Effect of using impact parameters on τ direction reconstruction

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The question

- (How Much) Does having a good measurement of the impact parameter of the decay products of the τ help improve τ direction reconstruction?
- τ direction reconstruction useful for τ polarization measurement.
- Tim Barklow's idea to look at this topic.
- Started working on this in January.

Data used

- Only had time to analyze $\tau \rightarrow h\nu$ decays, where $h \in \{\pi, K\}$ ($\Gamma_i/\Gamma \approx 10\%$.
- Data used was generated with WHIZARD. TAUOLA used to decay τ's.
- Original data had 0 τ decay time. Wrote code to fix .stdhep files. Did it wrong the first time (source of lots of headaches).
- About 30,000 $\tau \rightarrow h\nu$ events were analyzed.
- MC information used to detect analyzable events.

Reconstruction method (sketch)

- Maximum likelihood fit. Wrote observable parameters (h direction, h impact parameters) in terms of τ^- direction, τ arc lengths, h decay angles. Minimized χ^2 of the differences with MINUIT.
- Assumptions: Back-to-back τ's with same energy.
- But no filtering on decay angle. Any detected photons lowered center of mass energy.
- One fit without using the arclength / impact parameters and one with.
- Combination of Simplex / Migrad used in minimization

Part with no impact parameter

$$\chi^2(\Theta_{\tau^-}, \Phi_{\tau^-}, \theta^*_{h\tau}, \phi^*_{h\tau}, \bar{\theta}^*_{\bar{h}\tau}, \bar{\phi}^*_{\bar{h}\tau}) =$$
$$\frac{(p_h - p'_h(\theta^*_{h\tau}))^2}{\sigma^2_{p_h}} + \frac{(\bar{p}_{\bar{h}} - \bar{p}'_{\bar{h}}(\bar{\theta}^*_{\bar{h}\tau}))^2}{\sigma^2_{p_{\bar{h}}}} +$$
$$\frac{(\theta_h - \theta'_h(\Theta_{\tau^-}, \Phi_{\tau^-}, \theta^*_{h\tau}, \phi^*_{h\tau}))^2}{\sigma^2_{\theta_h}} + \frac{(\bar{\theta}_{\bar{h}} - \bar{\theta}'_{\bar{h}}(\Theta_{\tau^-}, \Phi_{\tau^-}, \bar{\theta}^*_{\bar{h}\tau}, \bar{\phi}^*_{\bar{h}\tau}))^2}{\sigma^2_{\bar{\theta}_{\bar{h}}}} +$$
$$\frac{(\phi_h - \phi'_h(\Theta_{\tau^-}, \Phi_{\tau^-}, \theta^*_{h\tau}, \phi^*_{h\tau}))^2}{\sigma^2_{\phi_h}} + \frac{(\bar{\phi}_{\bar{h}} - \bar{\phi}'_{\bar{h}}(\Theta_{\tau^-}, \Phi_{\tau^-}, \bar{\theta}^*_{\bar{h}\tau}, \bar{\phi}^*_{\bar{h}\tau}))^2}{\sigma^2_{\bar{\phi}_{\bar{h}}}} \quad (1)$$

Part with impact parameter

$$\chi'^2(\Theta_{\tau^-}, \Phi_{\tau^-}, \theta^*_{h\tau}, \phi^*_{h\tau}, \bar{\theta}^*_{\bar{h}\tau}, \bar{\phi}^*_{\bar{h}\tau}, s, \bar{s}) =$$
$$\frac{(\vec{r} - \vec{r}'(\Theta_{\tau^-}, \Phi_{\tau^-}, \theta^*_{h\tau}, \phi^*_{h\tau}, s))^2}{\vec{\sigma}_r^2} + \frac{(\vec{\bar{r}} - \vec{\bar{r}}'(\Theta_{\tau^-}, \Phi_{\tau^-}, \bar{\theta}^*_{\bar{h}\tau}, \bar{\phi}^*_{\bar{h}\tau}, \bar{s}))^2}{\vec{\sigma}_{\bar{r}}^2} \quad (2)$$

Initial values / step sizes used for MINUIT

Parameter	Initial Value	Step Size
s , $\bar{s}$	Since these are small, the initial value was set to 0.	For reconstruction without the p.c.a., these are fixed. Otherwise, the step size chosen was 0.1 mm.
$\Theta_{\tau-}$, $\Phi_{\tau-}$	The momentum vectors of the two h's are averaged to come up with the initial value for these.	A step size of 0.01 radians was chosen.
$\phi^*_{h\nu}$, $\bar{\phi}^*_{h\nu}$	The h momenta are rotated boosted from the lab frame to the τ rest frame. $\texttt{atan2}(p^*_y, p^*_x)$ is then used as the estimate.	A step size of 0.01 radians was chosen.
$\theta^*_{h\nu}$, $\bar{\theta}^*_{h\nu}$	After coming up with estimates for the other fit variables, the range 0 to π is scanned in increments of $\pi/100$ for each of these. The value that minimizes χ^2 (given the initial values for the other parameters) is chosen as the the initial value.	A step size of 0.05 radians was chosen.

