Charm Meson Decays from FOCUS to $K_S K_S X$

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Outline and Motivation

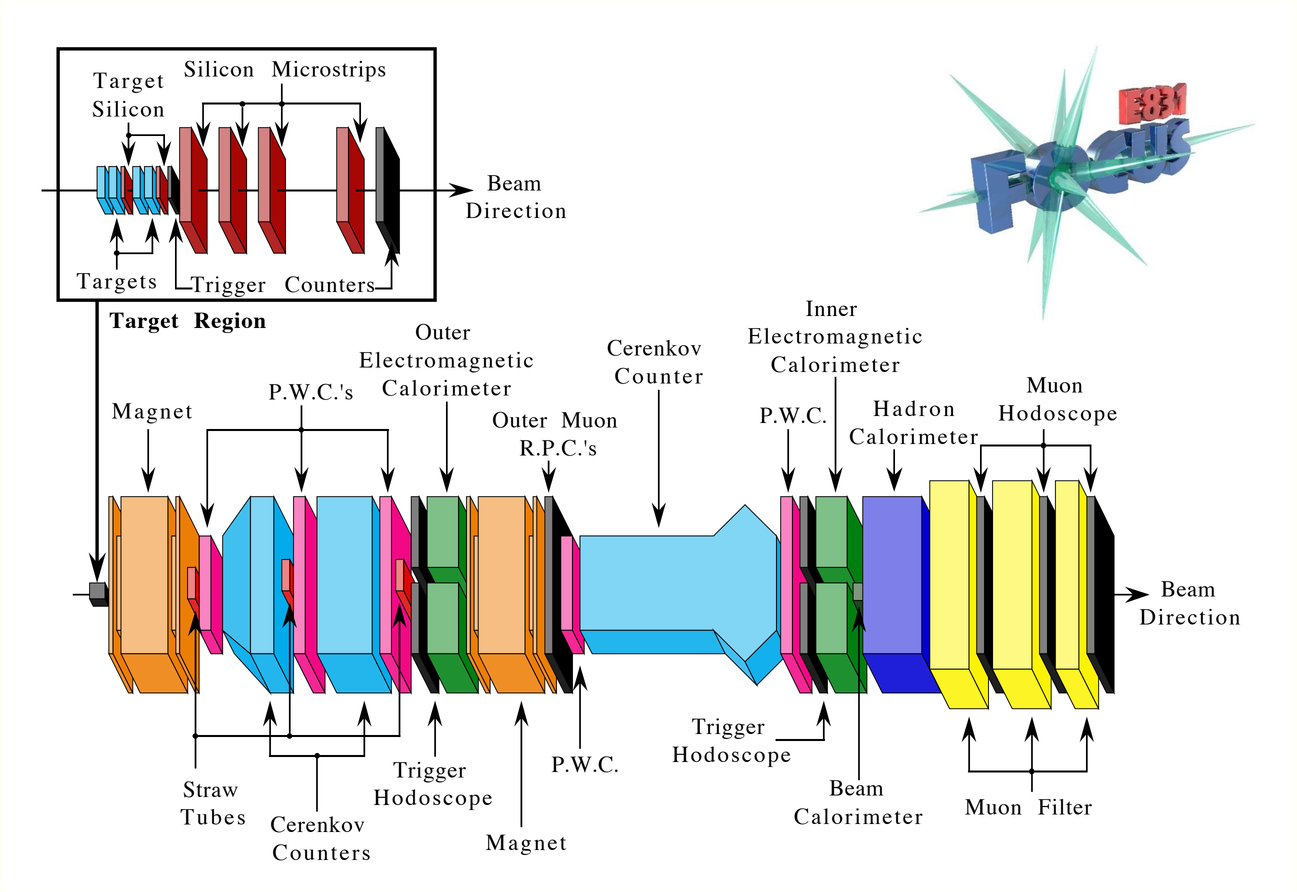
- Cabibbo Favored
  - $D^0 \rightarrow K_s K_s K^{\pm}\pi^{\mp}$
  - $D^0 \rightarrow K_S K_S K_S$
  - $D^+ \rightarrow K_S K_S K^+$
  - $D_S^+ \rightarrow K_s K_s \pi^+\pi^-\pi^+$
- Cabibbo Suppressed
  - $D^0 \rightarrow K_S K_S \pi^+\pi^-$
  - $D^0 \rightarrow K_S K_S$

- 2004 PDG Branching Fractions

Decay Mode	Branching Fraction
$D^0 \rightarrow K^0\overline{K}^0$	$7.1 \pm 1.9 \times 10^{-4}$
$D^0 \rightarrow K_S K_S K_S$	$9.1 \pm 1.6 \times 10^{-4}$
$D^0 \rightarrow K^0\overline{K}^0\pi^+\pi^-$	$7.5 \pm 2.9 \times 10^{-3}$
$D^0 \rightarrow K^0\overline{K}^0 K^-\pi^+$	-
$D^0 \rightarrow \overline{K}^0\overline{K}^0 K^+\pi^-$	-
$D^+ \rightarrow \overline{K}^0\overline{K}^0 K^+$	1.8±0.8 %
$D_S^+ \rightarrow K_S K_S \pi^+\pi^-\pi^+$	-

- Previous measurements of D decays into multi-K_S final states have large uncertainties.
- D^0 cabibbo favored decays to $K^+K^+K^-\pi^+$ (.020±.007)% and to $K^+K^-K^0\pi^0$ (0.7±.4)% differ by a factor of 35 - what about $D^0 \rightarrow K^0\overline{K}^0 K^{\pm}\pi^{\mp}$?

