Update on $K_{L,S} \rightarrow \pi^+\pi^-\gamma$

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KTeV meeting

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Outline For Today's Talk

- Review of godparent comments so far
  - Resolution Correction
  - Backgrounds
  - Parameter Functions/Increasing significance
  - Status of ehat signature plots
- Next steps

Resolution Correction

- I had originally used the result of the resolution study and treated it as the systematic error
  - Recall that the resolution error was defined as the difference in fit parameters obtained using MC truth for E_γ, τ and $\cos\theta$ and the fit parameters obtained using reconstructed values of the same
  - Doing so is <u>very</u> conservative

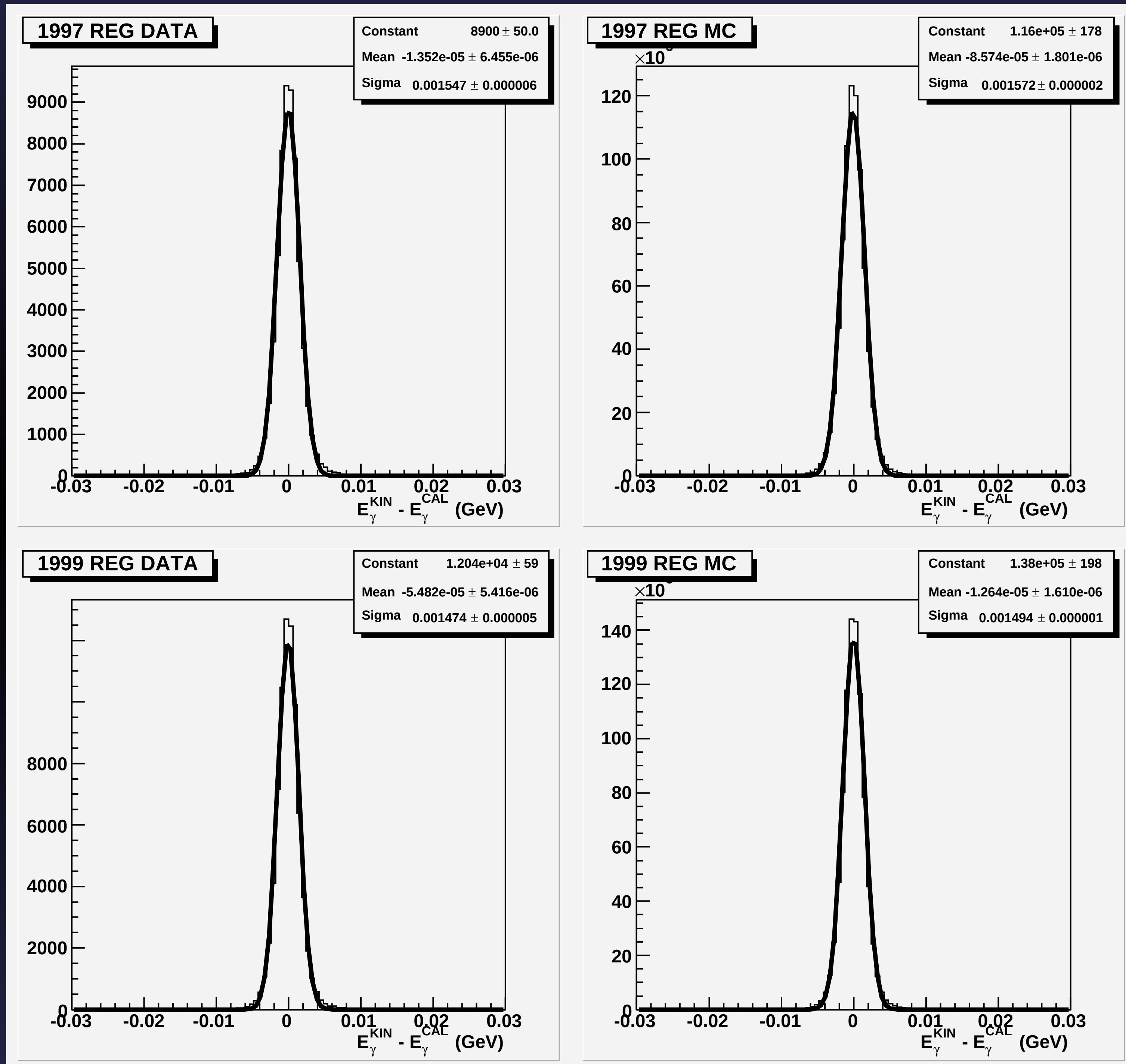
Resolution Correction

- Instead, treat this as a shift, and correct the result.
  - Following previous analyses, we take 10% of this shift as the systematic error due to the correction.

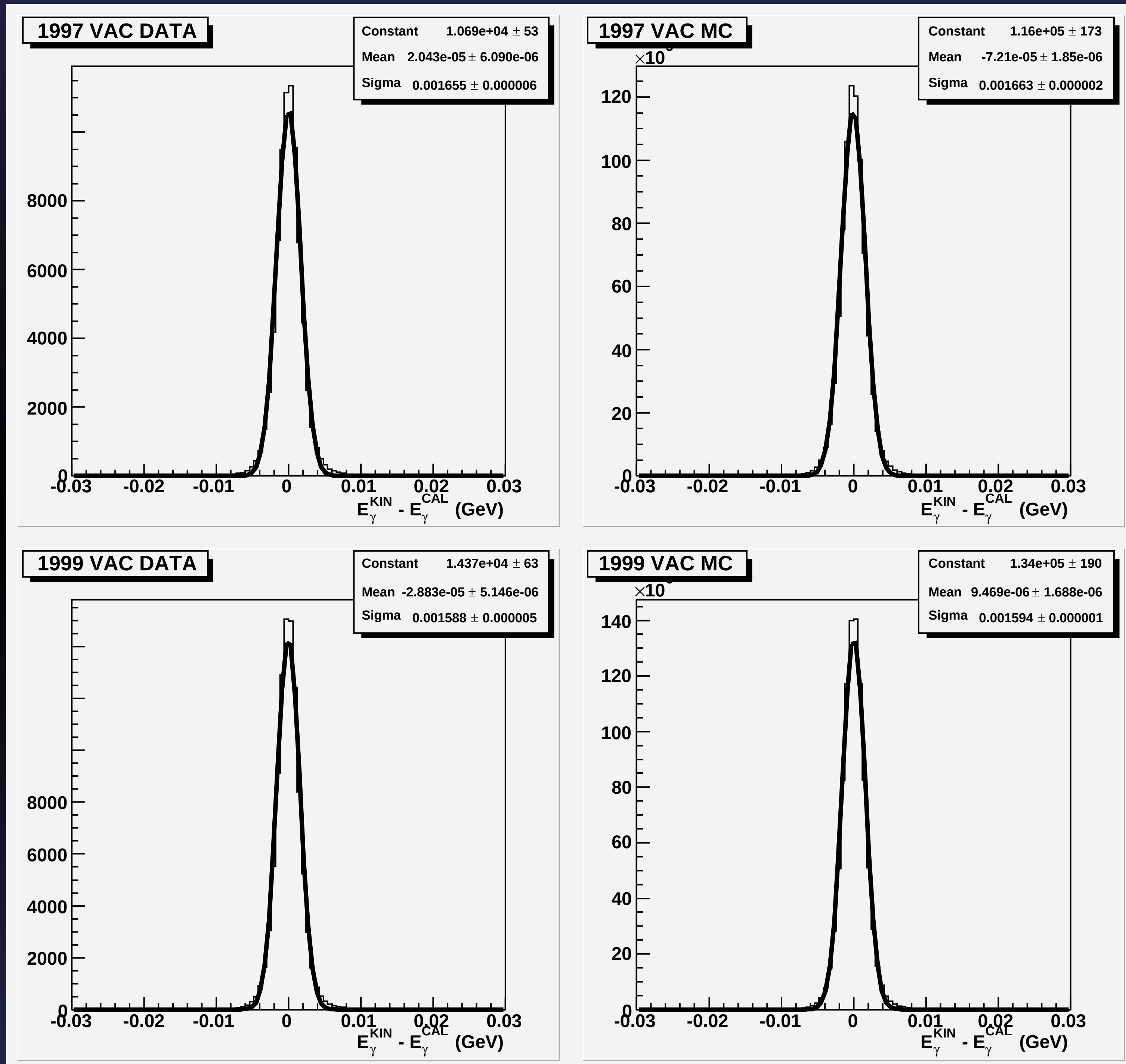
Resolution Correction

- The following are useful for comparing the resolution built into the MC to that of the actual detector:
  - $\pi^+\pi^-\gamma$ mass
  - Transverse momentum
  - E_γ^{KIN}-E_γ^{CAL}
- Width of these distributions gives some indication of the resolution.
  - Comparing widths in data to MC reveals that all agree within 2.4%
- 10% error is still quite conservative

