Measurement of $D_S^+ \to \tau^+\nu_\tau$ and Search for $B^+ \to \tau^+\nu_\tau$

with the L3 detector at LEP

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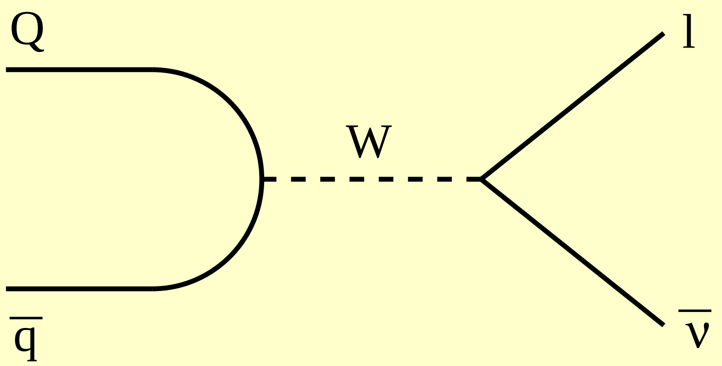
Introduction

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:

$$\begin{array}{rcl} f_D & : & 120 - 290 \ \ \mathrm{MeV} \\ f_{D_S} & : & 130 - 360 \ \ \mathrm{MeV} \\ f_B & : & 120 - 290 \ \ \mathrm{MeV} \end{array}$$

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

Introduction

Which decays are experimentally accessible?

Assume $f_B = f_{D_S} = f_D = 200$ MeV
and $|V_{cd}| = 0.21, |V_{cs}| = 0.97, |V_{ub}| = 0.003$

Decay channel	Branching Fraction
$D \to \tau\nu_\tau$	8×10^{-4}
$D \to \mu\nu_\tau$	3×10^{-4}
$D \to e\nu_e$	7×10^{-9}
$D_S \to \tau\nu_\tau$	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 $H^\pm$.

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

At LEP D_S is produced in $Z \to c\bar{c}$ decays
Use the 1994 data sample:

- $\mathcal{L} = 49.6\mathrm{pb}^{-1}$ at $\sqrt{s} = 91.2$ GeV.
- $\approx 1.475M\ q\bar{q}(\gamma)$ events.

Analyze the fragmentation and decay chain:

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

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

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D_S Reconstruction

The only visible decay product of D_S is the ℓ

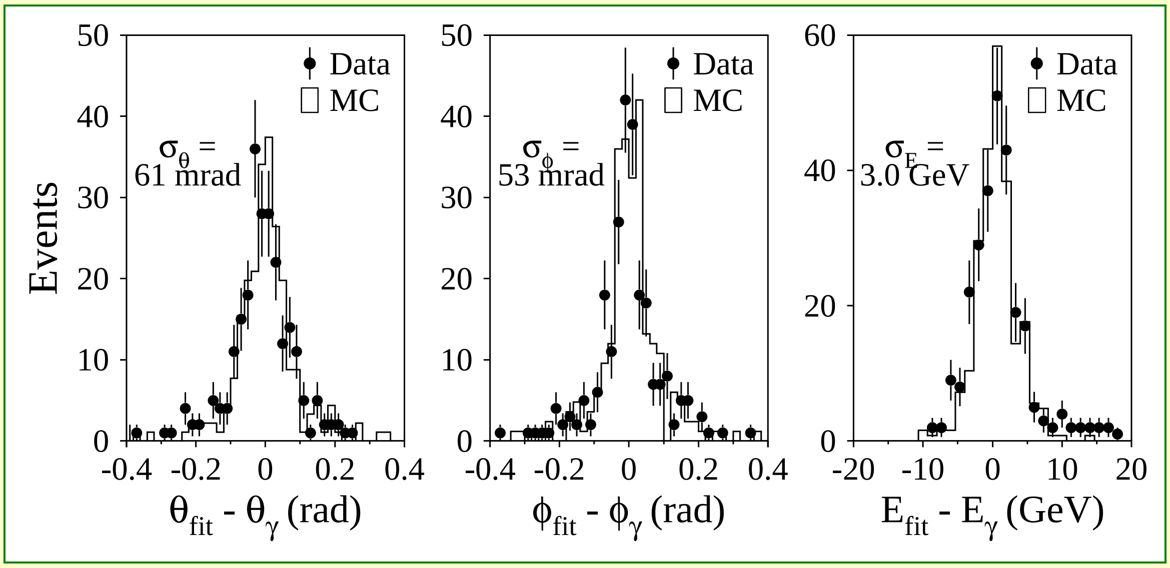
Conserve energy and momentum:

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

and constrain to D_S mass:

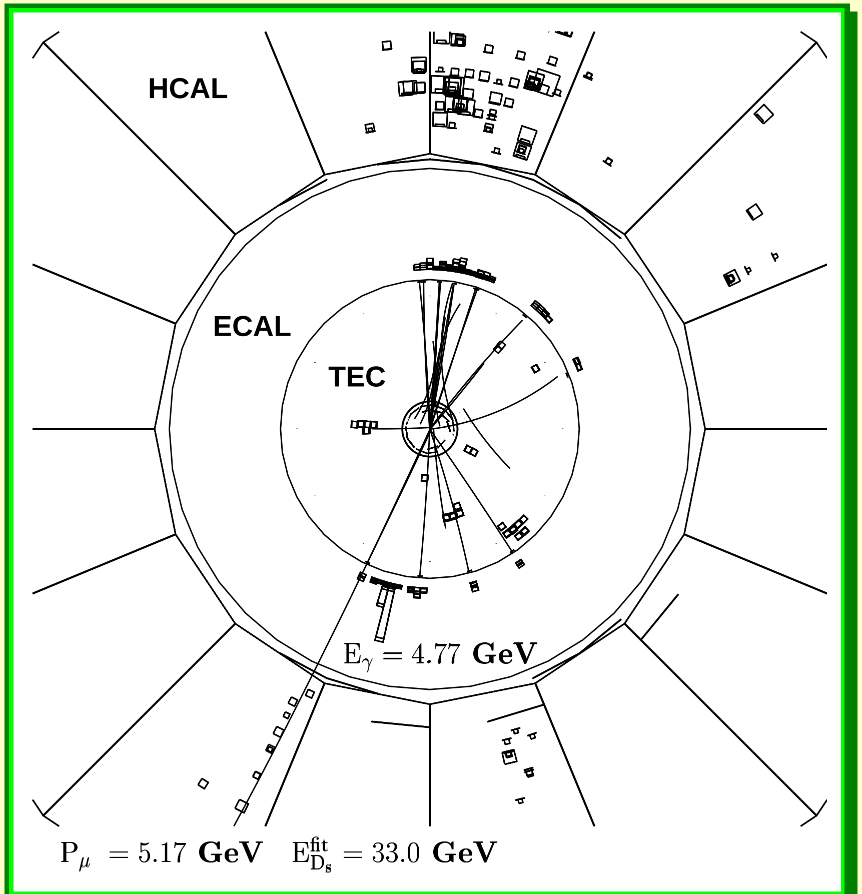
$$\chi^2 = \sum_{i \neq \ell} \frac{(E_i^{\rm fit} - E_i^{\rm meas})^2}{\sigma^2_{E_i^{\rm meas}}}, \;\; \sqrt{E_{D_S}^2 - \vec{P}_{D_S}^2} = M_{D_S}$$

