The Role of Apv in Hadron Structure Studies

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In collaboration with:
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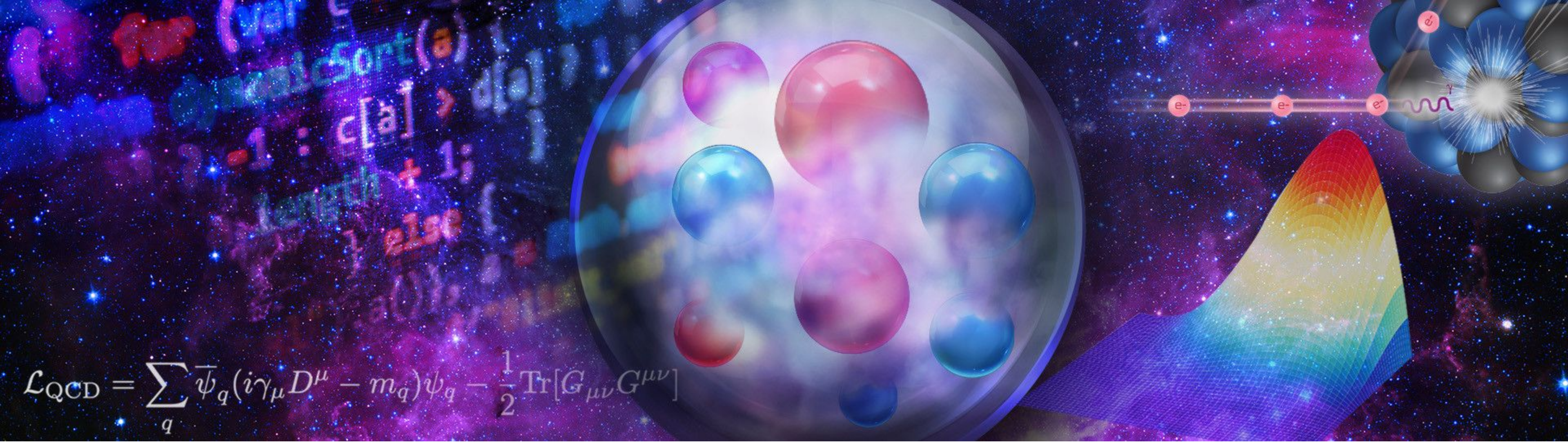
Parity-Violation and other Electroweak Physics at JLab 12 GeV and Beyond Jun/2022

Jefferson Lab

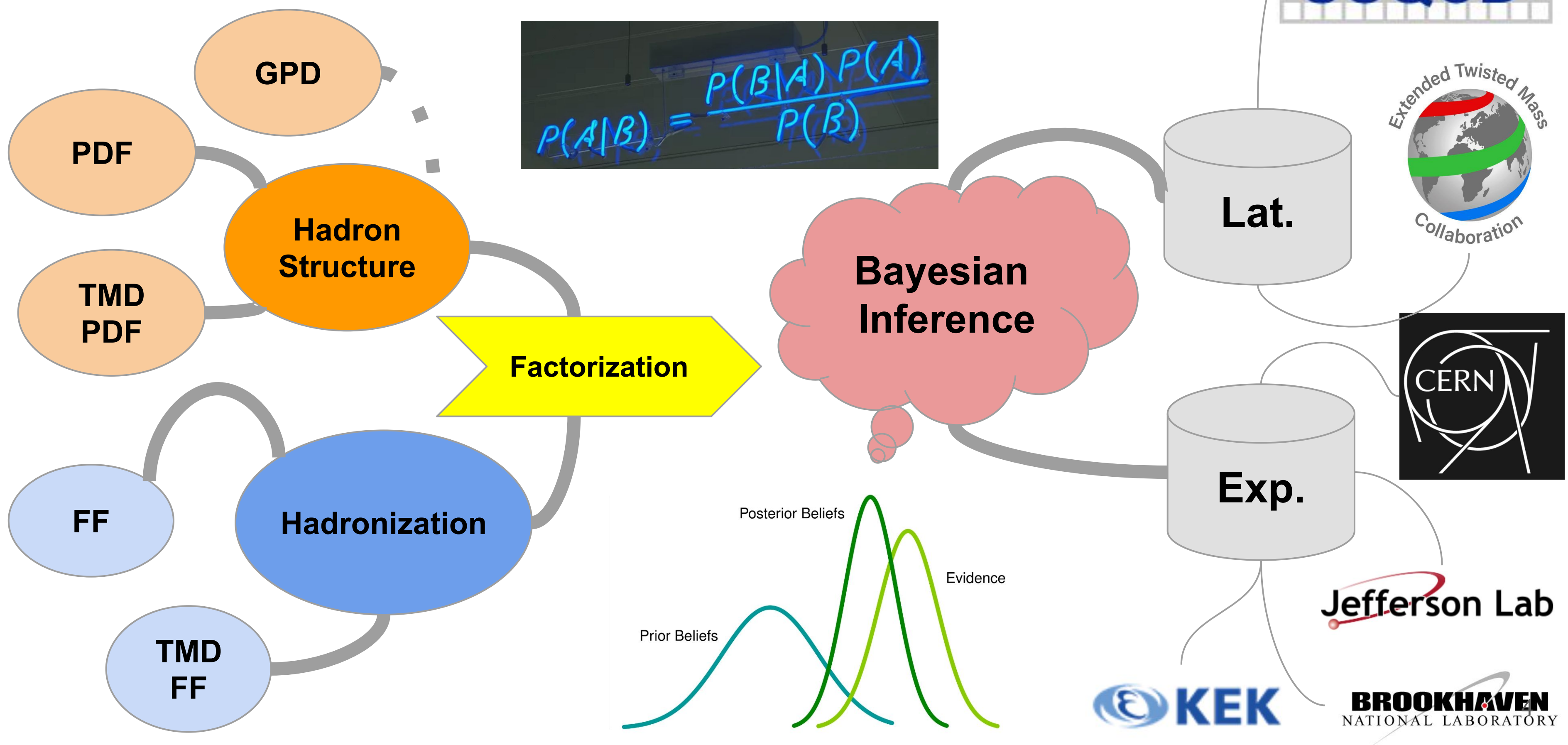
Motivations



JEFFERSON LAB ANGULAR MOMENTUM COLLABORATION

The Jefferson Lab Angular Momentum (JAM) Collaboration is an enterprise involving theorists, experimentalists, and computer scientists from the Jefferson Lab community using QCD to study the internal quark and gluon structure of hadrons and nuclei. Experimental data from high-energy scattering processes are analyzed using modern Monte Carlo techniques and state-of-the-art uncertainty quantification to simultaneously extract various quantum correlation functions, such as parton distribution functions (PDFs), fragmentation functions (FFs), transverse momemtum dependent (TMD) distributions, and generalized parton distributions (GPDs). Inclusion of lattice QCD data and machine learning algorithms are being explored to potentially expand the reach and efficacy of JAM analyses and our understanding of hadron structure in QCD.

