KY Electroproduction at CLAS12

Lucilla Lanza

The 12th international Workshop on the Physics of Excited Nucleons,
Bonn, Campus Poppelsdorf, 10-14 June 2019

INFN Roma Tor Vergata
13 June 2019

Outline

Physics motivation: Study of the nucleon excitation spectrum to understand its ground state.

Search for Hybrid Baryons contributions in the low Q^2 evolution of the cross section for $K^+\Lambda$ electroproduction with CLAS12.

- Endorsement of a LoI by the Program Advisory Committee, PAC43.
- PAC44 Proposal Approved with A- rating – 100 days assigned

- **CLAS12 and Forward Tagger (FT) @ JLAB**: Experimental setup description.

- **Simulation and Reconstruction** of $K^+\Lambda$ electroproduction events in CLAS12

- **Preliminary Results from Physics Runs**: KY channel studied exploiting a subset of data from Fall 2018 Physics Runs in Hall B at Jefferson Lab.

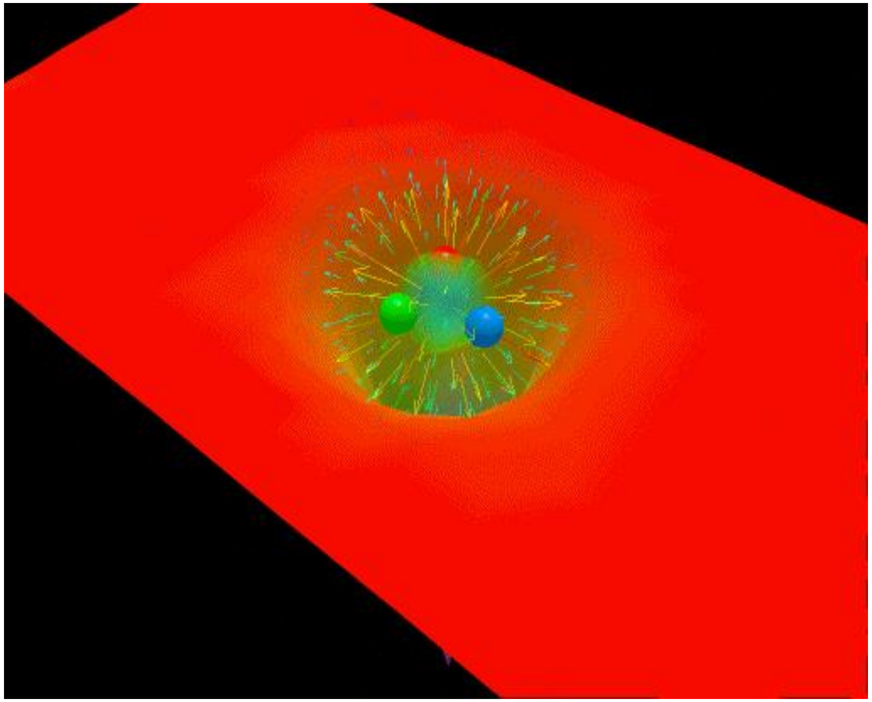
Why N* ?

Baryon Spectroscopy Reveals the Workings of QCD

"Nucleons are the stuff of which our world is made.

As such they must be at the center of any discussion of why the world we actually experience has the character it does."

Nathan Isgur, NStar2000, Newport News, Virginia



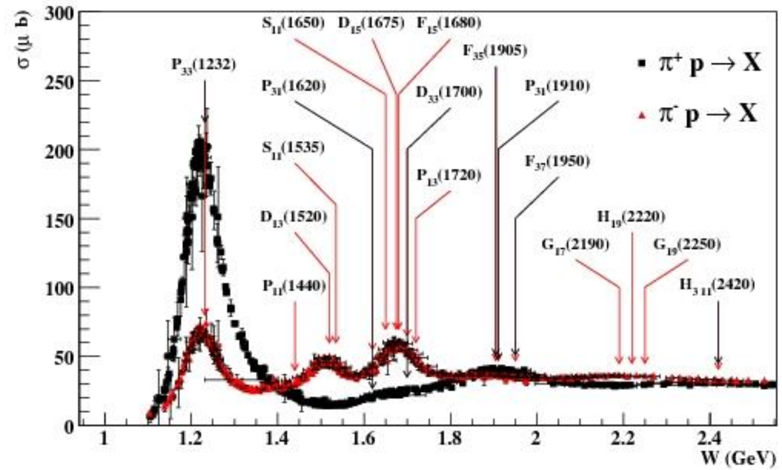
Derek B. Leinweber – University of Adelaide

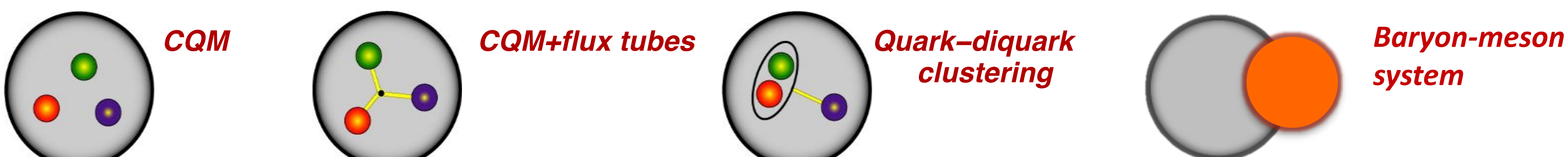
Why N* ?

From the N* Spectrum to QCD

- Understanding the proton's ground state requires understanding its excitation spectrum.

- The N* spectrum reflects the effective degrees of freedom and the forces.

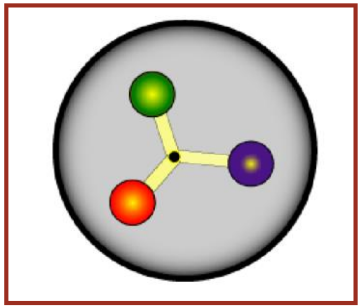




→ From the Constituent Quark model to QCD.

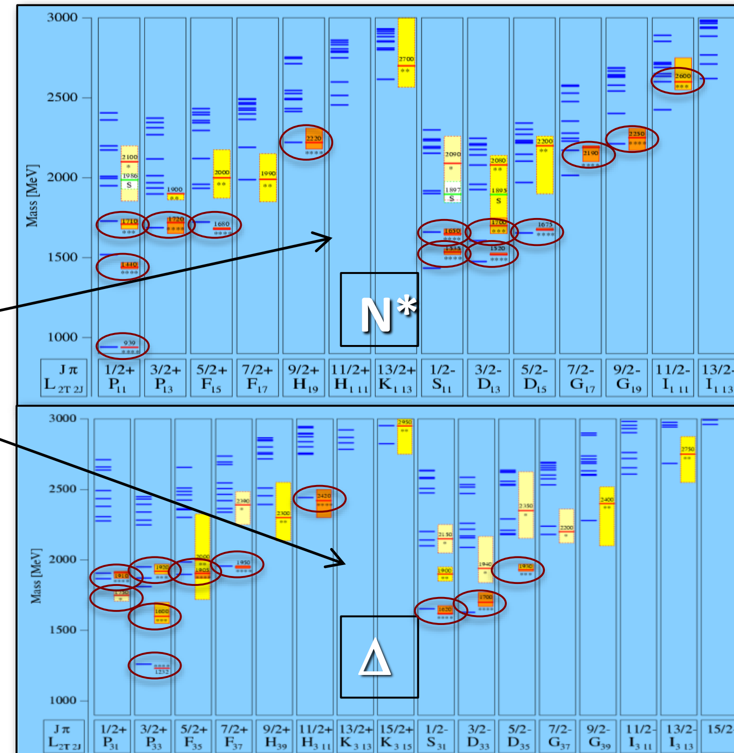
Why N* ?

From the N* Spectrum to QCD



Thick segments: Theoretical predictions | **Shaded boxes: experimental results**

Findings:



U. L¨oring, B. Metsch, H. Petry, Eur. Phys. J. A 10, 395 (2001).

- Linear Regge trajectories
- Only lowest few in each band seen with 4★ or 3★ status
- g(πN) couplings predicted to decrease rapidly with mass in each oscillator band
- Higher levels predicted to have larger couplings to KΛ, KΣ, ππN, …

Hybrid baryons emerge as **gluonic excitations of the nucleon** to states where a **constituent gluon** combines with **three quarks**

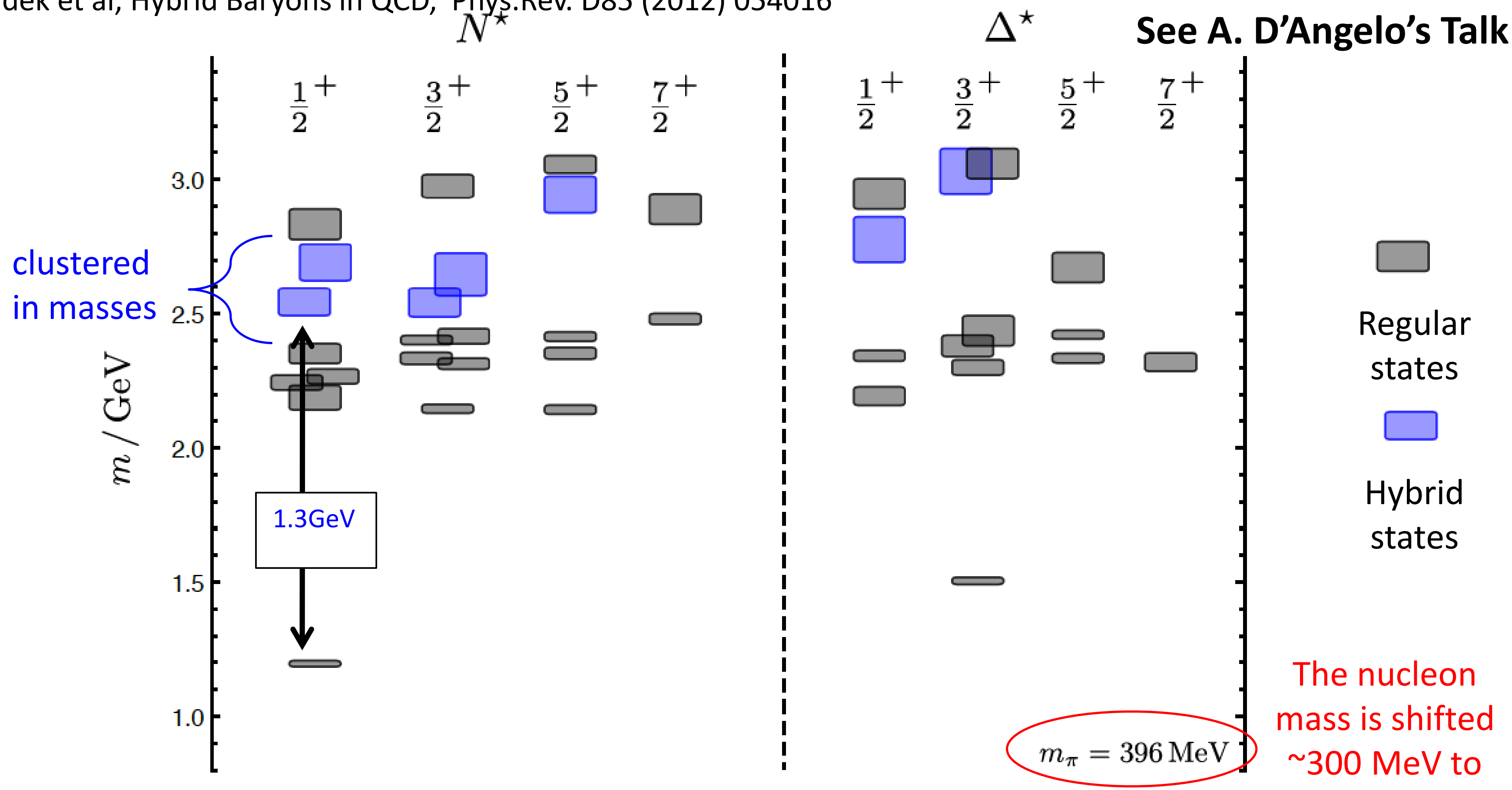
Hybrid Baryons in LQCD

QCD allows for the existence of Hybrid Baryons.

