Advances in the PDF description from QCD

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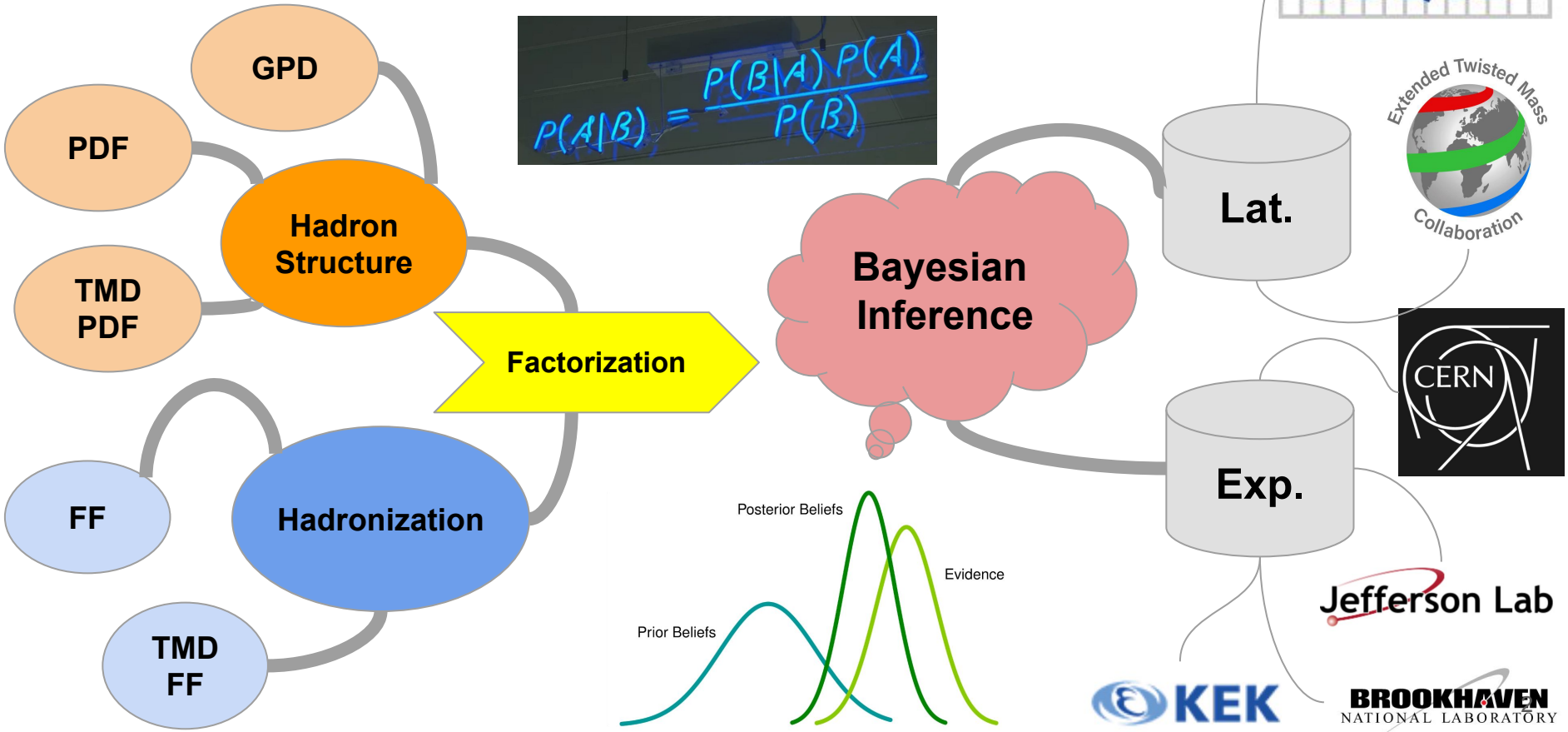
2020 Fall Meeting of the APS
Division of Nuclear Physics

