Alexander Golossanov
University of Virginia

Status of $K_L \to \pi^+\pi^-e^+e^-$ $\mathcal{BR}$ Measurement

March 12, 2005
KTeV Collaboration Meeting
Fermilab

1. Outline

1 Recap of previous analysis and results.

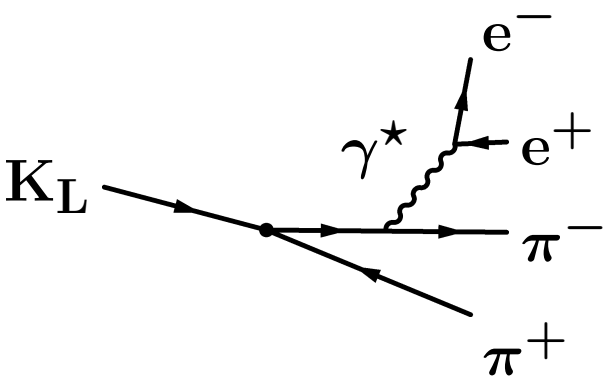
2 Background simulation and estimation.

3 Branching Ratio and statistical uncertainties.

4 Systematic uncertainties, inlcuding parameter and cut variations.

5 Status of Branching Ratio measurement. What remains to be done.

2. Amplitude has two major contributions: IB and M1 DE



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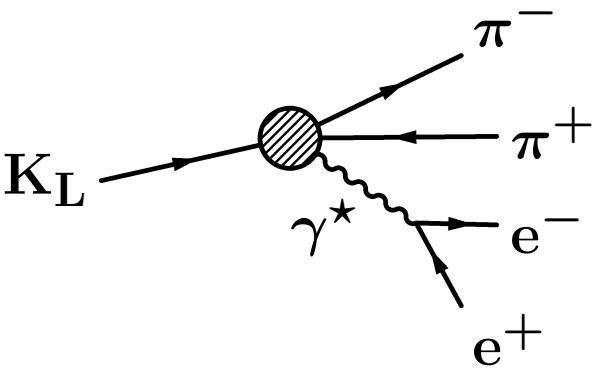
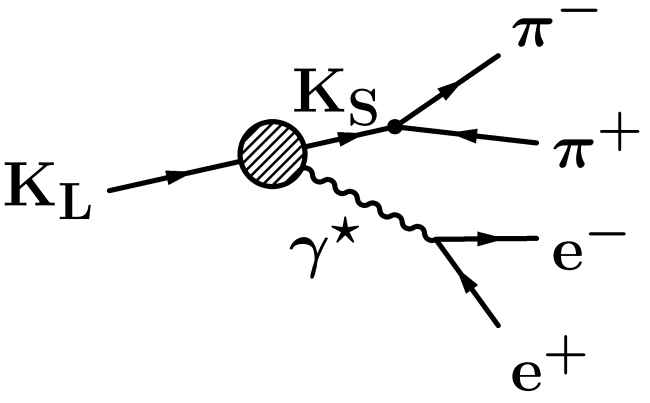


Internal Bremsstrahlung [IB]
Indirect CPV
CP-even

Direct Emission [DE]

M1 — CP Conserving
CP-odd

E1 — Indirect CPV
CP-even
Even smaller



Small, only few %

K^0 Charge Radius [CR]
CP Conserving
CP-odd

Sehgal et al
published in
1992 — 2000

3. Crunch Statistics

Data Set	N'^{97}	N'^{99}	$N'^{97+'99}$
4TRK	141,782,019	262,543,446	404,325,465
4TRPT	2,578,570	4,558,013	7,136,583
4TRGPT	25,970,536	45,876,658	71,847,194

4. Selection cuts

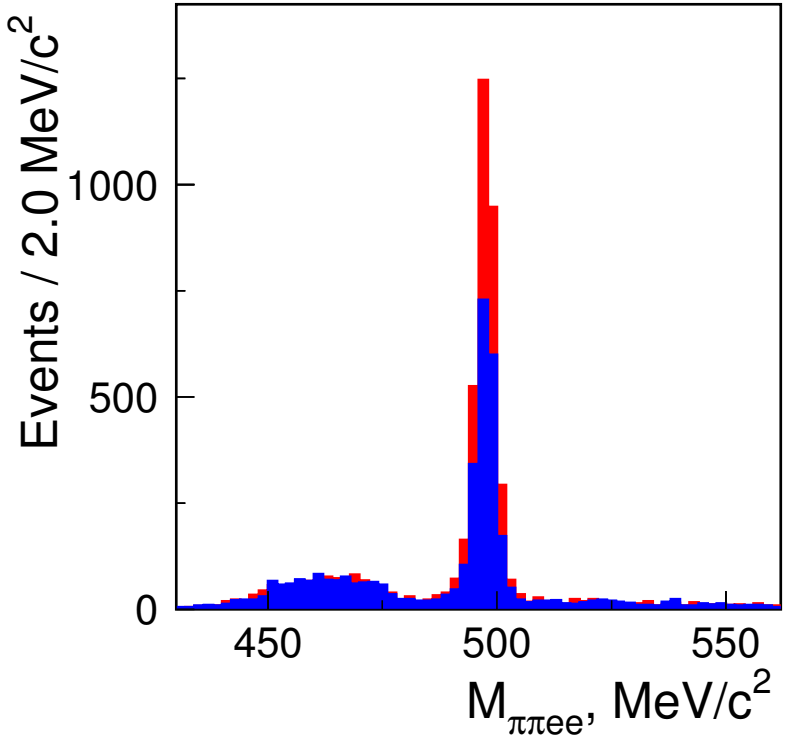
Cut	Meaning	N	$\varepsilon = \frac{N^{cut}}{N_{\mathtt{4TRKPT}}}$
4TRKPT	*Reduced 4-track trigger data.*	$7,136,580$	1.000
GRUNS	**Restrict range of runs.**	$6,972,730$	9.770×10^{-1}
T3TRAK	**Reconstruct particle tracks.**	$6,972,730$	9.770×10^{-1}
KTCLUS	**Reconstruct energy clusters.**	$6,972,730$	9.770×10^{-1}
COMBIN	**Reject high multiplicity events.**	$6,972,650$	9.770×10^{-1}
T3FVTX4	**Reconstruct 4-track vertex.**	$6,957,320$	9.749×10^{-1}
NTRK	**Require 4 tracks.**	$6,835,300$	9.578×10^{-1}
TWOPAIR	**Require 2 π's and 2 e's.**	$4,446,750$	6.231×10^{-1}
PMPM	**Require $\pi^+\pi^-e^+e^-$.**	$4,336,890$	6.077×10^{-1}
LPOKIN	**Suppress $K_L \to \pi^+\pi^-\pi^0_D$.**	$256,750$	3.598×10^{-2}
MEE	**Suppress $K_L \to \pi^+\pi^-\gamma$ decays.**	$204,488$	2.865×10^{-2}

