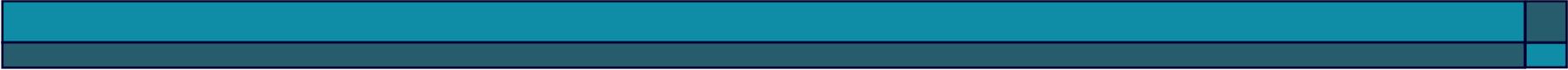


# Re( $\epsilon'/\epsilon$ ) Final Update

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Elizabeth Worcester

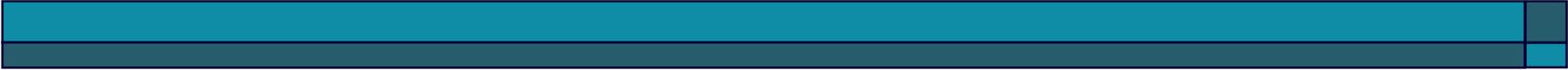
November 17, 2007



# Overview

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- Status in May 2007
- Solutions to problems from May
- Systematics
- Results
- Crosschecks
- Comparison to other measurements
- Documentation and Plans



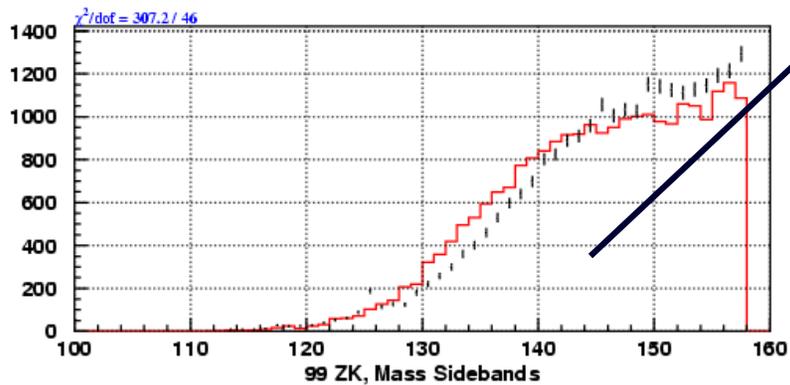
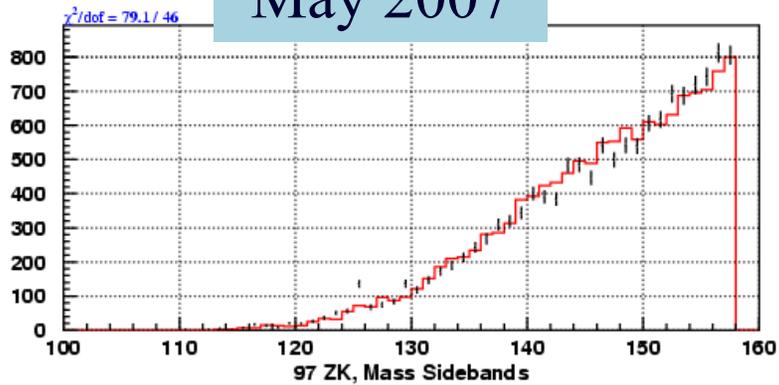
# Status in May 2007

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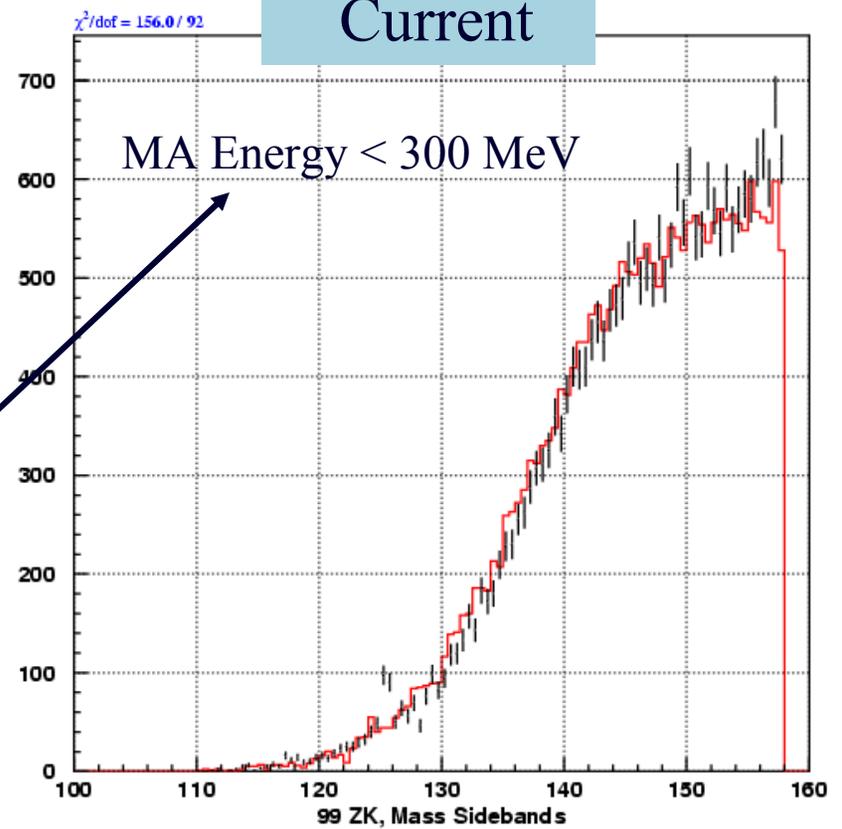
- Outstanding Issues
  - Neutral Mode:
    - $3\pi^0$  bg issue
    - Large chi-square in some fits
  - Charged Mode
    - L3 systematic
    - Regenerator edge systematic
- To Do:
  - 1996 analysis
  - Finalize systematics
  - Crosschecks

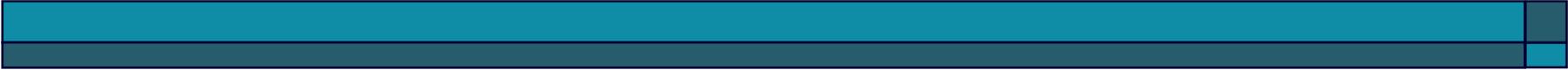
# 3pi0 bg problem

May 2007



Current





# Large $\chi^2$ for z-binned fits

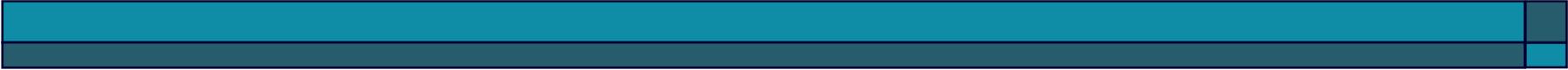
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- Bug in simulation of decays in regenerator
  - Momentum spectrum of decays in regenerator chosen from wrong distribution
  - Introduced in v6.01
  - Fixed in v7.00 only
- Fit  $\chi^2$  improves in z-binned fits
  - Neutral mode  $\Delta m$  and  $\tau_S$ 
    - Added 1996 data
    - 252/199  $\rightarrow$  227/199