Jefferson Lab

The QCD global analysis paradigm



The Bayesian inference

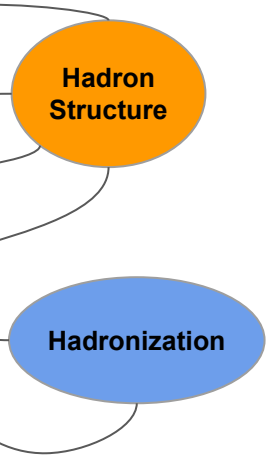
Experiments = theory + errors

$$d\sigma_{\rm DIS} = \sum_i H_i^{\rm DIS} \otimes f_i$$

$$d\sigma_{\rm DY} = \sum_{ij} H_{ij}^{\rm DY} \otimes f_i \otimes f_j$$

$$d\sigma_{\rm SIA} = \sum_i H_i^{\rm SIA} \otimes d_i$$

$$d\sigma_{\rm SIDIS} = \sum_{ij} H_{ij}^{\rm SIDIS} \otimes f_i \otimes d_j$$



$$f_i(\xi, \mu_0^2) = N_i \xi^{a_i} (1-\xi)^{b_i} (1 + \ldots)$$

$$d_i(\zeta, \mu_0^2) = N_i \zeta^{a_i} (1-\zeta)^{b_i} (1 + \ldots)$$

$$\mathbf{a} = (N_i, a_i, b_i, \ldots)$$

Posterior distribution

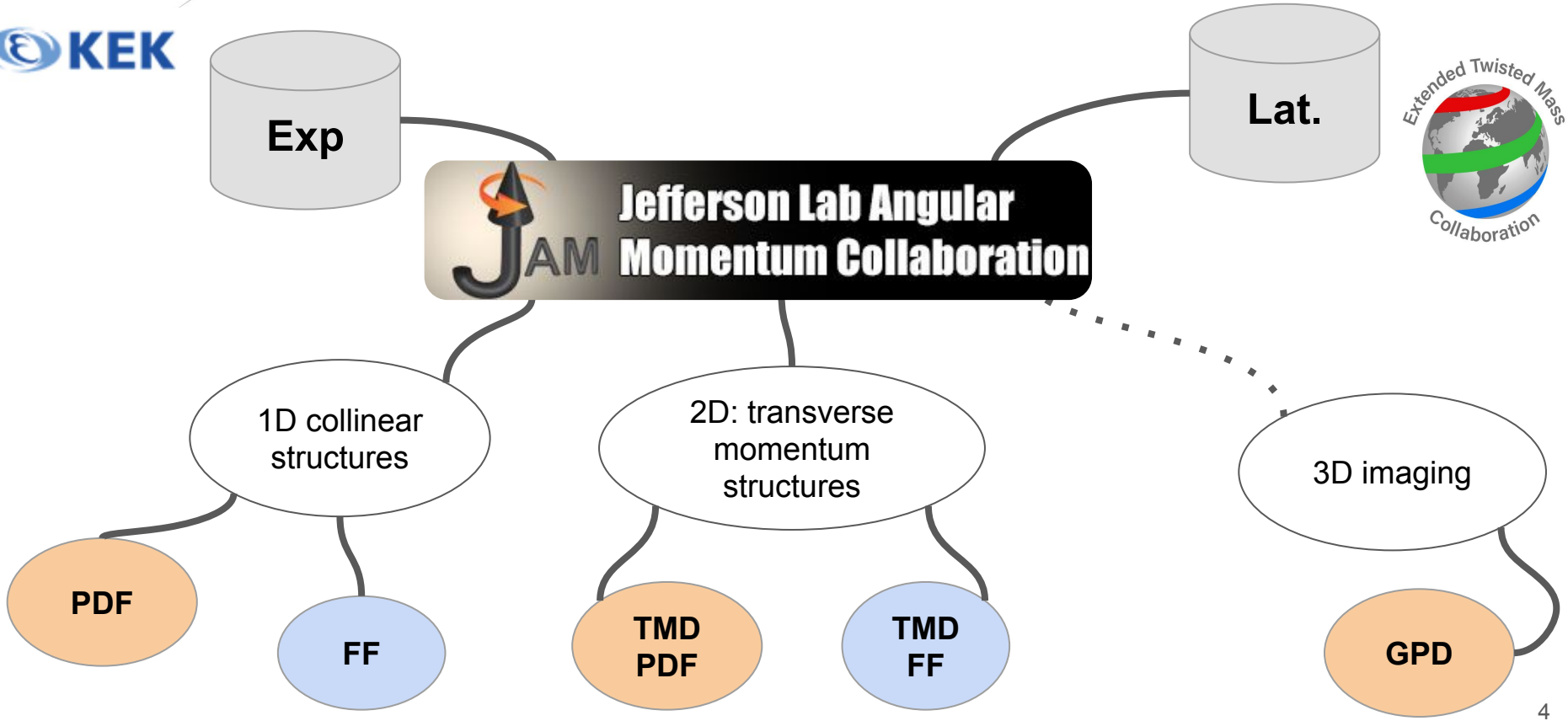
Prior distribution

$$\rho(\mathbf{a}|\text{data}) \sim \mathcal{L}(\mathbf{a}, \text{data})\pi(\mathbf{a})$$

Likelihood

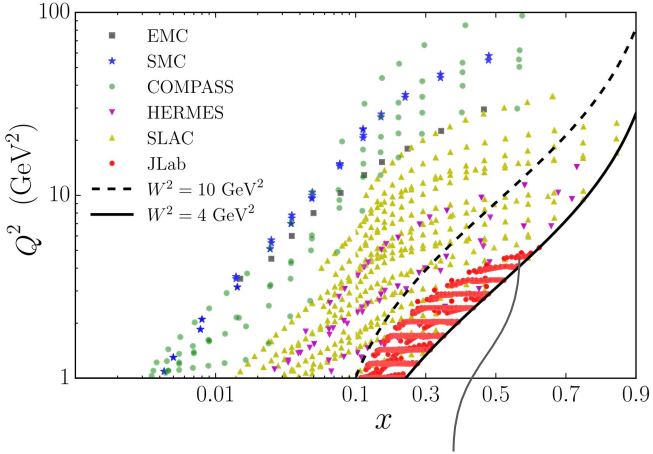
$$\mathrm{E}[f_i(\xi, \mu^2)] = \int \mathrm{d}^n\mathbf{a}\, \rho(\mathbf{a}|\text{data}) f_i(\xi, \mu^2; \mathbf{a})$$

$$\mathrm{V}[f_i(\xi, \mu^2)] = \int \mathrm{d}^n\mathbf{a}\, \rho(\mathbf{a}|\text{data}) \left[f_i(\xi, \mu^2; \mathbf{a}) - \mathrm{E}[f_i(\xi, \mu^2)]\right]^2$$