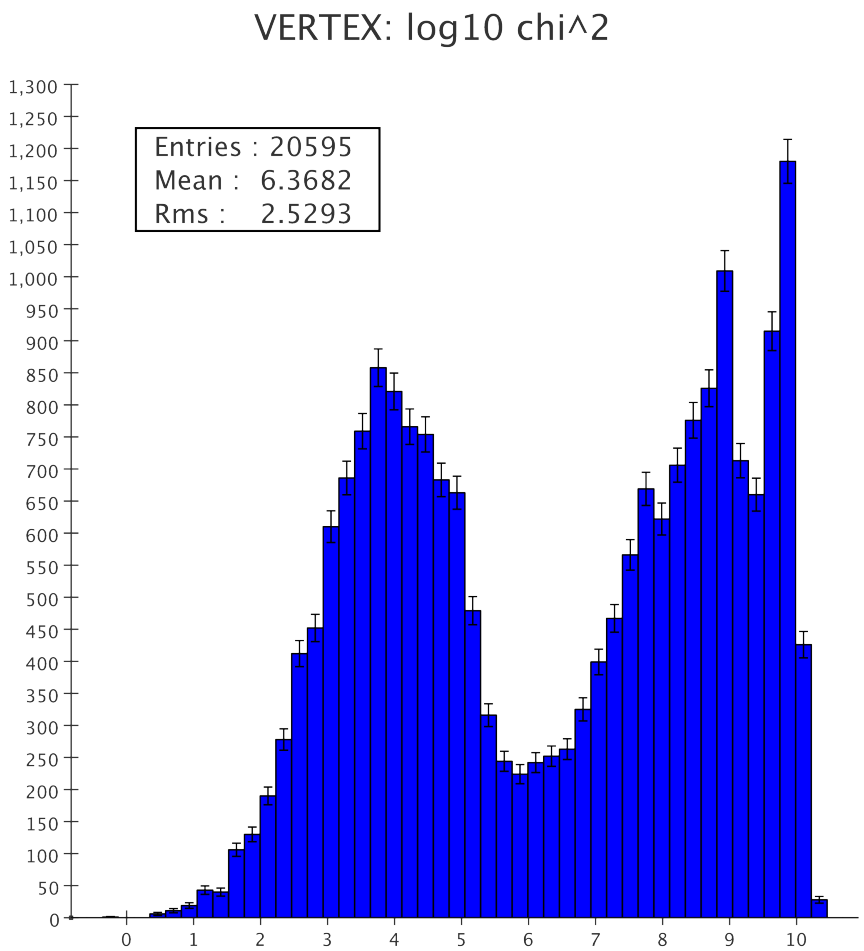
The Code

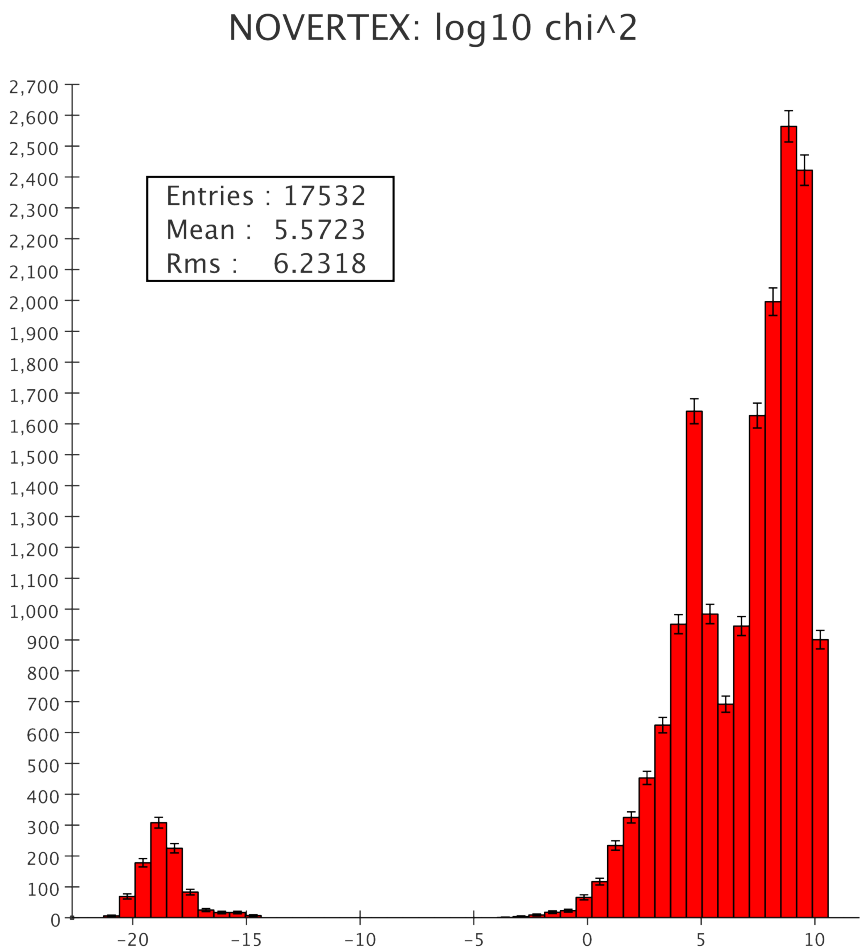
- Used separate project / version control for numbering (same namespace though)
- Clone of mercurial repository at `http://bitbucket.org/cozzyd/cosmintaupol/`
- Will soon merge back into lcsim-contrib

Results

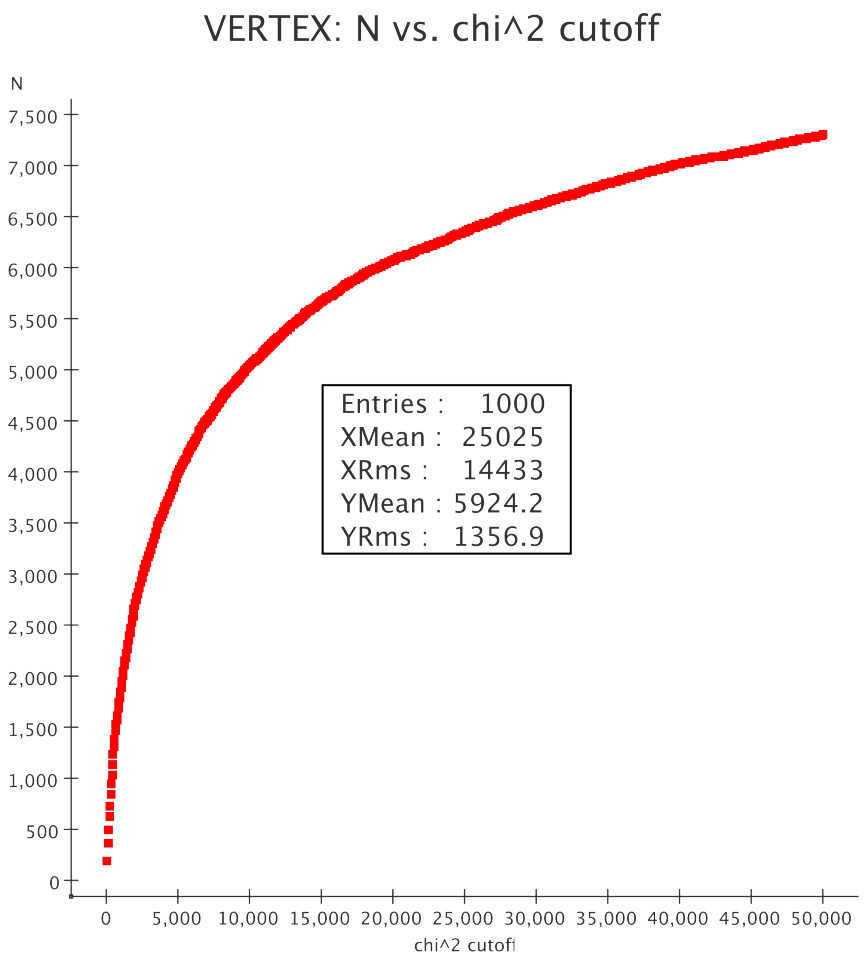
- Of the 30,011 events $\tau \longrightarrow hh$ events that were generated, 20,595 were logged for VERTEX and 17,532 were logged for NOVERTEX.
- Logging doesn't occur when MINUIT reports an invalid minimum.
- At cutoff of $\chi^2 = 1550$, nearly equal numbers of events from both methods.
- At that cutoff, rms for Θ residual improves by 29.9% and Φ residual improves by 21.43%.
- A bunch of plots follow. Note that axis scales usually not the same.

