# Measurement of CP Violation in the $K_L$ Charge Asymmetry by KTeV


The KTeV Collaboration

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Les Rencontres de Physique de la Vallee d’Aoste

# $K_L \to \pi e \nu$ Charge Asymmetry

- Relation to $K^0$–$\overline{K^0}$ mixing:

$$K_L \sim (1 + \varepsilon_L)\, K^0 \;-\; (1-\varepsilon_L)\, \overline{K^0}$$

$$K^0 \to e^+\pi^-\nu \qquad \overline{K^0} \to e^-\pi^+\nu$$

Assuming CPT conservation in $K^0 \to \pi e \nu$ decays and the $\Delta S = \Delta Q$ rule, these two decays tag $K^0$ and $\overline{K^0}$ separately.

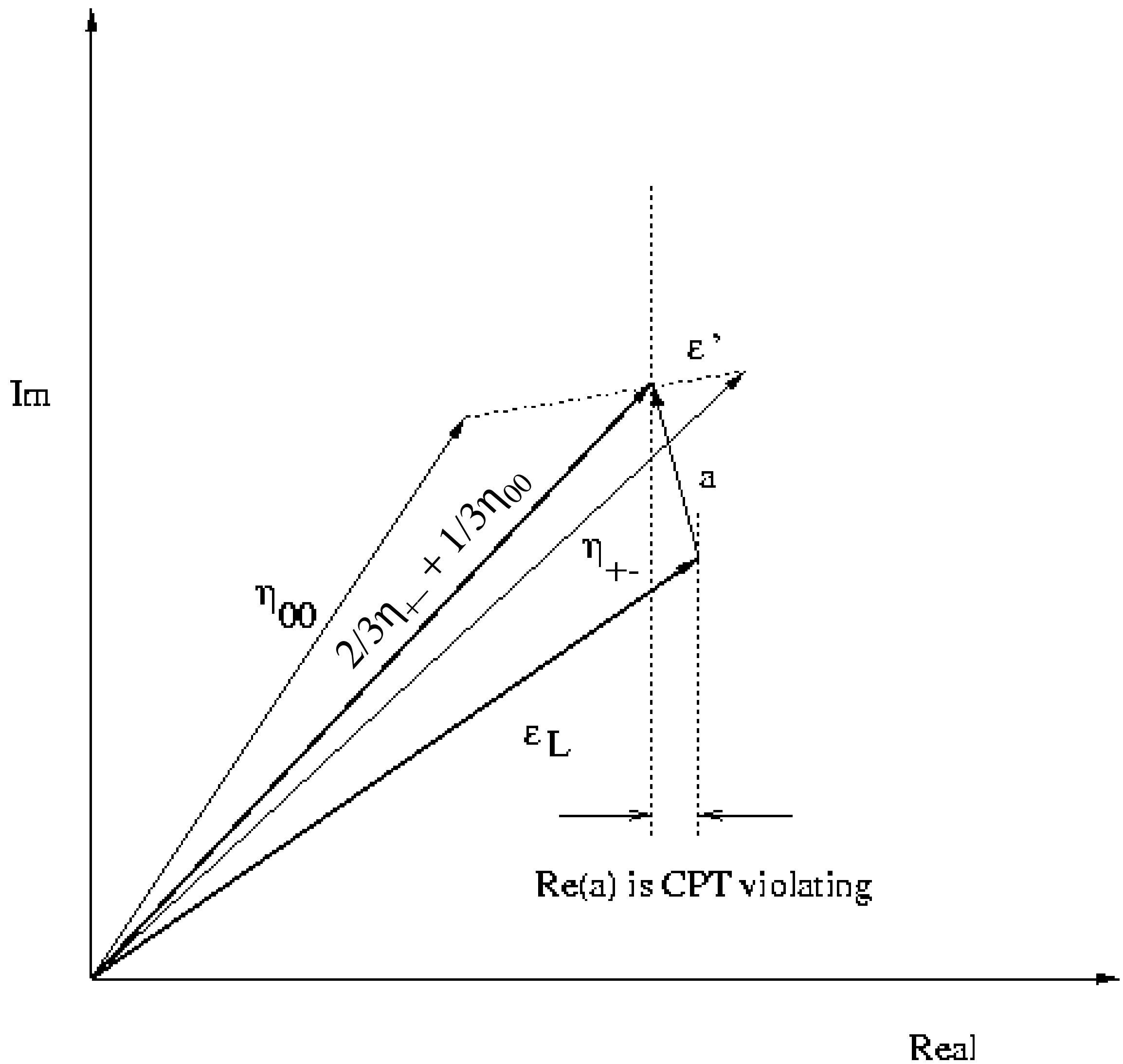
$$\delta_L = \frac{N(e^+) - N(e^-)}{N(e^+) + N(e^-)}$$

$$\boxed{\delta_L = 2\,\mathrm{Re}\;\varepsilon_L}$$

# Relationship between $\eta_{+-}$ , $\eta_{00}$ , and $\varepsilon_L$

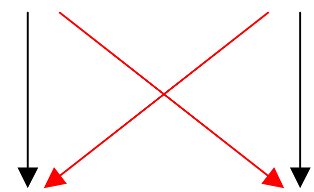
$$\eta_{+-} = \frac{A(K_L \rightarrow \pi^+\pi^-)}{A(K_S \rightarrow \pi^+\pi^-)} \qquad \eta_{00} = \frac{A(K_L \rightarrow \pi^0\pi^0)}{A(K_S \rightarrow \pi^0\pi^0)}$$

$2\pi$ amplitudes are sensitive to effects in both mixing and decay. The charge asymmetry can be used to untangle these effects.



