Measurement of CP Violation in the K_L Charge Asymmetry by KTeV

The KTeV Collaboration

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$K_L \rightarrow \pi e \nu$ Charge Asymmetry

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

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

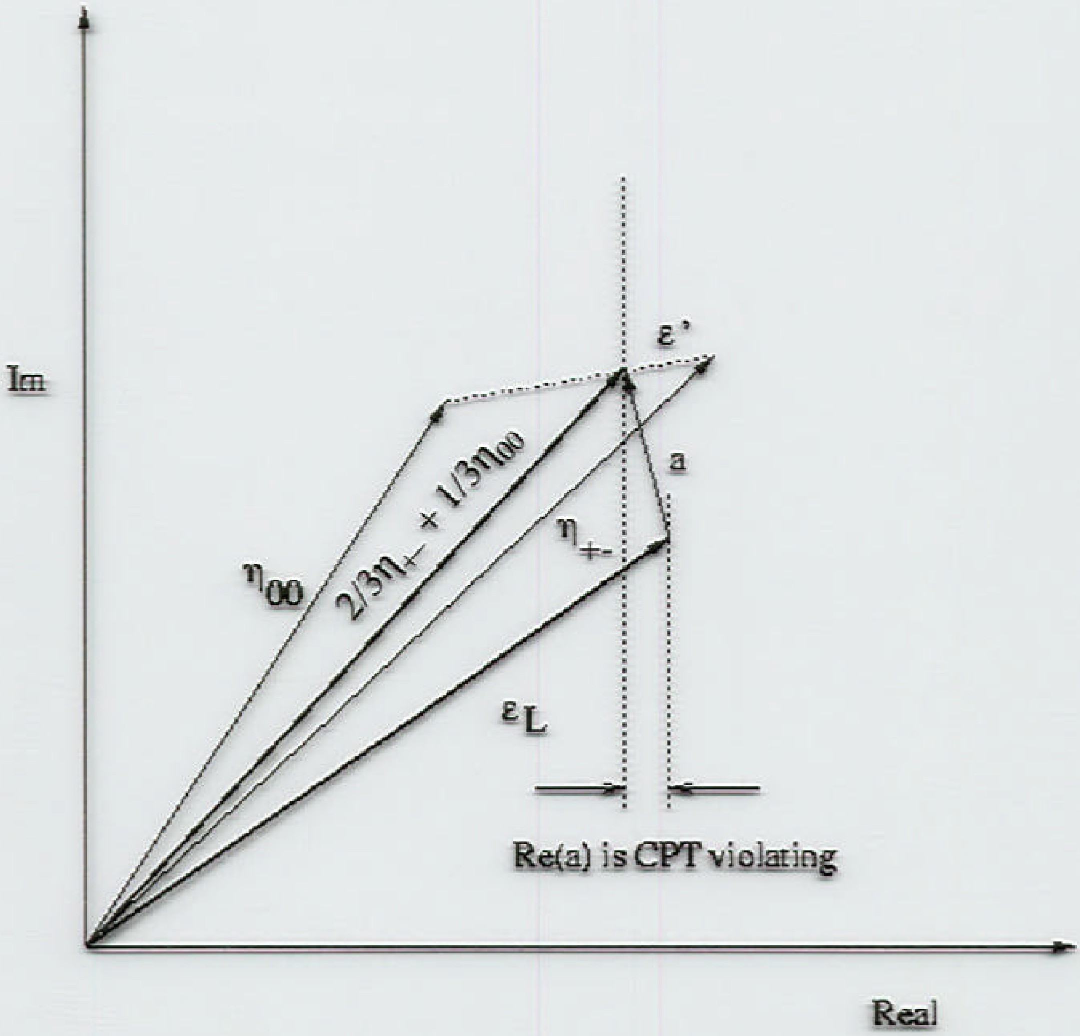
$$K^0 \rightarrow e^+\pi^-\nu \qquad \overline{K^0} \rightarrow e^-\pi^+\nu$$

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

$$\delta_L \equiv (\,N(e^+) - N(e^-)\,) \;/\; (\,N(e^+) + N(e^-)\,)$$

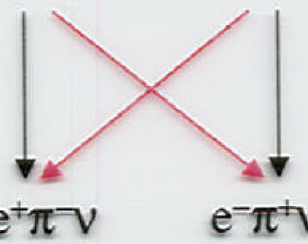
$$\boxed{\delta_L = 2\,\mathrm{Re}\;\varepsilon_L}$$

Relationship between η_{+-} , η_{00} , and ε_L



δ_L Contribution from New Physics

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



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

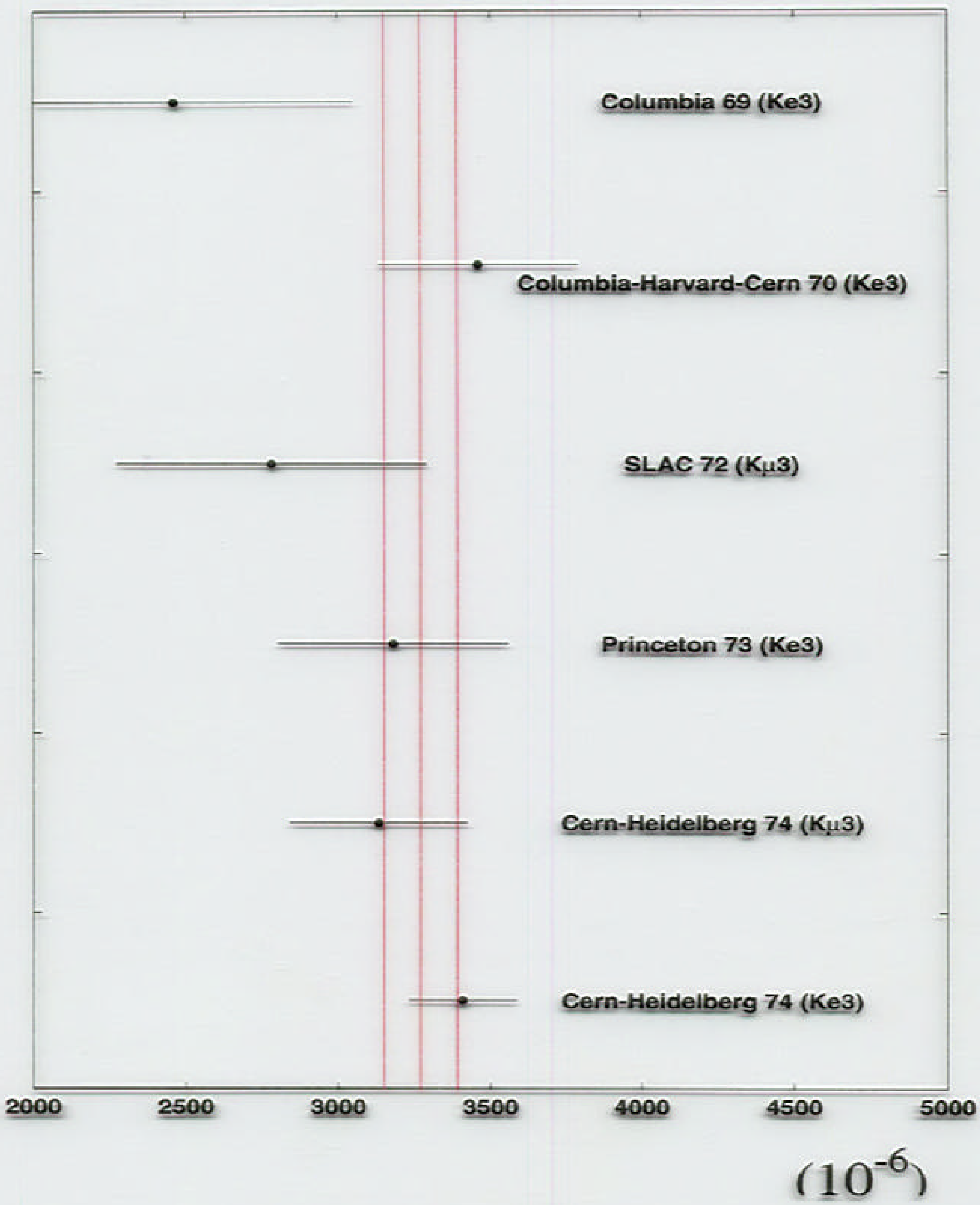
Comparisons with the 2π system would be ambiguous. However, if we see any deviations, it would be quite exciting !