The JAM global analysis paradigm



f_1, d_1

Strange quark suppression from a simultaneous Monte Carlo analysis of parton distributions and fragmentation functions

JAM Collaboration • N. Sato (Old Dominion U. and Jefferson Lab) et al. (May 9, 2019)

Published in: *Phys.Rev.D* 101 (2020) 7, 074020 • e-Print: 1905.03788 [hep-ph]

f_1, d_1

Simultaneous Monte Carlo analysis of parton densities and fragmentation functions

Jefferson Lab Angular Momentum (JAM) Collaboration • Eric Moffat (Old Dominion U.) et al. (Jan 12, 2021)

Published in: *Phys.Rev.D* 104 (2021) 1, 016015 • e-Print: 2101.04664 [hep-ph]

$f_1, \Delta f_1$

How well do we know the gluon polarization in the proton?

Jefferson Lab Angular Momentum (JAM) Collaboration • Y. Zhou (South China Normal U. and Cape Town U., D Math. and UCLA and William-Mary Coll. and Jefferson Lab) et al. (Jan 6, 2022)

Published in: *Phys.Rev.D* 105 (2022) 7, 074022 • e-Print: 2201.02075 [hep-ph]

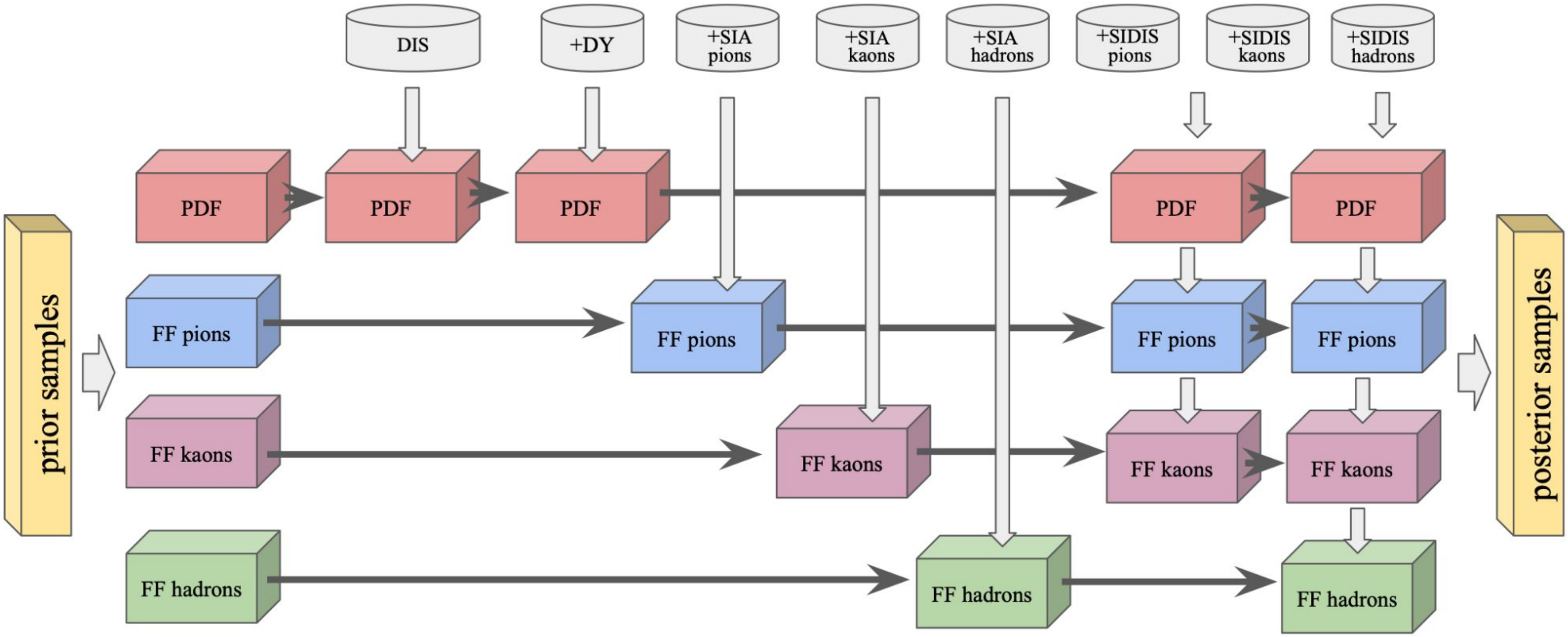
$f_1, \Delta f_1$
d_1

Polarized Antimatter in the Proton from Global QCD Analysis

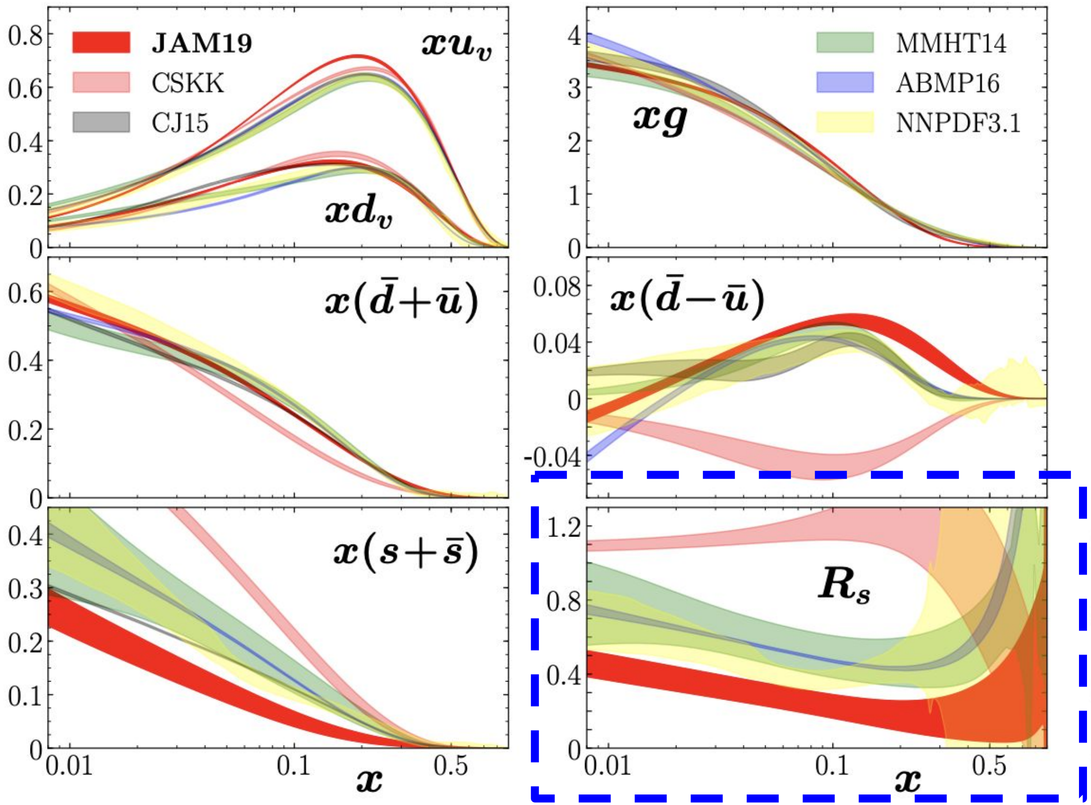
Jefferson Lab Angular Momentum (JAM) Collaboration • C. Cocuzza (Temple U.) et al. (Feb 7, 2022)

e-Print: 2202.03372 [hep-ph]

