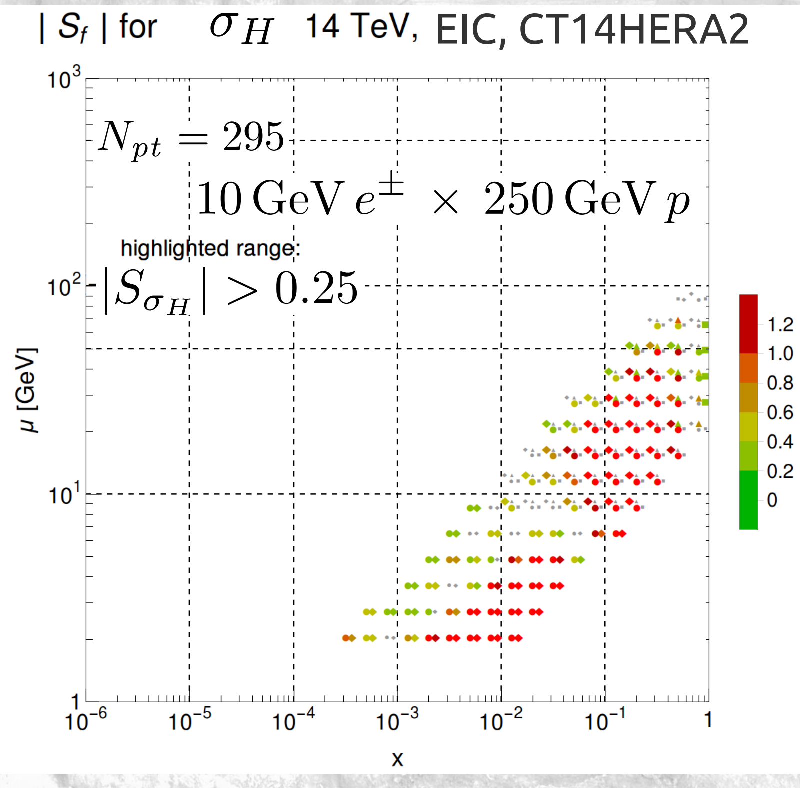
The **Electron Ion Collider** and its implications for high-energy phenomenology

10th International Workshop on Multiple Partonic Interactions at the LHC
Perugia, Italy

Thurs., Dec 13, 2018

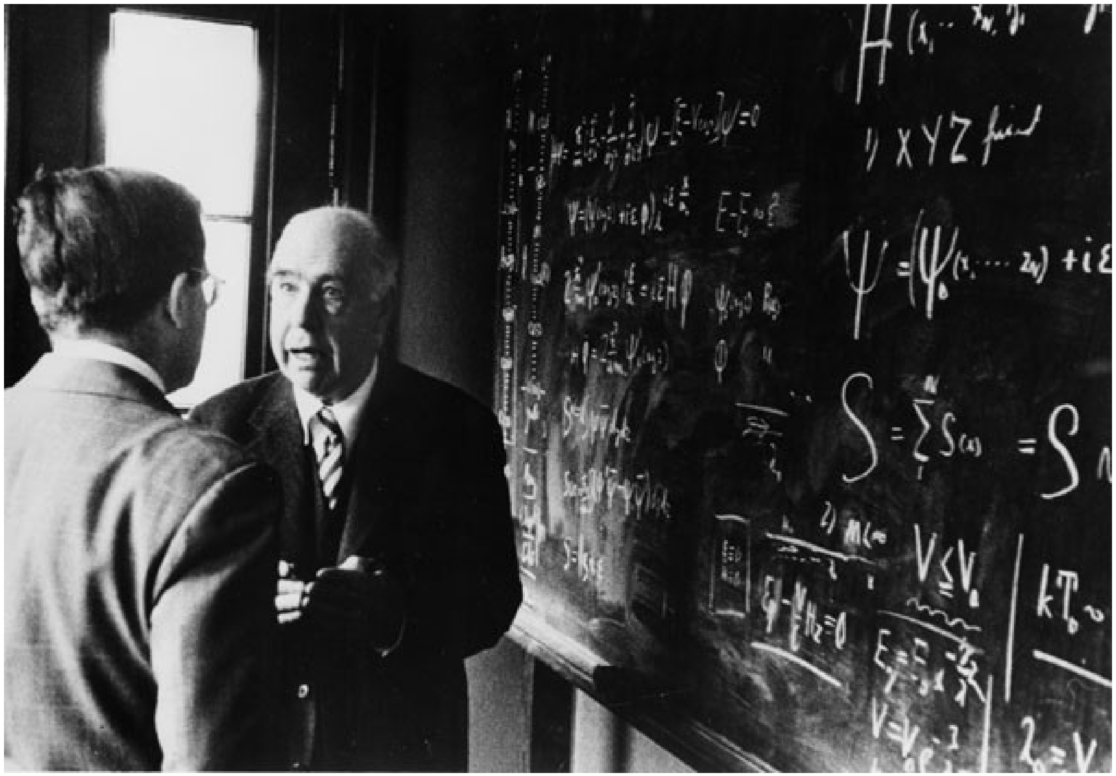


Tim Hobbs, Southern Methodist University & CTEQ
EIC Center at Jefferson Lab

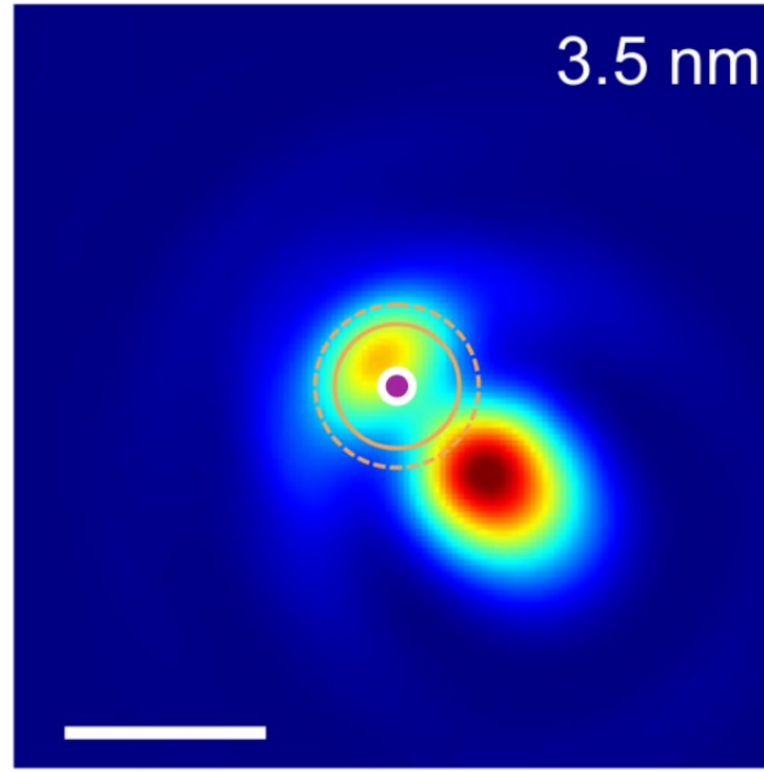
proton structure is today becoming a **precision field**

- the present moment is in many ways reminiscent of the situation in atomic structure theory in the early 20th Century:

Jeong et al., PRB93, 165140 (2016).



Niels with Aage at LANL.



Sr STEM simulated image

- much as the electronic structure of atomic matter has been mapped to high precision, we are entering an era of '**hadron tomography**'

… this is enshrined in the *2015 Nuclear Science Advisory Committee LRP*

→ AND motivation for **<u>EIC</u>**, JLab12, LHeC, collider data analyses

EIC is an essential future tool for hadron tomography and QCD

[See Tues. talk by **Marco Radici** for project status and hadron physics motivations.]

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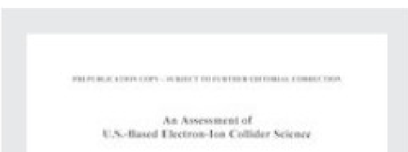

An Assessment of
U.S.-Based Electron-Ion Collider Science

An Assessment of U.S.-Based Electron-Ion Collider Science

"In summary, the committee finds a compelling scientific case for such a facility. The science questions that an EIC will answer are central to completing an understanding of atoms as well as being integral to the agenda of nuclear physics today."

"Top-level" physics objectives – connecting the bulk properties of hadrons to a parton-level description:

→ the origin of nucleon mass and spin in partonic degrees of freedom

→ understanding gluonic systems in the high density limit

→ imaging the nucleon's **multi-dimensional structure**

the capabilities that will allow EIC to address questions in QCD will also drive improvements in HEP

- EIC is a **very high luminosity** "femtoscope" – larger compared to HERA luminosities by a factor of $10^2 - 10^3$

- reach in center-of-mass energy, $10 \leq \sqrt{s} \leq 100\,\mathrm{GeV}$

  → upgradeable to $\sqrt{s} \leq 140\,\mathrm{GeV}$

- beam polarization of at least ~70% for e^-, p, light A

- as a generic scenario, we consider here the simulated impact of a machine with: $10\,\mathrm{GeV}\,e^\pm$ on $250\,\mathrm{GeV}\,p \quad (\sqrt{s} = 100\,\mathrm{GeV})$

  ~year of data-taking
  $\mathcal{L} = 100\,\mathrm{fb}^{-1}\; e^-$ pseudodata
  $\mathcal{L} = 10\,\mathrm{fb}^{-1}\; e^+$ pseudodata
  → **NC/CC**

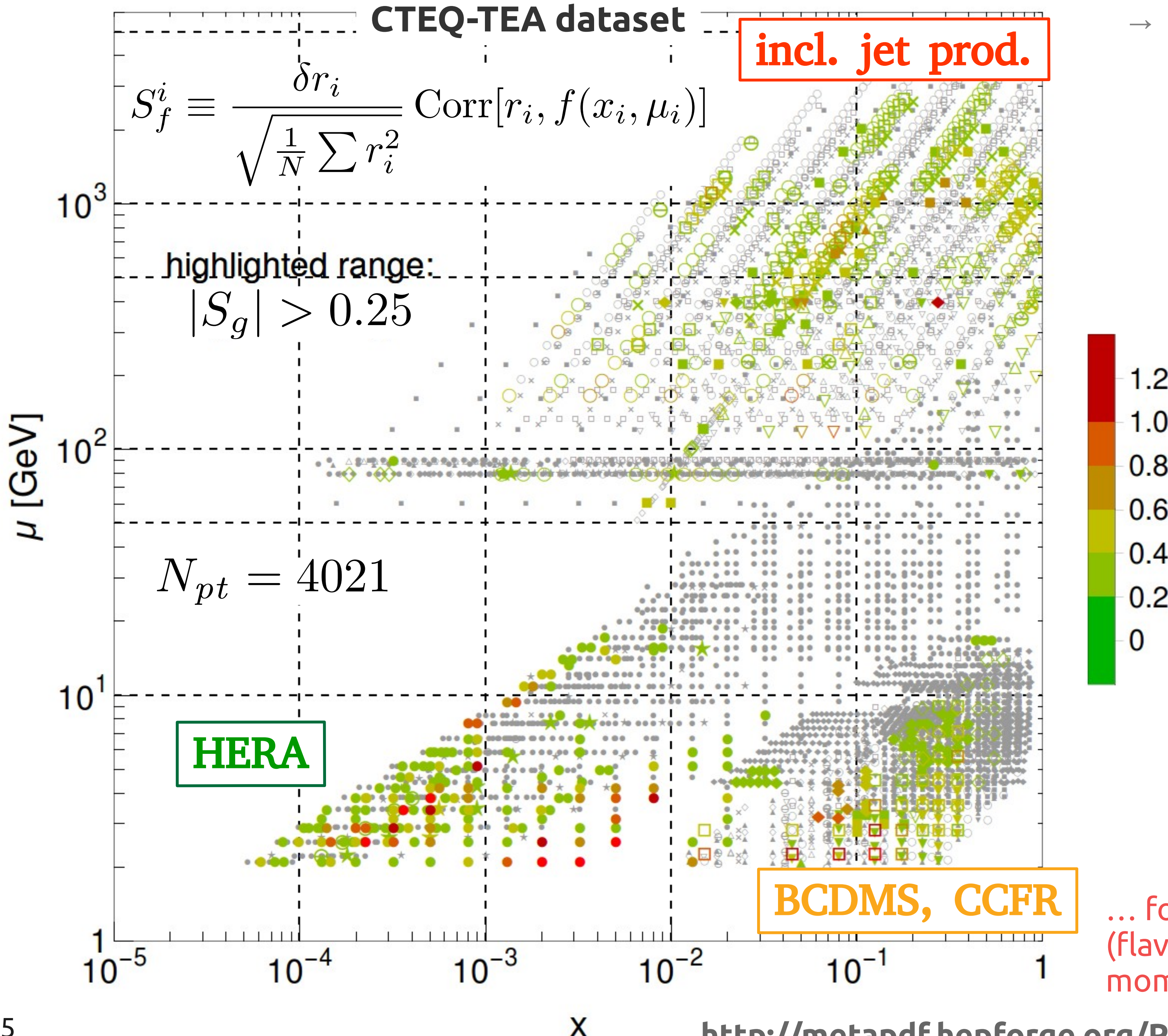
→ EIC will map the few GeV **quark-hadron transition** region

→ á la HERA, the combination of precision & kinematic coverage provide constraining 'lever arm' on QCD evolution

→ QCD evolution: (**high x, low Q**) ↔ (**low x, high Q**)

$| S_f |$ for $g(x,\mu)$, CT14HERA2NNLO

Wang, TJH, Doyle, Gao, Hou, Nadolsky, Olness,
PRD**98**, 094030 (2018).



