Cornell University
Laboratory for
Elementary-Particle Physics

$D_S^{*+} \to D_S^+ e^+ e^-$

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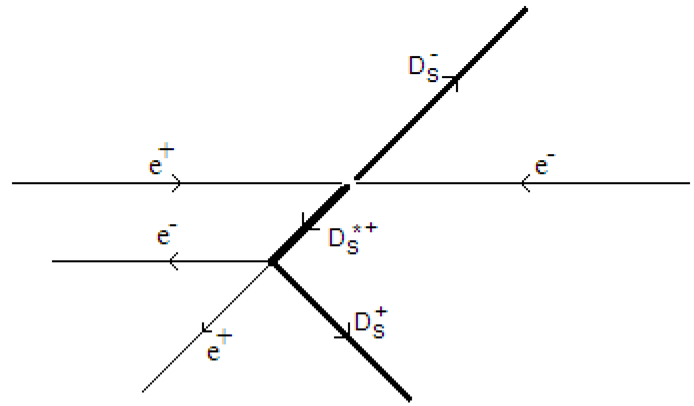
What Are We Looking For?

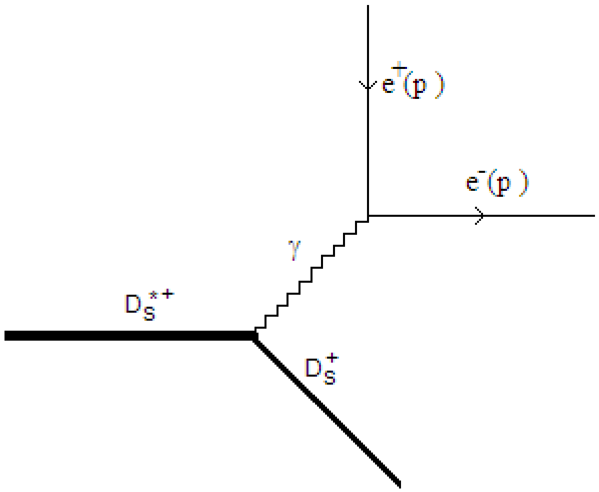


- We are looking for $D_S^{*+} \rightarrow D_S^+ e^+ e^-$ (+ c.c.) processes.

- We fully reconstruct the D_S^{*+}
  - The D_S^+ is reconstructed through several decay channels using DTag's default criteria. See [CBX 06-11](CBX 06-11).
  - The $e+$ $e-$ share ~ 144 MeV. Pion fitted tracks for electrons (default in CLEO) at such low energies may not be reliable. Need fitting to electron hypothesis.
  - Events are selected using m_{DS+} , m_{BC}, δm
  - Selection criteria on the e^+e^- tracks to reject conversion background $D_S^{*+} \rightarrow D_S^+ \gamma$

- Alternative analysis that reconstructs the D_S^- can give us more statistics.

Predicted $D_S^{*+} \rightarrow D_S^+ e^+ e^-$ Rate



If we write the decay of the D_S^{*+} to a real photon in the form:

$$M = \varepsilon^{\mu}_{D_S^{*+}} \varepsilon^{*\nu}_{\gamma} T_{\mu\nu}(P,k)$$

Then we can write the decay to e^+e^- in the form:

$$M = \varepsilon^{\mu}_{D_S^{*+}} T_{\mu\nu}(P,k) \left(\frac{-ig^{\upsilon\sigma}}{k^2} \right) \overline{u}(p) ie\gamma_{\sigma} v(p')$$

Evaluating the spin-average of the invariant amplitudes and integrating over phase space, we roughly predict the ratio of decay rates:

$$\frac{\Gamma\left(D_S^{*+} \rightarrow D_S^+ e^+ e^-\right)}{\Gamma\left(D_S^{*+} \rightarrow D_S^+ \gamma\right)} \approx 1.4\alpha = 0.01$$

Decay Modes of $D_S{}^+$ Used

We reconstruct the $D_s{}^+$ through the following decay modes:

$$D_S^+ \to K^+K^-\pi^+$$

$$D_S^+ \to K_SK^+$$

$$D_S^+ \to \eta\pi^+; \eta \to \gamma\gamma$$

$$D_S^+ \to \eta'\pi^+; \eta' \to \pi^+\pi^-\eta; \eta \to \gamma\gamma$$

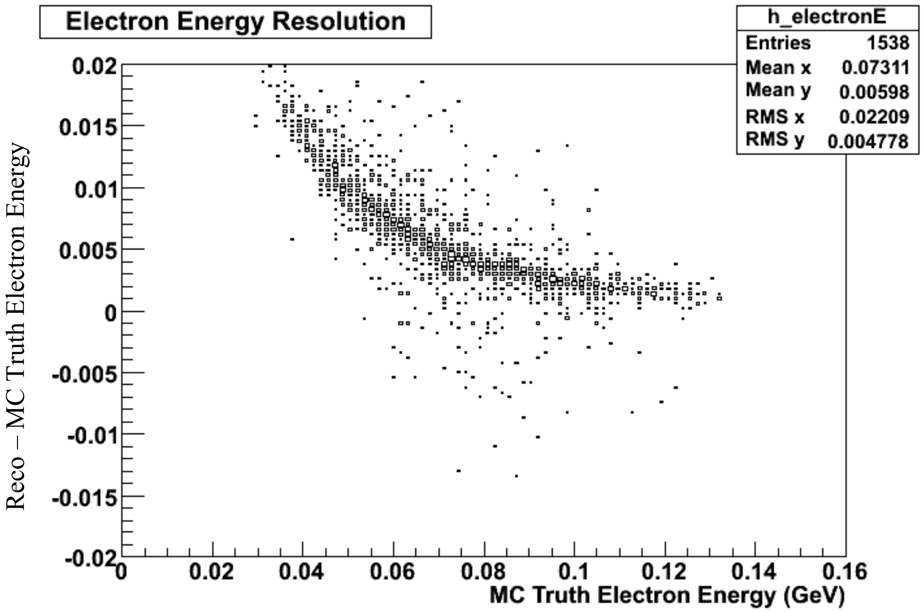
$$D_S^+ \to \pi^+\pi^+\pi^-$$

$$D_S^+ \to K^{*+}K^{*0}; K^{*+} \to K_S^0\pi^+; K^{*0} \to K^-\pi^+$$

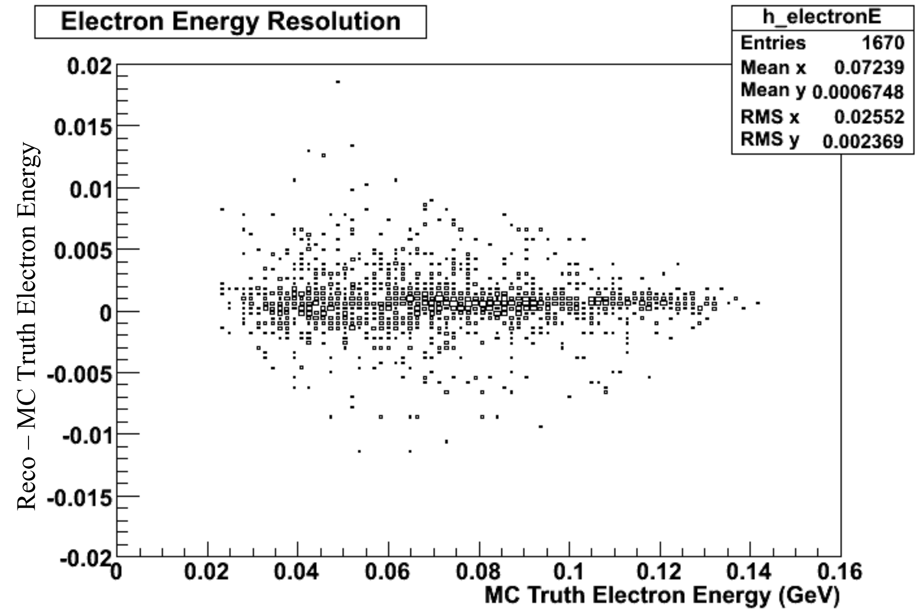
$$D_S^+ \to \eta\rho^+; \eta \to \gamma\gamma; \rho^+ \to \pi^+\pi^0$$

$$D_S^+ \to \eta'\pi^+; \eta' \to \rho^0\gamma$$

Fitting Soft Electrons to the Electron Hypothesis



Pion fit



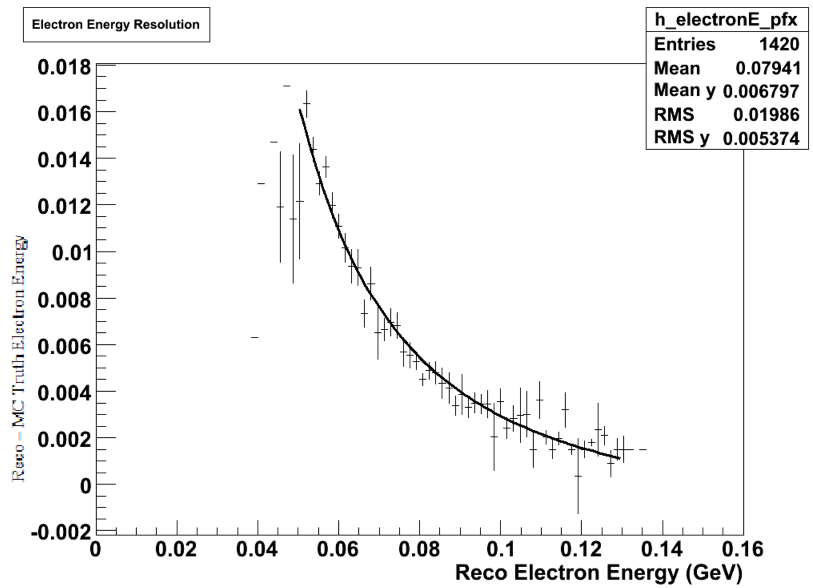
Electron fit

We expect soft electron tracks with $p_T < 70$ MeV. Fitting electrons to the pion hypothesis is not reliable in this domain. Fitting to the electron hypothesis gives better energy resolution.

