

Simultaneous Monte Carlo analysis of parton densities and fragmentation functions

Eric Moffat

EIC UG Early Career Workshop
7-30-2021

Collaborators: Wally Melnitchouk, Ted Rogers, Nobuo Sato

Phys.Rev.D 104 (2021) 1, 016015



Introduction

- Significant tension between large transverse momentum data and Fixed Order (FO) predictions using existing collinear Parton Distribution Functions (PDFs) and Fragmentation Functions (FFs)
- Resolving this tension is crucial for the study of Transverse Momentum Dependent (TMD) PDFs and FFs and Generalized PDFs (GPDs).
- To facilitate exploring the reasons for this tension in SIDIS, performed a new fit using Jefferson Lab Angular Momentum Collaboration (JAM) methodology:
 - Multi-Step Monte Carlo fit utilizing Bayesian Inference
 - Simultaneously fit PDFs and charged pion, kaon, and unidentified hadron FFs.
 - First such fit involving charged hadrons

JAM fit

- Simultaneously fit PDFs and charged pion, kaon, and unidentified hadron FFs
 - Functional form:

$$T(x; \mathbf{a}) = \mathcal{M} \frac{x^\alpha (1-x)^\beta (1 + \gamma\sqrt{x} + \delta x)}{\int_0^1 dx x^{\alpha+1} (1-x)^\beta (1 + \gamma\sqrt{x} + \delta x)}$$

- Unidentified charged hadron fragmentation function:

$$D_i^{h^+} = D_i^{\pi^+} + D_i^{K^+} + D_i^{\text{res}^+}$$

JAM fit

- Multi-Step Monte Carlo fit utilizing Bayesian Inference:

$$\mathcal{P}(\mathbf{a}|\text{data}) \sim \mathcal{L}(\mathbf{a}, \text{data}) \pi(\mathbf{a}) \quad \mathcal{L}(\mathbf{a}, \text{data}) = \exp \left(-\frac{1}{2} \chi^2(\mathbf{a}, \text{data}) \right)$$

$$\chi^2(\mathbf{a}) = \sum_{i,e} \left(\frac{d_{i,e} - \sum_k r_e^k \beta_{i,e}^k - T_{i,e}(\mathbf{a})/N_e}{\alpha_{i,e}} \right)^2 + \sum_k (r_e^k)^2 + \left(\frac{1 - N_e}{\delta N_e} \right)^2$$

$$\mathbb{E}[\mathcal{O}] = \int d^d \mathbf{a} \mathcal{P}(\mathbf{a}|\text{data}) \mathcal{O}(\mathbf{a}),$$

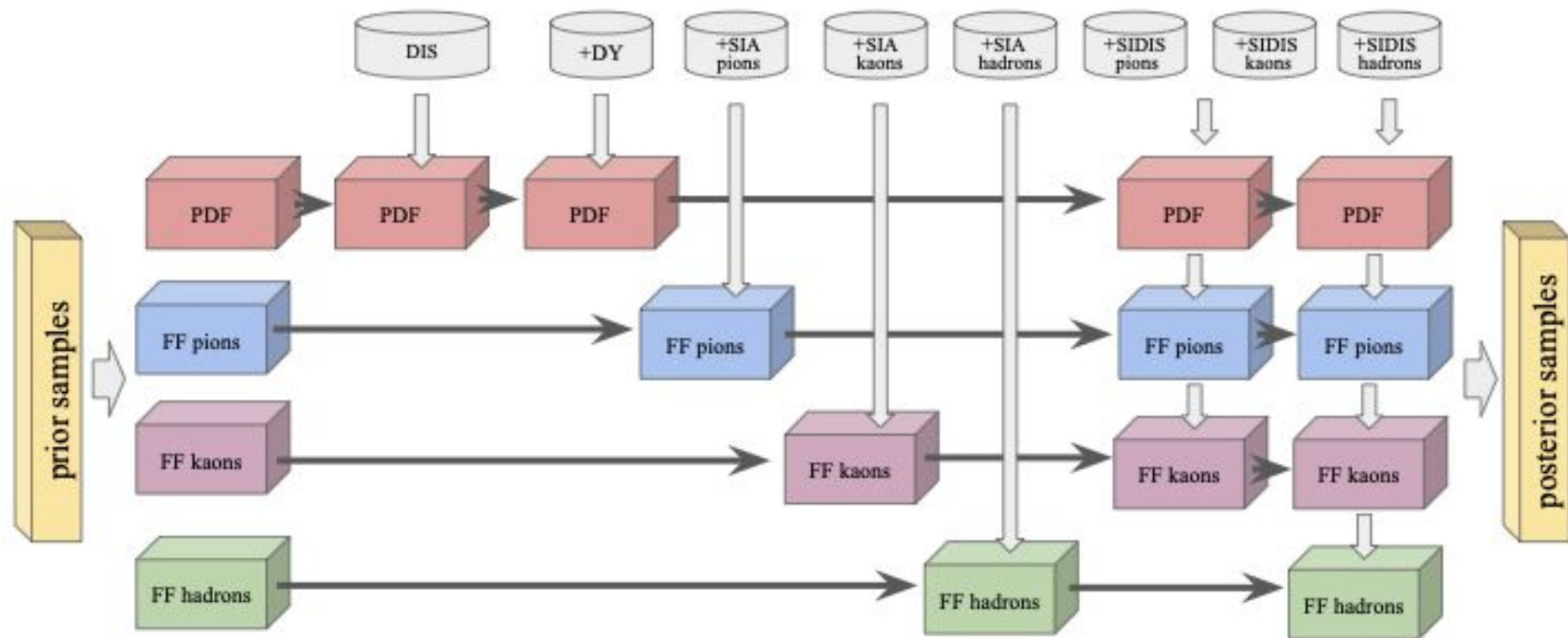
$$\mathbb{E}[\mathcal{O}] = \frac{1}{n} \sum_{k=1}^n \mathcal{O}(\mathbf{a}_k),$$