Multi-step strategy

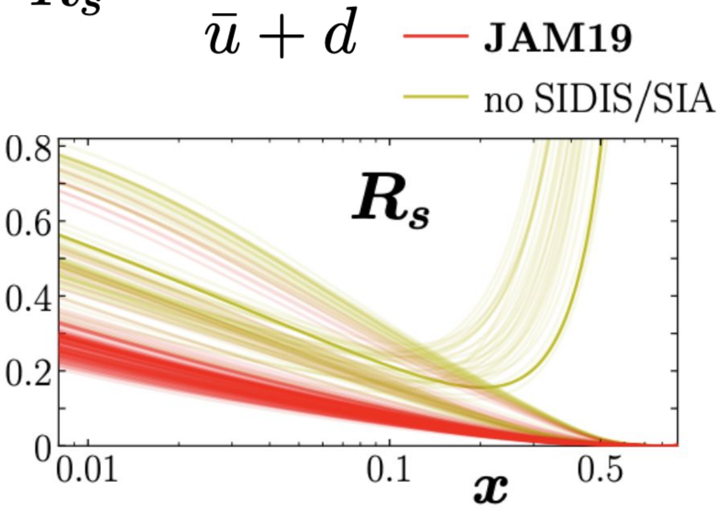


Strage suppression

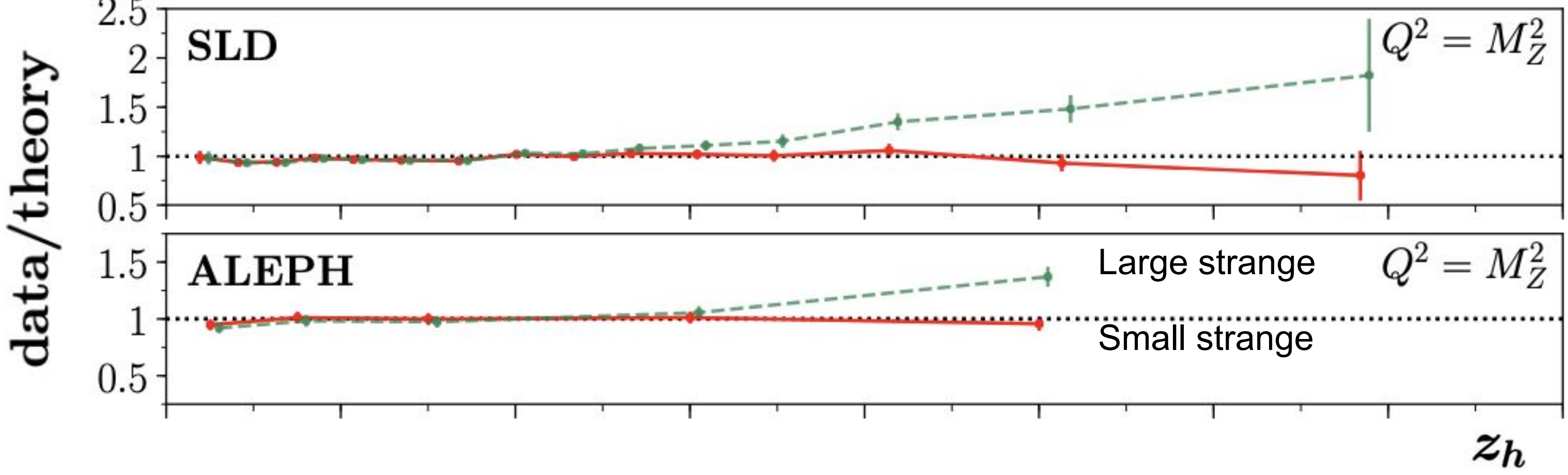


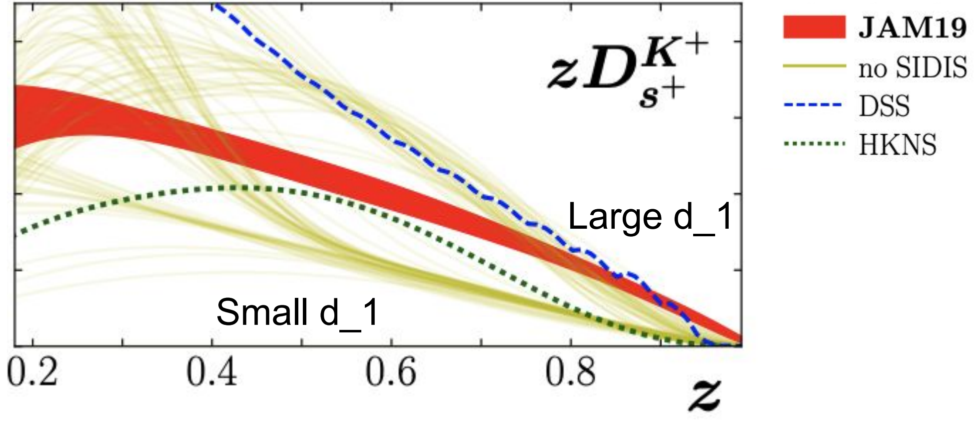
- Strange pdf is one of the least constrained f_1 pdfs
- Different analyzes have inferred different sizes of the strangeness

