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NEUTRAL PION MULTIPLICITY STUDIES WITH CLAS12: RADIATIVE CORRECTIONS

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MOTIVATION

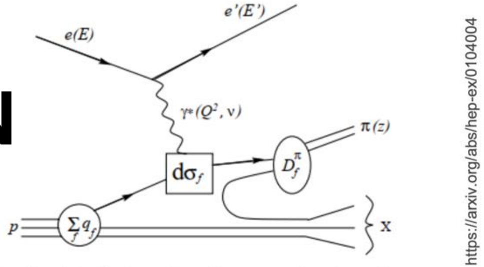


Fig. 1. Semi-inclusive pion electroproduction diagram

SIDIS XSEC:

$$\frac{d' \sigma}{dx dQ^2 dz d\phi_h d\mathbf{P}_{hT}^2} = \frac{2\pi\alpha^2}{xQ^4} \frac{y^2}{(1-\varepsilon)} [F_{UU,T} + \varepsilon F_{UU,L} + \lambda \sqrt{2\varepsilon(1-\varepsilon)}\, sin\phi_h\, F_{LU}^{\sin\phi_h} + \varepsilon\, cos(2\phi_h)\, F_{UU}^{\cos 2\phi_h} + \sqrt{2\varepsilon(1+\varepsilon)}\, cos(\phi_h)\, F_{UU}^{cos\phi_h}].$$

- Neutral pion multiplicities, the ratio of the π^0 production to the DIS production as a function of a kinematic variable, deals with the fundamental nature of QCD and hadron generation
- It allows for the exploration of the 3D structure of the proton and the fragmentation process in unpolarized ep scattering
- Hadronization is fundamentally non-perturbative and must be studied experimentally with the combination of perturbative hard scattering cross section and non-perturbative parton distribution and fragmentation functions
- Neutral pion multiplicities allows to probe the unpolarized TMD Parton Distribution Function f1 and help study isospin invariance as the neutral pion fragmentation function is thought to be dependent on the charged pion fragmentation functions

LO, gaussian approximation:

$$\frac{\mathrm{d}^2 M^h}{\mathrm{d}z\,\mathrm{d}P_T^2} = \left(\frac{\mathrm{d}^4\sigma}{\mathrm{d}x\,\mathrm{d}Q^2\,\mathrm{d}z\,\mathrm{d}P_T^2}\right) \Big/ \left(\frac{\mathrm{d}^2\sigma^{DIS}}{\mathrm{d}x\,\mathrm{d}Q^2}\right) = N\frac{e^{-P_T^2/\langle P_T^2\rangle}}{\pi\langle P_T^2\rangle}.$$

Connected to charged pion multiplicities

$$D_1^{\pi 0/q} = \frac{1}{2}(D^{\pi^+/q} + D^{\pi^-/q})$$

MOTIVATION

What do we extract?

- 5D multiplicity

$$\frac{dM_h}{dzdp^2{}_T} = \frac{d\sigma_{\pi 0}}{dxdQ^2dzdp^2{}_T} \div \frac{d\sigma_{DIS}}{dxdQ^2}$$

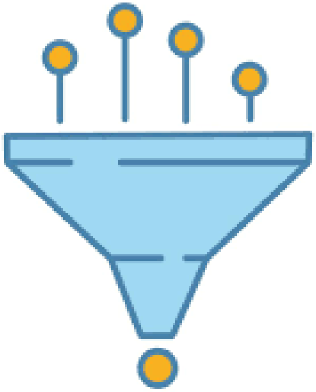
- M_h was integrated over φ_h. More MC is necessary for the fitting
- M_h was scaled by
  - — zp_T binwidth
  - — Acceptance
- What is left is 2D multiplicity

$$\frac{dM_h}{dzdp^2{}_T} = \frac{N_{\pi 0}}{N_{e\_dis}}$$ in x-Q^2 bin

PID AND EVENT SELECTION

The same to the last update

- Electron
  - $2 < p_e < 8$ GeV
  - $Q^2 > 2$ GeV^2
  - $W > 2$ GeV
  - $y < 0.75$
  - Z-Vertex cut
  - Bad PMTs knock out
  - DC and PCAL fiducial cuts
  - Electron – pion separation cut
  - Momentum dependent 3.5σ Sampling Fraction Cut



- Photon
  - $E_\gamma > 0.5$ GeV
  - e-γ opening angle > 8 deg
  - $0.9 < \beta < 1.1$
- π^0
  - Candidates are reconstructed from photon pairs
  - $x_F > 0$ [$x_F = 2P_{h,L}/\sqrt{s}$] : current fragmentation region
  - $M_x > 1.5$ GeV
  - $\alpha_{\gamma\gamma} > 6 \cdot \mathrm{Exp}(1 - p_\pi) + 0.5$ deg

More details are available at : https://indico.jlab.org/event/928/contributions/16229/attachments/12300/19489/Klimenko_pi0_collab.pdf

RADIATIVE CORRECTIONS

HapRad 2.0 updated by Alexander Ilyichev include:

- SIDIS structure functions for π^0 (https://github.com/prokudin/WW-SIDIS) using Wandzura-Wilczek-type approximation (https://arxiv.org/abs/1807.10606)

- MAID cross section for $\pi^0 p$: https://maid.kph.uni-mainz.de/maid2007/cross.html

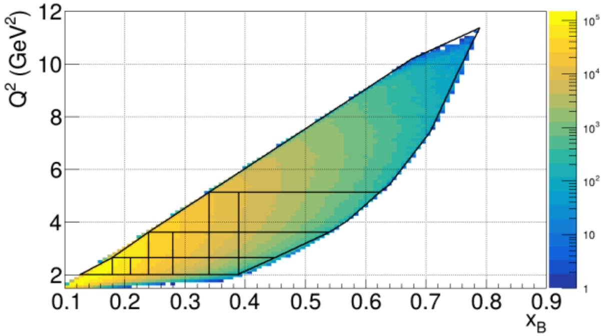
- Electron structure function method was added to speed-up RC estimation (*Phys.Rev.D* 109 (2024) 7, 076028)

