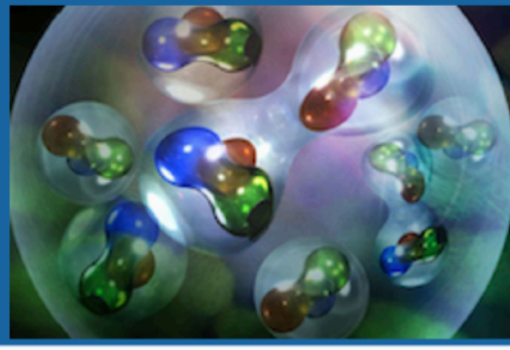


4th International Workshop on Quantitative Challenges in Short-Range Correlations and the EMC Effect Research

30 January 2023 to 3 February 2023
CEA Paris-Saclay

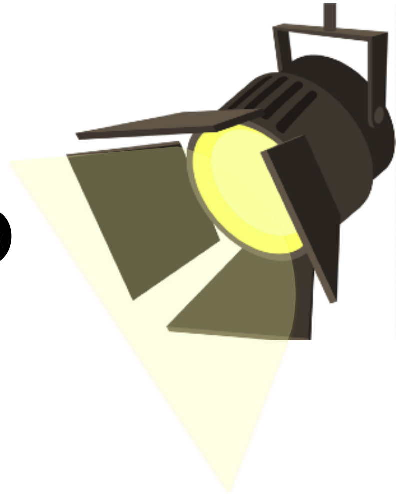
SIDIS study @ CLAS12

Erez O. Cohen,

Ofer Aviv, Dien T. Nguyen, Florian Hauenstein, Igor Korover,

Or Hen, Eli Piasetzky

Feb-03, 2023



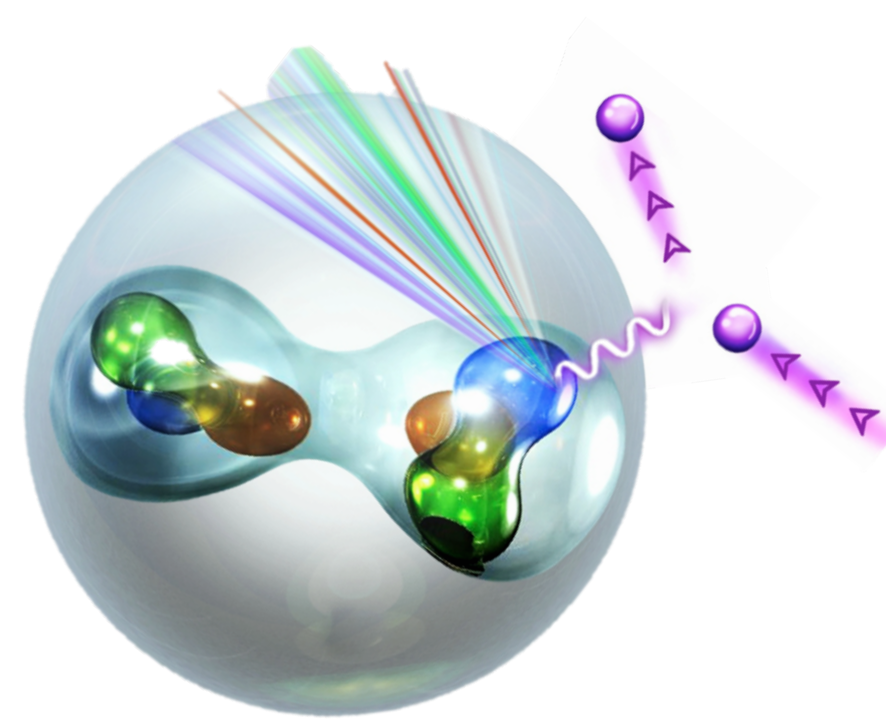
- We study π^+/π^- SIDIS cross-section ratio off *d* (and *p*) with & without tagging on SRC
- low Q^2 : consistent with published data
- high Q^2: approach Parton model
- Based on Parton model we extract *u/d* for *p*
- We study fragmentation at large p_T

DIS π^+/π^- production cross-section ratio

- PDFs of u and d in a bound p are potentially different from those in free p

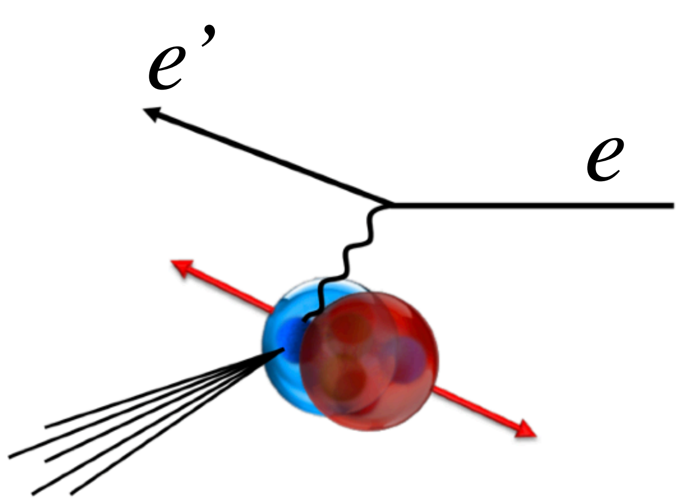
- Structure modification can be associated with u or d using π^+/π^- production cross-section ratio at high z

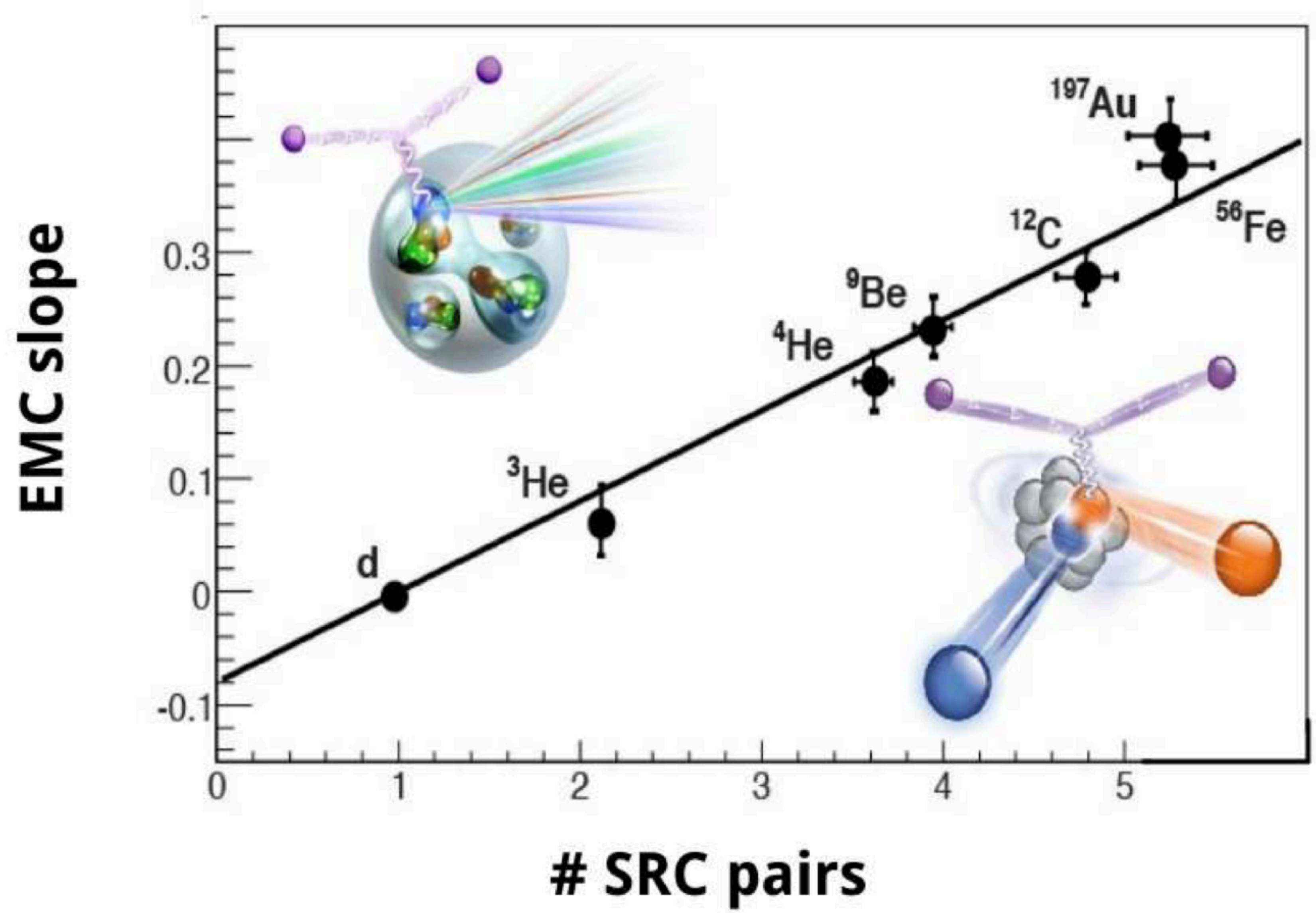
(π^+ is $u\bar{d}$, π^- is $d\bar{u}$)



EMC/SRC study in CLAS

- Some of the modification can be attributed to SRC
- We study this ratio for a "tagged *p*" from a SRC pairs (using a deuteron with CLAS)

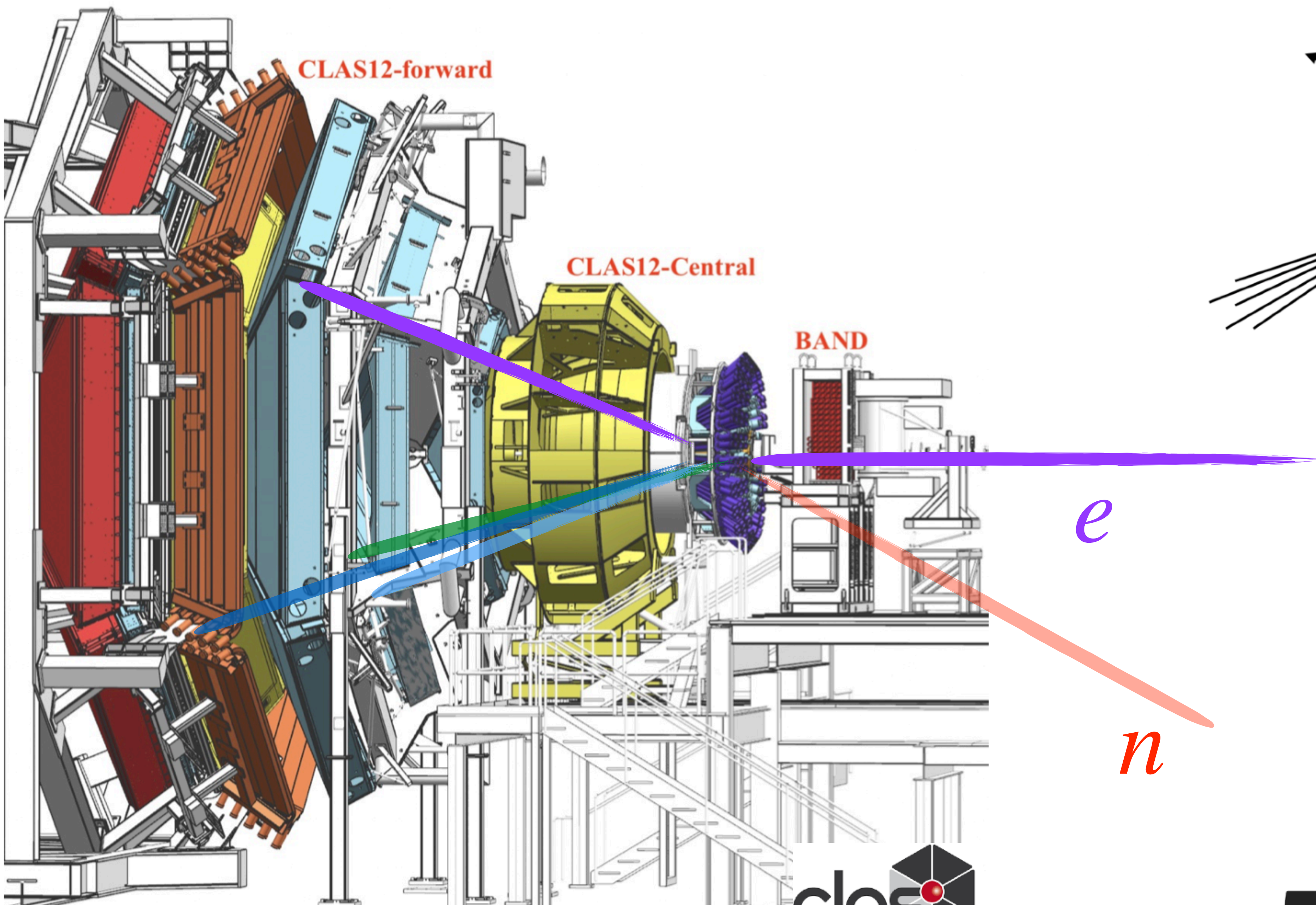




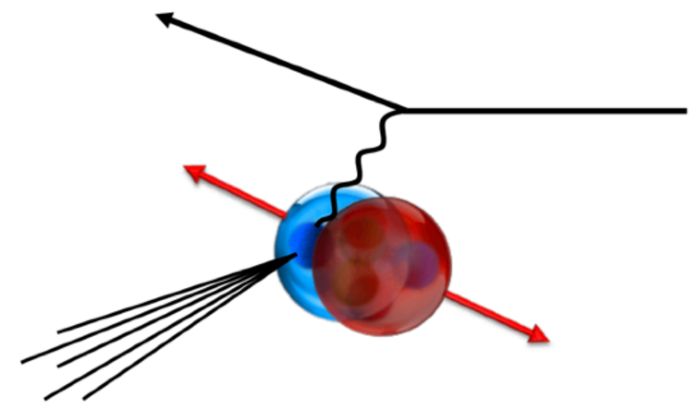
L. Weinstein, et al., PRL 106, 052301 (2011)
O. Hen, et al., PRC 85, 047301 (2012)
J. Arrington, et al., PRC 86, 065204 (2012)

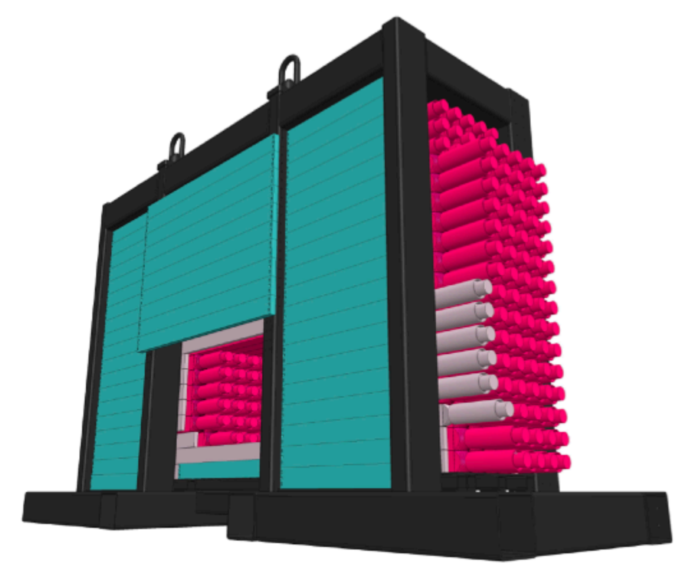
SRC-tagged SIDIS with CLAS + BAND

- BAND is a dedicated detector to tag SRC events with a backward recoiling neutron



[Nucl. Instrum. Meth. A 978 (2020) 164356]

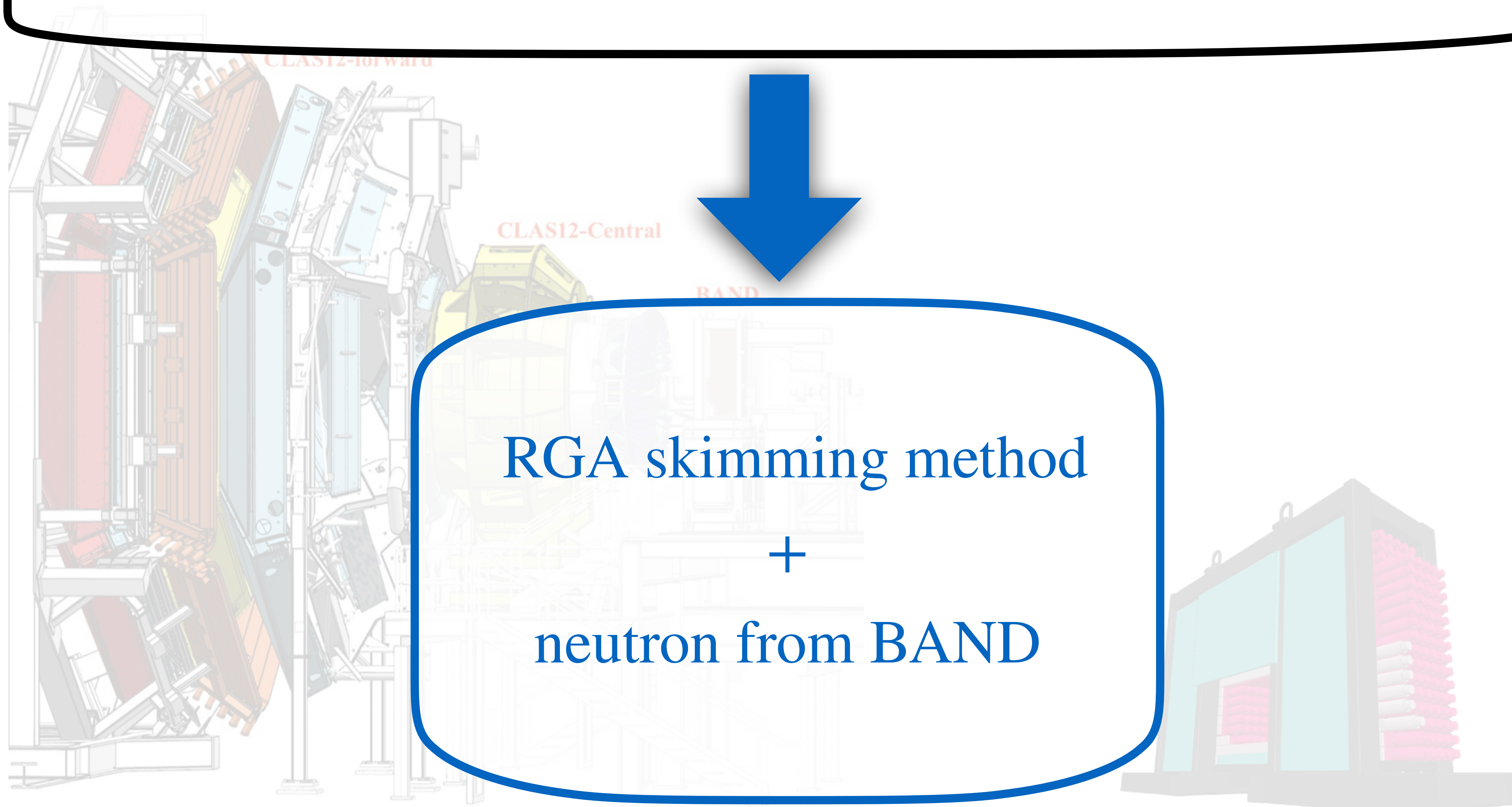




SRC-tagged SIDIS with CLAS + BAND

RGB data

Requirement: $(e, e'\pi)$ events with fast n recoil to BAND



RGA skimming method

+

neutron from BAND

Event selection criteria - Tagged SIDIS

DIS

- e and π Particle ID
- e and π fiducial cuts (PCAL, DC)
- Calorimetry energy deposition
- $5^\circ < \theta_e , \theta_\pi < 35^\circ$
- $|v_z^e - v_z^\pi| < 20$ cm
- $1.25 < p_\pi < 5.0$ GeV/c (π/K separation)
- $0.3 < z < 1.0$
- 2 (GeV/c)$^2 < Q^2$
- 2.5 GeV/c$^2 < W$
- $y = \dfrac{\omega}{E_{beam}} < 0.75$ (avoid QE)

