

Quark and Gluon Distributions in Mesons from Quarkonium Production

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Perceiving the Emergence
of Hadron Mass through
AMBER@CERN

30 November to 4 December 2020
CERN, Geneva - Switzerland



Scope of this talk

This talk is based on two recent papers on meson PDFs:

“A New Extraction of Pion Parton Distributions in the Statistical Model”

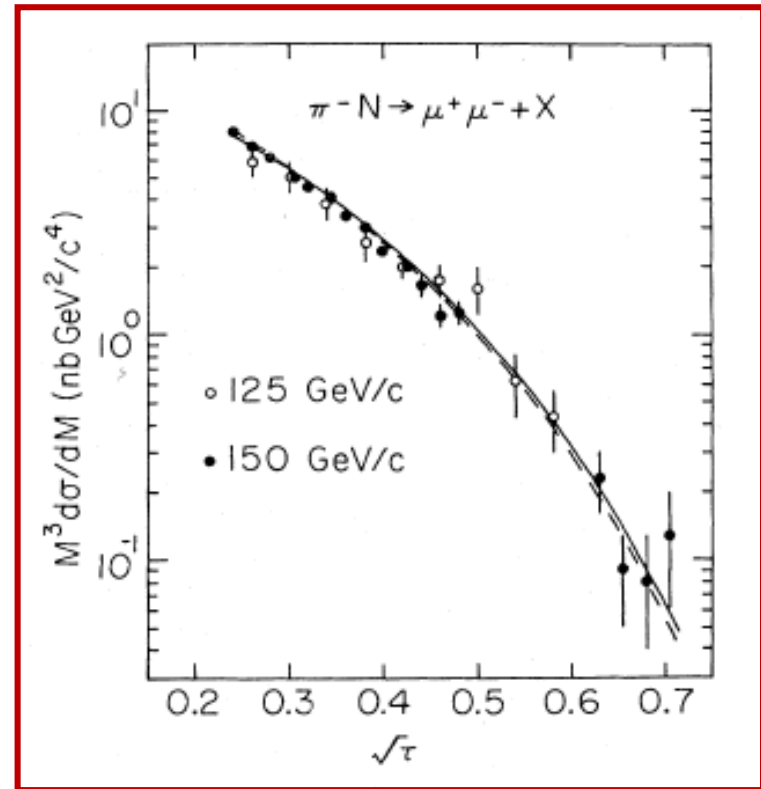
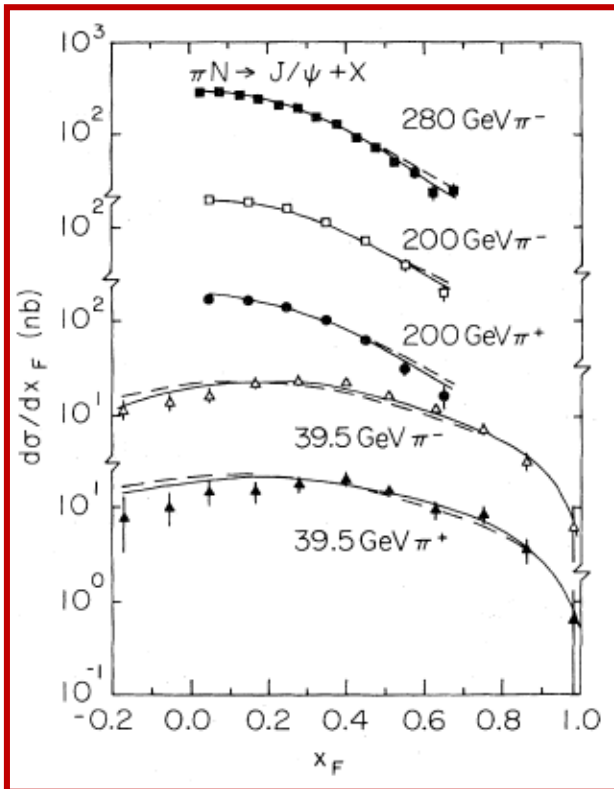
Claude Bourrely, Franco Buccella, Jen-Chieh Peng
([arXiv:2008.05703](https://arxiv.org/abs/2008.05703))

“Constraining Gluon Density of Pions at Large x by Pion-induced J/ψ Production”

Wen-Chen Chang, Jen-Chieh Peng, Stephane Platchkov,
Takahiro Sawada
([PRD 102 \(2020\) 054024, arXiv:2006.06947](https://arxiv.org/abs/2006.06947))

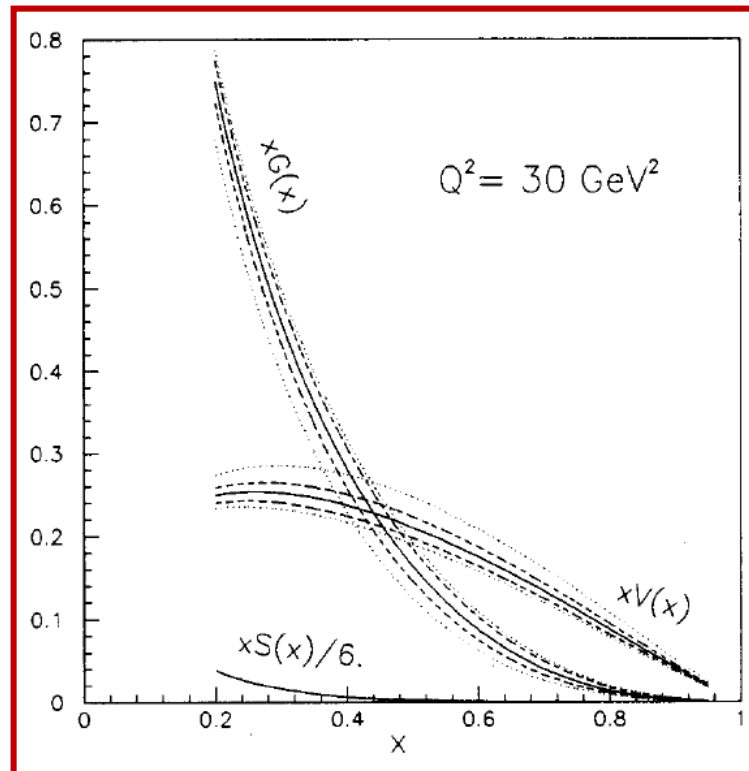
Four pion PDF sets available at LHAPDF library

- First: OW-P (PRD 30, 943 (1984))
 - LO QCD
 - J/ψ data from NA3 and WA39
 - D-Y data from E537 and NA3



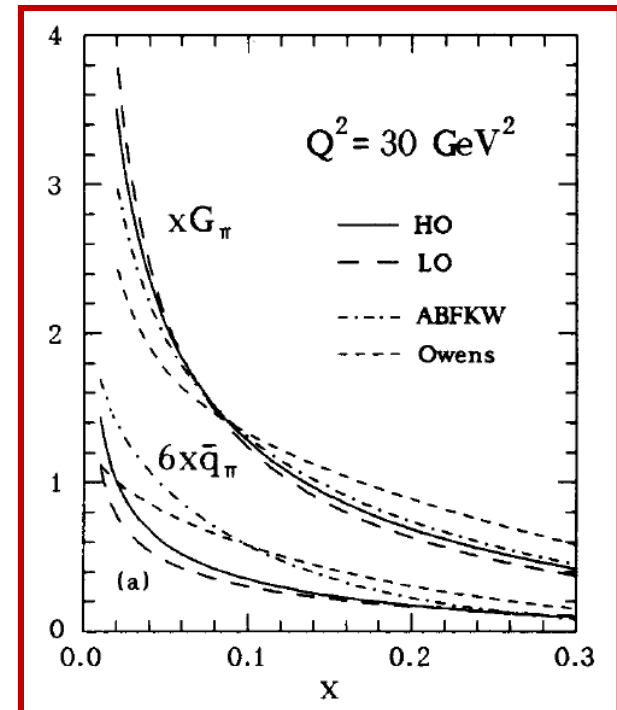
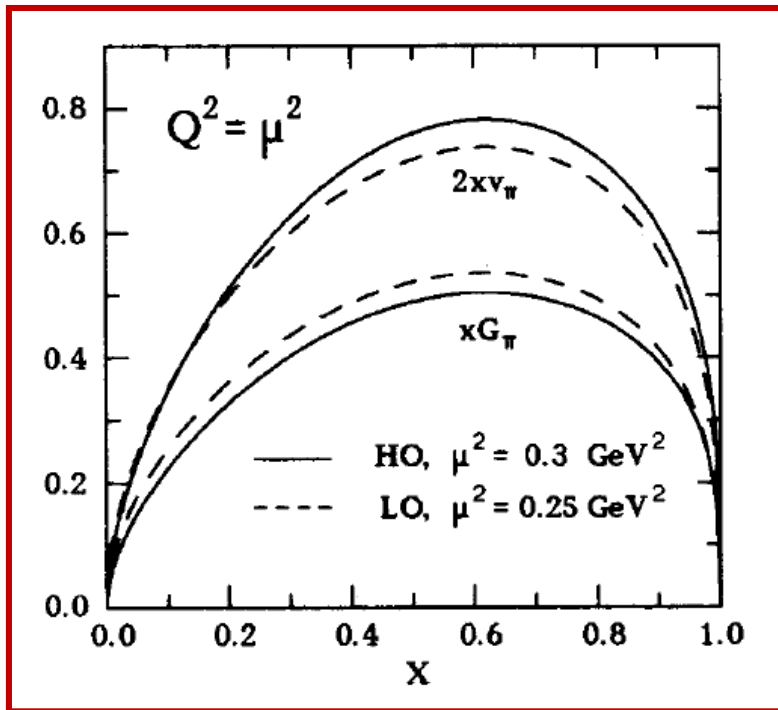
Four pion PDF sets available at LHAPDF library