# Charged mode L3 bias

- 5 runs from 1999 with large L3 bias excluded from data sample
- L3 trigger bias measured using B01 and crosschecked using B03
- Correct  $\text{Re}(\epsilon'/\epsilon)$  for bias and take error on correction as systematic
  - Correction:  $+0.3 \times 10^{-4}$
  - Systematic:  $\pm 0.12 \times 10^{-4}$

Trigger	Bias in $\text{Re}(\epsilon'/\epsilon)$ ( $\times 10^{-4}$ )		
	1997	1999	Combined
B01	$0.32 \pm 0.20$	$0.28 \pm 0.14$	$0.30 \pm 0.12$
B03	$0.58 \pm 0.59$	$-0.24 \pm 0.60$	$0.12 \pm 0.42$



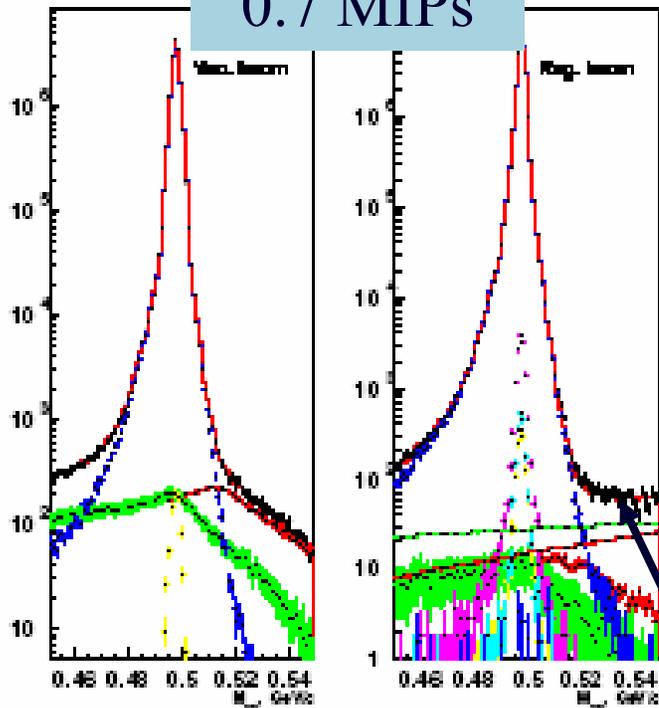
# Charged mode regenerator edge

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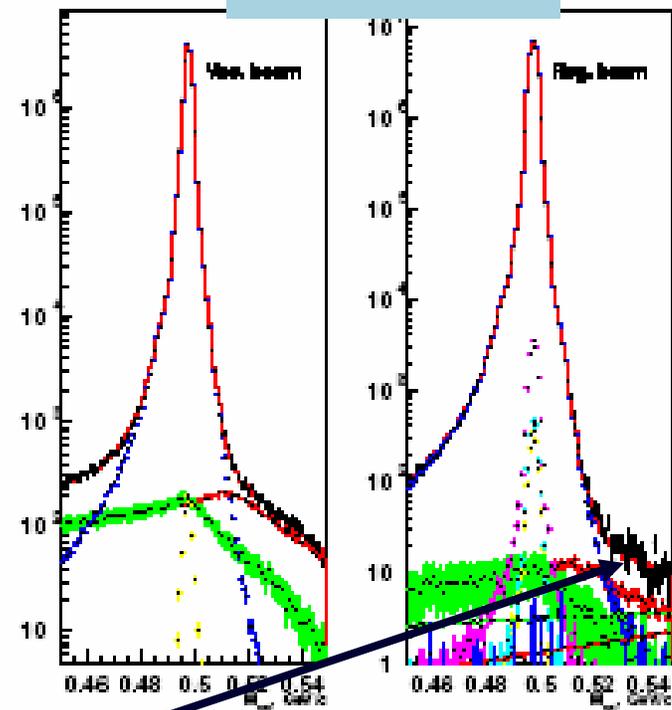
- Problems with 1999 reg veto
  - 1999 trigger threshold higher than offline cut of 0.7 MIPs
  - Large uncertainty in charged mode reg edge
    - $\pm 1.7 \text{ mm} \rightarrow \pm 0.7 \times 10^{-4}$  systematic on  $\text{Re}(\epsilon'/\epsilon)$
  - Run dependence of junk fraction
- Change offline cut to 0.25 MIPs for 1999
  - Junk fraction constant vs run
  - Junk background reduced
  - Effective regenerator edge determined more precisely
    - $\pm 0.4 \text{ mm} \rightarrow \pm 0.2 \times 10^{-4}$  systematic on  $\text{Re}(\epsilon'/\epsilon)$
- [http://hep.uchicago.edu/~glazov/may22\\_2007/junk.pdf](http://hep.uchicago.edu/~glazov/may22_2007/junk.pdf)

