Update on RG-D Experiments: Calibration and Analysis Status

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CLAS Collaboration (November 13th, 2024)

MISSISSIPPI STATE UNIVERSITY™

Run Group D

RG-D is composed of two experiments:

- Study of Color Transparency (CT) in Exclusive Vector Meson Electroproduction off Nuclei (E12-06-106):
  - Spokespeople: W. Armstrong[1] , L. El Fassi[3] , K. Hafidi[1] , M. Holtrop[4] and B. Mustapha[1]
- Nuclear Transverse Momentum Distributions (nTMDs) in CLAS12 (E12-06-106A):
  - Spokespeople: R. Dupré[2] , L. El Fassi[3] , Zein-Eddine Meziani[1] , and Holly Szumila-Vance[5]

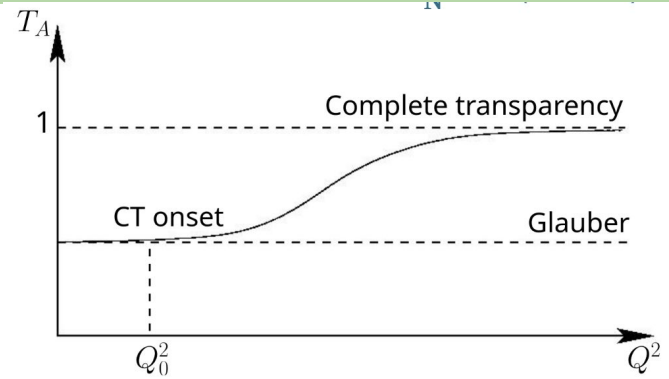
[1]: Argonne National Lab (ANL), [2]: IJCLAB, Orsay, France [3]: Mississippi State U. (MSSate), [4]: University of New-Hampshire (UNH), [5]: Jefferson Lab

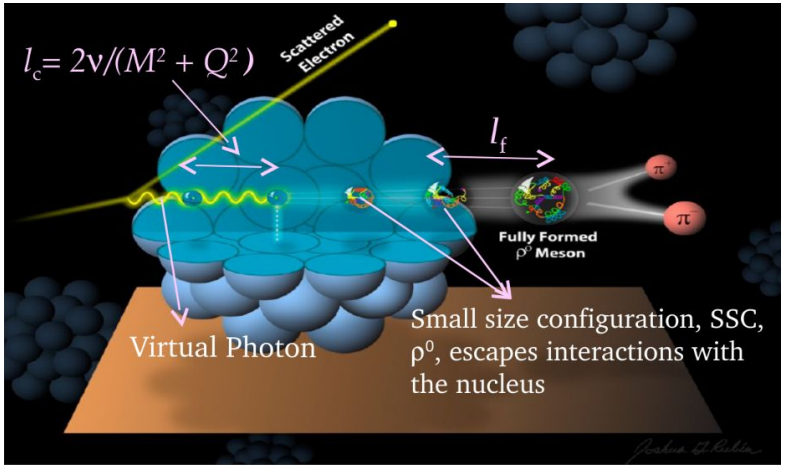
RG-D: CT Experiment

- E12-06-106, CT - the experimental signature of CT is the rise of the nuclear transparency, T_A as a function of Q^2:
  - T_A is defined as the 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

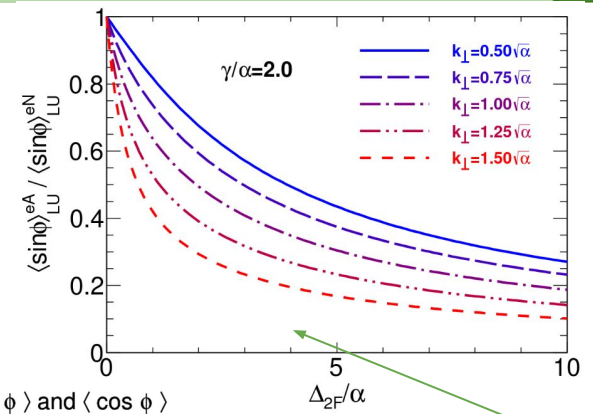




Coherence length, l_c: the lifetime of the qq-bar pair
Formation time, l_f: the time evolution of small size configurations (SSC) to an on-shell ρ^0 meson

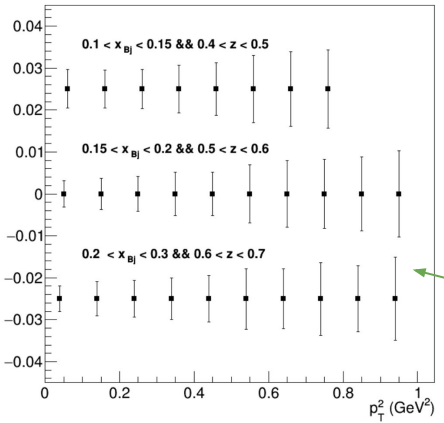
RG-D: Nuclear TMDs

- E12-06-106A: nTMDs study uses the same CT running conditions except the beam polarization, and aims to explore:
  - Fragmentation functions in nuclei
  - Nuclear asymmetries at the partonic level
  - Missing part of nuclear effects description
- Goal:
  - Measure the cos and sin modulations for p^2_T
  - Mesure multiplicity ratios
  - For both charged pions and kaons
  - Accesses transport coefficient at parton level



Ratio of sin asymmetries nuclei to nucleon

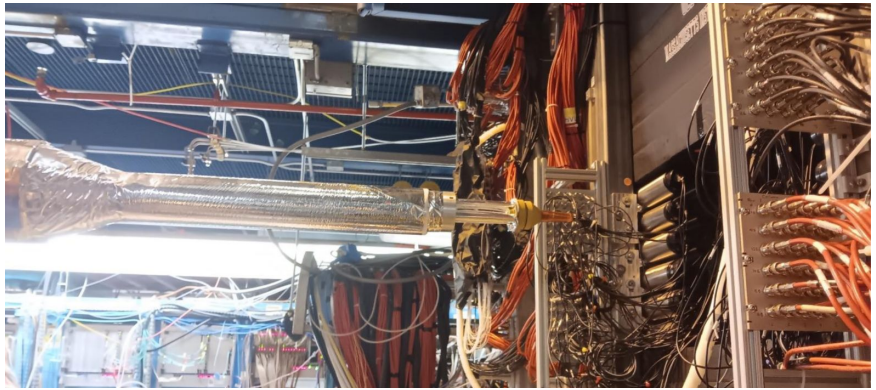
⟨ sin ϕ ⟩ and ⟨ cos ϕ ⟩

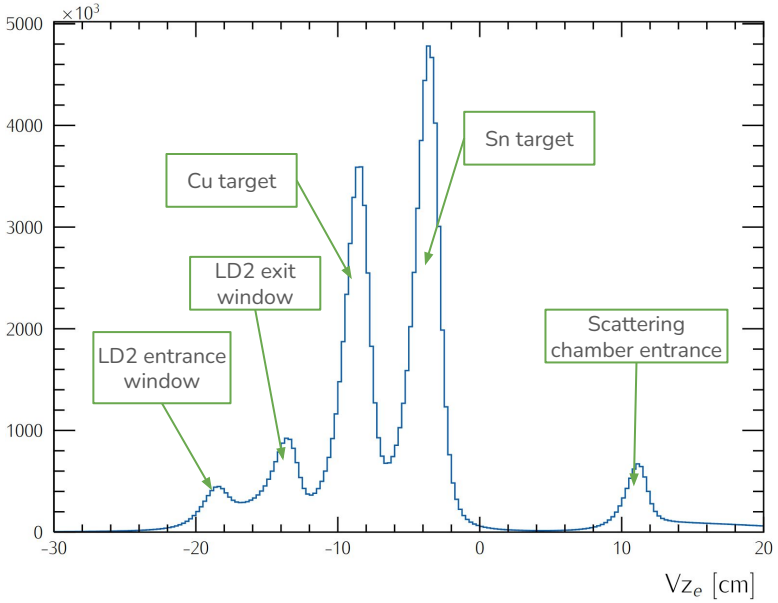


Projected statistical error bars for sin and cos moments

RG-D Run Configuration

- RG-D experiments ran with:
  - 10.54 GeV polarized beam with `I= 5-175 nA` for luminosity scans and production
  - Standard CLAS12 configuration with FT-OFF and three layers of FMT
  - Three target configurations, LD2, CxC, and CuSn, used with Inbending and Outbending torus magnet setup
  - 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





