KaonLT (E12-09-011) Analysis Update

Vijay Kumar

University of Regina

Hall A/C Summer Collaboration Meeting
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Outline

- Collaboration information
- Kaon LT experiment and its studies
- Rosenbluth separation overview
- The meson wave function (form factor)
- Analysis updates
- Summary and future perspectives

Collaboration

- Spokespersons:

  Garth Huber, Tanja Horn and Pete Markowitz.

- Graduate Students (students analyzing data):

  Vijay Kumar, Richard Trotta and Ali Usman.

Vijay Kumar

Richard Totta

Ali Usman

- Key Members:

  Stephen Kay, Muhammad Junaid, Love Preet, Nathan Heinrich Vladimir Berdnikov, and Petr Stepanov.

Kaon LT experiment (E12-09-011)

- Kaon LT experiment was conducted in Hall C at Jefferson Lab over fall 2018 and spring 2019.
  - It is an exclusive reaction system experiment. The experimental data were collected above the resonance region of the proton.
  - The experiment is to perform studies of the high precision separation cross-section terms, σ_L, σ_T, σ_{LT} & σ_{TT} of the kaon electroproduction.
  - Further studies for the "soft" and "hard" QCD factorization will be carried out.
  - The kaon electromagnetic form factor will be extracted if study shows that the kaon pole dominates σ_L.
- The reaction system of the experiment is,

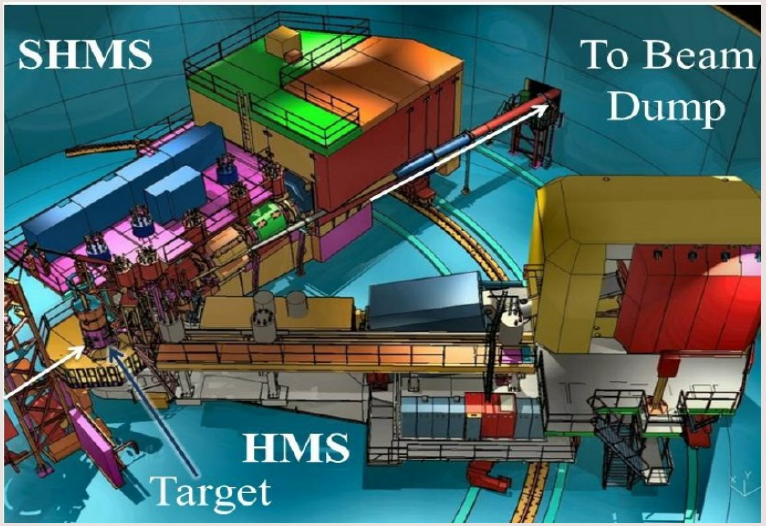
$$e + p \rightarrow e' + K^+ + \Lambda$$

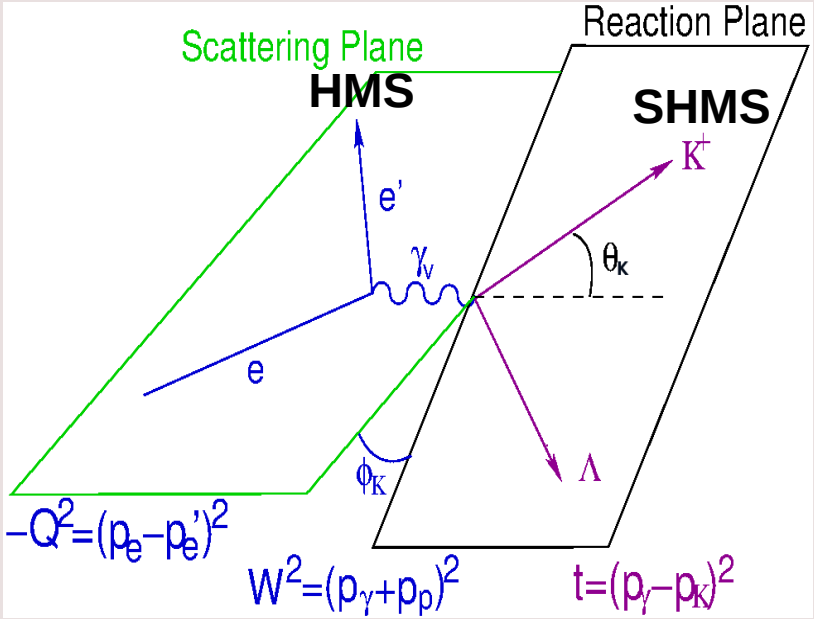
$$M_\Lambda = 1115.68\ MeV^2/c^2$$

Or

$$e + p \rightarrow e' + K^+ + \Sigma^0$$

$$M_{\Sigma^0} = 1192.64\ MeV^2/c^2.$$





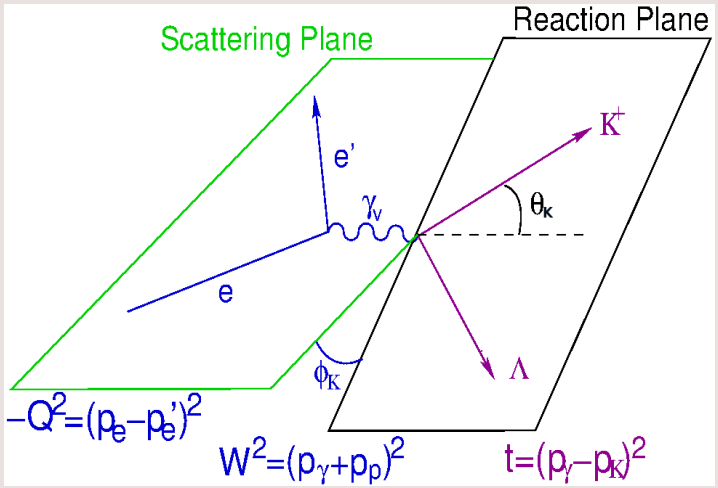
Rosenbluth separation overview (simple version)

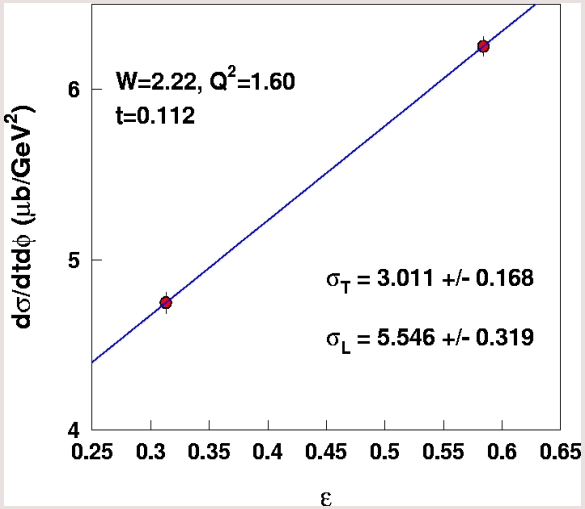
- To separate out the cross-section terms, we will utilize the Rosenbluth separation technique.
  - Measure the cross-section for at least two values of **ε** at fixed Q^2, W and -t.
  - The measured cross-section at two values of **ε** is then fitted to separate out the σ_L, σ_T, σ_{LT} & σ_{TT} cross-section terms.
- In parallel kinematics, $\theta_K = 0 (\theta_K w.r.t \vec{q})$.
  - The σ_L and σ_T are the only cross-section terms that contribute to the kaon electroproduction cross-section.
  - The mathematical form is simple but it requires uniform detector acceptance.

$$2\pi \frac{d^2\sigma}{dt d\phi} = \varepsilon \frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt}$$

Virtual-photon polarization:

$$\varepsilon = \left(1 + 2 \frac{(E_e - E_{e'})^2 + Q^2}{Q^2} \tan^2 \frac{\theta_{e'}}{2} \right)^{-1}$$





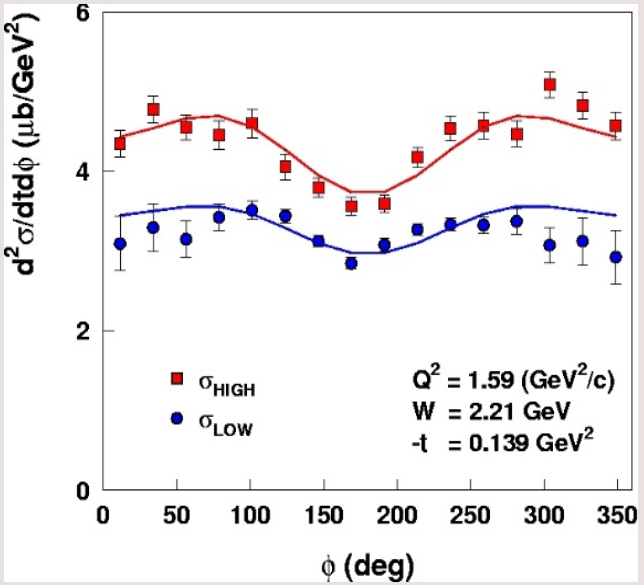
T. Horn, et al, PRL **97** *(2006)192001*

Rosenbluth separation overview (full version)

- In non-parallel kinematics, $\theta_K \neq 0 (\theta_K w.r.t \vec{q})$.
  - The cross-section at two values of **ε** is simultaneously fitted with a four variables function to determine all of the four cross-sections, σ_L, σ_T, σ_{LT} and σ_{TT}.

$$2\pi \frac{d^2\sigma}{dtd\phi} = \varepsilon \frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\varepsilon(\varepsilon+1)} \frac{d\sigma_{LT}}{dt} \cos\phi + \varepsilon \frac{d\sigma_{TT}}{dt} \cos 2\phi$$

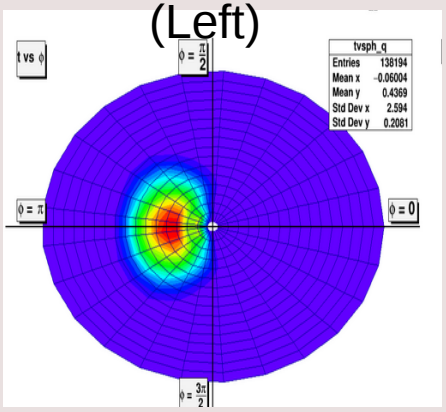
- We have acquired the data for parallel and non-parallel kinematics settings.



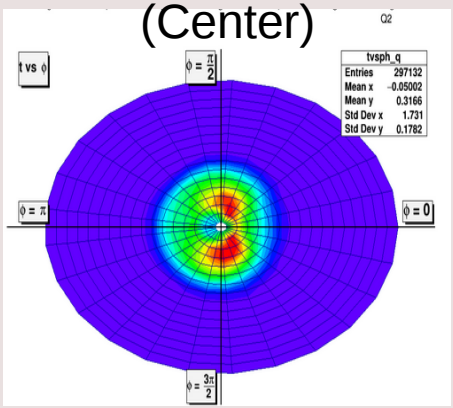
T. Horn, et al, PRL **97** (2006)192001

E_b = 10.6 GeV Q^2 = 3.0 GeV²/c² W = 3.14 GeV

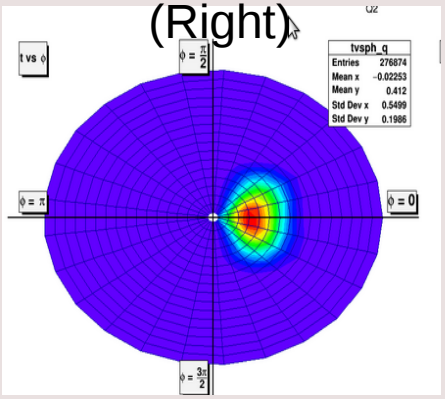
θ_{SHMS} = 12.42° (Left)



θ_{SHMS} = 9.42° (Center)



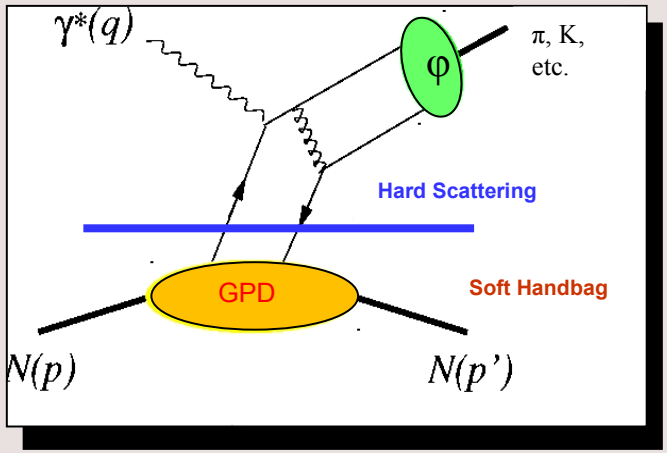
θ_{SHMS} = 6.65° (Right)

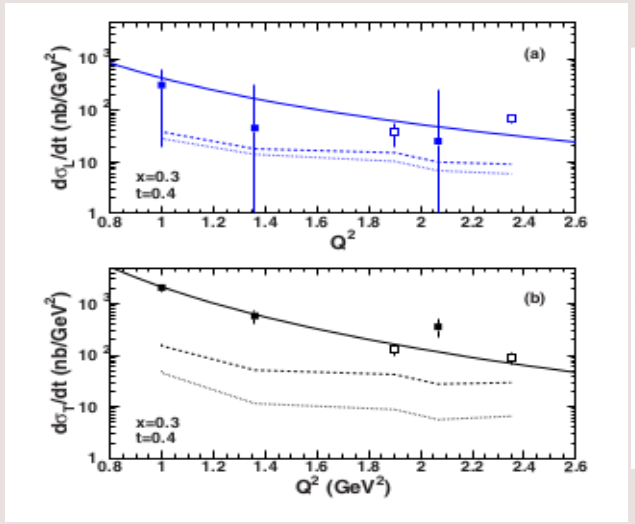


-t is the radius

e(p, e'K^+)Λ orΣ^0 L/T separation studies (QCD factorization)

- The Q^2 dependence studies at constant x_B are important to;
  - Test the factorization theorem and understand the dynamic effects in Q^2 and -t kinematics.
  - Understand the 'soft' and 'hard' contributions to the kaon wave function.
  - One of the predictions, $\sigma_L \sim 1/Q^6$ and $\sigma_T \sim 1/Q^8$ at fixed x_B.
- 6 GeV data analysis had made an effort to understand the QCD factorization test.
- We have acquired the data for the scaling studies (QCD factorization) at $x_B = 0.40$ and 0.25.

