Observation of ππ Scattering in $K_L \to 3\pi^0$ Decays by KTeV

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- Motivation to study $K_L \to \pi^0\pi^0\pi^0$ Dalitz Plot
- Overview of Analysis
- Results
- Summary

KTeV: Arizona, Chicago, Colorado, Elmhurst, Fermilab, Osaka, Rice, Sao Paolo, UCLA, Virginia, Wisconsin

Before 2004:

"Measurement of the quadratic slope parameter in the $K_L \rightarrow 3\pi^0$ decay Dalitz plot"

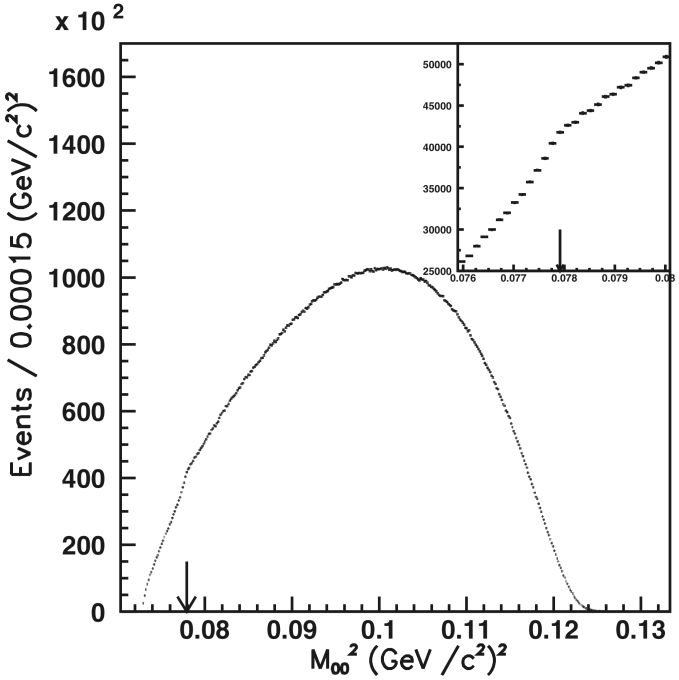
- S. Somalwar et al. (E731), PRL **68**, 2580 (1992)
- A. Lai et al. (NA48), PL **B515**, 261 (2001)

Density on Dalitz plot:

$$\left|M_{000}\right|^2 \propto 1 + h_{000} R_D^2 ,$$

where R_D is the distance from the center of the Dalitz plot.

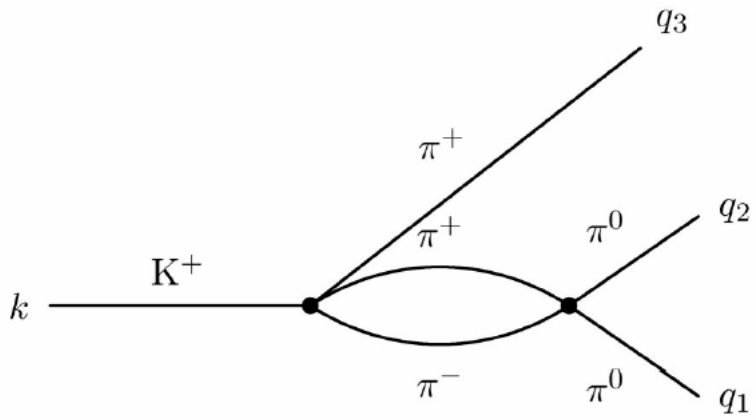
(Term with linear dependence on R_D is zero because of identical particles in final state.)



NA48/2 observed "cusp" in $K^{\pm}\to\pi^{\pm}\pi^0\pi^0$ decays collected during 2003

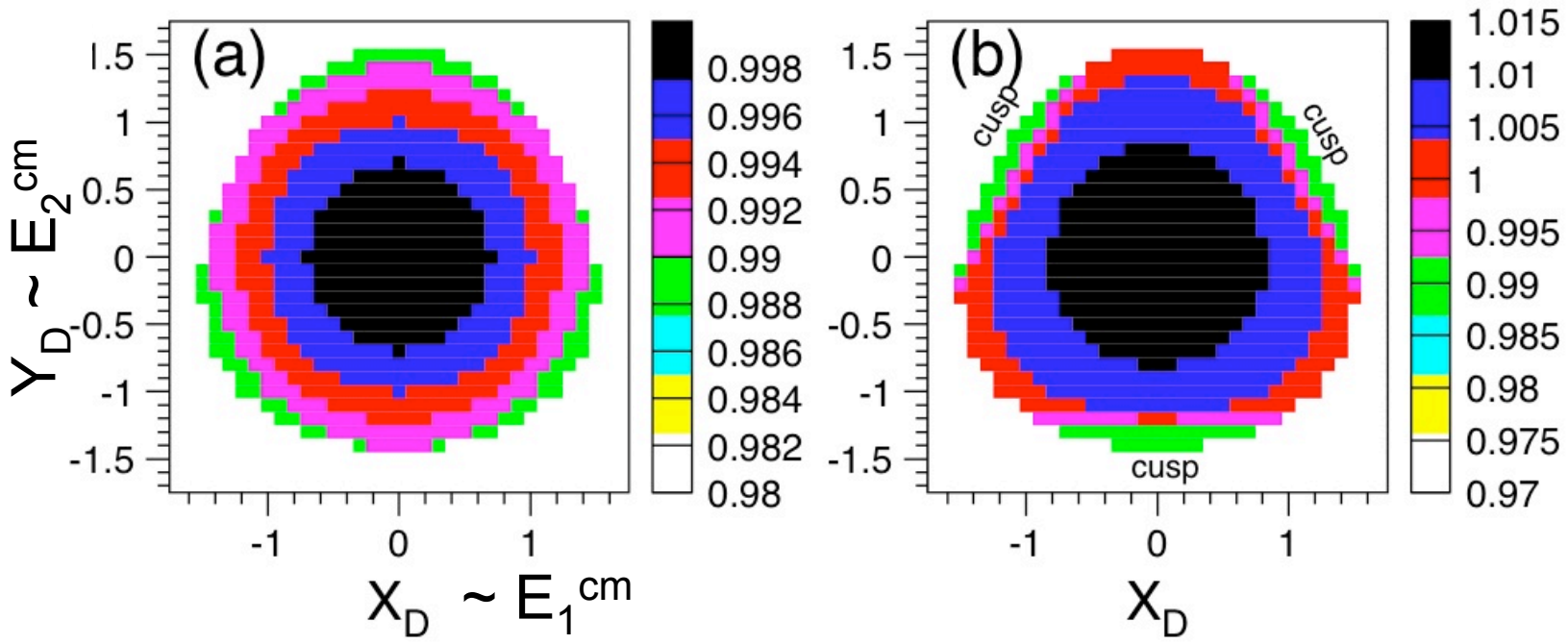
2004: Cabibbo pointed out that the $\pi^0\pi^0$ mass spectrum in $K^{\pm}\to\pi^{\pm}\pi^0\pi^0$ could be used to measure the difference in $\pi\pi$ scattering lengths between I=0 and I=2 states, a_0-a_2 – can be precisely calculated in chiral perturbation theory.

