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

Data Taken:
- ✓ 5.5 PAC days at 7.5 GeV
- ✓ 4.0 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 → $ep\pi^0$ *(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
- $L = 1 \times 10^{35}\ cm^{-2}s^{-1}$

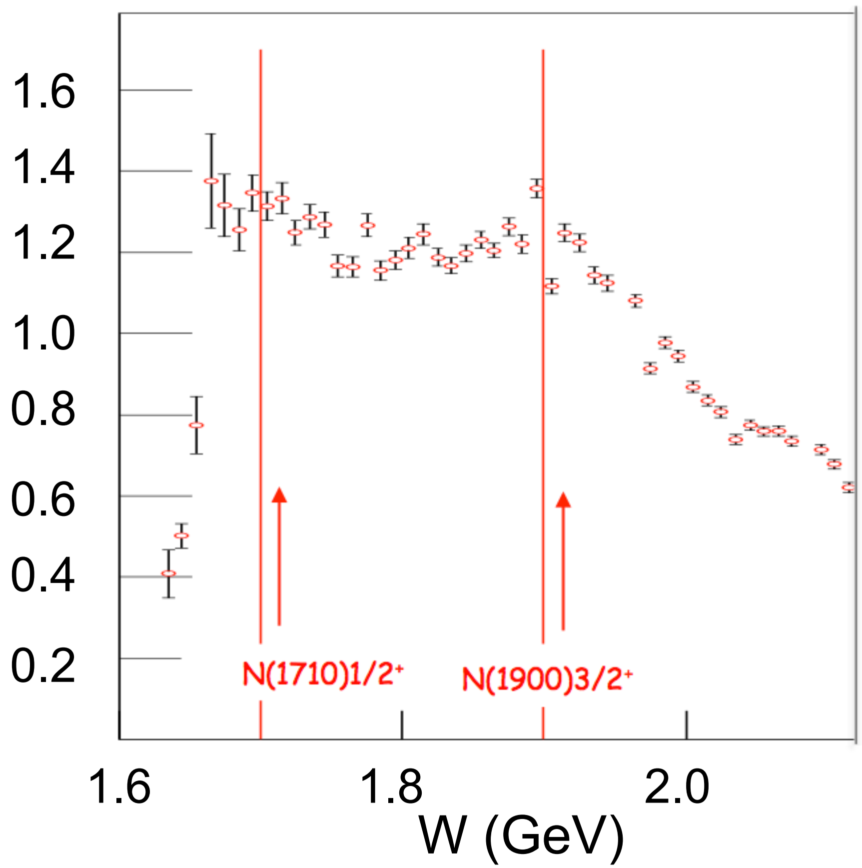
Evidence for New N* in KY and other Final States

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

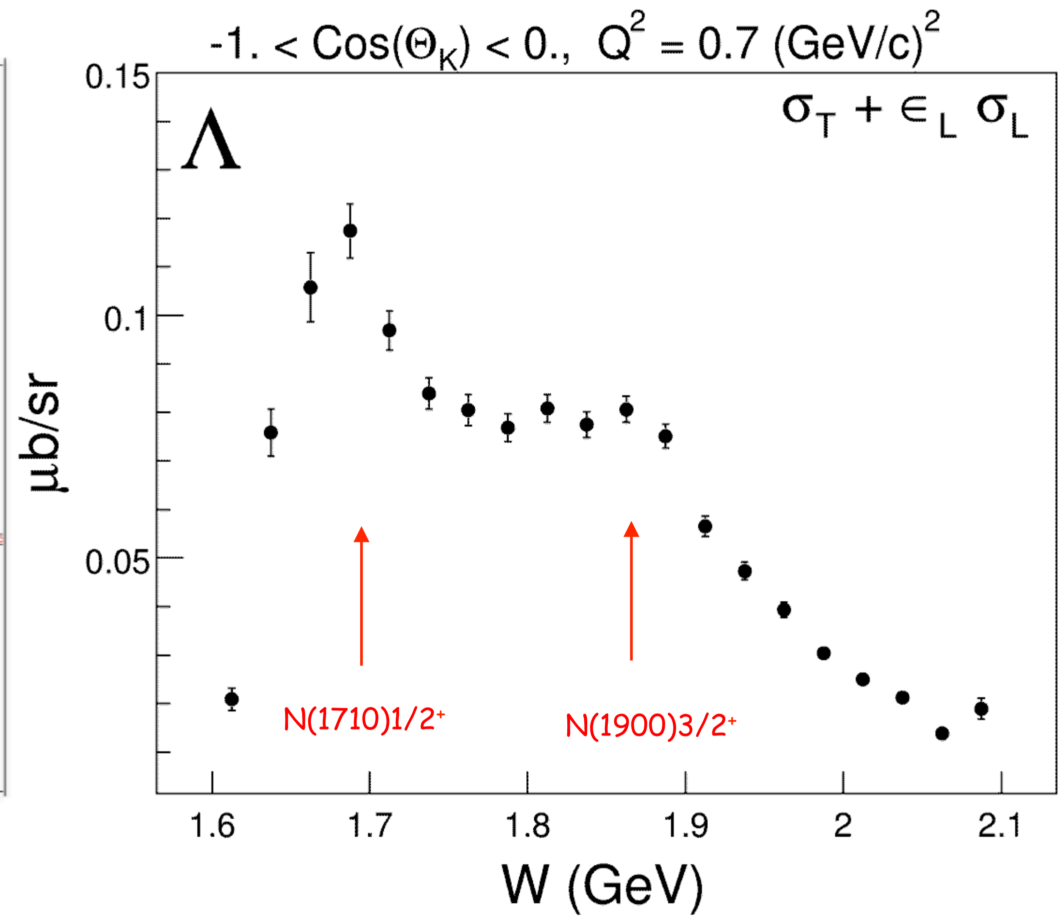
Study these states in electroproduction and extend to higher masses

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

- **Hybrid baryons** |qqqg> have the same quantum numbers J^P as |qqq> → exclusive electroproduction with CLAS12 (Hall B).

Theoretical predictions:

✧ MIT bag model - T. Barnes and F. Close, Phys. Lett. 123B, 89 (1983).

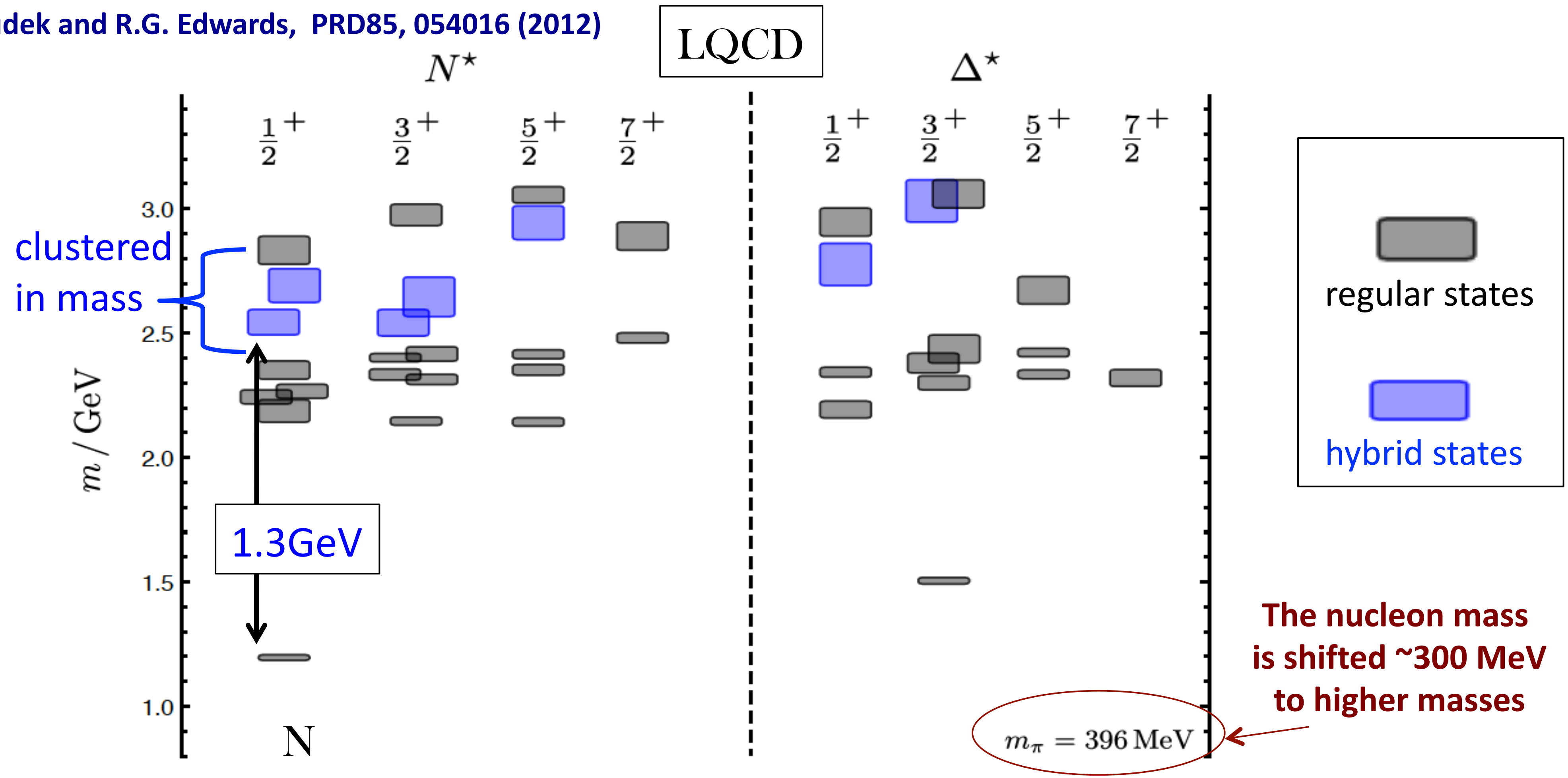
✧ QCD Sum Rule - L. Kisslinger and Z. Li, Phys. Rev. D 51, R5986 (1995).

