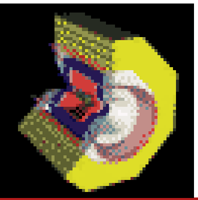

Cornell University
Laboratory for
Elementary-Particle Physics

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

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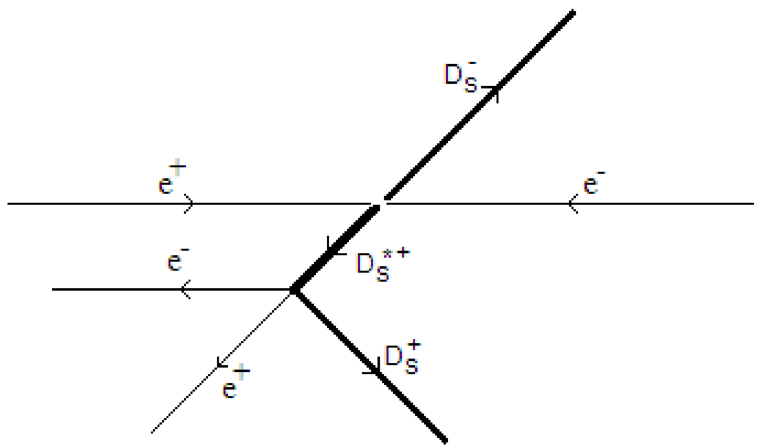
Contents

2 October 2009

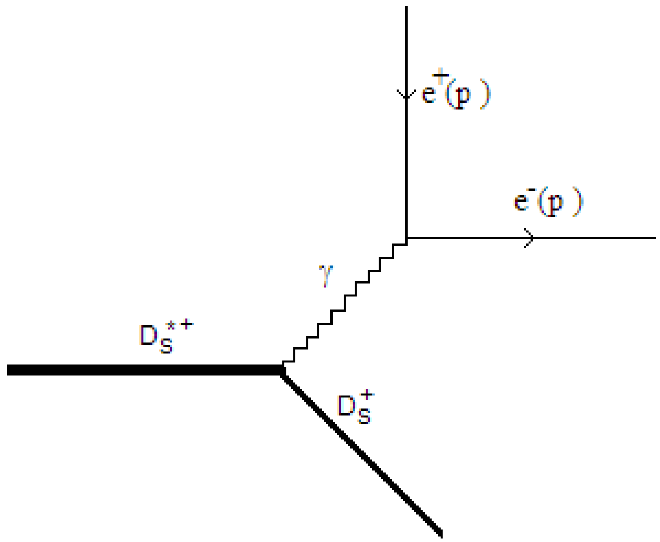
What Are We Looking For?



- 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.
  - The e^+e^- share ~ 144 MeV.
  - Events are selected using m_{DS+} , m_{BC}, δm, and…
  - Criteria on the e^+e^- tracks to reject conversion background $D_S^{*+} \rightarrow D_S^+\ \gamma$

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:

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

Tag Modes of D_s^+ Used

We reconstruct the D_s^+ through the following decay modes:

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

$$D_S^+ \to K_S K^+$$

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

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

$$D_S^+ \to K^+ K^- \pi^+ \pi^0$$

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

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

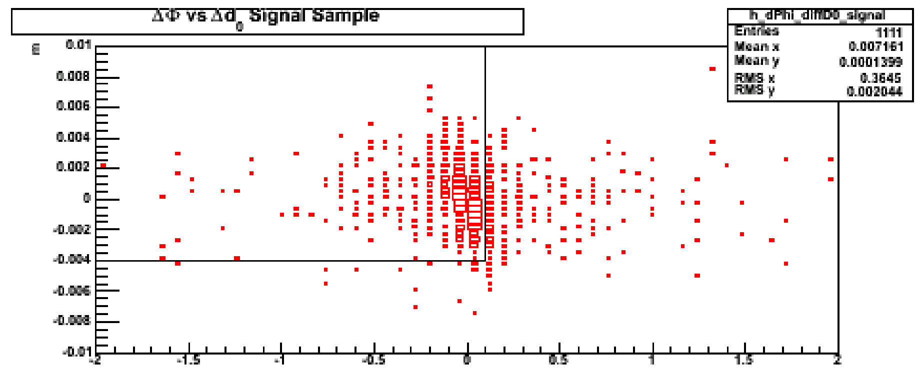
$$D_S^+ \to \eta \rho^+; \eta \to \gamma\gamma; \rho^+ \to \pi^+ \pi^0$$

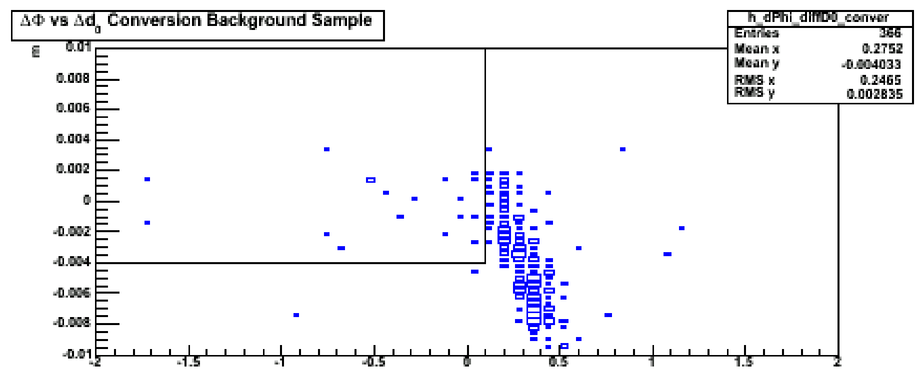
$$D_S^+ \to \eta' \pi^+; \eta' \to \rho^0 \gamma$$

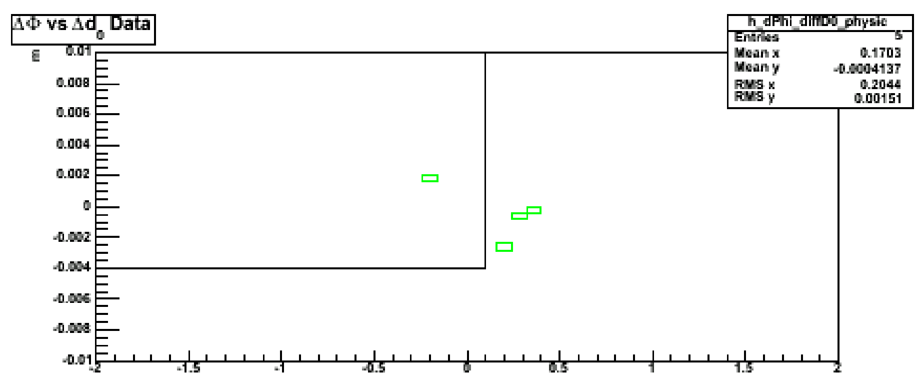
Backgrounds

Photon Conversion Background

- A background that resembles the signal is expected from D_s^{*+} decaying to $D_s^+\ \gamma$ 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 rate as the signal.
- Weapons of choice:
  - $\Delta d_0 = d_1 - d_2$, and
  - $\Delta \Phi = \Phi_1 - \Phi_2$



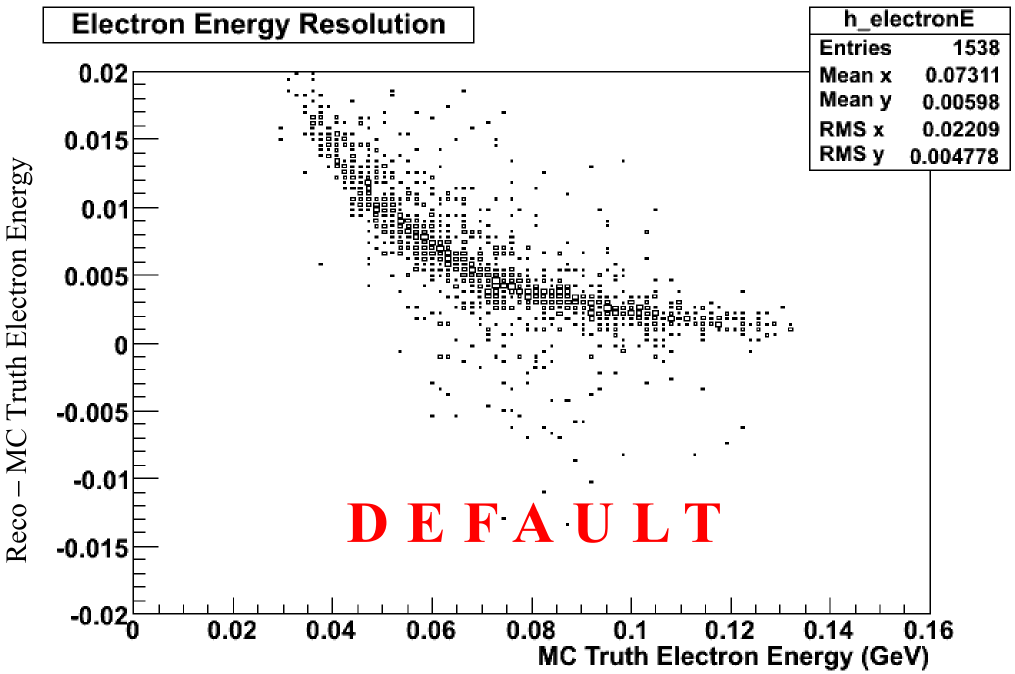




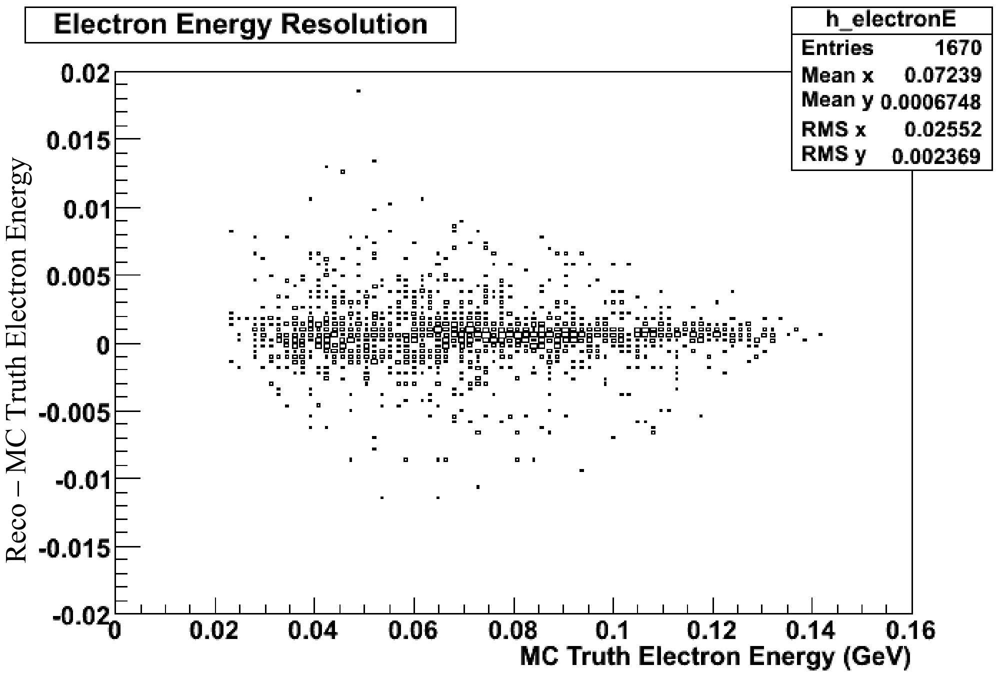
Other Backgrounds

- Dalitz decay of $\pi^0 \to \gamma\ e^+\ e^-$ also give equally soft electrons that appear to come from interaction point.
- Combinatorial backgrounds.

