Snowmass 2021 Letter of Interest: <u>Hadronic Tomography at the EIC</u>
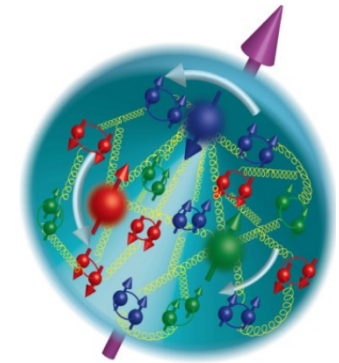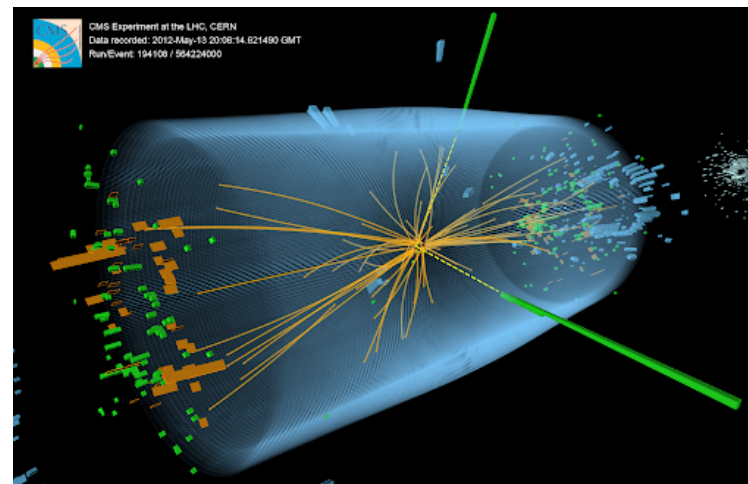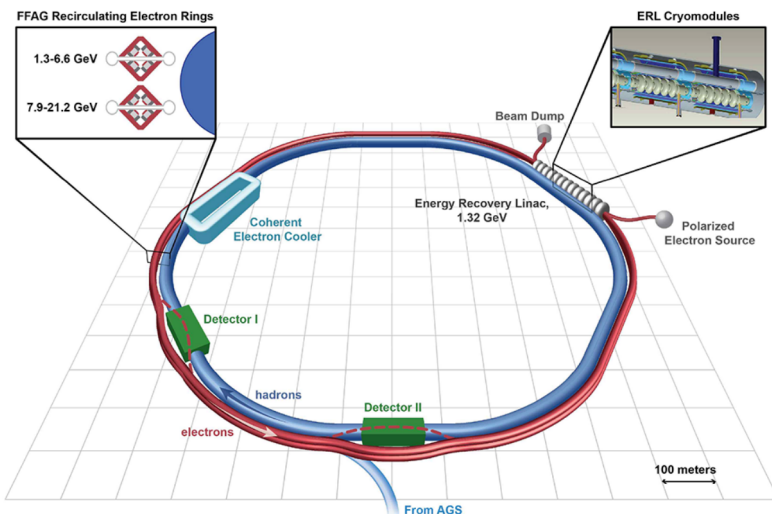
<u>… and the Energy Frontier</u>

Editors: Salvatore Fazio, <u>Tim Hobbs</u>, Alexei Prokudin, Alessandro Vicini

11 November 2020

possibilities and connections to nuclear and helicity PDFs

Hadronic Tomography at the EIC and the Energy Frontier

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→ broad document representing multiple sub-communities

completed LoI available here

- focus: EIC determinations of partonic distributions (**PDFs**, **GPDs**, TMDs)

- tomography encompasses a wide range of EIC ↔ HEP topics

▪ numerous 3D structure connections to LHC program/objectives

- **PDFs** and **GPDs**/TMDS: including helicity-odd M.E.s $\sim \langle \gamma^+ \gamma_5 \rangle$ select topics

- high-energy QCD (DIS measurements; heavy quarks/masses, jets, α_s)

- gluonic structure/Higgs (gluon PDF/GPD; improvements to gg$\rightarrow$ h production)

- QED effects (photon PDF; improved EW corrections)

- nuclear structure (nuclear PDFs; connections to heavy-ion UPCs)

▪ progress will depend on various methods

$\rightarrow$ phenomenological studies; global analyses [of **PDFs**, **GPDs** ...]

