COMPASS beyond 2020 Workshop
March 21-22, 2016

Progress and opportunities of unpolarised Drell-Yan program

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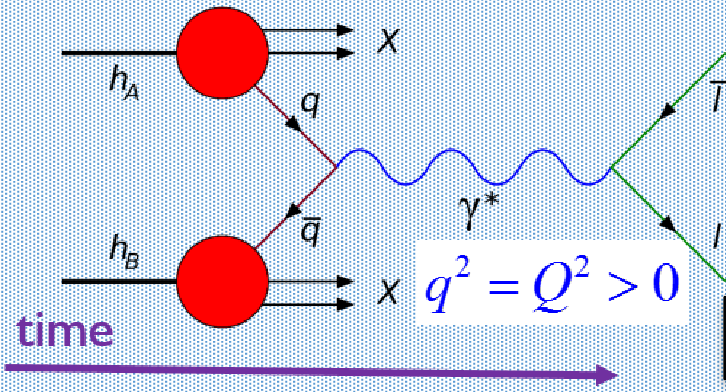
Outline

- **Progress made by Drell-Yan experiments in the past 20 years:**
  - FNAL E866
  - FNAL E906 (SeaQuest)
  - CERN COMPASS
- **Opportunities for Drell-Yan processes with pion/kaon/antiproton beams:**
  - Nucleon $x(s+\bar{s})$
  - Pion/kaon PDFs
  - Origin of Lam-Tung violation
  - Flavor dependence of nucleon Boer-Mulders functions
  - Pion/kaon/antiproton distribution amplitude
  - Flavor-dependent EMC effect
  - …
- **Feasibility for COMPASS (beyond 2020)**
- **Conclusions**

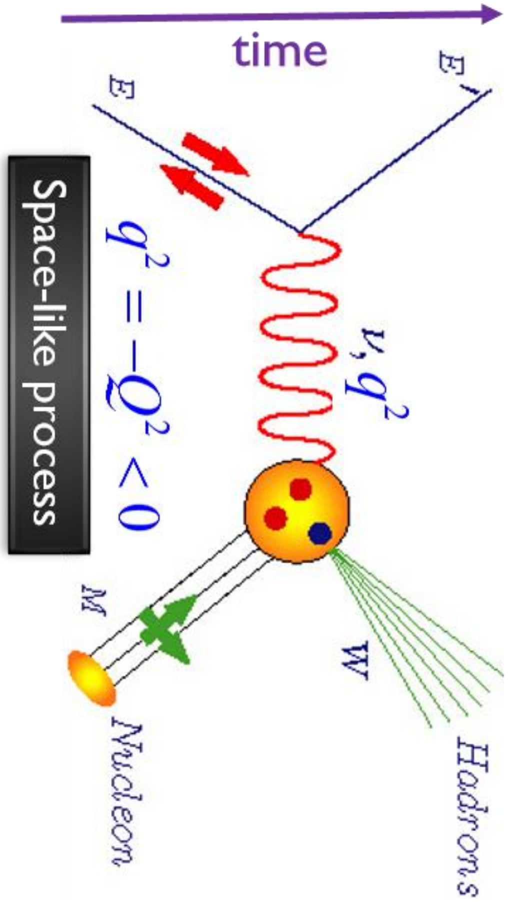


$$q^2 = Q^2 > 0$$

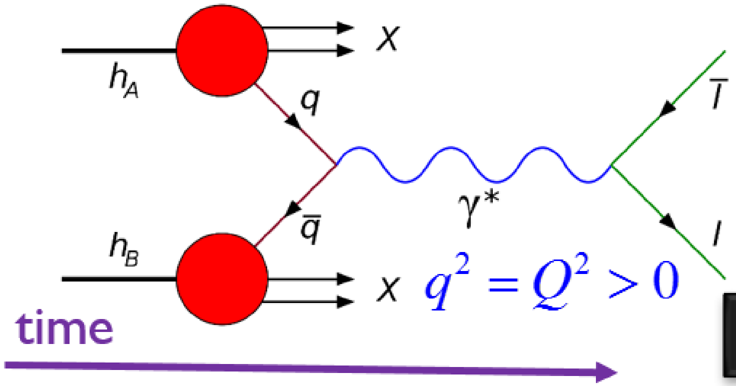
Time-like process

Progress of Drell-Yan Experiments in the past

Deep Inelastic Scattering (DIS) and Drell-Yan Processes

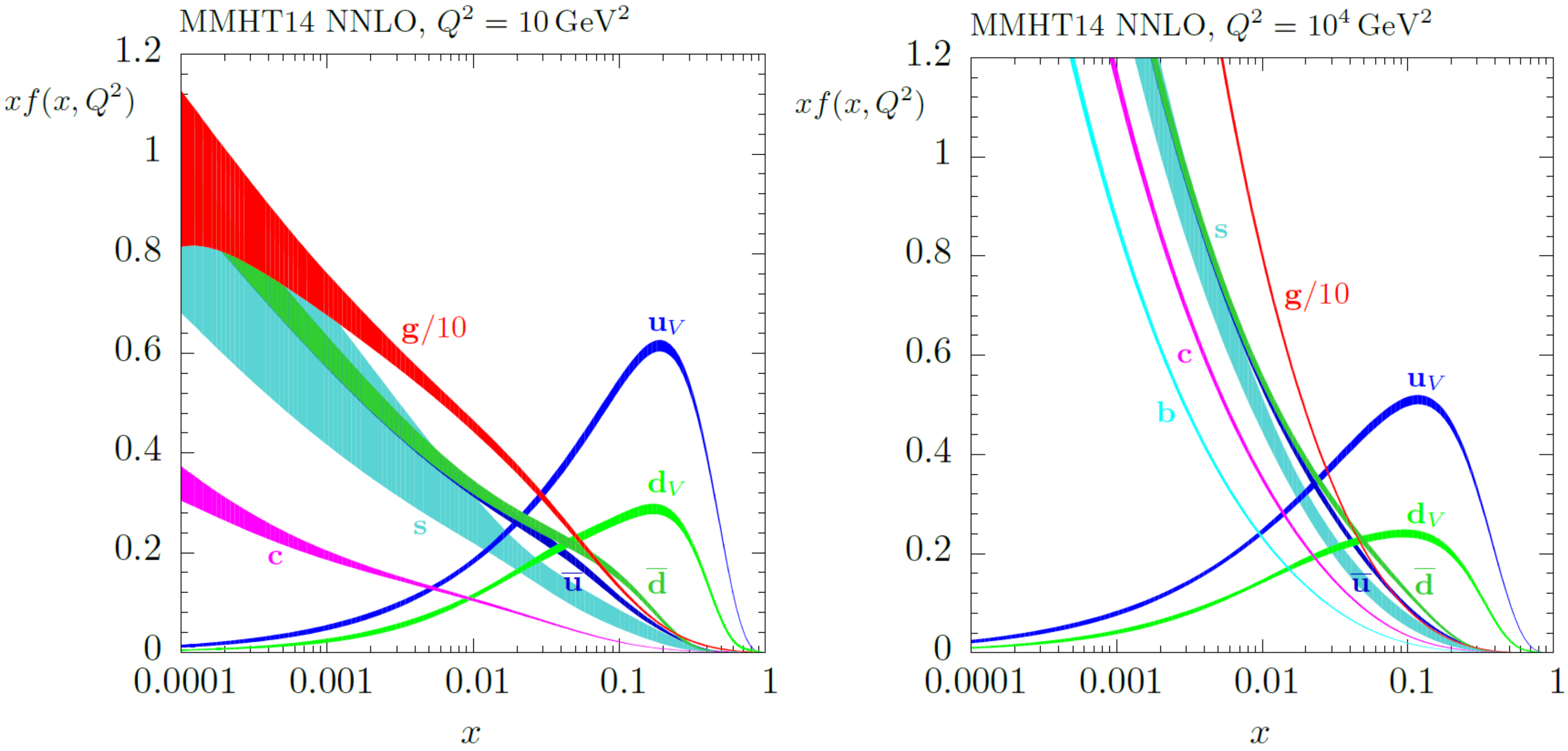


Space-like process



Time-like process

Parton Distribution Function (PDF) of Proton: MMHT 2014 PDFs



L. A. Harland-Lang, A. D. Martin, P. Motylinski, R.S. Thorne, arXiv:1412.3989

Light Antiquark Flavor Asymmetry: Drell-Yan Experiments

- Naïve Assumption: $\bar{d}(x) = \bar{u}(x)$
- NMC (Gottfried Sum Rule):

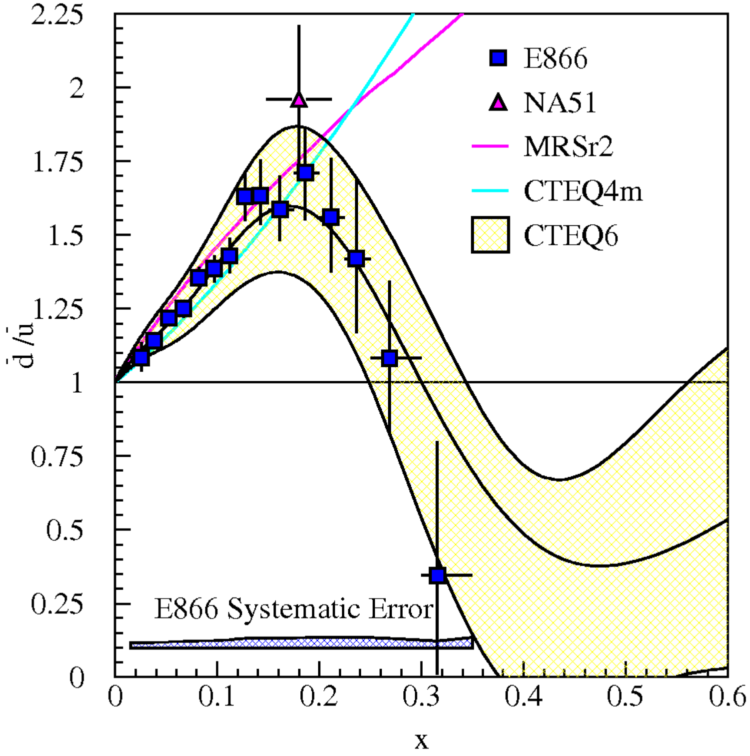
$$\int_0^1 \left[\bar{d}(x) - \bar{u}(x)\right] dx \neq 0$$

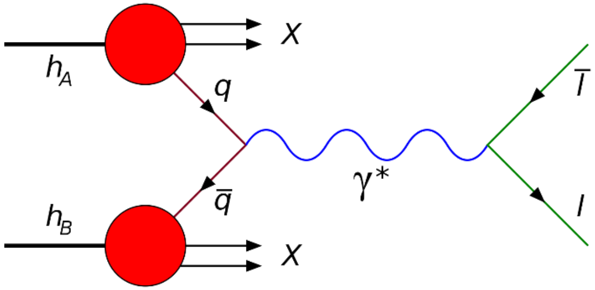
- NA51 (Drell-Yan, 1994):

$$\bar{d} > \bar{u} \text{ at } x = 0.18$$

- E866/NuSea (Drell-Yan, 1998):

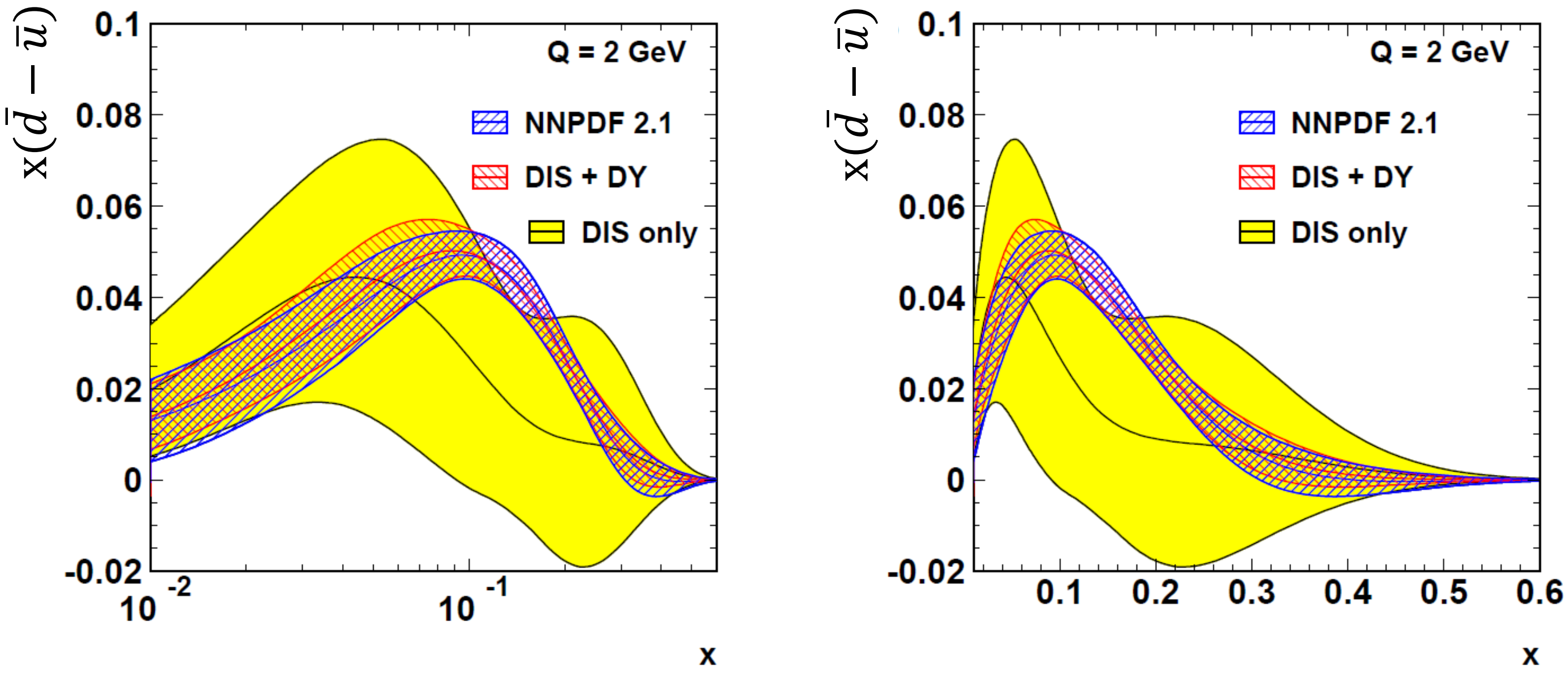
$$\bar{d}(x)/\bar{u}(x) \text{ for } 0.015 \leq x \leq 0.35$$





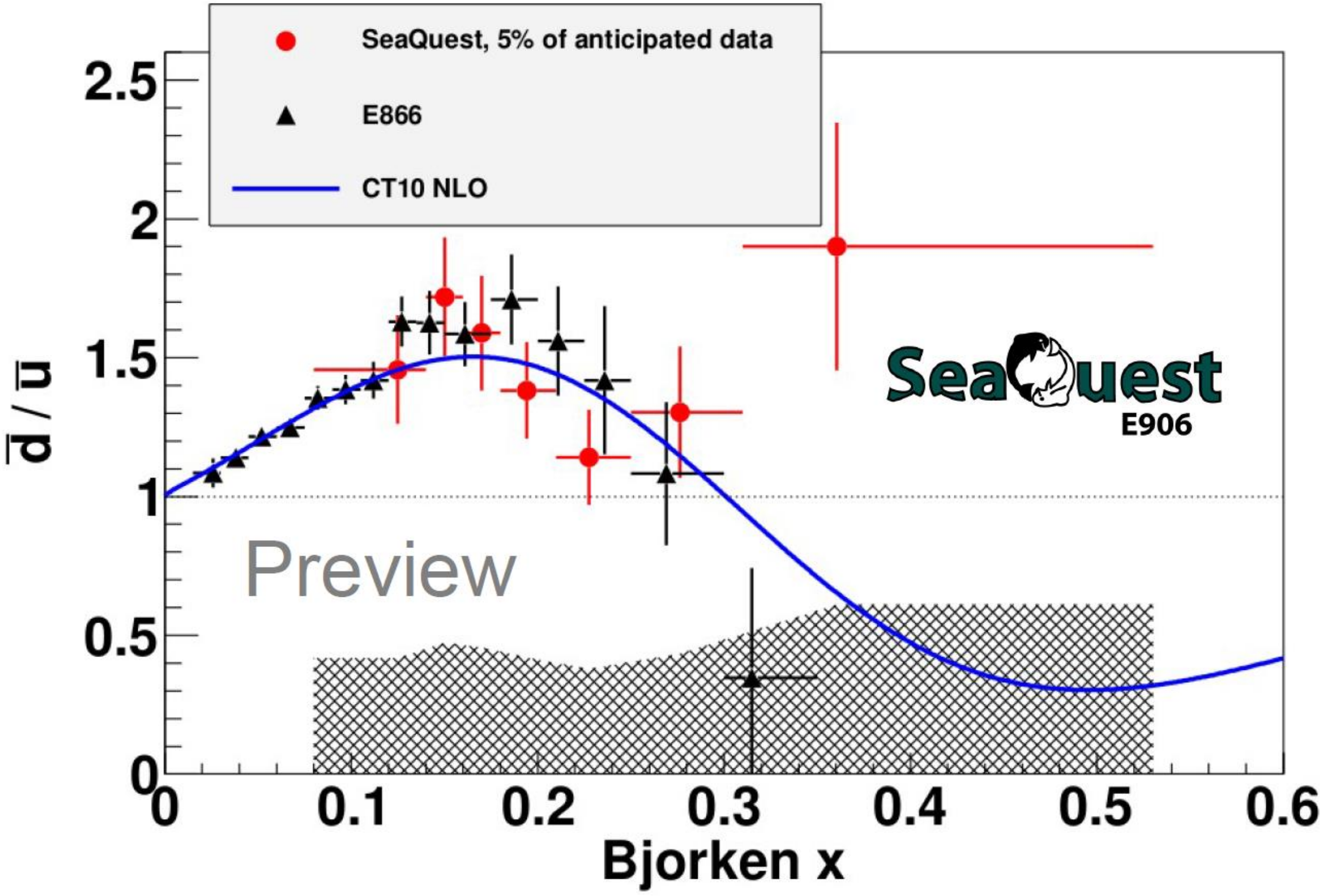
$$\left.\frac{\sigma^{pd}}{2\sigma^{pp}}\right|_{x_b \gg x_t} \approx \frac{1}{2}\left[1 + \frac{\bar{d}(x_t)}{\bar{u}(x_t)}\right]$$