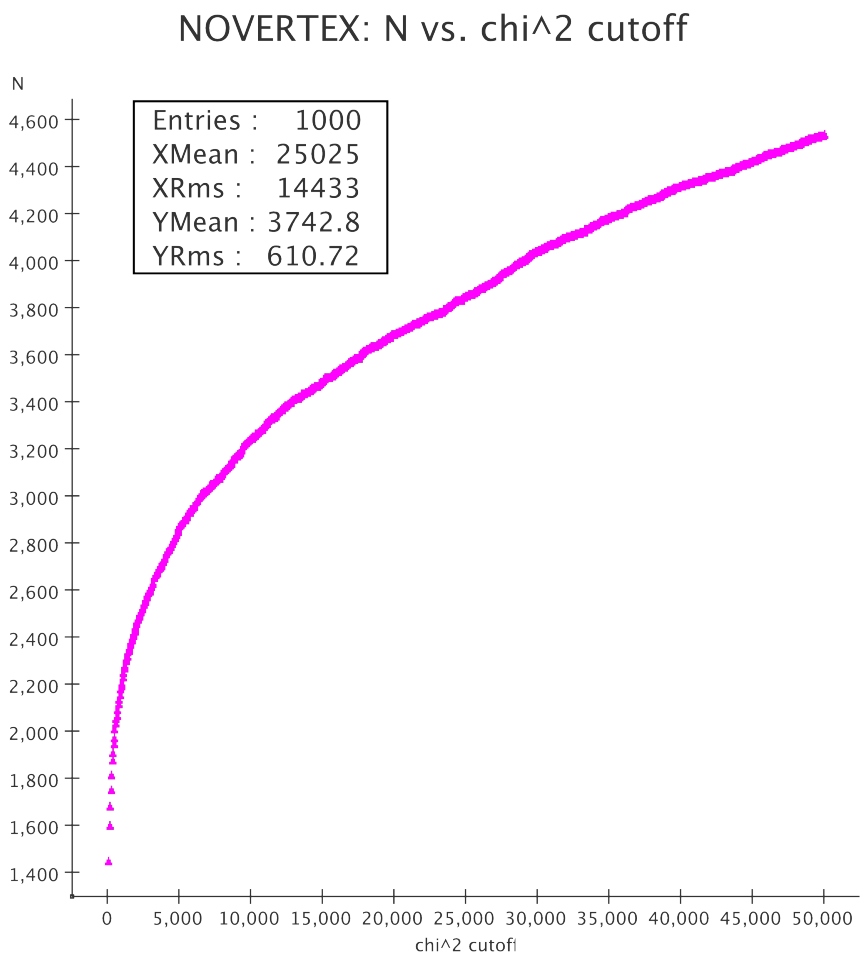
$\log_{10}(\chi^2)$ plots



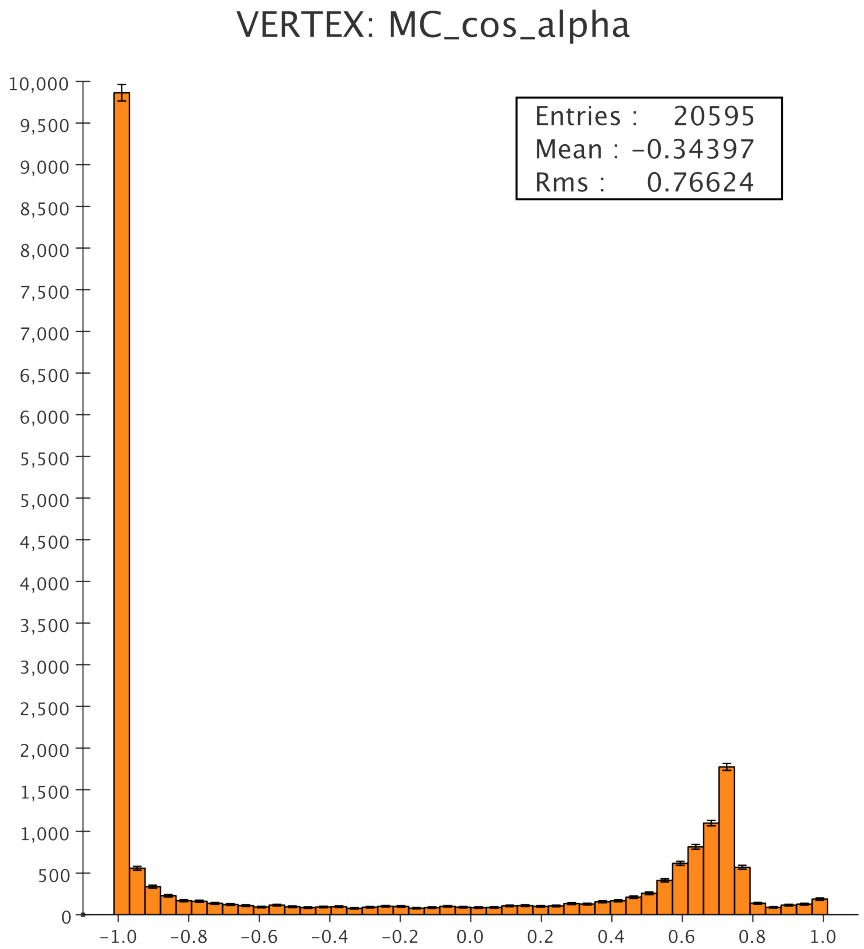


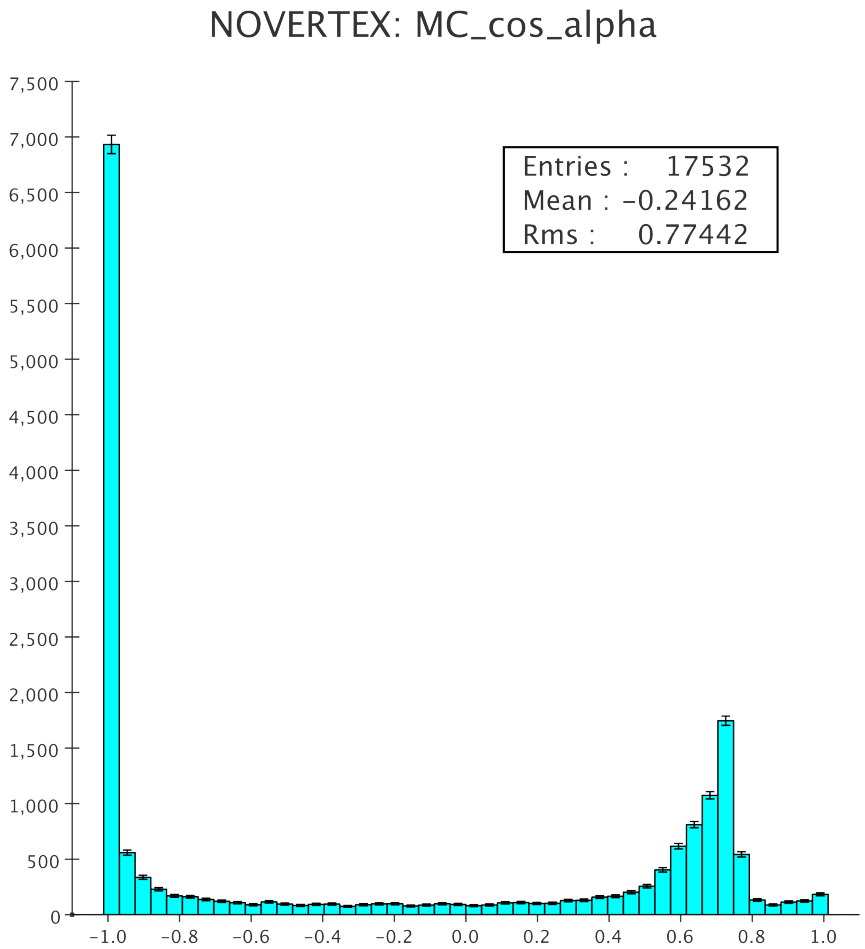
$\log_{10}(\chi^2)$ vs. N plots





