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

E12-16-010C Separation of the σ_L and σ_T contributions to the production of hadrons in electroproduction
Tim Hayward, Harut Avakian

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

Assigned Fall 2018:
5.5 PAC days at 7.5 GeV
4.0 PAC days at 6.5 GeV

Assigned Spring 2024:
2 PAC days commissioning at 6.5 GeV
16.5 PAC days at 6.4 GeV
13.5 PAC day at 8.5 GeV

Assigned Spring 2025:
30 PAC days

Gran Total: 42 PAC days of collected data + 30 PAC days of assigned data → **72 PAC days globally assigned**

Main Questions to Address

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

→ **Search for new baryon states -** E12-16-010

- How does meson-baryon cloud emerge?

→ **Measure the Q^2 dependence of electrocoupling amplitudes -** E12-16-010A

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

→ **Study GPDs and their moments from DVCS -** E12-16-010B

- What is the 3D internal structure of the nucleon?

→ **Study the nucleon structure function from SIDIS -** E12-16-010C

Run Group Proposal (RG K)

"Color Confinement and Strong QCD"

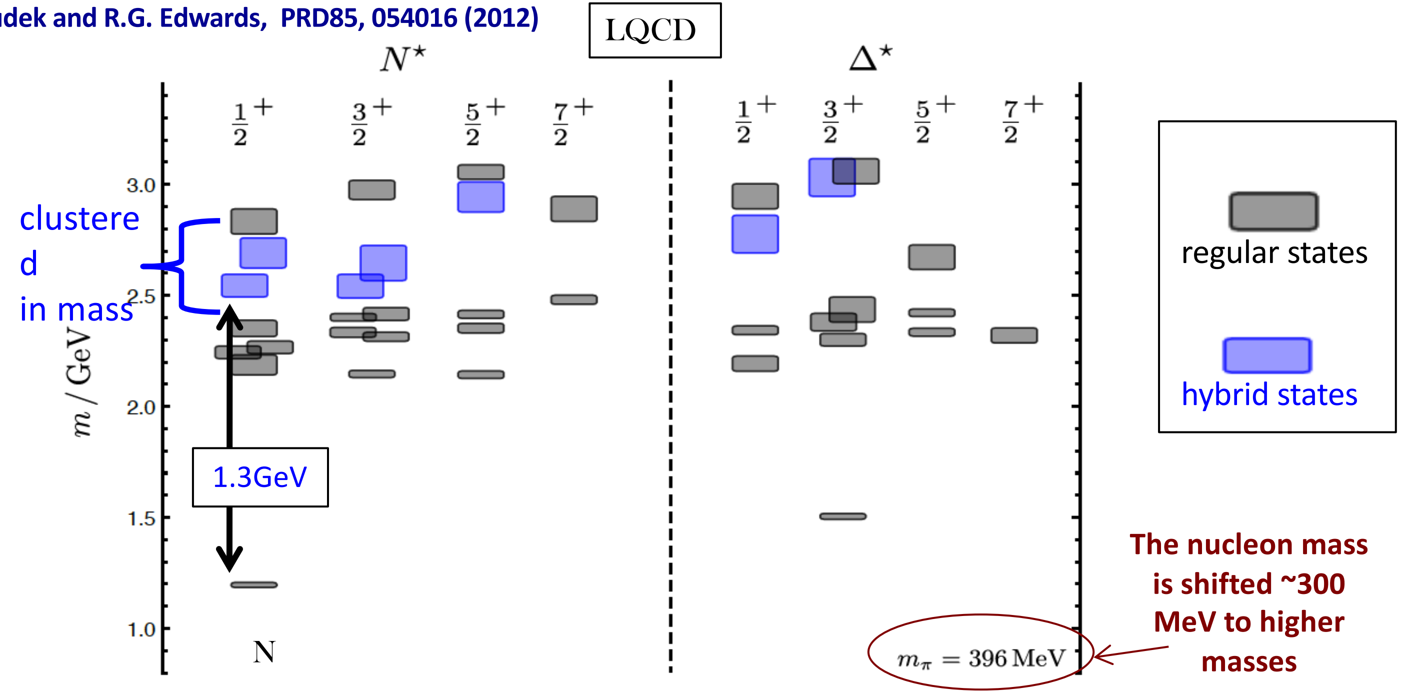
Hybrid Baryons E12-16-010	Search for hybrid baryons (qqqg) focusing on 0.05 $GeV^2 < Q^2 < 2.0\ GeV^2$ in mass range from 1.8 to 3 GeV in KΛ, Nππ, Nπ *(A. D'Angelo, V. Burkert, D.S. Carman, V. Mokeev, R. Gothe)*
KY Electroproduction E12-16-010A	Study N* structure for states that couple to KY through 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)*
SIDIS E12-16-010C	Measure the proton structure functions in the deep-inelastic scattering by Rosenbluth separation performed combining RG-K and RG-A data on semi-inclusive electro-production of hadrons. (*T. Tim Hayward, Harut Avakian*)

100 days approved by PAC 44 and confirmed by PAC 48 (Jeopardy)
E_b = 6.6 GeV, 50 days – 3 passes
E_b = 8.8 GeV, 50 days – 4 passes

RUN CONDITIONS	
Torus Current	100% (3375 A) - negative out-bending
Solenoid	-100 %
FT	**ON @ 7.5 GeV -> OFF @ 6.5 GeV and 8.5 GeV**
Beam/Target	Polarized electrons, un-polarized LH_2 target
Luminosity	• ~ 5 $10^{34}\ cm^{-2}s^{-1}$ @ 7.5 GeV ~ 0.87 $10^{34}\ cm^{-2}s^{-1}$ @ 6.5 GeV 0.87 $10^{35}\ cm^{-2}s^{-1}$ @ 6.4 GeV $10^{35}\ cm^{-2}s^{-1}$@8.5 GeV **FULL LUMINOSITY**

Hybrid Baryons in LQCD

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

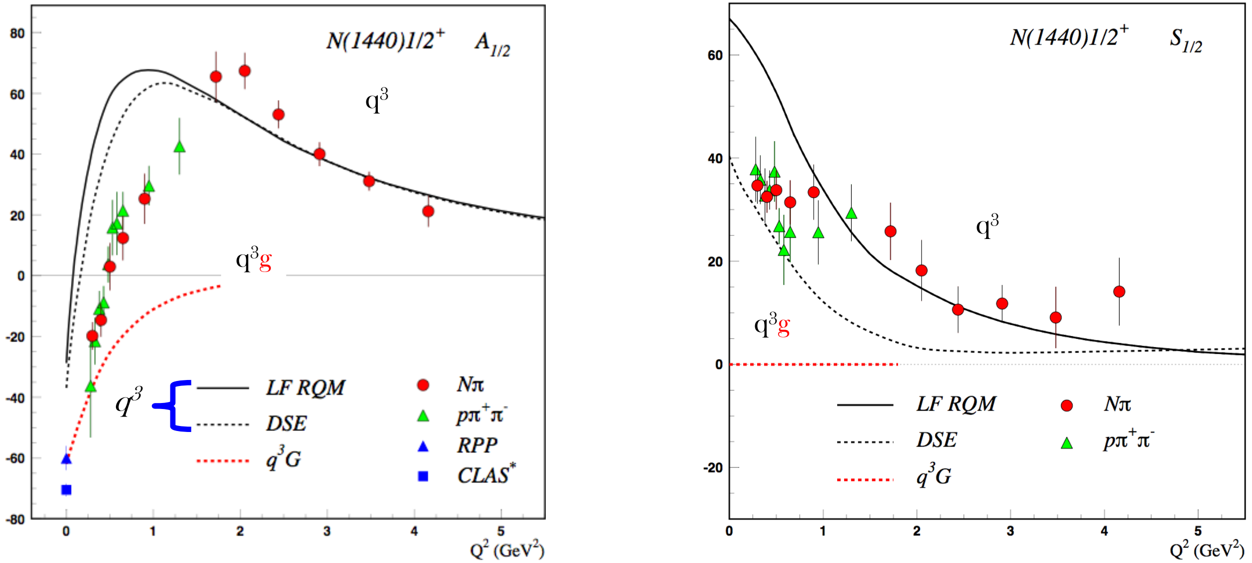


Hybrid states have same J^P values as qqq baryons. How to identify them?

