RG-D Experiments: Status and Analysis Plans

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07/10/25

CLAS Collaboration Meeting (8-11 July, 2025)

Run Group D

RG-D is comprised of two experiments:

Study of Color Transparency (CT) in Exclusive Vector Meson Electroproduction off Nuclei (E12-06-106):
Spokespeoples: W. Armstrong[1] , L. El Fassi[4], K. Hafidi[1], M. Holtrop[5], and B. Mustapha[1]

Nuclear Transverse Momentum Distributions (nTMDs) in CLAS12 (E12-06-106A):
Spokespeoples: R. Dupré[3], L. El Fassi[4], Zein-Eddine Meziani[1], and Holly Szumila-Vance[2]

[1]: Argonne National Lab, [2]: Florida International U., [3]: IJCLAB, Orsay, France, [4]: Mississippi State U., [5]: University of New-Hampshire

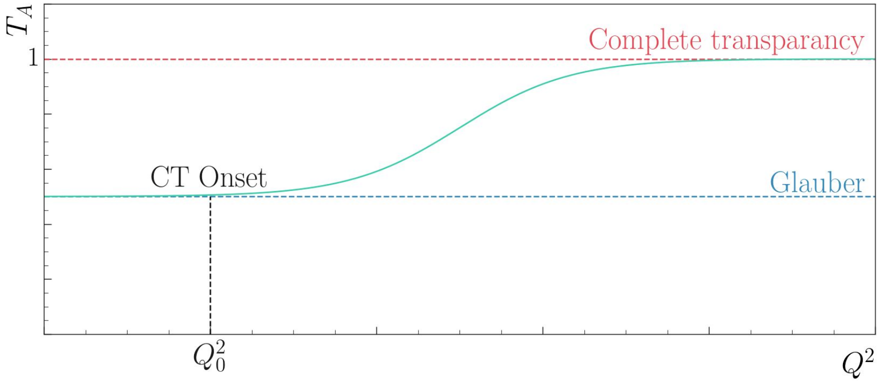
RG-D: CT Experiment

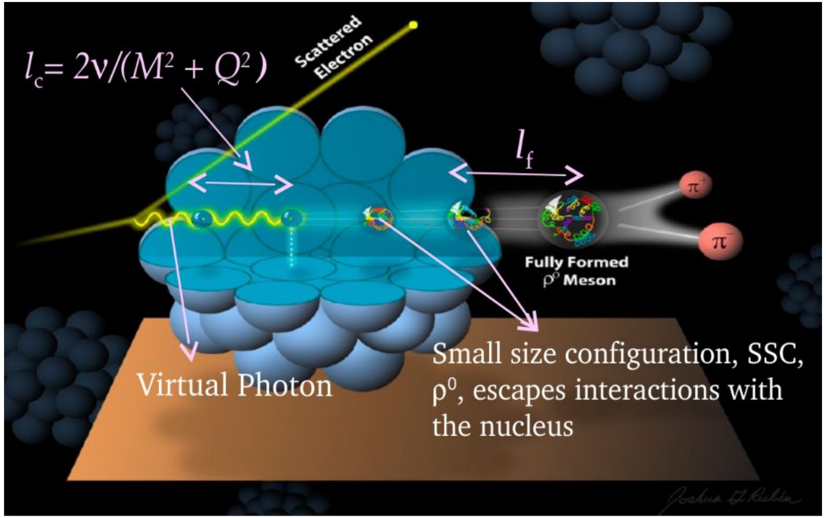
- Color Transparency: suppression of interactions of colorless SSC in nuclear medium
- Experimental signature: rise of the nuclear transparency, T_A, as a function of Q^2, where
  - T_A: ratio of the cross section per nucleon on a bound nucleon to that on a free nucleon

$$T_A = \frac{\sigma_A}{A\sigma_N}$$

σ_A – nuclei cross section
σ_N – free nucleon cross section

- Objective:
  - Understanding evolution from small-size configurations into ordinary hadrons
  - Validating the QCD factorization theorem





Coherence length, l_c: the lifetime of the qq-bar pair
Formation time, l_f: the time evolution of SSC to an on-shell ρ^0 meson

RG-D: Nuclear TMDs Study

- nTMDs study uses the same CT running conditions except the beam polarization, and aims to study:
  - Nuclear effects on SIDIS asymmetries
  - Transport coefficient of the nuclear matter
- Therefore, it aims to measure
  - cos φ, sin φ, and cos(2φ)[1] moments for different hadrons as

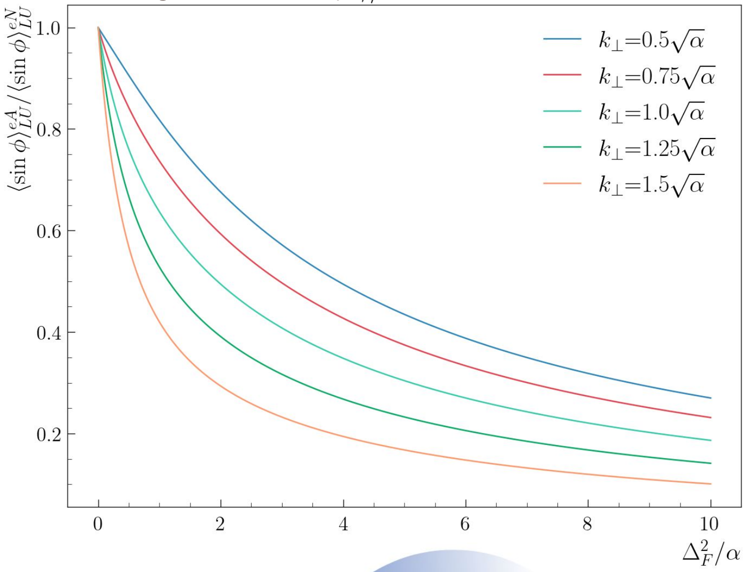
$$\frac{\langle \sin\phi\rangle^{eA}_{LU}}{\langle \sin\phi\rangle^{eN}_{LU}} \approx \frac{\alpha}{\alpha+\Delta_{2F}} \quad \text{and} \quad \frac{\langle \cos\phi\rangle^{eA}_{UU}}{\langle \cos\phi\rangle^{eN}_{UU}} \approx \frac{\alpha}{\alpha+\Delta_{2F}},$$

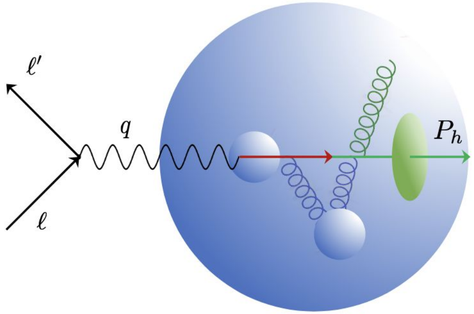
where, $\Delta_{2F} = \int d\xi_N^- \hat{q}_F(\xi_N),$ and

$q_F(\xi_N)$: quark transport parameter

[1] No predictions exist for this observable

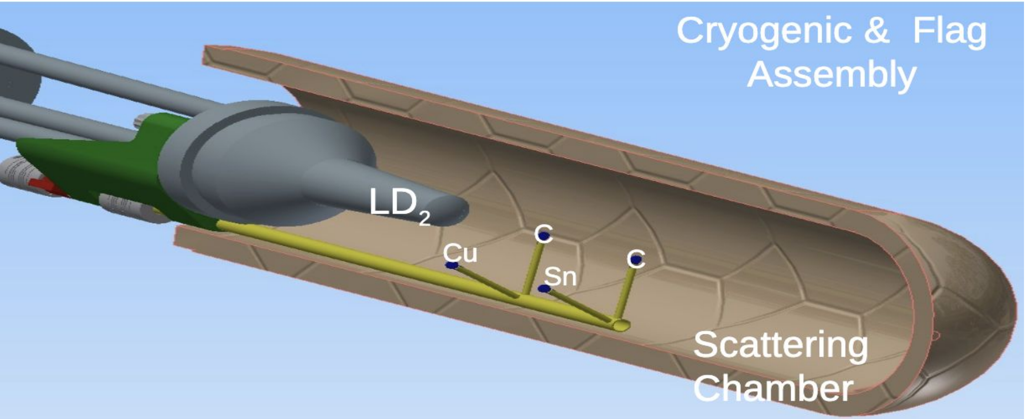
Song, Y. et al. (2014) Physical Review D, 89 014005