# Tight offline reg veto cut for 1999

May 2007:  
0.7 MIPs

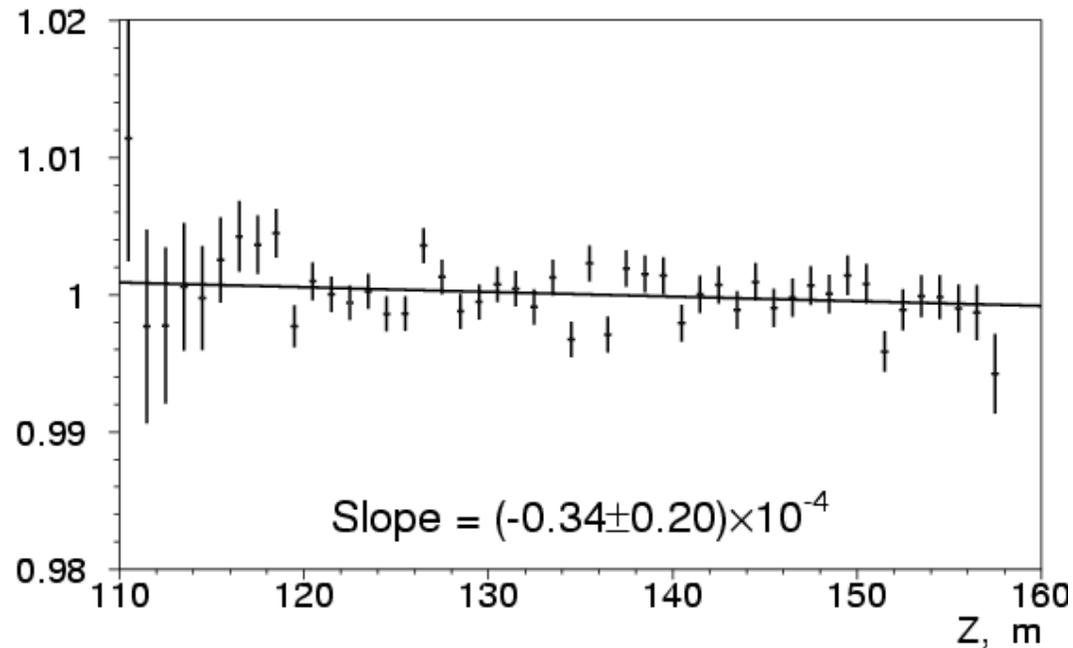


Current:  
0.25 MIPs



Reduced junk background

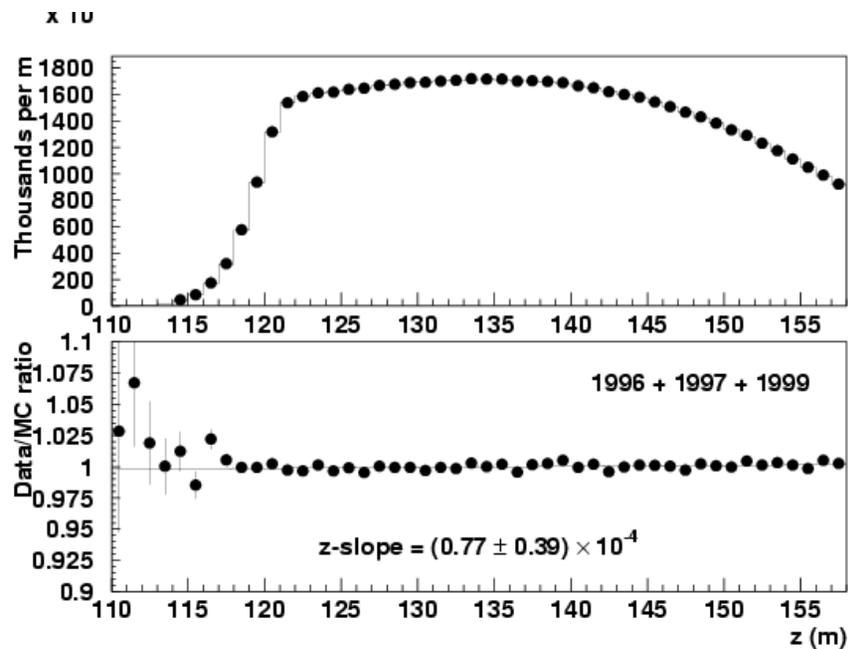
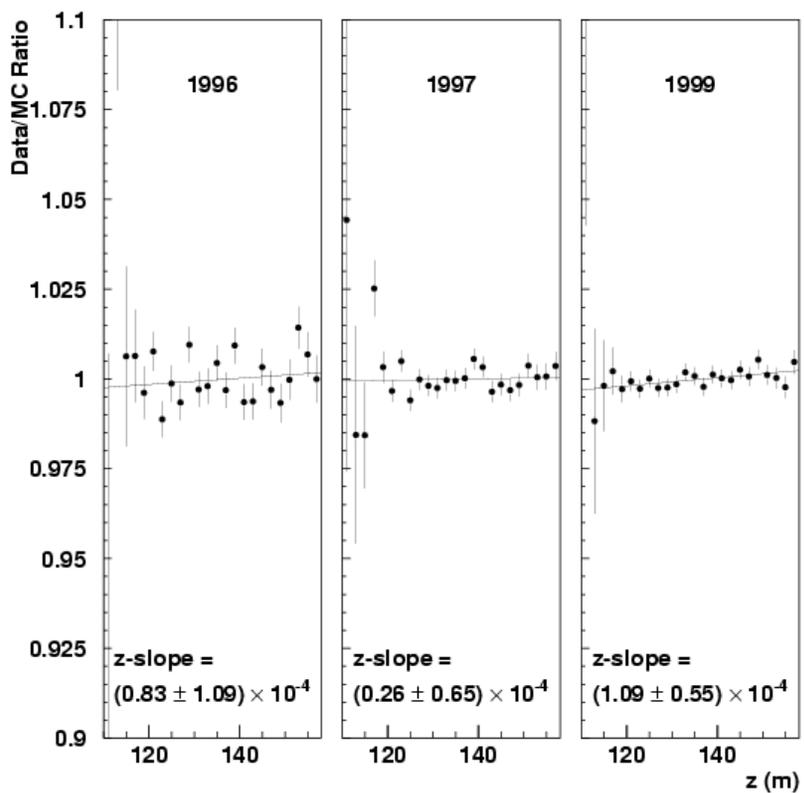
# Systematics: charged mode z-slope



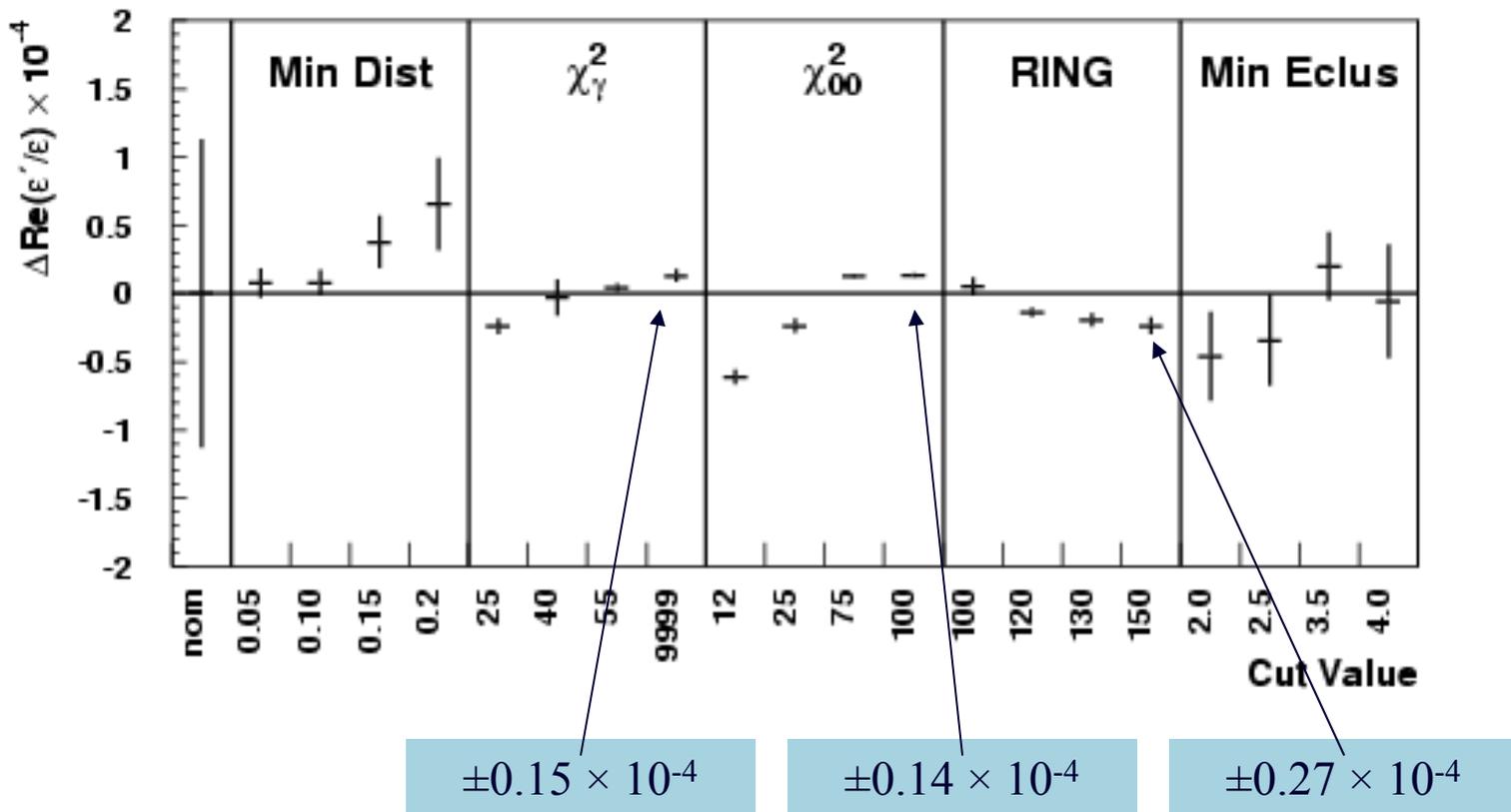
- Systematic on  $\text{Re}(\epsilon'/\epsilon)$ :  $\pm 0.41 \times 10^{-4}$