- 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

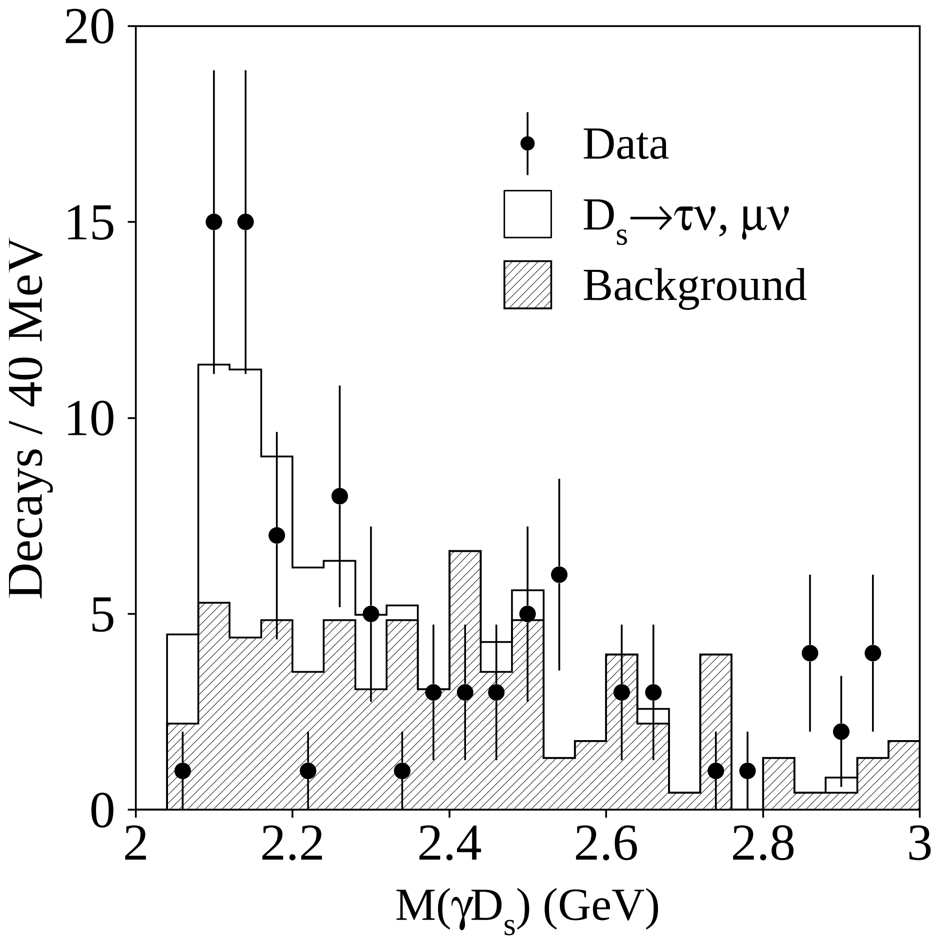
$D_S^* \to \gamma D_S, D_S \to \tau\nu, \tau \to \mu\nu\nu$



- 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 $3 \text{ GeV} < E_\gamma < 5 \text{ GeV}$.