→ special thanks to **Bo-Ting Wang**!

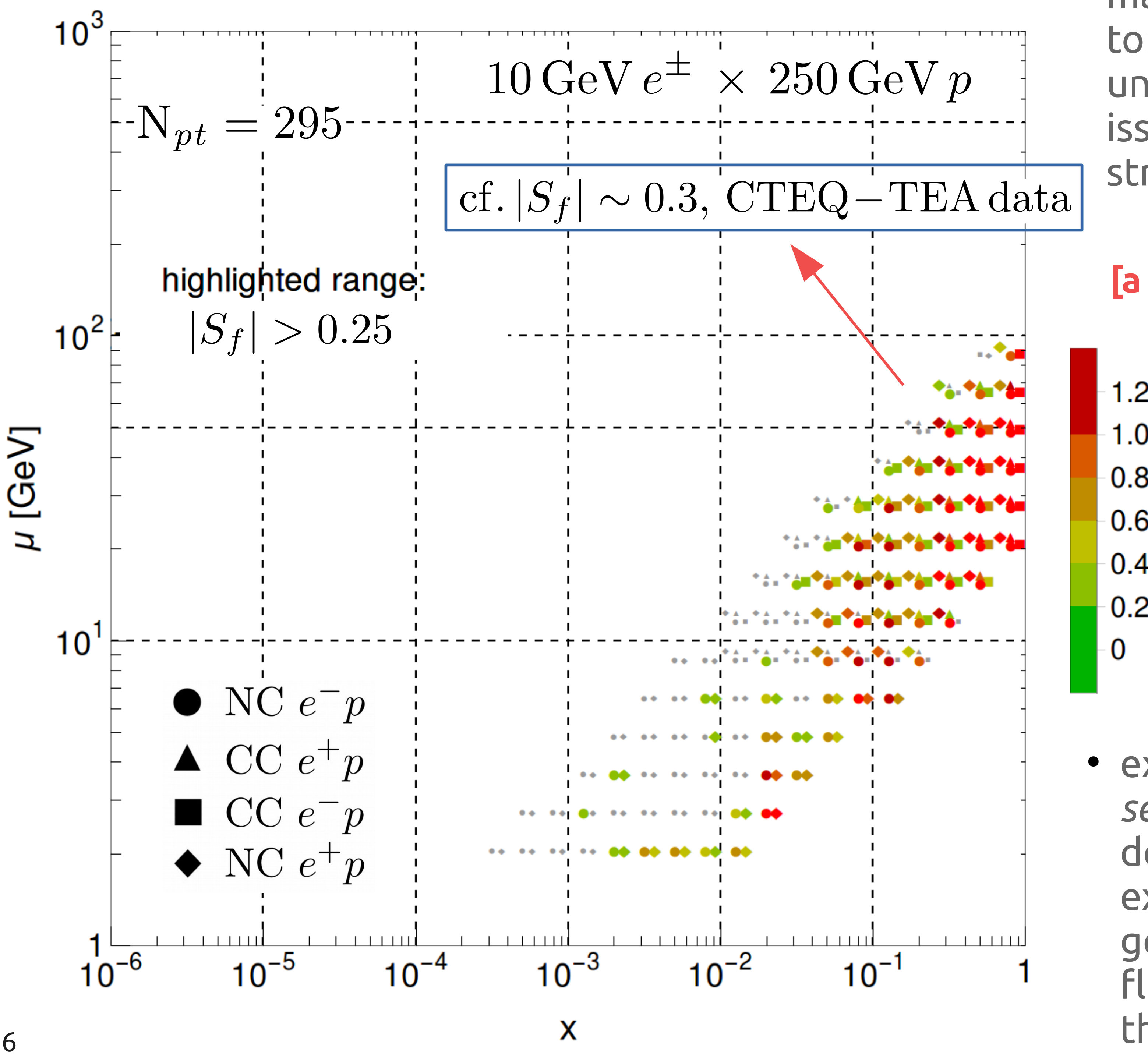
- used in this talk, **PDFSense**: a tool to quantify and visualize the sensitivity of measured data to the PDFs (or PDF-dependent quantities)

- alternative to computationally costly QCD global analyses; yields a generalized correlation (the `sensitivity') – a proxy for the expected impact in an actual fit

… for many other results (flavors, combinations, moments, cross sections):

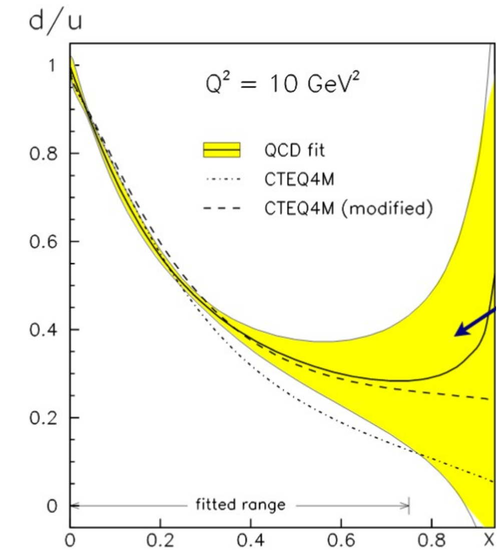
http://metapdf.hepforge.org/PDFSense/

$|S_f|$ for $d/u(x,\mu)$, CT14 HERA2 NNLO



- as a dedicated machine for hadron tomography, EIC can unravel stubborn issues in nucleon structure, *e.g.*,
  $d/u(x \approx 1)$

[a model discriminator]



- expected impact, or *sensitivity*, of EIC determined by examining pseudodata generated by fluctuating about CT14 theory predictions

the road ahead

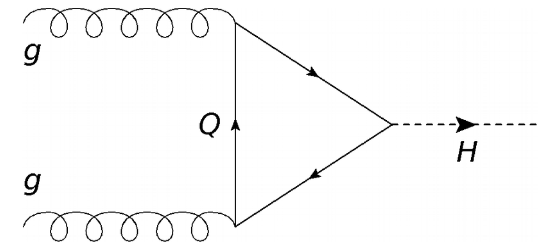
- the EIC will be a tool for **precise hadron tomography**
- BUT, also of importance to **HEP phenomenology**!
  - an EIC can be expected to enlighten:
    - → high energy QCD – *e.g.*, the gluon and saturation
    - → Higgs phenomenolgy
    - → the electroweak sector
    - → searches for New Physics
    - → theory of multi-parton interactions

…examples…

- the future: continuing to build the EIC physics case.

QCD at high energies: an EIC and control over the gluon

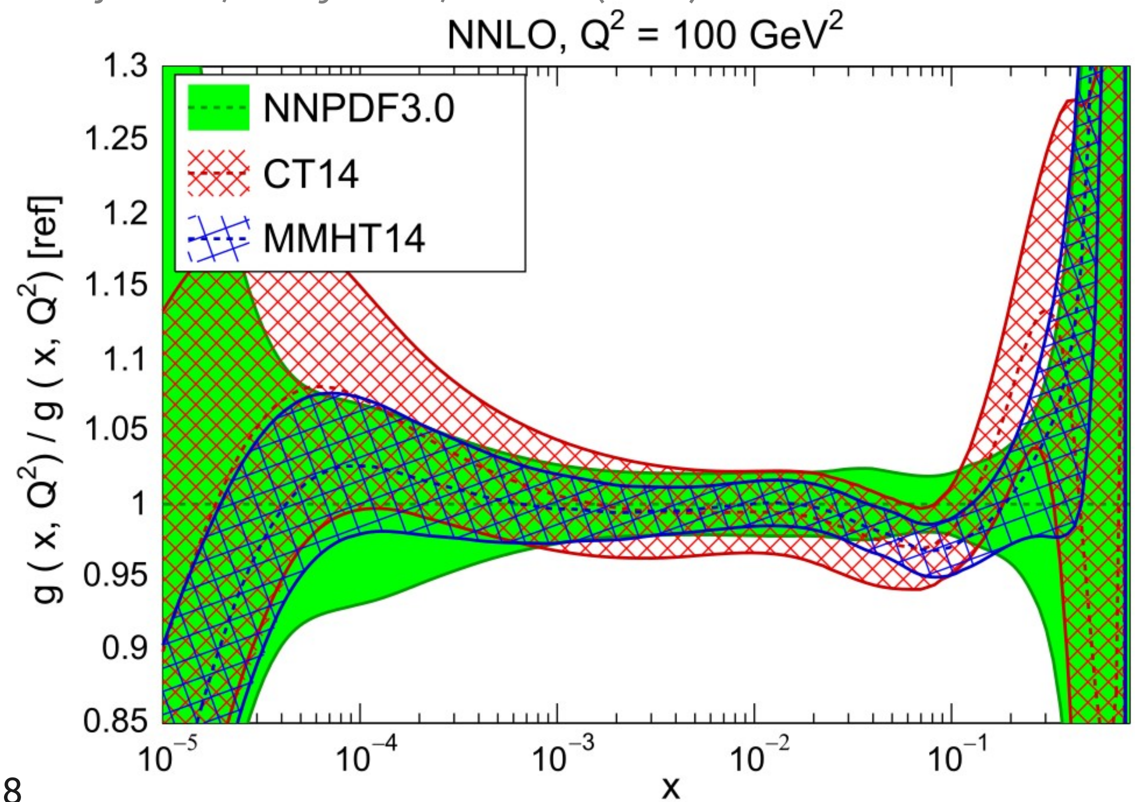
- the gluon is crucial to the mass of hadronic bound states, and $gg \to H$ is the dominant channel in Higgs production



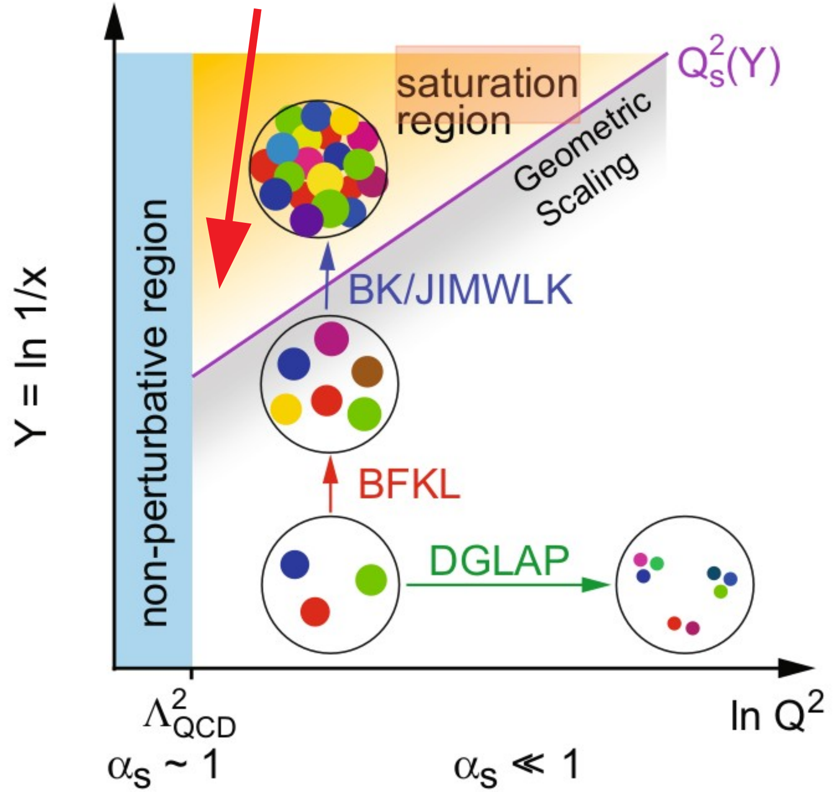
BUT

- while under better control at intermediate x, the collinear gluon PDF is poorly known toward the distribution endpoints, *i.e.*, $g(x,\mu)$ for $x \to 0,\ 1$