# Systematics: $2\pi^0$ z-slope



# Systematics: 2pi0 Cut Variations



Systematic error on  $\text{Re}(\epsilon'/\epsilon) = \pm 0.34 \times 10^{-4}$

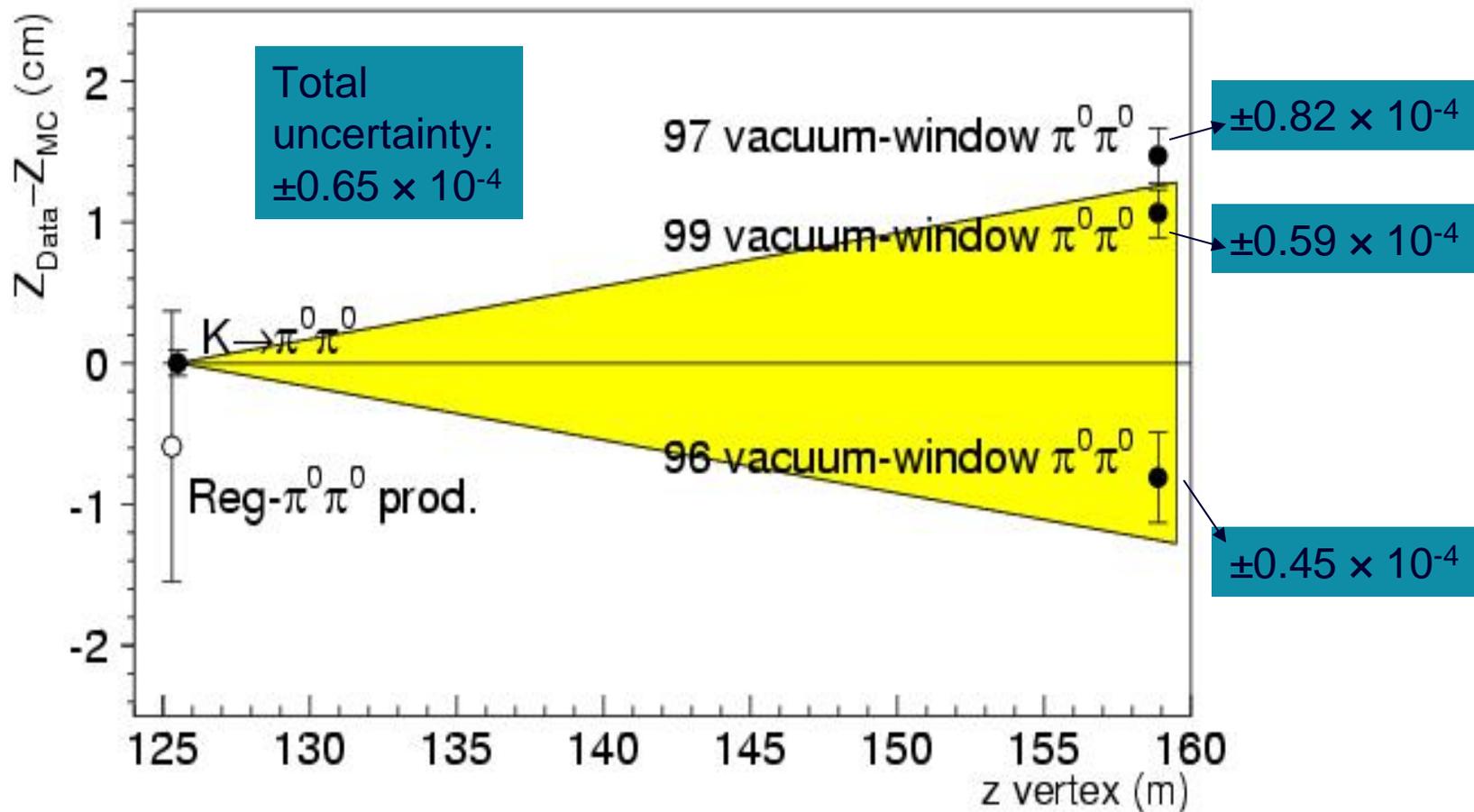
# Systematics: Energy Scale

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Year	Regenerator Junk $z_{data} - z_{WC}$ (cm)	Vacuum Window Junk $z_{data} - z_{WC}$ (cm)	Error on $\bar{R}_E(e'/e)$ ( $\times 10^{-4}$ )
1996	$0.24 \pm 0.75$	$-0.81 \pm 0.32$	0.45
1997	$-1.24 \pm 0.46$	$1.47 \pm 0.19$	0.82
1999	$-0.35 \pm 0.42$	$1.06 \pm 0.17$	0.59
Average	$-0.59 \pm 0.48$	$0.97 \pm 0.20$	0.65

- Regenerator junk consistent with  $2\pi^0$
- Vacuum window junk has significant mismatch in all years
- Combine vacuum window junk by evaluating systematic separately for 96, 97, and 99 and taking a weighted average of the errors

