22nd International Spin Symposium

September 25th-30th, 2016 - iHotel Conference Center, Champaign, IL

Charged-hadron lepto-production off unpolarized protons and deuterons at

hermes

ikerbasque

Basque Foundation for Science

Gunar.Schnell @ desy.de

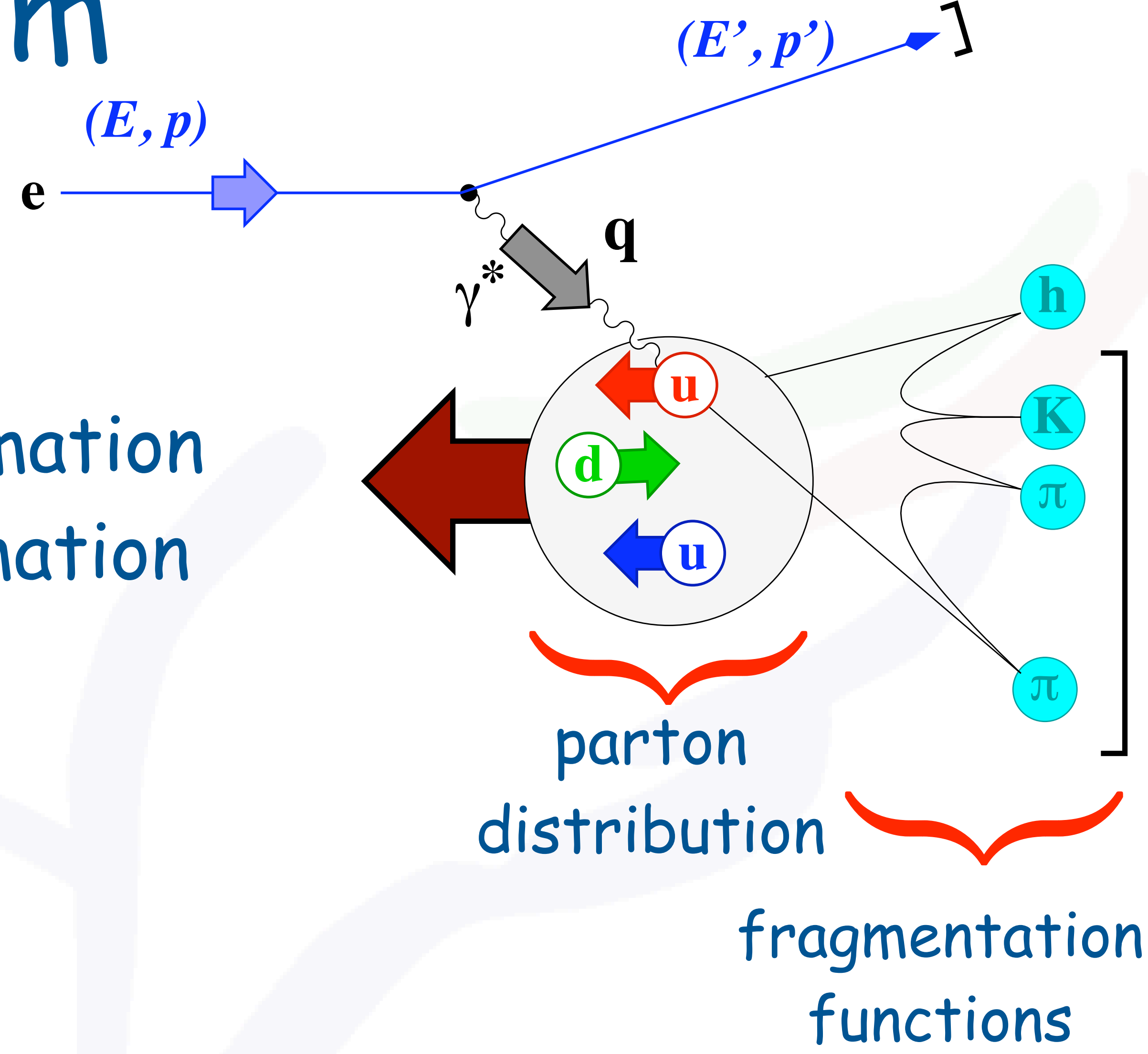
eman ta zabal zazu

Universidad del País Vasco

Euskal Herriko Unibertsitatea

Why study SIDIS from unpolarized targets?

- Semi-inclusive DIS provides information on both hadron structure and formation



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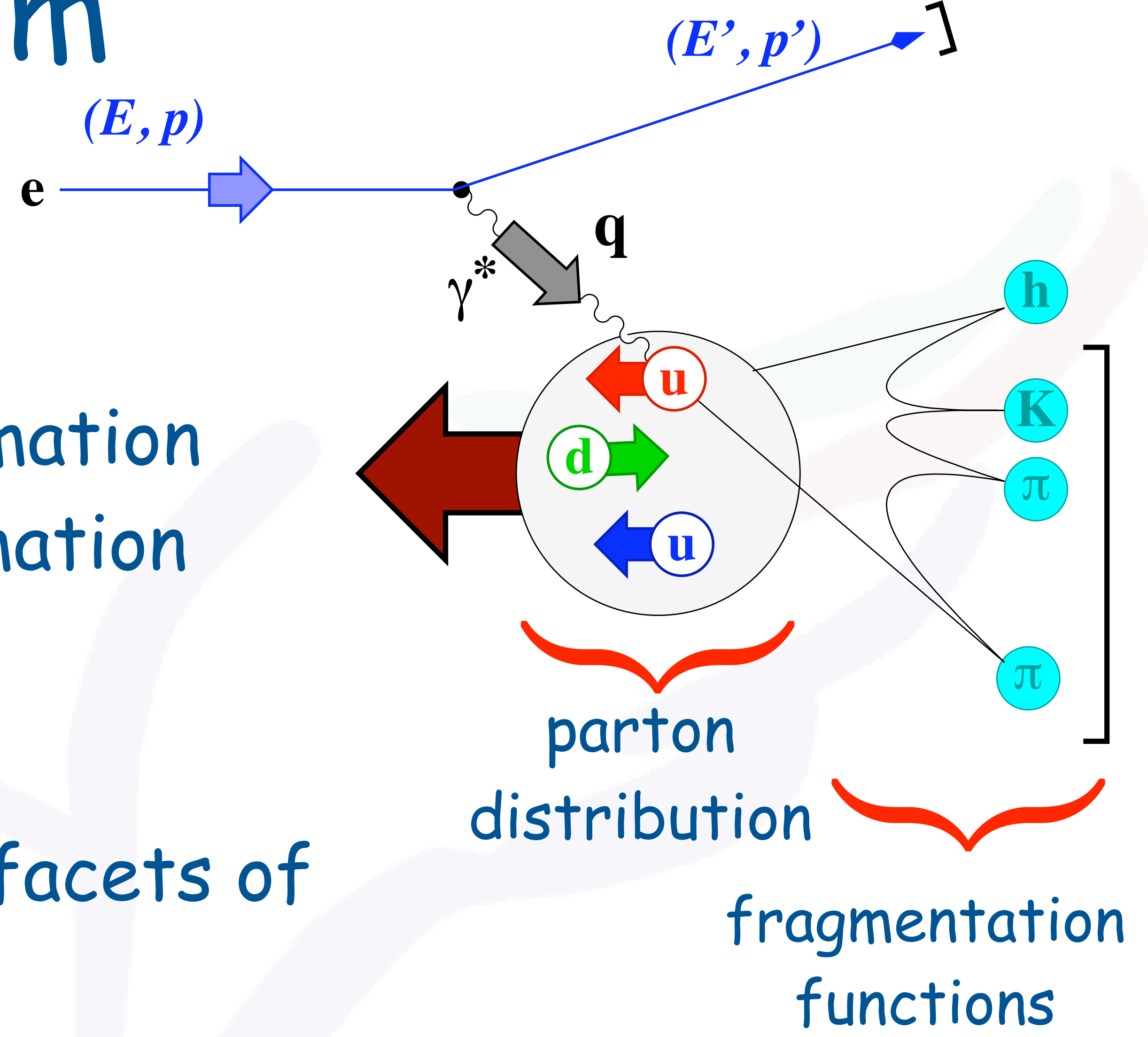

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  - (probably) easiest one to study facets of hadron structure, even in 3D

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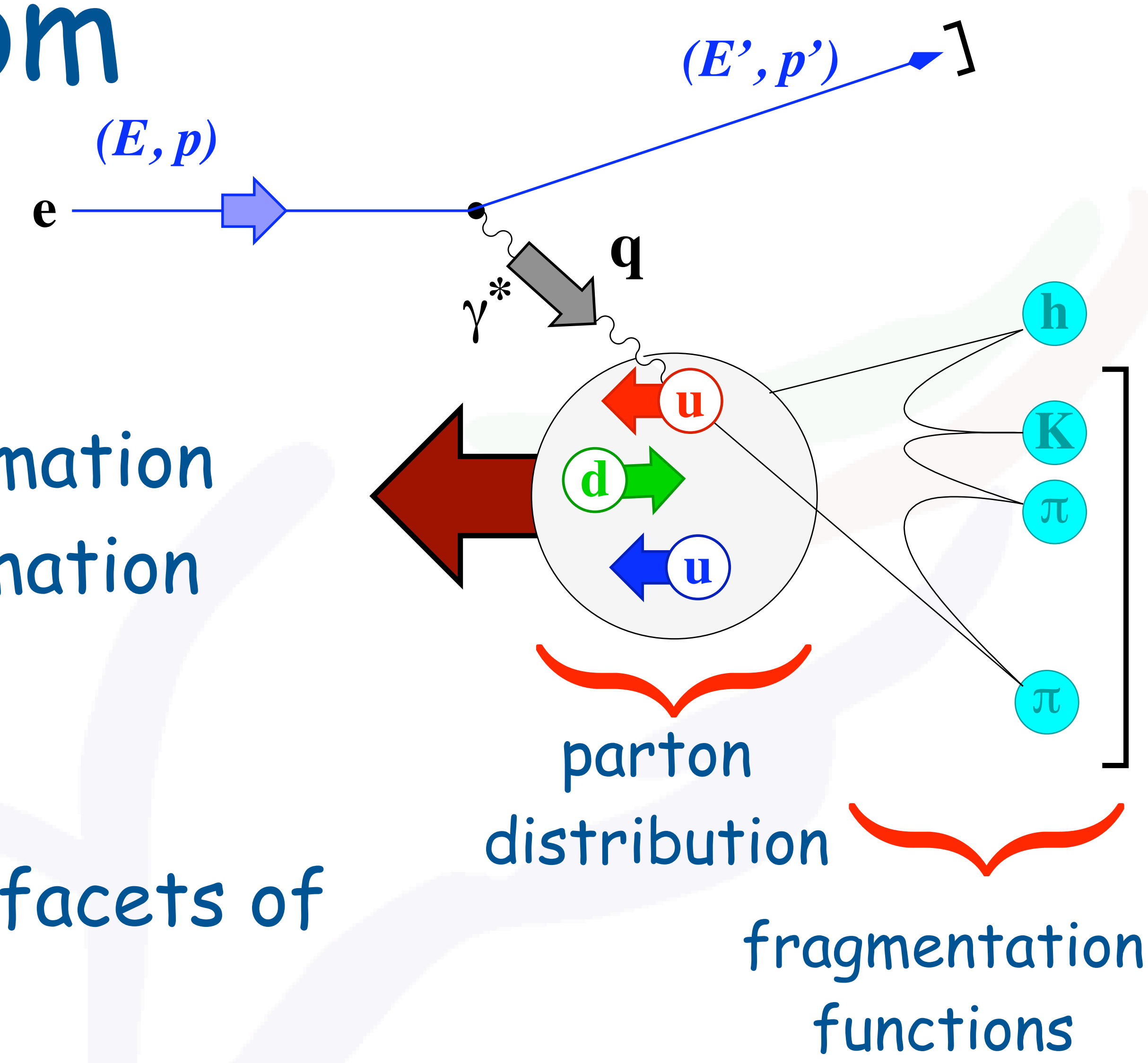

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  - both are ingredients of basically every (spin) asymmetry
  - may probe quark flavors less accessible in inclusive DIS

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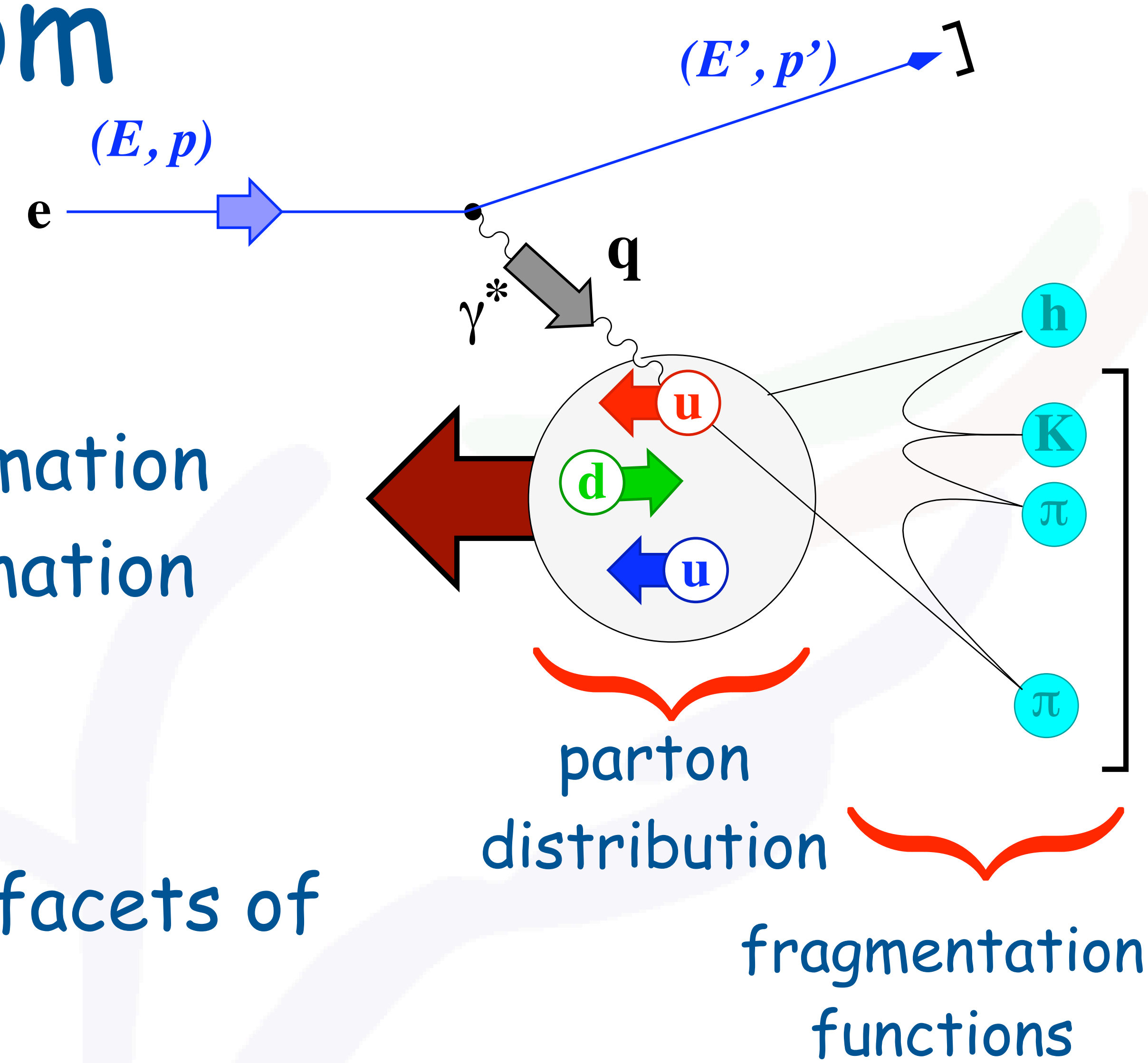

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  - may probe quark flavors less accessible in inclusive DIS
- complimentary info on FFs to e^+e^- (e.g., charge separation)

Polarization-averaged cross section

target polarization — $F_{XY,Z} = F_{XY,Z}(x, y, z, P_{h\perp})$ — beam polarization, virtual-photon polarization

$$\frac{d^5\sigma}{dx\,dy\,dz\,d\phi_h\,dP_{h\perp}^2} \propto \left(1+\frac{\gamma^2}{2x}\right)\{F_{UU,T} + \epsilon F_{UU,L}$$

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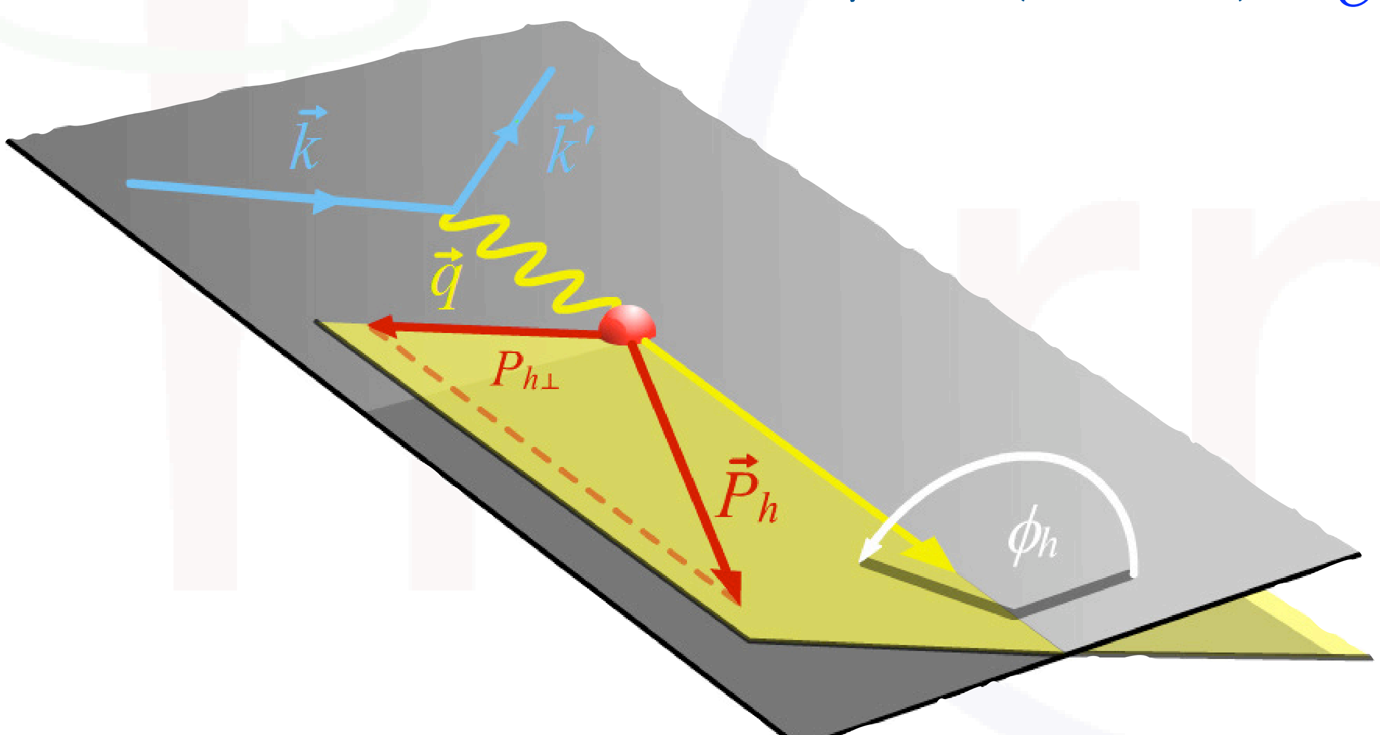

$$\gamma = \frac{2Mx}{Q}$$

$$\varepsilon = \frac{1-y-\frac{1}{4}\gamma^2y^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}\gamma^2y^2}$$

[see, e.g., Bacchetta et al., JHEP 0702 (2007) 093]

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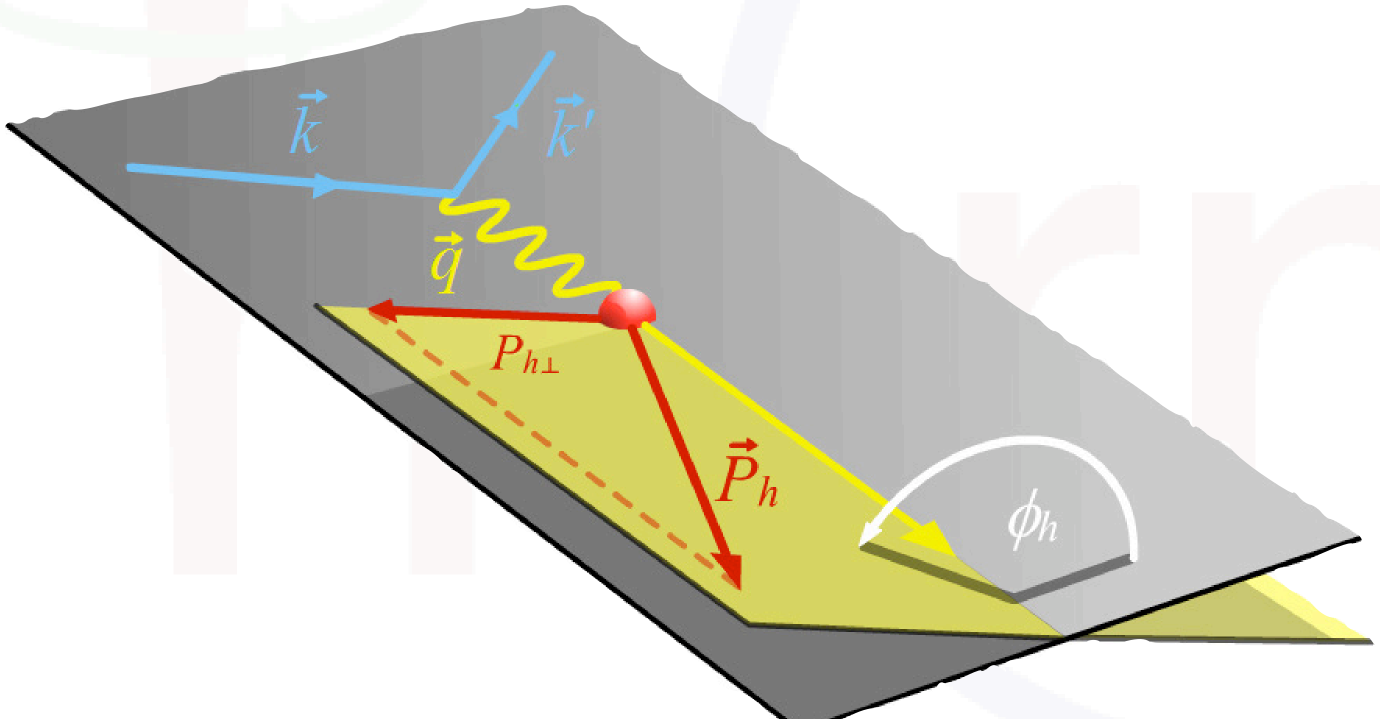

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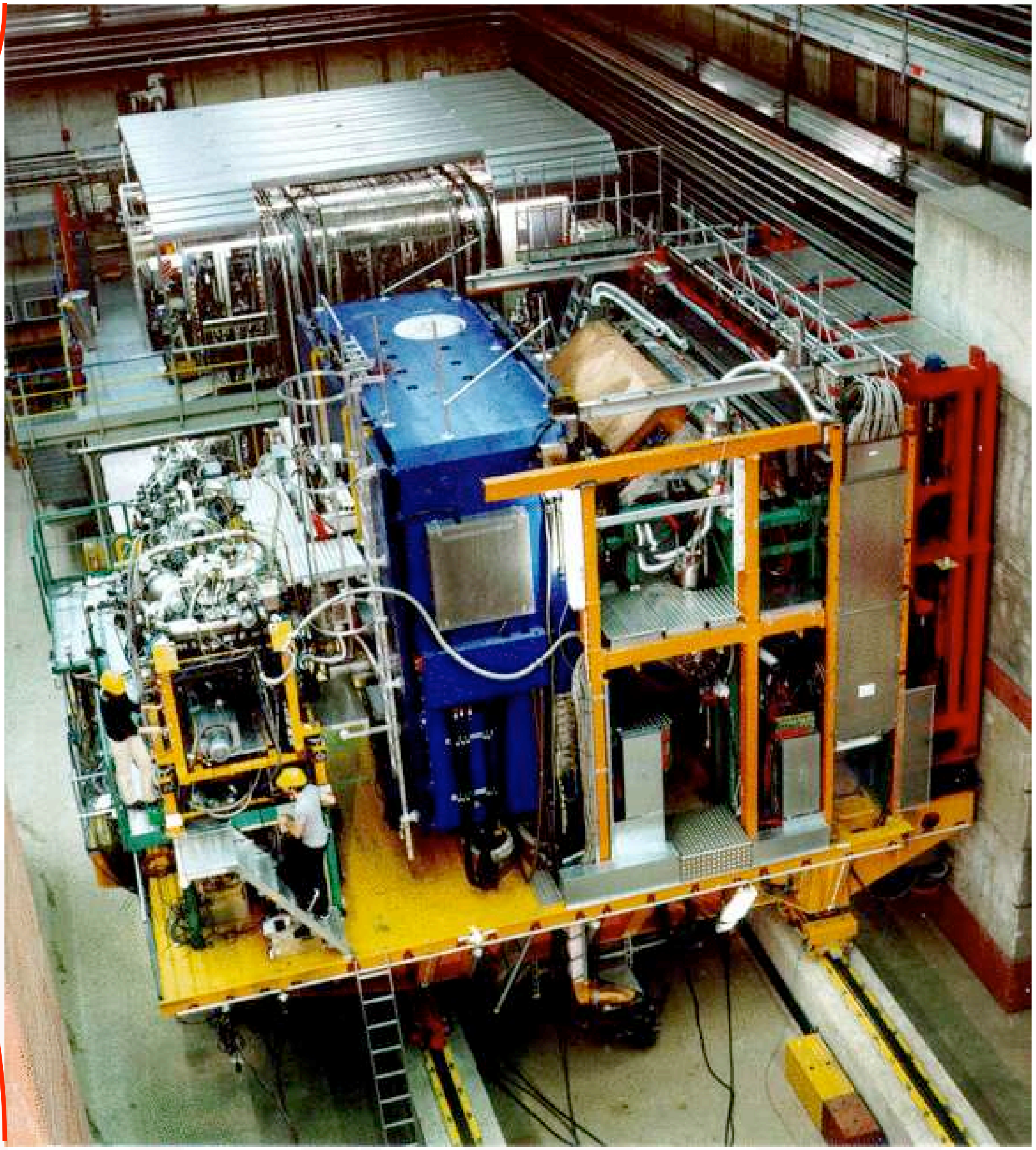
Some **experimental** challenges ...