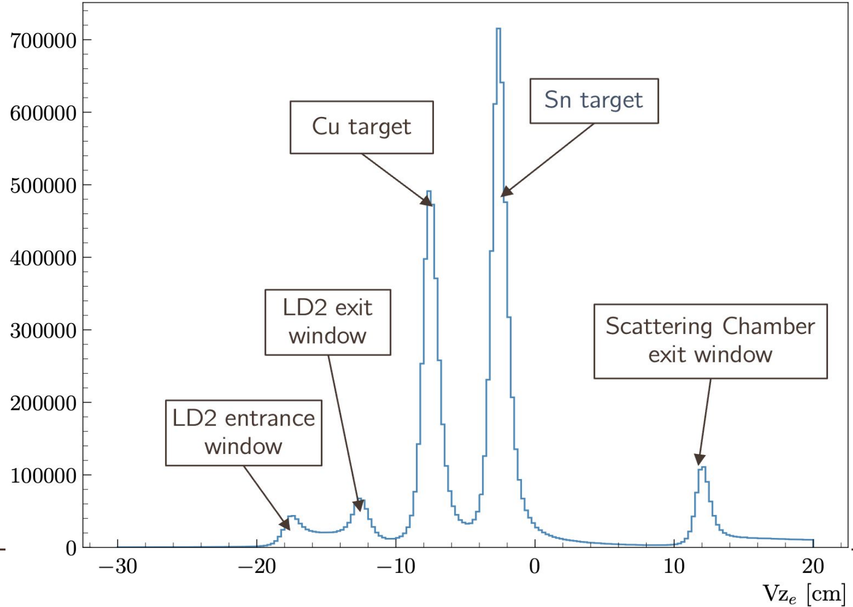




RG-D Run Configuration

- RG-D experiments collected data in the fall of 2023 with
  - 10.5 GeV polarized beam energy and I= 5–175 nA for luminosity scans and production
  - Standard CLAS12 configuration with FT-OFF and three layers of FMT
  - Three target-type, LD2, CxC, and CuSn, deployed with InBending and OutBending torus polarity
  - New cryogenic LD2 and the nuclear-foil flag assembly centered at -5 cm for each configuration
- Main run hiccups:
  - Faraday Cup vacuum contamination
  - Moller cone sagging





RG-D Status: Calibration & Cooking Summary

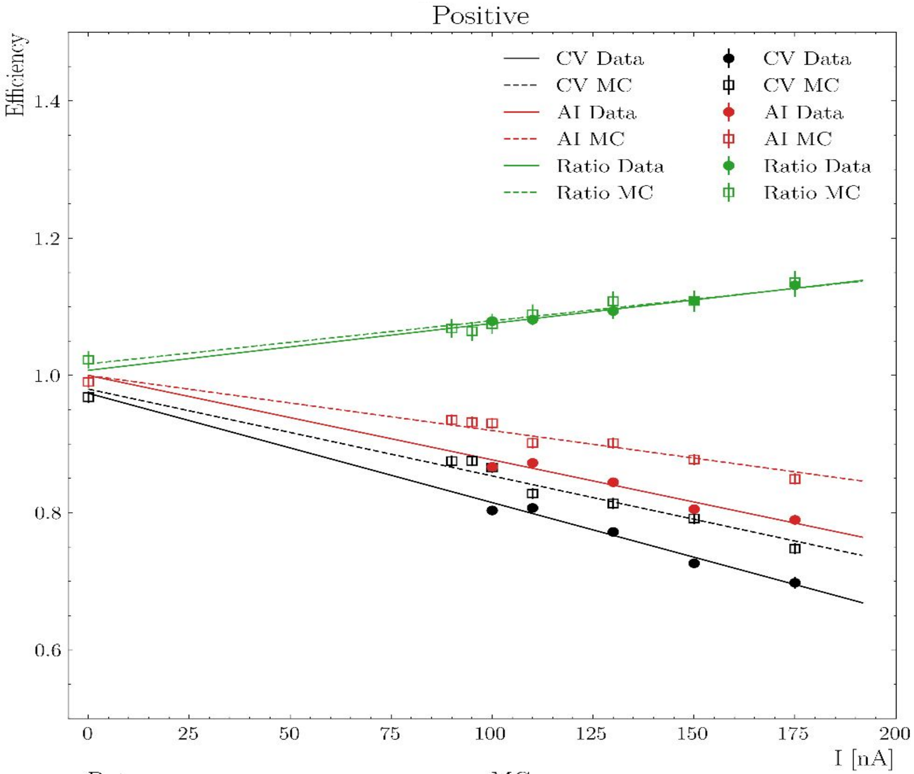
- Since March meeting update, RG-D fulfilled these milestones:
  - Completion of DC, the last piece of CLAS12 subsystems, calibration using the newest DCv2 suite
  - Training of three new AI-assisted networks and validating them on OB/IB LD2 and OB CuSn data
  - Sanity-check of the performance of the validated OB LD2 AI-assisted network on all RG-D datasets
  - Tracking efficiency and background merging studies based on simulation and real data comparison
  - Production of final Pass0 (v11) timelines and its associated high-level physics QA timeline with final calibration constants, adopted OB LD2 AI-assisted network, and denoising, as preparation for Pass1 cooking readiness review
- RG-D successfully passed the Pass1 review on May 27th
- Actual Pass1 cooking began on June 13th using the latest COATJAVA 13.0.0

RG-D is appreciably grateful to CalCom and Software Experts for their immense support

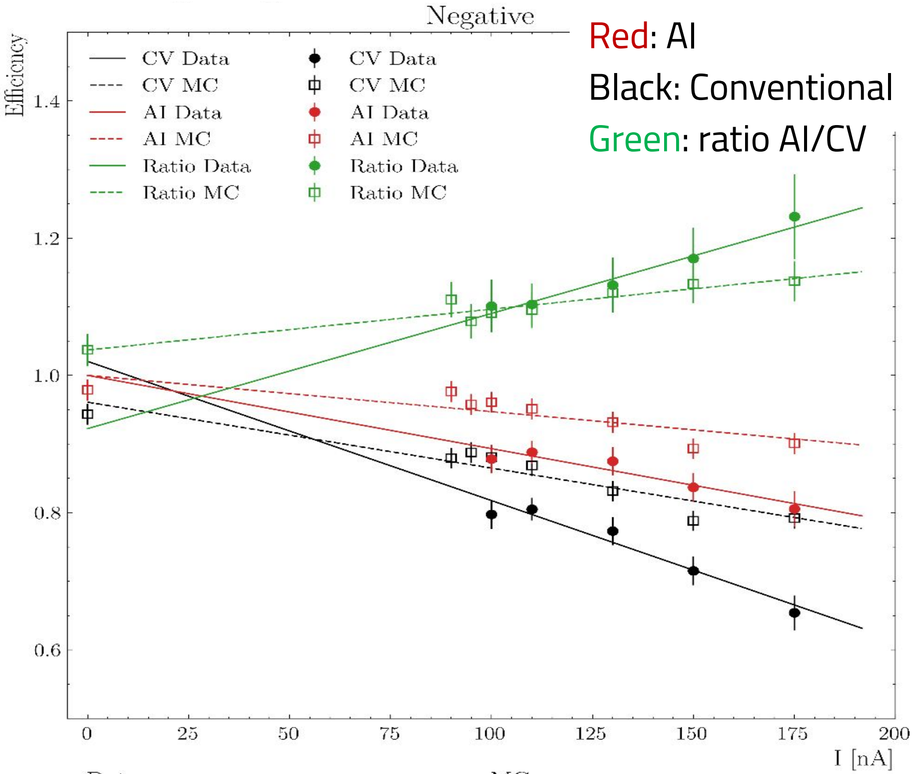
Tracking Efficiency & Background Merging Study

- Study DC efficiency vs. current for simulation and data:

Solid/Dash line: Data/MC
Red: AI
Black: Conventional
Green: ratio AI/CV



Data	MC
1.00000 + -0.001229 x (±0.000105)	1.00000 + -0.000803 x (±0.000060)
0.97399 + -0.001592 x (±0.000113)	0.98011 + -0.001265 x (±0.000059)



Data	MC
1.00000 + -0.001067 x (±0.000371)	1.00000 + -0.000529 x (±0.000112)
1.02041 + -0.002028 x (±0.000363)	0.96098 + -0.000960 x (±0.000110)

