ECT*

EUROPEAN CENTRE FOR THEORETICAL STUDIES
IN NUCLEAR PHYSICS AND RELATED AREAS

Exclusive Tensor-Polarized d(e,e'p)

July 13, 2023

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FIU

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Exploring the Nature of Matter

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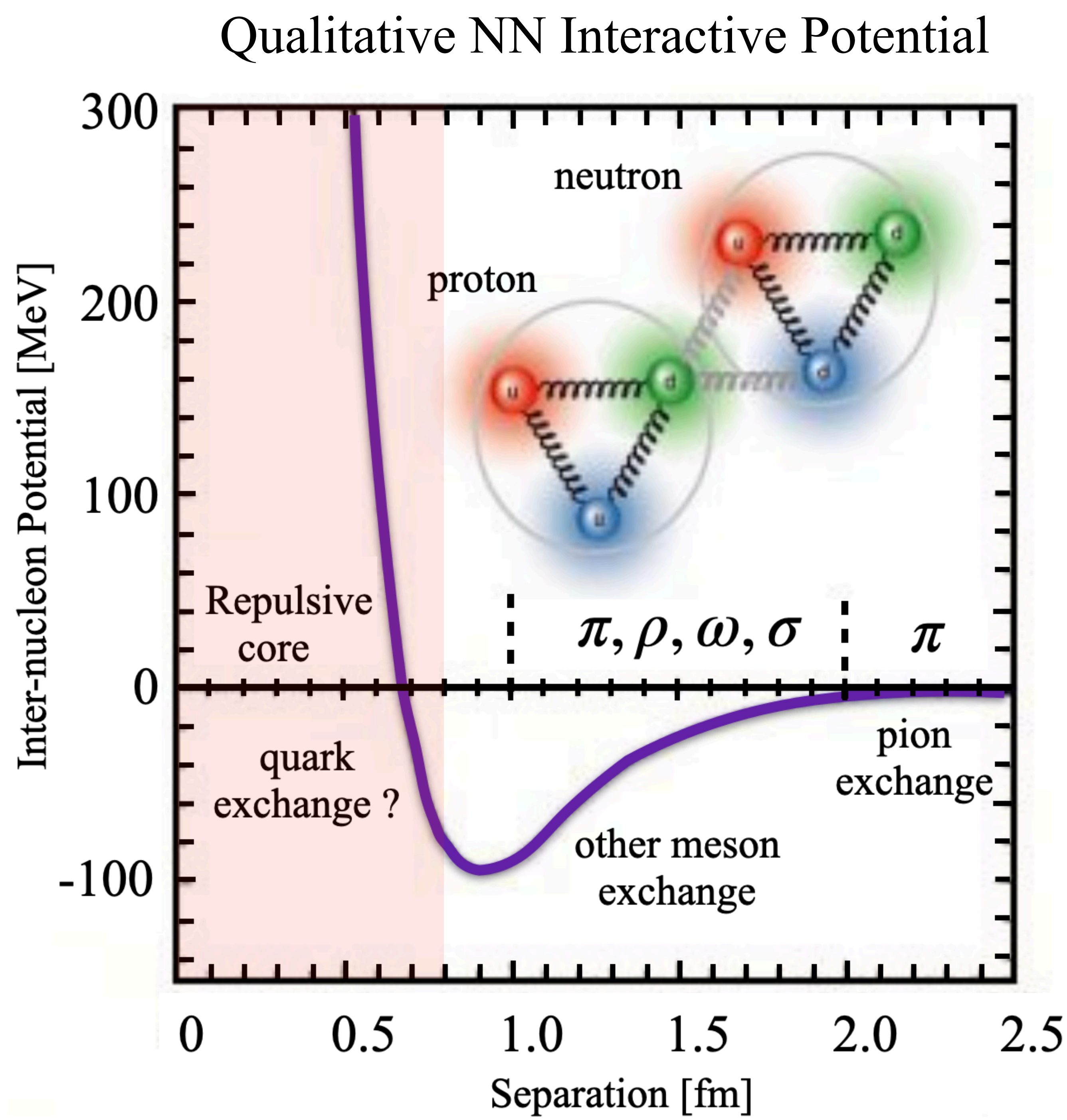
why study the deuteron ?

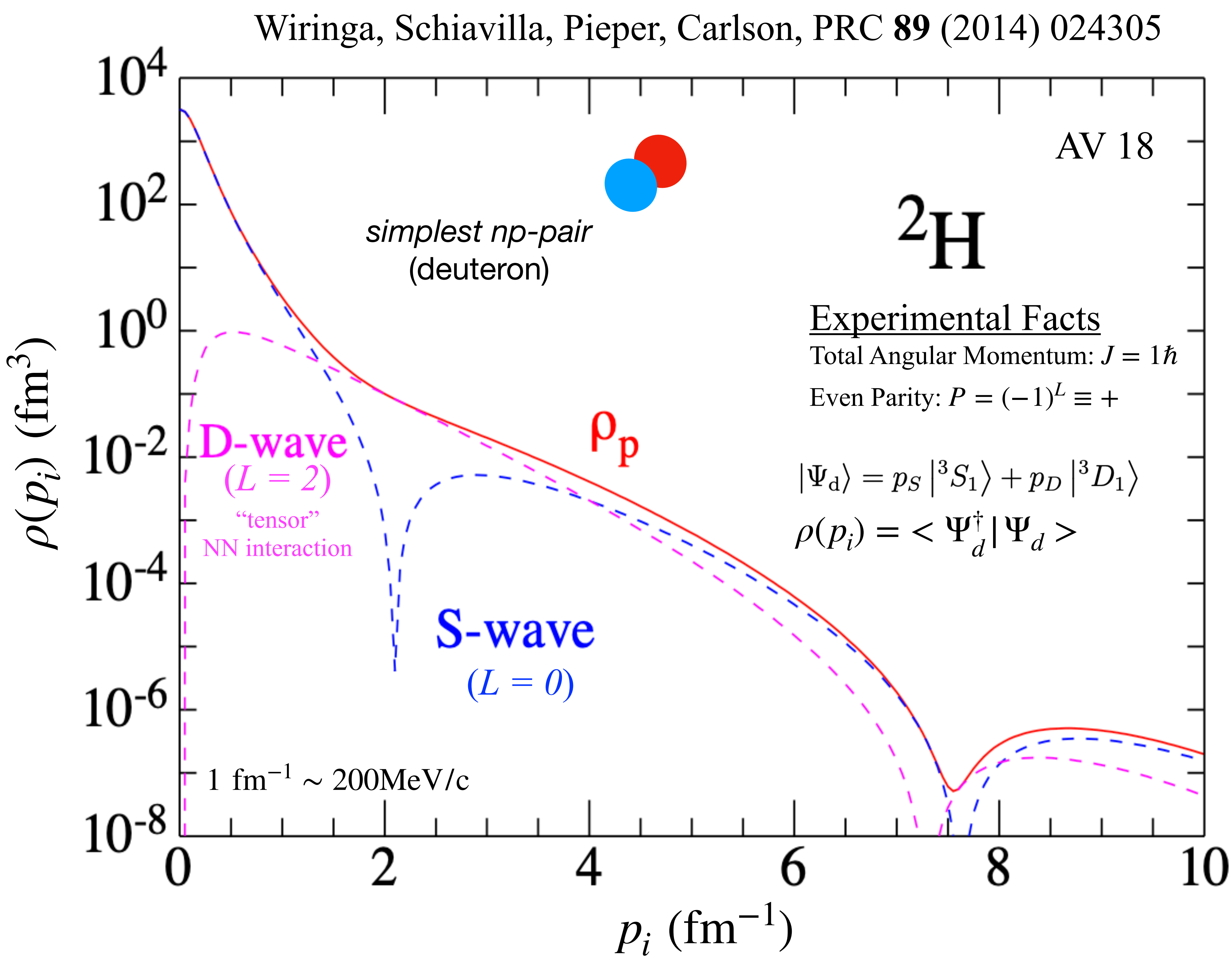
- most simple *np* bound state to study *NN* interaction at sub-Fermi scale (repulsive core)

- elementary system for studying short-range correlations (SRC) in A>2 nuclei

- final-state interactions (FSI) reliable and well-understood which is a requirement for directly probing short-range

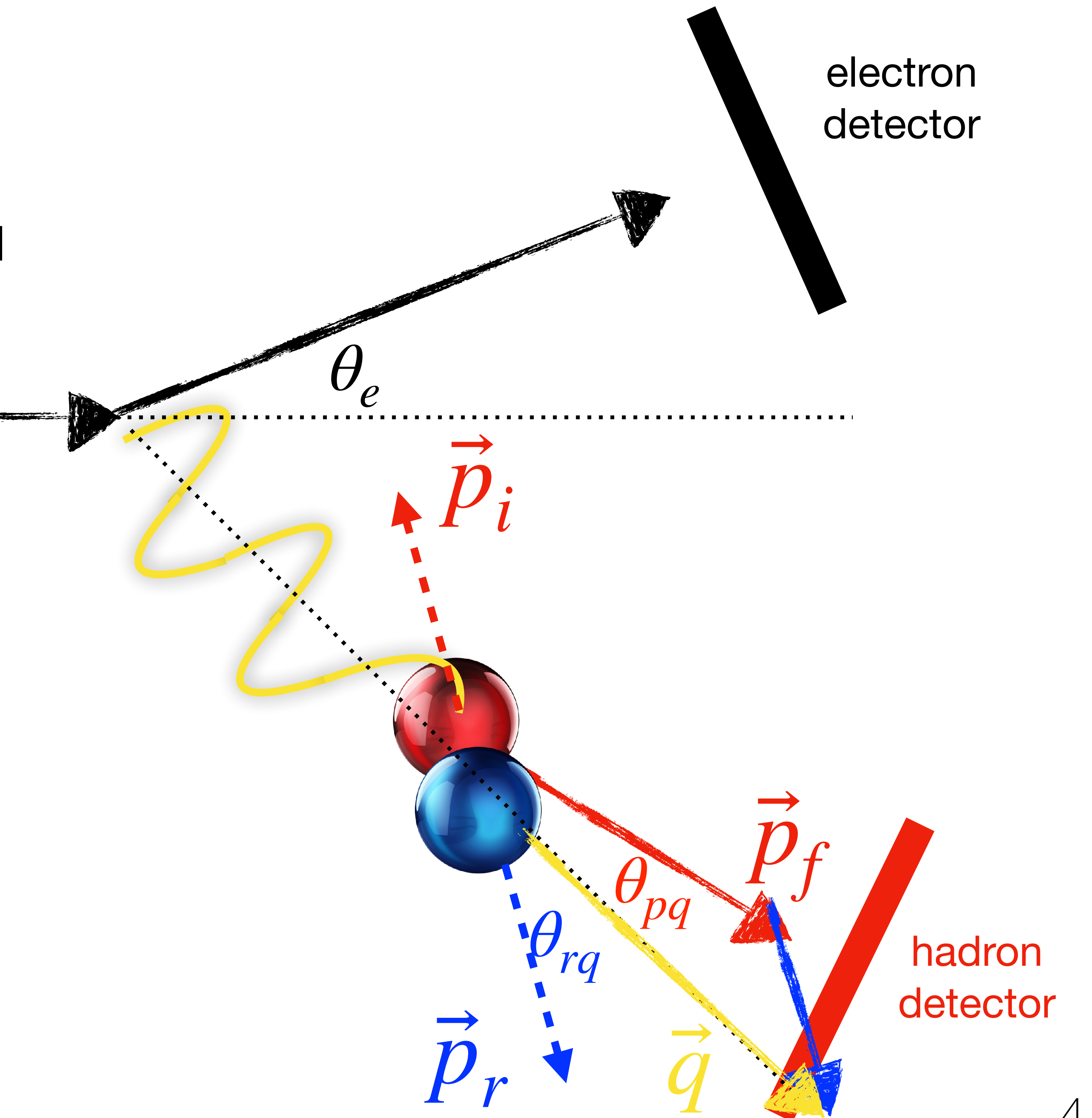


momentum distribution



probing high-momentum structure

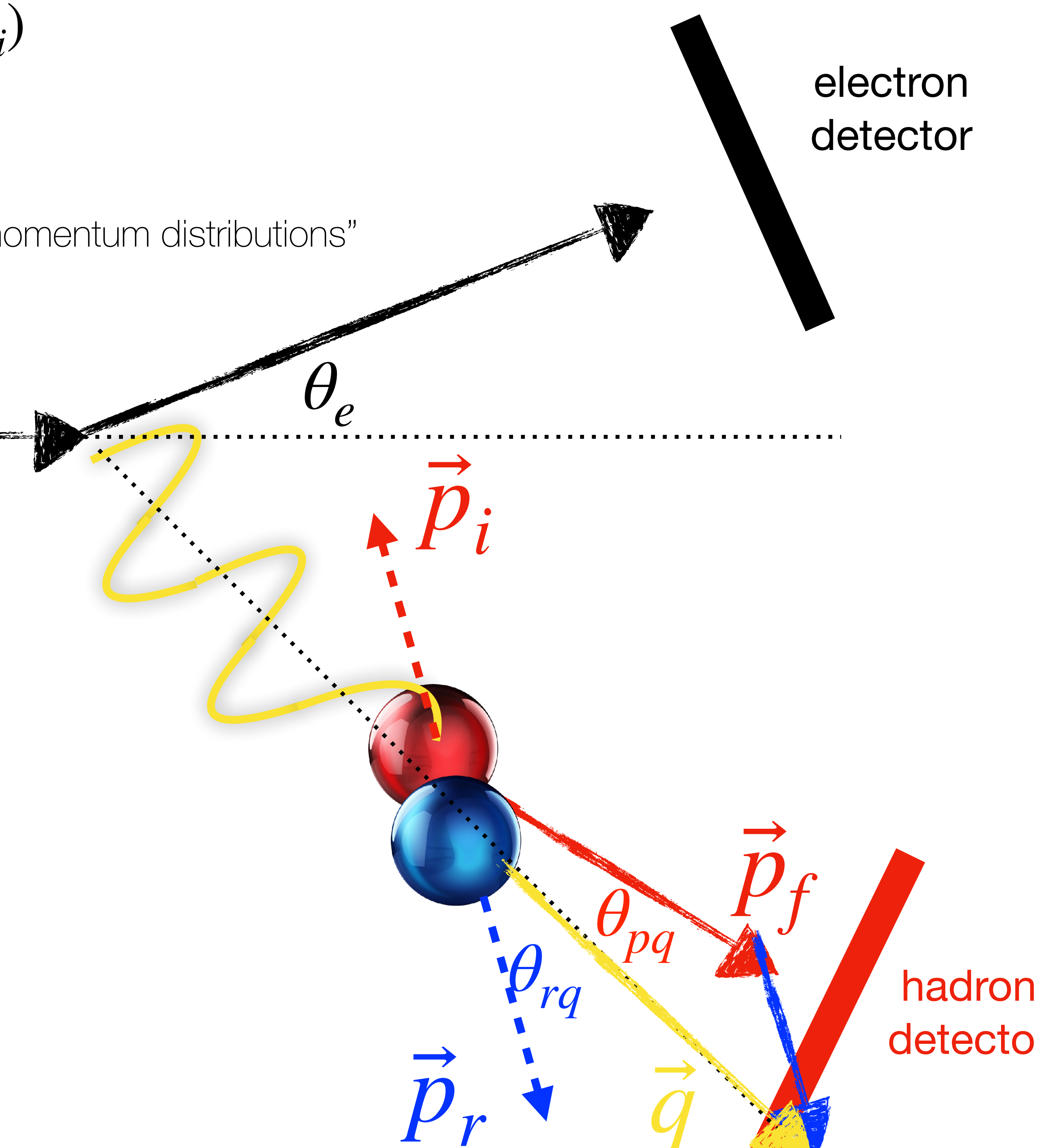
- e- scattering off bound nucleon with internal momenta, $\overrightarrow{p_i}$
- reconstructed (undetected) recoil nucleon momenta, $\vec{p}_r = \vec{q} - \vec{p}_f$



probing high-momentum structure

$$\sigma_{exp} \equiv \frac{d^5\sigma}{dE' d\Omega_e d\Omega_p} = k \cdot \sigma_{eN} \cdot \rho(p_i)$$

$$\sigma_{red} \equiv \frac{\sigma_{exp}}{k \cdot \sigma_{eN}} \sim \rho(p_i)$$ "experimental momentum distributions"



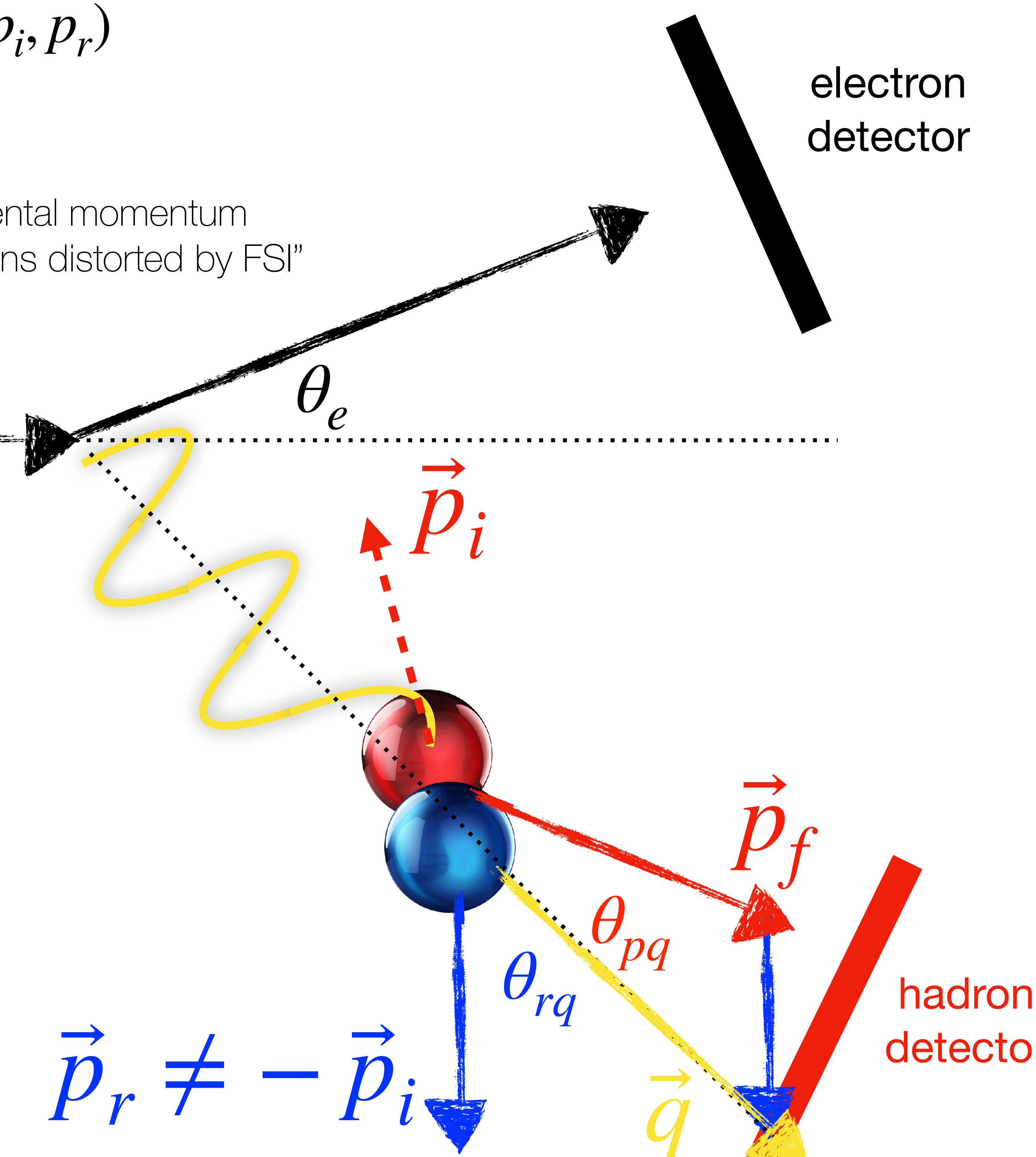
- plane-wave impulse approximation (PWIA)
    - no further re-interaction between knocked-out and recoil nucleon
    - recoil momentum unchanged, $\vec{p}_r \sim -\vec{p}_i$
    - $\vec{p}_r$ can be used to access internal nucleon momentum distributions

probing high-momentum structure

$$\sigma_{exp} \equiv \frac{d^5\sigma}{dE' d\Omega_e d\Omega_p} = k \cdot \sigma_{eN} \cdot \rho_D(p_i, p_r)$$

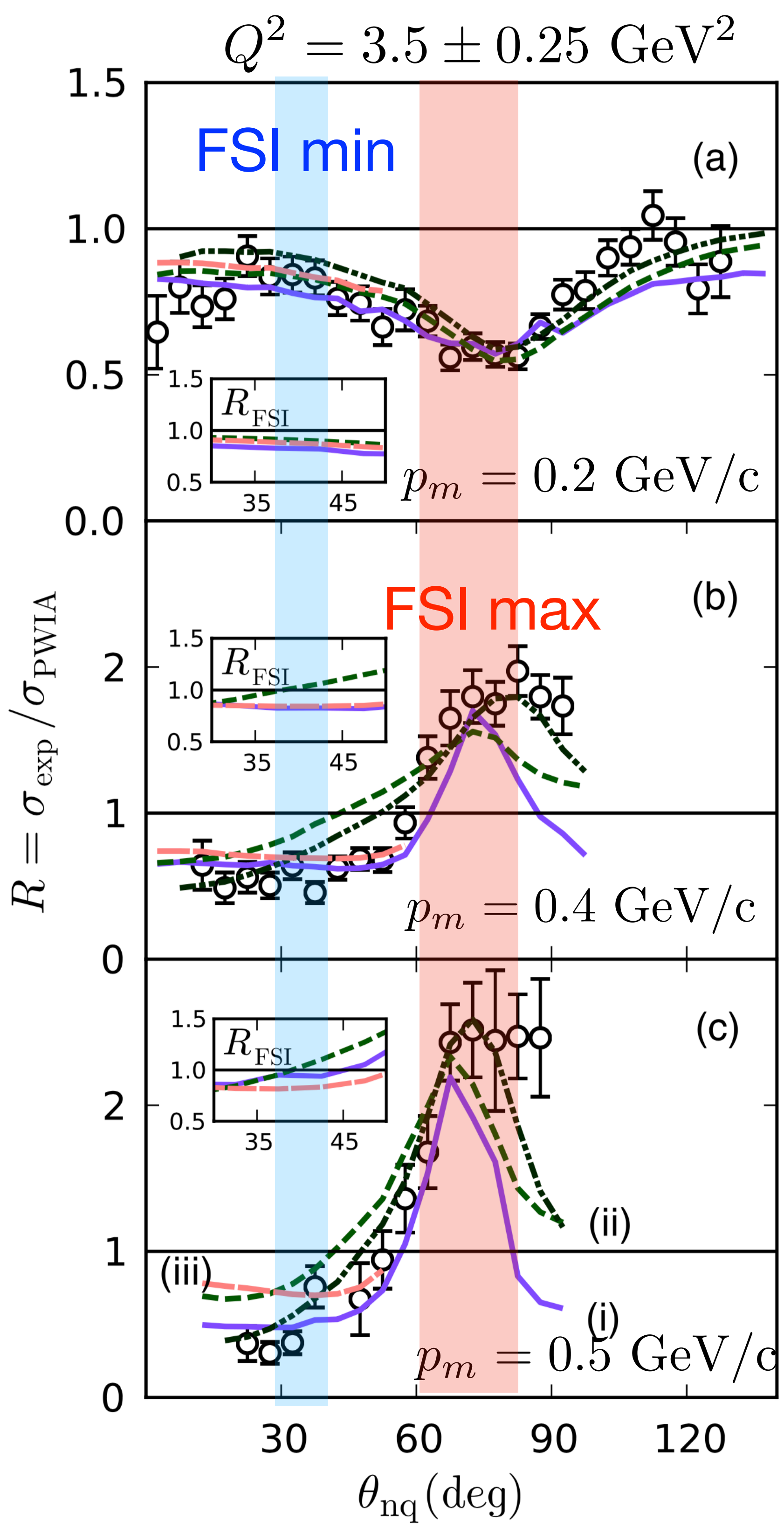
$$\sigma_{red} \equiv \frac{\sigma_{exp}}{k \cdot \sigma_{eN}} \sim \rho_D(p_i, p_r)$$

"experimental momentum distributions distorted by FSI"



- Final-state interactions (FSI):
    - recoil nucleon re-interacts with knocked-out nucleon
    - recoil momentum modified, $\vec{p}_r \neq -\vec{p}_i$
    - $\vec{p}_r$ cannot be used to access internal nucleon momentum distributions

controlling final-state interactions (FSI)



CD-Bonn FSI
(Calculations: Misak Sargsian)
Misak M. Sargsian Phys.Rev.C82014612 (2010)

JVO Model
(Calculations: J.W. Van Orden &
S. Jeschonnek)
S.Jeschonnek and J. W. VanOrden Phys.Rev.C80054001 (2009)

Paris FSI
(Calculations: J.M. Laget)
J. Laget Phys.Lett.B60949 (2005)

Paris FSI+MEC+IC
(Calculations: J.M. Laget)
J. Laget Phys.Lett.B60949 (2005)

DATA

FSI strongly anisotropic (angular-dependent):

- Sargsian uses GEA, Laget uses fully relativistic
- FSI peak at $\theta_{nq} \sim 70°$
- minimal FSI at $\theta_{nq} \sim 35 - 45°$

GEA theory:

L. L. Frankfurt, M. M. Sargsian, and M. I. Strikman Phys.Rev.C561124 (1997)

Boeglin et al. (Hall A) Phys.Rev.Lett. 107, 262501 (2011)
K. S. Egiyan et al. (CLAS) Phys. Rev. Lett. 98, 262502 (2007)

controlling final-state interactions (FSI)

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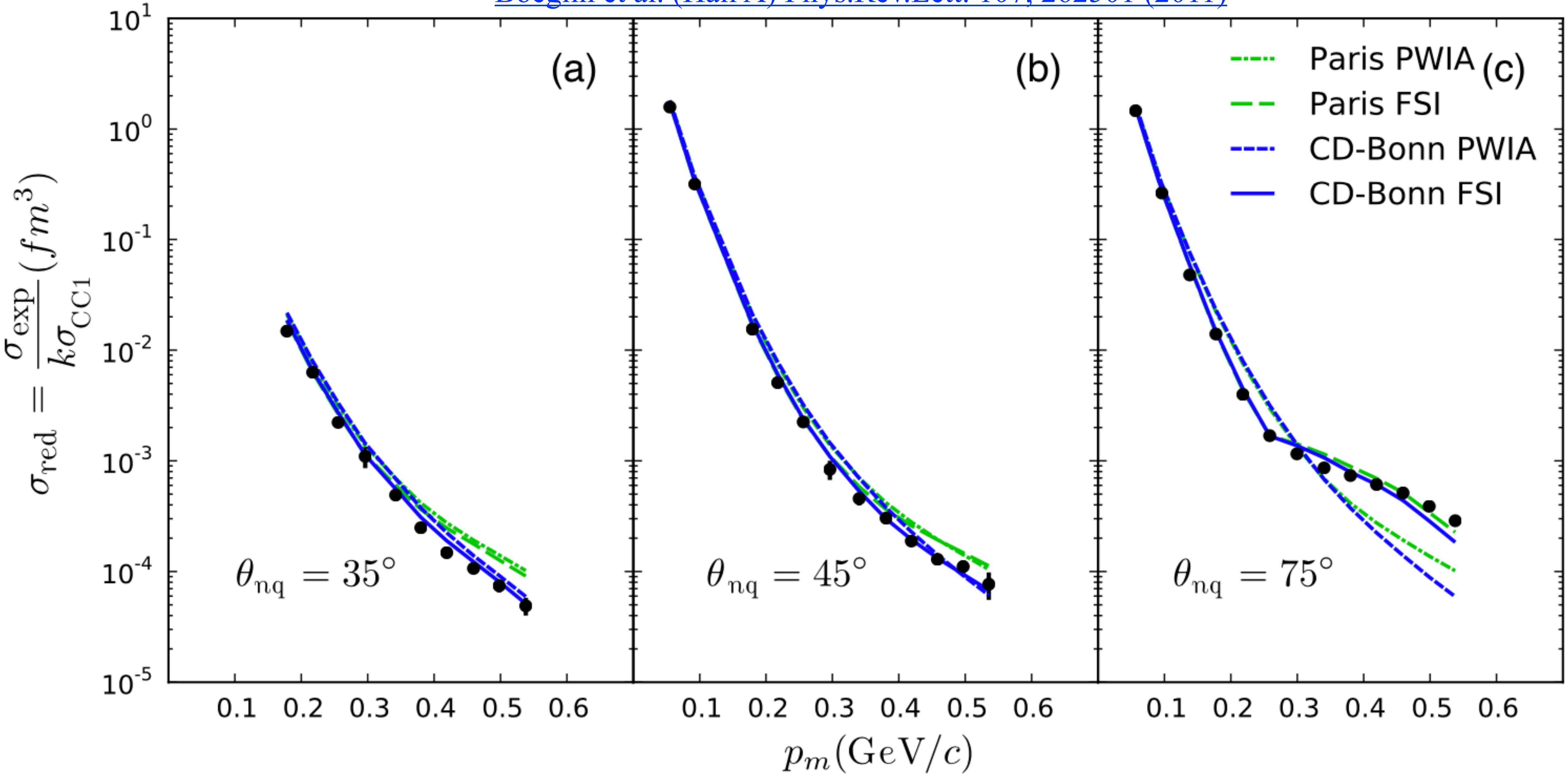

