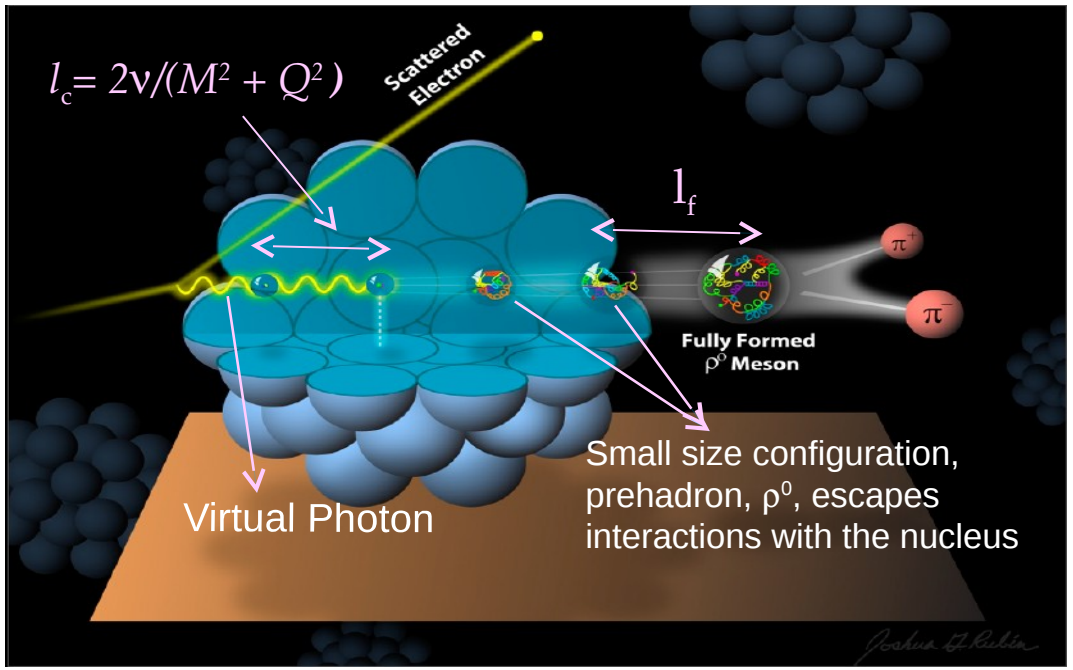
Brief Update on RG-D Readiness

CLAS Collaboration Meeting
November 13th, 2019

Lamiaa El Fassi
(for the RG-D Co-spokespersons)

RG-D, CT, Experiment

- E12-06-106, "Study of Color Transparency (CT) in Exclusive Vector Meson Electro-production off Nuclei", approved with 60 PAC days.



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

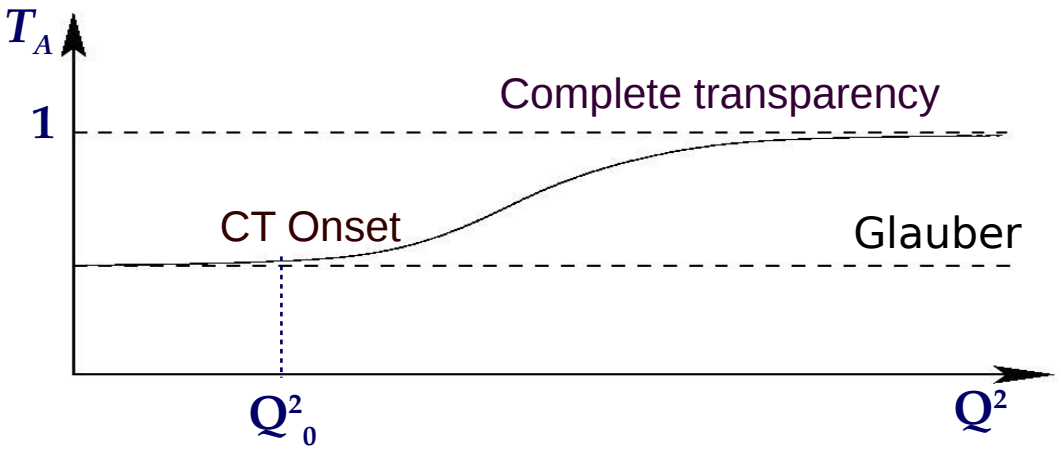
$$T_A = \frac{\sigma_A}{A\,\sigma_N}$$

σ_A is the nuclear cross section

σ_N is the free (nucleon) cross section

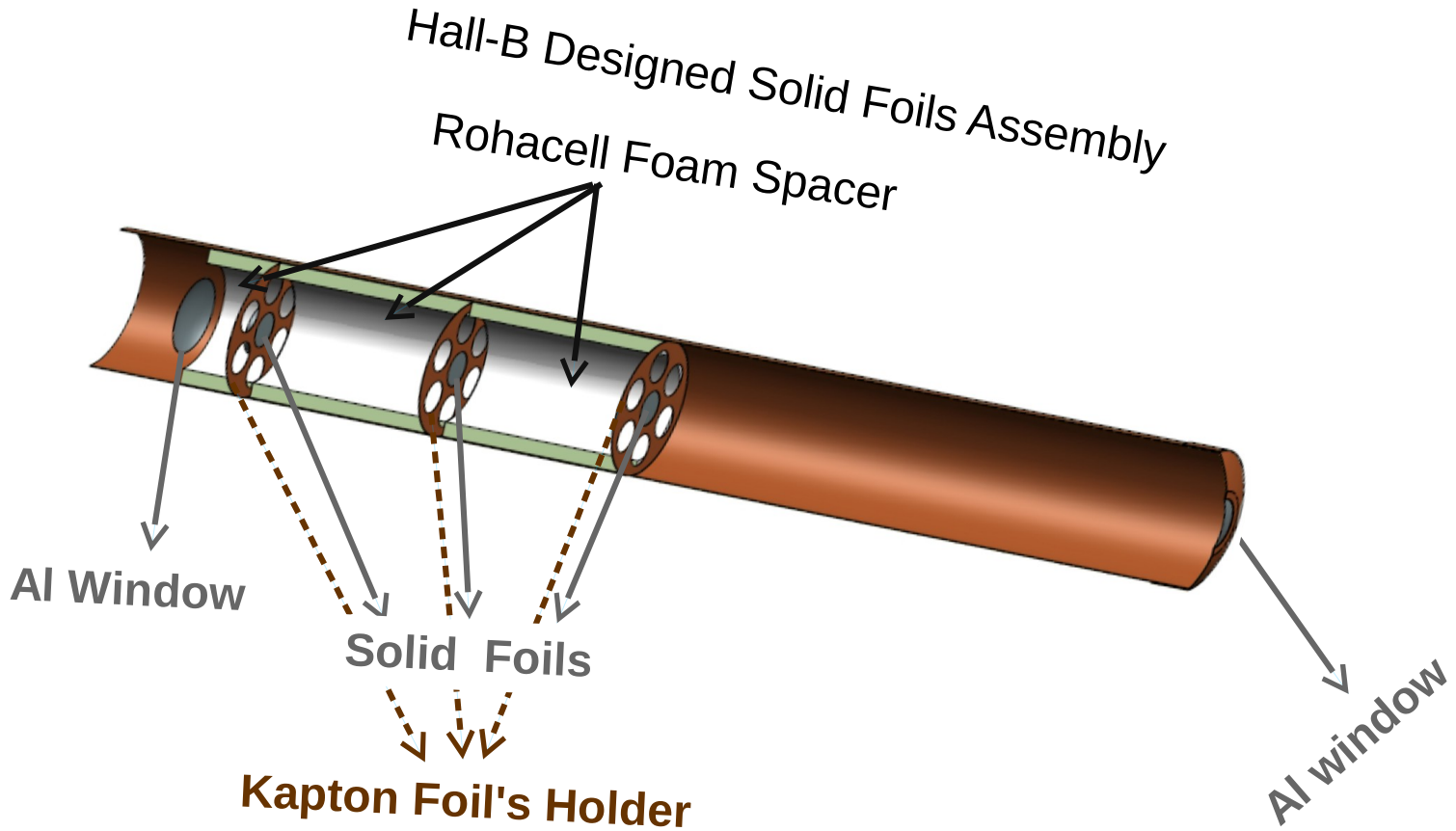
- Coherence length, l_c: the lifetime of the qq-bar pair.

- Formation time, l_f: the time needed for the small size configuration to evolve to an on-shell ρ^0 meson.



Running Conditions: Target Configuration

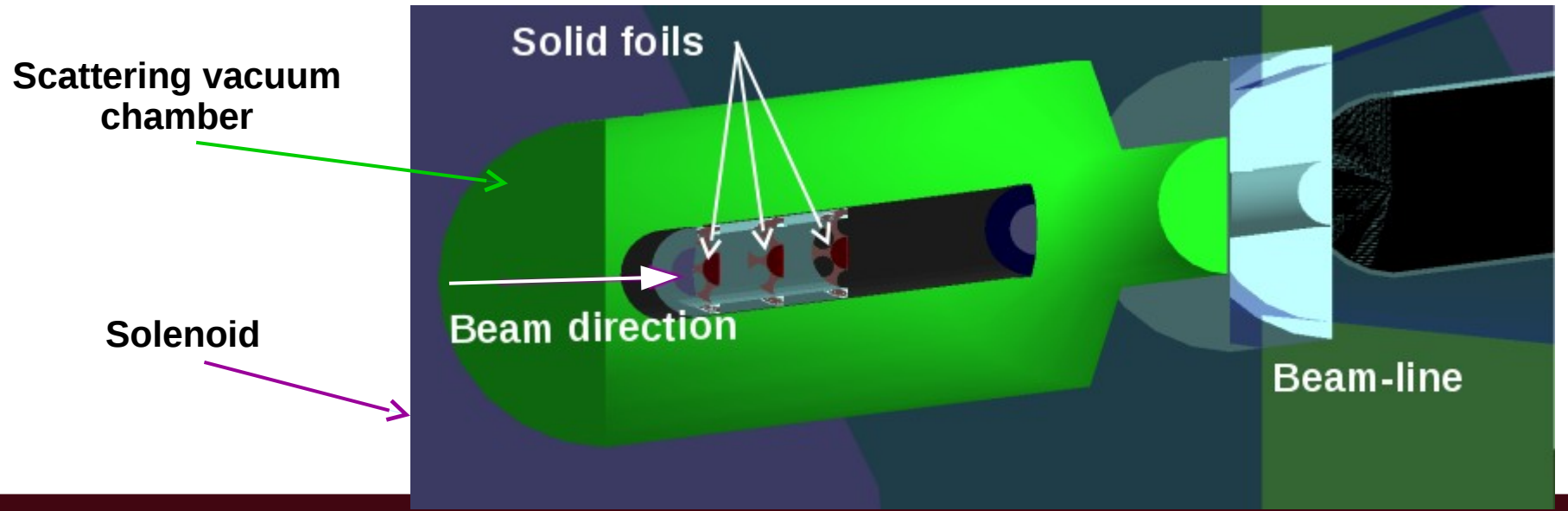
- Alternating the liquid deuterium (LD2) target with a set of three solid targets 5 cm apart:
  - ✔ Design already exists,
  - ✔ 5 cm guarantees a good vertex separation,
  - ✔ Solid foils are glued to a kapton disk, then to a foam cylinder, and mounted inside a 20 mm diameter Kapton cell (similar to the liquid target cell),
  - ✔ The cell will be purged with cold helium to dissipate heat from the beam interaction.



Running Conditions: Beam & Target Configuration

- Run with 11 GeV beam energy, different beam current to achieve the expected luminosity of 10^{35} $cm^{-2}s^{-1}$.

Targets	Thickness (3 foils) (cm)	Density ($g.cm^{-3}$)	Areal Density ($mg.cm^{-2}$)	Radiation Lengths (T/X_0)	Beam Current (nA)	Per-Nucleon Luminosity (cm^{-2} s^{-1})
D2	5	0.164	820	0.0065	35	10^{35}
^{12}C	0.172 (0.516)	1.747	300	0.007	30	10^{35}
^{63}Cu / ^{118}Sn / ^{118}Sn	0.036 / 0.03 / 0.03	8.96 / 7.31 / 7.31	322.56 / 219.3 / 219.3	0.025 / 0.025 / 0.025	35	10^{35}



Run Plan & Projections

- Proposed run plan for the separate cryo-target and solid targets runs:

Targets/Plan	Beam Time (PAC days)
^{12}C / ^{12}C / ^{12}C	10
LD_2	10
^{63}Cu / ^{118}Sn / ^{118}Sn	36
LH_2	4

- With this configuration, we need:
  - 4 calendar days for commissioning,
  - 4 calendar days for target configuration change:
    - ✔ 28h to switch for solid to liquid target,
    - ✔ 48h to switch from liquid to solid targets assembly,
    - ✔ 24h to switch from one set of solid foils to an other.

Detailed Target Configuration Change

- To change from solid targets assembly to LD2 (info from B. Miller):
  - 2 hours to decable target so target can be moved upstream far enough to remove scattering chamber.
  - 4 hours to change target cell, fill cell with N2 and leak check.
  - 4 hours to align cell and install scattering chamber.
  - 2 hours to reconnect cabling and establish beam line.
  - 12 hours to pump down vacuum in target vacuum vessel and fill the target cell with helium.
  - 4 hours to cool and fill the liquid target.
  - Total: **28 h**.
- To change from LD2 to solid targets assembly (info from B. Miller):
  - 24 hours to empty target and heat cryostat so vacuum vessel can be opened to change target. In parallel, bleed up beam line vacuum, remove beam pipe to move target upstream.
  - 2 hours to decable target so target can be moved upstream far enough to remove scattering chamber.
  - 4 hours to change target cell, fill cell with N2 and leak check.
  - 4 hours to align cell and install scattering chamber.
  - 2 hours to reconnect cabling and establish beam line.
  - 12 hours to pump down vacuum in target vacuum vessel and fill the target cell with helium.
  - Total: **48 h**.

Detailed Target Configuration Change

- To change a set of solid targets to an other (info from B. Miller):
  - 2 hours to decable target so target can be moved upstream far enough to remove scattering chamber.
  - 4 hours to change target cell, fill cell with N2 and leak check.
  - 4 hours to align cell and install scattering chamber.
  - 2 hours to reconnect cabling and establish beam line.
  - 12 hours to pump down vacuum in target vacuum vessel and fill the target cell with helium.
  - Total: **24 h**.

- The design of the solid target assembly has been done by the end of March (B. Miller):
  - ✔ Test of the Kapton cylinder, cap, and aluminum window was completed in August,
  - ✔ Remaining parts will be fabricated and assembled this Fall .
- This design will be used for the nuclear background test before (*or after*) BONuS12 experiment.

