Status of $\gamma p \rightarrow K^+\Sigma^0$ *analysis of G11A – Differential Cross Sections, Recoil Polarizations and some Physics*

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Outline

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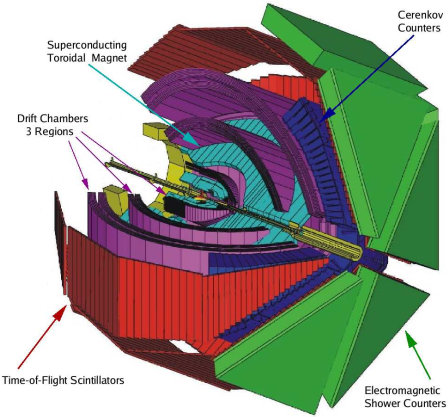
1. Introduction and Event Selection
2. Differential Cross Sections
3. Recoil Polarization
4. Physics
5. Summary

Introduction



Cebaf Large Angle Spectrometer

- G11A dataset – unpolarized photoproduction
- 20 billion event triggers recorded by CLAS (May-July 2004)
- Liquid Hydrogen cryotarget – 40 cm long, 2 cm radius
- 6 azimuthal "sectors" in CLAS – *at least* two "sector-based" charged tracks in Start Counter for triggering
- CM energy 1.55 GeV to 2.84 GeV – baryon spectroscopy for "missing" baryon resonances (amongst other physics goals)
- CMU PWA group is analysing $\gamma p \rightarrow K^+\Sigma^0$, $K^+\Lambda$, $p\omega$, $p\eta$, $p\eta'$, ...

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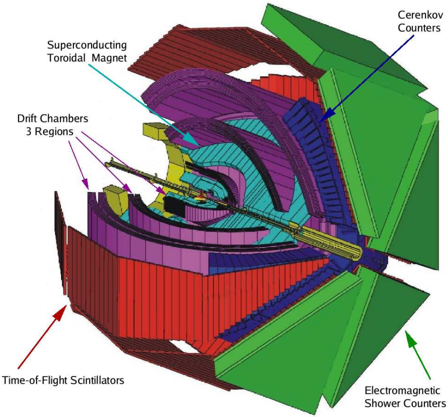

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Event Selection – 2- and 3-track "topologies"

Utilize the decay $\Sigma^0 \rightarrow \gamma\Lambda \rightarrow \gamma p\pi^-$

3-track: $\gamma p \rightarrow K^+ p\pi^- \, (\gamma_f)$

- Demand "+:+:-" final state and *Kinematically Fit* to "$K^+ : p : \pi-$" / "$p : K^+ : \pi^-$" with zero total missing mass (outgoing photon)
- KFit confidence level $\geq$ 1% and timing cuts for event selection
- Reconstruct γ_f from missing momentum
- All four final state 4-momenta, and thus both Σ^0 and Λ 4-momenta are known
- Λ decay vertex from tracking information – set this p/π^- for energy loss corrections
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2-track: $\gamma p \rightarrow K^+ p \, (\pi^- \gamma_f)$

- "+:+" final state. "$K^+ : p$" / "$p : K^+$" particle hypotheses with 0.15 GeV$\leq MM(K^+, p) \leq$0.28 GeV. *NO Kinematic fitting*
- Only timing cuts
- π^- and γ_f 4-momenta NOT known
- Only Σ^0 can be reconstructed
- Set p/π^- vertices to event vertex
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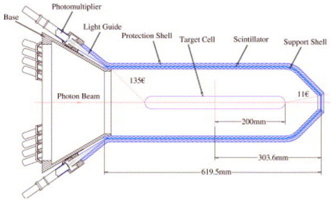
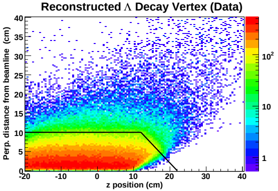
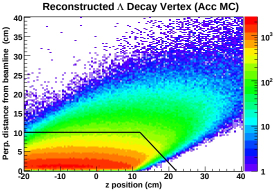
- 1.69 GeV$\leq \sqrt{s} \leq$2.84 GeV *and* greater coverage in backward angles (yay!)

