Workshop on parton distribution functions in the EIC era
June 17, 2025

Pion and Kaon PDFs constrained by J/Psi production

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In collaboration with
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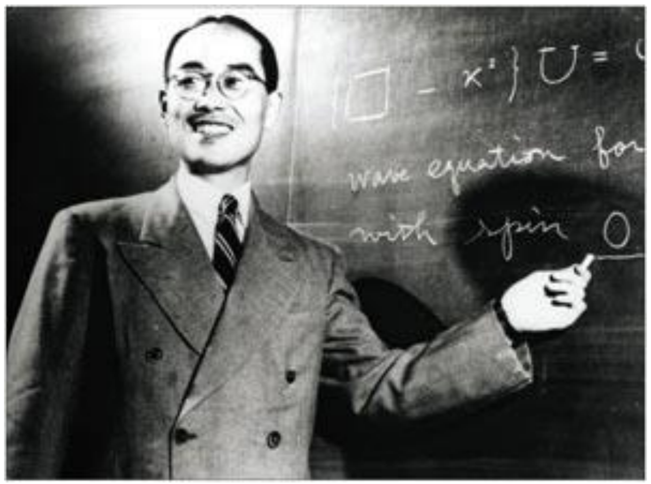
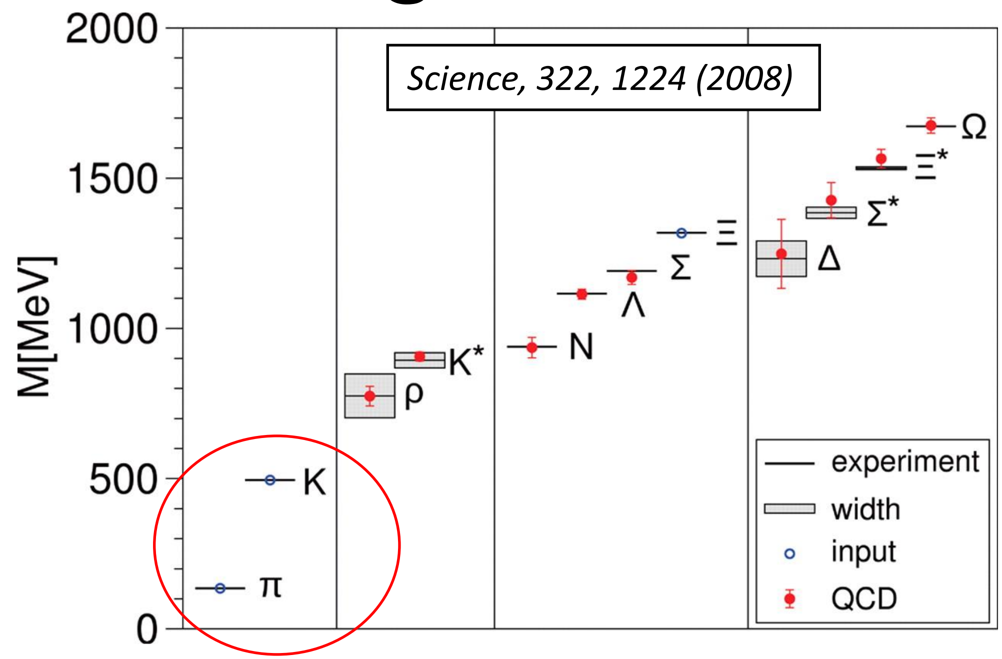
Stephane Platchkov and Takahiro Sawada

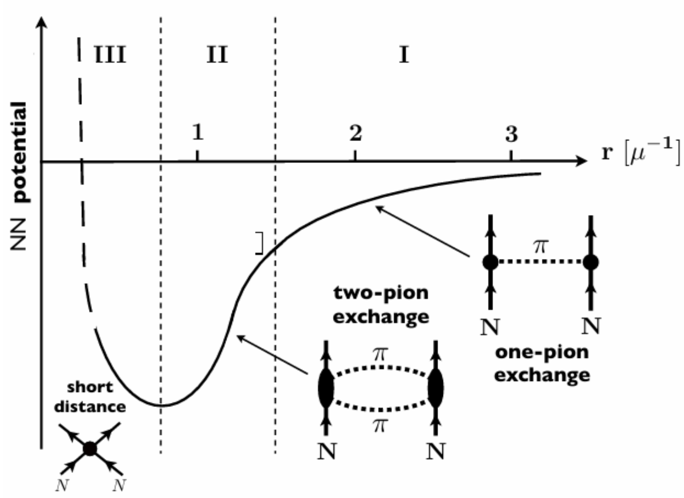
Pion/Kaon:
Goldstone Boson of Strong Interaction

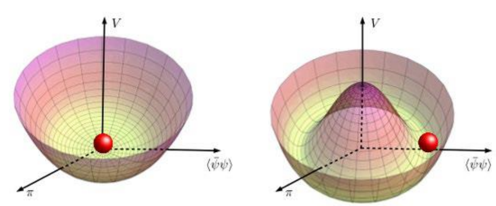


Hideki Yukawa, 1935

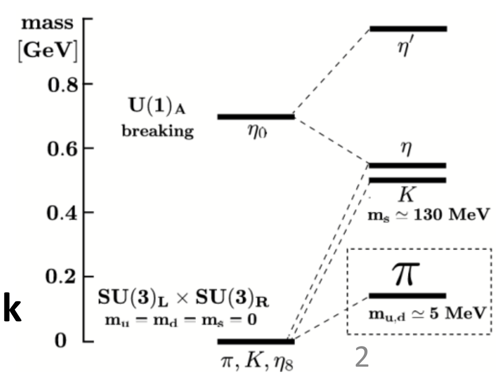


https://arxiv.org/pdf/0704.1992





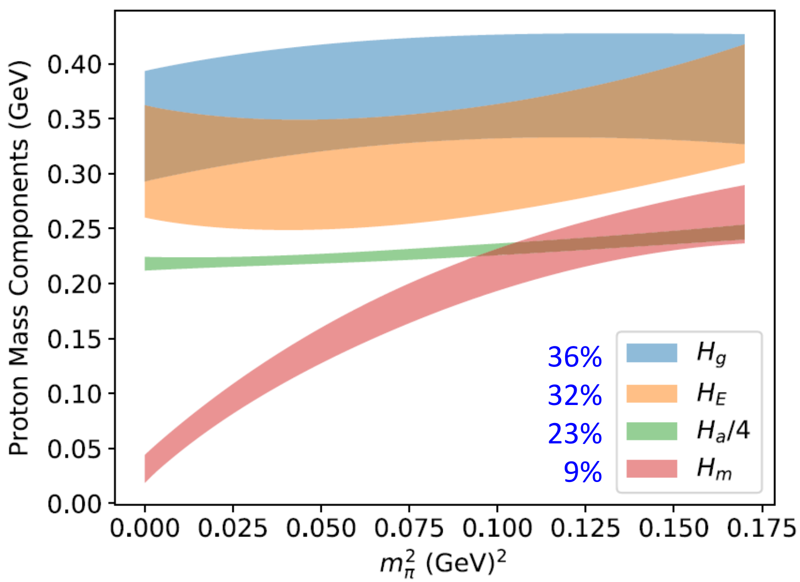
Spontaneous symmetry break



Mass Decomposition of Proton and Pion (Lattice)

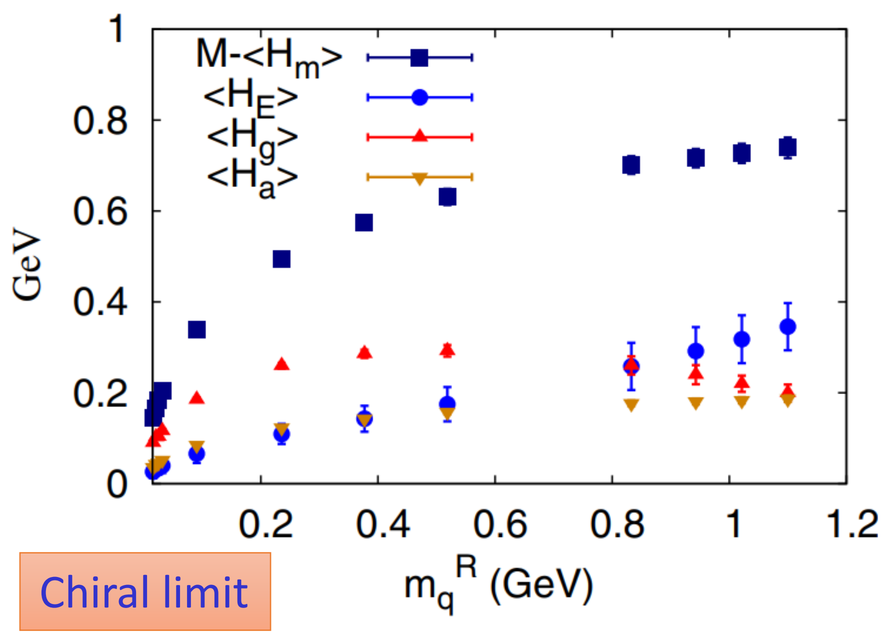
Proton

PRL 121, 212001 (2018)



Pion

PRD 91, 074516 (2015)



Quark energy

Trace Anomaly (gluon condensate)

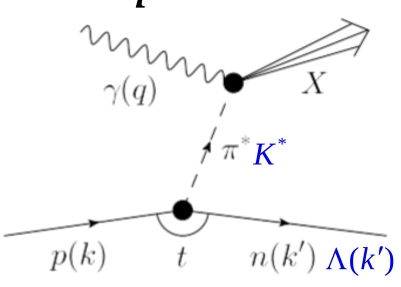
$$M = -\langle T_{44}\rangle = \langle H_m\rangle + \langle H_E\rangle(\mu) + \langle H_g\rangle(\mu) + \frac{1}{4}\langle H_a\rangle$$

Quark mass

Gluon energy

Pion/Kaon PDFs

- **Drell-Yan:** $\pi, K^{\pm}\, p \rightarrow \mu^{+}\mu^{-}X$ (LO: sensitive to valence quarks)
  - **LO:** $\boldsymbol{q\bar{q} \rightarrow \mu^{+}\mu^{-}}$
  - NLO: $q\bar{q} \rightarrow \mu^{+}\mu^{-}G,\, qG \rightarrow \mu^{+}\mu^{-}q$ (large p_T)
  - NNLO: $q\bar{q}G \rightarrow \mu^{+}\mu^{-}G,\, qG \rightarrow \mu^{+}\mu^{-}qG,\, GG \rightarrow \mu^{+}\mu^{-}q\bar{q}$
- **Direct photon:** $\pi, K^{\pm}\, p \rightarrow \gamma X$ (LO: sensitive to gluons)
  - **LO:** $\boldsymbol{q\bar{q} \rightarrow \gamma G,\, qG \rightarrow \gamma q}$
- **Jpsi:** $\pi, K^{\pm}\, p \rightarrow J/\psi X$ (LO: sensitive to gluons)
  - **LO:** $\boldsymbol{q\bar{q} \rightarrow c\bar{c} \rightarrow J/\psi X,\, GG \rightarrow c\bar{c} \rightarrow J/\psi X}$
  - NLO: $q\bar{q} \rightarrow c\bar{c}G \rightarrow J/\psi X,\, GG \rightarrow c\bar{c}G \rightarrow J/\psi X,\, qG \rightarrow c\bar{c}q \rightarrow J/\psi X$
- **Leading neutron (LN) electroproduction:** Sullivan processes from a nucleon's pion cloud



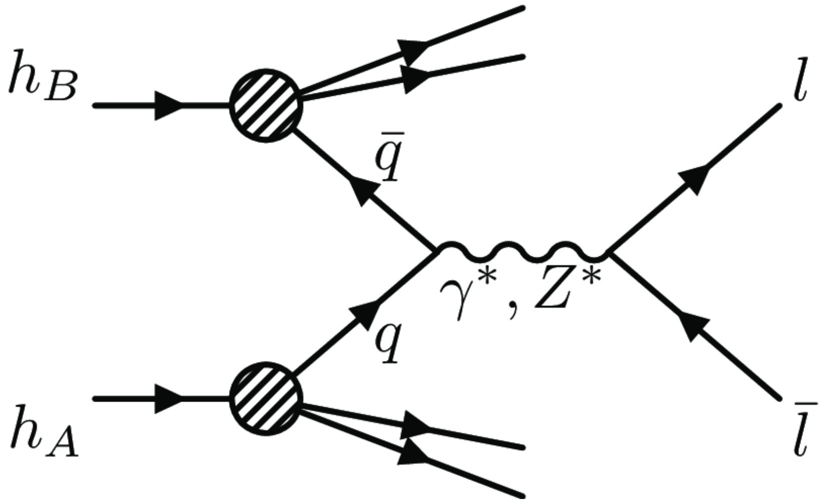
Drell-Yan Process

S.D. Drell and T.M. Yan, PRL 25 (1970) 316

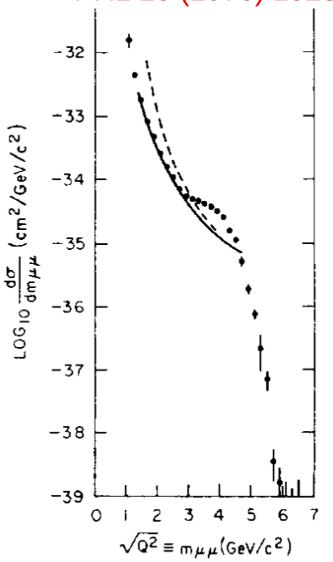
MASSIVE LEPTON-PAIR PRODUCTION IN HADRON-HADRON COLLISIONS AT HIGH ENERGIES*

Sidney D. Drell and Tung-Mow Yan
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305
(Received 25 May 1970)

On the basis of a parton model studied earlier we consider the production process of large-mass lepton pairs from hadron-hadron inelastic collisions in the limiting region, $s \to \infty$, Q^2/s finite, Q^2 and s being the squared invariant masses of the lepton pair and the two initial hadrons, respectively. General scaling properties and connections with deep inelastic electron scattering are discussed. In particular, a rapidly decreasing cross section as $Q^2/s \to 1$ is predicted as a consequence of the observed rapid falloff of the inelastic scattering structure function νW_2 near threshold.



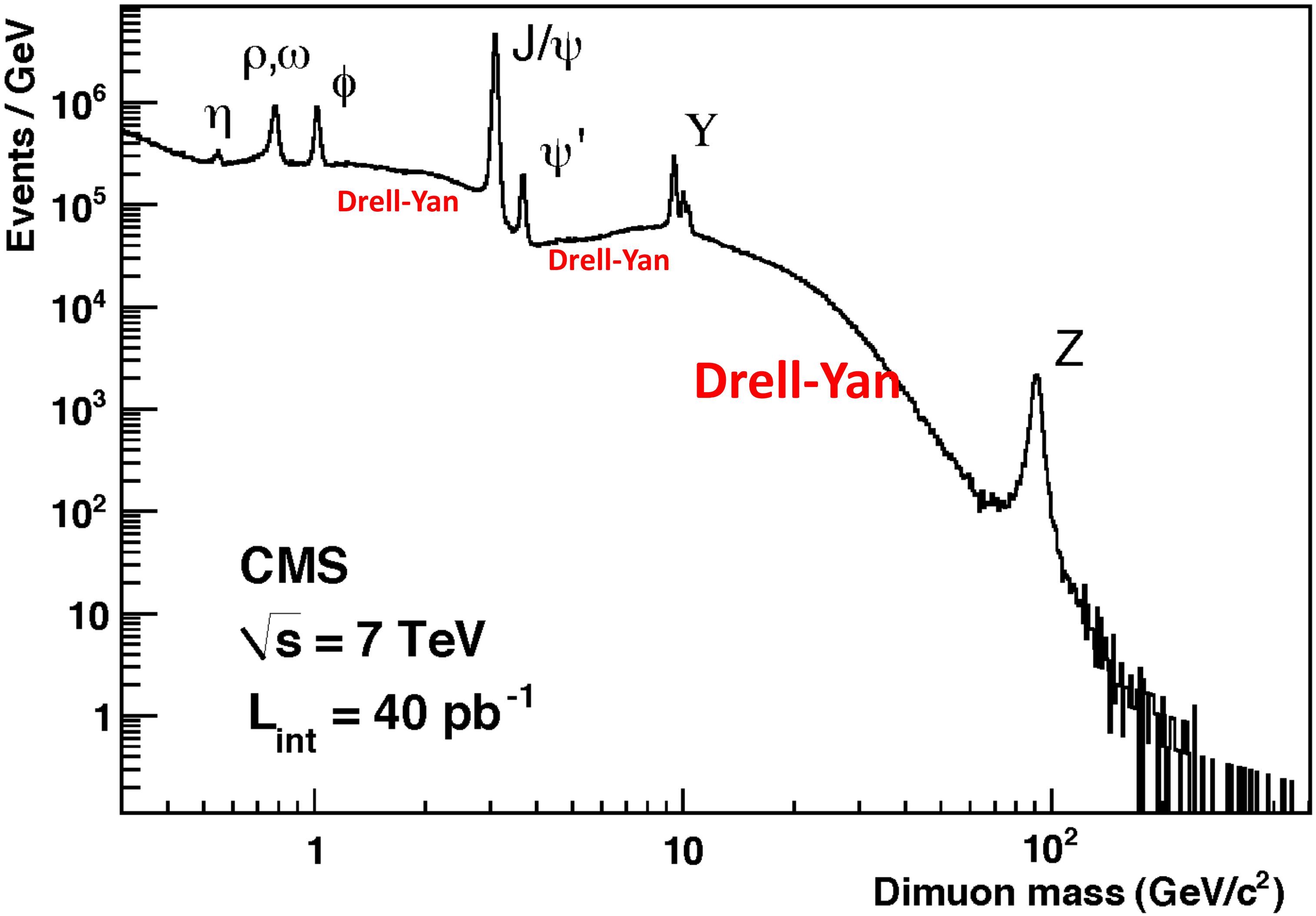
PRL 25 (1970) 1523



$$\tau = \frac{Q^2}{s} = x_1 x_2$$

$$\frac{d\sigma}{dQ^2} = \left(\frac{4\pi\alpha^2}{3Q^2}\right)\left(\frac{1}{Q^2}\right)\mathfrak{F}(\tau) = \left(\frac{4\pi\alpha^2}{3Q^2}\right)\left(\frac{1}{Q^2}\right)\int_0^1 dx_1 \int_0^1 dx_2 \delta(x_1 x_2 - \tau) \sum_a \lambda_a{}^{-2} F_{2a}(x_1) F_{2\bar{a}}{}'(x_2),$$