✧ 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)

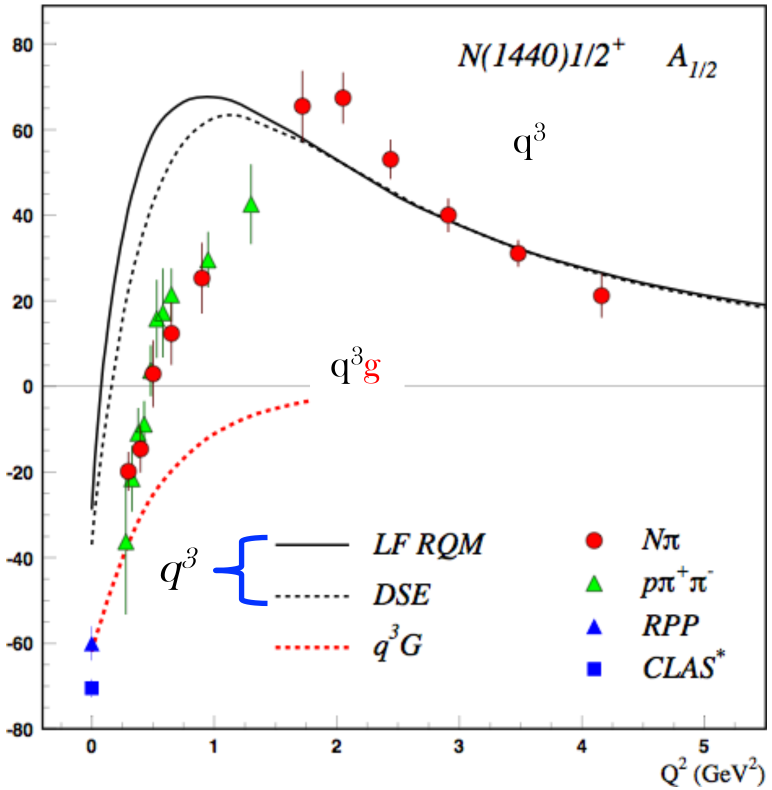


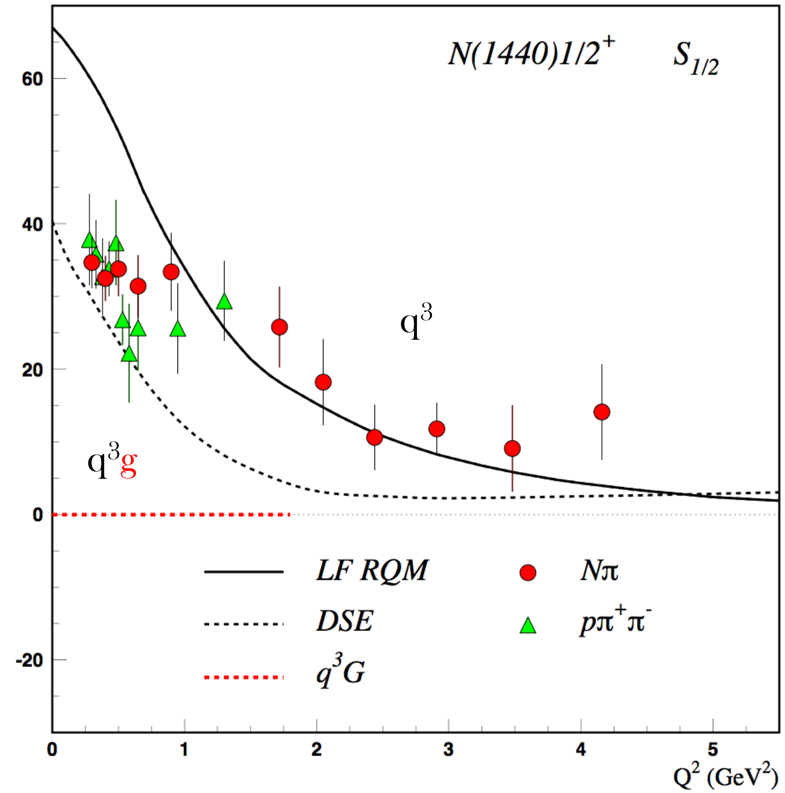
Hybrid states have same J^P values as qqq baryons. How to identify them?

- 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 $S_{1/2}(Q^2)$ ~ 0.

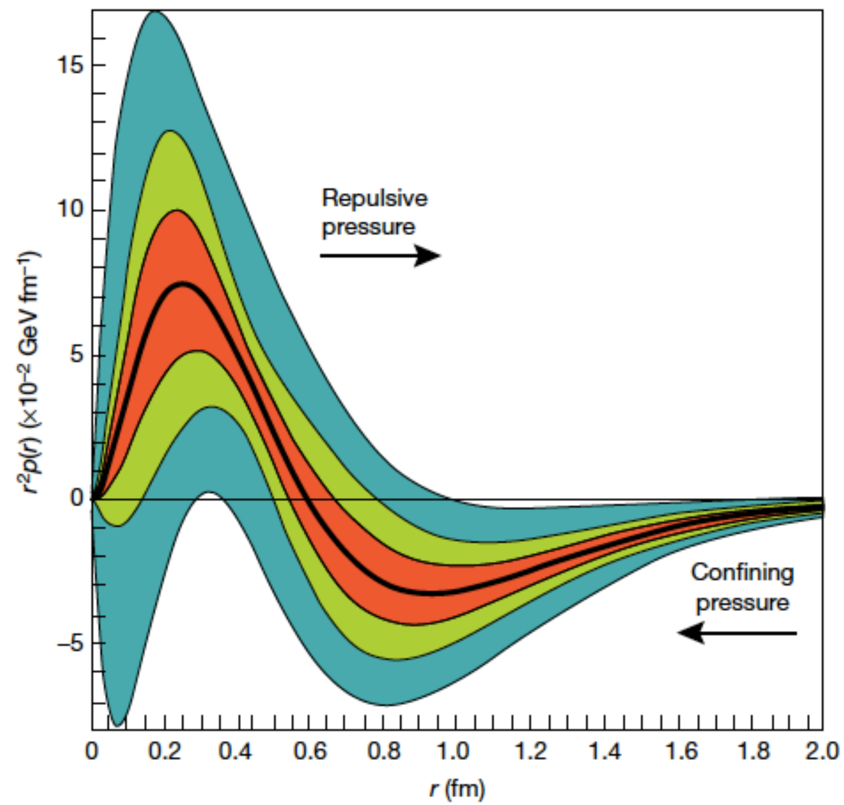
Accessing the Forces & Pressure on Quarks

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

Hall B

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)

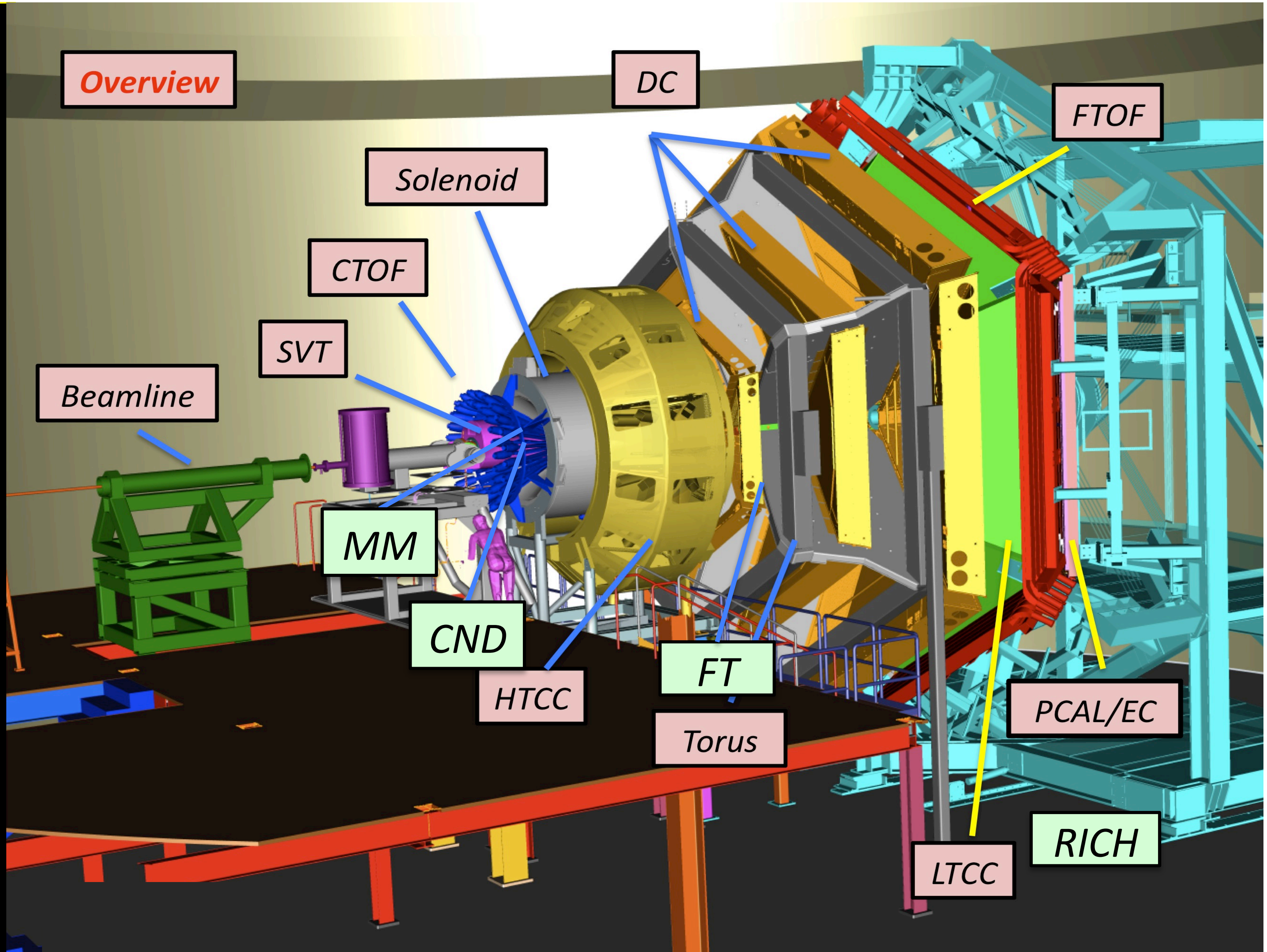
- SOLENOID magnet
- Silicon Vertex Tracker
- Central Time-of-Flight

