Update on RG-D Status and Run Preparation

International Workshop on CLAS12 Physics and Future Perspectives at JLab

March 23rd, 2023

Lamiaa El Fassi

for Run Group D

MISSISSIPPI STATE UNIVERSITY™

CEBAF Large Acceptance Spectrometer

Run Group D

RG-D Experiments

E12-06-106: Study of Color Transparency (CT) in Exclusive Vector Meson Electroproduction off Nuclei

Spokespeople: W. Armstrong[1], L. El Fassi[3], K. Hafidi[1], M. Holtrop[4], and B. Mustapha[1]

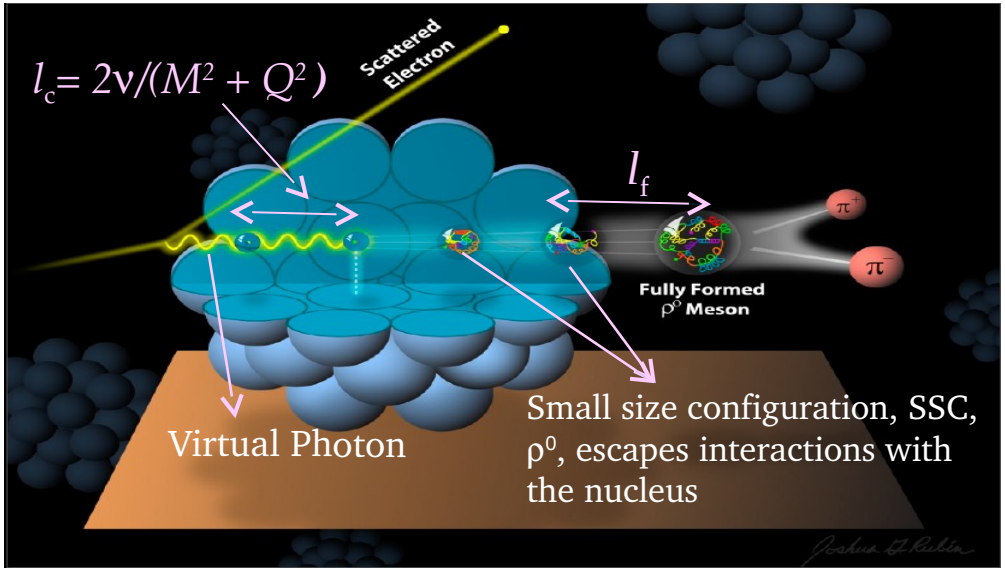
E12-06-106A (endorsed by *PAC-48*): Nuclear TMDs in CLAS12

Spokespeople: R. Dupré[2], L. El Fassi[3], Zein-Eddine Meziani[1], and Holly Szumila-Vance[5]

[1]: Argonne National Lab (ANL)
[2]: IJCLAB, Orsay, France
[3]: Mississippi State U. (MSSate)
[4]: University of New-Hampshire (UNH)
[5]: Jefferson Lab

RG-D: CT Experiment

- E12-06-106, CT, experiment was (re-)approved in PAC-48 Jeopardy review for 30 PAC days with B^+ rating.



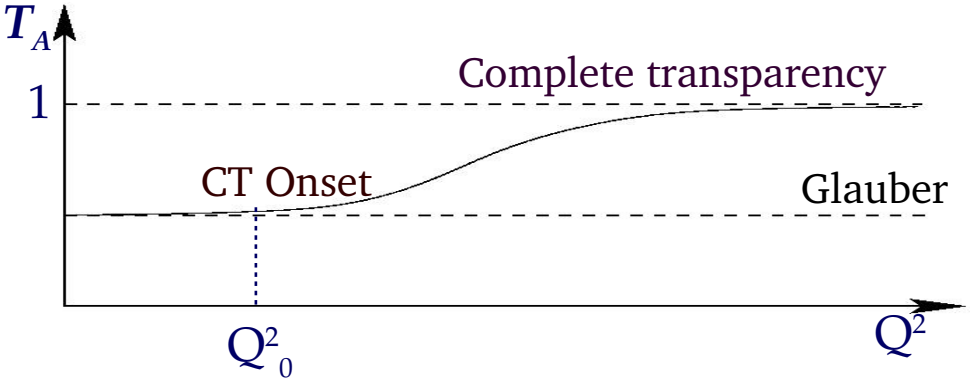
- Coherence length, l_c: the lifetime of the qq-bar pair.
- Formation time, l_f: the time evolution of SSC to an on-shell ρ^0 meson.

The CT signature is the increase of the medium "nuclear" transparency, T_A, as a function of the four-momentum transfer squared, Q^2.

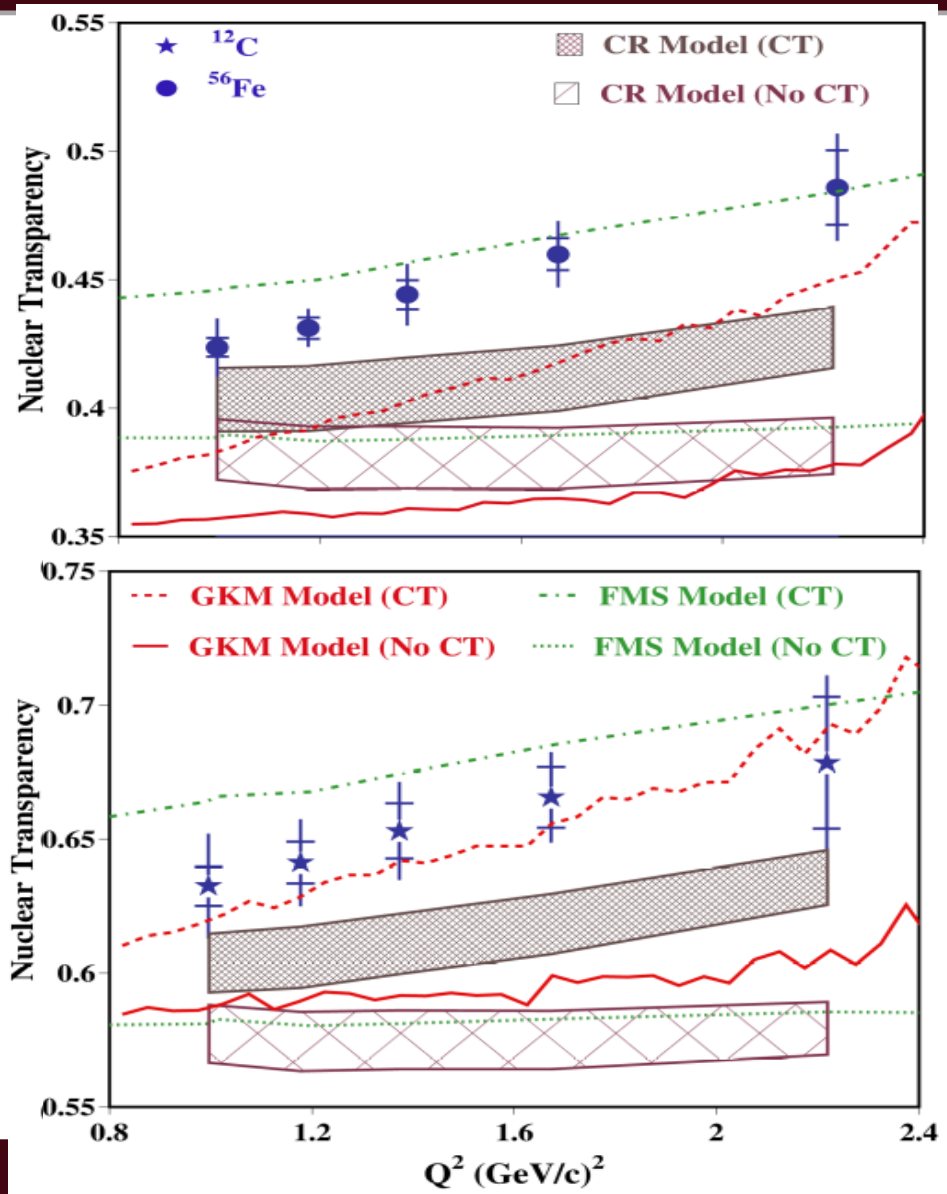
$$T_A = \frac{\sigma_A}{A\,\sigma_N}$$

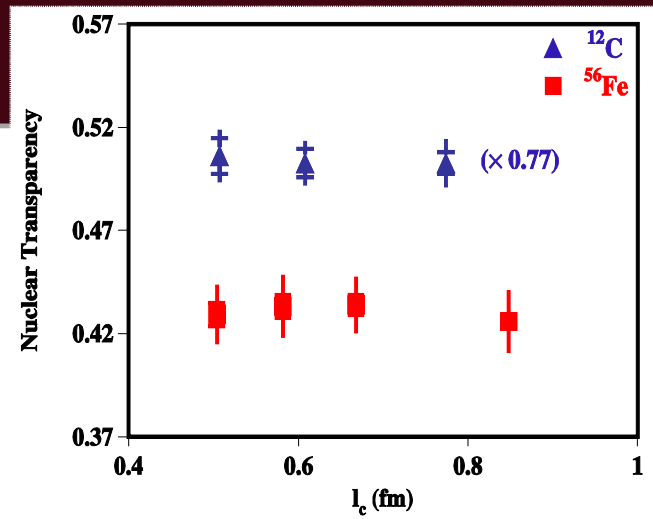
σ_A is the nuclear cross section

σ_N is the free (nucleon) cross section



CLAS6 ρ^0 CT Results





No l_c dependence observed

L. El Fassi *et al.*, PLB 712 (2012)
L. El Fassi, Physics 4, no. 3 (2022) (*review paper*)

- **FMS**: semi-classical Glauber formalism based on quantum diffusion model (QDM).
- Dashed-dotted curve includes CT effects, FSIs and ρ^0 decay.

