A Measurement of the Branching Ratio of $K^{\pm} \rightarrow \pi^{\pm} \mu^{+} \mu^{-}$ Decays in the HyperCP experiment

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Representing HyperCP collaboration

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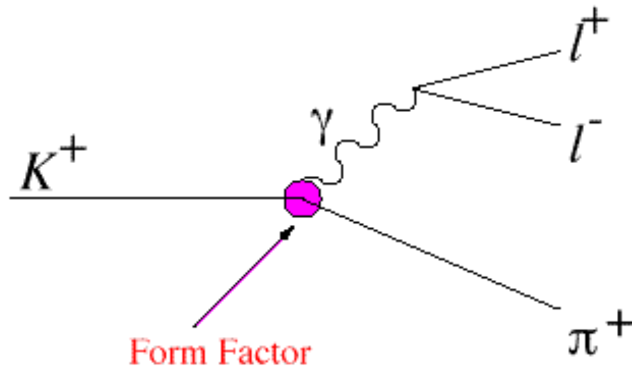
$K^{\pm} \rightarrow \pi^{\pm}\mu^{+}\mu^{-}$ Decay

- In the Standard Model, there is no FCNC at the tree level. Decay is dominated by long-distance one-photon exchange



- Recent Chiral Perturbation theory describes the form factor and branching ratio of $K^+ \rightarrow \pi^+ l^+ l^-$ in a model-independent calculation with two parameters, a_+ and b_+, which are extracted from the $K^+ \rightarrow \pi^+\pi^+\pi^-$ decay.

- Chiral Perturbation Theory predicts:

$$R = \frac{B(K^+ \rightarrow \pi^+\mu^+\mu^-)}{B(K^+ \rightarrow \pi^+ e^+ e^-)} > 0.23$$

- Experimental results on $B(K^+ \to \pi^+\mu^+\mu^-)$:

$$(5.0 \pm 0.4 \pm 0.7 \pm 0.6) \times 10^{-8} \qquad \text{(BNL E787)}$$

$$(9.22 \pm 0.60 \pm 0.49) \times 10^{-8} \qquad \text{(BNL E865)}$$

⇒ 3.3σ discrepancy !

- From the experimental inputs for

$$B(K^+ \to \pi^+e^+e^-) = (2.88 \pm 0.13) \times 10^{-8} \qquad \text{(PDG)}$$

and the measured $B(K^+ \to \pi^+\mu^+\mu^-)$, the value of R:

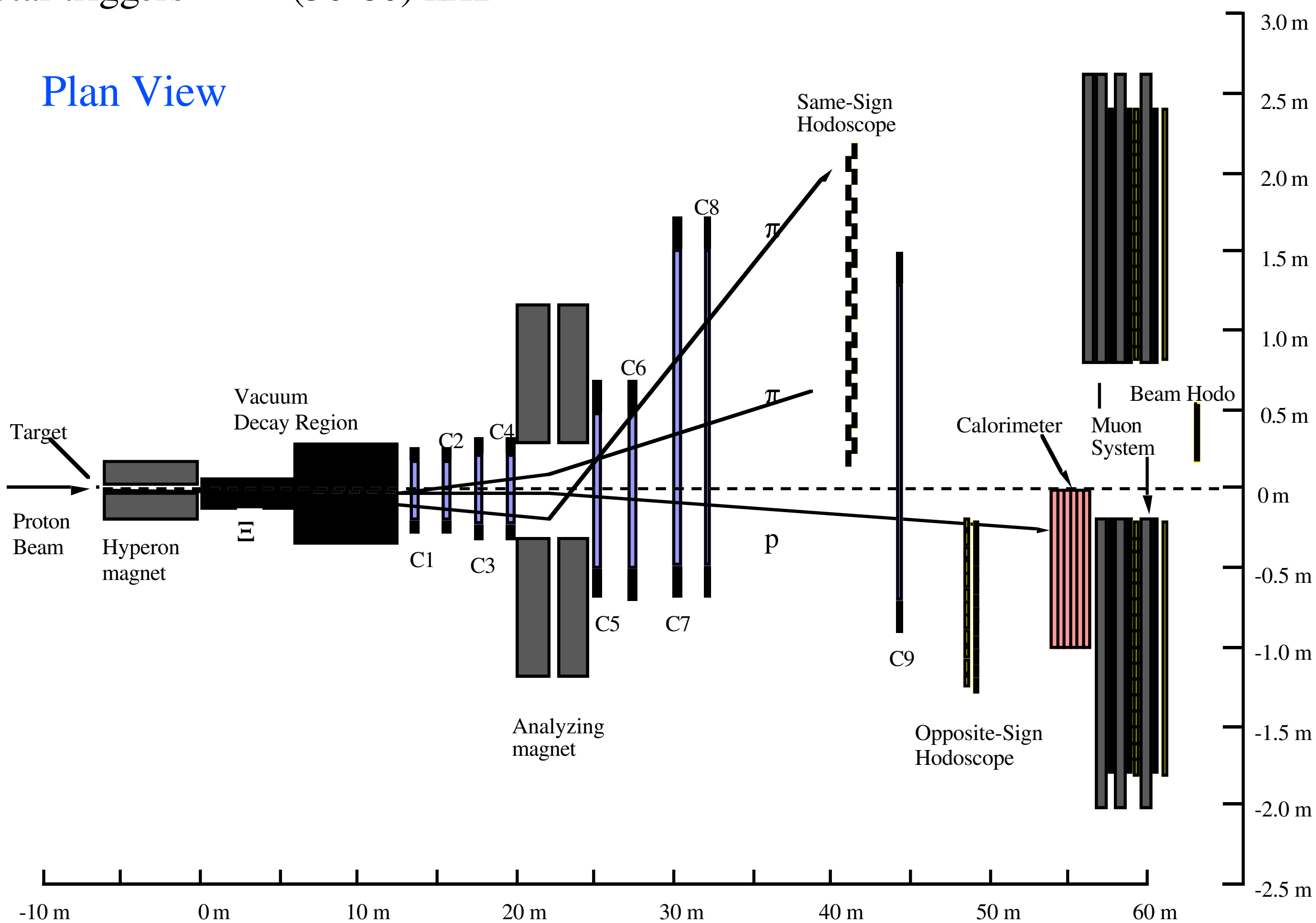
$$R = 0.17 \pm 0.03 \qquad \text{(BNL E787)}$$

$$R = 0.32 \pm 0.03 \qquad \text{(BNL E865)}$$

The HyperCP Spectrometer

- Protons on target = (7-8) GHz
- Sec. beam inten. = (10-15) MHz
- Total triggers = (50-80) kHz

Plan View



Statistics of The 1997 And 1999 Runs

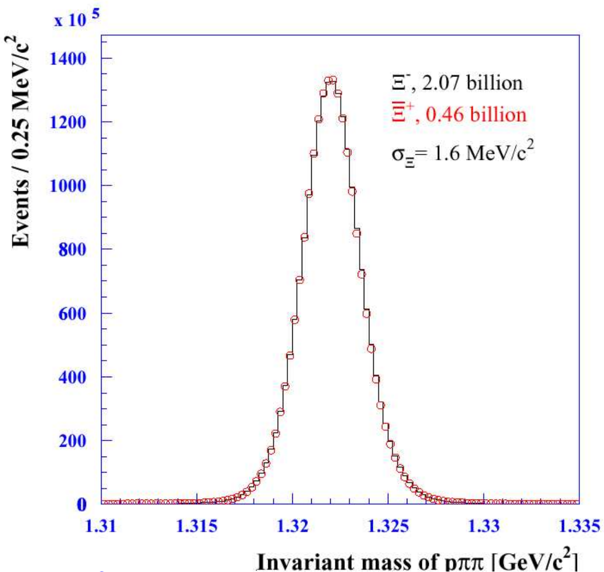
	1997 Run	1999 Run
Number of Tapes	9,376	18,838
Data Volume	38 TB	71 TB

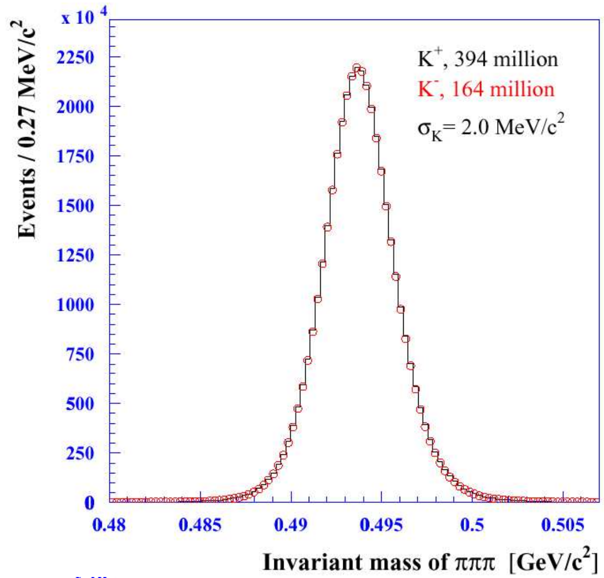
- Projected number of reconstructed events:

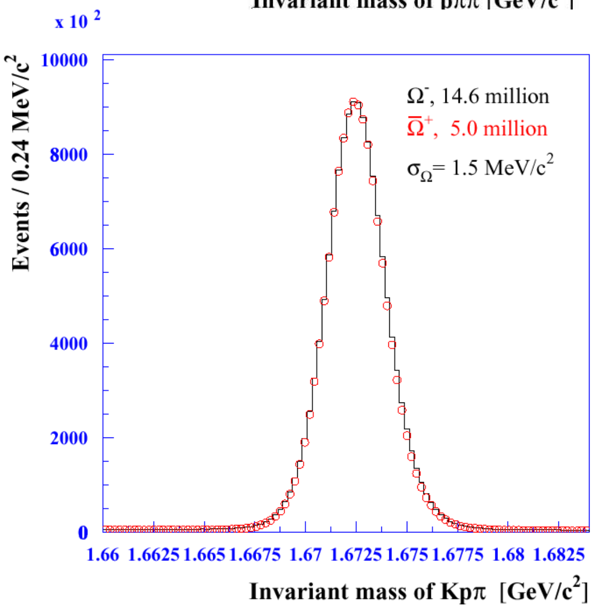
Ξ^- 2×10^9 K^- 0.16×10^9 Ω^- 14×10^6

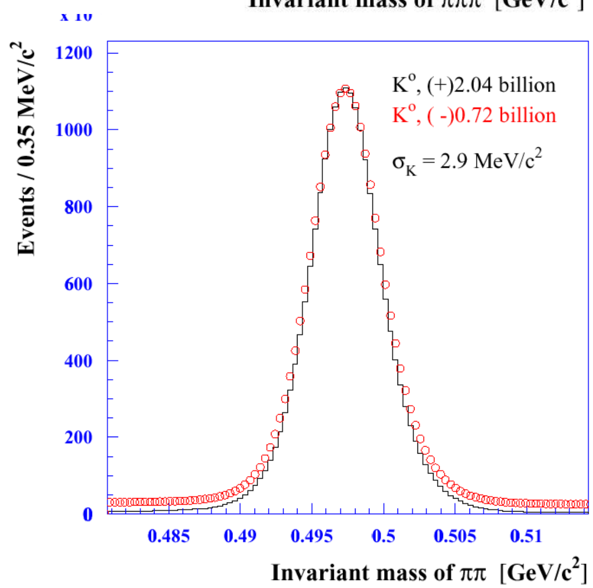
$\overline{\Xi}^+$ 0.5×10^9 K^+ 0.39×10^9 $\overline{\Omega}^+$ 4.9×10^6

Mass Plots of 1997 and 1999 Runs









Analyses in progress

- Search for CP violation in Ξ–Λ decays
- Search for CP violation in charged $K_{\pi 3}$ decay
- Measurement of the parameter β in Ξ^- to $\Lambda\pi^-$ decay
- Measurement of the parameter α in Ω^- to ΛK^- decay
- Measurement of production polarization of Ξ and Ω
- Production cross sections of strange particles
- Search for rare/forbidden decays

Measuring $B(K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-})$ in HyperCP

- Use $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ for normalization.
- Measure $B(K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-})$ according to the equation:

$$B(K \to \pi\mu^{+}\mu^{-}) = \frac{N^{obs}_{\pi\mu\mu} \cdot A_{3\pi} \cdot \varepsilon^{trig}_{3\pi} \cdot \varepsilon^{cut}_{3\pi} \cdot B(K \to 3\pi)}{N^{obs}_{3\pi} \cdot A_{\pi\mu\mu} \cdot \varepsilon^{trig}_{\pi\mu\mu} \cdot \varepsilon^{cut}_{\pi\mu\mu} \cdot \varepsilon^{\mu^{+}\mu^{-}}}$$

