Cornell University
Laboratory for
Elementary-Particle Physics

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

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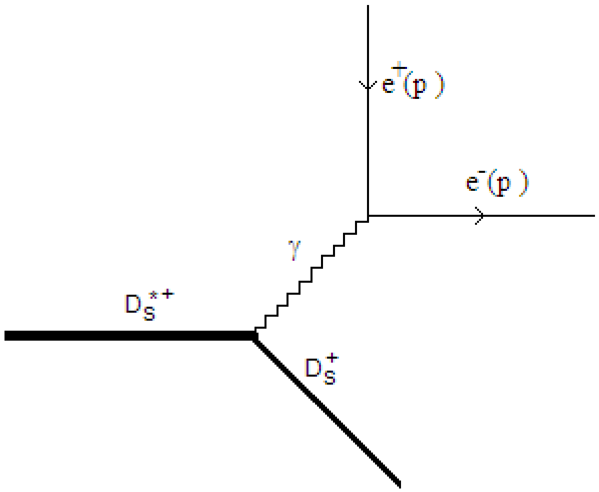
The $D_S^{*+} \to D_S^+ e^+ e^-$ Process



If we write the decay of the Ds*+ 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 predict the ratio of decay rates:

$$\frac{\Gamma\left(D_S^{*+} \to D_S^+ e^+ e^-\right)}{\Gamma\left(D_S^{*+} \to D_S^+ \gamma\right)} \approx 1.1\alpha$$

Dataset Used

- Use 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.

  Hence we expect ~ 602,000 $D_S^{*\pm}$ produced at this energy.
- So far, we have looked at 48.2 pb^{-1} of data.

Decay Channel of $D_S^{\pm}$ Used

Right now we are reconstructing the $D_S{}^{+}$ from the $D_S{}^{*+}$ and decaying via the channel:

$$D_S^{+} \rightarrow \phi\pi^{+}$$

$$\phi \rightarrow K^{+}K^{-}$$

This is known to have a branching fraction of $2.18 \pm 0.33\%$

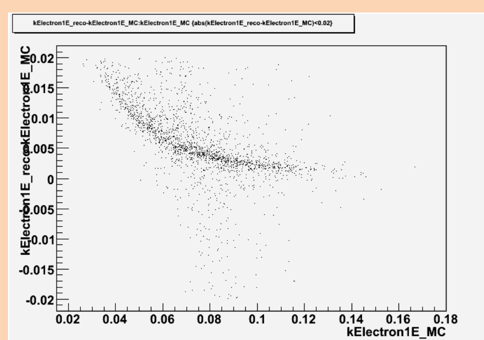
Signal

- Signal events with decay chain which we reconstruct:

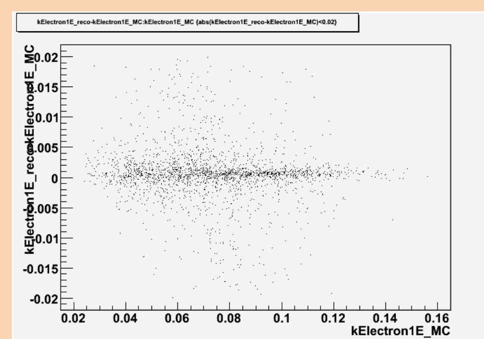
$$D_S^{*+} \to D_S^+ e^+ e^-$$
$$D_S^+ \to \phi \pi^+$$
$$\phi \to K^+ K^-$$

- predicted branching fraction = 94% * (1.1α) * 2.18% ~ 0.017%
- In 602 pb^{-1}, this would mean ~ 100 produced events.
- For signal Monte Carlo, we force e^+e^- collisions to decay into Ψ(4160), and then that to decay into the abovementioned channel.
- 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.
- We refitted electrons to the electron hypothesis instead of the pion hypothesis.

We expect soft electron tracks with pT < 70 MeV which the pion fit would not do justice to.



Pion fit



Electron fit

- We generated 9,988 signal MC events.

Signal

- Background events are expected, largely, to be:

$$D_S^{*+} \to D_S^+ \gamma$$

$$D_S^+ \to \phi \pi^+$$

$$\phi \to K^+ K^-$$

where the photon converts in the beampipe material: $\gamma \to e^+ e^-$

- Without the photon conversion, the branching fraction = 94.2% * 2.18% ~ 2.05%
- In 602 pb^{-1} , this would mean ~ 12,340 produced events which may yet undergo conversion.

- For background Monte Carlo, we force e^+e^- collisions to decay into Ψ(4160), and then that to decay into the abovementioned channel (without forcing the photon to convert in the beampipe).
- We refitted electrons to the electron hypothesis instead of the pion hypothesis.
- We generated 998,800 events.

Processor Level Cuts

- Kaon and pion tracks must pass track quality cuts:
  - 50 MeV < Track Momentum < 2.0 GeV
  - Number of hits / number expected > 0.5
  - chiSquared < 100,000
  - d0 < 5 mm, z0 < 5 cm
- Kaon and pion tracks' dE/dx are fitted to 3.0 σ

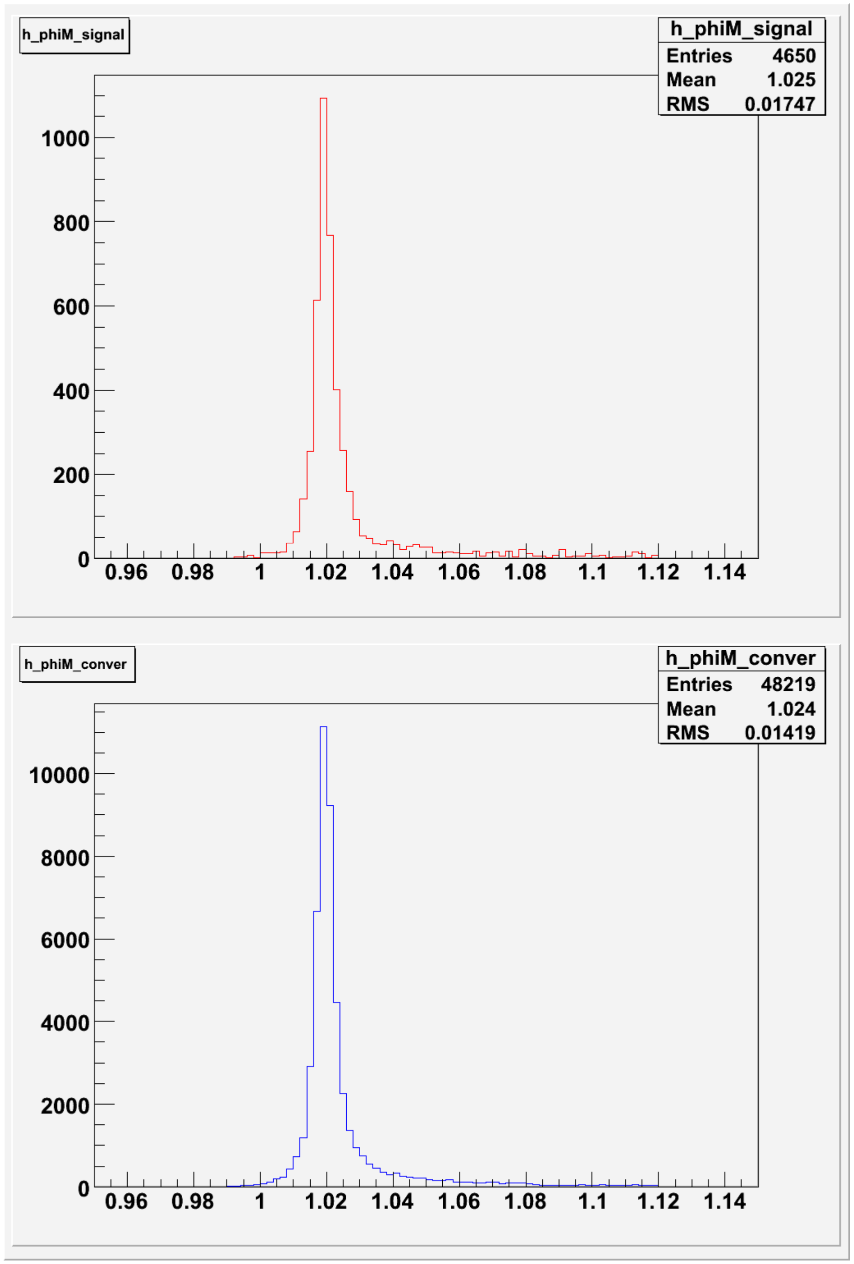
- Reconstructed φ mass peak from K^+, K^- cut on $| \varphi_{Mass\_reco} – 1019.5 \text{ MeV} | < 100 \text{ MeV}$