G11A Start Counter correction



- Start Counter sits ≈ 10 cm around target
- Requires 2 tracks to trigger
- $c\tau \approx 7.89$ cm for Λ
- A good % of Λ's decay *outside* the Start Counter. These events won't trigger in Data.
- Accepted Monte Carlo does not include this effect – needs correction



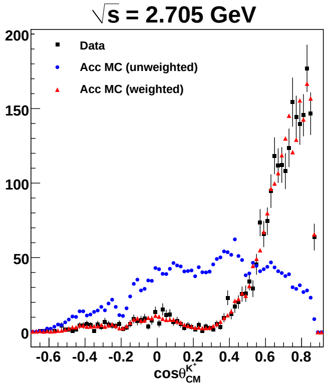


Only on the Monte Carlo:

- Earlier (3-track) : Λ decay vertices not stored by GSIM but probability based cut from $\vec{p}_\Lambda$
- 2-track – $\vec{p}_\Lambda$ not known. Needed to tweak GSIM code to produce Λ vertices directly (hard cut on the vertices at Start Counter boundary after this)

Outline

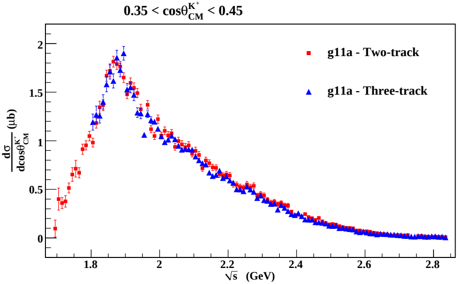
Acceptance Calculation



- Fit Data using a large number of partial waves $J^P = \frac{1}{2}^{\pm}, \ldots, \frac{11}{2}^{\pm}$
- Accepted Monte Carlo weighted by the fit results should match the Data
- Use weighted Acc MC for (physics-weighted) acceptance calculation.

- Above PWA requires knowledge of all final state 4-momenta – not available in 2-track dataset. Use unweighted Monte Carlo for acceptance calculation.
- However, breakup momenta in both Σ^0 and Λ decays are small
- Unweighted acceptance calculation (2-track) is a *very good approximation* to the physics-weighted acceptance calculation (3-track).

$d\sigma/d\cos\theta_{CM}^{K^+}$: 2- and 3-track results



- Even though they are from the same dataset, the two topologies employ widely different analysis techniques
- Agreement between the two results lends confirmation towards our overall understanding of the g11a systematics

Final g11a $d\sigma/d\cos\theta_{CM}^{K^+}$:

- Weighted average of the two results
- 10 MeV wide $\sqrt{s}$ binning. Energy coverage: 1.69 GeV$\leq \sqrt{s} \leq$2.84 GeV
- 0.1 wide binning in $\cos\theta_{CM}^{K^+}$. Angular coverage: -0.95$\leq \cos\theta_{CM}^{K^+} \leq$0.95
- Wide coverage in both energy and production angles – 2113 independent kinematic points

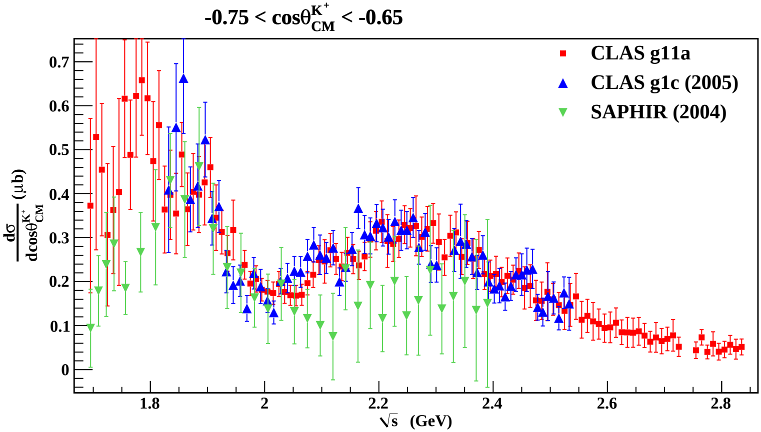
Systematic Uncertainties

- Kinematic Fitter Confidence Level (3-track) – 3%
- 3-track PID – 0.62%
- 2-track PID – 1.8%
- Acceptance calculation – $4-6\%$ ($\sqrt{s}$ dependent)
- $\Lambda \to p\pi^-$ branching fraction (PDG) – 0.5%
- Target characterestics: density – 0.11%, length – 0.125%
- Photon flux normalization – 7.3%
- Live time – 3%