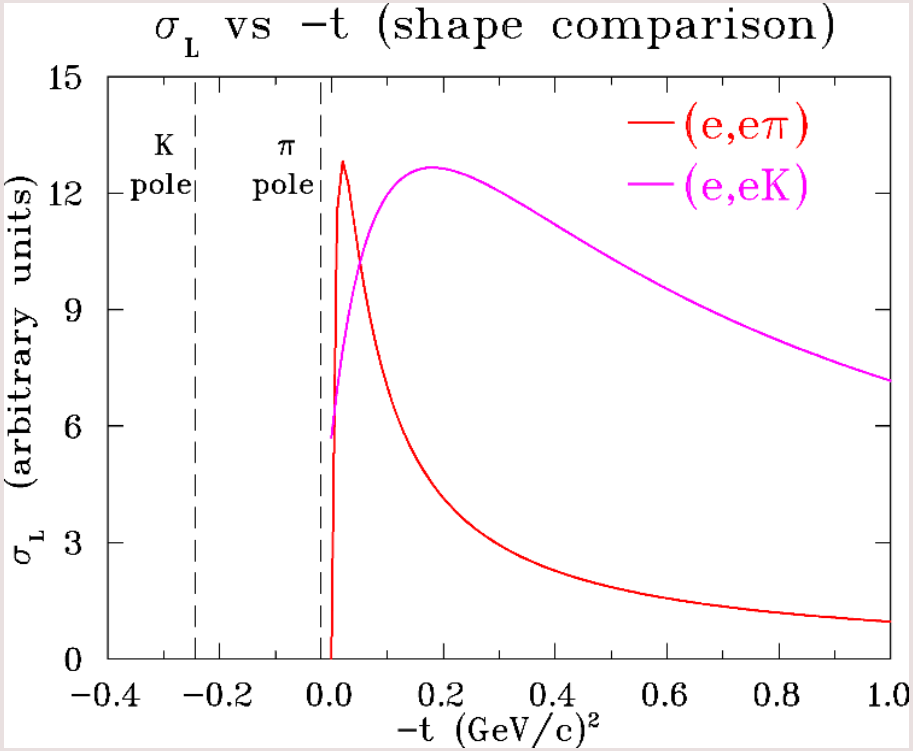


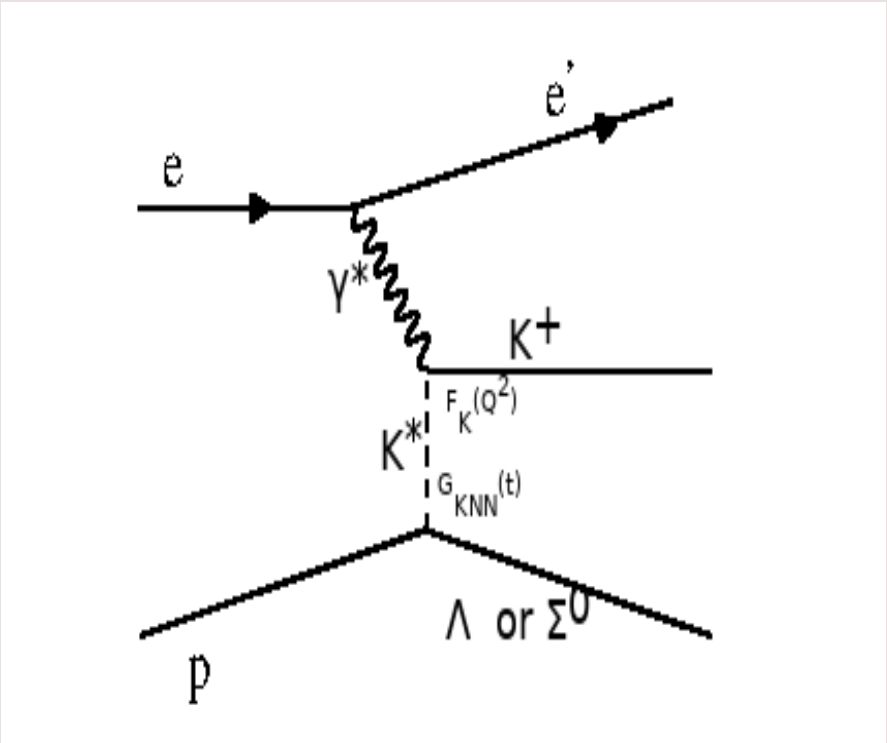


M. Carmignotto et al., PhysRevC 97(2018)025204

e(p, e'K^+)Λ orΣ^0 L/T separation studies (test for the kaon pole)

- The -t dependence studies at constant Q^2 are pivotal to;
  - Test the kaon pole dominates σ_L at smallest -t. This test is required to extract the kaon form factor from the σ_L. This test has never been done before.
  - The kaon pole is further away than pion from the kinematically allowed region.

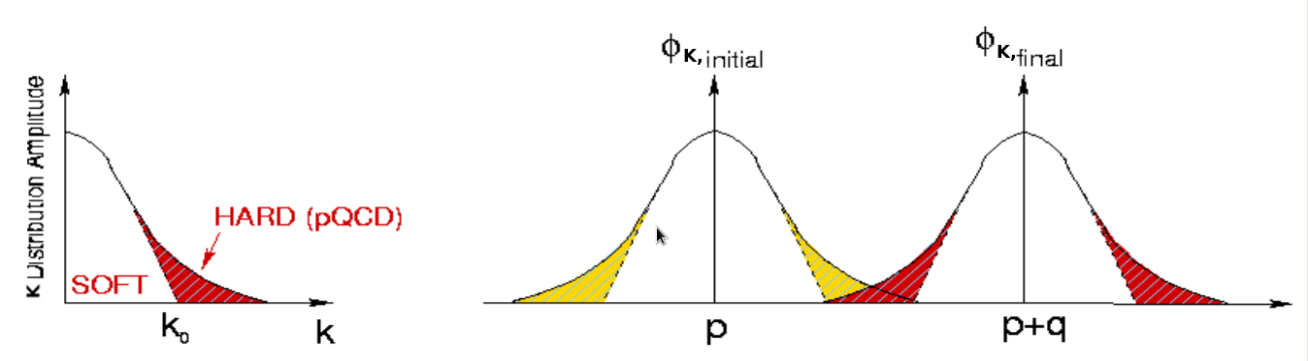




The meson wave function (form factor)

- The electromagnetic form factor is an important physical observable connected directly to the internal structure of mesons.
  - In quantum theory, the kaon form factor is the overlap of integral over the wave functions of the initial and final state kaon,

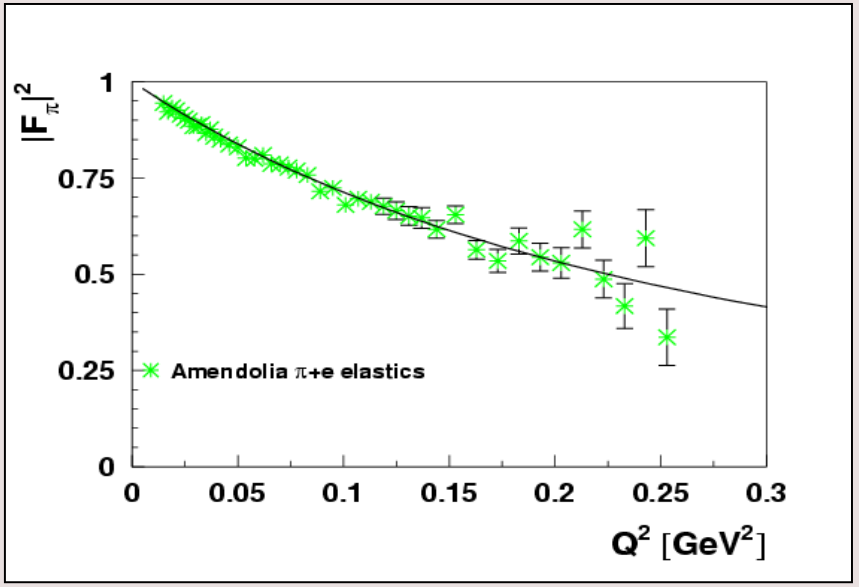
$$F_K(Q^2) = \int \phi_K^*(p)\phi_K(p+q)dp.$$



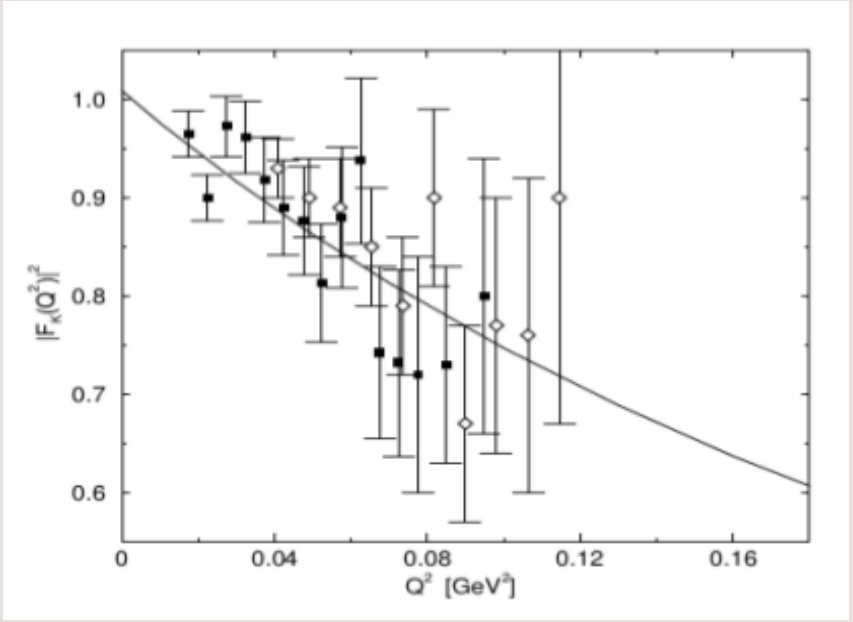
- The meson wave function can be separated into two regions.
  - Φ_K^{soft}, ($k < k_0$) low momentum contributions which can not be treated in pQCD.
  - Φ_K^{hard}, hard tail can be treated in pQCD.

π and K form factors at very low Q^2 (elastic scattering)

- $F_\pi(Q^2)$ and $F_K(Q^2)$ are known at very low Q^2 which were measured using π^-/K^- beams scattered elastically from atomic electrons.
  - π^- of 300 GeV, data were collected up to $Q^2 = 0.28$ GeV^2.
  - K^- of 250 GeV, data were collected up to $Q^2 = 0.13$ GeV^2.
- These measurements were used to determine the charge radius of the π and K.
  - The slope of the fitting function at $Q^2 = 0$ provides the charge radius.
  - $\langle r^2 \rangle = -(6dF/dQ^2)_{Q2=0}$.
  - π charge radius $\langle r^2 \rangle^{1/2} = 0.657 \pm 0.012$ fm.
  - K charge radius $\langle r^2 \rangle = 0.340 \pm 0.050$ fm^2.



[Amendolia, et al., NP **B277** (1986) 168]



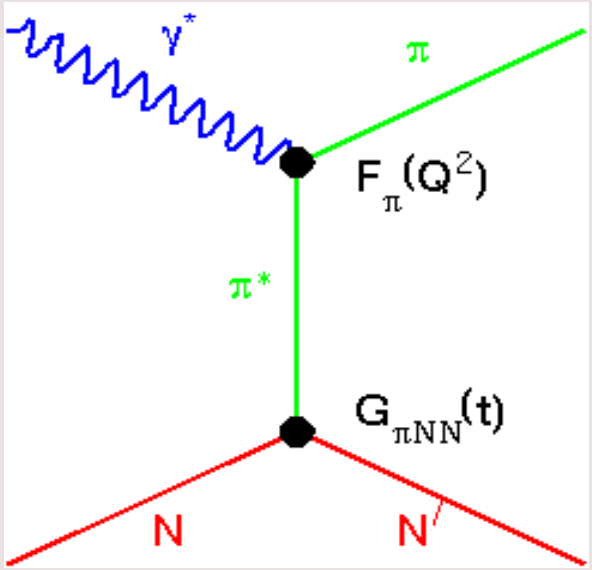
[Amendolia, et al., PL **B178** (1986) 435]

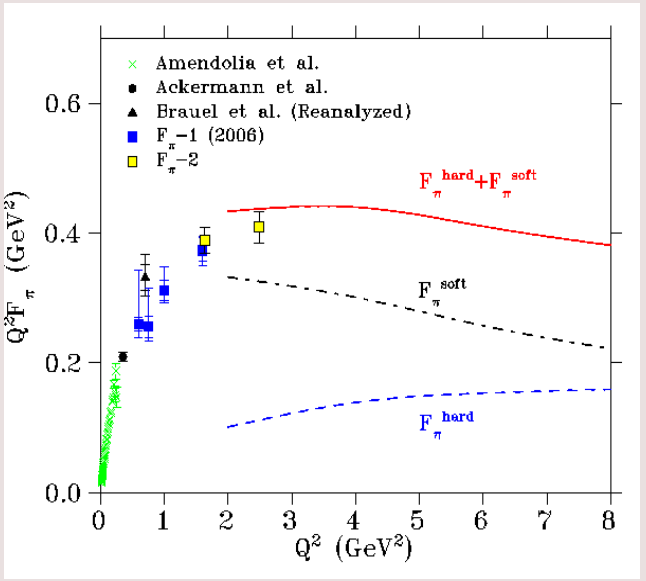
π and K form factors at high Q^2

- At high Q^2, direct scattering is not achievable.
  - This requires very high energy π/K beams. For example, Q^2 = 1 GeV^2 requires ~ 1 TeV π.
- To access the form factors at high Q^2, we must employ an alternative method.
  - "Virtual cloud" of the π and K inside the proton makes the measurements possible.
  - This attempt has been made at the 6 GeV era of JLab and a few other experimental facilities earlier.
- In Born term model, the form factor appears as,

$$\frac{d\sigma_L}{dt} \propto \frac{-tQ^2}{(t - m_K^2)} g_{K\Lambda N}^2(t) F_K^2(Q^2, t)$$

  - In our measurements, we will not use the Born term model.
  - The form factors are model dependent.