where

N^{obs} = number of observed events

A = geometric acceptance

ε^{trig} = trigger efficiency

ε^{cut} = event selection efficiency

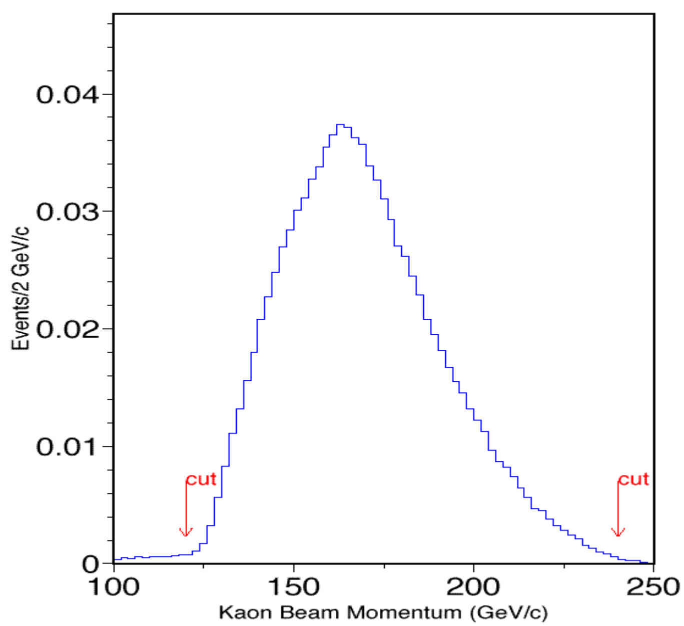
$\varepsilon^{\mu+\mu-}$ = efficiency of identifying $\mu^{+}\mu^{-}$

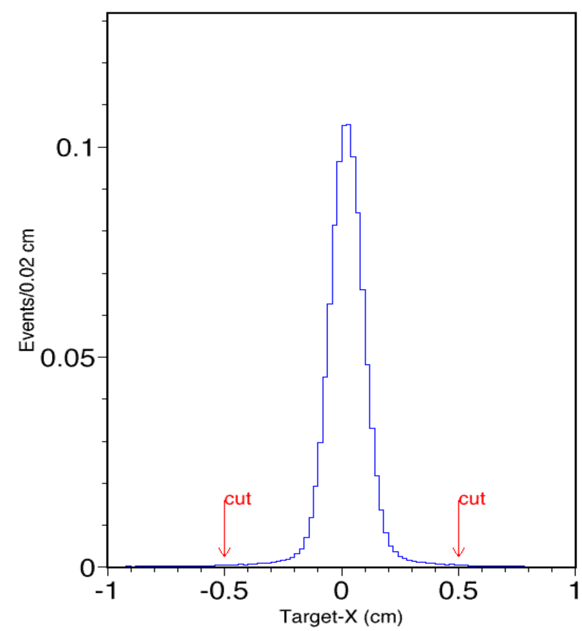
$B(K \to 3\pi) = (5.59 \pm 0.05)\%$, from PDG

Basic Event Selection

Requirements for selecting $K \rightarrow 3\pi$ and $K \rightarrow \pi\mu^{+}\mu^{-}$ events:

1. 2 tracks in Left side and 1 track in Right side
2. Total momentum
3. X and Y position at the target location
4. Single-vertex selection
5. Location of decay vertex