$\rightarrow$ continuum QCD approaches

$\rightarrow$ lattice QCD input

$\rightarrow$ AI/machine-learning and MCEGs

measuring hadron's multi-dimensional structure at the EIC

- extract unintegrated matrix elements from data: [schematic]

$$W(x, \vec{b}_T, \vec{k}_T) \sim \langle \gamma^+, \gamma^+ \gamma_5 \rangle \quad \textit{e.g.,} \text{ Wigner distribution}$$

→ related to other distributions via projections,

$$f(x, \vec{k}_T) = \int d^2\vec{b}_T \, W(x, \vec{b}_T, \vec{k}_T) \qquad \text{TMD}$$

$$f(x) = \int d^2\vec{k}_T \, f(x, \vec{k}_T) \qquad \text{PDF}$$

this generalizes to **helicity-odd distributions**; **GPDs**; also, light **nuclei**!

- precision goals at HL-LHC depend partly on hadron structure information

→ PDFs, GPDs → SM predictions in hadronic collisions

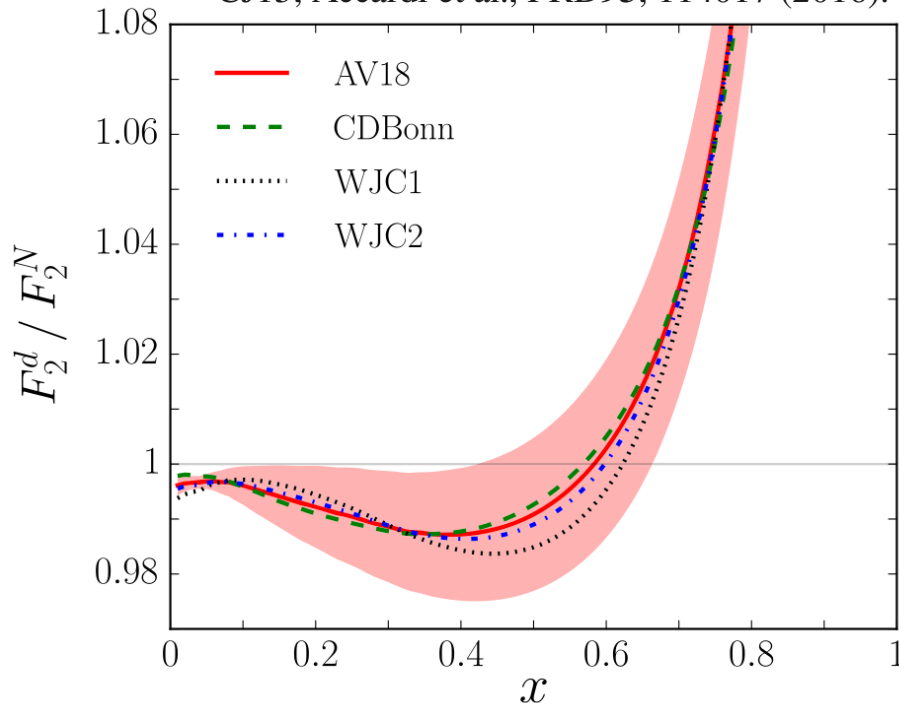→ tomography will be a collaborative theme between EIC/LHC

