Unpolarized and polarized PDFs from the JLab perspective

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PDFLattice2017

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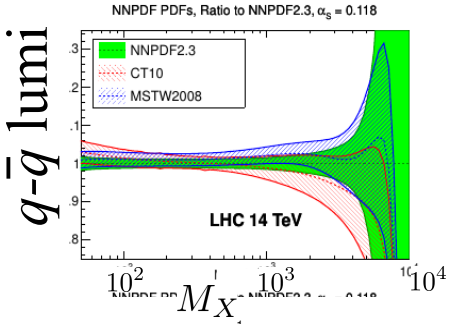
Why PDFs ?

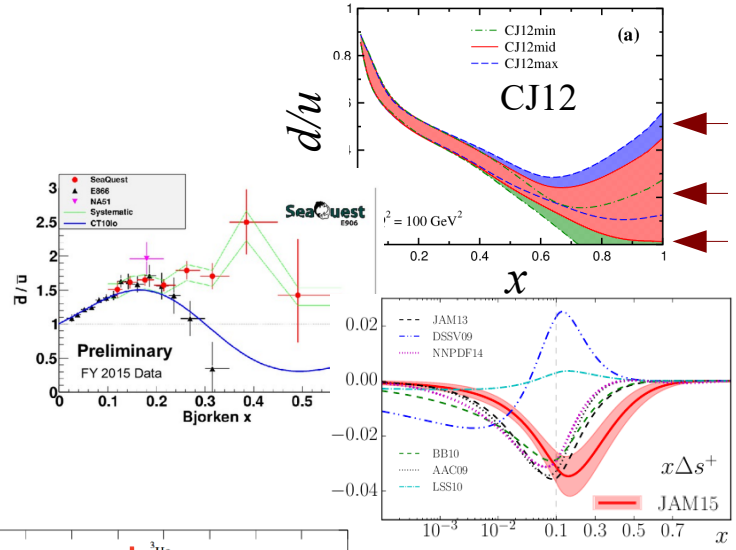
Accardi – PoS (DIS2015) 001
Jimenez-Delgado, Melnitchouk, Owens, JPG 40 (2013) 093102
Forte and Watt – Ann.Rev.Nucl.Part.Sci. 63 (2013) 291

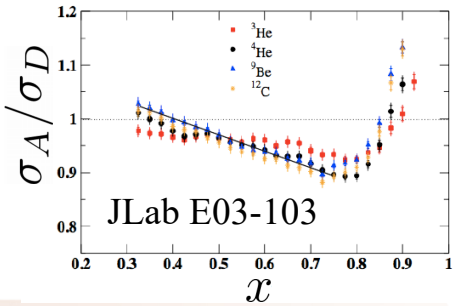
- **High-energy** *(large to small x)*
  - Beyond the Standard Model searches
  - Precision (Higgs) physics
  - Gluonic "matter" at small *x*

- **Hadron structure** *(large to medium x)*
  - Effects of confinement on valence quarks
  - q – qbar asymmetries; isospin asymmetry
  - Strageness, intrinsic charm → *Olness*

- **Nuclear physics**
  - Bound nucleons, EMC effect, SRC
  - p+A and A+A collisions at RHIC / LHC
  - Color propagation in nuclear matter

