Recent Update on the analysis of Λ(1405) Electroproduction with CLAS12

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CLAS Collaboration Meeting

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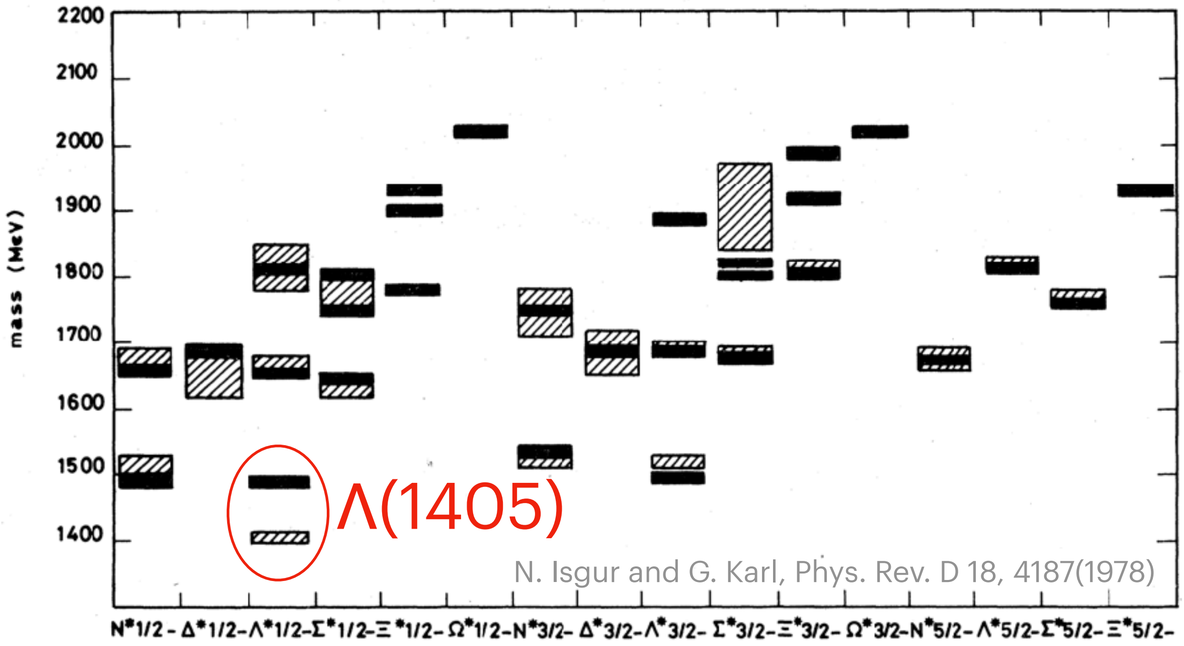
Contents

Λ(1405)

Hadron states in $SU(3)_f$ group

- Success on mass spectrum reproduction by the constituent quark model (CQM)
- Large discrepancy in first Λ resonant states, Λ(1405)
- →Beyond the CQM description → Exotic hadron