- 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?

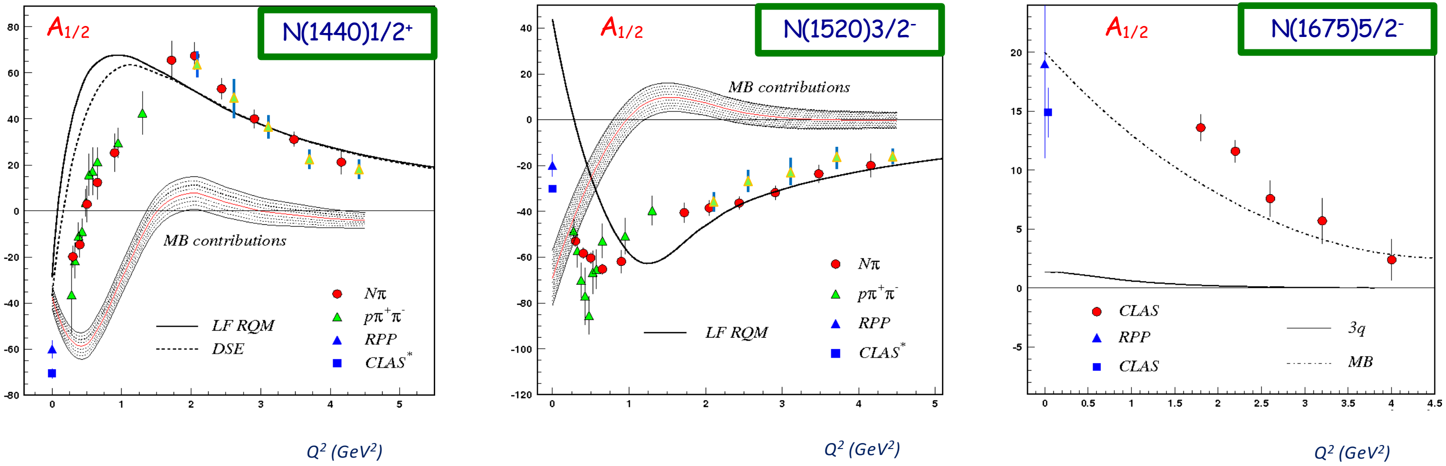
Precise CLAS results on electrocouplings clarified nature of the Roper



- $A_{1/2}$ 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 $S_{1/2}(Q^2) \sim 0$.

Q^2 Evolution of N* Electrocouplings



- Electrocouplings reveal different interplay between meson cloud and quark core:
  - -Important to study different N* states vs. distance scale
- Good agreement of the extracted N* electrocouplings from Nπ and Nππ:
  - -Compelling evidence for the reliability of the results
  - -Channels have very different mechanisms for the non-resonant background

Data from the KY channels is critical to provide an independent extraction of the electrocoupling amplitudes for the higher-lying N* states

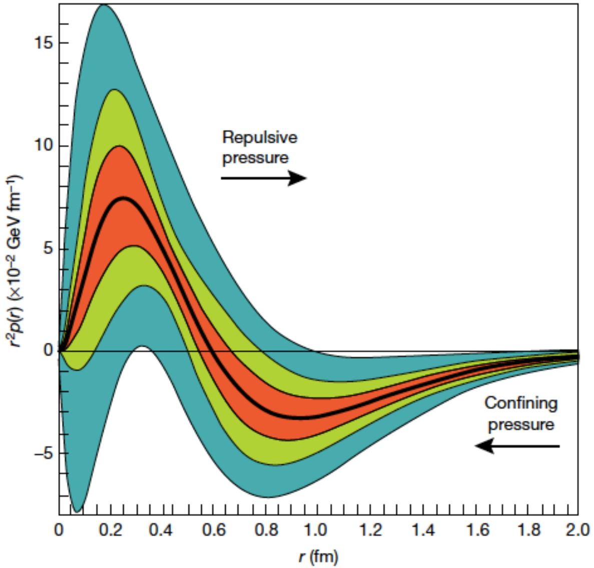
Accessing the Forces & Pressure on Quarks

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.