Updated Run Plan & Projections

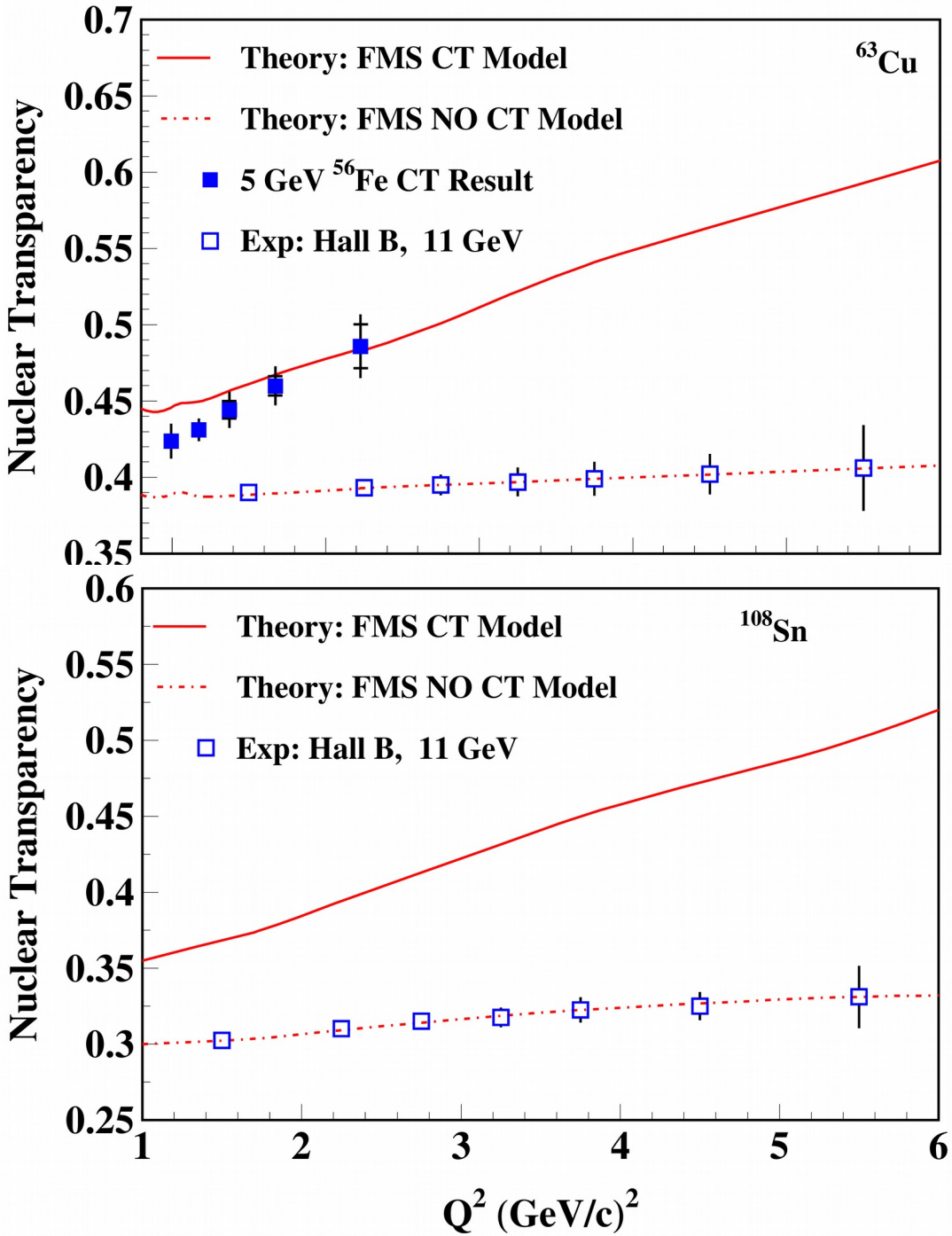
- Proposed run plan for the separate cryo-target and solid targets runs:

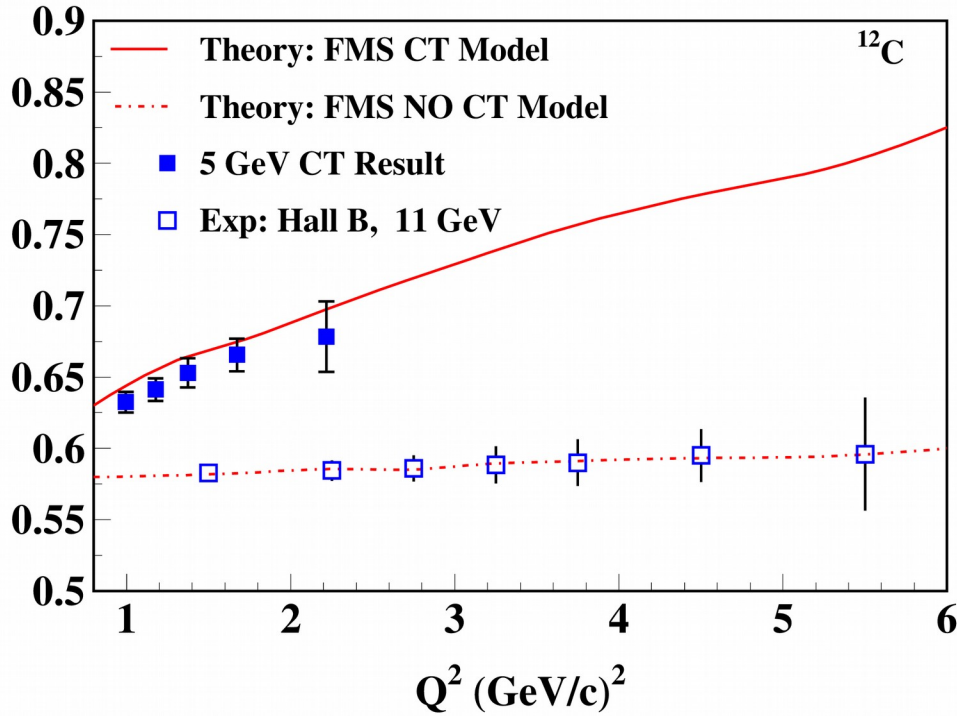
Targets/Plan	Beam Time (PAC days)
^{12}C / ^{12}C / ^{12}C	10
LD_2	10
^{63}Cu / ^{118}Sn / ^{118}Sn	36
LH_2	4

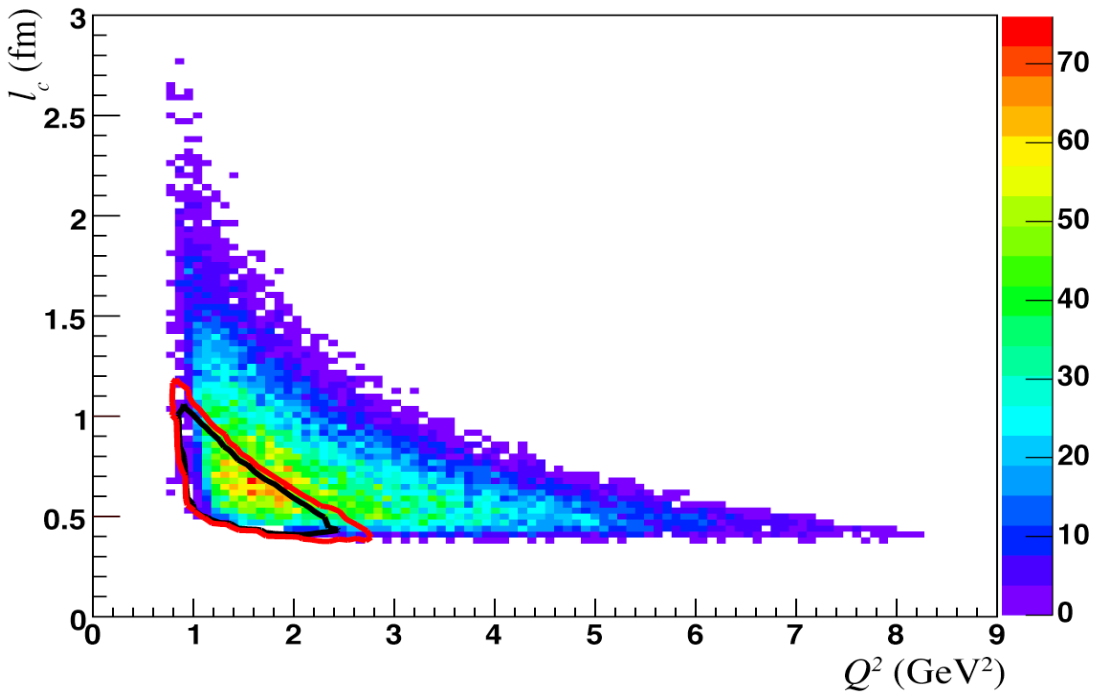
- Expected statistical precision for the lowest coherence length bin, [0.4–0.5[fm:

Q^2(GeV^2) / Targets	1.5 ± 0.5	2.25 ± 0.25	2.75 ± 0.25	3.25 ± 0.25	3.75 ± 0.25	4.5 ± 0.5	5.5 ± 0.5
^{12}C (%)	0.9	1.2	1.6	2.2	2.8	3.1	6.7
^{63}Cu (%)	1.1	1.4	1.7	2.4	2.9	3.4	7.2
^{118}Sn (%)	0.9	1.1	1.5	2.1	2.7	3.0	6.4

11 GeV CT Experiment Projections for lowest l_c bin



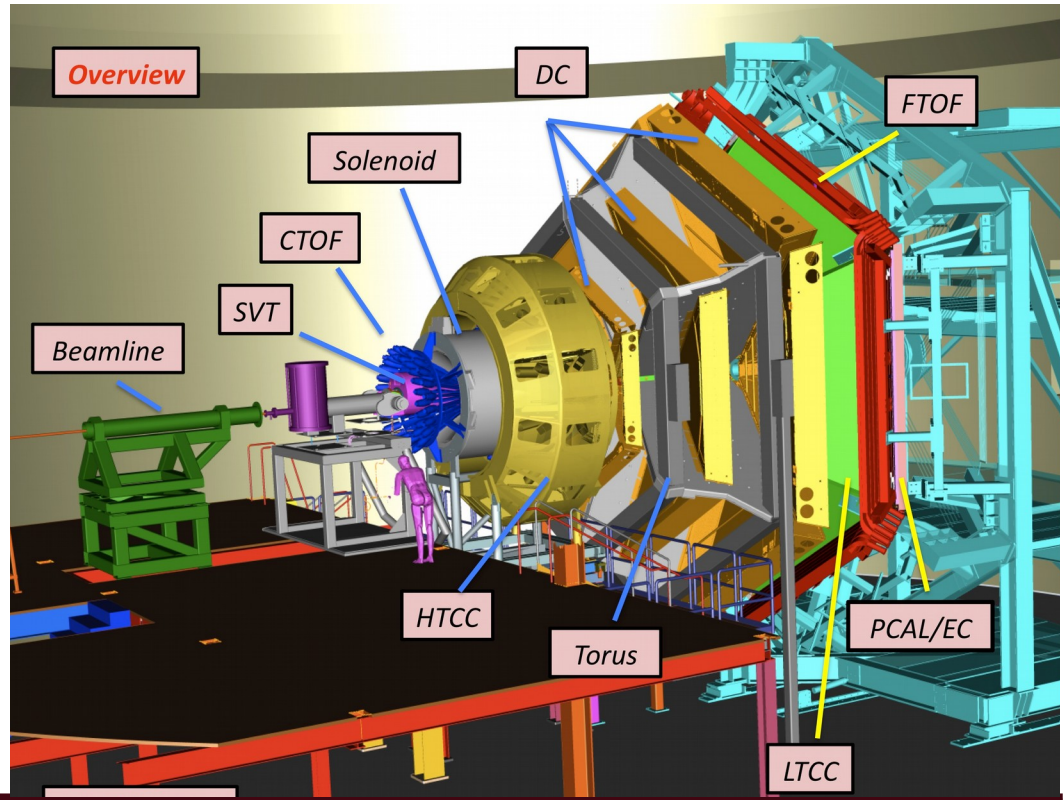




Running Conditions: Magnet & Detector Setup

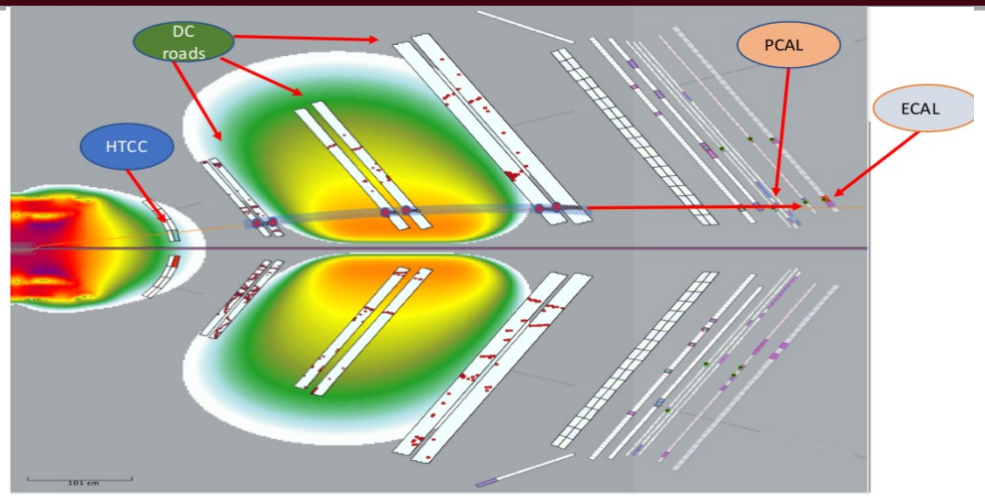
- Run with the default magnet's setting: inbending/upstream torus/solenoid field,

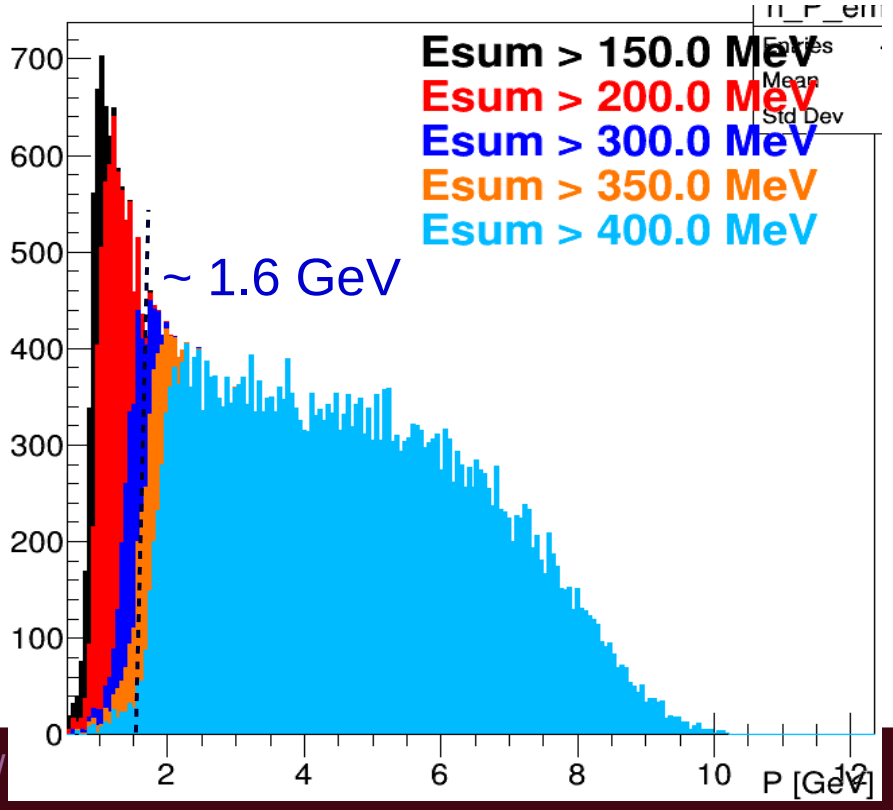
- Will use the CLAS12 in its standard configuration but with
  - **FT-OFF** because
    - the interest to a high-Q^2 region,
    - no interest to detect photons at small angles (2.5°- 4.5°),
    - Extended beamline vacuum reduces DC R1 background, hence improves the FD efficiency.
  - **FMT-Out** unless its light version that is currently made for the BONuS12 experiment is fully functional.