Beamline

- Cryo Target
- Moller polarimeter
- Shielding
- Photon Tagger

Upgrade to the baseline

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



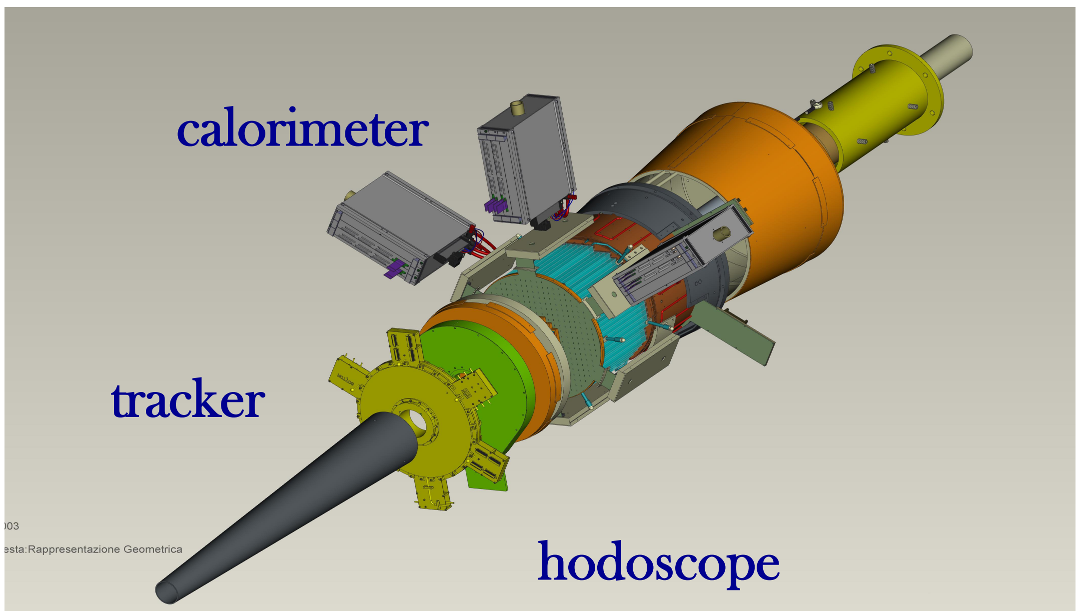
Forward Tagger

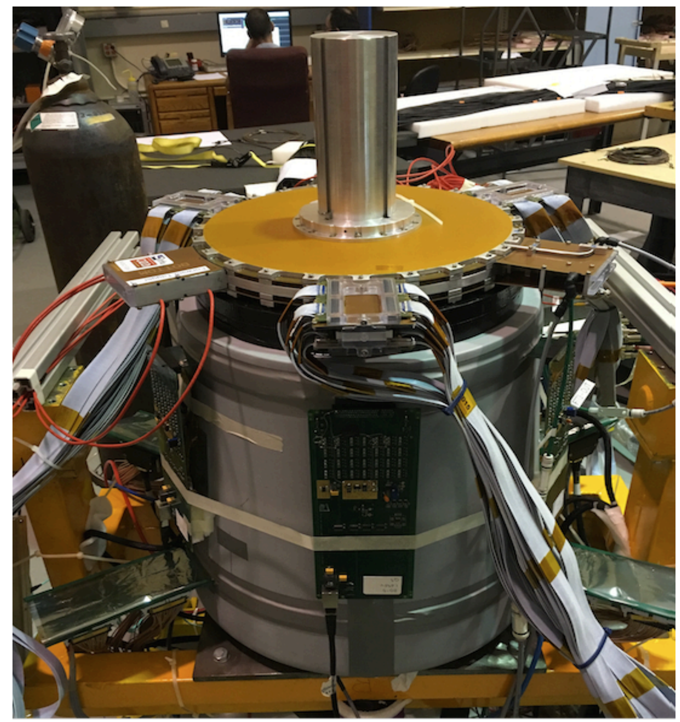
FT designed to detect electrons and photons at small angles

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

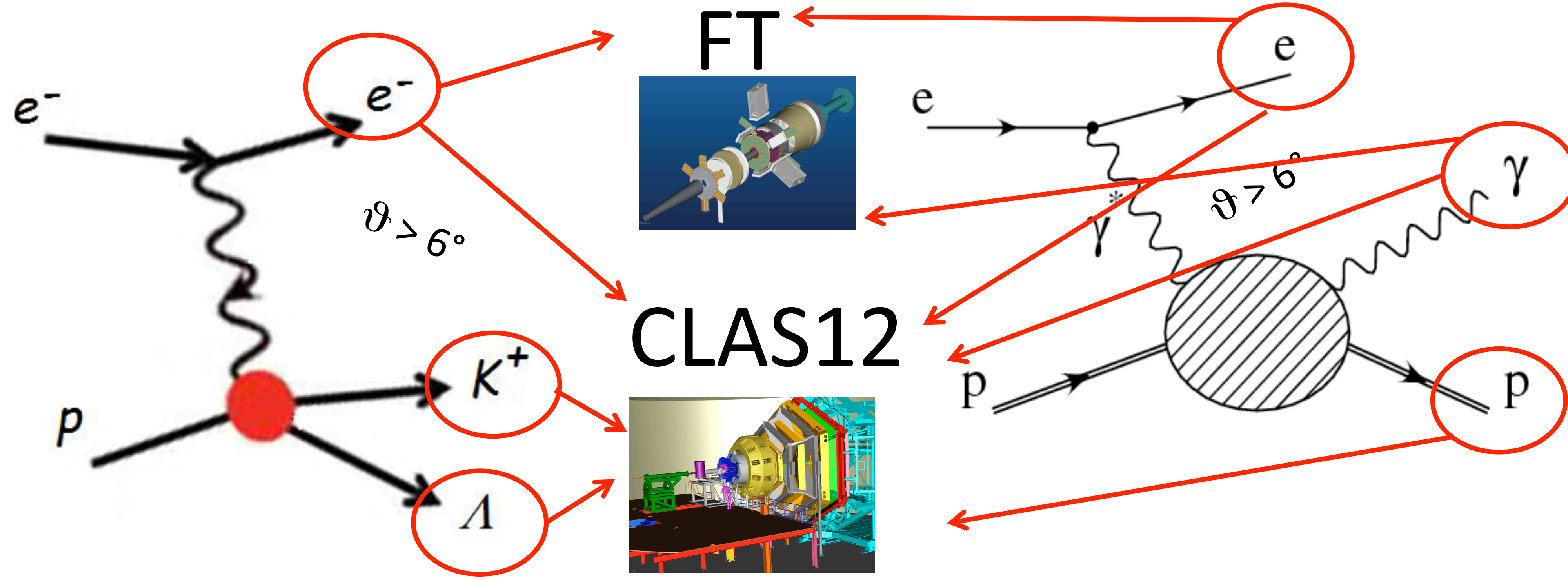
$$\theta = 2.5^\circ \rightarrow 4.5^\circ$$

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





The Experiment



Scattered electrons and photons are detected:

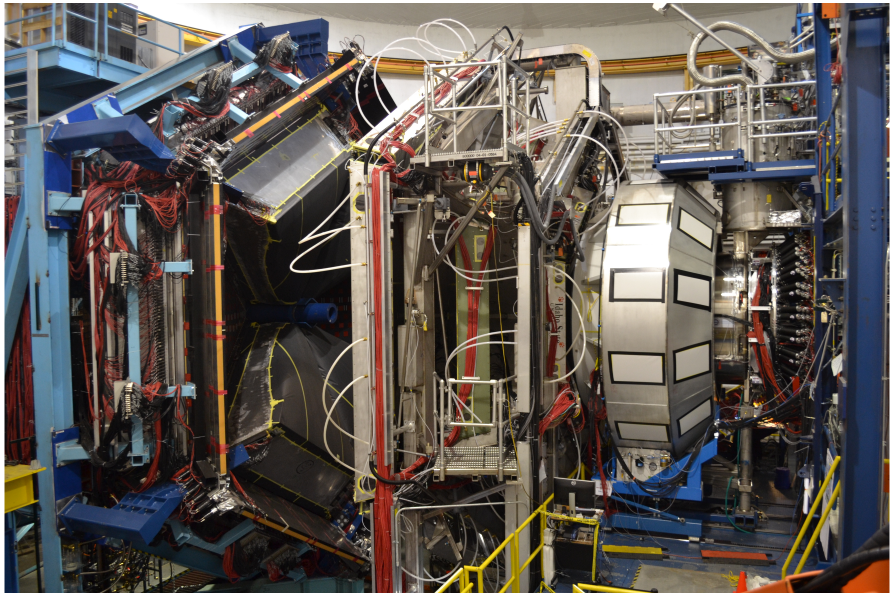
- in the Forward Tagger for angles from 2.5° to 4.5°
- in the Forward Detector of CLAS12 for scattering angles greater than about 6°

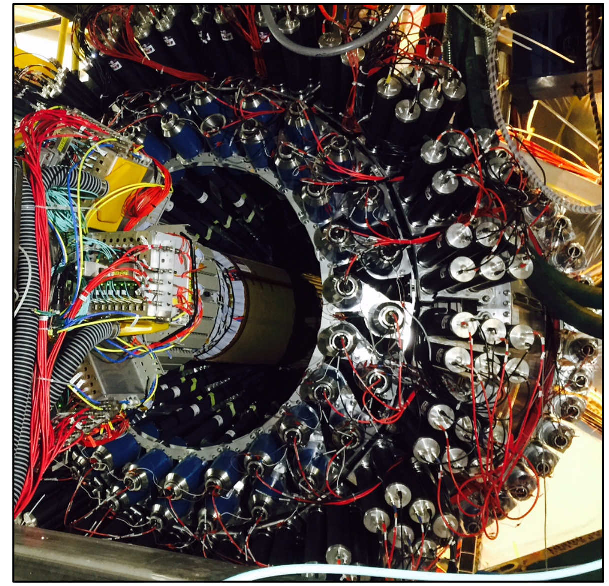
Charged hadrons are measured in the full range from 6° to 130°

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

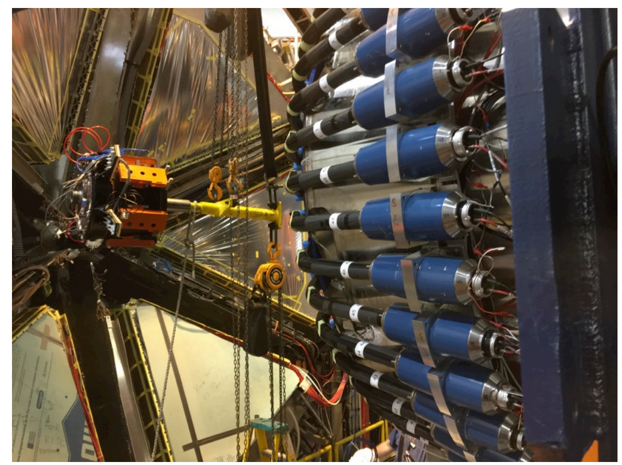
FT allows to probe the **crucial Q^2 range** where hybrid baryons may be identified due to their fast dropping $A_{1/2}(Q^2)$ amplitude and the suppression of the scalar $S_{1/2}(Q^2)$ amplitude.

Run Conditions





Torus Current	100% (3375 A) - **negative outbending**
Solenoid	-100 %
FT	**ON @ 7.5 GeV -> OFF @ 6.5 GeV**
MM RICH	ON
FMT	OFF
Beam/Target	Polarized electrons, unpolarized LH_2 target
Luminosity	~ 5 10^{34} $cm^{-2}s^{-1}$ @ 7.5 GeV 10^{35} $cm^{-2}s^{-1}$ @ 6.5 GeV **FULL LUMINOSITY**



Run Group K Triggers Configurations E=7.5 GeV

Data rate = 400 MB/sec → Maximum electron current = 35 nA

Trigger Number	Physics Definition	Detectors Conditions	Thresholds	pre-scale	Trigger rate
0	1 electron in CLAS	(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	11 KHz
29 (new)	Forward electron 1 forward hadron	FT (1800-6600) x DC x FTOFPCU x PCAL	PCAL>15 MeV	1	8.9 KHz

Total trigger rate = 20.5 KHz @ Lifetime = 93.5%

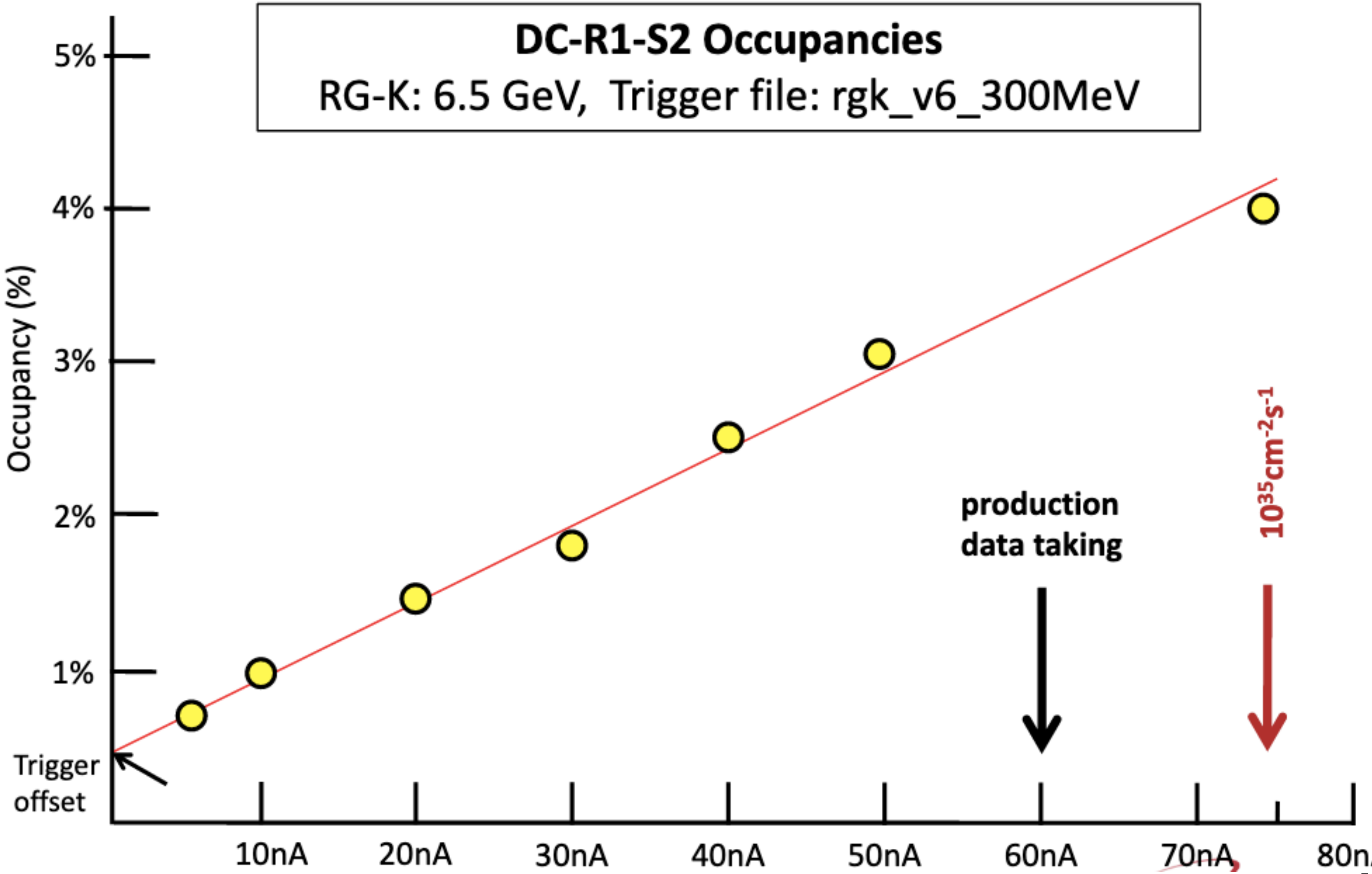
Data rate = 400 MB/sec → Maximum electron current = 45 nA

Trigger Number	Physics Definition	Detectors Conditions	Thresholds	pre-scale	Trigger rate
0	1 electron in CLAS	(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	2	7 KHz
29 (new)	Forward electron 1 forward hadron	FT (1800-6600) x DC x FTOFPCU x PCAL	PCAL>15 MeV	1	12 KHz

