# Impact of EIC on unpolarized PDFs: a preliminary study

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Hampton U. and Jefferson Lab

1st EIC Yellow Report e-Workshop

[Temple U.], March 19th, 2020

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

HAMPTON UNIVERSITY
THE STANDARD OF EXCELLENCE

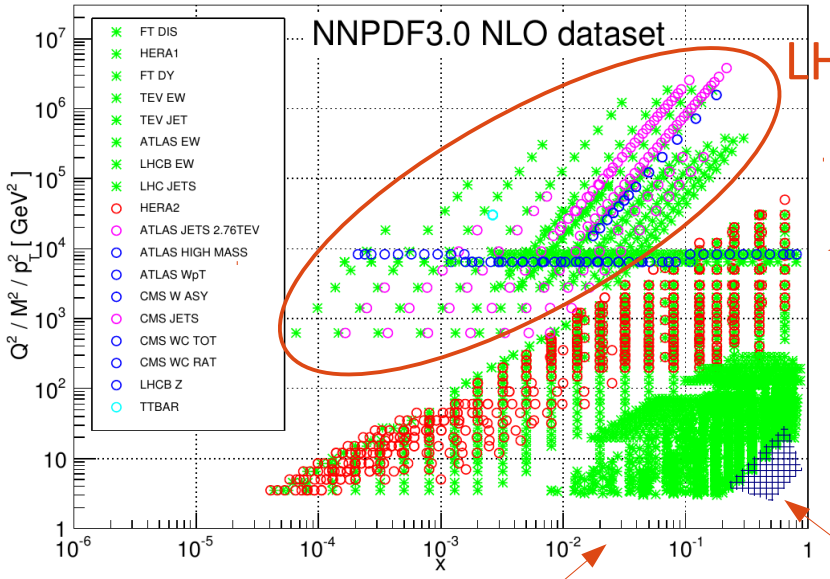
Jefferson Lab

# Overview

- Why better PDFs?
- Preliminary study
  - **NC, CC ; "free" neutrons**
    - Rough simulation
  - **Impact on PDF**
    - Focus on large *x* (for now)
  - Presented at EICUG Trieste 2017, but
    - Wet our appetite
    - Get rough guidance for WG detailed studies
    - Update on CC impact here
- Some final thoughts

# Why better PDFs?

# 1 - Data coverage for PDF fits




LHC data

W and Z

SLAC, JLab

DY and DIS
(on p, d)

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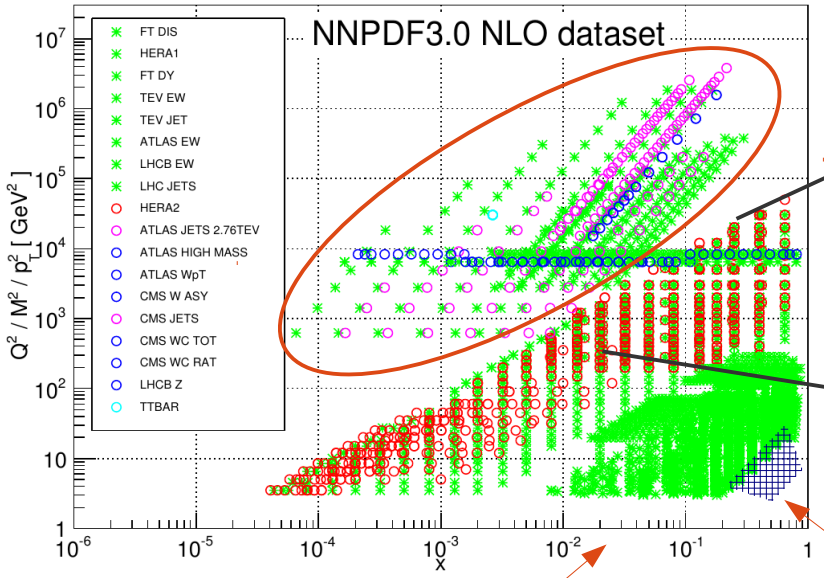
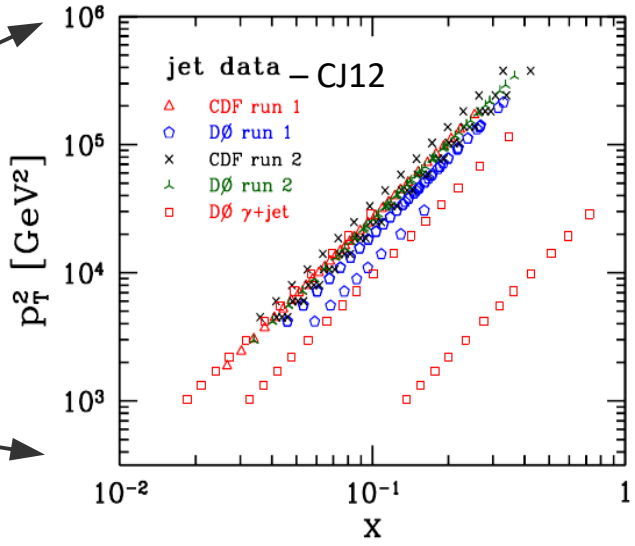



LHC data

Tevatron Jets

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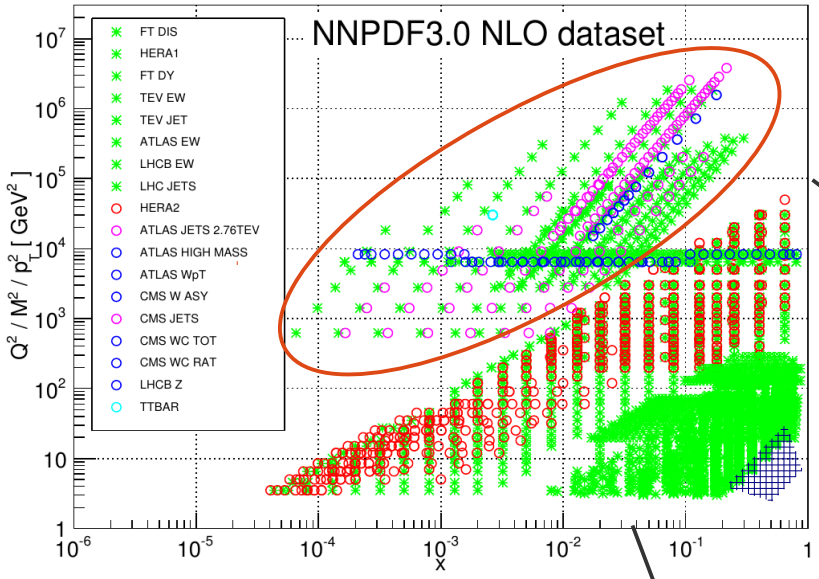
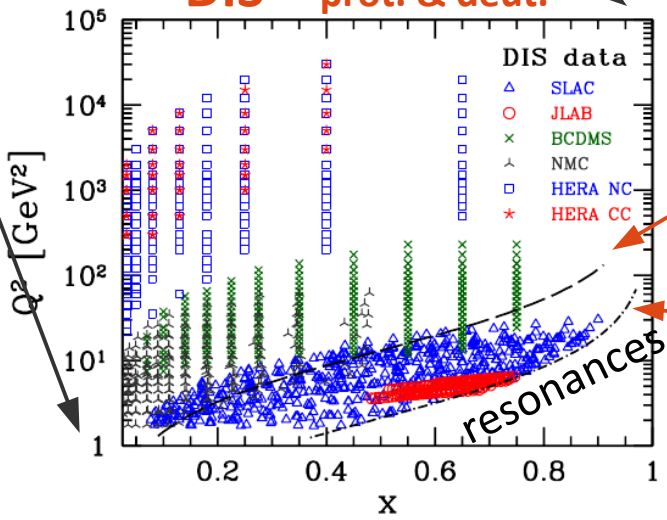