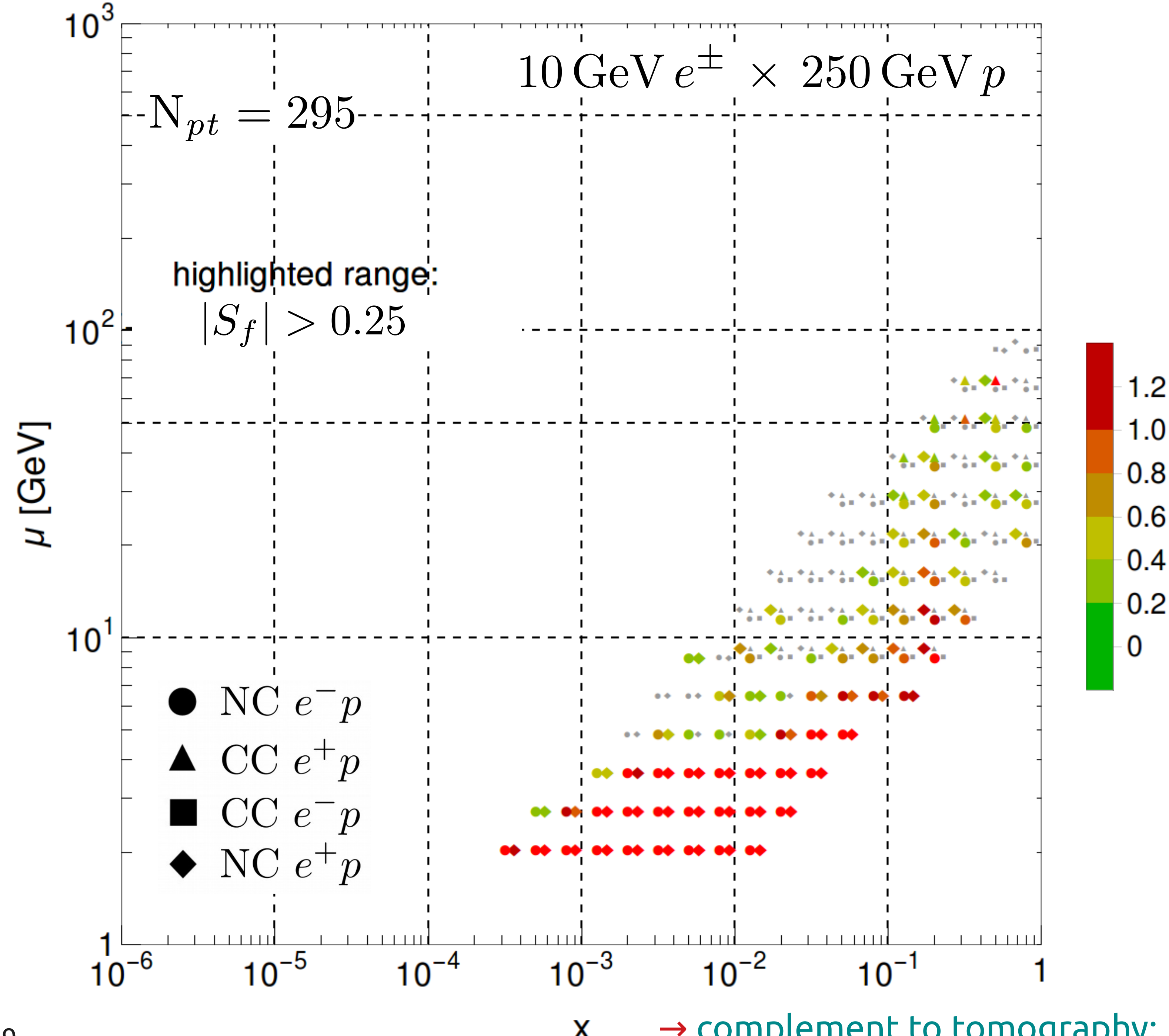
Rojo et al., J. Phys. G**42**, 103103 (2015).



can we begin to observe this transition?



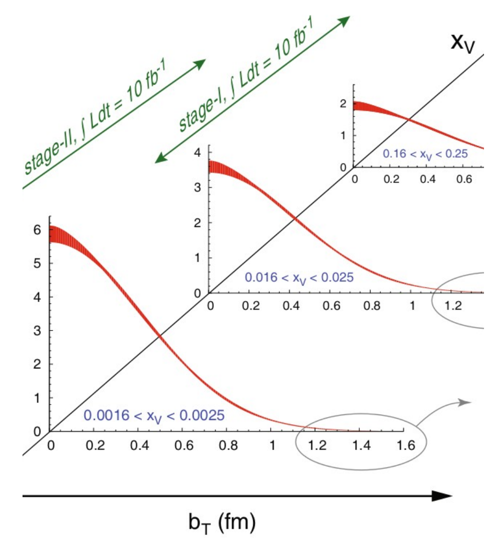
| S_f | for $g(x, \mu)$ CT14 HERA2 NNLO



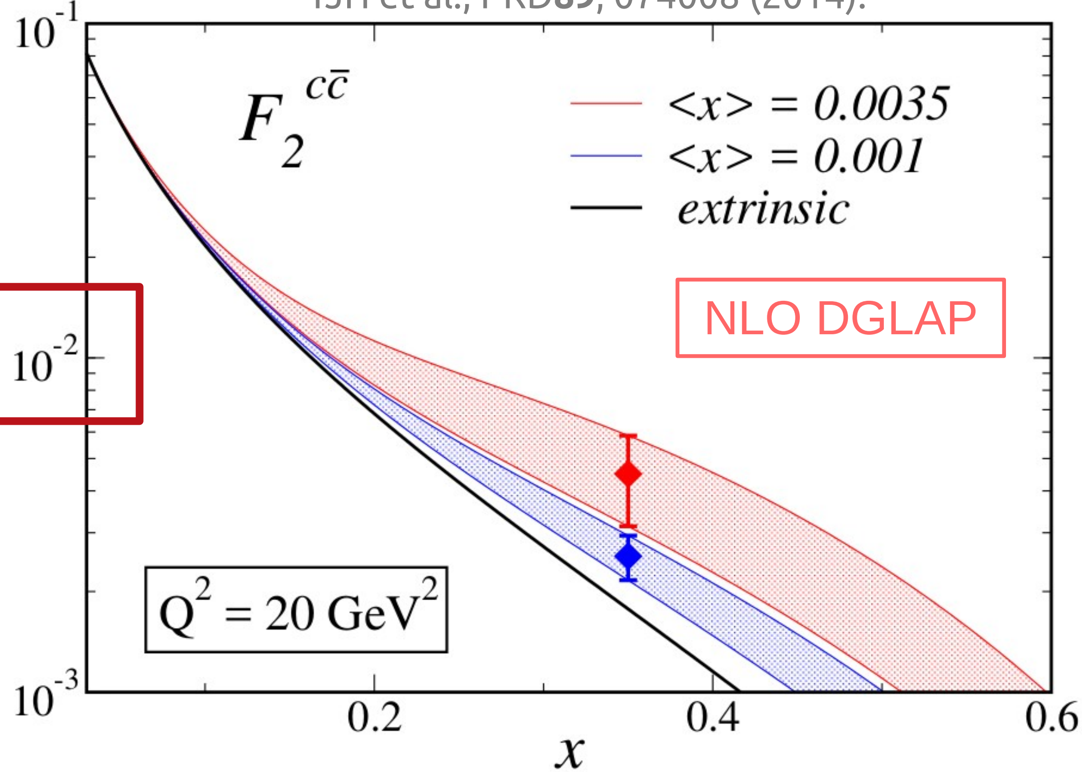
- an EIC will provide a sensitive probe to the gluon distribution – especially at low x
  $x \gtrsim 3 \times 10^{-4}$

- these constraints arise from high statistics neutral current data on $\sigma_{r,\mathrm{NC}}^{e^{\pm}p}$

→ complement to tomography:



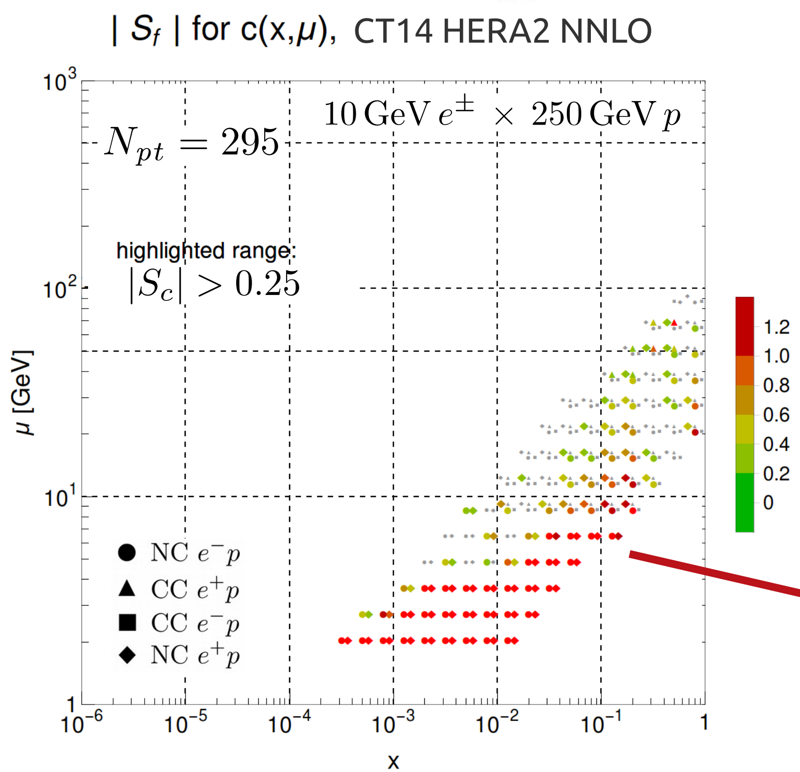
TJH et al., PRD89, 074008 (2014).



An EIC can finally resolve the **NP nucleon charm** question

- various models predict a nonpertubative (intrinsic) component to the nucleon structure function, but the normalization is small and undetermined

$$\langle x \rangle_{\rm IC} = \int_0^1 dx\, x \left[c + \bar{c}\right](x, m_c^2)$$
$$\lesssim 1 - 2\%$$



- the presence of a NP charm component has consequences for **heavy quark schemes**, **masses**, and global analyses

an EIC will measure very precisely in the ~few GeV, high x region in which typical NP charm signals are to be expected, à la EMC

Higgs production is now dominated by PDF and α_s uncertainties

- there remains considerable dependence (as large as ~13%) upon PDF paramatrization and running coupling

→ the situation is such that precision in Higgs phenom. is significantly **PDF-limited**