- Reconstructed D_S^+ mass peak from φ, π^+ cut on $| D_S^+{}_{Mass} – 1968.49 \text{ MeV} | < 100 \text{ MeV}$

- Electron tracks must pass track quality cuts:
  - 10 MeV < Track Momentum < 2.0 GeV
  - chiSquared < 100,000
  - d0 < 5 mm, z0 < 5 cm
- Electron track's dE/dx is fitted to 3.0 σ

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

φ_{Mass} Cut

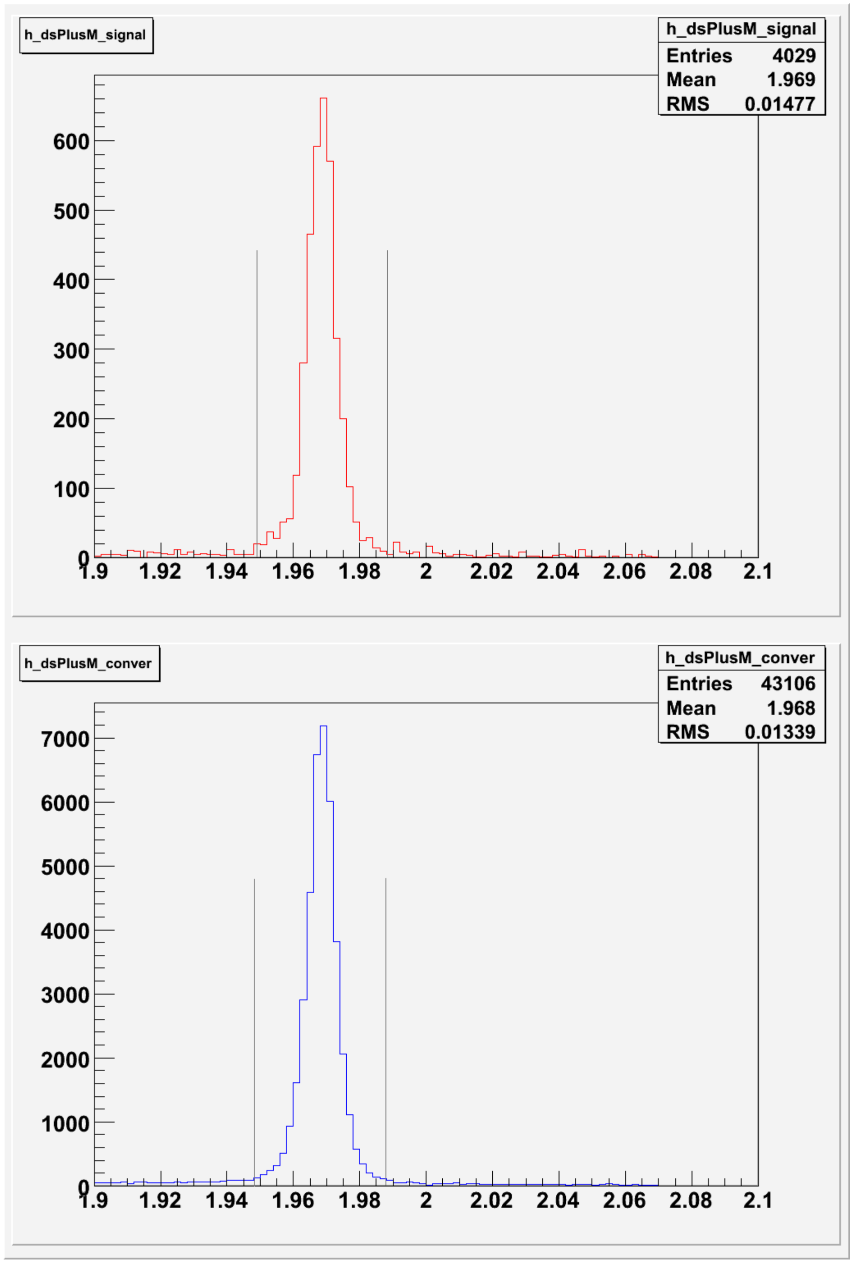


- Reconstructed φ_{Mass}

- We cut on:

$$|\ \varphi_{Mass} - 1019.5\ \text{MeV}\ | < 15\ \text{MeV}$$

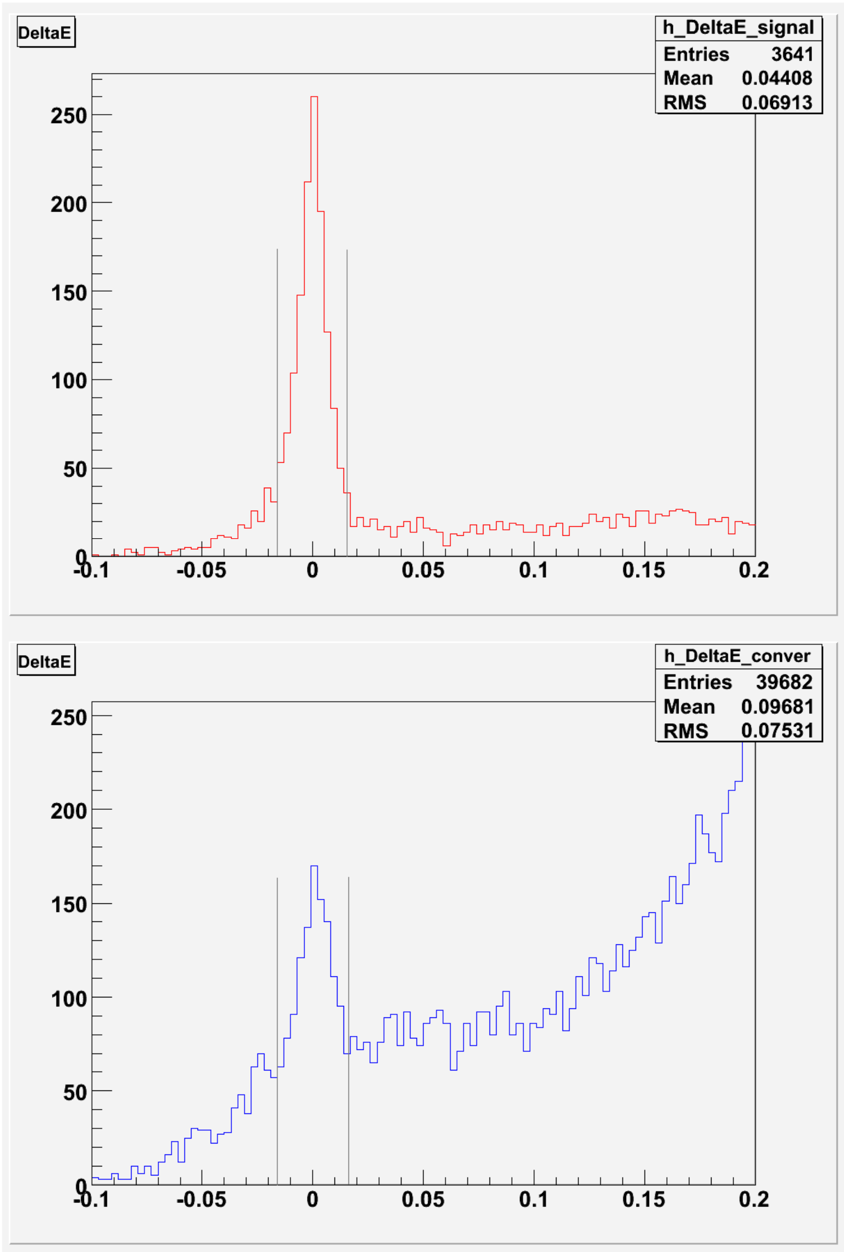
$D_S^+{}_{Mass}$ Cut



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

$$| D_S^+{}_{Mass} - 1968.49 \text{ MeV} | < 20 \text{ MeV}$$

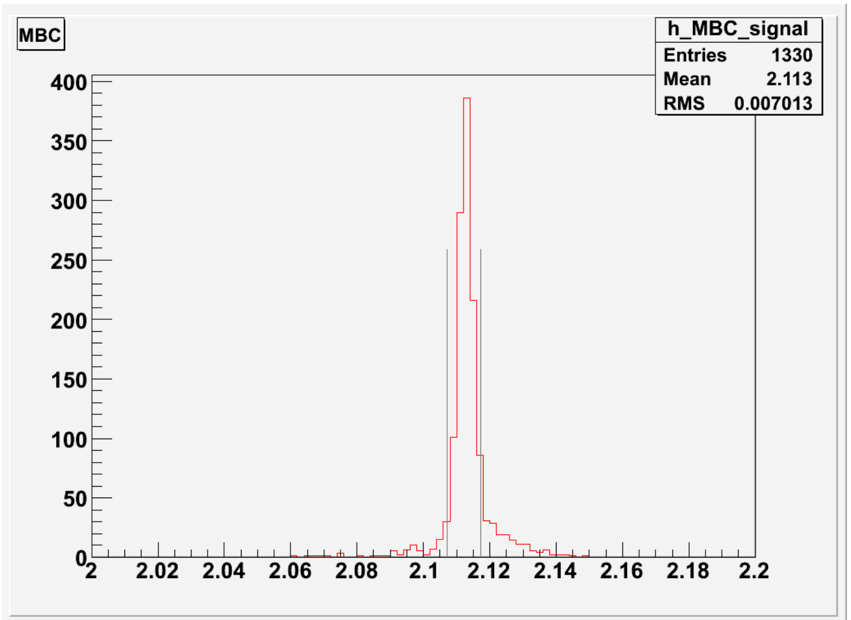
ΔE Cut

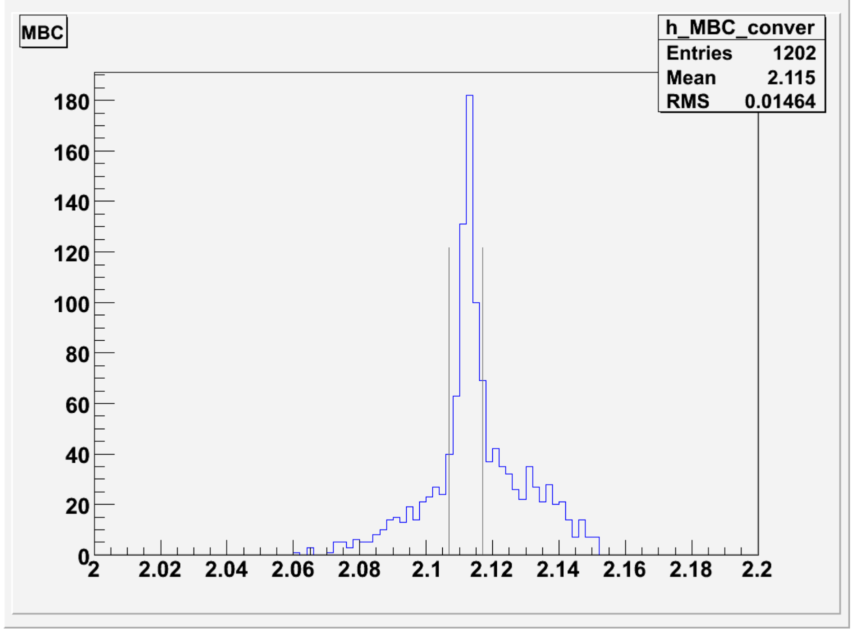


$$\Delta E = E(K^+K^-\pi^+e^+e^-) - E(D_S^{*+}beam)$$

- We cut on |ΔE|<0.016 GeV

m_{BC} Cut