Constraint of $x(\bar{d} - \bar{u})$ in Global Analysis

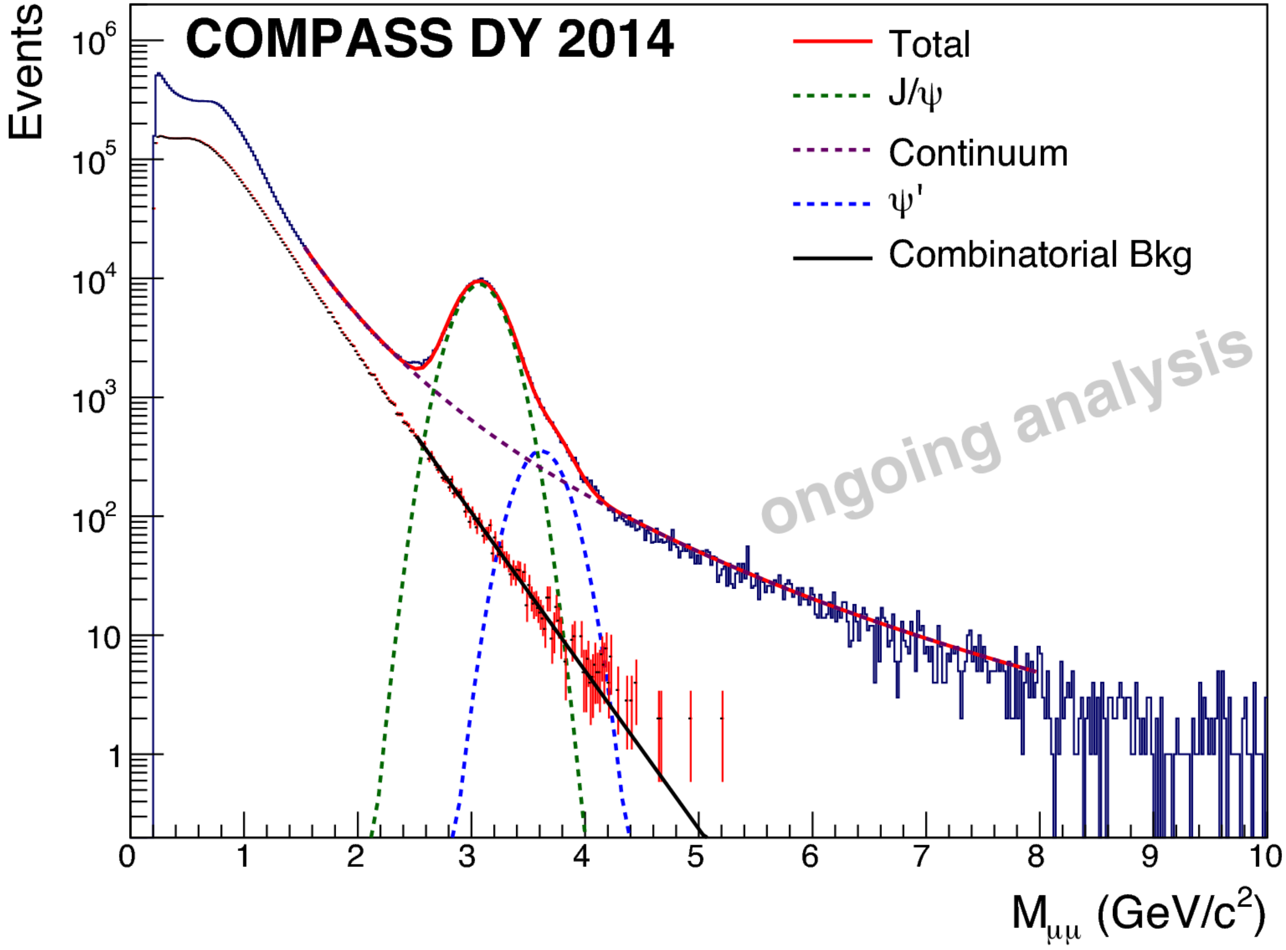


E. Pereza and E. Rizvib, arXiv:1208.1178

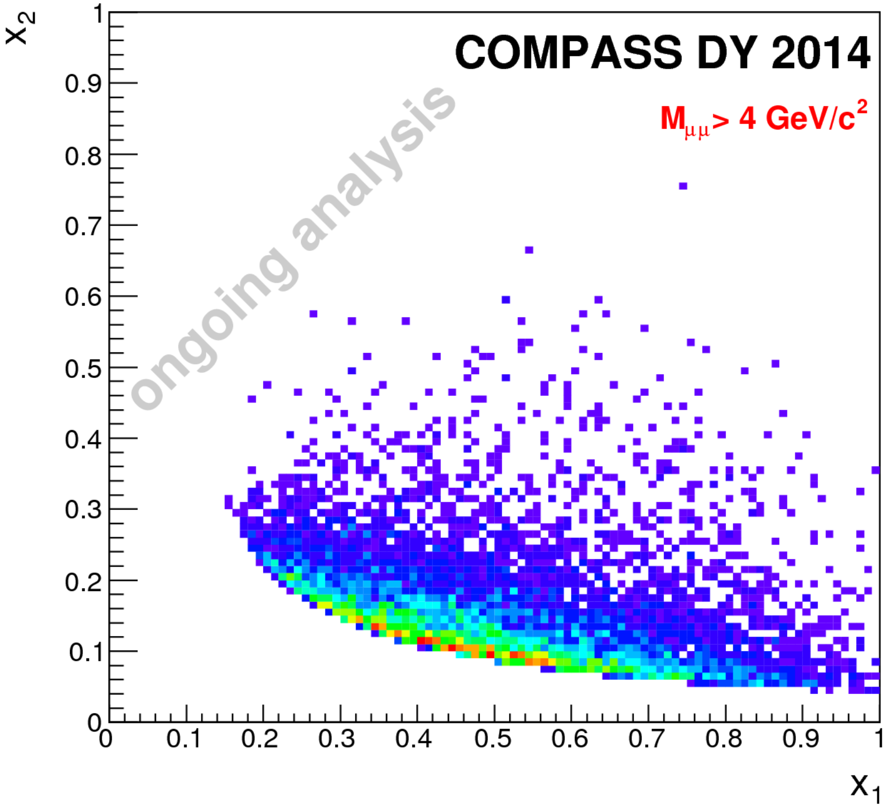
Preliminary Results of $\bar{d}/\bar{u}(x)$ from E906 (SeaQuest)

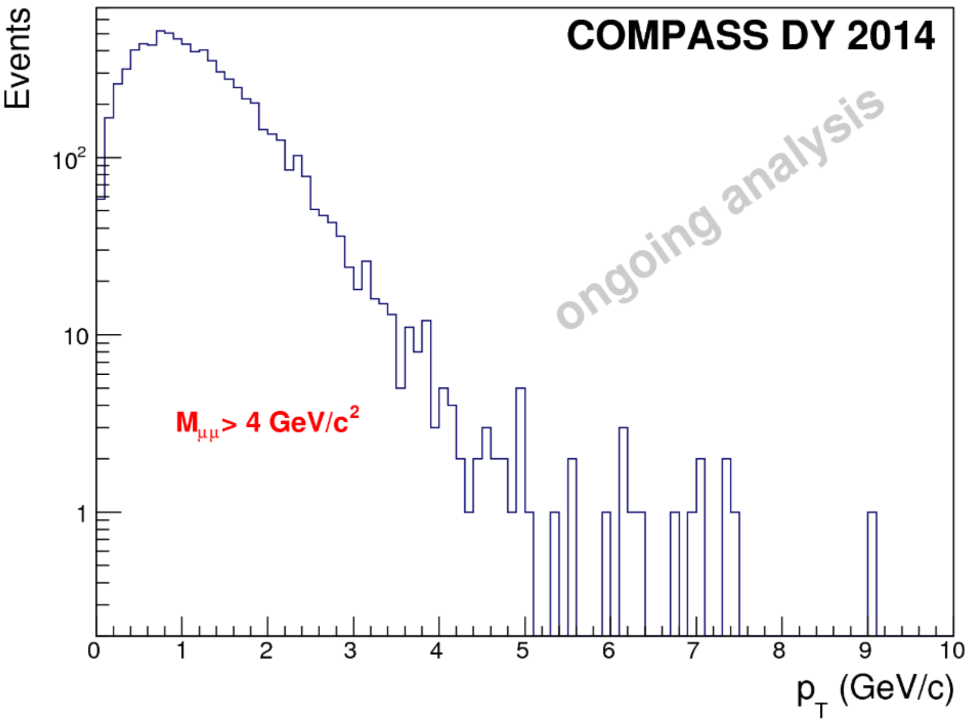


Dimuon Invariant-mass Distributions (2014 COMPASS DY)



Dimuon x_1,x_2 and p_T Distributions (2014 COMPASS DY)



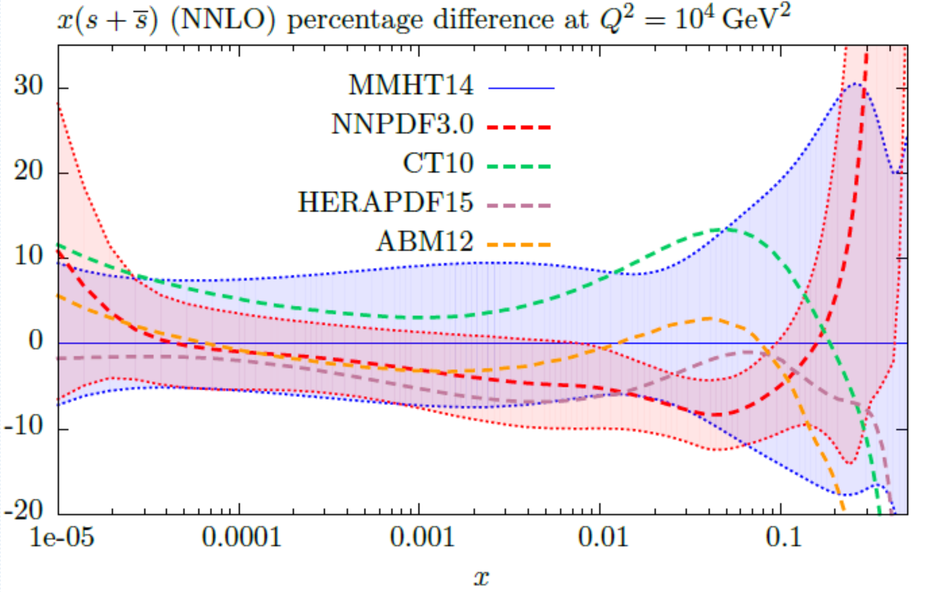


Projections:
COMPASS polarized DY

- **2015**: ~80 000 DY events M>4 GeV/c^2 from NH3 target

- **2018**: ~116 000 events (assuming same conditions, but 160 effective days)

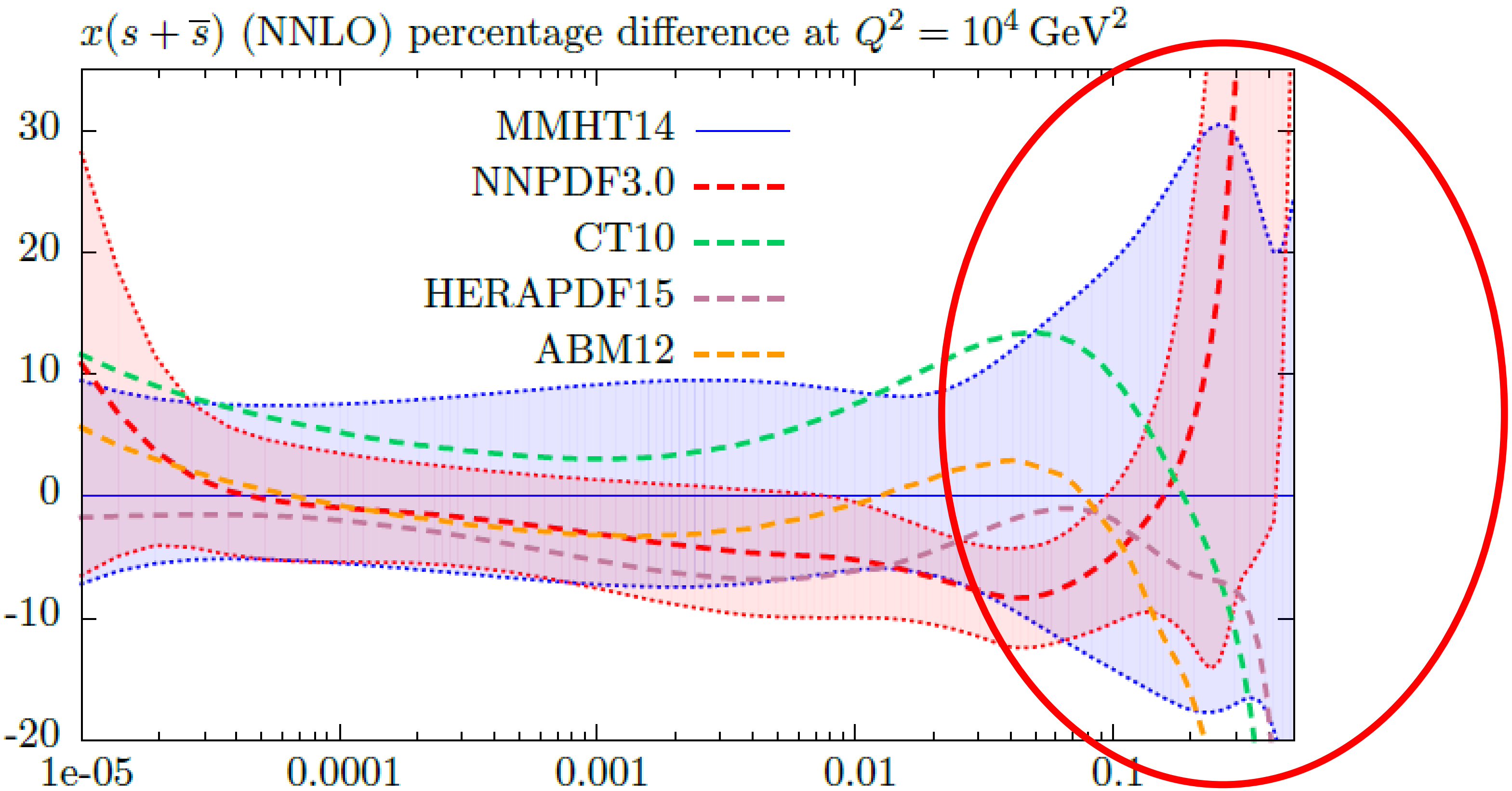
↳ Sivers asymmetry statistical error:~1.8%



Opportunity (1):

Nucleon $x(s+\bar{s})$ & Kaon PDFs

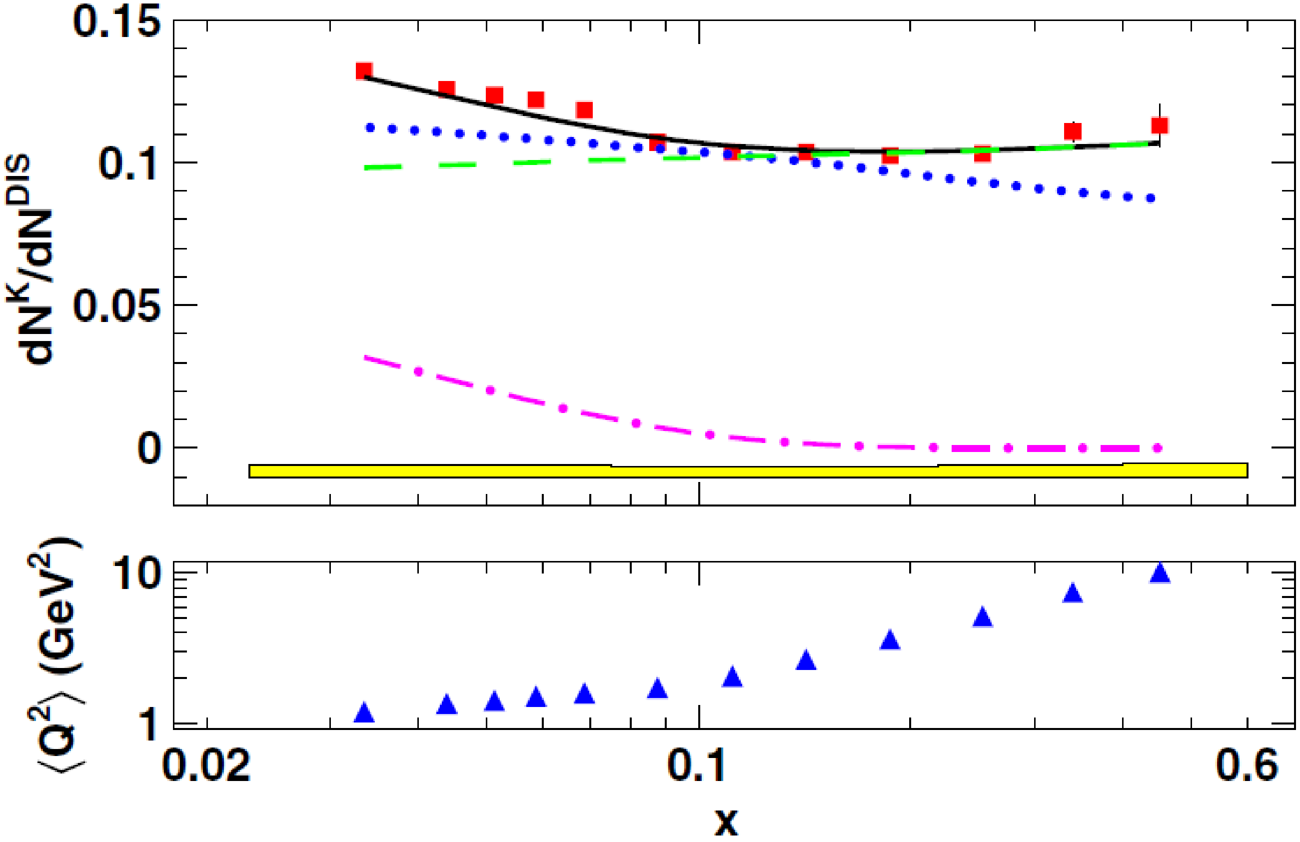
Large Uncertainty of $x(s+\bar{s})$ at valence-quark region



arXiv:1412.3989

Charged Kaon SIDIS

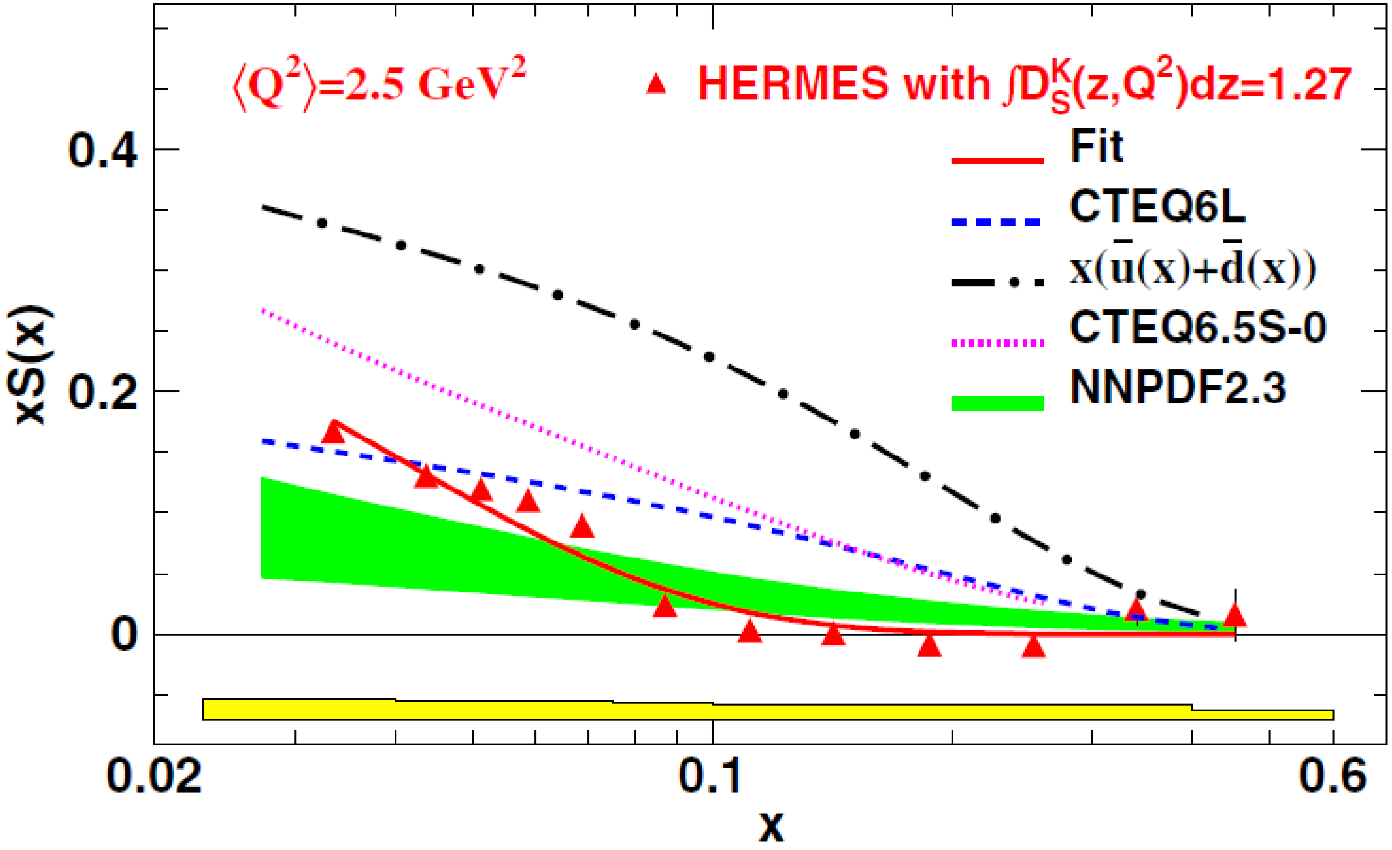
HERMES Collaboration, PRD 89, 097101 (2014)



$$\frac{dN^K(x,Q^2)}{dN^{\mathrm{DIS}}(x,Q^2)} = \frac{Q(x,Q^2)\int_{0.2}^{0.8} D_Q^K(z,Q^2)dz + S(x,Q^2)\int_{0.2}^{0.8} D_S^K(z,Q^2)dz}{5Q(x,Q^2)+2S(x,Q^2)},$$

$x(s+\bar{s})$ from SIDIS of kaons

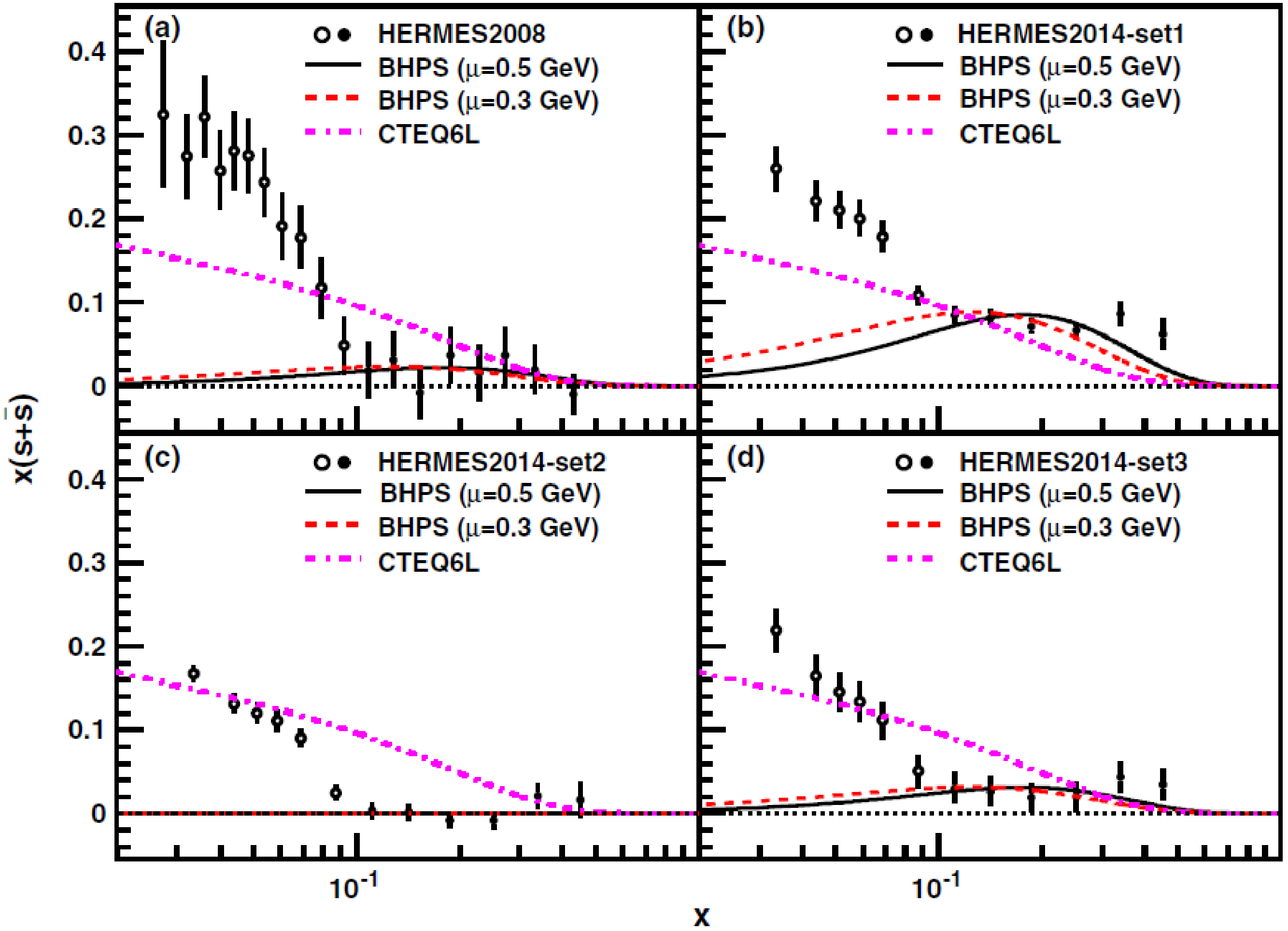
HERMES Collaboration, PRD 89, 097101 (2014)



With the input of D_Q^K and D_s^K and non-strange quark distributions Q(x), S(x) is extracted.