LQCD predicts several hybrid baryons states.

J. Dudek et al, Hybrid Baryons in QCD, Phys.Rev. D85 (2012) 054016

See A. D'Angelo's Talk

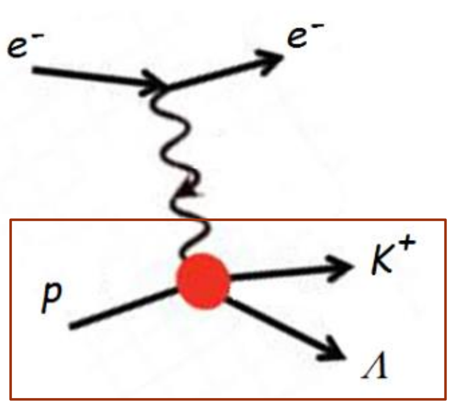


The nucleon mass is shifted ~300 MeV to higher masses

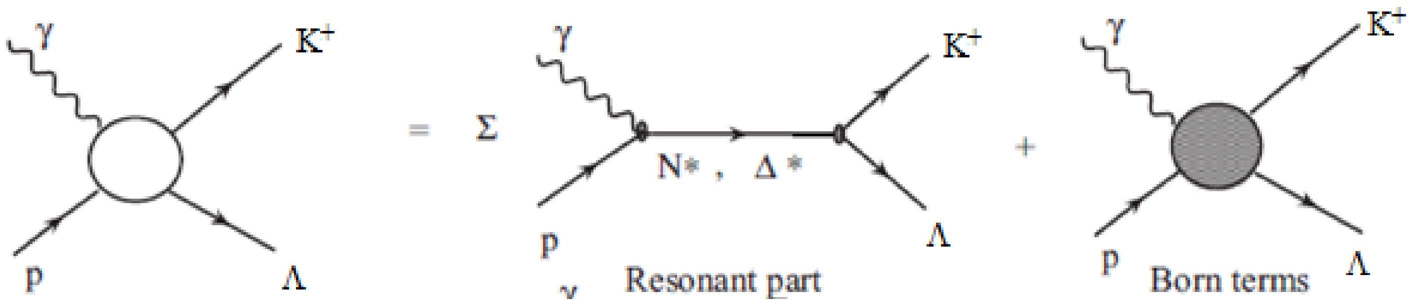
Differently from the case of hybrid mesons, hybrid baryons are predicted to have **same quantum numbers** of N* resonances

Separating Q^3G from Q^3 states: $A_{1/2,\,3/2}(Q^2)$ and $S_{1/2}(Q^2)$

Transverse helicity amplitudes $A_{1/2}(Q^2)$, $A_{3/2}(Q^2)$ and longitudinal helicity amplitude $S_{1/2}(Q^2)$ allow to distinguish Q^3G from Q^3 states

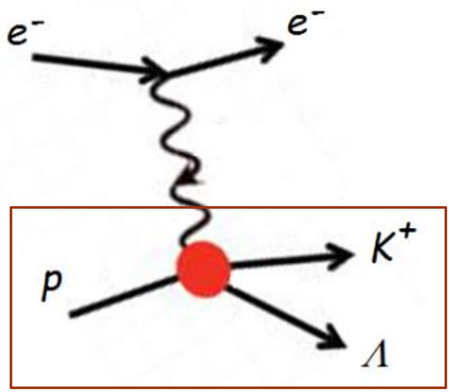


Electroexcitation via quasi-real photon exchange can be considered for practical purposes photo-production



V. I. Mokeev, CLAS Collaboration, PHYSICAL REVIEW C 86, 035203 (2012)

Separating Q^{3}G from Q^3 states: $A_{1/2, 3/2}(Q^2)$ and $S_{1/2}(Q^2)$



Hybrid resonance contribution in the helicity representation

Helicities of final state hadrons

Helicities of γ and p

N* helicity = $\lambda_\gamma - \lambda_p$

$$\langle \lambda_f | T_r | \lambda_\gamma \lambda_p \rangle = \sum_{N^*} \frac{\langle \lambda_f | T_{dec} | \lambda_R \rangle \langle \lambda_R | T_{em} | \lambda_\gamma \lambda_p \rangle}{M_r^2 - W^2 - i\Gamma_r(W) M_r}$$

where

Resonance mass

Invariant mass

Energy dependent total width

The **resonance electroexcitation amplitudes** can be related to the $\gamma_v NN^*$ electrocouplings $\mathbf{A_{1/2}}$, $\mathbf{A_{3/2}}$, and $\mathbf{S_{1/2}}$ for nucleons

$$\langle \lambda_R | T_{em} | \lambda_\gamma \lambda_p \rangle = \frac{W}{M_r} \sqrt{\frac{8 M_N M_r q_{\gamma_r}}{4\pi\alpha}} \sqrt{\frac{q_{\gamma_r}}{q_\gamma}}\, A_{1/2,3/2}(Q^2) \quad \text{with} \quad |\lambda_\gamma - \lambda_p| = \frac{1}{2}, \frac{3}{2} \text{ for transverse photons,}$$

$$\langle \lambda_R | T_{em} | \lambda_\gamma \lambda_p \rangle = \frac{W}{M_r} \sqrt{\frac{16 M_N M_r q_{\gamma_r}}{4\pi\alpha}} \sqrt{\frac{q_{\gamma_r}}{q_\gamma}}\, S_{1/2}(Q^2) \quad \text{for longitudinal photons}$$

The ***N**** **hadronic decay amplitudes** can be expanded in **partial waves** of total momentum *J*

$$\langle \lambda_f | T_{dec} | \lambda_R \rangle = \langle \lambda_f | T_{dec}^{J_r} | \lambda_R \rangle d_{\mu\nu}^{J_r}(\cos\theta^*) e^{i\mu\phi^*}$$

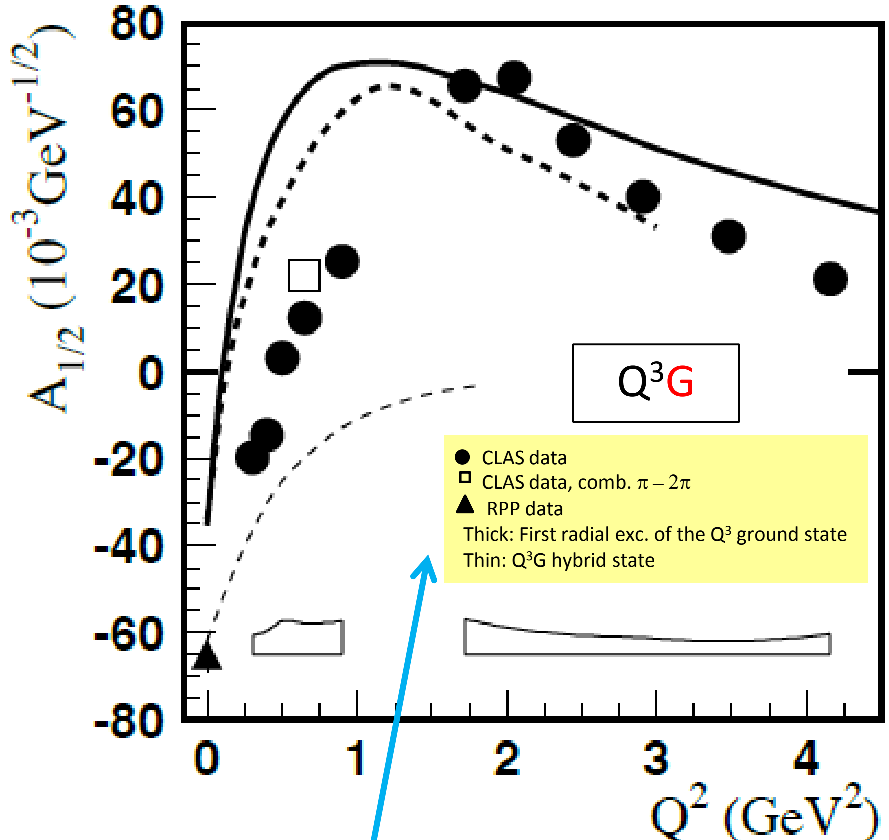
where

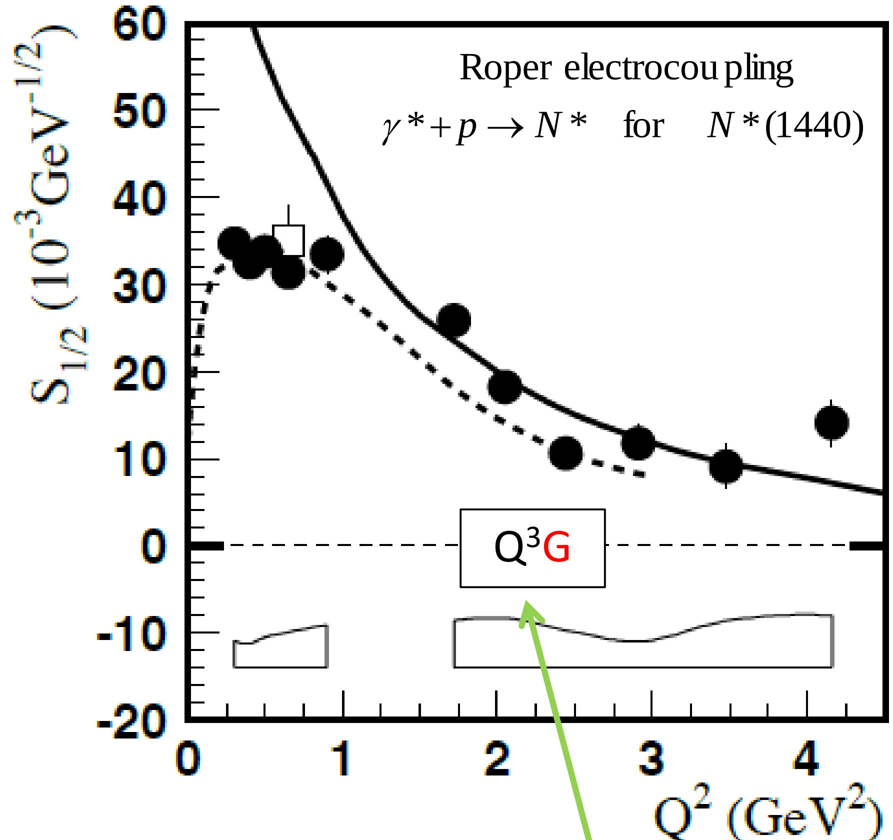
$$\langle \lambda_f | T_{dec}^{J_r} | \lambda_R \rangle = \frac{2\sqrt{2\pi}\sqrt{2J_r+1}\, M_r \sqrt{\Gamma_{\lambda_f}}}{\sqrt{\langle p_i^r \rangle}} \sqrt{\frac{\langle p_i^r \rangle}{\langle p_i \rangle}}$$