Dimuon Invariant Mass



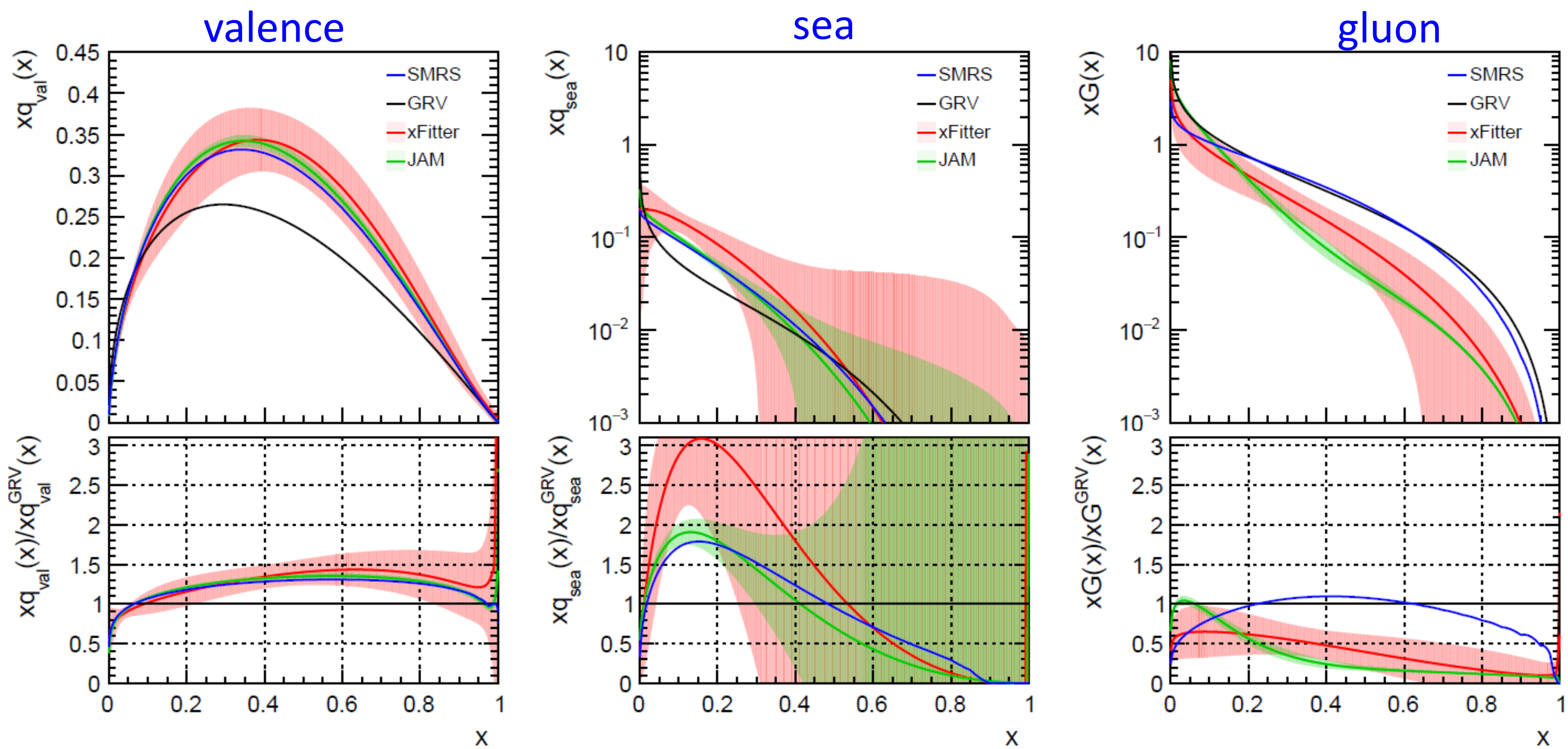
Pion PDFs (Global Analysis)

PDF	DY (xF, pT)	Direct γ	J/ψ	LN	Refs.
OW	*		*		PRD 1984
ABFKW	*	*			PLB 1989
SMRS	*	*			PRD 1992
GRV	*	*			ZPC 1992
GRS	*				EPJC 1999
JAM18	*			*	PRL 2018
BS, BBP	*				NPA 2019 PLB 2021
xFitter	*	*			PRD 2020
JAM21	*			*	PRD 2021 PRL 2021
Fanto	*	*		*	PRD 2024

Pion PDFs

$Q^2 = 9.6\ \text{GeV}^2$

PDF	$\int_0^1 x\bar{u}_{\text{val}}(x)dx$	$\int_0^1 x\bar{u}_{\text{sea}}(x)dx$	$\int_0^1 xG(x)dx$
OW	0.203	0.026	0.487
ABFKW	0.205	0.026	0.468
SMRS	0.245	0.026	0.394
GRV	0.199	0.020	0.513
JAM[a]	0.225 ± 0.003	0.028 ± 0.002	0.365 ± 0.016
xFitter[a]	0.228 ± 0.009	0.040 ± 0.020	0.291 ± 0.119



A large discrepancy of pion PDFs!

Theoretical Models of Pion/Kaon PDFs

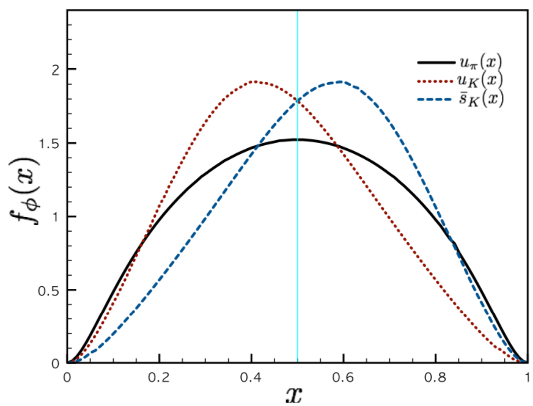
- **Nambu–Jona-Lasinio (NJL) Model:** PRC 94, 035201 (2016); PRD 105, 034021, (2022)
- **Chiral Constituent Quark Model:** PRD 86, 074005 (2012); PRD 97, 074015 (2018); PRD 109, 054040 (2024)
- **Dyson-Schwinger Equations (DSE):** PRD 93, 074021 (2016); PRD 93, 054029 (2018); PRL 124, 042002 (2020); EPJC 80, 1064 (2020)
- **Light-front & Holographic QCD:** PRD 101, 034024 (2020); PRD 106, 034003 (2022); PRD 107, 114023 (2023)
- **Maximum Entropy Input:** PLB 800, 135066 (2020); EPJC 81, 302 (2021)
- **Instanton Model:** PRD 102, 014039 (2020)

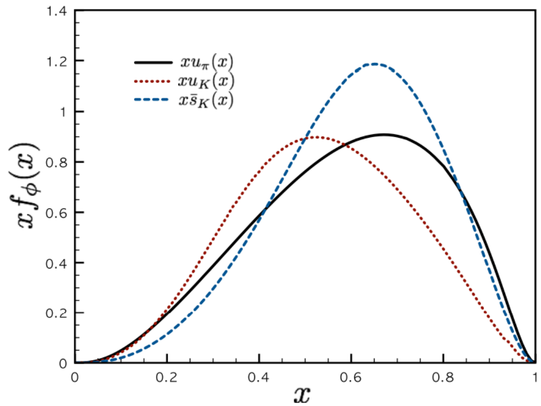
Gauge-invariant nonlocal chiral-quark model
[Seung-il Nam, PRD 86, 074005 (2012)]

Modeling of valence quark distributions at an initial scale Q_0

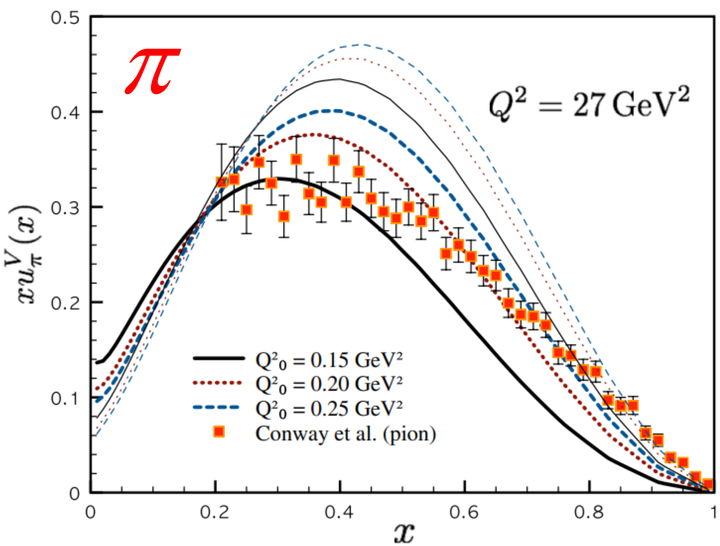
π

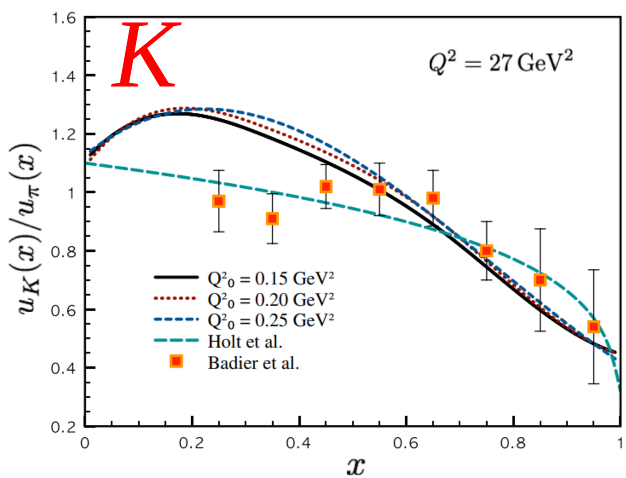
K





DGLAP QCD evolution





LQCD: Momentum Fractions

ETM Collaboration, PRL 134, 131902 (2025)

	π	K	p (B-ensemble)
$\langle x \rangle_{u,\mathrm{R}}$	0.249(28)	0.269(09)	0.354(30)
$\langle x \rangle_{d,\mathrm{R}}$	0.249(28)	0.059(09)	0.188(19)
$\langle x \rangle_{s,\mathrm{R}}$	0.036(15)	0.339(11)	0.052(12)
$\langle x \rangle_{c,\mathrm{R}}$	0.013(16)	0.028(21)	0.019(09)
$\langle x \rangle_{g,\mathrm{R}}$	0.402(53)	0.422(67)	0.427(92)
$\langle x \rangle_{q,\mathrm{R}}$	0.575(79)	0.683(50)	0.618(60)
$\langle x \rangle_{u+d-2s,\mathrm{R}}$	0.438(18)	−0.362(08)	$\cdots$
$\langle x \rangle_{u+d+s-3c,\mathrm{R}}$	0.521(51)	0.494(36)	$\cdots$
$\langle x \rangle_{\mathrm{g,R}} + \langle x \rangle_{\mathrm{q,R}}$	0.984(89)	1.13(11)	1.04(11)

The gluon part is about the same for π, K and p!

LQCD: Mellin moments

ETM Collaboration, PRD 104, 054504 (2021)

$$\langle x^2 \rangle^u_{\pi^+} = 0.110(7)(12),$$

$$\langle x^2 \rangle^u_{K^+} = 0.096(2)(2),$$

$$\langle x^2 \rangle^s_{K^+} = 0.139(2)(1),$$

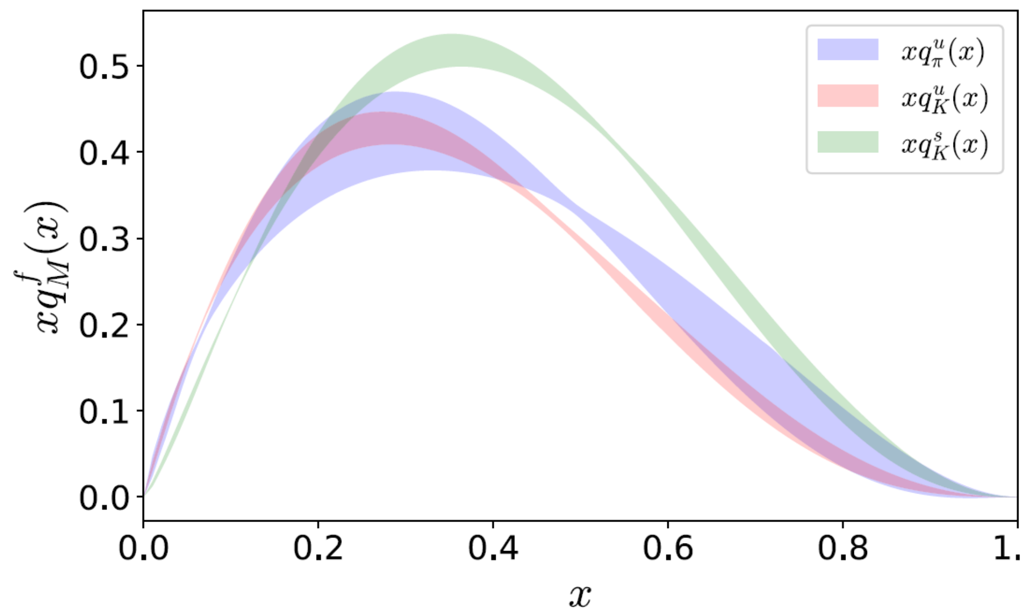
$$\langle x^3 \rangle^u_{\pi^+} = 0.024(18)(2),$$

$$\langle x^3 \rangle^u_{K^+} = 0.033(6)(1),$$

$$\langle x^3 \rangle^s_{K^+} = 0.073(5)(2),$$

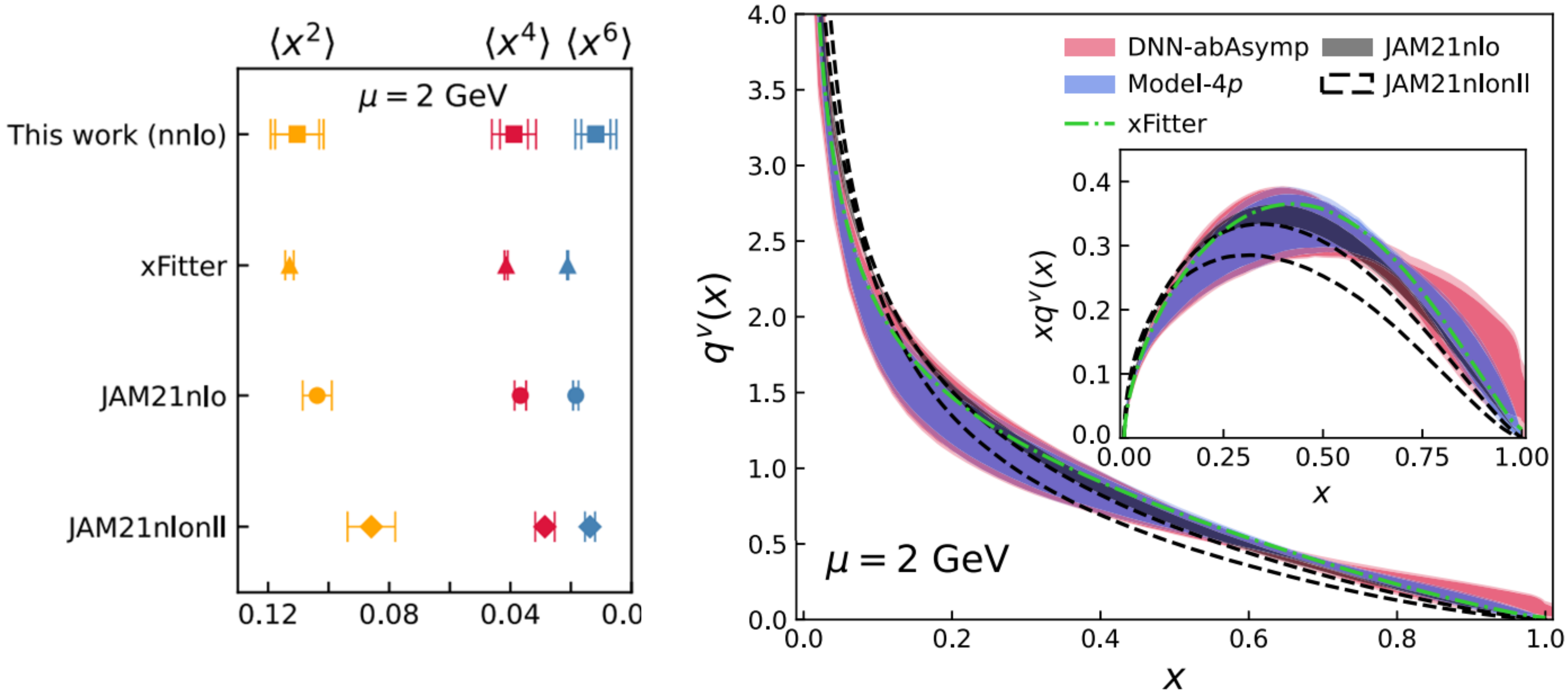
$$\langle x^n \rangle = N \int_0^1 dx x^\alpha (1-x)^\beta (1+\gamma x).$$

$$\langle x^n \rangle = \frac{\left(\prod_{i=1}^n (i+\alpha)\right)(n+2+\alpha+\beta+(i+1+\alpha)\gamma)}{\left(\prod_{i=1}^n (i+2+\alpha+\beta)\right)(2+\alpha+\beta+(1+\alpha)\gamma)}, \quad n>0.$$



Reconstructed by the lattice data up to <x^3>.

LQCD: Mellin Moments
[Gao et al., PRD 106, 114510 (2022)]



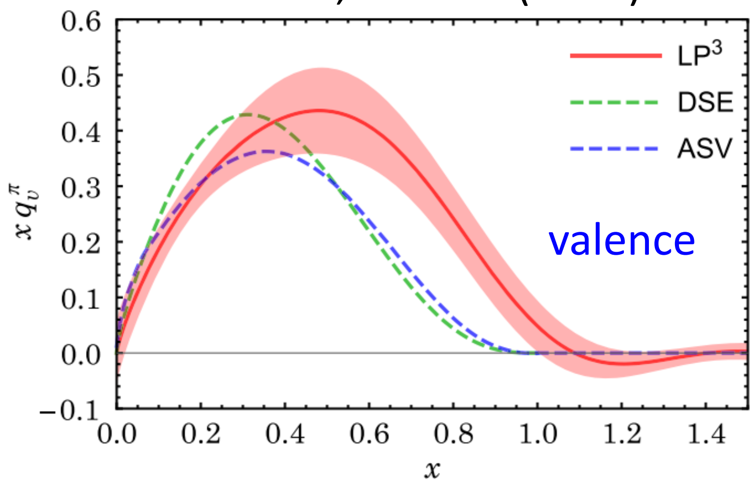
Reconstructed by the lattice data up to $<x^6>$.