Frankfurt, Miller & Strikman, PRC 78 (2008) & Private communication

- **GKM**: Transport Model (GiBUU) Dashed curve includes CT effects for ρ^0 produced in DIS regime only!

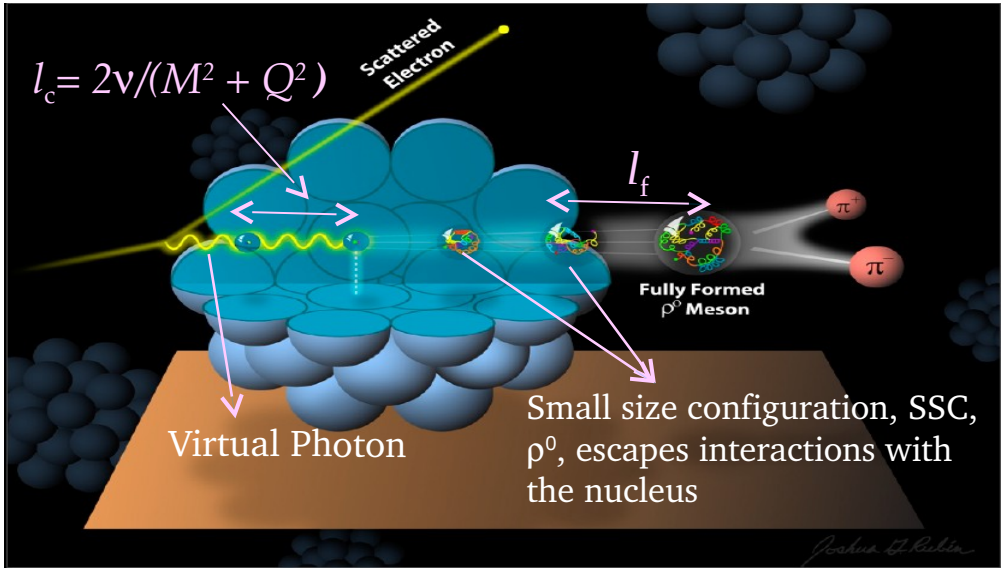
Gallmeister, Kaskulov & Mosel, PRC 83 (2011)

- **CR**: relativistic multiple scattering Glauber approximation.
- Hatched-band includes CT effects based on QDM.

W. Cosyn, and J. Ryckebusch PRC 87 (2013)

RG-D: CT Experiment

- E12-06-106, CT, experiment was (re-)approved in PAC-48 Jeopardy review for 30 PAC days with B^+ rating.



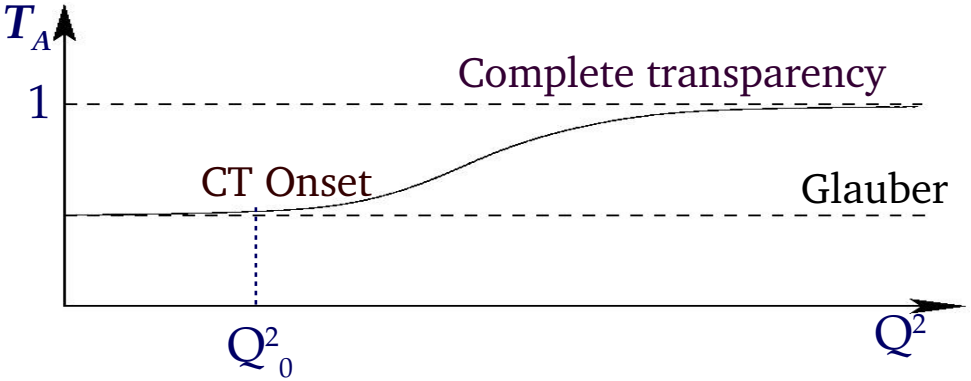
- Coherence length, l_c: the lifetime of the **qq-bar** pair.
- Formation time, l_f: the time evolution of SSC to an on-shell ρ^0 meson.

The CT signature is the increase of the medium "nuclear" transparency, T_A, as a function of the four-momentum transfer squared, Q^2.

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

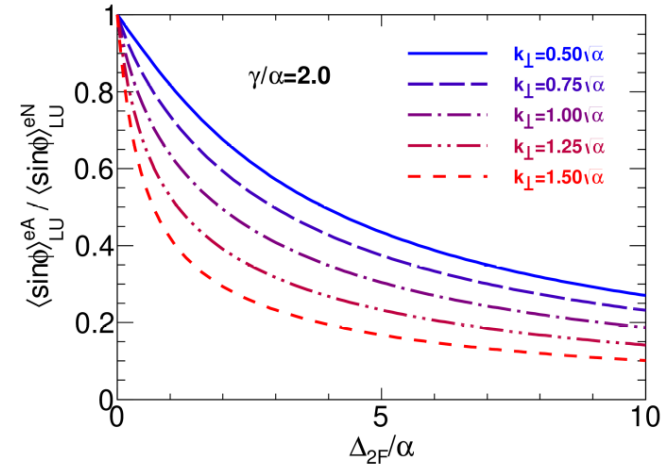
σ_A is the nuclear cross section

σ_N is the free (nucleon) cross section

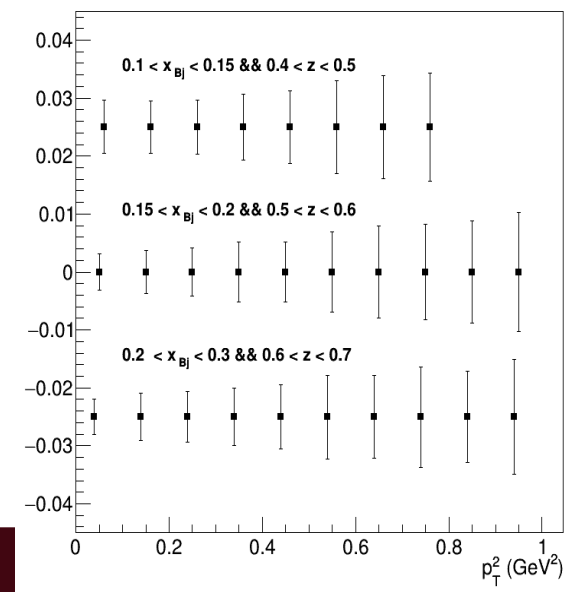


Nuclear TMDs Experiment: RG-D Addition

- E12-06-106A, Nuclear TMDs study will use the same CT running conditions except the beam polarization, and aim to explore
  - New approach for nuclear SIDIS
  - Fragmentation functions in nuclei
  - Missing part of nuclear effects description
  - Nuclear asymmetries at the partonic level
- Nuclear TMDs extraction
  - Is similar to nucleon TMDs
  - Has different modulation of cross section terms
  - Is complicated due to the convolution with fragmentation functions
  - Accesses transport coefficient at parton level from first moments
- Projections based on
  - Realistic simulation (HERMES gmc_trans generator + CLAS12 GEMC/ analysis chain)
  - Significant reach for the 1st measurement (even if p_T is smaller than RG-A reach for proton)
  - Control of systematics by comparing to proton measurement
  - Different targets to look for the A-dependence