LHC data

**Scant large-x coverage in DIS !**

**DIS – prot. & deut.**

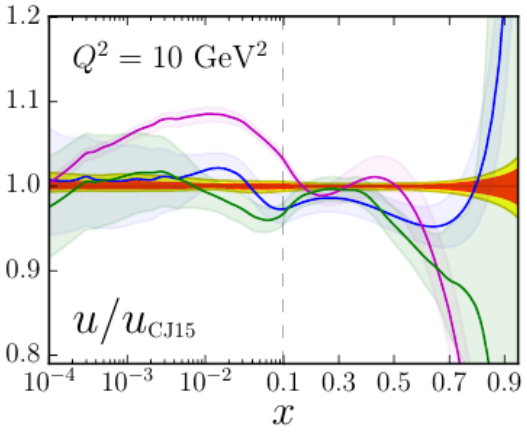


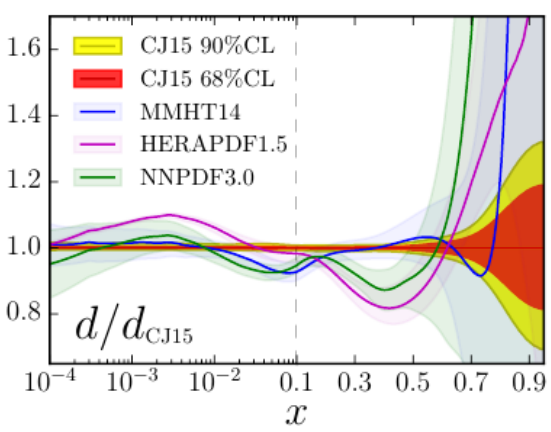

standard cut
$W^2 \gtrsim 14$ GeV$^2$

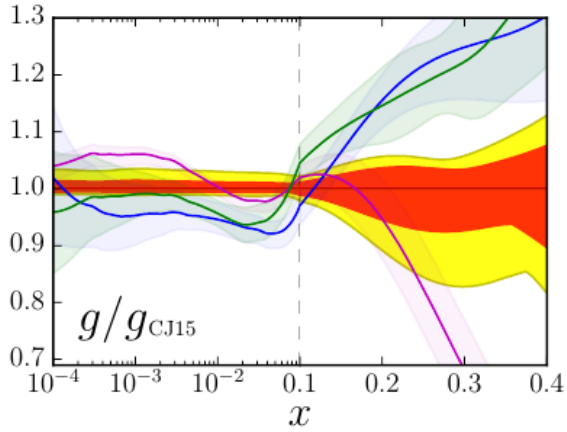
CJ15
$W^2 \gtrsim 3.5$ GeV$^2$

– CJ12

# …and after all this…

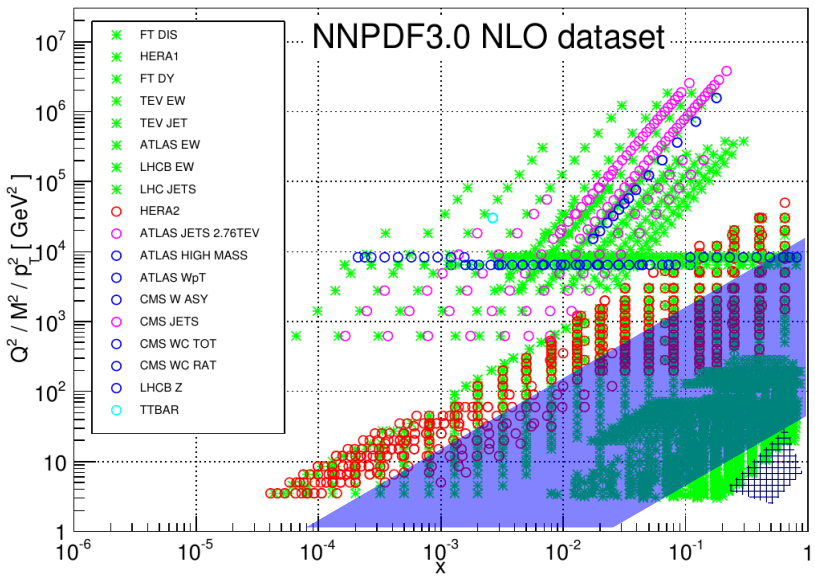



- Large uncertainties in up, down, gluons, esp. at large x
- Precision needed for:
  - Hadronic structure
  - BSM physics
  - Higgs physics
  - …

# Enters the EIC




- Interpolates fixed target and HERA
- Large $Q^2$ leverage:
  - More evolution at large *x*
  - Improved sensitivty to HT *vs.* LT
- High luminosity:
  - large *x* capabilities
  - Quick √s scan ⟶ L/T separation
  - Charged currents

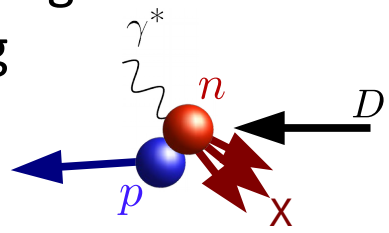
- **EIC can "do it all"**
  - "Easy" spectator tagging in DIS – Quasi-free neutron targets
  - Strong PID capabilities ⟶ $F_2^c$, $F_2^{cc}$, ...
  - High luminosity ⟶ CC, PVDIS ⟶ d/u, strange quarks, dbar/ubar, ...
  - Unpolarized & polarized scattering (also light ions) & Frag Fns.
  - Nuclear targets

# How can the EIC help? The large-*x* view

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

- **Gluons** through scaling violations, energy scan ("L/T separation")
  - require range in x, Q2; large-y reach
  - Scaling violations at large x
    - require the EIC for $Q^2$ leverage
  - L/T with fixed target cross sections limited in x,$Q^2$
    - Extend kinematic range beyond jet measurements reach

- **d-quarks** <u>without nuclear corrections</u>:
  - Precision CC cross sections on proton targets
  - "Free" neutrons with spectator tagging
    - easier than at Jlab
    - Also: p ∈ D;  p,n ∈ $^4$He, $^7$Li



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

**2016-2018 collaboration with:**
- R. Ent, C. Keppel, Y.Furletova, K. Park, R. Yoshida (JLab)
- M. Wing (UC London)

**Presented at EICUG, Trieste 2017**
- updated here regarding CC impact

# 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
  - Pythia, default settings
  - Eyeballed (x,Q2) bins, systematics from expereince with ZEUS
- ✓ $F_2^n$ from deuterium with tagged proton spectator *(K. Park & JLab LDRD*)*
- ✓ 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

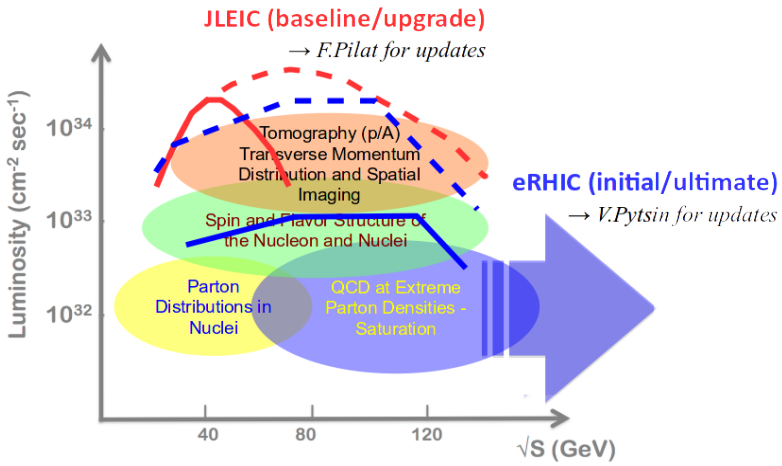
(Impact of deuteron target DIS was presented at EICUG Argonne, 2016)

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

# Projected data

- Note: energies chosen for JLEIC as of 2017

| $\sqrt{s}$ | electrons tag | electrons NC | electrons CC | positrons NC | positrons 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

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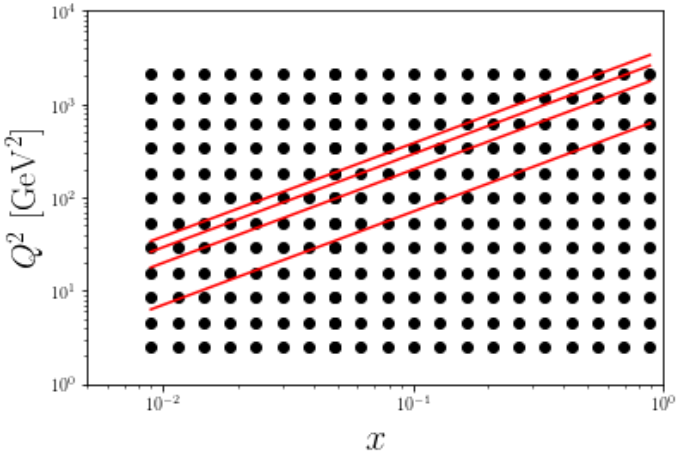


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# Projected data (so far)

- Note: energies chosen for JLEIC as of 2017 – will need to update...

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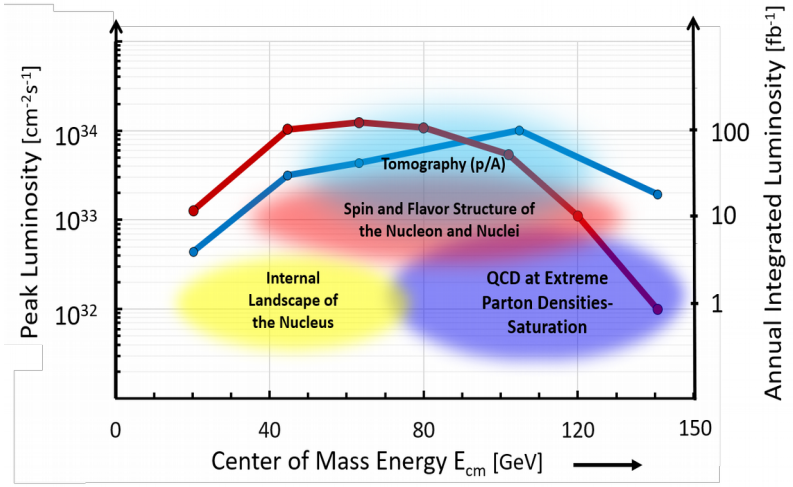