Large Uncertainty in the extraction of $x(s+\bar{s})$

W.C. Chang and J.C. Peng, PRD 92, 054020 (2015)

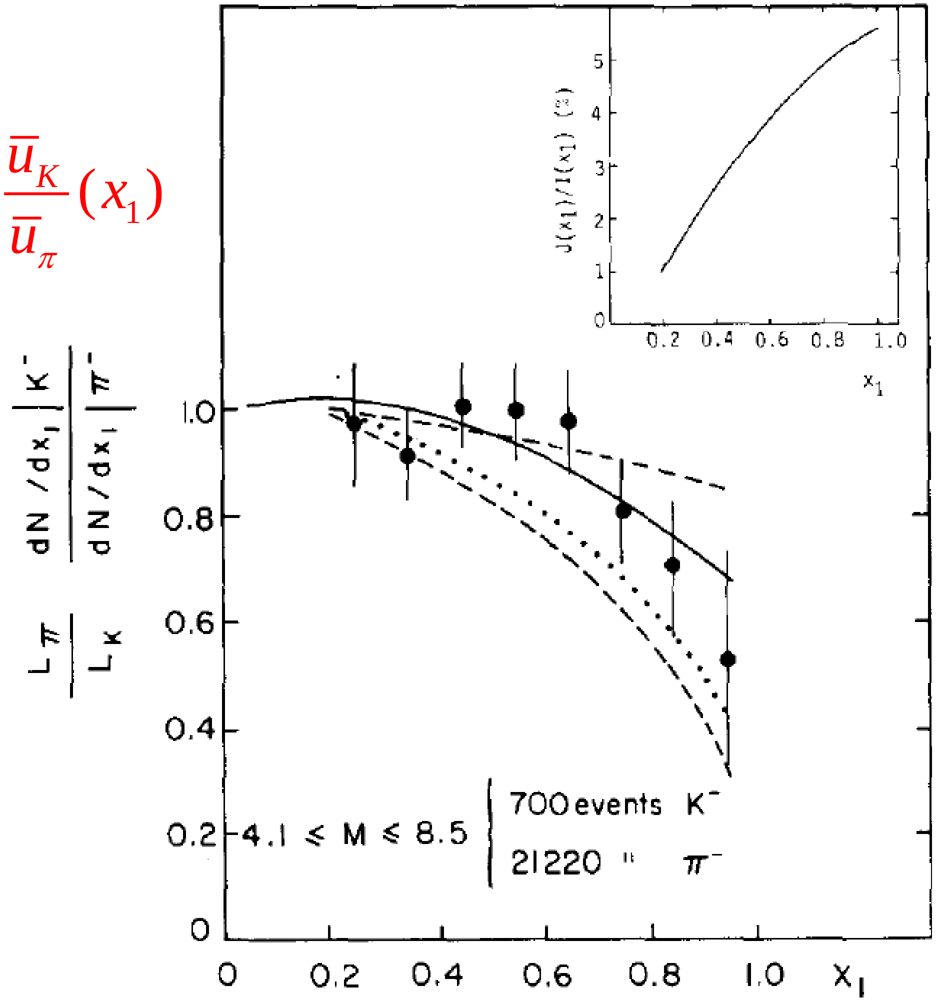


Unfortunately D_Q^K and D_s^K are not well determined…

Kaon Partonic Structure

NA3 Collaboration, PLB 93, 354 (1980)

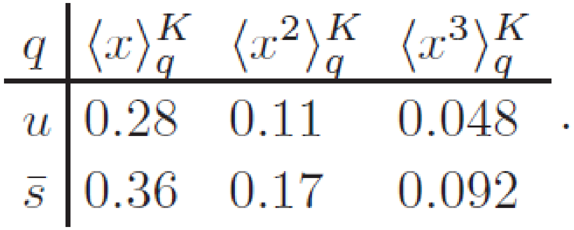
$$\frac{d\sigma^{K-}/dx_1}{d\sigma^{\pi-}/dx_1} = \frac{\bar{u}_K}{\bar{u}_\pi}(x_1)$$



Valence-quark distribution functions in the kaon and pion

Chen, et al., arXiv:1602.01502

Algebraic formulae for the dressed-quark propagators and pion and kaon Bethe-Salpeter amplitudes where SU(3) symmetry breaking is implemented.



q	$\langle x\rangle_q^K$	$\langle x^2\rangle_q^K$	$\langle x^3\rangle_q^K$
u	0.28	0.11	0.048
$\bar{s}$	0.36	0.17	0.092

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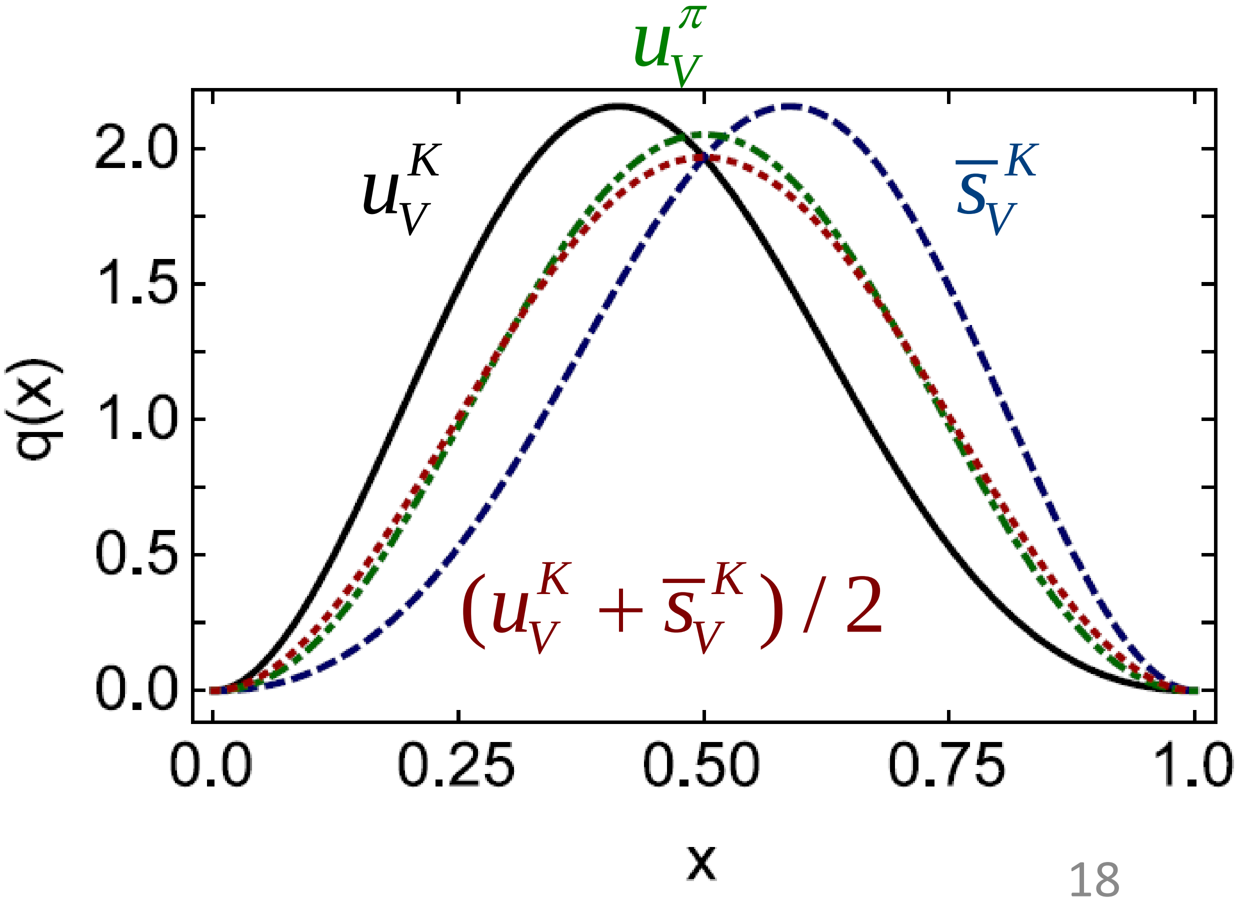

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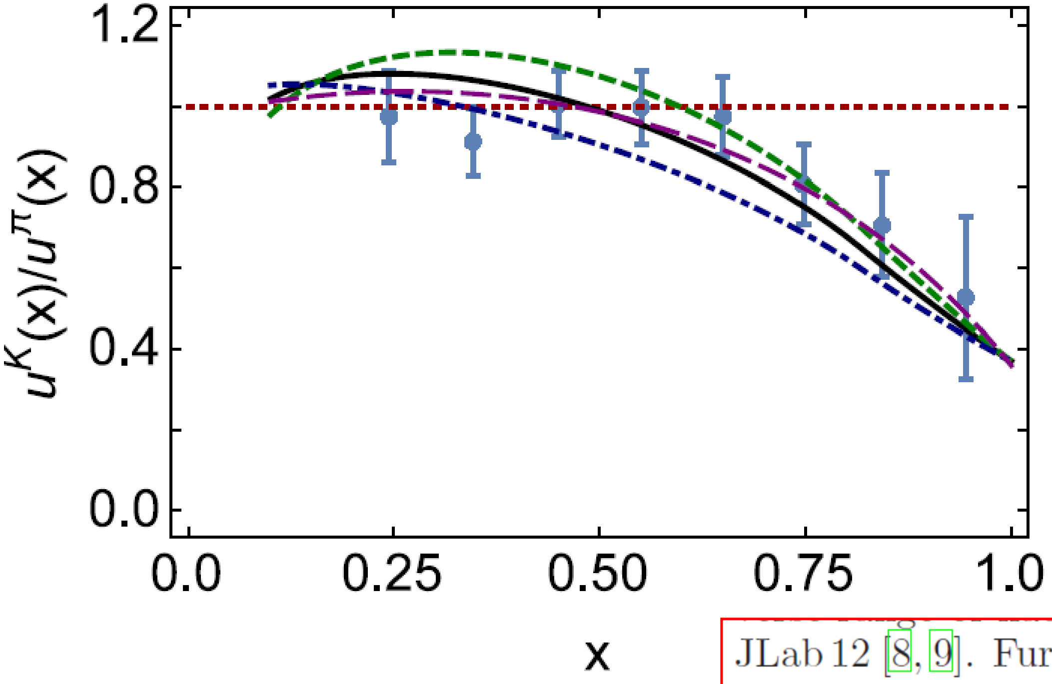
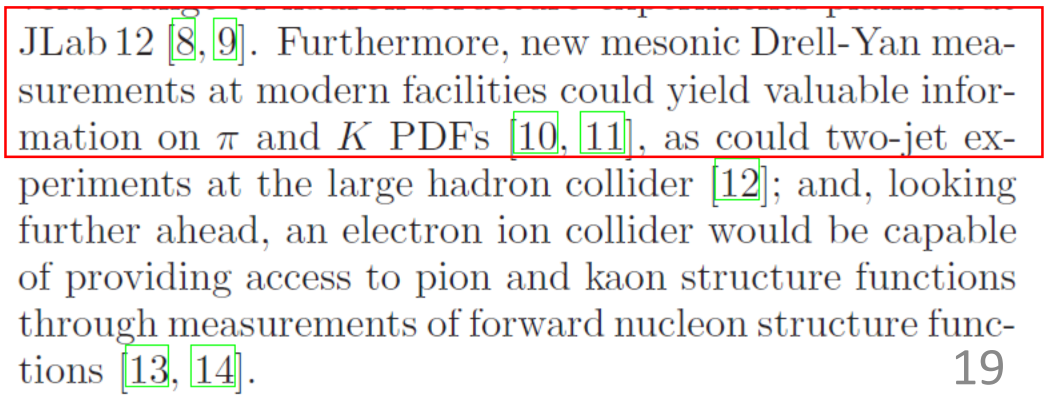



JLab 12 [8, 9]. Furthermore, new mesonic Drell-Yan measurements at modern facilities could yield valuable information on π and K PDFs [10, 11], as could two-jet experiments at the large hadron collider [12]; and, looking further ahead, an electron ion collider would be capable of providing access to pion and kaon structure functions through measurements of forward nucleon structure functions [13, 14].

Kaon-induced Drell-Yan Process:

Avoiding Fragmentation Functions Uncertainty

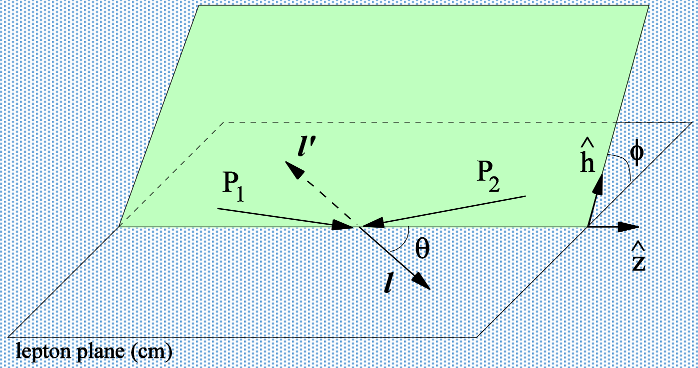
$$K^{+}p(x_f)=u^{K}(x_1)\bar{u}^{p}(x_2)+\boxed{\bar{s}^{K}(x_1)s^{p}(x_2)}$$

$$K^{-}p(x_f)=\bar{u}^{K}(x_1)u^{p}(x_2)+\boxed{s^{K}(x_1)\bar{s}^{p}(x_2)}$$

Kaon-induced Drell-Yan cross sections will determine

- nucleon strange quark structure
- kaon PDFs

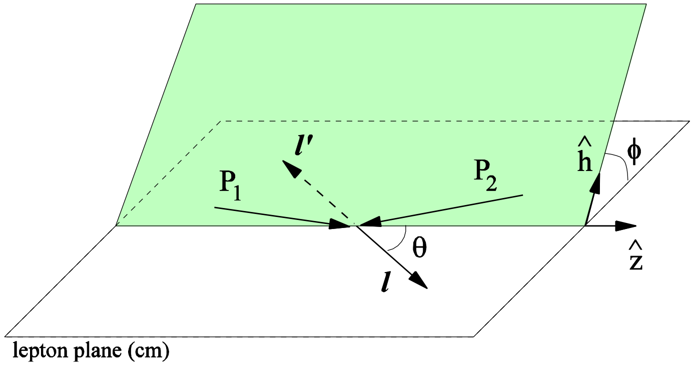
Kaon beam and LH$_2$ target



Opportunity (2):

Violation of Lam-Tung relation & Boer-Mulders Functions

Drell-Yan decay angular distributions



θ and ϕ are the decay polar and azimuthal angles of the μ^+ in the dilepton rest-frame

Collins-Soper frame

$$\frac{d\sigma}{d\Omega} \propto (1+\lambda\cos^2\theta+\mu\sin 2\theta\cos\phi+\frac{\nu}{2}\sin^2\theta\cos 2\phi)$$

$$\propto (W_T(1+\cos^2\theta)+W_L(1-\cos^2\theta)+W_\Delta\sin 2\theta\cos\phi+W_{\Delta\Delta}\sin^2\theta\cos 2\phi)$$

$q\bar{q}$ annilation parton model:

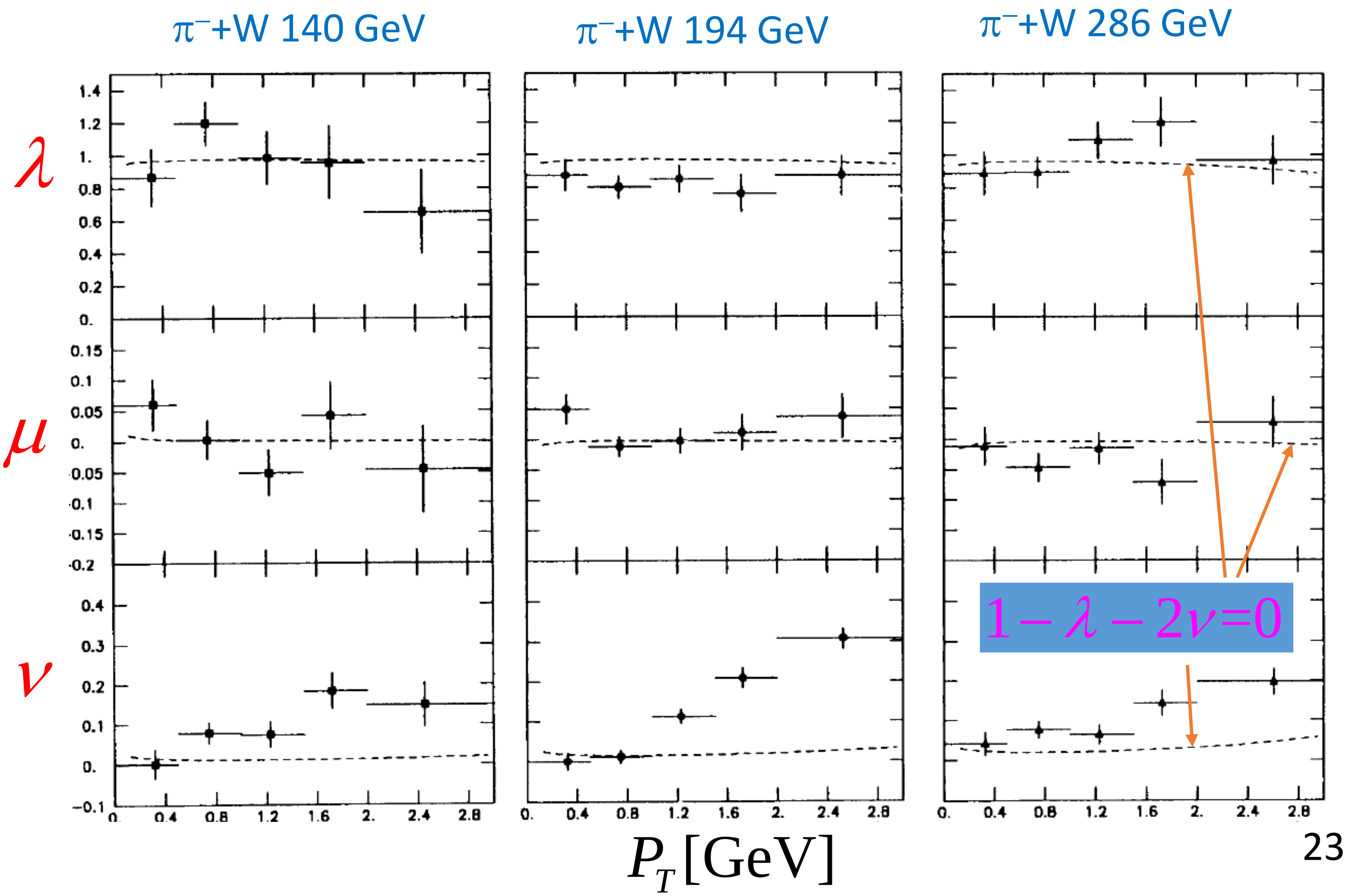
$O(\alpha_s^0)$ λ=1, μ=ν=0; $W_T = 1, W_L = 0$