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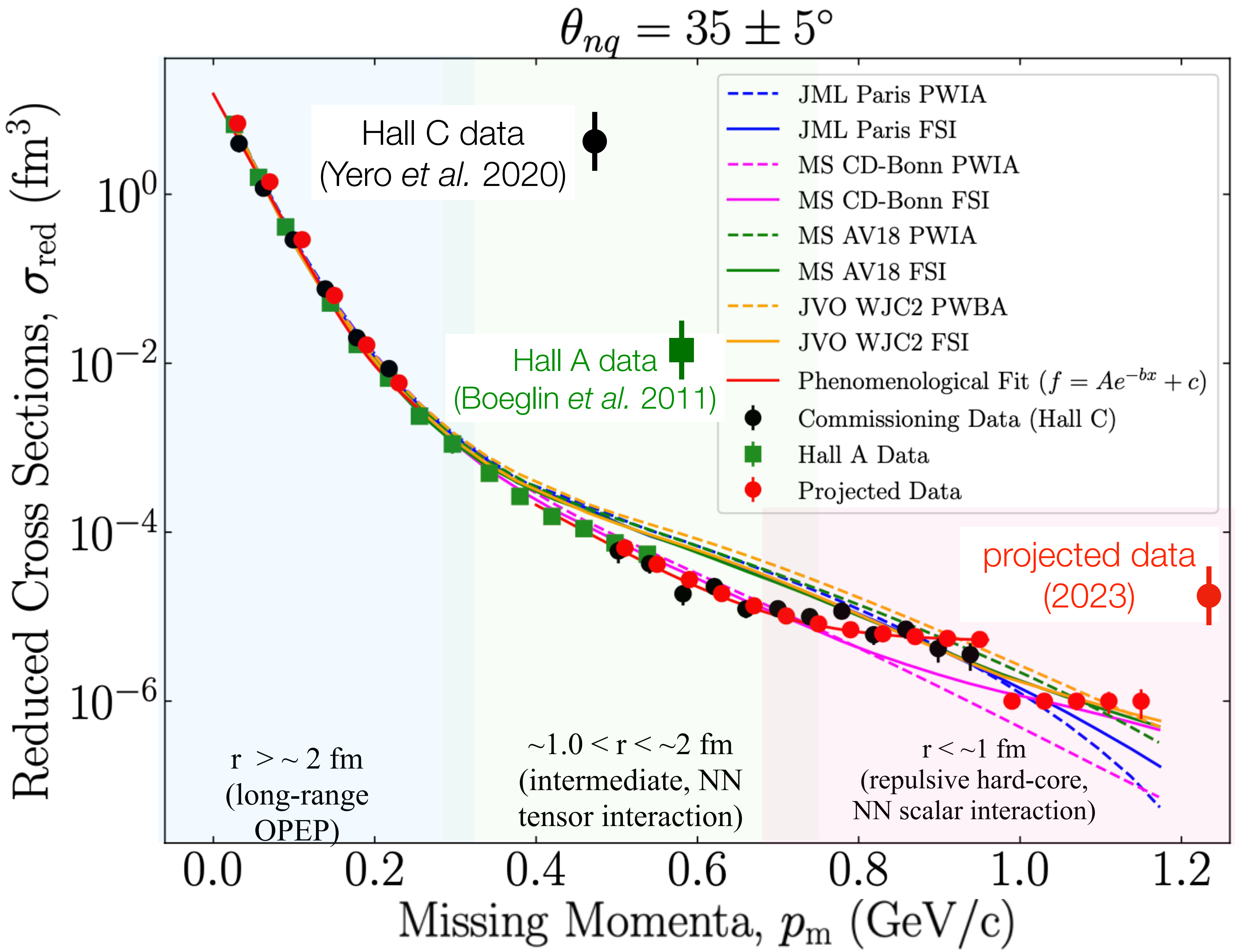
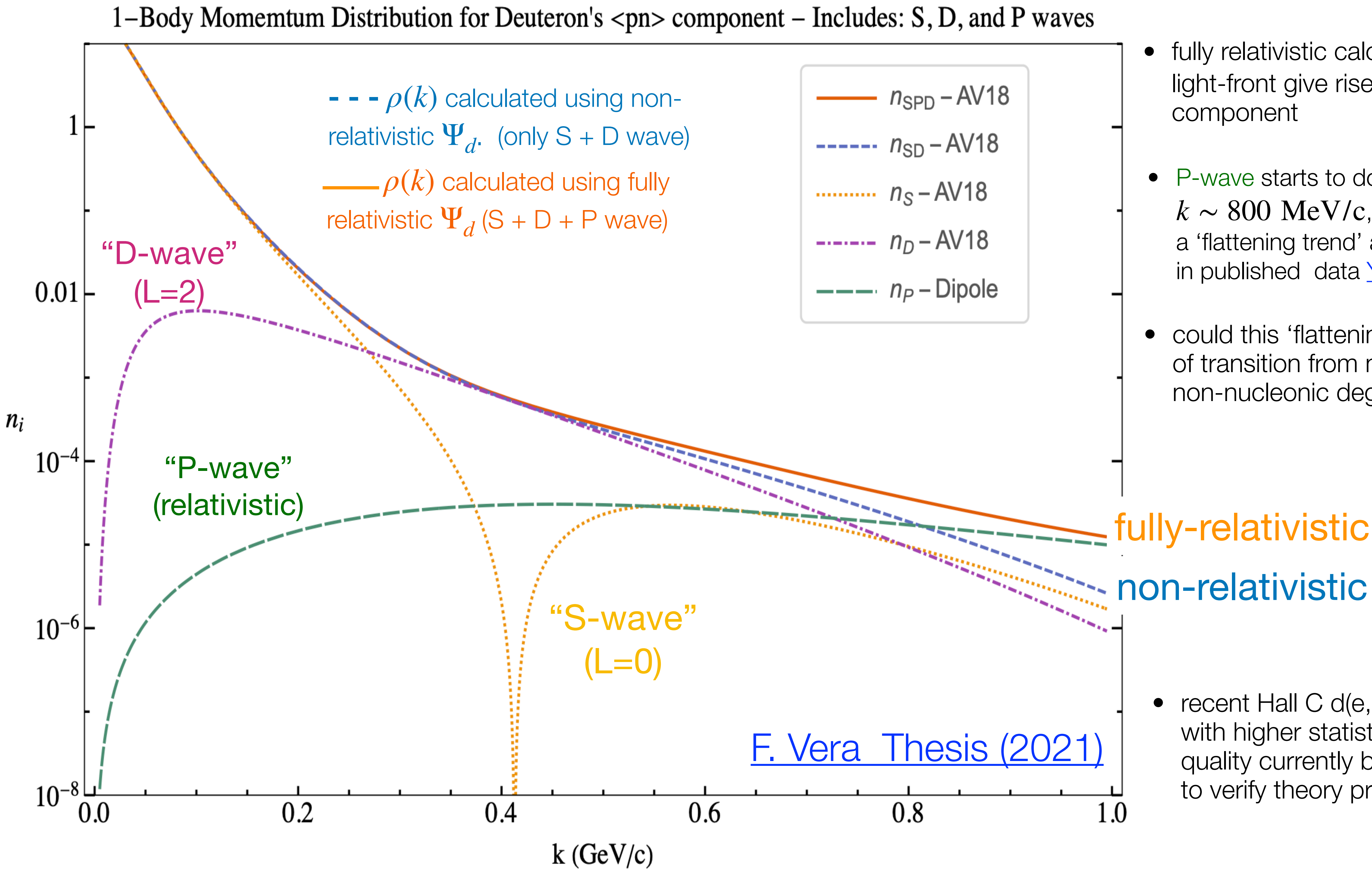
probing the *NN* repulsive core in unpolarized d(e, e'p)



- non-relativistic theory calc. using CD-Bonn (M. Sargsian) reproduce data up to $p_{\mathrm{m}} \sim 0.7$ GeV/c
- no model reproduces data $p_{\mathrm{m}} > 0.7$ GeV/c (non-nucleonic degrees of freedom?, quarks?)

C. Yero et al. Phys.Rev.Lett. 125, 262501 (2020)

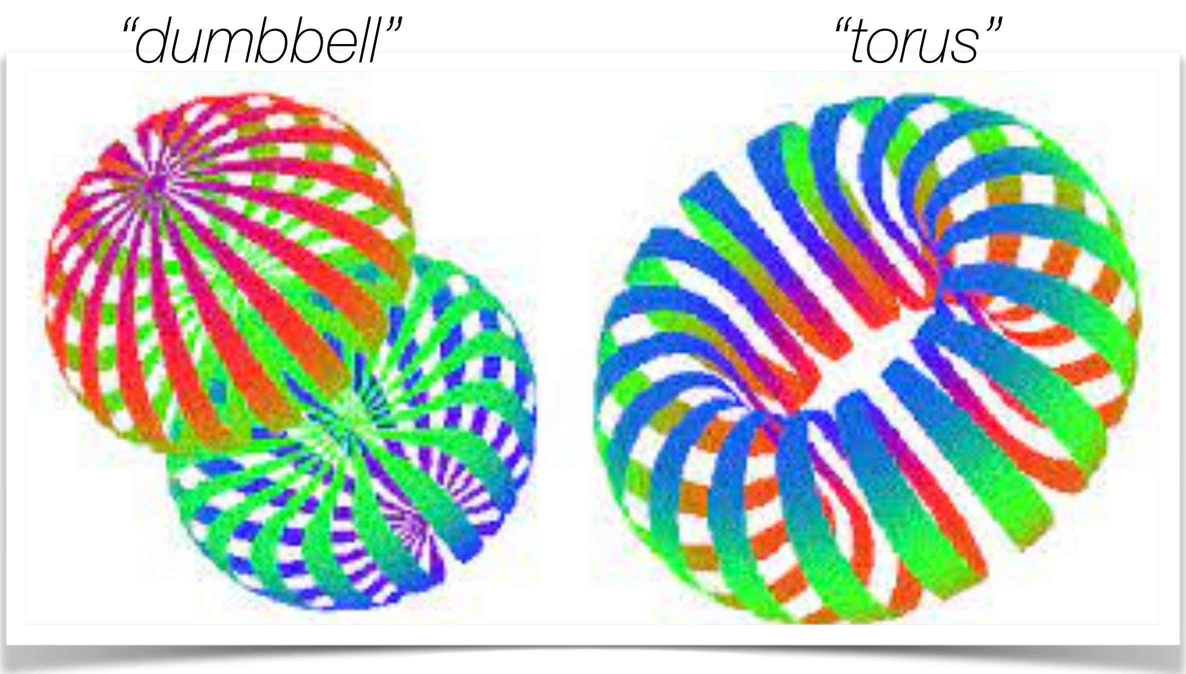
probing the *NN* repulsive core: recent theoretical advances



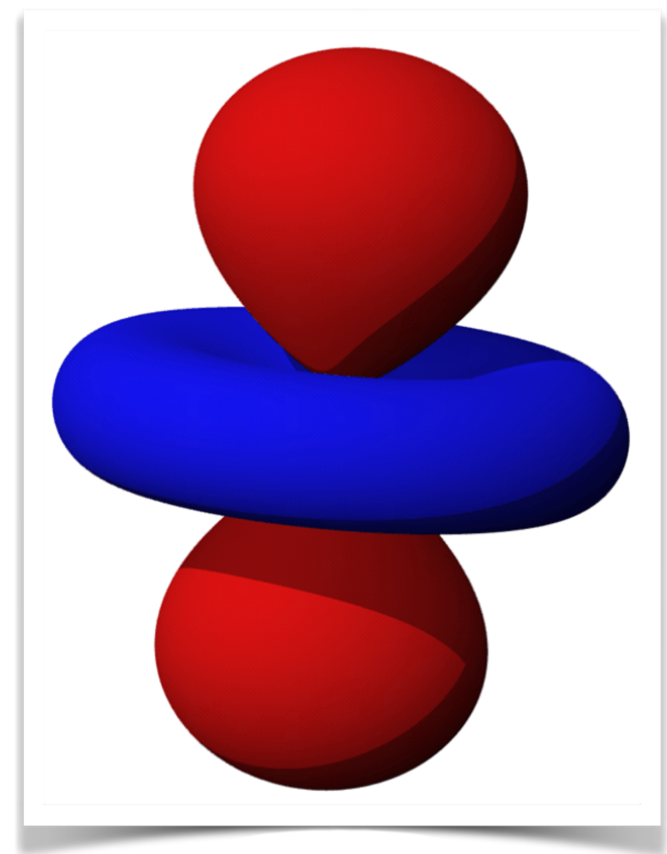
- fully relativistic calculation of Ψ_d in the light-front give rise to a 'P-wave' -like component
- P-wave starts to dominate at $k \sim 800$ MeV/c, characterized by a 'flattening trend' also observed in published data [Yero et al. 2020](#)
- could this 'flattening' be indication of transition from nucleonic to non-nucleonic degrees of freedom?
- recent Hall C d(e, e'p) experiment with higher statistics / improved quality currently being analyzed to verify theory prediction

See Misak Sargsian talk: [ECT Trento workshop 2023](#)

See recently published theoretical paper : "A New Structure in the Deuteron"
[Misak M. Sargsian and Frank Vera Phys. Rev. Lett. 130, 112502](#)



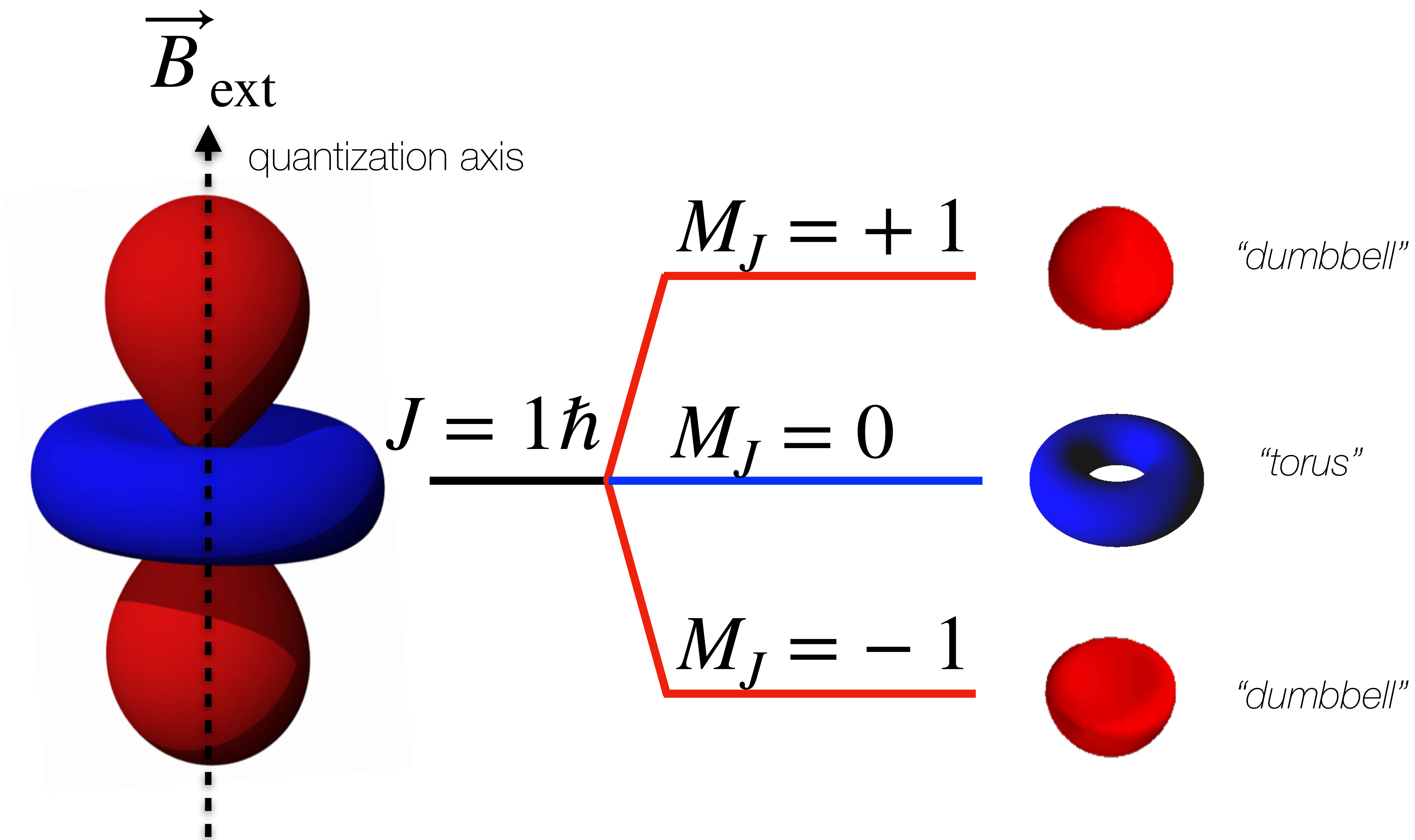
Polarizing the Deuteron



D Keller 2014 J. Phys.: Conf. Ser. 543 012015 (2014)

D. Keller, D. Crabb, D. Day Enhanced tensor polarization in solid-state targets *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment,* vol. 981, pp. 164503, 2020, issn: 0168-9002.

spin-1 (deuteron) system under magnetic field
splits into 3 spin-substates via Zeeman Interaction

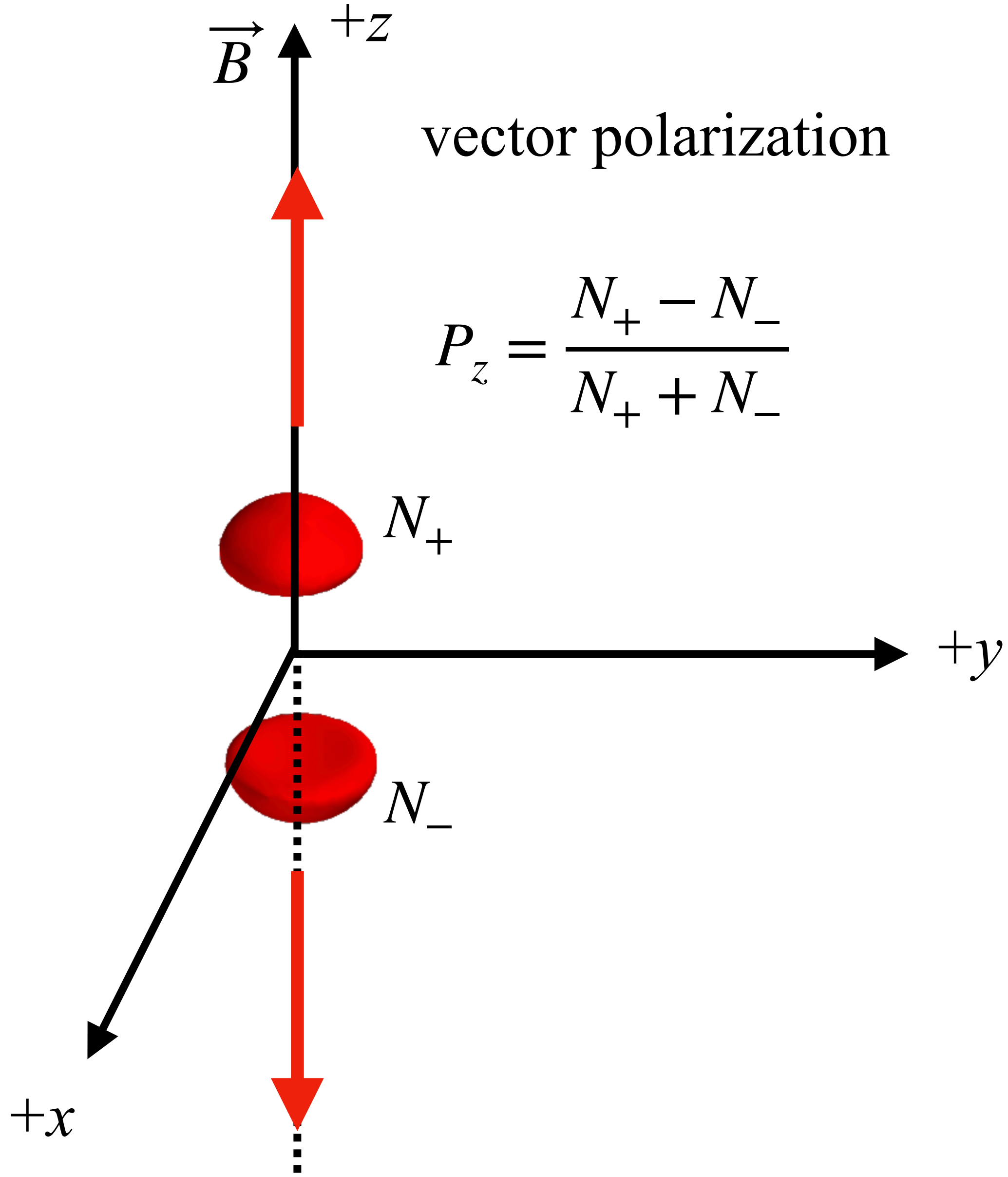


Forest J et al. 1996 Phys. Rev. C 54 646

target spin orientation

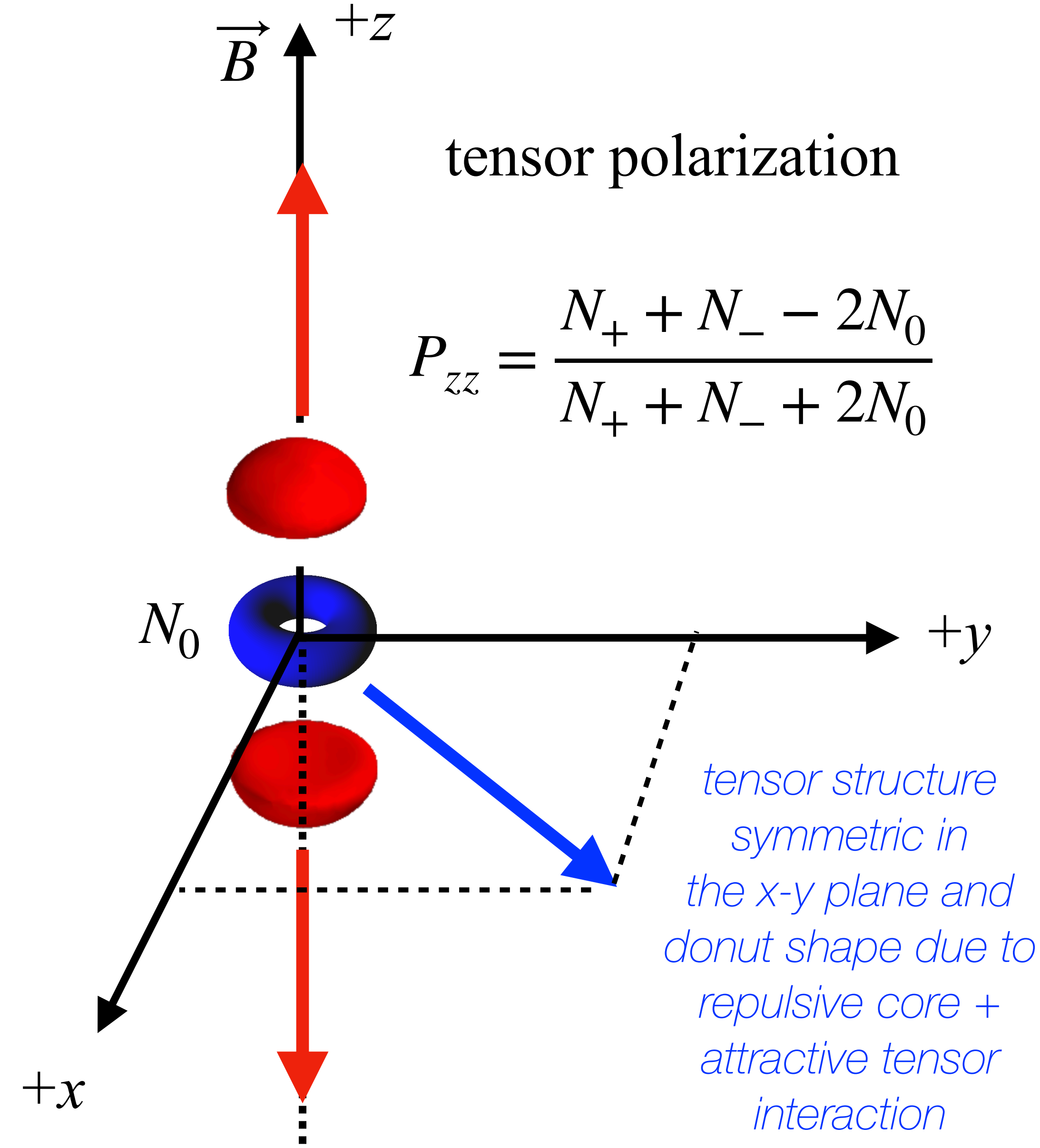
vector polarization

$$P_z = \frac{N_+ - N_-}{N_+ + N_-}$$



tensor polarization

$$P_{zz} = \frac{N_+ + N_- - 2N_0}{N_+ + N_- + 2N_0}$$

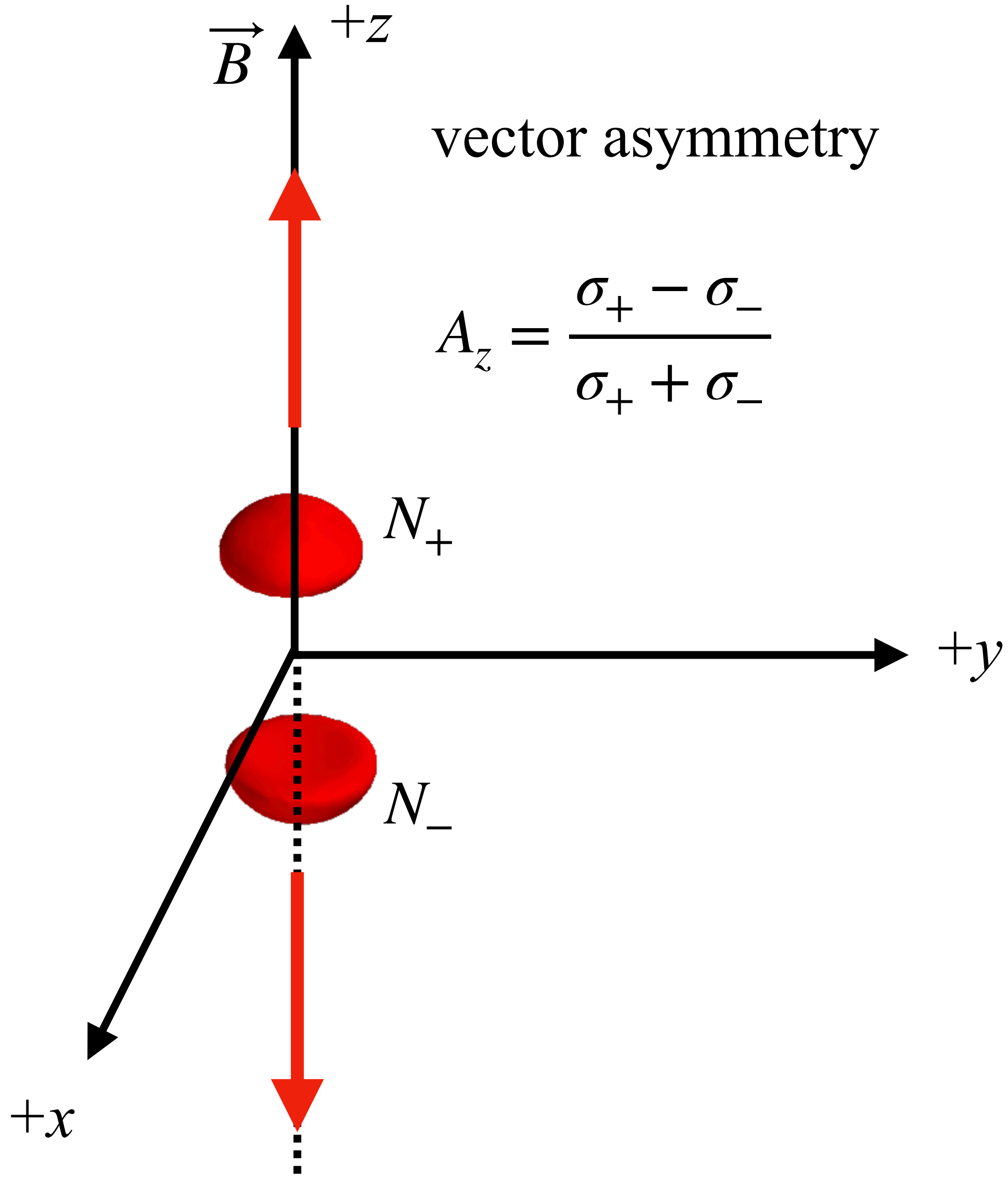


N_+, N_-, N_0 : relative population of target nuclei in a particular spin configuration

target spin asymmetry

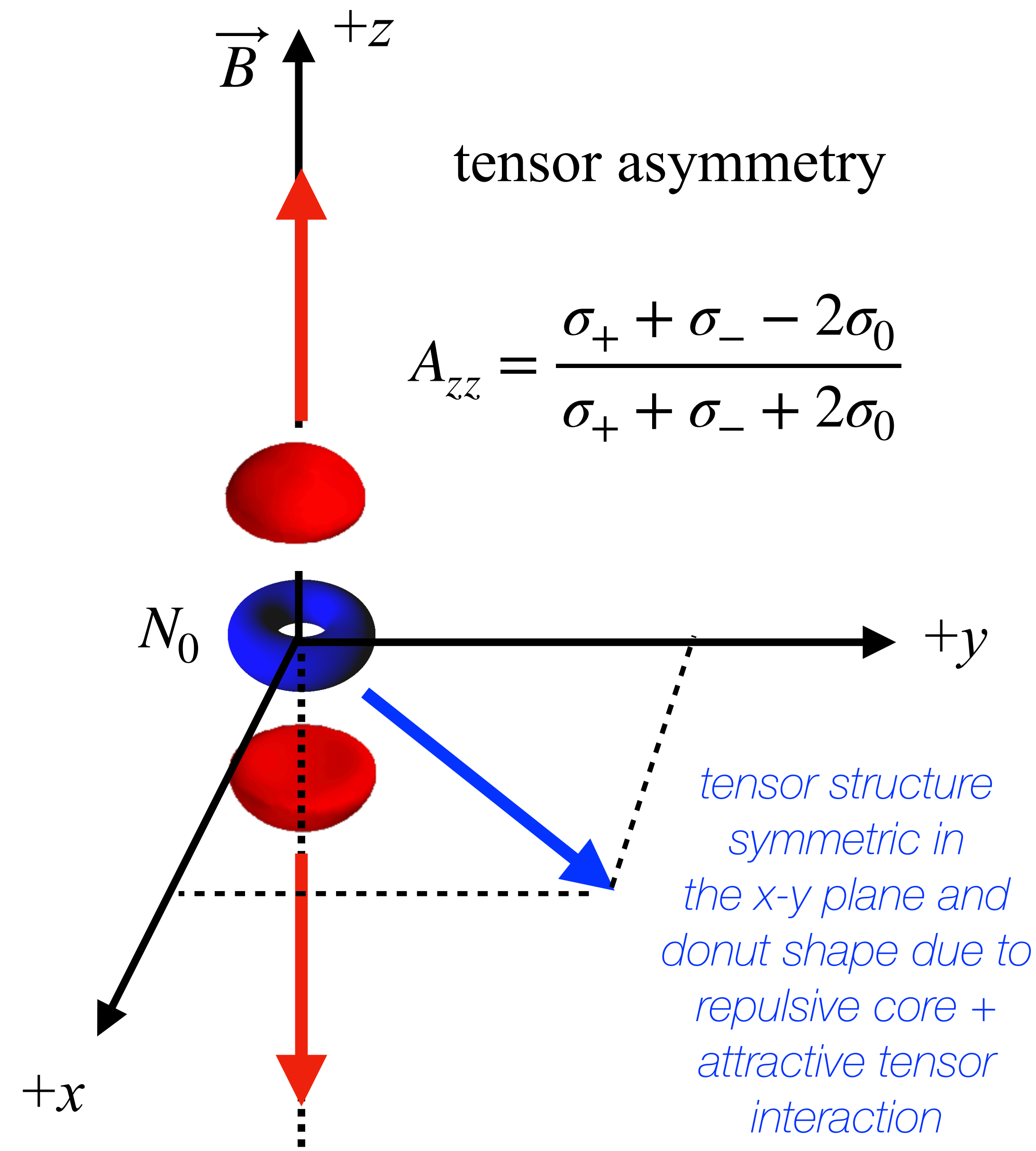
vector asymmetry

$$A_z = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$



tensor asymmetry

$$A_{zz} = \frac{\sigma_+ + \sigma_- - 2\sigma_0}{\sigma_+ + \sigma_- + 2\sigma_0}$$



