Status of $Re(\epsilon'/\epsilon)$ – charged mode

- Updates since the PRD
- Event yields.
- BG subtraction
- Z overlays
- Systematic uncertainties
- Kaon system parameter fits
- $Re(\epsilon'/\epsilon)$ results

Updates since the 97 publication

A lot of changes in Spectrometer Simulation. All of them were used for $|V_{us}|$ analysis.

- Decays in the regenerator. Updated M_K value.
- Full tracing in DC. Detailed Fringe field corrections. More detailed δ-ray simulation. Update of multiple scattering.
- Update of the pion shower library - CIA veto.
- In drift cell dependent position resolution. DC geometry update.
- Various bug fixes: pion decays bug, RC threshold bug.
- Update of selection cuts.

A document listing/explaining the updates in preparation.

Event Yields

Year	Vacuum Beam	Regenerator Beam
1997	10670688	18594207
1999	15229865	26510242
Total	25900533	45104449

A bit less (by 4%) events for 1997 data because of tighter cuts on X separation at CsI 6 cm vs 3 cm (3.6%), and different MA clearance cut (rest).

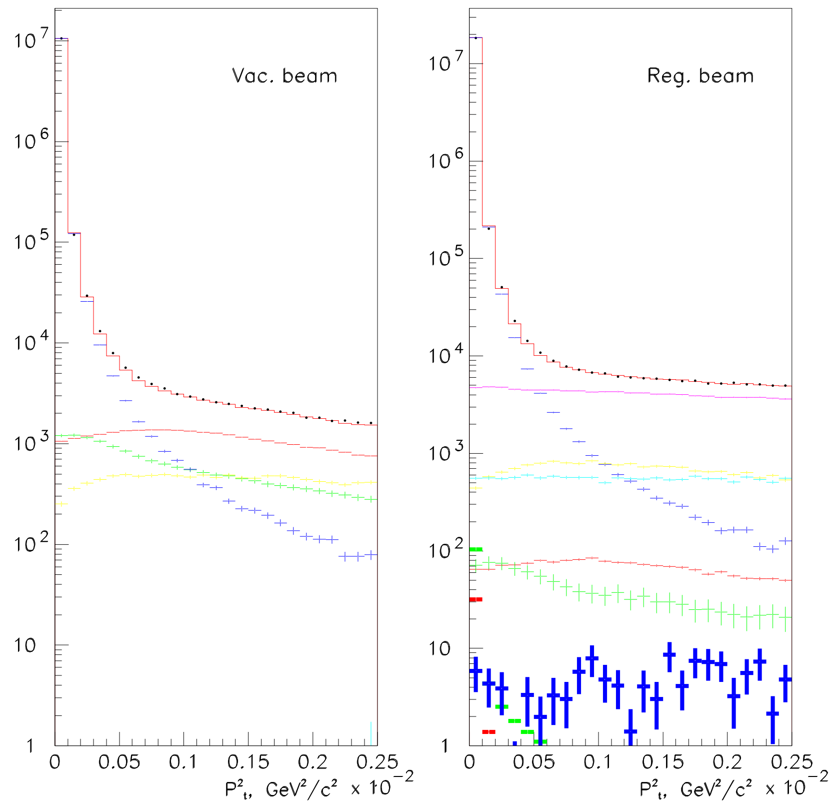
Background Subtraction

Source	Background level, %					
	97 PRD		97		99	
	Vac	Reg	Vac	Reg	Vac	Reg
$Ke3$	0.036	0.001	0.032	0.001	0.032	0.001
$K\mu3$	0.054	0.002	0.034	0.001	0.030	0.001
Collimator scattering	0.010	0.010	0.009	0.009	0.008	0.008
Regenerator scattering	—	0.074	—	0.073	—	0.075
Total background	0.100	0.087	0.074	0.083	0.070	0.085

- More BG sources: junk production at regenerator ($\Delta \to p\pi$, $K^* \to K^{\mp}\pi^{\pm}$, $K^* \to K_S\pi^0$. – help to describe $m(\pi\pi)$ distribution.
- Separation of $Ke3$, $K\mu3$ based on CsI responce. $K\mu3$ background is normalized first vs p_μ.
- Background sources are normalized in 10 GeV E_K bins.