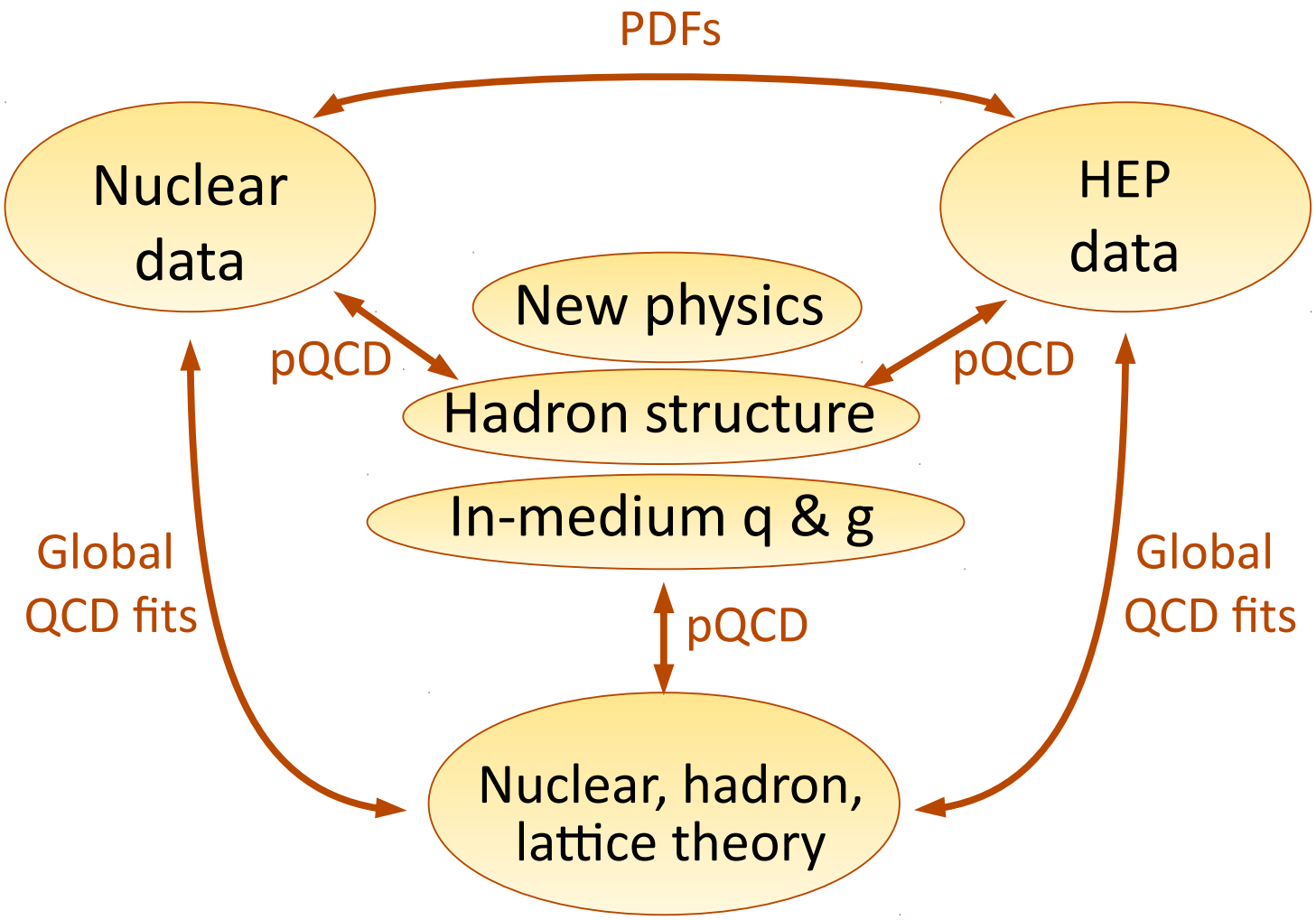






Needs the betrothal of HEP and NUCL

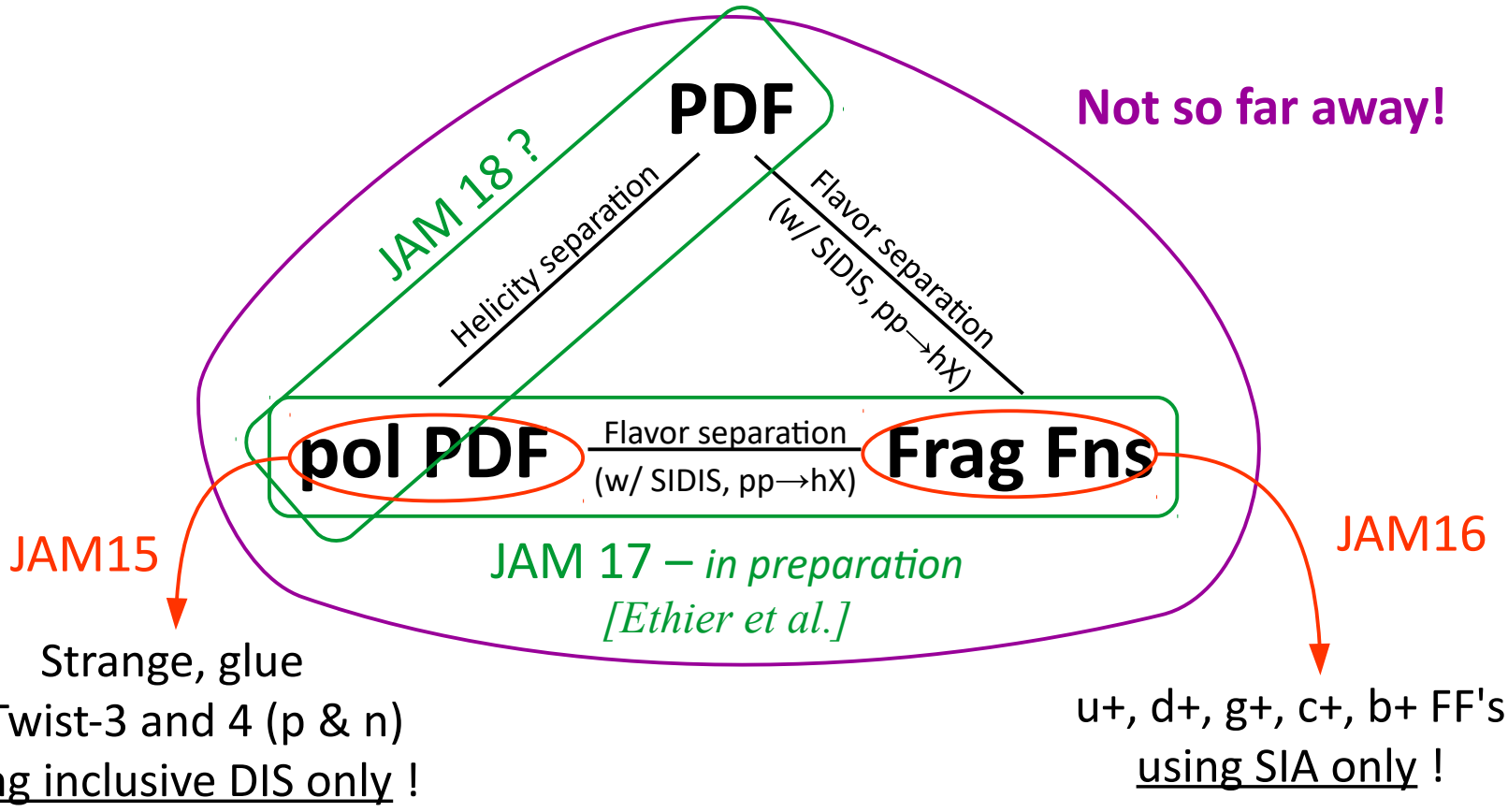
- **A global approach across subfields**



JAM - Iterative Monte Carlo approach

N.Sato et al [JAM], ***PRD93 (2016) 074005*** *and* ***PRD94 (2016) 114004***

- Provides control over large number of parameters
- Maximizes extraction of physics information from data
- Statistically robust uncertainties

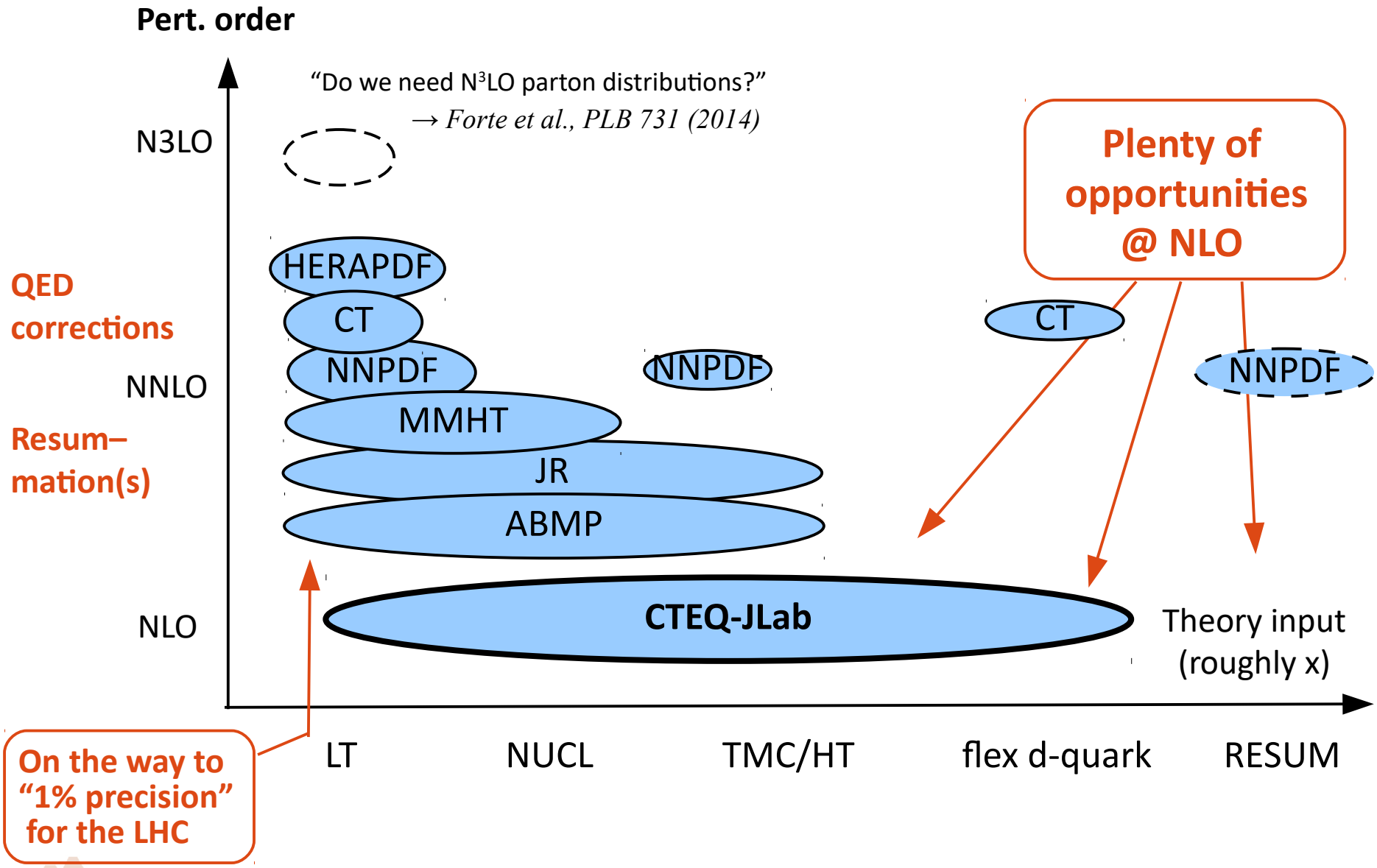


Proton and neutron PDFs
- the CJ15 global fit -

Accardi, Brady, Melnitchouk, Owens, Sato

PRD93 (2016) 114017

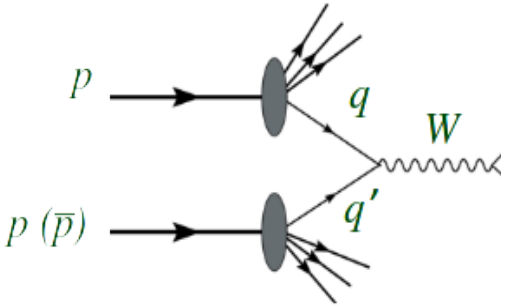
A PDF landscape



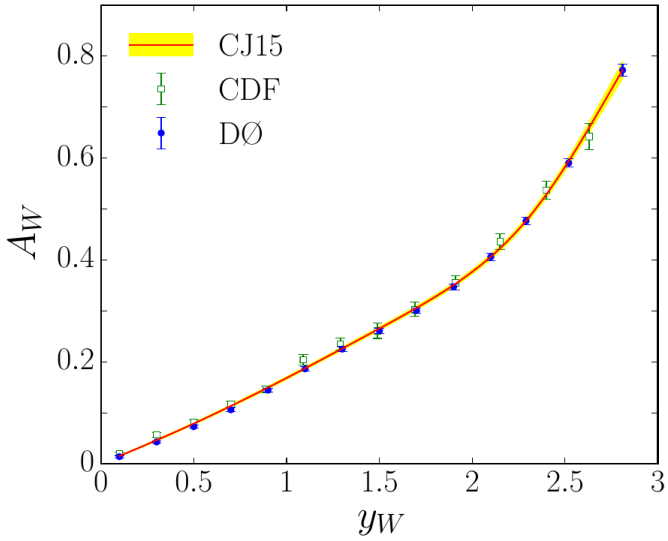
Example 1: Tevatron as NUCL facility (!)

