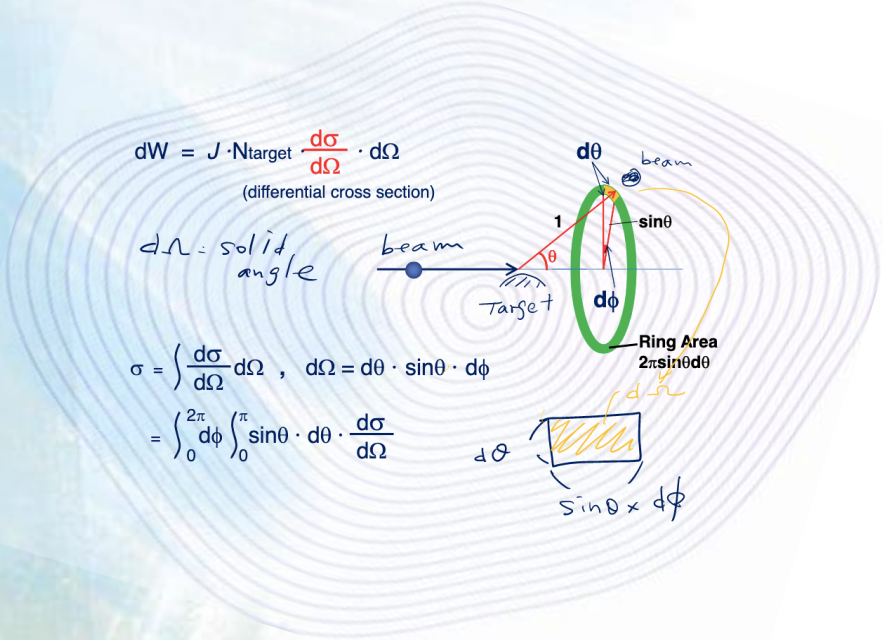
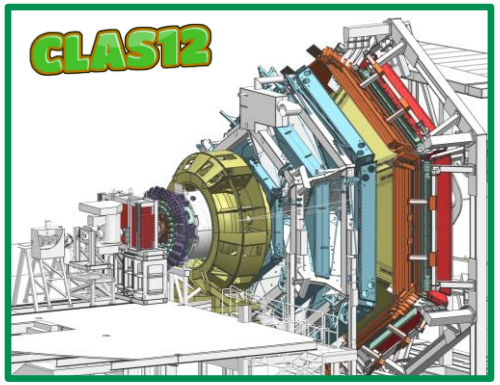
RG-K Spr24 Dataset
Extraction of KY Differential Cross Sections And Separated Structure Functions



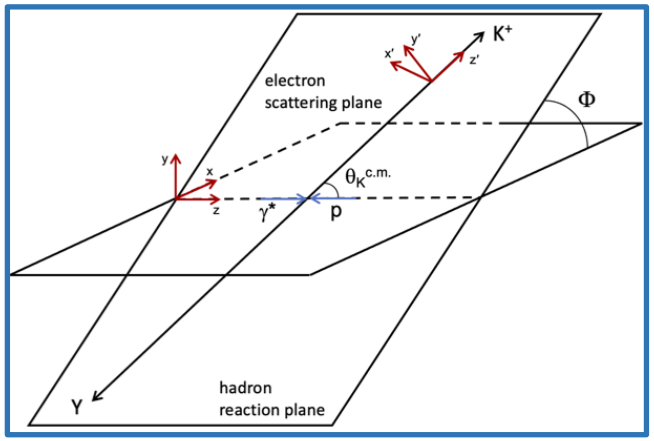


Outline:

- Introduction and overview
- Analysis approach
- Work in progress:
  - Energy loss corrections
  - Momentum corrections
  - ECAL sampling fraction cuts
  - DC fiducial cuts
- Monte Carlo update
- Summary and next steps

Physics Goals and Deliverables

1. Measure exclusive K^+Y ($Y=\Lambda,\Sigma^0$) electroproduction from unpolarized hydrogen target with longitudinally polarized beam
2. Extract differential cross sections and separated structure functions $\sigma_i(Q^2,W,\cos\theta_K^{c.m.})$
3. Provide new data far surpassing available world data from CLAS
   - P. Ambrozewicz et al. (CLAS Collaboration), PRC 75, 045203 (2007) [e1c]
   - D.S. Carman et al. (CLAS Collaboration), PRC 87, 025204 (2013) [e1f]
4. Study higher-lying N* states:
   - confirm signals of new baryon states seen in $\gamma p \rightarrow KY$
   - explore full regime of "missing" quark model states
5. Understand active d.o.f. that account for N* structure vs. Q^2 (or distance scale):
   - explore dynamical structure of N* states – evolution of meson-baryon cloud to quark degrees of freedom
   - search for predicted qqqg hybrid baryons
   - Insight into emergence of hadron mass



$$\frac{d\sigma}{d\Omega_K^{c.m.}} = \sigma_T + \epsilon\sigma_L + \sqrt{\epsilon(1+\epsilon)}\sigma_{LT}\cos\Phi + \epsilon\sigma_{TT}\cos 2\Phi + h\sqrt{\epsilon(1-\epsilon)}\sigma_{LT'}\sin\Phi$$

Datasets for KY Electroproduction – CLAS12

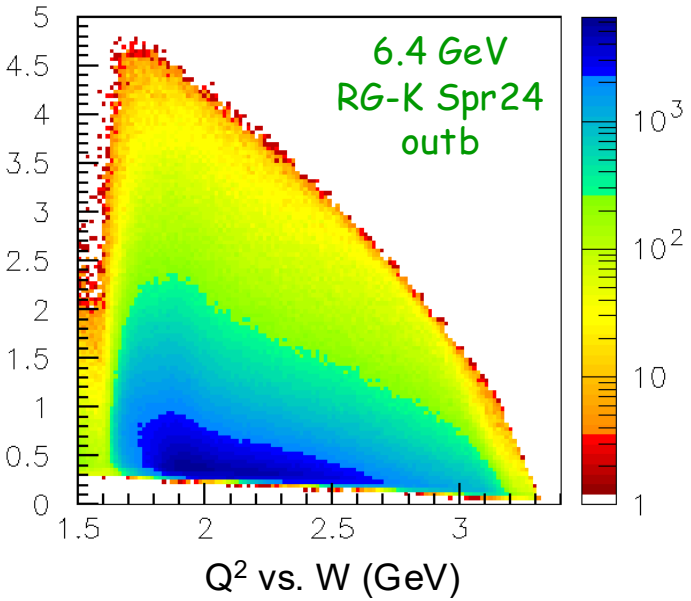
#	Run	E_b (GeV)	Trig. (M)
1	RG-A Spr18	10.6	56.0G
2	RG-A F18	10.6	23.7G
3	RG-A Spr19	10.2	12.6G
4	RG-K Win18	6.535	7.8G
5		7.546	7.8G
6	RG-K Spr24	6.395	38.3G
7		8.478	21.7G
8	RG-K 2028	6.6	TBD
9		8.8	TBD

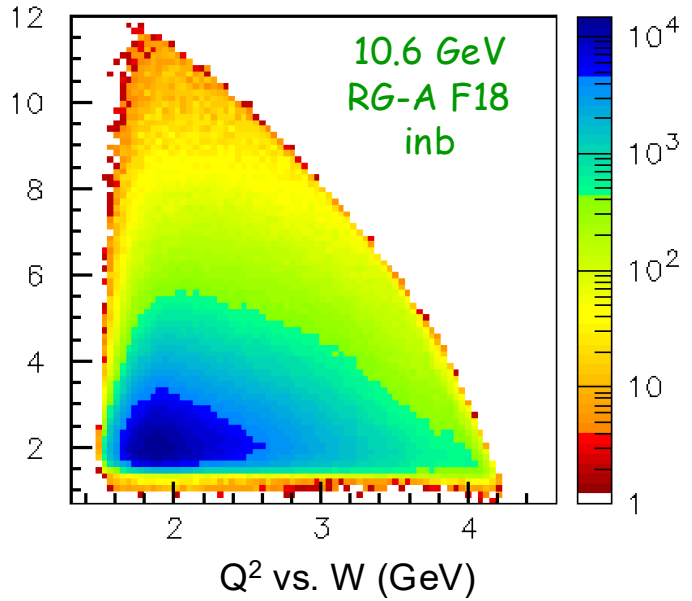


Publications:

- $K^+\Lambda$, $K^+\Sigma^0$ beam-recoil polarization transfer
  - W=1.6-2.4 GeV, Q^2=0.3 – 4.5 GeV^2
  D.S. Carman et al. (CLAS), PRC 105, 065201 (2022)
- $K^+\Lambda$, $K^+\Sigma^0$ recoil polarization
  - W=1.6-2.4 GeV, Q^2=0.3 – 4.5 GeV^2
  D.S. Carman et al. (CLAS), PRC 112, 035206 (2025)

RG-K Win18





Data Analysis

$$e + p \rightarrow e' + K^+ + \Lambda, \quad \Lambda \rightarrow p\pi^- \qquad e + p \rightarrow e' + K^+ + \Sigma^0, \quad \Sigma^0 \rightarrow \Lambda\gamma, \quad \Lambda \rightarrow p\pi^-$$

electrons

Cut	Value
Track Status	$2000 \leq$ abs(STATUS) < 4000
EB PID	11
p_e	$[1.0 : p_{beam}]$ GeV
TOF_e	[21:26] ns
v_z	$[-10:2]$ cm
ECAL S.F.	$\pm 3.5\sigma$
ECAL Fiducial Cut	7 cm edge cut on U, V, W
DC Fiducial Cuts	on

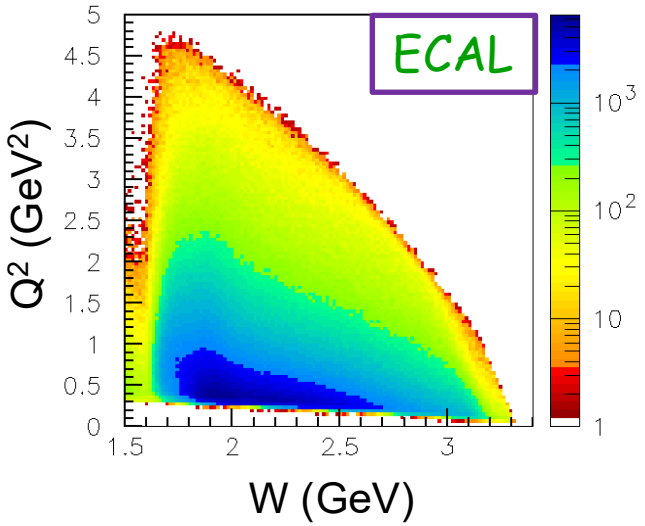
hadrons

Forward Detector

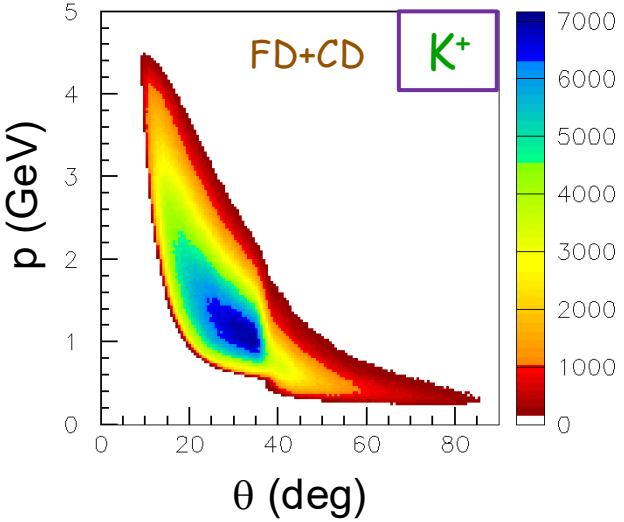
Cut	Value
Track status	$2000 \leq \lvert STATUS \rvert < 4000$
q	$\neq 0$
p_h	$[0.4 : p_{beam}]$ GeV
β_h	[0.4:1.1]
EB PID	± 211, ± 321, or ± 2212
TOF_h	[20:55] ns ($q > 0$), [20:35] ns ($q < 0$)
v_z (K^+)	$[-10:2]$ cm

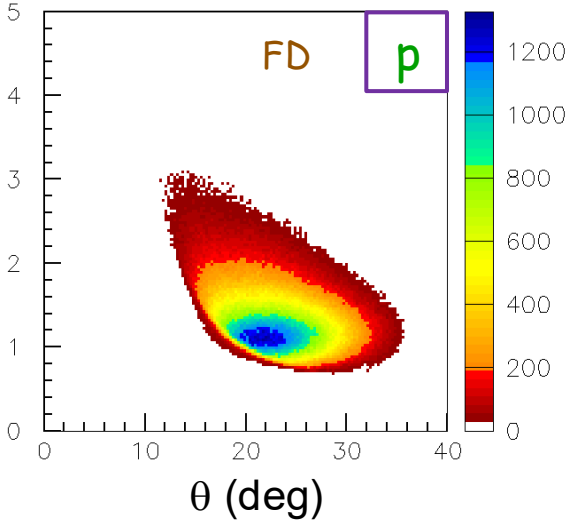
Central Detector

Cut	Value
Track status	$\lvert STATUS \rvert \geq 4000$
q	$\neq 0$
p_h	[0.2:1.5] GeV
β_h	[0.2:1.1]
EB PID	± 211, ± 321, or ± 2212
TOF_h	[0.5:4.0] ns
v_z (K^+)	$[-10:2]$ cm (K^+ candidates)



6.398 GeV

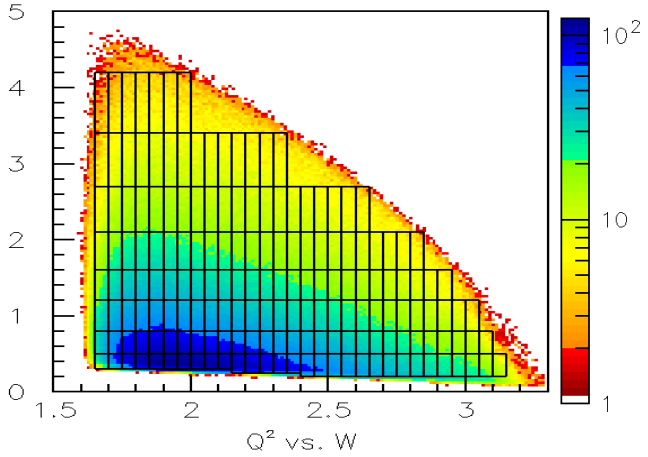


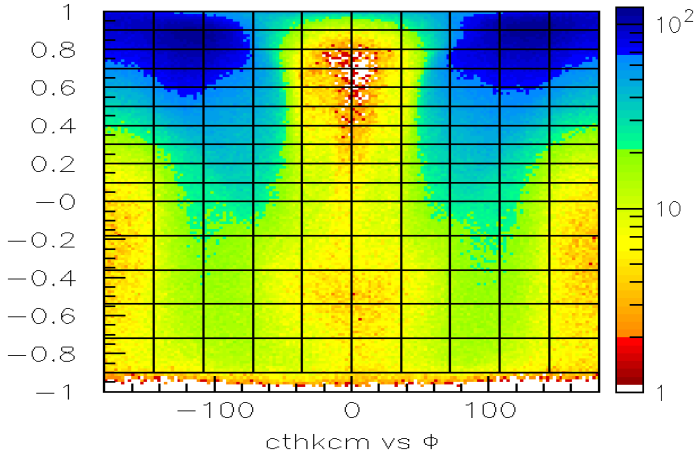


RG-K KY Binning and Yields – 6.4 GeV

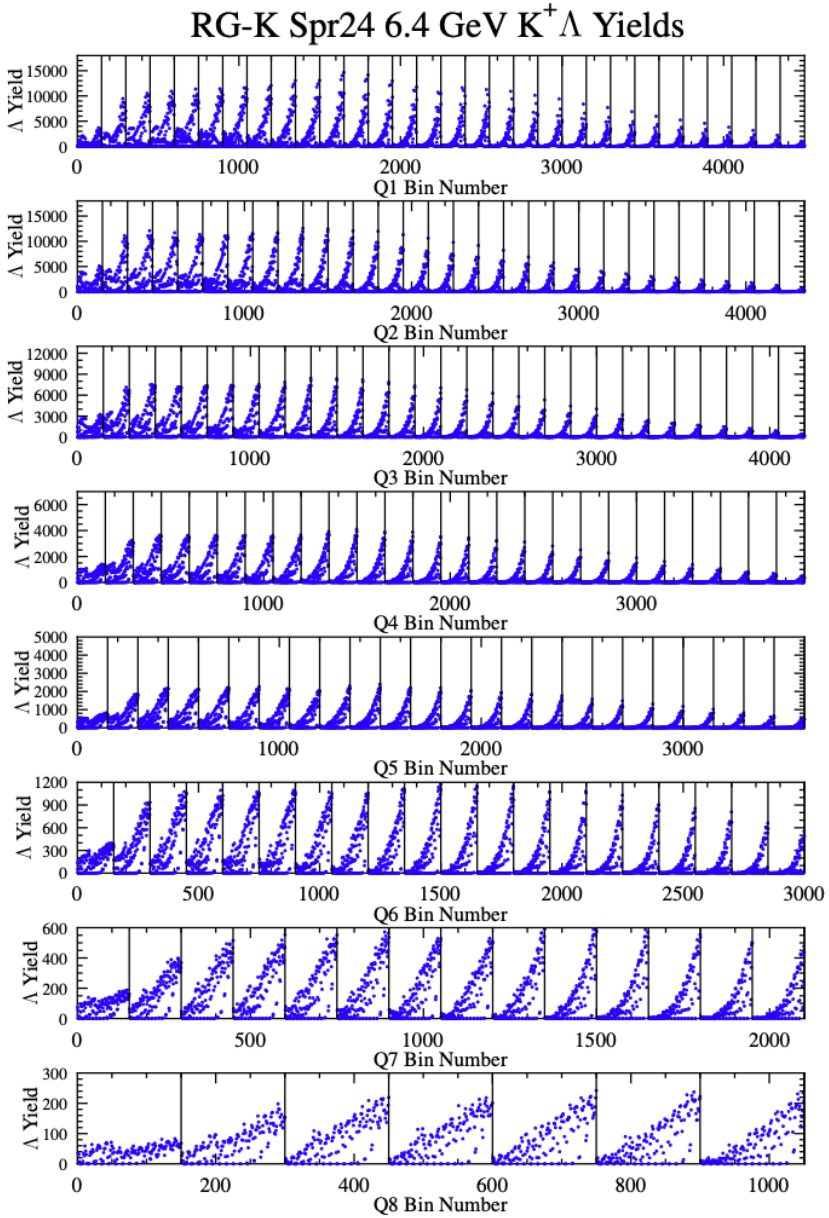
Spr24 datasets allow fine binning in the relevant kinematic variables:

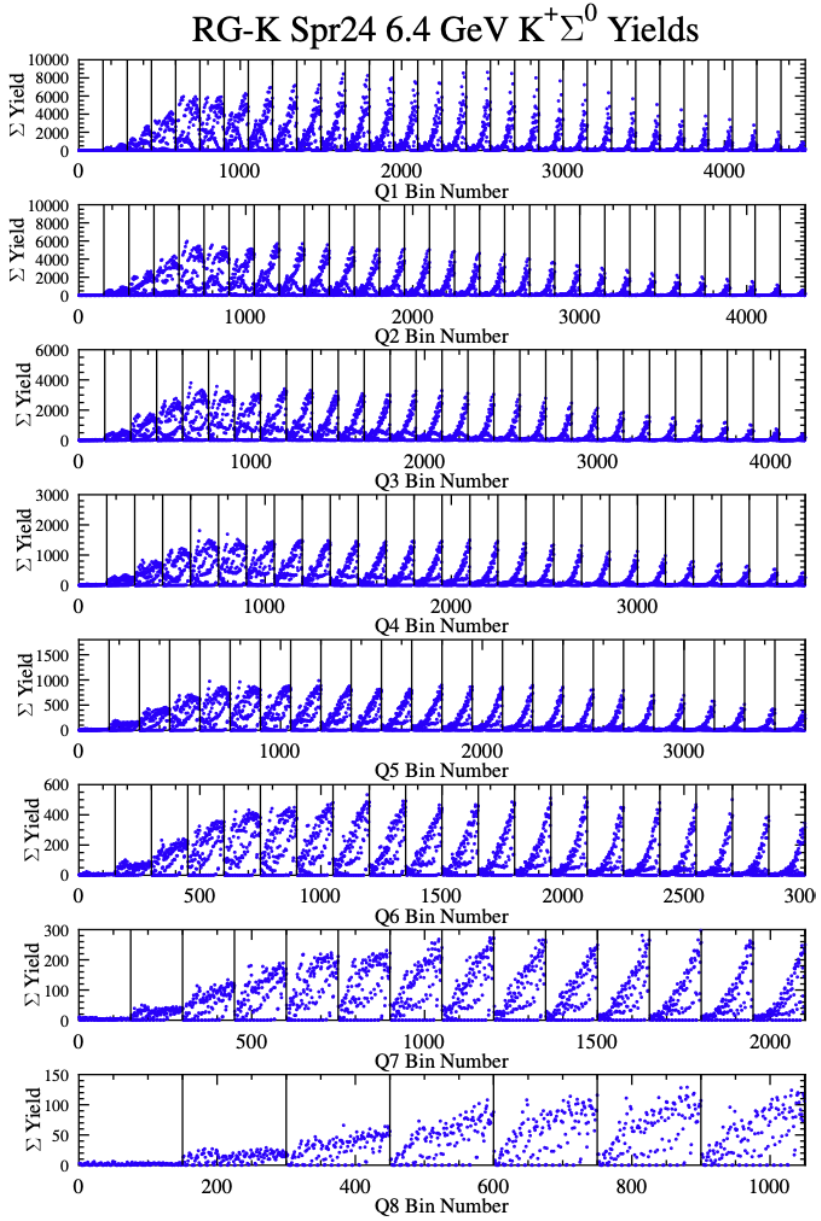
Q^2, W, cos $\theta_K^{c.m.}$, Φ





N_{bins} = 26,700 (x2 for h=±1)



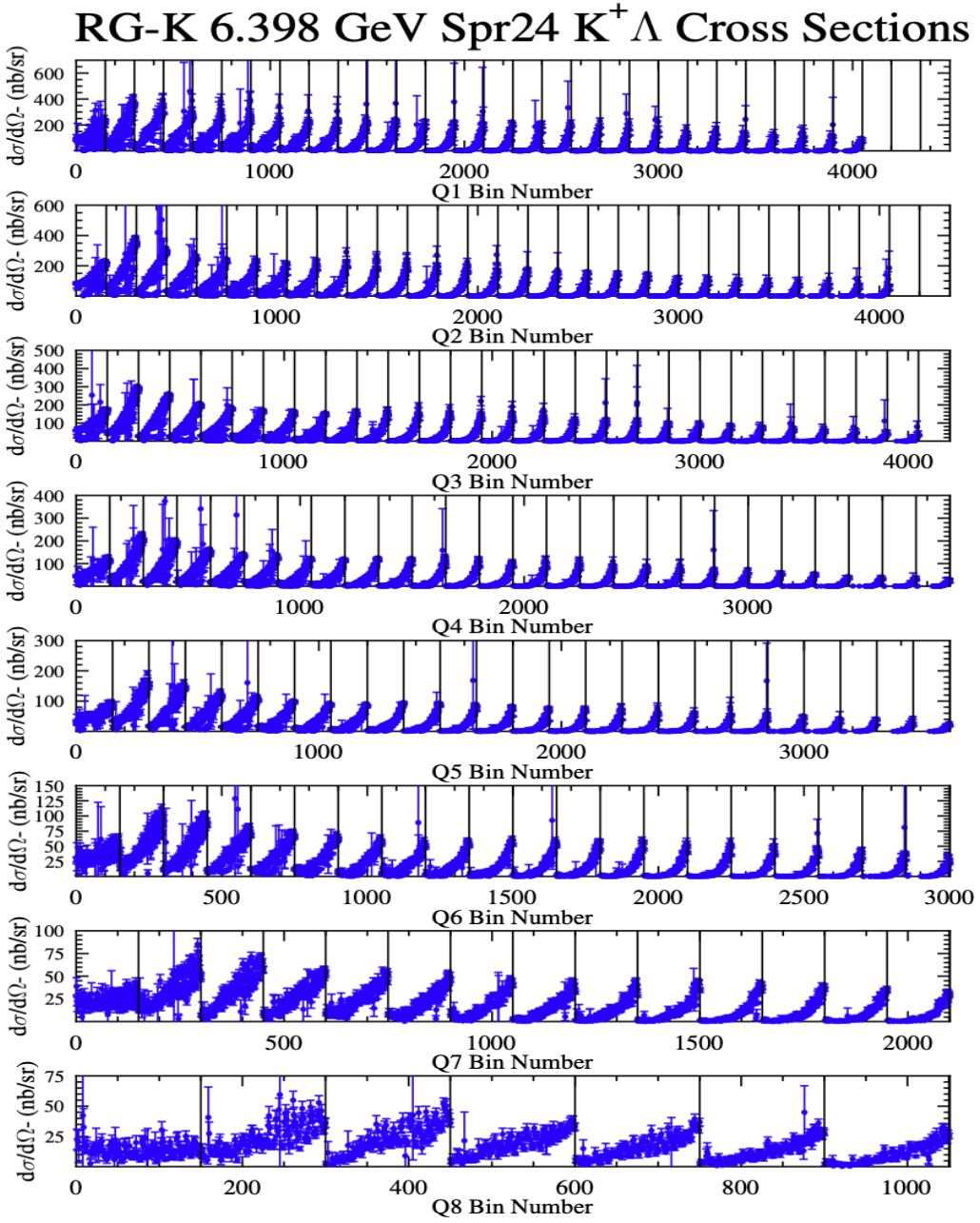


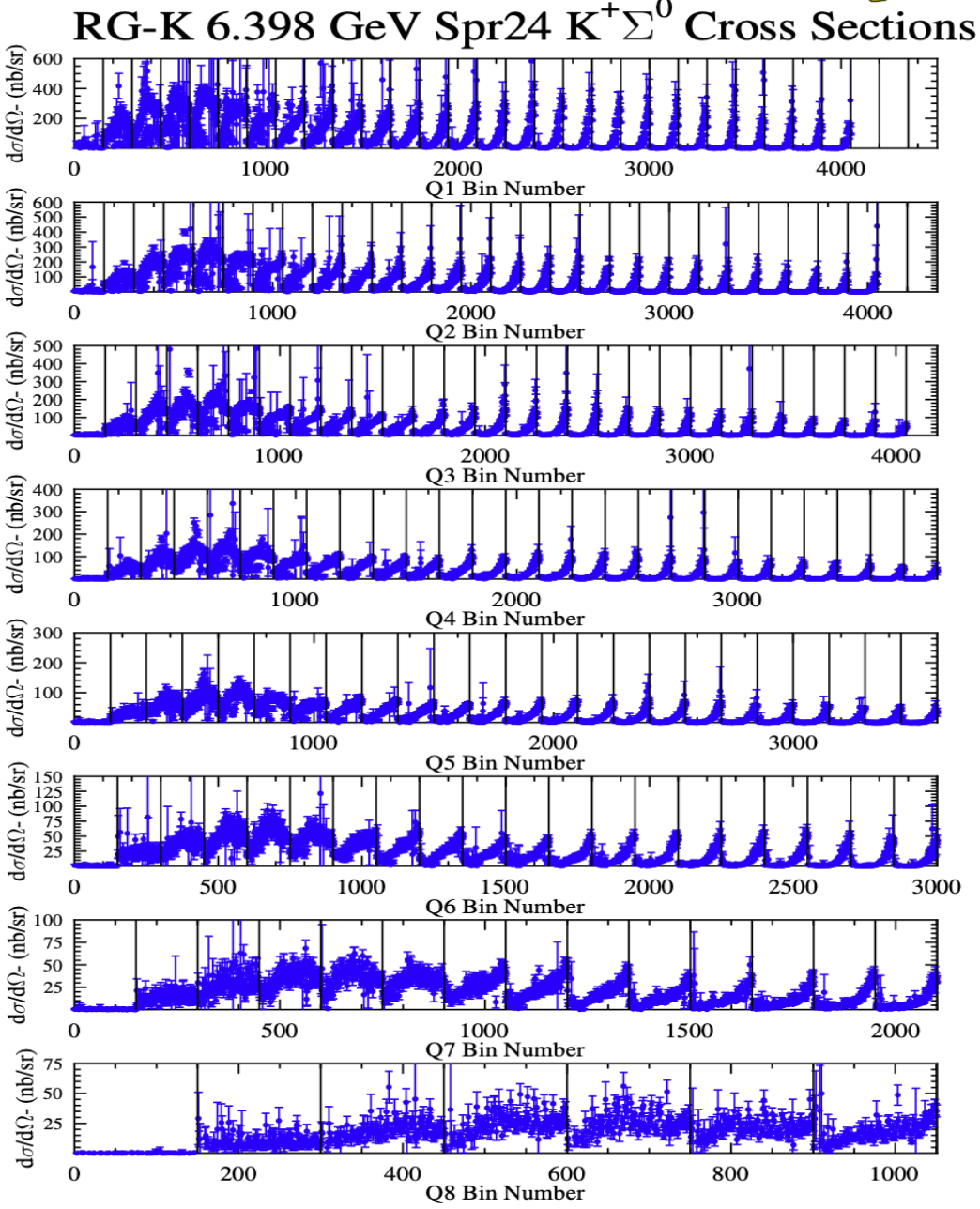
Differential Cross Section Calculation

$$\frac{d\sigma_i}{d\Omega_K^*} = \frac{1}{\Gamma_v} \cdot \frac{1}{(\Delta Q^2 \Delta W \Delta \cos\theta_K^* \Delta\Phi)} \cdot \frac{R_i \cdot N_i \cdot BC_i}{\eta_i \cdot N_0} \cdot \frac{1}{(N_A \rho t / M_w)}$$

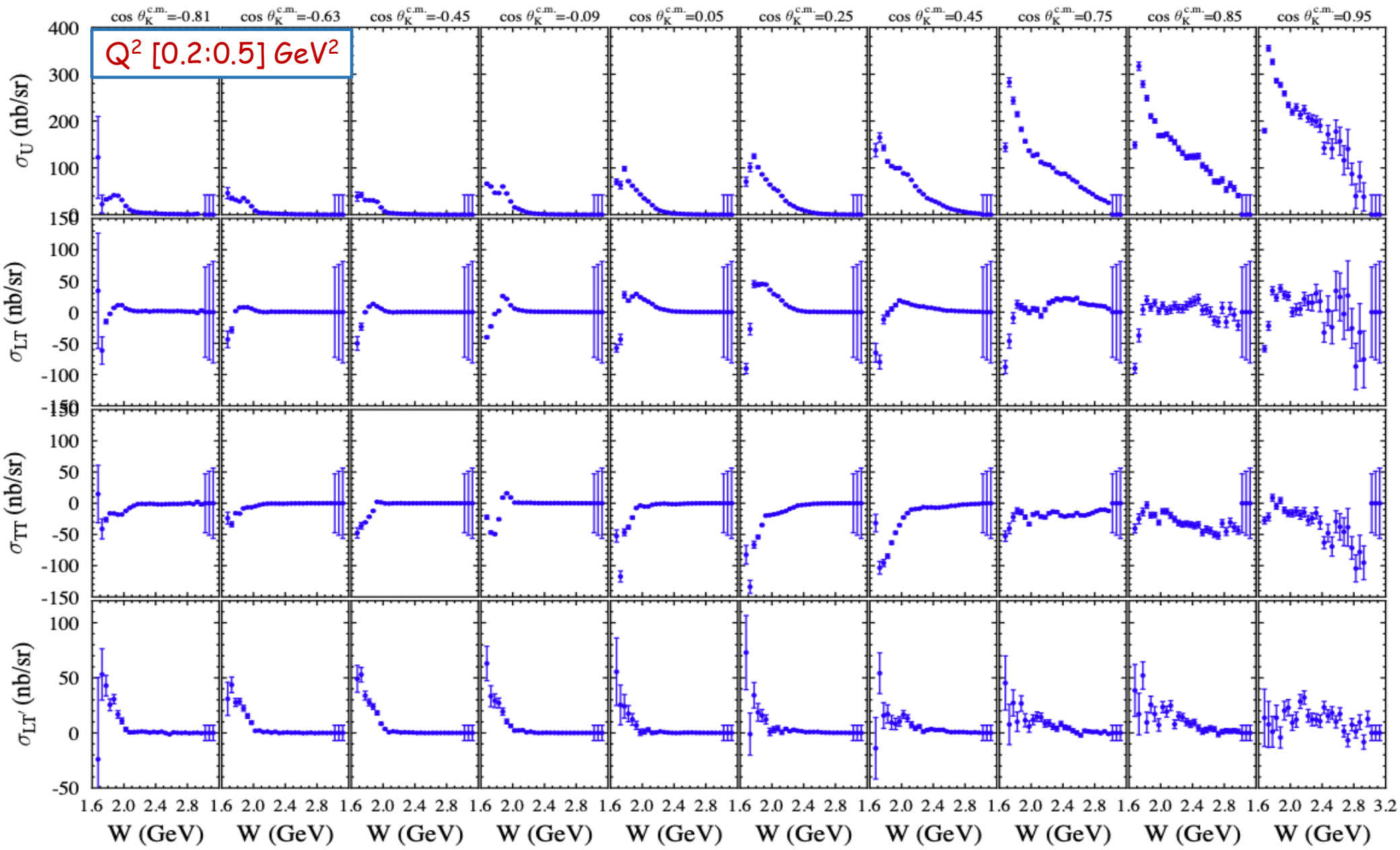
- Γ_v : virtual photon flux factor $\Gamma_v = \frac{\alpha}{4\pi} \cdot \frac{W}{ME_b^2} \cdot \frac{W^2 - M^2}{MQ^2} \cdot \frac{1}{1-\epsilon}$
- $\Delta Q^2 \Delta W \Delta \cos\theta_K^* \Delta\Phi$: kinematic bin volume
- R_i : radiative correction — Set RC =1 for now
- N_i : hyperon yield — Within MM limits
- BC_i : bin centering correction — Set to unity
- η_i : acceptance and efficiency correction — From WIN18 MC
- N_0 : incident electron flux — Q_{tot} = 90/80 mC for 6.398/8.478 GeV
- $N_A \rho t / M_w$ — N_A*0.07151 g/cm^3*5 cm/1.00794 g/mol = 1.079e23/cm^2

K^+Y Differential Cross Sections





$K^+\Lambda$ Structure Functions

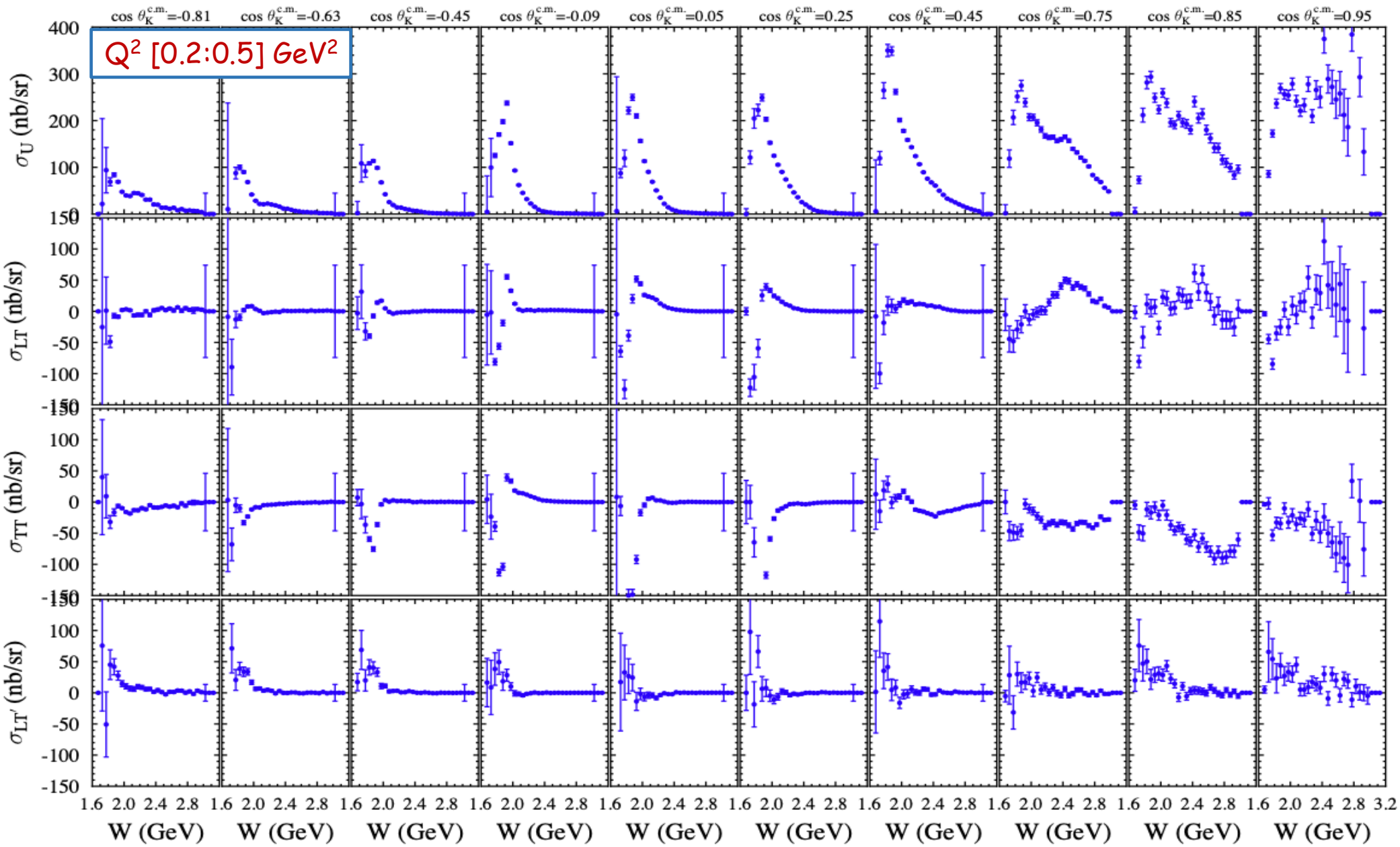


RG-K Spr24

6.4 GeV

- Precision/binning at low Q^2 comparable with CLAS γp data
- Peaks from $N^* \rightarrow KY$, interference effects, coupled-channel contributions

