Hall B - Run Group K
Color Confinement and Strong QCD
Status Update

E12-16-010 **A Search for Hybrid Baryons in Hall B with CLAS12**
Annalisa D'Angelo

E12-16-010A Nucleon Resonance Structure Studies Via Exclusive KY Electroproduction at 6.6 GeV and 8.8 GeV
Daniel Carman

E12-16-010B Deeply Virtual Compton Scattering with CLAS12 at 6.6 GeV and 8.8 GeV
Latifa Elouadrhiri

Approved:
- ✓ 50 PAC days at 8.8 GeV
- ✓ 50 PAC days at 6.6 GeV

Assigned:
- ✓ 6.0 PAC days at 7.5 GeV
- ✓ 3.5 PAC days at 6.5 GeV

Main Questions to Address

- The N* spectrum: what is the role of glue?

  → **Search for new baryon states**

  E12-16-010

- How do massless quarks acquire mass?

  → **Measure the Q^2 dependence of electrocoupling amplitudes**

  E12-16-010A

- How is color confinement realized in the force and pressure distributions and stabilize nucleons?

  → **Study GPDs and their moments from DVCS**

  E12-16-010B

Run Group Proposal (RG K)

"Color Confinement and Strong QCD"

Hybrid Baryons E12-16-010	Search for hybrid baryons (qqqg) focusing on 0.05 GeV^2 < Q^2 < 2.0 GeV^2 in mass range from 1.8 to 3 GeV in KΛ, Nππ, Nπ *(A. D'Angelo, V. Burkert, D.S. Carman, V. Mokeev, E. Golovach, R. Gothe)*
KY Electroproduction E12-16-010A	Study N* structure for states that couple to KY through measurements of cross sections and polarization observables that will yield Q^2 evolution of electrocoupling amplitudes *(D.S. Carman, V. Mokeev, R. Gothe)*
DVCS E12-16-010B	Access GPDs H, E, $\tilde{H}$, $\tilde{E}$ using DVCS process ep → epγ and the DVMP process ep → epπ^0 *(L.Elouadrhiri, F.X. Girod)*

Run Group conditions 100 days approved by PAC44:
E_b = 6.6 GeV, 50 days
E_b = 8.8 GeV, 50 days

- Torus I = -3375 A (negatives outbending) 100%
- Solenoid = - 100%
- FT ON, MM, RICH
- Polarized electrons, unpolarized LH_2 target
- L = 1x10^{35} cm^{-2}s^{-1}

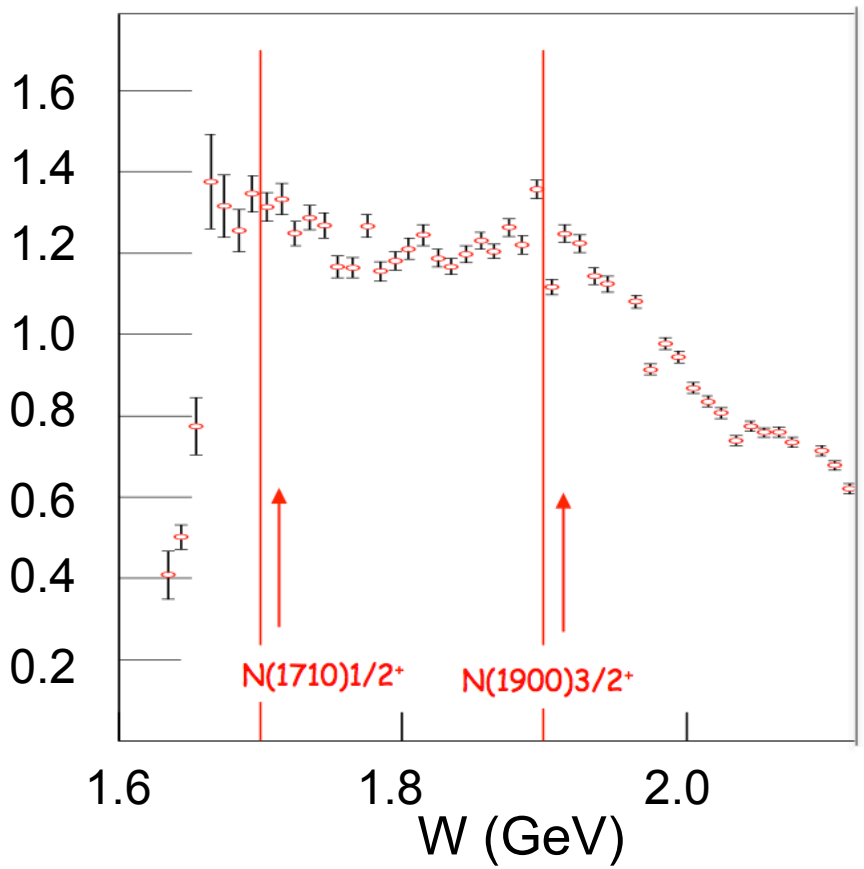
Evidence for New N* in KY and other Final States

State $N(mass)J^P$	PDG pre 2010	PDG 2018	KΛ	KΣ	Nγ
$N(1710)1/2^+$	***	****	****	**	****
$N(1880)1/2^+$		***	**		**
$N(1895)1/2^-$		****	**	*	**
$N(1900)3/2^+$	**	****	***	**	***
$N(1875)3/2^-$		***	***	**	***
$N(2120)3/2^-$		***	**		**
$N(2000)5/2^+$	*	**	**	*	**
$N(2060)5/2^-$		***		**	**

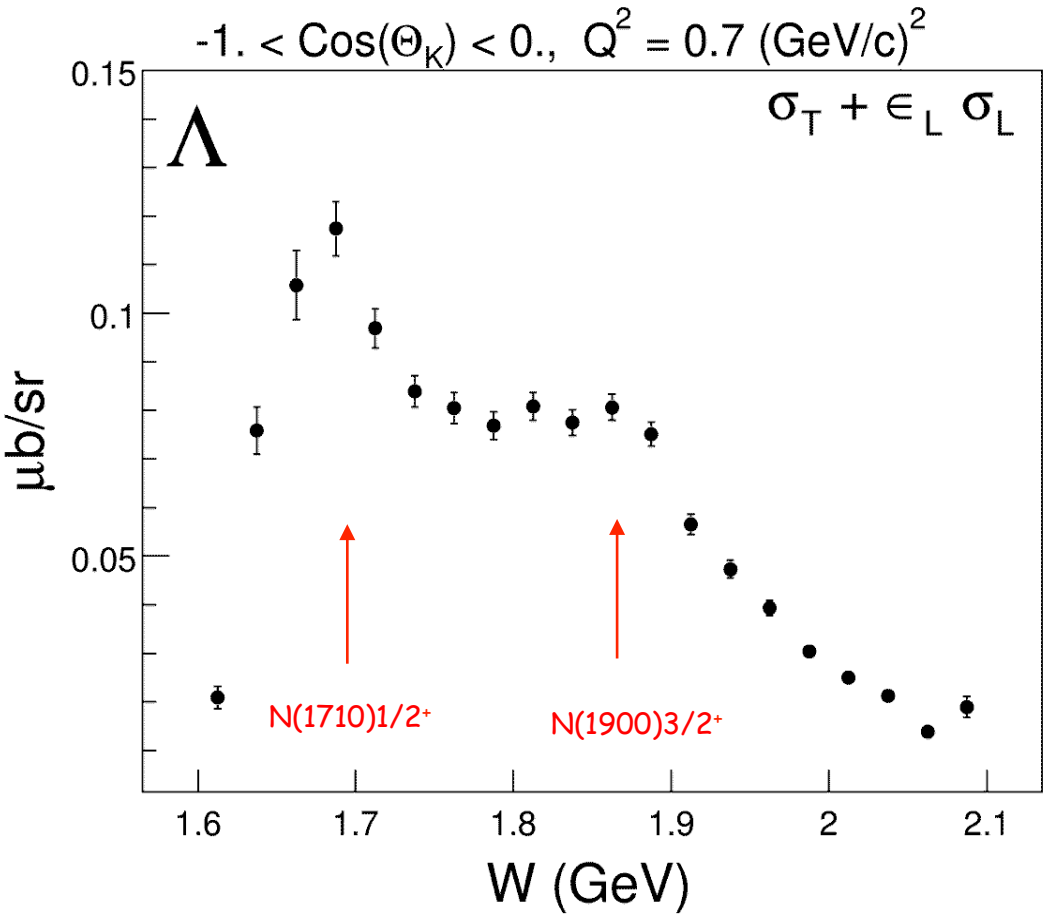
Study these states in electroproduction and extend to higher masses

Studying Baryons in γ*p → KΛ/Σ ?

Photoproduction



Electroproduction



➢ **Strangeness electroproduction is a fertile ground in studying S=0 baryon states with masses above 1.6 GeV.**

Hybrid Baryons: Baryons with Glue as a Structural Component

Hybrid hadrons with dominant gluonic contributions are predicted to exist by QCD.

Experimentally:

- **Hybrid mesons** $|q\bar{q}g\rangle$ states may have exotic quantum numbers J^{PC} not available to pure $|q\bar{q}\rangle$ states ⟶ GlueX, MesonEx, COMPASS, PANDA ….

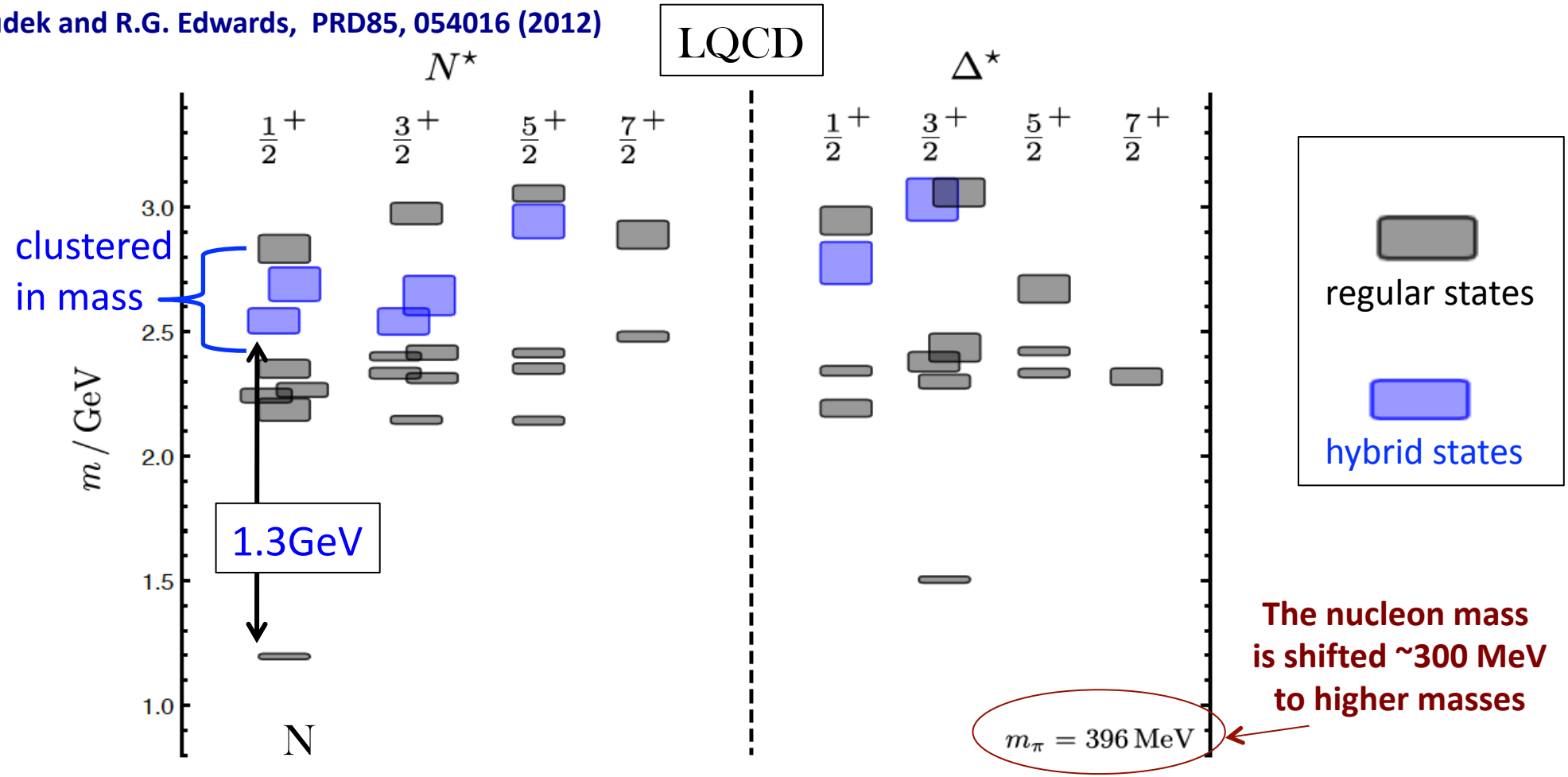
- **Hybrid baryons** $|qqqg\rangle$ have the same quantum numbers J^{P} as $|qqq\rangle$ ⟶ exclusive electroproduction with CLAS12 (Hall B).