* as of Mar 2020

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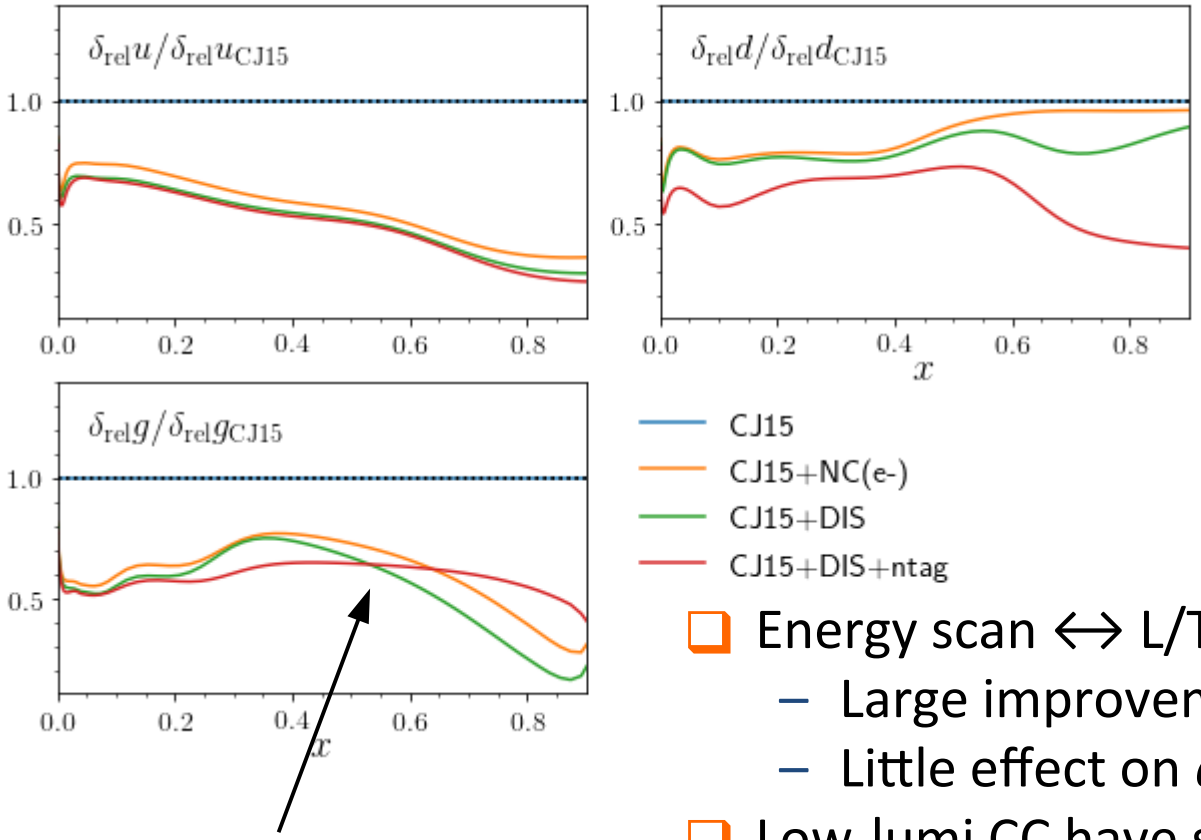
# Impact - summary

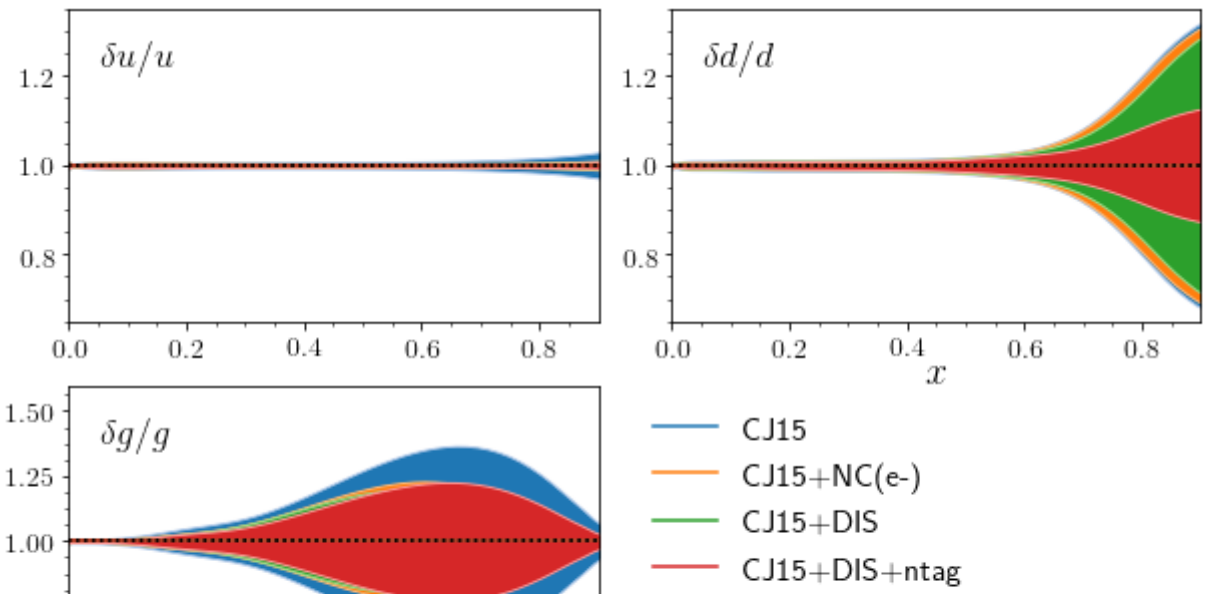



40-50% better d-quarks

40-50% better gluons

- Energy scan ↔ L/T separation
  - Large improvement in gluon uncertainty
  - Little effect on *d*-quarks
- Low-lumi CC have some effects on *d*, *g*
- Tagged neutrons
  - Noticeable improvement for d-quarks

# Impact - summary

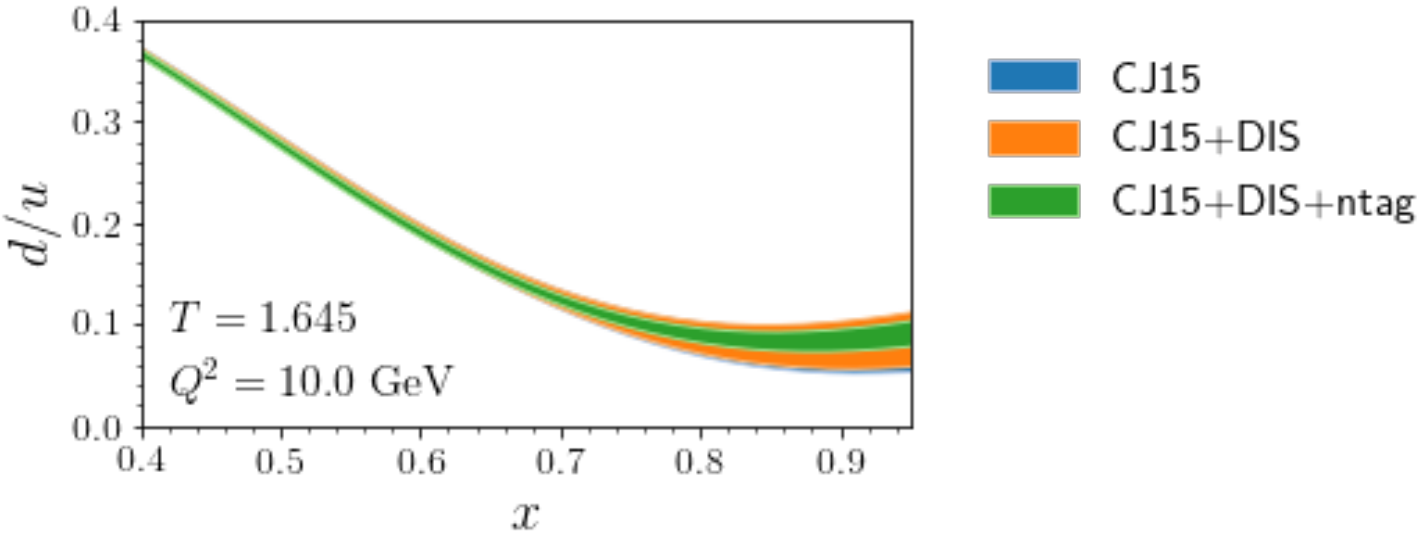



40-50% better d-quarks

40-50% better gluons

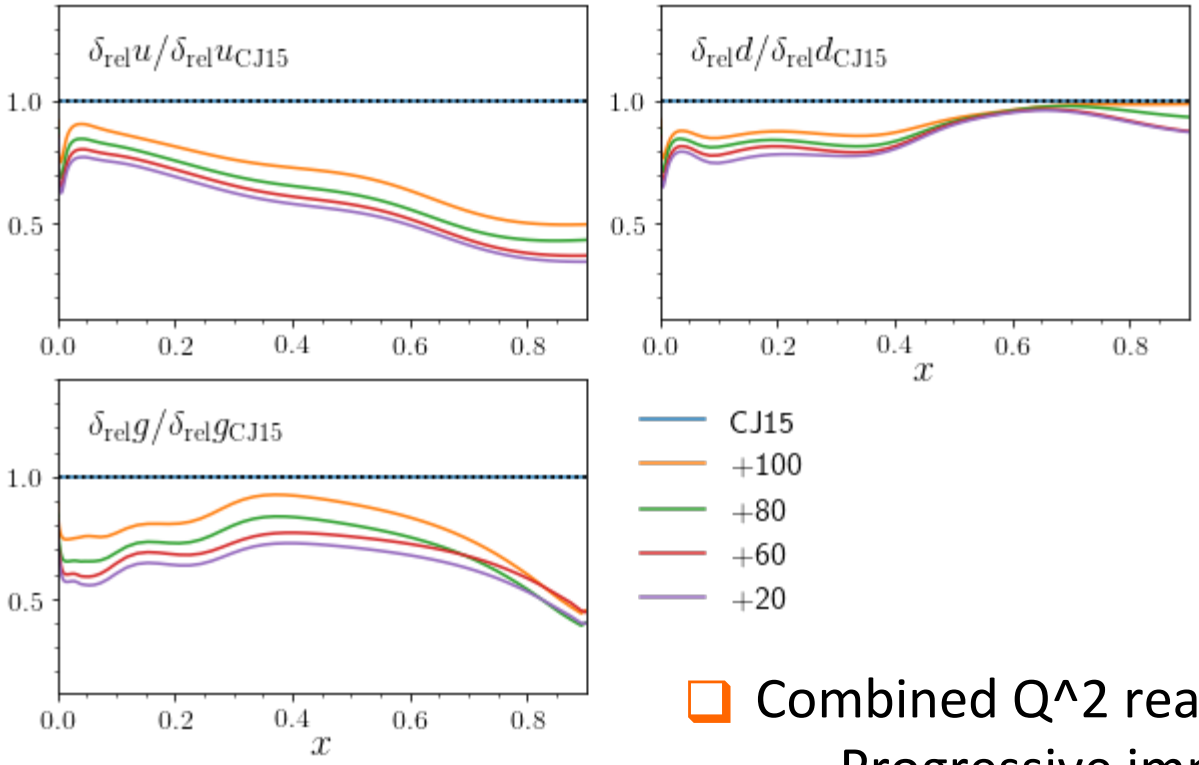
- Precise gluons at x=0.01-0.1 for Higgs Physics
- Unprecedented reach at large x > 0.1
  - Precise photon PDFs for LHC
  - Baseline for gluon anti-shad./EMC effect in nuclei
- u-quark at 1% precision, may be important for large mass BSM new particles