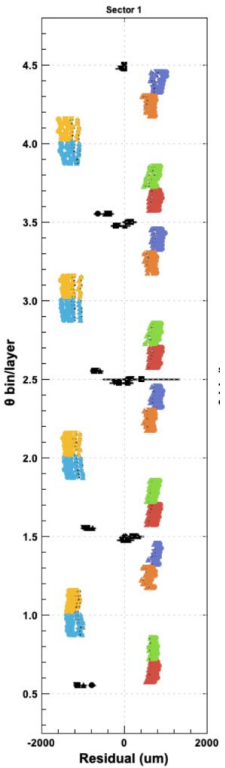
RG-D Status: DC Alignment

- Alignment:
  - DC alignment using zero-field run is completed

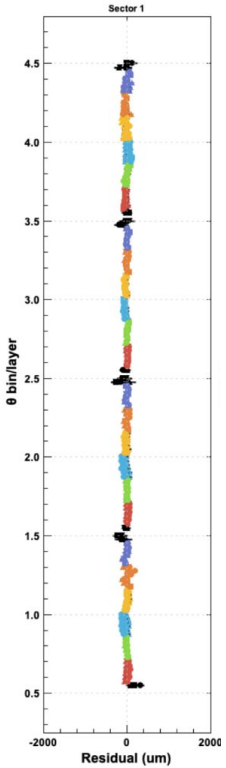
- Plots show tracks:
  - Fit residuals (colored points) and vertex residuals (black symbols) vs. θ bin.
  - Different symbols (circle, square, triangle, etc.) represent different φ bins
  - Colors denote different superlayers
  - Y-axis represents θ bins

Thanks to R. De Vita and M. Maynes

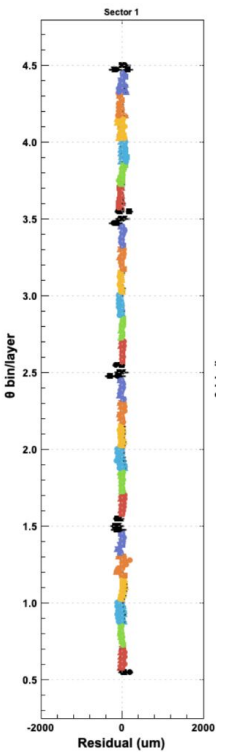
Nominal geometry



First+Second alignment



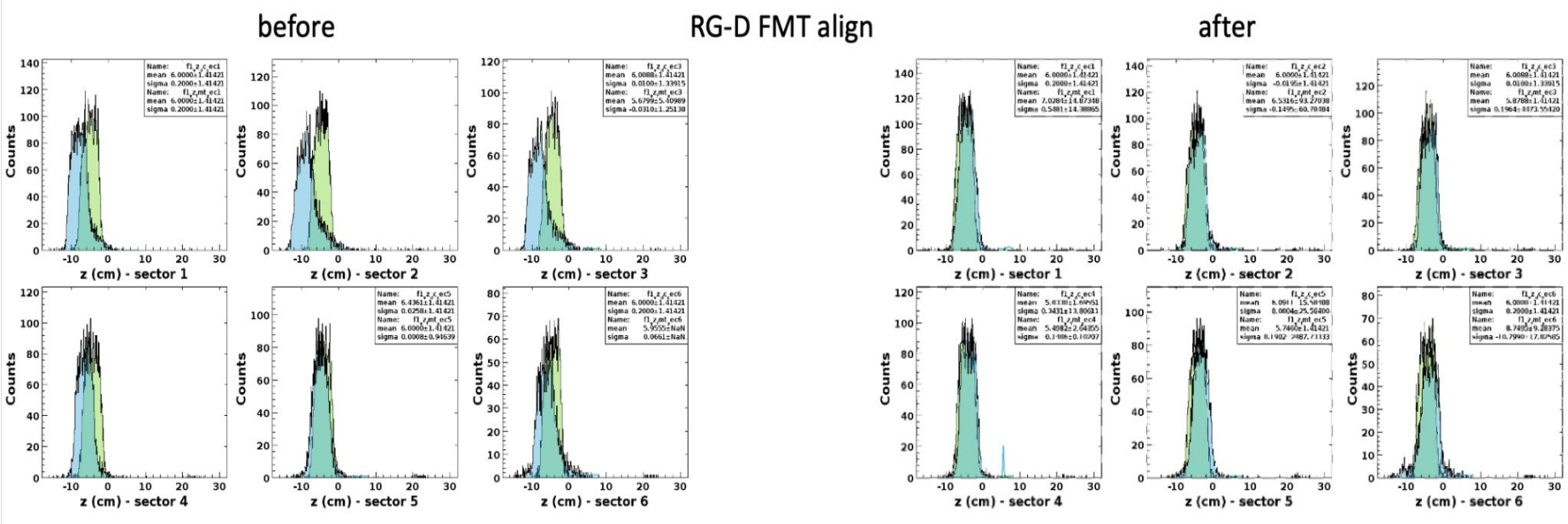
Final alignment



RG-D Status: FMT Alignment

- The final FMT alignment constants were extracted using the zero-field and cosmic runs, and uploaded for layers 2 and 3 (*layer 1 disk was not functional in RG-D*).

Thanks to Y. Gotra



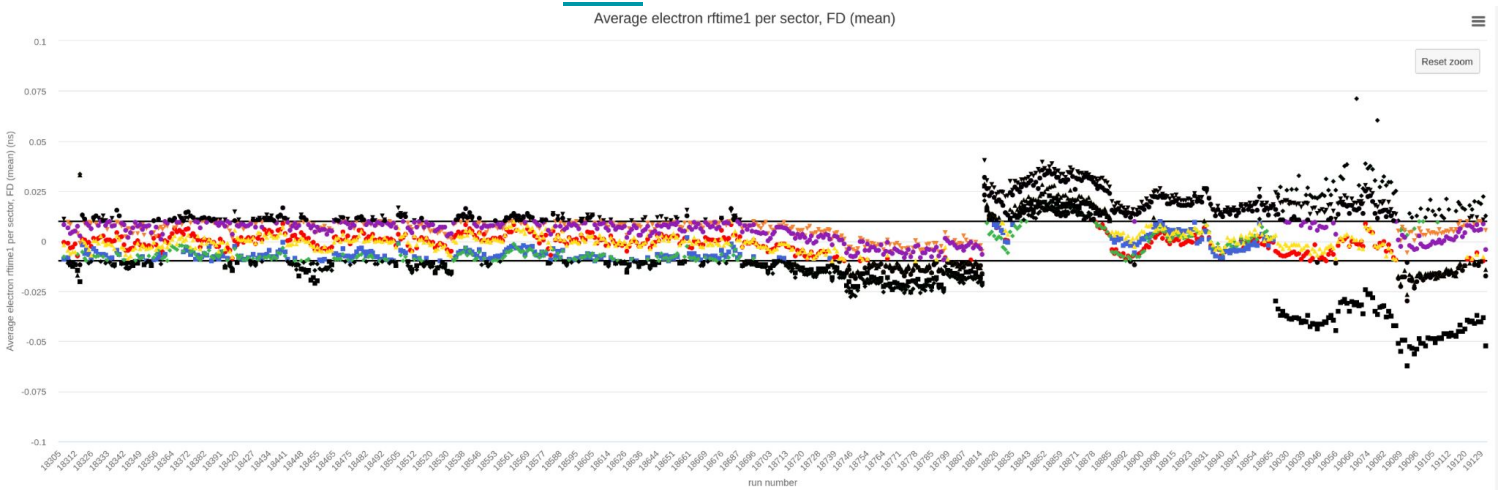
RG-D Status: Calibration Summary

- Beam offsets: transverse *X* and *Y* positions for FD and CD were calibrated and CVT z-offset was adjusted
- RF calibration is done
- FTOF and CTOF calibrations are almost finalized depending on the to-be-produced timelines after the latest iterations
- RICH: time calibration is finalized
- LTCC: calibration of the per-sector number of photoelectrons is completed
- ECal: time residual offsets were updated for IB and OB datasets (*awaits timelines check*)
- CND calibration is almost finalized depending on the to-be-produced timelines after the latest iterations
- HTCC and DC calibrations are in progress

