Purely Leptonic Decays of Bottom and Charm Mesons

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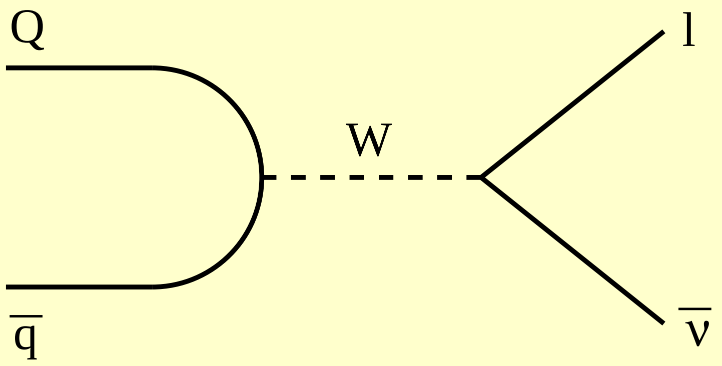
22-28 June
WIN 97, Capri

Leptonic decays of D_S^+ from:
BES,CLEO,E653,L3,WA75

Leptonic decays of B^+ from:
ALEPH,CLEO,L3

Introduction

Study decays of the type:



$$\Gamma = \frac{G_F^2 f_M^2 \left|V_{Qq}\right|^2 M_\ell^2 M_M}{8\pi} \left(1 - \frac{M_\ell^2}{M_M^2}\right)^2$$

- Purely leptonic decays give us access to $f_M \left|V_{Qq}\right|$
- f_M gives absolute normalization for various heavy flavor transitions.
  (for example, $B^0 - \overline{B^0}$ mixing $\Delta m \sim f_B^2 \left|V_{tb}^* V_{td}\right|^2$)
- Theoretical predictions * vary:

$$\begin{aligned} f_D &: \quad 120 - 290 \text{ MeV} \\ f_{D_S} &: \quad 130 - 360 \text{ MeV} \\ f_B &: \quad 120 - 290 \text{ MeV} \end{aligned}$$

*J.Richman and P.Burchat, *Rev.Mod.Phys.* **67**, 895(1995)

Introduction

Which decays are experimentally accessible?

Assume $f_B = f_{D_S} = 200$ MeV
and $|V_{cs}| = 0.97, |V_{ub}| = 0.003$

Decay channel	Branching Fraction
$D_S \to \tau\nu_\tau$	2×10^{-2}
$D_S \to \mu\nu_\mu$	3×10^{-3}
$D_S \to e\nu_e$	7×10^{-8}
$B \to \tau\nu_\tau$	7×10^{-5}
$B \to \mu\nu_\mu$	3×10^{-7}
$B \to e\nu_e$	7×10^{-11}

$$\begin{array}{ccc} \text{Theory} & & \text{Experiment} \\ f_{D_S} & \longleftarrow & f_{D_S} \\ \downarrow & & \\ f_B & & f_B \end{array}$$

... but $\mathcal{B}(B \to \ell\nu_\ell)$ could be enhanced by $H^\pm$.

$D_S^+ \to \mu^+\nu_\mu$ from CLEO

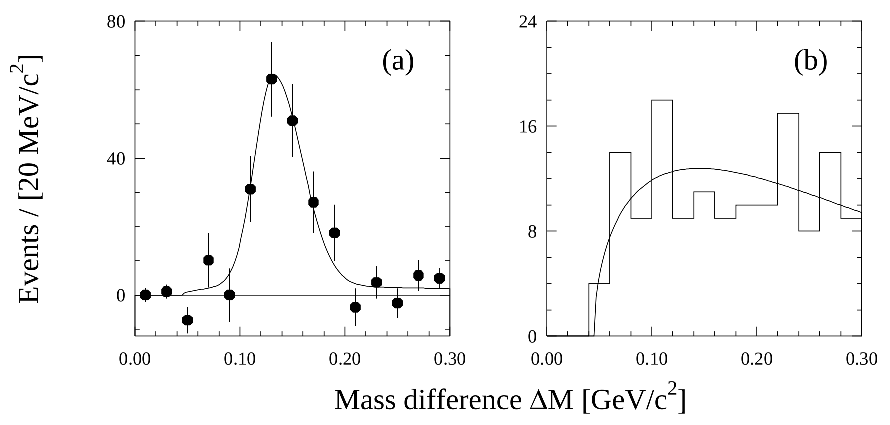
Use the decay chain:

$$D_S^{+*} \longrightarrow D_S^+\gamma$$
$$\hookrightarrow \mu^+\nu_\mu$$

- μ and γ directly observed
- p_ν computed from missing momentum in the hemisphere with μ
- Look for a signal in $\Delta M = M(\gamma\mu\nu) - M(\mu\nu)$

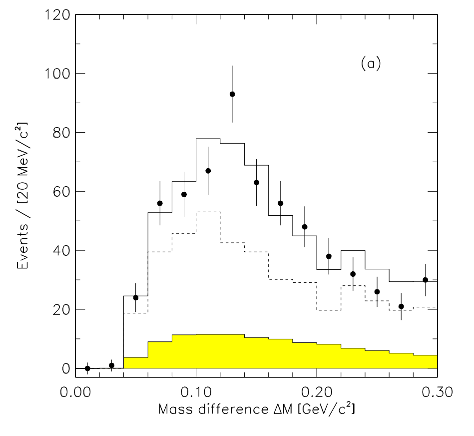
Evaluation of the method:

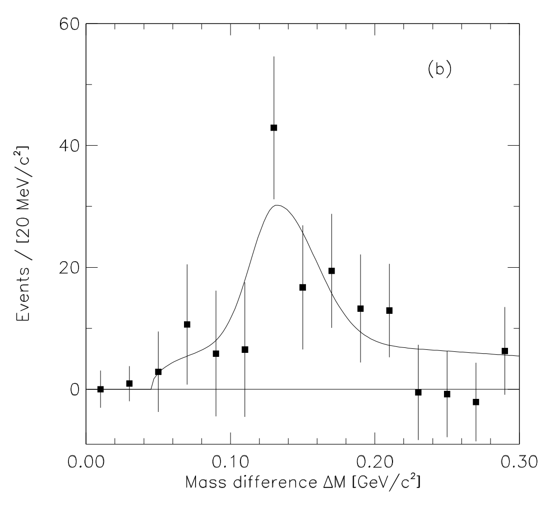
- Check $M(\mu\nu)$ using $D^{+*} \to D^0\pi^+$, $D^0 \to K^-\pi^+$
- Check ΔM using $D^{*0} \to \gamma D^0$, $D^0 \to K^-\pi^+$
- where K^- treated as μ, π^+ treated as ν