Total trigger rate = 20.5 KHz @ Lifetime = 93.5%

Drift Chamber Occupancies

Luminosity scan



Run Group K Triggers Configurations E=6.5 GeV

FT OFF   Full Luminosity

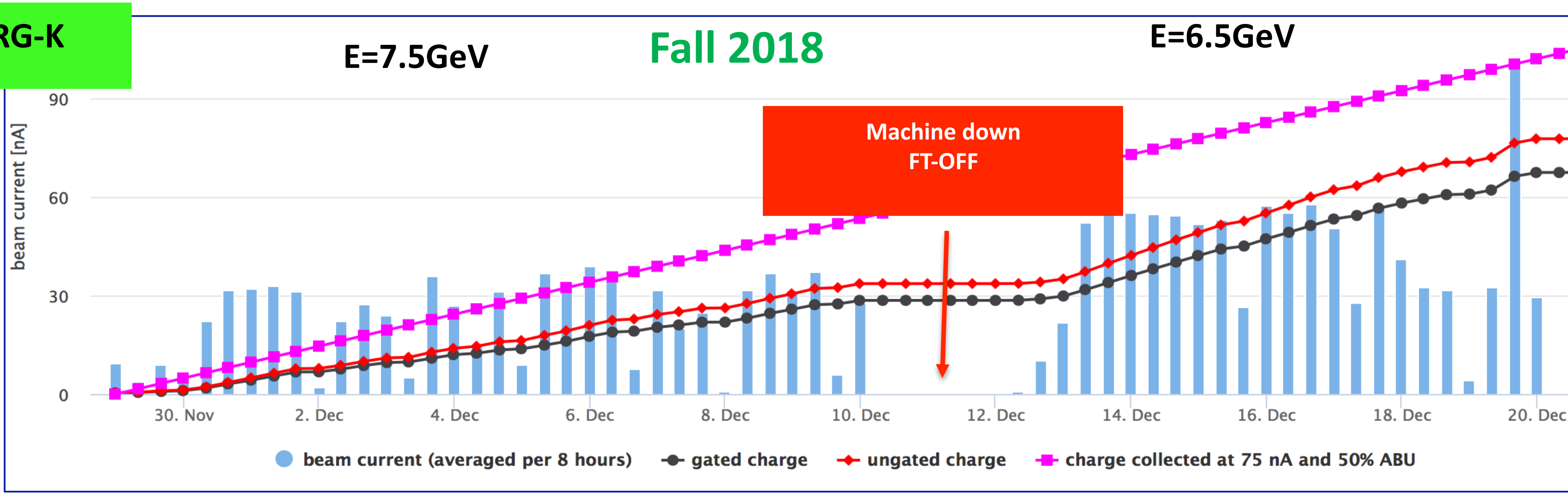
Data rate = 450 MB/sec → Maximum electron current = 60 nA

Trigger Number	Physics Definition	Detectors Conditions	Thresholds	pre-scale	Trigger rate
0	**1 electron in CLAS**	(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	25 KHz

Total trigger rate = 25 KHz @ Lifetime = 91%

Run Group K Production

RG-K



CHARGE

Q~45mC = 7% of Expected 648mC

Beam Energy	Beam Current	Target	Trigger	Collected Events
7.5 GeV	35 nA	LH_2	e in CLAS e in FT + 1 Fwd Hadron	3.5 G
7.5 GeV	435 nA	LH_2	e in CLAS - prescaled e in FT + 1 Fwd Hadron	4.3 G
6.5 GeV	60 nA	LH_2	e in CLAS	7.8 G

EVENTS

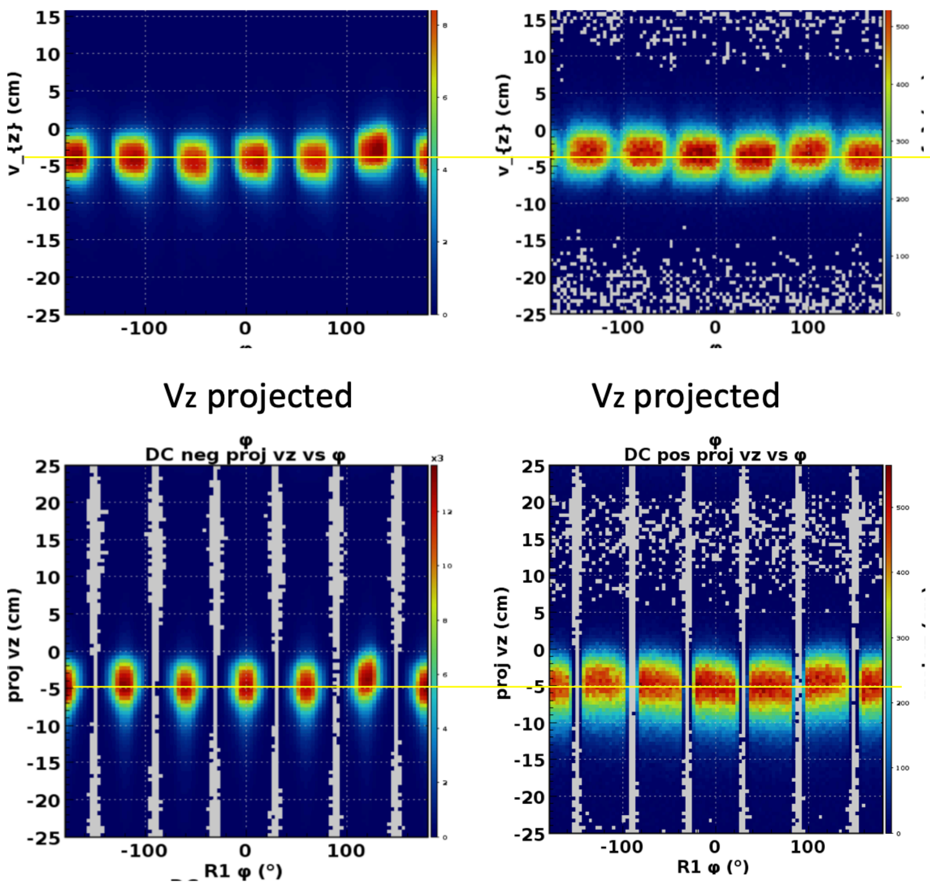
15.6 G

RG-K Run 5990 Alignment

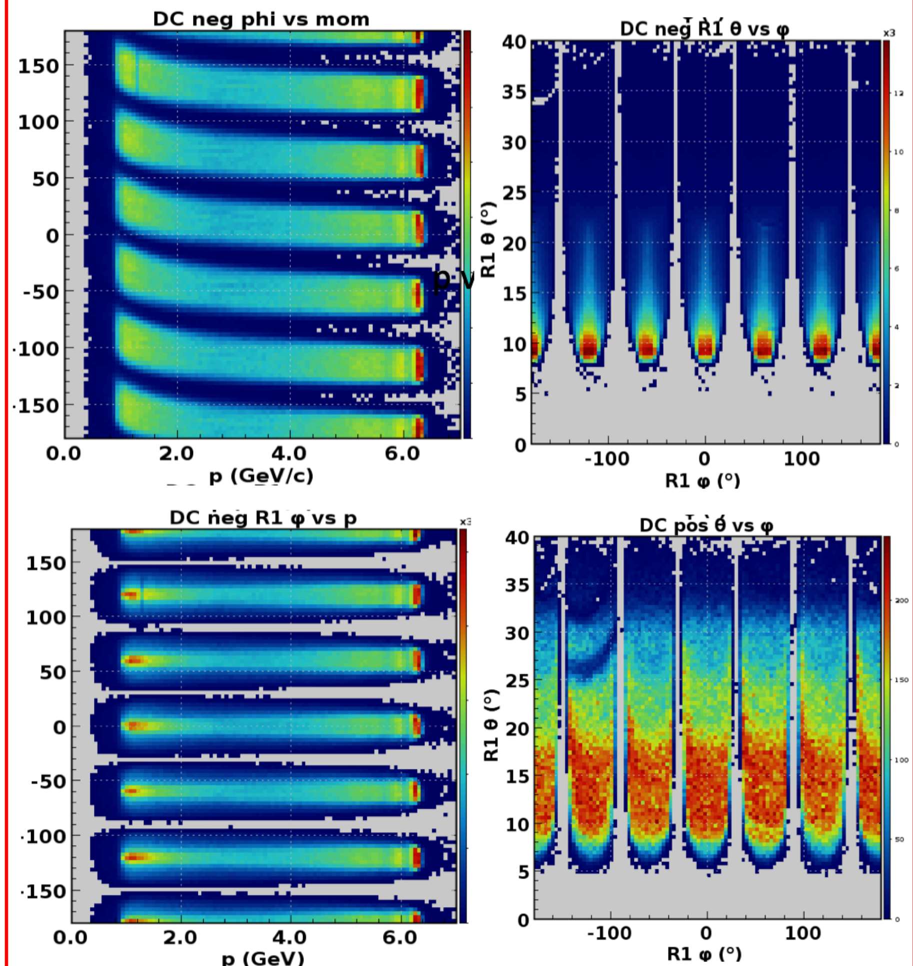
Vertex Alignment

Vz for outbending | Vz for inbending

Vz projected | Vz projected



Detector performance



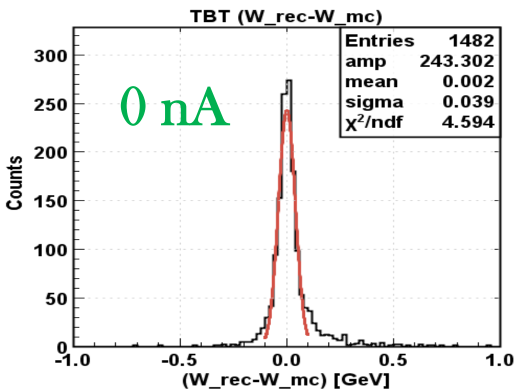
With few exceptions all detector channels working well