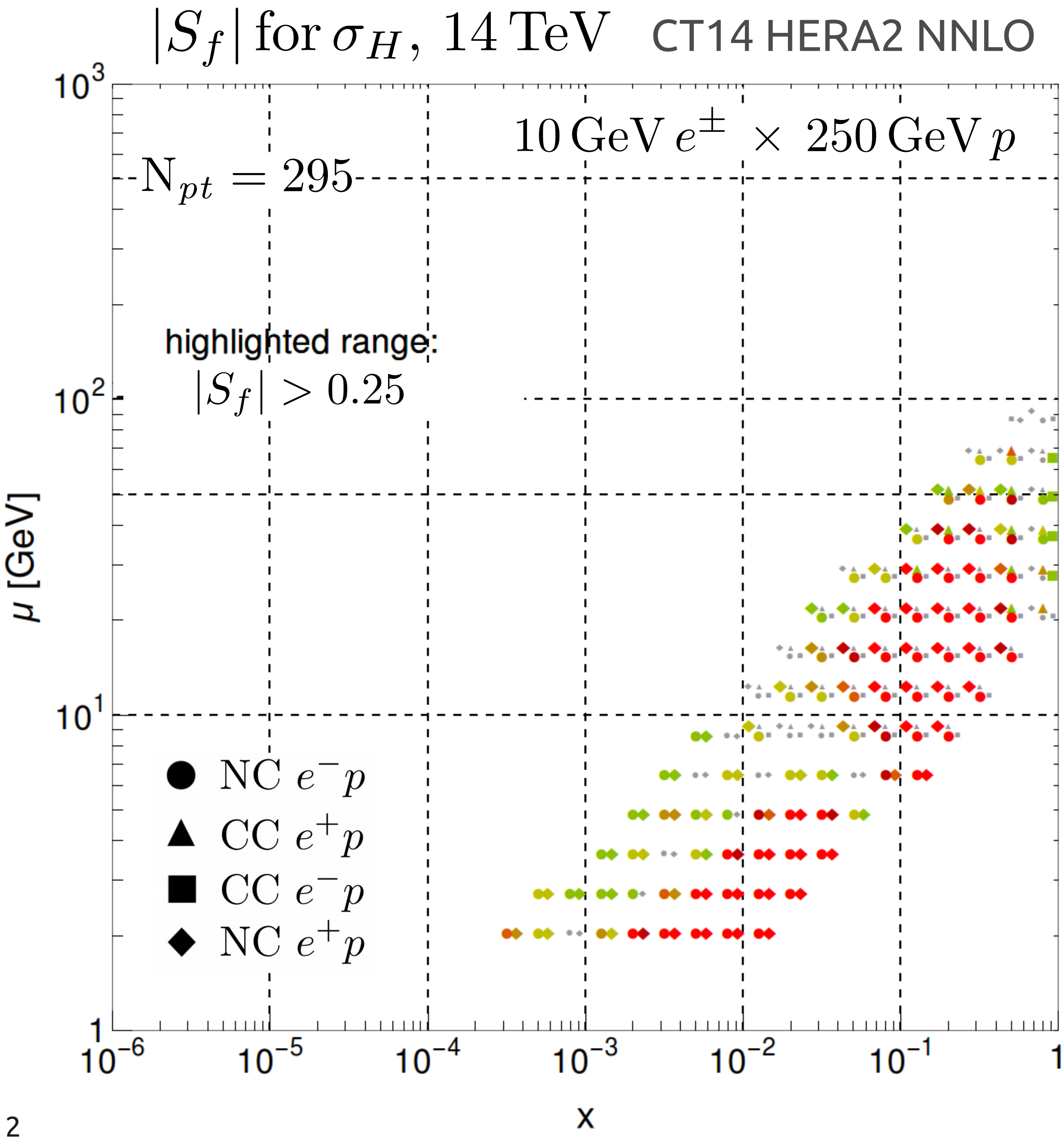
Accardi et al., EPJC**76**, 471 (2016).

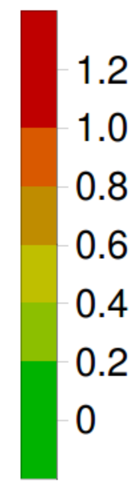
PDF sets	$\sigma(H)^{\text{NNLO}}$ (pb) nominal $\alpha_s(M_Z)$	$\sigma(H)^{\text{NNLO}}$ (pb) $\alpha_s(M_Z) = 0.115$	$\sigma(H)^{\text{NNLO}}$ (pb) $\alpha_s(M_Z) = 0.118$
ABM12 [2]	39.80 ± 0.84	41.62 ± 0.46	44.70 ± 0.50
CJ15 [1][a]	$42.45^{+0.43}_{-0.18}$	$39.48^{+0.40}_{-0.17}$	$42.45^{+0.43}_{-0.18}$
CT14 [3][b]	$42.33^{+1.43}_{-1.68}$	$39.41^{+1.33}_{-1.56}$ (40.10)	$42.33^{+1.43}_{-1.68}$
HERAPDF2.0 [4][c]	$42.62^{+0.35}_{-0.43}$	$39.68^{+0.32}_{-0.40}$ (40.88)	$42.62^{+0.35}_{-0.43}$
JR14 (dyn) [5]	38.01 ± 0.34	39.34 ± 0.22	42.25 ± 0.24
MMHT14 [6]	$42.36^{+0.56}_{-0.78}$	$39.43^{+0.53}_{-0.73}$ (40.48)	$42.36^{+0.56}_{-0.78}$
NNPDF3.0 [7]	42.59 ± 0.80	39.65 ± 0.74 (40.74 ± 0.88)	42.59 ± 0.80
PDF4LHC15 [8]	42.42 ± 0.78	39.49 ± 0.73	42.42 ± 0.78

$$\sigma_H \text{ at NNLO and } \sqrt{s} = 13\,\text{TeV};\ \ \mu_F = \mu_R = m_H$$

→ enhancing the discovery potential in the Higgs sector will require improving these uncertainties!

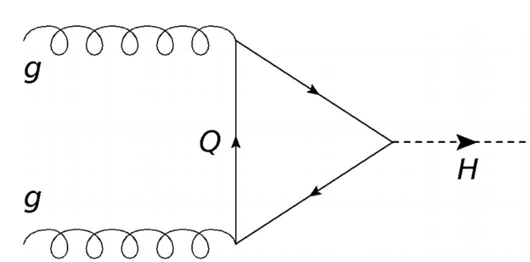
potentially strong impact on the Higgs sector





- the impact of an EIC upon the theoretical predictions for inclusive Higgs production arises from a very broad region of the kinematical space it can access

- impact rather closely tied to that of the integrated gluon PDF:



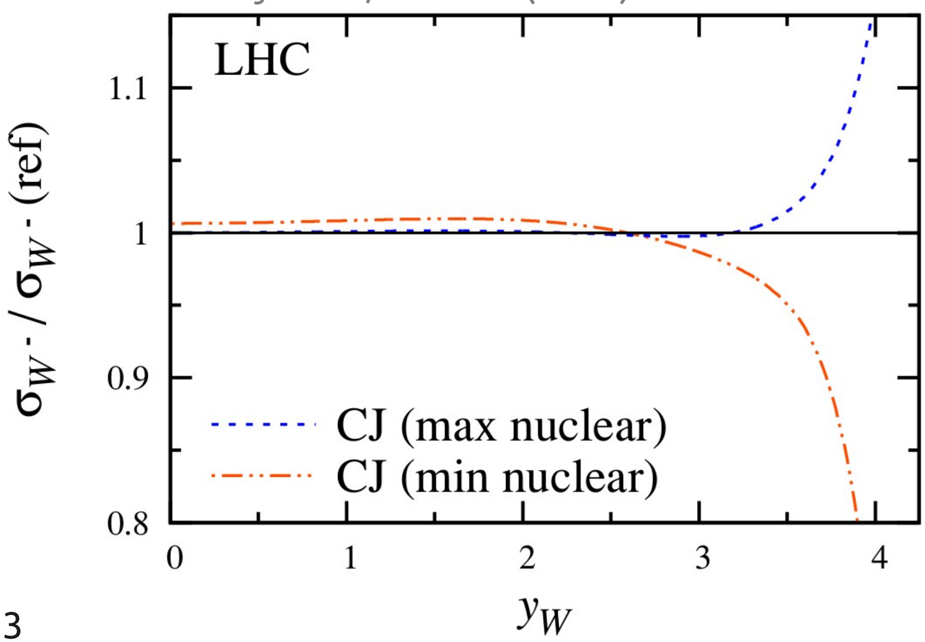
EIC and an era of (higher) precision **electroweak physics** (?)

- theory predictions for the production of gauge bosons are quite sensitive to the nucleon PDFs: *e.g.*, d(x) at x ~ 1, which is poorly constrained

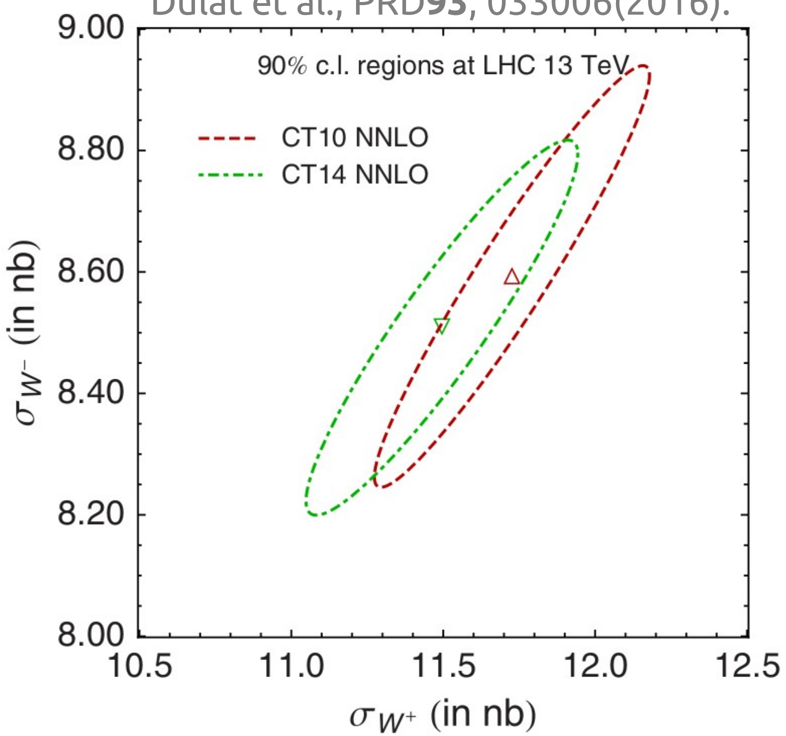
$$x_{1,2} = \frac{M}{\sqrt{s}} e^{\pm y}$$

$$\frac{d\sigma}{dy}(pp \to W^- X) = \frac{2\pi G_F}{3\sqrt{2}} x_1 x_2 \Big(\cos^2\theta_C \{ d(x_1)\bar{u}(x_2) + \bar{u}(x_1)d(x_2) \} + \sin^2\theta_C \{ s(x_1)\bar{u}(x_2) + \bar{u}(x_1)s(x_2) \} \Big)$$

Brady et al., JHEP**06** (2012) 019.



Dulat et al., PRD**93**, 033006(2016).



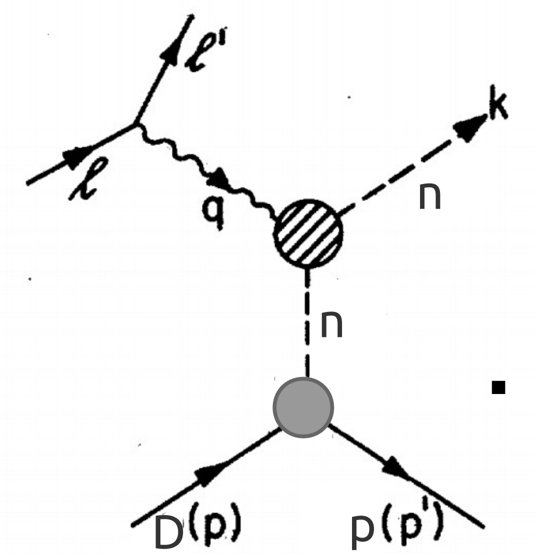
historically, extractions of $d(x),\ x \to 1$ have depended on nuclear targets (and corrections!)