$D_S^+ \to \mu^+\nu_\mu$ from CLEO

Selected μ data





- (dashed line) Semileptonic background taken from events that pass selection, but have an identified e instead of μ. ($D_S \to e\nu$ helicity suppressed.)
- (shaded region) Excess μ fakes.
- (solid line) Likelihood fit with fixed background. Normalization of signal is floated, shape of signal from D^{+*}, D^{0*} samples.

$$\frac{\Gamma(D_S \to \mu\nu)}{\Gamma(D_S \to \phi\pi)} = 0.184 \pm 0.038 \pm 0.038$$

$$\boxed{f_{D_S} = (284 \pm 30 \pm 30 \pm 18)\ \text{MeV}}$$

CLEO CONF 95-22, also *Phys.Rev.***D49**,5690(1994)

$D_S^+ \to \tau^+\nu_\tau$ from L3

Use the decay chain:

$$\begin{aligned} D_S^{+*} &\longrightarrow D_S^+\gamma \\ &\hookrightarrow \tau^+\nu_\tau \\ &\qquad \hookrightarrow \ell^+\nu_\ell\bar{\nu}_\tau \end{aligned}$$

- e or μ and missing energy in hemisphere.
- Reconstruct D_S energy and direction from the rest of the event and M_{D_S}.
- Look for a signal in $M(\gamma D_S)$.

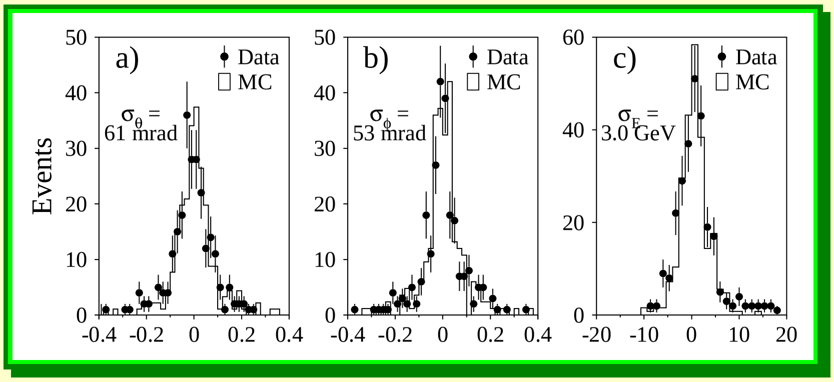
Conserve energy and momentum:

$$E_{D_S} = \sqrt{s} - \sum_{i\neq\ell} E_i, \;\; \vec{P}_{D_S} = -\sum_{i\neq\ell}\vec{P}_i$$

and constrain to D_S mass:

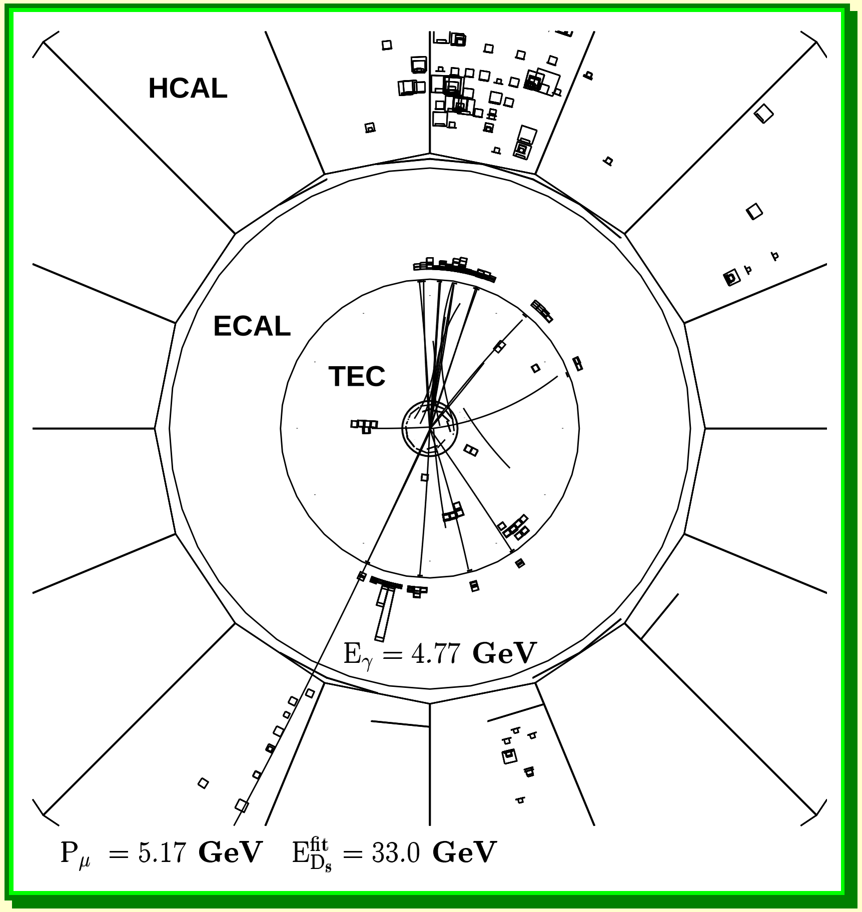
$$\chi^2 = \sum_{i\neq\ell}\frac{(E_i^{\text{fit}} - E_i^{\text{meas}})^2}{\sigma^2_{E_i^{\text{meas}}}}, \;\; \sqrt{E^2_{D_S} - \vec{P}^2_{D_S}} = M_{D_S}$$

- Check using $q\bar{q}\gamma$ events with a hard photon.
- Exclude the γ and reconstruct its energy and direction as above
- Now the constraint is $E_\gamma = P_\gamma$.



