Search for Direct CP violation in the Decay of $K^{\pm} \to \pi^{\pm}\pi^{\pm}\pi^{\mp}$

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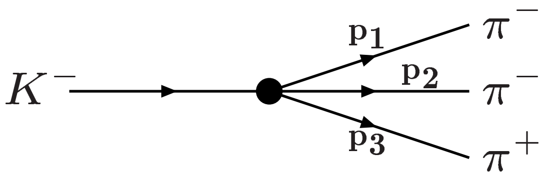
$K \to 3\pi$ Decay Amplitudes



- For a three-body decay:

$$d\Gamma = \frac{1}{(2\pi)^5 16 m_K} |A|^2 dE_1 dE_2 d\alpha d(cos\beta) d\gamma$$

  where (α, β, γ) are the Euler angles that specify the orientation of the final system relative to the initial particle.

- Since the decay particles are pseudo-scalar, we can integrate over the Euler angles.
  $\to$ Decay amplitudes depends only on two independent kinematical variables:

$$X = \frac{s_2 - s_1}{m_\pi^2}$$

$$Y = \frac{s_3 - s_0}{m_\pi^2}$$

  where

$$s_i = (\mathbf{p}_K - \mathbf{p}_i)^2 = (m_K - m_i)^2 - 2 m_K T_i \, , i = 1, 2, 3$$

$$s_0 = \frac{1}{3} \sum_i s_i = \frac{1}{3}(m_K^2 + m_1^2 + m_2^2 + m_3^2)$$

$K \to 3\pi$ Decay Amplitudes (cont)

$$|A(K \to 3\pi)|^2 \propto 1 + gY + hY^2 + kX^2$$

PDG: $g = -0.2154 \pm 0.0035$, $h = 0.012 \pm 0.008$, $k = -0.0101 \pm 0.0034$

- The three-pion states have $I = 1, 2, 3$.
- Restricting to $\Delta I \leq 3/2$ the isospin channel for the decay $K^\pm \to \pi^\pm\pi^\pm\pi^\mp$ are $I = 1, 2$.

$$\begin{aligned} A(K^+ \to \pi^+\pi^+\pi^-) &= \\ (a_{11} + a_{13})e^{i\delta_{1S}} &+ [(b_{11} + b_{13})e^{i\delta_{1M}} + b_{23}e^{i\delta_2}]Y \\ + c(Y^2 + X^2/3)e^{i\delta_{1S}} &+ d(Y^2 - X^2/3)e^{i\delta_{1M}} \end{aligned}$$

  where $a's, b's, c$ and d represent the transition amplitudes to different final isospin states with the first subscript referring to the isospin of the final state and the second is twice the change in isospin between the initial and final states. The δ's are the final-state strong interaction phases.
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$$\left.\begin{array}{l} g \neq \bar{g} \\ h \neq \bar{h} \\ k \neq \bar{k} \end{array}\right\} \Rightarrow CP\ symmetry\ is\ broken.$$

CP-violating Observables

Slope asymmetry

$$\delta g = \frac{g - \bar{g}}{g + \bar{g}}$$

$$\delta g = \frac{Im[(a_{11} + a_{13})^*(b_{11} + b_{13})]sin(\delta_{1S} - \delta_{1M}) + Im[(a_{11} + a_{13})^* b_{23}]sin(\delta_{1S} - \delta_2)}{Re[(a_{11} + a_{13})^*(b_{11} + b_{13})]cos(\delta_{1S} - \delta_{1M}) + Re[(a_{11} + a_{13})^* b_{23}]cos(\delta_{1S} - \delta_2)}$$

- The dominant CP-violating effect is due to the interference between two $|\Delta I = 1/2|$ amplitudes (a_{11} and b_{11}).
- No cancellation between gluonic and electroweak penguin diagrams at large top mass.