- Second: ABFKW-P (PL 233, 517 (1989))
 - NLO QCD
 - Direct photon data from WA70 and NA24
 - Sea-quark distribution from NA3



Four pion PDF sets available at LHAPDF library

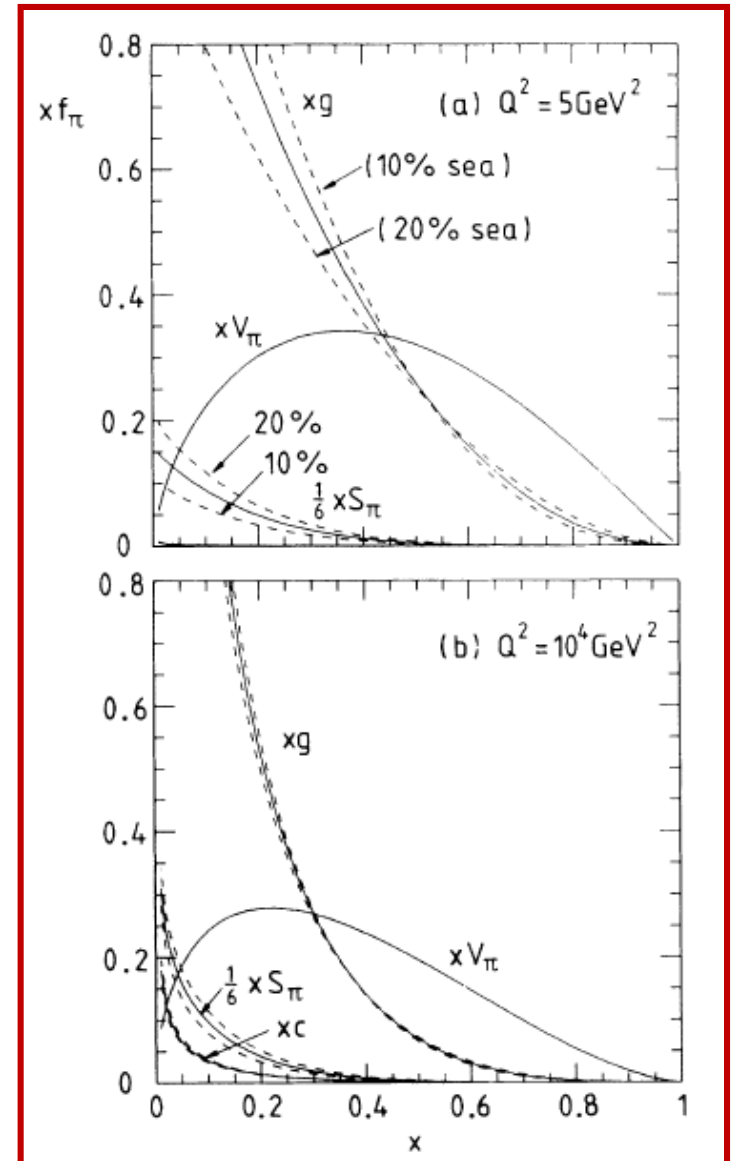
- Third: GRV-P (Z. Phys. C53, 651 (1992))
 - Only valence and valence-like gluon at initial scale. Sea is entirely from QCD evolution
 - Valence distribution from fit to direct photon data



Four pion PDF sets available at LHAPDF library

- Fourth: SMRS (PR D45, 2349 (1992))
 - NLO QCD
 - NA10 and E615 D-Y data
 - WA70 direct photon data

- Need new global fits to all existing data
- Need new experimental data with pion and kaon beams



First Monte Carlo global QCD analysis of pion parton distributions

P. C. Barry,¹ N. Sato,² W. Melnitchouk,³ and Chueng-Ryong Ji¹

¹*North Carolina State University, Raleigh, North Carolina 27607, USA*

²*University of Connecticut, Storrs, Connecticut 06269, USA*

³*Jefferson Lab, Newport News, Virginia 23606, USA*

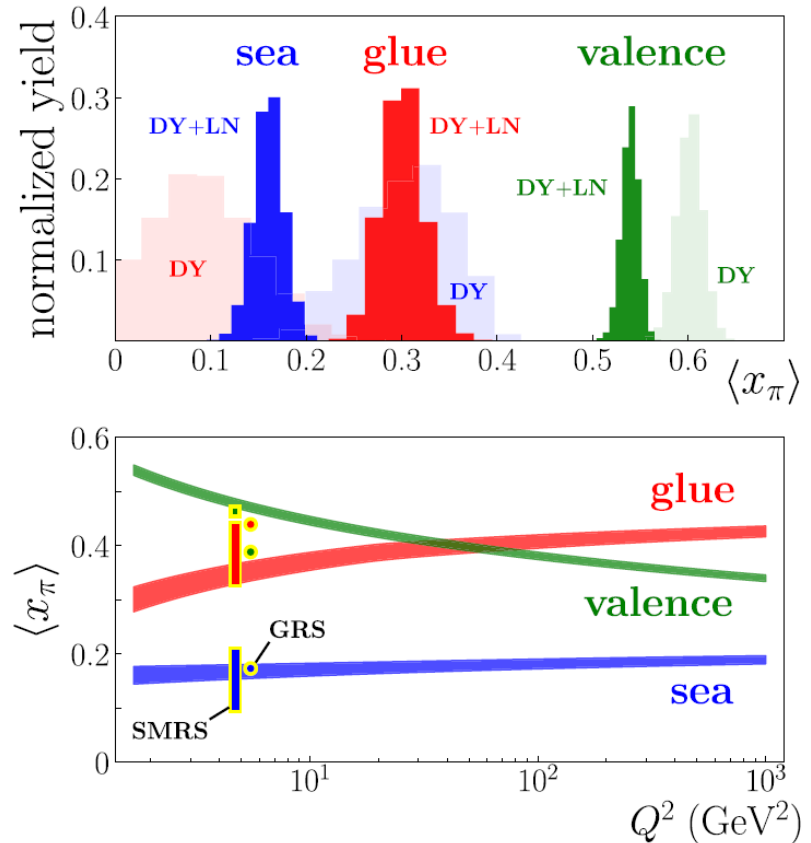
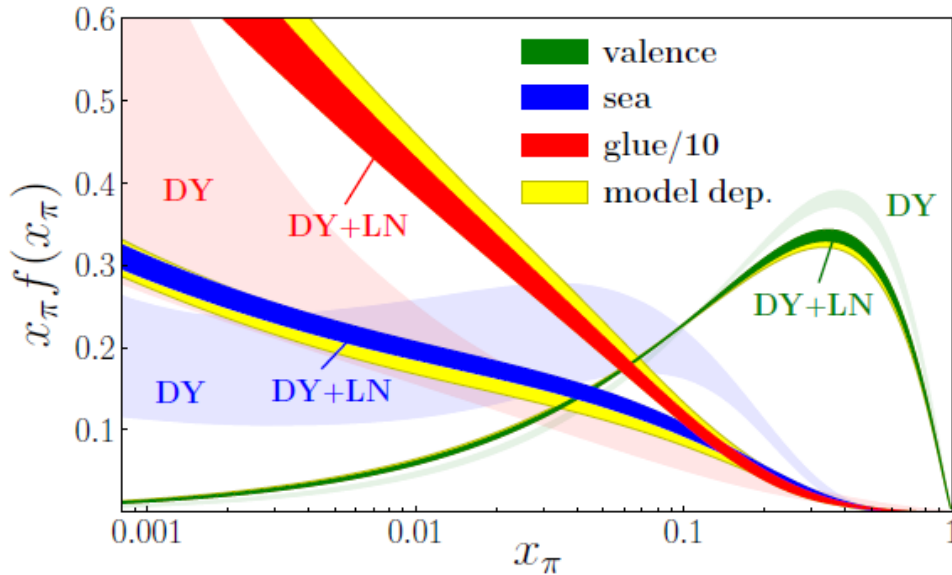
JAM Collaboration