Approved PID developed by RGA SIDIS group

- π^+/π^- acceptance matching in $p - \theta$
- 1.3 GeV/c$^2 < M_x$

"Cleaning" the event-sample

Neutrons in BAND

- "Good - n" cluster algorithm
- Fiducial cuts
- 5 MeV $< \Delta E_{dep}$
- Cut on top TOF bars in BAND
- 0.275 GeV/c $< p_n$

BAND analysis

SIDIS off the (SRC part in the) deuteron

- We are studying the π^+/π^- cross-section ratio

  - Goal: SRC-tagged ratio

$$\frac{\sigma_{d(e,e'\pi^+n)}}{\sigma_{d(e,e'\pi^-n)}}$$

Mainly scatter off a high-virtuality *p* in *np*-SRC

  - 1st step: untagged ratio

$$\frac{\sigma_{d(e,e'\pi^+)}}{\sigma_{d(e,e'\pi^-)}}$$

Scatter off *n* or *p* in *d*

SIDIS off the (SRC part in the) deuteron

SRC-tagged data

1.7 k events → $\sigma_{d(e,e'\pi^+n)}$

0.8 k → $\sigma_{d(e,e'\pi^-n)}$

$$\frac{\sigma_{d(e,e'\pi^+n)}}{\sigma_{d(e,e'\pi^-n)}}$$

Untagged data

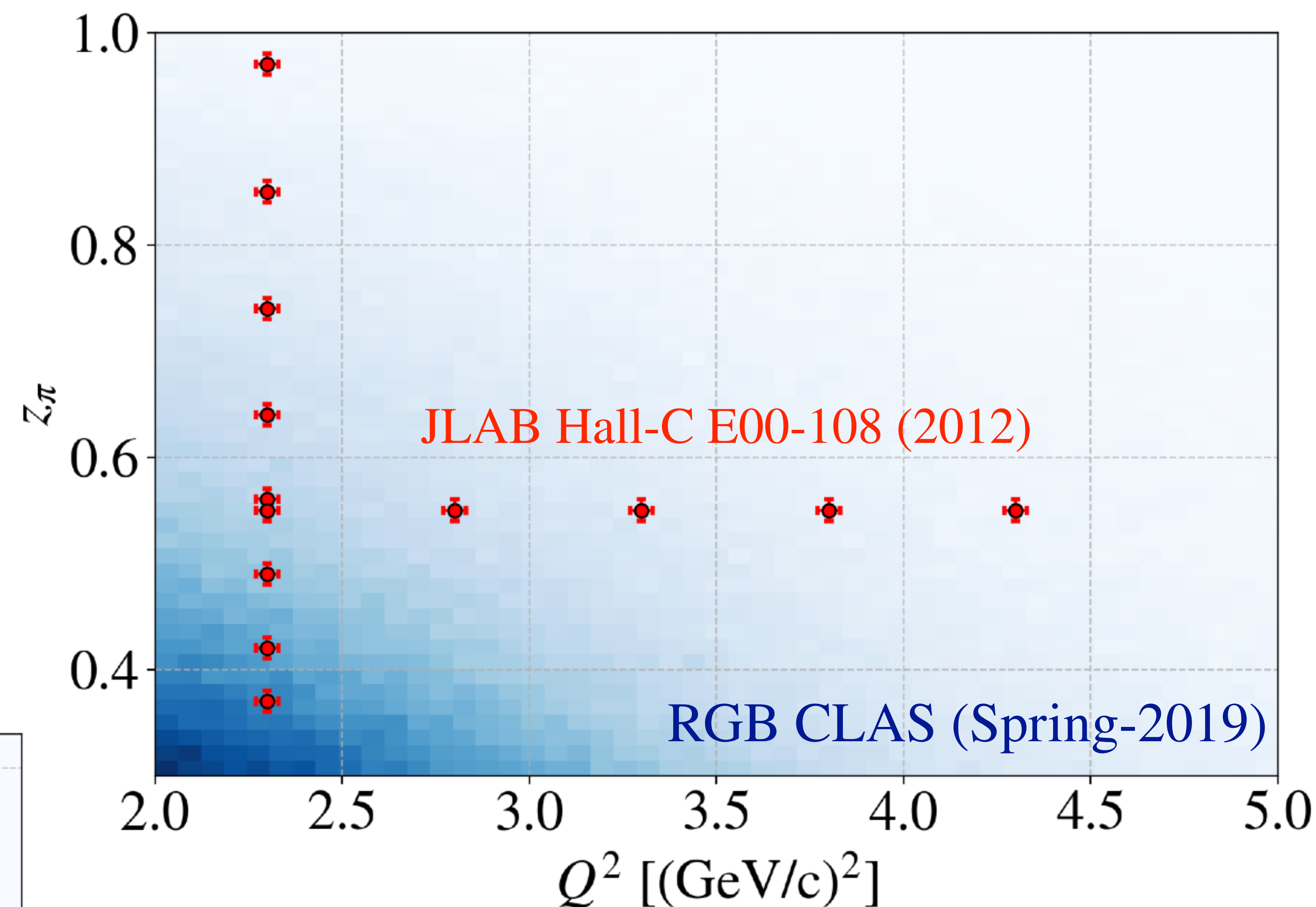
17.1 M → $\sigma_{d(e,e'\pi^+)}$

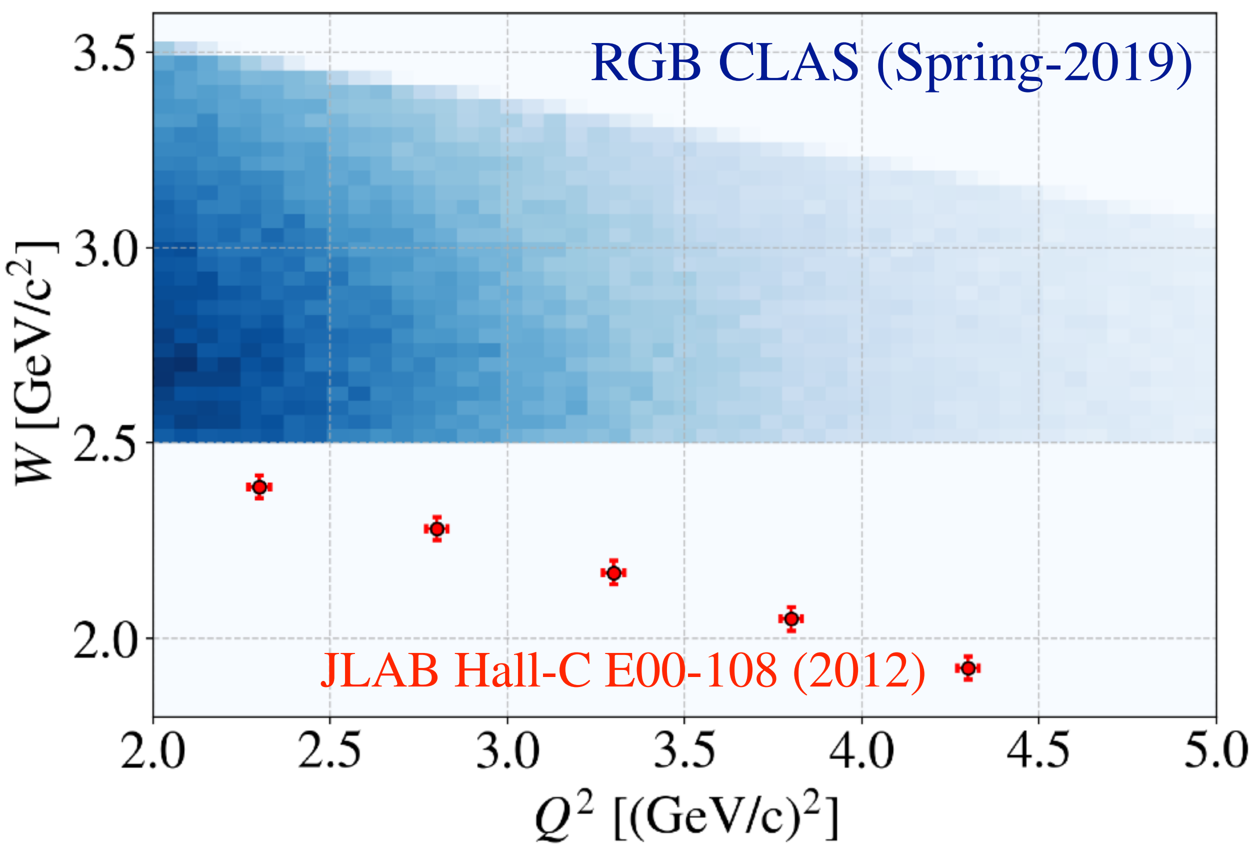
10.2 M → $\sigma_{d(e,e'\pi^-)}$

$$\frac{\sigma_{d(e,e'\pi^+)}}{\sigma_{d(e,e'\pi^-)}}$$

RGB + BAND: 10.2 GeV all data

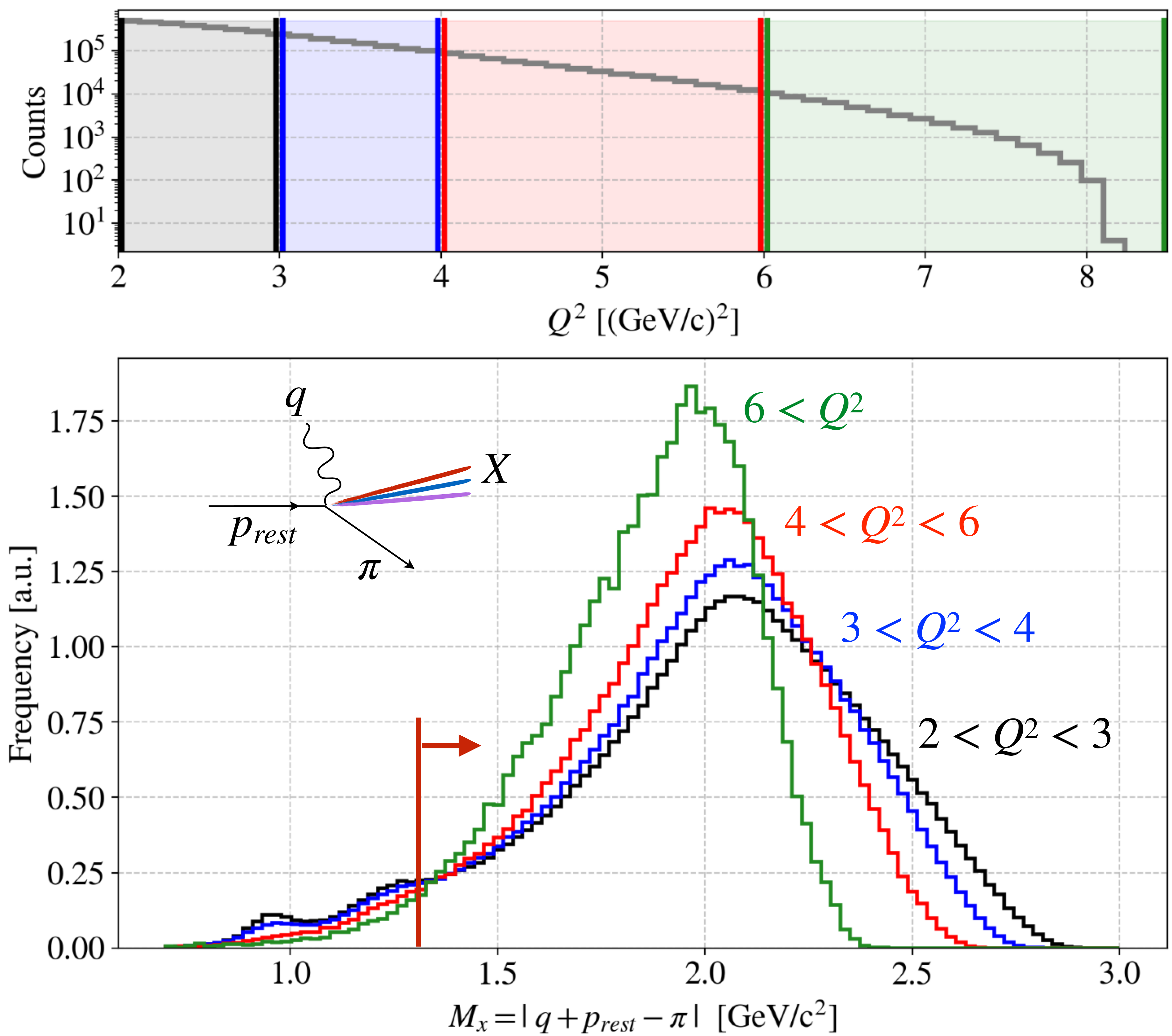
Kinematical coverage





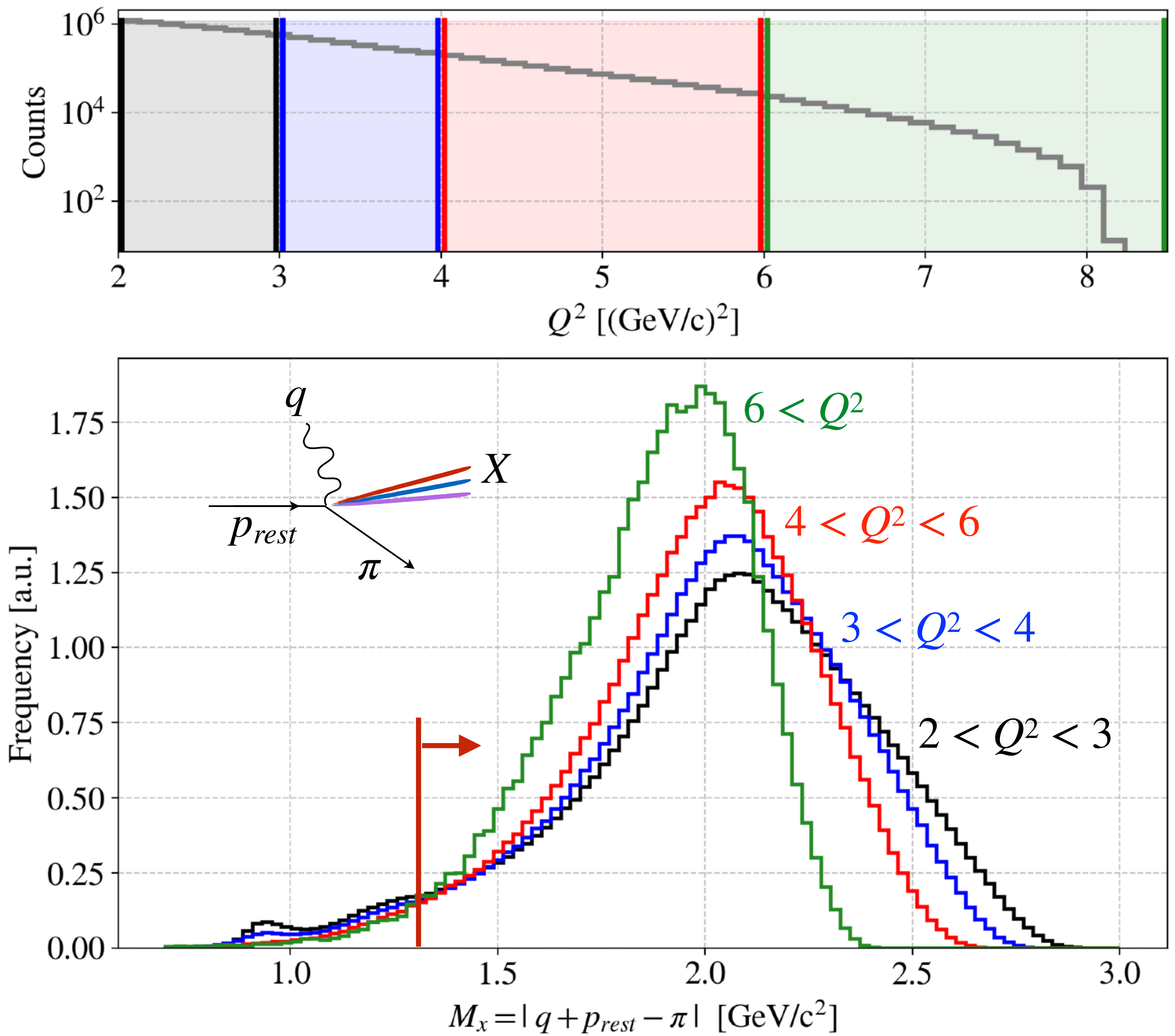
RGB + BAND: 10.2 GeV all data

M_x in bins of Q^2 for $d(e, e'\pi^+)$



RGB + BAND: 10.2 GeV all data

M_x in bins of Q^2 for $d(e, e'\pi^-)$



RGB + BAND: 10.2 GeV all data

Parton model expectation

- The Mott cross section for the scattering off a quark ξ is $\sigma_{(e,e'\xi)} \propto q_{\xi}^{2} f_{\xi}$