(i) importance of nuclear data in free nucleon QCD analyses

- ## information involving light nuclei

  → the d-quark is predominantly determined from deuterium data with model-dependent nuclear correction(s):

  $$f^{q/d} = f^{q/N} \otimes f^{N/d}$$

CJ15, Accardi et al., PRD**93**, 114017 (2016).
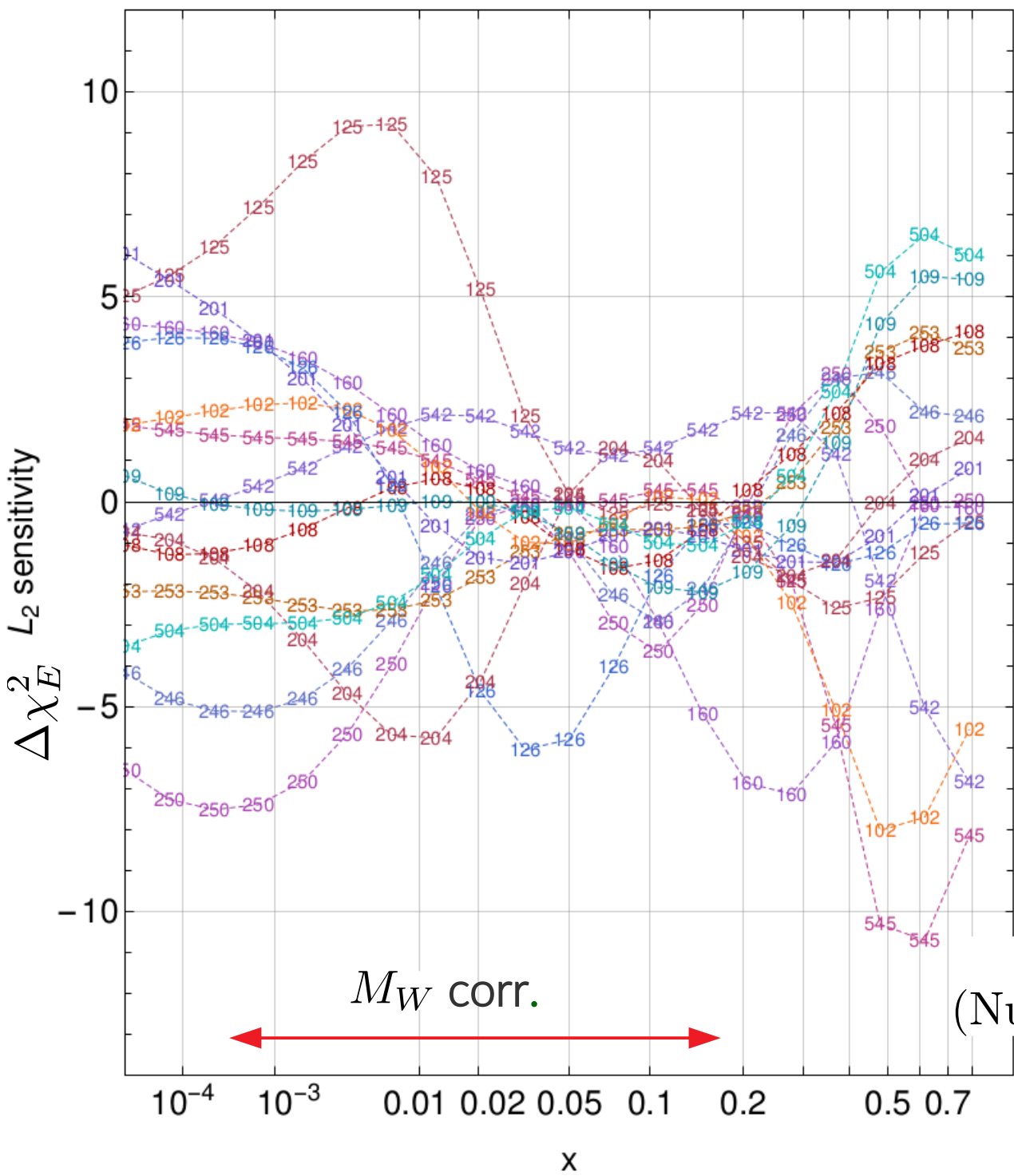

$$F_2^{e^- n} \sim x(4d + u)/9$$

nuclear uncertainties and corrections can propagate to free-nucleon PDF determinations...

