A Search For $B^-, \bar{B} \rightarrow D_s^- X_u$ With CLEO II and II.5

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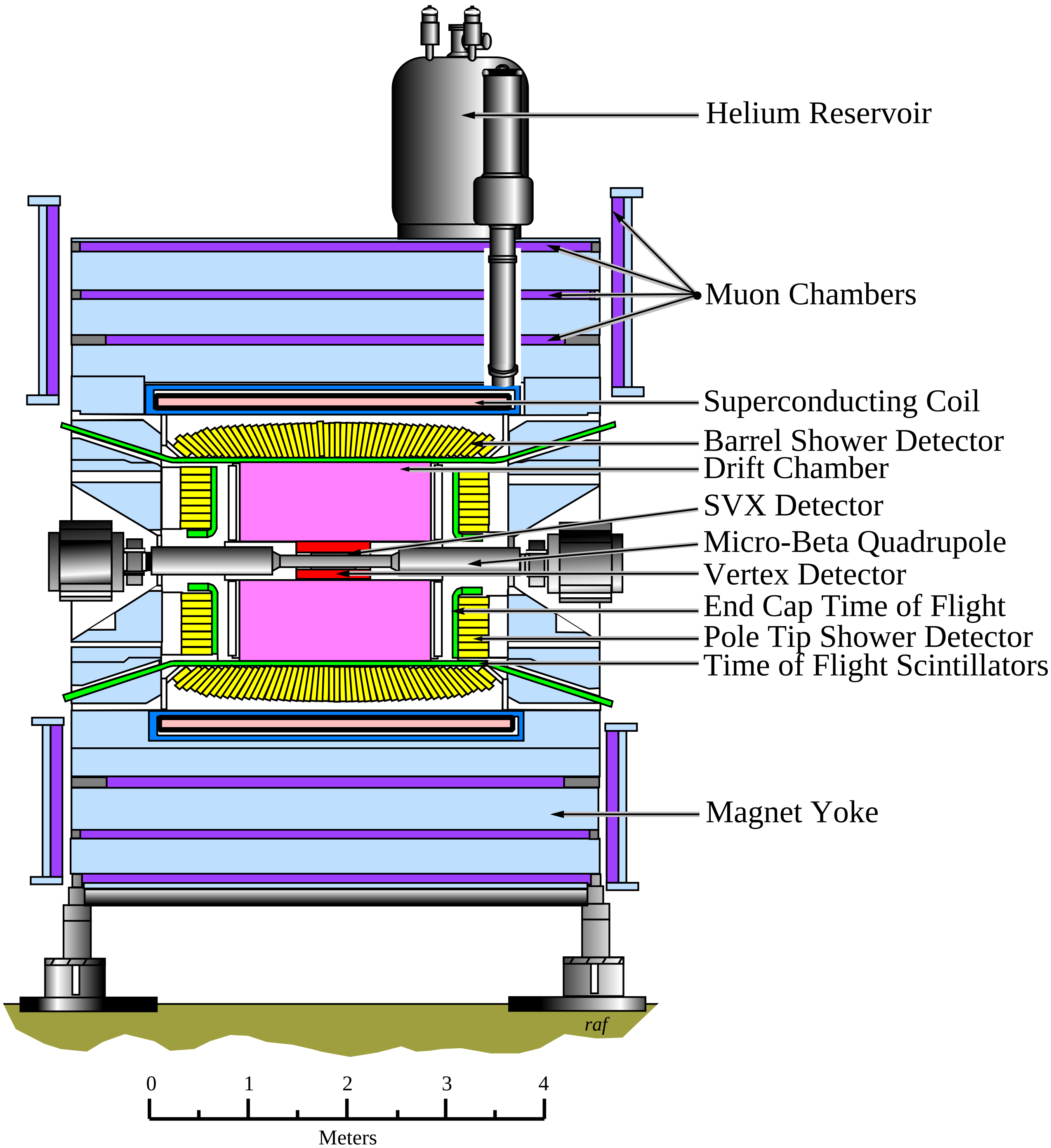
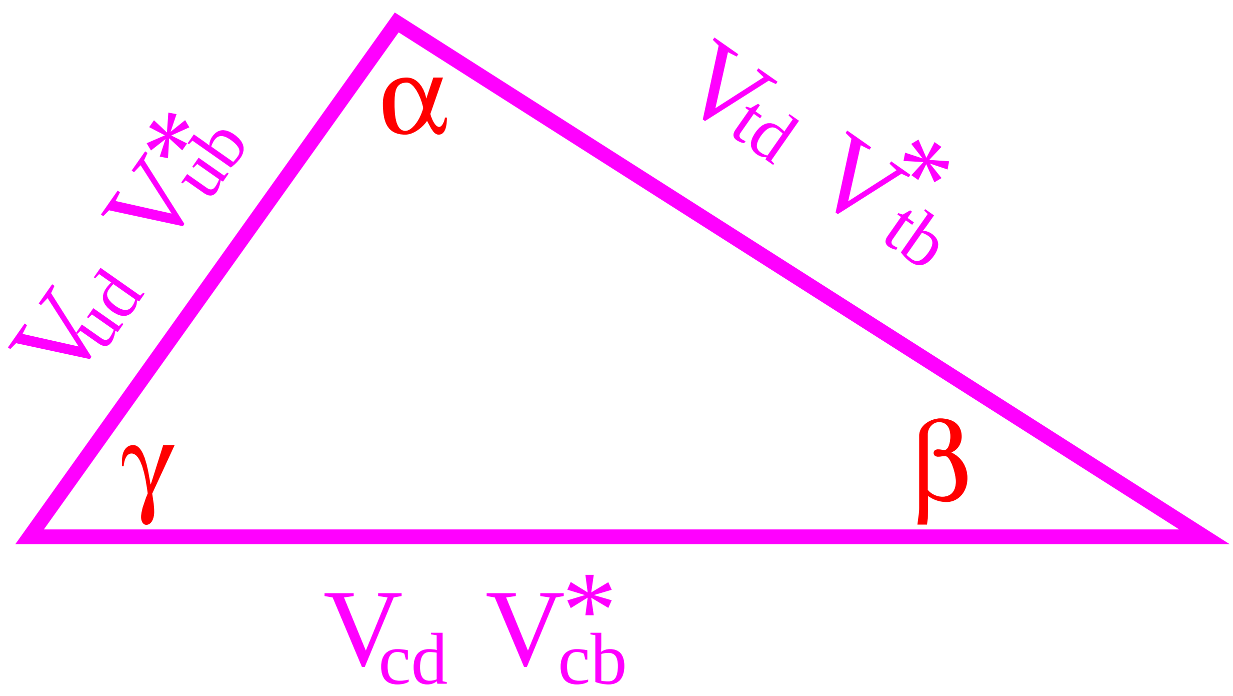
The CLEO II.V Detector



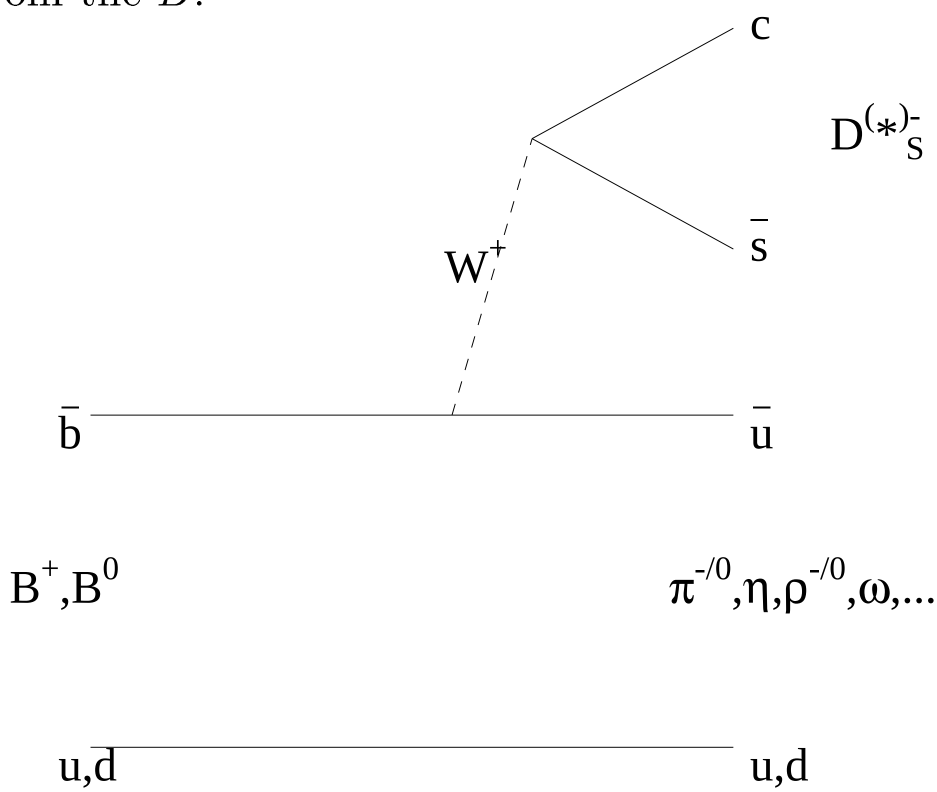
Why V_{ub}?

- Measuring the elements of the Cabibbo-Kobyashi Maskawa (CKM) matrix, which describes the weak transitions of quarks, is one of the central themes of B-physics.
- Interferences between different processes, which expose phase differences between CKM elements, are required to measure the angles of the "unitarity triangle".
- Determination of the magnitudes of the CKM elements, the sides of the triangle, is a prerequisite to understanding these effects.



Measuring V_{ub} from $b \to uW^-, W^- \to \bar{c}s$

- $b \to u(\bar{c}s)$ transitions ($b \to u$ with upper-vertex charm) should be as strong as the charmless decays $b \to u(\bar{u}d)$, and are less complicated by interference between the quarks from the W and those from the B.



- One even expects an *enhancement* of $\bar{B} \to D_s^- X_u$ w.r.t. $\bar{B} \to \pi^- X_u$ of about 400% due to the ratio of decay constants, even with the reduced phase space:

$$\frac{\Gamma(B \to D_s^- X_u)}{\Gamma(B \to \pi^- X_u)} = \frac{P(D_s) f_{D_s}^2}{P(\pi) f_{\pi^-}^2} \tag{1}$$

neglecting those Penguin contributions, exchange terms, and QCD phases that complicate $\pi\pi$.

V_{ub} Measurement Method: Inclusive vs Exclusive

- In V_{ub} induced B-decays, the D_s from the upper-vertex is produced with higher momentum than in V_{cb} transitions.
- This suggests an inclusive analysis of the end-point spectrum of D_s production.
- This would mainly be limited by statistics in the subtraction of D_s's from the continuum ($e^+e^- \to q\bar{q}$, $q = u, d, s, c$). as determined from off-resonance data.
- Given CLEO's sample of 9.7×10^6 $B\bar{B}$ events, detecting such an inclusive signal at expected rates of $\approx 5 \times 10^{-4}$, requires continuum suppression approximately $5\times$ stronger than that used in CLEO's inclusive measurement of $b \to s\gamma$ in order to observe a 3σ effect.
- So, instead, we search for exclusive $B \to u(\bar{c}s)$ decays:

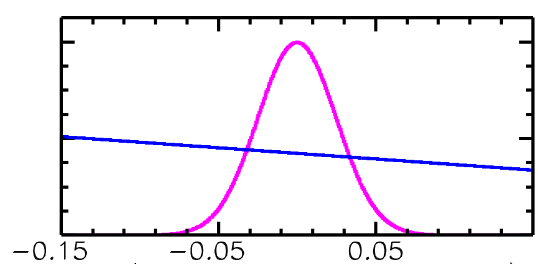
$$B \to D_s^{-(*)} P, \ (P = \pi^{\pm}, \ \pi^0), \qquad (2)$$

  where we are able to use the dynamics of the decay to suppress backgrounds.
- This also allows the combination of several D_s decays with different requirements tuned to the respective background levels.