Exp
Lat.
Jefferson Lab Angular Momentum Collaboration
1D collinear structures
2D: transverse momentum structures
3D imaging
PDF
FF
TMD PDF
TMD FF
GPD

JAM'15 (1D spin-PDFs)

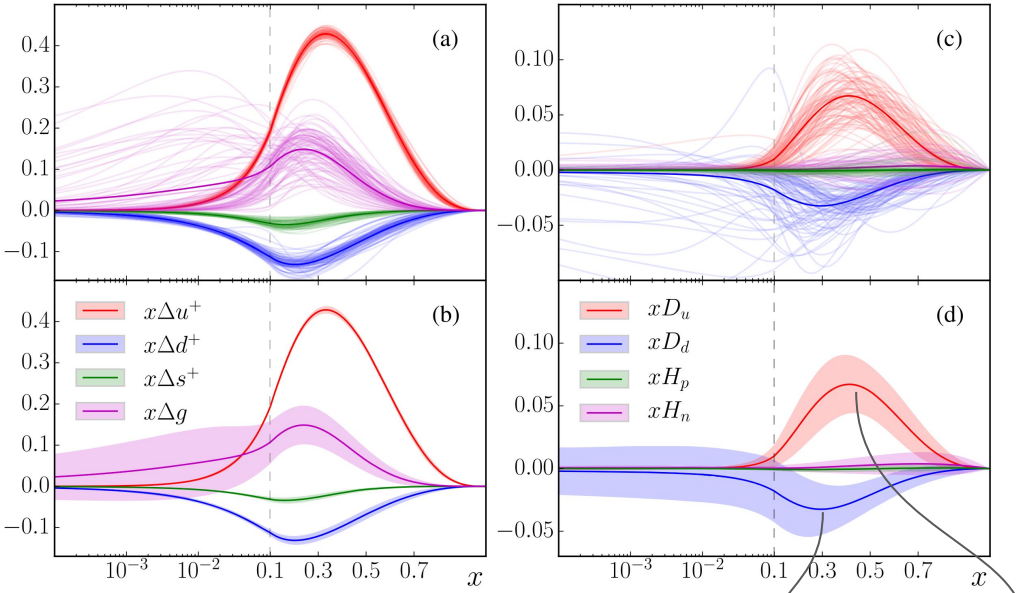
$$A_{\parallel} = \frac{\sigma^{\downarrow\Uparrow} - \sigma^{\uparrow\Uparrow}}{\sigma^{\downarrow\Uparrow} + \sigma^{\uparrow\Uparrow}} \qquad A_{\perp} = \frac{\sigma^{\downarrow\Rightarrow} - \sigma^{\uparrow\Rightarrow}}{\sigma^{\downarrow\Rightarrow} + \sigma^{\uparrow\Rightarrow}}$$