Thanks to the CalCom group support

Data Processing Summary

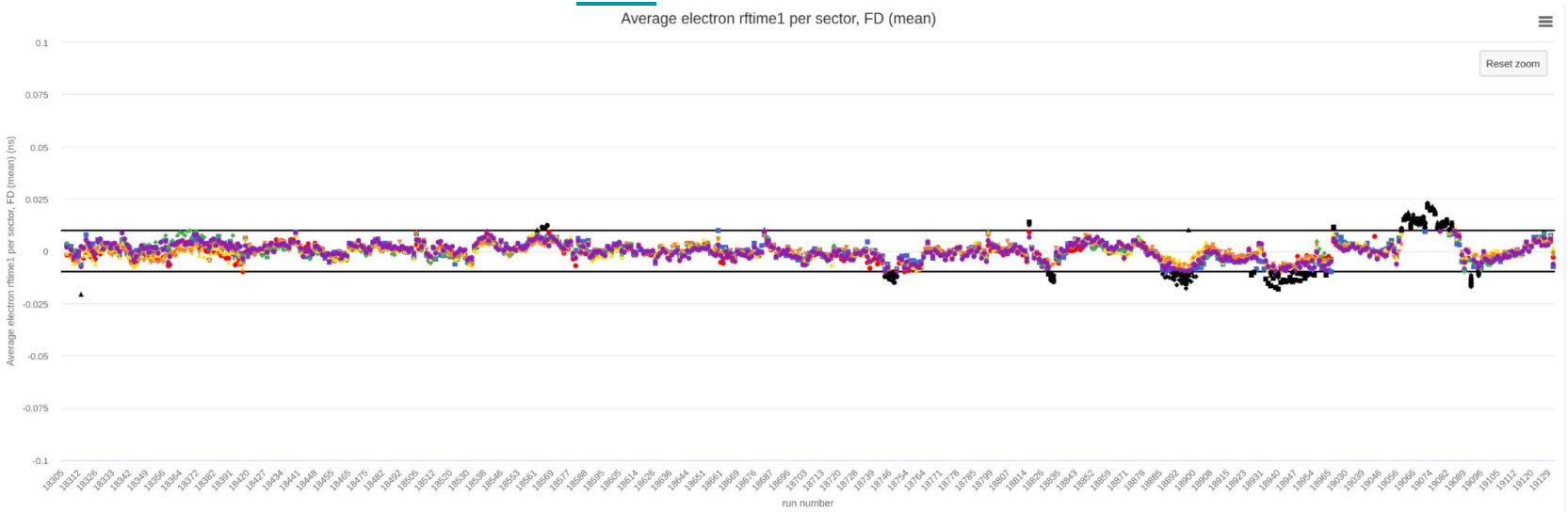
- Timelines monitoring:
  - The first three timelines for RG-D datasets were done online
  - September 4th: Pass0v4 was processed after the final DC alignment, beam offsets, and CVT z-offset adjustment
    - Timelines are available here



- For more details, please visit the RG-D analysis wikipage

Data Processing Summary

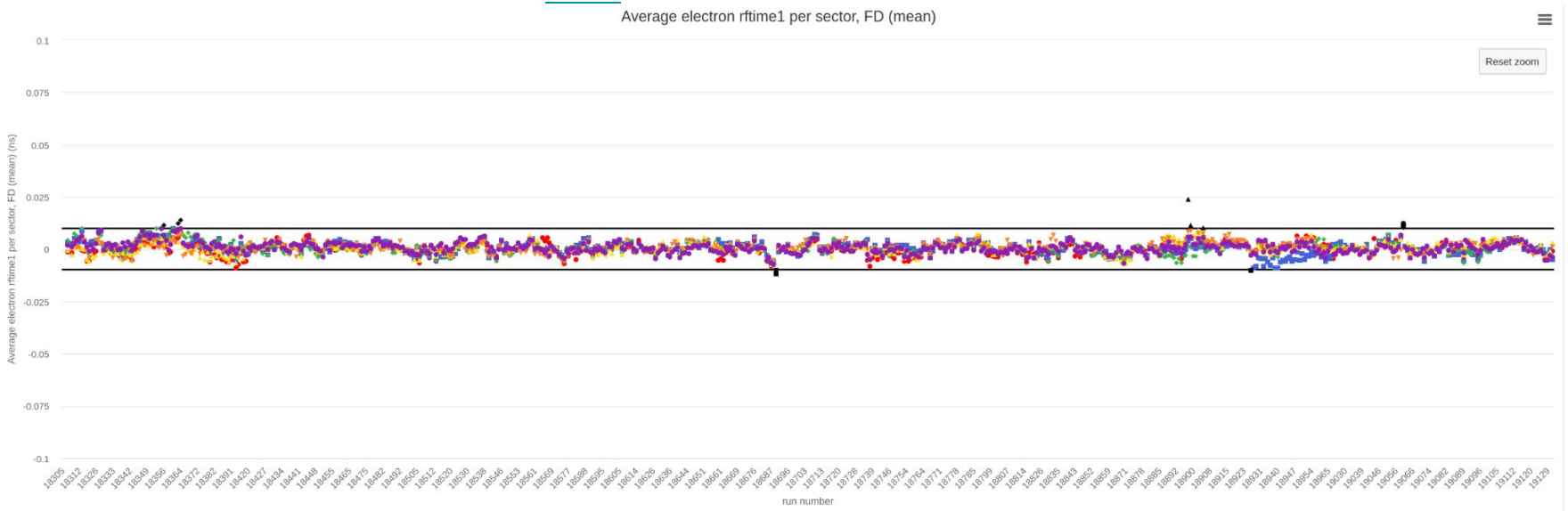
- Timelines monitoring:
  - October 14th: Pass0v5: Pass0v4 conditions + first-round of FTOF and CTOF, and partial ECal energy calibrations
    - Timelines are available here



- For more details, please visit the RG-D analysis wikipage

Data Processing Summary

- Timelines monitoring:
  - October 23th: Pass0v6: Pass0v5 conditions + first round of RF calibration
    - Timelines are available here