Parton model expectation

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f_ξ is the nuclear PDF $\xi = u, d, s, \ldots$

Parton model expectation

- The Mott cross section for the scattering off a

  quark ξ is $\sigma_{(e,e'\xi)} \propto q_\xi^2 f_\xi$

- π^+ production off a p:

$$\sigma_p^{\pi^+} \propto 4u_v + rd_v + (\textit{sea contributions})$$

Parton model expectation

- The Mott cross section for the scattering off a quark ξ is $\sigma_{(e,e'\xi)} \propto q_\xi^2 f_\xi$
- π^+ production off a p:

$$\sigma_p^{\pi^+} \propto 4u_v + rd_v + (sea\ contributions)$$

r is the ratio unfavored/favored fragmentation probability

$r(x, z, p_\perp) = D^- / D^+$

$D^+ \equiv D_p^{\pi^+} = D_n^{\pi^-}$ Favored fragmentation

$D^- \equiv D_p^{\pi^-} = D_n^{\pi^+}$ Unfavored fragmentation

Parton model expectation

- Assuming isospin symmetry, i.e. $u_n = d_p, d_n = u_p$

  and neglecting sea contributions,

$$\sigma_d^{\pi^+} = \sigma_p^{\pi^+} + \sigma_n^{\pi^+} \sim (4 + r)(u_v + d_v)$$

$$\sigma_d^{\pi^-} = \sigma_p^{\pi^-} + \sigma_n^{\pi^-} \sim (4r + 1)(d_v + u_v)$$

- π^+/π^- cross-section ratio $\rightarrow$ fragmentation ratio

$$r = \frac{4 - \left(\sigma_d^{\pi^+}/\sigma_d^{\pi^-}\right)}{4\left(\sigma_d^{\pi^+}/\sigma_d^{\pi^-}\right) - 1}$$

Parton model expectation

- Assuming isospin symmetry, i.e. $u_n = d_p, d_n = u_p$

and neglecting sea contributions

We extract r from the data

$$\sigma_d^{\pi^+} = \sigma_p^{\pi^+} + \sigma_n^{\pi^+} \sim (4 + r)(u_v + d_v)$$

$$\sigma_d^{\pi^-} = \sigma_p^{\pi^-} + \sigma_n^{\pi^-} \sim (4r + 1)(d_v + u_v)$$

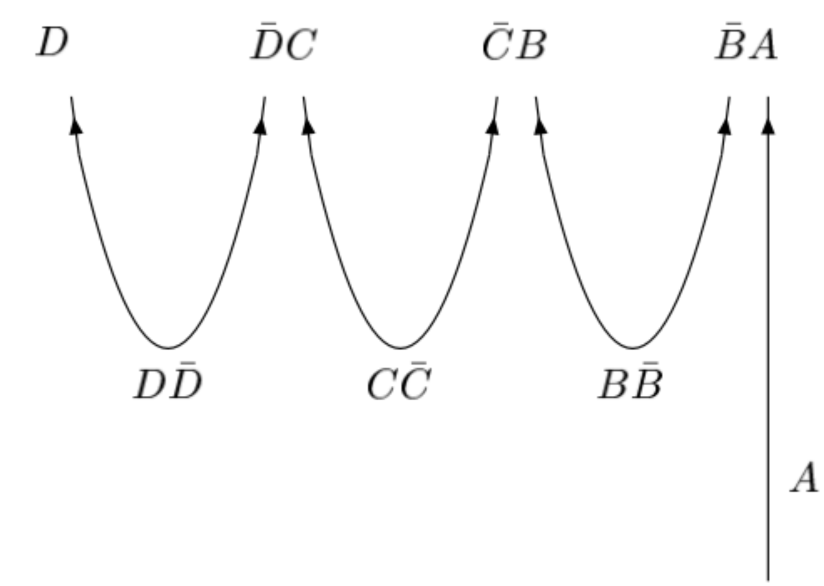
- cross-section ratio → fragmentation ratio

$$r = \frac{4 - \left(\sigma_d^{\pi^+}/\sigma_d^{\pi^-}\right)}{4\left(\sigma_d^{\pi^+}/\sigma_d^{\pi^-}\right) - 1}$$

Field & Feynman expectation

- Quark A emerges with momentum fraction z and creates a color field in which new quark-antiquark pairs are produced
- Quark A combines with an antiquark $\bar{B}$….
- Quark jets analyzed recursively
- Result: $r = (1-z)/(1-z+z/\beta_u)$ with $\beta_u = 0.46$

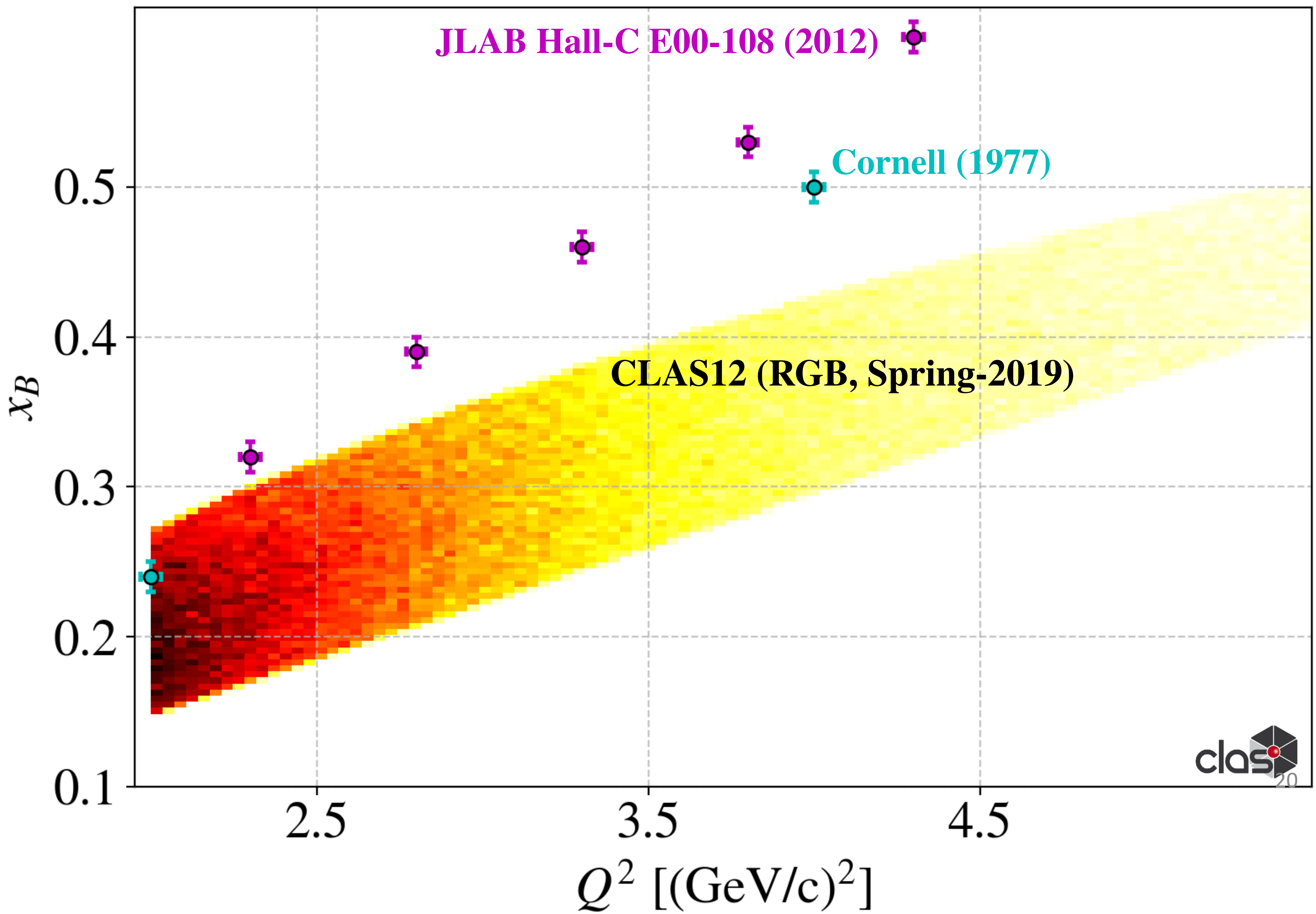
We assume that quark jets can be analyzed on the basis of a recursive principle. The ansatz is based on the idea that a quark of type "a" coming out at some momentum W_0 in the z direction creates a color field in which new quark-antiquark pairs are produced. Quark "a" then combines with an antiquark, say "$\bar{b}$", from the new pair $\bar{b}b$ to form a meson "$a\bar{b}$" leaving the remaining quark "b" to combine with further antiquarks. The "meson" $a\bar{b}$ may be directly observed as a pseudoscalar meson, or it may be a vector or higher-spin unstable resonance which subsequently decays into the observed mesons. To avoid complicating the ideas, we will call "$a\bar{b}$" the "primary" meson state and shall discuss secondary decay processes later. A "hierarchy" of primary mesons is formed of which $a\bar{b}$ is first in "rank", $b\bar{c}$ is second in rank, $c\bar{d}$ is third in rank, etc., as shown in fig. 1. (The "rank" in "hierarchy" should *not* be confused with order in momentum, but only order in the flavor relationships. The rank-2 primary meson may sometimes obtain a larger momentum than the rank-1 primary meson.)



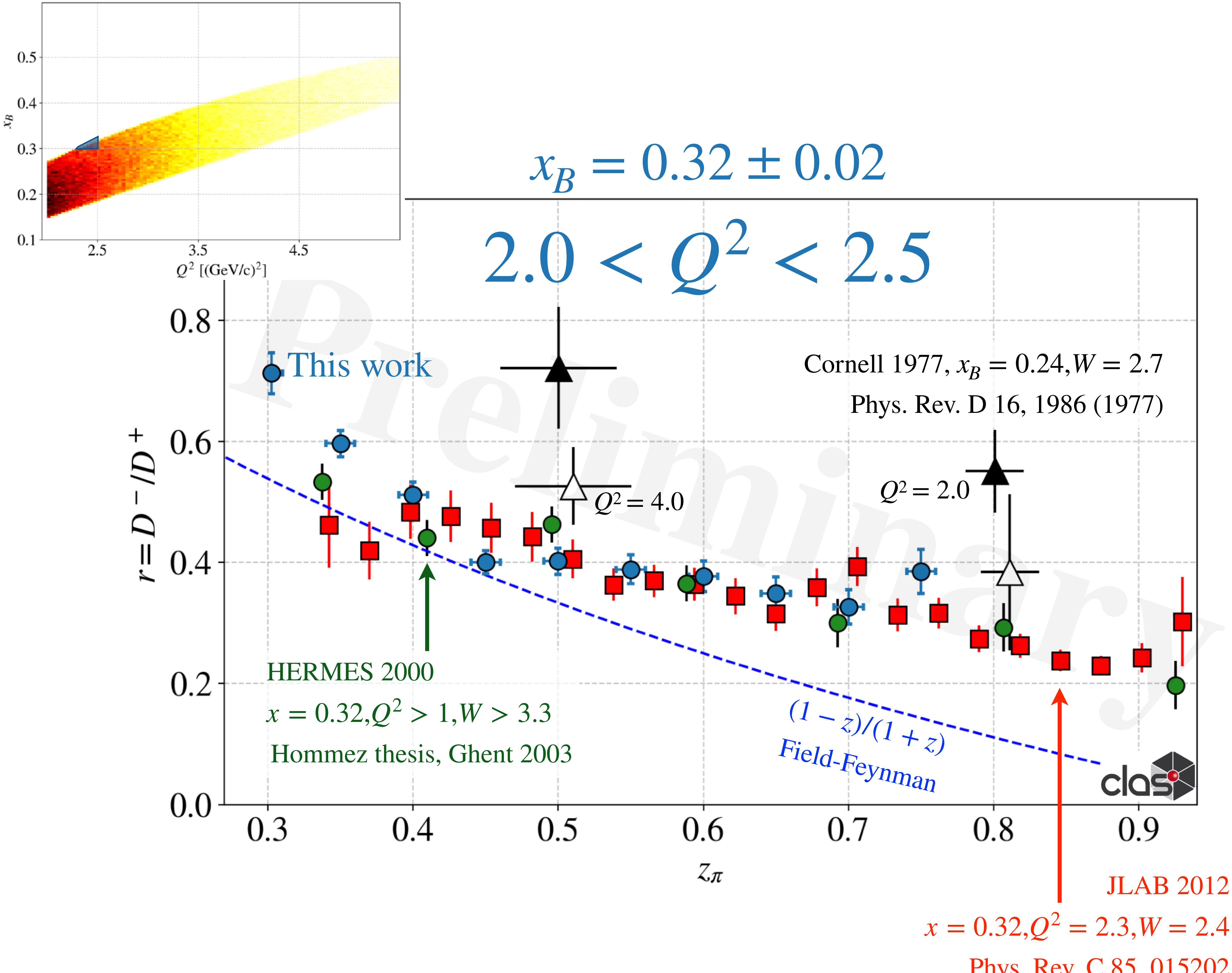
$$D_d^{\pi^+}(z)/D_u^{\pi^+}(z) = \frac{\beta_u(1/z-1)}{(1-\beta_u+\beta_u/z)}$$

[R. D. Field and R. P. Feynman, Nucl. Phys. B136, 1 (1978)]
[J. Hua and B.Q. Ma Eur.Phys.J.C30:207-212, 2003]