Signal and conversion background samples we generate have electrons fitted to the electron hypothesis.

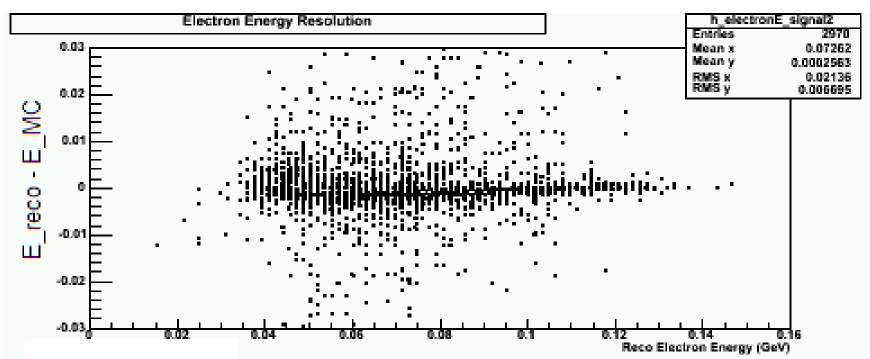
CLEO data does not have tracks fitted to the electron hypothesis.

Parameterizing Energy of Soft Pion Fitted Electrons

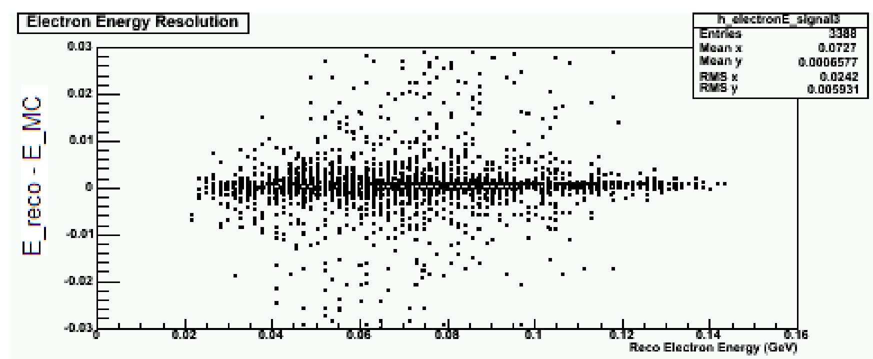


We fitted the energy resolution of the soft pion-fitted electrons with:

$$E_{reco} - E_{MC} = -1.636 \times 10^{-3} + \frac{4.518 \times 10^{-5}}{E_{reco}{}^{2}}$$



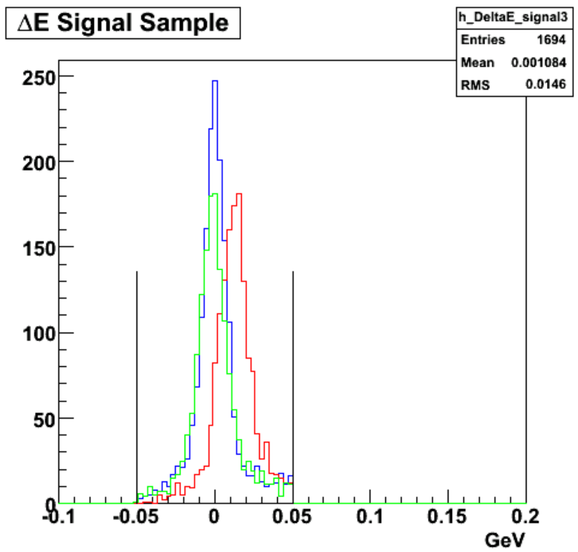
Parameterized energy correction to pion fitted electrons.

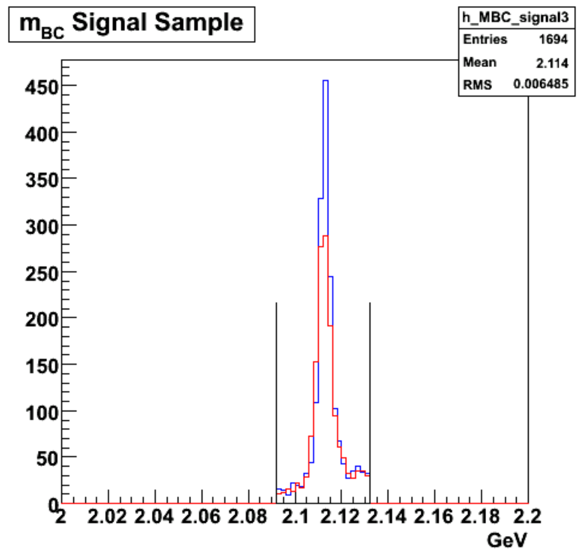


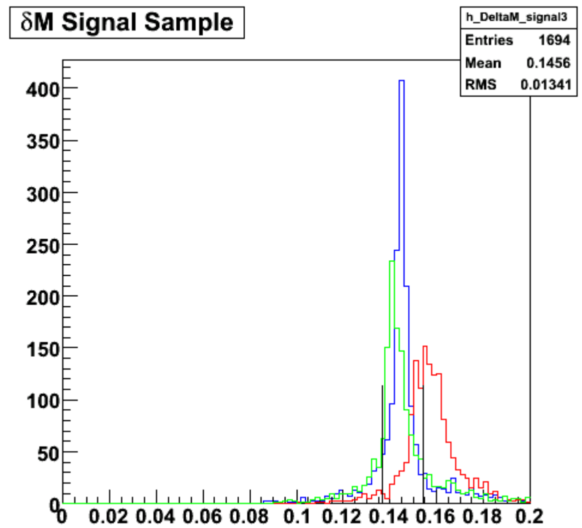
Energy resolution of electron fitted electrons.

Parameterizing Energy of Soft Pion Fitted Electrons

- Red are the pion-fitted electron sample
- Green are the parameterized pion-fitted electron sample.
- Blue are the electron-fitted electron sample.







Applied cuts:

- |dsPlusM - 1.96849| < 0.011 GeV
- |deltaE| < 0.05 GeV
- |mBC - 2.112| < 0.02 GeV

Parameterizing Energy of Soft Pion Fitted Electrons

- Parameterizing energy of soft pion fitted tracks only shifts peaks of kinematic cuts, doesn't increase signal yield.

- MC matched electrons with \theta=0.05.

  (# matched e in pi-fit) / (# matched e in e-fit) ~ 0.93

  Close to ratio of events under electron-fit and parameterized pion-fit peaks in the kinematic variables.

- Suggests a fundamental reconstruction/track-fitting inefficiency when using pion hypothesis for low energies.

- We need electron fits.

Interdependence of Kinematic Variables

We defined our kinematic variables:

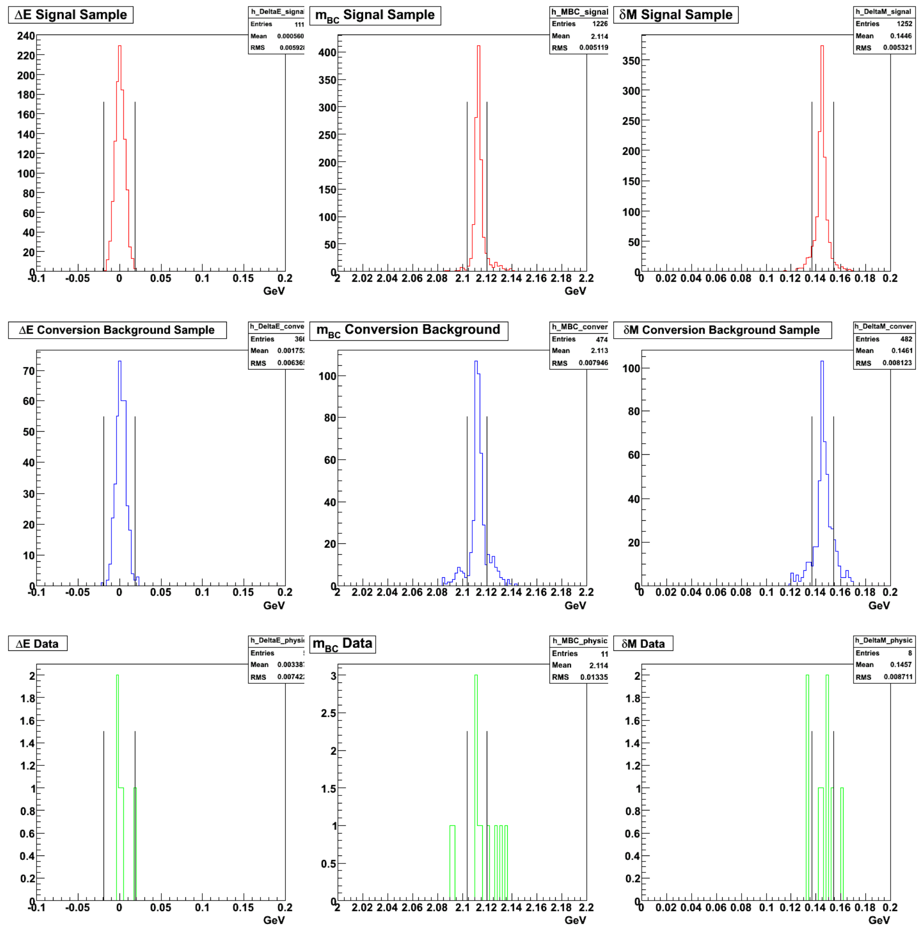
- $\Delta E = E(D_s^{*} decay) - E(D_s^{*} beam)$
- $m_{BC} = \sqrt{E(D_s^{*} beam)^2 - P(D_s^{*} decay)^2}$
- $\delta m = M(D_s^{*} decay) - M(D_s decay)$

We can write a relationship between these variables

$$(\Delta E)^2 + 2E(D_s^{*} beam)\Delta E + m_{BC}^2 = (\delta m + M(D_s decay))^2$$

So having cut on M(Ds decay) as well, we may cut on only 2 of the 3 kinematic variables.