Theoretical predictions:

- ✧ MIT bag model - T. Barnes and F. Close, Phys. Lett. 123B, 89 (1983).
- ✧ QCD Sum Rule - L. Kisslinger and Z. Li, Phys. Rev. D 51, R5986 (1995).
- ✧ Flux Tube model - S. Capstick and P. R. Page, Phys. Rev. C 66, 065204 (2002).
- ✧ LQCD - J.J. Dudek and R.G. Edwards, PRD85, 054016 (2012).

Hybrid Baryons in LQCD

J.J. Dudek and R.G. Edwards, PRD85, 054016 (2012)

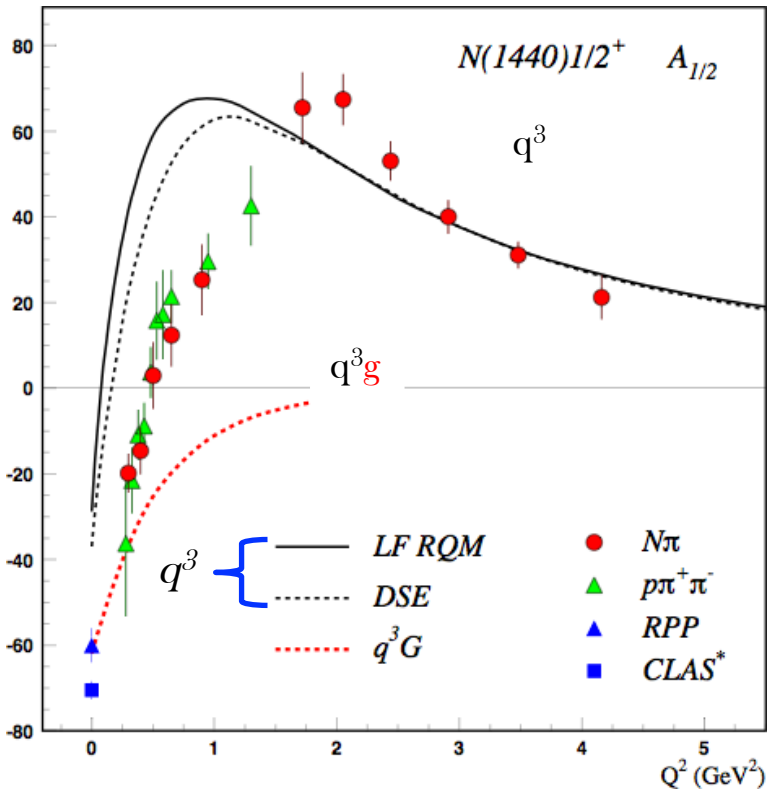


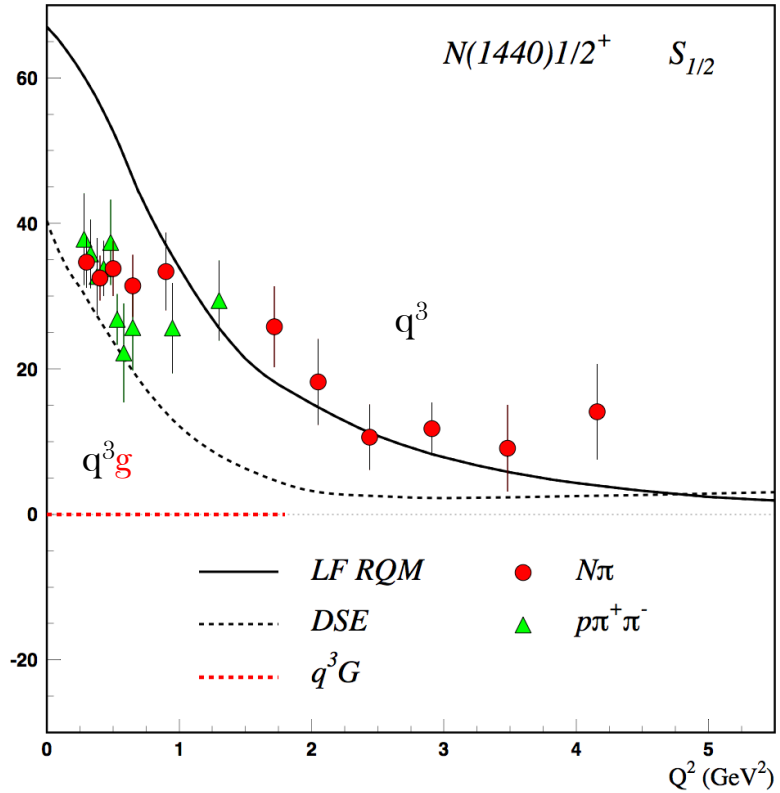
Hybrid states have same J^P values as qqq baryons. How to identify them?

- Overpopulation of N $1/2^+$ and N $3/2^+$ states compared to QM projections.
- **$A_{1/2}$ ($A_{3/2}$) and $S_{1/2}$ show different Q^2 evolution. Can we do it?**

Separating q^3g from q^3 States?

Precise CLAS results on electrocouplings clarified nature of the Roper





- $A_{1/2}$ and $S_{1/2}$ amplitudes at high Q^2 indicate 1st radial q^3 excitation
- Significant meson-baryon coupling at small Q^2

For hybrid "Roper", $A_{1/2}(Q^2)$ drops off faster with Q^2 and $S_{1/2}(Q^2) \sim 0$.

Accessing the Forces & Pressure on Quarks

Nucleon matrix element of EMT contains:

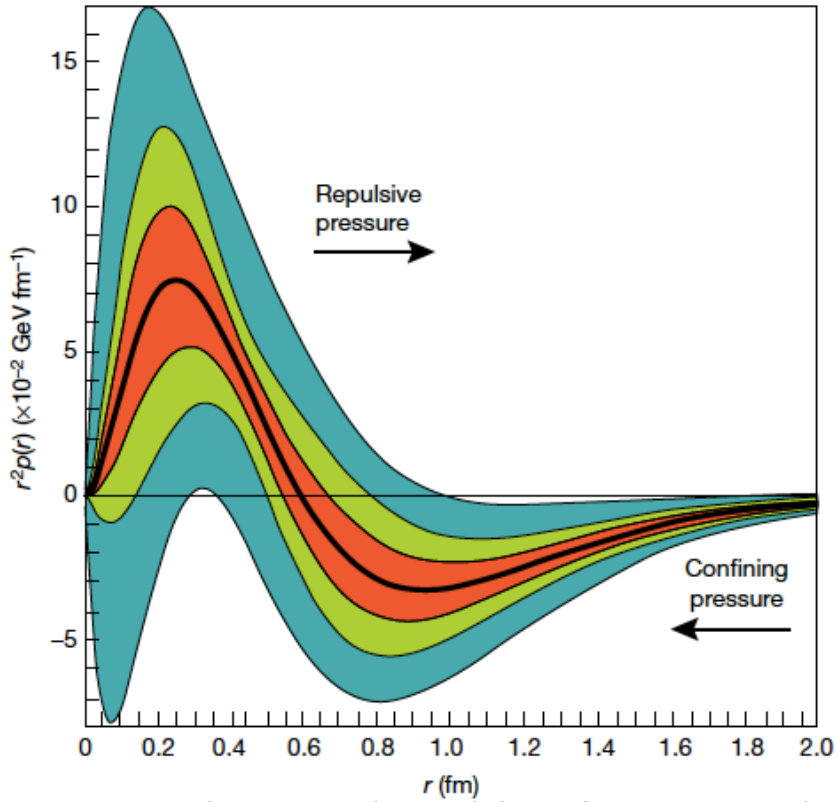
$M_2(t)$: Mass distribution inside the nucleon

$J(t)$: Angular momentum distribution

$d_1(t)$: **Shear forces and pressure distribution**

$$\int xH(x,\xi,t)\mathrm{d}x = M_2(t) + \frac{4}{5}\xi^2 d_1(t)$$

Separate $M_2(t)$ and $d_1(t)$ through measurements at small/large ξ.



V. D. Burkert, L. Elouadrhiri & F. X. Girod
Nature, 557 396-399 (2018)

Measuring these form factors, we learn about confinement forces.

Equipment

Forward Detector (FD)

- TORUS magnet
- HT Cherenkov Counter
- Drift chamber system
- LT Cherenkov Counter
- Forward TOF System
- Pre-shower calorimeter
- E.M. calorimeter

Central Detector (CD)