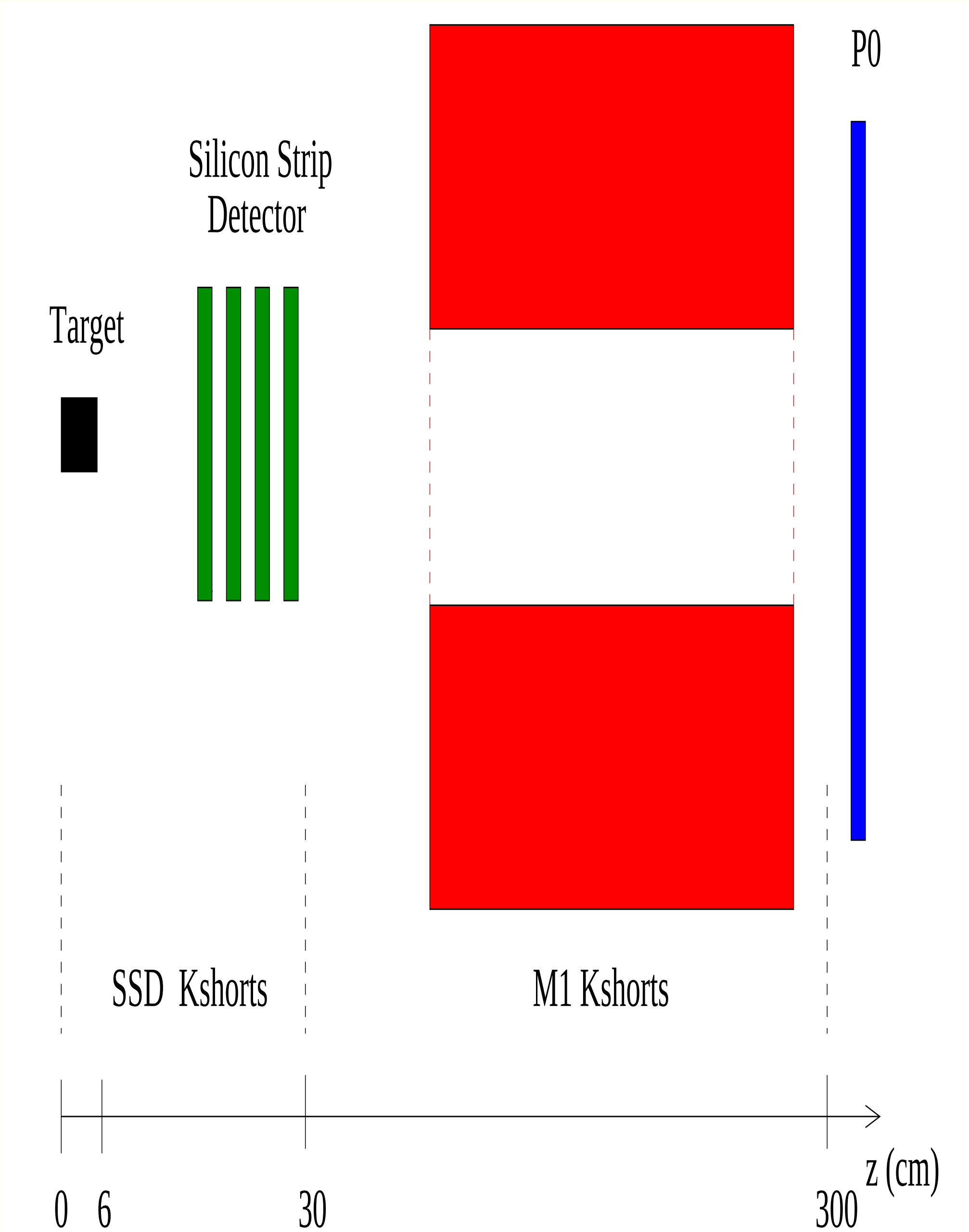
FOCUS Spectrometer



Highlights:

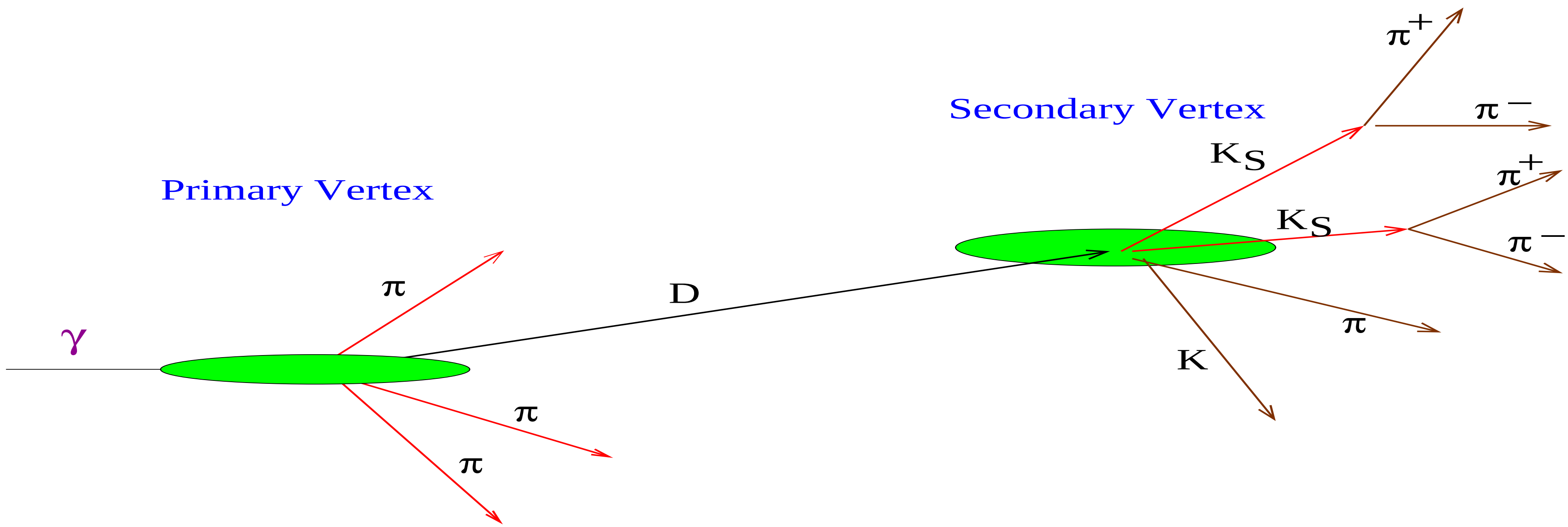
- Segmented target
- Silicon vertexing
- MWPC tracking
- Threshold Čerenkov
- EM/hadronic calorimeters
- Muon detectors

K_S Reconstruction



- Only use $K_S \to \pi^+\pi^-$
- SSD K_S
  - Decay in front of SSD
  - Composed of two linked (hits in SSDs and PWCs) tracks
  - Used in identifying secondary vertex
  - About 15% of K_S decays
- M1 K_S
  - Decay after SSD
  - Composed of two unlinked (only hits in PWCs) tracks
  - Kinematic Constraints
  - About 85% of K_S decays