N. Isgur and G. Karl, Phys. Rev. D 18, 4187(1978)

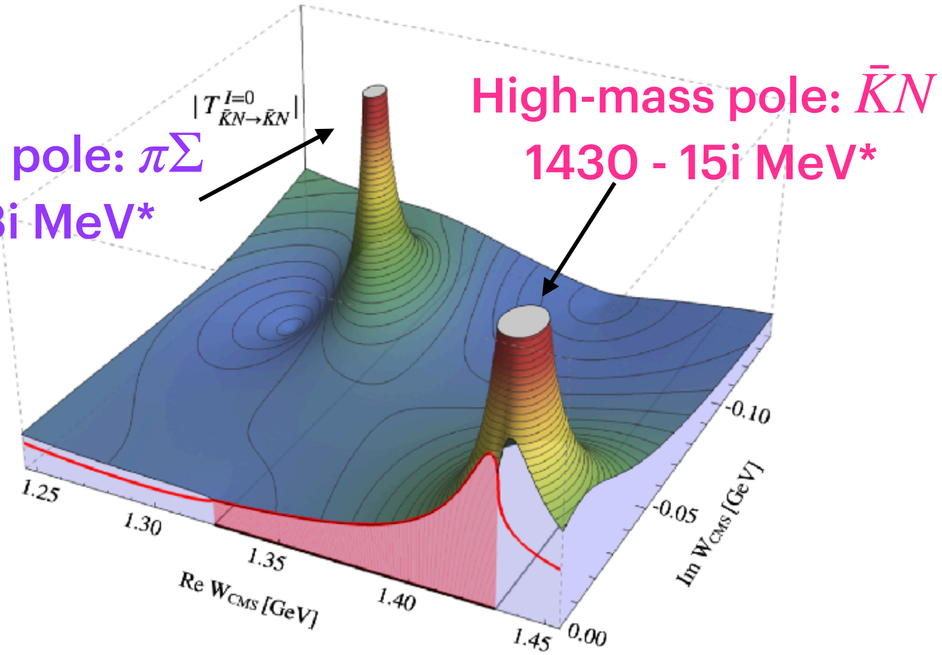
Two-pole structure of $\Lambda(1405)$

Hadron molecular states of $\pi\Sigma$ and $\bar{K}N$ are expected

Chiral unitary model(ChUM) calculation

Low-mass pole: $\pi\Sigma$
1364-43i MeV*

High-mass pole: $\bar{K}N$
1430 - 15i MeV*

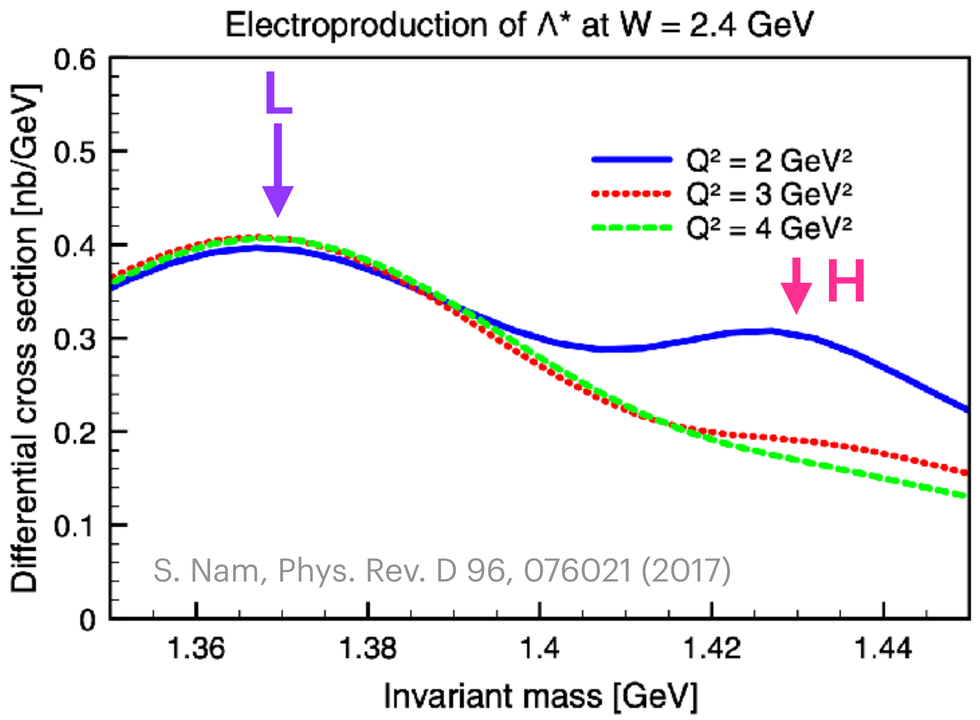


M. Mai, Eur. Phys. J. Spec. Top. (2021) 230:1593-1607

* S. Navas et al. (Particle Data Group), "83. Pole Structure of the Λ(1405) Region", Phys. Rev. D 110, 030001 (2024)

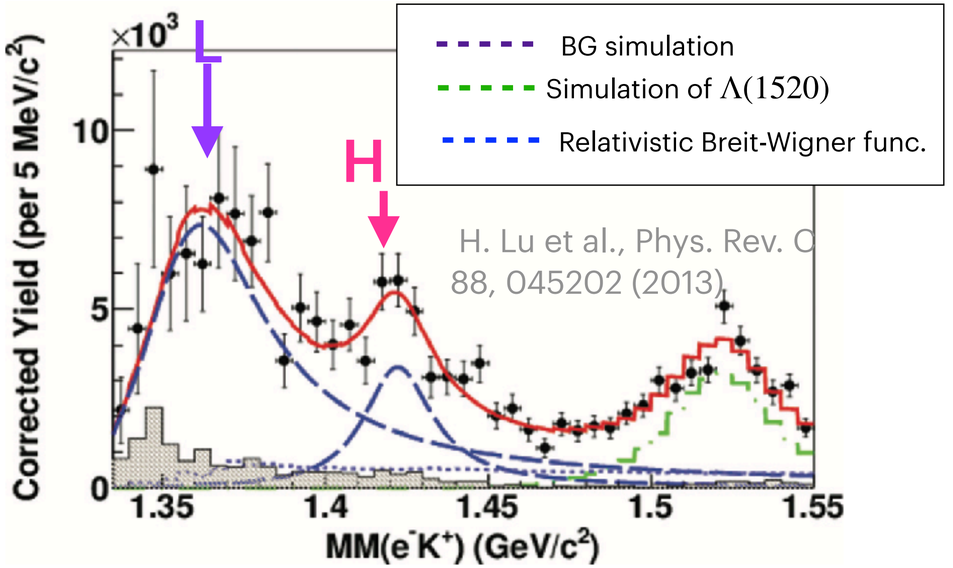
Q^2 dependence of Λ(1405)

Theoretical calculation of Λ(1405) electroproduction



- Considered EM form factor of Λ(1405) assuming charge rms radii by ChUM
- It results in different Q^2 dependence of each cross section for H and L

Λ(1405) electroproduction at CLAS e1f experiment



- Previous research (CLAS, e1f)
  - ✦ Two peaks(H and L poles) by pole structures
  - ✦ Statistics limitation → Very few Q2 dependence data
- Present research (CLAS12, RGK'18/RGK'24)
  - ✦ More statistics
  - ✦ Access to Q^2 dependence more precisely

Decay modes and Analysis flow

Associated decay modes of $\{e', K^+, \pi^-, p, \pi^0\}$

$\gamma^* + p$

Λ^*

$$K^+ + \Lambda^* \rightarrow K^+ + \Sigma^+ + \pi^0 \rightarrow K^+ + p + (\pi^0) + \pi^-$$

Σ^*

$$K^+ + \Sigma(1385) \rightarrow K^+ + \Lambda + \pi^0 \rightarrow K^+ + p + (\pi^0) + \pi^-$$

K^{*0}

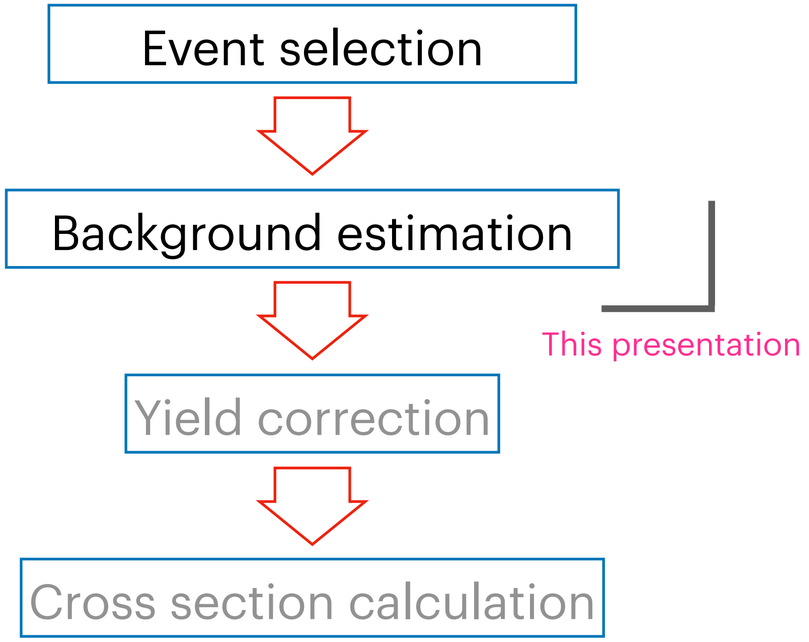
$$K^{*0} + \Sigma^+ \rightarrow K^+ + \pi^- + p + \pi^0$$