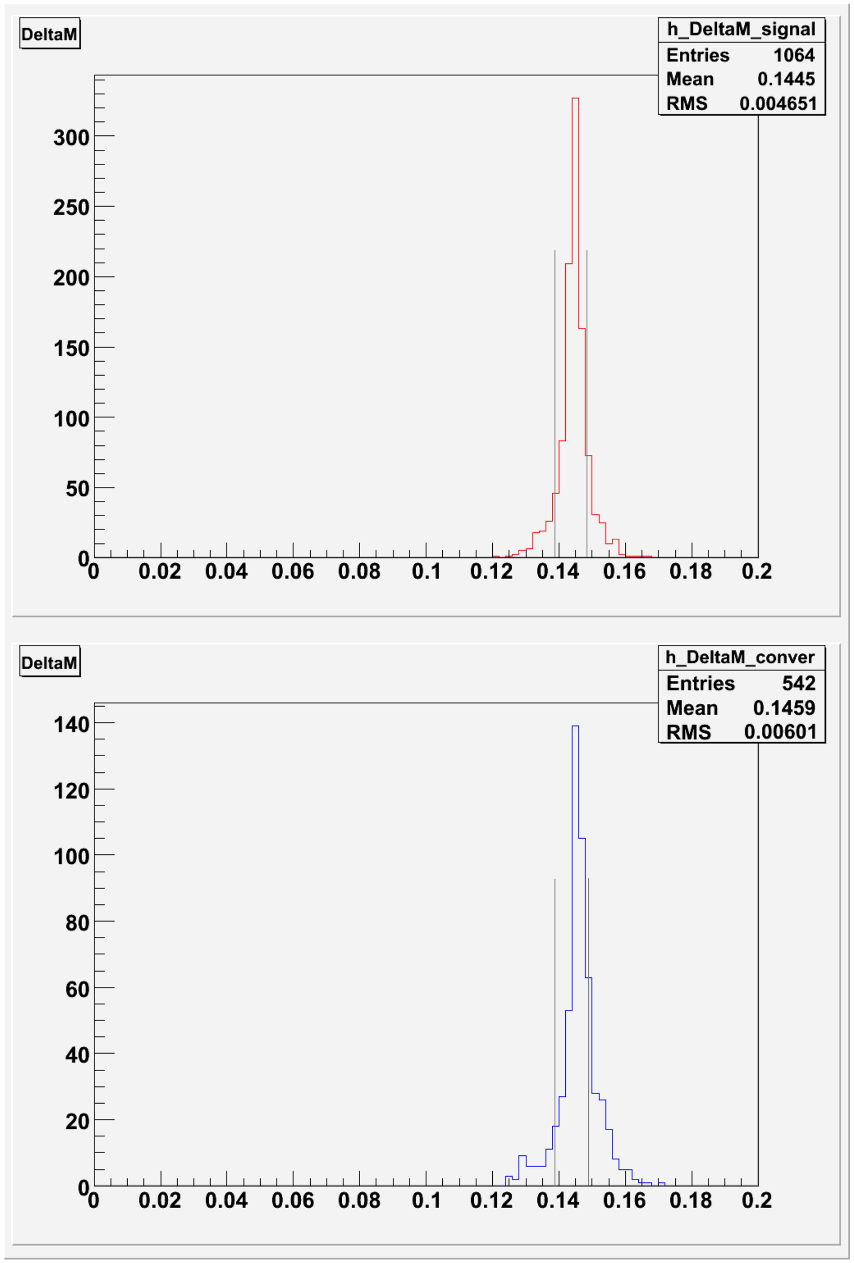




$$m_{BC} = \sqrt{E^2(D_S^{*+} beam) - P^2(K^+K^-\pi^+e^+e^-)}$$

- Will cut on $| m_{BC} - 2.112 \text{ GeV} | < 0.005$ GeV

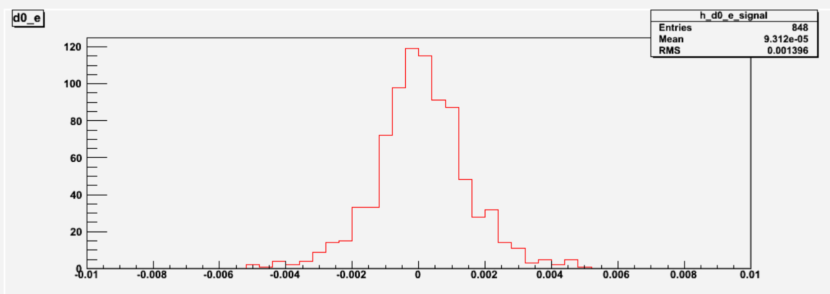
δm Cut

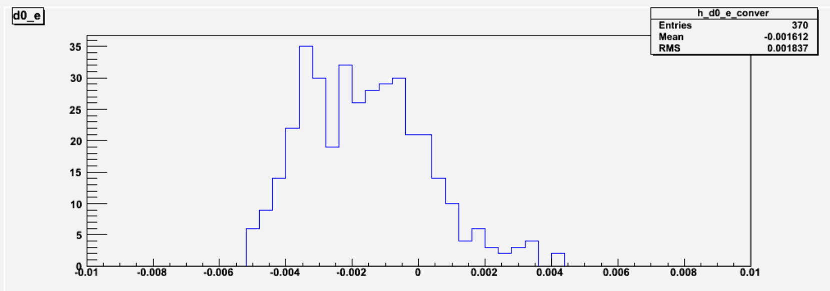


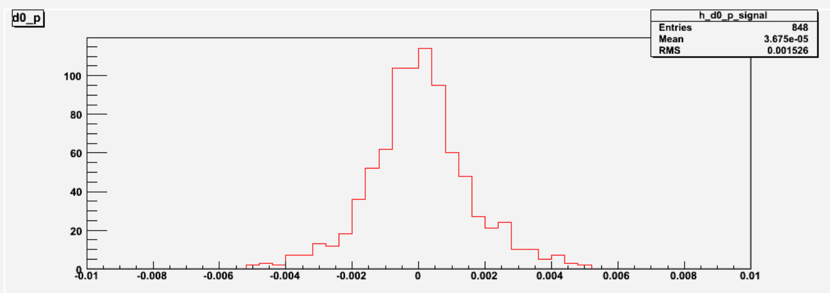
$$\delta m = M(K^+K^-\pi^+e^+e^-) - M(K^+K^-\pi^+)$$

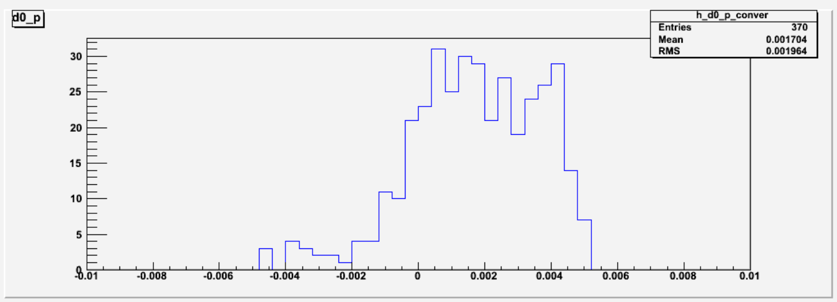
- We cut on $|\delta m - 0.144 \text{ GeV}| < 0.005 \text{ GeV}$