Tracking Efficiency & Background Merging Study

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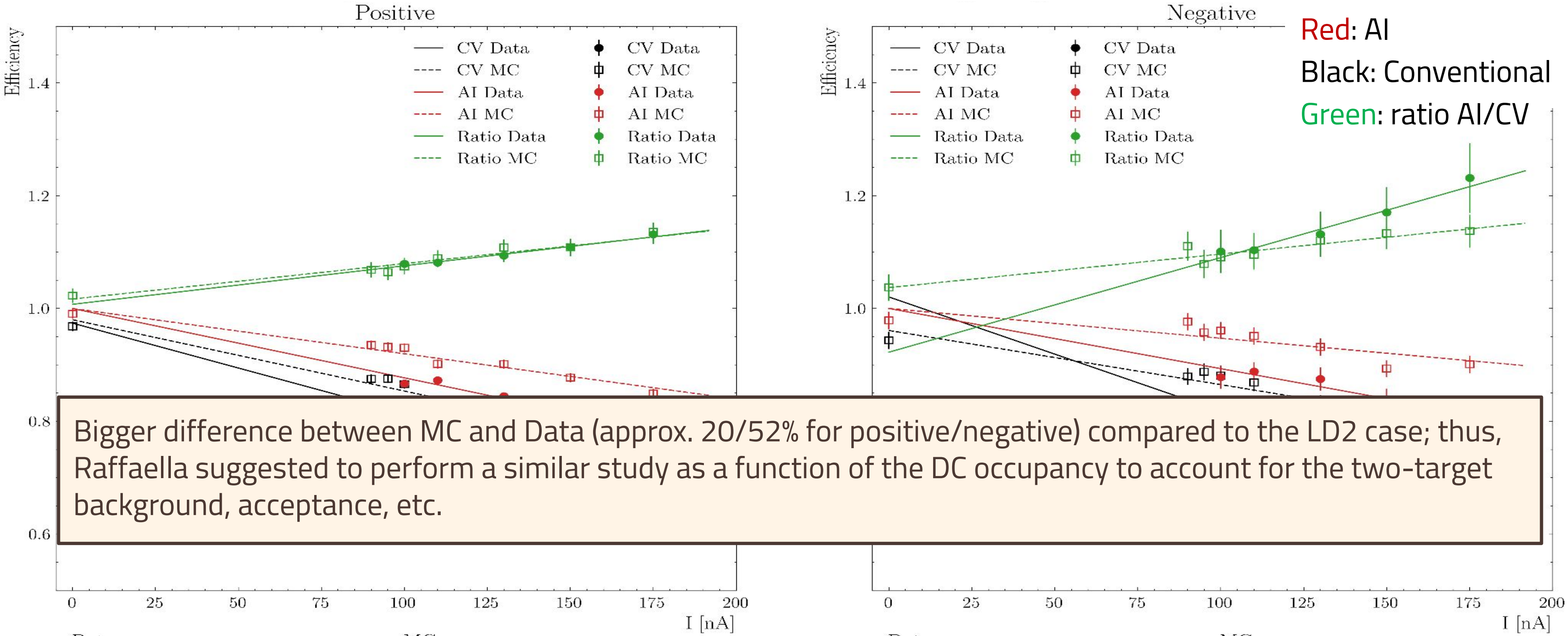

Bigger difference between MC and Data (approx. 20/52% for positive/negative) compared to the LD2 case; thus, Raffaella suggested to perform a similar study as a function of the DC occupancy to account for the two-target background, acceptance, etc.

Positive

Data	MC
1.00000 + -0.001229 x (±0.000105)	1.00000 + -0.000803 x (±0.000060)
0.97399 + -0.001592 x (±0.000113)	0.98011 + -0.001265 x (±0.000059)

Negative

Data	MC
1.00000 + -0.001067 x (±0.000371)	1.00000 + -0.000529 x (±0.000112)
1.02041 + -0.002028 x (±0.000363)	0.96098 + -0.000960 x (±0.000110)

Tracking Efficiency & Background Merging Study

- Study DC efficiency vs. DC occupancy for simulation and data:

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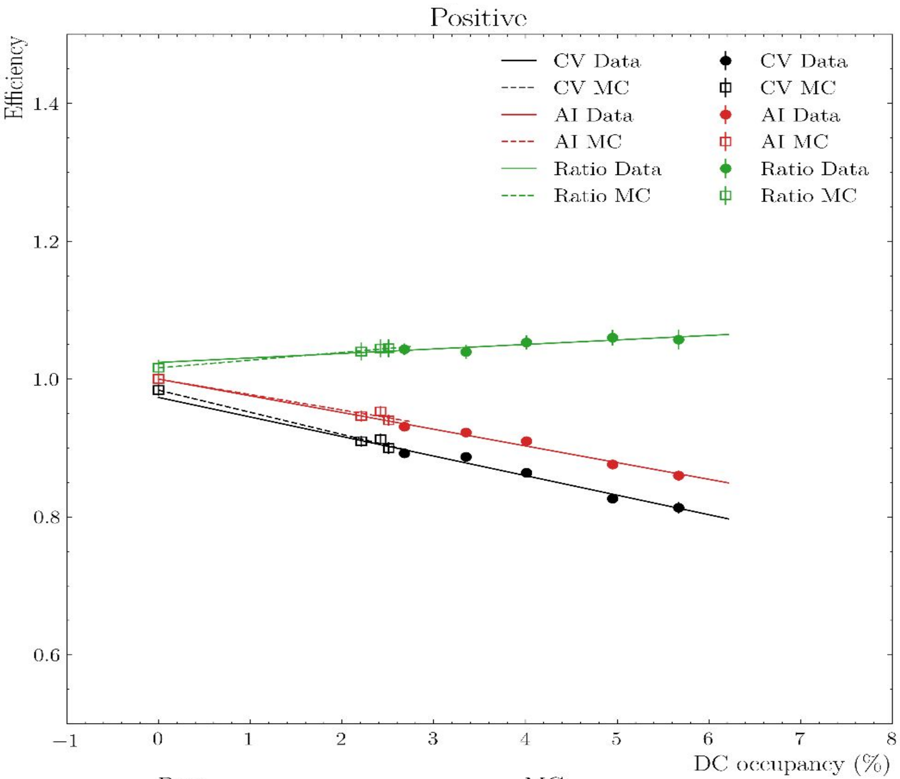
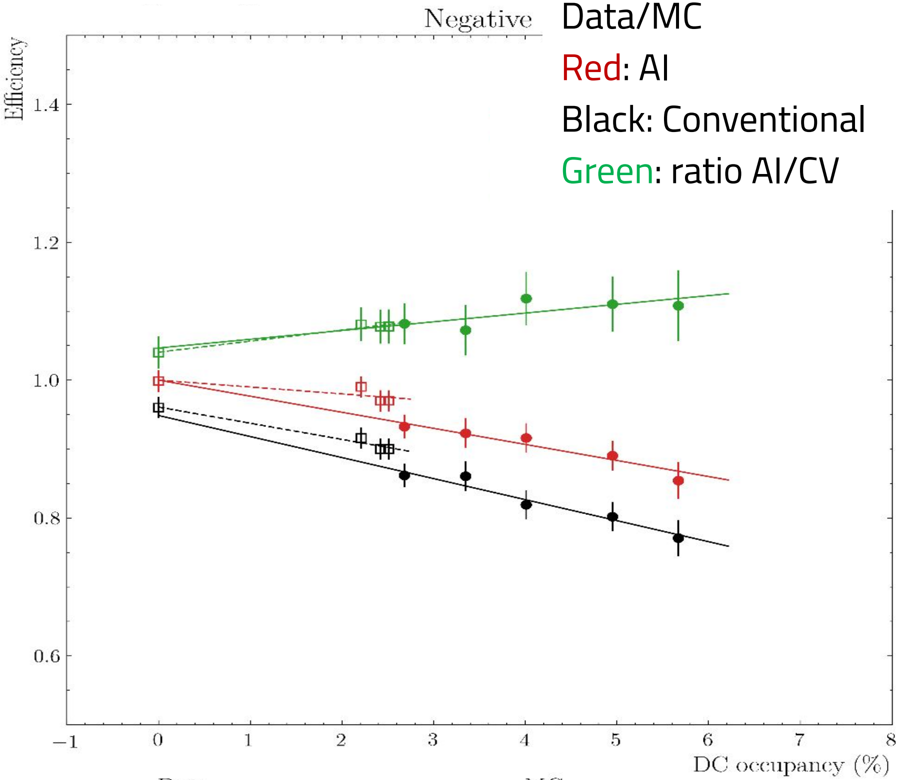
Black: Conventional
Green: ratio AI/CV



Data
1.00000 + -0.024227 x (±0.002598)
0.97343 + -0.028359 x (±0.002719)

MC
1.00000 + -0.022399 x (±0.004022)
0.98396 + -0.032093 x (±0.004015)