- pureness of targets
- large kinematic acceptance
- excellent particle identification
- no spin asymmetry -> worry more about systematics, e.g.,
  - efficiencies
  - absolute luminosity
  - acceptance
  - smearing

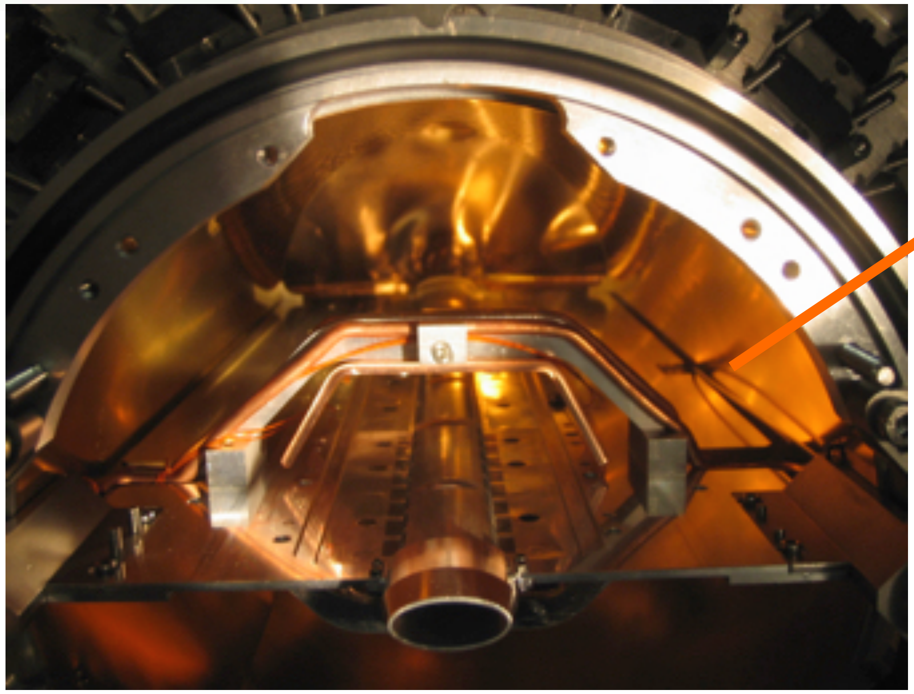
The HERMES Experiment

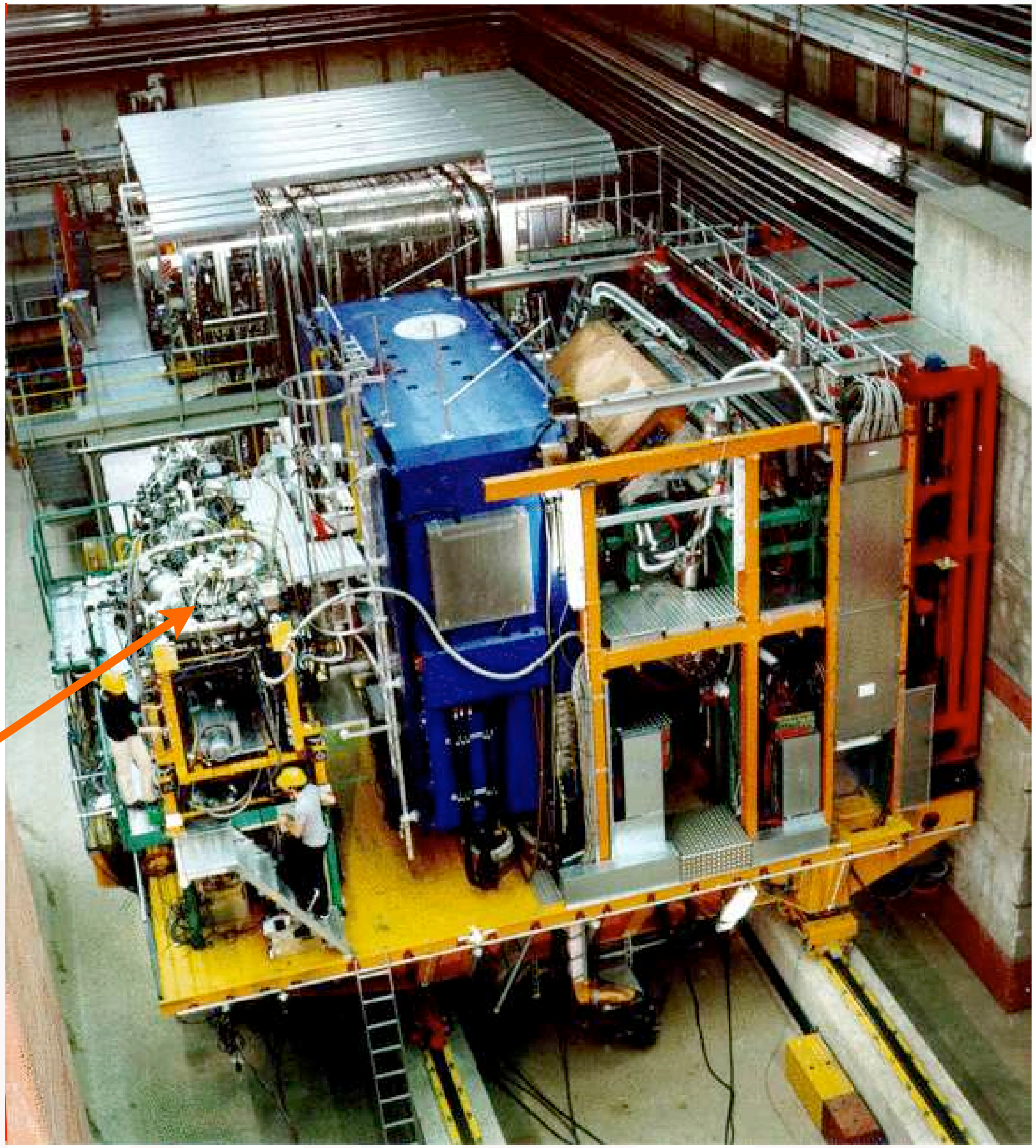
27.5 GeV e^+/e^- beam of HERA



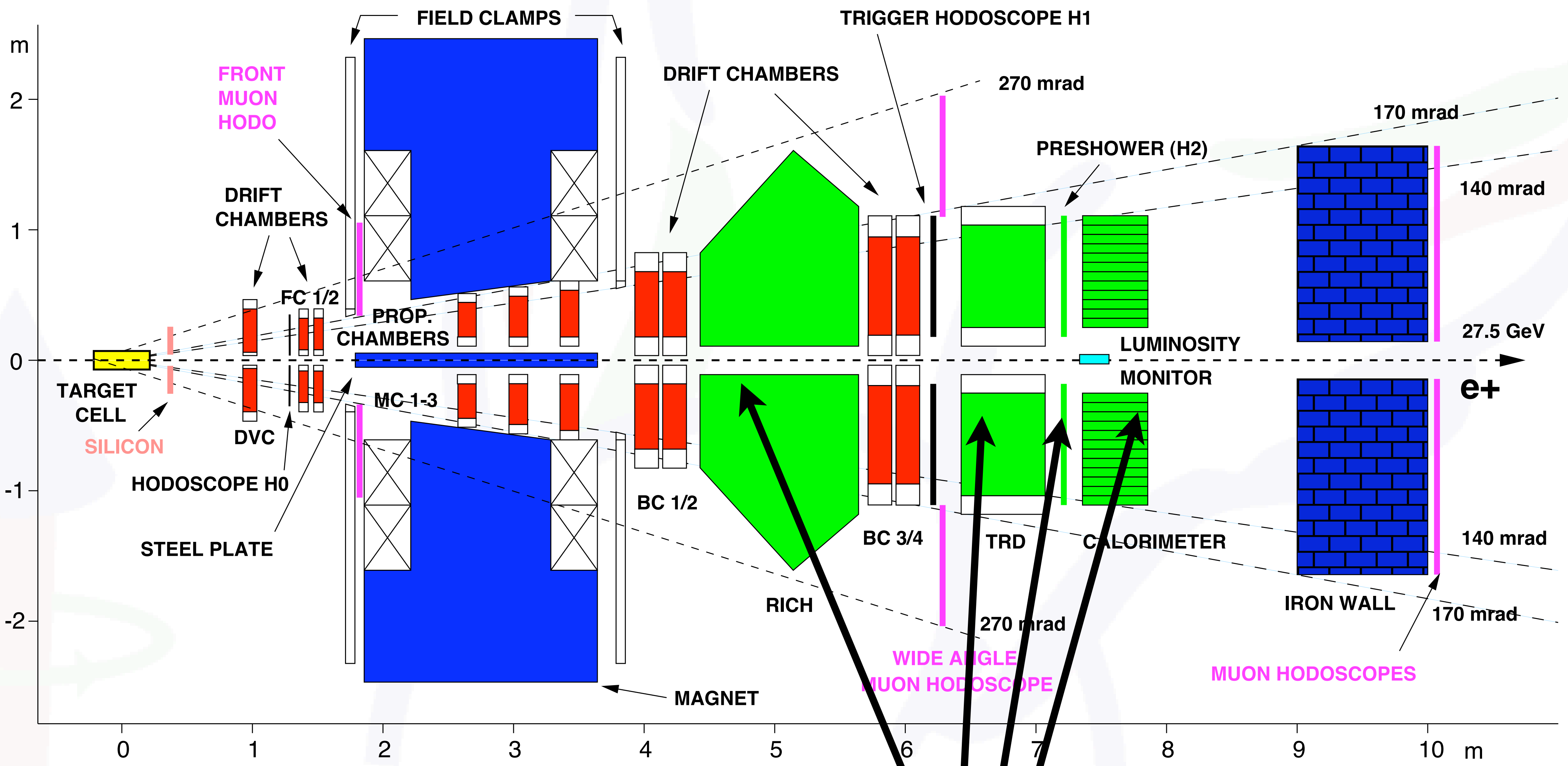
The HERMES Experiment

- pure gas targets
- internal to lepton ring
- unpolarized (^{1}H … Xe)
- long. polarized: ^{1}H, ^{2}H, ^{3}He
- transversely polarized: ^{1}H





… schematically



Particle ID detectors allow for
- lepton/hadron separation
- RICH: pion/kaon/proton discrimination 2GeV<p<15GeV

accessing the various terms

$$\frac{d^5\sigma}{dx\,dy\,dz\,d\phi_h\,dP_{h\perp}^2} \propto \left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T}+\epsilon F_{UU,L}$$

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normalize to inclusive DIS cross section

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this talk

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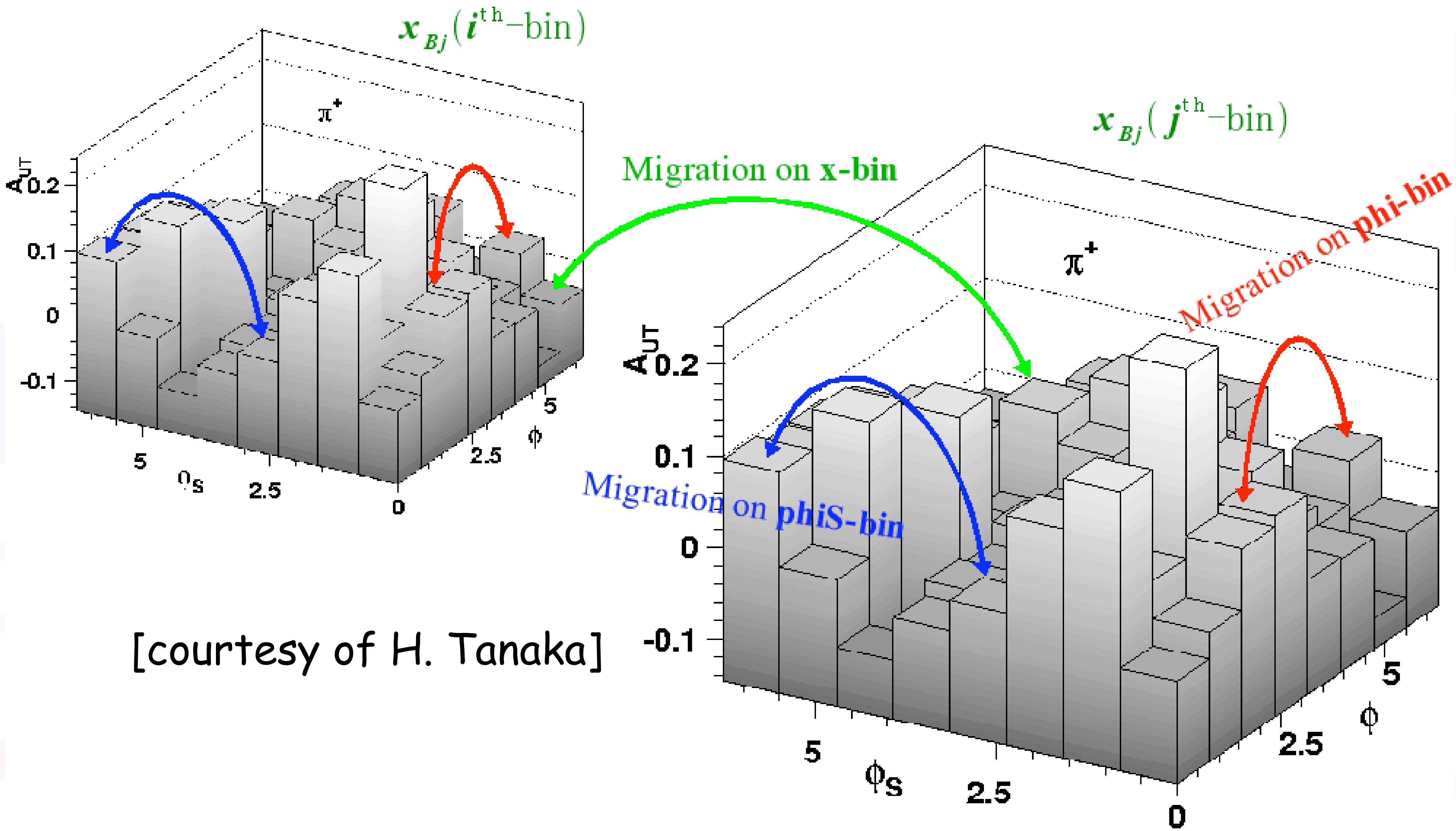
☛ TMD session

… event migration …



[courtesy of H. Tanaka]

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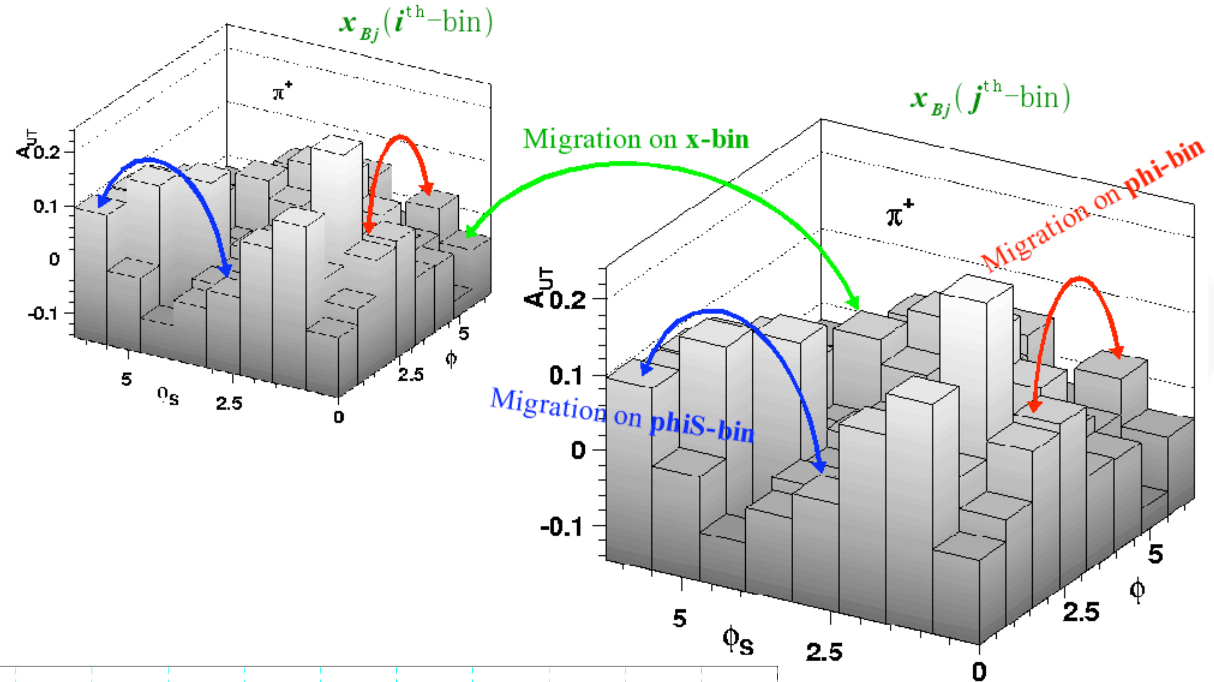

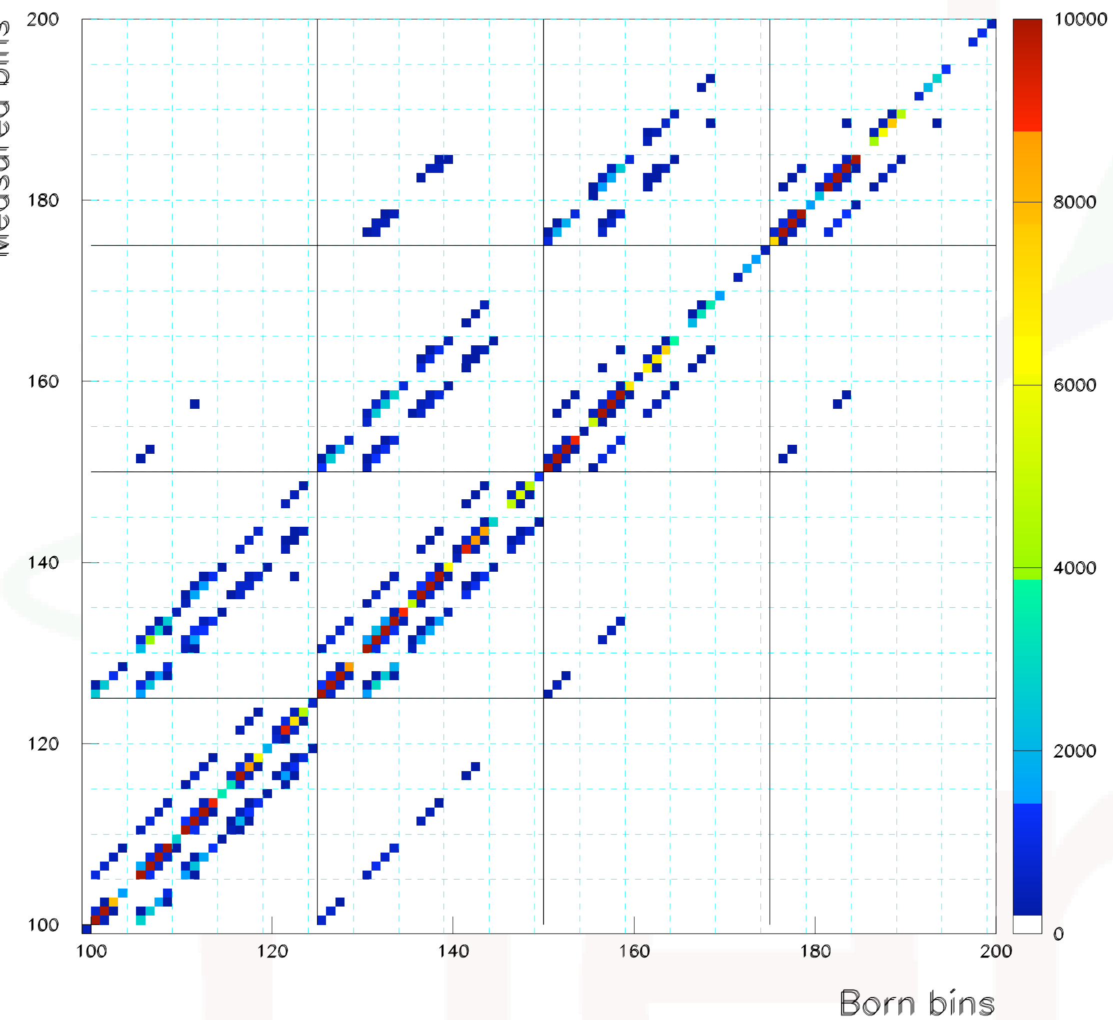

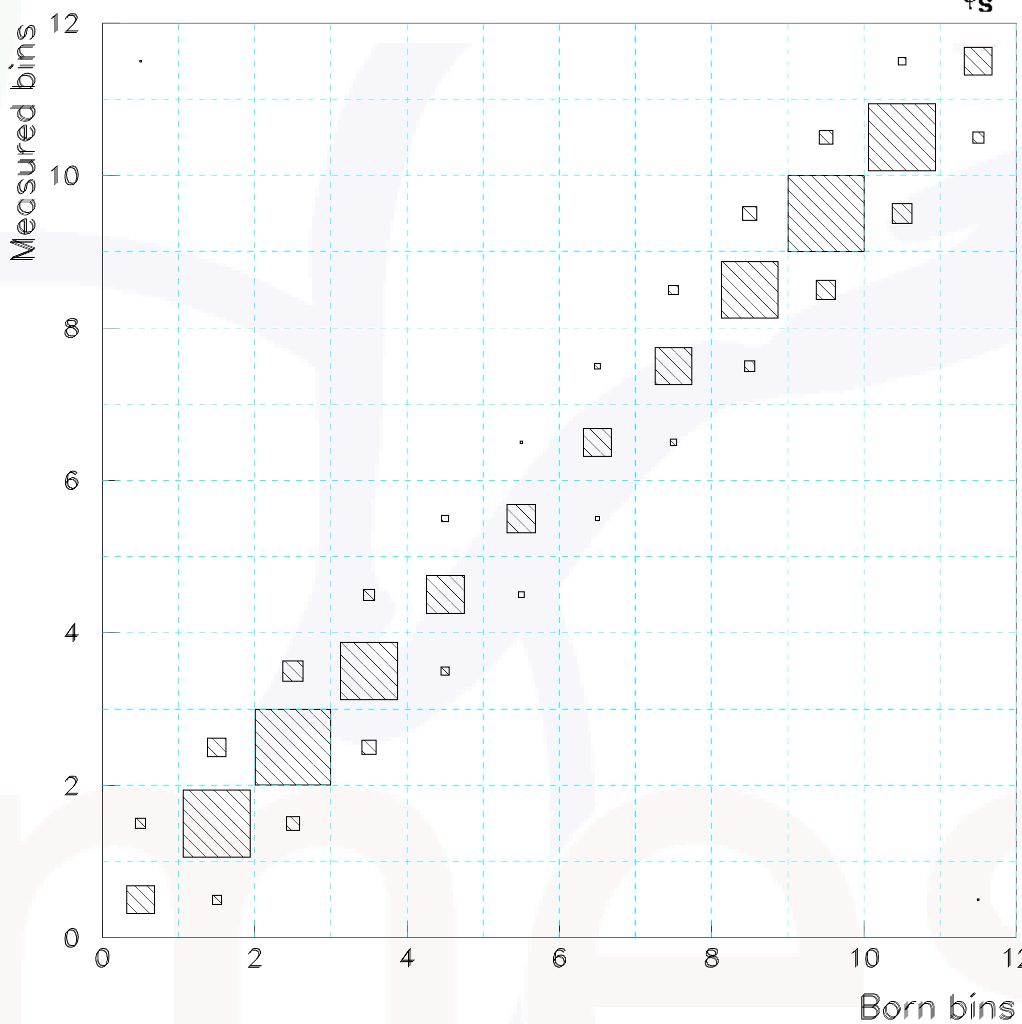

- migration correlates yields in different bins
- can't be corrected properly in bin-by-bin approach