$K^+\Sigma^0$ Structure Functions



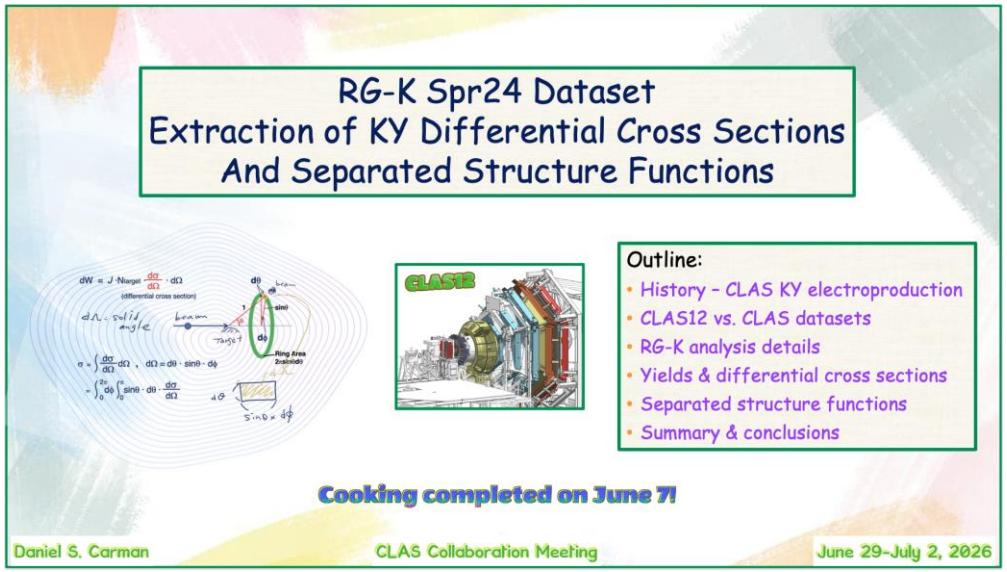
RG-K Spr24

6.4 GeV

- Precision/binning at low Q^2 comparable with CLAS γp data
- Peaks from $N^* \rightarrow KY$, interference effects, coupled-channel contributions

Work Tasks

First public presentation of RG-K KY cross section and structure function analysis at June/July CLAS Meeting



Previous presentation focused on:

- dataset quality
- "machinery" development
- promise of new RG-K data vs. world data

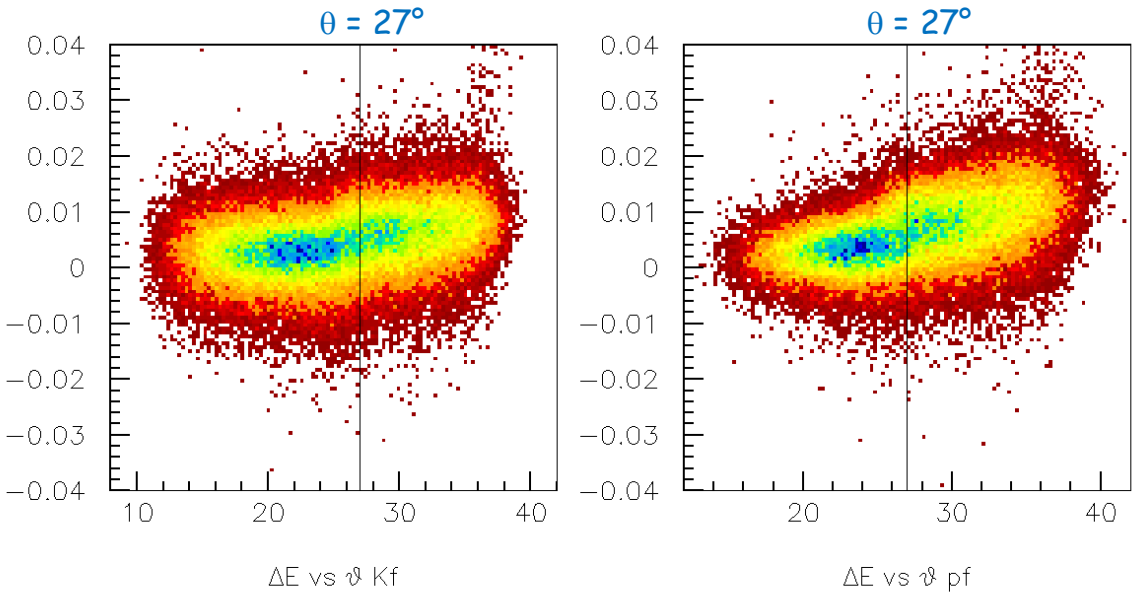
Now the detailed work is required:

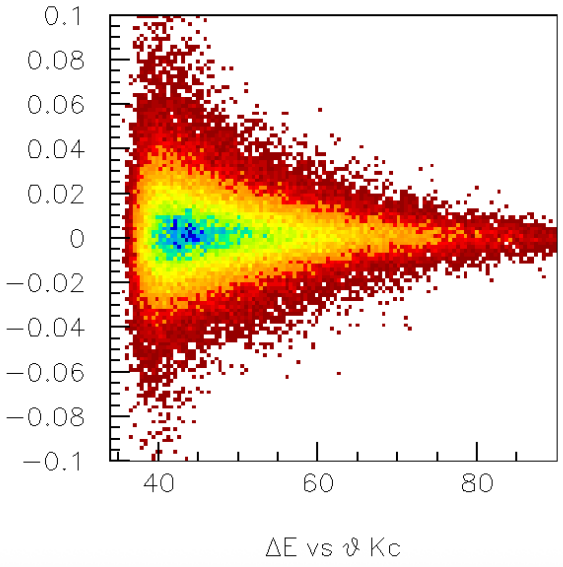
- Hadron energy loss corrections
- ECAL sampling fraction cuts
- DC fiducial cuts
- Electron and hadron momentum corrections
- Data selection
- Implementation of QADB protocols
- Event generator development
- Documentation of work

This work is the focus of today's presentation …

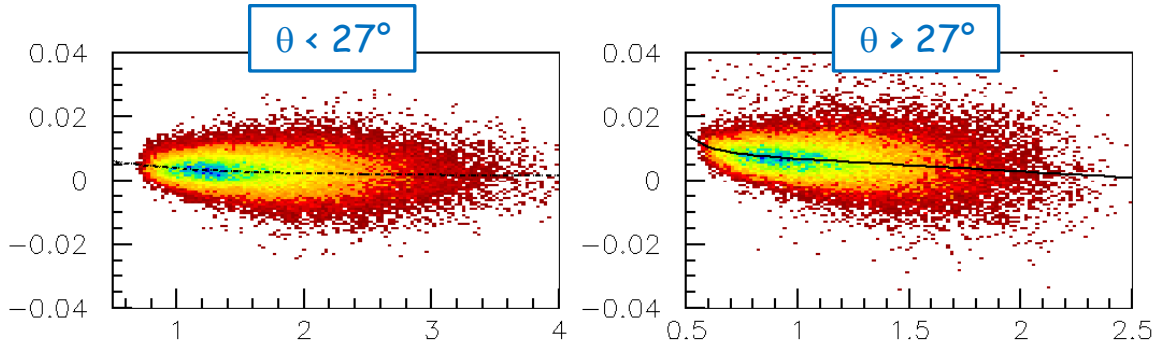
Energy Loss Corrections

$$\Delta E = A + B\exp(Cp) + Dx$$

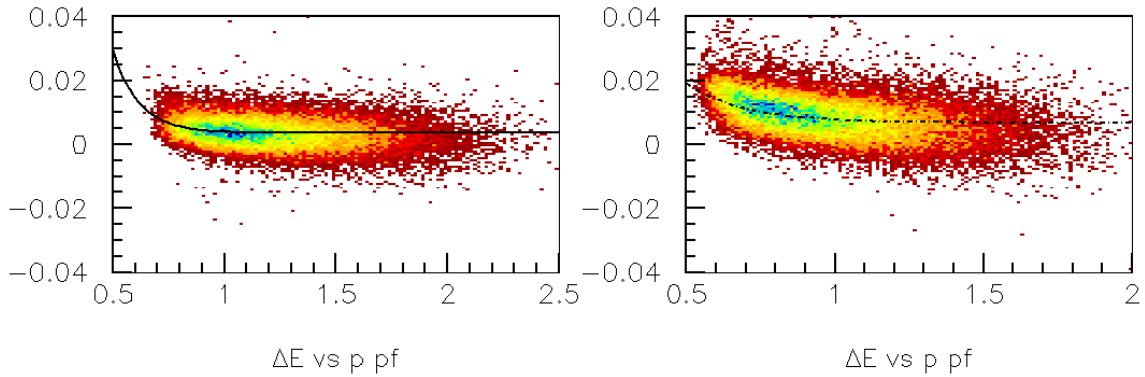


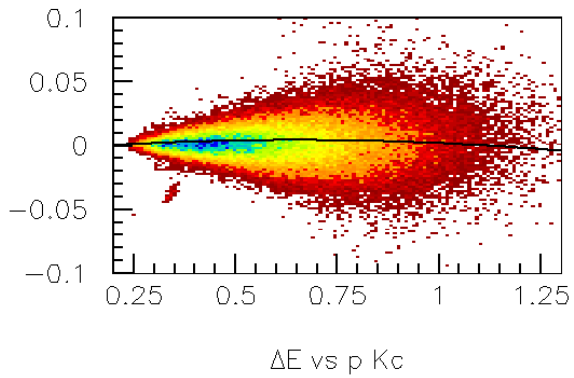


- θ = 27° separates the FD
- CD Kalman filter corrects for enery loss



FD





CD

$$\Delta E = A + Bx + Cx^2 + Dx^3$$

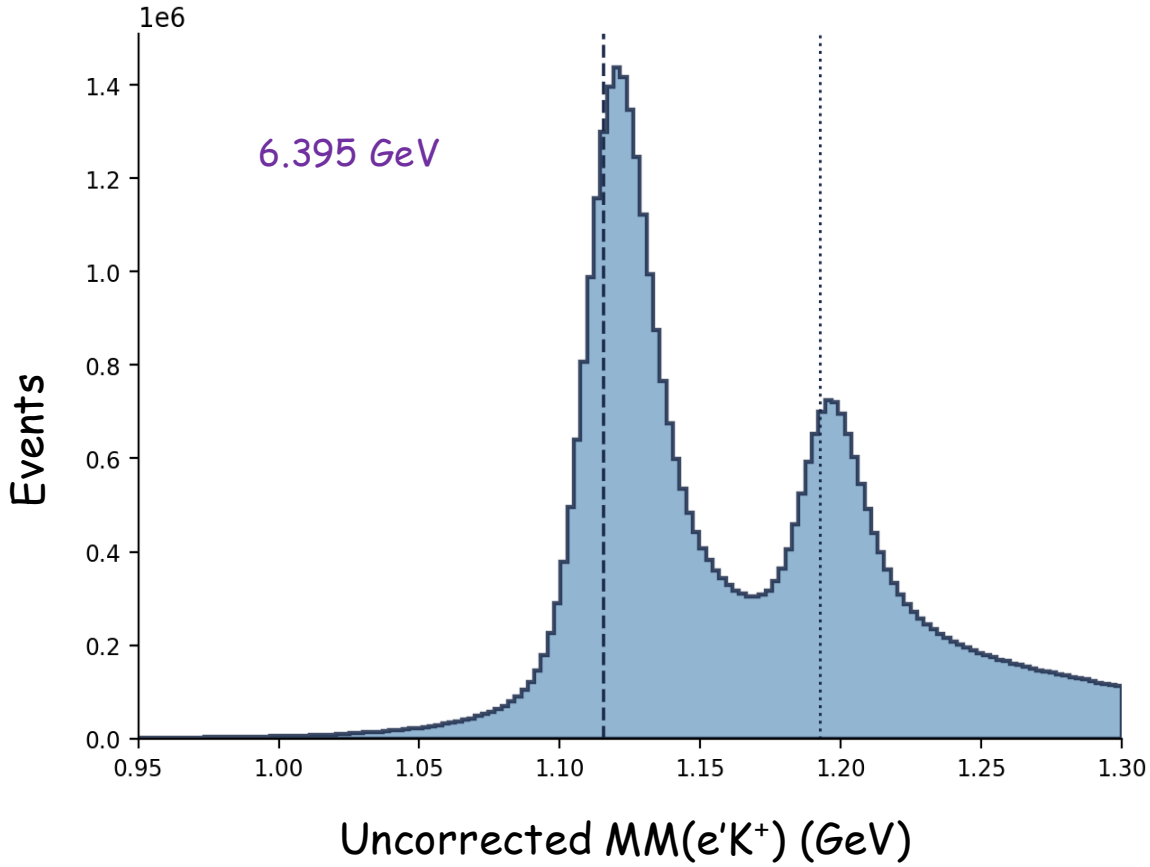
Momentum Corrections

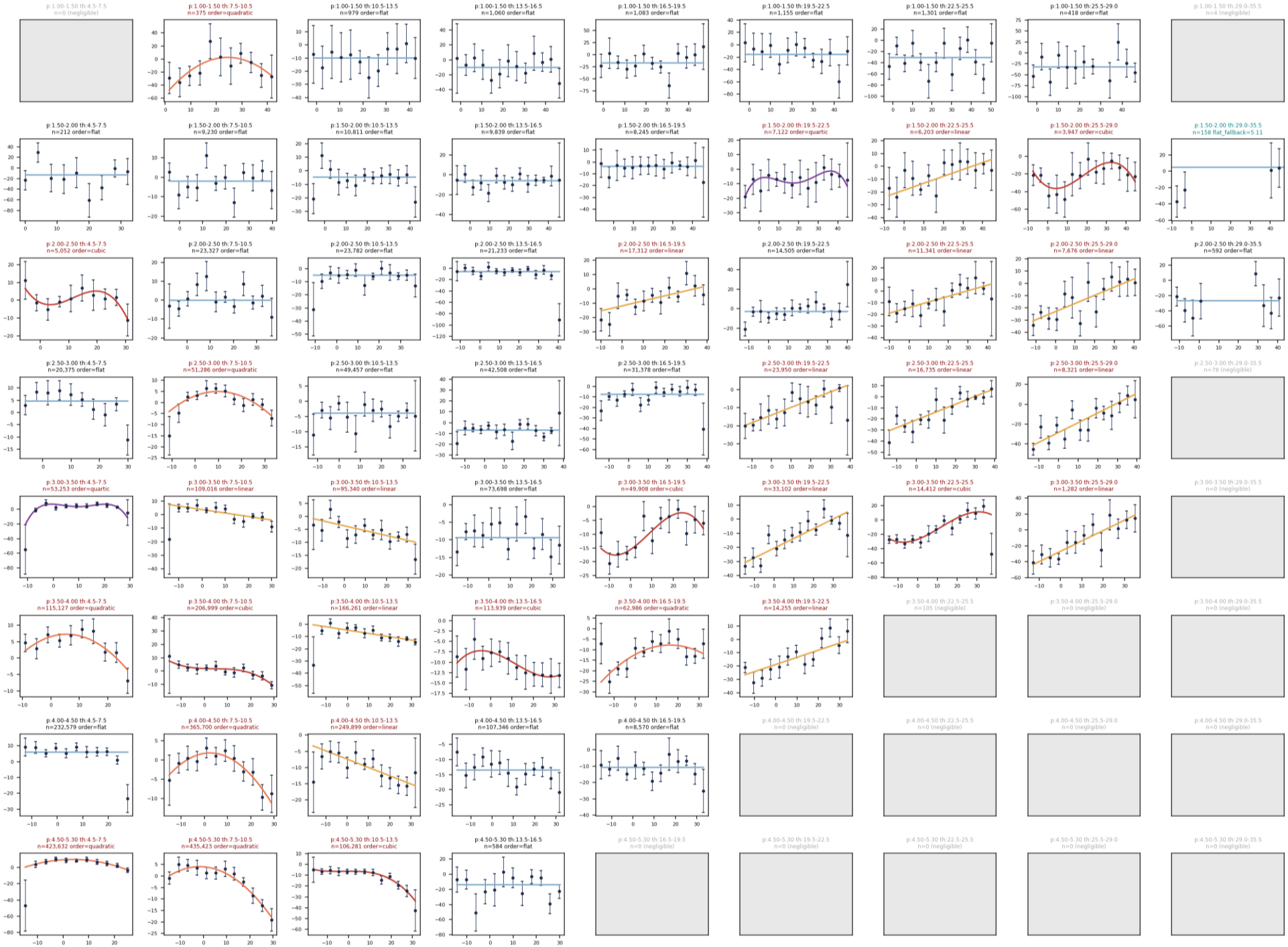
Momentum Correction Procedure Assumptions:

- The polar and azimuthal angles are reconstructed correctly
- The beam energy is precise
- Only the 3 momentum magnitude is corrected using $\Delta p(p,\theta,\phi)$

Procedure:

- Step #1: select $K^+\Lambda$ events and assume the K^+ momentum is correct, compute Δp_e and fit vs. p, θ, ϕ
- Step #2: select $K^+\Lambda$ events and assume the e′ momentum is correct, compute Δp_K and fit vs. p, θ, ϕ (after using updated e′ momentum)
- Step #3: interate on e′ and K^+ corrections until convergence – defined as Λ/Σ^0 peaks to within 1 MeV of their PDG masses





S1 electrons

- v3 fits for 3p data
- p_e: 1.0-5.3 *GeV*
- θ: 4.5°-35.5°
- adaptive binning

flat
linear
quadratic
cubic
quartic
below threshold (N<200)

Momentum Corrections

$e'K^+_{FD}$

3p

Sector	Λ		Σ^0		Λ		Σ^0	
	Cent [GeV]	σ [MeV]	Cent [GeV]	σ [MeV]	Cent [GeV]	σ [MeV]	Cent [GeV]	σ [MeV]
Uncorrected								
1	1.119	11.43	1.194	10.58	1.118	14.98	1.193	14.36
2	1.120	11.52	1.196	10.58	1.120	14.87	1.195	13.97
3	1.119	11.17	1.195	10.35	1.120	14.84	1.197	12.69
4	1.123	10.78	1.199	9.71	1.128	13.56	1.204	11.60
5	1.118	11.10	1.195	10.61	1.118	14.41	1.194	13.83
6	1.119	11.45	1.195	11.07	1.119	15.68	1.195	13.97
Corrected								
1	1.115	10.79	1.192	9.76	1.116	13.46	1.192	11.88
2	1.114	11.17	1.191	10.16	1.115	14.11	1.191	13.83
3	1.114	10.98	1.191	10.25	1.115	14.28	1.192	12.21
4	1.113	11.07	1.190	10.04	1.115	13.96	1.191	12.43
5	1.115	10.95	1.192	10.52	1.115	13.89	1.192	12.94
6	1.115	11.10	1.192	10.61	1.116	13.77	1.193	12.87

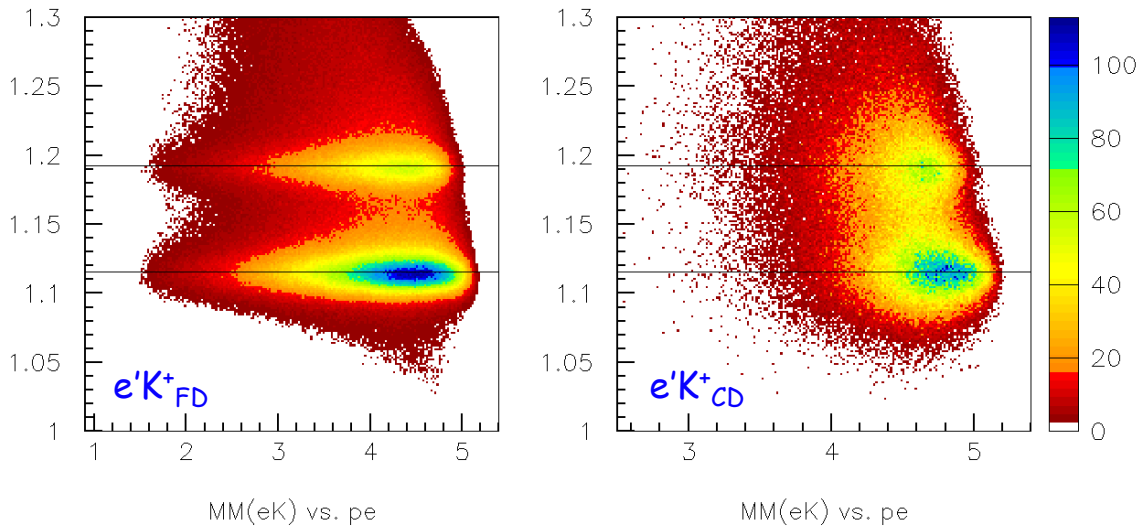
4p

$e'K^+_{CD}$

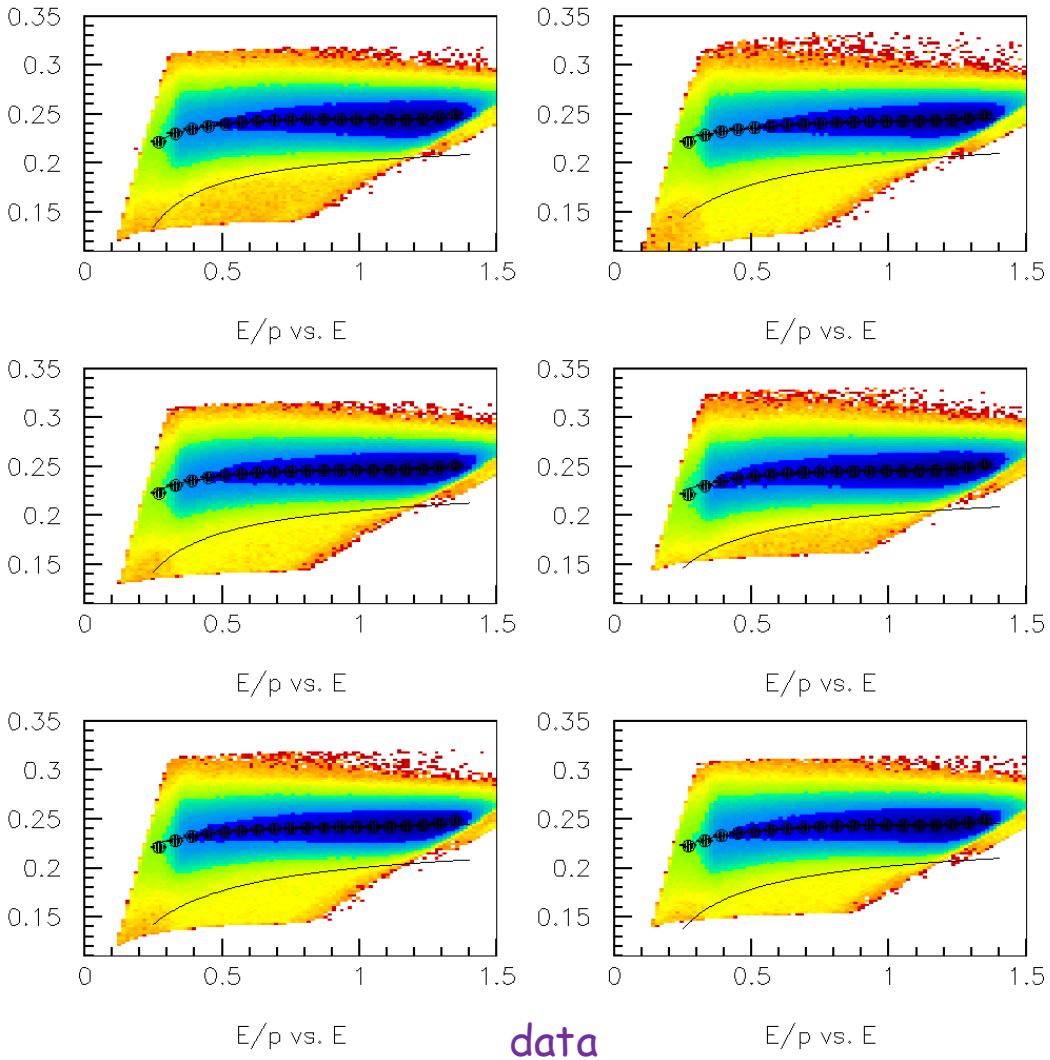
3p

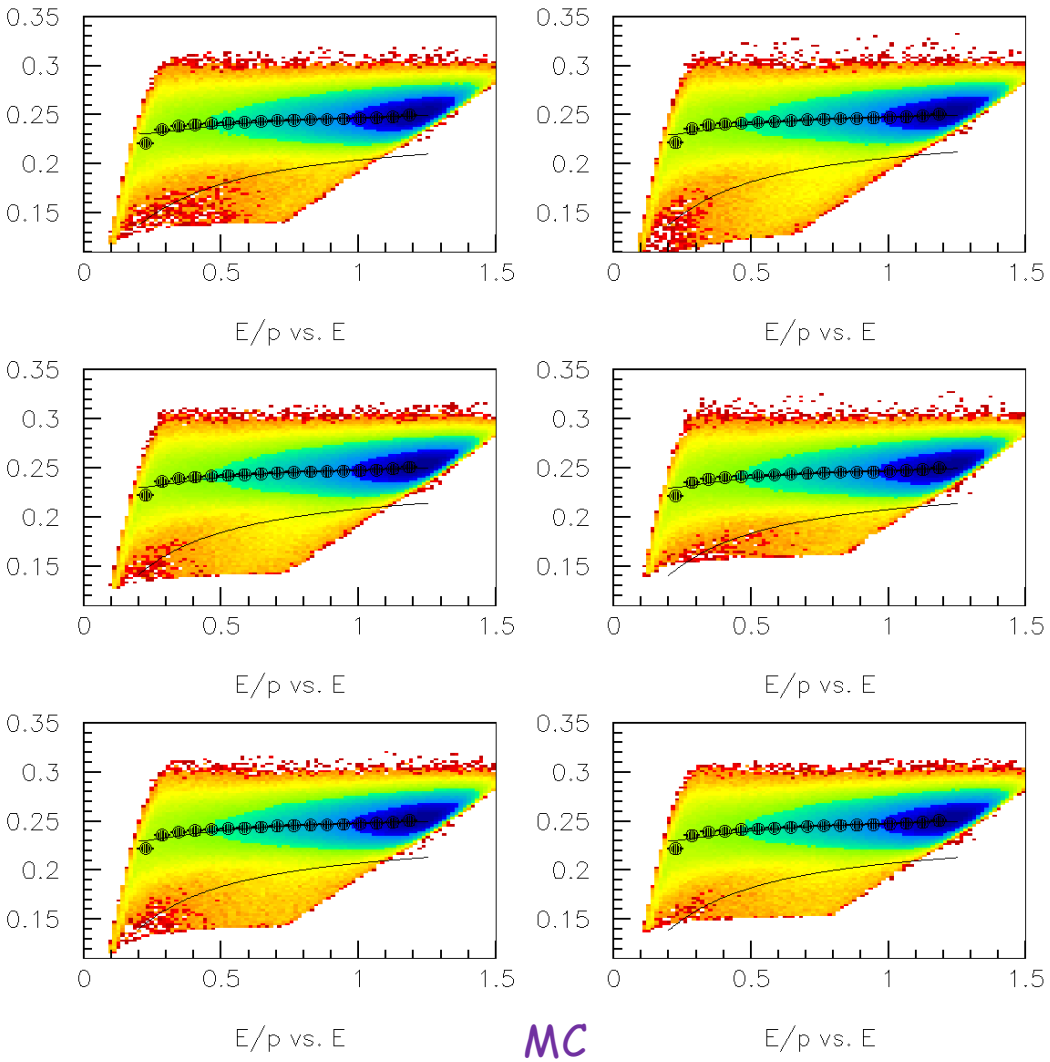
Sector	Λ		Σ^0		Λ		Σ^0	
	Cent [GeV]	σ [MeV]	Cent [GeV]	σ [MeV]	Cent [GeV]	σ [MeV]	Cent [GeV]	σ [MeV]
Uncorrected								
1	1.119	14.51	1.198	13.08	1.118	18.18	1.193	23.00
2	1.114	14.94	1.191	13.56	1.117	18.69	1.200	22.91
3	1.127	15.85	1.209	11.61	1.125	17.27	1.208	22.37
Corrected								
1	1.116	13.99	1.193	12.55	1.114	15.46	1.184	22.94
2	1.112	15.22	1.186	15.97	1.113	18.50	1.190	17.53
3	1.115	15.19	1.194	16.96	1.117	16.59	1.191	22.94

4p



ECAL SF Cuts





$$\mu_{SF}(E_{\text{dep}}) = A + \frac{B}{E_{\text{dep}}} + \frac{C}{E_{\text{dep}}^2}$$

$$\sigma_{SF}(E_{\text{dep}}) = \sqrt{a^2 + \frac{b^2}{E_{\text{dep}}}}$$

nominal cut at -3.5σ

3p

QADB Preparations

Index of Raw Table Files

Dataset	Table	Columns
pass1/rga_fa18_inbending	Table	Columns
pass1/rga_fa18_outbending	Table	Columns
pass1/rga_sp18_inbending	Table	Columns
pass1/rga_sp18_outbending	Table	Columns
pass1/rga_sp19	Table	Columns
pass1/rgb_fa19	Table	Columns
pass1/rgb_sp19	Table	Columns
pass1/rgb_wi20	Table	Columns
pass1/rgc_fa22	Table	Columns
pass1/rgc_sp23	Table	Columns
pass1/rgc_su22	Table	Columns
pass1/rgk_fa18_6.5GeV	Table	Columns
pass1/rgk_fa18_7.5GeV	Table	Columns
pass1/rgk_fa23_6.4GeV	Table	Columns
pass1/rgk_sp24_6.4GeV	Table	Columns
pass1/rgk_sp24_8.5GeV	Table	Columns