Accardi, Brady, Melnitchouk, Owens, Sato, PRD93 (2016) 114017

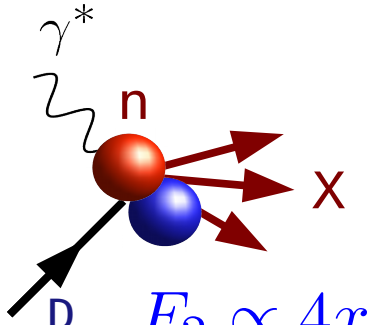
- ***Reconstructed W*** $\longrightarrow$ constrain ***d*-quark** at largest x on proton targets



$$A_W(y) \xrightarrow{y \to y_{max}} \frac{1 - d/u(x_1)}{1 + d/u(x_1)}$$



- Compare to abundant deuteron ***DIS data:***
  - $\longrightarrow$ constrain **deuteron corrections**
  - $\longrightarrow$ **precise *u*, *d*** flavor separation

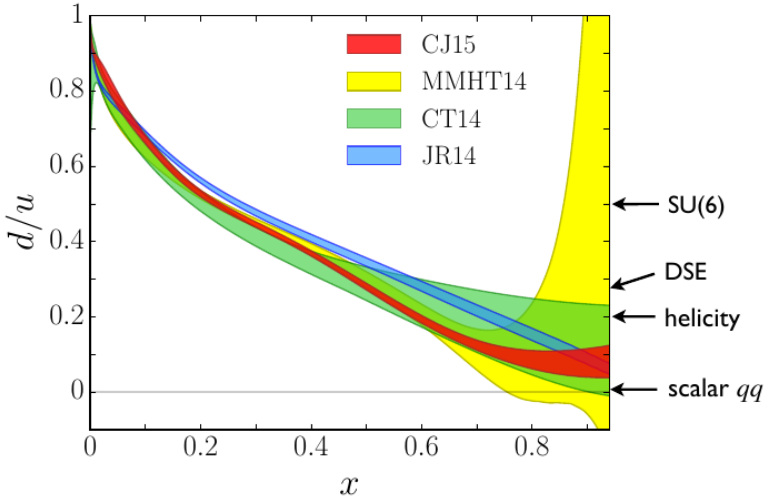


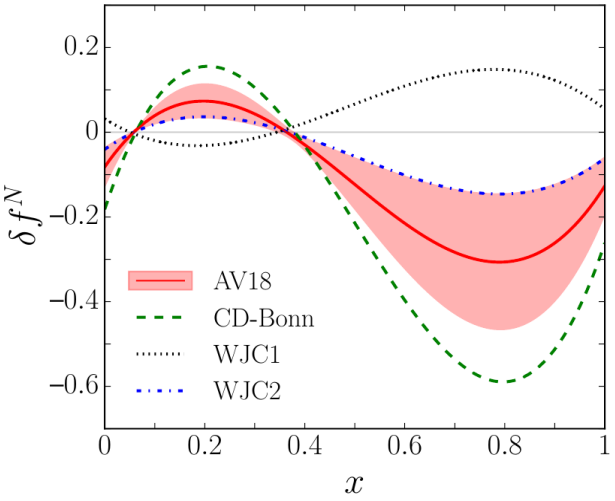
$$F_2 \propto 4xu(x) + xd(x)$$

Example 1: Tevatron as NUCL facility (!)

Accardi, Brady, Melnitchouk, Owens, Sato, PRD93 (2016) 114017

- **Two results in 1:**
  - → confinement at large x (using flexible large-x d-quark)
  - → bound nucleon corrections in deuteron PDFs





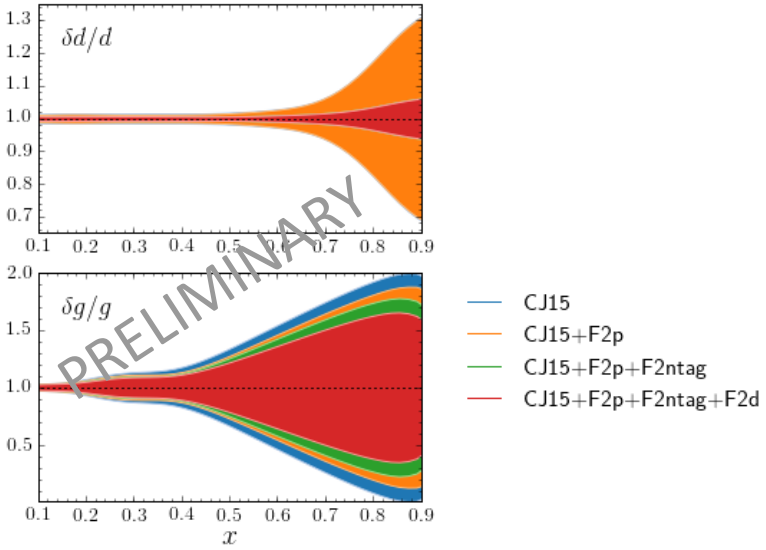
- **Opens novel possibilities**: test theory ideas against <u>other</u> data:
  - Test "EMC effect" models (of course)
  - On the lattice: "nucleon response to external color field"
    → for discussion

Accardi, Ent, Keppel, Park, Yoshida – in progress

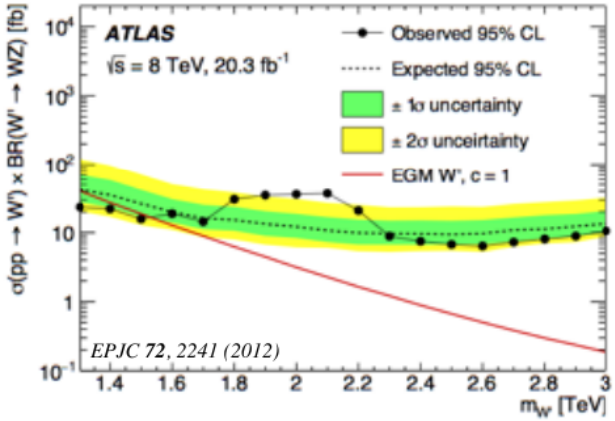
Example 2: EIC and BSM searches

- Include **EIC projected data**
  - The ***d* quark precision will become comparable to current *u* !!**
  - 20% better g(x) through evolution

JLab12 & BONuS12 → not much worse!



- Can impact BSM searches, e.g., heavy W' boson production at LHC



- $3.4\,\sigma$ excess in WZ diboson channel at ~ 2 TeV
- extended gauge model $W' \to WZ$ with $M < 1.5$ TeV excluded at 95% c.l.

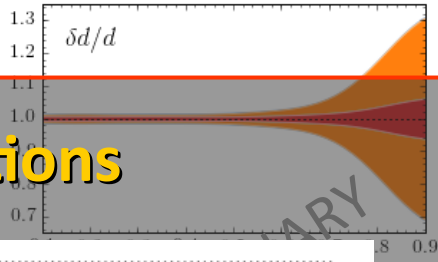
$$\mathcal{L}_{W'} \to d(x_1)\,\bar{u}(x_2) \quad \text{at large } y_{W'} \text{ or } M_{W'} \qquad x_{1,2} \approx \frac{M_{W'}}{\sqrt{s}} e^{\pm y_{W'}} \gtrsim 0.25$$

Accardi, Ent, Keppel, Park, Yoshida – in progress

Example 2: EIC and BSM searches

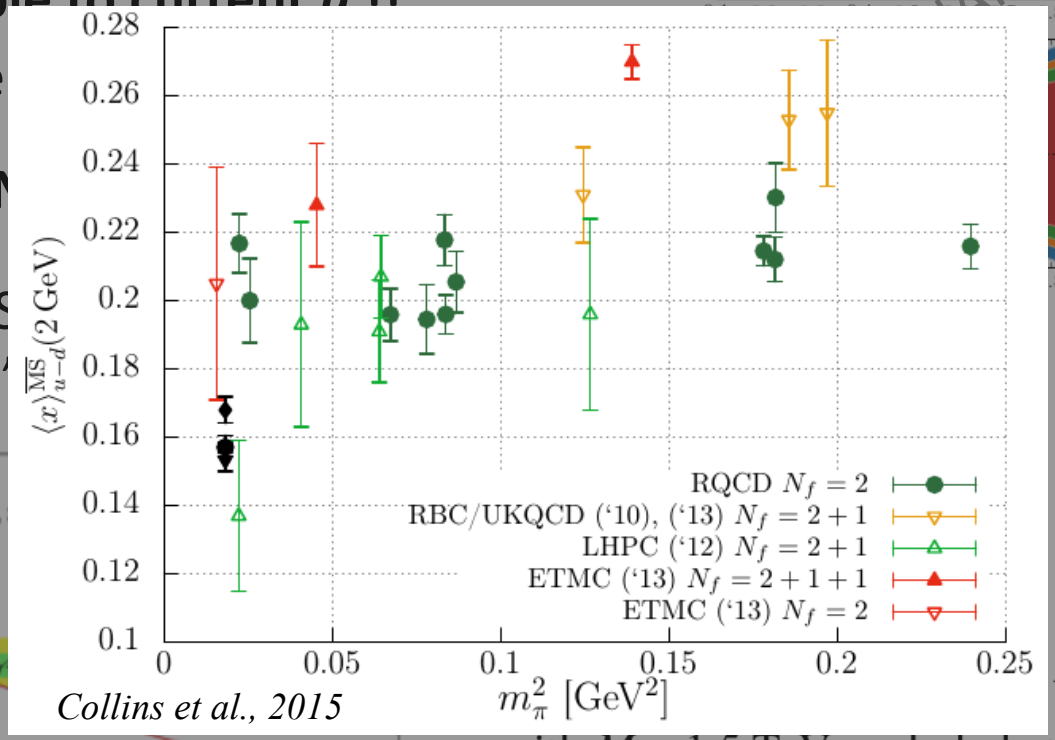
- Include **EIC projected data**
  - The ***d* quark precisio… comparable to current *u* ll**
  - 20% bette…