Rescattering process:
$K^{\pm}\to\pi^{\pm}\pi^+\pi^-\to\pi^{\pm}\pi^0\pi^0$



The same rescattering affects dynamics of $K_L\to\pi^0\pi^0\pi^0$ decays, but effect is expected to be much smaller.

$K_L \to 3\pi^0$ Dalitz plot will show effect of two contributions:



Intrinsic $K_L \to 3\pi^0$ dynamics

$$|M_{000}|^2 \propto 1 + h_{000} R_D^2 \quad (R_D^2 = X_D^2 + Y_D^2)$$

(PDG: $h_{000} = -0.005$)

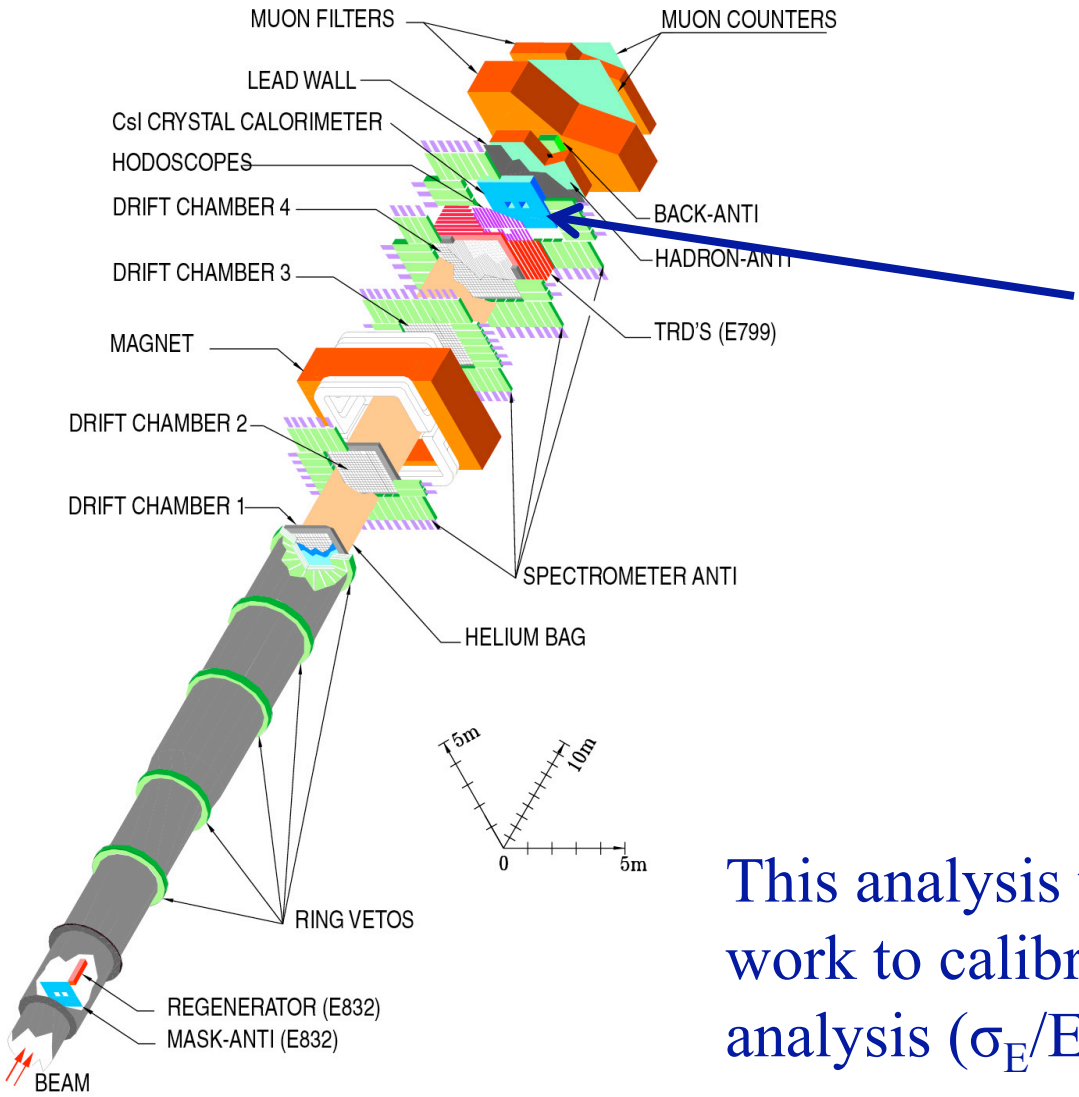
Rescattering

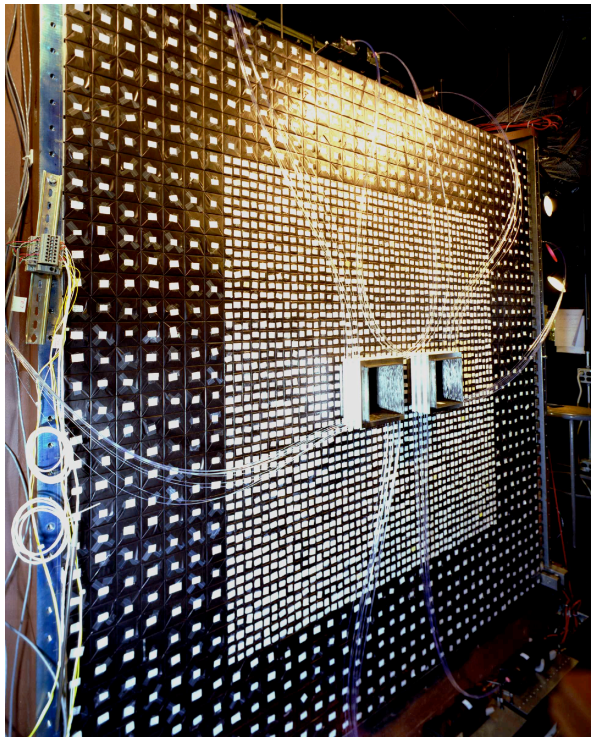
$K_L \to \pi^+\pi^-\pi^0 \to \pi^0\pi^0\pi^0$

(shown with $h_{000}=0$)

Previous results on h_{000} (E731 & NA48) ignored rescattering; KTeV presents first measurement of h_{000} that accounts for rescattering.