… event migration -> unfolding

$$\mathcal{Y}^{\exp}(\Omega_i) \propto \sum_{j=1}^{N} S_{ij} \int_j d\Omega \, d\sigma(\Omega) + \mathcal{B}(\Omega_i)$$

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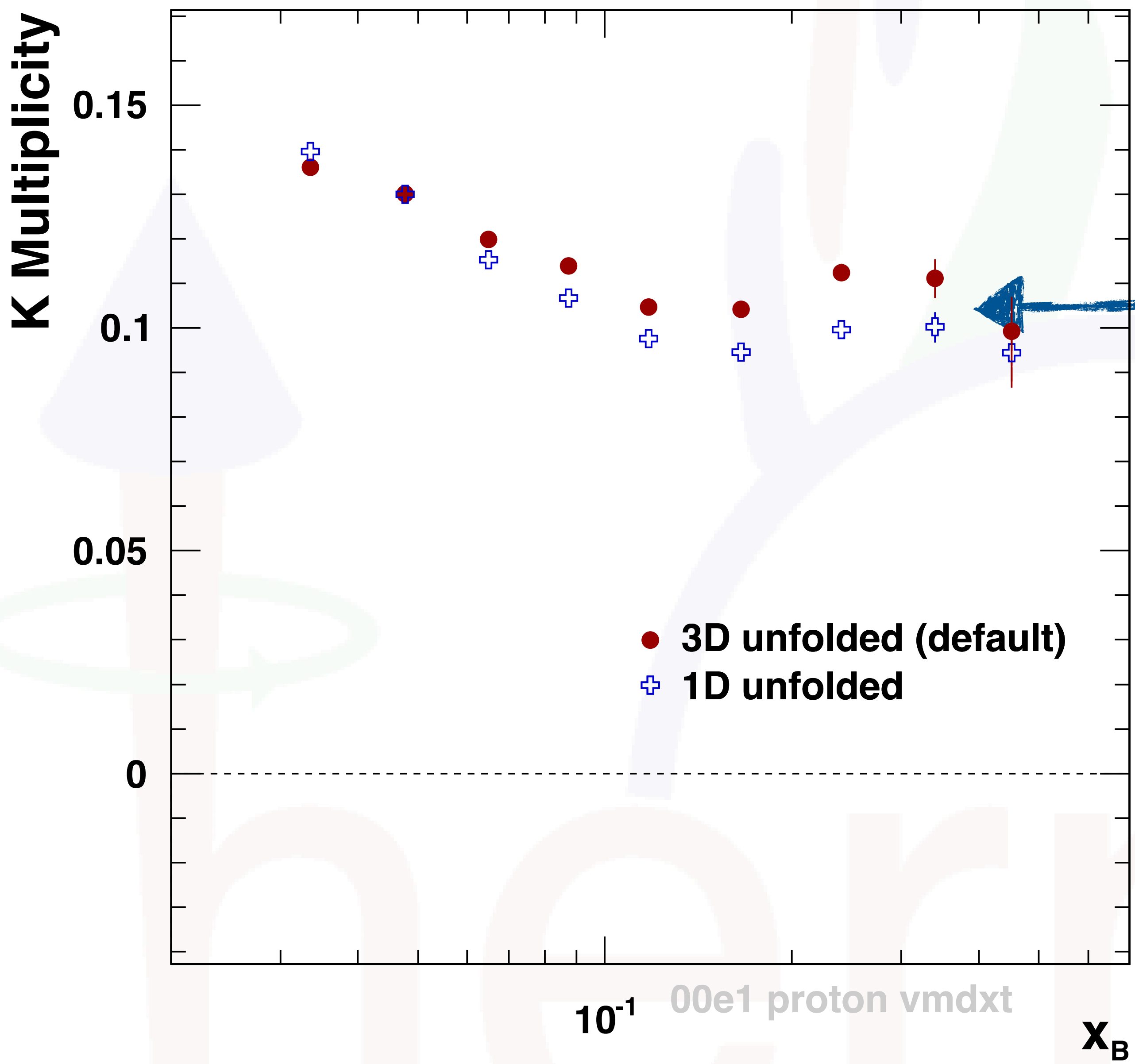
  - in real life: dependence on BG and physics model due to finite bin sizes
- inversion of relation gives Born cross section from measured yields

Multi-D vs. 1D unfolding at work

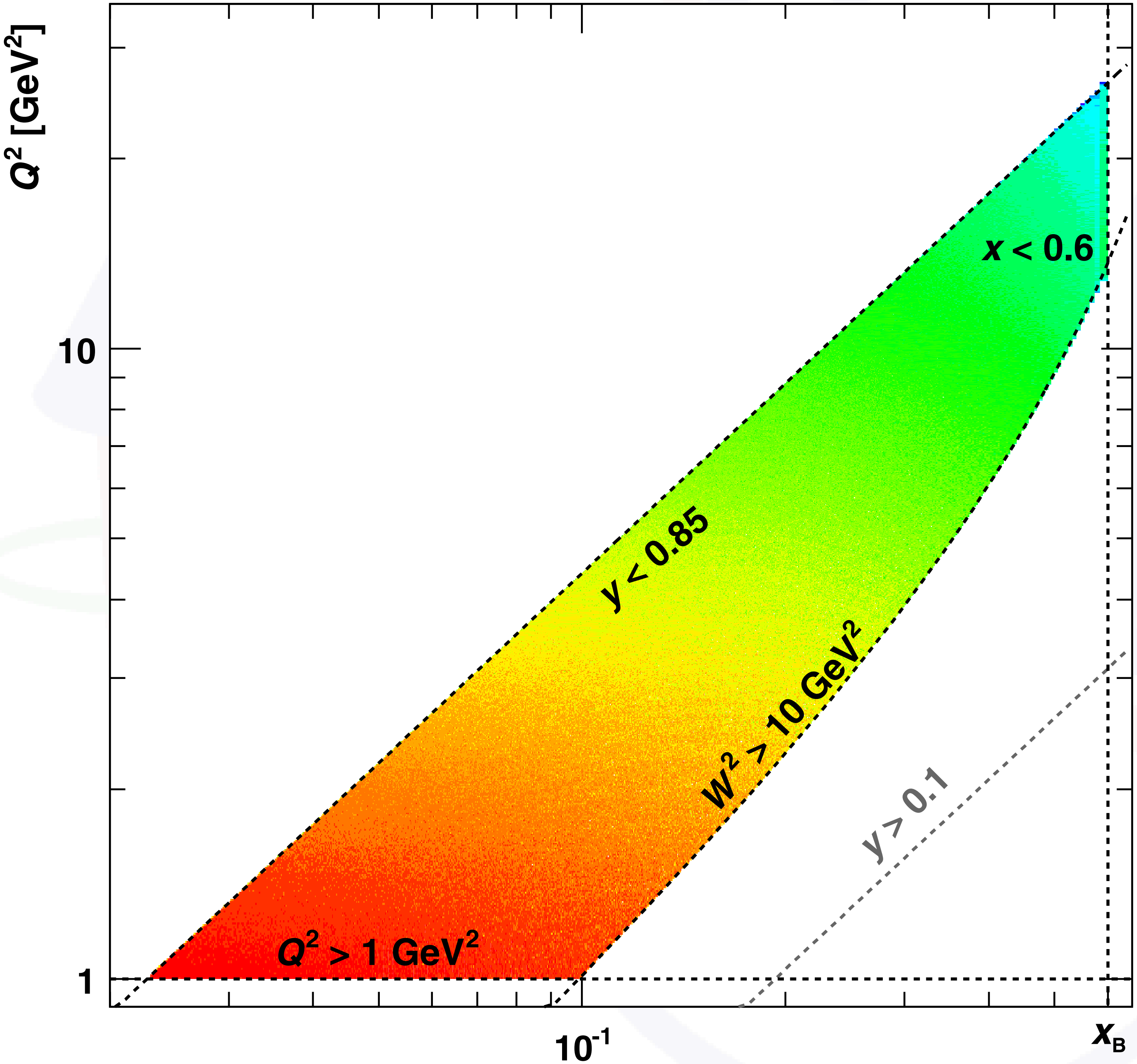
[S.J. Joosten, PhD thesis UIUC (2013)]



Neglecting to unfold in z changes x dependence dramatically

➡ 1D unfolding clearly insufficient

kinematic range used at HERMES

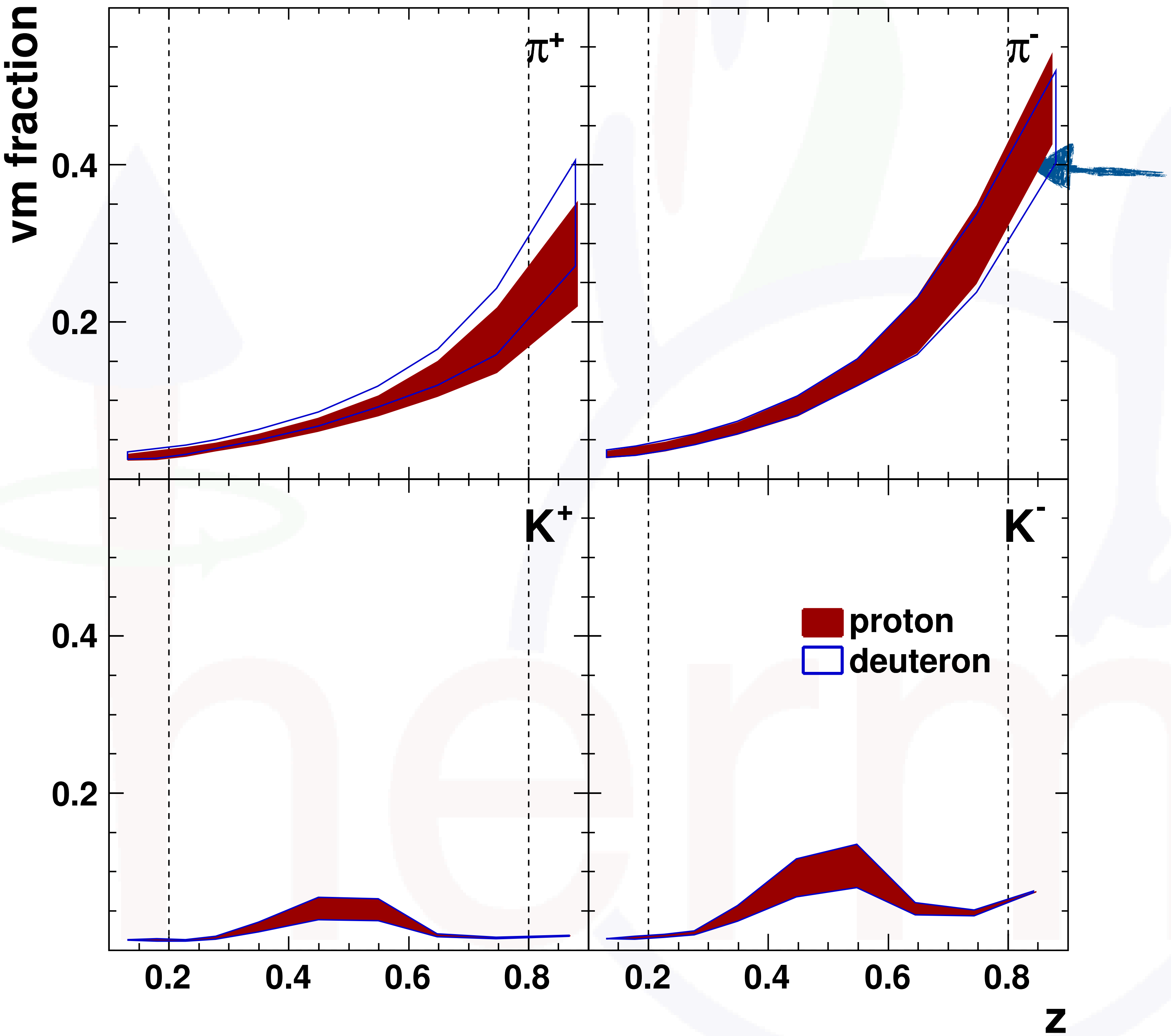


- $0.023 < x < 0.6$
- $0.1 < y < 0.85$
- $0.2 < z < 0.8$
- $W^2 > 10$ GeV^2
- $Q^2 > 1$ GeV^2

Influence from exclusive VM

for instance: $ep \to ep\,\rho^0 \to ep\,\pi^+\pi^-$

[Airapetian et al., PRD 87 (2013) 074029]



partially large contribution from exclusive VM production, in particular at high z -> (optionally) **subtracted** from both numerator and denominator

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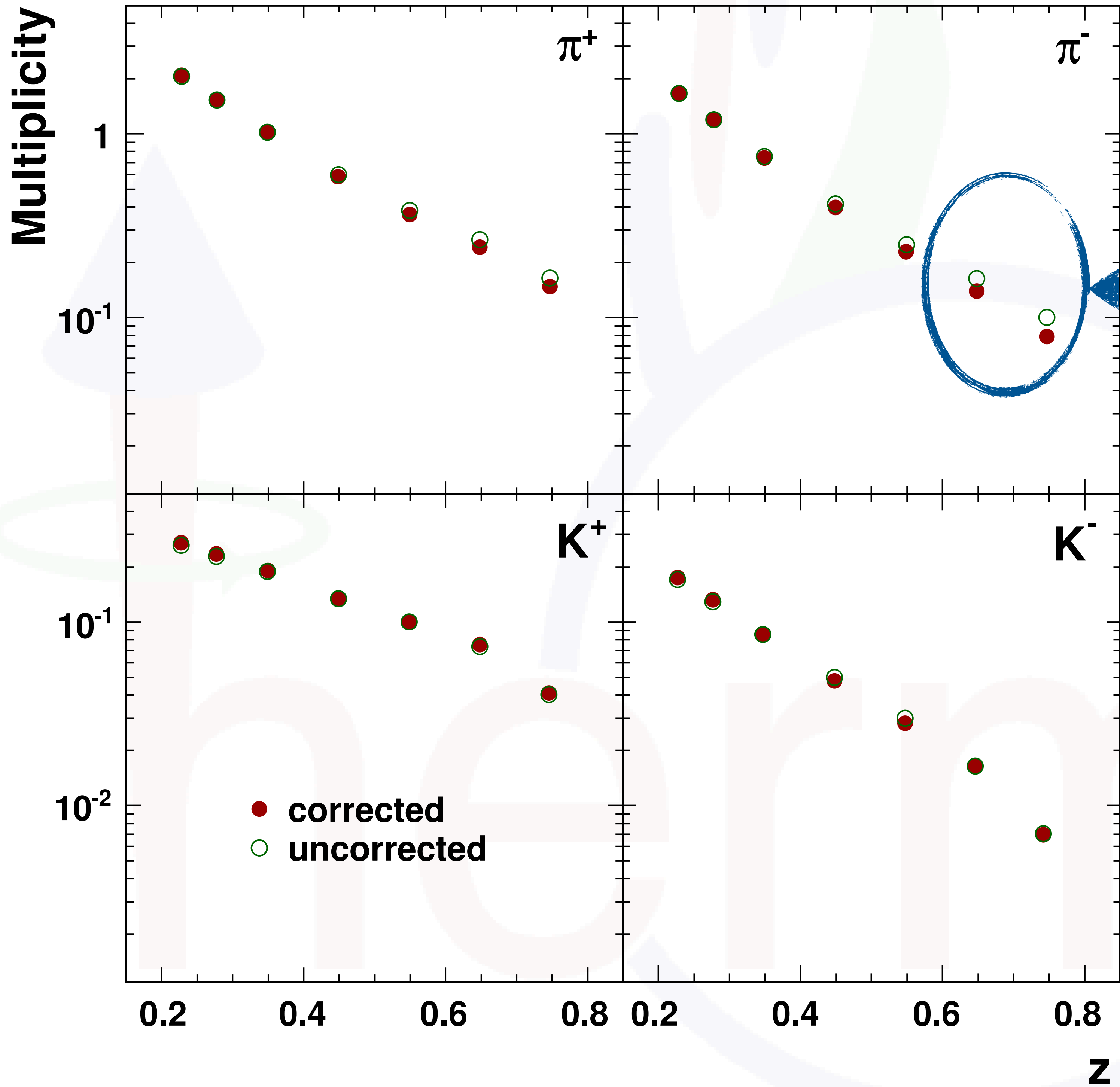
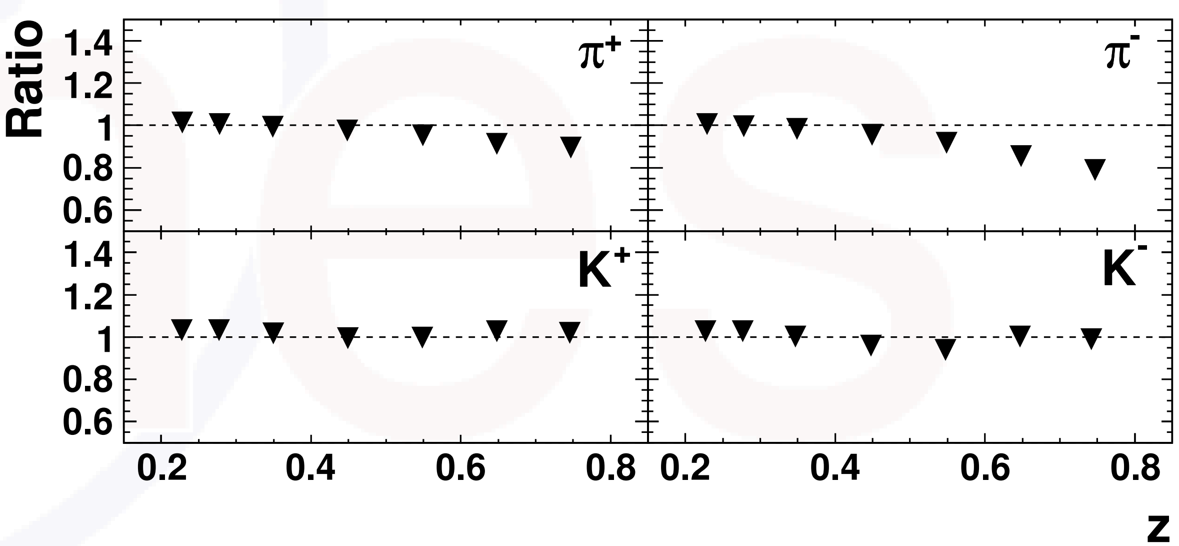


multiplicities before and after subtraction of contributions from exclusively produced VMs



Multiplicities: z projection

most exhaustive data set on ($P_{h\perp}$-integrated) electro-production of charged identified mesons on nucleons

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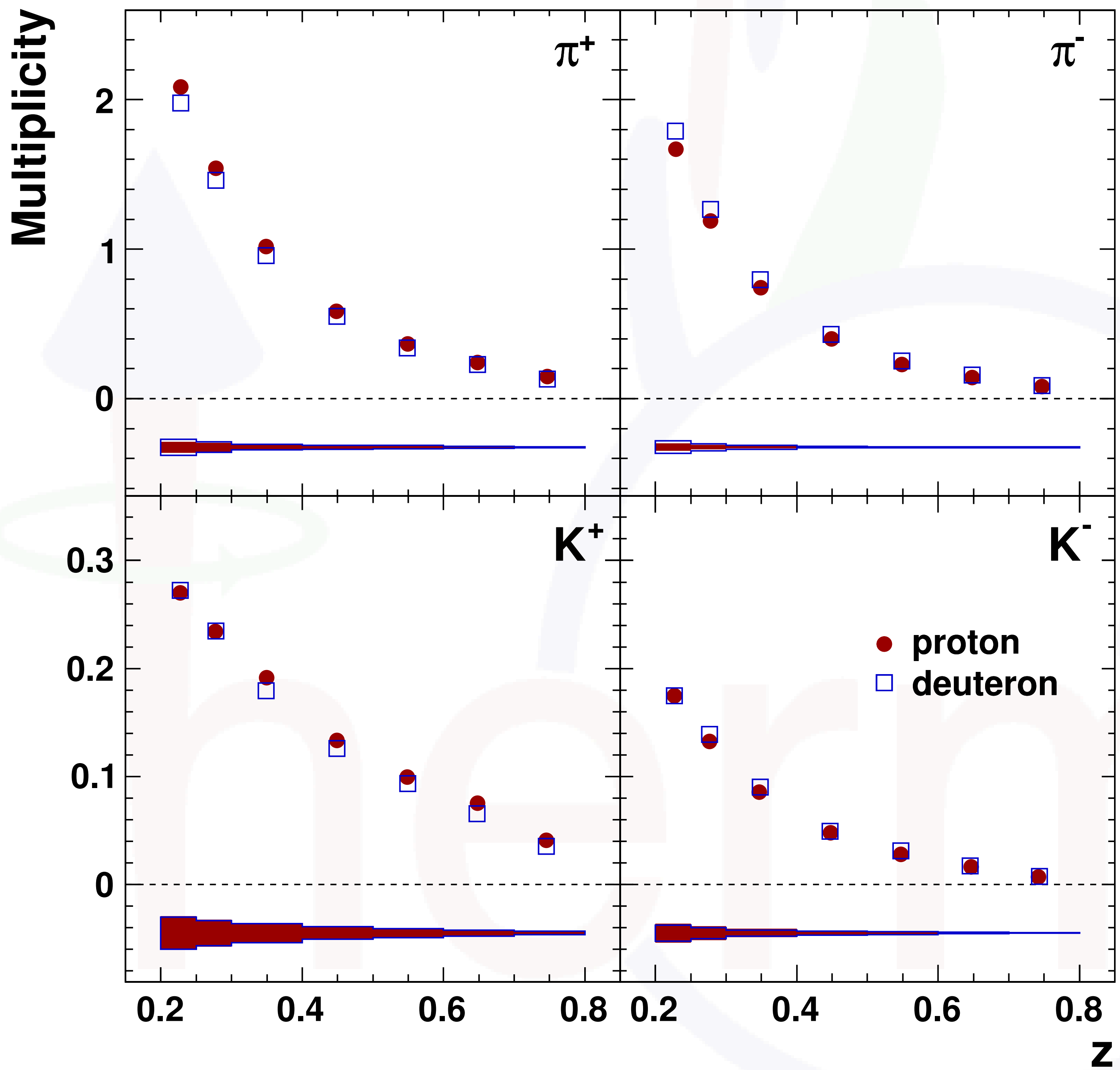

➡ slight differences between proton and deuteron targets: reflection of valence structure of target and produced meson, e.g.