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

Invariant mass distribution for selected events

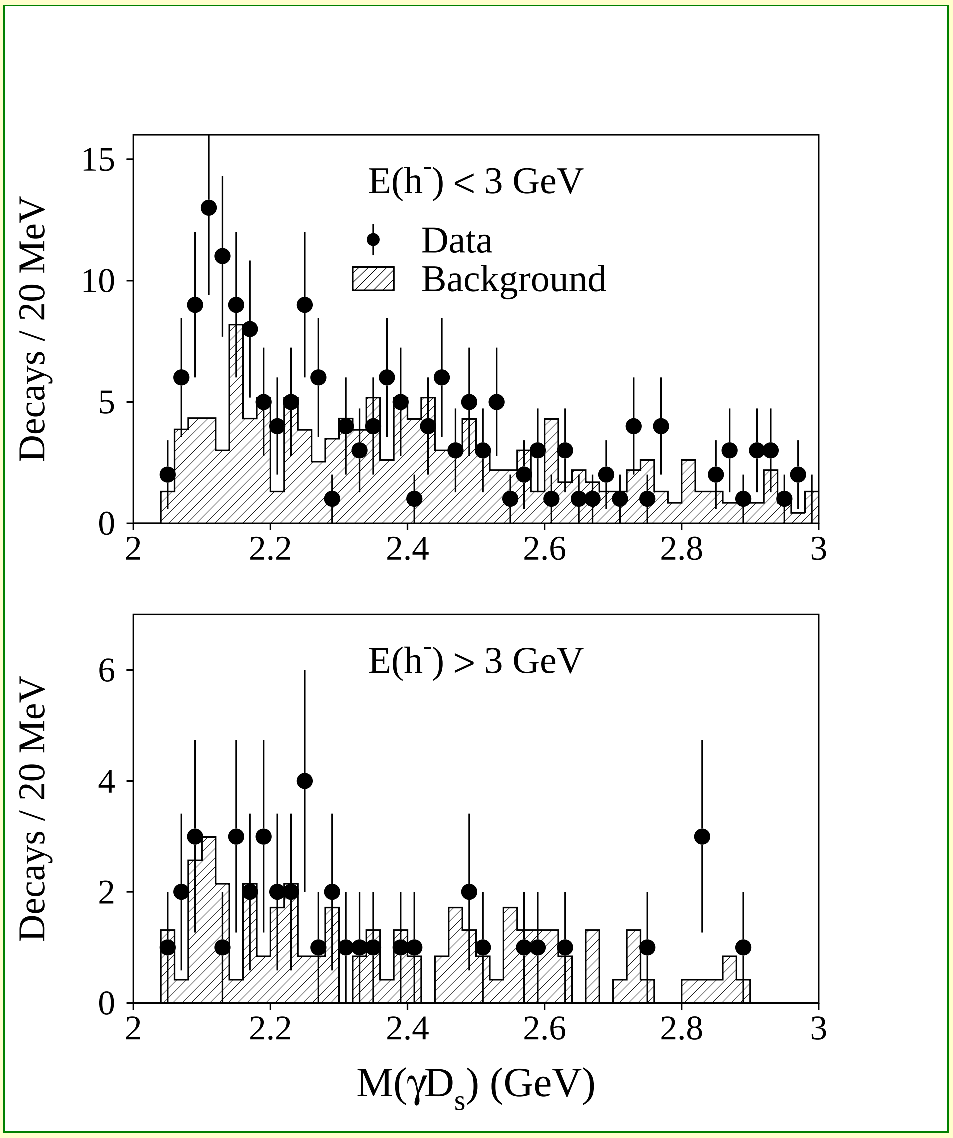


(note $M_{D_S^*} \cong \mathbf{2.11}$ GeV)

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.

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.