Data sample: 68 million $K_L \rightarrow \pi^0\pi^0\pi^0$ decays collected for acceptance studies as part of KTeV ε' analysis.



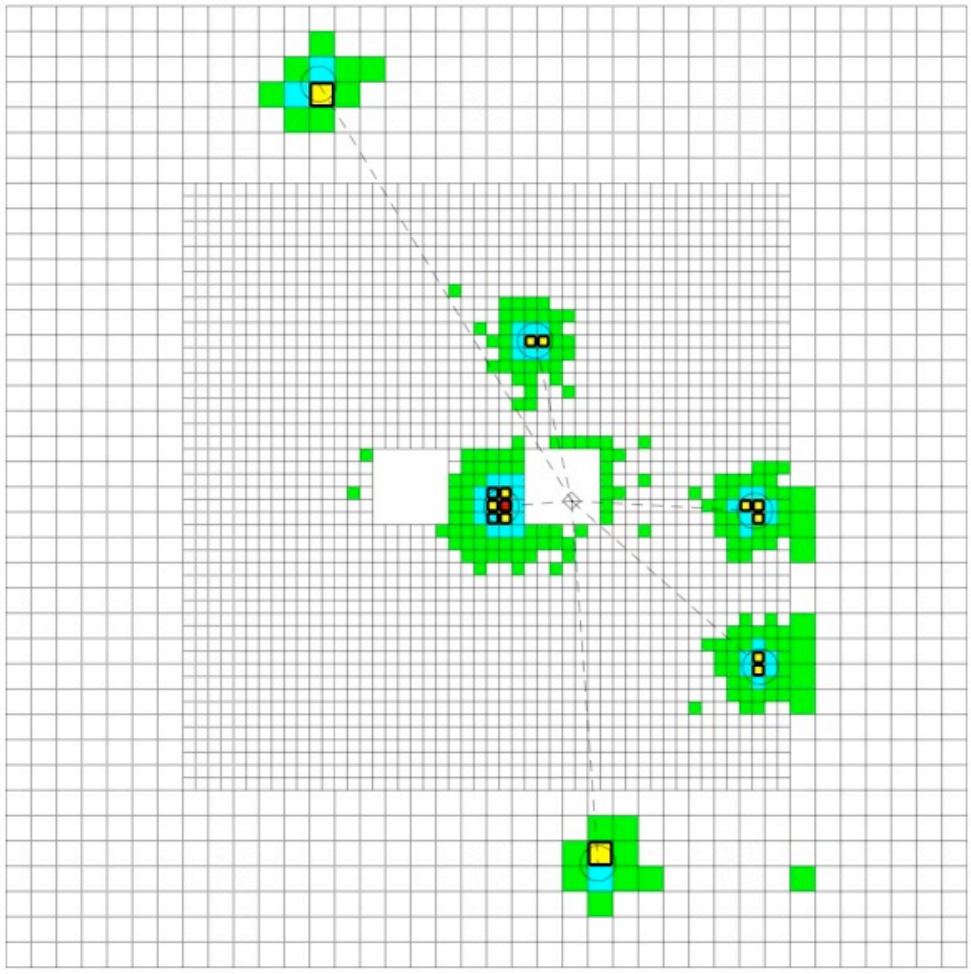


This analysis takes advantage of years of work to calibrate CsI calorimeter for ε'/ε analysis ($\sigma_E/E < 1\%$)