Resolution Correction



Resolution Correction



Resolution Correction

- The resolution study was done by fitting a single sample of Monte Carlo, used as fake data
  - I should run the study on a few more fake data samples to ensure the observed shift isn't effected by the statistical error that is due to the size of the Monte Carlo sample.

Resolution Correction

- Updated systematic errors are:

Source of Error	***Ehat error***	***GE1 error***	***GM1 error***	***a1/a2 error***
Uncertainty from Input Parameter Values	0.000346	0.000358	0.00746	0.000708
Unceraintiy From Cut Values	0.000642	0.00271	0.0355	0.00685
PHOTOS Uncertainity	0.00016	0.00101	0.0165	0.00537
Uncertainity in Accidental Activity Sim	0.000027	0.00013061	0.00053	0.000157
Reconstruction Errors	0.000052	0.0000325	0.00033	0.000009
Background	0.000185	0.00	0.00603	0.00177
Incoherent Regeneration	0.000123	0.000109	0.00	0.00
Flattened Distributions	0.00052	0.00136	0.0032	0.00062
Total Error	0.00094	0.00322	0.0404	0.00893

New

Updated Results

- The old results were:
  - $\hat{\varepsilon}$ =(3.87 ± 0.65(stat) ± 1.07(syst)) x 10^{-3}
  - g_{E1}=(-6.1±1.5(stat)±3.2(syst)) x 10^{-3}
  - $\tilde{g}_{M1}$=1.133± 0.030(stat)± 0.041(syst)
  - a_1/a_2=-0.750±0.007(stat)±0.009(syst)
- after the resolution correction we have:
  - $\hat{\varepsilon}$ = (3.35 ± 0.65(stat) ± 0.94(syst)) x 10^{-3}
  - g_{E1}=(-5.8 ± 1.5(stat) ± 3.2(syst)) x 10^{-3}
  - $\tilde{g}_{M1}$=1.137± 0.030(stat) ± 0.040 (syst)
  - a_1/a_2 = -0.750 ± 0.007(stat) ± 0.009 (syst)

Background

- The cut variation of p_T^2 results is one of the larger systematics being assigned
  - Variation of this cut may result in more or less background being allowed into the data, so this systematic could be due to background.
  - A dedicated systematic error has already been assigned from the background study.
    - Result: double counting of background systematic?
- The source of the p_T^2 systematic should be studied and if actually due to background, ought to be removed

Background

- There are at least two ways to attack the problem:
- 1)
  - Use signal MC and data to determine an estimate of the number of background events removed or added by each change in the p_T^2 cut.
  - Compare the shift and the number of background events lost or gained to the same quantities in the background study
  - If comparable, then we are seeing a background effect

Background

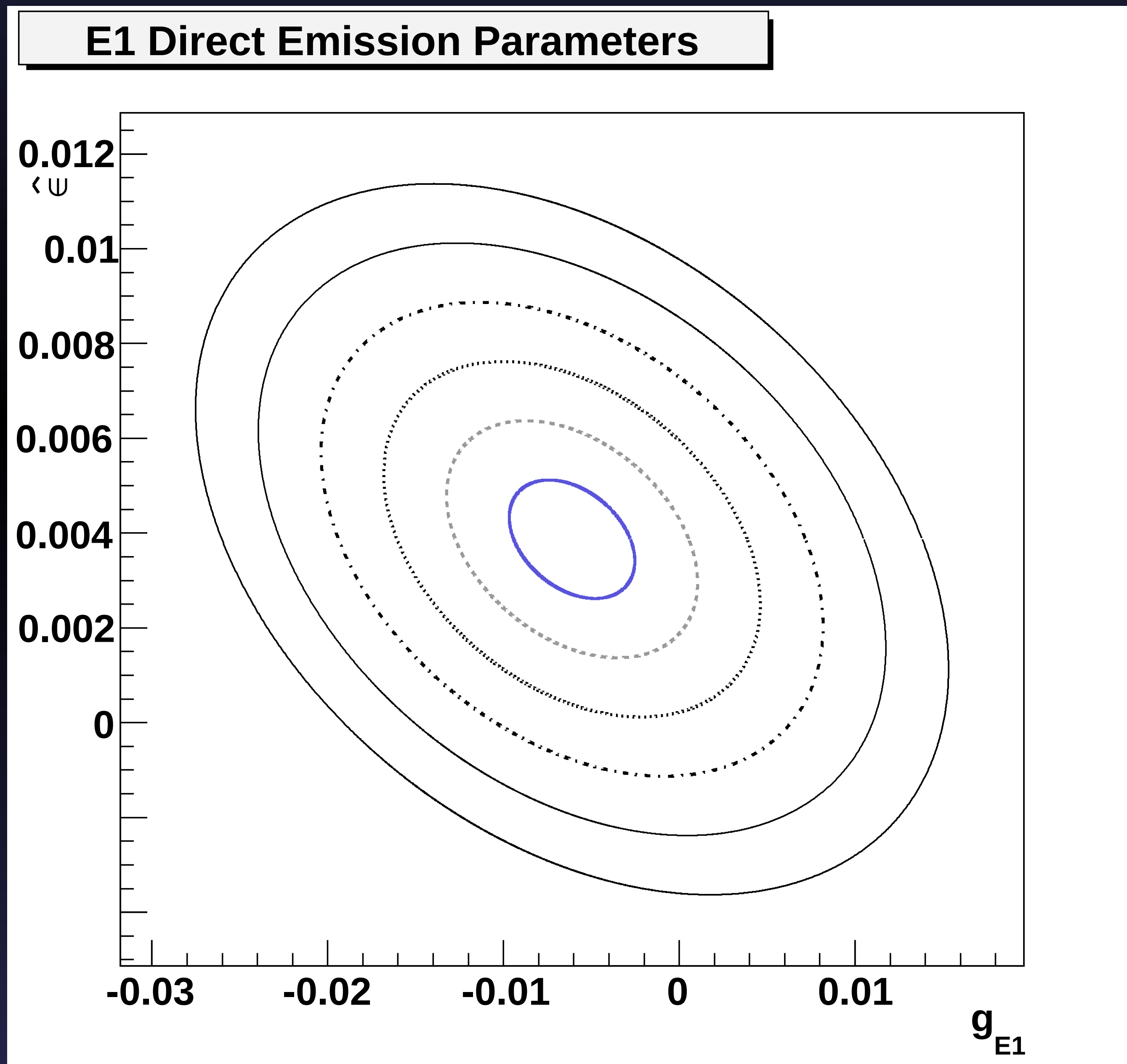
- There are at least two ways to attack the problem:
- 2)
  - Take the wing events used in the background study (these came from the data) and add these to a sample of signal MC.
  - Do a cut variation on this hybrid sample.
  - If the cut variation yields similar results, then neglect the p_T^2 systematic.

Significance of result

- Right now significance of ehat is about 3 σ. g_{E1} is smaller than 1.7 σ.
- Can we use some tricks to obtain a result with more significance?
- Try looking at the existence of the E1 Direct Emission amplitude in general:
  - Looking in ehat versus g_{E1} space, how far is the fit result from (0,0)?