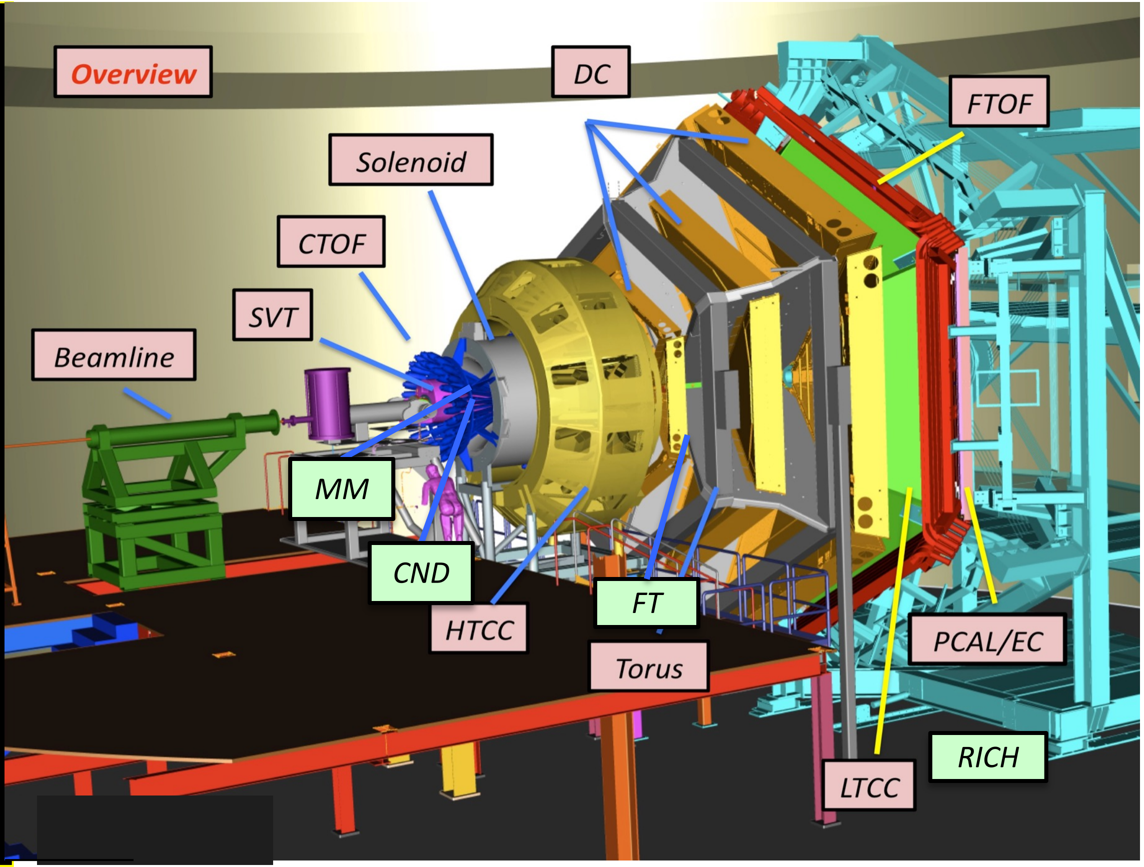
Equipment

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

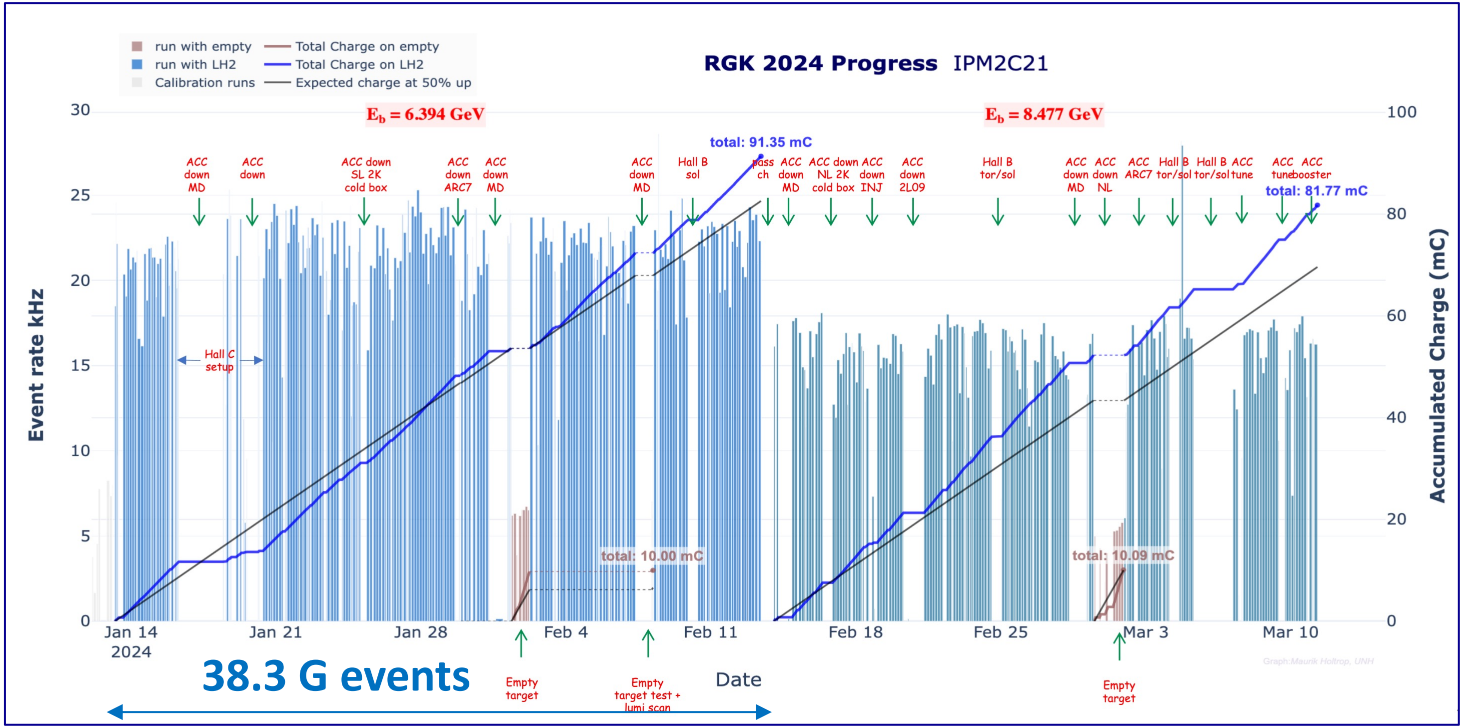
Upgrade to the baseline
- Central Neutron Detector
- MicroMegas
- Forward Tagger
- RICH detector
- Polarized target



Run Group K - SPRING 2024 Data Taking Overview

December 15-19, 2023 – 4 calendar days
Commissioning

January 11 - March 11, 2024 – 60 calendar days
Alignment and Production



3-passes
E_e = 6.39463 GeV
I_e = 65 nA
Lum. = 0.87 10^{35} cm^{-2} s^{-1}

Run Range:
19200 – 19659
259 Production Runs
38.3 G prod events
10 Empty tgt runs @ 200 nA
0.41 G ET events (~1% full)

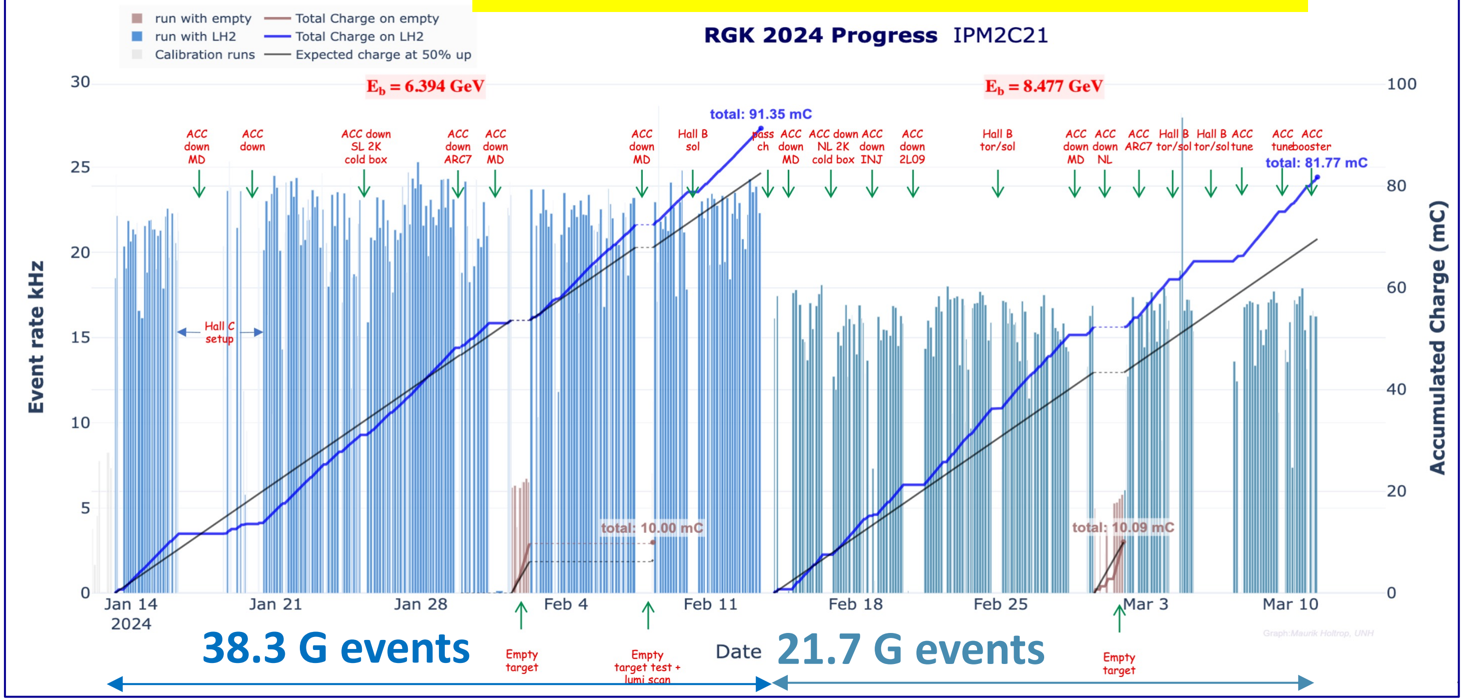
Accumulated Charge:
Full tgt = 91 mC
Empty tgt = 10 mC
Total = 101 mC

Run Group K - SPRING 2024 Data Taking Overview

December 15-19, 2023 – 4 calendar days
Commissioning

January 11 - March 11, 2024 – 60 calendar days
Alignment and Production

30 Assigned PAC days → 37 effective PAC days



4-passes

E_e = 8.47757 GeV

I_e =75 nA

Lum. = 10^{35} cm^{-2} s^{-1}

Run Range:

19660 – 19893

174 Production Runs

21.7 G events

8 Empty tgt runs @ 200 nA

0.32 G ET events (~1.4% full)

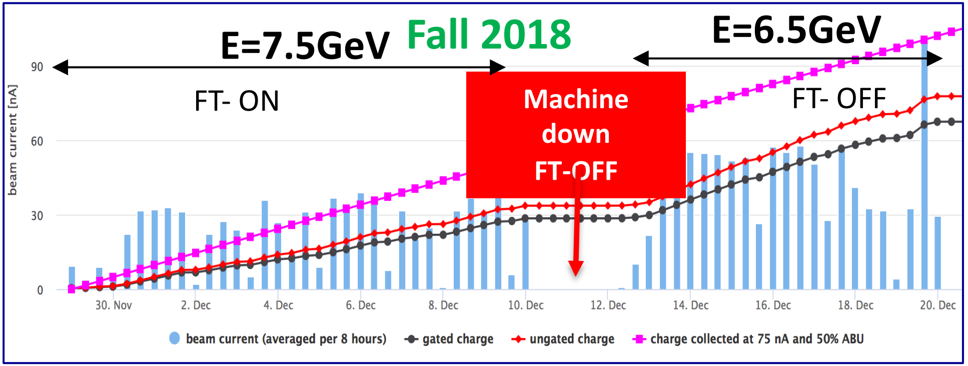
Accumulated Charge:

Full tgt = 81.77 mC

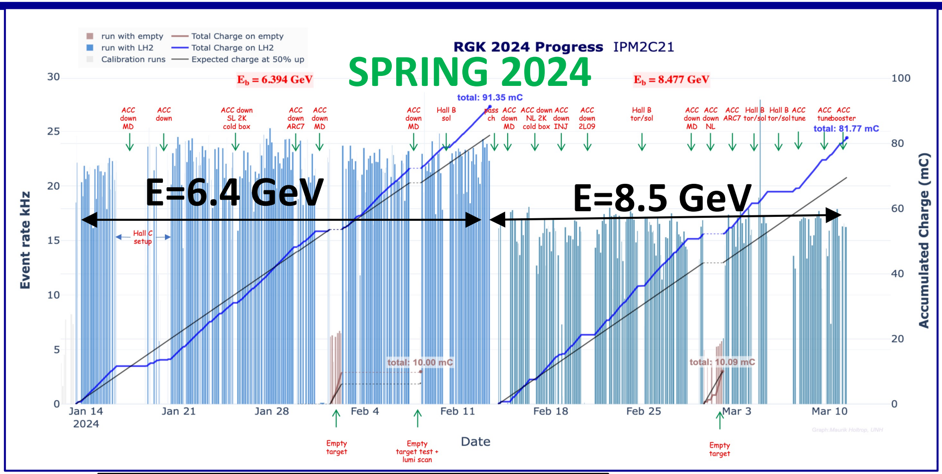
Empty tgt = 10 mC

Total = 91.77 mC

Run Group K Production



45mC of accumulated charge



193mC of accumulated charge

Fall 2018		
Beam Energy	Beam Current	Collected Events
7.5 GeV	35 nA	3.5 G
7.5 GeV	45 nA	4.3 G
6.5 GeV	60 nA	7.8 G

EVENTS
15.6 G

Spring 2024		
Beam Energy	Beam Current	Collected Events
6.4 GeV	65 nA	38.3 G
8.5 GeV	75 nA	21.7 G

EVENTS
60 G

Statistics increased by a factor 4

Run Group K - Commissioning and Calibration Runs

December 15-19, 2023

- Trigger Studies - Valery Kubarosky
- Luminosity Scans
- DC HV scans - Florian Hauenstein
- Reversed solenoid polarization runs

Service studies useful for all Run Groups

January 11-13, 2024

- Warm/cold empty target alignment studies: zero magnetic fields – Raffaella De Vita
- DC studies
- Empty target runs
- Luminosity scans

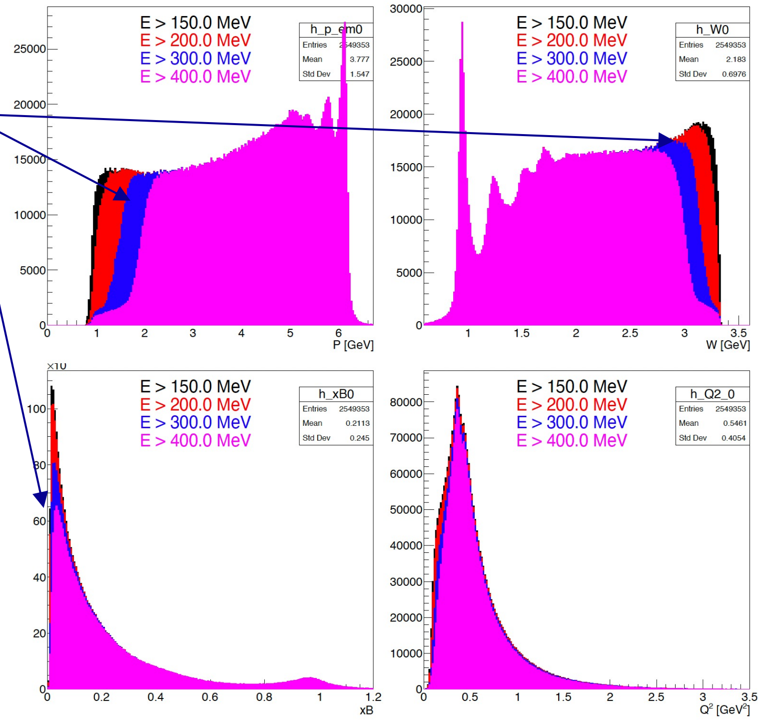
Trigger Validation Studies

TABLE I. RGK trigger files

Trigger File	Description	PCAL+ECAl	TORUS	Comments
rgk_noDC_v1.0_150MeV	No DC roads	150 MeV	Any	Production
rgk_noDC_v1.0_200MeV		200 MeV		
rgk_noDC_v1.0_300MeV		300 MeV		Production, HOLDOFF=3 us
rgk_noDC_v1.1_300MeV		300 MeV		Production, HOLDOFF=2 us
rgk_noDC_v1.2_300MeV		300 MeV		Production, HOLDOFF=1 us
rgk_noDC_empty_v1.1_300MeV		300 MeV		Empty target
rgk_noHTCC_noDC_v1.1_300MeV	no HTCC	300 MeV		wrong trigger delay
rgk_noHTCC_noDC_v2.0_300MeV	no HTCC	300 MeV		trigger delay 84 ns
rgk_out_v1.0_150MeV	With DC roads	150 MeV	Outbending	Production
rgk_out_v1.0_200MeV		200 MeV		
rgk_out_v1.0_300MeV		300 MeV		
rgk_out_v1.1_300MeV		300 MeV		Production, HOLDOFF=2 us
rgk_inb_v1.0_150MeV	With DC roads	150 MeV	Inbending	Production
rgk_inb_v1.0_200MeV		200 MeV		
rgk_v1.0_zero_150MeV	No DC roads	150 MeV	Zero	Alignment run
rgk_v1.0_zero_200MeV		200 MeV		
rgk_v1.0_30kHz_150MeV	Random 30 kHz	150 MeV	Any	Trigger Validation
rgk_v1.0_30kHz_200MeV		200 MeV		
rgk_noDC_v1.0_validation.trg		150 MeV	Any	Includes 150,200,250 and 300 MeV

TABLE II. Electron Trigger Rates

Beam Energy	6.4 GeV	8.5 GeV
Trigger file	rgk_noDC_v1.1_300MeV.trg	rgk_noDC_v1.1_300MeV.trg
Beam current	67 nA	79.9 nA
Electron trigger rate	29.2 kHz	21.5 kHz
Faraday cup trigger rate (no prescale)	57.0 kHz	68.6 kHz
FC prescale	129	129
Faraday trigger rate	0.23 kHz	0.53 kHz
Total trigger rate (with prescale)	29.4 kHz	22.0 kHz
Data rate	620 MB/s	520 MB/s
Live time	90.9%	93.4%



Optimized trigger was chosen: no DC roads, PCAL+ECAL threshold at 300 MeV, 2 μs holdoff time