Non-resonant

$$K^+ + \Sigma^+ + \pi^0 \rightarrow K^+ + p + (\pi^0) + \pi^-$$

Backgrounds

Analysis flow



- RG-K, 2018, 6-GeV datasets
- No Q2 binning for now
- Yield correction and Calculation of cross section have not started

Event Selection

- Event Selection: Select $\{e', K^+, \pi^-, p\}$ events and select missing π^0

- <u>Selection Steps</u>

  ✓ Final state cut … Select $\{e', K^+, \pi^-, p\}$

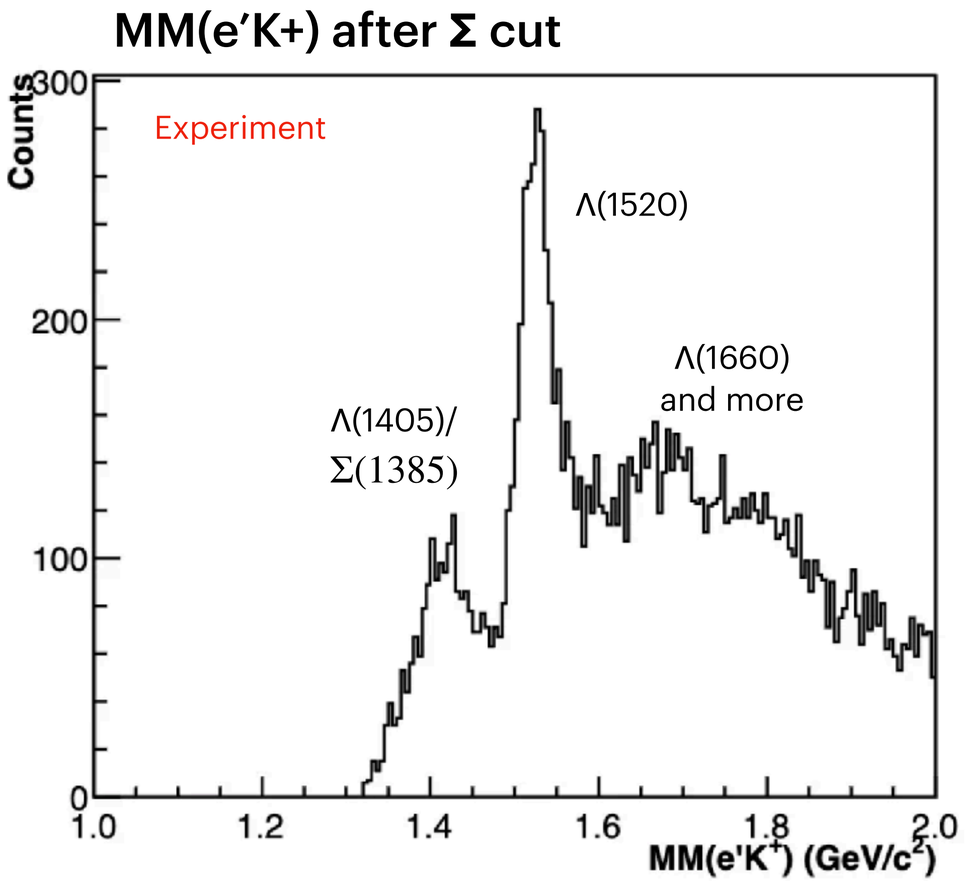
  ✓Z-vertex cut … Vertex peaks with 3σ range

  ✤Fiducial cut … Not applied

  ✓PID cut … Good identification for mom vs ΔTOF

  ✓Missing particle cut … Missing π^0 peak with 3σ range

  ✓Σ cut … Missing Σ^+ peak with 3σ range



Background Estimation

Resonant backgrounds

$\Sigma(1385)$

$$K^+ + \Sigma(1385) \rightarrow K^+ + \Lambda + \pi^0 \rightarrow K^+ + p + \pi^- + (\pi^0)$$

Invariant mass

Not completed

K^{*0}

$$K^{*0} + \Sigma^+ \rightarrow K^+ + \pi^- + p + \pi^0$$

Invariant mass

Performed

- Number of events: Invariant mass
- Shape: Estimate by simulation

Other backgrounds

Non-resonant

$$K^+ + \Sigma^+ + \pi^0 \rightarrow K^+ + p + (\pi^0) + \pi^-$$

Performed

Accidental coin.

