Impact of EIC NC and CC inclusive data on PDFs

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Hampton U. and Jefferson Lab

EIC Users Group Meeting

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In collaboration with: *R. Ent, C.E. Keppel, Y. Furletova, K. Park, M. Wing, R. Yoshida*

HAMPTON UNIVERSITY
THE STANDARD OF EXCELLENCE

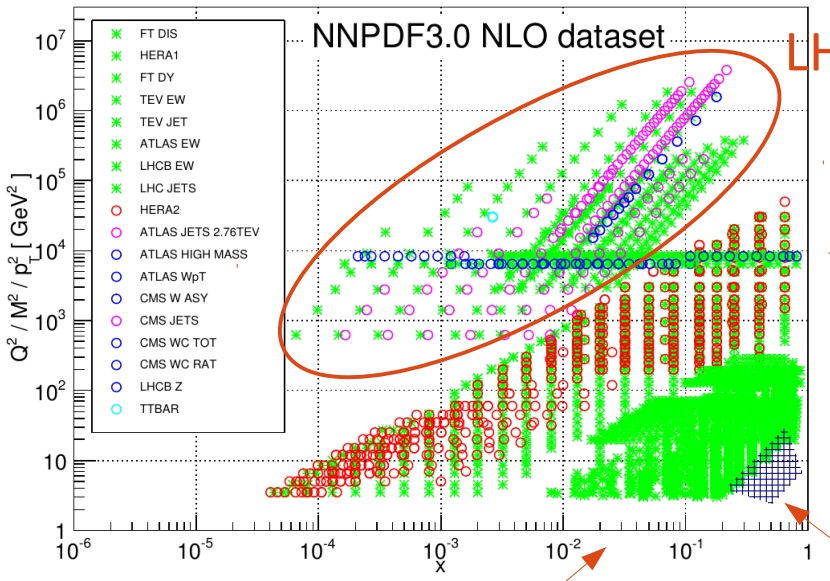
Jefferson Lab

Overview

- **Why EIC?**
- **NC, CC, and "free" neutron simulations**
- **Impact on PDF**
  - Focus on large x (for now)
- **Some final thoughts**

Why EIC?

1 - Data coverage for PDF fits



LHC data

W and Z

SLAC, JLab

DY and DIS
(on p, d)

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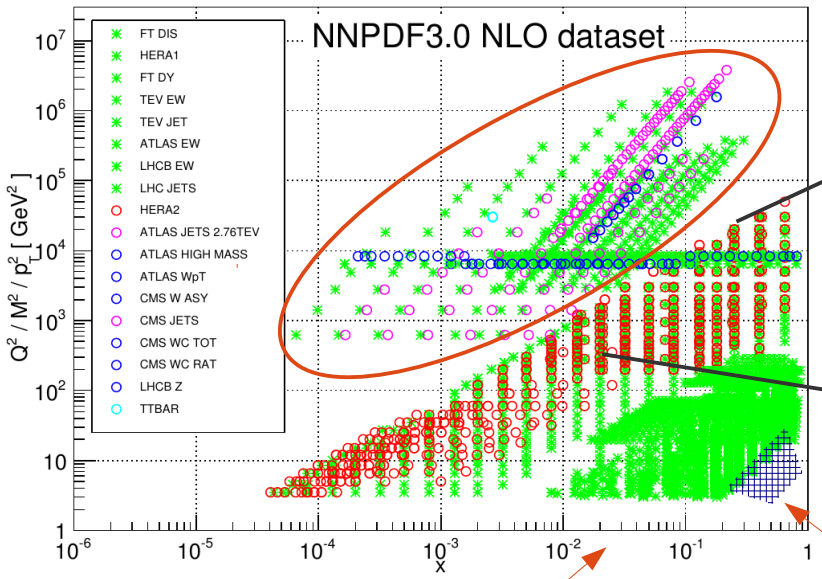
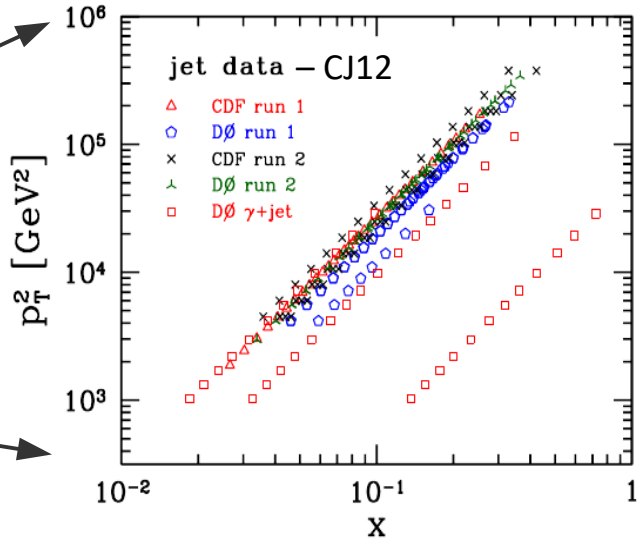


LHC data

Tevatron Jets



SLAC, JLab

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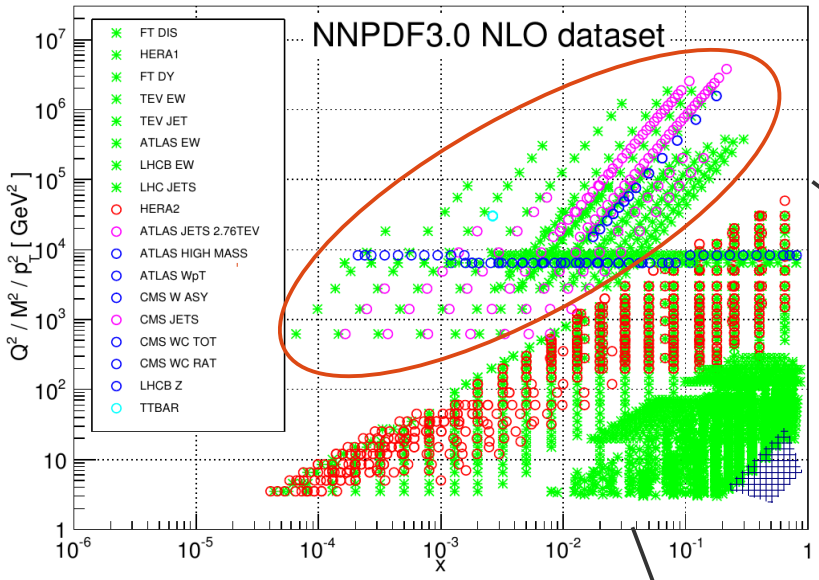
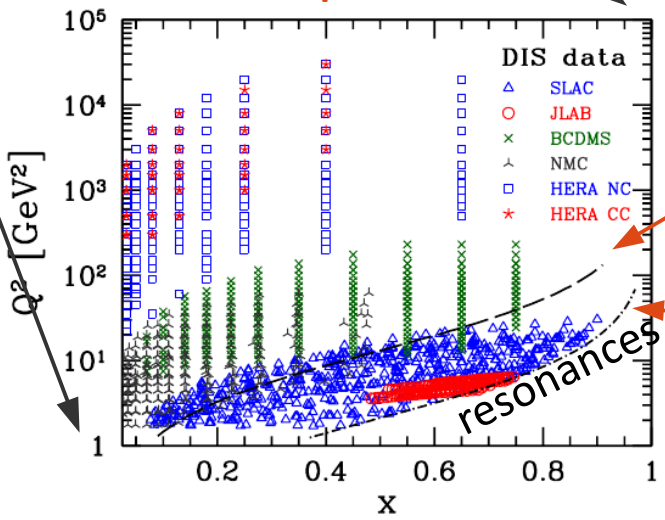


LHC data

Scant large-x coverage in DIS !