High-x data

Bayesian MC framework

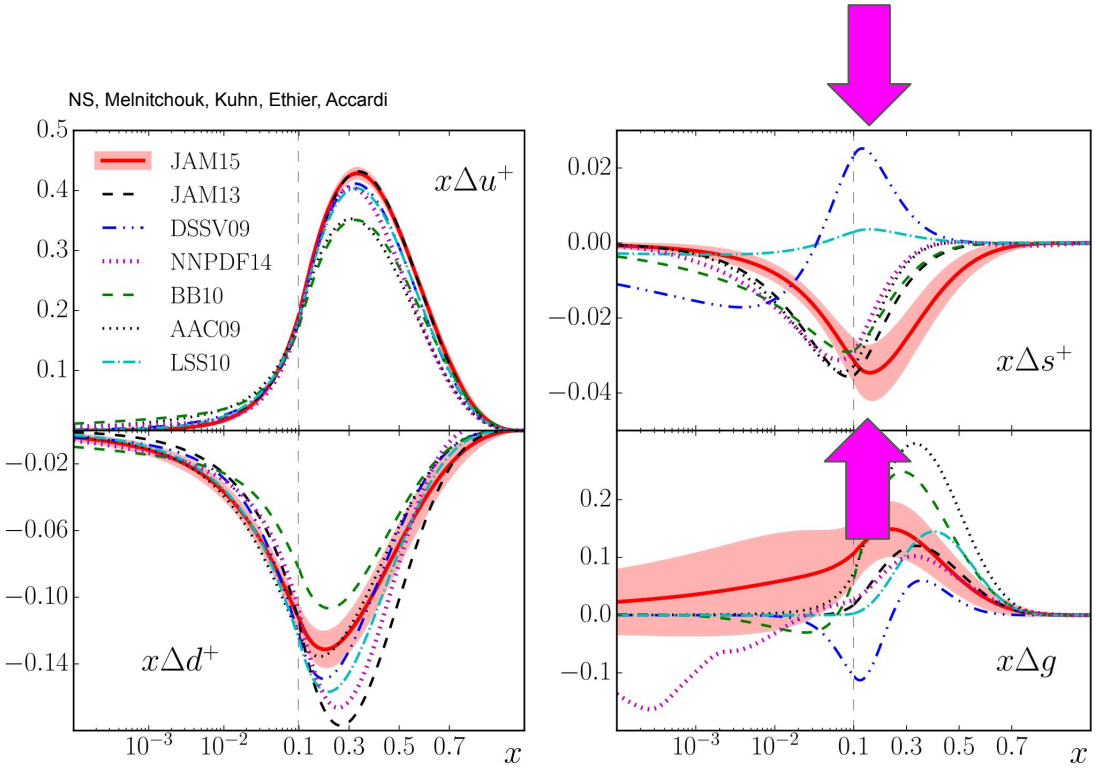
NS, Melnitchouk, Kuhn, Ethier, Accardi



Genuine twist 3 effects

JAM'15 (1D spin-PDFs)

NS, Melnitchouk, Kuhn, Ethier, Accardi



A Possible Resolution of the Strange Quark Polarization Puzzle ?

Elliot Leader, Alexander V. Sidorov, Dimiter B. Stamenov

The strange quark polarization puzzle, i.e. the contradiction between the negative polarized strange quark density obtained from analyses of inclusive DIS data and the positive values obtained from combined analyses of inclusive and semi-inclusive SIDIS data using de Florian et. al. (DSS) fragmentation functions, is discussed. To this end the results of a new combined NLO QCD analysis of the polarized inclusive and semi-inclusive DIS data, using the Hirai et. al. (HKNS) fragmentation functions, are presented. It is demonstrated that the polarized strange quark density is very sensitive to the kaon fragmentation functions, and if the set of HKNS fragmentation functions is used, the polarized strange quark density obtained from the combined analysis turns out to be negative and well consistent with values obtained from the pure DIS analyses.

"...It is demonstrated that the polarized strange quark density is very sensitive to Kaon FF."

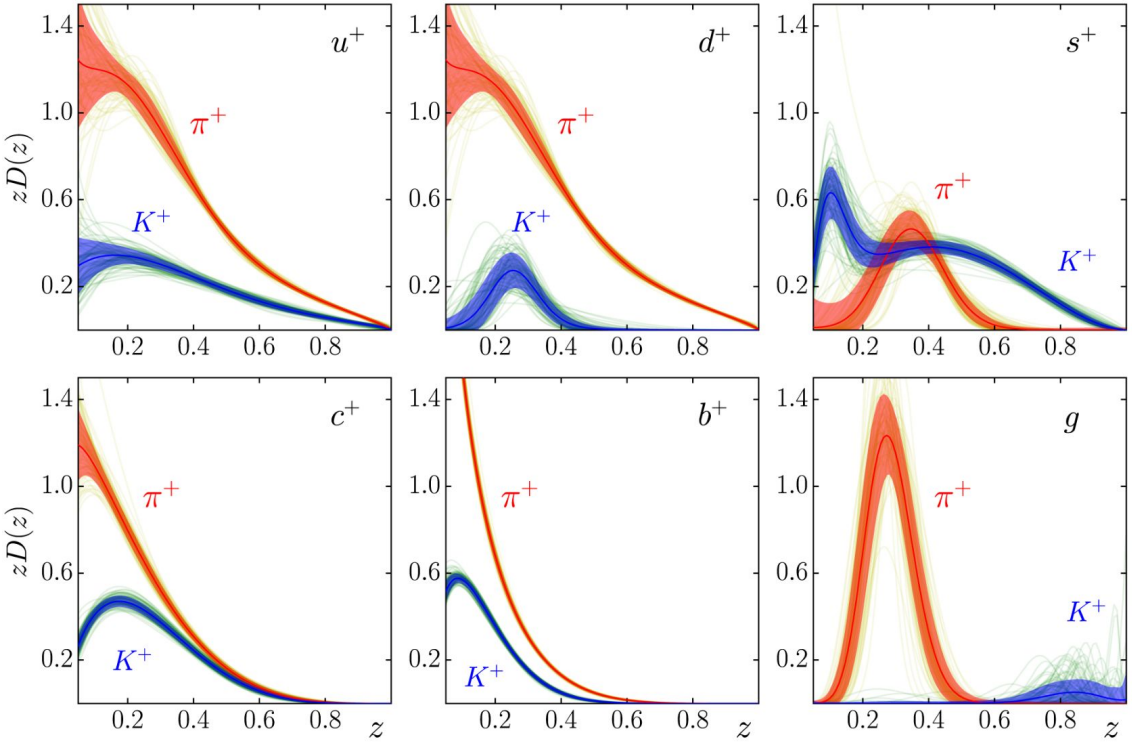
SU(3) constraints:

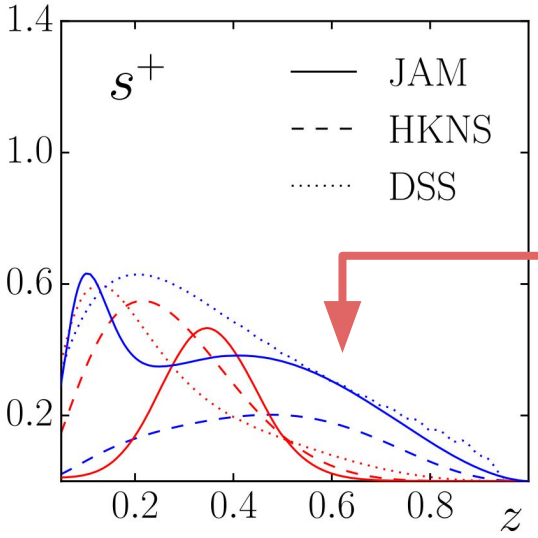
$$\Delta u^+(1,Q^2) + \Delta d^+(1,Q^2) - 2\Delta s^+(1,Q^2) = a_8,$$

Role of SIDIS and SIA ?

JAM'16 (1D FFs)

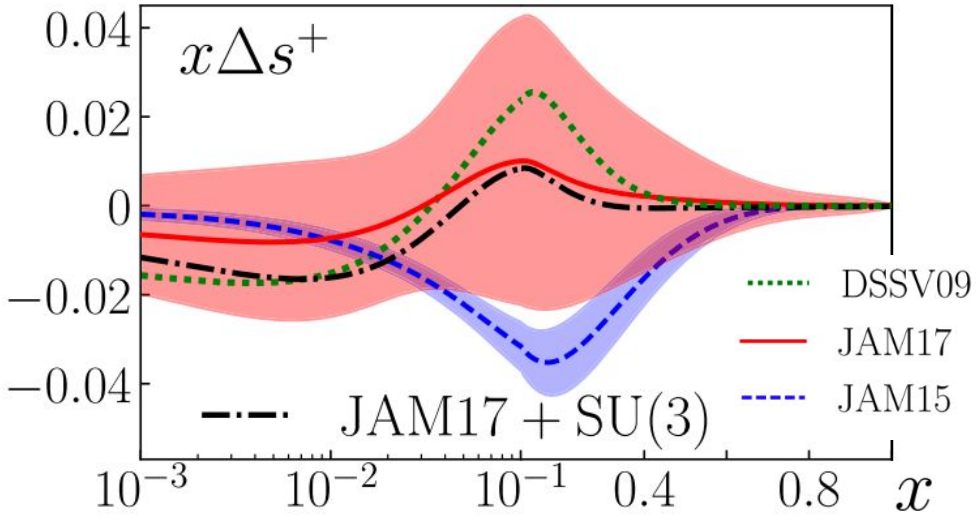
NS, Ethier, Melnitchouk, Hirai, Kumano

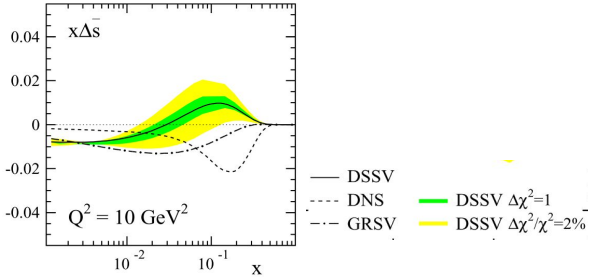




FF kaon:
JAM closer to DSS at large z

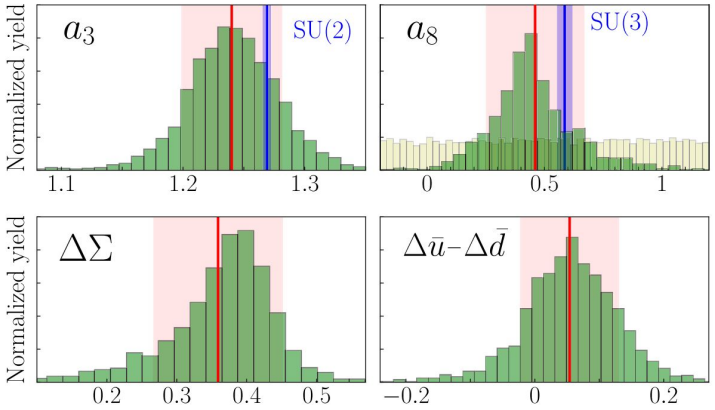
JAM'17 (1D simultaneous extraction of spin PDFs and FFs)