https://jeffersonlab.github.io/clas12-qadb/tables/index_raw.html

C. Dilks

Defect Bits

1	runnum	Run number
2	binnum	QA bin number
3	evnumMin	Event number minimum
4	evnumMax	Event number maximum
5	sectorDefects_1	Defect bit field for sector 1
6	sectorDefects_2	Defect bit field for sector 2
7	sectorDefects_3	Defect bit field for sector 3
8	sectorDefects_4	Defect bit field for sector 4
9	sectorDefects_5	Defect bit field for sector 5
10	sectorDefects_6	Defect bit field for sector 6
11	defect	Full defect bit field: OR of sectors' defect bit fields
12	fcChargeMin	DAQ-gated integrated FC charge [nC] at bin lower boundary, or zero for newer DBs, or bin minimum for older DBs
13	fcChargeMax	DAQ-gated integrated FC charge [nC] at bin upper boundary, or bin maximum for older DBs; subtract fcChargeMin for total bin's charge
14	ufcChargeMin	Full (ungated) integrated FC charge [nC] at bin lower boundary, or zero for newer DBs, or bin minimum for older DBs
15	ufcChargeMax	Full (ungated) integrated FC charge [nC] at bin upper boundary, or bin maximum for older DBs; subtract ufcChargeMin for total bin's charge
16	livetime	Live time
17	nElec_1	Number of FD trigger electrons for sector 1
18	nElec_2	Number of FD trigger electrons for sector 2
19	nElec_3	Number of FD trigger electrons for sector 3
20	nElec_4	Number of FD trigger electrons for sector 4
21	nElec_5	Number of FD trigger electrons for sector 5
22	nElec_6	Number of FD trigger electrons for sector 6
23	fcChargeHelicity_-1	DAQ-gated charge [nC] latched to negative beam helicity states
24	fcChargeHelicity_0	DAQ-gated charge [nC] latched to invalid/undefined beam helicity states
25	fcChargeHelicity_1	DAQ-gated charge [nC] latched to positive beam helicity states

```
19308 0 1 360 264242 264242 264242 264242 264242 264242 264242 0.0 0.0 0.0 0.0 0.0 0.0 0 0 0 0 0 0 0 -0.0011032295878976583 0.0 0.0
19308 1 360 1497560 2097 2097 2097 2097 2097 2097 2097 0.0 0.16243082284927368 0.0 0.19752424955368042 0.7202554791028263 0 0 0 0 0 0 0 0.038220781832933426 0.010357165709137917 0.05365492030978203
19308 2 1497560 2957760 2081 2081 2081 2081 2081 2081 2081 0.0 0.4330748915672302 0.0 0.4737268090248108 0.7060626527621546 0 0 0 0 0 0 0 0.1767143011091396 0.015340348705649376 0.1711827665567398