...and theory predictions at the LHC

- ## heavy nuclear targets

  → additional flavor separation often provided by nuclear DIS, including neutrino scattering
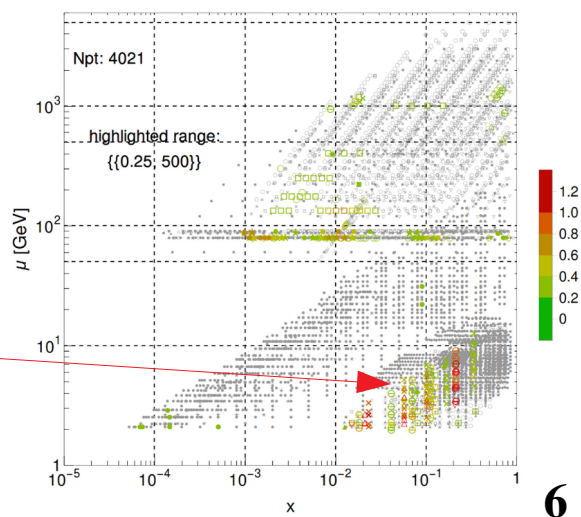
CT18 NNLO, s(x, 100 GeV)

$\Delta \chi^2_E$ L_2 sensitivity

M_W corr.

nuclear (neutrino) DIS data are used in single-nucleon fits

$\rightarrow \nu A$ data play a vital role flavor-separation in contemporary global fits; e.g., for nucleon strangeness

--246--	LHCb8Zeer	--109--	cdhswf3 ■
--250--	LHCb8WZ	--125--	NuTvNbChXN ■
--253--	ATL8ZpTbT	--126--	CcfrNuChXN ■
--542--	CMS7jtR7y6T	--201--	e605 ■
--545--	CMS8jtR7T	--204--	e866ppxf
--160--	HERAIpII	--504--	cdf2jtCor2
--102--	BcdF2dCor ■		
--108--	cdhswf2 ■		

(■ νA ■ A)