## $\delta_L$ Contribution from New Physics

$$K_L \sim (1 + \varepsilon_L)\, K_0 \; - \; (1-\varepsilon_L)\, \overline{K_0}$$



$$e^+\pi^-\nu \qquad\qquad e^-\pi^+\nu$$

If there are CPT violating effects in Ke3 decays or the $\Delta S = \Delta Q$ rule is violated, then:

$$\delta_L = 2\,\mathrm{Re}\,(\,\varepsilon_L - Y - X_-)$$

Y = CPT Violation in $\Delta S = \Delta Q$ amplitude

X_ = CPT Violation in $\Delta S = -\Delta Q$ amplitude

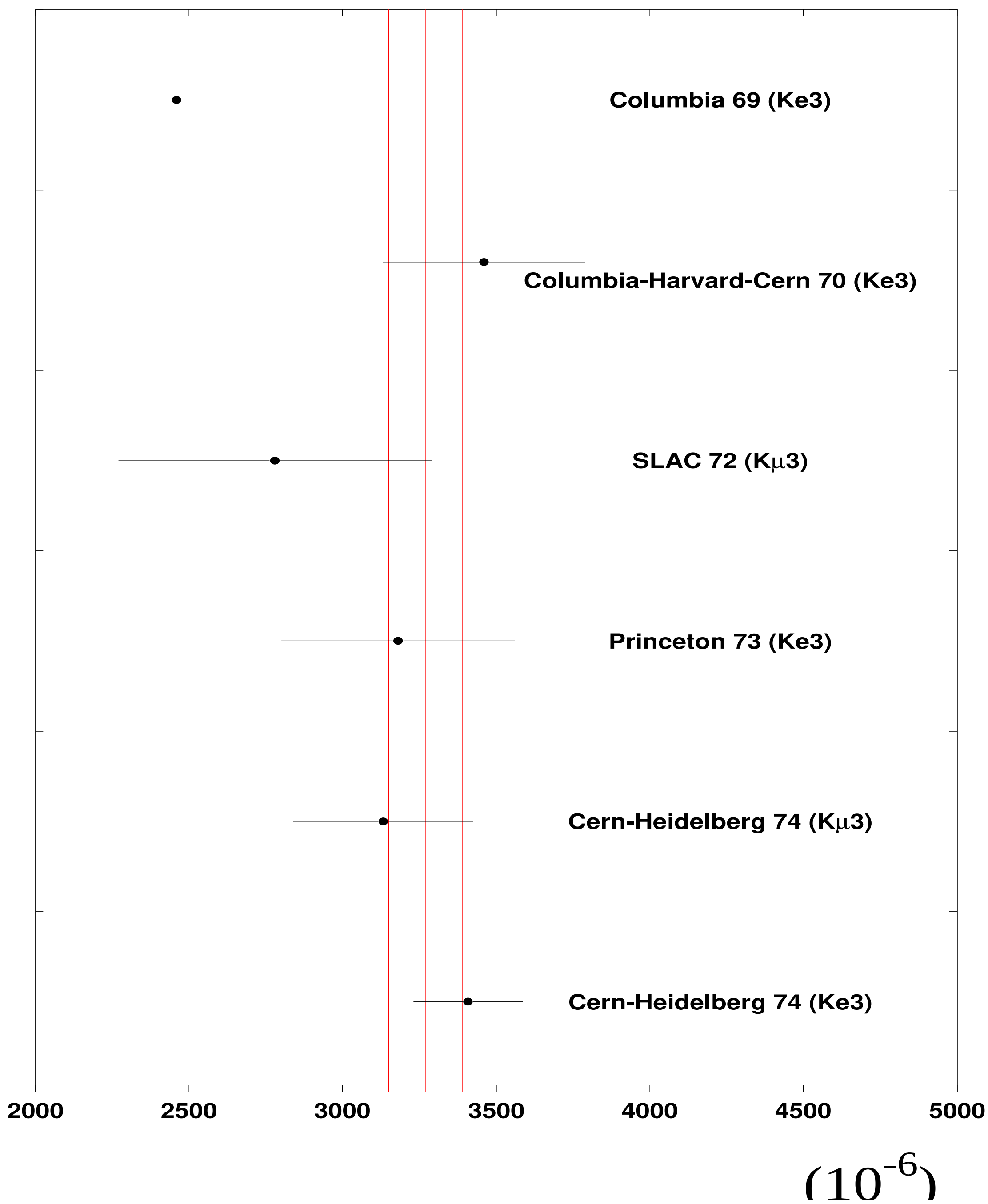
Comparisons with the $2\pi$ system would be ambiguous. However, if we see any deviations, it would be quite exciting !