# Systematics: Energy Scale



# Summary of Systematic Errors

Source	Error on $Re(\epsilon'/\epsilon)$ ( $\times 10^{-4}$ )			
	PRD	1997	1999	Total
L1 and L2 Trigger	0.20	0.20	0.20	0.20
L3 Trigger	0.54	0.20	0.14	0.12
Alignment and Calibration	0.28	0.20		0.20
Momentum scale	0.16	0.10		0.10
$p_T^2$	0.25	0.10		0.10
DC efficiency modeling	0.37	0.15		0.15
DC resolution modeling	0.15	0.15		0.15
Background	0.20	0.20		0.20
Wire Spacing	0.22	0.22		0.22
Rag Edge	0.20	0.20	0.20	0.20
Acceptance	0.79	0.87	0.25	0.41
Upstream z	—	0.33	0.48	0.40
Monte Carlo Statistics	0.41	0.28	0.28	0.20
Total	1.26	1.12	0.81	0.81

Source	Error on $Re(\epsilon'/\epsilon)$ ( $\times 10^{-4}$ )				
	PRD	1996	1997	1999	Total
L1 Trigger	0.10	0.01	0.01	0.03	0.02
L2 Trigger	0.13	0.20	0.12	0.23	0.19
L3 Trigger	0.08	0.20	0.04	0.05	0.07
Ring Number	0.24		0.27		0.27
Pairing $\chi^2$	0.20		0.14		0.14
Shape $\chi^2$	0.20		0.15		0.15
Energy Nonlinearity	0.66	0.10	0.10	0.20	0.15
Energy Scale	1.27	0.45	0.82	0.59	0.65
Position Reconstruction	0.35		0.35		0.35
Background	1.07	1.14	1.06		1.07
CeI Inner Aperture	0.42		0.42		0.42
MA Aperture	0.18		0.18		0.18
Rag Edge	0.04		0.04		0.04
CeI Size	0.15		0.15		0.15
Acceptance	0.39		0.48		0.48
MC Statistics	0.40	0.75	0.37	0.41	0.25
Total	2.01	1.69	1.63	1.56	1.55

# Summary of Systematic Errors

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Source	Error on $\text{Re}(e'/e)$ ( $\times 10^{-4}$ )	
	$K \rightarrow \pi^+\pi^-$	$K \rightarrow \pi^0\pi^0$
Trigger	0.23	0.20
CsI cluster reconstruction	—	0.75
Track reconstruction	0.22	—
Selection efficiency	0.23	0.34
Apertures	0.30	0.48
Acceptance	0.57	0.48
Backgrounds	0.20	1.07
MC statistics	0.20	0.25
Total	0.81	1.55
Fitting	0.25	
Total	1.77	

# Results: $\text{Re}(\epsilon'/\epsilon)$

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- $\text{Re}(\epsilon'/\epsilon) = [19.2 \pm 1.1 (\text{stat}) \pm 1.8 (\text{syst})] \times 10^{-4}$   
 $= (19.2 \pm 2.1) \times 10^{-4}$ 
  - $\text{Chisq} = 22.9/21$

Year	$K \rightarrow \pi^0 \pi^0$ sample	$K \rightarrow \pi^+ \pi^-$ sample	$\text{Re}(\epsilon'/\epsilon)$ $\times 10^{-4}$
1996	1996	1997	$20.8 \pm 2.8 \pm 2.0$ $= 20.8 \pm 3.4$
1997	1997	1997	$18.9 \pm 1.7 \pm 2.0$ $= 18.9 \pm 2.6$
1999	1999	1999	$19.0 \pm 1.4 \pm 1.8$ $= 19.0 \pm 2.3$

# Results: $\Delta m$ and $\tau_S$

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## □ Charged fit

- $\Delta m = [5269.0 \pm 3.8 (stat) \pm 10.5 (syst)] \times 10^6 \text{ ħs}^{-1}$   
 $= (5269.0 \pm 11.2) \times 10^6 \text{ ħs}^{-1}$
- $\tau_S = [89.620 \pm 0.019 (stat) \pm 0.047 (syst)] \times 10^{-12} \text{ s}$   
 $= (89.620 \pm 0.051) \times 10^{-12} \text{ s}$
- Chisq = 198.8/199

## □ Neutral fit

- $\Delta m = [5257.6 \pm 7.9 (stat) \pm 10.7 (syst)] \times 10^6 \text{ ħs}^{-1}$   
 $= (5257.6 \pm 13.3) \times 10^6 \text{ ħs}^{-1}$
- $\tau_S = [89.667 \pm 0.037 (stat) \pm 0.094 (syst)] \times 10^{-12} \text{ s}$   
 $= (89.667 \pm 0.101) \times 10^{-12} \text{ s}$
- Chisq = 226.5/199

## □ Combined Results

- $\Delta m = (5265 \pm 11) \times 10^6 \text{ ħs}^{-1}$
- $\tau_S = (89.62 \pm 0.05) \times 10^{-12} \text{ s}$