| S_f | for s(x,μ), CT14HERA2NNLO
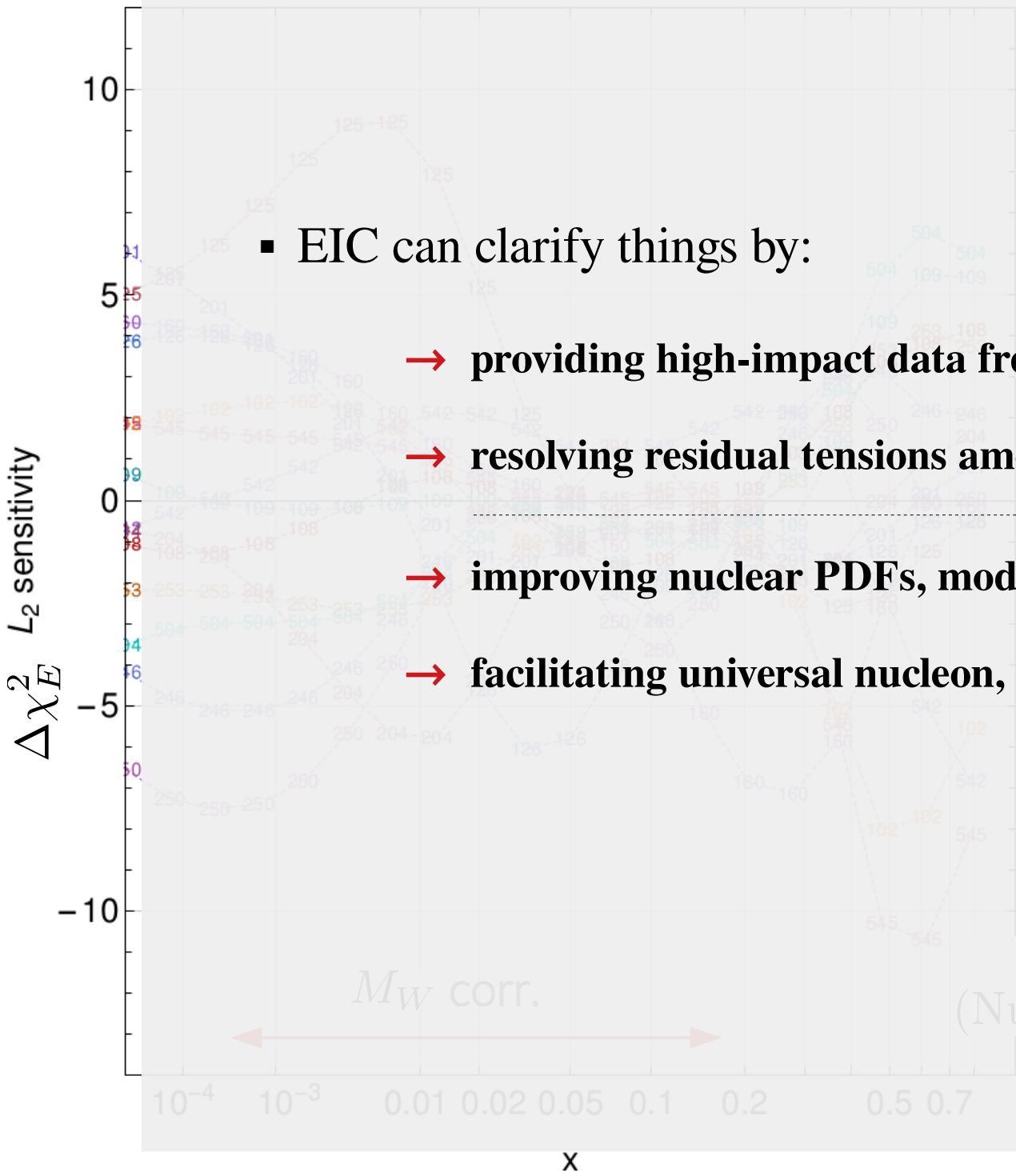
νDIS (NuTeV, ...)

6

CT18 NNLO, s(x, 100 GeV)

nuclear (neutrino) DIS data
are used in single-nucleon fits

→ νA data play a vital role
flavor-separation in
contemporary global fits;
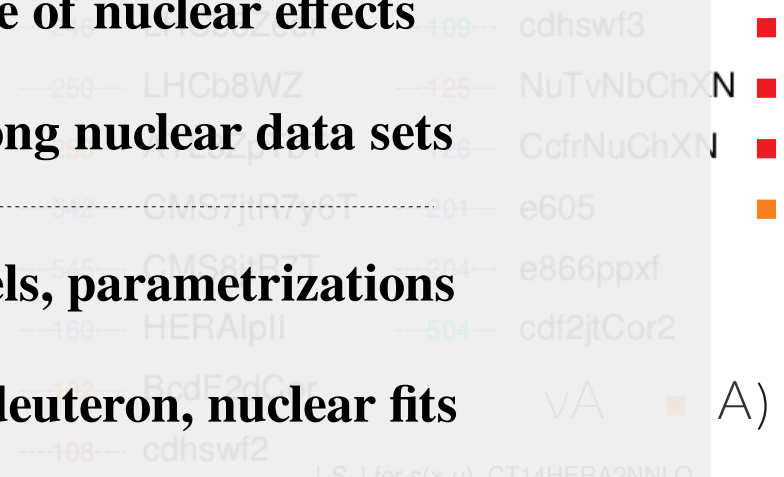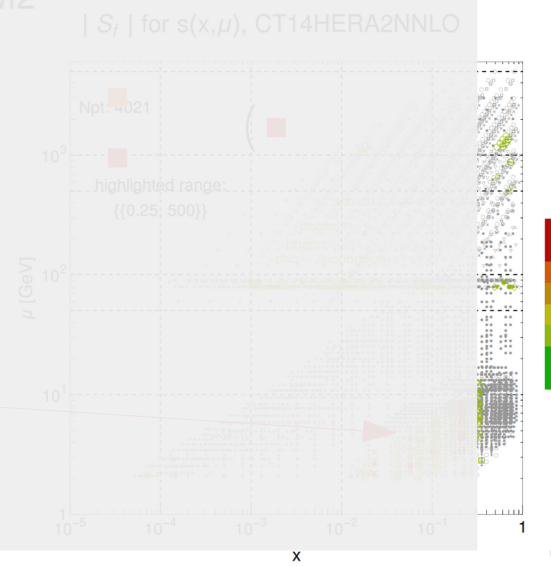e.g., for nucleon strangeness