DIS – prot. & deut.



standard cut

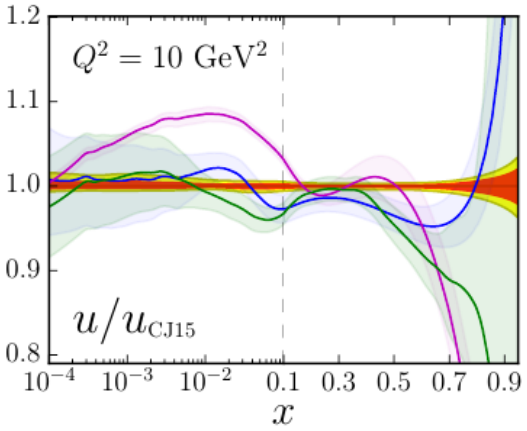
$W^2 \gtrsim 14$ GeV^2

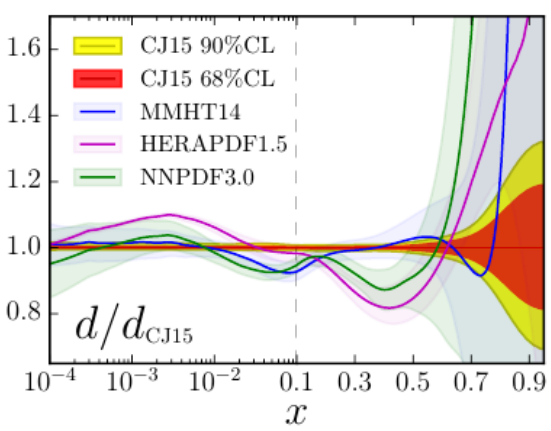
CJ15

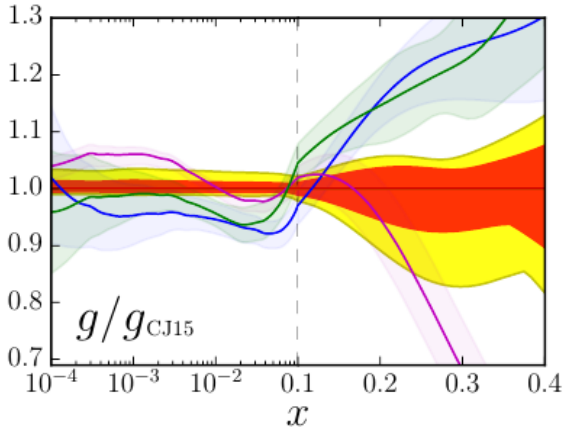
$W^2 \gtrsim 3.5$ GeV^2

– CJ12

…and after all this…

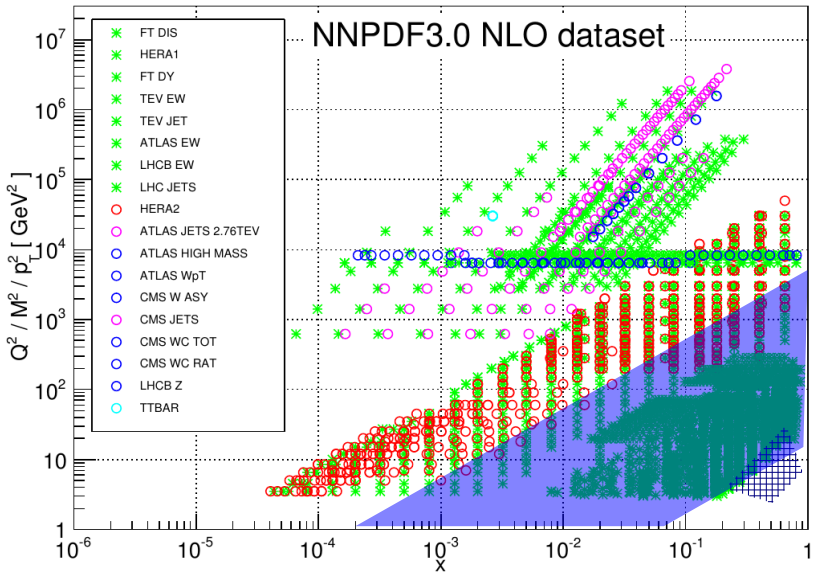






- Large uncertainties in up, down, gluons, esp. at large x
- Precision needed for:
  - Hadronic structure
  - BSM physics
  - Higgs physics
  - …

Enters the EIC



- Interpolates fixed target and HERA
- Large Q^2 leverage
  - More evolution at large *x*
  - Better separation of LT and HT
- High luminosity
  - large *x* capabilities
  - Quick √s scan ⟶ L/T separation

- **EIC can "do it all"**
  - "Easy" spectator tagging in DIS – Quasi-free neutron targets
  - Strong PID capabilities ⟶ F_2^c, F_2^{cc}, ...
  - High luminosity ⟶ CC, PVDIS ⟶ d/u, strange quarks, dbar/ubar, ...
  - Unpolarized & polarized scattering (also light ions) & Frag Fns.
  - Nuclear targets

PVDIS → Y. Zhao

Preliminary simulations
- impact of EIC on d,u,g -

In collaboration with:

– R. Ent, C. Keppel, Y.Furletova, K. Park, R. Yoshida (JLab), M. Wing (UC London)

Can EIC help?

- Flavor separation, nuclear corrections with F2(p) and F2(d)
  - "bread and butter", but: how large in x, what precision?
  - What impact on PDFs ?

→ *R.Ent, EICUG @ Argonne, 2016*

- **Gluons** through L/T separation, scaling violation
  - require range in y, x, Q2
  - L/T partially from fixed target cross sections
  - Scaling violations at large x require the EIC