Tracking Soft Electrons



Pion fit



Electron fit

- With electron tracks of $p_T < 70$ MeV, fitting to the pion mass hypothesis no longer reliable.
- We tried parameterizing deviations. Selection criteria shown to work much better with electron-fitted tracks.
- Motivates us to re-pass2 datasets collected at 4170 MeV for events with a D_S-Tag

Reprocessing Data

- Raw dataset 48 (200 pb^{-1}) and parts of dataset 47 **staged in** by Dan Riley

- **Pass2'ed on solaris** batch machines with Suez and constants versions used historically. (20071023_P2 and PASS2-C_6)

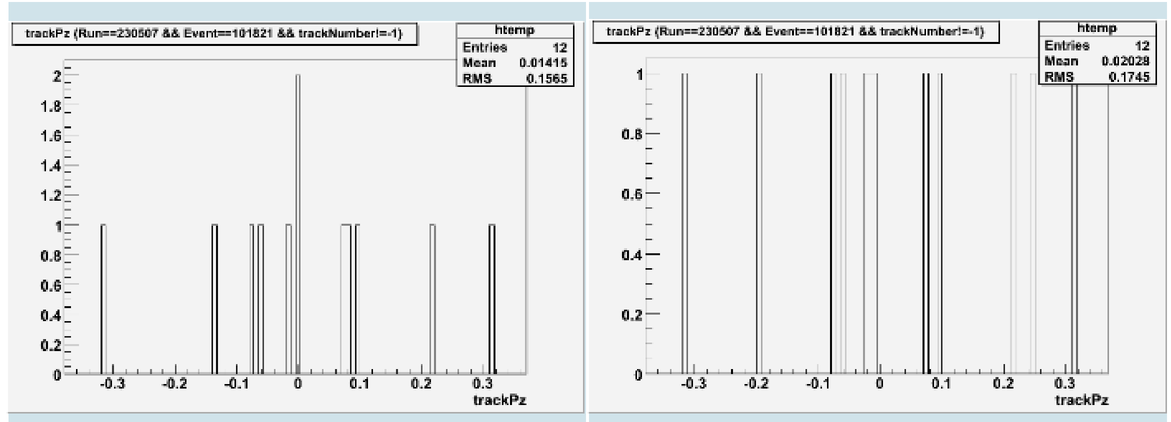
- **D-Tagged** on linux batch machines with Suez and constants versions used historically. (20060224_FULL and Analysis-C_6)

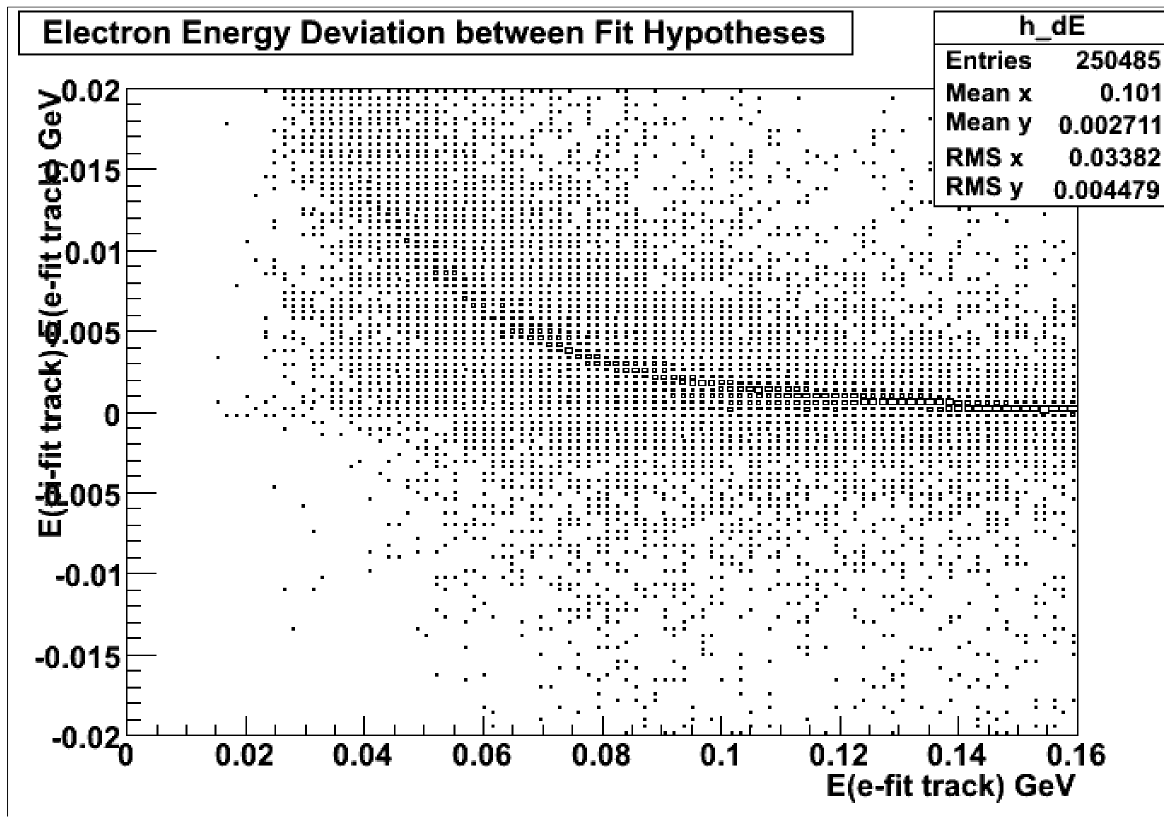
- Dan Riley will stage in datasets:
  - data39, 40, 41, 47 and 48 (done) all taken at 4170 MeV for total of ~ 600 pb^{-1}
  - data42 at $\psi(2S)$ resonance for **low energy electron tracking efficiency** study. ~ 50 pb^{-1}

Validating Reprocessed Data

- D_S-Tags missed is ~ 0.3% (due to events dropped by unknown filter)
- D_S-Tags new is ~ 0.1% (due to occasional corrections to single tracks in events)
- We will live with this per-mill deviation as this is not a precision measurement but a search.
- E(pion-fitted tracks) – E(e-fitted tracks) have functional form expected from MC study

Mysterious re-fitting of tracks

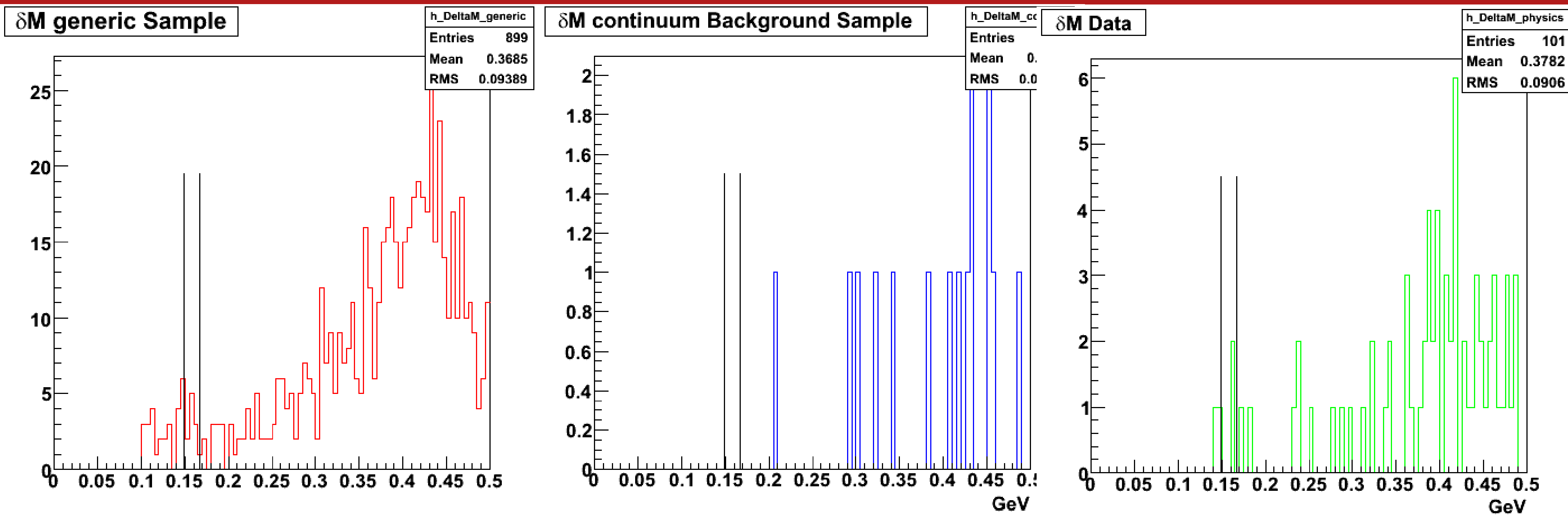




How far do we trust our generic and continuum Monte Carlo for estimating backgrounds in our signal region?

What other backgrounds could we be missing?