# Impact - summary



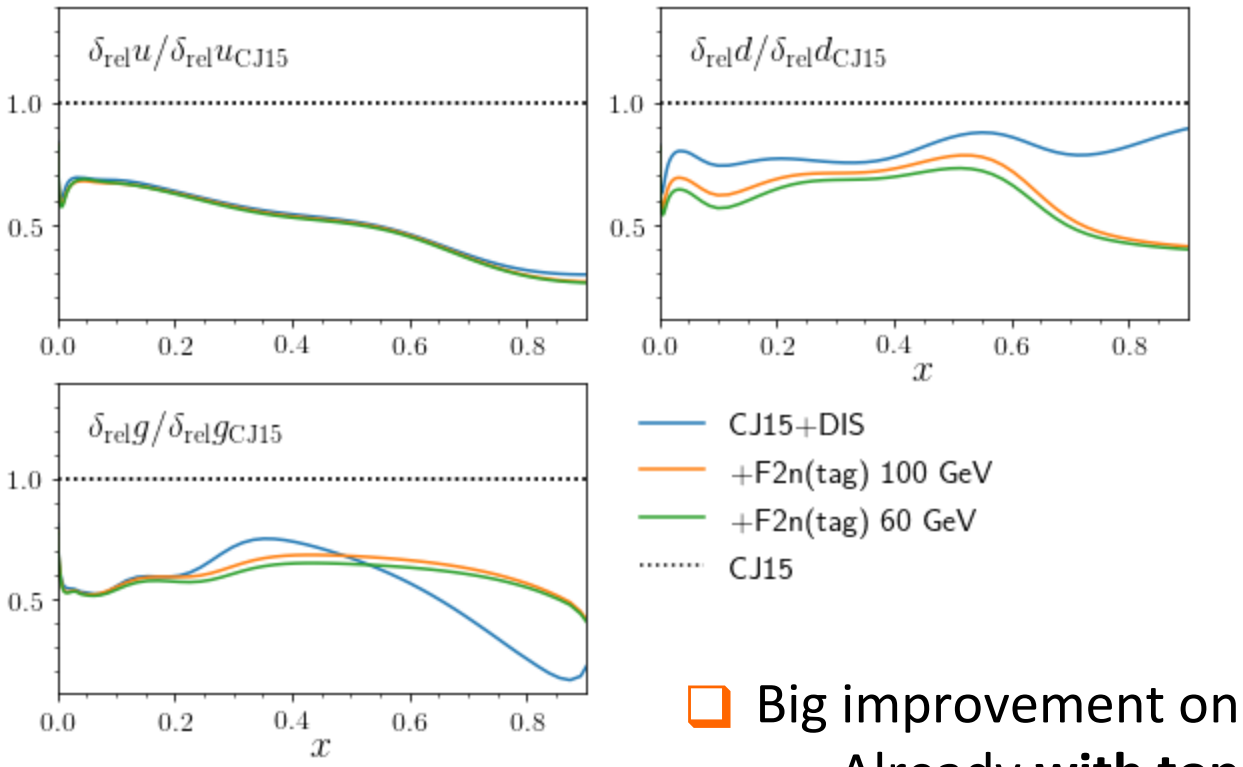

- **The d-quark goes from 30% to <~10% percent level**
- **Resolve long-standing mystery of d/u at large x,**
  → Can explore in detail fundamental models nucleon structure
- **D/(p+n) in one experiment for the first time** (possible, not discussed here)
  → unprecedented handle on nuclear medium modifications
  → 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



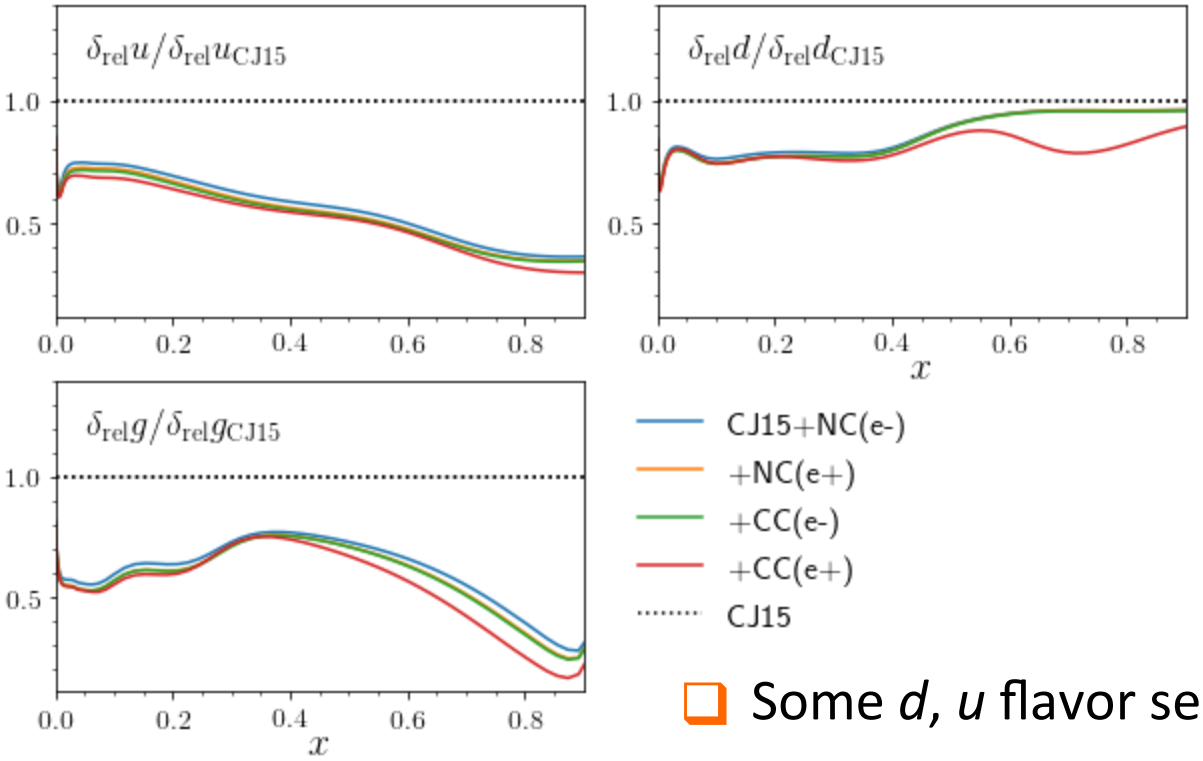

- Combined Q^2 reach and y range:
  - Progressive improvement in gluon PDF
- Last nrg set seem to have minor impact
- But:
  - **Need to optimize energy choices**
  - **Binning: (x,$Q^2$) or (x,y) ?**

# Neutron tagging



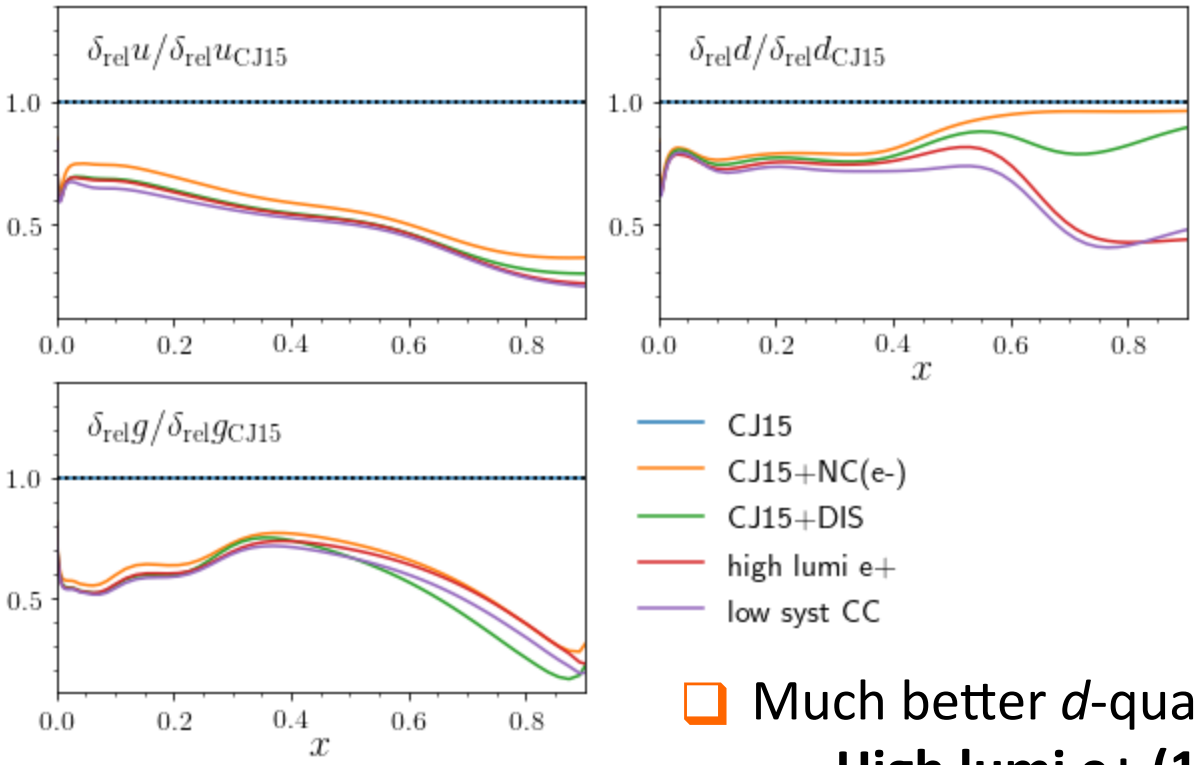

- Big improvement on *d* quark
  - Already **with top energy tagging**
  - Minor effect with low energy data
- Effect similar to pushin lumi, syst for CC