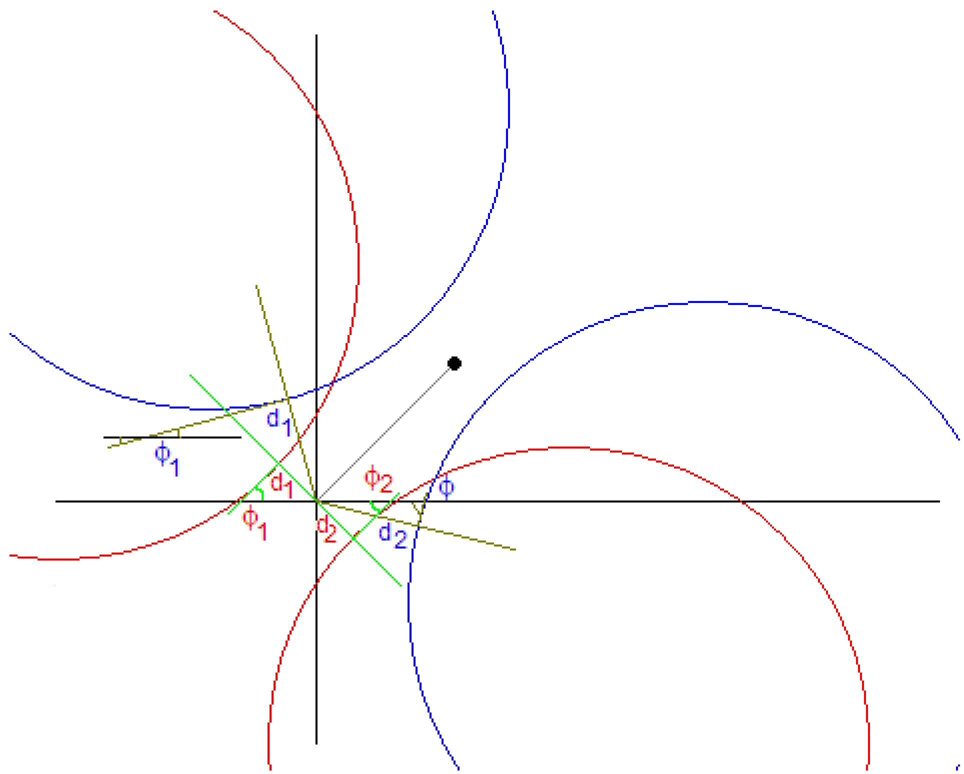
Impact Parameters of the Electron and Positron