δm Sidebands

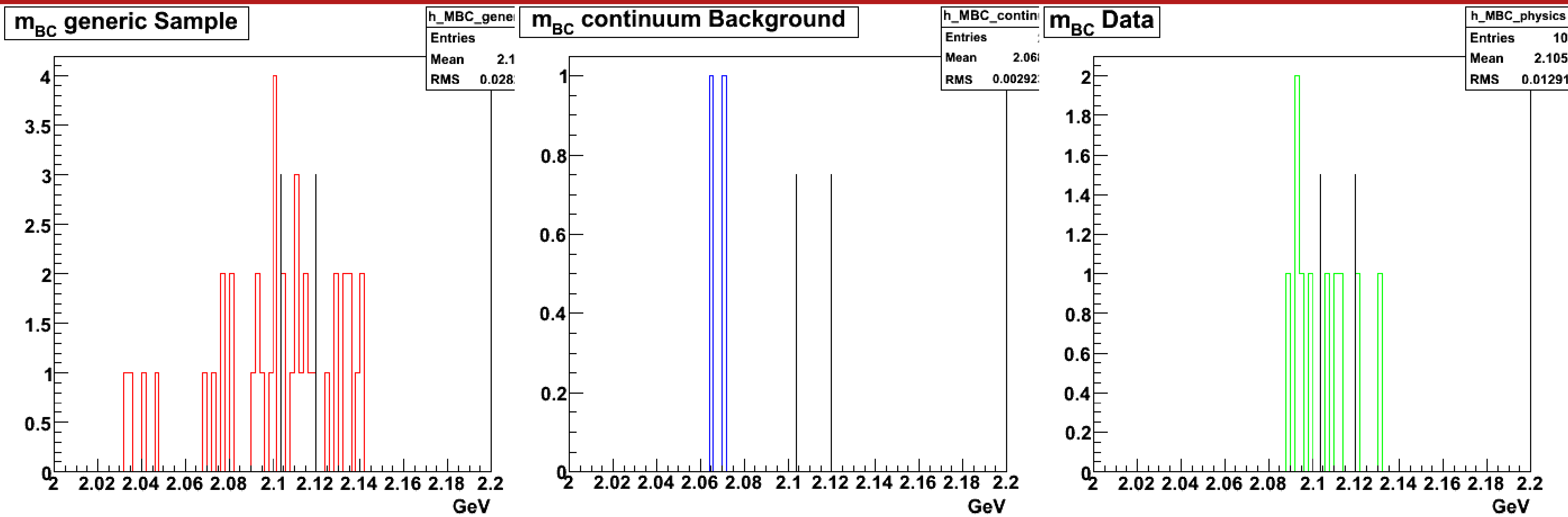


δm for the Generic MC, Continuum MC and Physics Data for $D_S \to KK\pi$ after all other cuts for the pion-fit on 110 pb^{-1} of data47

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

Mode	$\Delta M < 0.5$ GeV					$\Delta M < 0.3$ GeV				
	ddmix MC	cont MC	tot MC	data	$\frac{\text{data}}{\text{MC}}$	ddmix MC	cont MC	tot MC	data	$\frac{\text{data}}{\text{MC}}$
$K^+K^-\pi^+$	43 ± 1.5	6.2 ± 1.1	49 ± 1.8	97 ± 9.8	2 ± 0.21	4.3 ± 0.46	0.4 ± 0.28	4.7 ± 0.54	9 ± 3	1.9 ± 0.68
$K_S K^+$	13 ± 0.82	7.2 ± 1.2	21 ± 1.5	28 ± 5.3	1.4 ± 0.27	2.2 ± 0.33	0.8 ± 0.4	3 ± 0.52	4 ± 2	1.3 ± 0.71
$\eta\pi^+$	3.1 ± 0.4	13 ± 1.6	16 ± 1.6	26 ± 5.1	1.6 ± 0.36	0.35 ± 0.13	2.2 ± 0.66	2.6 ± 0.68	4 ± 2	1.6 ± 0.89
$\eta'\pi^+$	2.5 ± 0.35	0.2 ± 0.2	2.7 ± 0.4	3 ± 1.7	1.1 ± 0.68	0.2 ± 0.1	0 ± 0	0.2 ± 0.1	0 ± 0	0
$K^+K^-\pi^+\pi^0$	150 ± 2.73	23.8 ± 2.18	173 ± 3.5	400 ± 20	2.31 ± 0.12	17.1 ± 0.9	3 ± 0.8	20.1 ± 1.2	41 ± 6.4	2.03 ± 0.34

m_{BC} Sidebands



m_{BC} for the generic MC, continuum MC and physics data for $D_S \to KK\pi$ after all other cuts for the pion-fit on 110 pb^{-1} of data47

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

Mode	$m_{BC} < 2.102$ GeV					$m_{BC} > 2.122$ GeV				
	ddmix MC	cont MC	tot MC	data	$\frac{data}{MC}$	ddmix MC	cont MC	tot MC	data	$\frac{data}{MC}$
$K^+K^-\pi^+$	1.1 ± 0.23	0.4 ± 0.28	1.5 ± 0.36	5 ± 2.2	3.4 ± 1.8	0.5 ± 0.16	0 ± 0	0.5 ± 0.16	2 ± 1.4	4 ± 3.1
$K_S K^+$	0.8 ± 0.2	1 ± 0.45	1.8 ± 0.49	3 ± 1.7	1.7 ± 1.1	0.2 ± 0.1	0.2 ± 0.2	0.4 ± 0.22	2 ± 1.4	5 ± 4.5
$\eta\pi^+$	0.05 ± 0.05	0.6 ± 0.35	0.65 ± 0.35	2 ± 1.4	3.1 ± 2.7	0.05 ± 0.05	0 ± 0	0.05 ± 0.05	0 ± 0	0
$\eta'\pi^+$	0.2 ± 0.1	0 ± 0	0.2 ± 0.1	0 ± 0	$0 \pm$ nan	0.1 ± 0.071	0 ± 0	0.1 ± 0.07	0 ± 0	0
$K^+K^-\pi^+\pi^0$	8.5 ± 0.7	1.8 ± 0.6	10 ± 0.9	8 ± 3	0.78 ± 0.28	3.1 ± 0.4	0.8 ± 0.4	3.9 ± 0.6	7 ± 2.6	1.8 ± 0.7

Monte Carlo is off by a factor of ~ 2

In the Signal Region

Mode	Generic MC Signal Region	Continuum MC Signal Region	Total MC Signal Region	Data	Signal Expected	Conversions Expected
$K^+K^-\pi^+$	0.55 ± 0.17	0 ± 0	0.55 ± 0.17	3 ± 1.7	4.0	0.23
K_SK^+	0.15 ± 0.09	0.4 ± 0.28	0.55 ± 0.30	0 ± 0	1.1	0.04
$\eta\pi^+$	0.05 ± 0.05	0 ± 0	0.05 ± 0.05	2 ± 1.4	0.5	0.02
$\eta'\pi^+$	0.1 ± 0.07	0 ± 0	0.1 ± 0.07	1 ± 1	0.3	0.008
$K^+K^-\pi^+\pi^0$	1.65 ± 0.29	0.2 ± 0.2	1.85 ± 0.35	4 ± 2	1.7	0.18
		Total:	**3.1**	**10**	**7.6**	**0.478**

Factor of 2?

Plans

- Need to understand generic and continuum MC closely.
- Rely on data to estimate background in the analysis.
- Look into sidebands and signal region for a few more modes.

- Continue with data reprocessing and validation with help from Dan.

- Optimization of selection criteria by plotting significance and precision of signal as cuts are varied.

- Continue low energy electron tracking efficiency study in parallel.

Backup Slides

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

To find backgrounds other than the conversion background, we studied 109 /pb of generic MC for 4170 MeV. The generic MC is **scaled by a factor of 20**, i.e. 20 events are generated for every 1 event in data.

We used pion-fitted signal and background samples and after applying our selection criteria, we expected ~ 5 conversion events (i.e. 5/20 events if it were data), but we see only 2 conversion events in the 10 events left over in the generic MC.

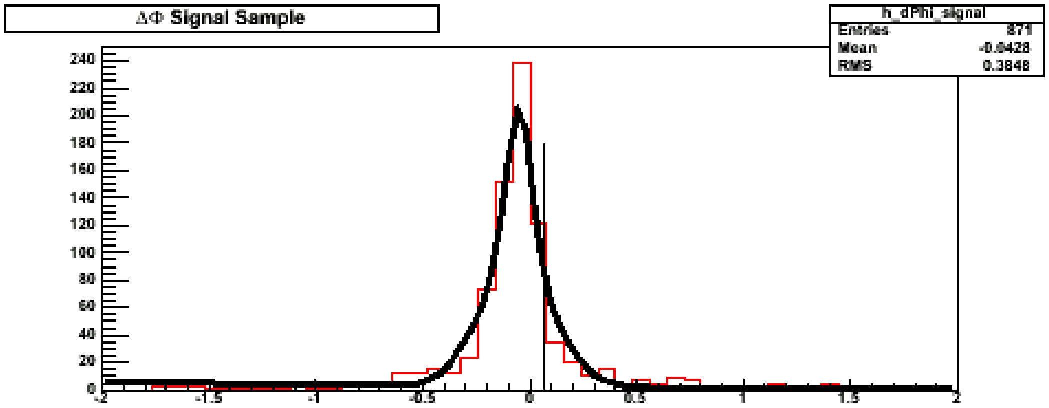
8 of them have pi0 -> e+ e- gamma events:

Run 23085, event 14904
psi(4160) --> D*- D+ pi0;
D*- --> D- pi0;
pi0 --> e+ e- gamma

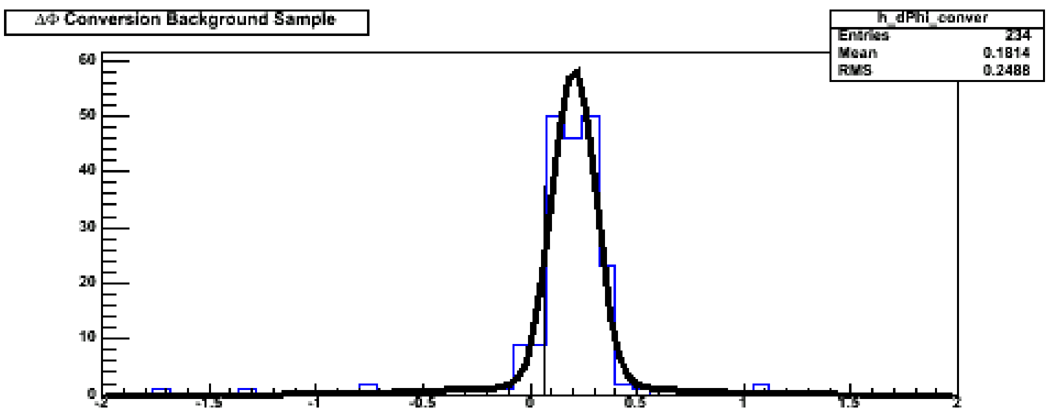
Run 230812, event 1070
psi(4160) --> D_s*+ D_s-;
D_s*+ --> D_s+ gamma;
D_s+ --> rho+ eta‘;
eta' --> pi0 pi0 eta;
pi0 --> e+ e- gamma

This background will peak in Δd0 and ΔΦ, and will have to estimated from sidebands in the kinematic variables in data where it should be a part of the combinatoric background.