Florian, Sassot, Stratmann, Vogelsang

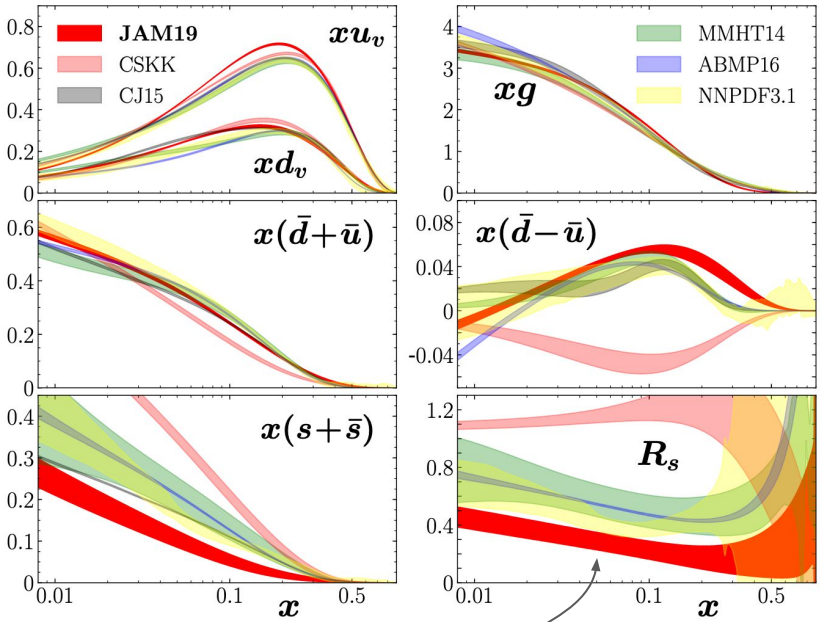
Ethier, NS, Melnitchouk



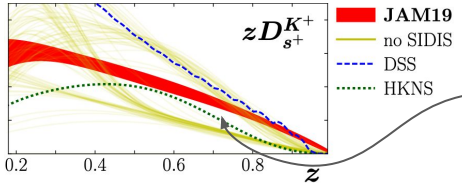
- Use of pol. DIS, SIDIS and SIA
- No SU(2) nor SU(3) constraints
- Empirical evidence of g_3 ~ g_A 2%
- **No strange puzzle - need more data**

JAM'19 (1D simul. extraction of spin-averaged PDFs and FFs)