Analysis Strategy

- We combine several D_s decay channels:
  - my analyses using D_s^- decays to $\phi\pi^-$,$\phi\rho^-$,$\phi 3\pi$ (using $\phi \to K^+K^-$ and $\rho^- \to \pi^-\pi^0(\gamma\gamma)$)
  - analyses by S.Marka (now at LIGO) of D_s^- decays to $\eta\pi$,$\eta\rho$ (using $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0(\gamma\gamma)$)
  - Only the channels with a ϕ will be described here.
  - 15% of D_s branching fraction (including subdecays) is used.
  - The $D_s\gamma$ decay is used to reconstruct D_s^* candidates
- The D_s candidates from reasonable hadronic events are combined with π^- or π^0 and considered as possible reconstructed $B \to D_s^{(*)} X_u$ events if their energy loosely matches the beam energy:

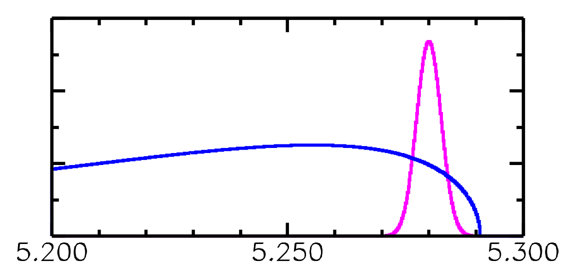
- $\Delta E = |E_{beam} - E_{D_s^{(*)}\pi}| < 0.3\,\mathrm{GeV}$
- $\sigma(\Delta E) = 25(D_s^{(*)}\pi^+) - 50(D_s^{(*)}\pi^0)$ MeV.



ΔE(–signal,–background)

and their momentum is close to that expected for a B:

- $M_{beam} = \sqrt{(E^2_{beam} - p^2_{D_s^{(*)}\pi})} > 5.2\,\mathrm{GeV/c^2}$
- $\sigma(M_B) = 2.8(D_s^{(*)}\pi^+) - 3.4(D_s^{(*)}\pi^0)$ MeV



M_B(–signal,–background)

Backgrounds

After requiring that the dE/dX measured for the $K^{\pm}$ and $\pi^{\pm}$ is consistent $2.25\sigma - 3.0\sigma$, and making loose cuts on reconstructed masses:

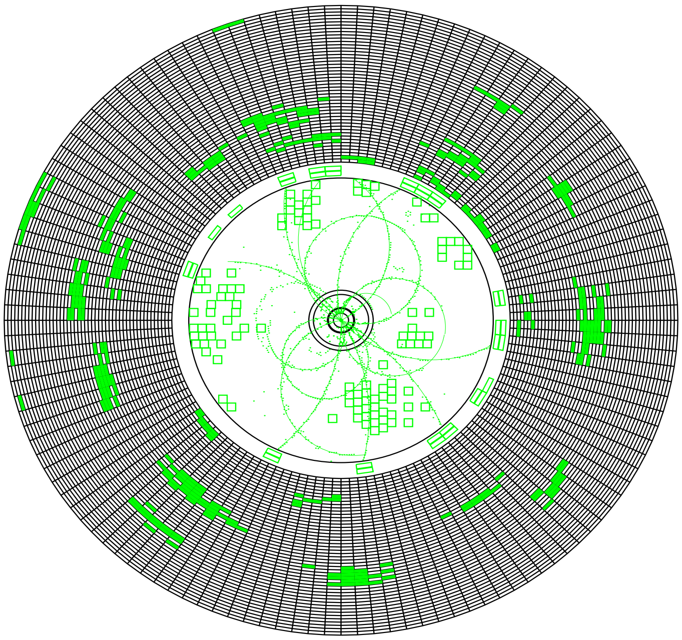
- $\chi^2 < 5$ for those particles with no significant natural width
- $\delta_M(\rho^- \to \pi^-\pi^0) < 150$ MeV/c^2
- $\delta_M(\phi \to K^-K^+) < 20$ MeV/c^2
- $\delta_M(D_s) < 20$ MeV/c^2
- $\delta^* = |M(D_s^*) - M(D_s)| < 20$ MeV/c^2

one finds rates many times larger than any signal expected to be $O(10^{-5})$, but with no enhancement near $M(D_s^{(*)}\pi) = M_B$ and $\Delta E = 0$.

So...how to eliminate the backgrounds?

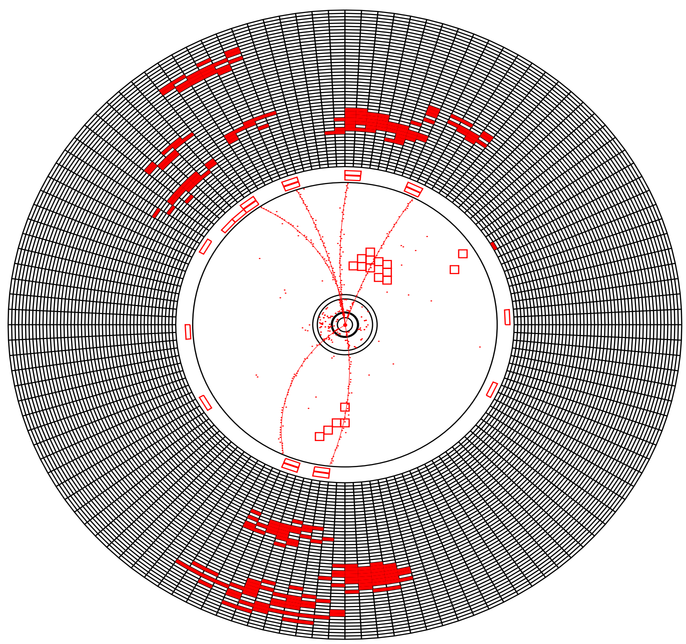
- $b \to cX$ transitions constitute approximately 100% of B decays
- but $B \to D_s\pi$ decay have higher momenta ($P(D_s) \approx 2.28 \pm 0.18$ GeV/c, $P(\pi) \approx 2.28 \pm 0.14$ GeV/c).
- So $b \to cX$ backgrounds should be low, the best levers against them are tighter cuts on δE, M_B, helicity angles and daughter particle masses.
- Continuum ($e^+e^- \to q\overline{q}$, $q = u, d, s, c$) is the main background.
- So use difference in event shape between continuum (two light quark jets tend to produce a clear axis) and $B\bar{B}$ (the B mesons are slow, ≈ 330 MeV/c, resulting in an isotropic event).

Event Shapes



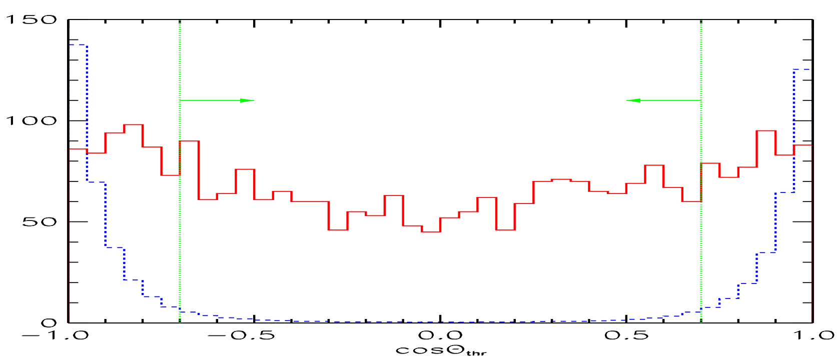
A $B\overline{B}$ Event

A Continuum ($q\overline{q}$) Event:

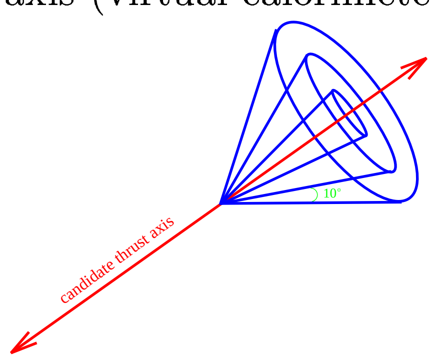


Continuum Suppression

- $\cos\theta_B$: angle between the B candidate and the beam axis ($\propto \sin^2\theta$ for B-decays, flat for continuum backgrounds)
- $\cos\theta_{thrust}$: angle between the B candidate thrust axis and the thrust axis of the rest of the event (continuum peaks near ± 1, signal candidates produce flat distributions)



- 2nd Fox-Wolfram Moment R2 (peaks at 1 for continuum, 0 for $B\overline{B}$)
- Sums of charged and neutral momenta in 9 10^o double cones about the candidate thrust axis (virtual calorimeter).

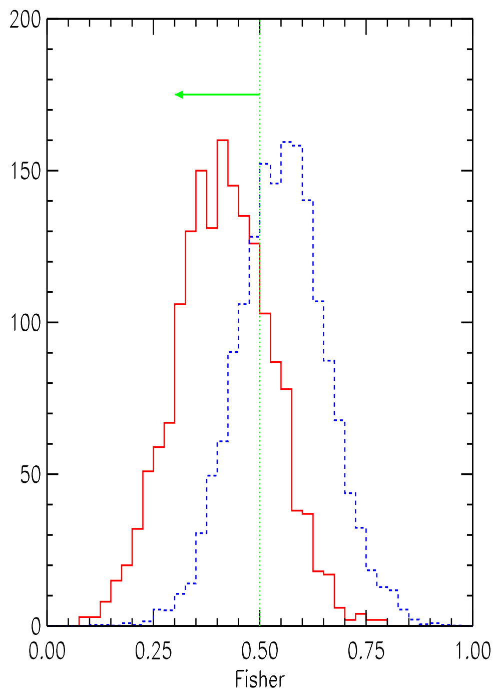


- Fisher Discriminant (optimum combination of the above variables)
- With $B \to D_s^{(*)-}\pi_{fast}$ and $D_s \to \phi X$ one can cut on the $\phi\pi_{fast}$ angle in the D_s rest frame (anticorrelated for jetty events).

Fisher Discriminant

A Fisher Discriminant is a linear combination of measurements with coefficients optimized such that it emphasizes the *differences* between two phenomena.

CLEO uses the 9 virtual calorimeter momentum sums, the B thrust-axis direction ($\propto (\vec{p}_1 - \vec{p}_2)$ in a two body decay),and the B direction ($\propto (\vec{p}_1 - \vec{p}_2)$).