$D_S^+ \to \tau^+ \nu_\tau$ from L3

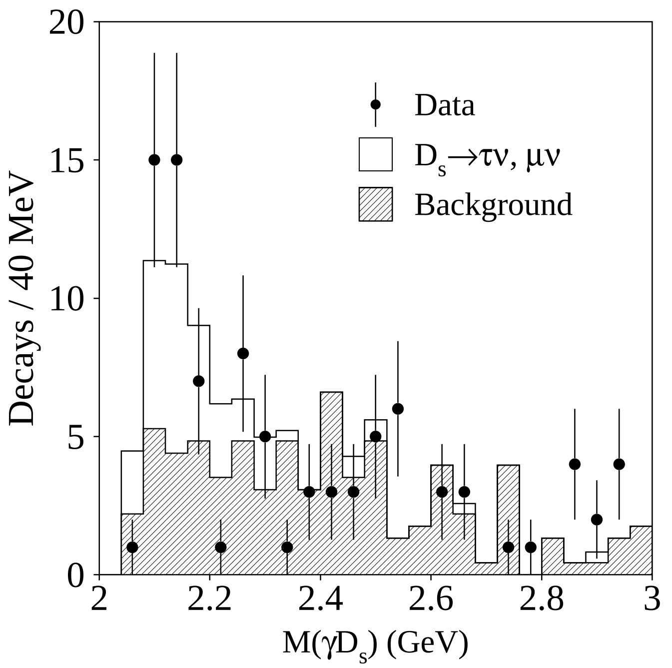
$D_S^* \to \gamma D_S, D_S \to \tau\nu, \tau \to \mu\nu\nu$



- Start with events with large missing E_T.
- Require e or μ in least energetic hemisphere.
- Other tracks point to IP
- $E_{D_S} > 30$ GeV. Energy of hadron that decays semileptonically is underestimated
- Energy of most energetic particle in hemisphere with charge opposite to lepton must have $E < 3\ GeV$. Suppress semileptonic D decays
- Combine D_S with photons in same hemisphere with $3\ GeV < E_\gamma < 5\ GeV$.

$D_S^+ \to \tau^+\nu_\tau$ from L3

Invariant mass distribution for selected events



(note $M_{D_S^*} \cong 2.11$ GeV)

Extract $N(D_S^{+*} \to \gamma D_S^+, D_S^+ \to \tau^+\nu_\tau)$ using a binned maximum likelihood fit with background fixed to the MC prediction.

$$\mathcal{B}(D_S^+ \to \tau^+\nu_\tau) = (7.4 \pm 2.8 \pm 1.6 \pm 1.8)\%$$

$$\boxed{f_{D_S} = 309 \pm 58 \pm 33 \pm 38 \text{ MeV}}$$

*Phys.Lett.***B396**,327 (1997)

$D_S^+ \to \mu^+(\tau^+)\nu_\mu(\nu_\tau)$ from BES

$$e^+e^- \to D_S^+ D_S^- \qquad \sqrt{s} = 4.03 GeV$$

• Tag one D_S by fully reconstructing:

$$\begin{array}{cccc} D_S^+ & \to & \phi\pi^+ & \phi \to K^+K^- \\ & \to & \overline{K^*}K^+ & \overline{K^*} \to K^-\pi^+ \\ & \to & \overline{K^0}K^+ & \overline{K^0} \to \pi^+\pi^- \end{array}$$

• Look for single track consistent with e or μ on the recoil side, and find:

2	μ candidates	$(D_S \to \mu\nu, D_S \to \tau\nu$	$\tau \to \mu\nu\nu)$
1	e candidate	$(D_S \to \tau\nu$	$\tau \to e\nu\nu)$

• From fit that accounts for expected missing mass in $D_S \to \mu\nu$ vs. that in $D_S \to \tau\nu$:

$$\begin{aligned} \mathcal{B}(D_S \to \mu\nu) &= 2.0^{+4.4}_{-1.7}\% \\ \mathcal{B}(D_S \to \tau\nu) &= 12^{+20}_{-10}\% \end{aligned}$$

• Assume lepton universality and account for helicity suppression:

$$\mathcal{B}(D_S \to \mu\nu) = 1.5^{+1.3}_{-0.6}{}^{+0.3}_{-0.2}\%$$

$$\boxed{f_{D_S} = (430^{+150}_{-130}{}^{+40}_{-40})\ \text{MeV}}$$

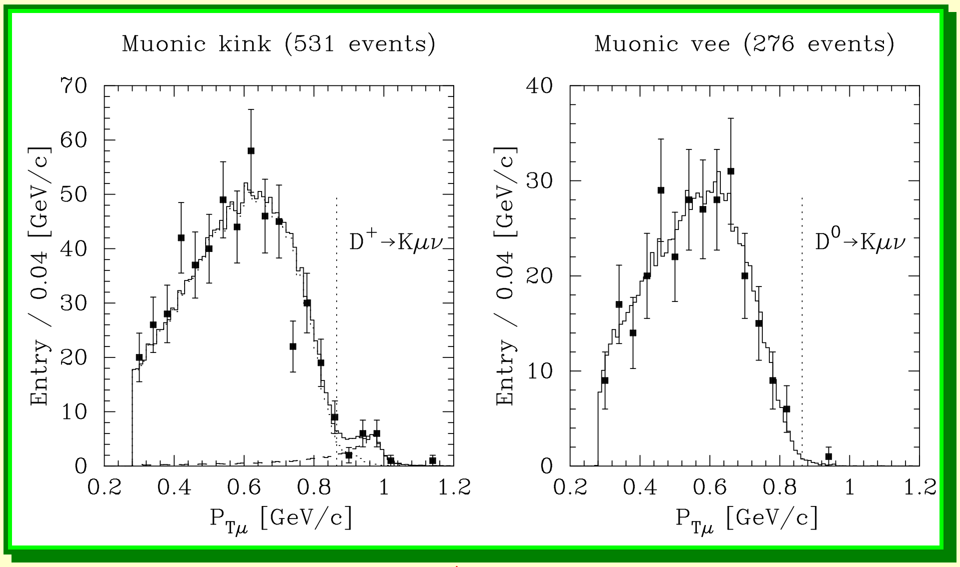
N.B. This method is not normalized to other D_S modes.

Phys.Rev.Lett **74**,4599 (1995)

$D_S^+ \to \mu^+\nu_\mu$ from E653

- Produce charm particles with 600 GeV π's on an emulsion target
- μ trigger to provide enriched sample of semi-muonic decays ($P_{T\mu}^{\mathrm{beam}} > 0.8$ GeV)
- Scan emulsions (with guidance from downstream electronic detectors) and analyze 2 topologies:

Charged $\to$ 1 prong Neutral $\to$ 2 prong



Kinematic limit for $D^+ \to K\mu\nu < 0.865$ GeV

$$\frac{\Gamma(D_S \to \mu\nu)}{\Gamma(D_S \to \phi\mu\nu)} = 0.16 \pm 0.06 \pm 0.03$$

$$\boxed{f_{D_S} = (195 \pm 35 \pm 20 \pm 24)\ \text{MeV}}$$

WA75 (similar experiment) reported the first observation of $D_S^+ \to \mu^+\nu_\mu$: $f_{D_S} = (232 \pm 45 \pm 20 \pm 48)$ MeV

*Phys.Lett.***B382**,299(1996) and *Prog.Theor.Phys.***89**,131 (1993)