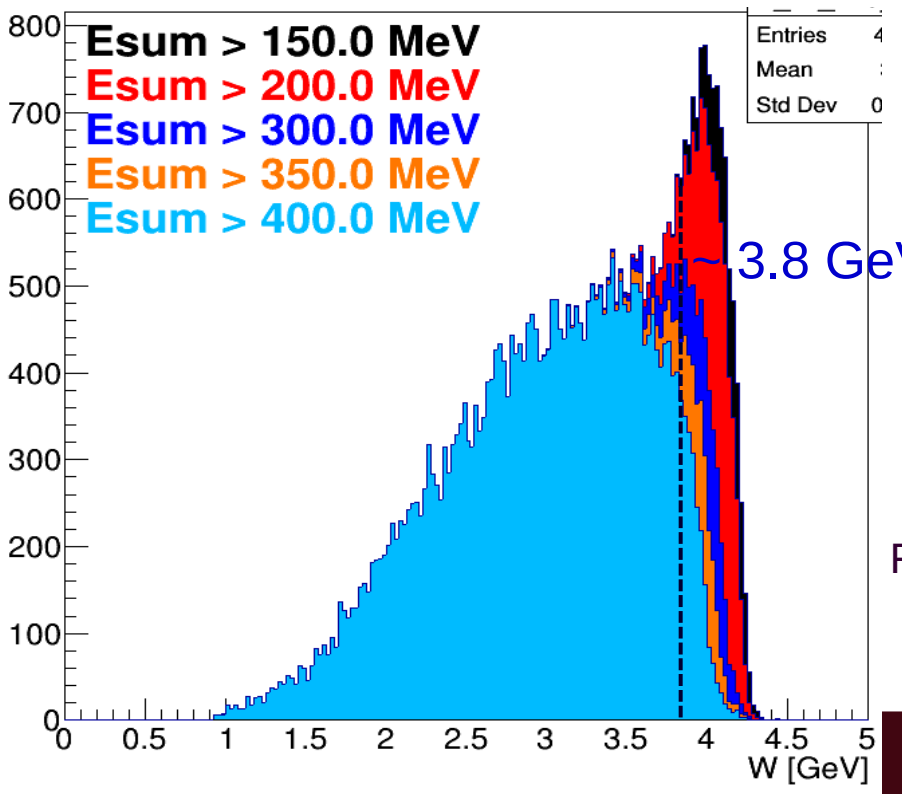


Running Conditions: Trigger

- Use the RG-A/B electron trigger:
  - ✔ Minimum number of HTCC photoelectrons >2
  - ✔ Minimum PCAL cluster energy > 60 MeV
  - ✔ Sum of the energy deposition in PCAL & ECAL greater than 250 - 300 MeV.
  - ✔ DC segments 5 out of 6
  - ✔ Negative DC roads matching the PCALU cluster
- The main trigger parameter is $E_{sum} = E_{PCAL} + E_{ECAL}$ because it controls the trigger rates (expecting ~ 8 kHz which is below the DAQ limit).
- This threshold affects the scattered electron momentum and kinematics, mainly W!







Courtesy of
R. Paremuzyan
&
V. Kubarovsky

Running Conditions: Trigger

- Use the RG-A/B electron trigger:
  - ✔ Minimum number of HTCC photoelectrons >2
  - ✔ Minimum PCAL cluster energy > 60 MeV
  - ✔ Sum of the energy deposition in PCAL & ECAL greater than **250 MeV**.
  - ✔ DC segments 5 out of 6
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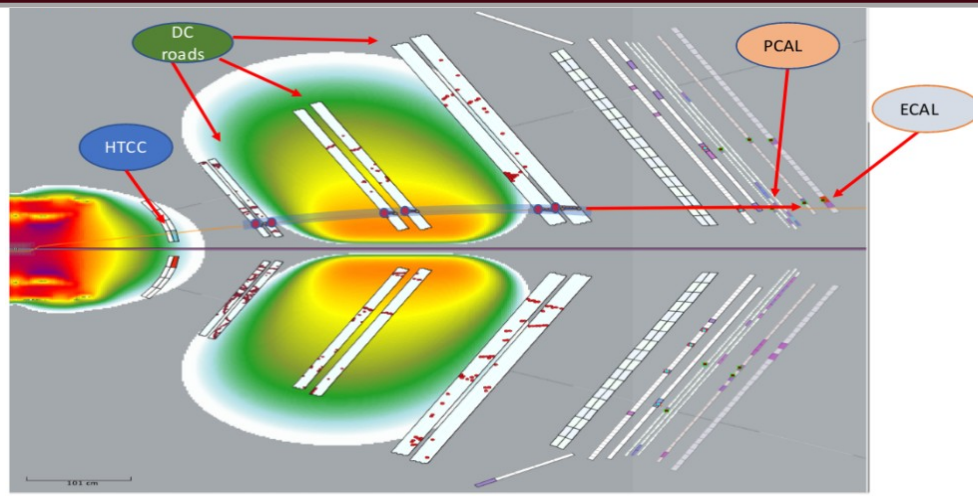
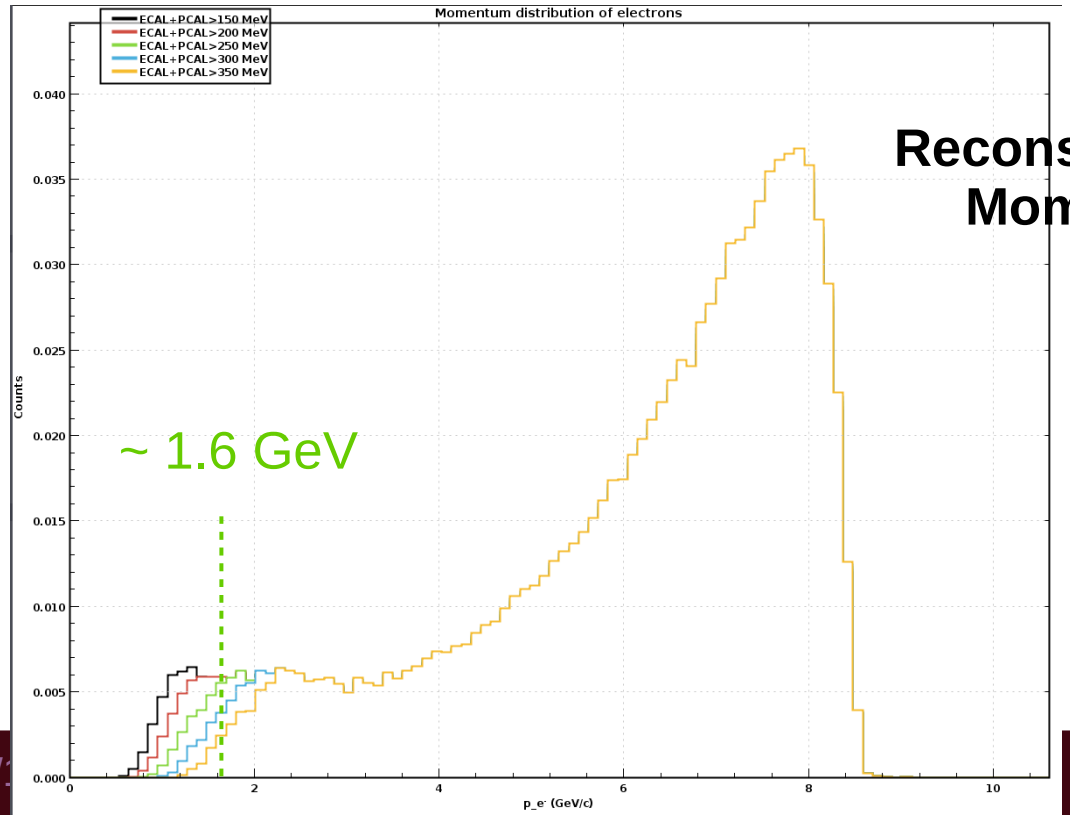
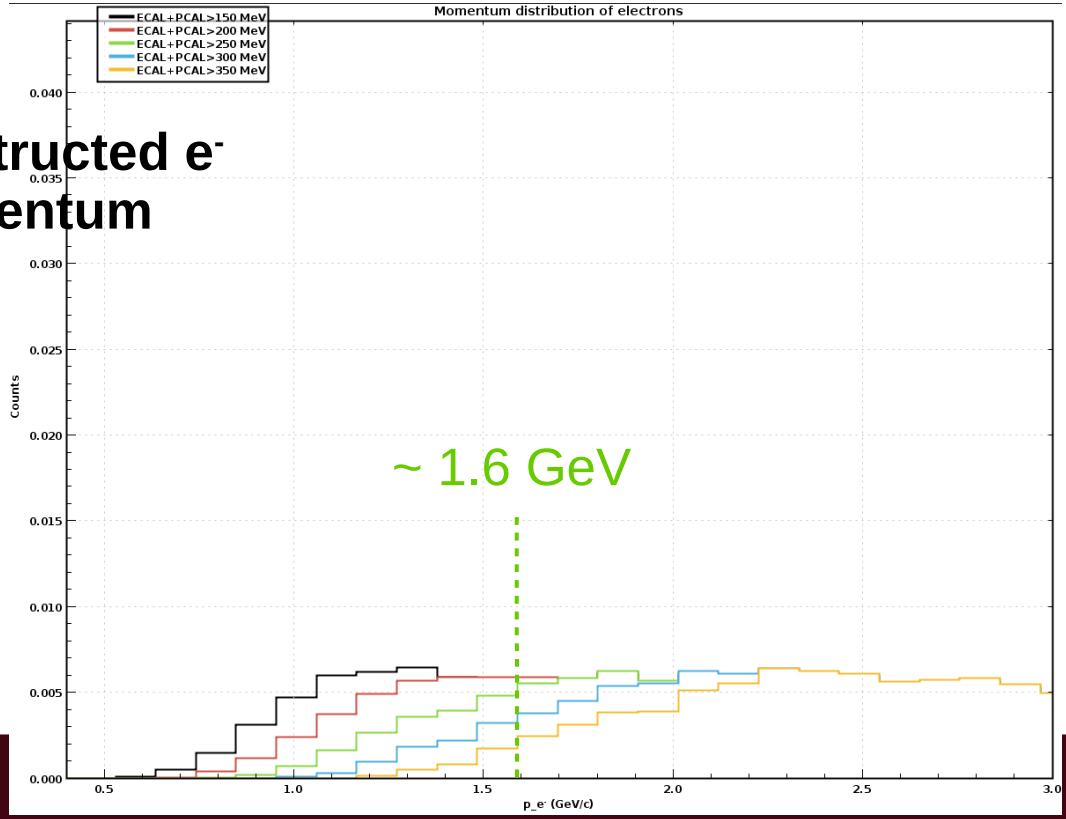




Reconstructed e⁻ Momentum



Running Conditions: Trigger

- Use the RG-A/B electron trigger:
  - ✔ Minimum number of HTCC photoelectrons >2
  - ✔ Minimum PCAL cluster energy > 60 MeV
  - ✔ Sum of the energy deposition in PCAL & ECAL greater than **250 MeV**.
  - ✔ DC segments 5 out of 6
  - ✔ Negative DC roads matching the PCALU cluster
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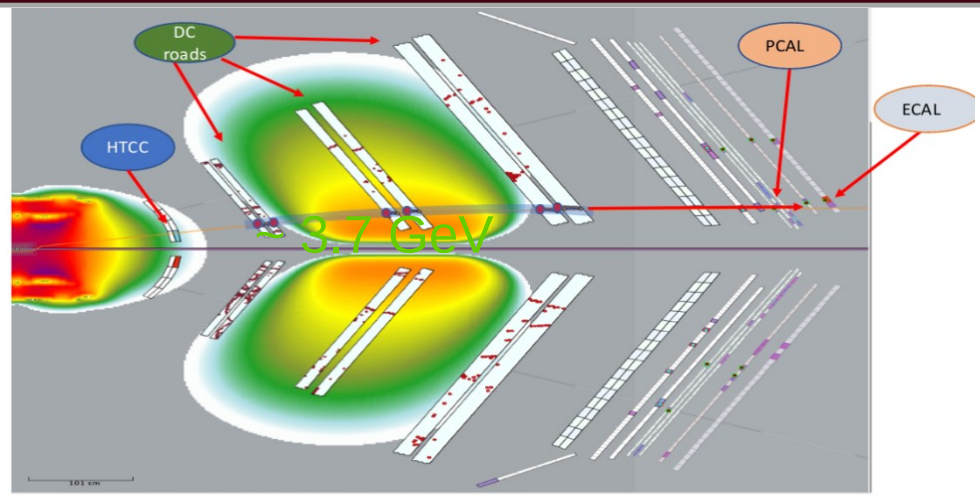
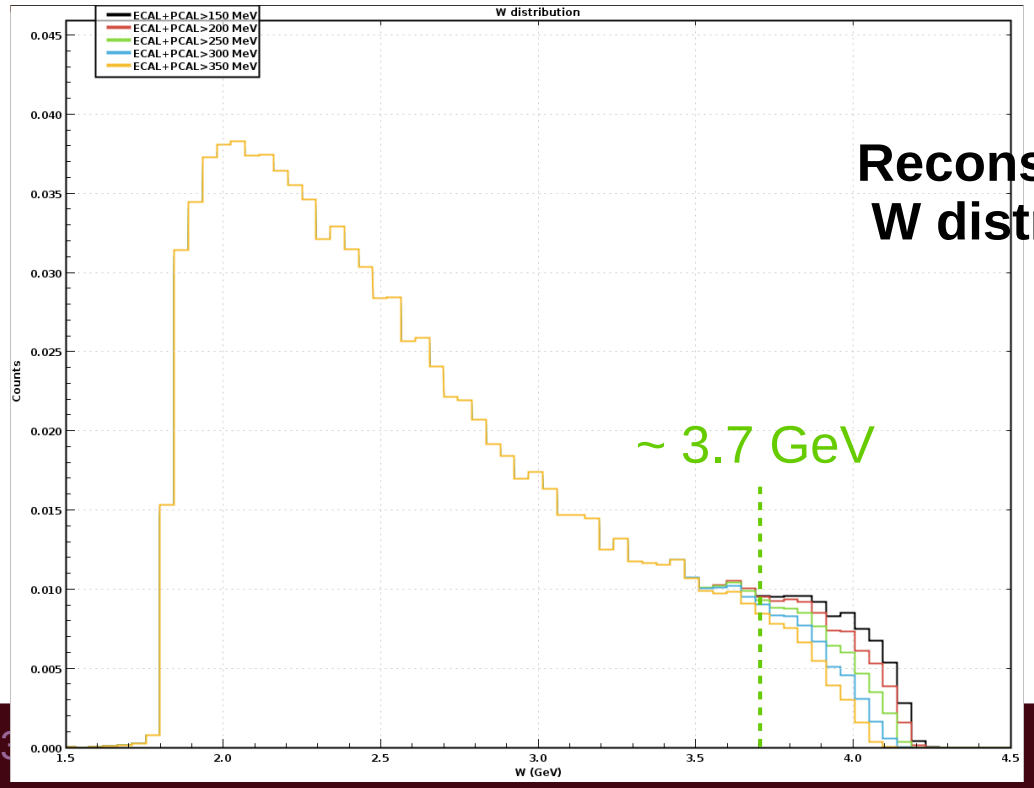
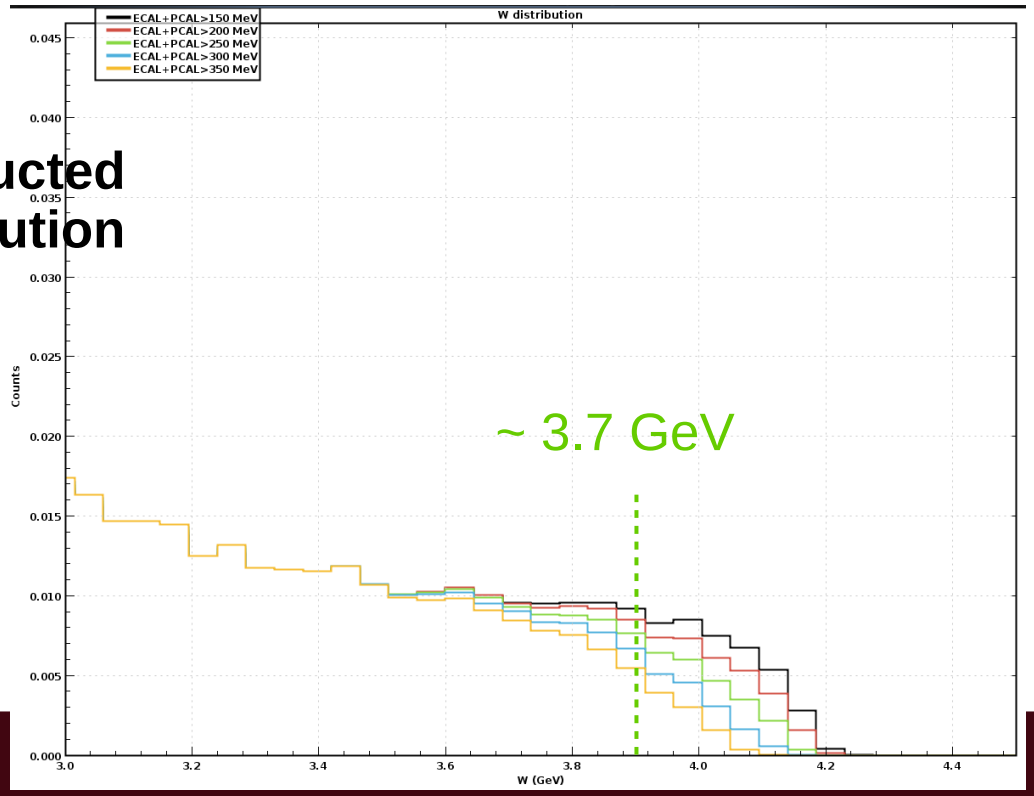
- This threshold affects the scattered electron momentum and kinematics, mainly W!