Event Reconstruction

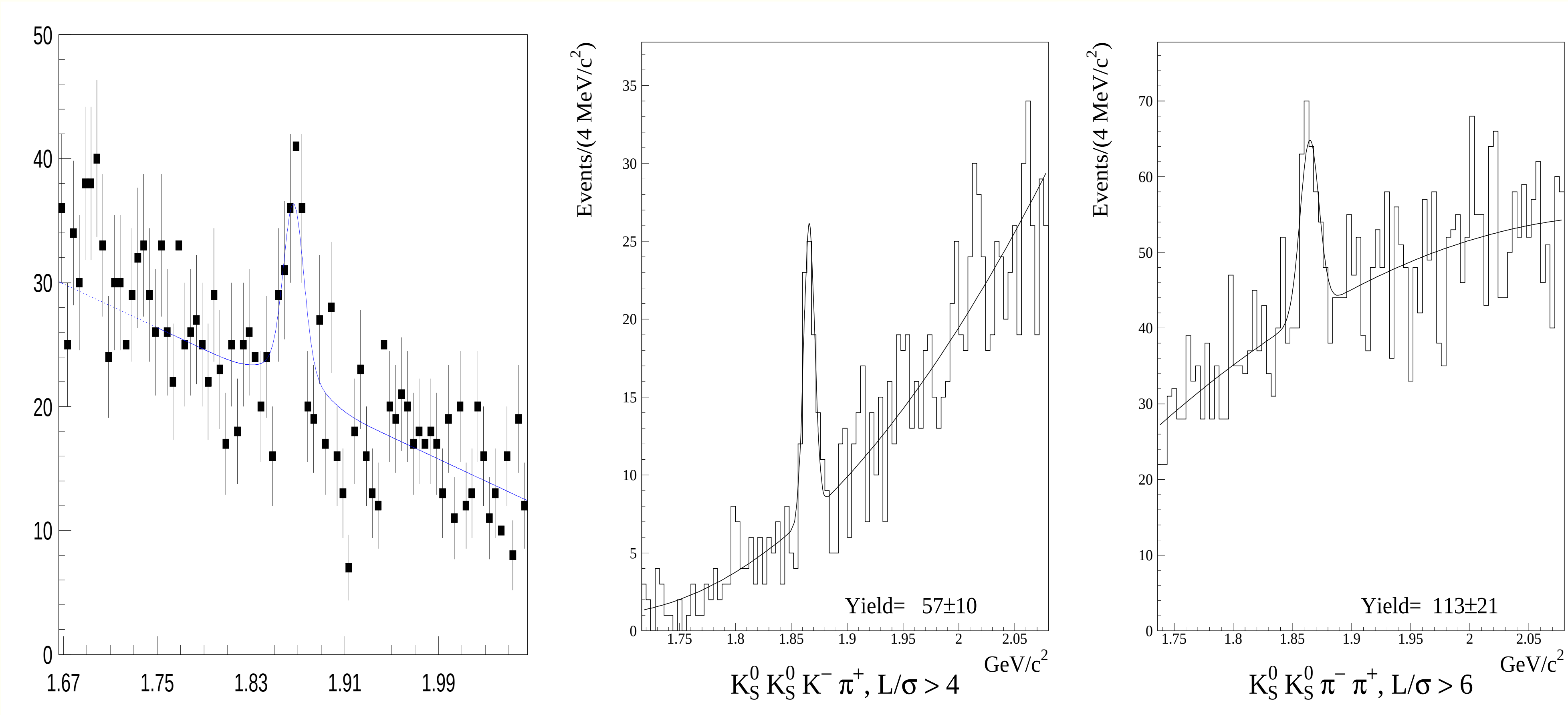


- Secondary found by combining K_S candidates and charged tracks.
- For $D^0 \to K_S K_S$ and $D^0 \to K_S K_S K_S$, a stand-alone algorithm is used to reconstruct the primary vertex.
- For $D \to K_S K_S K^+ (K\pi), (\pi\pi), (\pi\pi\pi)$, the D candidate is used to intersect the other tracks in the event to find the primary vertex. In these cases we also cut on the confidence level of the secondary, isolation of the primary and secondary vertices, and significance of separation between the two vertices.

Event Selection

- $D^0 \to K_S K_S K_S$
  - No cuts needed as mass resolution is 5 MeV/c^2.
- $D^0 \to K_S K_S$
  - Cut on angle between the D^0 flight direction and the K_S direction in the D^0 rest frame.
  - Cut on $|M(D^* - D^0) - 0.14542| < 0.002$ GeV/c^2.
- $D^0 \to K_S K_S K\pi(\pi\pi)$, $D_S^+ \to K_S K_S \pi^+\pi^-\pi^+$
  - Cerenkov cuts for charged tracks.
  - Vertex quality cuts: CLP, CLS, Isolation of secondary
  - Cut on significance of separation of vertices.
  - Cut on $D^{*+} - D^0$ to distinguish D^0 from $\overline{D}^0$.
- $D^0 \to K_S K_S K^+$
  - Cerenkov cuts for the kaon.
  - Vertex quality cuts: CLP
  - Cut on significance of detachment of kaon from primary.

D^0 Mass Plots



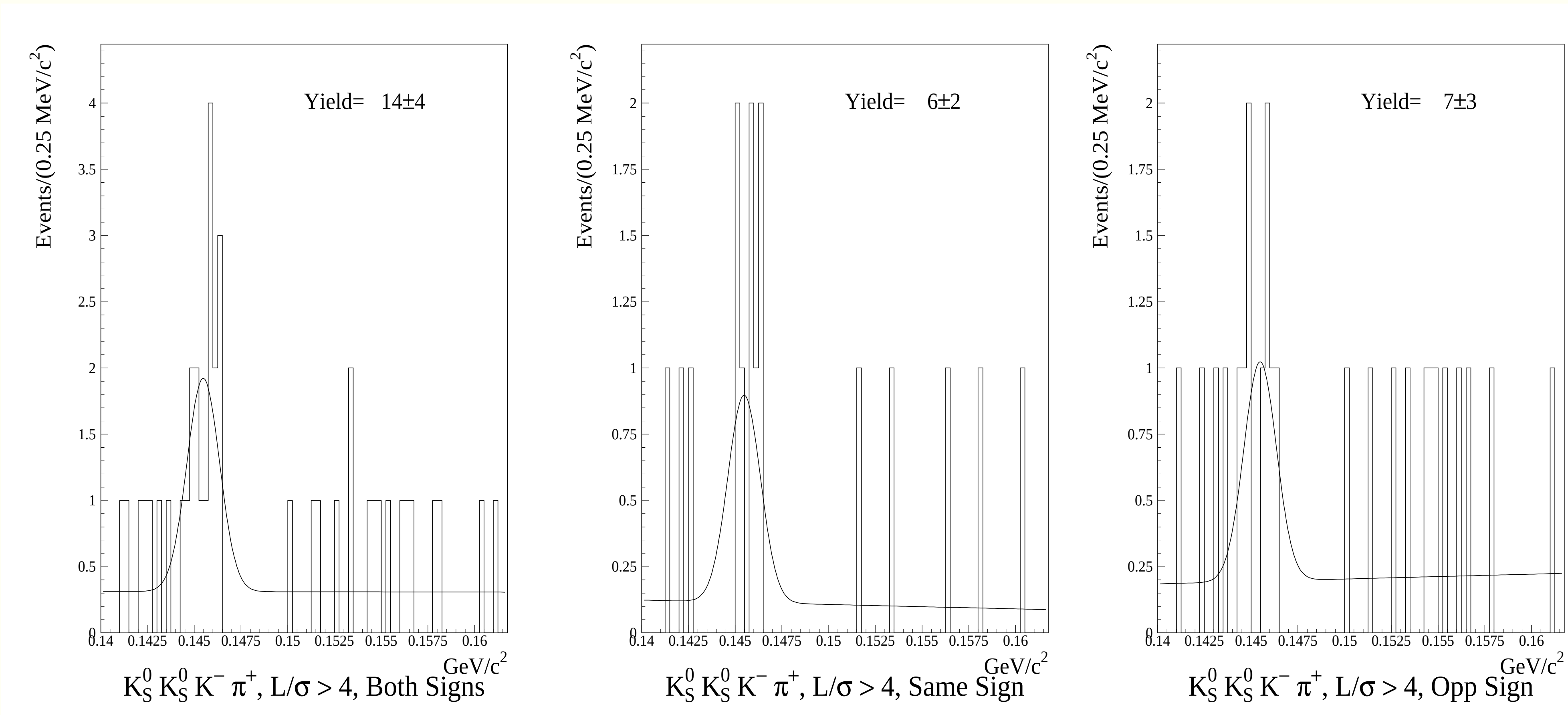
- $D^0 \to K_S K_S$, 101 ± 19 events
- σ = 12.7 MeV/c^2
- Acc $\times \epsilon$ = 0.65%

