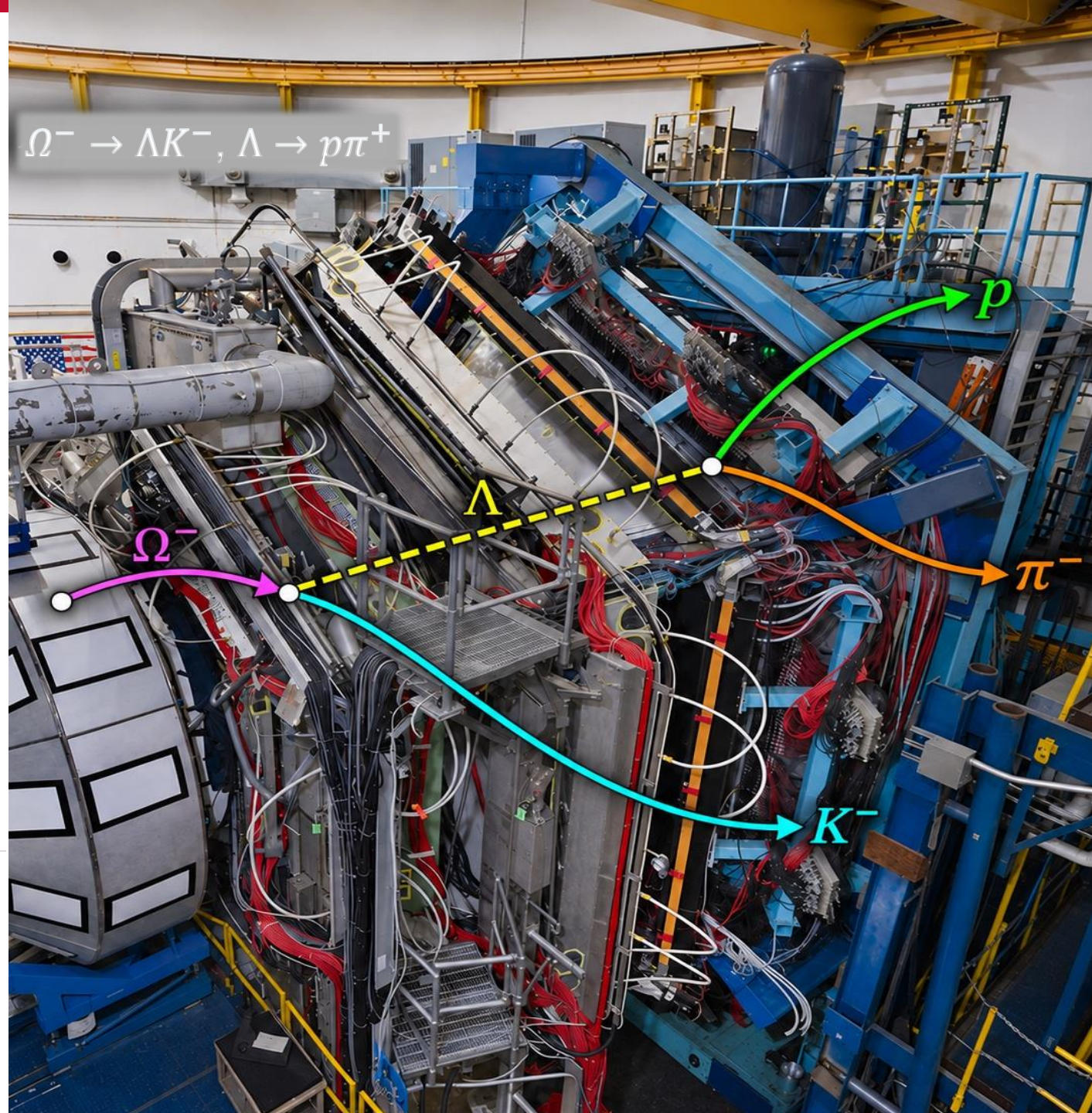
The search for the Ω^- baryon in electroproduction



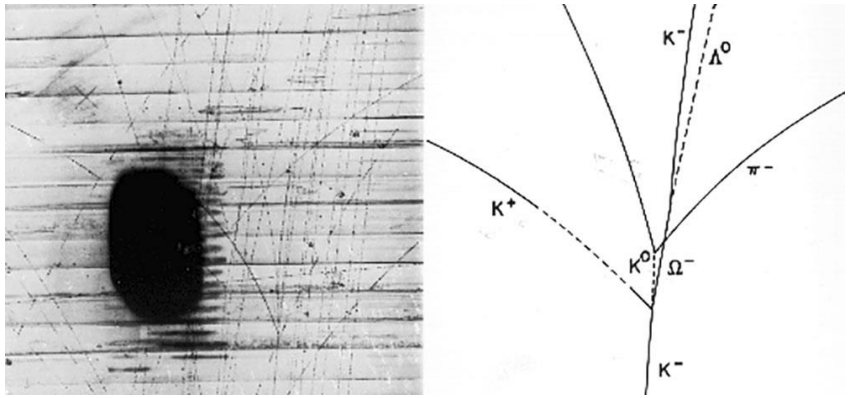
CLAS12 Collaboration Meeting
November 17-20, 2026, JLAB

Veronique Ziegler

University of Richmond

Ω^- production and electroproduction

Observed production



1964 discovery at Brookhaven

$K^- p \rightarrow K^+ K^0 \Omega^-$

Hadron beams, $\bar{p}p$ and heavy-ion collisions
associated and inclusive Ω^- production.

Electron–positron annihilation and charmonium
inclusive Ω^- and $\Omega^-\Omega^+$ pairs, including ψ(3686) decays.

Weak heavy-baryon decays

$\Xi_c^0 \rightarrow \Omega^- K^+, \quad \Omega_c^0 \rightarrow \Omega^- \pi^+, \quad \Omega_b^- \rightarrow J/\psi\, \Omega^-$

Electroproduction with CLAS12

Minimal associated channel

$\gamma^* p \rightarrow K^+ K^+ K^0 \Omega^-$

Formation of an all-strange baryon
The Ω(sss) shares no light valence flavor with the proton. Its production provides a distinct test of multistrange baryon formation.

Production mechanism
Q^2 and W dependence tests production dynamics.
The rate and kinematic distributions can constrain sequential production through intermediate hyperons and other descriptions of the reaction.

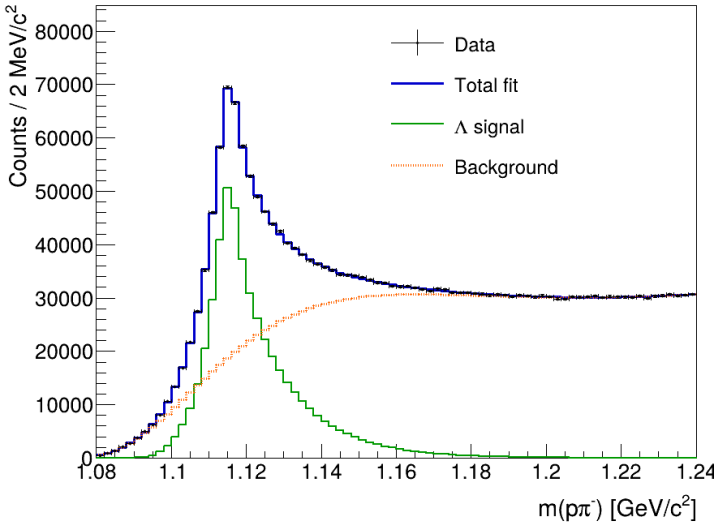
An experimental constraint on the rate
A cross section or sufficiently sensitive upper limit would constrain a poorly known electromagnetic production channel.

A basis for Ω spectroscopy
Establishing ground-state production to provide information on the rates and acceptance needed for future studies of excited Ω states.

RGA Λ selection with and without a kaon

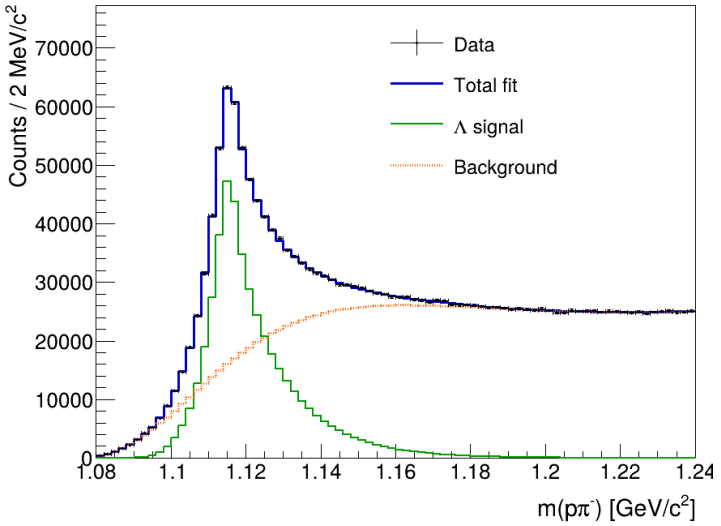
Fall 2018 outbending dataset

Initial Λ selection



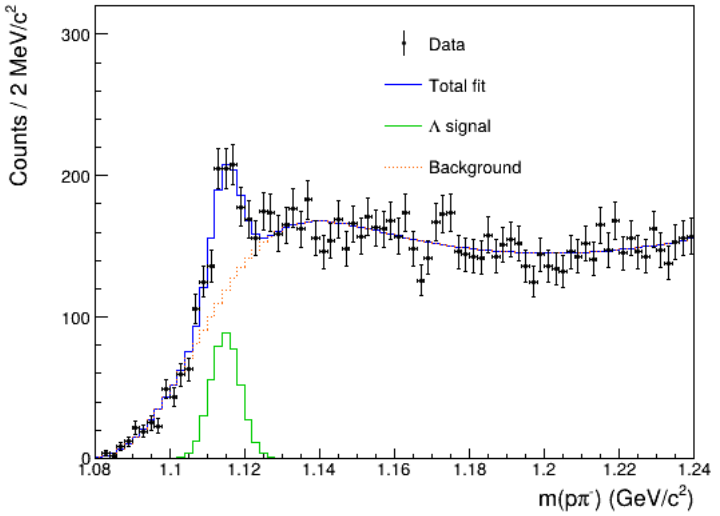
483,200 ± 43,200 fitted yield
392,917 in 7 MeV mass window
$D/\mathrm{ndf} = 86.8/63$

Additional Λ displacement cuts



445,800 ± 34,700 fitted yield
355,733 in 7 MeV mass window
$D/\mathrm{ndf} = 90.5/63$

Same cuts plus an FD K⁻



1 443 ± 79 fitted yield
1,243 in 7 MeV mass window
$D/\mathrm{ndf} = 72.5/63$

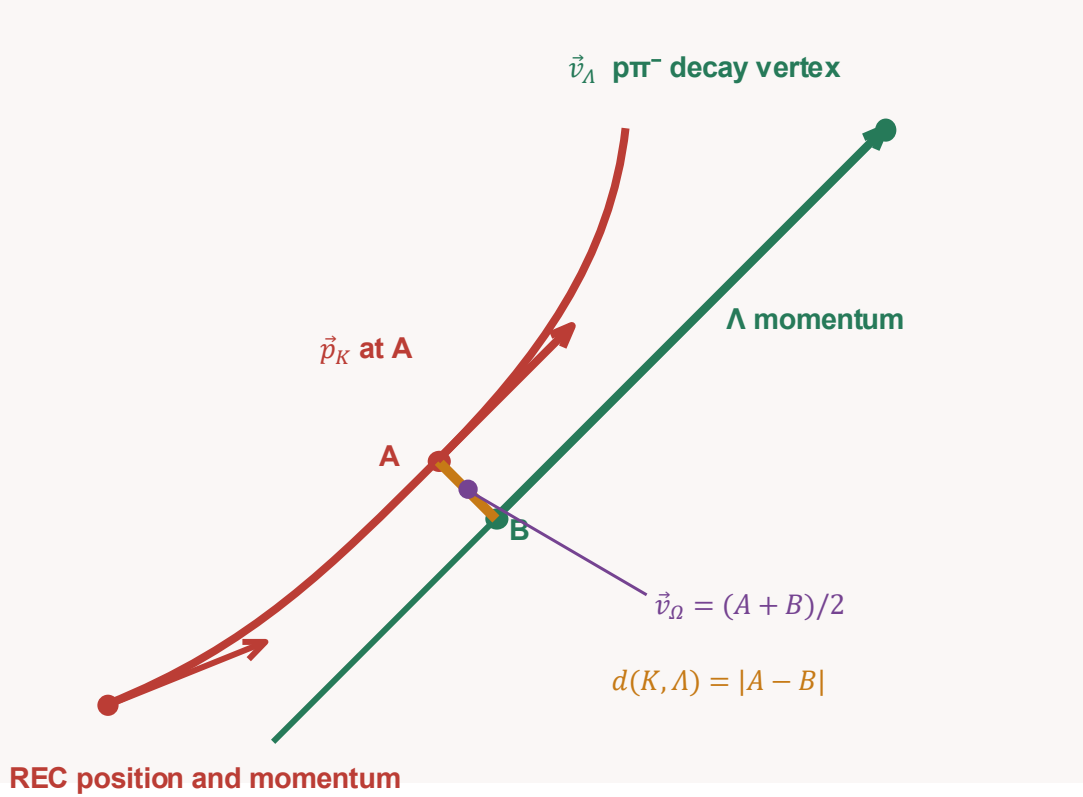
Raw-count window: PDG Λ mass ±7 MeV/c². Baseline uses FD e⁻, p and π⁻, $\mathrm{DOCA}(p,\pi^-) < 5\,\mathrm{cm}$ and $-1 \le \cos\delta \le 1$.
Initial PID: $|\chi_{\mathrm{PID},e}| \le 10, \quad |\chi_{\mathrm{PID},p,\pi}| < 15, \quad \Delta z_\Lambda \ge 0.$
Additional Λ cuts: $\Delta r_T \ge 0.1\,\mathrm{cm}, \quad \Delta z_\Lambda \ge 1\,\mathrm{cm}, \quad L_\Lambda \ge 0.1\,\mathrm{cm}$ Kaon: FD REC K⁻, $|\chi_{\mathrm{PID},K}| \le 10$. Each Λ counted once.
Vertex variables: $\Delta z_\Lambda = z_\Lambda - z_e, \quad \Delta r_T = |\vec{v}_{\Lambda,T} - \vec{v}_{e,T}|, \quad L_\Lambda = (\vec{v}_\Lambda - \vec{v}_e)\cdot\hat{p}_\Lambda.$
Each Λ counted once.

Current sample produced with β vs p cut on the proton that is losing ~7% of Λ yield.

Previous analysis CM angular cut that was changing the momentum acceptance. Clean Λ spectrum alone did not establish that it improved the Ω measurement.

Kaon momentum at the Ω decay vertex

Closest approach of the transported kaon and backward Λ trajectory



The kaon momentum is tangent at A. The midpoint of A and B estimates the Ω decay vertex.

Closest approach

$$\vec{r}_\Lambda(t) = \vec{v}_\Lambda - t\hat{p}_\Lambda, \quad t \geq 0$$

Minimize $|\vec{r}_K(s) - \vec{r}_\Lambda(t)|$ over the two paths.

Magnetic transport

$$\frac{d\vec{r}}{ds} = \frac{\vec{p}}{|\vec{p}|}, \qquad \frac{d\vec{p}}{ds} = qC\left[\frac{\vec{p}}{|\vec{p}|} \times \vec{B}(\vec{r})\right]$$

Fourth-order Runge–Kutta in the solenoid and torus fields.

$q = -1, \quad C = 0.00299792458$ for cm, GeV/c and tesla.