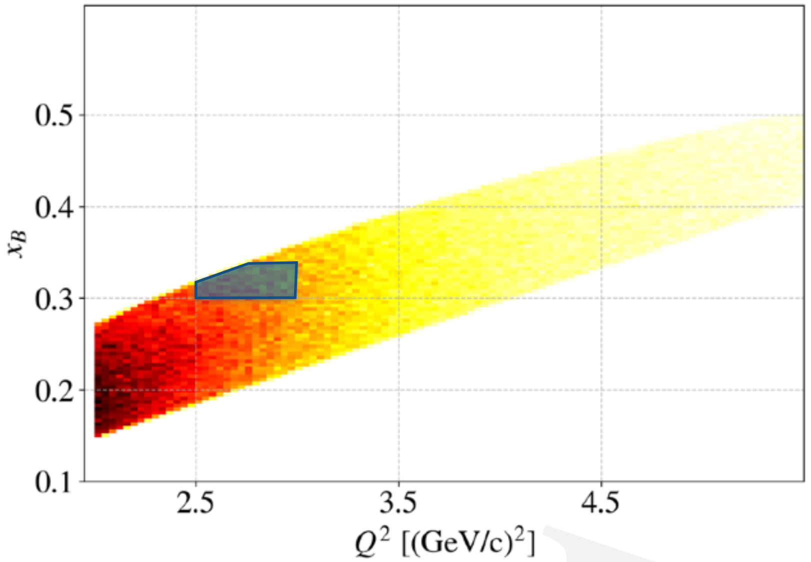
Kinematical coverage



RGB + BAND: 10.2 GeV all data

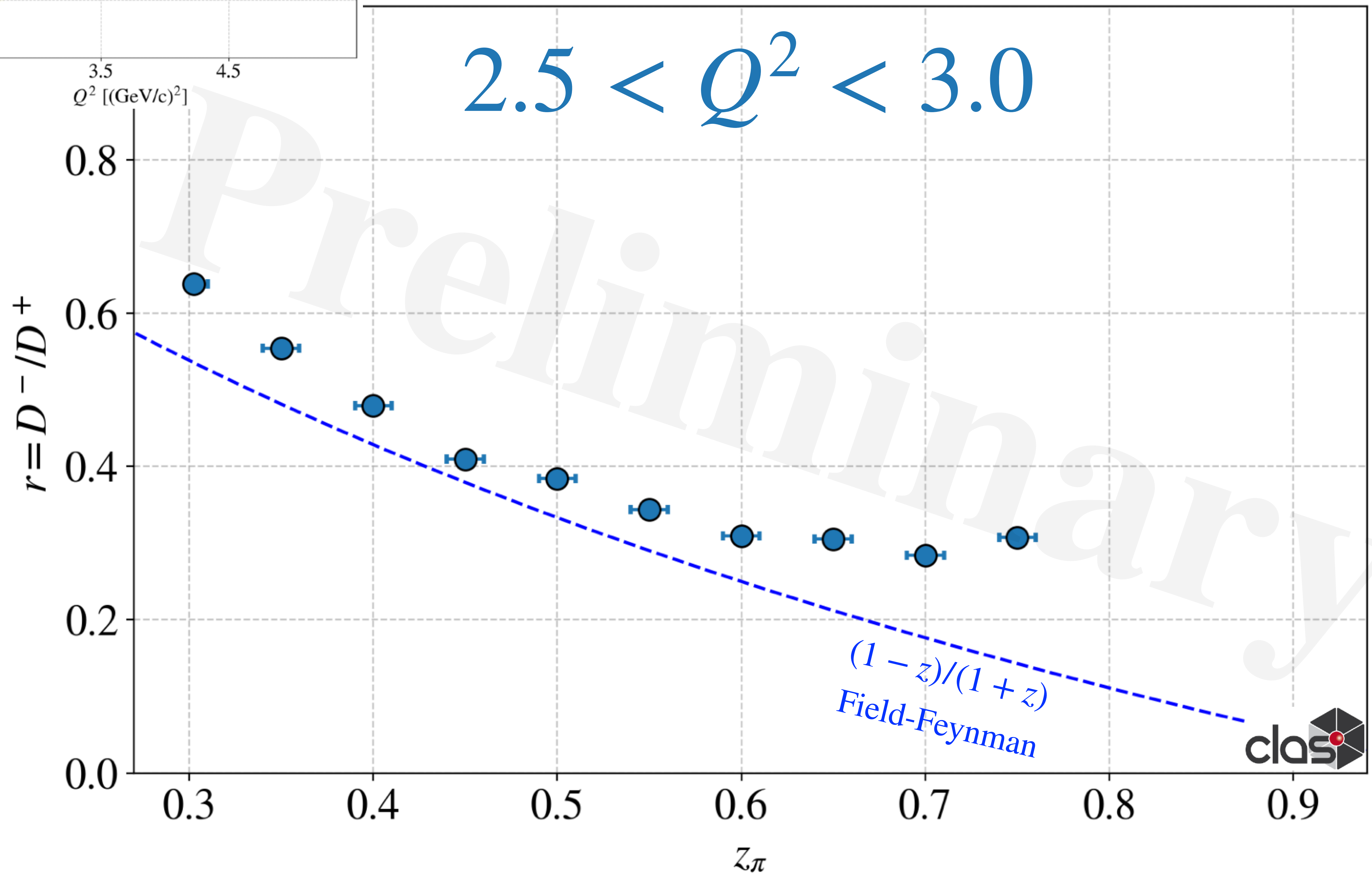


RGB + BAND: 10.2 GeV all data

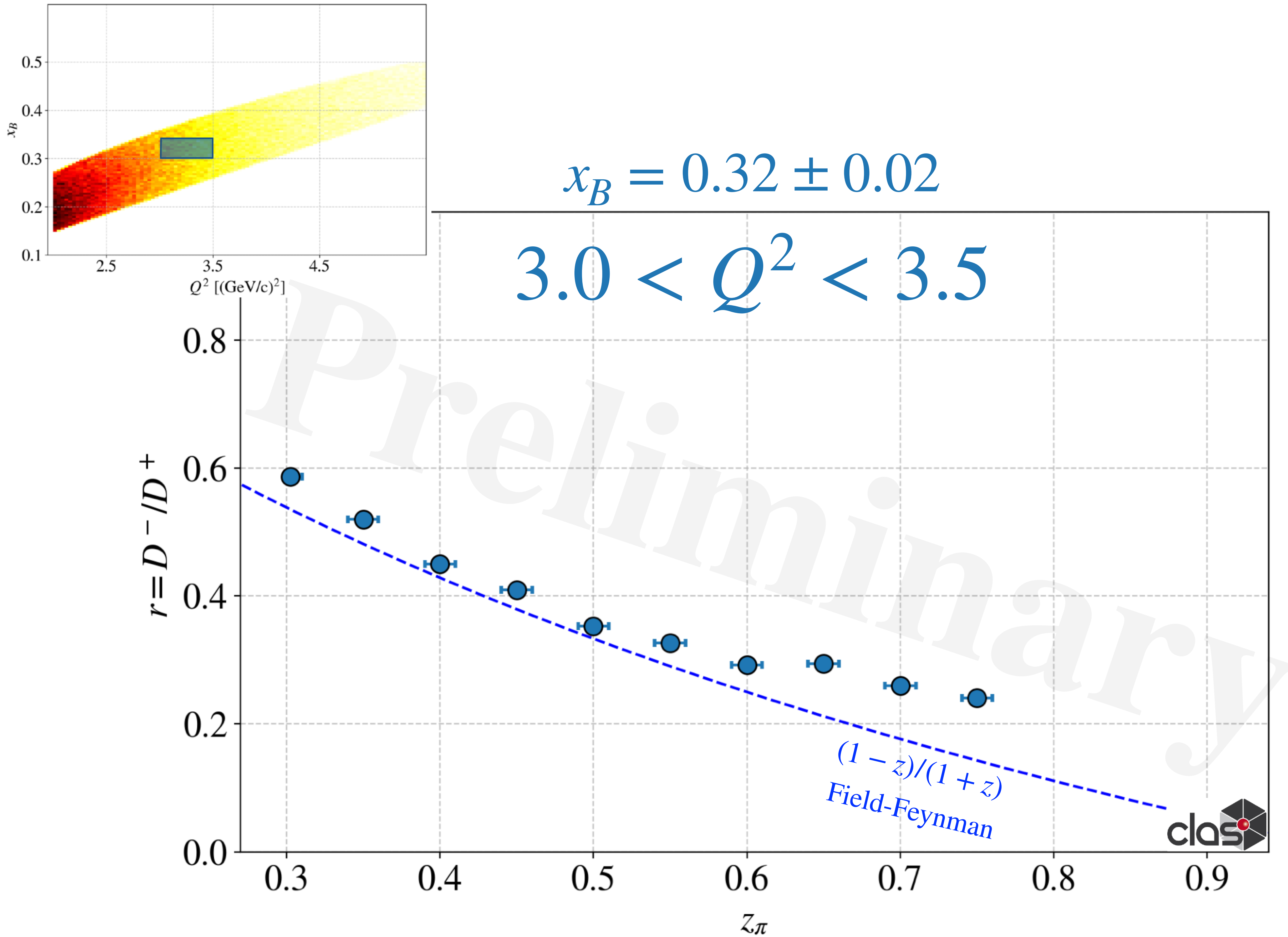


$x_B = 0.32 \pm 0.02$

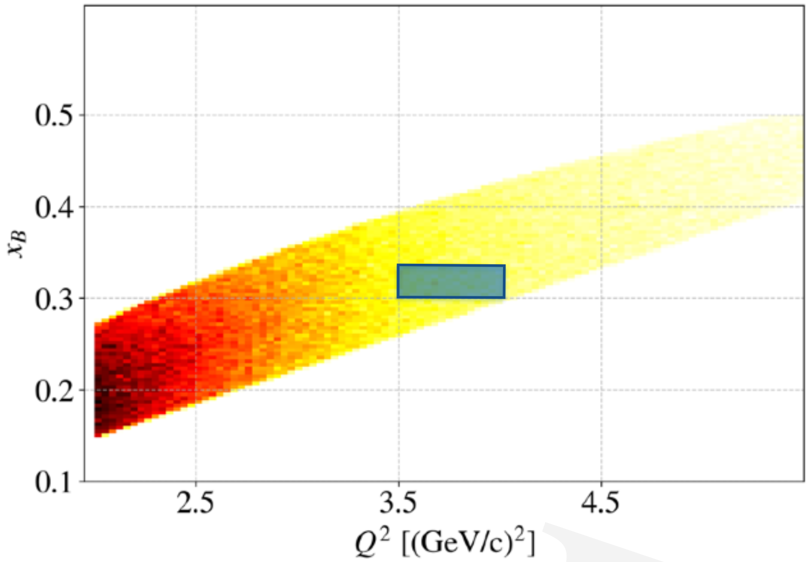
$2.5 < Q^2 < 3.0$

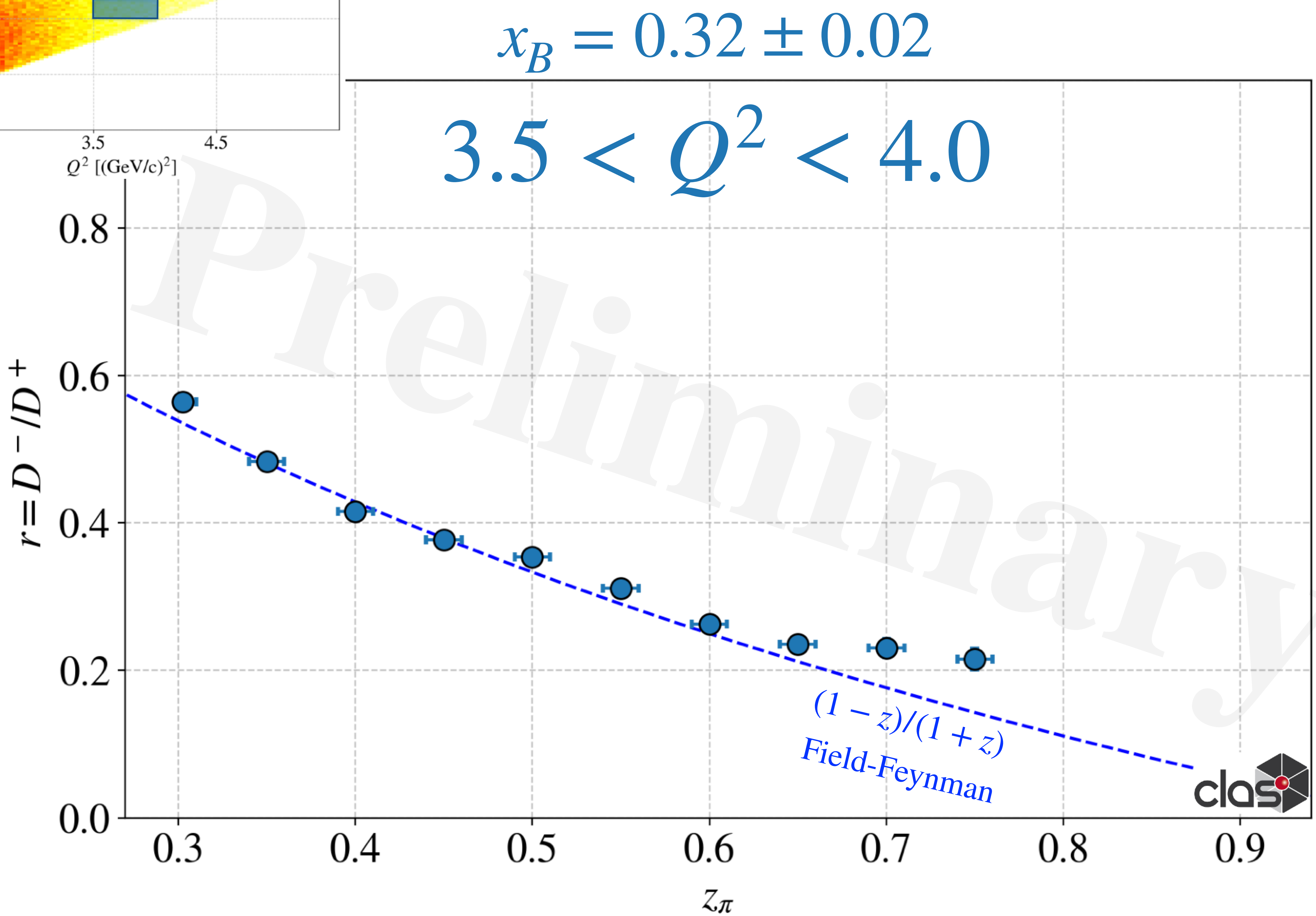


RGB + BAND: 10.2 GeV all data

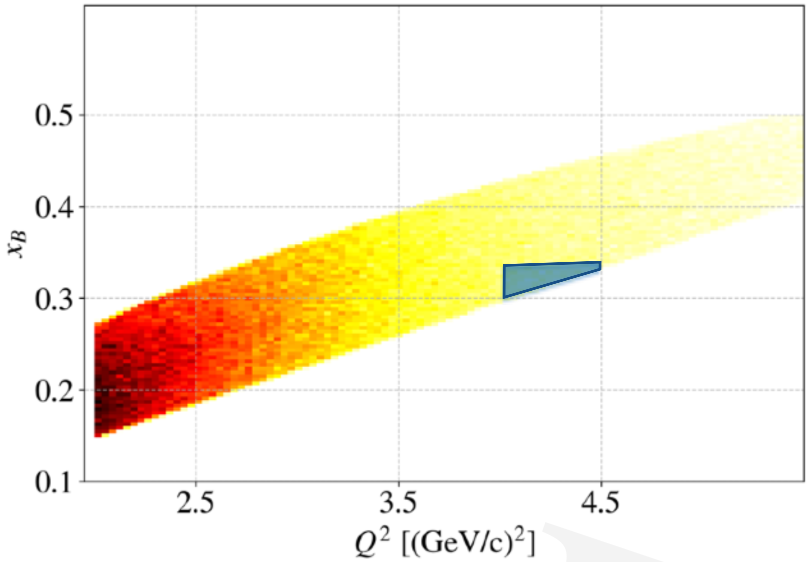


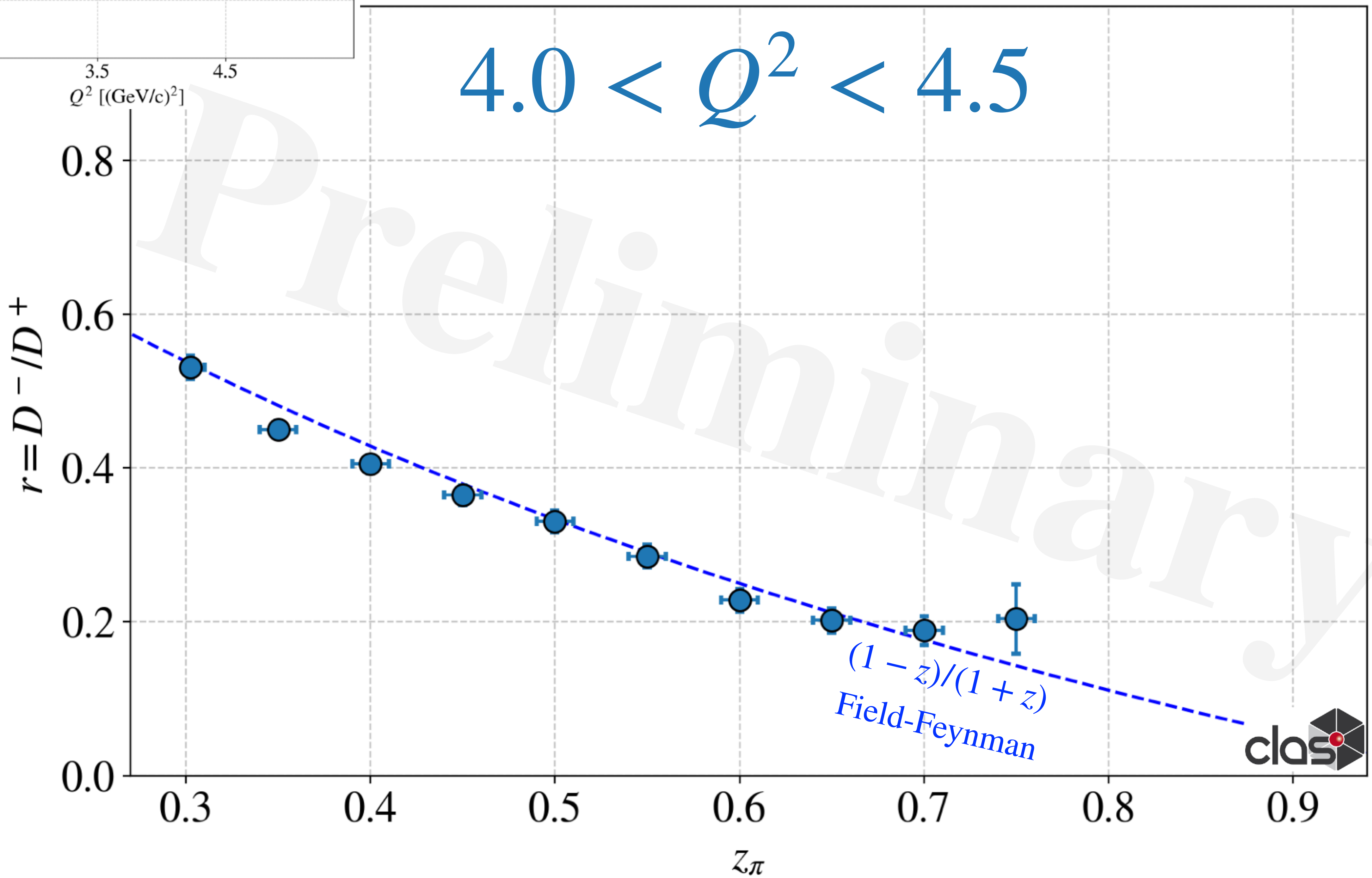
RGB + BAND: 10.2 GeV all data


0.5
0.4
0.3
0.2
0.1
x_B
2.5
3.5
4.5
Q^2 [(GeV/c)^2]


$x_B = 0.32 \pm 0.02$
$3.5 < Q^2 < 4.0$
Preliminary
$r = D^-/D^+$
0.8
0.6
0.4
0.2
0.0
0.3
0.4
0.5
0.6
0.7
0.8
0.9
z_π
$(1-z)/(1+z)$
Field-Feynman
clas