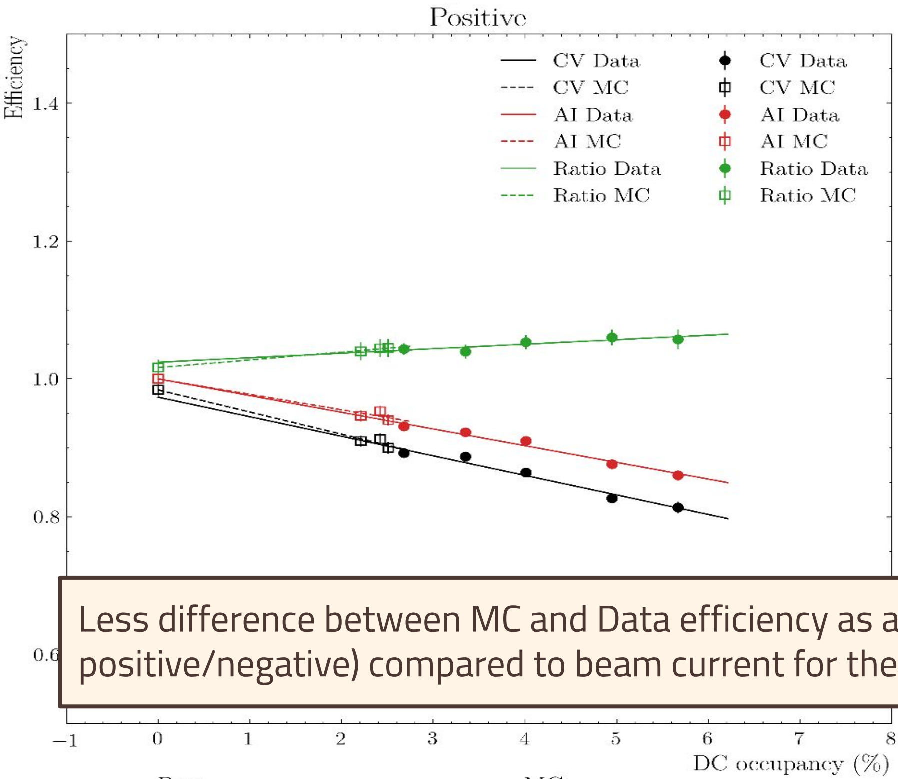
Data
1.00000 + -0.023314 x (±0.009004)
0.94867 + -0.030517 x (±0.008893)

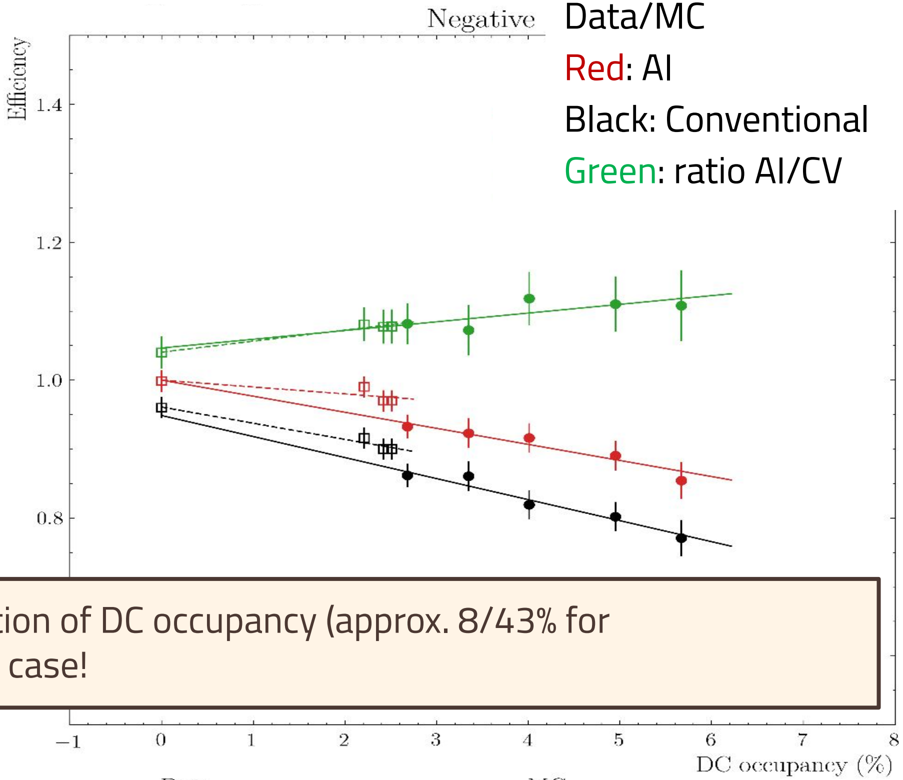
MC
1.00000 + -0.009977 x (±0.007531)
0.96093 + -0.023445 x (±0.007413)

Tracking Efficiency & Background Merging Study

- Study DC efficiency vs. DC occupancy for simulation and data:

Solid/Dash line: Data/MC
Red: AI
Black: Conventional
Green: ratio AI/CV





Less difference between MC and Data efficiency as a function of DC occupancy (approx. 8/43% for positive/negative) compared to beam current for the CuSn case!

Positive:

Data	MC
1.00000 + -0.024227 x (±0.002598)	1.00000 + -0.022399 x (±0.004022)
0.97343 + -0.028359 x (±0.002719)	0.98396 + -0.032093 x (±0.004015)

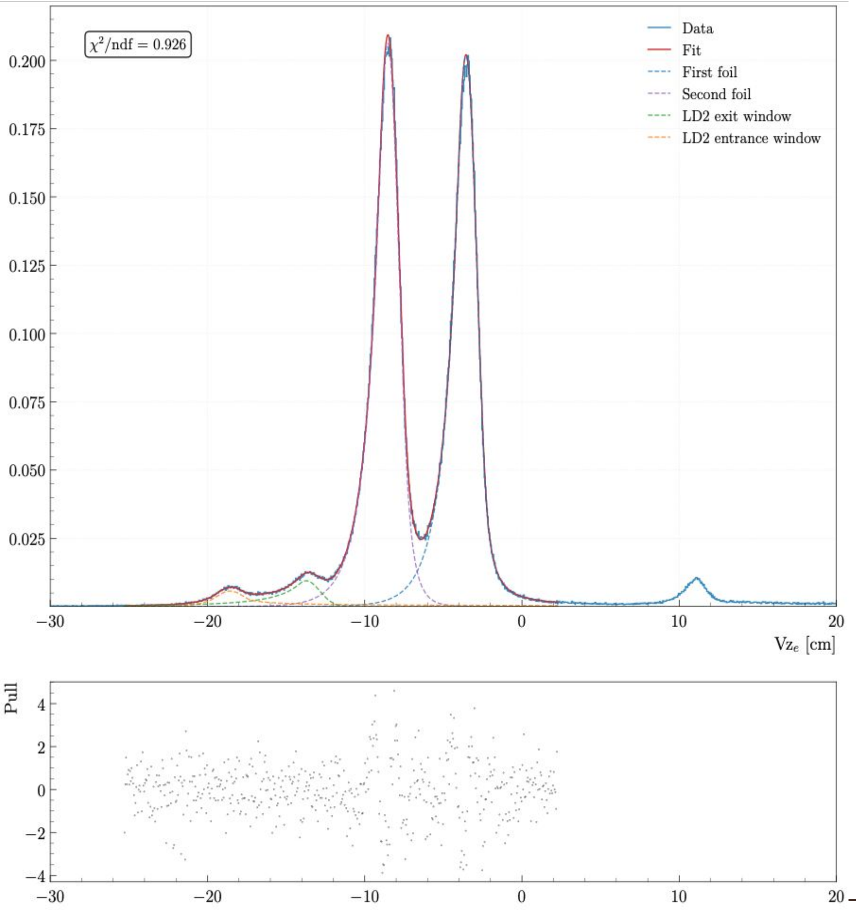
Negative:

Data	MC
1.00000 + -0.023314 x (±0.009004)	1.00000 + -0.009977 x (±0.007531)
0.94867 + -0.030517 x (±0.008893)	0.96093 + -0.023445 x (±0.007413)

RG-D Refined Vz Cuts

- The study aims to
  - Remove the beamline windows, empty LD2 cell windows for solid-foil runs in addition to the scattering chamber exit window for liquid and solid target runs
- Fit with a four Double-Sided Crystal Ball function