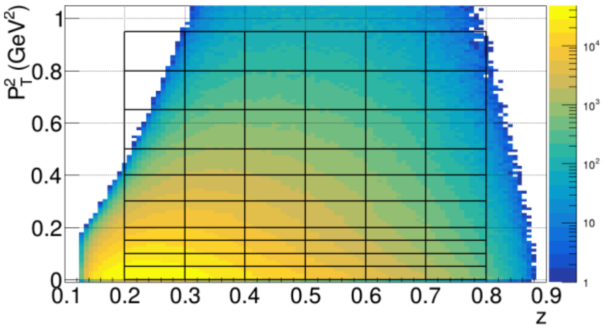
SIDIS

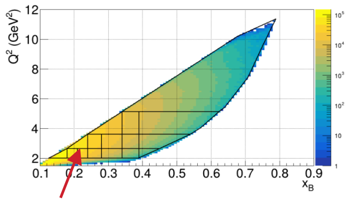
Procedure

- φ_h range was set to [0-π] because of symmetry. # φ_h bins is 8.
- Number of sub bins per x-Q^2-z-p_T^2 is 16.
- Radiated Cross Section includes (*Phys.Rev.D* 109 (2024) 7, 076028):
  - — Continues spectra corrections
  - — Exclusive tail contribution
- φ_h dependence was fitted with A * (1 + B * cosφ + C * cos2φ)
- SIDIS RC:

$$\frac{\sigma_{rad}}{\sigma_{born}} = \frac{A_{rad}}{A_{born}}, hadron\ mass = \pi\ mass$$

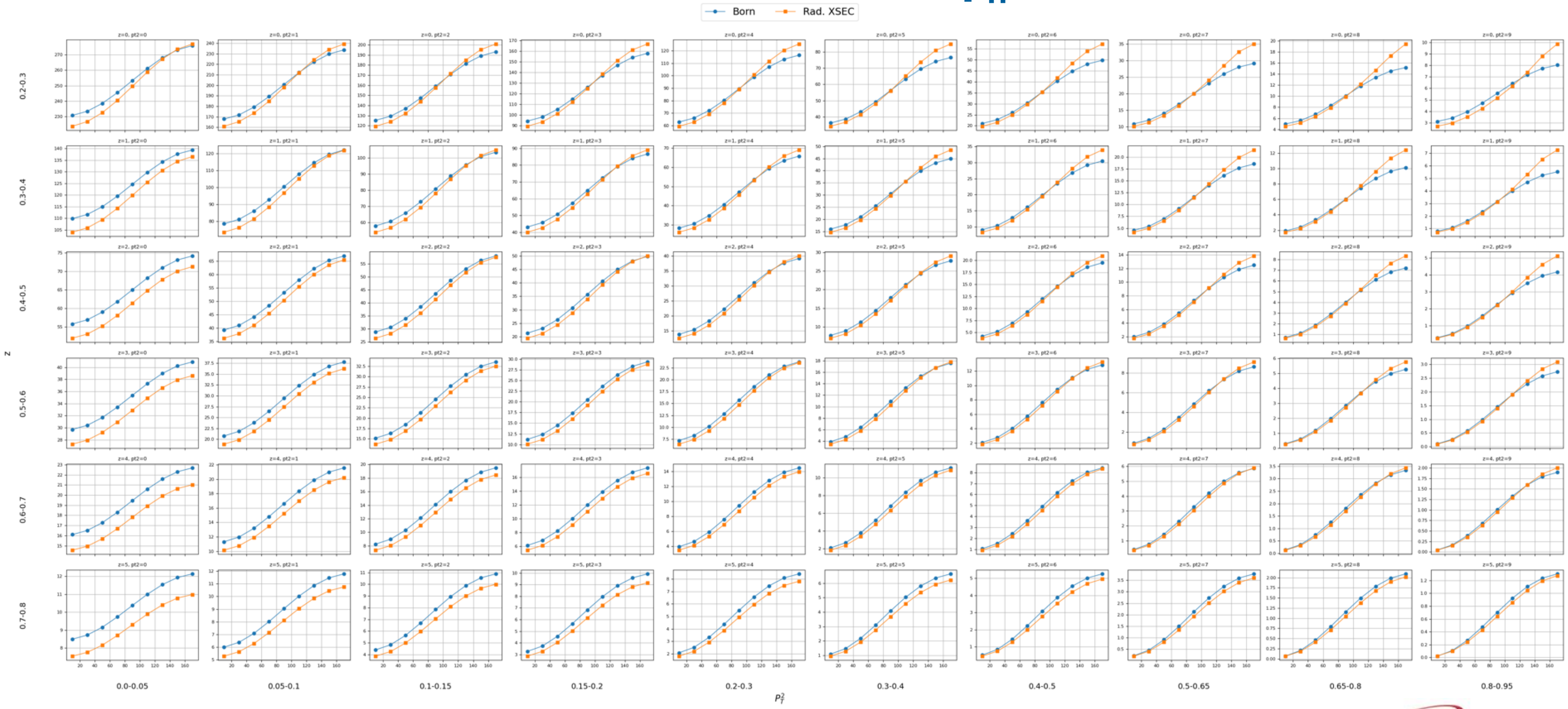






SIDIS

Born and Rad. XSECs as a function of ϕ_h for the second xQ^2 bin

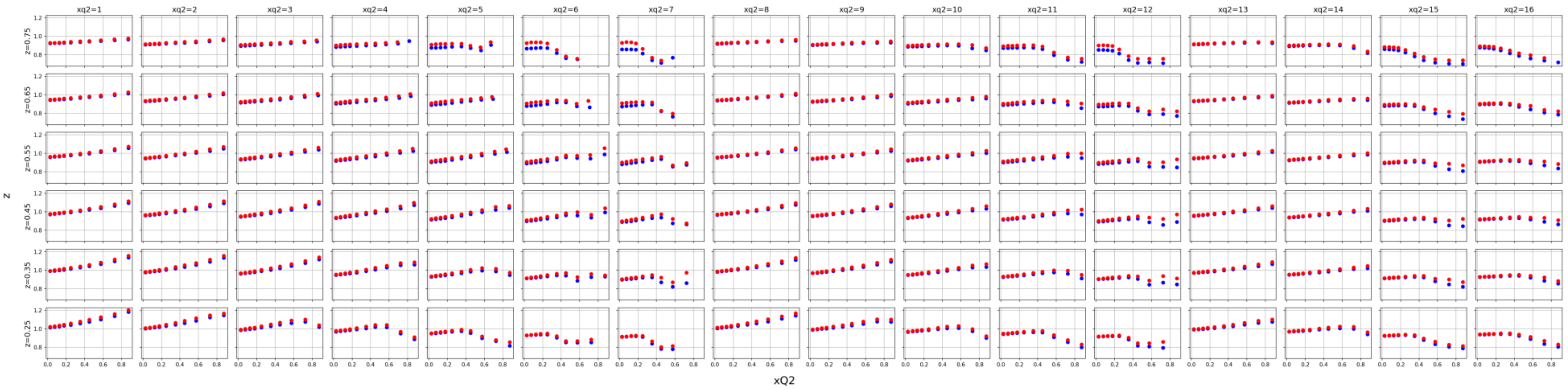


$2.0 < Q^2 < 2.66\ \mathrm{GeV}^2,\ 0.18 < x < 0.21,\ \phi_H$ in $[0-\pi]$

SIDIS

RCs for π^0(blue) and and π^+(red) in all x-Q2 bins as a function of p_T^2 explicitly integrated over φ_H