LQCD: quasi-PDFs / pseudo-PDFs

MSULat

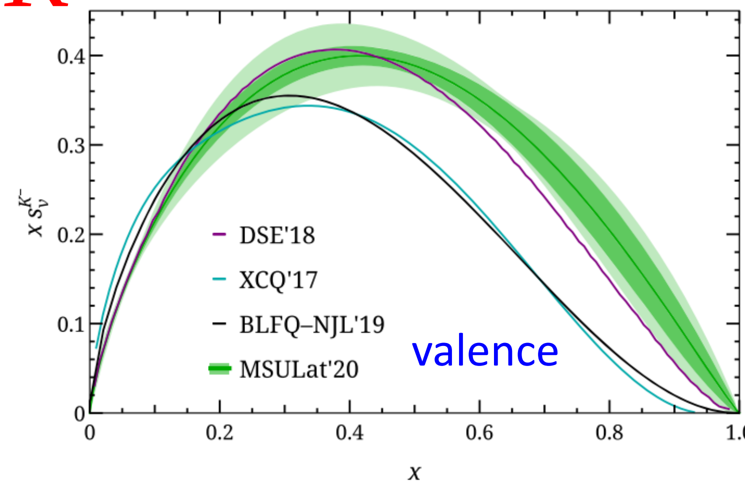
π

PRD 100, 034505 (2019)

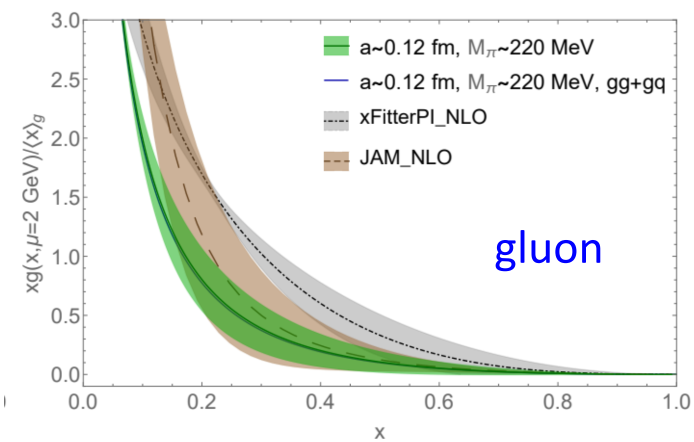


K

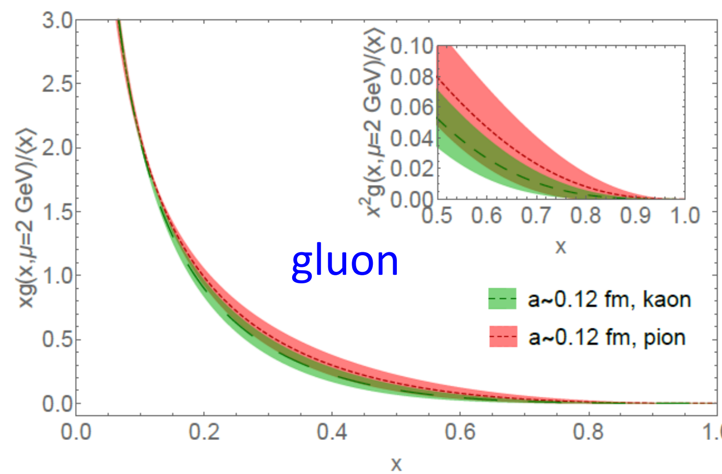
PRD 103, 014516 (2021)



PLB 823, 136778 (2021)



PRD 106, 094510 (2022)



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- **Direct photon**: $\pi, K^{\pm} p \rightarrow \gamma X$ (LO: sensitive to gluons)
  - **LO:** $\boldsymbol{q\bar{q} \rightarrow \gamma G, qG \rightarrow \gamma q}$
- **Jpsi**: $\pi, K^{\pm} p \rightarrow J/\psi X$ (LO: sensitive to gluons)
  - **LO:** $\boldsymbol{q\bar{q} \rightarrow c\bar{c} \rightarrow J/\psi X, GG \rightarrow c\bar{c} \rightarrow J/\psi X}$
  - NLO: $q\bar{q} \rightarrow c\bar{c}G \rightarrow J/\psi X, GG \rightarrow c\bar{c}G \rightarrow J/\psi X, qG \rightarrow c\bar{c}q \rightarrow J/\psi X$
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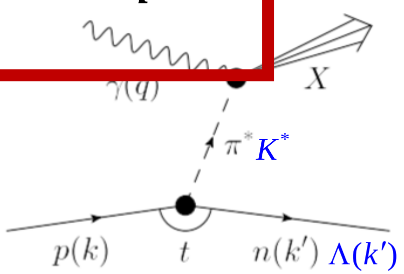
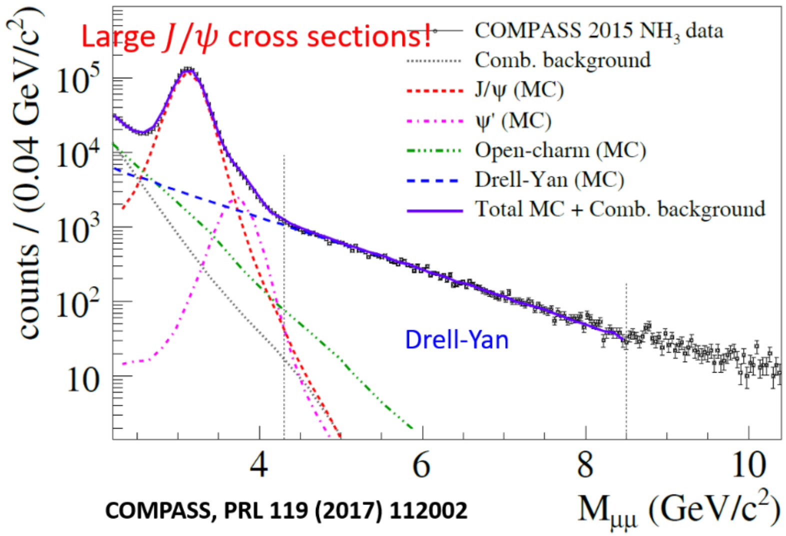


Pion-induced J/psi Production - Fixed-target Experiments

Paper	Reference	Year	Collab	E (GeV)	sqrt(s) (GeV)	Beam	Targets
Fermilab							
Branson	PRL 23, 1331	1977	Princ-Chicago	225	20.5	π-, π+, p	C, Sn
Anderson	PRL 42, 944	1979	E444	225	20.5	π-, π+, K+, p, ap	C, Cu, W
Abramov	Fermi 91-062-E	1991	E672/E706	530	31.5	π-	Be
Kartik	PRD 41, 1	1990	E672	530	31.5	π-	C, AL, Cu, Pb
Katsanevas	PRL 60, 2121	1988	E537	125	15.3	π-, ap	Be, Cu, W
Akerlof	PR D48, 5067	1993	E537	125	15.3	π-, ap	Be, Cu, W
Antoniazzi	PRD 46, 4828	1992	E705	300	23.7	π-, π+	Li
Gribushin	PR D53, 4723	1995	E672/E706	515	31.1	π-	Be
Koreshev	PRL 77, 4294	1996	E706/E672	515	31.1	π-	Be
CERN							
Abolins	PLB 82, 145	1979	WA11/Goliath	150	16.8	π-	Be
McEwen	PLB 121, 198	1983	WA11	190	18.9	π-	Be
Badier	Z.Phys. C20, 101	1983	NA3	150	16.8	π-, π+, K-, K+, p, ap	H, Pt
"	"	1983	NA3	200	19.4	π-, π+, K-, K+, p, ap	H, Pt
"	"	1983	NA3	280	22.9	π-, π+, K-, K+, p, ap	H, Pt
Corden	PLB 68, 96	1977	WA39	39.5	8.6	π-, π+, K-, K+, p, ap	Cu
Corden	PLB 96, 411	1980	WA39	39.5	8.6	π-, π+, K-, K+, p, ap	W
Corden	PLB 98, 220	1981	WA39	39.5	8.6	π-, π+, K-, K+, p, ap	p
Corden	PLB 110, 415	1982	WA40	39.5	8.6	π-, π+, K-, K+, p, ap	p, W
Alexandrov	NPB 557, 3	1999	Beatrice	350	25.6	π-	Si, C, W



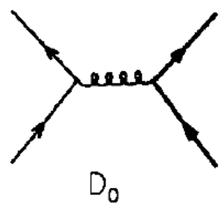
COMPASS, PRL 119 (2017) 112002

LO & NLO Diagrams of $c\bar{c}$ Production

LO

A. Petrelli et al./Nuclear Physics B 514 (1998) 245–309

$q\bar{q}$



GG

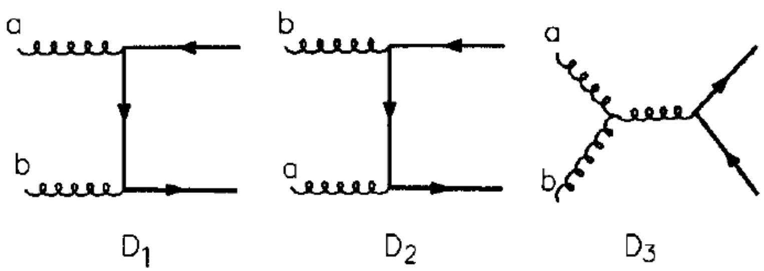
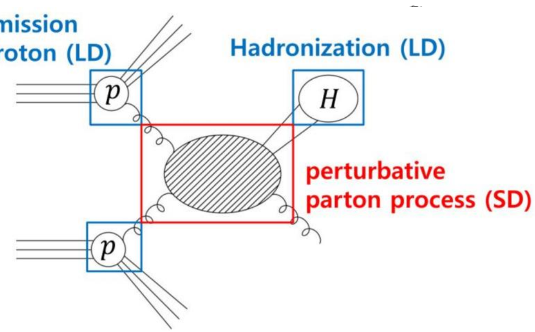


Fig. 2. Diagrams for the $q\bar{q}$ and g



NLO

A. Petrelli et al./Nuclear Physics B 514 (1998) 245–309 287

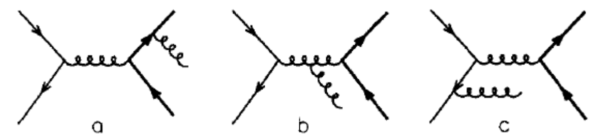
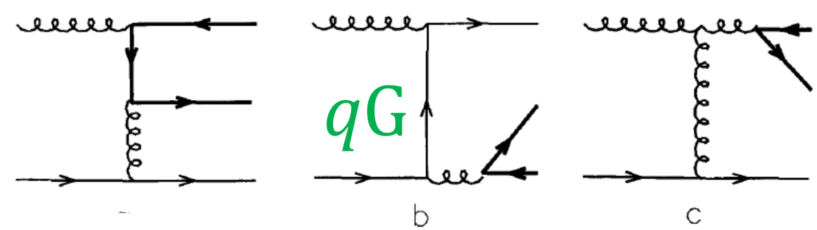


Fig. 8. Diagrams for the real corrections to the $q\bar{q}$ channels. Permutations of outgoing gluons and/or reversal of fermion lines are always implied.

286 A. Petrelli et al./Nuclear Physics B 514 (1998) 245–309

qG



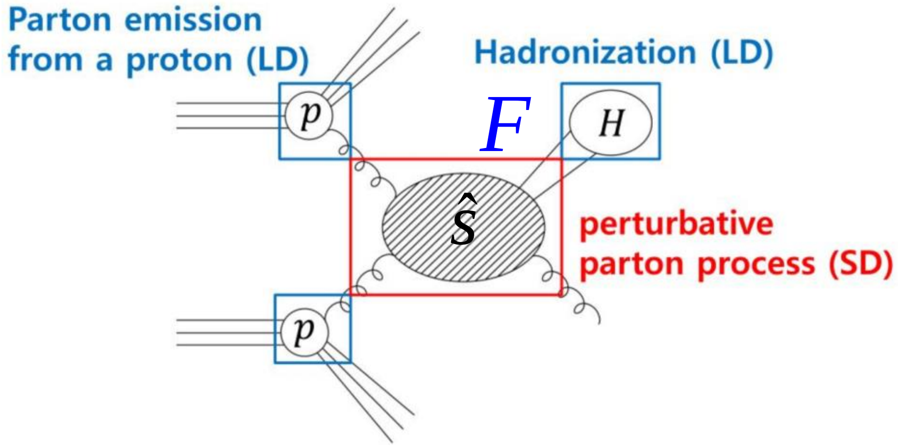
the gq channels. Reversal of fermion lines is always implied.

Color Evaporation Model

$$\sigma[AB \to J/\psi X]$$

$$= F \sum_{i,j} \int_{2m_c}^{2m_D} d\hat{s} \int dx_1 dx_2 \, f_{i/A}(x_1, \mu_F) f_{j/B}(x_2, \mu_F)$$

$$\hat{\sigma}[ij \to c\bar{c}X](x_1 P_A, x_2 P_B, \mu_F, \mu_R) \delta(\hat{s} - x_1 x_2 s)$$



$$\left.\frac{d\sigma}{dx_F}\right|_{J/\psi} = F \sum_{i,j=q,\bar{q},G} \int_{2m_c}^{2m_D} dM_{c\bar{c}} \frac{2M_{c\bar{c}}}{s\sqrt{x_F^2 + 4M_{c\bar{c}}^2/s}} \times f_i^{\pi}(x_1, \mu_F) f_j^N(x_2, \mu_F) \times \hat{\sigma}[ij \to c\bar{c}X](x_1 p_\pi, x_2 p_N, \mu_F, \mu_R),$$

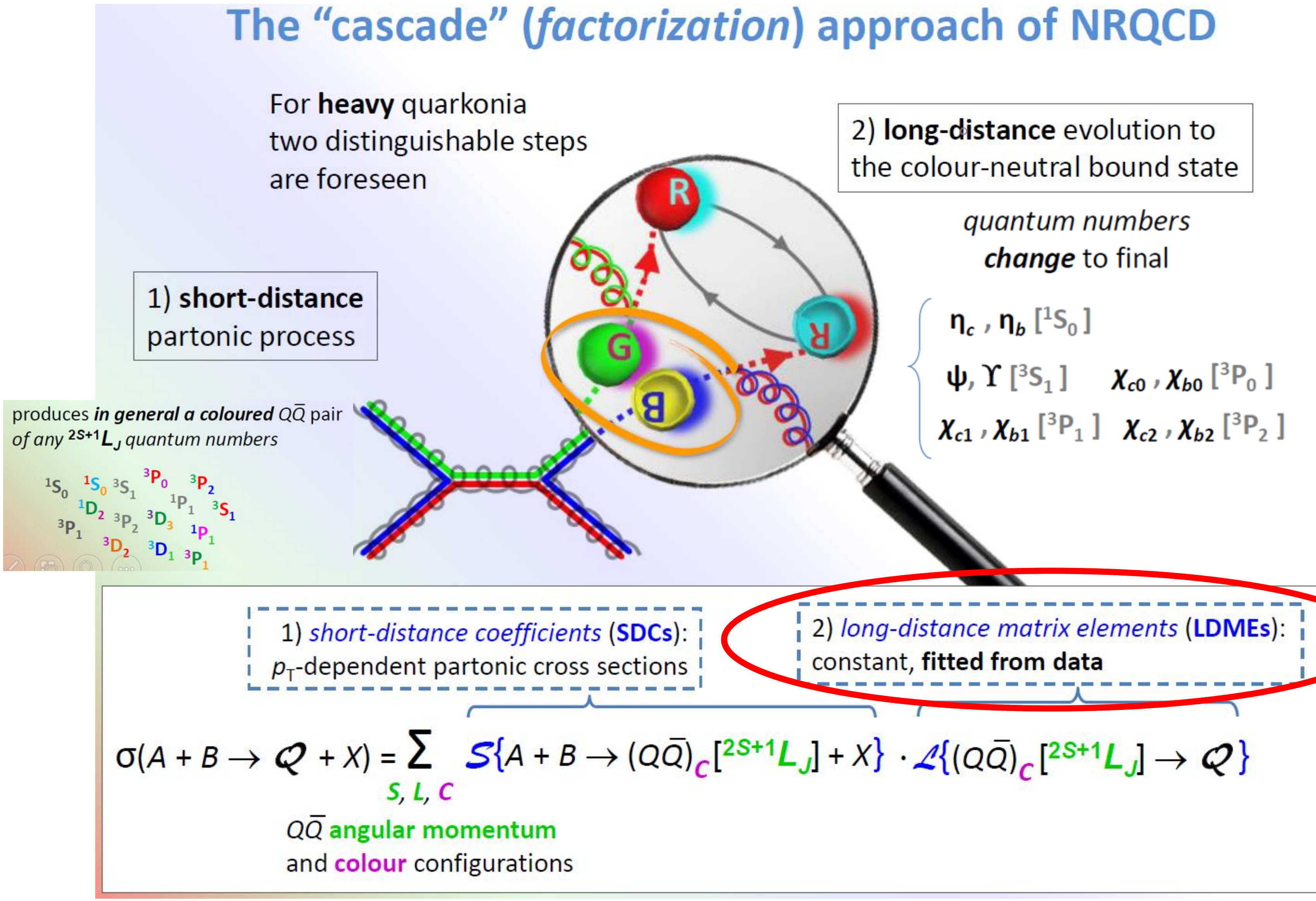
$$x_F = 2p_L/\sqrt{s}, \qquad x_{1,2} = \frac{\sqrt{x_F^2 + 4M_{c\bar{c}}^2/s} \pm x_F}{2},$$

LO/NLO calculations of $\hat{\sigma}[ij \to c\bar{c}X]$:

- P.Nason, S. Dawson and R.K. Ellis, Nucl. Phys. B303 (1988) 607
- M.L. Mangano, P. Nason and G. Ridolfi, Nucl. Phys. B405 (1993) 507

https://agenda.infn.it/event/20446/contributions/124767/attachments/76906/99037/PietroFaccioli_Trieste2020.pdf

NRQCD



Color evaporation model (CEM)

Phys. Rev. D 102, 054024 (2020); arXiv: 2006.06947

PHYSICAL REVIEW D **102,** 054024 (2020)

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

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(Received 12 June 2020; accepted 8 September 2020; published 24 September 2020)

The gluon distributions of the pion obtained from various global fits exhibit large variations among them. Within the framework of the color evaporation model, we show that the existing pion-induced J/ψ

Non-relativistic QCD model (NRQCD)

Chin.J.Phys. 73 (2021) 13; arXiv: 2103.11660

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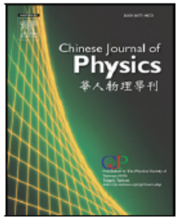

Check for updates

NRQCD analysis of charmonium production with pion and proton beams at fixed-target energies

Chia-Yu Hsieh [a,b,1], Yu-Shiang Lian [a,c,1], Wen-Chen Chang [a,*], Jen-Chieh Peng [d], Stephane Platchkov [e], Takahiro Sawada [f]

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[b] Department of Physics, National Central University, 300 Jhongda Road, Jhongli 32001, Taiwan
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ARTICLE INFO

Keywords:
Charmonium production
Pion PDFs
NRQCD
Color-octet matrix elements
Gluon

ABSTRACT

We present an analysis of hadroproduction of J/ψ and $\psi(2S)$ at fixed-target energies in the framework of non-relativistic QCD (NRQCD). Using both pion- and proton-induced data, a new determination of the color-octet long-distance matrix elements (LDMEs) is obtained. Compared with previous results, the contributions from the $q\bar{q}$ and color-octet processes are significantly enhanced, especially at lower energies. A good agreement between the pion-induced J/ψ production data and NRQCD calculations using the newly obtained LDMEs is achieved. We find that the pion-induced charmonium production data are sensitive to the gluon density of pions, and favor pion PDFs with relatively large gluon contents at large x.