Plots of one kinematic variable with cuts on the other two suggest dE as dispensable.



Signal Samples

- For signal Monte Carlo, we force the e^+e^- collision to produce a *Ψ(4160)*, and that to decay into D_s^{*+} , D_s^-
- We added an EVTGEN plug-in to generate vector (D_s^{*+}) to scalar (D_s^+), lepton (e^-), lepton (e^+) distributions with the invariant amplitude in consideration, apart from the invariant phase space factor.
- The D_s^+ was forced to decay through each of the previously mentioned channels. The D_s^- was allowed to decay generically.
- We fitted electrons to the electron hypothesis instead of the pion hypothesis.
- We generated 10,000 signal MC events for each decay mode of the D_s^+.

Conversion Background Samples

- A background that resembles the signal is expected from D_s^{*+} decaying to D_s^+, γ and the γ converting to e^+e^- in the beam-pipe material.
- Given that the beam-pipe is ~ 0.5% of a radiation length, we can estimate this conversion background to occur at roughly the same frequency as the signal.

- For this conversion background Monte Carlo, we force the e^+e^- collision to produce a $\Psi(4160)$, and then that to decay into the D_s^{*+}, D_s^-. The D_s^{*+} now decays via D_s^+, γ . The conversion of the photon to e^+e^- is taken care of in the detector simulation.
- We fitted electrons to the electron hypothesis instead of the pion hypothesis.
- We generated 100,000 events for each decay mode of the D_s^+.

Dataset Looked At

- We have looked at 110 pb^{-1} of data to determine the feasibility of this analysis.

- We used data collected at E_{CM} = 4170 MeV (dataset 47)

- CLEO-c has 602 pb^{-1} of data at this energy.

  $D_S^{*+}D_S^- + D_S^{*-}D_S^+$ cross section is ~ 1 nb at this energy.

Selection Criteria Common to All D_S^+ Decay Modes

- Electron tracks must pass track quality cuts:
  - 10 MeV < Track Momentum < 2.0 GeV
  - $\chi^2 < 100{,}000$
  - $d_0 < 5$ mm, $z_0 < 5$ cm
- The track's *dE/dx* is required to be within 3.0 σ of that expected for an electron.

- The DTag tools applied their default criteria for the eight investigated modes.

- These cuts, and the reconstruction of a D_S^{*+} were required for filling our n-tuples on which we applied subsequent cuts.

The $K^+K^-\pi^+$ Decay Mode

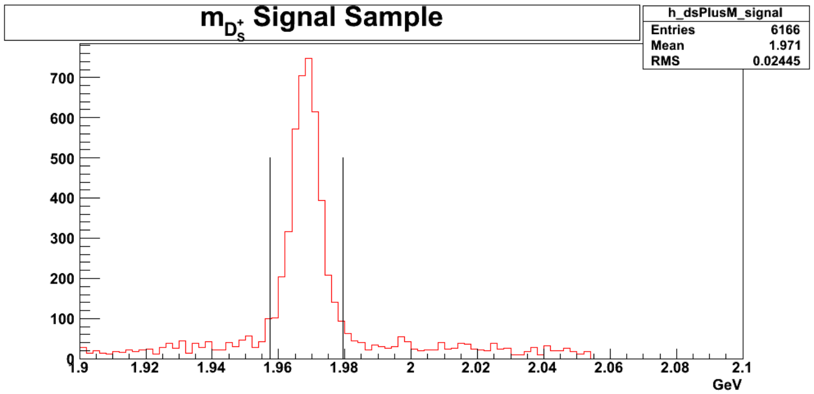
The following slides illustrate the selection criteria used to distinguish the signal from the conversion background by focusing on the $D_s^+ \rightarrow K^+K^-\pi^+$ channel.

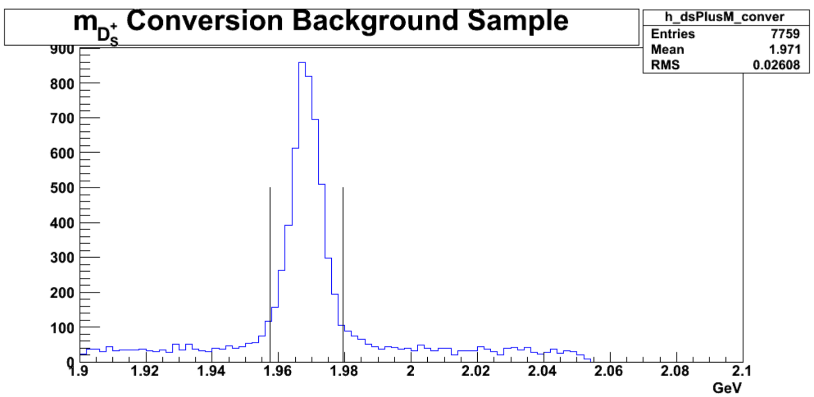
The top plot in red is the signal.

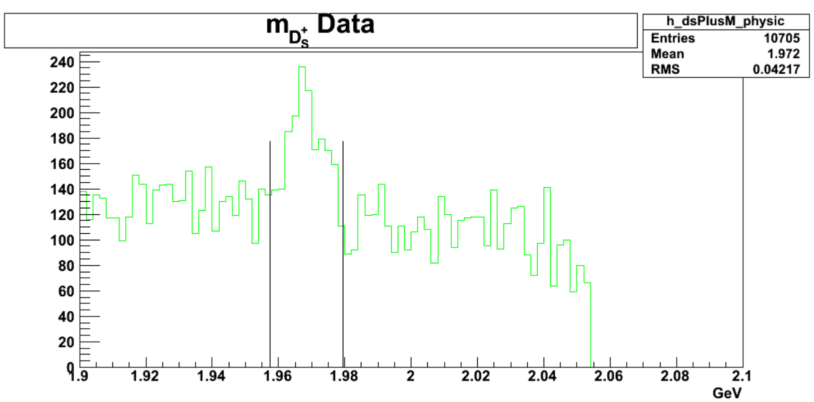
The middle plot in blue is the conversion background.

The bottom plot in green is the data.