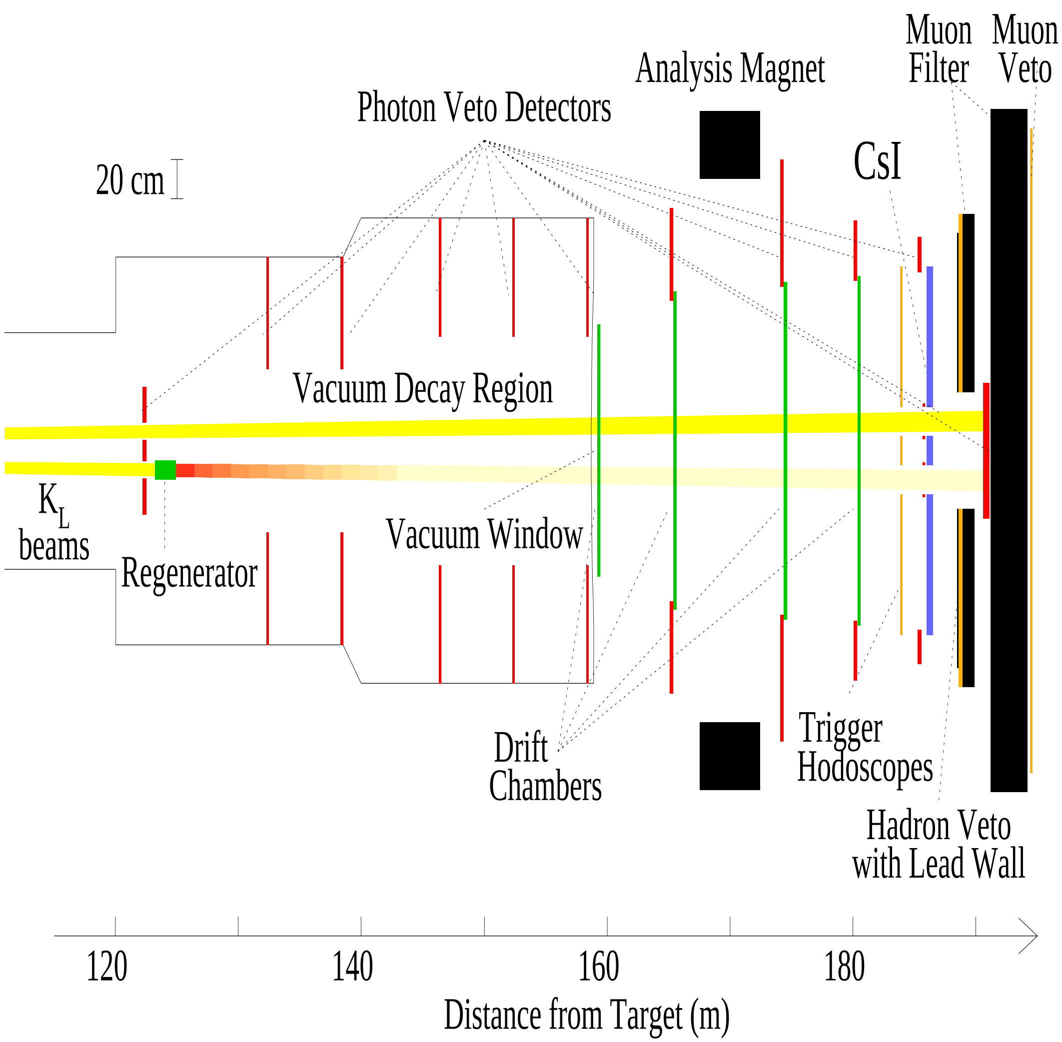
# Measurements of $K_L \rightarrow \pi l \nu$ Charge Asymmetry

PDG 2000 Average: 3270 ± 120 ppm

Current Best Measurement: 3408 ± 174 ppm

CERN-Heidelberg 74 based on 34 Million Ke3s






## Overview of Strategy

Since each of the two beams are not centered with respect to the detector, the detector has a significant left-right asymmetry.

- Rely on combining data collected with opposite magnet polarities in order to cancel the left-right asymmetry of the detector.

- Some biases are not related to acceptance, and so must be studied using other techniques.

# 8 Configurations of Ke3 decays (cont)

A single ratio is formed to cancel the acceptances, the beam fluxes, and beam optics.

$$
R^4 = \frac{Br(e^+\pi^-)\ \cancel{N(K_L\ east+41)}\ \cancel{A(e^+\pi^-\ east+41)}}{Br(e^-\pi^+)\ \cancel{N(K_L\ east-41)}\ \cancel{A(e^-\pi^+\ east-41)}}
\bullet
\frac{Br(e^+\pi^-)\ \cancel{N(K_L\ east-41)}\ \cancel{A(e^+\pi^-\ east-41)}}{Br(e^-\pi^+)\ \cancel{N(K_L\ east+41)}\ \cancel{A(e^-\pi^+\ east+41)}}
\bullet
\frac{Br(e^+\pi^-)\ \cancel{N(K_L\ west+41)}\ \cancel{A(e^+\pi^-\ west+41)}}{Br(e^-\pi^+)\ \cancel{N(K_L\ west-41)}\ \cancel{A(e^-\pi^+\ west-41)}}
\bullet
\frac{Br(e^+\pi^-)\ \cancel{N(K_L\ west-41)}\ \cancel{A(e^+\pi^-\ west-41)}}{Br(e^-\pi^+)\ \cancel{N(K_L\ west+41)}\ \cancel{A(e^-\pi^+\ west+41)}}
$$