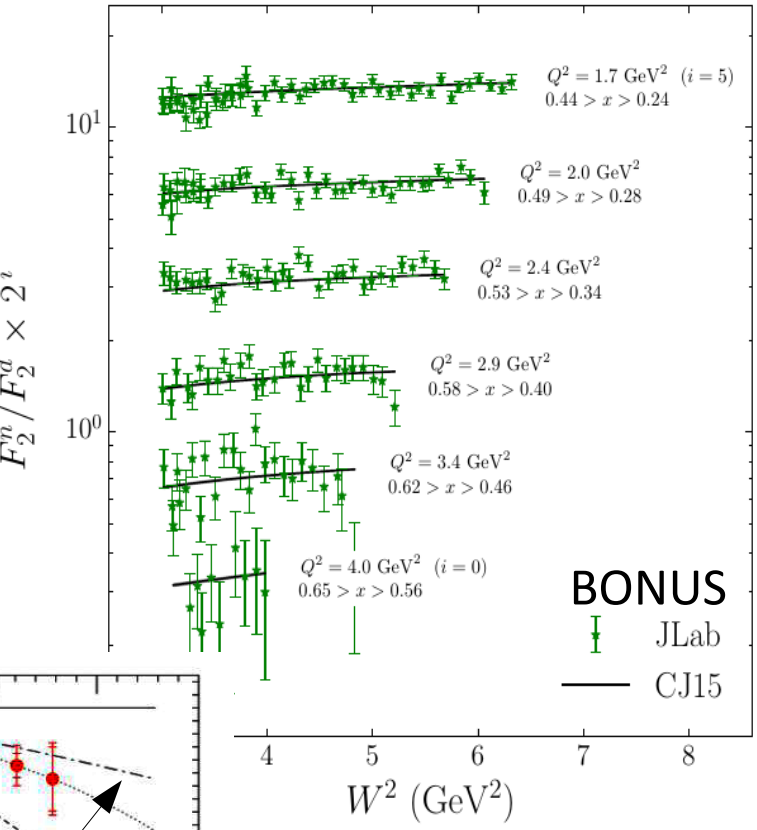
- **d-quarks** wtithout nuclear corrections: F2(n)
  - possible with planned EIC spectator tagging capabiities → *W. Cosyn*

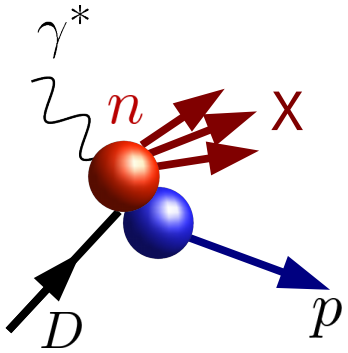
- Extend the 2016 analysis:
  - NC & CC cross sections on proton targets
  - Free neutrons from proton tagging revisited

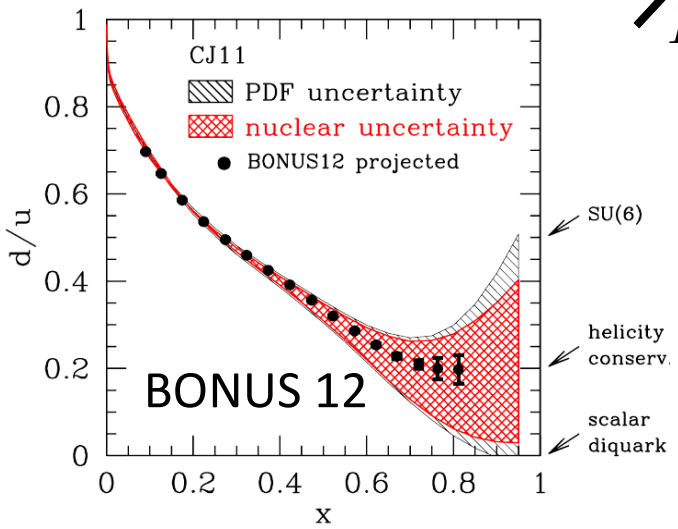
Spectator tagging at JLab: quasi-free neutrons

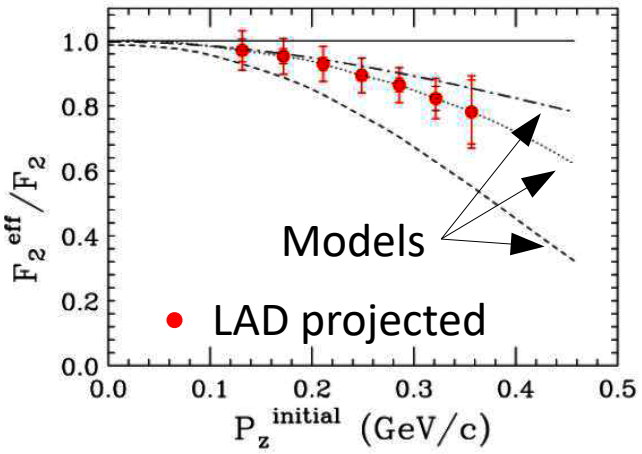
- Neutron off-shellness depends on on spectator momentum:
  - Slow: nearly on-shell (BONUS 6 & 12)
  - Fast: more and more off-shell (LAD)

N.Baillie et al., PRL 108 (2012) 199902







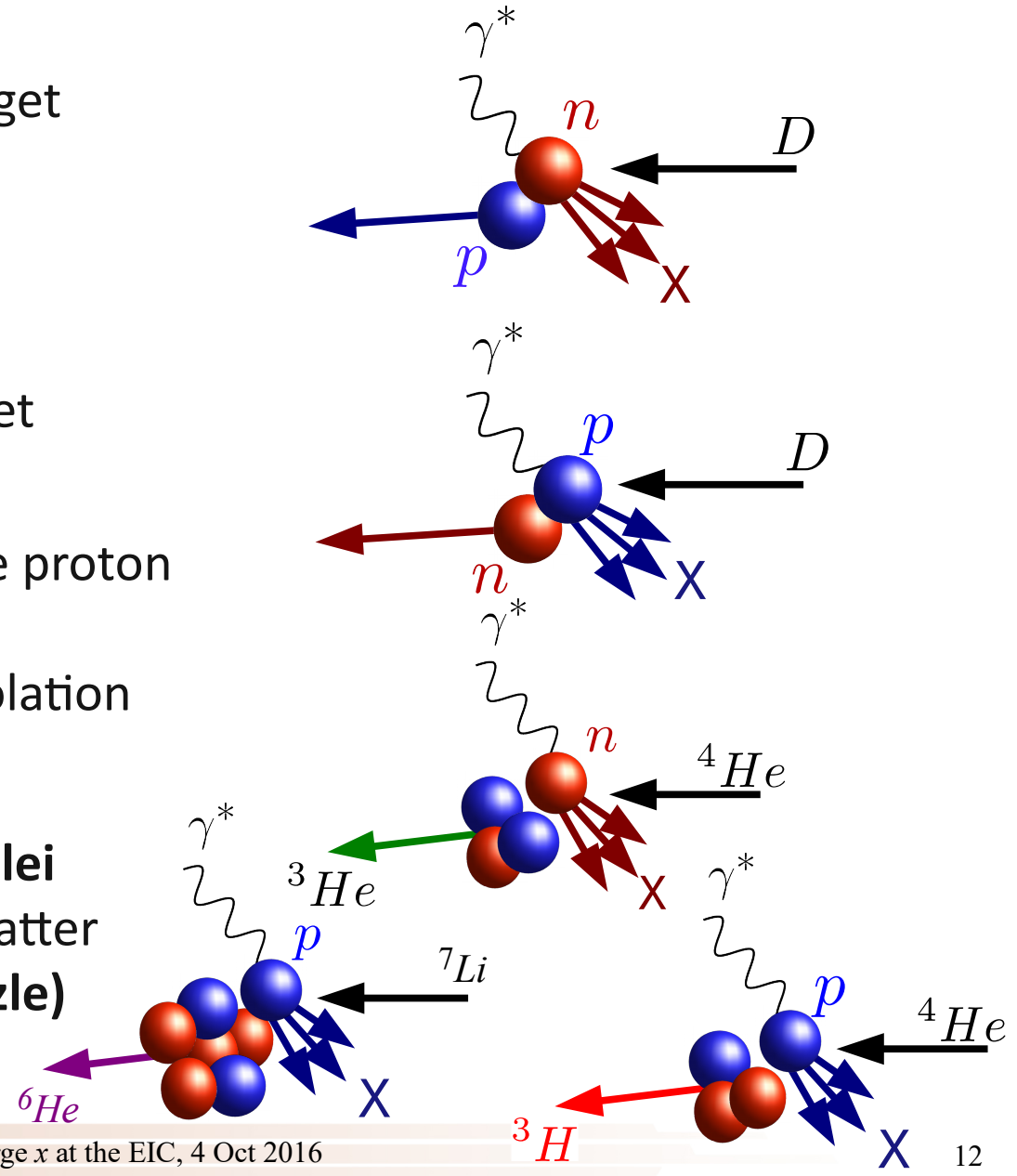


Spectator tagging at EIC: even better!