V. I. Mokeev, CLAS Collaboration, PHYSICAL REVIEW C 86, 035203 (2012)

Separating Q^3G from Q^3 states

Transverse helicity amplitude $A_{1/2}(Q^2)$ and longitudinal helicity amplitude $S_{1/2}(Q^2)$ allow to distinguish Q^3G from Q^3 states





A drop of the transverse helicity amplitudes $A_{1/2}(Q^2)$ faster than for ordinary three quark states, because of extra glue-component in valence structure

A suppressed longitudinal amplitude $S_{1/2}(Q^2)$ in comparison with transverse electro-excitation amplitude

I. G. Aznauryan et al., CLAS Collaboration, PHYSICAL REVIEW C 80, 055203 (2009)

Signature

Based on available knowledge, the ***signature*** for hybrid baryons may consist of ***:***

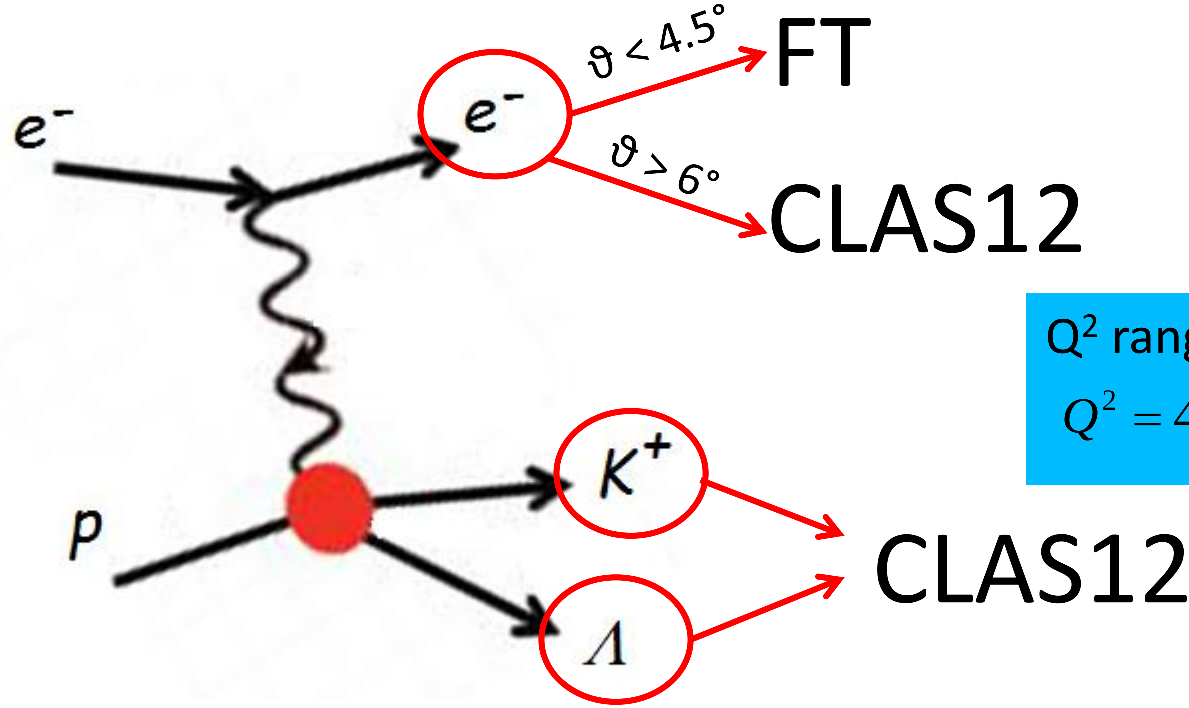
- Extra resonances with $J^p=1/2^+$ and $J^p=3/2^+$, with masses from 1.8 GeV to 2.5 GeV and decays to $N\pi\pi$ or KY final states

- A drop of the transverse helicity amplitudes $A_{1/2}(Q^2)$ and $A_{3/2}(Q^2)$ faster than for ordinary three quark states, because of extra glue-component in valence structure

- A suppressed longitudinal amplitude $S_{1/2}(Q^2)$ in comparison with transverse electro-excitation amplitude

Experiment

Scattered electrons are detected in Forward Tagger for angles from 2.5° to 4.5°. FT allows to probe the **crucial Q^2 range** where hybrid baryons may be identified due to their fast dropping $A_{1/2}(Q^2)$ amplitude and the suppression of the scalar $S_{1/2}$ (Q^2) amplitude.



Q^2 range of interest: 0.05 - 2 GeV^2

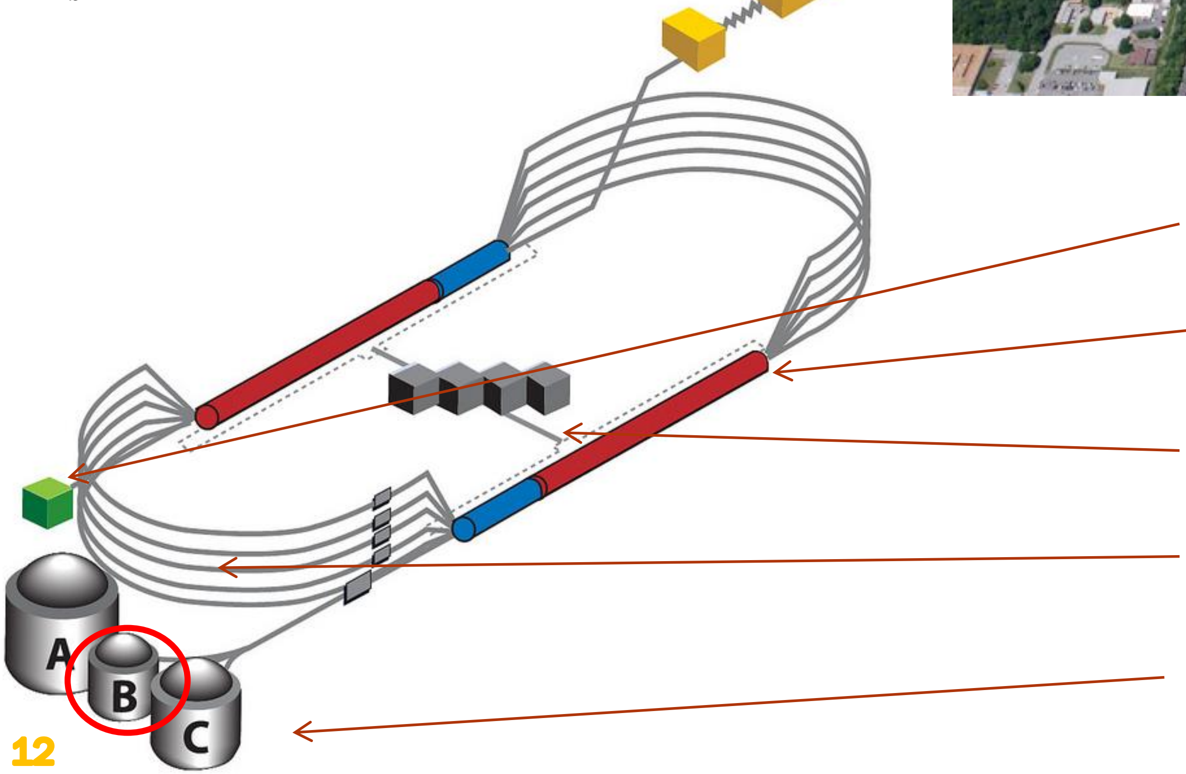
$$Q^2 = 4E_{Beam}E_{e'}\sin^2\frac{\vartheta}{2} \quad \Rightarrow \quad \vartheta < 5^\circ$$

Scattered electrons are detected in the Forward Detector of CLAS12 for scattering angles greater than about 6°. Charged hadrons will be measured in the full range from 6° to 130°.

Experimental Setup: CEBAF

Important parameters:

- Injector energy: 45 MeV
- Temporal separation of the bunches 0,7 ns
- 1200 MeV each loop
- Halls A, B, C receive a 11 GeV electron beam, Hall D a 12 GeV electron with a 2 ns time interval
- High work frequency: almost continuum beam
- Maximal intensity of the beam: 200 μA
- P_b (long. polarization) up to 90%



Components:

Injector

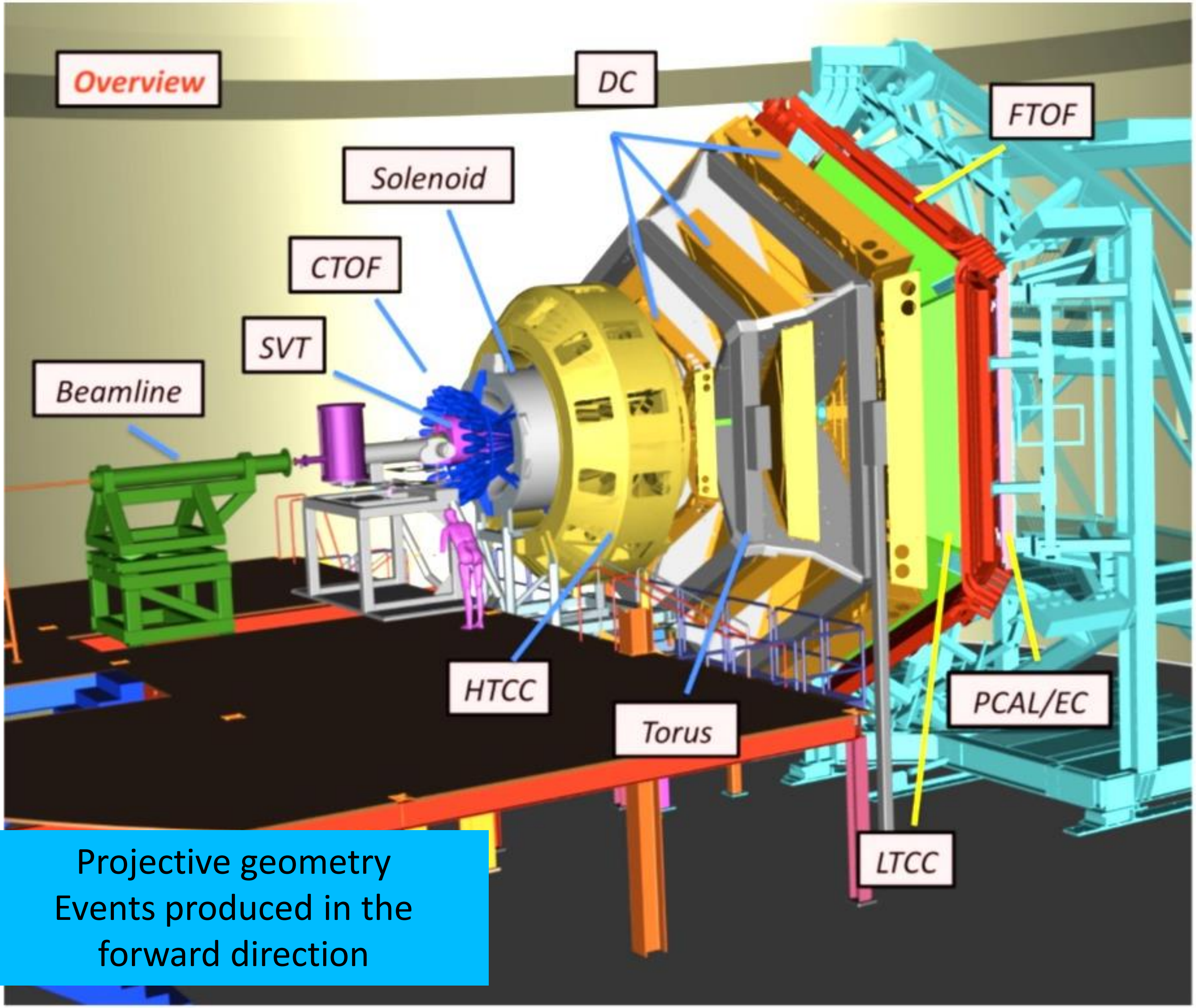
LINAC

Refrigeration plant

Magnets

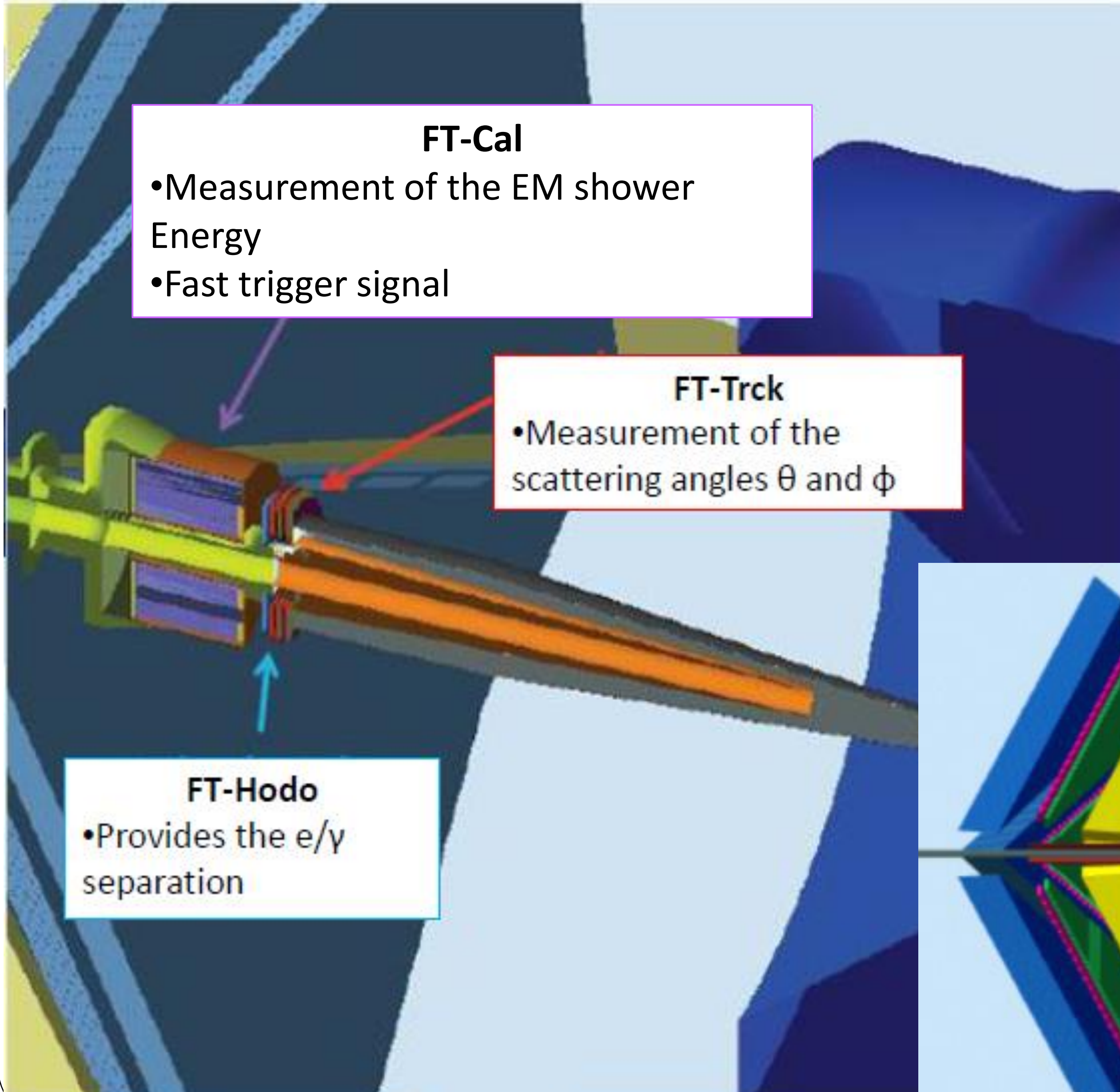
Experimental Halls

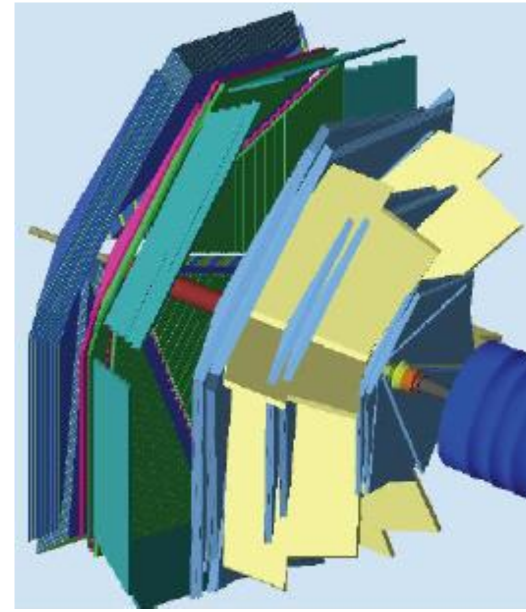
Experimental Setup: CLAS12

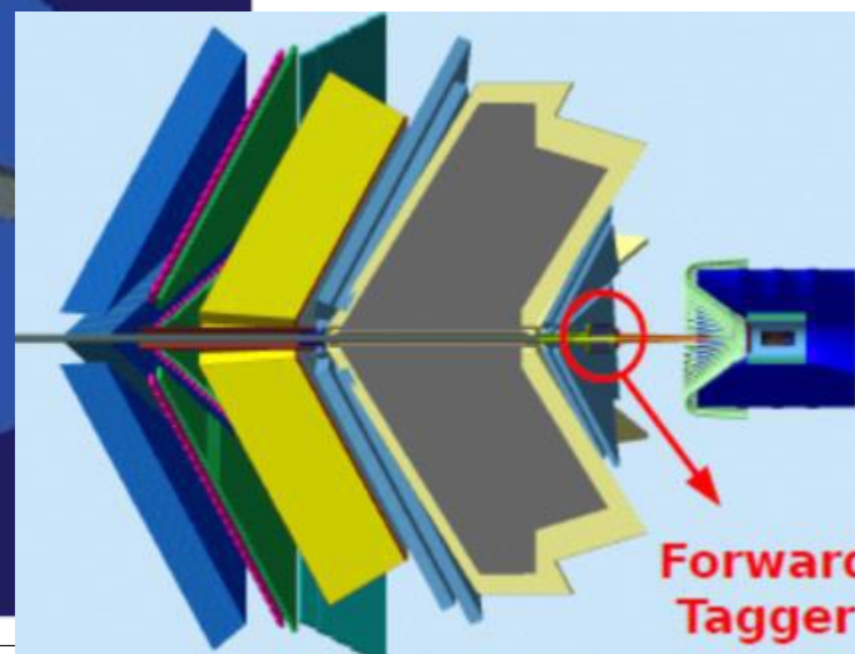


Projective geometry
Events produced in the forward direction

Experimental Setup: Forward Tagger (FT)







Simulation and FASTMC Reconstruction of $K^+\Lambda$ Electroproduction Events in CLAS12 using the Ghent RPR-2011 Model

How to determine the best run conditions for the experiment?

Simulations

Simulations have been performed using:

- Event Generator based on the Ghent RPR-2011 Model to produce electroproduction events and a
- FASTMC to simulate CLAS12 acceptance effects.

Available data on "Strange Calc" web site

StrangeCalc

http://rprmodel.ugent.be/calc/

Reaction type: Electroproduction

Reaction: $p(e,e'K^+)\Lambda$ | $p(e,e'\pi^+)n$ | $p(e,e'K^+)\Sigma^0$ | $n(e,e'\pi^-)p$ | $p(e,e'K^0)\Sigma^+$

Non-interference cross sections: $d\sigma_U$ $d\sigma_L$ $d\sigma_T$

Interference cross sections: $d\sigma_{LT}$ $d\sigma_{TT}$ $d\sigma_{LT'}$ $d\sigma_{TT'}$

Induced recoil polarization: $P^0_{y''}$ P^0_n

Transferred recoil polarization: $P'_{x''}$ $P'_{z''}$ P'_l P'_t

Clear

$x''y''z''$-frame: The z''-axis is along the virtual photon's three-momentum, the $x''z''$-plane is the electron plane, and the x''-axis' direction is such that the final electron's x''-component is positive.

ntl-frame: The l-axis is along the final baryon's three-momentum, the tl-plane is the hadron plane, and the t-axis' direction is such that the virtual photon's t-component is positive.

Energy variable: W s $E_{\gamma,\mathrm{c.m.}}$ $E_{\gamma,\mathrm{lab}}$

Fixed Range List

GeV

For the options 'Fixed' and 'Range', unphysical entries will be corrected if the variable's minimum/maximum value is not fixed. E.g.: $W = 0$ GeV will be corrected to $W = W_0$, with W_0 being the threshold energy, and $-t = 0$ GeV² will be corrected to $-t = -t_0$, with $-t_0$ being the minimum value of $-t$.

Angular variable: $\cos\theta_{\mathrm{c.m.}}$ $-t$ $-u$

Fixed Range List

StrangeCalc data have been used for the Event Generator.

Photon virtuality (Q^2): Fixed Range List

GeV^2

Model: RPR-2011 | RPR-2007 | VR

No resonance contributions

RPR-2011 model: Phys. Rev. C **86**, 015212 (2012)

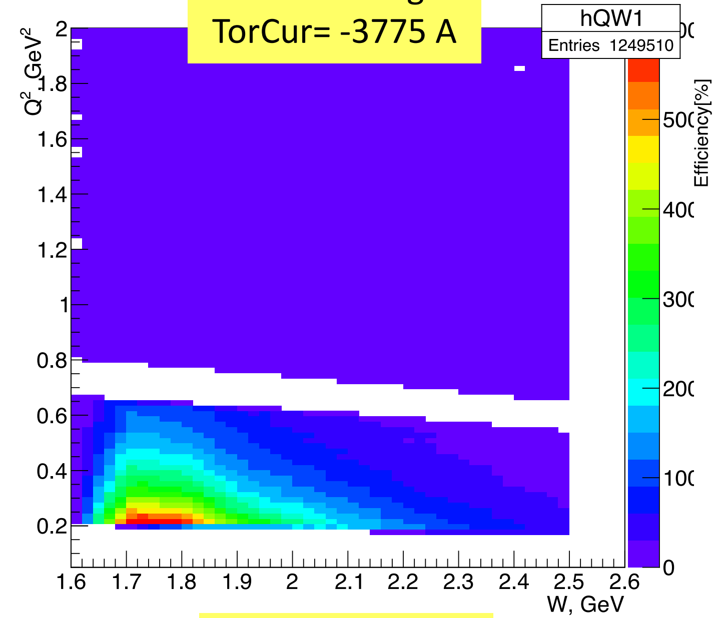
RPR-2007 model: Phys. Rev. C **73**, 045207 (2006) and Phys. Rev. C **75**, 045204 (2007)

VR model: Phys. Rev. C **89**, 025203 (2014) and Phys. Rev. C **89**, 065202 (2014)