Invariant mass

$$\vec{p}_{K,\mathrm{corr}} = \vec{p}_K(s^*), \quad E_K = \sqrt{|\vec{p}_{K,\mathrm{corr}}|^2 + m_K^2}$$

$$M^2(\Lambda K^-) = (E_\Lambda + E_K)^2 - |\vec{p}_\Lambda + \vec{p}_{K,\mathrm{corr}}|^2$$

RGA Λ spectrum with an FD kaon

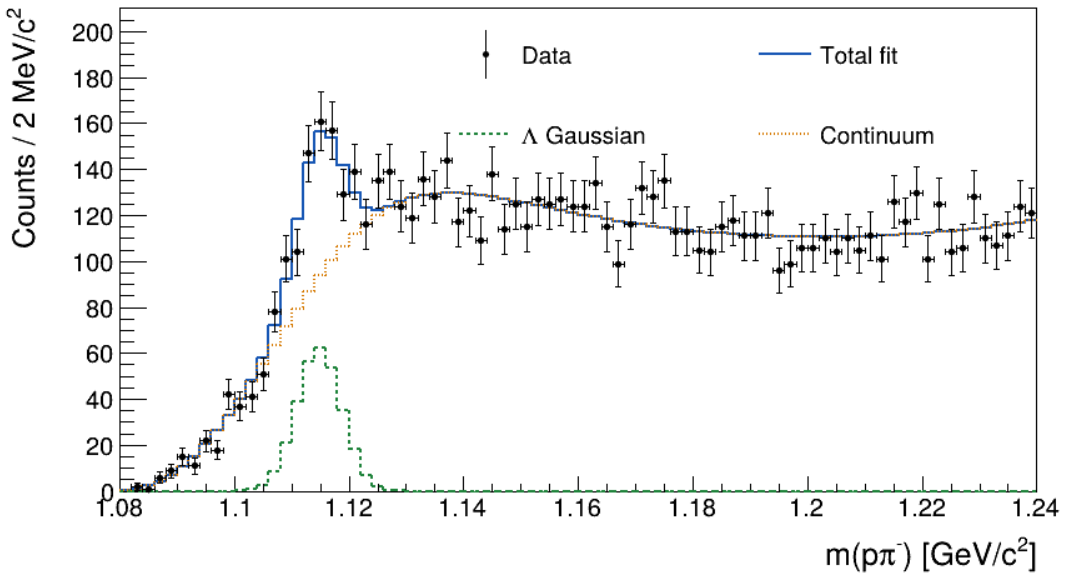
The loose recoil cut reduces the continuum while retaining a similar fitted Λ yield.

Before the missing-mass cut

μ = 1114.81 ± 0.57 MeV; σ = 3.89 ± 0.75 MeV

S = 284 ± 56; B = 665 ± 44; D/ndf = 65.12/72

8806 Λ candidates; 8207 in displayed range

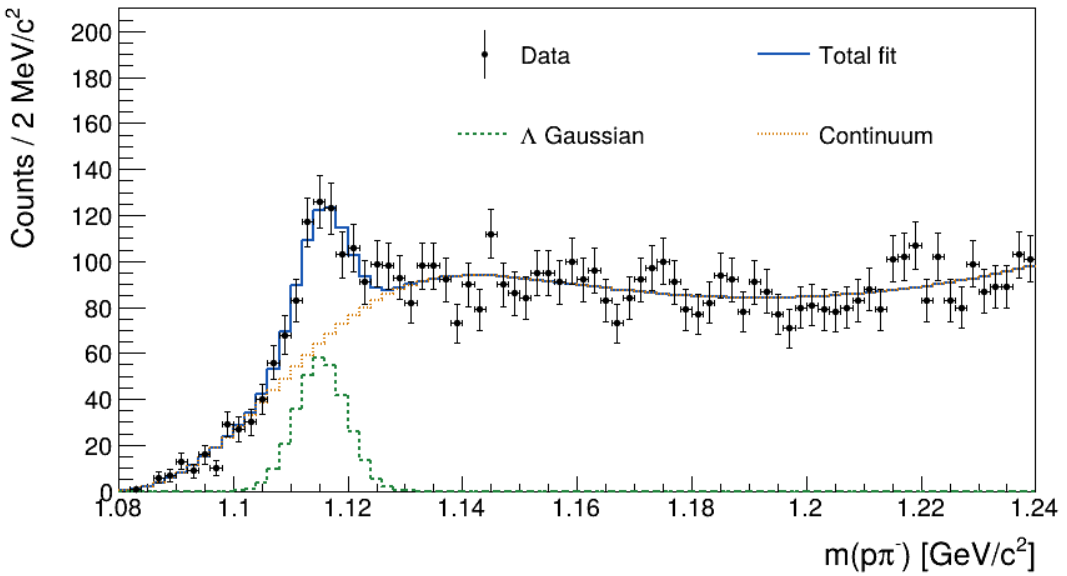


With MM(e'ΛK⁻) > 1 GeV/c²

μ = 1115.40 ± 0.64 MeV; σ = 4.38 ± 0.92 MeV

S = 287 ± 53; B = 454 ± 42; D/ndf = 68.56/72

6712 Λ candidates; 6226 in displayed range



FD p, π⁻ and K⁻. $|\chi_{\mathrm{PID},p,\pi}| < 15, \quad |\chi_{\mathrm{PID},K}| \leq 10 \quad \mathrm{DOCA}(p,\pi^-) < 5\,\mathrm{cm} \quad -1 \leq \cos\delta \leq 1$

Λ relative to e⁻. $\Delta r_T \geq 0.1\,\mathrm{cm}, \quad \Delta z_\Lambda \geq 1\,\mathrm{cm}, \quad L_\Lambda \geq 0.1\,\mathrm{cm} \quad \mathrm{DOCA}(K^-,\Lambda) \leq 3\,\mathrm{cm}$

Each Λ contributes once across the full mass spectrum. S and B are fitted integrals within ±7 MeV/c² of the PDG Λ mass.

Missing mass and associated strangeness

The two minimal associated channels have different recoil thresholds.

$$\mathbf{MM}^2 = (k + P - k' - P_\Lambda - P_K)^2$$

k and k′ are the incident and scattered electron four-momenta. P is the target proton four-momentum.

P_Λ and P_K are the reconstructed Λ and kaon four-momenta.

Ω^- production

$ep \to e'K^+K^+K^0\Omega^-, \quad \Omega^- \to \Lambda K^-$

$2m_{K^\pm} + m_{K^0} \approx 1.485\ \mathrm{GeV}/c^2$

$\Xi(1690)^-$ production

$ep \to e'K^+K^+\Xi(1690)^-, \quad \Xi(1690)^- \to \Lambda K^-$

$2m_{K^\pm} = 0.987354\ \mathrm{GeV}/c^2$

Loose selection: $\mathrm{MM} > 1.000\ \mathrm{GeV}/c^2$ **Tight selection:** $\mathrm{MM} \geq 1.455\ \mathrm{GeV}/c^2$

The tight cut sits about 30 MeV/c² below the three-kaon threshold.

Statistical toys for the Ω & Ξ(1690) mass fits

Poisson pseudoexperiments test the yield fit under specified signal and continuum shapes.

$$\nu_i = N_\Omega G_{\Omega,i} + N_{1690} V_{1690,i} + N_B C_i, \qquad n_i \sim \mathrm{Poisson}(\nu_i)$$

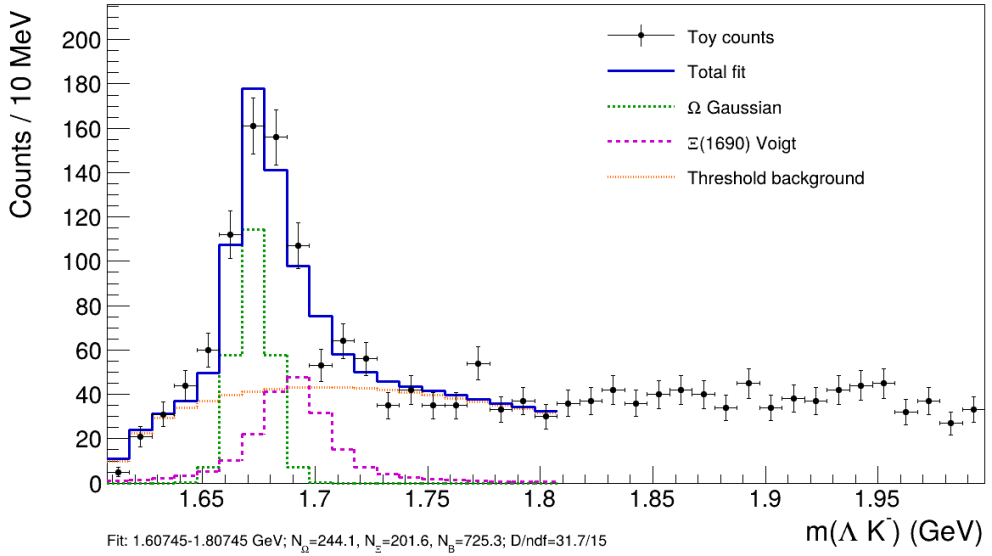
The Ω Gaussian, Ξ(1690) Voigt and positive threshold continuum each integrate to one over the fit bins.

Injected parameter	Value
Expected yields	$N_\Omega = 250, \quad N_{1690} = 200, \quad N_B = 700$
Masses and natural width	$m_\Omega = 1672.45, \quad m_{1690} = 1690\ \mathrm{MeV}/c^2; \quad \Gamma_{1690} = 20\ \mathrm{MeV}$
Shared Gaussian resolution	Input $\sigma = 10\ \mathrm{MeV}/c^2$. Refit the same histogram at 8, 10 and 12 MeV/c².
Threshold continuum	$\sqrt{\max(m - m_{\mathrm{thr}}, 0)}\, e^{-0.30t}, \quad m_{\mathrm{thr}} = 1.609360\ \mathrm{GeV}/c^2$ $t = (m - 1.705)/0.095\ \mathrm{GeV}/c^2$.
Fitted interval	$1.60745 \le m(\Lambda K^-) \le 1.80745\ \mathrm{GeV}/c^2$

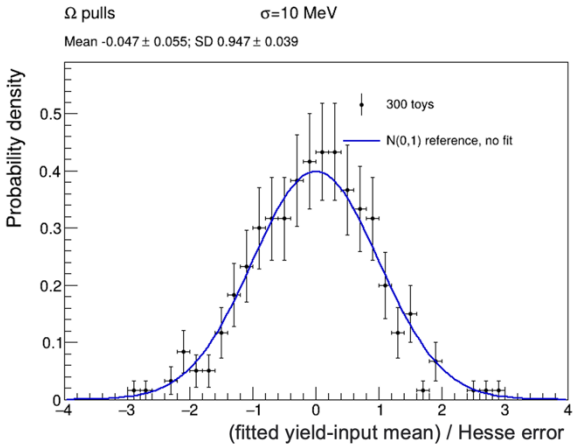
The shared resolution changes both overlapping peaks.

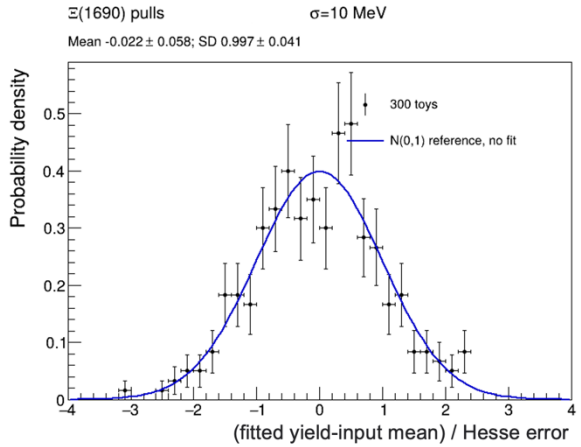
Toy fit with an 8 MeV/c² resolution

Generating 300 toy pseudo-experiments to validate the fit procedure



Toy yield pulls at the input resolution





Input fit-range yields

Ω signal 250

Ξ(1690) 200

Continuum 700

Observed total 1,171

Fit settings

Both masses and the Ξ(1690) natural width of 20 MeV are fixed. The fit varies the yields and continuum coefficients.

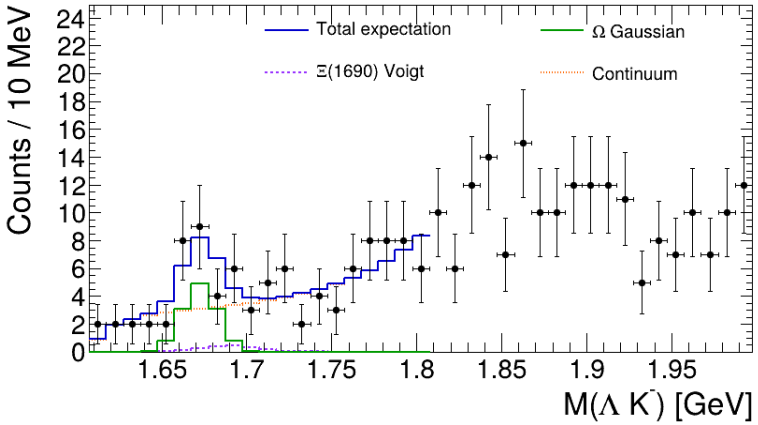
10 MeV/c² bins. Fit range 1.60745–1.80745 GeV/c². The plot extends to 2 GeV/c².

RGA Λ four-momentum treatments

Sample of 573 combinations with a successful mass-constrained Λ fit

Using Λ, K⁻ 4-momentum addition

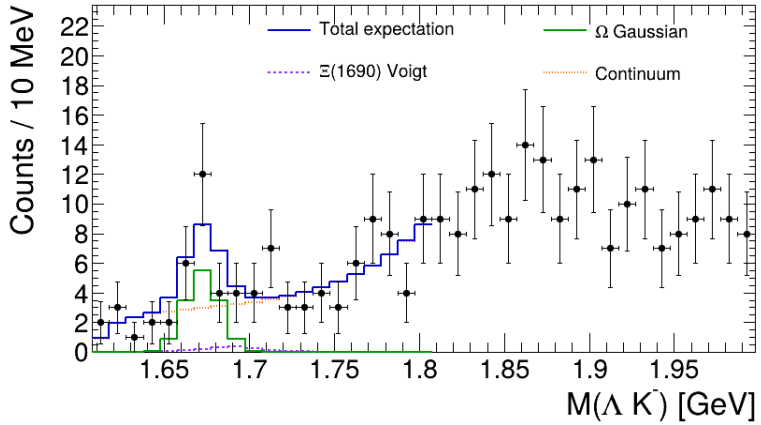
Fit-range counts: Ω 12.8 -5.8/+6.4; Ξ 2.1 -2.1/+9.9; continuum 81.0
Omega m 1672.45 MeV (fixed PDG); sigma 10.00 MeV (fixed)
Fixed Xi m 1690.0 MeV; natural Gamma 20.0 MeV
Background a -0.018, b 0.499; Poisson D/ndf 10.02/15



$$P_\Lambda = P_p + P_{\pi^-}$$

Λ-mass constraint recomputing E from Λ PDG mass

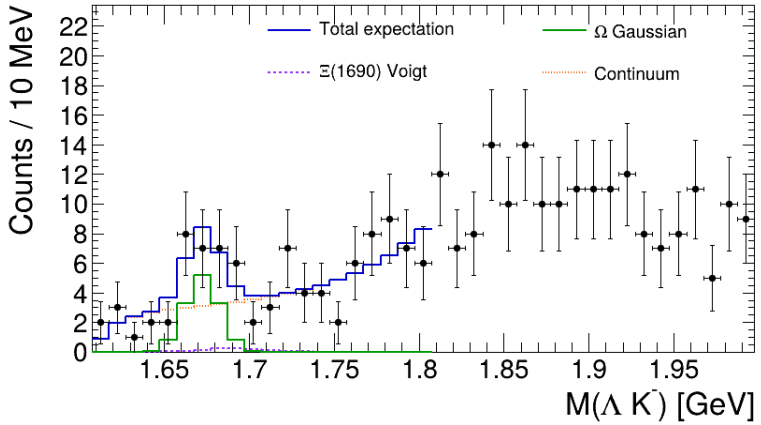
Fit-range counts: Ω 14.3 -5.7/+6.2; Ξ 1.6 -1.6/+10.2; continuum 80.0
Omega m 1672.45 MeV (fixed PDG); sigma 10.00 MeV (fixed)
Fixed Xi m 1690.0 MeV; natural Gamma 20.0 MeV
Background a -0.014, b 0.565; Poisson D/ndf 13.68/15



$$E_\Lambda = \sqrt{|\vec{p}_\Lambda|^2 + m^2_{\Lambda,\mathrm{PDG}}}$$

Λ-mass constraint from vertex-and-momentum fit

Fit-range counts: Ω 13.5 -6.2/+6.5; Ξ 1.2 -1.2/+9.9; continuum 81.3
Omega m 1672.45 MeV (fixed PDG); sigma 10.00 MeV (fixed)
Fixed Xi m 1690.0 MeV; natural Gamma 20.0 MeV
Background a -0.022, b 0.488; Poisson D/ndf 12.50/15



Fitted daughter four-momenta

FD p, π⁻, K⁻. $|m(p\pi^-) - m_{\Lambda,\mathrm{PDG}}| \leq 7\,\mathrm{MeV}/c^2$ $|\chi_{\mathrm{PID},K}| \leq 10$ $\mathrm{DOCA}(p,\pi^-) \leq 5\,\mathrm{cm}$
$\Delta z_\Lambda \geq 1\,\mathrm{cm}$ $\mathrm{DOCA}(K^-,\Lambda) \leq 3\,\mathrm{cm}$ $\mathrm{MM} \geq 1.000\,\mathrm{GeV}/c^2$. The selection applies no Ω displacement cut.

The fit adjusts the proton and pion tracks, accounting for their uncertainties, to meet at a common decay vertex with m(p, π⁻) equal to the PDG Λ mass.