$$\{e', K^+, p, \pi^-\}$$

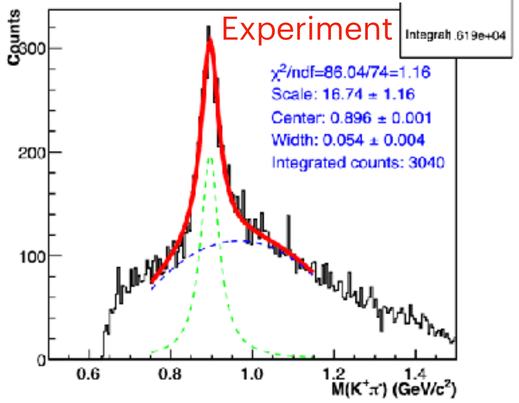
Performed

- Number of events: Estimate by simulation
- Shape: Estimate by simulation

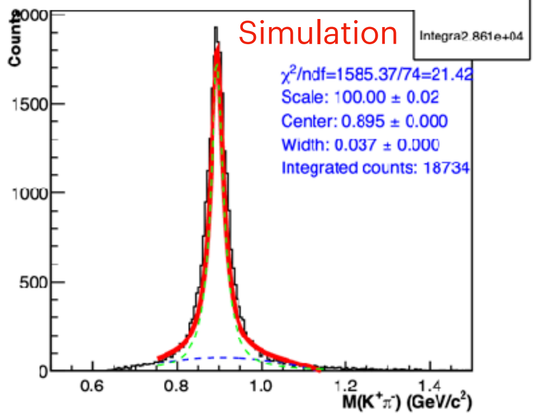
Resonant Backgrounds

K^{*0} events

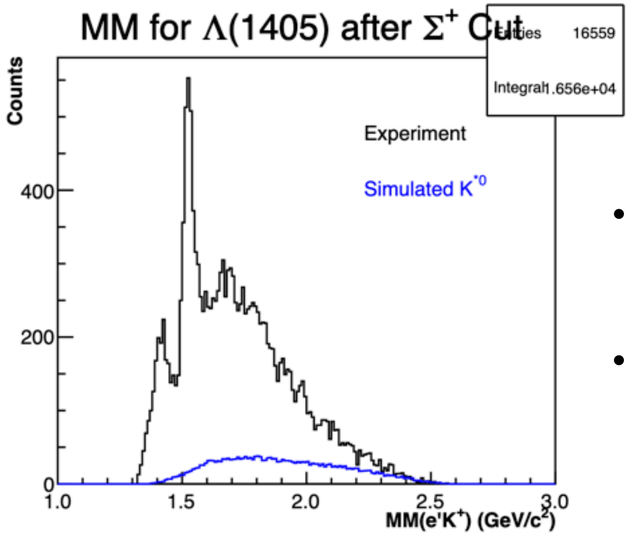
Invariant mass of K^{*0}



Invariant mass of K^{*0}



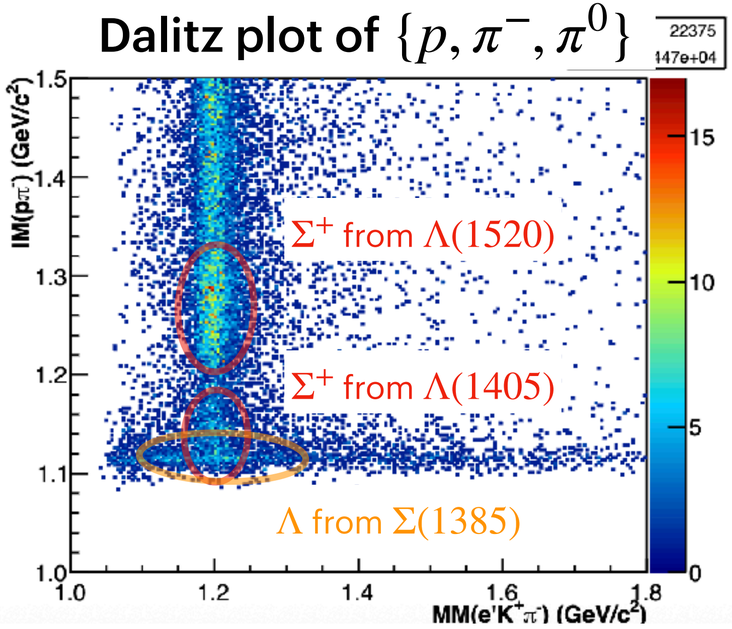
MM for Λ(1405) after Σ^+ Cut



- Derive K^{*0} count ratio of exp./sim.
- Scaling simulated background by the ratio

$\Sigma(1385)$ events

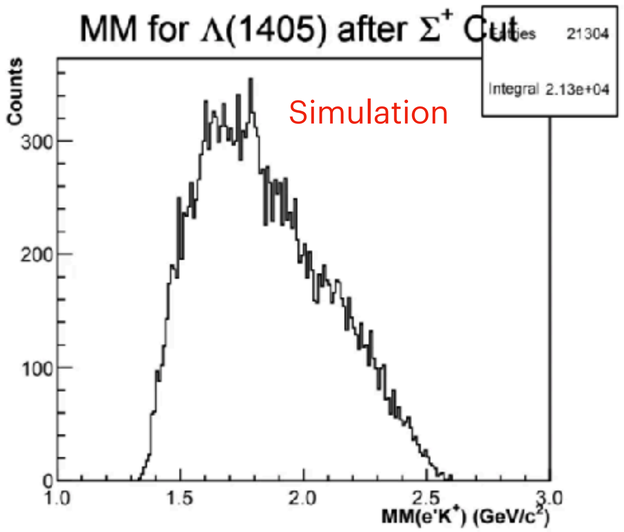
Dalitz plot of $\{p, \pi^-, \pi^0\}$

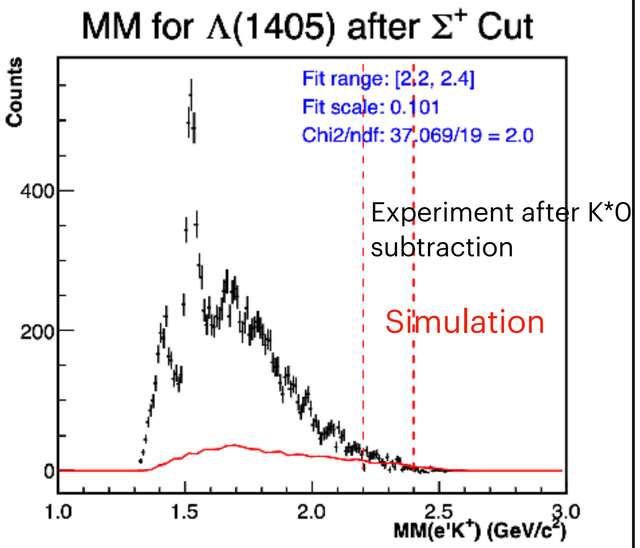


- Λ band and Σ+ band can be seen
- Events of Λ(1405) and Σ(1385) overlaying
- → Difficult to separate them by using only cuts
- Simulation estimation is needed