$u/d \to \pi^+ / \pi^-$

$p = |uud\rangle$ and $n = |udd\rangle$

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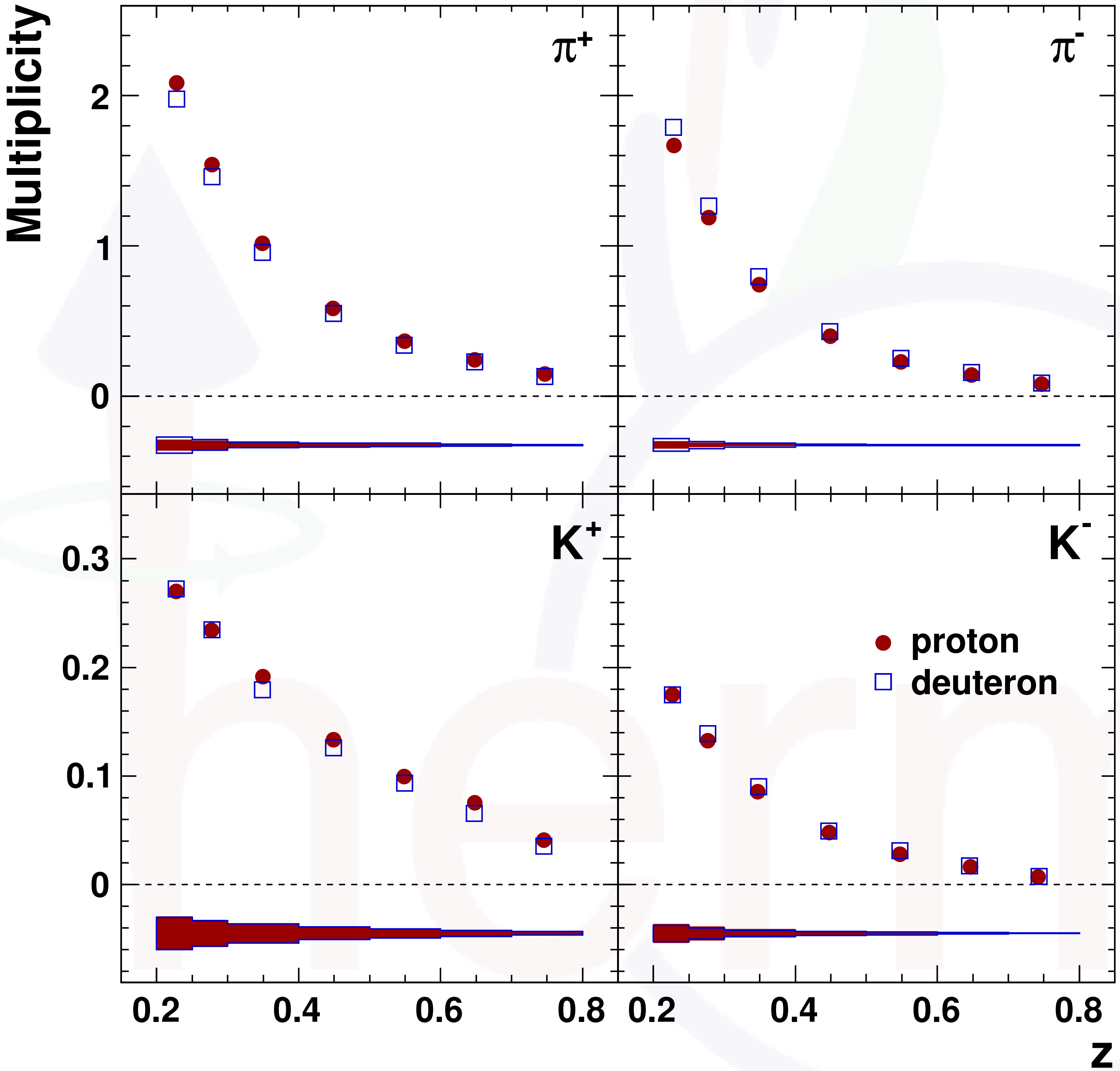

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➡ K^- pure "sea object" hence suppressed and hardly any difference for proton and deuteron

Multiplicities: z projection

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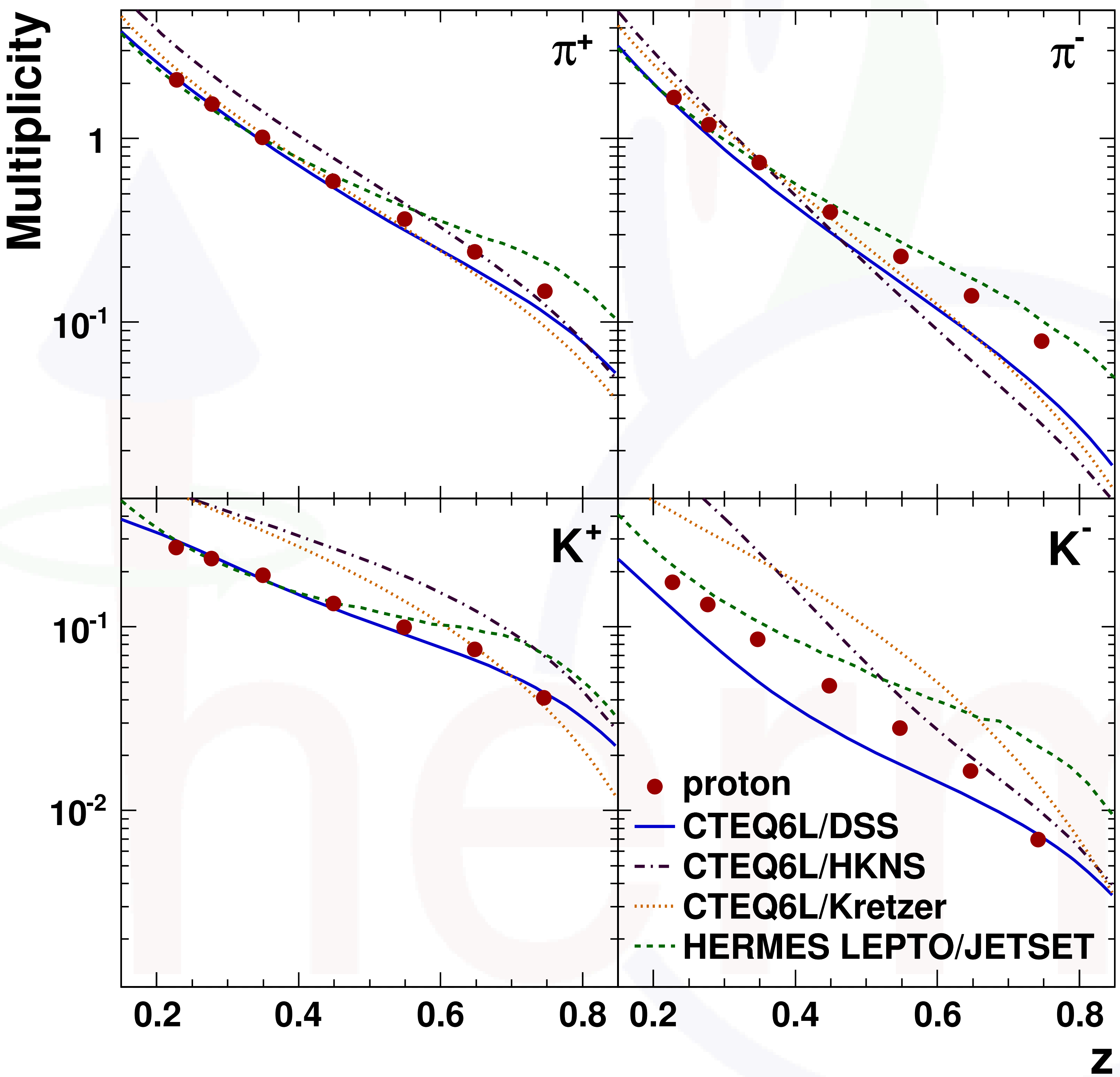


proton target:
(deuteron similar)

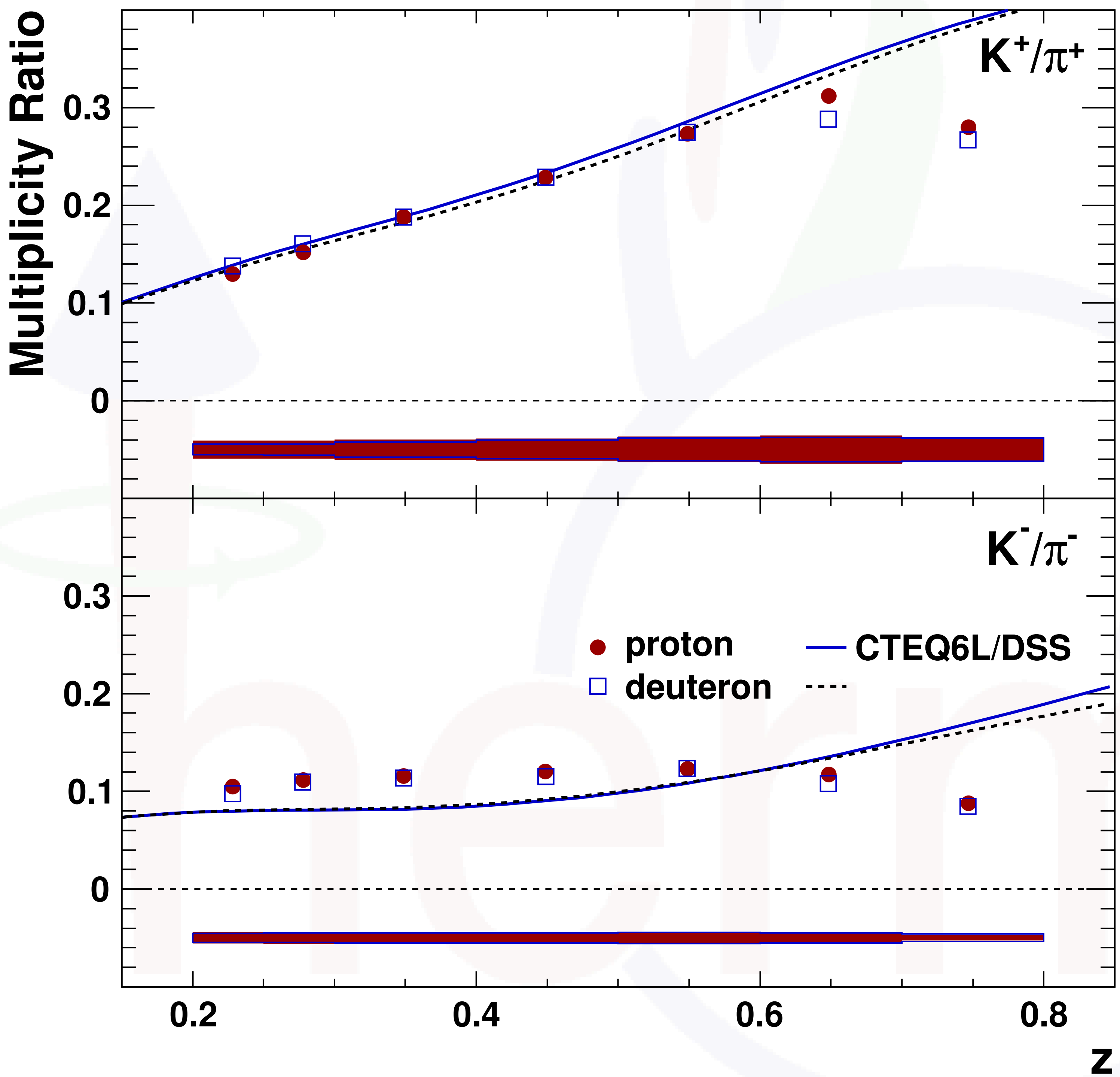
positive hadrons in general better described than negative ones

- ➡ better understanding of favored fragmentation?
- ➡ best described by HERMES Jetset tune and DSS FF set

kaons best described by DSS FF set, though all with problems in describing K^-

Multiplicity ratio: z projection

[http://www-hermes.desy.de/multiplicities]



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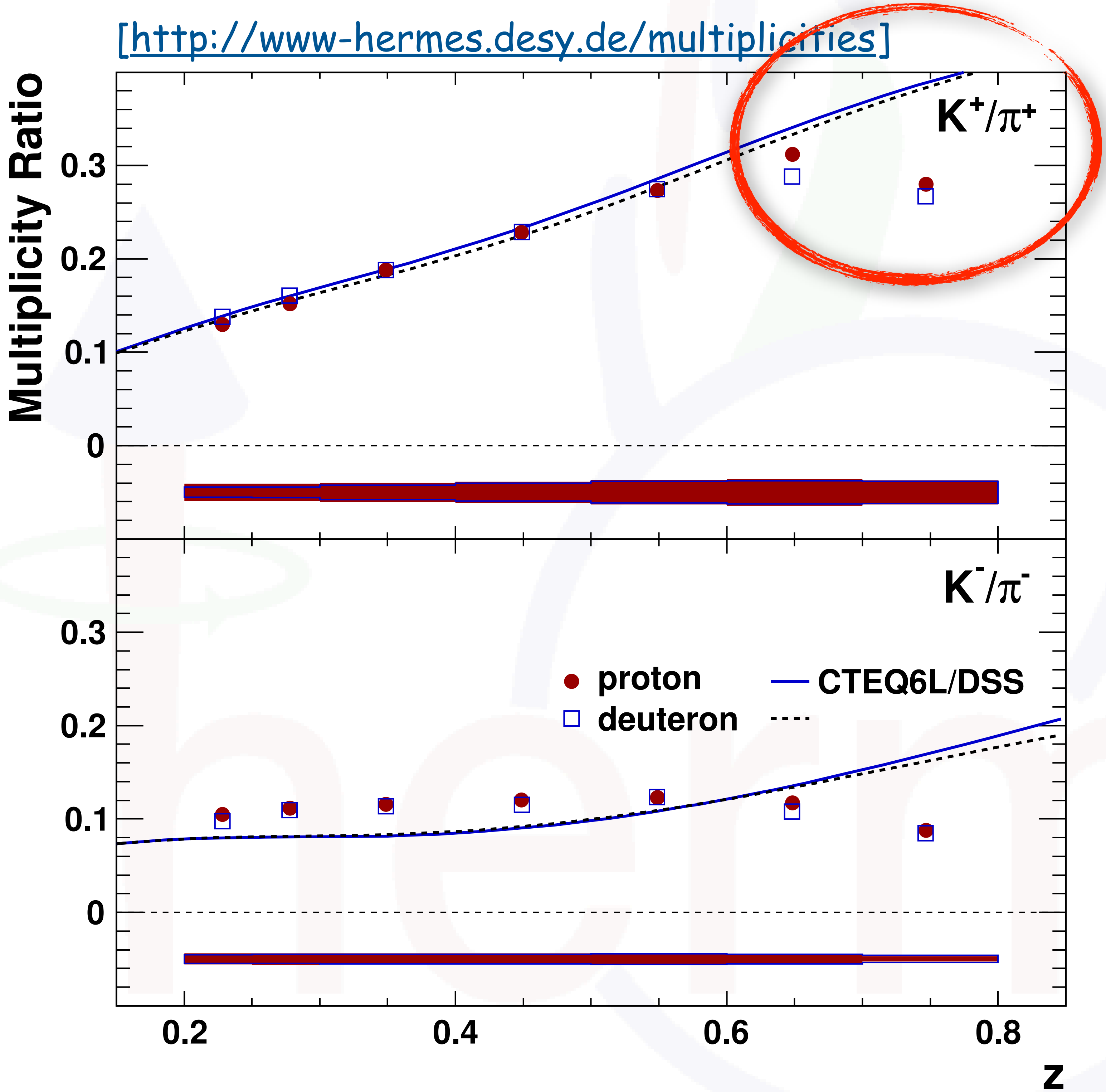


at large z mainly favored fragmentation:

➡ dominated by up quarks

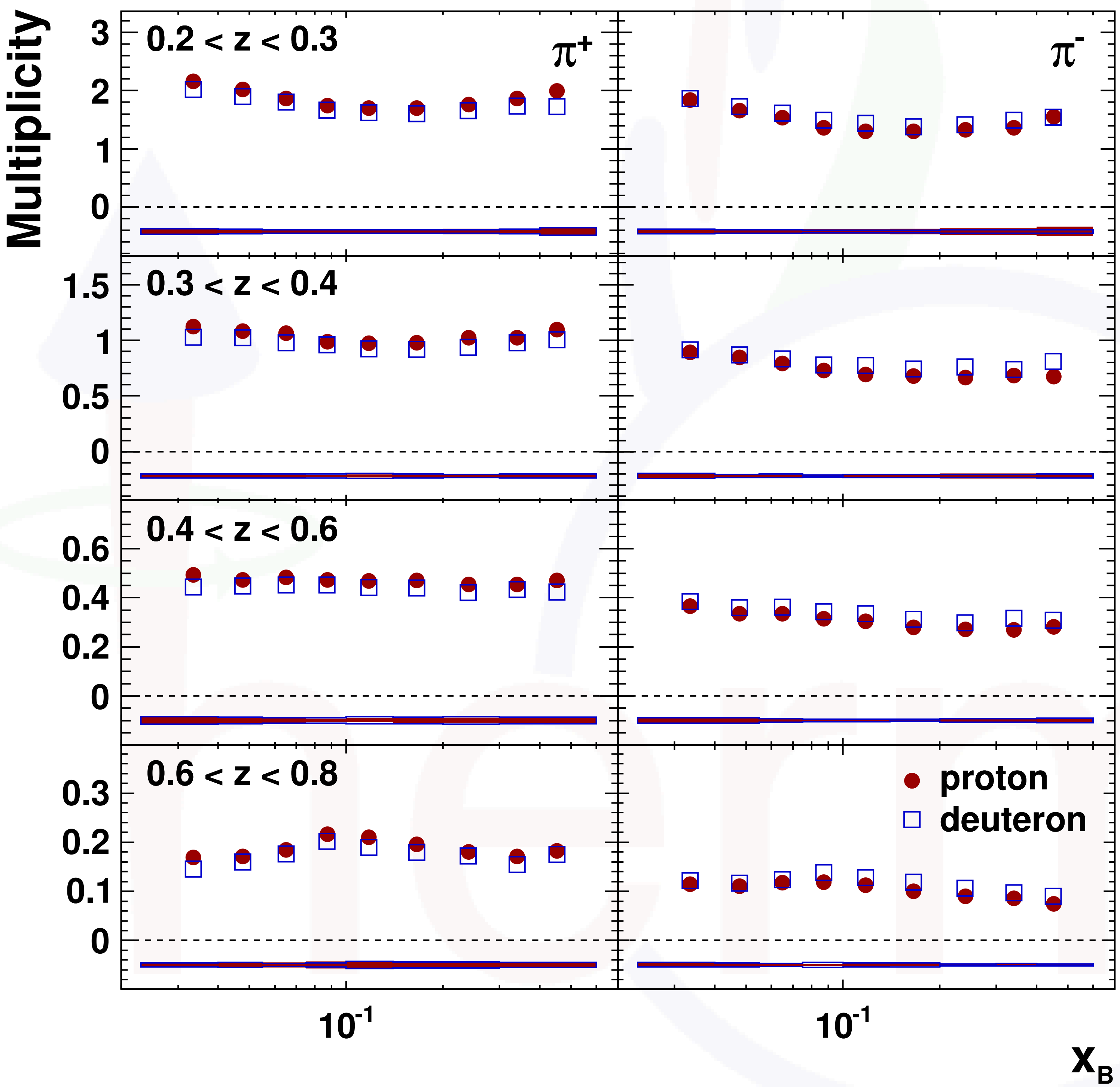
➡ kaon requires strangeness production

➡ strangeness suppression of about 0.3 (apparently stronger than modeled in DSS FF set)

➡ in rough agreement with typical ansatz of 1/3

Multiplicities: x-z projection

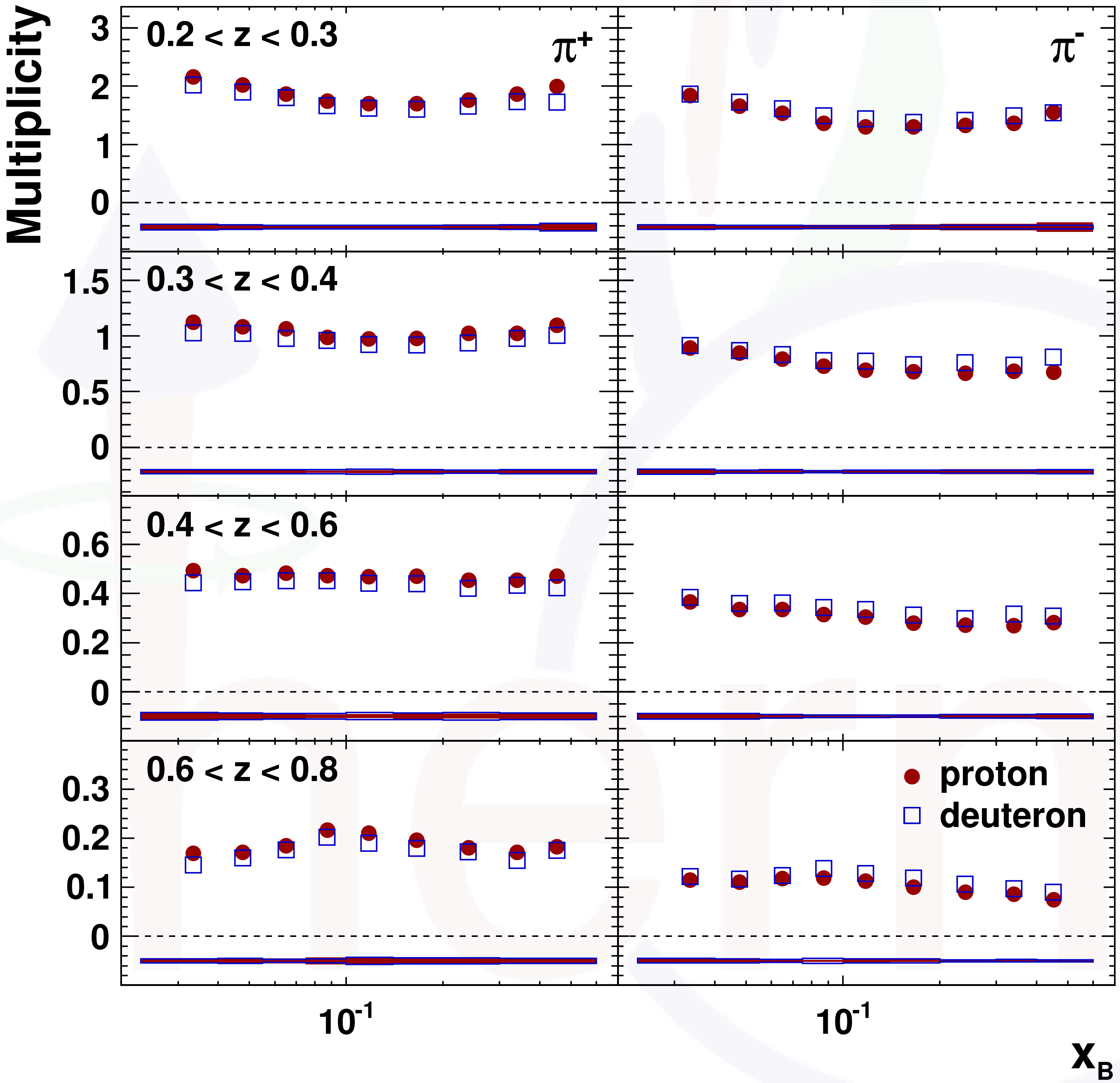
[Airapetian et al., PRD 87 (2013) 074029]



$$\sum_q \frac{e_q^2 f_1^q(x)}{\sum_{q'} e_{q'}^2 f_1^{q'}(x)} D_1^{q\to\pi}(z)$$

Multiplicities: x-z projection

[Airapetian et al., PRD 87 (2013) 074029]