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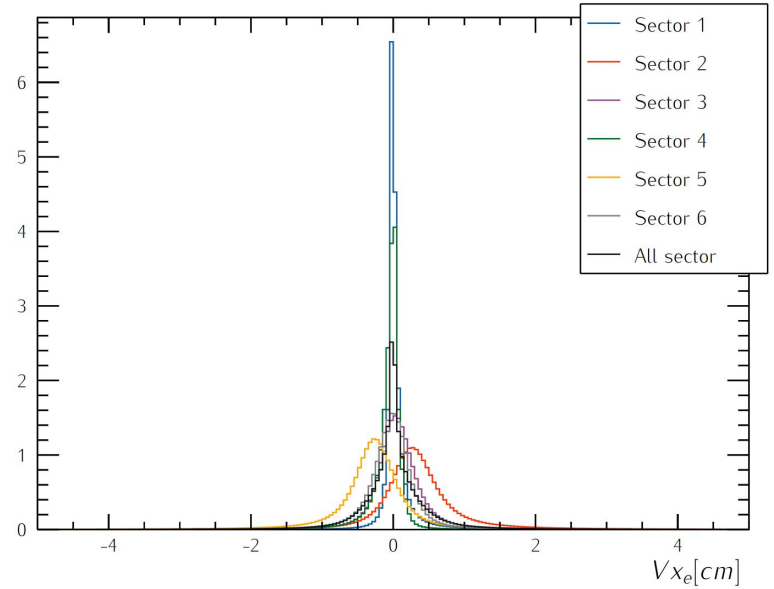
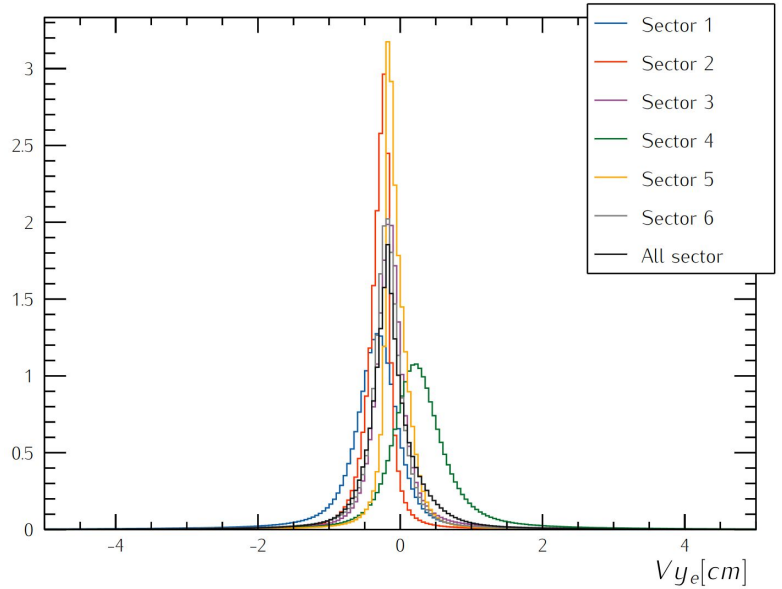
RG-D Vertex Studies

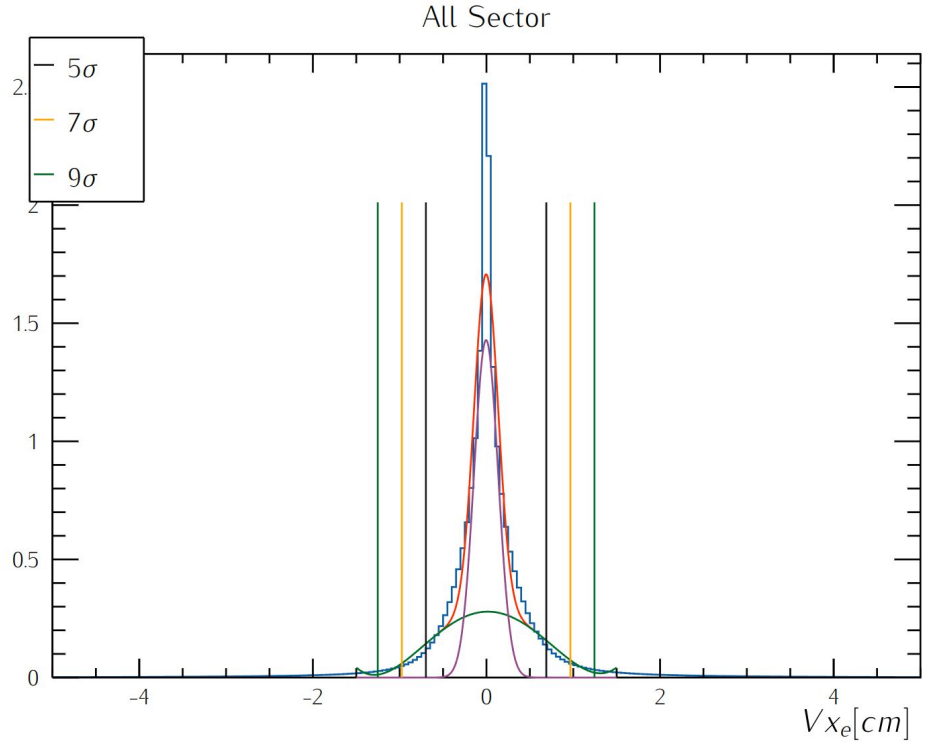
- Goal:
  - Check whether all sectors are well aligned in Vx, Vy and Vz distributions
  - Could sector-independent cuts on Vx, Vy and Vz be applied?
  - Reduce the contamination for the target configuration with two different foils, Cu and Sn