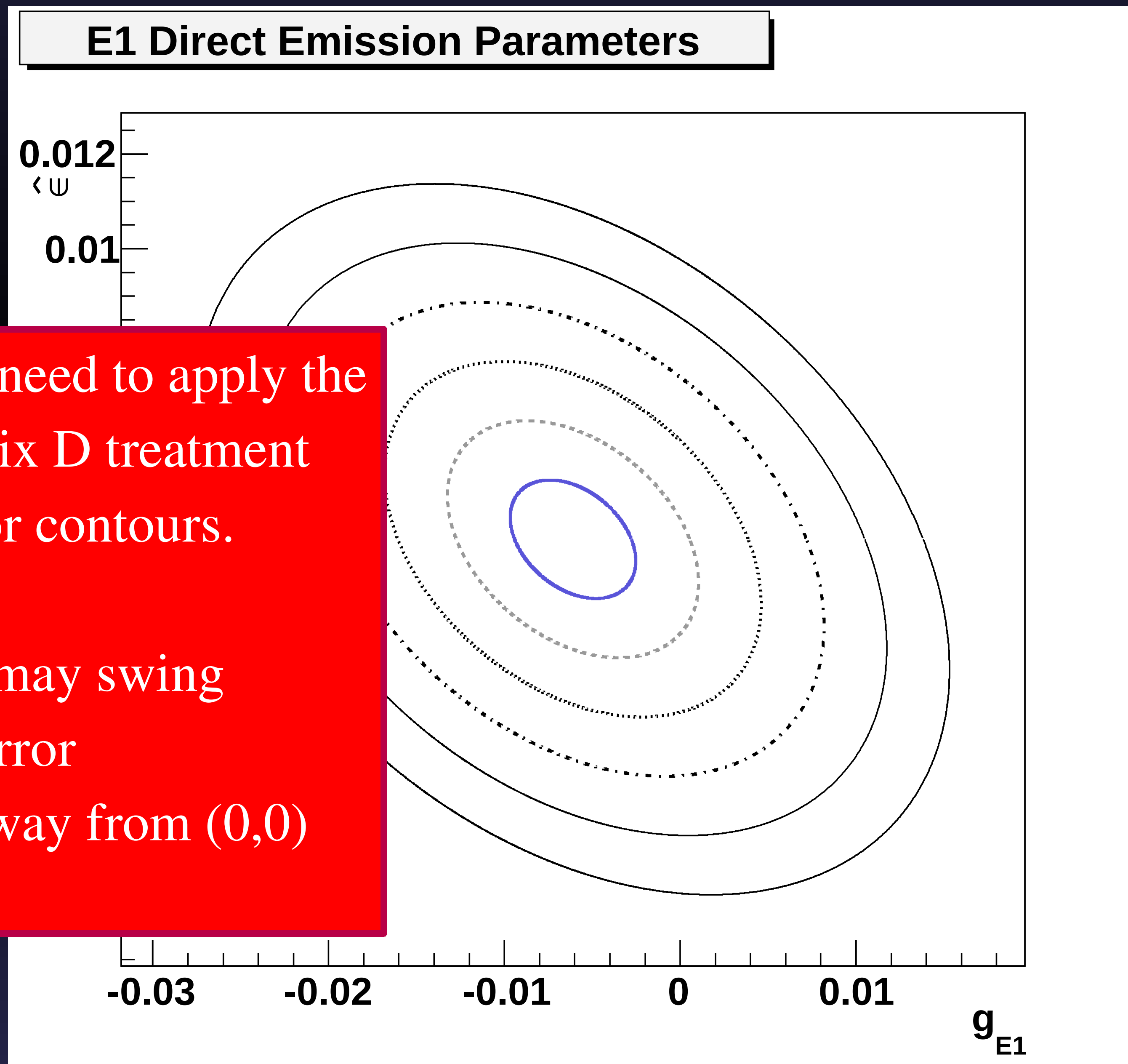
Significance

- Answer: about 3 sigma.



Significance

- Answer: about 3 sigma.



But I still need to apply the ε' Appendix D treatment to the error contours.

Doing so may swing the total error contour away from (0,0)

Significance

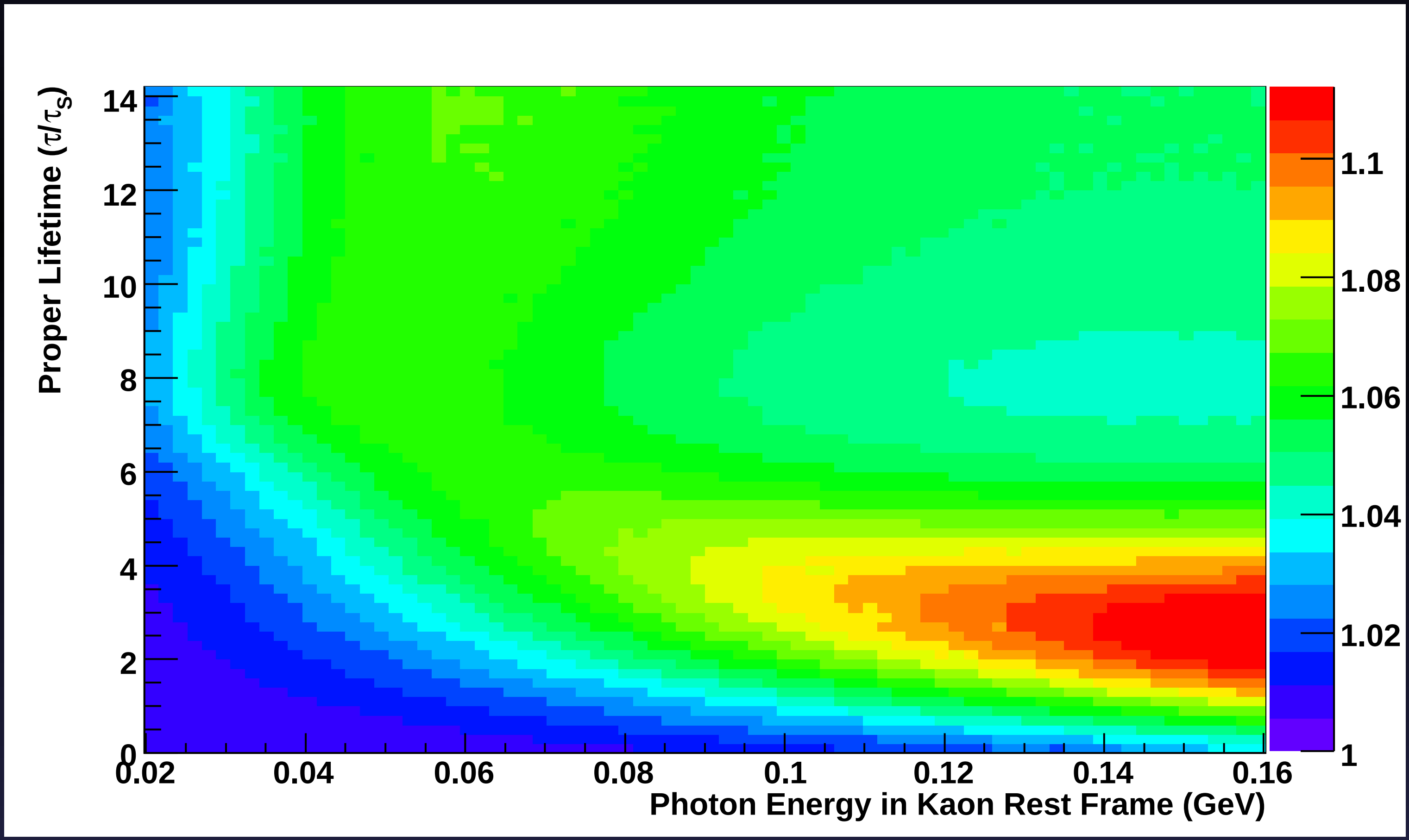
- We could try to define a quantity (function of the fit parameters) which would allow the systematic errors of ehat and g_{E1} cancel each other.
  - One example is Im(Ede)/Re(Ede), which if non-zero is an indication of direct CP violation.
  - No parameter functions currently seem to yield better results than ehat.
  - BUT the cut variation study still needs to be repeated for each parameter function in order for this method to work properly

Significance

- Another idea is to attempt an alternative treatment for propagating systematic errors into the error contour
  - Brad has an idea as to how to do this, instead of the ε' Appendix D treatment
  - Not sure how this will work. Only way to find out is to try.