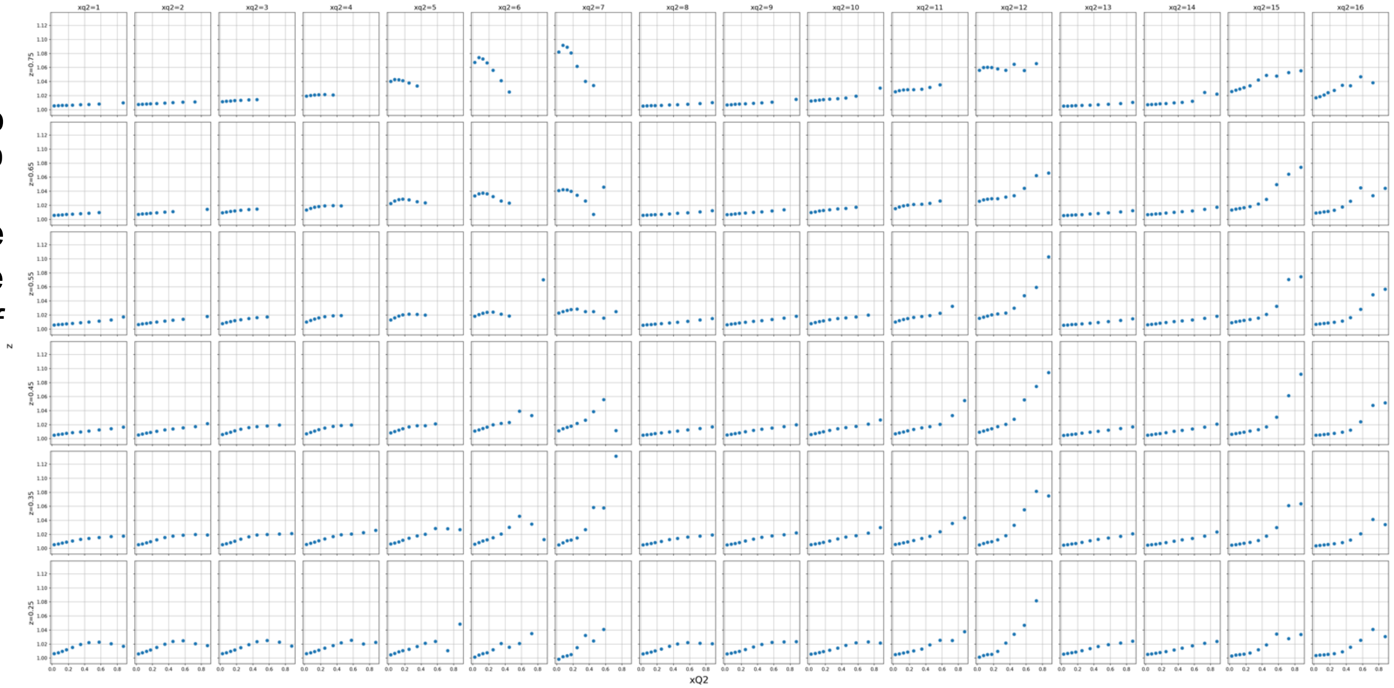
- RCs are in range of 0.8 to 1.2
- 20% variation within each bin
- RC for π^+ is up to 10% larger than for π^0



SIDIS

Ratio of π^+ to π^0 in all x-Q2 bins as a function of p_T^2

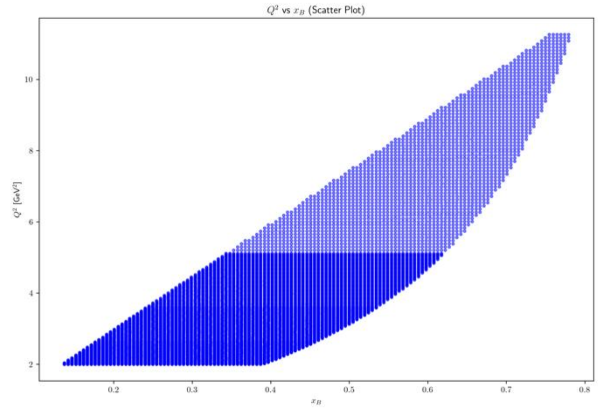
- RC for π^+ is up to 10% larger than for π^0
- The main difference at the edge of phase space, contribution of exclusive tail



DIS

DIS

Definition of RCs



- RCs were defined the following way:

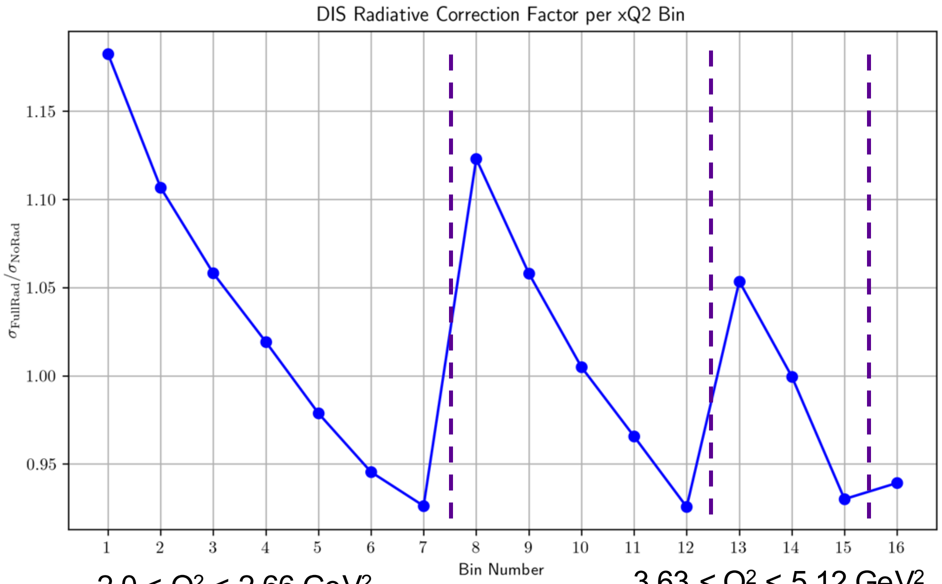
$$\frac{\sigma_{rad}}{\sigma_{born}} = \frac{\sigma_{elas\,rad} + \sigma_{elas\,tail} + \sigma_{inelas\,rad}}{\sigma_{born}}$$