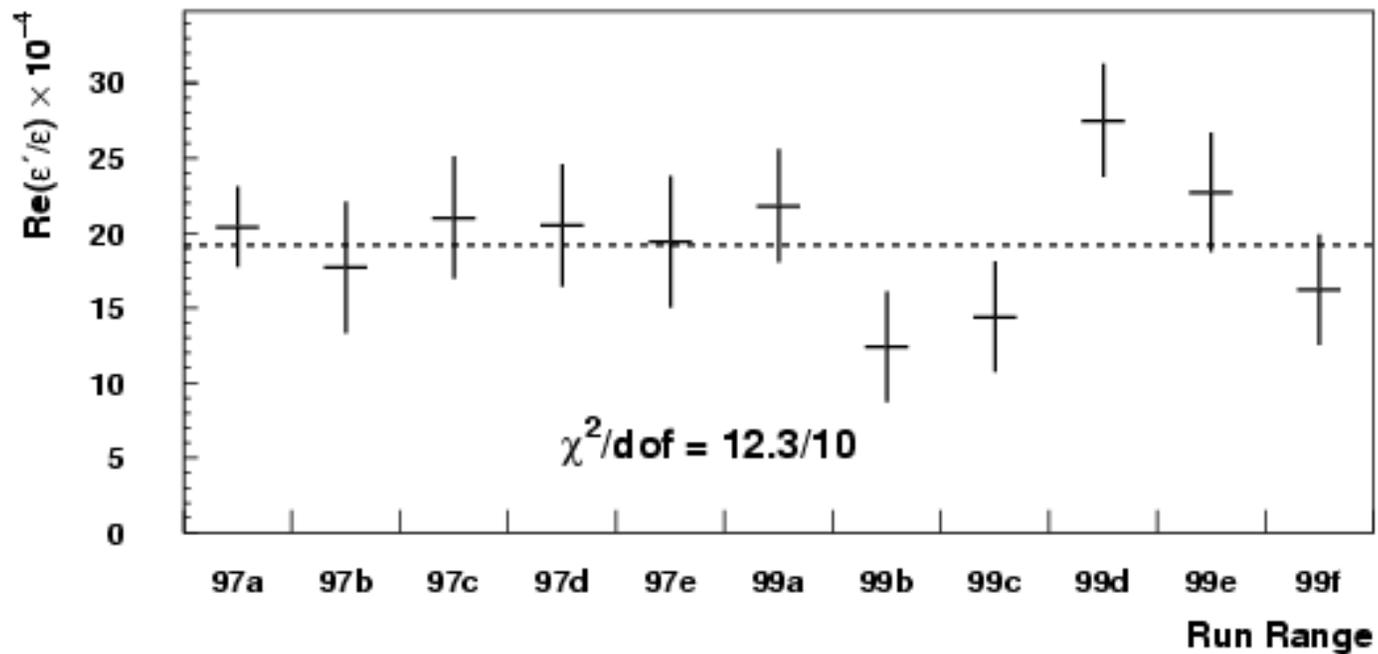
# Results: CPT Tests

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- $\Phi_{+-} = [44.09 \pm 0.43 (stat) \pm 0.90 (syst)]^\circ$   
 $= (44.09 \pm 1.00)^\circ$ 
  - $\text{Chisq} = 196.8/198$
- $\Phi_{+-} - \Phi_{SW} = [0.59 \pm 0.38 (stat) \pm 0.78 (syst)]^\circ$   
 $= (0.59 \pm 0.87)^\circ$ 
  - $\text{Chisq} = 196.8/198$
- $\Delta\Phi = [0.29 \pm 0.15 (stat) \pm 0.27 (syst)]^\circ$   
 $= (0.29 \pm 0.31)^\circ$ 
  - $\text{Chisq} = 425.6/399$

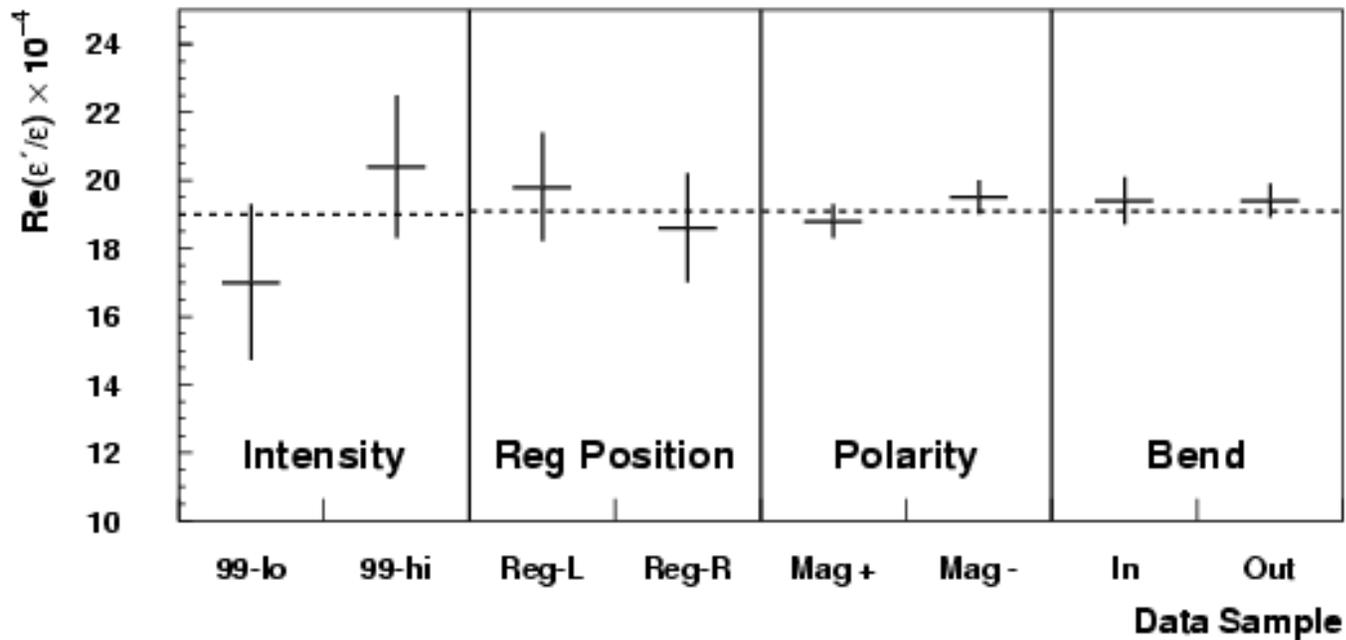
# Crosschecks: Run Ranges

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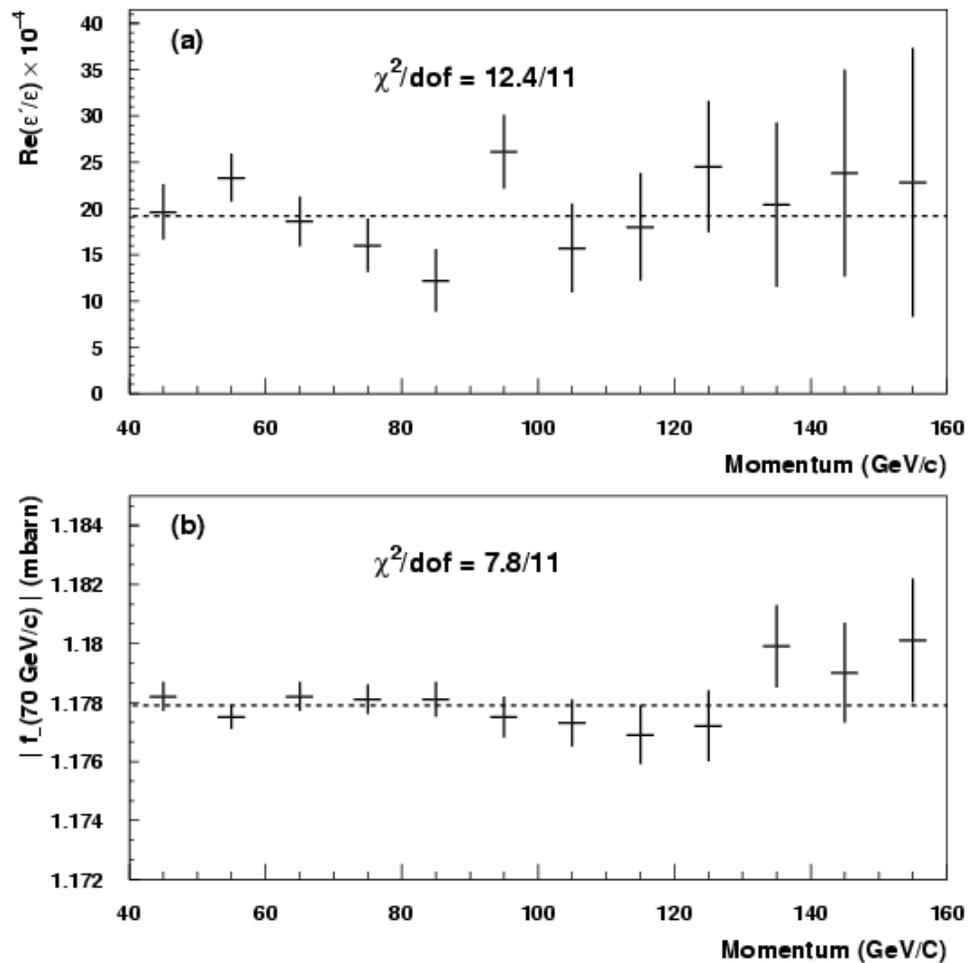