- EIC can clarify things by:

→ **providing high-impact data free of nuclear effects**

→ **resolving residual tensions among nuclear data sets**

→ **improving nuclear PDFs, models, parametrizations**

→ **facilitating universal nucleon, deuteron, nuclear fits**

$\Delta\chi^2_E$ L_2 sensitivity

x

νDIS
(NuTeV, ...)

M_W corr.

A)
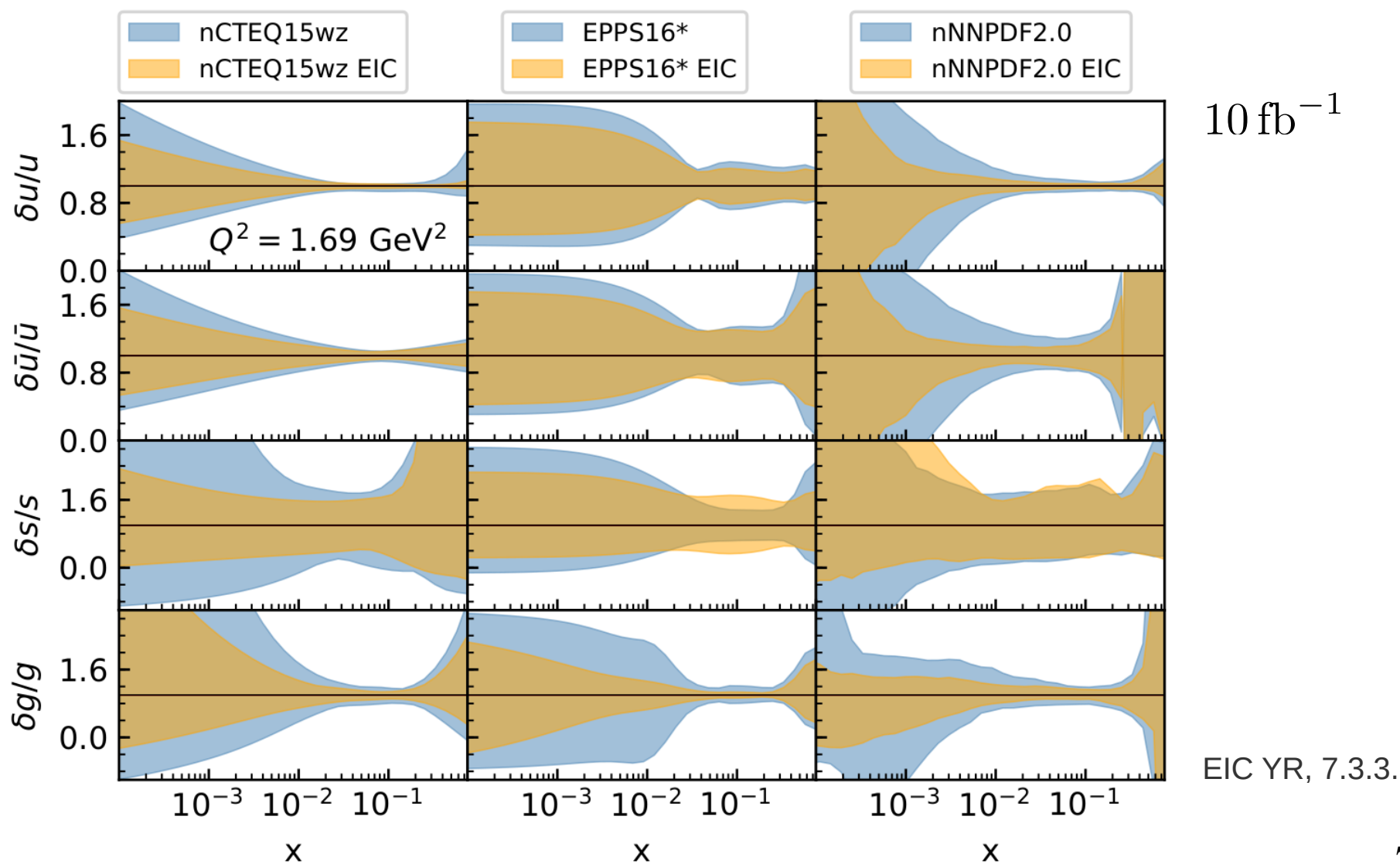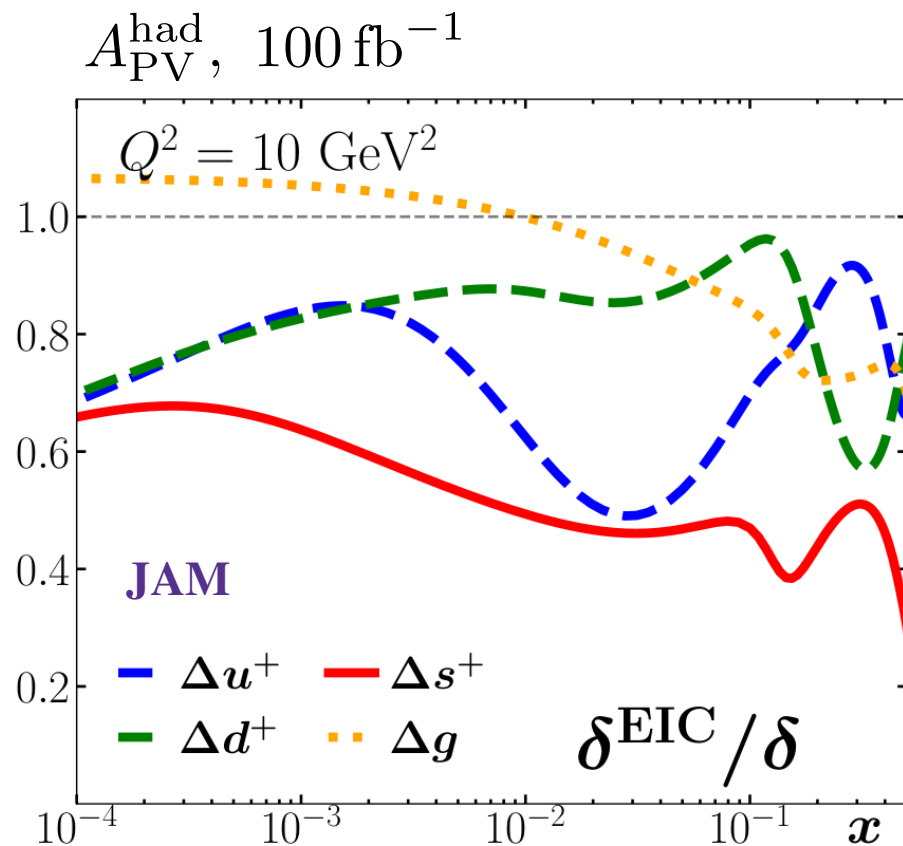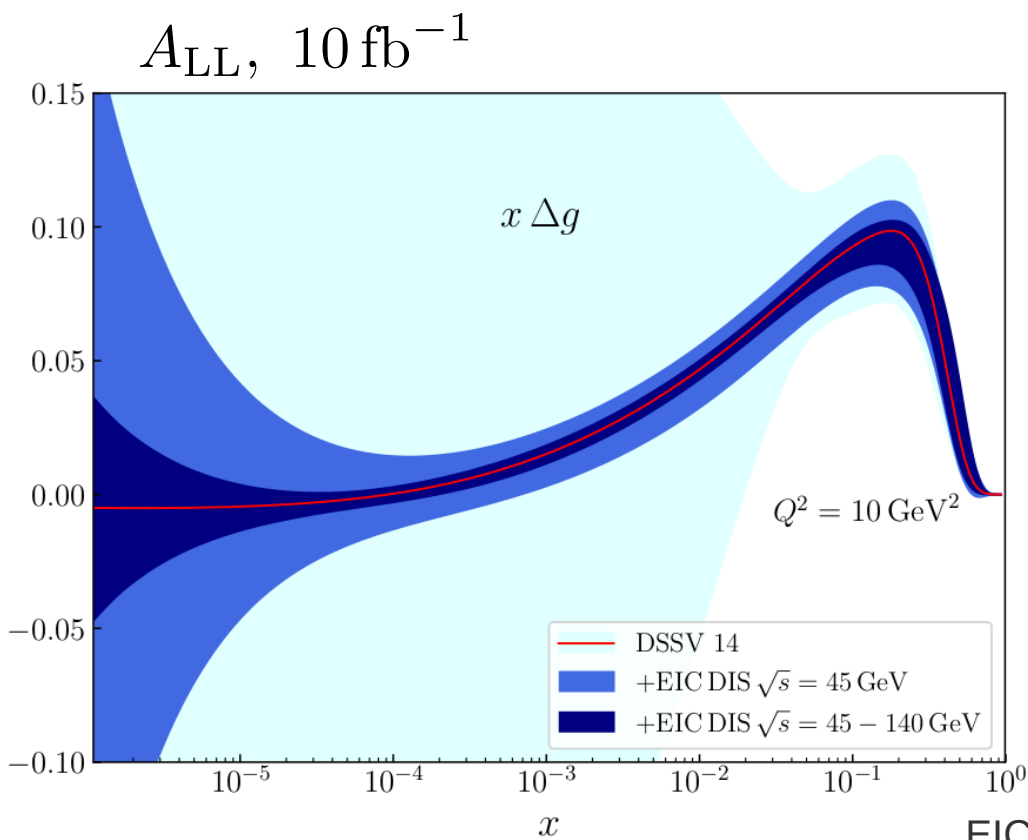
EIC potential impact on nPDFs