$\sigma_+, \sigma_-, \sigma_0$: absolute cross sections in particular spin configuration

general d(e, e'p) polarized cross section

$$\sigma_{\text{pol}} = \sigma_{\text{unpol}}\left[1 + P_z A_z + \frac{1}{2} P_{zz} A_{zz} + h_e (A_e + P_z A_{e,z} + P_{zz} A_{e,zz})\right]$$

$$\sigma_i \equiv \frac{d^5\sigma_i}{dE' d\Omega_e d\Omega_p}$$

P_z : target vector polarization

P_{zz} : target tensor polarization

h_e : electron beam helicity

A_e : electron beam analyzing power

$A_{z,(zz)}$: target vector (tensor) analyzing power

$A_{e,z(zz)}$: beam – target vector (tensor) analyzing power

Arenhövel, H., Leidemann, W. & Tomusiak, E.L. The role of the neutron electric form factor in d(e, e′ N)N including polarization observables. Z. Physik A - Atomic Nuclei 331, 123–138 (1988)

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integrate over
electron beam-helicity

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P_{zz} : target tensor polarization

h_e : electron beam helicity

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$$\sigma_i \equiv \frac{d^5\sigma_i}{dE' d\Omega_e d\Omega_p}$$

integrate over vector polarization

integrate over electron beam-helicity

P_z : target vector polarization

P_{zz} : target tensor polarization

h_e : electron beam helicity

A_e : electron beam analyzing power

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general d(e, e'p) polarized cross section

$$\sigma_{\text{pol}} = \sigma_{\text{unpol}}\left[1 + \frac{1}{2}P_{zz}A_{zz}\right]$$

Simplified tensor-polarized cross sections from which tensor-asymmetry is extracted

$$\Longrightarrow A_{zz} = \frac{2}{P_{zz}}\left(\frac{\sigma_{\text{pol}}}{\sigma_{\text{unpol}}} - 1\right)$$

P_{zz} : target tensor polarization

$\sigma_{\text{pol, unpol}}$: polarized, unpolarized cross sections

A_{zz} : target tensor analyzing power

Azz can also be expressed in terms of the spin-dependent cross sections and can be substituted above and solve for spin-dependent absolute cross sections →

$$A_{zz} = \frac{(\sigma_{+1} - \sigma_0) + (\sigma_{-1} - \sigma_0)}{\sigma_{-1} + \sigma_0 + \sigma_{+1}} = \frac{2}{3}\frac{(\sigma_{\pm 1} - \sigma_0)}{\sigma_{unpol}}$$

See W U Boeglin 2014 J. Phys.: Conf. Ser. 543 012011
for detailed step-by-step calculations of the above Azz expressions

spin-dependent d(e, e'p) polarized cross section

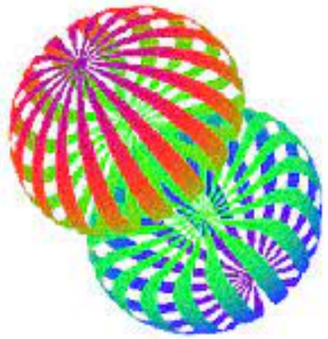
spin-dependent cross sections may be expressed as: $\sigma_m = \sigma_m(P_{zz}, \sigma_{\text{pol}}, \sigma_{\text{unpol}})$

$$\sigma_0 = \sigma_{\text{unpol}}\left(1 - \frac{2}{P_{zz}}\left(\frac{\sigma_{\text{pol}}}{\sigma_{\text{unpol}}} - 1\right)\right)$$

"torus" component

$$\sigma_{\pm 1} = \sigma_{\text{unpol}}\left(1 + \frac{1}{P_{zz}}\left(\frac{\sigma_{\text{pol}}}{\sigma_{\text{unpol}}} - 1\right)\right)$$

"dumbbell" component



Under PWIA assumption: spin-dependent ~momentum distributions ($\rho(p_m)_{0,\pm 1}$) can be extracted from the spin-dependent cross sections $\sigma_{0,\pm 1}$

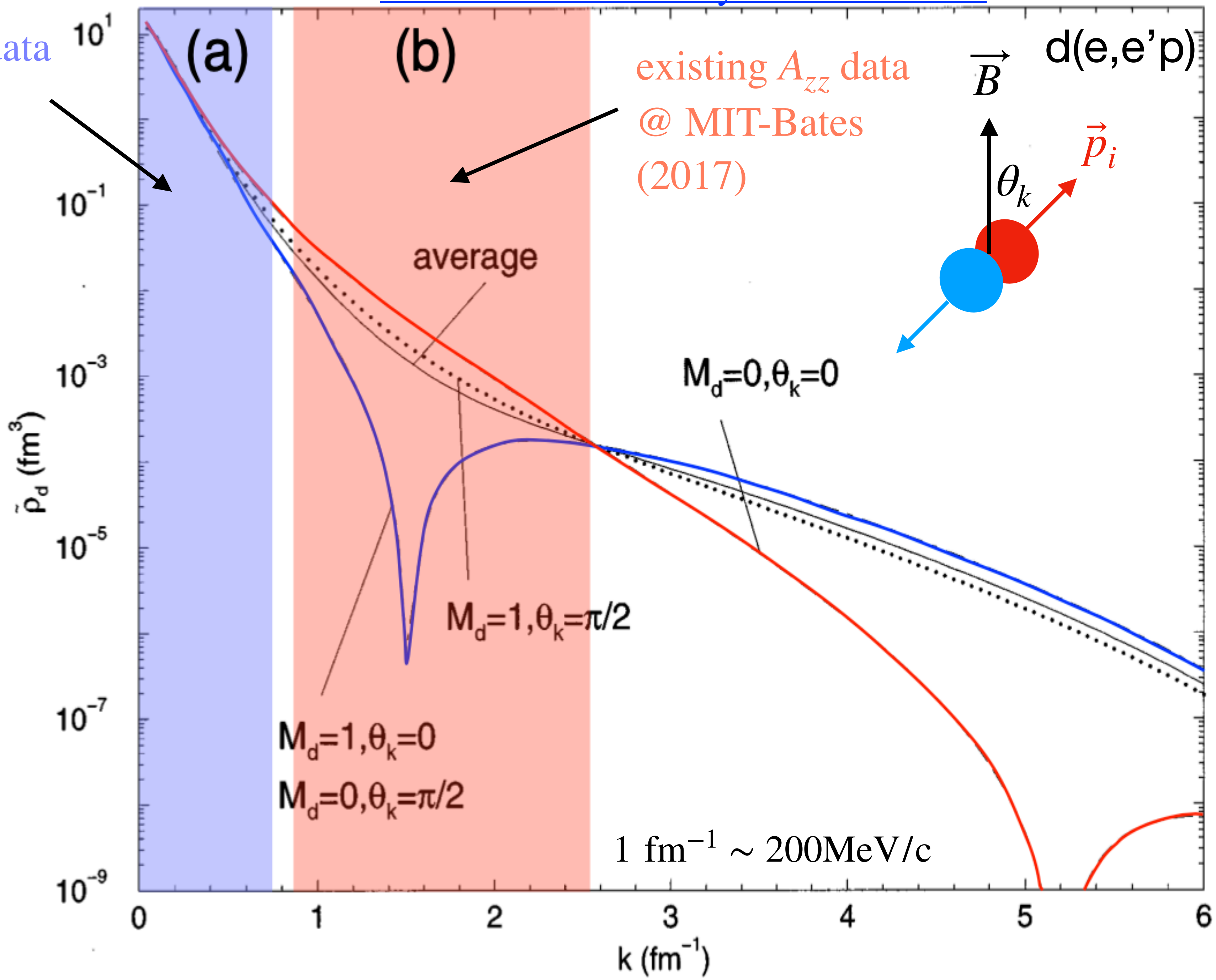
$$\sigma_{red} \equiv \frac{\sigma_{0,\pm 1}}{k \cdot \sigma_{eN}} \sim \rho_{0,\pm 1}(p_i)$$

spin-dependent reduced cross sections
(are ~spin-dependent momentum distributions under PWIA)

See W U Boeglin 2014 J. Phys.: Conf. Ser. 543 012011
for detailed step-by-step calculations of the above formulas

theoretical spin-dependent momentum distributions

Forest J et al. 1996 Phys. Rev. C 54 646



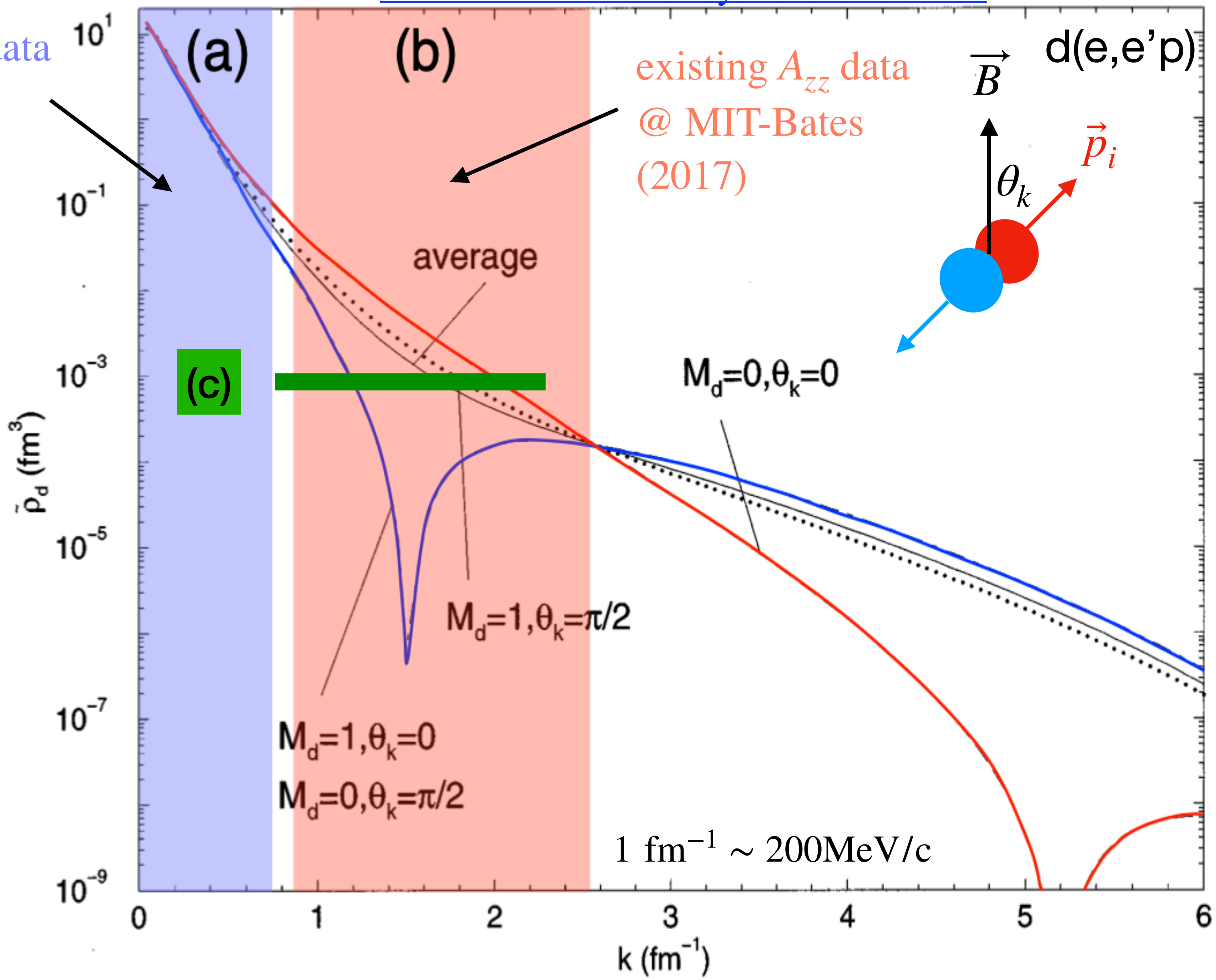
(a) $k < 150$ MeV/c missing momenta covered by NIKHEF: Zhou Z L et al. 1999 Phys. Rev. Lett. 82 687

(a), (b) $k < 500$ MeV/c missing momenta covered by MIT-Bates: A. DeGrush *et al*. (BLAST Collaboration) Phys. Rev. Lett. **119**, 182501 (2017)

theoretical spin-dependent momentum distributions

Forest J et al. 1996 Phys. Rev. C 54 646

existing A_{zz} data @ NIKHEF (1997)



(c) proposed kinematic coverage @ Hall C:

missing momenta k ~ 150 - 450 MeV/c and $Q^2 = 2.9$ or 3.5 GeV^2 or …

(to be determined)

previous tensor-polarized d(e, e'p) measurements

Z.-L. Zhou *et al.* Phys. Rev. Lett. **82**, 687 (1999)

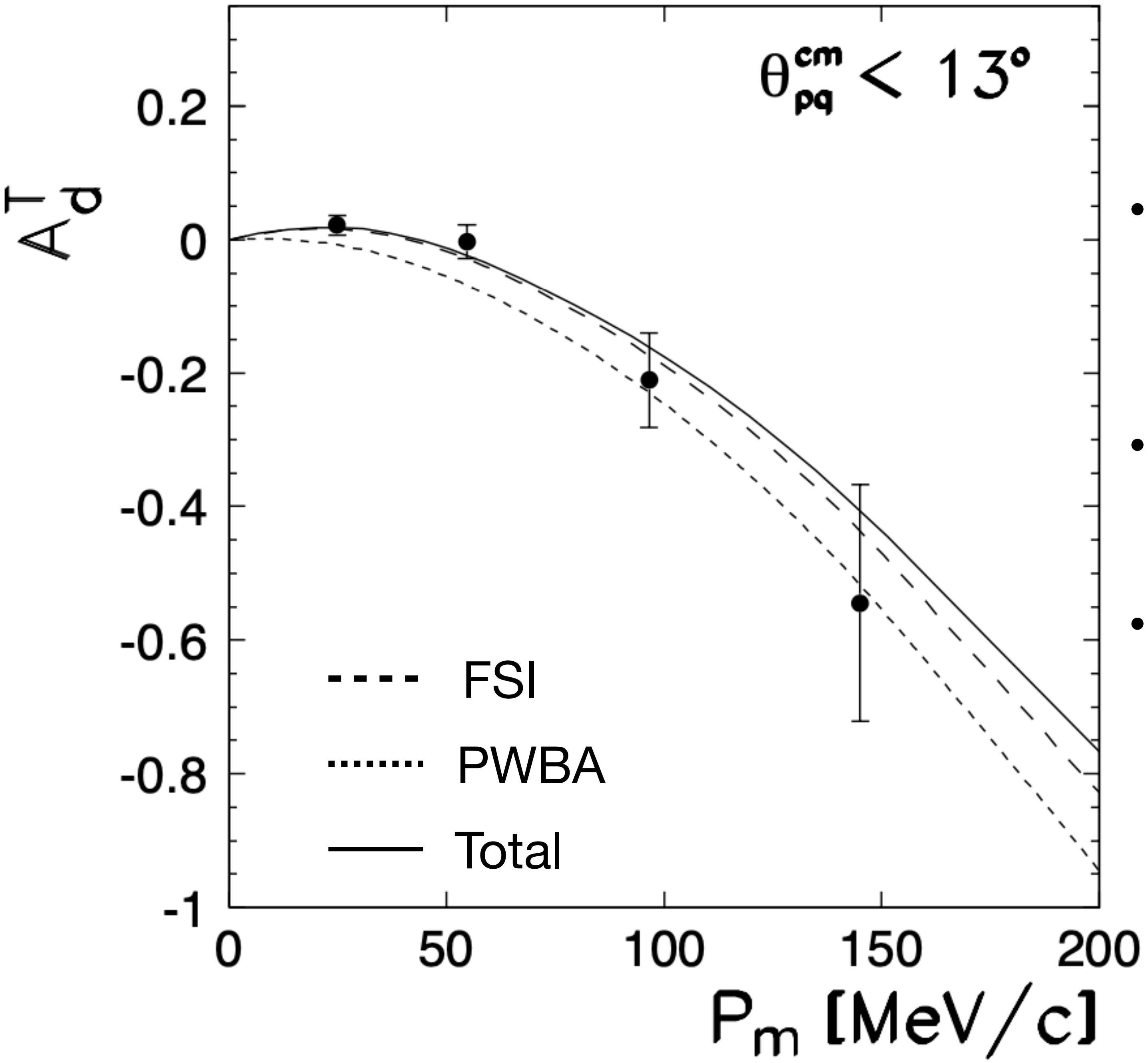


FIG. 3. A_d^T as a function of p_m for parallel kinematics (i.e., $\theta_{pq}^{cm} < 13°$). The short-dashed curve represents the result for PWBA; in the long-dashed curve FSI effects are also included, and the solid curve represents the full calculation.

- **@ NIKHEF:** first-ever exclusive d(e, e'p) tensor-polarized data ($Q^2 < 1$ GeV^2 , Pm < 150 MeV/c)
- extracted deuteron tensor-asymmetry A_d^T(or, A_{zz}) at 3-momentum transfers $|\vec{q}| = 1.7\text{fm}^{-1}$ (~340 MeV)
- dominated by FSI, MEC, IC, but effects well described by theoretical model

Theory calculations:
H. Arenhövel, W. Leidemann, and E.L. Tomusiak, Phys. Rev. C **52**, 1232 (1995).

previous tensor-polarized d(e, e'p) measurements

A. DeGrush *et al.* (BLAST Collaboration) Phys. Rev. Lett. **119**, 182501 (2017)

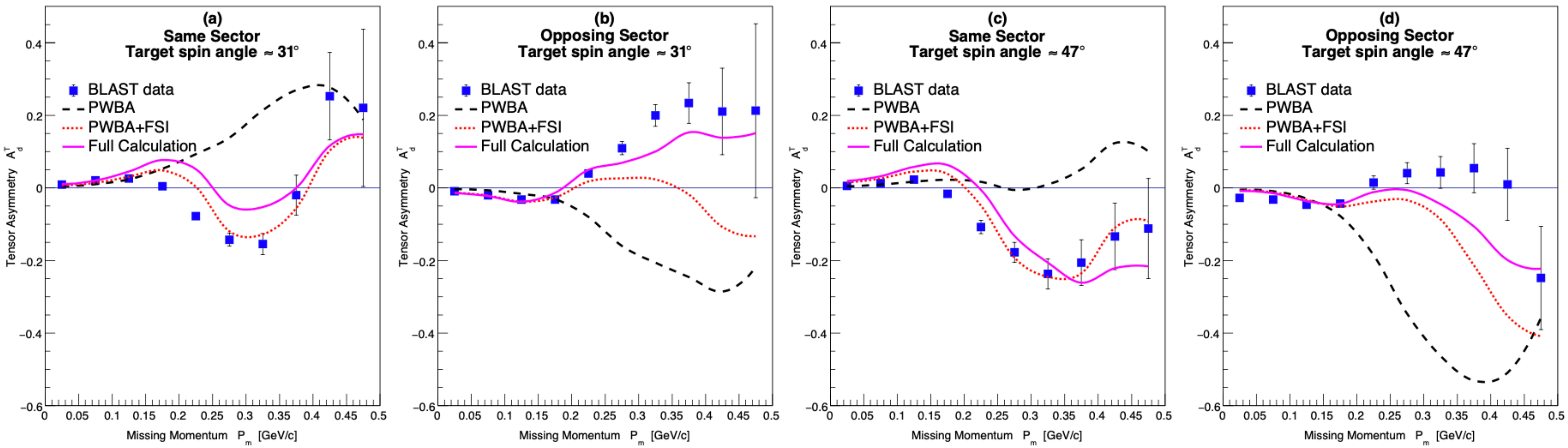


FIG. 3. Tensor asymmetries A_d^T for $0.1 < Q^2 < 0.5$ (GeV/c)^2 vs. p_m. Panels (a) and (c) refer to *same sector* kinematics for target spin angles ≈ 32° and ≈ 47°. Panels (b) and (d) refer to *opposing sector* kinematics for the same target spin angles.

- **@ MIT-Bates:** exclusive d(e, e'p) tensor-polarized data ($Q^2 \sim 0.1 - 0.5$ GeV^2 , up to Pm ~ 500 MeV/c, the highest-to-date)

- extracted A_{zz} analyzing power dominated by FSI, MEC, IC, but effects mostly well-described by theoretical calculations

Theory calculations: H. Arenhovel, W. Leidemann, and E.L. Tomusiak, Eur. Phys. J. **A23**, 147–190 (2005)

tensor-polarized d(e, e'p) measurements @ Hall C at large Q^2 and $x_{bj} > 1$

NO exclusive d(e, e'p) A_{zz} measurements
at $Q^2 > 1\ \mathrm{GeV}^2$ exist to-date

NO $\rho_{0,\pm}$ spin-dependent d(e, e'p)
momentum distributions exist to-date

We propose to:

(1) measure tensor-analyzing power A_{zz},

(2) measure absolute unpolarized/polarized cross sections, $\sigma_{\mathrm{pol,unpol}}$

(3) extract the spin-dependent momentum distributions $\rho_{0,\pm}$

exclusive tensor-polarized d(e, e’p) rates estimates

Selecting Optimal Central Kinematics

$E_b = 10.549[\text{GeV}]$ $\rho_t = 0.167[\text{g/cm}^3]$
LD2 10 cm $\sigma_t = 1670[\text{mg/cm}^2]$
$I_b = 100$ [nA] 168 [hrs]

radiative_effects: ON

limiting_factor: 5T magnet opening angle +/- 35 deg
limits HMS (proton) angles we can explore to < 35 deg
(will need to re-calculated !)

P_{miss}[MeV]	k_f[GeV]	θ_e[deg]	p_f[GeV]	θ_p[deg]	$\|\vec{q}\|$[GeV]	θ_q[deg]	θ_{rq}[deg]	θ_{pq}[deg]	Q^2[GeV^2]
300	9.7261	8.204	1.4322	63.346	1.6665	56.3924	35.311	6.9542	2.1
300	9.3870	9.817	1.8241	56.346	2.0616	50.9282	35.0368	5.4179	2.9
300	9.1252	10.941	2.1142	52.191	2.3510	47.4551	35.5878	4.7366	3.5

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-----------------------------
  d(e,e'p) Rate Estimates
-----------------------------

Q2 = 2.1 GeV^2
Pm Setting: 300
Model: Laget FSI
Ib [uA]      = 0.100
time [hr]    = 168.000
charge [mC] = 60.480
Pm counts   = 1535.644
d(e,e'p) Rates [Hz] = 2.539E-03
DAQ Rates [Hz] = 0.032
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```
-----------------------------
  d(e,e'p) Rate Estimates
-----------------------------

Q2 = 2.9 GeV^2
Pm Setting: 300
Model: Laget FSI
Ib [uA]      = 0.100
time [hr]    = 168.000
charge [mC] = 60.480
Pm counts   = 3275.409
d(e,e'p) Rates [Hz] = 5.416E-03
DAQ Rates [Hz] = 0.010
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  d(e,e'p) Rate Estimates
-----------------------------