$K^+K^-\pi^+$ Mode $D_S^+{}_{Mass}$ Cut



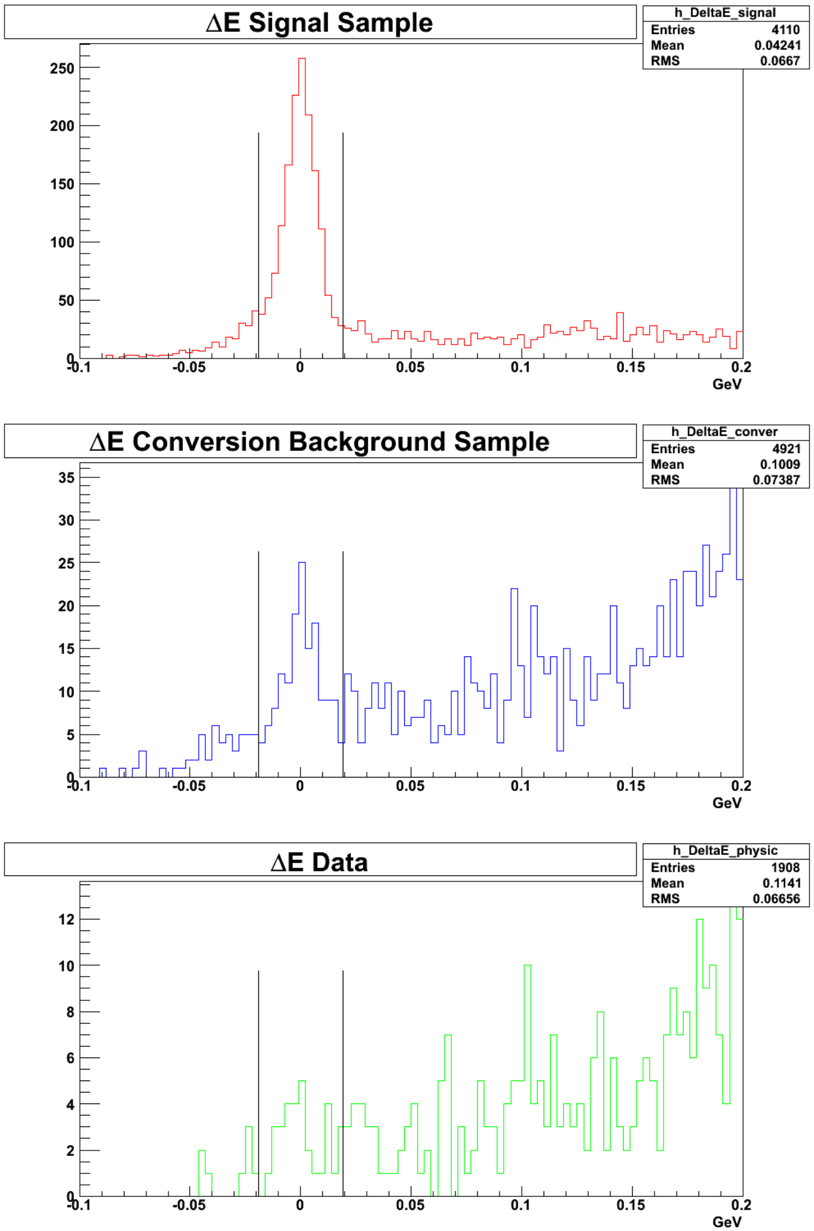




- Reconstructed $D_S^+{}_{Mass}$
- We cut on

$$| D_S^+{}_{Mass} - 1.969 \text{ GeV} | < 0.011 \text{ GeV}$$

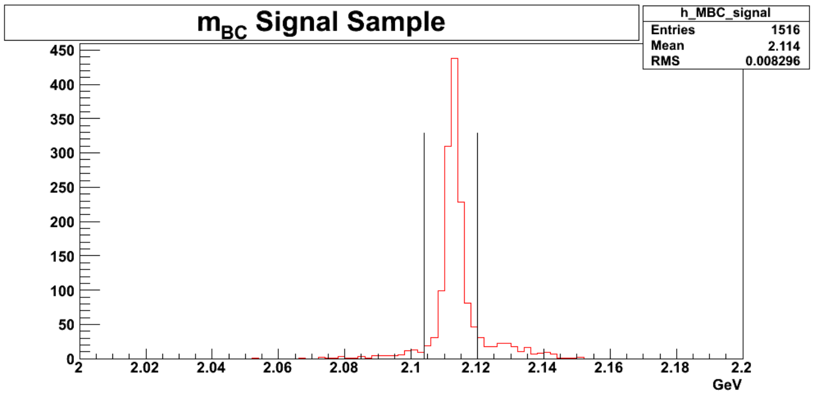
$K^+K^-\pi^+$ Mode ΔE Cut

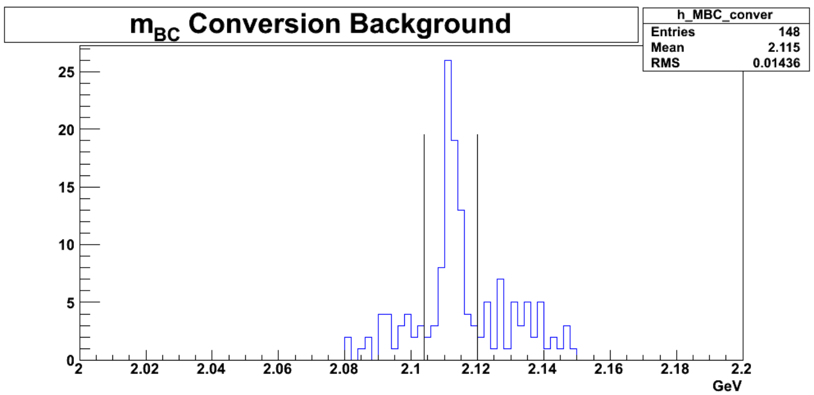


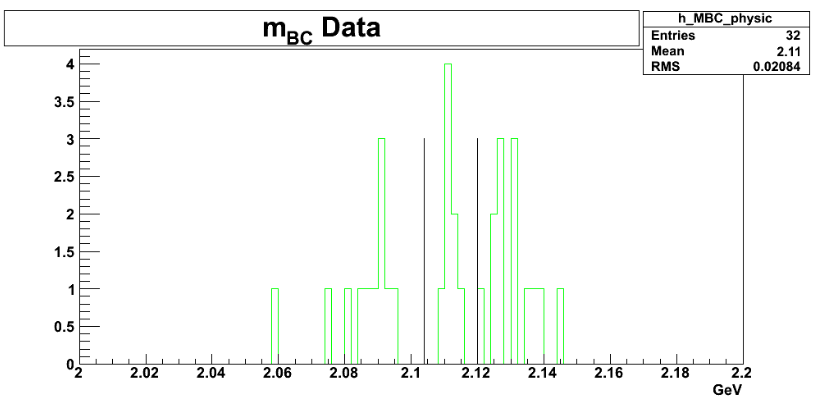
$$\Delta E = E(K^+K^-\pi^+e^+e^-) - E(D_S^{*+}beam)$$

- We cut on |ΔE|<0.019 GeV

$K^+K^-\pi^+$ Mode m_{BC} Cut



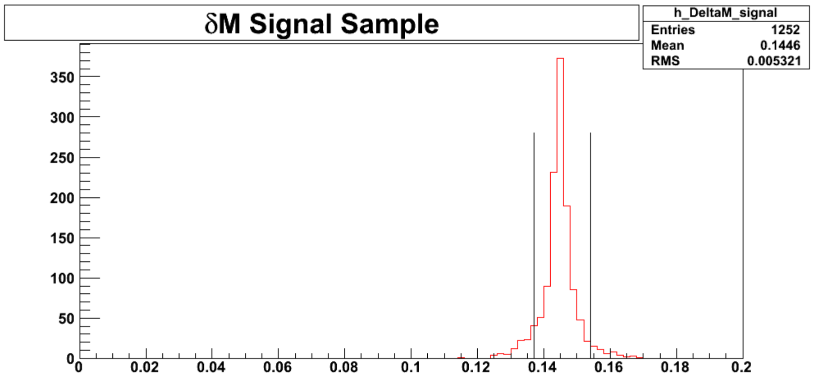


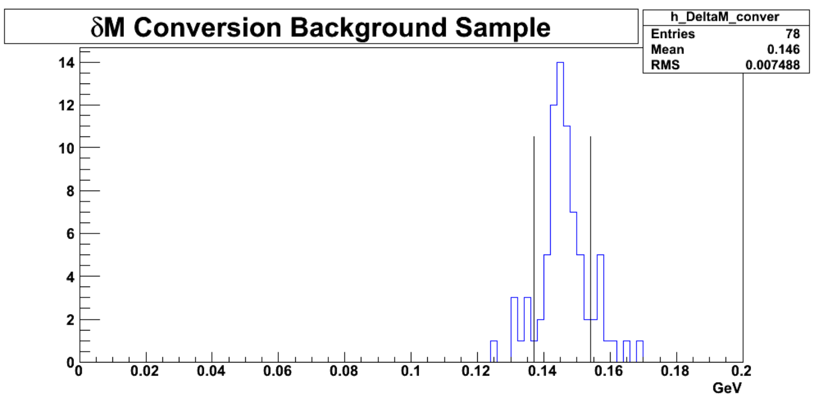


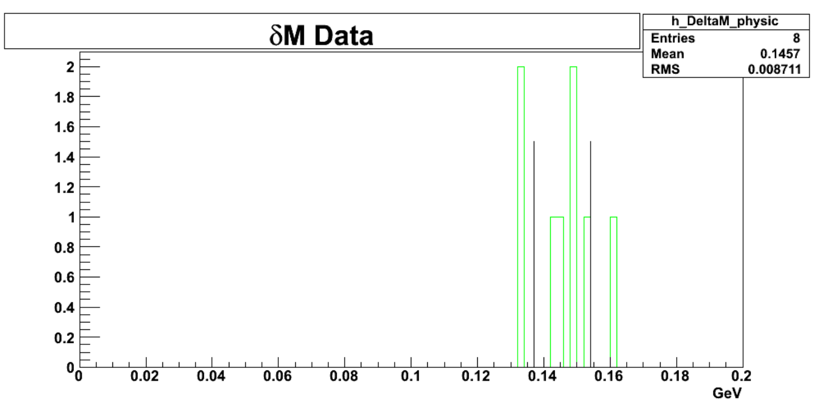
$$m_{BC} = \sqrt{E^2(D_S^{*+}beam) - P^2(K^+K^-\pi^+e^+e^-)}$$

- Will cut on | m_{BC} – 2.112 GeV | < 0.008 GeV

$K^+K^-\pi^+$ Mode δm Cut



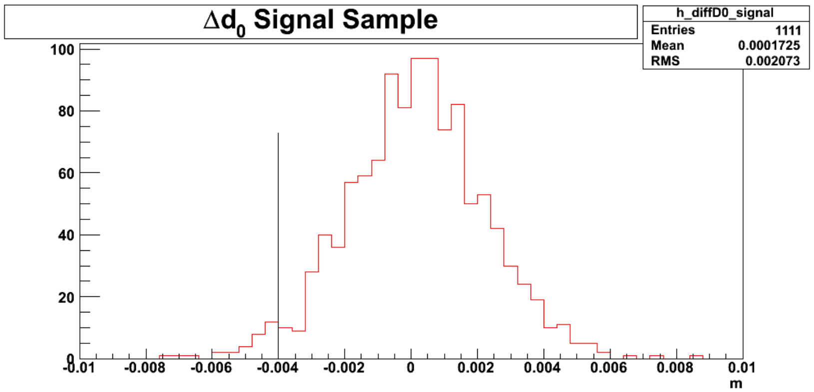


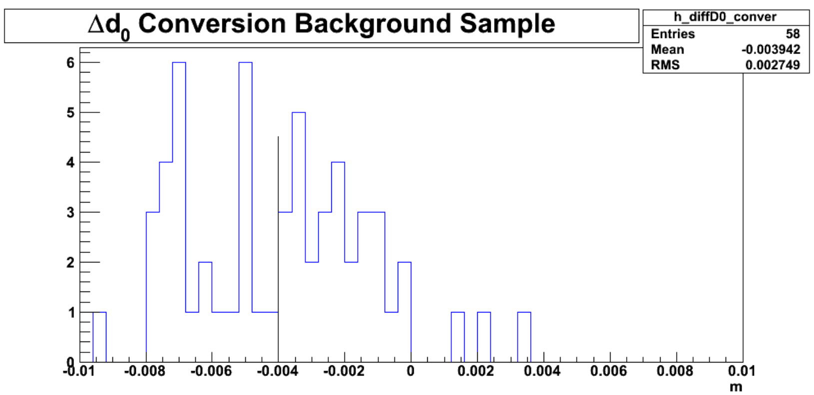


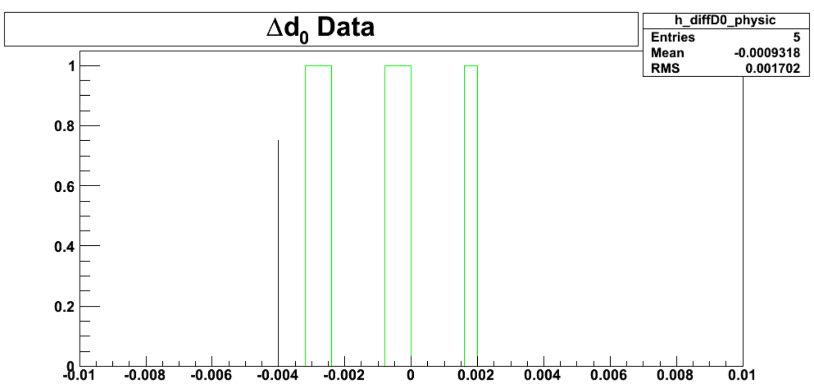
$$\delta m = M(K^+K^-\pi^+e^+e^-) - M(K^+K^-\pi^+)$$