$9-12\%$ estimated overall systematic uncertainty

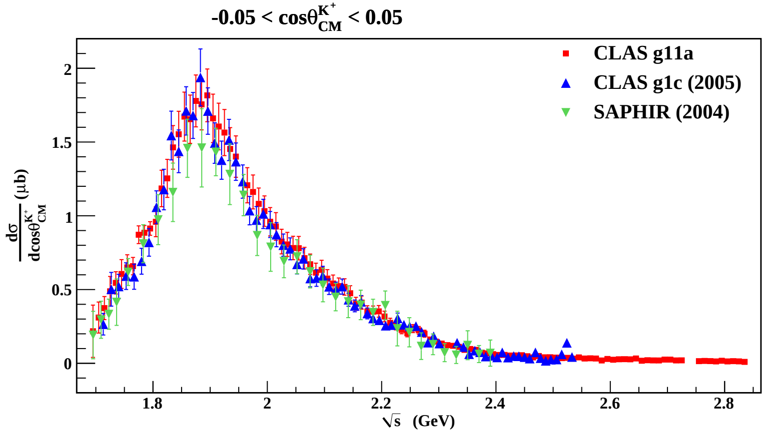
Comparison with World Data

Backward angles



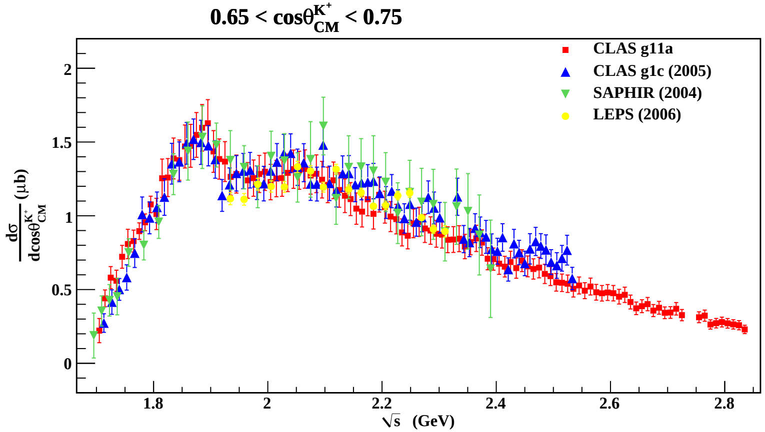
Comparison with World Data

Mid angles



Comparison with World Data

Forward angles



g11a $d\sigma/d\cos\theta_{CM}^{K^+}$ RESULTS – PROMINENT FEATURES

- Backward angles:- excellent agreement with previous CLAS $g1c$. Confirms structure around $\sqrt{s} \approx 2.2$ GeV. Absent in SAPHIR.
- Mid angles:- excellent agreement with $g1c$. Prominent peak at 1.9 GeV.
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Note:- backward angle measurements were possible only with the (new!) 2-track analysis.

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- General pseudo-scalar meson photoproduction – 4 complex CGLN amplitudes. Seems like, we need 7 independent quantities (4 magnitudes, 3 relative phases)

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GRAAL, LEPS

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CLAS *g1c*

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(new!) CLAS $g11a$ – much higher statistics, wide kinematic coverage

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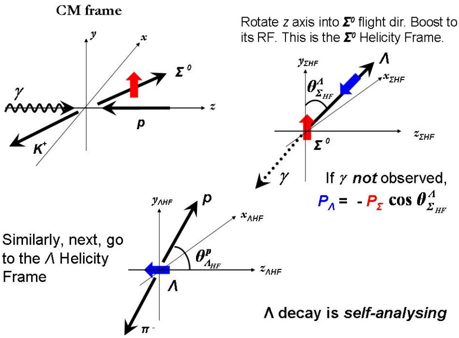
(upcoming!) CLAS $g9$ (FROST)

Recoil Polarization P_Σ



"Traditional" approach

$$\mathcal{I} \propto 1 + \alpha \langle \vec{P}_\Lambda \rangle \cos\theta^p_{\Lambda_{HF}} =$$
$$1 + \alpha \left(-\langle \vec{P}_{\Sigma^0} \rangle \cos\theta^{\Lambda}_{\Sigma_{HF}} \right) \cos\theta^p_{\Lambda_{HF}}$$

"PWA" approach

PWA fit amplitudes carry $m_\Sigma = \pm\frac{1}{2}$ spin-projections.