# Charged currents and positrons



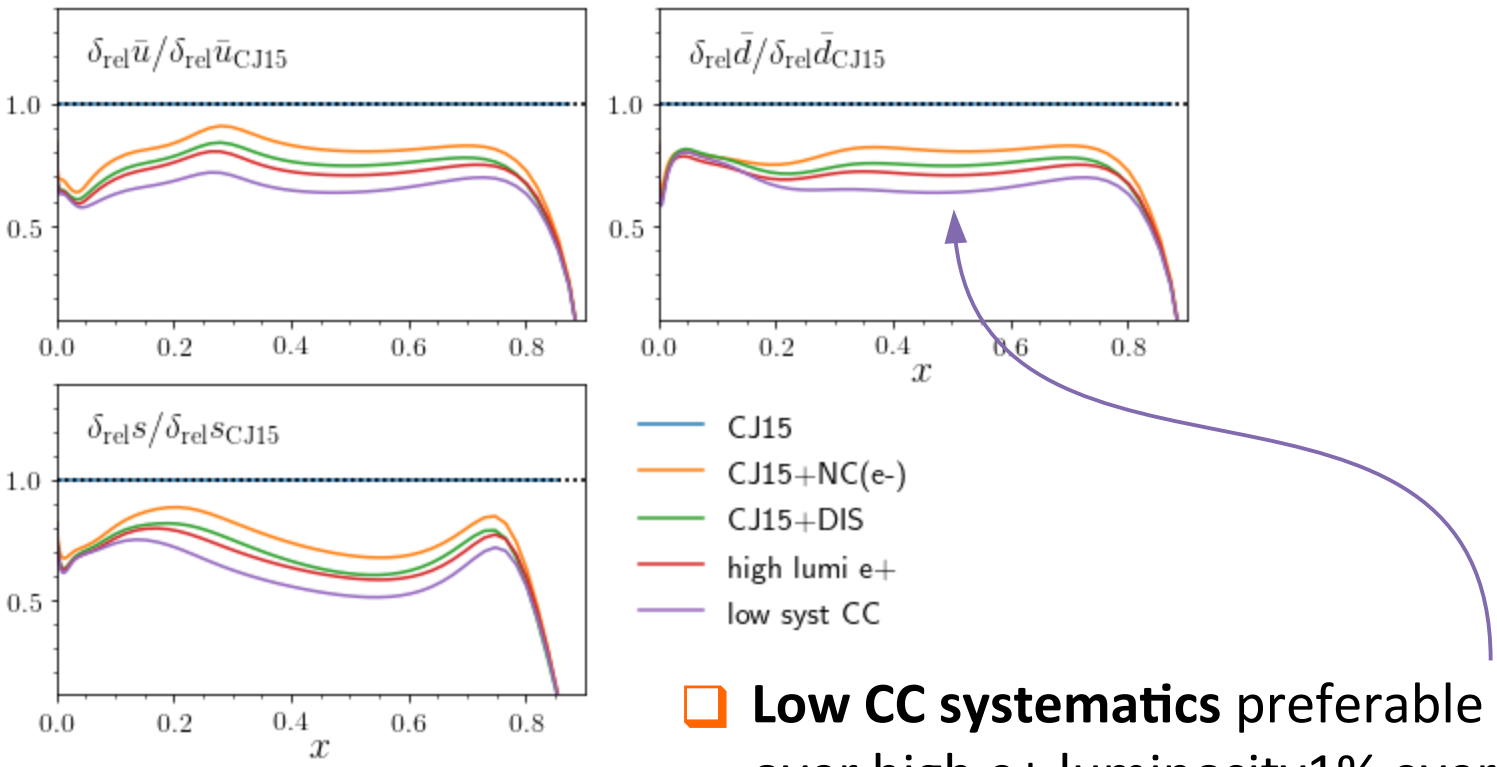

- Some *d*, *u* flavor separation power
- Limited by:
  - Large systematic:
    5% y>0.8 or $Q^2$<125 , 2% elsewhere
  - Low lumi

# Charged currents and positrons




- Much better *d*-quark separation if:
  - **High lumi e+ (100/fb)**, or
  - **Low CC systematics** (1% everywhere)
- It may be worthwhile pushing the detector envelope

# Sea quarks




- **Low CC systematics** preferable over high e+ luminosity1% everywhere)
- Good sea q improvement already with NC
  - "Standard" CC not so effective (but √s is low in this exercise)

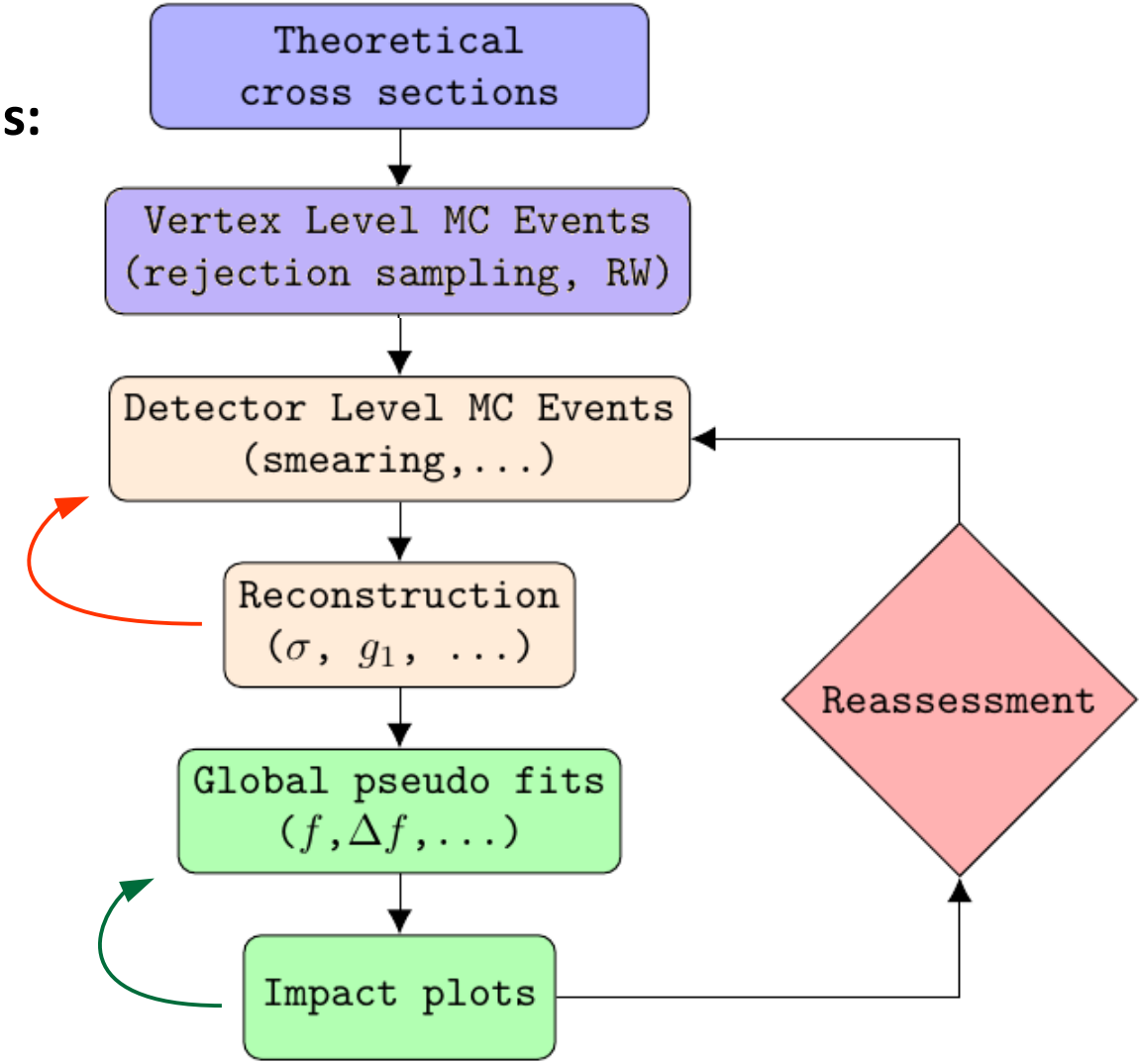
# Some final thoughts

# 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**
- **Spectator tagging** improves flavor separation at large x
  - Need to explore **synergy with diffraction and tagging WG**
- **Detection requirements:**
  - In this study, **CC events at large *x* push the envelope**
- **Needs more work:** detectors, realistic systematics, grid optimization, ...