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19308 4 4446560 5948080 2081 2081 2081 2081 2081 2081 2081 0.0 0.27301812171936035 0.0 0.2875479459762573 0.715003243078874 0 0 0 0 0 0 0 0.0984473004937172 0.007761174812912941 0.10173546522855759
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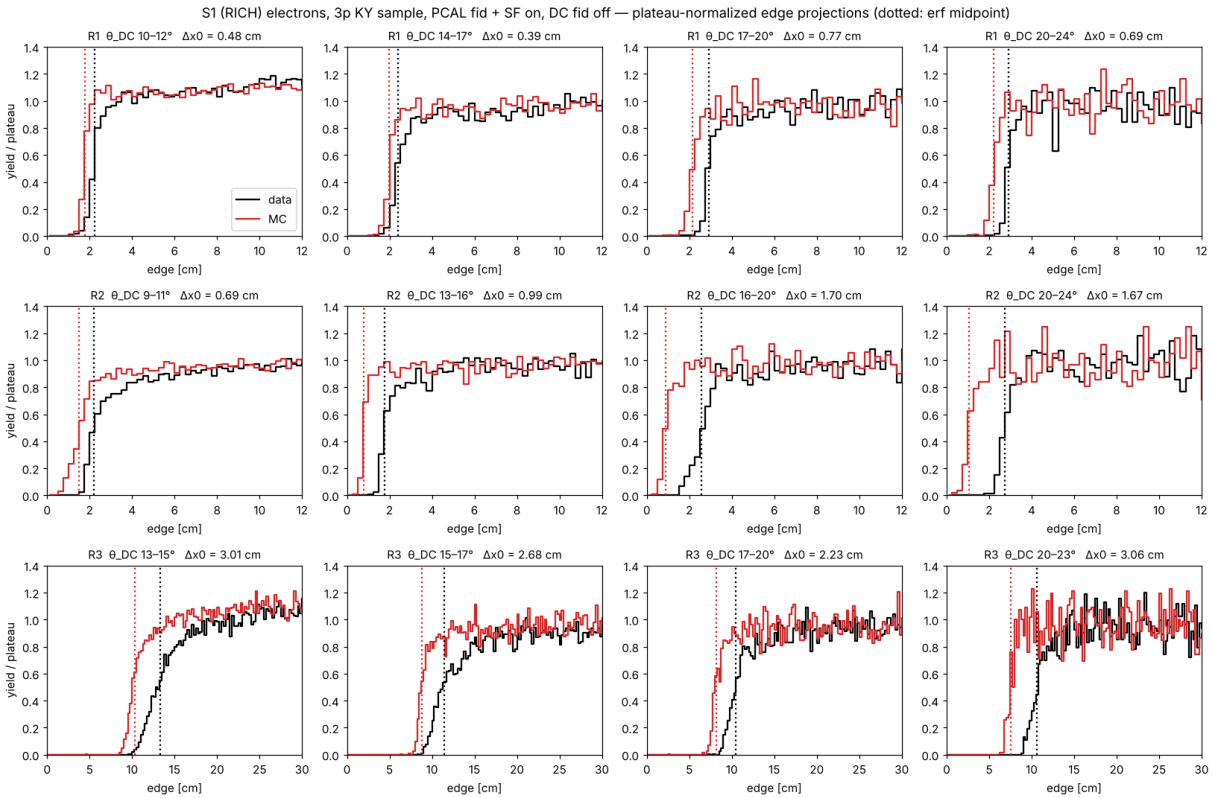
DC Fiducial Cuts

Electron edge vs. polar angle (at origin)

S1



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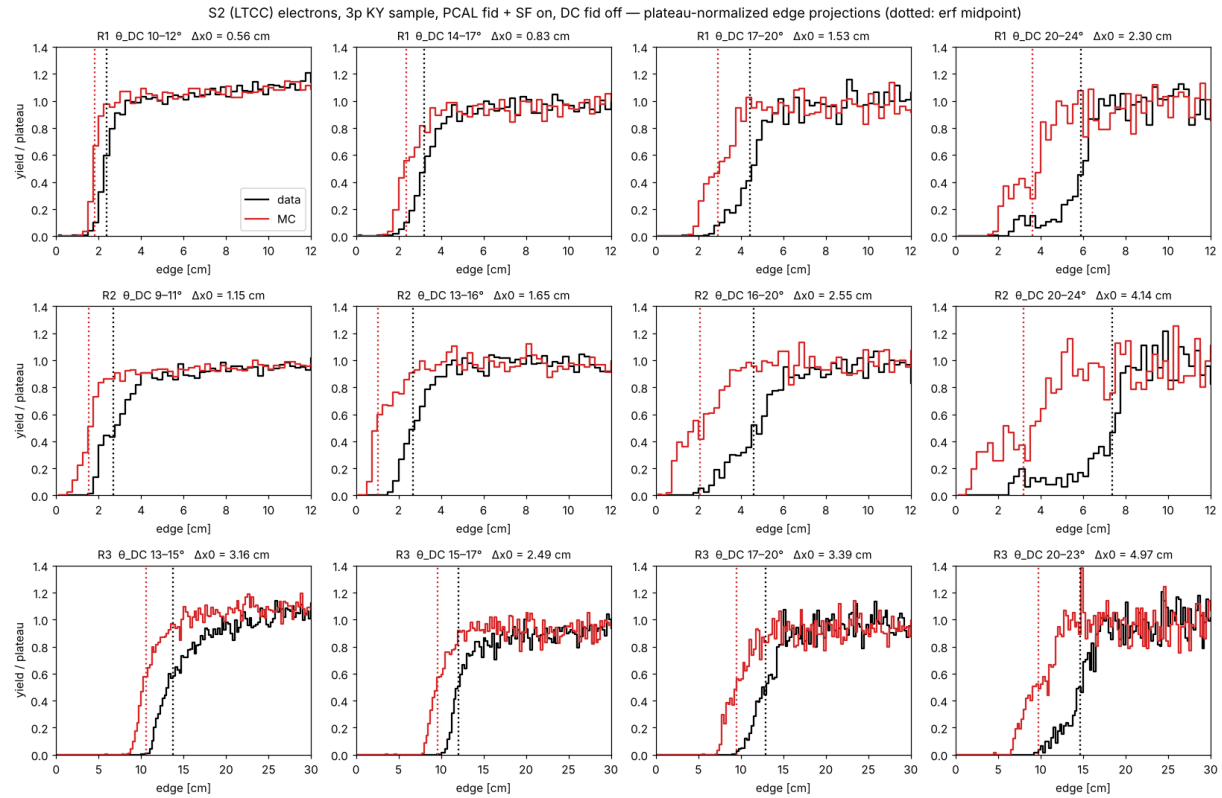
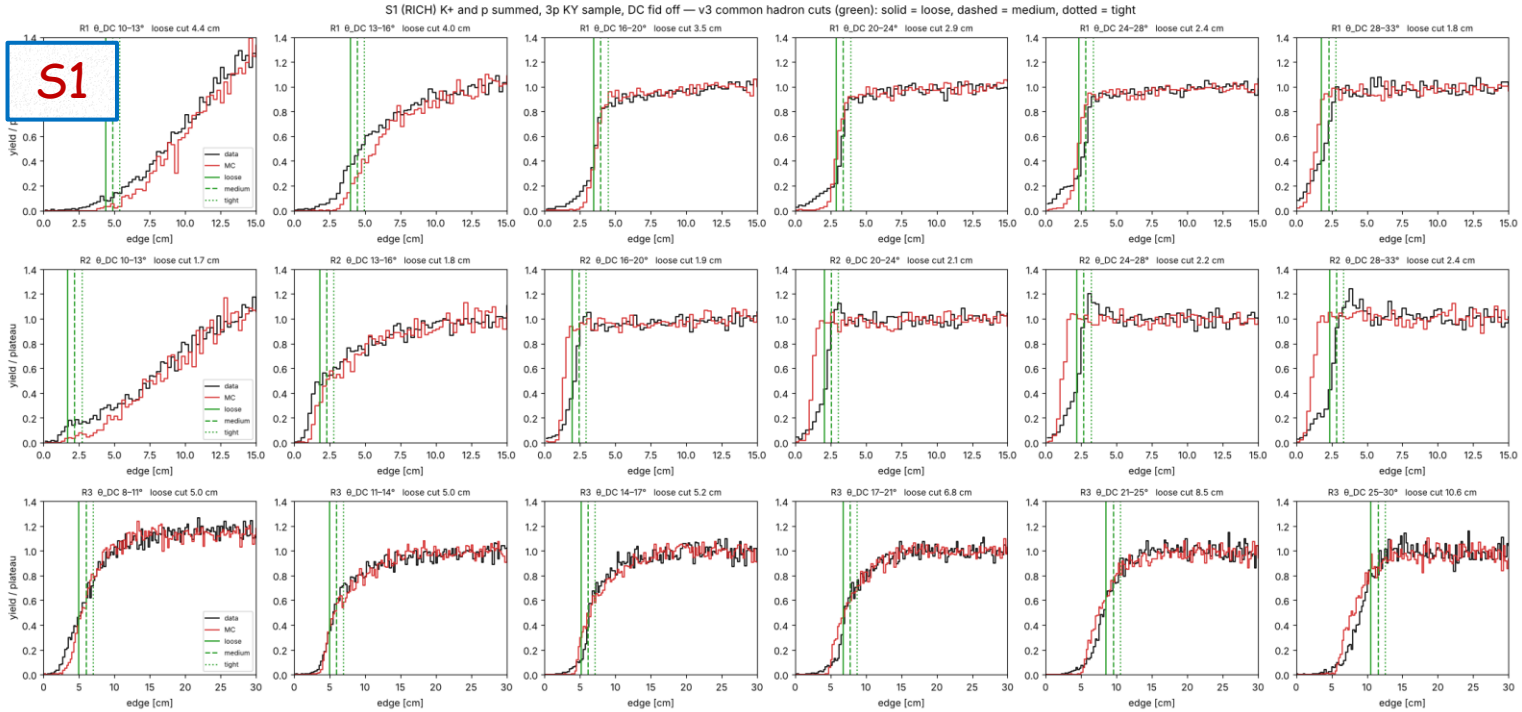


Studied in conjunction with PCAL fiducial cuts on U, V, W edges for shower containment

Cuts set by matching data and MC acceptance to match within 2%

DC Fiducial Cuts

S1



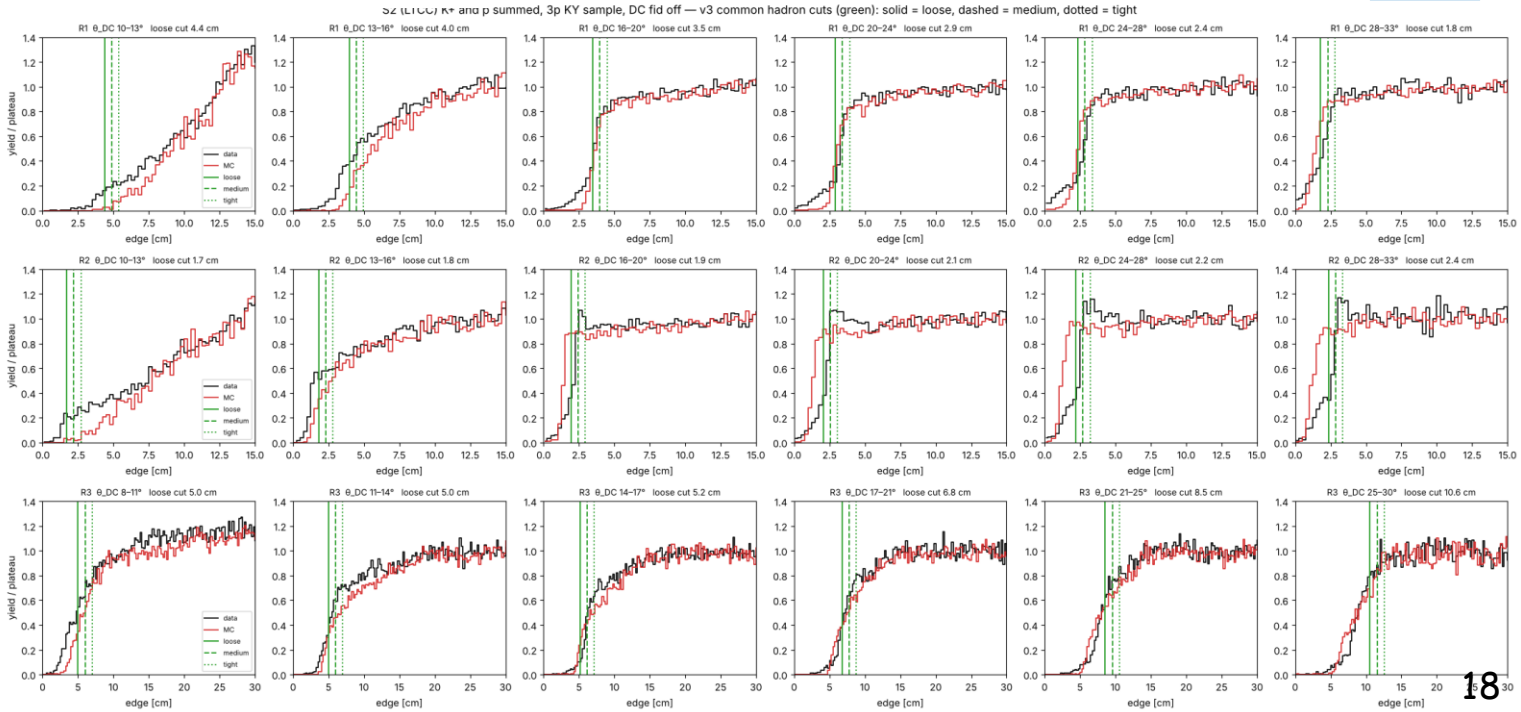
Hadron edge vs. polar angle at origin

Fiducial cut routine with loose, medium, and tight cuts installed in analysis code

		Loose		Medium		Tight	
Particle	Region	Data	MC	Data	MC	Data	MC
K^+	R1	1.3	0.7	2.2	1.8	3.6	3.2
K^+	R2	1.1	2.5	2.2	3.9	3.7	5.3
K^+	R3	1.7	1.6	2.9	2.9	4.6	4.4
p	R1	1.4	0.9	2.1	1.9	3.2	3.2
p	R2	0.9	2.7	1.9	4.3	3.5	5.9
p	R3	0.6	0.9	1.1	1.6	1.9	2.6

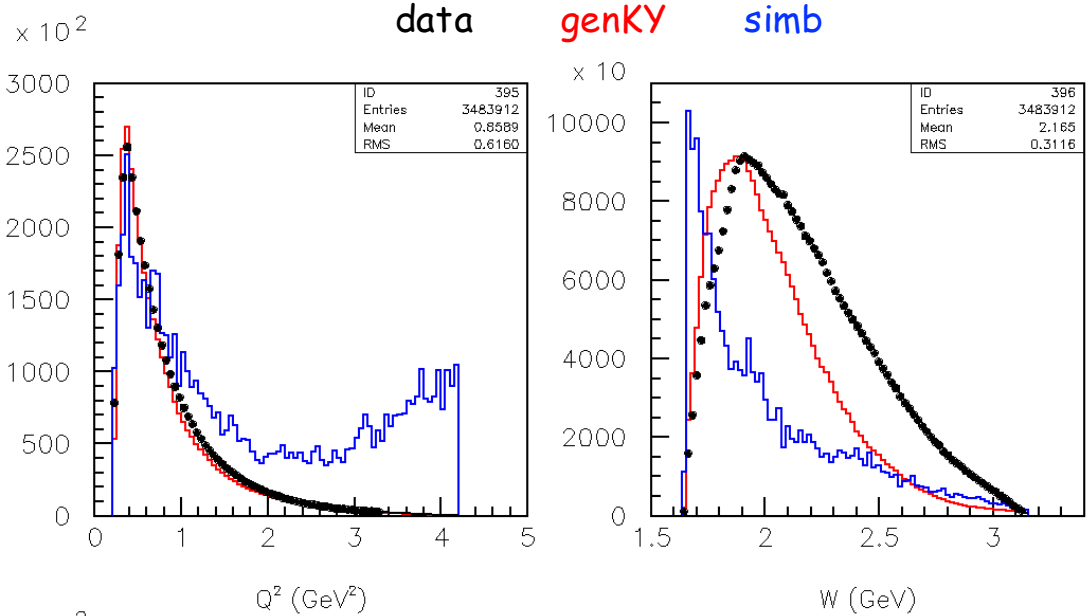
Single set of cuts for positively charged hadrons works well

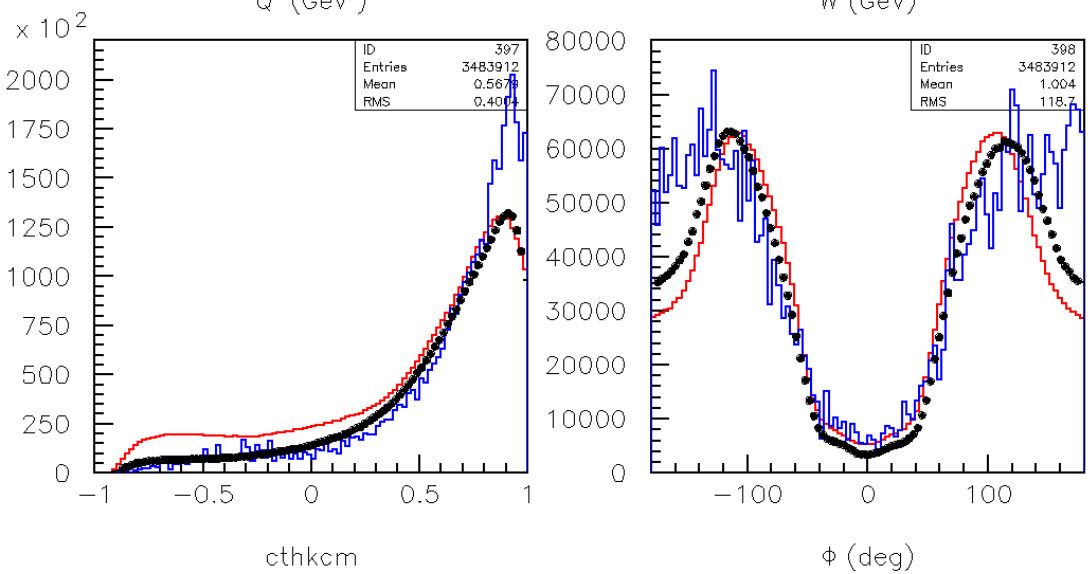
S2



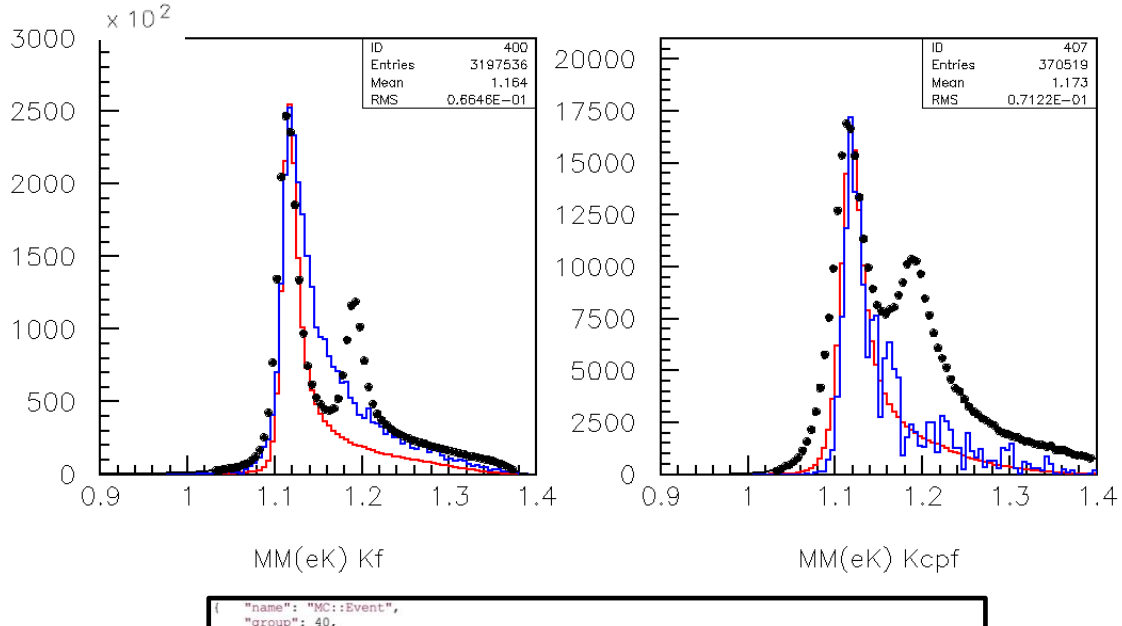
Monte Carlo Update

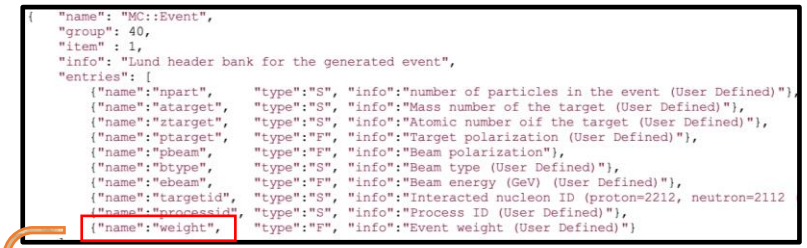
data genKY simb

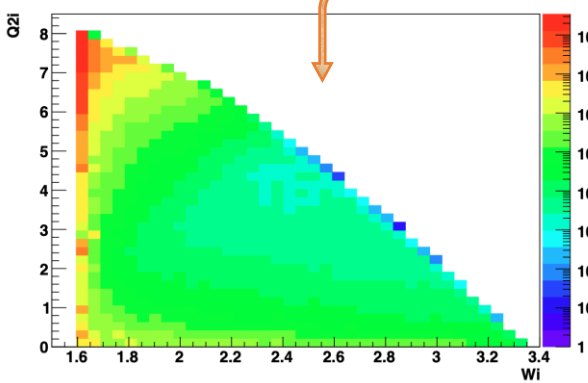


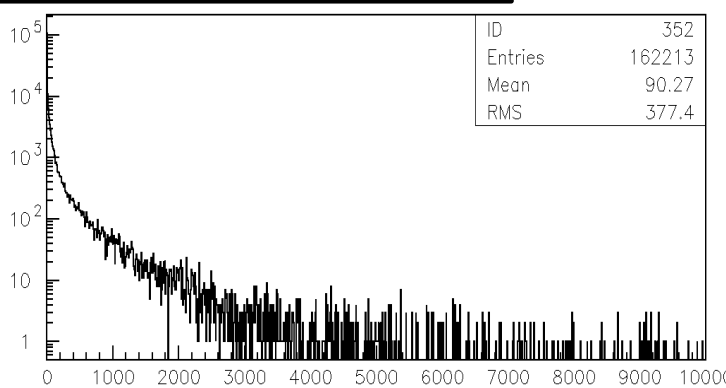


Allows for iterations without regenerating MC









G. Niculescu

Analysis Note

Differential Cross Section and Separated Structure Function Extraction from CLAS12 RG-K Spr24 for the Reactions $p(\vec{e}, e'K^+)\Lambda$ and $p(\vec{e}, e'K^+)\Sigma^0$

D.S. Carman, Jefferson Laboratory

(Dated: November 9, 2026)