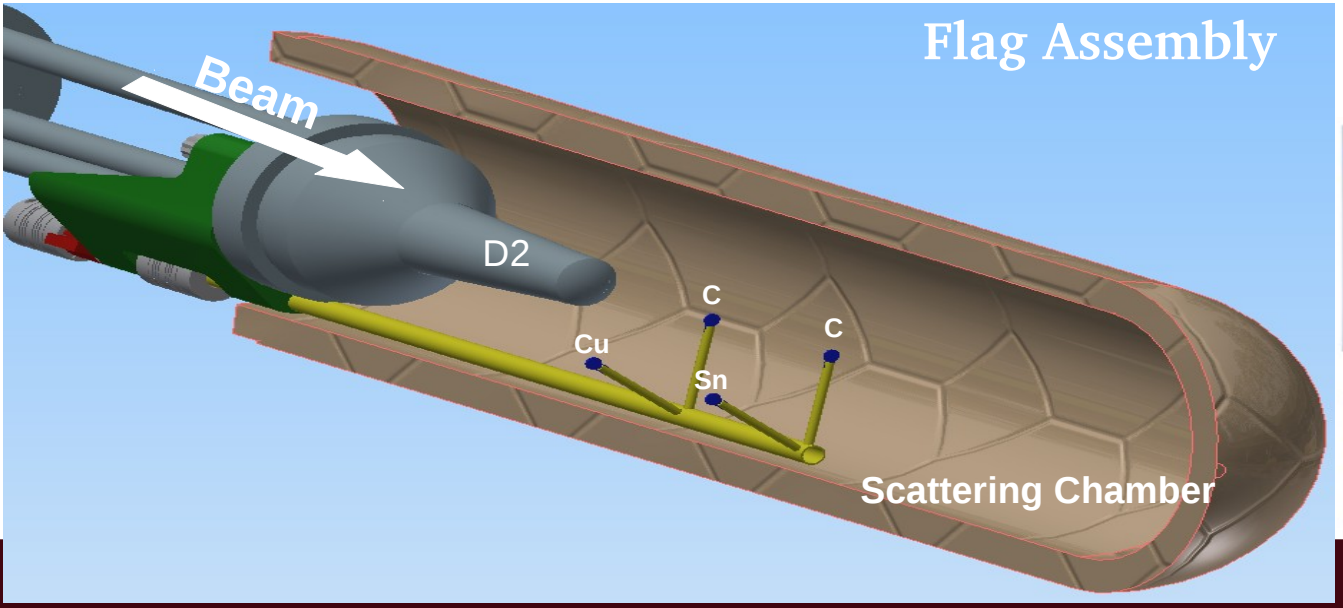
⟨ sin ϕ ⟩ and ⟨ cos ϕ ⟩



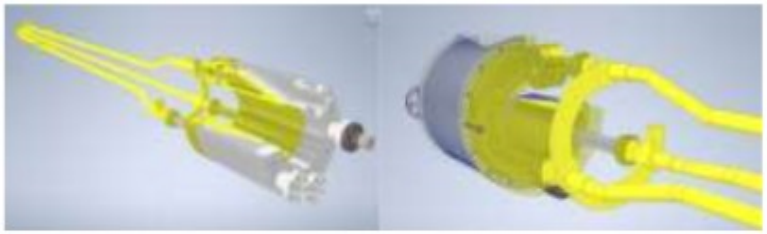
See D. Matamoros' talk

RG-D Experiments: Run Configuration

- RG-D experiments require
  - 11 GeV (*or the maximum possible*) polarized beam;
  - Standard CLAS12 configuration with FT-OFF;
  - Separate runs of Hall-B LD2 and the nuclear-foils flag assembly at backward position (*centered @ -5 cm for both solid and liquid targets runs*);
  - Different beam currents and target thicknesses to achieve the nominal per-nucleon luminosity of 10^{35} $cm^{-2}s^{-1}$ in production runs.



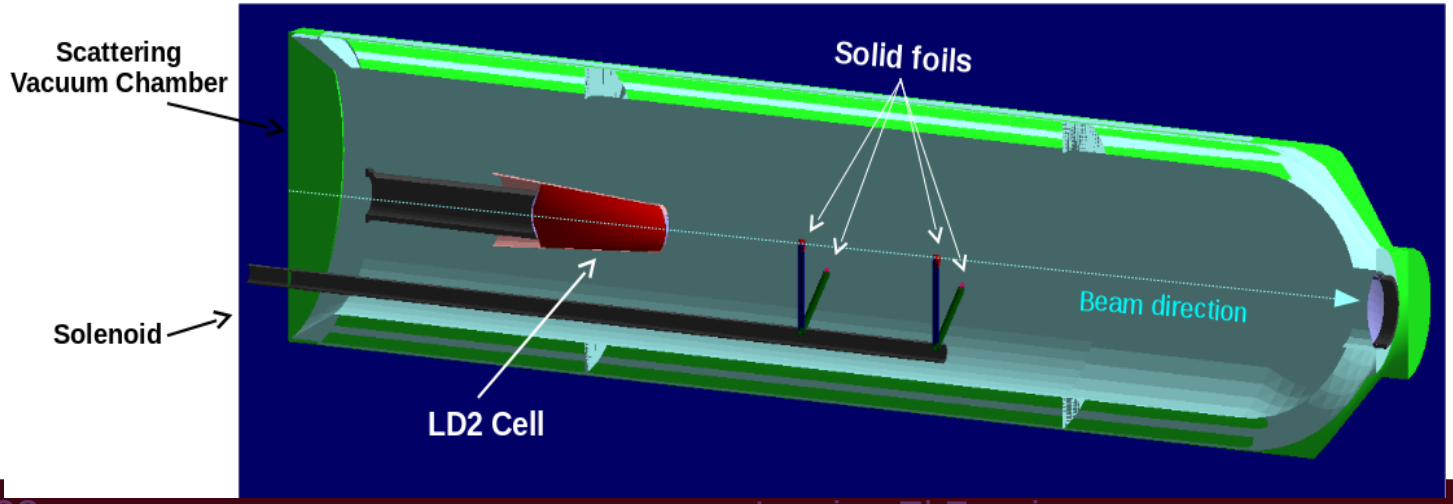
New JLab cryogenic target replacing the Saclay target



RG-D Experiments: Target & Current Setting

- Anticipated beam currents and target thicknesses (*within 2%* X_0) for production runs;
  - ✔ Currents could increase to ~ 150 nA in luminosity scans and detector efficiency studies.

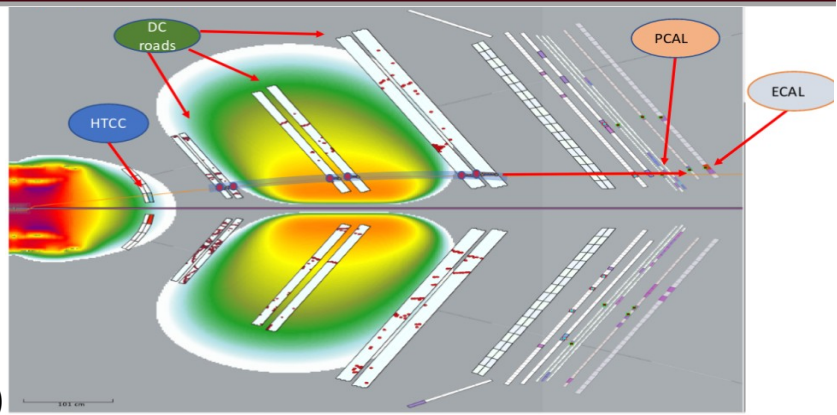
Targets	Thickness (2 foils) (cm)	Density (g cm^{-3})	Areal Density (T) (mg cm^{-2})	Radiation Length (X_0) (g cm^{-2})	Radiation Lengths (T/X_0) (%)	Beam Current (nA)	Per-Nucleon Luminosity (10^{35} cm^{-2} s^{-1})
LD2	5	0.164	820	125.98	0.65	~ 35	1
^{12}C	0.2 (0.4)	2.2	440	42.7	1.03 (2.06)	~ 30	1
^{63}Cu / ^{118}Sn	0.009 / 0.018	8.96 / 7.31	80.64 / 131.58	12.86 /8.82	0.63 / 1.49	~125	1



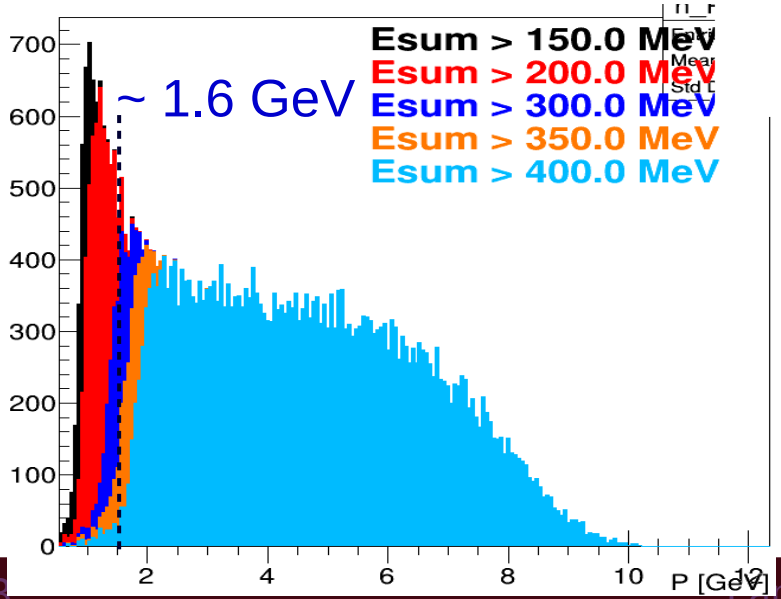
GEMC Snapshot of the Hall-B Flag Assembly