- $D^0 \to K_S K_S K \pi$, 57 ± 10 events
- σ = 5.0 MeV/c^2
- Acc $\times \epsilon$ = 0.15%

- $D^0 \to K_S K_S \pi \pi$, 113 ± 21 events
- σ = 6.5 MeV/c^2
- Acc $\times \epsilon$ = 0.16%

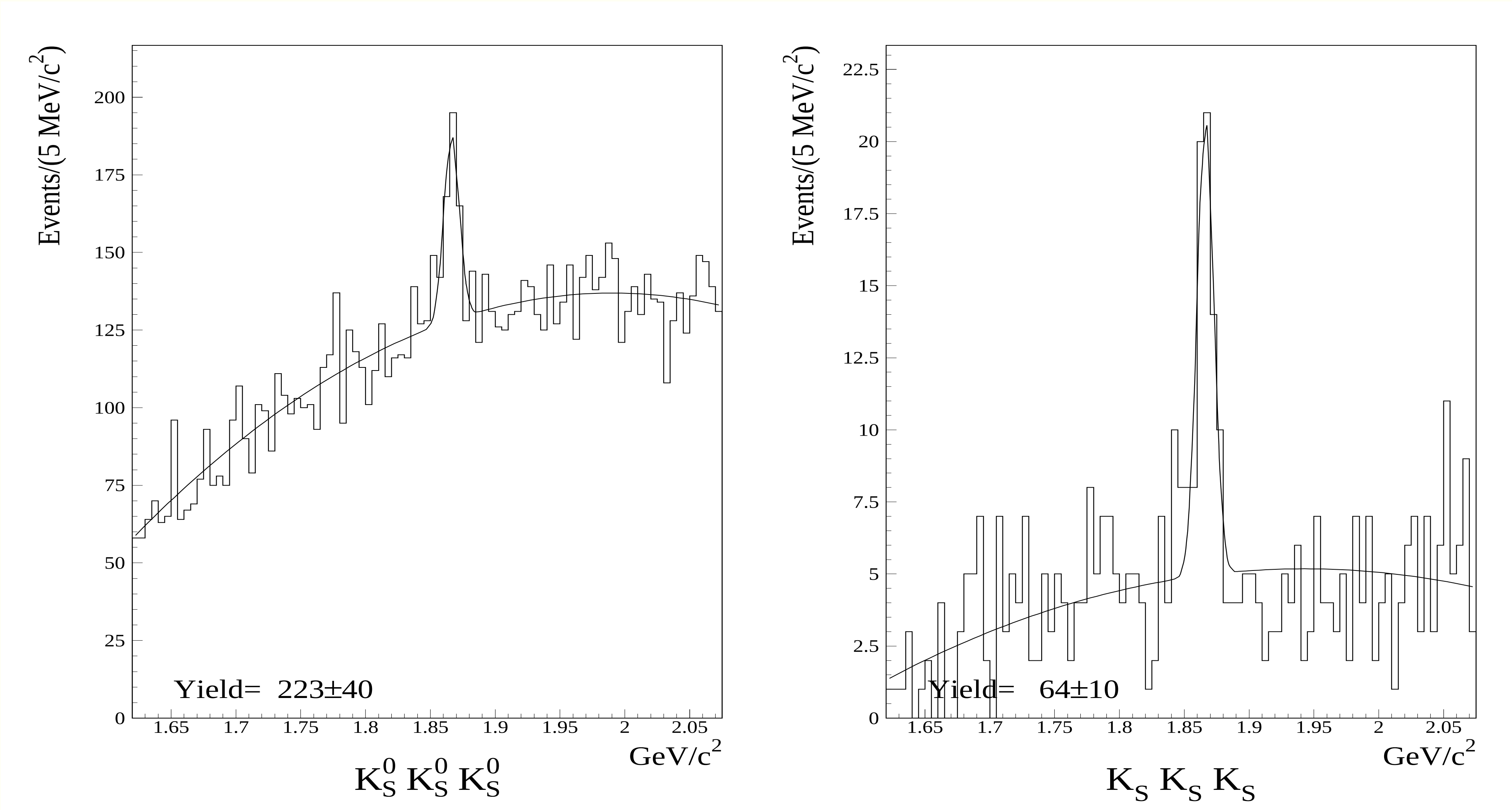
$D^0 \rightarrow K_S K_S K^{\pm}\pi^{\mp}$

- Use the soft pion tag from D^*+ to determine the decay channel. There is evidence for both Cabibbo favored decay modes.