Lam-Tung relation (1978): $\boxed{\text{test of QCD effect}}$

Collinear pQCD: $O(\alpha_s^1)$, $W_L = 2W_{\Delta\Delta}$; $1-\lambda-2\nu=0$

NA10 @ CERN: Violation of Lam-Tung Relation

Z. Phys. 37 (1988) 545



π^-+W 140 GeV

π^-+W 194 GeV

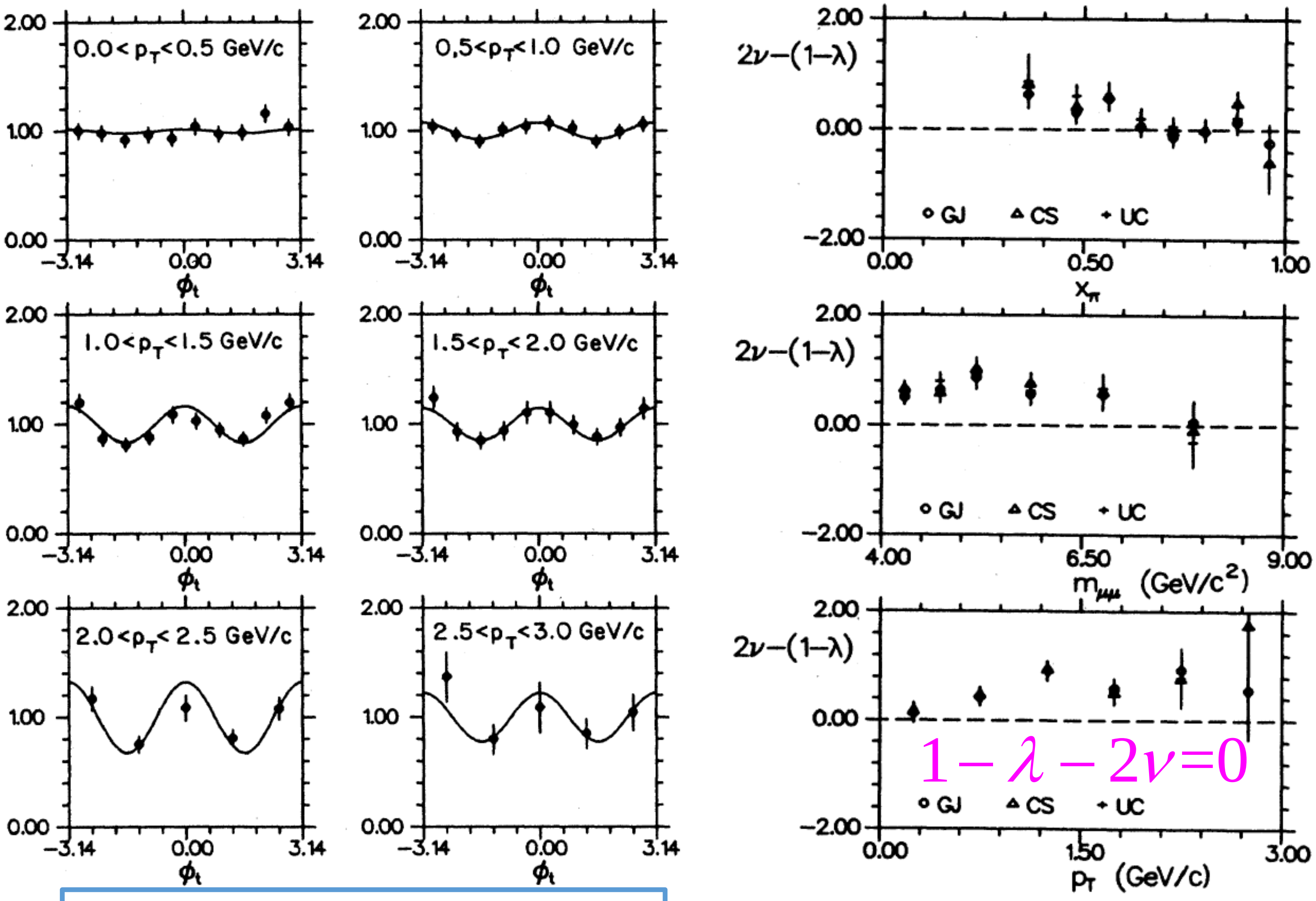
π^-+W 286 GeV

$1-\lambda-2\nu=0$

E615 @ FNAL: Violation of Lam-Tung Relation

PRD 39, 92 (1989)

252-GeV π^{-}+W



$1-\lambda-2\nu=0$

$\cos 2\phi$ modulation at large p_T

Azimuthal Asymmetries Require Nontrivial Spin Correlation

The most general $q\bar{q}$ spin density matrix

$$\rho^{(q,\bar{q})}=\frac{1}{4}\{1\otimes 1+F_j(\vec{\sigma}\bullet\vec{e}_j)\otimes 1+G_j 1\otimes(\vec{\sigma}\bullet\vec{e}_j)+\mathrm{H}_{ij}(\vec{\sigma}\bullet\vec{e}_i)\otimes(\vec{\sigma}\bullet\vec{e}_j)\}$$

$$\text{Violation of LT relation: } \kappa=-\frac{1}{4}(1-\lambda-2\nu)\approx\left\langle\frac{H_{22}-H_{11}}{1+H_{33}}\right\rangle$$

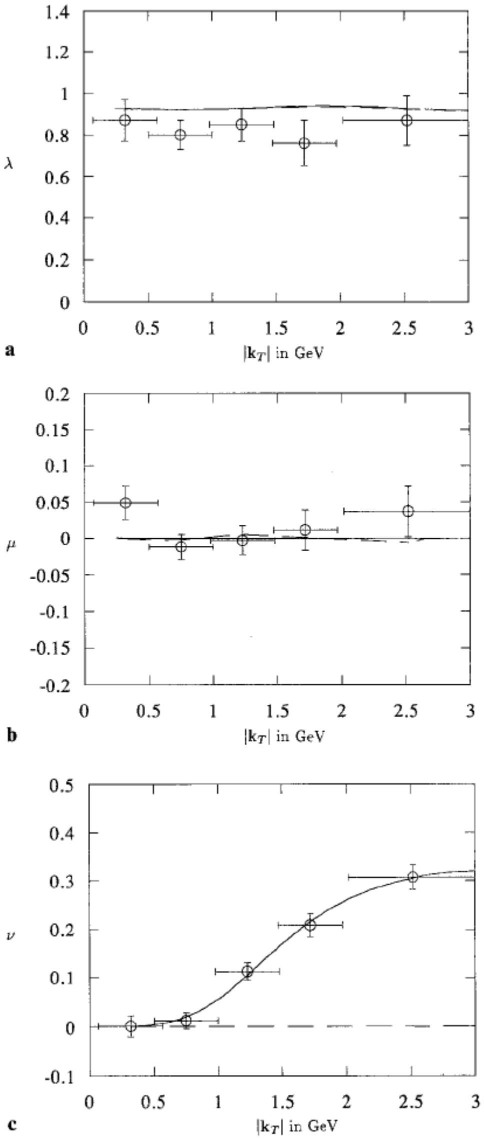
$$\text{Collinear case: } H_{11}=H_{22},\ H_{23}=H_{32}=0,\ \ \kappa=0$$

Brandenburg, Nachtmann & Mirkes, ZPC 60 (1993) 697

Nonzero κ requires *the correlation of the spins of quark and antiquark.*

What will be the mechanism?

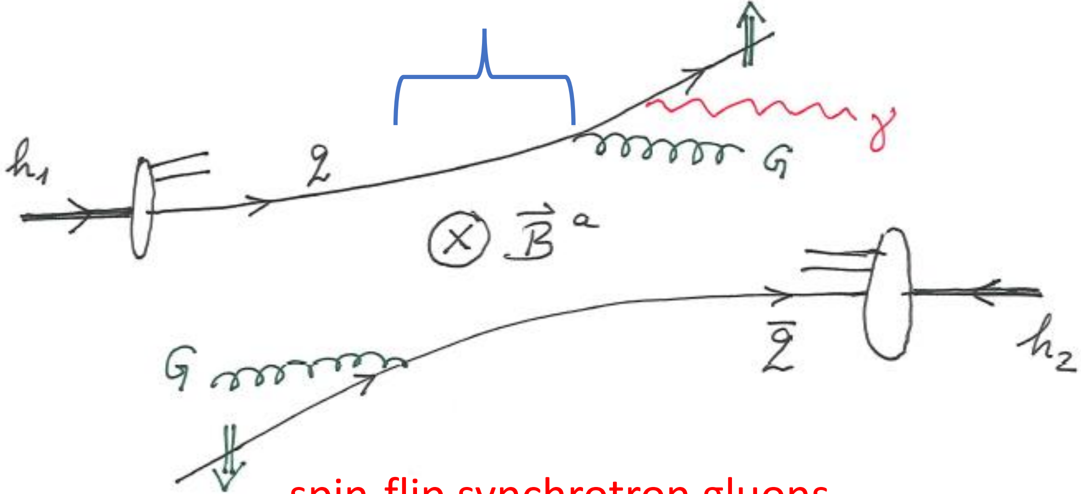
Brandenburg, Nachtmann & Mirkes [Z. Phy. C 60 (1993) 697]:
QCD Vacuum Effect



O. Nachtmann, ECT DY workshop, 2012

What may happen in a high-energy collision to quarks and antiquarks travelling through these strong chromomagnetic background fields?

0.2-0.3 fm

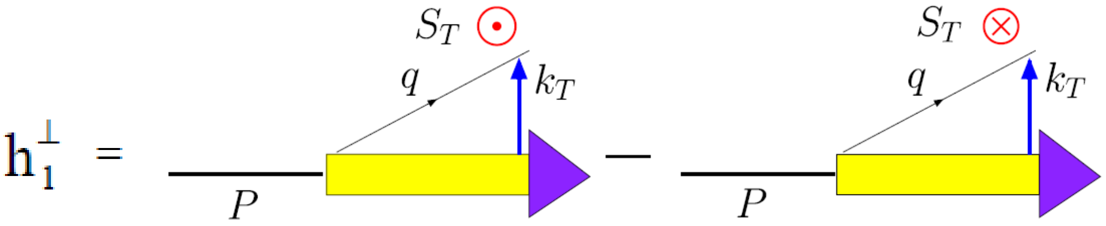


spin-flip synchrotron gluons

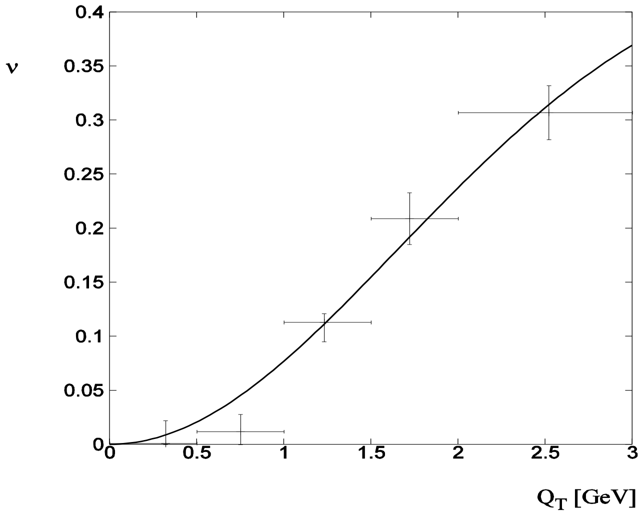
O. Nachtmann / Annals of Physics 350 (2014) 347–378

Boer [PRD 60, 014012 (1999)]: Hadronic Effect, Boer-Mulders Functions

Spin-orbit correlation of transversely polarized *noncollinear partons* inside an unpolarized hadron



- Boer-Mulders Function $h_1^\perp$: a correlation between quark's k_T and transverse spin S_T in an unpolarized hadron
- $h_1^\perp$ can lead to an azimuthal dependence with $\frac{\nu}{2} \propto h_1^\perp(N)\overline{h}_1^\perp(\pi)$



$$h_1^\perp(x, k_T^2) = C_H \frac{\alpha_T}{\pi} \frac{M_C M_H}{k_T^2 + M_C^2} e^{-\alpha_T k_T^2} f_1(x),$$

$$\nu = 16\kappa_1 \frac{p_T^2 M_C^2}{(p_T^2 + 4M_C^2)^2}, \qquad \kappa_1 = C_{H_1} C_{H_2}/2$$

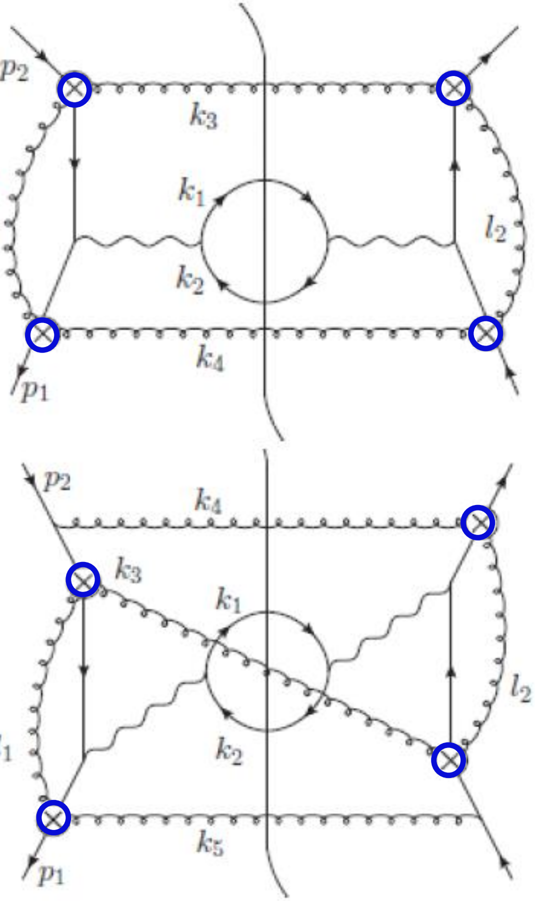
$\kappa = \frac{\nu}{2} \to 0$ for large $|k_T|$

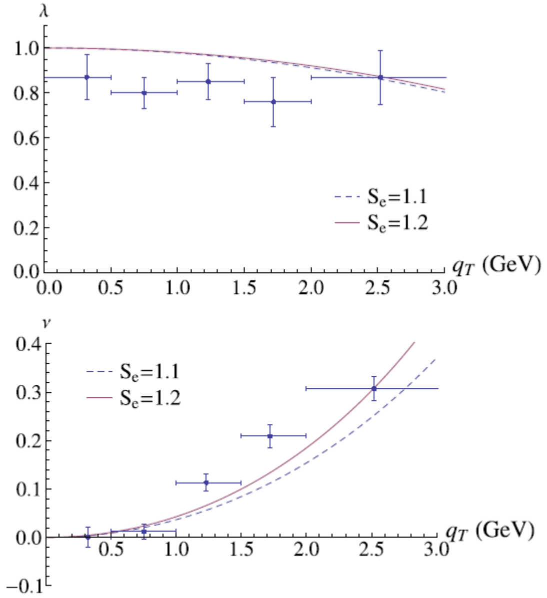
Consistency of factorization in term of TMDs

Chen & Li [PLB 726 (2013) 262]
Breaking of Factorization by Glauber Gluons

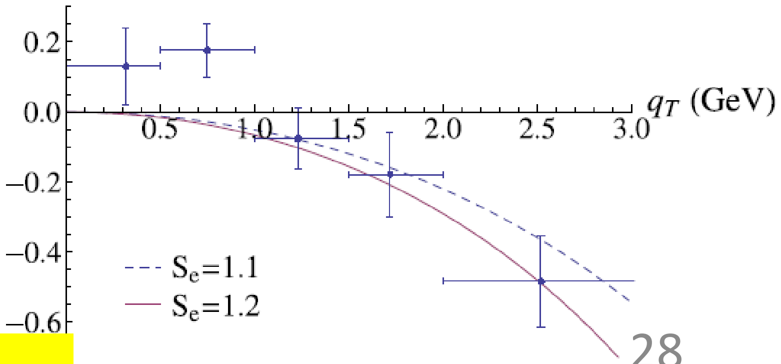
Glauber gluon →

loop gluon with tiny $-l_T^2$





$1-\lambda-2\nu$



Glauber Phase Factor: $\exp(iS_e)$

S_e is large only for the pion as Nambu-Goldstone boson.

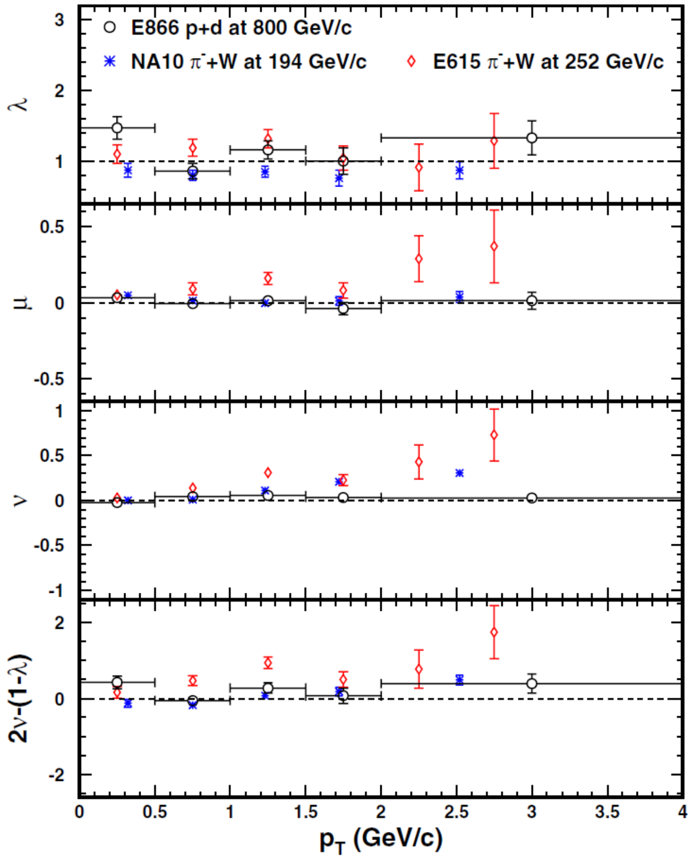
Theoretical Interpretations of Lam-Tung Violation in pion-induced DY

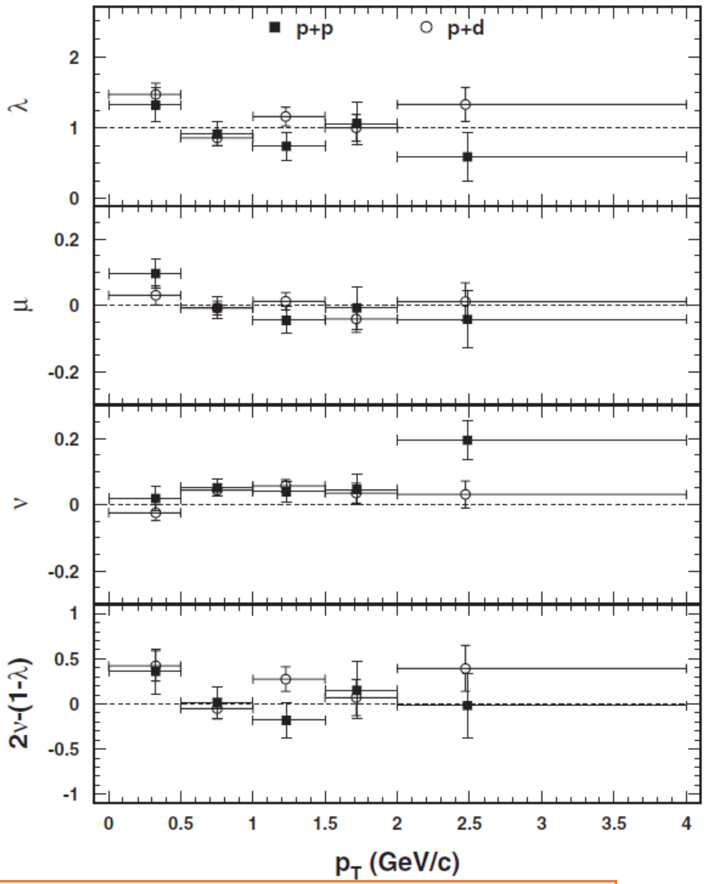
	Boer-Mulders Function	**QCD chromo-magnetic effect**	**Glauber gluon**
Origin of effect	Hadron	QCD vacuum	Pion specific
Quark-flavor dependence	Yes	No	No
Hadron dependence	Yes	No	Yes
Large P_T limit	0	Nonzero	0
Violation for πp	Yes (valence quarks involved)	Yes	Yes
Violation for Kp	Yes (valence quarks involved)	Yes	Yes/No
Violation for $\bar{p}p$	Yes (valence quarks involved)	Yes	No
Violation for pp	No (sea quarks involved)	Yes	No
References	PRD 60, 014012 (1999)	Z. Phy. C 60,697 (1993)	PLB 726, 262 (2013)

Measurements with different beams $\pi, p, K, \bar{p}$ over wide kinematical ranges would help differentiating the origin of Lam-Tung violation.