Theoretical Predictions

	$\|\delta g\|$
H.-Y. Cheng (1991)	$< 1 \times 10^{-5}$
D'Ambrosio *et al.* (1991)	$\leq 1 \times 10^{-5}$
Isidori *et al.* (1992)	$\sim 1 \times 10^{-6}$
E.P. Shabalin (1993)	$\leq (5 \pm 2) \times 10^{-5} \|sin\delta\|$
A.A. Bel'kov *et al.* (1993)	$\sim 0.5 \times \|\epsilon'/\epsilon\|$
D'Ambrosio *et al.* (1998)	$\sim 2 \times 10^{-6}$
E.P. Shabalin (1998)	$\sim 2 \times 10^{-4}$

Experimental Efforts

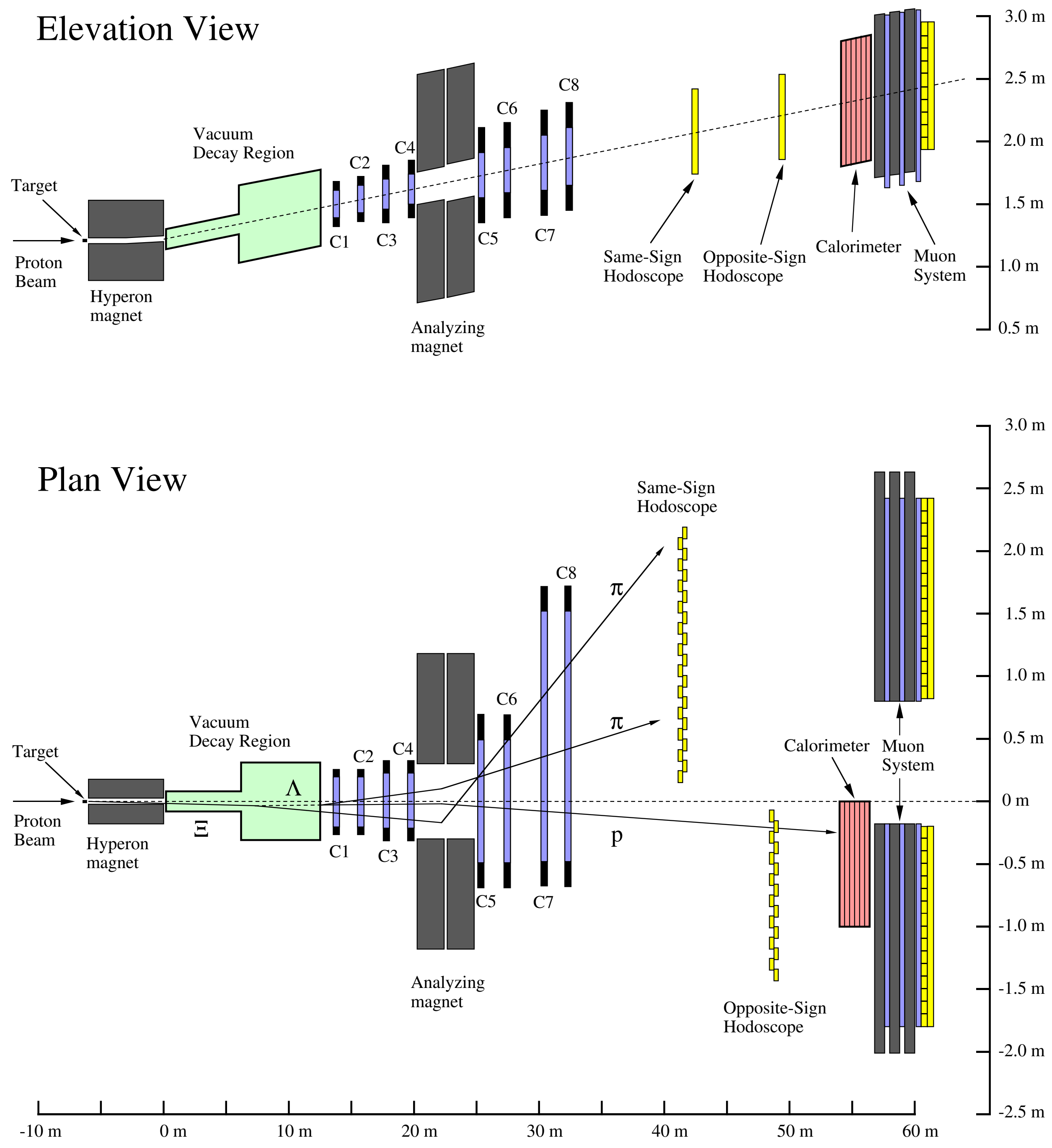
- Past

  1. 1970: Dedicated search at BNL AGS.
     Collected 1.6 million of $K^{\pm} \to \pi^{\pm}\pi^{\pm}\pi^{\mp}$ decays for each charge.
     $\delta g = (-0.70 \pm 0.53) \times 10^{-2}$

- Present and Future

  1. FNAL E871 (HyperCP)
  2. KLOE at DAFNE: Projects to collect about 5×10^{8} $K^{\pm} \to \pi^{\pm}\pi^{\pm}\pi^{\mp}$ decays in one year of running with luminosity of $5 \times 10^{32}\ cm^{-2}s^{-1}$.