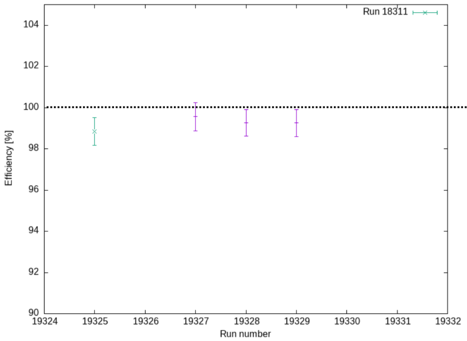
Trigger rates: 30 kHz @ 6.4 GeV and 20 kHz @8.5 GeV – Live times > 90%

DC HV Scans

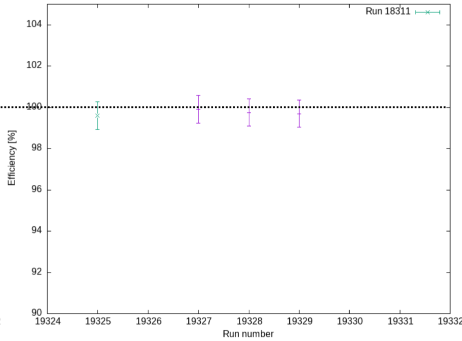
R1 DC HV setting	R2 DC HV setting	R3 DC HV setting	Current
10	11	11	40 nA
11	12	12	40 nA
9	10	10	40 nA
10	10	10	40 nA
10	10	11	40 nA
10	10	11	40 nA
10	12	11	40 nA
10	11	10	40 nA
10	11	12	40 nA
12	13	13	40 nA
11	11	11	40 nA
10	12	10	40 nA

- **HV 11,12,12**
  - **Threshold 30,45,45 (run 19327)**
  - **Threshold 45,60,60 (run 19328)**
  - **Threshold 60,60,60 (run 19329)**
- **Comparison RGD with threshold 30,45,45**

Sec 1 SL1



Sec 1 SL4



- **No decrease in efficiency for higher thresholds**

(11, 12, 12) – SPRING 2024 – 3-passes configuration

(10, 12, 11) – SPRING 2024 – 4-passes configuration

(9, 10, 10) – FALL 2018 configuration

By Florian Hauenstein

Warm/Cold empty target Alignment

Standard procedure: DC alignment done with empty target (cold) with torus & solenoid @ zero field

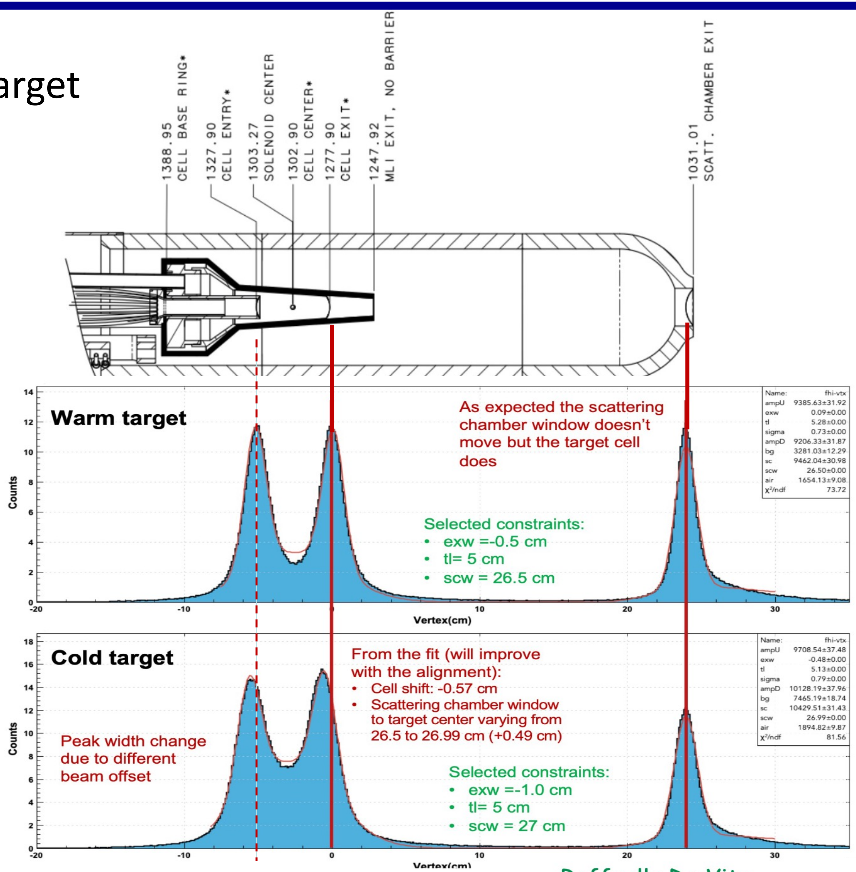
- **Target "foils":** cryotarget entrance + exit windows, scattering chamber exit window

At start of RG-K run, 1 full day was dedicated to alignment runs:

- 12 hr with empty/warm target (first time)
- 12 hr with empty/cold target

Alignments have not taken **thermal contraction of cryo-target system** into account

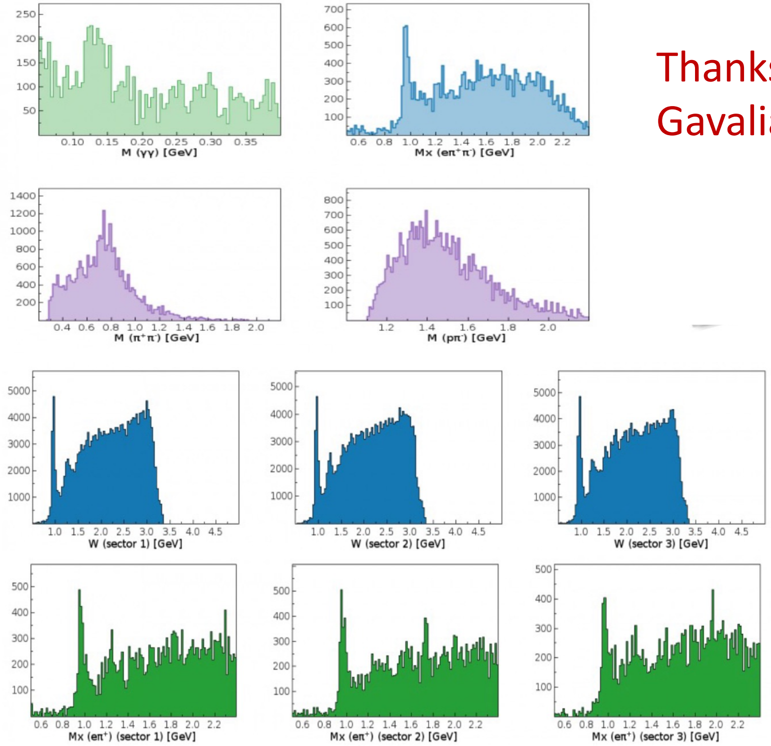
- FEA computed upstream shift of cell by 5 mm
- Data agree with engineering calculation and survey



Raffaella De Vita

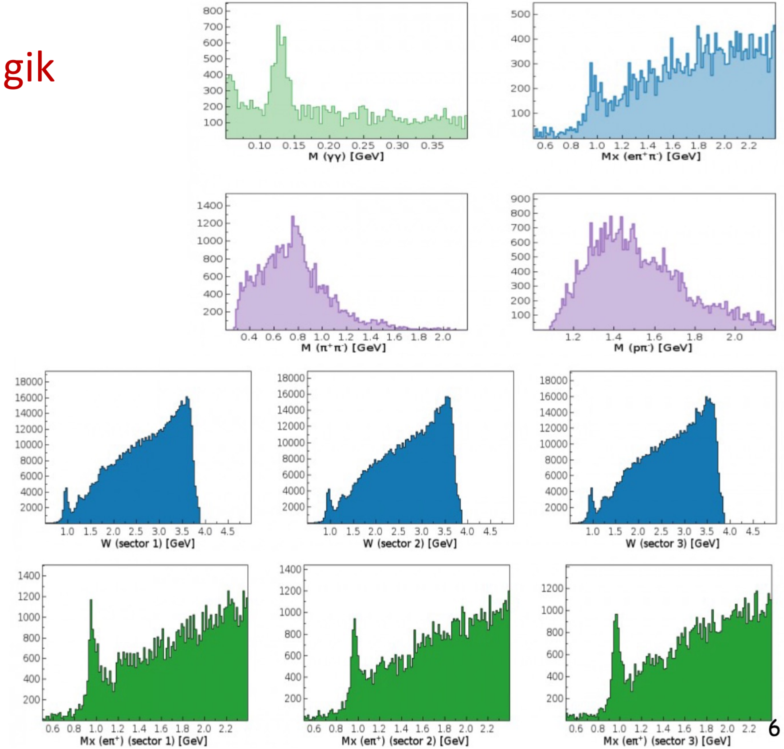
RG-K Production – on-line reconstruction