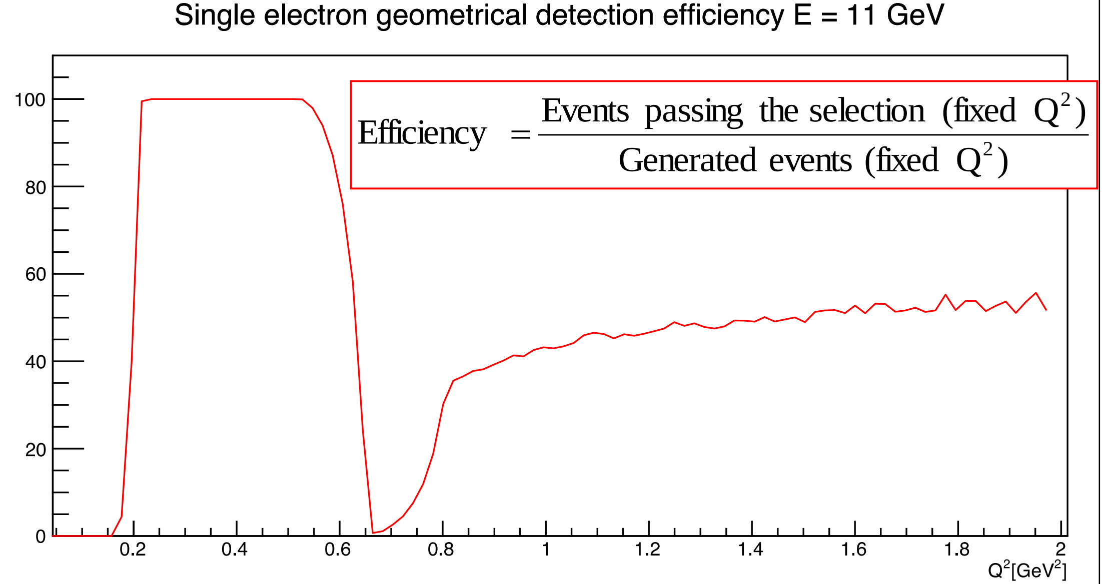
Calculate

Magnetic field: inbending or outbending?

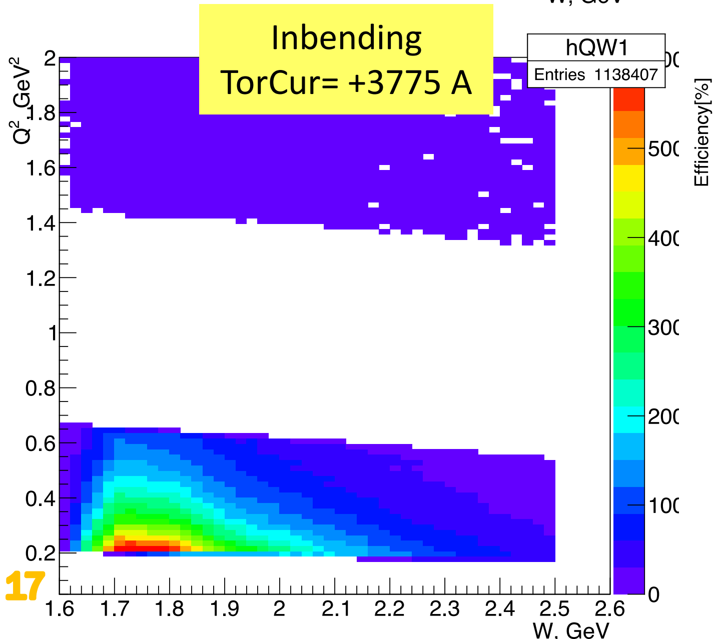
Q^2 vs W

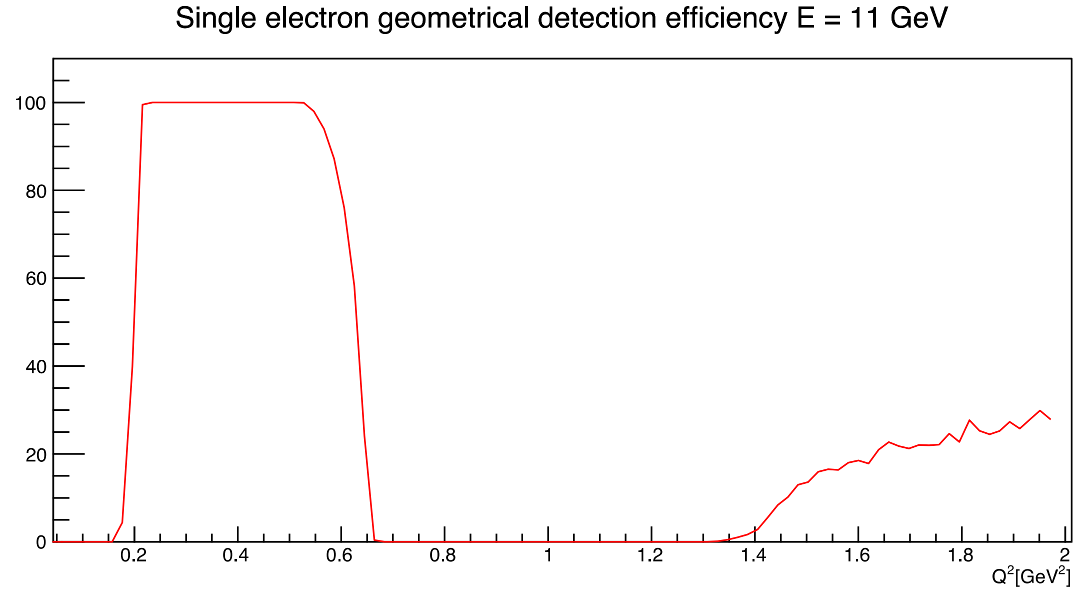


Efficiency curve

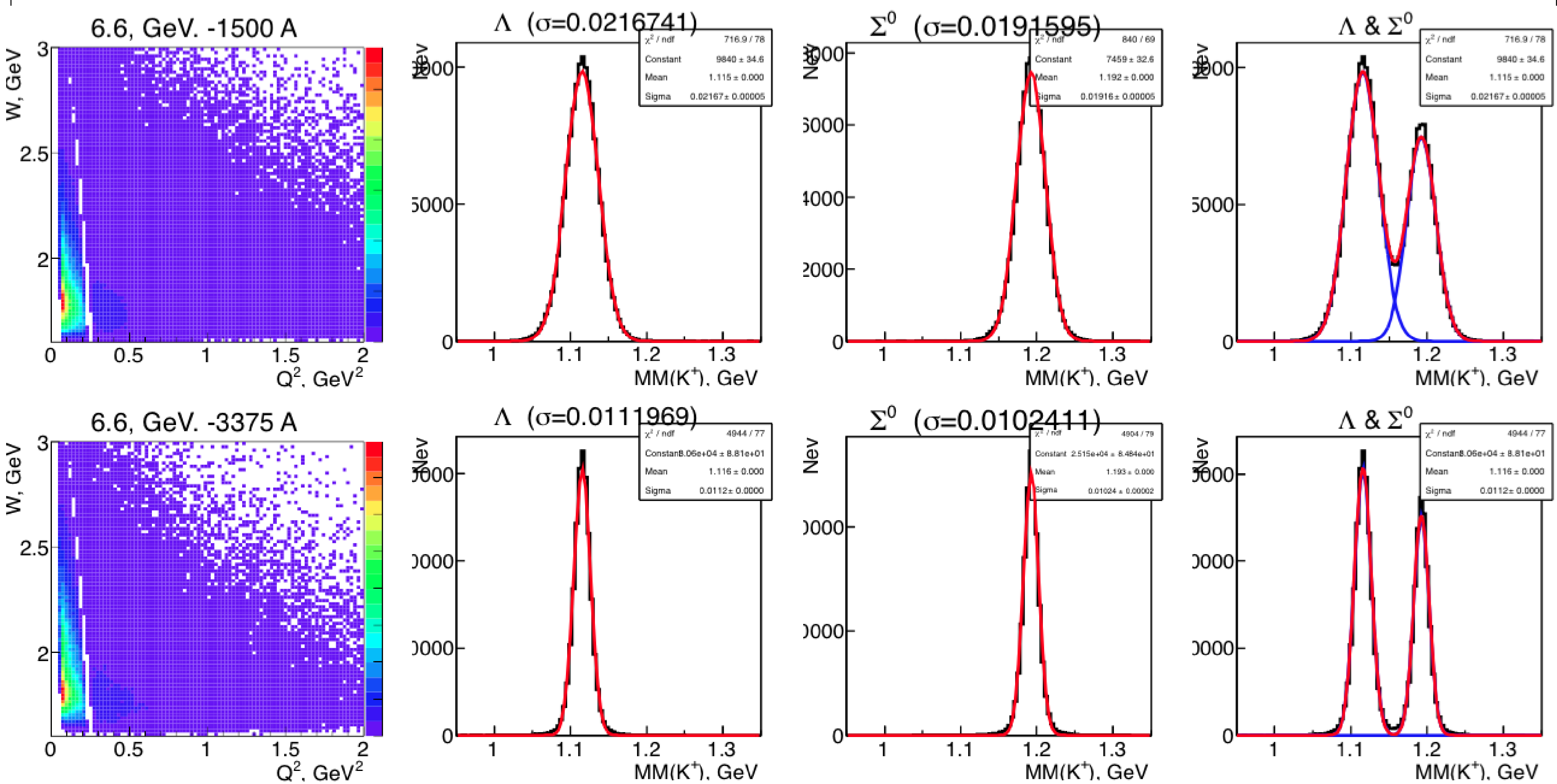


$$\text{Efficiency} = \frac{\text{Events passing the selection (fixed } Q^2)}{\text{Generated events (fixed } Q^2)}$$





Strength of Torus current



e′K⁺ missing mass to reconstruct Λ

e′K⁺ missing mass to reconstruct Σ^0

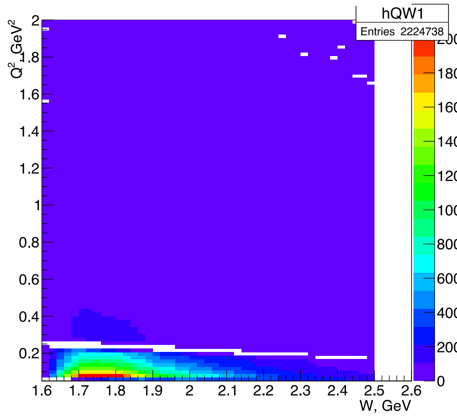
$K^+\Lambda$ and $K^+\Sigma^0$ overlap histograms
↓
Advantage of high CLAS12 torus currents