Non-relativistic QCD model (NRQCD)

[Phys. Rev. D 107, 056008 (2023)]; [arXiv: 2209.04072]

PHYSICAL REVIEW D **107,** 056008 (2023)

Fixed-target charmonium production and pion parton distributions

Wen-Chen Chang,[1] Jen-Chieh Peng,[2] Stephane Platchkov,[3] and Takahiro Sawada[4]

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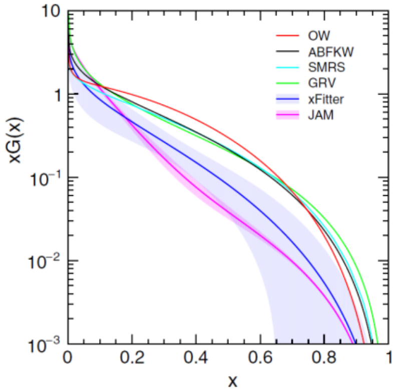
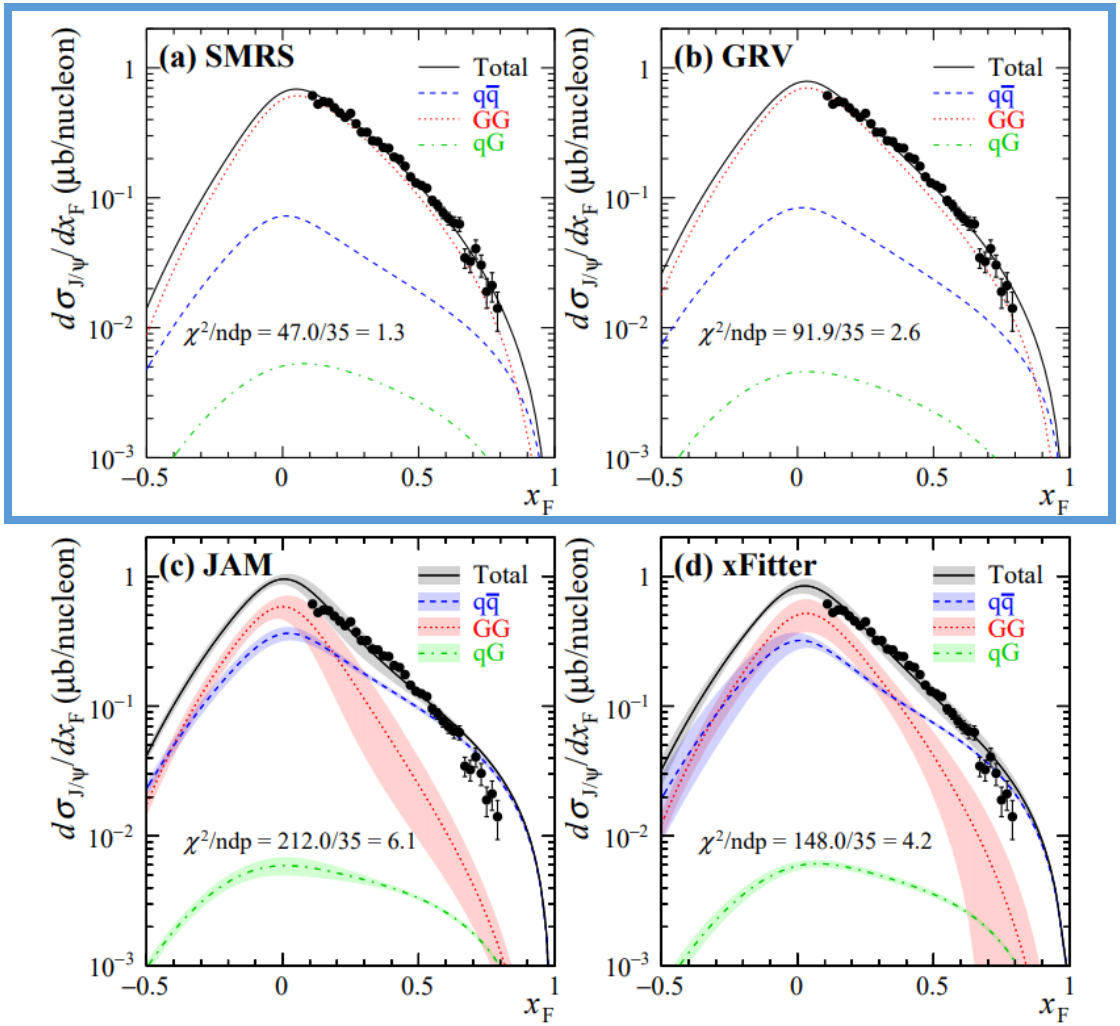
(Received 8 September 2022; accepted 31 January 2023; published 7 March 2023)

We investigate how charmonium hadroproduction at fixed-target energies can be used to constrain the gluon distribution in pions. Using nonrelativistic QCD (NRQCD) formulation, the J/ψ and $\psi(2S)$ cross sections as a function of longitudinal momentum fraction x_F from pions and protons colliding with light targets, as well as the $\psi(2S)$ to J/ψ cross section ratios, are included in the analysis. The color-octet long-distance matrix elements are found to have a pronounced dependence on the pion parton distribution functions (PDFs). This study shows that the x_F differential cross sections of pion-induced charmonium production impose strong constraints on the pion's quark and gluon PDFs. In particular, the pion PDFs with larger gluon densities provide a significantly better description of the data. It is also found that the production of the $\psi(2S)$ state is associated with a larger quark-antiquark contribution, compared with J/ψ.

Data vs. NRQCD

[$\pi^- + Be \rightarrow Jpsi + X$ at 515 GeV, PRD 53, 4723 (1996)]

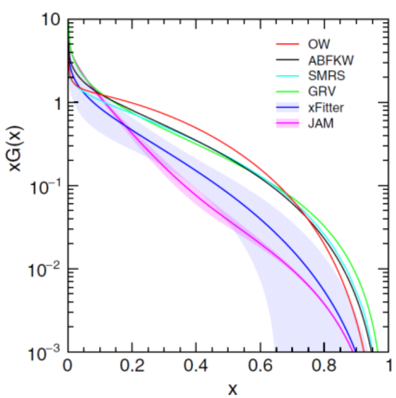


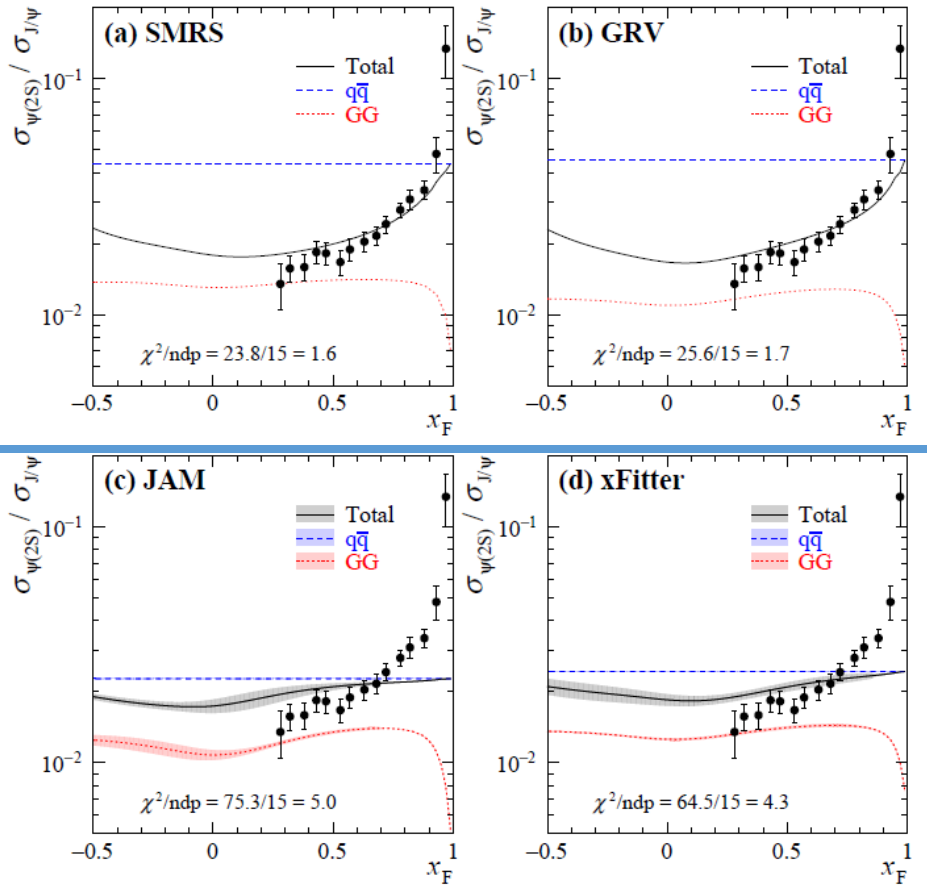


Data favor SMRS and GRV PDFs with larger gluon densities at x > 0.1.

Data vs. NRQCD

[$\pi^- + W \rightarrow Jpsi/psi' + X$ at 252 GeV, PRD 44, 1909 (1991)]





Data favor SMRS and GRV PDFs with larger gluon densities at x > 0.1.

Kaon PDFs

PLB 855,138820, (2024); arXiv: 2402.02860

Phys. Lett. B 855 (2024) 138820

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Letter

Constraining kaon PDFs from Drell-Yan and J/ψ production

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ARTICLE INFO

Editor: H. Gao

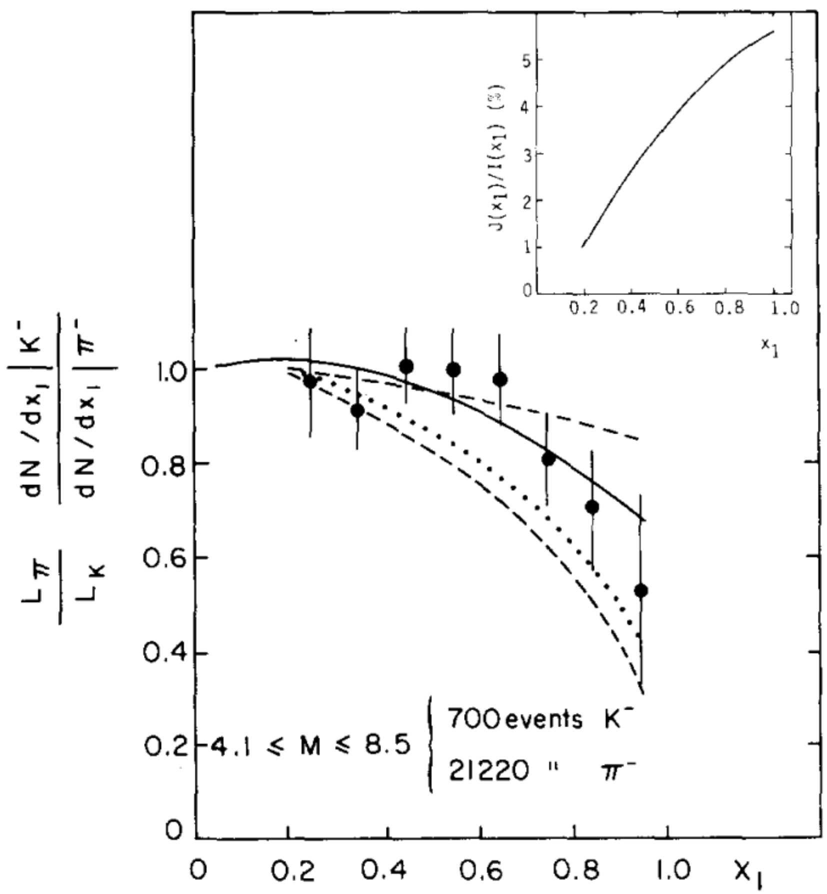
ABSTRACT

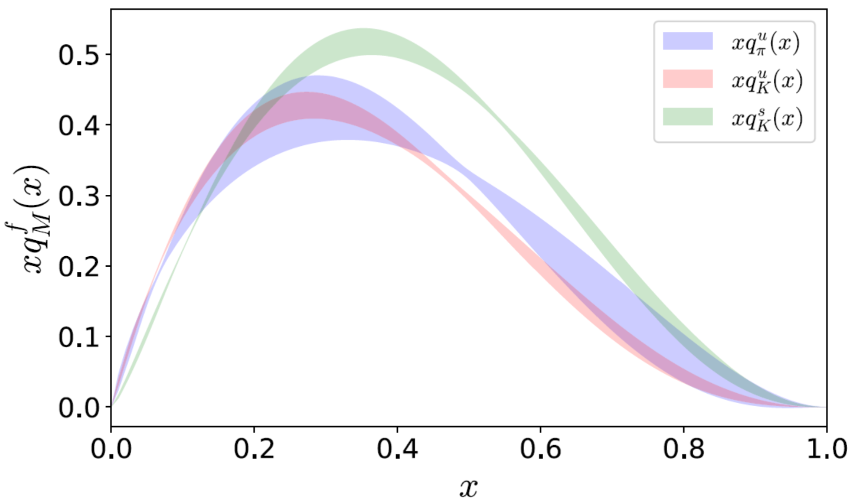
The kaon parton distribution functions (PDFs) are poorly known due to paucity of kaon-induced Drell-Yan data. Nevertheless, these Drell-Yan data suggest a softer valence u quark distribution of the kaon compared to that of the pion. We discuss the opportunity to constrain the kaon PDFs utilizing the existing kaon-induced J/ψ production data. We compare the K^-/π^- and K^+/π^+ cross-section ratio data with calculations based on two global-fit parametrizations and two recent theoretical predictions for the kaon and pion PDFs, and test the results with two quarkonium production models. The K^-/π^- cross-section ratio for J/ψ production provides independent evidence of different valence quark distributions in pion and kaon. The K^+/π^+ J/ψ data are found to be sensitive to the gluon distribution in kaon. We show that these J/ψ production data provide valuable constraints for evaluating the adequacy of currently available sets of kaon PDFs.

Kaon/Pion Drell-Yan Ratios

NA10: J. Badier et al., Phys. Lett. B 93, 354 (1980)

$$\frac{\sigma^{DY}(K^-)}{\sigma^{DY}(\pi^-)}(x_F) = \frac{\bar{u}^K(x_1)u^N(x_2)}{\bar{u}^\pi(x_1)u^N(x_2)} = \frac{\bar{u}^K}{\bar{u}^\pi}(x_1)$$





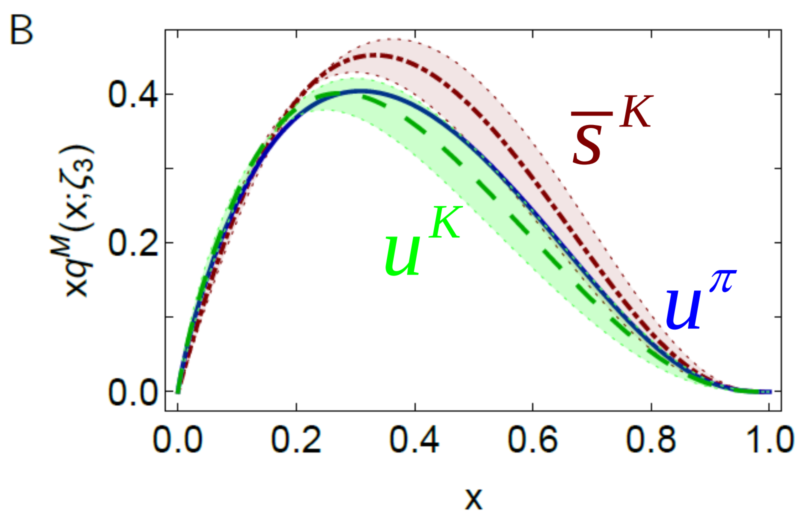
The $\bar{u}$ distribution of kaon is softer than pion's.

Kaon PDFs: Dyson-Schwinger Equation (DSE)

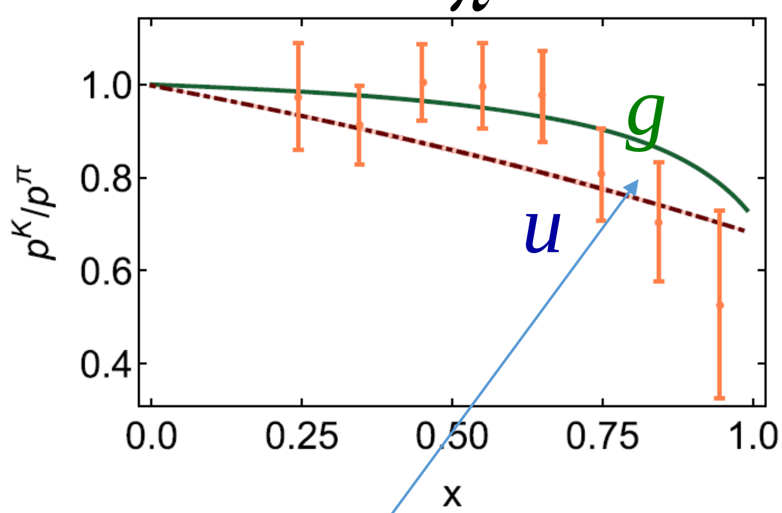
Eur. Phys. J. C (2020) 80:1064

This paper contains comprehensive numerical information of determined kaon/pion PDFs.