- measure **neutron F_2** in D target
  - flavor separation

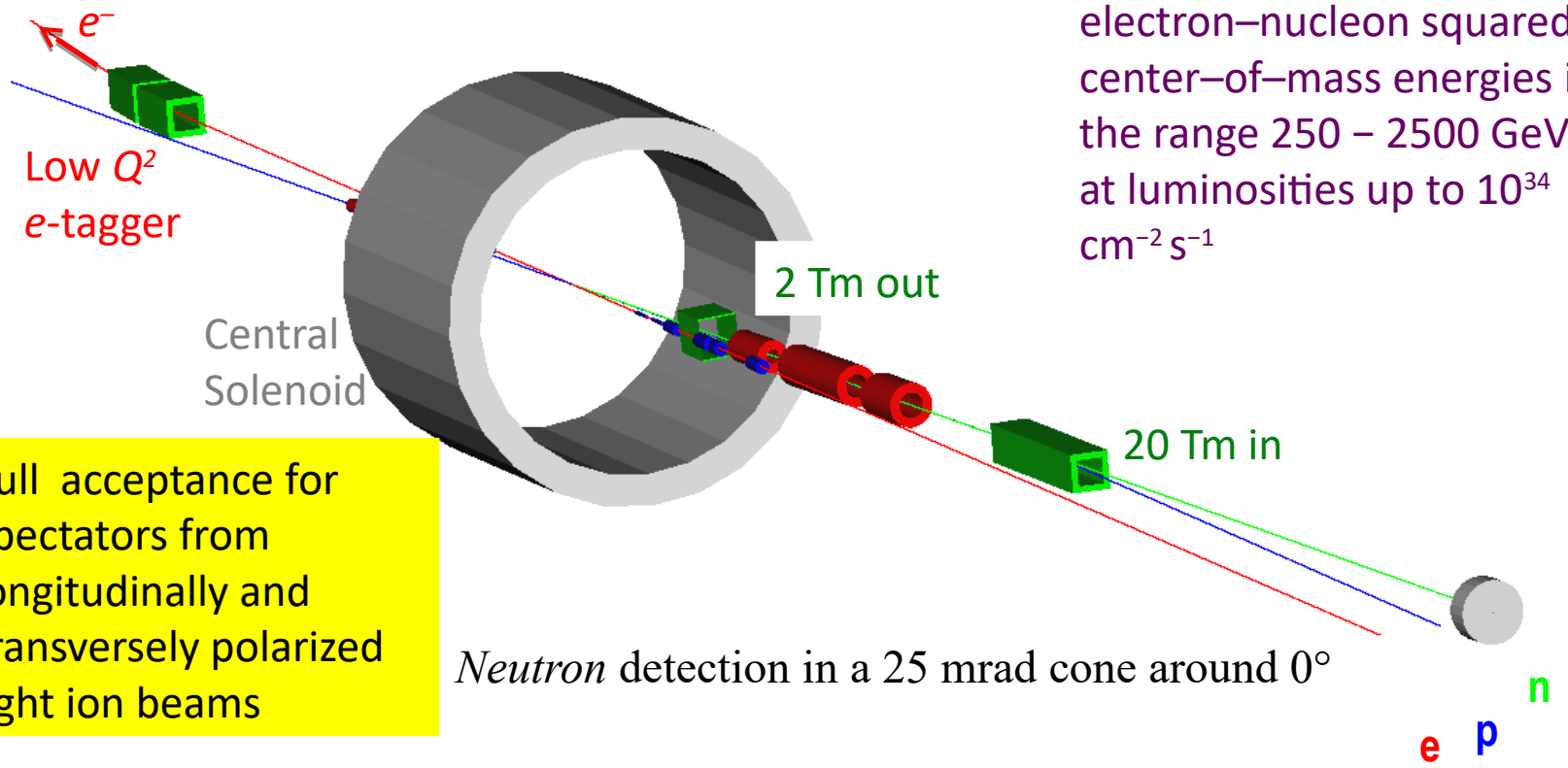
- measure **proton F_2** in D target
  - **Unique at colliders**
  - Compare off-shell to free proton
  - Establish nuclear effects
  - Validate on-shell extrapolation techniques

- **proton, neutron in light nuclei**
  - embedding in nuclear matter **(a piece of the EMC puzzle)**



Tagged structure functions at the EIC

→ *W. Cosyn*



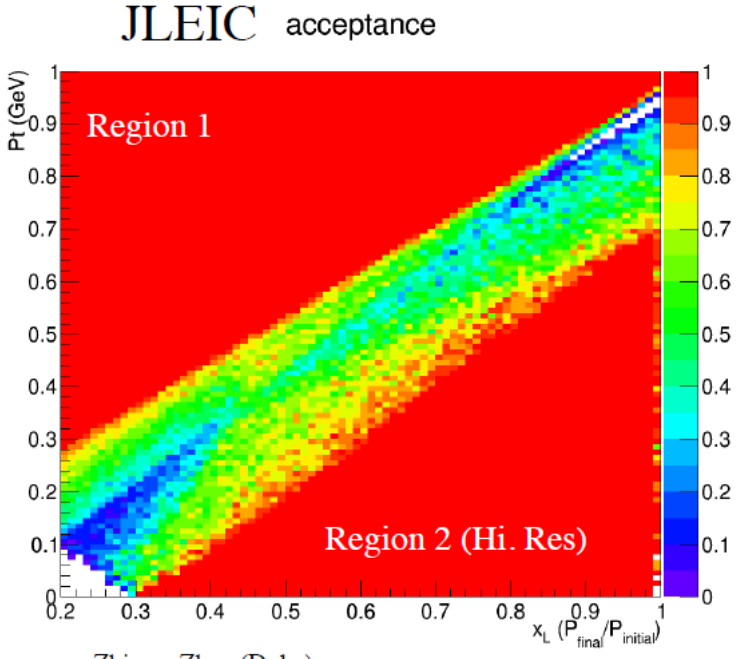
The JLEIC design provides electron–nucleon squared center–of–mass energies in the range 250 – 2500 GeV² at luminosities up to 10^{34} $cm^{-2}\,s^{-1}$