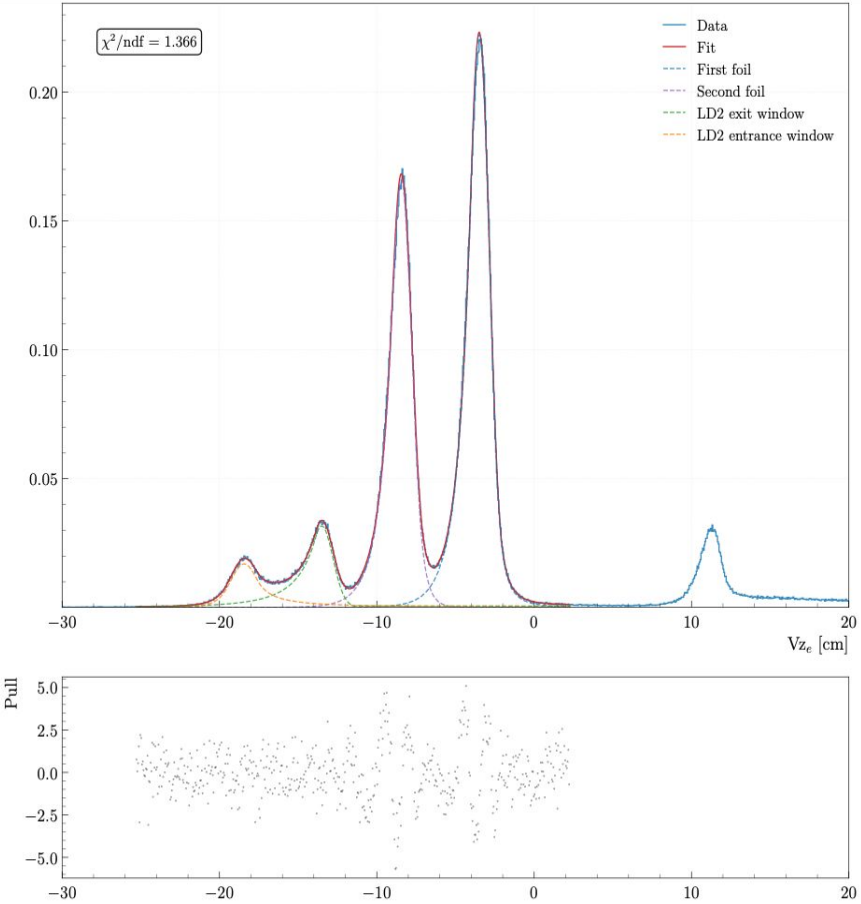
Parameter	Before refinement	After refinement	Improvement (%)
$\sigma_{\text{Exit LD2}}$	0.7691	0.7068	6.23
$\sigma_{\text{Entrance LD2}}$	0.7799	0.7158	6.41
σ_{CxC1}	1.1182	0.8586	25.96
σ_{CxC2}	1.2309	0.9139	31.70



RG-D Refined Vz Cuts

- The study aims to
  - Remove the beamline windows, empty LD2 cell windows for solid-foil runs in addition to the scattering chamber exit window for liquid and solid target runs
  - Separate the Cu and Sn solid-foil peaks prior to performing a proper contamination study
- Fit with a four Double-Sided Crystal Ball function

Parameter	Before refinement	After refinement	Improvement (%)
$\sigma_{\text{Exit LD2}}$	1.0045	0.8754	12.91
$\sigma_{\text{Entrance LD2}}$	0.8162	0.7000	11.62
σ_{Cu}	0.7625	0.6798	8.27
σ_{Sn}	0.7439	0.6631	8.08



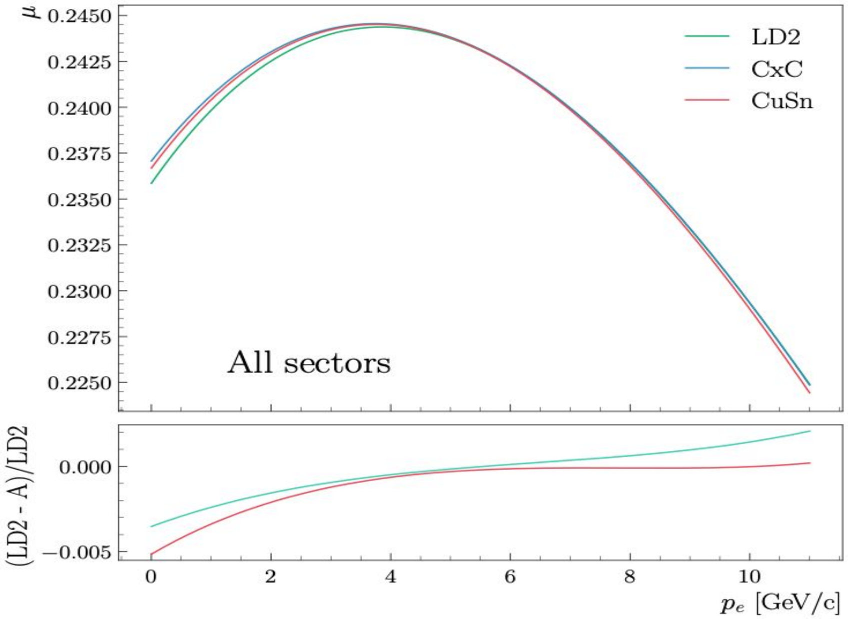
Electron Fiducial Cuts

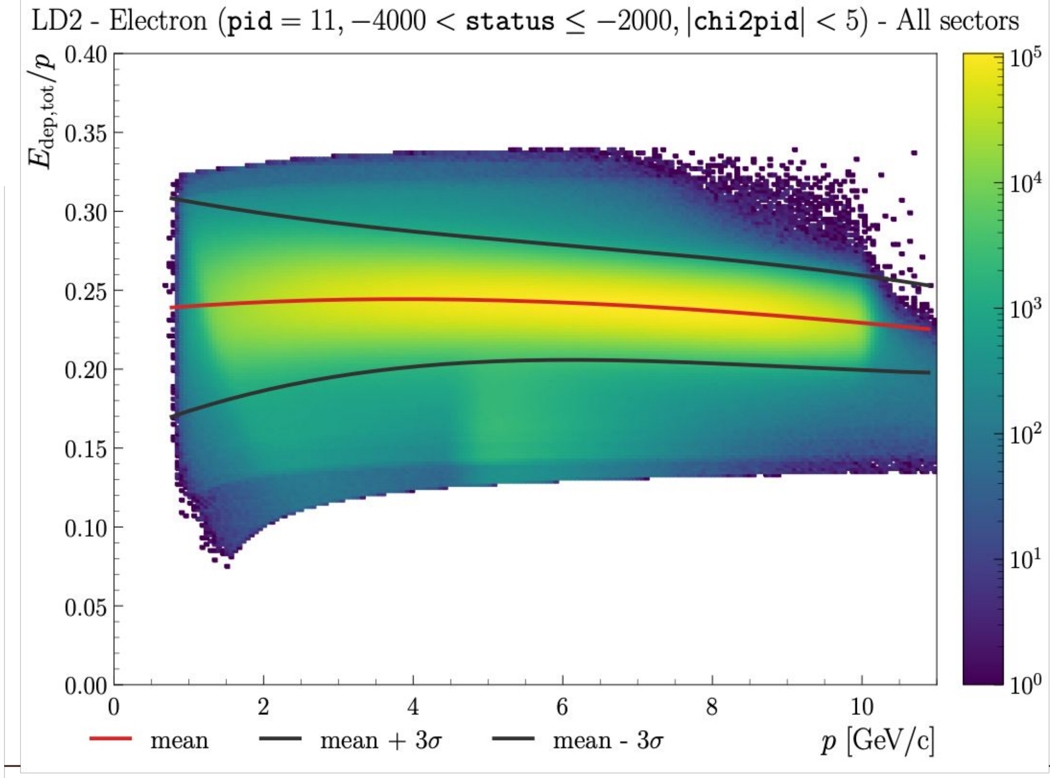
- Event builder Particle IDentification is used as a basis for all particle types, but some refinements are developed to improve electron ID
- Raw electron cuts:
  - PID = 11, status< 0
  - 2000≤ |status| < 4000: status represents the detector topology and is the sum of numbers associated to detector hits
  - |chi2pid| < 5: chi2pid is the number of σ_{SF} from the expected Sampling Fraction using the fit as function of deposited energy, E_{dep}, in ECal and PCal
- Refinements:
  - Vz cut: select the target peak from where the scattered electron originated
  - Sampling Fraction vs. momentum: should be constant for electrons
  - V and W ECal views: defined at lengths that are multiples of 4.5 cm
  - DC fiducial cut using θ_{DC} vs. edge to remove edges of the three regions

Electron FCs: SF vs. Momentum

- Using a 3σ cut after performing a fit of sector-integrated SF for various momentum bins:
  - ➢ 50 slices, fit with a Gaussian
  - ➢ Extract μ and σ, then deploy this function to select the desired band