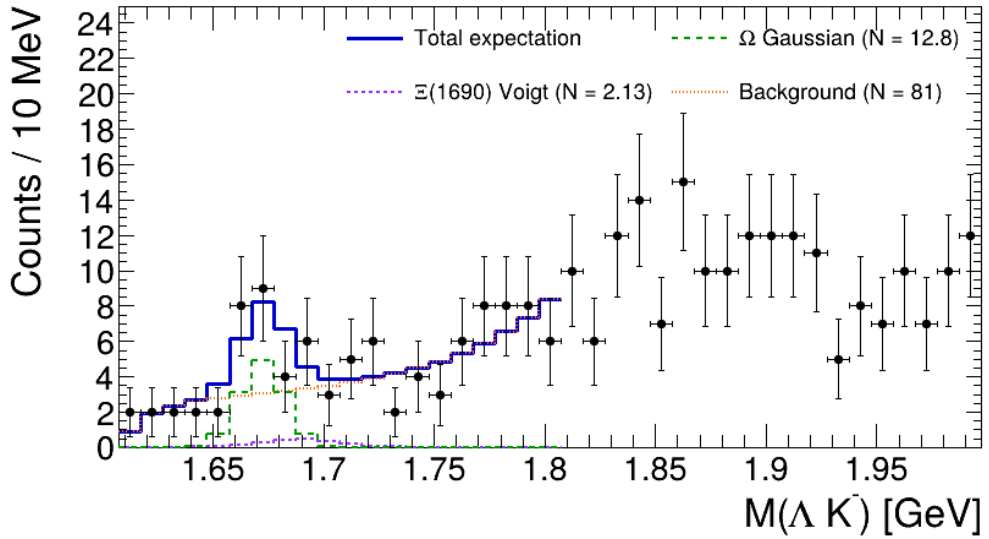
Exploratory: covariance matrix not valid in this cooking.

Effect of recoil cuts

Measured Λ four-momentum. Component fits shown separately for each missing-mass threshold.

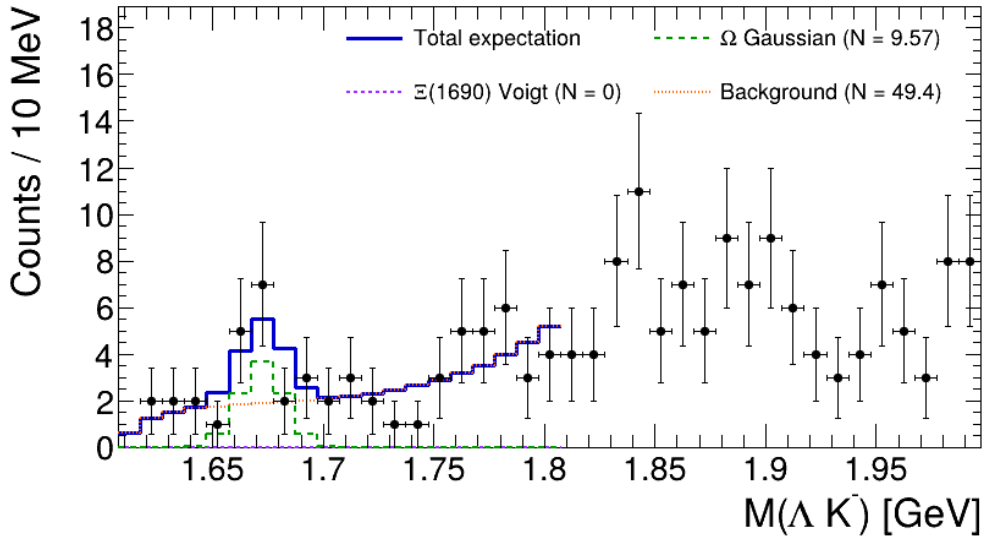
$\mathbf{MM} > 1.000\,\mathbf{GeV}/c^2$

Fit-range counts: Ω 12.8 -5.8/+6.4; Ξ 2.1 -2.1/+9.9; continuum 81.0
Omega m 1672.45 MeV (fixed PDG); sigma 10.00 MeV (fixed)
Fixed Xi m 1690.0 MeV; natural Gamma 20.0 MeV
Background a -0.018, b 0.499; Poisson D/ndf 10.02/15



$\mathbf{MM} \geq 1.455\,\mathbf{GeV}/c^2$

Fit-range counts: Ω 9.6 -4.3/+4.8; Ξ 0.0 -0.0/+5.8; continuum 49.4
Omega m 1672.45 MeV (fixed PDG); sigma 10.00 MeV (fixed)
Fixed Xi m 1690.0 MeV; natural Gamma 20.0 MeV
Background a -0.067, b 0.590; Poisson D/ndf 10.78/15

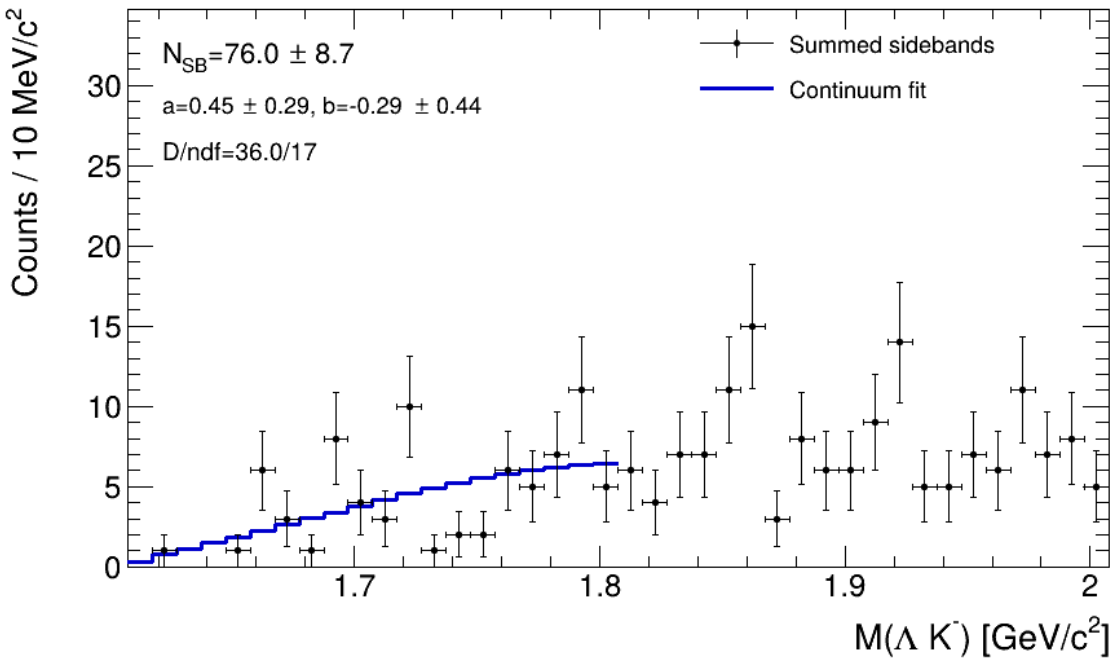


The tighter cut reduces the sample from 573 to 317 entries with consistent yield within errors.
The fitted Ξ(1690) yield reaches zero.

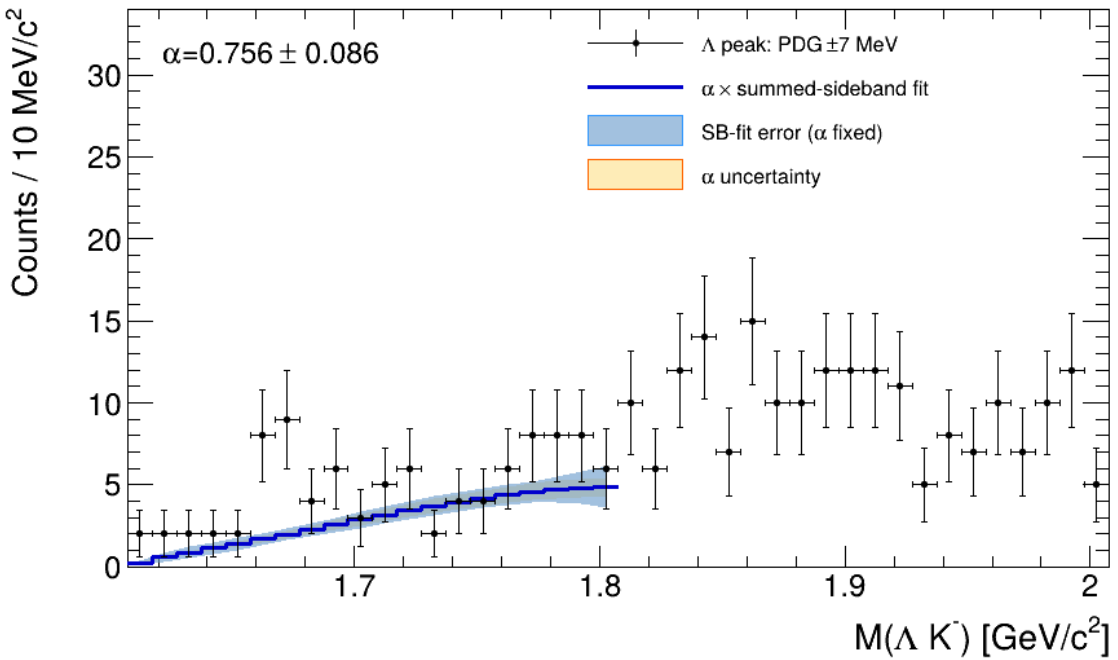
Λ-sideband background estimate

Measured Λ four-momentum with $\mathrm{MM}(e'\Lambda K^-) > 1.000\ \mathrm{GeV}/c^2$

Lower + upper Λ sidebands



Λ signal region + sideband template



Sidebands in m(pπ⁻): 1.080–1.094 and 1.145–1.159 GeV/c². Signal window: PDG Λ mass ±7 MeV/c².

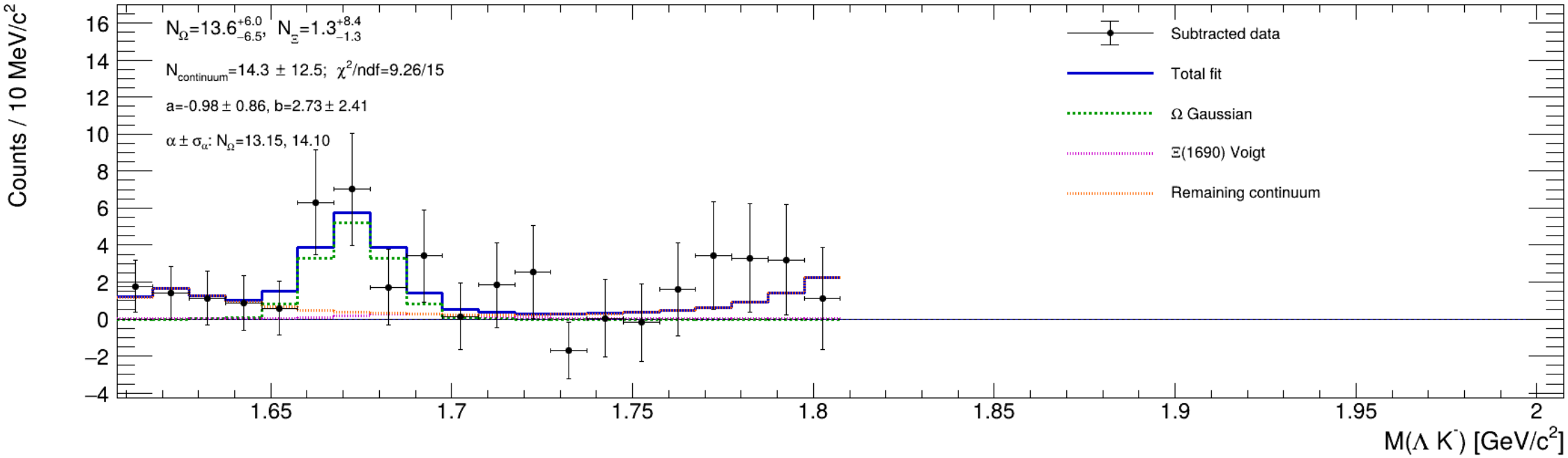
Sideband model: $\sqrt{m - m_{\Lambda,\mathrm{PDG}} - m_K}\, e^{at+bt^2}, \quad t = (m - 1.705)/0.095.$

Normalization factor $\alpha = 0.756 \pm 0.086$.

$$\alpha = \frac{\int_{\Lambda\ \text{signal window}} B_\Lambda(m)\, dm}{\int_{\text{lower sideband}} B_\Lambda(m)\, dm + \int_{\text{upper sideband}} B_\Lambda(m)\, dm}$$

Fit after Λ-mass-sideband subtraction

Same measured Λ candidates and the same loose recoil requirement



Fitted yield $N_\Omega = 13.6^{+6.0}_{-6.5}$

Fit interval: $1.60745 \leq m(\Lambda K^-) \leq 1.80745\,\mathrm{GeV}/c^2$. Correlated χ^2 includes sideband-template covariance.

Looking for the Ω^- in RGK data

RGA shows a small, fit-dependent excess near the Ω^- mass. RGK offers a large independent check at a lower beam energy, where the Λ is expected to have better signal-to-background ratio.

At 8.477 GeV, RGK can reach a hadronic mass (W) of about **4.10 GeV**, above the **3.16 GeV** threshold for (Ω^- $K^+K^+K^0$) production.

RGK Spring 2024 Λ train

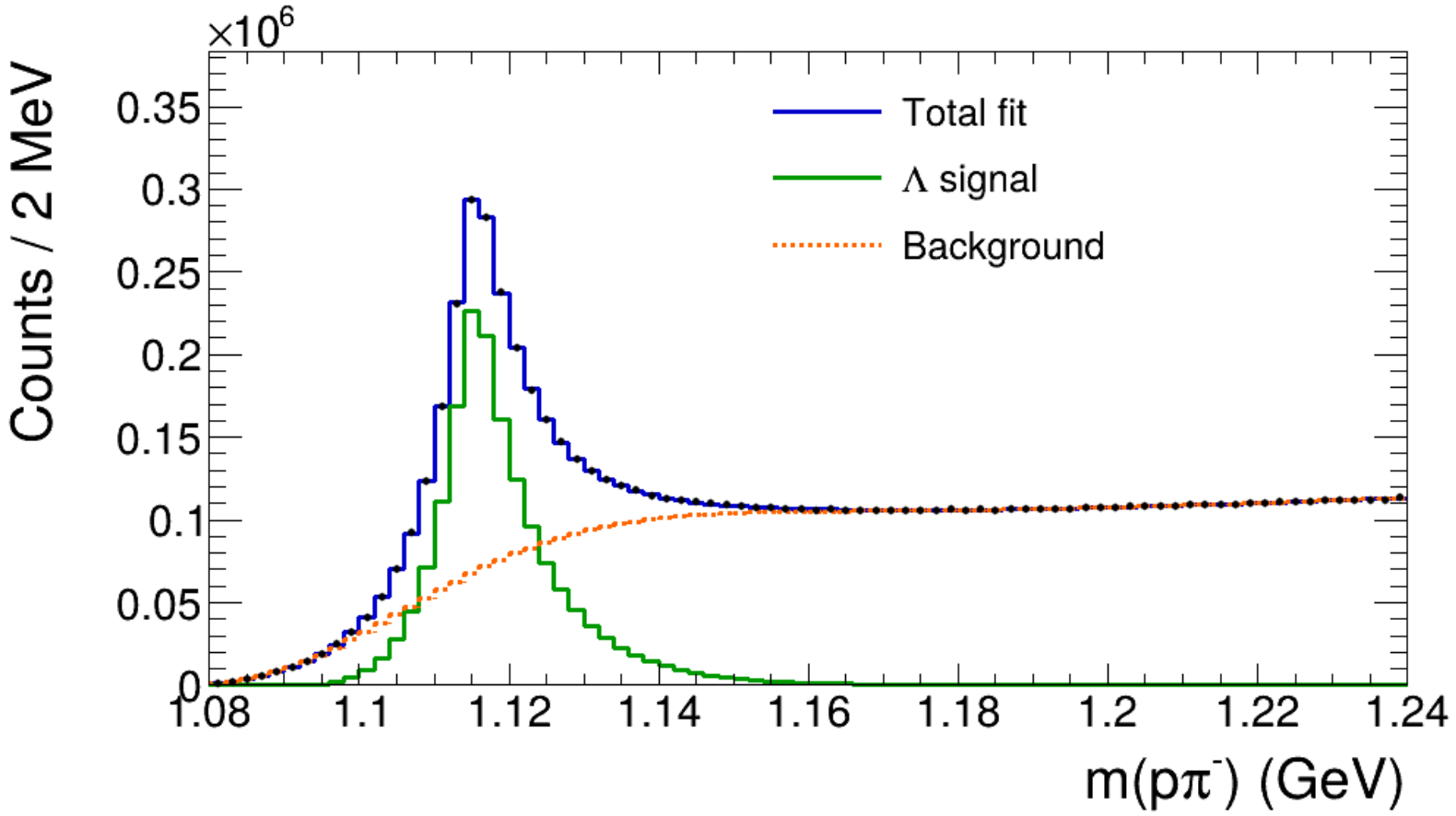
An event enters the train if at least one $p\pi^-$ candidate passes the train conditions.