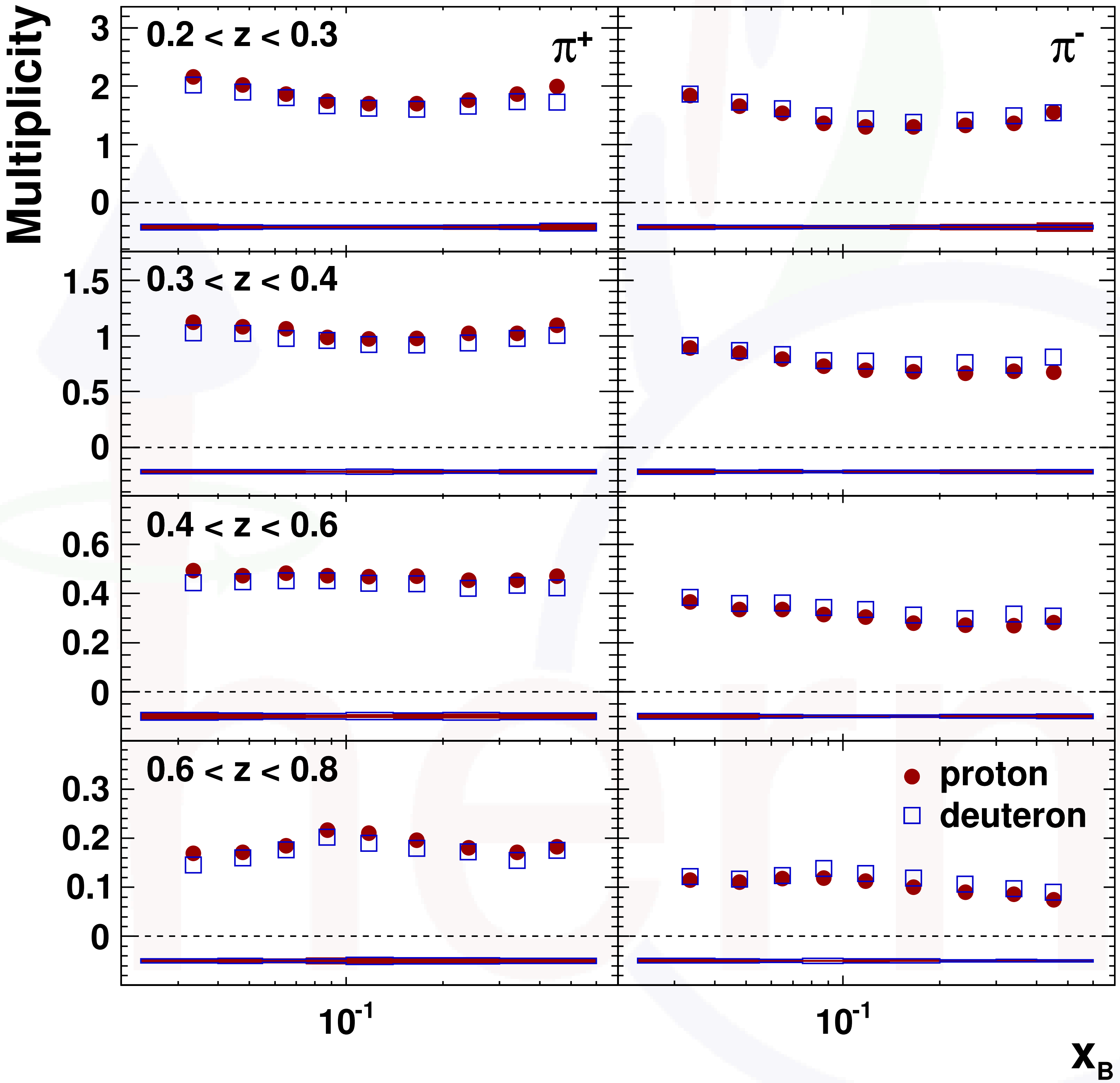


➡ weaker dependence on x

$$\sum_q \frac{e_q^2 f_1^q(x)}{\sum_{q'} e_{q'}^2 f_1^{q'}(x)} D_1^{q\rightarrow\pi}(z)$$

Multiplicities: x-z projection

[Airapetian et al., PRD 87 (2013) 074029]



➡ weaker dependence on x

➡ remaining dependence from f_1 - D_1 convolution over quark flavors

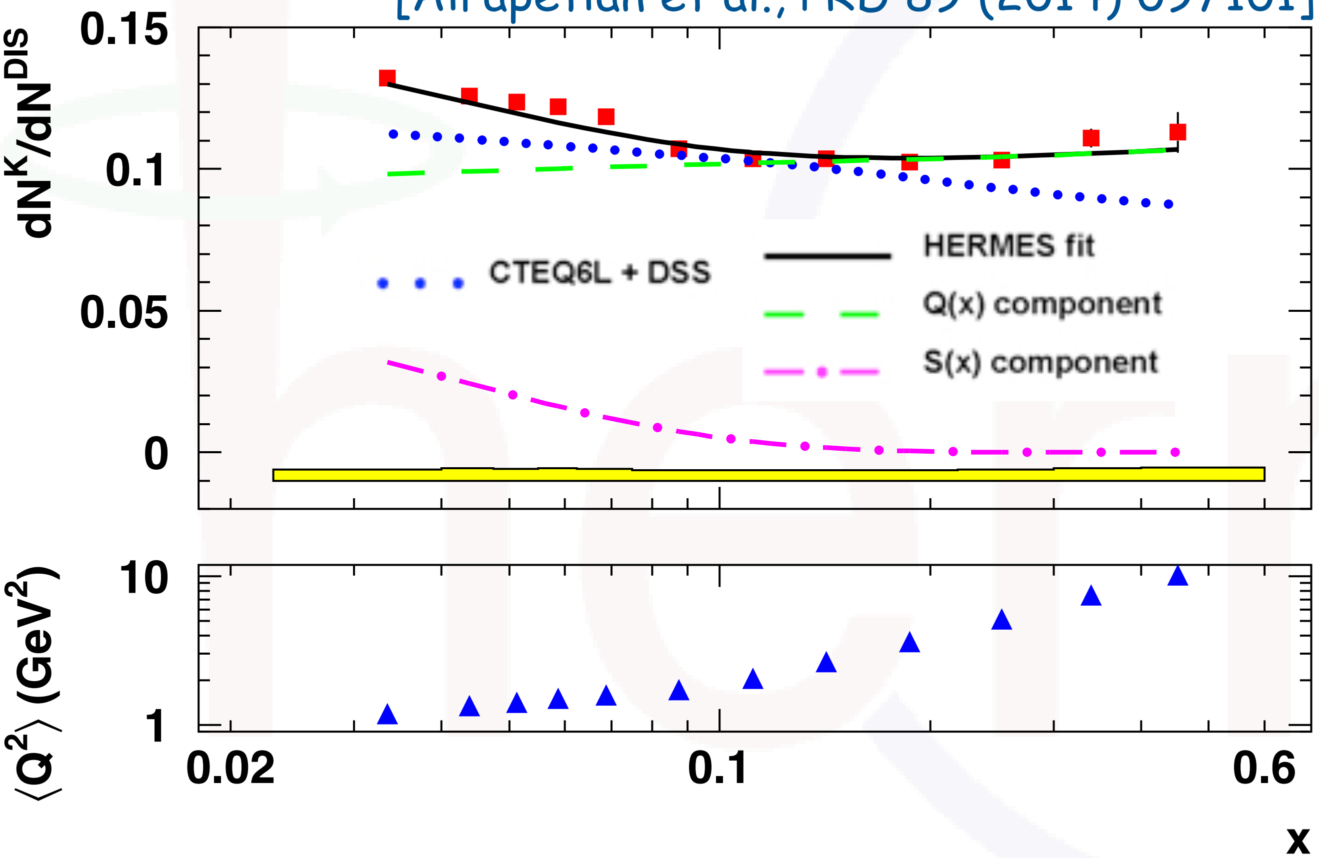
$$\sum_q \frac{e_q^2 f_1^q(x)}{\sum_{q'} e_{q'}^2 f_1^{q'}(x)} D_1^{q\to\pi}(z)$$

Strange-quark distribution

- use isoscalar probe and target to extract (here at LO!) strange-quark distribution
- only need K⁺+K⁻ multiplicities on deuteron

$$\boxed{S(x)}\int \mathcal{D}_S^K(z)\,\mathrm{d}z \simeq Q(x)\left[5\frac{\mathrm{d}^2N^K(x)}{\mathrm{d}^2N^{\mathrm{DIS}}(x)} - \int \mathcal{D}_Q^K(z)\,\mathrm{d}z\right]$$

[Airapetian et al., PRD 89 (2014) 097101]



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

$$Q(x) = u(x) + \bar{u}(x) + d(x) + \bar{d}(x)$$

$$\mathcal{D}_S^K = D_1^{s\to K^+} + D_1^{\bar{s}\to K^+} + D_1^{s\to K^-} + D_1^{\bar{s}\to K^-}$$

$$\mathcal{D}_Q^K = 4D_1^{u\to K^+} + 4D_1^{\bar{u}\to K^+} + D_1^{d\to K^+} + D_1^{\bar{d}\to K^+} + \ldots$$

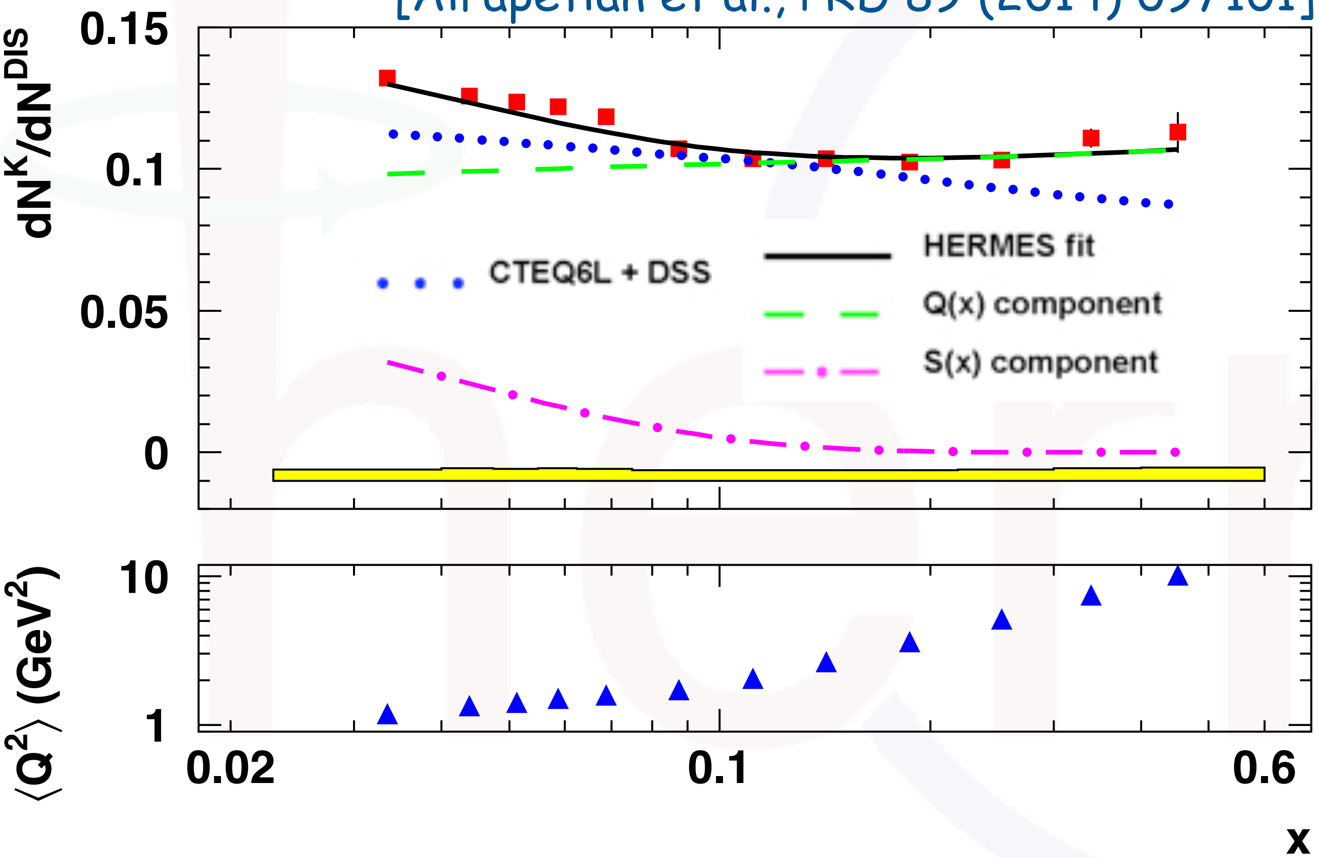
Strange-quark distribution

- use isoscalar probe and target to extract (here at LO!) strange-quark distribution
- only need K^++K^- multiplicities on deuteron

$$\boxed{S(x)}\int \mathcal{D}_S^K(z)\,\mathrm{d}z \simeq Q(x)\left[5\frac{\mathrm{d}^2N^K(x)}{\mathrm{d}^2N^{\mathrm{DIS}}(x)} - \int \mathcal{D}_Q^K(z)\,\mathrm{d}z\right]$$

- assume vanishing strangeness **at high x** to **extract non-strange fragmentation**

[Airapetian et al., PRD 89 (2014) 097101]



$$\mathbf{S(x) = s(x) + \bar{s}(x)}$$

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$$\mathcal{D}_{\mathbf{Q}}^{\mathbf{K}} = \mathbf{4D_1^{u\to K^+} + 4D_1^{\bar{u}\to K^+} + D_1^{d\to K^+} + D_1^{\bar{d}\to K^+} + \ldots}$$

Strange-quark distribution

- use isoscalar probe and target to extract (here at LO!) strange-quark distribution
- only need $K^{+}+K^{-}$ multiplicities on deuteron

$$\boxed{S(x)}\int \mathcal{D}_{S}^{K}(z)\,\mathrm{d}z \simeq Q(x)\left[5\frac{\mathrm{d}^2 N^K(x)}{\mathrm{d}^2 N^{\mathrm{DIS}}(x)} - \int \mathcal{D}_{Q}^{K}(z)\,\mathrm{d}z\right]$$

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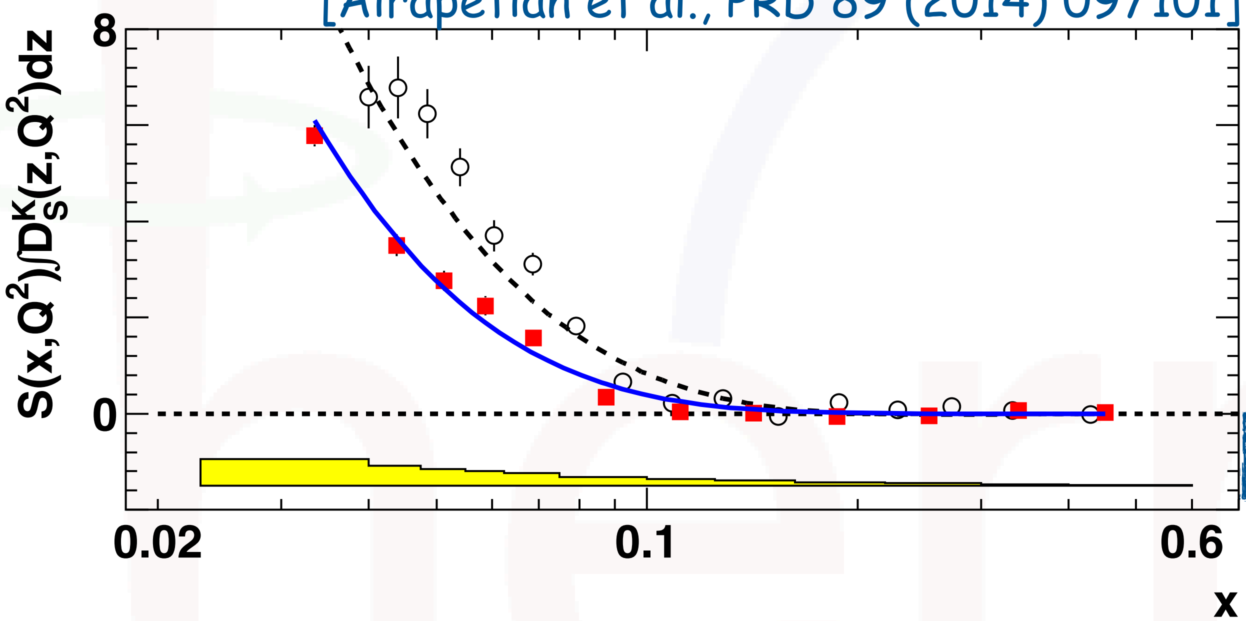
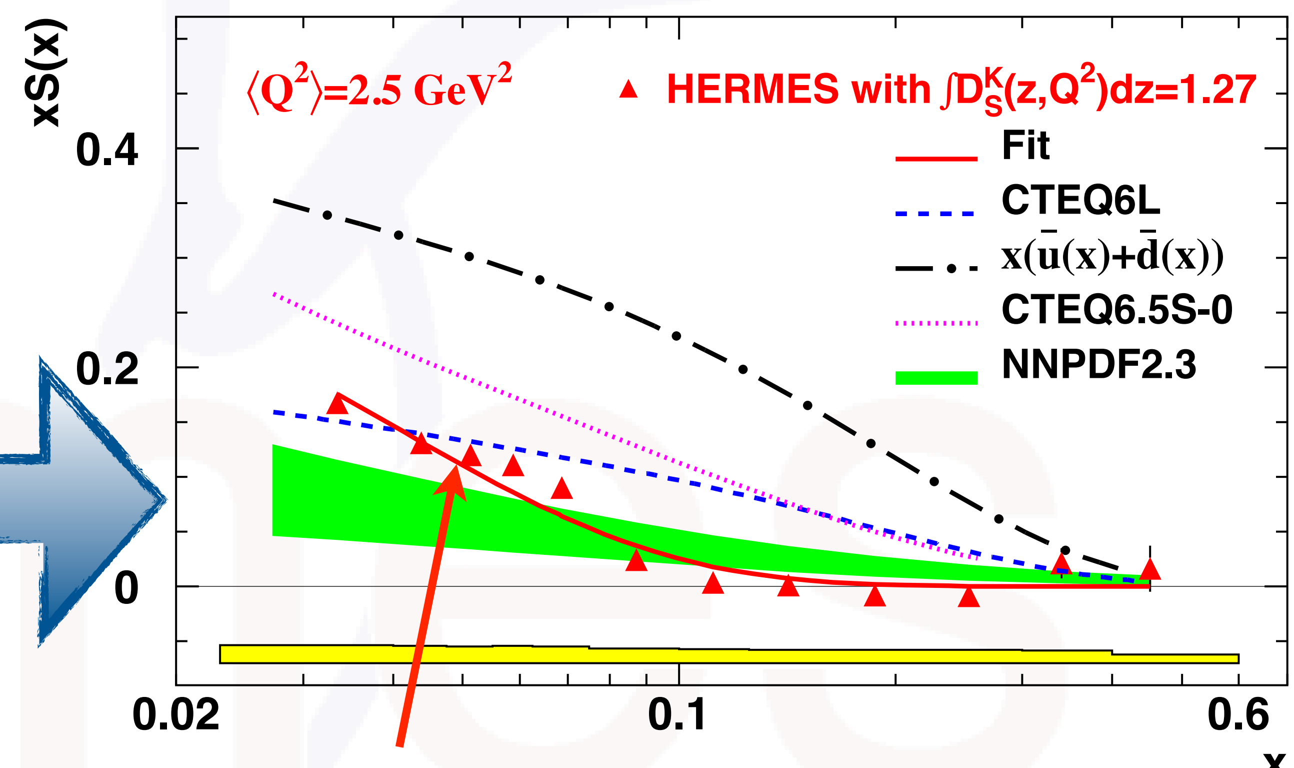




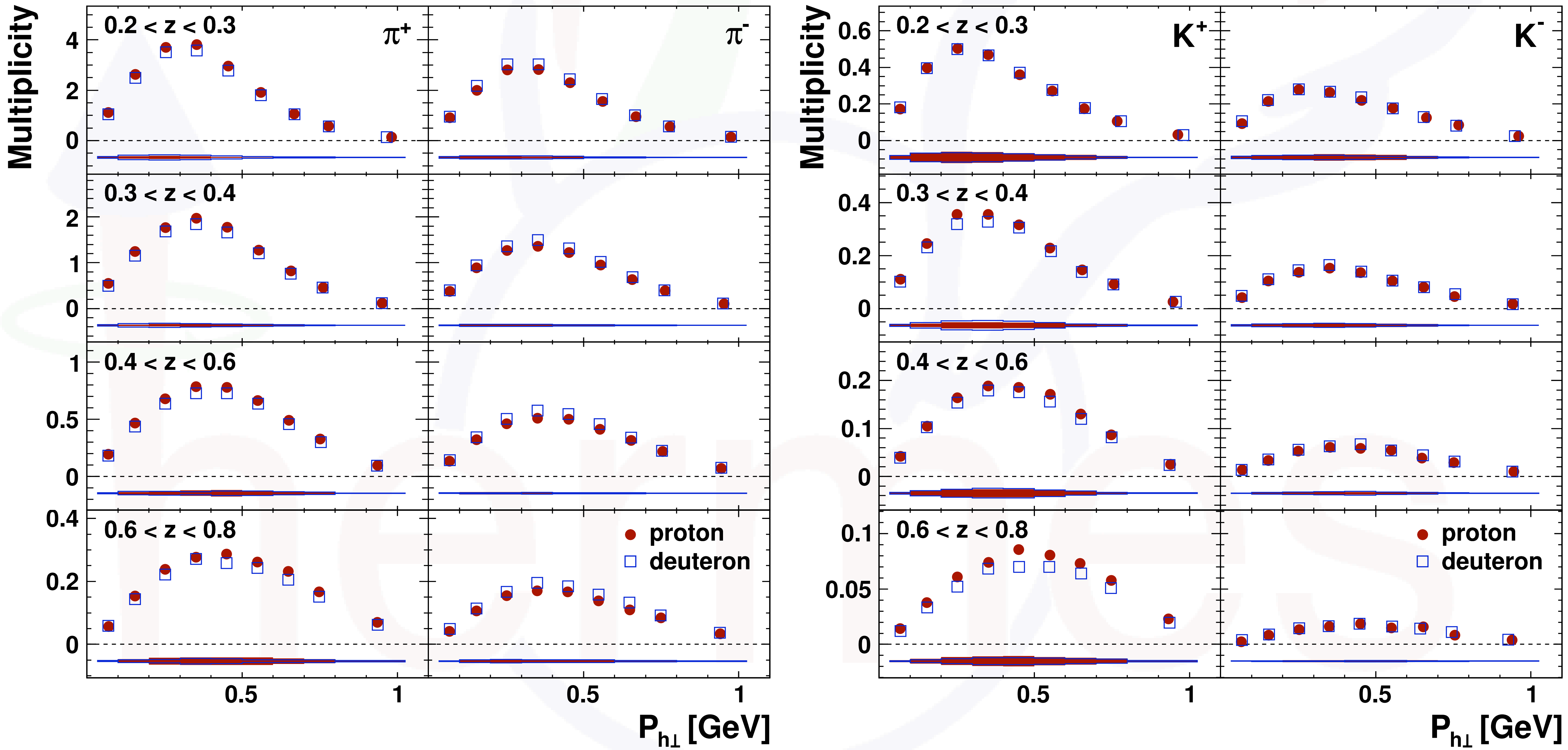
strange-quark distribution

softer than (maybe) expected

Transverse momentum dependence

- multi-dimensional analysis allows going beyond collinear factorization
- flavor information on transverse momenta via target variation and hadron ID

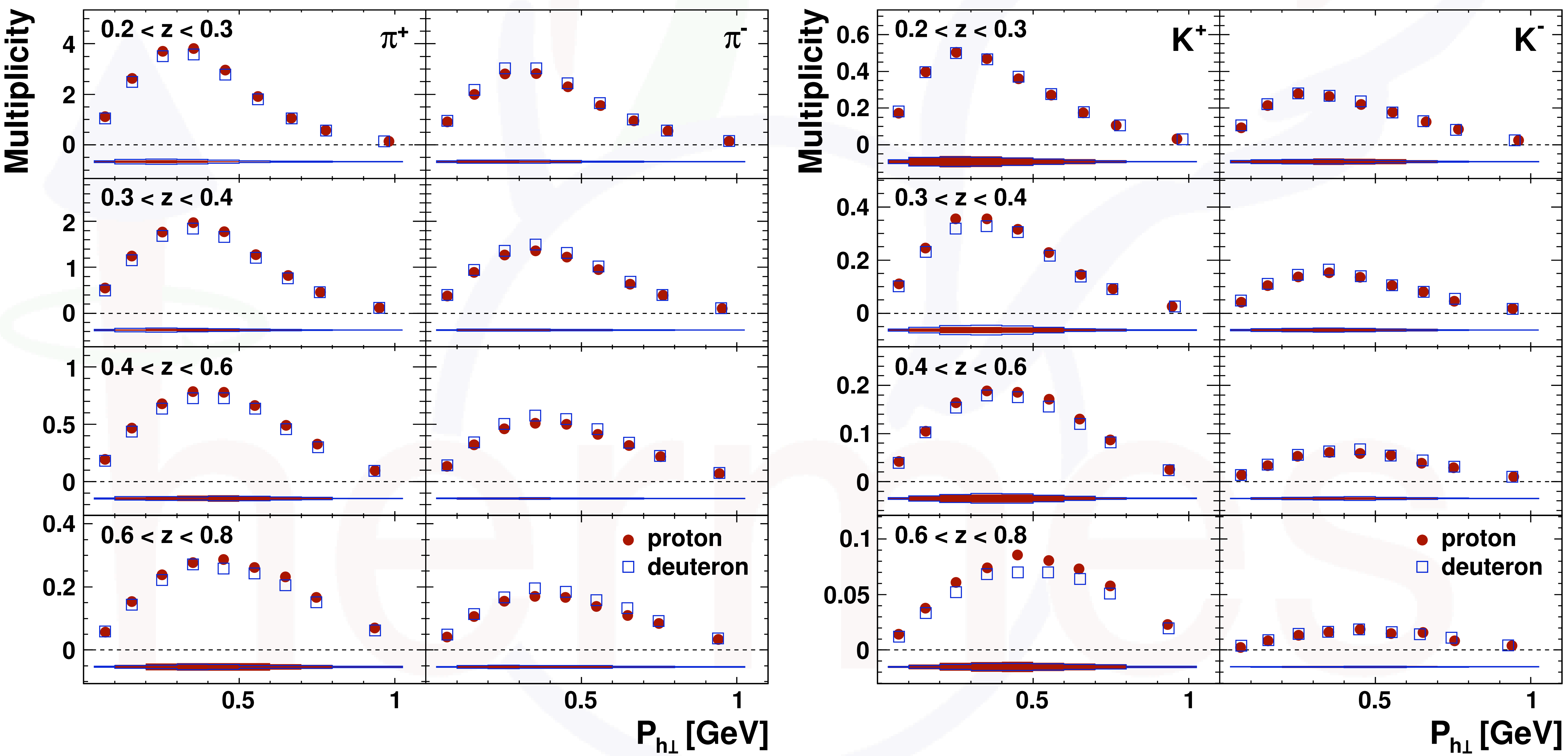
[Airapetian et al., PRD 87 (2013) 074029]