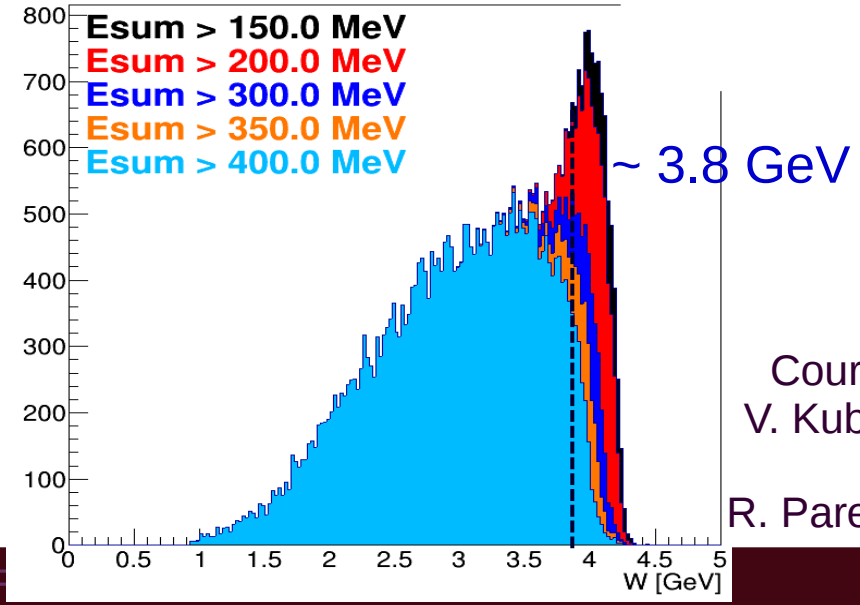
Running Conditions: Magnets & Trigger

- Use the RG-A/B (in-bending) electron trigger:
  - ✔ Minimum number of HTCC photoelectrons > 2
  - ✔ Minimum PCAL cluster energy > 60 MeV
  - ✔ DC segments 5 out of 6
  - ✔ Negative DC roads matching the PCALU cluster
  - ✔ Sum of the energy deposited in PCAL & ECAL greater than **250** MeV (*RG-B setting -> 5.7 kHz e- trigger rate; TBC for RG-D*)



- This threshold affects the scattered electron momentum and kinematics, mainly W!
- Assume a maximum field for both torus and solenoid magnets.

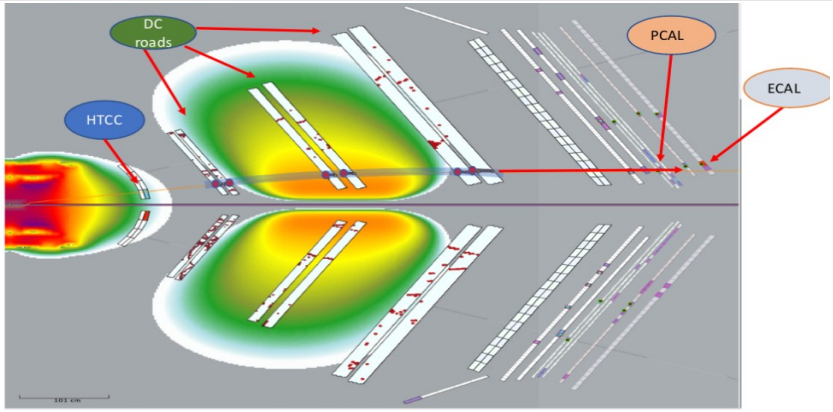




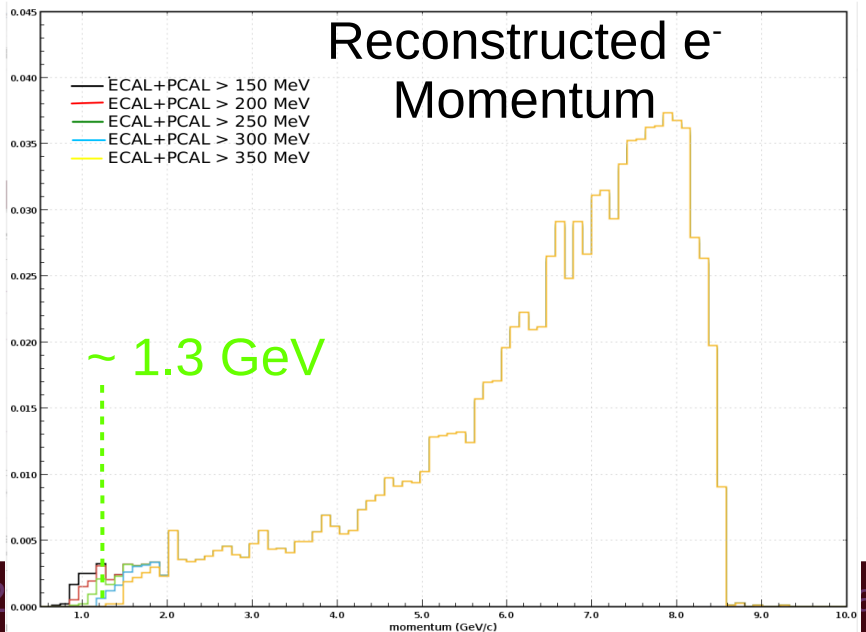
Courtesy of V. Kubarovsky & R. Paremuzyan

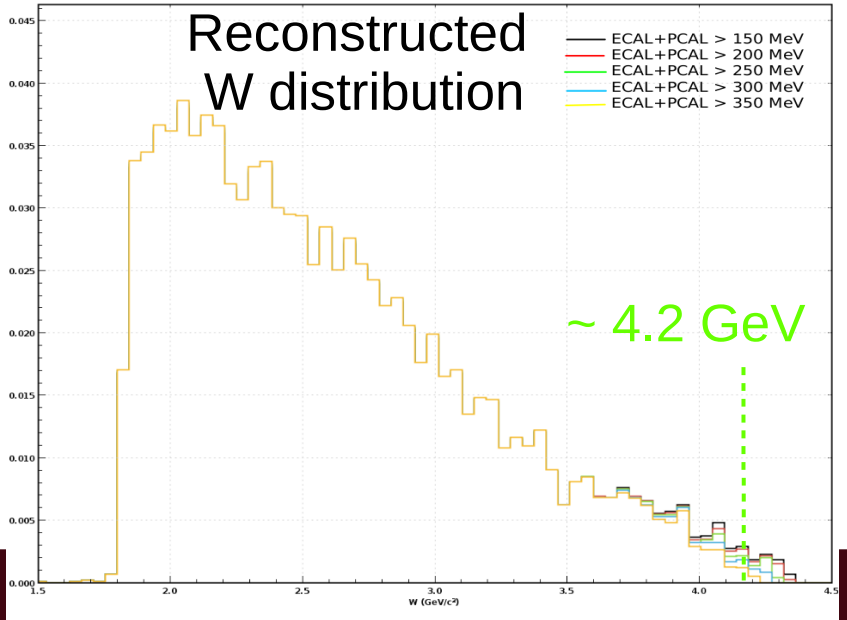
Running Conditions: Magnets & Trigger

- Use the RG-A/B (in-bending) electron trigger:
  - ✔ Minimum number of HTCC photoelectrons > 2
  - ✔ Minimum PCAL cluster energy > 60 MeV
  - ✔ DC segments 5 out of 6
  - ✔ Negative DC roads matching the PCALU cluster
  - ✔ Sum of the energy deposited in PCAL & ECAL greater than **250** MeV (*RG-B setting -> 5.7 kHz e- trigger rate; TBC for RG-D*)



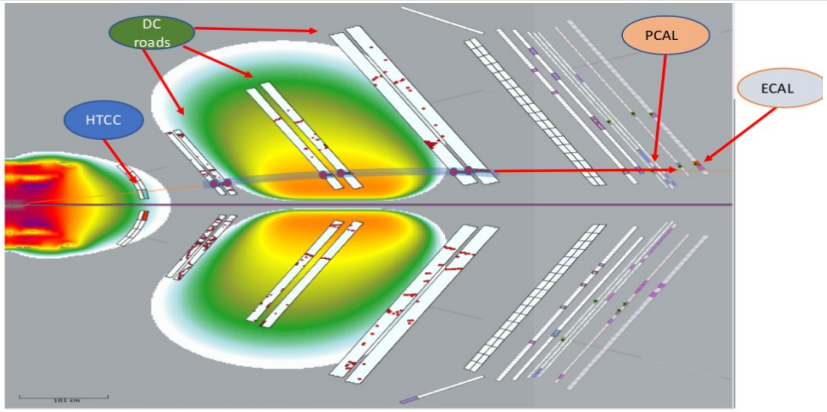
- This threshold affects the scattered electron momentum and kinematics, mainly W!
- Assume a maximum field for both torus and solenoid magnets.