$$R_s = \frac{s + \bar{s}}{\bar{u} + \bar{d}}$$

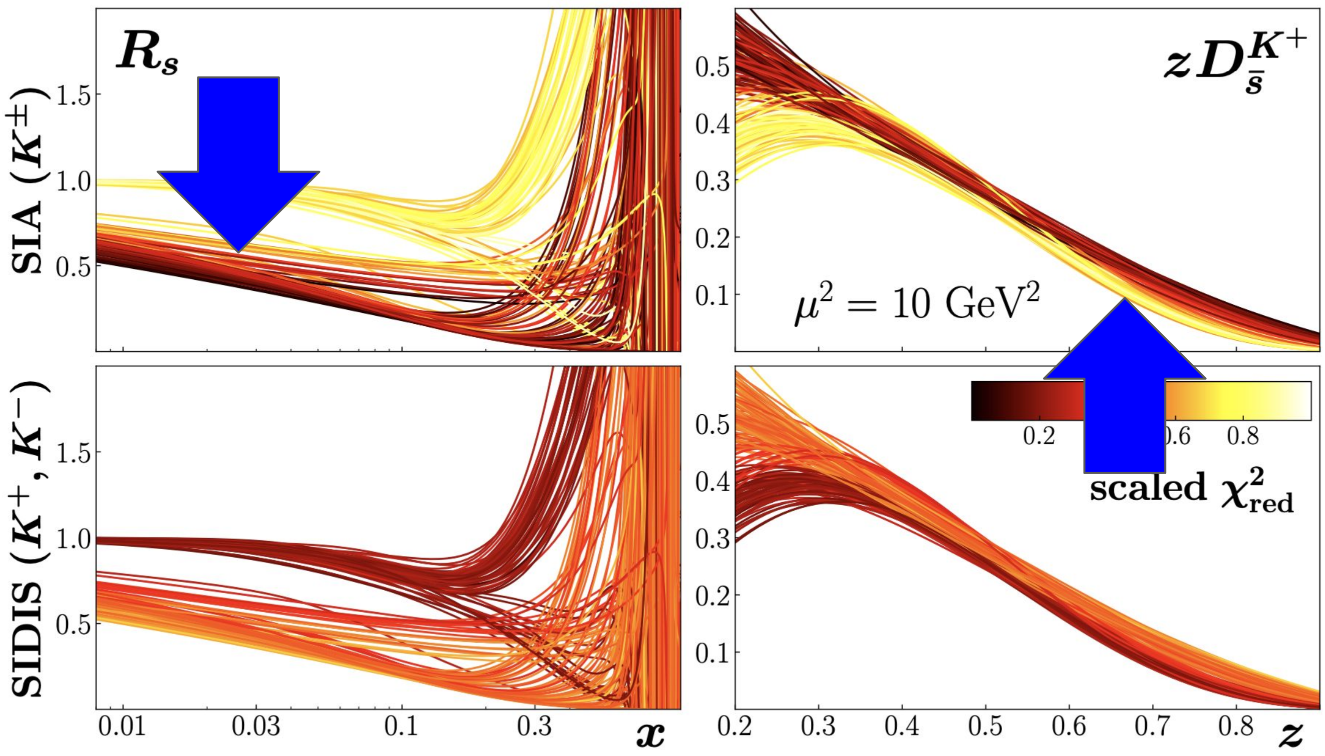


$e^+e^- \to K^\pm + X$





- LEP kaon data disfavors small s->K fragmentation
- SIDIS data compensates large strange FF by suppressing the strange PDF

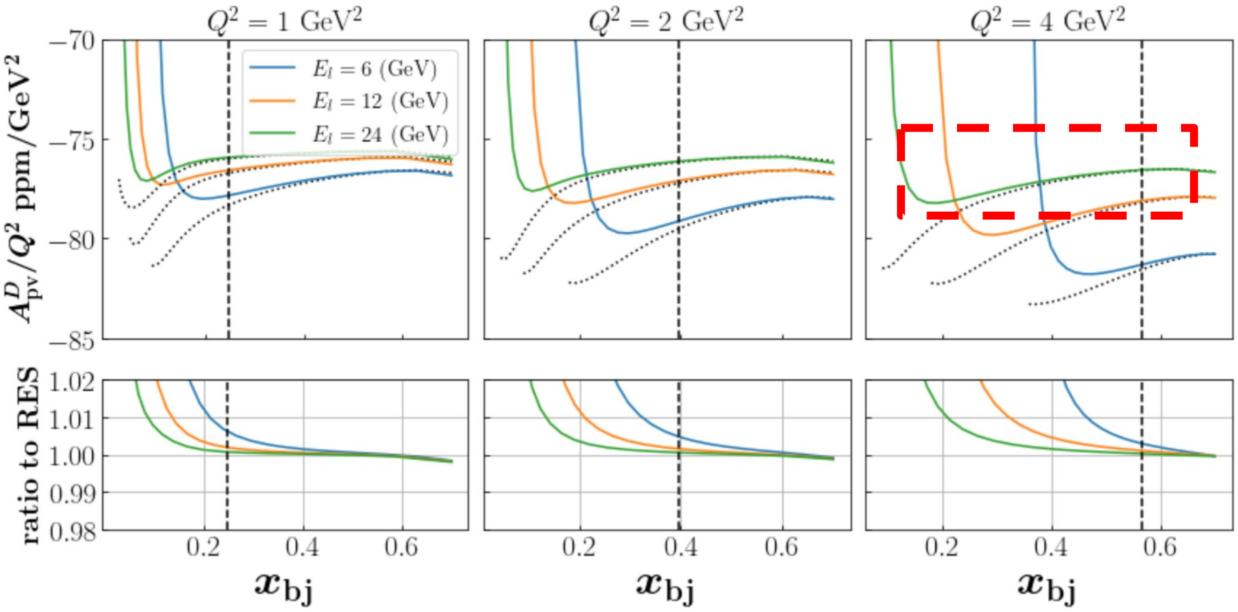


Bottom-line:

Simultaneous analysis suggest a strong strange suppression and differs from other global analysis using LHC data

APV

Comment on the selection of kinematics



- For 24 GeV we can have a wide range in x at Q=2 GeV where QED effects are controllable
- In this talk we explore Apv at El= 24 GeV and Q=2 GeV

See talk by T. Liu

PHYSICAL REVIEW D VOLUME 18, NUMBER 9 1 NOVEMBER 1978

Model-independent remarks on electron-quark parity-violating neutral-current couplings

J. D. Bjorken
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305
(Received 10 July 1978)

$$\frac{A^{eD}(Q^2,\nu,y)_{AV}}{Q^2} \propto \frac{l_{\mu\nu}\int \langle D|[j^\mu(x)J^\nu(0)+J^\mu(x)j^\nu(0)]\,|D\rangle e^{iq\cdot x}d^4x}{l_{\mu\nu}\int\langle D\,|j^\mu(x)j^\nu(0)\,|D\rangle e^{iq\cdot x}d^4x}\,;$$

$$\frac{A^{eD}}{Q^2}\bigg|_{y=0} = -\frac{3G}{10\pi\alpha\sqrt{2}}\left[2\epsilon_{AV}(e,u)(1+\tfrac{3}{10}\delta)-\epsilon_{AV}(e,d)(1-\tfrac{6}{5}\delta)\right].$$

$$\epsilon_{VA}(e,u)=\tfrac{1}{2}(1-4\sin^2\theta_W)\,,$$
$$\epsilon_{VA}(e,d)=-\tfrac{1}{2}(1-4\sin^2\theta_W)\,,$$
$$\epsilon_{AV}(e,u)=\tfrac{1}{2}(1-\tfrac{8}{3}\sin^2\theta_W)\,,$$
$$\epsilon_{AV}(e,d)=-\tfrac{1}{2}(1-\tfrac{4}{3}\sin^2\theta_W)\,.$$

If δ is small then Apv on deuteron is highly sensitive to $\sin^2\theta_W$

1978 -> 2014

From currents to partons

Measurement of Parity-Violating Asymmetry in Electron-Deuteron Inelastic Scattering

D. Wang, R. Subedi,[*] G. D. Cates, M. M. Dalton, X. Deng, D. Jones, N. Liyanage, V. Nelyubin,
K. D. Paschke, S. Riordan, K. Saenboonruang,[†] R. Silwal, W. A. Tobias, and X. Zheng
University of Virginia, Charlottesville, Virginia 22904, USA . . . . .