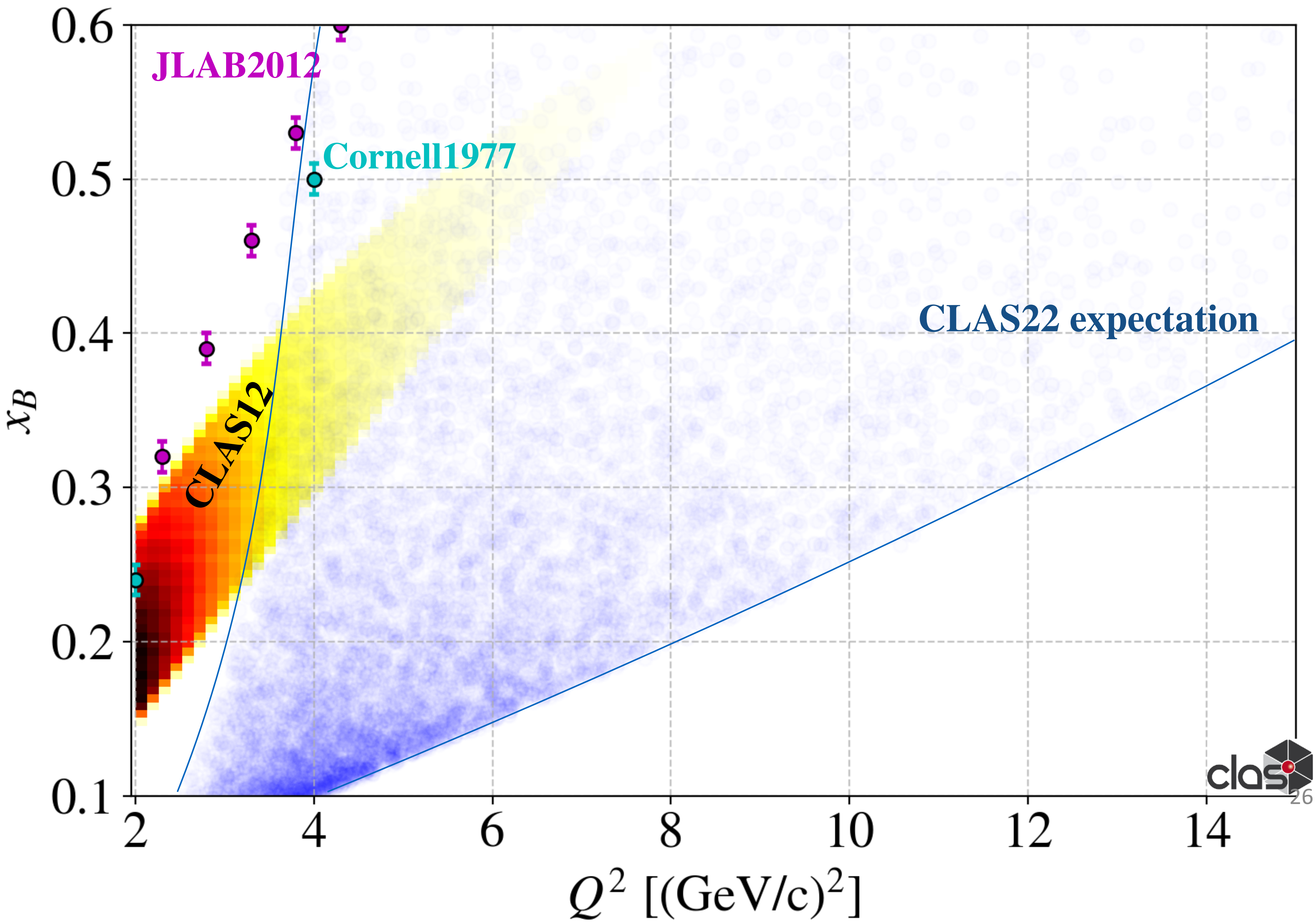
$x_B = 0.32 \pm 0.02$





RGB + BAND: 10.2 GeV all data

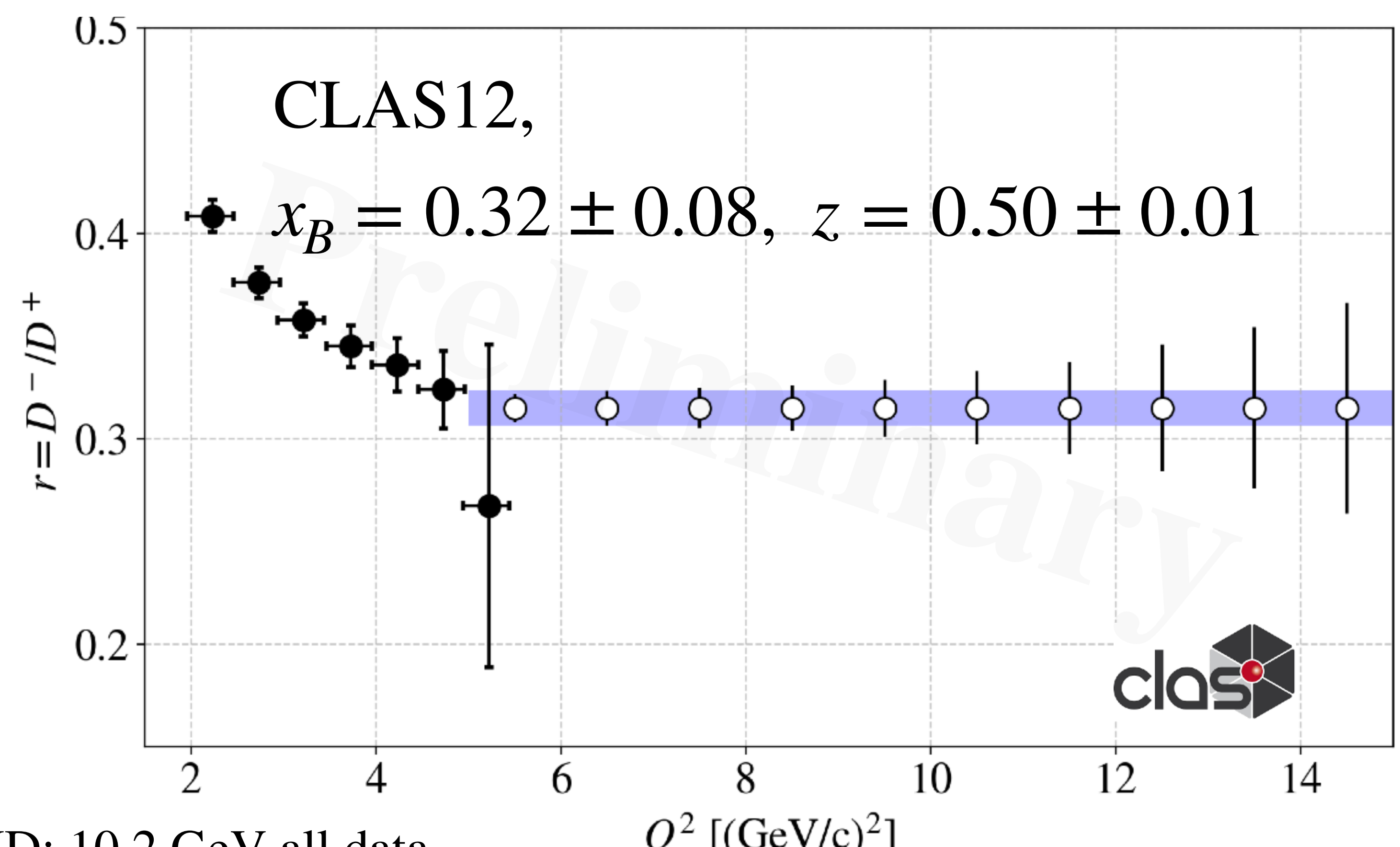
Prospects @ CLAS22



RGB + BAND: 10.2 GeV all data

Prospects at JLAB 22 GeV

- @12 GeV we observe an approach to the Parton Field-Feynman limit
- @22 GeV this can be verified