This write-up includes the analysis details and systematic uncertainty evaluation associated with the extraction of the differential cross sections in bins of $(Q^2, W, \cos\theta_K^{c.m.}, \Phi)$ and the separated structure functions σ_U, σ_{LT}, σ_{TT}, and $\sigma_{LT'}$ in bins of $(Q^2, W, \cos\theta_K^{c.m.})$ for the reactions $p(e, e'K^+)\Lambda$ and $p(e, e'K^+)\Sigma^0$ using the RG-K Spr24 dataset. These data were acquired with electron beam energies of 6.395 GeV and 8.478 GeV in the period from Jan. - Mar. 2024. The data span a broad range of momentum transfer Q^2 from $0.2 - 6.1$ GeV^2 and invariant energy W from threshold to 3.2 GeV, while spanning nearly the full center-of-mass angular range of the kaon.

Overleaf

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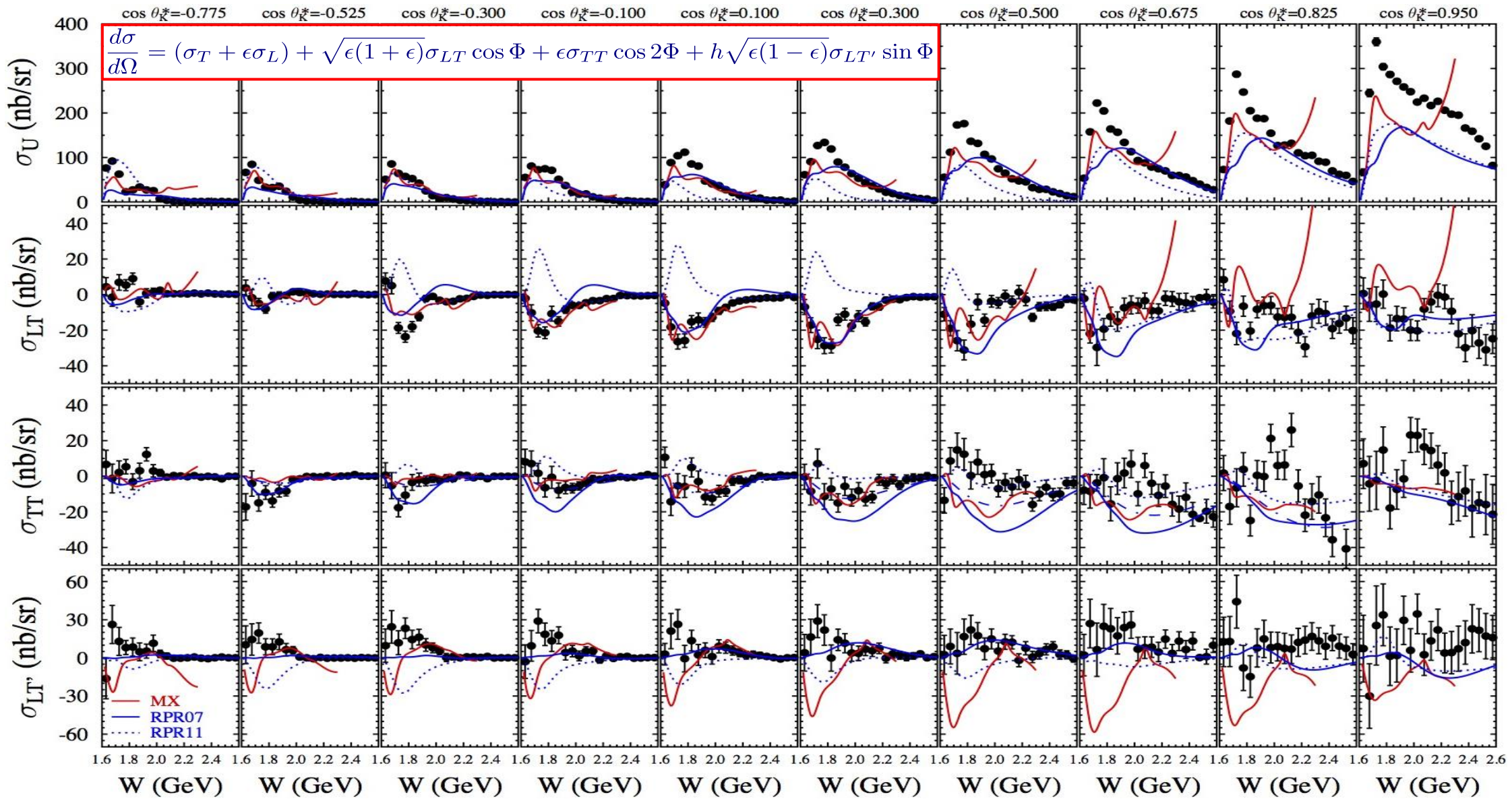
Summary & Next Steps

- A preliminary extraction of the $K^+\Lambda$ and $K^+\Sigma^0$ differential cross sections and separated structure functions has been completed for the 6.395 GeV and 8.478 GeV RG-K Spr24 datasets
  - Two topologies have been combined: $e'K^+_F$ and $e'K^+_C p_F$
  - Note that the proton requirement is necessary in the $e'K^+_C$ topology due to the overwhelming background
  - Extract σ_U, σ_{LT}, σ_{TT}, $\sigma_{LT'}$
- Since the June CLAS Collaboration meeting work has focused on:
  - Optimize analysis cuts
  - Determine hadron energy loss corrections
  - Develop electron sampling fraction cuts
  - Determine electron/hadron momentum corrections
  - Develop electron and hadron fiducial cuts
  - Development of alternate event generator with radiation model and event weights
- Upcoming work:
  - Complete development/testing/validation of new event generator and install on OSG (with documentation)
  - Begin to run large-scale MC samples
  - Develop iteration procedure to tune event generator
  - Begin study of systematic uncertainties
  - Optimize yield fitting procedure based on already developed code

Backup

CLAS $K^+\Lambda$ Structure Functions

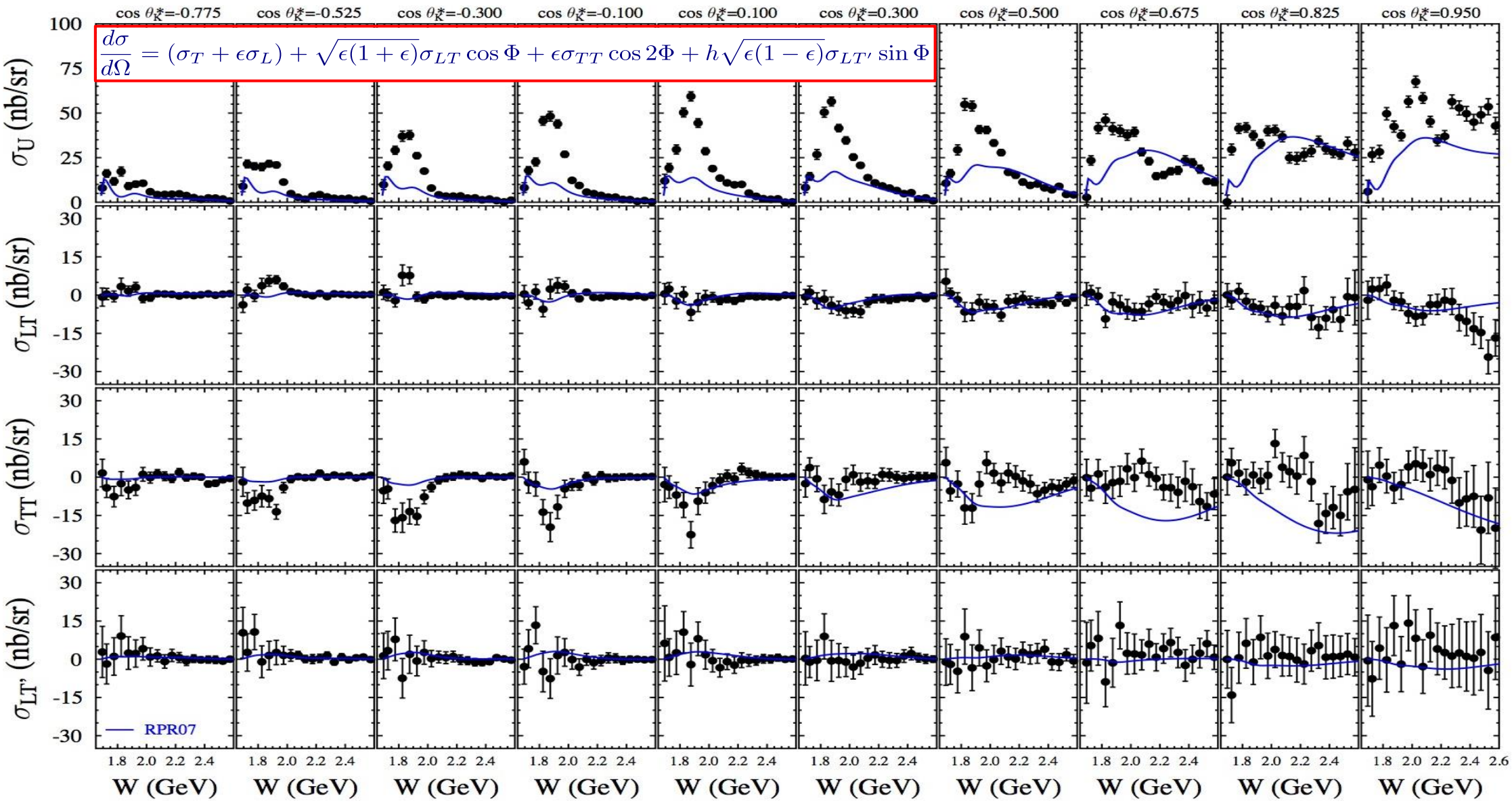
E = 5.5 GeV
W: thr – 2.6 GeV
Q^2 = 1.80, 2.60, 3.45 GeV^2



D.S. Carman et al. (CLAS), PRC 87, 025204 (2013)

CLAS $K^+\Sigma^0$ Structure Functions

E = 5.5 GeV
W: thr – 2.6 GeV
Q^2 = 1.80, 2.60, 3.45 GeV^2

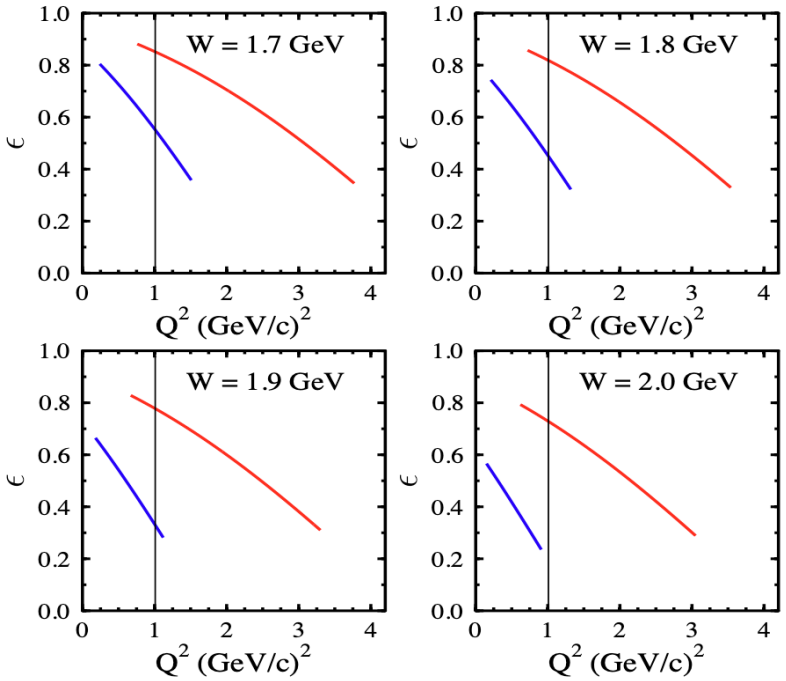


D.S. Carman et al. (CLAS), PRC 87, 025204 (2013)

Rosenbluth Separation

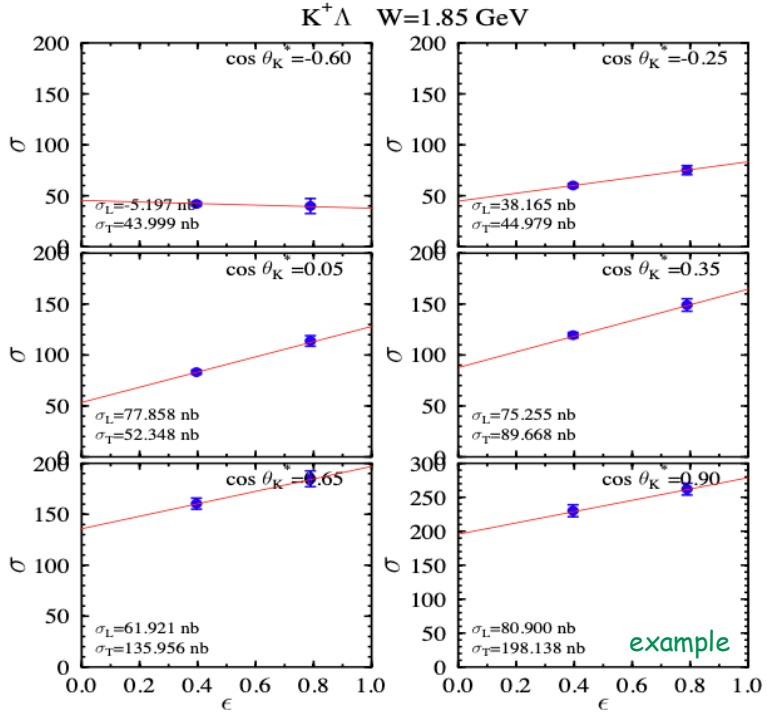