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

It is nearly impossible to build a detector to have equal detection efficiency to both charges at the required level.

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

8 Configurations of Ke3 Decays

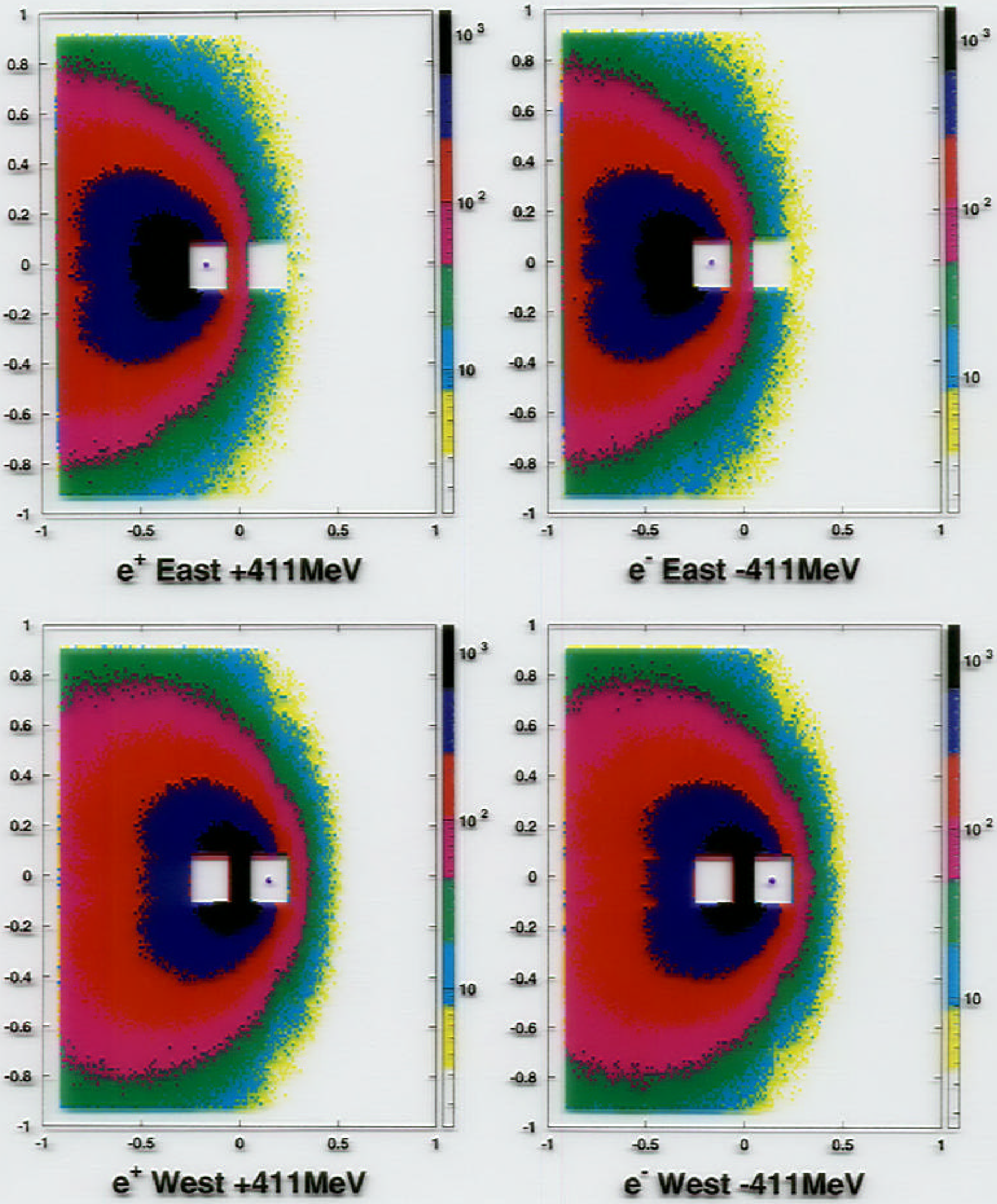
- positron or electron
- east or west vacuum beam
- + 411 or –411 MeV analysis magnet polarity

Each configuration has a partner that has an identical geometrical acceptance:

e^+ East +411 MeV	⟷	e^- East –411 MeV
e^+ West +411 MeV	⟷	e^- West –411 MeV
e^+ East –411 MeV	⟷	e^- East +411 MeV
e^+ West –411 MeV	⟷	e^- West +411 MeV

However, a given configuration and its partner do not necessarily have the same beam flux