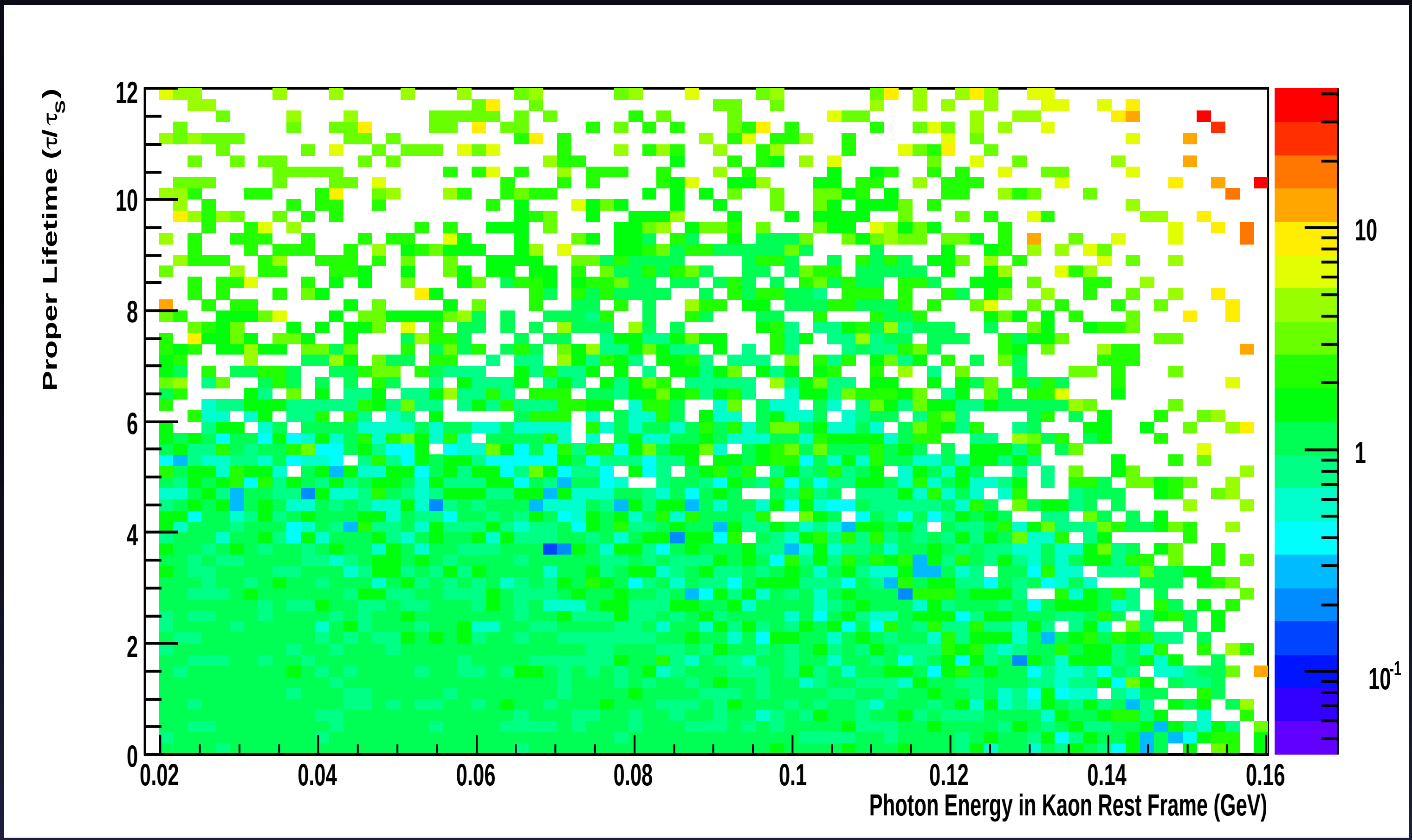
Ehat signature plots

- It would be nice to show the signature of ehat in some plots.



Ehat signature plots

- But the statistics are not so good in the data....