Train condition	Requirement
Electron trigger	REC row 0, PID 11, negative status. $2000 < \lvert\text{status}\rvert < 4000$
Forward daughter tracks	Proton (PID 2212) and π^- (PID −211), each with $2000 < \lvert\text{status}\rvert < 4000$
Particle identification	$\lvert\chi_{\text{PID},e}\rvert \leq 10, \quad \lvert\chi_{\text{PID},p}\rvert < 15, \quad \lvert\chi_{\text{PID},\pi^-}\rvert < 15$
Λ vertex	REC::VertDoca, $\text{DOCA}(p,\pi^-) < 5\,\text{cm}$ and $z_\Lambda - z_e \geq 0\,\text{cm}$
Physical opening angle	$-1 \leq \cos\delta \leq 1$ using REC momenta and the PDG Λ mass
Λ mass window	No explicit mass-window requirement

The train stores all candidates in accepted events. Later candidate-level selections apply separately.

Λ candidates in the RGK train

Λ candidates before additional analysis cuts or a kaon requirement



Fitted Λ yield

1,087,965 ± 11,136

Within ±7 MeV/c² of the PDG Λ mass.

Core Gaussian

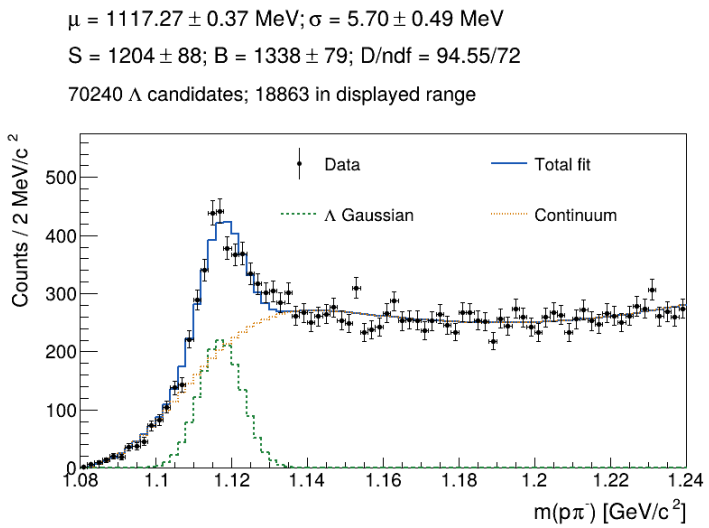
$\mu = 1115.51\,\mathrm{MeV}/c^2$

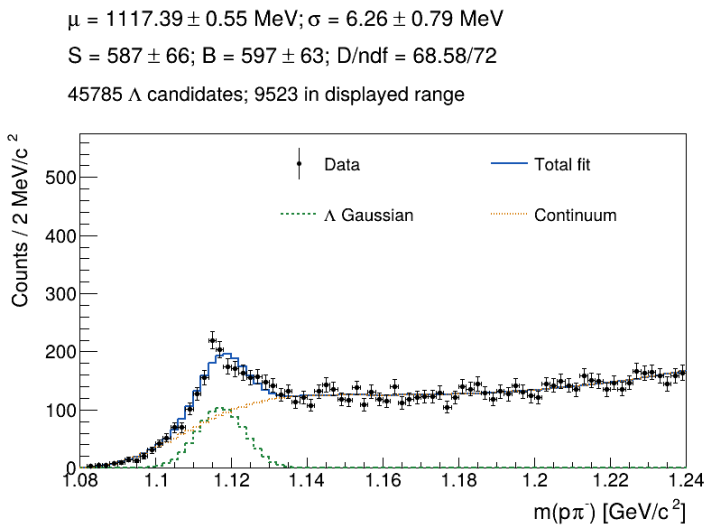
$\sigma = 1.63\,\mathrm{MeV}/c^2$

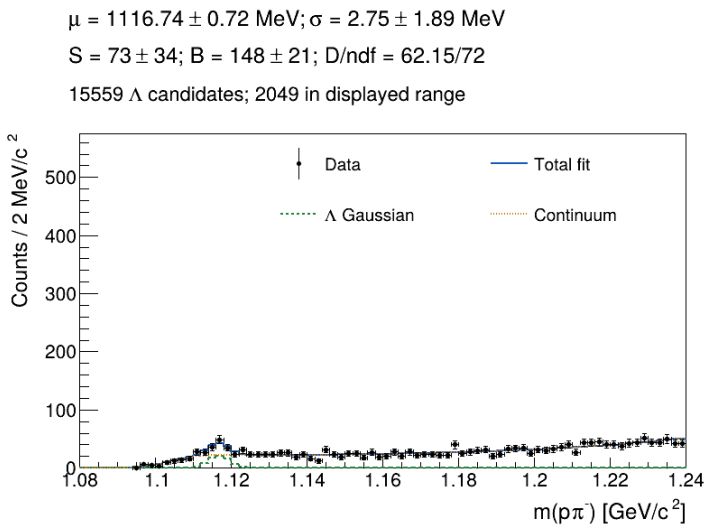
RGK Λ yield across recoil cuts

Same selections and fit model as RGA comparison. Fitted signal within the PDG Λ mass ±7 MeV/c².

RGK, 8.477 GeV







Before recoil cut

1,204 ± 88

MM $> 1.000\ \mathrm{GeV}/c^2$

587 ± 66

MM $\geq 1.455\ \mathrm{GeV}/c^2$

73 ± 34

Forward detector (FD) electron trigger, proton, pion and kaon. $|\chi_{\mathrm{PID},e}| \leq 10$, $|\chi_{\mathrm{PID},p,\pi}| < 15$, $|\chi_{\mathrm{PID},K}| \leq 10$ $\mathrm{DOCA}(p,\pi^-) < 5\,\mathrm{cm}$

Λ displacement relative to the electron vertex. $\Delta r_T \geq 0.1\,\mathrm{cm}$, $\Delta z_\Lambda \geq 1\,\mathrm{cm}$, $L_\Lambda \geq 0.1\,\mathrm{cm}$

$\mathrm{DOCA}(K^-,\Lambda) \leq 3\,\mathrm{cm}$ $-1 \leq \cos\delta \leq 1$ Count each Λ once.

The tight recoil cut reduces the fitted Λ yield substantially.

RGA Λ yield across recoil cuts

Same FD kaon and Λ selections in all three panels. Fitted signal within the PDG Λ mass ±7 MeV/c².

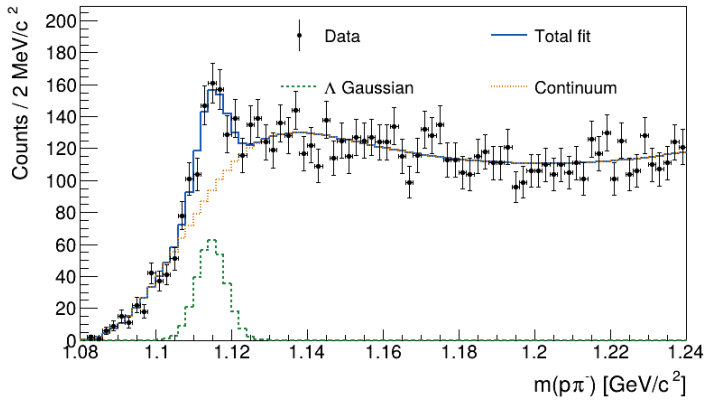
RGA, 10.6041 GeV

Before the missing-mass cut

μ = 1114.81 ± 0.57 MeV; σ = 3.89 ± 0.75 MeV

S = 284 ± 56; B = 665 ± 44; D/ndf = 65.12/72

8806 Λ candidates; 8207 in displayed range

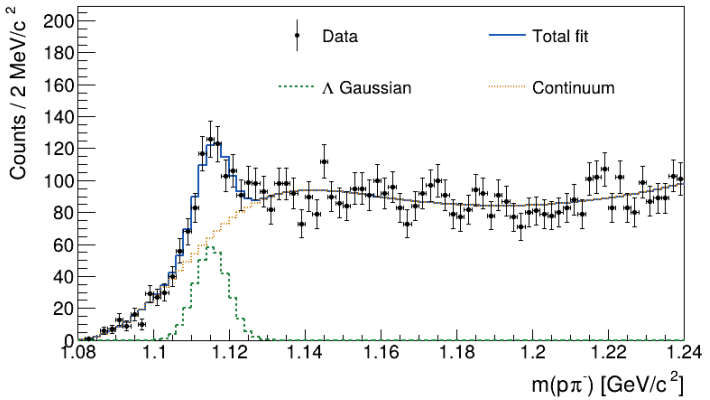


MM(e'ΛK⁻) > 1 GeV/c²

μ = 1115.40 ± 0.64 MeV; σ = 4.38 ± 0.92 MeV

S = 287 ± 53; B = 454 ± 42; D/ndf = 68.56/72

6712 Λ candidates; 6226 in displayed range

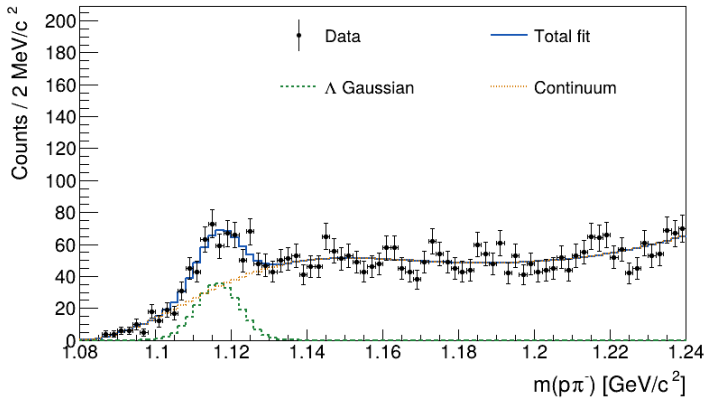


MM(e'ΛK⁻) ≥ 1.455 GeV/c²

μ = 1116.61 ± 0.81 MeV; σ = 5.69 ± 0.81 MeV

S = 198 ± 28; B = 223 ± 20; D/ndf = 74.82/72

3917 Λ candidates; 3598 in displayed range



Before recoil cut

284 ± 56

MM > 1.000 GeV/c^2

287 ± 53

MM ≥ 1.455 GeV/c^2

198 ± 28

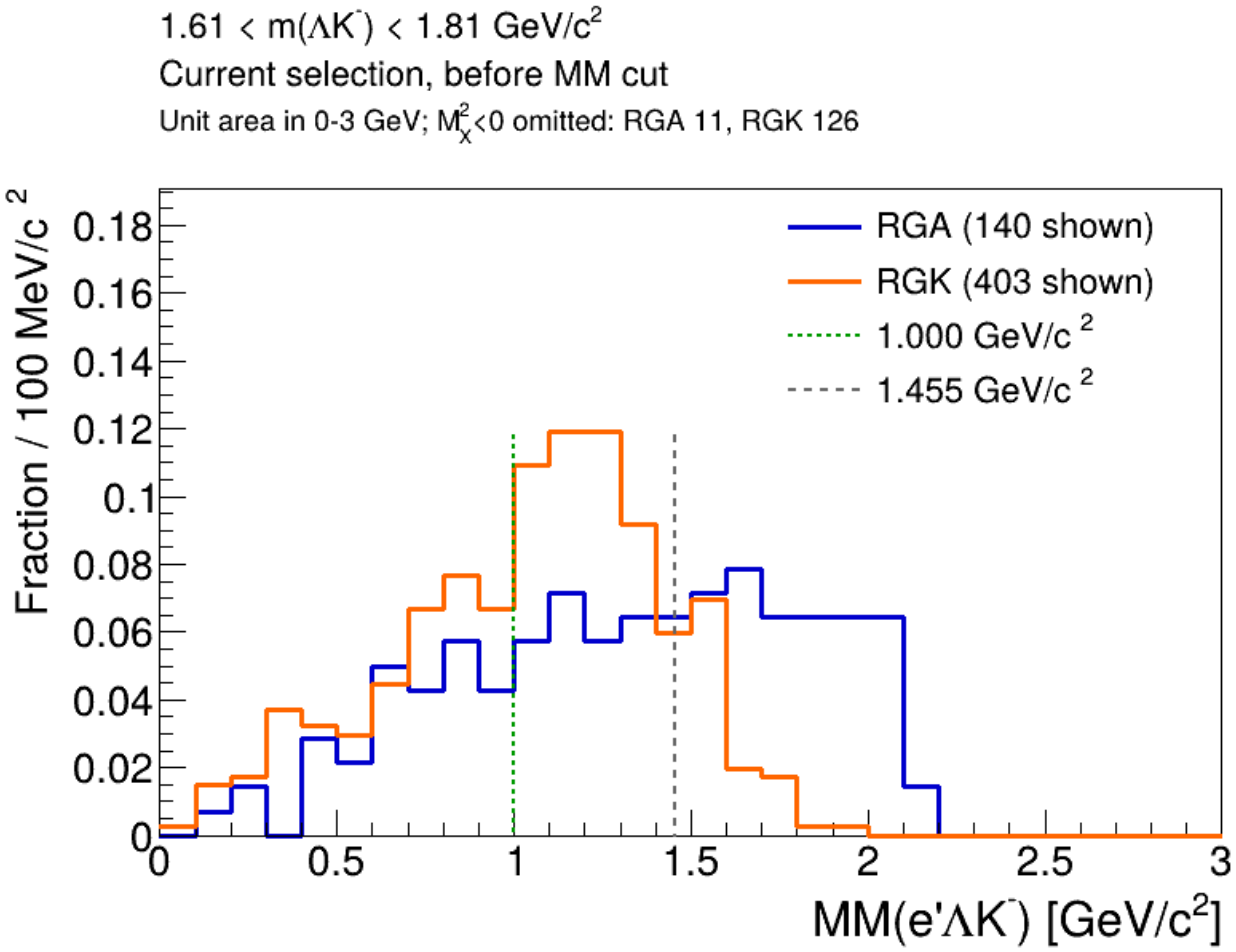
Forward detector (FD) electron trigger, proton, pion and kaon. $|\chi_{\mathrm{PID},e}| \leq 10$, $|\chi_{\mathrm{PID},p,\pi}| < 15$, $|\chi_{\mathrm{PID},K}| \leq 10$ $\mathrm{DOCA}(p,\pi^-) < 5\,\mathrm{cm}$

Λ displacement relative to the electron vertex. $\Delta r_T \geq 0.1\,\mathrm{cm}$, $\Delta z_\Lambda \geq 1\,\mathrm{cm}$, $L_\Lambda \geq 0.1\,\mathrm{cm}$

$\mathrm{DOCA}(K^-,\Lambda) \leq 3\,\mathrm{cm}$ $-1 \leq \cos\delta \leq 1$ Count each Λ once.