Transverse momentum dependence

- multi-dimensional analysis allows going beyond collinear factorization
- flavor information on transverse momenta via target variation and hadron ID ☛ TMD VII session

[Airapetian et al., PRD 87 (2013) 074029]



caveats

the HERMES multiplicity database

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- all the data available at http://hermes.desy.de/multiplicities

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  - only the bins where $z > 0.2$ should be used
  - multiplicities are integrated quantities, where both numerator and denominator are integrated separately over the full space within each kinematic bin

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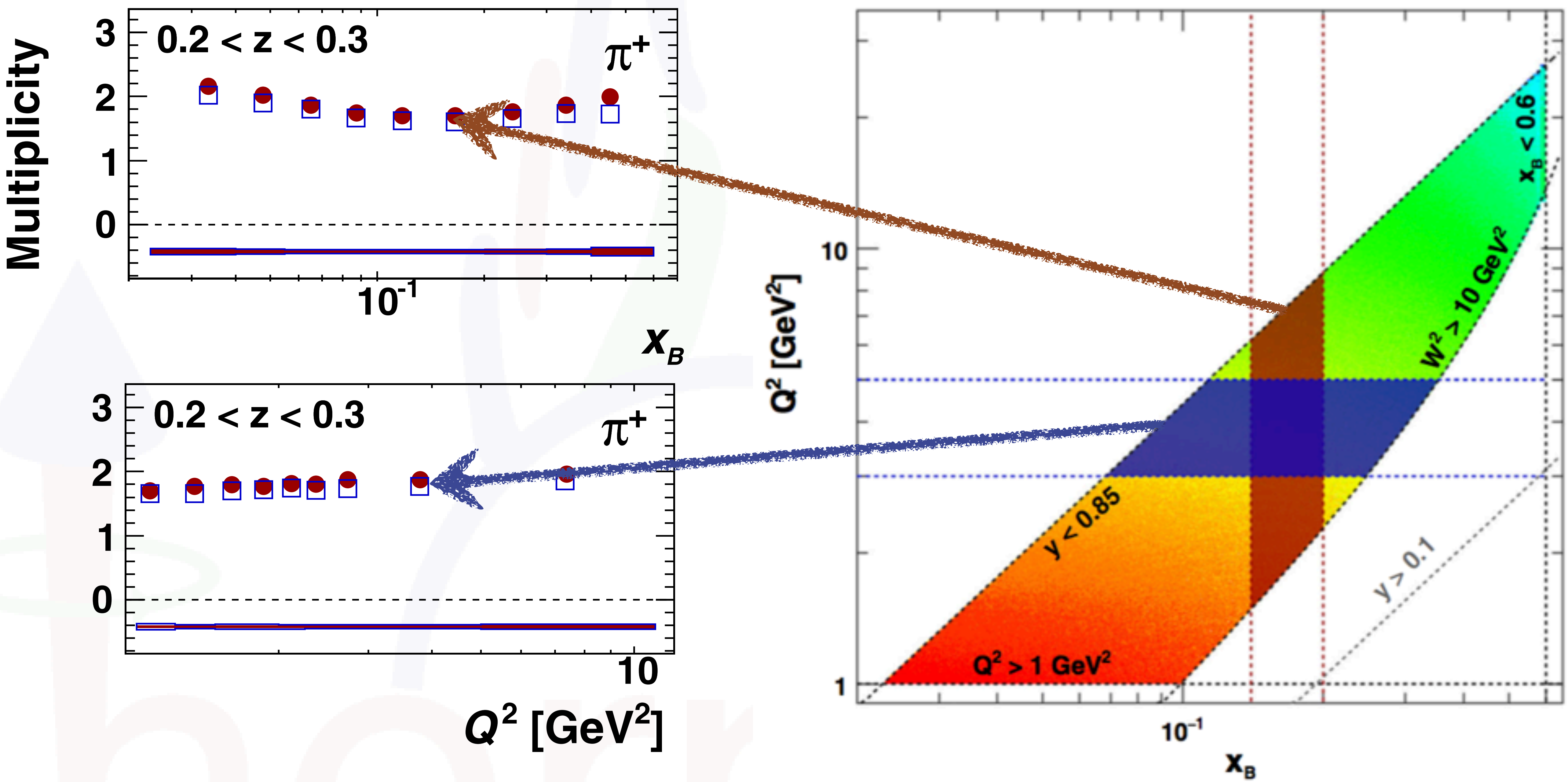
- when using the data base, please read carefully the "Important information", in particular,
  - only the bins where $z > 0.2$ should be used
  - multiplicities are integrated quantities, where both numerator and denominator are integrated separately over the full space within each kinematic bin
- important consequences
  - comparison to calculations best done performing the same integration over phase space
  - average multiplicity is not multiplicity at average kinematics

$$\langle \mathcal{M}(Q^2) \rangle_{Q^2} \neq \mathcal{M}(\langle Q^2 \rangle)$$



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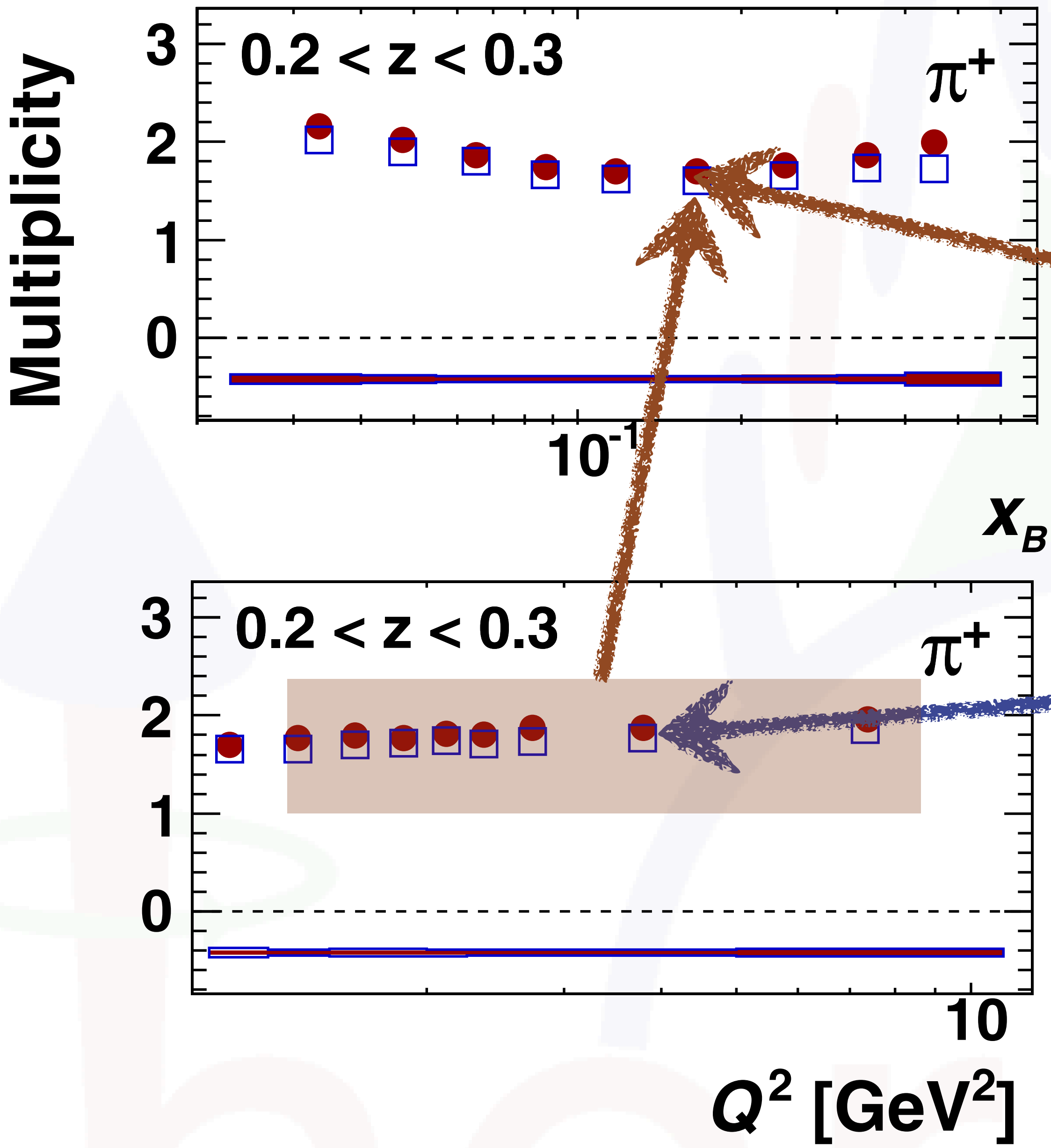

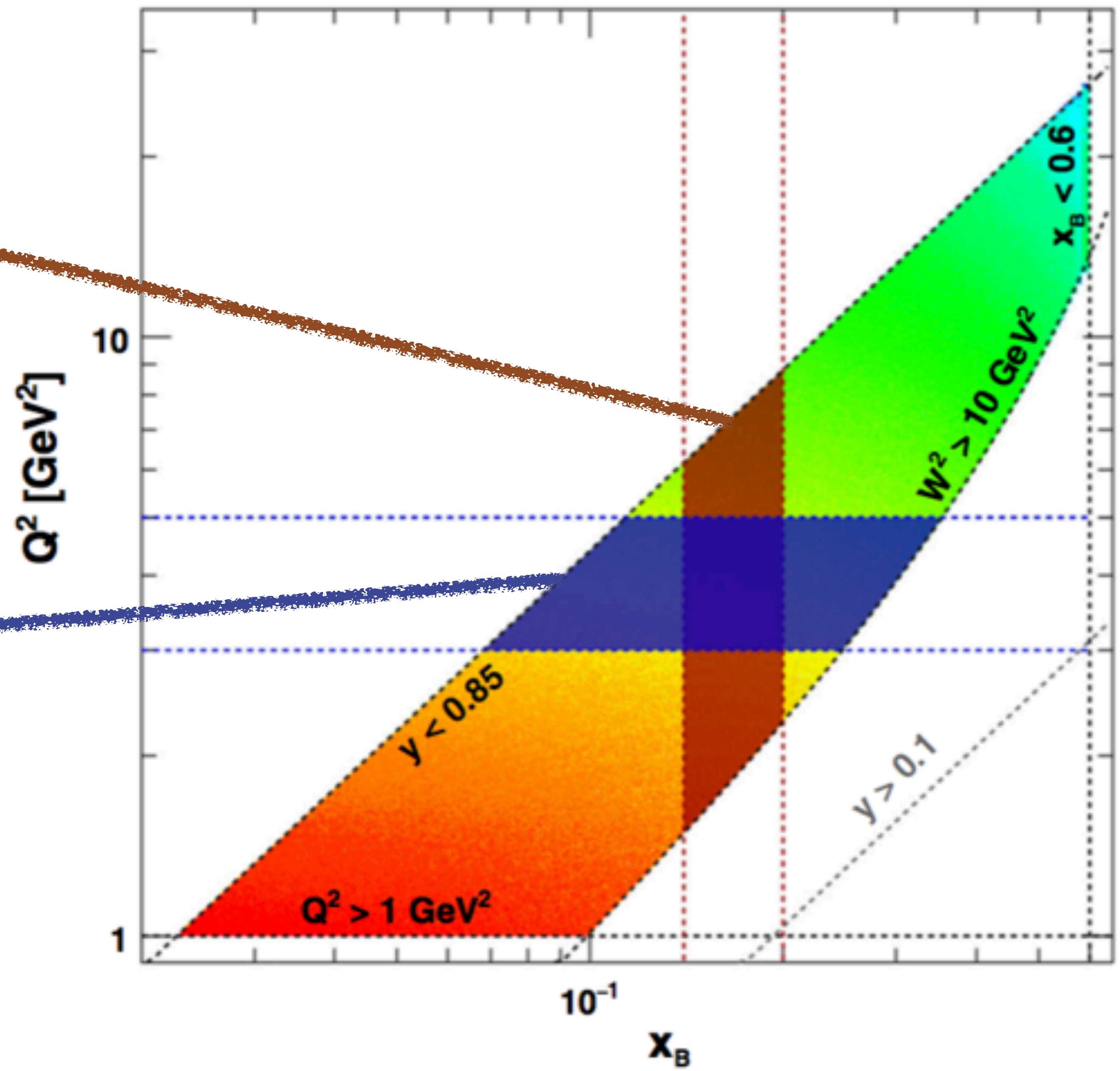

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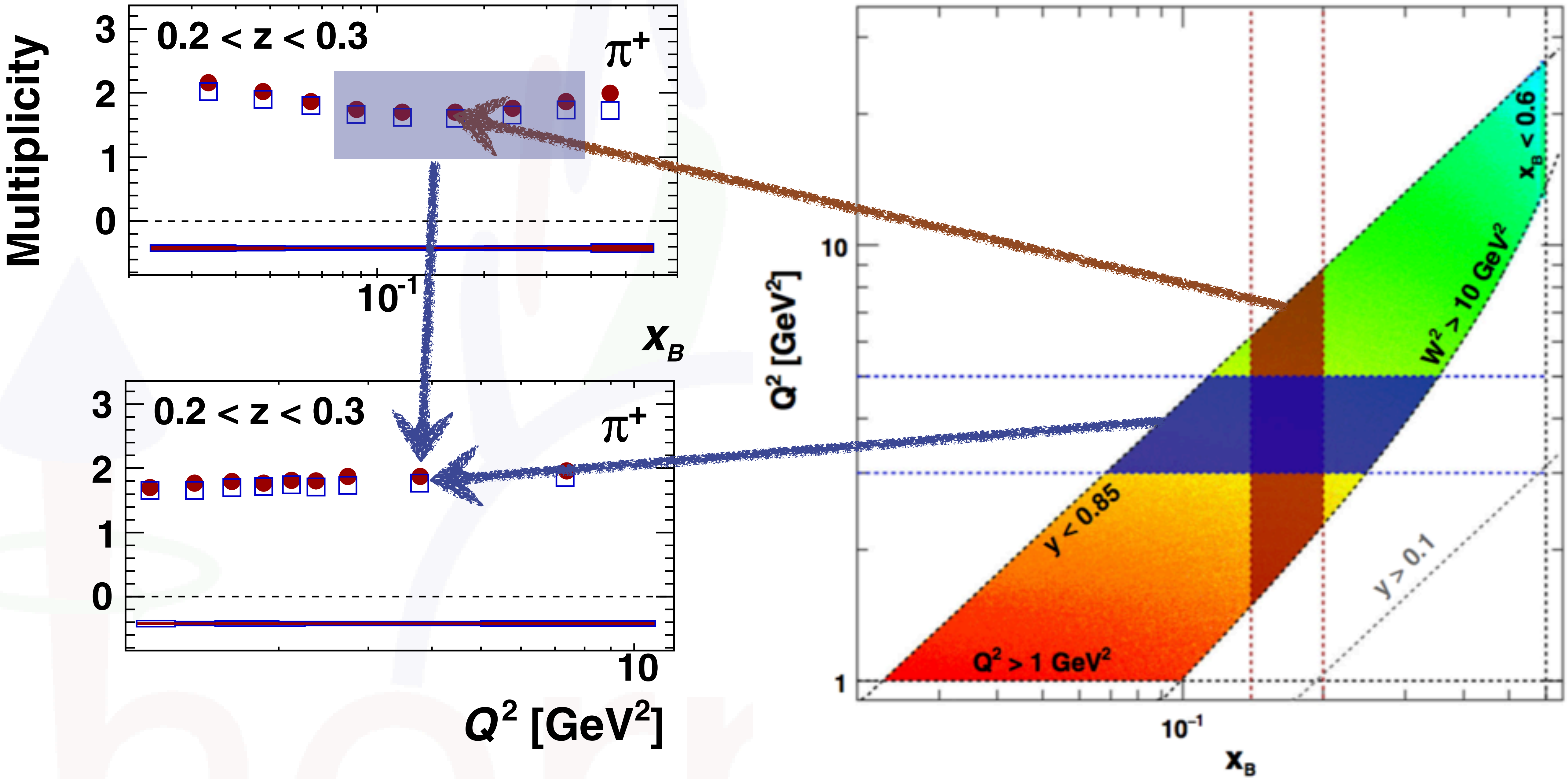

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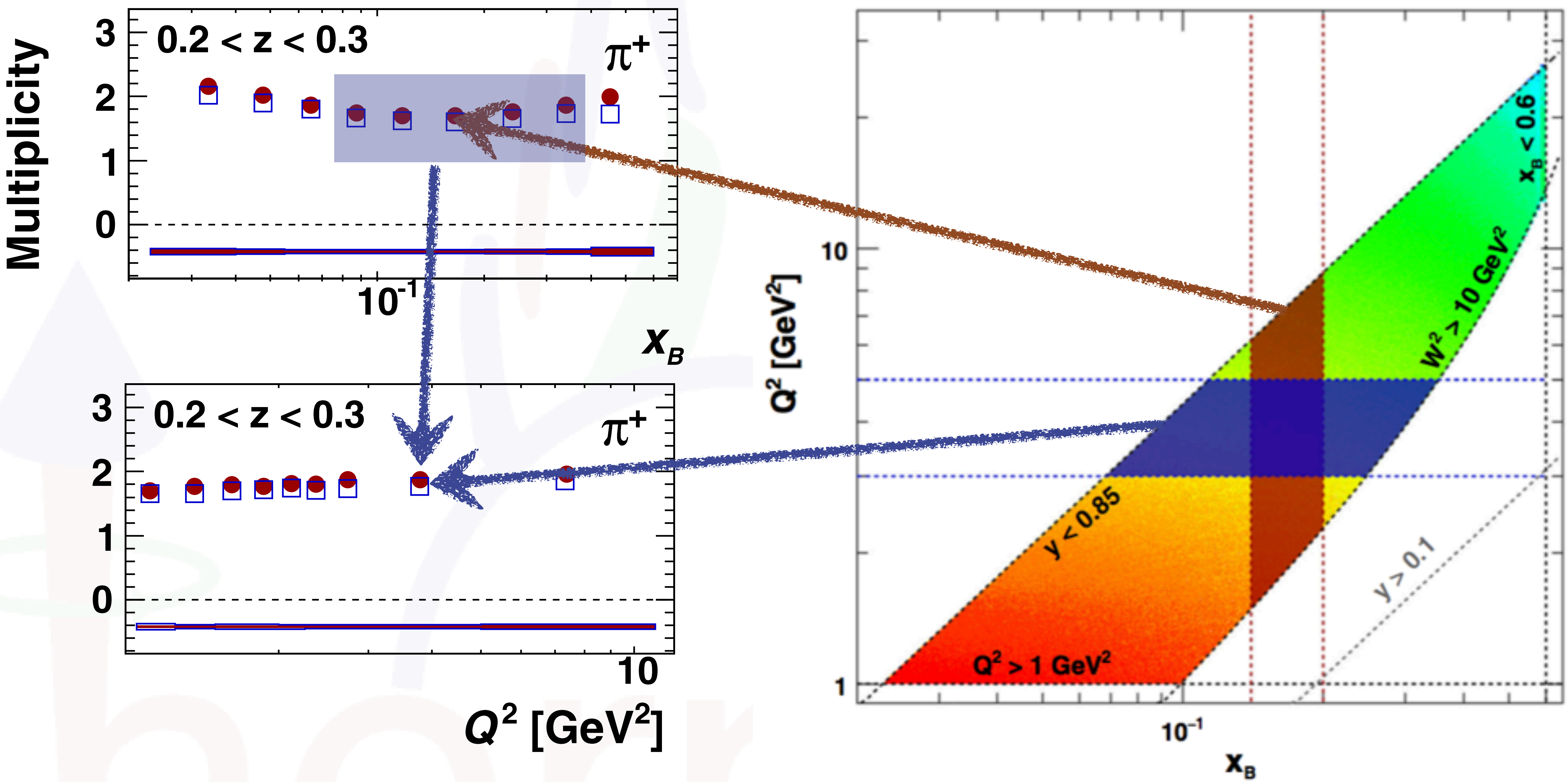
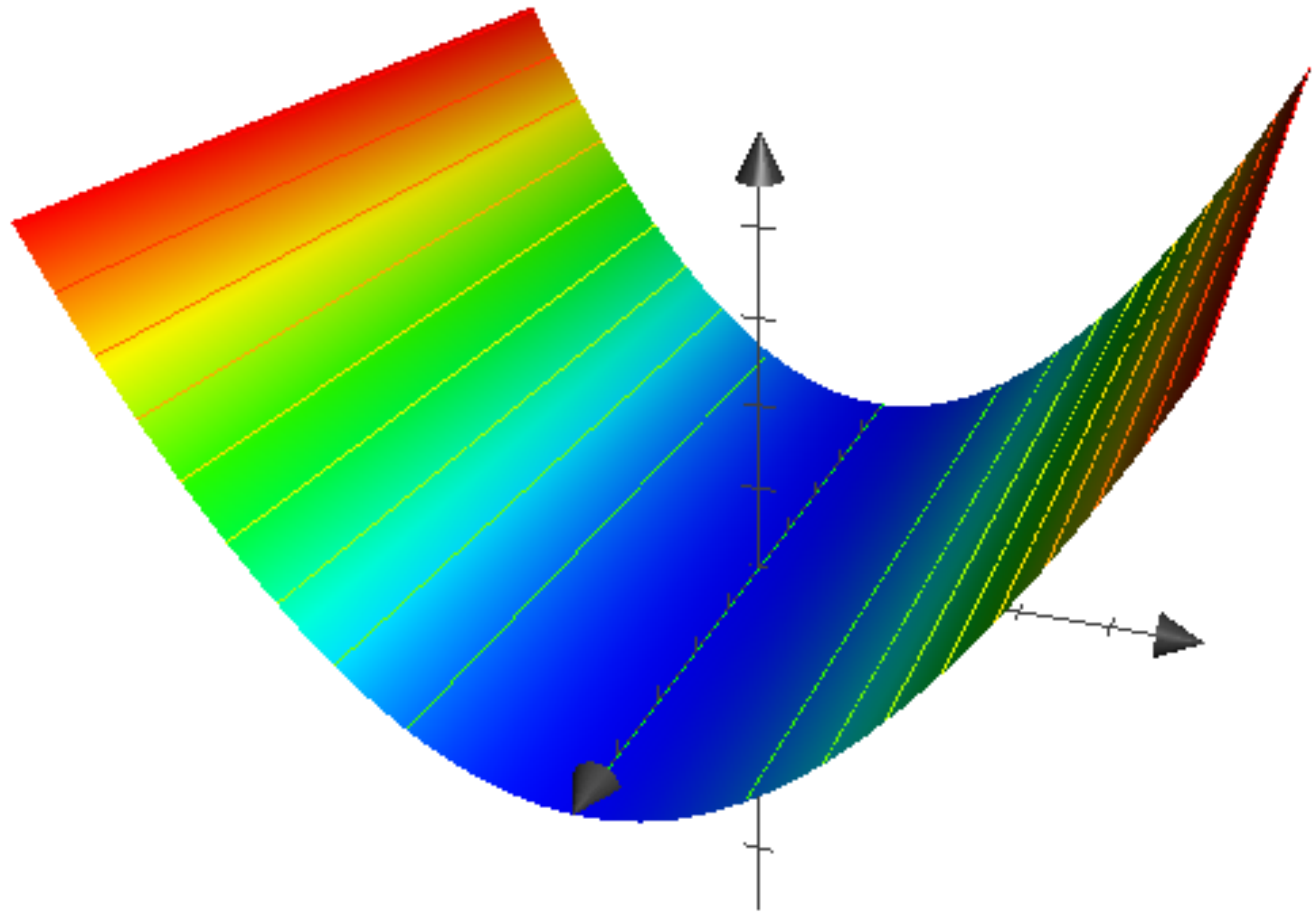
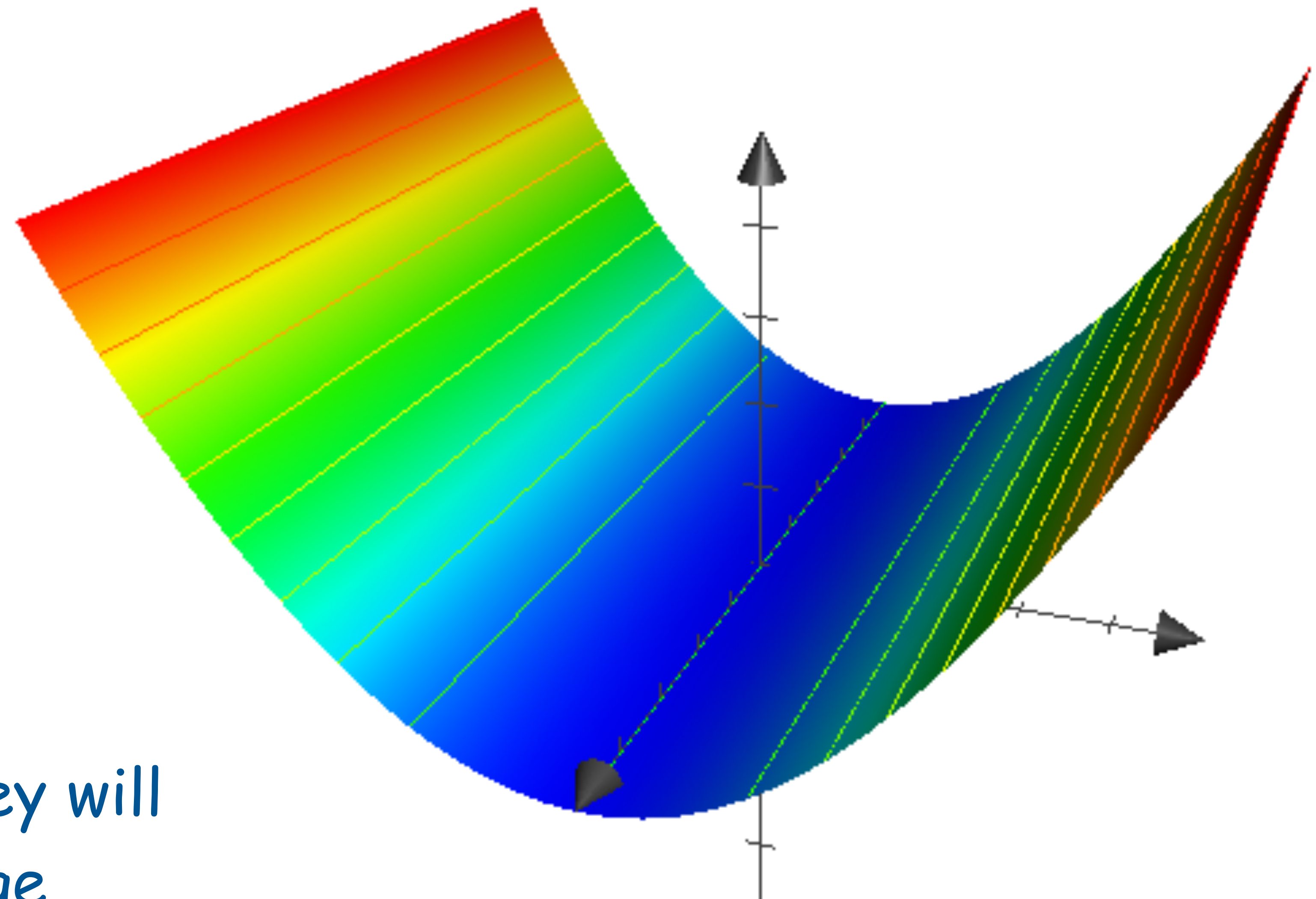