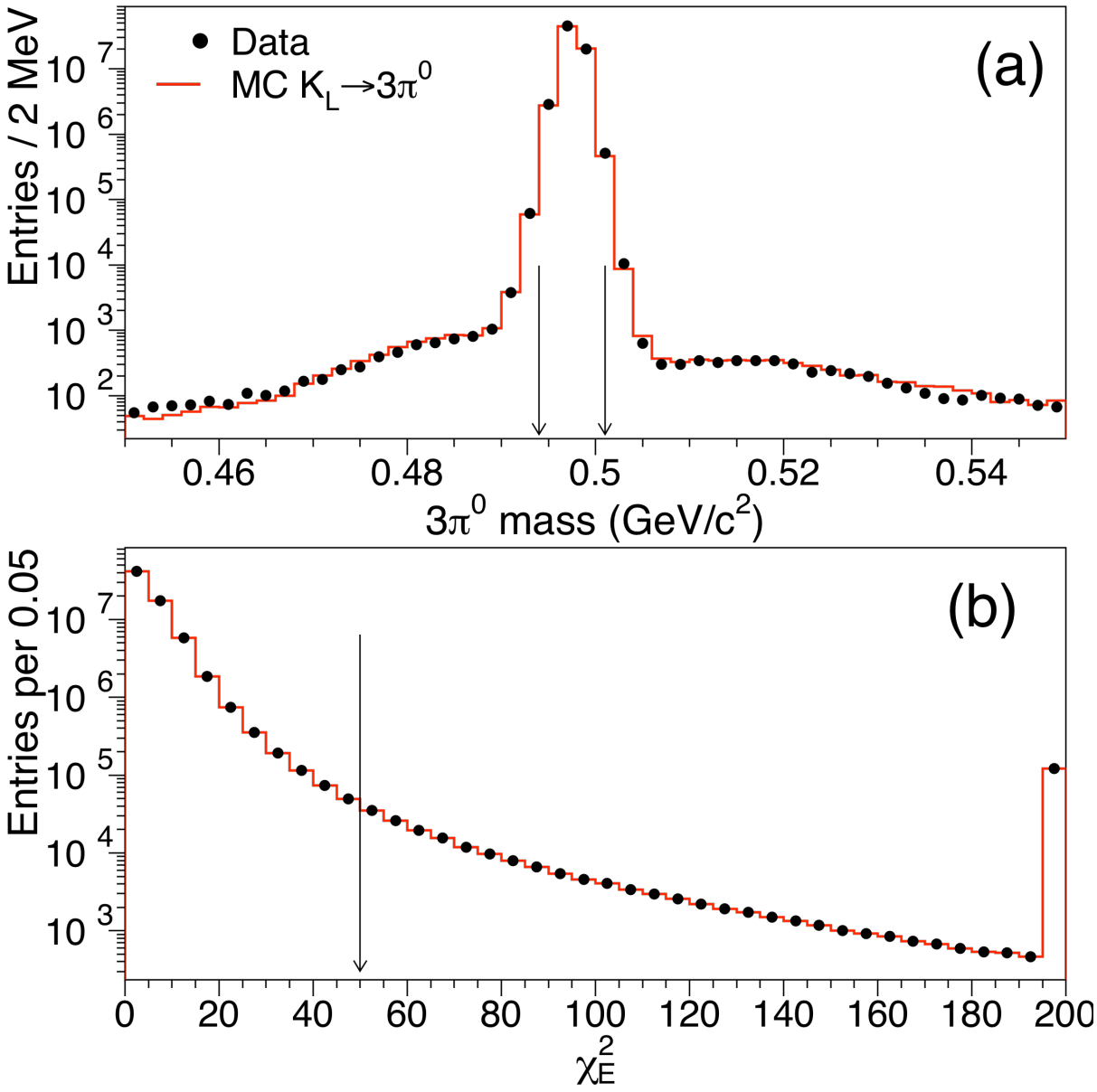
Event Reconstruction

- $K_L \rightarrow \pi^0\pi^0\pi^0$ reconstruction identical to $K_L \rightarrow \pi^0\pi^0$
- To improve resolution in Dalitz plot variables, we fit 6 E_γs in each event using m_K and m_π constraints:

$\sigma(R_D^2)=0.070 \rightarrow 0.014$

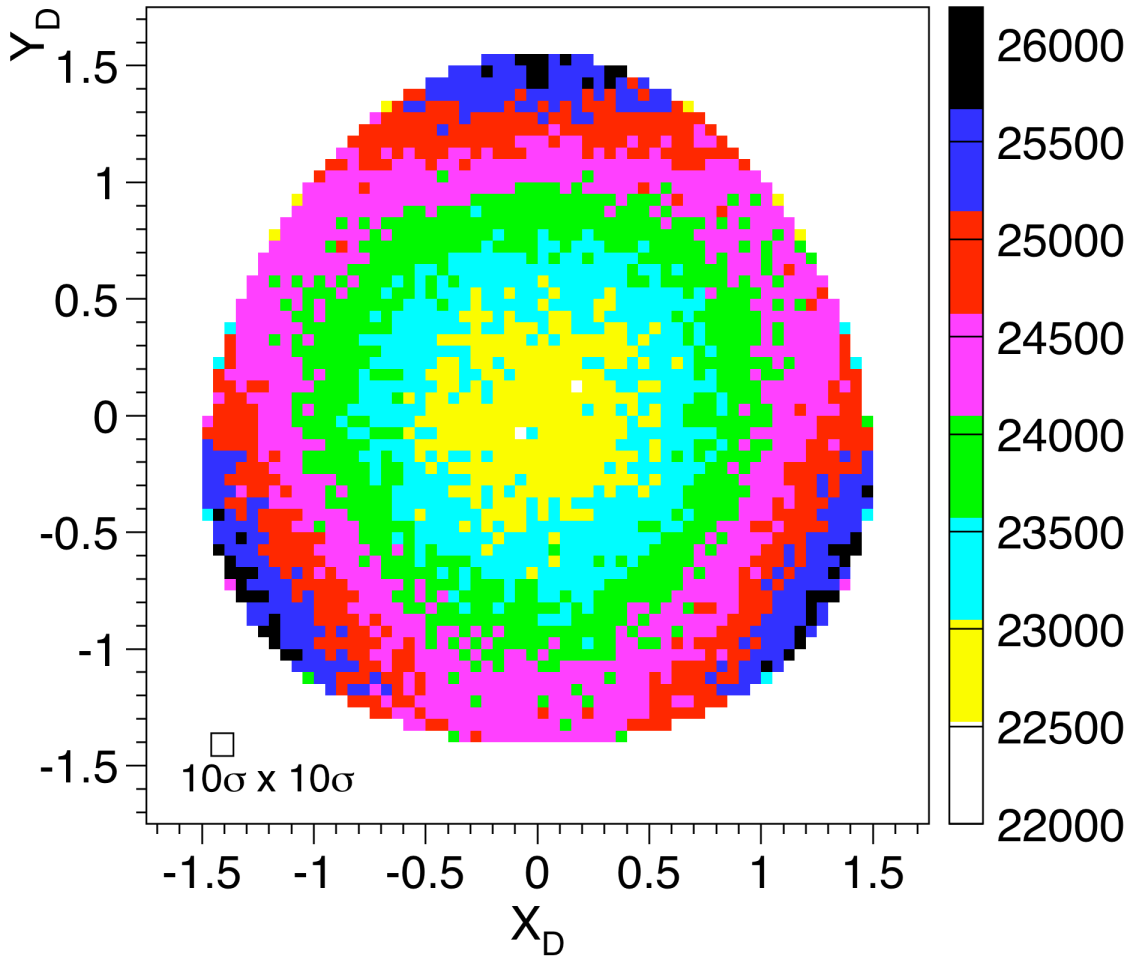


$K_L \to \pi^0\pi^0\pi^0$ Data – Monte Carlo Comparisons



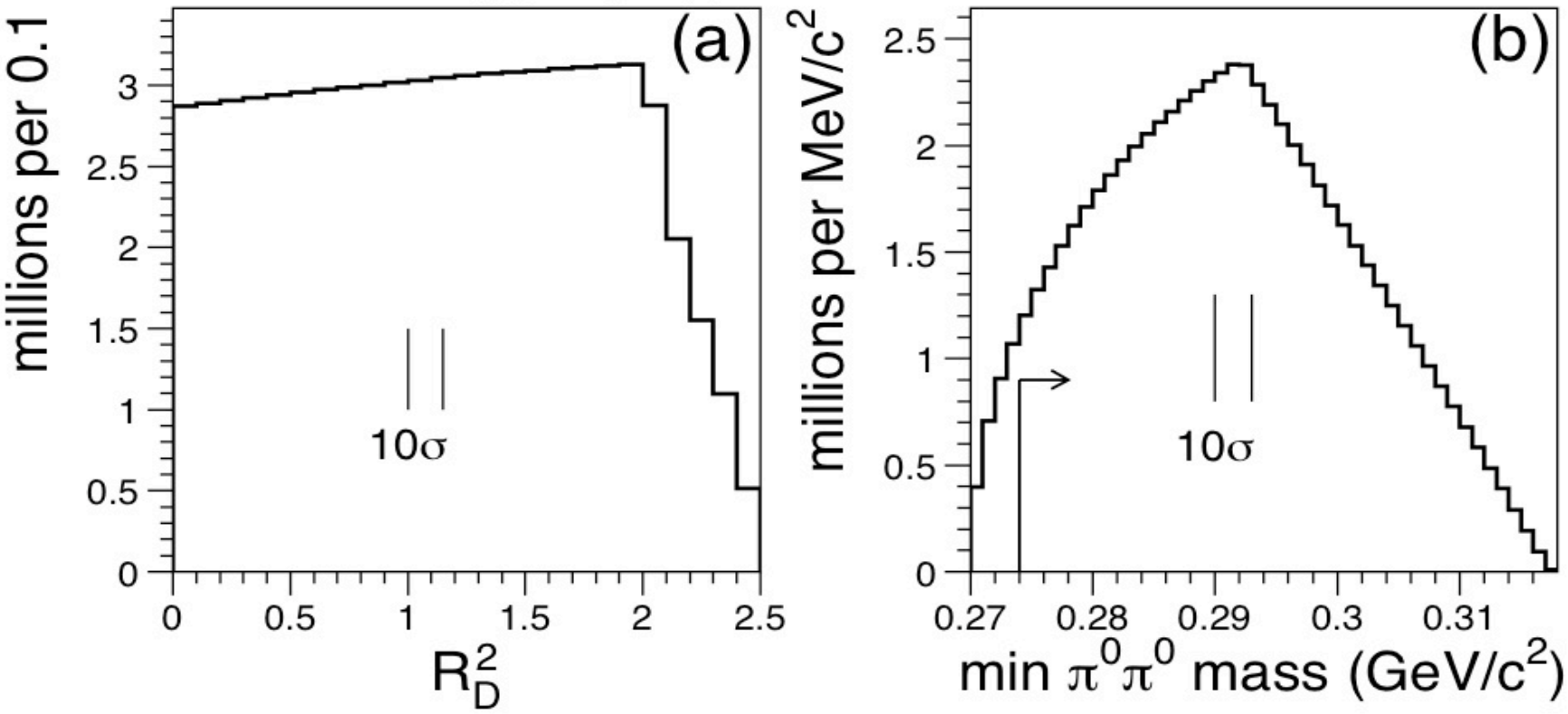
$$\chi^2_E = \sum_{i=1}^{6} \frac{(E_i - E_i^{fit})^2}{\sigma_i^2}$$

Raw Dalitz plot: 68 million events

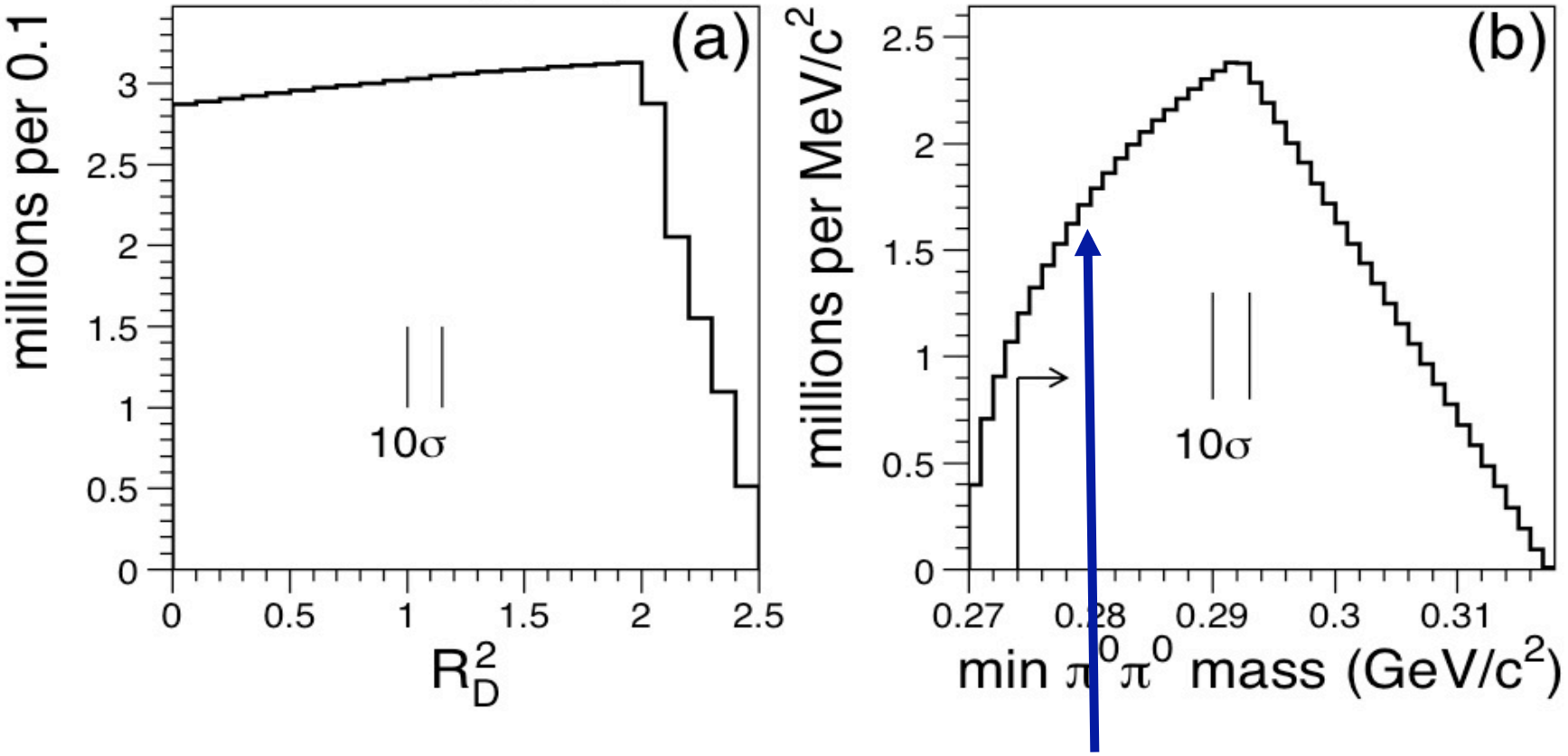


10% variation is mostly from acceptance effects; physics effects give ~1% variations,