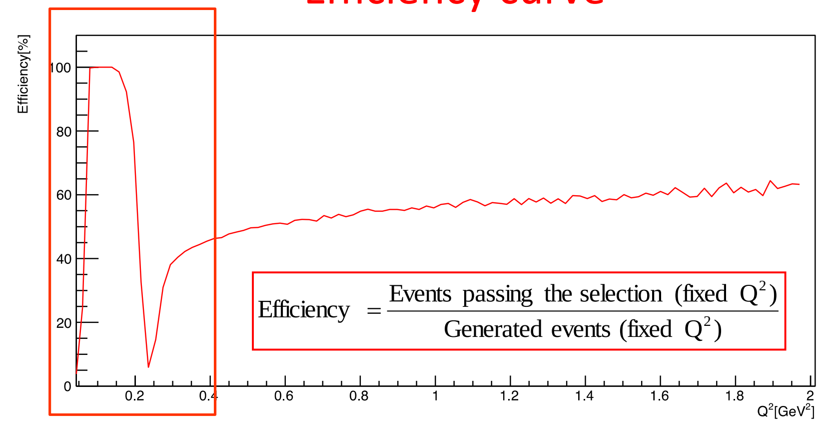
Covering the whole Q^2 range

Q^2 vs W

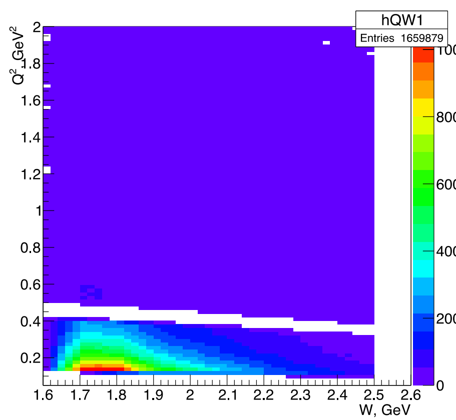
Efficiency curve

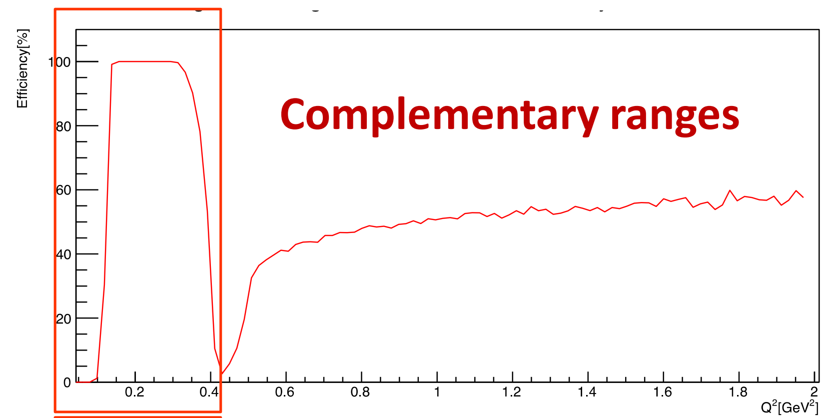
E = 6.6 GeV
TorCur= -3775 A





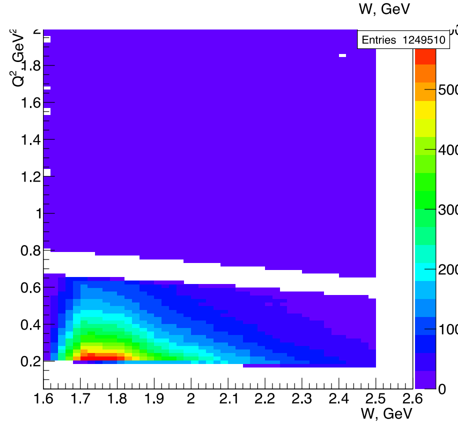
E = 8.8 GeV
TorCur= -3775 A

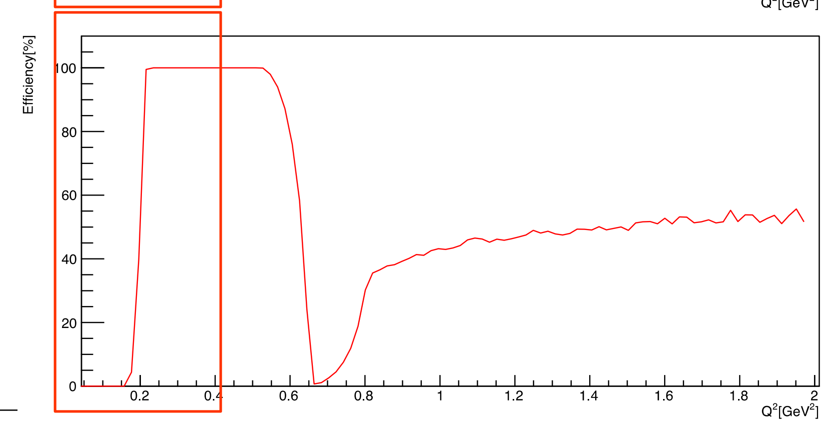




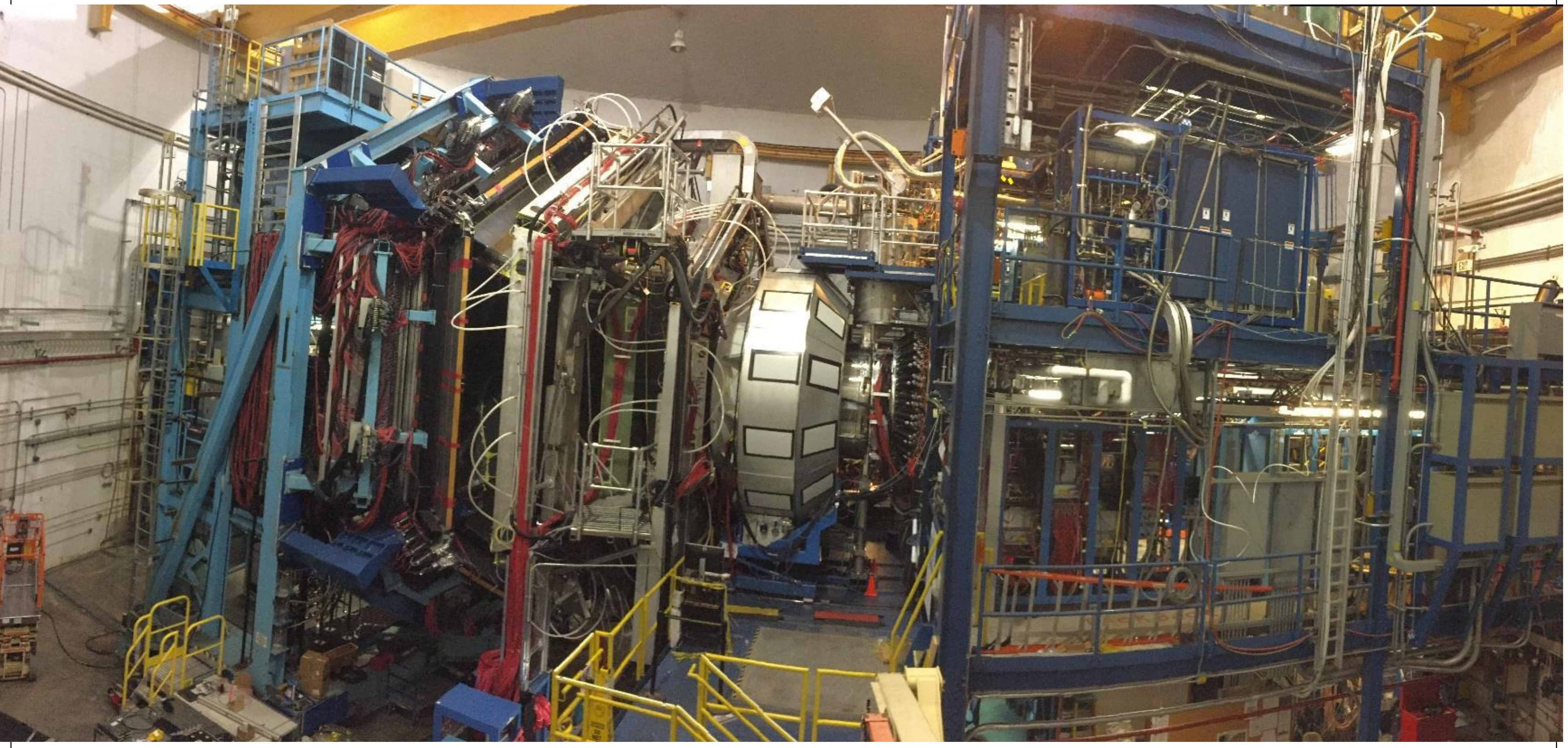
Complementary ranges

E = 11 GeV
TorCur= -3775 A





12 GeV electron with CLAS12



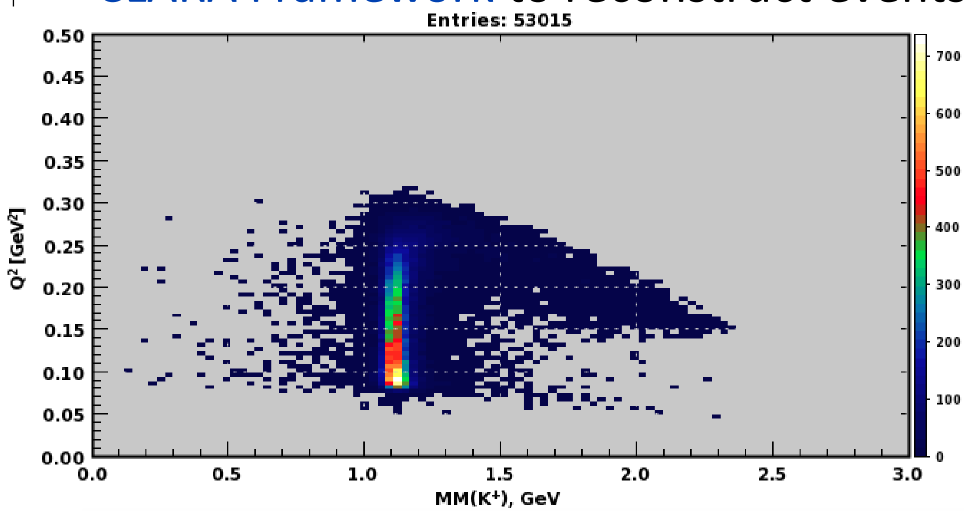
Physics Run started in February 2018.

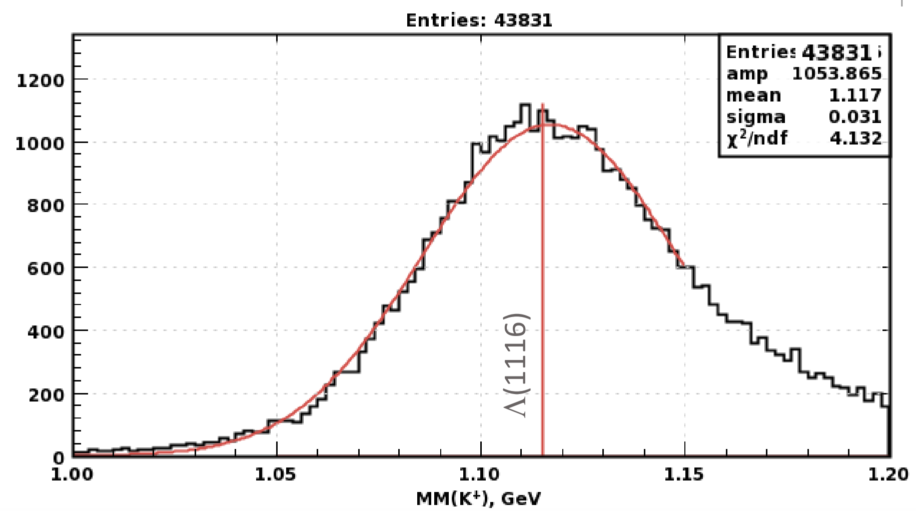
RGK dedicated Run took data during Fall 2018.