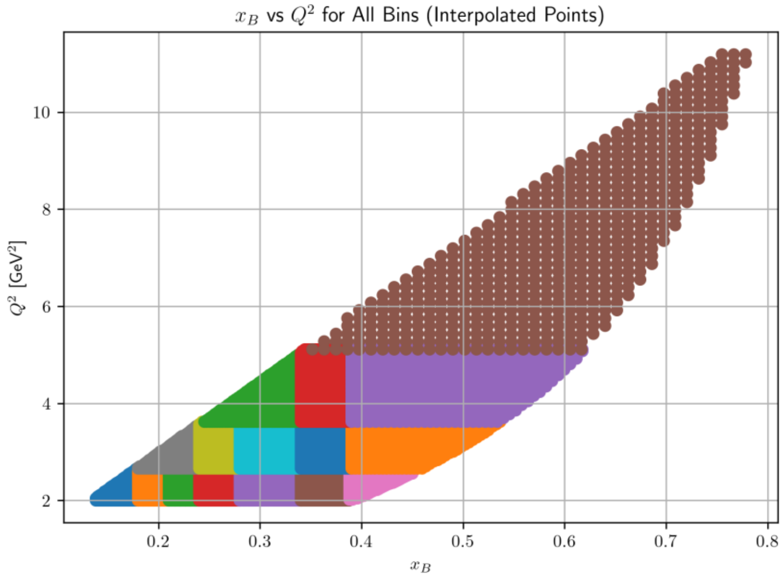
where inelastic cross section comes from iterated Bodek parametrization

- The Mo and Tsai corrections was implemented by Mikhail Osipenko and used in two inclusive measurements (2003 and 2025). It was cross checked with an independent implementation done by Misak Sargsian.

DIS

RCs for every xQ2 bin





$2.0 < Q^2 < 2.66$ GeV^2

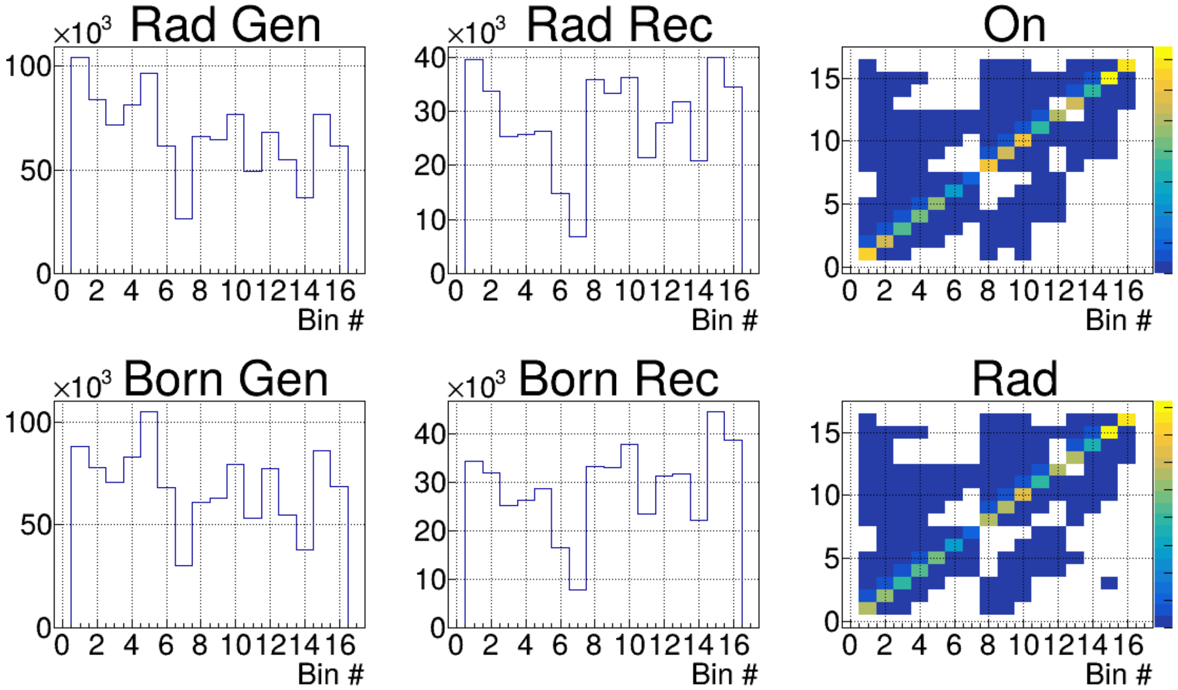
$3.63 < Q^2 < 5.12$ GeV^2

$2.66 < Q^2 < 3.63$ GeV^2

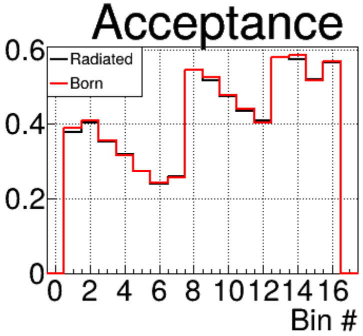
$Q^2 > 5.12$ GeV^2

DIS

How does it affect acceptance?