The HyperCP Spectrometer



Summary of the 1997 Run

- Data collected between April 1997 and September 1997.

- Accumulated about 75 billion triggers on over 10,000 Exabytes 5 Gb tapes ($\sim$33 Tb).

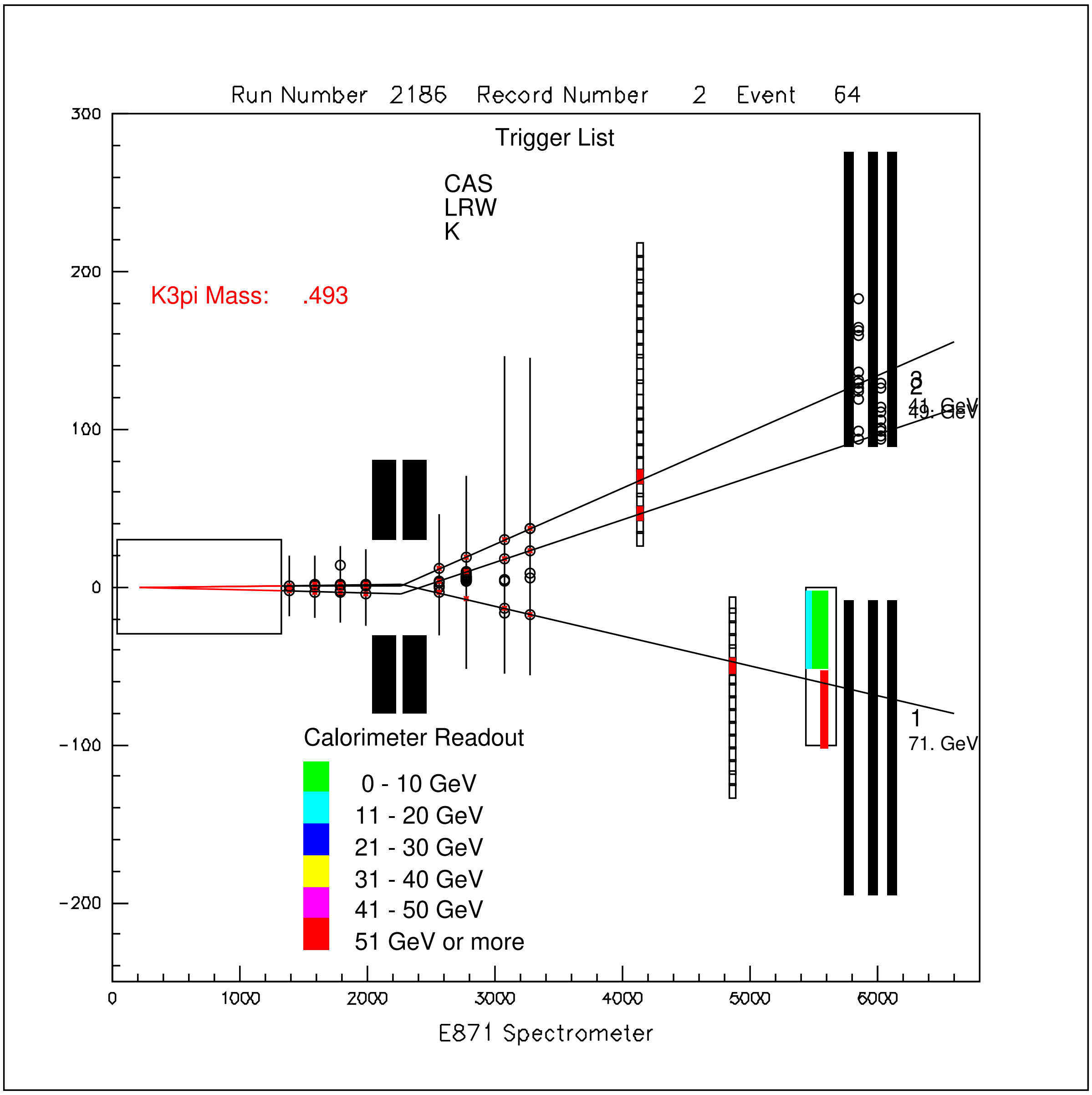
	Positive	Negative
All triggers	48.8×10^9	25.6×10^9
K triggers	40.8×10^9	21.3×10^9
Expected $K \to 3\pi$	109×10^6	48×10^6