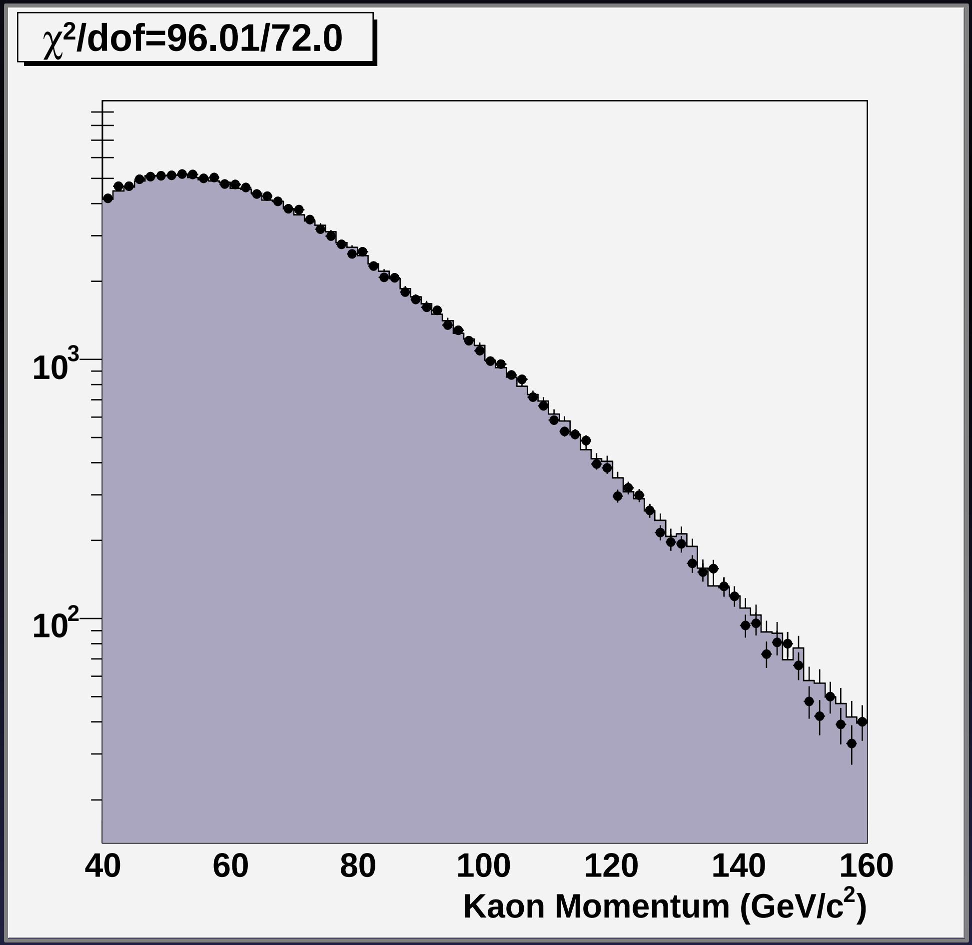


Ehat signature plots

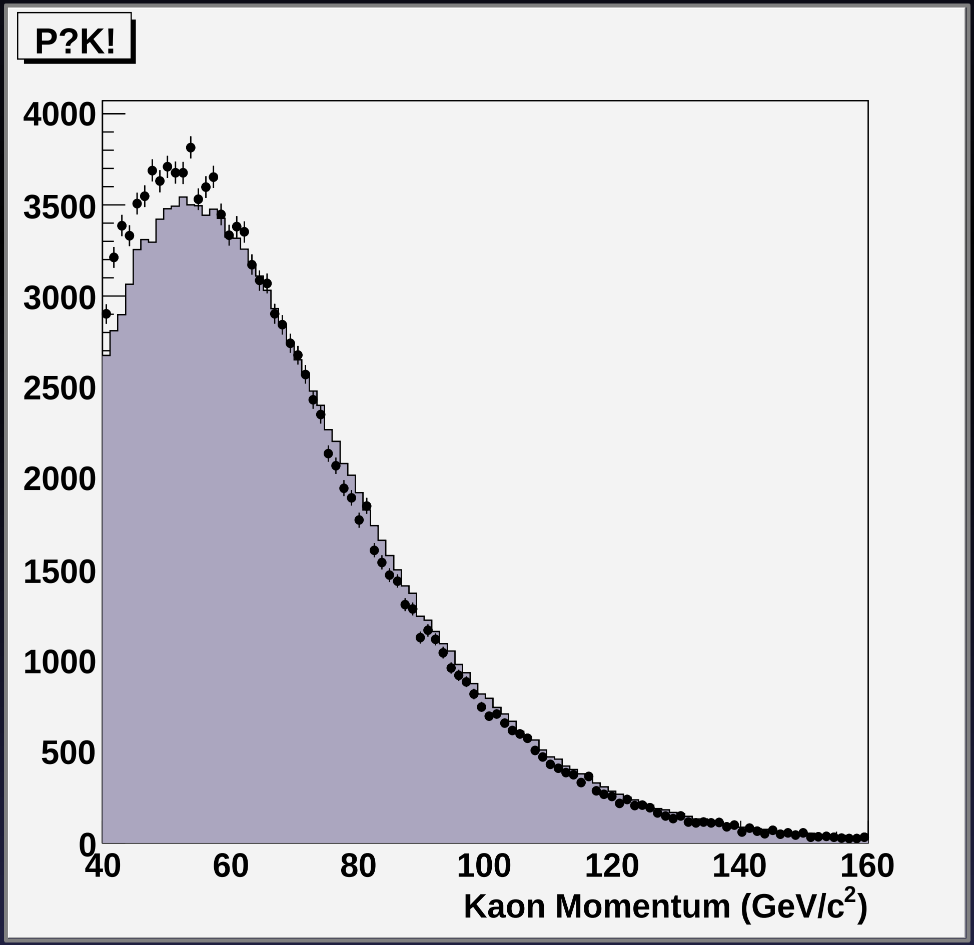
- The best way of doing this is to use the high statistics MC sample used in the nominal fit.
  - Reweight the sample using best fit parameters
    - This is what the data should match
  - Reweight the sample with ehat=0
    - This is what the data should NOT match
- Then look at the projections from the E_γ vs τ plot
- The fitter is already setup to do reweighting, so it should make these plots.

Momentum Spectra

- Only problem is that the fitter is plotting a momentum spectrum which is wrong.
- Best fit MC doesn't have this problem



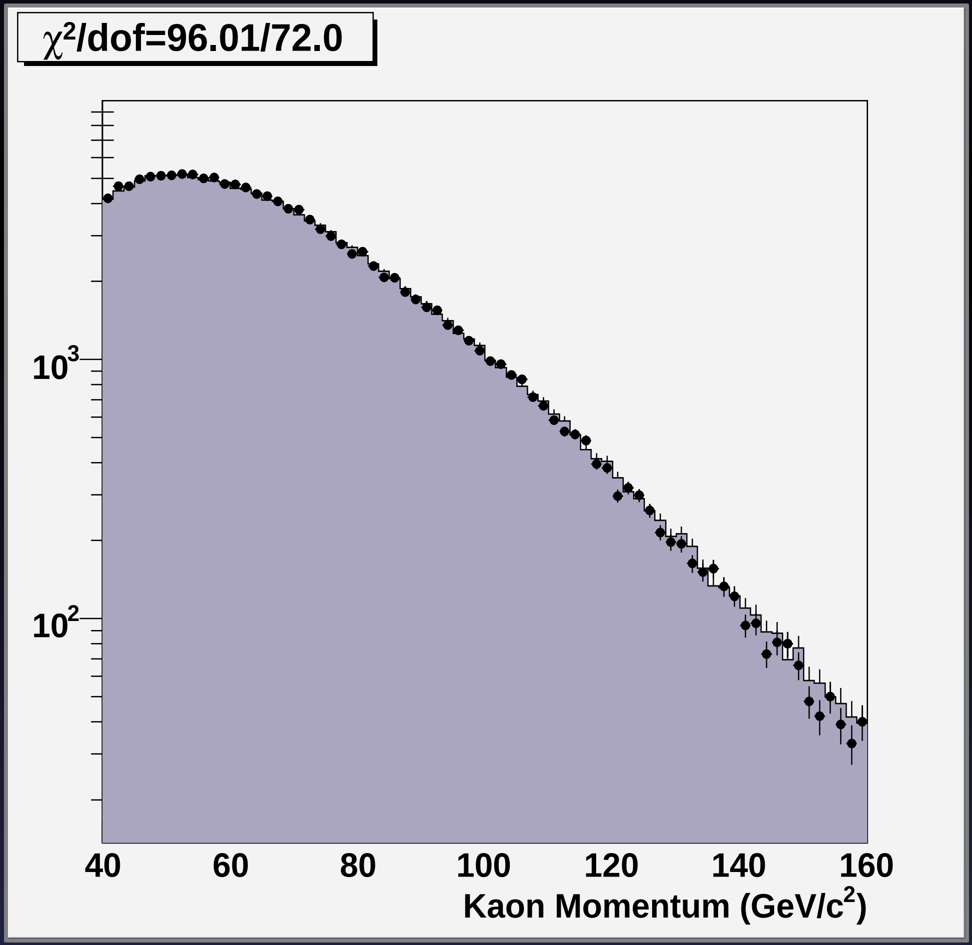
From Best Fit MC Sample



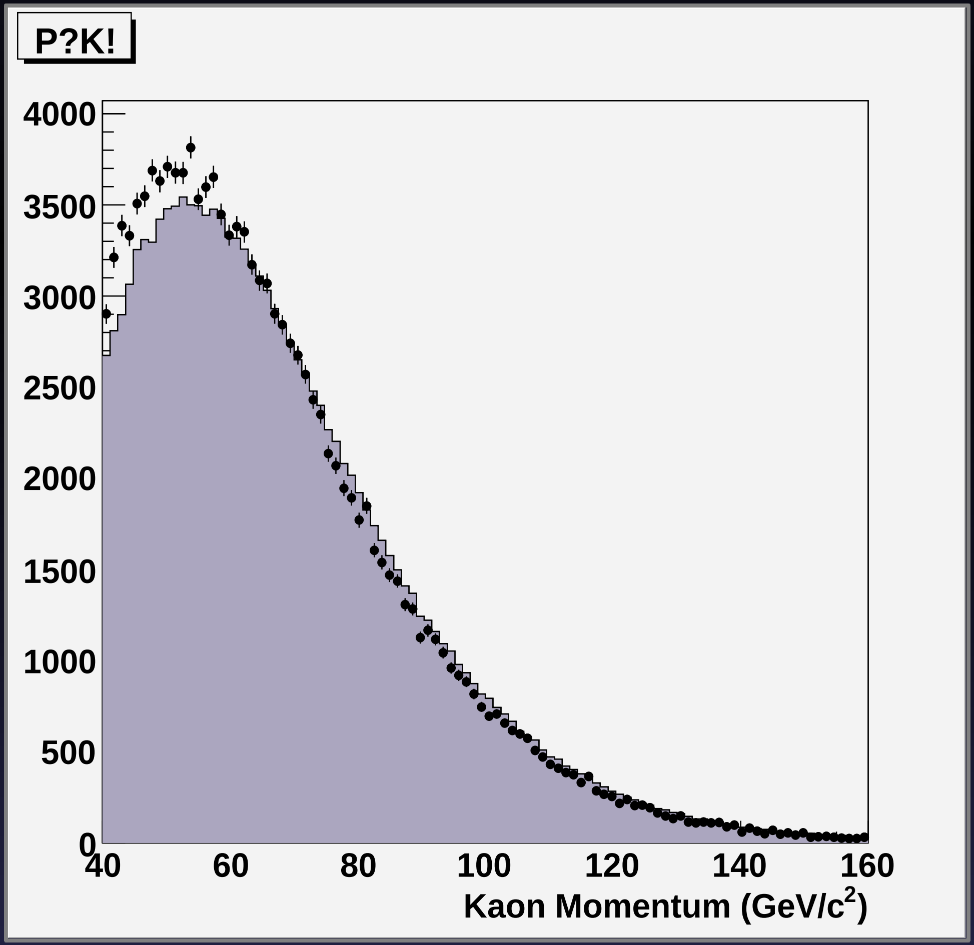
From Fitter (reweighted)