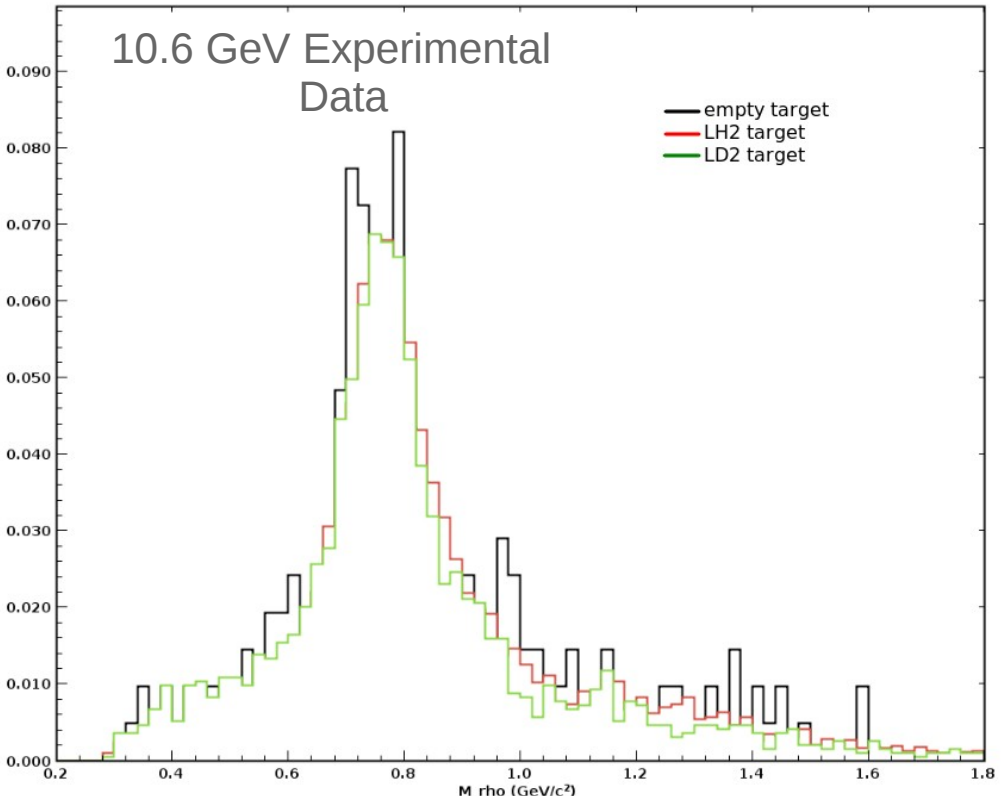


Reconstructed W distribution

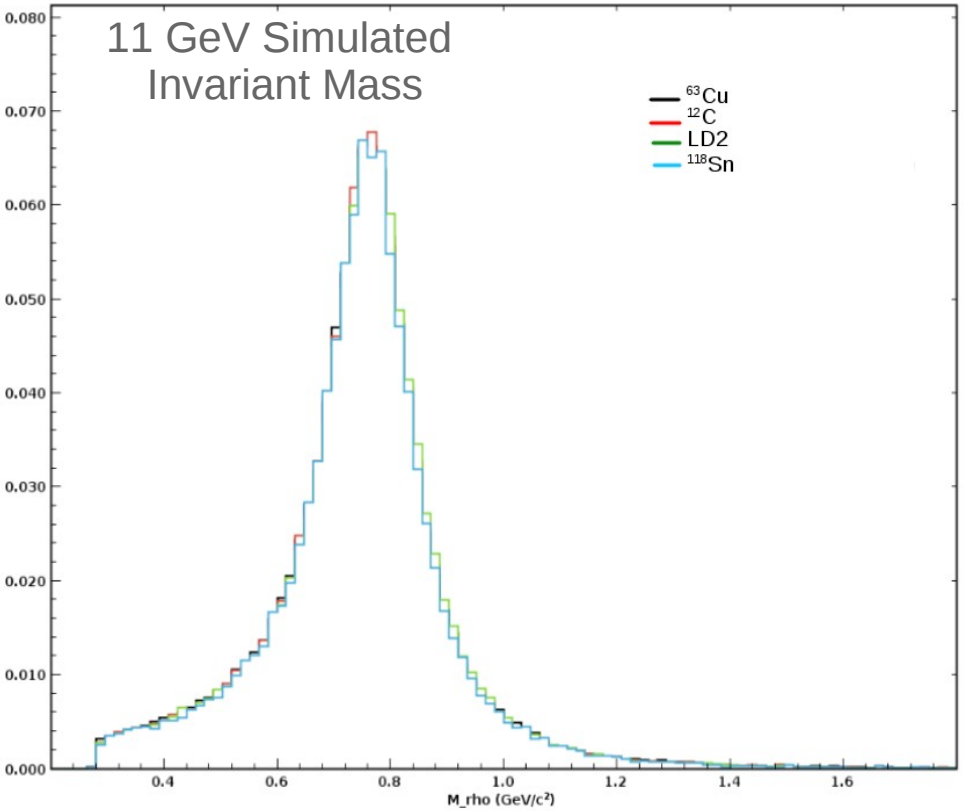


Negative Polarity Data

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



$M_{\rho 0}(GeV/c^2)$



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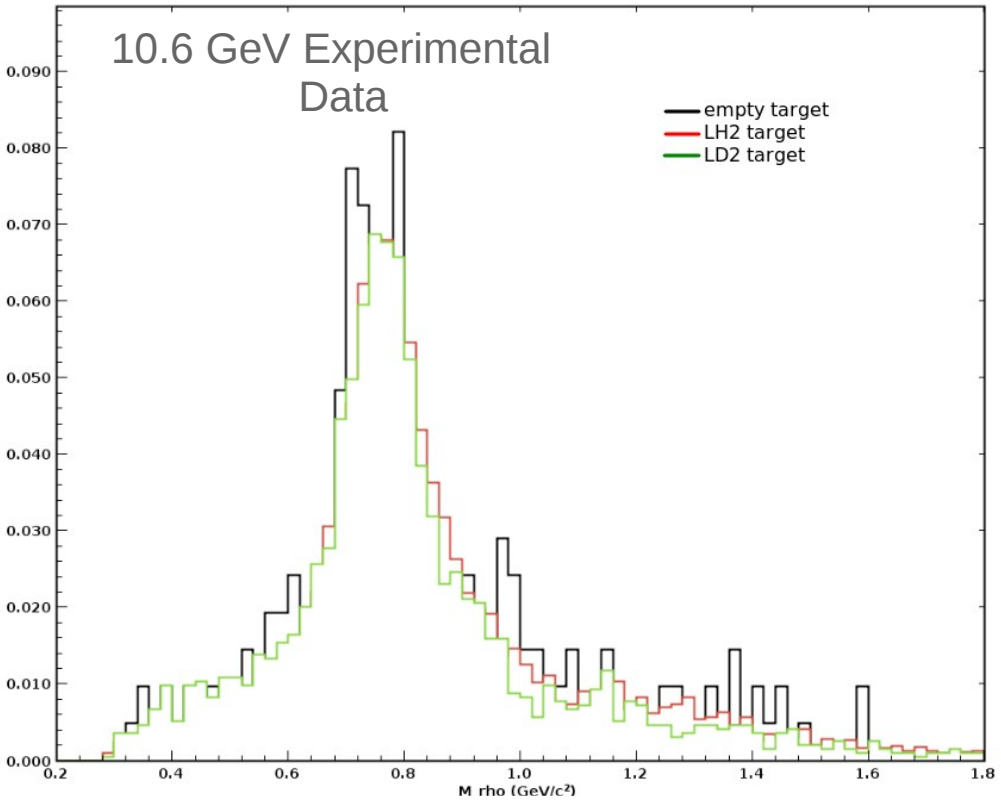

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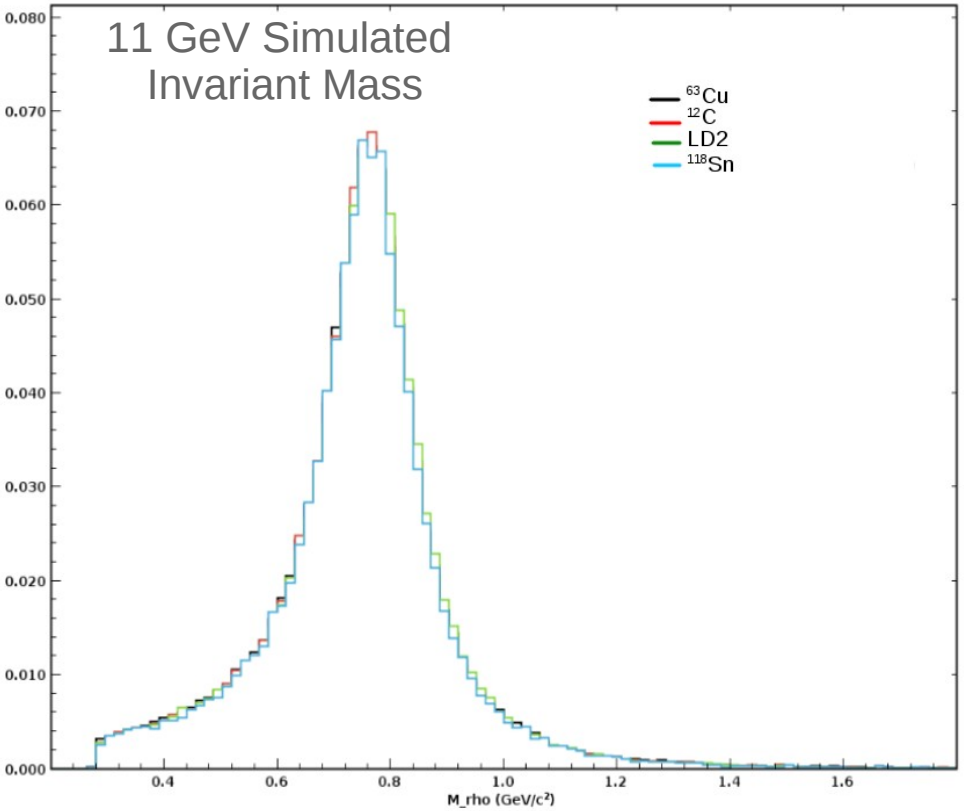
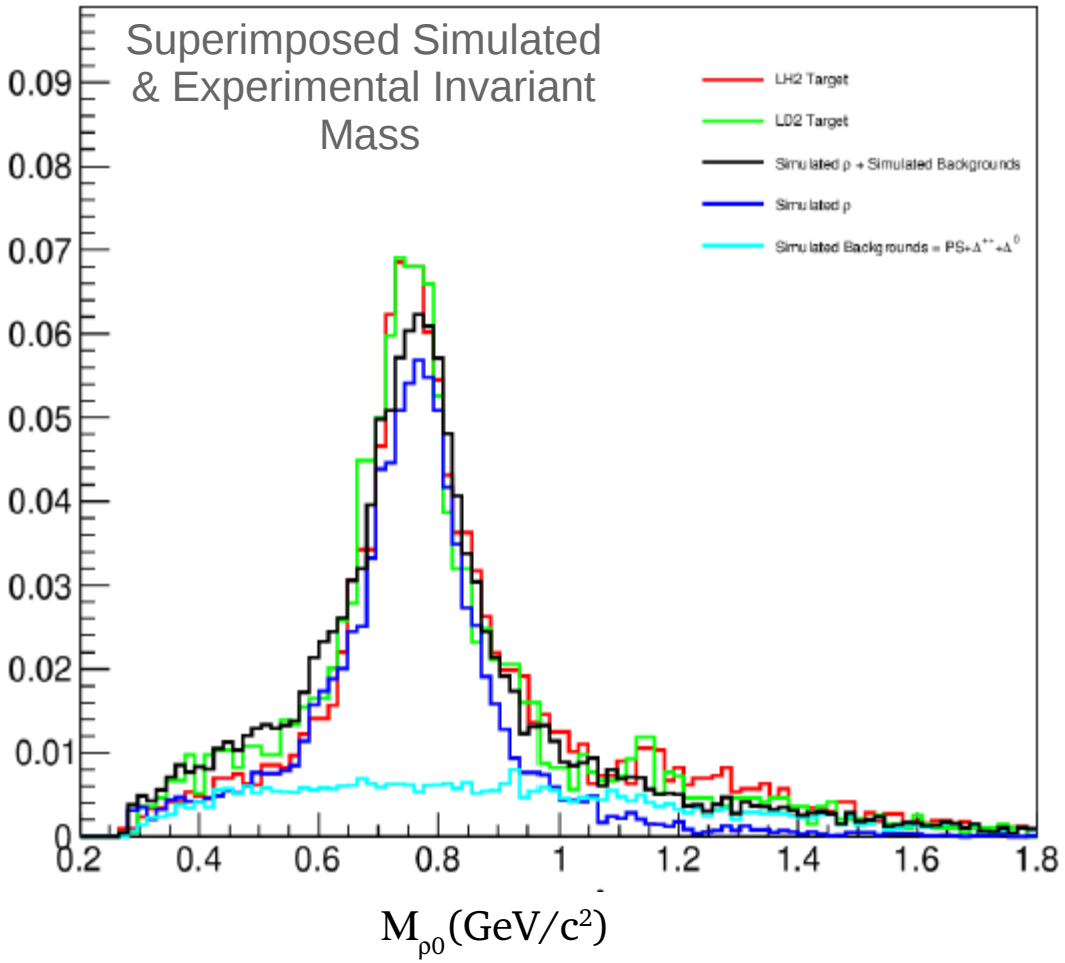


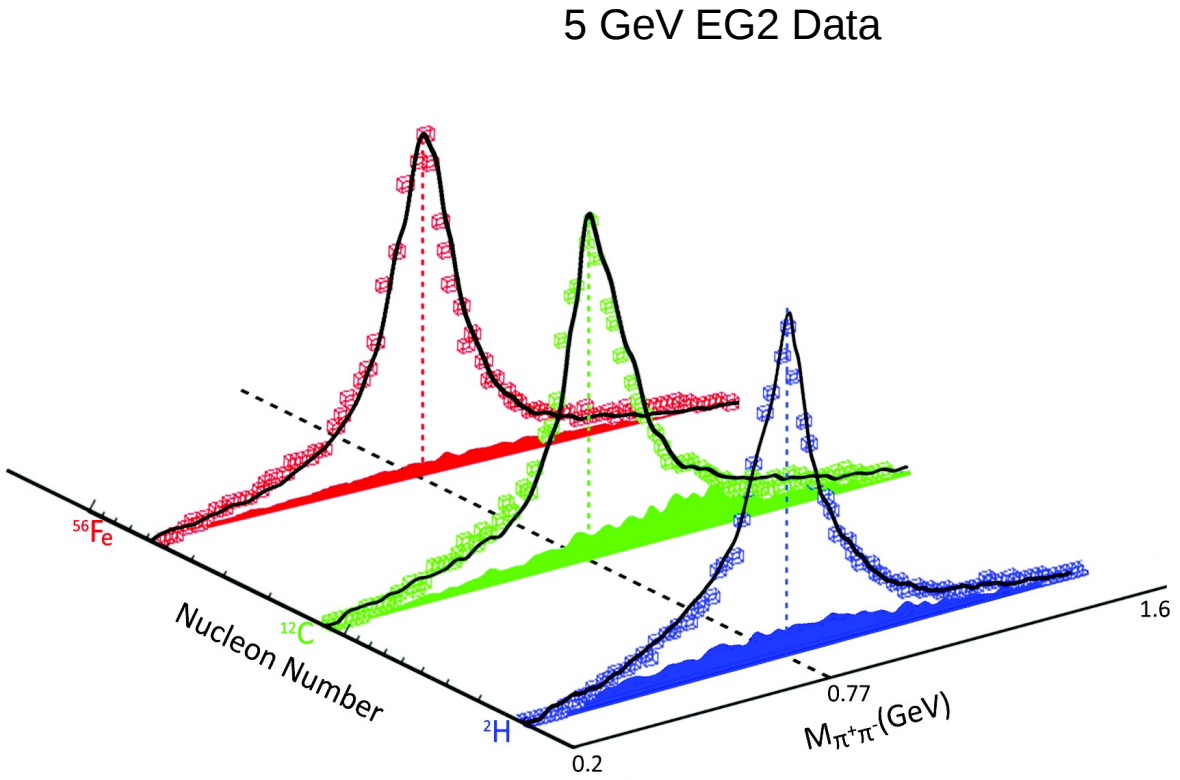
$M_{\rho 0}(GeV/c^2)$

- Redid the background simulation after the 1st round review of the ERR committee to resolve the issue of the underestimated background.