- The error in δg is given by

$$\sigma_{\delta g} = \frac{1}{2g}\sqrt{\frac{3.9}{N^+} + \frac{3.9}{N^-}}$$

giving us a statistical sensitivity in δg of about 7×10^{-4}.

Event Display of a $K \to 3\pi$ Decay



Analysis Strategy

Experimentally, we measure the number of events in the X and Y bin of the Dalitz plot. Assume that

$N^+(X,Y) \equiv$ number of positive events in X and Y bin.

$N^-(X,Y) \equiv$ number of negative events in X and Y bin.

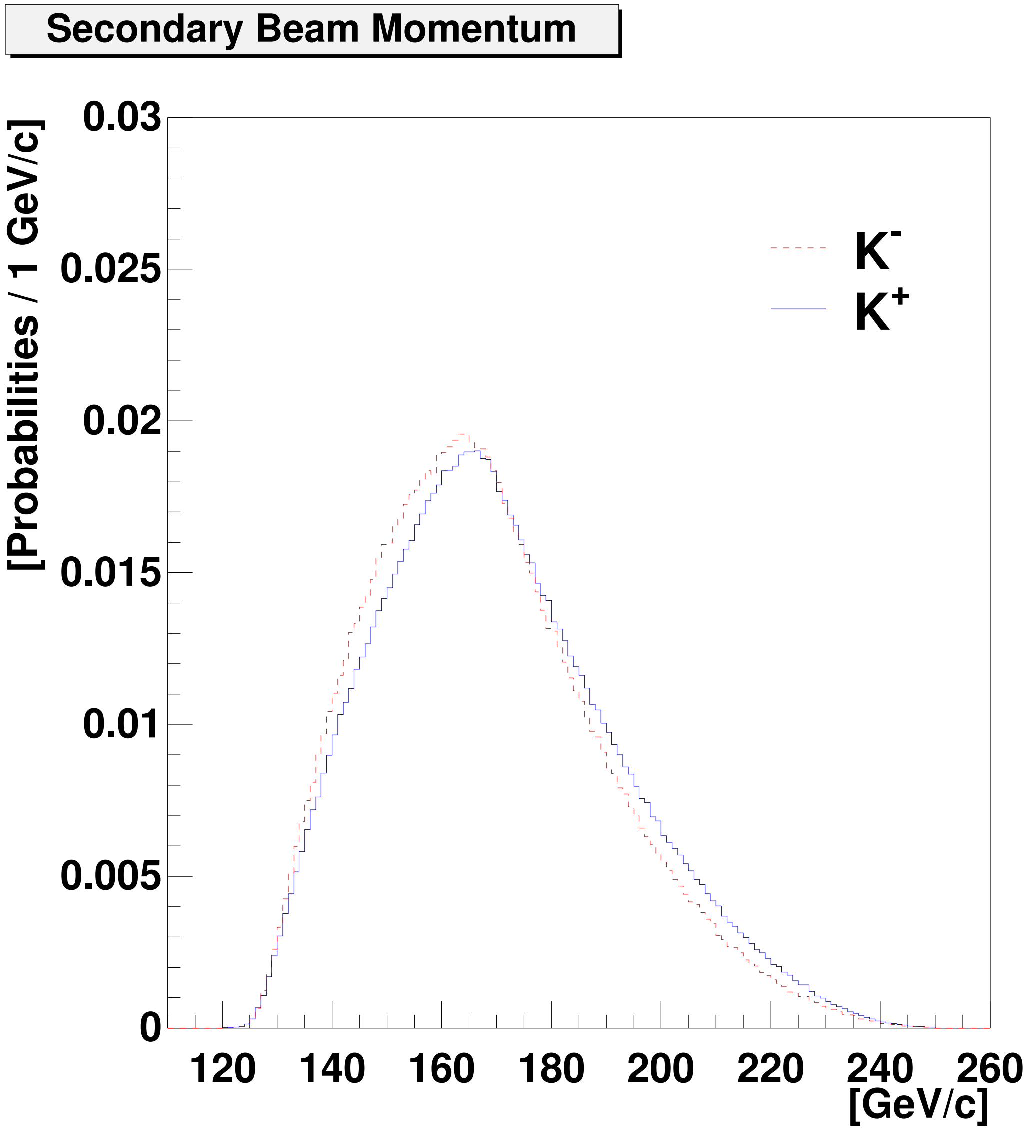
Then the asymmetry we measure is given by

$$\begin{aligned}\mathcal{A}(X,Y) &= \frac{N^+(X,Y) - N^-(X,Y)}{N^+(X,Y) + N^-(X,Y)} \\ &= \frac{\epsilon^+(X,Y)(1+gY) - \epsilon^-(X,Y)(1+\bar{g}Y)}{\epsilon^+(X,Y)(1+gY) + \epsilon^-(X,Y)(1+\bar{g}Y)}\end{aligned}$$