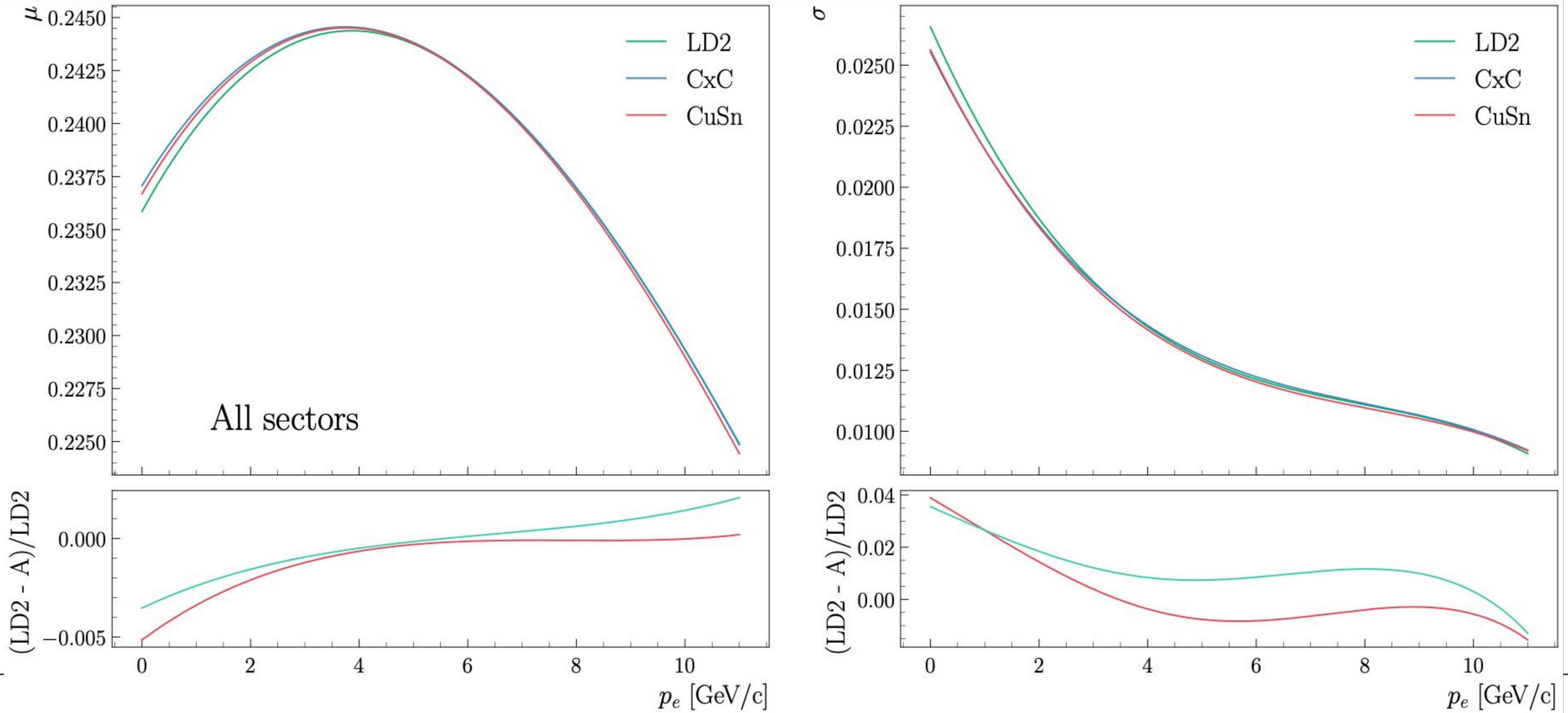
$$f(p; a, b, c, d) = a + bp + cp^2 + dp^3$$





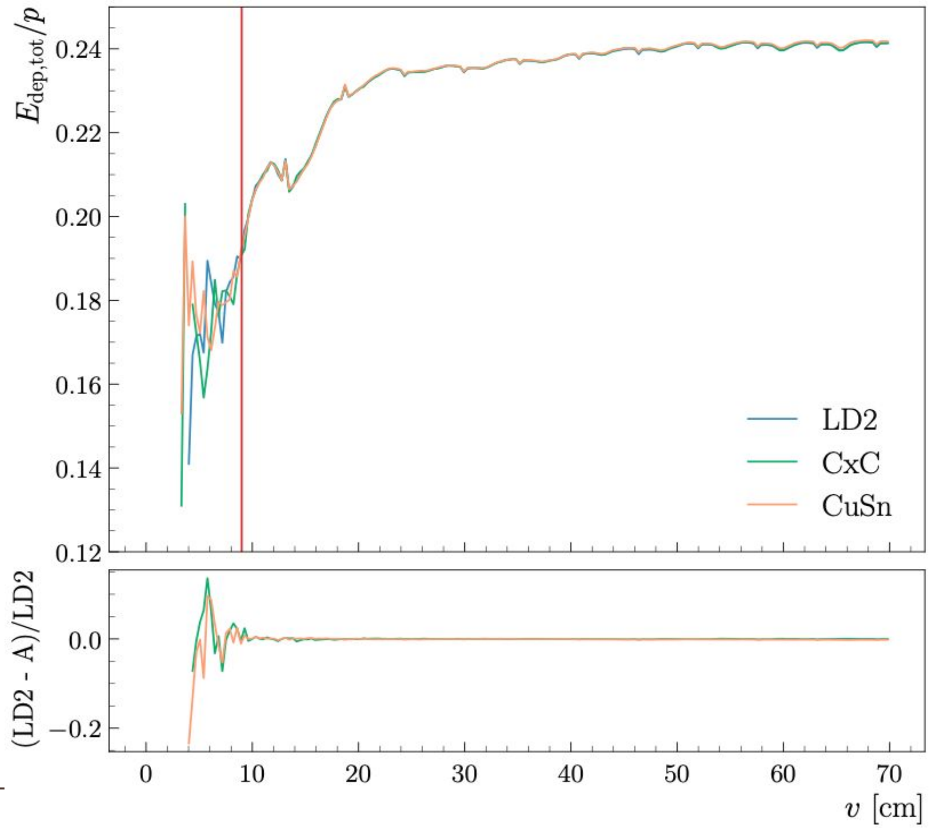
Electron FCs: SF vs. Momentum

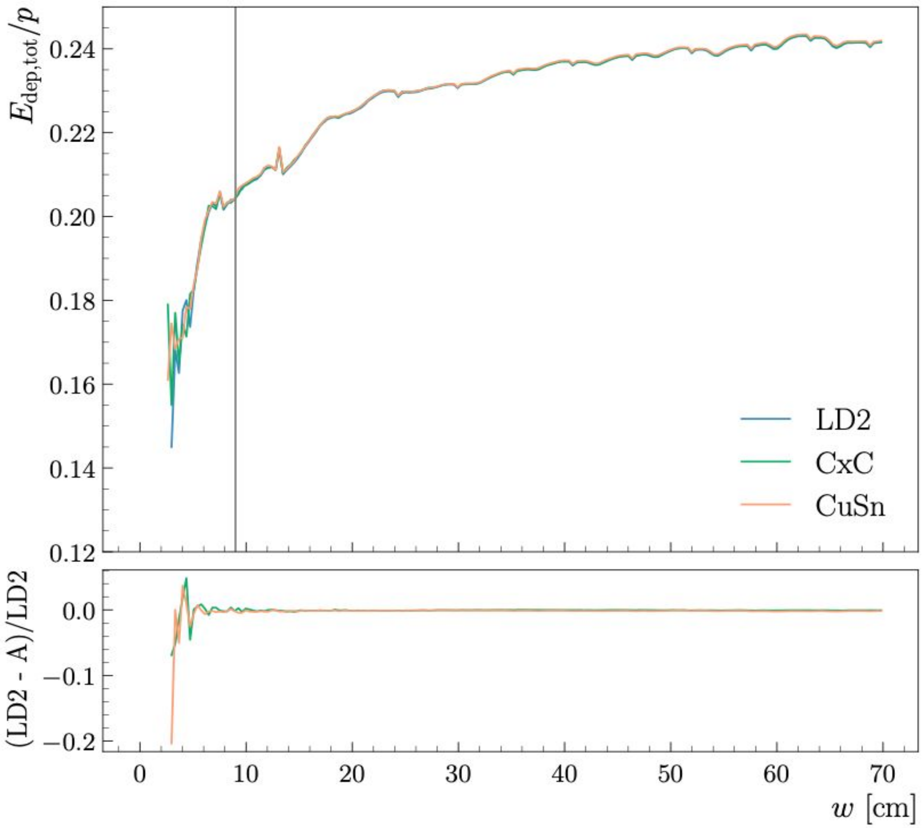
- Various targets comparison:



Electron FCs: ECal V and W Cuts

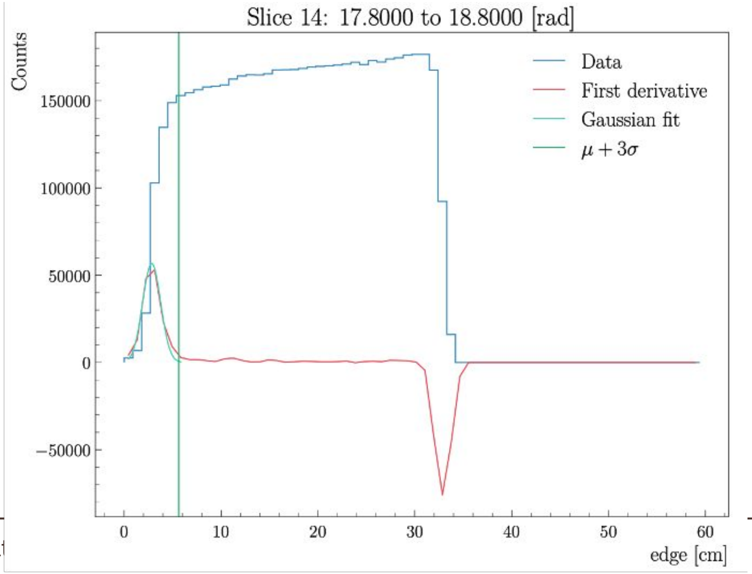
- Use standard CLAS12 cuts for ECal: V, W> 9 cm; exclude 2 bars to minimize shower leakage!