$$\mathbb{V}[\mathcal{O}] = \int d^d \mathbf{a} \mathcal{P}(\mathbf{a}|\text{data}) (\mathcal{O}(\mathbf{a}) - \mathbb{E}[\mathcal{O}])^2$$

$$\mathbb{V}[\mathcal{O}] = \frac{1}{n} \sum_{k=1}^n (\mathcal{O}(\mathbf{a}_k) - \mathbb{E}[\mathcal{O}])^2$$

- Use least squares to obtain maximum likelihood (minimum chi squared) for each replica.

Multi-step process



Data sets

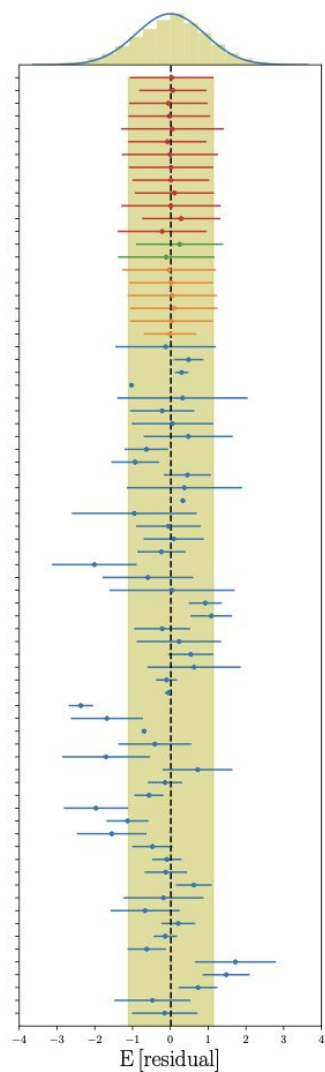
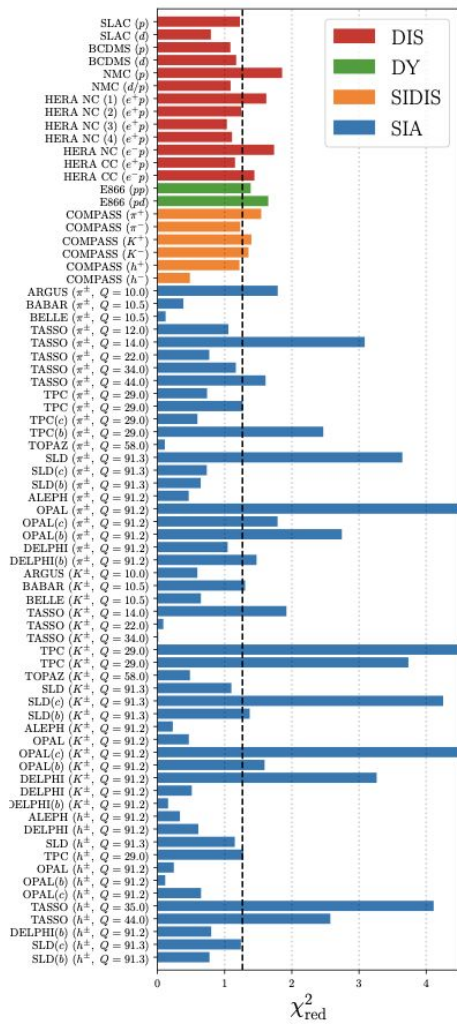
- Data Sets:
 - Inclusive Deep Inelastic Scattering (DIS)
 - BCDMS, NMC, SLAC, HERA
 - Semi-Inclusive DIS (SIDIS)
 - COMPASS
 - Single-Inclusive e^+/e^- Annihilation (SIA)
 - TASSO, TPC, TOPAZ, BELLE, BABAR, ARGUS, DELPHI, ALEPH, OPAL, SLD
 - Drell-Yan Scattering (DY)
 - E866