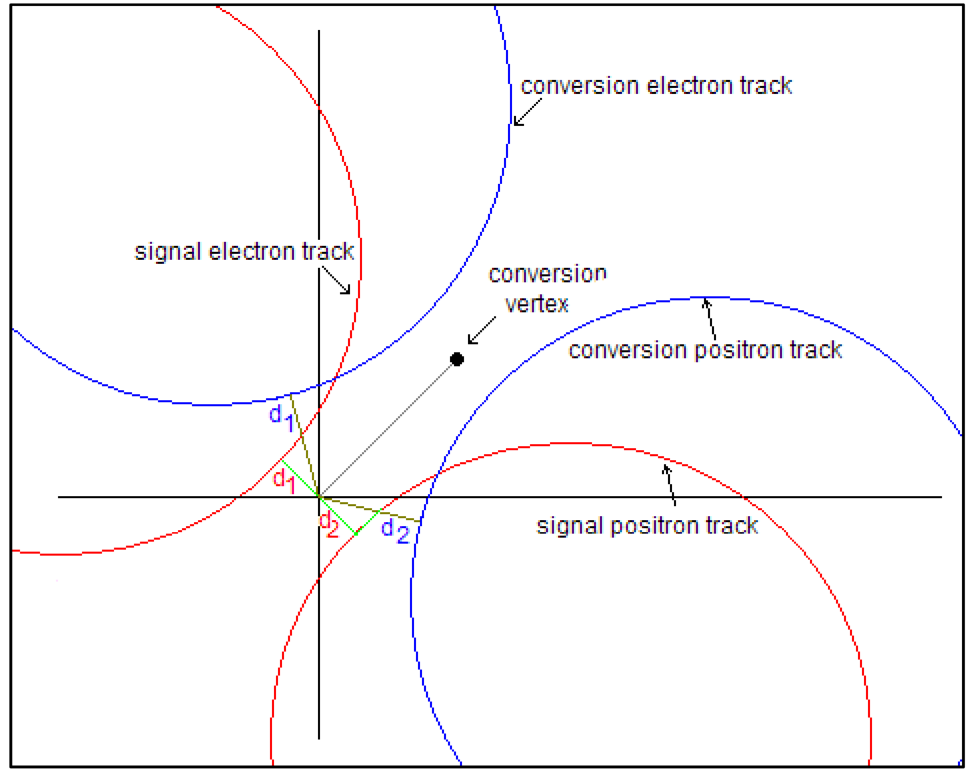
- We cut on |δm – 0.1455 GeV | < 0.0085 GeV

$K^+K^-\pi^+$ Mode Δd_0 Cut







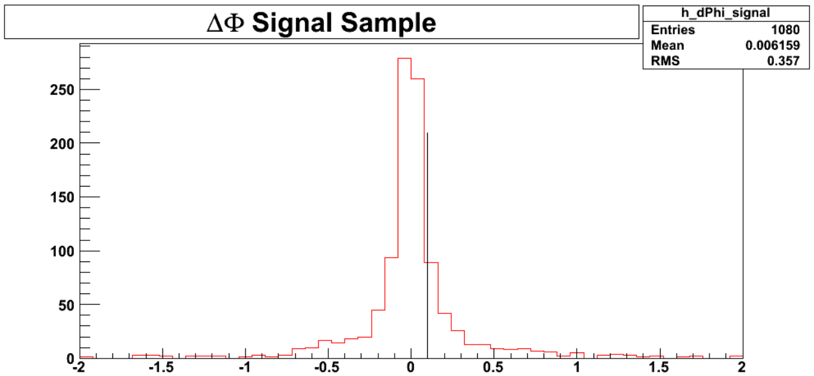


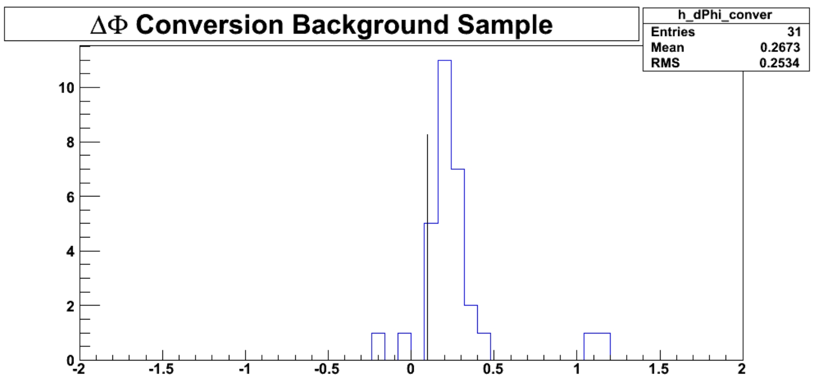
Δd_0 between the electron and positron in the signal (red) and conversion (blue)

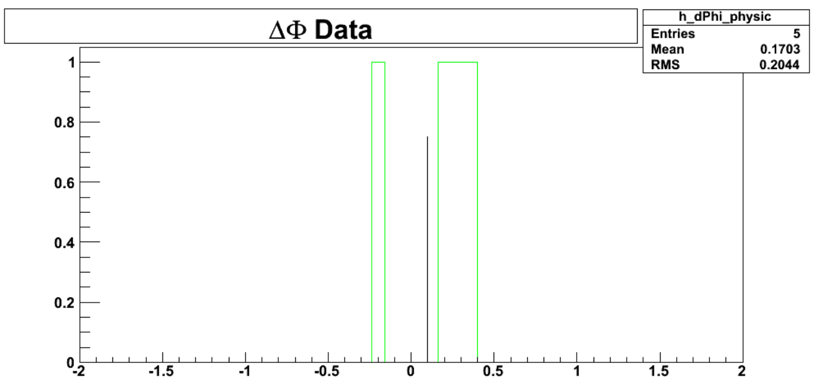
- The $\Delta d_0 = d_1 - d_2$ is centered around 0 for the signal and offset from 0 for conversion backgrounds

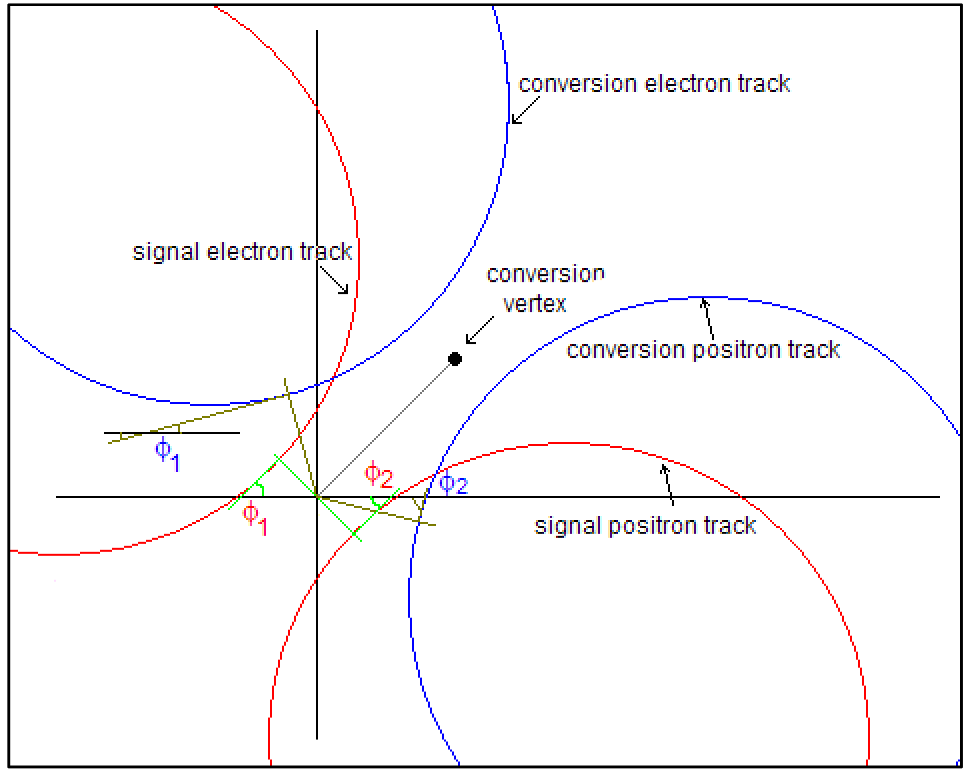
- We require $d_1 - d_2 > -0.004$ m

$K^+K^-\pi^+$ Mode $\Delta\Phi$ Cut







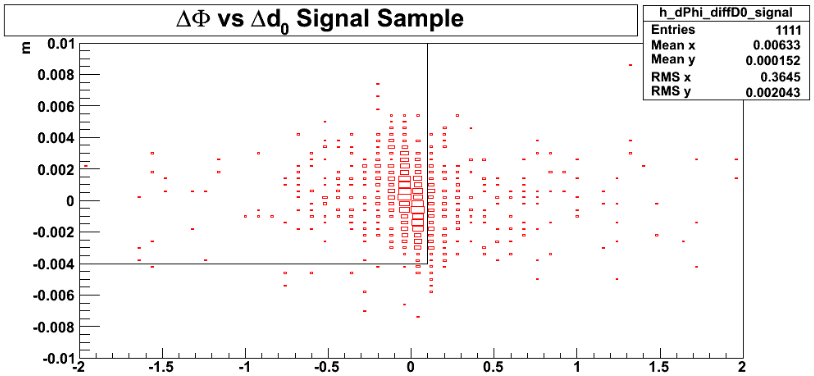


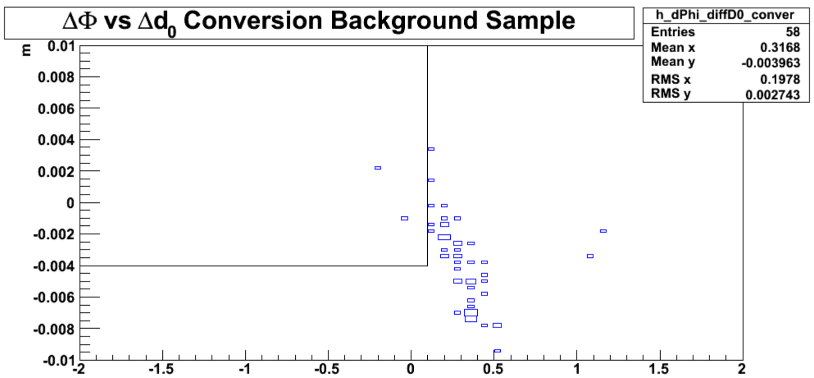
$\Delta\Phi$ between the electron and positron in the signal (red) and conversion (blue)