Negative Polarity Data

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





Simulated Background's Shapes

e + p → e + p + π^+ + π^-

e + p → e + Δ^{++} + π^-

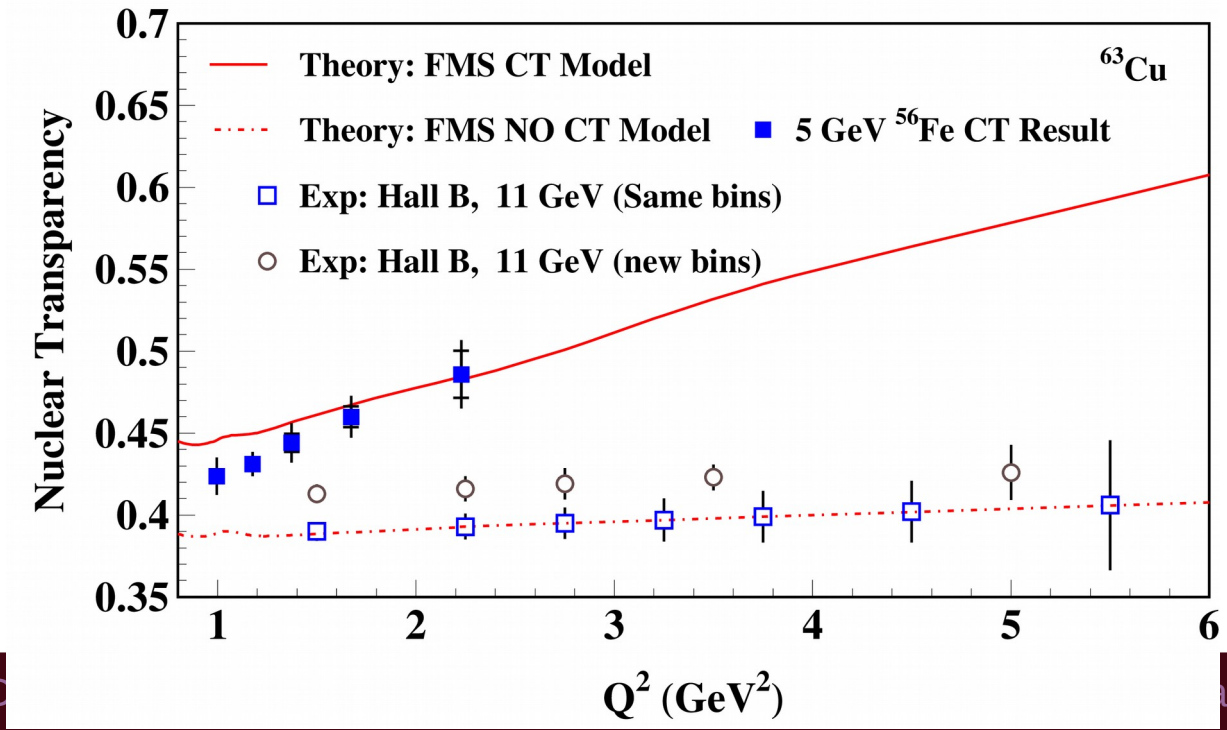
e + p → e + Δ^0 + π^+

ρ^0 production: **e + p → e + p +** ρ^0

Reduced Beam Time Physics Reach

- If scheduled to run with ½ approved beam time (*no more than that*) we can still have publishable results by either
  - Dropping one nuclear target, or
  - Re-binning our nuclear transparency Q^2 dependence range.

Q^2(GeV^2) / Targets	1.5 ± 0.5	2.25 ± 0.25	2.75 ± 0.25	3.25 ± 0.25	3.75 ± 0.25	4.5 ± 0.5	5.5 ± 0.5
^{63}Cu (%) (Same bins)	1.5	2.0	2.5	3.4	4.1	4.8	10.1
^{63}Cu (%) (new bins)	1.5	2.0	2.5	Q^2: 3.5 ± 1 2.1		Q^2: 5 ± 1 4.4	



Nuclear Background & Beam Request

- ERR committee concluded that the understanding of the nuclear background will be reached after the conclusion of the investigations led by the Hall-B and RadCon task force.
- After submitting the 2nd round reply to the ERR committee, I submitted the beam time request by mid-August for RG-D 30 PAC days scheduling, https://misportal.jlab.org/railsForms/beam_schedules/88916/, targeting Spring 2021:

From: **Approval Signature Service** <noreply@jlab.org>
Date: Wed, Nov 6, 2019 at 12:01 PM
Subject: Items still pending approval
To: <elfassi@jlab.org>

-DO NOT REPLY TO THIS EMAIL-

This email is to inform you that after 7 days, you still have some items that are pending someone else's approval/signature. You may need to manually get some of these folks to electronically sign your item(s). Its possible that they may have their notification preferences turned off and did not receive the automated email regarding their signature being needed.
You can choose to email them directly or you may use the link below to generate a single email to multiple people that you select.
You may also choose to do nothing if you know that approval is pending some type of other action. If this is the case, please disregard this email.
If this item no longer needs approval, you should remove/delete it.

https://misportal.jlab.org/mis/apps/personal/pending_approvals.cfm

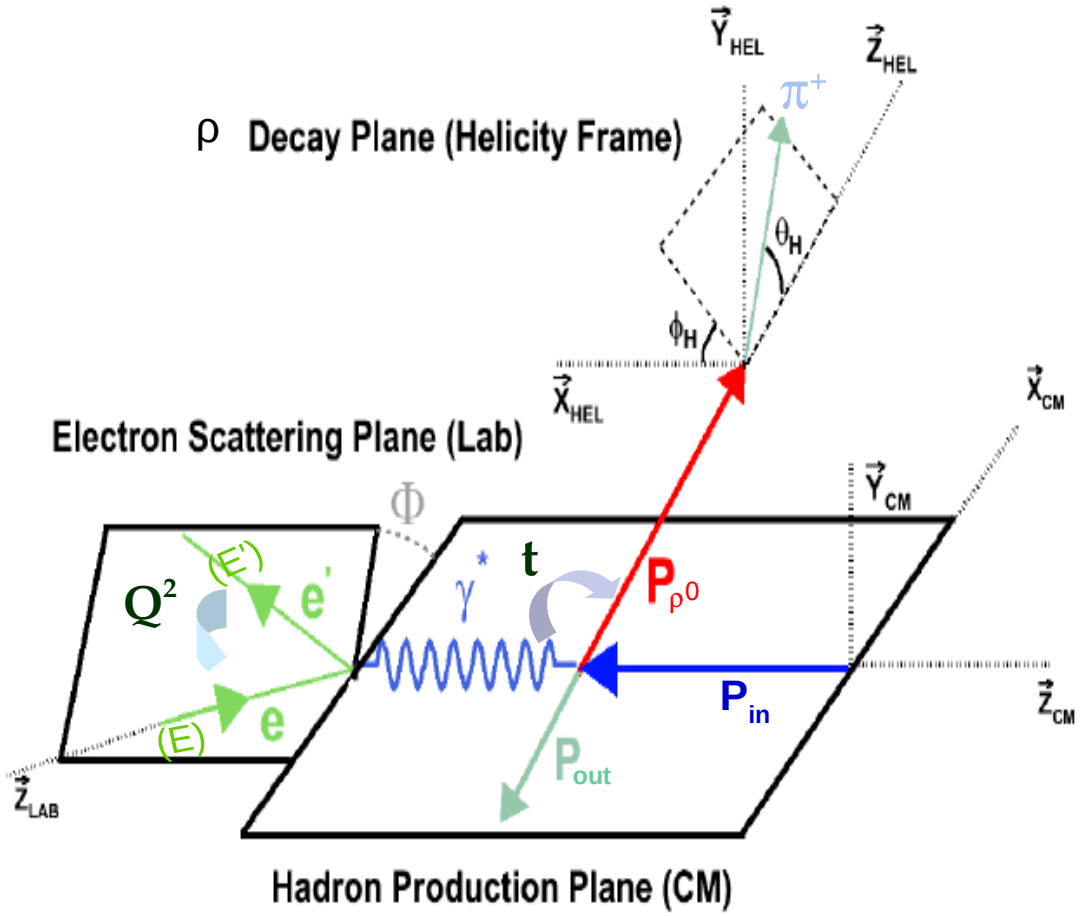
Type	No.	Date Submitted	URL
Beam Scheduling Request	88916	8/16/2019 11:26 AM	https://misportal.jlab.org/railsForms/beam_schedules/default?ENTRY_ID=88916

- Sent the new Hall-B leader, Marco, a 4-pages summary of the status and readiness of RGD experiment in September.
- Different nuclear targets run-groups will meet with the Hall-B management early this afternoon to discuss the FY21 scheduling.

Backup Slides

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

Two pions Invariant Mass

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

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

Simple Breit-Wigner

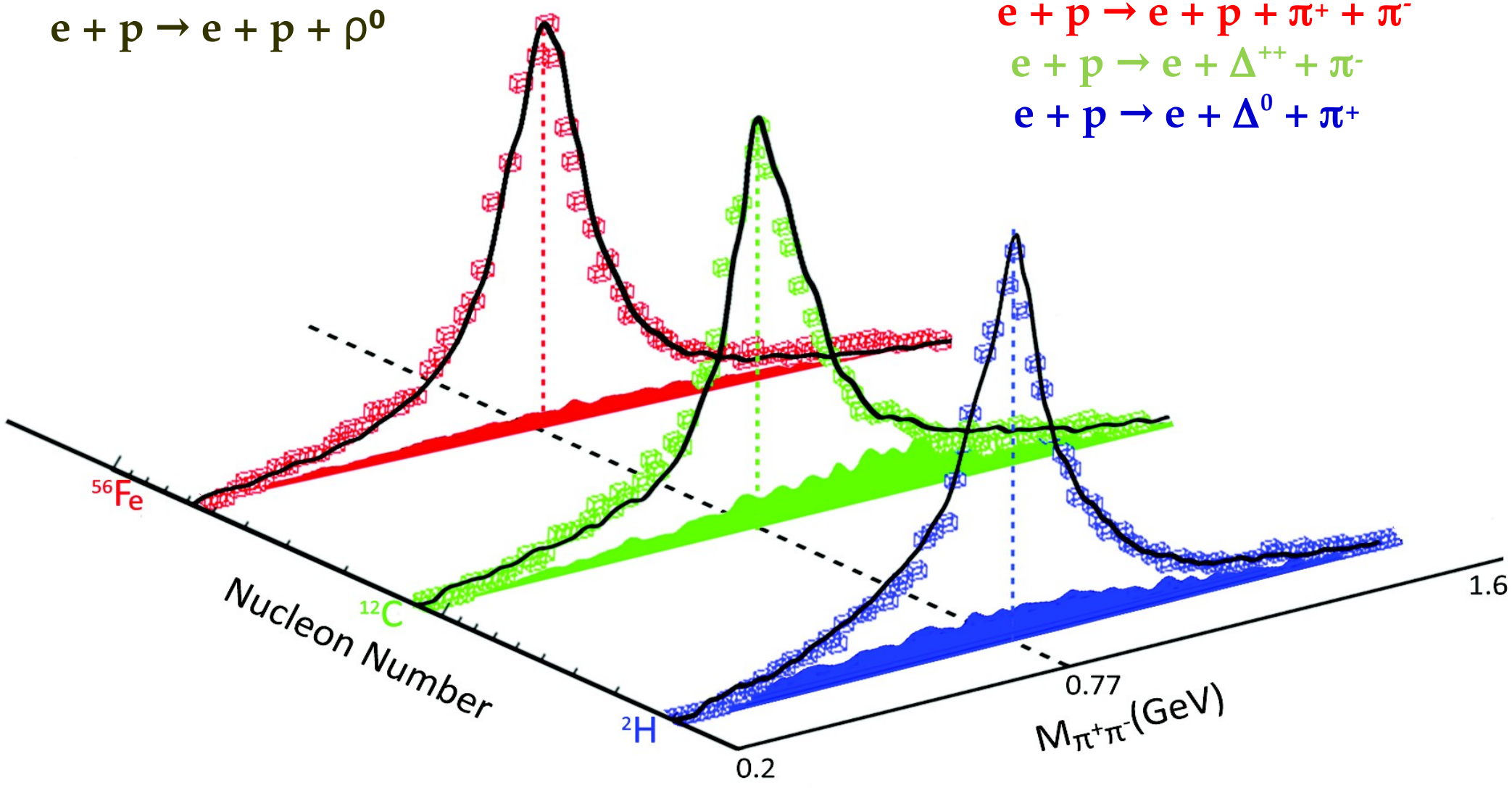
$e + p \rightarrow e + p + \rho^0$

Simulated Background's Shapes

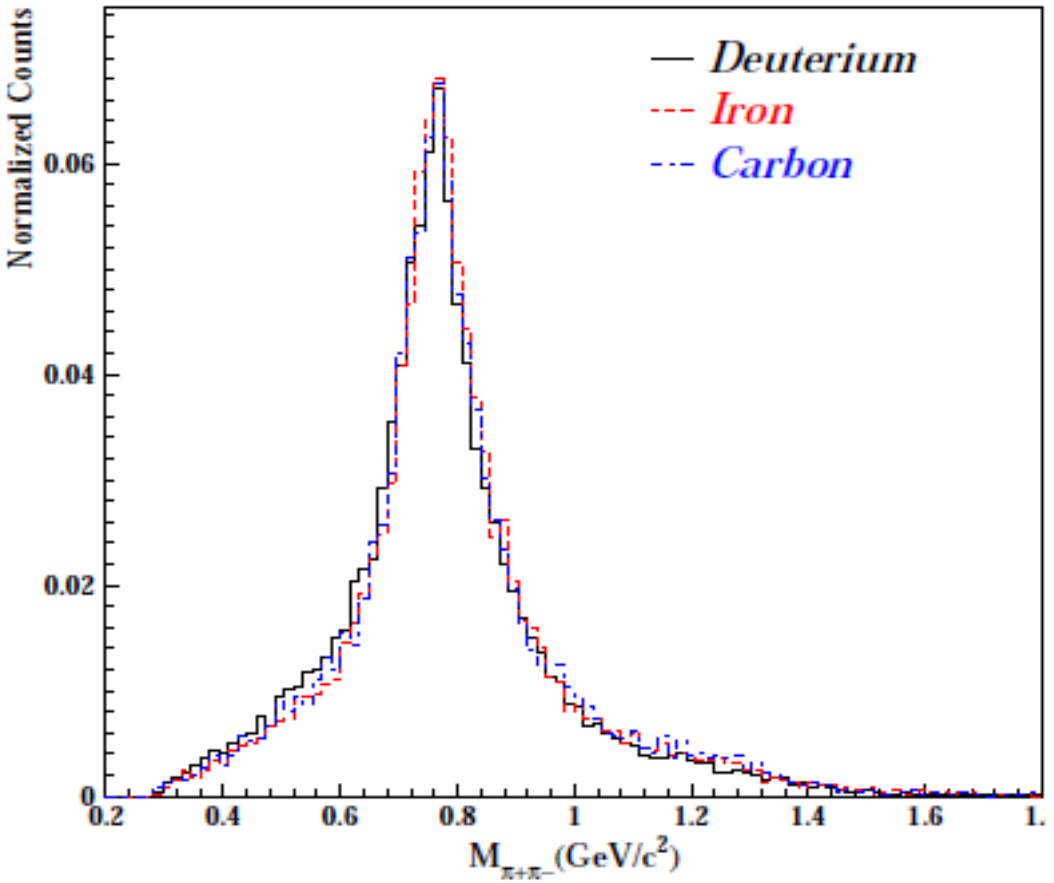
$e + p \rightarrow e + p + \pi^+ + \pi^-$