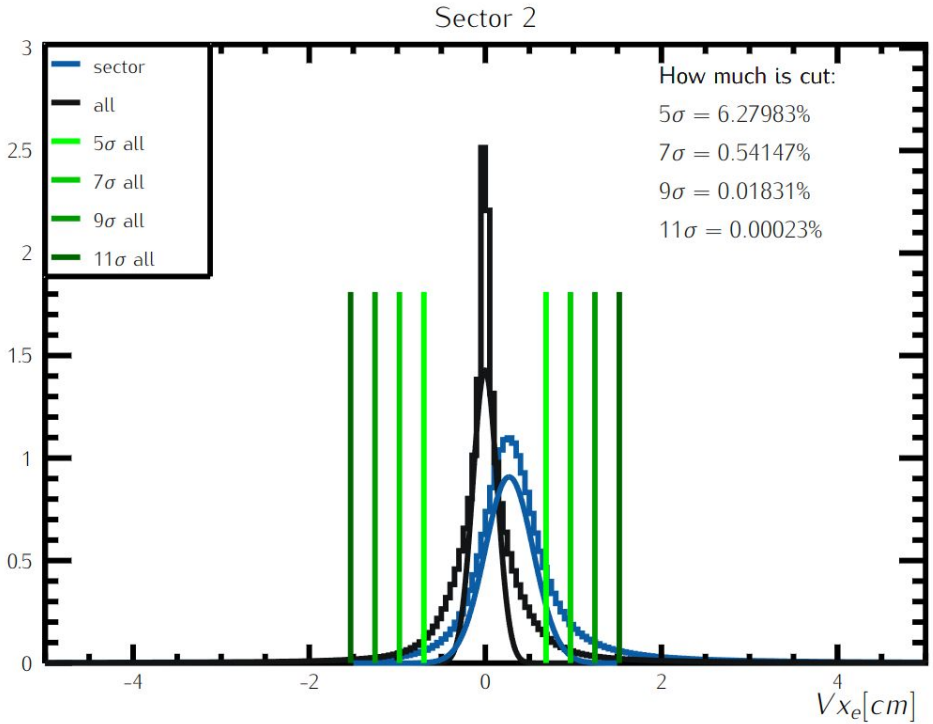




RG-D Vertex Studies: Transverse Components

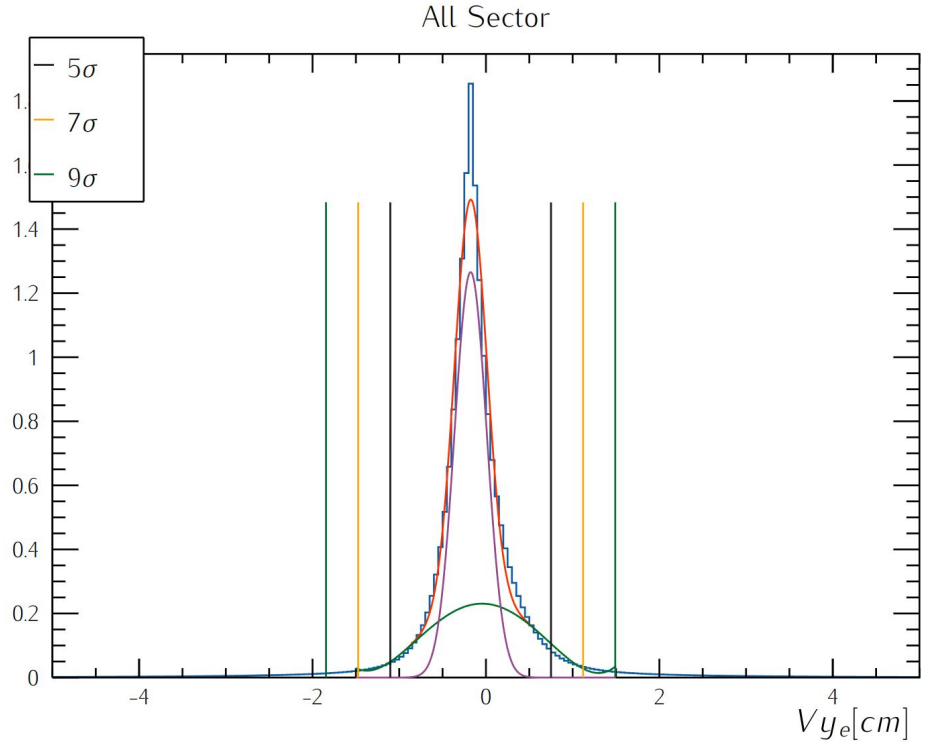
- Get rid of sector-dependent cuts for Vx

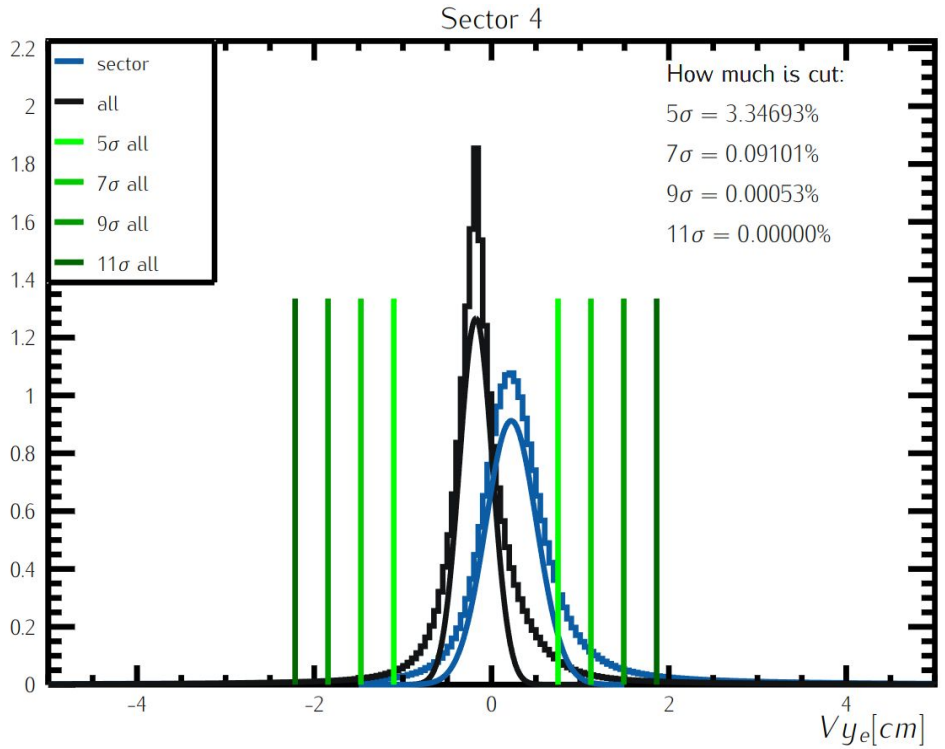




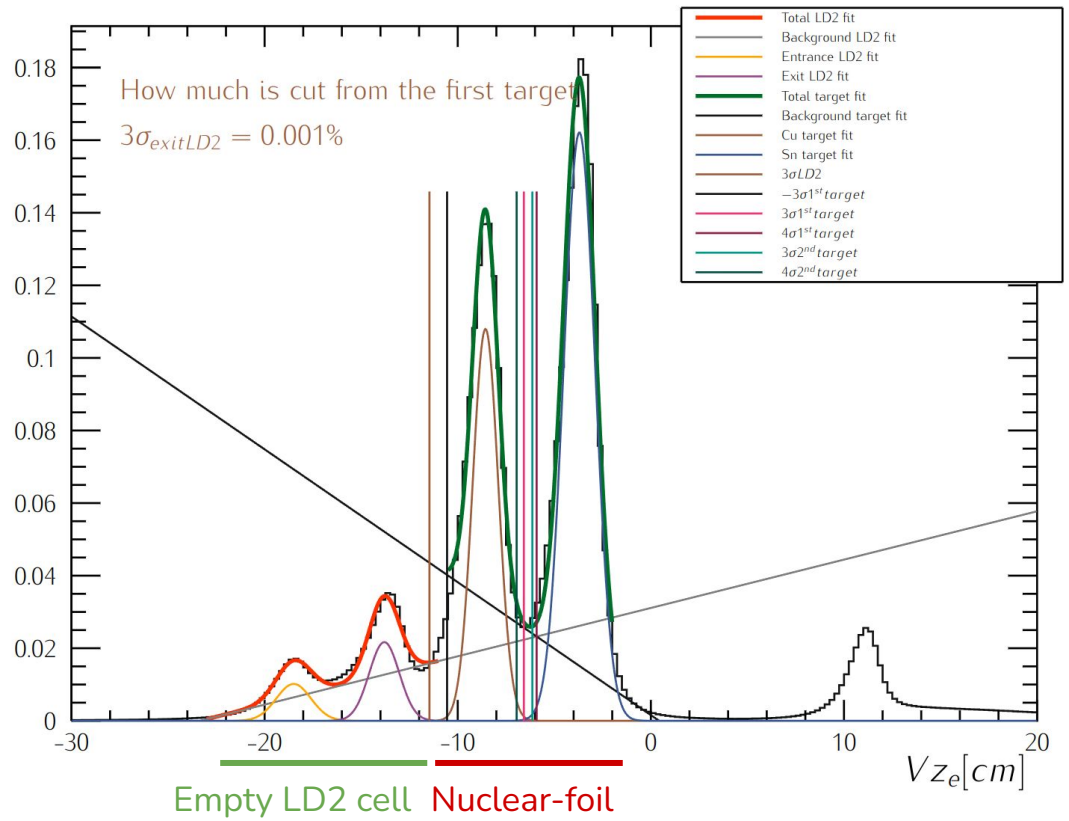
RG-D Vertex Studies: Transverse Components