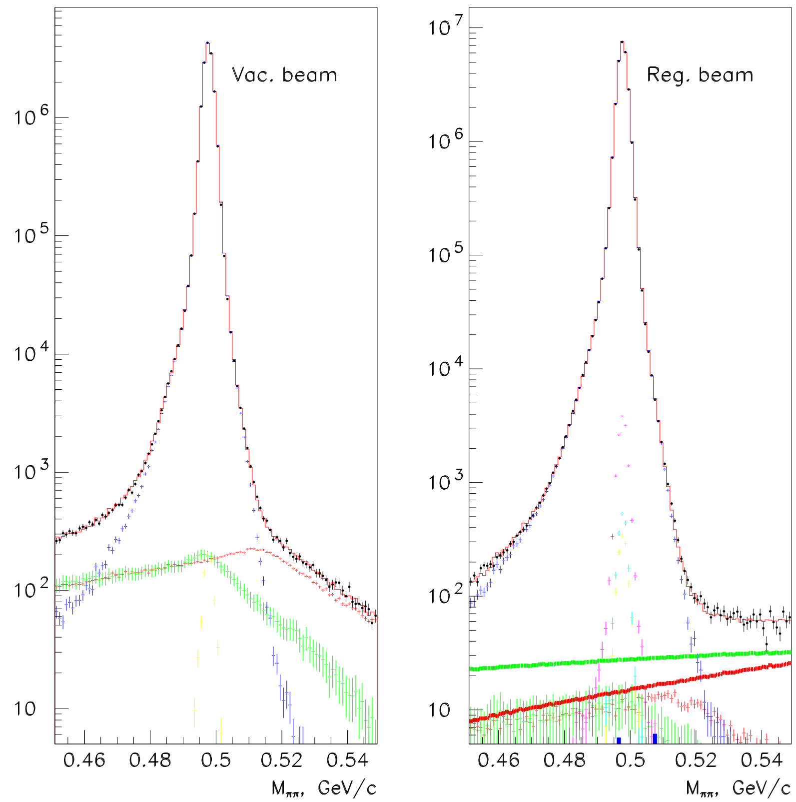
$K\mu3$ backgound is smaller vs Jim's estimate but closer to Peters (?). If mistake, 0.3×10^{-4} effect on $Re(\epsilon'/\epsilon)$.

BG: $P_\perp$ plots for 97 data



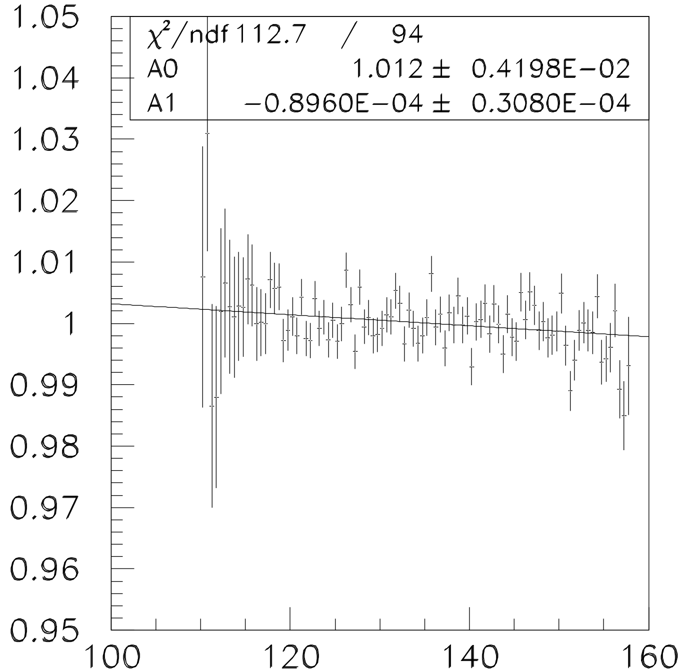
Dots – data, red line – sum of all MC, blue – signal MC, pink – diffractive reg. scat, red – $Ke3$, green – $K\mu3$, yellow – Col. Scattering. Light blue – inelastic reg. scat.