G.M. Huber et al., PRC **78** (2008) 045203.

KaonLT data and students analysis focus

10.6, 4.9 and 3.8 GeV data acquired in fall 2018.

Richard: Analyzing kaon for 10.6, 8.2 and 6.2 GeV.

Ali: Analyzing pion from the kaon data for 10.6, 8.2 and 6.2 GeV.

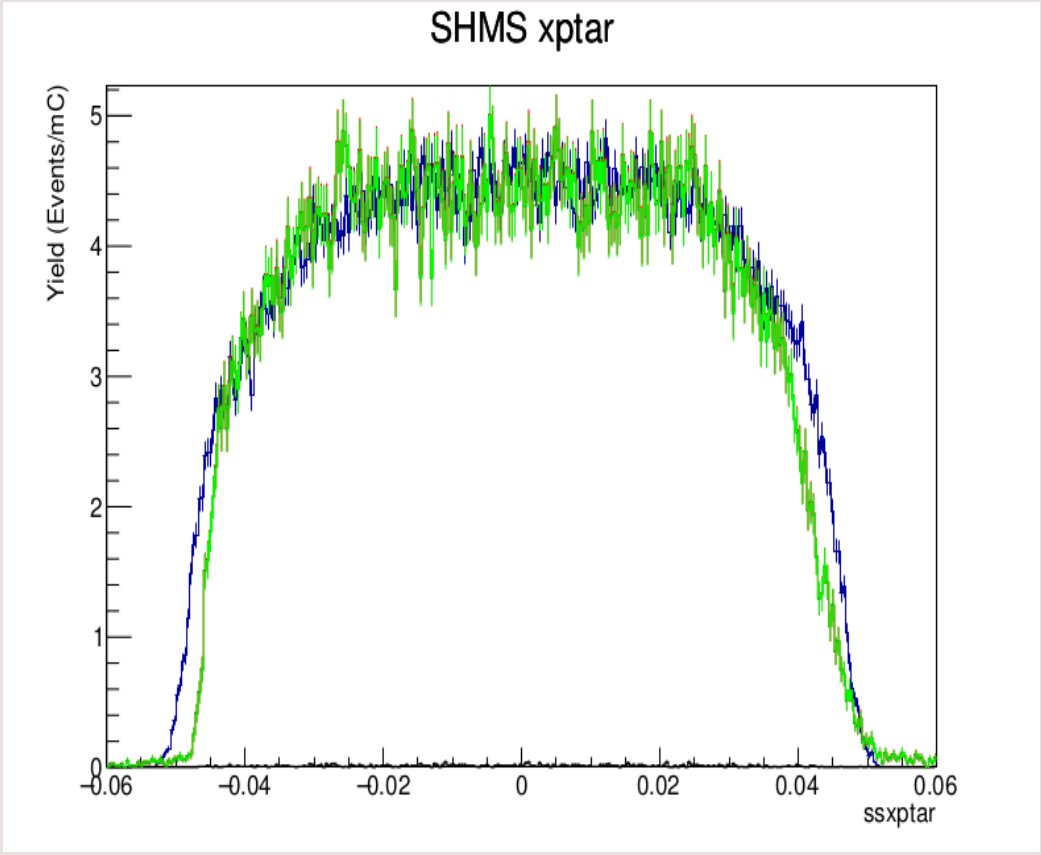
Vijay: Analyzing kaon for 3.8 and 4.9 GeV.

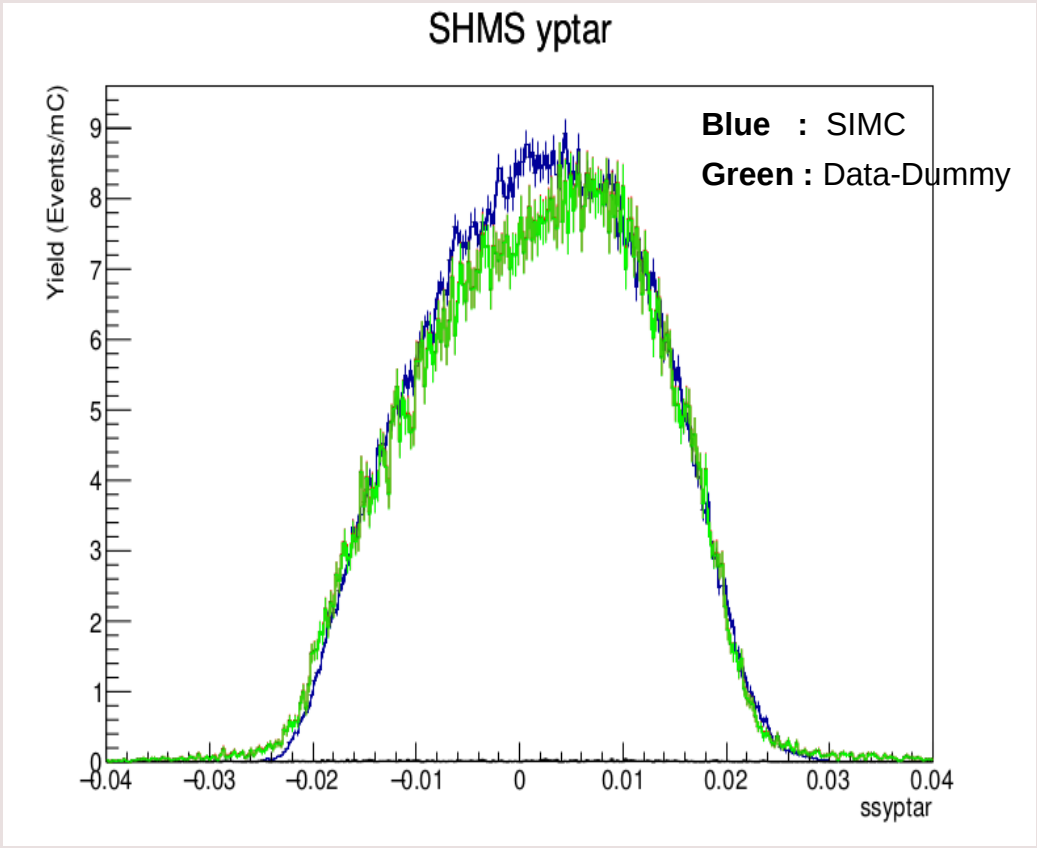
E_b (GeV)	Q^2 (GeV^2/c^2)	W (GeV)	x_B	$\varepsilon_{High}/\varepsilon_{Low}$	Study Type
10.6/8.2	5.5	3.02	0.40	0.53/0.18	scaling
10.6/8.2	4.4	2.74	0.40	0.72/0.48	scaling
10.6/8.2	3.0	3.14	0.25	0.67/0.39	both
10.6/6.2	3.0	2.32	0.40	0.88/0.57	scaling
10.6/6.2	2.115	2.95	0.21	0.79/0.25	both
4.9/3.8	0.5	2.40	0.09	0.70/0.45	FF

8.2 and 6.2 GeV data acquired in winter 2019.

Analysis update ('Heep', $^1H(e,e'p)$, Analysis)

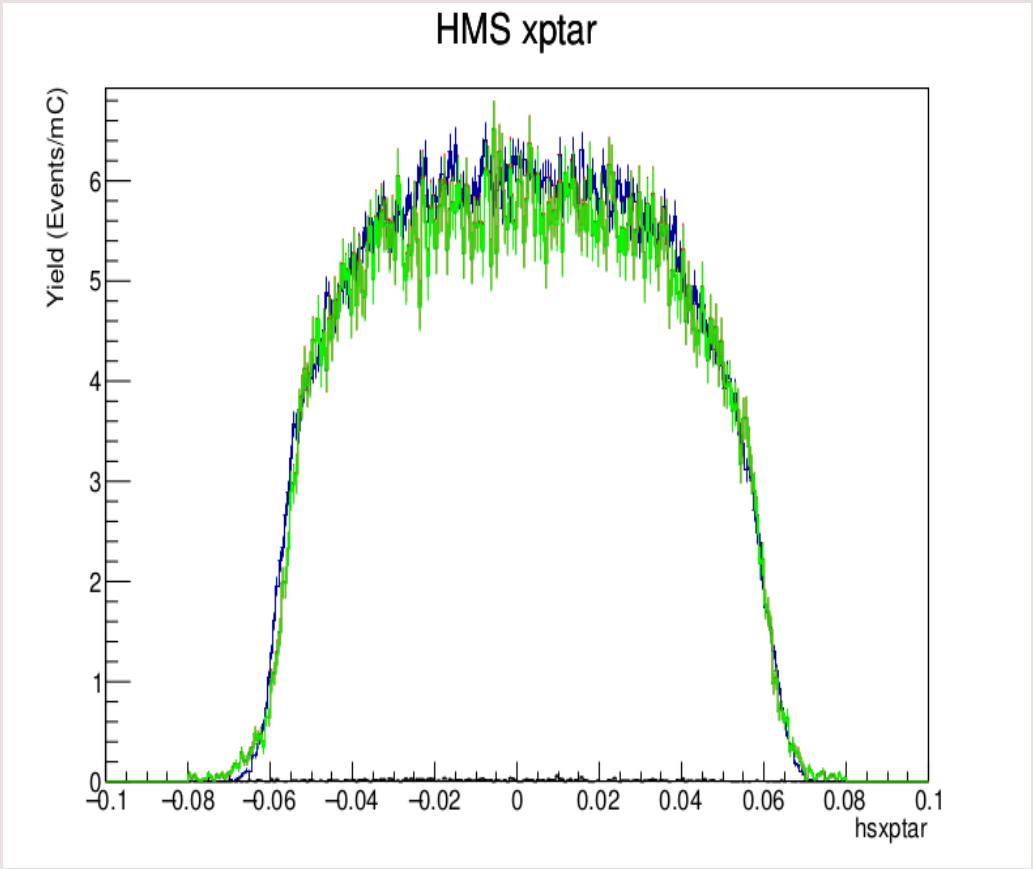
- We did check the first round of the elastics cross section to understand the data.
  - The plots in this talk are E_b = 3.9 GeV, P_{SHMS} = 2.583 GeV, P_{HMS} = 2.026 GeV, θ_{SHMS} = 29.305° & θ_{HMS} = 38.605° setting. These plots are the preliminary comparison of data and MC.
- Reconstructed proton's vertical (xptar) and horizontal (yptar) angles at the target.

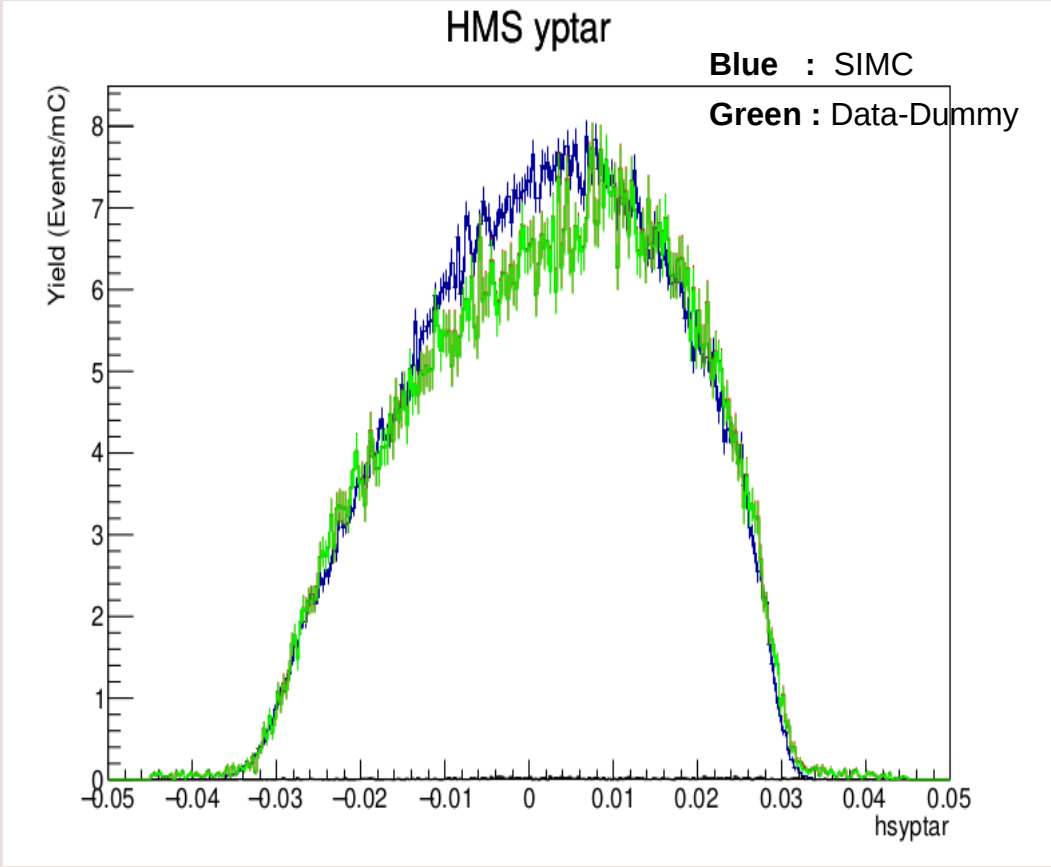




Analysis update ('Heep', $^1H(e,e'p)$, Analysis)