# Crosschecks: Half Samples

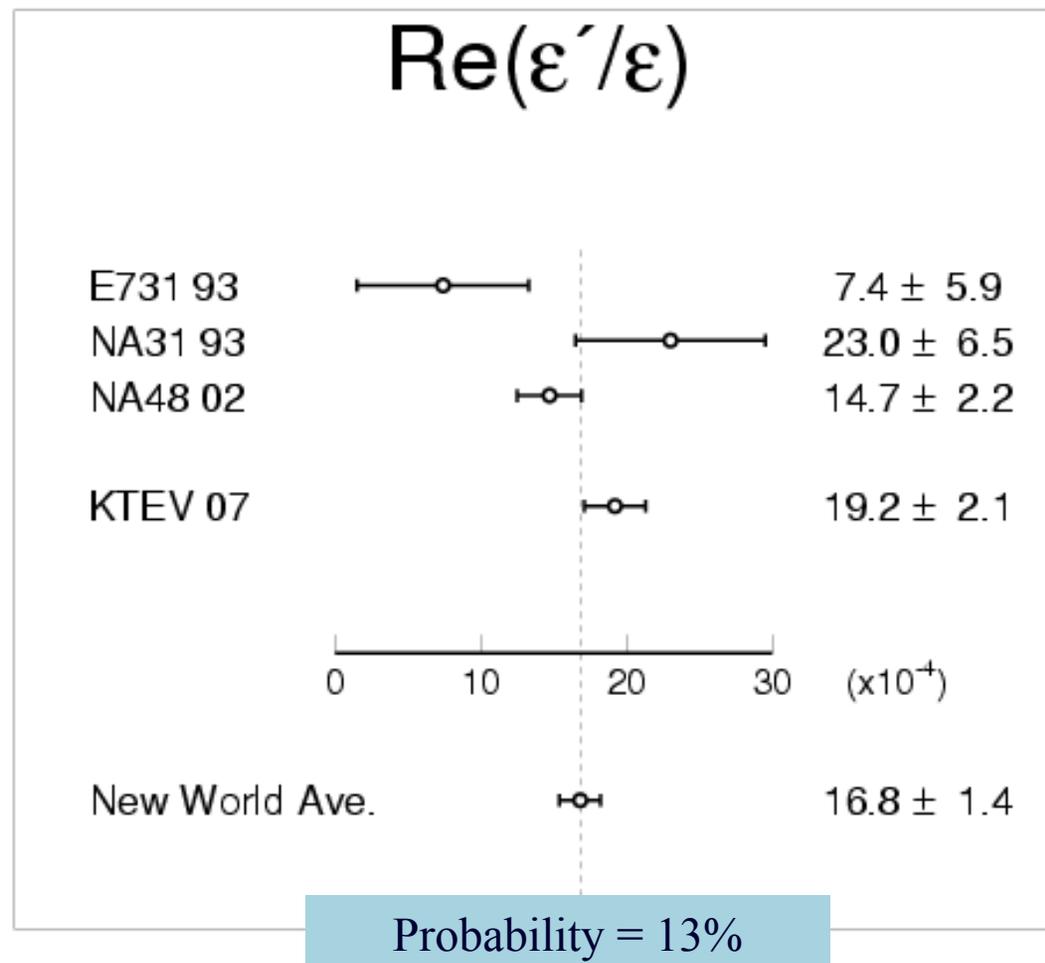
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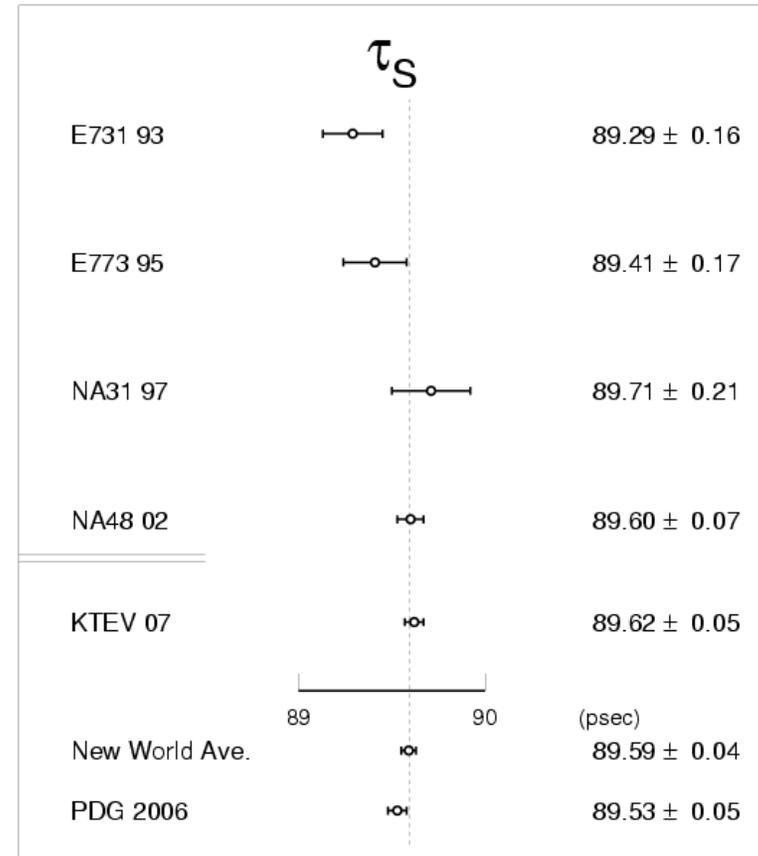
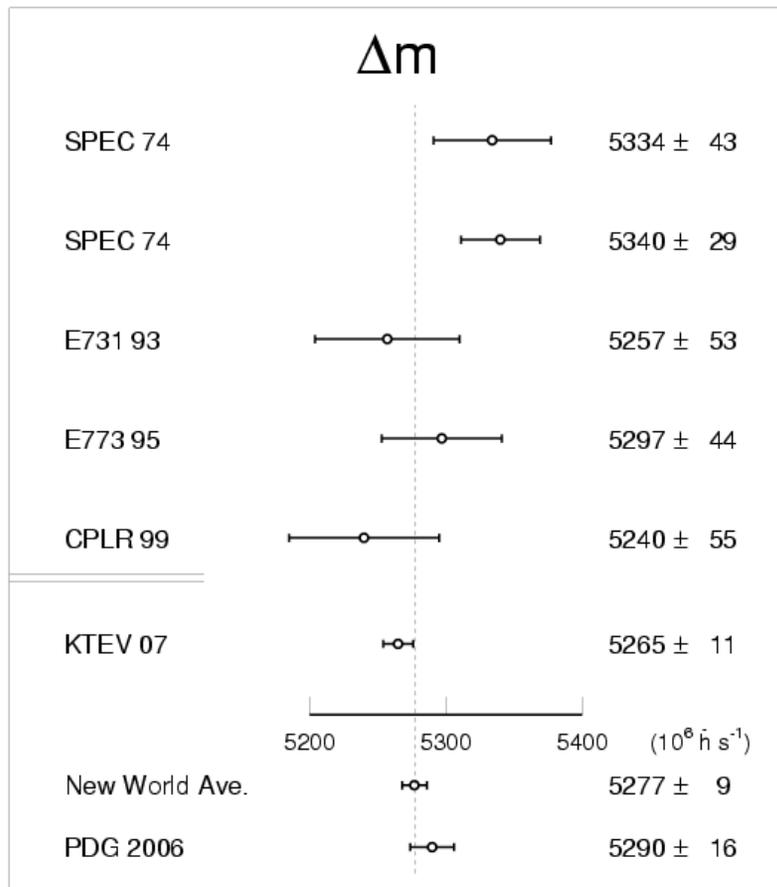
# Crosschecks: Momentum Bins