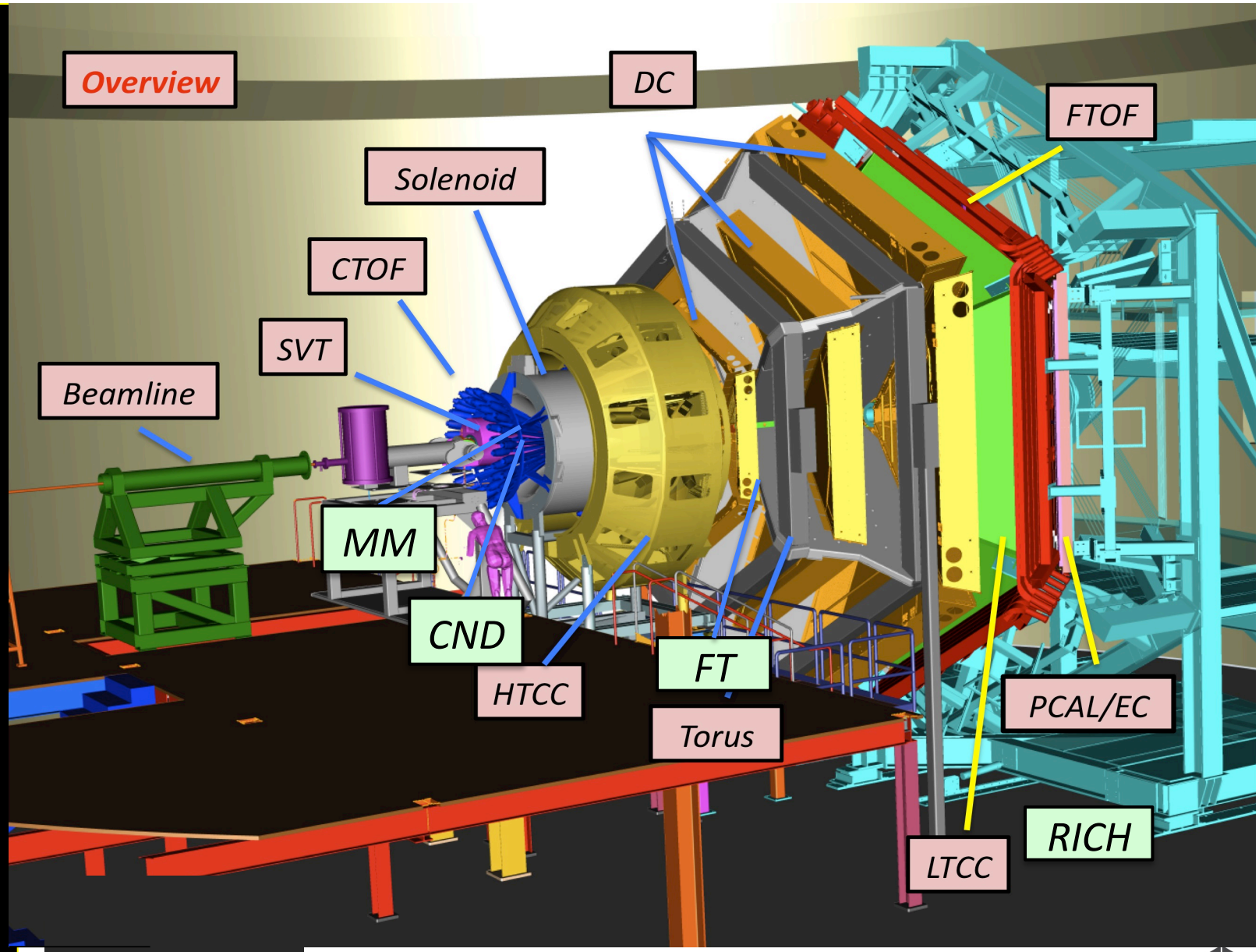
- SOLENOID magnet
- Silicon Vertex Tracker
- Central Time-of-Flight

Beamline

- Cryo Target
- Moller polarimeter
- Shielding
- Photon Tagger

Upgrade to the baseline

- Central Neutron Detector
- MicroMegas
- Forward Tagger
- RICH detector
- Polarized target



Forward Tagger

FT designed to detect electrons and photons at small angles

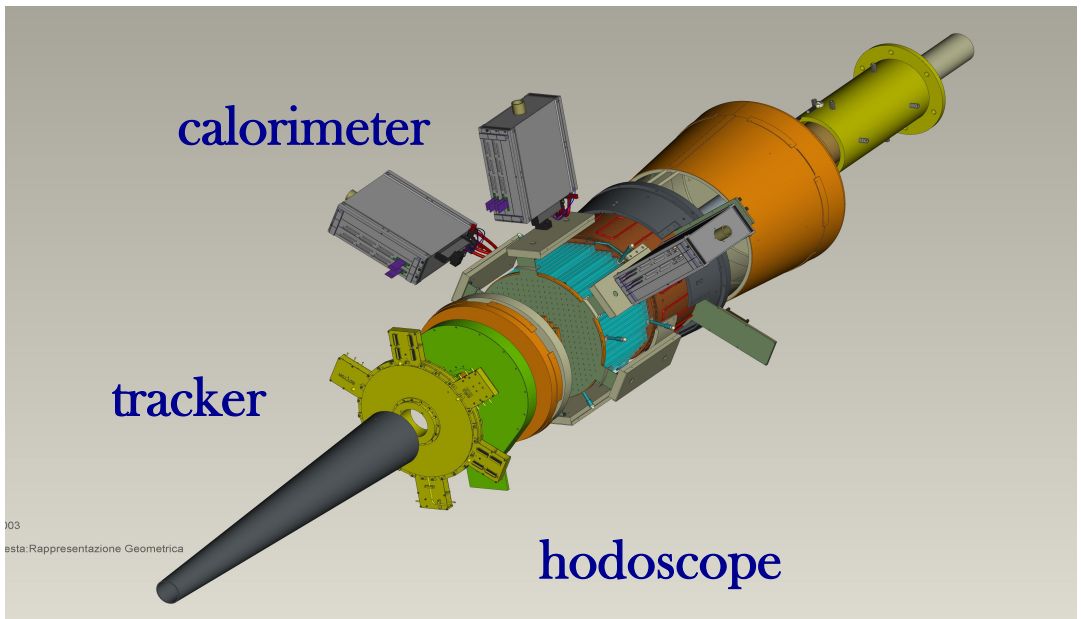
FT-Cal: calorimeter to measure electron energy/ momentum

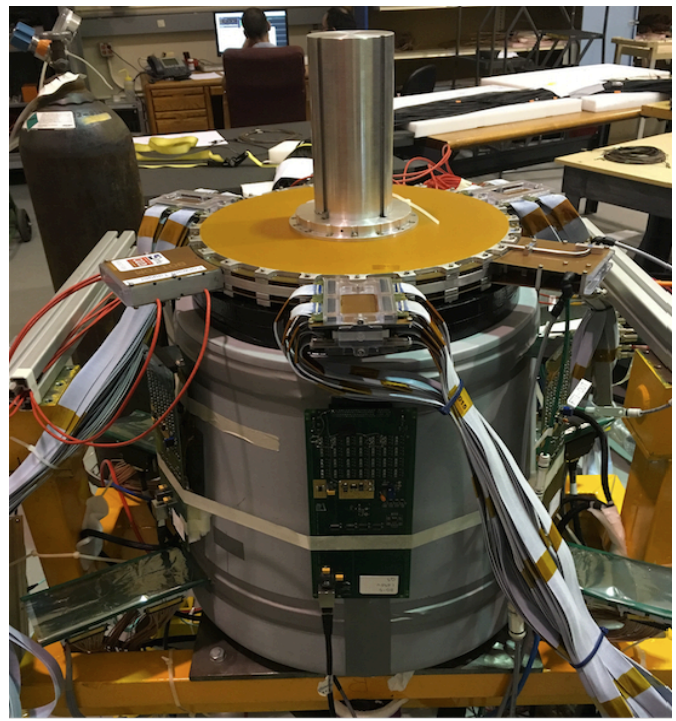
FT-Hodo: scintillation hodoscope to veto photons & backsplash

FT-Trk: micro-mega detector to measure electron angles, polarization plane

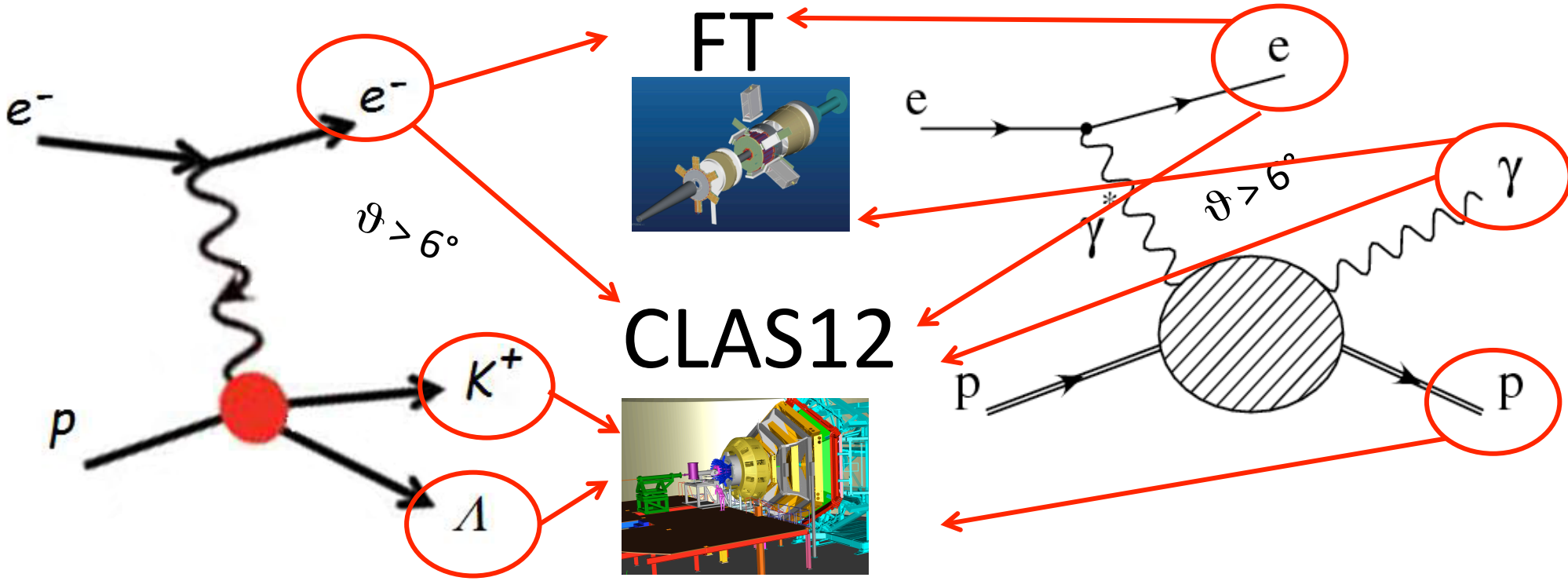
$$\theta = 2.5^\circ \rightarrow 4.5^\circ$$

$$\frac{\sigma(E)}{E} \leq \frac{0.02}{\sqrt{E\ (\mathrm{GeV})}} + 0.01$$





The Experiment



Scattered electrons and photons will be detected:

- in the Forward Tagger for angles from 2.5° to 4.5°
- in the Forward Detector of CLAS12 for scattering angles greater than about 6°

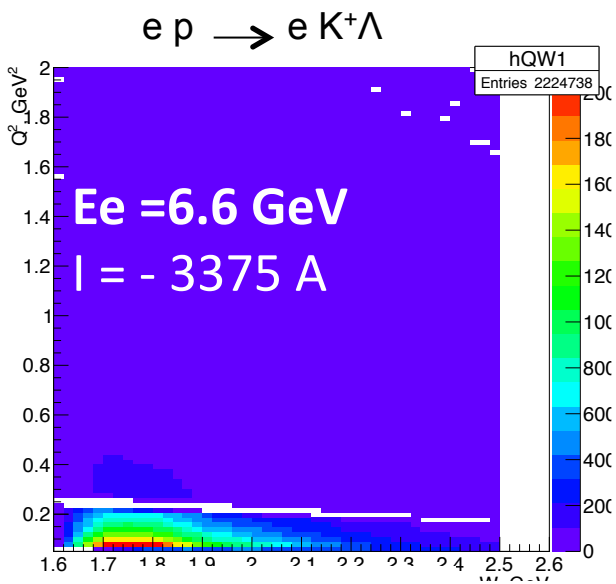
Charged hadrons will be measured in the full range from 6° to 130°

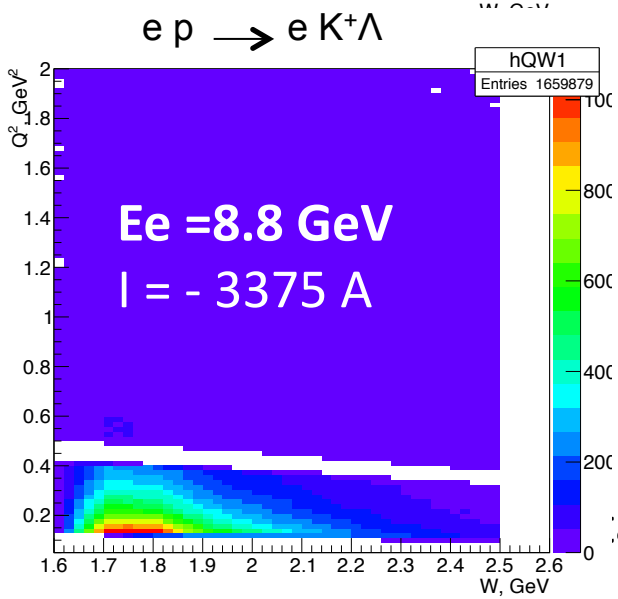
W < 3 GeV Q^2 range of interest: **0.05 - 6 GeV²** $Q^2 = 4E_{Beam}E_{e'}\sin^2\frac{\vartheta}{2} \Rightarrow \vartheta < 5°$

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.