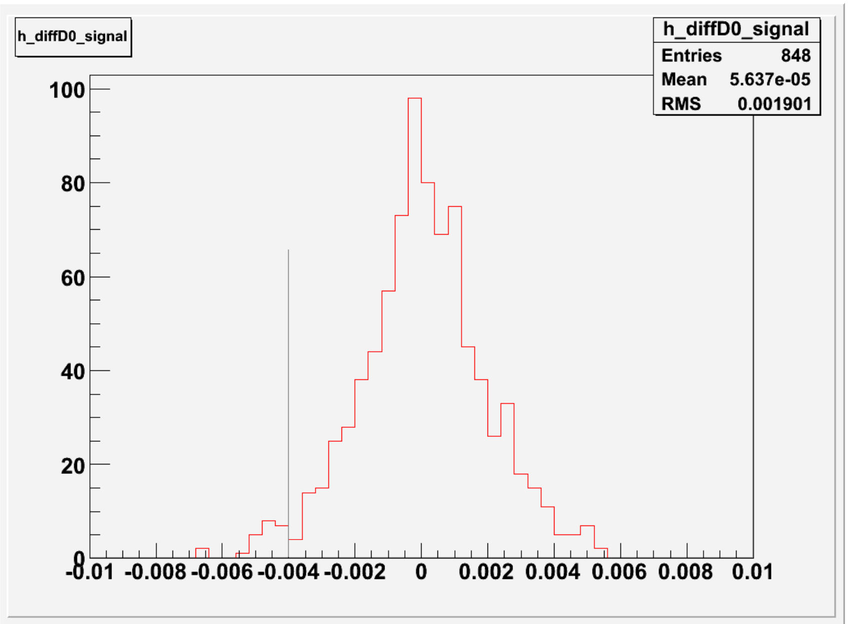


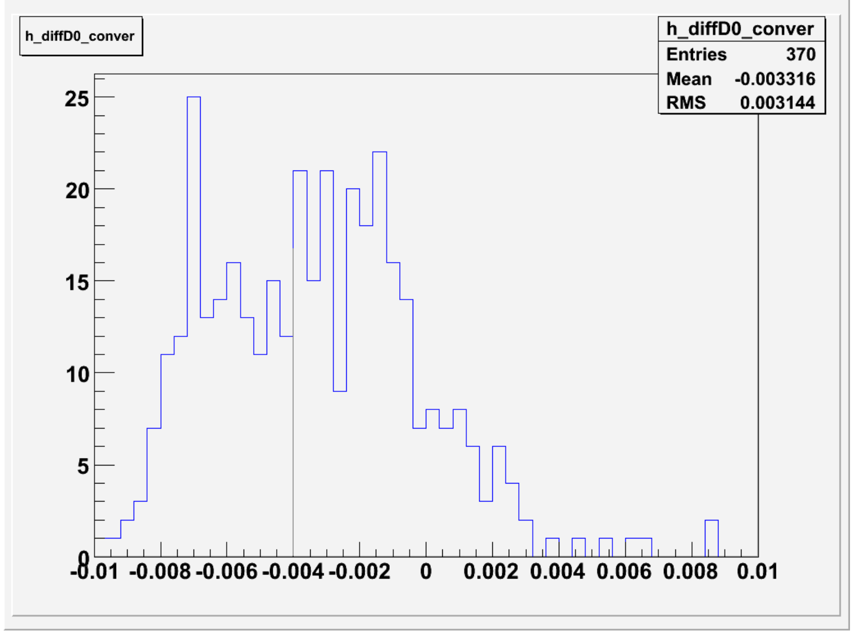


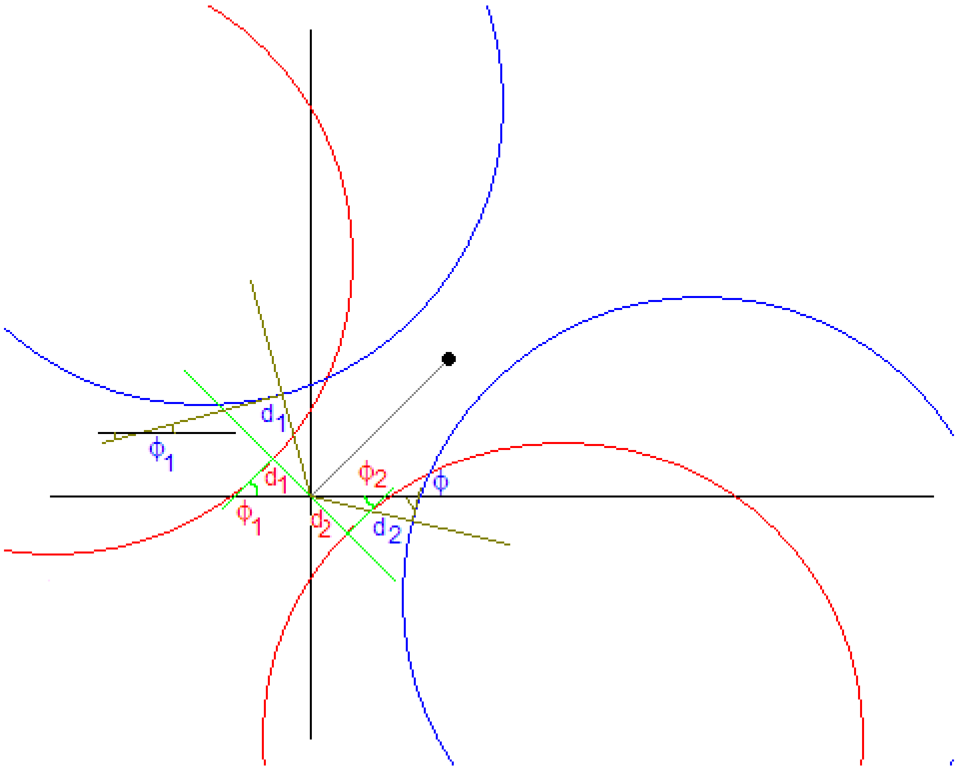




Difference between Impact Parameters of the Electron and Positron

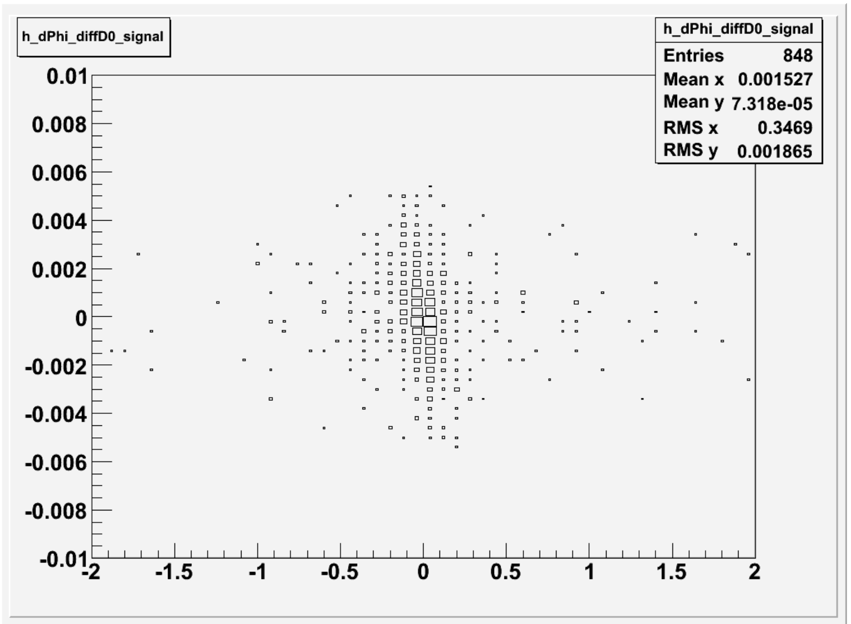




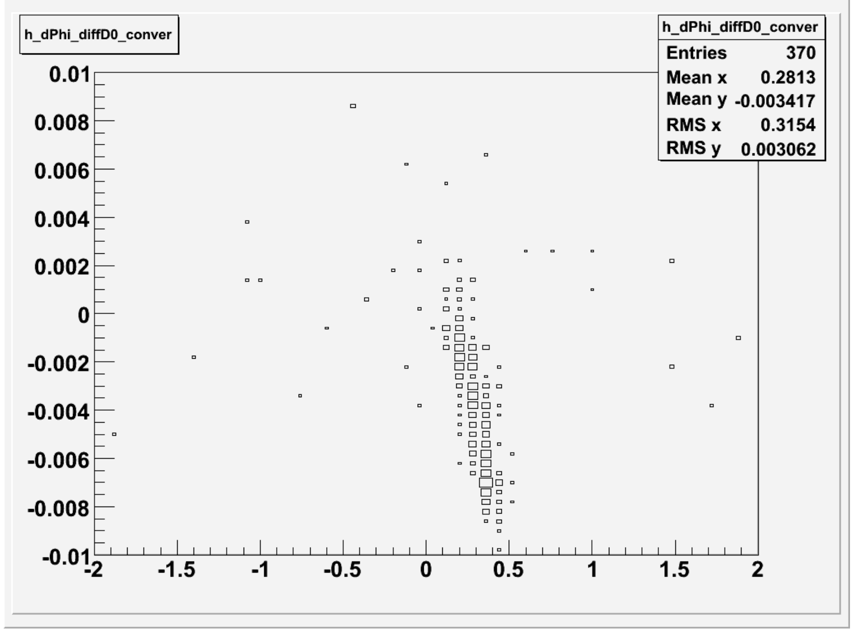


- We require $d0_e - d0_p > -0.004$ m

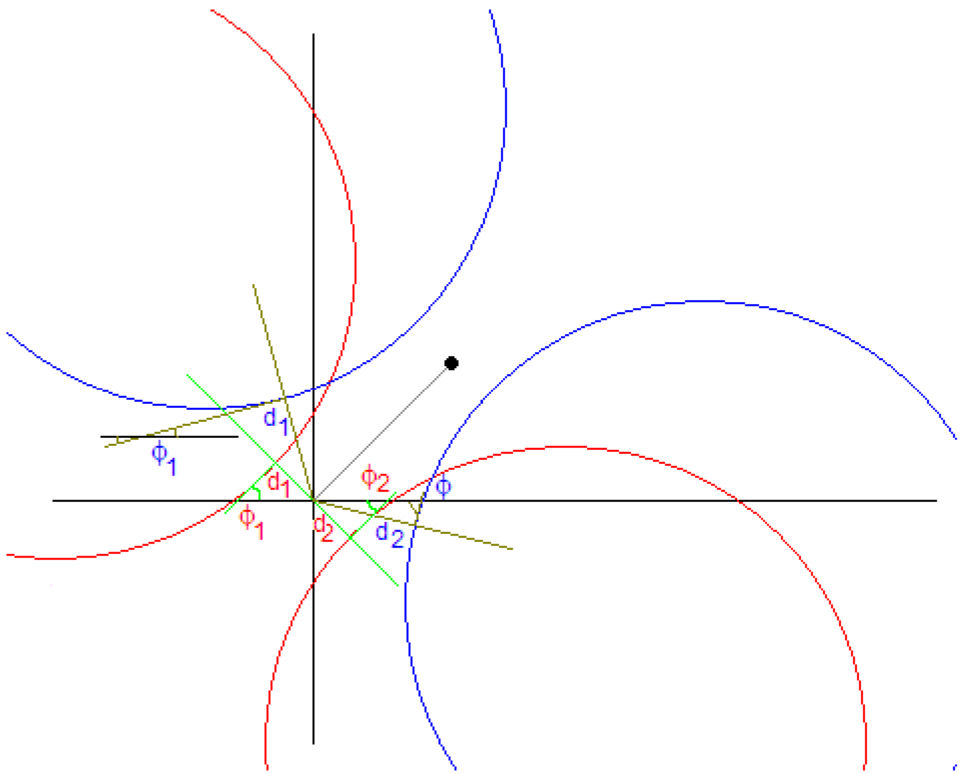
diffD0 vs dΦ



h_dPhi_diffD0_signal
h_dPhi_diffD0_signal
Entries 848
Mean x 0.001527
Mean y 7.318e-05
RMS x 0.3469
RMS y 0.001865
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