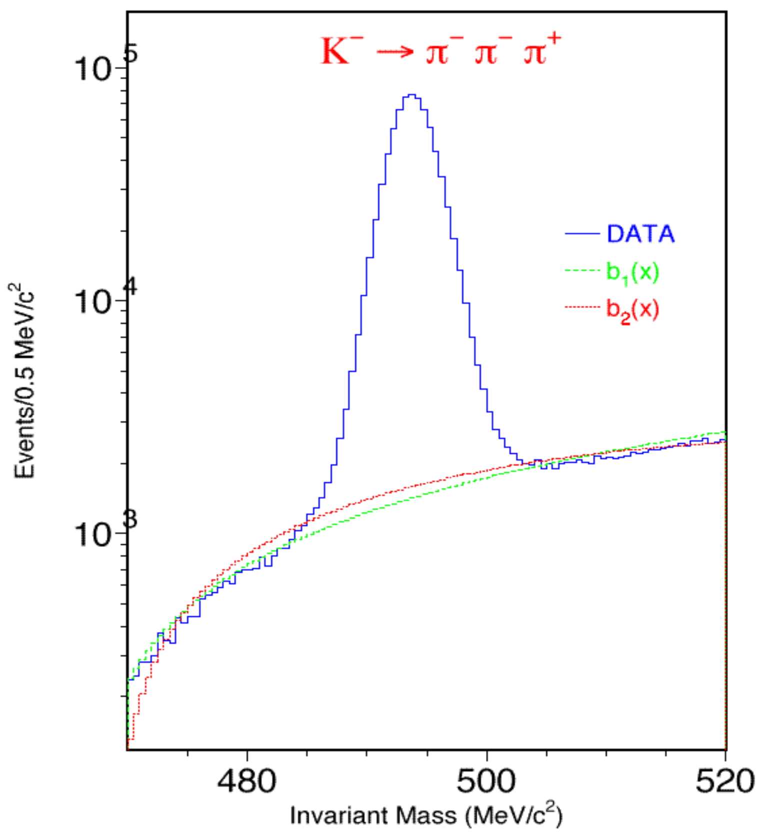
Estimating Number of $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$ Events

- Fit side band of mass peak with the following background functions:

$$b_1(m) = c_1 + c_2 m$$
$$b_2(m) = c_1 + c_2 m + c_3 m^2$$

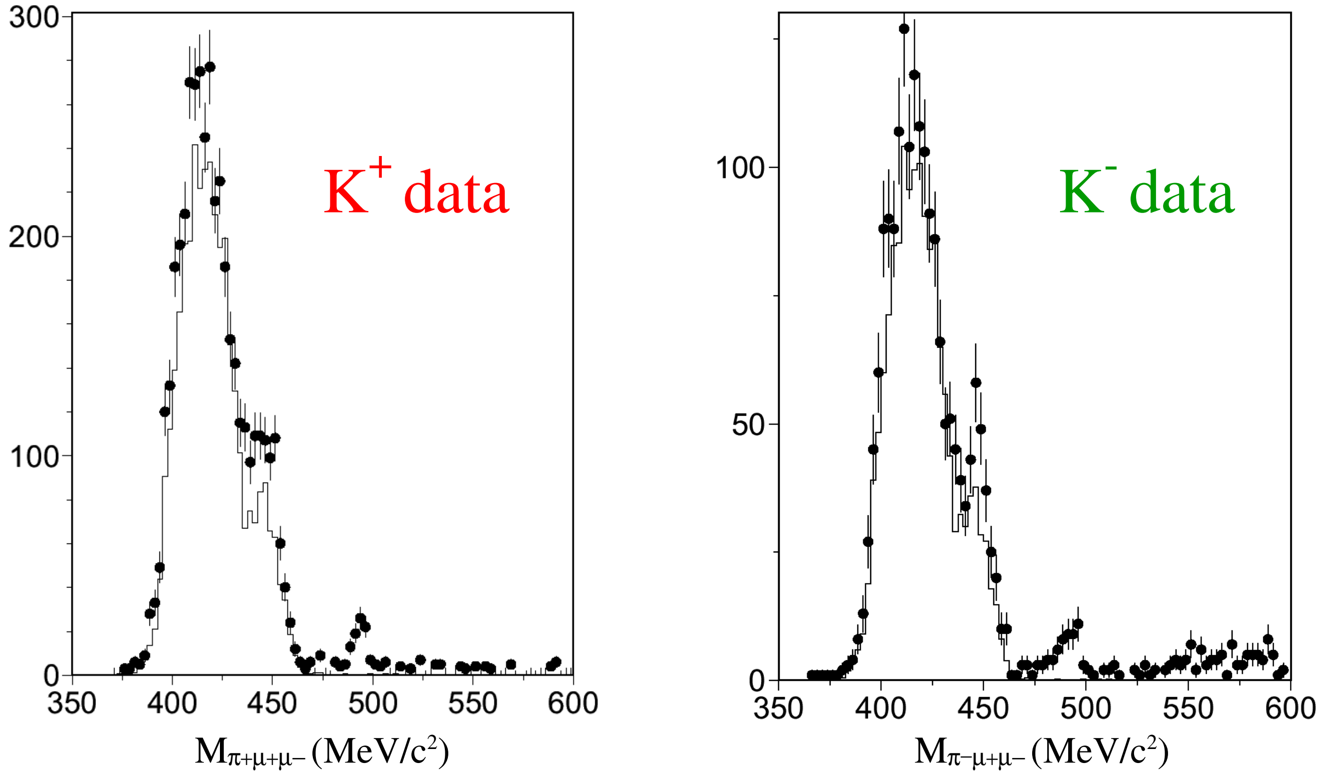
- Estimated numbers of events in the 1997 run:

$$N_{K^+ \rightarrow 3\pi} = (7.288 \pm 0.033) \times 10^7$$
$$N_{K^- \rightarrow 3\pi} = (3.691 \pm 0.015) \times 10^7$$