Project out expectation value of σ_y: $P_\Sigma = \frac{Tr[\rho\sigma_y]}{Tr[\rho]}$

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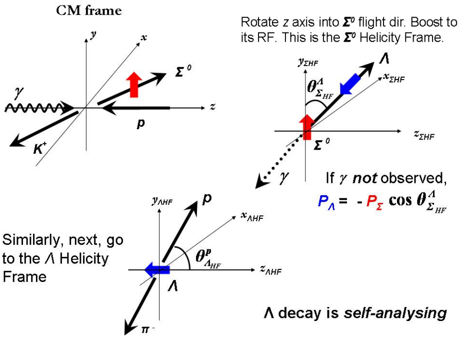

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$$1 + \alpha\left(-\langle\vec{P}_{\Sigma 0}\rangle \cos\theta^{\Lambda}_{\Sigma_{HF}}\right)\cos\theta^{p}_{\Lambda_{HF}}$$

If Λ is not measured (2-track analysis):

$$\mathcal{I} \propto 1 - \frac{\alpha}{3.9}\langle\vec{P}_\Sigma\rangle \cos\theta^{p}_{\Sigma_{HF}}$$

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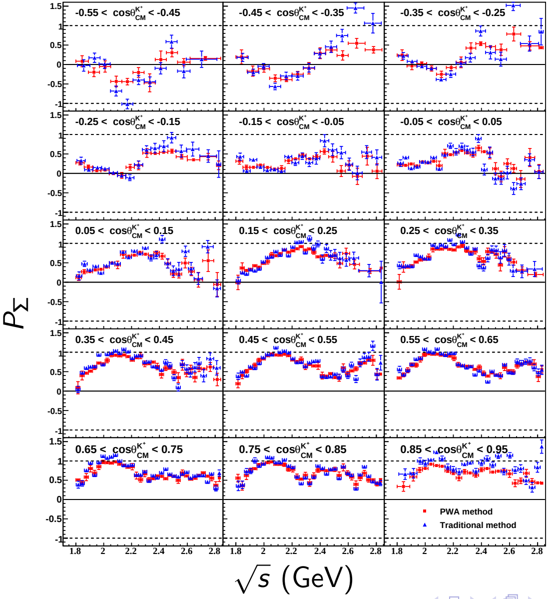
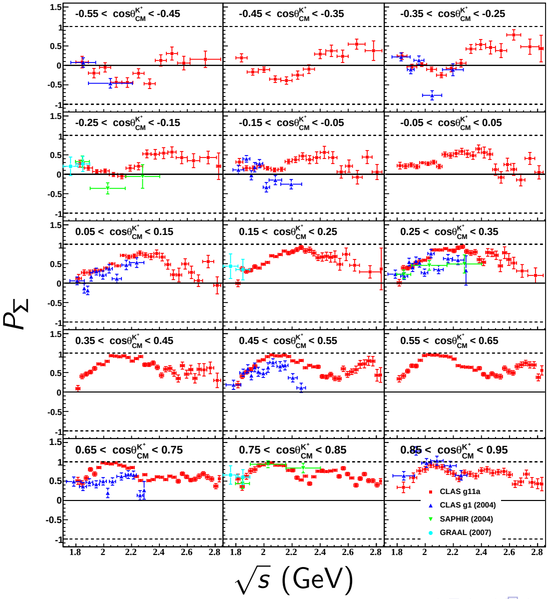
Compare: *PWA* / *Traditional* method of Polarization extraction



Compare: P_Σ world data



P_Σ: FEATURES

- P_Σ "tends towards" zero/negative values in the backward angles.
- Predominently positive with high degree of polarization in the forward direction.
- Data shows lots of structures.
- Systematic errors are estimated $\sim 3\%$