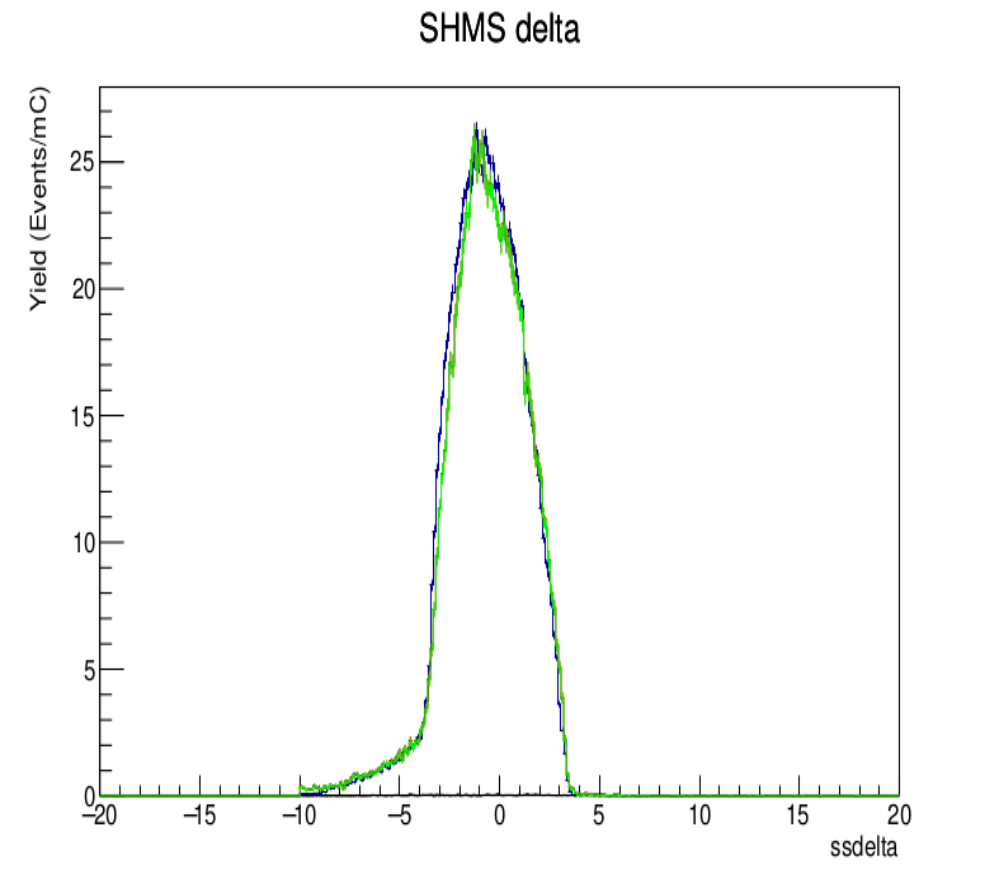
- Reconstructed electron's vertical (xptar) and horizontal (yptar) angles at the target.

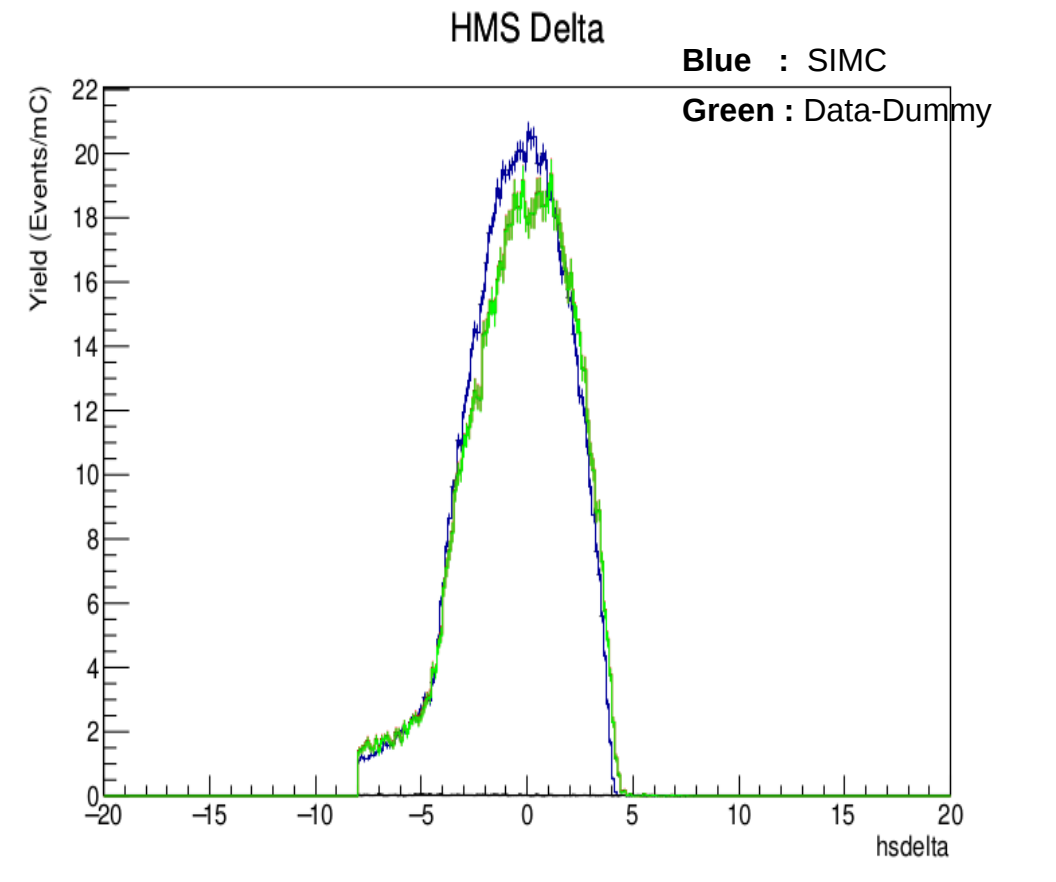




Analysis update ('Heep', $^1H(e,e'p)$, Analysis)

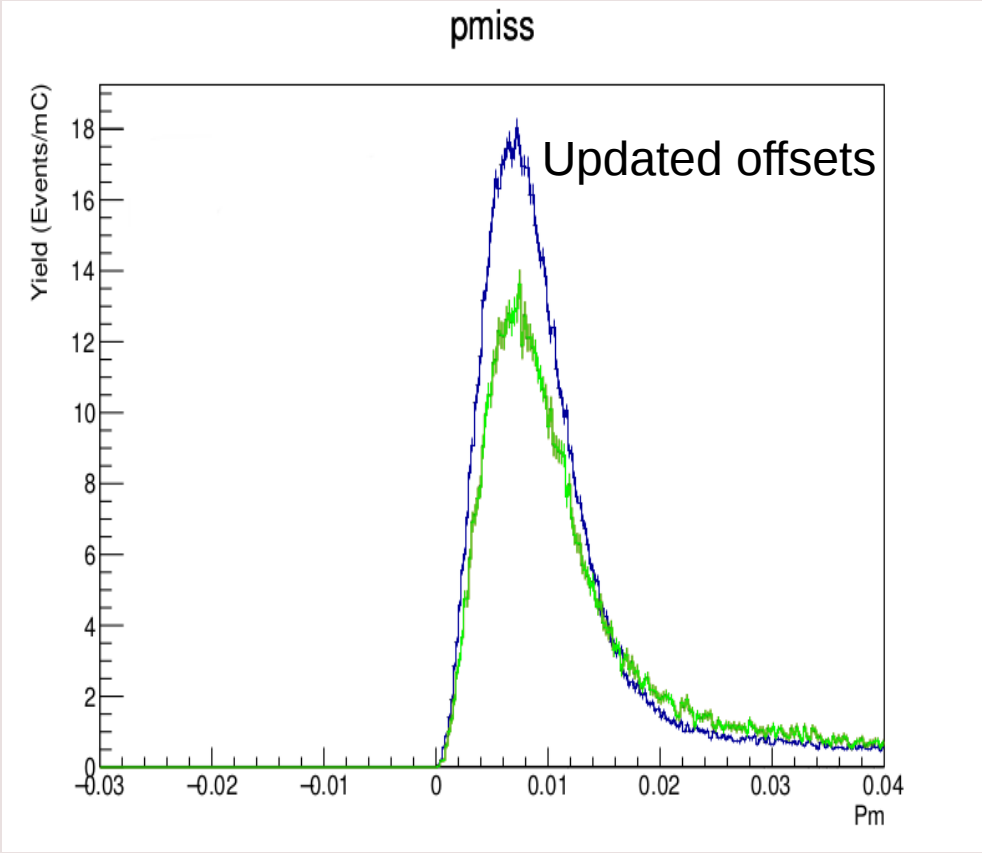
- Reconstructed the SHMS and HMS deltas.

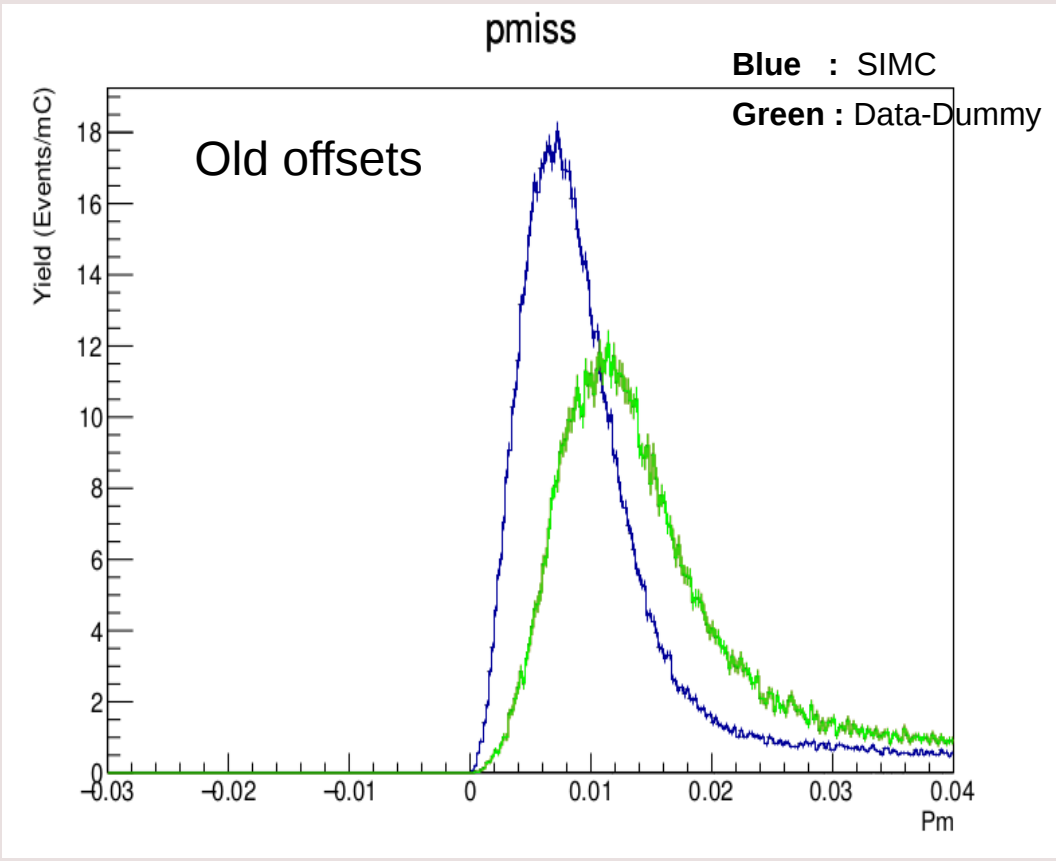




Analysis update (‘Heep’, $^1H(e,e'p)$, Analysis, Offsets)

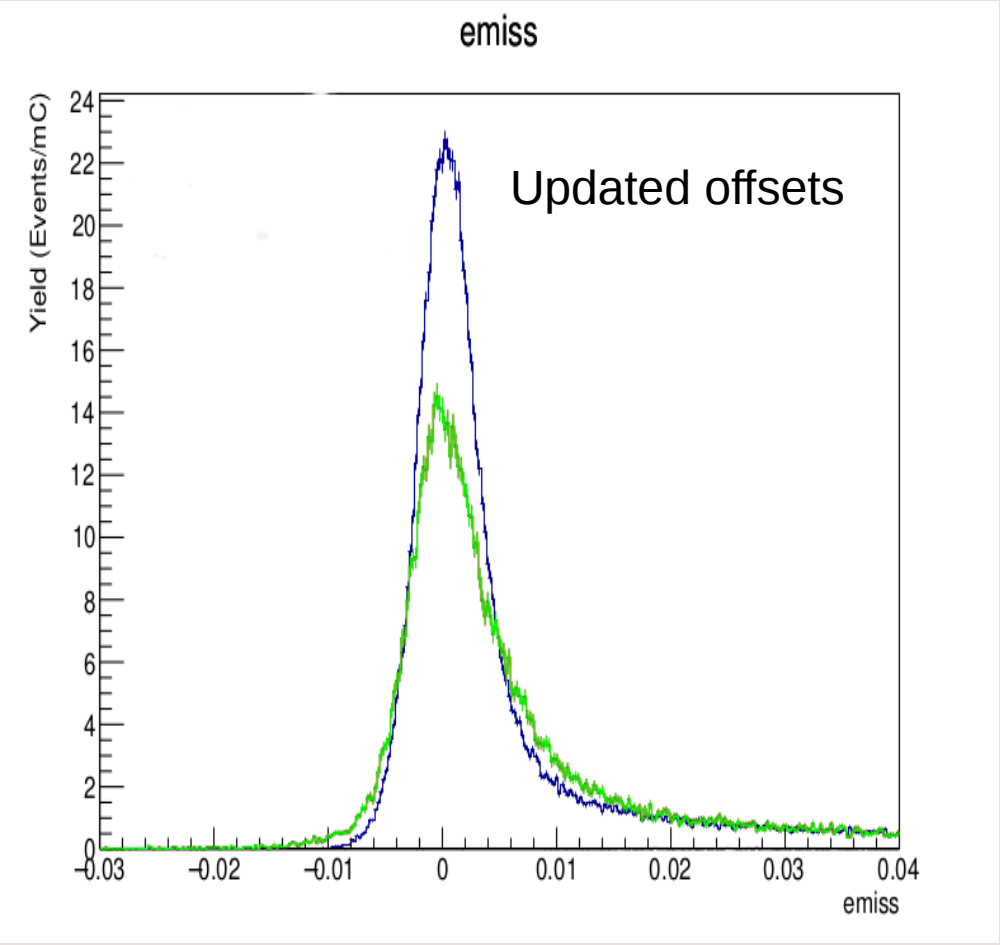
- The preliminary investigation of the offsets at 3.8 GeV data has been completed with the help of the ‘heepcheck’ program.
  - -0.13% HMS central momentum offset is determined.
  - Effect of -0.13% HMS central momentum offset on missing momentum.