  JLab12 & BoN…
- Can impact BS… e.g., heavy W'…

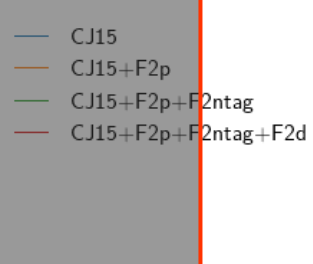


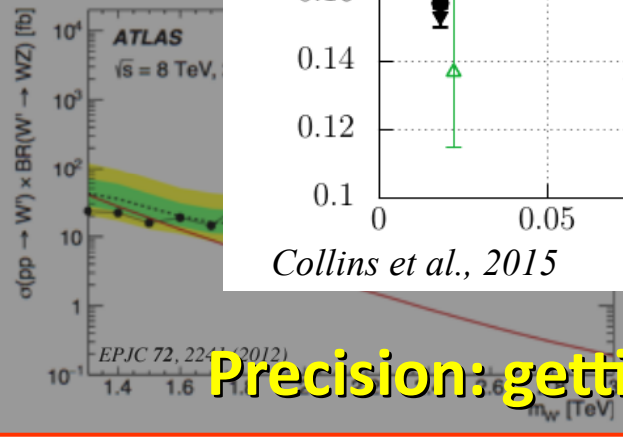
Lattice calculations

Bali et al., 2014



Collins et al., 2015





WZ

with $M < 1.5$ TeV excluded at 95% c.l.

Precision: getting there – Accuracy ?

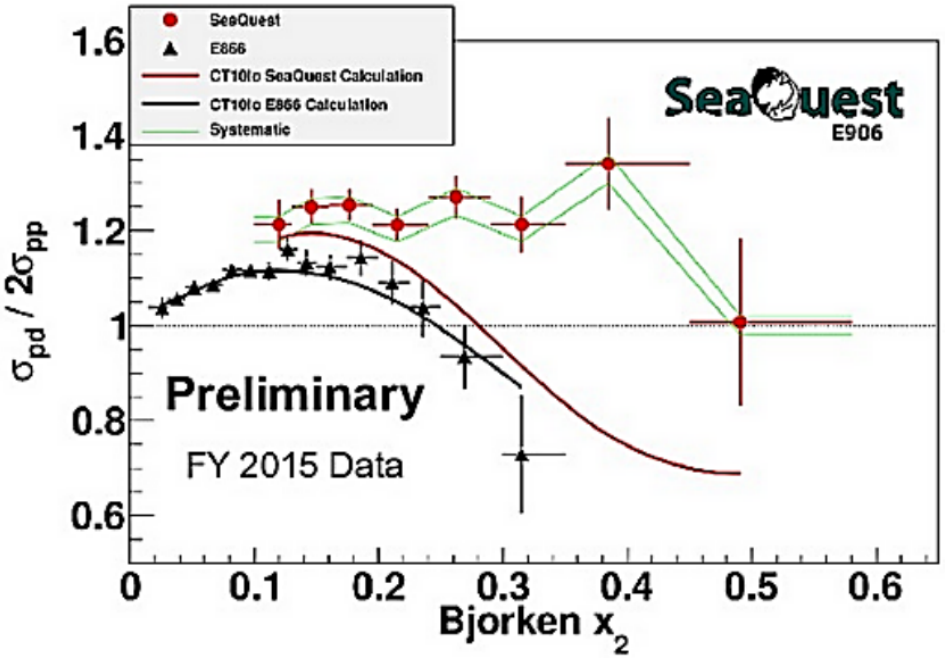
$$\mathcal{L}_{W'} \to d(x_1)\,\bar{u}(x_2) \quad \text{at large } y_{W'} \text{ or } M_{W'} \qquad x_{1,2} \approx \frac{M_{W'}}{\sqrt{s}} e^{\pm y_{W'}} \gtrsim 0.25$$

Into the sea: dbar/ubar

- **SeaQuest:** no sign change at large x !
  - **Does db/ub stays positive all the way?**

$$\frac{\sigma_{pp}}{\sigma_{pp}} \approx 1 + \frac{\bar{d}(x_2)}{\bar{u}(x_2)}$$

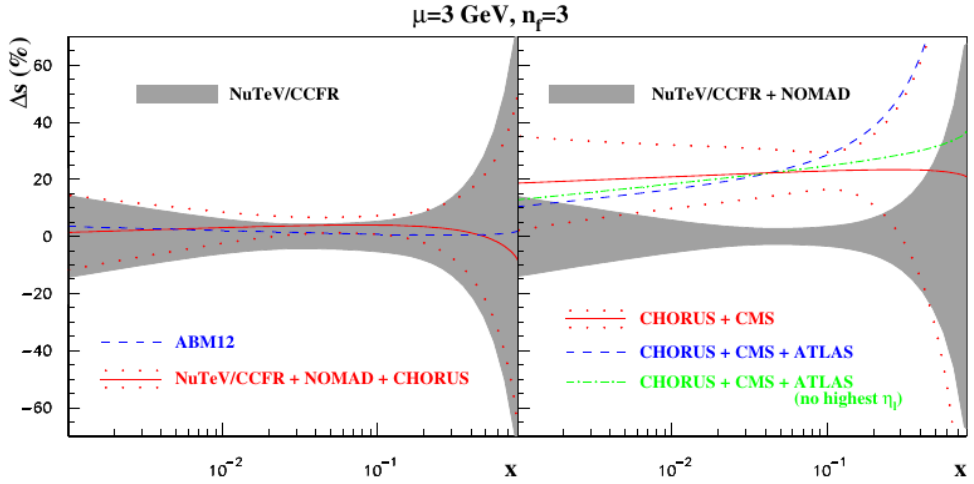
- **Guidance from lattice?**
  - What are the challenges?
  - Are quasi-PDF calcs already robust enough?
  - How many moments can be calculated?



Interlude

Strange strange quarks

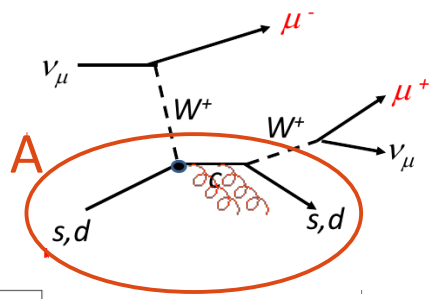
- **ν+*A* → dimuons** *vs.* **p+p → *W*+*c* at LHC** *Alekhin et al., arXiv:1404.6469*



$$g\, s_p \rightarrow W\, c$$

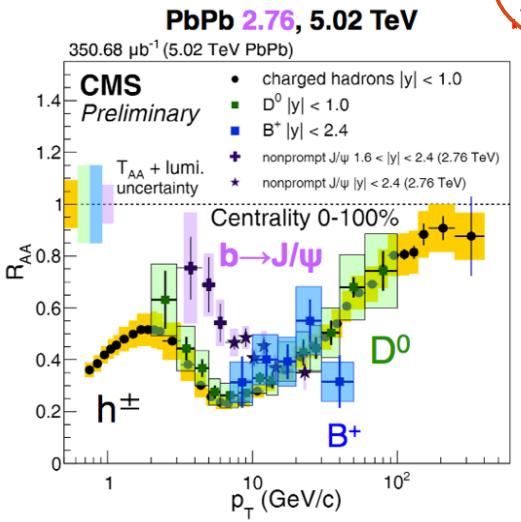
$$\nu\, s_A \rightarrow \mu^-\, \mu^+\, \nu_\mu\, s$$

FSI ?