BG: $M(\pi\pi)$ plots for 99 data

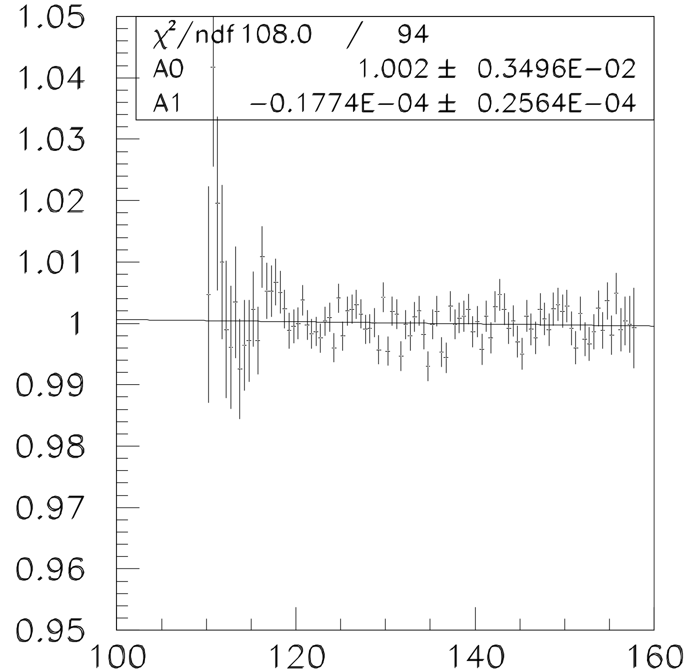


Compared to PRD lower level of $K\mu3$. Fixed π decay bug and fixed RC thresholds.