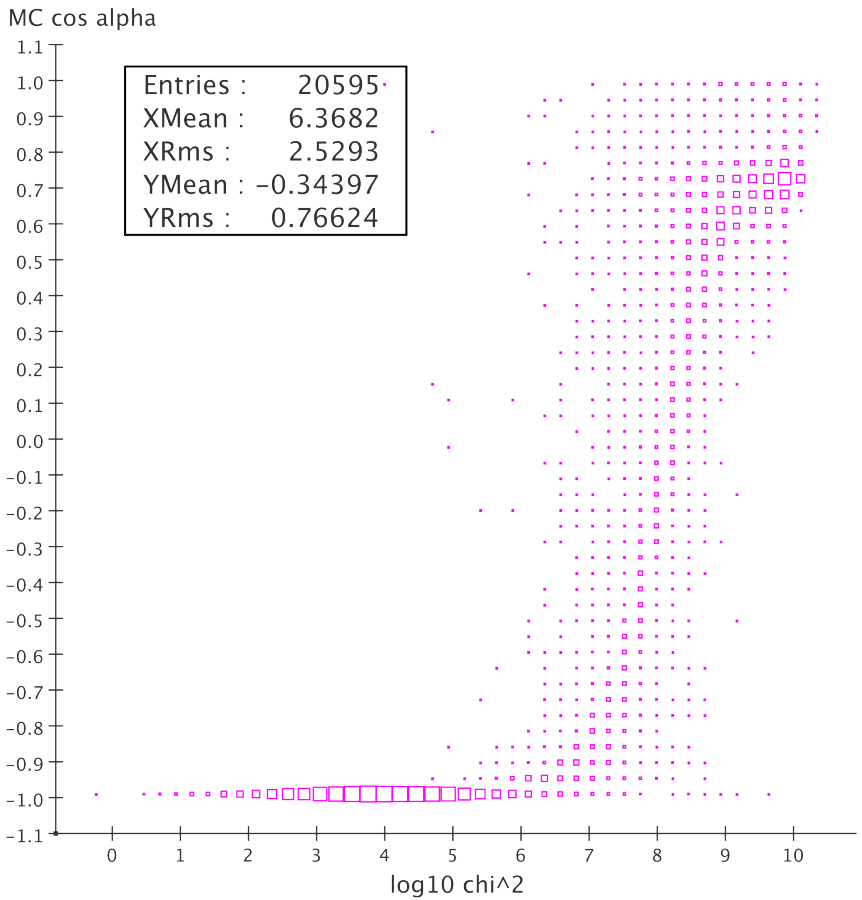
$\cos\alpha$ plots



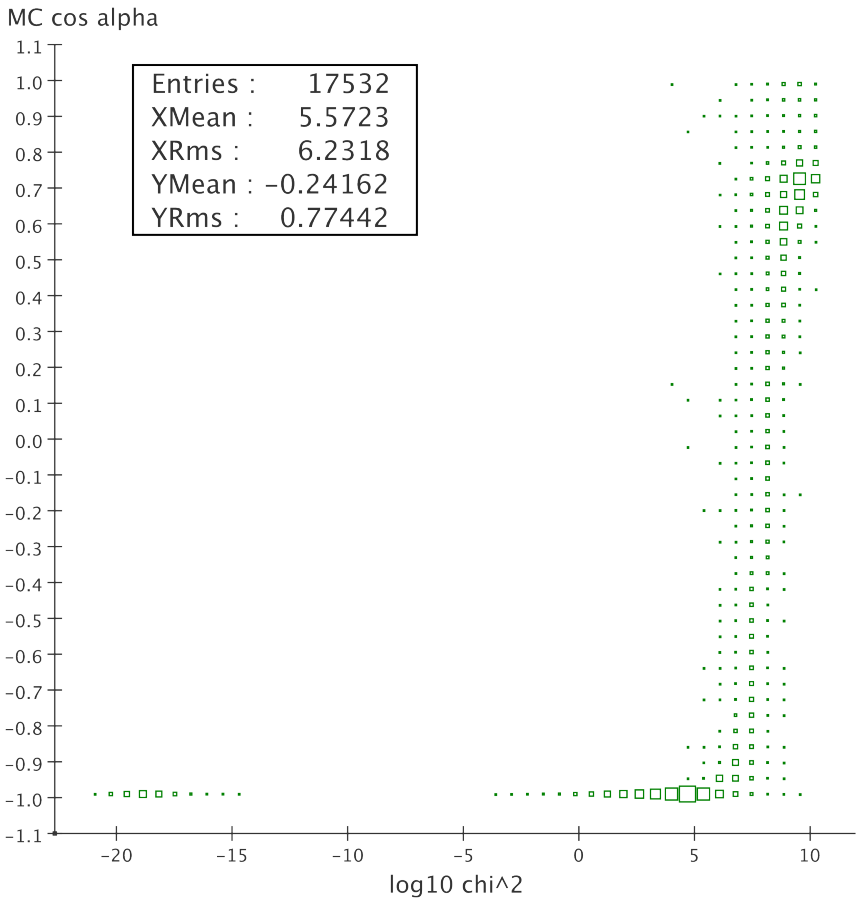


$\log_{10}(\chi^2)$ vs. $\cos\alpha$ plots

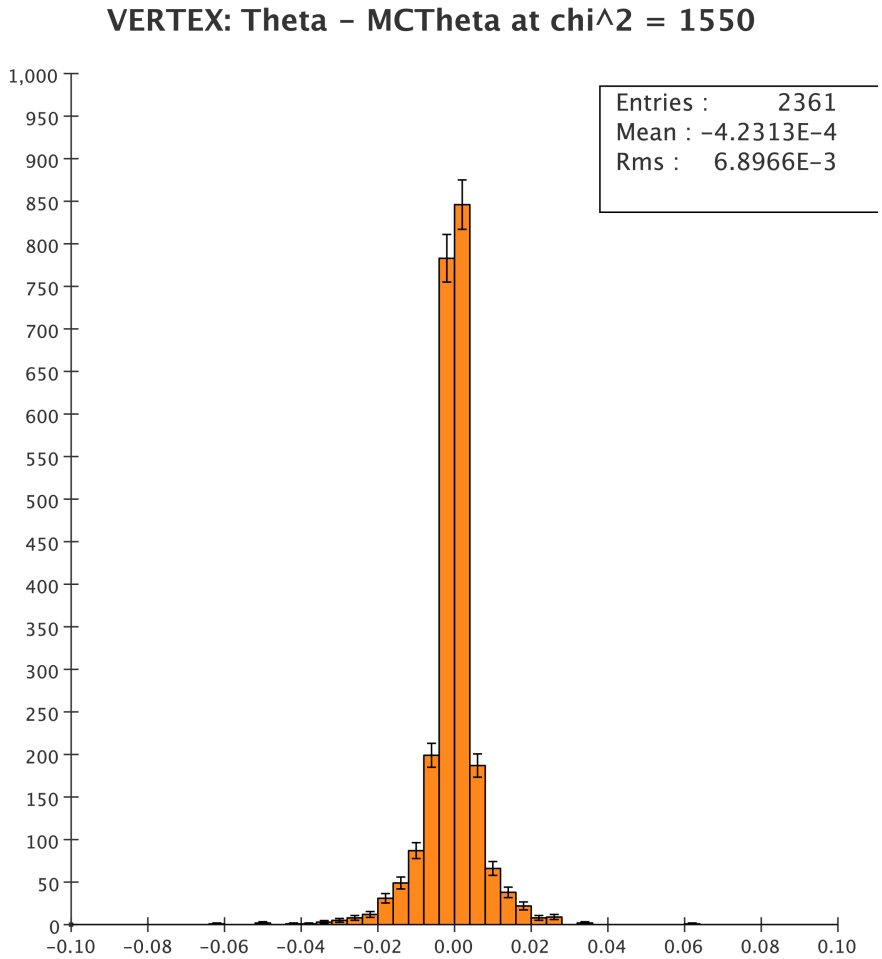