Q2 = 3.5 GeV^2
Pm Setting: 300
Model: Laget FSI
Ib [uA]      = 0.100
time [hr]    = 168.000
charge [mC] = 60.480
Pm counts   = 1503.470
d(e,e'p) Rates [Hz] = 2.486E-03
DAQ Rates [Hz] = 0.005
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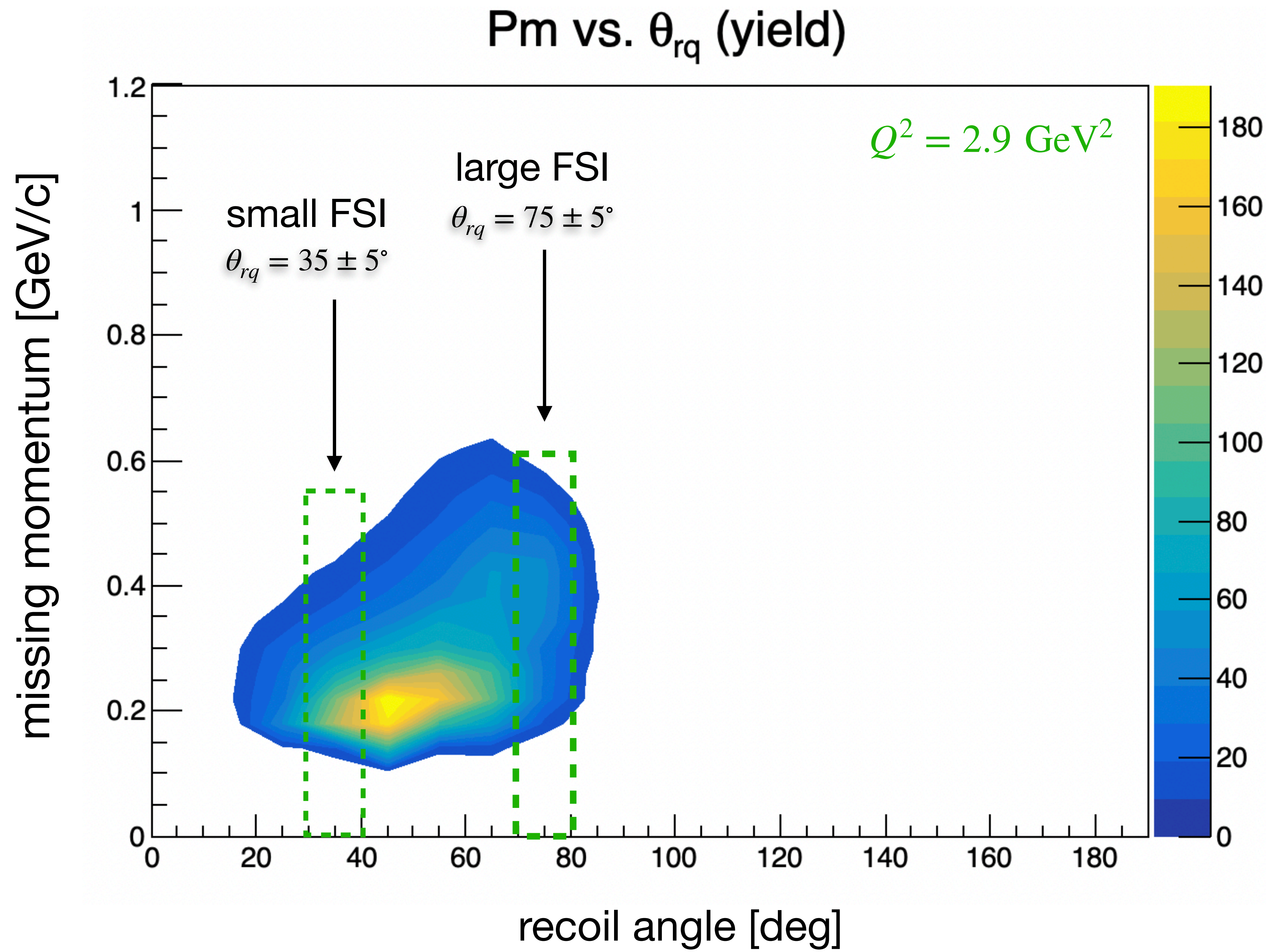
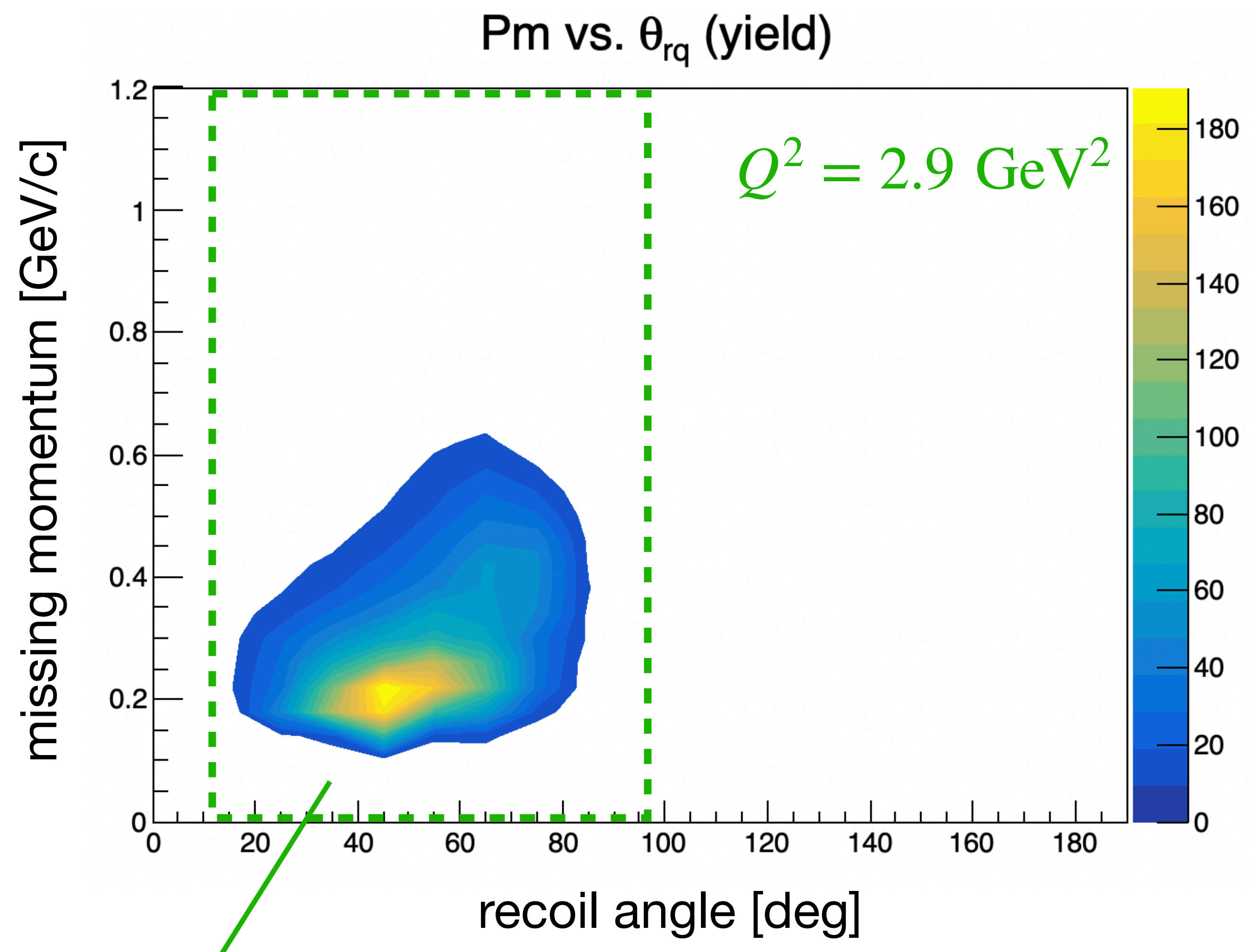
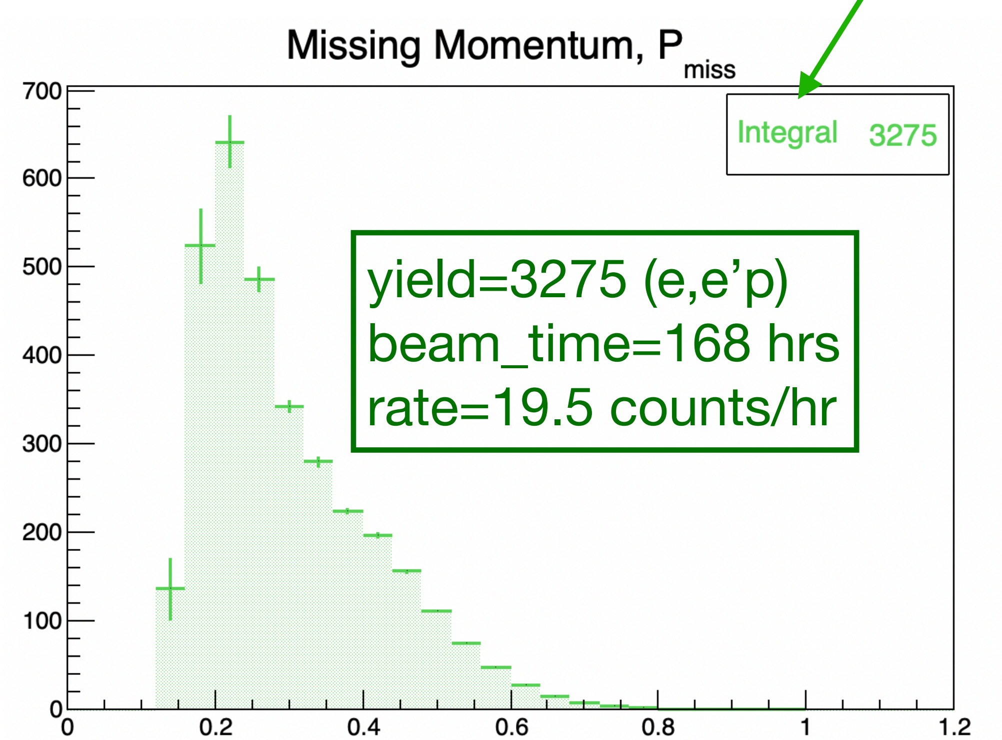
Selecting minimal FSI d(e, e'p) kinematical bins



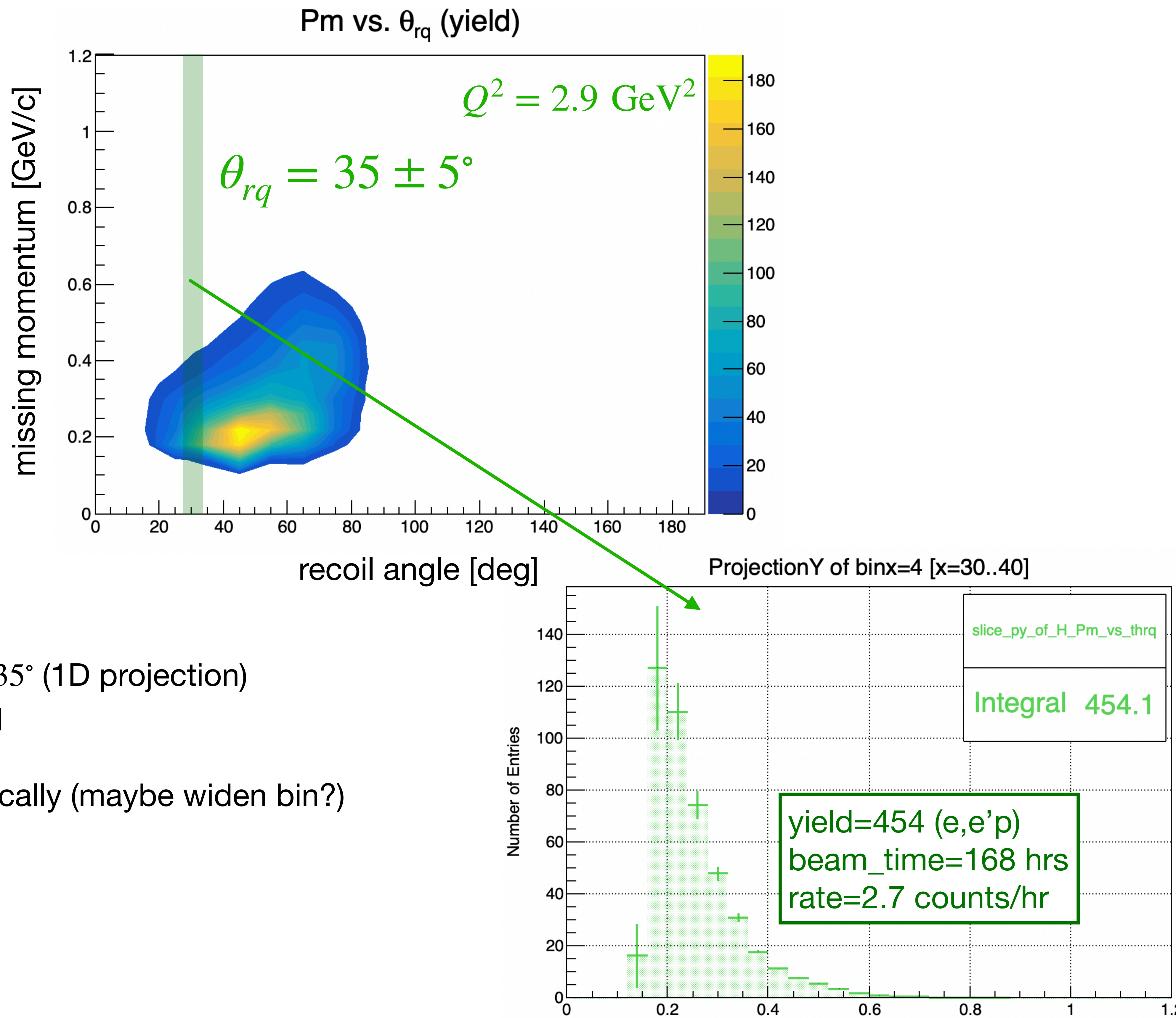
Selecting minimal FSI d(e, e'p) kinematical bins





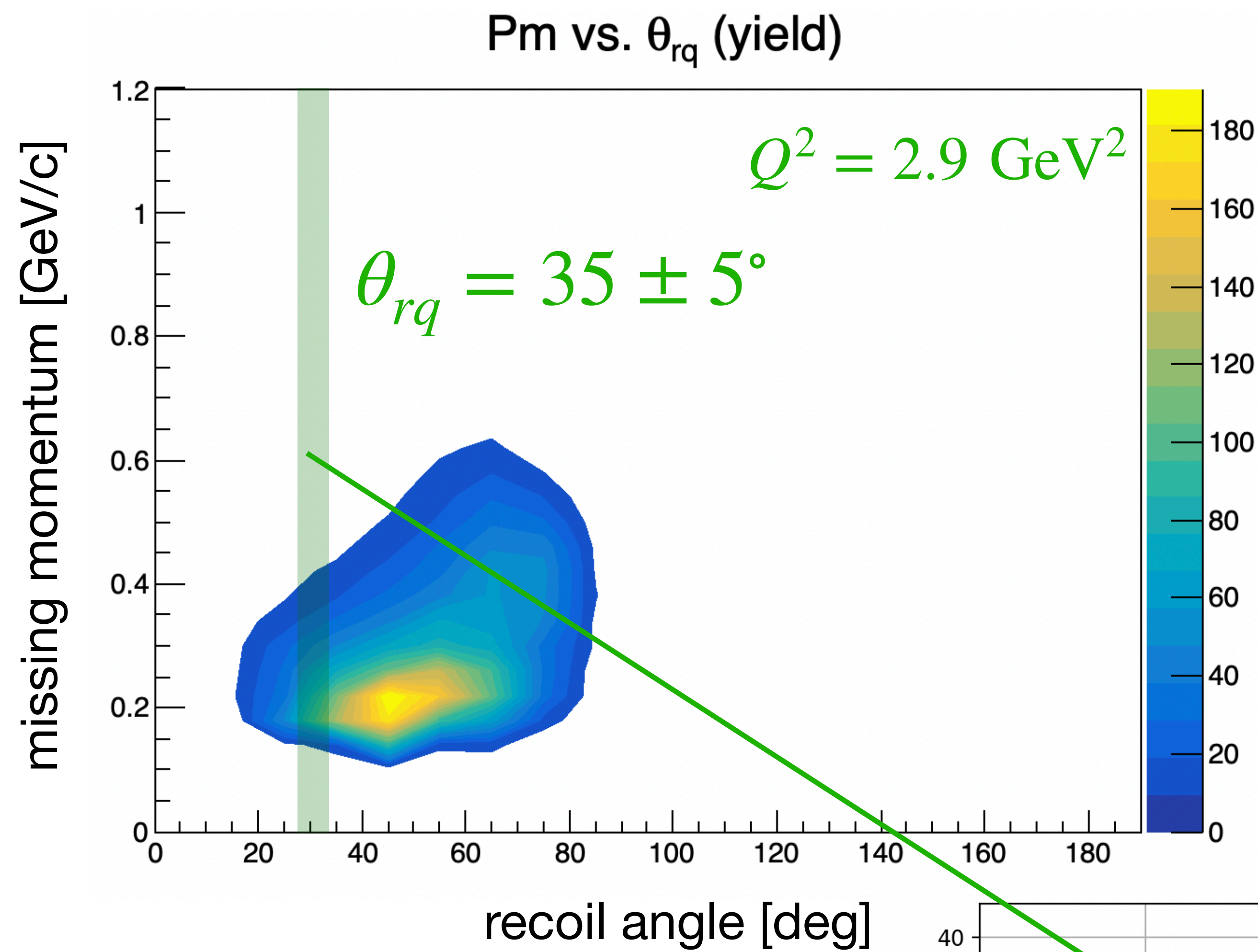
- integrated over all recoil θ_{rq} angles (1D projection)
- includes bins where FSI are large (>45 deg), therefore NOT ideal for extracting momentum distributions $\rho(p_m)_{o,\pm}$, as PWIA condition NOT met

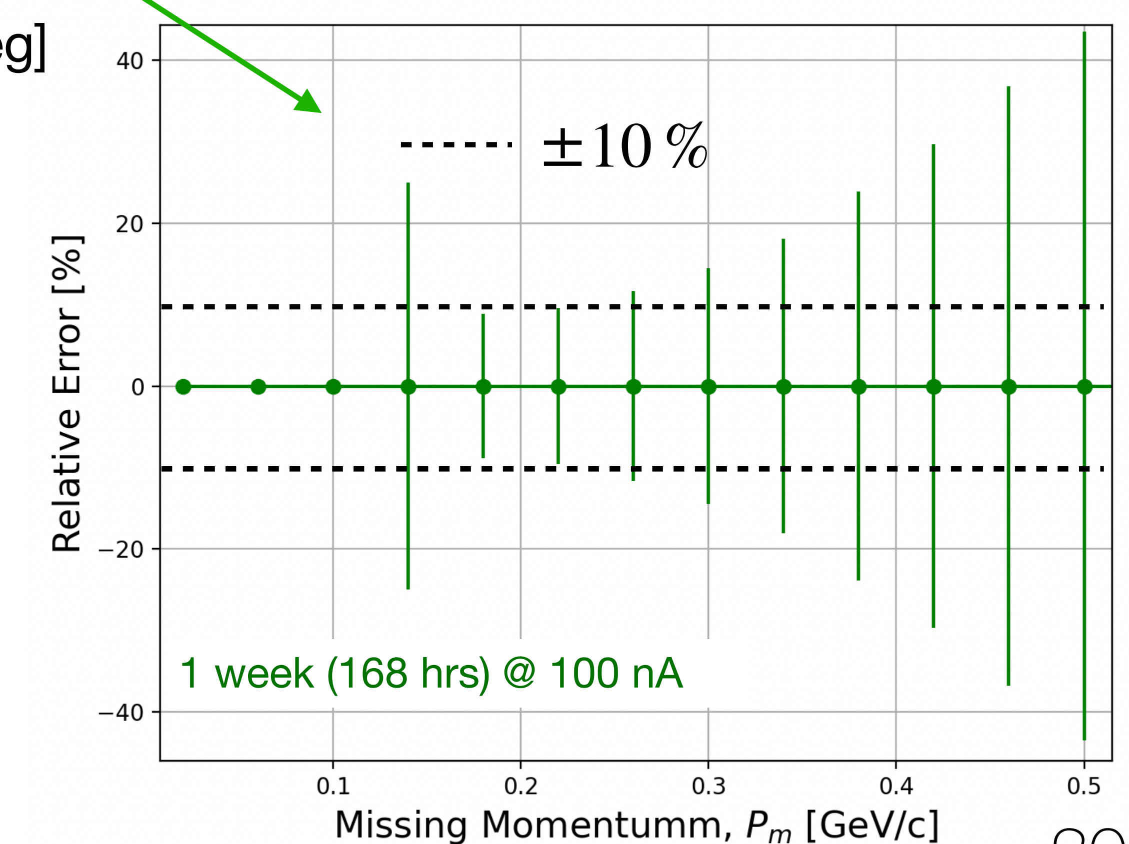
Selecting minimal FSI d(e, e'p) kinematical bins



- selected bin $\theta_{rq} \sim 35°$ (1D projection) where FSI reduced
- rates drop dramatically (maybe widen bin?)

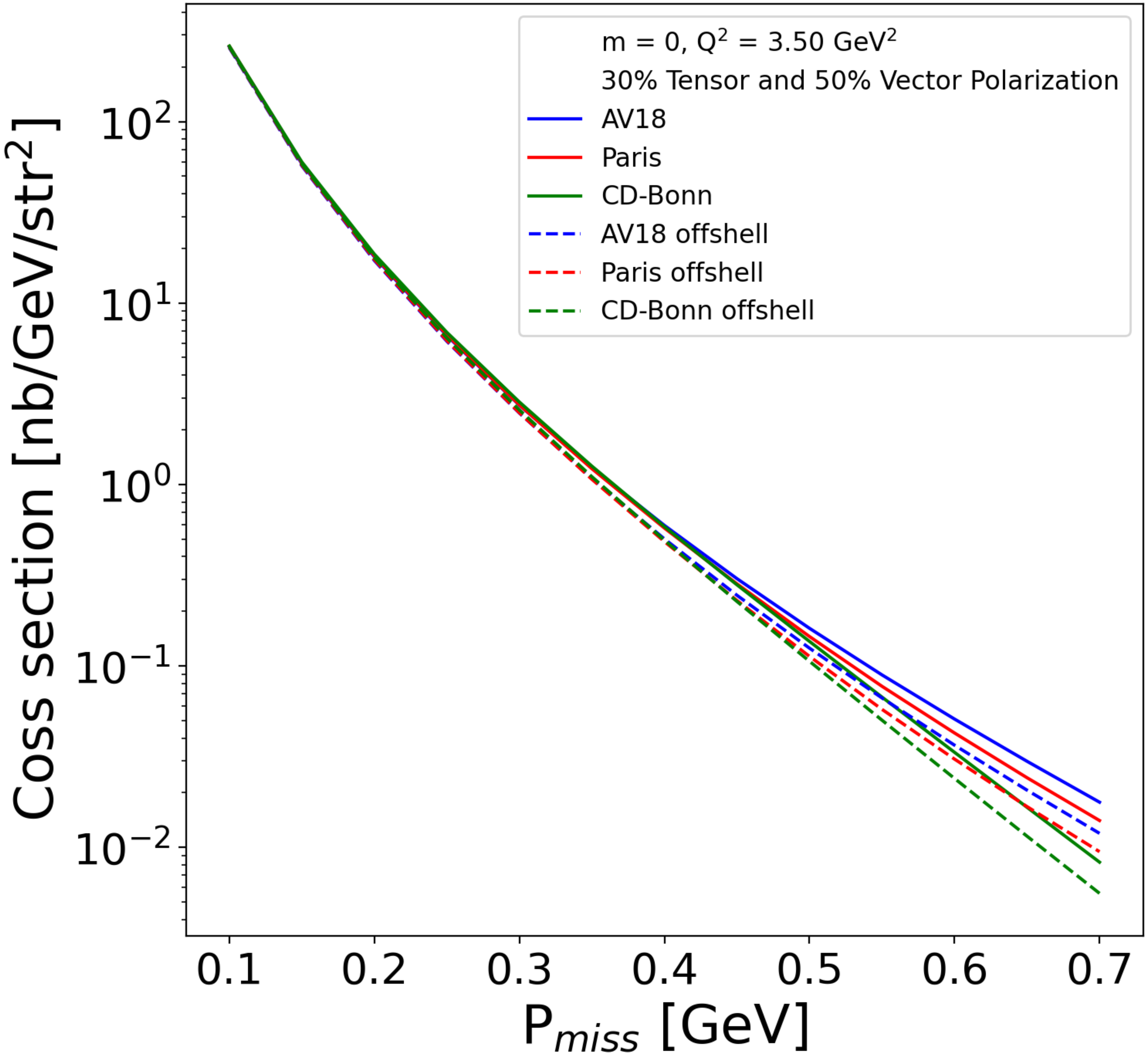
Selecting minimal FSI d(e, e'p) kinematical bins





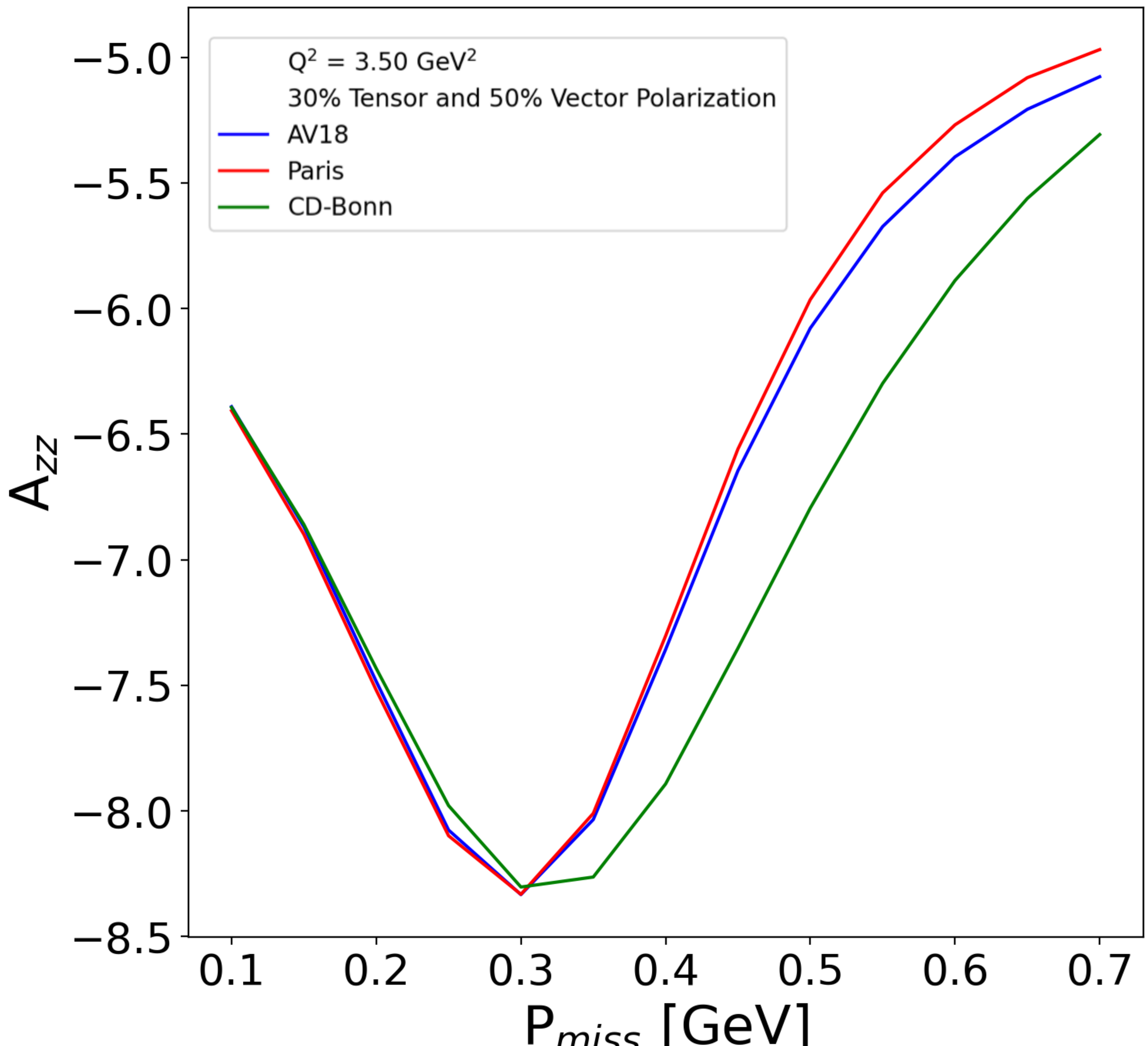
- selected bin $\theta_{rq} \sim 35^\circ$ (1D projection) where FSI reduced
- rates drop dramatically (maybe widen bin?)
- 1 week (168 hrs) @ 100 nA (unpolarized)
  < 20 % stats error for missing momenta
  Pm ~ 180 - 340 MeV/c

exclusive tensor-polarized
d(e, e'p) theory calculations
@ $Q^2 = 3.5\ \mathrm{GeV}^2$



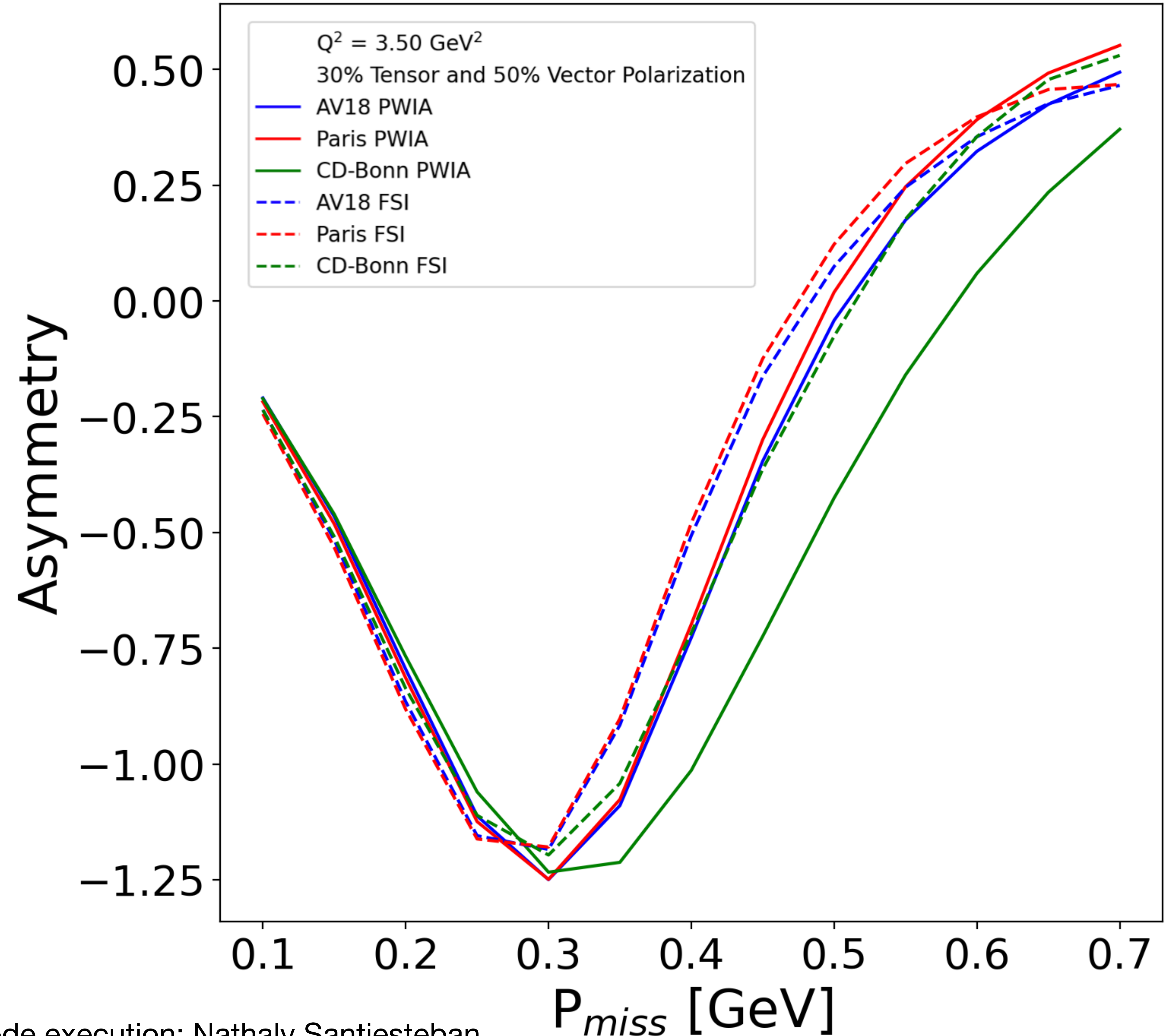
Plots / code execution by: Nathaly Santiesteban
Theoretical calculation by: Misak Sargsian

polarized d(e,e'p) Tensor Asymmetry



Plots / code execution by: Nathaly Santiesteban
Theoretical calculation by: Misak Sargsian