Z slopes



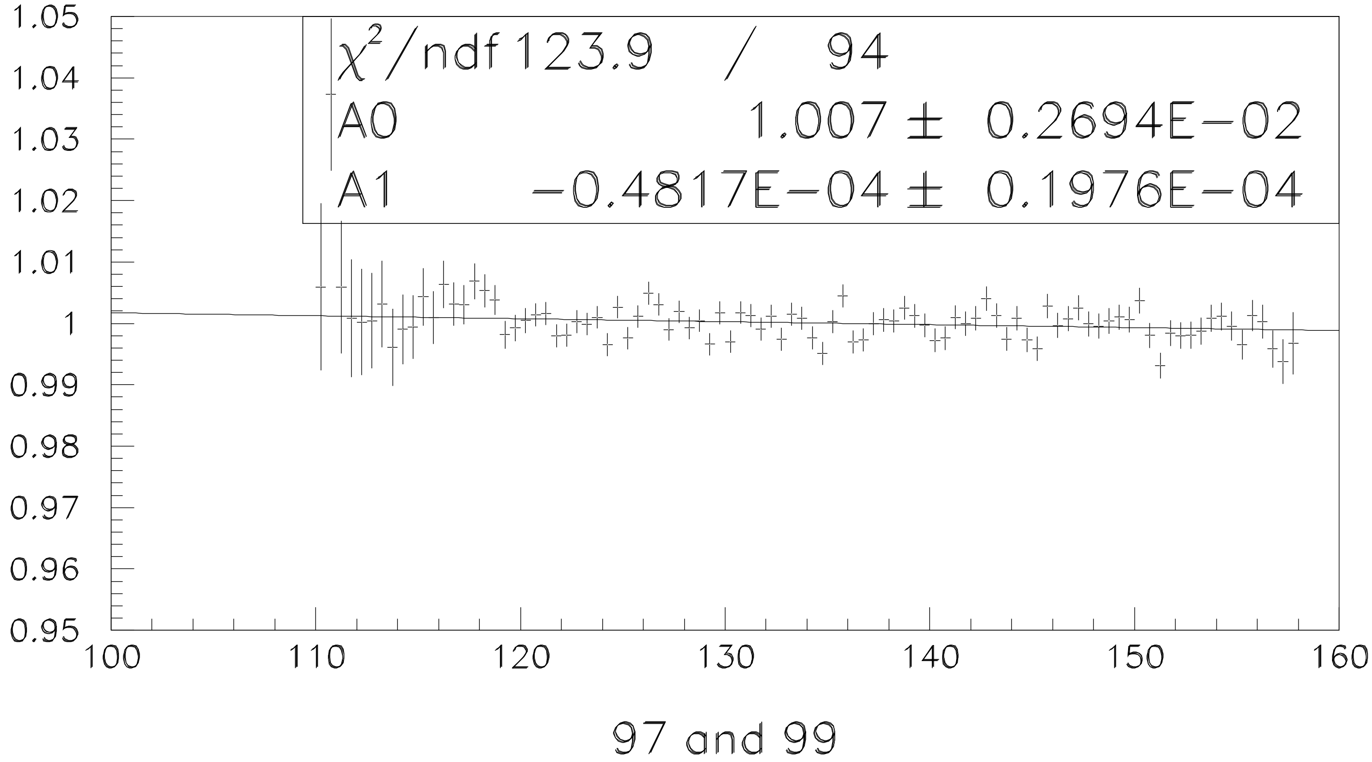
97



99

New generation of ~ 4 data sets of MC with updated collimator positions. 97 slope got worse vs PRD (0.9 vs 0.7). No slope for 99, as before. But at some point "no slope" had positive sign.

Combined Z slope



2.5σ significant Z slope ... 0.6×10^{-4} systematic uncertainty on $Re(\epsilon'/\epsilon)$.

Decay region upstream of MA

Decays upstream of MA are prone to additional systematic effects

- No Reg beam — direct data to MC comparison.
- Pion scattering in MA requires MA clearance cut. The shape of Z distribution is sensitive to the value of the cut. One can tune to fix any data to MC problem ...
- Decays downstream of MA are almost insensitive to the beam profile; upstream – very sensitive.
- The meaning of Z slope is misleading for a local acceptance problem around MA. Localized loss in data Vac beam upstream of MA leads to positive Z slope, but positive Z slope is interpreted as larger loss in Reg beam, which is exactly opposite to the reality.

Proposal: introduce additional syst. uncertainty evalulated by inclusion/exculusion of data with $Z < 122.5$ m.

Decays upstream of MA systematics

Change in selection	Bias in $Re(\epsilon'/\epsilon)$, $\times 10^4$		
	97	99	Combined
$Z > 122.5$ m cut	-0.35 ± 0.27	-0.55 ± 0.17	-0.50 ± 0.16
expected from Z_{ave} change	-0.37	-0.08	-0.20
No MA clearance cut	$+0.52 \pm 0.20$	-0.84 ± 0.13	-0.27 ± 0.10
expected from Z slope change	-0.26	$+0.67$	

"No MA clearance" cut leads to large problem in upstream Z distribution for 99 data, this could be because of pion scattering/not perfect MA thersholds — not to be taken as systematics but as an illustration of wrong exepectation from Z slope change.

Systematic uncertainty for $Re(\epsilon'/\epsilon)$ for combined, subtracting the change expected from average Z change, is 0.38×10^{-4}.