- **Heavy quark puzzle at RHIC / LHC:**
  - Color propagation in QCD matter not under theoretical control!

$$R_{AA}^h = \frac{\left(dN^h/d^2p_T\right)_{AA}}{N_{col} \times \left(dN^h/d^2p_T\right)_{pp}}$$



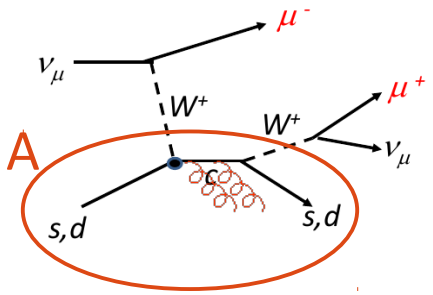
Yen-Jie , Quark Matter 2017

Strange strange quarks

- What next?
  - **Use data on proton targets to fix s** → *CJ17, in progress*

	Observable	x	Q^2 [GeV^2]
LHC	W, Z, W+c	$10^{-4} – 10^{-1}$	> 6400
JLab 12 [M.Dalton]	PVDIS	0.1 – 0.4	1 – 4
EIC [Y.Zhao, Aschenauer]	PVDIS, CC	$10^{-3} – 0.5$	1 – 5000

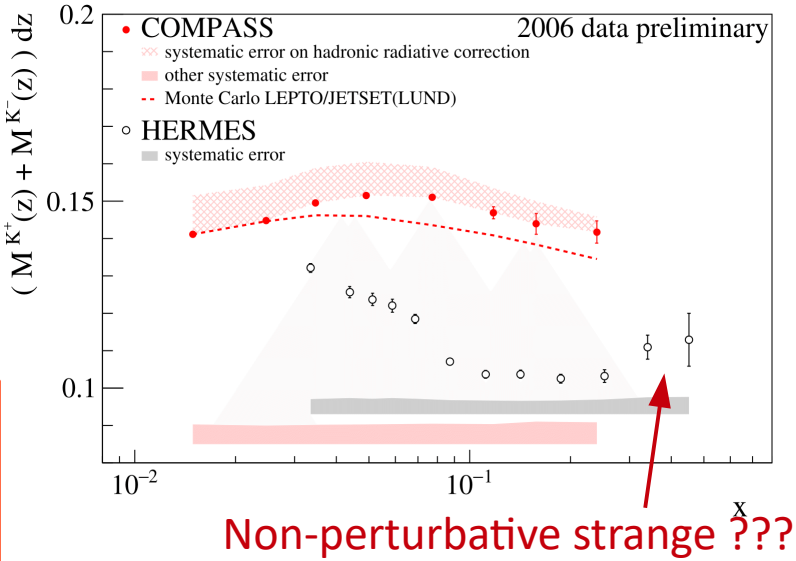
  - **Use dimuons on nuclear targets to study charm quark propagation in nuclear matter**



Strange strange kaons

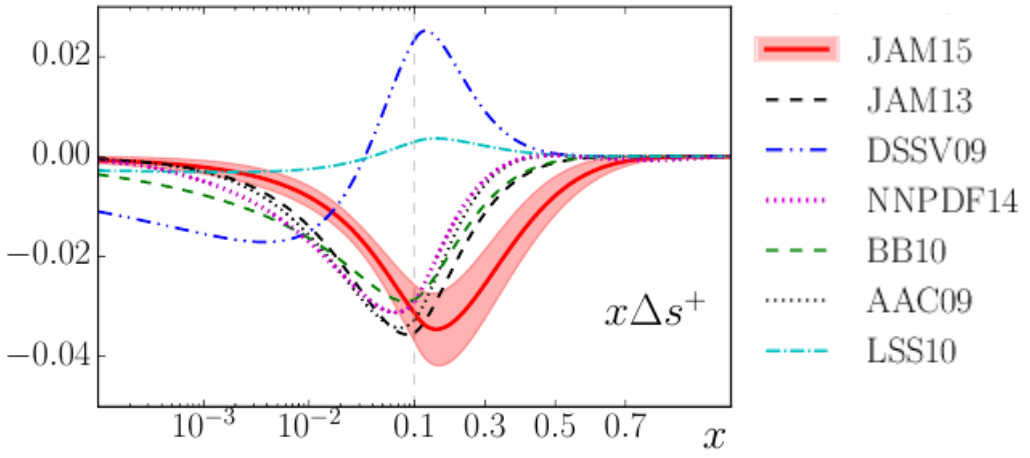
- **s : large or small?**
  - Possibly, large Hadron Mass effects
    Guerrero, Accardi, in preparation
  - Extraction of s(x) strongly affected by **kaon FF systematic uncertainty**

Lattice guidance?
(does not need precision)

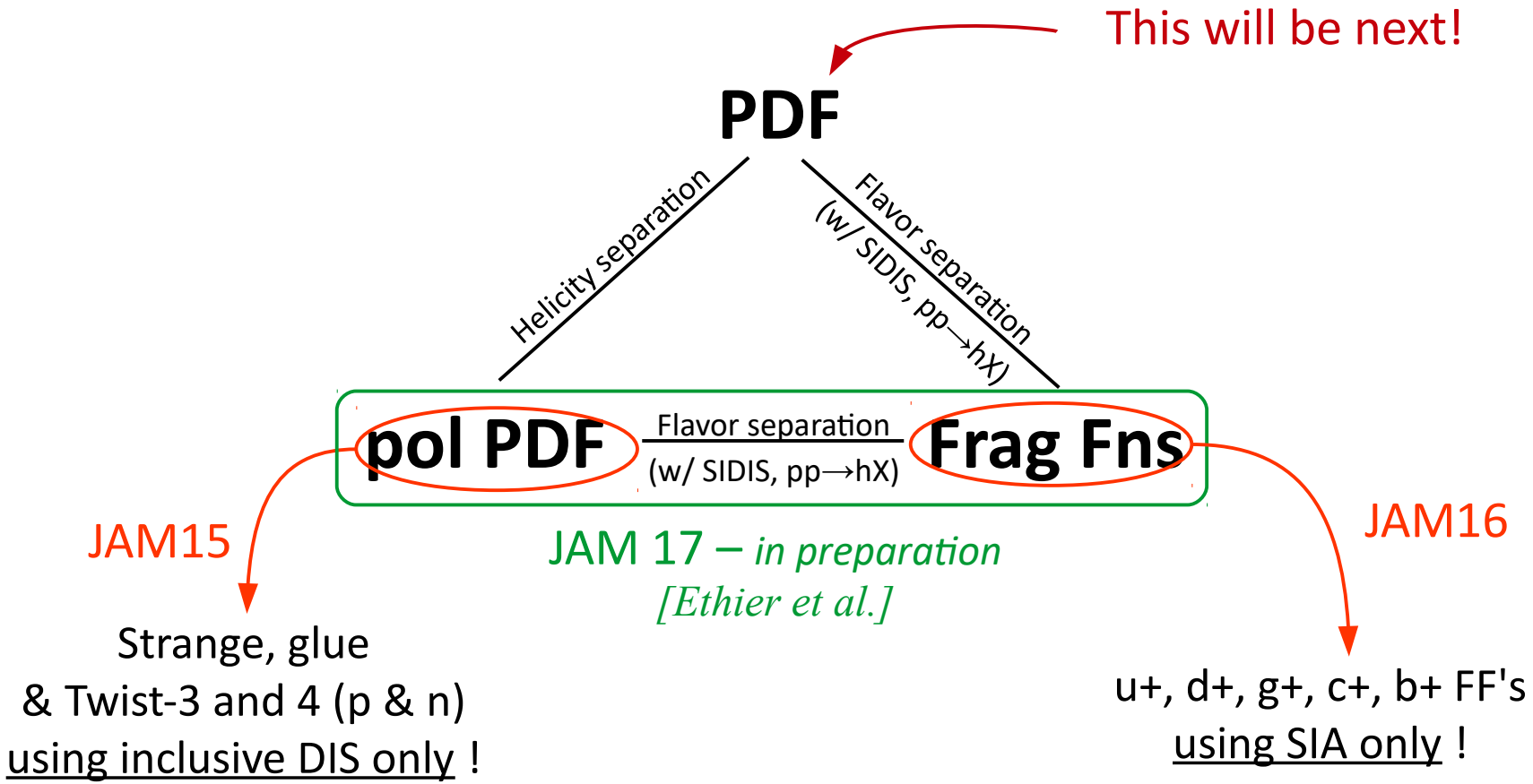


Non-perturbative strange ???

- **Δs : positive or negative?**
  - Depends on **kaon FF used in SIDIS calculations!**
  - What about the unpol s ?



Need combined fits!