- inclusive charged-lepton nuclear-DIS data have significant impact (Au, below)

- additional avenues: heavy-quark production; nuclear tomography data

EIC YR, 7.3.3.

(ii) EIC possibilities with spin-polarized PDFs

- EIC will record data in multiple channels to constrain spin-PDFs (below)

- independent measurements of helicity-odd GPDs and spin-dependent TMDs can provide additional constraint(s)

- interactions with lattice QCD in EIC era

$A_{\mathrm{LL}}, \ 10 \, \mathrm{fb}^{-1}$

$x \Delta g$

$Q^2 = 10 \, \mathrm{GeV}^2$

DSSV 14
+EIC DIS $\sqrt{s} = 45 \, \mathrm{GeV}$
+EIC DIS $\sqrt{s} = 45 - 140 \, \mathrm{GeV}$

$A_{\mathrm{PV}}^{\mathrm{had}}, \ 100 \, \mathrm{fb}^{-1}$

$Q^2 = 10 \, \mathrm{GeV}^2$

JAM

Δu^+ $\qquad$ Δs^+
Δd^+ $\qquad$ Δg

$\delta^{\mathrm{EIC}}/\delta$

moving forward

- EIC tomography LOI wraps multiple topics

  → dedicated studies or contributions may be natural

  → must coordinate these efforts/inputs

  → lessons from EIC YR studies should be included

  [also opportunities for extension studies]

- more effort required to develop phenomenlogical implications

- inter-relations among spin, nuclear PDFs an intriguing EIC capability

thanks