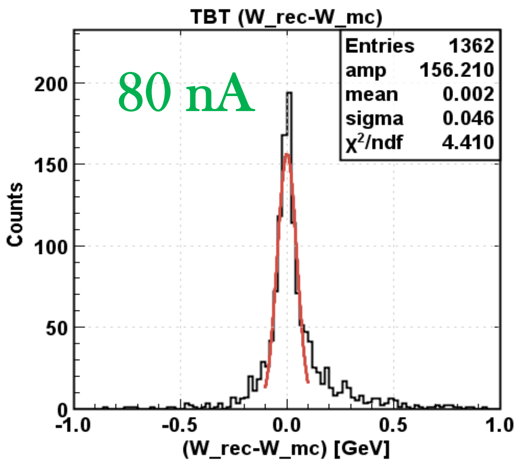
FD tracking efficiency - RG-K Run Low Luminosity Runs

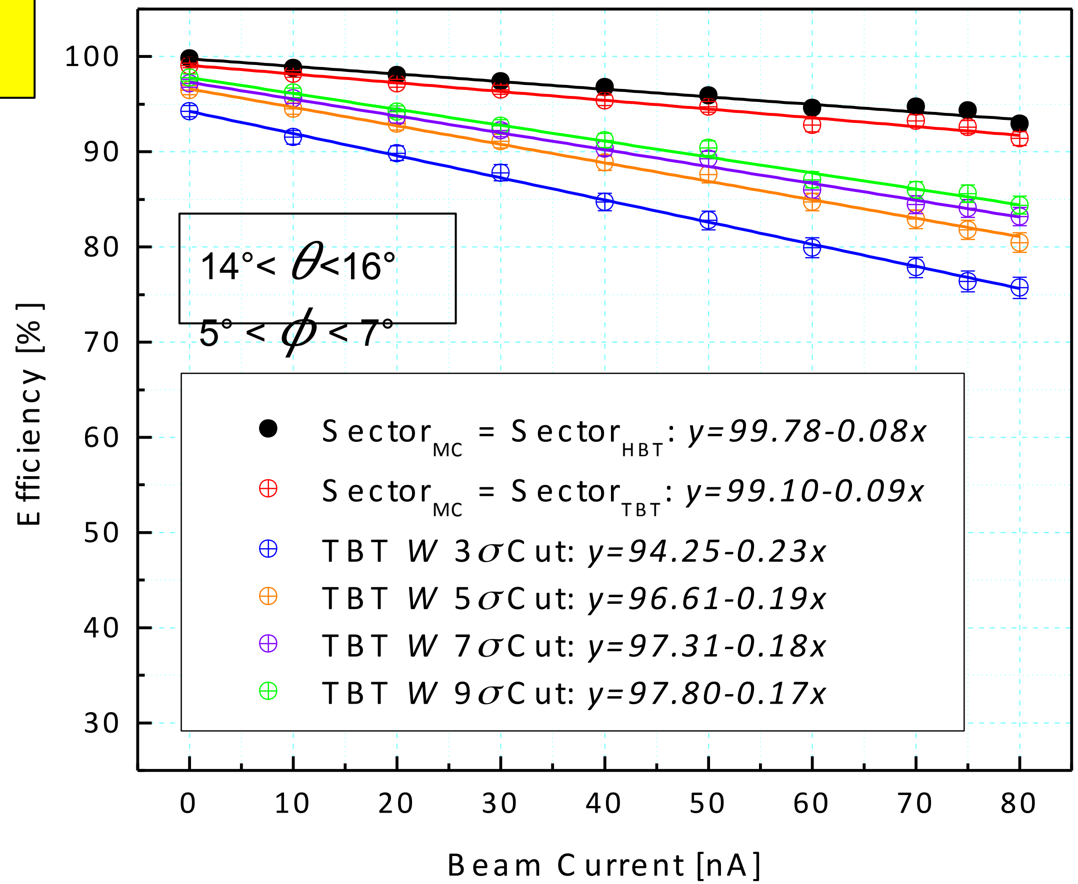
Extensive effort to understand luminosity dependence of event reconstruction efficiency.

$\mu^- p \to \mu^- p$ 6.5 GeV

Use μ's to avoid radiative tail

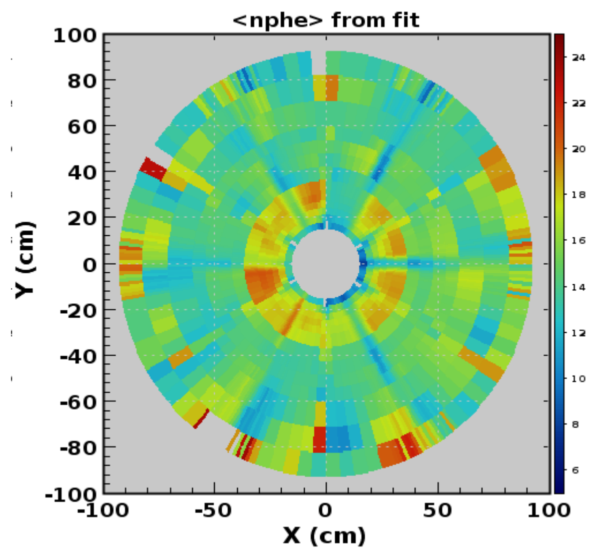


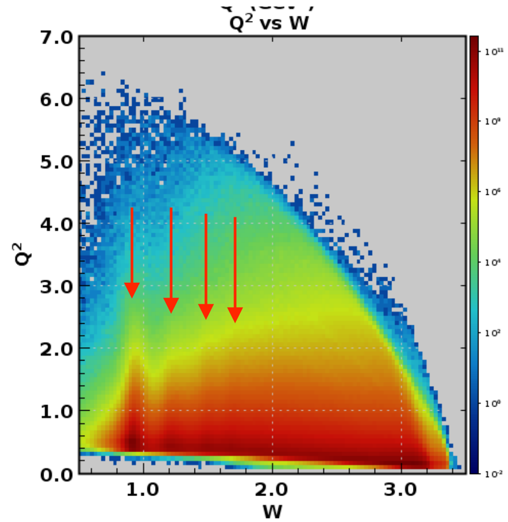


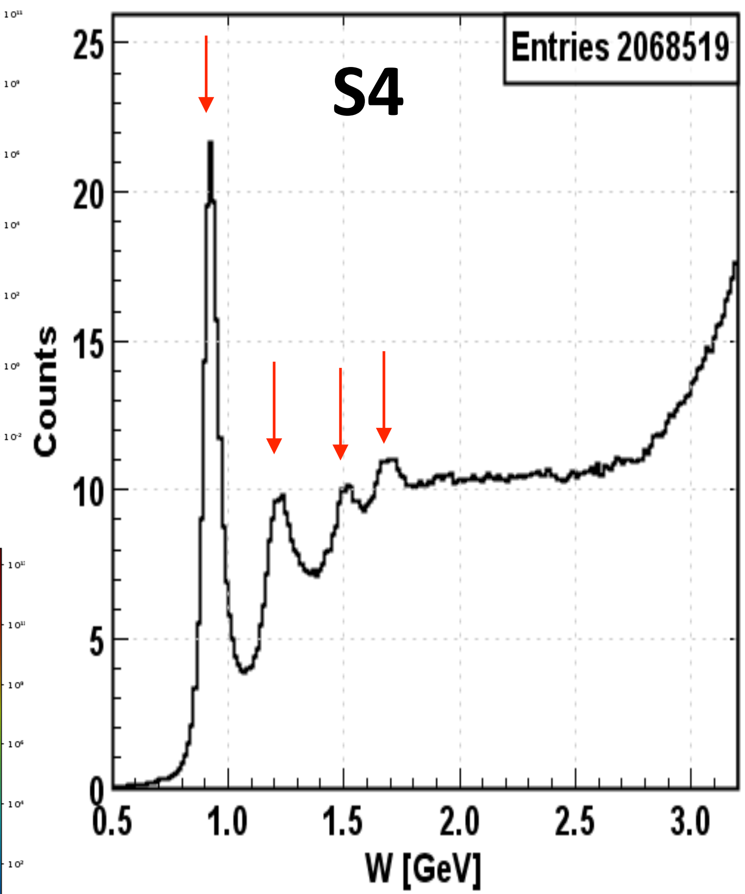


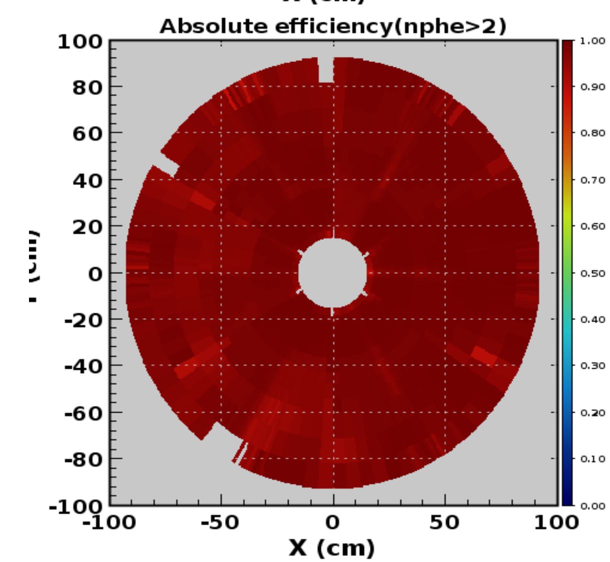
Realistic Simulations critical for normalized results