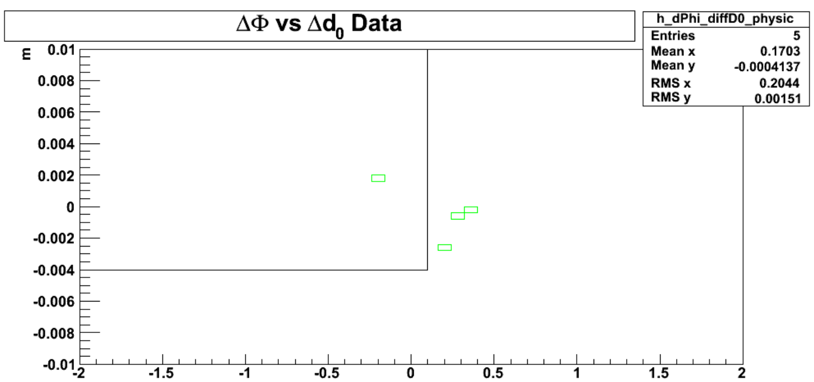
- $\Delta\Phi = \Phi_1 - \Phi_2$ is centered around 0 for the signal and offset for the conversion background.

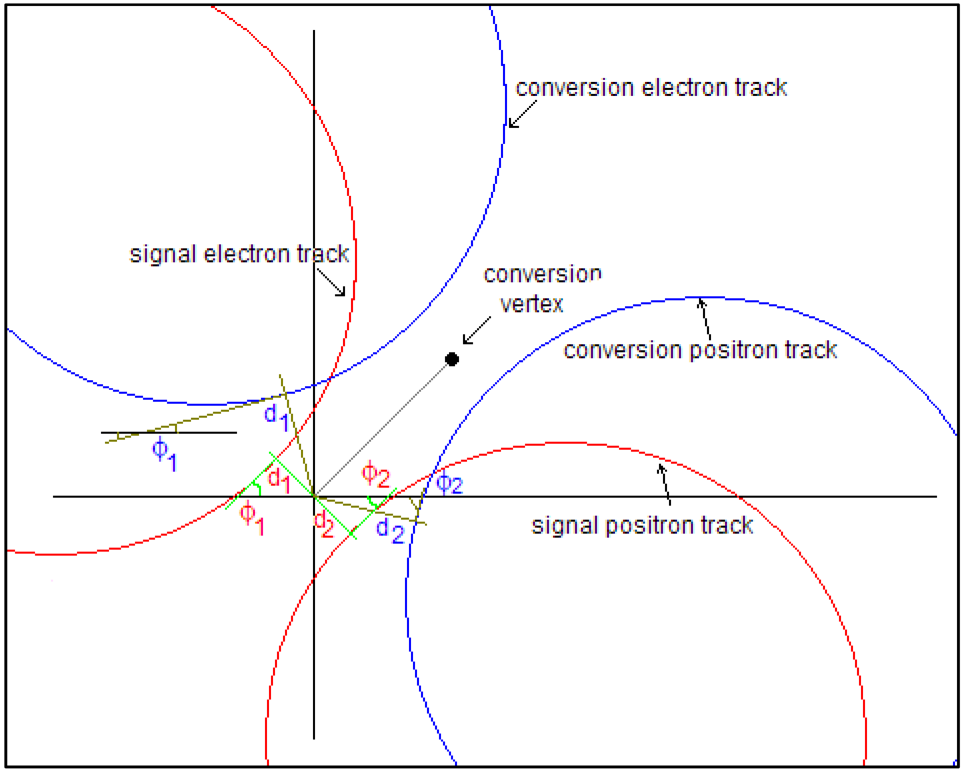
- We require $\Delta\Phi < 0.1$

$K^+K^-\pi^+$ Mode $\Delta\Phi$ vs Δd_0









The $\Delta\Phi$ & Δd_0 between the electron and positron in the signal (red) and conversion (blue)

Prediction for Data

Decay Mode of the D_S^+	Remaining in Signal Sample starting from 10,000 events	Remaining in Background Sample starting from 100,000 events	Signal Events Expected in 110 pb^{-1}	Background Events Expected in 110 pb^{-1}	Events in 110 pb^{-1} (electrons still fitted to pion hypothesis)
$K^+K^-pi^+$	815	2	4.743	0.114	2
K_sK^+	712	3	1.123	0.046	0
$\pi^+\eta;\ \eta\rightarrow\gamma\gamma$	839	2	0.551	0.129	0
$\pi^+\acute{\eta};\ \acute{\eta}\rightarrow\pi^+\pi^-\eta;\ \eta\rightarrow\gamma\gamma$	504	1	0.356	0.007	1
$\pi^+\pi^-\pi^+$	1200	2	1.415	0.023	2
$K^{*+}K^{*0};\ K^{*+}\rightarrow K^0_S\pi^+;\ K^{*0}\rightarrow K^-\pi^+$	453	2	0.789	0.034	2
$\eta\rho^+;\ \eta\rightarrow\gamma\gamma;\ \rho^+\rightarrow\pi^+\pi^0$	641	8	3.492	0.427	6
$\acute{\eta}\pi^+;\ \acute{\eta}\rightarrow\rho^0\gamma$	875	8	1.032	0.092	0
Total			13.74	0.757	13

Total number of signal events expected in 602 inv-pb ~ **74**
Total number of conversion background events expected in 602 inv-pb ~ **4**

$\pi_0 \rightarrow e^+ e^- \gamma$ in Generic Monte Carlo

As a sanity check, we studied 109 /pb of generic MC for 4170 MeV with the usual selection criteria. We expected ~ 5 conversion events after selection criteria, but we see only 2 conversion events in the 10 events left over in the generic MC.

8 of them have pi0 -> e+ e- gamma events.

Run 23085, event 14904

psi(4160) --> D*- D+ pi0;
D*- --> D- pi0;
pi0 --> e+ e- gamma

Run 230812, event 1070
psi(4160) --> D_s*+ D_s-;
D_s*+ --> D_s+ gamma;
D_s+ --> rho+ eta‘;
eta' --> pi0 pi0 eta;
pi0 --> e+ e- gamma

$\pi_0 \rightarrow e^+ e^- \gamma$!

Run 230819, event 1534
psi(4160) --> D_s*+ D_s-;
D_s*+ --> D_s+ gamma;
D_s+ --> eta mu+ nu_mu;
eta --> pi0 pi0 pi0;
pi0 --> e+ e- gamma

Run 231112, event 845
psi(4160) --> D_s*- D_s+;
D_s+ --> pi+ pi+ pi- pi0;
pi0 --> e+ e- gamma

Run 231200, event 1217
Conversion

Run 231443, event 3126
psi(4160) --> D_s*- D_s+;
D_s*- --> D_s- gamma;
D_s- --> rho- eta;
eta --> pi0 pi0 pi0;
pi0 --> e+ e- gamma

R un 231637, event 13649
psi(4160) --> D_s*+ D_s-;
D_s- --> phi rho-;
rho- --> pi- pi0;
pi0 --> e+ e- gamma

Run 231923, event 5080
Conversion, but e+e- doesn't match reco!

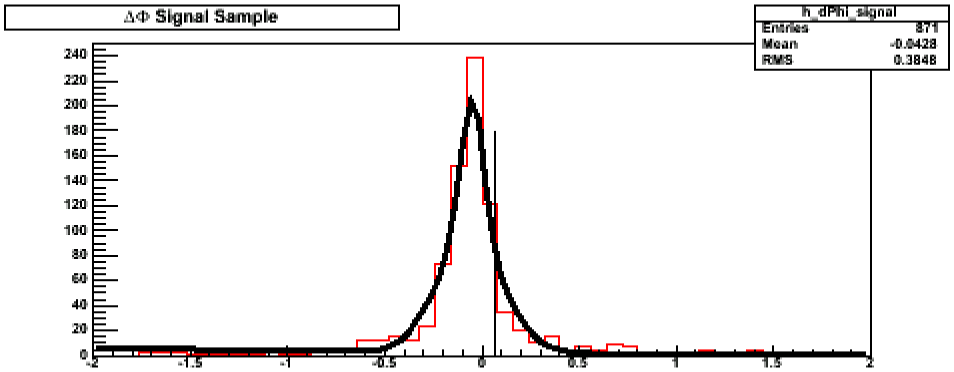
Run 232008, event 8741
psi(4160) --> D*0 anti-D*0;
D*0 --> D0 pi0;
D0 --> a_1+ K-;
a_1+ --> rho+ pi0;
pi0 --> e+ e- gamma

Run 232222, event 14279
psi(4160) --> D_s*- D_s+;
D_s*- --> D_s- gamma;
D_s- --> pi- pi- pi+ pi0 pi0 pi0;
pi0 --> e+ e- gamma

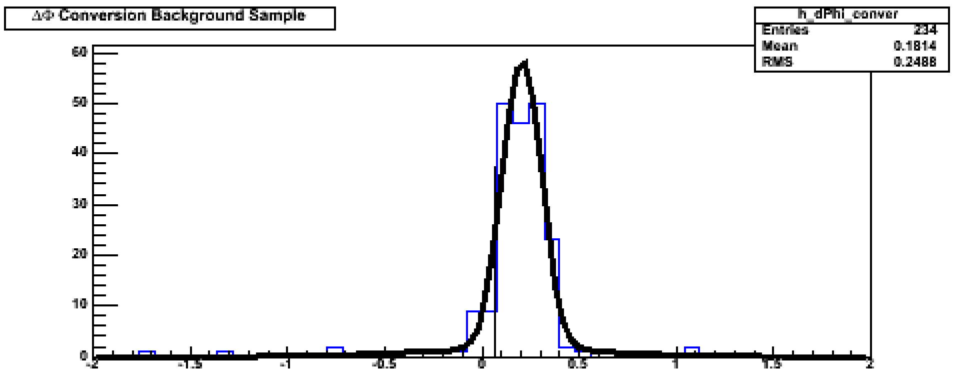
$\pi_0 \rightarrow e^+ e^- \gamma$ in Generic Monte Carlo

This background will have to estimated from data. Why the kinematic variables peak within selection ranges is a mystery – perhaps we shape it. Need more data.