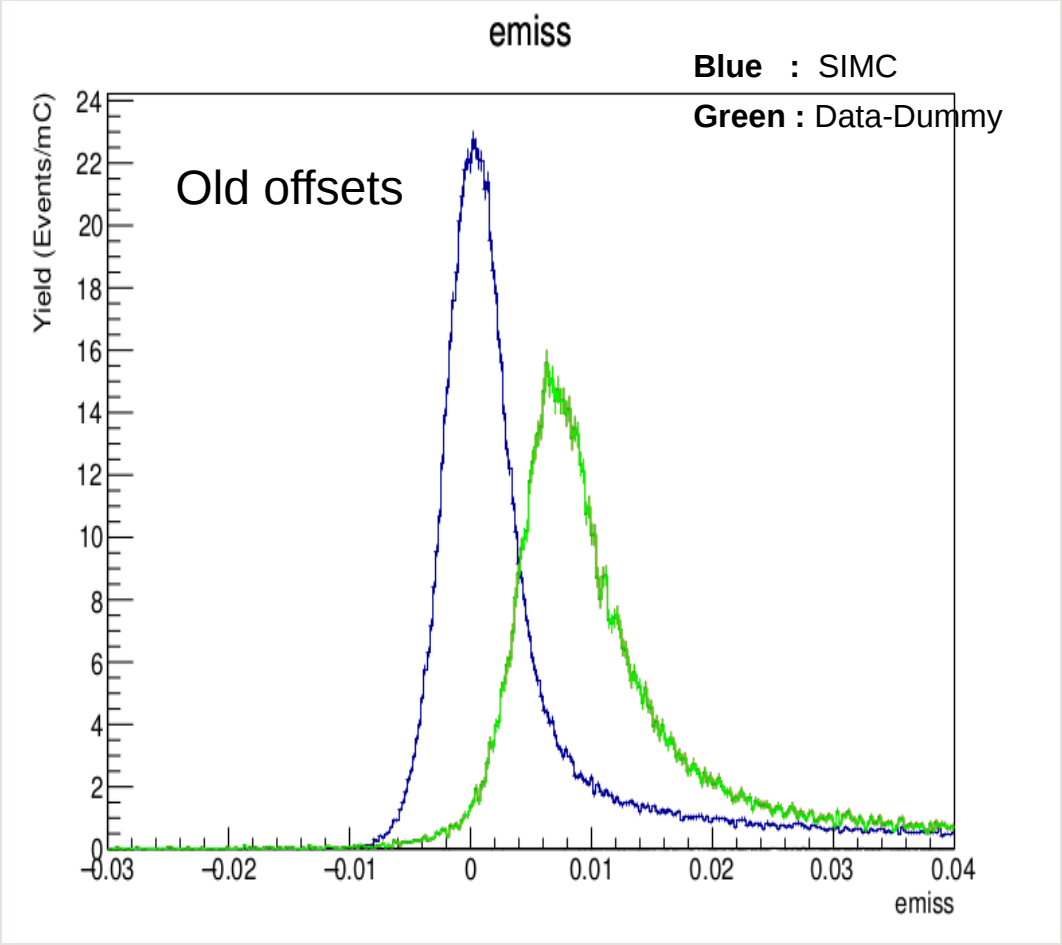




Analysis update ('Heep', $^1H(e,e'p)$, Analysis, Offsets)

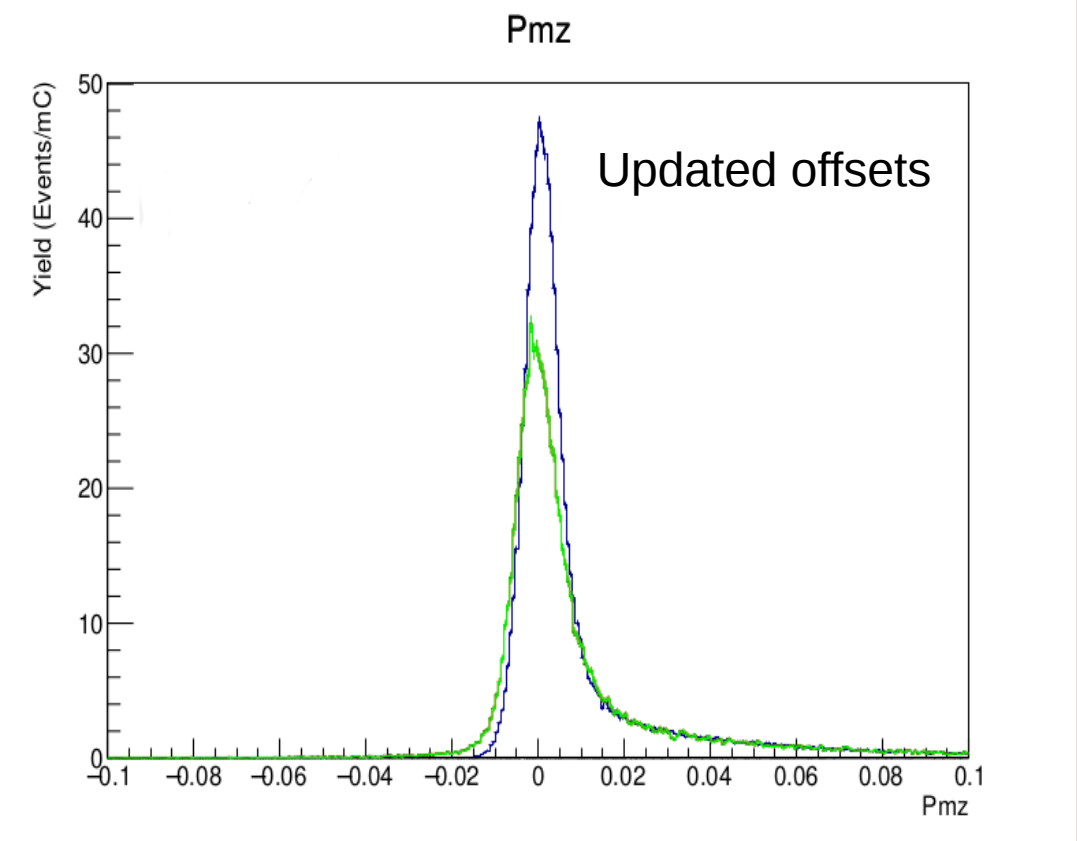
- Effect of -0.13% HMS central momentum offset on missing energy.

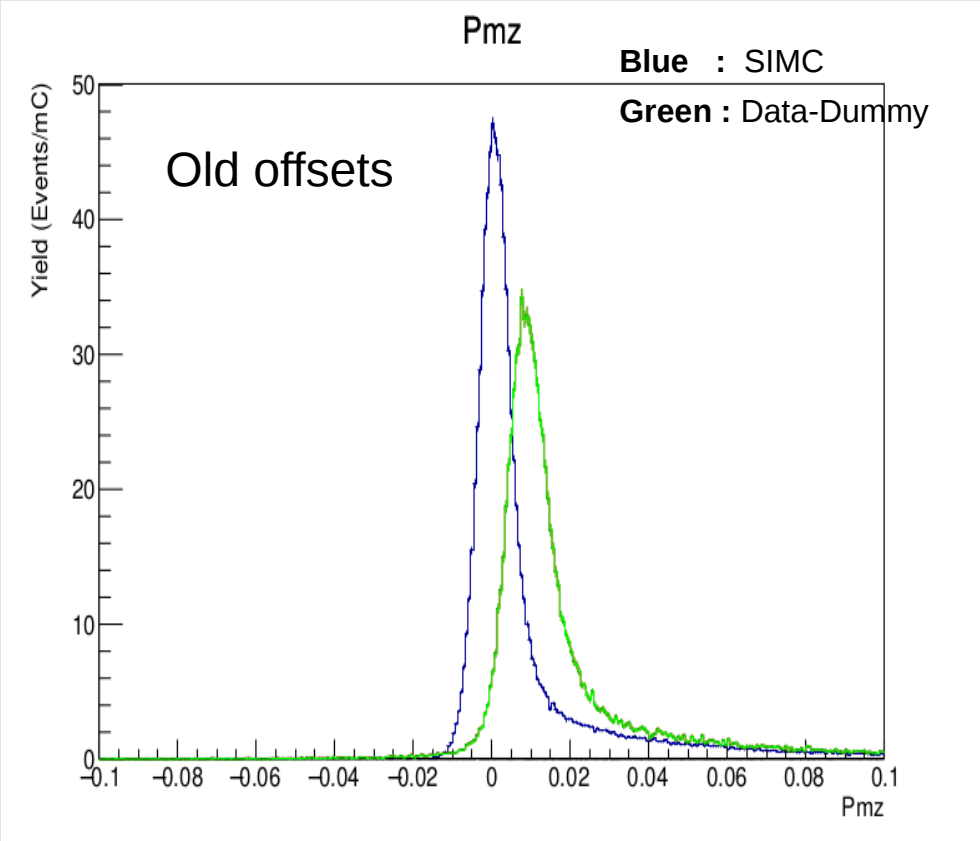




Analysis update ('Heep', $^1H(e,e'p)$, Analysis, Offsets)

- Effect of -0.13% HMS central momentum offset on momentum's z-component.

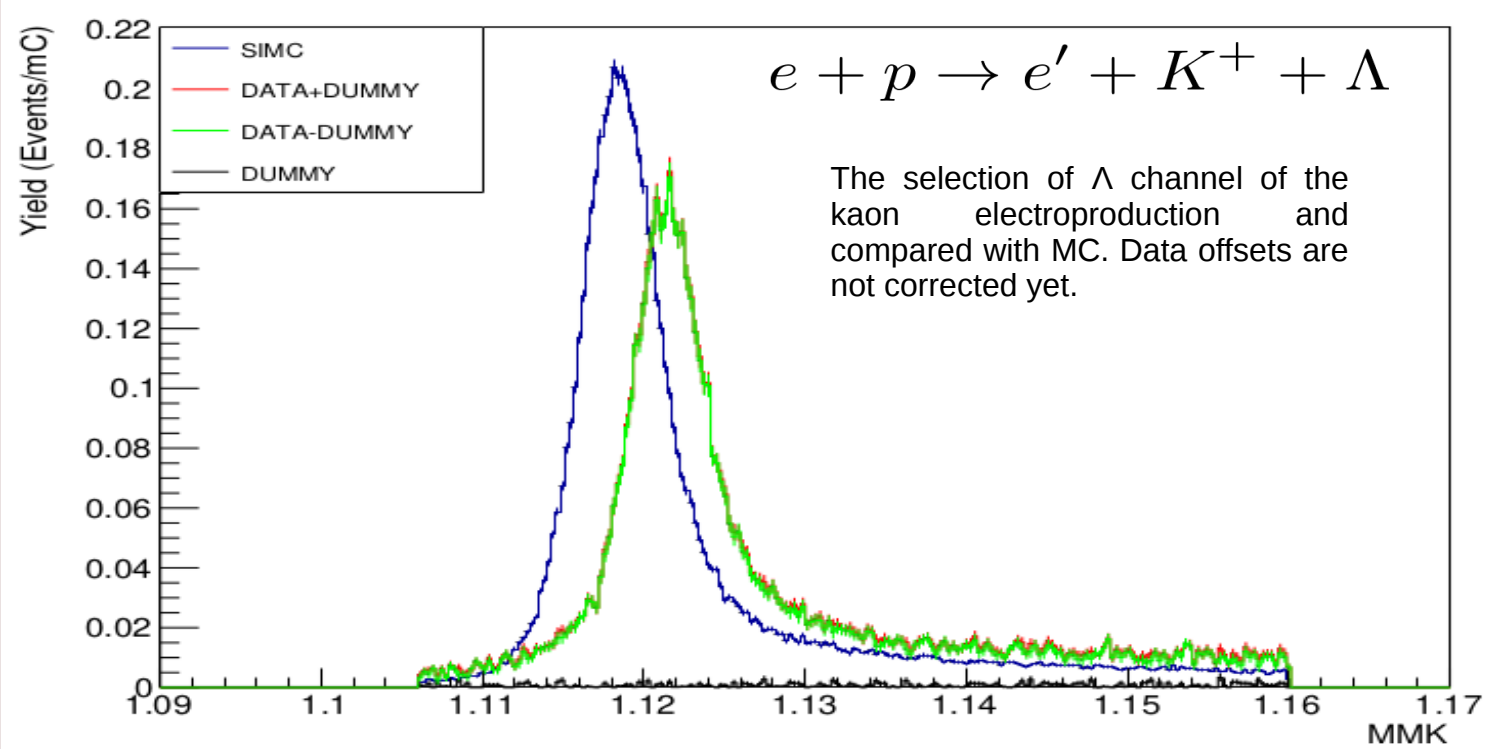




- The offsets study is still in progress, we are working to optimize the offsets and better understand them for the kaon electroproduction analysis.
- The first round of the heep (elastic) coin/singles study at 4.9 GeV data is also completed.