$D_S^+ \to \tau^+ \nu_\mu$ from E653

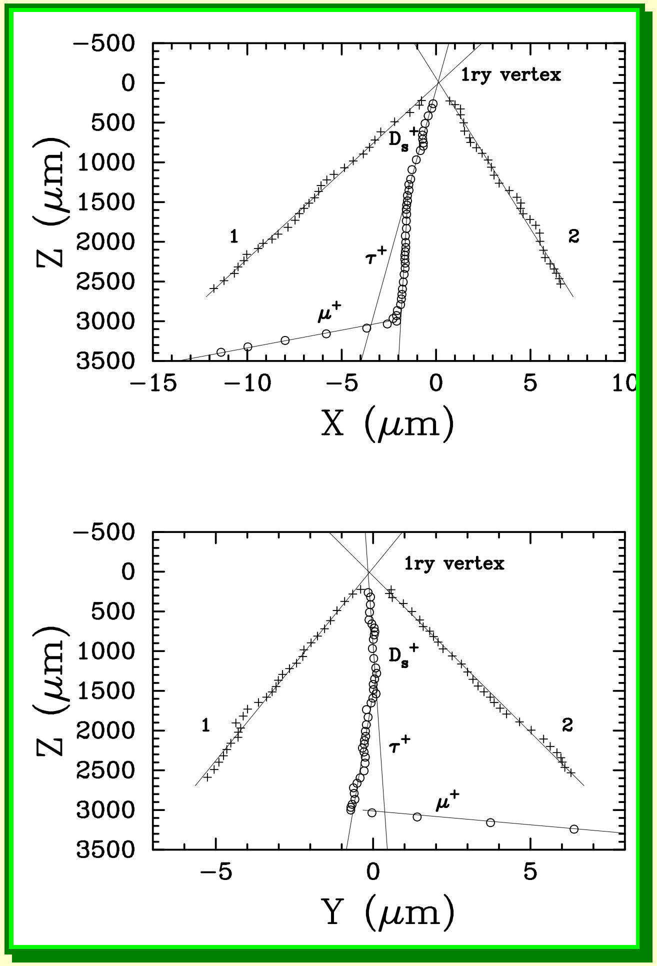
$$D_S^+ \to \tau^+ \nu_\tau$$
$$\tau^+ \to \mu^+ \nu_\mu \nu_\tau$$

- primary and decay vertices lie in emulsion
- $\delta\theta(D_S - \tau) \sim 1 - 5$ mrad, which is resolvable
- 4 candidate events

Preliminary Result:

$$\mathcal{B}(D_S^+ \to \tau^+ \nu_\tau) = 3.9 \pm 2.5 \pm 0.9 \pm 1.0\%$$

$$\boxed{f_{D_S} = 224 \pm 62 \pm 24 \pm 28 \text{ MeV}}$$

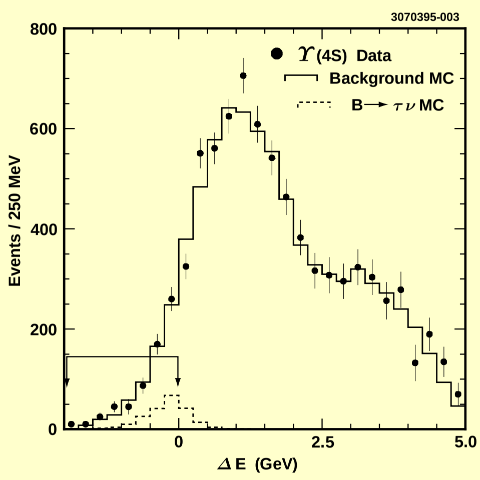


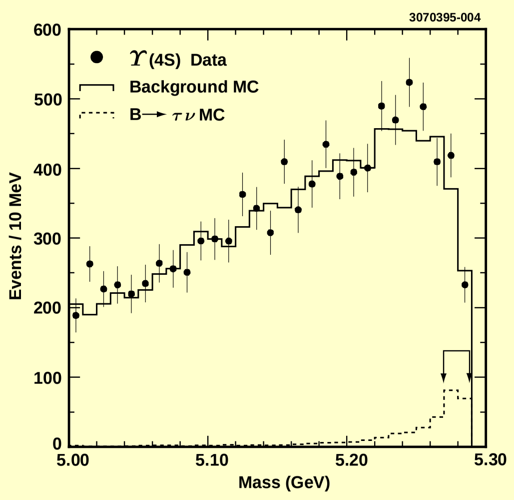
Search for $B^+ \to \ell^+ \nu_\ell$ from CLEO

Search for $B^+ \to \mu^+\nu_\mu$,$B^+ \to e^+\nu_e$,
$B^+ \to \tau^+\nu_\tau$, $\tau \to \ell\overline{\nu}_\tau\nu_\ell$

- Single lepton
- Remaining particles consistent with decay of a 2'nd B:

$$
\begin{aligned}
M &= (E_{\text{beam}}^2 - \vec{p}_2^{\,2})^{1/2} \cong M_B \\
\Delta E &= E_2 - E_{\text{beam}} \cong 0
\end{aligned}
$$





- 2-D fit in E and ΔM to determine $\mathcal{B}^+ \to \tau^+\nu_\tau$
- Additional constraint $p_\ell^* = M_B/2$ for $B^+ \to \mu^+\nu_\mu$,$B \to e^+\nu_e$

No evidence for a signal. Set 90% C.L. limits:

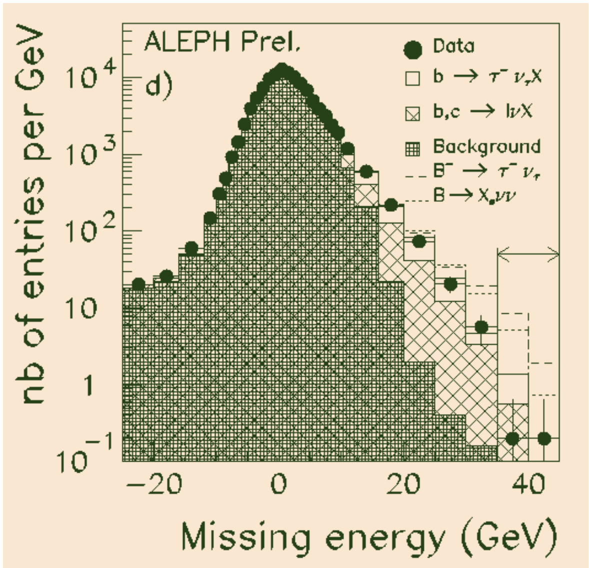
$\mathcal{B}(B^+ \to \tau^+\nu_\tau) < 2.2 \times 10^{-3}$ $\quad \mathcal{O}10^{-5}$
$\mathcal{B}(B^+ \to \mu^+\nu_\mu) < 2.1 \times 10^{-5}$ $\quad \mathcal{O}10^{-7}$
$\mathcal{B}(B^+ \to e^+\nu_e) < 1.5 \times 10^{-5}$ $\quad \mathcal{O}10^{-11}$

*Phys.Rev.Lett.***75**,785 (1995)

Search for $B^+ \to \tau^+\nu_\tau$ from ALEPH

Search for $b \to B^+ \to \tau^+\nu_\tau, \tau^+ \to h^+\overline{\nu}_\tau$

- Veto event halves with identified e or μ
- Lifetime tag on opposite hemisphere to further reject non-b events
- Look for events halves with large missing energy



Observe 2 candidate events in signal region with 7.1 ± 4.2 expected from background.