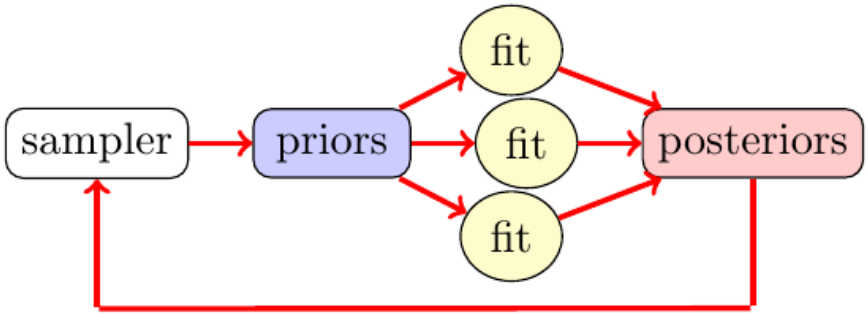


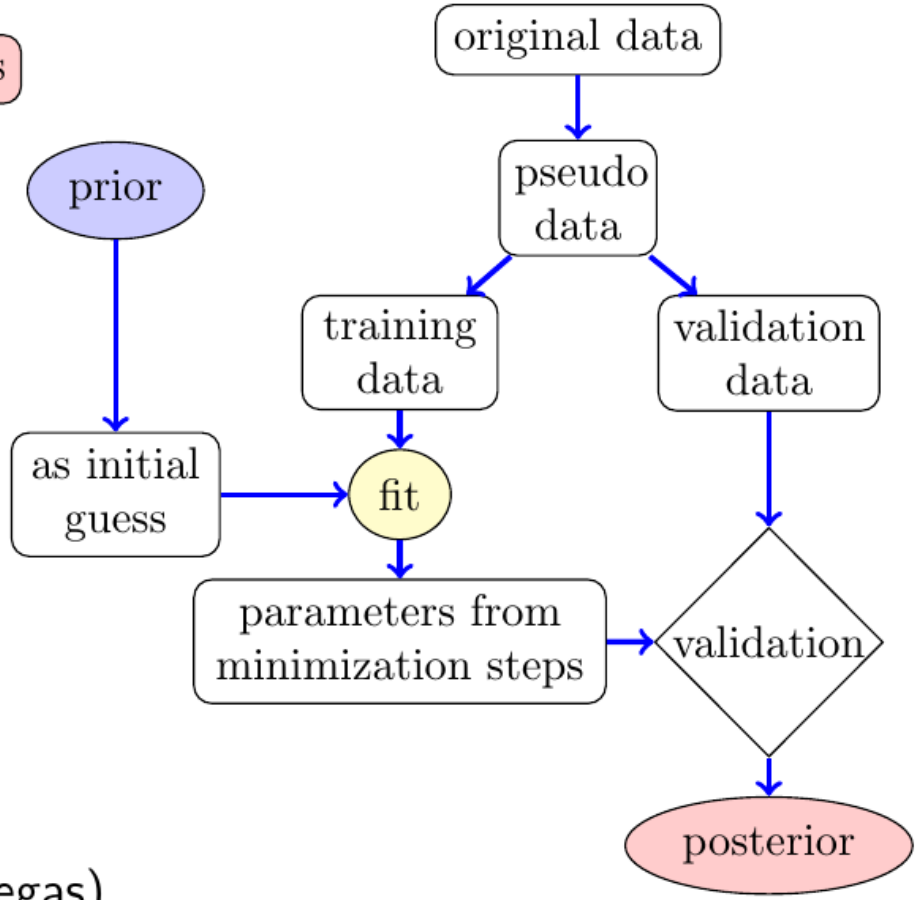
Iterative Monte Carlo: the JAM approach

Sato, Ethier, Melnitchouk, Kuhn, Accardi, Hirai, Kumano

PRD93 (2016) 074005 and PRD94 (2016) 114004

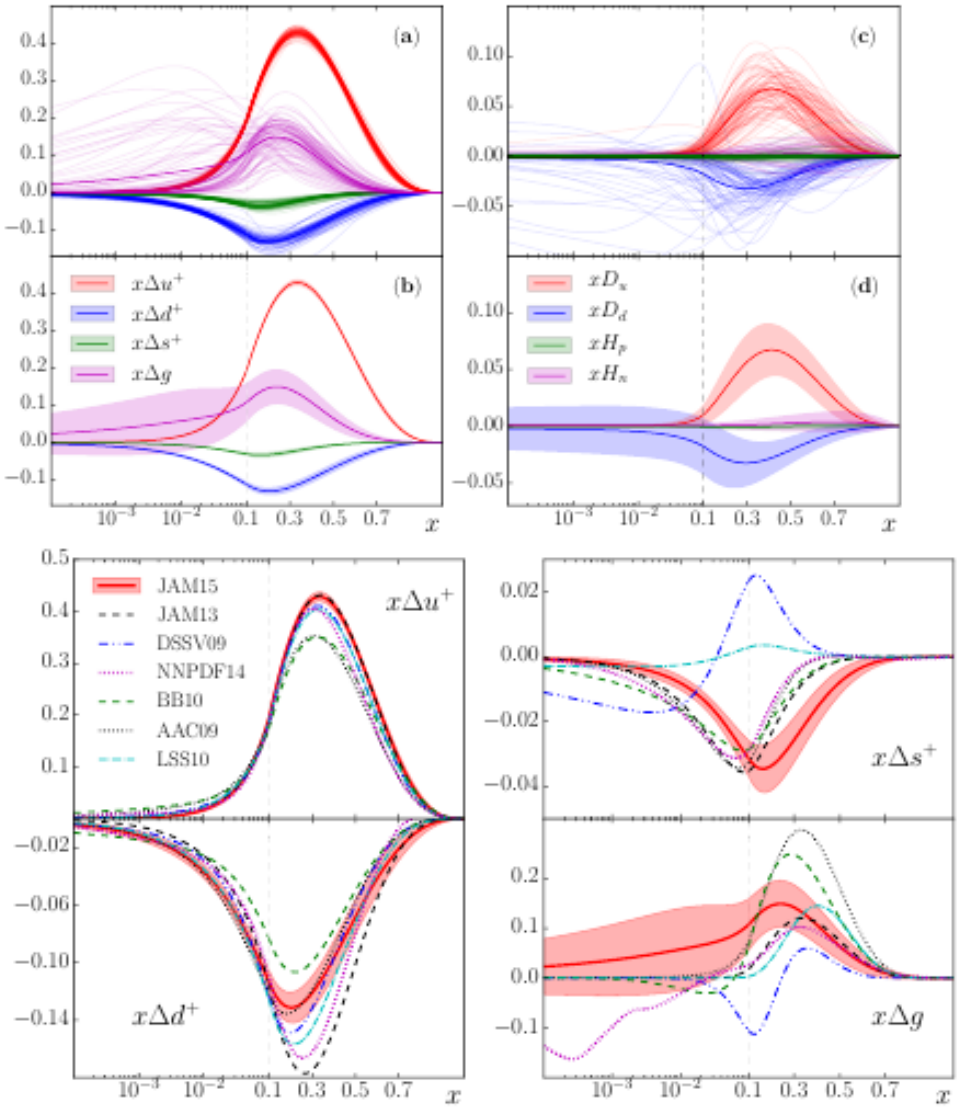
Iterative Monte Carlo (IMC) analysis





- Use traditional ansatz
  $xf(x) = Nx^a(1-x)^b(1+c\sqrt{x}+dx)$
- Keep all the parameters free.
  No assumptions on the exponents
- Avoid over-fitting by Cross-Validation
- **Iterative procedure**
  $\rightarrow$ Adaptive MC integration (like in Vegas)
- Robust estimation of uncertainties

The JAM15 polarized PDFs



moment	truncated	full
Δu^+	0.82 ± 0.01	0.83 ± 0.01
Δd^+	-0.42 ± 0.01	-0.44 ± 0.01
Δs^+	-0.10 ± 0.01	-0.10 ± 0.01
$\Delta\Sigma$	0.31 ± 0.03	0.28 ± 0.04
ΔG	0.5 ± 0.4	1 ± 15
d_2^p	0.005 ± 0.002	0.005 ± 0.002
d_2^n	-0.001 ± 0.001	-0.001 ± 0.001
h_p	-0.000 ± 0.001	0.000 ± 0.001
h_n	0.001 ± 0.002	0.001 ± 0.003

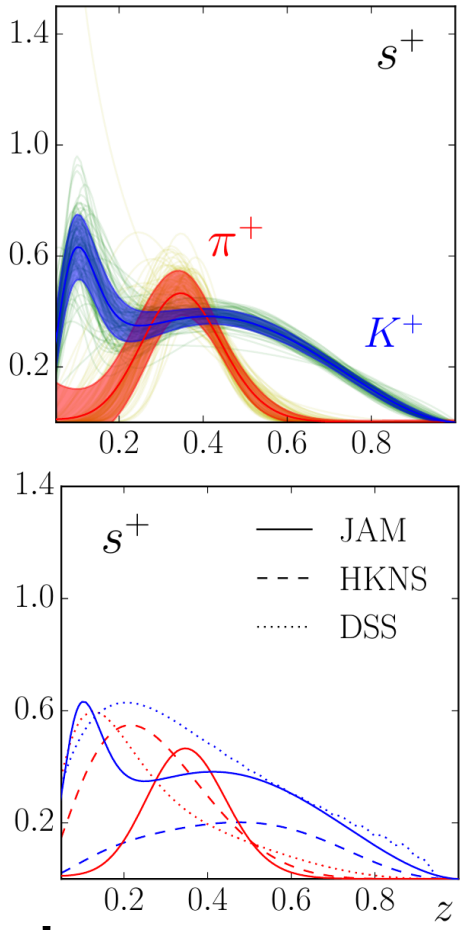
- Significant constraints on Δs^+ and Δg
- Non zero T3 quark distributions
- T4 contribution to g_1 consistent with zero
- **Negative** Δs^+
- JAM15 Δg compatible with recent DSSV fits.