Momentum Spectra

- Only problem is that the fitter is plotting a momentum spectrum which is wrong.
- Other plots out of the fitter look okay.....



From Best Fit MC Sample



From Fitter (reweighted)

To Do

- Fix the fitter's momentum spectrum plot
  - Everything else looks okay, so the problem may be the plot itself
  - Or there could be a bug in the fitter....
- Redo the cut variations, except this time focus on how the various parameter functions shift. This will determine if this technique is truly useful.
- Check shape of total error contour after Appendix D's (or Brad's) method

To Do

- Check statistical error on resolution study
- See if p_T^2 cut variation is double counting the systematic error due to background.
- Continue to hammer away at the PRD/PRL for this analysis.

Extra Slides

Decay Rate for $K_{L,S} \to \pi^+\pi^-\gamma$

- The decay rate is:

$$\frac{dN}{d\tau\, dE_\gamma\, d\cos(\theta)} = N_K \left[|\rho^2| \left[\frac{d\Gamma_{K_S\to\pi^+\pi^-\gamma}}{dE_\gamma\, d\cos(\theta)} \right] e^{-\frac{\tau}{\tau_s}} + \left[\frac{d\Gamma_{K_L\to\pi^+\pi^-\gamma}}{dE_\gamma\, d\cos\theta} \right] e^{-\frac{\tau}{\tau_L}} + 2\,Re\left[\rho \frac{d\gamma^*_{LS}}{dE_\gamma\, d\cos(\theta)} e^{i\Delta m_K \tau} \right] e^{-\left(\frac{1}{\tau_L}+\frac{1}{\tau_S}\right)\frac{\tau}{2}} \right]$$

where:

$$\frac{d\gamma_{LS}}{dE_\gamma\, d\cos(\theta)} \propto \left[E_{IB}(K_L)+E_{DE}(K_L)\right] * \left[E^*_{IB}(K_S)+E^*_{DE}(K_S)\right] + M(K_L)M^*(K_S)$$

$$\frac{d\Gamma_{K_L\to\pi^+\pi^-\gamma}}{dE_\gamma\, d\cos(\theta)} \propto \left|E_{IB}(K_L)+E_{DE}(K_L)\right|^2 + \left|M(K_L)\right|^2$$

$$\frac{d\Gamma_{K_S\to\pi^+\pi^-\gamma}}{dE_\gamma\, d\cos(\theta)} \propto \left|E_{IB}(K_S)+E_{DE}(K_S)\right|^2$$

Direct Vs Indirect CP Violation in E1

- The E1-DE K_L amplitude is a mixture of direct CP and indirect CP violating terms
- g_{E1} part of amplitude is present in K_L and K_S
- E-hat part is present in K_L only

$$|K_L\rangle \propto |K_2\rangle + \epsilon |K_1\rangle$$

Indirect CP Violation
(via mixing)

g_{E1}

$\pi^+\pi^-\gamma$ via E1

Direct CP Violation
(In Decay)

$\hat{\epsilon}$

$\pi^+\pi^-\gamma$ via E1

Decay Amplitudes

$$E_{IB}(K_S)=\left(4\frac{M_K^{\ 2}}{E_\gamma^2}\right)\frac{e^{i\delta_0}}{1-\beta^2\cos^2(\theta)}$$

CP conserving

$$E_{IB}(K_L)=\left(4\frac{M_K^{\ 2}}{E_\gamma^2}\right)\frac{\overbrace{\eta_{+-}}^{\epsilon+\epsilon'}e^{i\delta_0}}{1-\beta^2\cos^2(\theta)}$$

CP violating

$$M(K_S)=i\,\epsilon\,g_{M1}\left(\frac{a_1/a_2}{M_\rho^2-M_K^2+2E_\gamma M_K}+1\right)e^{i\delta_1}$$

CP violating

$$M(K_L)=i\,g_{M1}\left(\frac{a_1/a_2}{M_\rho^2-M_K^2+2E_\gamma M_K}+1\right)e^{i\delta_1}$$

CP conserving

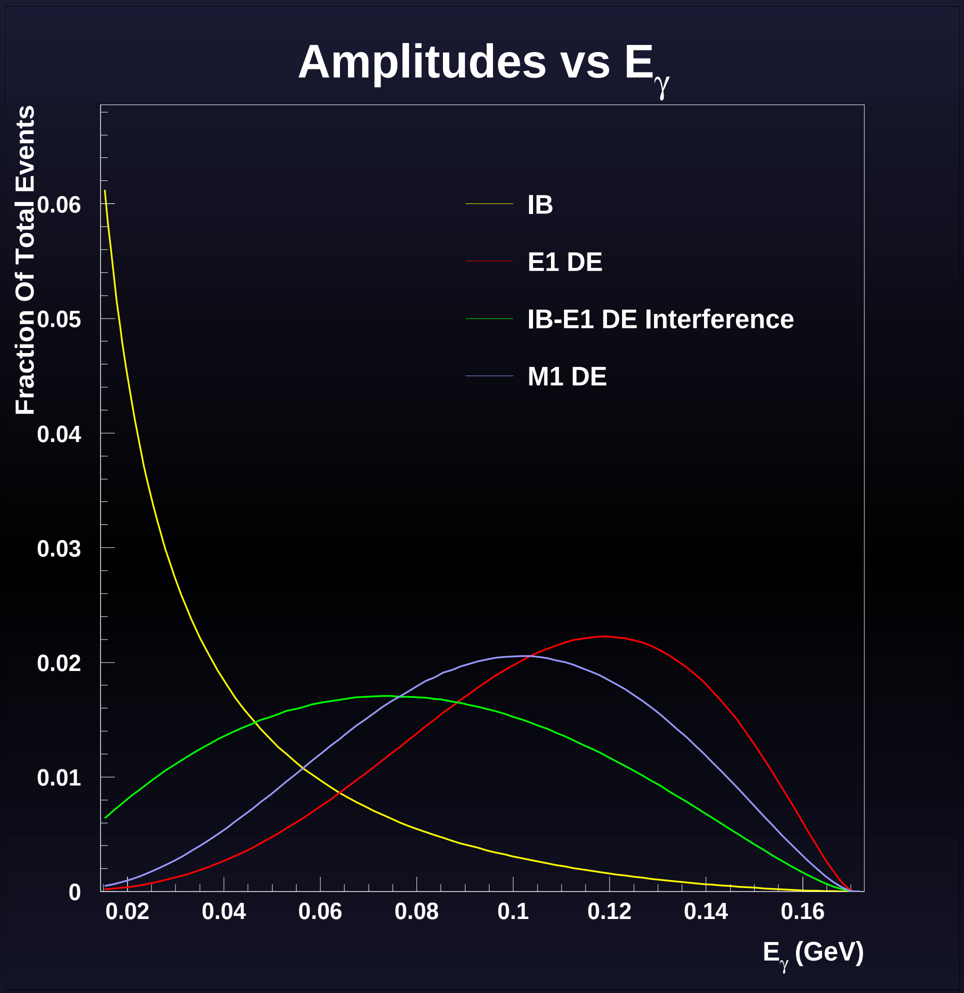
$$E_{DE}(K_S)=\frac{g_{E1}}{\epsilon}e^{i(\delta_1+\phi_\epsilon)}$$