# What next for our WG ?

- **Need detailed simulations:**
  - Detector effect
  - realistic systematics
  - grid optimization
  - …
- **Modular approach proposed by Nobuo:**
  - Flexibility
  - Consistency
  - Factorization

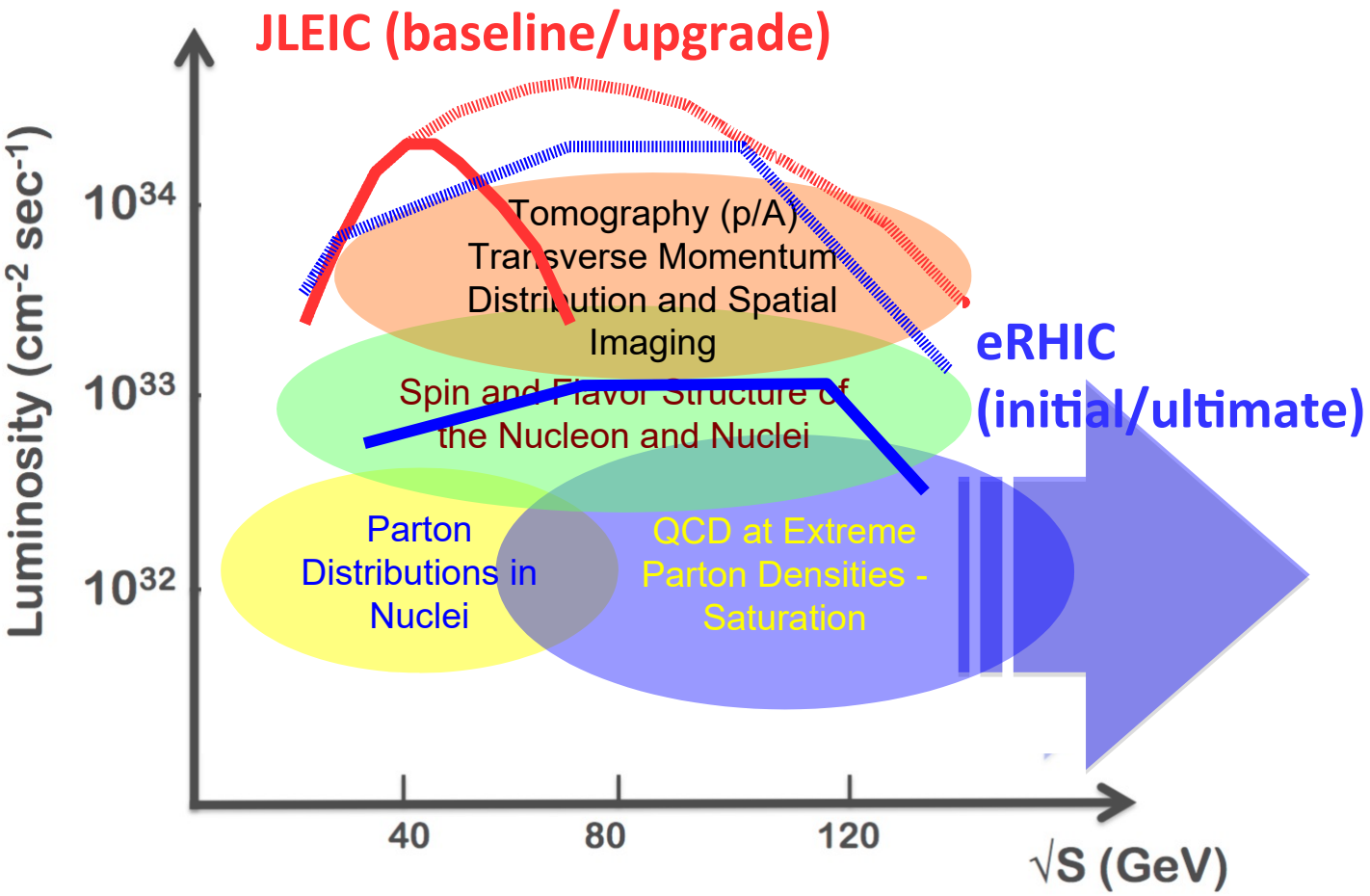


# What else can we do or dream of?

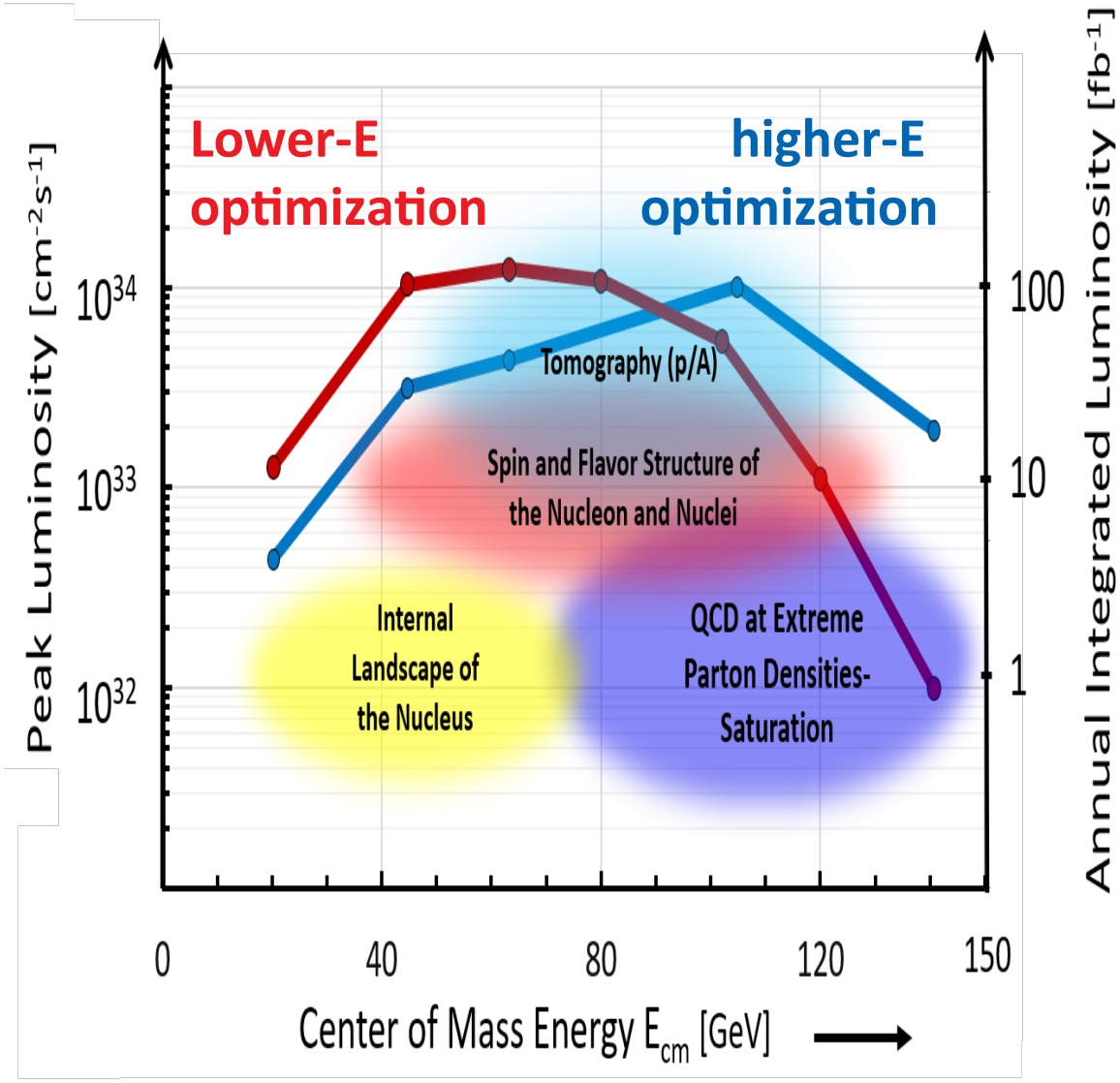
- **Isospin violations**
  - Play free n from BONUS/EIC vs. free p from D0, RHIC W-asym.
- **Strangeness from PVDIS**
  - Strange quarks are quaint: LHC vs fixed target; HERMES SIDIS; …
- **Intrinsics charm**
  - Positive signal only from (contested) EMC data
  - Take new and better data with EIC !
- **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 ⟷ helicity separation
- …