Upgraded Simulation and Reconstruction of $K^+\Lambda$ Electroproduction Events in CLAS12 using the RPR-2011 Model, GEMC and CLARA

Simulations have been performed using:

- Event Generator based on the Ghent RPR-2011 Model to produce electroproduction events
- GEMC to simulate CLAS12 acceptance effects.
- CLARA Framework to reconstruct events





- 1.6 GeV < W < 3 GeV
- E_{beam} = 7.5 GeV
- Torus/Solenoid current: 100%/ -100%
- 529948 KΛ Events analized

Preliminary Results from 5700 Run

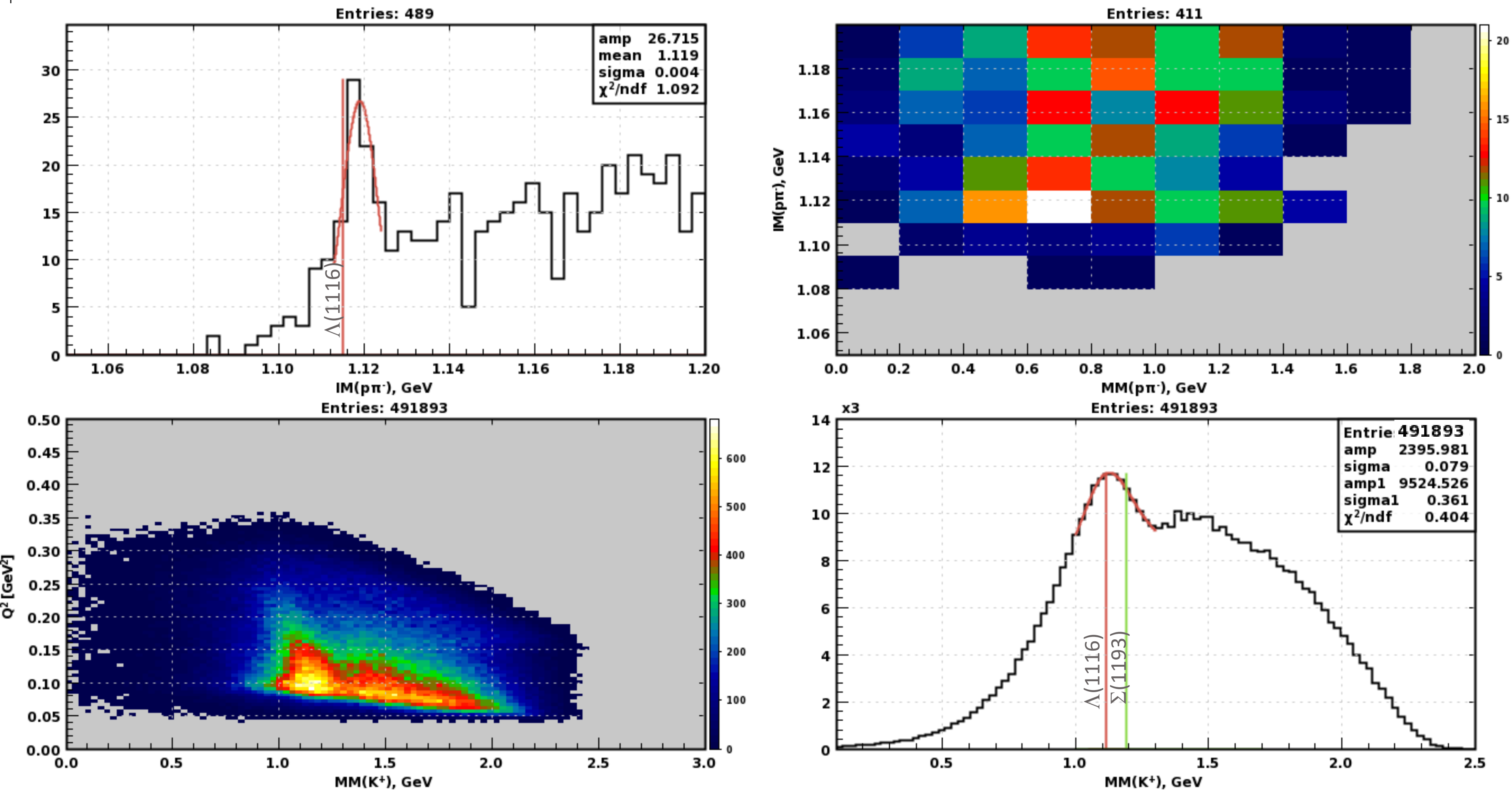
5700 Run Conditions:

- E_{beam} = 7.546 GeV
- Total Events: ~100 M
- Current: 30 nA
- Trigger Config: rgk v2.cnf1 e^- in CLAS with PCAL+ECAL ≥ 300 MeV

1 e^- in FT and 1 charged fwd

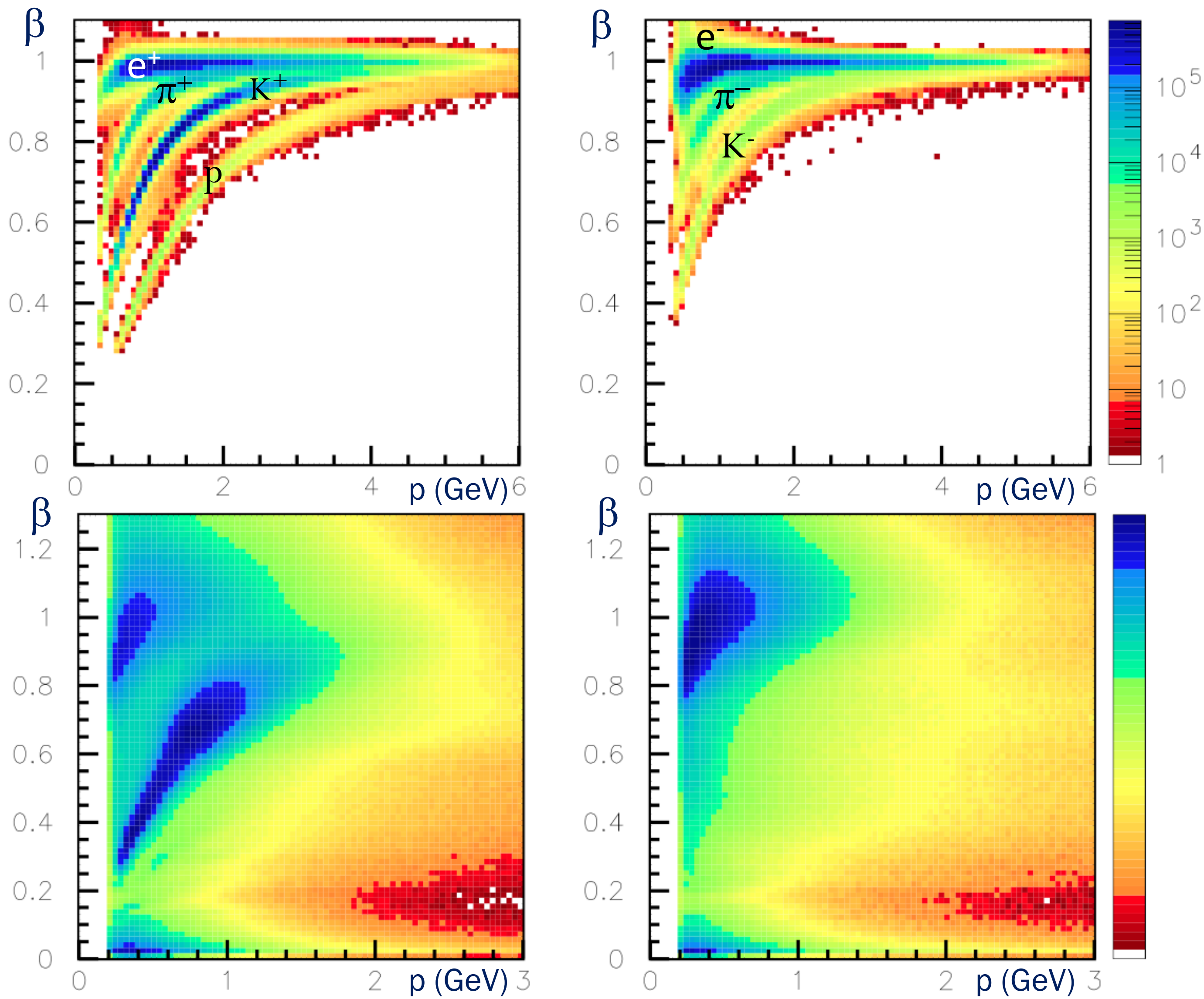
- Torus/Solenoid current: 100%/ -100% (Negative Outbending, -3775)
- Target: LH_2