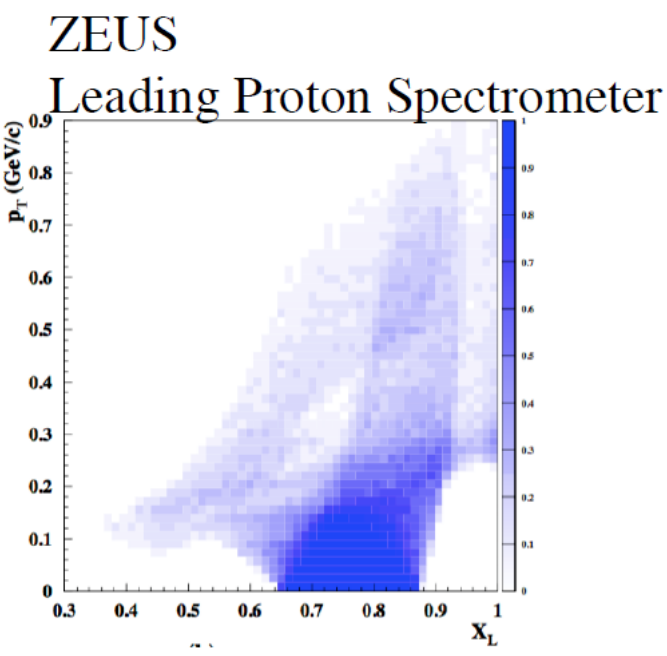
- Full acceptance for spectators from longitudinally and transversely polarized light ion beams

Neutron detection in a 25 mrad cone around 0°

EIC: full acceptance for forward physics

Example: acceptance for p' in e + p → e' + p' + X





Acceptance in diffractive peak (X_L>~.98)

ZEUS: ~2%

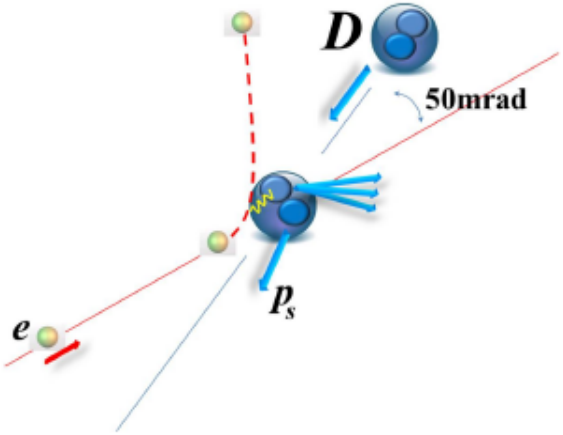
JLEIC: ~100% (also covers much higher X_L than ZEUS)

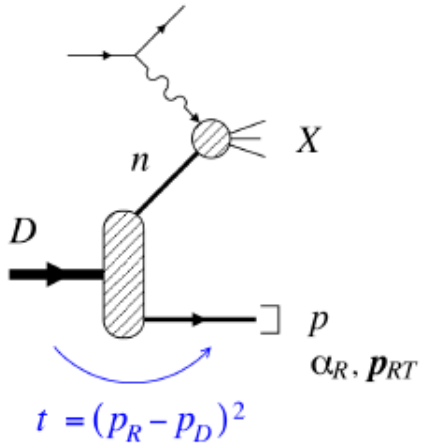
Huge gain in acceptance for forward tagging to measure F_2^n and diffractive physics!!!

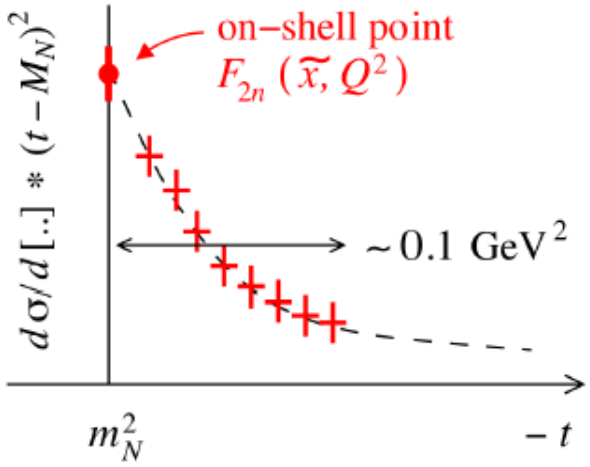
(Tagged) neutron structure extrapolation in t

JLab LDRD project 2014/15 – C.Weiss et al. – www.jlab.org/theory/tag/

→ W. Cosyn







- t resolution better than 20 MeV, < fermi momentum
  - Resolution limited/given by ion momentum spread
  - Allows precision extraction of F2n neutron structure function

(Tagged) neutron structure extrapolation in t

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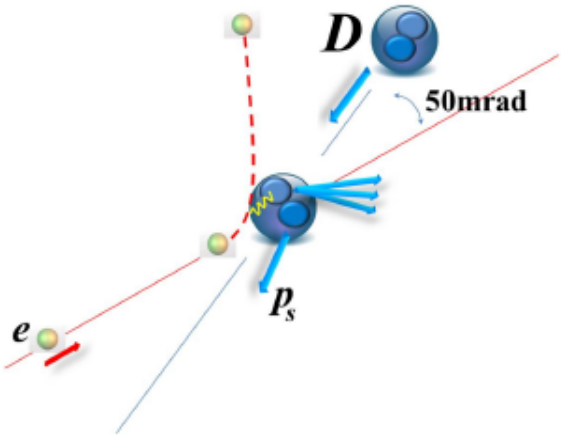
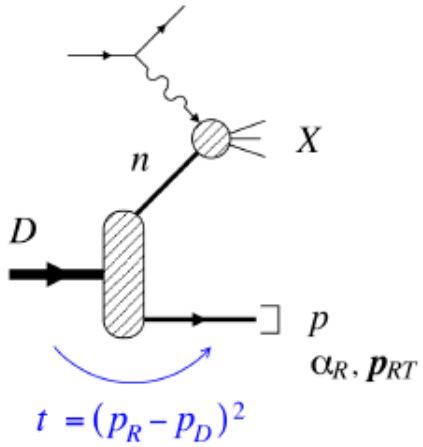
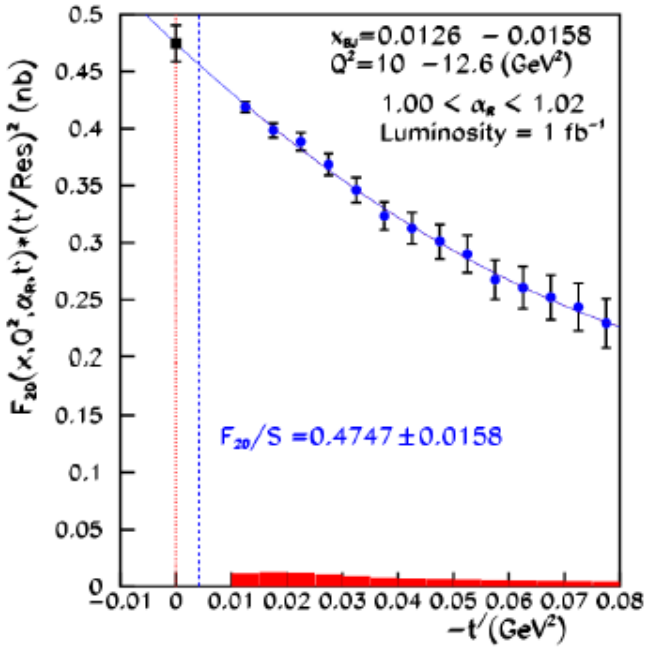