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$$A_{PV} = -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha(Q^2)}\left[\underline{a_1(x,Q^2)Y_1(x,y,Q^2)} + \underline{a_3(x,Q^2)Y_3(x,y,Q^2)}\right]$$

$$a_1(x) = 2g_A^e \frac{F_1^{\gamma Z}}{F_1^{\gamma}}$$

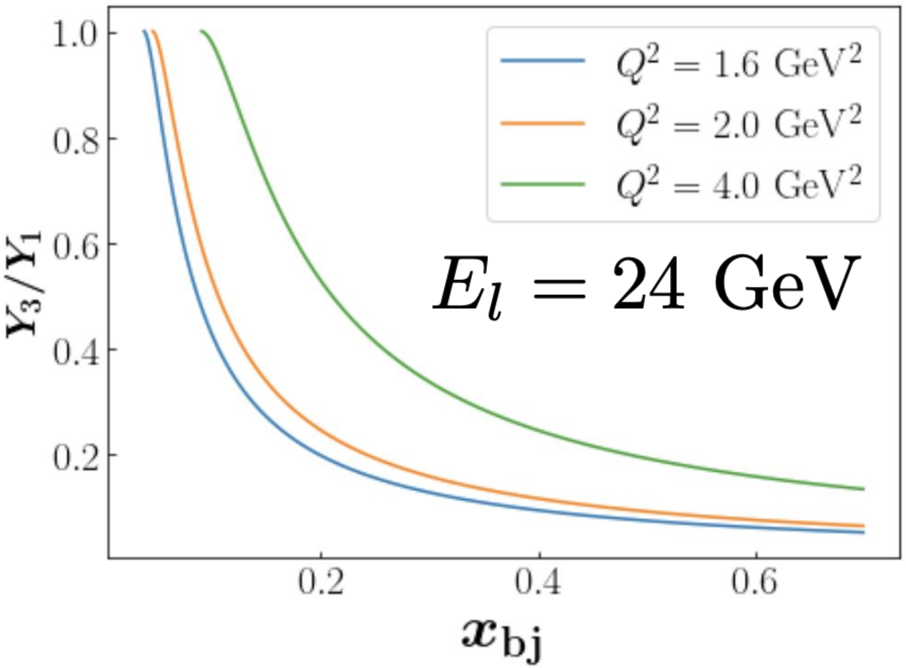
$$a_3(x) = g_V^e \frac{F_3^{\gamma Z}}{F_1^{\gamma}},$$

$$Y_1 = \left[\frac{1+R^{\gamma Z}}{1+R^{\gamma}}\right]\frac{1+(1-y)^2-\frac{y^2}{2}\left[1+r^2-\frac{2r^2}{1+R^{\gamma Z}}\right]}{1+(1-y)^2-\frac{y^2}{2}\left[1+r^2-\frac{2r^2}{1+R^{\gamma}}\right]}$$

$$Y_3 = \left[\frac{r^2}{1+R^{\gamma}}\right]\frac{1-(1-y)^2}{1+(1-y)^2-\frac{y^2}{2}\left[1+r^2-\frac{2r^2}{1+R^{\gamma}}\right]}.$$

The y dependence....

$$A_{PV} \;=\; -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha(Q^2)}\left[\underline{a_1(x,Q^2)Y_1(x,y,Q^2)} + \underline{a_3(x,Q^2)Y_3(x,y,Q^2)}\right]$$



$$Y_1 \;=\; \left[\frac{1+\cancel{R^{\gamma Z}}}{1+\cancel{R^{\gamma}}}\right]\frac{1+(1-y)^2-\frac{y^2}{2}\left[1+r^2-\frac{\cancel{2r^2}}{1+R^{\gamma Z}}\right]}{1+(1-y)^2-\frac{y^2}{2}\left[1+r^2-\frac{\cancel{2r^2}}{1+R^{\gamma}}\right]}$$

$$Y_3 \;=\; \left[\frac{r^2}{1+\cancel{R^{\gamma Z}}}\right]\frac{1-(1-y)^2}{1+(1-y)^2-\frac{y^2}{2}\left[1+r^2-\frac{\cancel{2r^2}}{1+R^{\gamma}}\right]}\,.$$

$$r^2 = 1 + \frac{\cancel{Q^2}}{\nu^2}$$

Parton level view...

$$a_1(x) \;=\; 2g_A^e \frac{F_1^{\gamma Z}}{F_1^{\gamma}} \qquad\qquad a_3(x) \;=\; g_V^e \frac{F_3^{\gamma Z}}{F_1^{\gamma}}$$

At LO in QCD we have

$$\begin{aligned}
F_1^{\gamma}(x,Q^2) &= \frac{1}{2}\sum Q_{q_i}^2 \left[q_i(x,Q^2)+\bar{q}_i(x,Q^2)\right] \\
F_1^{\gamma Z}(x,Q^2) &= \sum Q_{q_i} g_V^i \left[q(x,Q^2)+\bar{q}_i(x,Q^2)\right] \\
F_3^{\gamma Z}(x,Q^2) &= 2\sum Q_{q_i} g_A^i \left[q_i(x,Q^2)-\bar{q}_i(x,Q^2)\right]
\end{aligned}$$

$$a_1(x) = 2g_A^e \frac{F_1^{\gamma Z}}{F_1^{\gamma}}$$

$$a_1 = \frac{2\left(c^+ + u^+\right)\left(8s_w^2 - 3\right) + \left(d^+ + s^+\right)\left(4s_w^2 - 3\right)}{4c^+ + d^+ + s^+ + 4u^+}$$