To be conservative, perform no background subtraction:

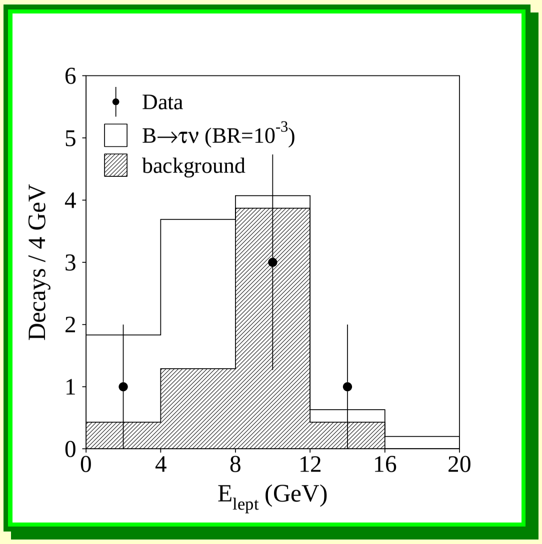
$$\mathcal{B}(B^+ \to \tau^+\nu_\tau) < 1.6 \times 10^{-3} \text{ at } 90\% C.L.$$

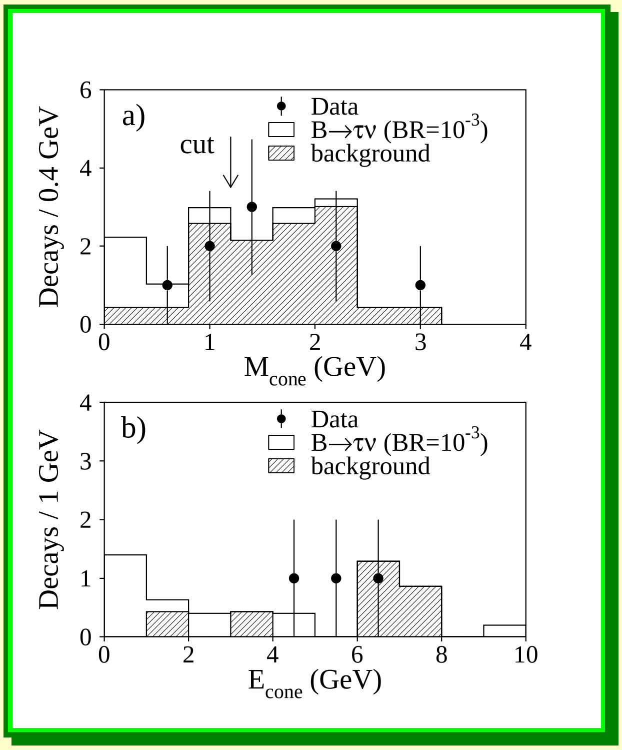
PA10-019 Preliminary

$B^+ \to \tau^+\nu_\tau$ from L3

Search for $b \to B^+ \to \tau^+\nu_\tau, \tau \to X\overline{\nu}_\tau$

- Lepton or hadron with $E > 1\ GeV$ in least energetic hemisphere.
- Associated track must not point to IP ($> 4\sigma$ away).
- B^+ energy reconstructed (in the same way as D_S^+); require $E_{B+} > 30\ GeV$.
- For hadrons, low energy and invariant mass in cone around τ decay product.