NS, Andres, Melnitchouk

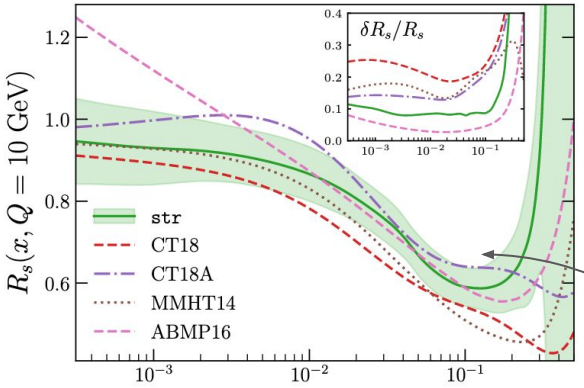


SIDIS (kaon) suppresses strange PDF



SIA (kaon) prefers large strange -> Kaon FF

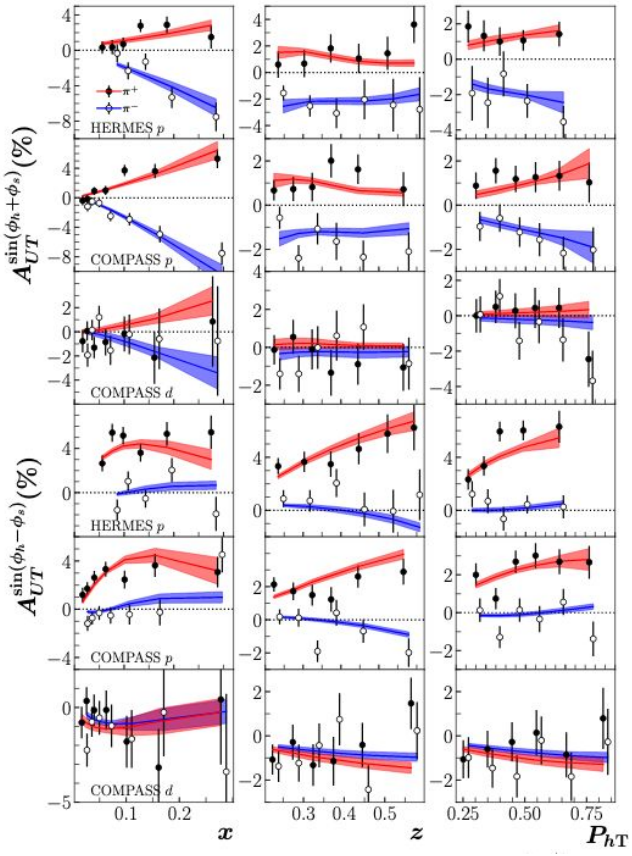
Faura, Iranipour, Nocera, Rojo, Ubiali

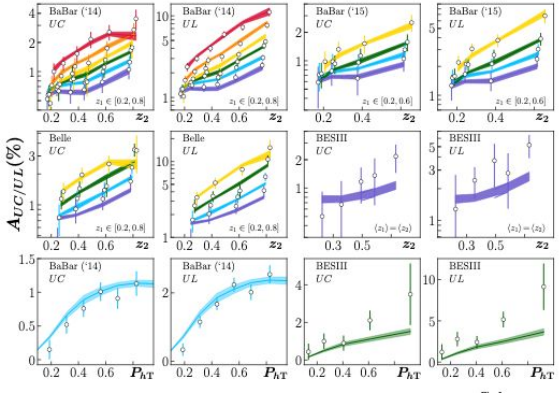


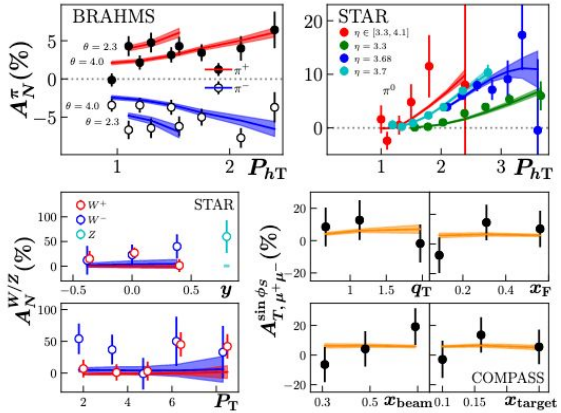
Strange suppression disfavored by collider W+c data

JAM'20 (3D zoo of correlation functions)

Cammarota, Gamberg, Kang, Miller, Pitonyak, Prokudin, Rogers, NS

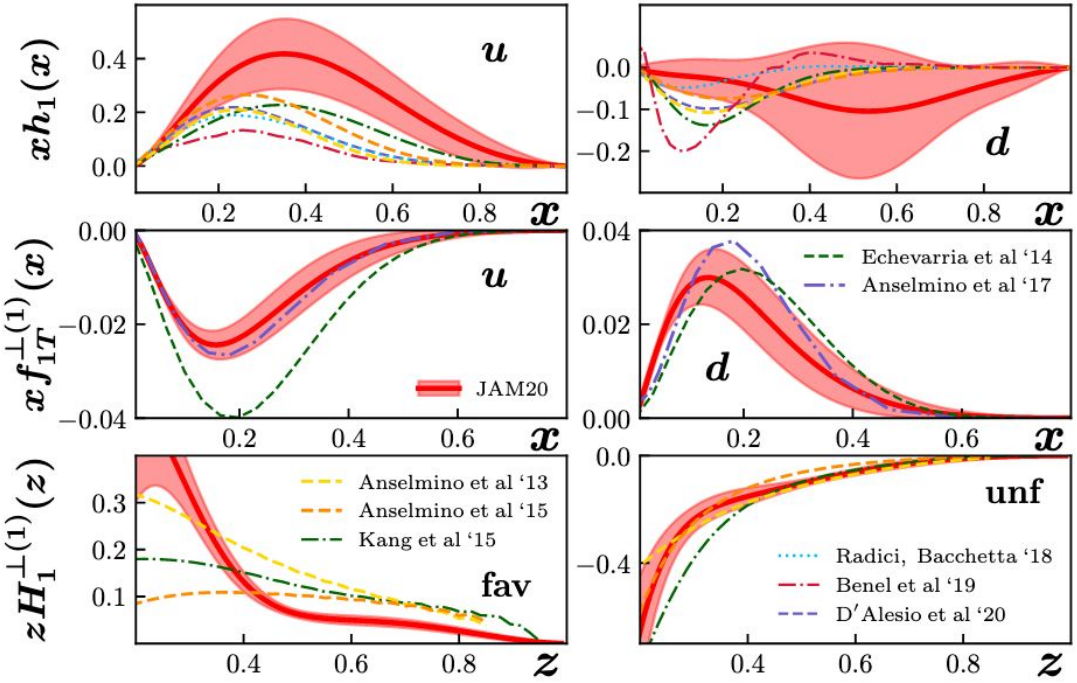




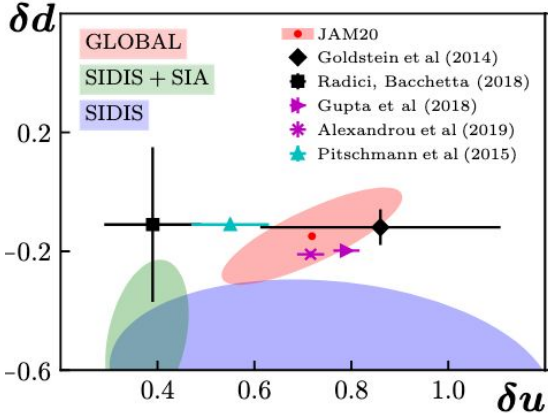


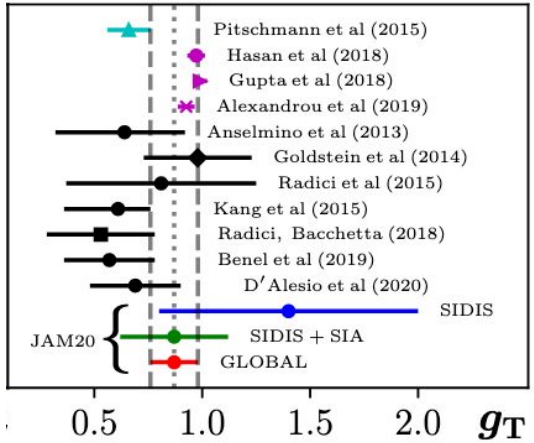
Observable	Reactions
$A_{\rm SIDIS}^{\rm Siv}$	$e+(p,d)^{\uparrow}\to e+(\pi^+,\pi^-,\pi^0)+X$
$A_{\rm SIDIS}^{\rm Col}$	$e+(p,d)^{\uparrow}\to e+(\pi^+,\pi^-,\pi^0)+X$
$A_{\rm SIA}^{\rm Col}$	$e^++e^-\to\pi^+\pi^-(UC,UL)+X$
$A_{\rm DY}^{\rm Siv}$	$\pi^-+p^{\uparrow}\to\mu^+\mu^-+X$
$A_{\rm DY}^{\rm Siv}$	$p^{\uparrow}+p\to(W^+,W^-,Z)+X$
A_N^h	$p^{\uparrow}+p\to(\pi^+,\pi^-,\pi^0)+X$