- Get rid of sector-dependent cuts for Vy





RG-D Vertex Studies: z-Vertex

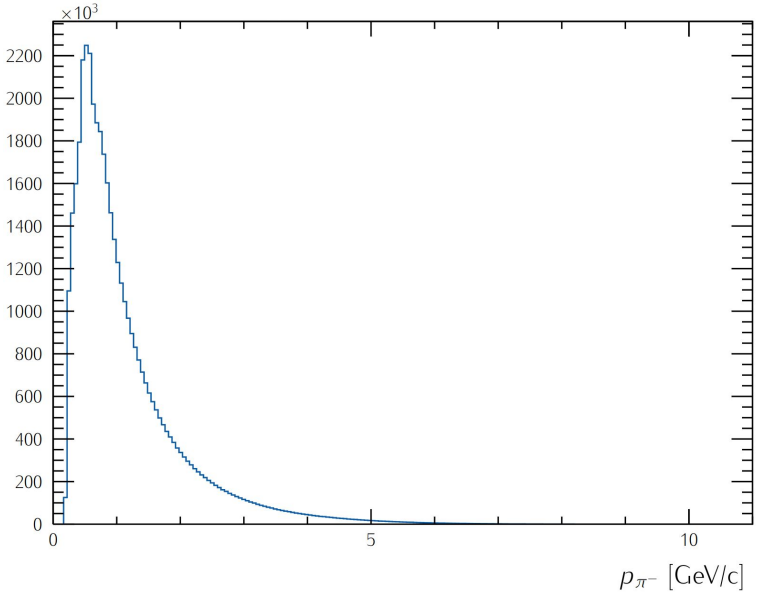


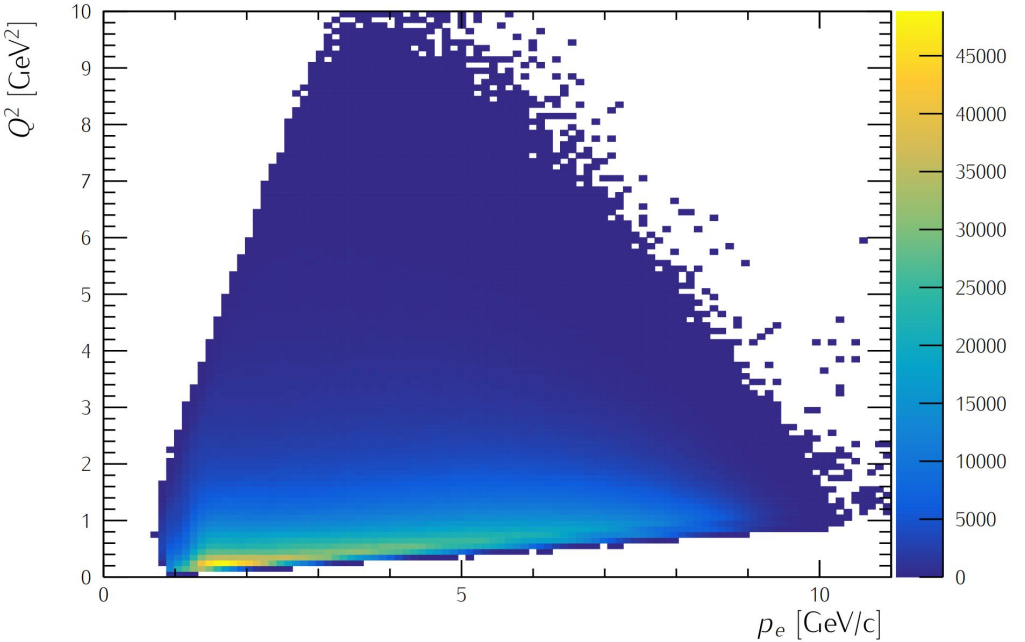
- Fits:
  - Fit the empty LD2 cell and nuclear-foil regions with double gaussians and first-order polynomial
  - Separate the two different foils, Cu and Sn from each other
  - Same study is performed for carbon
  - Similar study is underway for hadrons

Target	z-Vertex (cm)
LD2	[-20, 5]
C	[-10.784, 5]
Cu	[-11.463, -6.576]
Sn	[-6.137, 5]

RG-D Analysis Study: Particle IDentification

- Electron:
  - PID= 11
  - Status< 0
  - -5 < chi2pid < 5
- Charged pions, $\pi^{\pm}$:
  - PID (+/-) = (+/-) 211
  - -10 < chi2pid < 10