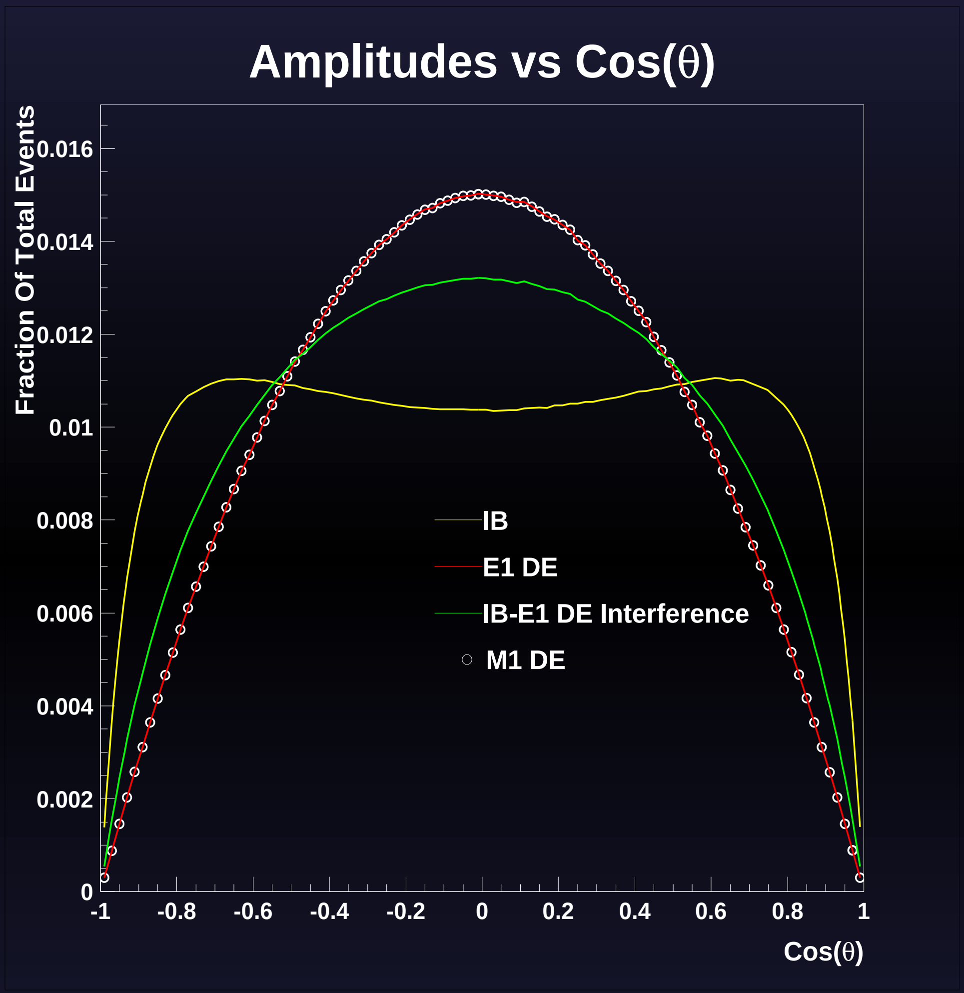
CP conserving

$$E_{DE}(K_L)=\underbrace{g_{E1}e^{i(\delta_1+\phi_\epsilon)}}_{\text{indirect CPV}}+\underbrace{i\,16\,\hat{\epsilon}\,e^{i\delta_1}}_{\text{direct CPV}}$$