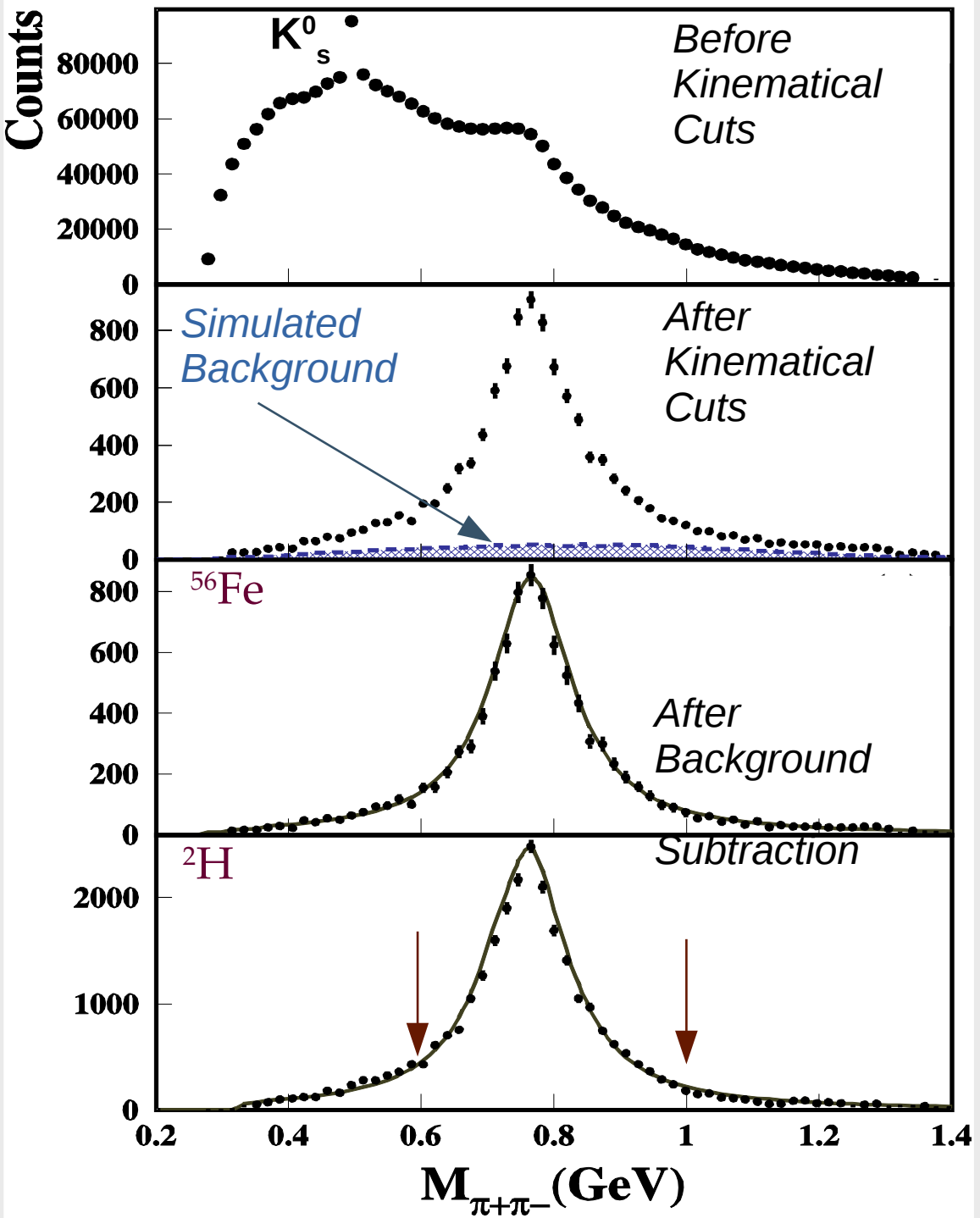
$e + p \rightarrow e + \Delta^{++} + \pi^-$

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



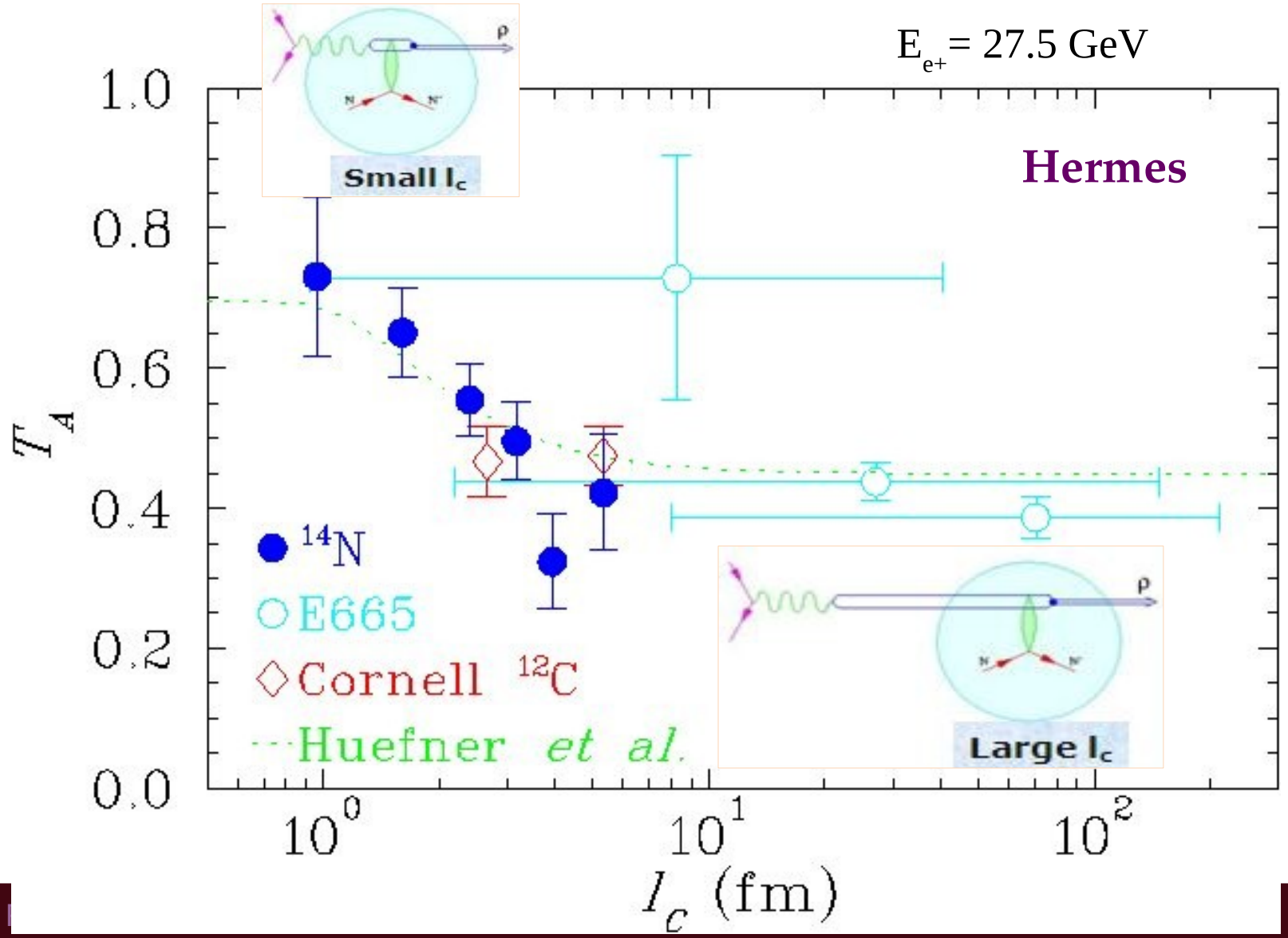
Two Pions Invariant Mass





Coherence Length effect (CL) could mimic CT signal?

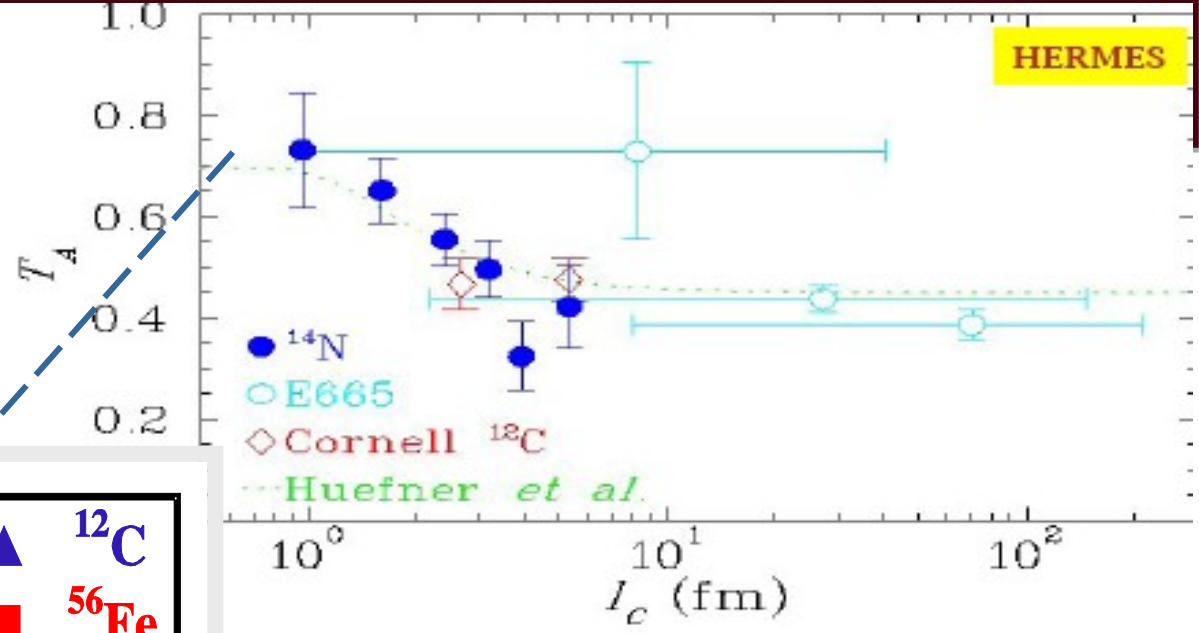
- CT signature is the T_A increase with Q^2, however, as $l_c = 2/(M^2 + Q^2)$, the CL effect manifests also the T_A increase with Q^2.
- To exclude CL, the Q^2 dependence of T_A must be measured at small or fixed l_c.

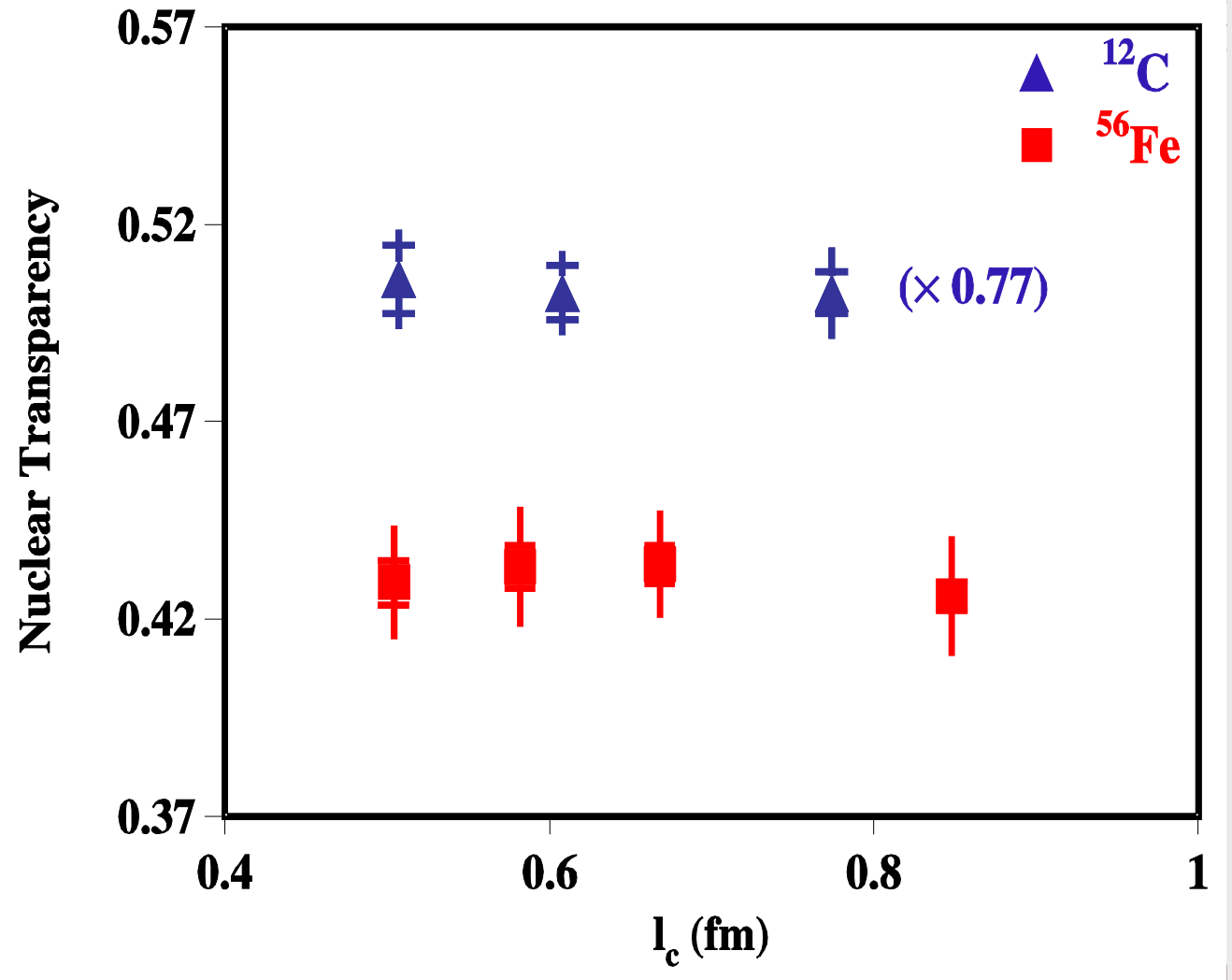


l_c Dependence on T_A

Coherence Length

$l_c = 2\,\nu/(M^2 + Q^2)$





Nuclear Transparency

$$T^{\rho}_{A} = N^{\rho}_{A} / N^{\rho}_{D} \times (\rho_D \times t_D) / (\rho_A \times t_A)$$

- ρ_D and ρ_A are target's densities
- t_A is the solid target thickness
- t_D= 2 cm, liquid target length