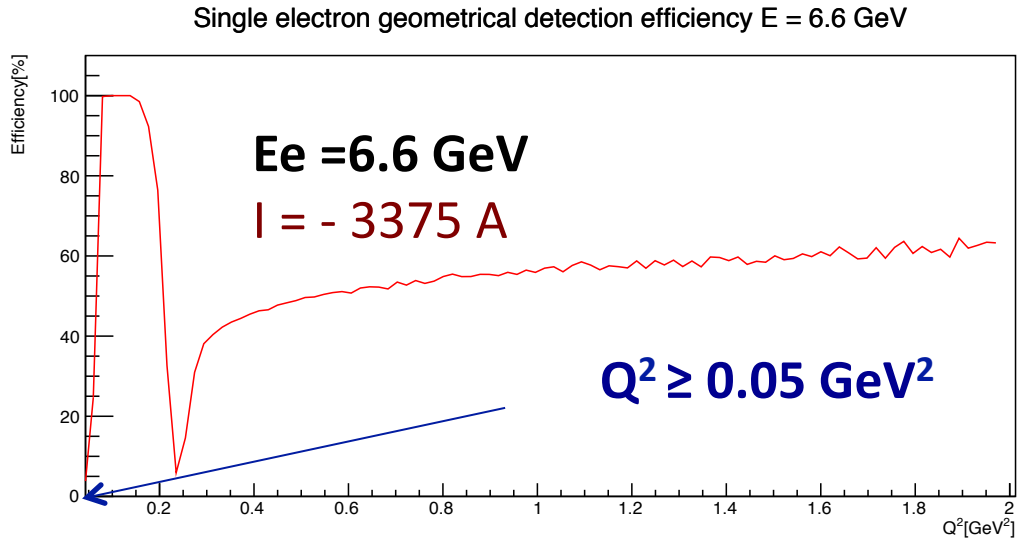
Kinematical Coverage: Full Q^2 Range - Proposal

Q^2 vs W

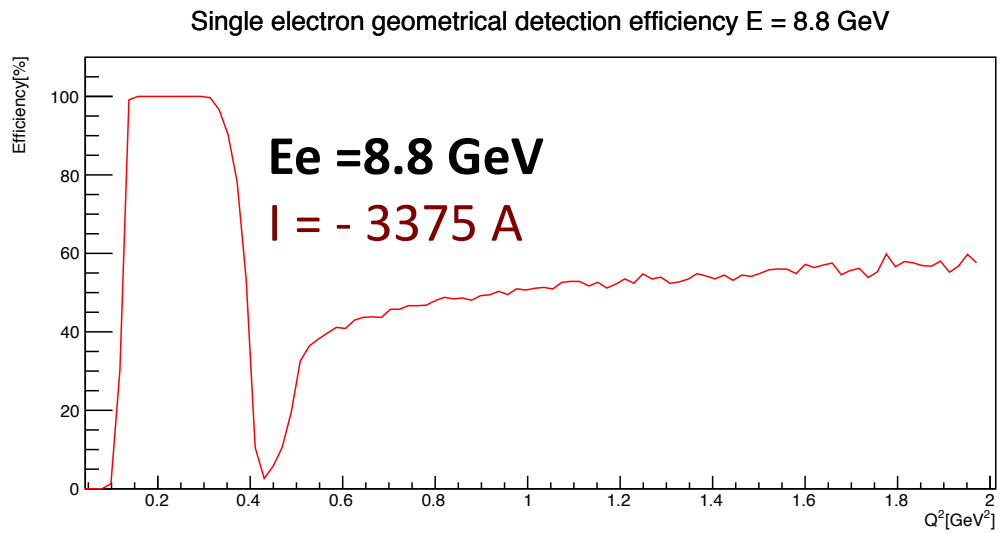




Ee = atistics for 2



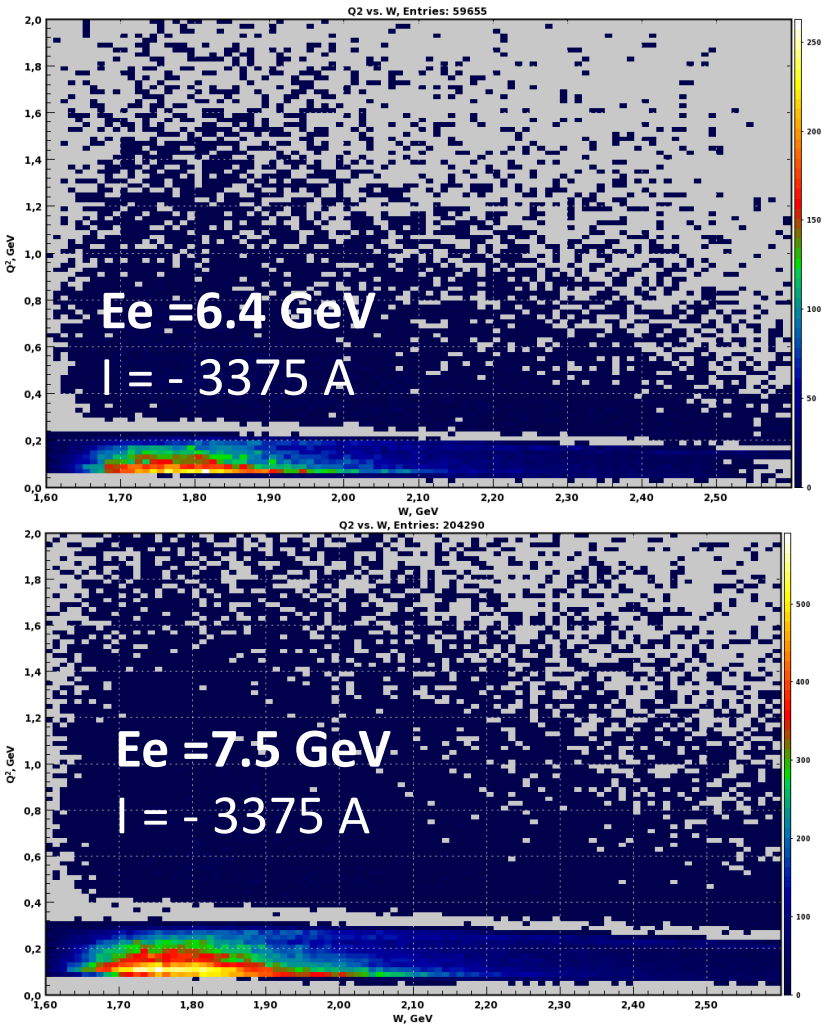
Q^2 as low as 0.05 GeV^2 may be reached

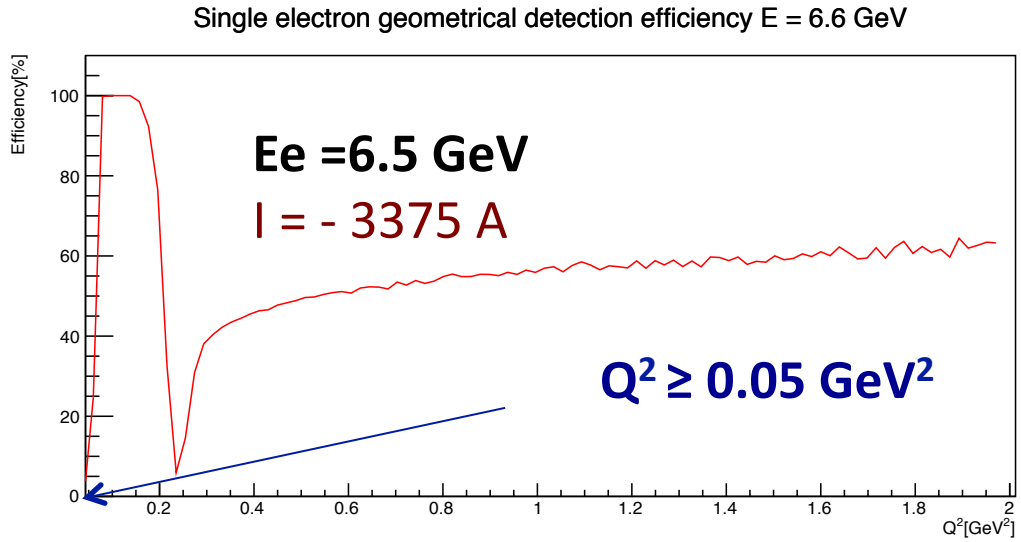


Complementary Q^2 ranges using different E_e

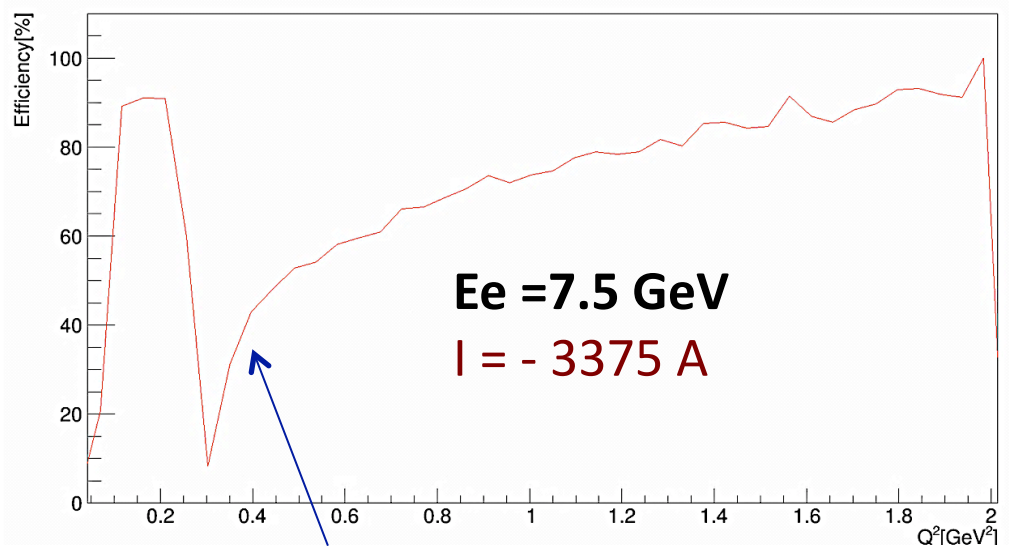
Kinematical Coverage: GEMC-CLARA

Q^2 vs W





Q^2 as low as 0.05 GeV^2 may be reached

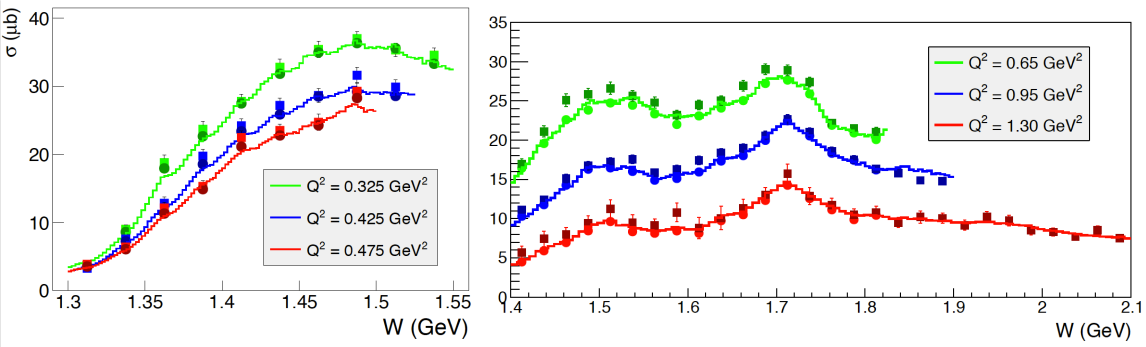


Complementary Q^2 ranges are obtained.