Dalitz Plot Projections

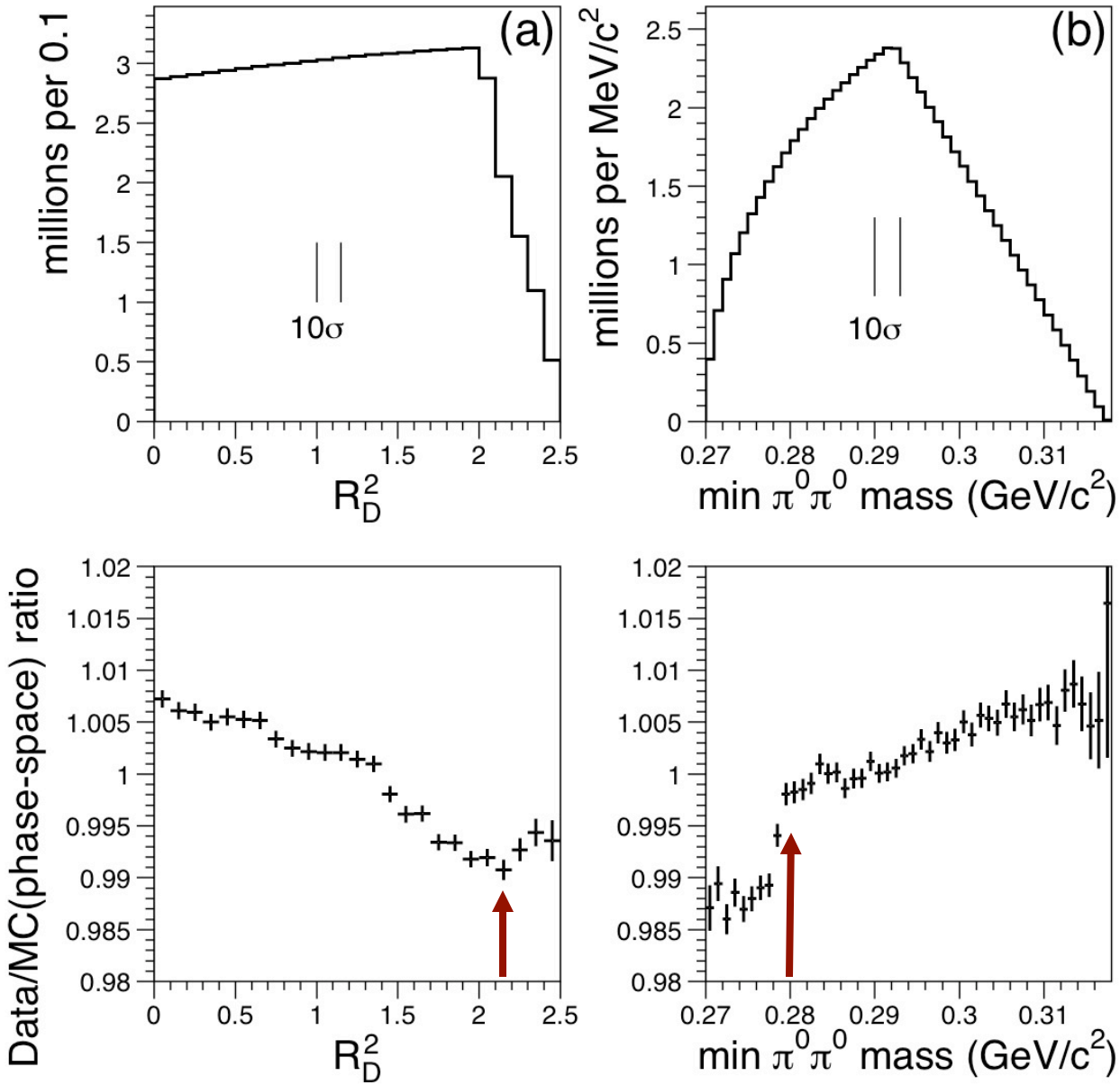


Dalitz Plot Projections



no obvious cusp effect as in $K^{\pm}$

Cusp in $K_L \to \pi^0\pi^0\pi^0$



$$\frac{\text{Raw Dalitz Density}}{\text{MC Phase Space}}$$

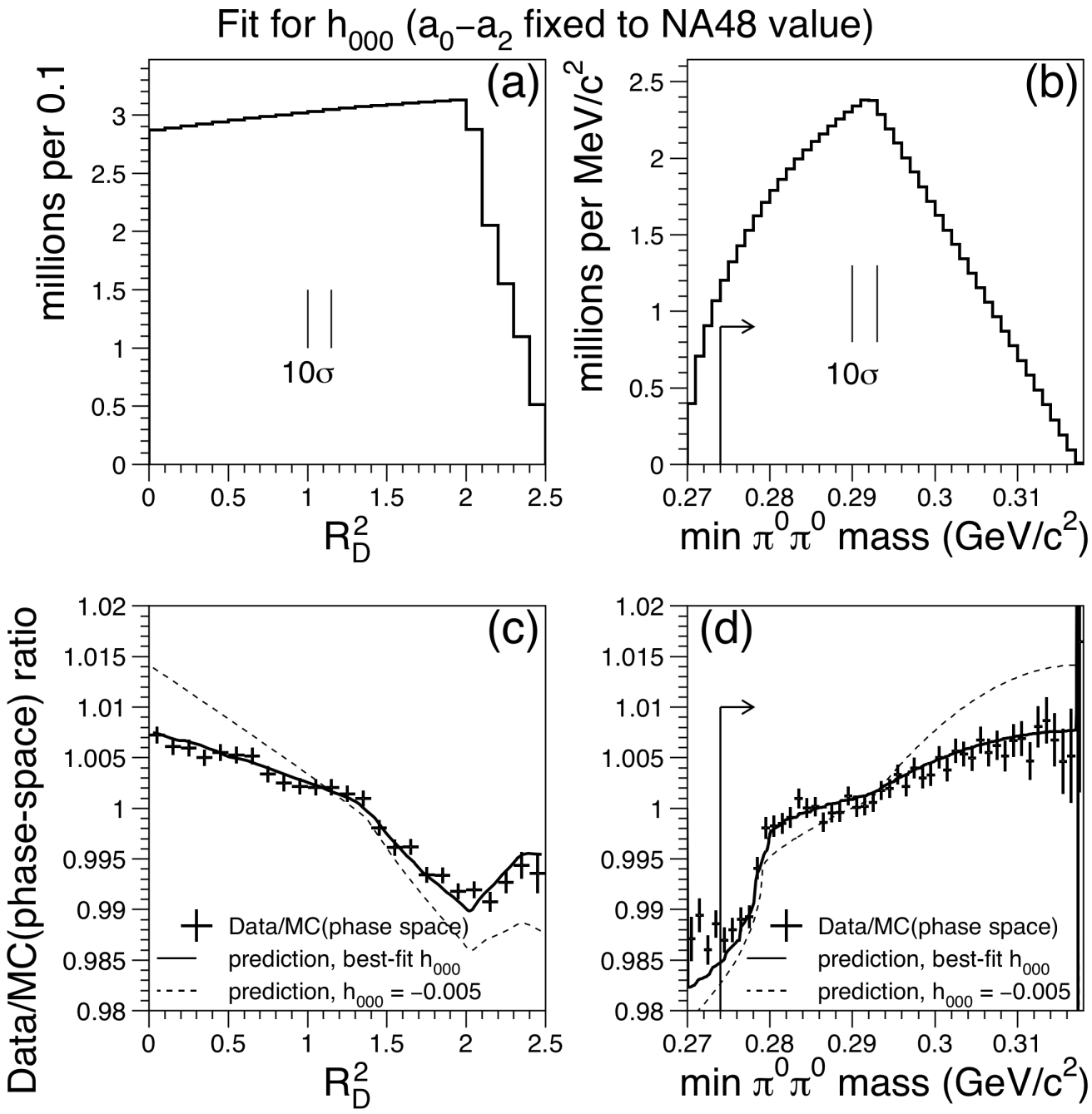
⇩

Visible cusp

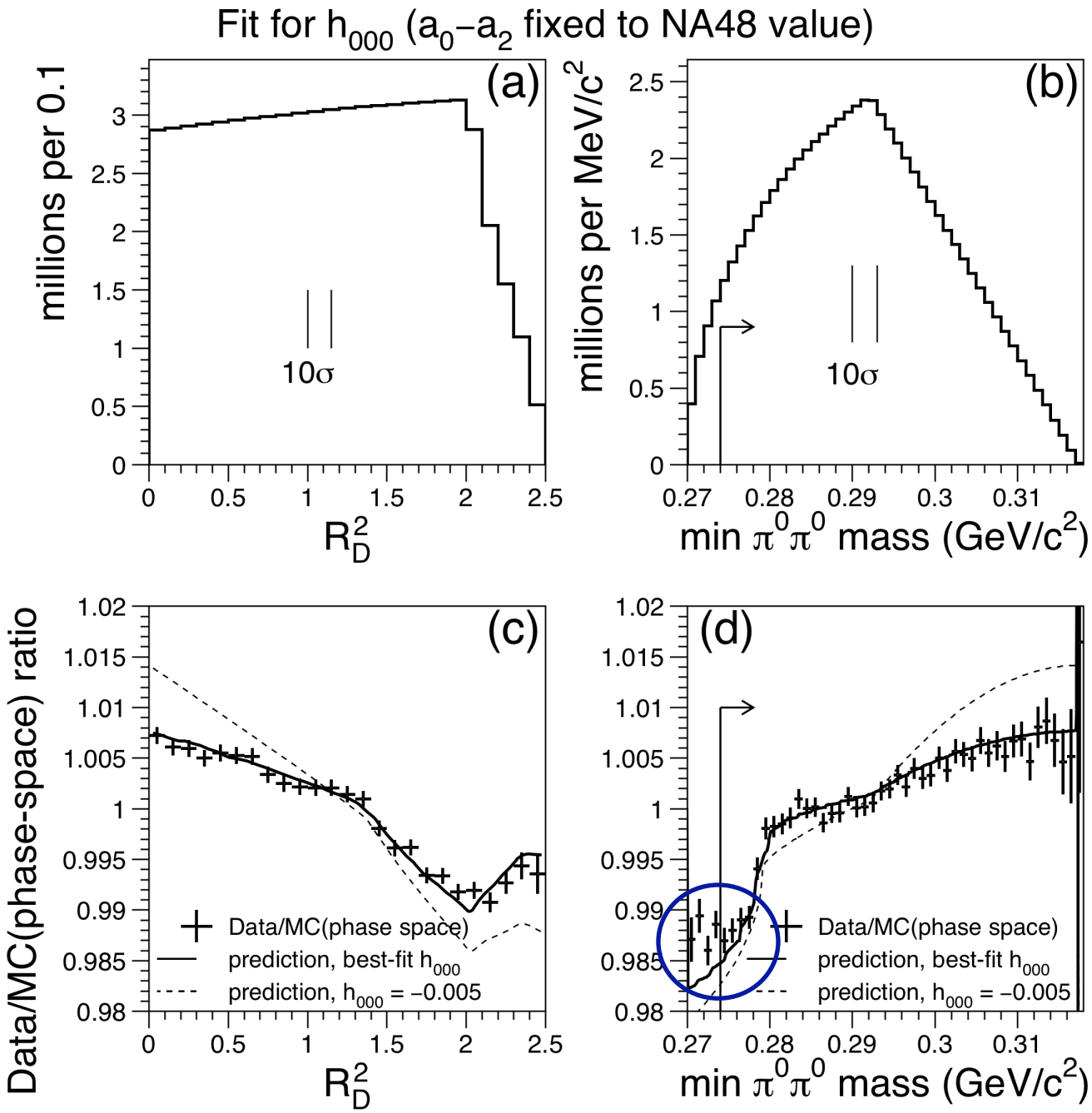
- We fit our data using model of Cabibbo and Isidori: JHEP 503, 21 (2005) – includes all one and two loop rescattering processes.
- h_{000} and $a_0 - a_2$ are two free parameters for $K_L \to \pi^0\pi^0\pi^0$

We perform two fits:

1. Fixing a_0-a_2 to the NA48 value: $m_{\pi^+}(a_0 - a_2) = 0.268 \pm 0.017$
2. Floating both h_{000} and $a_0 - a_2$



Good agreement with model except for $m_{\pi^0\pi^0} < 0.274\ GeV/c^2$



Good agreement with model except for $m_{\pi^0\pi^0} < 0.274\ GeV/c^2$

This region is excluded for central values of fits, but is included in systematic error.

Fit Results

1. Using NA48 result $m_{\pi^+}(a_0 - a_2) = 0.268 \pm 0.017$,

$h_{000} = (+0.59 \pm 0.20_{stat} \pm 0.48_{syst} \pm 1.06_{ext}) \times 10^{-3} = (+0.59 \pm 1.19) \times 10^{-3}$

$\chi^2 / dof = 2805.3 / 2765$ (all pixels)

$\chi^2 / dof = 125.3 / 130$ (edge pixels)

2. Floating both h_{000} and $a_0 - a_2$:

$h_{000} = (-2.09 \pm 0.62_{stat} \pm 0.72_{syst} \pm 0.28_{ext}) \times 10^{-3} = (-2.09 \pm 0.99) \times 10^{-3}$