PRL 121, 152001 (2018)

- Drell-Yan data from NA10 and E615
- Leading-neutron tagged DIS from HERA (H1 and ZEUS) provides information on the pion PDFs at small x
- Uncertainties of the pion PDFs are determined













Implications of the JAM results

PRL 121, 152001 (2018)



- The tagged-DIS data significantly reduce the uncertainty of the pion PDFs
- Further measurements of tagged-DIS can be pursued at JLab and EIC

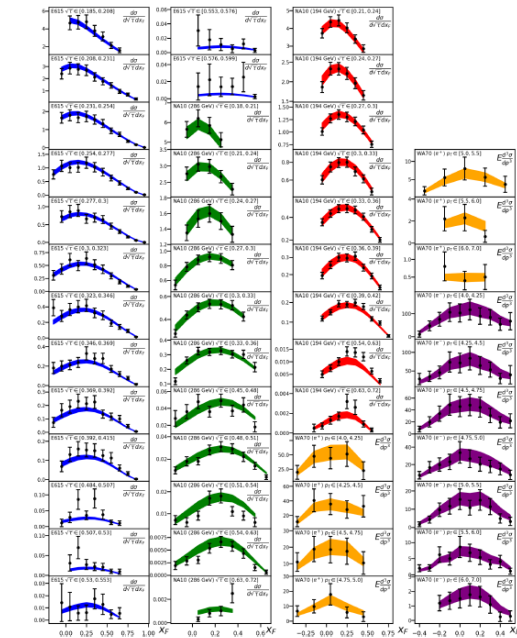
**Parton distribution functions of the charged pion
within the xFitter framework**

Ivan Novikov ^{1,2,*} Hamed Abdolmaleki ³ Daniel Britzger ⁴ Amanda Cooper-Sarkar ⁵ Francesco Giuli ⁶
Alexander Glazov ^{2,†} Aleksander Kusina ⁷ Agnieszka Luszczak ⁸ Fred Olness ⁹ Pavel Starovoitov ¹⁰
Mark Sutton ¹¹ and Oleksandr Zenaiev ¹²

(xFitter Developers' team)

- Drell-Yan data from NA10 and E615
- Direct photon production data from WA70
- Uncertainties of the pion PDFs are determined
- Valence distribution is well determined, but not the sea and gluon distributions

See talk by Fred Olness



Results from the xFitter pion PDFs:

- Similar to JAM pion PDFs
- Different from GRV PDFs
- Larger uncertainties than JAM

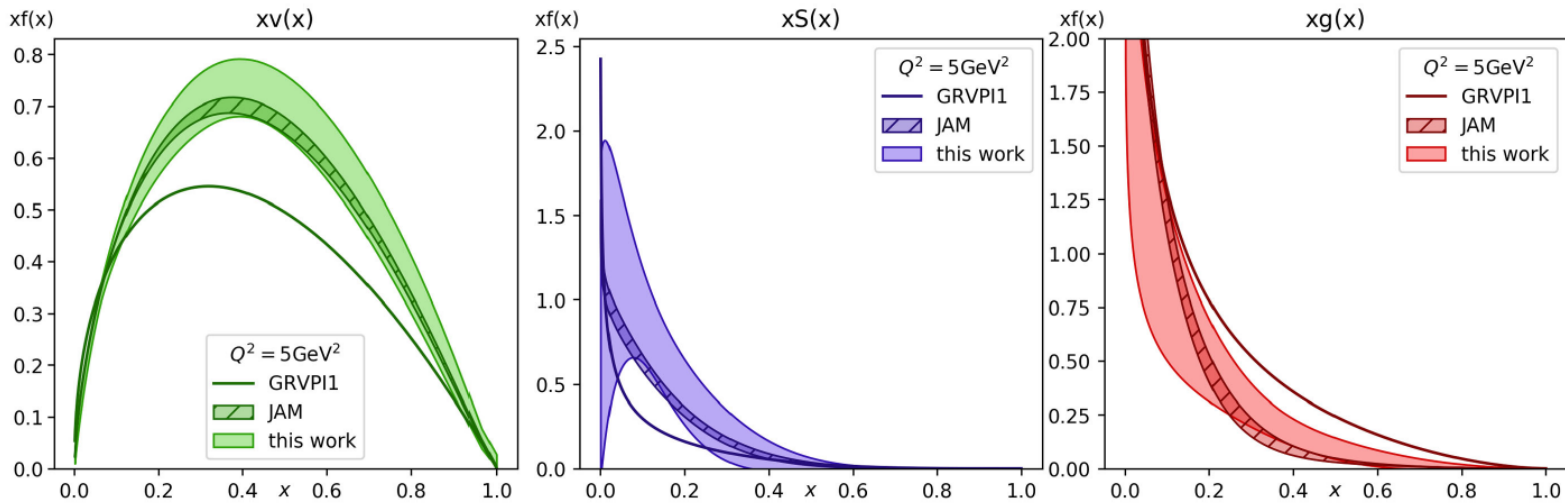
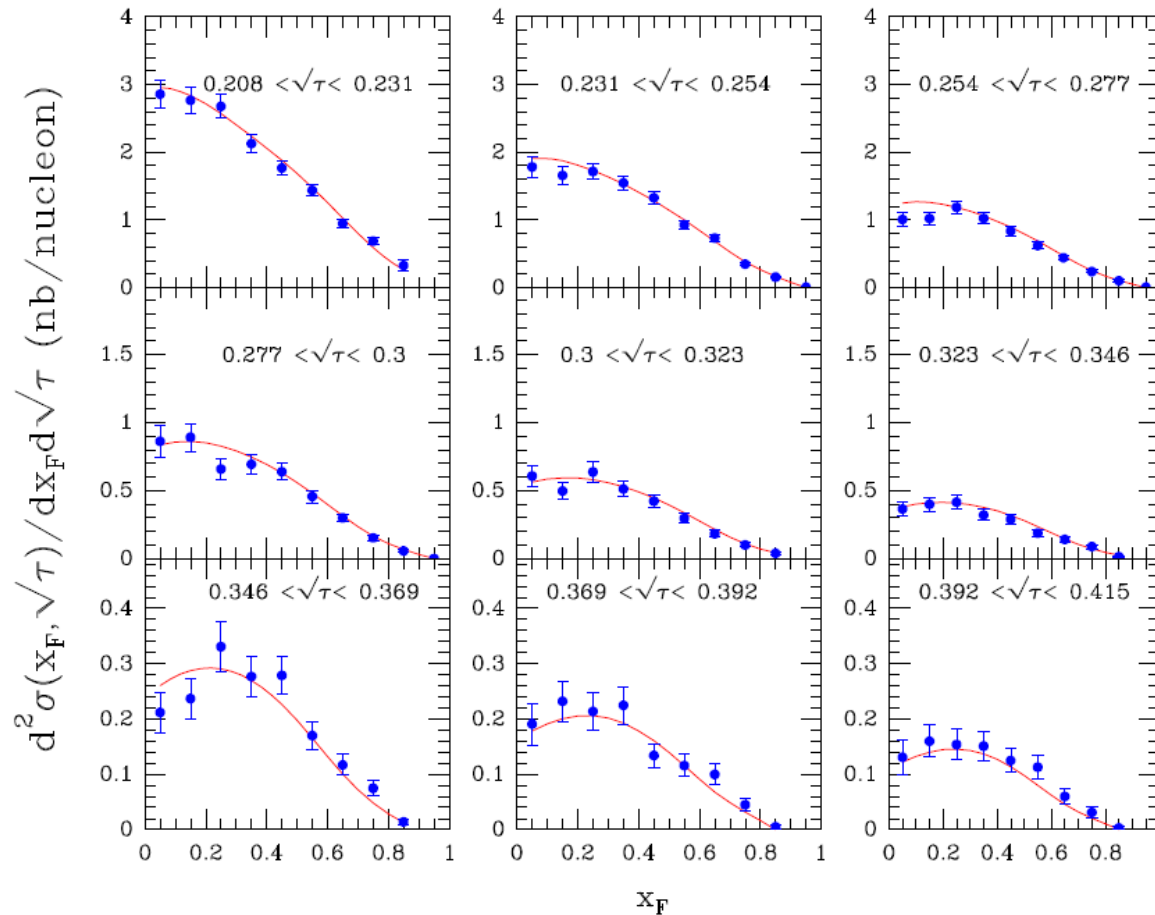


FIG. 3. Comparison between the pion PDFs obtained in this work, a recent determination by the JAM collaboration [31], and the GRVPI1 pion PDF set [27].