Tensor Asymmetry (after multiplying Azz by some kinematical factors)



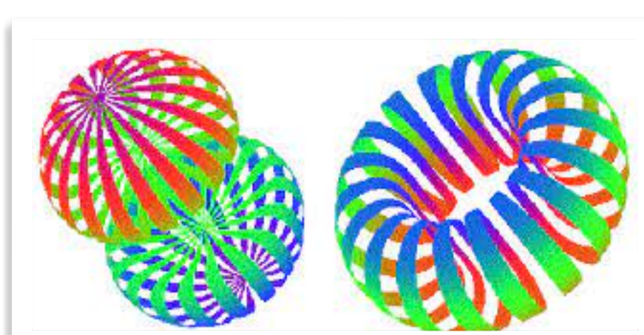
Plots / code execution: Nathaly Santiesteban
Theoretical calculation by: Misak Sargsian

Summary

- tensor-polarized d(e, e'p) provides unique opportunity to carry out detailed study of deuteron short-range structure

- we propose:
  - measure exclusive tensor asymmetry A_{zz} (at unprecedented large Q^2)
  - measure absolute spin projection dependent absolute cross sections, $\sigma_{0,\pm}$
  - extract spin-dependent reduced cross sections, which under PWIA ~ momentum distributions $\rho(p_m)_{o,\pm}$

- these measurements will complementary to the inclusive b1/Azz approved experiments and will provide great insight into the toroidal structure of the deuteron which is directly related to the tensor (attractive) and repulsive core of the deuteron



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Thank You

University of New Hampshire

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Old Dominion University

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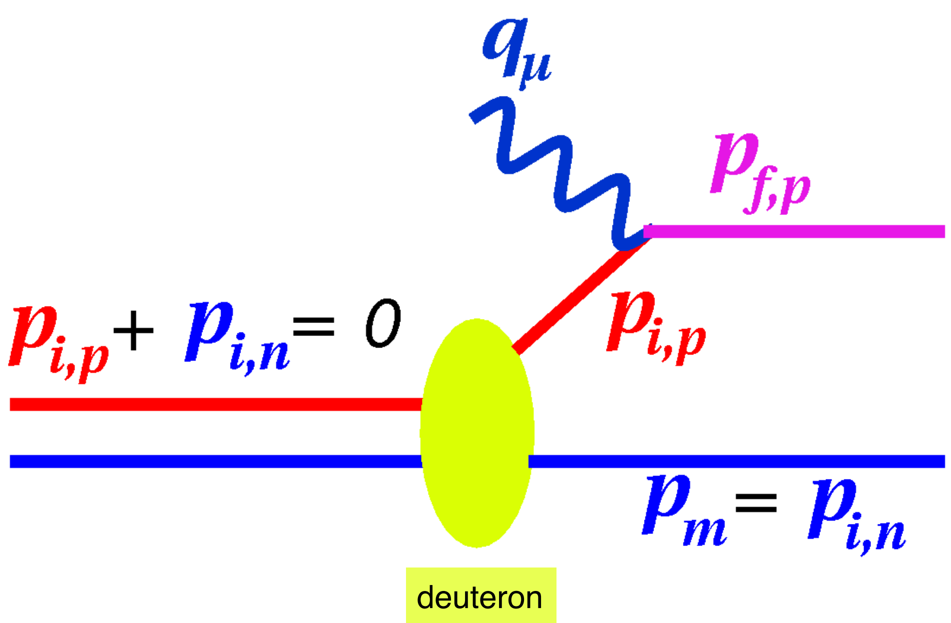
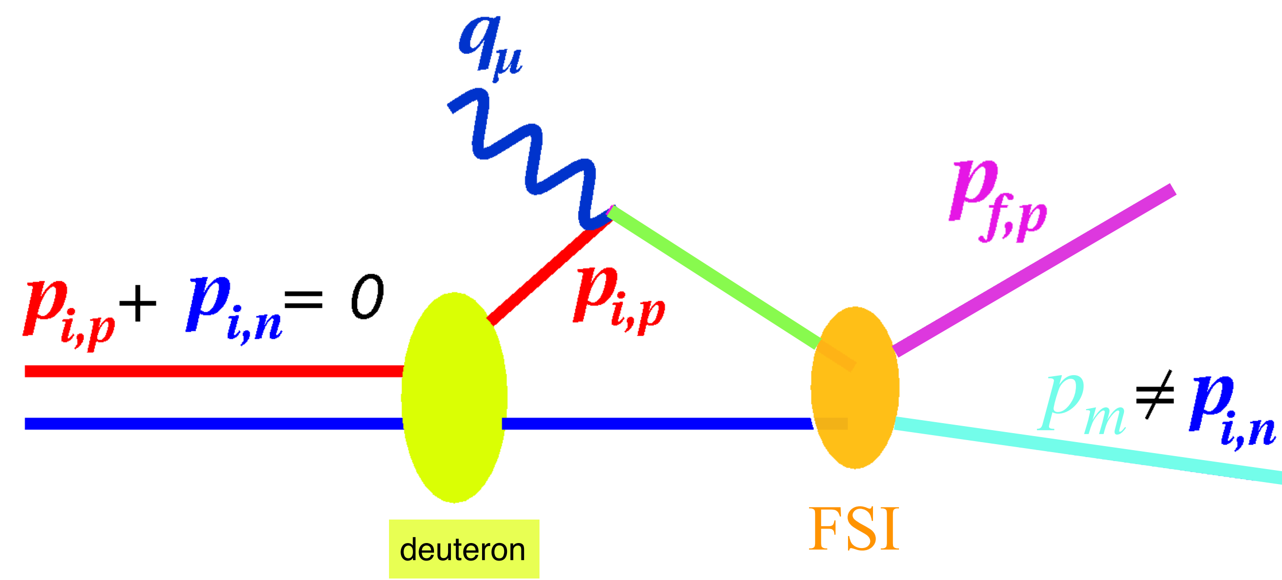
back-up slides

d(e, e'p) reaction mechanisms

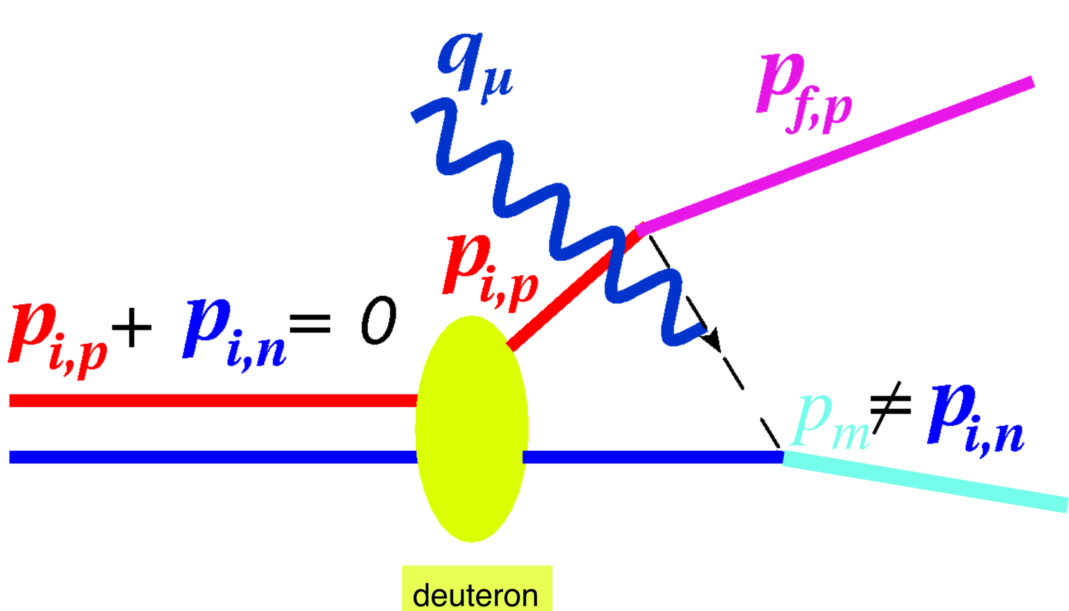


Plane Wave Impulse Approximation (PWIA)



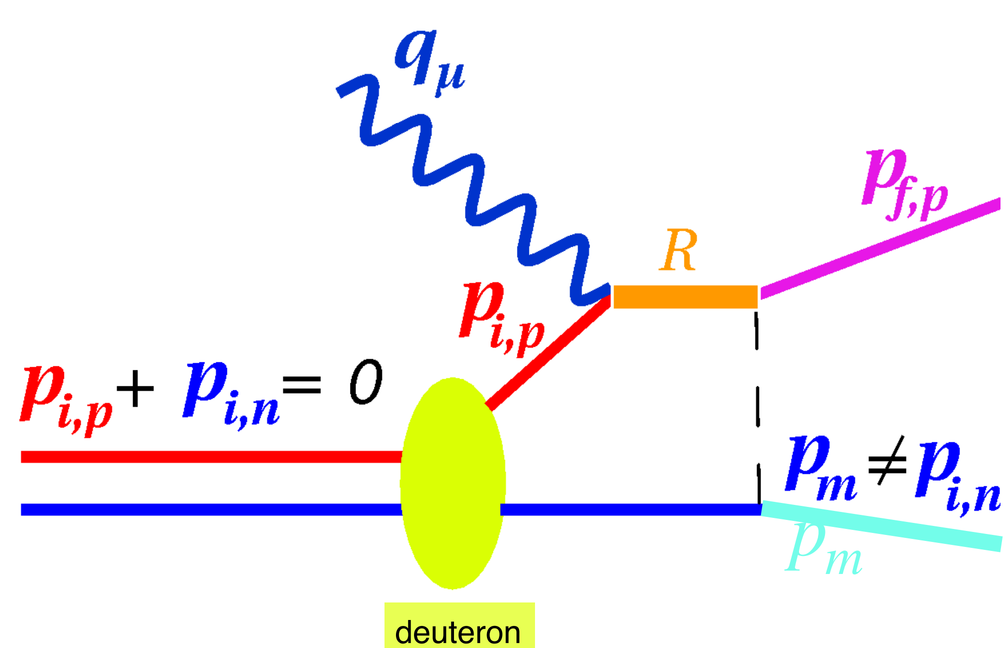
Final State Interactions (FSI)

suppressed at specific $\theta_{nq} \sim 35°$



Meson-Exchange Currents (MEC)

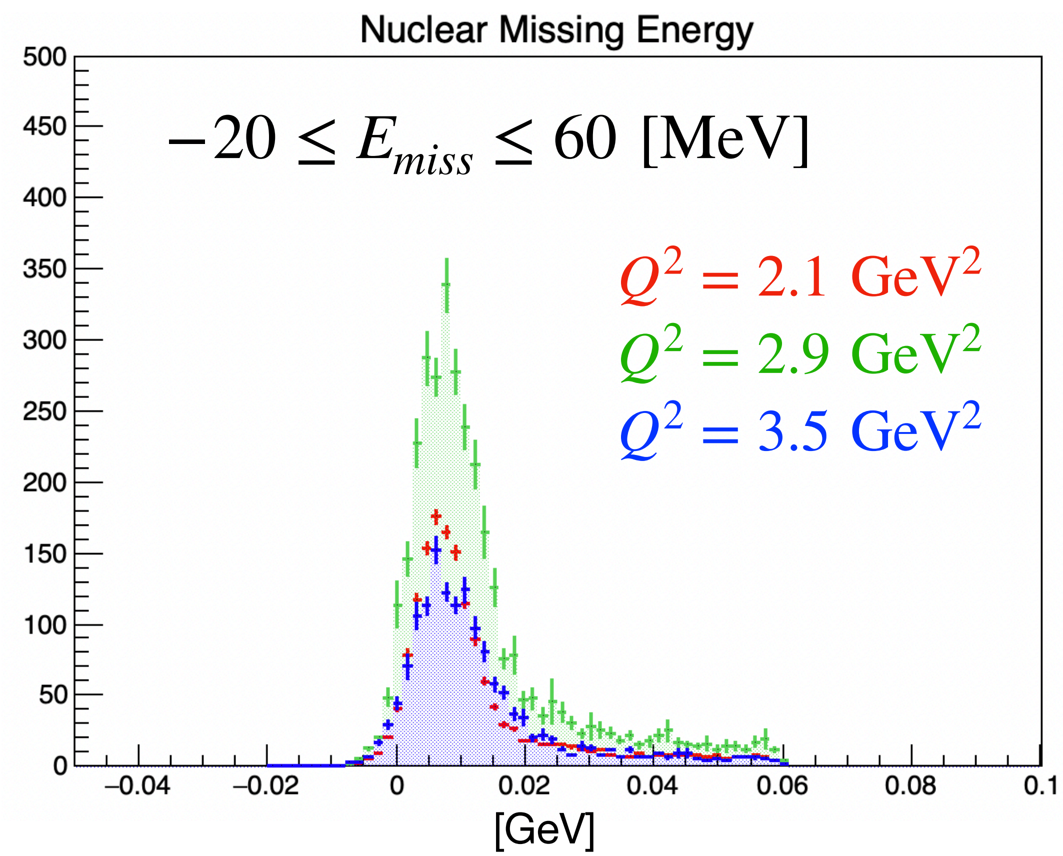
suppressed at $Q^2 > 1(\mathrm{GeV/c})^2$

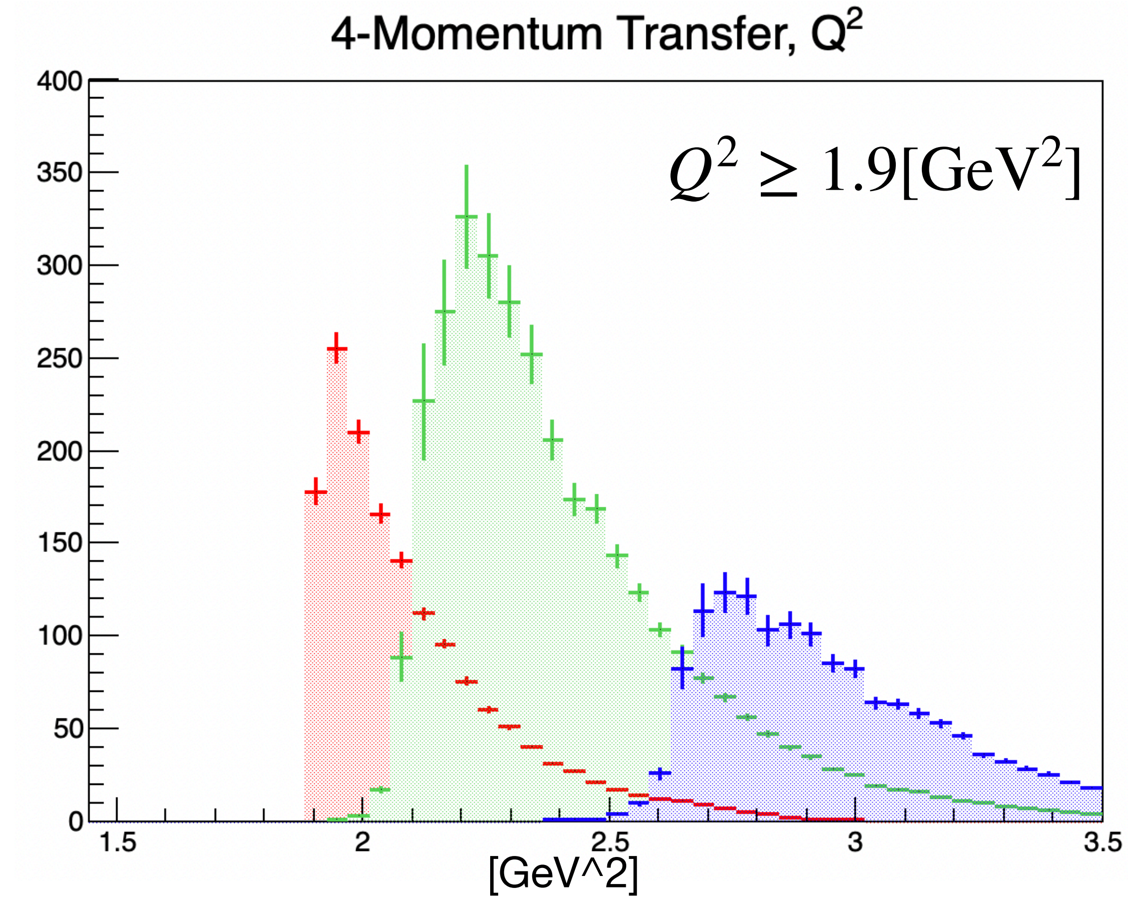


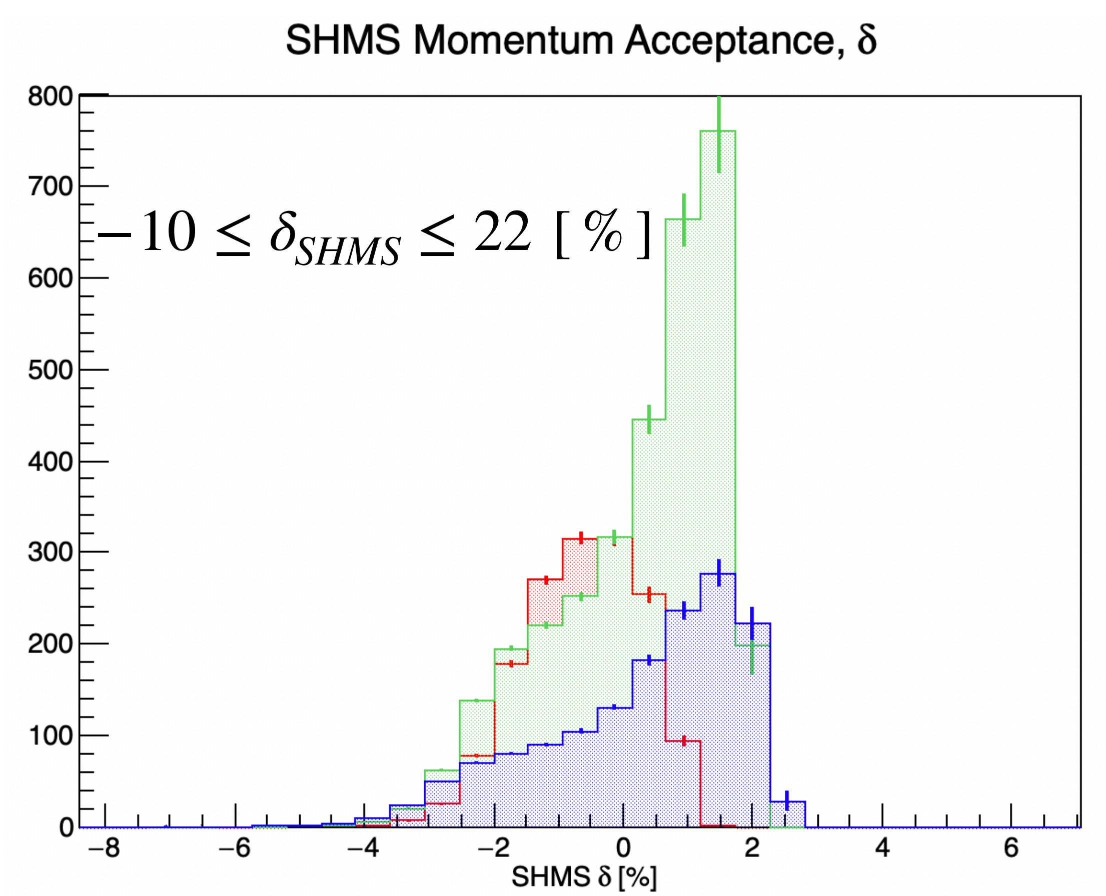
Isobar Configurations (IC)

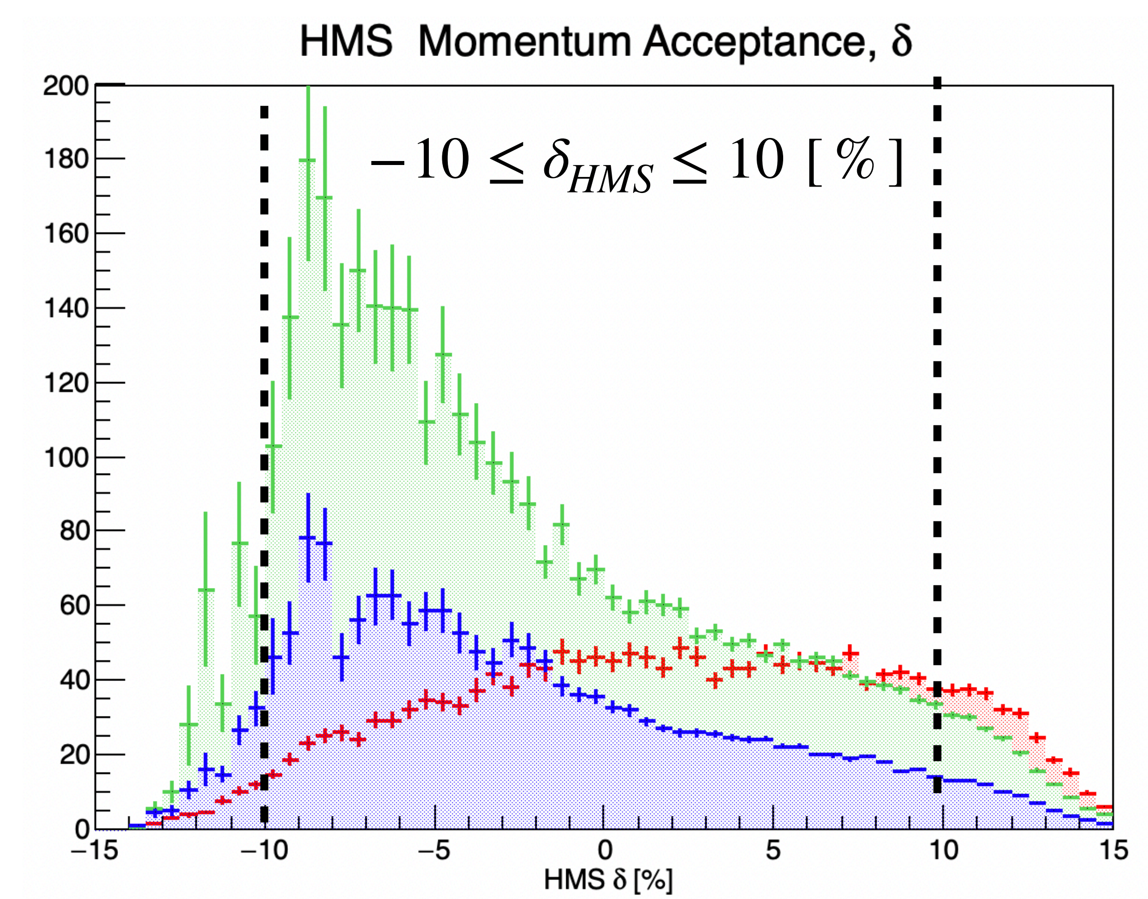
suppressed at $x_{\mathrm{Bj}} > 1$

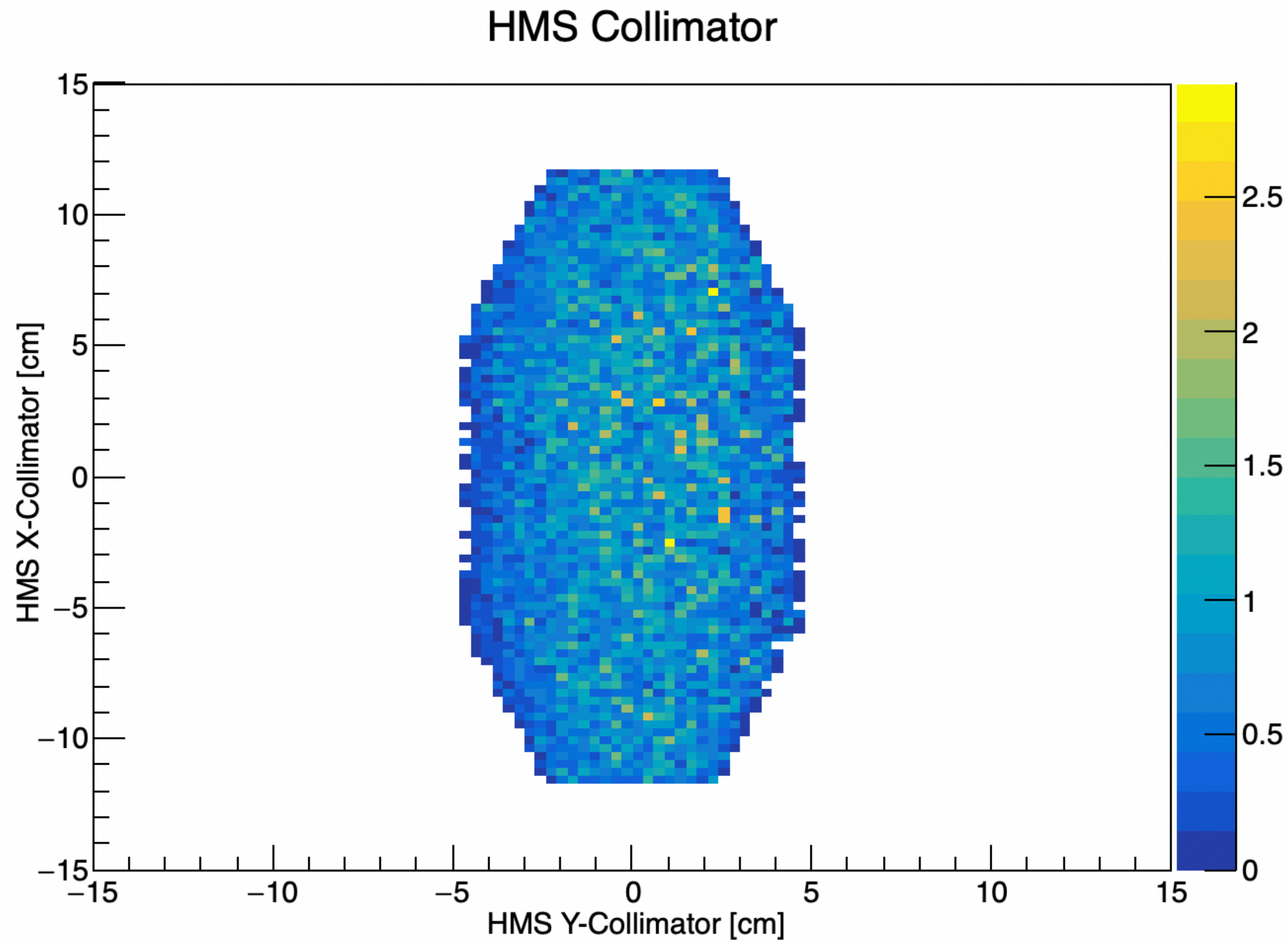
SIMC Analysis Cuts

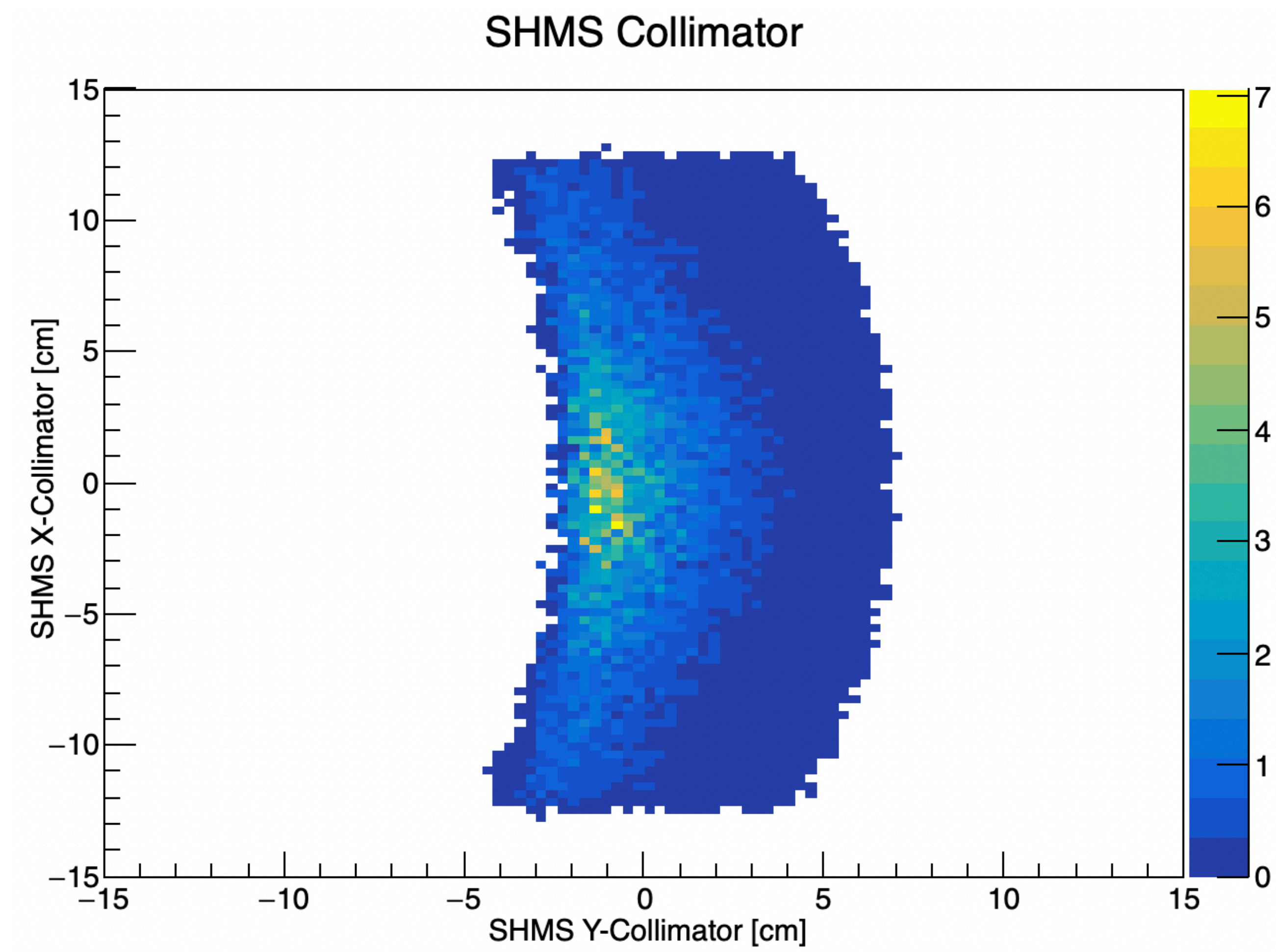

Nuclear Missing Energy
$-20 \leq E_{miss} \leq 60$ [MeV]
$Q^2 = 2.1$ GeV^2
$Q^2 = 2.9$ GeV^2
$Q^2 = 3.5$ GeV^2
[GeV]