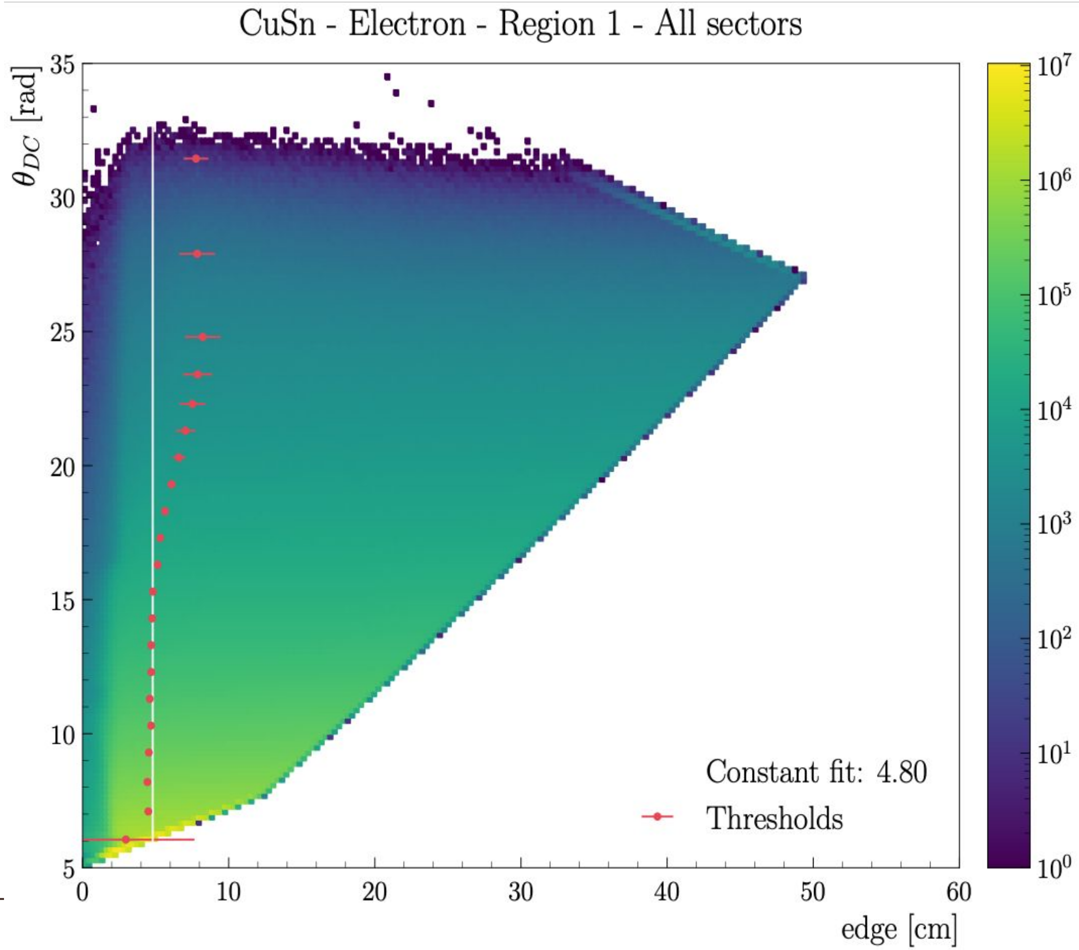




Electron FCs: θ_{DC} vs. Edge

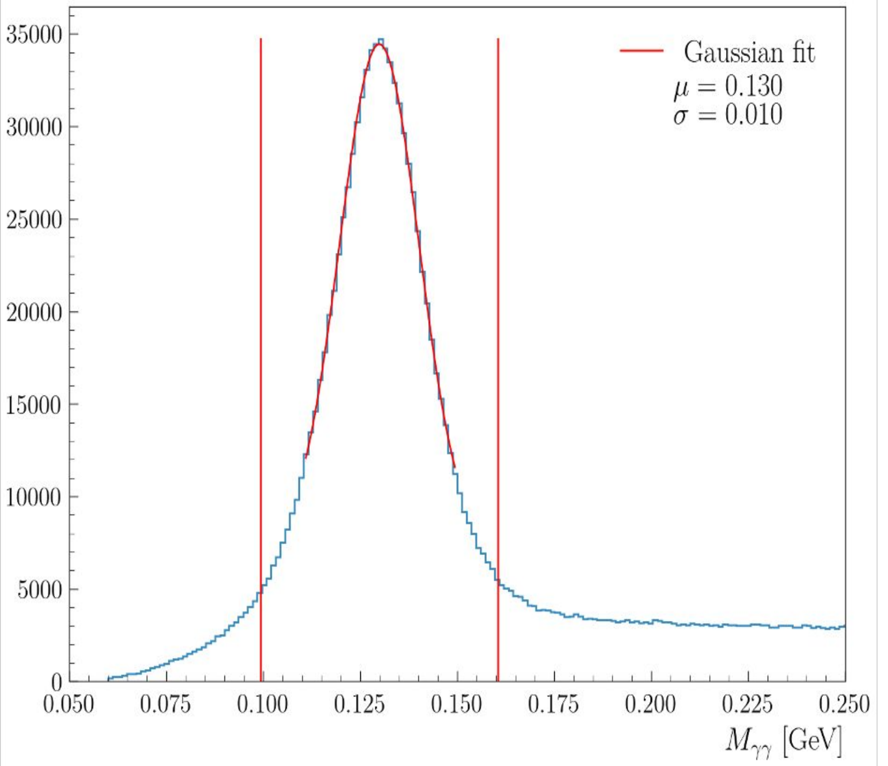
- Remove the DC edges for all regions and target types:
  - Slice the θ_{DC} vs. edge histogram
  - Fit the peak of the derivative with a Gaussian to obtain the threshold ($\mu+3\sigma$)
  - Fit all thresholds with a constant





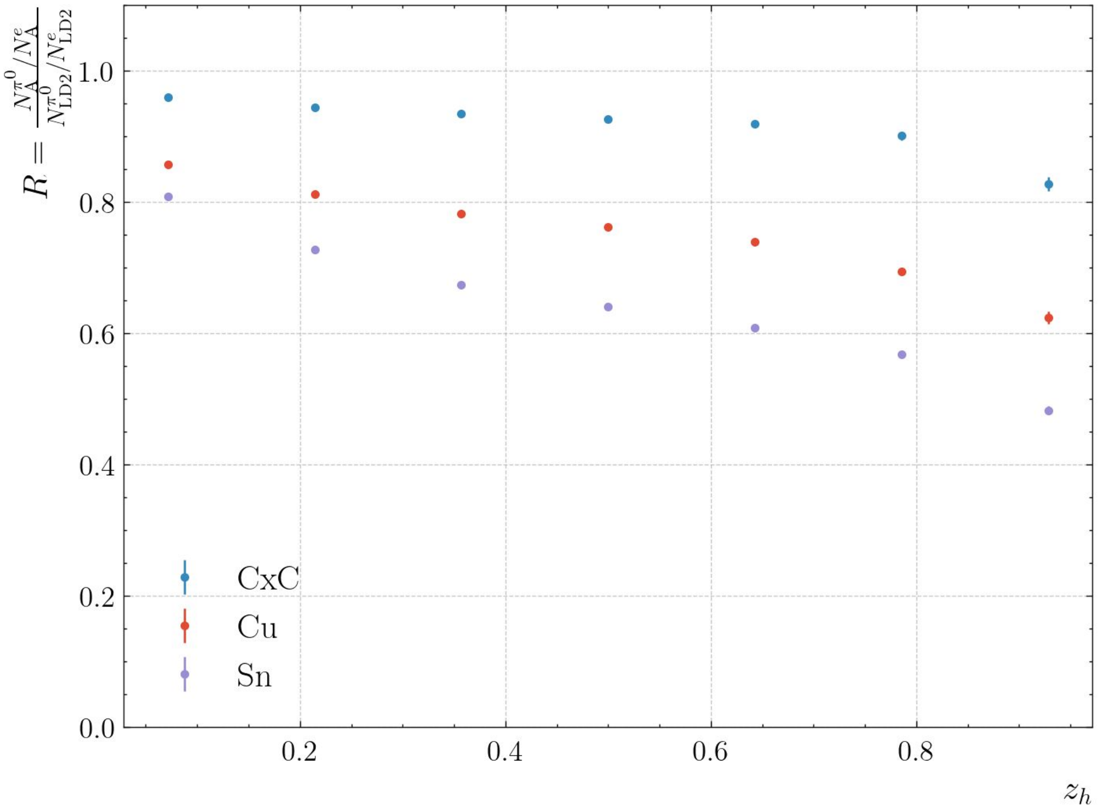
RG-D nTMDs Studies: π^0 Analysis

- First look at the π^0 channel to extract multiplicity ratios and azimuthal asymmetries
  - Ongoing efforts to employ the event mixing technique to subtract the background underneath the two-photon mass peak
- Electron cuts:
  - PID = 11, status< 0, 2000≤ |status|< 4000, |chi2pid|< 5, and Vz cut
- Photon cuts:
  - PID= 22 and E> 0.2 GeV
  - AI-assisted cut developed by Gregory Matousek
  - $\mu \pm 3\sigma$ to select the two-photon π^0 peak
- SIDIS cuts:
  - Q^2> 1 GeV^2, W> 2 GeV, and y (= ν/E_{beam})< 0.85, where ν is the virtual photon energy