- even though having similar average kinematics, multiplicities in the two projections are different

$\langle \mathcal{M}(Q^2) \rangle_{Q^2} \neq \mathcal{M}(\langle Q^2 \rangle)$

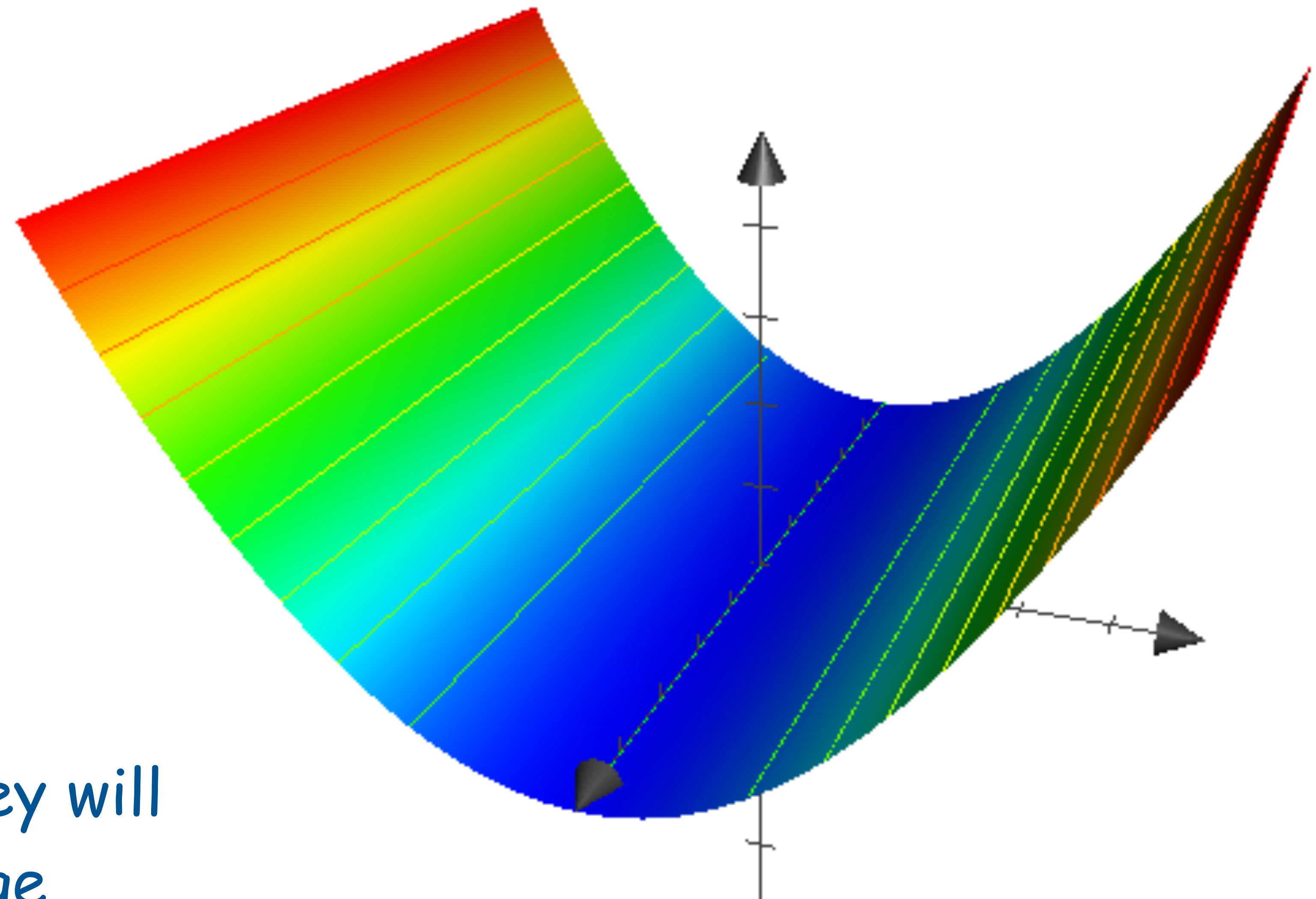


$\langle \mathcal{M}(Q^2) \rangle_{Q^2} \neq \mathcal{M}(\langle Q^2 \rangle)$



- the average along the valley will be smaller than the average along the gradient

$\langle \mathcal{M}(Q^2) \rangle_{Q^2} \neq \mathcal{M}(\langle Q^2 \rangle)$

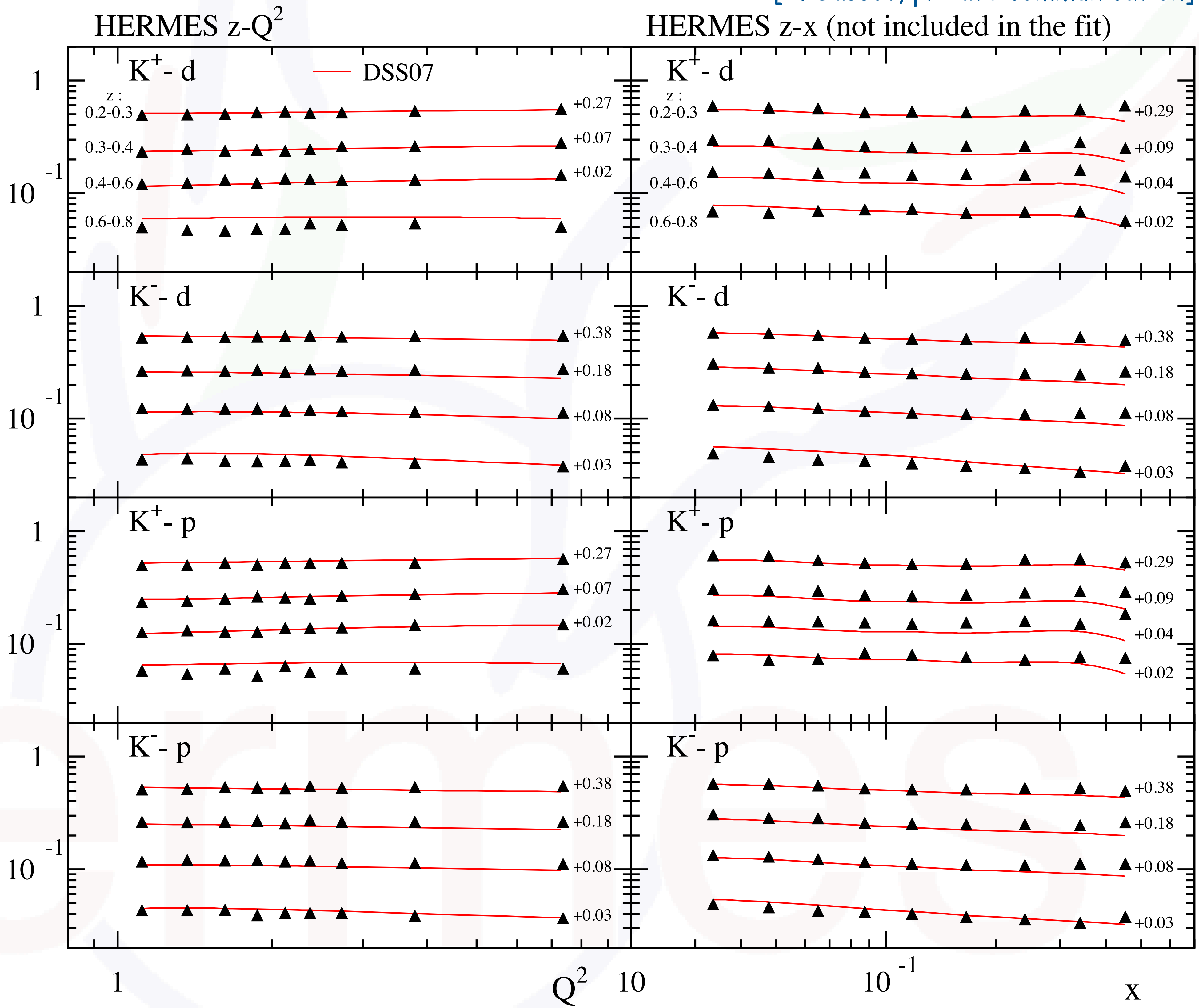


- the average along the valley will be smaller than the average along the gradient
- still the **average kinematics** can be the same

integrating vs. using average kinematics

- (by now old) **DSS07** FF fit to z-Q^2 projection
- z-x "prediction" reasonable well when using **integration** over phase-space limits (red lines)

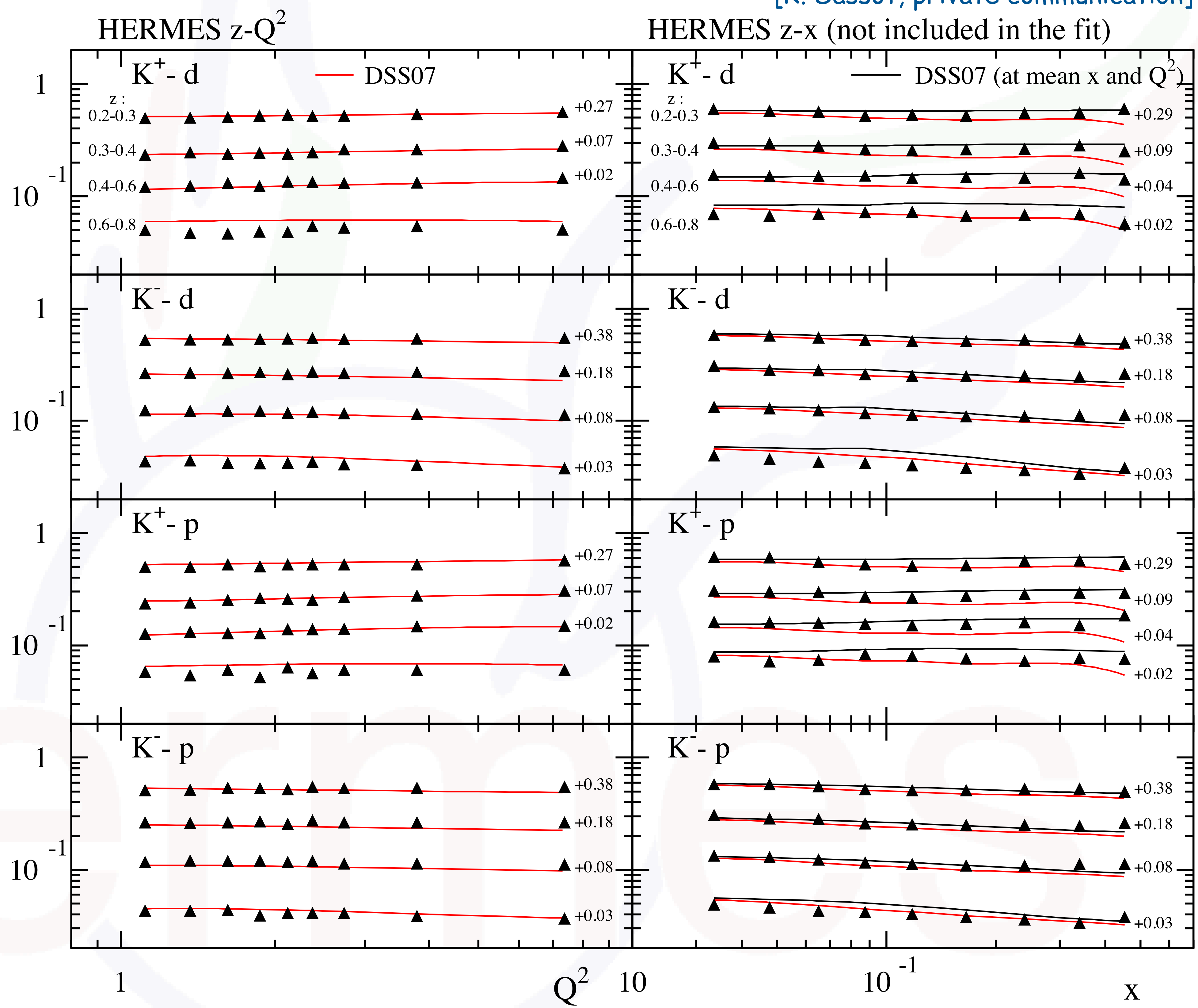
[R. Sassot, private communication]



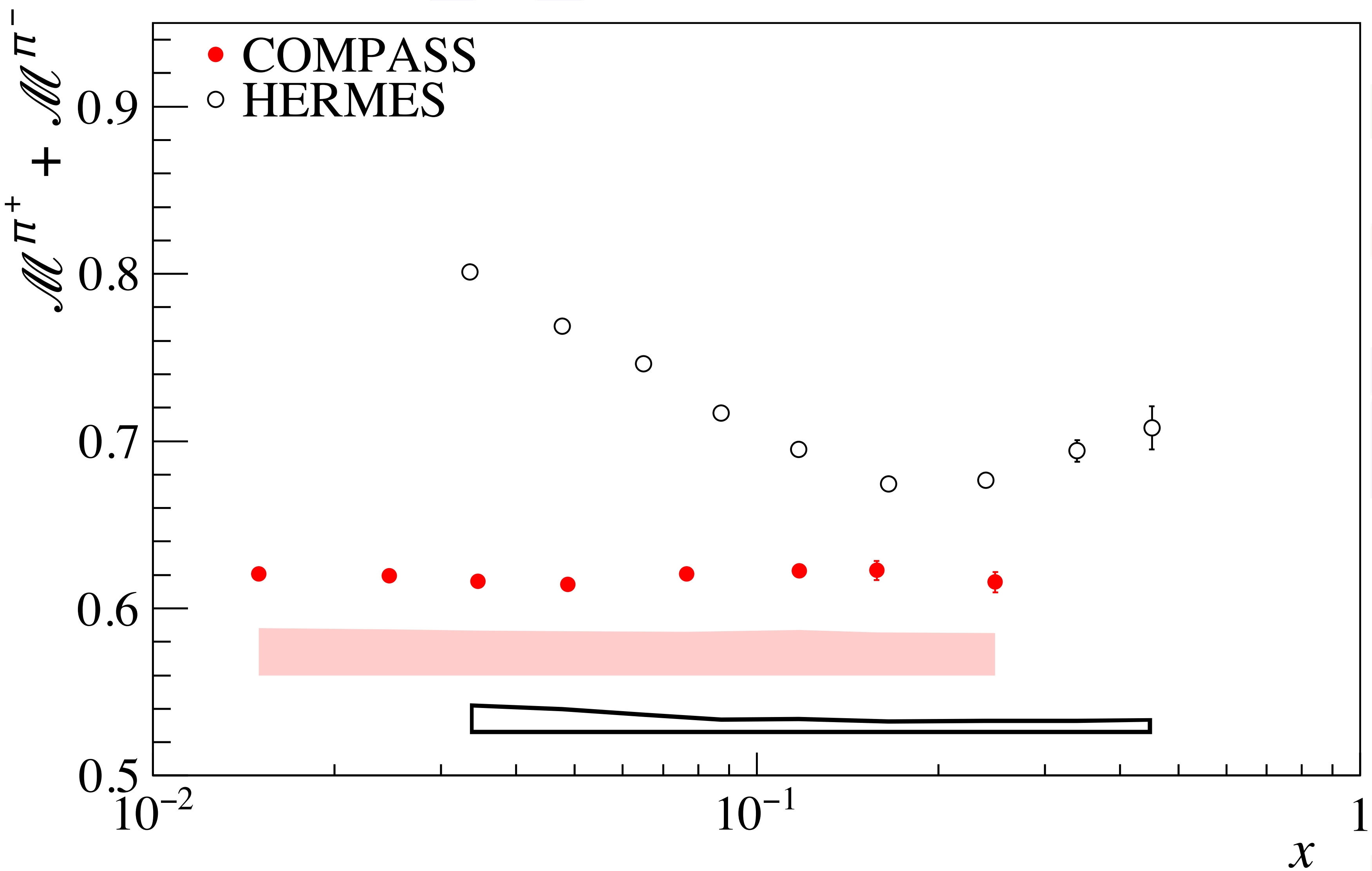
integrating vs. using average kinematics

- (by now old) **DSS07** FF fit to z-Q^2 projection
- z-x "prediction" reasonable well when using **integration** over phase-space limits (red lines)
- significant changes when using **average kinematics**

[R. Sassot, private communication]