- 1 year of EIC @ luminosity of
  - 10^{32} gives about 1 fb^{-1}
  - 10^{33} gives about 10 fb^{-1}
  - → 10^{34} gives about 100 fb^{-1}

Projected data (so far)

This exercise: projections in 0.01 < x < 0.9 bins for:

- ✓ Cross sections on proton target: *(Y. Furletova)*
  - NC and CC; electrons and positrons
- ✓ F_2^n from deuterium with tagged proton spectator *(K. Park)*
- ✓ Max energy: 10x100 GeV^2 at 100/fb, energy scan at 10/fb

Finally,

- bootstrap projected data around CJ15 calculations
- fit along rest of CJ15 data sets
- examine impact on u, d, g

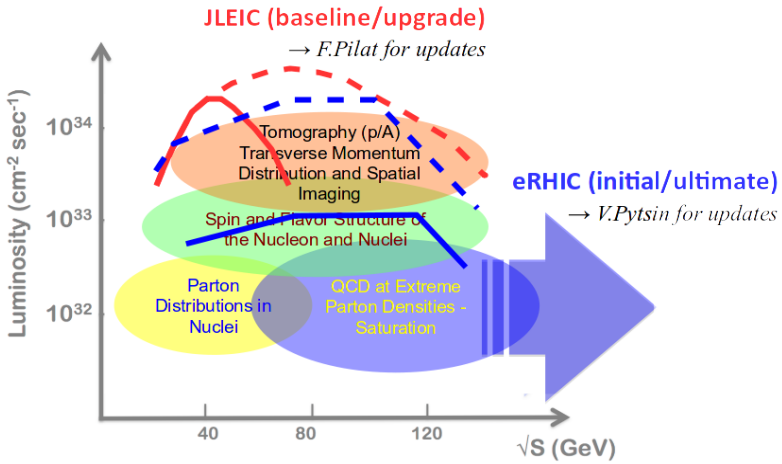
(Impact of deuteron target DIS was presented in Argonne, 2016)

Projected data (so far)

$\sqrt{s}$	electrons			positrons	
	tag	NC	CC	NC	CC
63					
57					
49					
28					

$L = 100/fb$

$L = 10/fb$



* as of Jan 2017

Cuts

$W^2 > 3.5$ GeV^2 (standard CJ15 cut)

$Q^2 > 2$ GeV2 (NC) ; 100 GeV^2 (CC)

$0.05 < y < 0.95$

Systematics

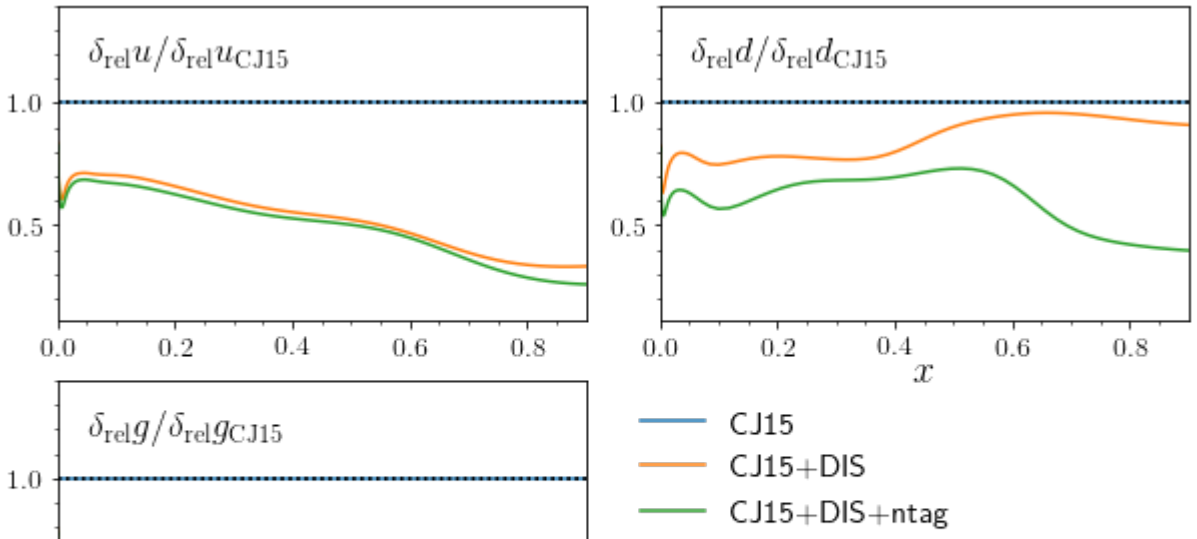
Normalization: 1%

NC: 1.5% y>0.8 , 0.5% elsewhere

CC: 5% y>0.8 or Q^2<125 , 2% elsew.

Tag: 5% x>0.3 , 2% elsewhere

Impact - summary

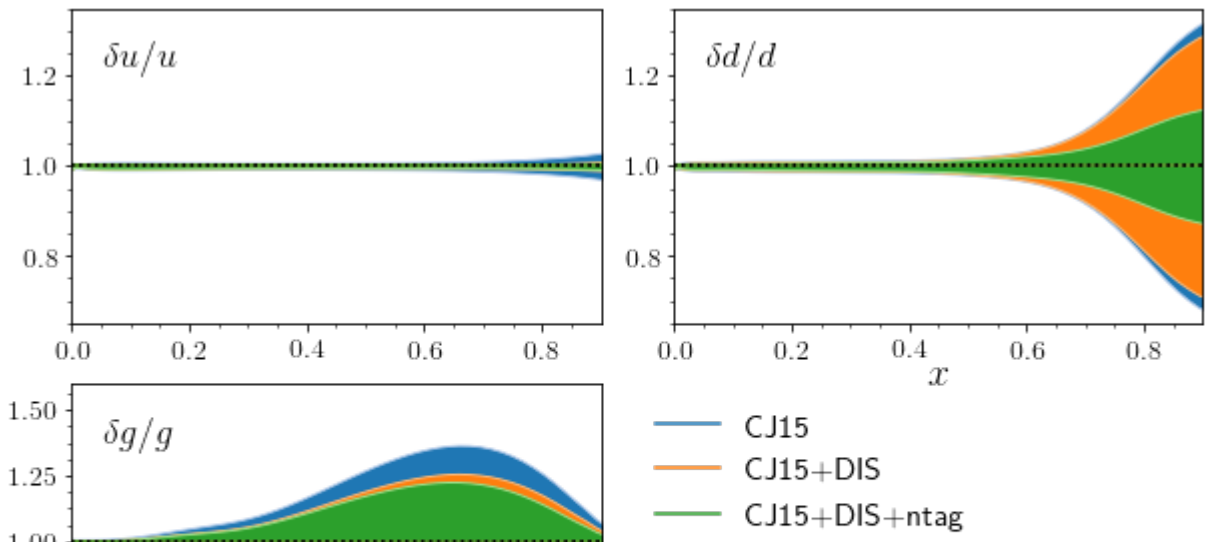


40-50% better d-quarks

40-50% better gluons

- Energy scan ↔ L/T separation
  - Large improvement in gluon uncertainty
  - Little effect on *d*-quarks
  - (CC have very little effects on u,d,g)
- Tagged neutrons
  - Noticeable improvement for d-quarks u
  - Some effects on gluons