VERTEX: MC_cos_alpha vs. log10 chi^2

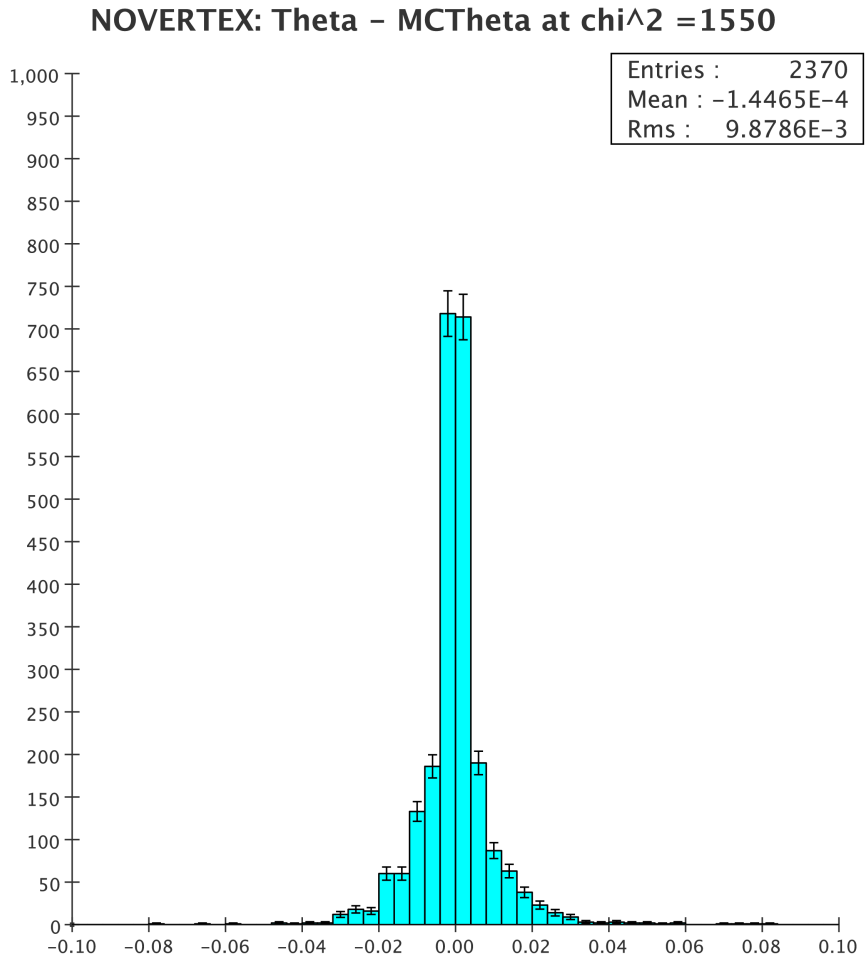


NOVERTEX: MC_cos_alpha vs. log10 chi^2

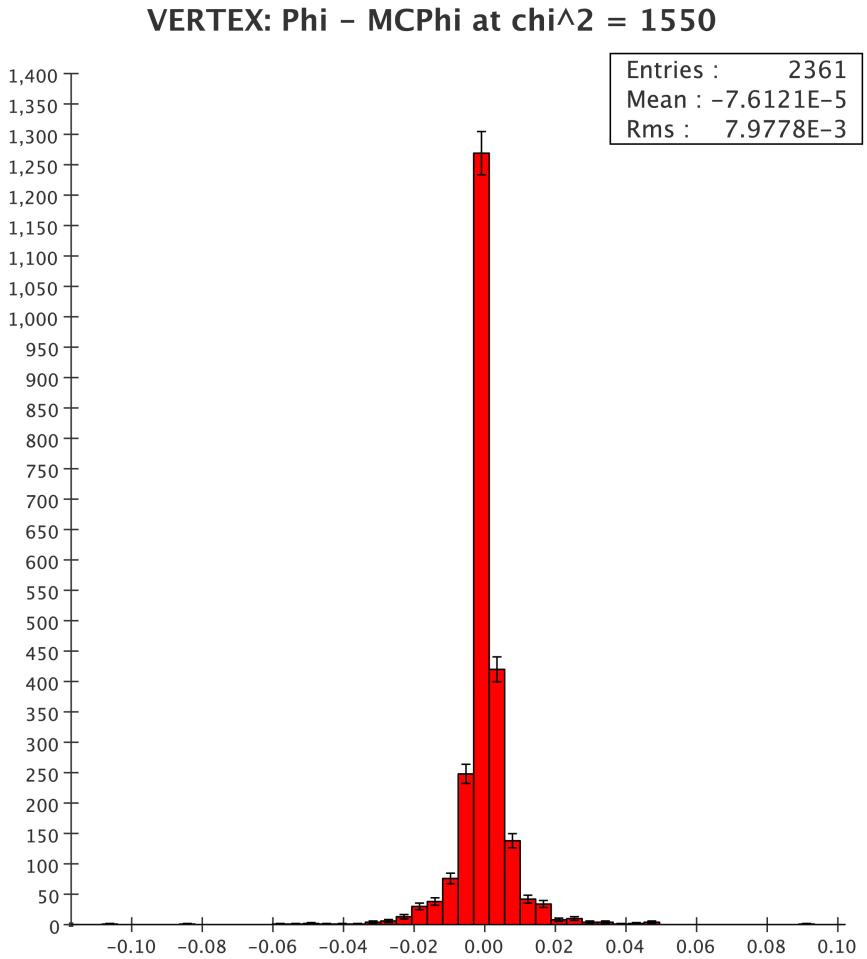


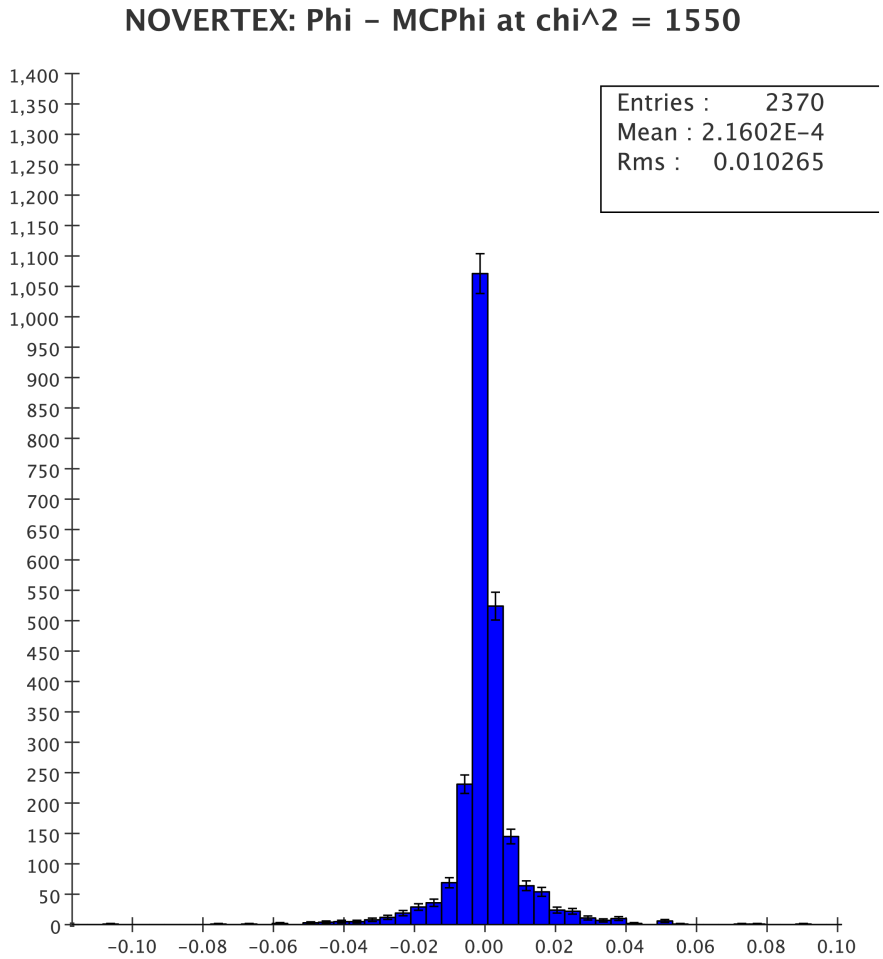