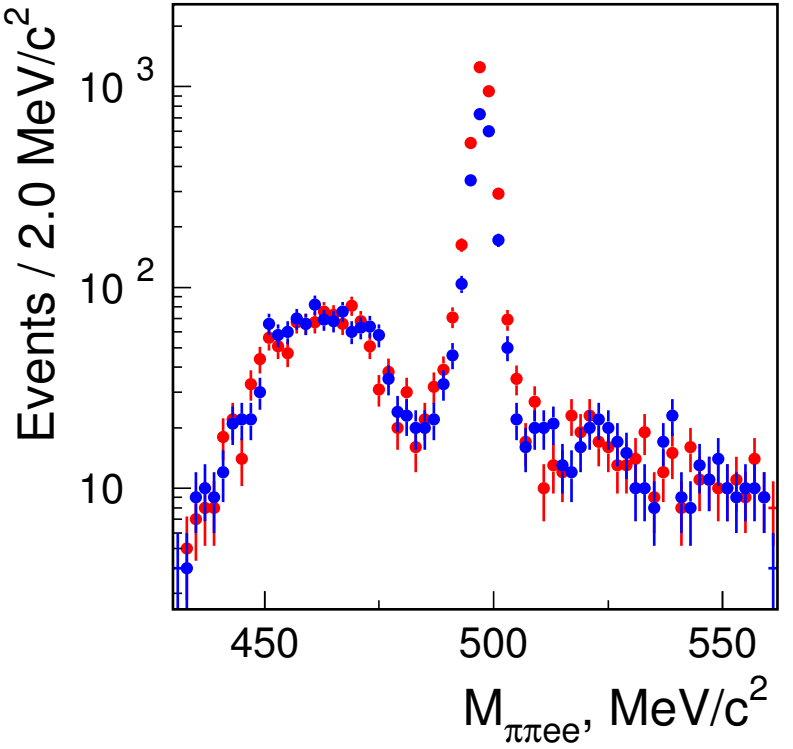
5. Selection cuts (continued)

Cut	Meaning	N	$\varepsilon = \frac{N^{cut}}{N_{\mathtt{4TRKPT}}}$
TRIG	Verify trigger requirements.	$122,629$	1.718×10^{-2}
VTXCHI	Require good vertex quality.	$67,479$	9.455×10^{-3}
ZVTX	Constrain vertex z-position.	$63,809$	8.941×10^{-3}
TPT2ONE	Momentum conservation.	$14,865$	2.083×10^{-3}
EKAON	Constrain kaon energy range.	$13,869$	1.943×10^{-3}
MAGOFF	Match tracks in the magnet.	$11,057$	1.549×10^{-3}
TEOP	Tighten particle ID for e's.	$9,915$	1.389×10^{-3}
HCLUS	Require hardware clusters for e's.	$9,786$	1.371×10^{-3}
MKAON	Constrain kaon mass region.	$5,241$	7.344×10^{-4}

6. Selected sample of $K_L \to \pi^+\pi^-e^+e^-$ candidates

Clean signal after all cuts





— $sin\phi \cdot cos\phi > 0$

— $sin\phi \cdot cos\phi < 0$

Background has no asymmetry

7. Summary of previous results

1 Sample of 5241 $K_L \to \pi^+\pi^-e^+e^-$ candidates was selected from entire KTeV dataset. Estimated background 185 ± 14.