Other backgrounds

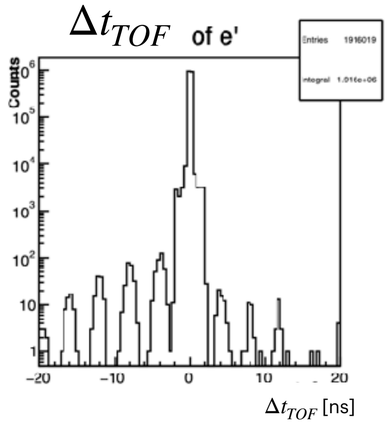
Non-resonant events

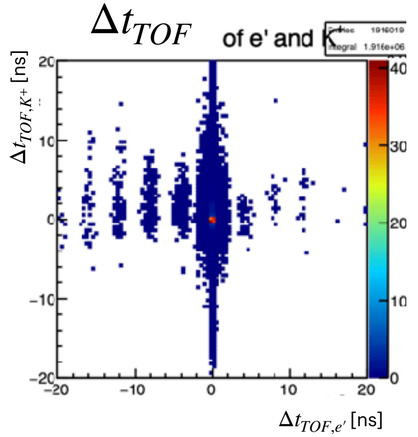


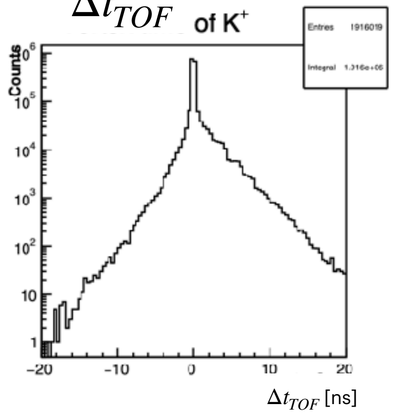


- Simulate non-resonant events
- Subtract K*0 events in advance
- Fitting to adjust higher-mass tail ([2.2, 2.4] GeV) with simulated shape

Accidental events

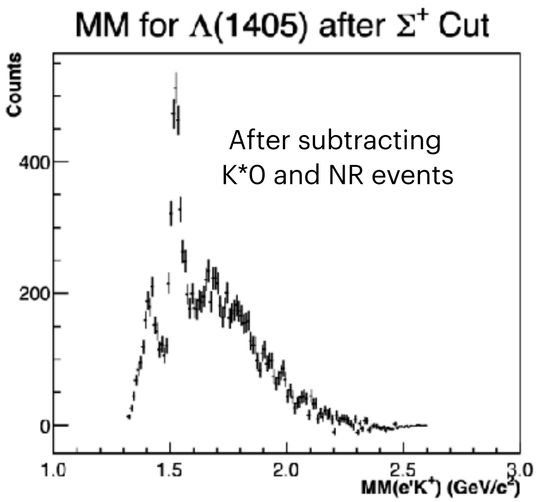


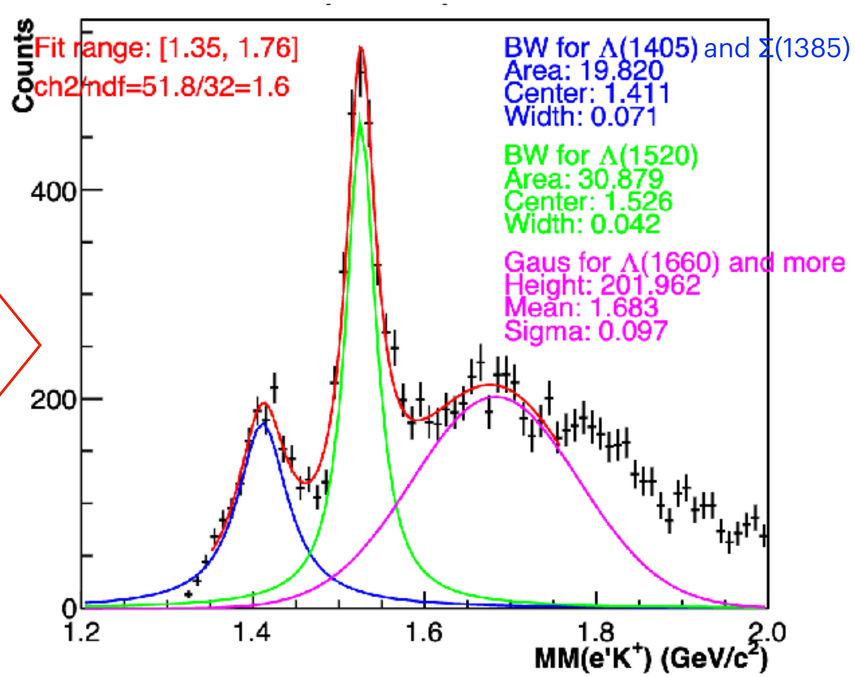




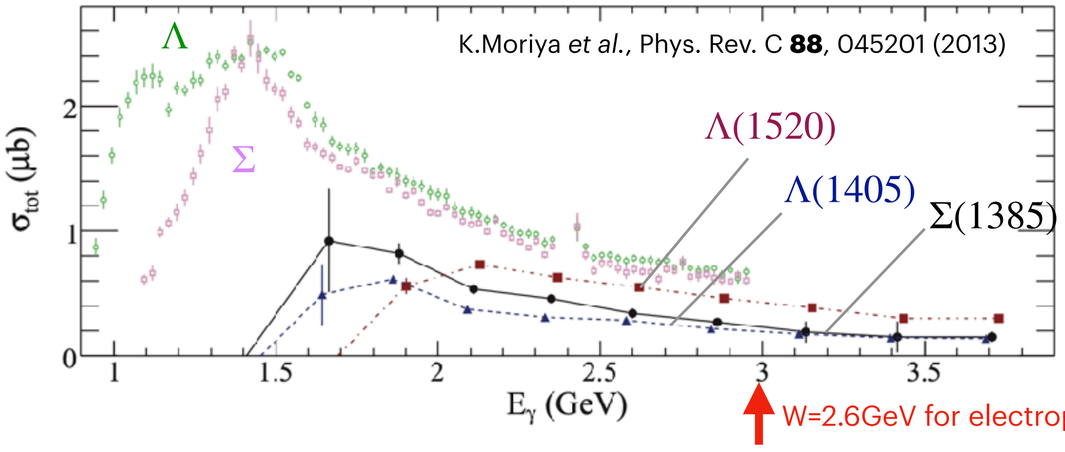
- $\Delta t_{TOF} = t_{time} - t_{mom.} = (t_{\mathrm{hit}} - t_{\mathrm{vertex}}) - \dfrac{d}{c\beta_{mom.}}$
- →True events are centered around 0 ns
- ΔTOF correlation between e' and K^+
  - ✦ Another bunch clusters can be seen
  - ✦ (Acc. coin. events) / (true coin. events) ~ 10^{-3} → The accidental events are negligible