Kaon and antiproton beams

Consistency of LT relation in p+p and p+d DY:
E866 (PRL 99 (2007) 082301; PRL 102 (2009) 182001)





$\nu(\pi^- W \rightarrow \mu^+\mu^- X) \sim [\text{valence } h_1^{\perp}(\pi)] * [\text{valence } h_1^{\perp}(p)]$

$\nu(pd \rightarrow \mu+\mu- X) \sim [\text{valence } h_1^{\perp}(p)] * [\text{sea } h_1^{\perp}(p)]$

Sea-quark BM functions are much smaller than valence quarks.

Boer-Mulders functions from unpolarized pD and pp Drell-Yan data

$\sigma_{UU} \propto f_1^{(A,\bar{q})} f_1^{(B,q)} + h_1^{\perp(A,\bar{q})} h_1^{\perp(B,q)} \cos 2\phi$

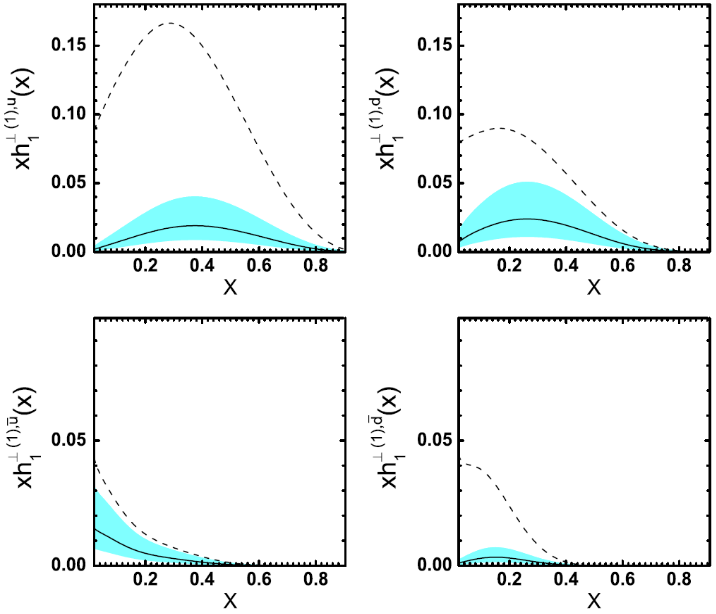
Z. Lu and I. Schmidt,

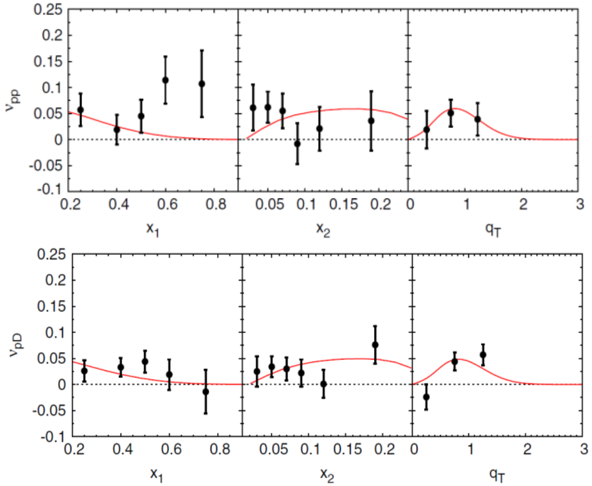
PRD 81, 034023 (2010)

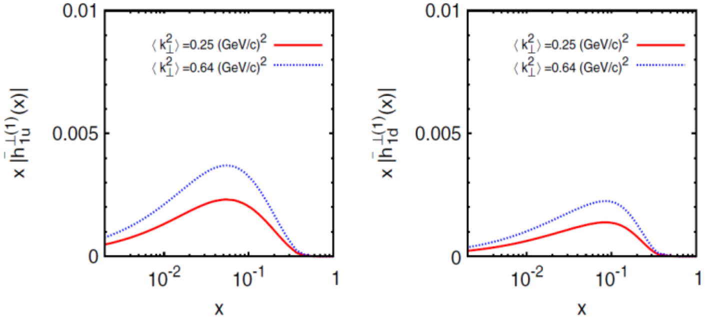
V. Barone et al.,

PRD 82, 114025 (2010)

$$h_1^{\perp q}(x, \boldsymbol{p}_T^2) = h_1^{\perp q}(x) \frac{1}{\pi p_{bm}^2} \exp\left(-\frac{\boldsymbol{p}_T^2}{p_{bm}^2}\right).$$



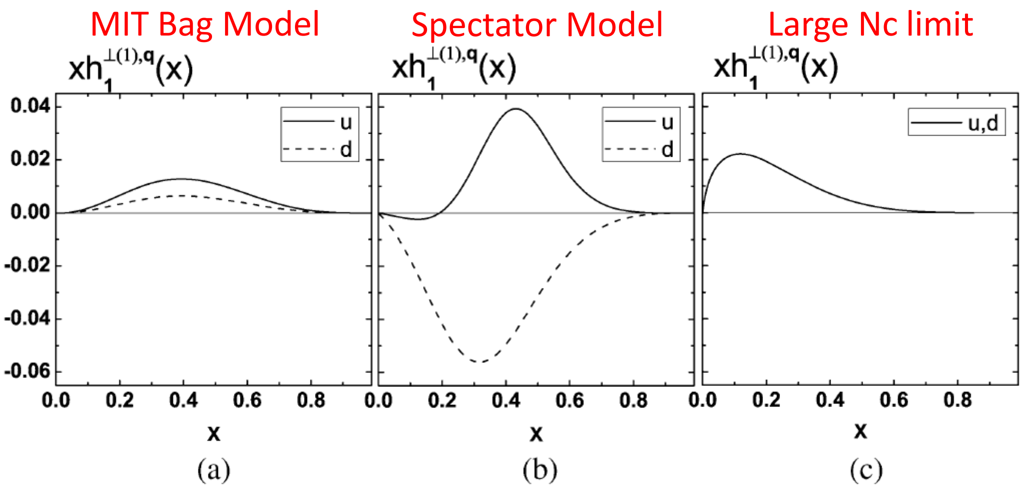


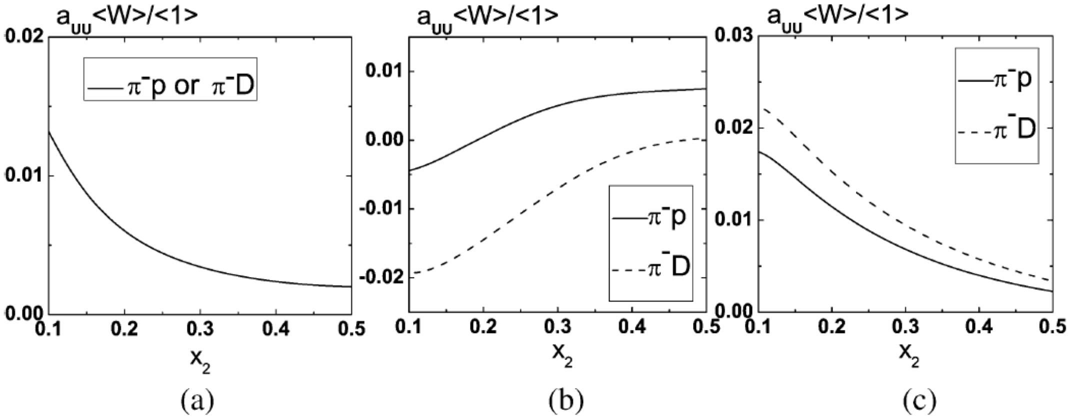


Sign of BM functions and flavor dependence?

Lu, Ma & Schimdt [PLB 639 (2006) 494]:

Flavor separation of the Boer–Mulders functions



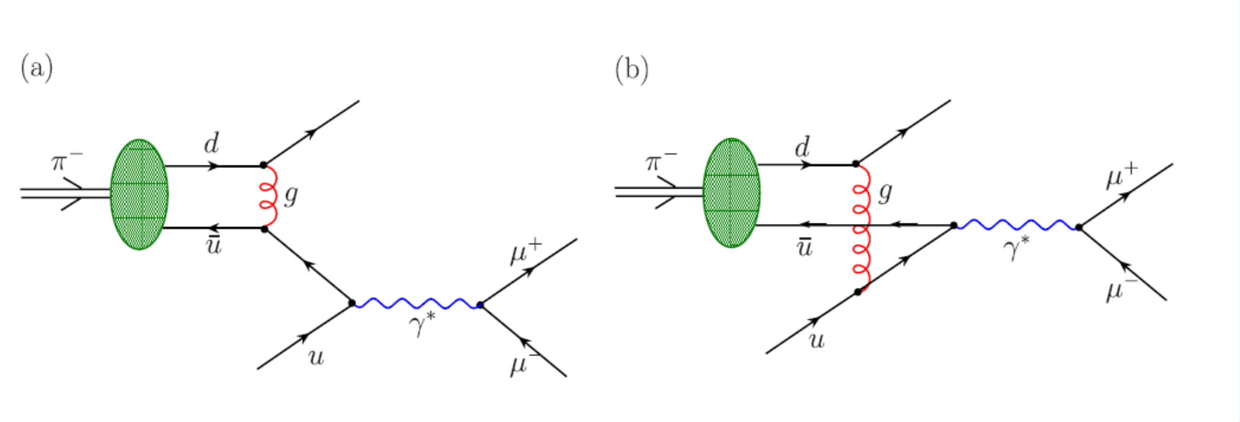


$$\sigma_{UU} \propto f_1^{(\pi,\bar{q})} f_1^{(\mathrm{N,q})} + h_1^{\perp(\pi,\bar{q})} h_1^{\perp(\mathrm{N,q})} \cos 2\phi$$

$$\langle W \rangle = \left\langle \frac{q_T^2 \cos 2\phi}{4 M_A M_B} \right\rangle$$

$$\frac{\langle W \rangle_{\pi D}(x_1, x_2)}{2 \langle W \rangle_{\pi p}(x_1, x_2)} = \frac{1}{2}\left(1 + \frac{h_1^{\perp,d}(x_2)}{h_1^{\perp,u}(x_2)}\right)$$

LD_2 target



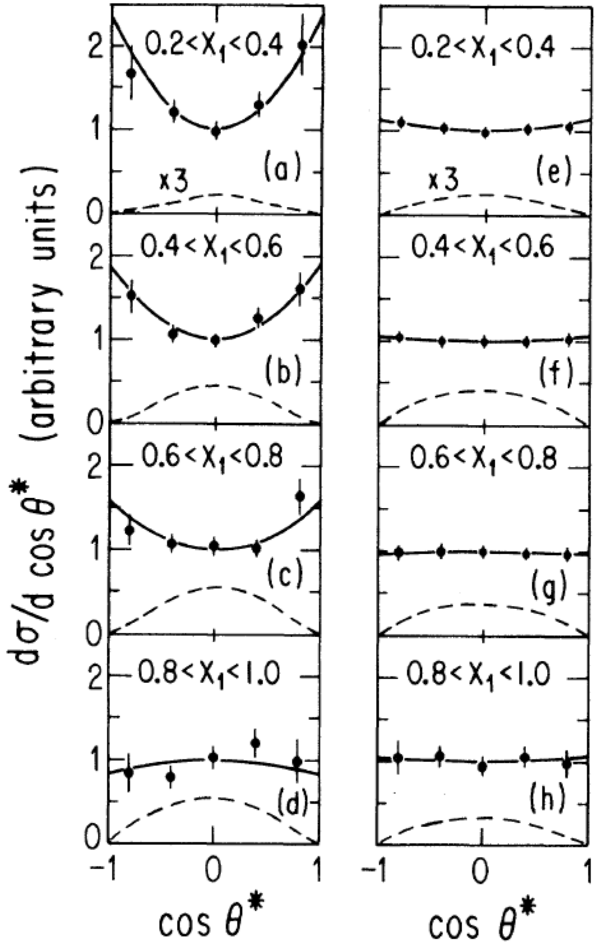
Opportunity (3):

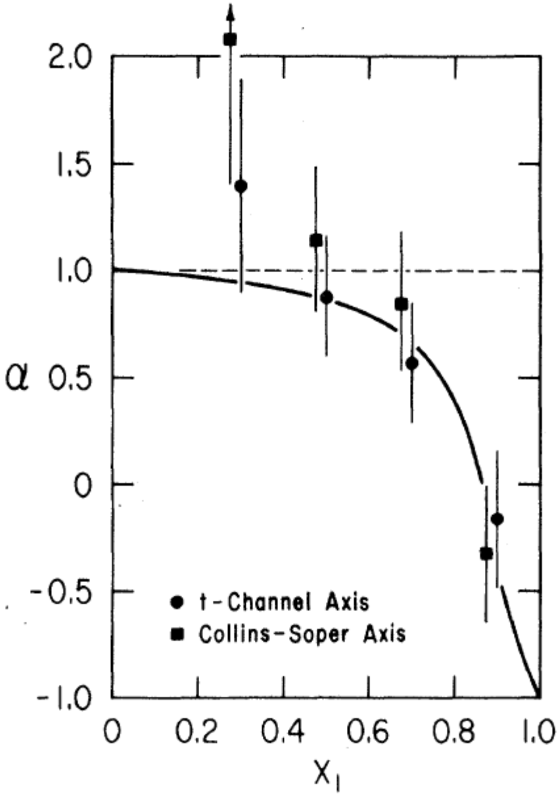
Distribution amplitudes

CIP (PRL 43, 1219, (1979)) :

Longitudinally Polarized Photon at large x_1

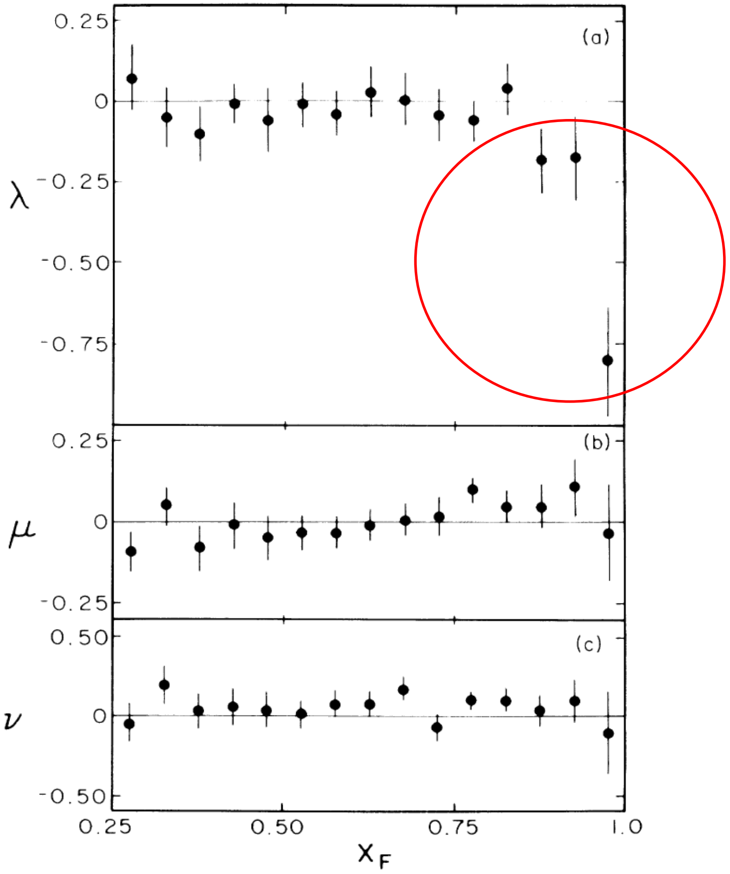
$$\frac{d\sigma}{d\Omega} \propto [W_T(1+\cos^2\theta)+W_L(1-\cos^2\theta)+W_\Delta \sin 2\theta\cos\phi+W_{\Delta\Delta}\sin^2\theta\cos 2\phi]$$





CIP (PRL 58, 2523 (1987)) : $\pi W \rightarrow J/\psi X$

Sign of $q\bar{q}$ annihilation dominating?



$$d^2\sigma/d\cos\theta\, d\phi \propto 1 + \lambda\cos^2\theta + \mu\sin 2\theta\cos\phi + \tfrac{1}{2}\nu\sin^2\theta\cos 2\phi.$$

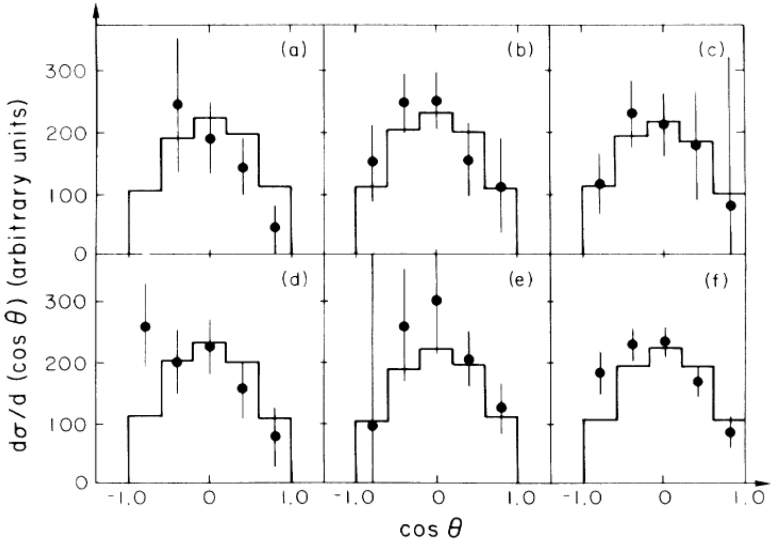
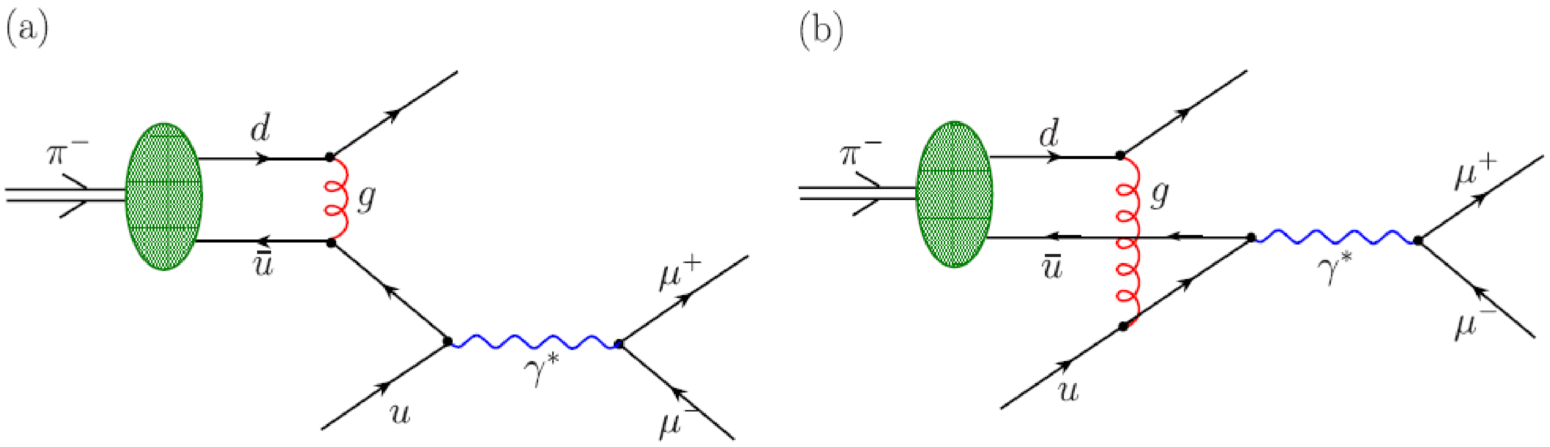


FIG. 4. The J/ψ decay angular distribution vs $\cos\theta$ for the five regions of ϕ, and summed over all ϕ in the highest x_F bin, $0.95 < x_F < 1.0$. The histograms are the result of the fit described in the text. (a) $-\pi < \phi < -0.6\pi$, (b) $-0.6\pi < \phi < -0.2\pi$, (c) $-0.2\pi < \phi < 0.2\pi$, (d) $0.2\pi < \phi < 0.6\pi$, (e) $0.6\pi < \phi < \pi$, (f) $-\pi < \phi < \pi$.