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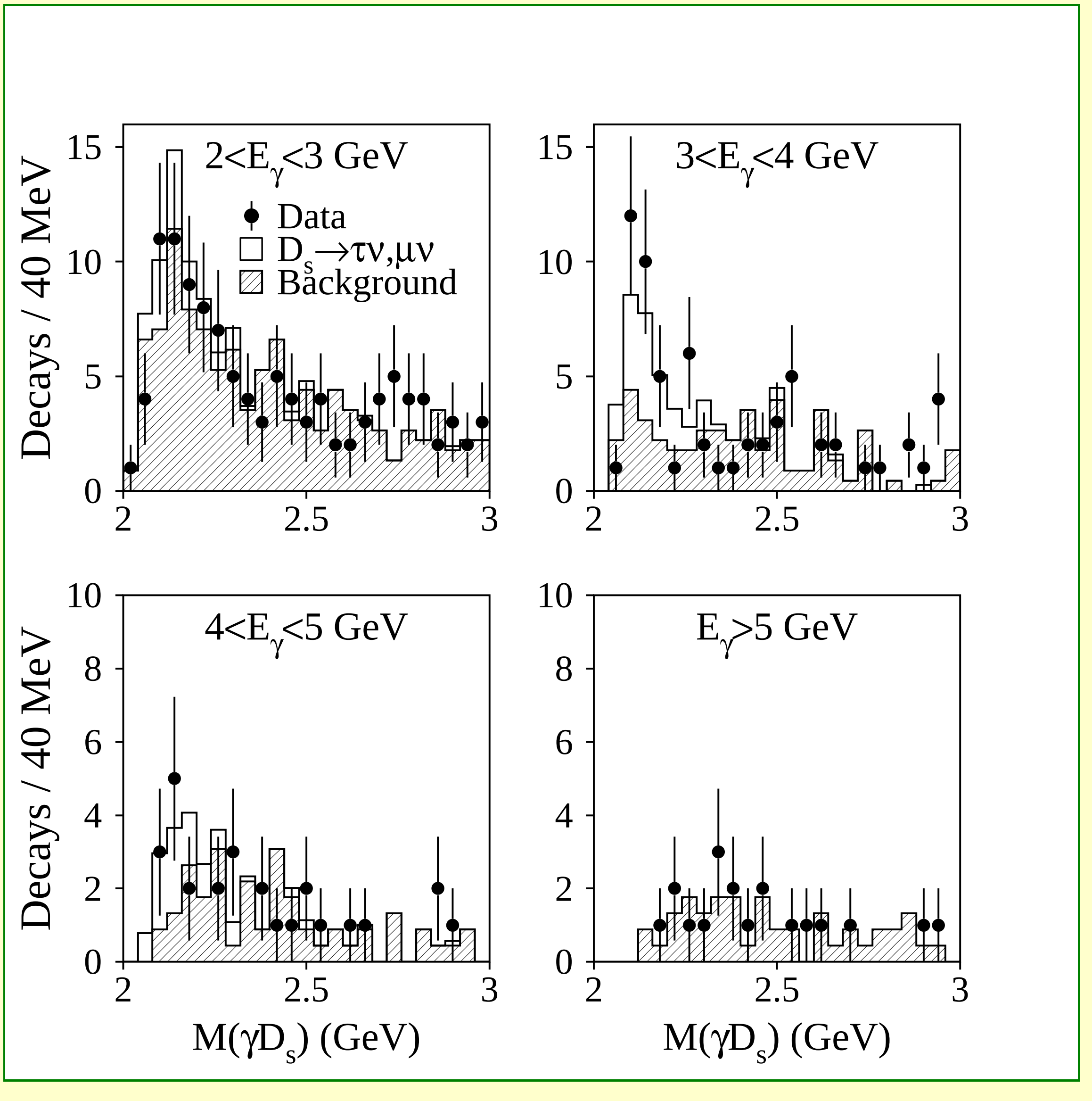
Crosschecks for $D_S \to \tau\nu$