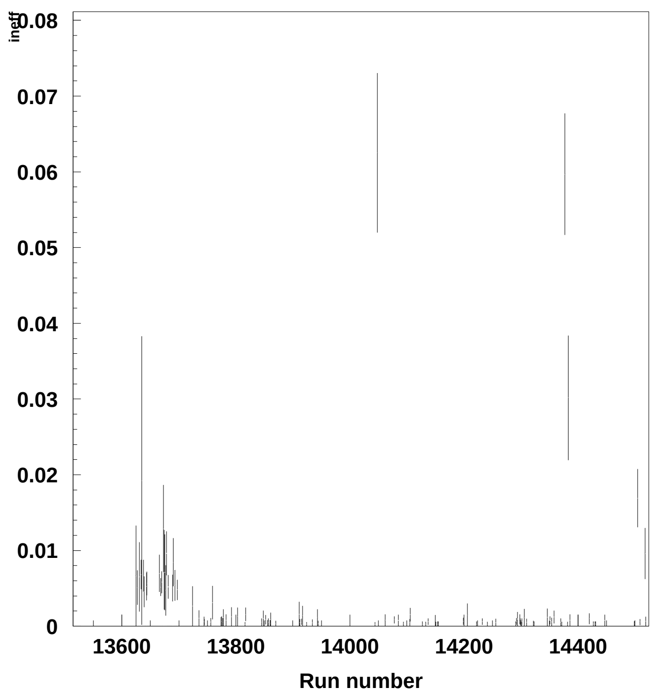
Systematics: L3

- Use B01 random accept events
- Use also B03 (prescale 500) as a cross check — inclusive check of L2 and L3

Reference Trigger	Bias in $Re(\epsilon'/\epsilon)$		
	97	99	Combined
B01	0.32 ± 0.20	0.41 ± 0.17	0.37 ± 0.13
B03	0.58 ± 0.59	-0.15 ± 0.63	0.05 ± 0.36

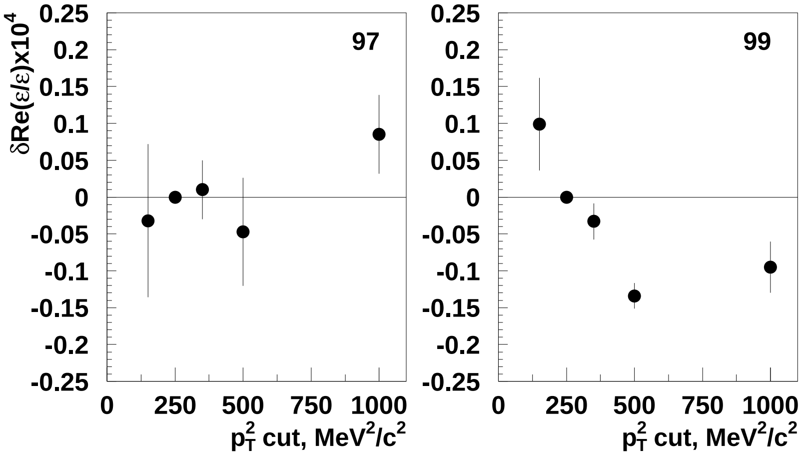
For some reason bias for 97 is smaller compared to PRD, $(0.46 \pm 0.20) \times 10^{-4}$, but this does not change estimated error significantly, 0.42×10^{-4} vs 0.56×10^{-4}. The combined error is 0.43×10^{-4}.