Illumination of $e^{\pm}$ at the CsI



8 Configurations of Ke3 decays (cont)

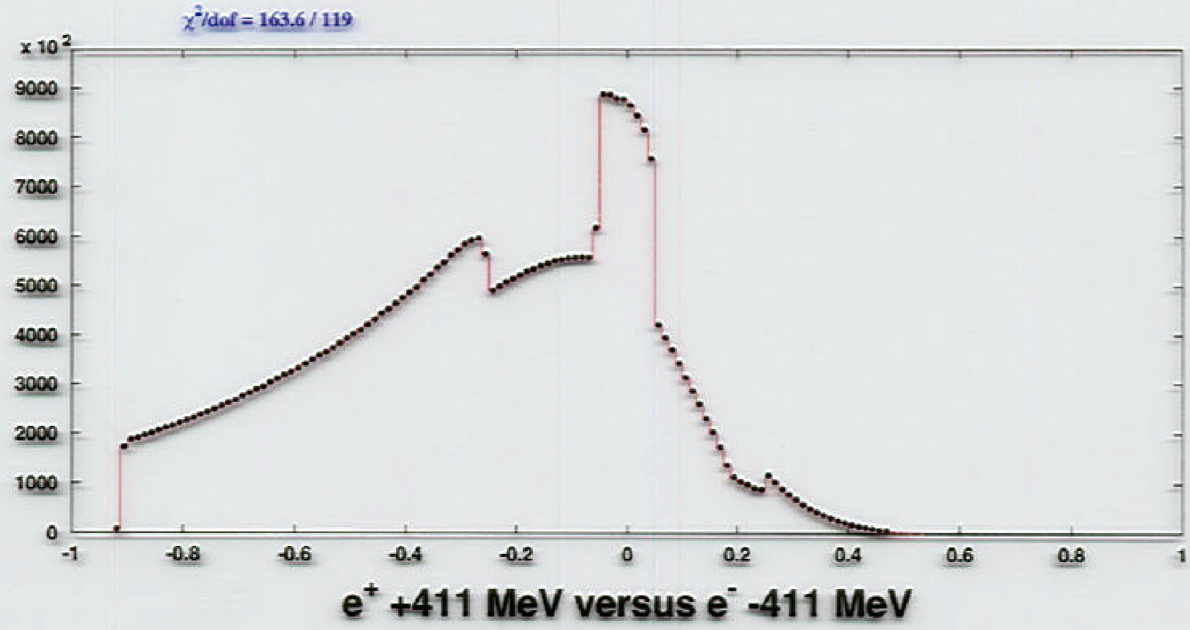
A single ratio is formed to cancel the acceptances, the beam fluxes, and beam optics.

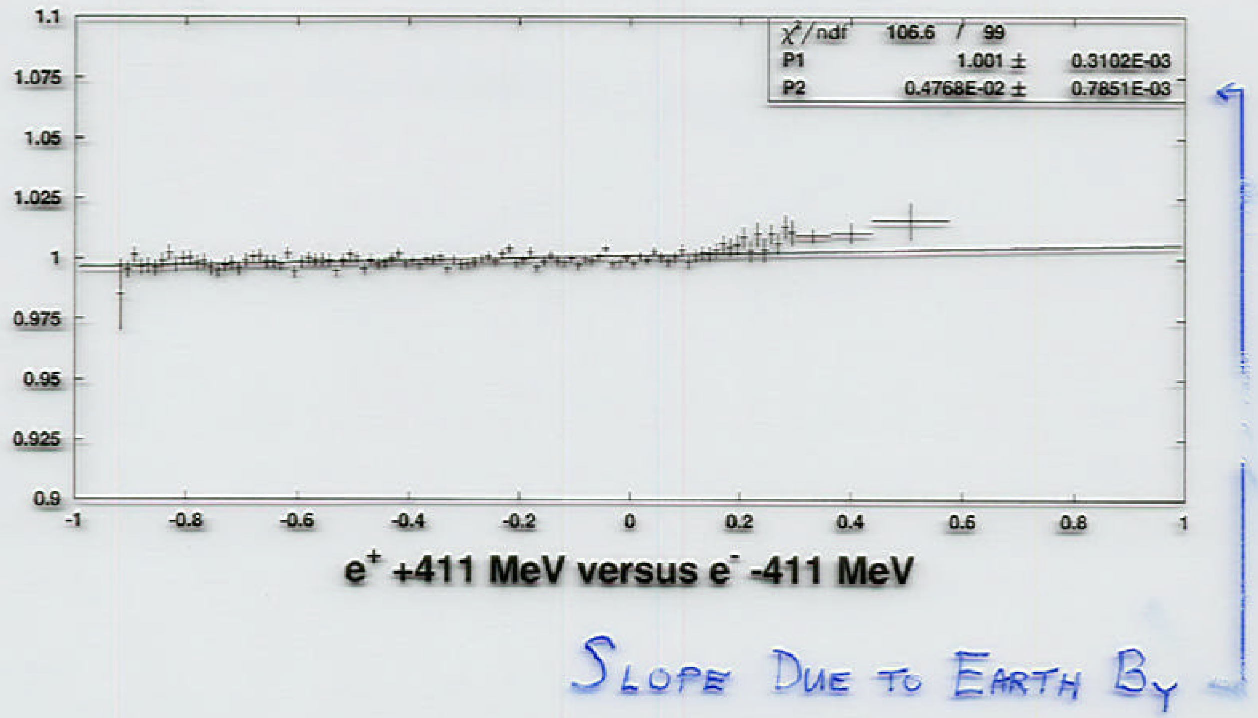
$$R^4 = \frac{BR(e+\pi-)\, N(K_L\ east\ +411)\, A(e+\pi-\ east\ +411)}{BR(e-\pi+)\, N(K_L\ east\ -411)\, A(e-\pi+\ east\ -411)} \times \frac{BR(e+\pi-)\, N(K_L\ east\ -411)\, A(e+\pi-\ east\ -411)}{BR(e-\pi+)\, N(K_L\ east\ +411)\, A(e-\pi+\ east\ +411)} \times \frac{BR(e+\pi-)\, N(K_L\ west\ +411)\, A(e+\pi-\ west\ +411)}{BR(e-\pi+)\, N(K_L\ west\ -411)\, A(e-\pi+\ west\ -411)} \times \frac{BR(e+\pi-)\, N(K_L\ west\ -411)\, A(e+\pi-\ west\ -411)}{BR(e-\pi+)\, N(K_L\ west\ +411)\, A(e-\pi+\ west\ +411)}$$

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

Acceptance Checks of Configuration Pairs

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





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^+ and e^- differences:

  e^+ annihilation

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

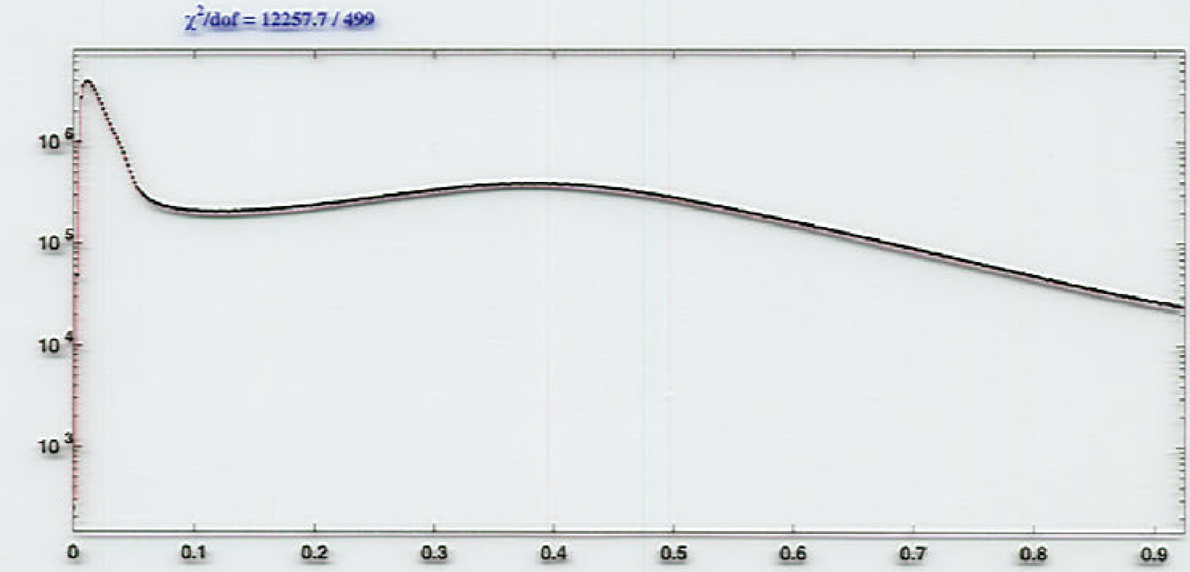
- $\pi^+ \pi^-$ differences:

  Isospin dependence in nuclear interactions

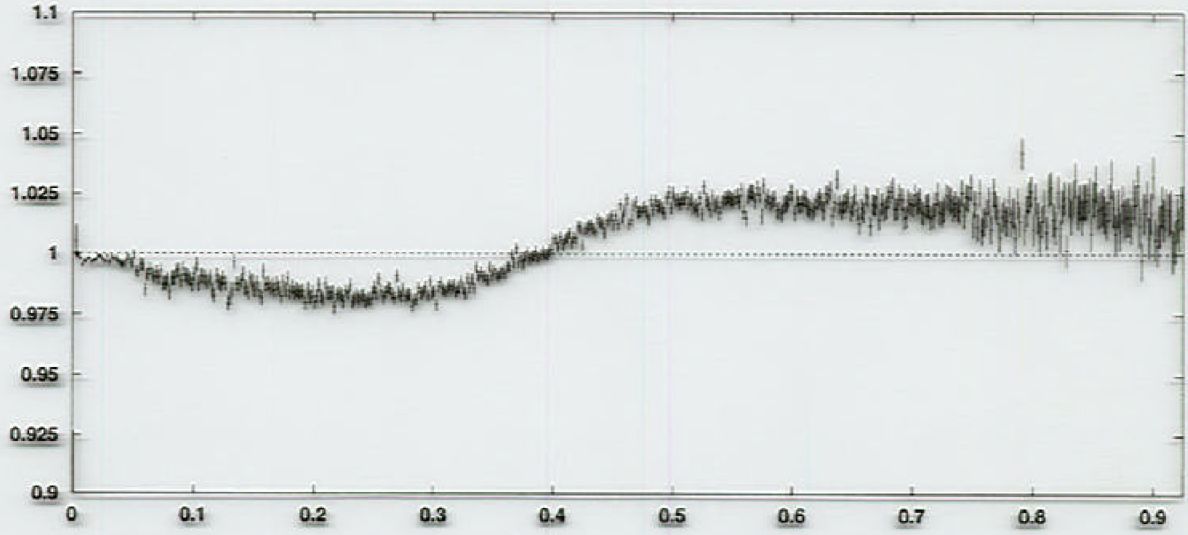
These effects bias the reconstruction of track kinematics and particle identification.