Recent extraction of pion PDF using a statistical model

Bourenly and Soffer (NP A981 (2019) 118)

E615 $\pi^- W \rightarrow \mu^- \mu^+ X$ 252 GeV



Definitions of the pion PDFs

$$U = u_{\pi^+} = \bar{u}_{\pi^-}, D = \bar{d}_{\pi^+} = d_{\pi^-}, \bar{U} = \bar{u}_{\pi^+} = u_{\pi^-}, \bar{D} = d_{\pi^+} = \bar{d}_{\pi^-}. \quad (1)$$

This paper assumes that U and D can be different;
 \bar{U} and \bar{D} can also be different

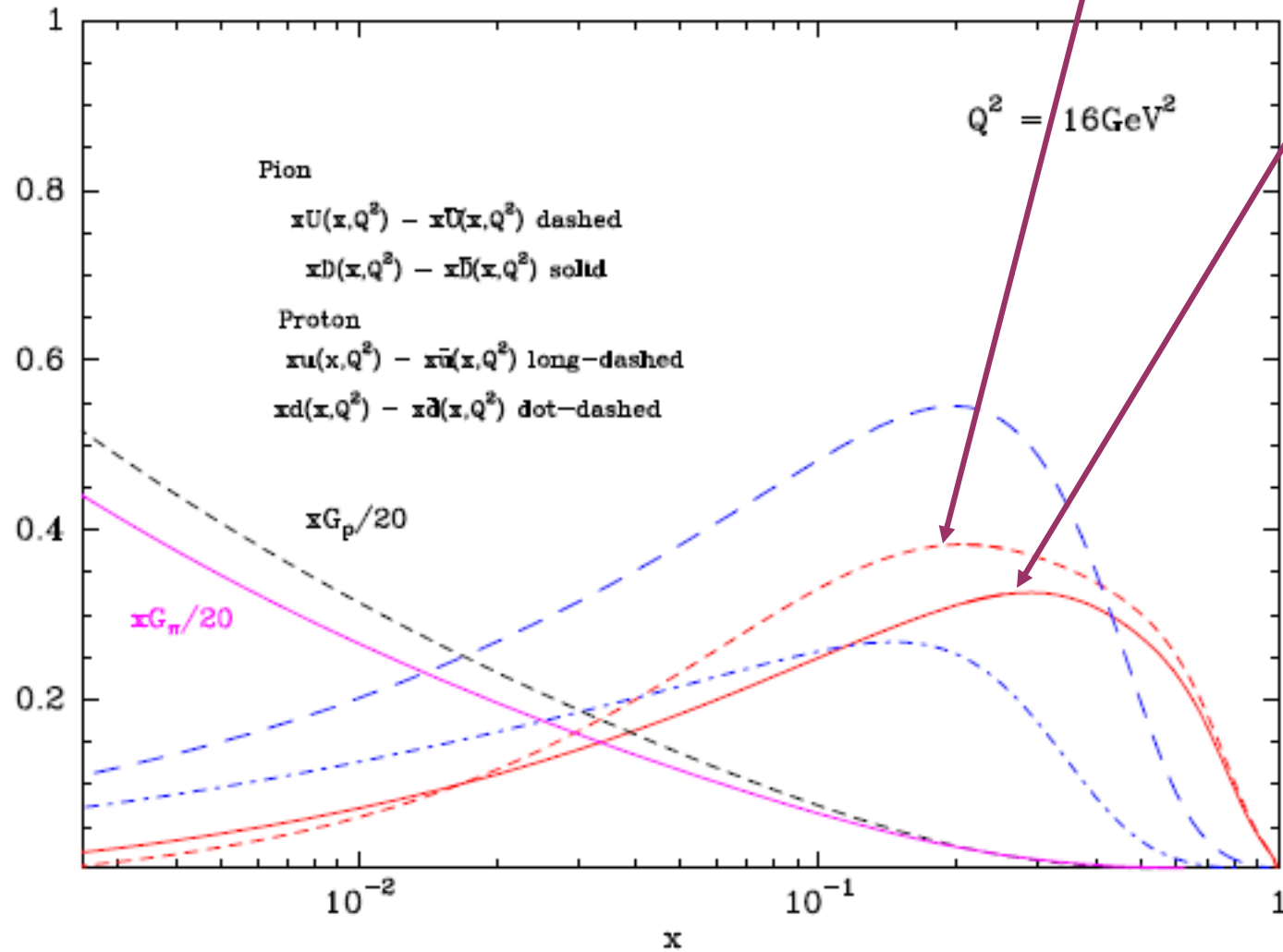
$$xQ^\pm(x) = \frac{A_Q X_Q^\pm x^{b_Q}}{\exp[(x - X_Q^\pm)/\bar{x}] + 1}, \quad (2)$$

$$\begin{aligned} A_U &= 0.537 \pm 0.100, & A_D &= 0.346 \pm 0.050, \\ b_U &= 0.048 \pm 0.001, & b_D &= 0.466 \pm 0.014, \end{aligned} \quad (12)$$

and four potentials

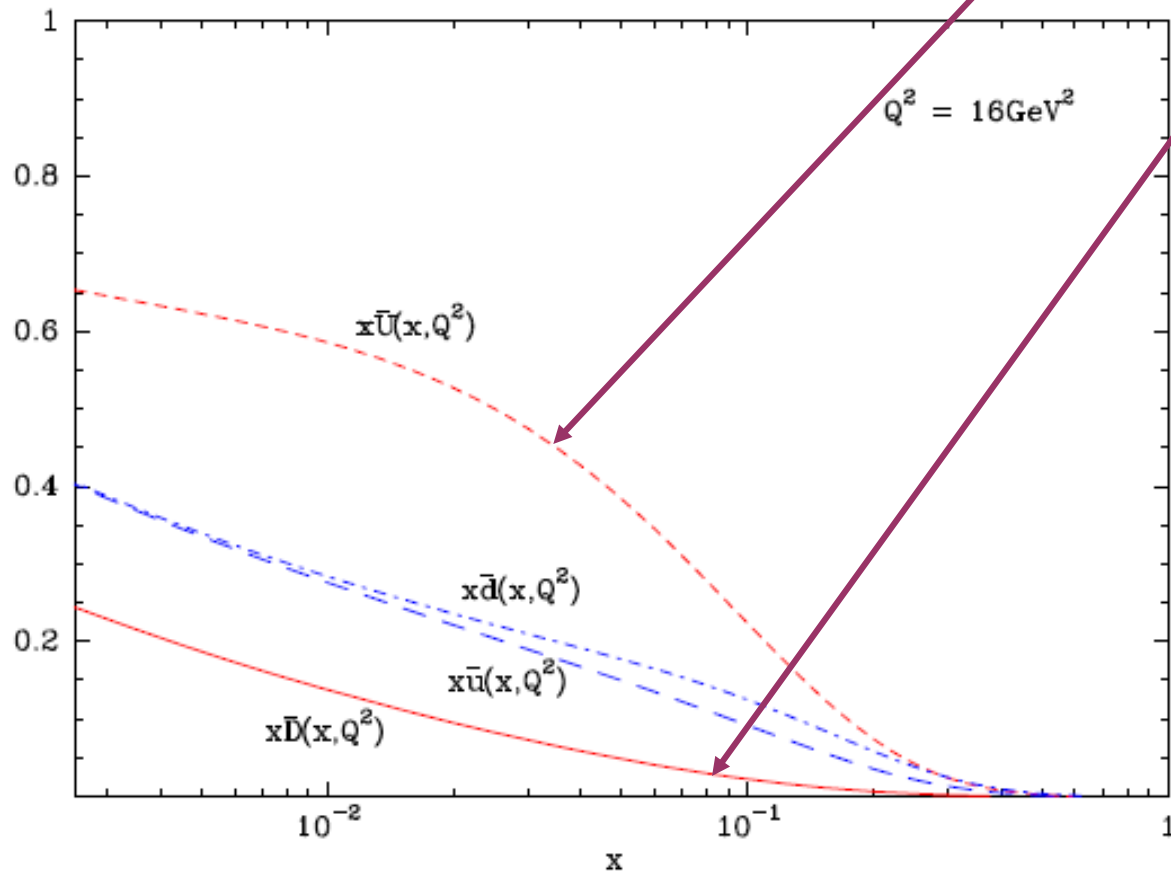
$$\begin{aligned} X_U^+ &= 0.787 \pm 0.007, & X_U^- &= 0.185 \pm 0.030, \\ X_D^+ &= 0.866 \pm 0.024, & X_D^- &= 0.718 \pm 0.044. \end{aligned} \quad (13)$$