Background subtraction & Fitting





Total cross sections of hyperon photoproductions



- Fit with BW+BW+Gaus
- Width ($\Gamma_{fit}^2 \sim \Gamma_{nat}^2 + (2.35\sigma_{det})^2$)
  - $\sigma_{det} = 21$ MeV from $\Lambda(1405)$
  - $\sigma_{det} = 17$ MeV from $\Lambda(1520)$
- Area
  - $\Lambda(1405)/\Lambda(1520) \sim 0.6$
  - ~0.5 at W=2.6 GeV from previous data

- Σ(1385) is still remaining, but reasonable result on width and area for Λ(1405) and Λ(1520) are obtained

Summary

- Present status
  - ✦ Background estimation was performed for K^{*0}, non-resonant, and accidentals
  - ✦ After subtracting, the fitting result is reasonable

- Next analysis step
  - ✦ Background estimation of Σ(1385)
  - ✦ Improving kinematics distribution of simulation
  - ✦ Acceptance correction

Backup

Datasets & Kinematical Range

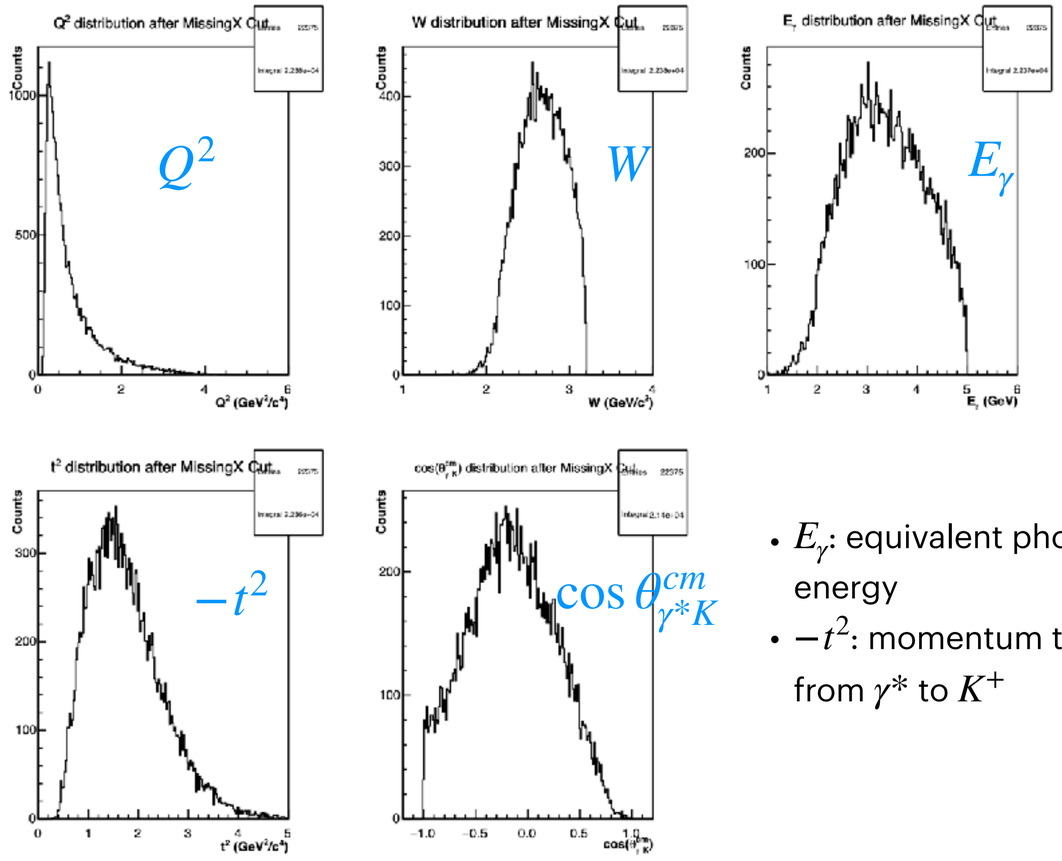
Table of RG-K datasets

Run Period	Beam Energy (GeV)	Target	Collected Charge (mC)
Spr2024	6.394	Full	91.35
Spr2024	6.394	Empty	10.0
Spr2024	8.477	Full	81.77
Spr2024	8.477	Empty	10.09
Dec2018	6.535	Full	18.23
Dec2018	6.535	Empty	2.35
Dec2018	7.546	Full	10.77
Dec2018	7.546	Empty	0.0

Calibrated

- As a first step, develop analysis method using 6 GeV dataset of RG-K'18
- Then, integrate events over all datasets
- → More statistics than the previous result

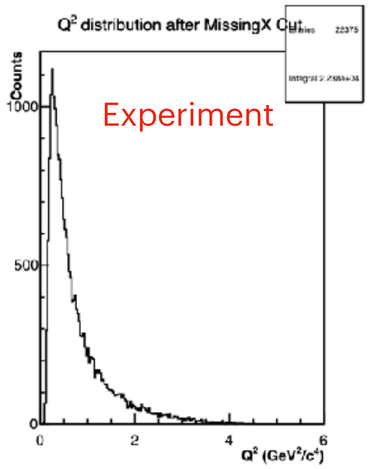
Ranges of kinematical parameter from a dataset