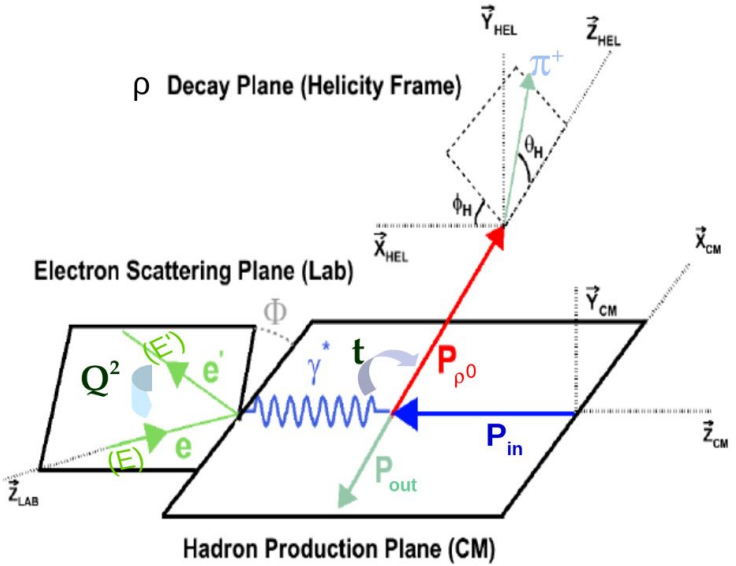




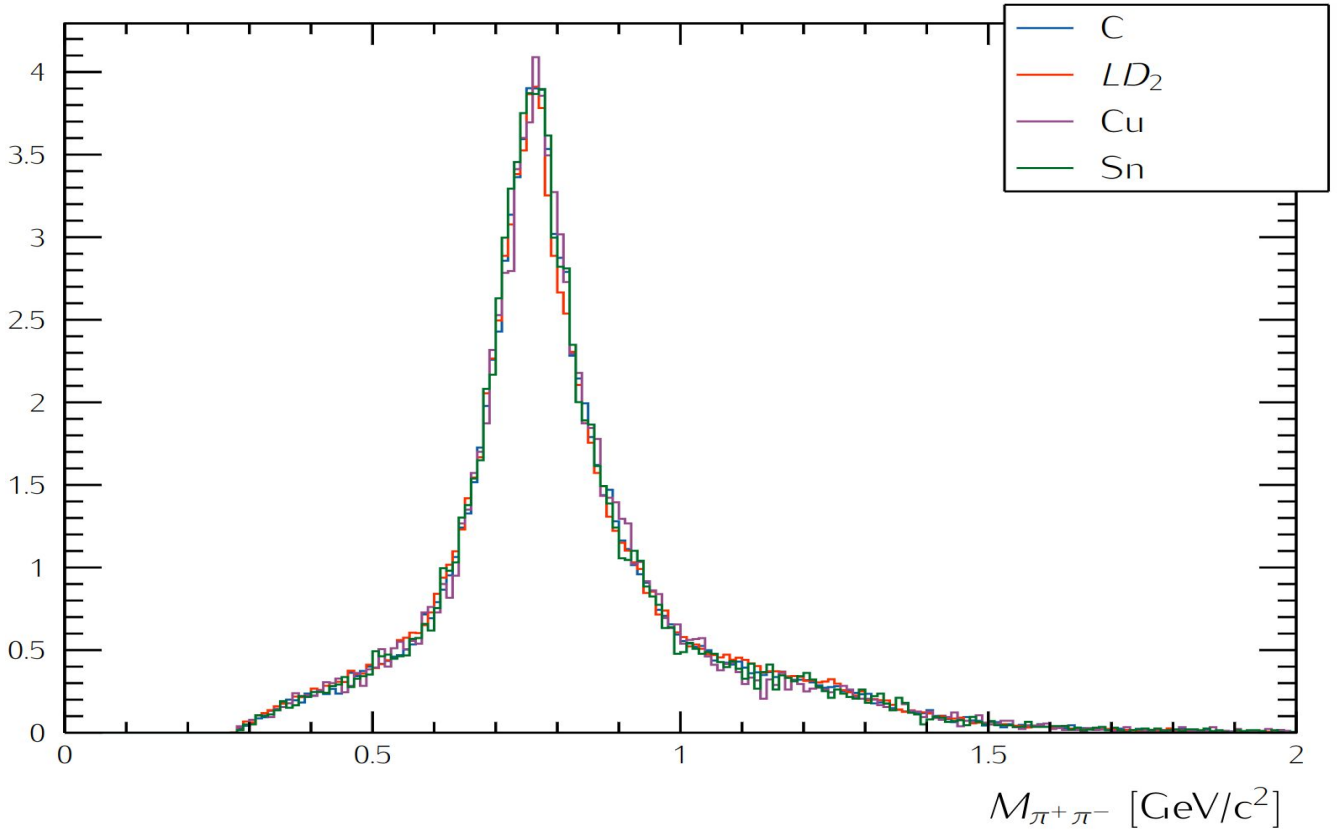
RG-D CT Study: Kinematical Cuts

- $\nu = E - E'$: virtual photon(γ^*) energy in the Lab frame,
- $Q^2 = -(P_e - P_{e'})^2 = 4EE'\sin^2(\theta/2)$: photon virtuality,
- $t = (P_{\gamma^*} - P_\gamma)^2$: 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).

- Kinematical cuts:
  - $W > 2$ GeV ↦ avoid resonance region
  - $z_h = E_h/\nu > 0.9$ ↦ select elastic channel
  - $-t > 0.1$ GeV^2 ↦ exclude coherent production
  - $-t < 0.5$ GeV^2 ↦ select diffractive process

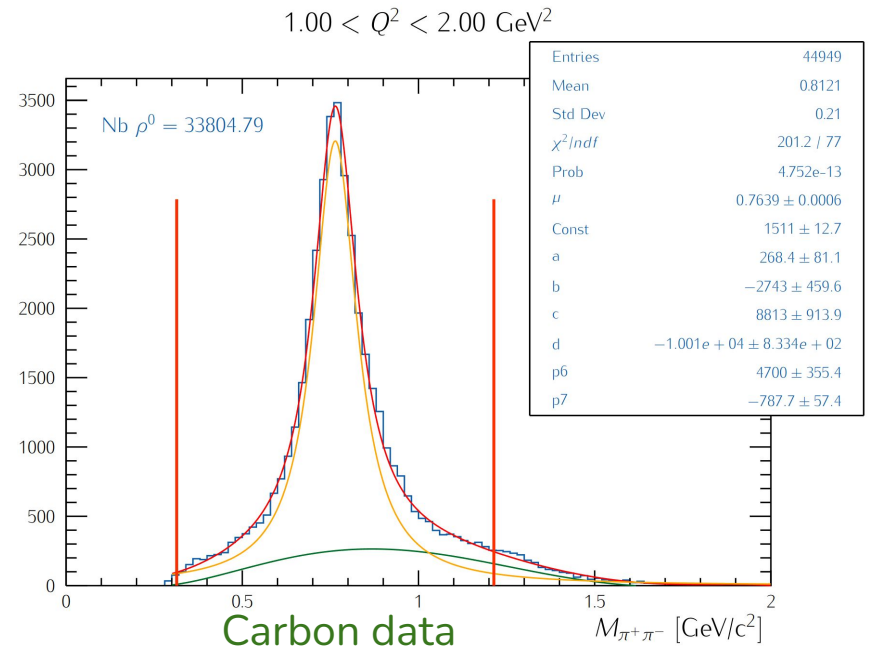


CT Study: Two-pion Invariant Mass

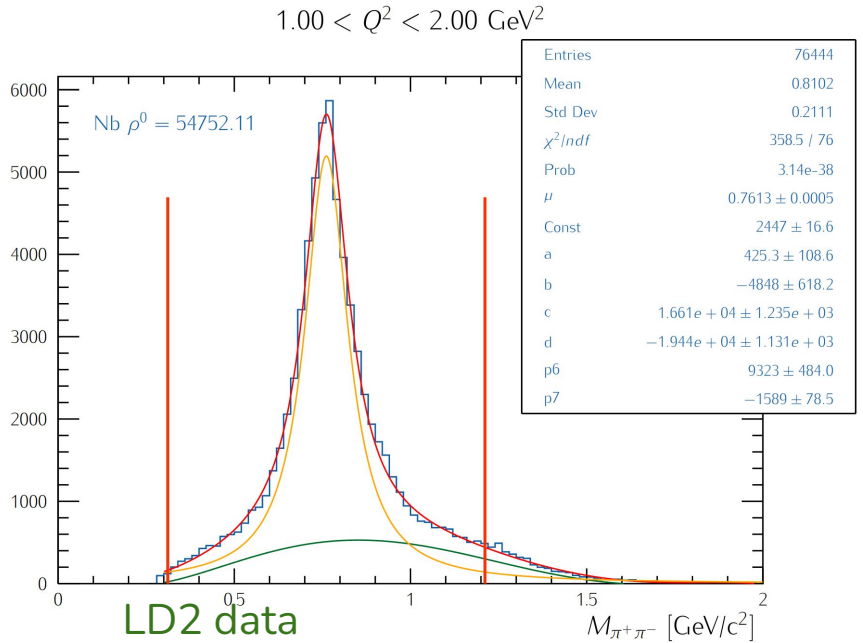


CT Study: Two-pion Invariant Mass

- Fit the invariant mass shapes for the two-oppositely charged pions with a Breit-Wigner and three-order polynomial function (*the latter will be replaced with the simulated background shape*)
- Extract ρ^0 yield by integrating the background-subtracted BW within a 3σ range



Carbon data



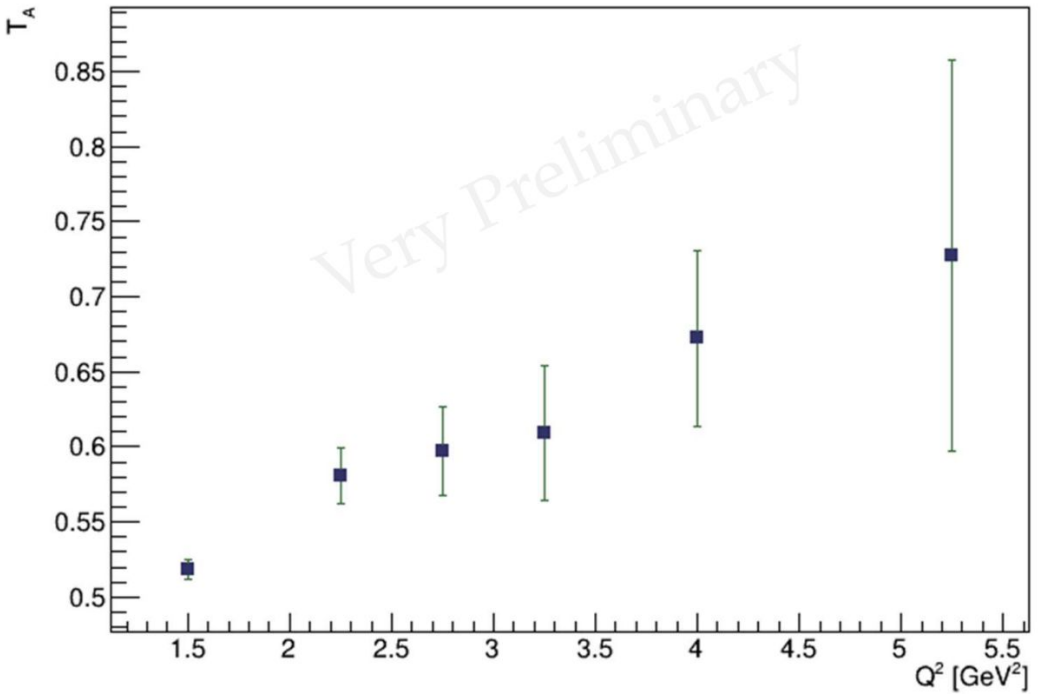
LD2 data

RG-D Color Transparency Study

- Extract the nuclear transparency:

$$T_A = \frac{N^C_{\rho^0}}{N^{LD2}_{\rho^0}} \frac{r_{LD2}\rho_{LD2}}{r_C\rho_C}$$