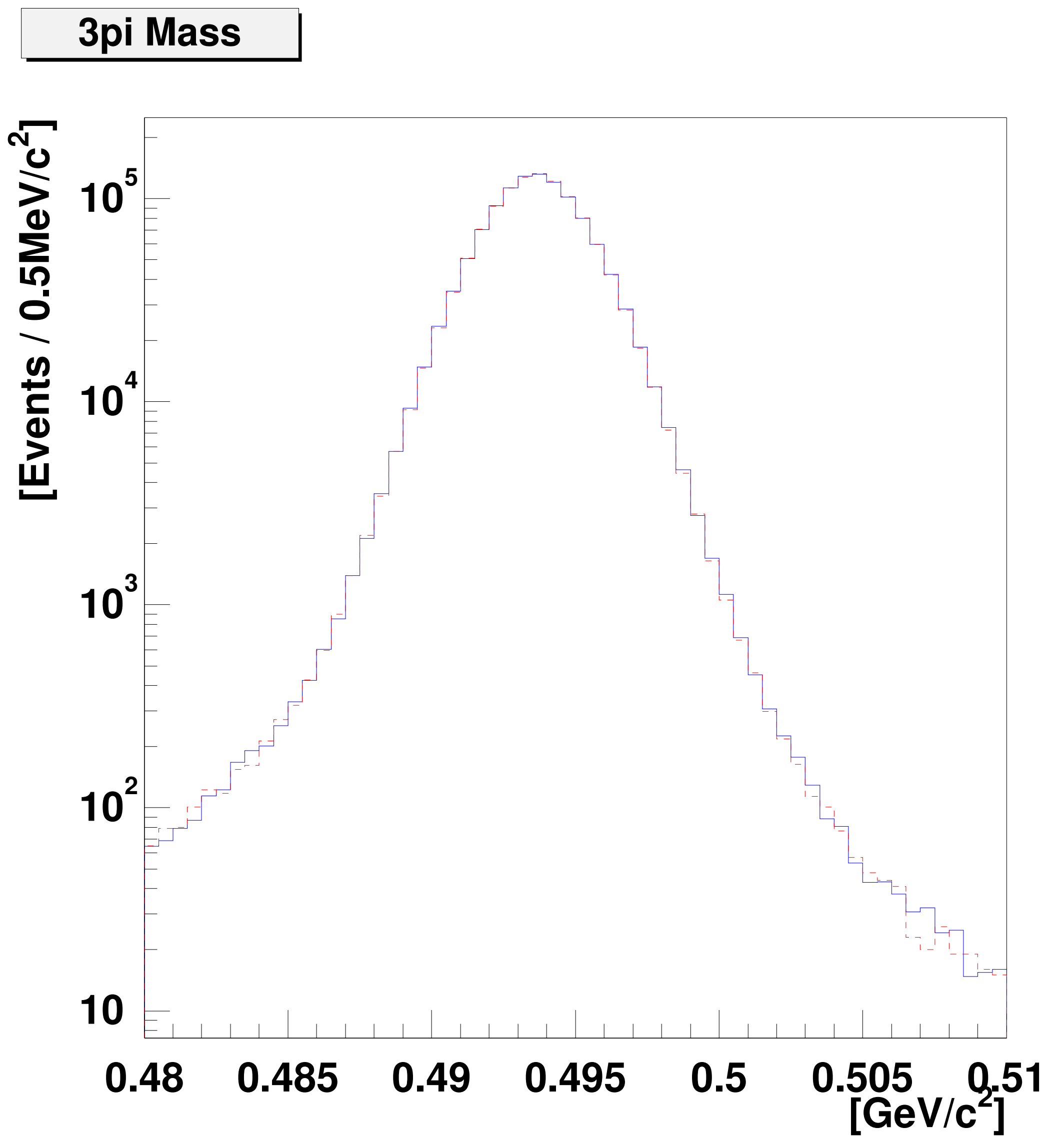
where $\epsilon^{\pm}(X,Y) \equiv$ acceptance.

Use real data to show that the acceptances between positive and negative are the same down to the level that they will not introduce a fake asymmetry of the sensitivity that we are capable of measuring.