Fitting Generic Monte Carlo ΔΦ with Cuts for Pion Fitted Electrons

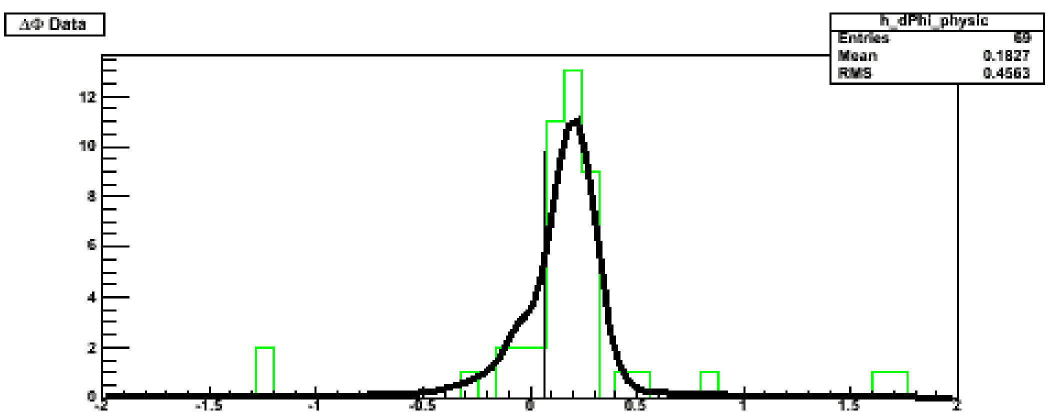


The signal was maximum likelihood fit to 3 Gaussians within |ΔΦ| < 2.



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

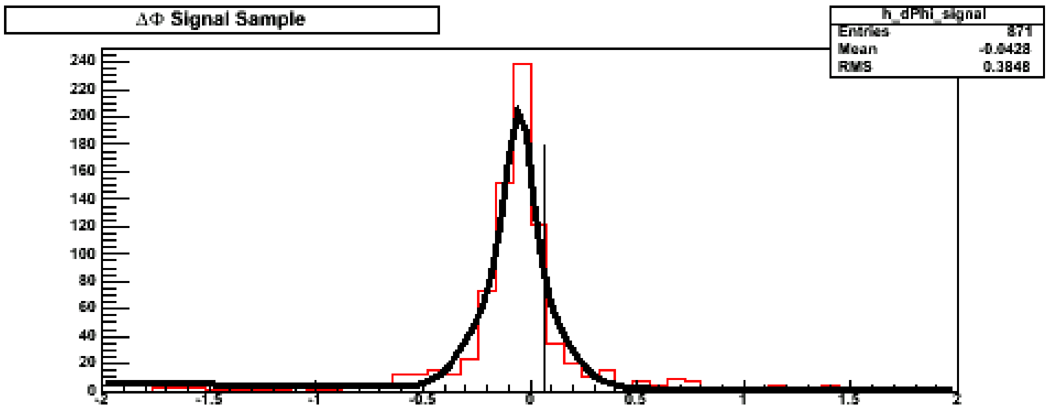
(10±5)/20 signal events were found. Consistent with the combinatorial background and zero signal for generic MC.



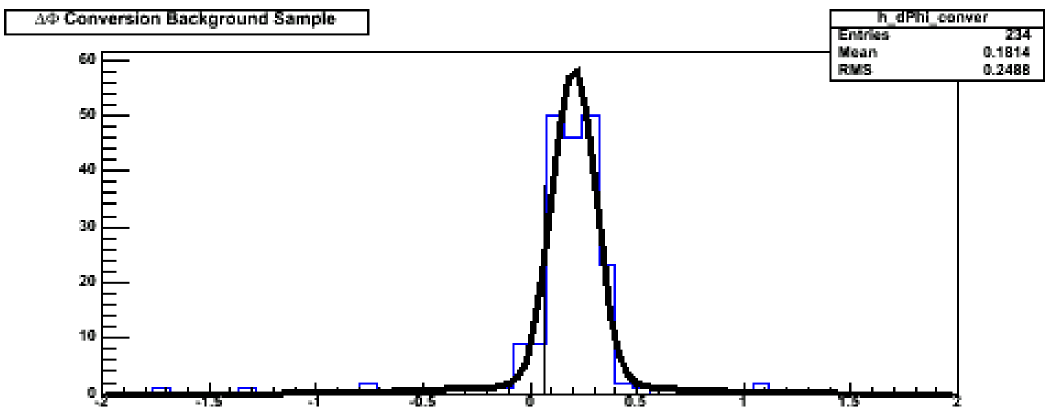
For the expected signal branching fraction, we would predict 80/20 signal events.

(37±7)/20 conversion events were fit and (39±3)/20 were expected.

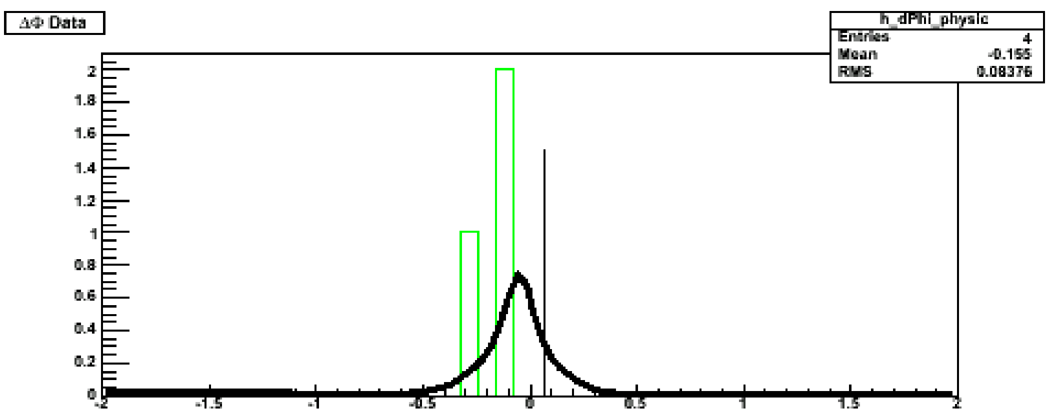
Fitting Data ΔΦ with Cuts for Pion Fitted Electrons



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



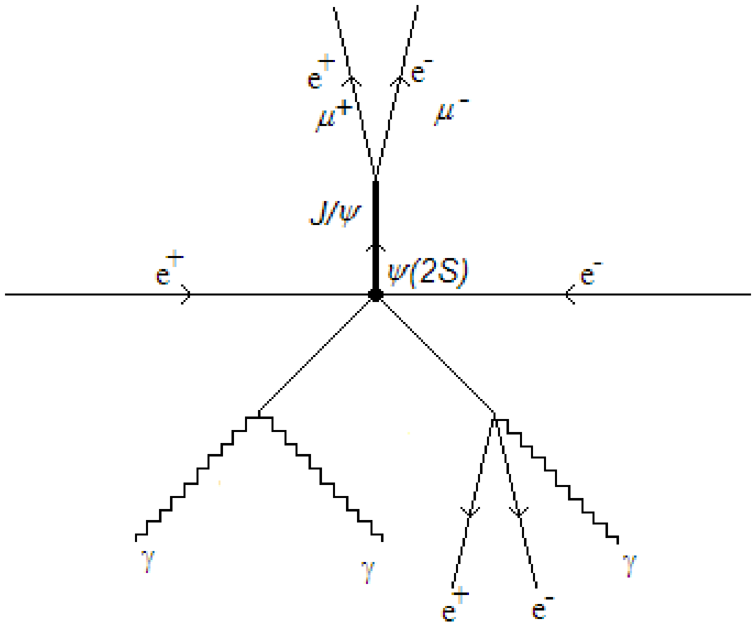
The conversion background was maximum likelihood fit to 2 Gaussians within |ΔΦ| < 2.



3 signal events were fit under the peak.

2×10^{-6} conversion events were found.

Low Energy Electron Reconstruction Efficiency



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

•We seek to exploit the electrons from Dalitz decay of the π^0 in this channel to measure the tracking efficiency for soft electrons at CLEO.

• Dataset 42 that has 53 /pb of data at psiprime resonance is used for this study.

•The J/ψ is reconstructed from e^+e^- or $\mu^+\mu^-$. One π^0 is reconstructed from two showers. The shower and an electron from the other π^0 are reconstructed and the expected 4-vector of the last electron is constructed from the above information.