The JAM FF 2016 fit

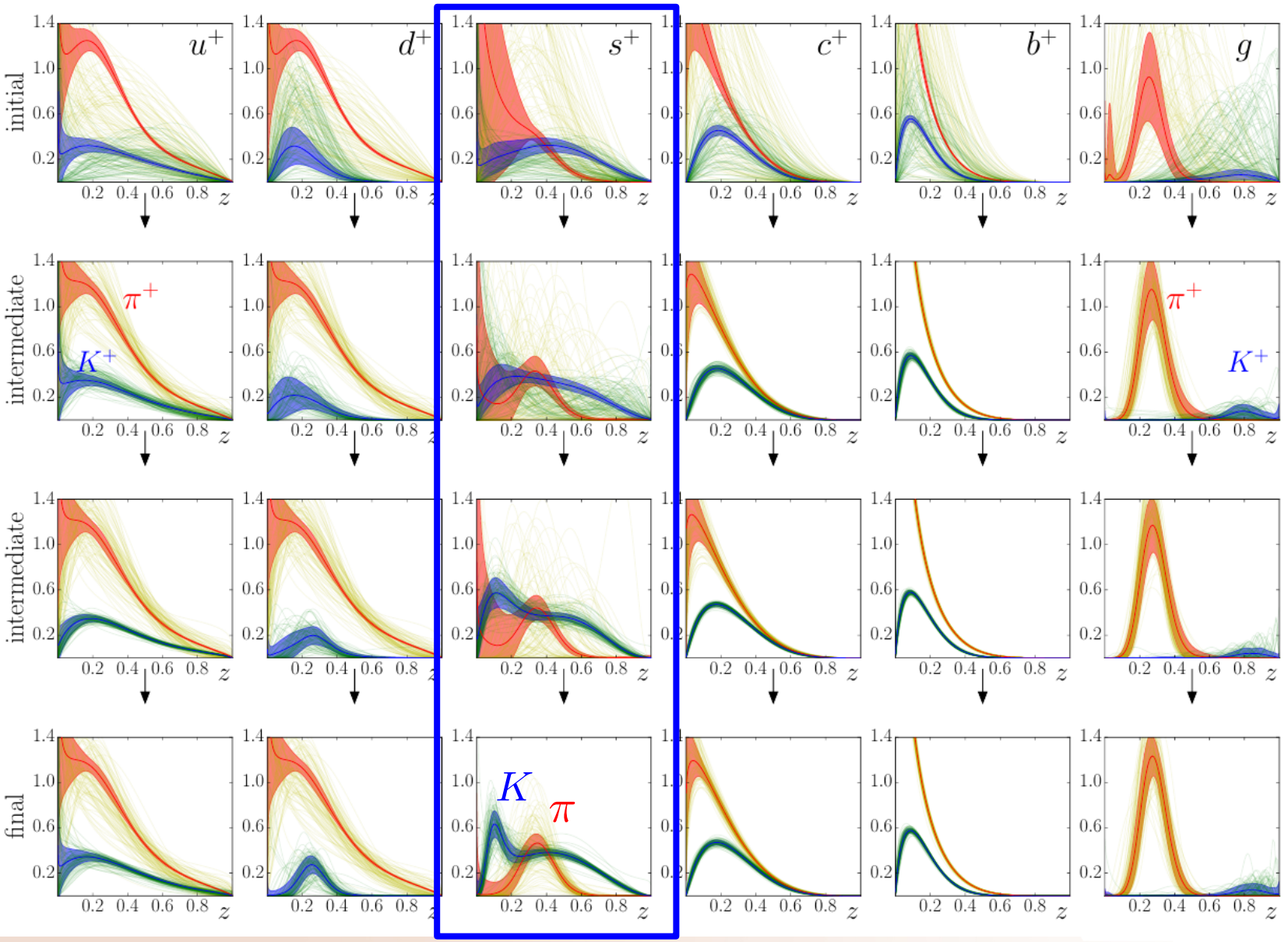
- Kaon FF too uncertain, correlated to strange PDF in SIDIS
  - Cannot take kaon FF off the shelf
  - Need in-house extraction

- **Iterative MC approach**
  - Only SIA data used :
    npts=245, χ2 = 305.2

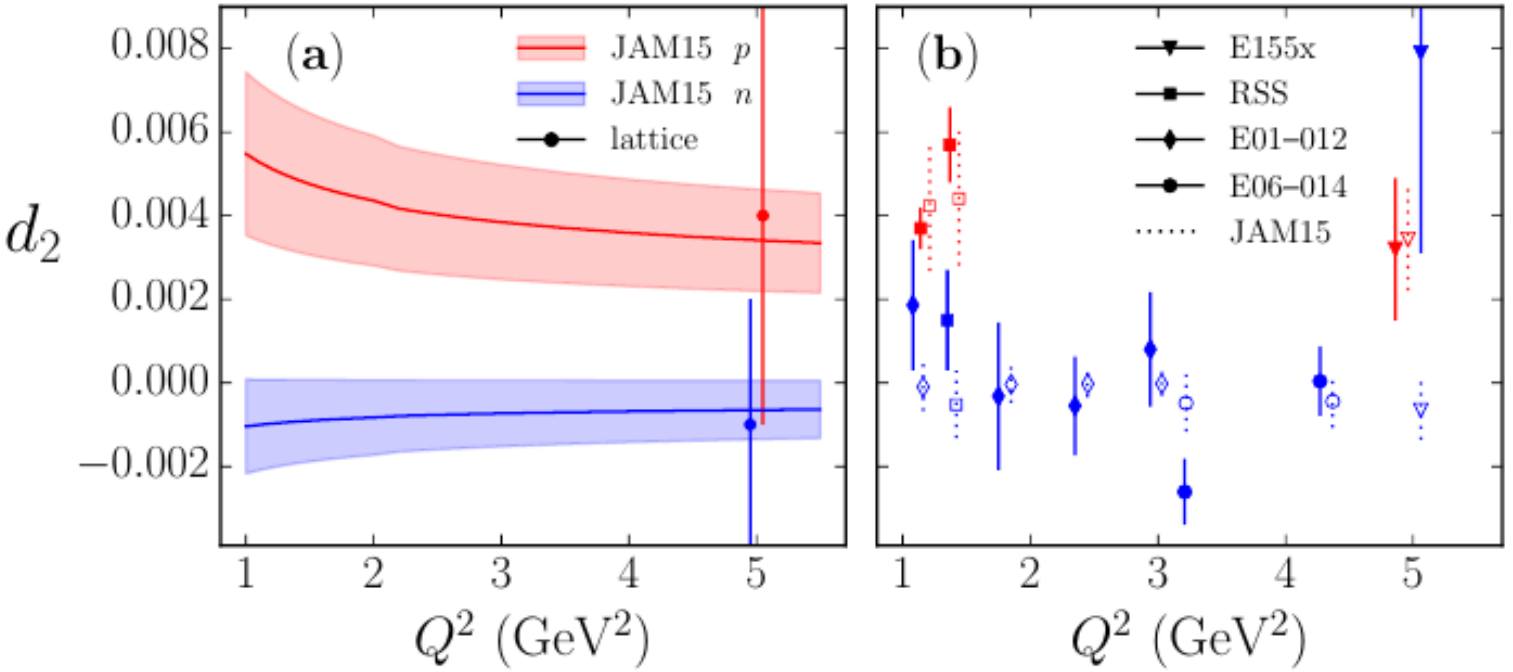
- **Strange-to-kaon FF:**
  - Between HKNS and DSS
  - Will it give a negative Δs ??
  - **Combined pol SIDIS + FF analysis underway!**



IMC method in action



Higher twist and color polarizability



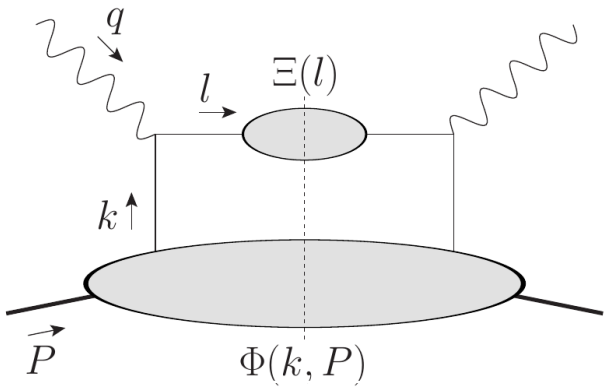
- $d_2(Q^2) \equiv \int_0^1 dx x^2 \left[2g_1^{T3}(x,Q^2) + 3g_2^{T3}(x,Q^2)\right]$
- d_2 is related to "color polarizability" or the "transverse color force" acting on quarks.