Finding Dimuon Events

- Track is identified as a muon if 2 out of 3 proptube planes and muon hodoscope in a muon arm have hits inside the projected road
- Reconstruct dimuon events under the $\pi\mu^+\mu^-$ hypothesis.



Estimating Number of $K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$ Events

- Estimate the number of $K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$ events using unbinned maximum likelihood fits:

$$L = e^{-(N_S + N_B)} \prod_{i=1}^{N} \left(N_S f_S(m_i) + N_B f_B(m_i) \right)$$

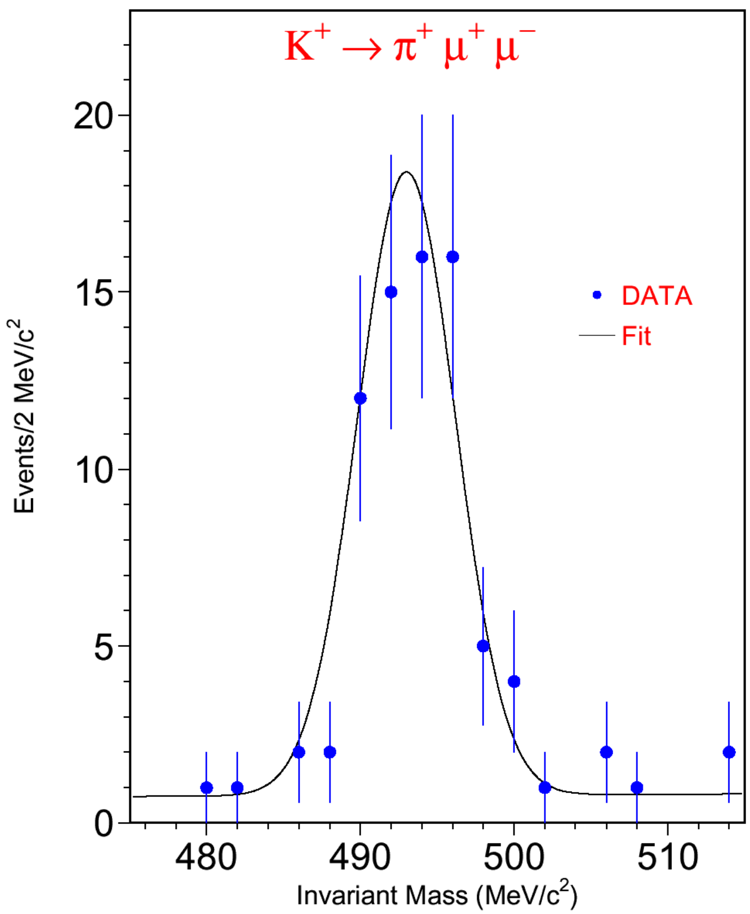
where

N_S = number of signal events
N_B = number of background events
m_i = invariant mass of event i