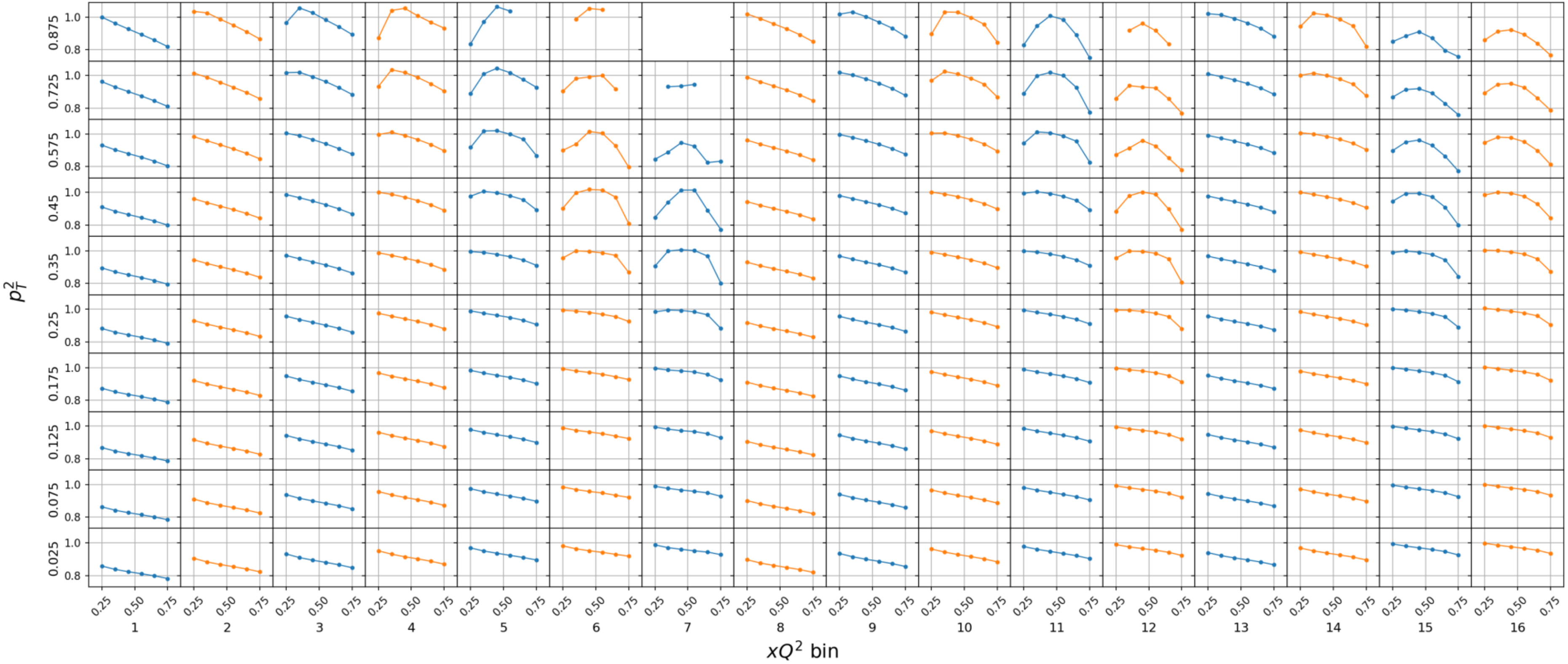
$$\frac{N_{rec\,Born}}{N_{gen\,born}} \; vs \; \frac{N_{rec\,rad}}{N_{gen\,rad}}$$



RC FOR SIDIS/DIS

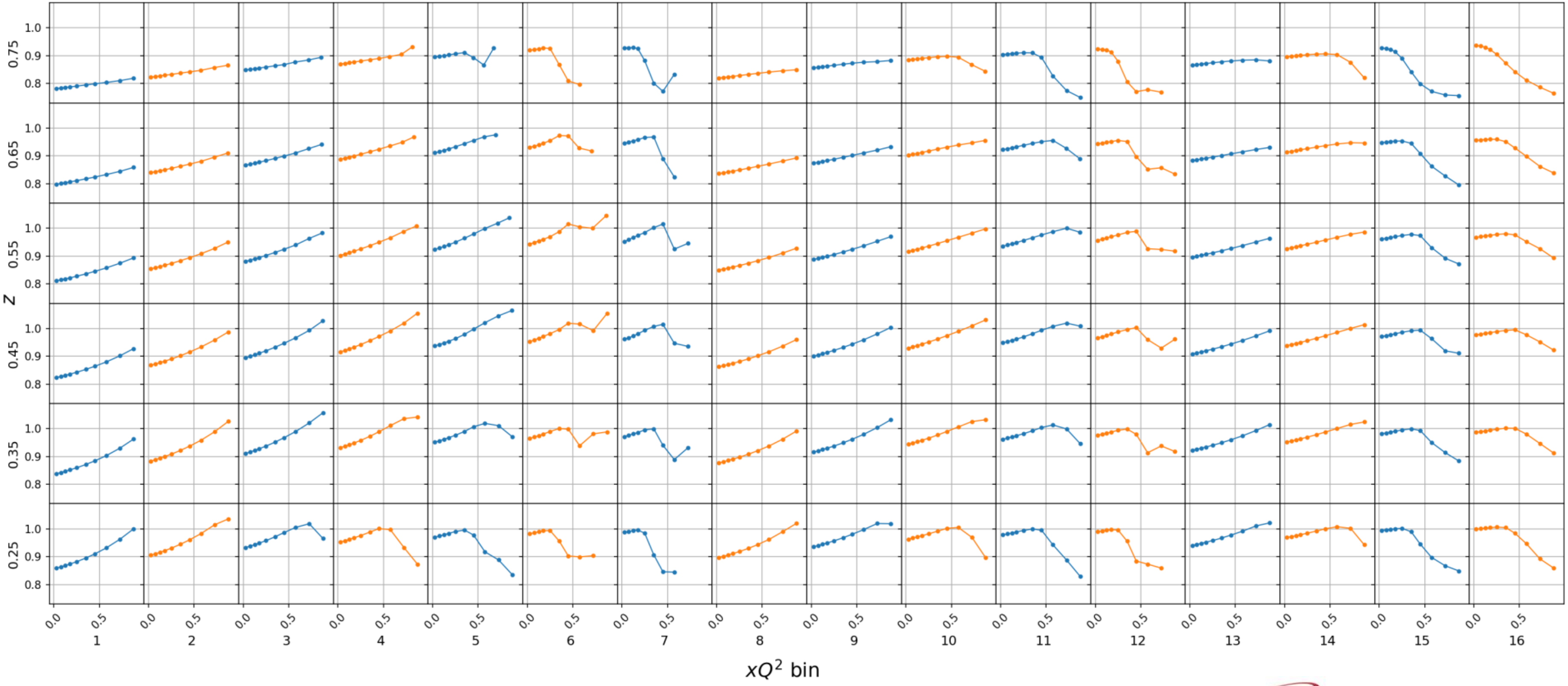
M_H RADIATIVE CORRECTIONS (Z)