Lattice calcs from Goeckele et al. 2005 – time to revist?
(needs about 10 x precision, see next)

Transversity from inclusive DIS

Accardi, Bacchetta – in preparation

- **Jet correlator needed:** quarks are not asymptotic states



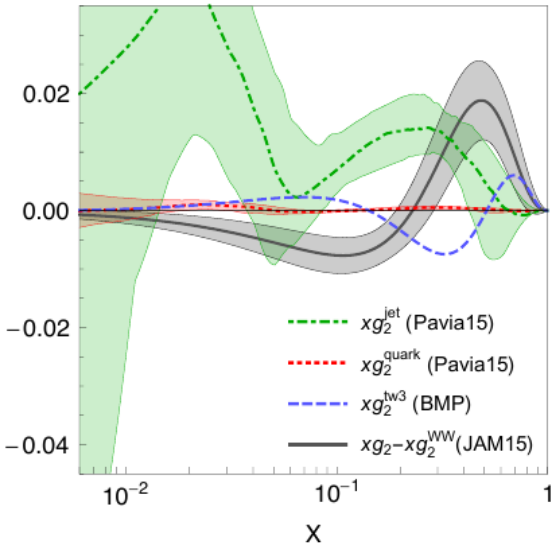
$$\Xi(l) = \text{F.T.}\langle 0|\bar{\psi}(z^-)\psi(0)|0\rangle = \int d\mu^2 \left[J_1(\mu^2)\mu + J_2(\mu^2)\not{l}\right]\delta(l^2-\mu^2)$$

$$\int d\mu^2 J_2(\mu^2) = 1$$ **recovers usual pert. result**

Chiral condensate!

$$\int d\mu^2 J_1(\mu^2)\mu = M_{\text{“jet”}} = \langle 0|\bar{\psi}(0)\psi(0)|0\rangle$$ **couples to transversity!**

$$g_2(x_B) = g_2^{WW}(x_B) + g_2^{tw-3}(x_B) + \frac{M_{\text{“jet”}}}{\Lambda}\frac{h_1(x_B)}{x_B}$$



Novel non-perturbative sum rules

Accardi, Bacchetta – in preparation

Burkardt-Cottingham

$$\int_0^1 g_2(x) = M_{\text{“}jet\text{”}} \int_0^1 h_1(x)/x$$

Efremov-Teryaev-Leader

$$\int_0^1 x g_2^{q-\bar{q}}(x) = 2\, M_{\text{“}jet\text{”}} \underbrace{\int_0^1 h_1^{q-\bar{q}}(x)}_{g_T}$$

Color polarizability

$$\int_0^1 \left[3x^2 g_2(x) - 2x^2 g_1(x)\right] = d_2 + 3\, M_{\text{“}jet\text{”}} \underbrace{\int_0^1 x h_1(x)}_{\text{Lattice ?}}$$

Lattice (2005)

Novel non-perturbative sum rules

Accardi, Bacchetta – in preparation

"Universal" PDF fits:

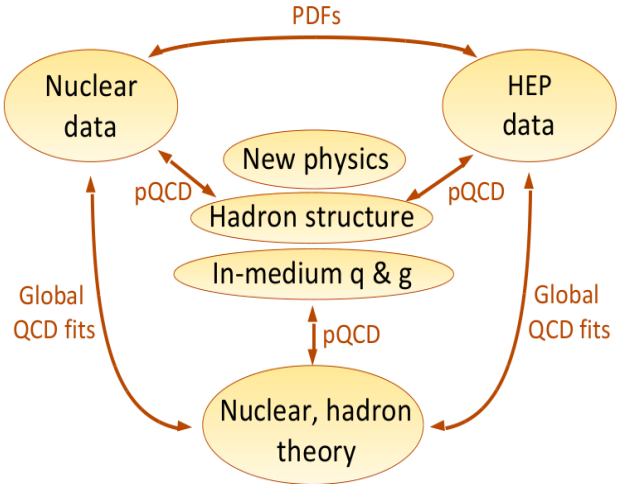
- Interplay of q, Δq, δq
- **Can measure chiral condensate**
- Novel handles on g_T

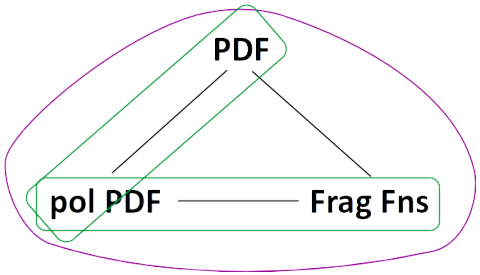
Lattice:

- **calculate $M_{\text{"jet"}}$**
  (matching, renormalization, evolution?)
- **… ?**

Final thoughts

- **Entering a new PDF precision era:**
  - 2 ways toward high precision:
    - N^nLO & nucl/power/resum corrections
  - New combined fitting approaches
    - Hadronic, nuclear physics output
    - Improved PDF accuracy and precision
  - Entering the **Jlab12 & LHC era**
    - With the complicity of RHIC… and crowned by the **EIC** !
  - Conquering the world:
    - towards unified PDF+pPDF+FF fits

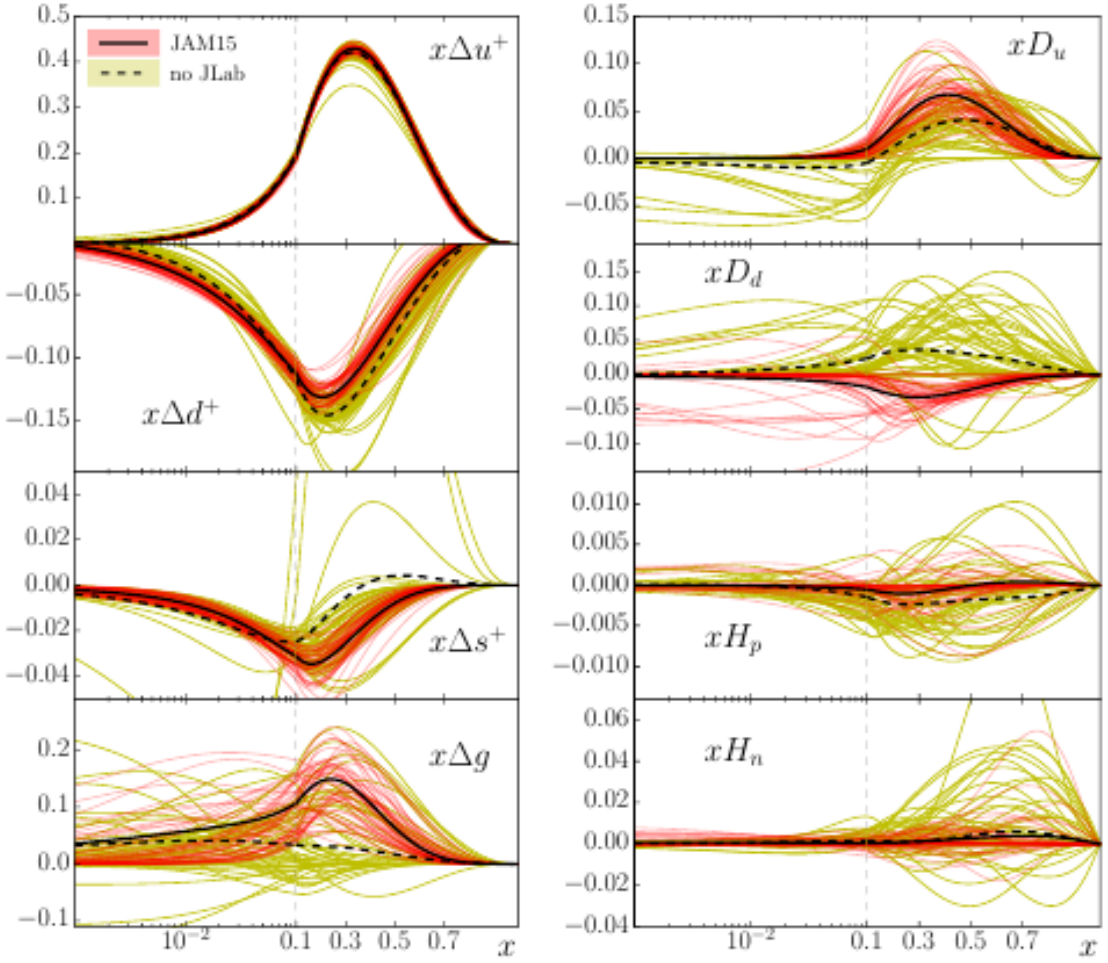




- **Interplay with lattice QCD:**
  - Precision: (should we) use "lattice QCD" data points in a fit?
  - Guidance where experimental info lacking
  - Exploring the unexplored: nuclear embedding of PDFs

Backup

Impact of JLab data



- JLab data $\rightarrow$ $0.1 < x < 0.7$
- Constraints on small x from large $x \rightarrow$ weak baryon decay constraints
- Large uncertainties in Δs^+, Δg removed by JLab data
- Non vanishing T3 quark distributions
- T4 distributions consistent with zero