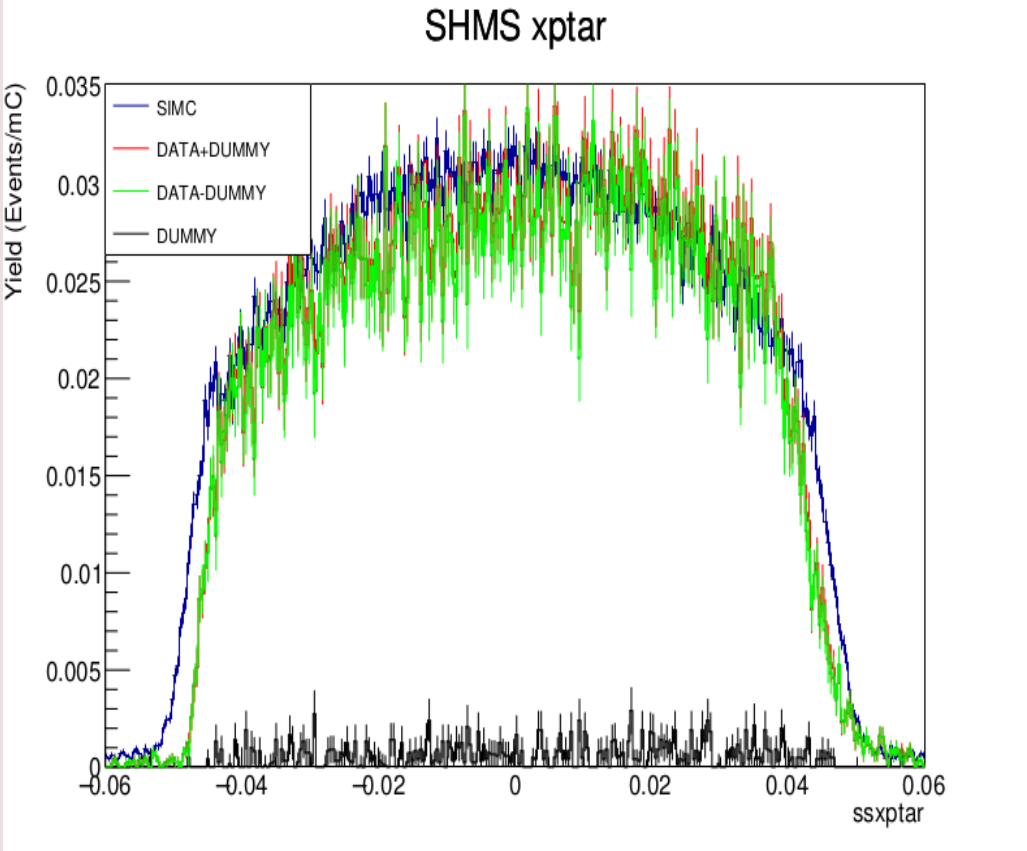
Analysis update ('Physics' , $e + p \rightarrow e' + K^+ + \Lambda$, Analysis)

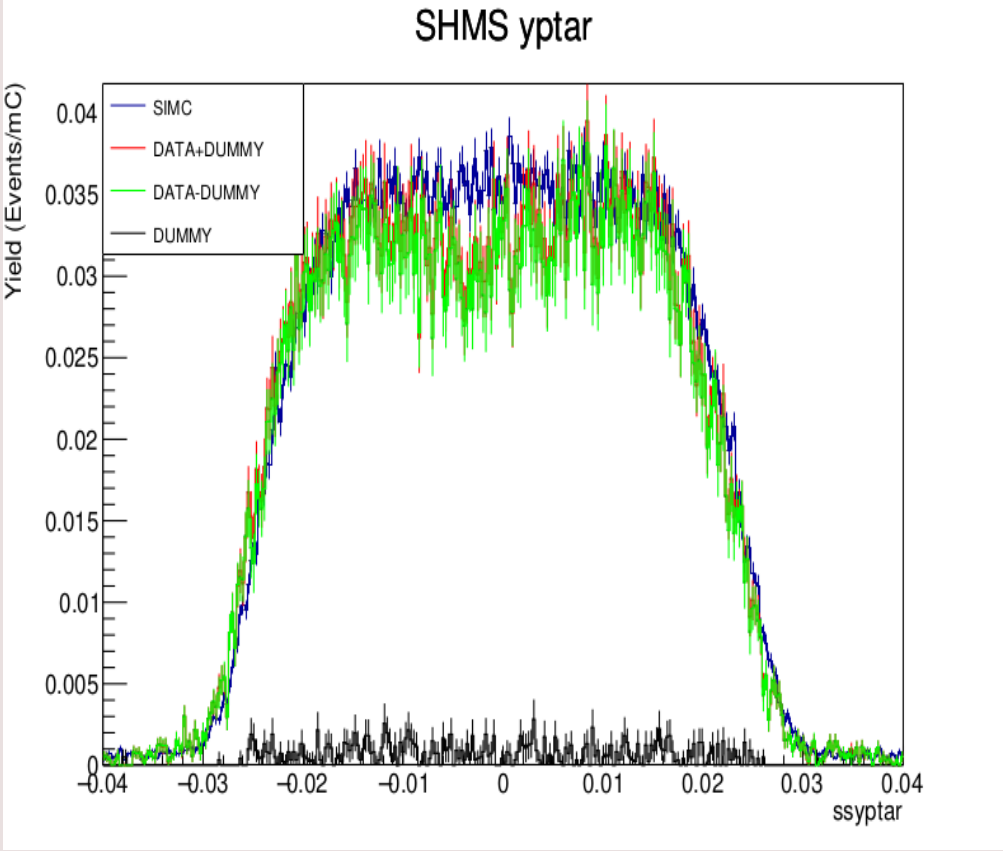
- We have completed the first round of the physics analysis (comparison between the experimental data and MC) of the kaon electroproduction data.
  - The plots in this talk are E_b = 3.9 GeV, P_{SHMS} = 2.583 GeV, P_{HMS} = 0.968 GeV, θ_{SHMS} = 6.79° & θ_{HMS} = 21.14° setting. These plots are the preliminary comparison of data and MC.
  - The comparison is made for Λ channel, $e + p \rightarrow e' + K^+ + \Lambda$.
  - The offsets from the heep analysis **are NOT applied yet**. Work is still in progress.
- Comparison of simulated and data MMK for Λ channel.



Analysis update ('Physics' , $e + p \rightarrow e' + K^+ + \Lambda$, Analysis)

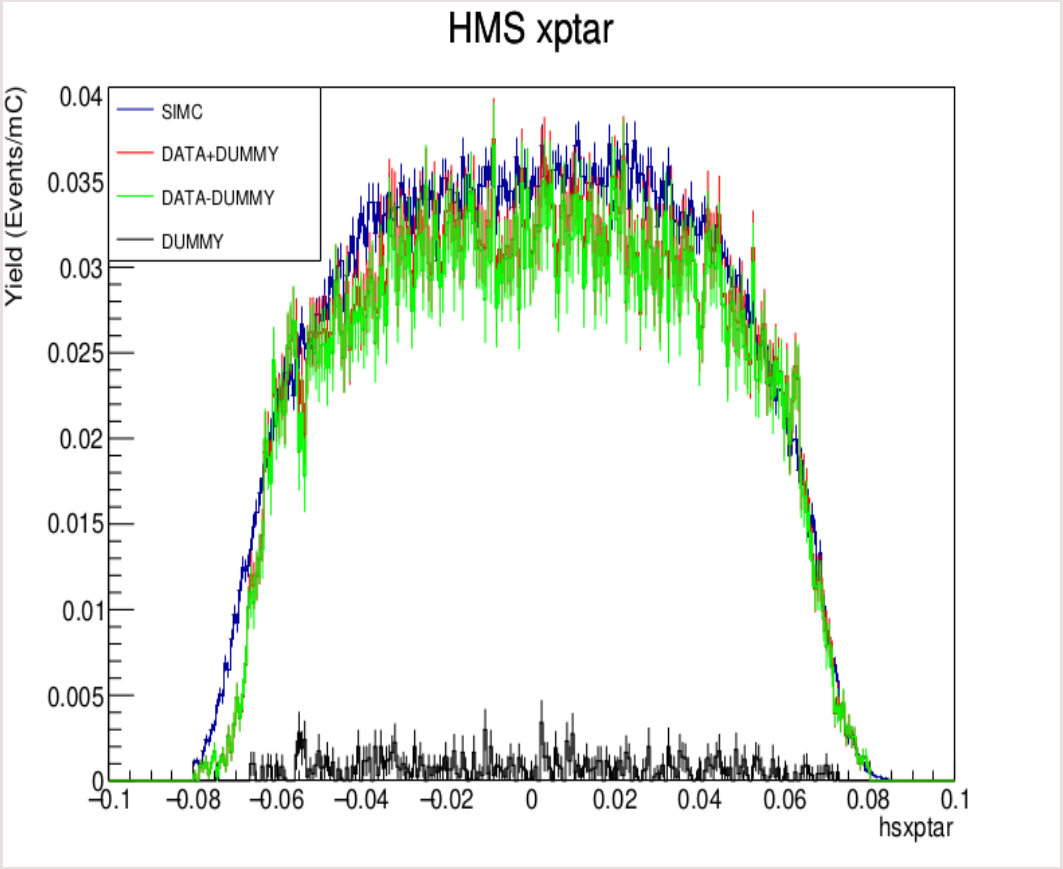
- Reconstructed kaon's vertical (xptar) and horizontal (yptar) angels at the target .

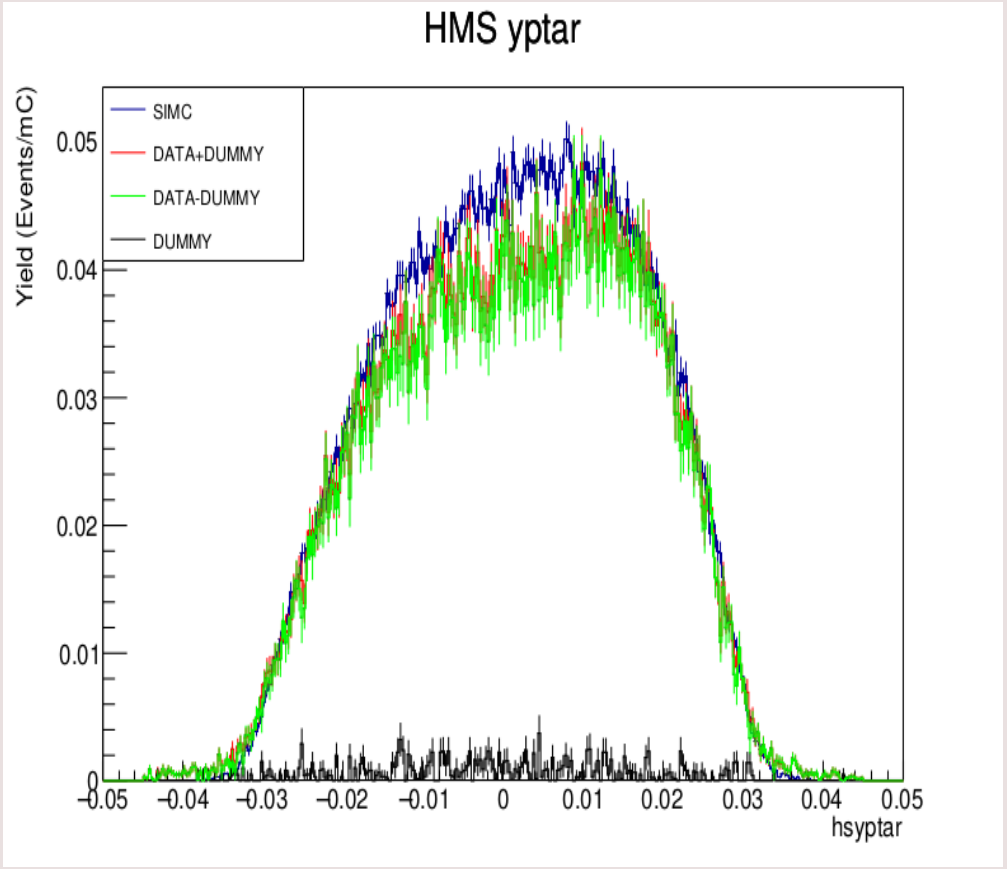




Analysis update ('Physics' , $e + p \rightarrow e' + K^+ + \Lambda$, Analysis)