- in principle, a neutron target would allow the flavor separation needed to access $d(x, Q^2)$

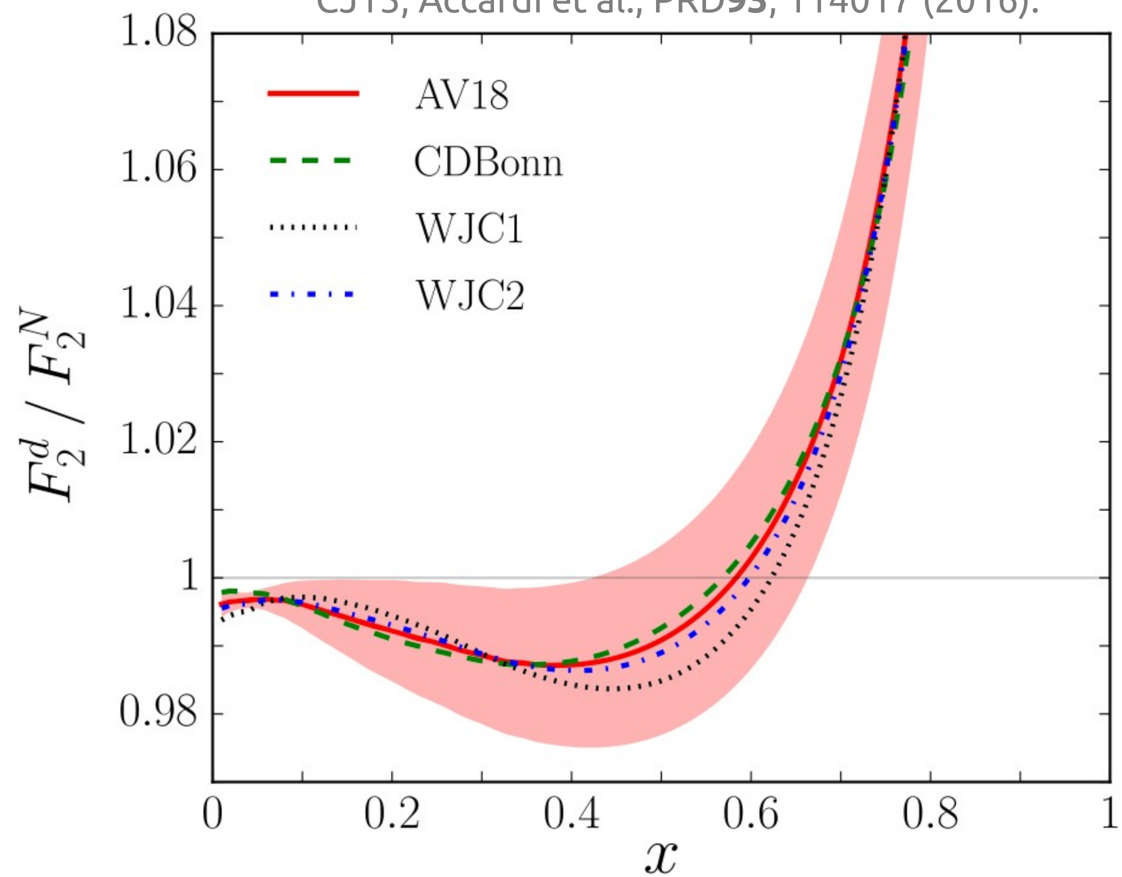
$$F_2^{e^- n} \sim x(4d + u)/9$$

— vs —

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



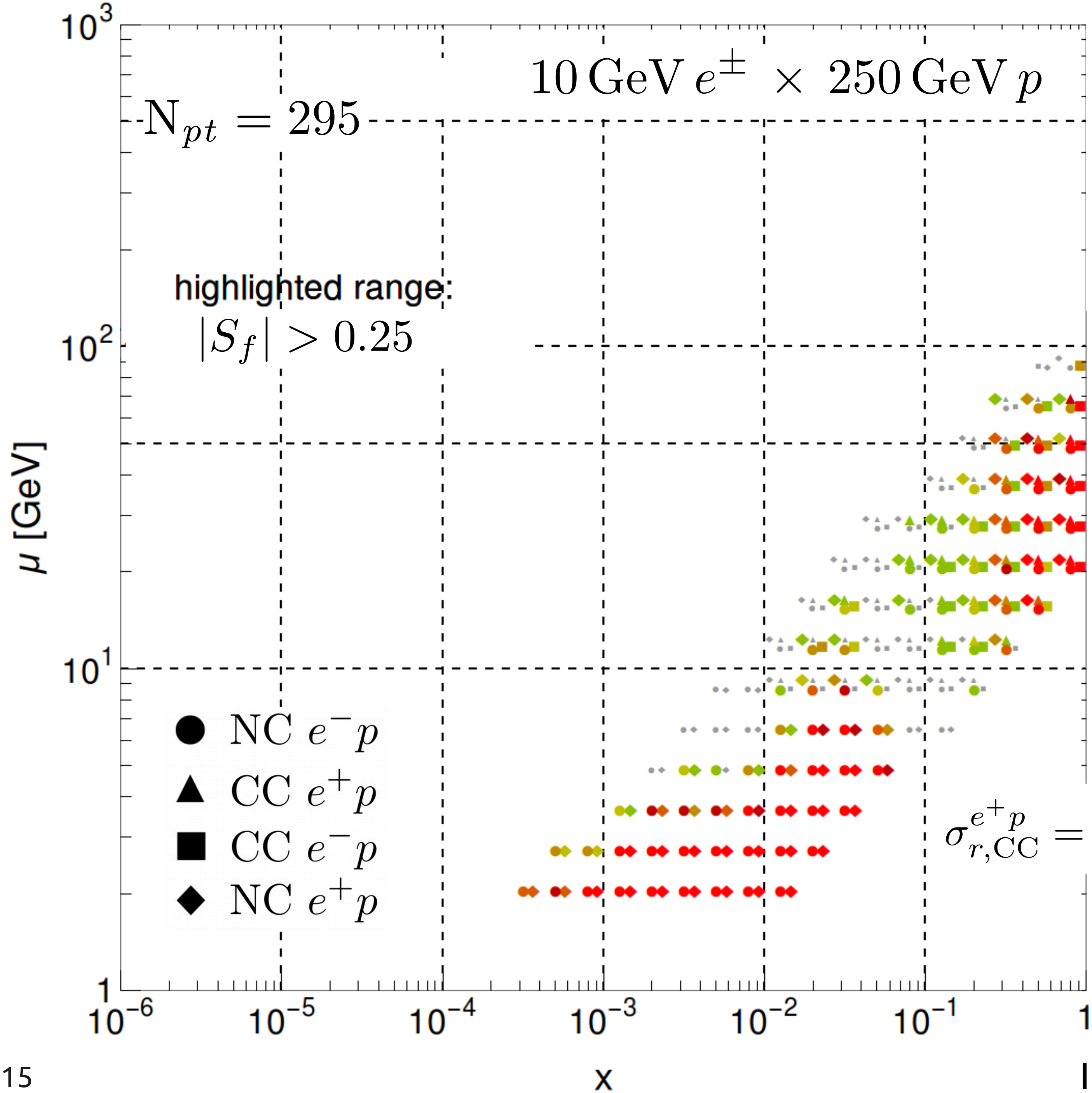
CJ15, Accardi et al., PRD**93**, 114017 (2016).

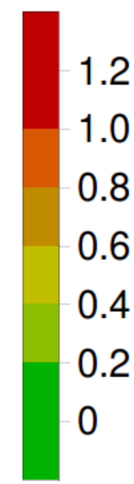


- **BUT**: in the absence of a free neutron target, scattering from nuclei (e.g., the deuteron) is necessary

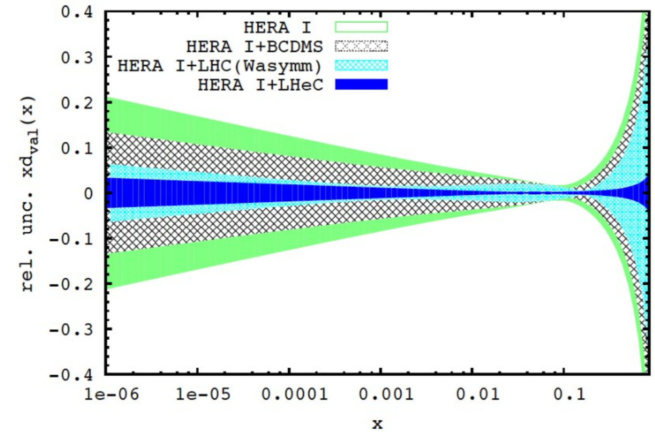
→ **nuclear corrections (Fermi motion) are sizable, especially for large x**

$|S_f|$ for $d(x,\mu)$ CT14 HERA2 NNLO





EIC Whitepaper:1206.2913



- an EIC affords **strong sensitivities** **without a nuclear target**; here, at both very high and very low x

for $x \to 1$

$$\sigma_{r,CC}^{e^+p} = \frac{Y_+}{2} W_2^+ \mp \frac{Y_-}{2} x W_3^+ - \frac{y^2}{2} W_L^+$$

$$\simeq [1-y]^2\, x(d+s)$$

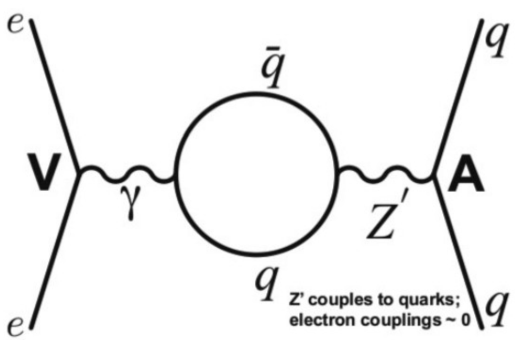
In the **LO quark-parton model**

the electroweak sector and **New Physics** searches at EIC

- if measured to sufficient precision, the quark-level electroweak couplings may be sensitive to an extended EW sector, e.g., Z'

$$\mathcal{L}^{\rm PV} = \frac{G_F}{\sqrt{2}} \left[\bar{e}\gamma^\mu\gamma_5 e \left(C_{1u}\bar{u}\gamma_\mu u + C_{1d}\bar{d}\gamma_\mu d\right) + \bar{e}\gamma^\mu e \left(C_{2u}\bar{u}\gamma_\mu\gamma_5 u + C_{2d}\bar{d}\gamma_\mu\gamma_5 d\right)\right]$$

$$C_{1u} = -\frac{1}{2} + \frac{4}{3}\sin^2\theta_W$$



- a unique strength of an EIC is its combination of very high precision and **beam polarization**, which allows the observation of **parity-violating helicity asymmetries**:

$$A^{\rm PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \quad ({\rm R/L} : e^- \text{ beam helicities})$$

selects γ-Z interference diagrams!

TJH and Melnitchouk, PRD**77**, 114023 (2008).

$$A^{\rm PV} = -\left(\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\right)\left(Y_1\, a_1 + Y_3\, a_3\right)$$

$$a_1 = \frac{2\sum_q e_q\, C_{1q}\, (q+\bar{q})}{\sum_q e_q^2\, (q+\bar{q})} \qquad a_3 = \frac{2\sum_q e_q\, C_{2q}\, (q-\bar{q})}{\sum_q e_q^2\, (q+\bar{q})}$$

the electroweak sector and **New Physics** searches at EIC

- if measured to sufficient precision, the quark-level electroweak couplings may be sensitive to an extended EW sector, e.g., Z'

$$\mathcal{L}^{\mathrm{PV}} = \frac{G_F}{\sqrt{2}} \left[\bar{e}\gamma^\mu\gamma_5 e \left(C_{1u}\bar{u}\gamma_\mu u + C_{1d}\bar{d}\gamma_\mu d \right) + \bar{e}\gamma^\mu e \left(C_{2u}\bar{u}\gamma_\mu\gamma_5 u + C_{2d}\bar{d}\gamma_\mu\gamma_5 d \right) \right]$$

$$C_{1u} = -\frac{1}{2} + \frac{4}{3}\sin^2\theta_W$$

→ with sufficient precision, an EIC (which will be statistics-limited in these measurements) can extract $\sin^2\theta_W$

- this measurement is potentially sensitive to the TeV-scale in a complementary fashion to energy-frontier searches!

TJH and Melnitchouk, PRD**77**, 114023 (2008).