π^+ and π^- Response in CsI

- The requirement of E/P < 0.925 rejects more π^+ than π^-



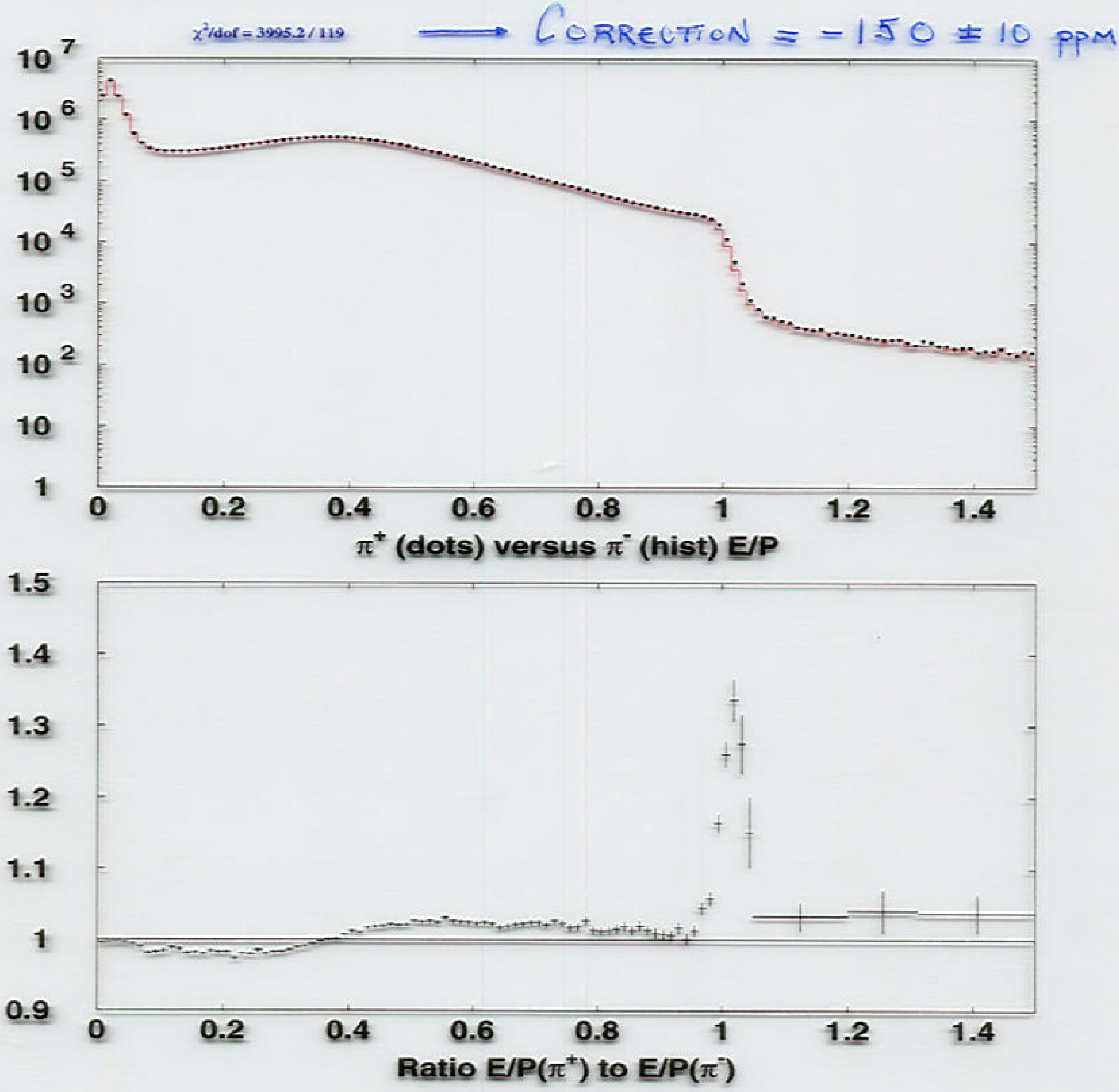
π^+ versus π^- E/P



π^+ versus π^- E/P

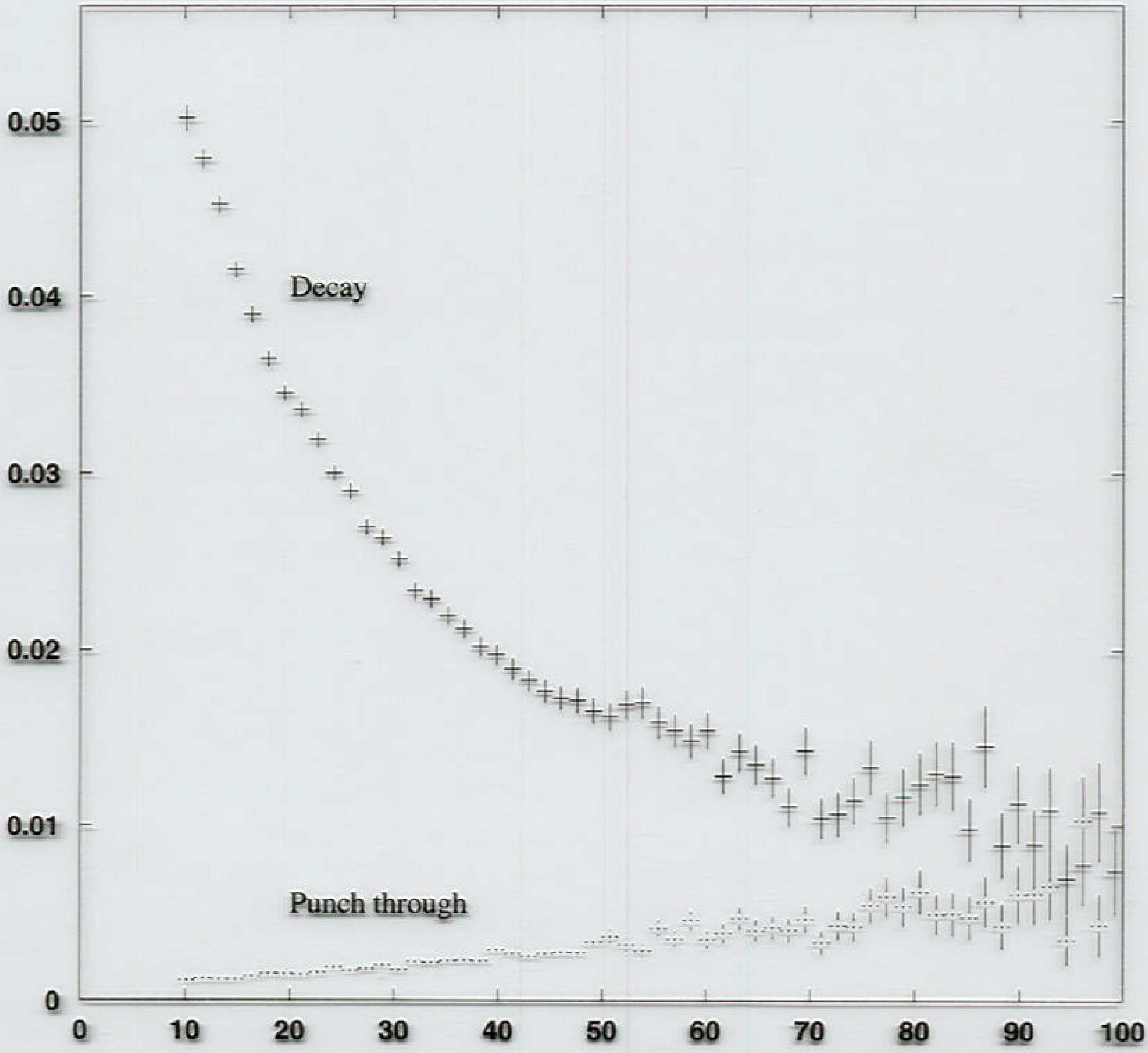
π^+ and π^- Response in CsI (cont.)

- Measured the E/P shape of pions using $K_L \Rightarrow \pi^+\pi^-\pi^0$ and pions identified in E799 using the TRD.



$\pi^{\pm}$ Punch Through Correction

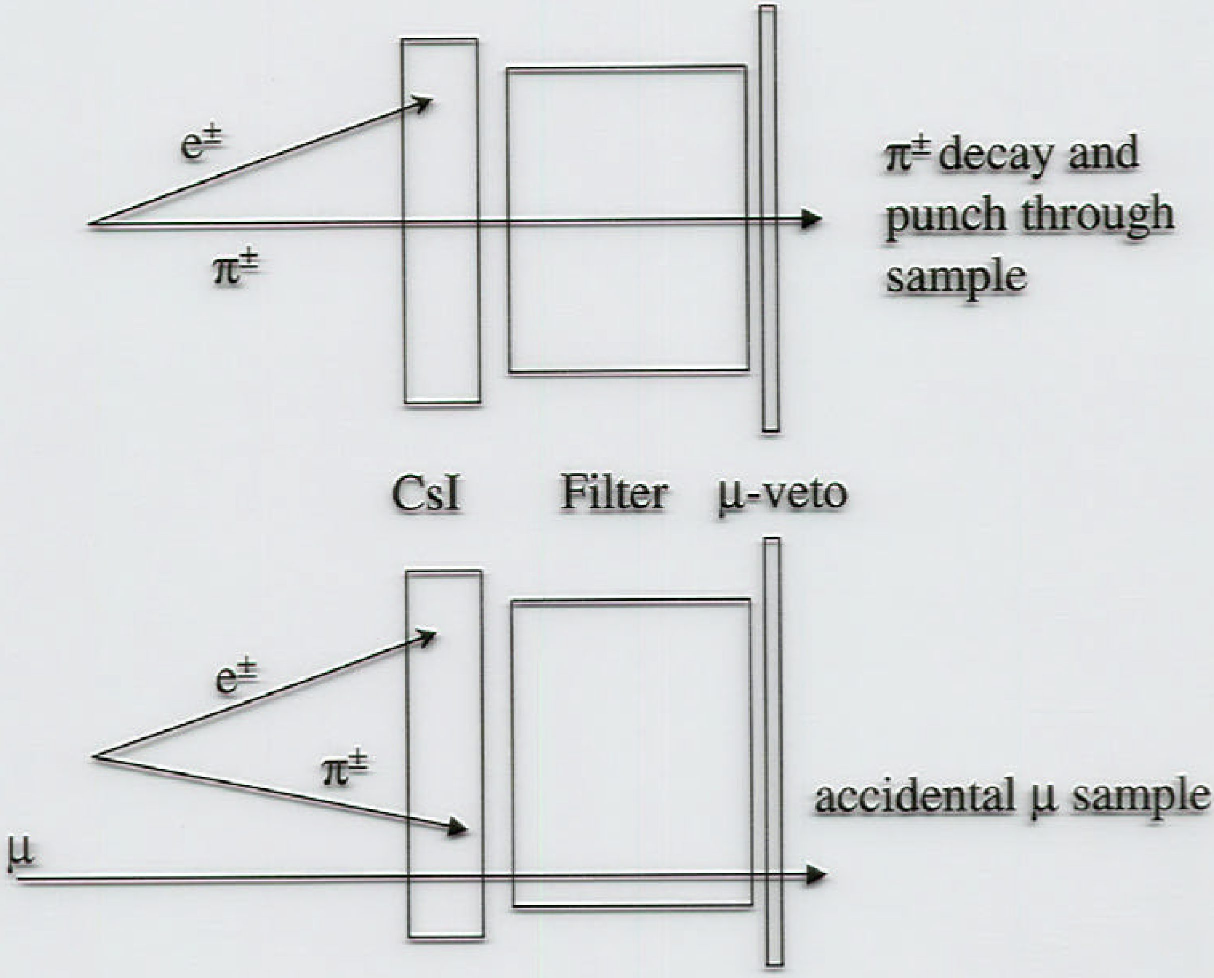
- To reduce the trigger rate, the trigger required no activity in muon veto.
- This vetoes pion decay-in-flight and punch through, which could cause a bias.