L3 bias vs run for 99 data

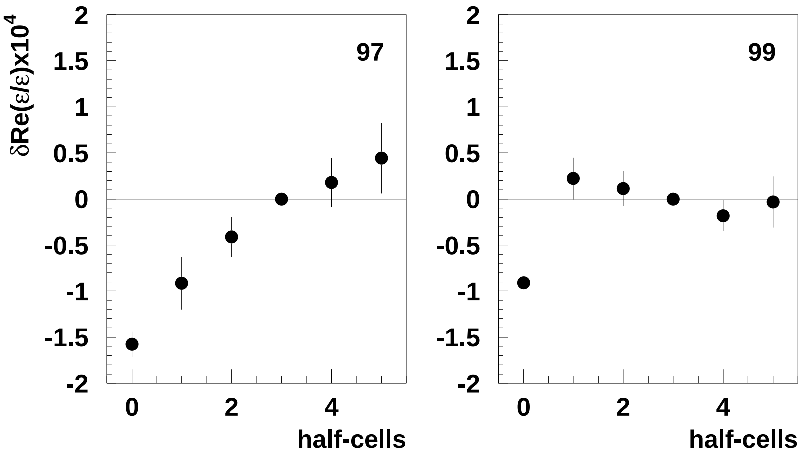


Larger loss for runs < 13705 stems from different L3 steering. The five runs with large sporadic L3 loss are 14377,14383,14048,14505 and 14518. No obvious reason for this loss. The loss is seen in Vac, Reg beam and for B01/B03 reference sample.

Selection efficiency



Walk vs $p_\perp$ is reduced (was about 0.25×10^{-4}) $\rightarrow$ 0.15×10^{-4} uncertainty on $Re(\epsilon'/\epsilon)$.

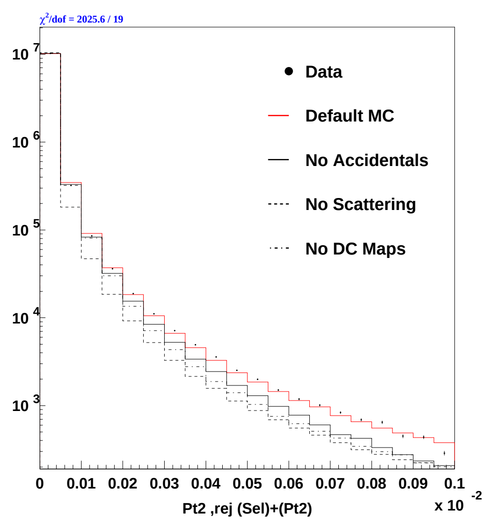


For cell separation cut situation is better for 99, 97 – as for PRD

DC simulation

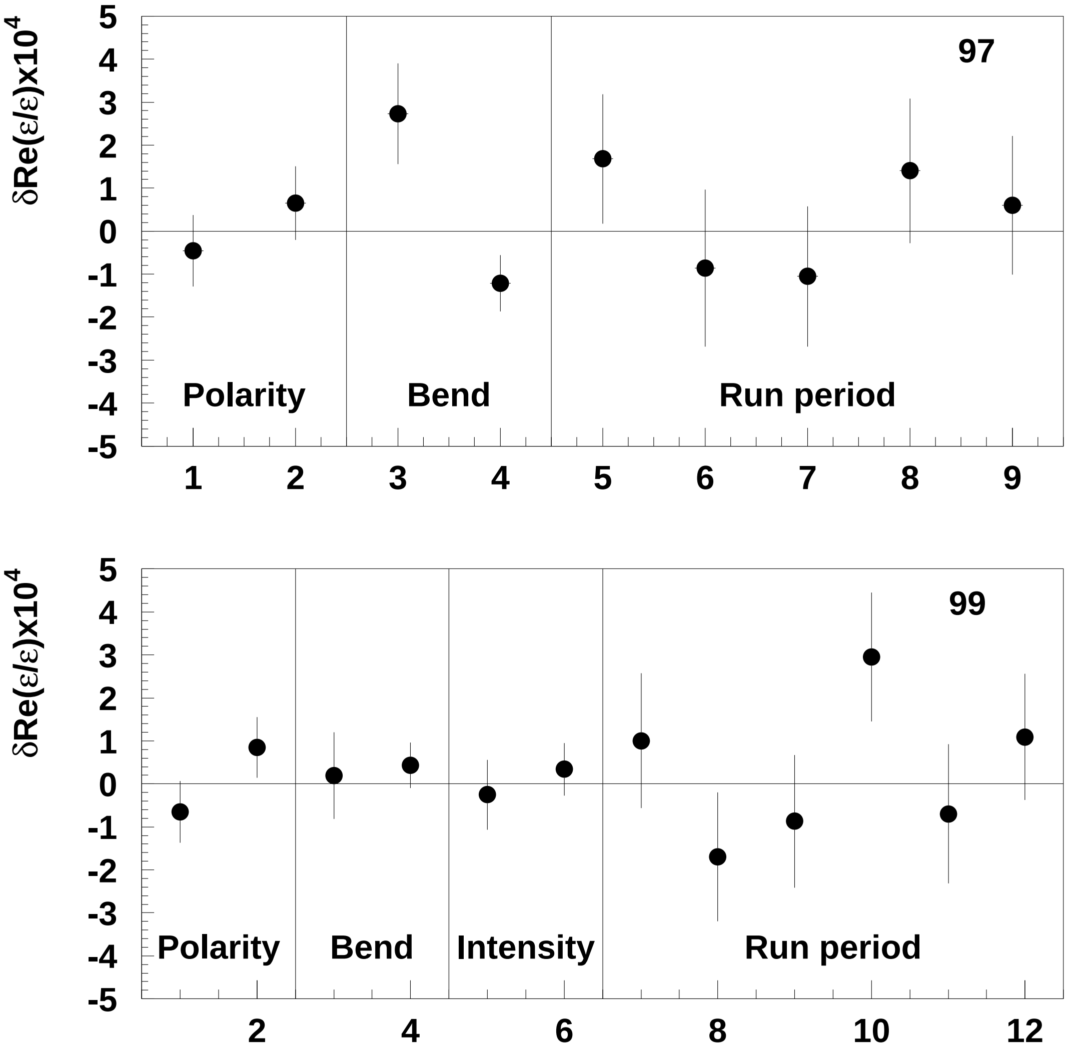
Follow $|V_{us}|$ analysis prescription: generate separate MC with scattering, DC maps, accidental events switched off, take 10% of the change as systematics.