$$\frac{RC_{SIDIS}}{RC_{dis}}$$



M_H RADIATIVE CORRECTIONS (P_T^2)

$$\frac{RC_{SIDIS}}{RC_{dis}}$$



RESULTS $M_H(P_T^2)$

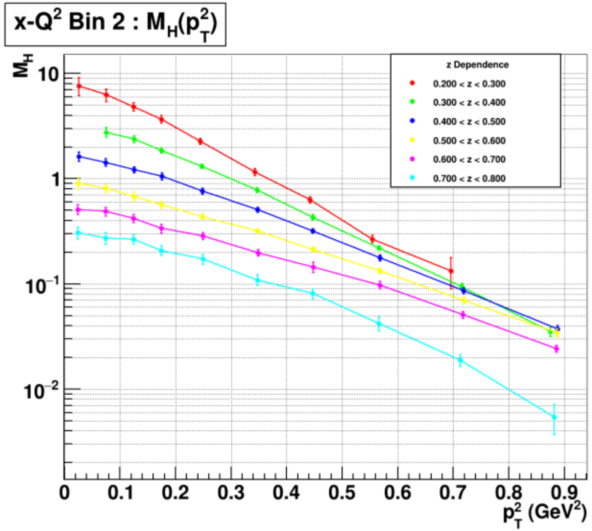
RESULTS

$M_h(p_T^2)$ bins #2-4, $2.0 < Q^2 < 2.66$ GeV^2

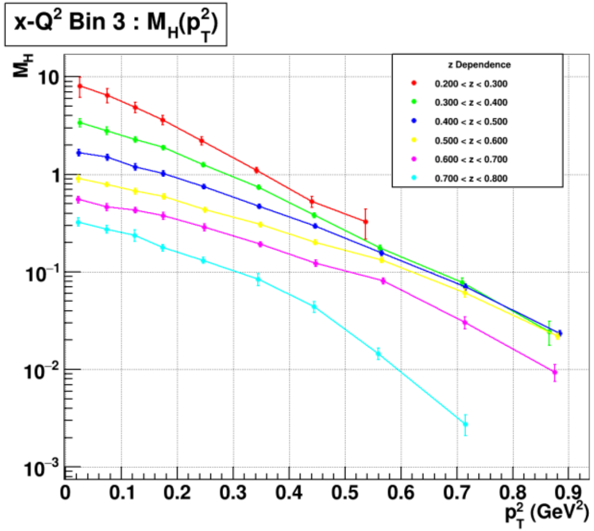
LO, gaussian approximation:

$$\frac{d^2 M^h}{dz\, dP_T^2} = \left(\frac{d^4\sigma}{dx\, dQ^2\, dz\, dP_T^2}\right) \Big/ \left(\frac{d^2\sigma^{DIS}}{dx\, dQ^2}\right)$$

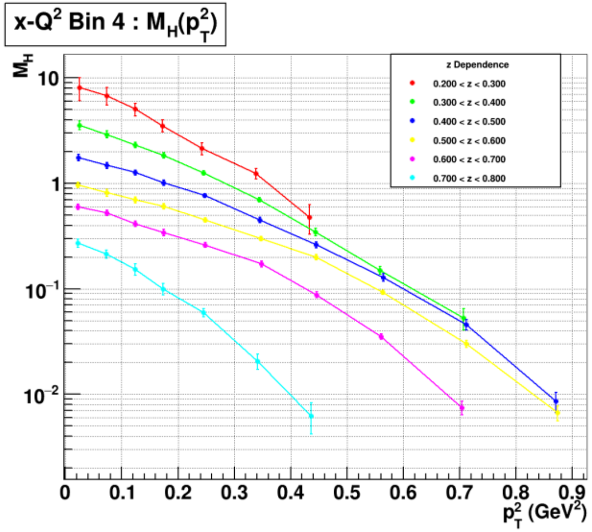
$$= N \frac{e^{-P_T^2/\langle P_T^2\rangle}}{\pi\langle P_T^2\rangle}.$$