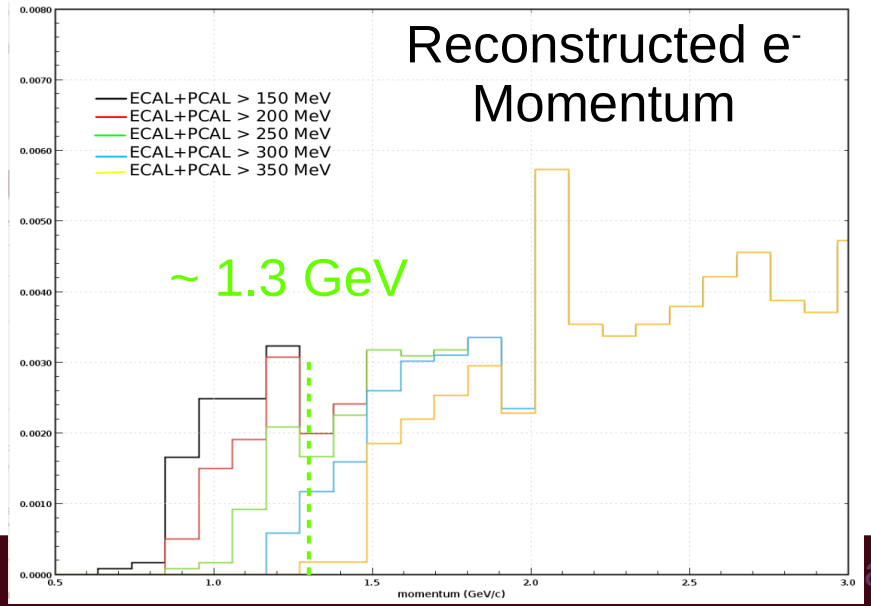


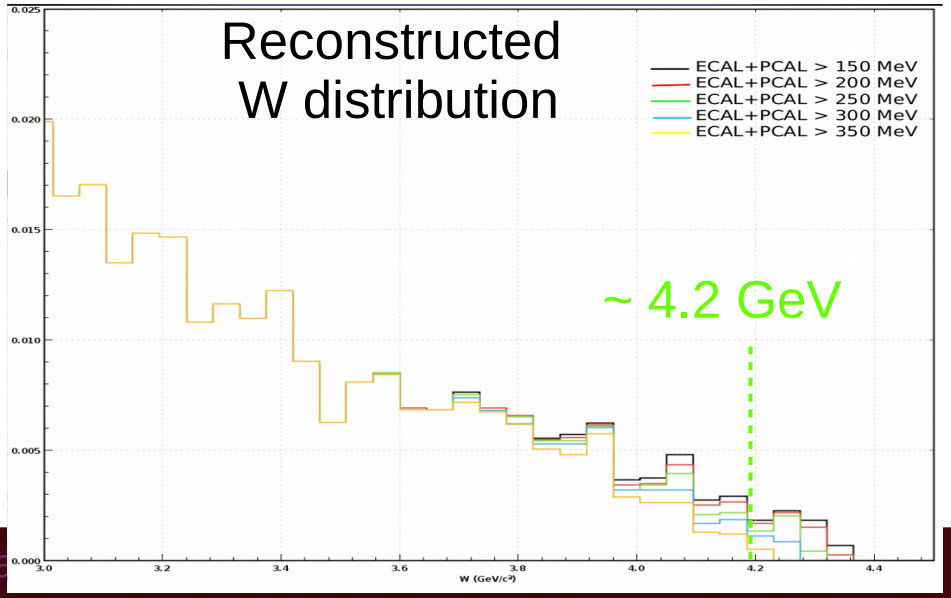
Running Conditions: Magnets & Trigger

- Use the RG-A/B (in-bending) electron trigger:
  - ✔ Minimum number of HTCC photoelectrons > 2
  - ✔ Minimum PCAL cluster energy > 60 MeV
  - ✔ DC segments 5 out of 6
  - ✔ Negative DC roads matching the PCALU cluster
  - ✔ Sum of the energy deposited in PCAL & ECAL greater than **250** MeV (*RG-B setting -> 5.7 kHz e- trigger rate; TBC for RG-D*)



- This threshold affects the scattered electron momentum and kinematics, mainly W!
- Assume a maximum field for both torus and solenoid magnets.