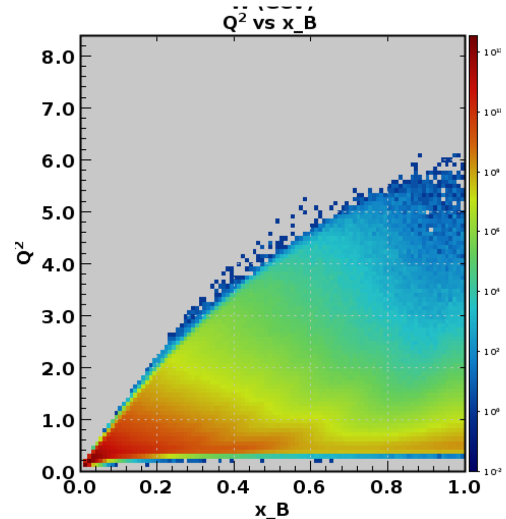
RGK 6.5 GeV p(e,e')X







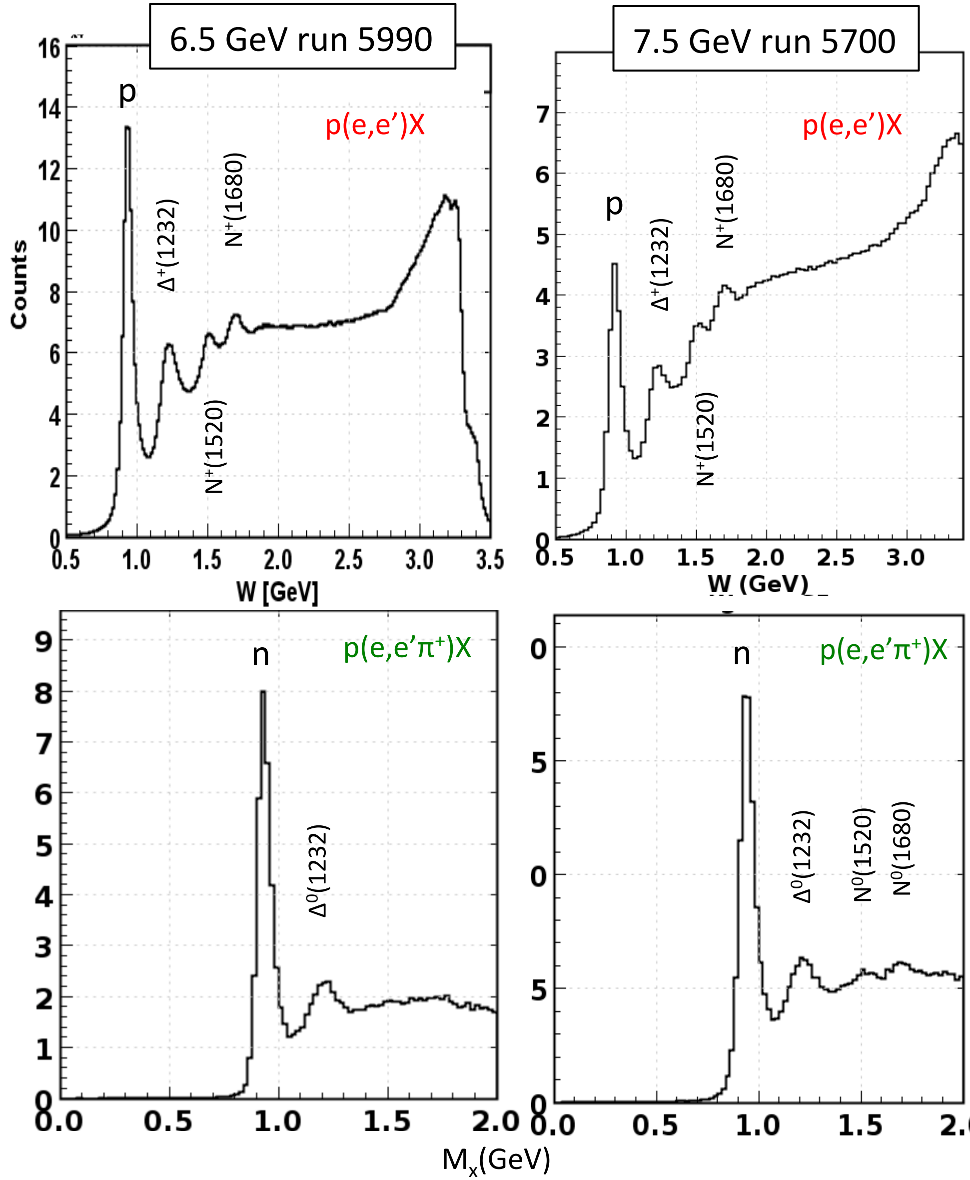




Electron detection efficiency > 98% in most part

The number of events corresponds to about **0.0025%** of expected RG-K 6.5GeV data of 2018