Brandenburg et al. (PRL 73, 939 (1994))
Higher-twist Effect & Pion Distribution Amplitude



$$\frac{Q^2\, d\sigma(\pi^- N \rightarrow \mu^+ \mu^- X)}{dQ^2\, dQ_T^2\, dx_L\, d\Omega} = \frac{1}{(2\pi)^4} \frac{1}{64} \int_0^1 dx_u\, G_{u/N}(x_u) \int_0^1 dx_{\bar{u}} \frac{x_{\bar{u}}}{1 - x_{\bar{u}} + Q_T^2/Q^2} |M|^2$$
$$\times\, \delta(x_L - x_{\bar{u}} + x_u - Q_T^2 s^{-1}(1 - x_{\bar{u}})^{-1})$$
$$\times\, \delta(Q^2 - s x_u x_{\bar{u}} + Q_T^2 (1 - x_{\bar{u}})^{-1}) + \{u \rightarrow \bar{d}, \bar{u} \rightarrow d\}.$$

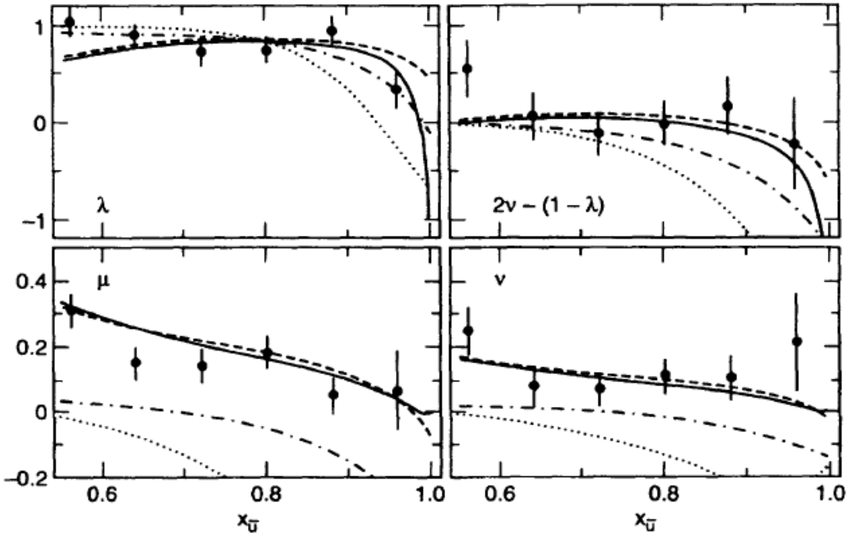
$$M = \int_0^1 dz\, \phi(z, \tilde{Q}^2) T\,,$$

Pion distribution amplitude: distribution of LC momentum fractions in the lowest-particle number valence Fock state.

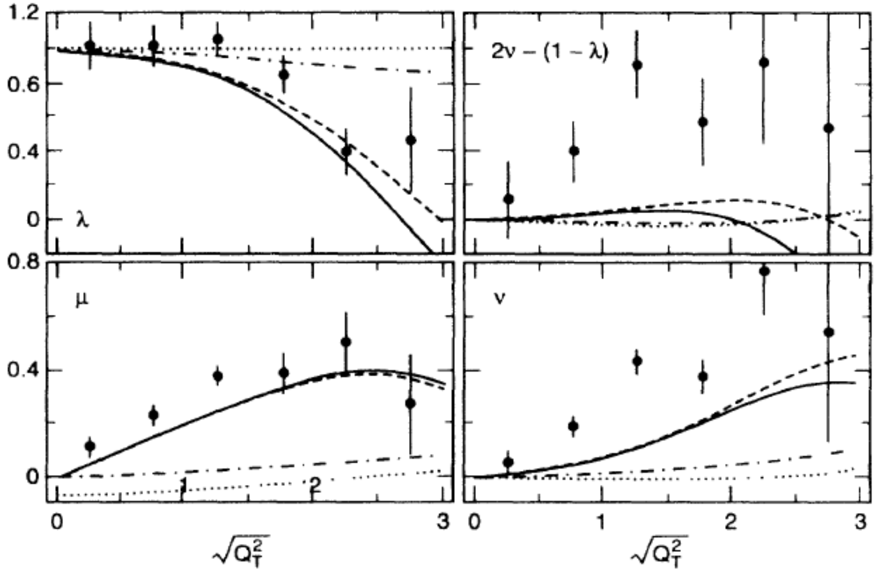
Brandenburg et al. (PRL 73, 939 (1994)) Pion Distribution Amplitude

λ, μ, ν becomes functions of $x_L, \frac{Q_T^2}{Q^2}, \frac{Q^2}{s}$, and sensitive to $\phi(\mathrm{z})$.

● :E615



● :E615

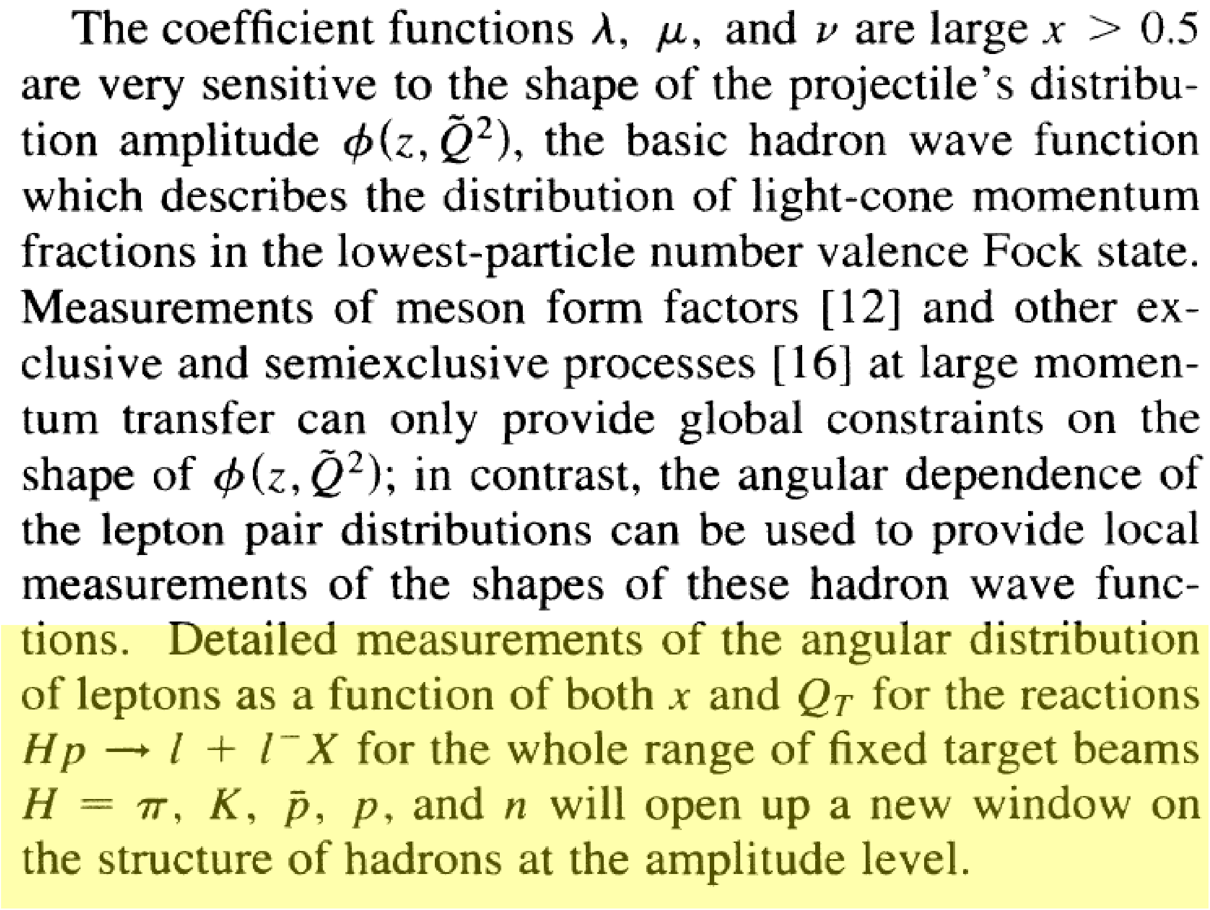


··················· $\phi(\mathrm{z}) = \delta(\mathrm{z} - 1/2)$ simplest form

—·—·—·—·—·—· $\phi(\mathrm{z}) = 6\mathrm{z}(1 - \mathrm{z})$ asympotic form

- - - - - - - - - - / ———— $\phi(\mathrm{z}) = 6z(1 - z)[1 - 50/13z(1 - z)]$ CZ form

Brandenburg et al. (PRL 73, 939 (1994)): Pion/Kaon/Antiproton Distribution Amplitude

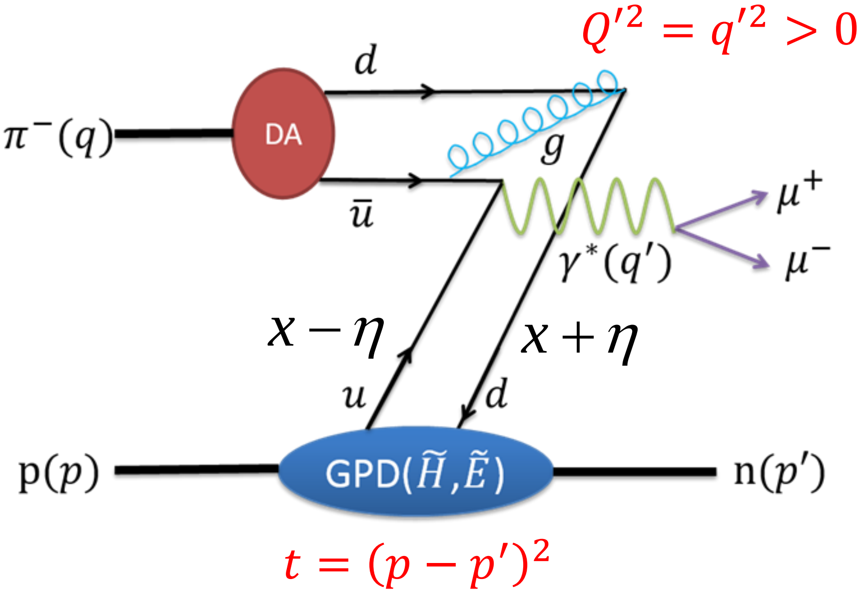


The coefficient functions λ, μ, and ν are large $x > 0.5$ are very sensitive to the shape of the projectile's distribution amplitude $\phi(z, \tilde{Q}^2)$, the basic hadron wave function which describes the distribution of light-cone momentum fractions in the lowest-particle number valence Fock state. Measurements of meson form factors [12] and other exclusive and semiexclusive processes [16] at large momentum transfer can only provide global constraints on the shape of $\phi(z, \tilde{Q}^2)$; in contrast, the angular dependence of the lepton pair distributions can be used to provide local measurements of the shapes of these hadron wave functions. Detailed measurements of the angular distribution of leptons as a function of both x and Q_T for the reactions $Hp \rightarrow l + l^- X$ for the whole range of fixed target beams $H = \pi, K, \bar{p}, p$, and n will open up a new window on the structure of hadrons at the amplitude level.

Kaon and antiproton beams

$\pi N \to \gamma^* N$ (Exclusive Drell-Yan)

E.R. Berger, M. Diehl, B. Pire, PLB 523 (2001) 265

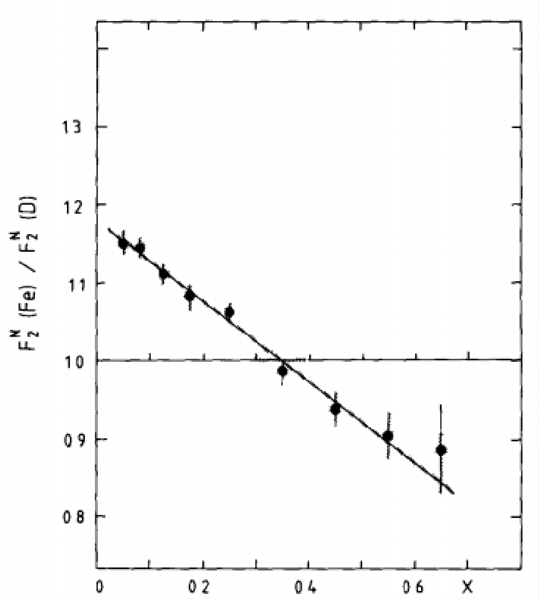


$$\tau = \frac{Q'^2}{2pq} \approx \frac{Q'^2}{s - M_N^2} \qquad \eta = \frac{(p-p')^+}{(p+p')^+}$$

$$\frac{d\sigma}{dQ'^2\, dt\, d(\cos\theta)\, d\varphi} = \frac{\alpha_{\rm em}}{256\pi^3} \frac{\tau^2}{Q'^6} \sum_{\lambda',\lambda} |M^{0\lambda',\lambda}|^2 \sin^2\theta,$$

$$\begin{aligned} &M^{0\lambda',\lambda}(\pi^- p \to \gamma^* n) \\ &= -ie\frac{4\pi}{3}\frac{f_\pi}{Q'}\frac{1}{(p+p')^+}\bar{u}(p',\lambda') \\ &\times \Big[\gamma^+\gamma_5 \tilde{\mathcal{H}}^{du}(-\eta,\eta,t) \\ &\qquad + \gamma_5 \frac{(p'-p)^+}{2M}\tilde{\mathcal{E}}^{du}(-\eta,\eta,t)\Big] u(p,\lambda). \end{aligned}$$

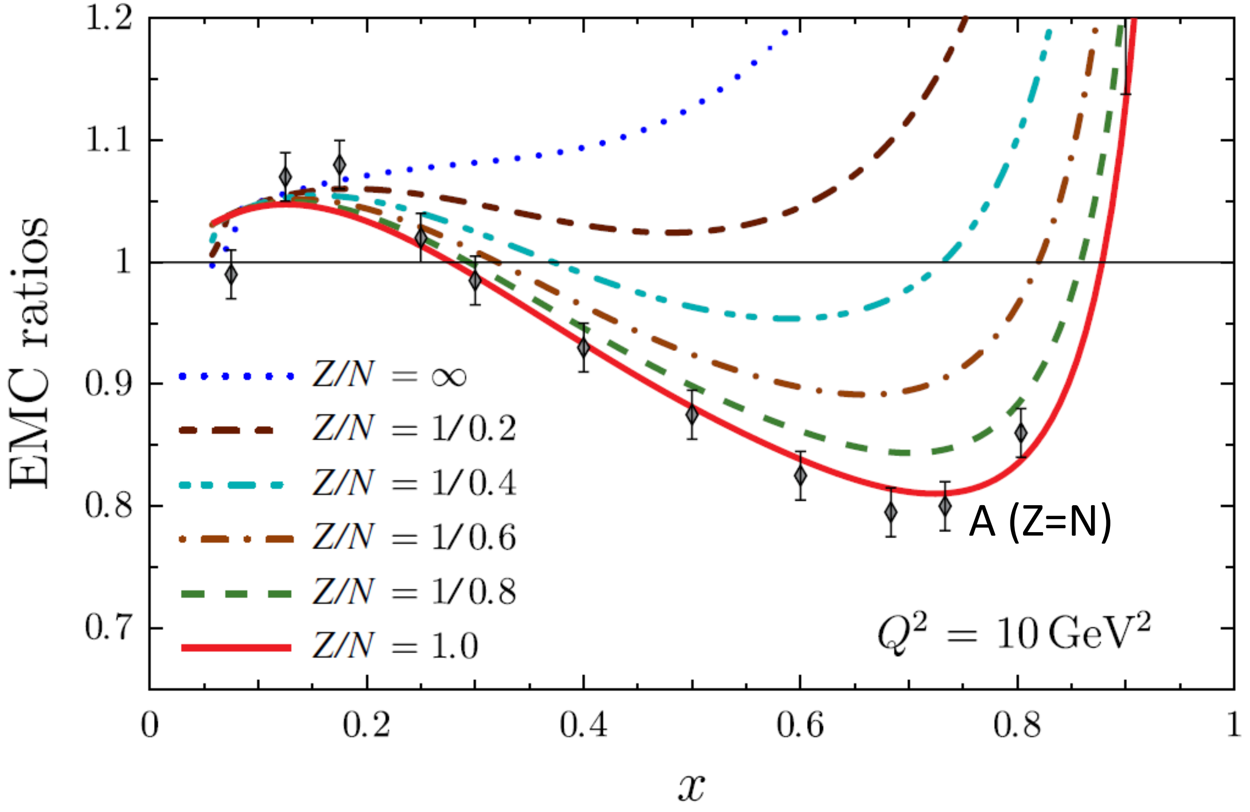
$$\begin{aligned} &\tilde{\mathcal{I}}^{du}(\xi,\eta,t) \\ &= \frac{8}{3}\alpha_S \int_{-1}^{1} dz\, \frac{\phi_\pi(z)}{1-z^2} \\ &\times \int_{-1}^{1} dx \left[\frac{e_d}{\xi - x - i\epsilon} - \frac{e_u}{\xi + x - i\epsilon}\right] \\ &\times \left[\tilde{H}^d(x,\eta,t) - \tilde{H}^u(x,\eta,t)\right], \end{aligned}$$



Opportunity (4):
Flavor-dependent EMC effect

Cloet et. al (PRL 102, 252301, 2009): Flavor dependence of the EMC effect?

$$\frac{F_2^A}{F_2^D}$$

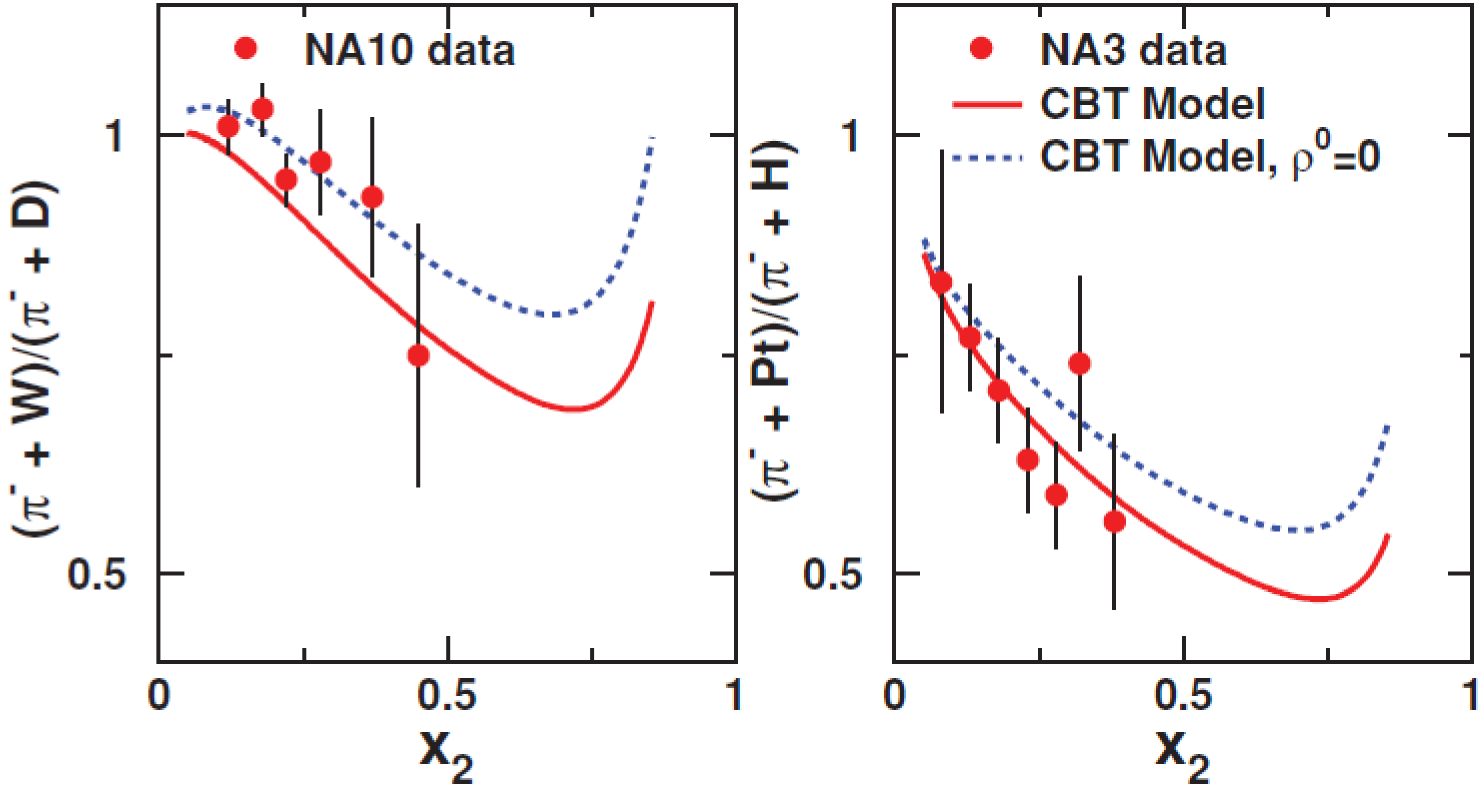


CBT model: the iso-vector ρ^0 mean-field generated in Z≠N nuclei can modify nucleon's *u* and *d* PDFs differently.