Probability to Register MU2 Hit Versus Momentum

$\pi^{\pm}$ Punch-through Correction (cont.)

•Measure δ_L using a complementary sample that contain events rejected by the main trigger.



δ_L (decay/punch) $= (4.4 \pm 1.3) \cdot 10^{-3}$

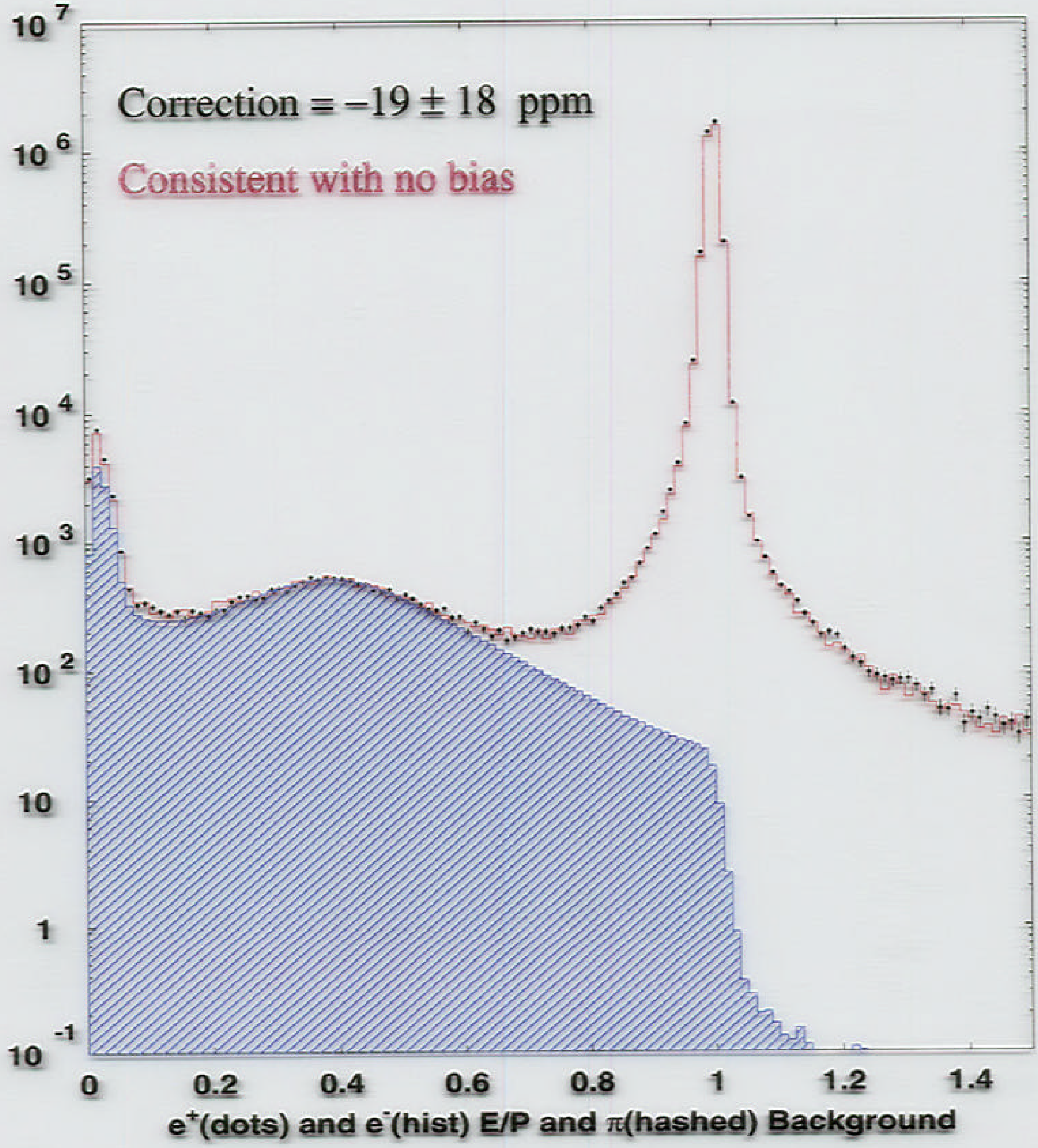
δ_L (accidental μ) $= (3.3 \pm 1.0) \cdot 10^{-3}$

Correction = 33.6 ± 39.8 ppm

Largest systematic uncertainty for this analysis

e^+ and e^- Response in the CsI

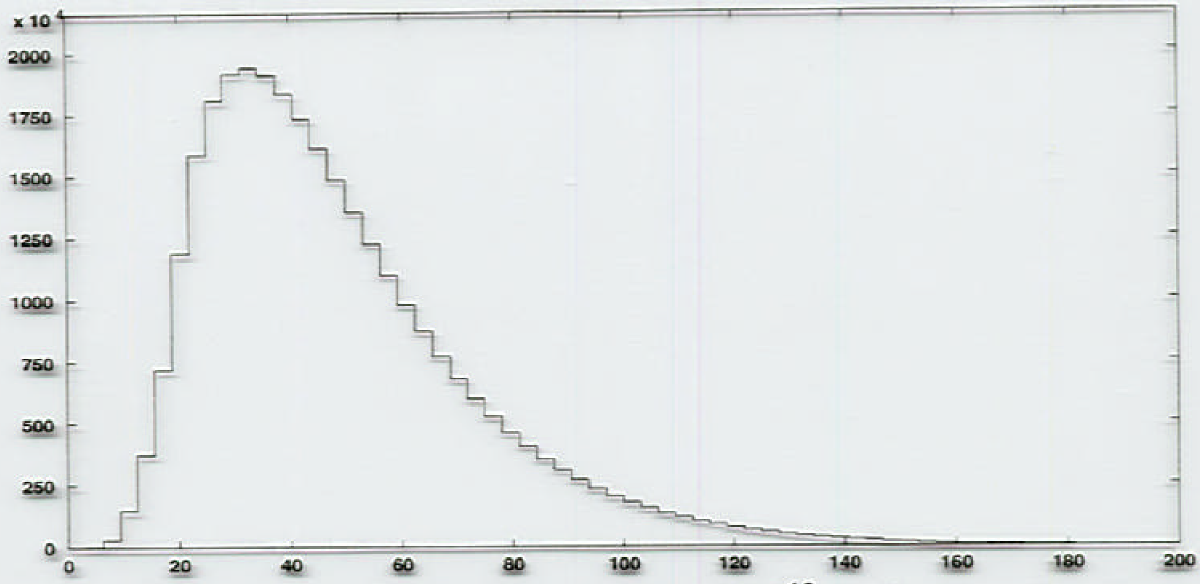
- Analysis requires $e^{\pm}$ $E/P > 0.925$. Though no bias is expected, we use the data to limit any possible effect.