Very large difference between U_v and D_v



Data allow a large charge-symmetry breaking at a partonic level

Even larger difference between \bar{U} and \bar{D}



More studies and data are needed to check this surprising and interesting result

A New Extraction of Pion Parton Distributions in the Statistical Model

Claude Bourrely^a, Franco Buccella^b, Jen-Chieh Peng^c

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^c*Department of Physics, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, USA*

$$xU(x) = xD(x) = \frac{A_U X_U x^{b_U}}{\exp[(x - X_U)/\bar{x}] + 1} + \frac{\tilde{A}_U x^{\tilde{b}_U}}{\exp(x/\bar{x}) + 1} . \quad (7)$$

$$x\bar{U}(x) = x\bar{D}(x) = \frac{A_U (X_U)^{-1} x^{b_U}}{\exp[(x + X_U)/\bar{x}] + 1} + \frac{\tilde{A}_U x^{\tilde{b}_U}}{\exp(x/\bar{x}) + 1} . \quad (8)$$

$$xS(x) = x\bar{S}(x) = \frac{\tilde{A}_U x^{\tilde{b}_U}}{2[\exp(x/\bar{x}) + 1]} . \quad (9)$$

$$xG(x) = \frac{A_G x^{b_G}}{\exp(x/\bar{x}) - 1} . \quad (10)$$

New Features:

1) Impose Charge Symmetry:

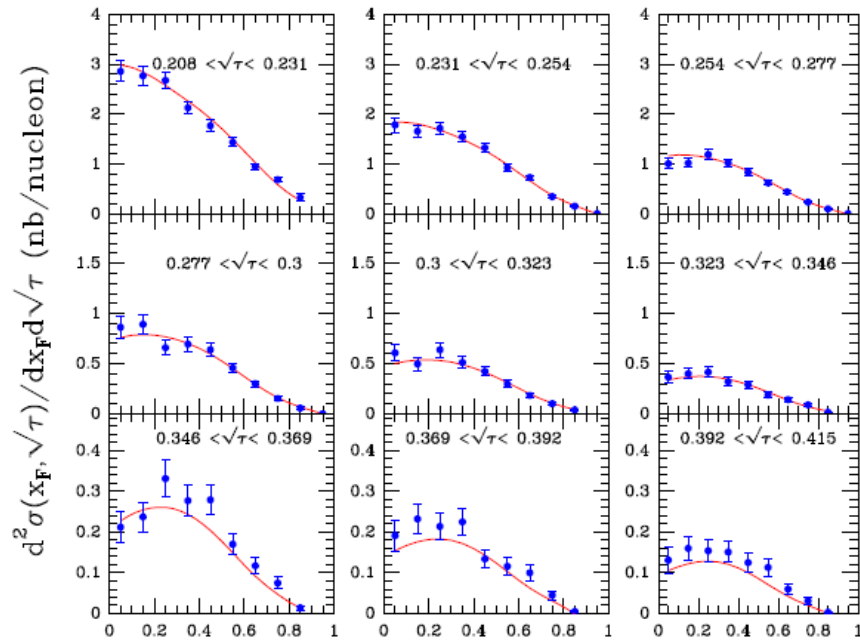
$$U(x) = D(x); \quad \bar{U}(x) = \bar{D}(x)$$

2) Remove helicity dependence

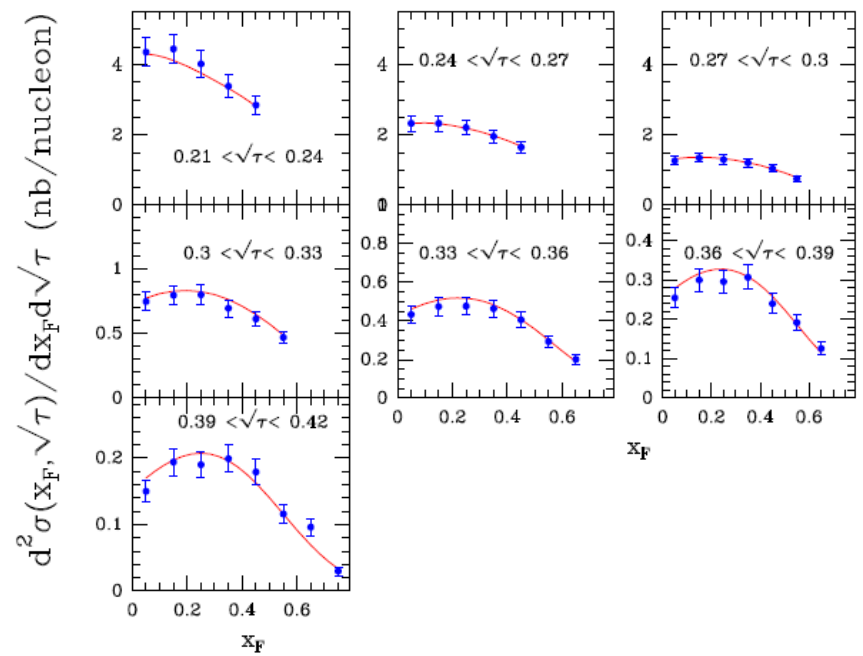
3) Add strange quark distributions

$$S(x) = \bar{S}(x)$$

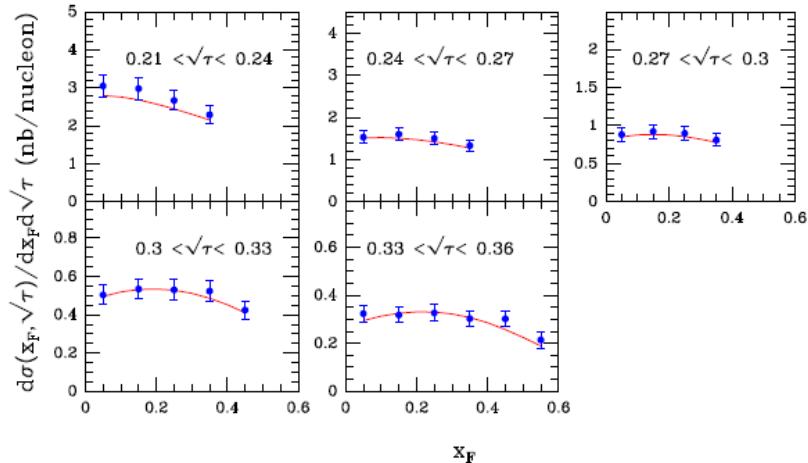
E615 $\pi^- W \rightarrow \mu^- \mu^+ X$ 252 GeV