Event Simulation in **CLAS12** using **GEMC** and **CLARA**

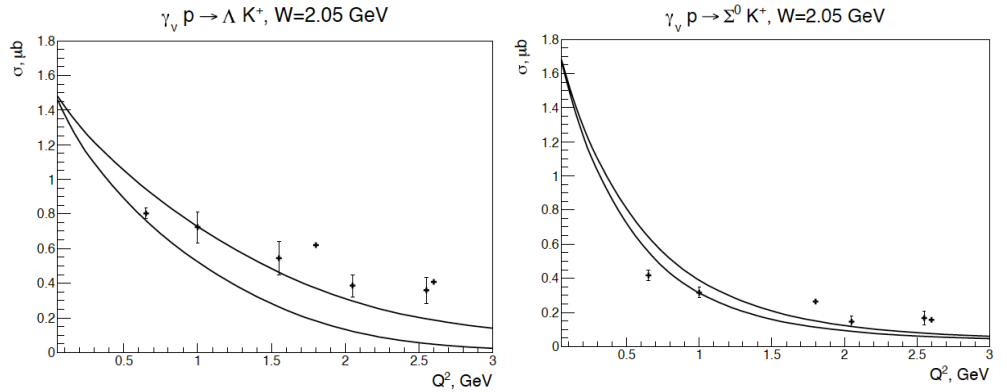
$e\,p \longrightarrow e\,p\,\pi^+\,\pi^-$

JLab - Moscow (JM) model



$e\,p \longrightarrow e\,K^+Y$

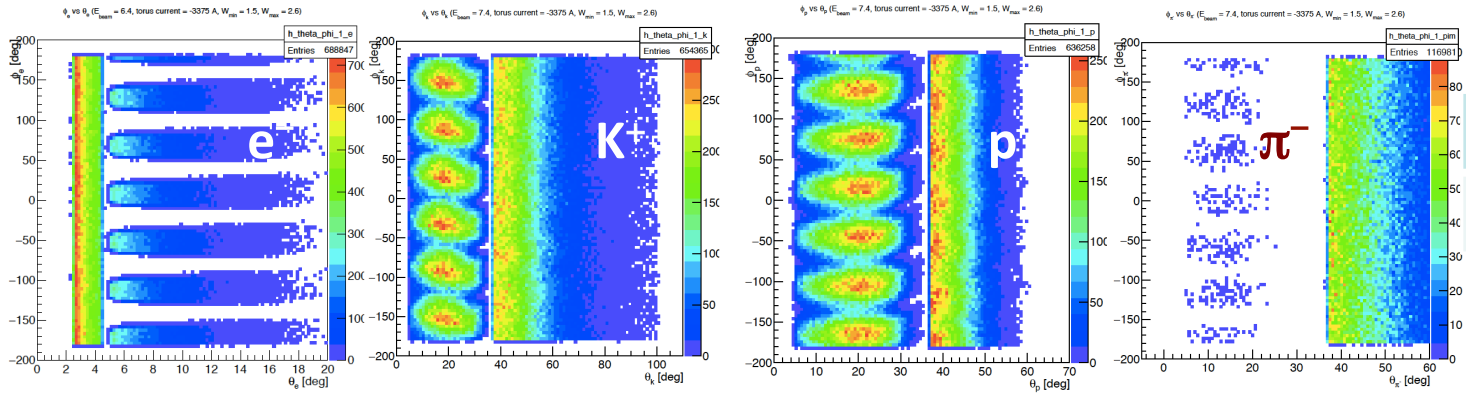
Regge + Resonance (RPR) Gent model



- Development of a realistic event generator using the best presently available models.
- Simulation of events with both Fast MC and full GEMC − CLARA reconstruction.
- Selection of trigger conditions:
  scattered electron (FT or CLAS12) + at least 1 hadron in CLAS12.
- Events analysis to determine final resolutions and efficiencies.

Results for e p ⟶ e K^+ Y

ϕ vs θ angular acceptance for final particles

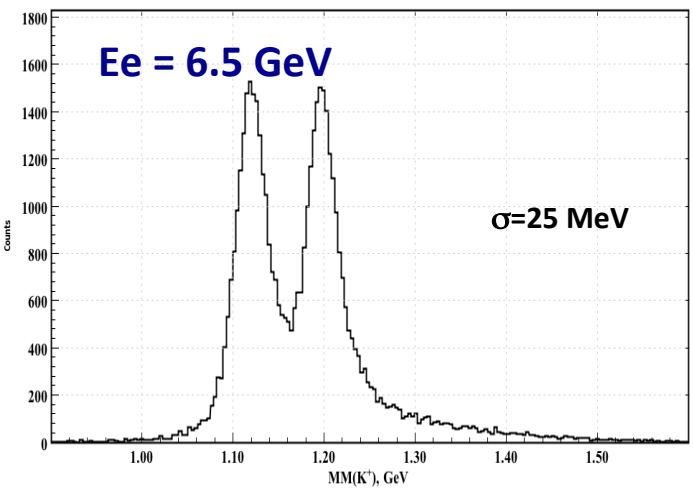


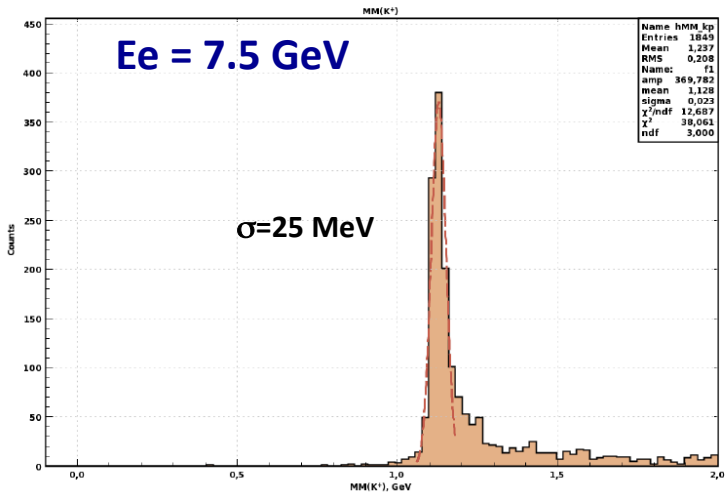
Minimum measurable Q^2

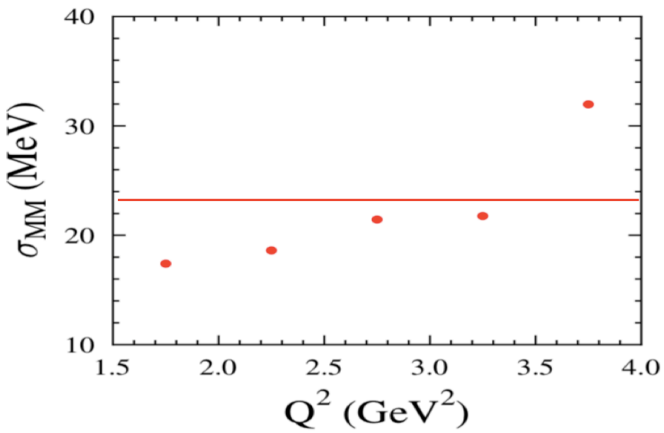
Ee = 6.5 GeV	0.05 GeV^2
Ee = 7.5 GeV	0.08 GeV^2