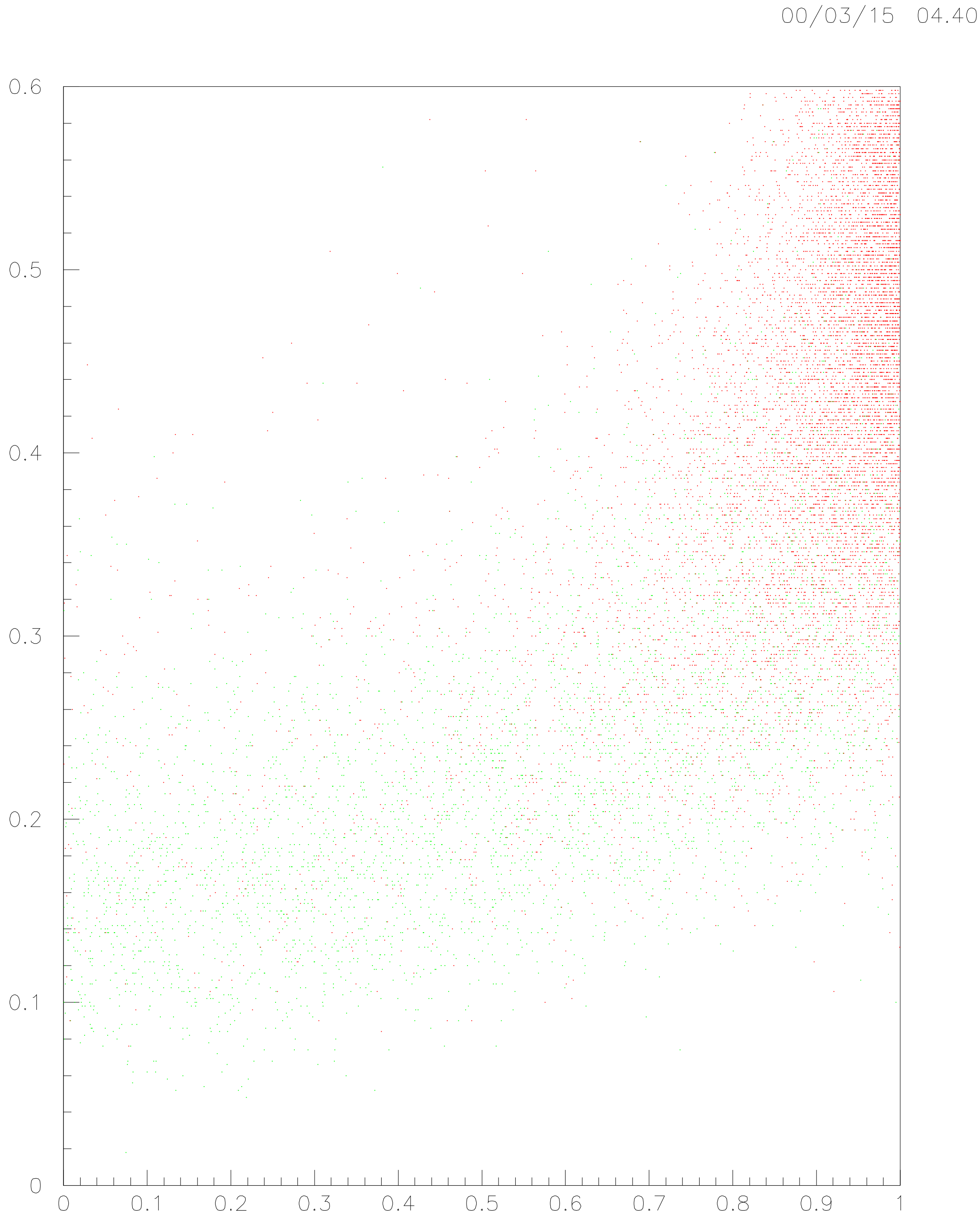


$$\mathcal{F} = \sum_{i=1}^{11} \alpha_i X_i$$

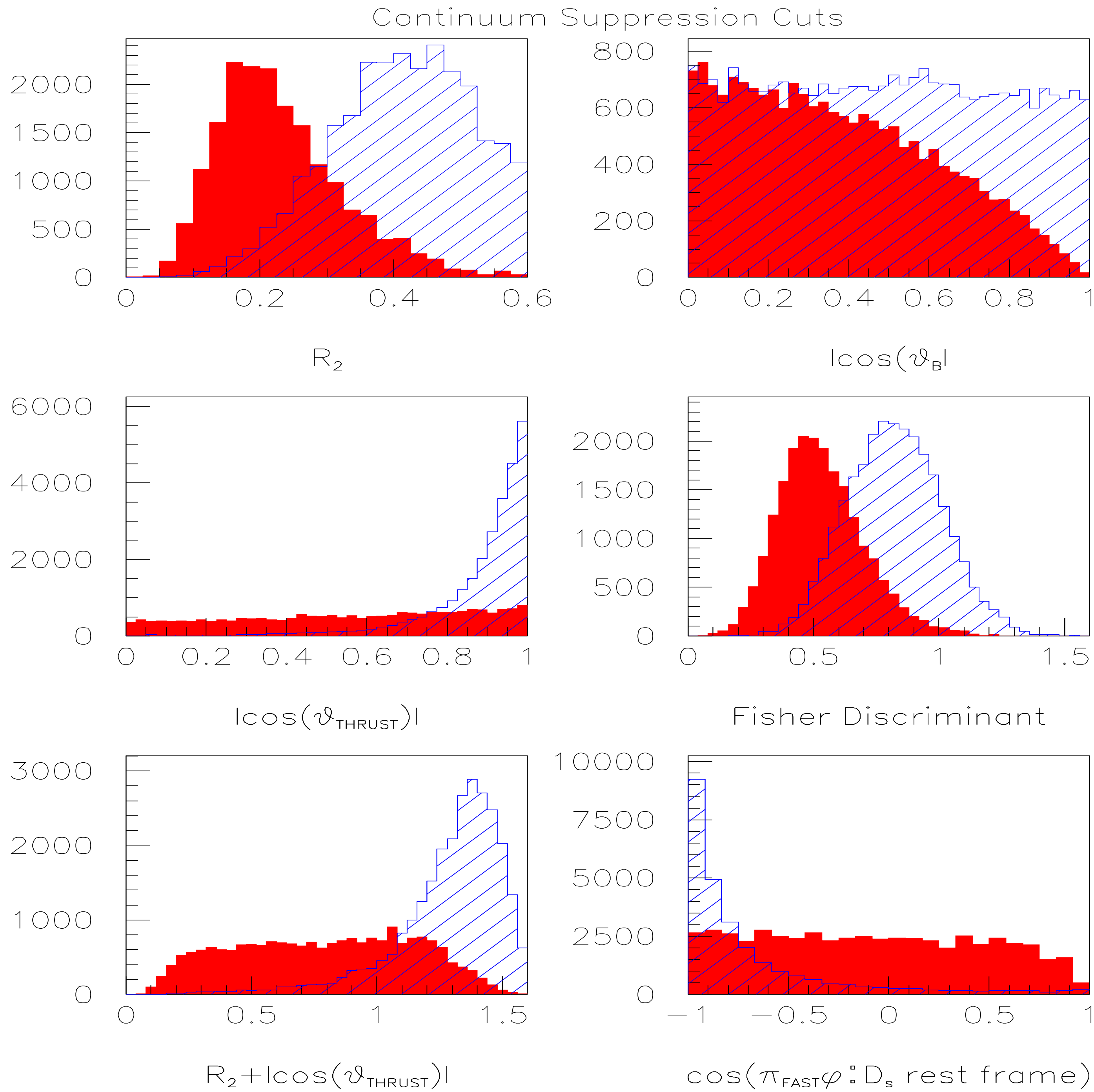
$$\alpha_i = \frac{< X_i >_{background} - < X_i >_{signal}}{\sigma(X_i)^2_{background} + \sigma(X_i)^2_{signal}}$$

The Fisher discriminant is almost independent of the decay mode under study since it is determined by the behaviour of the rest of the event, whether miscellaneous B decay, or continuum.

$R_2 + |\cos_{thrust}|$



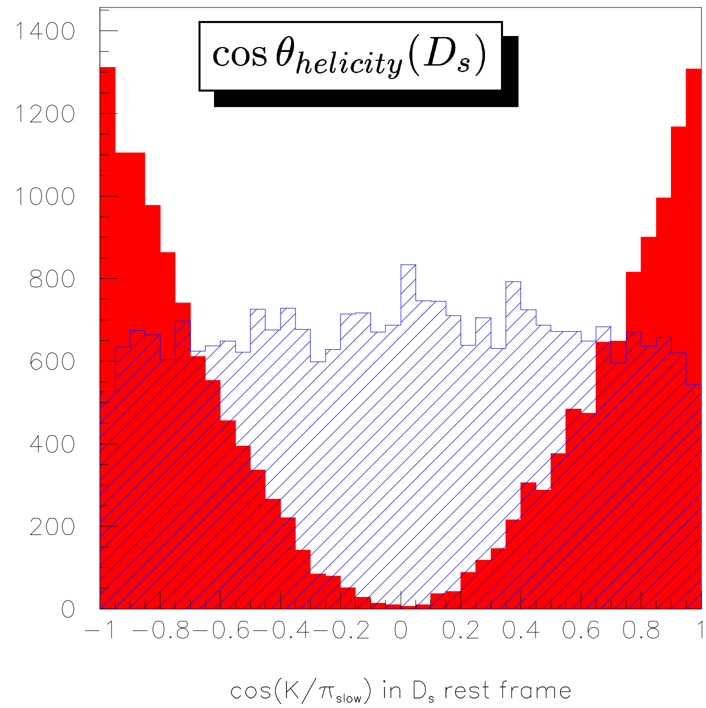
Event Shape Variables



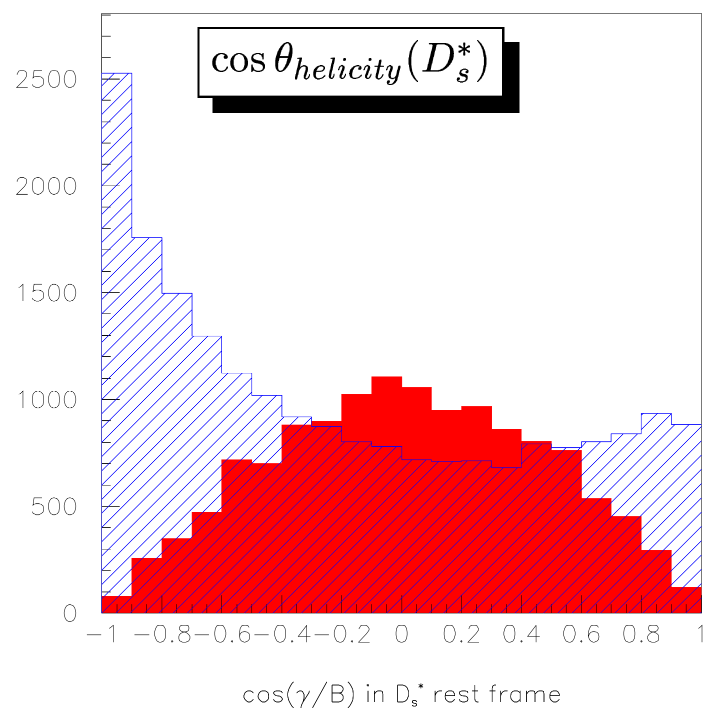
Signal Monte Carlo ($D_s \to \phi\pi$) is shown in solid red, the continuum background (off-resonance data) is shown in hatched blue.