- First look at the π^0 channel to extract multiplicity ratios and azimuthal asymmetries
  - As of now, extract 1-D multiplicity ratio as a function of z_h, defined as

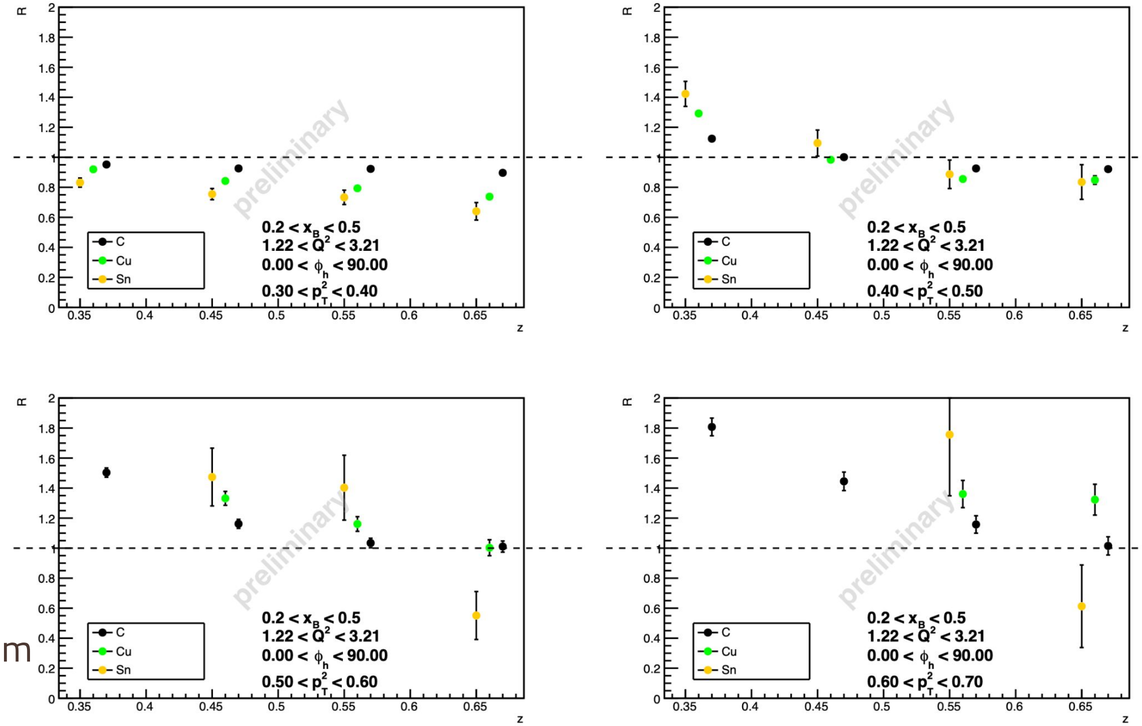
$$R = \frac{N_{\mathrm{A}}^{\pi^0}(z_h)}{N_{\mathrm{A}}^{e}} \frac{N_{\mathrm{LD2}}^{e}}{N_{\mathrm{LD2}}^{\pi^0}(z_h)}$$



RG-D nTMDs Studies: π^+ analysis

- Pass0v11 preliminary results
- Binning: Q^2, x_B, ϕ_h, p_T^2, and z
- Multiplicity Ratio results for one $1.2<Q^2<3.2$ and $0.2<x_B<0.5$ bins by comparing the three nuclei
- Expected behavior for preliminary results:
  - Nuclear hierarchy respected, suppression increases with nuclear mass
  - Increased suppression at higher z and lower p_T^2 could indicate absorption
  - Reversal of nuclear hierarchy at high p_T^2 suggests hadronization in the nuclear medium
- Ongoing Unfolding

$$R_A^\pi\left(Q^2, x_B, \phi_h, z, p_T^2\right) = \frac{N_\pi^A\left(Q^2, x_B, \phi_h, z, p_T^2\right)/N_e^A\left(Q^2, x_B\right)}{N_\pi^D\left(Q^2, x_B, \phi_h, z, p_T^2\right)/N_e^D\left(Q^2, x_B\right)}$$

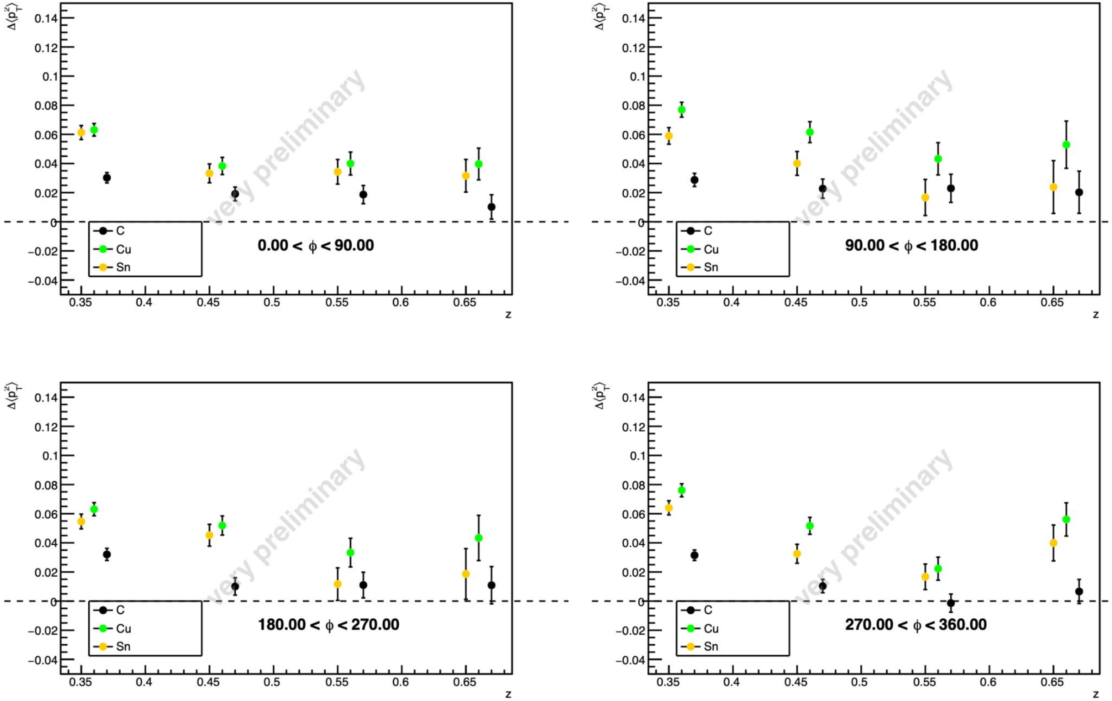


Ongoing analysis by D. Matamoros

RG-D nTMDs Studies: π^+ analysis

- Transverse momentum broadening
- Results for one $1.2<Q^2<3.2$ and $0.2<x_B< 0.5$ bins by comparing the three nuclei:
  - Hierarchy between nuclei remains, coherent tendencies
  - Possible decrease with increasing z, could suggest hadron formation outside the nucleus
- Inconclusive results, as corrections remain to be incorporated

$$\Delta\langle p_T^2\rangle = \langle p_T^2\left(x_b, Q^2, \phi_h, z\right)\rangle_{\mathrm{A}} - \langle p_T^2\left(x_b, Q^2, \phi_h, z\right)\rangle_{\mathrm{LD_2}}$$



Ongoing analysis by D. Matamoros

Summary and Outlook

- RG-D has passed the Pass1 review, and the estimated 90-days Pass1 cooking began on June 13th

- Optimizing analysis tools for CT and nTMDs studies to
  - improve PIDs and implement fiducial cuts for all final-state particles
  - correct for any solid-foil contamination associated with the CuSn target configuration
  - deploy the ρ^0 event generator for its two-pion invariant mass background subtraction and apply necessary corrections to extraction the preliminary CT results
  - Finalize the π^0 event mixing background-subtraction and extract its preliminary asymmetries
  - Obtain the preliminary asymmetry results for charged pions nTMDs studies


THANKS

Back-up