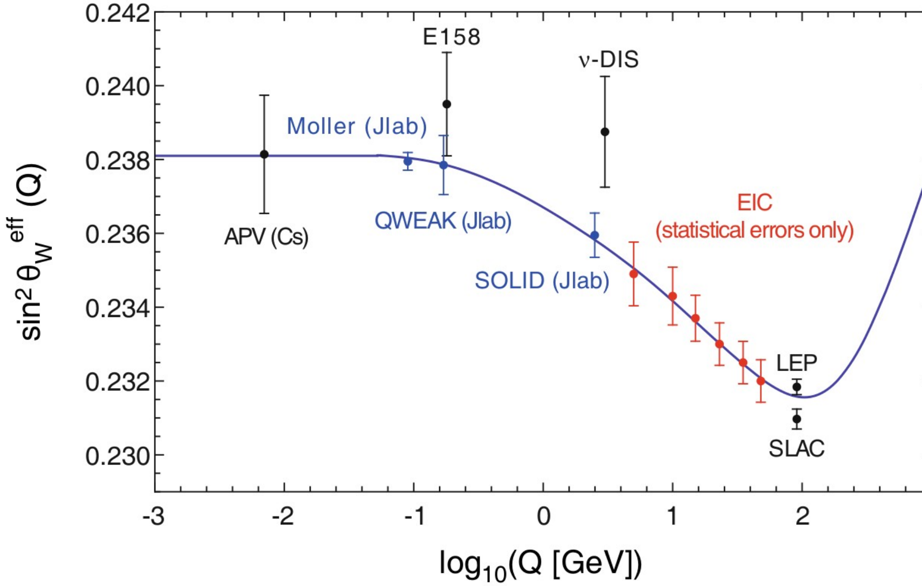
$$A^{\mathrm{PV}} = -\left(\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\right)\left(Y_1\, a_1 + Y_3\, a_3\right)$$

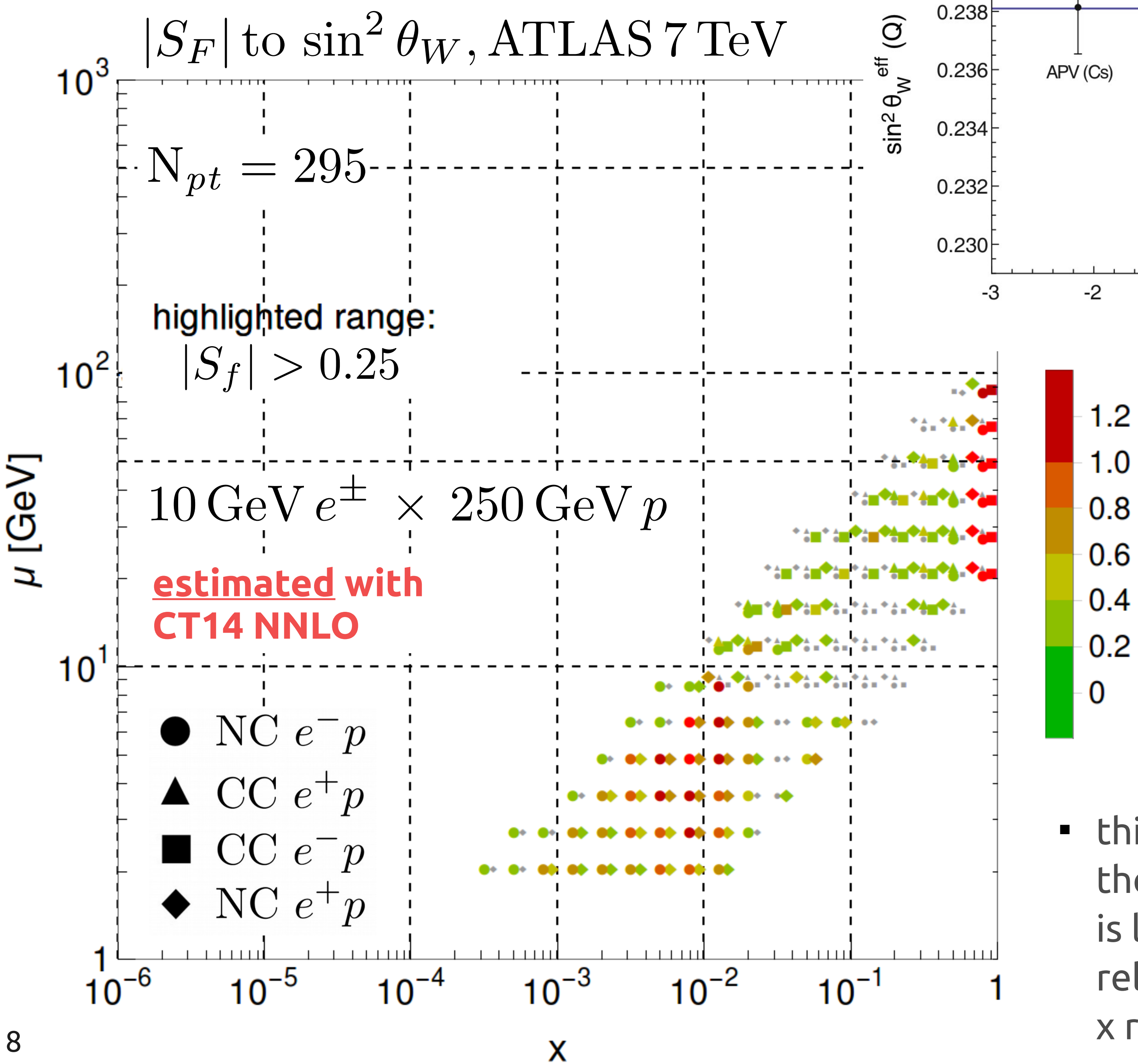
N.B.: extractions are dependent upon knowledge of the PDFs

$$a_1 = \frac{2\sum_q e_q\, C_{1q}\, (q+\bar{q})}{\sum_q e_q^2\, (q+\bar{q})} \qquad a_3 = \frac{2\sum_q e_q\, C_{2q}\, (q-\bar{q})}{\sum_q e_q^2\, (q+\bar{q})}$$

an EIC will probe EW parameters and New Physics!

Accardi et al., EPJA**52**, 268 (2016).





- observe a pronounced sensitivity to the Weinberg angle, especially low and high x, even at $\mathcal{L} = 100\mathrm{fb}^{-1}$

- this corresponds closely to the kinematics at which EIC is likely to measure $A^{\rm PV}$ — relatively large Q² and in the x range $0.2 \lesssim x \lesssim 0.5$

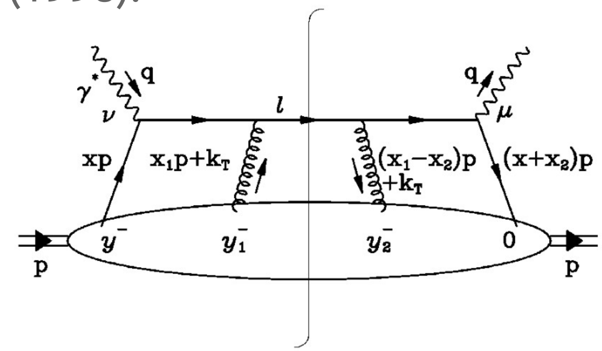
interactions with multiple partons at EIC: **nuclear case**

- **consider jet production in electron-nucleus vs. electron-nucleon DIS**

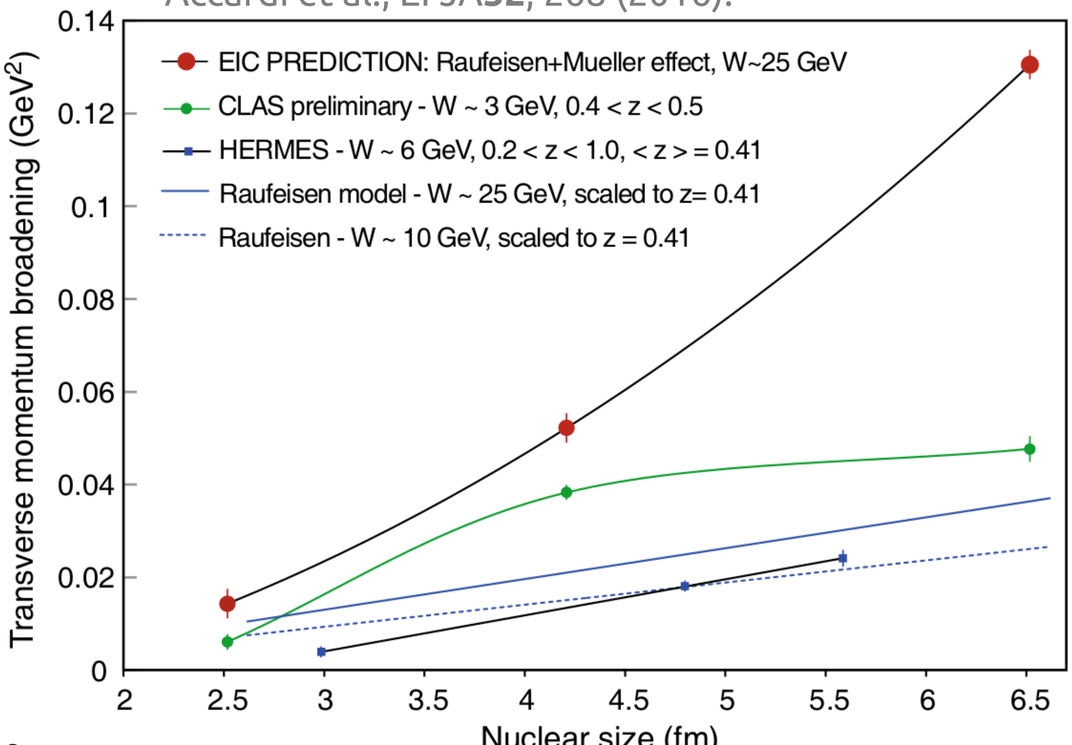
X. Guo, PRD**58**, 114033 (1998).

$$\Delta\langle p_T^2\rangle \equiv \langle p_T^2\rangle_{eA} - \langle p_T^2\rangle_{ep}$$

$$\langle p_T^2\rangle = \int dp_T^2 p_T^2 \frac{d\sigma}{dx_B dQ^2 dp_T^2} \Big/ \frac{d\sigma}{dx_B dQ^2}$$



Accardi et al., EPJA**52**, 268 (2016).



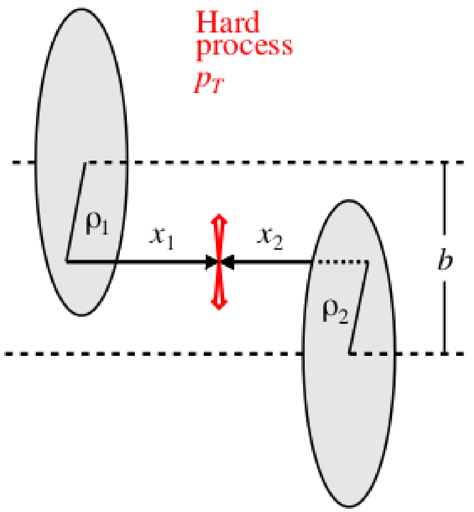
- multi-parton interactions in nuclear scattering:

  → multiple scatterings of produced quark with nuclear medium

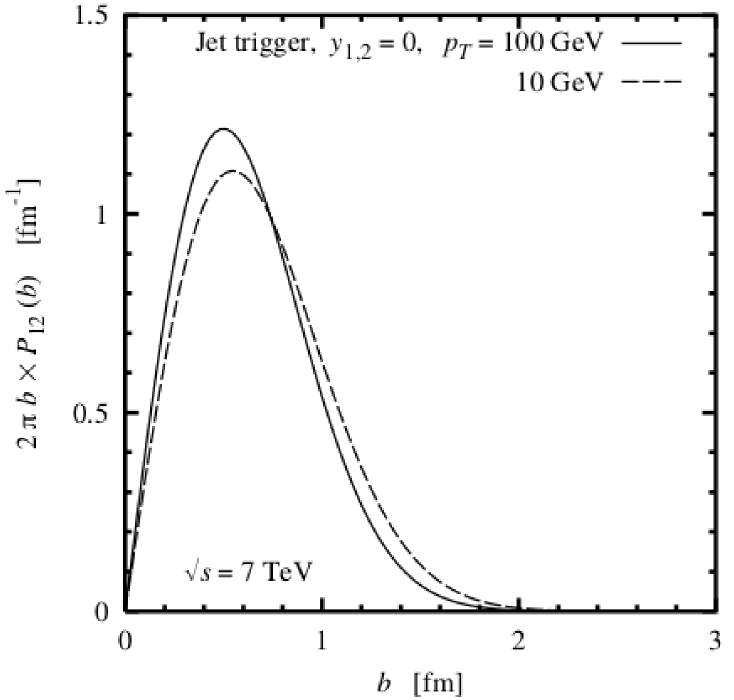
  → **qualitatively different dependence on nuclear size predicted at EIC energies**

  → more phase space for radiation, larger $\Delta\langle p_T^2\rangle$

Transverse geometry in pp: Hard processes



Thanks to **Christian Weiss**!