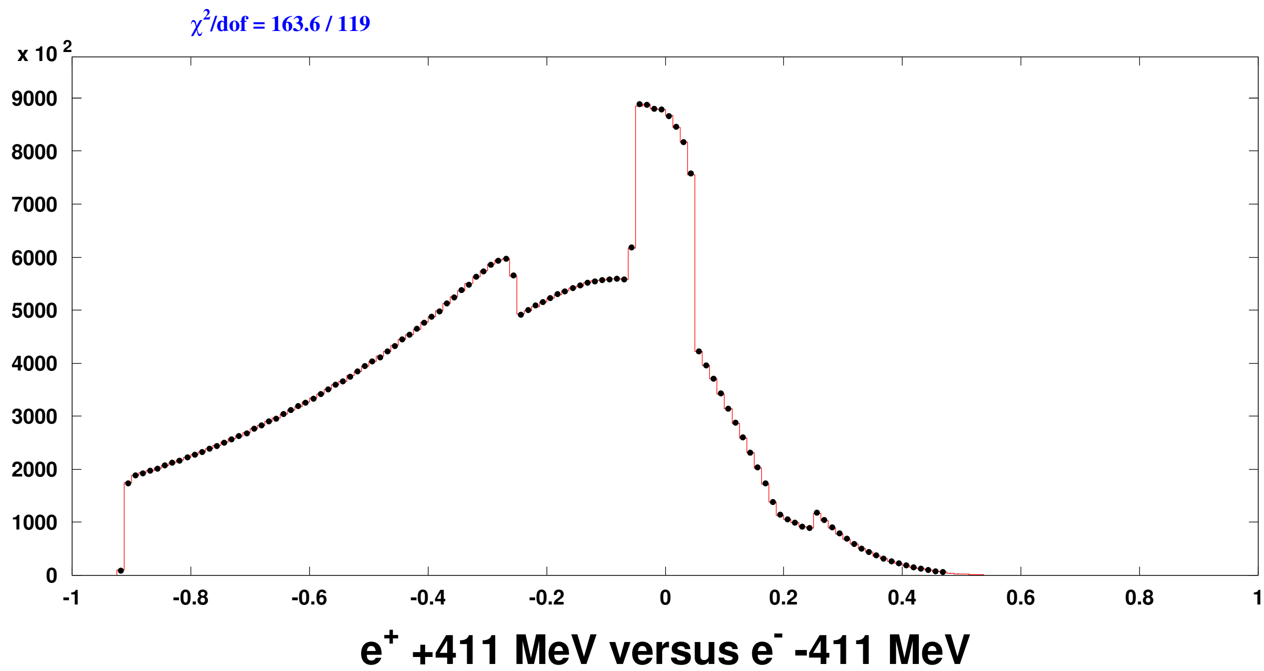
$$
\delta_L = \frac{R-1}{R+1}
$$

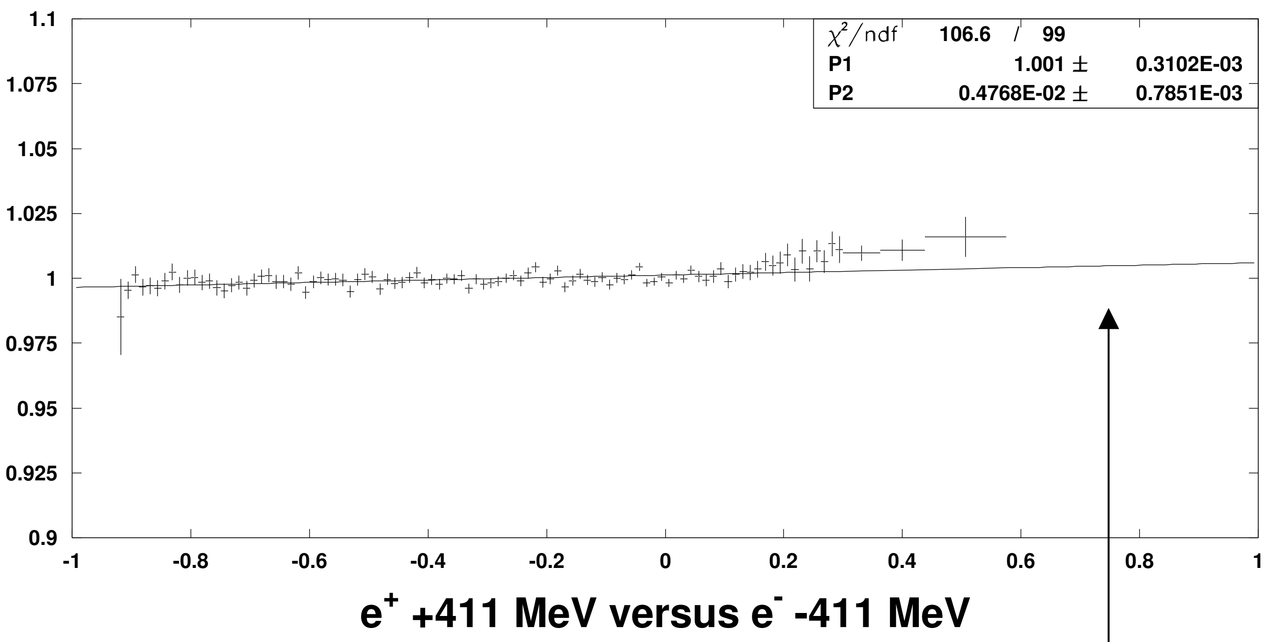
Fluxes Cancel

Must Check if the Acceptances Really Cancel !