$$\boxed{a_1 = 4s_w^2 - \frac{9}{5}}$$

$$a_3(x) = g_V^e \frac{F_3^{\gamma Z}}{F_1^{\gamma}}$$

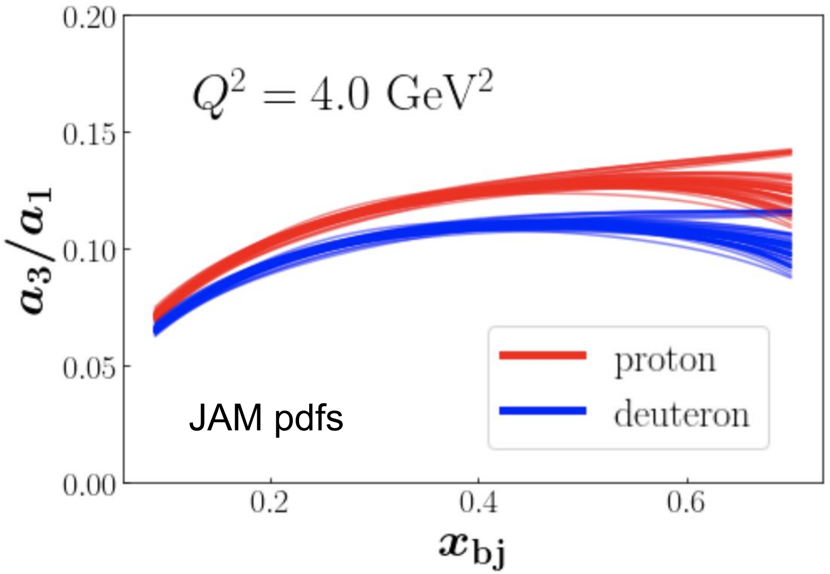
$$a_3 = \frac{3\left(4s_w^2 - 1\right)\left(2c^- + d^- + s^- + 2u^-\right)}{4c^+ + d^+ + s^+ + 4u^+}$$

If we ignore s and c and use deuteron target

$$a_3 = \frac{3\left(d^- + 2u^-\right)\left(4s_w^2 - 1\right)}{5u^+}$$

$$A_{PV} = -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha(Q^2)}\left[\underline{a_1(x,Q^2)Y_1(x,y,Q^2)} + \underline{a_3(x,Q^2)Y_3(x,y,Q^2)}\right]$$

$E_l = 24\ \mathrm{GeV}$




```
a1
```

$$\frac{2\left(c^+ + u^+\right)\left(8s_w^2 - 3\right) + \left(d^+ + s^+\right)\left(4s_w^2 - 3\right)}{4c^+ + d^+ + s^+ + 4u^+}$$

```
a3
```

$$\frac{3\left(4s_w^2 - 1\right)\left(2c^- + d^- + s^- + 2u^-\right)}{4c^+ + d^+ + s^+ + 4u^+}$$

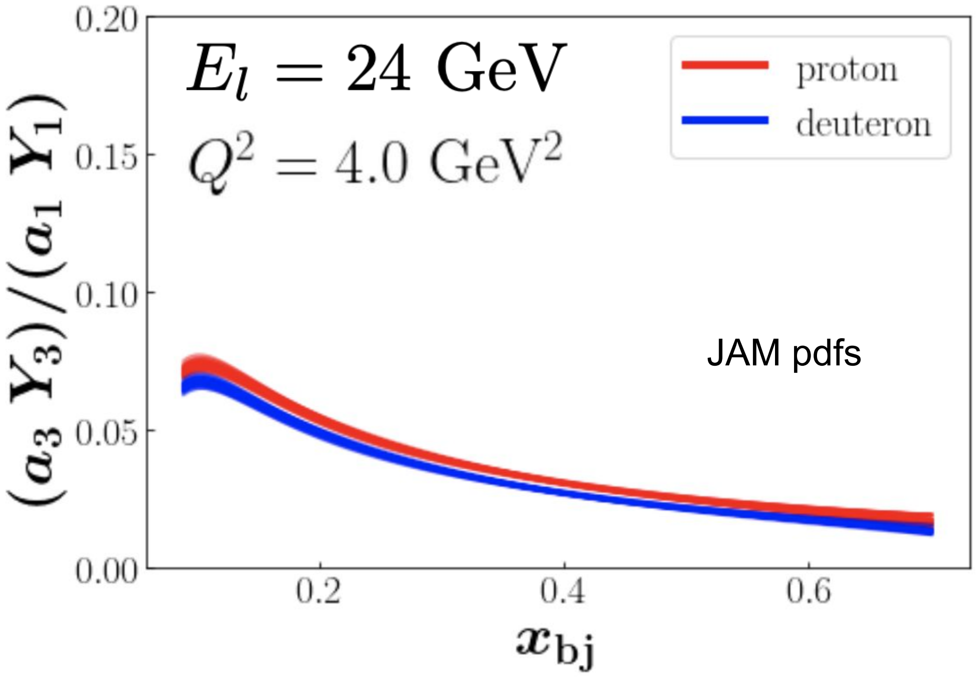
```
expr=a3/a1
expr=expr.subs(s2w,236/sy.S(1000))
expr=expr.subs(cp,0).subs(sp,0).subs(cm,0).subs(sm,0)
expr=expr.subs(dm,dp).subs(um,up).subs(up,2*dp)
sy.Eq(sy.S('a_3/a_1'),expr.simplify())
```

$$\frac{a_3}{a_1} = \frac{35}{271}$$

```
35/271
```

```
0.12915129151291513
```

$$A_{PV} = -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha(Q^2)}\left[a_1(x,Q^2)Y_1(x,y,Q^2) + a_3(x,Q^2)Y_3(x,y,Q^2)\right]$$