- Hard process from parton-parton collision

  Local in transverse space $p_T^2 \gg (\text{transv. size})^{-2}$

- Cross section as function of pp impact par

$$\sigma_{12}(b) = \int d^2\rho_1 \, d^2\rho_2 \, \delta(\boldsymbol{b} - \boldsymbol{\rho}_1 + \boldsymbol{\rho}_2) \times G(x_1, \rho_1) \, G(x_2, \rho_2) \, \sigma_{\text{parton}}$$

→ **precise GPDs furnished by EIC will be crucial!**

  Calculable from known transverse distributions
  Integral $\int d^2 b$ reproduces inclusive formula

  Normalized distribn $P_{12}(b) = \sigma_{12}(b)/[\int \sigma_{12}]$

- New information available

  Model spectator interactions depending on b
  Underlying event

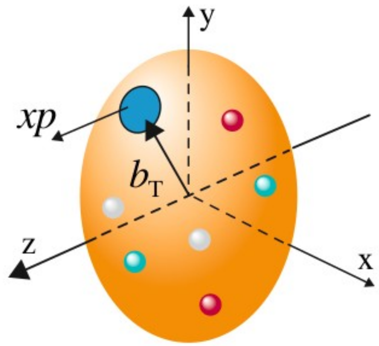
  Predict probability of multiple hard processes
  Dynamical correlations? FSW04

  Diffraction: Gap survival probability
  Determined largely by transverse geometry FHSW 07

conclusions… …and **the future.**

- the commisioning and operation of an EIC is now the priority of the US nuclear and hadronic physics communities

→ the dedicated aim of this effort will be the resolution of long-standing issues in QCD, and the precise determination of the nucleon's multi-dimensional structure



→ the impact of this work will **NOT** be relegated purely to hadronic/nuclear physics!

rather, the expected impact upon high energy physics is substantial

→ controlling SM backgrounds; BSM searches; CGC; **MPIs**; …

- exploring the physics implications of EIC (including in HEP) requires a **community effort**, esp. to optimize the output of the eventual program

… many opportunities to get involved.

supplementary material

the goal is to quantify the strength of the constraints placed on a particular set of PDFs by both individual and aggregated measurements *without direct fitting*

- for single-particle hadroproduction of gauge bosons at, e.g., LHC, factorization gives

$$\sigma(AB \to W/Z+X) = \sum_n \alpha_s^n(\mu_R^2) \sum_{a,b} \int dx_a dx_b$$

$$\times f_{a/A}(x_a, \mu^2)\, \hat{\sigma}^{(n)}_{ab\to W/Z+X}\left(\hat{s},\, \mu^2, \mu_R^2\right) f_{b/B}(x_b, \mu^2)$$

PDFs determined by fits to data; e.g., "CT14H2"

pQCD matrix elements – specified by theoretical formalism in a given fit

- *idea* : study the statistical <u>correlation</u> between PDFs and the quality of the fit at a measured data point(s); fit quality encoded in a (Theory) – (shifted Data) *residual* :

$$r_i(\vec{a}) = \frac{1}{s_i}\left(T_i(\vec{a}) - D_{i,sh}(\vec{a})\right)$$

s_i : uncorrelated uncert.

$\vec{a}$: PDF parameters

a brief statistical aside, i

- **the CTEQ-TEA global analysis relies on the Hessian formalism for its error treatment**

$$\chi^2_E(\vec{a}) = \sum_{i=1}^{N_{pt}} r_i^2(\vec{a}) + \sum_{\alpha=1}^{N_\lambda} \overline{\lambda}_\alpha^2(\vec{a})$$

nuisance parameters to handle correlated errors

$$r_i(\vec{a}) = \frac{1}{s_i}\left(T_i(\vec{a}) - D_{i,sh}(\vec{a})\right)$$

these result in systematic shifts to data central values:

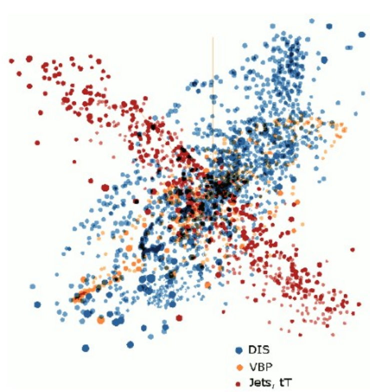
$$D_i \to D_{i,sh}(\vec{a}) = D_i - \sum_{\alpha=1}^{N_\lambda} \beta_{i\alpha}\overline{\lambda}_\alpha(\vec{a})$$

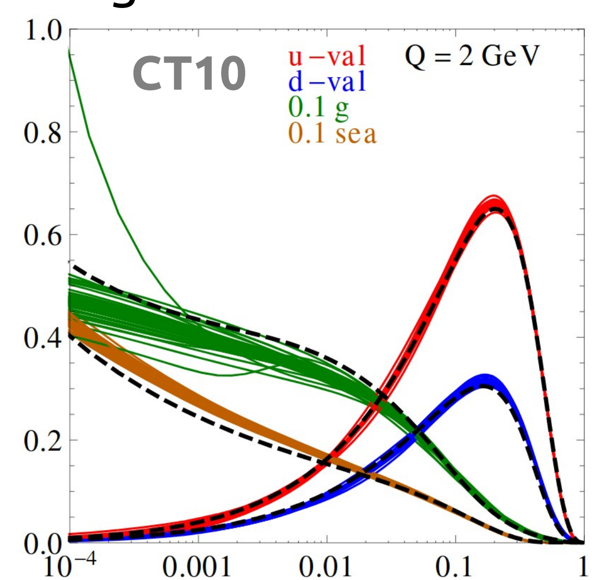
- a 56-dimensional parametric basis $\vec{a}$ is obtained by diagonalizing the Hessian matrix H determined from χ^2 (following a 28-parameter fit)

use this basis to compute 56-component "normalized" residuals :

$$\delta^{\pm}_{i,l} \equiv \left(r_i(\vec{a}^{\pm}_l) - r_i(\vec{a}_0)\right) / \langle r_0 \rangle_E$$

where $\langle r_0 \rangle_E \equiv \sqrt{\frac{1}{N_{pt}} \sum_{i=1}^{N_{pt}} r_i^2(\vec{a}_0)}$



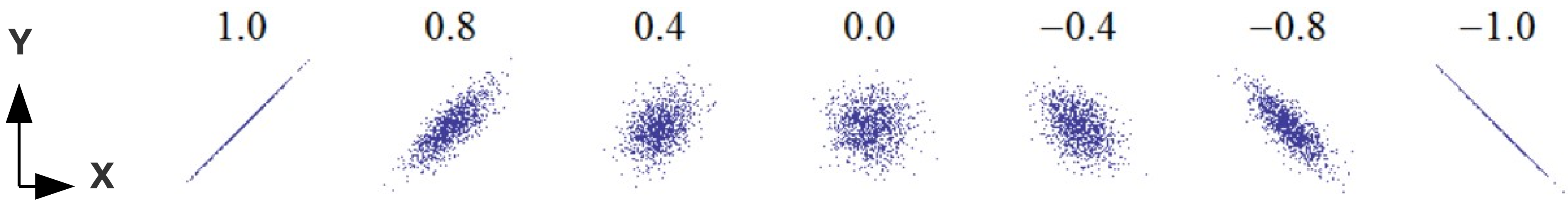


a brief statistical aside, ii

- **… but how does the behavior of these residuals relate to the fitted PDFs and their uncertainties?**

for example, how does the PDF uncertainty (at specific x, μ) correlate with the residual associated with a theoretical prediction at the same x, μ?

examine the Pearson correlation over the 56-member PDF error set between a PDF of given flavor and the residual



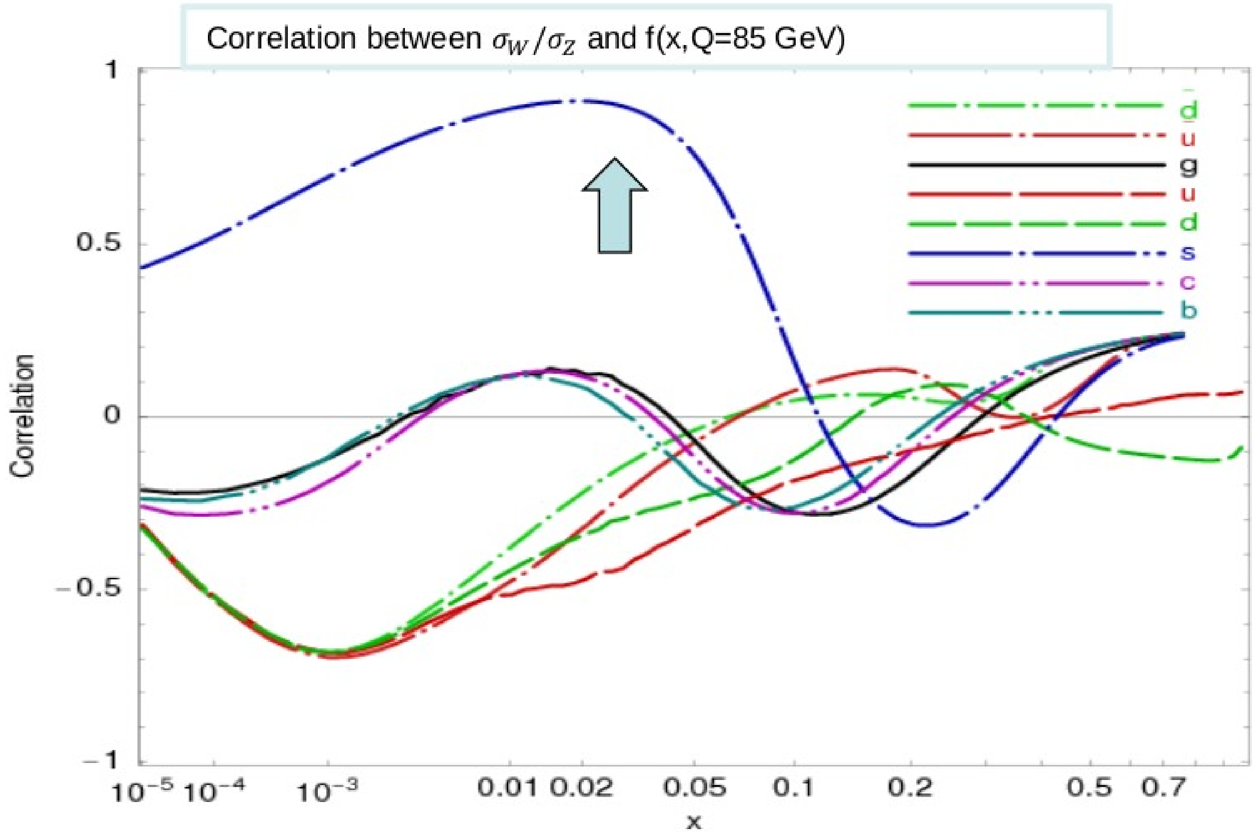
[X,Y] are exactly (anti-)correlated at the far (right) left above.

- we may then evaluate correlations between arbitrary PDF-derived quantities over the ensemble of error sets ([X,Y] may be PDFs, cross sections, residuals,…):

$$\mathrm{Corr}[X,Y] = \frac{1}{4\Delta X \Delta Y}\sum_{j=1}^{N}(X_j^+ - X_j^-)(Y_j^+ - Y_j^-) \qquad \Delta X = \frac{1}{2}\sqrt{\sum_{j=1}^{N}(X_j^+ - X_j^-)^2}$$

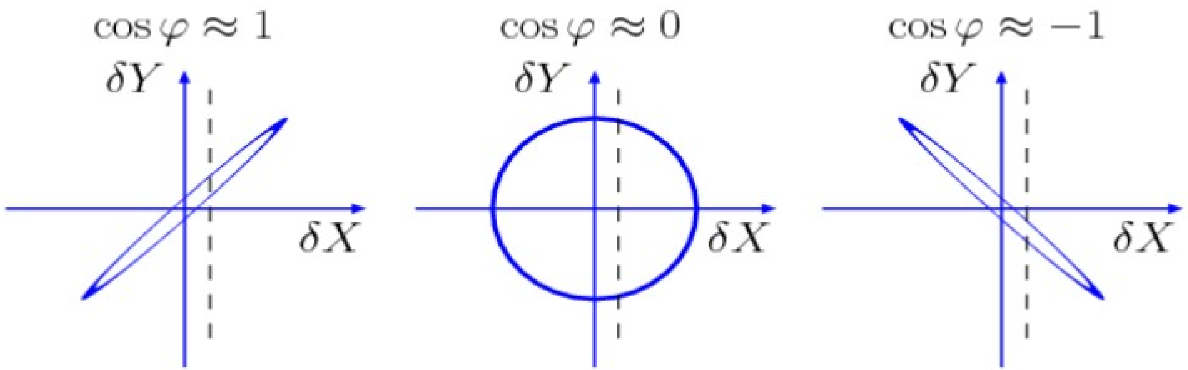
...we may turn to the Pearson correlations between PDFs and δ_i, but we first note

Correlations carry useful, but limited information



CTEQ6.6 [arXiv:0802.0007]: $\cos\varphi > 0.7$ shows that the ratio σ_W/σ_Z at the LHC must be sensitive to the strange PDF $s(x,Q)$