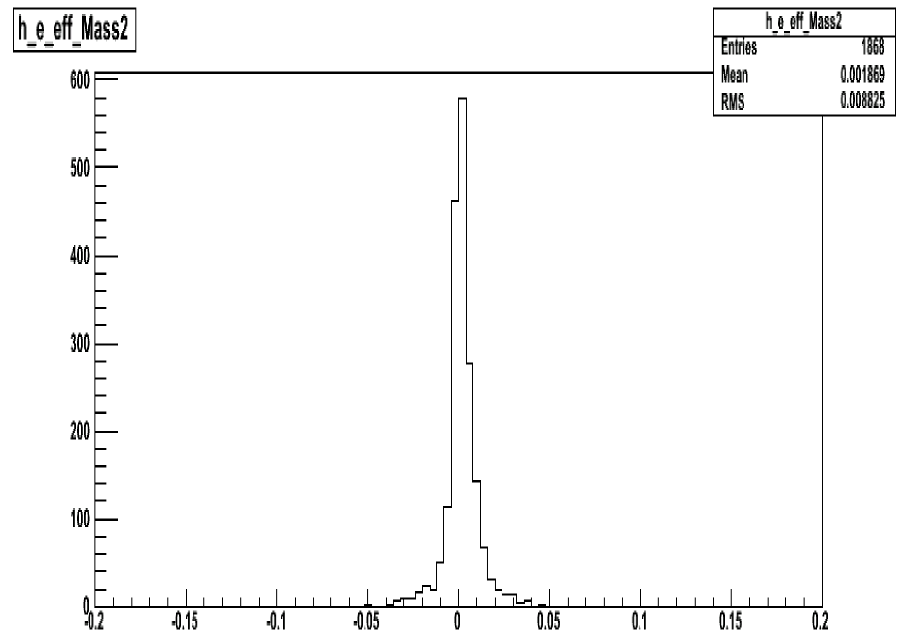
Low Energy Electron Reconstruction Efficiency

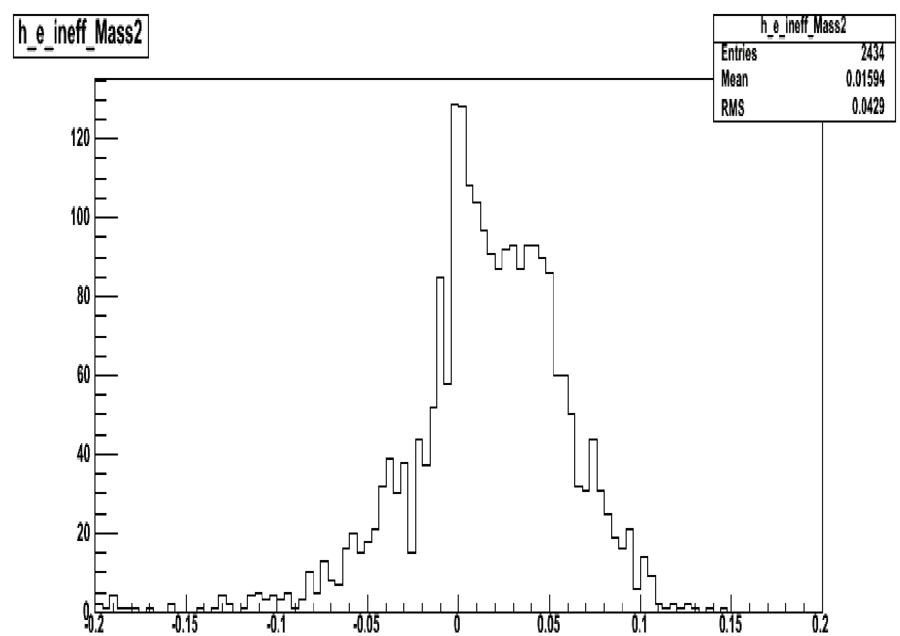
•The missing mass of this last electron is split into two plots:

- •the Efficient plot where the $\psi(2S)$ is correctly reconstructed (top plot)
- •the Inefficient plot where the $\psi(2S)$ is not correctly reconstructed (bottom plot)

•By cutting and counting, we can roughly estimate the efficiency of electron reconstruction to be ~ 90%

•We will generate Monte Carlo to fit these plots for a more precise measurement.



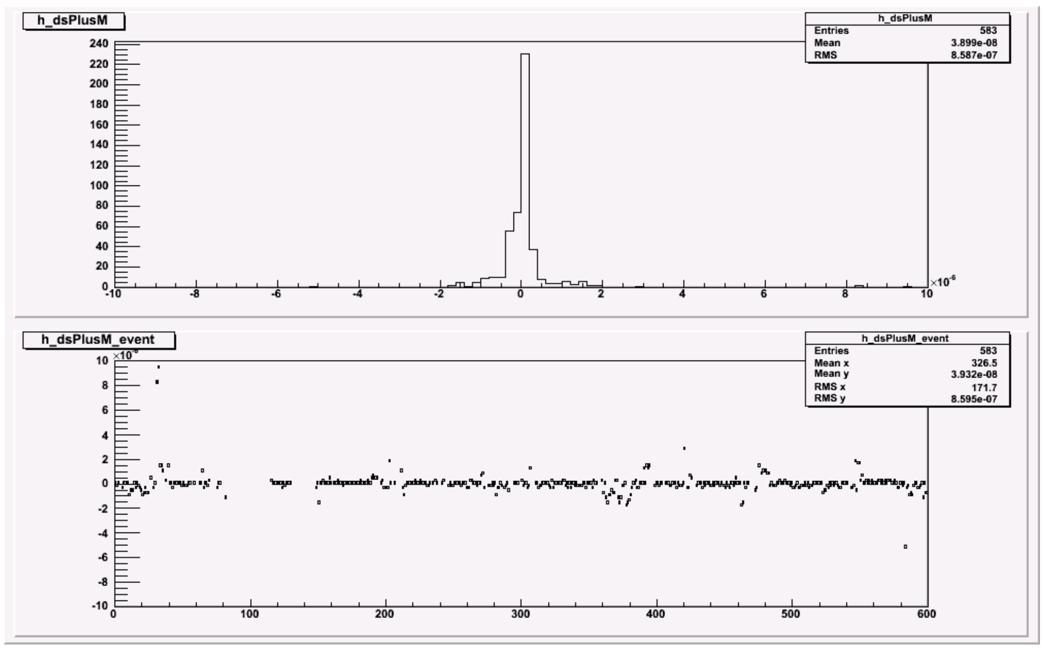


Electron Fitting Tracks in Data

•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! 1% of the time a DsTag in the original sample is missed and 2% of the time a new DsTag is created!



Summary and Plans

•Proceeding with fitting tracks to the electron hypothesis in data.

•Studying generic MC to find further backgrounds.

•Estimating the reconstruction efficiency for low energy electrons.

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

•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.

•We can reconstruct the other D_S^{-} in the event in an alternative analysis and increase statistics.

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 for a fixed signal/background ratio.

•MC matched electrons with $\Delta\theta$=0.05.

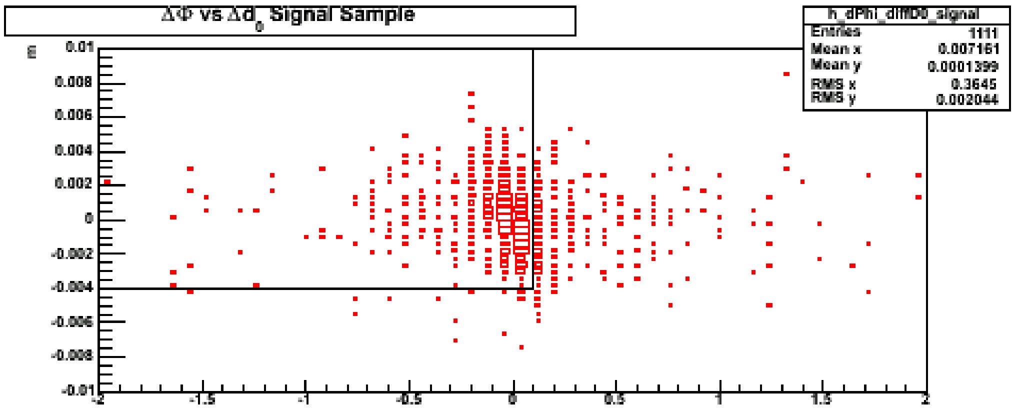
(# matched electrons in pi-fit) / (# matched e in e-fit) ~ 0.93

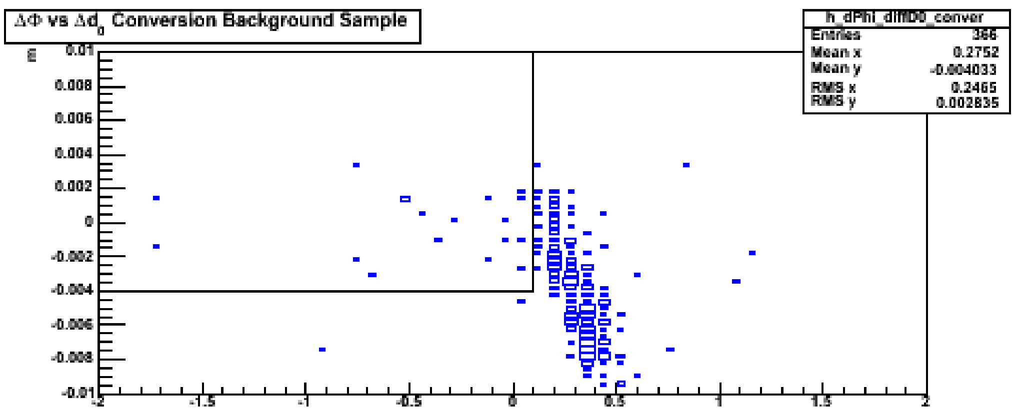
Close to ratio of events under electron-fit and parameterized pion-fit peaks in the kinematic variables.

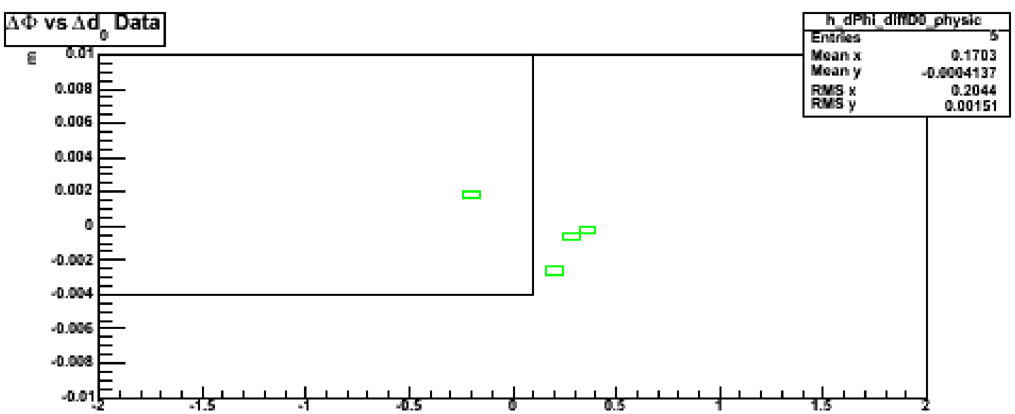
•Suggests a fundamental reconstruction/track-fitting inefficiency when using pion hypothesis for low energies.