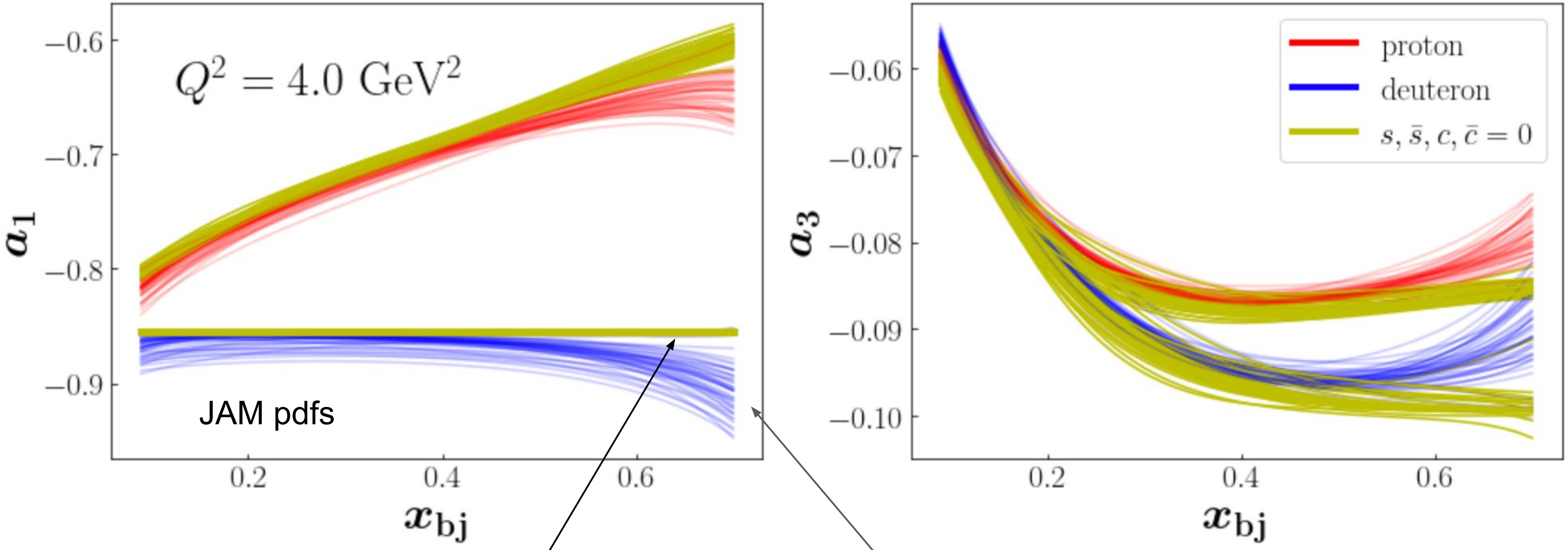


$$a_1(x) = 2g_A^e \frac{F_1^{\gamma Z}}{F_1^{\gamma}}$$

$$a_3(x) = g_V^e \frac{F_3^{\gamma Z}}{F_1^{\gamma}},$$

At this kinematics, F3 is very suppressed, so most of the action is from F1

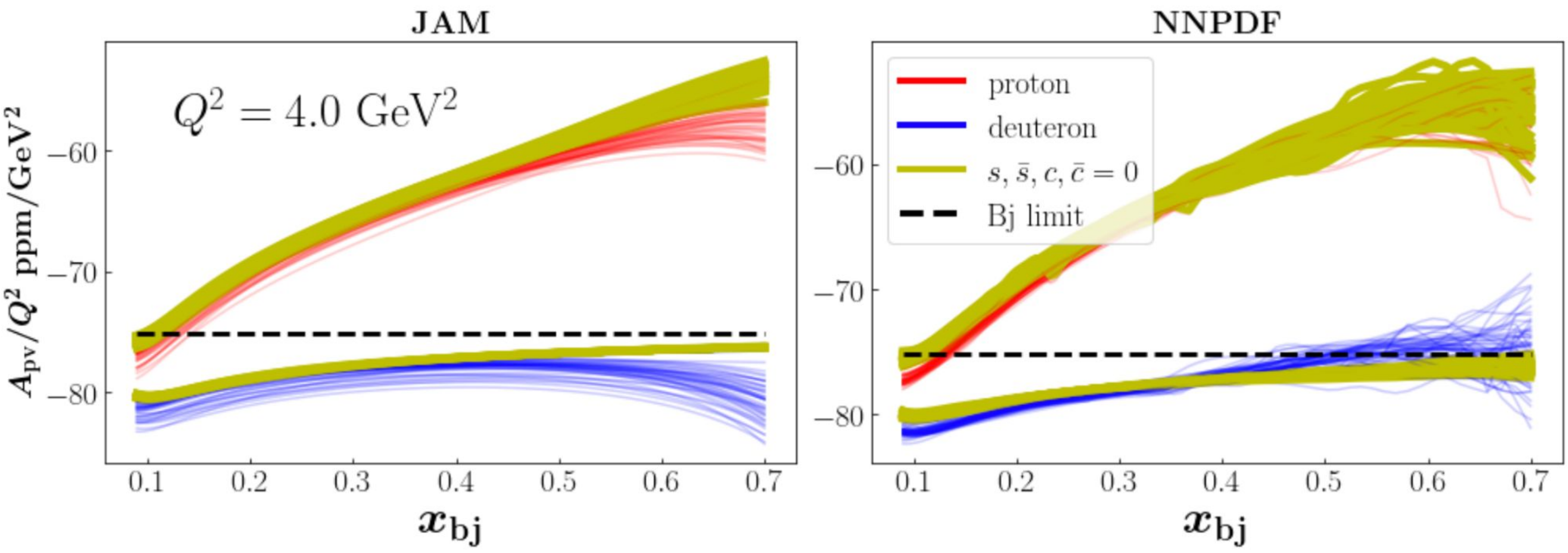
$$s,\ sb,\ c,\ cb = 0$$



If s,c=0 and u=d

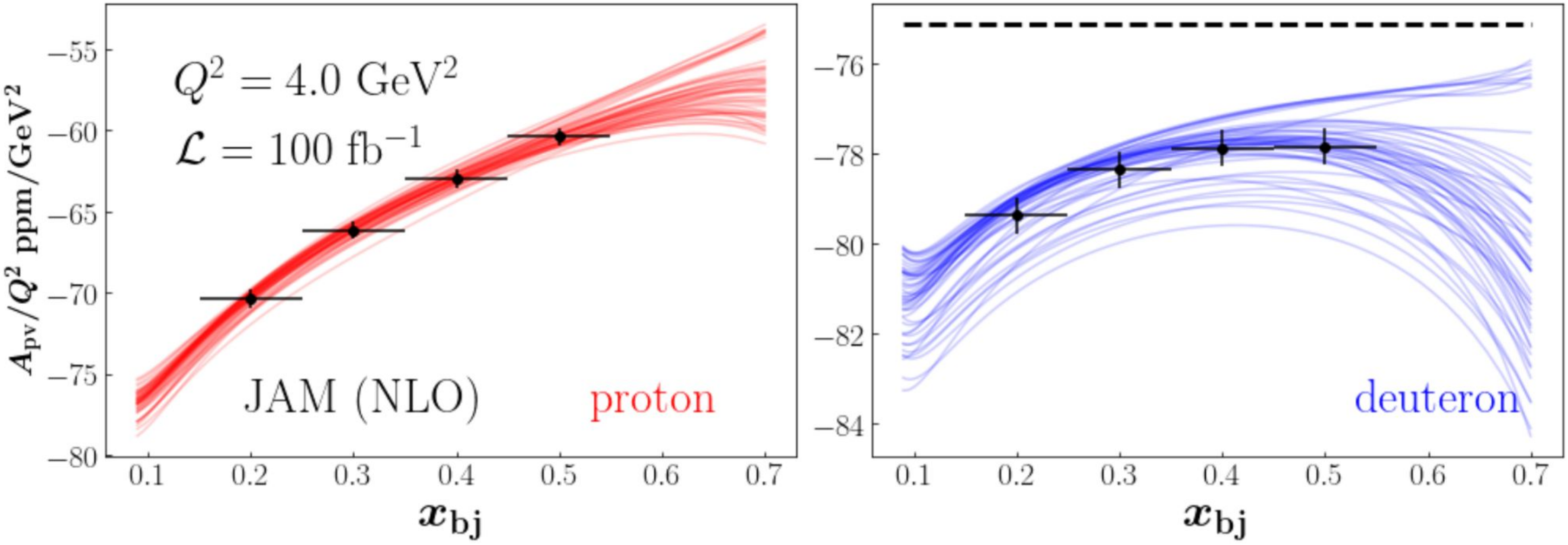
$$a_1 = 4s_w^2 - \frac{9}{5}$$

But not all the replicas goes to the Bj limit -> so s, sb is not zero

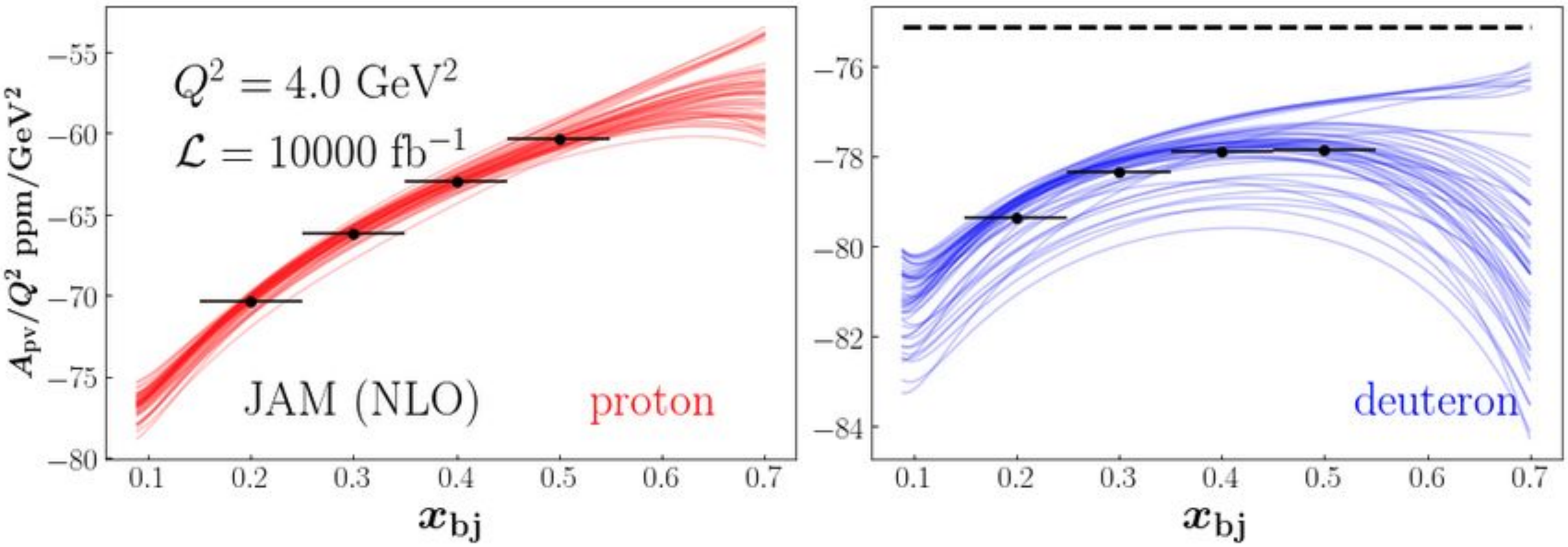


- Do re really know strangeness at large x?
- Apv has the potential to pin down the strangeness.