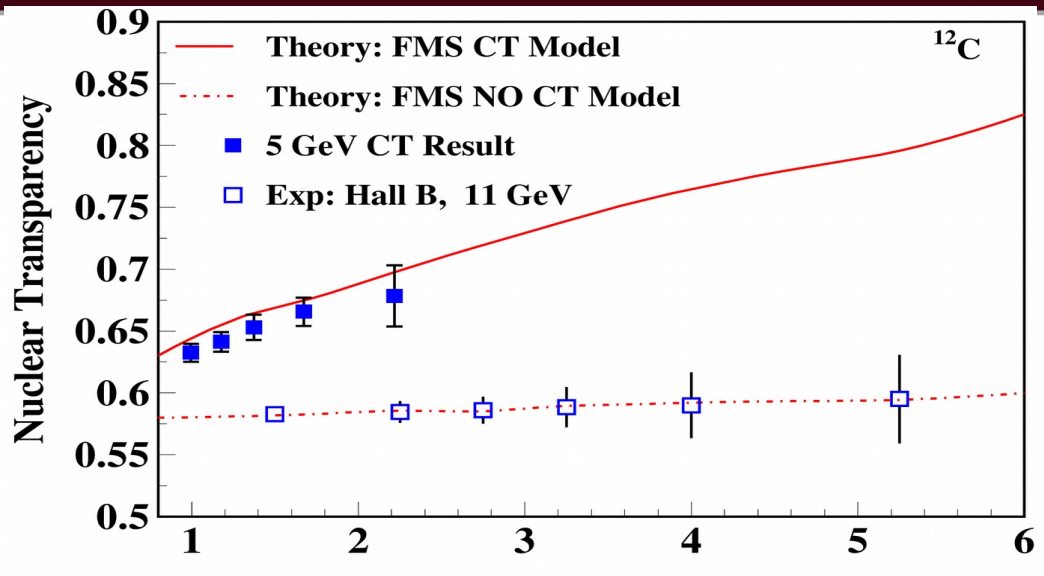


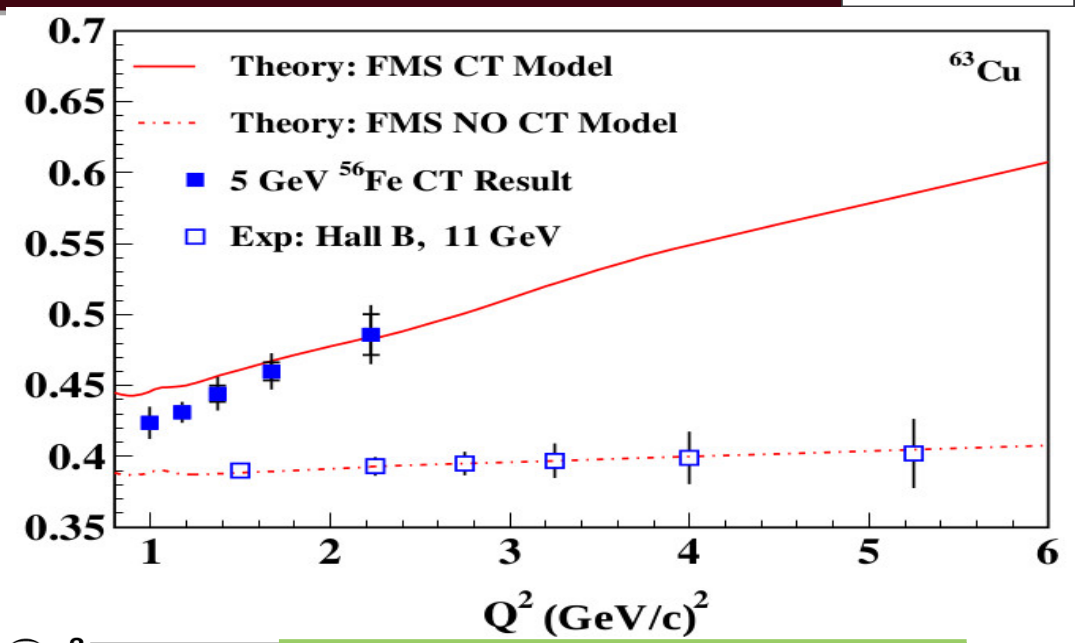
Run Plan

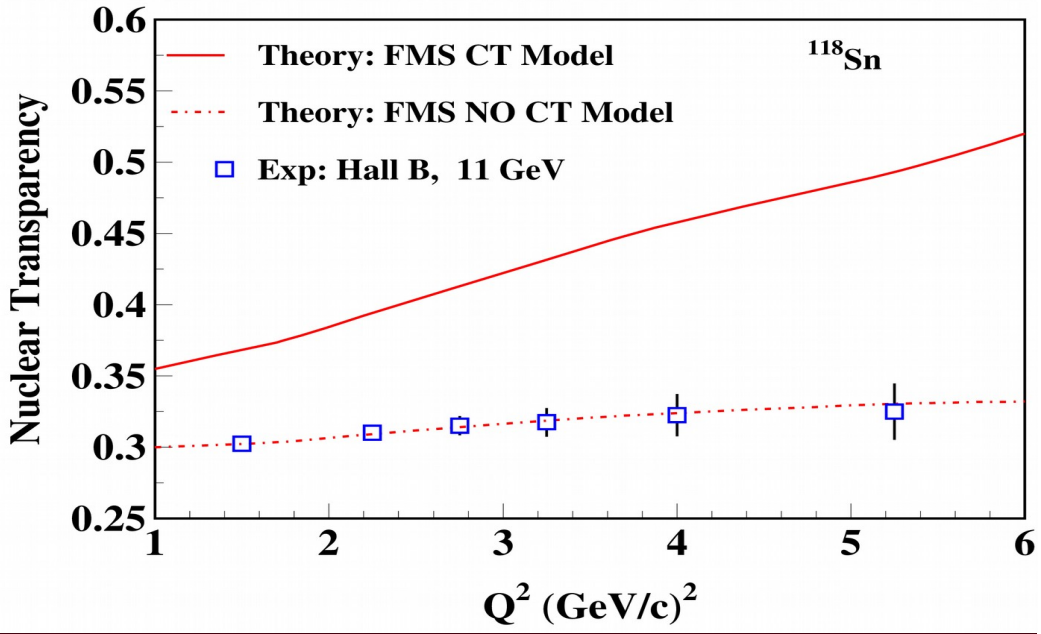
- Beam time allocation for the approved 60 calendar days:

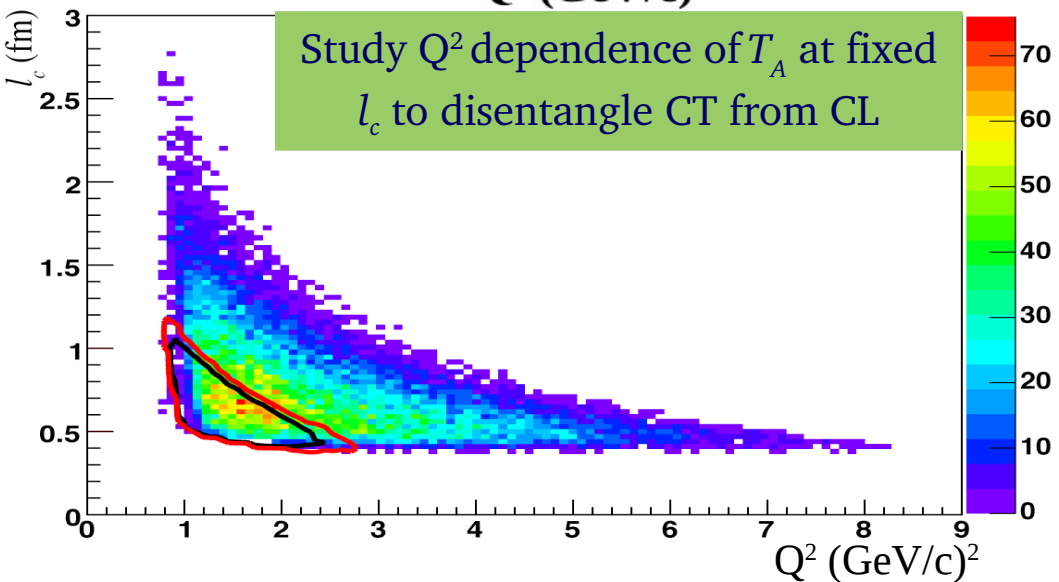
Targets/Plan	Beam Time (PAC days)
LD2	1.5
^{63}Cu / ^{118}Sn	4
LD2	1.5
^{12}C / ^{12}C	3.5
LD2	1
^{63}Cu / ^{118}Sn	4.5
LD2	1.5
^{12}C / ^{12}C	3.5
LD2	1.5
^{63}Cu / ^{118}Sn	5.5
LH2 (*or target change + Moller Meas.*)	2

CLAS12 ρ^0 CT Projections: Lowest l_c-bin









Study Q^2 dependence of T_A at fixed l_c to disentangle CT from CL

Assigned Responsibilities

- **Analysis Coordinator**: Lamiaa El Fassi
- **Cooking Chef**: Mikhail Yurov (*AC postdoc*)
- **Run Coordinators** list is complete and will be posted shortly in RG-D run-wiki:

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
RG-D Run Coordinators Sign up Sheet for 60 Calendar Days Run Period														
	July 2023				**August 2023**					**September 2023**				
	Monday 17th (Start Date; Could be *pushed back*!)	**Mon. 24th**	**Wed. 26th**	**Mon. 31st**	**Wed. 2nd**	**Wed. 9th**	**Wed. 16th**	**Wed. 23rd**	**Wed. 30th**	**Fri. 1st**	**Wed. 6th**	**Wed. 13th**	**Sunday 17th (End Date; Could be *pushed back* depending on the Start date!)**	**Wed. 20th**
Week 1	Lamiaa El Fassi													
Week 2			Yordanka Ilieva											
Week 3					Raphael Dupre									
Week 4						Holly Szumila-Vance								
Week 5							Maurik Holtrop							
Week 6								Mikhail Yurov						
Week 7									Whitney Armstrong					
Week 8											Utsav Shrestha			
Week 9												Lamiaa El Fassi		If needed!

Interested/Committed Groups

- ✔ **ANL**:
  - ✗ Staff**:** Whitney Armstrong, Sylvester Joosten, Zein-Eddine Meziani, Chao Peng, and Maria Zurek
  - ✗ Postdocs: Jihee Kim, Shivangi Prasad, Marshall Scott
  - ✗ Graduate Student: Suman Shrestha (jointly w/. **TU**; co-advised by AC)
- ✔ **IJCLAB**: Raphäel Dupré + Daniel Matamaros
- ✔ **JLab**: Holly Szumila-Vance
- ✔ **MSState**: L. El Fassi, Matthew Maynes, and Mikhail Yurov
- ✔ **Temple U.**: Hamza Atac, Suman Shrestha, Nikolaos Sparveris
- ✔ **UCONN**: Kyungseon Joo, Timothy Hayward, Utsav Shrestha,....
- ✔ **UNH**: Maurik Holtrop
- ✔ **USC**: Yordanka Ilieva
- ✔ **USM**: Ahmed El Alaoui,.....
- ✔ **Others** are welcome!

Summary Notes

- ESAD/RSAD, Experiment/Radiological, Safety Assessment/Analysis Documents are being finalized in coordination with the Hall-B Task Force.
- Analysis tools are being developed for both CT & nTMDs studies.
- Detailed run plan for RG-D experiments will be drafted soon.

Summary Notes

- ESAD/RSAD, Experiment/Radiological, Safety Assessment/Analysis Documents are being finalized in coordination with the Hall-B Task Force.
- Analysis tools are being developed for both CT & nTMDs studies.
- Detailed run plan for RG-D experiments will be drafted soon.
- Thank you to JLab/Hall-B {TF, staff, and engineers}, PDL (Baltzell), RC, shift takers, and all collaborators for their help in making this summer RG-D run a success!

Summary Notes

- ESAD/RSAD, Experiment/Radiological, Safety Assessment/Analysis Documents are being finalized in coordination with the Hall-B Task Force.
- Analysis tools are being developed for both CT & nTMDs studies.
- Detailed run plan for RG-D experiments will be drafted soon.
- Thank you to JLab/Hall-B {TF, staff, and engineers}, PDL (Baltzell), RC, shift takers, and all collaborators for their help in making this summer RG-D run a success to *shrink* ρ^0 *again* and extract all interesting results from these nuclear-target datasets!