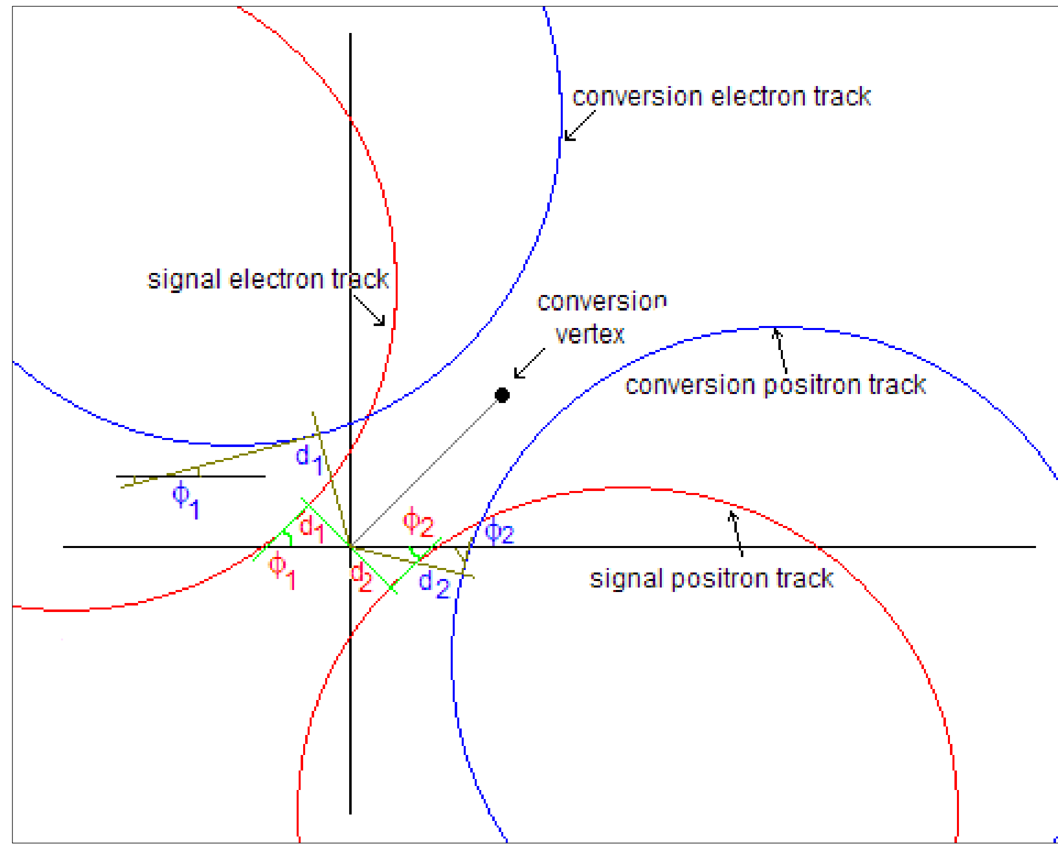
•We need electron fits.

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









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

Re-Pass2 and Re-DSkim 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 and D-Tag should be run as per the Original conditions.

- •Code release 20071023_P2 and constants PASS2-C_6 is used for pass2 processing.
- •Pass2 release was compiled under Solaris2.8.
- •D skim (version2 with 20060224_FULL_A_3) is available in EventStore dtag grade

•Pass2 has been run on this with electron fitting included.

•Known difference between Linux and Solaris pass2:
https://www.lepp.cornell.edu/~wsun/private/linux/index.html

•Following discussion only w.r.t run number = 230474. It has 612 Ds-tagged events in the eventstore data.

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

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

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**

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.

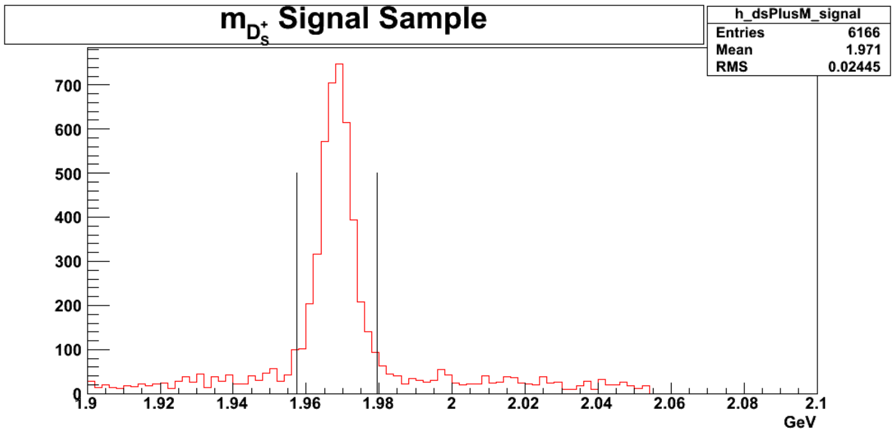
The top plot in red is the signal.

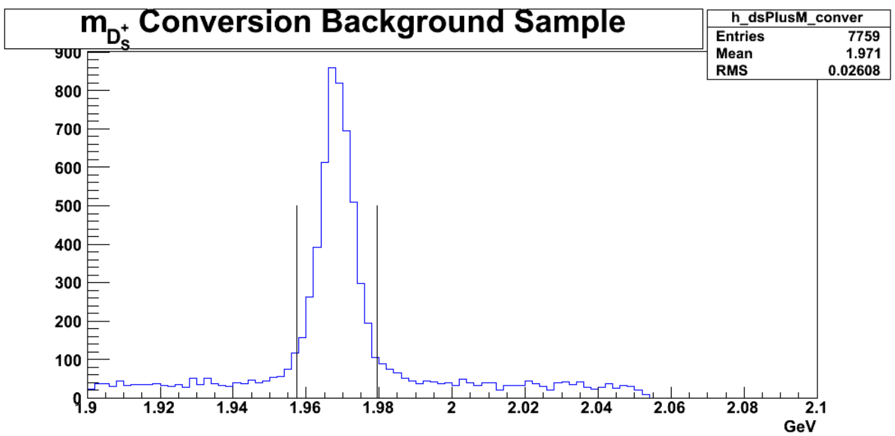
The middle plot in blue is the conversion background.

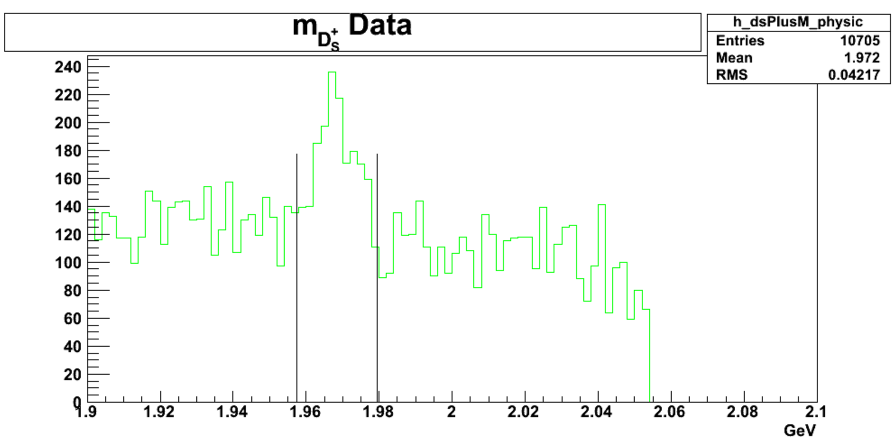
The bottom plot in green is the data.

The signal and background plots have electron-fitted electrons while the data has pion-fitted electrons. We repeated the study for pion-fitted signal and background samples as well.

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



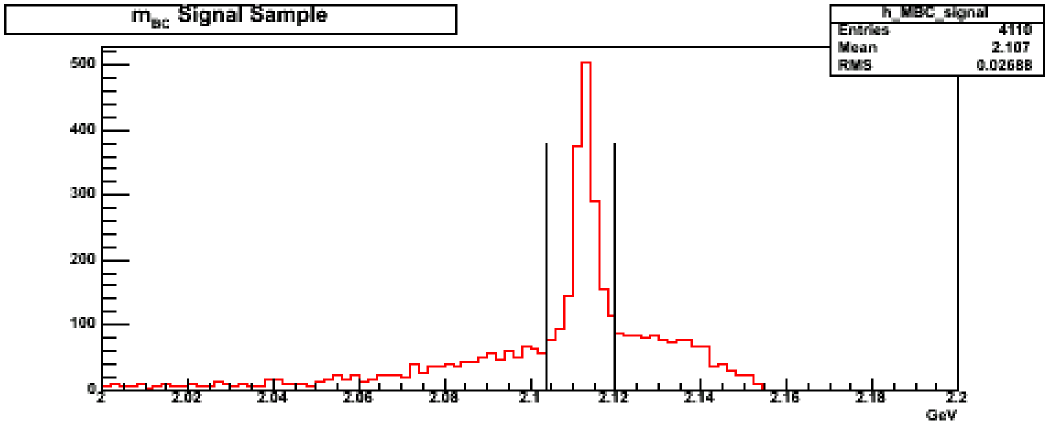


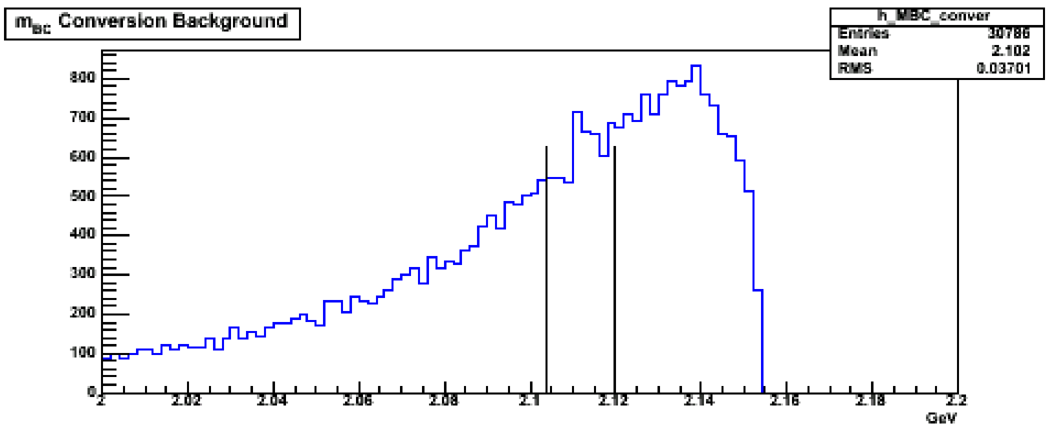


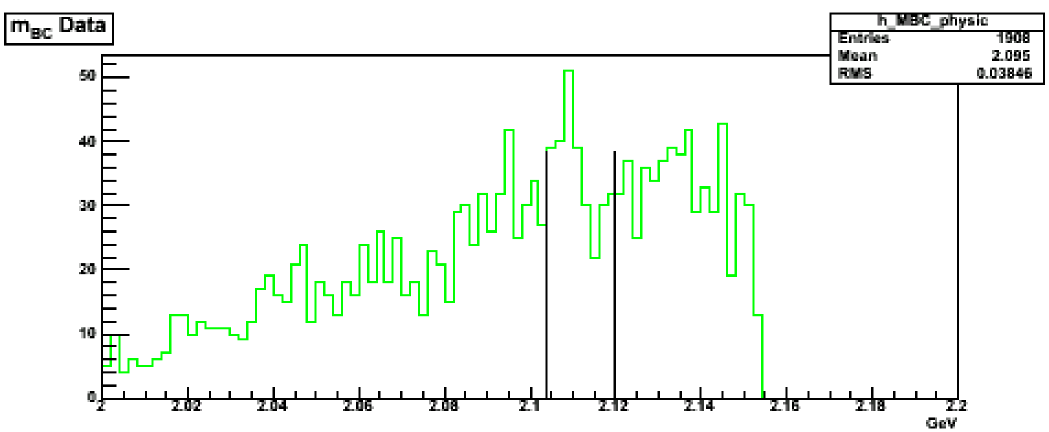
- Reconstructed $D_S^+{}_{Mass}$
- We cut on