2 Form factors of individual contributions to the decay amplitude were measured:

$$\tilde{g}_{M1} = 1.11 \pm 0.12(stat) \pm 0.07(syst)$$

$$\frac{a_1}{a_2} = [-0.744 \pm 0.022(stat) \pm 0.032(syst)] \ (GeV)^2$$

$$|g_{CR}| = 0.163 \pm 0.017(stat) \pm 0.023(syst)$$

$$\frac{|g_{E1}|}{|g_{M1}|} < 0.04 \ (90\% \ CL)$$

3 Calculated from FF's

$$\langle |g_{M1}| \rangle_{E^\star_\gamma} = 0.74 \pm 0.04$$

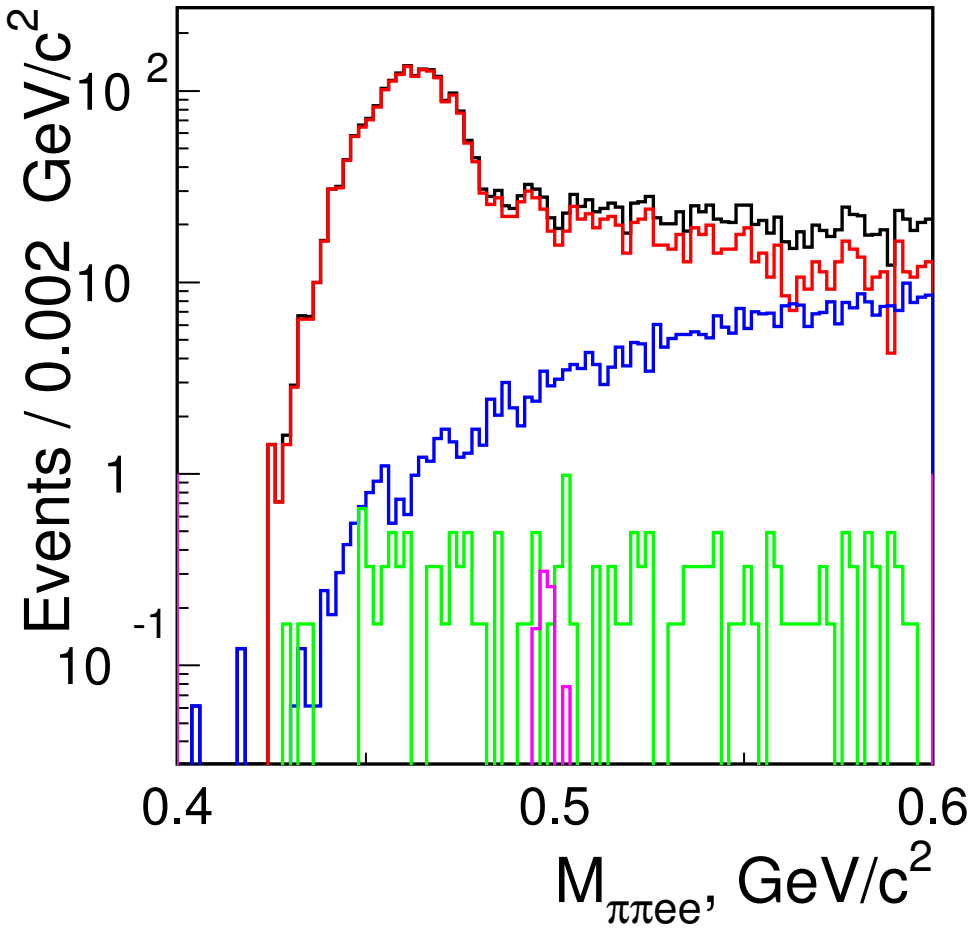
$$\langle |g_{E1}| \rangle_{E^\star_\gamma} < 0.03 \ (90\% \ CL)$$

$$\langle r^2_{K^0} \rangle = [-0.077 \pm 0.008(stat) \pm 0.011(syst)] \ (fm)^2$$

4 Measured CPV asymmetry:

$$\mathcal{A} = [13.7 \pm 1.4(stat) \pm 1.5(syst)] \ \%$$

8. Background is well understood



87% $K_L \to \pi^+\pi^-\pi^0,\ \pi^0 \to e^+e^-\gamma$
with missing γ

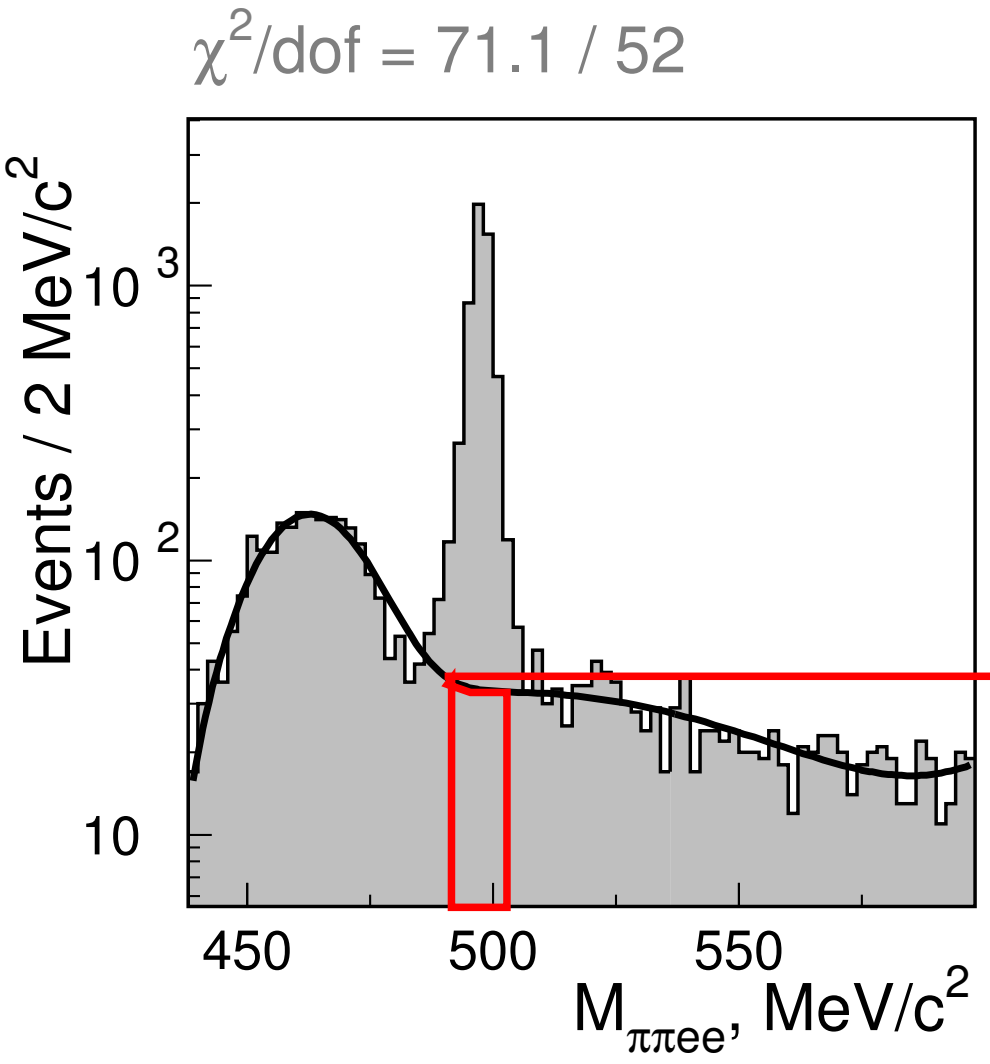
11% $\Xi \to \Lambda\pi^0$
$\Lambda \to p\pi^-,\ \pi^0 \to e^+e^-\gamma$
misidentified p **and missing** γ