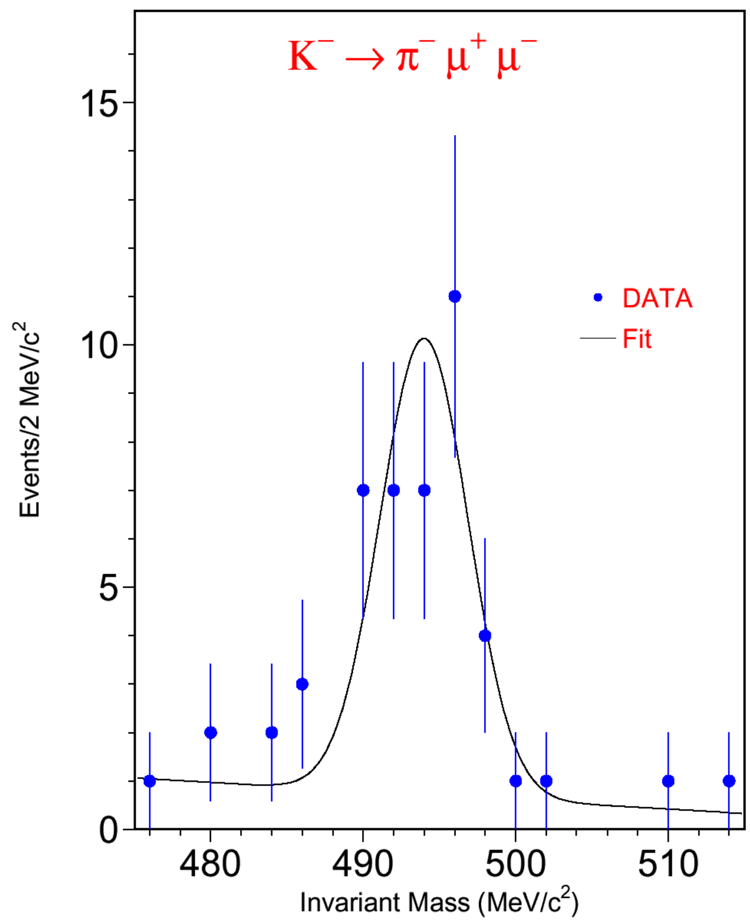
$$f_S(m_i) = \frac{1}{p_1\sqrt{2\pi}} e^{-\frac{(p_2 - m_i)^2}{2p_1^2}}$$

$$f_B(m_i) = p_3 + p_4 m_i$$

$K^{\pm} \rightarrow \pi^{\pm}\mu^{+}\mu^{-}$ Events in 1997 Run



$70.28^{+9.45}_{-8.83}$



$34.09^{+7.16}_{-6.39}$

Summary of Acceptance and Efficiency

	Positive	Negative
$A_{3\pi}$	0.633	0.619
$A_{\pi\mu\mu}$	0.476	0.477
$\varepsilon^{cut}_{3\pi}$	0.803	0.788
$\varepsilon^{cut}_{\pi\mu\mu}$	0.805	0.793
$\varepsilon^{trig}_{3\pi}$	0.985	0.985
$\varepsilon^{trig}_{\pi\mu\mu}$	0.943	0.936
$\varepsilon^{\mu^+\mu^-}$	0.820	0.820

Systematics

- Run-by-run variation:

- X and Y position of proton beam on target	±0.5 mm
- Vertical and Horizontal targetting angle	±0.5 mrad
- Magnetic field in collimator and analysis magnets	±0.1%
- $K \rightarrow 3\pi$ trigger efficiency	±2.0%
- Muon trigger efficiency	±2.0%
- Efficiency of muon identification	±1.8%

- Variation of mass interval in likelihood fit:

  $470 \text{ MeV} < m_{\pi\mu\mu} < 520 \text{ MeV}$
  $475 \text{ MeV} < m_{\pi\mu\mu} < 515 \text{ MeV}$
  $480 \text{ MeV} < m_{\pi\mu\mu} < 510 \text{ MeV}$

- Uncertainty in normalization:

  Choose different parametrization for modelling background

Systematics

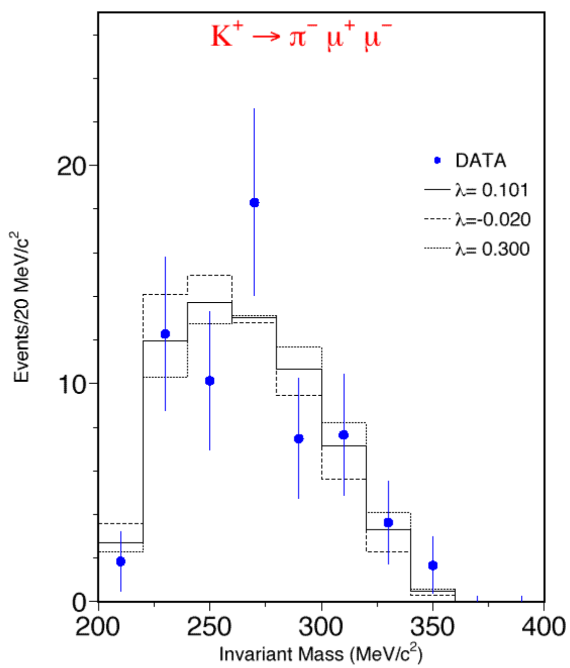
- Dalitz decay parameters for $K^+ \rightarrow \pi^+\pi^+\pi^-$ decay:

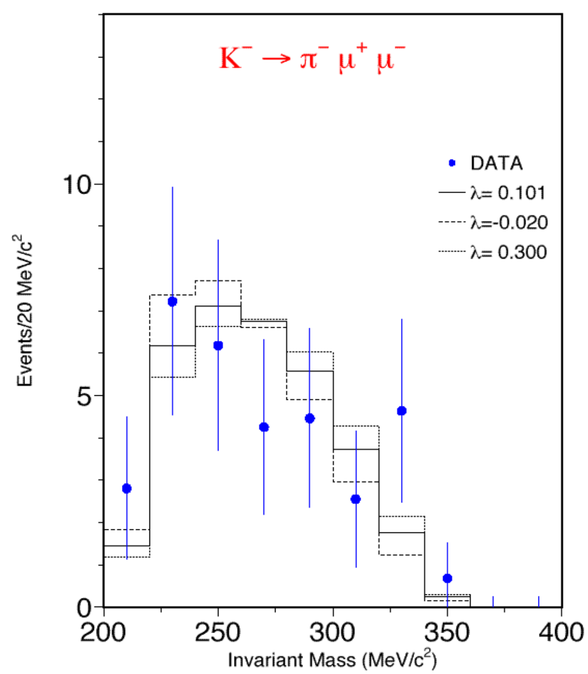
  $g = -0.2154 \pm 0.0035 \qquad (-0.217 \pm 0.007)$

  $h = \quad 0.012 \pm 0.008 \qquad (0.010 \pm 0.006)$

- Form factor in $K \rightarrow \pi\mu^+\mu^-$ decay: $\lambda = 0.101^{+0.199}_{-0.121}$

  $d\Gamma/dm_{\mu\mu} \sim (1+\lambda m^2_{\mu\mu}/m^2_\pi)^2$





Summary of Systematics

Source	σ_B/B (%,+)	σ_B/B (%,-)	Combined
Targetting	3.17	2.35	2.91
Magnetic field	0.51	0.45	0.49
K trigger	1.50	1.50	1.50
Dimuon trigger	2.10	2.10	2.10
Muon identification	1.81	1.81	1.81
Normalization	0.45	0.41	0.44
Fitting error	2.39	5.98	3.53
Geometric acceptance	2.02	1.59	1.87
Dalitz parameters	0.27	0.25	0.26
Form factor	0.81	0.79	0.80
$B(K \rightarrow \pi\pi\pi)$	0.89	0.89	0.89
Total	5.64	7.45	6.02

Preliminary Results

- Based on the 1997 data, we obtained

$$B(K^+ \to \pi^+\mu^+\mu^-) = (9.13^{+1.22}_{-1.15} \pm 0.51) \times 10^{-8}$$

$$B(K^- \to \pi^- \mu^+\mu^-) = (8.54^{+1.79}_{-1.60} \pm 0.64) \times 10^{-8}$$

Combined result (preliminary):

$$B(K^\pm \to \pi^\pm\mu^+\mu^-) = (8.94 \pm 0.98 \pm 0.54) \times 10^{-8}$$

in good agreement with the result of BNL E865.

- Measured CP asymmetry:

$$\Delta = \frac{B(K^+ \to \pi^+\mu^+\mu^-) - B(K^- \to \pi^-\mu^+\mu^-)}{B(K^+ \to \pi^+\mu^+\mu^-) + B(K^- \to \pi^-\mu^+\mu^-)}$$

$$= 0.03 \pm 0.12 \pm 0.05$$

- Expected 3 times more events from 1999 data set

Conclusions

- HyperCP has observed $K^{-} \rightarrow \pi^{-} \mu^{+}\mu^{-}$ decay for the first time.
- A preliminary branching ratio was measured:

$$B(K^{\pm} \rightarrow \pi^{\pm}\mu^{+}\mu^{-}) = (8.94 \pm 0.98 \pm 0.54) \times 10^{-8}$$

- The result is consistent with Chiral Perturbation Theory prediction.
- We have collected large samples of Ξ, Ω, and K decays in 1997 and 1999 runs.
- A rich program of charged hyperons and kaon physics is in progress.