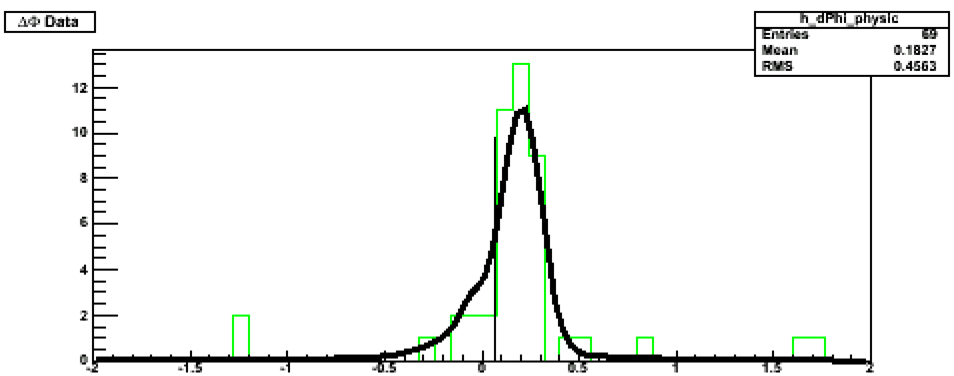
Fitting Generic Monte Carlo ΔΦ



The signal was maximum likelihood fit to 3 Gaussians within |ΔΦ| < 2.



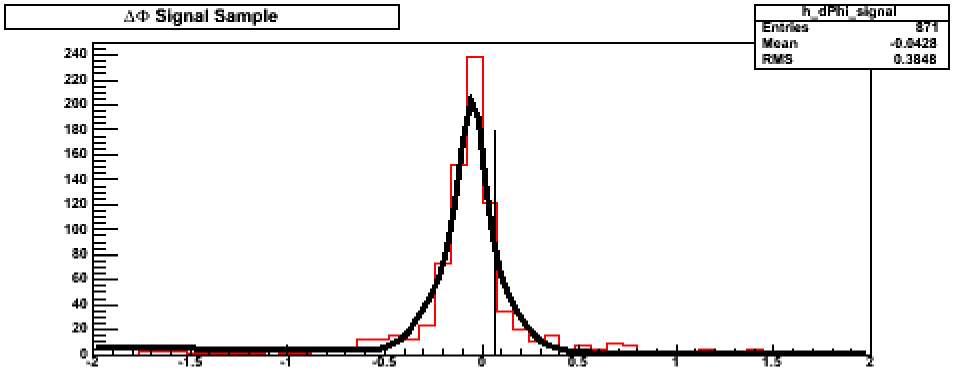
The conversion background was maximum likelihood fit to 2 Gaussians within |ΔΦ| < 2.



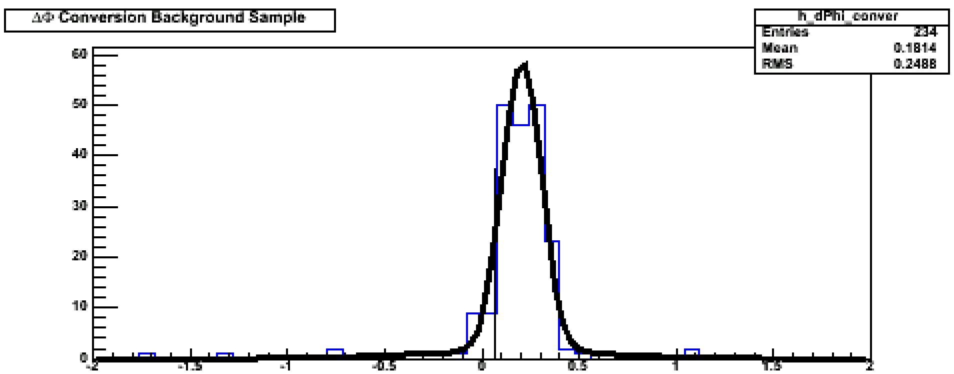
10 ± 5 signal events were fit under the peak. Zero are expected (not estimating pi0 Dalitz decays)

37 ± 7 conversion events were fit and 39 ± 3 were expected.

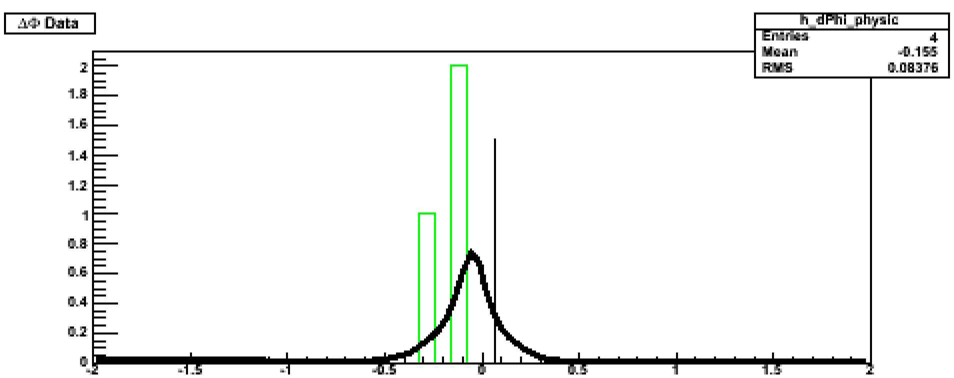
Fitting Data ΔΦ



The signal was maximum likelihood fit to 3 Gaussians within |ΔΦ| < 2.



The conversion background was maximum likelihood fit to 2 Gaussians within |ΔΦ| < 2.



3 signal events were fit under the peak.

2e-6 conversion events were fit.

Low Energy Electron Reconstruction Efficiency

•We are using the Dalitz decay of the π^0 in:

$$\Psi(2S) \rightarrow J/\psi\ \pi^0\ \pi^0$$
$$J/\psi \rightarrow e^+ e^-;\ \mu^+ \mu^-$$
$$\pi^0 \rightarrow \gamma\ \gamma$$
$$\pi^0 \rightarrow \gamma\ e^+\ e^-$$

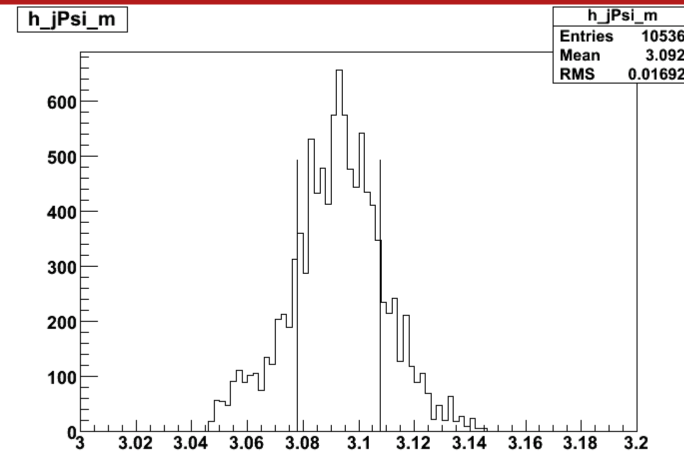
to estimate the efficiency for reconstructing electrons at energies between 40 and 140 MeV.

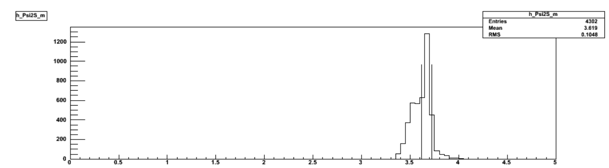
We cut on the J/Psi mass reconstructed from e+e- or mu+mu- (describe track criteria).

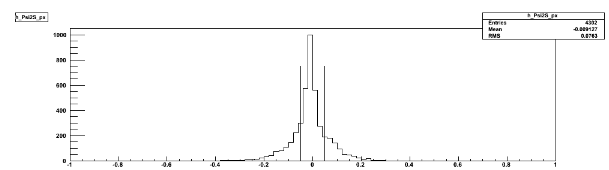
We cut on the pi0 pull mass at 1 sigma. (Describe shower criteria.)

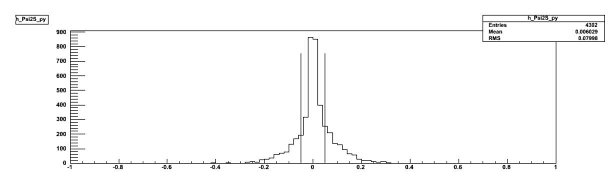
Using the J/Psi, a photon and an electron, and assuming the Psi(2S) was created at rest, we construct an expected 4-vector for the last electron.

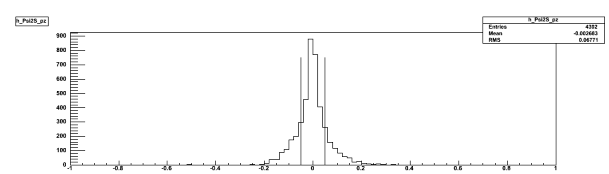
Looping over all last electrons in the event, we reconstruct a Psi(2S) 4-vector. This is required to be at rest and have the right mass.











Low Energy Electron Reconstruction Efficiency

•If the Psi(2S) satisfies the previous conditions, we plot the invariant mass squared of the expected electron (missing mass squared) in the "efficient reconstruction plot". (Top plot.)