# Extra

# EIC luminosity curve 2017



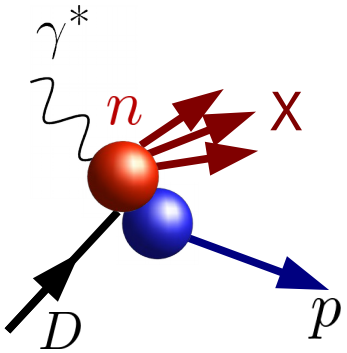
# EIC luminosity curve 2020

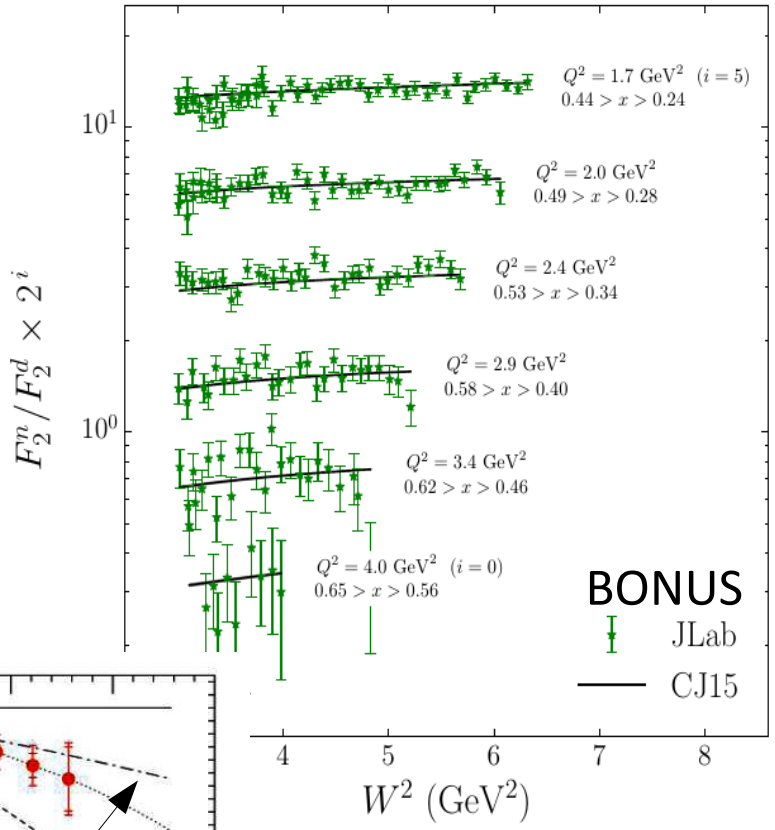


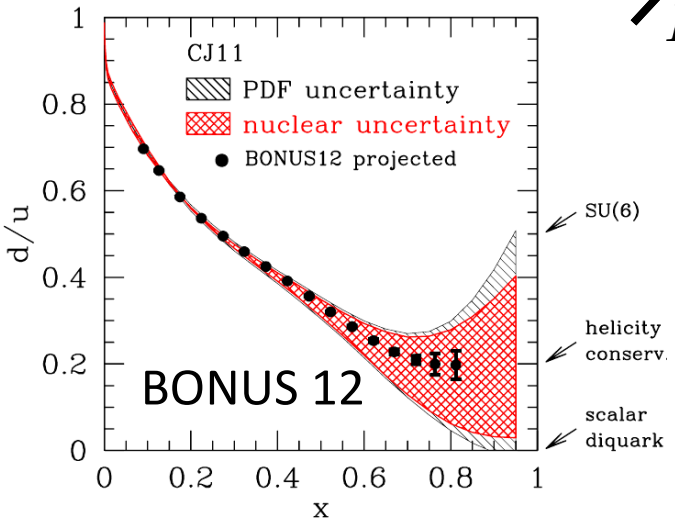
# Spectator tagging at JLab: quasi-free neutrons

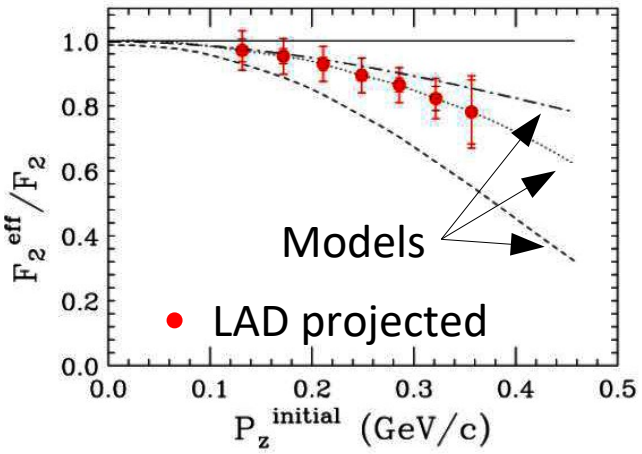
- Neutron off-shellness depends on on spectator momentum:
  - Slow: nearly on-shell (BONUS 6 & 12)
  - Fast: more and more off-shell (LAD)

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



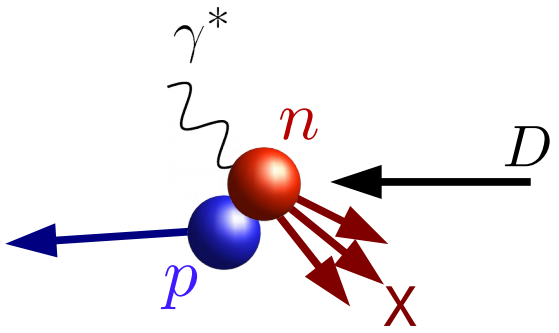



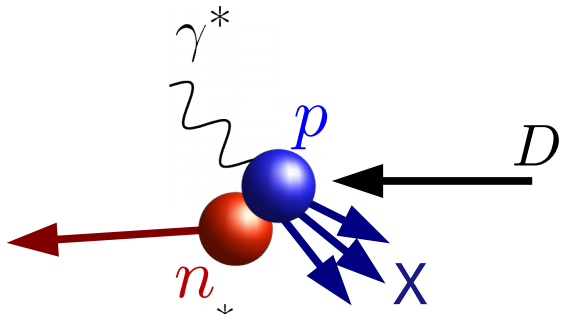



# Spectator tagging at EIC: even better!

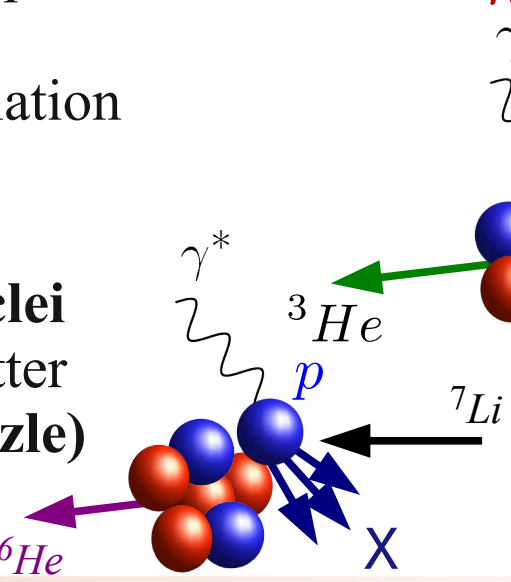
- measure **neutron $F_2$** in D target
  - flavor separation

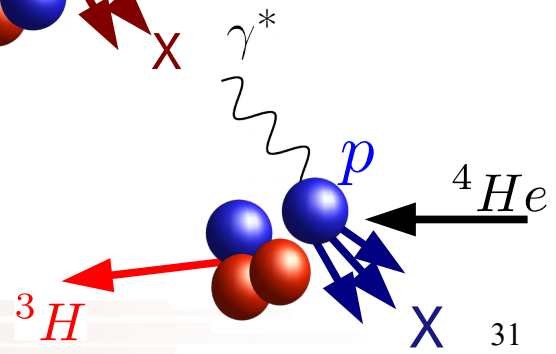



- measure **proton $F_2$** in D target
  - **Unique at colliders**
  - Compare off-shell to free proton
  - Establish nuclear effects
  - Validate on-shell extrapolation techniques

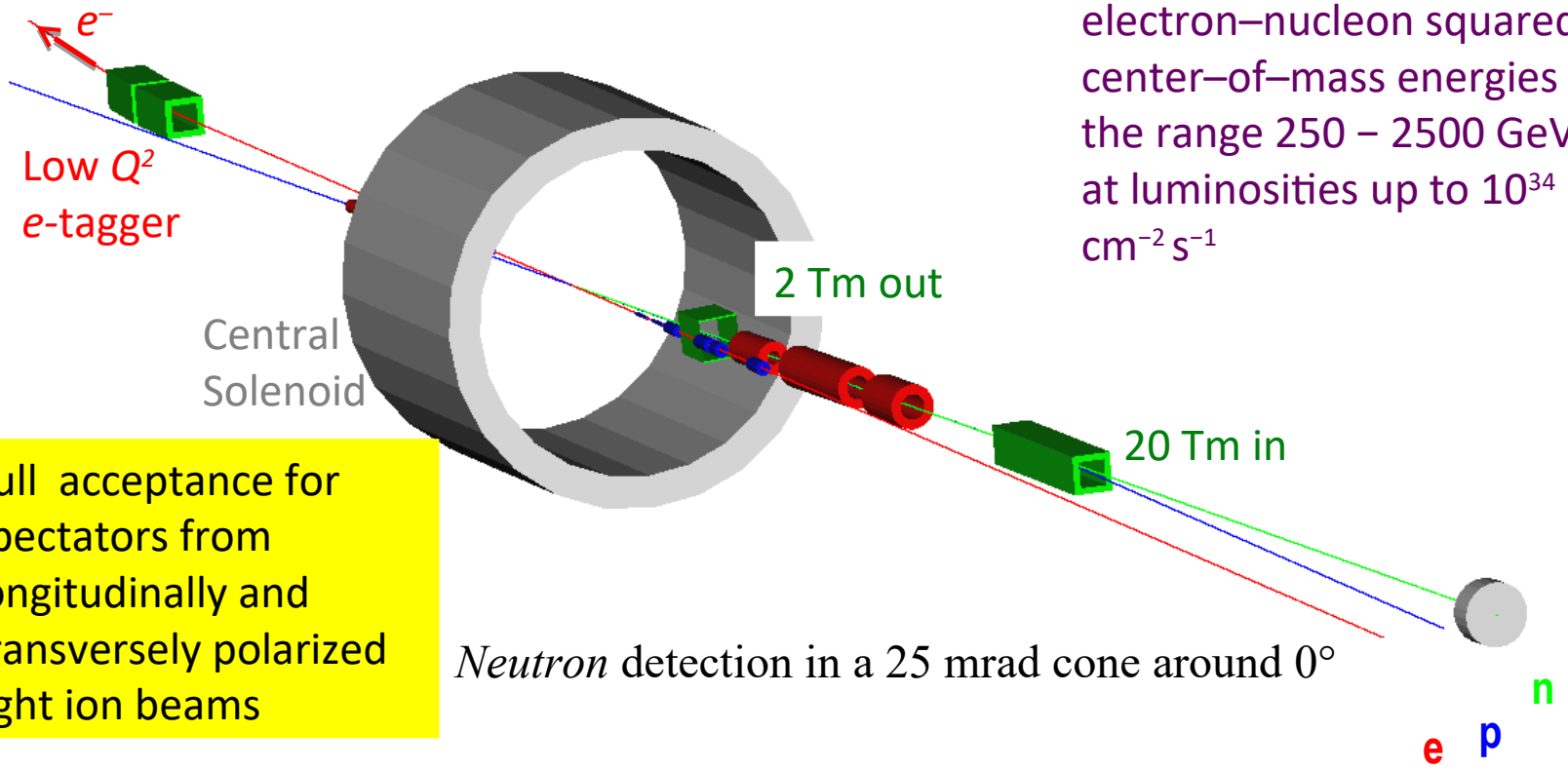



- **proton, neutron in light nuclei**
  - embedding in nuclear matter **(a piece of the EMC puzzle)**