6394.63 MeV



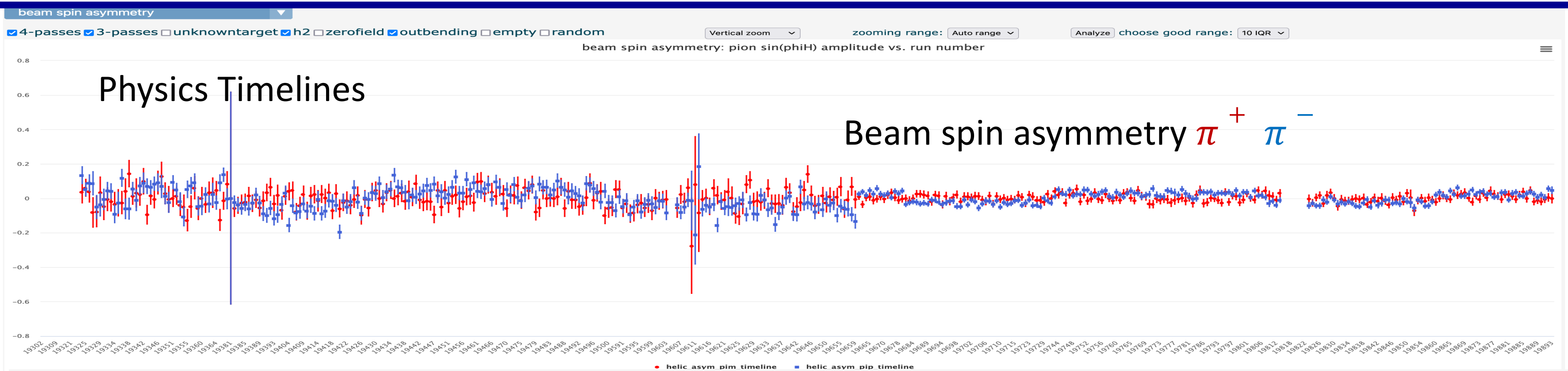
Thanks to Gagik Gavalian !

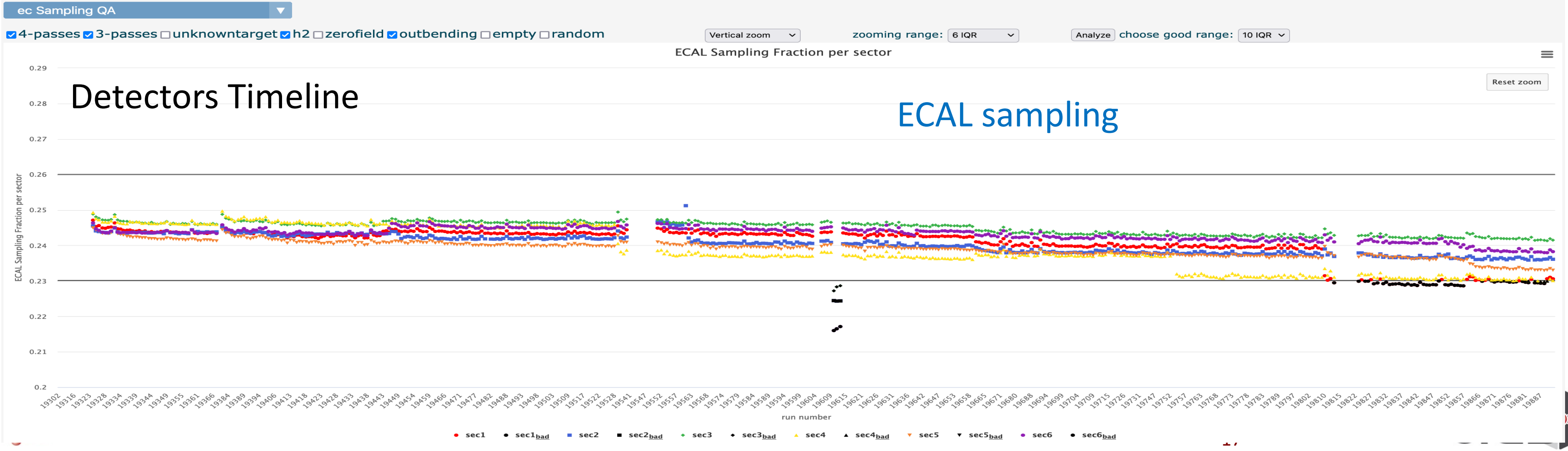
8477.57 MeV



6

RG-K Production – on-line timelines



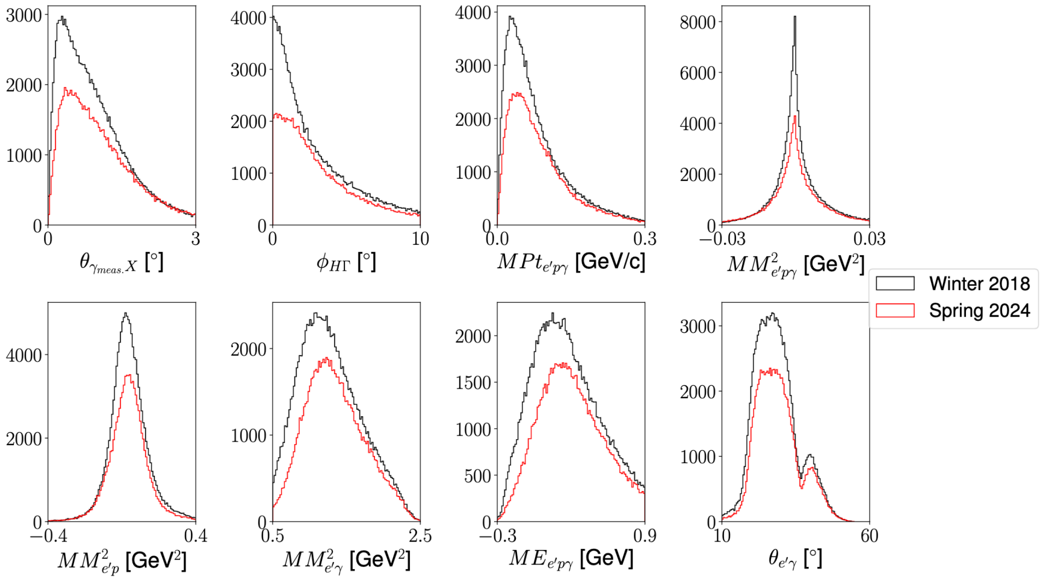


RG-K Production – DVCS Data analysis

Comparison of data analysis: 16 runs from Fall 2018 10 runs from Spring 2024

E=6.5 GeV
E=6.4 GeV

Narrower cuts for the BSA



1. $\theta_{\gamma_{meas.}X} < 3^\circ$
2. $\phi_{H\Gamma} < 10^\circ$
3. $MPt_{e'p\gamma} < 0.3$ GeV/c
4. $|MM^2_{e'p\gamma}| < 0.03$ GeV^2
5. $|MM^2_{e'p}| < 0.4$ GeV^2
6. 0.5 GeV$^2 < MM^2_{e'\gamma} < 2.5$ GeV^2
7. -0.3 GeV $< ME_{e'p\gamma} < 0.9$ GeV
8. $\theta_{e'\gamma} > 10^\circ$