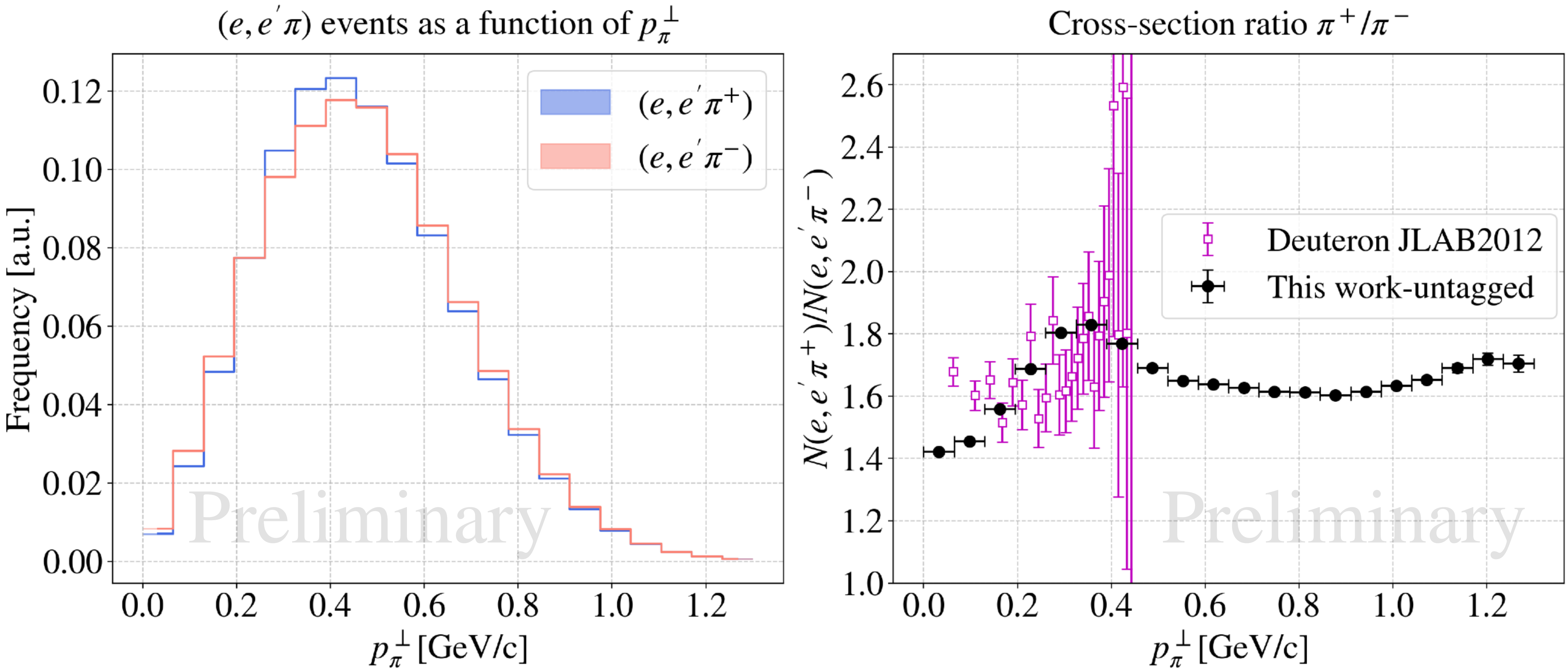


$(1-z)/(1+z)$
FF prediction / CLAS22
Estimated uncertainties for ~ 15 PAC days

RGB + BAND: 10.2 GeV all data

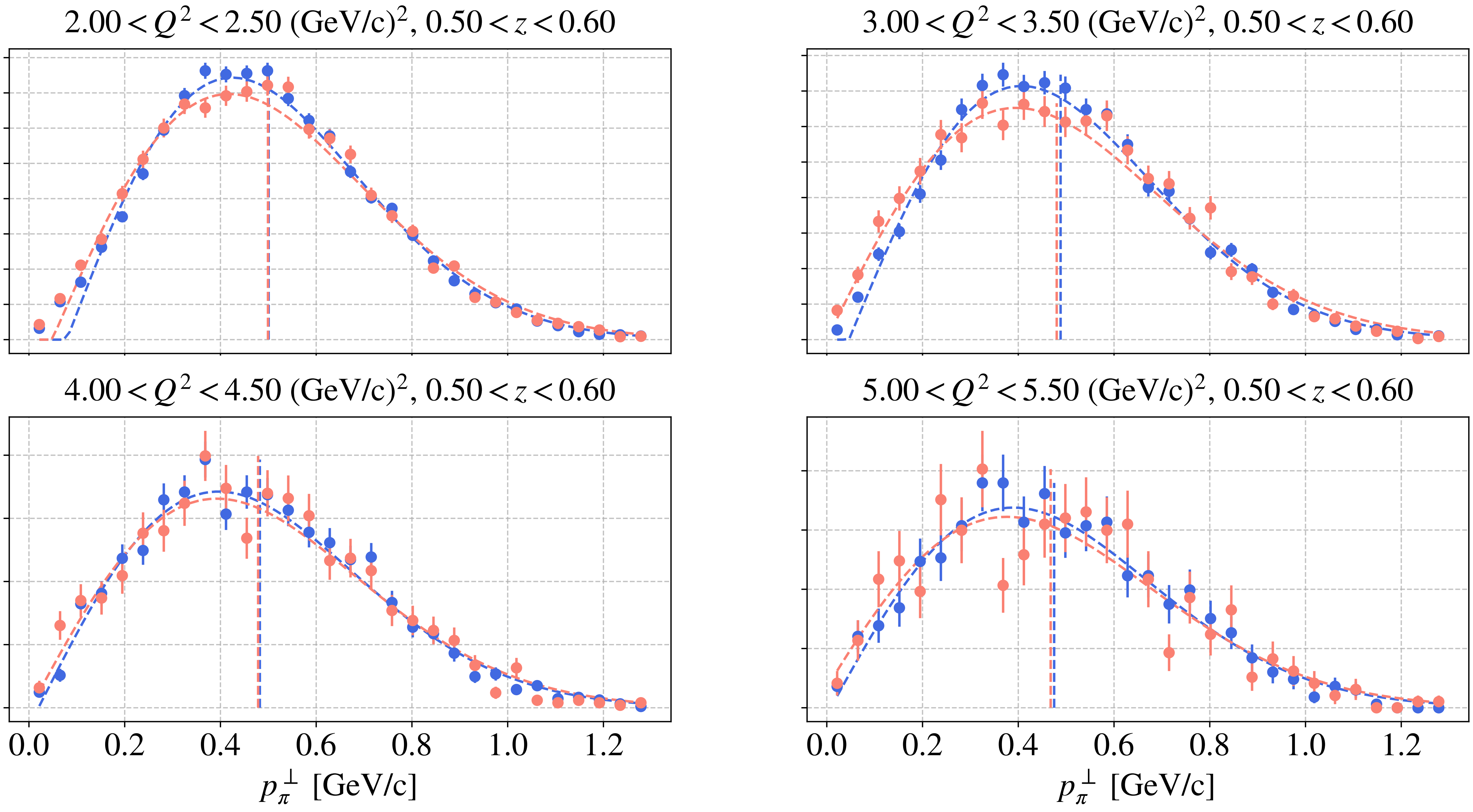
$$p_T$$

Pion transverse momentum

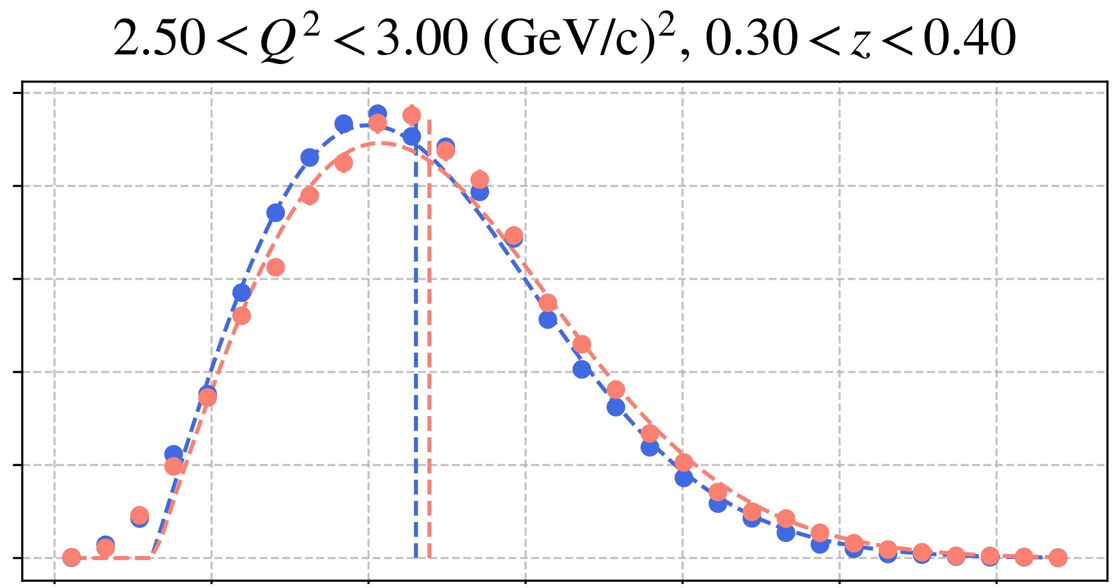


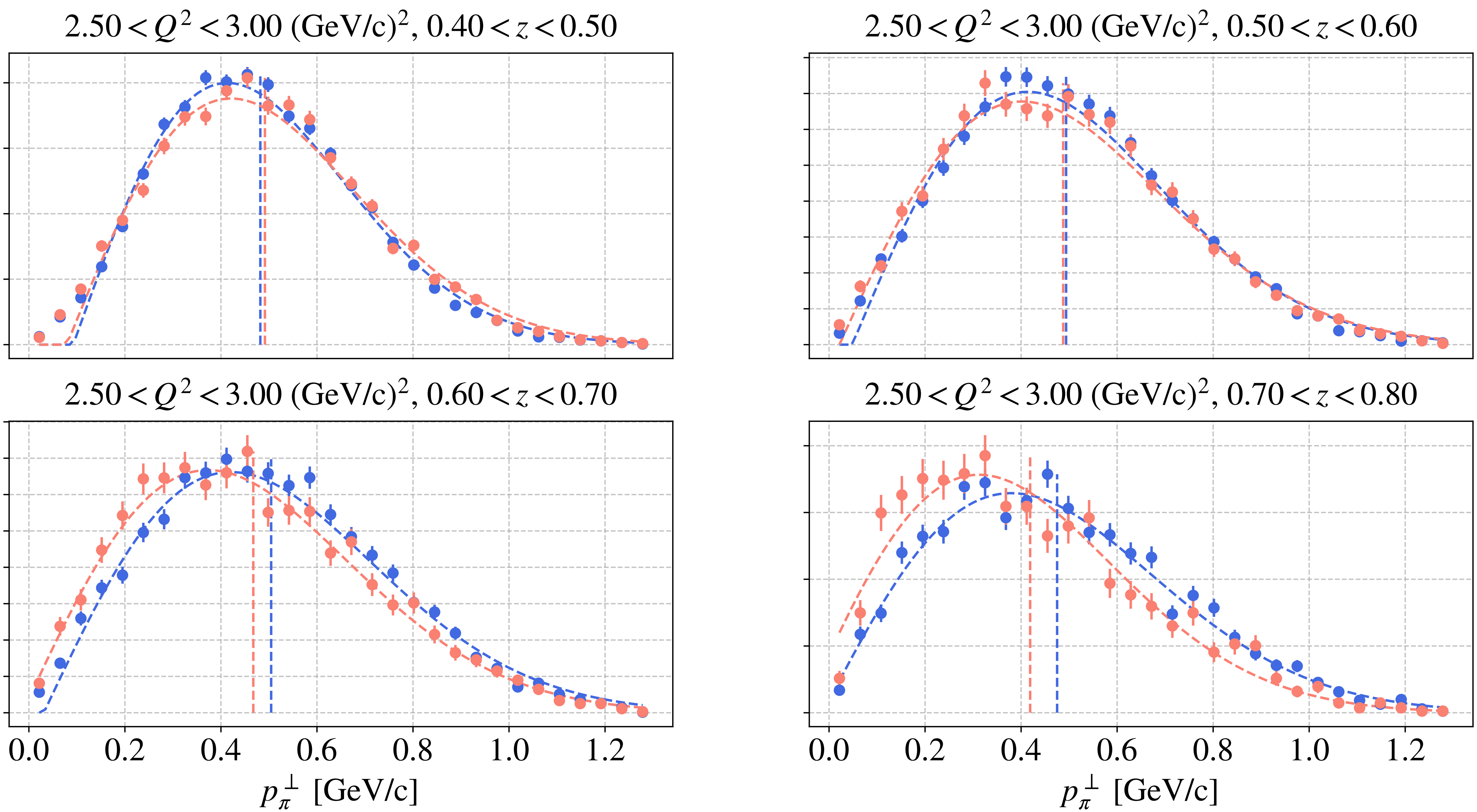
Broad p_T range

Q^2 evolution of p_T

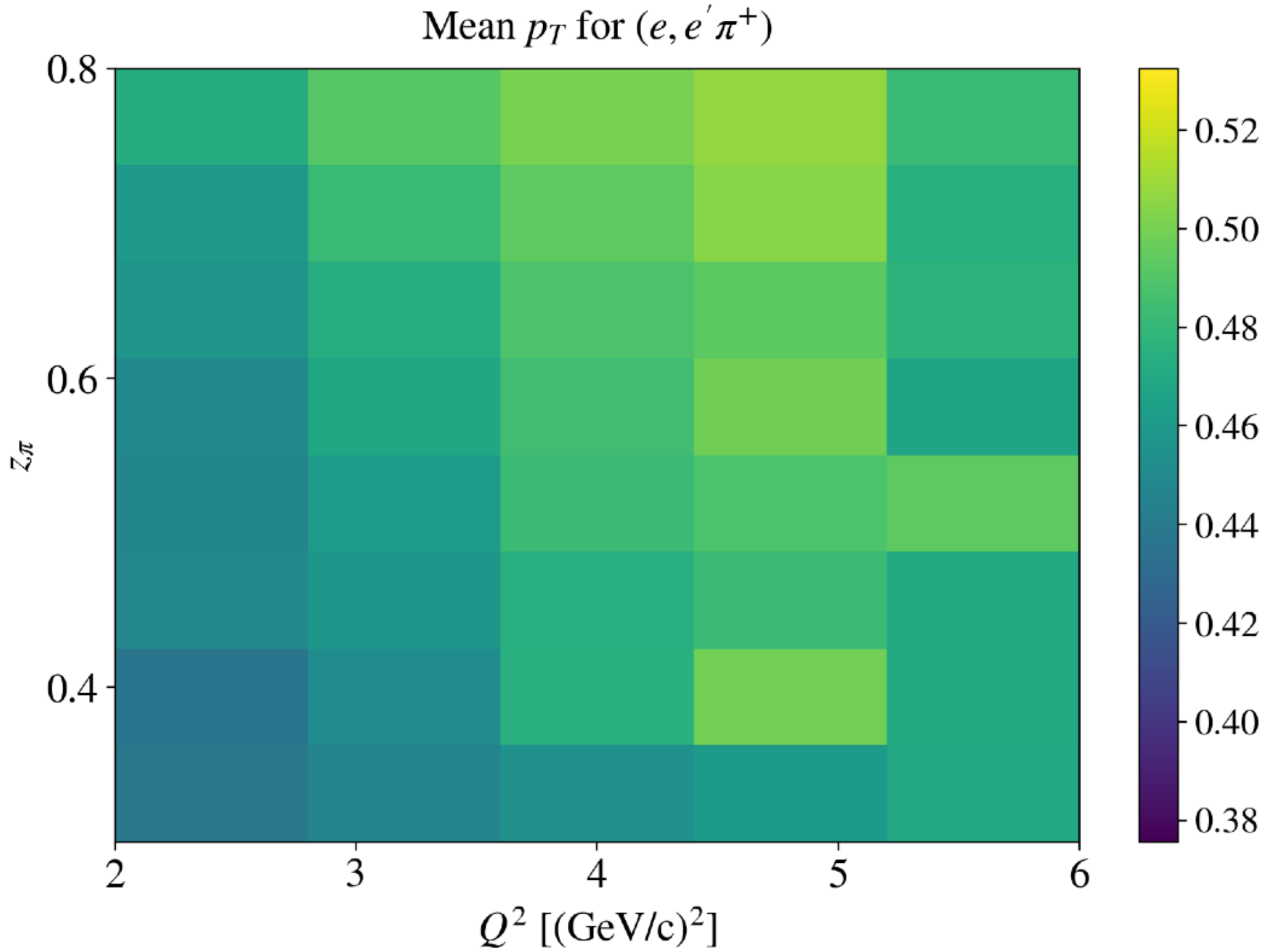


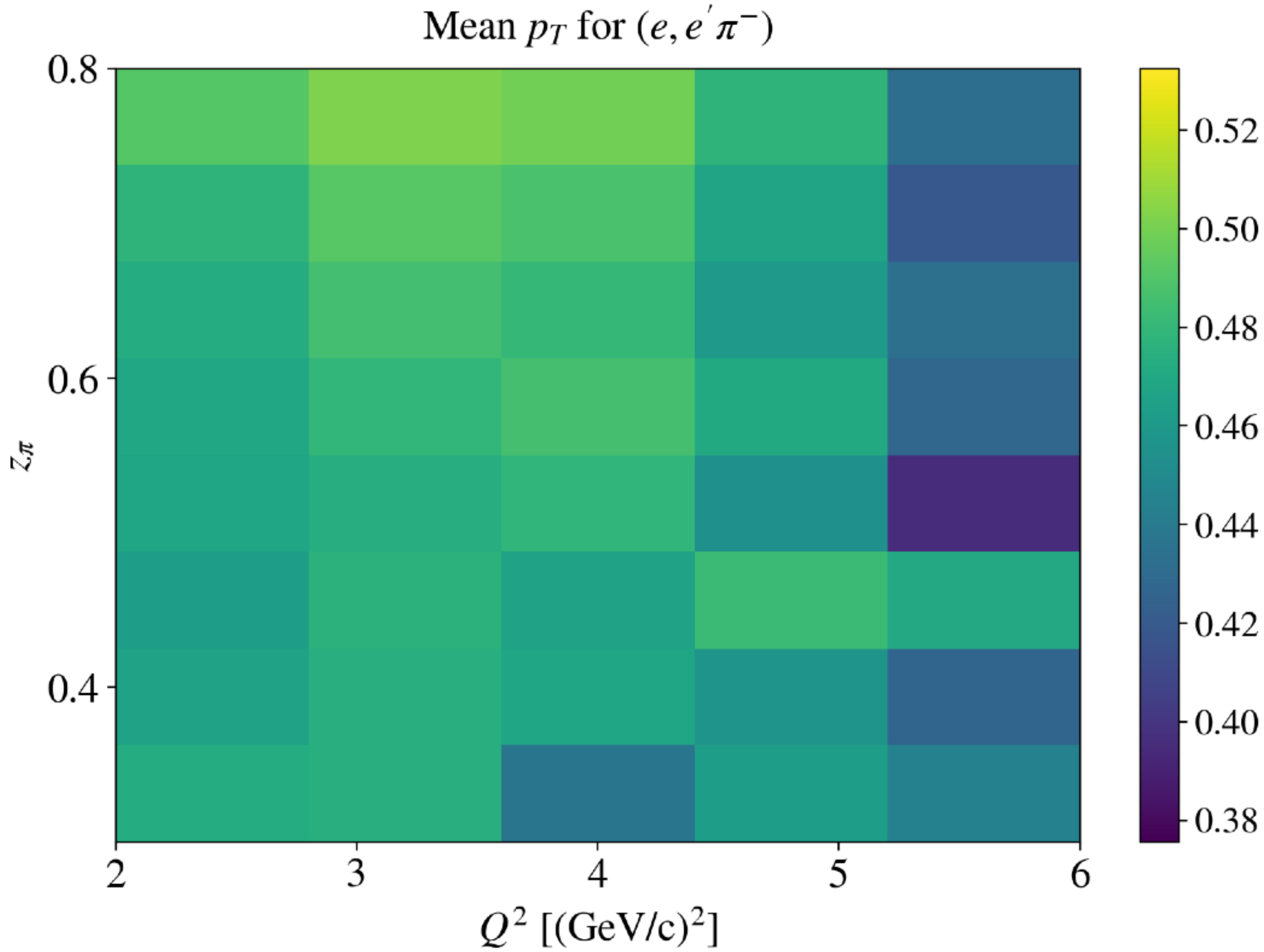
z evolution of p_T



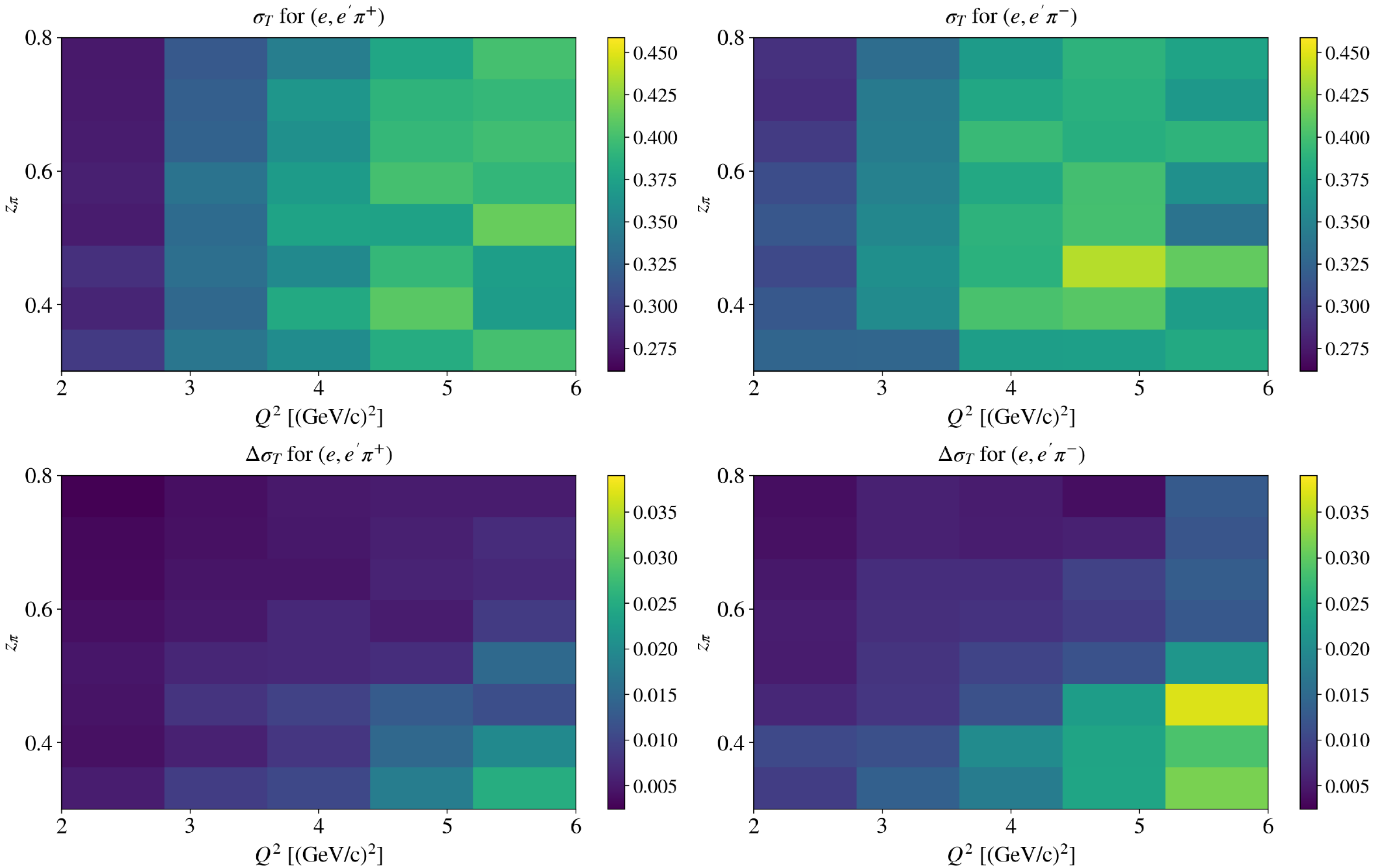


Mean p_T in bins of z and Q^2





p_T fit results $\sigma_x = \sigma_y \equiv \sigma_T$



p_T fit results $\sigma_x = \sigma_y \equiv \sigma_T$

To be done: Acceptance corrections to p_T and more

Extract d_v/u_v from free-p data

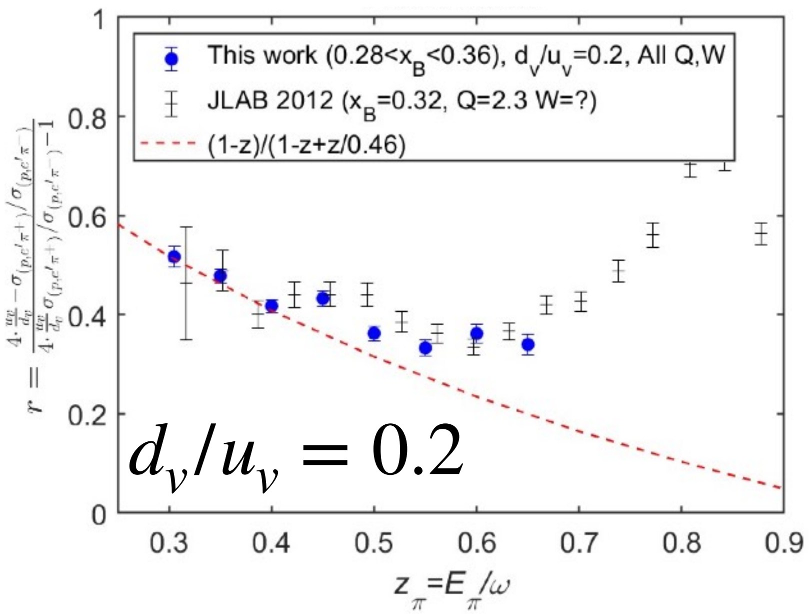
S_{RC}^{IDIS}@BAND | Parton model expectation

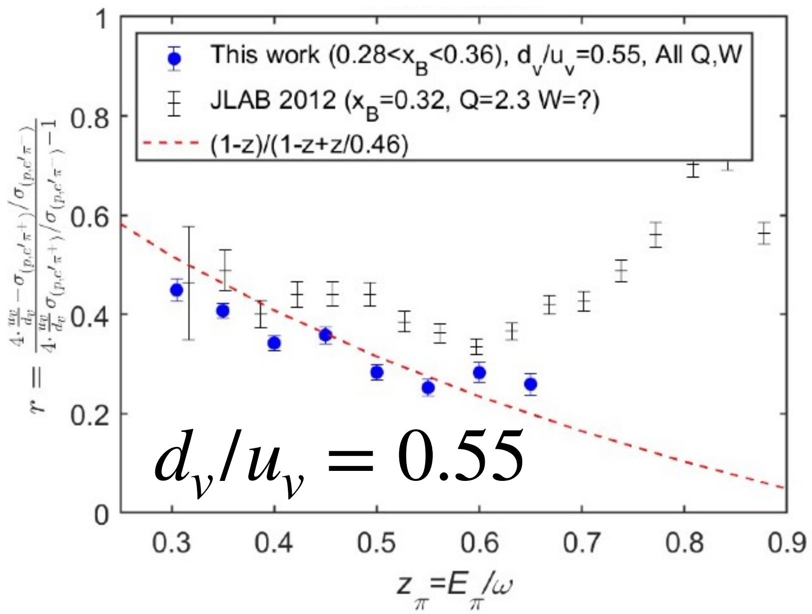
- For SIDIS off a free proton

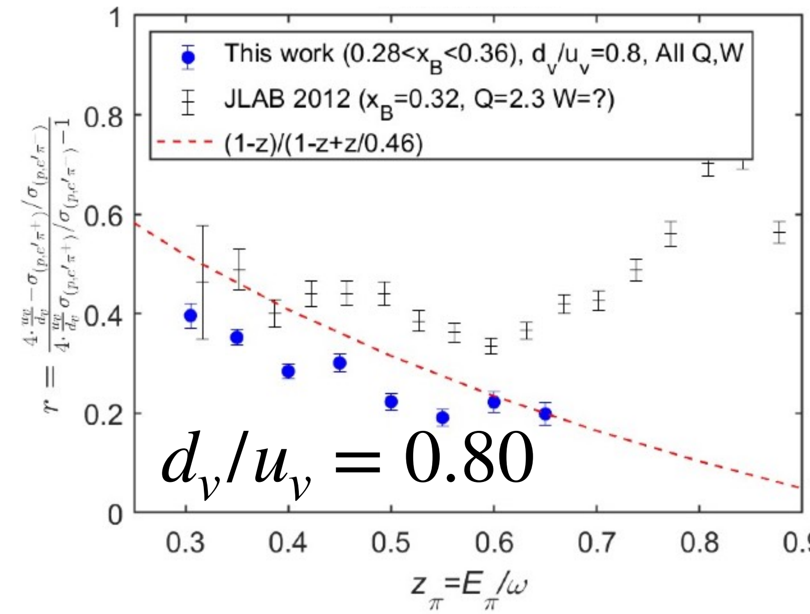
$$r = \frac{4\frac{u_v}{d_v} - \left(\sigma_p^{\pi^+}/\sigma_p^{\pi^-}\right)}{4\frac{u_v}{d_v}\left(\sigma_p^{\pi^+}/\sigma_p^{\pi^-}\right) - 1}$$