Dutta et al. (PRC 83, 04220, 2011):

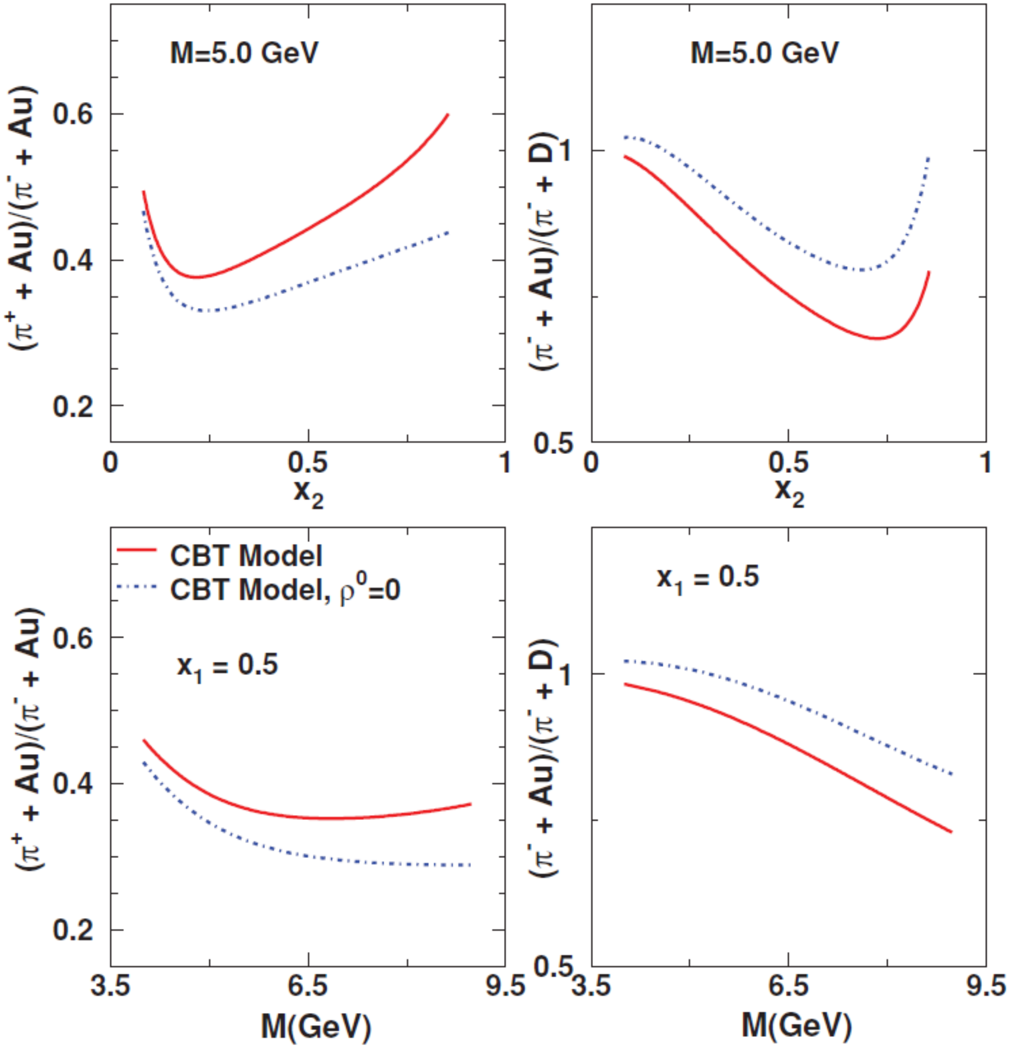
Pion-induced Drell-Yan and the flavor-dependent EMC effect

$$\frac{\sigma^{DY}(\pi^- + A)}{\sigma^{DY}(\pi^- + D)} \approx \frac{u_A(x)}{u_D(x)}$$



Dutta et al. (PRC 83, 04220, 2011):

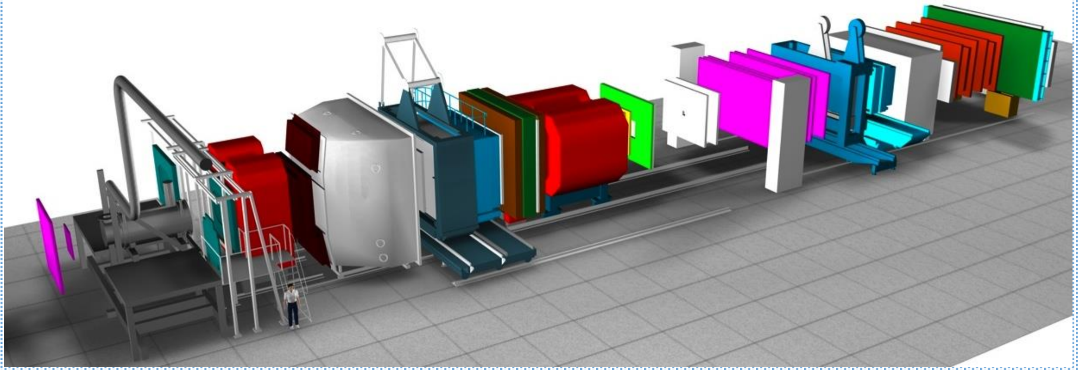
Pion-induced Drell-Yan and the flavor-dependent EMC effect



$$\frac{\sigma^{DY}(\pi^+ + A)}{\sigma^{DY}(\pi^- + A)} \approx \frac{d_A(x)}{4u_A(x)}$$

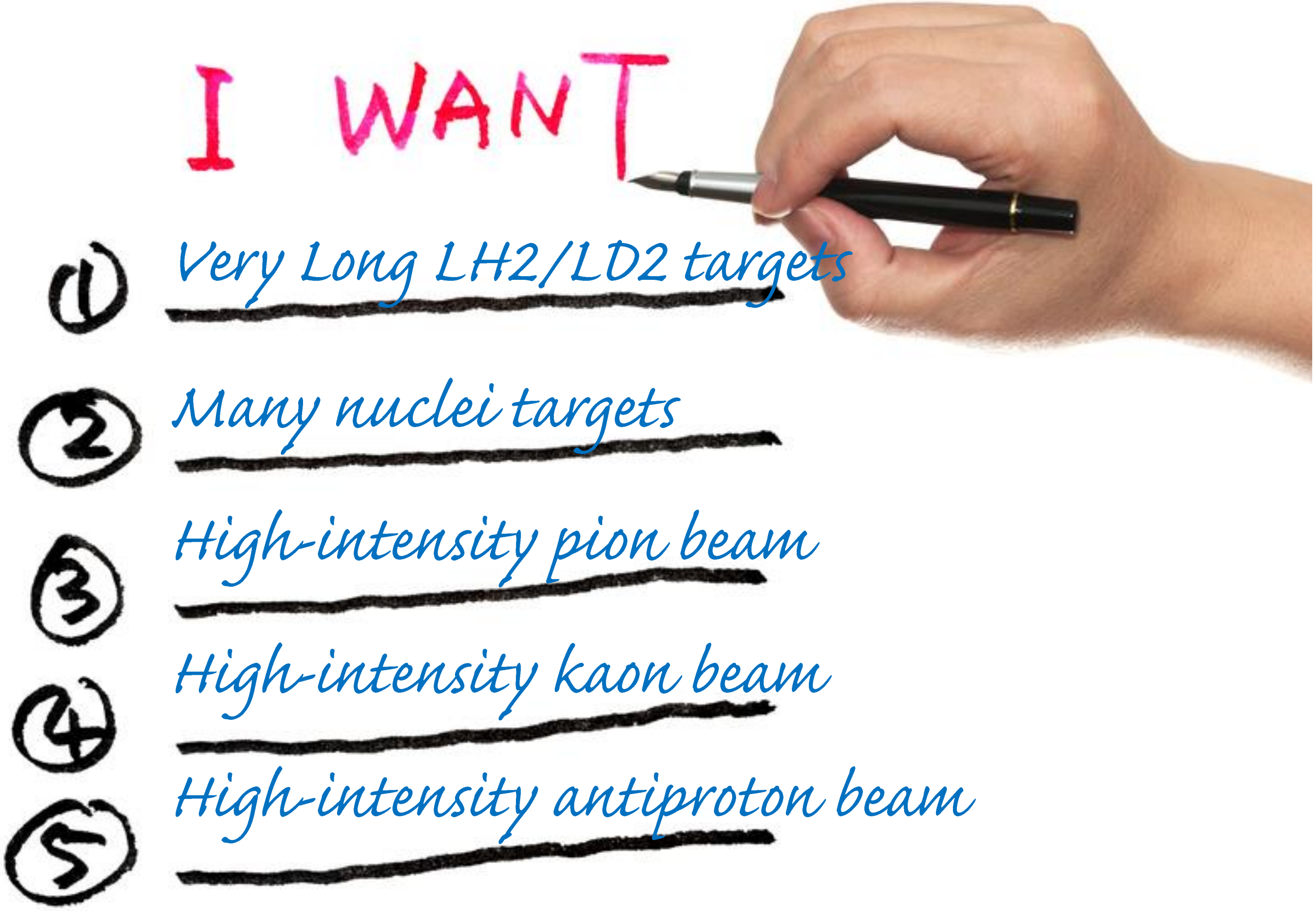
$$\frac{\sigma^{DY}(\pi^- + A)}{\sigma^{DY}(\pi^- + D)} \approx \frac{u_A(x)}{u_D(x)}$$

LD_2 and nuclear targets



Feasibility for COMPASS (Beyond 2020)

Wish List of COMPASS from Unpolarized Drell-Yan Program



① Very Long LH2/LD2 targets

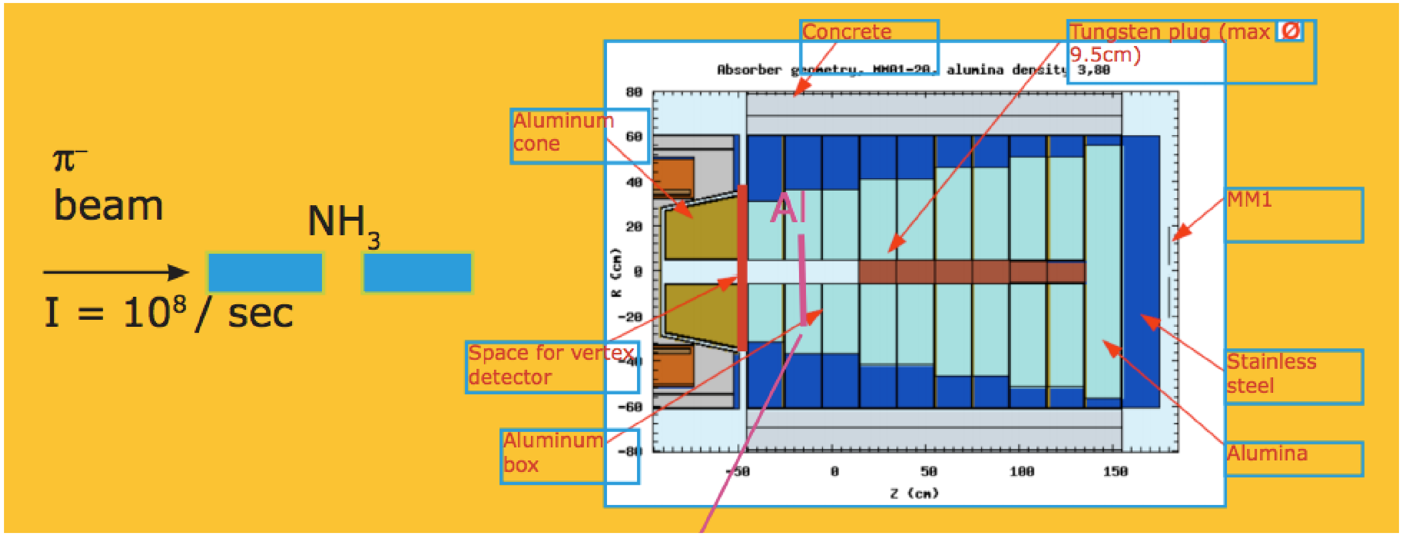
② Many nuclei targets

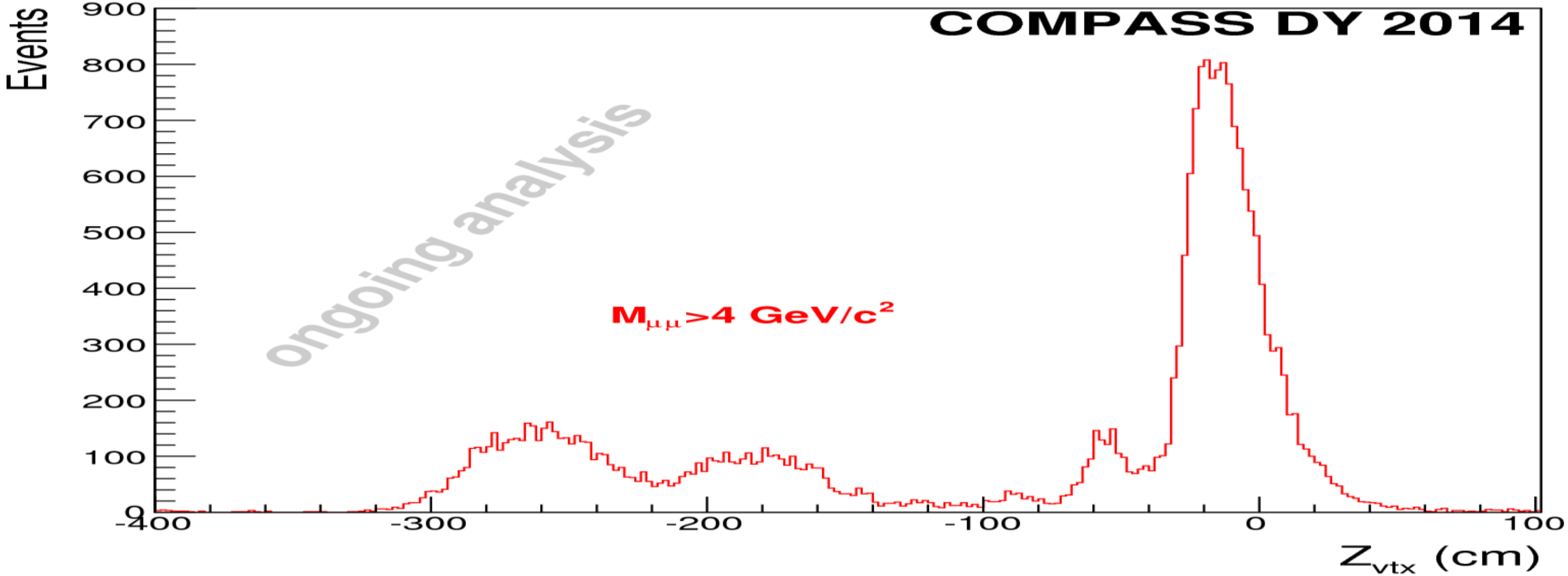
③ High-intensity pion beam

④ High-intensity kaon beam

⑤ High-intensity antiproton beam

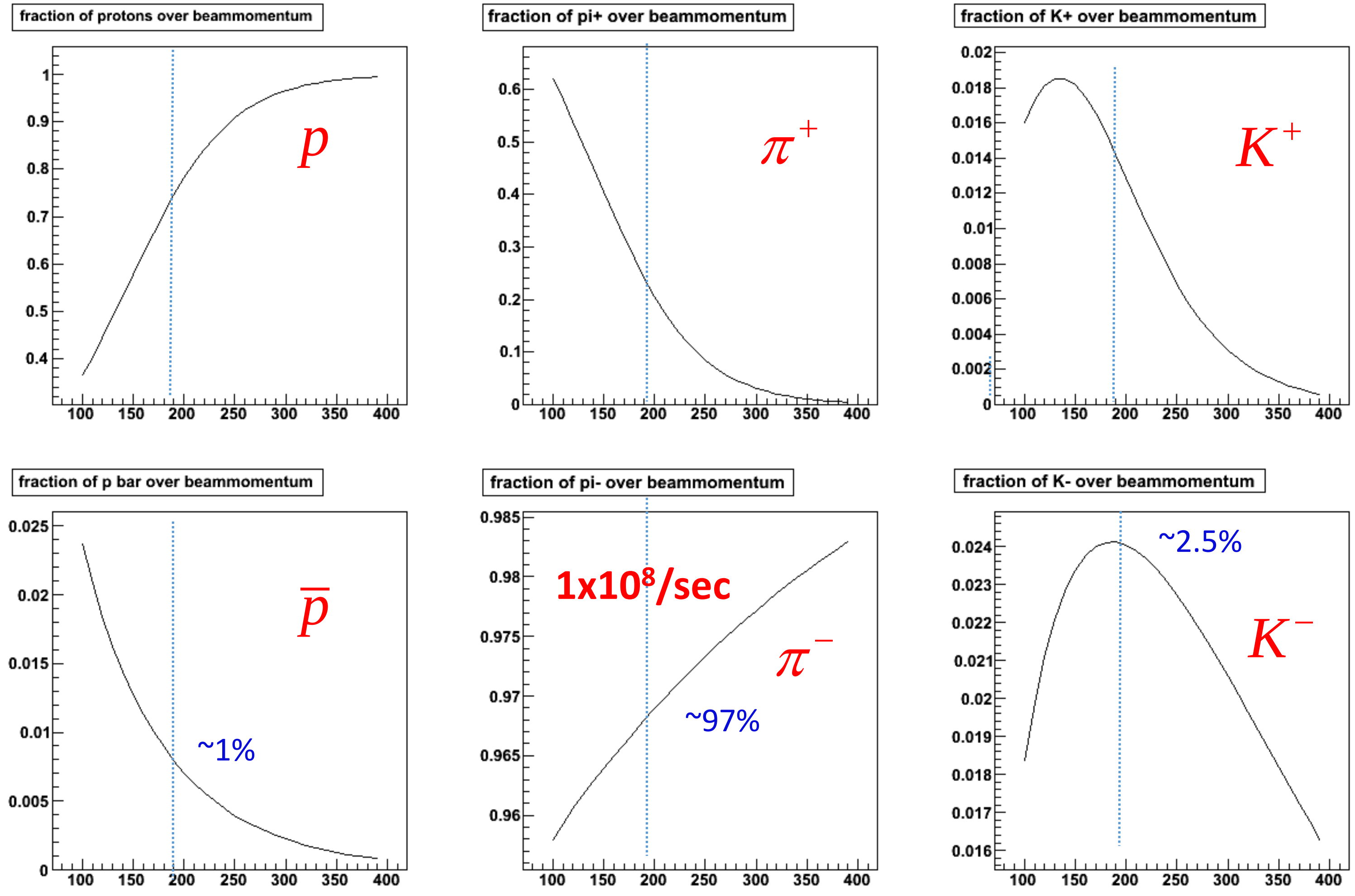
Dimuon Vertex Distributions (2014 DY)



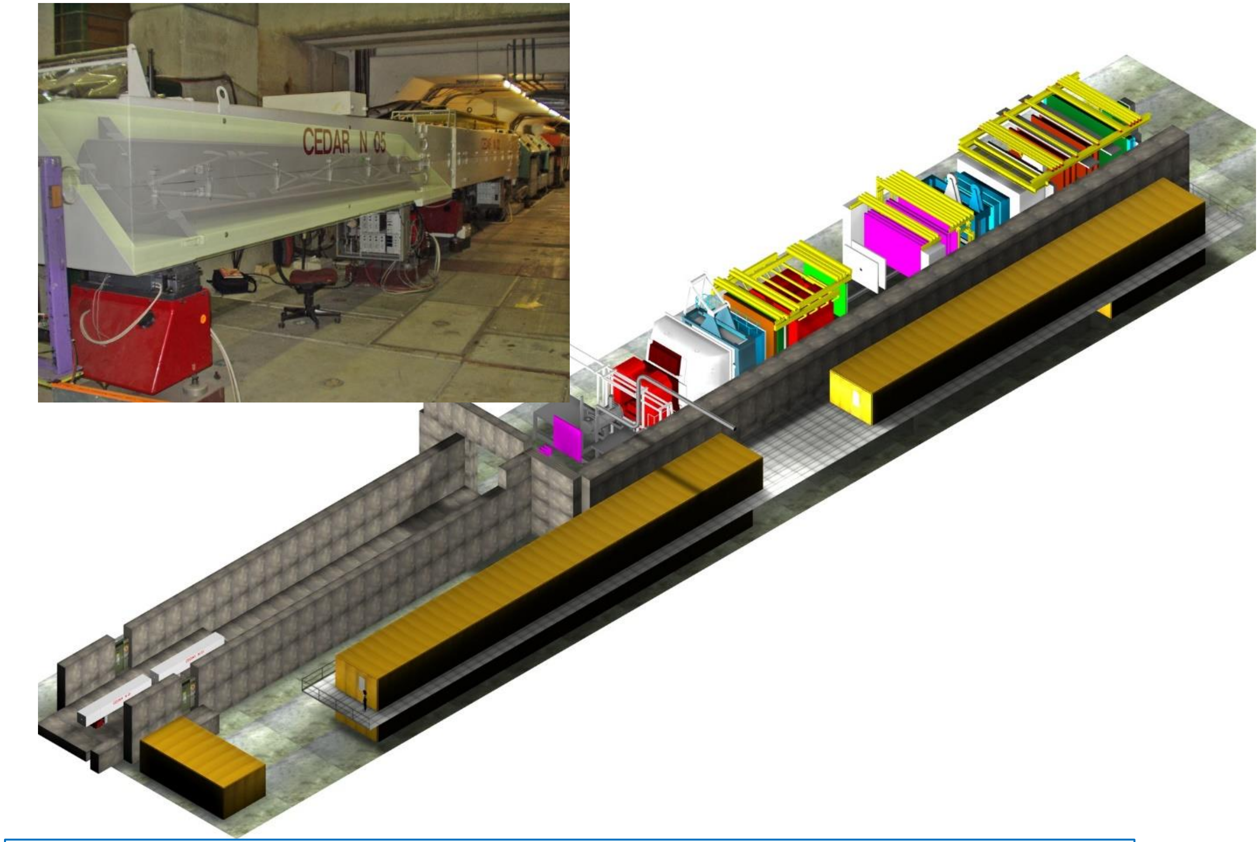


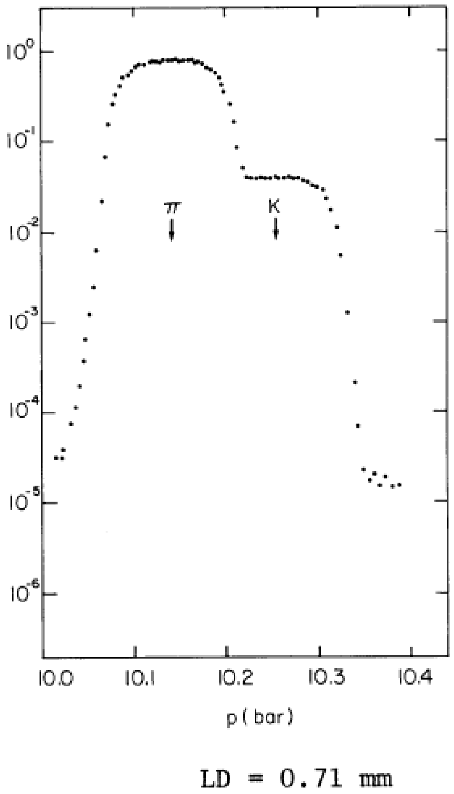
Fraction of particles in the positive or negative M2-Hadron-beam at COMPASS target

http://www.staff.uni-mainz.de/jasinsk/index.htm



Beam PID:
CEDAR (Cerenkov Differential Counters with Achromatic Ring Focus)