Θ residuals at $\chi^2 = 1550$



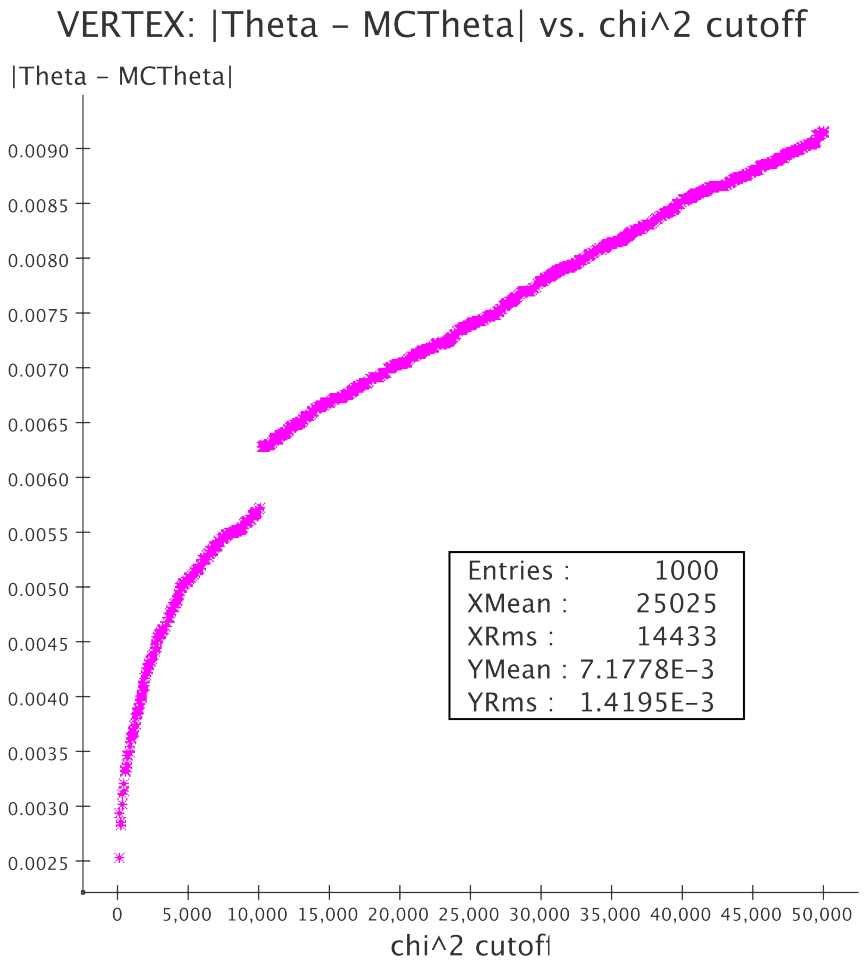


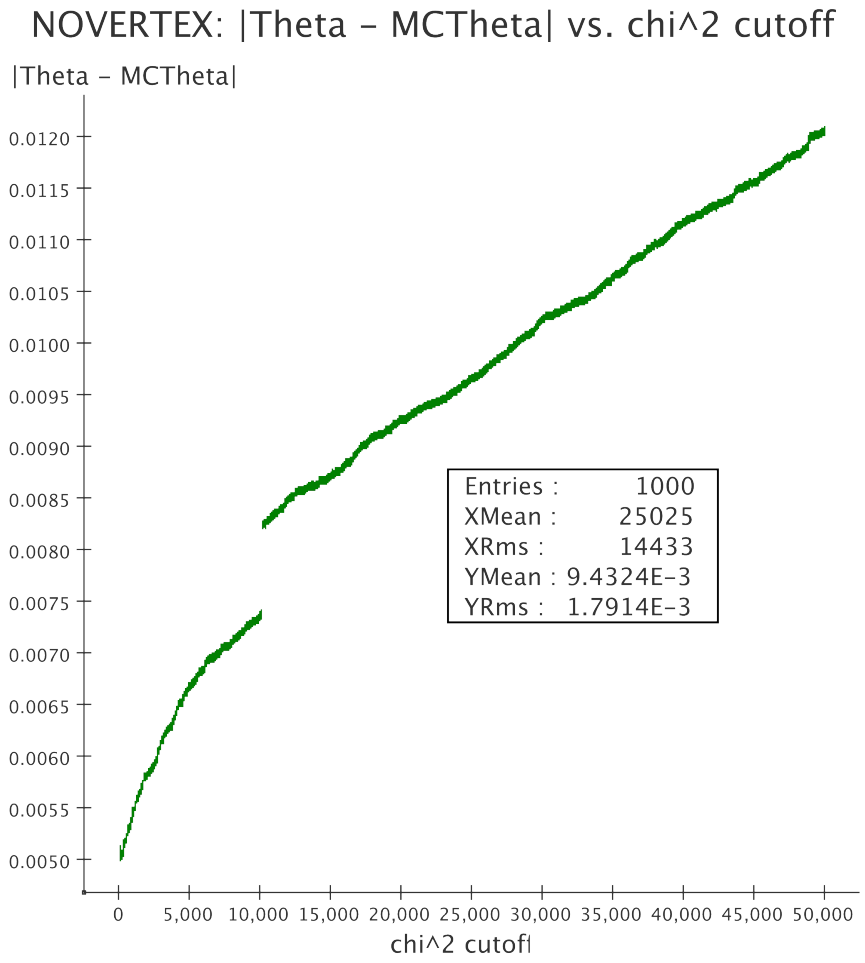
Φ residuals at $\chi^2 = 1550$





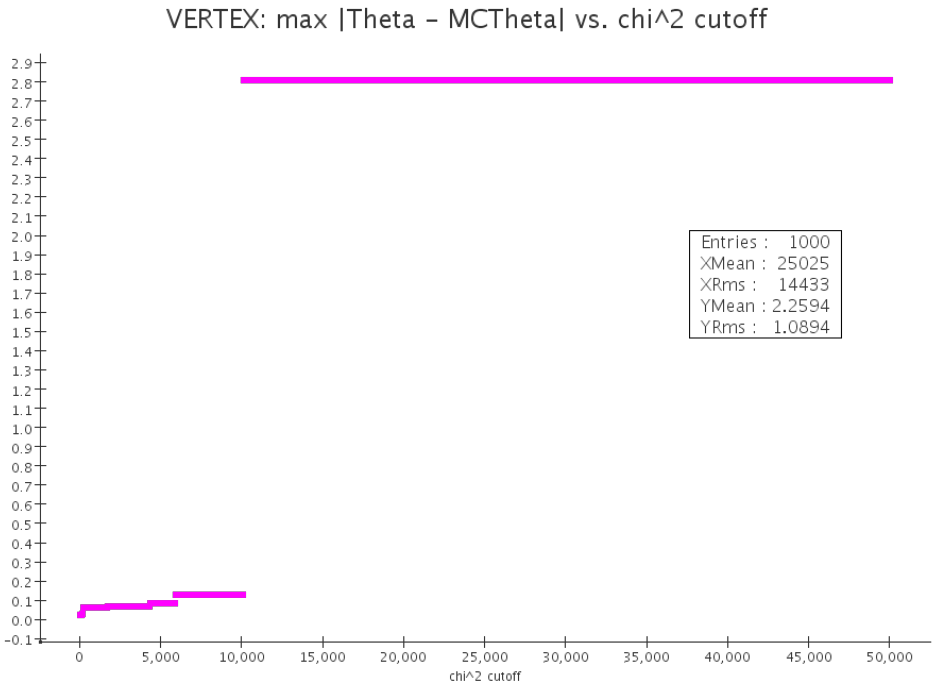