χ_{red}^2

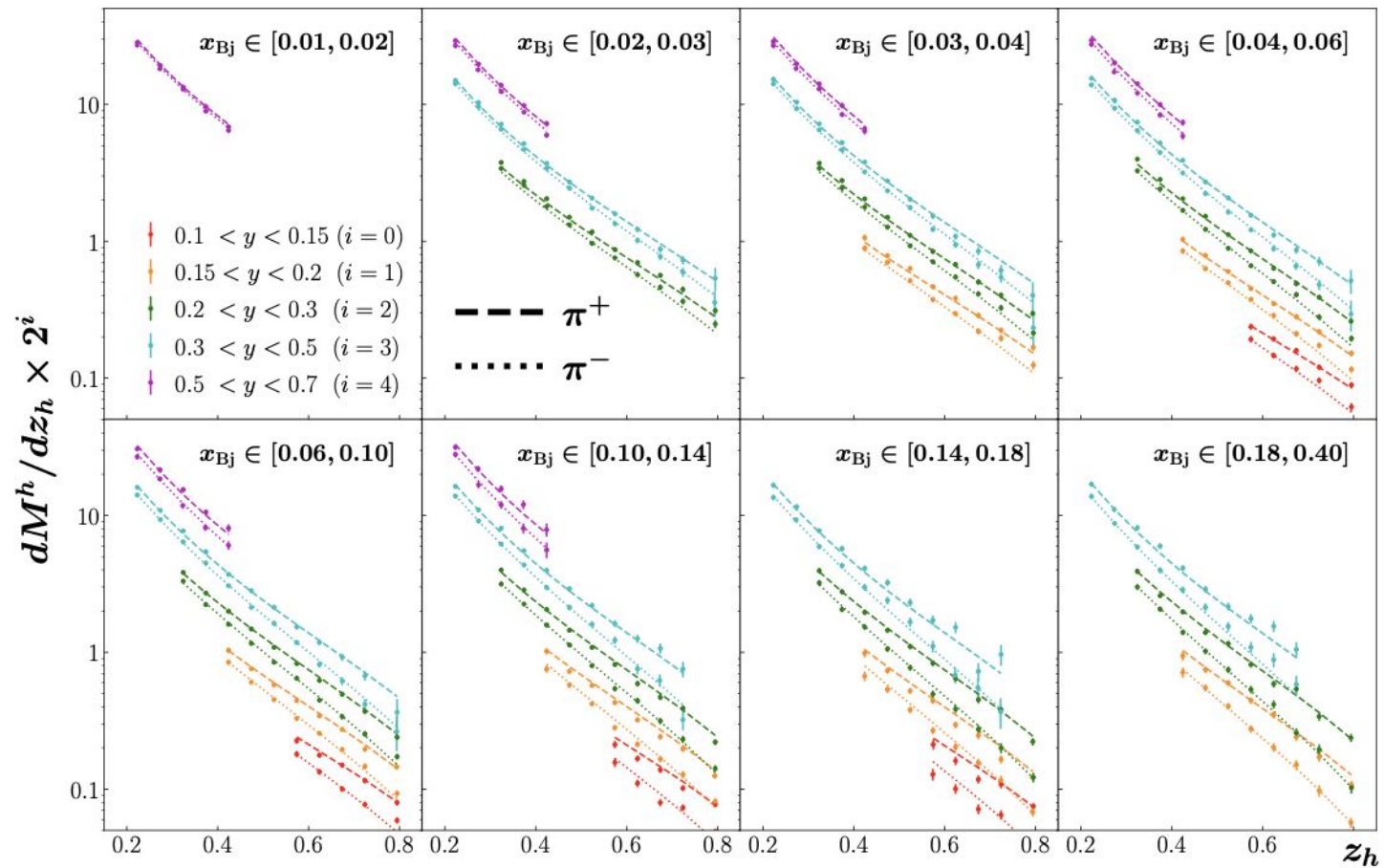
reaction	χ_{red}^2	N_{dat}
DIS	1.29	2680
DY	1.52	250
SIDIS π^\pm	1.39	498
K^\pm	1.38	494
h^\pm	0.85	498
SIA π^\pm	1.09	231
K^\pm	1.37	213
h^\pm	1.15	120
total	1.26	4984

$$\chi_{\text{red}}^2 = \frac{1}{N} \sum_{i,e} \frac{1}{\alpha_{i,e}^2} \left(d_{i,e} - \text{E} \left[\sum_k r_e^k \beta_{i,e}^k + T_{i,e}/N_e \right] \right)^2$$