Quick simulation @ JLab 24 GeV

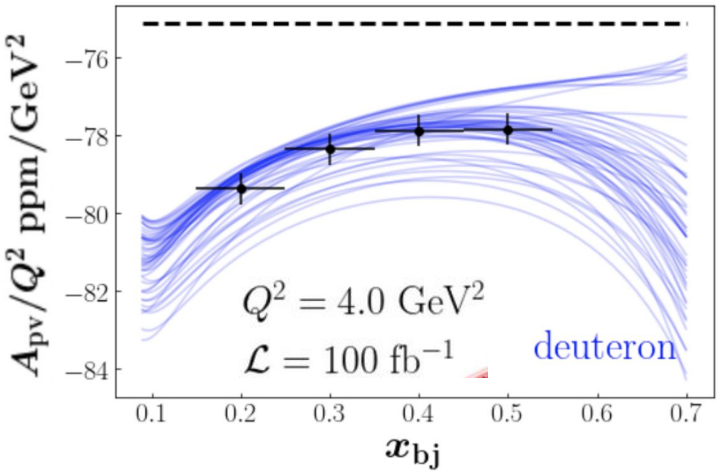


Quick simulation @ JLab 24 GeV (because Xiaochao said "add two more zeros")

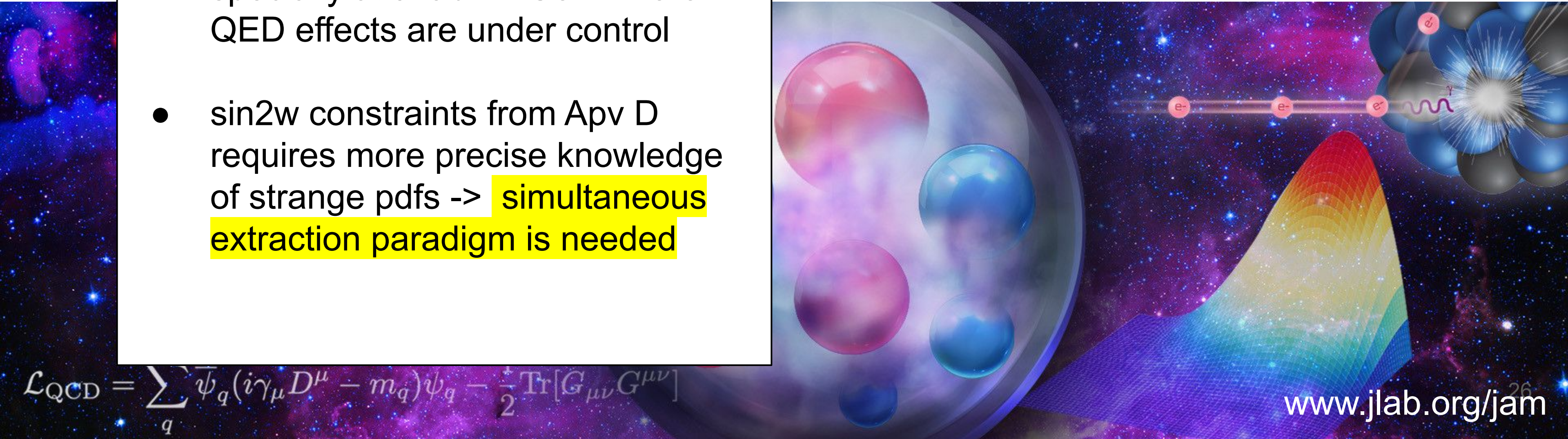


Is this happens, this will be remarkable.

Summary/Outlook



- Sea quark pdfs at large-x is still elusive, specially the strange sector
- Apv offers important constraints specially at JLab 24 GeV where QED effects are under control
- sin2w constraints from Apv D requires more precise knowledge of strange pdfs -> simultaneous extraction paradigm is needed



www.jlab.org/jam