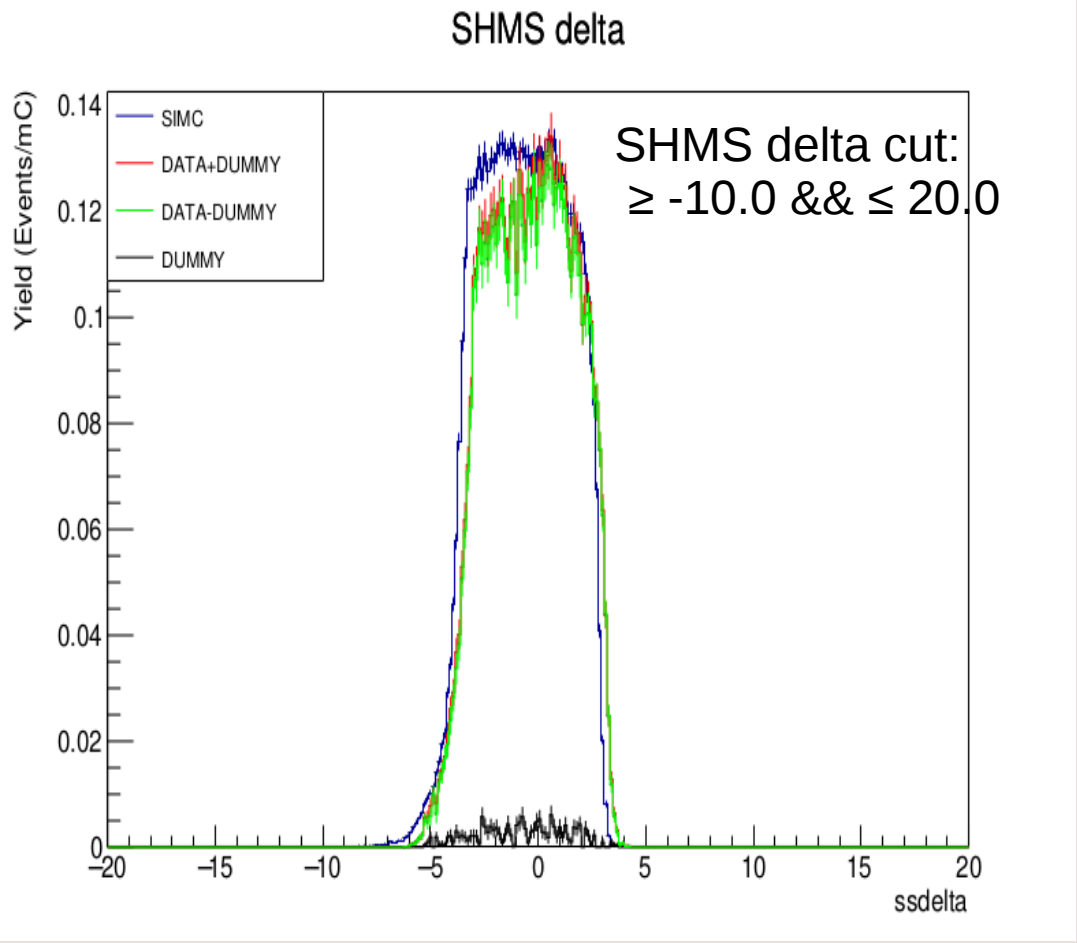
- Reconstructed electron's vertical (xptar) and horizontal (yptar) angels at the target.

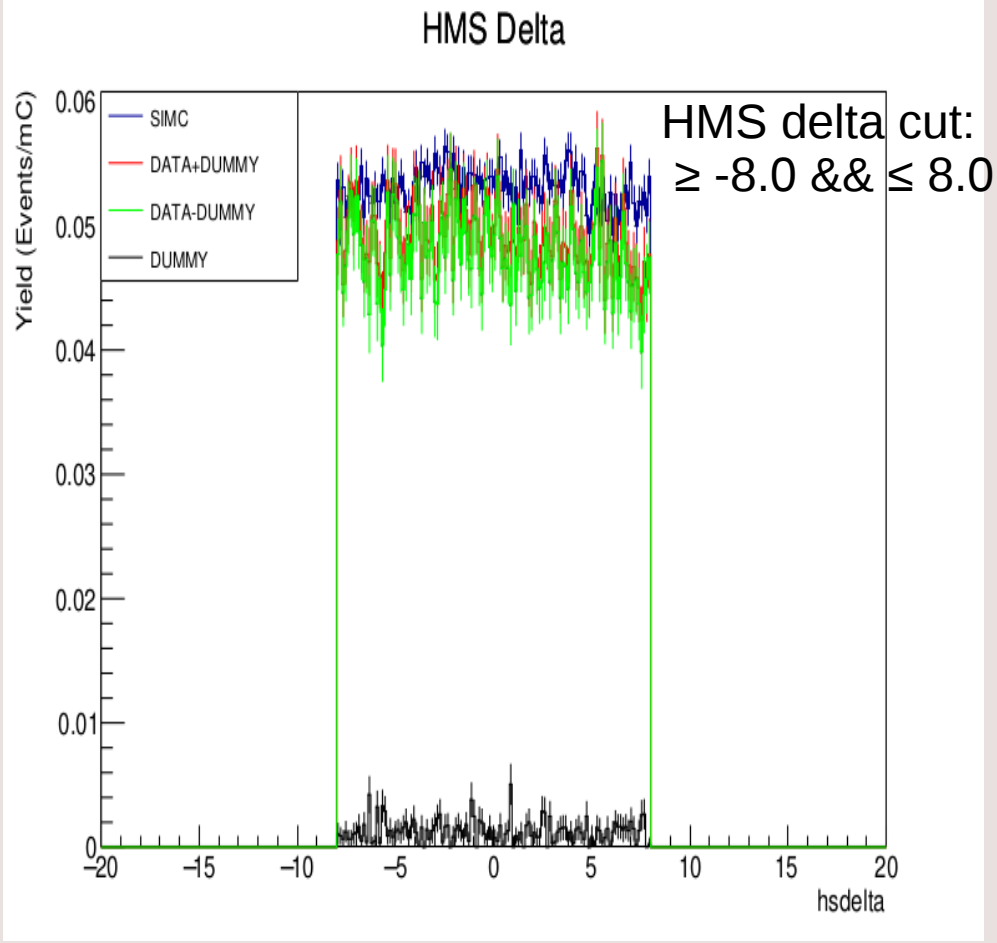




Analysis update ('Physics' , $e + p \rightarrow e' + K^+ + \Lambda$, Analysis)

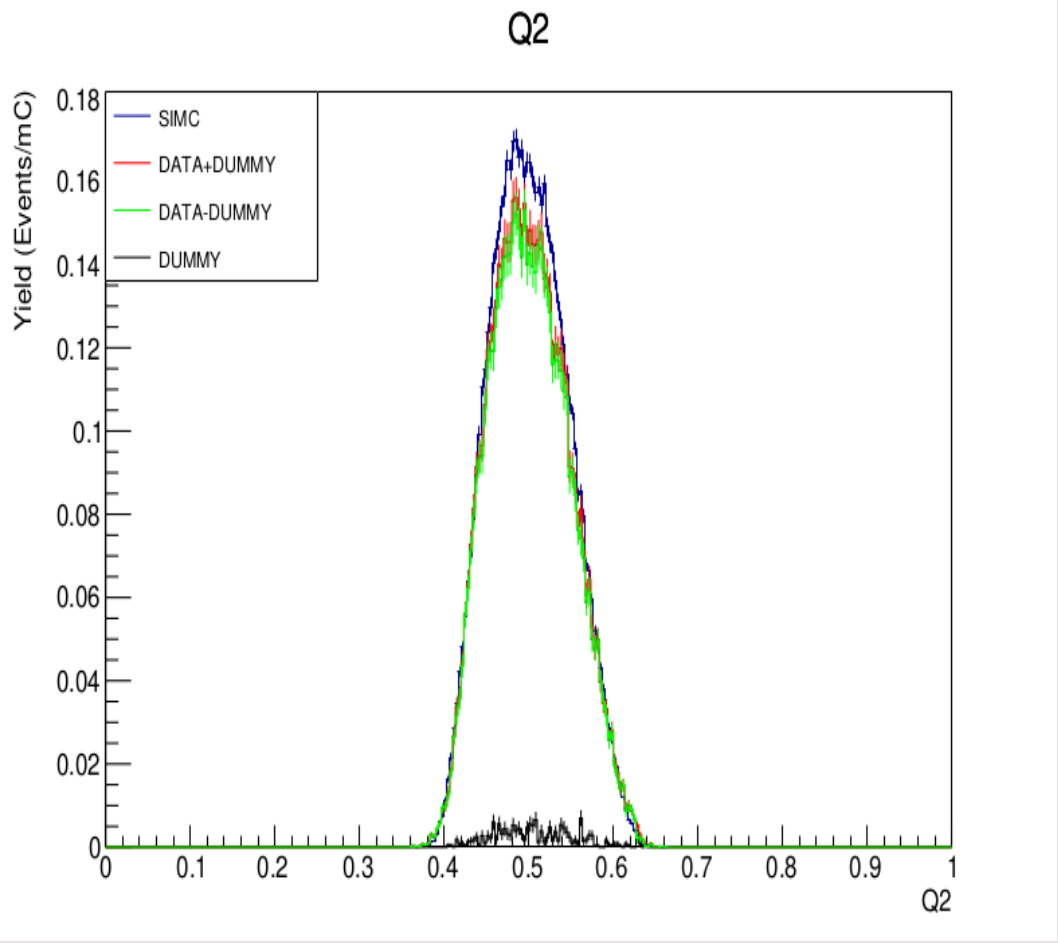
- Reconstructed the SHMS and HMS deltas.

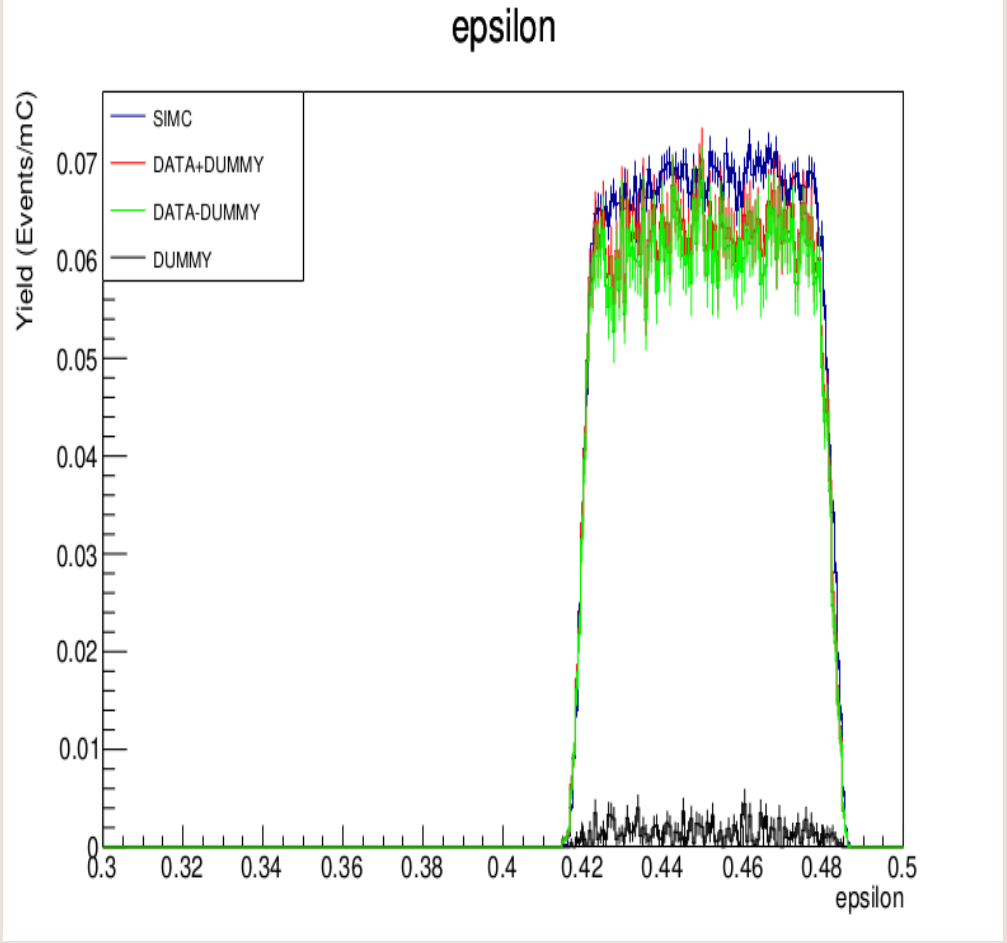




Analysis update ('Physics' , $e + p \rightarrow e' + K^+ + \Lambda$, Analysis)

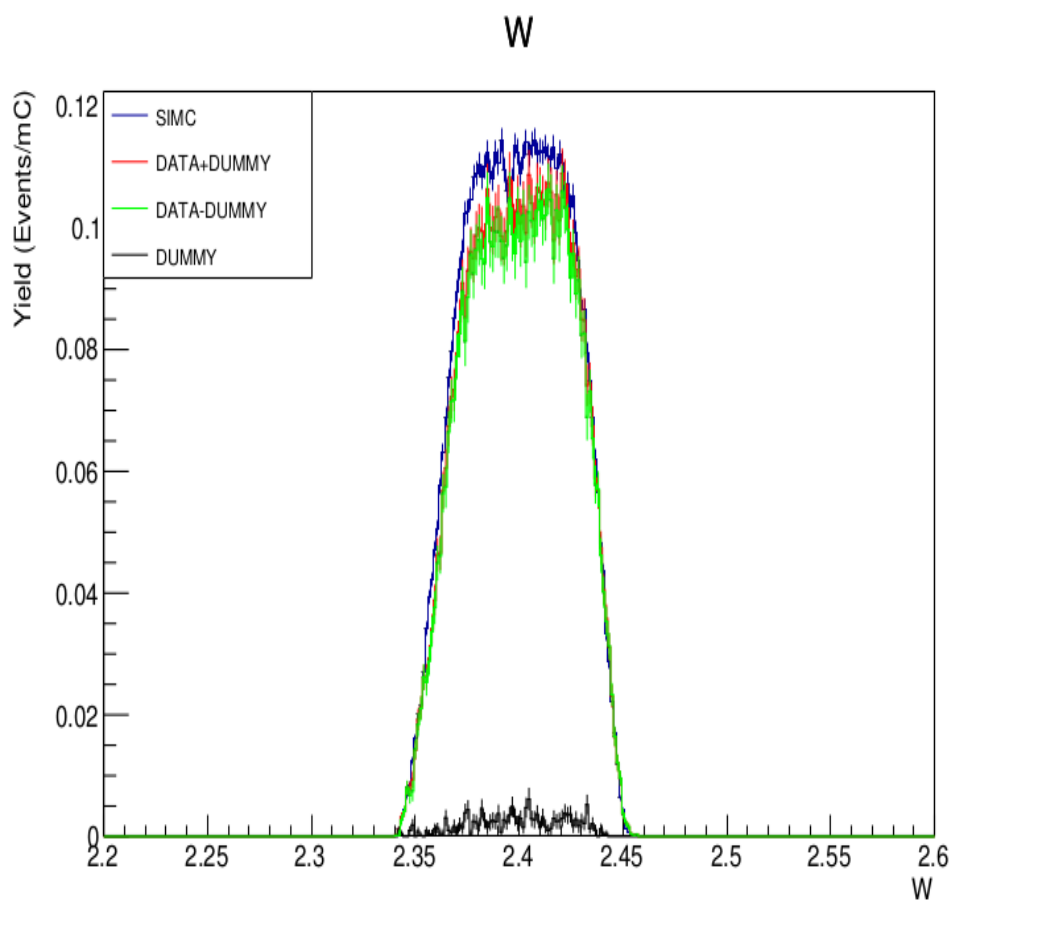
- Comparison of data and MC for the physics quantities Q^2 and **ε**.