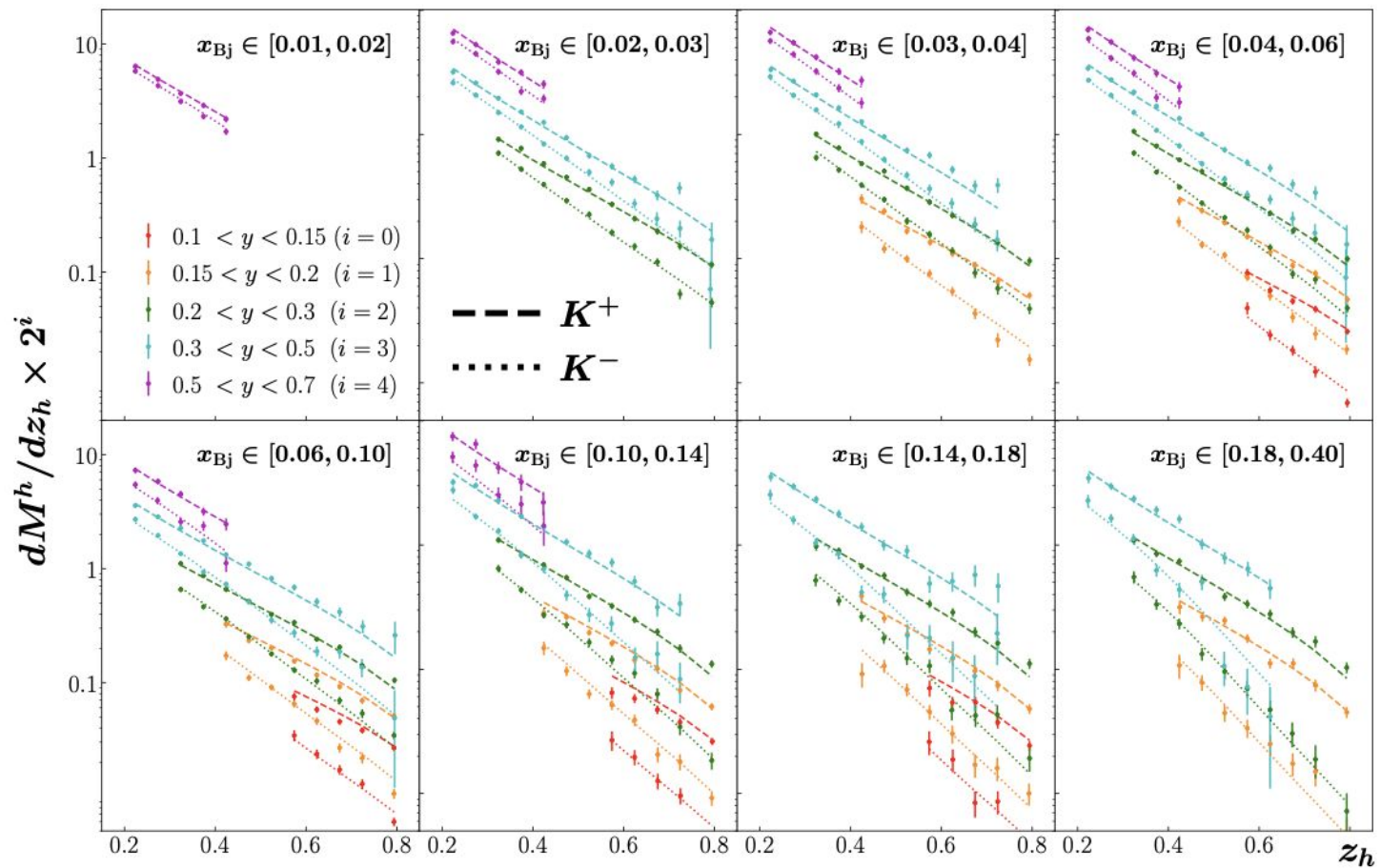
$$\text{residual}(e, i) = \frac{1}{\alpha_{i,e}} \left(d_{i,e} - \text{E} \left[\sum_k r_e^k \beta_{i,e}^k + T_{i,e}/N_e \right] \right)$$