CP violating

Amplitudes



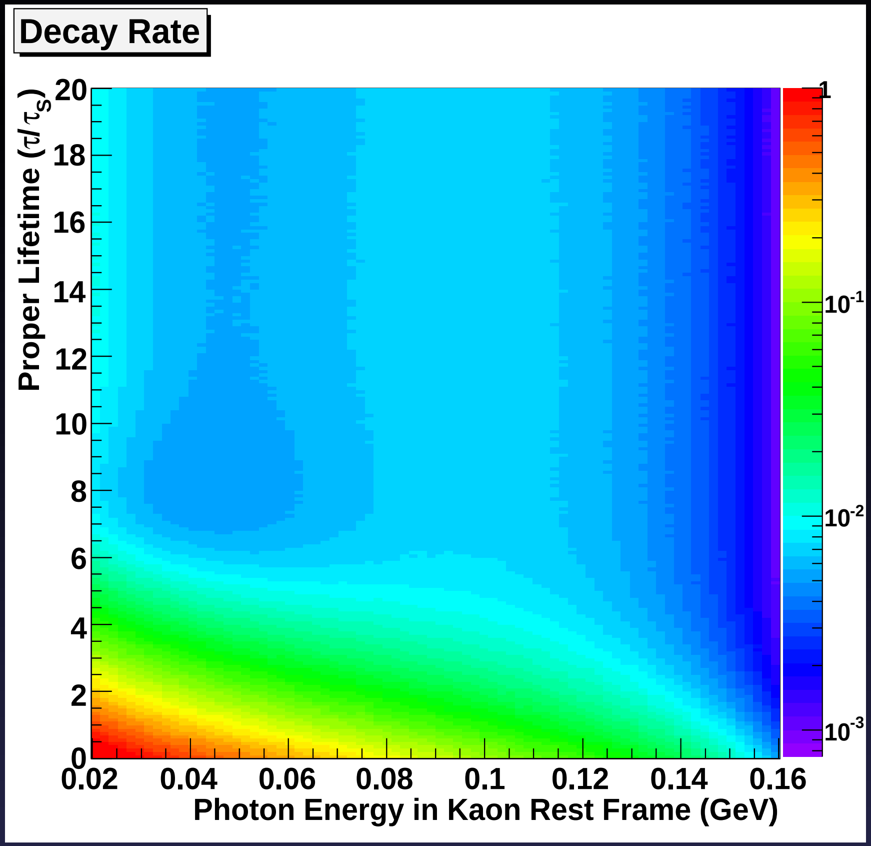


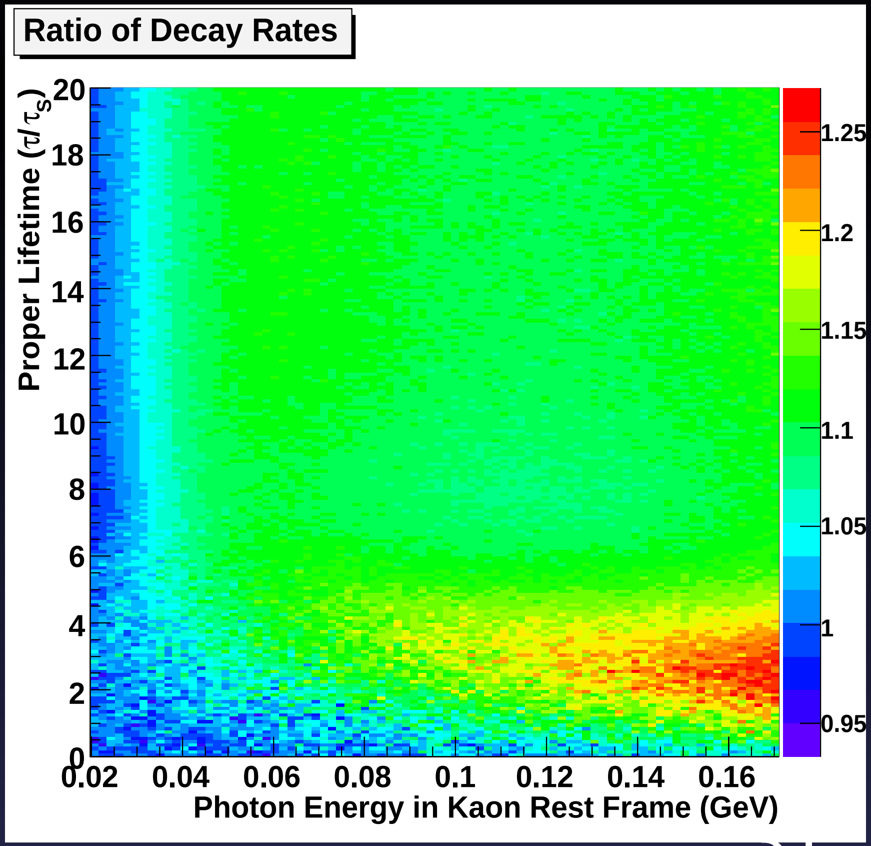
Dependence On E_γ

Dependence On Cosθ

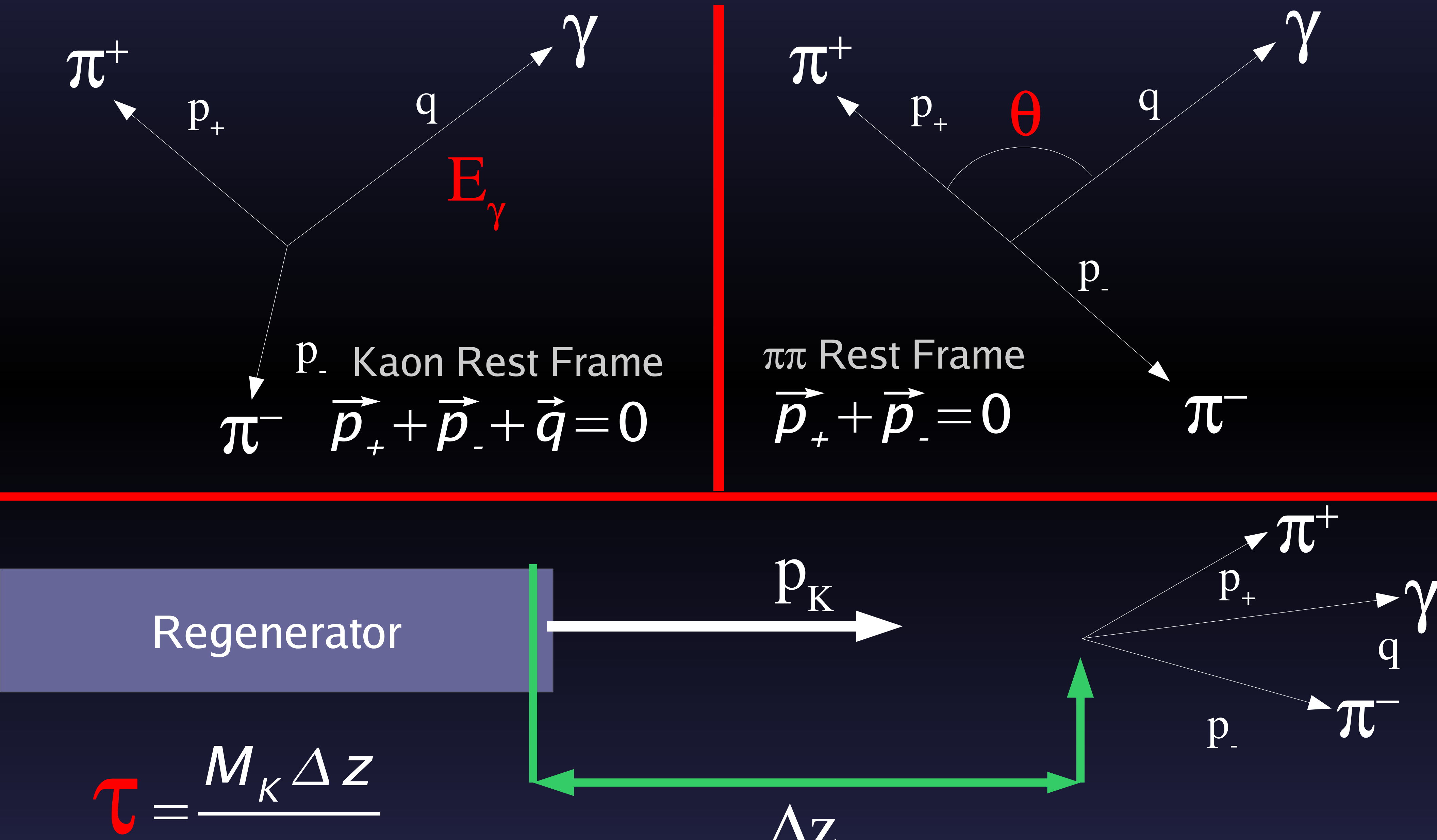
Projections of Decay Rate

- The decay rate will give the density of events in phase space (τ, E_γ, $\cos\theta$)
- Plot of photon energy versus proper lifetime is interesting:





Kinematic Variables for $K \to \pi^+\pi^-\gamma$



$$\vec{p}_+ + \vec{p}_- + \vec{q} = 0$$

$$\vec{p}_+ + \vec{p}_- = 0$$

$$\tau = \frac{M_K \Delta z}{p_K}$$

Analysis Cuts

Cut Variable	Keep Event If...
Kaon Mass	$0.48967\ GeV/c^2 < M_{\pi^+\pi^-\gamma} < 0.50567\ GeV/c^2$
P_T^2w.r.t Regenerator	$P_T^2 < 2.5 \times 10^{-4}\ GeV^2/c^2$
Kaon Momentum	40.0 GeV/c $< P_{\pi^+\pi^-\gamma} <$ 160.0 GeV/c
Photon Energy in Lab Frame	$E_\gamma^* > 1.5$GeV
Photon Energy in Kaon Rest Frame, From Calorimeter	20.0MeV $< E_\gamma^* <$ 175.0 MeV
Photon Energy in Kaon Rest Frame, From Kinematics	20.0MeV $< E_\gamma^* <$ 175.0 MeV
$\pi\pi$ Invariant Mass, Implied From Above Cut	$0.2711\ GeV/c^2 < M_{\pi\pi} < 0.4772\ GeV/c^2$
Shape χ^2 For Photon Cluster	$\chi^2 < 48$
Outer Fiducial Cut For Photon Cluster	ISEEDRING < 18.1 cm
Inner Fiducial Cut For Photon Cluster	ISMLRING2 > 4.5 cm
Photon/Track Separation at CsI	d > 30 cm
Number of CsI clusters	NCLUS ≥ 3
pp0kin w.r.t. Target	-0.10 $GeV^2/c^2 < P^2_{\pi^0} <$ -0.0055 GeV^2/c^2
L3 pp0kin	passes
Z vertex	125.5 m < VTXZ < 158.0 m
E/p	E/p < 0.85
Track Momentum	TRKP > 8.0 GeV
Vertex χ^2	VTXCHI < 50.0
Magnet Offset χ^2	TRKOCHI < 50.0
Track x separation at CsI	$\Delta x > 3.0$ cm
Track y separation at CsI	$\Delta y > 3.0$ cm
Total track separation at CsI	$\Delta r > 20.0$ cm
Number of Tracks	NTRK = 2
$\Lambda \rightarrow p\pi$ invariant mass	$M_{p\pi} < 1.112 GeV/c^2$ or $M_{p\pi} > 1.119 GeV/c^2$
Early energy in photon cluster	ADCSI_EARLY < 150 counts
In-time energy in photon cluster	ADCSI_INTIM > 115 counts
Photon/Upstream Track Projection at CsI	d > 2.0cm distance
Reconstruction Routines	Return no errors
Veto Cuts	All pass
Level 1 Trigger Verification	Event passes
Fiducial Cuts	All pass
Number of Photon Candidates That Pass ALL Cuts	$N_{COMBINATIONS} = 1$ ONLY