Recoil mass in the Ω -- Ξ(1690) region

RGA and RGK before the missing-mass cut



ΛK⁻ mass window

$1.61 < m(\Lambda K^-) < 1.81\,\mathrm{GeV}/c^2$

Displayed candidates

RGA 140

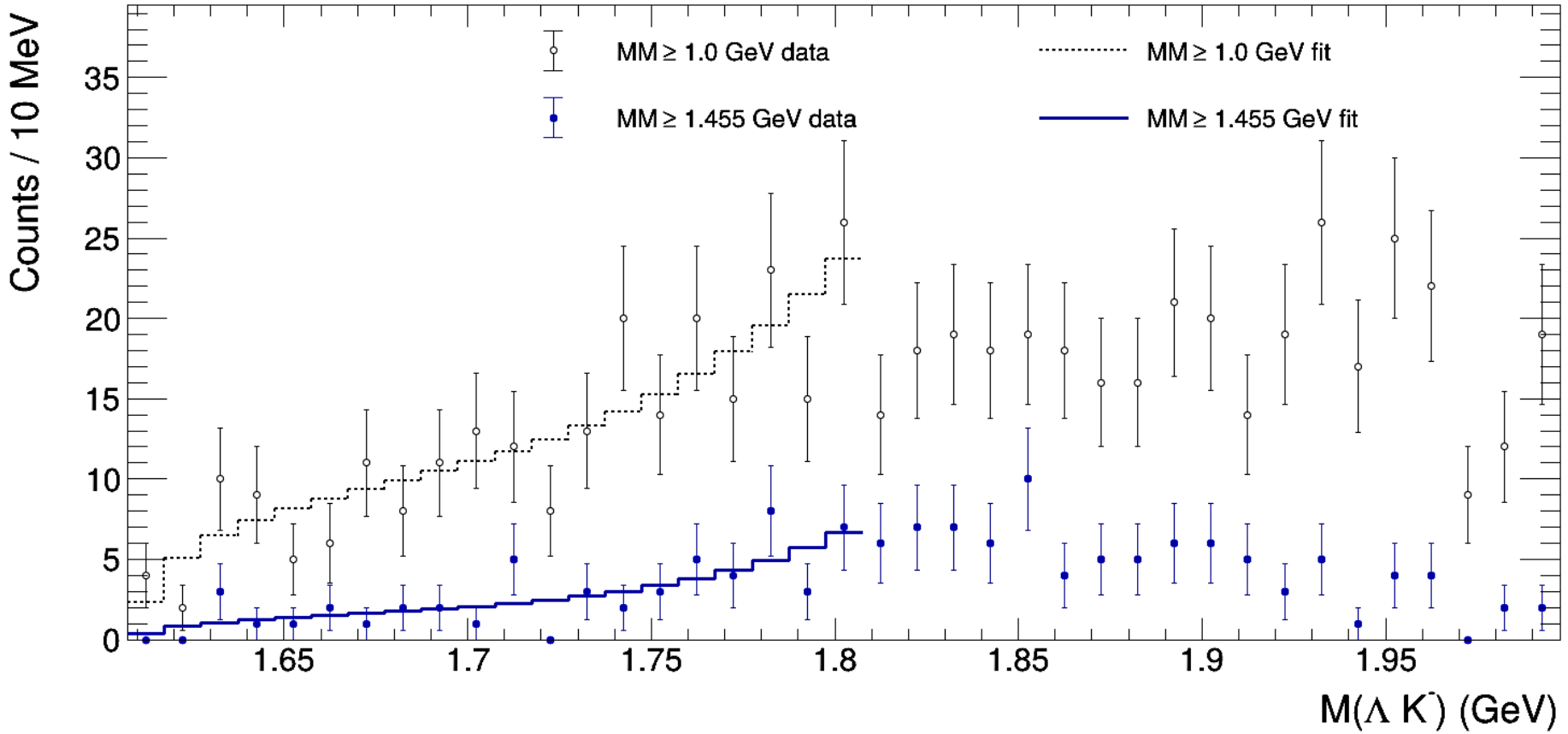
RGK 403

Negative missing-mass squared entries omitted: 11 RGA and 126 RGK.

100 MeV/c² bins. Unit-area normalization over 0–3 GeV/c² compares the recoil shapes.

RGK ΛK^- invariant mass for loose & tight recoil cuts

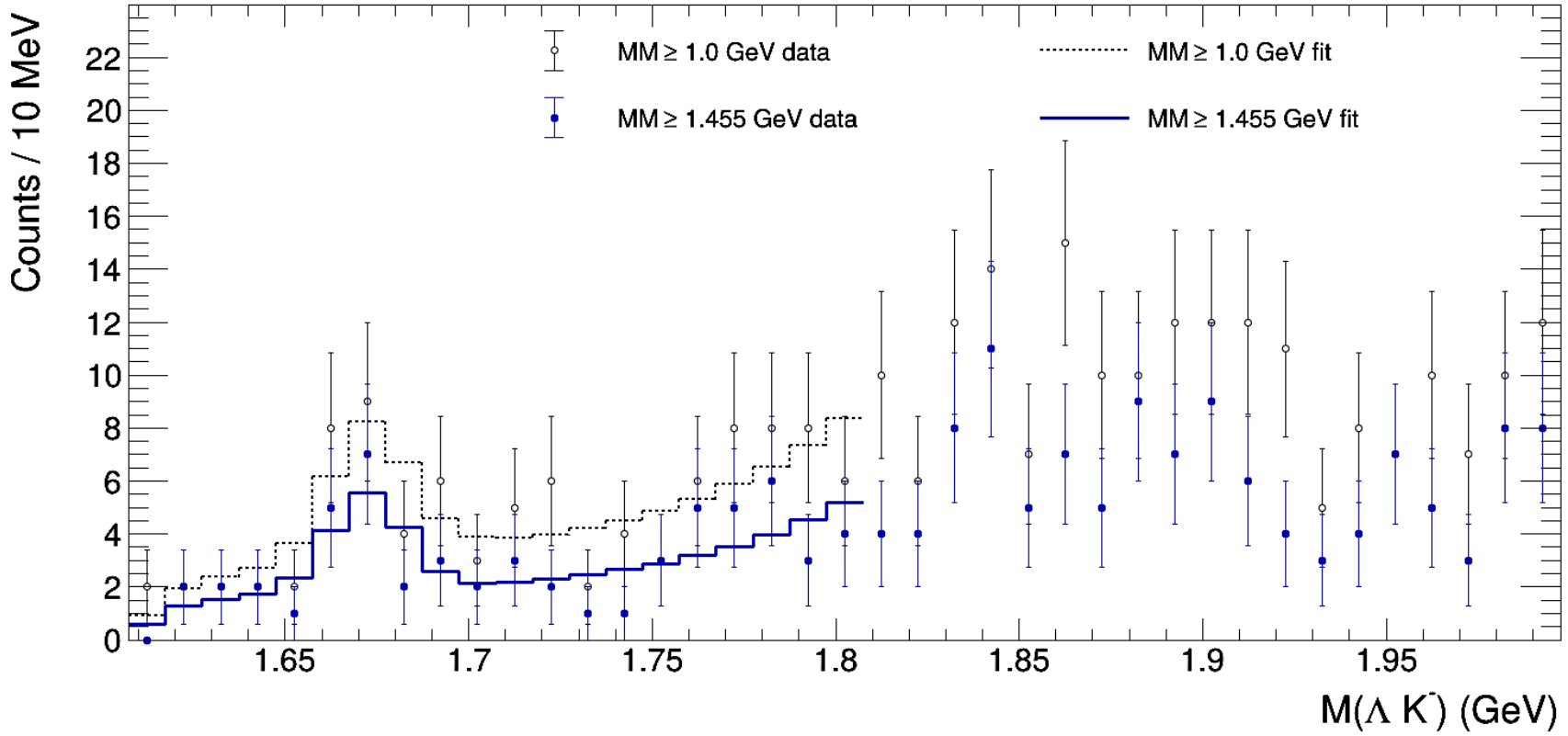
Measured Λ four-momentum with the K^- propagated to the Λ line



The obtained RGK spectra show no clear Ω peak under either recoil selection.

RGA ΛK^- invariant mass for loose & tight recoil cuts

Measured Λ four-momentum with the K^- propagated to the Λ line



MM ≥ 1.000 GeV/c^2

$N_\Omega = 12.8^{+6.4}_{-5.8}$, $N_{1690} = 2.1^{+9.9}_{-2.1}$

MM ≥ 1.455 GeV/c^2

$N_\Omega = 9.6^{+4.8}_{-4.3}$, $N_{1690} = 0$ at the fit boundary

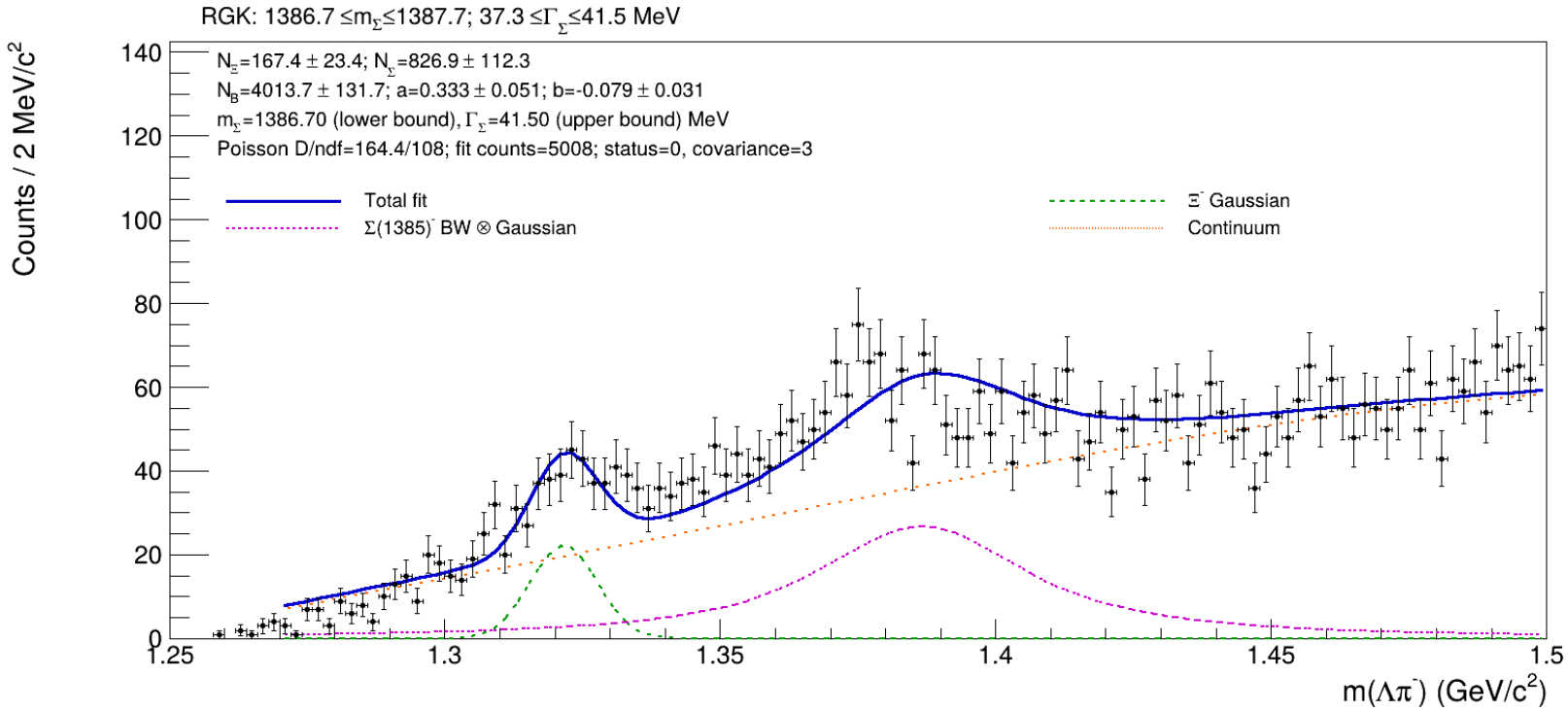
Ξ^- reconstruction as a cross-check

The $\Xi^- \rightarrow \Lambda\pi^-$ decay (seen in electroproduction with CLAS12 using missing mass technique) has the same cascade topology as $\Omega^- \rightarrow \Lambda K^-$.

A clear Ξ^- peak observation checks that the method can reconstruct a displaced Λ, combine it with a bachelor track, and obtain the Ξ^- at the correct mass.

RGK Λπ⁻ spectrum with an FD bachelor pion

The fit includes Ξ⁻, Σ(1385)⁻ hypotheses and a continuum.



FD Λ daughters, electron trigger. $|m(p\pi^-) - m_{\Lambda,\mathrm{PDG}}| \leq 7\,\mathrm{MeV}/c^2$ $\mathrm{DOCA}(p,\pi^-) \leq 5\,\mathrm{cm}$ $-1 \leq \cos\delta \leq 1$

Λ relative to e⁻: $\Delta r_T \geq 0.1\,\mathrm{cm}$, $\Delta z_\Lambda \geq 1\,\mathrm{cm}$, $L_\Lambda \geq 0.1\,\mathrm{cm}$. Λ four-momentum is measured, with no momentum cut.

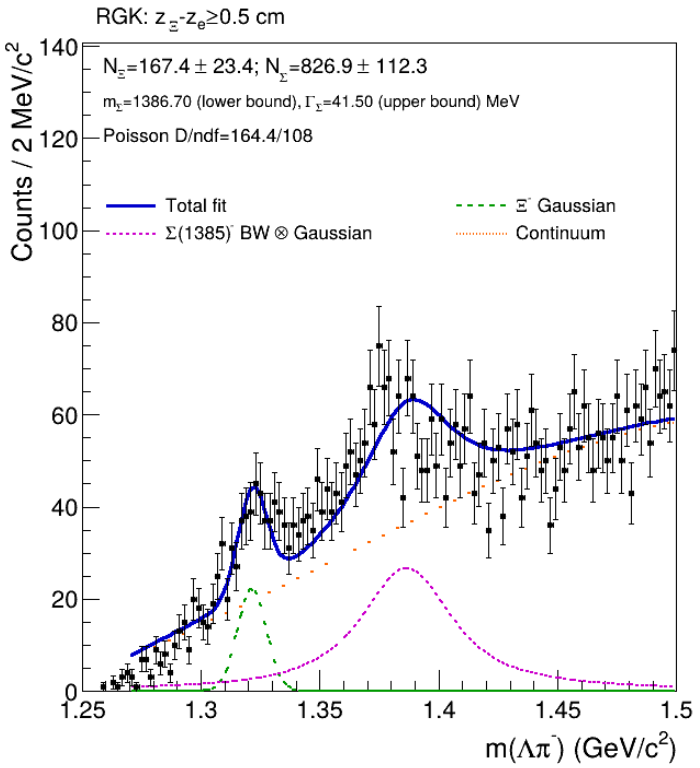
FD bachelor: $p_\pi \geq 0.300\,\mathrm{GeV}/c$, $|\chi_{\mathrm{PID}}| \leq 10$, $\mathrm{DOCA}(\pi,\Lambda) \leq 0.5\,\mathrm{cm}$ $\Delta z_\Xi = z_\Xi - z_e \geq 0.5\,\mathrm{cm}$ $\mathrm{MM}(e'\Lambda\pi^-) \geq 0.957354\,\mathrm{GeV}/c^2$

Fixed Ξ⁻ parameters: $m_\Xi = 1321.71\,\mathrm{MeV}/c^2$, $\sigma = 6\,\mathrm{MeV}/c^2$ Allowed Σ(1385)⁻ range: $m_\Sigma \in [1386.7,1387.7]\,\mathrm{MeV}/c^2$, $\Gamma_\Sigma \in [37.3,41.5]\,\mathrm{MeV}$

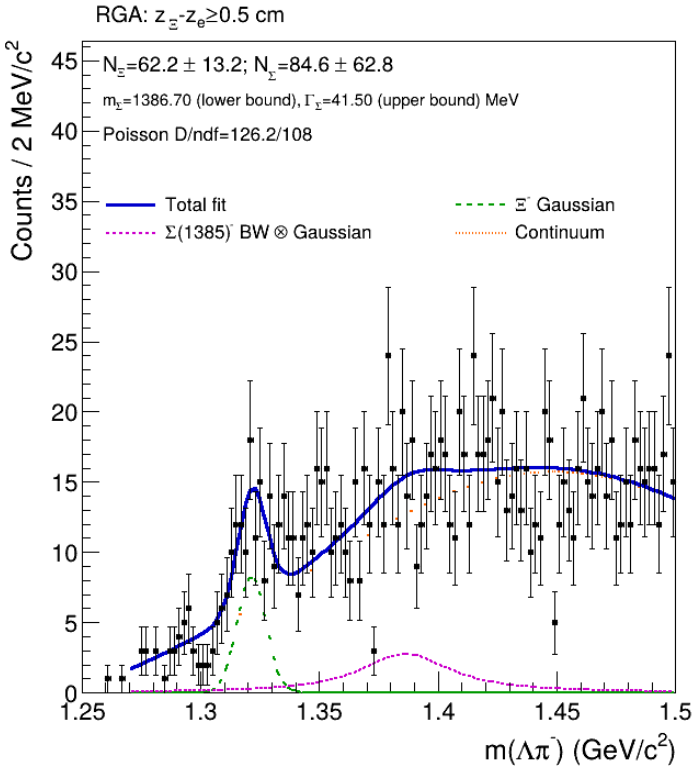
Ξ^- reconstruction in RGK and RGA

Forward bachelor π^- and a common Λ selection

RGK Spring 2024



RGA Fall 2018



Vertex selection

$$\Delta z_\Xi = z_\Xi - z_e \geq 0.5\,\mathrm{cm}$$

The Λ must be downstream of the Ξ vertex.

$$(\vec{v}_\Lambda - \vec{v}_\Xi) \cdot \hat{p}_\Lambda > 0$$

$$\mathrm{MM}(e'\Lambda\pi^-) \geq 0.957354\,\mathrm{GeV}/c^2$$

Fit requirements

$m_\Xi = 1321.71\,\mathrm{MeV}/c^2$ and $\sigma = 6\,\mathrm{MeV}/c^2$ fixed.