Improvement of CEDARs system performance for higher rate capability:
"CEDARs for DY run ", Ivan Gnesi in 2014 June COMPASS TB Meeting

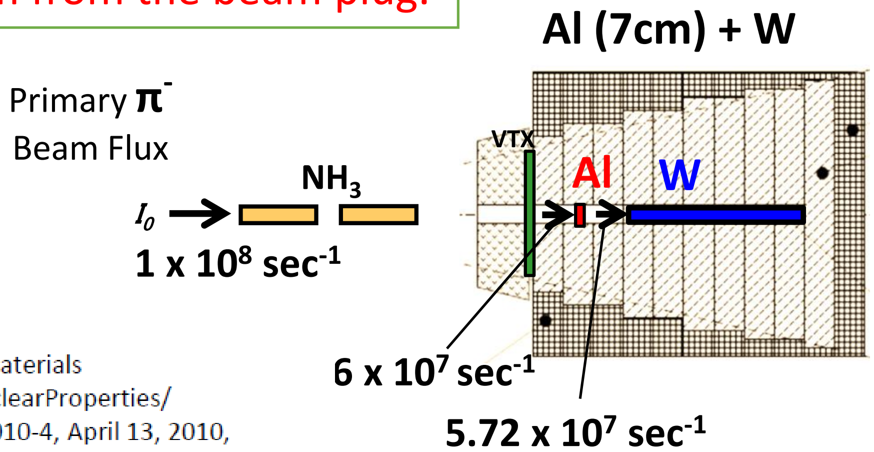
Attenuation of hadron beams in target materials

Primary π^- Beam Flux into each target

	Z_{eff}	A_{eff}	Z_{eff}/A_{eff}	Density ρ (g/cm^3)	pion interaction length λ_{int} (g/cm^2)	Thickness L (cm)	Effective Thickness L_{eff} (cm)	Primary π^- Beam Flux
NH_3	5.94	11.71	0.507	0.85 x 0.5 (F_f)	114.81	110	90.36	**1×10^8**
Vertex Detector: Polystyrene $[C_6H_5CHCH_2]_n$	5.62	11.16	0.504	1.06	113.7	1.5	1.49	6.66×10^7
Al	13	**26.98**	**0.482**	2.70	136.7	**7.0**	6.54	**6.56×10^7**
W (Beam Plug)	74	**183.8**	**0.403**	19.25	218.7	120	11.36	**5.72×10^7**

Final configuration:
7-cm Al target, 267 mm from the beam plug.

Pion interaction length (Aluminum) = 50.64 cm
7.0 cm = 13.8 % of pion interaction length



- Atomic and Nuclear Properties of Materials http://pdg.lbl.gov/2012/AtomicNuclearProperties/
- M. Chiosso et al., COMPASS Note 2010-4, April 13, 2010, http://wwwcompass.cern.ch/compass/notes public/2010-4.pdf.

Takahiro Sawada

Attenuation of beam hadrons in material

Estimation of #DY

Assumption:
K- : 2.5 % x 0.5 (PID efficiency)
anti-p : 1% x 0.8 (PID efficiency)

K^- Beam Flux into each target

	K^- interaction length λ_{int} (g/cm^2)	Thickness L (cm)	Effective Thickness L_{eff} (cm)	Primary K^- Beam Flux	(scale)
NH_3	127	110	92.0	**1x10^8 *(0.025*0.5)** = 1,250,000	(1)
Vertex Detector: Polystyrene [$C_6H_5CHCH_2$]$_n$	125	1.5	1.49	865,000	(0.692)
Al	149	7.0	6.57	854,000	(0.683)
W (Beam Plug)	234	120	12.2	752,000	(0.602)

$\bar{p}$ Beam Flux into each target

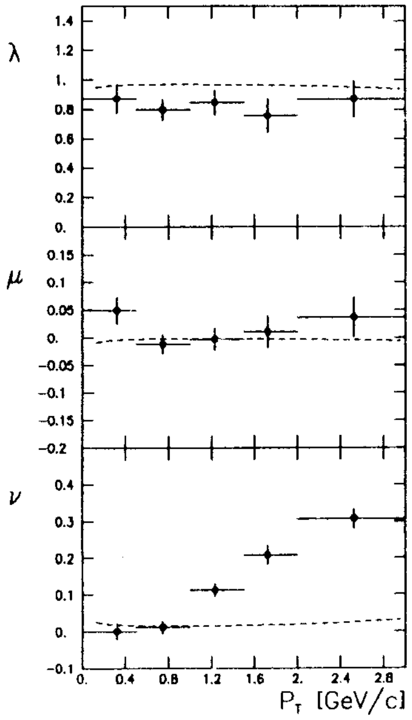
	$\bar{p}$ interaction length λ_{int} (g/cm^2)	Thickness L (cm)	Effective Thickness L_{eff} (cm)	Primary $\bar{p}$ Beam Flux	(scale)
NH_3	82.5	110	84.0	**1x10^8 *(0.01*0.8)** = 800,000	(1)
Vertex Detector: Polystyrene [$C_6H_5CHCH_2$]$_n$	81.3	1.5	1.49	454,000	(0.567)
Al	103	7.0	6.40	445,000	(0.556)
W (Beam Plug)	183	120	9.51	371,000	(0.463)

Expected Statistical Precision of Dimuon Angular Distributions

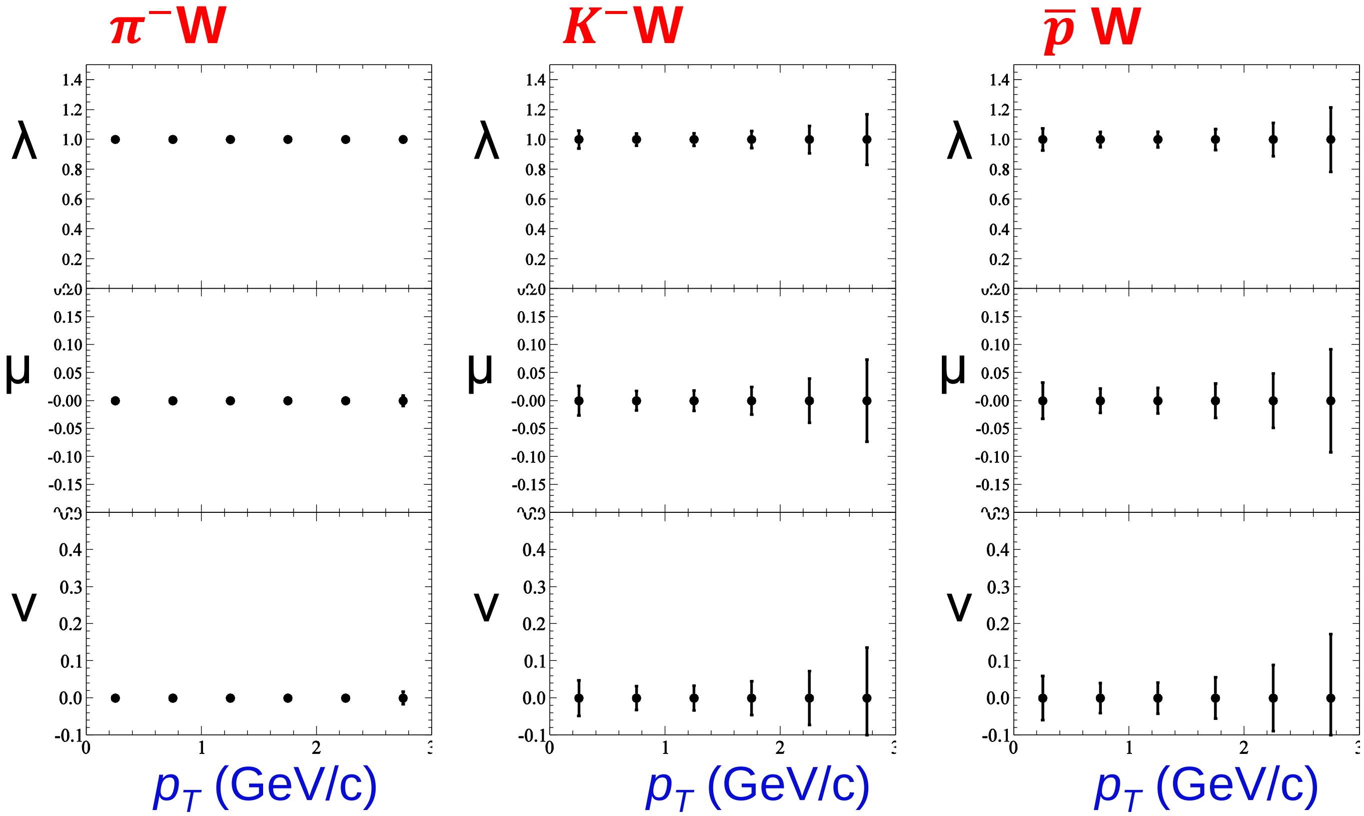
$4 < M_{\mu\mu} < 9$ *GeV/c²*

NA10

194 GeV/c



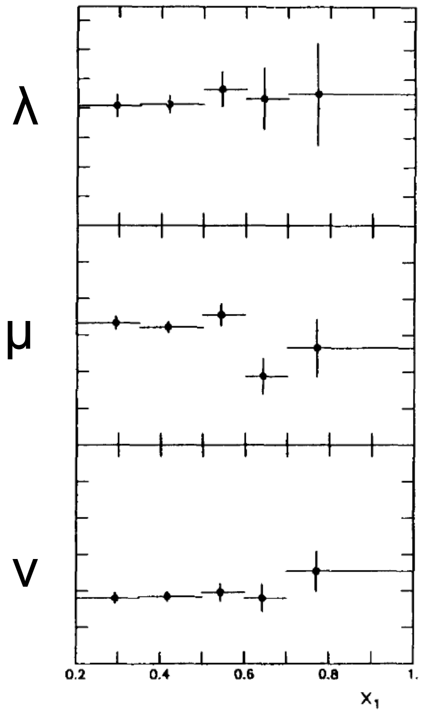
COMPASS, DY on **W target**, 140-day data taking



Expected Statistical Precision of Dimuon Angular Distributions

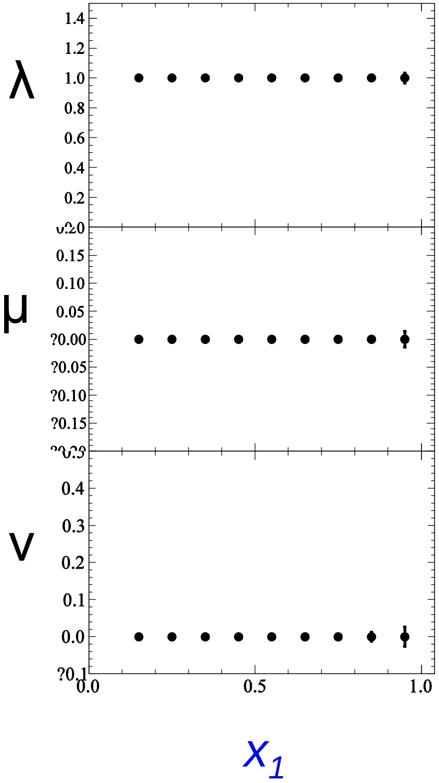
$4 < M_{\mu\mu} < 9\ GeV/c^2$

NA10

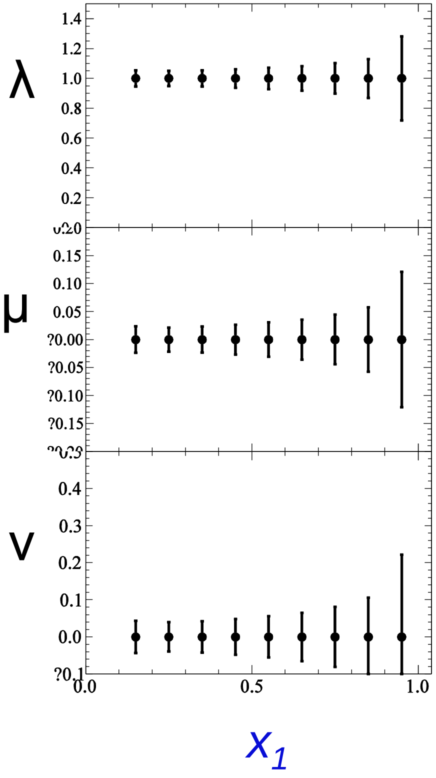


COMPASS, DY on **W target**, 140-day data taking

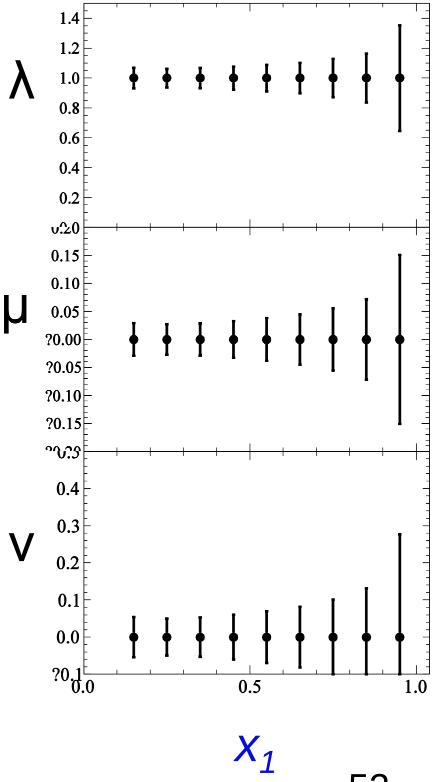
$\pi^- W$



$K^- W$



$\bar{p}$ W



Improved CEDAR:

Expected Statistics of Unpolarized Drell-Yan Events

DY ($4 < M_{\mu\mu} < 9\ GeV/c^2$)

140-day data taking, with the efficiencies of 2015 DY run.

	NH_3	Al (7cm)	W	NA3	NA10	E537	E615
π^- beam	140,000	27,100	270,000	21,220	284,200		27,977
K^- beam	1,750	350	3,700	700			
$\bar{p}$ beam	1,260	220	1,800			387	

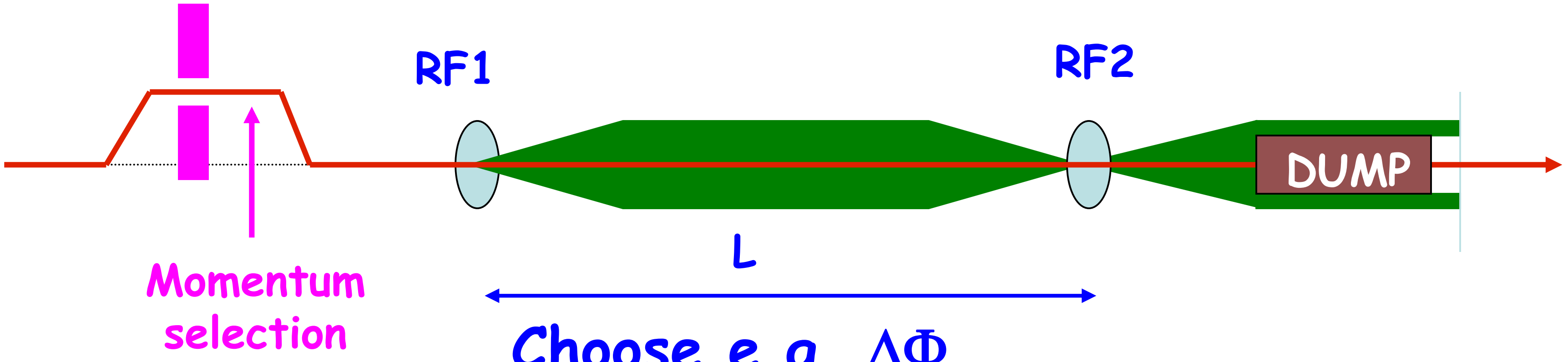
COMPASS could improve the existing statistics of π, K and $\bar{p}$-induced DY by a factor of **2-10**!

WHAT ABOUT A RF SEPARATED $\bar{p}$ BEAM ???

First and very preliminary thoughts, guided by

- recent studies for P326
- CKM studies by J.Doornbos/TRIUMF, e.g. http://trshare.triumf.ca/~trjd/rfbeam.ps.gz

E.g. a system with two cavities:



Choose e.g. $\Delta\Phi_{\pi p}$

$$\Delta\Phi = 2\pi\,(L\,f\,/\,c)\,(\beta_1^{-1} - \beta_2^{-1}) \text{ with } \beta_1^{-1} - \beta_2^{-1} = (m_1^2 - m_2^2)/2p^2$$

Base rough estimates on acceptance values for RF separated K^+ beam (as provided by J.Doornbos)

	CKM K^+ beam	**$\bar{p}$ beam**
Beam momentum [GeV/c]	60	100
Momentum spread [%]	±2	±1
Angular emittance H, V [mrad]	±3.5, ±2.5	±3.5, ±2.5
Solid angle [μsterad]	10-12 π	10-12 π
% wanted particles lost on stopper	37	20

As the $\bar{p}$ kick is more favourable than for K^+, I assume that 80% of $\bar{p}$ pass beyond the beam stopper.

➡ Acceptance 10π μsterad, 2 GeV/c

VERY PRELIMINARY CONCLUSION

H.W.Atherton formula tells us : 0.42 $\bar{p}$ / int.proton / GeV

Assume target efficiency of 40%

Then for 10^{13} ppp on target one obtains:

$0.4 \cdot 10^{13} \cdot 0.42 \cdot \pi \cdot 10^{-5} \cdot 2 \cdot 0.8$ $\bar{p}$pp = **8 10^{7} $\bar{p}$pp**

for a total intensity probably not exceeding 10^{13} ppp,
knowing that e^{-} and π are well filtered, but K^{+} only partly.

Due to 10^{8} limit on total flux, max antiproton flux remains limited by purity (probably about 50%). Hence **≈ 5 10^{7} $\bar{p}$pp**

RF/Separated Kaon/antiproton :

Expected Statistics of Unpolarized Drell-Yan Events

A flux of **1×10^7 /sec** for kaon/antiproton is assumed.

DY ($4 < M_{\mu\mu} < 9\ GeV/c^2$)

140-day data taking, with the efficiencies of 2015 DY run.

	NH_3	**Al (7cm)**	**W**	**NA3**	**NA10**	**E537**	**E615**
π^- beam	**140,000**	**27,100**	**270,000**	**21,220**	**284,200**		**27,977**
K^- beam	**14,000**	**2,800**	**29,600**	**700**			
$\bar{p}$ beam	**15,750**	**2,750**	**22,500**			**387**	

COMPASS could improve the existing statistics of K and $\bar{p}$-induced DY by a factor of **50-100**!

Conclusions

- Drell-Yan process is a powerful tool to explore the partonic structures of nucleons and (unstable) mesons.
- Drell-Yan program with Improved CEDAR/RF-separated beam and LH_2/LD_2/nuclear targets will bring unique opportunities for COMPASS to address many important unresolved issues in understanding the flavor and TMD structures of proton, antiproton, pion, kaon and nuclei.