Thank you for your attention

This work is supported in part by the US DOE award # DE-FG02-07ER41528

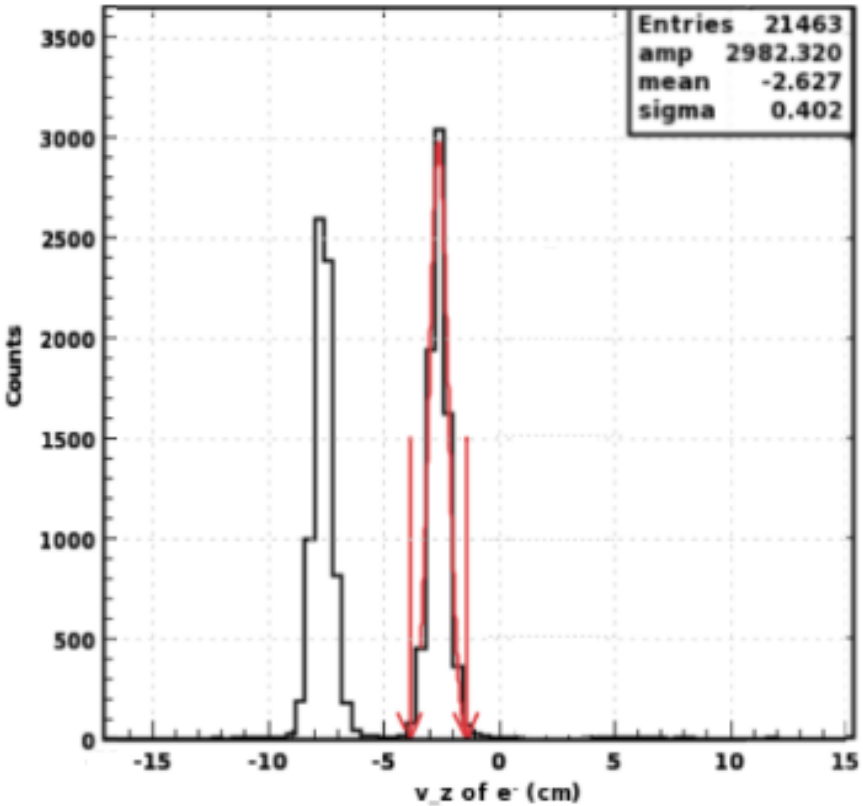
Backup Slides

Projections with Hall-B Flag Assembly

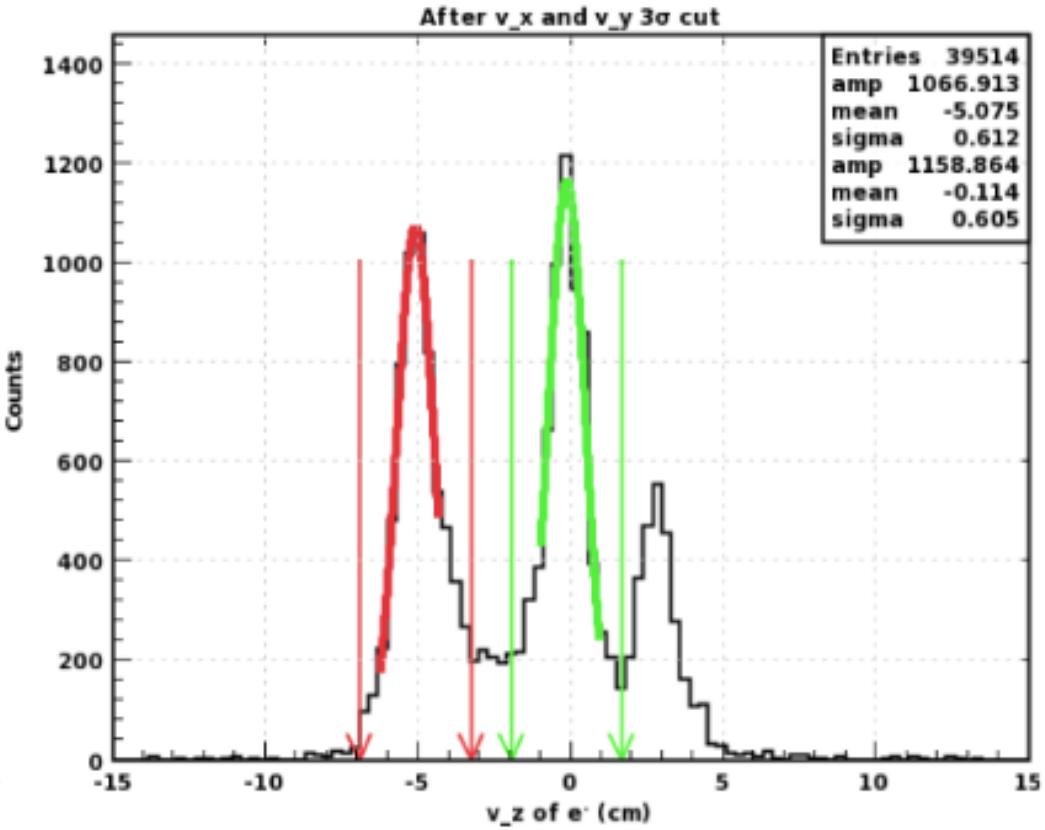
- Expected statistical precision for the lowest l_c bin: (revised after Jeopardy)

Q^2(GeV^2) / Targets	1.5 ± 0.5	2.25 ± 0.25	2.75 ± 0.25	3.25 ± 0.25	4.0 ± 0.5	5.25 ± 0.75
^{12}C (%)	1.1	1.5	2.0	2.7	4.6	6.1
^{63}Cu (%)	1.3	1.7	2.1	3.1	4.8	6.3
^{118}Sn (%)	1.3	1.8	2.6	3.2	4.8	6.3

RG-D Experiments: Target/Vertex Reconstruction



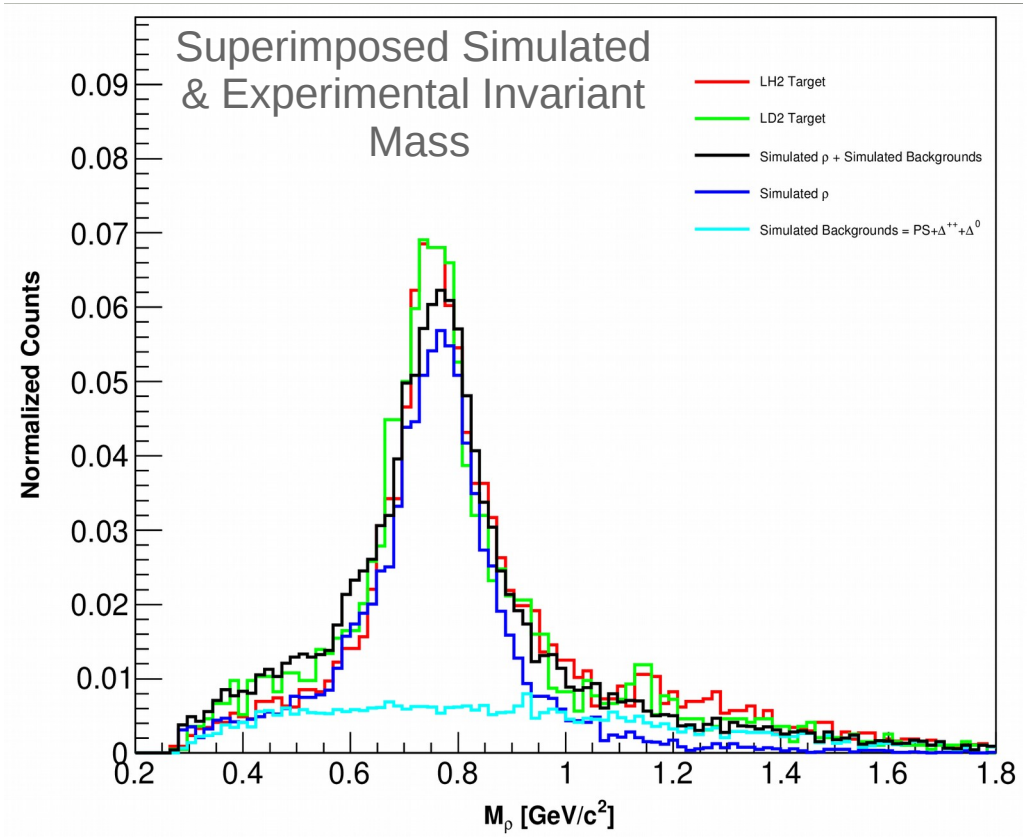
Simulated Electron z-vertex distribution for the 5 cm apart solid foils assembly