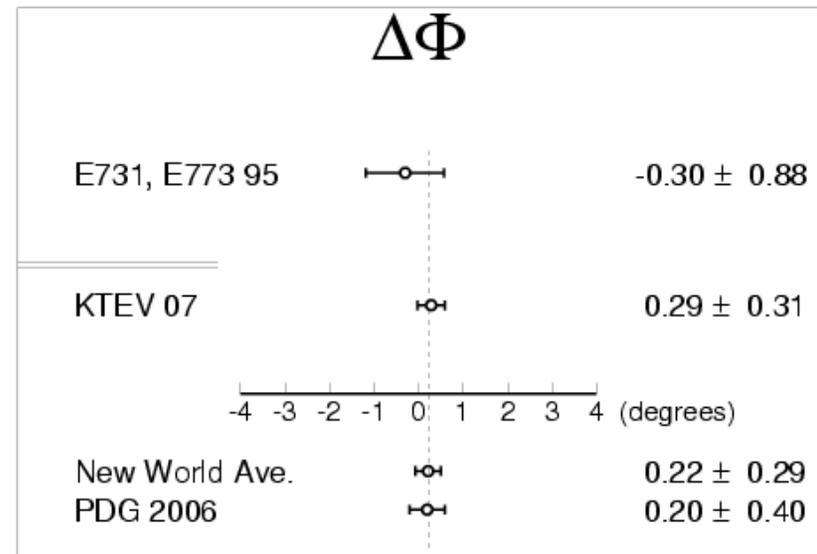
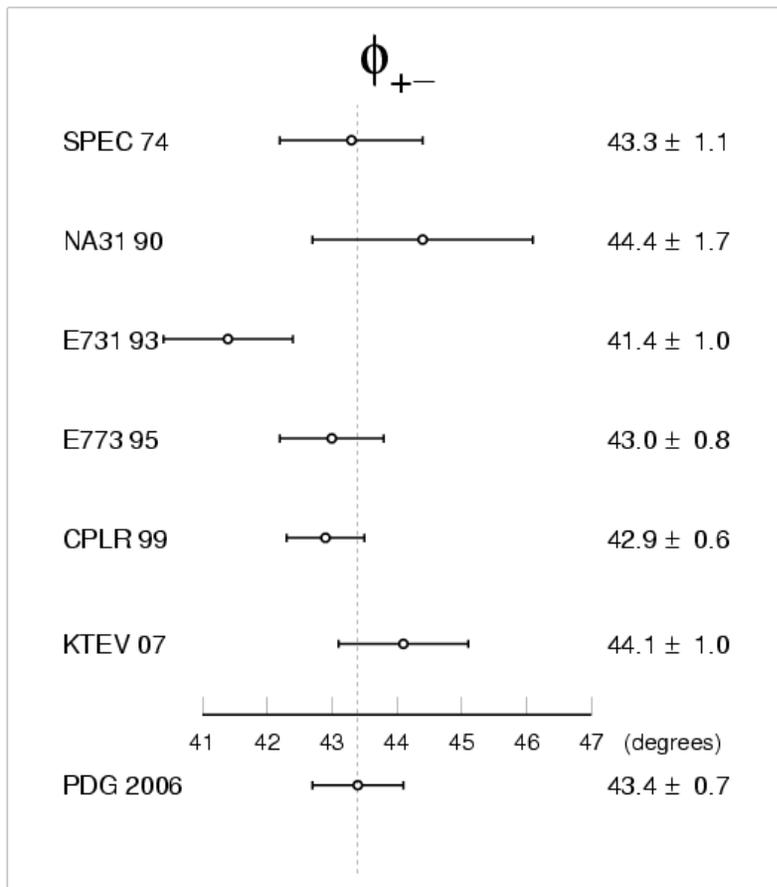
# Comparison to Other Measurements

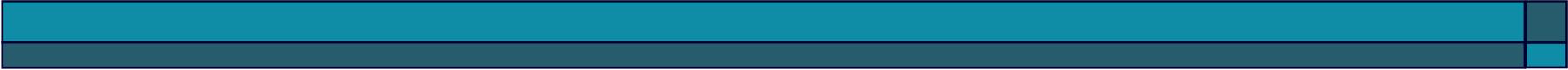


# Comparison to Other Measurements



# Comparison to Other Measurements





# Conclusion

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- $\text{Re}(\epsilon'/\epsilon) = (19.2 \pm 2.1) \times 10^{-4}$
- $\Delta m = (5265 \pm 11) \times 10^6 \text{ h s}^{-1}$
- $\tau_S = (89.62 \pm 0.05) \times 10^{-12} \text{ s}$
- Phase measurements consistent with CPT symmetry
- Documentation
  - <http://hep.uchicago.edu/~seturner/thesis.ps>
  - <http://hep.uchicago.edu/~glazov/chsyst.pdf>
- Plans
  - Thesis defended July 2007, submitted to university November 2007
  - Sasha visiting Chicago December-January to work on paper
  - Release paper and result simultaneously Winter 2008