K^+ missing mass resolution

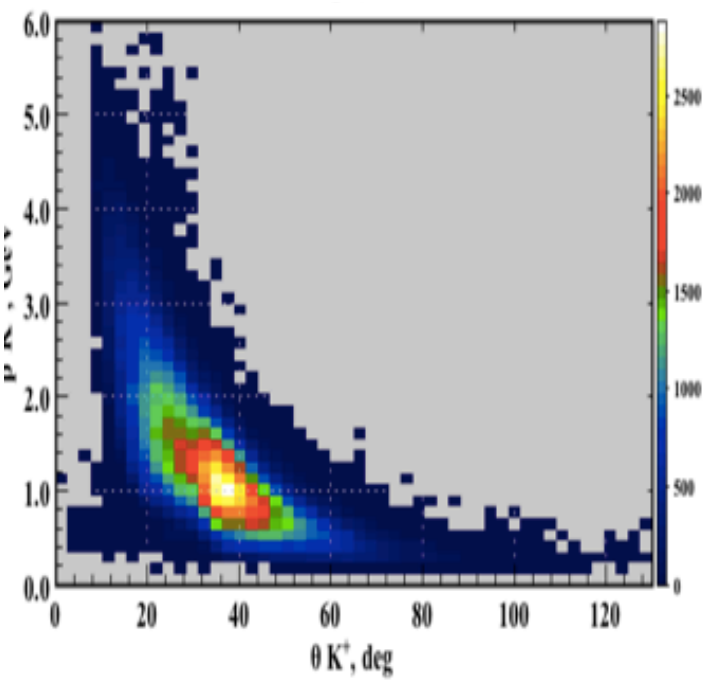
$MM(K^+)$



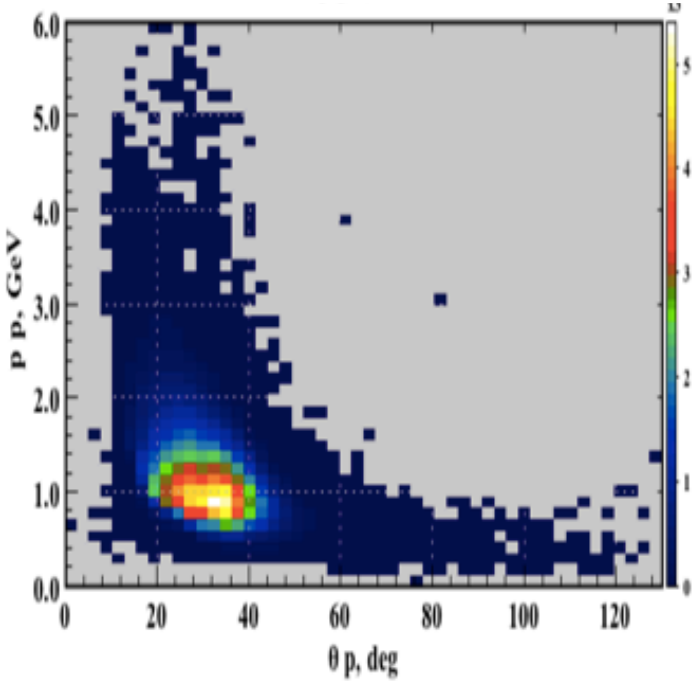




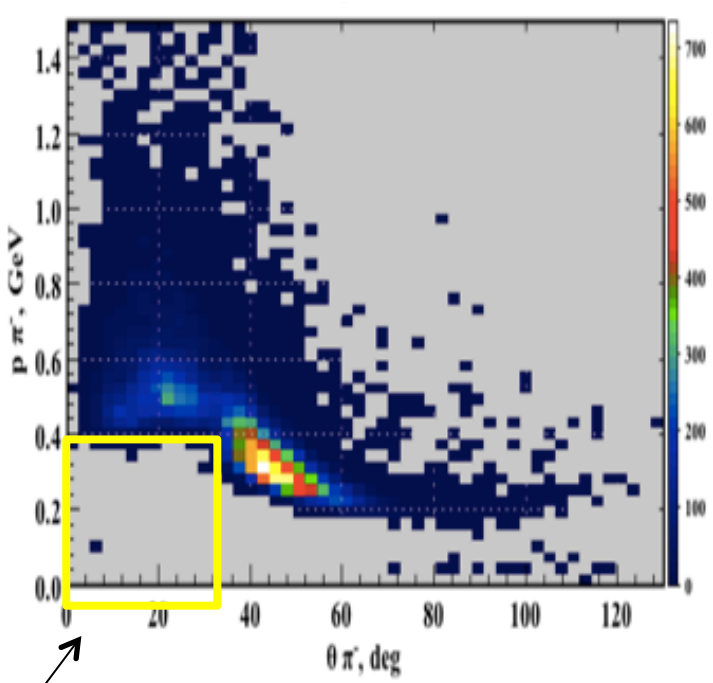
Reconstructed hadrons



K⁺ recon



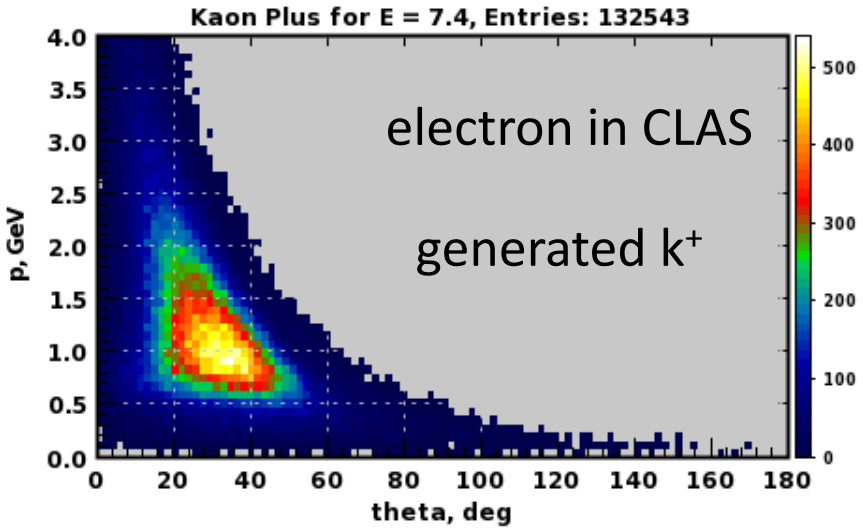
p recon

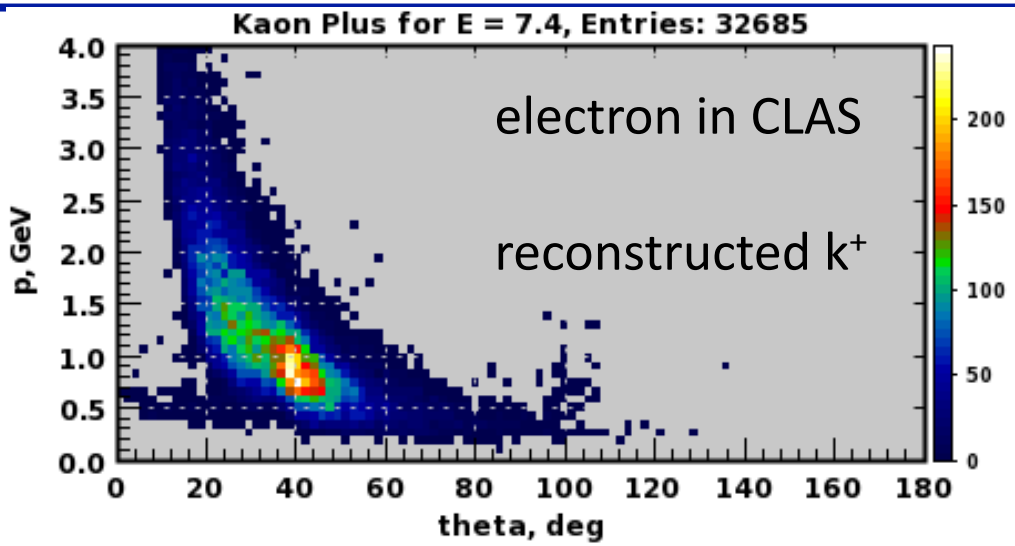


π⁻ recon

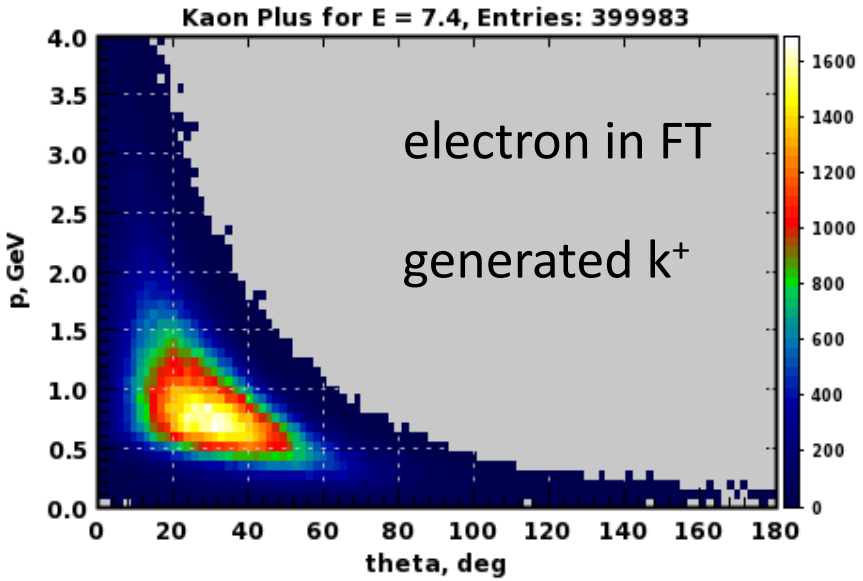
Low momentum forward pions are not reconstructed

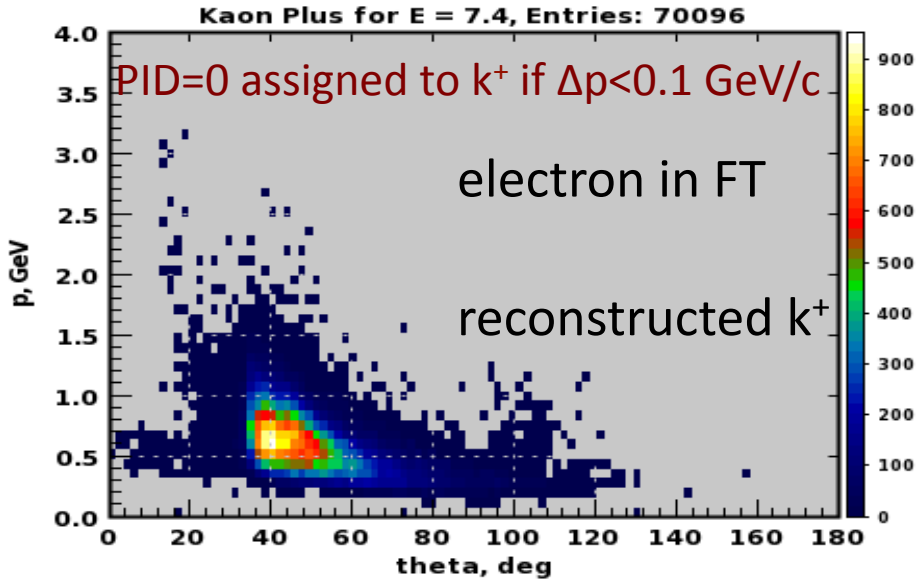
Event Simulation in **CLAS12 - GEMC - CLARA**
E=7.4 GeV -100% Solenoid +100% Torus