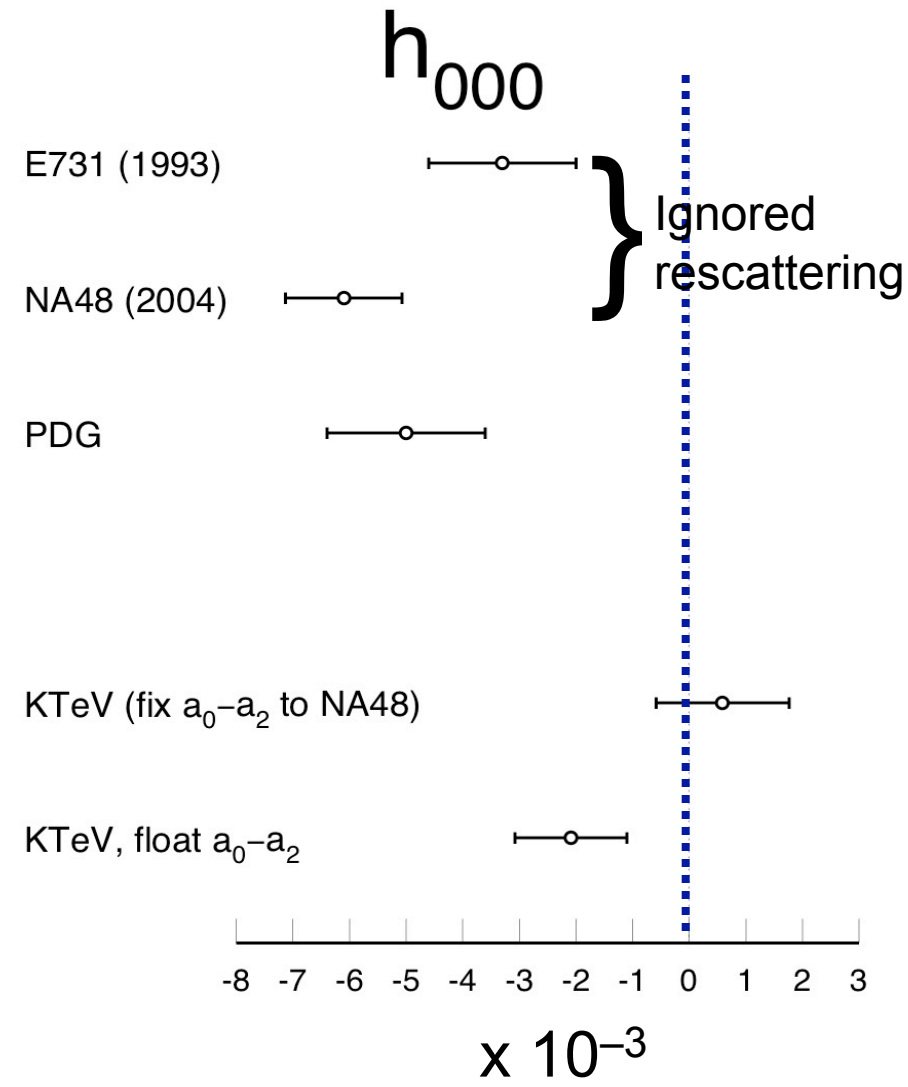
$m_{\pi^+}(a_0 - a_2) = 0.215 \pm 0.014_{stat} \pm 0.025_{syst} \pm 0.006_{ext} = 0.215 \pm 0.031$

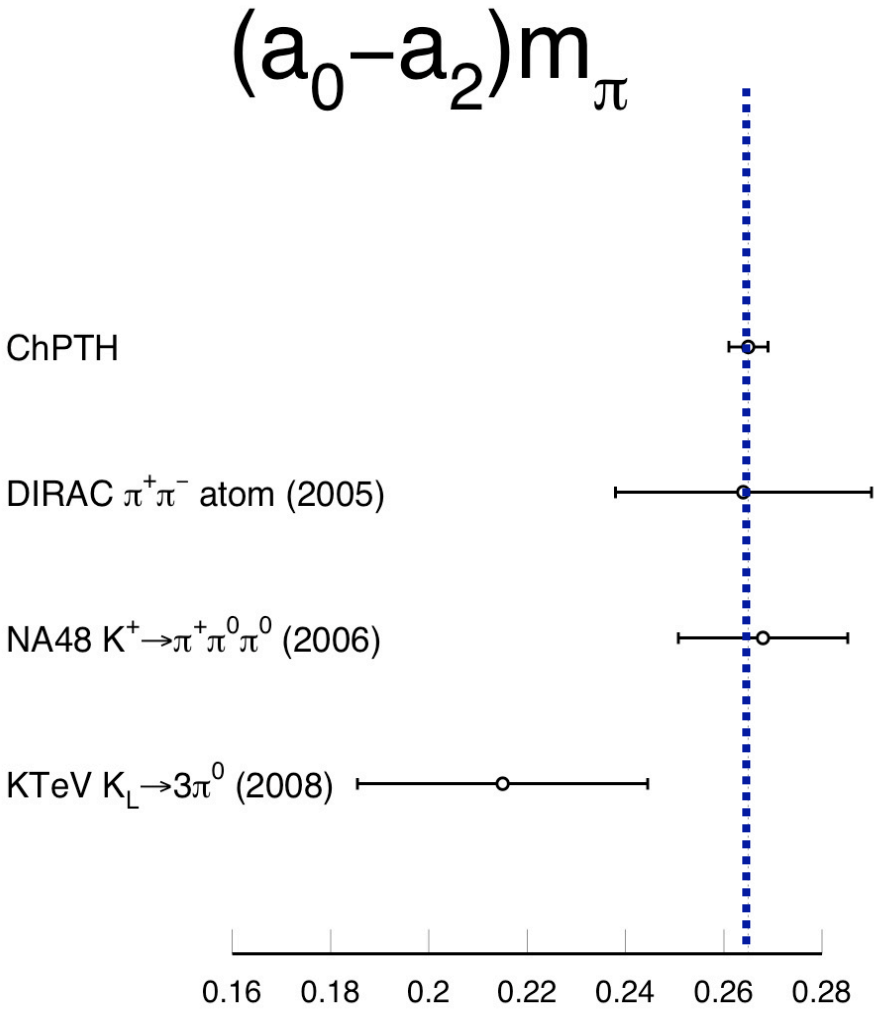
$\chi^2 / dof = 2790.6 / 2764$ (all pixels)

$\chi^2 / dof = 126.3 / 130$ (edge pixels)

ChPT (Colangelo et al.): $m_{\pi^+}(a_0 - a_2) = 0.265 \pm 0.004$

Comparison with Other Results





Summary

- Rescattering effect observed in $K_L \to 3\pi^0$
- Data well described by model of Cabbibo and Isidori, except for $m_{\pi\pi} < 0.274$ GeV/c^2
- Measured $a_0 - a_2$ consistent with but less precise than NA48 measurement in $K^\pm \to \pi^\pm\pi^0\pi^0$ decays (isospin decomposition favors $K^\pm$ over K^0)
- After including rescattering effect, no evidence for nonzero h_{000}

Results published in E. Abouzaid et al. [KTeV Collaboration], Phys. Rev. D **78**, 032009 (2008).