Spin Structure

In $D_s \to \phi\pi$, helicity conservation forces the K_ϕ/π angle to be distributed like $\cos\theta^2$ in the ϕ rest frame. Background is randomly distributed so one makes a cut $|\cos\theta_{helicity}| > 0.2 - 0.55$

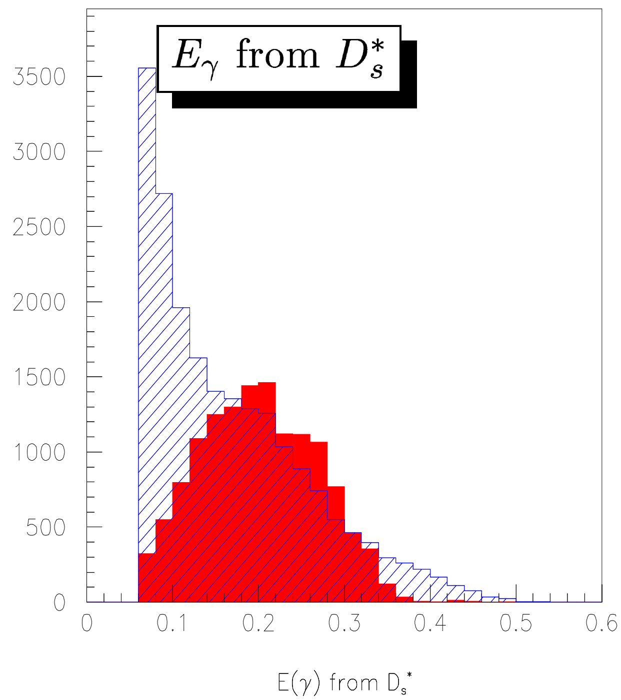


In $B \to D_s^* \pi_{fast}$ there is similarly a $\sin\theta^2$ distribution for the $\gamma\pi_{fast}$ angle in the D_s^* rest frame. Background is flat with some peaking at -1 because it is correlated with γ energy, so one makes an asymmetric cut $[-1,-0.5] < \cos\theta_{helicity} < [0.78, 1.0]$

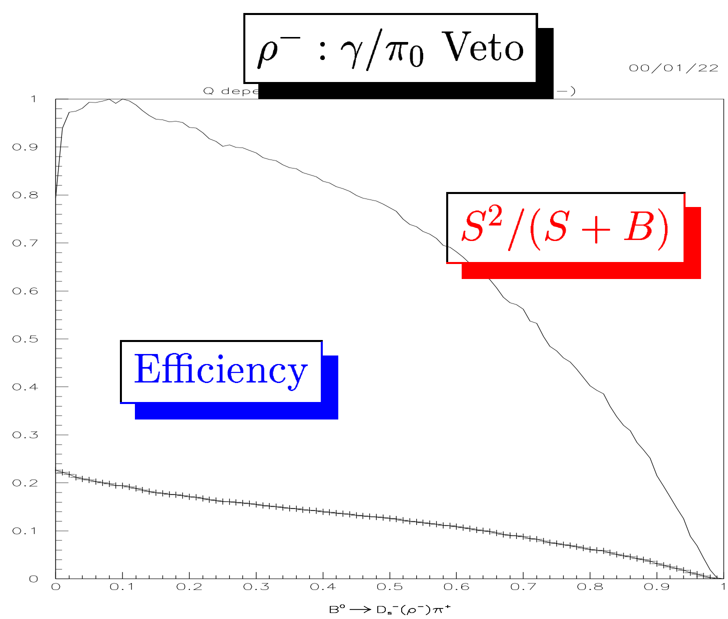


Combinatorics

- For $D_s \to \phi(\rho, 3\pi)$ where there are no helicity cuts one can suppress random combinations by cutting on pion momentum.
- For photon combinatorics:
  - veto γs that form a good $\pi^0 s$ with unused γs in the event
  - increase the $E(\gamma)$ threshold when there are more combinatorics ($D_s^*(\gamma D_s)$, $\rho^-(\pi^+\pi^0)$).
  - require a $p(\pi^0)$ threshold similarly ($D_s^- \to \phi\rho^-$)
  - limit photons to the best part of the detector: $|\cos\theta| < 0.71$

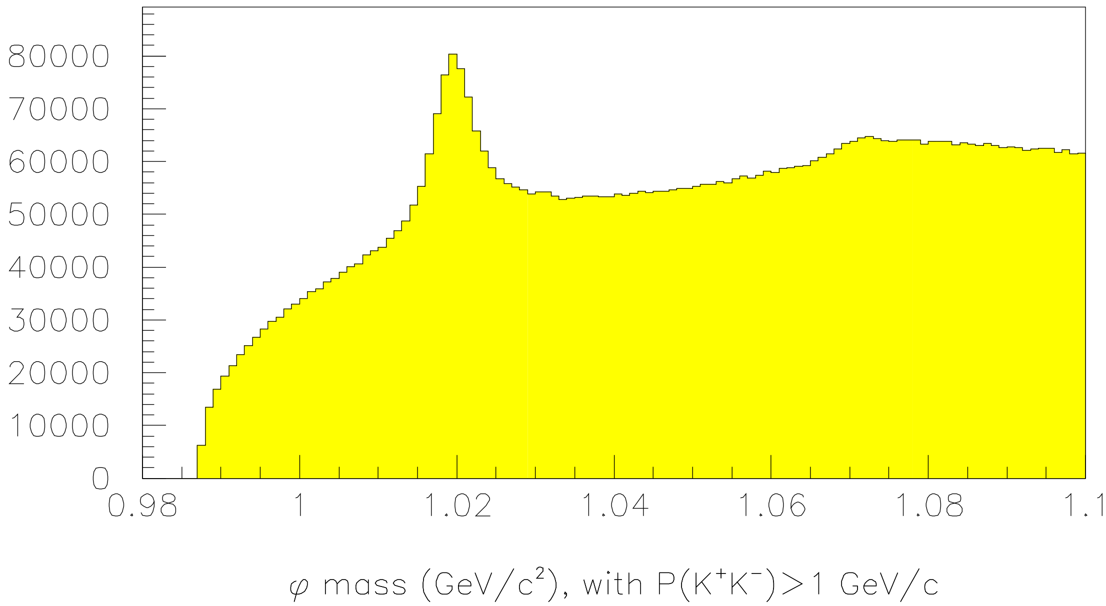


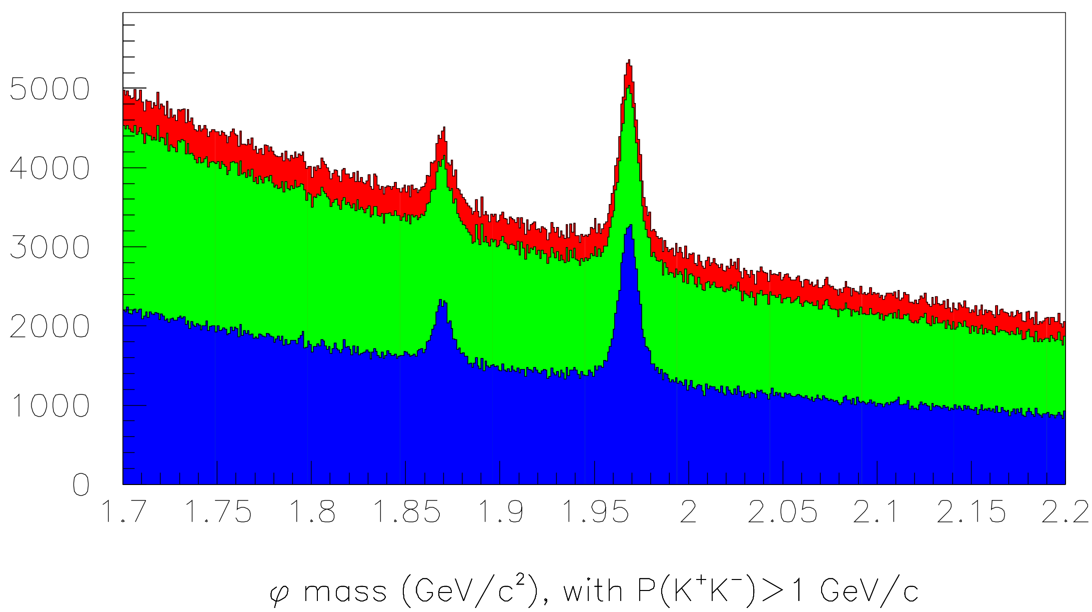
The fast π^0 is clean so that only the π^0 from $D_s^\pm \to \phi\rho^-$ needs a γ/π^0 veto, producing a 25% improvement in S^2/N. Several pieces of information were synthesised into a likelihood for π^0 "goodness".



ϕ, $\phi\pi$ inclusive signals in data

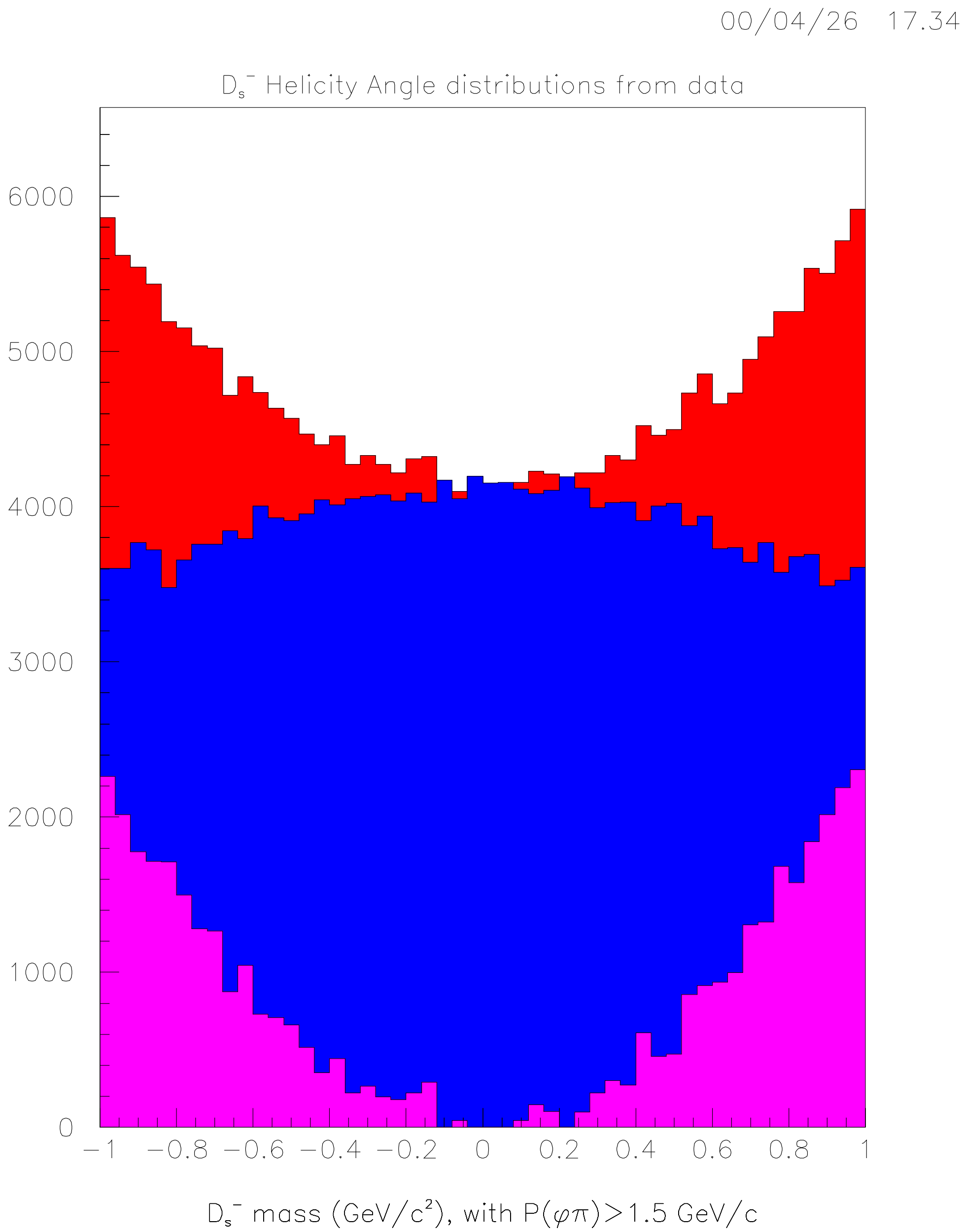
A ϕ signal is clearly visible after a 3σ consistency cut on the K dE/dX:





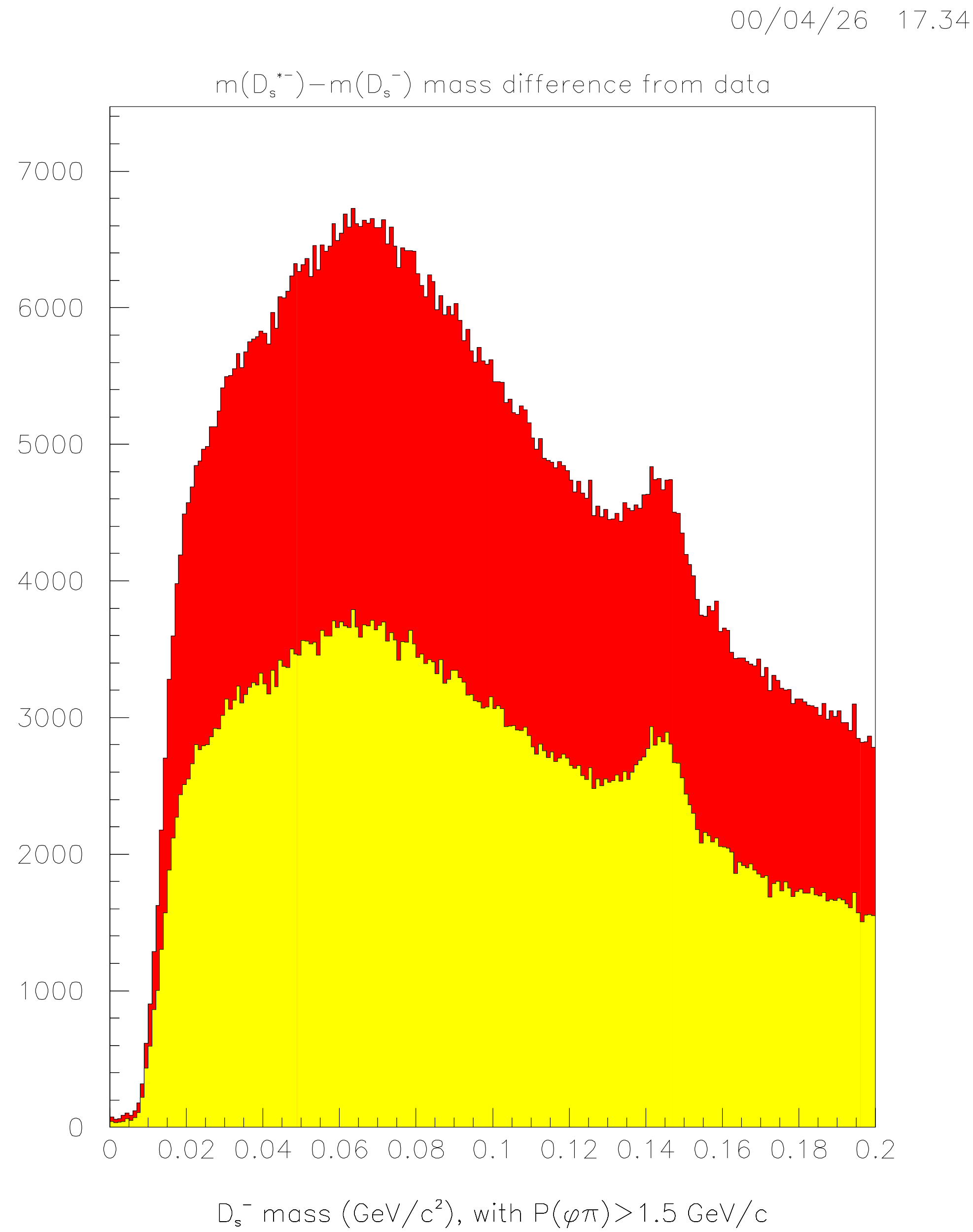
After a 10 MeV/c^2 $m(\phi)$ cut, a D_s signal is evident , even if all charged tracks are accepted as pions, a 3σ dE/dX requirement improves the signal a bit, but the cut $|\cos\theta_{helicity}| > 0.5$ is much more powerful.

$\phi\pi$ Inclusive Peaks



The topmost distribution is in a centerband (12 MeV) about the D_s mass, the second is the sideband, the lowest plot is the difference of the two.

$\phi\pi$ Inclusive Peaks



The upper distribution has a weak 3σ dEdX cut on the D_s's pion, while the lower plot has a hard (0.5) cut on the the cosine of the D_s helicity angle.

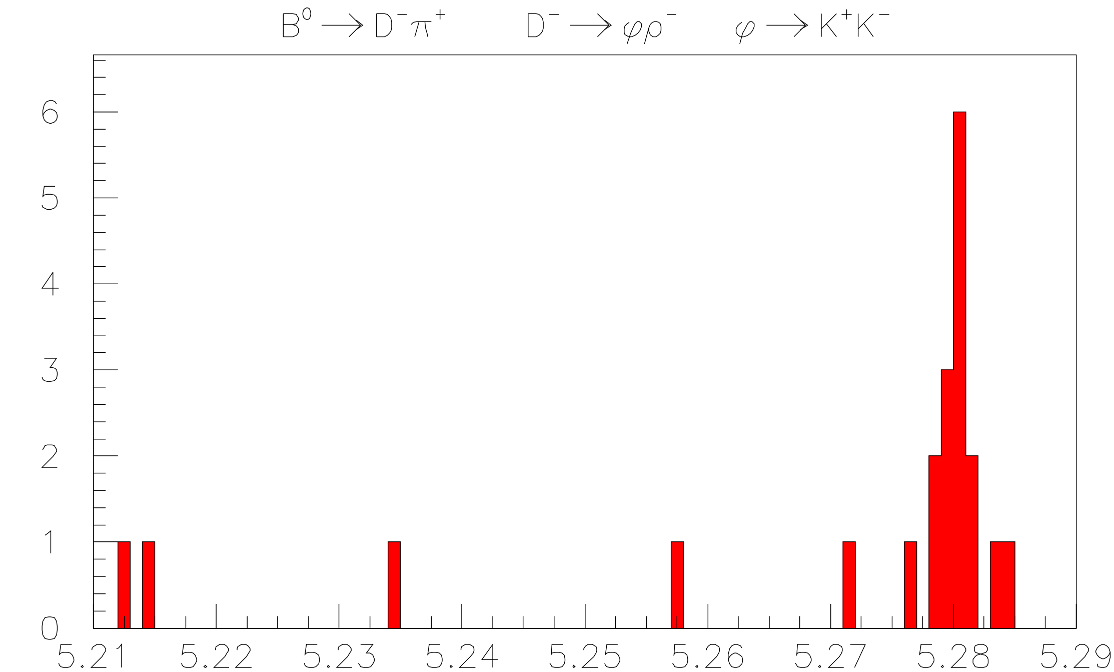
Some Results

- Once we determined those quantities that can be used to reject backgrounds, we tune cuts on these variables (along with those on the signal region in the $M_B, \delta E$ plane, and the mass intervals accepted for ϕ and $D_s^{(*)}$) by maximizing a *Gaussian significance* $Q = S^2/(S+B)$ assuming a branching ratio of 5×10^{-5} in calculating S.
- It is still nice to verify that the methodology and cuts chosen makes sense, so:

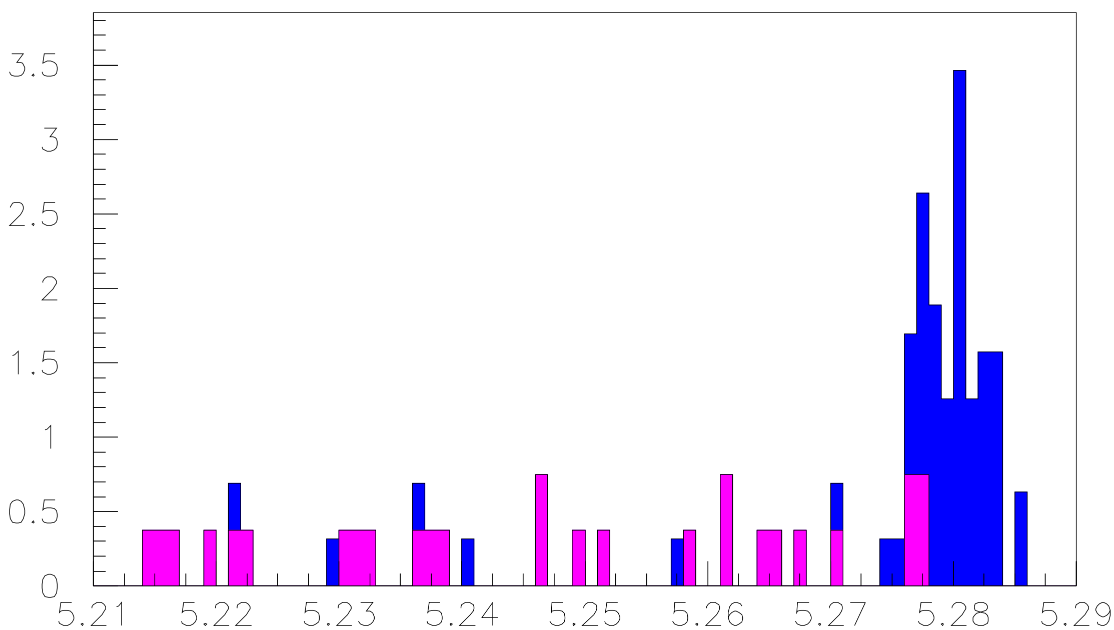
An Actual Observation: $B^0 \rightarrow D^-\pi^+$ with $D^- \rightarrow \phi(K^+K^-)\pi^-$

- This decay should appear with the branching ratio of $B(B^0 \rightarrow D^-\pi^+) \times B(D^- \rightarrow \phi\pi^-) \times B(\phi \rightarrow K^+K^-)$ of $((6.1 \pm 0.6) \times 10^{-3}) \times ((3.0 \pm 0.4) \times 10^{-3}) \times 0.491 = 9 \times 10^{-6}$ resulting in about 87 events in our data sample.
- Making the same cuts as used in the $B^0 \rightarrow D_s^-\pi^+$ with $D_s^- \rightarrow \phi(K^+K^-)\pi^-$ decay chain (but centering the D mass cut) we see 16 events in the signal box.
- Simulation predicts a background of 1.5 continuum events on a signal of 14.5 events, data sidebands predict a background of 1.2 events.
- This yields s an *experimentally determined efficiency* for the channel of $(16.7 \pm 5.0)\%$ only 1.4σ away from that calculated for $B^0 \rightarrow D_s^-\pi^+$ with $D_s^- \rightarrow \phi(K^+K^-)\pi^-$.