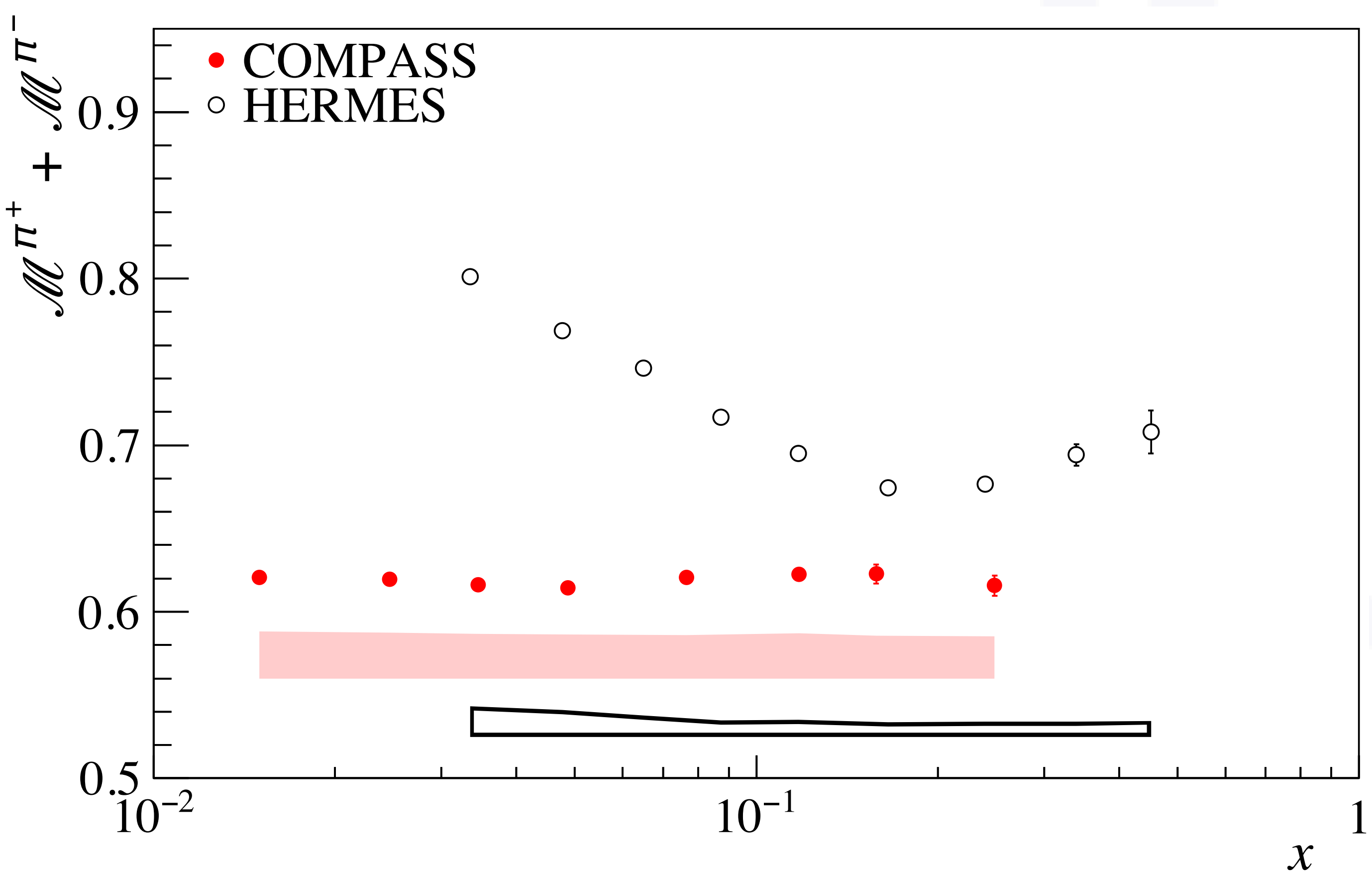


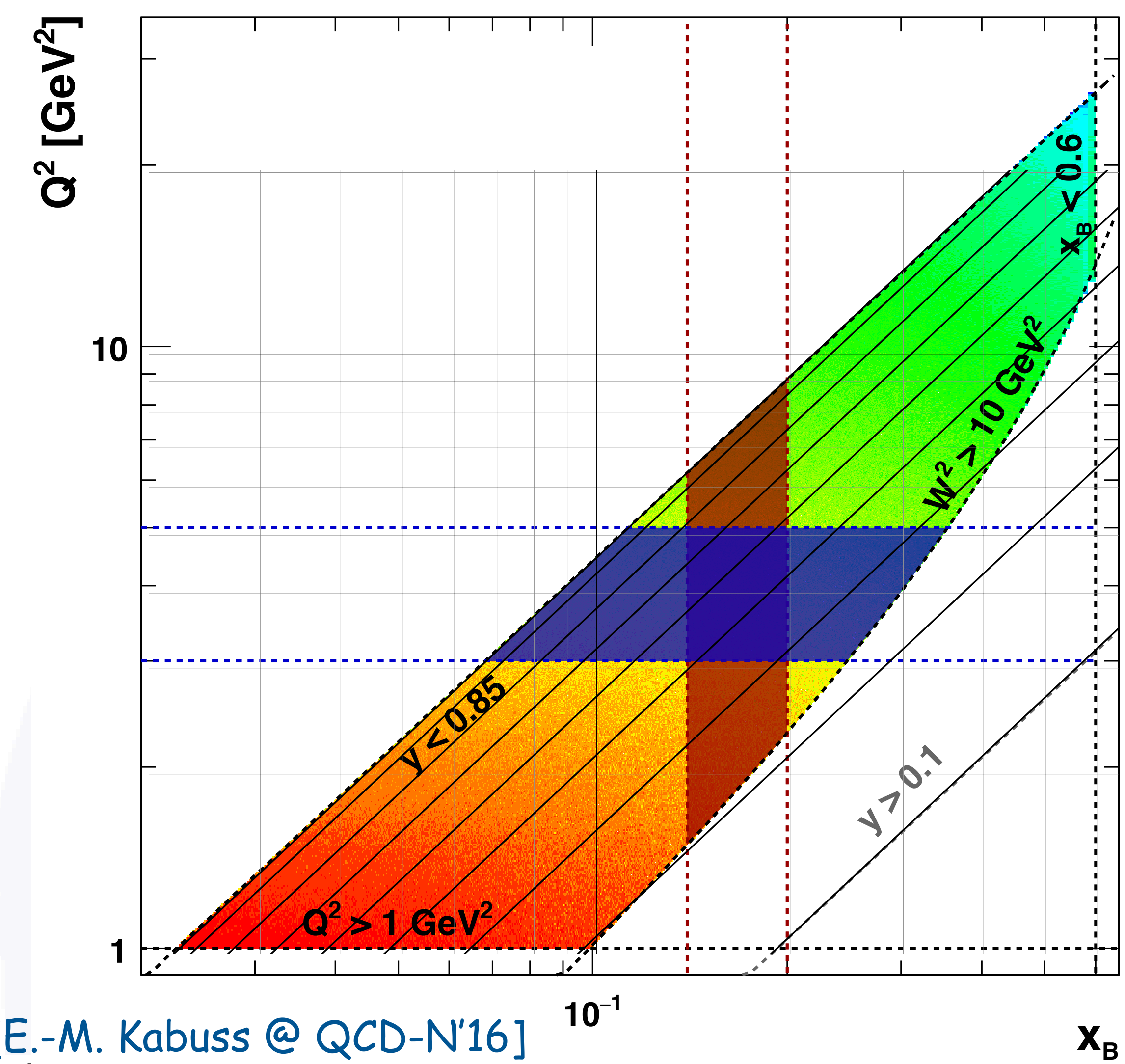
… anticipating the COMPASS talk



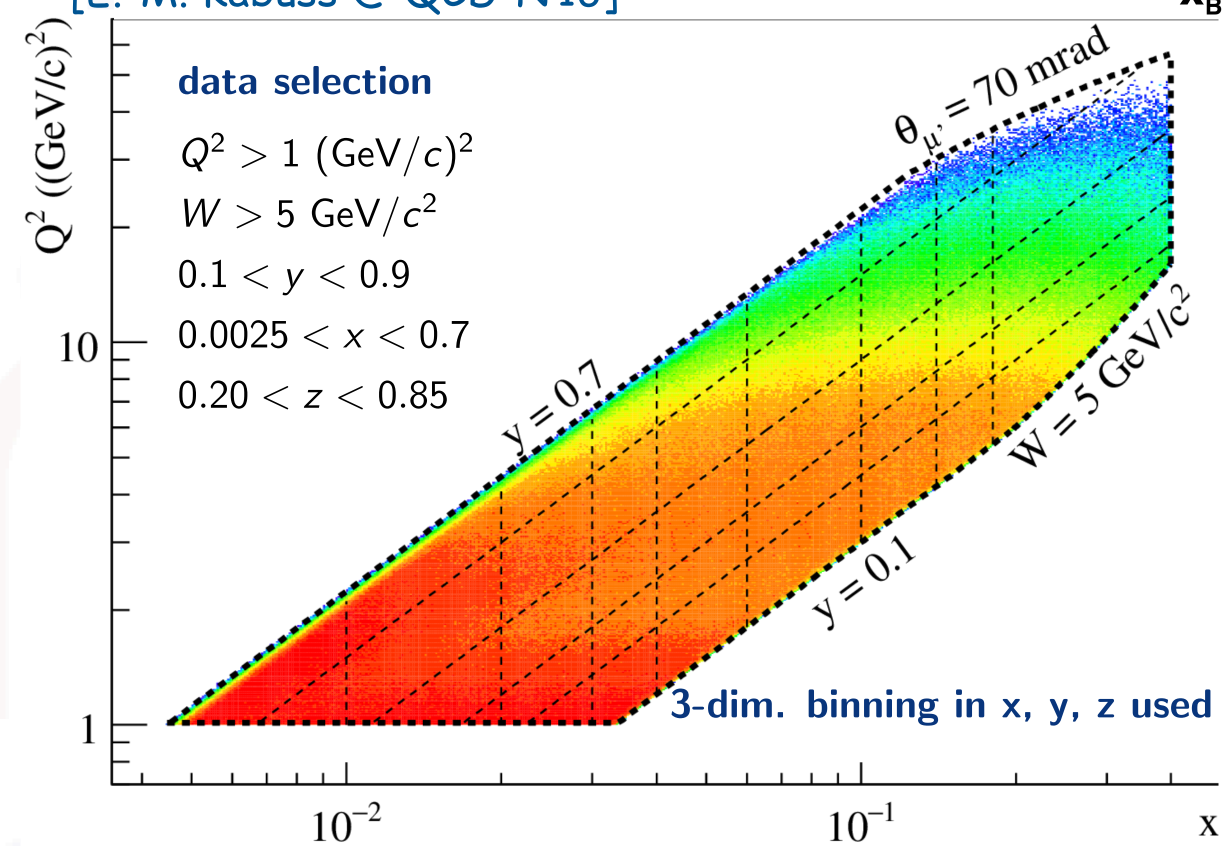
$$\mathscr{M}^{\pi^\pm} = \int \langle M^{\pi^\pm}(x,y,z)\rangle_y \, \mathrm{d}z \quad \text{(COMPASS)}$$

COMPASS vs. HERMES





[E.-M. Kabuss @ QCD-N'16]



$$\mathscr{M}^{\pi^\pm} = \int \langle M^{\pi^\pm}(x,y,z)\rangle_y \,\mathrm{d}z$$

- not clear that indeed we compare the same here, needs more thinking
- averaging over different regions in y gives different answers [see, e.g., talk by R. Sassot at QCD-N'16]

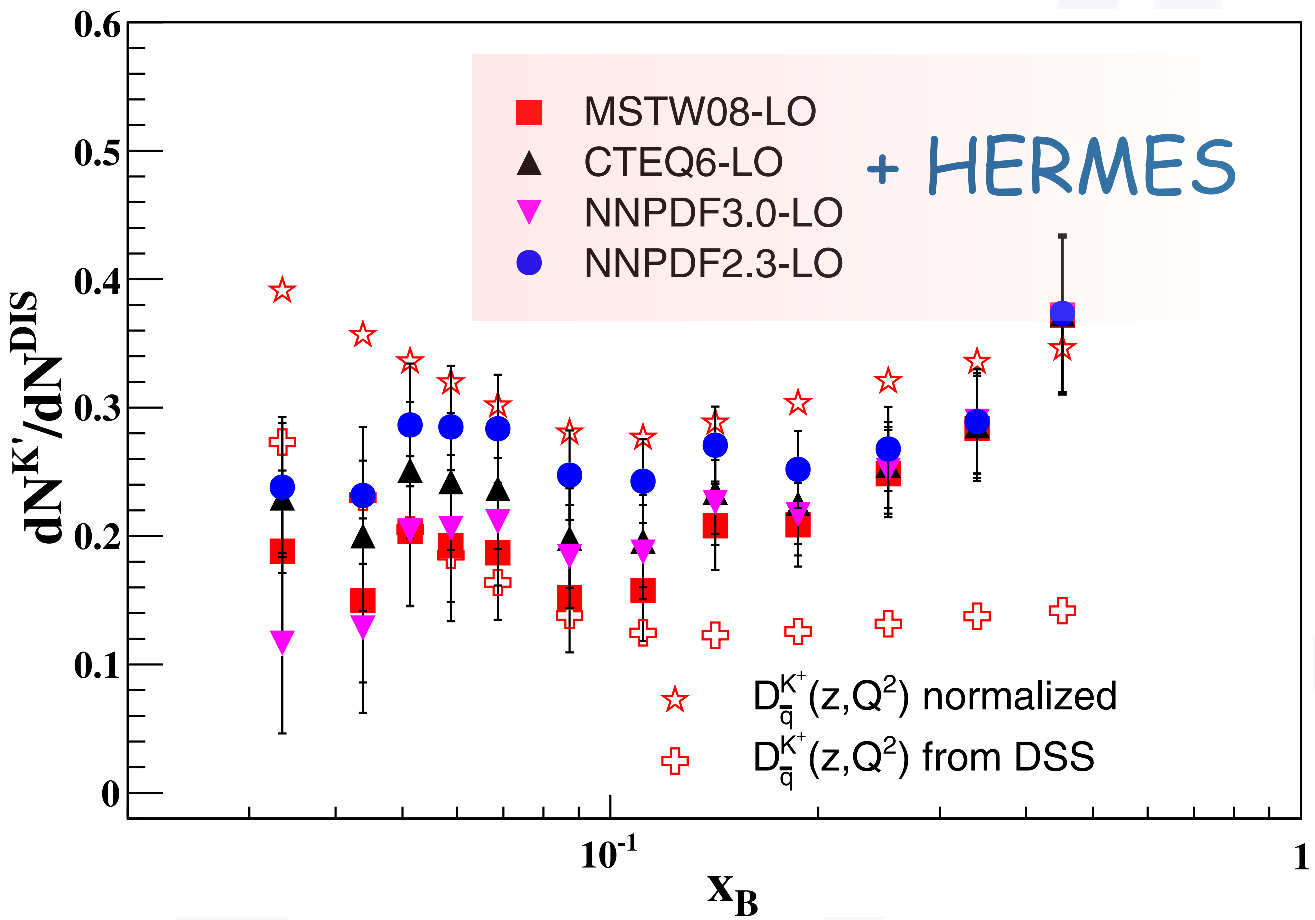
not all can (yet) be extracted from data

- e.g., observables that rely on perfect cancelations of large quantities in order to access inherently small quantities
  - it was suggested to look at a different combination of multiplicities than in the isoscalar extraction of s(x) to test the latter
  - involves difference of multiplicities, which emphasizes small corrections that might be needed to perfectly describe multiplicities:

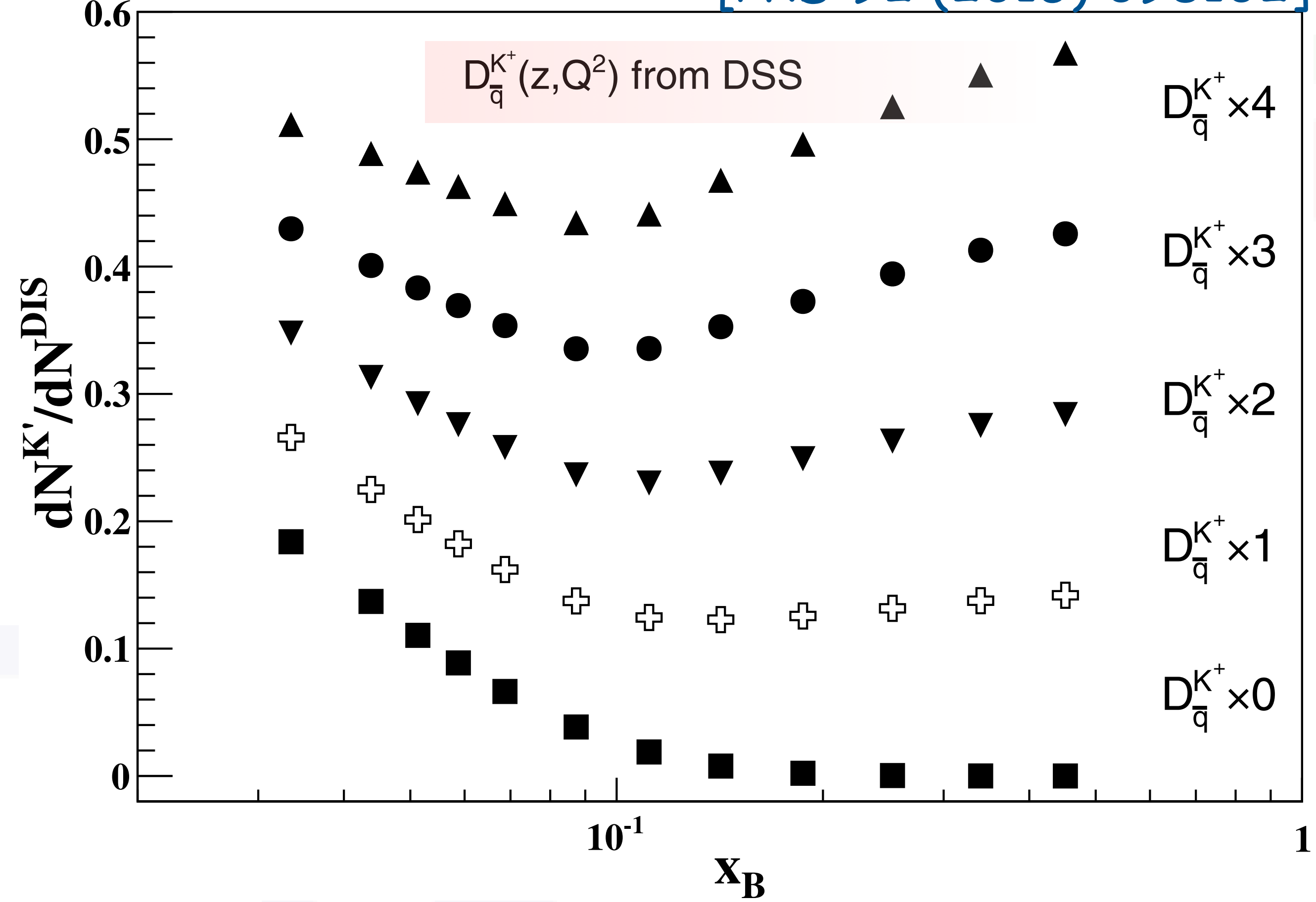
$$\frac{\mathrm{d}N^{K'}}{\mathrm{d}N^{\mathrm{DIS}}} \equiv \frac{5Q+2S}{Q}\frac{\mathrm{d}N^{K}}{\mathrm{d}N^{\mathrm{DIS}}} - \frac{5Q+2S}{u_v+d_v}\frac{\mathrm{d}N^{K^{\mathrm{diff}}}}{\mathrm{d}N^{\mathrm{DIS}}}$$

$$\stackrel{\mathrm{LO},s=\bar{s}}{=} 8D_{\bar{u}}^{K^+} + 2D_{\bar{d}}^{K^+} + \frac{S}{Q}D_S^K$$

not all can (yet) be extracted from data



[PRD 92 (2015) 098102]



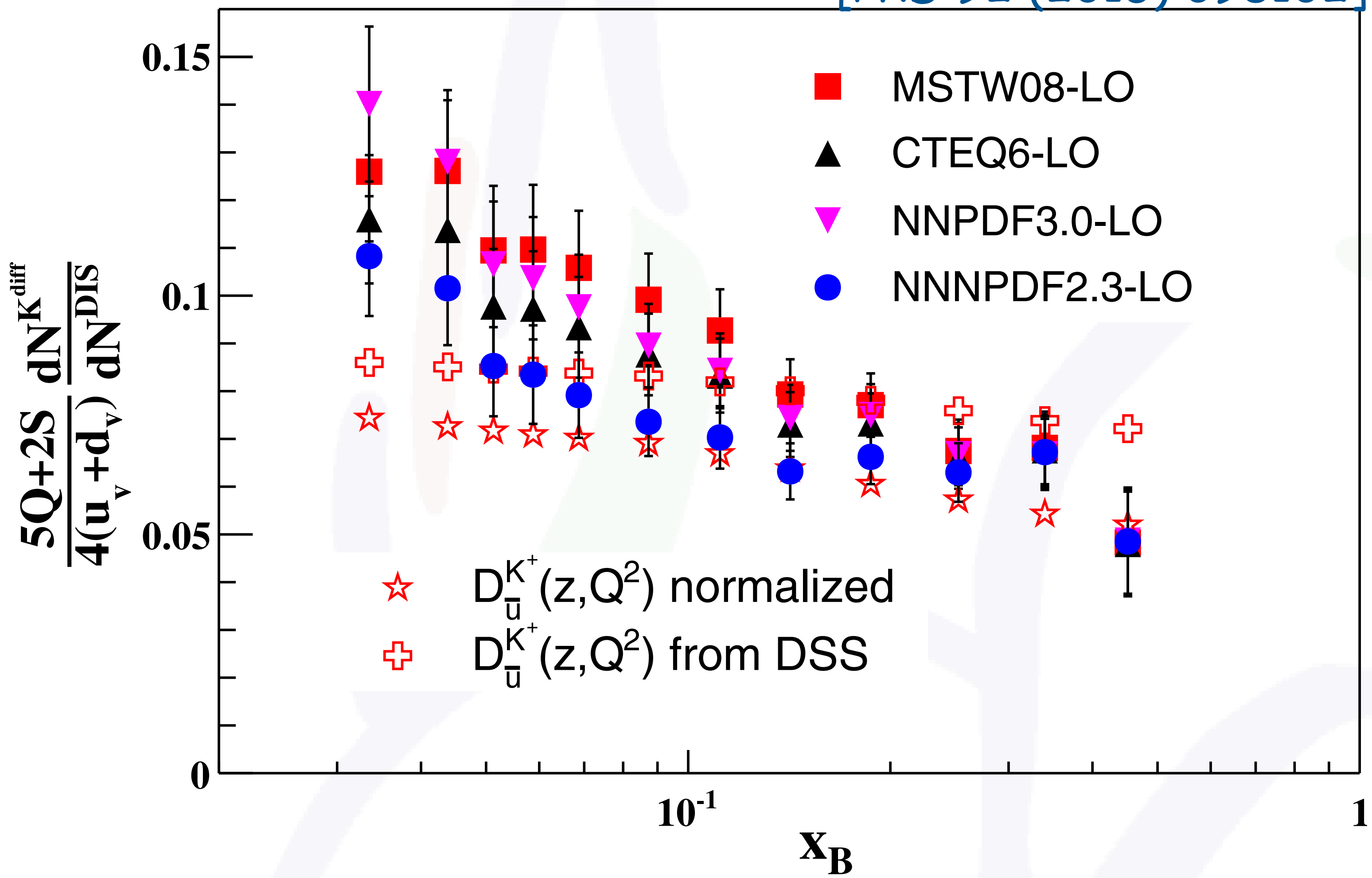
- large spread both from (limited) knowledge of PDFs (left) and FFs (right)
- no high-x limit to be used to constrain disfavored kaon FFs

$$\frac{\mathrm{d}N^{K'}}{\mathrm{d}N^{\mathrm{DIS}}} \equiv \frac{5Q+2S}{Q}\frac{\mathrm{d}N^{K}}{\mathrm{d}N^{\mathrm{DIS}}} - \frac{5Q+2S}{u_v+d_v}\frac{\mathrm{d}N^{K^{\mathrm{diff}}}}{\mathrm{d}N^{\mathrm{DIS}}}$$

$$\overset{\mathrm{LO},s=\bar{s}}{=} 8D_{\bar{u}}^{K^+} + 2D_{\bar{d}}^{K^+} + \frac{S}{Q}D_S^K$$

not all can (yet) be extracted from data

[PRD 92 (2015) 098102]



- similar problem when look at just the ("scaled") difference multiplicity

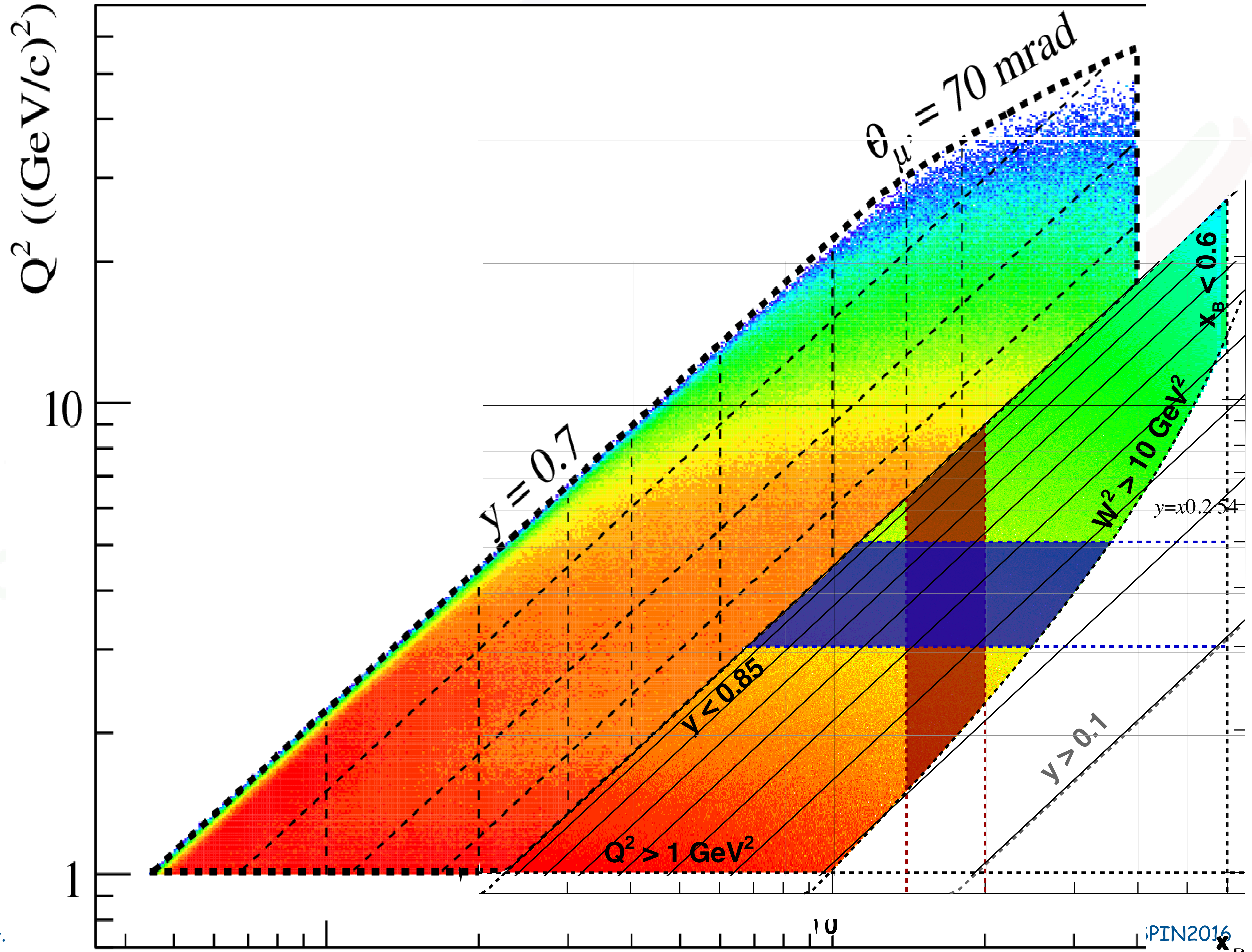
$$\frac{dN^{K^{\text{diff}}}}{dN^{\text{DIS}}} \equiv \frac{d(N^{K^+} - N^{K^-})}{dN^{\text{DIS}}}$$

$$\stackrel{\text{LO},s=\bar{s}}{=} \frac{(u_v + d_v)(4D_u^{K^+} - 4D_{\bar{u}}^{K^+} + D_d^{K^+} - D_{\bar{d}}^{K^+})}{5Q + 2S}$$

Conclusions

- HERMES managed step from spin-asymmetry experiment to unpolarized-target experiment
- most comprehensive data set on charged-separated identified meson lepto-production on both proton and deuterons
- multi-dimensional analysis and various targets allow study of correlations and flavor dependences
- analysis of averages requires careful consideration of kinematic ranges averaged over
- transverse-momentum dependence -> TMD Session VII

backup slides



Q^2 ((GeV/c)^2)
10
1
θ_μ' = 70 mrad
y = 0.7
y < 0.85
x_B < 0.6
W^2 > 10 GeV^2
y=x0.2/54
y > 0.1
Q^2 > 1 GeV^2
10
x_B

G.

SPIN2016

COMPASS multi-D binning