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

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



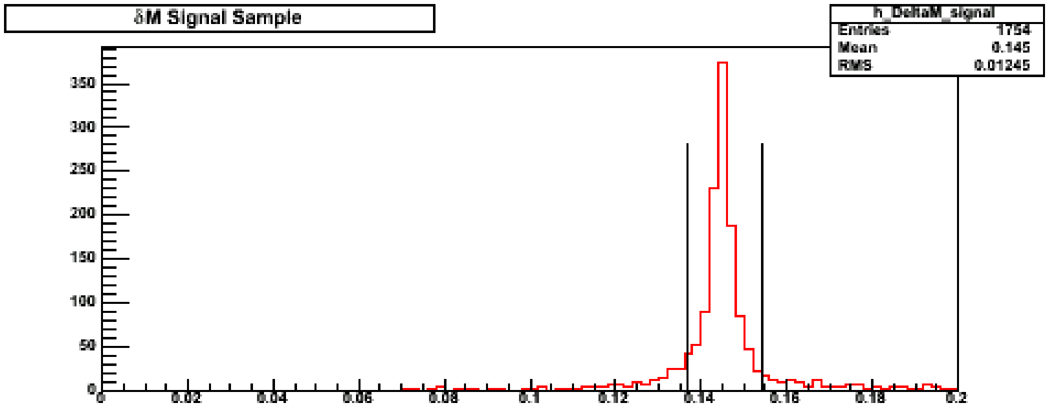


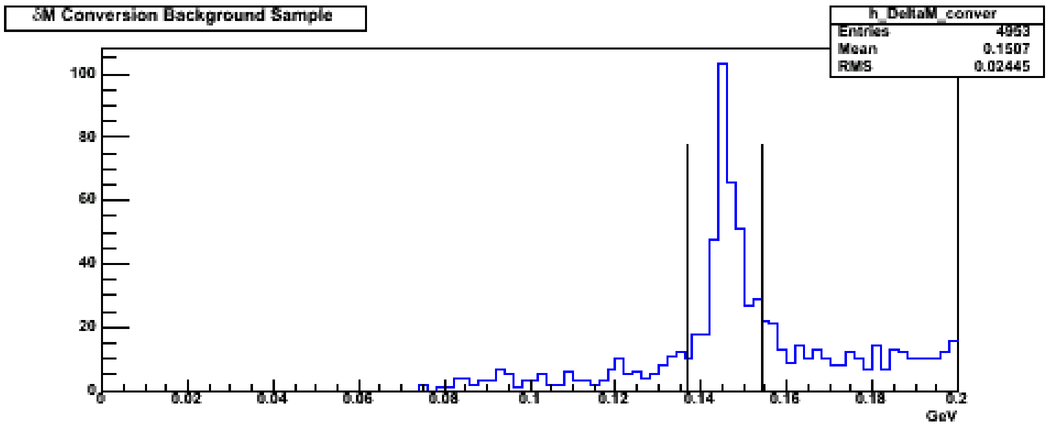


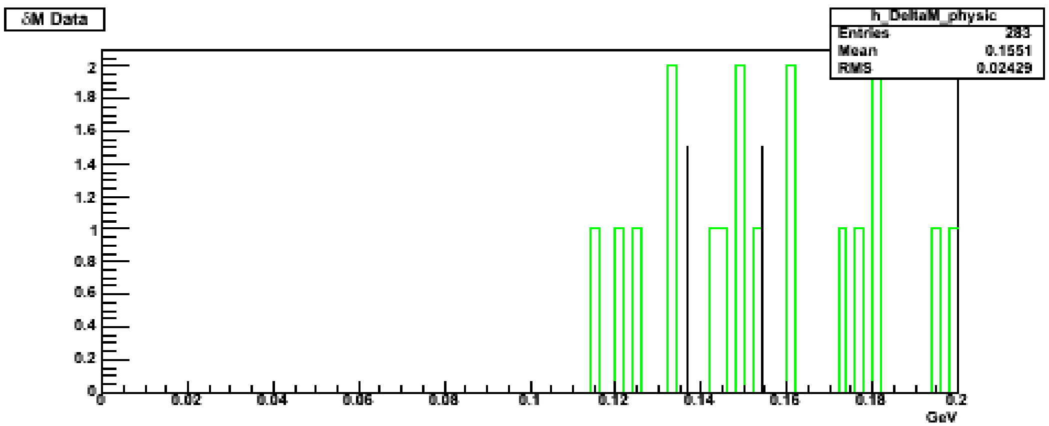
$$m_{BC} = \sqrt{E^2(D_S^{*+} beam) - P^2(K^+K^-\pi^+e^+e^-)}$$

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

$K^+K^-\pi^+$ Mode δm Cut



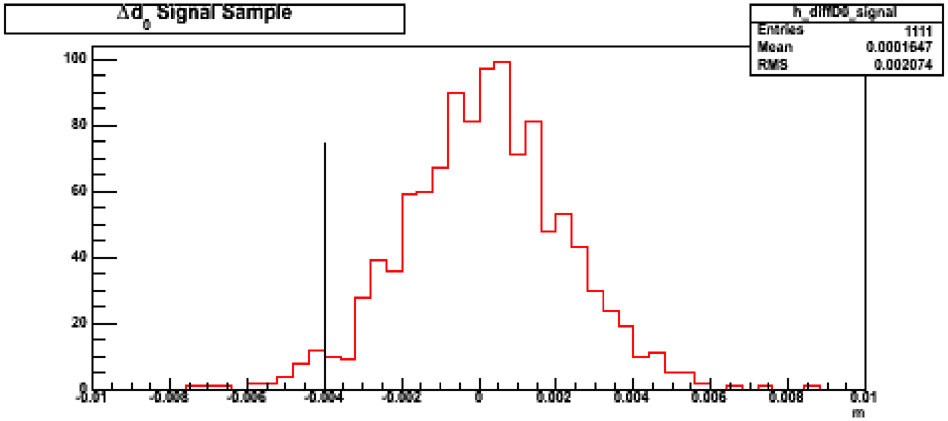


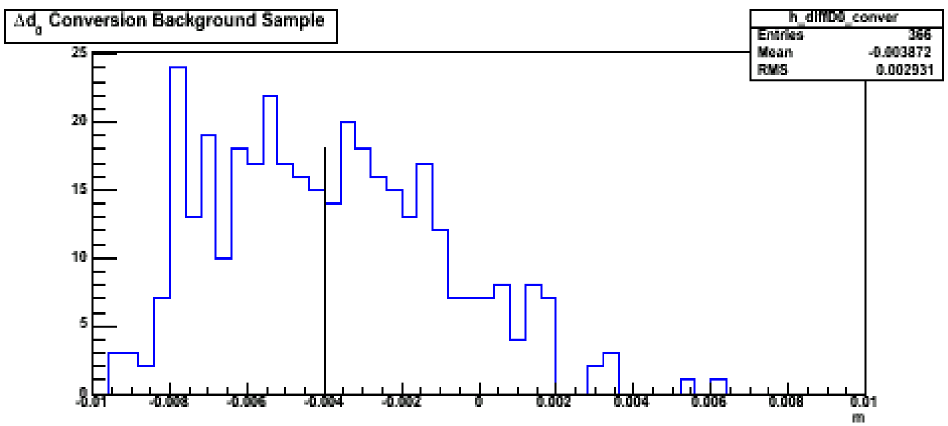


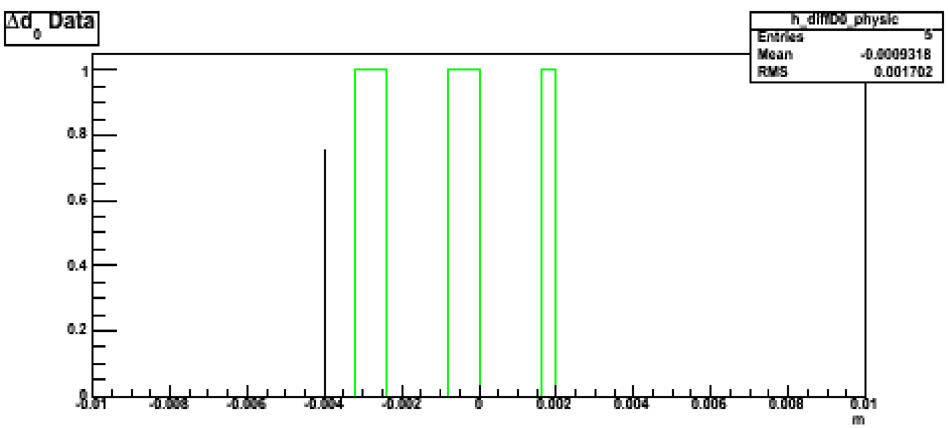
$$\delta m = M(K^+K^-\pi^+e^+e^-) - M(K^+K^-\pi^+)$$