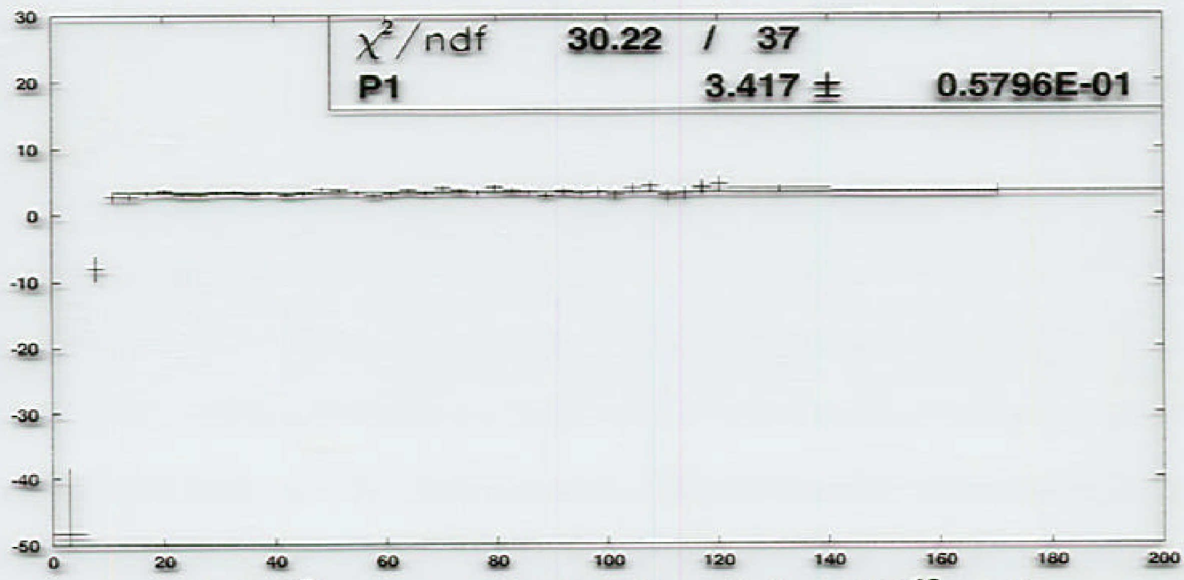
Target/Absorber Interference Correction

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

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



τ for low P_K solution (10^{-10} sec)



δ_L (10^{-3}) versus τ for low P_K solution (10^{-10} sec)

Summary of Corrections

Effect	Correction (ppm)
$\pi^+\pi^-$ difference in CsI	-150 ± 10
$\pi^+\pi^-$ lost in trigger scintillator	54 ± 10
$\pi^+\pi^-$ lost in spectrometer	3 ± 3
$\pi^+\pi^-$ punch through	34 ± 40
e^+e^- difference in CsI	-19 ± 18
δ–ray production	-8.5 ± 4.3
e^+ annihilation in spectrometer	11 ± 1
$\pi^+\pi^-\pi^0$, $K\mu3$, Λ background	0.5 ± 0.7
Target/absorber interference	-12 ± 1
K_L scattering in final collimator	-1.2 ± 2.3
K_L scattering in regenerator	0 ± 0
B-field reversal mismatch	-3.1 ± 1.6
Sum	-97 ± 46 (ppm)

Preliminary Result for $K_L \rightarrow \pi e \nu$ Charge Asymmetry

- 298 Million $K_L \rightarrow \pi e \nu$ collected in 1997 run of KTeV-E832

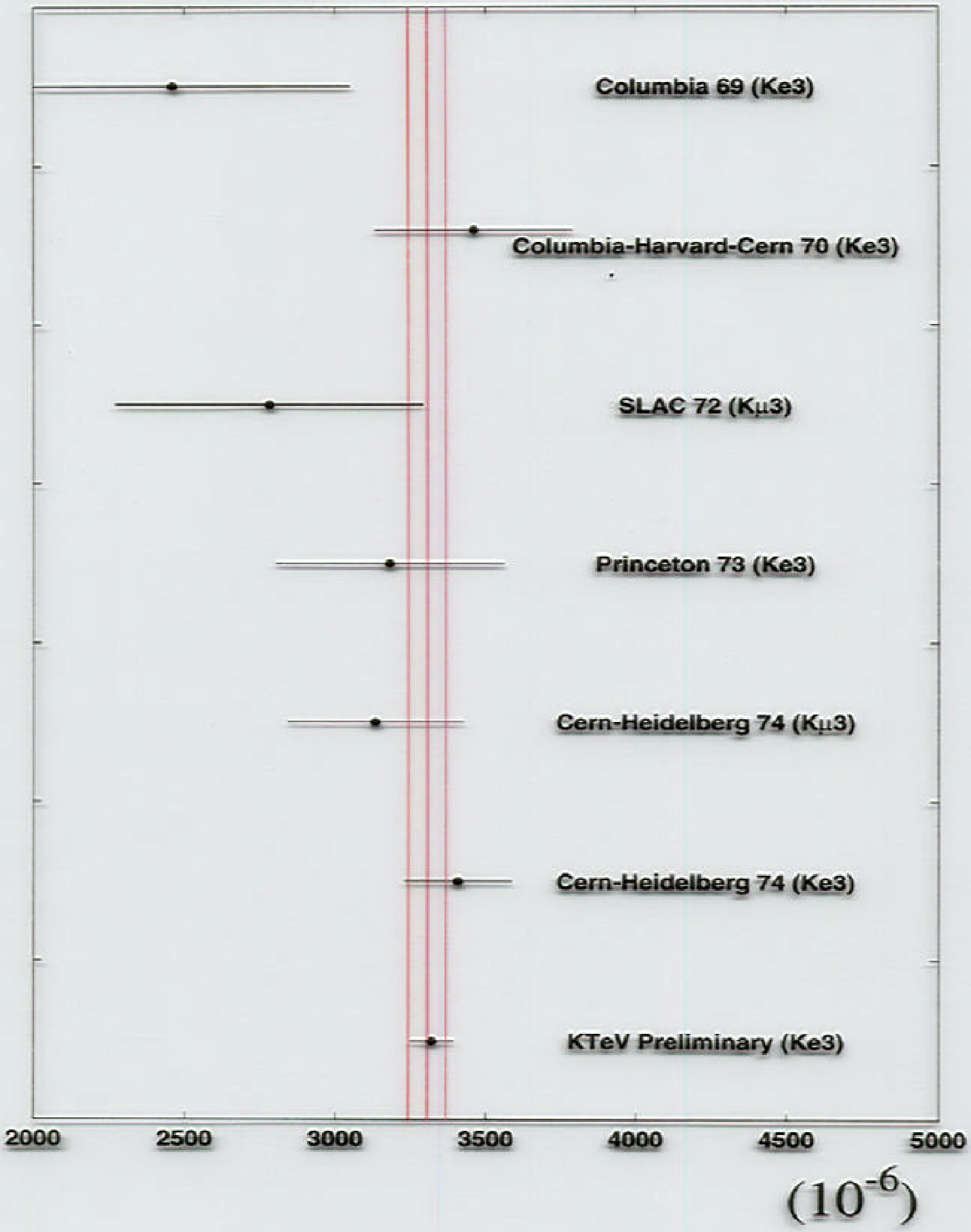
$$\text{Raw } \delta_L = 3417 \pm 58 \text{ ppm}$$