Q=3.1 GeV



$\frac{K}{\pi}$

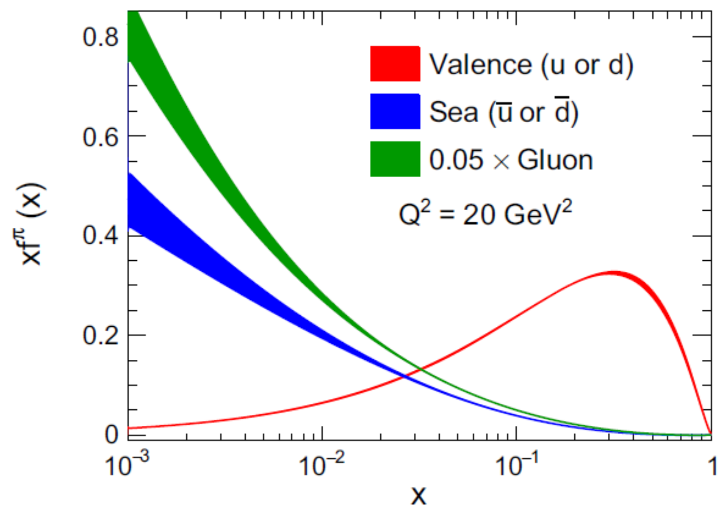


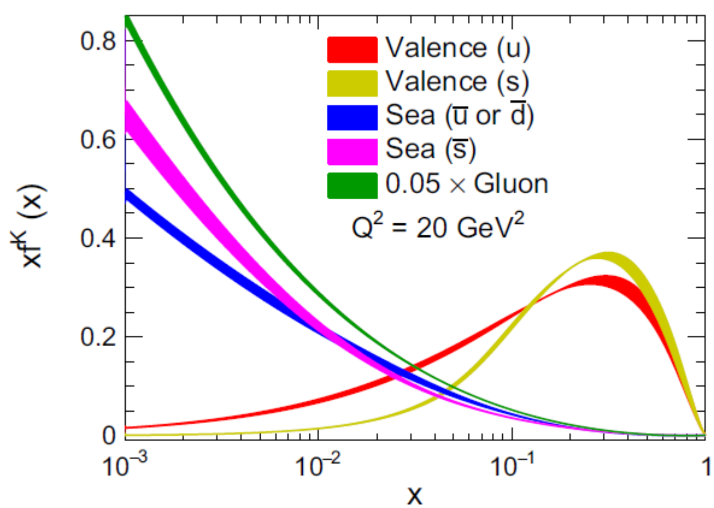
$$\langle x[2u^\pi(x;\zeta_3) + g^\pi(x;\zeta_3) + S^\pi(x;\zeta_3)]\rangle = 1$$

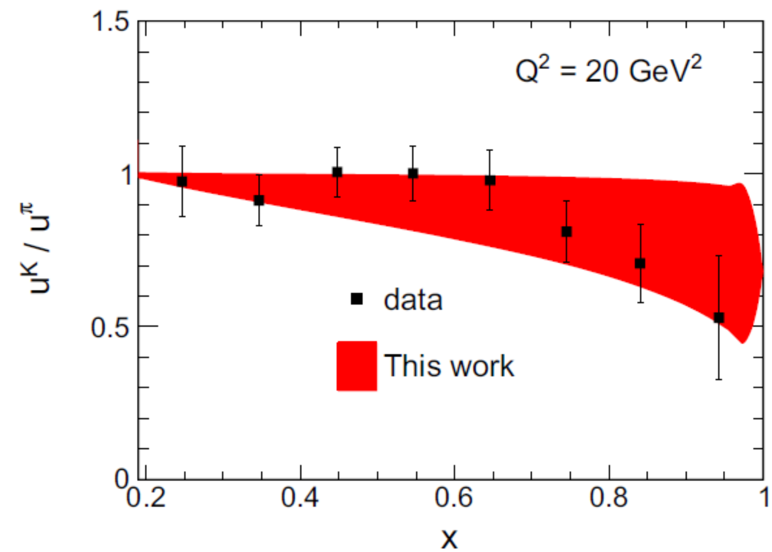
A slightly smaller kaon gluon distribution at large x, compared to the pion.

Kaon PDFs: Maximum Entropy Input

Eur. Phys. J. C (2021) 81:302



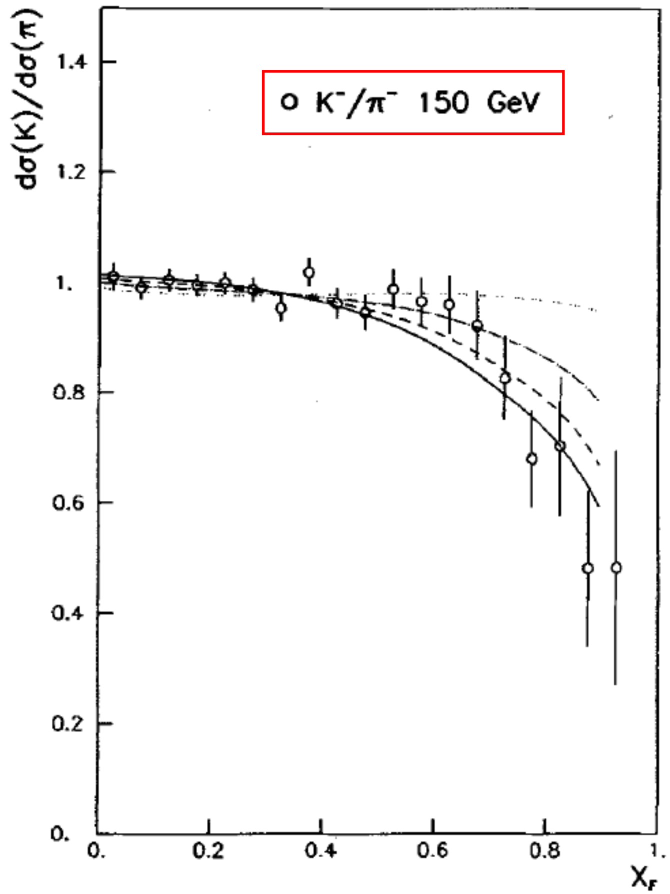


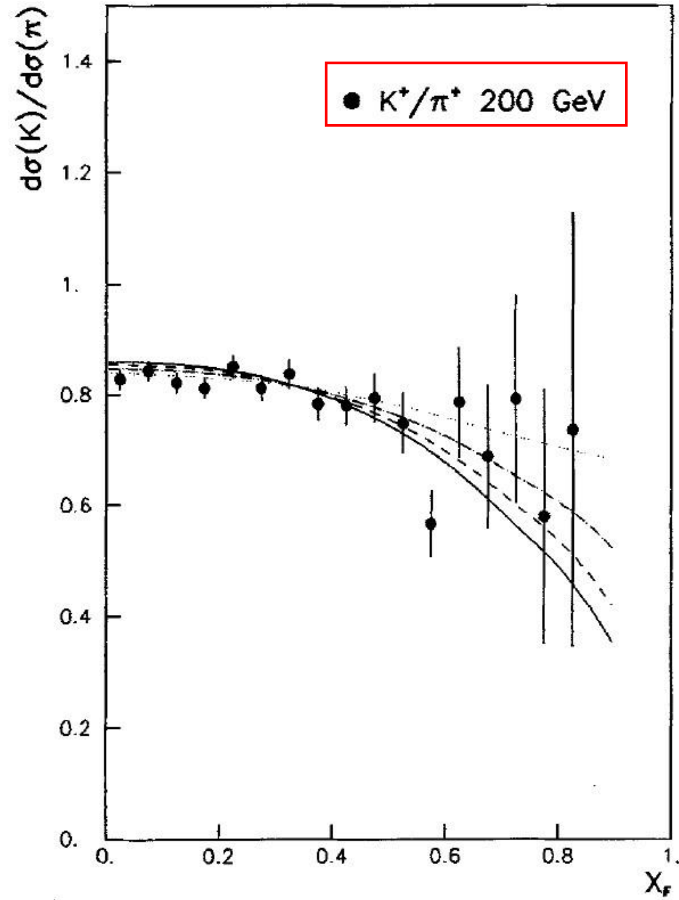


Kaon/Pion Jpsi Ratios

NA3: Z. Phys. C 20, 101 (1983)

$$\frac{\sigma^{Jpsi}(K^-)}{\sigma^{Jpsi}(\pi^-)}(x_F) = \frac{\sigma(\bar{u}^K(x_1)u^N(x_2)) + \sigma(G^K(x_1)G^N(x_2))}{\sigma(\bar{u}^\pi(x_1)u^N(x_2)) + \sigma(G^\pi(x_1)G^N(x_2))} \quad \frac{\sigma^{Jpsi}(K^+)}{\sigma^{Jpsi}(\pi^+)}(x_F) = \frac{\sigma(u^K(x_1)\bar{u}^N(x_2)) + \sigma(\bar{s}^K(x_1)s^N(x_2)) + \sigma(G^K(x_1)G^N(x_2))}{\sigma(u^\pi(x_1)\bar{u}^N(x_2)) + \sigma(\bar{d}^\pi(x_1)d^N(x_2)) + \sigma(G^\pi(x_1)G^N(x_2))}$$

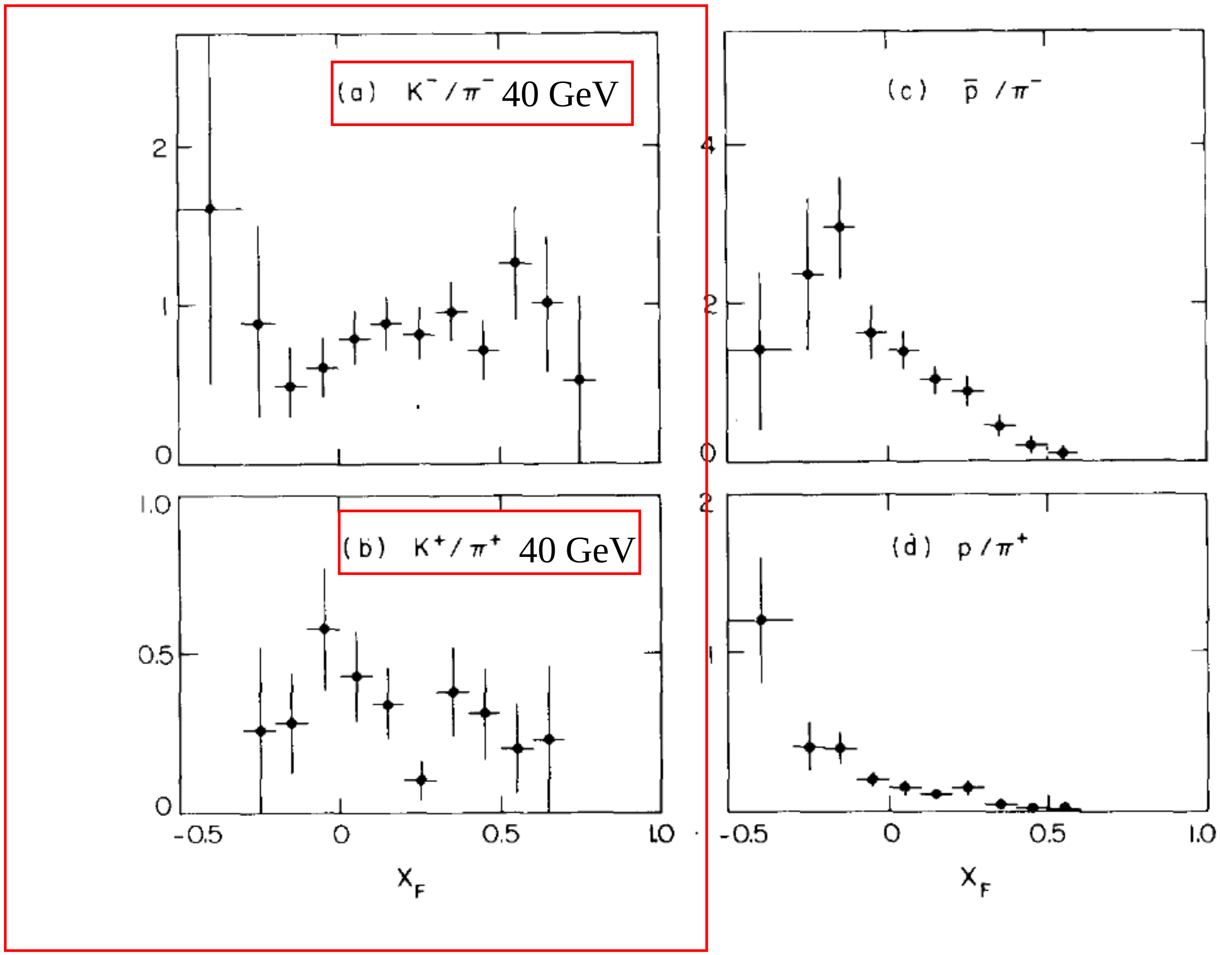




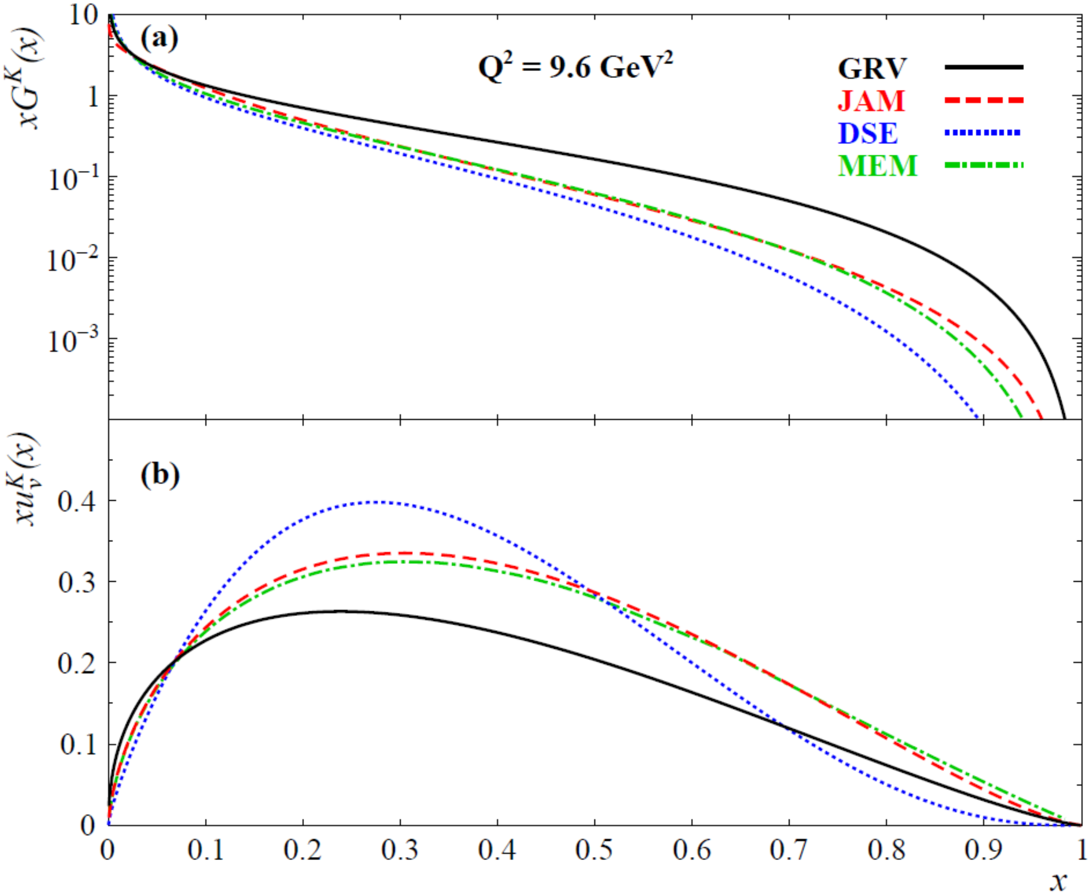
Kaon/Pion Jpsi Ratios

WA39: Phys. Lett. B 96, 411 (1980)

$$\frac{\sigma^{Jpsi}(K^-)}{\sigma^{Jpsi}(\pi^-)}(x_F) = \frac{\sigma(\bar{u}^K(x_1)u^N(x_2)) + \sigma(G^K(x_1)G^N(x_2))}{\sigma(\bar{u}^\pi(x_1)u^N(x_2)) + \sigma(G^\pi(x_1)G^N(x_2))} \quad \frac{\sigma^{Jpsi}(K^+)}{\sigma^{Jpsi}(\pi^+)}(x_F) = \frac{\sigma(u^K(x_1)\bar{u}^N(x_2)) + \sigma(\bar{s}^K(x_1)s^N(x_2)) + \sigma(G^K(x_1)G^N(x_2))}{\sigma(u^\pi(x_1)\bar{u}^N(x_2)) + \sigma(\bar{d}^\pi(x_1)d^N(x_2)) + \sigma(G^\pi(x_1)G^N(x_2))}$$