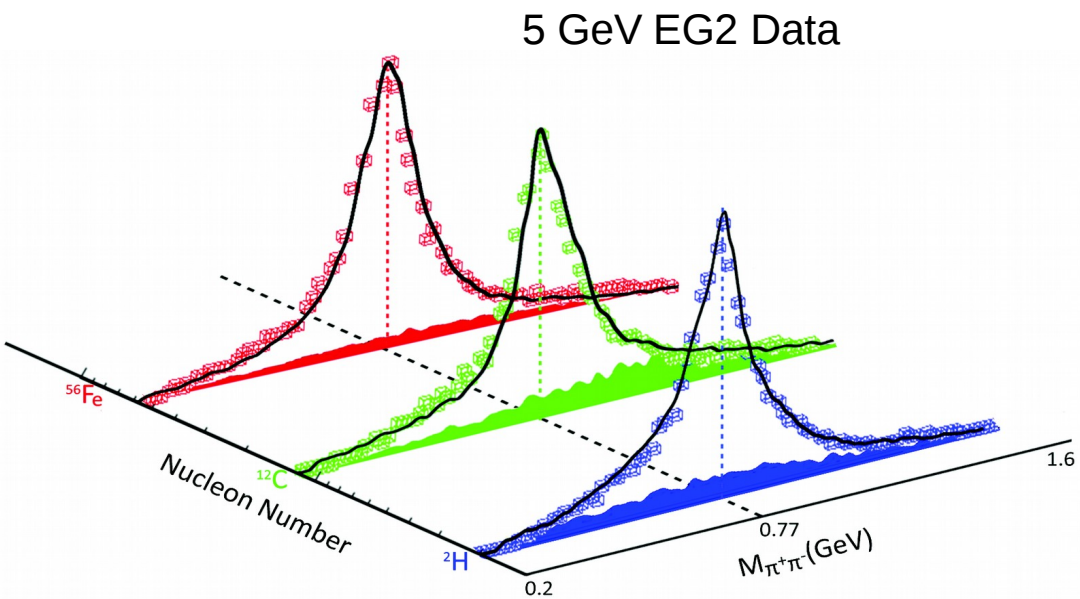


Electron z-vertex distribution from an empty target RG-A run

Negative Polarity Data

- The reconstructed ρ^0 invariant mass distribution in our kinematics range,





Simulated Background's Shapes

$e + p \rightarrow e + p + \pi^+ + \pi^-$

$e + p \rightarrow e + \Delta^{++} + \pi^-$

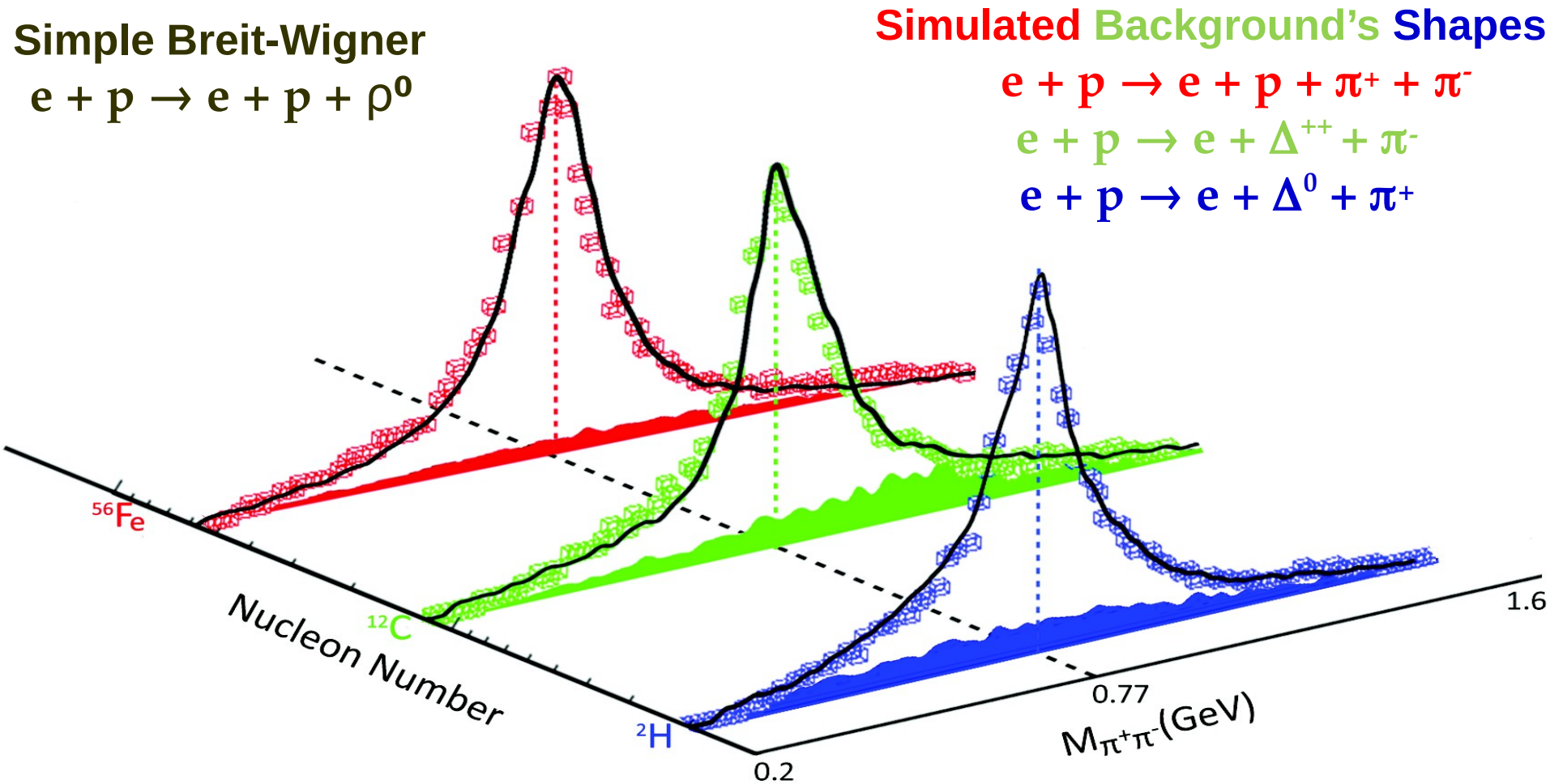
$e + p \rightarrow e + \Delta^0 + \pi^+$

ρ^0 production: $e + p \rightarrow e + p + \rho^0$

Two-pion Invariant Mass

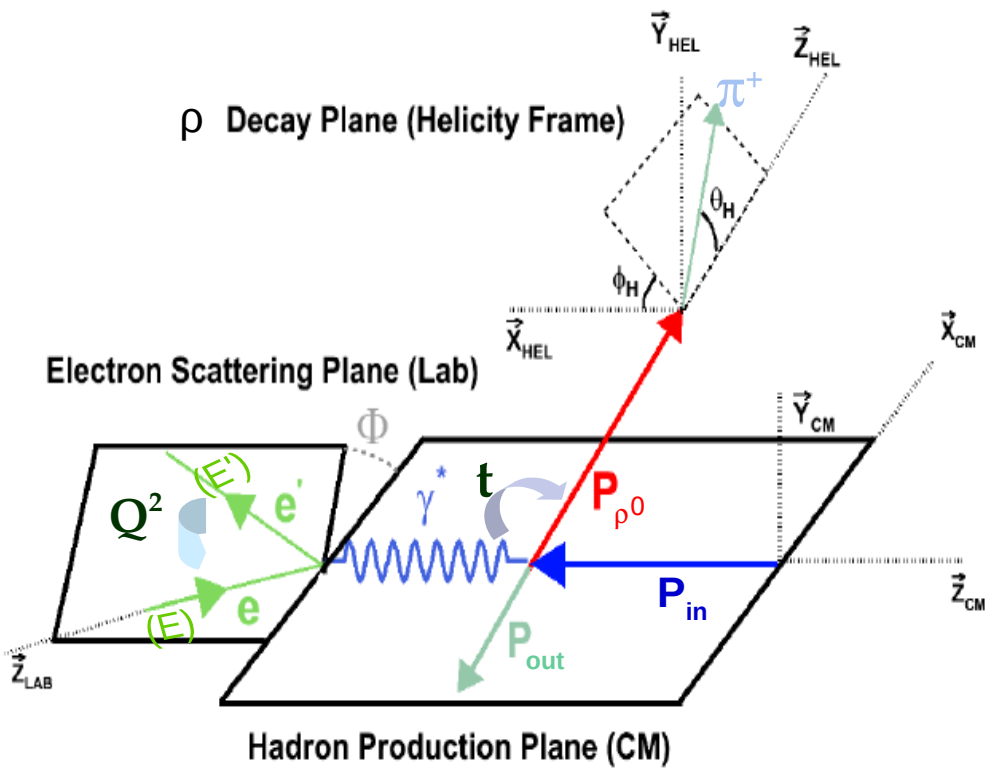
- Our event generator incorporates the measured cross sections for the electroproduction of ρ^0 and main background processes by Cassel *et al.*

D. G. Cassel *et al.*, Phys. Rev. D 24, 2787 (1981)



ρ^0 Electro-production Kinematics

- $\nu = E - E'$: virtual photon (γ^*) energy in the Lab frame,
- $Q^2 = -(P_e - P_{e'})^2 = 4\,E\,E'\sin^2(\theta/2)$: photon virtuality,
- $t = (P_{\gamma^*} - P_\rho)^2$: momentum transfer square,
- $W^2 = (P_{in} + P_{\gamma^*})^2 = -Q^2 + M_p^2 + 2M_p\nu$: invariant mass squared in (γ^*, p) center of mass (CM).



- $W > 2$ GeV
  $\Rightarrow$ avoid resonance region
- $-t < 0.4$ GeV^2
  $\Rightarrow$ select diffractive process
- $-t > 0.1$ GeV^2
  $\Rightarrow$ exclude coherent production
- $Z_h = E_h/\nu \geq 0.9$
  $\Rightarrow$ select elastic channel

Coherence Length (CL) effect could mimic CT signal?

- CT signature is the T_A increase with Q^2, however, as $l_c = 2/(M^2 + Q^2)$, the CL effect manifests also the T_A increase with Q^2.
- To exclude CL, the Q^2 dependence of T_A must be measured at small or fixed l_c.