$$\text{Correction} = -97 \pm 46 \text{ ppm}$$

$$\text{Corrected } \delta_L = 3320 \pm 58(\text{stat}) \pm 46(\text{sys}) \text{ ppm}$$
$$= 3320 \pm 74(\text{comb}) \text{ ppm}$$

- 2.4 x more accurate than the previous best result (CERN-Heidelberg 1974)
- Excellent agreement with all previous measurements

K*l*3 Charge Asymmetry Measurements



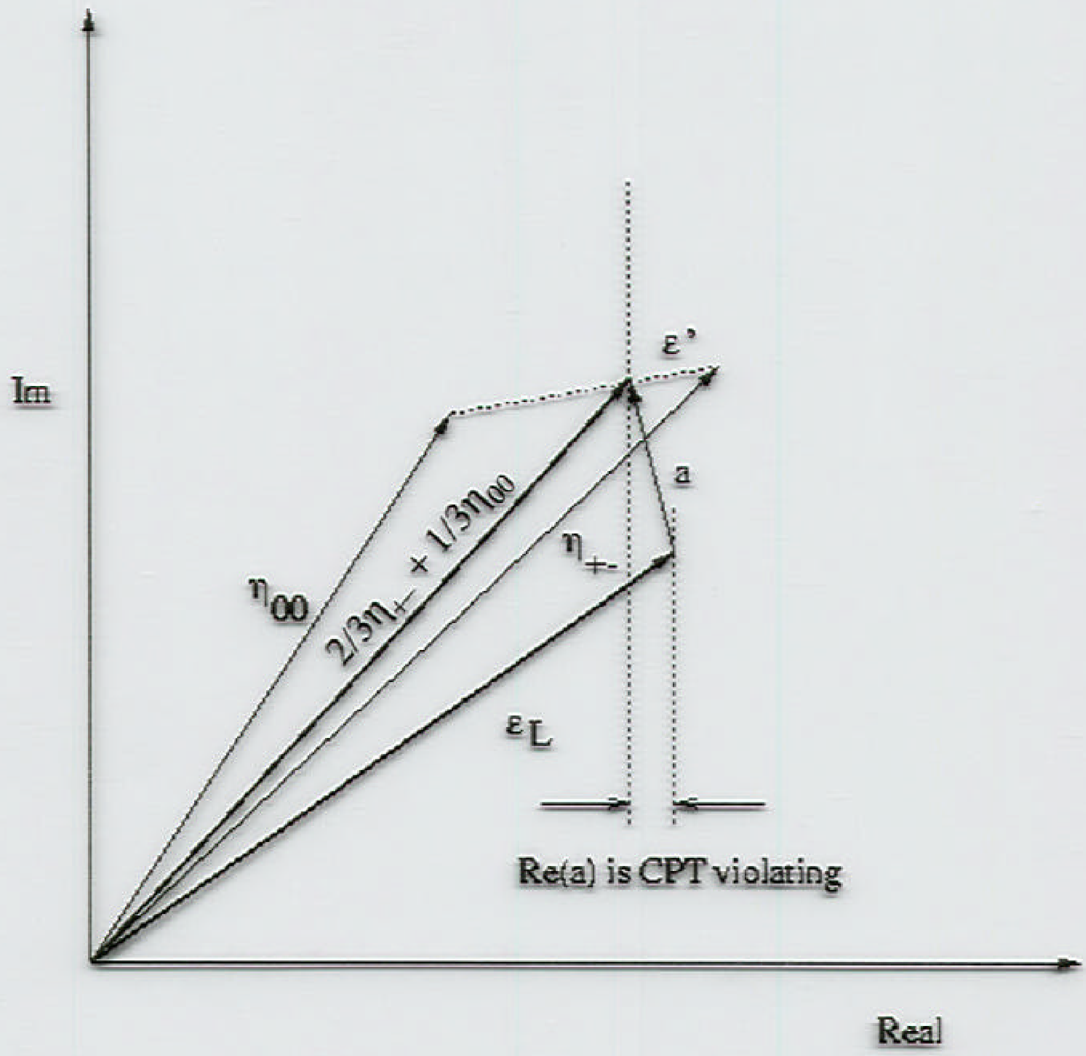
PDG 2000 Average: 3270 ± 120 ppm ($\chi^2 = 4.1/5$ d.o.f.)
New Average: 3305 ± 63 ppm ($\chi^2 = 4.2/6$ d.o.f.)

Comparison to $K_L \rightarrow \pi\pi$

Consistency among η_{+-} , η_{00}, and $Re(\varepsilon_L)$:

Parameter	PDG2000 averages
$\|\eta_{+-}\|$	2276 ± 17 ppm
$\|\eta_{00}\|$	2262 ± 17 ppm
ϕ_{+-}	$43.5 \pm 0.5\,°$
ϕ_{00}	$43.2 \pm 1.0\,°$
$2Re(\eta_{+-})$	3302 ± 37 ppm
$2Re(\eta_{00})$	3298 ± 60 ppm
δ_L	3305 ± 63 ppm (PDG avg and this result)

Limit on CPT violation in $K_L \rightarrow \pi\pi$:



$$\mathrm{Re}(a) = 2/3\ \mathrm{Re}\ \eta_{+-} + 1/3\ \mathrm{Re}\ \eta_{00} - \mathrm{Re}\ \varepsilon_L$$

$$= -2 \pm 35\ \mathrm{ppm} \quad (\text{assuming } \Delta S = \Delta Q)$$