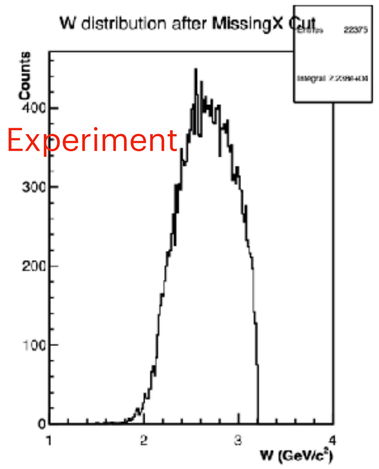


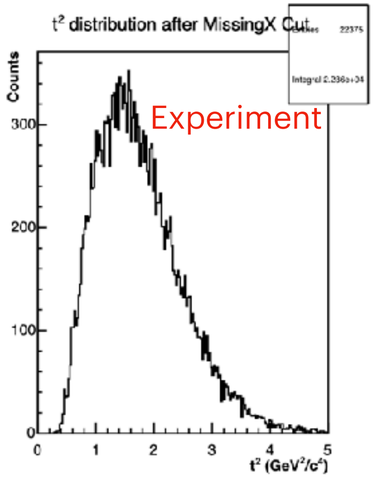
- E_γ: equivalent photon energy
- $-t^2$: momentum transfer from γ^* to K^+

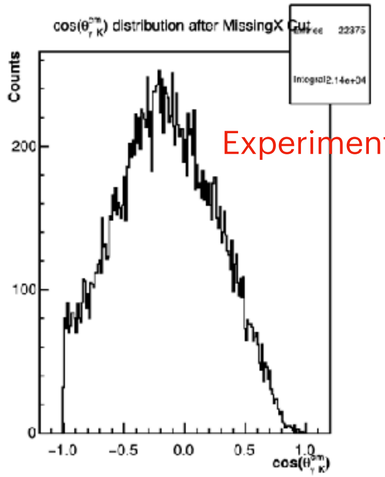
- Dataset of RG-K'18 6 GeV
- After exclusively select $\{e', K^+, \pi^-, p\}$ and applying analysis cuts, the ranges are obtained