Impact - summary

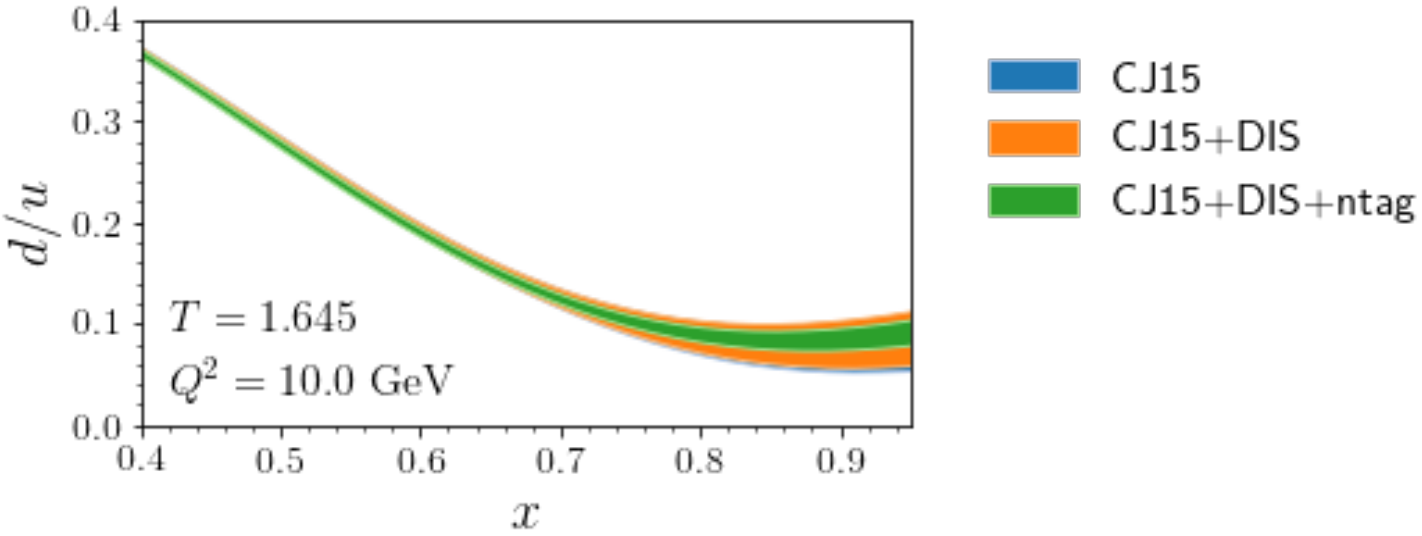


40-50% better d-quarks

40-50% better gluons

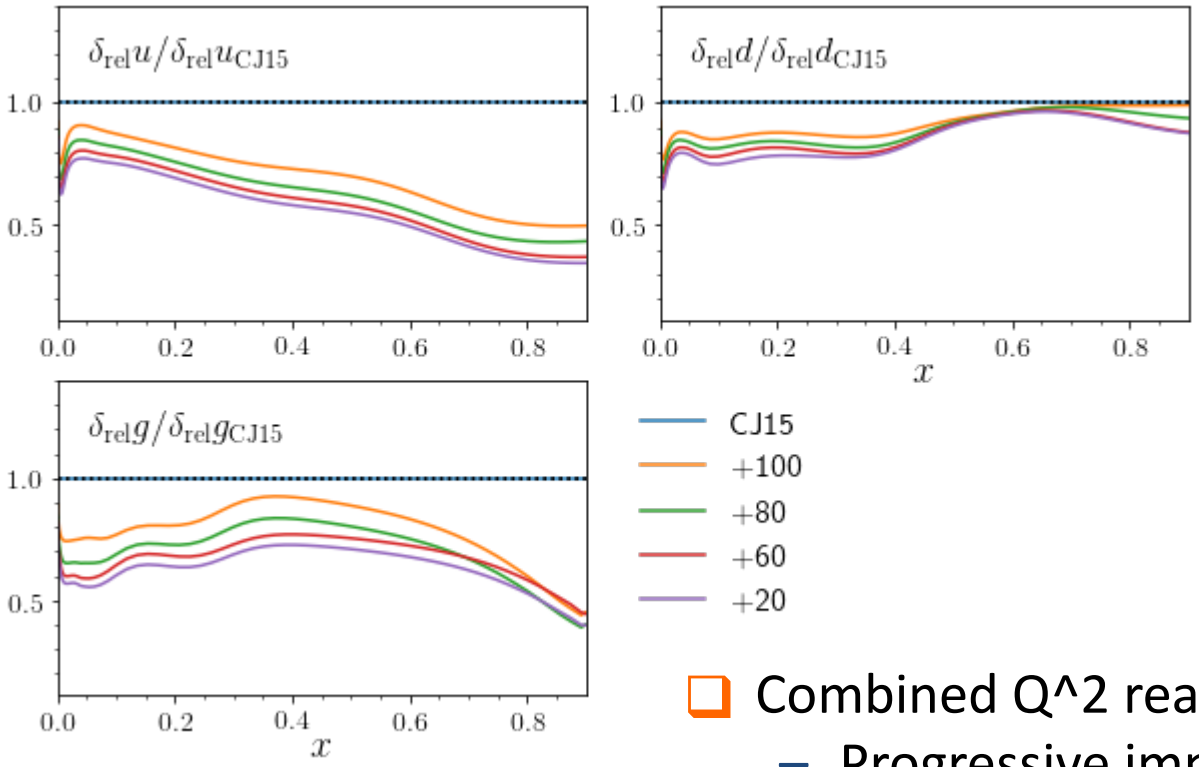
- Precise gluons at x=0.01-0.1 for Higgs Physics
- Unprecedented reach at large x > 0.1
  - Precise photon PDFs for LHC
  - Baseline for gluon anti-shad./EMC effect in nuclei
- u-quark at 1% precision, may be important for large mass BSM new particles