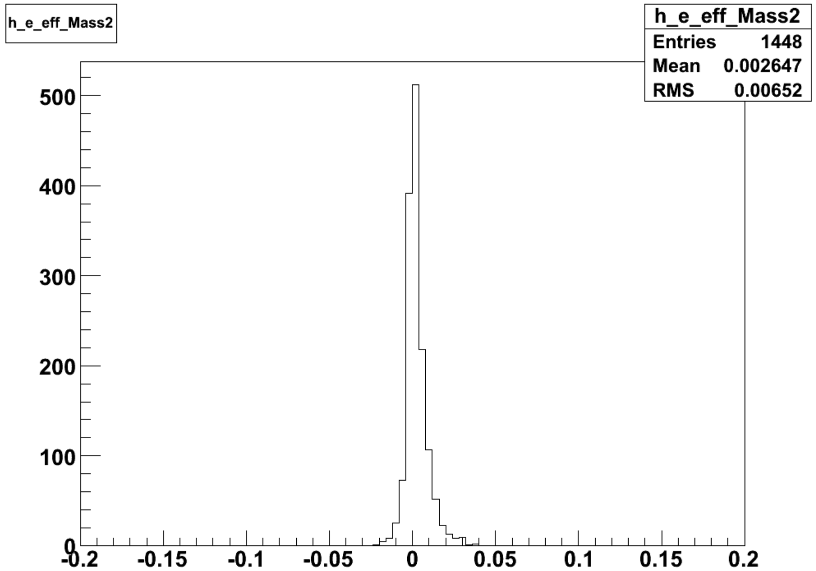
•If the Psi(2S) does not satisfy its conditions, this means no corresponding electron was found. (Bottom plot.)

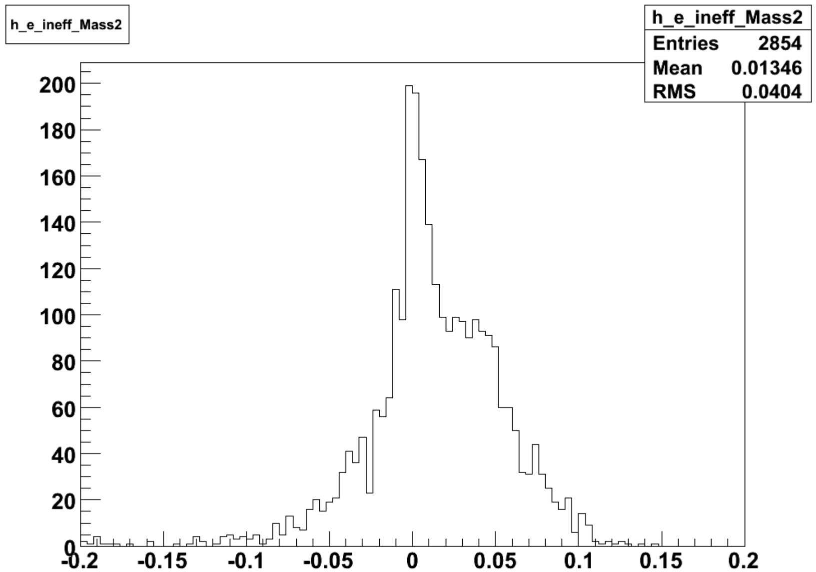
•Events under the peak in the top plot are those where an electron was expected and reconstructed.

•Events outside the peak in the top plot are interpreted as those we did not expect but find.

•Events under the peak in the bottom plot are those where we expected an electron and didn't find any.

•Events outside the peak in the bottom plot are those where we didn't expect an electron and didn't find any.





Low Energy Electron Reconstruction Efficiency

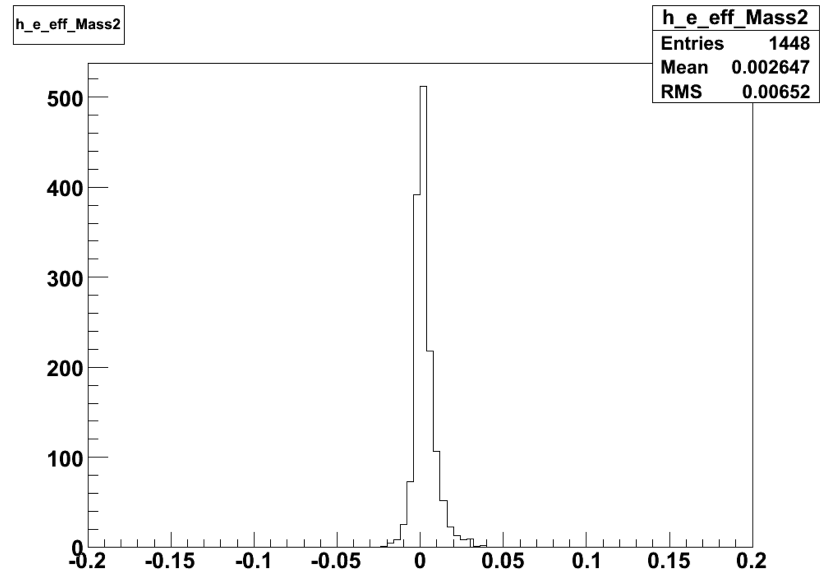
- By just cutting and counting, we estimate the efficiency of electron reconstruction by the ratio of events under the two peaks while keeping the background in mind.

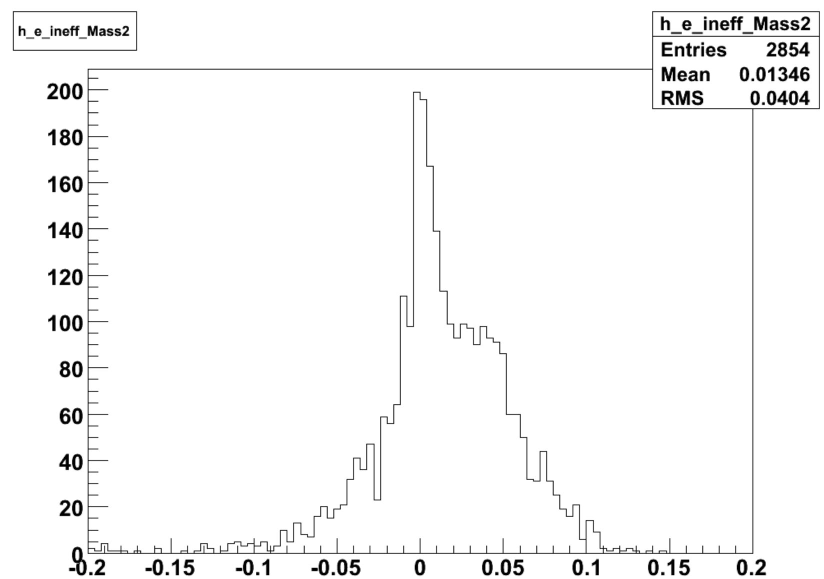
- 80%

- We should fit the plots for a better measurement.

- We should limit the expected 4-vector within the theta range of the CLEO detector.

- We should break this down into a few bins of energy to get numbers for various ranges of energies.





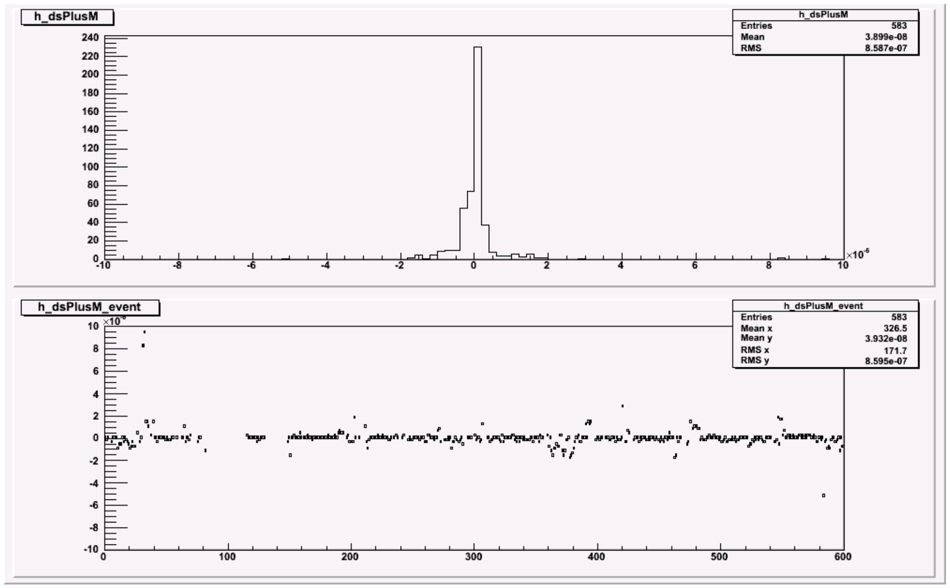
Electron Fitting of Data

•Dan Riley staged out runs 230474 to 230617 of dataset 47.

•We generated an IDXA file containing the run and event numbers we are interested in, i.e. events with any Ds tag in them.

•Using this IDXA file we skimmed those events into a local PDS file in raw format.

•Pass2 has been run on this with electron fitting included. The electron tracks are seen to have slightly different track parameters from their corresponding pion tracks. We are now checking to make sure that the DTag information, like the Ds mass, is exactly reproduced. This is not the case, however!



Summary and Plans

- This analysis is feasible with the data available at CLEO.

- The theoretically predicted ratio of the rate of $D_S^{*+} \rightarrow D_S^+ e^+ e^-$ to the rate of $D_S^{*+} \rightarrow D_S^+ \gamma$ can be refined.

- Selection criteria for all the decay modes need to be optimized systematically.

- Still studying how best to separate signal from conversion background.

- We can reconstruct the other D_S^- in the event and increase statistics.

- We need to measure the tracking efficiency for low momentum electrons.

- Events in data that pass some loose selection criteria will need to have tracks fitted to the electron hypothesis.

Backup Slides