Θ residuals (rms) vs. χ^2 cutoff (with discontinuities)

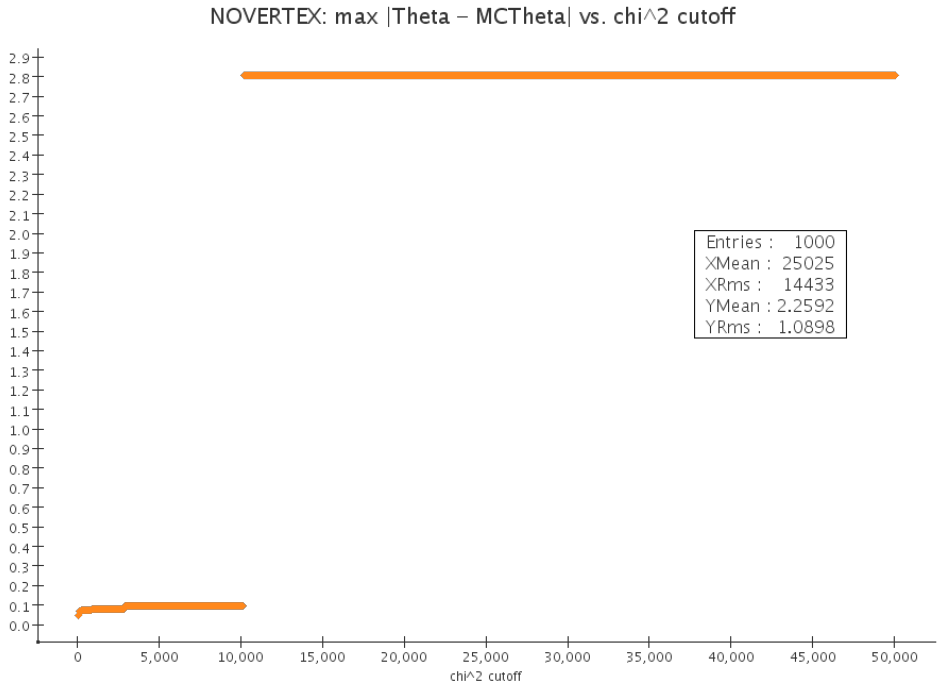




Source of discontinuities...

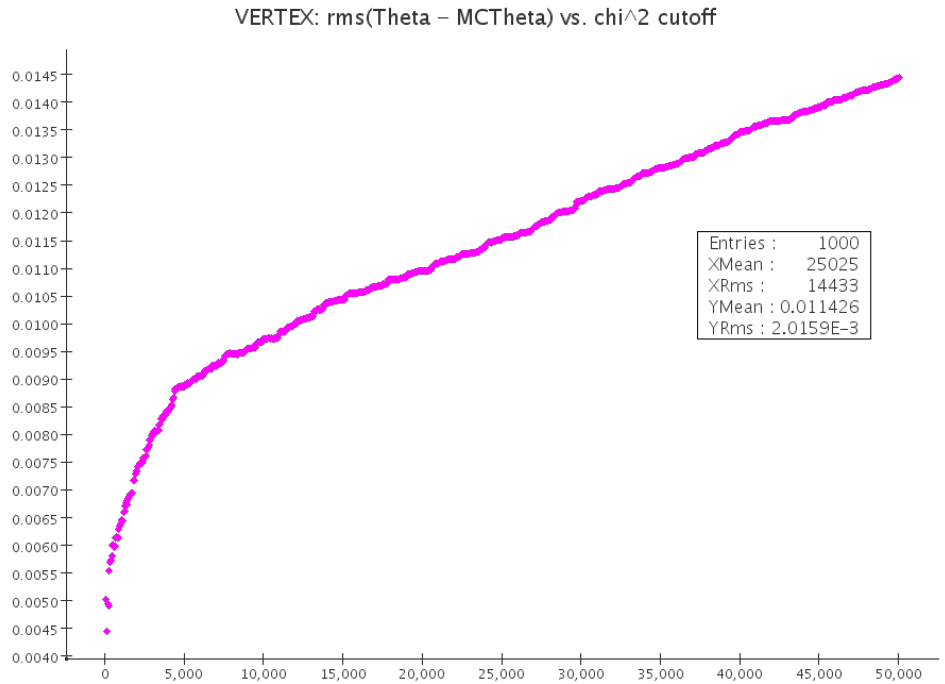
Doh! It's from outliers.