4-Momentum Transfer, Q^2
$Q^2 \geq 1.9$[GeV^2]
[GeV^2]


SHMS Momentum Acceptance, δ
$-10 \leq \delta_{SHMS} \leq 22$ [%]
SHMS δ [%]

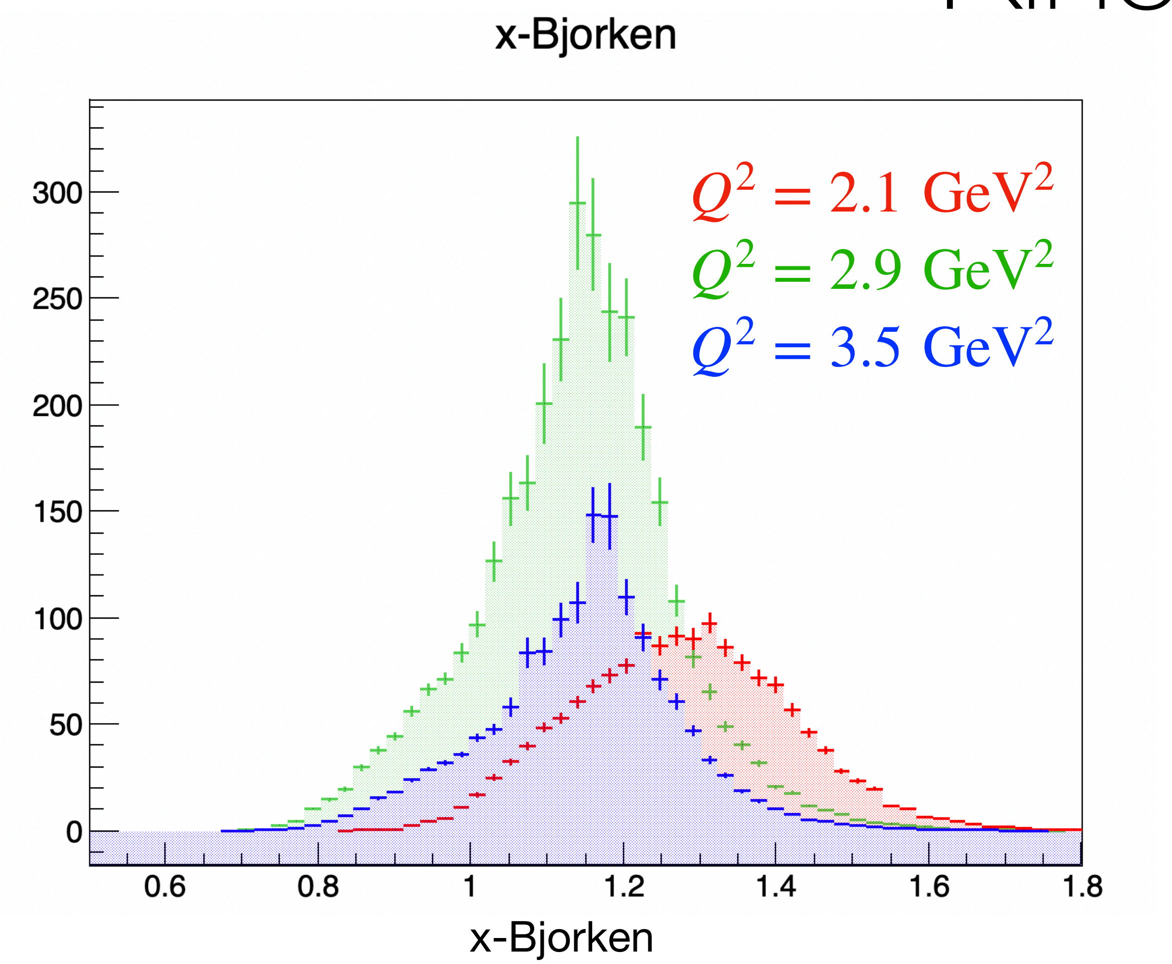

HMS Momentum Acceptance, δ
$-10 \leq \delta_{HMS} \leq 10$ [%]
HMS δ [%]

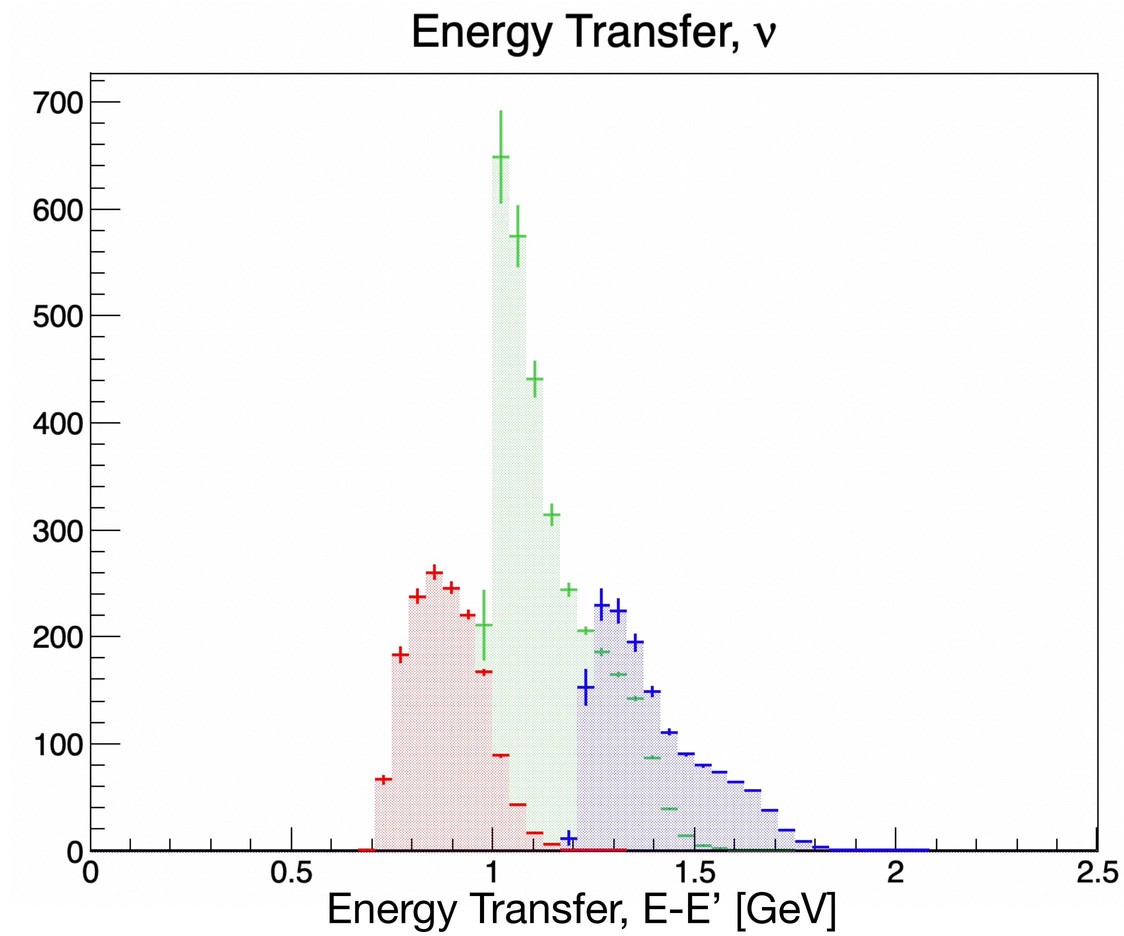


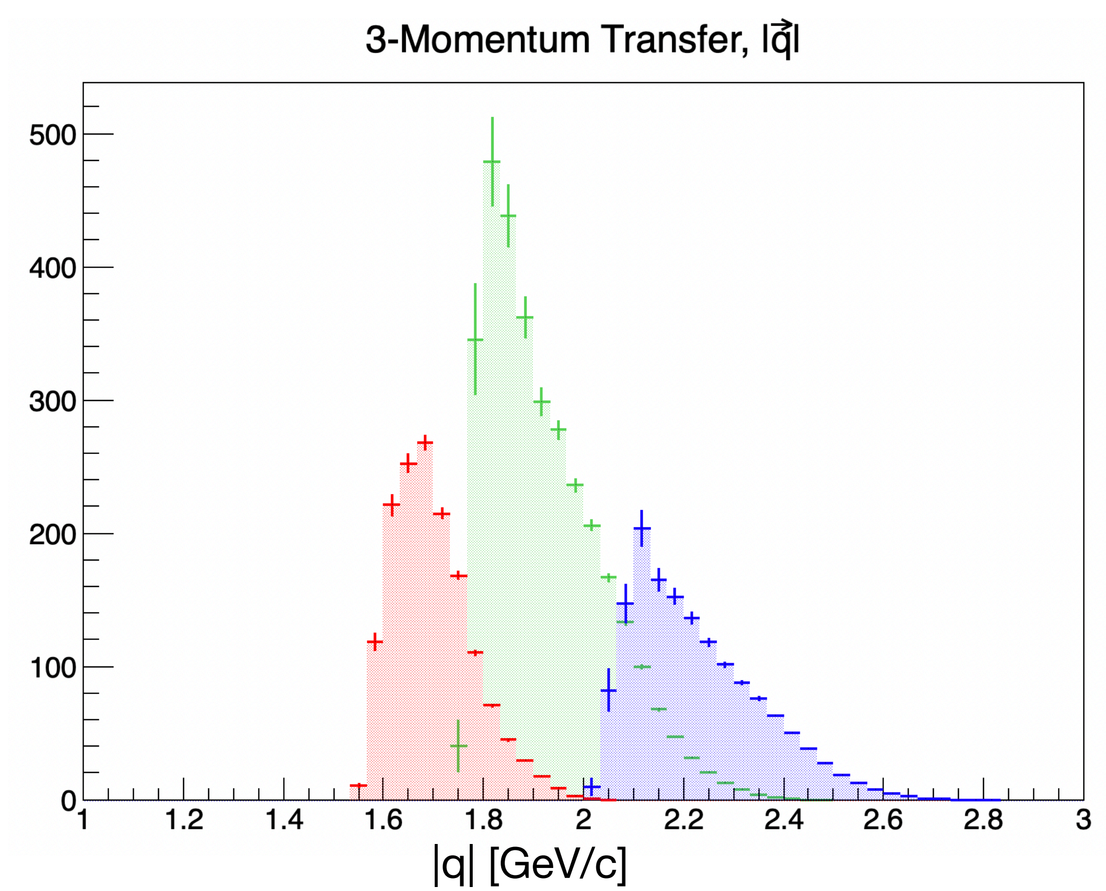


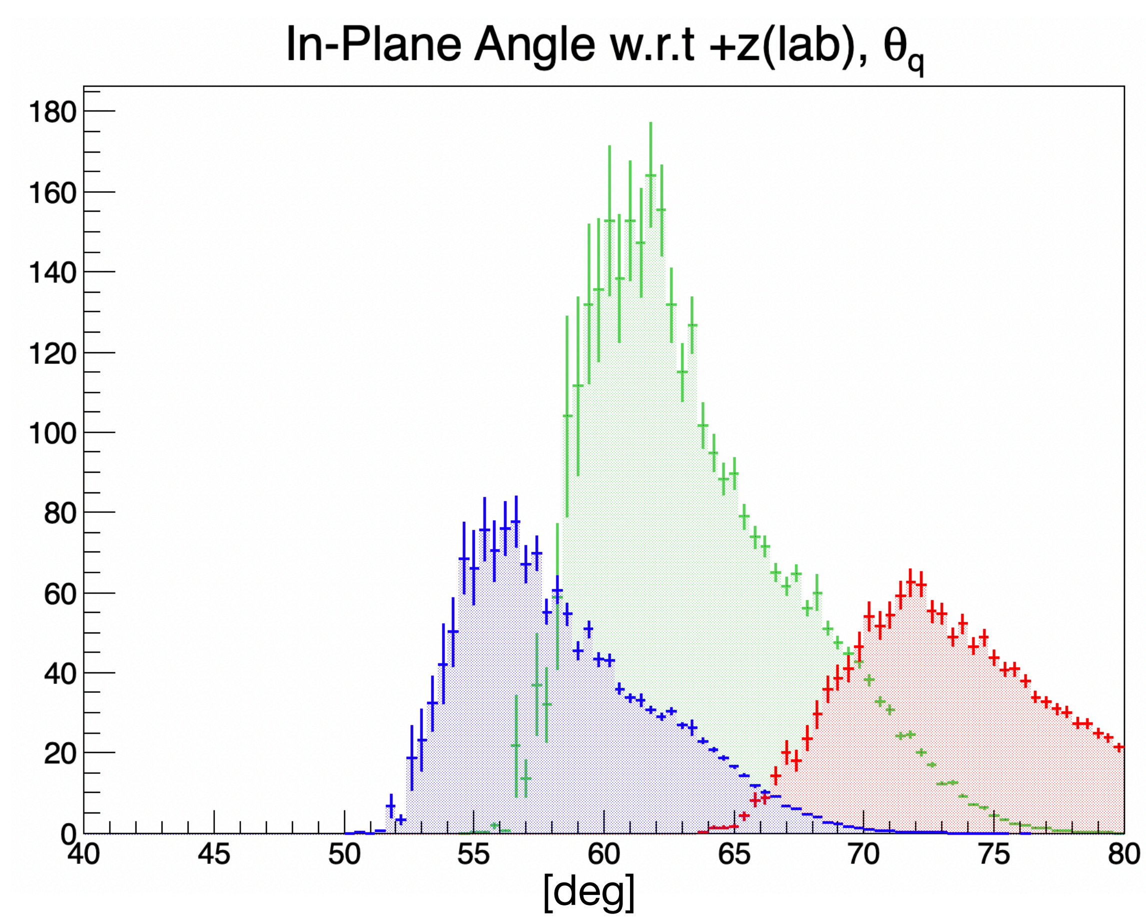
- angular acceptance (geometrical cut on collimator)
- HMS determines acceptance

Kinematics

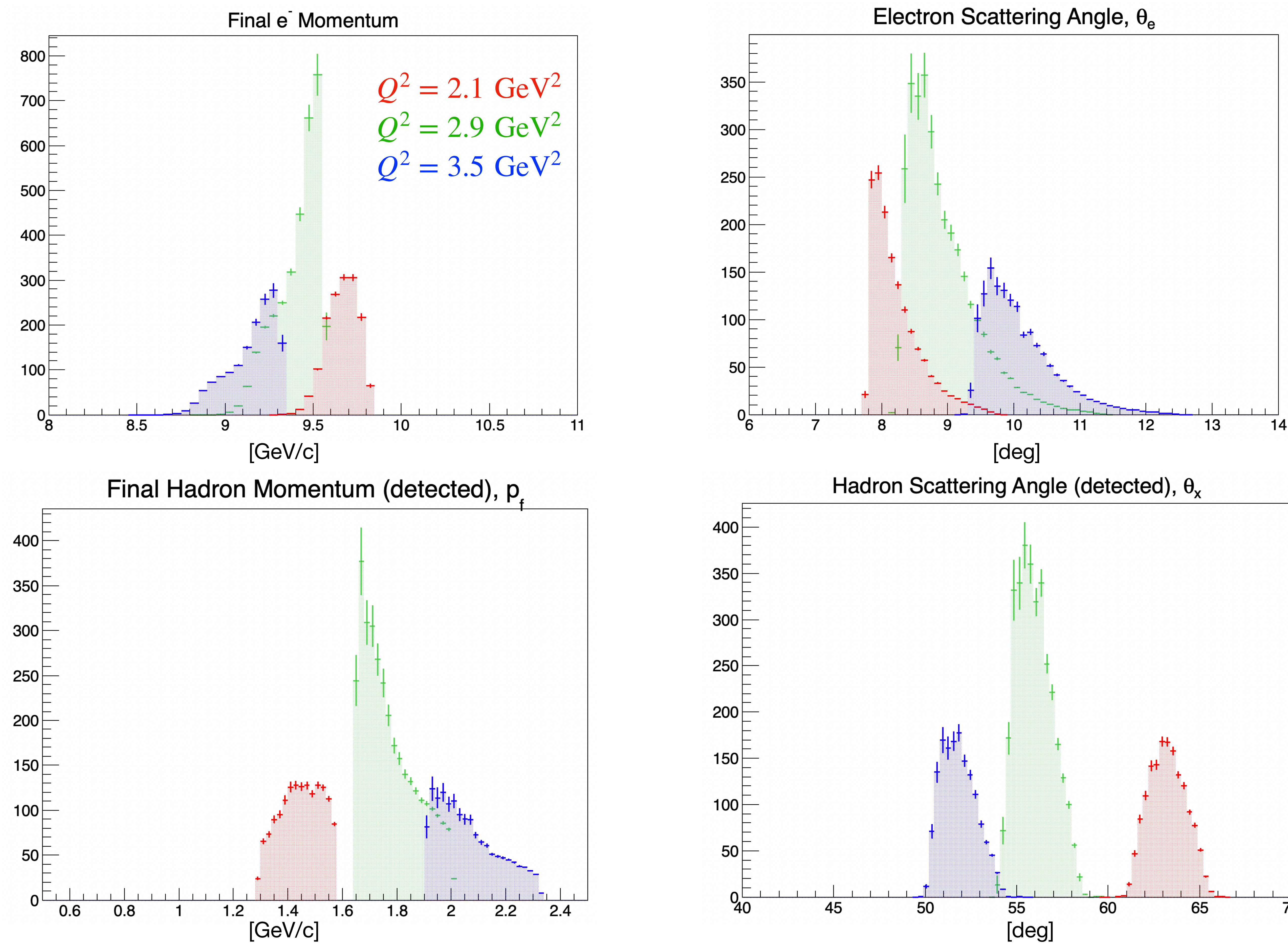

x-Bjorken
$Q^2 = 2.1\ \mathrm{GeV}^2$
$Q^2 = 2.9\ \mathrm{GeV}^2$
$Q^2 = 3.5\ \mathrm{GeV}^2$
300
250
200
150
100
50
0
0.6
0.8
1
1.2
1.4
1.6
1.8
x-Bjorken


Energy Transfer, ν
700
600
500
400
300
200
100
0
0
0.5
1
1.5
2
2.5
Energy Transfer, E-E' [GeV]

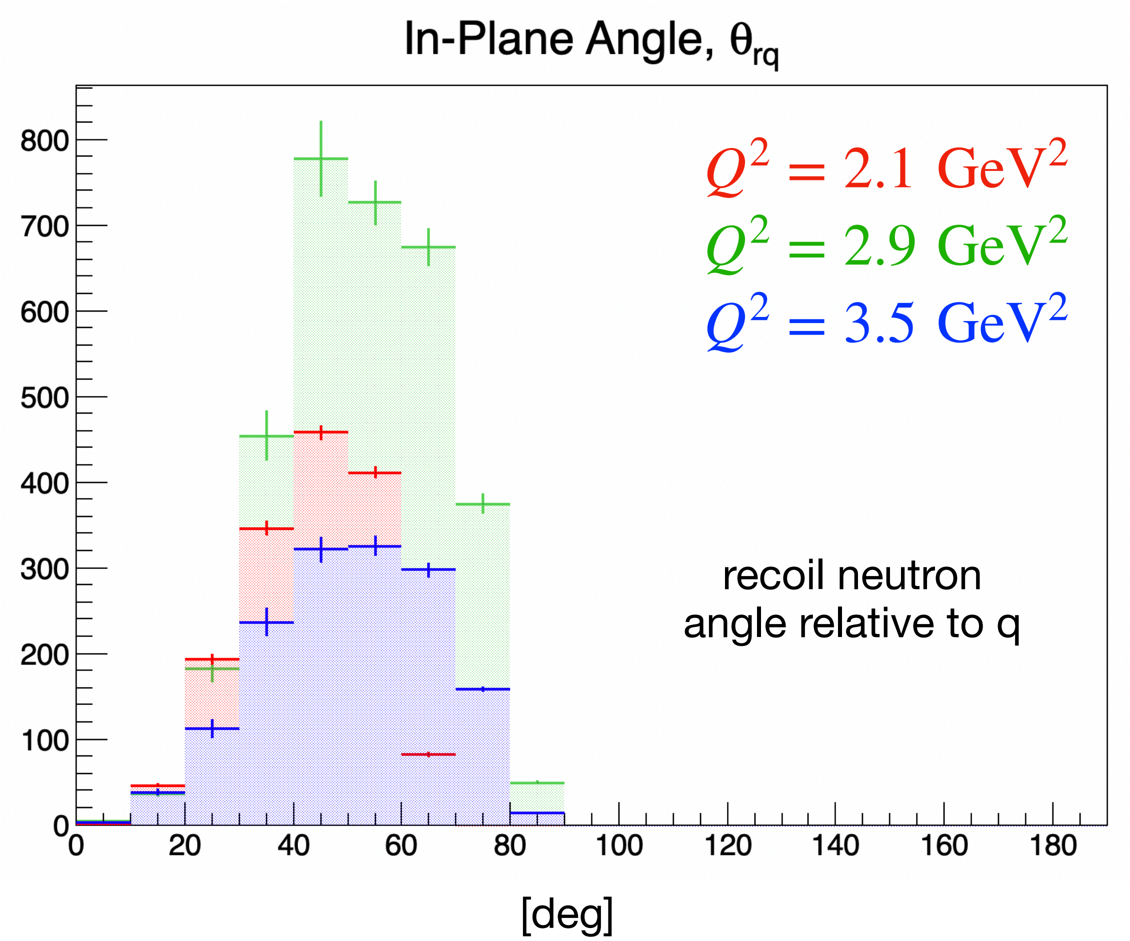

3-Momentum Transfer, $|\vec{q}|$
500
400
300
200
100
0
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
|q| [GeV/c]


In-Plane Angle w.r.t +z(lab), θ_q
180
160
140
120
100
80
60
40
20
0
40
45
50
55
60
65
70
75
80
[deg]

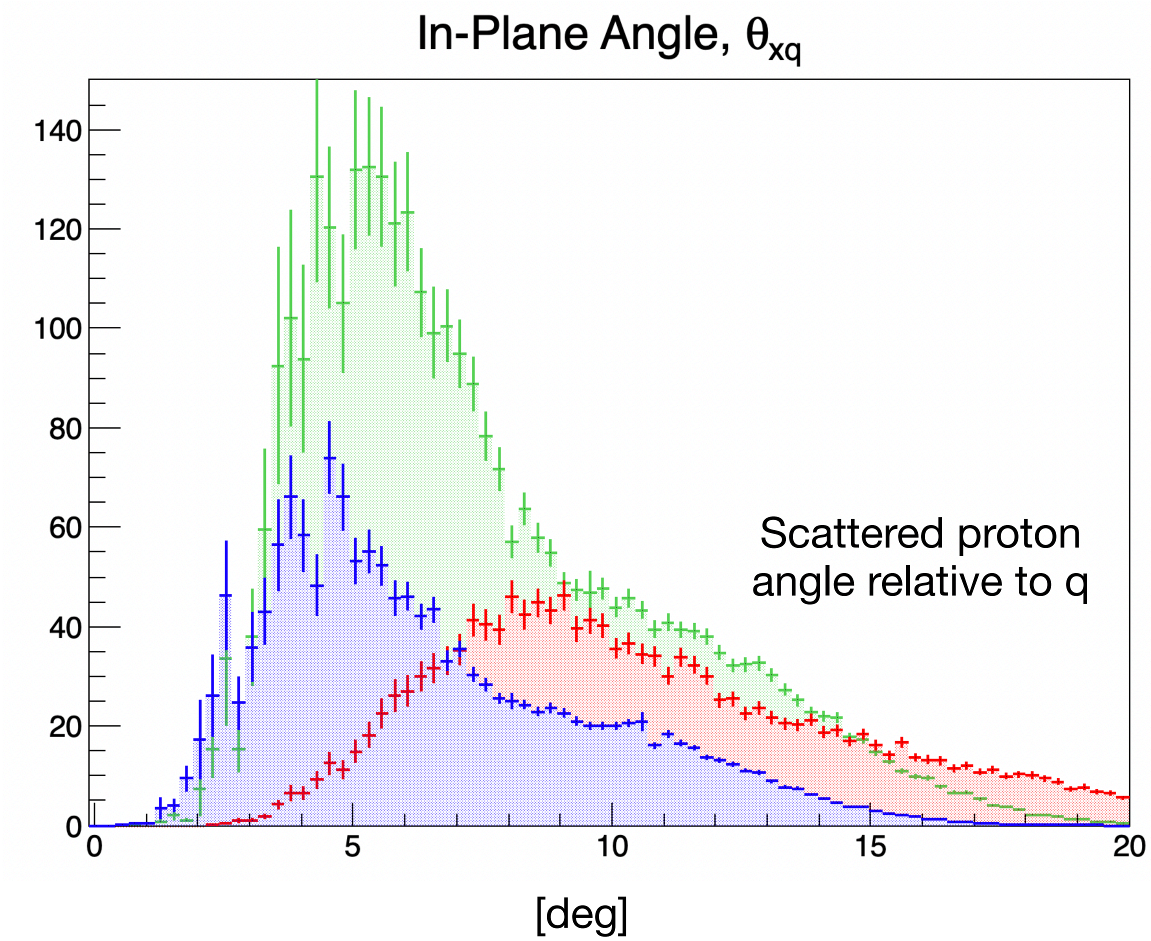
Kinematics


Final e⁻ Momentum
$Q^2 = 2.1\ \mathrm{GeV}^2$
$Q^2 = 2.9\ \mathrm{GeV}^2$
$Q^2 = 3.5\ \mathrm{GeV}^2$
[GeV/c]
Electron Scattering Angle, θ_e
[deg]
Final Hadron Momentum (detected), p_f
[GeV/c]
Hadron Scattering Angle (detected), θ_x
[deg]

Kinematics



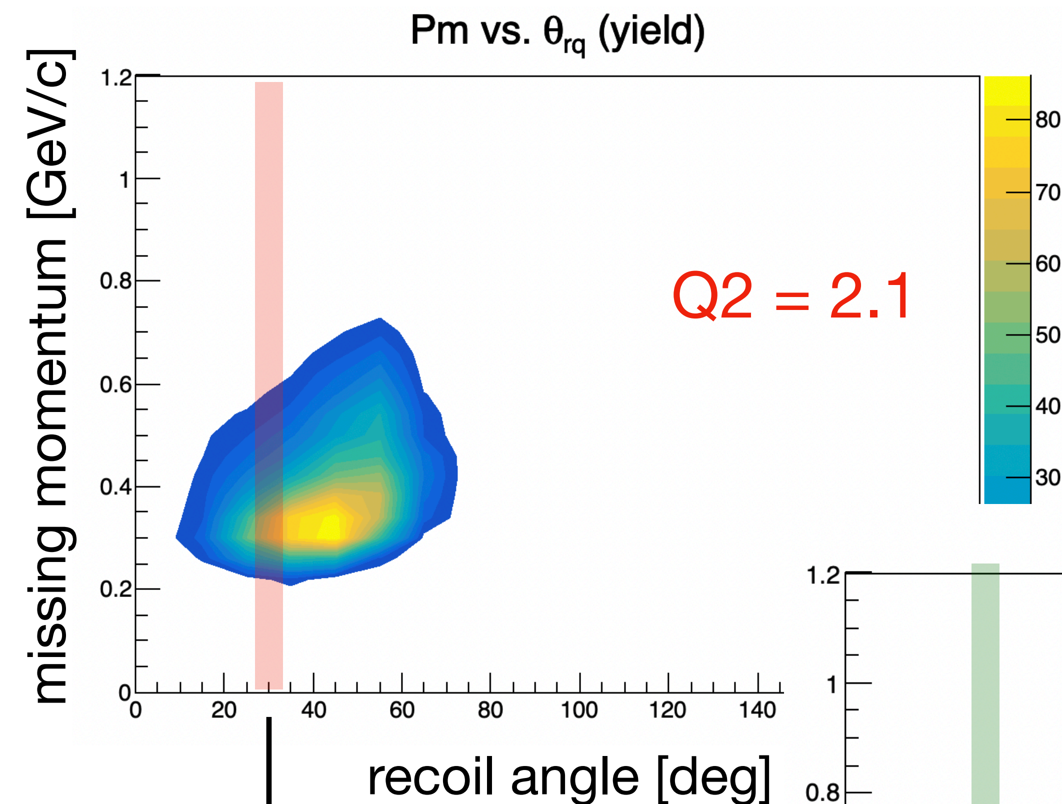
In-Plane Angle, θ_{rq}
$Q^2 = 2.1\ \mathrm{GeV}^2$
$Q^2 = 2.9\ \mathrm{GeV}^2$
$Q^2 = 3.5\ \mathrm{GeV}^2$
recoil neutron
angle relative to q
[deg]