A Real Signal: $B^0 \to D^-\pi^+$ with $D^- \to \phi(K^+K^-)\pi^-$

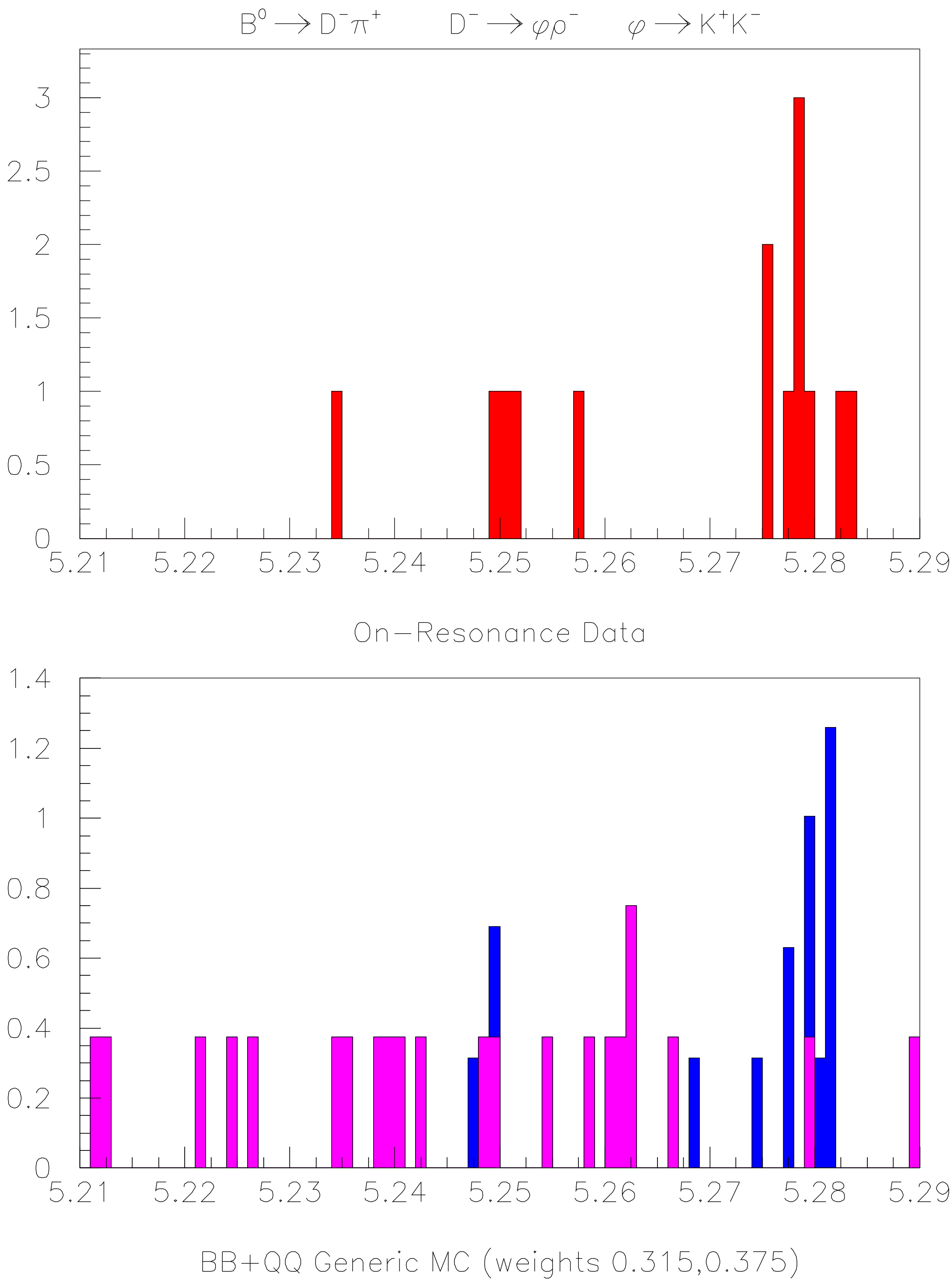


On−Resonance Data

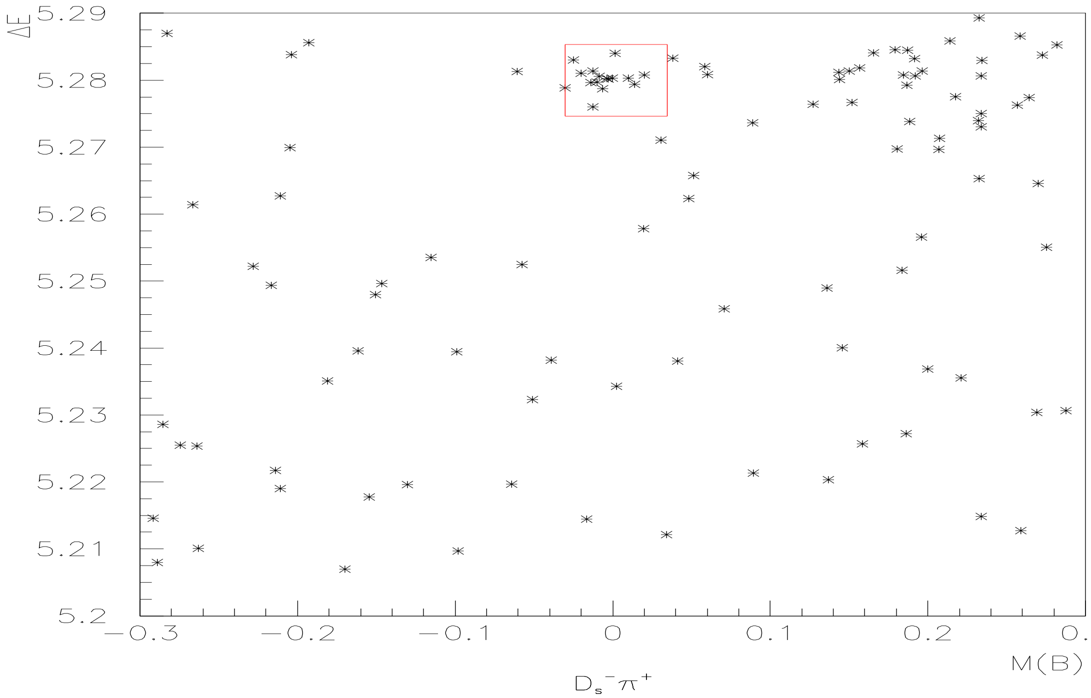


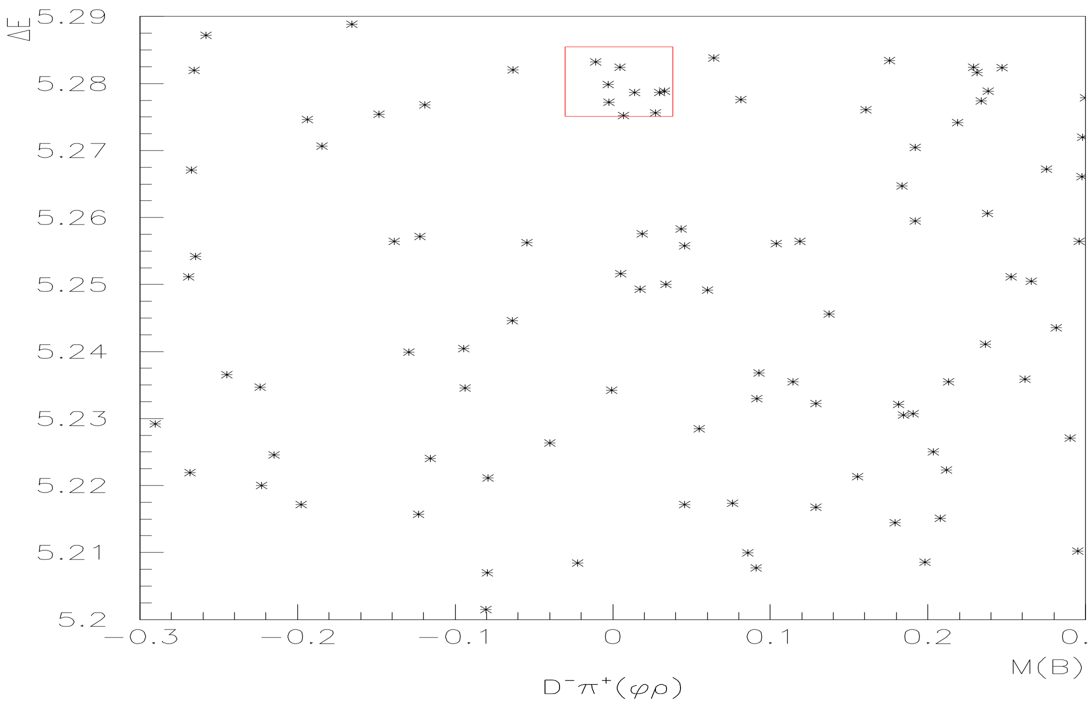
BB+QQ Generic MC (weights 0.315,0.375)