# Acceptance Checks of Configuration Pairs

X-view illum. of $e^+$ (+411,W) and $e^-$(−411,W) tracks at CsI




Slope due to Earth's Magnetic Field

## Systematic Effects

Particles and anti-particles behave differently in matter

Configuration acceptances do not cancel

Regenerative scattering by the beam

Backgrounds

## Particle/antiparticle differences in matter

$e^+$ annihilation

$\delta$-ray production differences between Moller ($e^- e^-$) and Bhabha ($e^+e^-$) scattering

$\pi^+ \pi^-$ interaction differences in material (isospin)

These effects bias the reconstruction of track kinematics and particle identification.

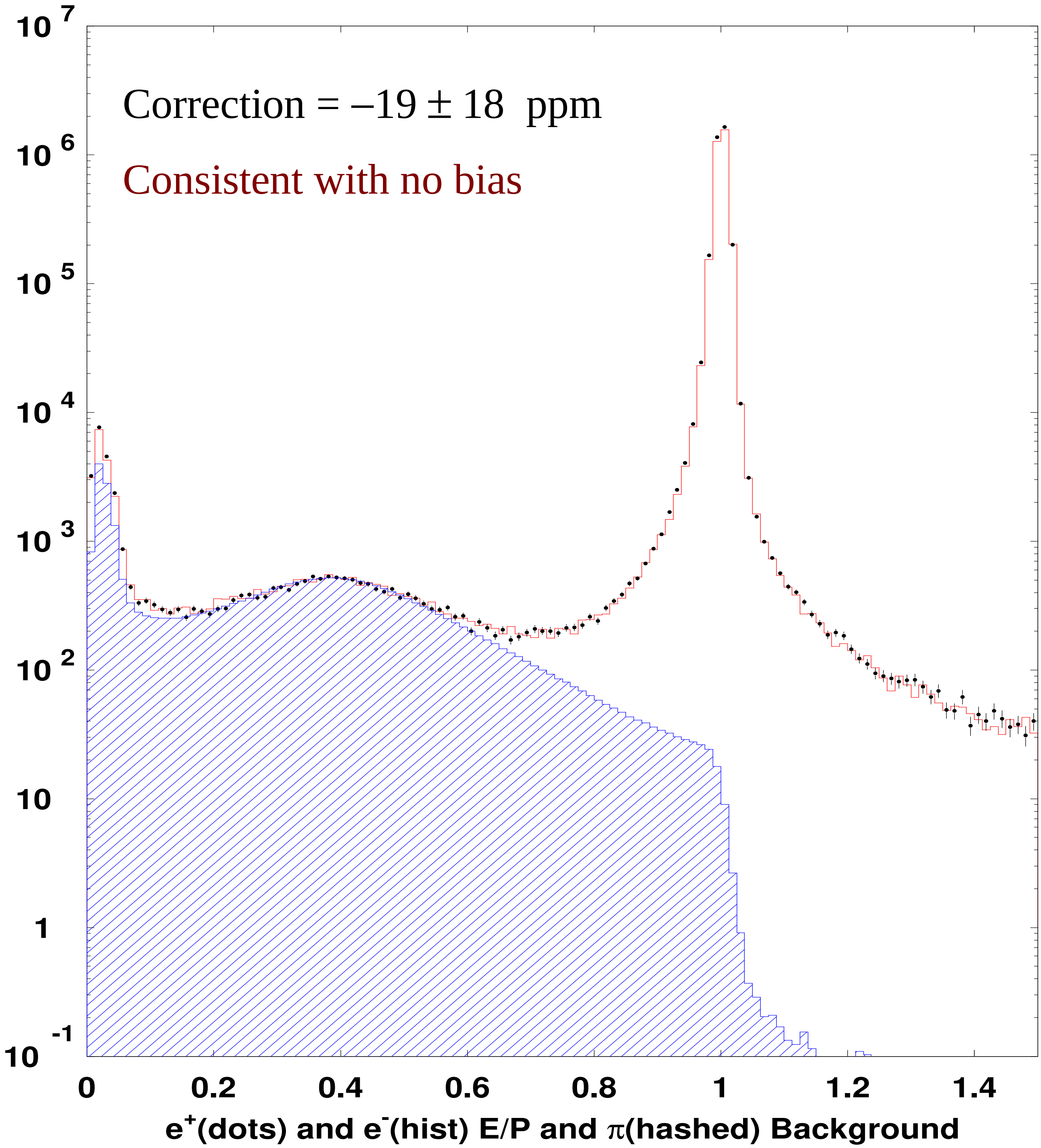
$f^+ \equiv$ inefficiency (background) to $e^+ \pi^-$ configuration