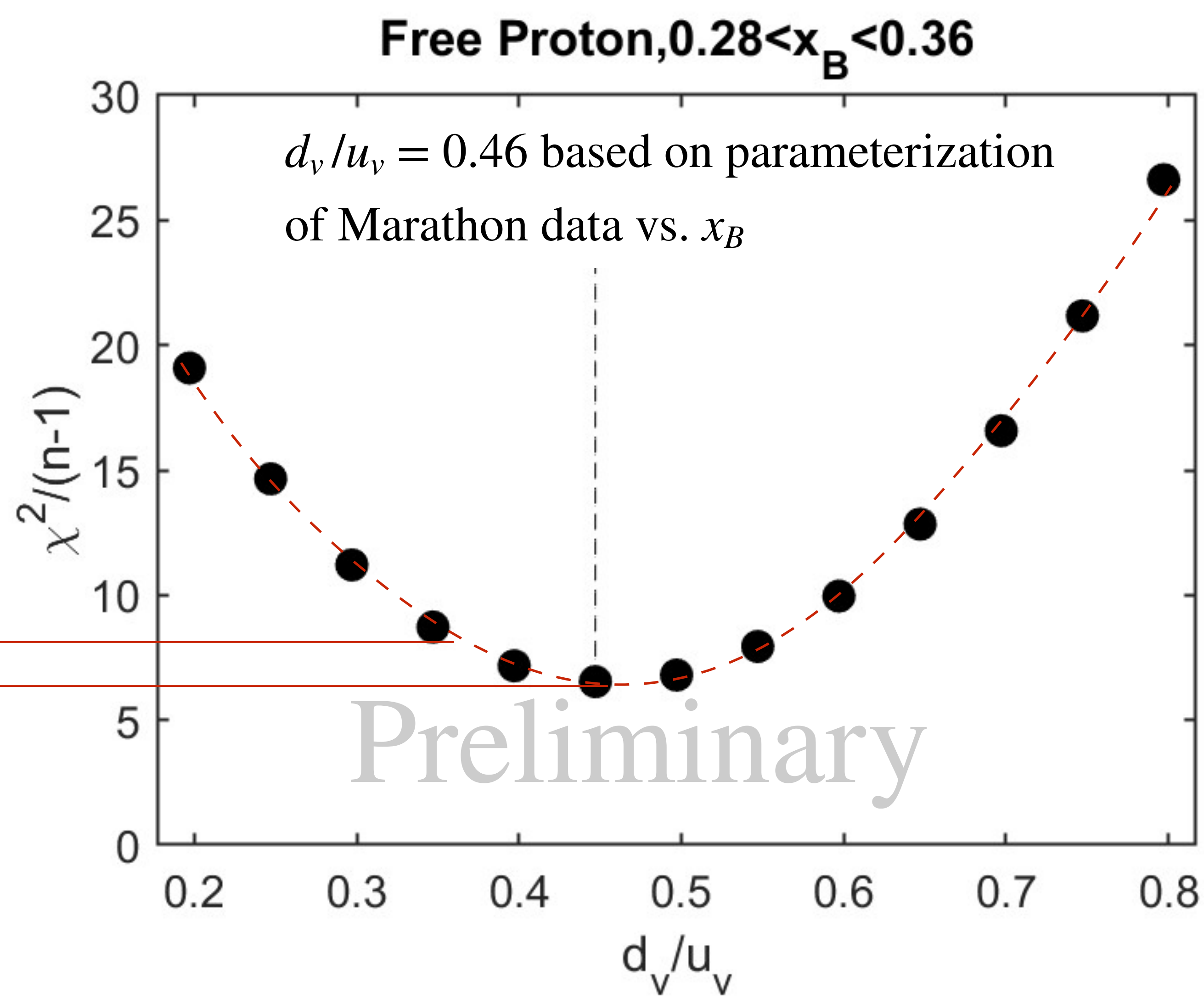
- We extract $\sigma_p^{\pi^+}/\sigma_p^{\pi^-}$ from RGA data
- By comparing to FF model we extract u_v/d_v from the proton data only

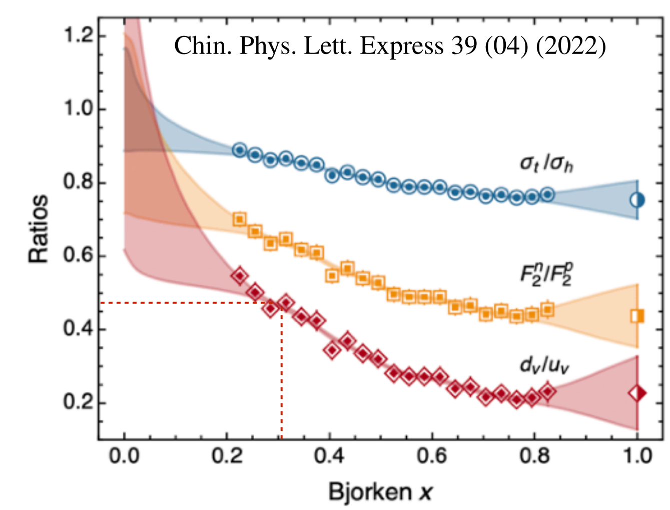
SIDIS@RGB | Extraction of d_v/u_v from free-p data







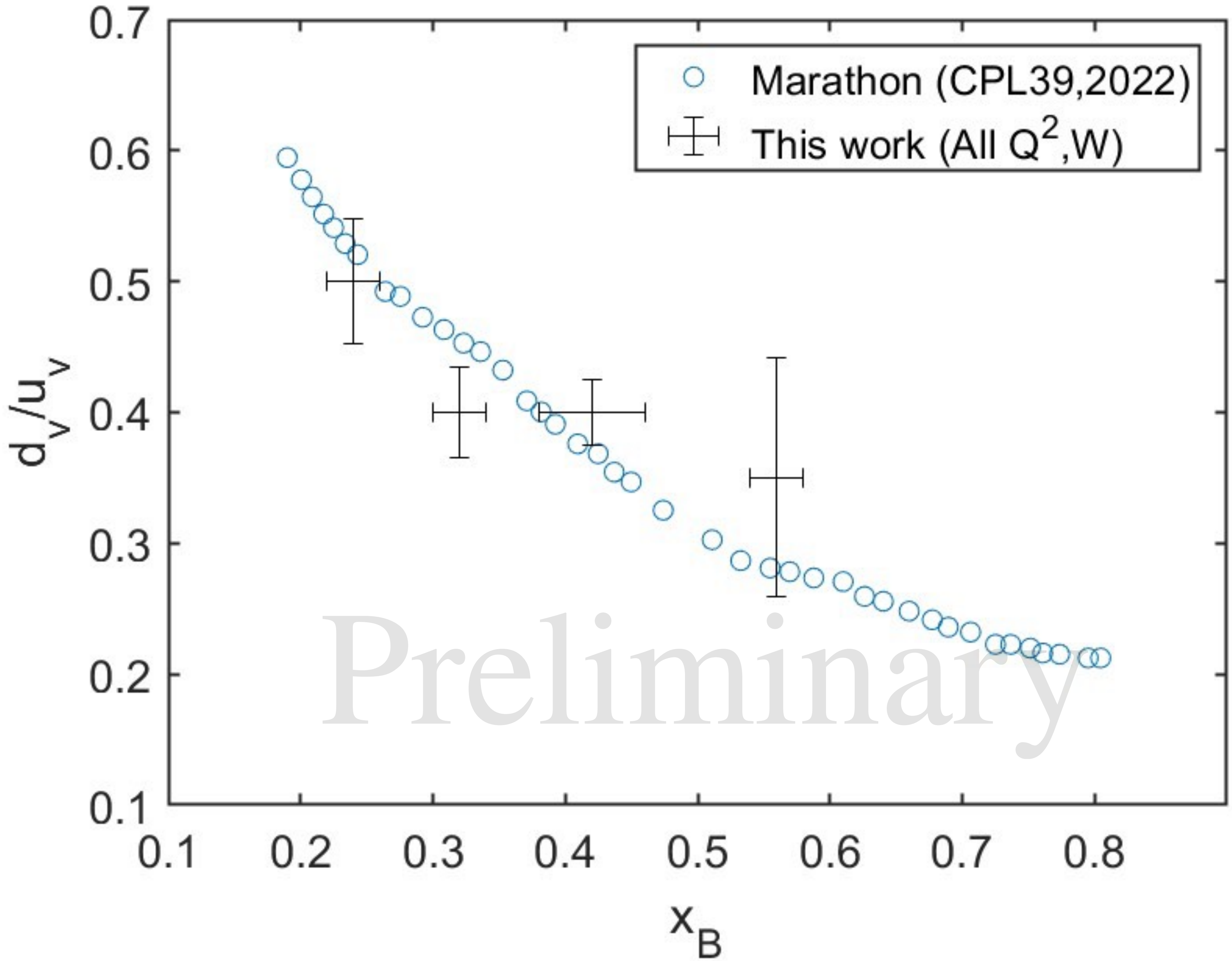


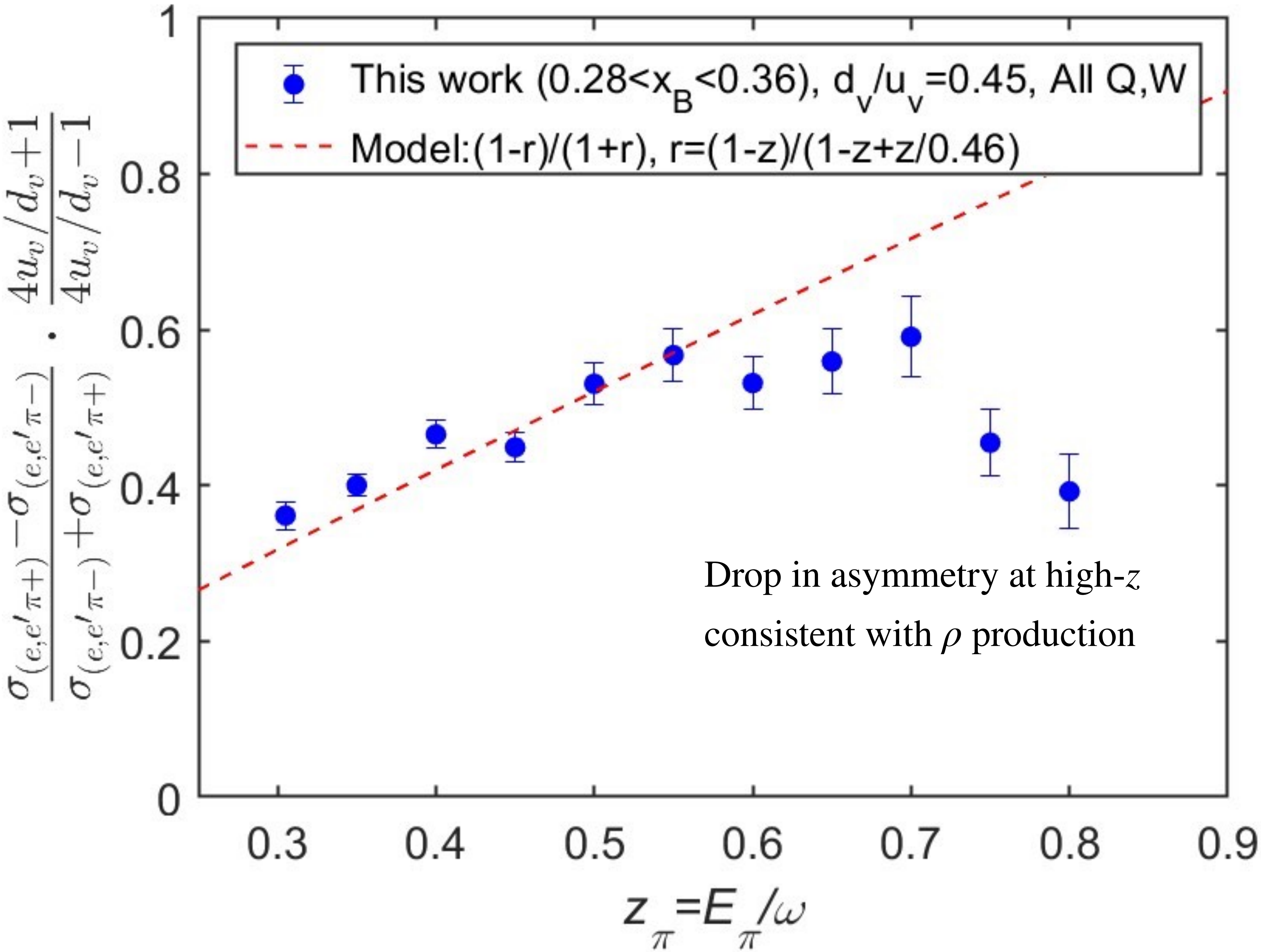


Our results:

$d_v/u_v = 0.45 \pm 0.1$

SIDIS@RGB | Extraction of d_v/u_v from free-*p* data





Drop in asymmetry at high-z consistent with ρ production

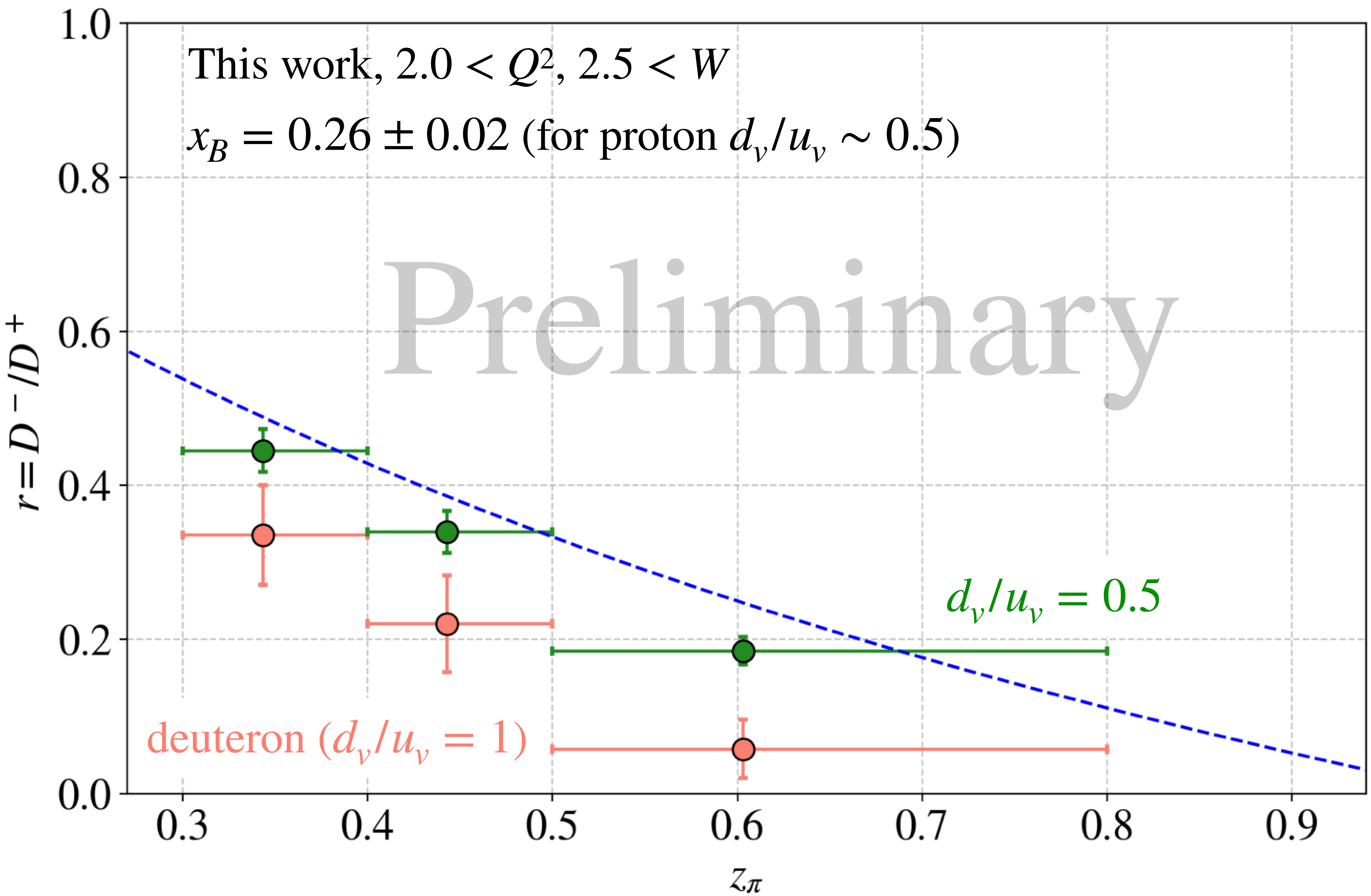
SRC-tagged data

- For SIDIS off the proton in the deuteron

$$r = \frac{4\frac{u_v}{d_v} - \left(\sigma_d^{\pi^+}/\sigma_d^{\pi^-}\right)}{4\frac{u_v}{d_v}\left(\sigma_d^{\pi^+}/\sigma_d^{\pi^-}\right) - 1}$$

- $u_v/d_v = 1$ for inclusive scattering off a deuteron

Our tagged data show clearly a scattering of a p, but not enough to tell the difference between free/bound



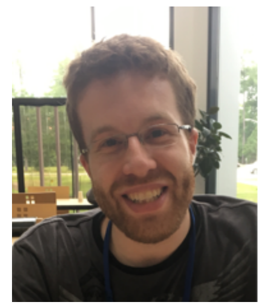
S^{IDIS}_{RC}@BAND | Summary

- We study $(e,e'\pi^{\pm})$ ratio untagged / tagged (with recoil n)

  CLAS12 + BAND

- 1st step: Untagged π^{+}/π^{-} ratio
  - Consistent with published data at low Q^2
  - Approach Parton model at high Q^2
  - Extract u_v/d_v for free-p based on Parton model
  - Fragmentation at large p_T
- Next: SRC-tagged data, looking for difference between bound and free p