0.18 < x < 0.21



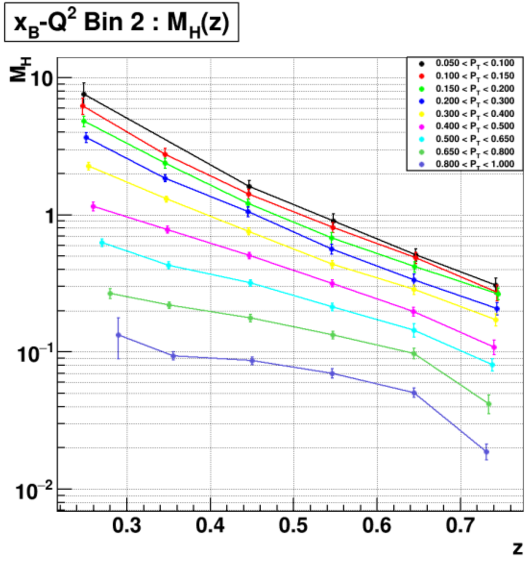
0.21 < x < 0.24



0.24 < x < 0.28

RESULTS

$M_h(z)$ bins #2-4, $2.0 < Q^2 < 2.66$ GeV^2



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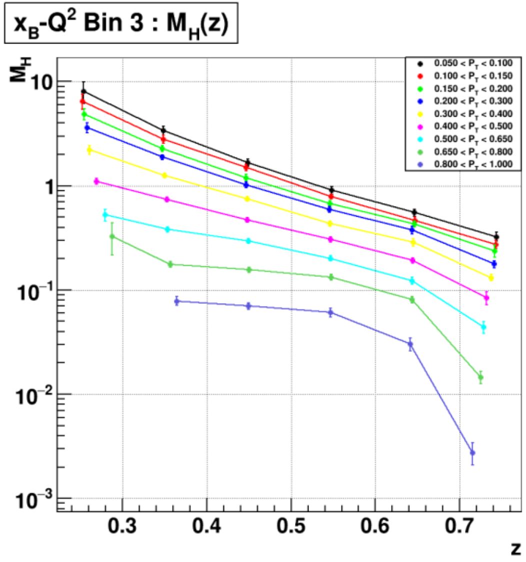
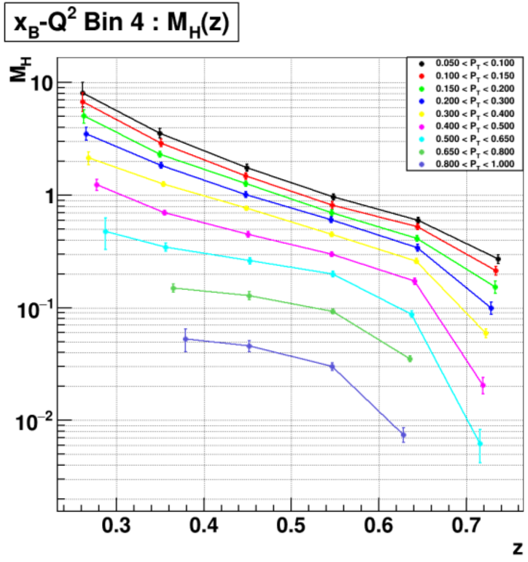


0.21 < x < 0.24



0.24 < x < 0.28

WORK IN PROGRESS

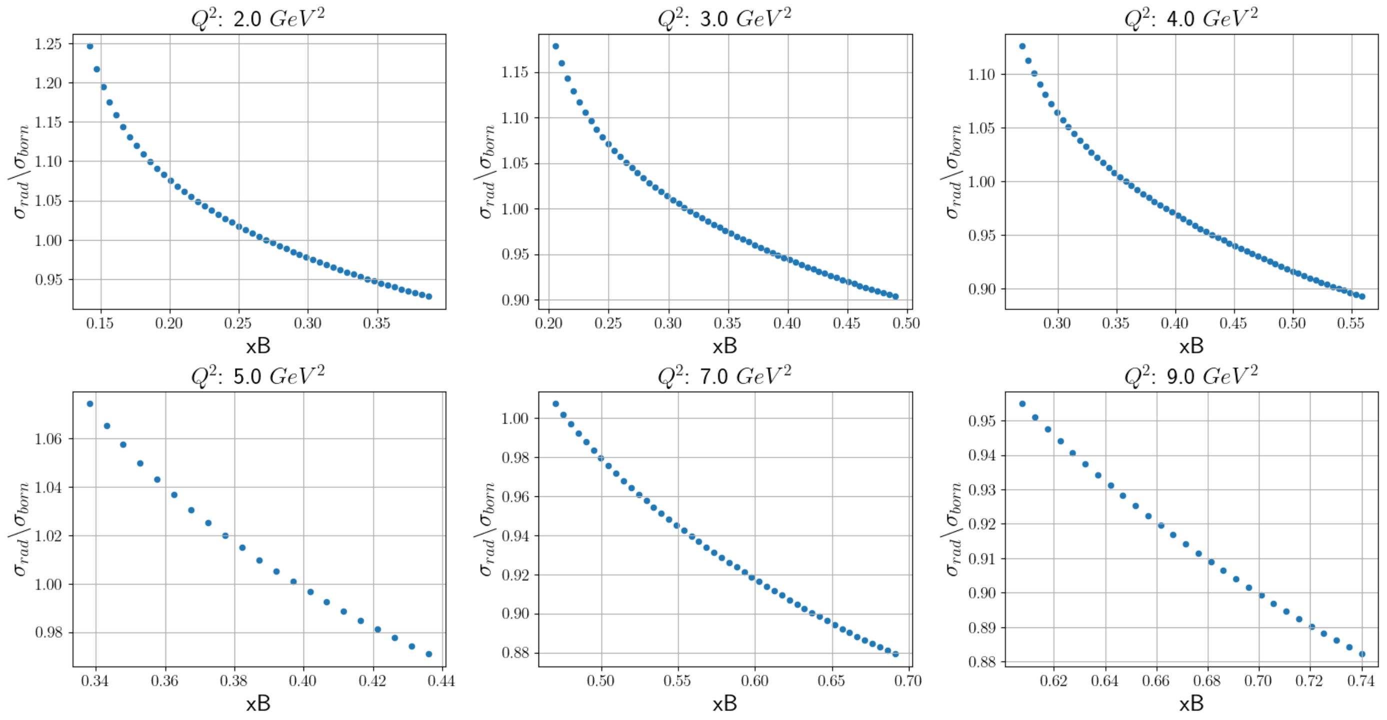
WORK IN PROGRESS

- Instead of averaging over the φ_h bins, the number of pions will be fitted within each φ_h bin with $A \cdot (1 + B \cdot \cos(\varphi_h) + C \cdot \cos(2 \cdot \varphi_h))$
- Introducing matrix deconvolution procedure
- ρ^+ contamination
- Systematic studies