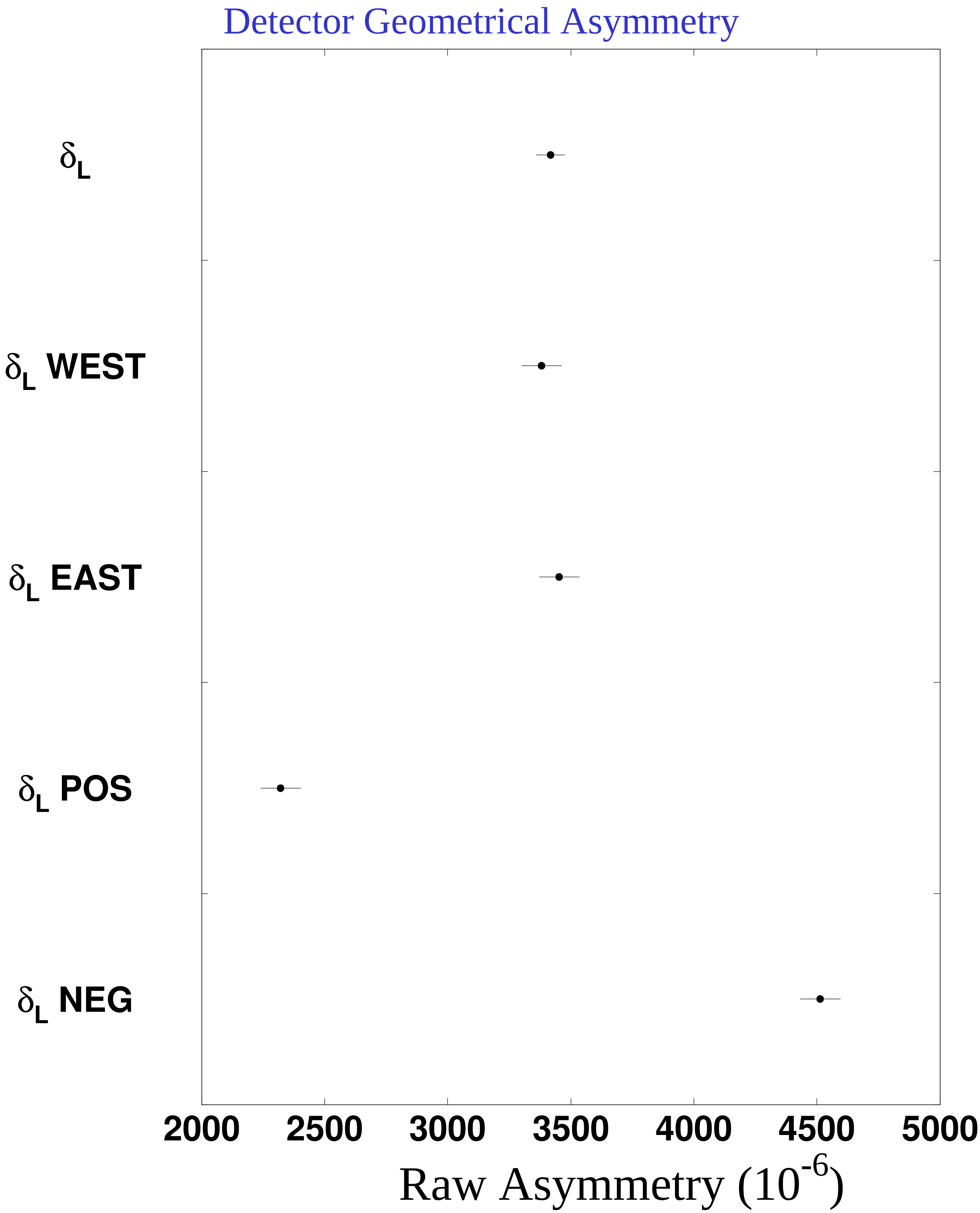
$f^- \equiv$ inefficiency (background) to $e^- \pi^+$ configuration