Kaon PDFs:
GRV, JAM, DSE, MEM

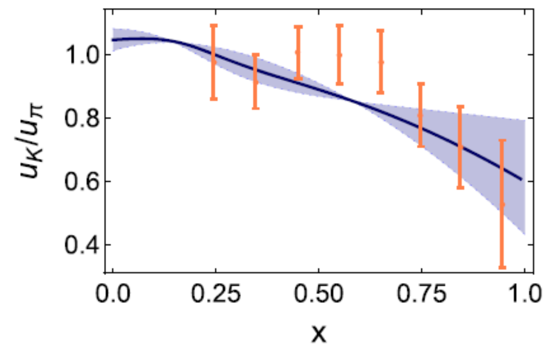


K (GRV, JAM): GRS ansatz

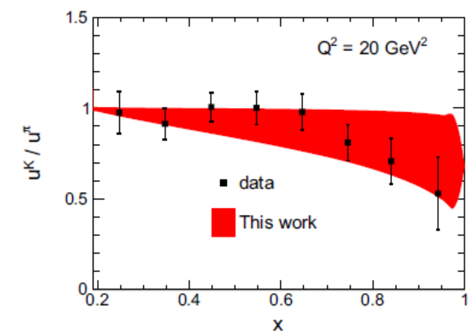
$$\bar{u}_v^K(x) = N_u \bar{u}_v^\pi(x)(1-x)^{0.17}$$

$$s_v^K(x) = 2\bar{u}_v^\pi(x) - \bar{u}_v^K(x)$$

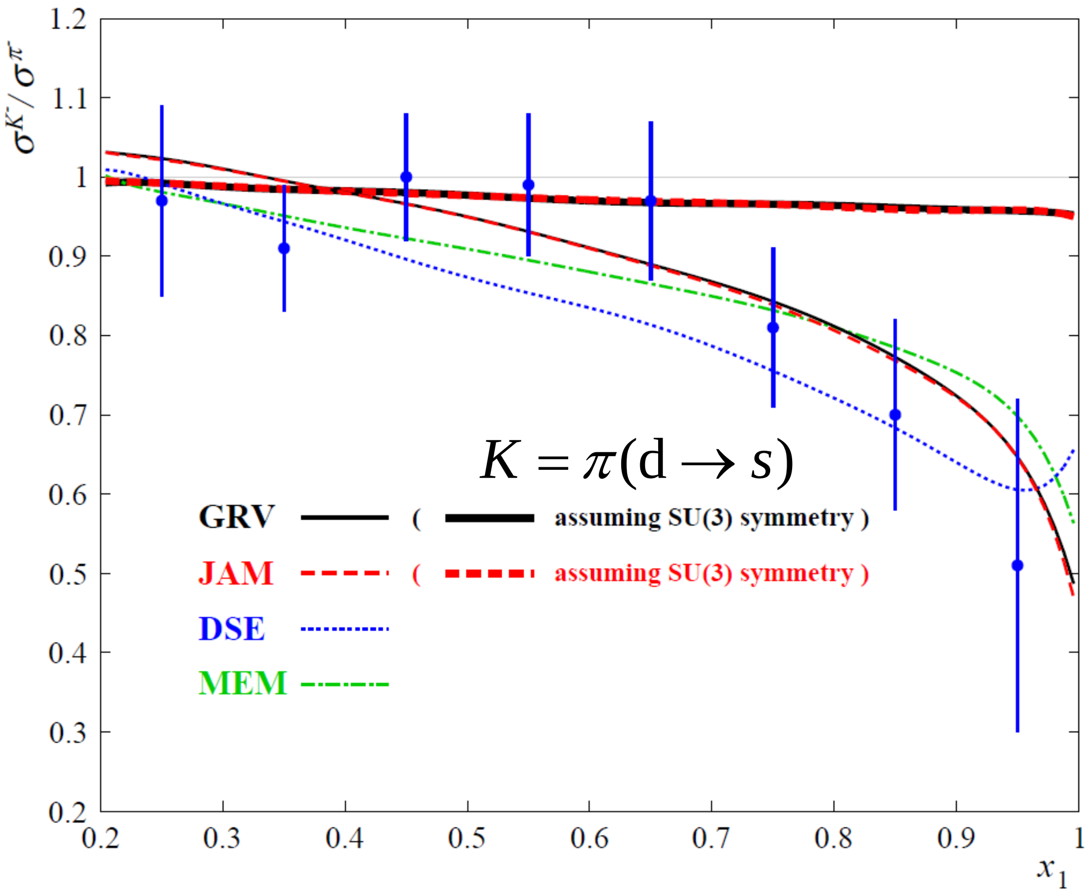
DSE: Eur. Phys. J. C (2020) 80:1064

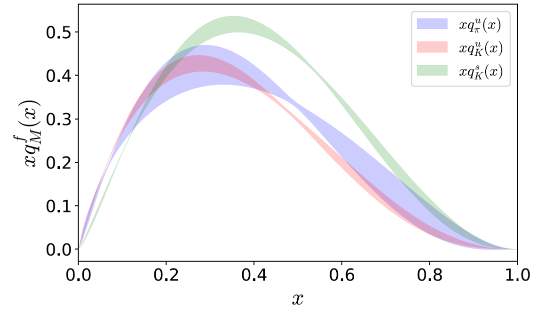


MEM: Eur. Phys. J. C (2021) 81:302



K/pion Drell-Yan Ratios



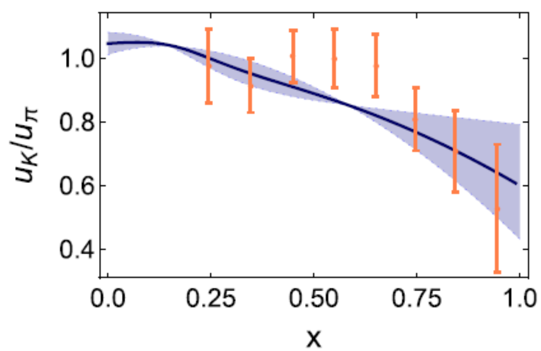


GRV, JAM: GRS ansatz

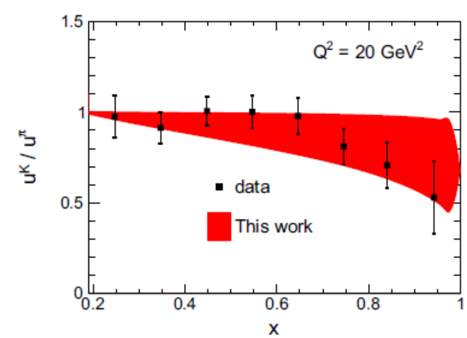
$$\bar{u}_v^K(x) = N_u \bar{u}_v^\pi(x)(1-x)^{0.17}$$

$$s_v^K(x) = 2\bar{u}_v^\pi(x) - \bar{u}_v^K(x)$$

DSE: Eur. Phys. J. C (2020) 80:1064

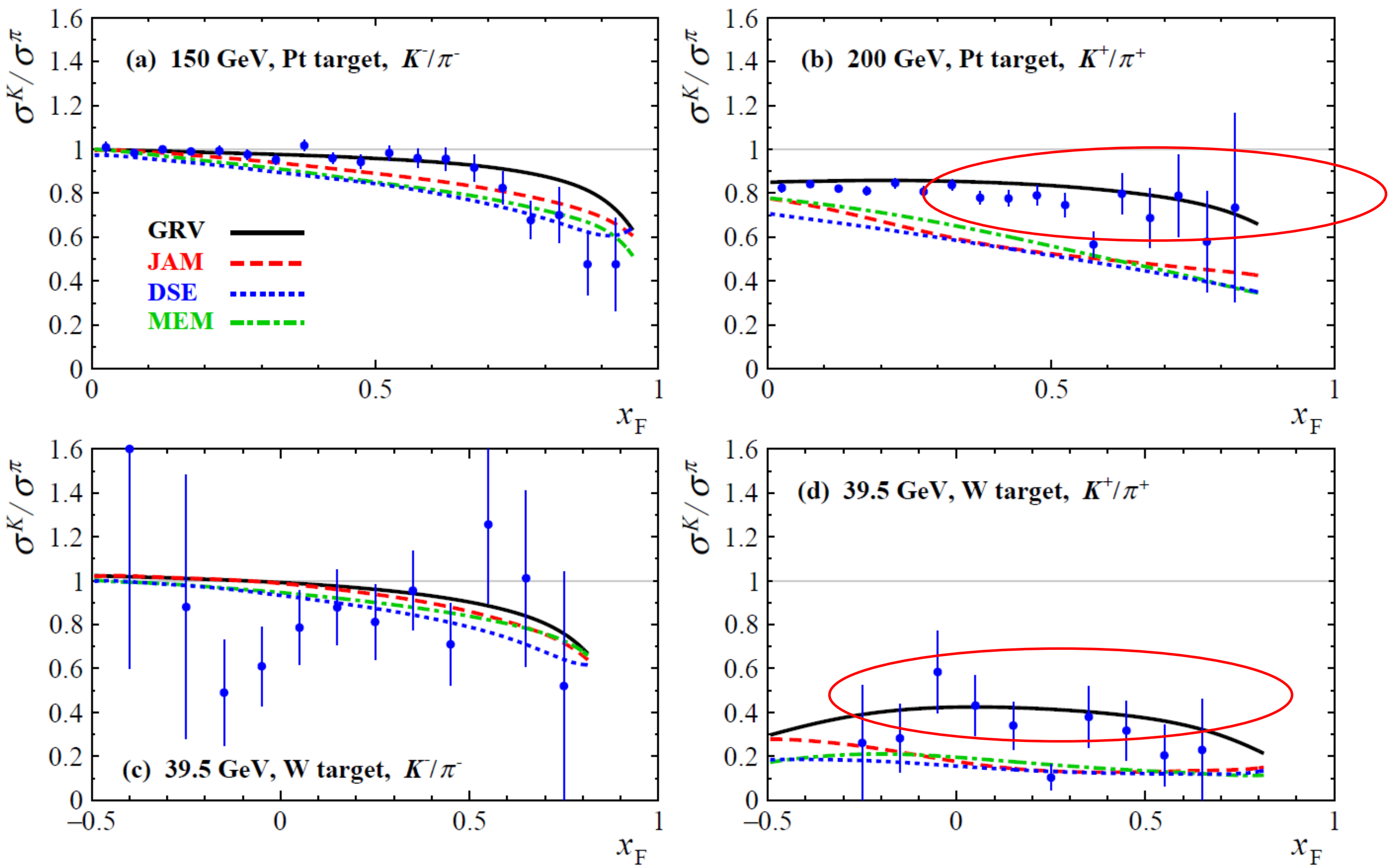


MEM: Eur. Phys. J. C (2021) 81:302



K/pion Jpsi Ratios: CEM

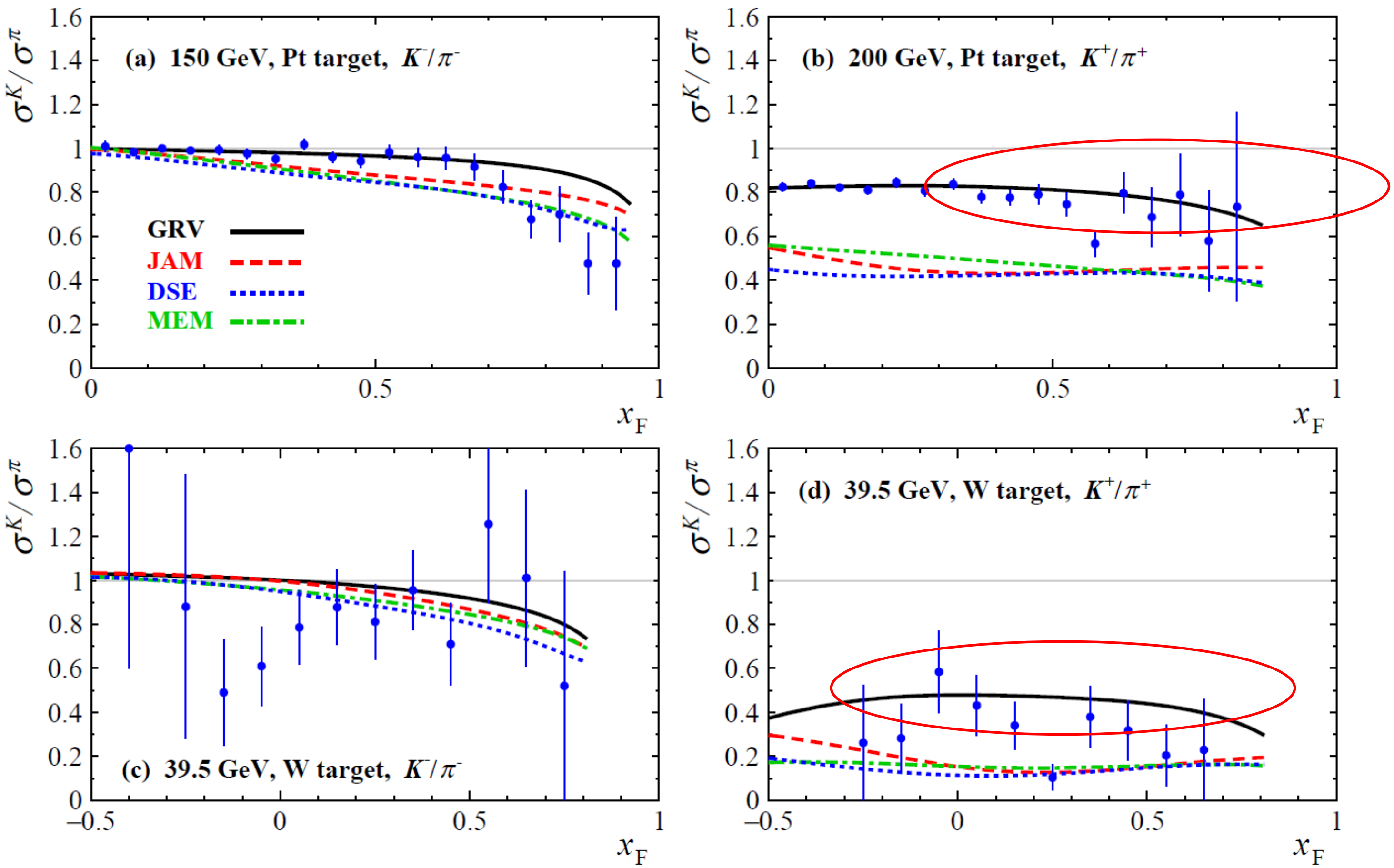
W.C. Chang et al., PLB 855, 138820 (2024); arXiv: 2402.02860



Data favor GRV PDFs with larger gluon densities at x > 0.1.

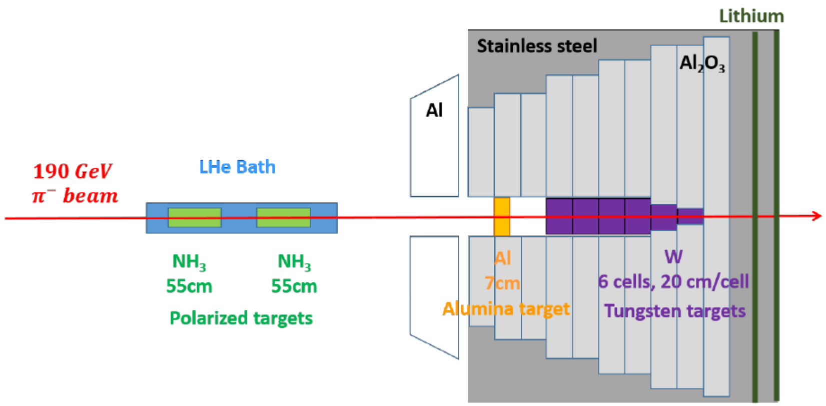
K/pion Jpsi Ratios: NRQCD

W.C. Chang et al., PLB 855, 138820 (2024); arXiv: 2402.02860



Data favor GRV PDFs with larger gluon densities at x > 0.1.

COMPASS
:190 GeV π^--induced DY/Jpsi

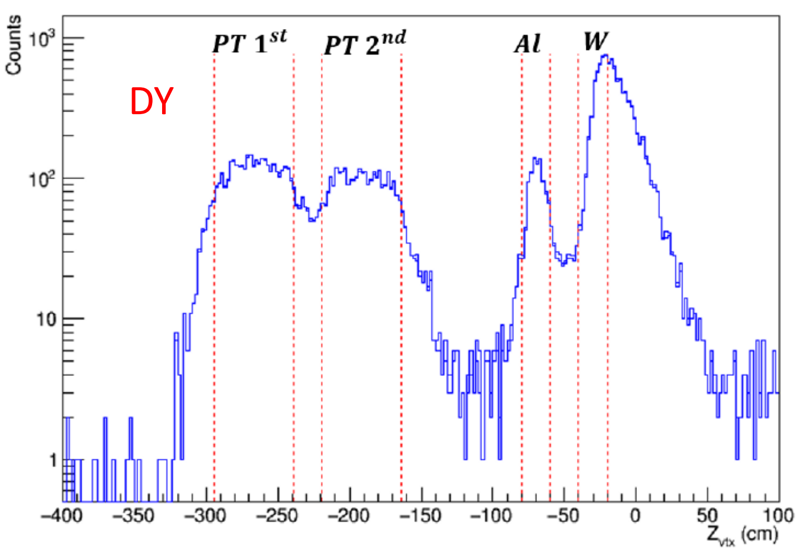


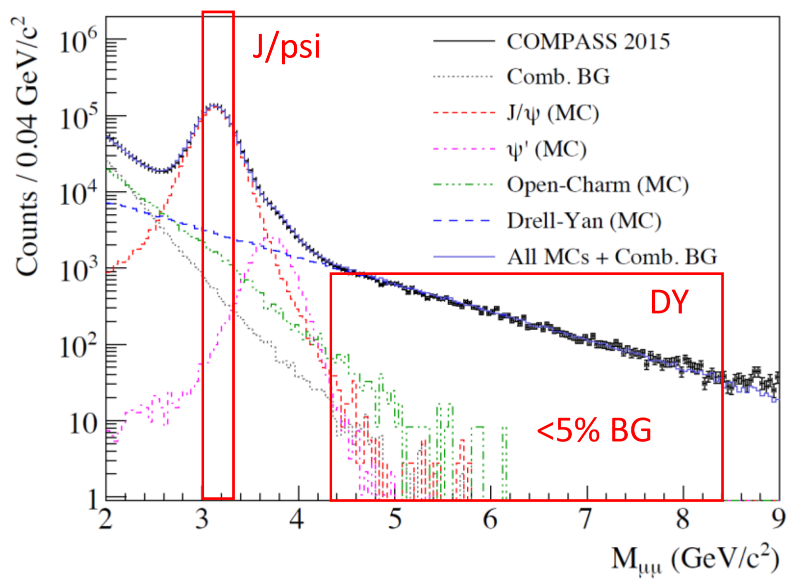
$\pi^- + p \rightarrow \mu + \mu^- + X$

π^- beam | NH_3, Al, W targets | *Dimuon events* | *Hadron absorber*

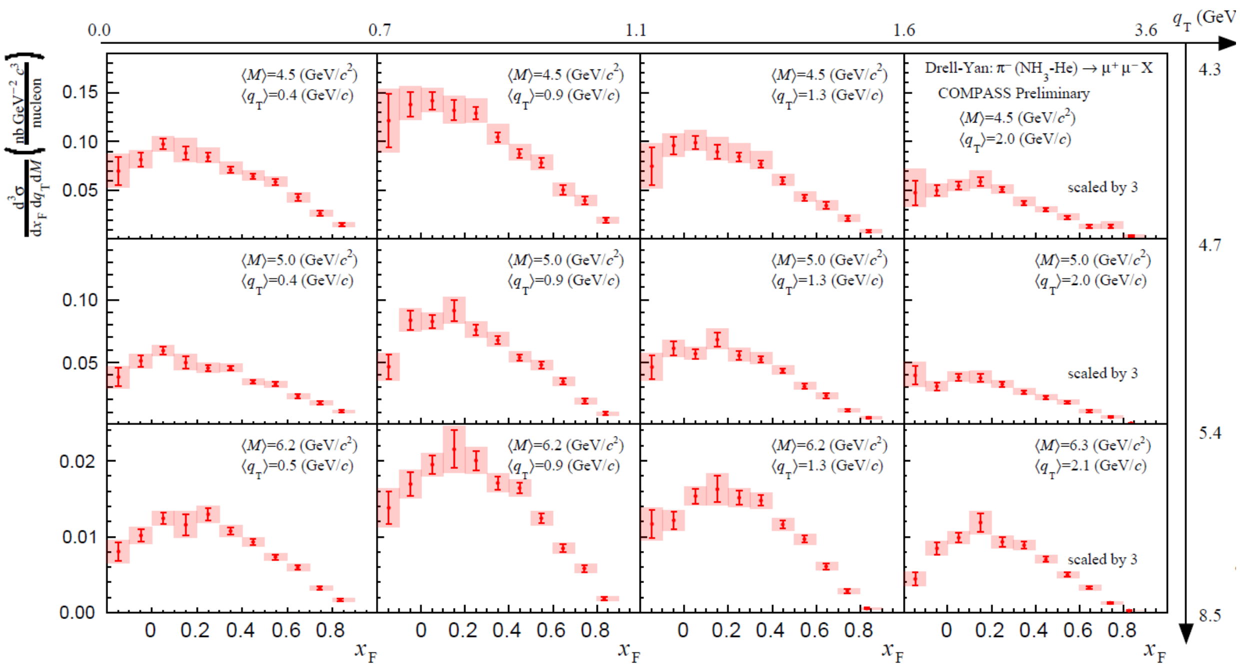
- **Beam : ** 190 GeV π^-
- **Target :**