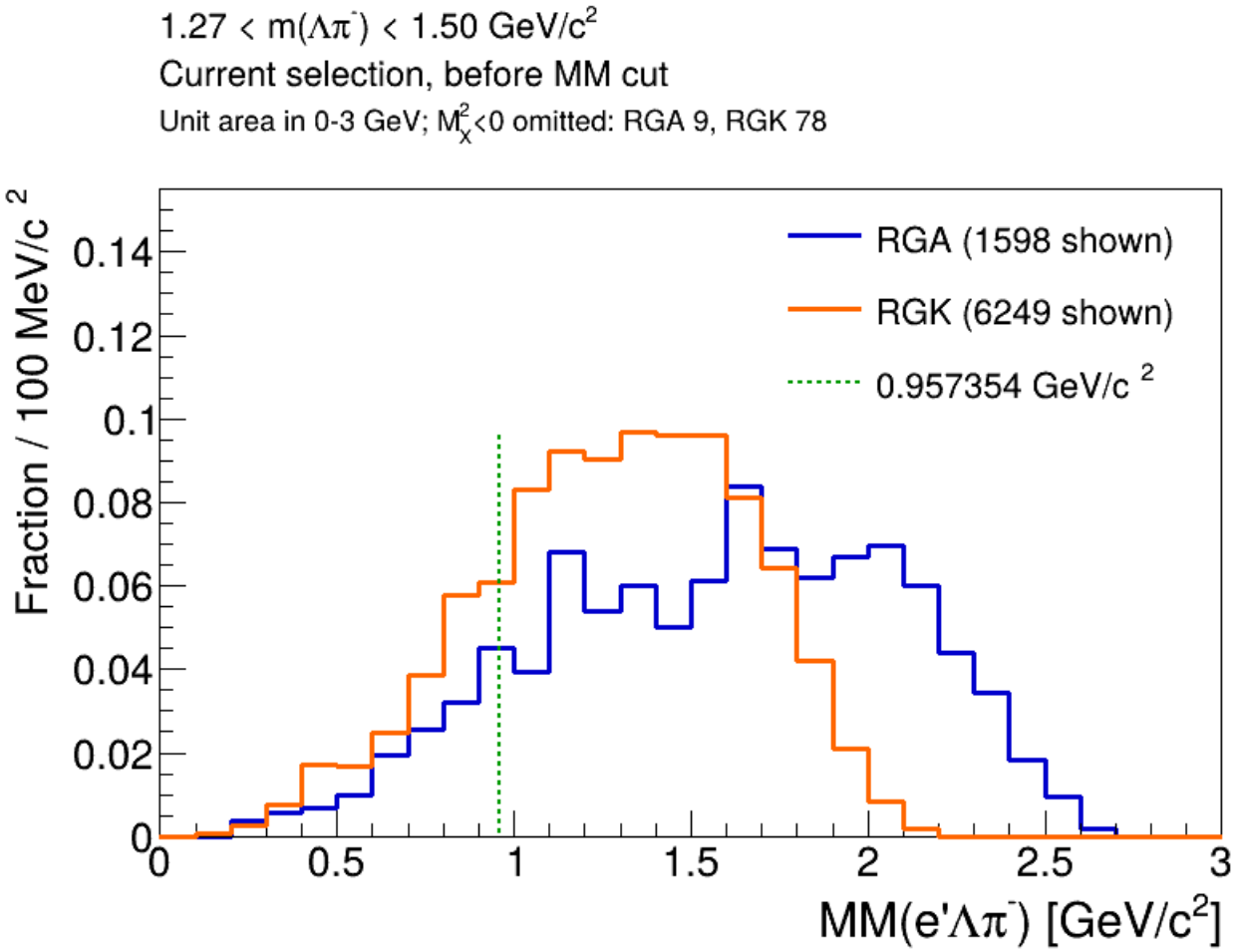
Broad component: $\Sigma(1385)^-$ hypothesis.

Mass range 1386.7–1387.7 MeV/c².

Natural width range 37.3–41.5 MeV.

Missing mass for the Ξ^- selection

RGA and RGK with the same cuts before the recoil requirement



$\Lambda\pi^-$ mass window

$$1.27 < m(\Lambda\pi^-) < 1.50\ \mathrm{GeV}/c^2$$

Recoil threshold

$$\mathrm{MM}(e'\Lambda\pi^-) \geq 0.957354\ \mathrm{GeV}/c^2$$

The cut is 30 MeV/c² below the K^+K^+ mass threshold.

100 MeV/c² bins. Histograms have unit area over 0–3 GeV/c² range

Large fraction of events retained by MM cut for both RGA and RGK

Event generation and detector simulation

Generate Ω^- and $\Xi(1690)^-$ separately to compare acceptance, mass migration and vertex response.

Stage	Implementation
Associated channels	$ep \to e'K^+K^+K^0\Omega^-, \quad \Omega^- \to \Lambda K^-$ $ep \to e'K^+K^+\Xi(1690)^-, \quad \Xi(1690)^- \to \Lambda K^-$ $\Lambda \to p\pi^-$
elSpectro generators	VeryStrange_KpKpK0Omega_LambdaKm.C VeryStrange_KpKpXi1690_LambdaKm.C
Production model	Associated kaons production follow phase space.
Decays	Generate displaced Ω^- and Λ vertices based on their lifetimes and treat $\Xi(1690)^-$ as prompt. Vary the angular hypotheses.
Detector response	Run GEMC and reconstruction using each dataset's beam energy, field polarity and detector conditions.

Ω^- decay angular distribution

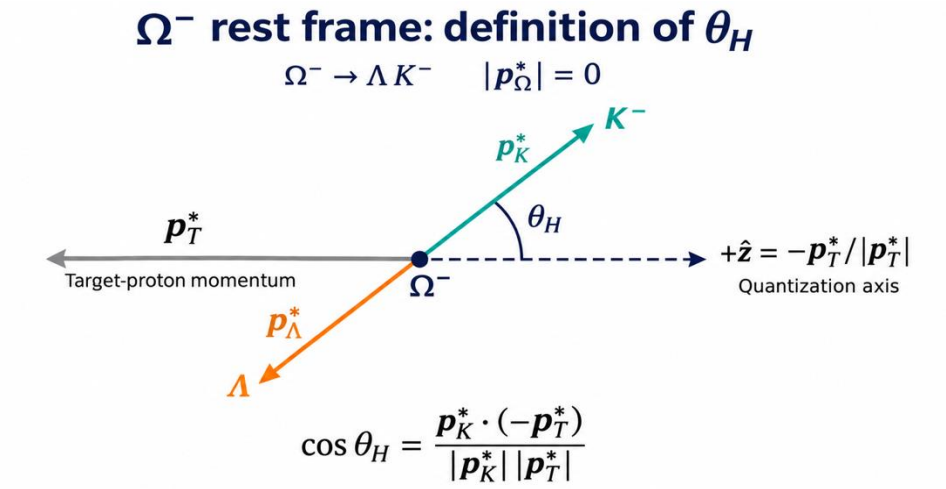
Spin-3/2 parent decaying to ΛK^- in the CLAS quantization-axis convention

Angle and reference frame

$$P_\Omega = P_\Lambda + P_{K^-}$$

$$\hat{z} = -\frac{\vec{p}^{\,*}(T)}{|\vec{p}^{\,*}(T)|}$$

$$c \equiv \cos\theta_H = \hat{p}^{\,*}(K^-) \cdot \hat{z}$$



Spin-projection mixture

$$w(c;f) = \frac{1}{N_\Omega}\frac{dN_\Omega}{dc}, c = \cos\theta_H,$$

$$\int_{-1}^{1} w(c;f)\,dc = 1, 0 \le f \le 1.$$

$$w(c;f) = \frac{f}{4}(1+3c^2) + \frac{3(1-f)}{4}(1-c^2)$$

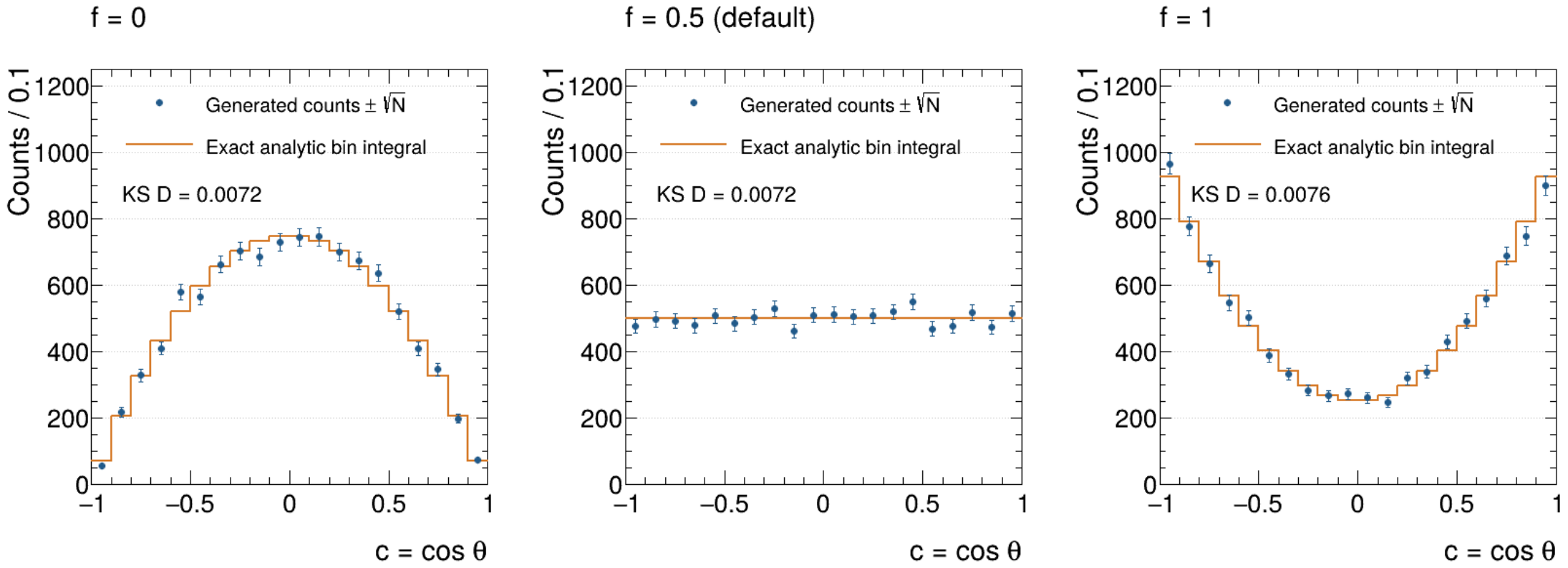
f is the combined $m = \pm\frac{1}{2}$ population. The remainder occupies $m = \pm\frac{3}{2}$.

The model assumes equal opposite-spin populations and integrates over decay azimuth. It is flat at $f = \frac{1}{2}$.

Derivation note

Ω spin-projection mixture in the generator

The kaon angle is measured relative to the negative target direction in the Ω rest frame.

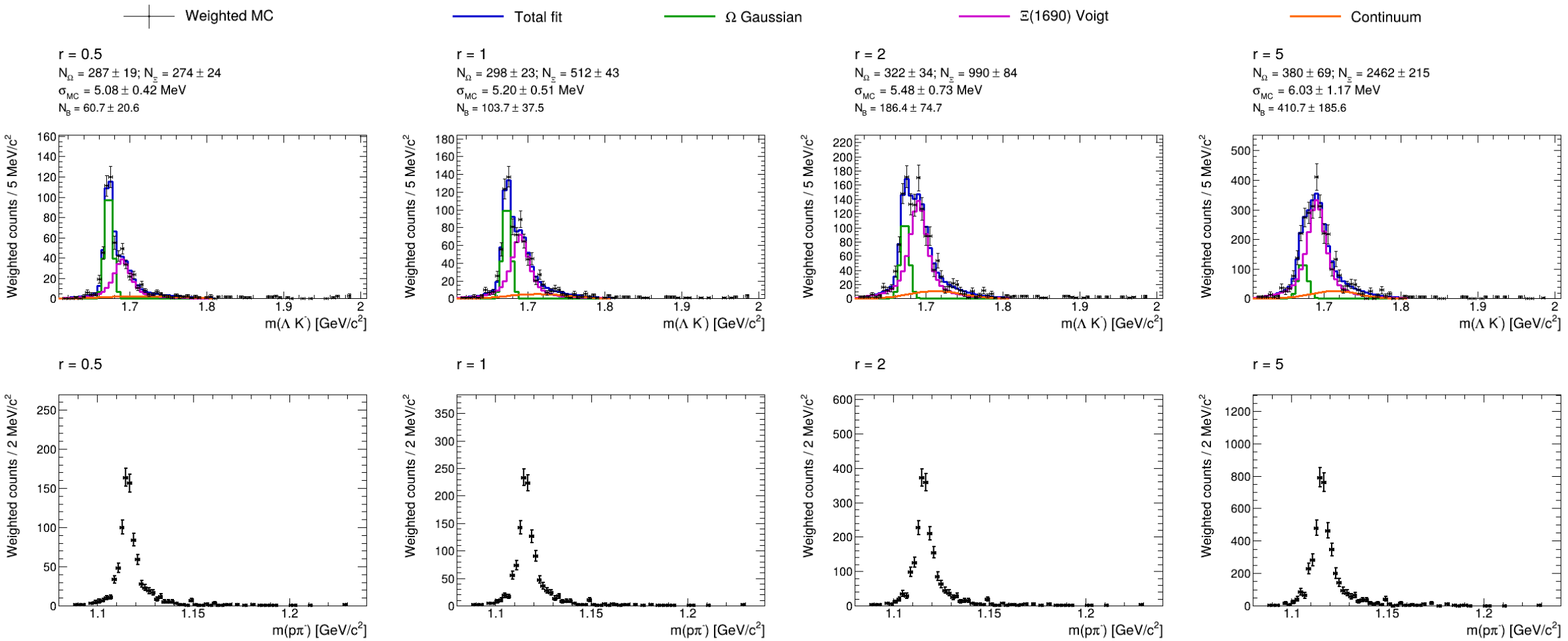


$c = \cos\theta_H, \quad f \in \{0, 0.5, 1\}$ in the three generated samples. The curves are analytic generation inputs.

Reconstruct each hypothesis to test acceptance in the decay angle and the production-plane angles.

Reconstructed Ω^- and $\Xi(1690)$ MC

Generated events: Ω 285,000; Ξ 290,000. Nominal RGA analysis selection.



Assumed generated Ξ/Ω ratios: r = 0.5, 1, 2, 5. Ξ event weight = r × 285,000/290,000.

Additional crosschecks

Datasets

RGA

Fall-2018, Spring-2019 inbending
Spring-2018 →large dataset, preliminary studies show acceptable Λ S/B and resolution

RGC

≈10.5 GeV; NH_3
Use NH_3 data which contains free hydrogen.

RGB

Revisit cuts from previous exploration (not seen).

Alternate analysis method

Missing mass technique

2-kaon train used for Ξ^- resonance analyses and study the recoil against $K^+K^+K^0$;
reconstruct $K_S^0 \rightarrow \pi^+\pi^-$ (displaced vertex analysis method)

Detector MC and systematic studies

For a cross section or an upper limit

Separate signal samples

Generate Ω^- and $\Xi(1690)^-$ with elSpectro. Apply GEMC, reconstruction and the same Λ selection as in data.

Mass and background response

Test pion–kaon misidentification, Λ sidebands and vertex dependence. Vary the resolution and continuum shapes.

Angular acceptance and low counts

Vary spin populations and production kinematics. Use low-count pseudoexperiments to test fit bias and interval coverage.

Final measurement

Use luminosity, efficiency and branching fractions to report a cross section or a 95% upper limit.

Conclusions

RGA Fall 2018 Outbending	The fit with background parametrization and using the sideband-subtraction method return about 13–14 counts. The yield depends on the fit, the potentially overlapping Ξ(1690) and the background model. *Plan: rerun samples with new Lambda train, also re-analyze Fall-2018-Inbending and Spring-2019 datasets*
RGK Spring 2024	The 8.477 GeV RGK sample does not populate the Ω-compatible recoil-mass region sufficiently to reveal an Ω^- peak.
Ξ^- control and next tests	The Ξ^- signal tests sequential decays reconstruction. RGA Spring 2018 and reconstructed detector MC will test the Ω interpretation and estimate efficiency.

Backup slides

Associated-production thresholds

Electromagnetic production on a proton conserves charge, baryon number and strangeness

Produced hyperon	Lightest recoil X	M(X), minimum	W threshold
$\Xi^-(1321)$	K^+K^+	0.9874 GeV	2.3091 GeV
$\Xi(1690)^-$	K^+K^+	0.9874 GeV	2.6774 GeV
Ω^-	$K^+K^+K^0$	1.4850 GeV	3.1574 GeV

$ep \rightarrow e' H^- X$ **$W^2 = m_p^2 + 2m_p(E - E') - Q^2$**

H^-: produced hyperon. X: associated hadrons. W: total hadronic invariant mass.
E and E′: incident and scattered electron energies. m_p: proton mass. $Q^2 = -q^2$.
$q = k - k'$: virtual-photon four-momentum; k and k′: electron four-momenta.

Absolute W ceilings: 4.097 GeV at 8.477 GeV and 4.558 GeV at 10.604 GeV.
These limits assume $E' \rightarrow 0$ and $Q^2 \rightarrow 0$. Electron selection reduces the accessible range.