JAM'20 (3D zoo of correlation functions)



Cammarota, Gamberg, Kang, Miller, Pitonyak, Prokudin, Rogers, NS

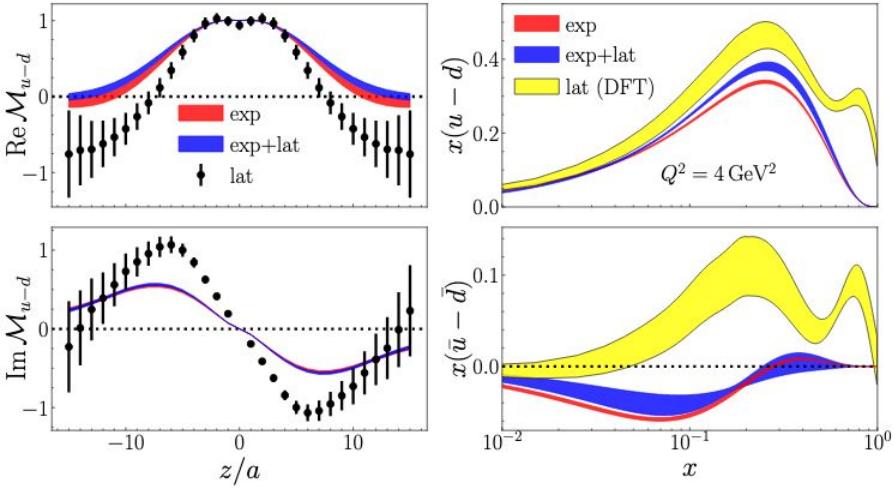




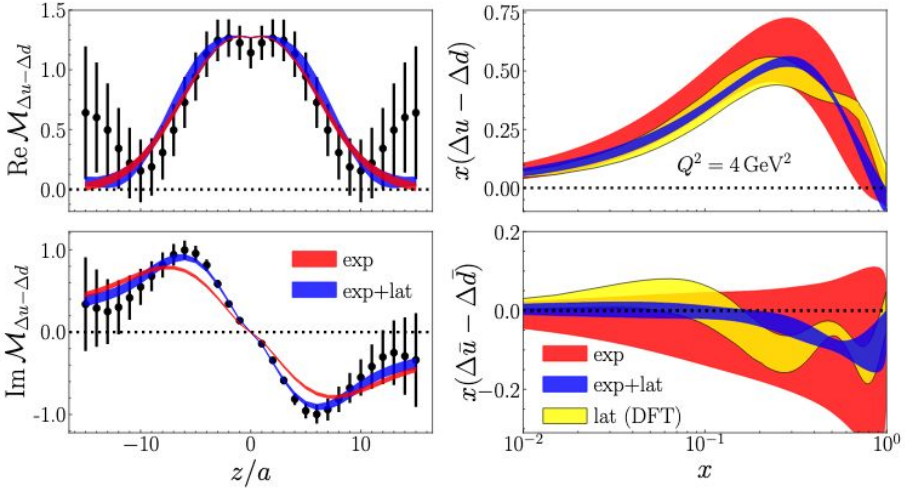
JAM'20 (1D experiment + lattice QCD: quasi-PDFs)

Bringewatt, NS, Melnitchouk, Qiu, Steffens, Constantinou

Spin-averaged PDFs



Spin-dependent PDFs



$$\mathcal{M}_q(z,\mu) = \int_{-\infty}^{\infty} dx\, e^{-ixP_3 z} \int_{-1}^{1} \frac{d\xi}{|\xi|}\, C_q\!\left(\frac{x}{\xi}, \frac{\mu}{\xi P_3}\right) f_q(\xi,\mu)$$

$$\mathcal{M}_{\Delta q}(z,\mu) = \int_{-\infty}^{\infty} dx\, e^{-ixP_3 z} \int_{-1}^{1} \frac{d\xi}{|\xi|}\, C_{\Delta q}\!\left(\frac{x}{\xi}, \frac{\mu}{\xi P_3}\right) \Delta f_q(\xi,\mu)$$

Summary and Outlook

A new paradigm

- Simultaneous extraction of all hadronic structures
- MC methods for reliable uncertainty quantification
- Inclusion of lattice data as Bayesian priors

Near future

- Inclusion of all RHIC spin data
- Combined analysis of PDFs and TMDs
- Inclusion of JLab 12 GeV data

JAM Collaboration

Staff / Faculty

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