1% $K_L \to \pi^+\pi^-\pi^0,\ \pi^0 \to e^+e^-e^+e^-$
2 e's are missing

0.5% $K_L \to \pi^+\pi^-\gamma,\ \gamma \to e^+e^-$
external conversion

Sum fits Gaussian + 5th order polynominal

9. Different estimation of residual background level

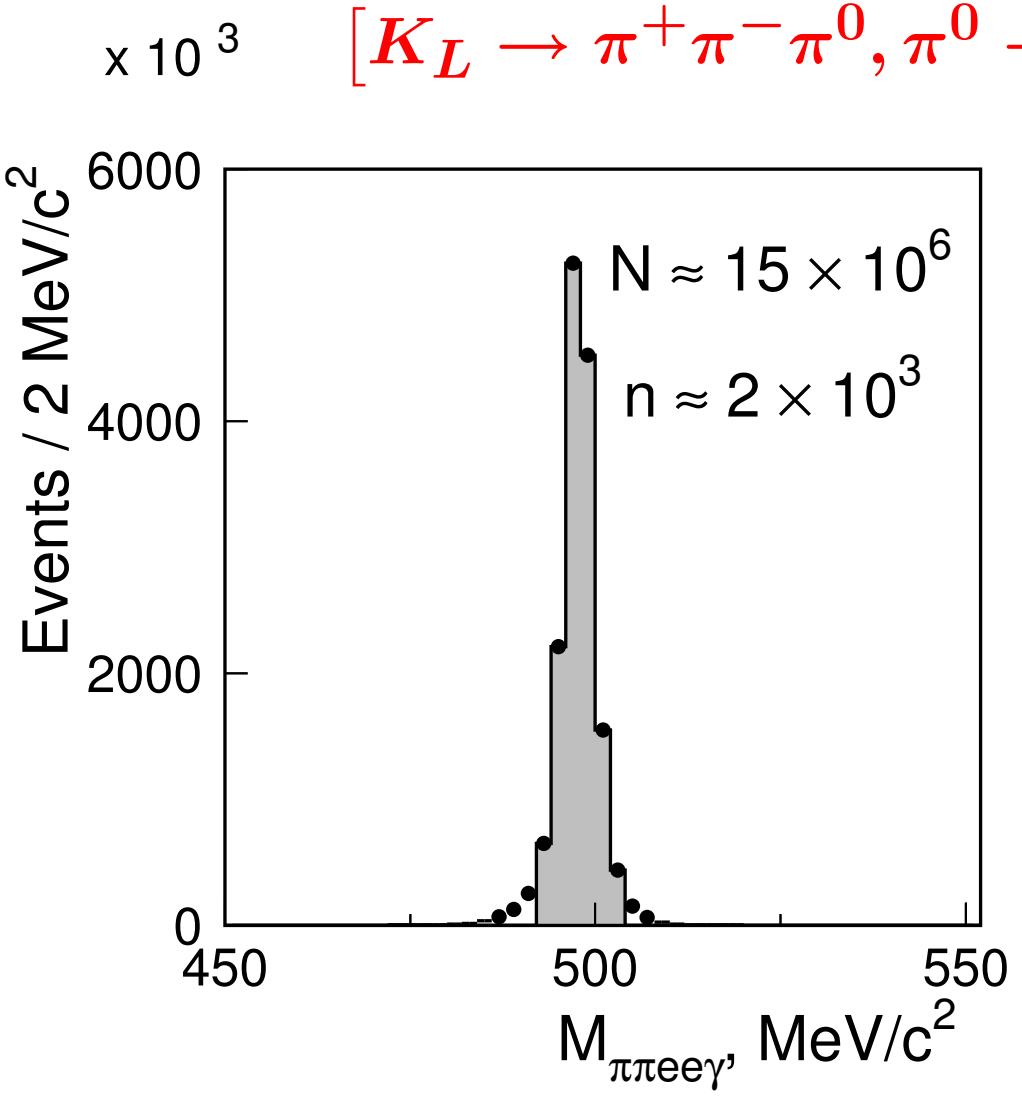


Fit wing regions then estimate background in the signal region

214 ± 16
versus
185 ± 14 **before**

10. Selected large $K_L \to \pi^+\pi^-\pi^0_D$ normalization sample

$[K_L \to \pi^+\pi^-\pi^0, \pi^0 \to e^+e^-\gamma]$



Almost same data selection as $K_L \to \pi^+\pi^-e^+e^-$