Mass-fit model

$$v_i = N_\Omega G_i + N_{1690} V_i + N_B C_i$$

v_i: expected count in bin i. N_Ω, N_{1690} and N_B: fitted yields within the fit interval.
G_i, V_i and C_i: normalized bin integrals of the Ω, Ξ(1690) and continuum shapes.

Ω: Gaussian, m = 1672.45 MeV/c². Ξ(1690): Voigt, m = 1690 MeV/c², Γ = 20 MeV.
Shared Gaussian σ = 10 MeV/c², with 8 and 12 MeV/c² model checks.
10 MeV/c² bins. Fit interval 1.60745–1.80745 GeV/c².

$$D = 2 \Sigma_i [v_i - n_i + n_i \ln(n_i / v_i)]$$

n_i: observed bin count. D: binned Poisson likelihood-ratio statistic.
For $n_i = 0$ the logarithmic term is zero. ndf: fitted bins minus free parameters.

D approaches a χ^2 distribution only under large-sample conditions.

Λ-sideband normalization and subtraction

Measured Λ four-momentum with the MM(e′ΛK⁻) > 1.0 GeV/c² selection

Signal: $m_{\Lambda,PDG}$ ± 7 MeV/c²
Sidebands: 1.080–1.094 and 1.145–1.159 GeV/c²

$$\alpha = \left[\int_{signal} B_\Lambda(M)\, dM\right] / \left[\int_{low} B_\Lambda(M)\, dM + \int_{high} B_\Lambda(M)\, dM\right]$$

M = m(pπ⁻). $B_\Lambda(M)$: fitted Λ-mass continuum density.
Recorded normalization: α = 0.756 ± 0.086.

$$d_i = n_i - \alpha h_i \qquad \chi^2 = (d-\mu)^T V^{-1} (d-\mu)$$

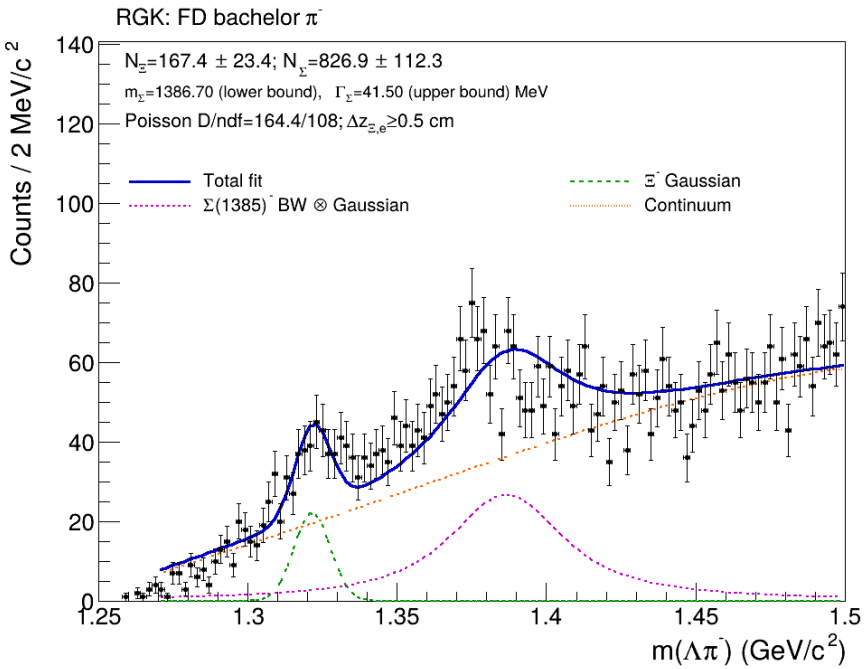
n_i: ΛK⁻ count from the Λ signal window. h_i: fitted summed-sideband count.
d_i: subtracted count. μ_i: expected residual count. V: covariance of the subtracted bins.

The scale factor assumes the sidebands describe the combinatorial ΛK⁻ background under the Λ peak after identical cuts.

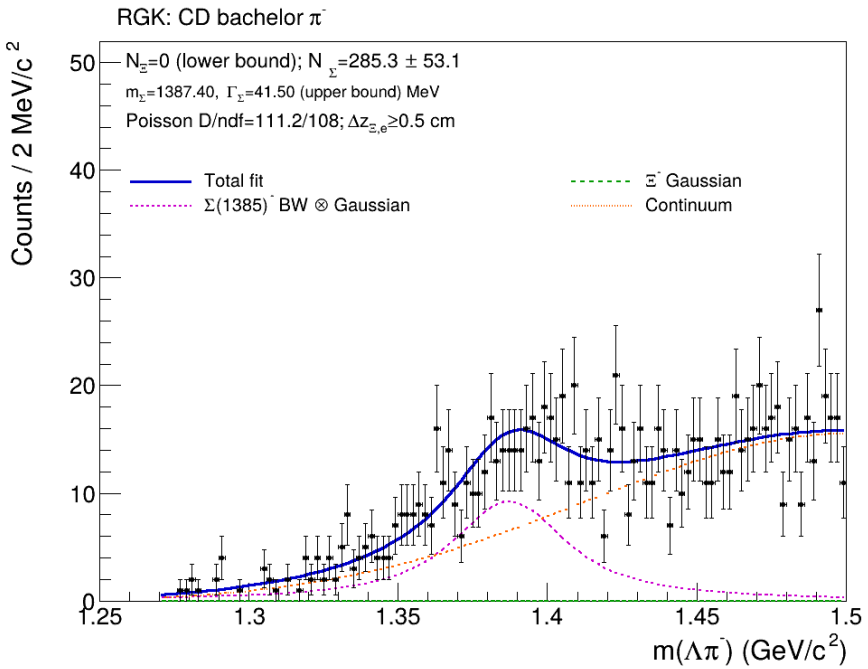
RGK forward and central bachelor pions

The proton and pion from Λ decay remain in the forward detector for both samples.

Forward detector (FD)



Central detector (CD)



Common Λ selection: $|m(p\pi^-) - m_{\Lambda,\mathrm{PDG}}| \leq 7\,\mathrm{MeV}/c^2 \quad \mathrm{DOCA}(p,\pi^-) \leq 5\,\mathrm{cm} \quad -1 \leq \cos\delta \leq 1$

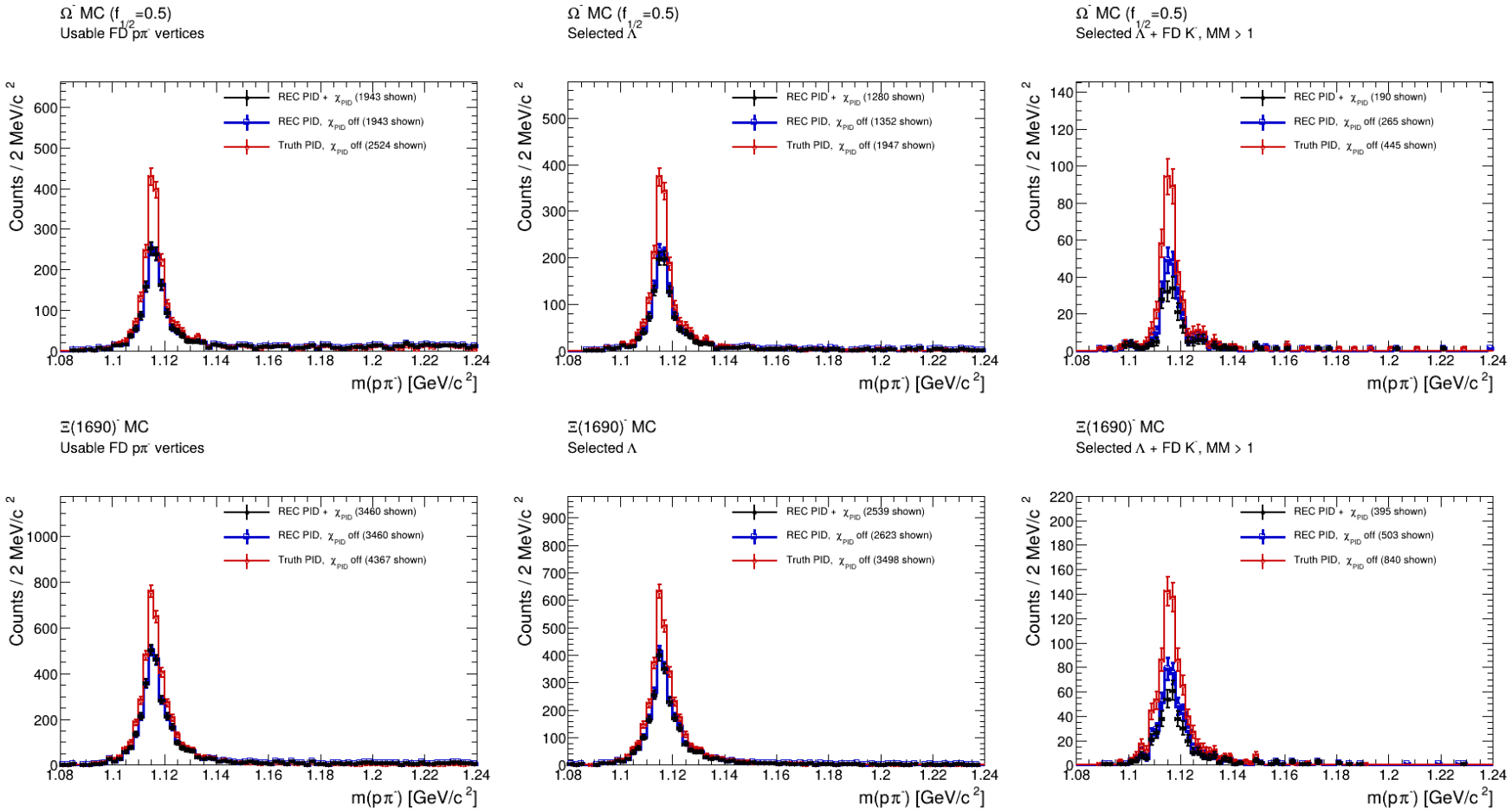
Electron trigger. $\Delta r_T \geq 0.1\,\mathrm{cm}, \quad \Delta z_\Lambda \geq 1\,\mathrm{cm}, \quad L_\Lambda \geq 0.1\,\mathrm{cm}$. No Λ momentum cut or mass constraint.

Bachelor: $p_\pi \geq 0.300\,\mathrm{GeV}/c, \quad |\chi_{\mathrm{PID}}| \leq 10, \quad \mathrm{DOCA}(\pi,\Lambda) \leq 0.5\,\mathrm{cm} \quad \Delta z_\Xi = z_\Xi - z_e \geq 0.5\,\mathrm{cm} \quad \mathrm{MM}(e'\Lambda\pi^-) \geq 0.957354\,\mathrm{GeV}/c^2$

Fit hypothesis: $m_\Sigma \in [1386.7, 1387.7]\,\mathrm{MeV}/c^2, \quad \Gamma_\Sigma \in [37.3, 41.5]\,\mathrm{MeV} \quad \sigma = 6\,\mathrm{MeV}/c^2$. 2 MeV/c² bins, 1.270–1.500 GeV/c².

MC Λ spectra and PID selection

Ω sample (top) and Ξ(1690) sample (bottom)



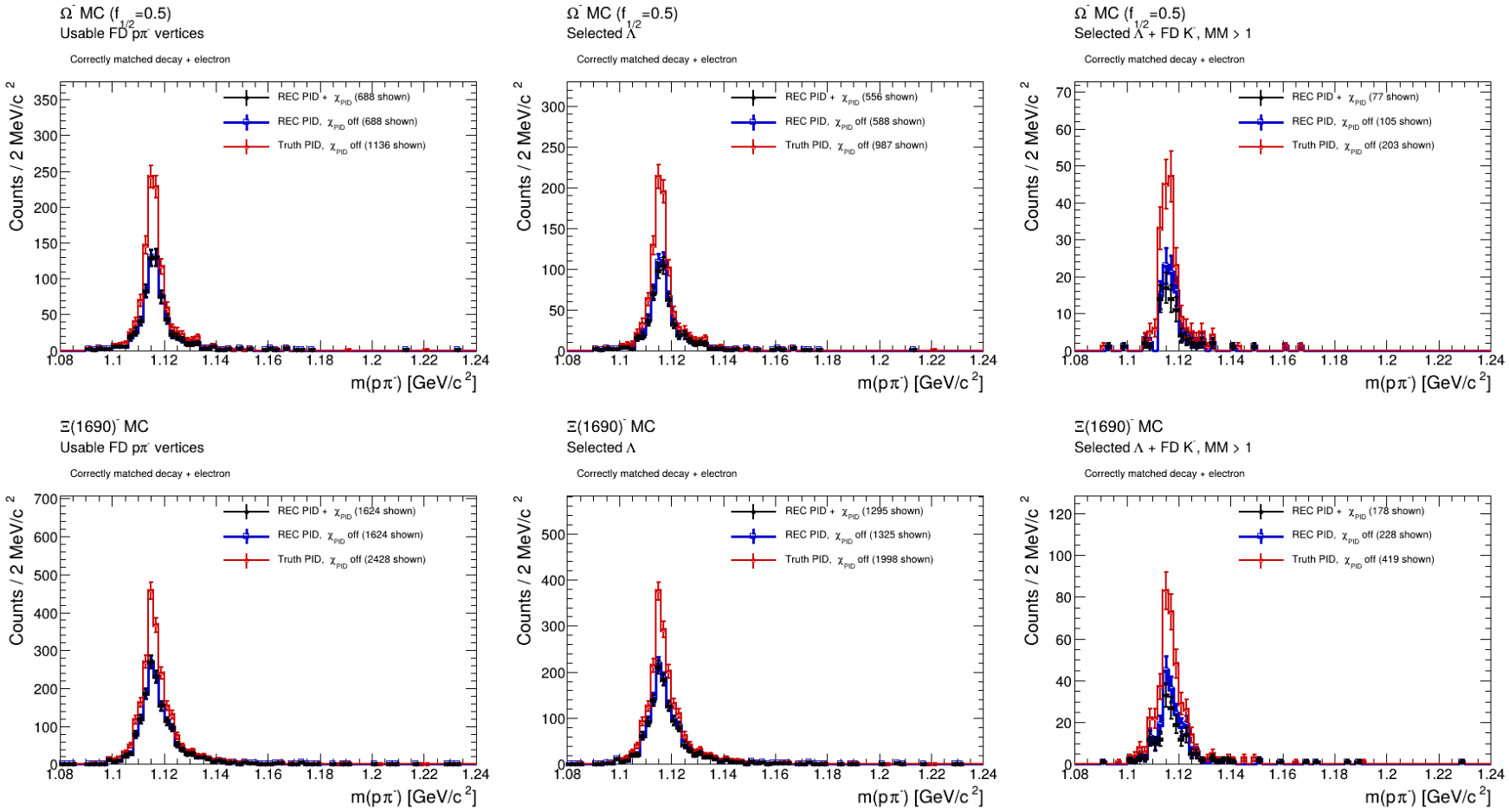
Selected Λ: FD e,p,π; DOCA(p,π)<5 cm; -1≤cosδ≤1; $\Delta r_{T,\Lambda} \geq 0.1$, $\Delta z_{\Lambda} \geq 1$, $L_{\Lambda} \geq 0.1$ cm.

Selected Λ + K⁻: FD K⁻, valid FTOF; DOCA(K,Λ)≤3 cm; downstream Λ; MM(e'Λ K⁻)>1 GeV. No Λ mass-window cut.

black uses the reconstructed PID and nominal χ_{PID} cuts;
blue keeps the reconstructed PID but removes χ_{PID} cuts;
red assigns the generated PID to reliably matched reconstructed tracks, with χ_{PID} cuts off.