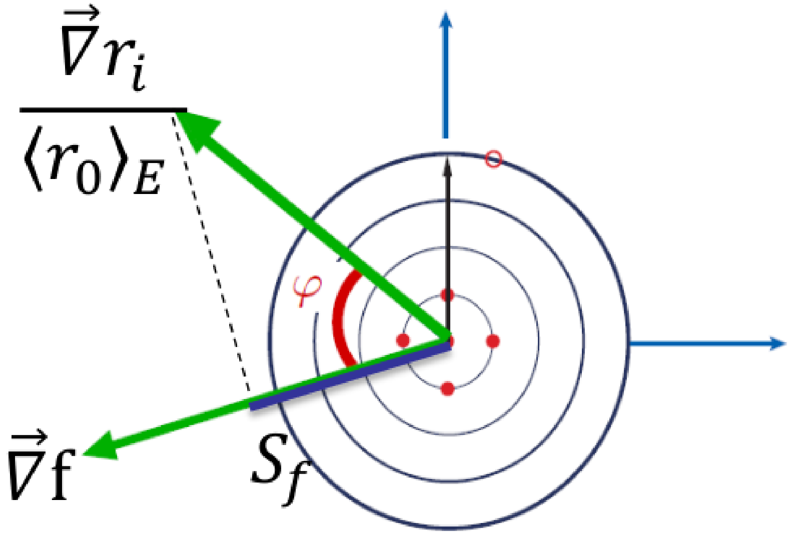
$\cos\varphi \approx \pm 1$ suggests that a measurement of X **may** impose tight constraints on Y



But, Corr[X,Y] between **theory** cross sections X and Y does not tell us about **experimental** uncertainties

Correlation C_f and sensitivity S_f

The relation of data point i on the PDF dependence of f can be estimated by:



- $C_f \equiv \mathrm{Corr}[\rho_i(\vec{a})), f(\vec{a})] = cos\varphi$

$\vec{\rho}_i \equiv \vec{\nabla} r_i / \langle r_0 \rangle_E$ -- gradient of r_i normalized to the r.m.s. average residual in expt E;

$$\left(\vec{\nabla} r_i\right)_k = \left(r_i(\vec{a}_k^+) - r_i(\vec{a}_k^-)\right)/2$$

$$\mathrm{Corr}[X, Y] = \frac{1}{4\Delta X \Delta Y} \sum_{j=1}^{N} (X_j^+ - X_j^-)(Y_j^+ - Y_j^-)$$

C_f is **independent** of the experimental and PDF uncertainties. In the figures, take $|C_f| \gtrsim 0.7$ to indicate a large correlation.

- $S_f \equiv |\vec{\rho}_i| cos\varphi = C_f \frac{\Delta r_i}{\langle r_0 \rangle_E}$ -- projection of $\vec{\rho}_i(\vec{a})$ on $\vec{\nabla} f$

S_f is proportional to $\cos\varphi$ and the ratio of the PDF uncertainty to the experimental uncertainty. We can sum $|S_f|$.

In the figures, take $|S_f| > 0.25$ to be significant.

2nd aside: **kinematical matchings**

- residual-PDF correlations and sensitivities are evaluated at parton-level kinematics determined according to leading-order matchings with physical scales in measurements

x_i : parton mom. fraction

μ_i : factorization scale

deeply-inelastic scattering:

$$\mu_i \approx Q\big|_i\,,\ x_i \approx x_B\big|_i$$

hadron-hadron collisions:

$AB \to CX$

$$\mu_i \approx Q\big|_i\,,\ x_i^{\pm} \approx \frac{Q}{\sqrt{s}}\,\exp(\pm y_C)\bigg|_i$$

single-inclusive jet production: $Q = 2p_{Tj}\,,\ y_C = y_j$

$t\bar{t}$ pair production: $Q = m_{t\bar{t}},\ y_C = y_{t\bar{t}}$

etc...

$d\sigma/dp_T^Z$ measurements: $Q = \sqrt{(p_T^Z)^2 + (M_Z)^2},\ y_C = y_Z$

Sensitivity ranking tables

… to assess the impact of separate experiments

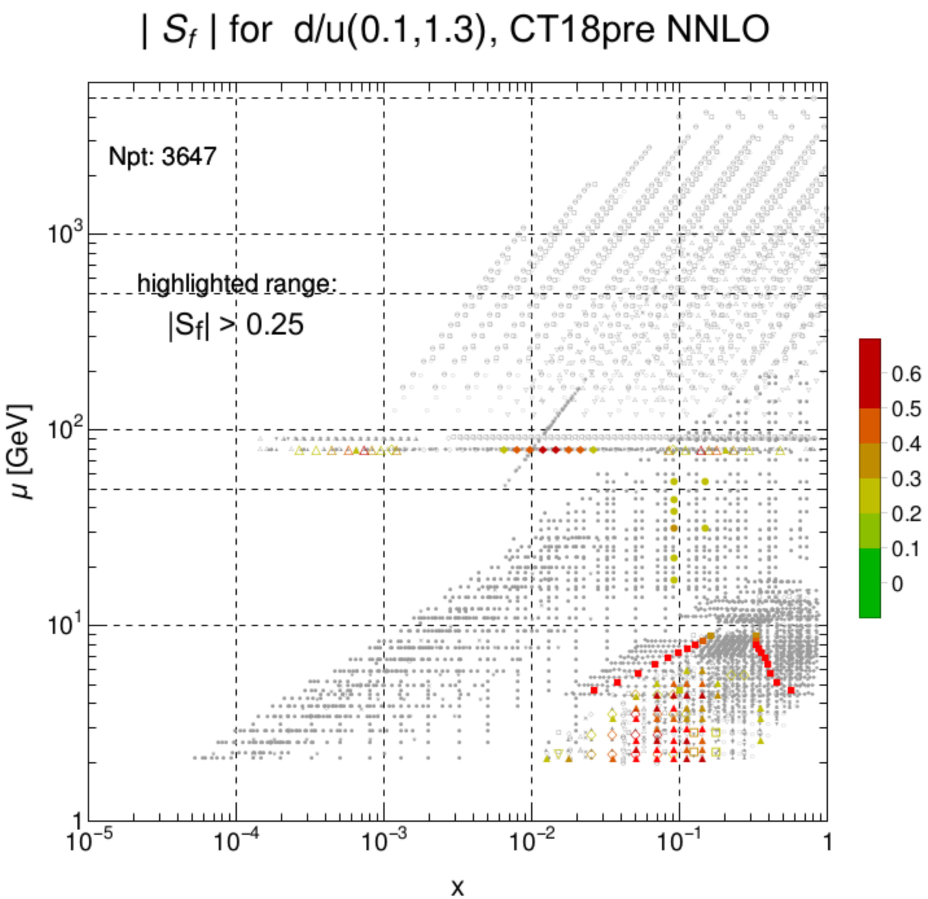
No.	Expt.	N_{pt}	$\sum_f \lvert S_f^E \rvert$	$\langle \sum_f \lvert S_f^E \rvert \rangle$	$\lvert S_{\bar{d}}^E \rvert$	$\langle \lvert S_{\bar{d}}^E \rvert \rangle$	$\lvert S_{\bar{u}}^E \rvert$	$\langle \lvert S_{\bar{u}}^E \rvert \rangle$	$\lvert S_g^E \rvert$	$\langle \lvert S_g^E \rvert \rangle$	$\lvert S_u^E \rvert$	$\langle \lvert S_u^E \rvert \rangle$	$\lvert S_d^E \rvert$	$\langle \lvert S_d^E \rvert \rangle$	$\lvert S_s^E \rvert$	$\langle \lvert S_s^E \rvert \rangle$
			Rankings, **CT14 HERA2 NNLO PDFs**													
1	HERAI+II'15	1120.	620.	0.0922	B		**A**	3	**A**	3	**A**	3	B		C	
2	CCFR-F3'97	86	218.	0.423	C	**1**	C	**1**		3	B	**1**	C	2		
3	BCDMSp'89	337	184.	0.0908			C		C		B	3	C			
4	NMCrat'97	123	169.	0.229	C	2					C	2	B	2		
5	BCDMSd'90	250	141.	0.0939	C				C	3	C	3	C	3		
6	CDHSW-F3'91	96	115.	0.199	C	2	C	2		3	C	2	C	3		
7	E605'91	119	113.	0.158	C	2	C	2				3				
8	E866pp'03	184	103.	0.0935		3	C	3			C	3				
9	CCFR-F2'01	69	89.1	0.215		3		3	C	2		3		2		3
10	**CMS8jets'17**	185	87.6	0.0789					C	3						
11	CDHSW-F2'91	85	82.4	0.162		3		3		3		3	C	3		
12	CMS7jets'13	133	63.8	0.0799					C	3						
13	NuTeV-nu'06	38	58.9	0.259		3		3				3		3	C	**1**
14	**CMS7jets'14**	158	57.5	0.0606					C	3						
15	CCFR SI nub'01	38	49.4	0.217		3		3				3		3	C	**1**
16	**ATLAS7jets'15**	140	48.2	0.0574						3						
17	CCFR SI nu'01	40	48.	0.2		3		3				3		3	C	**1**

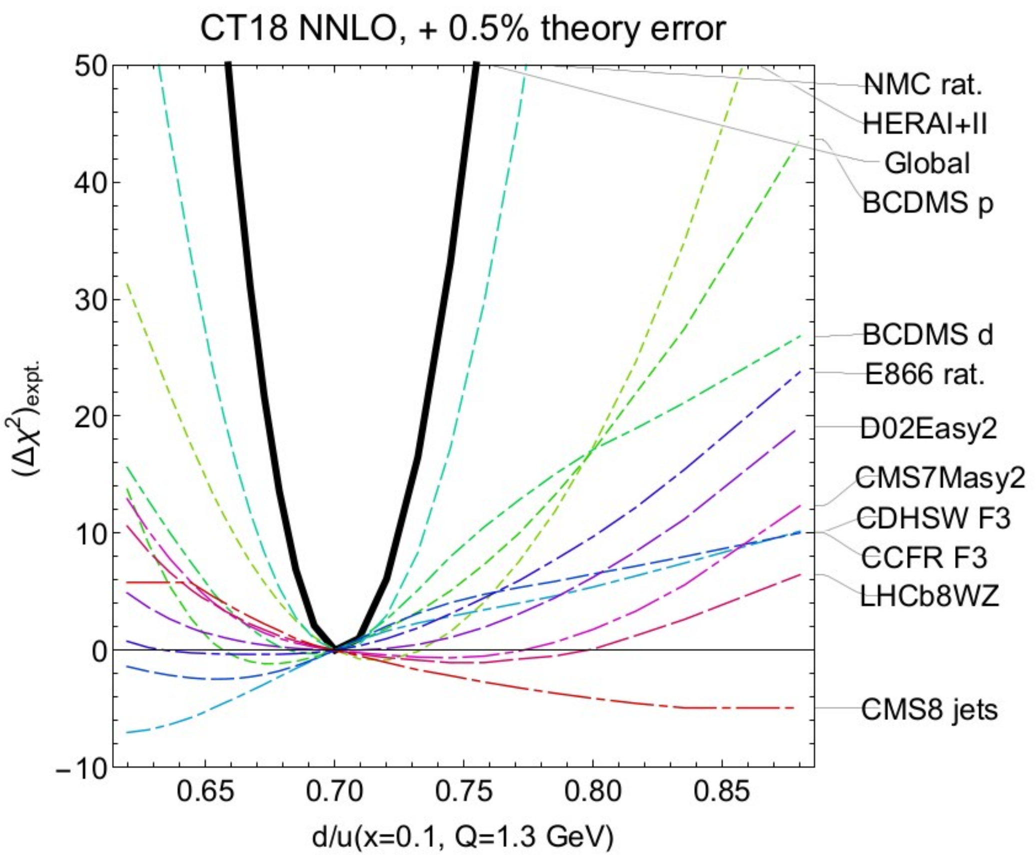
Experiments are listed in the descending order of the summed sensitivities to $\bar{d}, \bar{u}, g, u, d, s$

For each flavor, A and 1 indicate the strongest total sensitivity and strongest sensitivity per point

C and 3 indicate marginal sensitivities; low sensitivities are not shown

PDFSense predictions can be validated against actual fits





- PDFSense successfully predicts the highest impact data sets *before* fitting, as shown in this illustration for the large x PDF ratio d/u
- Lagrange Multiplier scans provide an independent test of which datasets most drive the global fit in connection with specific PDFs

HERA and fixed-target (BCDMS, NMC) data are dominant!