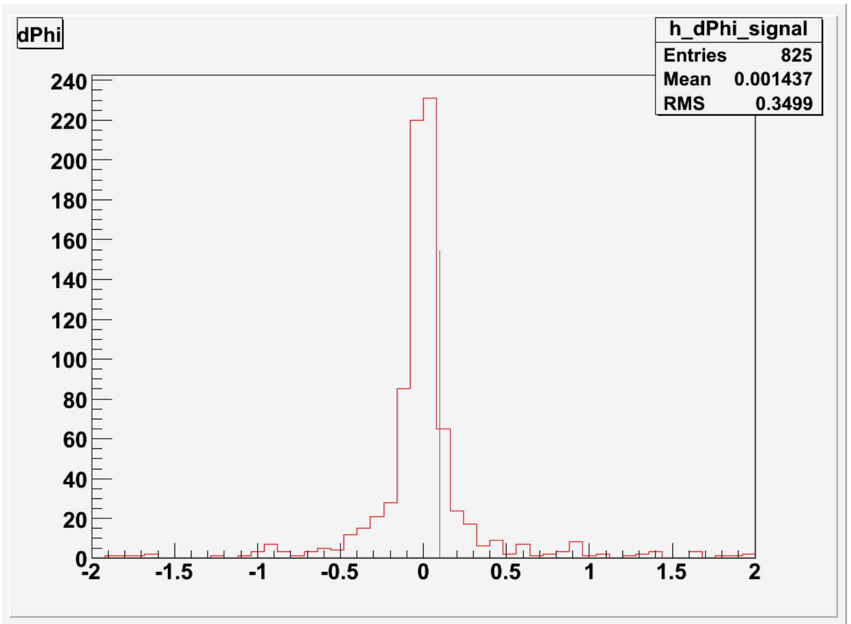


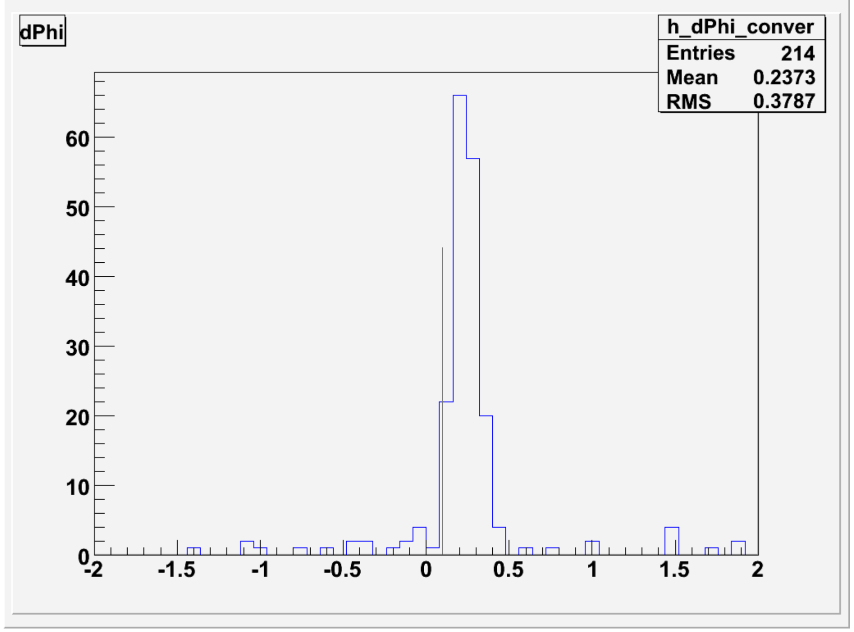
h_dPhi_diffD0_conver
h_dPhi_diffD0_conver
Entries 370
Mean x 0.2813
Mean y -0.003417
RMS x 0.3154
RMS y 0.003062
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