electron-kaon acceptance = 24 % - electron in CLAS

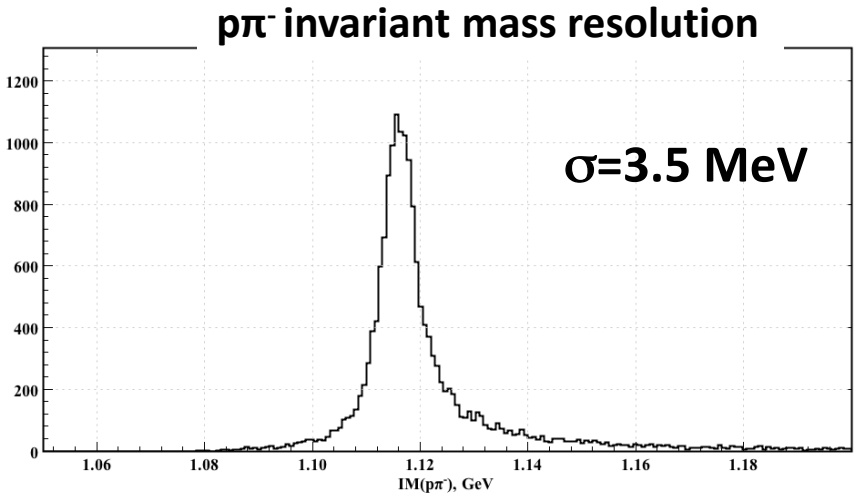




electron-kaon acceptance = 17 % - electron in the FT

Event Simulation in **CLAS12 - GEMC - CLARA**

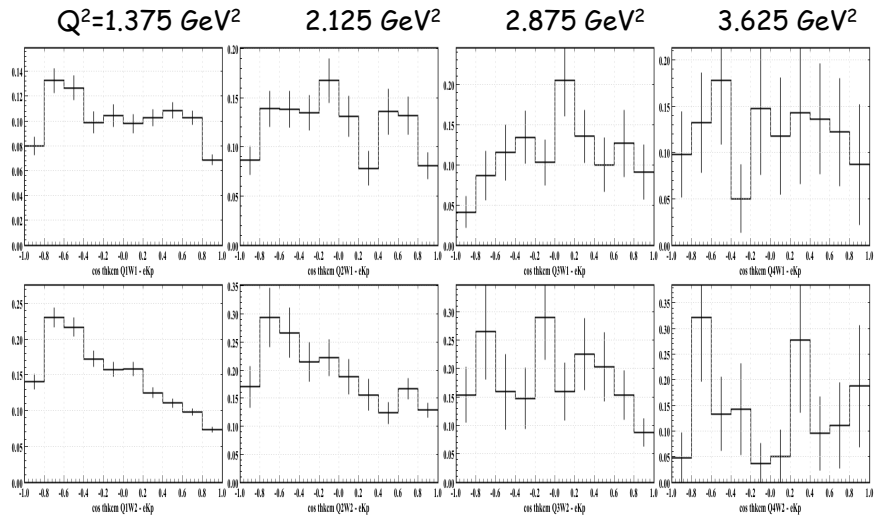
Results for e p ⟶ e K^+ Y



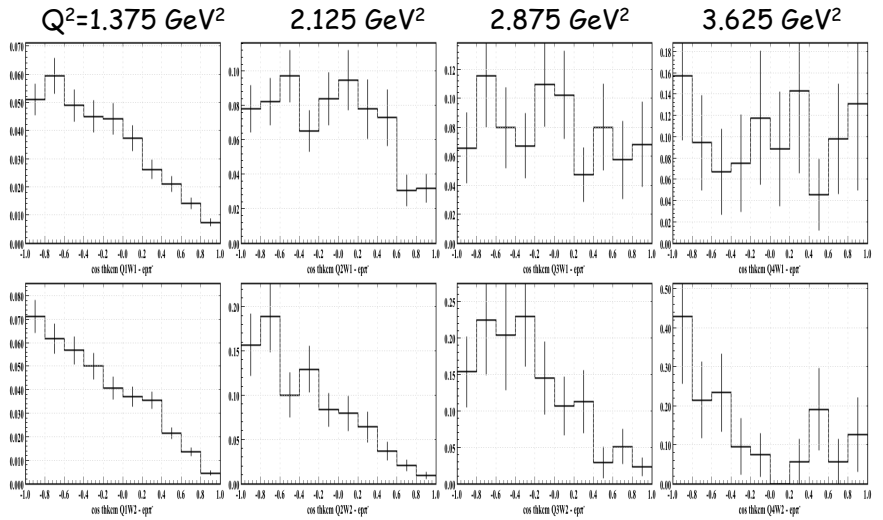
Acceptance

Ee	one missing hadron
Ee = 6.5 - 7.5 GeV	8 - 10 %

e'K^+p Acceptance



e'pπ⁻ Acceptance

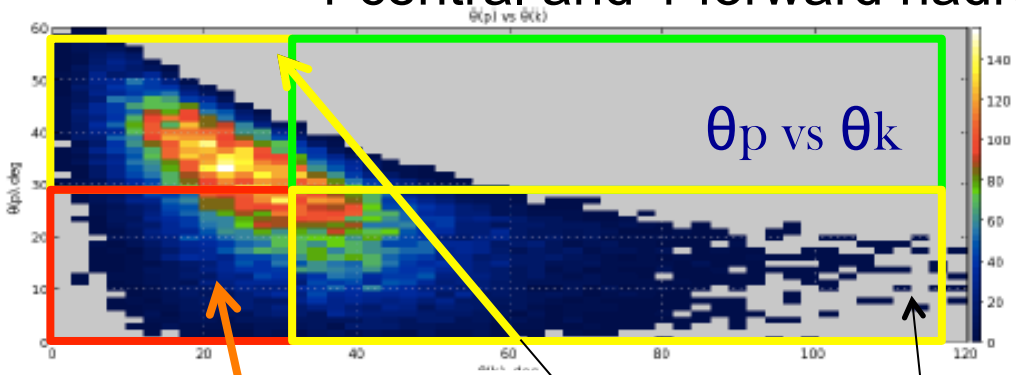


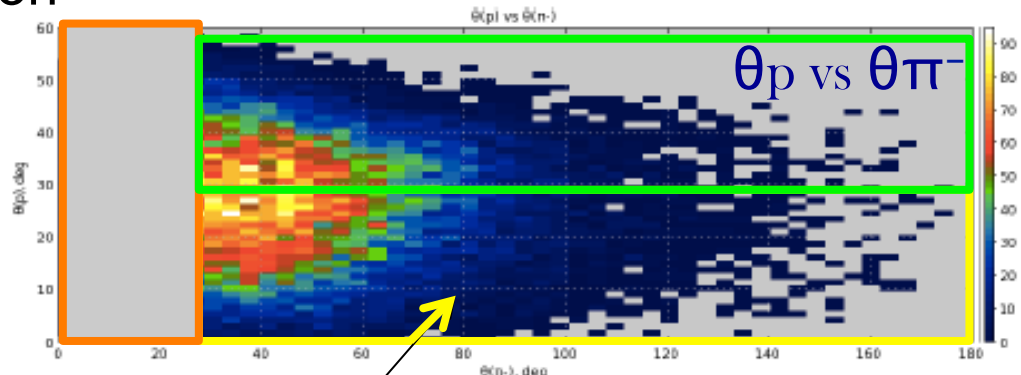
Generated particles: angular correlations

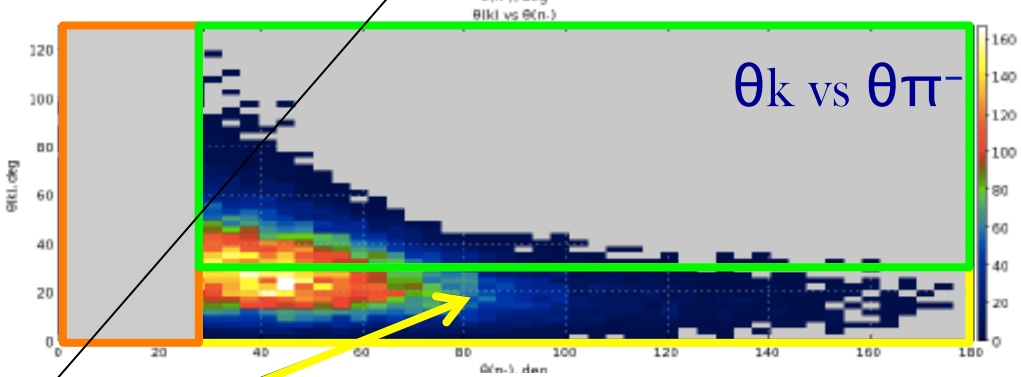
two forward hadrons

two central hadrons

1 central and 1 forward hadron







- Two forward hadrons may only correspond to a $p - K^+$ couple

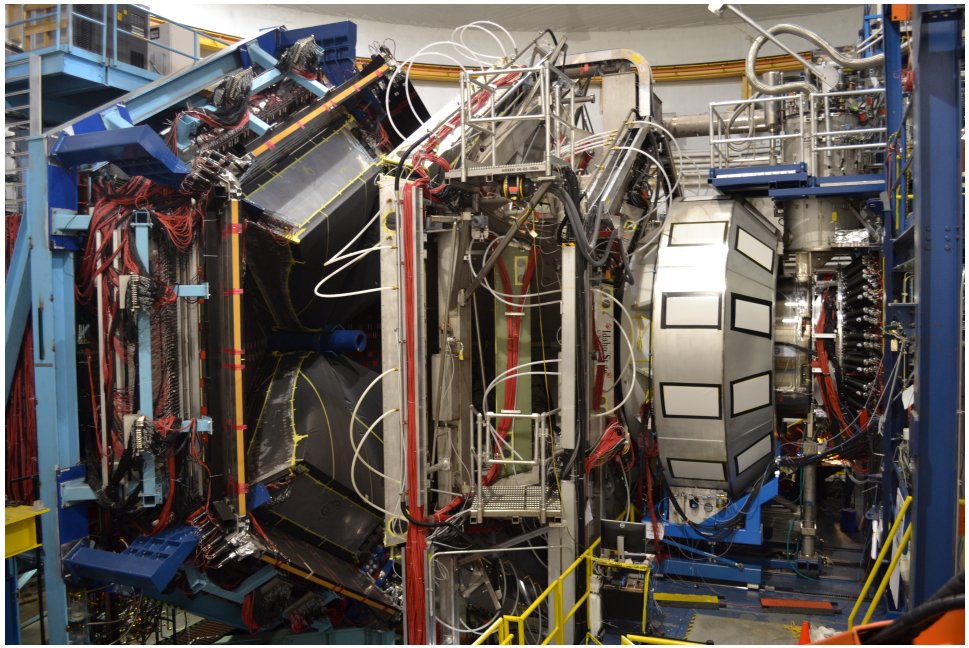
Acceptance ~ 0.5%

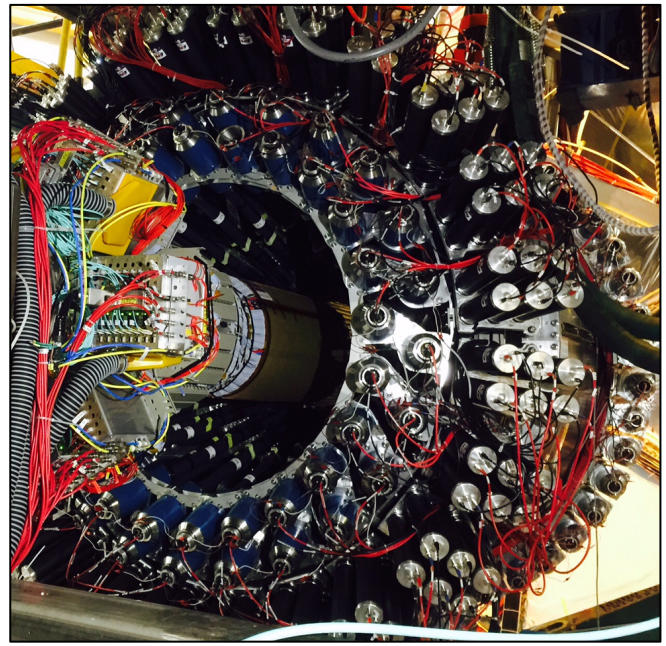
- A forward and a central hadron trigger covers most but not all the phase space: the fine tuning of the trigger configuration requires further studies

(FT x HD x FTOF x PCAL x CTOF x CND)
OR(FT x HD x (FTOF x PCAL)^2)

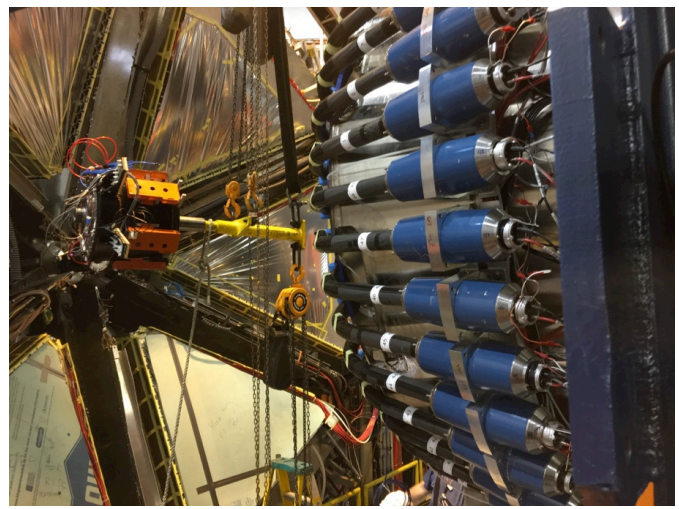
Trigger: FT +	Acceptance
(1 fwd + 1 cntrl hadron) or (2 fwd hadrons)	5-6 %
1 forward hadron	20 %

Run Conditions





Torus Current	100% (3375 A) - **negative outbending**
Solenoid	-100 %
FT	**ON**
MM RICH	ON
FMT	OFF
Beam/Target	Polarized electrons, unpolarized LH_2 target
Luminosity	$10^{35}\ cm^{-2}s^{-1}$