MC Λ spectra matched to generated daughters

Same PID comparisons, requiring reciprocal generated-track matches

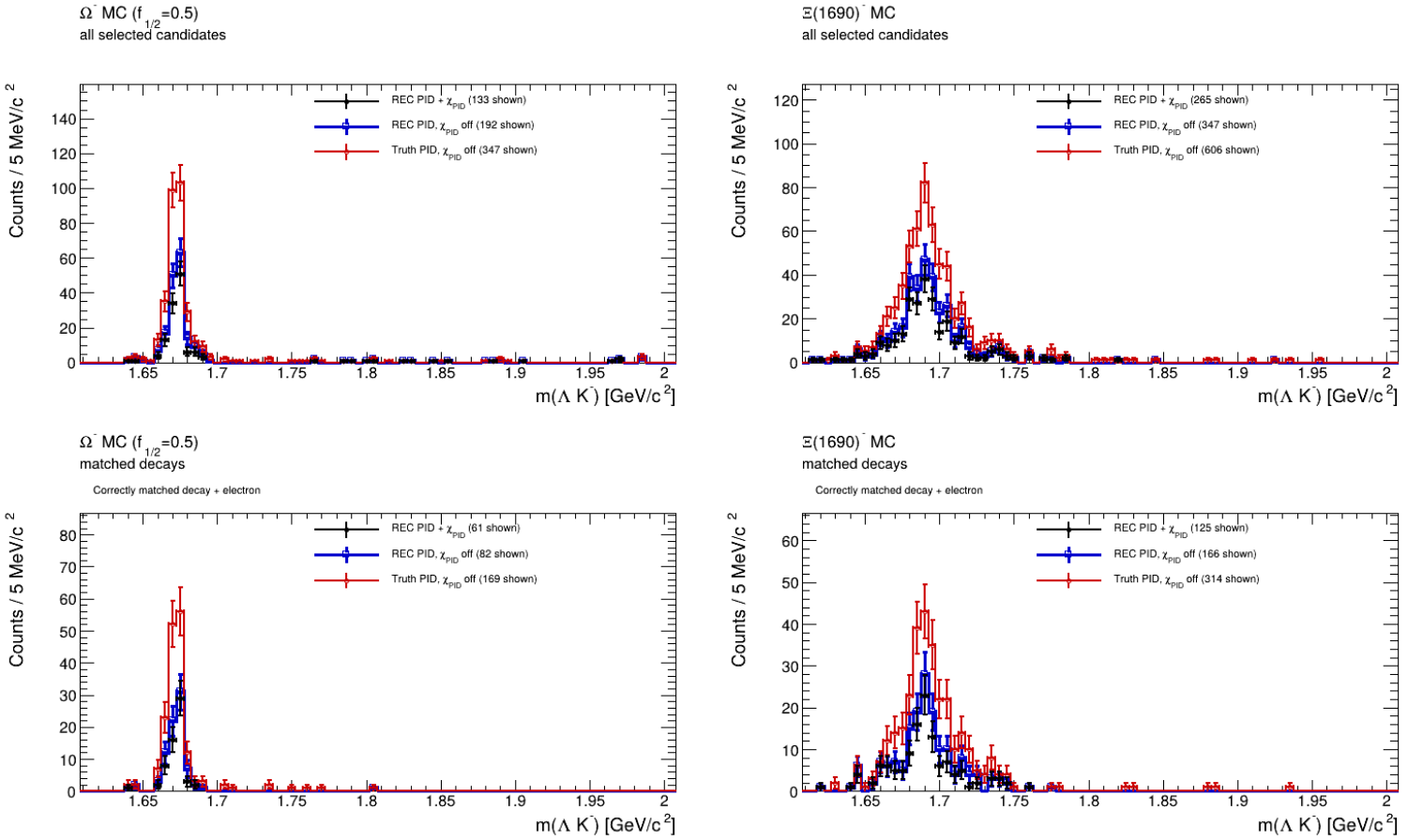


Selected Λ: FD e,p,π; DOCA(p,π)<5 cm; $-1 \le \cos\delta \le 1$; $\Delta r_{T,\Lambda} \ge 0.1$, $\Delta z_{\Lambda} \ge 1$, $L_{\Lambda} \ge 0.1$ cm.

Selected Λ + K^-: FD K^-, valid FTOF; DOCA(K,Λ)≤3 cm; downstream Λ; MM(e'Λ K^-)>1 GeV. No Λ mass-window cut.

MC ΛK⁻ spectra and PID selection

All selected combinations (top), matched generated decays (bottom)



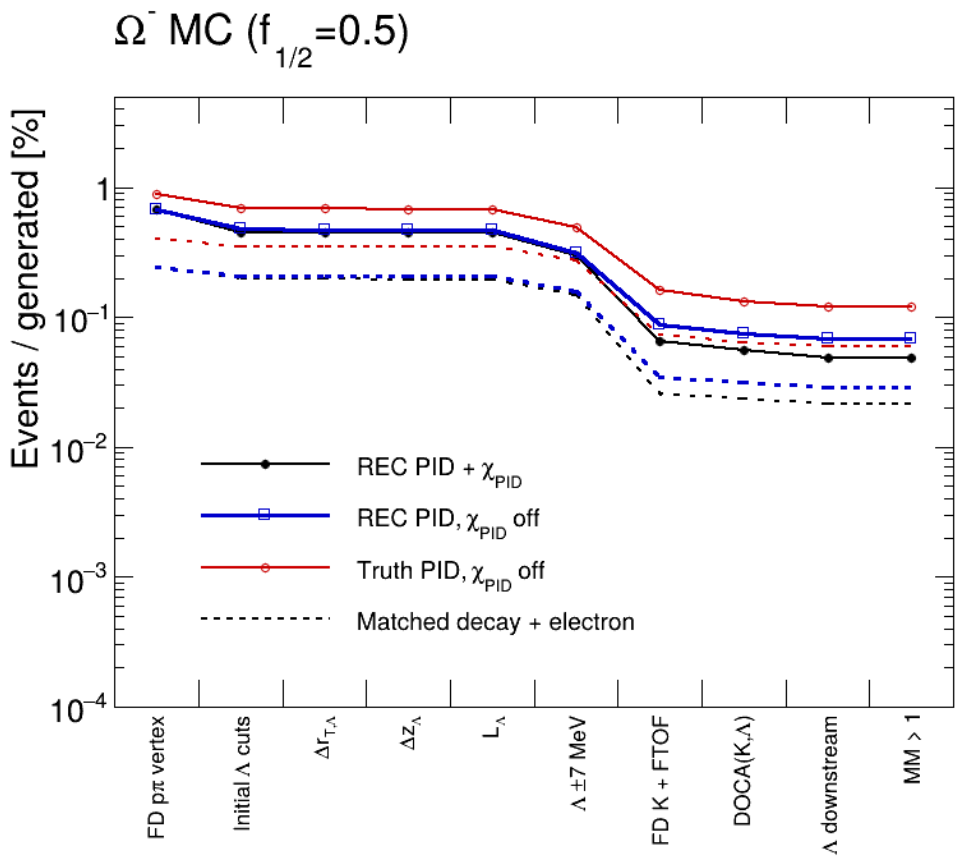
FD e,p,π,K; $|m(p\pi)-m_{\Lambda,PDG}|\leq 7$ MeV; DOCA(K,Λ)≤3 cm; downstream Λ; MM(e'Λ K⁻)>1 GeV.

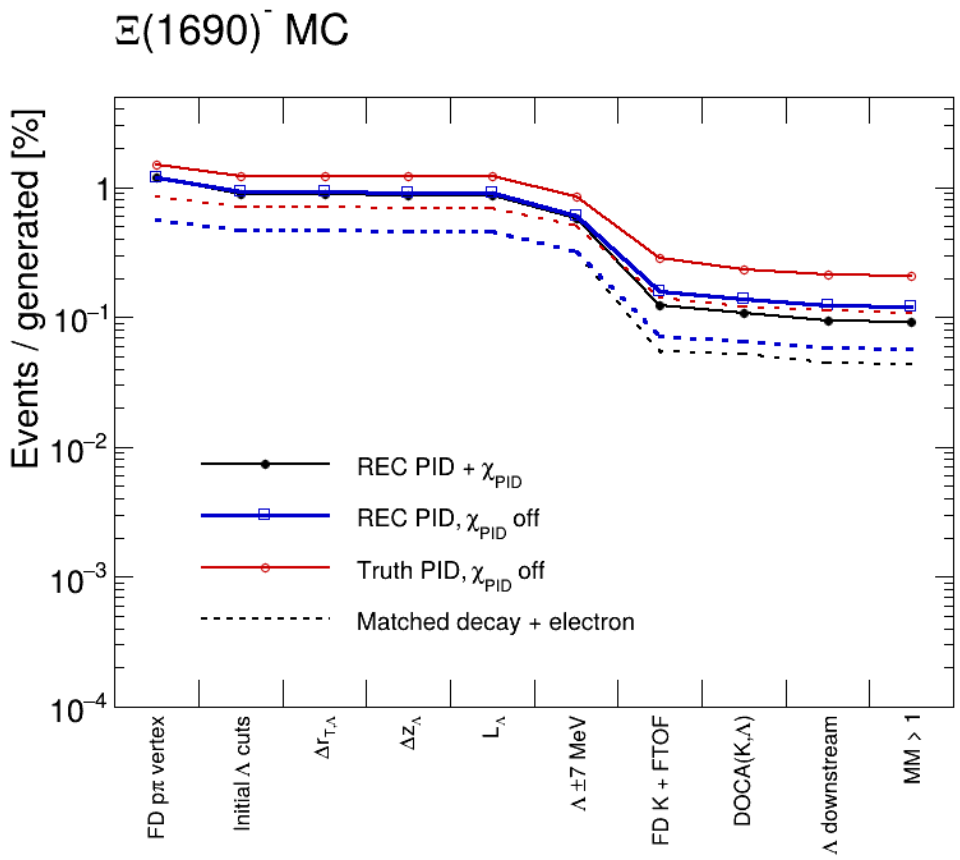
Λ-electron $\Delta r_T \geq 0.1$ cm, $\Delta z \geq 1$ cm, L≥0.1 cm; DOCA(p,π)<5 cm; $-1 \leq \cos\delta \leq 1$. No Ω displacement or Λ/K momentum cut.

m(Λ K⁻): measured Λ + field-map-propagated K⁻.

MC efficiency through the RGA selection

Cumulative event efficiency relative to the generated samples





MC selection efficiency

Truth-reassigned PID, χPID cuts off. Cumulative matched events and efficiency.

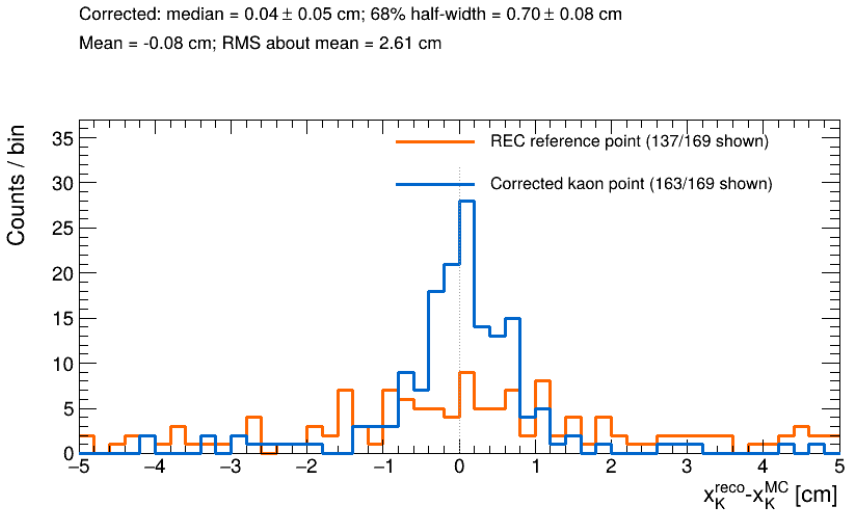
Cumulative selection	Ω events	Ω (%)	Ξ events	Ξ (%)
FD e^-, p, π^- and reconstructed pπ vertex	1,136	0.39860	2,428	0.83724
pπ DOCA < 5 cm, physical cos δ, $\Delta z\Lambda \geq 0$	999	0.35053	2,036	0.70207
Λ transverse displacement ≥ 0.1 cm	996	0.34947	2,034	0.70138
Λ longitudinal displacement ≥ 1 cm	987	0.34632	1,998	0.68897
Λ displacement along its momentum ≥ 0.1 cm	987	0.34632	1,998	0.68897
m($p\pi^-$) within ±7 MeV of PDG Λ mass	781	0.27404	1,446	0.49862
FD K^- and valid FTOF response	210	0.07368	407	0.14034
K^-–Λ DOCA ≤ 3 cm	180	0.06316	348	0.12000
Λ downstream of the Ω vertex	169	0.05930	322	0.11103
MM(e′ΛK^-) > 1 GeV	169	0.05930	314	0.10828

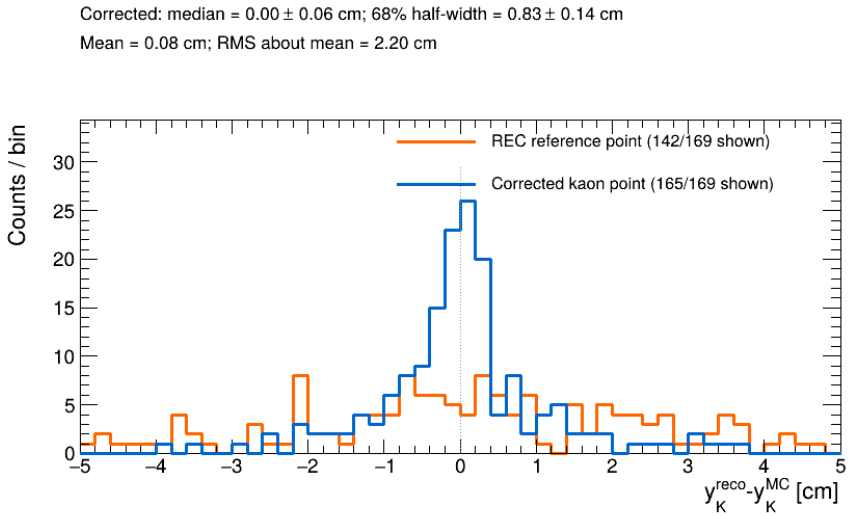
Final matched efficiency for each PID selection

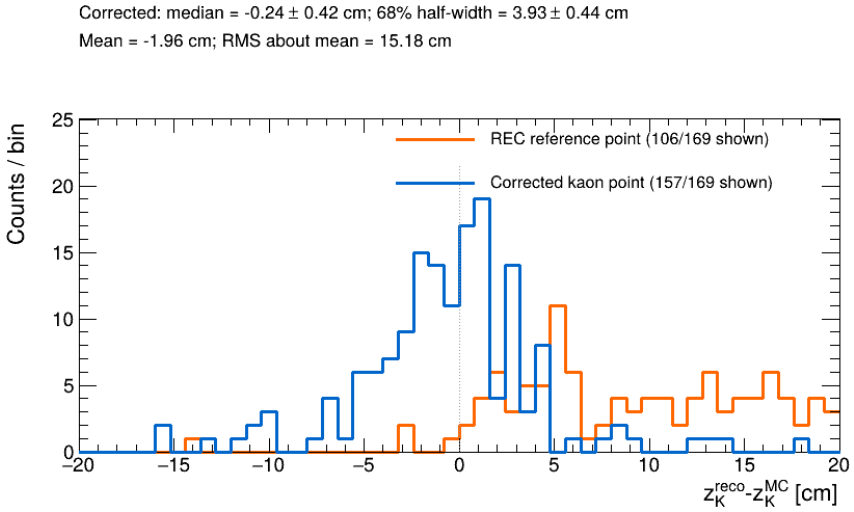
PID selection	Ω events	Ω (%)	Ξ events	Ξ (%)
Original PID, nominal χPID cuts	61	0.02140	125	0.04310
Original PID, χPID cuts off	82	0.02877	166	0.05724
Truth-reassigned PID, χPID cuts off	169	0.05930	314	0.10828

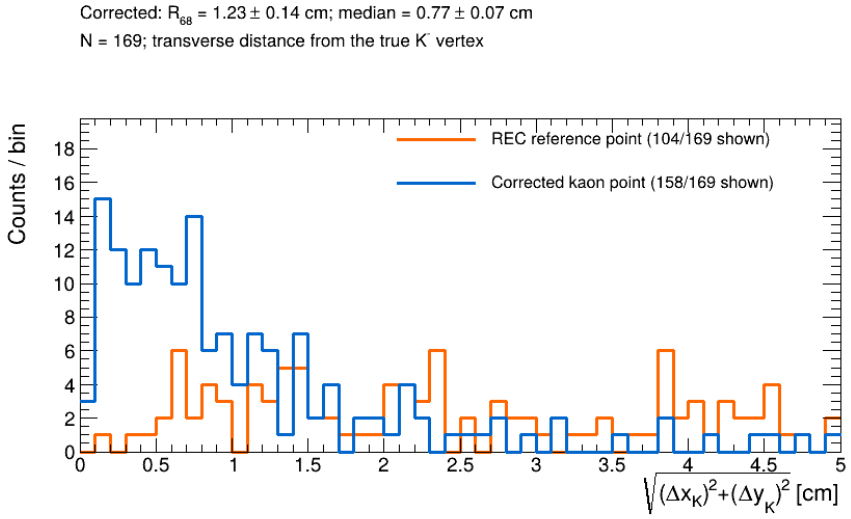
Generated events: Ω 285,000; Ξ 290,000. Efficiencies include the matching requirement and exclude branching fractions.

$\Omega^- \rightarrow \Lambda K^-$ corrected kaon vertex residuals









Nominal RGA selection; FD p, π^-, K^-; truth PID, χ_{PID} off; 169 matched decays; MM(e' ΛK^-) > 1 GeV/c^2.