Cut ranges are also visualized on the x-axis.
After this cut, statistics:

	FD proton	CD proton	Total
16 runs winter 2018	14k	77k	91k
10 runs spring 2024	18k	106k	124k

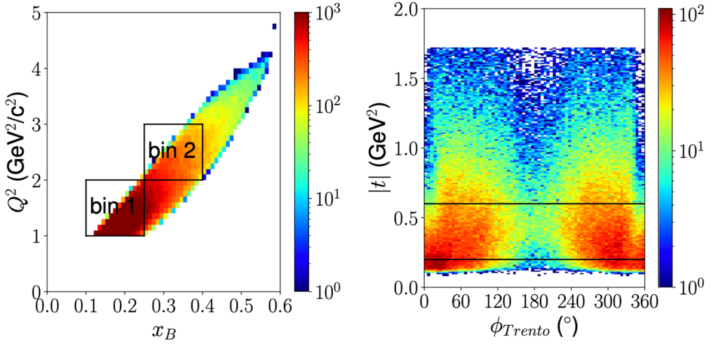
By: Sangbaek Lee

RG-K Production – DVCS Data analysis

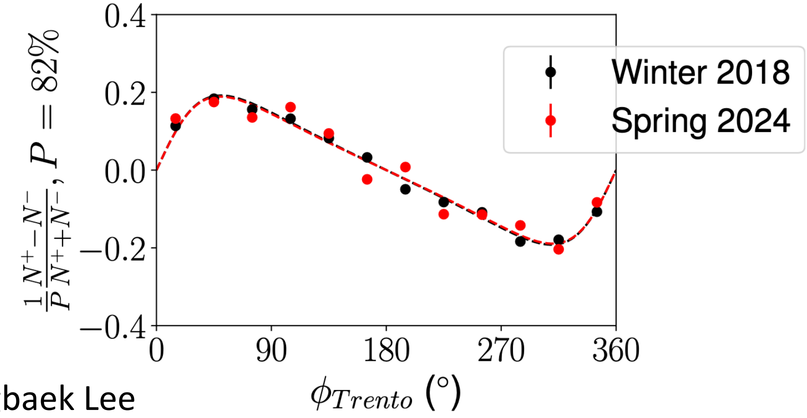
BSA preliminary results

$$BSA(\phi_{Trento}) = \frac{A \sin \phi_{Trento}}{1 + B \cos \phi_{Trento}}$$

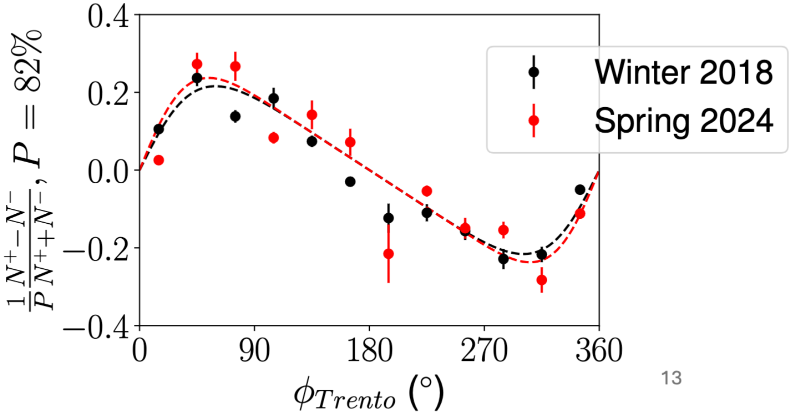
	A, bin 1	B, bin 1	A, bin 2	B, bin 2
16 runs winter 2018	0.148	0.635	0.186	-0.509
10 runs spring 2024	0.145	-0.644	0.192	-0.585



1. $0.1 < x_B < 0.25$, $1 < Q^2[\mathrm{GeV^2/c^2}] < 2$, $0.2 < |t|[\mathrm{GeV^2}] < 0.6$



2. $0.25 < x_B < 0.4$, $2 < Q^2[\mathrm{GeV^2/c^2}] < 3$, $0.2 < |t|[\mathrm{GeV^2}] < 0.6$