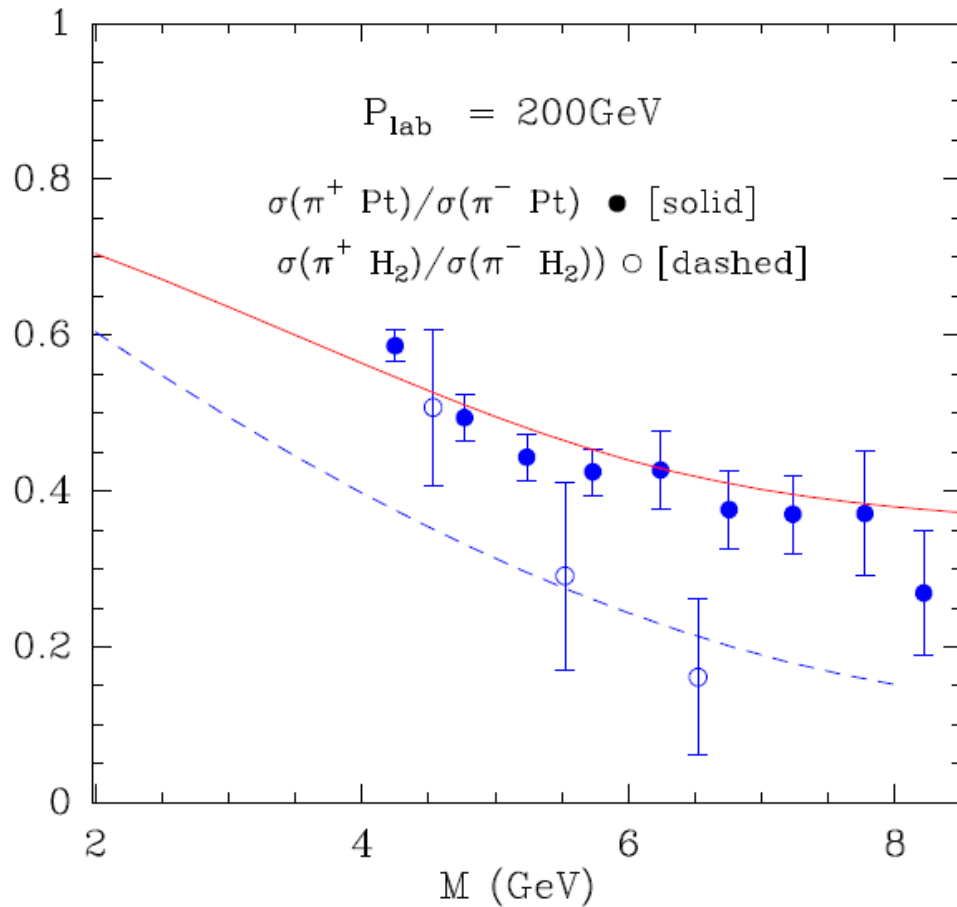
NA10 $\pi^- W \rightarrow \mu^- \mu^+ X$ 194 GeV



NA10 $\pi^- W \rightarrow \mu^- \mu^+ X$ 286 GeV



- With much simpler pion PDF parametrizations, the E615 and NA10 Drell-Yan data are well described by the statistical model



- The statistical model can also describe well the $\pi^+ + \text{Pt} / \pi^- + \text{Pt}$ Drell-Yan data, which were not included in the fit.

Comparison between proton and pion PDFs in the statistical model

$$xQ^\pm(x) = \frac{A_Q X_Q^\pm x^{b_Q}}{\exp[(x - X_Q^\pm)/\bar{x}] + 1},$$

$$A_U = 0.80536 \pm 0.10$$

$$b_U = 0.5161 \pm 0.02$$

$$X_U = 0.7551 \pm 0.01$$

$$\bar{x} = 0.10614 \pm 0.004$$

$$\tilde{A}_U = 2.2773 \pm 0.324$$

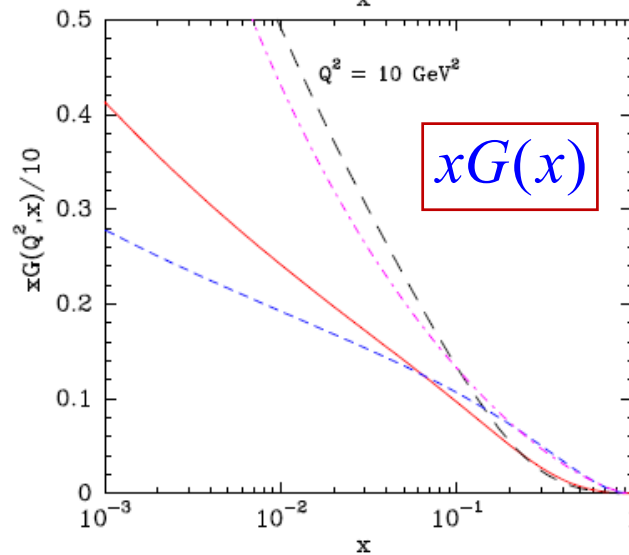
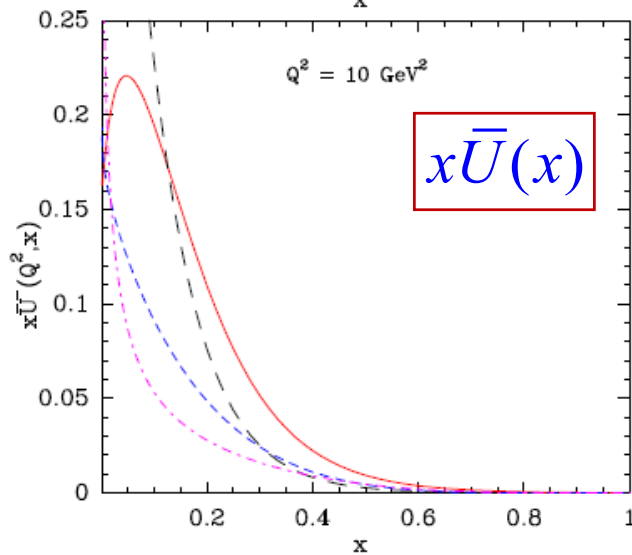
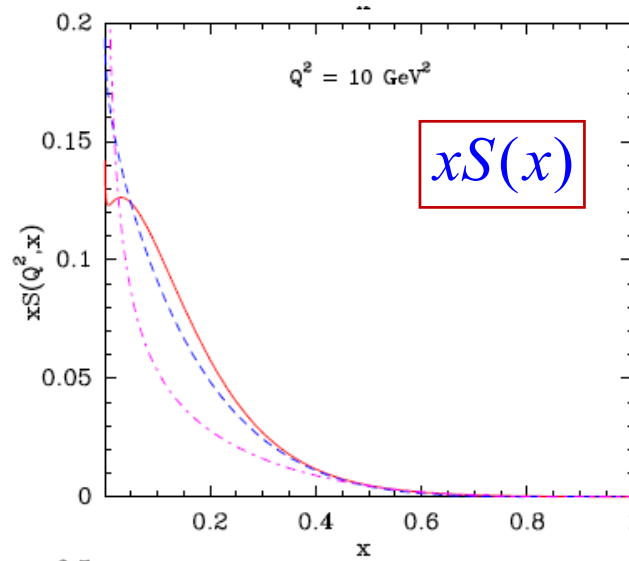
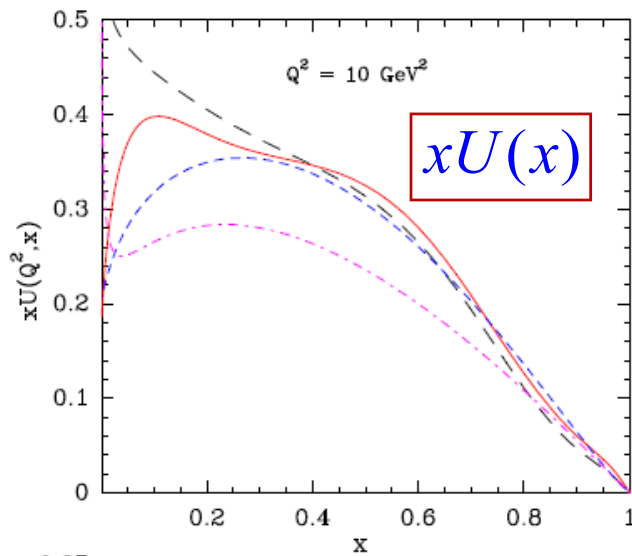
$$\tilde{b}_U = 0.4911 \pm 0.0092$$

$$A_G = 31.0019 \pm 1.68$$

$$b_G = 1 + \tilde{b}_U.$$

- The temperature, $\bar{x} = 0.106$, found for pion is very close to that obtained for proton, $\bar{x} = 0.090$, suggesting a common feature for the statistical model description of baryons and mesons
- The chemical potential of the valence quark for pion, $X_U = 0.755$, is significantly larger than for proton, $X_U = 0.39$