BACK UP SLIDES

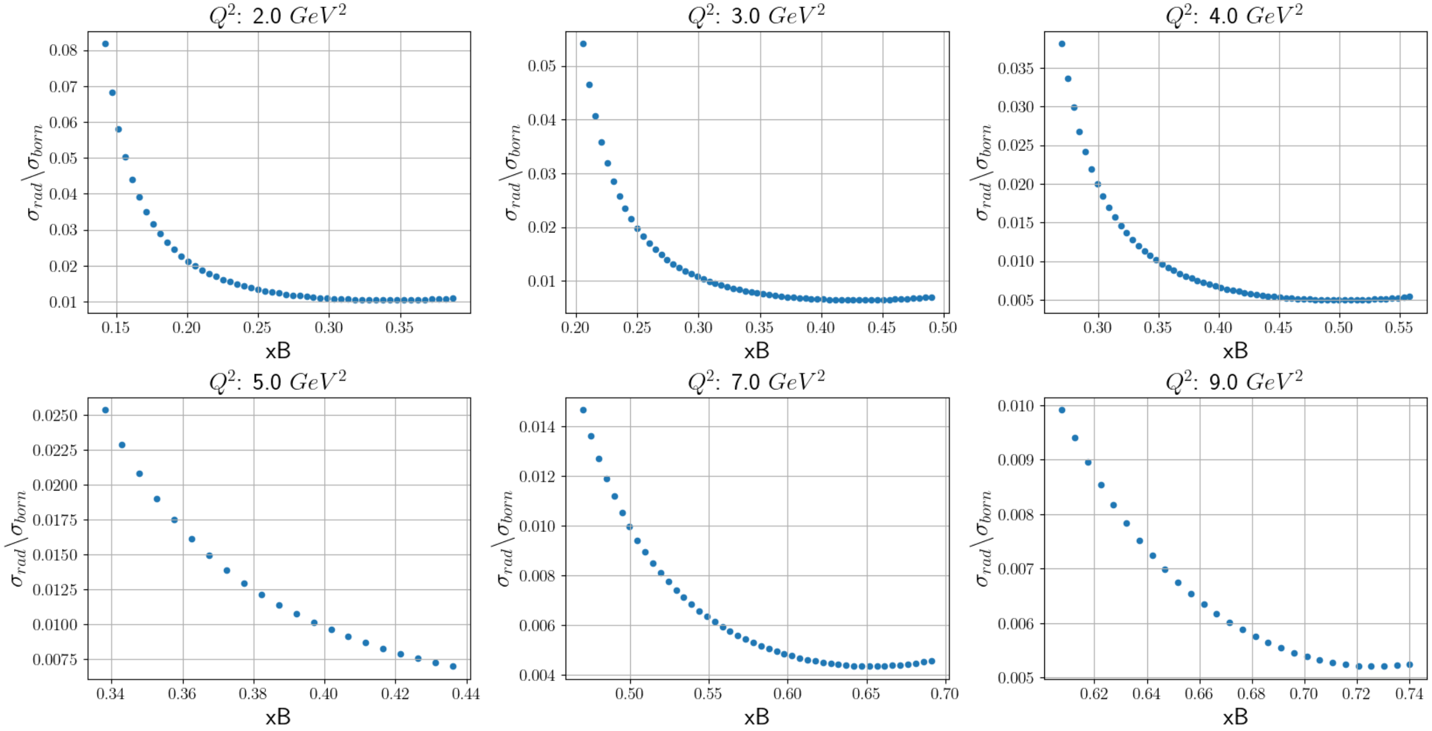
DIS

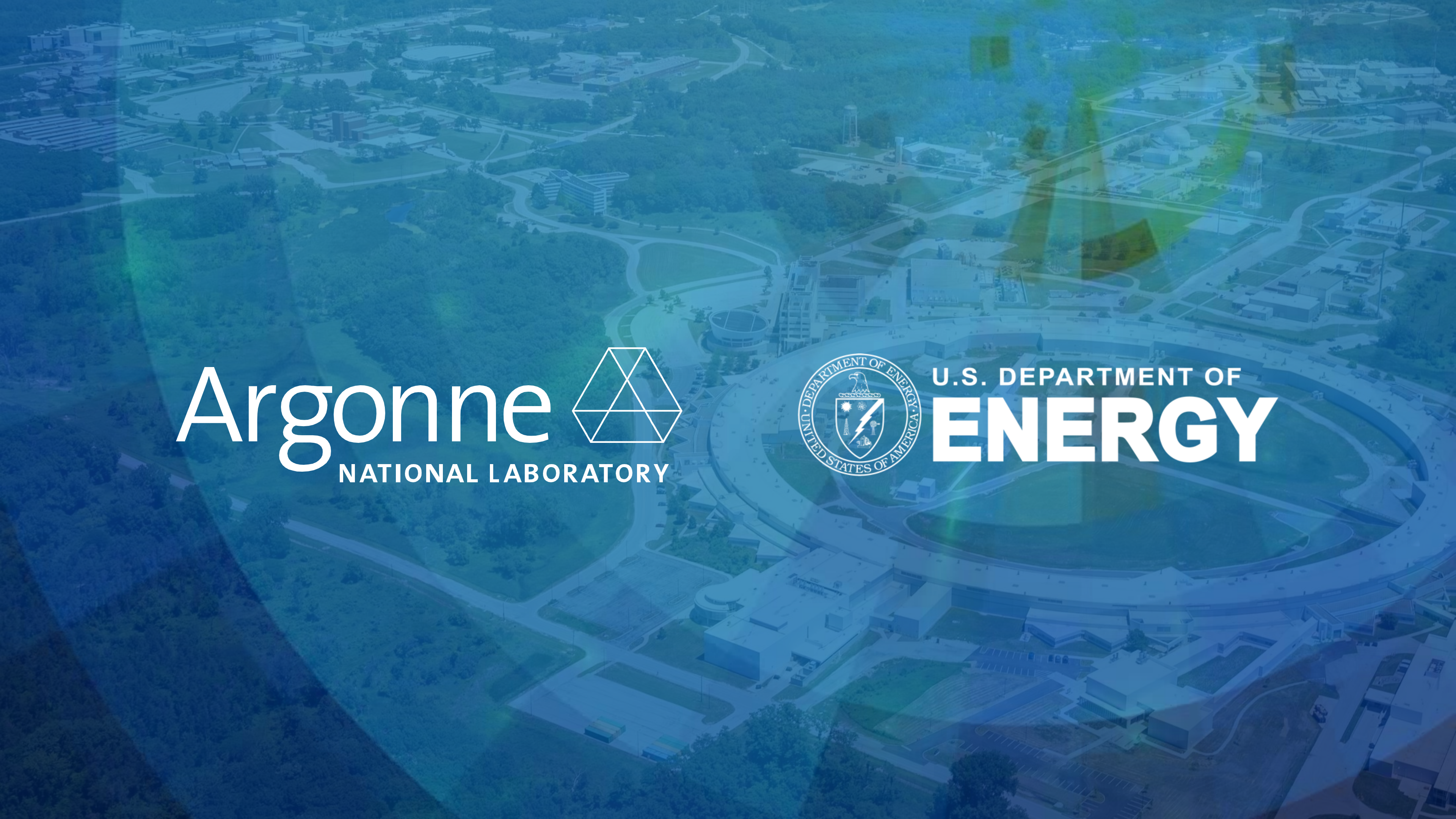
Results for fixed Q^2 values (y < 0.75, W > 2 GeV)



DIS

Elastic tail contribution for fixed Q^2 values ($y < 0.75$, $W > 2$ GeV)

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