Run Group K Triggers Configuration E=7.5 GeV

Trigger Number	Physics Definition	Detectors Conditions	Thresholds	prescale
0	1 electron in CLAS All sectors − with DC	(DC x HTTC x ECAL x PCAL) or (DC x HTTC x PCAL)	(PCAL+ECAL)> 300 MeV PCAL>60 MeV ECAL>10 MeV or PCAL> 300 MeV	1
1-6	1 electron in CLAS Fixed Sector − with DC	(DC x HTTC x ECAL x PCAL) or (DC x HTTC x PCAL)	(PCAL+ECAL)> 300 MeV PCAL>60 MeV ECAL>10 MeV or PCAL> 300 MeV	1
24	Forward electron 1 forward and 1 central	FT (1800-6600) x DC x FTOFPCU x PCAL x CTOF	PCAL>15 MeV CTOF clusters>2 MeV	1
25	Forward electron 2 forward	FT (1800-6600) x (DC x FTOFPCU x PCAL x CTOF)^2	PCAL>15 MeV	1
28 (new)	Forward electron 1 forward and 1 central	FT (1800-6600) x DC x FTOFPCU x PCAL x CTOF X CND	PCAL>15 MeV CTOF vs CND map no additional threshold	1

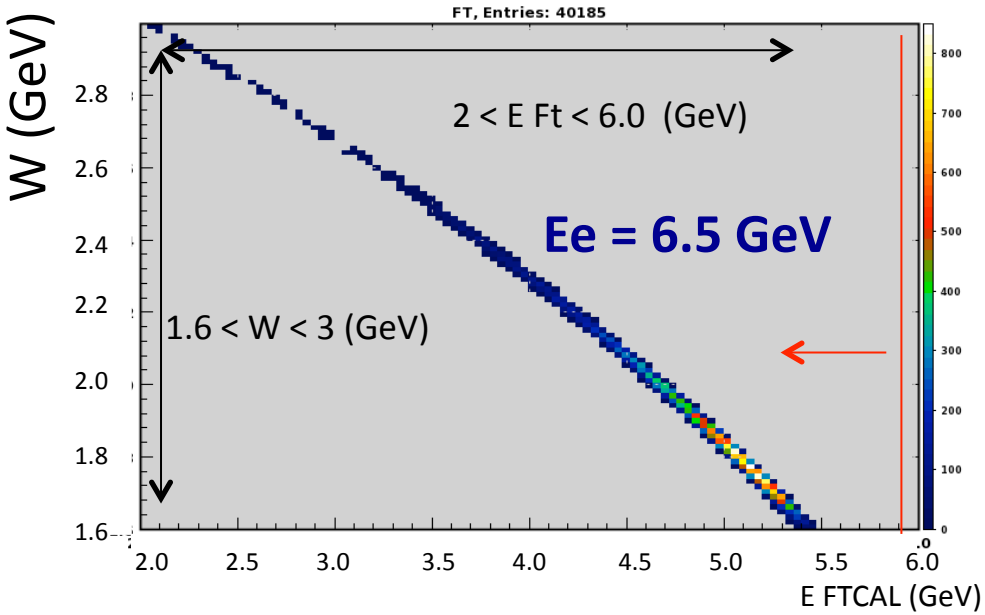
Accept 13 kHz events @ 91% live time

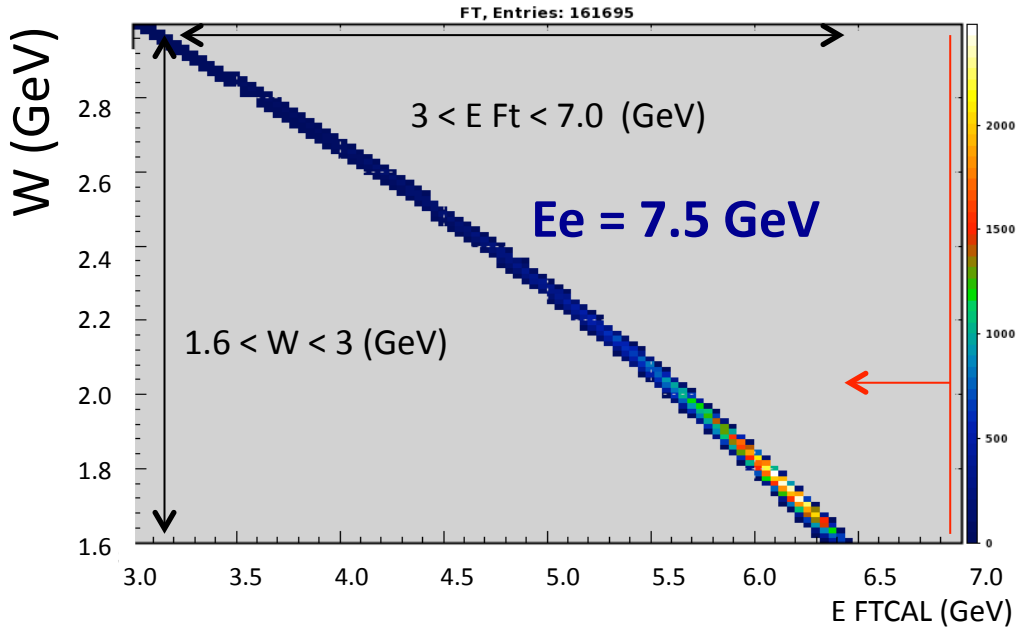
Run Group K Triggers Configuration E=6.5 GeV

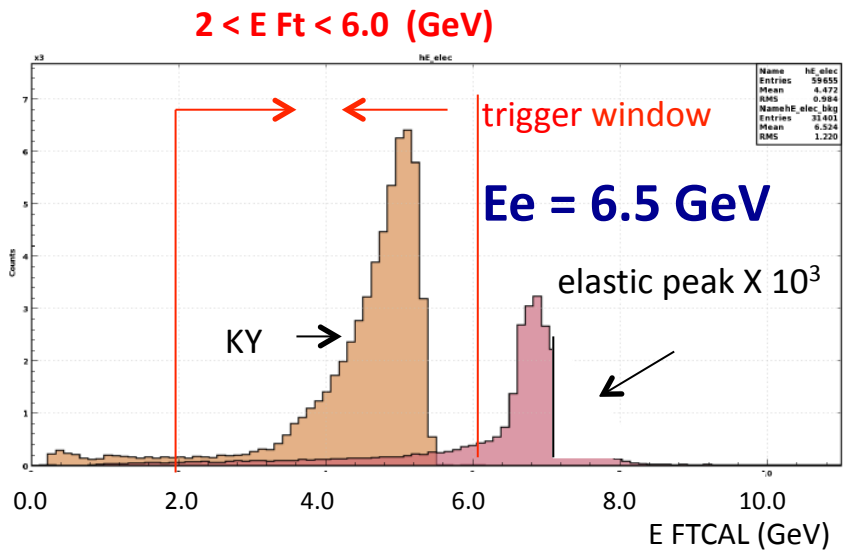
Trigger Number	Physics Definition	Detectors Conditions	Thresholds	prescale
0	1 electron in CLAS All sectors − with DC	(DC x HTTC x ECAL x PCAL) or (DC x HTTC x PCAL)	(PCAL+ECAL)> 300 MeV PCAL>60 MeV ECAL>10 MeV or PCAL> 300 MeV	1
1-6	1 electron in CLAS Fixed Sector − with DC	(DC x HTTC x ECAL x PCAL) or (DC x HTTC x PCAL)	(PCAL+ECAL)> 300 MeV PCAL>60 MeV ECAL>10 MeV or PCAL> 300 MeV	1
24	Forward electron 1 forward and 1 central	FT (1800-5600) x DC x FTOFPCU x PCAL x CTOF	PCAL>15 MeV CTOF clusters>2 MeV	1
25	Forward electron 2 forward	FT (1800-5600) x (DC x FTOFPCU x PCAL x CTOF)^2	PCAL>15 MeV	1
28 (new)	Forward electron 1 forward and 1 central	FT (1800-5600) x DC x FTOFPCU x PCAL x CTOF X CND	PCAL>15 MeV CTOF vs CND map no additional threshold	1

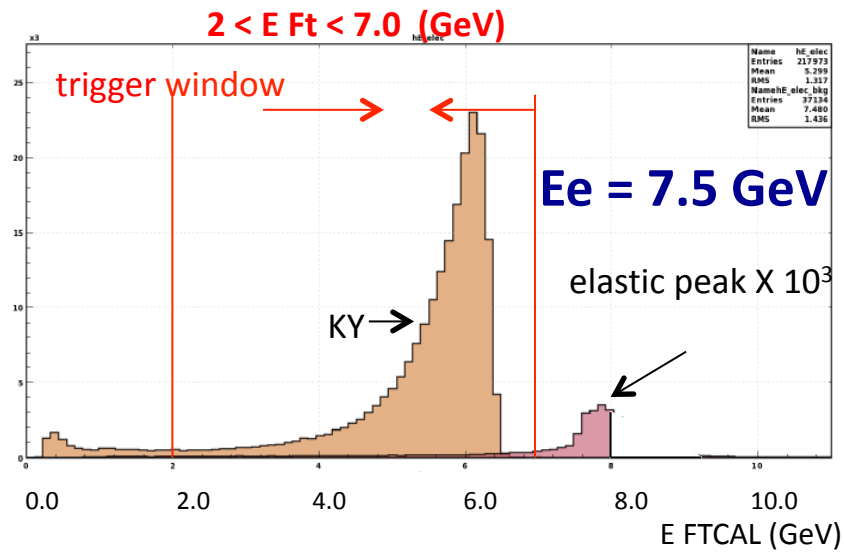
Accept 13 kHz events @ 91% live time

Trigger – FTcal energy window









Expected Data Volume and Events

Inputs: $L = 10^{35}\ cm^{-2}s^{-1}$ Trigger rate = 12 kHz

	Event	Beam-second	Week	2018 – 9 PAC days
Row EVIO	50 kB	600 MB	180 TB	231 TB
Decoded Hipo	13 kB	195 MB	59 TB	75 TB
DST Hipo	2.2 kB	33 MB	10 TB	13 TB

Assuming data compression achieved -> x 0.7 event size reduction

	Event	Beam-second	Week	2018 – 9 PAC days
Row EVIO	35 kB	420 MB	125 TB	160 TB

K Λ expected events at full luminosity

	efficiency	event rate Hz	Week	2018 – 9 PAC days
KΛ events prod	1	70	21 M	27 M
KΛ events trigg	0.13	9	2.7 M	3.5 M

Manpower

Run group K experiments would benefit of the collaboration with similar experiment of Run group A running at 10 GeV :

- E12-06-108A Exclusive N* -> KY Studies with CLAS12 - D.S. Carman
- E12-06-119 (a) Deeply Virtual Compton Scattering - F. Sabatie

Run Coordinators:

- Annalisa D'Angelo 29 November – 6 December
- Volker Burkert 6 December – 13 December
- Latifa Elouadrhiri 13 December –19 December

Same analysis working group of Run Group A will be involved.
Analysis coordinator: to be decided among the spokespersons.
Chef: FX Giraud
Dedicated Post-doc: Lucilla Lanza

The Run Group A Calibration Team will also be available.
Leader: Dan Carman

Conclusions

- ✓ Run group K has agreed to take the opportunity of an early run at energies 6.5 GeV and 7.5 GeV. -> **GEMC + CLARA** full simulation performed
- ✓ Complementary Q^2 ranges are still available with lower statistics expected for $2.5 < W < 3$ GeV
- ✓ Run conditions are similar to run Group A, but limited to **negative outbending** torus field and optimized trigger.
- ✓ **Trigger conditions** include: 1 electron in CLAS + 1 electron in the FT (higher energy window respect to MesonX trigger) in coincidence with 1 Forward and 1 Central hadron or two forward hadrons.

  1 electron in CLAS + 1 e^- FT and 2 hadrons in CLAS
- ✓ Manpower of run group A is foreseen to strongly contribute.
- ✓ 160 TB raw EVIO data, 13 TB reconstructed DST and 3.5 M KY events are expected.