Comparison with other pion PDFs



Solid curves:
new statistical model

Long-dashed curves:
previous statistical
model

Dashed curves:
SMRS

Dotted-dashed
Curves:
GRV

**Constraining gluon density of pions at large x by
pion-induced J/ψ production**

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Takahiro Sawada 

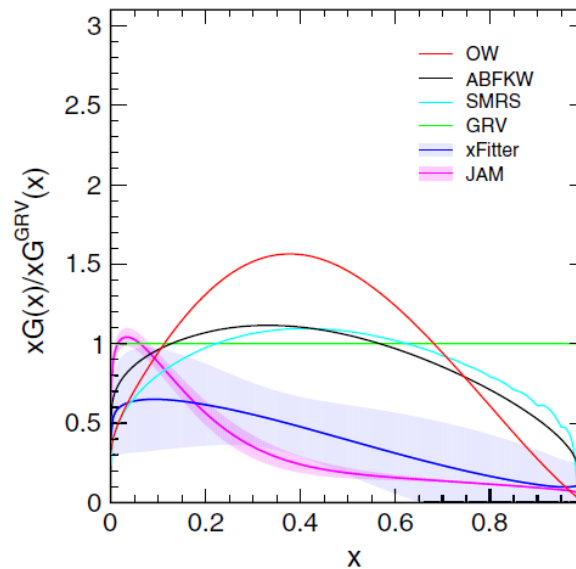
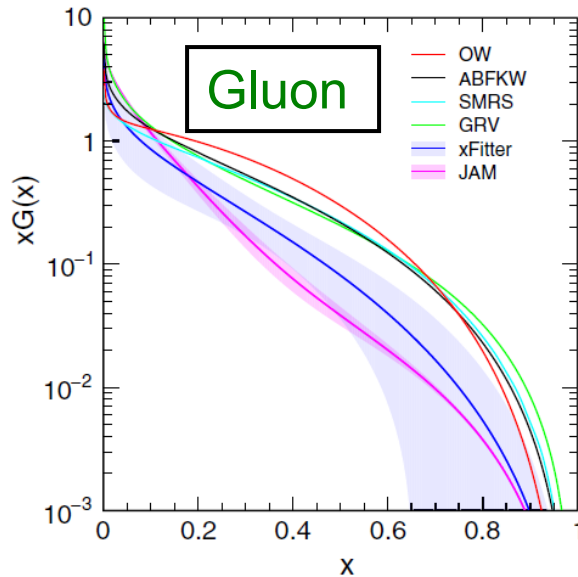
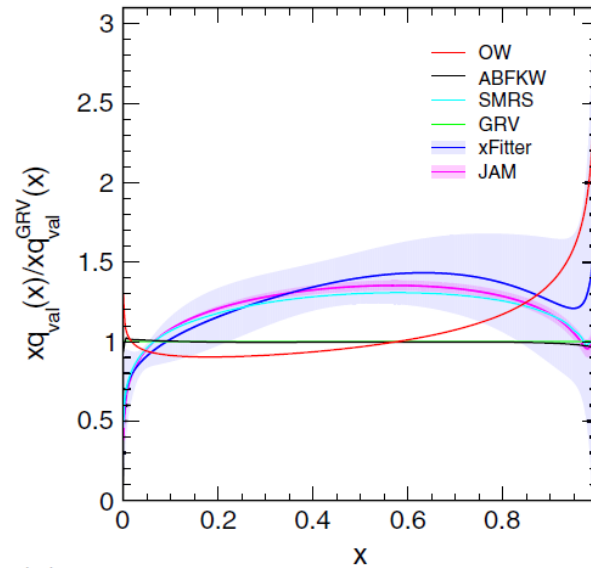
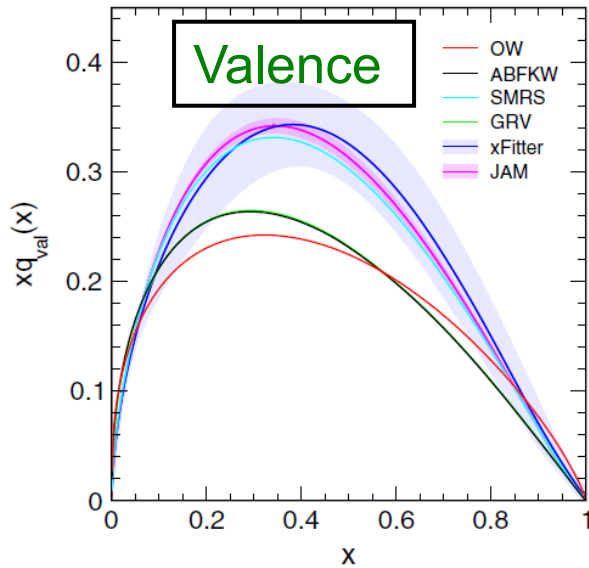
Department of Physics, Osaka City University, Osaka 558-8585, Japan

- An attempt to compare existing pion PDFs in their abilities to describe existing pion-induced J/ψ production data
- The existing data are sensitive to the gluon PDF in pion, which is poorly known and is of much theoretical interest

Procedures

- Select π^- - induced J/Ψ production data with proton or light-nucleus targets to minimize correction of nuclear effects
- Select data covering a broad range of beam energies and x_F coverage
- Use NLO QCD code to calculate the charm production
- Use Color Evaporation Model (CEM) to describe the hadronization of charm pairs to J/Ψ

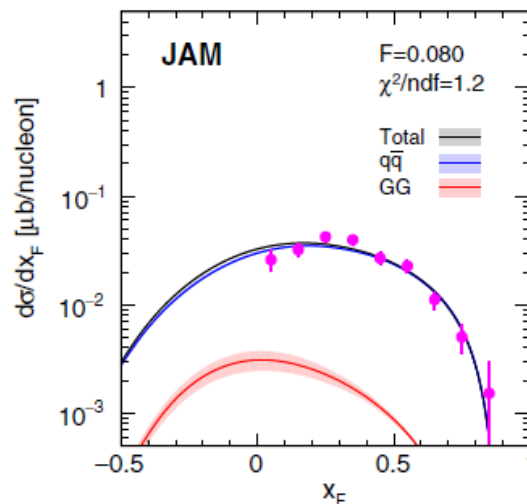
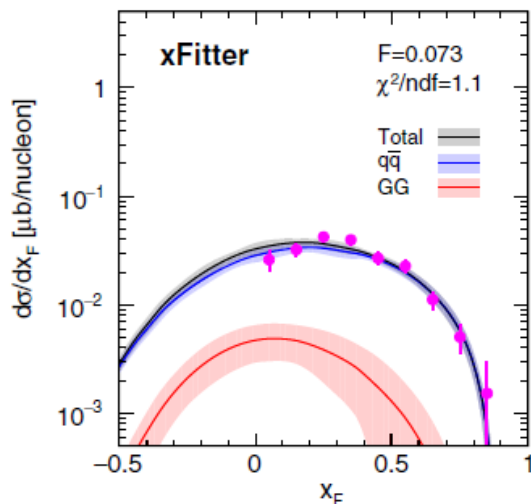
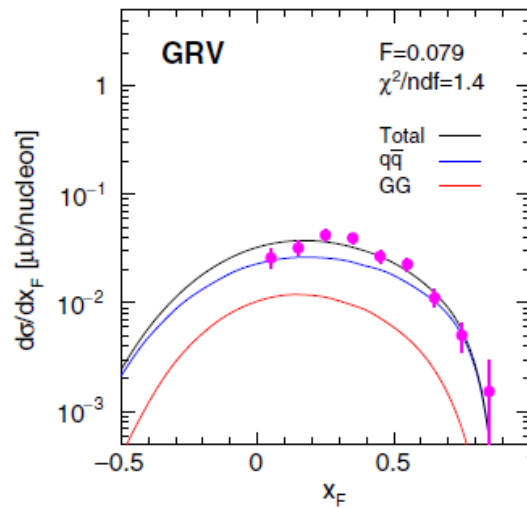
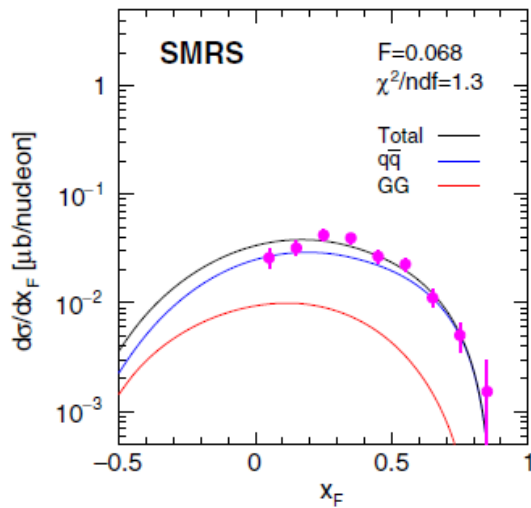
Valence and gluon distributions for various pion PDFs