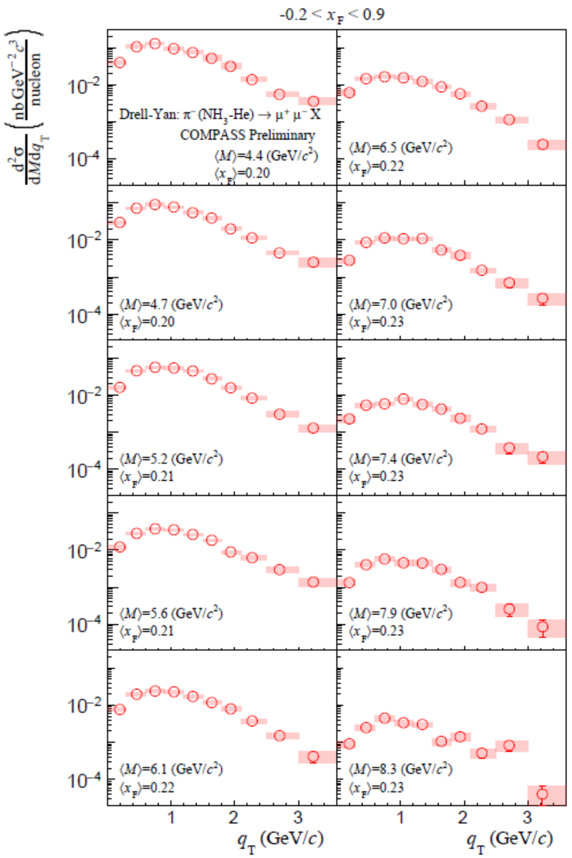
Polarized ammonia targets(PT), Al, W





COMPASS
:190 GeV π^--induced DY





Important information to construct the PDFs and transverse-momentum distributions of pions

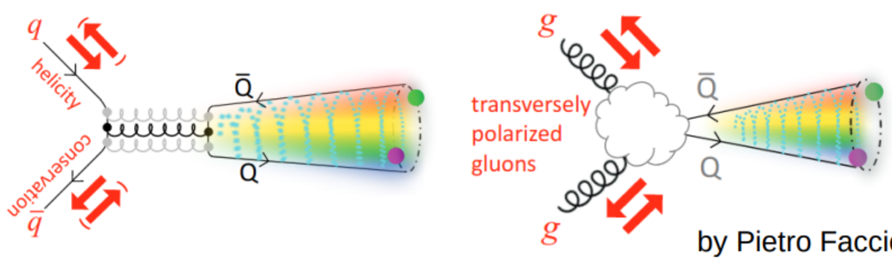
SPIN2023 https://indico.jlab.org/event/663/contributions/13272/

AMBER
:$\pi^{\pm}$/ $K^{\pm}$ -induced DY/Jpsi

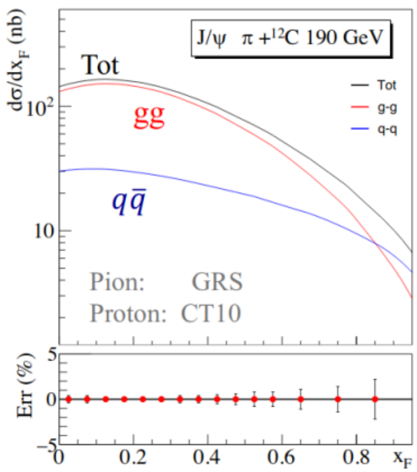
AMBER Apparatus for Meson and Baryon Experimental Research

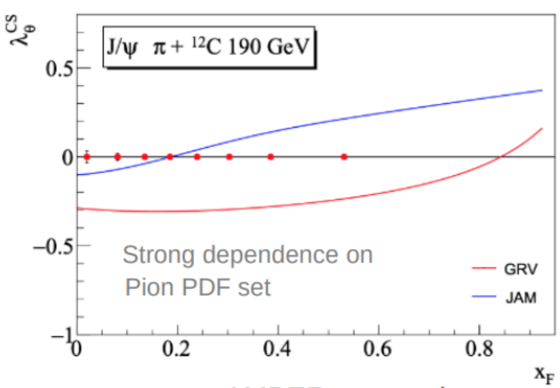
Phase-I: J/Ψ & Gluon content in the pion

- Large statistics on J/ψ production at dimuon channel
- Inclusive: due to the hadron absorber, we cannot distinguish prompt production from the rest
- Expected significant feed-down: ψ(2S), χ_{c1}, χ_{c2}
- In the low-pT regime
- Expected to have dominant contribution from $2 \rightarrow 1$ processes
- Use J/ψ polarization to distinguish production mechanism:



by Pietro Faccioli





AMBER proposal

https://indico.lip.pt/event/1183/contributions/4269/attachments/3462/5360/CQuintans_Jornadas2022.pdf

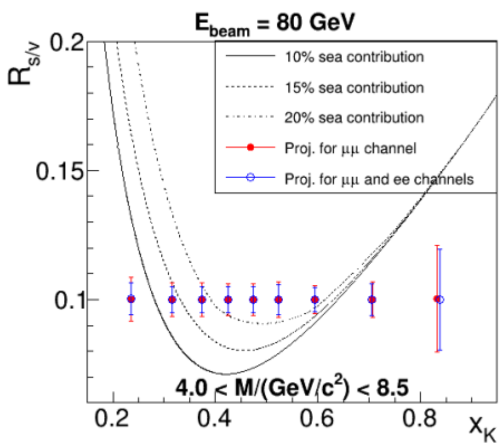
AMBER
: $\pi^{\pm}$/ $K^{\pm}$ -induced DY/Jpsi

AMBER
Apparatus for Meson and Baryon Experimental Research

Phase-II: Kaon structure

Kaon structure: a window to the region of interference between the Higgs mechanism and the EHM mechanism

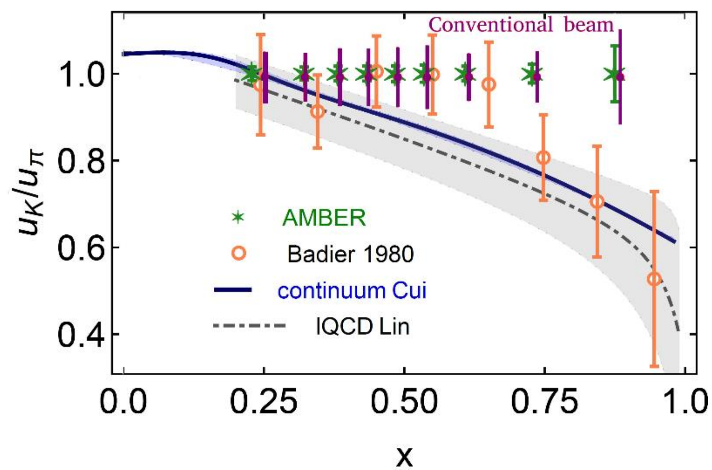
The only available experimental data:
NA3 → 200 GeV K⁻ beam on 6 cm Pt target
→ 700 kaon-induced Drell-Yan events



Kaon sea-valence separation using both charges kaon beams:

$$R_{s/v} = \frac{\sigma^{K^+C}}{\sigma^{K^-C} - \sigma^{K^+C}} \propto u_v^K u_v^p$$

Z-F. Cui, *et al.* EPJC80(2020)1064, H-W. Lin *et al.*, PRD103(2021)014516



Assumed an RF-separated beam of 2 x 10⁷ kaons/second.

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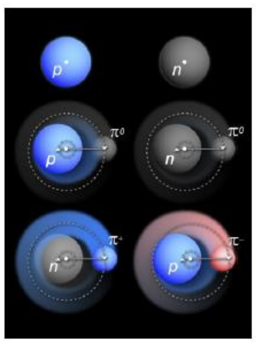
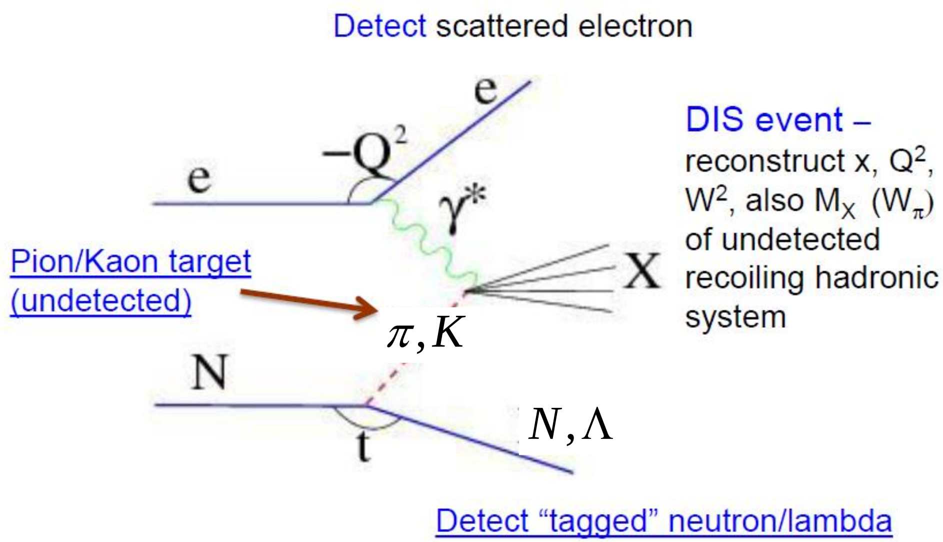
https://indico.lip.pt/event/1183/contributions/4269/attachments/3462/5360/CQuintans_Jornadas2022.pdf

EIC: Tagged processes of DIS

Physics Objects for Pion/Kaon Structure Studies

- ❑ Sullivan process – scattering from nucleon-meson fluctuations





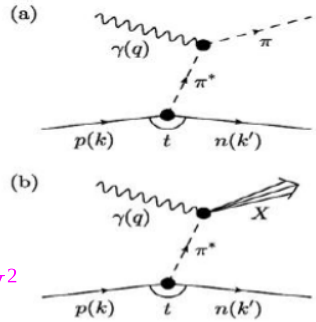
https://indico.bnl.gov/event/8315/contributions/36990/attachments/28487/43882/CFNS-Pion-Kaon-Structure-Horn-nbk.pdf

https://arxiv.org/abs/1907.08218

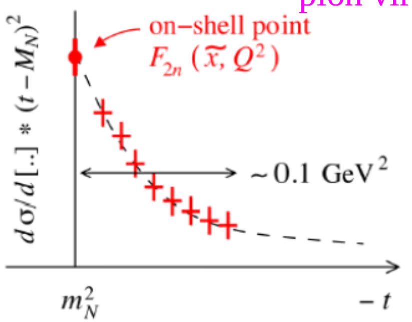
EIC: Sullivan Process

Pion and Kaon Sullivan Process

❑ The **Sullivan process can provide reliable access to a meson target** as *t* becomes space-like if the pole associated with the ground-state meson remains the dominant feature of the process and the structure of the related correlation evolves slowly and smoothly with virtuality.



pion virtuality $v_\pi = \frac{m_\pi^2 - t}{m_\pi^2} \leq 30 \rightarrow -t \leq 0.6\ \mathrm{GeV}^2$



❑ To **check these conditions** are satisfied empirically, one can **take data covering a range in *t*** and compare with phenomenological and theoretical expectations.

❑ Recent **theoretical calculations found that for -t ≤ 0.6 GeV^2, all changes in pion structure are modest** so that a well-constrained experimental analysis should be reliable Similar analysis for the kaon indicates that Sullivan processes can provide a valid kaon target for -t ≤ 0.9 GeV^2

*[S.-X. Qin, C. Chen, C. Mezrag and C. D. Roberts, Phys. Rev. C **97** (**2018**) 015203.]*

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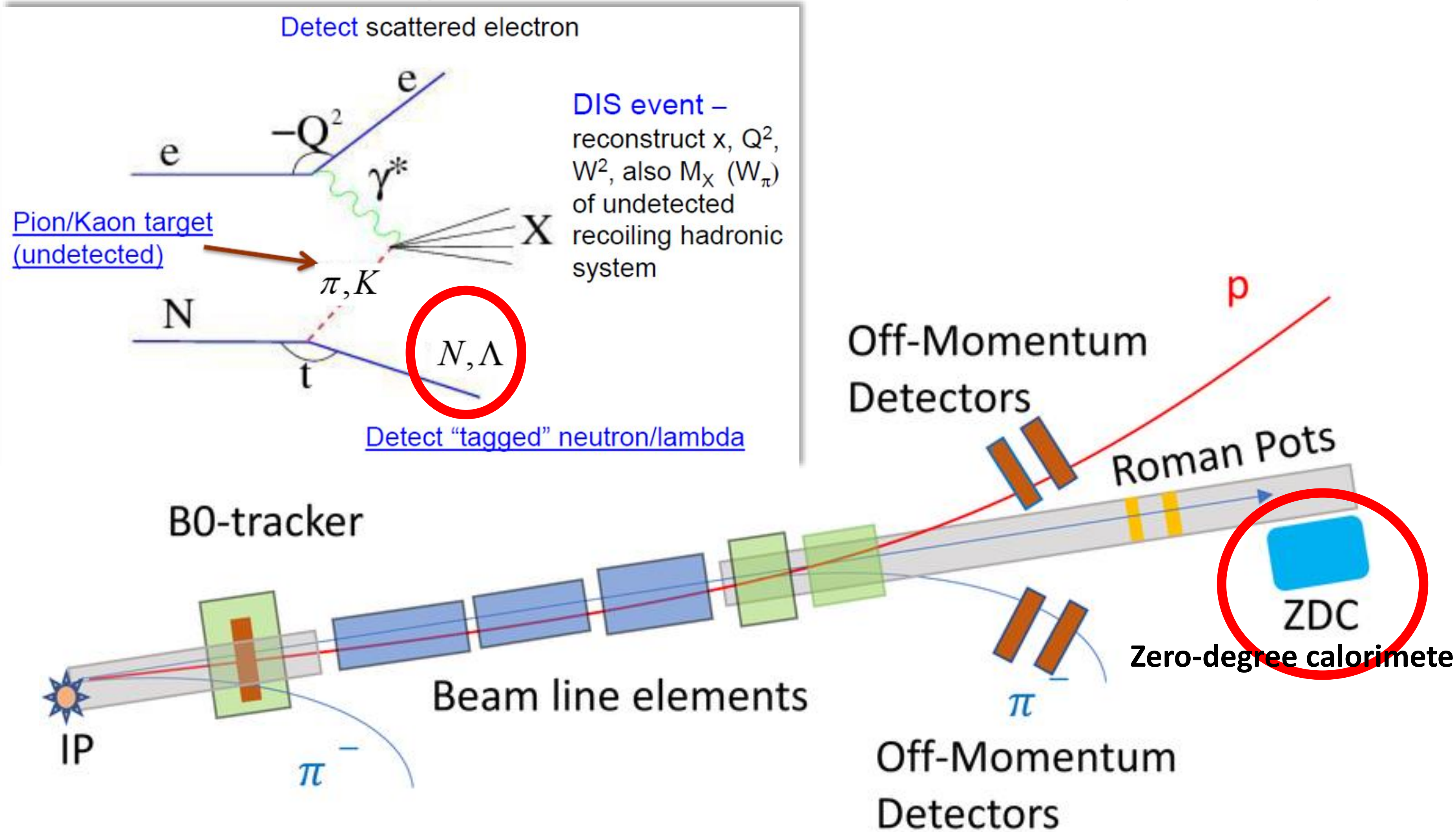
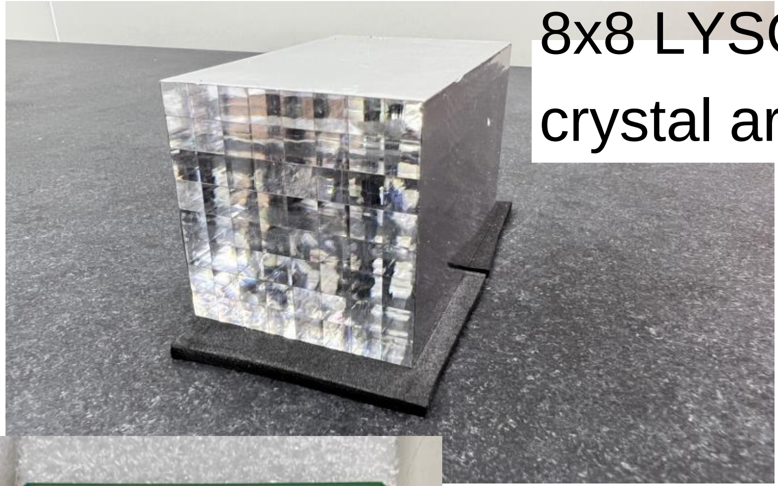
https://indico.bnl.gov/event/8315/contributions/36990/attachments/28487/43882/CFNS-Pion-Kaon-Structure-Horn-nbk.pdf

https://arxiv.org/abs/1907.08218

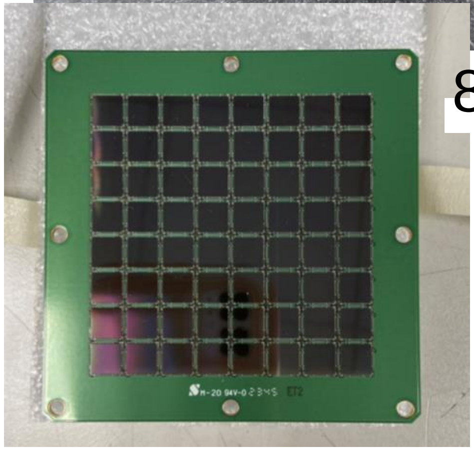
Far-Forward detectors: Zero-degree calorimeter (ZDC)