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Background contributions: t-channel and u-channel interplay

t-channel: $|t| \longrightarrow 0$ (forward angles)

u-channel: $|u| \longrightarrow 0$ (backward angles)

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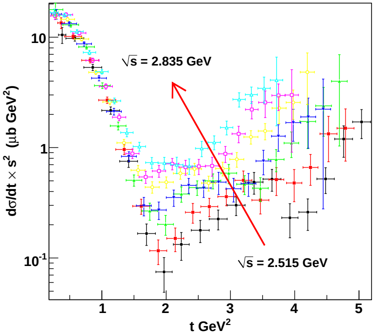
Strong presence of *both* t- and u-channel non-resonant background contributions.

Scaling behaviour at high energies – t-channel

- At high s, Bradford *et al* (PRC 73, 035202) saw scaling of $d\sigma/dt$ with s^2 in CLAS $g1c$ data.
- $g1c$ went till $\sqrt{s} \approx 2.53$ GeV. With $g11a$ data, similar behavior seen at even higher s



Regge scaling – t-channel (contd.)

- Scaling is reminiscent of Regge behavior – $\frac{d\sigma}{dt} \sim D(t) \left(\frac{s}{s_0}\right)^{2\alpha(t)-2}$
- Scaling *power* reveals what Regge exchanges occurring. s^2 means $\alpha(t) \sim 0$ near $t \sim 0$
- Guidal, Laget and Vanderhaegan (Nucl. Phys. A627, 645): t-channel Regge exchanges in kaon photoproduction similar to pion production. Correspondence:

$$\pi \leftrightarrow K^+$$
$$\rho \leftrightarrow K^*(892)$$

- Reasonable fits to both $K^+\Lambda$ and $K^+\Sigma^0$ at forward angle high $\sqrt{s}$ using just K^+ and $K^*(892)$ exchanges
- Bradford *et al* noted: $\alpha(t)_{K^+} + \alpha(t)_{K^*(892)} \sim 0$ near $t \sim 0$.
- *Could* explain why α is *effectively* zero around $t \sim 0$

Regge scaling – u-channel

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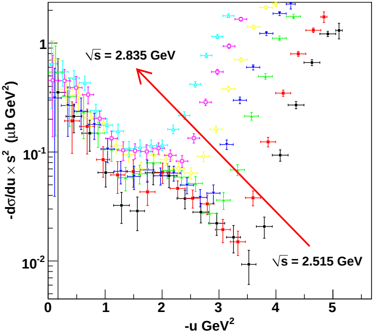
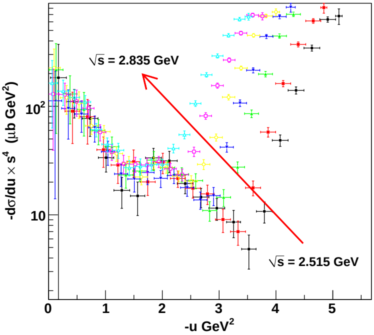
- Do we see scaling at high $\sqrt{s}$ and $|u| \rightarrow 0$? Yes!



s^2 scaling



s^4 scaling

Regge scaling – u-channel (contd.)

- u-channel – hyperon exchanges. What are the Regge trajectories ?

$$\alpha(t)_\Lambda \sim -0.6 + 0.9t$$
$$\alpha(t)_\Sigma \sim -0.8 + 0.9t$$

- u-channel: $t \longrightarrow u$, physical region: $u < 0$
- At $|u| \longrightarrow 0$:

$$(2\alpha - 2)_\Lambda \approx -3.2$$
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- It is thus *conceivable* that the scaling power $-(2\alpha - 2)$ be > 2.

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Questions:

- Do we *need* a Regge description (as opposed to usual Feynman propagators) for the u-channel?
- Theoretical difficulties from lowest pole $u = m_\Lambda^2$ being far removed from the physical region ($u < 0$).
- Can we *extract* a best fit "effective" $\alpha(u)$ from the scaling behavior?

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To summarize ...