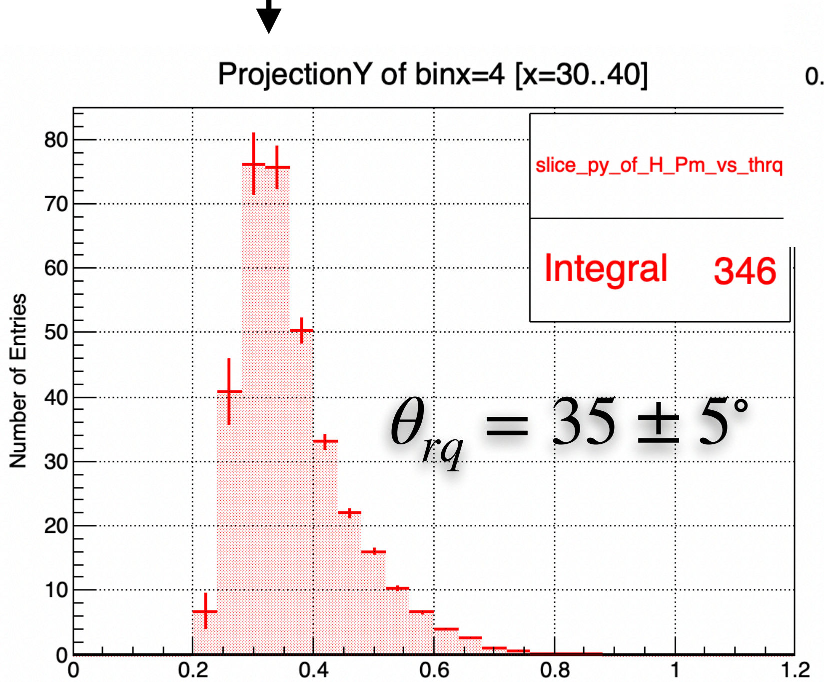


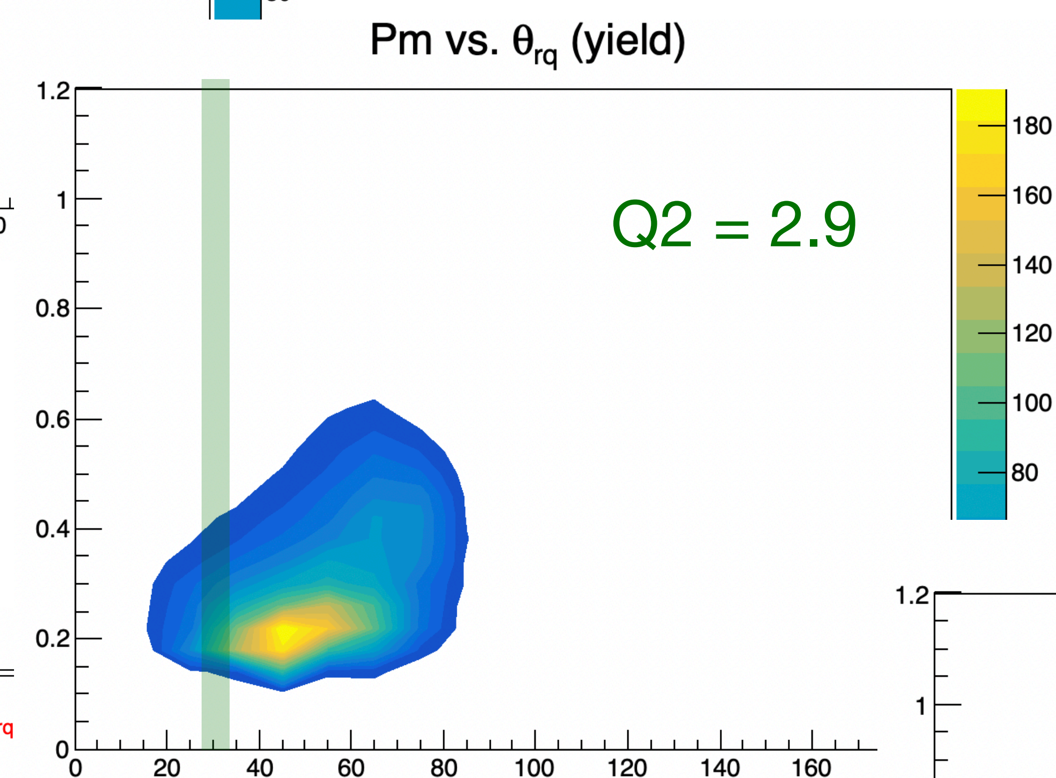
In-Plane Angle, θ_{xq}
Scattered proton
angle relative to q
[deg]

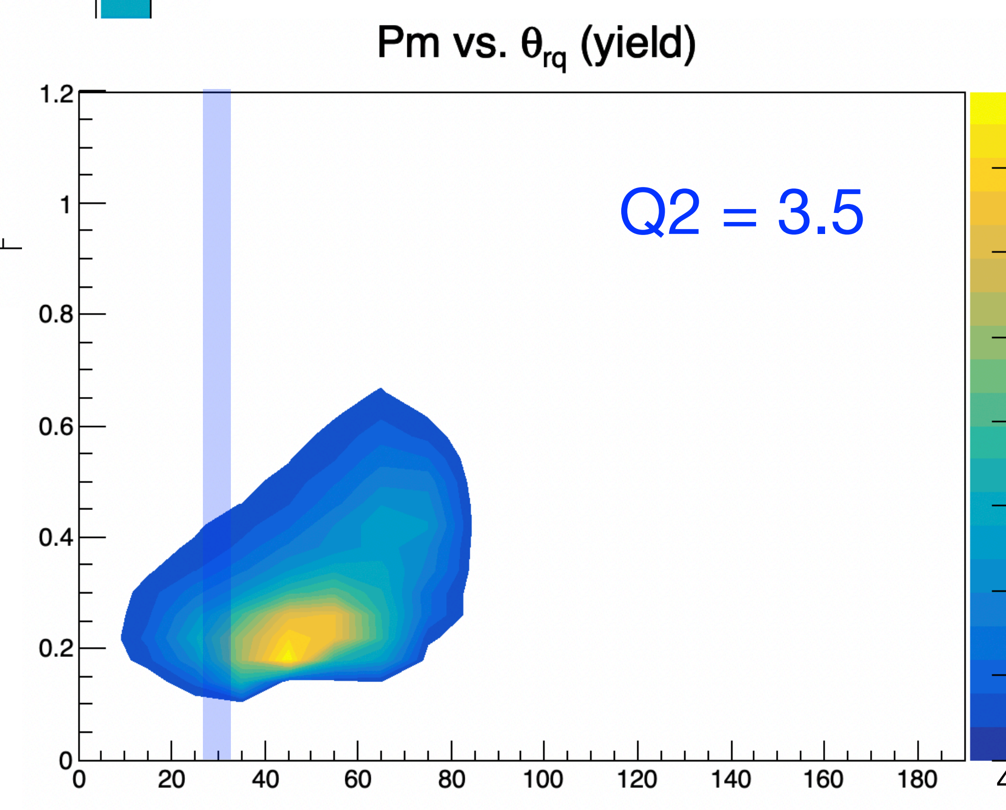
Selecting minimal FSI d(e, e'p) kinematical bins

- Yield binned in (P_{miss}, θ_{rq})
- Reduced FSI $\theta_{rq} \sim 35°$
- Maximum FSI $\theta_{rq} \sim 75°$

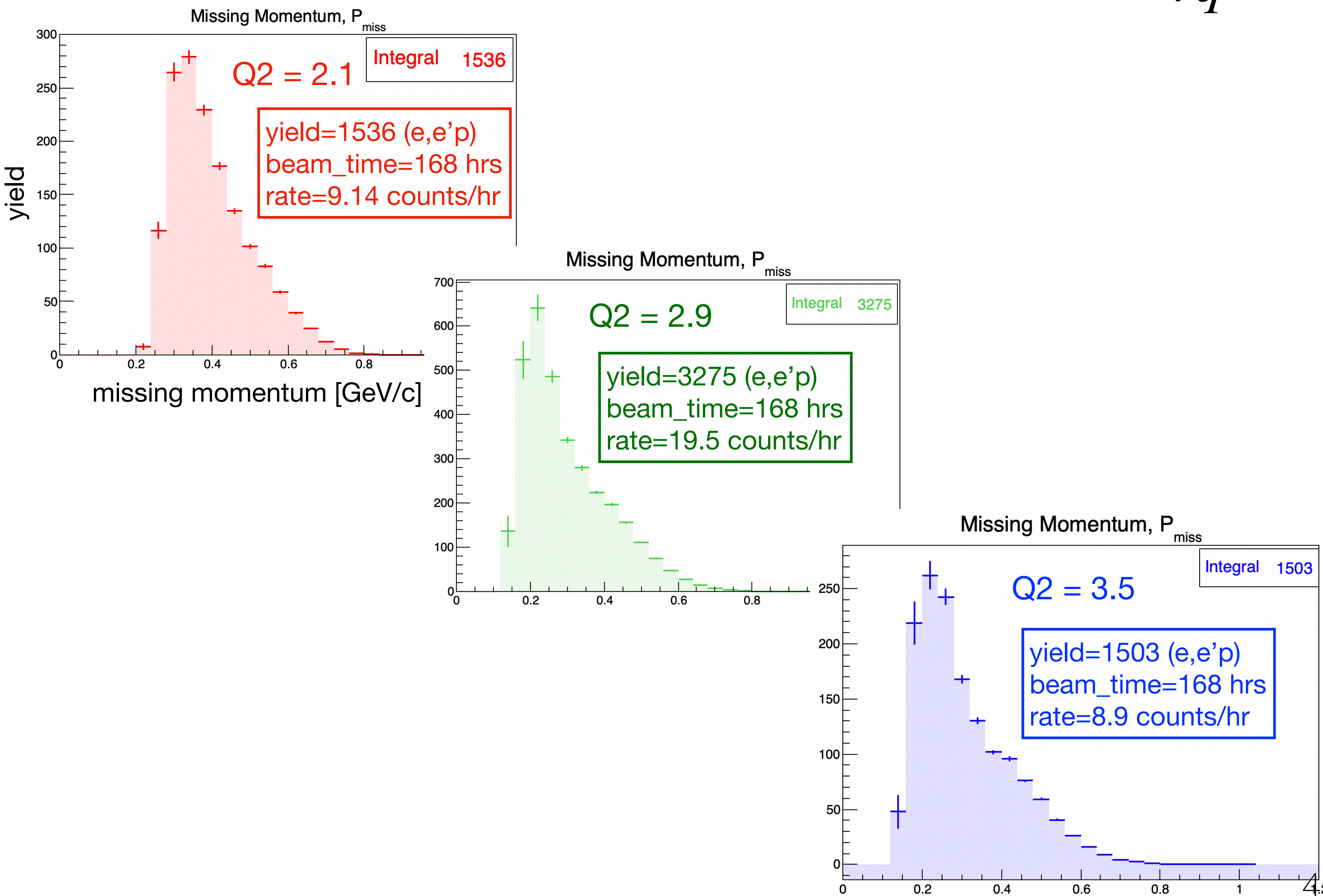




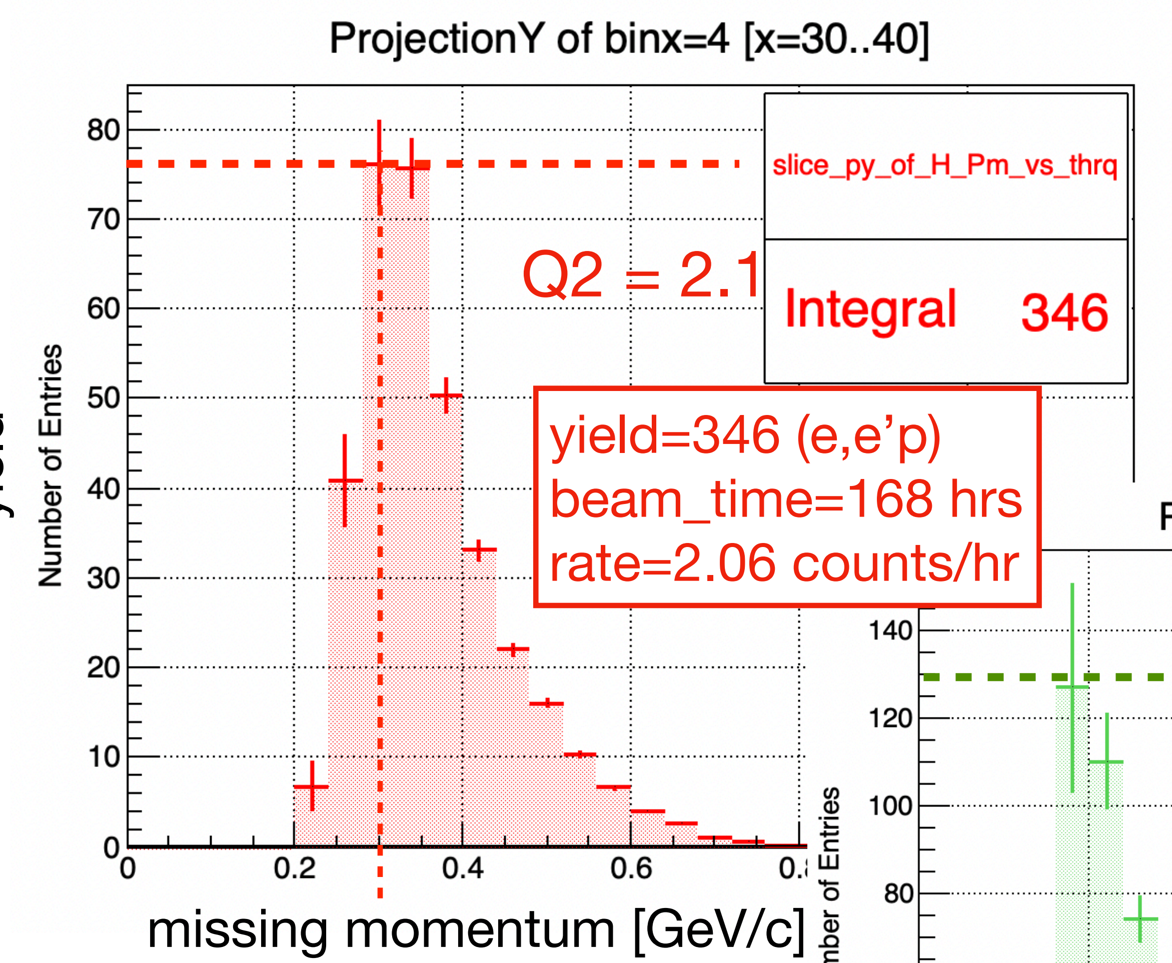


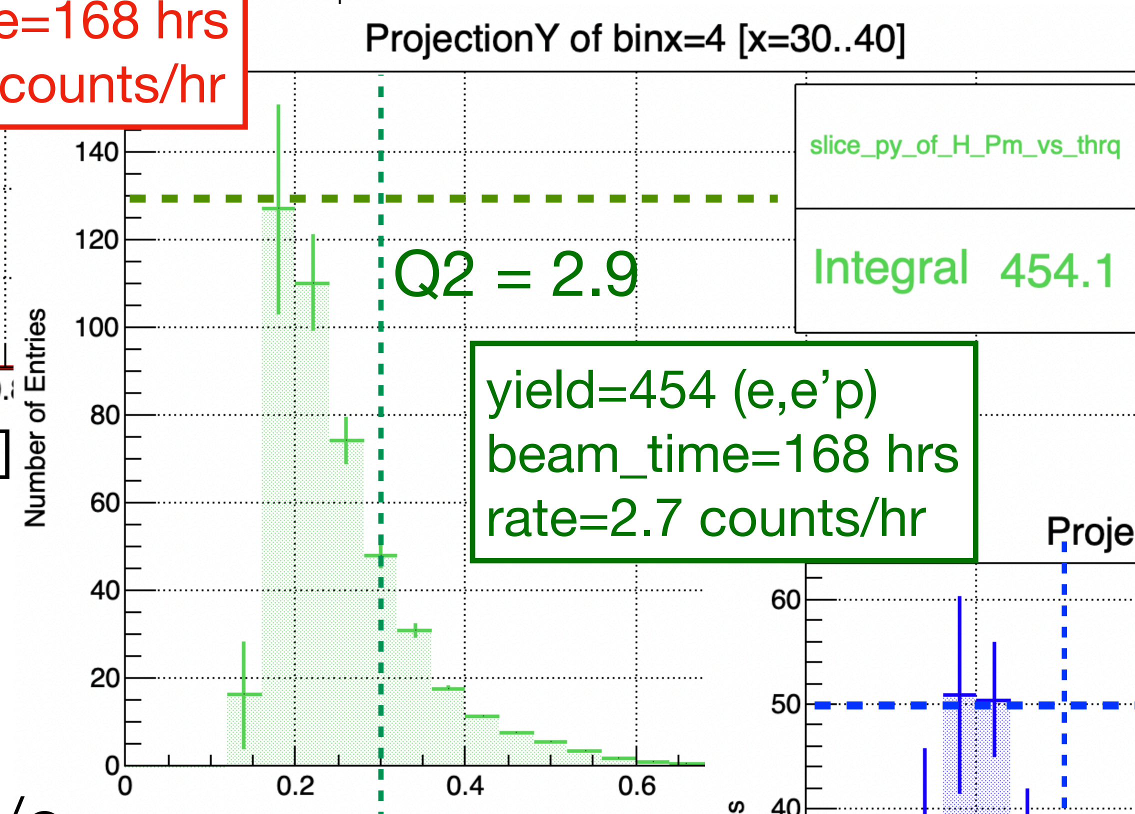


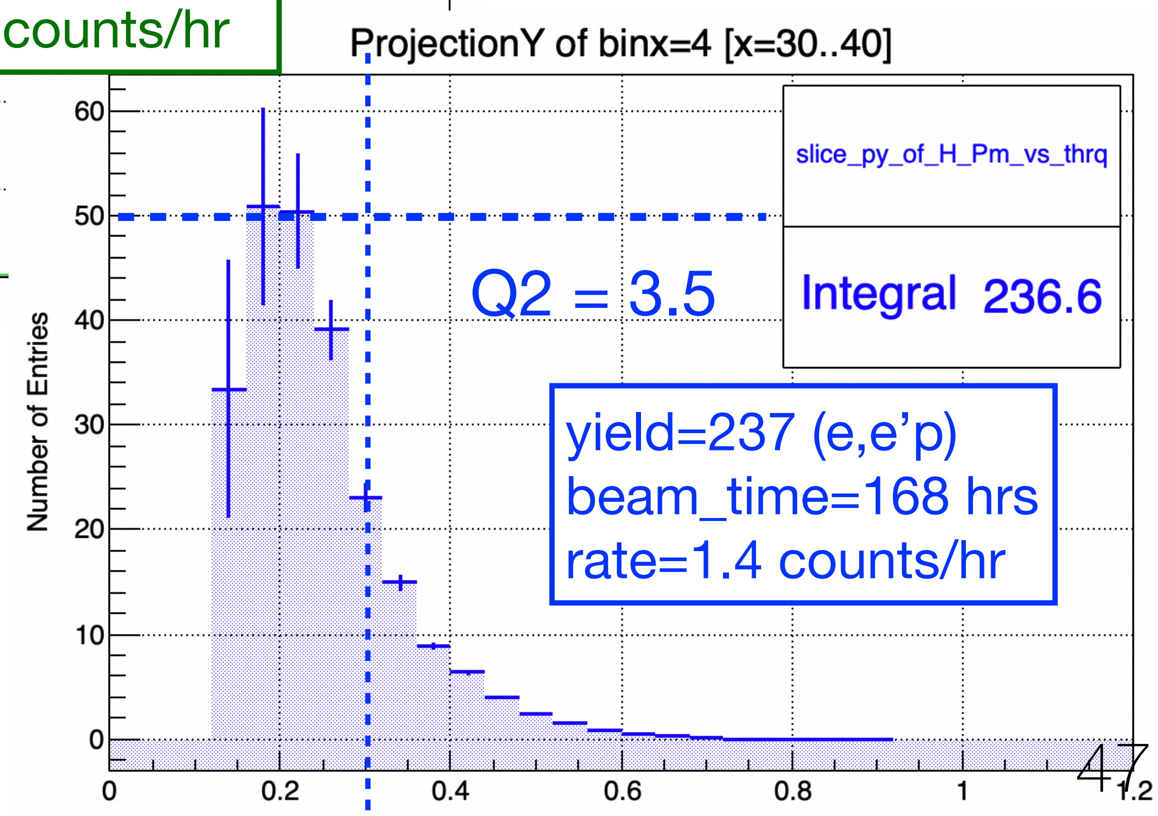
yields and rates (integrated over all θ_{rq})



yield and rates (selected bin $\theta_{rq} = 35 \pm 5°$)







- peak relative stat error: $1/\sqrt{78}$ ~ 11.3 %
- peak relative stat error: $1/\sqrt{130}$ ~ 8.7 %
- peak relative stat error: $1/\sqrt{50}$ ~ 14.1 %

Pm bin = 300+/-20 MeV/c

- relative stat error: $1/\sqrt{78}$ ~ 11.3 %
- relative stat error: $1/\sqrt{50}$ ~ 14.1 %
- relative stat error: $1/\sqrt{25}$ ~ 20 %

d(e, e'p) kinematical bins

- the **highest** (peak missing momentum bin) stats that can be collected @ *bin 35+/-5 deg* for 168 hrs beam-on-target (~ 1 week):

  - Q2=2.1 Pm bin~ 300-350 MeV/c ~ 11.3 % (78 counts)
  - Q2=2.9 Pm bin~ 200 MeV/c ~ 8.7 % (130 counts)
  - Q2=3.5 Pm bin~ 200-250 MeV/c ~ 14.1 % (50 counts)

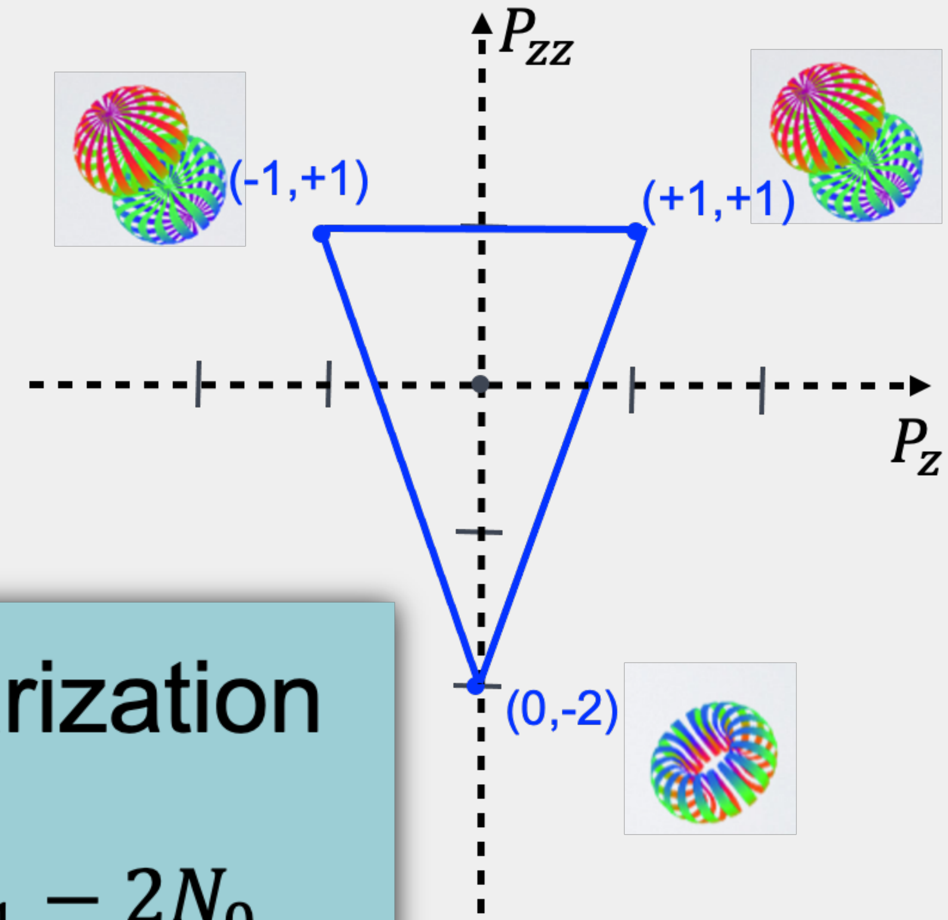
- the **highest** stats that can be collected @ bin *(35 +/-5 deg, 300 +/-20 MeV)* for 168 hrs beam-on-target (~ 1 week):

  - Q2=2.1 Pm bin~ 300 +/- 20 MeV/c ~ 11.3 % (78 counts)
  - Q2=2.9 Pm bin~ 300 +/-20 MeV/c ~ 14.1 % (50 counts)
  - Q2=3.5 Pm bin~ 300 +/-20 MeV/c ~ 20 % (25 counts)