5700 e^-K^+: electron in FT



1.6 GeV < W < 3 GeV

Particle ID: electron in CLAS



Forward Detector

Central Detector

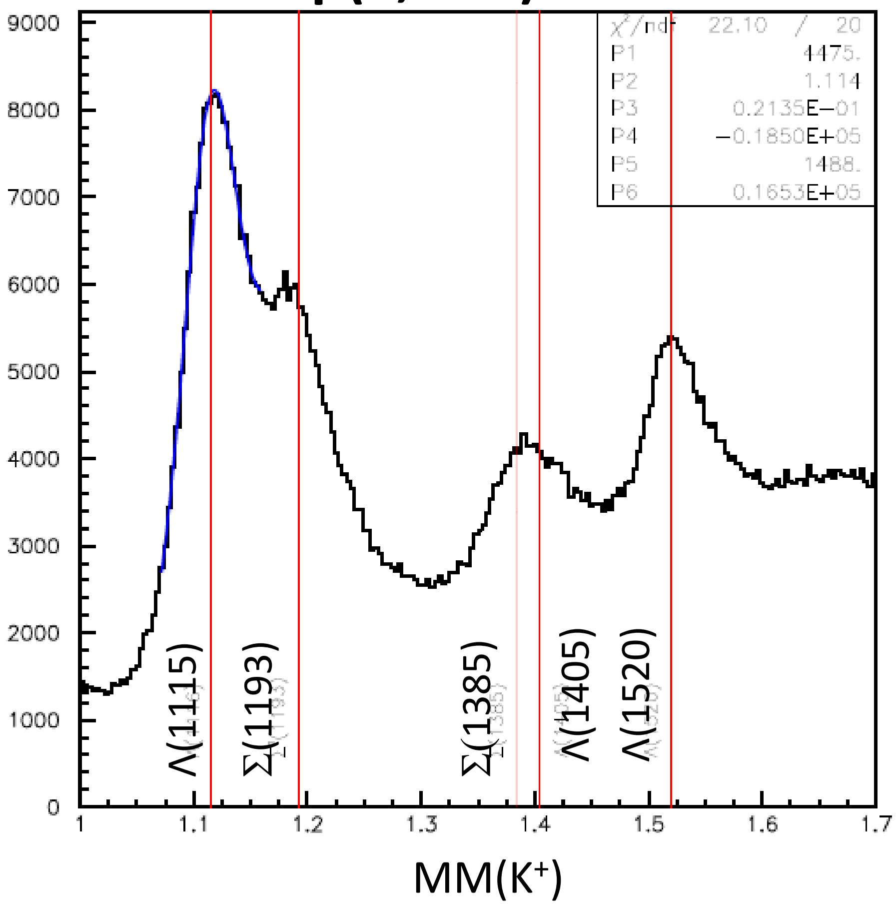
Positive particles

Negative particles

Courtesy of D. Carman

First Results: electron in CLAS

p(e,e'K⁺)X



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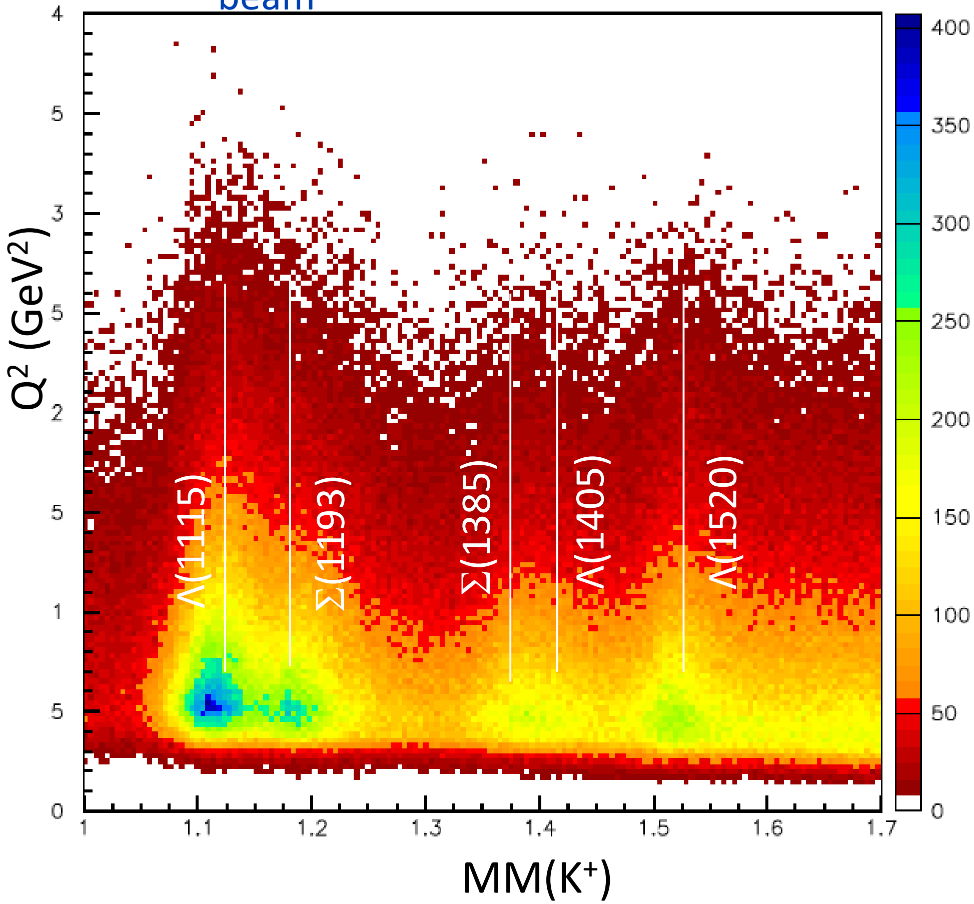


1.6 GeV < W < 3 GeV

Courtesy of D. Carman

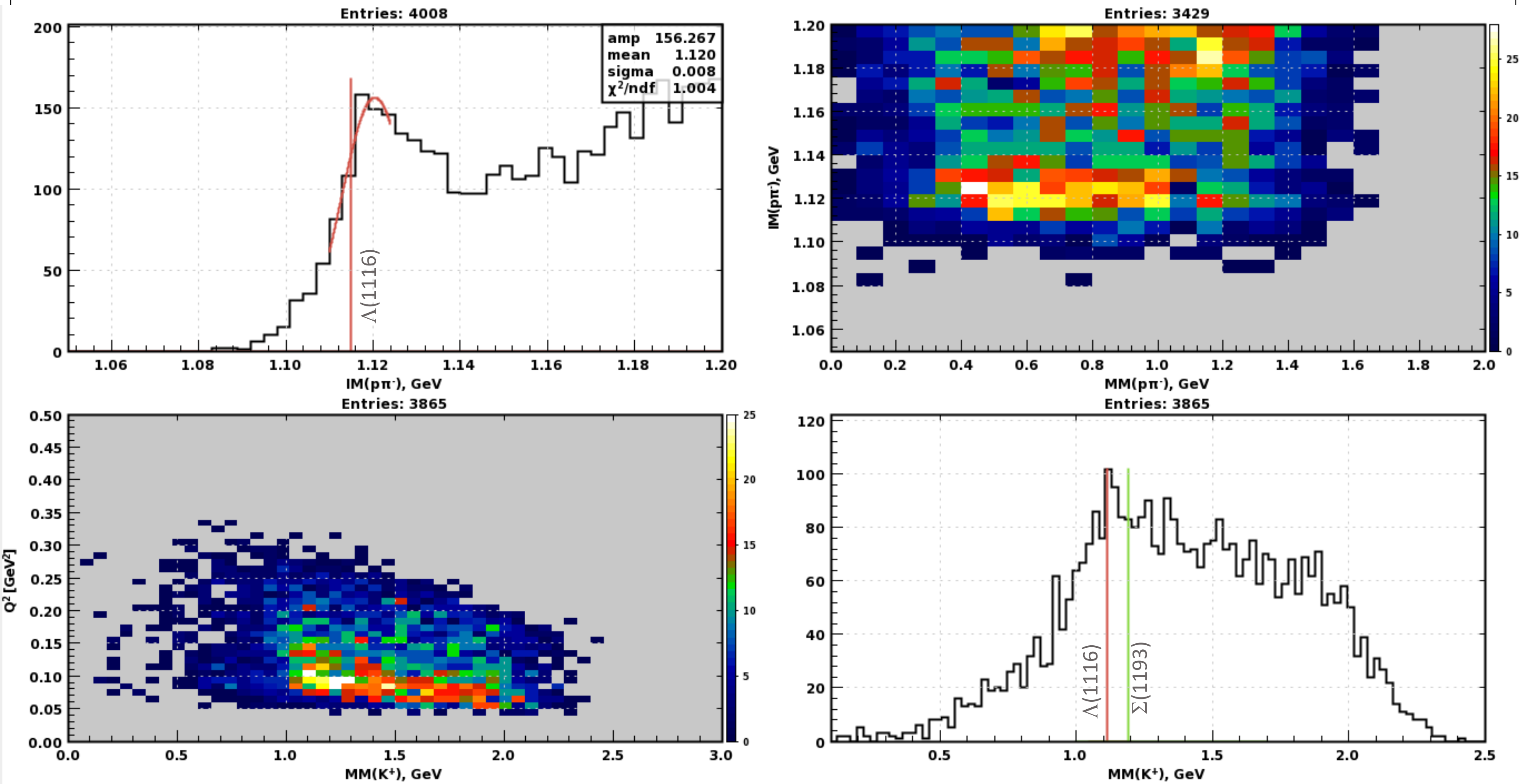
MESONEX-VERYSTRANGE Trains

- e^- in FT + (F+F- or F+F+ or F+C+ or F-C+ or C+C+ or F+C- or C-C+ or F+C- or C+C-)
- Runs: 5681, 5682, 5683, 5684, 5700, 5701, 5702, 5703, 5704, 5705, 5706, 5707, 5708, 5771, 5772
- 7.5 GeV period (FT-on)
- Torus/Solenoid Scale: 1/-1
- Torus/Solenoid Current: -3770.0 A (negative outbending)/ 2416.0 A
- Target: LH_2

Selection:

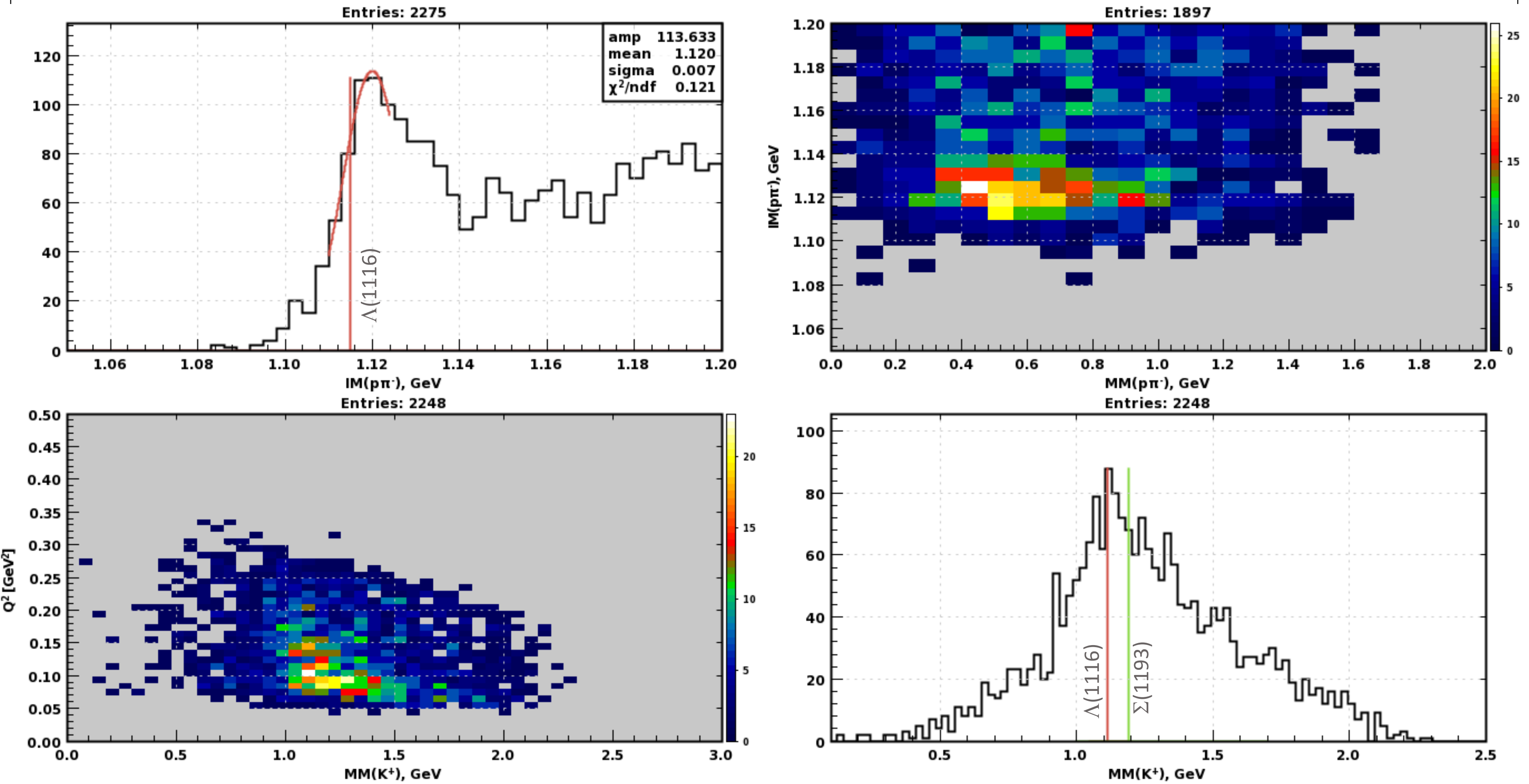
- Study of Exclusive channel: final state with e^- p $\pi^- K^+$
- $|p_x(e^- p\, \pi^- K^+)|<0.2$ GeV and $|p_y(e^- p\, \pi^- K^+)|<0.2$ GeV
- $\sim$ 186 M events analized

Trains Exclusive Channel: electron in FT



1.6 GeV < W < 3 GeV

Trains Exclusive Channel without $|p_{x,y}(e^- p \pi^- K^+)|<0.2$ GeV selection: electron in FT



1.6 GeV < W < 3 GeV

Conclusions and Outlook

- Preliminary results for KY channel available using a subset of data
- Full implementation in CLAS12 simulation and reconstruction
  - GEMC
  - CLARA framework

Next step:

- Upgraded version for CLARA, new calibrated data will be available

- Reconstruction of the interaction strength from data

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Thank you

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