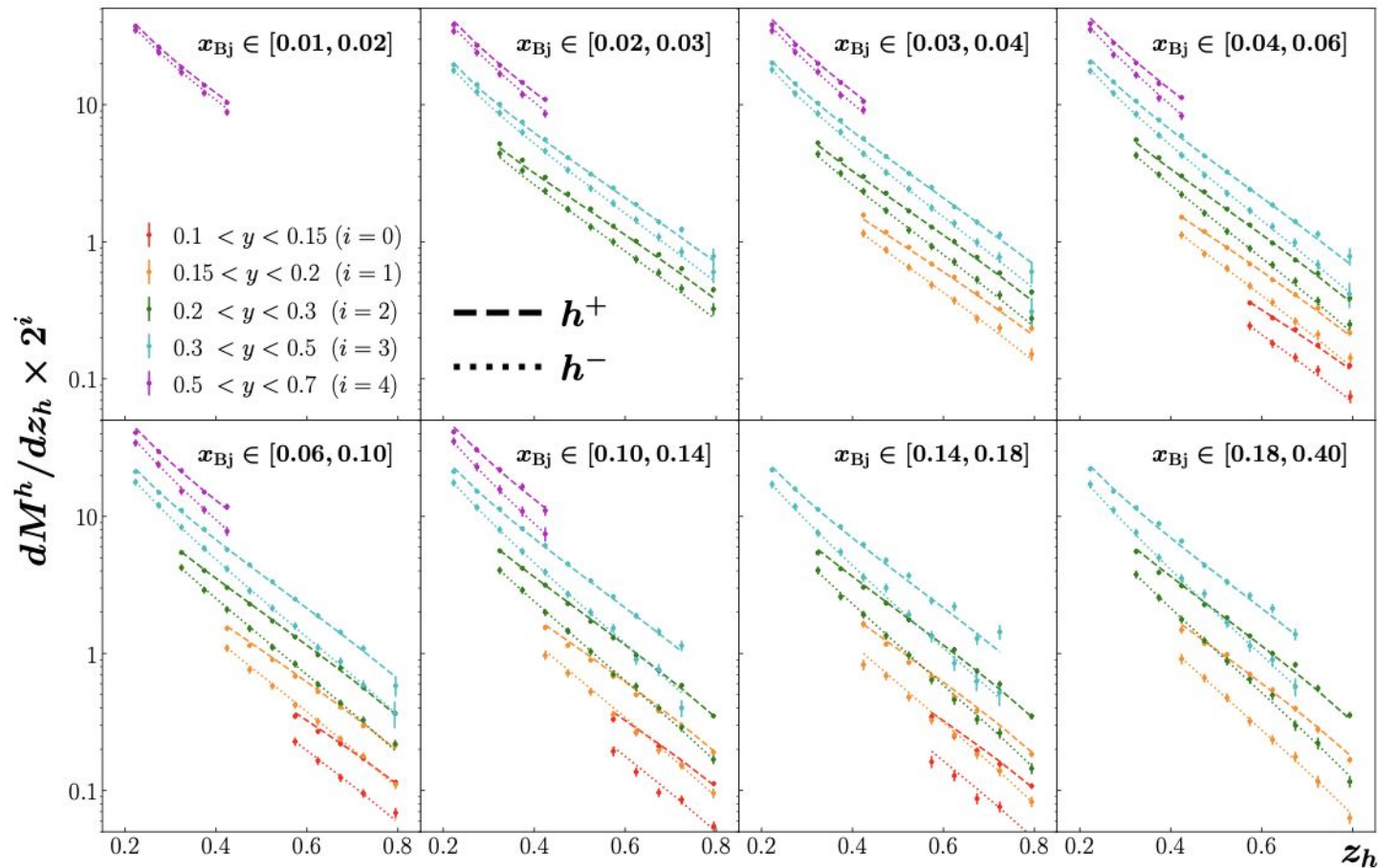
SIDIS Data and theory comparison: pions



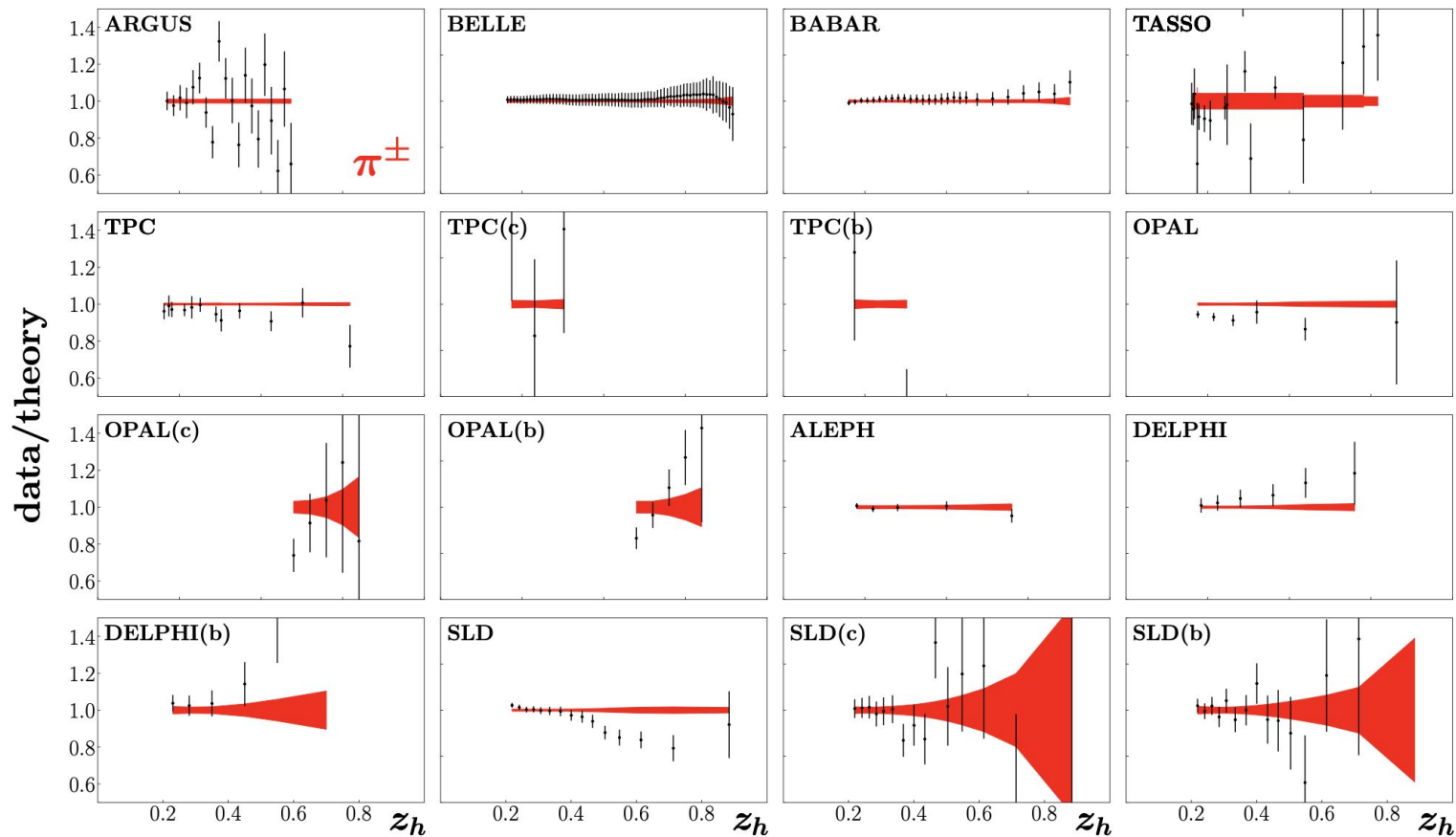