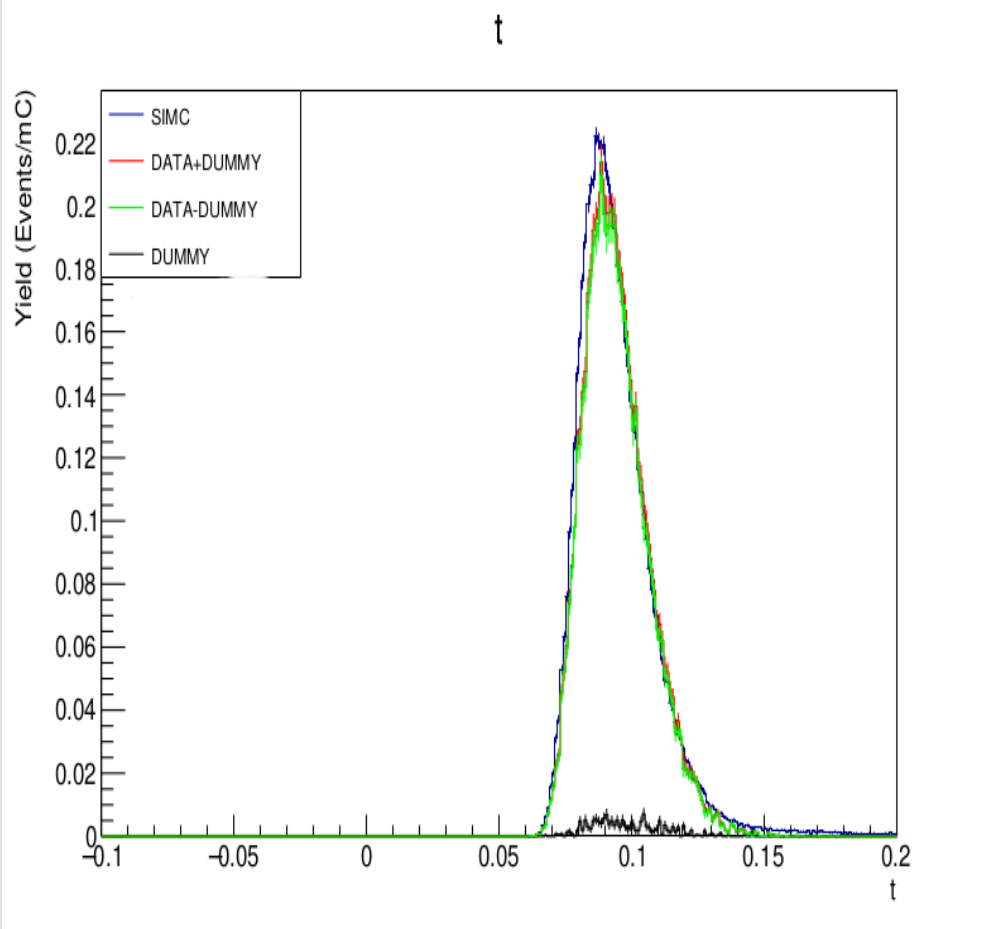




Analysis update ('Physics' , $e + p \rightarrow e' + K^+ + \Lambda$, Analysis)

- Comparison of data and MC for the physics quantities W and **t**.





- The first round of the physics analysis at 4.9 GeV data (comparison between the experimental data and MC) is also completed.

Systematics Study

Update from Ali Usman and Richard Trotta.

- As discussed earlier, L/T separation requires data at two beam energies.
  - Very careful attention is needed to understand the spectrometer acceptance, kinematics, detector efficiency, etc.
- Understanding systematics is challenging as Kaon-LT data were taken under different detector and trigger rates at low and high ε.
- A dynamic mechanism has been developed to understand systematics (efficiencies, live times etc) and correlations.
  - This involves new ReportFiles and efficiency scripts.

Live Time Studies

Update from Ali Usman and Richard Trotta.

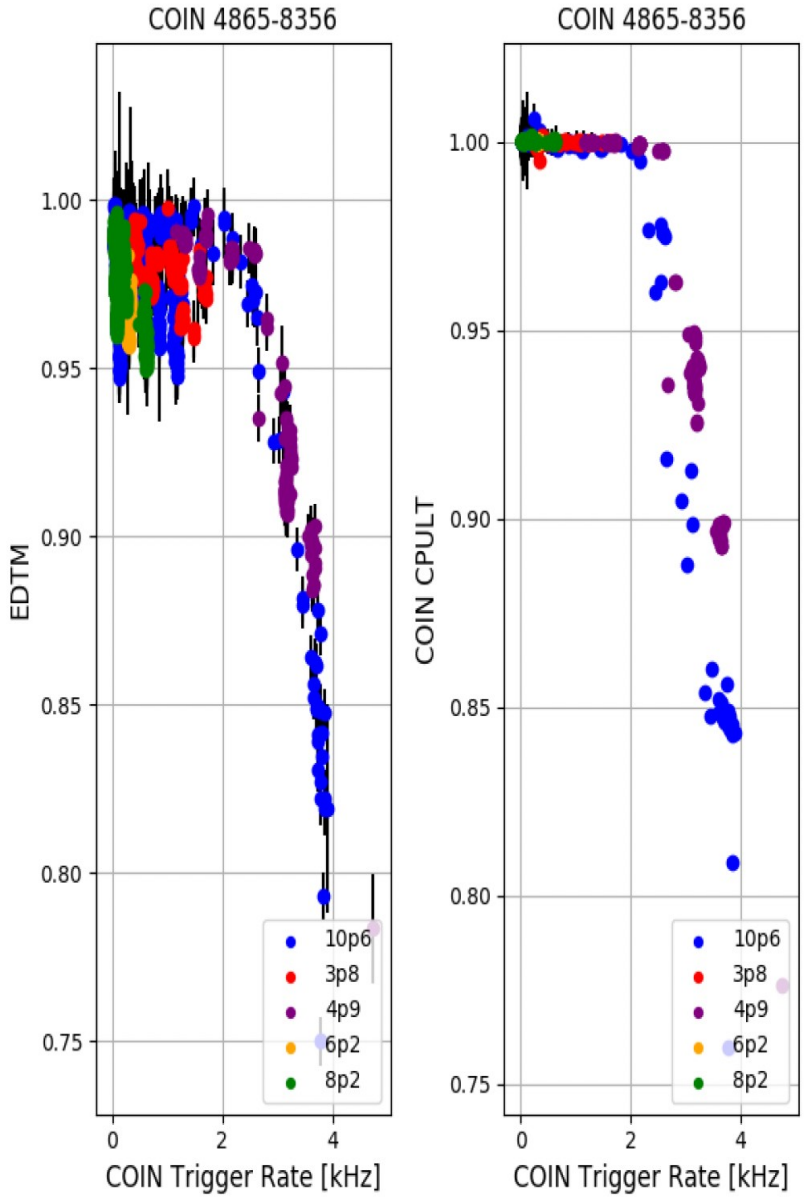
- Live times can be calculated using different sources (e.g. EDTM, CPULT etc).
- **EDTM Live Time**

$$\frac{Accepted\ EDTM\ Triggers}{Total\ EDTM\ Scalers}$$

- **CPU Live Time**

$$\frac{Accepted\ COIN\ Triggers}{Total\ COIN\ Scalers}$$

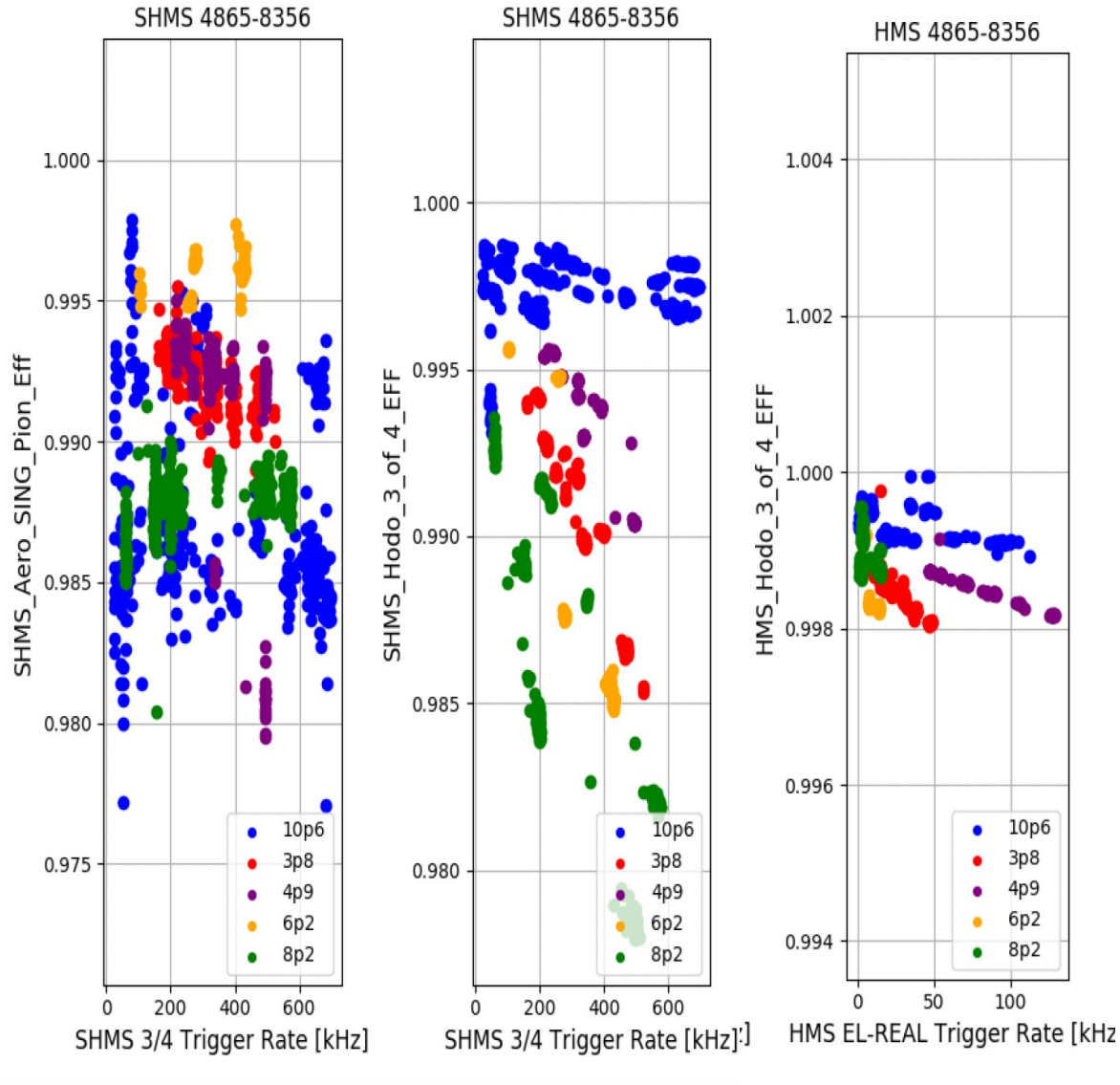
- Both CPU Live Time and EDTM Live Time show consistent trends.
- As expected, live times decrease with increase in rate.



Detector Efficiency Studies

Update from Ali Usman and Richard Trotta.

- Detector efficiency studies are still in progress.
- HMS hodoscopes are more efficient as compared to SHMS due to high rates and quartz bar in SHMS.
- Aerogel is highly efficient and therefore will be critical detector for *Kaon-Pion* separation.



Summary and future perspectives

- The preliminary heep (elastic) coin/single study at 3.9 and 4.9 GeV has been completed.
- The preliminary investigation of the offsets in the heep study at 3.9 and 4.9 GeV data has been performed.
- The preliminary comparison study (without the offsets) of the Λ channel at 3.9 and 4.9 GeV data has been completed.
- Some of the efficiency studies were performed to better understand the detectors used in the experiment.
- An effort has been made to understand the systematic uncertainties in the experiment.
- We will start the $p(e, e'K^+)\Lambda$ L/T/LT/TT separation cross-sections studies at various Q^2 settings after having a proper understanding on the heep study (most probably in fall 2022).
- In conclusion, the final data analysis is in progress, the analysis is for the high precision L/T/LT/TT separation cross-sections studies which is a complicated study.

University of Regina

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Thank You!

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