Change of MC simulation	Bias in $Re(\epsilon'/\epsilon)$, $\times 10^4$	
	1997	1999
No Scattering in Spectrometer	+0.19	-0.55
No DC maps	-0.87	-0.31
No Accidental Overlays	0.26	+0.03



$\leftarrow$ each of the variations lead to big change in $P_\perp^2$ distribution. Total systematic uncertainty estimated to be 0.15×10^{-4}

Cross checks



An interesting new test is 99 intensity dependence. Works very well.

Out-/In- bends were not perfect for Jim as well. For 99 — no problem.

Source	Uncertainty $\times 10^{-4}$			
	97 PRD	97	99	Combined
Online selection				
L1 and L2	0.20			
L3	0.54	0.42	0.49	0.43
Track reconstruction				
Alignment and Calibration	0.28			
Momentum scale	0.16			
Selection efficiency				
$p_{\perp}^2$ cut	0.25	0.15	0.15	0.15
DC efficiency modeling	0.37	0.15	0.15	0.15
DC resolution modeling	0.15			
Apertures				
Wire spacing	0.22	0.22	0.22	0.22
Effective regenerator edge	0.20	0.20		
Z-slope	0.79	0.99	0.30	0.58
Z-upstream	—	0.27	0.46	0.38
Background subtraction	0.20	0.20	0.20	0.20
Monte Carlo statistics	0.41	0.42	0.38	0.28
Total	1.26	1.32	1.01	1.04