- Quite good agreements for valence quark PDFs
- Much larger variations for the gluon PDFs

Comparison between data and calculations for different PDFs

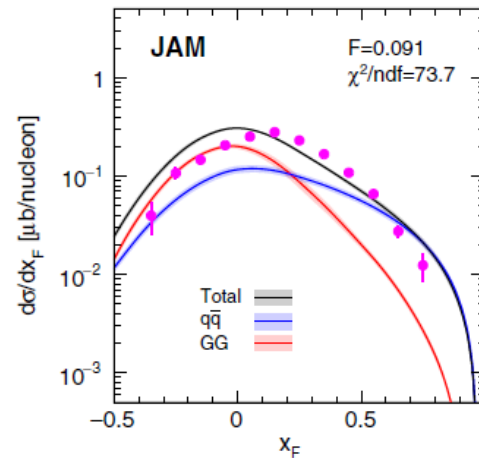
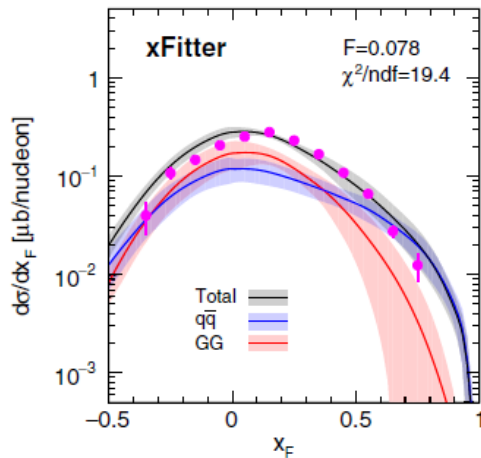
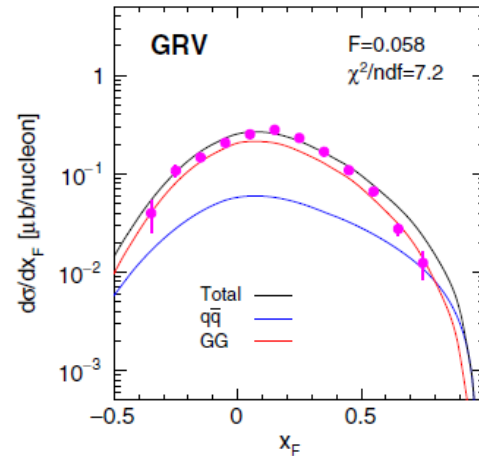
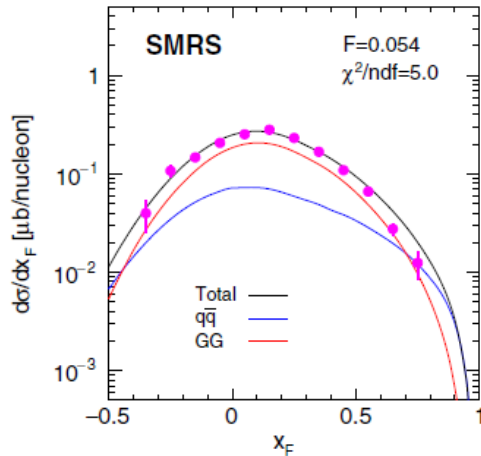
π^-p at 39.5 GeV/c, NLO



- At the lowest beam energy (39.5 GeV), $q\bar{q}$ annihilation dominates
- All PDFs are in good agreement with data, reflecting similar valence quark distributions

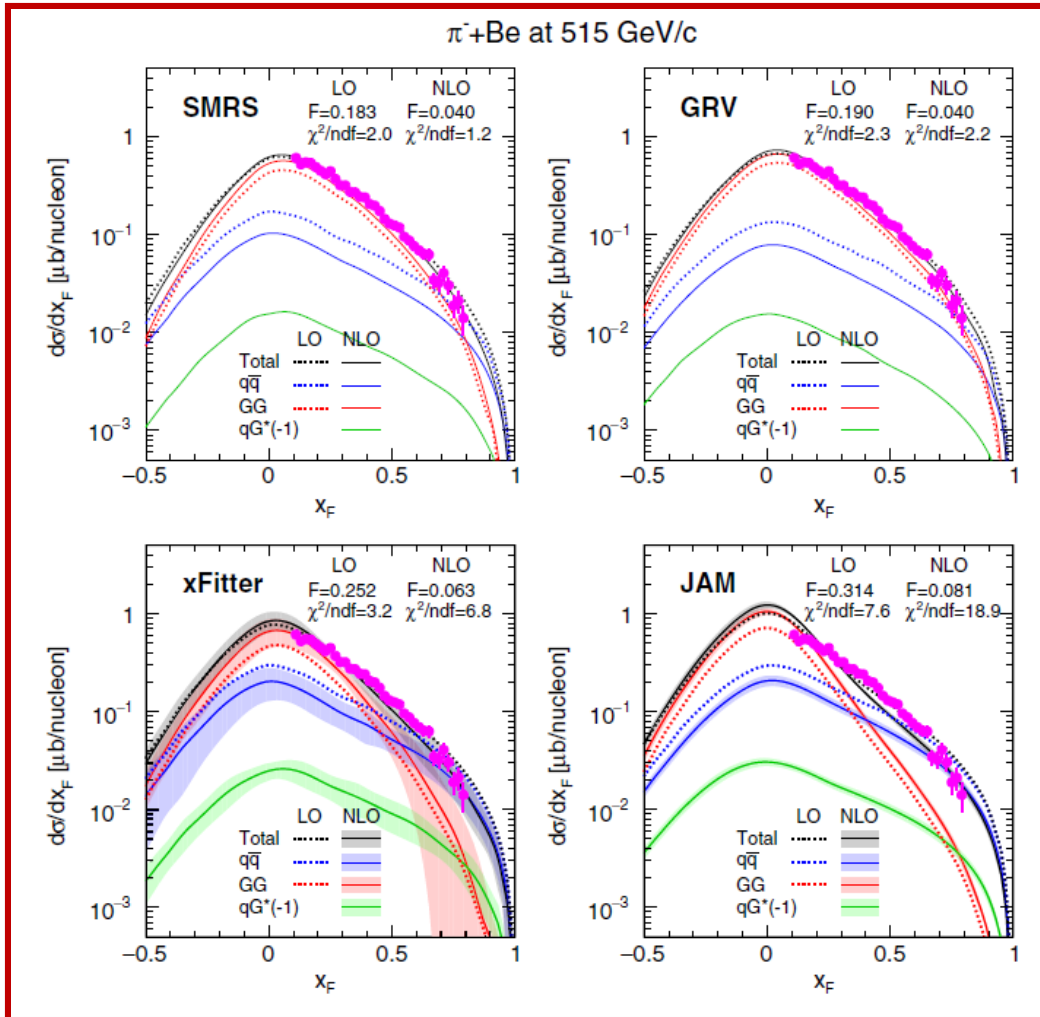
Comparison between data and calculations for different PDFs

π^+ +Be at 190 GeV/c, NLO



- At the COMPASS beam energy (190 GeV), GG fusion dominates at $x_F \sim 0$ for all PDFs
- At forward x_F , $q\bar{q}$ annihilation dominates
- JAM and xFitter GG fusion contribution falls off rapidly at large x_F

Comparison between data and calculations for different PDFs



- At the highest available beam energy (515 GeV), GG fusion dominates at wider range of x_F for all PDFs
- JAM and xFitter GG fusion contribution falls off rapidly at large x_F

Summary and future prospect

- Meson parton distributions represent
 - * New territory for theory and experiment
 - * Unique opportunities at COMPASS, JLab, J-PARC, and EIC
- J / ψ production provides useful information on meson quark and gluon contents
 - * Existing data should be included in the global fits for constraining the gluon distribution in pion and kaon
 - * Analysis is underway to find possibly different gluon distributions in kaon and pion
- Statistical model study of the meson PDFs can be extended to kaon including the kaon-induced J / ψ production data