ZDC Prototype: LYSO Crystals

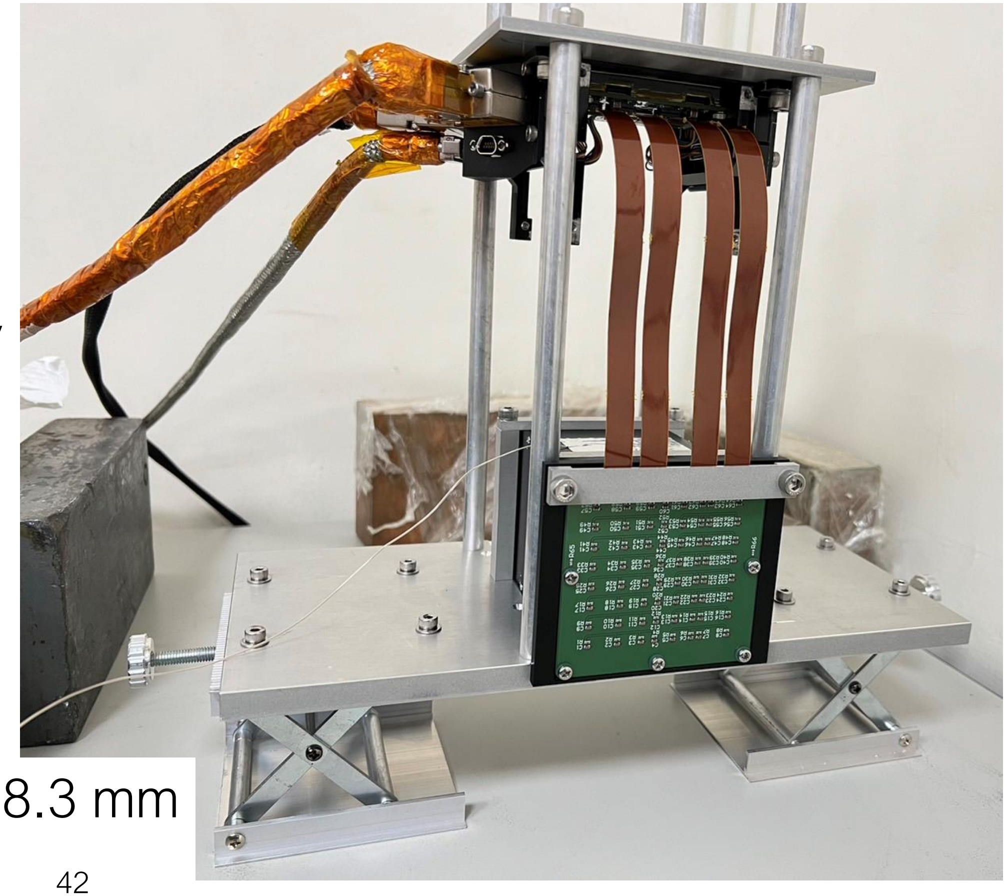


8x8 LYSO crystal array



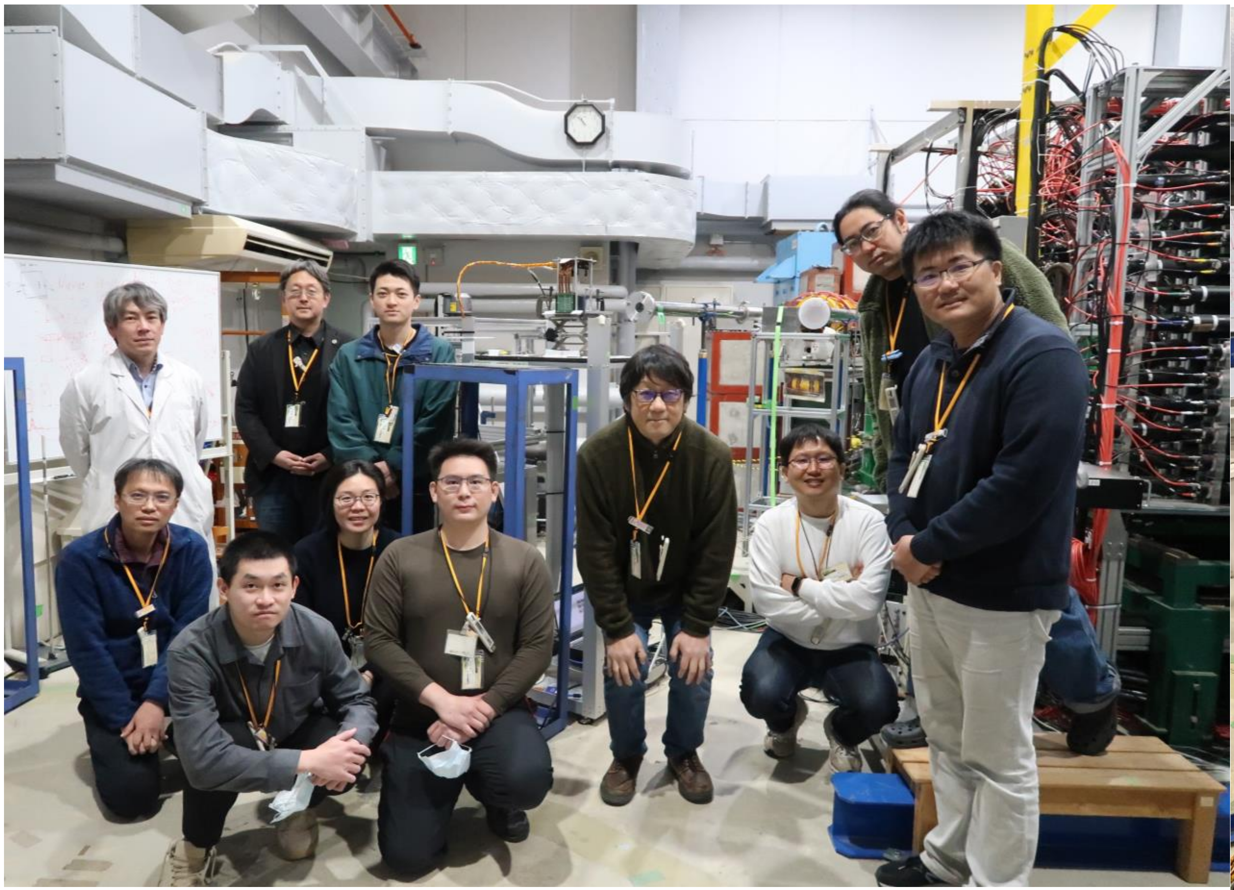
8x8 SiPM array

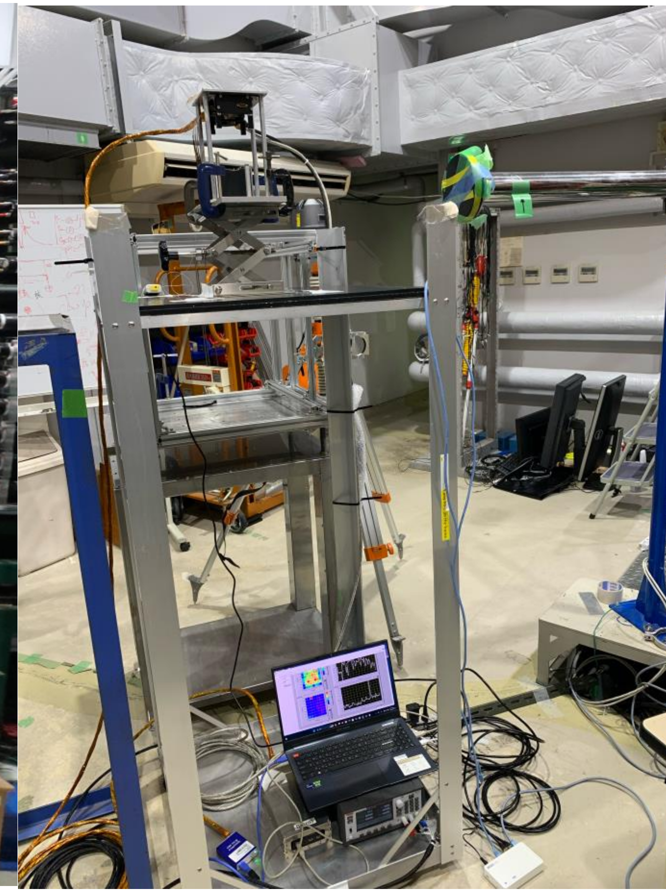
LYSO calorimeter prototype



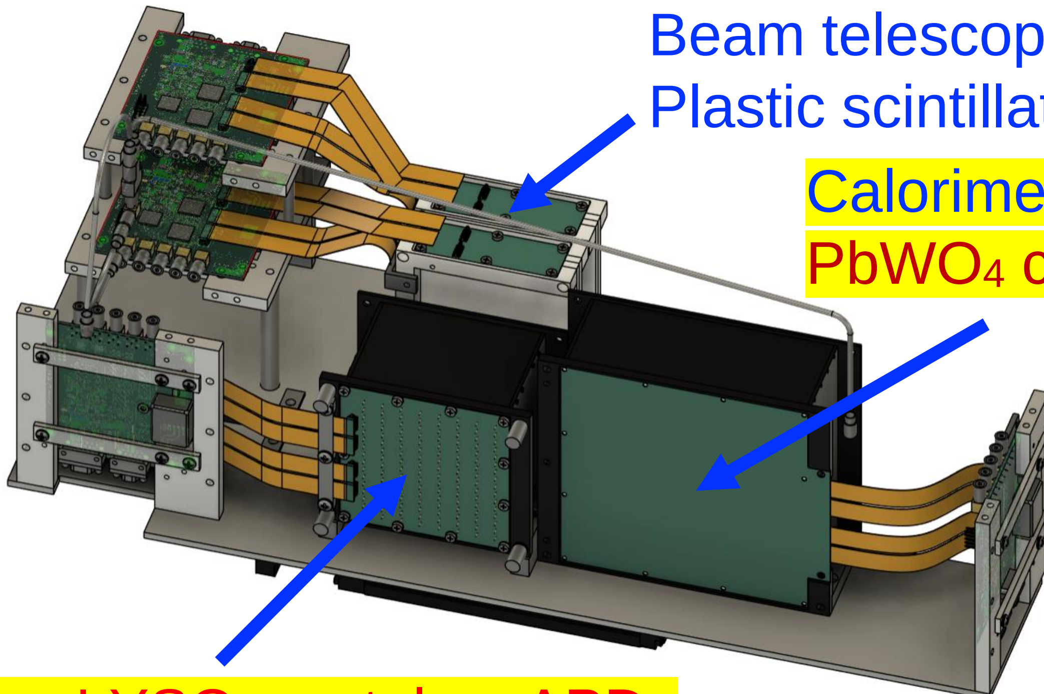
One crystal: 7.12 mm x 7.12 mm x 88.3 mm
8x8 array: 56.96 mm x 56.96 mm

Beam test @ RARIS, Japan 2024/2 [Teams of Japan, Korea and Taiwan]



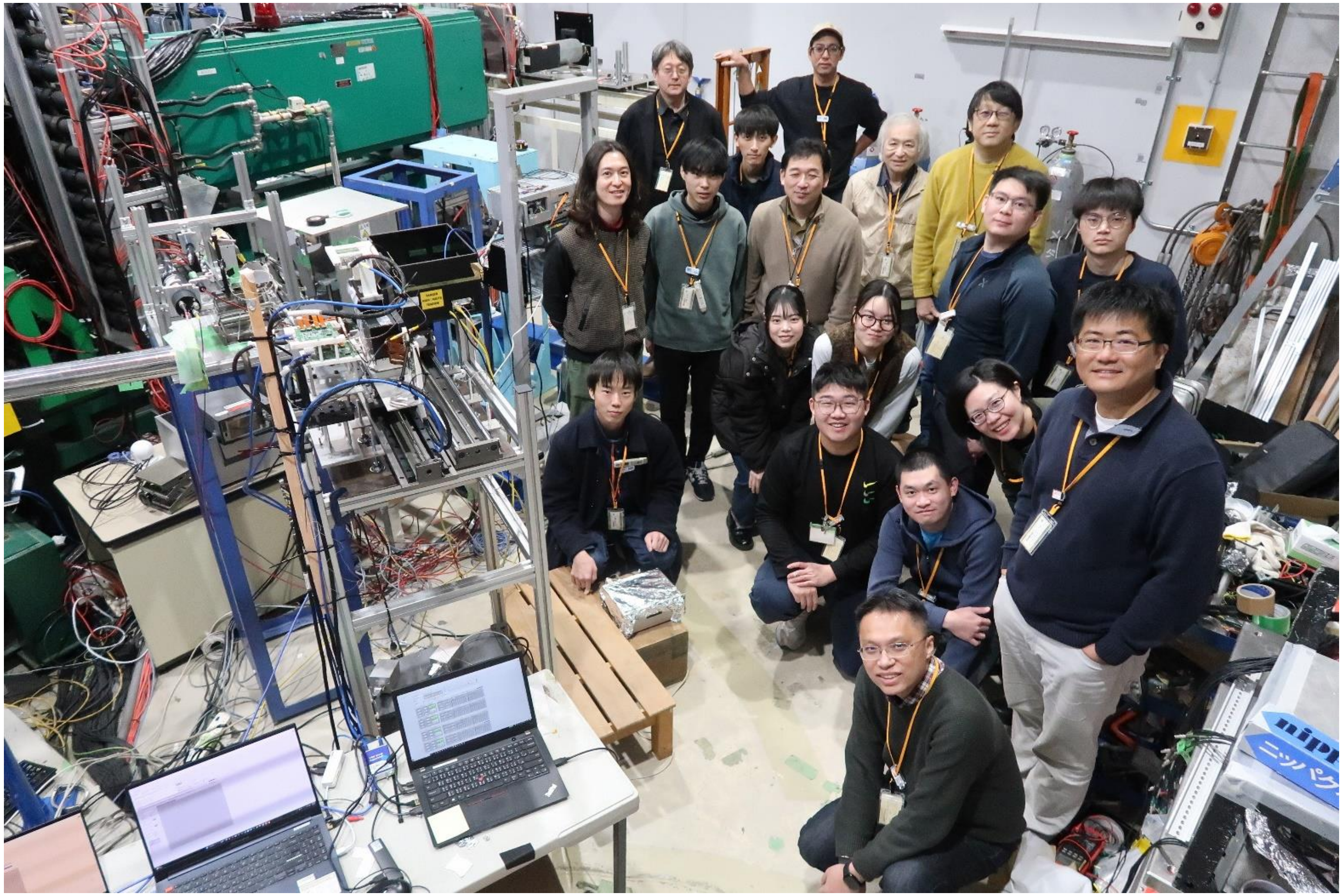


2nd beam test @ RARIS

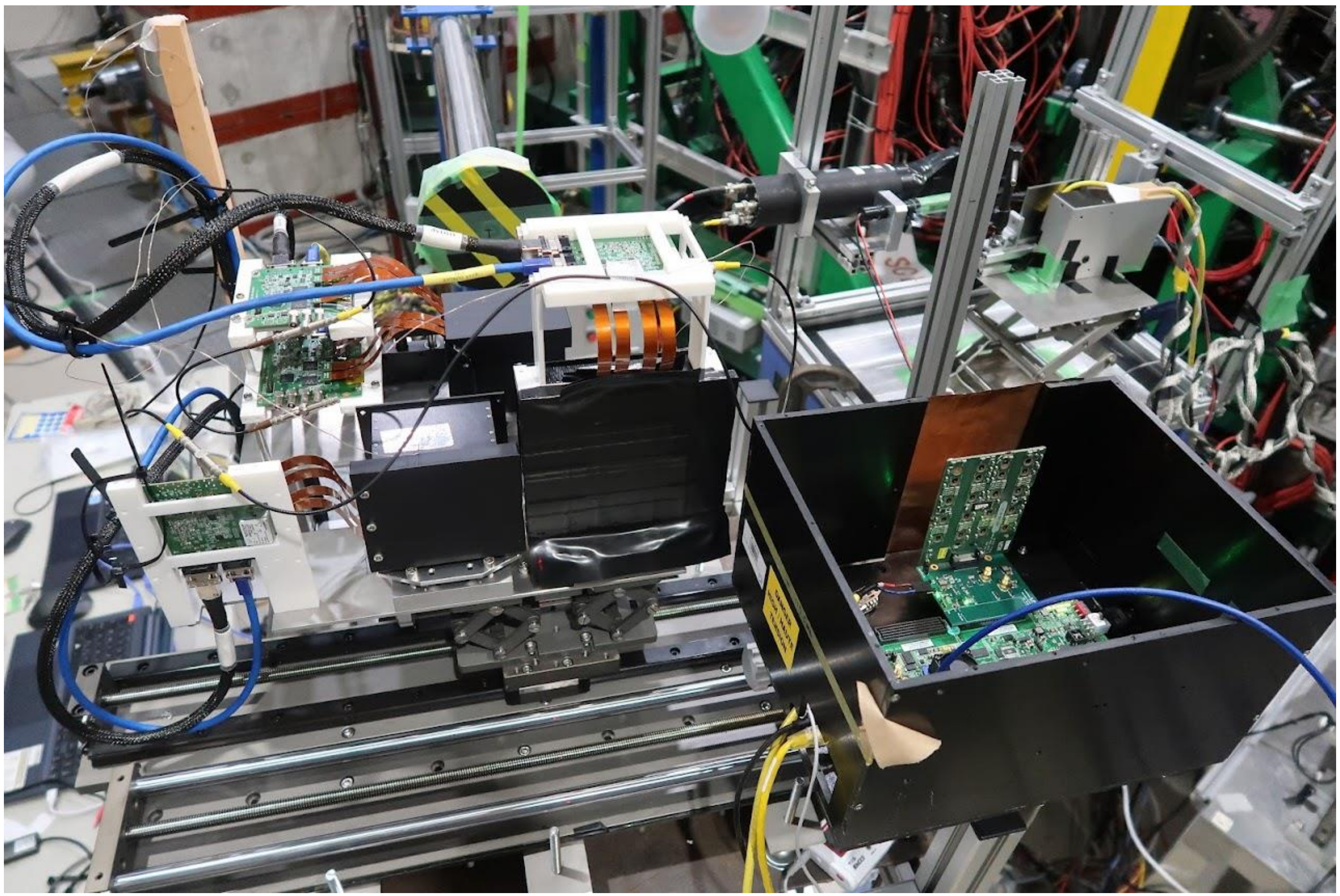


- Scheduled for February 2025
- Test two proptypes: LYSO+APD and $PbWO_4$+SiPM

Beam test @ RARIS, Japan 2025/2
[Teams of Japan, Korea and Taiwan]



Beam test @ RARIS, Japan 2025/2 [Teams of Japan, Korea and Taiwan]



Summary

- Pion/kaon PDFs are poorly known. **DY process** is mostly sensitive to the **valence quarks**. Existing fixed-target **charmonium** data could provide valuable constraints on the **gluons**.
- Theoretical efforts are required to extract pion/kaon PDFs from charmonium production and **Sullivan process** reliably.
- **Outlook**
  - Coming COMPASS results of pion-induced DY/Jpsi
  - Future AMBER measurements of $\pi\pm/K\pm$-induced DY/Jpsi
  - Future measurements of Sullivan process in U.S. EIC.