$$\sigma_0 = \sigma_T(Q^2, W, \cos\theta_K^{c.m.}) + \epsilon\sigma_L(Q^2, W, \cos\theta_K^{c.m.})$$

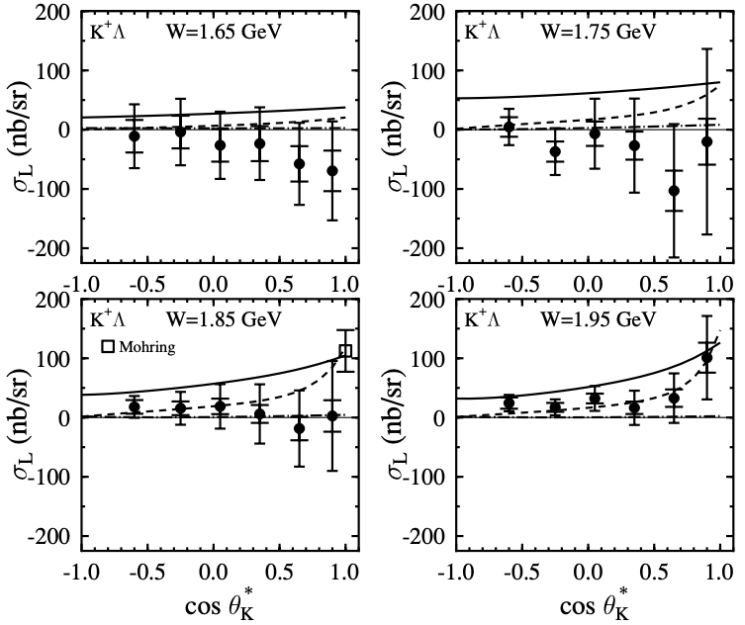
CLAS e1c data @ 2.5 & 4.0 GeV

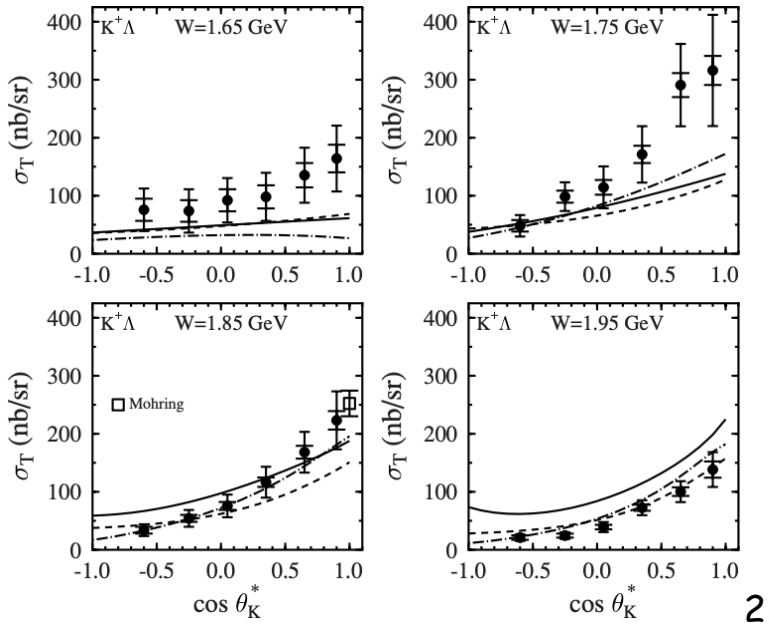


Linear fit to dσ/dΩ vs. ε:

- slope gives σ_L
- y-intercept gives σ_T







The only publication of separated σ_L and σ_T in Hall B to date

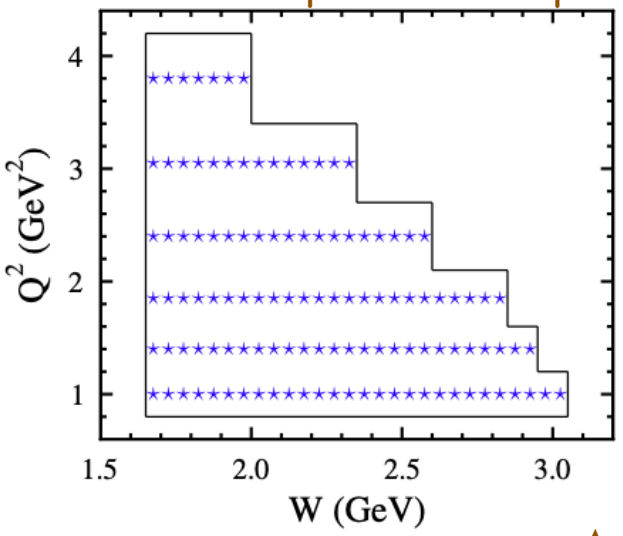
P. Ambrozewicz et al. (CLAS), PRC 75, 045203 (2007)

RG-K KY Rosenbluth Separation



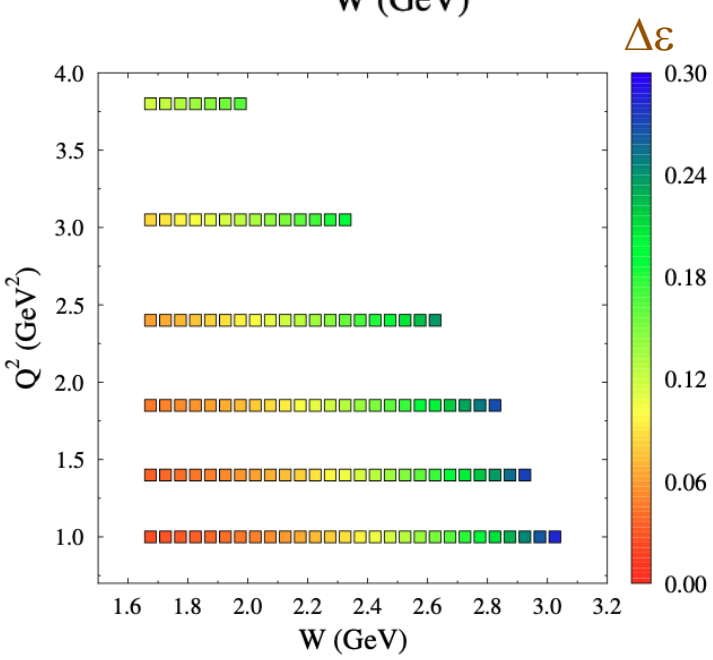
$K^+\Lambda$

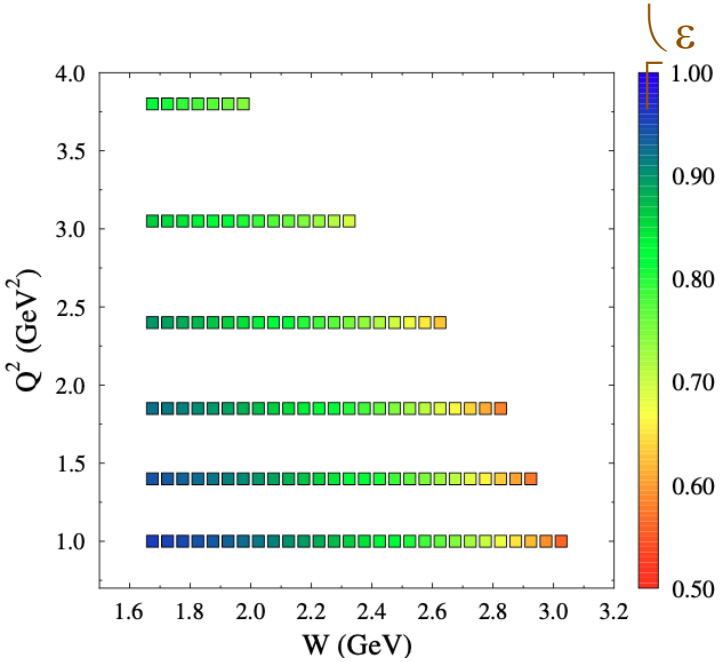
Landscape of Overlap

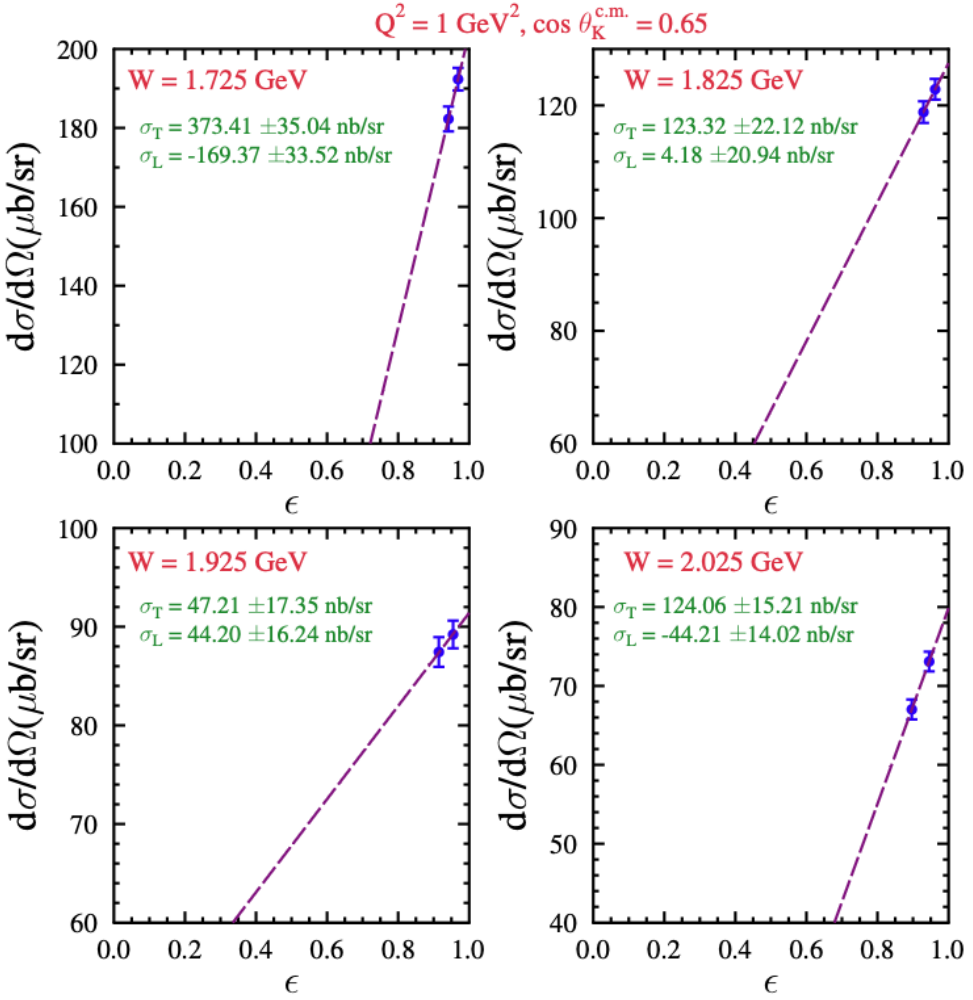


Note:

- Full overlap landscape not practically accessible
- At 6.4 and 8.5 GeV most kinematic points have εH0.8-0.9 with ΔεH0!

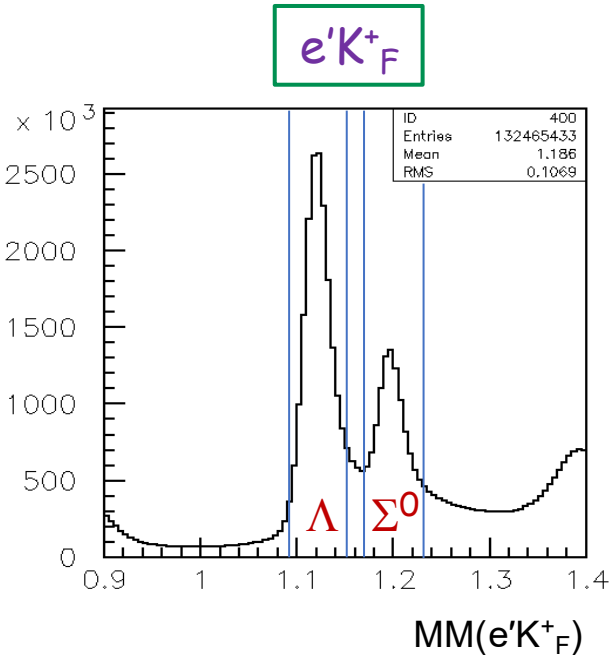


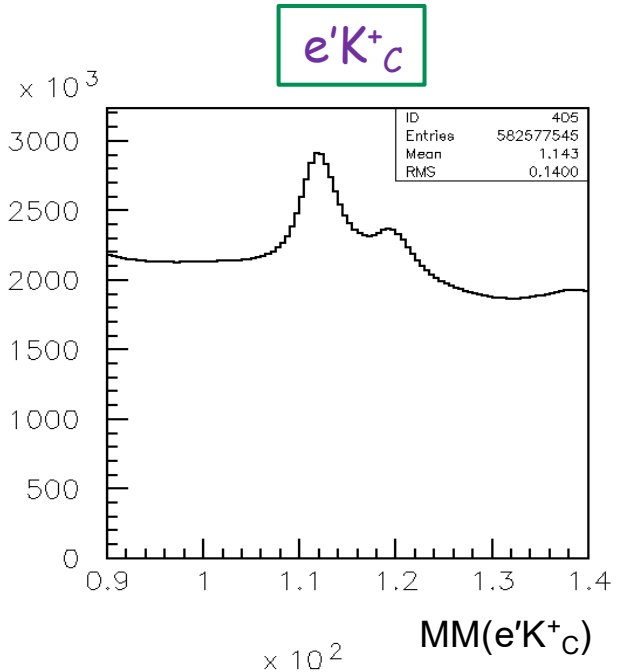




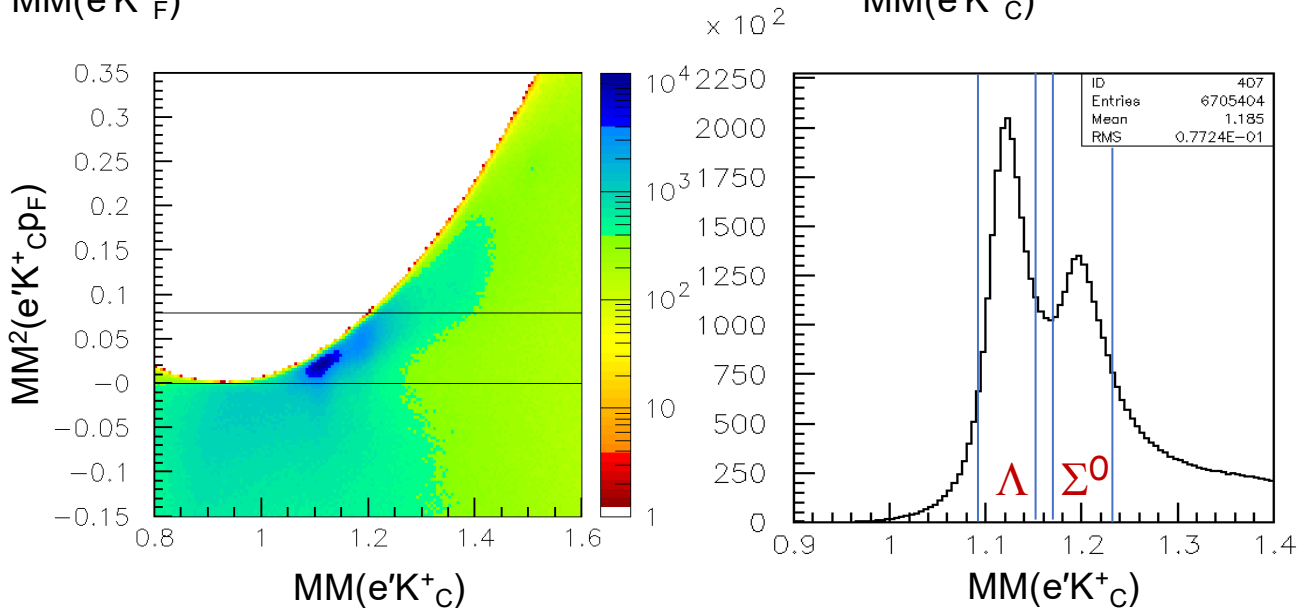
O.K., there is still some work to do …

Topology Selection





"simple" yield extraction



Topology Selection:

1) $e'K^+_F$
2) $e'K^+_C p_F$

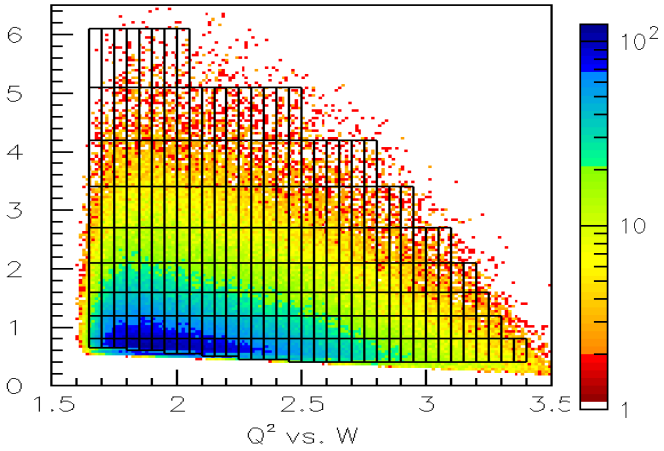
Notes:

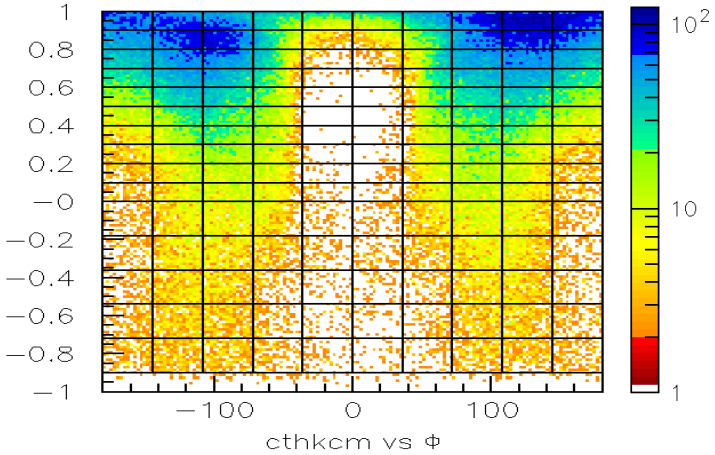
- Detection of p_F for K^+_C topology necessary to reduce backgrounds in CD
- Account for $\Lambda \rightarrow p\pi^-$ B.R. with weight to $e'K^+_C p_F$ events

RG-K KY Binning and Yields – 8.5 GeV

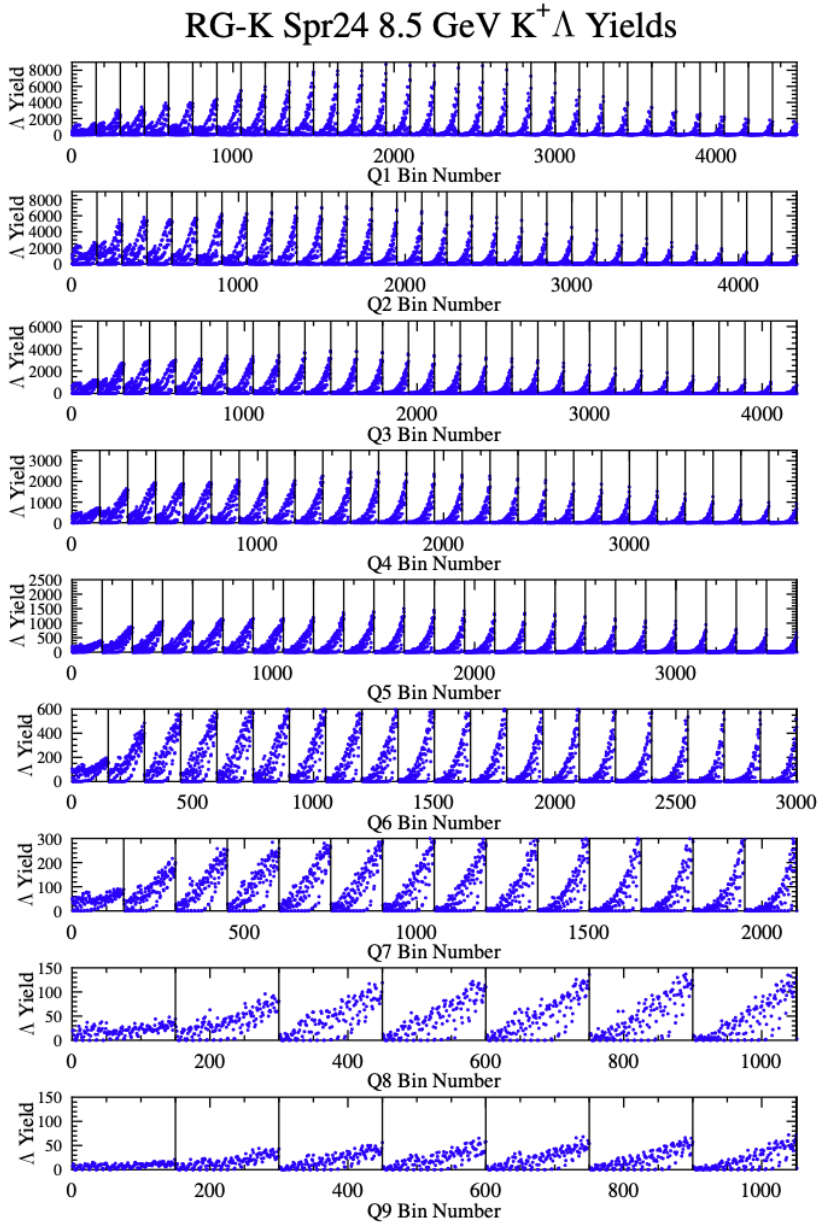
Spr24 datasets allow fine binning in the relevant kinematic variables:

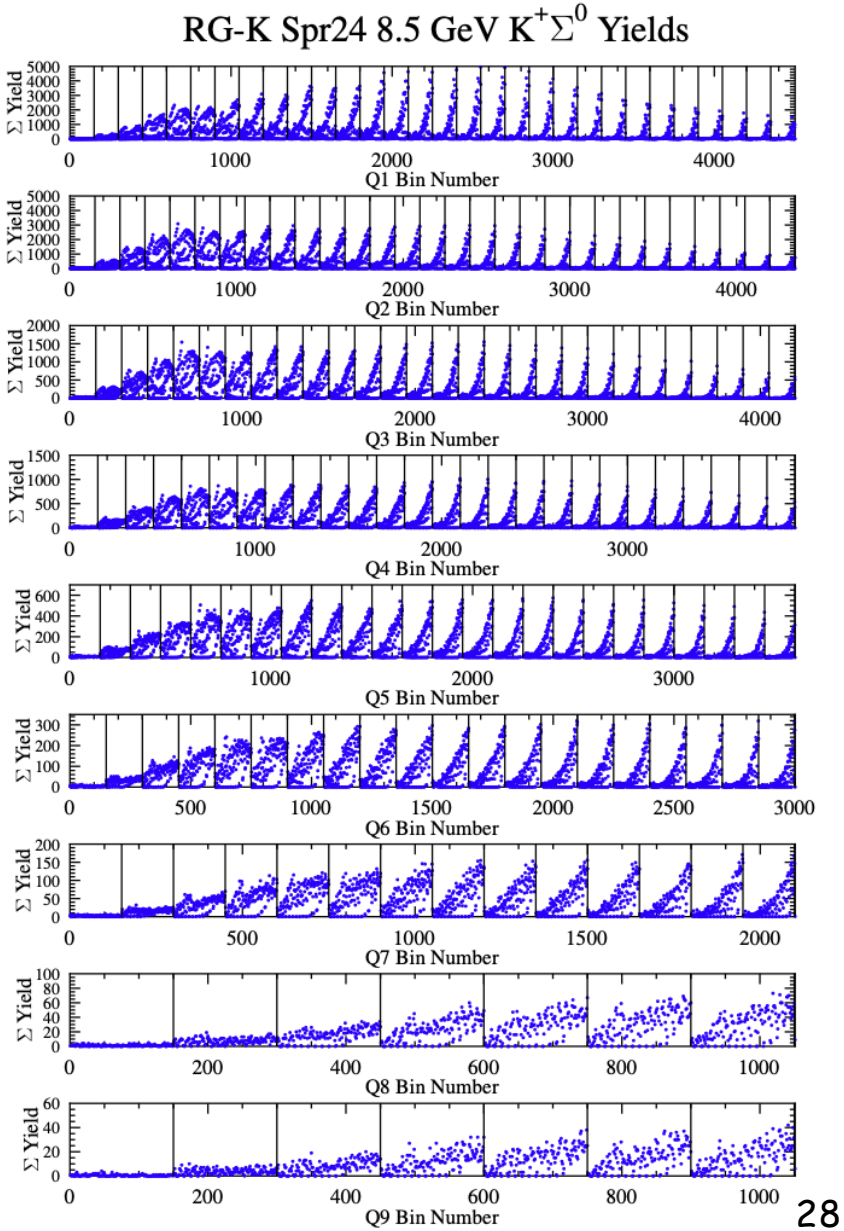
Q^2, W, cos $\theta_K^{c.m.}$, Φ

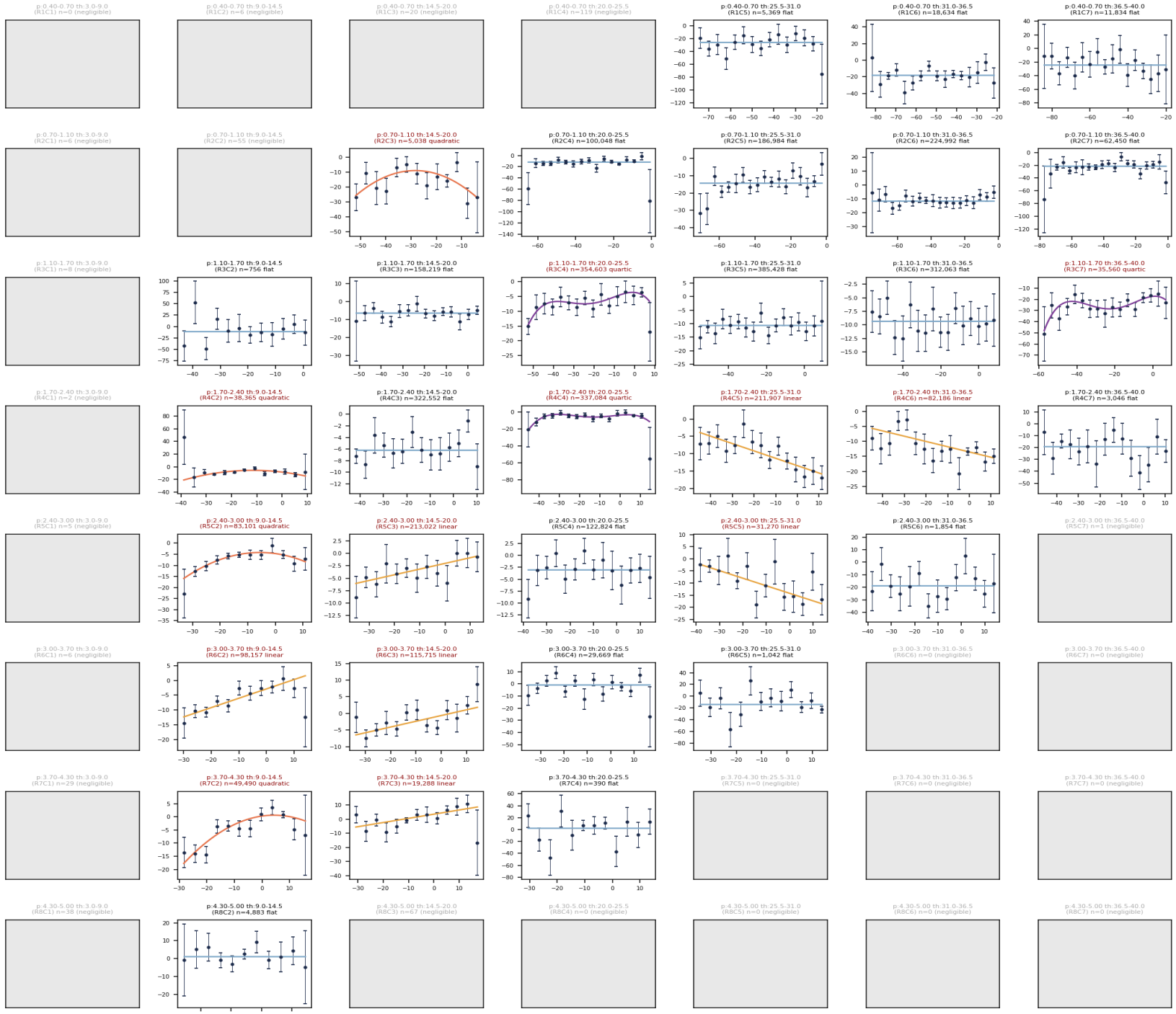




N_{bins} = 35,100 (x2 for h=±1)



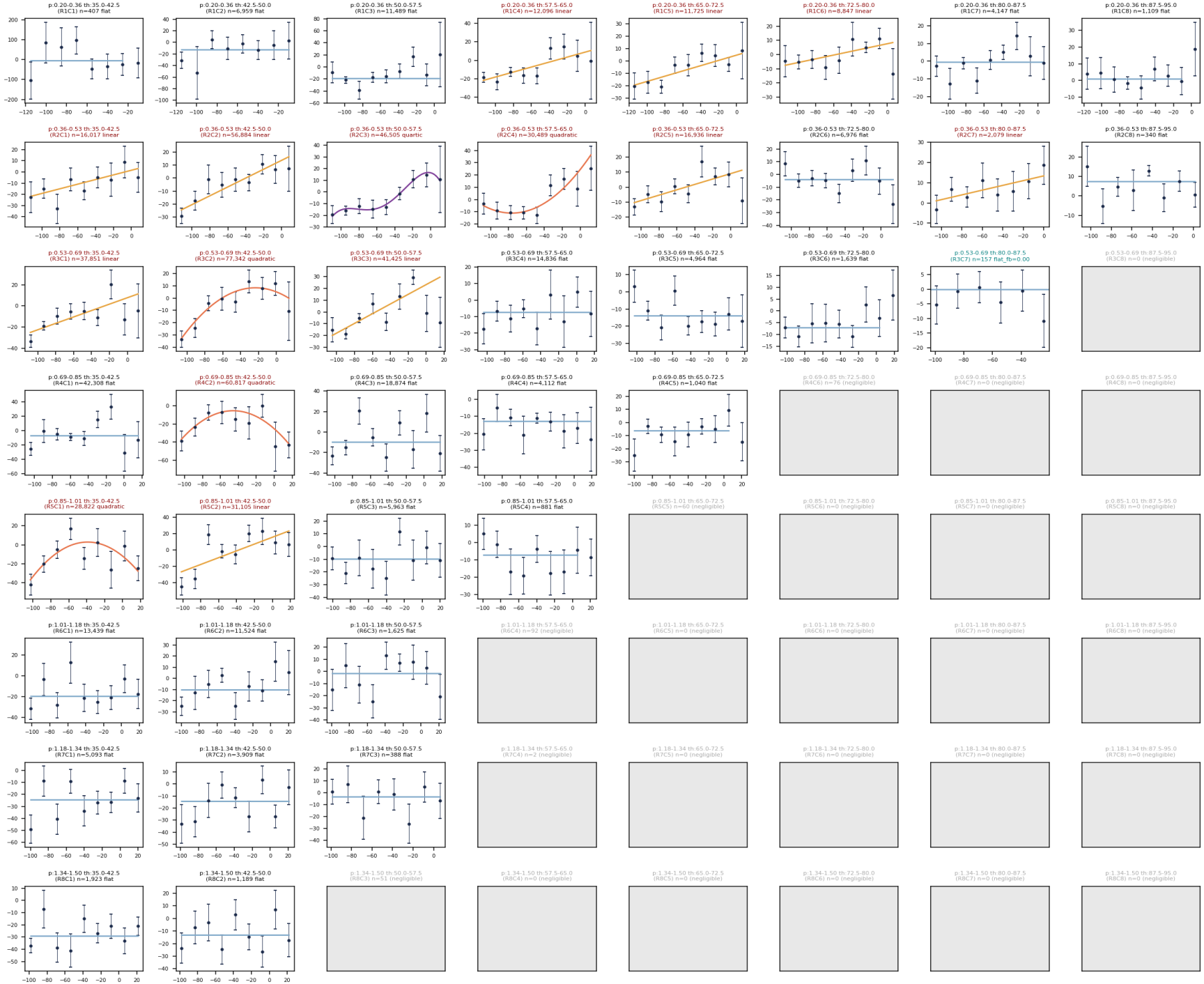




S1 K^+ FD

- v3 fits
- p_K: 0.4-5.0 GeV
- θ: 3.0°-40.0°
- adaptive binning

flat
linear
quadratic
cubic
quartic
below threshold (N<200)



S1 K^+ CD

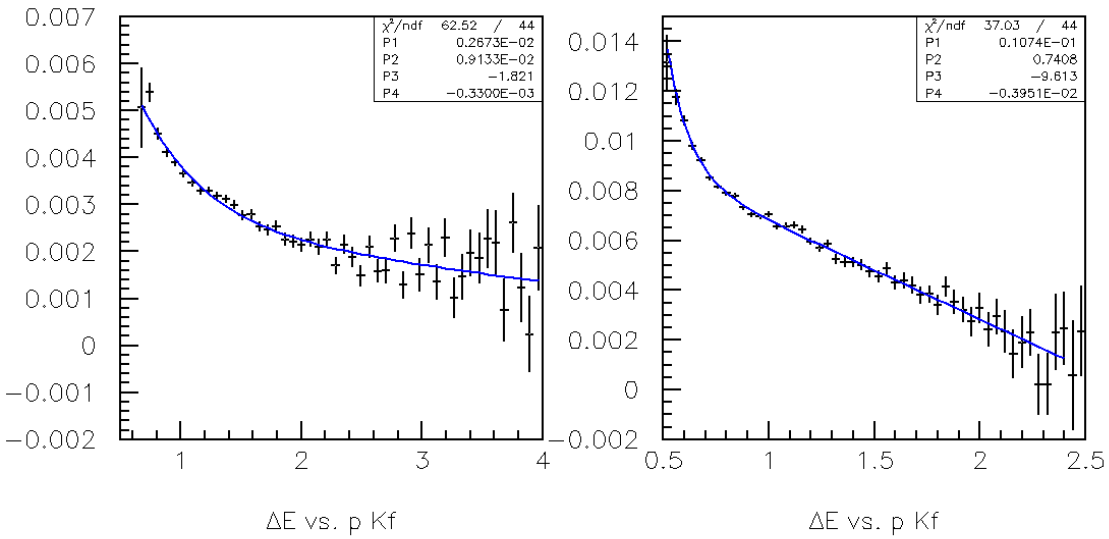
- v3 fits
- p_K: 0.2-1.5 GeV
- θ: 35.0°-95.0°
- adaptive binning

flat
linear
quadratic
cubic
quartic
below threshold (N<200)

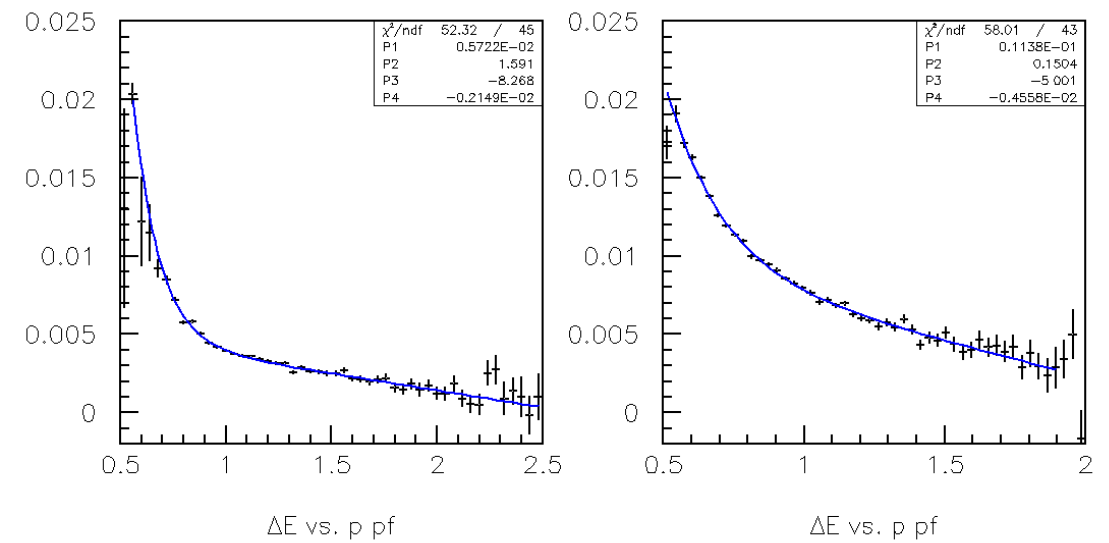
Energy Loss Corrections

FD

θ < 27°

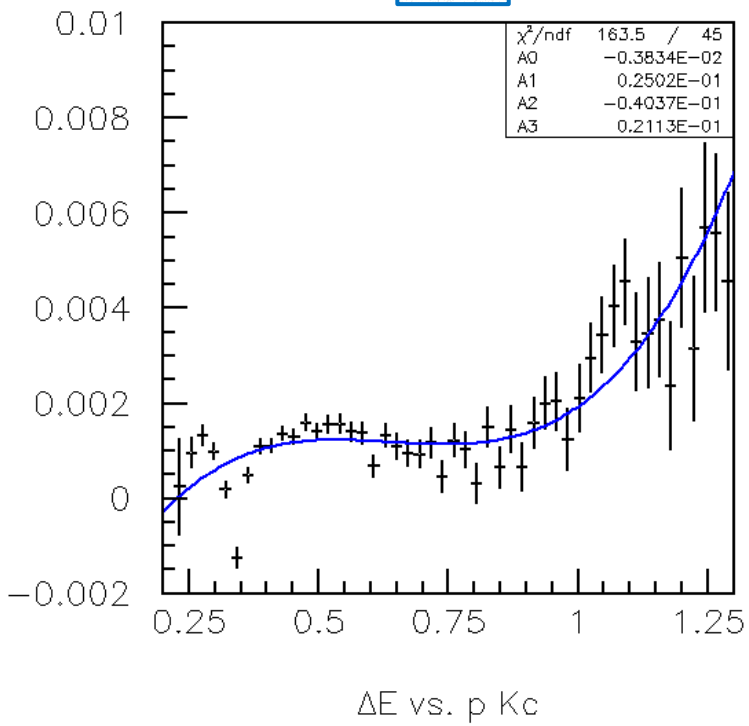


θ > 27°



$$\Delta E = A + B\exp(Cp) + Dx$$

CD



$$\Delta E = A + Bx + Cx^2 + Dx^3$$