Impact - summary



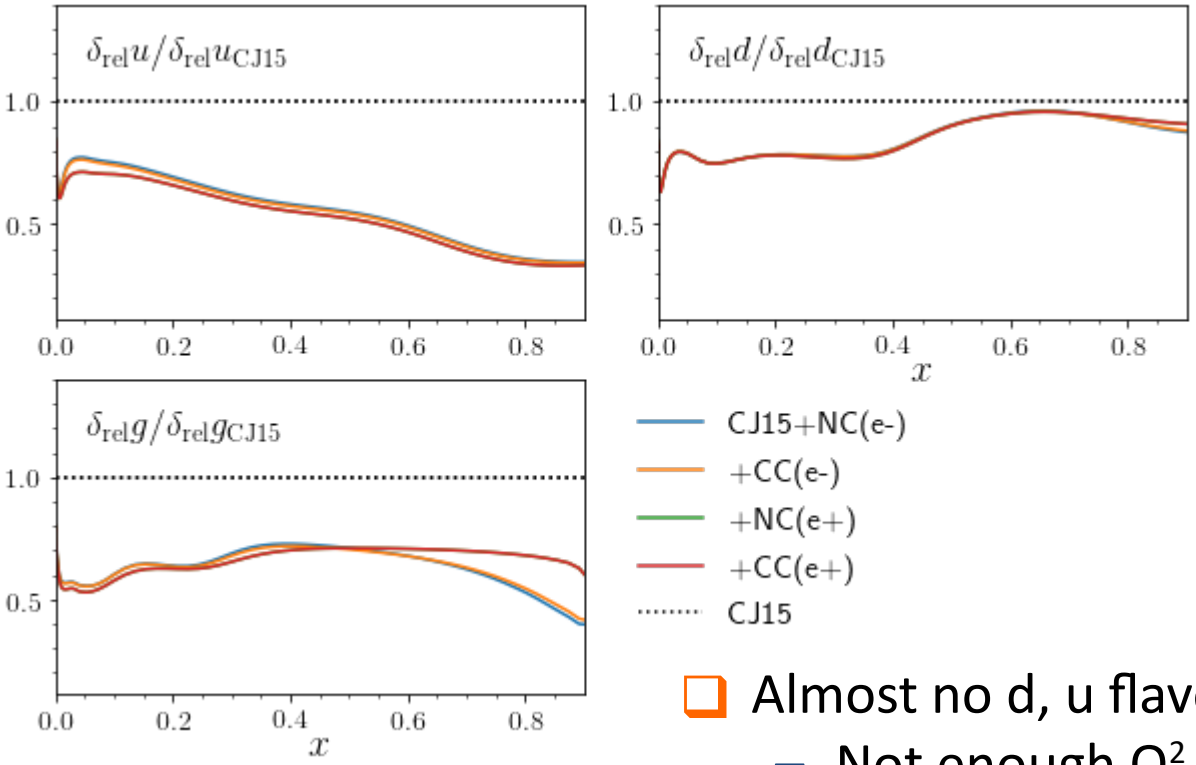
- The d-quark goes from 30% to <~10% percent level
- Resolve long-standing mystery of d/u at large x,
  → Can explore in detail fundamental models nucleon structure
- D/(p+n) in one experiment for the first time (possible, not discussed here)
  → unprecedented handle on nuclear medium modifications
  → can quantitatively address interplay of hard scattering and (soft) nucleon dynamics
- Facilitate accurate neutron excess/isoscalar corrections
  - Important also for neutrino physics and nuclear PDFs

Energy scan ↔ L/T separation



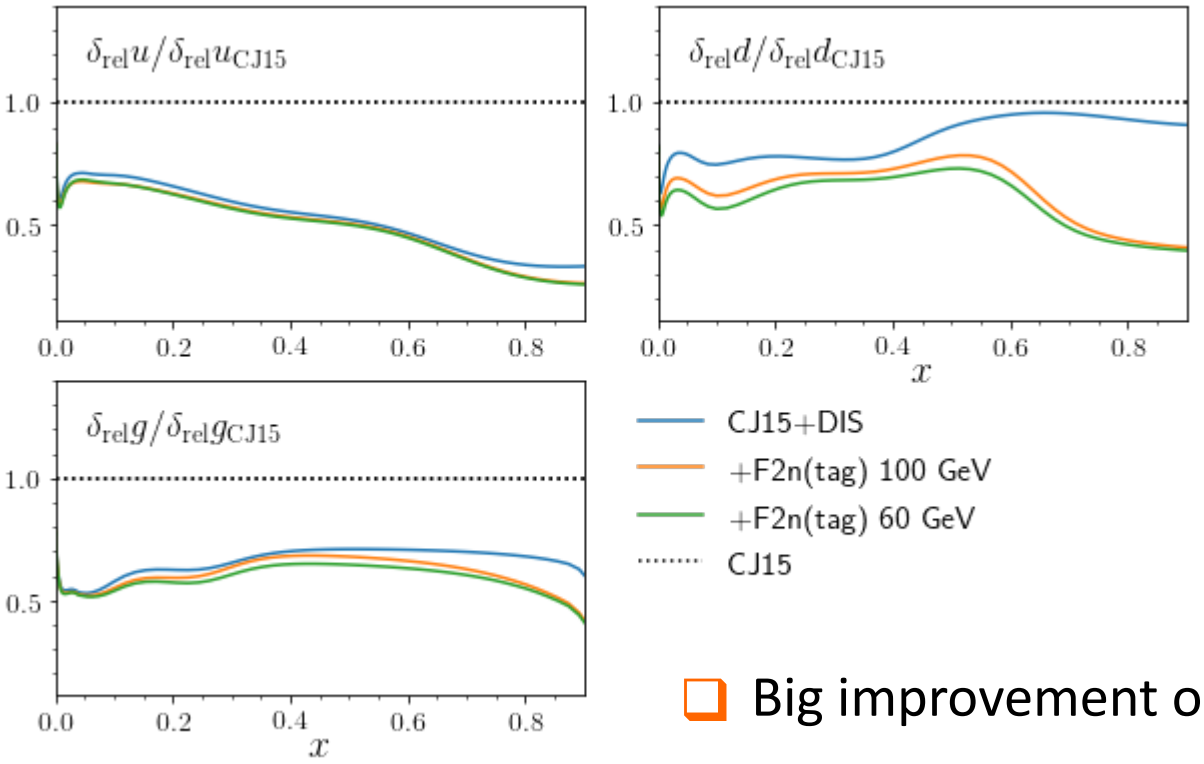
- Combined Q^2 reach and y range:
  - Progressive improvement in gluon PDF
- Last nrg set seem to have minor impact
- But:
  - **Need to optimize energy choices**
  - **Binning: (x,Q^2) or (x,y) ?**

Charged currents and positrons



- Almost no d, u flavor separation power:
  - Not enough Q^2 leverage
  - Large systematic:
    5% y>0.8 or Q^2<125 , 2% elsewhere

Neutron tagging



- Big improvement on d- quark with top nrg

Some final thoughts

EIC has big potential

- EIC has excellent potential for
  - **u, d, g flavor determination at large x**
    ⟷ hadronic structure
    ⟷ BSM
    ⟷ Photon PDFs for LHC
  - Revolutionizing **nuclear structure studies using hard probes**
- Needs more work, realistic systematics, grid optimization, ...

What else can we dream of doing at the EIC?

- **Isospin violations**
  - Play free n from BONUS/EIC vs. free p from D0, RHIC W-asym.
- **Strangeness from PVDIS**
  - Strange quarks are quaint: LHC vs fixed target; HERMES SIDIS; …
- **Intrinsics charm**
  - Positive signal only from (contested) EMC data
  - Take new and better data with EIC !
- **Large leverage in A – from light to heavy**
  - Combined PDF / nPDF fits
  - Study propagation of charm in cold nuclei using nu+A dimuon data
- **Polarized and unpolarized data at large Q2 from same machine**
  - Another combined fit $\longleftrightarrow$ helicity separation
- …

Extra

Projected data (so far) and impact on PDFs