).
- [39] M. Alrashed, D. Anderle, Z.-B. Kang, J. Terry, and H. Xing, Nuclear modification of transverse momentum dependent parton distribution functions by a global QCD analysis, *Phys. Rev. Lett.* **129**, 242001 (2022).
- [40] M. Alrashed, Z.-B. Kang, J. Terry, H. Xing, and C. Zhang, Nuclear modified transverse momentum dependent parton distribution and fragmentation functions, [arXiv:2312.09226](https://arxiv.org/abs/2312.09226).
- [41] M. L. Miller, K. Reygers, S. J. Sanders, and P. Steinberg, Glauber modeling in high-energy nuclear collisions, *Annu. Rev. Nucl. Part. Sci.* **57**, 205 (2007).
- [42] L. Zheng, E. C. Aschenauer, and J. H. Lee, Determination of electron-nucleus collision geometry with forward neutrons, *Eur. Phys. J. A* **50**, 189 (2014).
- [43] W. Chang, E.-C. Aschenauer, M. D. Baker, A. Jentsch, J.-H. Lee, Z. Tu, Z. Yin, and L. Zheng, Benchmark eA generator for lepton production in high-energy lepton-nucleus collisions, *Phys. Rev. D* **106**, 012007 (2022).
- [44] W. Ke, Y.-Y. Zhang, H. Xing, and X.-N. Wang, Event generator for jet tomography in electron-ion collisions, *Phys. Rev. D* **110**, 034001 (2024).
- [45] R. Bruce, D. Bocian, S. Gilardoni, and J. M. Jowett, Beam losses from ultraperipheral nuclear collisions between $^{82}\text{Pb}^{208+}$ ions in the large hadron collider and their alleviation, *Phys. Rev. ST Accel. Beams* **12**, 071002 (2009).
- [46] A. Trzcińska, J. Jastrzębski, P. Lubiński, F. J. Hartmann, R. Schmidt, T. von Egidy, and B. Kłos, Neutron density distributions deduced from antiprotonic atoms, *Phys. Rev. Lett.* **87**, 082501 (2001).
- [47] C. J. Horowitz, J. Piekarewicz, and B. Reed, Insights into nuclear saturation density from parity-violating electron scattering, *Phys. Rev. C* **102**, 044321 (2020).
- [48] T. Sjöstrand, S. Mrenna, and P. Skands, A brief introduction to PYTHIA 8.1, *Comput. Phys. Commun.* **178**, 852 (2008).
- [49] S. Dulat, T.-J. Hou, J. Gao, M. Guzzi, J. Huston, P. Nadolsky, J. Pumplin, C. Schmidt, D. Stump, and C.-P. Yuan, New parton distribution functions from a global analysis of quantum chromodynamics, *Phys. Rev. D* **93**, 033006 (2016).
- [50] K. J. Eskola, P. Paakkinen, H. Paukkunen, and C. A. Salgado, EPPS21: a global QCD analysis of nuclear PDFs, *Eur. Phys. J. C* **82**, 413 (2022).
- [51] M. Cacciari, G. P. Salam, and G. Soyez, The anti- k_t jet clustering algorithm, *J. High Energy Phys.* **04** (2008) 063.

- [52] M. Cacciari, G. P. Salam, and G. Soyez, FastJet user manual, *Eur. Phys. J. C* **72**, 1896 (2012).
- [53] Z.-B. Kang, X. Liu, S. Mantry, M. C. Spraker, and T. Wilson, Dynamic jet charge, *Phys. Rev. D* **103**, 074028 (2021).
- [54] Z.-B. Kang, A. J. Larkoski, and J. Yang, Towards a nonperturbative formulation of the Jet charge, *Phys. Rev. Lett.* **130**, 151901 (2023).
- [55] Z.-B. Kang, X. Liu, S. Mantry, and J.-W. Qiu, Probing nuclear dynamics in jet production with a global event shape, *Phys. Rev. D* **88**, 074020 (2013).
- [56] D. P. Anderle, V. Bertone, X. Cao, L. Chang, N. Chang, G. Chen, X. Chen, Z. Chen, Z. Cui, L. Dai, W. Deng, M. Ding, X. Feng, C. Gong, L. Gui, F.-K. Guo, C. Han, J. He, T.-J. Hou, H. Huang, *et al.*, Electron-ion collider in China, *Front. Phys.* **16**, 64701 (2021).
- [57] X.-f. Guo, Jet broadening in deeply inelastic scattering, *Phys. Rev. D* **58**, 114033 (1998).
- [58] Z.-B. Kang, E. Wang, X.-N. Wang, and H. Xing, Next-to-leading order QCD factorization for semi-inclusive deep inelastic scattering at twist 4, *Phys. Rev. Lett.* **112**, 102001 (2014).
- [59] P. Ru, Z.-B. Kang, E. Wang, H. Xing, and B.-W. Zhang, Global extraction of the jet transport coefficient in cold nuclear matter, *Phys. Rev. D* **103**, L031901 (2021).
- [60] P. Ru, Z.-B. Kang, E. Wang, H. Xing, and B.-W. Zhang, Probing the jet transport coefficient of cold nuclear matter in electron-ion collisions, *Chin. Phys. C* (2026), doi:10.1088/1674-1137/ae9924.
- [61] X.-f. Guo and X.-N. Wang, Multiple scattering, parton energy loss, and modified fragmentation functions in deeply inelastic eA scattering, *Phys. Rev. Lett.* **85**, 3591 (2000).
- [62] E. Wang and X.-N. Wang, Jet tomography of hot and cold nuclear matter, *Phys. Rev. Lett.* **89**, 162301 (2002).
- [63] H. T. Li and I. Vitev, Nuclear matter effects on jet production at electron-ion colliders, *Phys. Rev. Lett.* **126**, 252001 (2021).
- [64] R. Abdul Khalek, R. Gauld, T. Giani, E. R. Nocera, T. R. Rabemananjara, and J. Rojo, nNNPDF3.0: evidence for a modified partonic structure in heavy nuclei, *Eur. Phys. J. C* **82**, 507 (2022).
- [65] K. Kovařík, A. Kusina, T. Ježo, D. B. Clark, C. Keppel, F. Lyonnet, J. G. Morfin, F. I. Olness, J. F. Owens, I. Schienbein, and J. Y. Yu, nCTEQ15: Global analysis of nuclear parton distributions with uncertainties in the CTEQ framework, *Phys. Rev. D* **93**, 085037 (2016).
- [66] S.-L. Zhang, X.-N. Wang, and B.-W. Zhang, Quenching of jets tagged with W bosons in high-energy nuclear collisions, *Phys. Rev. C* **105**, 054902 (2022).