Correction to $\delta = (f^+ - f^-)/2$

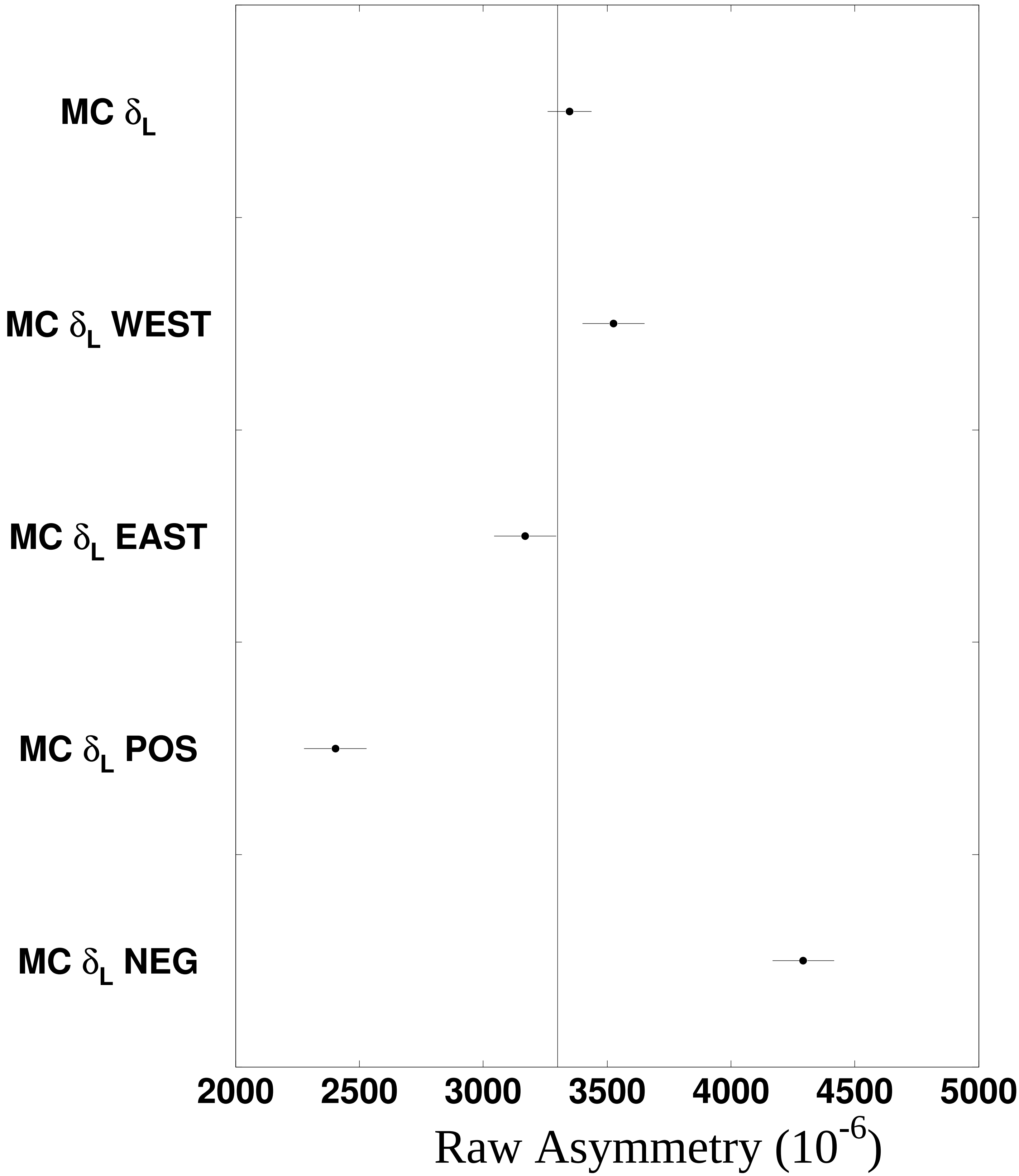
# $e^+$ and $e^-$ Response in the CsI

•Analysis requires $e^\pm$ E/P > 0.925. Though no bias is expected, we use the data to limit any possible effect.




Detector Geometrical Asymmetry
δL
δL WEST
δL EAST
δL POS
δL NEG
2000
2500
3000
3500
4000
4500
5000
Raw Asymmetry (10-6)

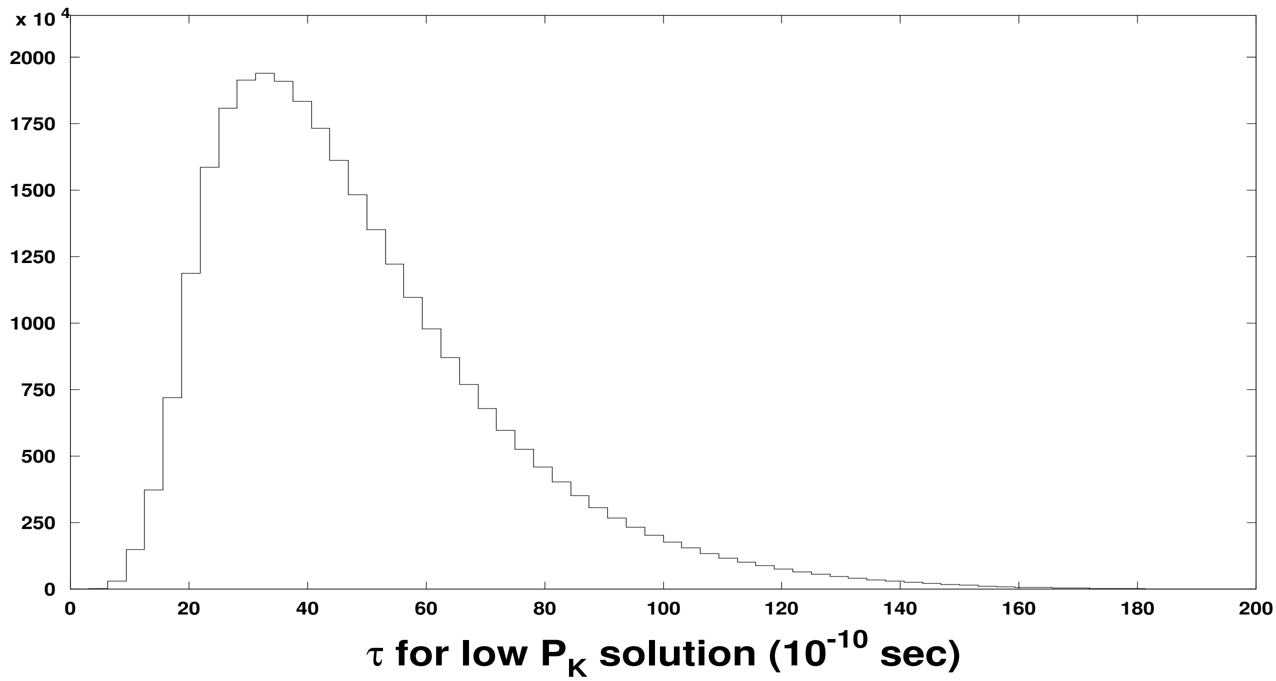
# MC Simulation of Detector Geometrical Asymmetry