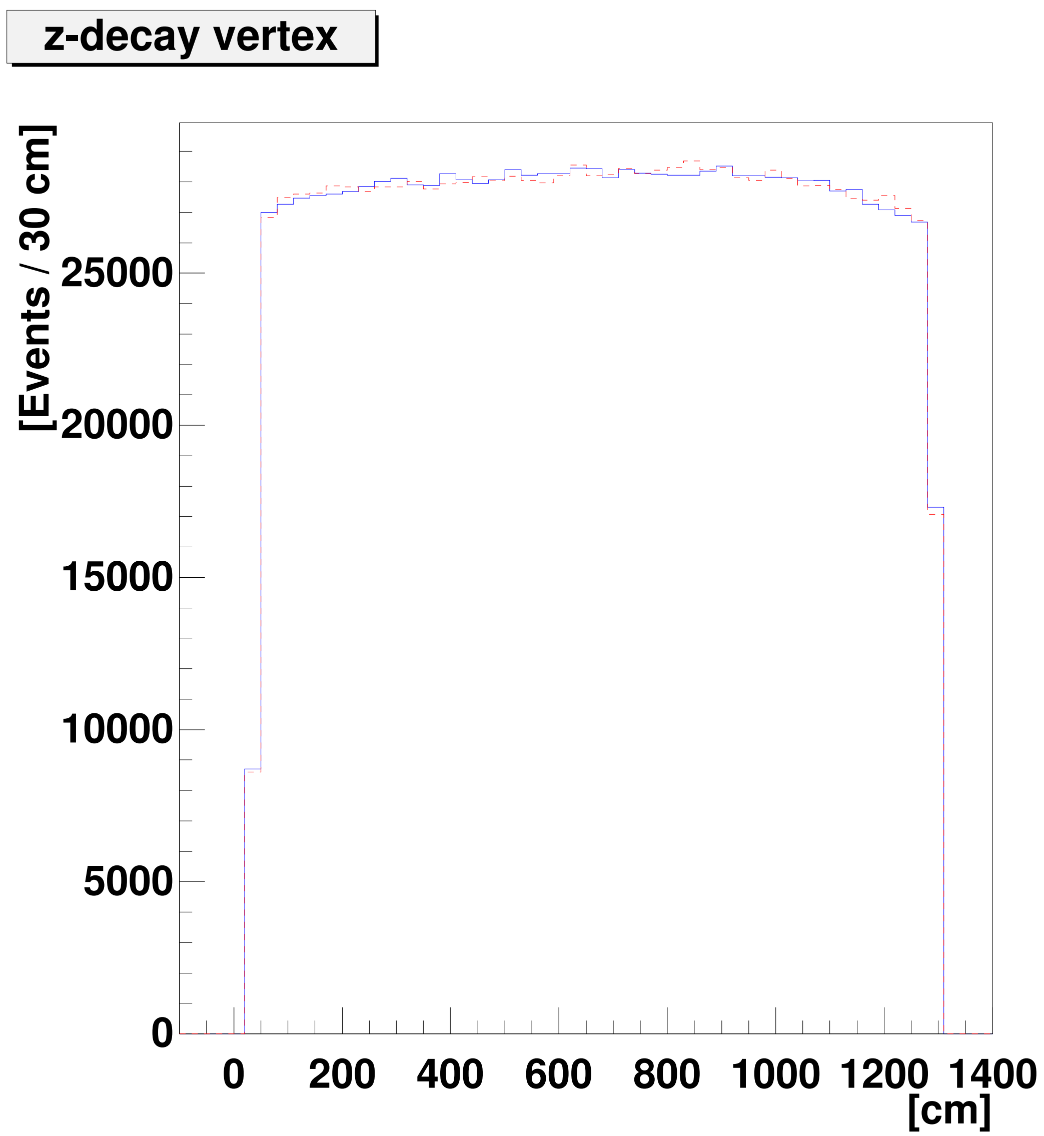
Plots shown in this talk are based on 2% of our dataset and are VERY PRELIMINARY.