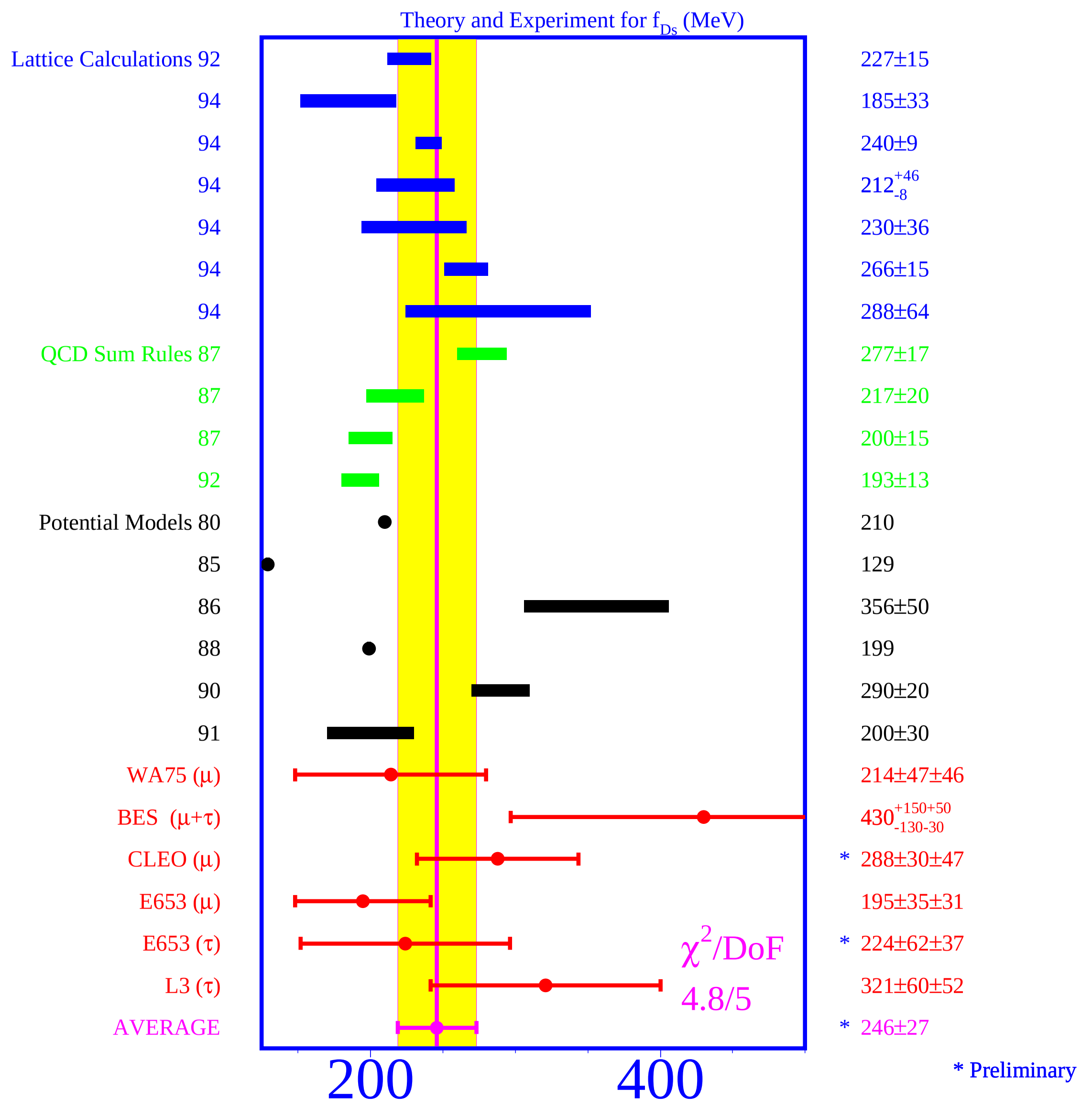




No evidence for a signal.
Extract limit from a fit to lepton and hadron energy spectra.

$$\mathcal{B}(B^+ \to \tau^+\nu_\tau) < 5.6 \times 10^{-4} \text{ at } 90\% C.L.$$

Summary of f_{D_S}



Note: Measurements from CLEO, E653, WA75 are corrected for more recent measurements of the branching fractions used for their normalizations.

$$\boxed{f_{D_S} = 246 \pm 27 \text{ MeV}}$$

Summary

Much progress in last few years measuring f_{D_S}

- Sample of $\sim 100\ D_S \to \tau/\mu\nu$ decays
- $f_{D_S} = 246 \pm 27$ MeV (preliminary)

No signal observed for $B \to \tau\nu$

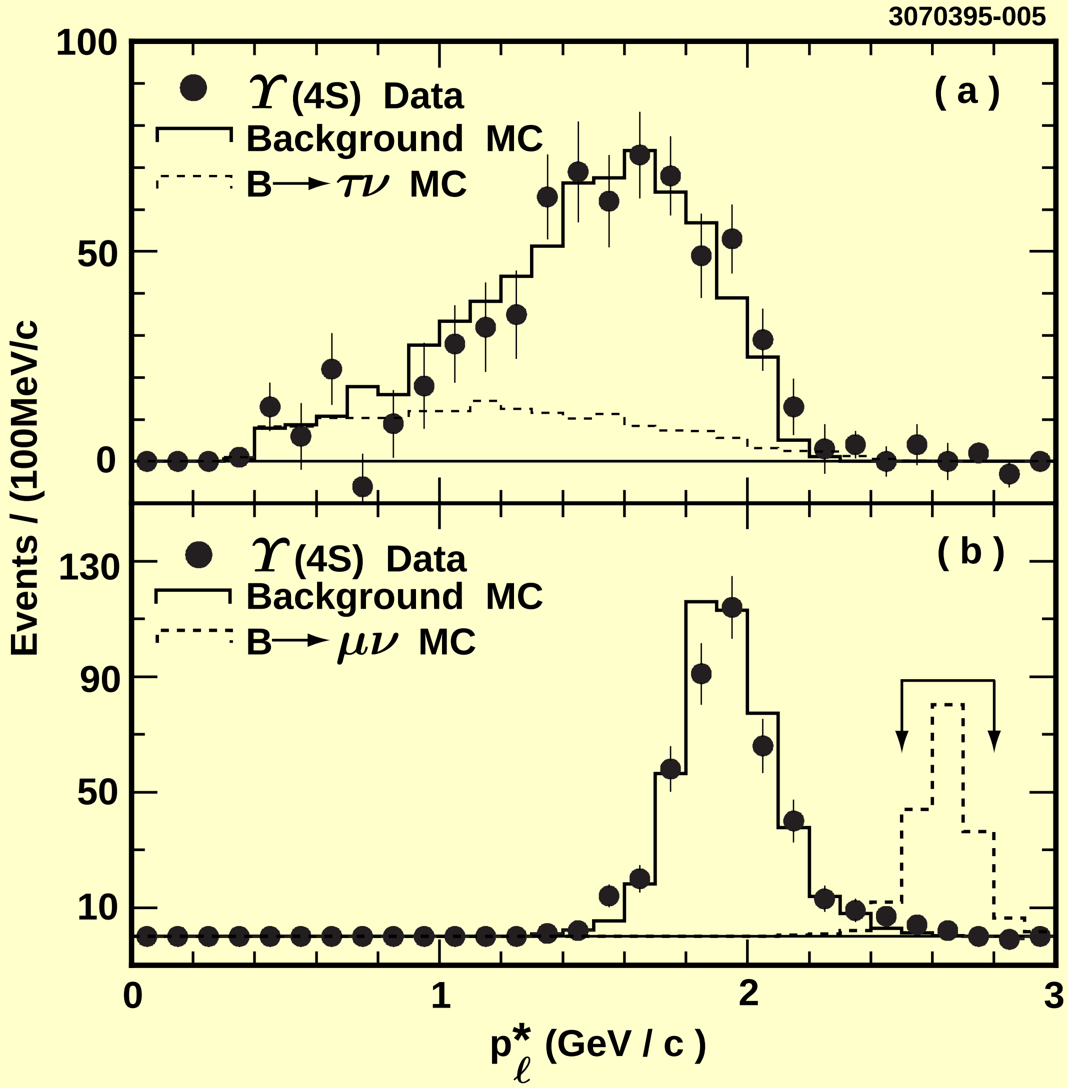
- $\mathcal{B}(B \to \tau\nu) < 5.6 \times 10^{-4}$ is about an order of magnitude above expected values.
- In type II Higgs models, $H^{\pm}$ could enhance this mode: $\tan\beta/M_{H^{\pm}} < 0.38\ GeV^{-1}$ at 90% CL*
- Look forward to future CLEO, BaBar, BELLE for f_B measurement.