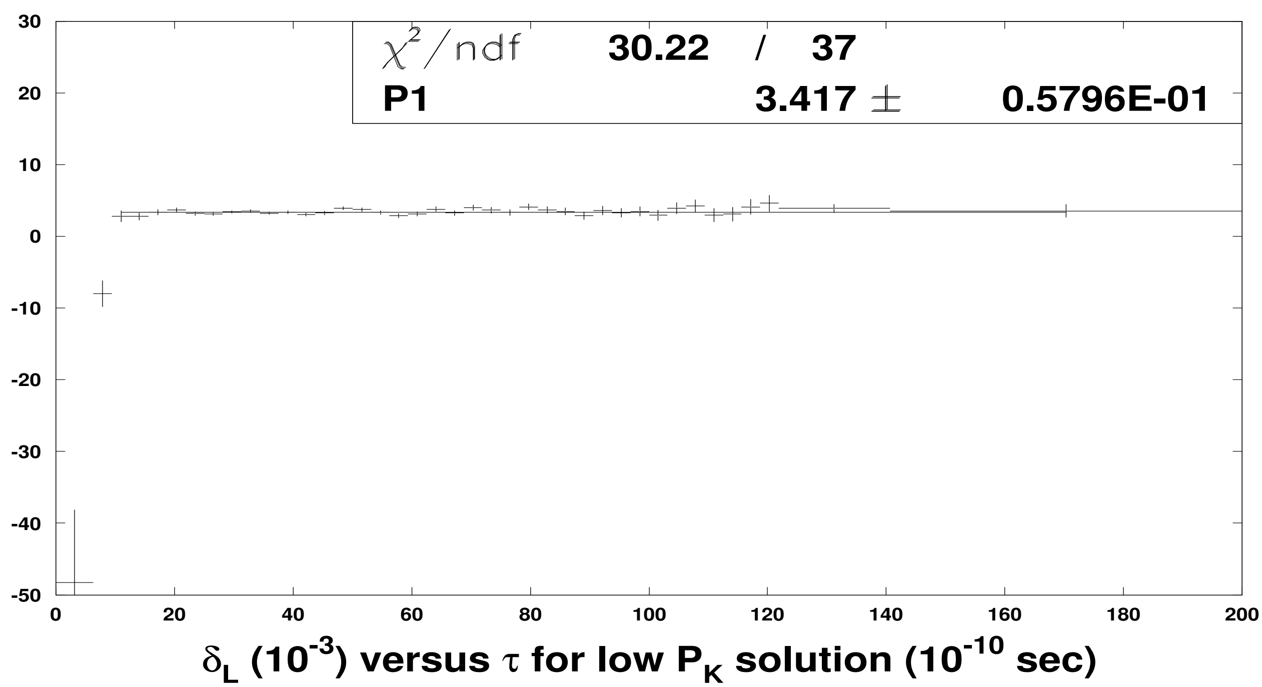


# Target/Absorber Interference Correction

Analysis removes events with propertime $\tau < 10.5\ \tau_S$ since they have large $K_S$-$K_L$ interference effects.

Correction of $-12 \pm 1$ ppm assigned to account for residual interference and propertime misreconstructions.



# Summary of Corrections

| Effect | Correction (ppm) |
|---|---|
| $\pi^+\pi^-$ difference in CsI | $-156 \pm 10$ |
| $\pi^+\pi^-$ lost in trigger scintillator | $54 \pm 10$ |
| $\pi^+\pi^-$ lost in spectrometer | $3 \pm 3$ |
| $\pi^+\pi^-$ punch through | $34 \pm 40$ |
| $e^+e^-$ difference in CsI | $-19 \pm 18$ |
| $\delta$–ray production | $-8.5 \pm 4.3$ |
| $e^+$ annihilation in spectrometer | $11 \pm 1$ |
| $\pi^+\pi^-\pi^0$, K$\mu$3, $\Lambda$ background | $0.5 \pm 0.7$ |
| Target/absorber interference | $-12 \pm 1$ |
| $K_L$ scattering in final collimator | $-1.2 \pm 2.3$ |
| $K_L$ scattering in regenerator | $0 \pm 0$ |
| B-field reversal mismatch | $-3.1 \pm 1.6$ |
| Sum | $-97 \pm 46$ (ppm) |