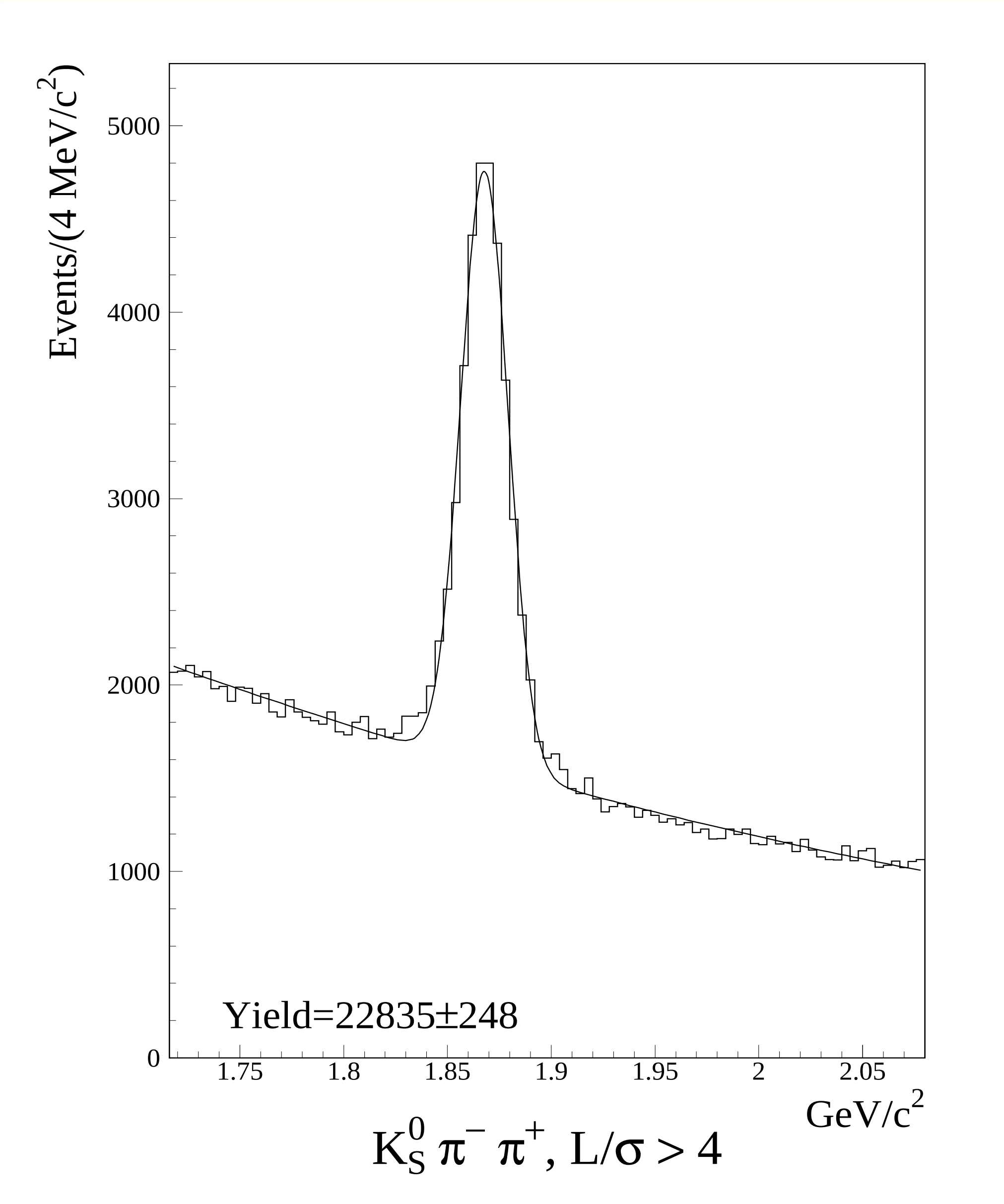
- $D^0 \rightarrow K_S K_S K^{\pm}\pi^{\mp}$
- $D^0 \rightarrow K_S K_S K^{+}\pi^{-}$
- $D^0 \rightarrow K_S K_S K^{-}\pi^{+}$

$D^0 \to K_S K_S K_S$



- $D^0 \to K_S K_S K_S$, 223 ± 40 events
- No vertex cuts!
- $D^0 \to K_S K_S K_S$, 64 ± 10 events
- D^* tag used

$D^0 \to K_S \pi^+ \pi^-$



- $D^0 \to K_S \pi^+ \pi^-$ used as a normalization for branching ratios to minimize systematic errors connected with K_S reconstruction.
- Selection criteria as much as possible equal to each channel $D^0 \to K_S K_S (K\pi, \pi\pi)$ we are measuring, ie. same vertexing techniques, D^* tag, etc.
- Cerenkov cuts on charged tracks.