# Tagged structure functions at the EIC



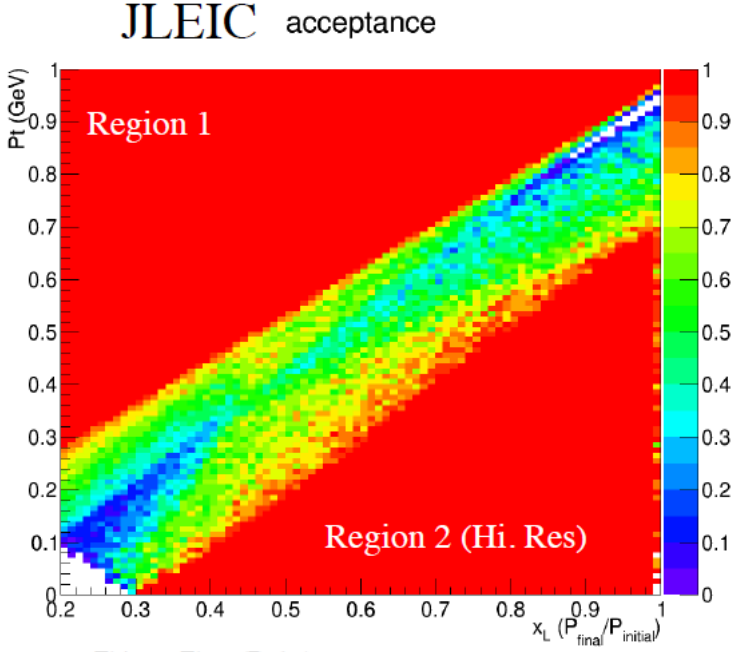

The JLEIC design provides electron–nucleon squared center–of–mass energies in the range 250 – 2500 GeV$^2$ at luminosities up to $10^{34}$ cm$^{-2}$ s$^{-1}$

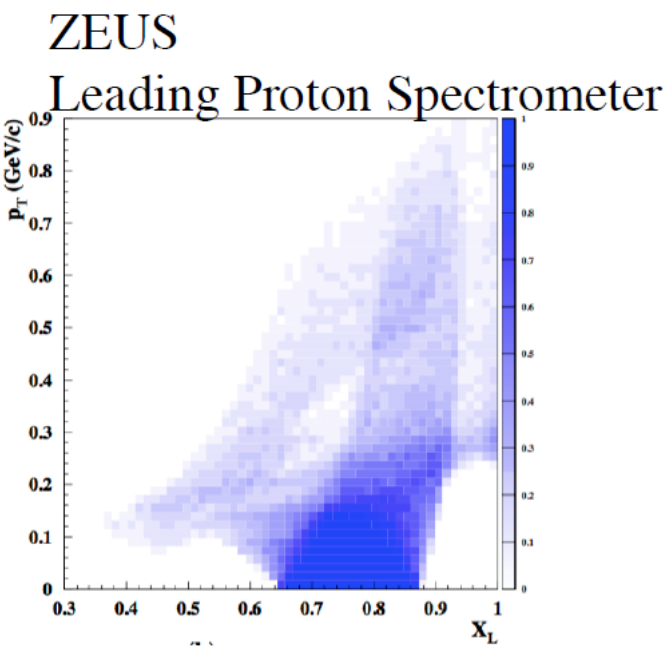
- Full acceptance for spectators from longitudinally and transversely polarized light ion beams

*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%

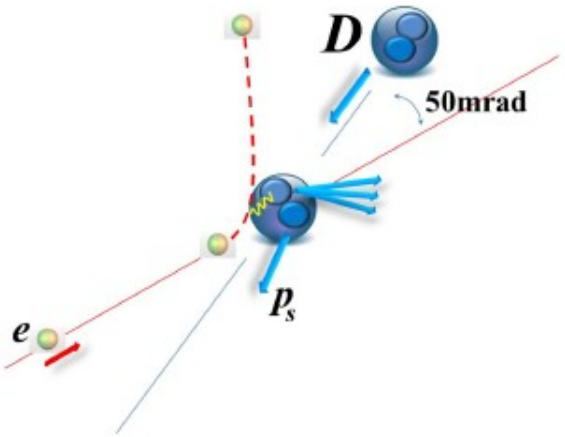
JLEIC: ~100% (also covers much higher $X_L$ than ZEUS)

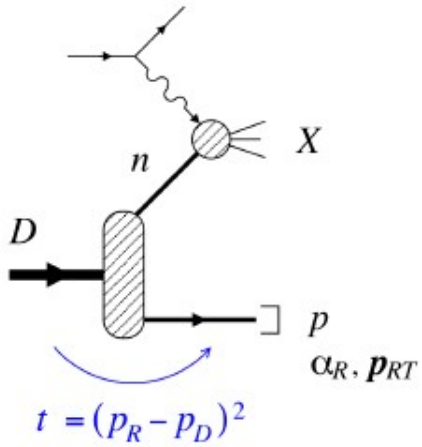
Huge gain in acceptance for forward tagging to measure $F_2^n$ and diffractive physics!!!

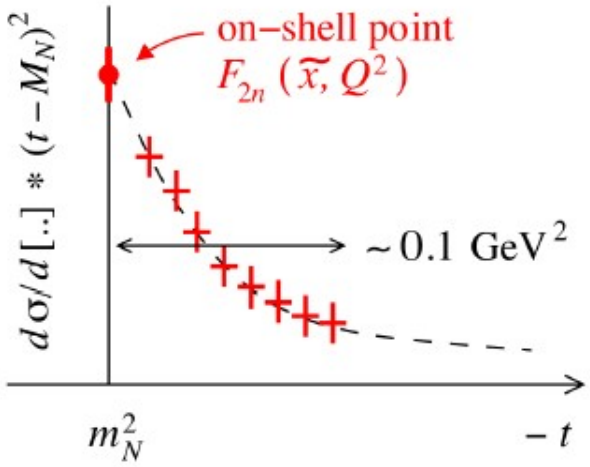
# (Tagged) neutron structure extrapolation in t

*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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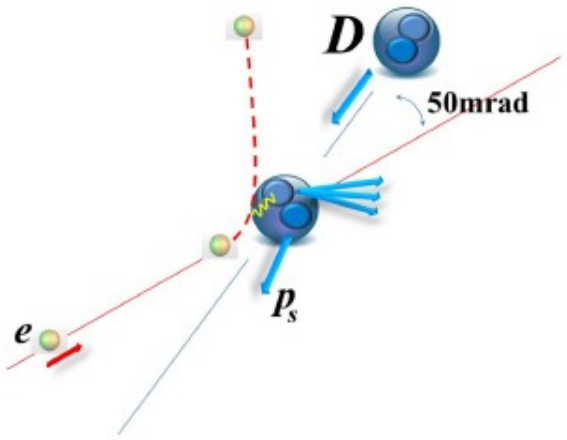


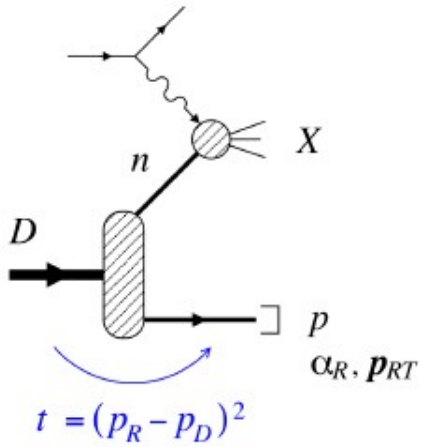


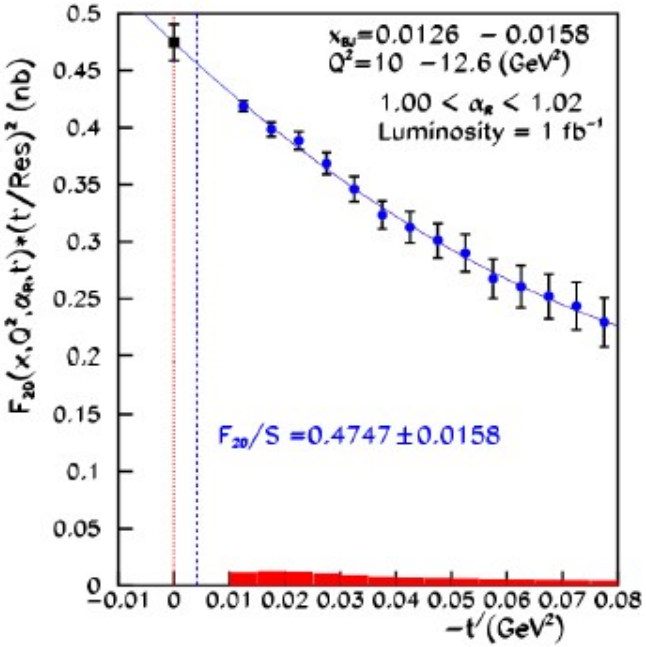


- 1 year of EIC @ luminosity of $10^{32}$ gives about 1 fb$^{-1}$
  $10^{33}$ gives about 10 fb$^{-1}$
  → $10^{34}$ gives about 100 fb$^{-1}$