but

1. reconstruct γ and π^0
2. looser P_t^2
3. $[P_L^2]_{\pi^0} > 0$

Large sample no background

11. Branching Ratio central value

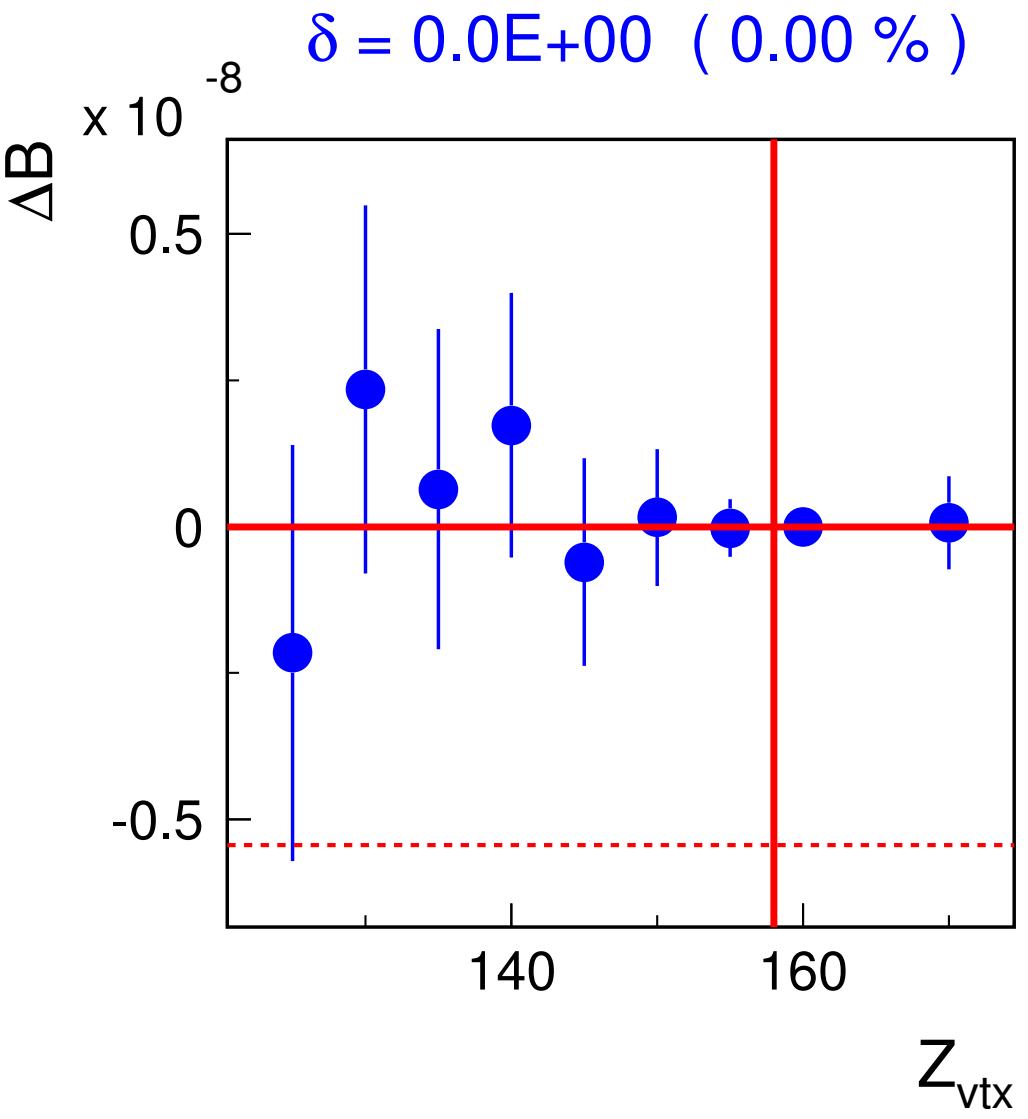
$$\mathcal{B} = 3.80 \cdot 10^{-7}$$

Source	Error	
Data stat.	$5.40 \cdot 10^{-9}$	(1.42%)
MC stat.	$6.60 \cdot 10^{-10}$	(0.17%)
Total stat.	$5.44 \cdot 10^{-9}$	(1.43%)
$\mathcal{B}(K_L \to \pi^+\pi^-\pi^0_D)$	$1.16 \cdot 10^{-8}$	(3.07%)

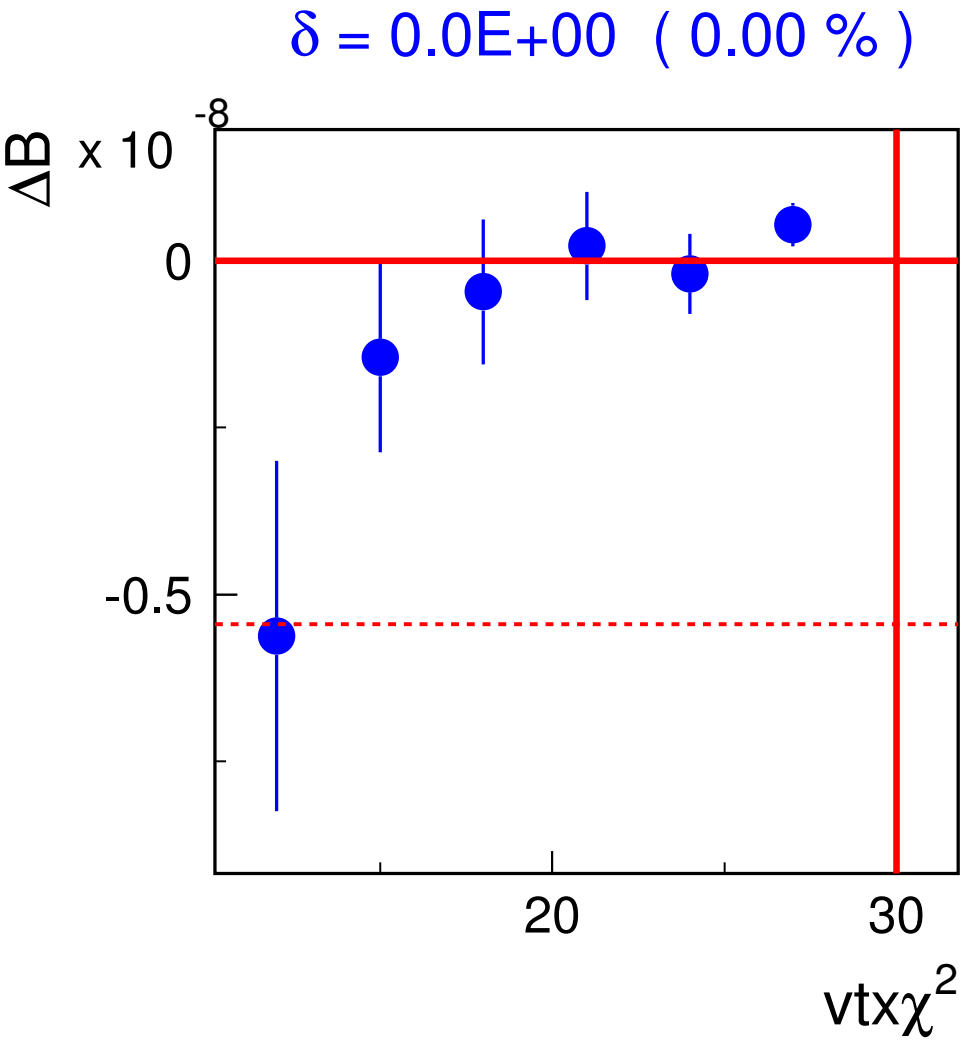
12. Background error and uncertainties on parameters