SIDIS Data and theory comparison: kaons



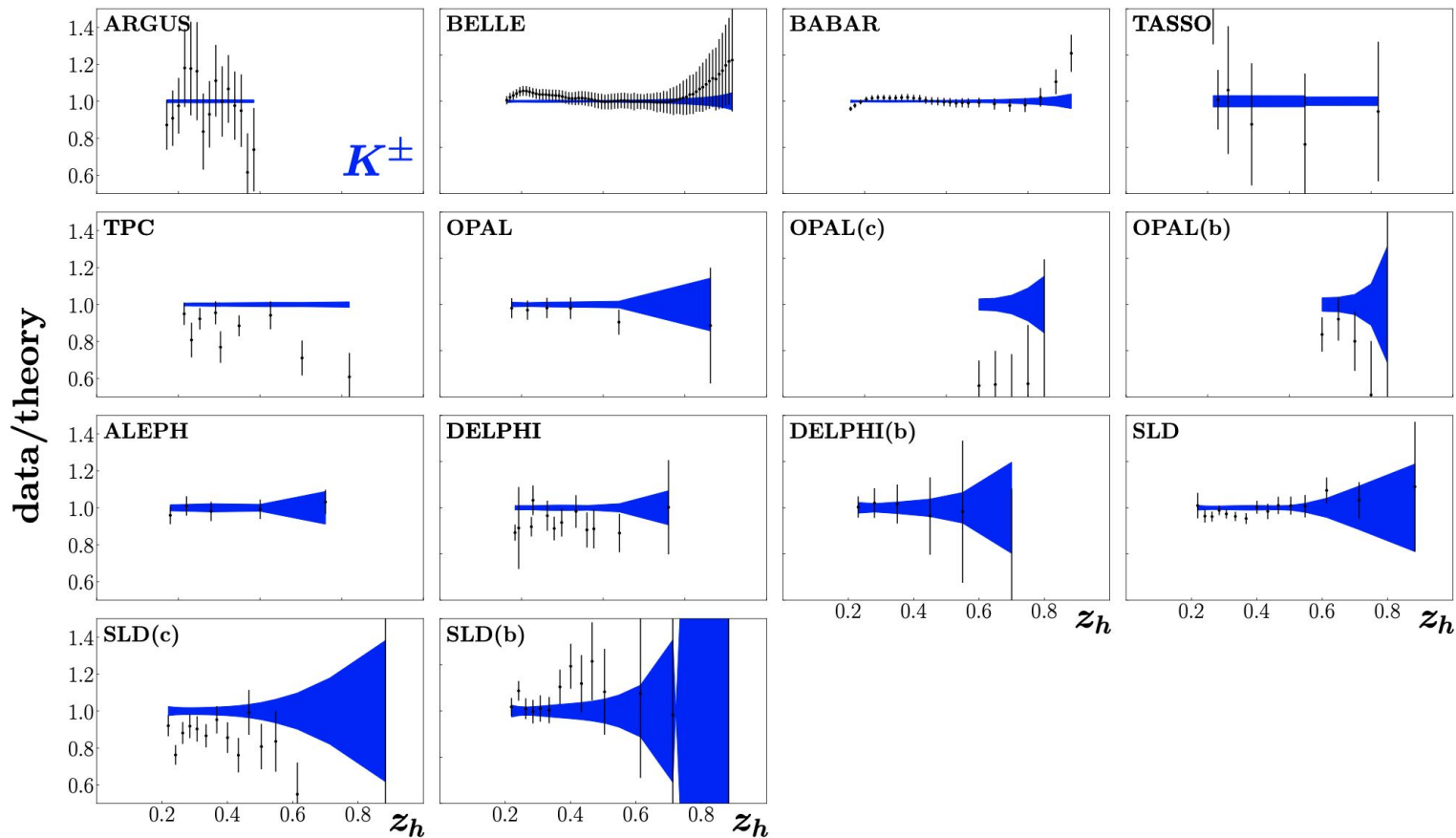
SIDIS Data and theory comparison: hadrons