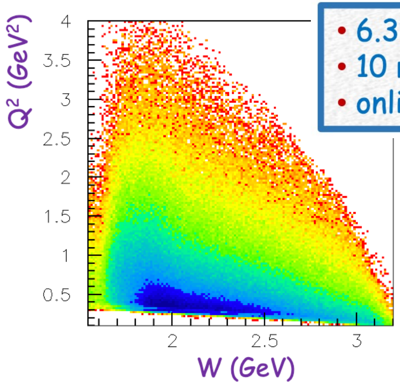


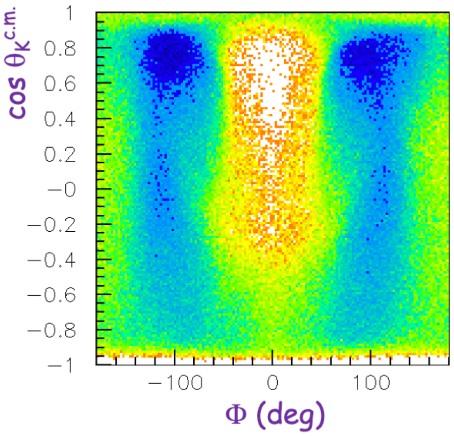
13

By: Sangbaek Lee

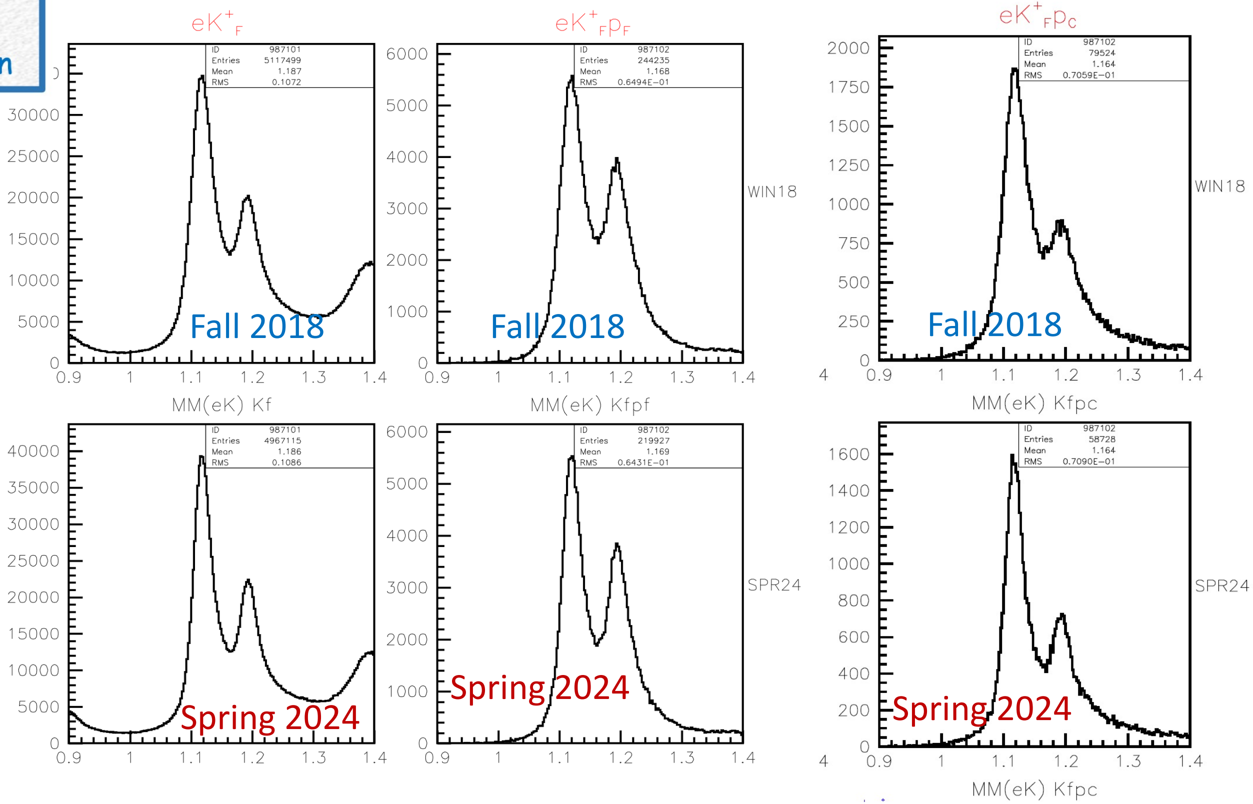
RG-K Production – KY Data analysis

- 6.394 GeV
- 10 runs
- online calib/align





Forward k⁺ | forward k⁺ forward p | forward k⁺ central p

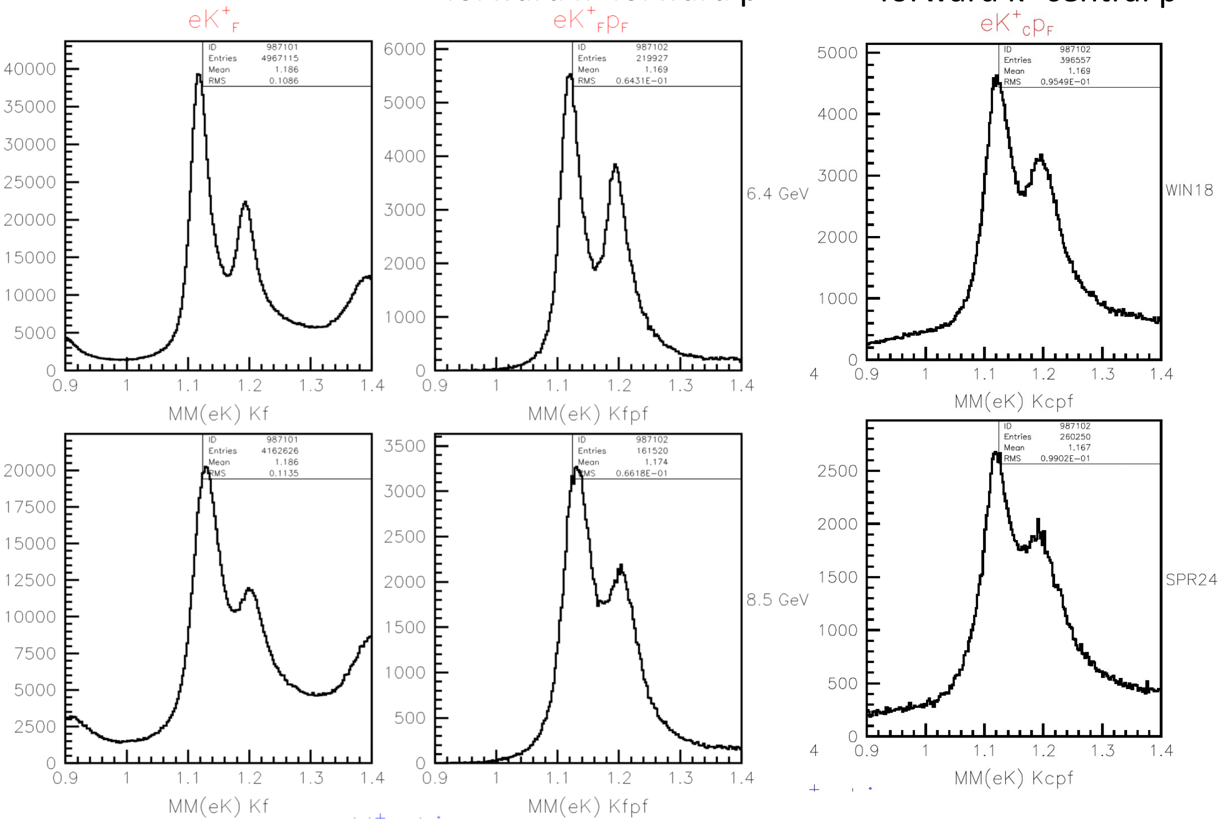


By: Daniel Carman

Resolution is improved with higher DC HV settings

RG-K Production – KY Data analysis

Forward k^+ | forward k^+ forward p | forward k^+ central p



Comparison of 10 cooked files

E= 6.4 GeV

E= 8.5 GeV

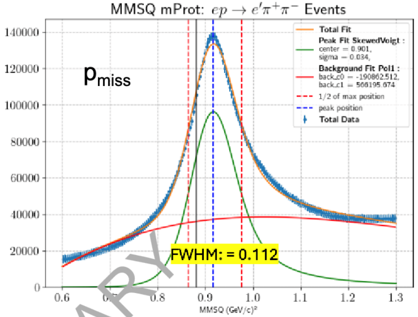
By: Dan Carman

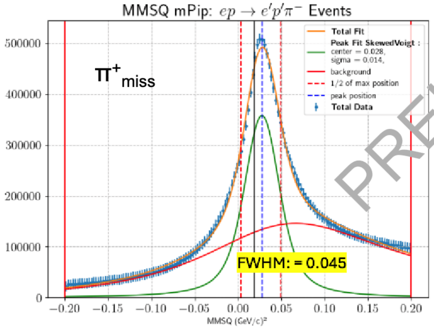
RG-K Production – on-line Data analysis

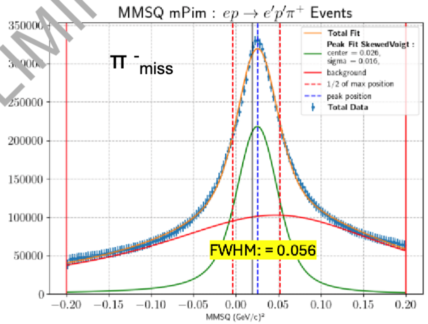
- 6.394 GeV
- 10 runs
- online calib/align

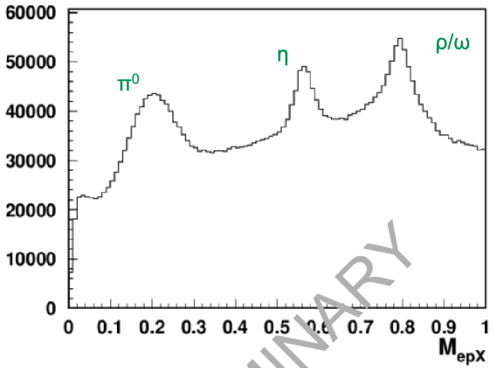
2π Analysis

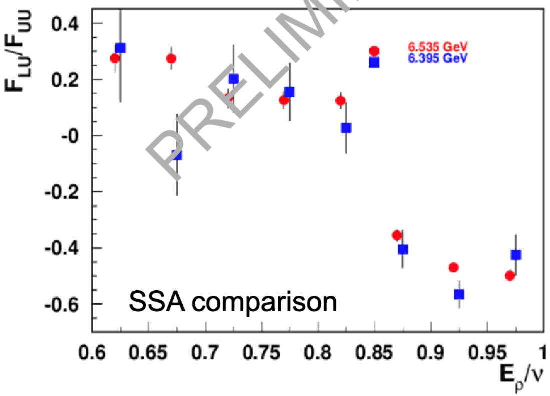
[Krishna Neupane]











Harut Havakian

RG-K Workforce

Analysis Coordinator:
Annalisa D'Angelo

Data Chef:
Lucilla Lanza

Run Coordinators:
Bill Briscoe
Dan Carman
Axel Schmidt
Susan Schadmand

Thanks to the Hall-B scientific staff
Thanks to all the Hall-B Engineers and Technicians
Thanks to all the Shift Takers

Thanks to the PD: Daniel Carman

Conclusions

- ✓ Run group K has successfully collected data at 6.4 GeV and 8.5 GeV.
- ✓ Full luminosity has been reached at 8.5 GeV with FT - OFF
- ✓ 193 mC of charge has been accumulated – dataset has increased by a factor 4
- ✓ On-line calibration and Analysis shows very high quality data