L. El Fassi *et al.* PLB 712, 2012

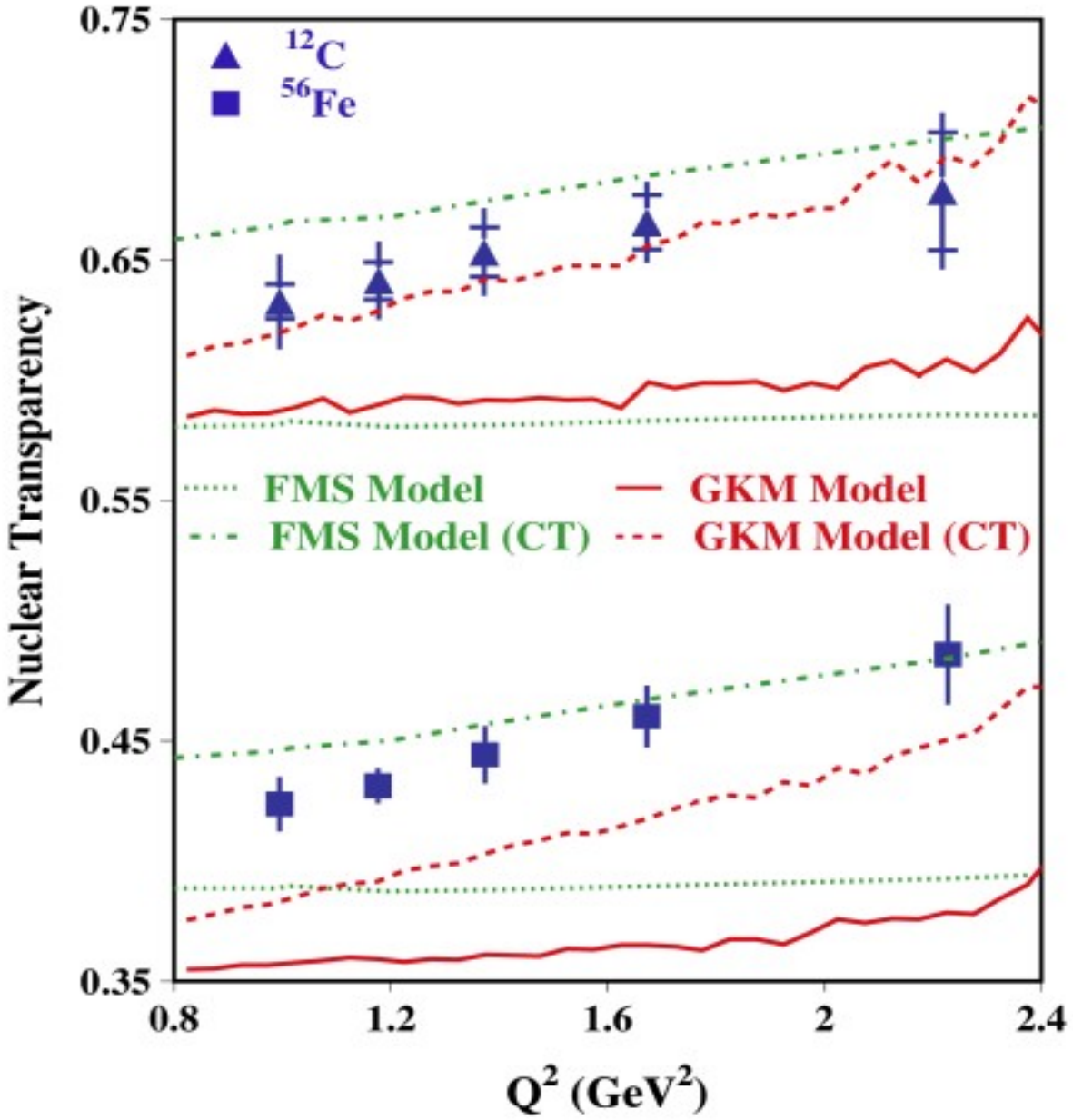
ρ^0 CT Results for 5 GeV Iron & Carbon data-sets

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

Frankfurt, Miller & Strikman, PRC 78 (08) & Private communication

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

Gallmeister, Kaskulov & Mosel, PRC 83, 015201 (2011)



L. El Fassi *et al.* PLB 712, 2012

Approved 11 GeV CT Experiment Projections

- Initially approved beam time with the dual target setup.

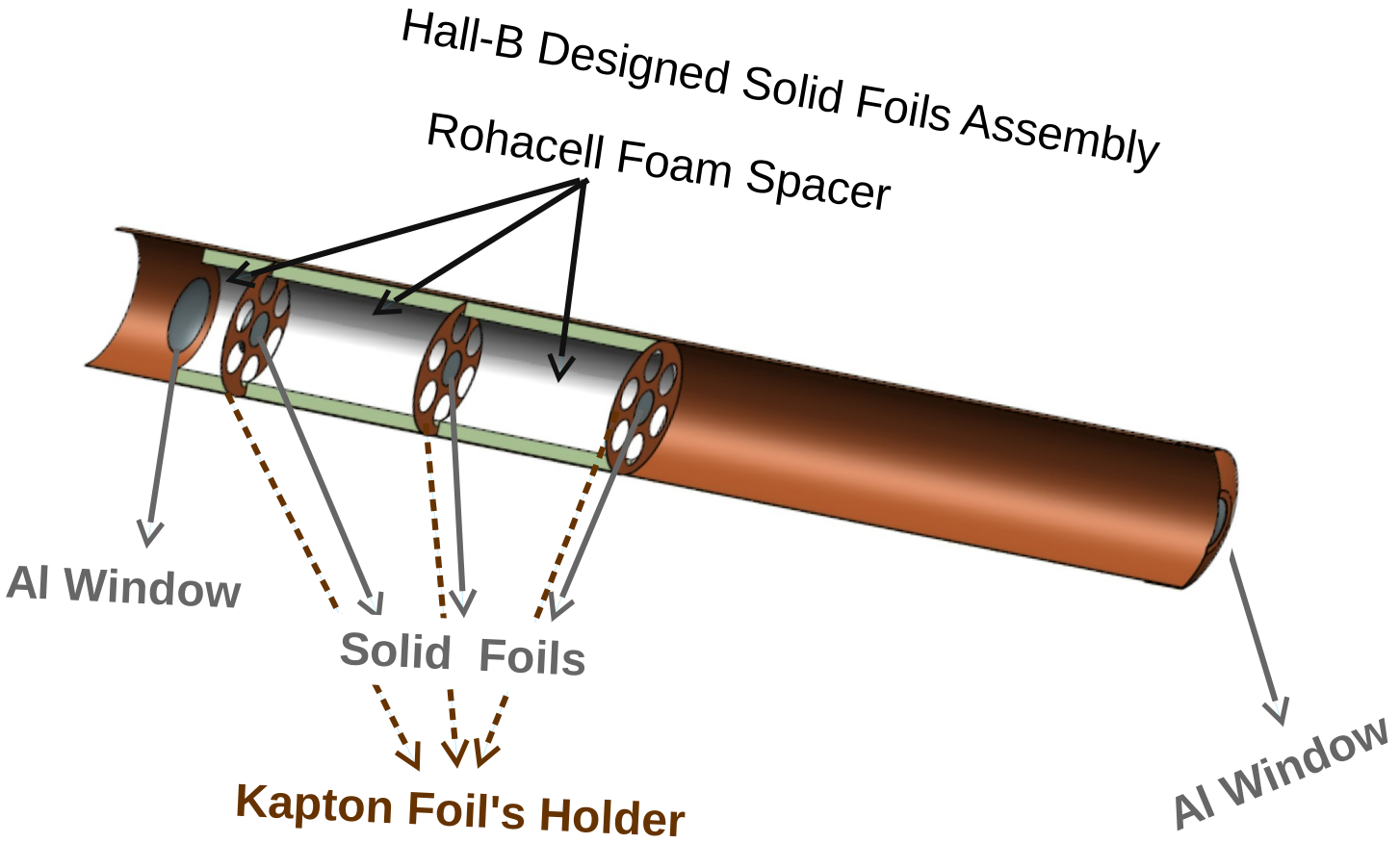
Targets	Beam Time (PAC days)
^{1}H	8
^{12}C (+ LD_2)	12
~~^{56}Fe~~ ^{63}Cu (+ LD_2)	16
^{118}Sn (+ LD_2)	24

- Expected statistical uncertainties for the approved beam time and one coherence length bin (0.4 – 0.5 fm):

$Q^2(GeV^2)$ / Targets	1.25 ± 0.25	1.75 ± 0.25	2.25 ± 0.25	2.75 ± 0.25	3.25 ± 0.25	3.75 ± 0.25	4.5 ± 0.5	5.5 ± 0.5
^{12}C (%)	0.6	0.5	0.8	1.2	2	3	3.5	7
^{63}Cu (%)	0.6	0.5	0.8	1.2	2	3.2	3.6	7.4
^{118}Sn (%)	0.6	0.5	0.6	1	1.6	2.4	3.4	6.9

Hall-B Target Assembly Advantage

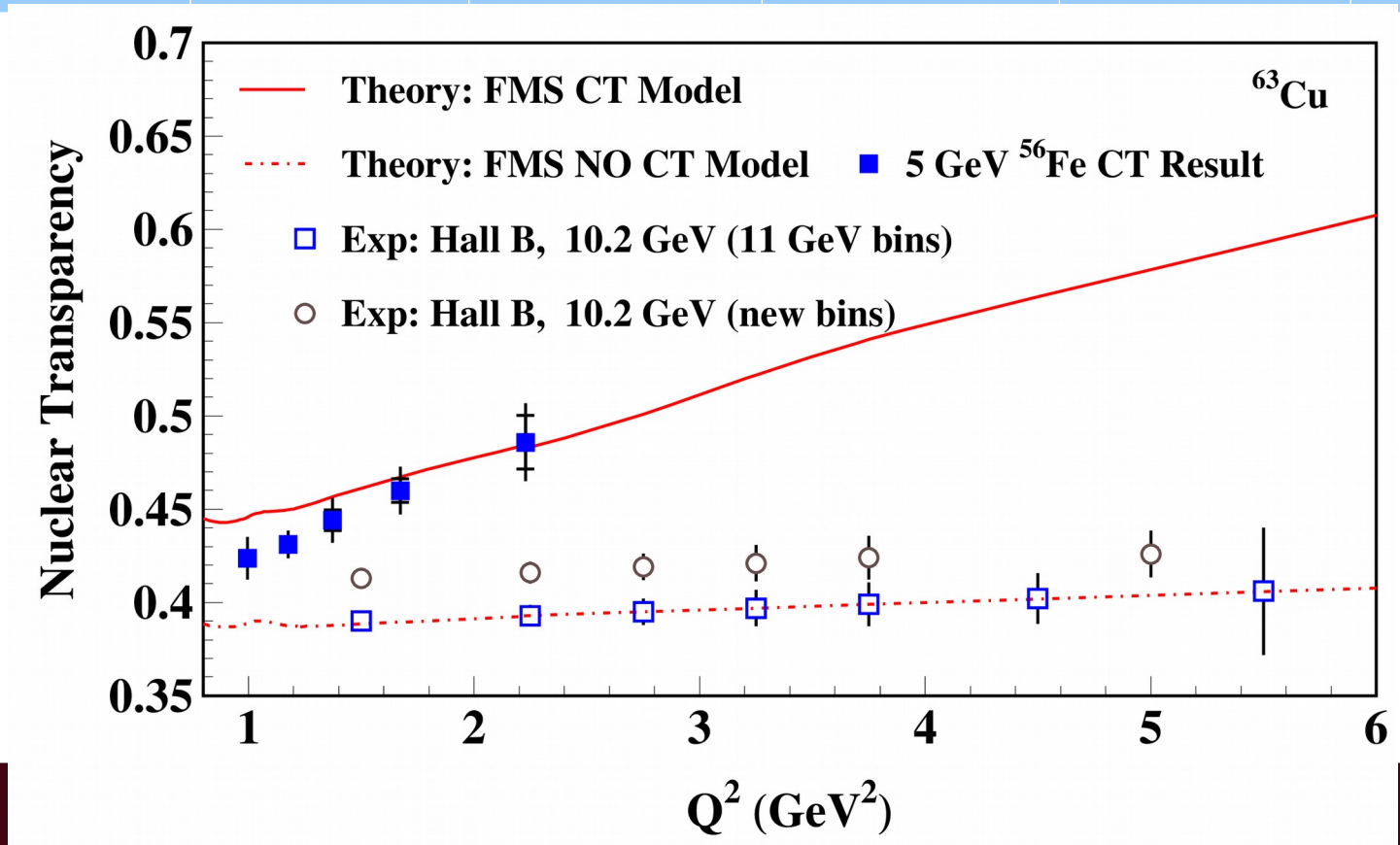
- Take liquid and solid targets data in similar vertex position which will minimize the acceptance correction,
- Reduce the amount of collected deuterium data as one set can be used with all nuclear targets to extract the physics results,
- Can accommodate several thinner solid targets, allowing to take full luminosity even on heavy targets.



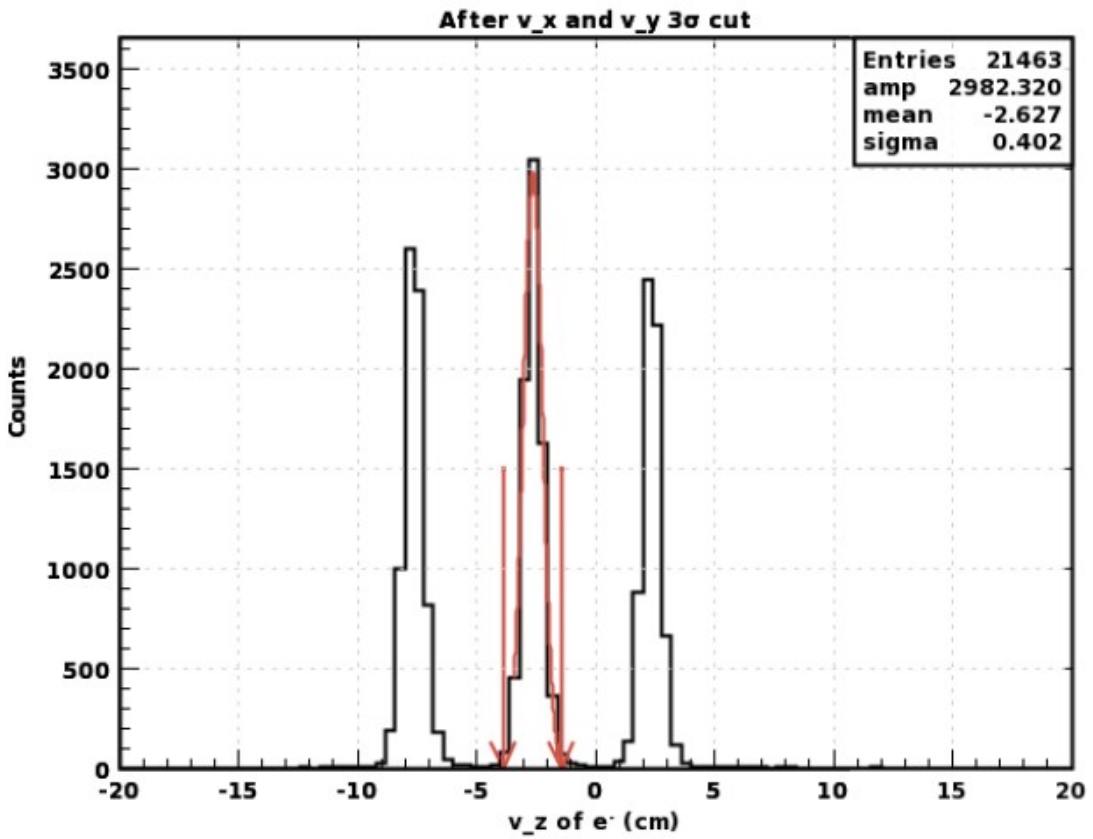
Running Conditions: Lower Beam Energy

- A lower beam energy, say 10.2 GeV, will reduce the highest Q^2 bin statistics by roughly 30% based on simulation.