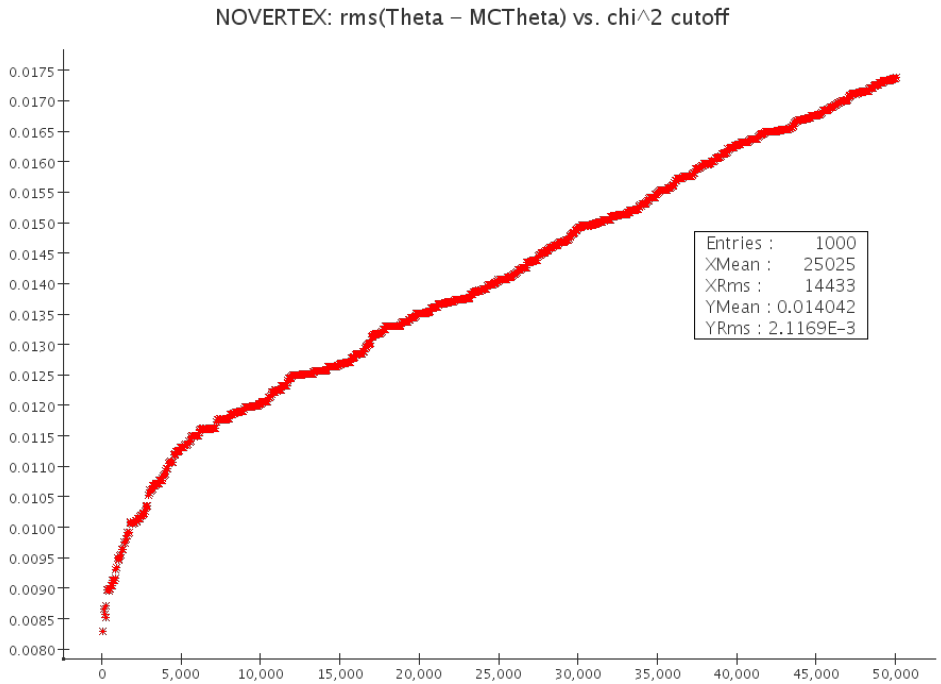




Θ residuals (rms) vs. χ^2 cutoff (no outliers)

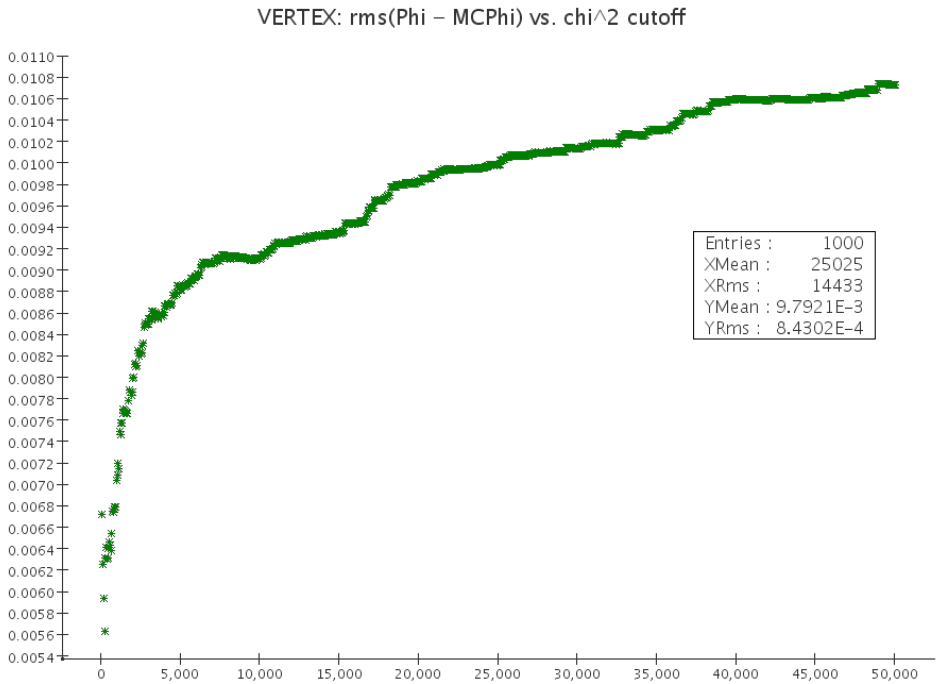
Used rough definition of outlier = residual > 0.1

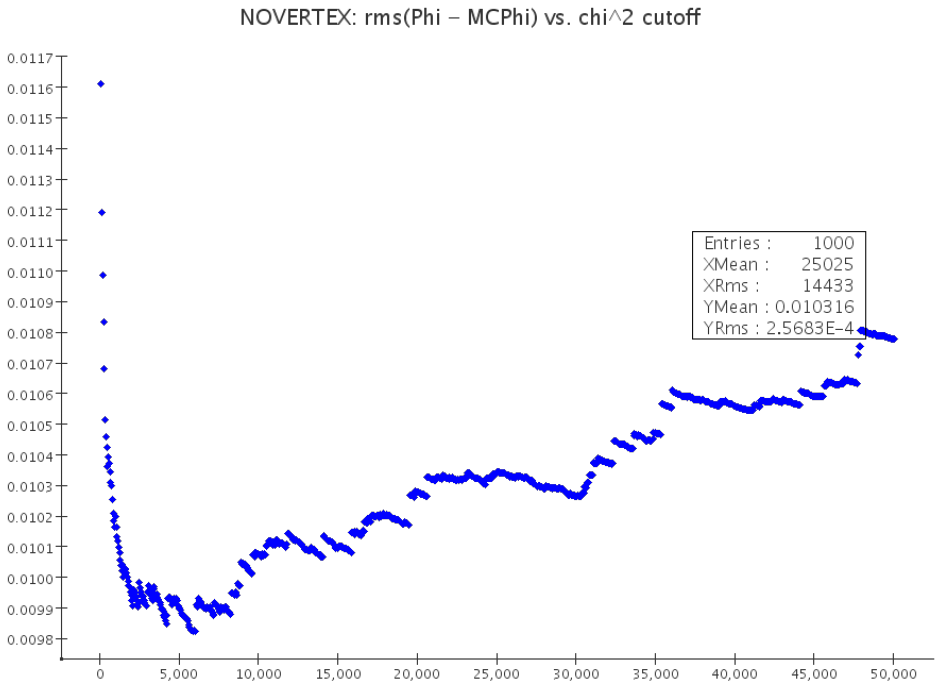




Φ residuals (rms) vs. χ^2 cutoff (no outliers)

Used rough definition of outlier = residual > 0.1





Stuff that could still be done

- Look at additional decay channels ($\tau \longrightarrow \rho\nu$ probably next easiest).
- Could use both τ directions with fit with impact parameter... there exist enough parameters
- Fit Gaussians to residual plots

Thank you everyone

- I've had a great time here at SLAC. Thanks for having me!
- I'm graduating on Sunday.
- Going to MIT in fall...