Experimental Setup

Vector Polarization

$$P_z = N_{+1} - N_{-1}$$
$$-1 < P_z < +1$$

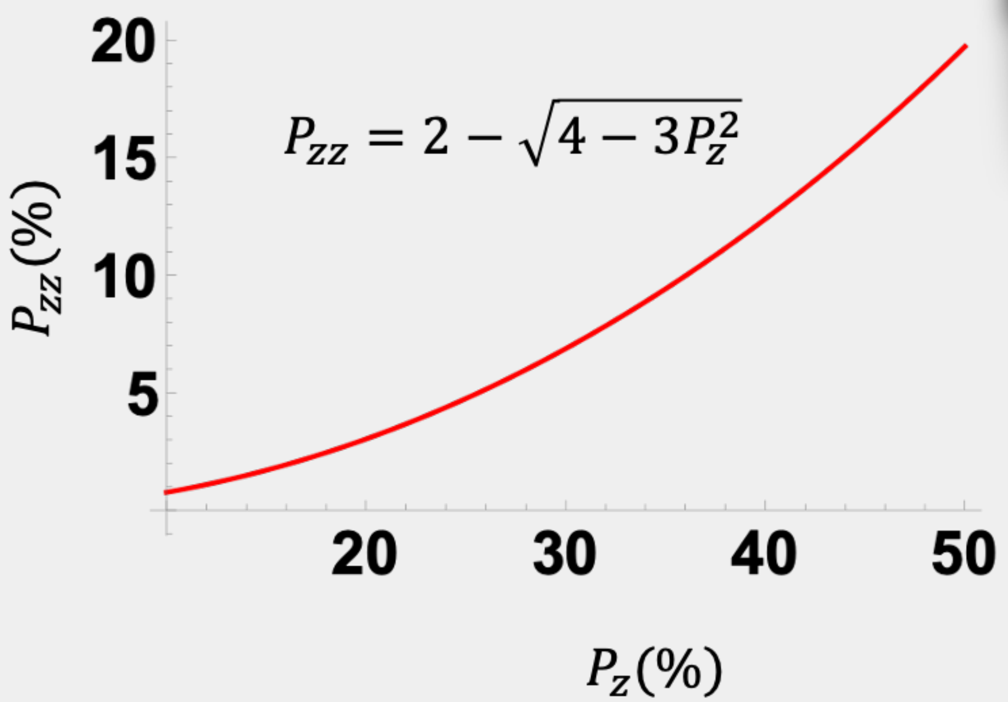


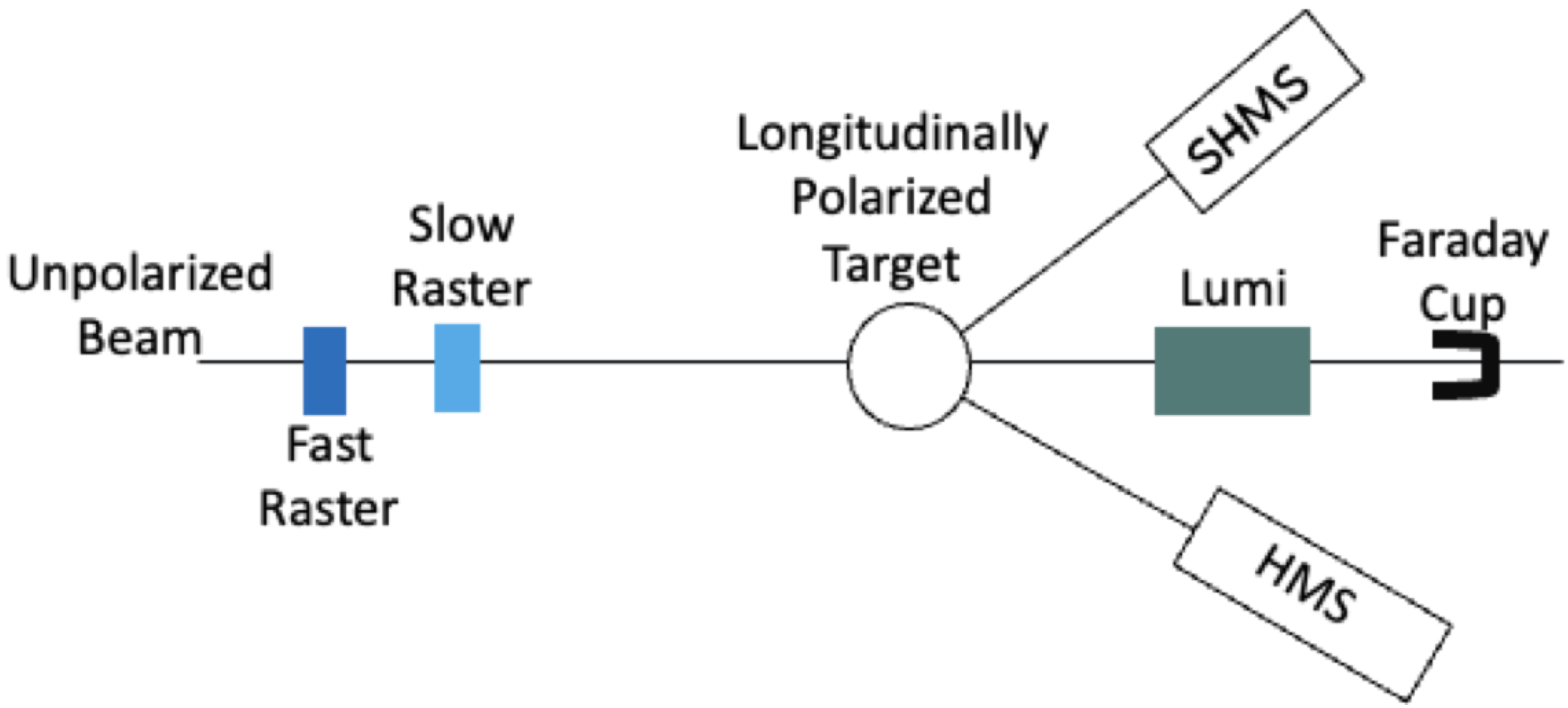
Tensor Polarization

$$P_{zz} = N_{+1} + N_{-1} - 2N_0$$
$$-2 < P_{zz} < +1$$

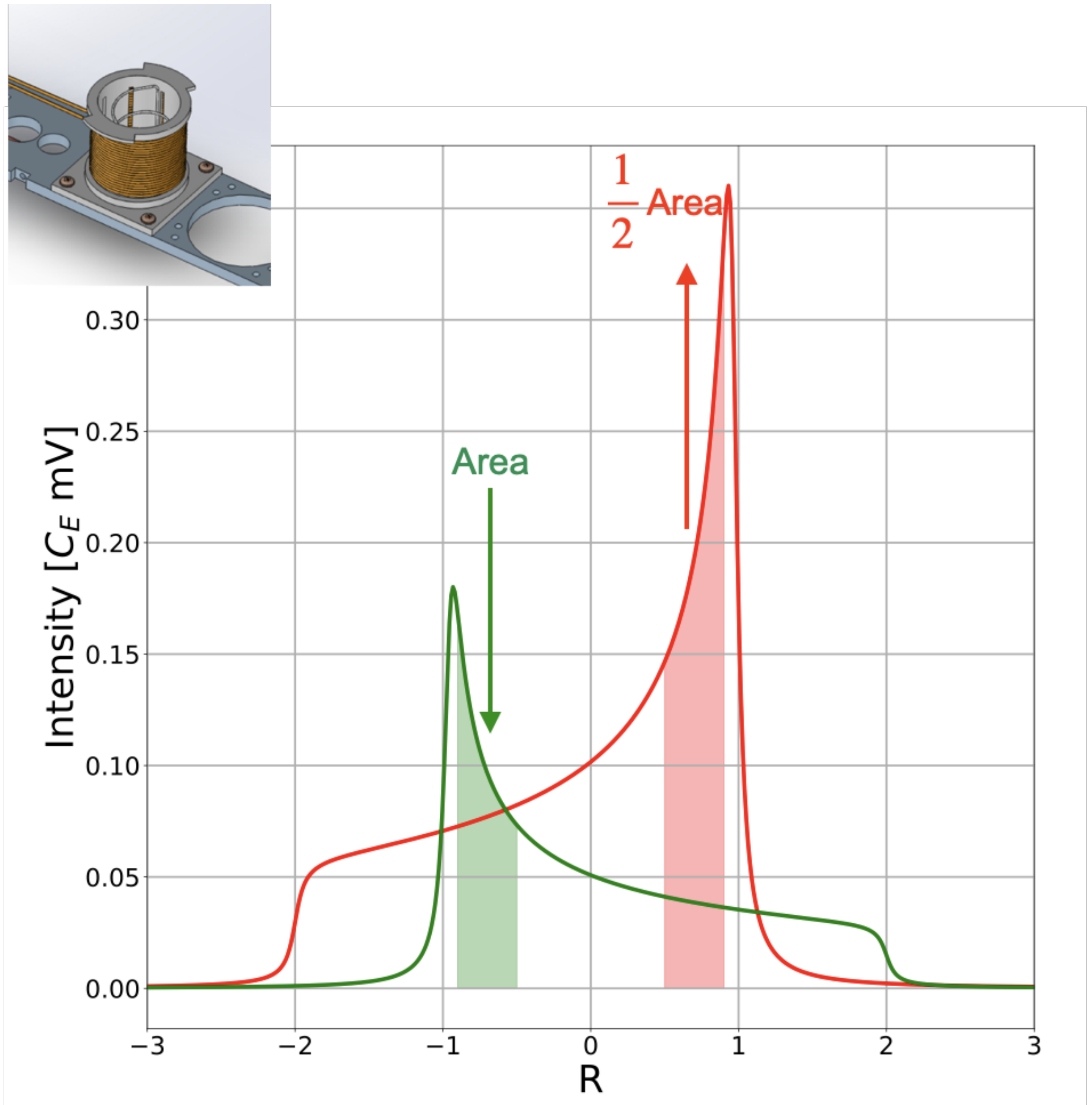
Normalization:

$$N_{+1} + N_{-1} + N_0 = 1$$




Unpolarized
Beam
Fast
Raster
Slow
Raster
Longitudinally
Polarized
Target
SHMS
HMS
Lumi
Faraday
Cup

Using the same target technology as the b1 and Azz experiment approved at JLab



Material

Irradiated Butanol (C_4D_9OH)

Note: Tensor enhancement can be treated similarly for materials with the same lineshape (ND_3).

Measurement:

1. Differential binning
2. Spin temperature consistency

$$P = C(I_+ + I_-)$$
$$Q = C(I_+ - I_-)$$

3. Rate response

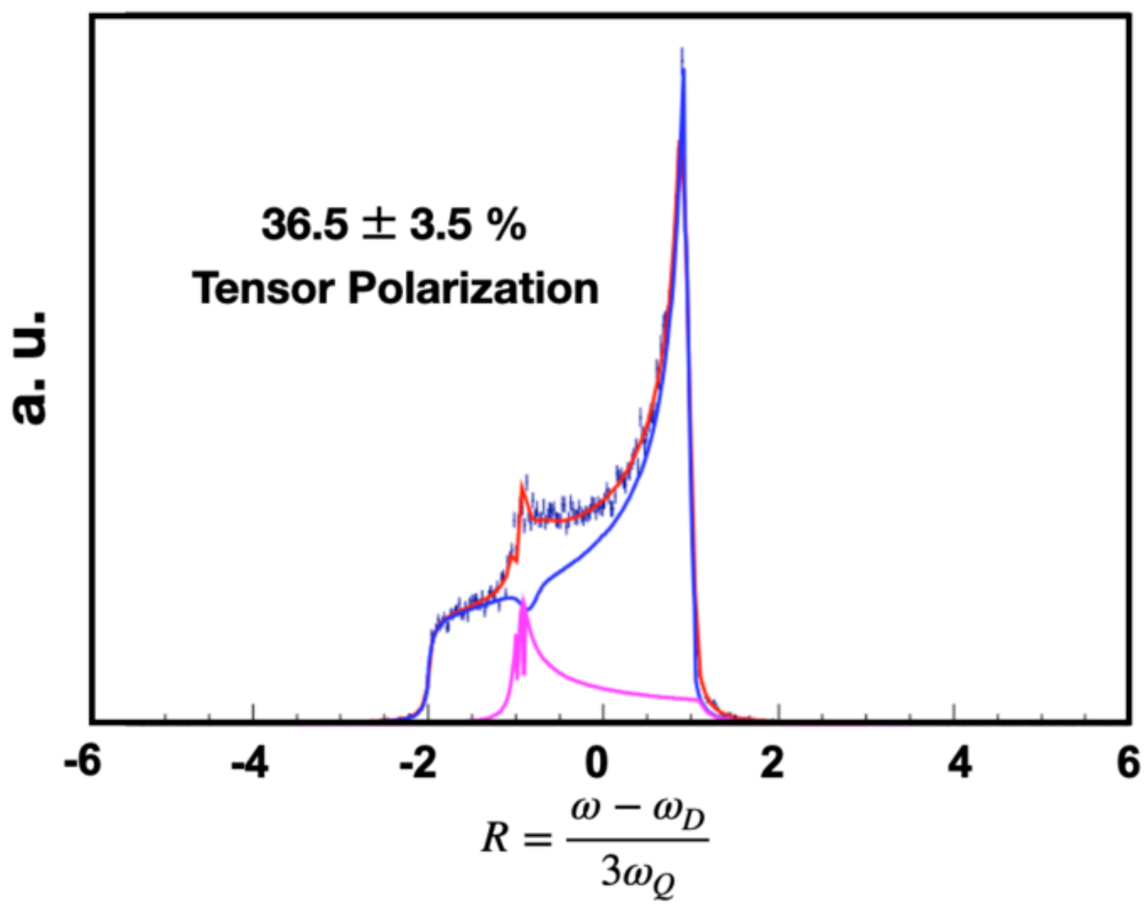
$$A_{lost} = \frac{1}{2} A_{gained}$$

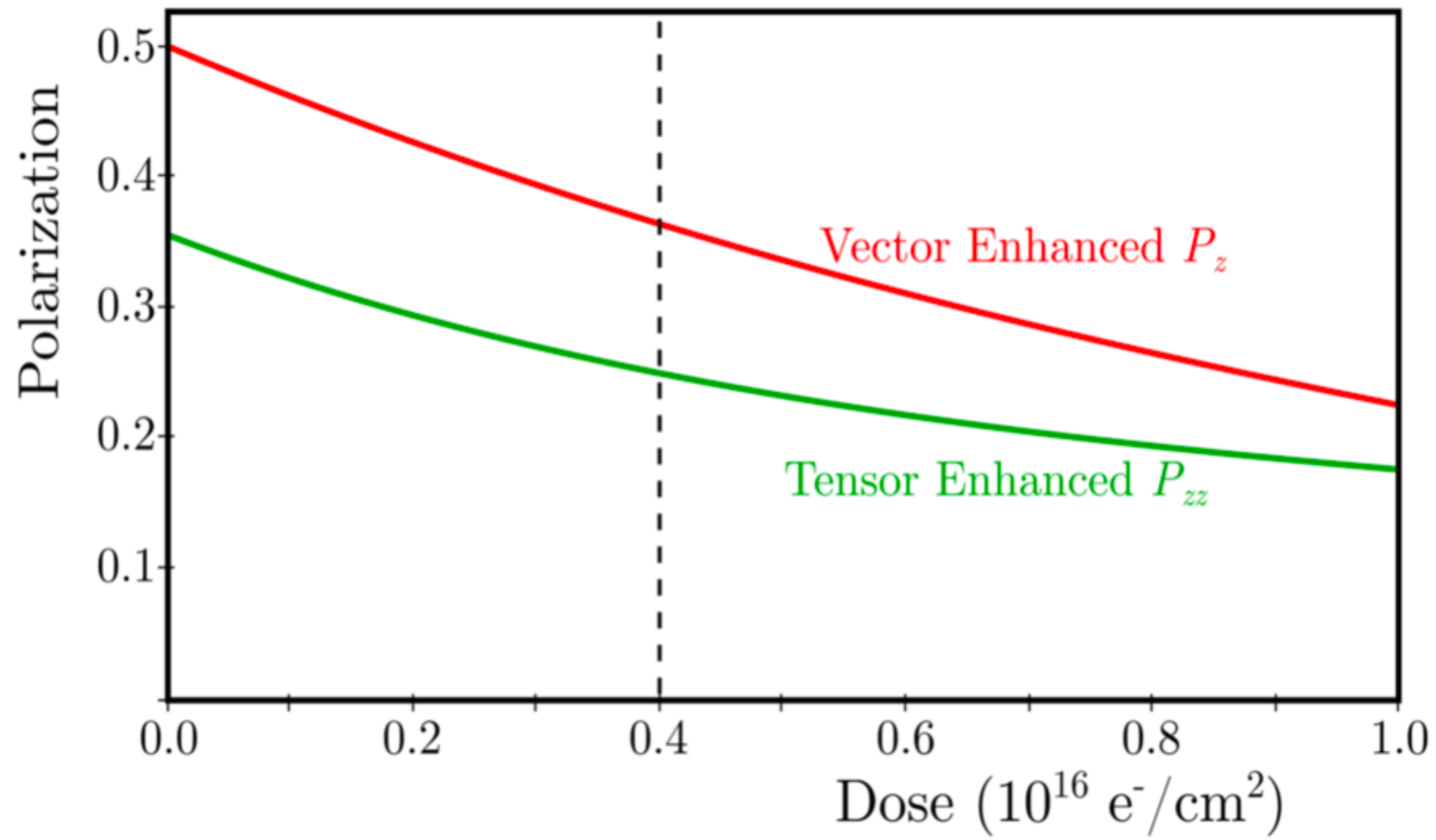
J. Clement, D. Keller, Submitted to Nucl. Instr. Meth. A (2022)

Solid Polarized Target Group at the University of Virginia

Using the same target technology as the b1 and Azz experiment approved at JLab

Expected target polarization under beam conditions





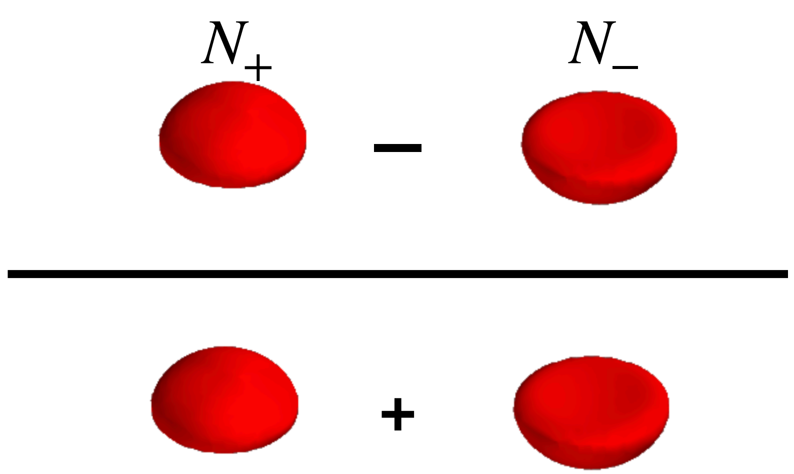
Deuteron Shapes

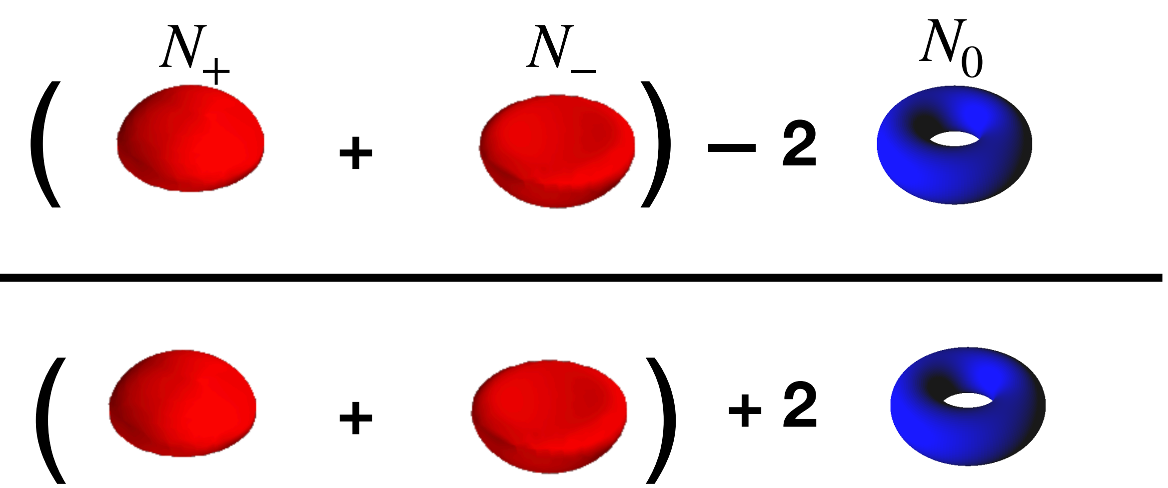
vector polarization

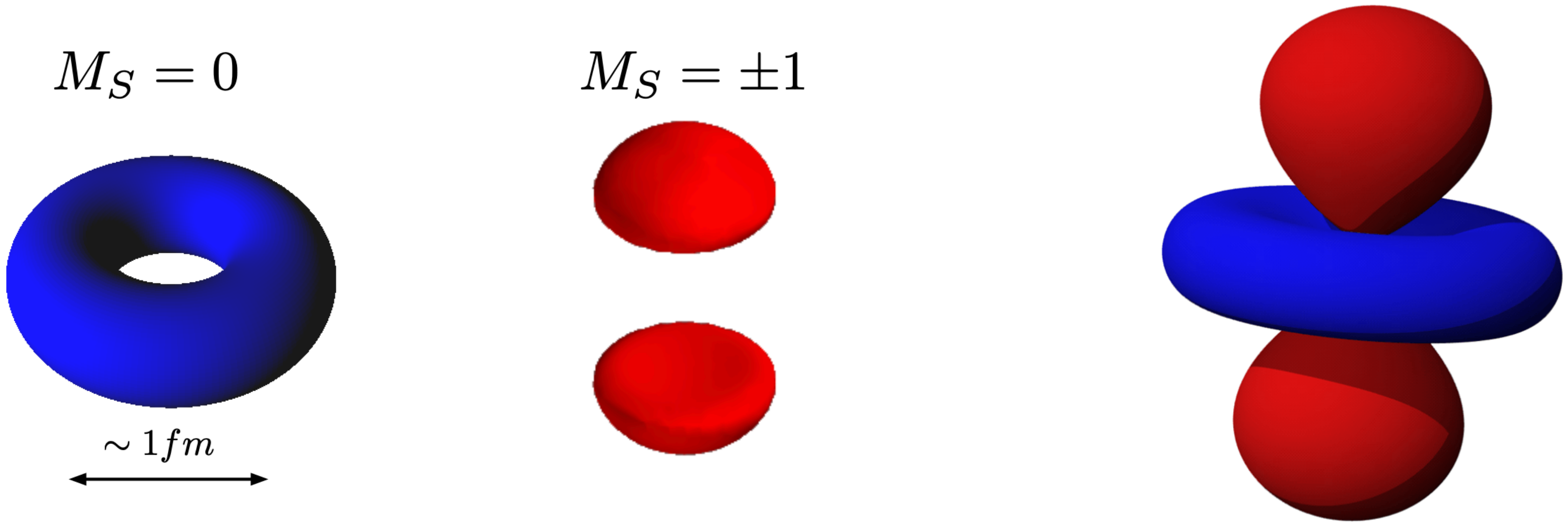
$$A_z = \frac{N_+ - N_-}{N_+ + N_-}$$

tensor polarization

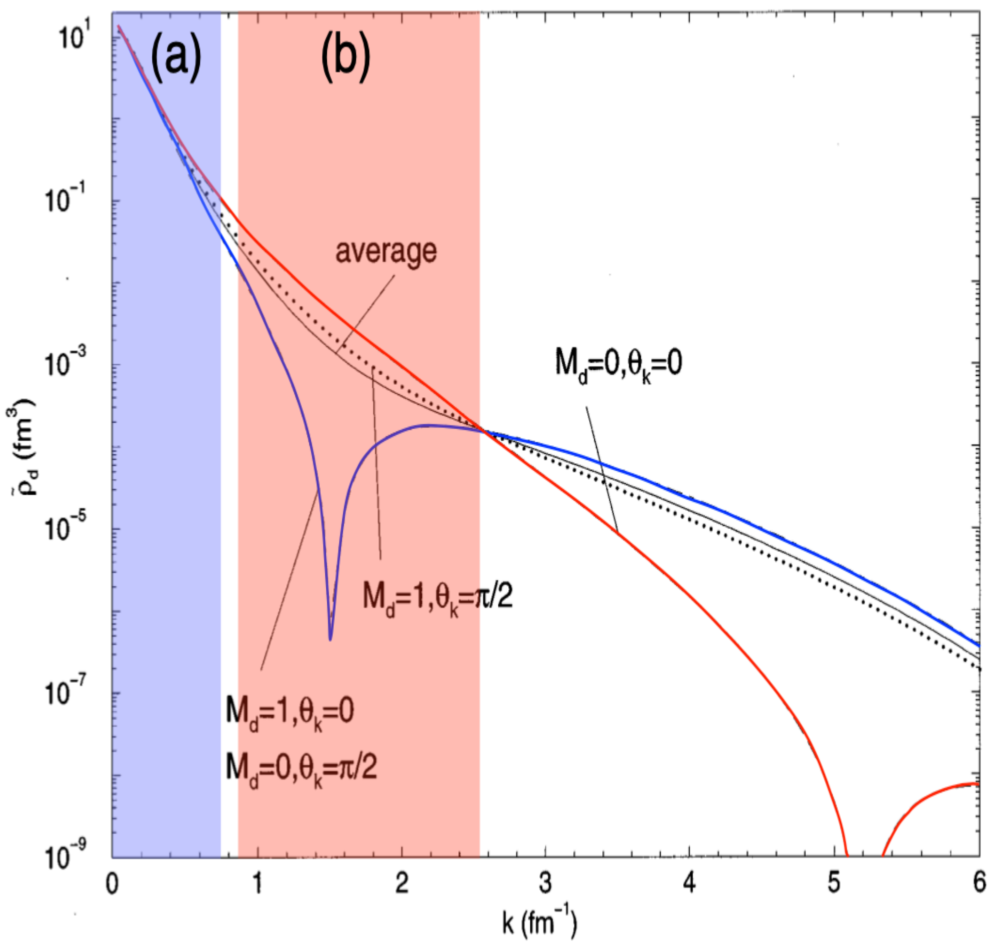
$$A_{zz} = \frac{N_+ + N_- - 2N_0}{N_+ + N_- + 2N_0}$$







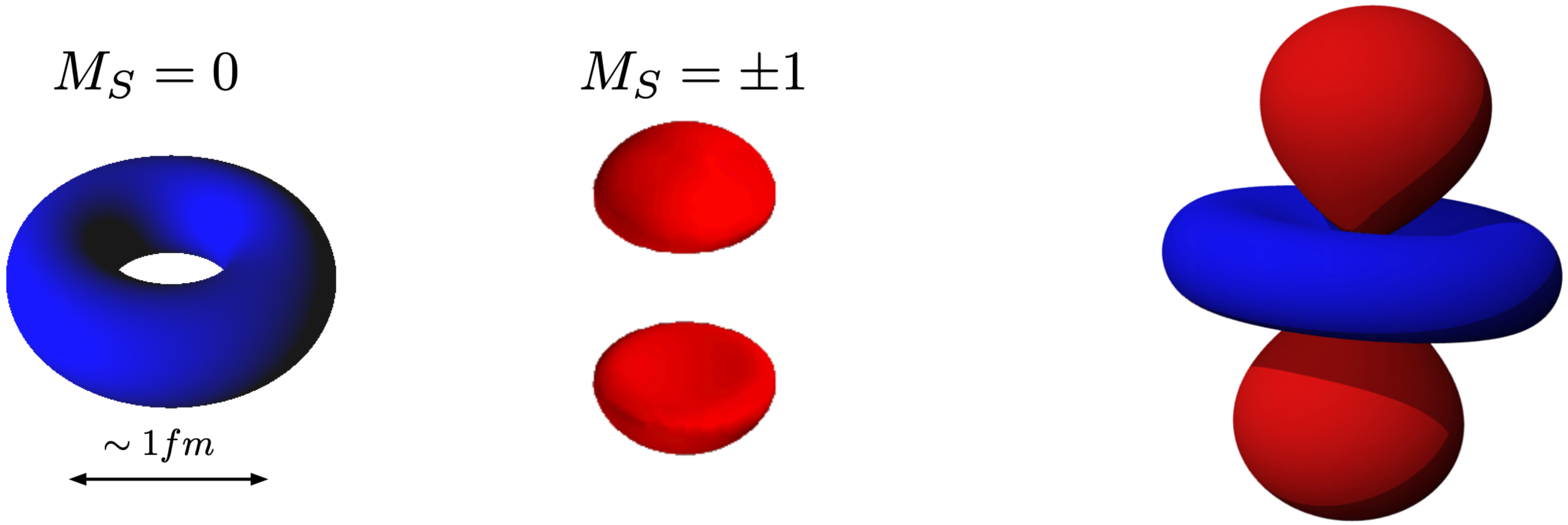
L + S = 1
L=0 (S-wave), 2 (D-wave)



- For surfaces of constant density (momentum dist) on deuteron S-wave and D-wave, the deuteron can be found in either an Ms=0 (torus) or Ms=+/-1 (dumbbell) shape
- For unpolarized deuteron, the S and D wave are essentially contain both torus and dumbbell shapes integrated, however, once deuteron becomes tensor polarized (to a certain extent, ~30%), the S-wave can be separated into an Ms=0 and Ms=+1 or -1 state? Similarly, the D-wave can be separated into an Ms=0 and Ms=+1, or -1 state, leading to spin-projection dependent momentum distributions

Figure 2. The calculated deuteron momentum distribution for different values of M_S and θ_k from reference [8]. The area (a) indicates the missing momentum range covered by the NIKEF experiment [9] and area (b) represents the kinematic range that could be explored at Jefferson Lab. [10]

$M_S = 0$ $M_S = \pm 1$



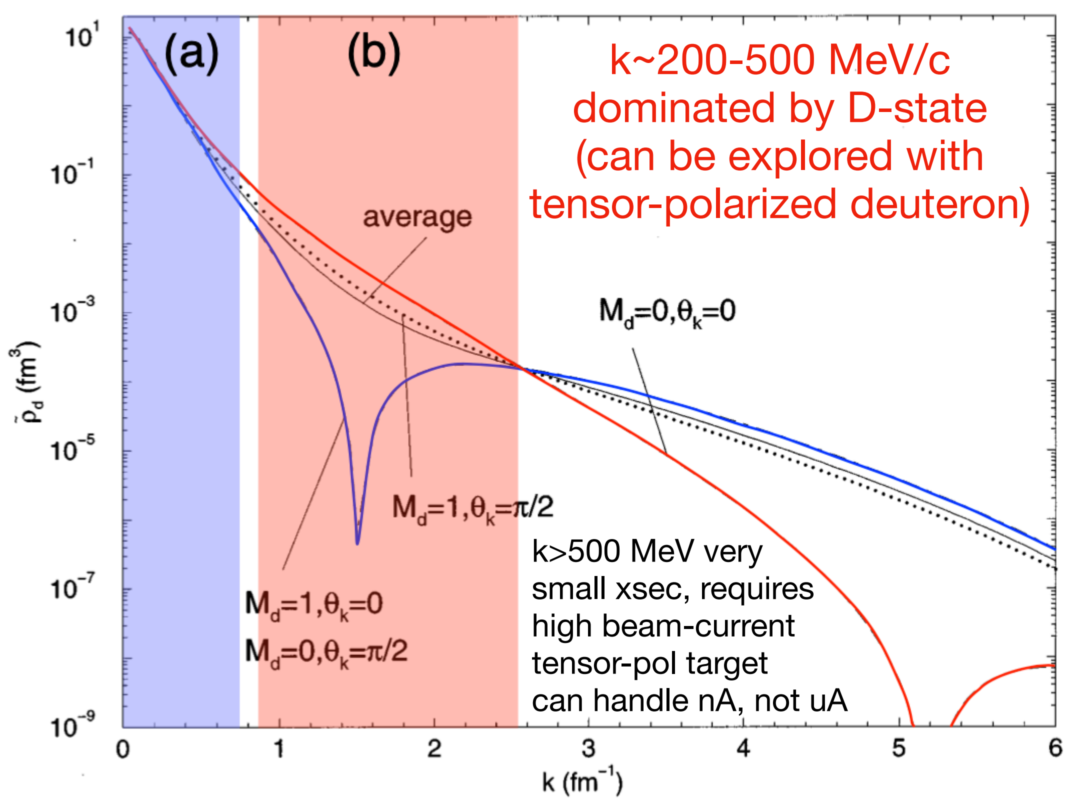


Figure 2. The calculated deuteron momentum distribution for different values of M_S and θ_k from reference [8]. The area (a) indicates the missing momentum range covered by the NIKEF experiment [9] and area (b) represents the kinematic range that could be explored at Jefferson Lab. [10]

- We can separate the torus from the dumbbell shape, so essentially we can have:
  rho_torus = a|S-wave> + b|D-wave>
  rho_dumbbell = a|S-wave> + b|D-wave>
  but for a given shape (torus or dumbbell) we cannot experimentally separate the S-wave from the D-wave?