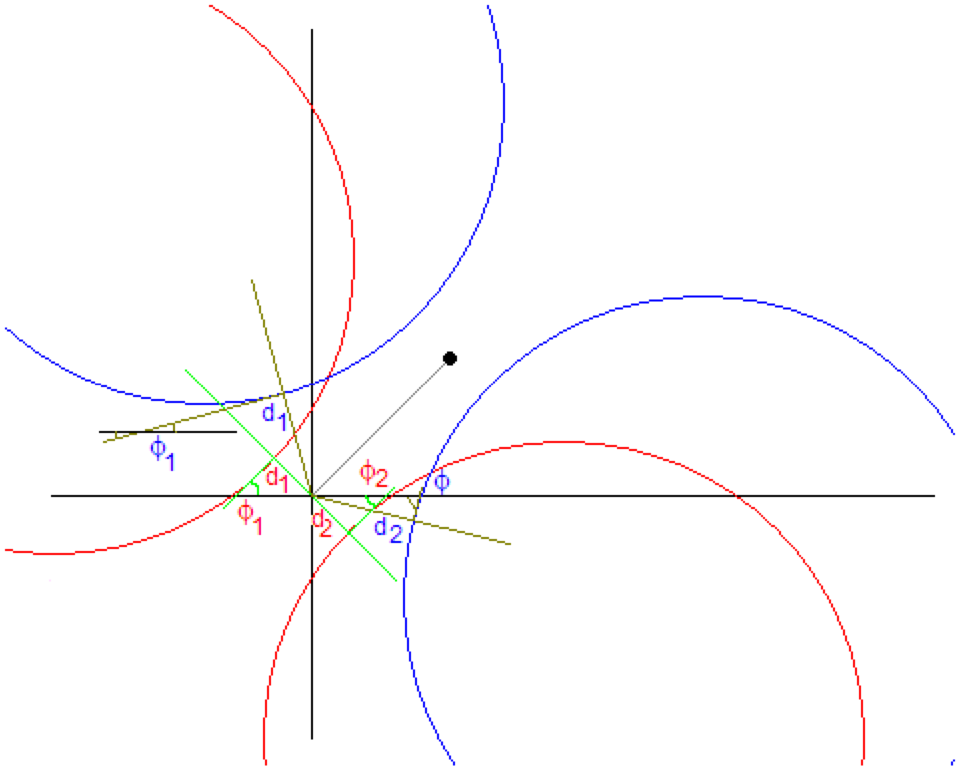


d1
ϕ1
d1
ϕ1
ϕ2
d2
d2
ϕ

dΦ Cut

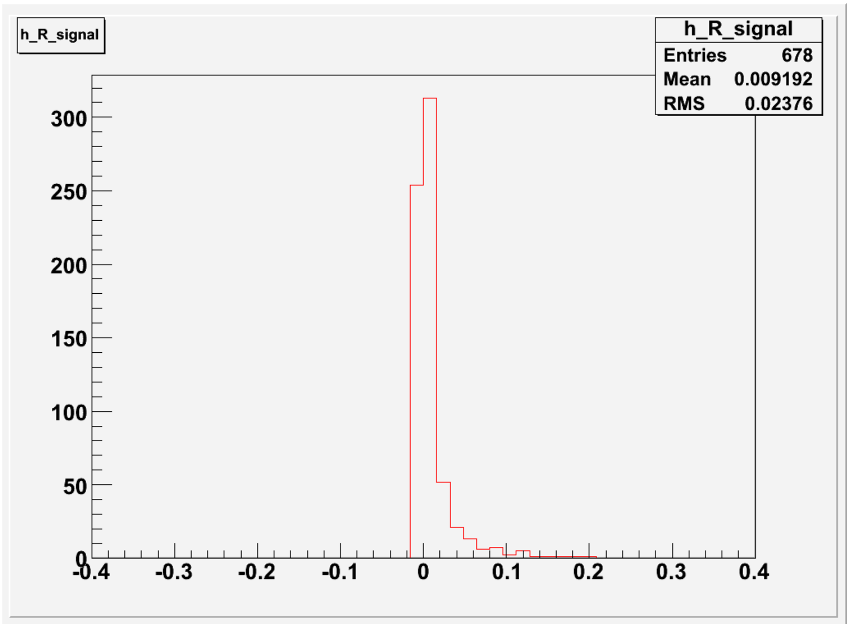


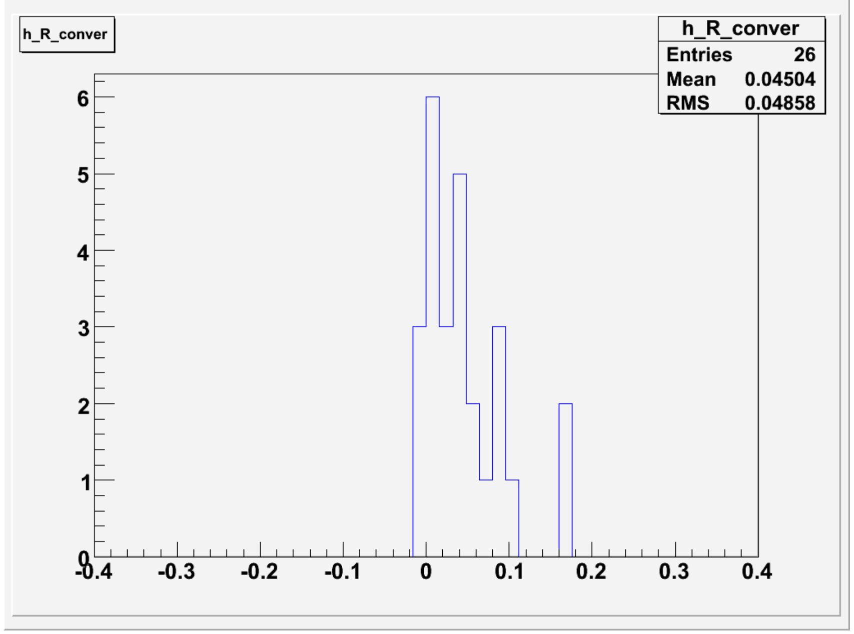


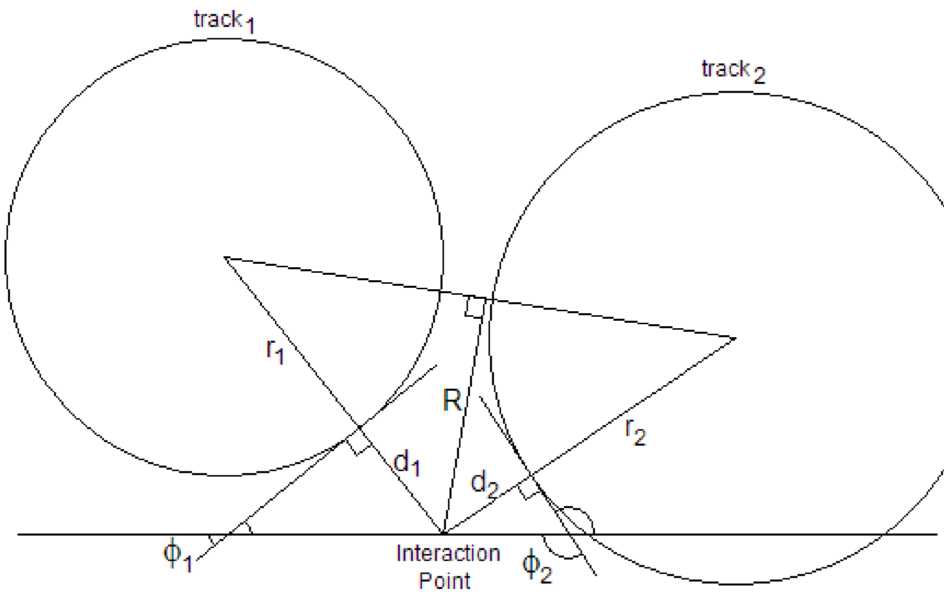


- We require $d0_e - d0_p > -0.004$ m

R Cut







$$a_1 = r_1 + d_1$$

$$a_2 = r_2 + d_2$$

$$\theta = \Phi_1 - \Phi_2$$

$$R = \frac{a_1 a_2 \sin\theta}{\sqrt{a_1^2 + a_2^2 + 2a_1 a_2 \cos\theta}}$$

Expected in Data

We have 678 signal events out of 99,880 and 26 background events out of 998,800.

In a sample of 602 pb^{-1}, we should expect to see:
602,000 × 0.017% × 678/9,988 ~ 7.0 signal events
602,000 × 2.05% × 26/998,800 ~ 0.3 background events

Performance of Cuts

Selection Cut	Signal			Background			Data
	# of Events	Marginal Efficiency	Events in 48.2 pb^{-1}	# of Events	Marginal Efficiency	Events in 48.2 pb^{-1}	Events in 48.2 pb^{-1}
	4650		3.8	48219		47.7	1189
φ_{Mass}	4029	86.7%	3.3	43106	89.4%	42.6	424
$D_S{}^+{}_{Mass}$	3641	90.4%	3.0	39682	92.1%	39.3	174
ΔE	1330	36.5%	1.1	1202	3.0%	1.2	5
m_{BC}	1064	80%	0.9	542	45.1%	0.5	2
δm	848	79.7%	0.7	370	68.3%	0.4	1
$d0_e - d0_p$	825	97.3%	0.7	214	57.8%	0.2	1
$d\Phi$	678	82.2%	0.6	26	12.2%	0.03	0

Things To Do

- Optimize selection cuts
- Calculate predicted rate more accurately.
- Use the DTagging tools and use other decay modes:

$$K^+K^-\pi^-$$
$$K_SK^-$$
$$\eta\pi^-;\ \eta \to \gamma\gamma$$
$$\eta'\pi^-;\ \eta' \to \pi^+\pi^-\eta,\ \eta \to \gamma\gamma$$
$$K^+K^-\pi^-\pi^0$$
$$\pi^+\pi^-\pi^-$$
$$K^{*-}K^{*0};\ K^{*-} \to K^0_S\pi^-,\ K^{*0} \to K^+\pi^-$$
$$\eta\rho^-;\ \eta \to \gamma\gamma,\ \rho^- \to \pi^-\pi^0$$
$$\eta'\pi^-;\ \eta' \to \rho^0\gamma,$$

- Reconstruct the *other* Ds (and cut on slightly different kinematic quantities)
- Electron-refit the data…