Systematic Studies

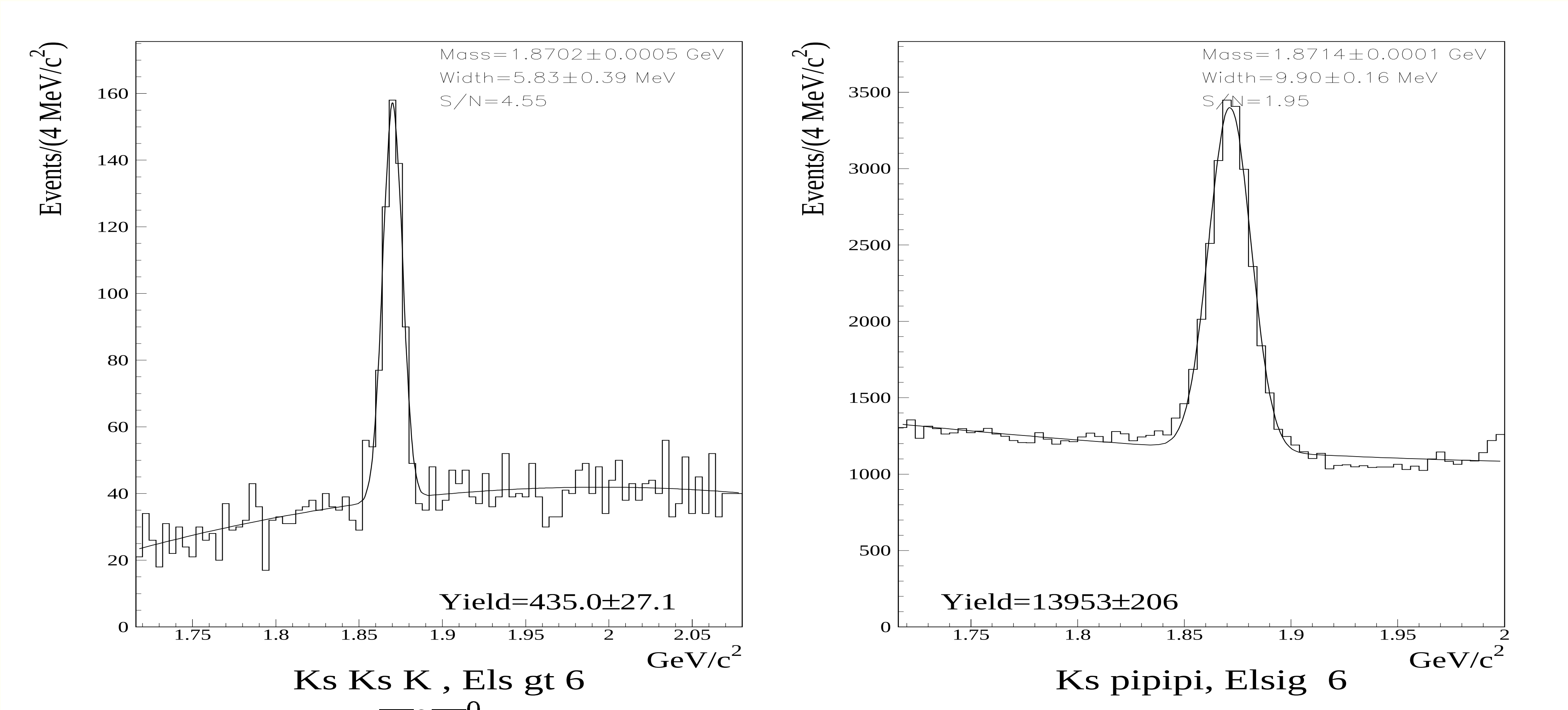
- Split Samples
  - Different Run Period Conditions (run numbers)
  - Particle/ Antiparticle
  - High/Low Charm Momentum
  - K_S reconstruction type
- Fit Variants
- Possible Resonant Conditions
- Charm background
- Absolute Tracking Efficiency for different multiplicities.
- Limited Monte Carlo Statistics - negligible, but considered.

Preliminary Branching Ratios

Decay Mode	Branching Ratio	PDG 2004
$\frac{\Gamma(D^0 \to K^0 \overline{K}^0)}{\Gamma(D^0 \to \overline{K}^0 \pi^+ \pi^-)}$	1.44±0.32 %	1.20±0.33 %
$\frac{\Gamma(D^0 \to K_S K_S K_S)}{\Gamma(D^0 \to \overline{K}^0 \pi^+ \pi^-)}$	1.79±0.27 %	1.54±0.25 %
$\frac{\Gamma(D^0 \to K_S K_S K^\pm \pi^\mp)}{\Gamma(D^0 \to \overline{K}^0 \pi^+ \pi^-)}$	1.06±0.19 %	-
$\frac{\Gamma(D^0 \to K_S K_S \pi^+ \pi^-)}{\Gamma(D^0 \to \overline{K}^0 \pi^+ \pi^-)}$	2.08±0.35 %	3.1±1.0 %