A Signal: $B^0 \to D^-\pi^+$ with $D^- \to \phi(K^+K^-)\rho^-$

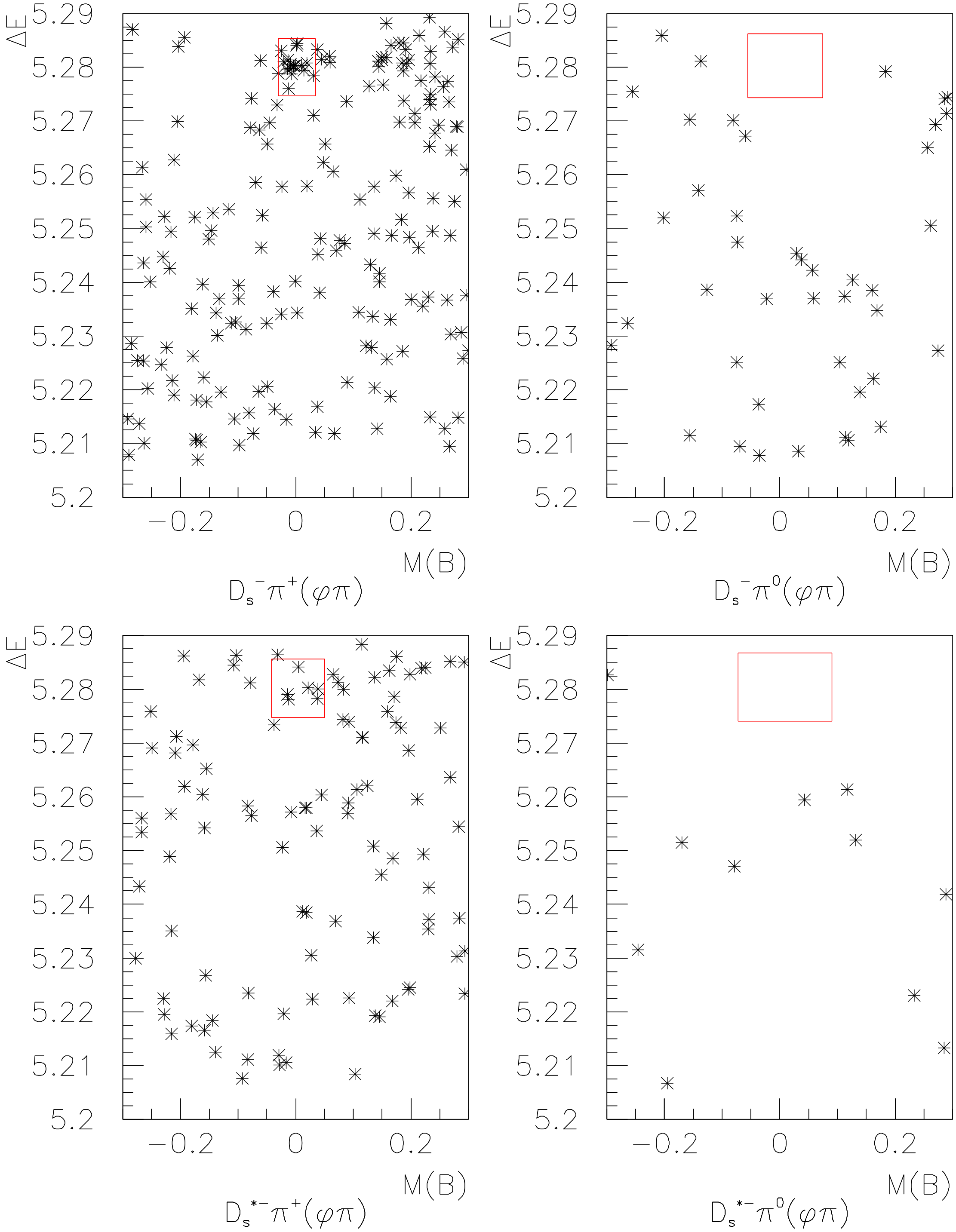


M_B,ΔE Data For $D^- \to \phi(\pi^-/\rho-)$

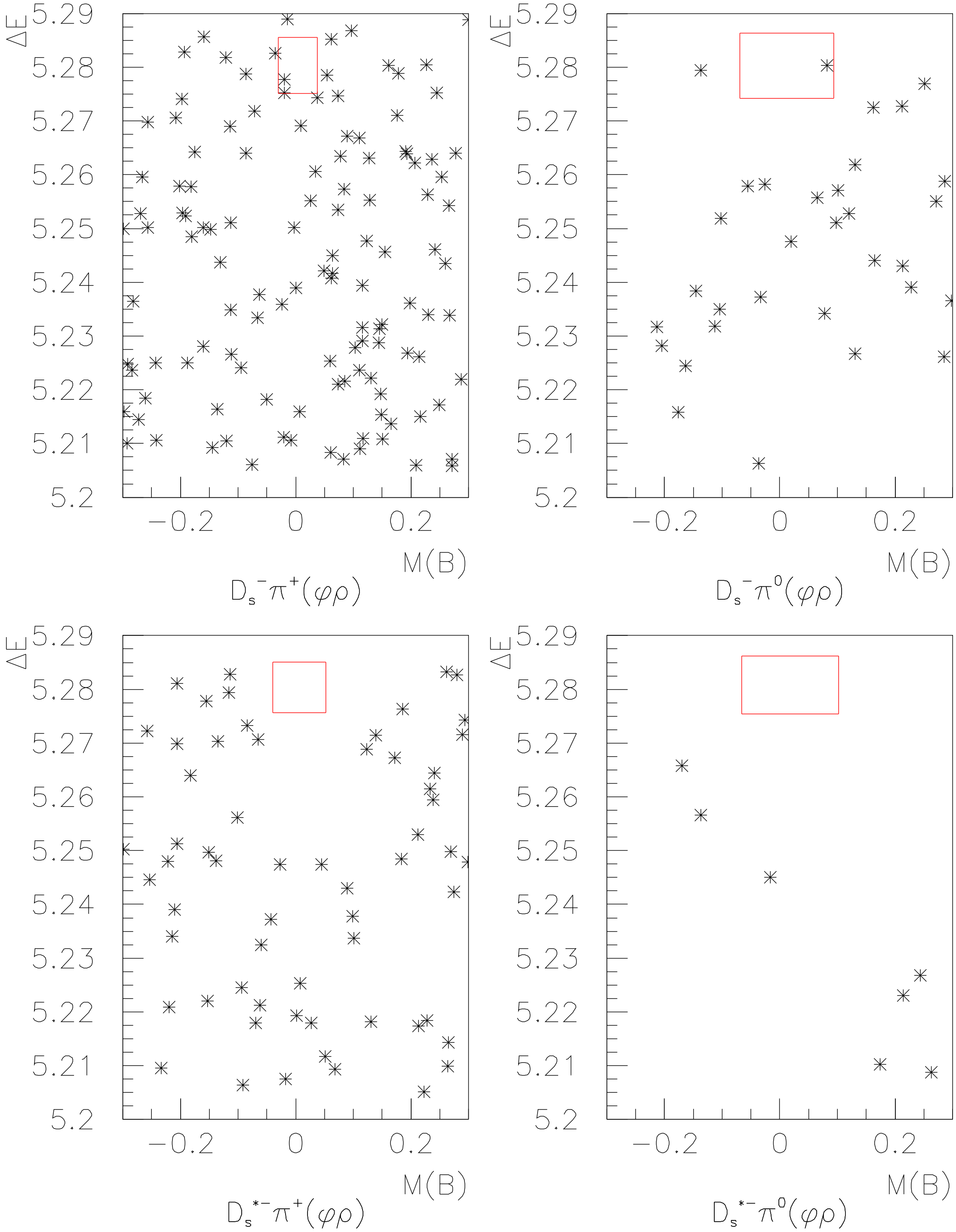




M_B,ΔE Data For $D_s^- \to \phi\pi^-$



M_B,ΔEData For $D_s^- \to \phi\rho^-$



$D_s^- \to \phi\pi^-$ **Channels**

Channel	$D_s^-\pi^+$	$D_s^-\pi^0$	$D_s^{*-}\pi^+$	$D_s^{*-}\pi^0$
$\lvert\delta M_B\rvert <$	5.4	6.2	5.4	6.3
$\lvert\Delta E\rvert <$	32	65	46	81
$\lvert\delta m(\phi)\rvert$	9.7	10.0	10.7	9.5
$\lvert\delta m(D_s)\rvert <$	13.5	12.5	11.3	10.8
$\lvert\delta(m(D_s^*) - m(D_s))\rvert <$			13.1	11.3
$\lvert\cos\theta_{helicity}(D_s^-)\rvert >$	0.33	0.33	0.33	0.32
$\lvert\cos\theta_B\rvert <$	0.92	0.92	0.91	0.92
Fisher$<$	0.75	0.71	0.79	0.69
$\cos\theta(\phi\pi_{fast} : D_s^-) >$	-0.81	-0.86	-0.82	-0.82
$\cos\theta_{helicity}(D_s^*) >$			-0.83	-.82
$D_s^*\ E_\gamma >$			91	81
$\cos\theta(\gamma(\pi^0_{fast})) <$	0.94	0.94	0.94	0.81
$R_2 + \lvert\cos\theta_{thrust}\rvert <$	1.32	1.24	1.30	1.21

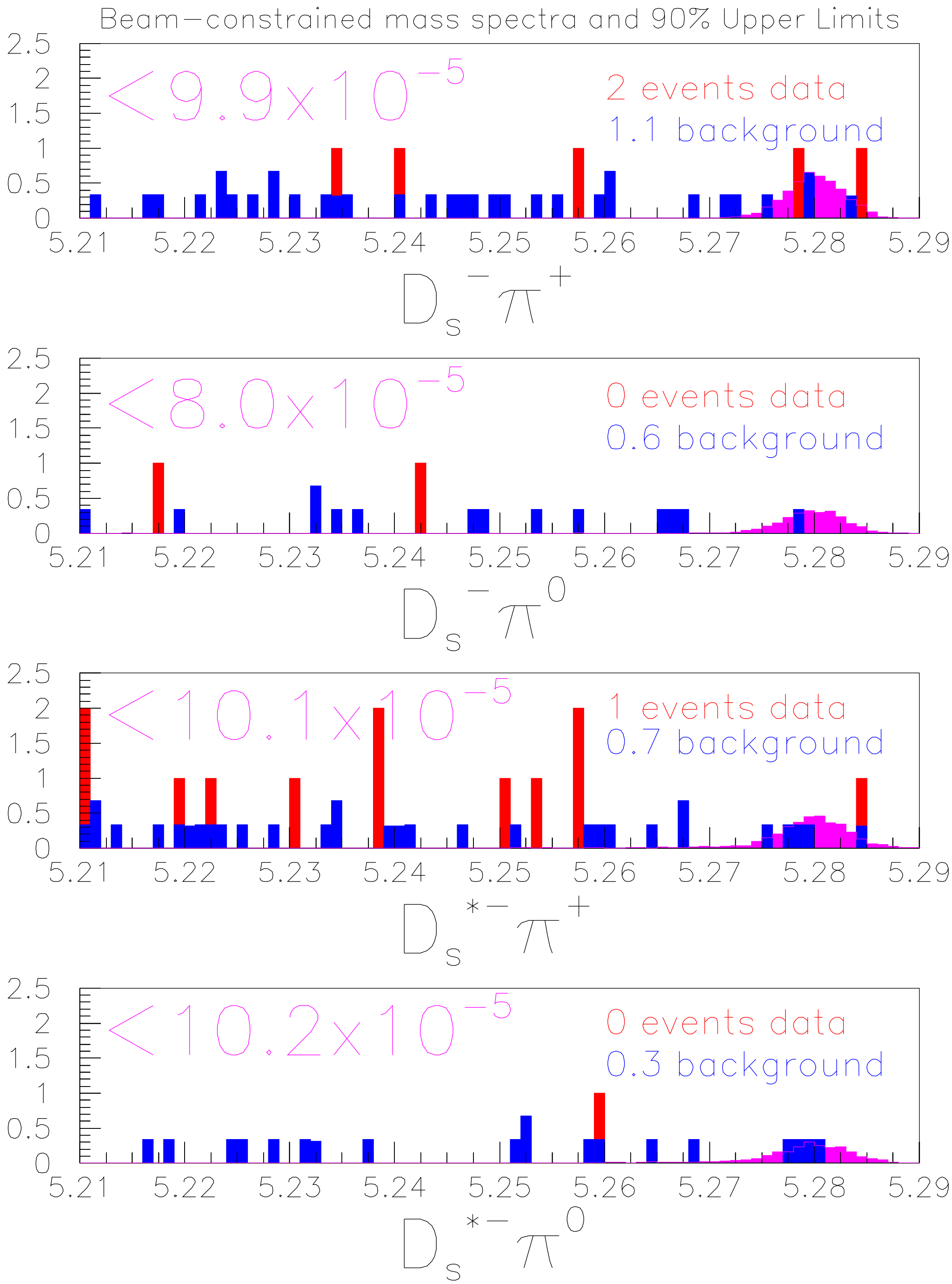
Table 1: Units for mass are MeV/c^2, units for momentum are MeV/c