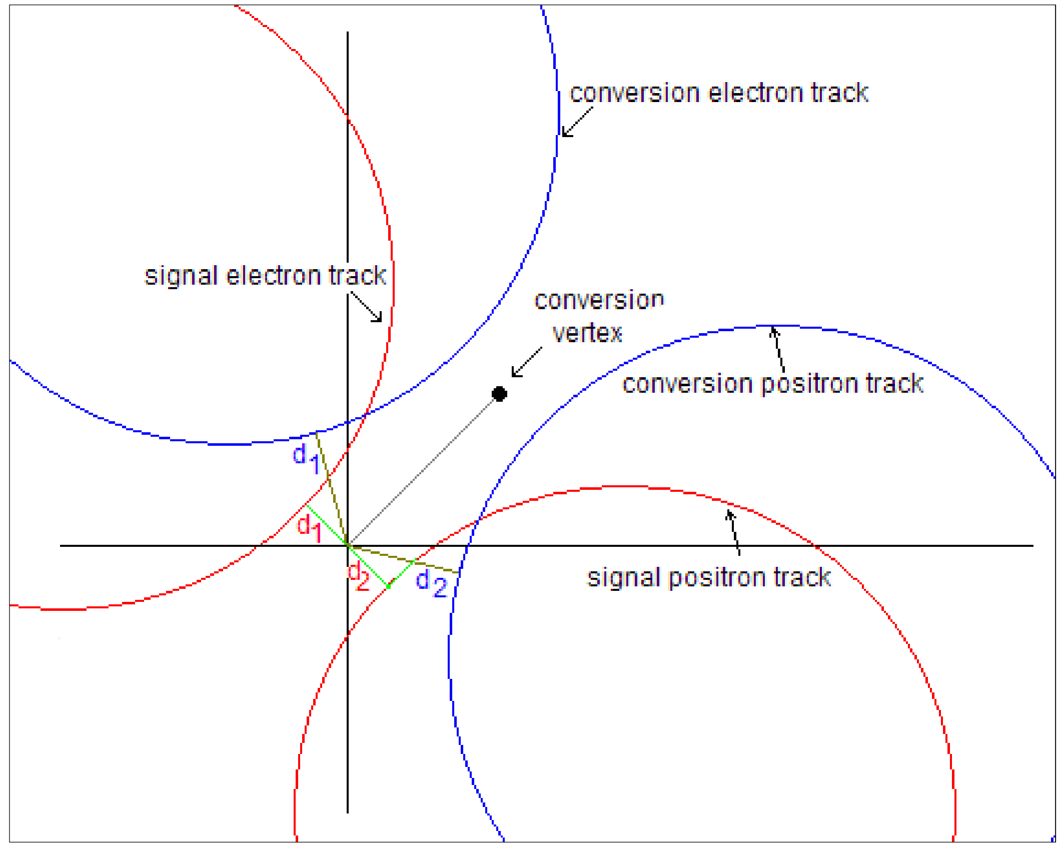
We cut on |δm – 0.1455 GeV | < 0.0085 GeV

$K^+K^-\pi^+$ Mode Δd_0 Cut







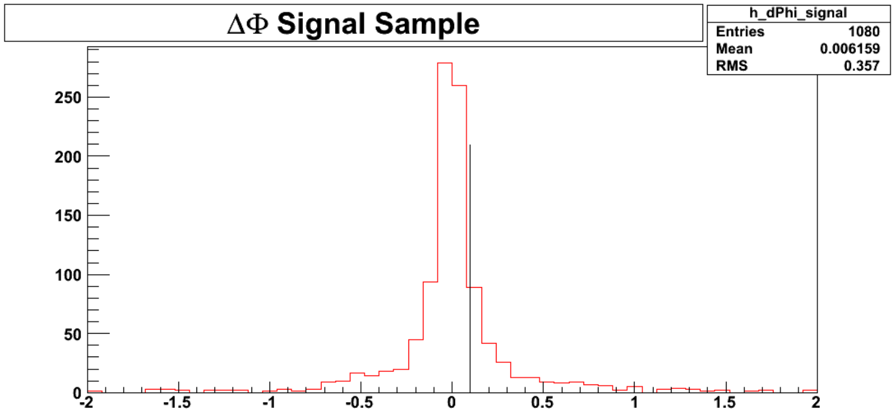


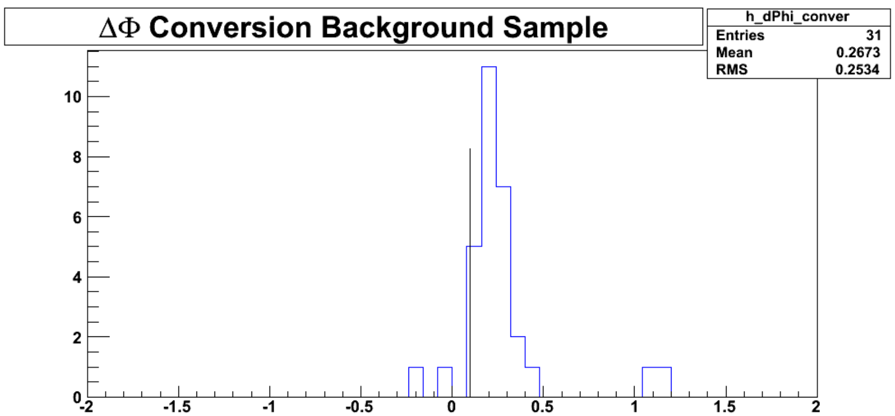
Δd_0 between the electron and positron in the signal (red) and conversion (blue)

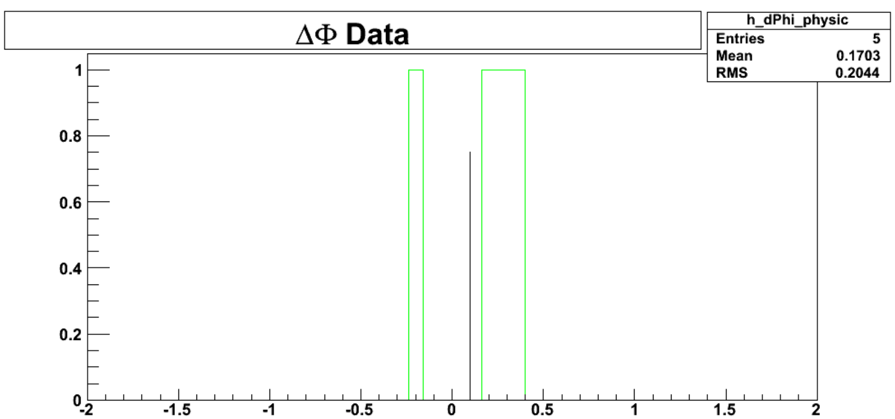
- The $\Delta d_0 = d_1 - d_2$ is centered around 0 for the signal and offset from 0 for conversion backgrounds

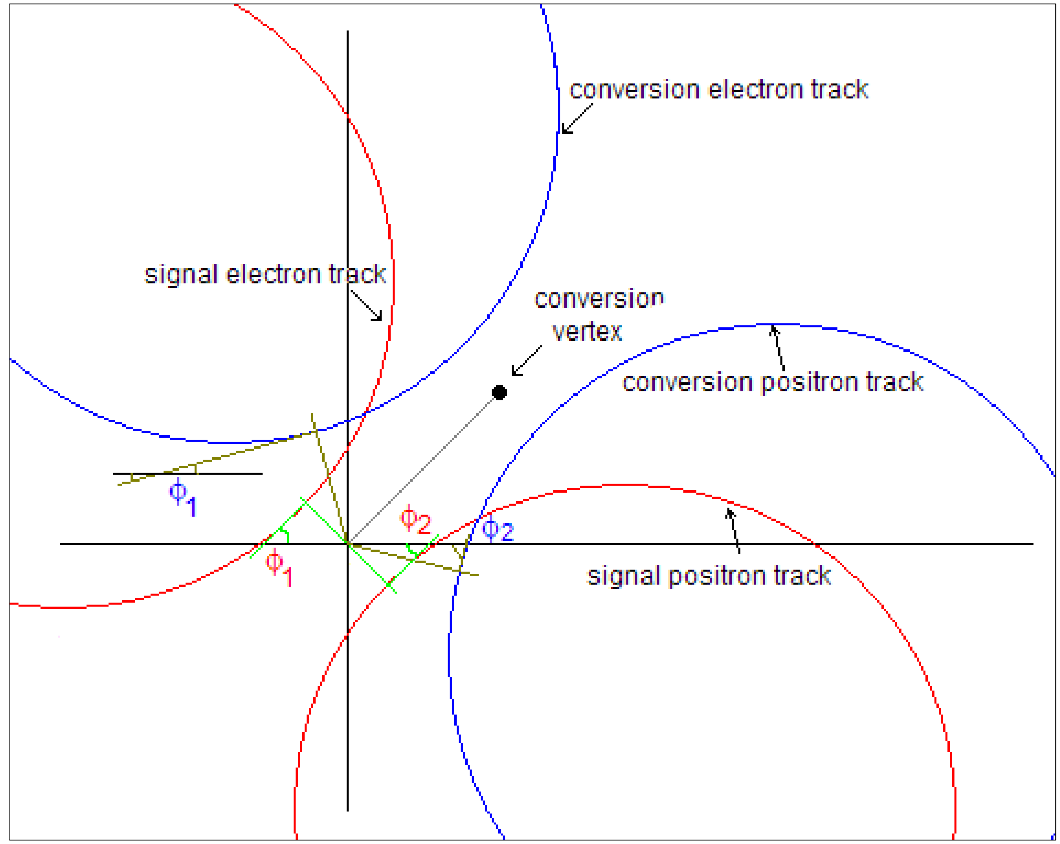
- We require $d_1 - d_2 > -0.004$ m

$K^+K^-\pi^+$ 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 $\Delta\Phi < 0.1$

Prediction for Data in $K^+K^-\pi^+$ +c.c. Mode

Signal and conversion background samples have electron fitted electrons.

Decay Mode of the D_S	Signal Efficiency	Background Efficiency	Signal Events Expected in 110 pb^{-1}	Background Events Expected in 110 pb^{-1}	Events Seen in 110 pb^{-1} (electrons still fitted to pion hypothesis)
$K^+K^-pi^+$	8.14×10^{-2}	3.25×10^{-5}	4.88	0.17	2
$K^-K^+pi^-$	8.65×10^{-2}	2.77×10^{-5}			

Signal and conversion background samples have pion fitted electrons.

Decay Mode of the D_S	Signal Efficiency	Background Efficiency	Signal Events Expected in 110 pb^{-1}	Background Events Expected in 110 pb^{-1}	Events Seen in 110 pb^{-1} (electrons still fitted to pion hypothesis)
$K^+K^-pi^+$	6.73×10^{-2}	4.49×10^{-5}	4.00	0.23	2
$K^-K^+pi^-$	7.04×10^{-2}	3.62×10^{-5}			