Thank you for your time



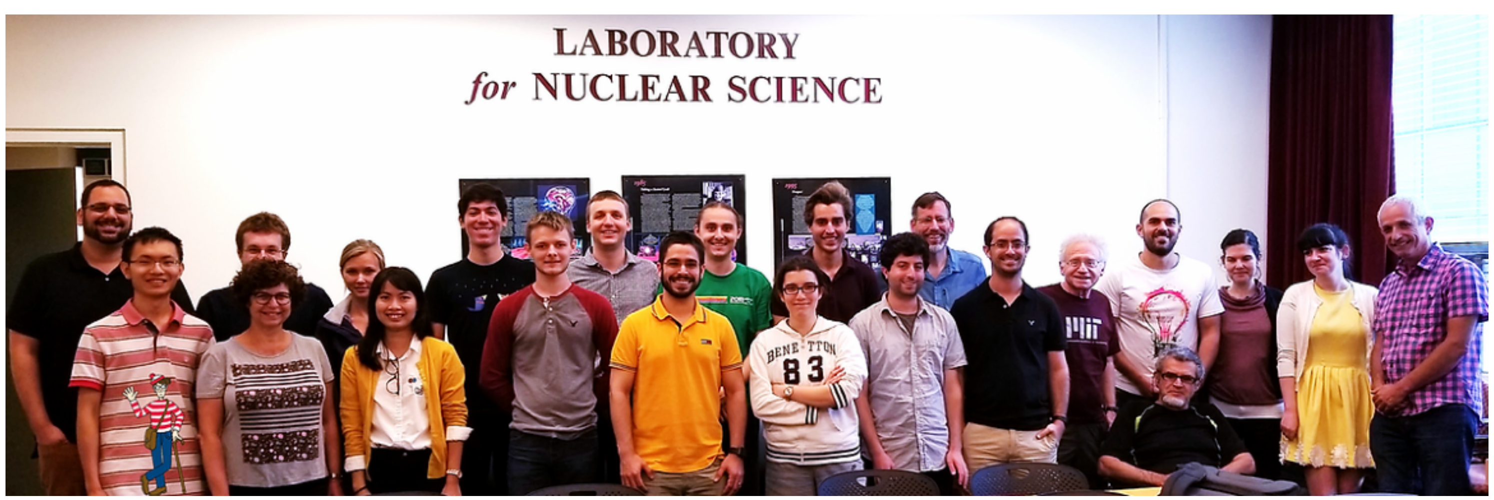


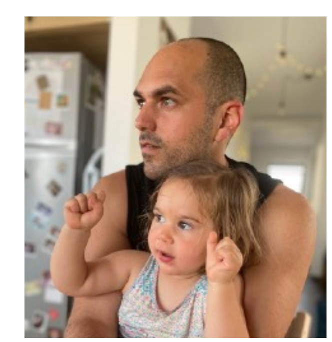






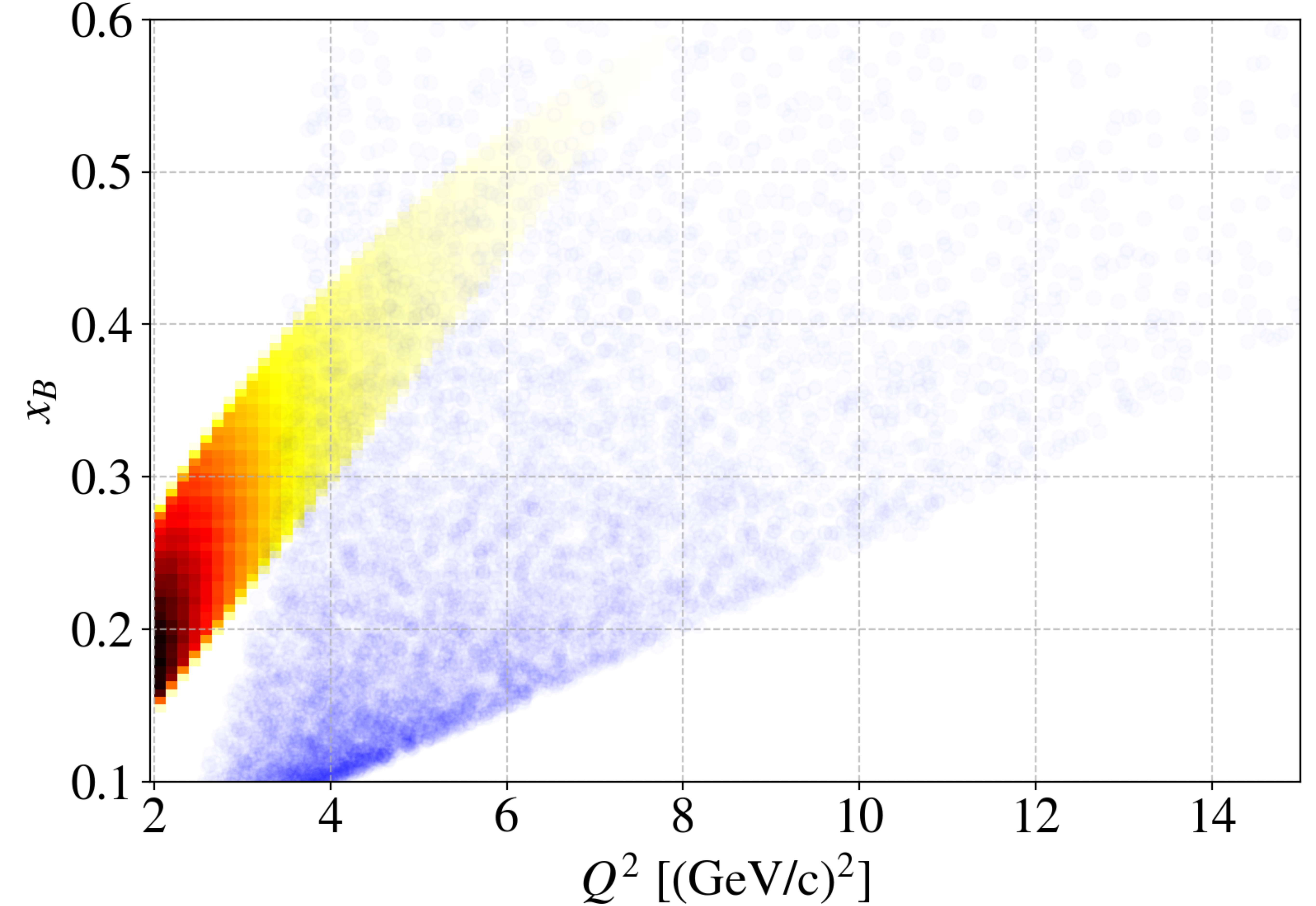




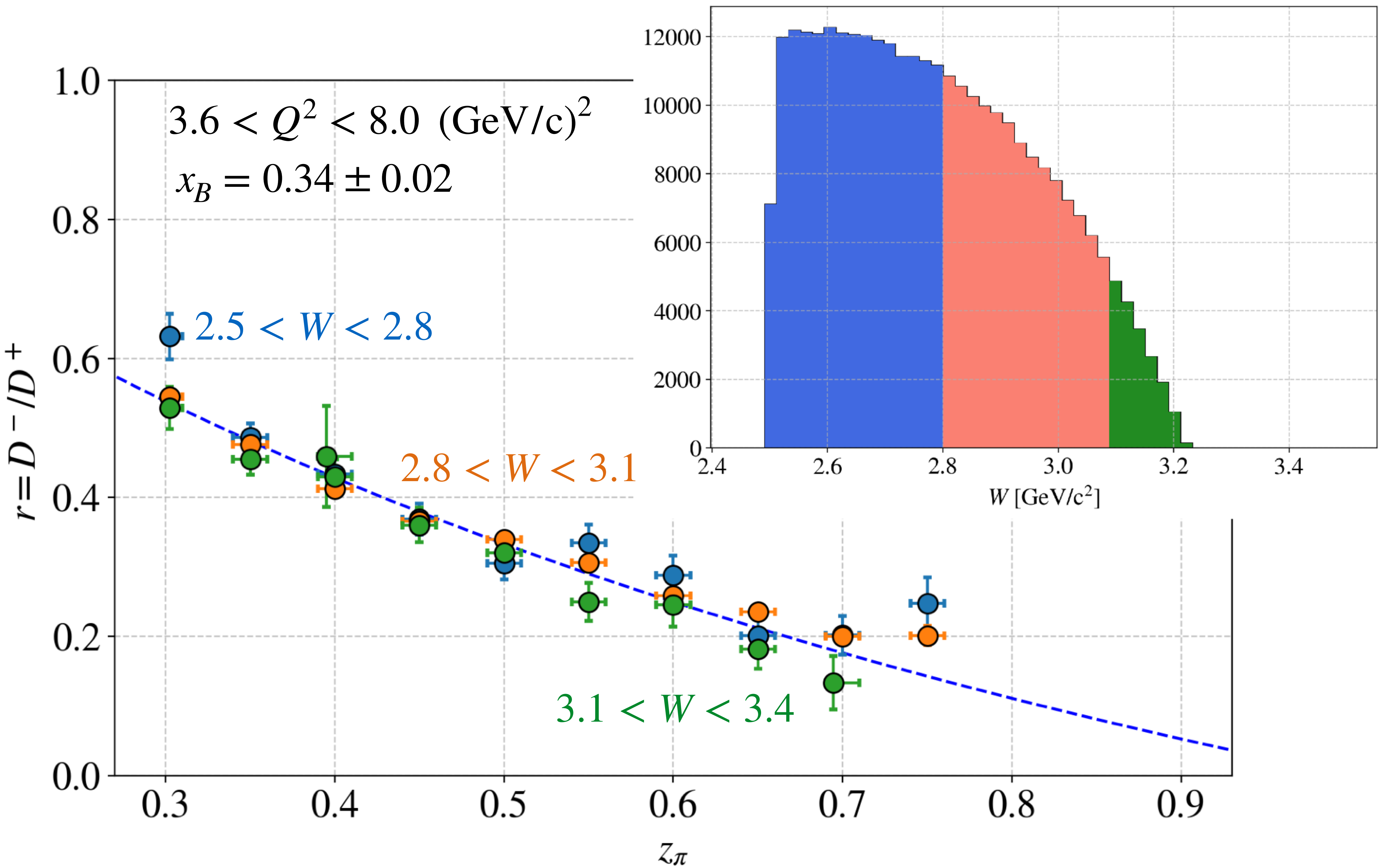
cohen.erez7@gmail.com

Backups

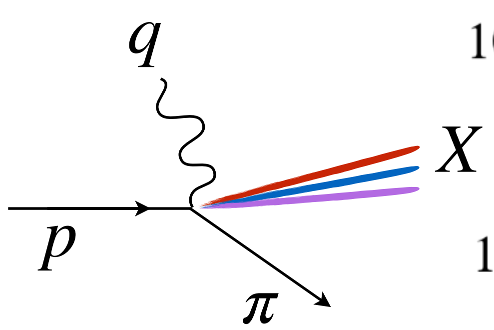


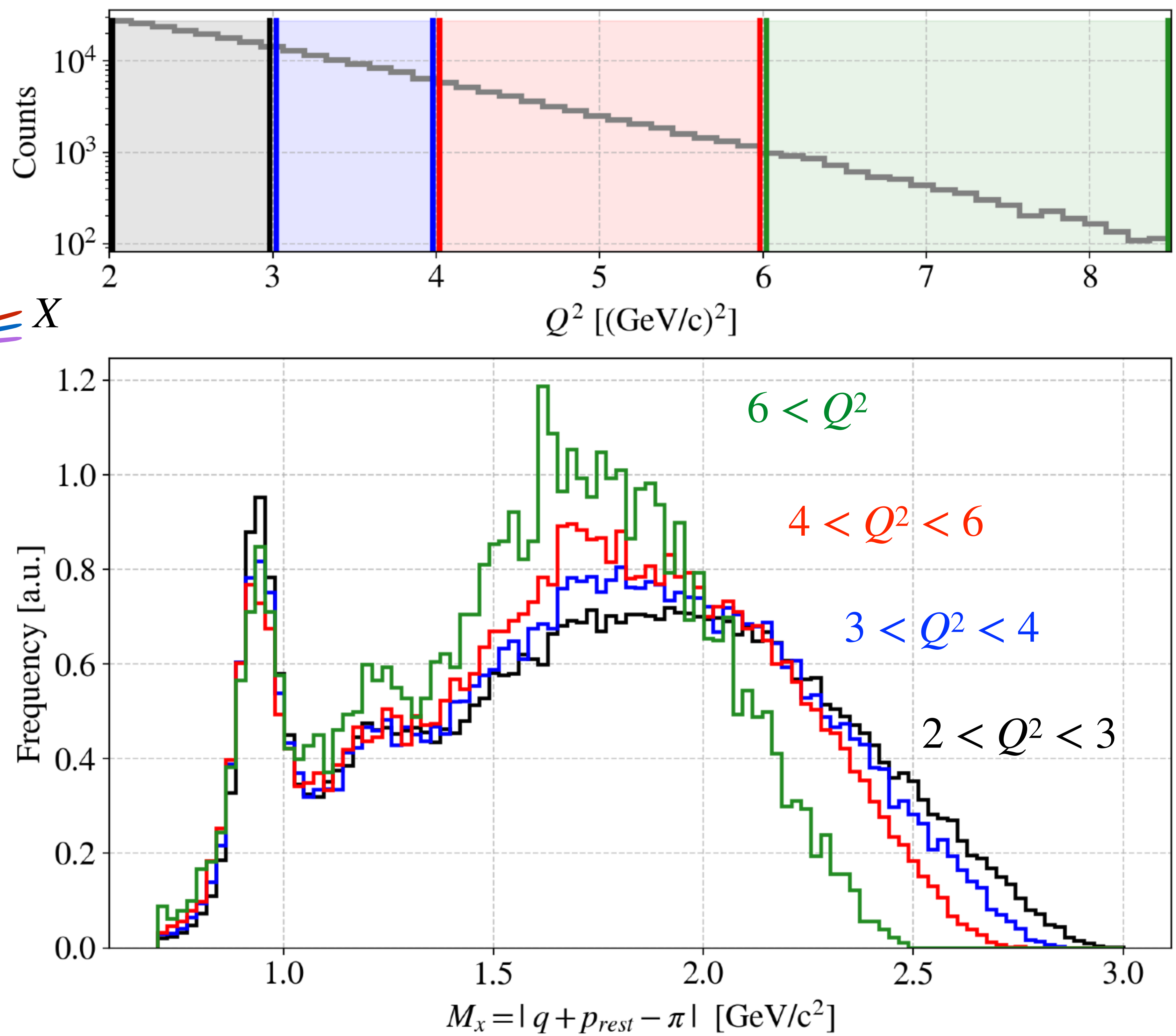
0.6
0.5
0.4
0.3
0.2
0.1
x_B
2
4
6
8
10
12
14
Q^2 [(GeV/c)^2]

SIDIS@RGB | Weak dependence on W (high Q^2)

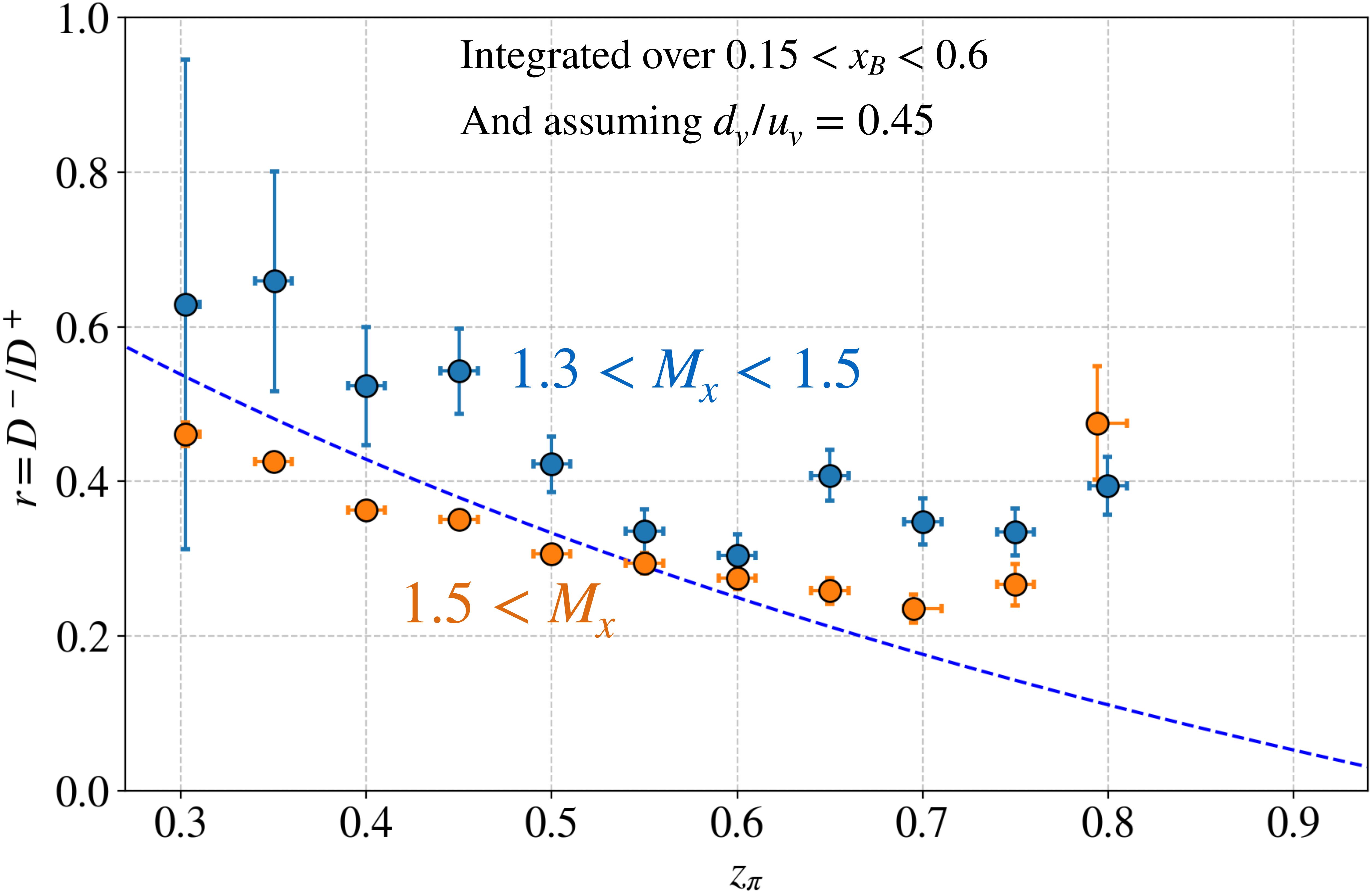


SIDIS@RGB | M_x vs. Q^2 - for free proton





SIDIS@RGB | Free-proton dependence on M_x



RGB + BAND: 10.2 GeV all data