$D_s^- \to \phi\rho^-$ Channels

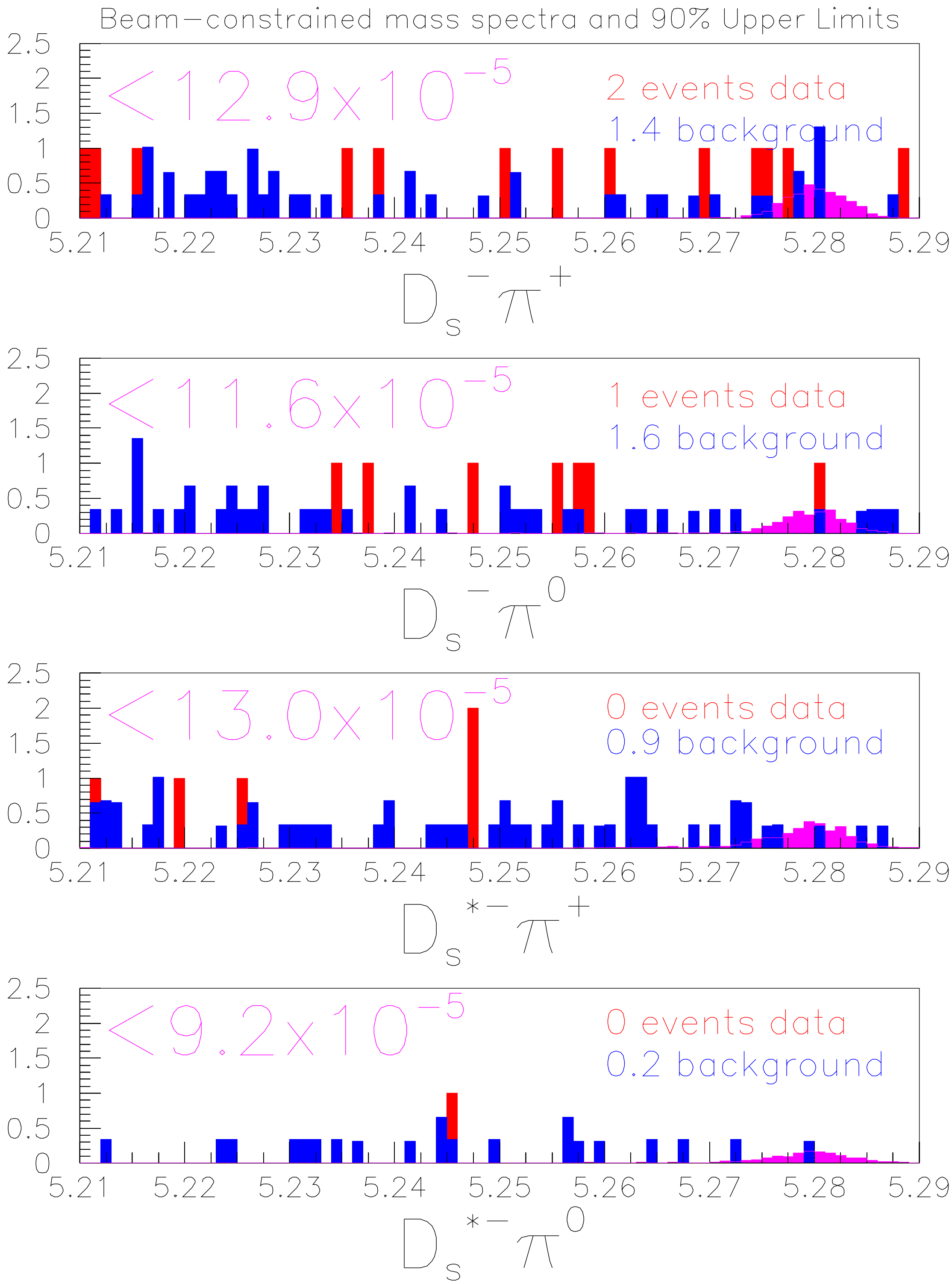
Channel	$D_s^-\pi^+$	$D_s^-\pi^0$	$D_s^{*-}\pi^+$	$D_s^{*-}\pi^0$
$\lvert\delta M_B\rvert <$	5.0	6.1	4.6	5.4
$\lvert\Delta E\rvert <$	34	81	46	84
$\lvert\delta m(\phi)\rvert$	10	8.8	7.9	8.2
$\lvert\delta m(D_s)\rvert <$	18	20	20	18
$\lvert\delta(m(D_s^*) - m(D_s))\rvert <$			11.7	13.1
$\lvert\cos\theta_B\rvert <$	0.9	0.9	0.9	0.9
$P(\pi^0) >$	250	270	250	190
Fisher<	0.78	0.68	0.77	0.66
$\cos\theta(\phi\pi_{fast} : D_s^-) >$	-0.93	-1.00	-0.99	-0.96
$\cos\theta_{helicity}(D_s^*) >$			-0.80	-.72
$D_s^*\ E_\gamma >$			85	100
$\cos\theta(\gamma(\pi^0_{fast})) <$	0.94	0.94	0.94	0.81
$R_2 + \lvert\cos\theta_{thrust}\rvert <$	1.26	1.19	1.29	1.13
Slow π_0 veto >	0.10	0.05	0.06	0.03
Slow π_0 γ shape >	0.82	0.82	0.82	0.82
Slow π_0 Endcap E_γ >	0.12	0.12	0.12	0.12

Table 2: Units for mass are MeV/c^2, units for momentum are MeV/c

Preliminary Results For $D_s^- \to \phi\pi^-$



Preliminary Results For $D_s^- \to \phi\rho^-$



Background Estimation

For a background estimate we take an average of several estimates:

- We count events in the Grand Side Band or GSB ($|\delta E| < 0.2\,\mathrm{GeV}$, $m_B > 5.2\,\mathrm{GeV/c^2}$) excluding the signal region (SR) and a safety margin of the same area around it. This number is scaled by the ratio of areas.
- We count events in D_s sidebands with m_B and δE in the SR, and scale linearly.
- We count events in D_s sidebands with m_B and δE in the GSB, and scale linearly.
- We count $B\bar{B}$ and $q\bar{q}$ generic MC events (and also cross-check consistency of the previous three methods)

Preliminary Results

$\rho\phi$ **Channels**	$D_s^-\pi^+$	$D_s^-\pi^0$	$D_s^{*-}\pi^+$	$D_s^{*-}\pi^0$
Data	2	1	0	0
Background	1.42	1.62	0.90	0.22
90% UL	4.17	3.08	2.3	2.3
MC @5×10^{-5}	1.62	1.33	0.89	1.25
$\mathcal{BR}(B \to D_s^{(*)}\pi)$	12.9×10^{-5}	11.6×10^{-5}	12.9×10^{-5}	9.2×10^{-5}
$\pi\phi$ **Channels**	$D_s^-\pi^+$	$D_s^-\pi^0$	$D_s^{*-}\pi^+$	$D_s^{*-}\pi^0$
Data	2	0	1	0
Background	1.07	0.64	0.72	0.29
90% UL	4.40	2.30	3.39	2.30
MC @5×10^{-5}	2.22	1.44	1.68	1.13
$\mathcal{BR}(B \to D_s^{(*)}\pi)$	9.9×10^{-5}	8.0×10^{-5}	10.1×10^{-5}	10.2×10^{-5}
$3\pi\phi$ **Channels**	$D_s^-\pi^+$	$D_s^-\pi^0$	$D_s^{*-}\pi^+$	$D_s^{*-}\pi^0$
Data	0	0	0	0
Background	0	0	0	0
90% UL	2.3	2.3	2.3	2.3
MC @5×10^{-5}	0.065	0.061	0.082	0.14
$\mathcal{BR}(B \to D_s^{(*)}\pi)$	177×10^{-5}	189×10^{-5}	140×10^{-5}	82×10^{-5}
$\Sigma\phi$ **Channels**	7.3×10^{-5}	5.3×10^{-5}	5.9×10^{-5}	4.6×10^{-5}

Preliminary Combined Results

With CLEO's 9.7×10^6 $B\bar{B}$s we determine upper limits, including only statistical contributions, of:

B decay topology	90% UL $\mathcal{BR}$		
	η channels	ϕ channels	All channels
$D_s^- \pi^0$	21.2×10^{-5}	5.4×10^{-5}	5.2×10^{-5}
$D_s^- \pi^+$	29.5×10^{-5}	7.5×10^{-5}	8.5×10^{-5}
$D_s^{*-} \pi^0$	27.9×10^{-5}	4.5×10^{-5}	4.8×10^{-5}
$D_s^{*-} \pi^+$	59.3×10^{-5}	8.9×10^{-5}	7.9×10^{-5}

Including systematics of about 30% (dominated by $\mathcal{BR}(D_s \to \phi\pi)$):

B decay topology	90% UL $\mathcal{BR}$ with systematics	CLEO 1992	Theory 1995 $V_{ub} = 0.0035$
$D_s^- \pi^0$	5.1×10^{-5}	$20. \times 10^{-5}$	2.7×10^{-5}
$D_s^- \pi^+$	8.9×10^{-5}	$27. \times 10^{-5}$	5.6×10^{-5}
$D_s^{*-} \pi^0$	3.9×10^{-5}	$32. \times 10^{-5}$	1.9×10^{-5}
$D_s^{*-} \pi^+$	7.5×10^{-5}	$44. \times 10^{-5}$	7.2×10^{-5}

Using the calculations of Z.Z.Xing (hep-ph/9502339) and assuming that $\mathcal{BR}(D_s^{(*)}\pi)$ scales as $|V_{ub}/V_{cb}|^2$ we estimate:

$$V_{ub}/V_{cb} < 0.135 \quad \textit{Preliminary} \qquad (3)$$

Theoretical and experimental uncertainties contributing to Xing's results total at least O(50%) (my estimate).

Items For The Near Future

There are several other channels included in our current skim that we have not yet finished analyzing:

- $\mathbf{B^0 \to D_s^{(*)\mp} K^\pm}$. This decay proceeds by W-exchange followed by popping an $s\bar{s}$ pair from the background. Predictions are $O(10^{-6})$. The analysis is basically identical to $D_s^{(*)-}\pi^+$.
- $\mathbf{B^\pm \to D_s^{*\pm}}\gamma$. This decay proceeds by W-annihilation. I have allready looked at the generic MC backgrounds for this process, it is very clean. Perhaps clean enough to increase the fraction of the D_s decays used to 25.4% using the η' channels.
- Introduce $D_s^- \to K_s^0 K^-, \overline{K^*} K^-$ channels - an increase of perhaps 20% in sensitivity.
- Move on to $B \to D_s^{(*)-}(\omega/\eta/\rho^\pm/a_1)$ decays, with larger predicted rates. However, more combinatorics intrude as well as $B \to D_s X_c$ contributions (which can also help check normalization).