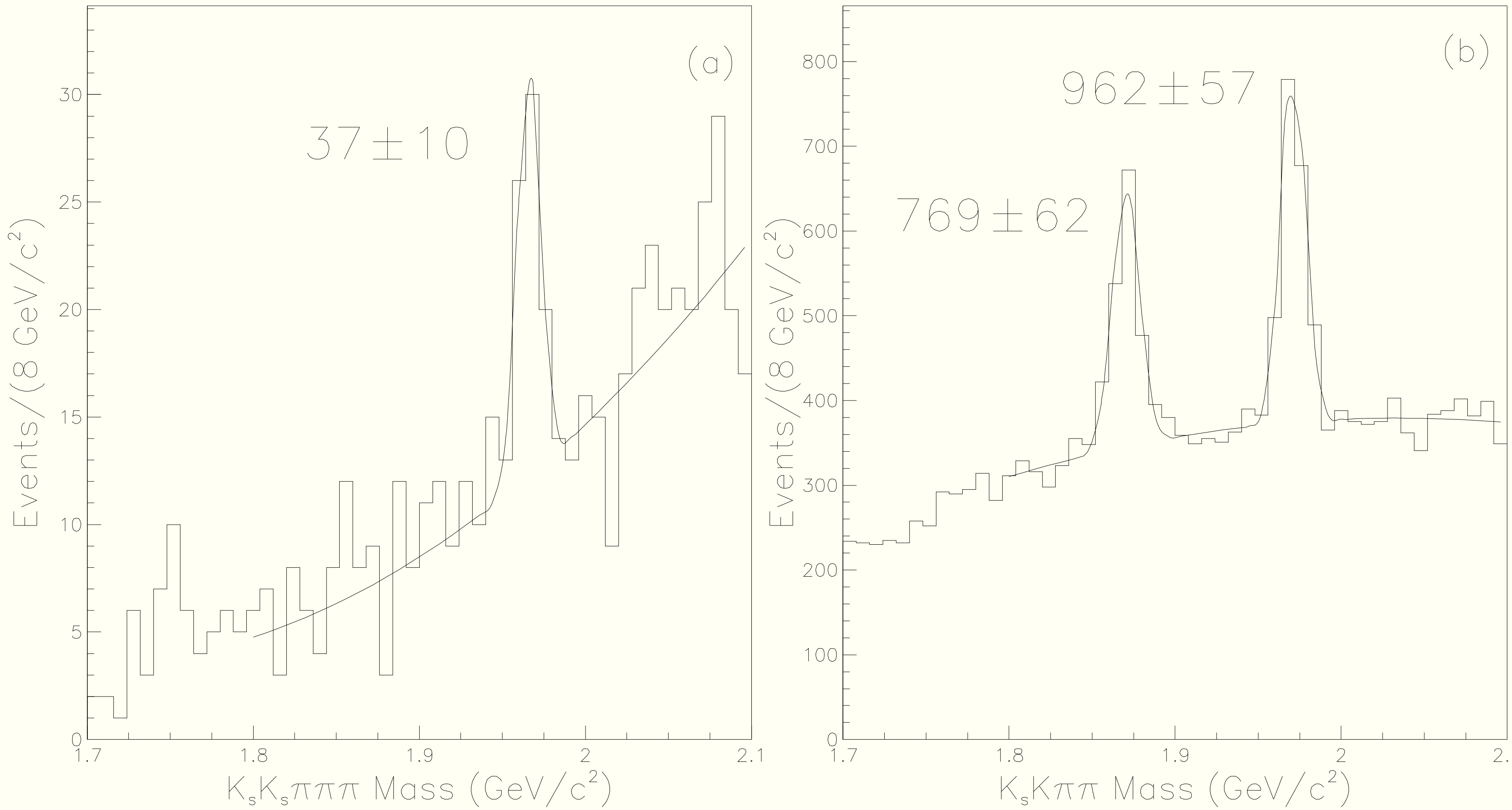
- Improved measurements on D^0 decays into multi-K$_S$ final states.
- First Evidence for $D^0 \to K_S K_S K \pi$ Modes
  - Branching ratio is smaller than $D^0 \to K^+ K^- \overline{K}^0 \pi^0$
  - Branching ratio is larger than $D^0 \to K^+ K^- K^- \pi^+$

A first look at $D^+ \to \overline{K}^0 K^0 K^+$



- Find $\frac{\Gamma(D^+\to\overline{K}^0\overline{K}^0K^+)}{\Gamma(D^+\to\overline{K}^0\pi^+\pi^-\pi^+)} = 0.206 \pm 0.013.$
- Using $\Gamma(D^+ \to \overline{K}^0\pi^+\pi^-\pi^+)/\Gamma(D^+ \to All) =$ 7.0±0.9 %, FOCUS finds 1.44±0.22%.
- ARGUS found 1.54±0.44%
- CLEO found 3.7±0.8%

$D_s^+ \to K_s K_s \pi^+ \pi^+ \pi^-$



(a) $D_s^+ \to K_s K_s \pi^+ \pi^+ \pi^-$

(b) Normalizing mode, $D_s^+ \to K_s K^- \pi^+ \pi^+$.

Branching Ratio Calculation

- Nonresonant Generation for $D_s^+ \to K_s K_s \pi^+\pi^+\pi^-$
- Systematic Errors - contributions added in quadrature
  - Split Sample Variance - run number and momentum; 0.020
  - Signals fit with 1^{st}, 2^{nd} and 3^{rd} order polynomials; 0.009
  - Monte Carlo statistics; 0.002
  - Variation with Vee category; 0.013
  - Uncertainty in Absolute Tracking Efficiency; 0.004
  - Resonant Substructure Uncertainty: Calculate BR using 3 different MC: $(D_s^+ \to K_s K_s \pi^+\pi^+\pi^-)_{NR}$, $D_s^+ \to f_0 \rho^0 \pi^+$, and $D_s^+ \to K^{*+} K^{*-} \pi^+$; 0.012
- Results:

Decay Mode	Branching Ratio
$\frac{\Gamma(D_s^+ \to K_s K_s \pi^+\pi^+\pi^-)}{\Gamma(D_s^+ \to K_s K^- \pi^+\pi^+)}$	0.102±0.029±0.029

Conclusions

- Several branching fractions containing multi-K_S final states have been measured with uncertainties equal to or better than PDG.
  - $D^0 \to \overline{K}^0\overline{K}^0K^+\pi^-$ (new)
  - $D^0 \to K^0\overline{K}^0K^-\pi^+$ (new)
  - $D_S^+ \to K_SK_S\pi^+\pi^+\pi^-$ (new)
- Work needs to done on $D^+ \to \overline{K}^0\overline{K}^0K^+$ Dalitz.
- Would be nice to have a measurement of Cabibbo favored channels $D^0 \to K^+K^-\overline{K}^0\pi^0$ and $D^0 \to K_SK_SK_S\pi^0$. All five four-body Cabibbo favored channels could then be compared.