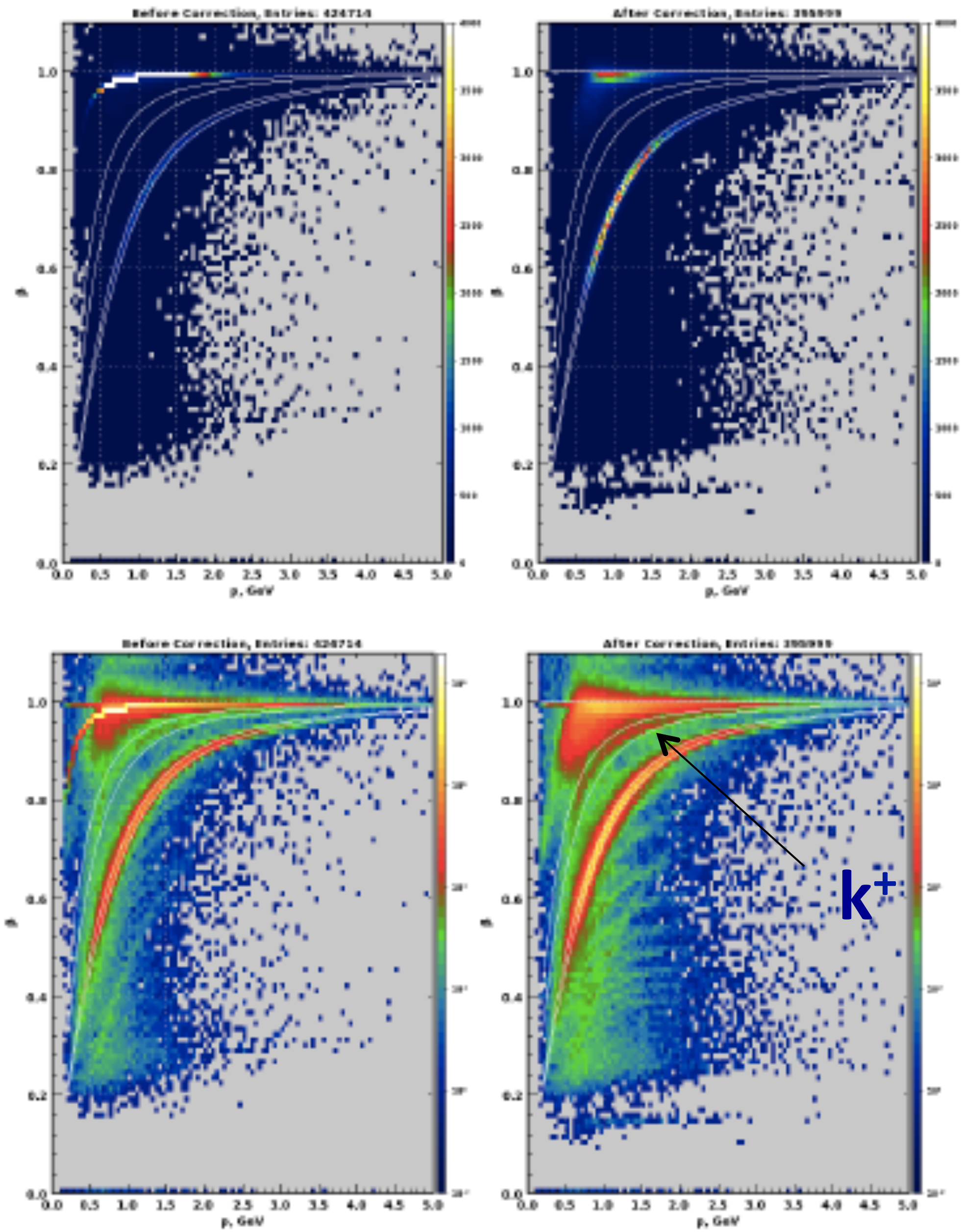
RGK 6.5 GeV p(e,e')X p(e,e'π⁺)X



electron detected in CLAS

All sectors combined

RGK 7.5 GeV Start time correction



electron detected in FT

Event start time should be corrected using the FT start time

↓

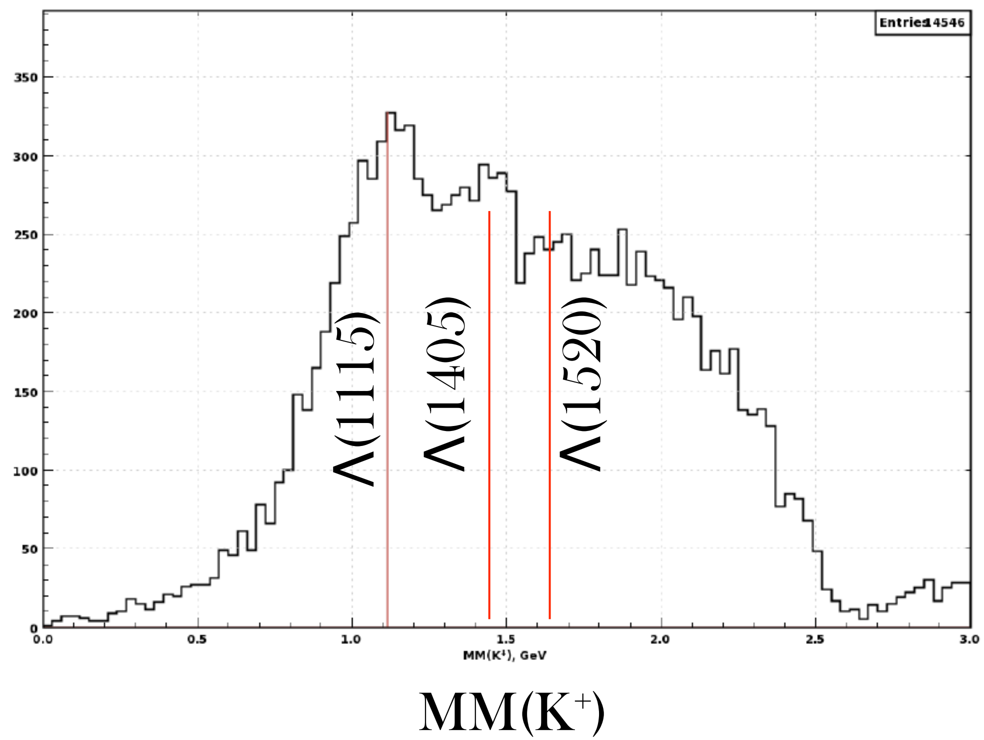
new value for β

↓

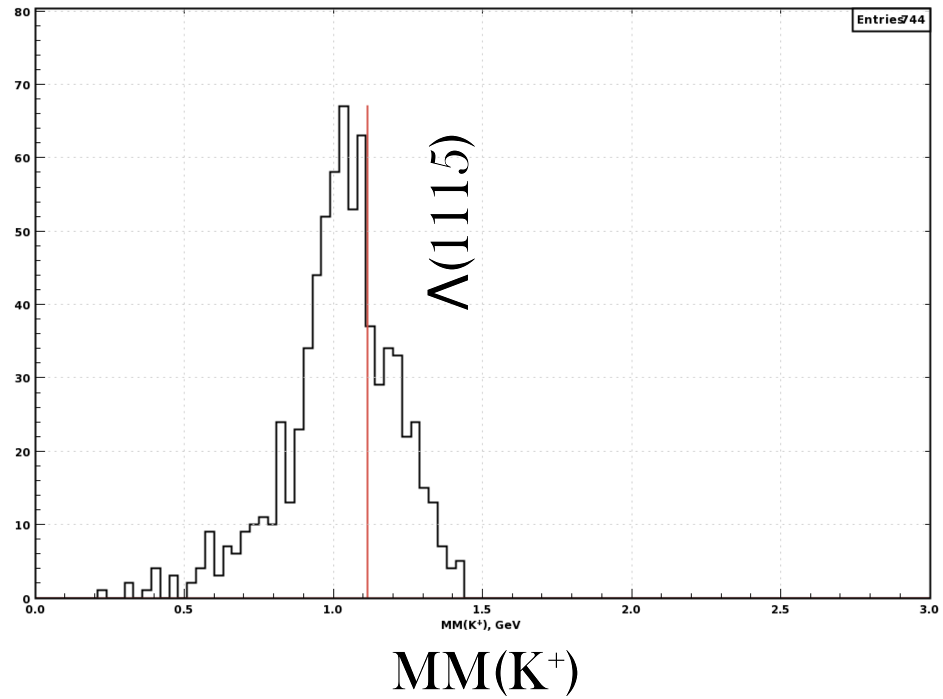
better particle ID

RGK 7.5 GeV p(e,e'K+)X electron in FT

1.6 GeV < W < 3 GeV



1.6 GeV < W < 2.2 GeV

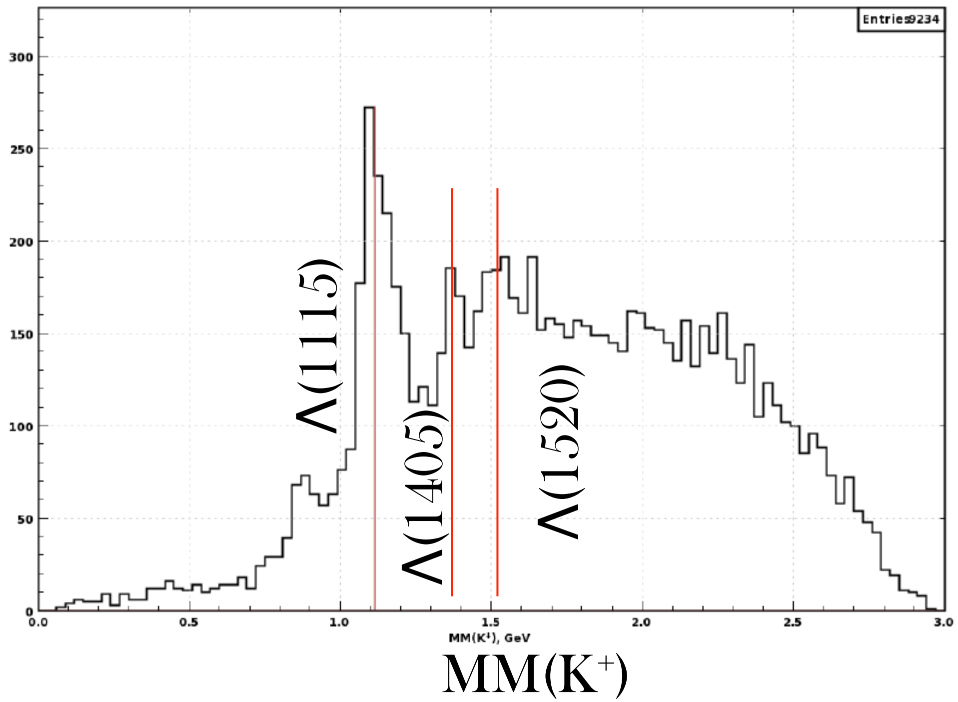


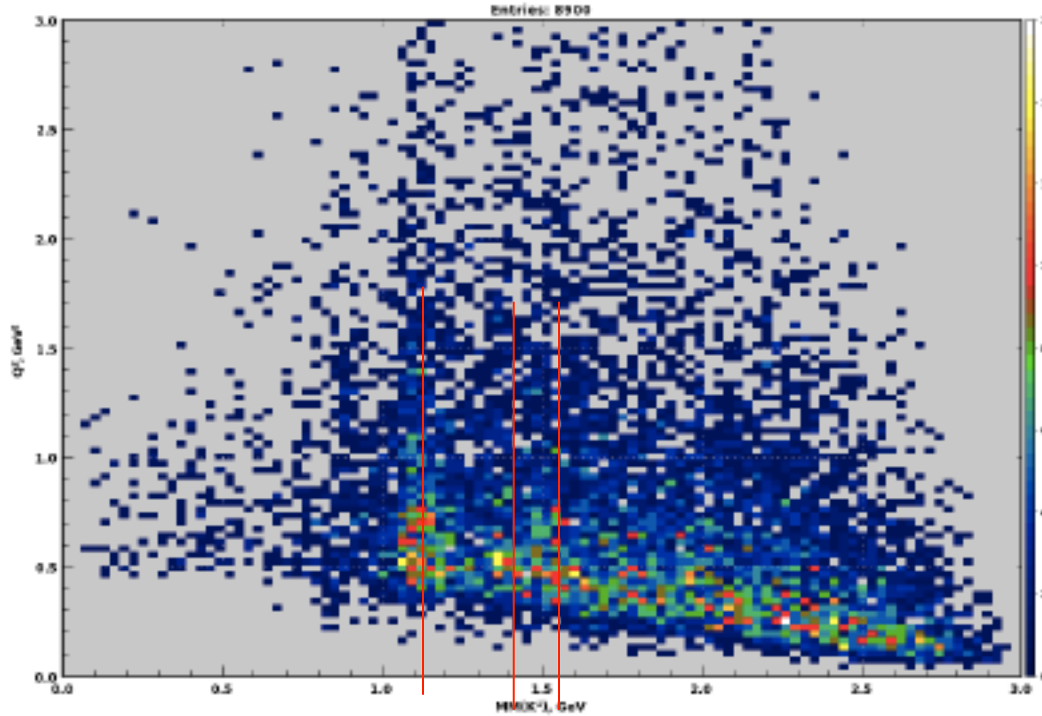
~500 KY events among 2.5M FT triggers → 920 10^3 KY events from all 7.5 GeV runs (4.6 G FT triggers)

$0.05 GeV^2 < Q^2 < 0.35 GeV^2$

RGK 7.5 GeV p(e,e'K+)X electron in CLAS

1.6 GeV < W < 3 GeV





MM(K+)

~500 KY events among 2.5M CLAS triggers → 2.3 10^6 KY events from all RGK runs (11.7 G CLAS triggers)

0.5GeV^2 < Q^2 < 2 GeV^2

Manpower

Run group K experiments benefits 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

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

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

Pass 0 and Pass1 cooking is being implemented together with Run Group A team

Conclusions

- ✓ Run group K has successfully collected data at 6.5 GeV and 7.5 GeV.
- ✓ Full luminosity has been reached at 6.5 GeV with FT - OFF
- ✓ 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 in coincidence with 1 Forward hadron in CLAS
- ✓ Manpower of run group A is foreseen to strongly contribute to calibrate and cook the data - PASS1 is planned after fall run
- ✓ Data quality is very good
- ✓ 7% of total expected charge has been accumulated - 15.5 G events collected
  - ✓ ~ 3.3 M KY total events