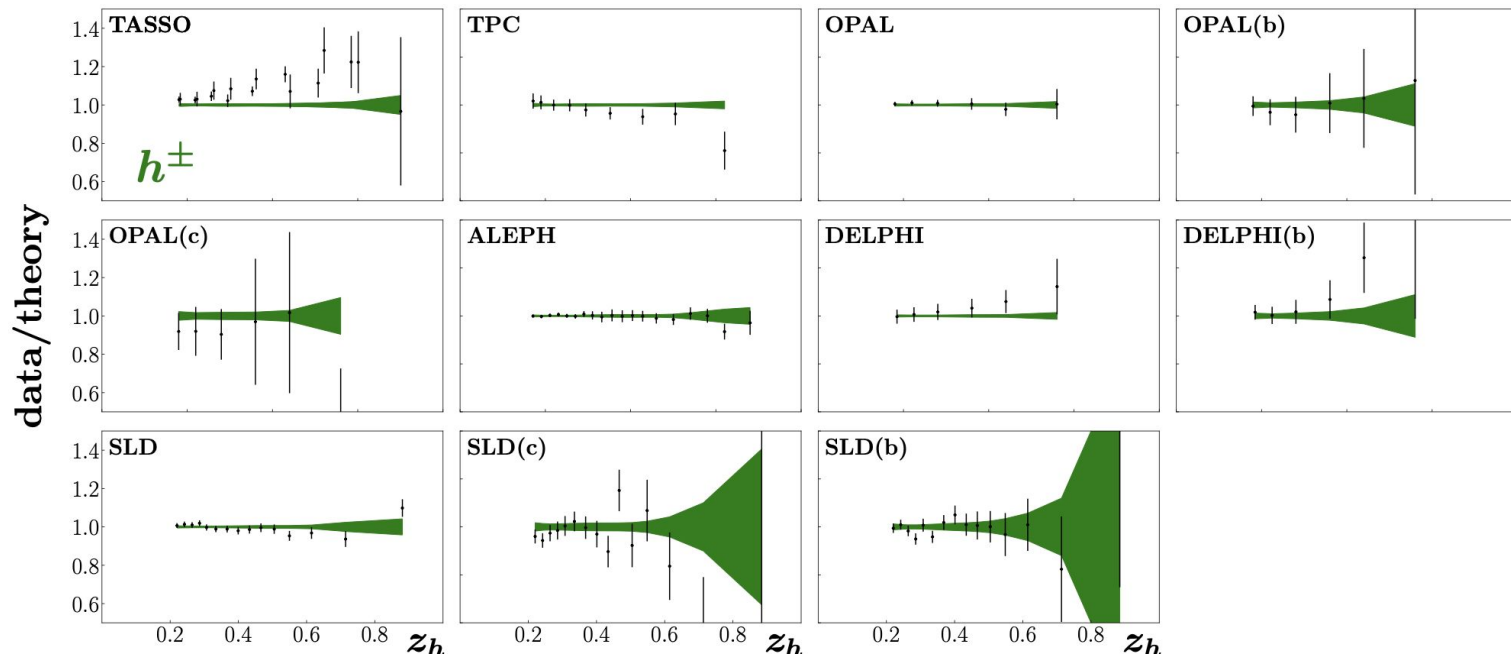
SIA Data over theory comparison: pions



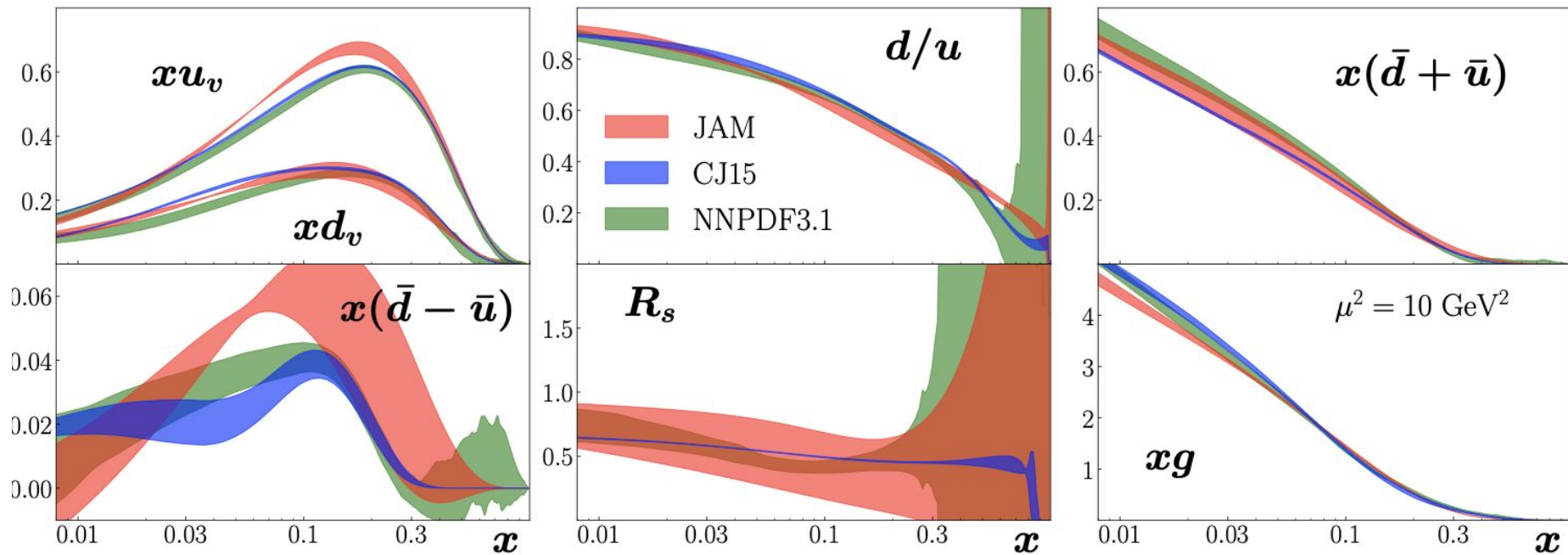
SIA Data over theory comparison: kaons



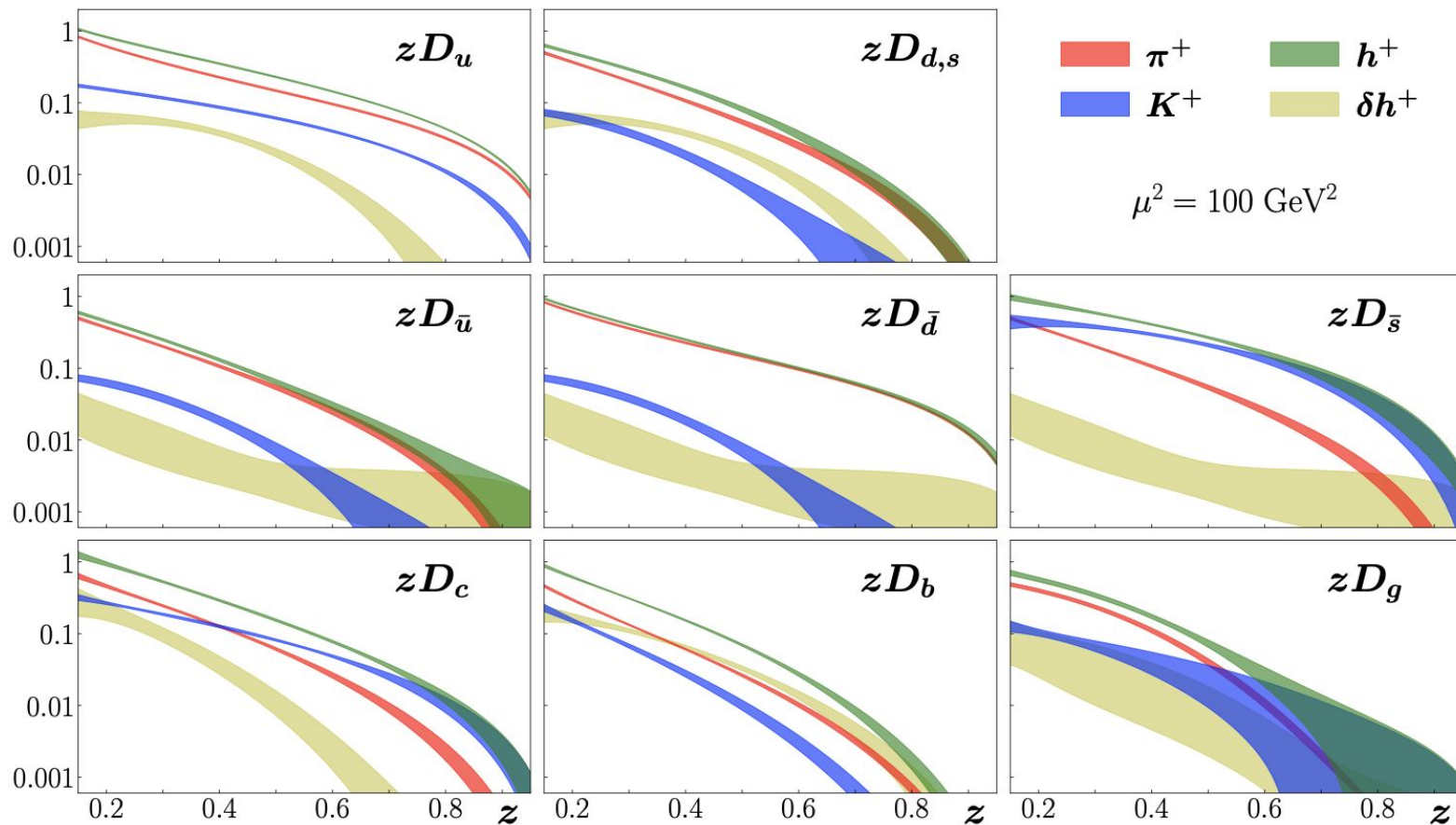
SIA Data over theory comparison: hadrons



PDFs

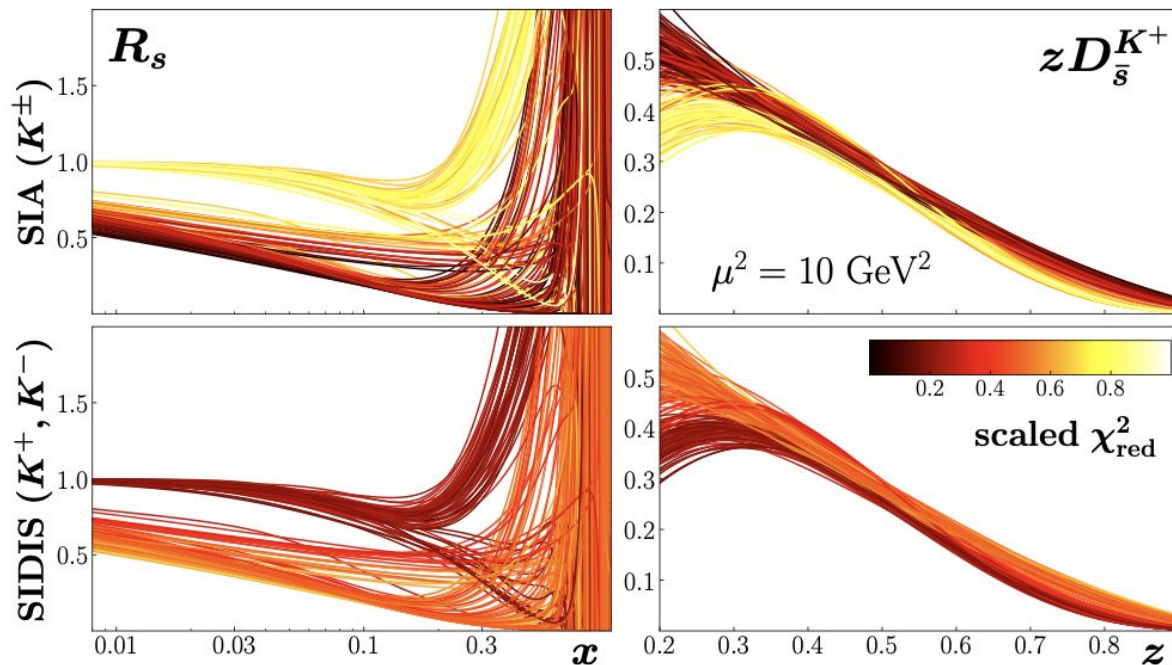


FFs



Strange PDF suppression

- Best fits to kaon SIA data favor smaller strange PDFs
- Consistent with JAM19 findings



Conclusions

- Successfully performed simultaneous global extraction of PDFs and pion, kaon, and hadron FFs.
- Observed similar strange PDF suppression as was observed in JAM19.
- Compare FO predictions using these results with COMPASS transverse momentum dependent data. Explore effect of including this data in the fit.