Δm, τ_S fits

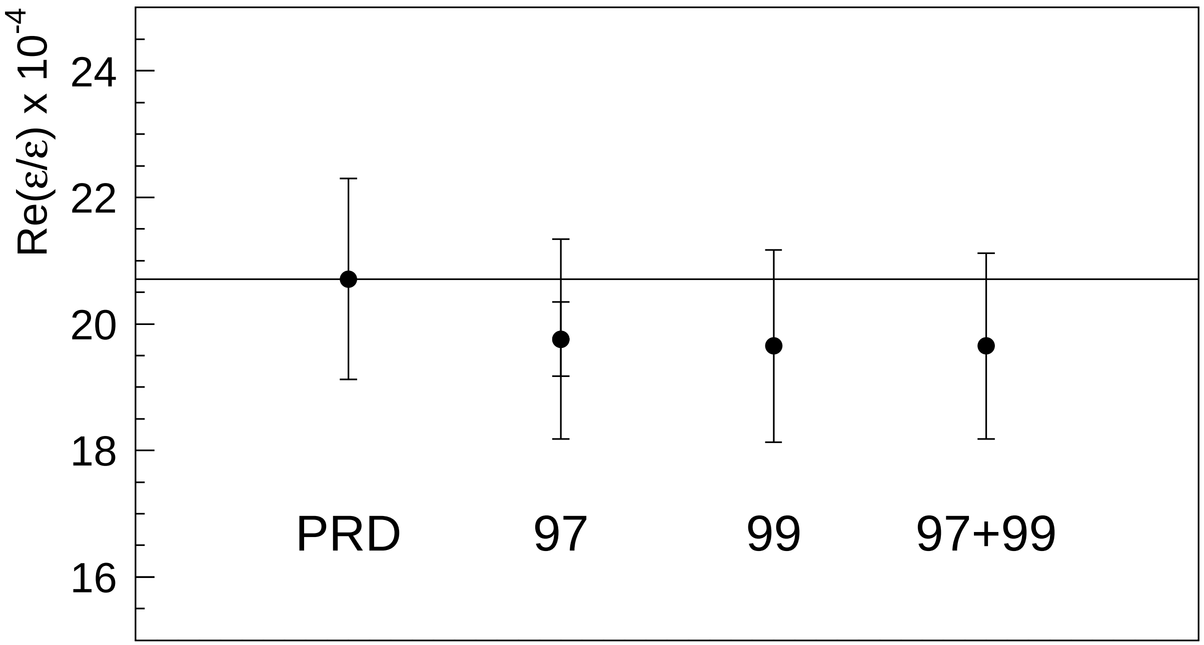
	PRD	97	99	97-99
$\Delta m \times 10^5 \hbar s^{-1}$	5266.7 ± 6.4	5263.9 ± 6.5	5265.7 ± 5.4	5265.0 ± 4.2
$\tau_S \times 10^{-12} s$	89.650 ± 0.030	89.639 ± 0.031	89.602 ± 0.025	89.618 ± 0.020
χ^2/dof	$228/199$	$193/198$	$210/198$	$198/198$

(errors include both data and MC stats).

PRD and new 97 analysis agree within MC statistics uncertainty (3.6 and 0.017 for Δm and τ_S); also agree very well with 99 result.

$Re(\epsilon'/\epsilon)$ Results

Using PRD neutral mode:



(errors include both data and MC stats. Inner bar for 97 shows uncorrelated MC stat. error to PRD result).

Differnce between PRD and new 97 analysis is 0.95×10^{-4}. Uncorrelated MC stat. error between PRD and new 97 result is 0.59×10^{-4}, the results agree within 1.6σ.

Effect of 99 data on charged mode uncertainty

Charged mode contribution to the stat. error for new $Re(\epsilon'/\epsilon)$ is 0.55×10^{-4} compared to PRD 0.77×10^{-4}. Thus

$$\delta^{PRD}_{charged} Re(\epsilon'/\epsilon) = (0.77_{stat} \pm 1.26_{syst}) \times 10^{-4} = 1.48 \times 10^{-4}$$

becomes, using estimated systematics

$$\delta_{charged} Re(\epsilon'/\epsilon) = (0.55_{stat} \pm 1.04_{syst}) \times 10^{-4} = 1.18 \times 10^{-4}$$

$\rightarrow$ about 25% reduction.

Next steps for charged mode

- Finalize L3 loss study
- Finalize systematic uncertainties.
- Repeat $Ke3$ analysis – Z_v slope cross check
- $\pi^+\pi^-\pi^0$ data should be used to improve attenuation measurement, combined with $3\pi^0$ to measure pseudo-$Re(\epsilon'/\epsilon)$.