Source	Error	
background	$1.28 \cdot 10^{-9}$	(0.34%)
η_{+-}	$2.28 \cdot 10^{-9}$	(0.60%)
ϕ_{+-}	$9.08 \cdot 10^{-10}$	(0.24%)
g_{CR}	$2.74 \cdot 10^{-9}$	(0.72%)
g_{E1}	$7.21 \cdot 10^{-10}$	(0.19%)
g_{M1}	$5.96 \cdot 10^{-9}$	(1.57%)
$\delta's$	$1.79 \cdot 10^{-10}$	(0.05%)

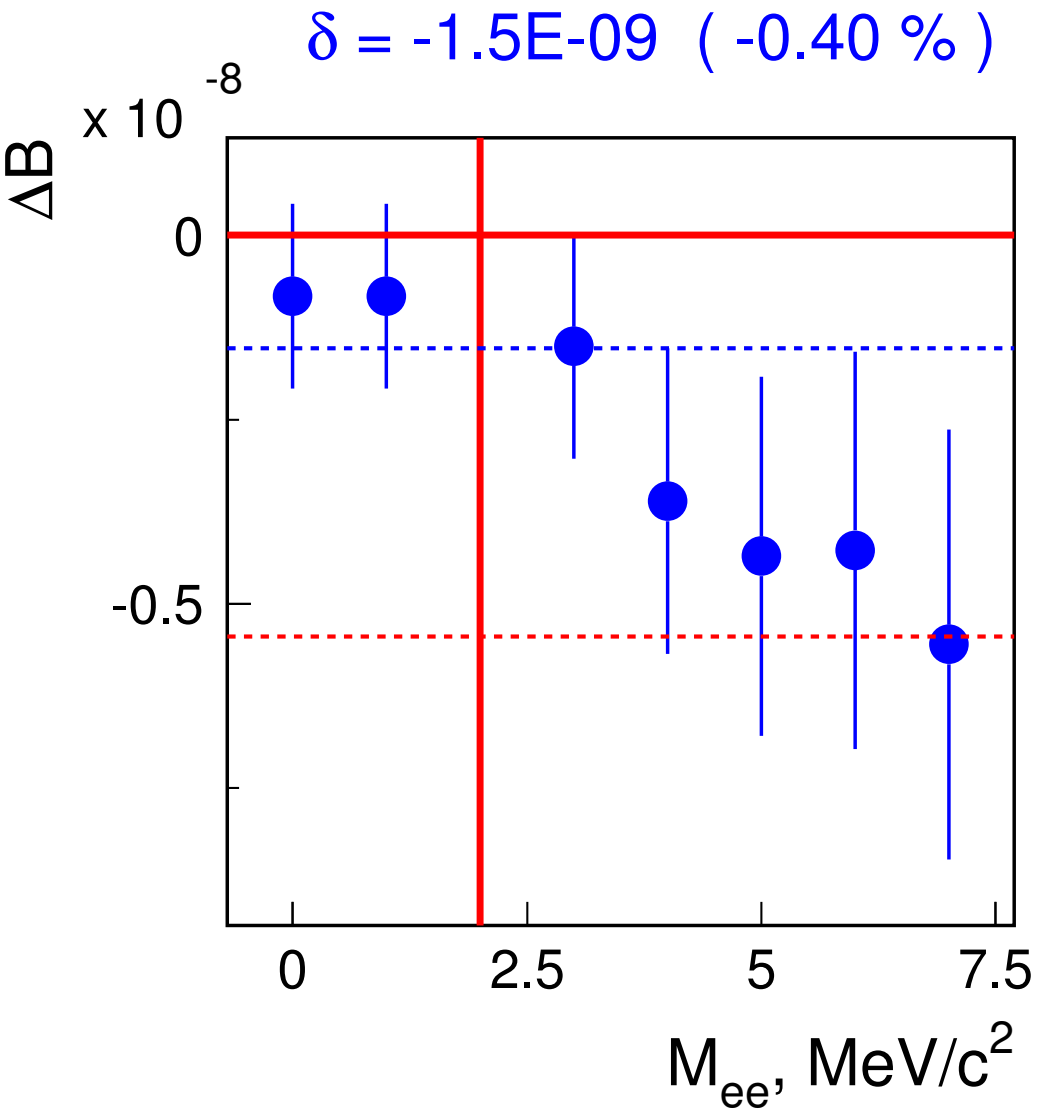
13. Cut variation: z_{vtx}



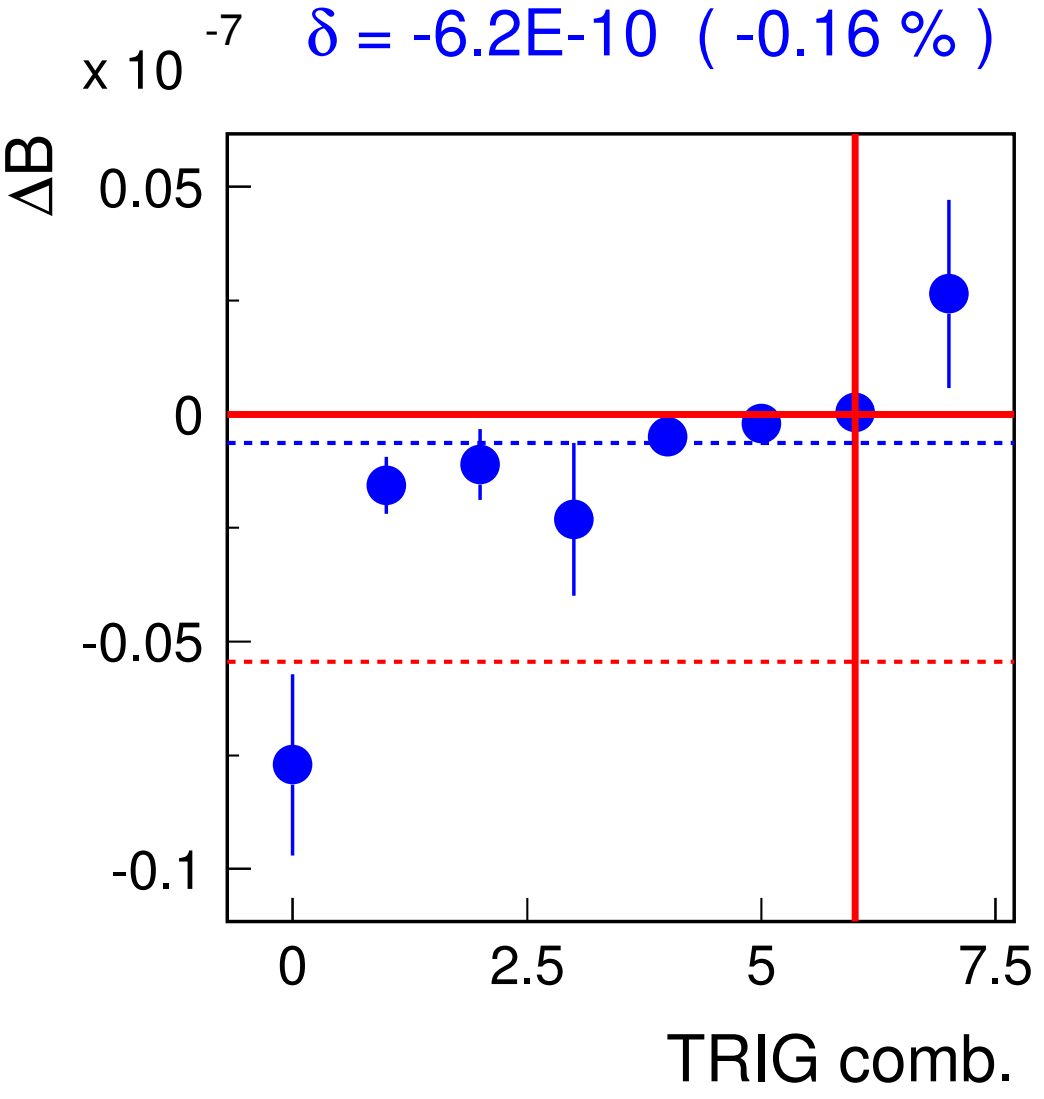
14. Cut variation: χ^2_{vtx}