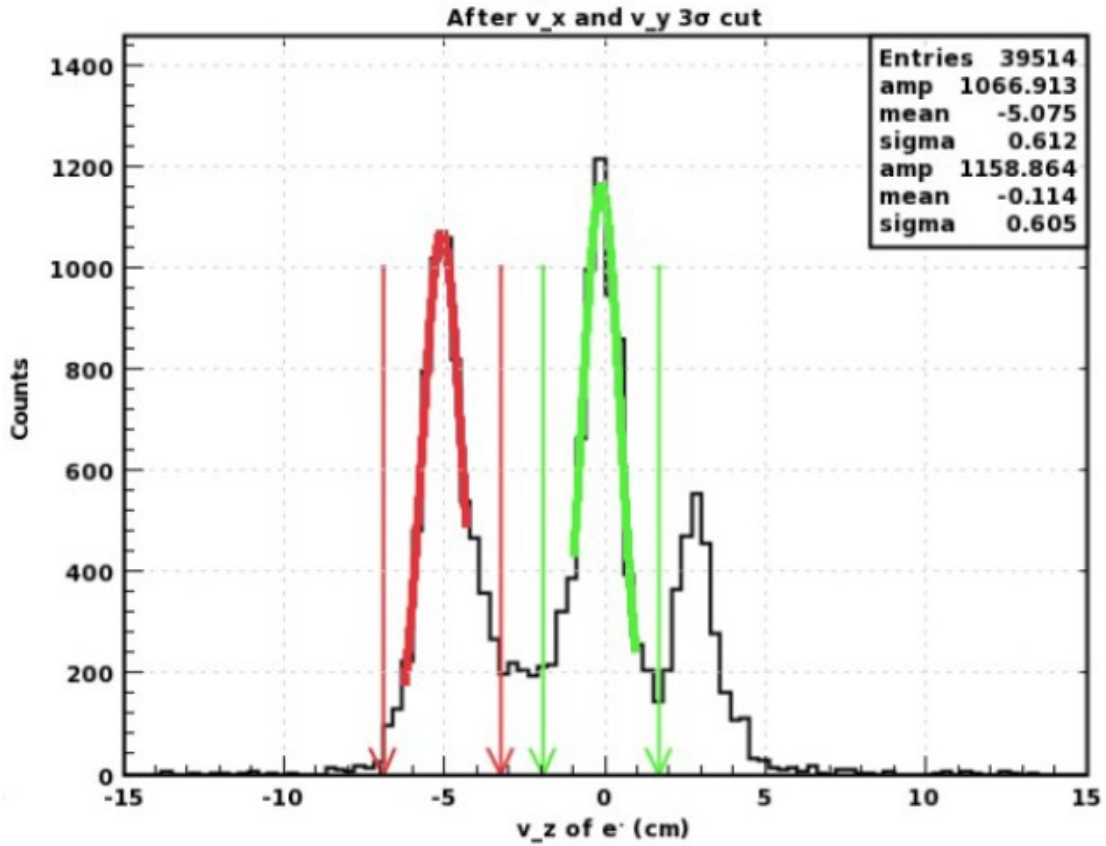
Q^2(GeV^2) / Targets	1.5 ± 0.5	2.25 ± 0.25	2.75 ± 0.25	3.25 ± 0.25	3.75 ± 0.25	4.5 ± 0.5	5.5 ± 0.5
^{63}Cu (%) (11 GeV bins)	1.1	1.5	1.8	2.5	3.0	3.5	8.7
^{63}Cu (%) (10.2 GeV new bins)	1.1	1.5	1.8	2.5	3.0	Q^2: 5 ± 1	
						3.4	



Vertex Distribution



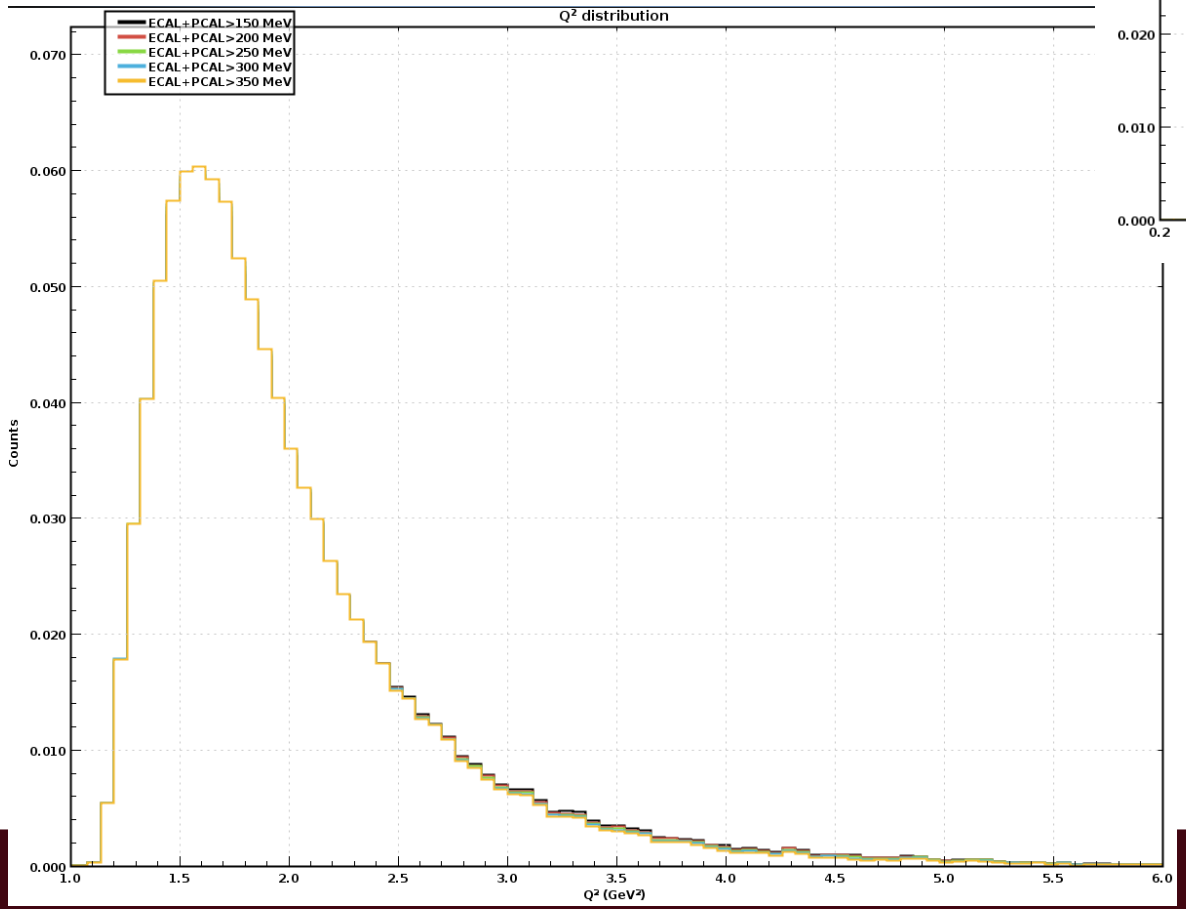
Simulated Electron z-vertex distribution for the Hall-B 5 cm apart solid foils assembly

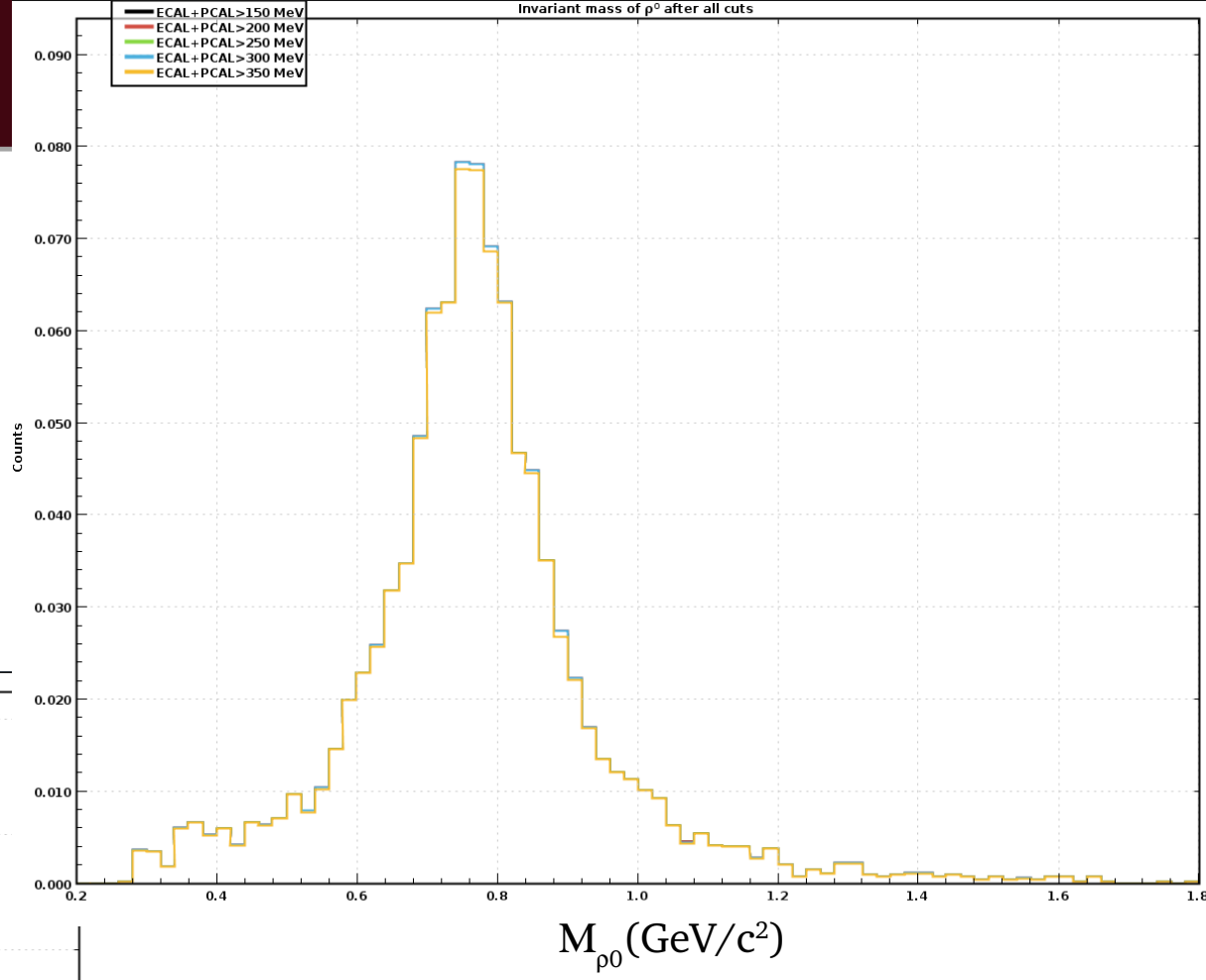


Electron z-vertex distribution from a newly calibrated, aligned and reconstructed empty target RG-A run

Running Conditions: Trigger

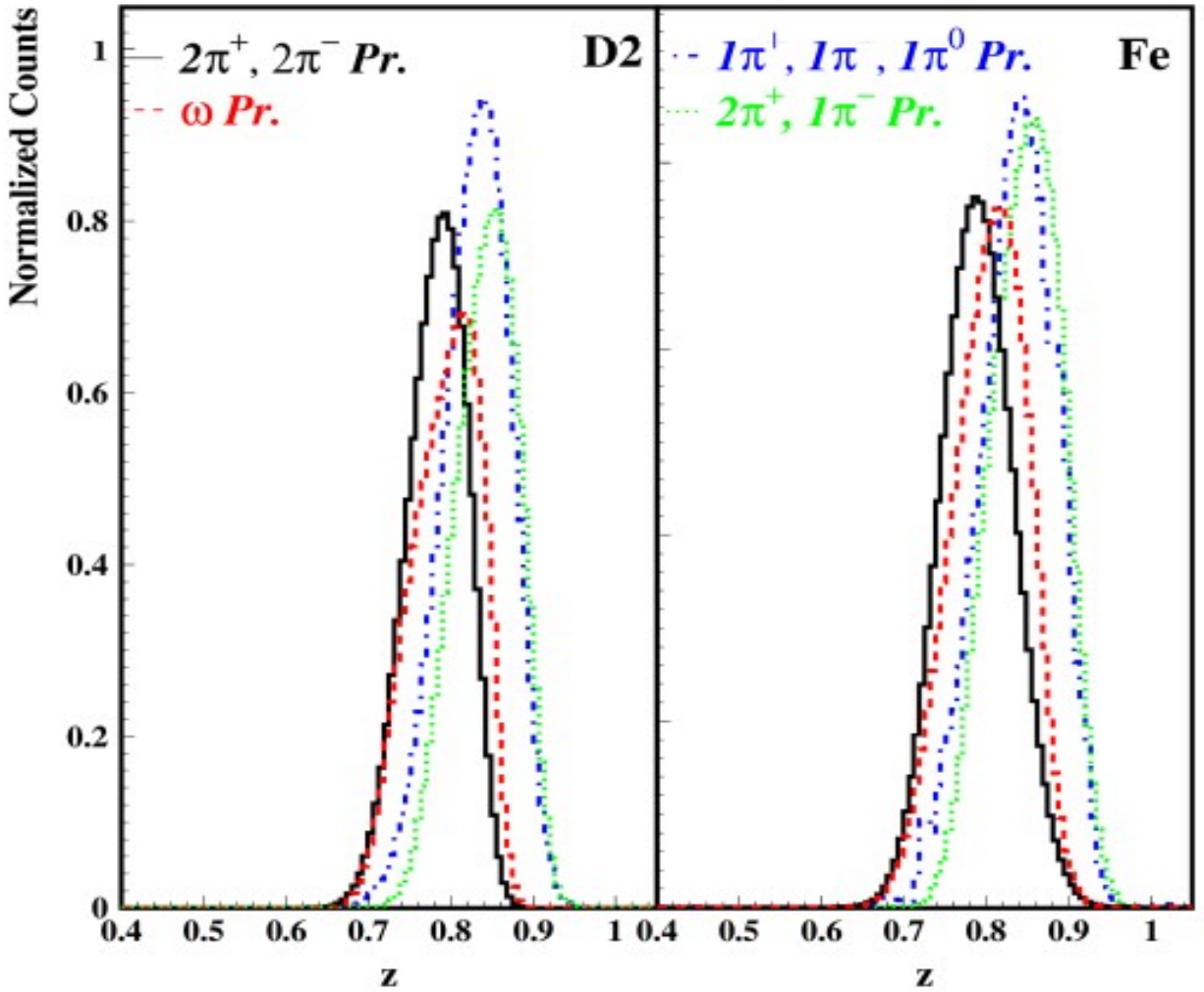
- ✔ No visible effect on Q^2 nor the invariant mass up to $E_{sum} = E_{PCAL} + E_{ECAL} > 350$ MeV.





Multi-pions Processes

- $Z_h \geq 0.9$ is effective in removing muti-pions final state contribution.



Running Conditions: Detector Setup

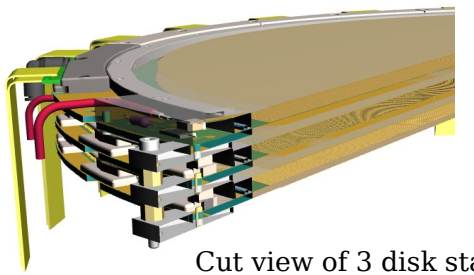
- Will use the CLAS12 in its standard configuration but with
  - **FT-OFF** because
    - the interest to a high-Q^2 region,
    - no interest to detect photons at small angles (2.5°- 4.5°),
    - to reach the highest luminosity possible of 2 10^{35} $cm^{-2}s^{-1}$.
  - **FMT-Out** since the forward detector resolution is good enough for the 5 cm target separation.
    - But, if the light version that Saclay is currently making for the BONUS experiment is fully functional before the run, then we can use the FMT.
    - The light FMT version:

Metal screw replaced by nylon, plastic fixation, 3D print HV cover
Aluminum (RL 8.9 cm) fixation between disk replaced by Peek (RL 31.9 cm)

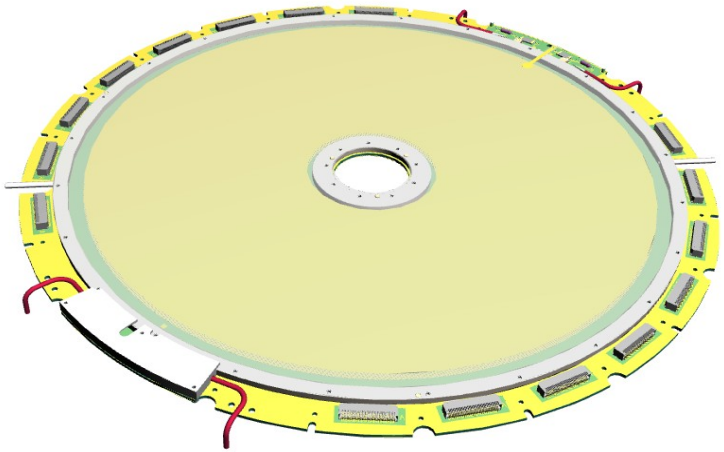
Preliminary schedule

06/2019: drawing and material study
09/2019: Change and test disk 1
12/2019: upgrade disk 2-3
06/2020: upgrade disk 4 to 7

Volker, CLAS Collaboration Meeting, March 2019.



Cut view of 3 disk stack



FMT disk

Multi-pions Processes

- $Z_h \geq 0.9$ is effective in removing muti-pions final state contribution.