*limit assumes $f_B = 190$ MeV and $|V_{ub}| = 0.0033 \pm 0.0008$

CLEO systematics on width ratio

Source of error	Value	Size of error (%)
muon fake rate	$(0.73 \pm 0.07)\%$	12
electron fake rate	$(0.25 \pm 0.04)\%$	8
μ/e normalization	1.04 ± 0.03	9
Detection efficiency	$(2.6 \pm 0.2)\%$	7
D_S^{*+}/D_S^+ prod. ratio	1.03 ± 0.2	11
$\phi\pi^+$ normalization	$9740 \pm 620 \pm 580$	6
Total		21

CLEO plot of p_ℓ^* in $B \to \ell\nu search$



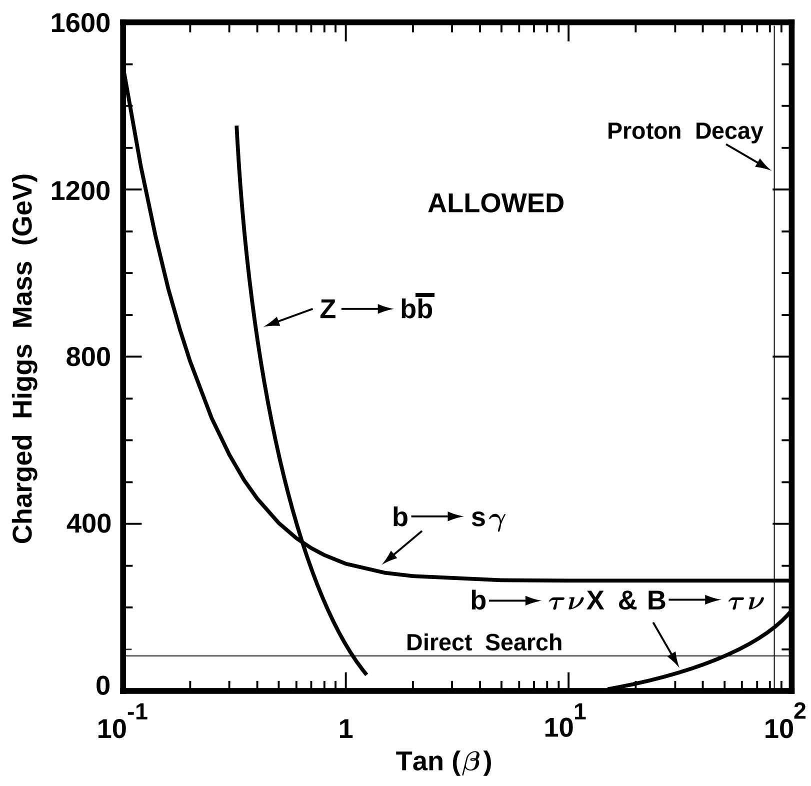
Limits on $H^{\pm}$

For Type II Two Higgs doublet models:

$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}(B \to \tau\nu)_{SM} \left[1 - \frac{M_B^2}{M_H^2} \tan^2\beta \right]$$

Assume $f_B = 190$ MeV and $|V_{ub}| = 0.0033 \pm 0.0008$:

$$\frac{\tan^2\beta}{M_{H^\pm}} < 0.38 \text{ at } 90\% \text{ CL.}$$



CLEO CONF 96-16

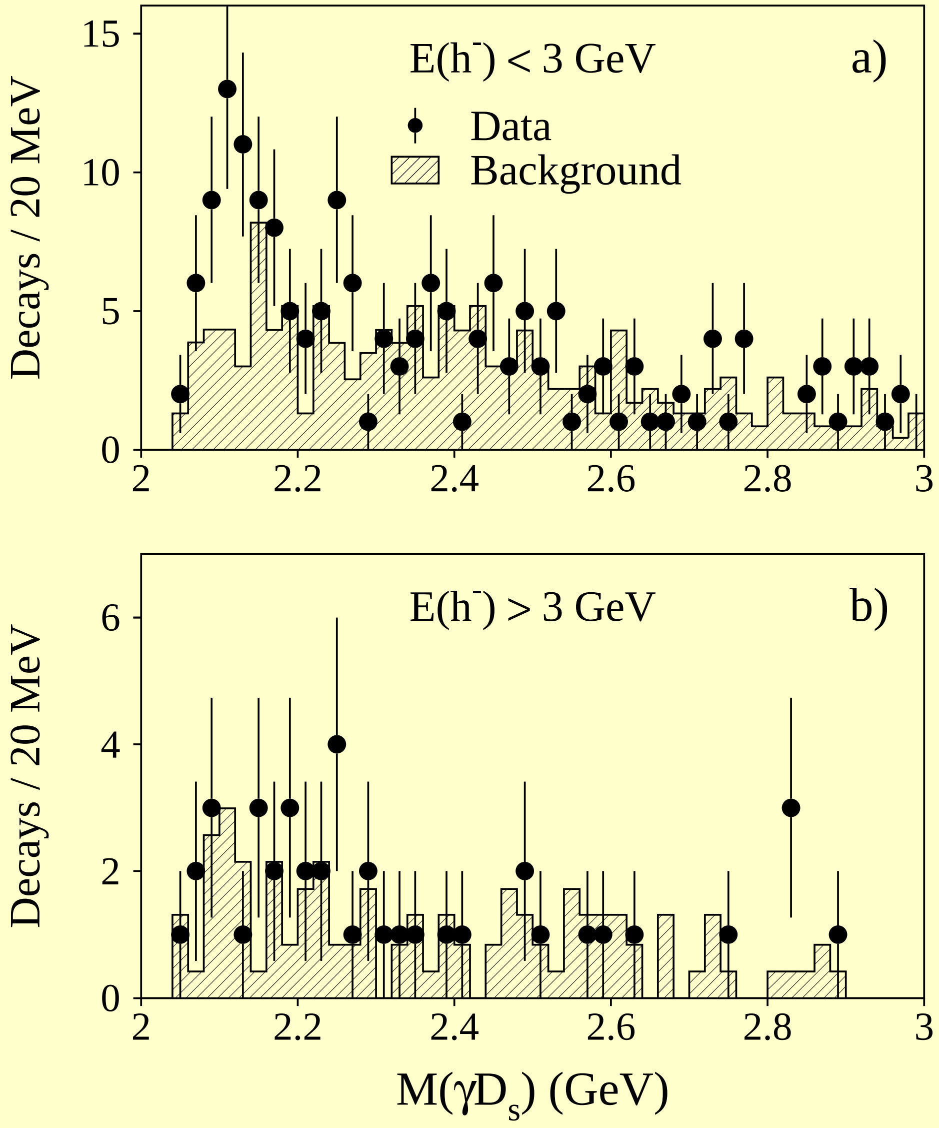
Errors

Systematic uncertainties for $D_S \to \tau\nu$:

Source		ΔN
	resolution fcn	1.6
Systematics	efficiency (stat)	2.5
	efficiency (frag)	1.6
	background (Br frac.)	0.5
	background (frag)	0.6
	$\mathcal{B}(D^* \to \pi^0 \mathrm{D_s^-})$	0.3
Subtotal	ΔN	3.4
Normalisation	$\mathrm{D_s^*/D_s}$ frac	2.4
	$\mathrm{D_s}/c$ frac	2.8
Subtotal	ΔN	3.7

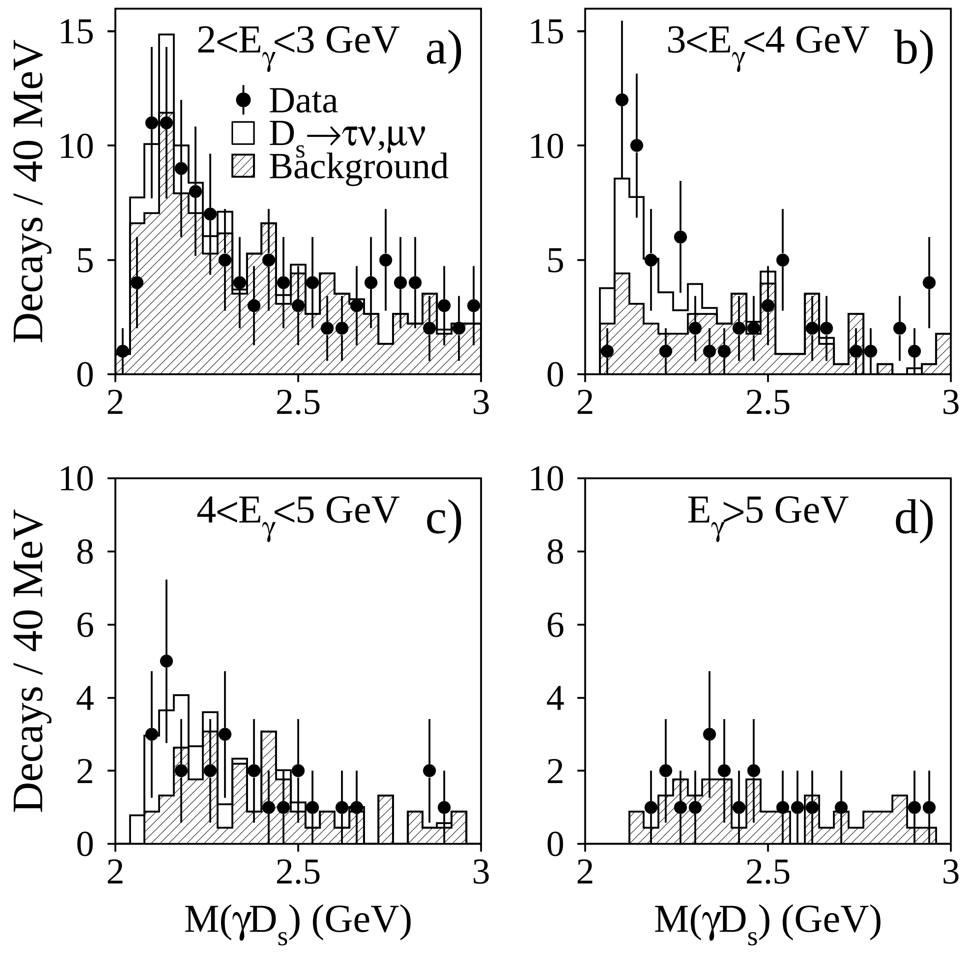
Crosschecks for $D_S \to \tau\nu$

$E(h^-)$ is energy of the most energetic particle with charge opposite to that of the lepton. $E(h^-) > 3\ GeV$ is mostly from semileptonic background, since the hadron in this case originates from the primary quark and so tends to higher energies. If the peak were an artifact, it should appear in both plots.



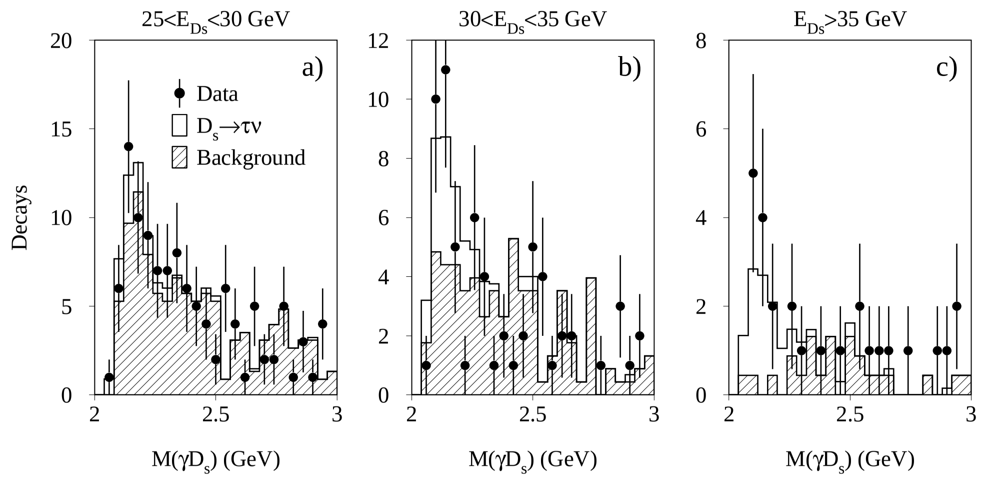
Crosschecks for $D_S \to \tau\nu$

Peak appears only in region of γ energies that are kinematically allowed in $D_S^* \to \gamma D_S$.



Cross checks for $D_S \to \tau\nu$

$E_{D_S} < 30\ GeV$ is swamped by semileptonic background, and there is no sign of a signal there.



Summary of branching fractions

$D_S \to \tau\nu_\tau$

Experiment	Branching Fraction (%)
E653	$3.9 \pm 2.5 \pm 0.9 \pm 1.0$
BES	12^{+20}_{-10}
L3	$7.4 \pm 2.8 \pm 1.6 \pm 1.8$

$D_S \to \mu\nu_\mu$

Experiment	Branching Fraction (%)
WA75	$0.37 \pm 0.16 \pm 0.07 \pm 0.19$
E653	$0.30 \pm 0.12 \pm 0.06 \pm 0.08$
CLEO	$0.66 \pm 0.14 \pm 0.14 \pm 0.17$
BES	$2.0^{+4.4}_{-1.7}$
BES combined	$1.5^{+1.3+0.3}_{-0.6-0.2}$

Branching for WA75,CLEO,E653 have been corrected for more recent measurements of the branching fractions used for normalization.