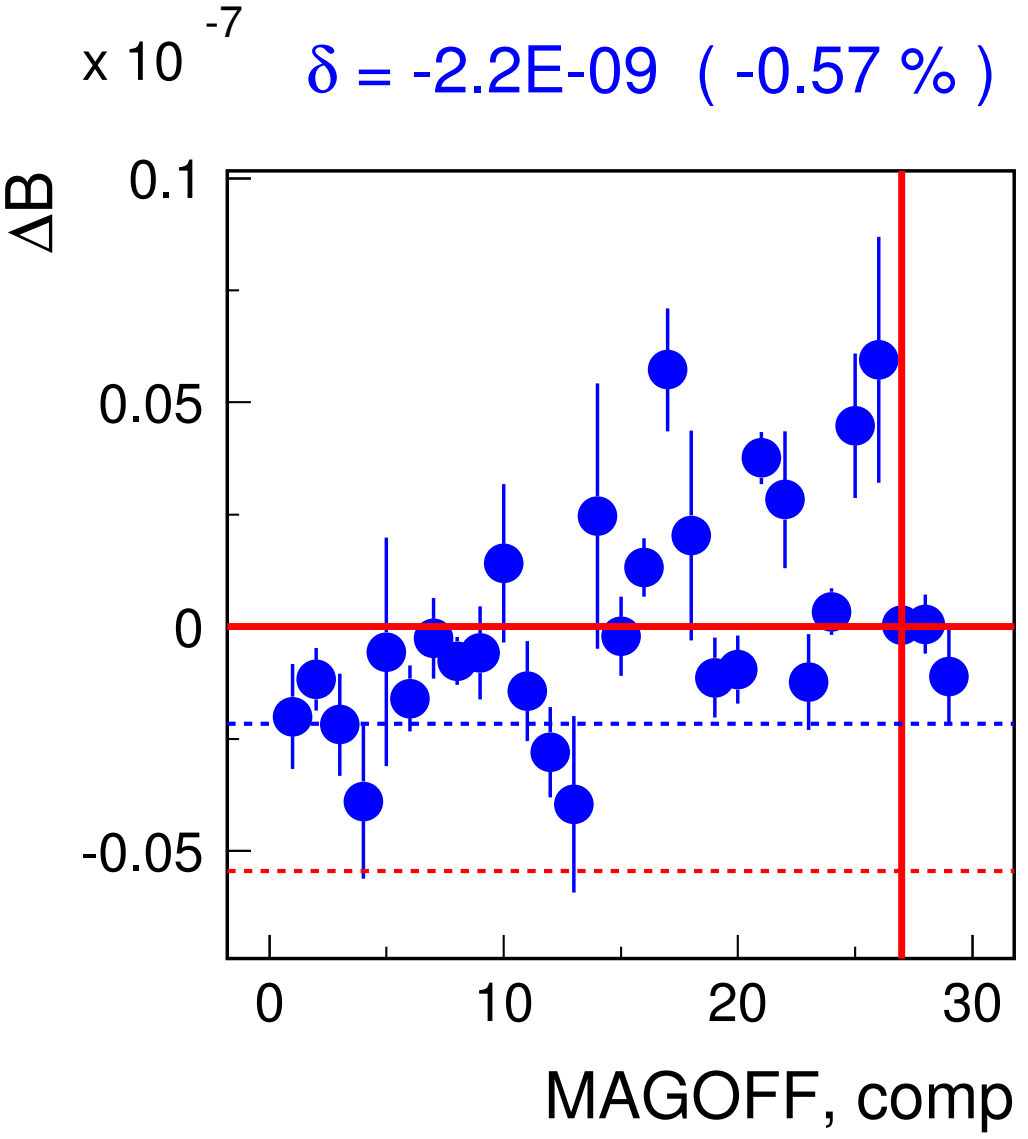
15. Cut variation: M_{ee}



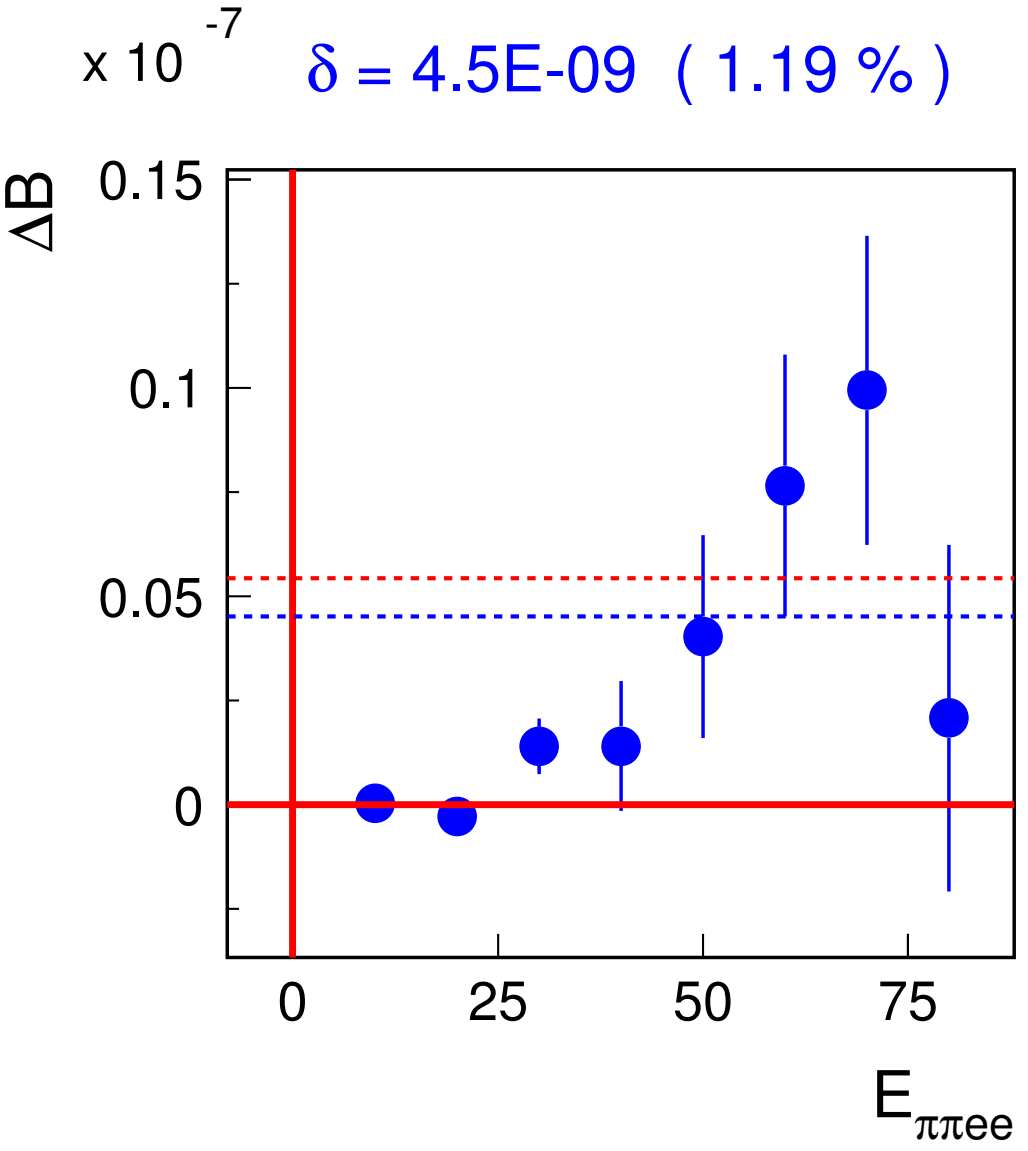
16. Cut variation: trigger verification



17. Cut variation: magnet offsets



18. Cut variation: $E_{\pi\pi ee}$



19. Errors due to Data/MC disagreement

Cut	Error
M_{ee}	$1.53 \cdot 10^{-9}$ (0.40%)
TRIG	$6.25 \cdot 10^{-10}$ (0.16%)
MAGOFF	$2.17 \cdot 10^{-9}$ (0.57%)
$E_{\pi\pi ee}$	$4.52 \cdot 10^{-9}$ (1.19%)

20. Status and plans

Latest number

1 $\mathcal{B} = (3.80 \pm 0.05(stat) \pm 0.12(\mathcal{B}_{\pi^0}) \pm 0.09(syst) \pm ...(syst2)) \cdot 10^{-7}$

2 **Published results**

$(3.2 \pm 0.72) \cdot 10^{-7}$	FNAL KTeV, 1998
$(4.4 \pm 1.39) \cdot 10^{-7}$	KEK, 1998
$(3.08 \pm 0.20) \cdot 10^{-7}$	CERN NA48, 2003

3 **Complete systematic studies. Update all the results.**

4 **Submit paper and documentation to collaboration.**