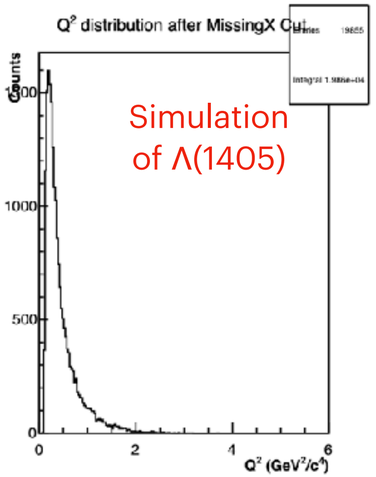
Reproducibility of Simulation

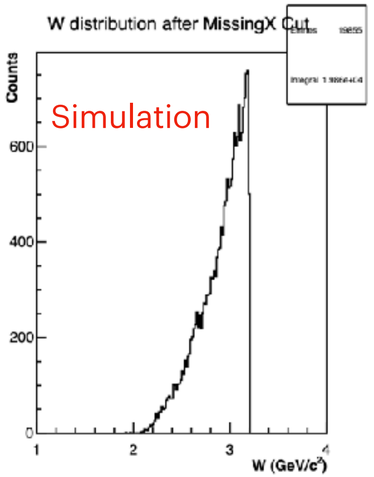


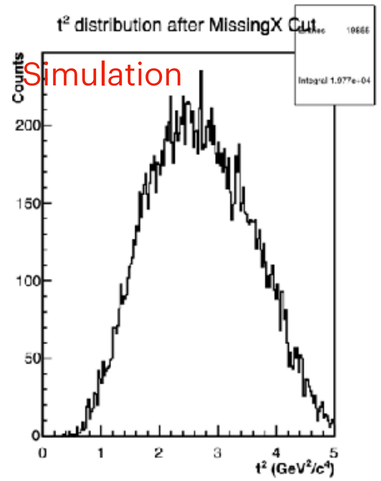


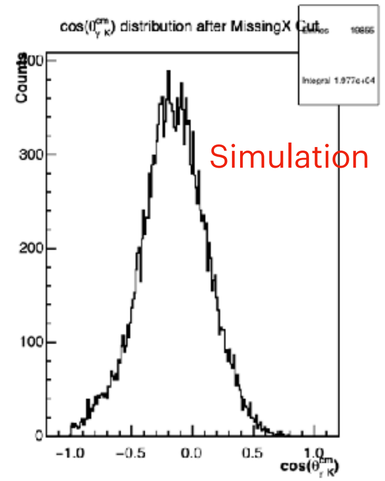










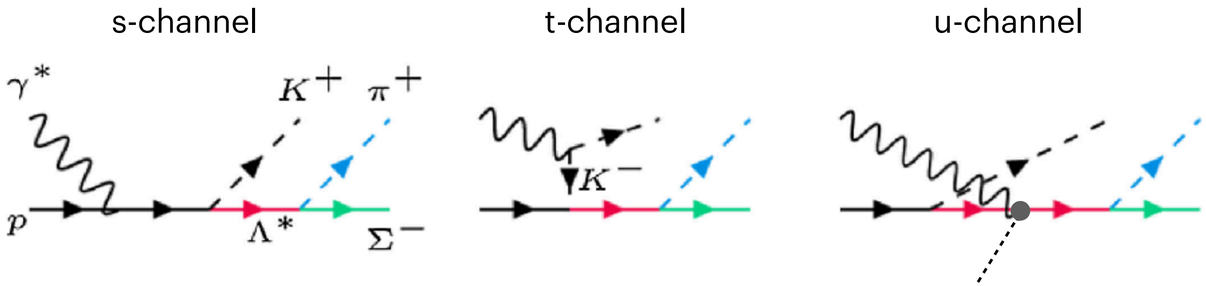


- Generator: clas12-elSpectro
- GEMC & COATJAVA: latest version

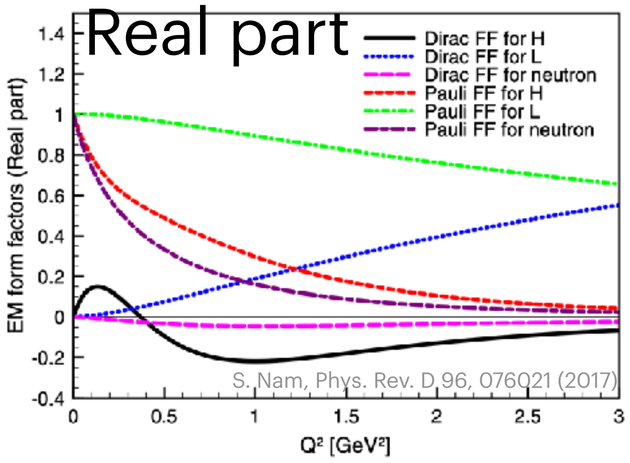
- Compare kinematics of experiment and Λ(1405) simulation
- Simulated kinematics doesn’t match well
- →Effect on background shape of non-resonant events
- Need to adjust it

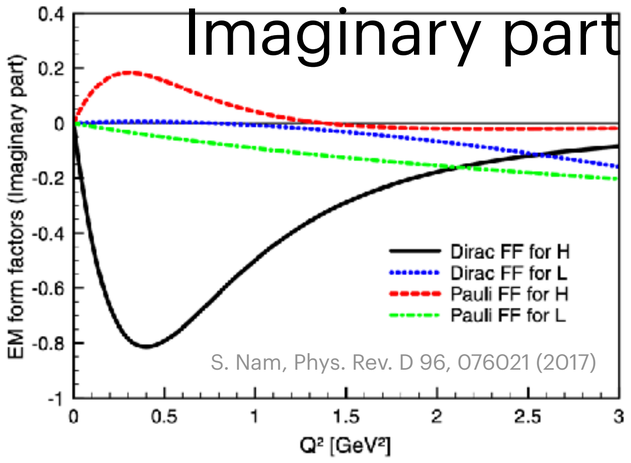
Theoretical suggestion

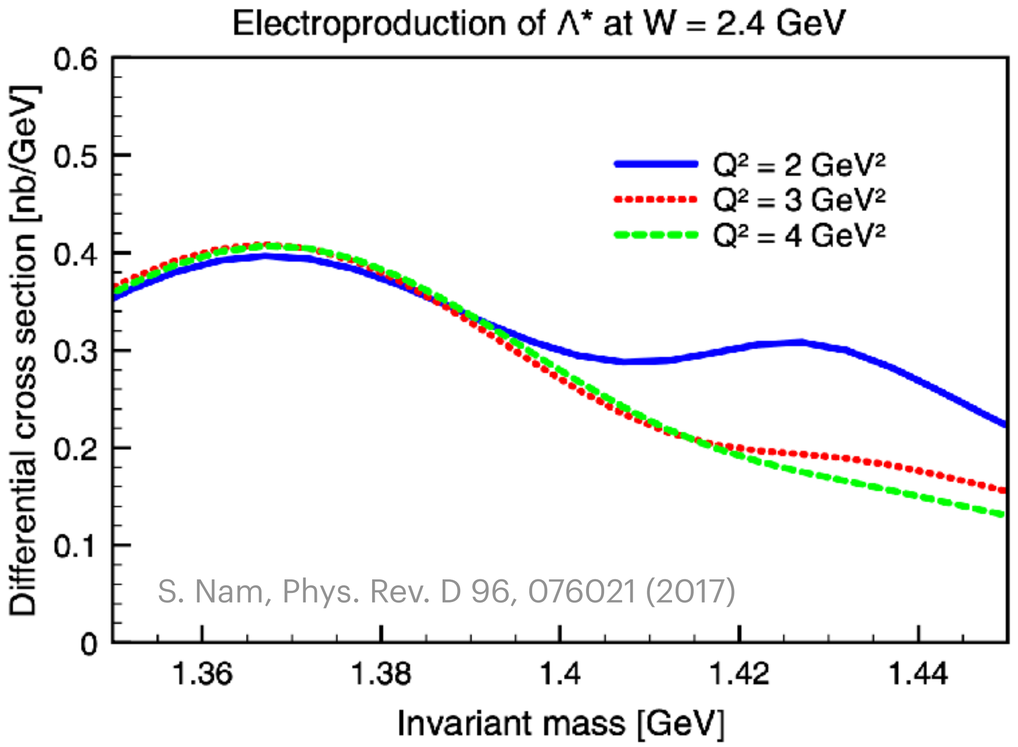
Feynman diagrams of Λ(1405) electroprodction



Include Λ* Dirac and Pauli form factor using charge rms radii by ChUM







- EM form factors of higher and lower poles are largely different
- Use charge rms radii of ChUM
- There should be Q2 dependence of the cross section if form factor is as predicted

Survival ratio

```
------------------------------------------------------------------
| Step                                  | Event Count|  Percent |
------------------------------------------------------------------
| Total events processed                |     5000000| 100.0000 |
| After final state selection           |       43571|   0.8714 |
| After Z-vertex cut                    |       39555|  90.7829 |
| After PID cut                         |       35003|  88.4920 |
| After Missing Particle cut            |       19855|  56.7237 |
| After Sigma cut                       |       19749|  99.4661 |
------------------------------------------------------------------
```

Survival ratio using Λ(1405) simulated data

Selection Step	Event Count	Efficiency	Survival ratio
No cut	5.00 M	-	1.0
Final state	43.6 k	0.008	0.0087
Z-vertex	39.6 k	0.90	0.0079
PID	35.0 k	0.88	0.007
Missing particle	19.9 k	0.57	0.004
Σ	19.7 k	0.99	0.0039