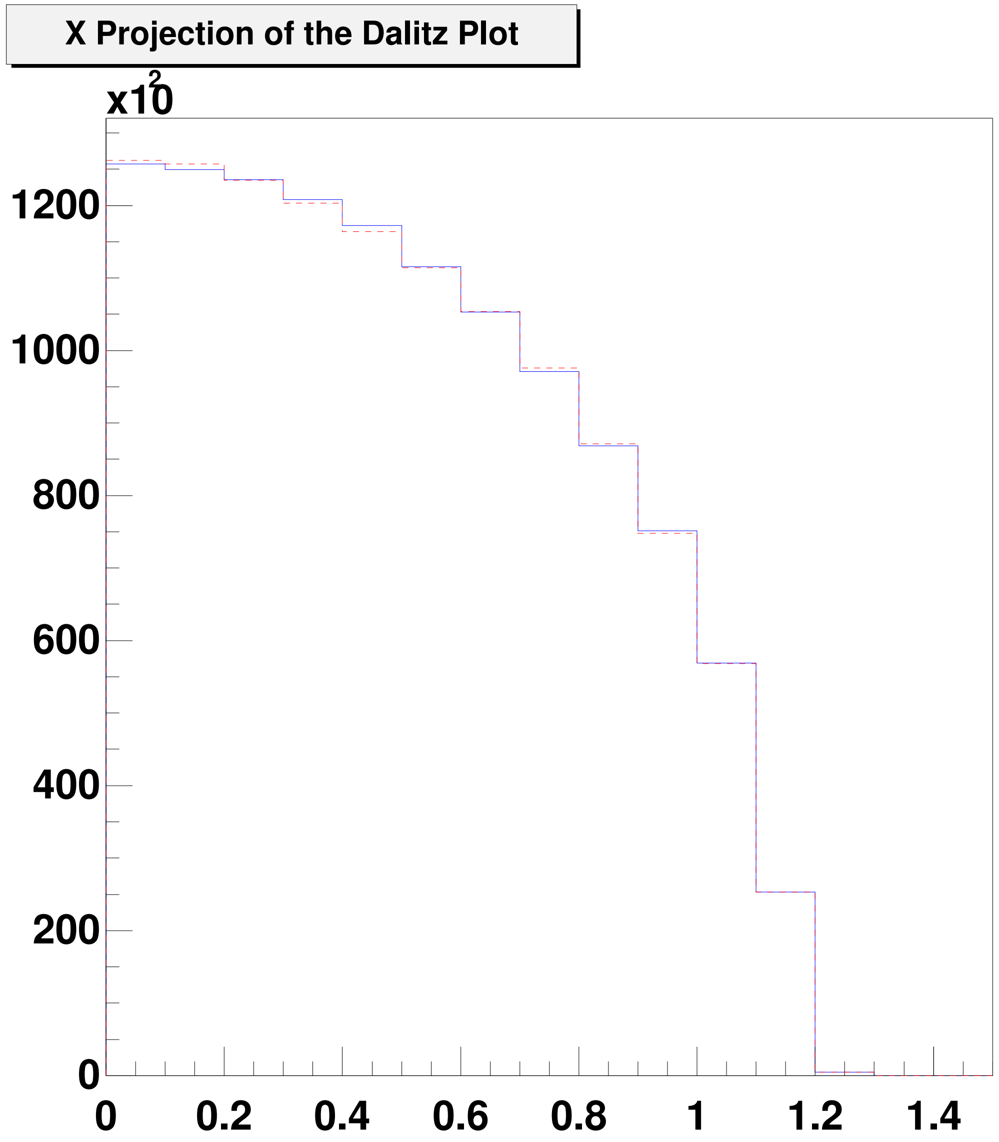
- Due to different production physics of particle and anti-particle, the momentum spectra for K^+ and K^- are different which can introduce an acceptance difference between K^+ and K^-.
- K^+ and K^- dataset are normalized such as to make their momentum spectra the same.



- Good mass resolution ($\sigma_{mass} \sim 1.9 MeV/c^2$).
- Good signal to background ratio ($B/S < 10^{-3}$).
- We have not corrected for possible differences (e.g, magnetic field, background.) between positive and negative dataset.



- The vacuum decay volume is between $z = 0.32\ m$ and $z = 13.32\ m$.
- $\bar{p}_K \sim 150\ GeV/c \Rightarrow \gamma\beta c\tau \sim 1100\ m$.



- The asymmetry in the X projection of the Dalitz plot is expected to be zero.
- Any observed asymmetry would indicate an acceptance difference between the positive and negative dataset.
- We have not looked at the Y projection of the Dalitz plot as we are performing a blind analysis.

Conclusions

- HyperCP has built an excellent spectrometer with very good resolution.

- HyperCP has a successful 1997 run and has collected a lot of data with many physics topics. In particular, we expect to reconstruct about 160 million charged $K \rightarrow 3\pi$ decay.

- We are in the early stage of the analysis and a lot more work has to be done.

- The projected statistical sensitivity in the asymmetry in the slope parameter of the Dalitz plot is 7×10^{-4}, almost one order of magnitude better than the present limit.