- $K^+\Sigma^0$ differential cross sections from $g11a$ from threshold (1.169 GeV) till 2.84 GeV and almost the entire angular range have been measured (allowed by newer 2-track topology measurements).
- Fair to excellent agreement with previous world data – besides higher statistics, $\sim$ 300 MeV increase in energy coverage.
- Prominent structure at $\sim$ 1.9 GeV. We also confirm structure at $\sim$ 2.2 GeV seen in CLAS $g1c$ data in the backward angles.
- Our recoil polarizations (P_Σ) measurements respresent a vast improvement over previous world data – in statistics, kinematic coverage and precision (intermediate Λ directions no longer summed over)
- P_Σ is large and positive at forward angles. "Tends towards" zero/negative values in backward directions. Lots of structures seen.
- Confirm scaling at forward angles, high $\sqrt{s}$ seen in previous CLAS $g1c$ data indicating t-channel Regge exchange.
- Results very strongly suggests presence of u-channel for $K^+\Sigma^0$. For the first time, scaling seen at backward angles at high $\sqrt{s}$ indicating u-channel Regge behavior. Needs further investigation.
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To summarize ...

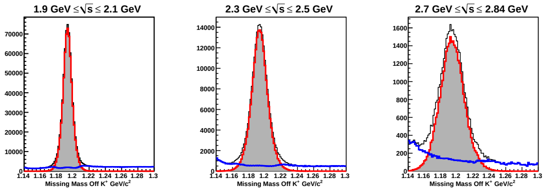
- $K^+\Sigma^0$ differential cross sections from $g11a$ from threshold (1.169 GeV) till 2.84 GeV and almost the entire angular range have been measured (allowed by newer 2-track topology measurements).
- Fair to excellent agreement with previous world data – besides higher statistics, $\sim$ 300 MeV increase in energy coverage.
- Prominent structure at $\sim$ 1.9 GeV. We also confirm structure at $\sim$ 2.2 GeV seen in CLAS $g1c$ data in the backward angles.
- Our recoil polarizations (P_Σ) measurements respresent a vast improvement over previous world data – in statistics, kinematic coverage and precision (intermediate Λ directions no longer summed over)
- P_Σ is large and positive at forward angles. "Tends towards" zero/negative values in backward directions. Lots of structures seen.
- Confirm scaling at forward angles, high $\sqrt{s}$ seen in previous CLAS $g1c$ data indicating t-channel Regge exchange.
- Results very strongly suggests presence of u-channel for $K^+\Sigma^0$. For the first time, scaling seen at backward angles at high $\sqrt{s}$ indicating u-channel Regge behavior. Needs further investigation.
- Our differential cross-section and polarization results are almost ready to be submitted to the CLAS review committee. Begun running initial PWA to look for missing resonances.

Event-background separation

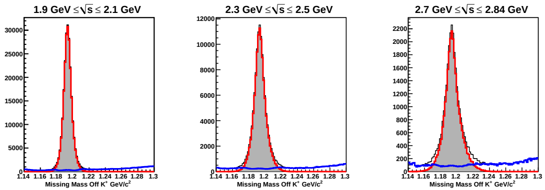
"Quality factor" Q extracted for each event from *event-based* fits

Weigh: signal (Q) background $(1 - Q)$

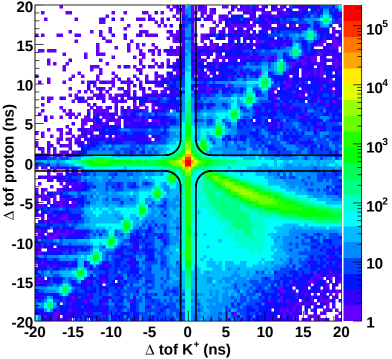
2-track:



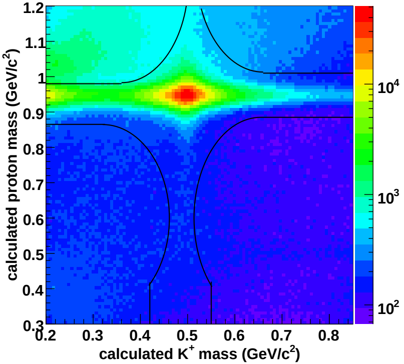
3-track:



Timing Cuts



Three-track



Two-track

Dilution effect of averaging over intermediate Λ's in measuring P_Σ