- r_{LD2}= 5 cm: LD2 thickness
- r_{CxC} = 0.4 cm: is CxC thickness
- ρ_{LD2}= 0.164 g/cm^3: LD2 density
- ρ_C= 2.2g/cm^3 : carbon density

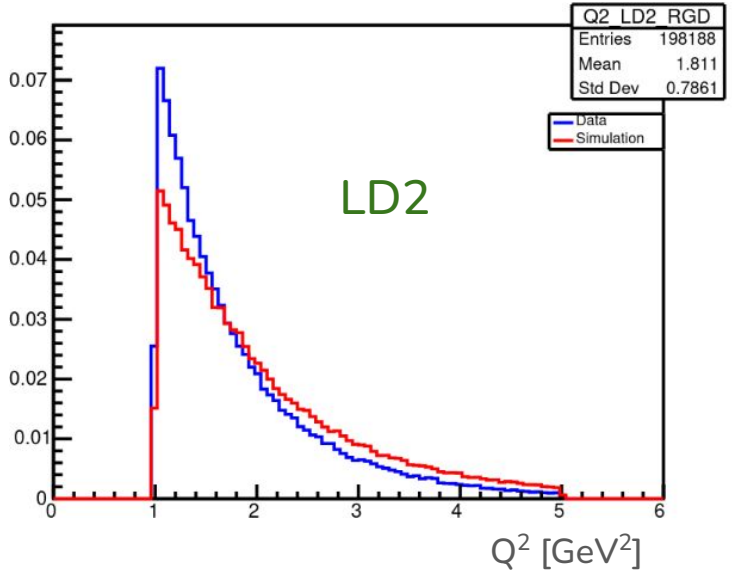


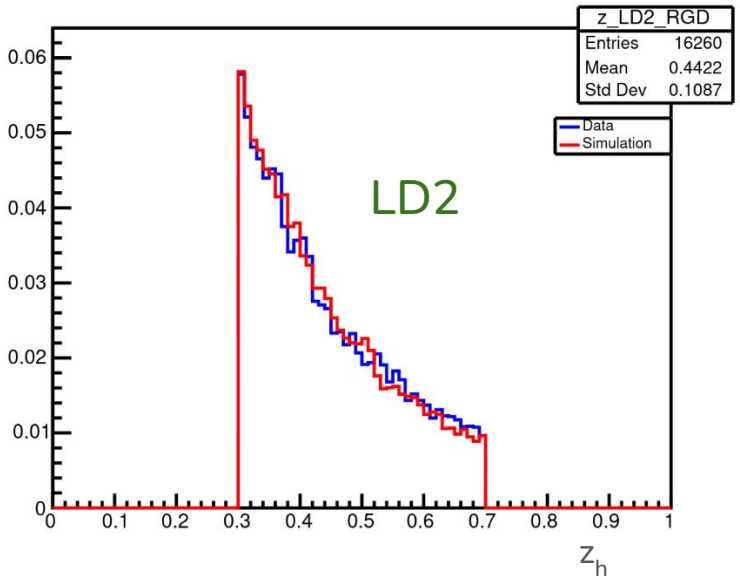
Ongoing analysis by M. Maynes

RG-D nTMDs Studies: Positively-charged Pion

- Ongoing simulation efforts: preliminary results
  - Simulations are produced using modified version of Pythia
  - Comparing experimental data to simulation

Analysis by D. Matamoros



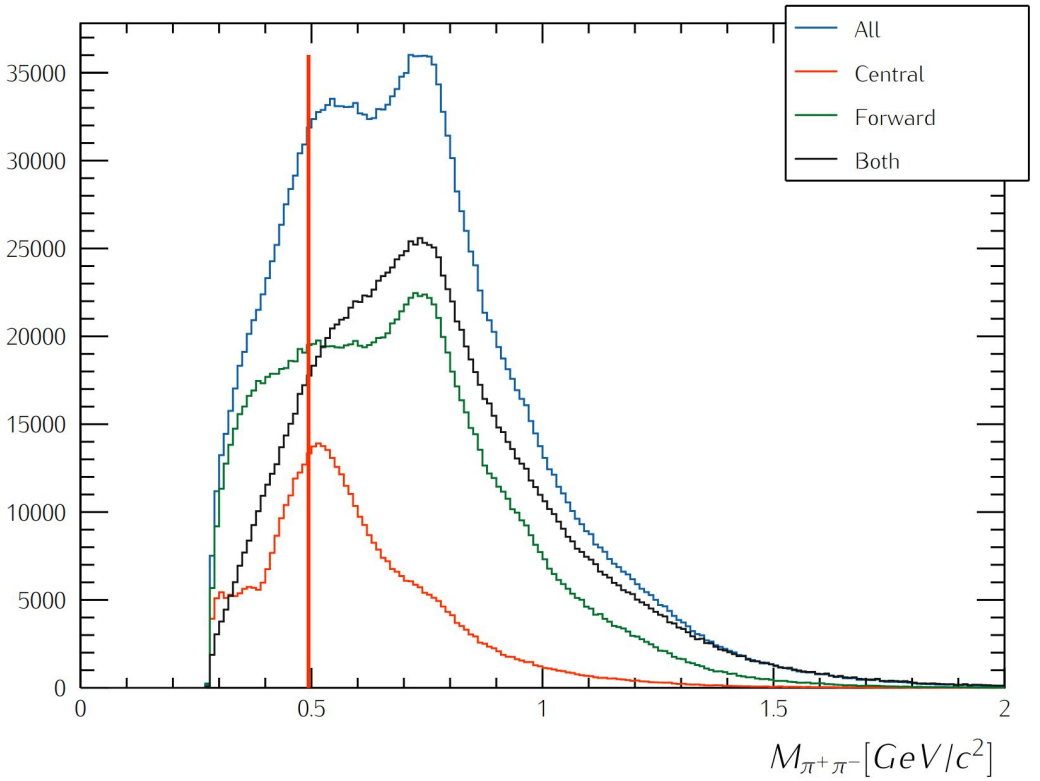


- Parallel nTMDs analysis for charged pions by S. Shrestha

RG-D nTMDs Studies: K-short Channel

- First look at the K^0 channel to extract multiplicity ratios and azimuthal asymmetries:
  - In-progress studies to improve the two-pion invariant mass reconstruction in the mass region of interest

- Kinematical cuts:
  - W> 2 GeV
  - Q^2>1 GeV^2
  - z_h< 0.7
  - |ΔVz| < 3 cm



by M. Ouillon

Summary and Outlook

- Calibration is progressing as planned within the three-month timeframe:
  - RF, LTCC, and RICH calibrations are completed
  - DC and HTCC calibrations are underway
  - FTOF, CTOF, ECal, and CND are almost done depending on the to-be-produced timelines
  - New AI network will be trained after finalizing the DC calibration
- Developing analysis tools for CT and nTMDs studies to
  - improve vertex cuts and corrections, if needed, due to any observed angular dependencies
  - implement fiducial cuts
  - perform background merging
  - use the ρ^0 event generator for its two-pion invariant mass background subtraction
  - extract the CT signal for Cu and Sn in addition to C
  - improve the K^0 identification method and extract its preliminary asymmetry results
  - obtain the preliminary asymmetry results for charged pions nTMDs studies

Backup

CT Study: Two-pion Invariant Mass

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

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