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



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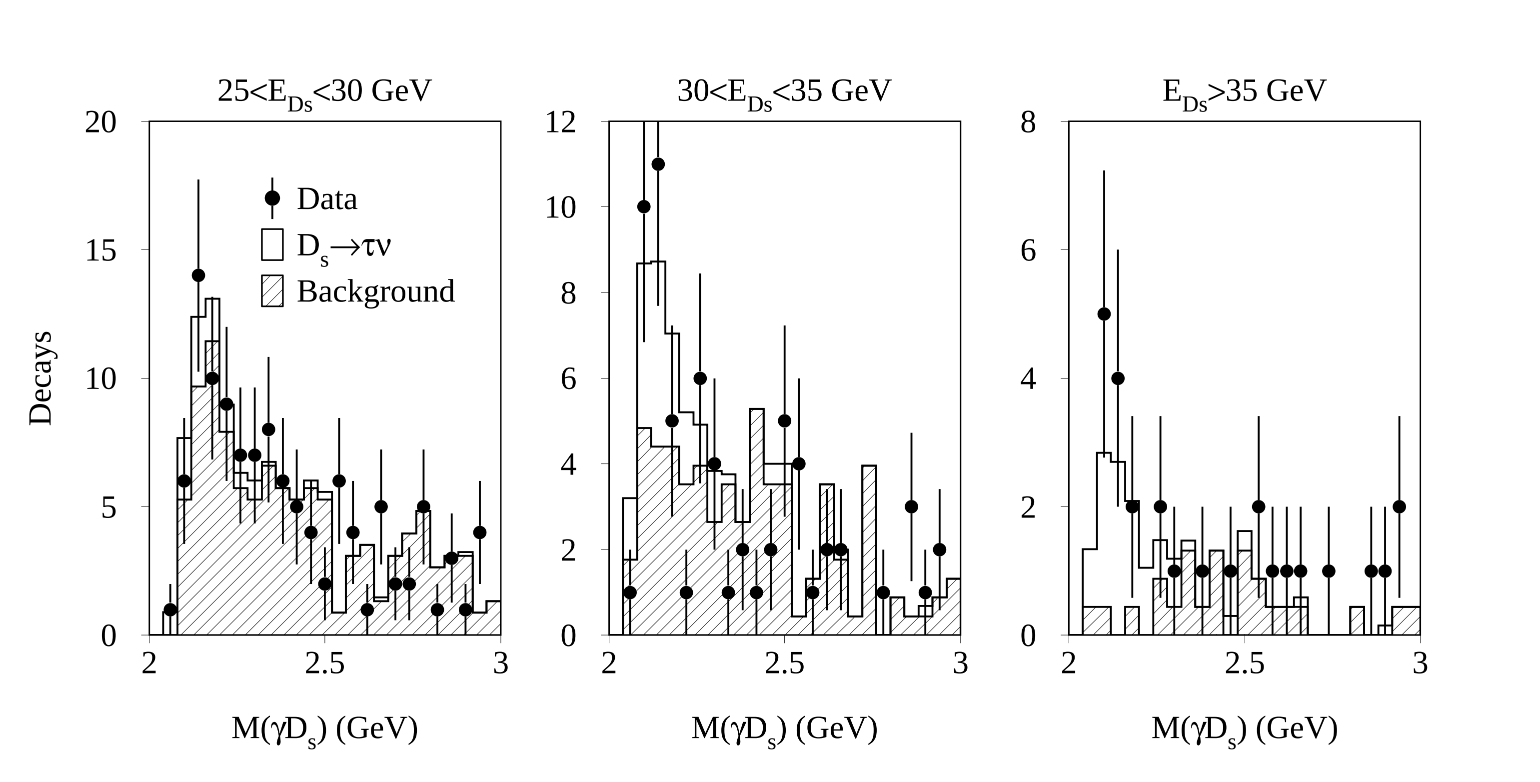
Cross checks for $D_S \to \tau\nu$

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



Final result on $D_s \to \tau\nu$

Number of $D_s \to \tau\nu$ events:

$$15.6 \pm 6.0 \text{ (stat)}$$

Systematic uncertainties:

Source	ΔN
resolution fcn ($q\bar{q}\gamma$)	1.6
efficiency (stat)	2.5
$< X_E^c >= 0.49 \pm 0.01$	0.6
$\mathcal{B}(D \to \ell\nu_\ell K^0 X)$ (PDG)	0.5
$< X_E^b >= 0.70 \pm 0.01$	0.6
$\mathcal{B}(D_S^{*-} \to \pi^0 D_S^-) = 0.062^{+0.020}_{-0.018} \pm 0.22$	0.3
Normalisation Uncertainties	
$D_s^*/D_s = 0.65 \pm 0.10$	2.4
$D_s/c = 0.11 \pm 0.02$	2.8
ΔN	3.7

This corresponds to:

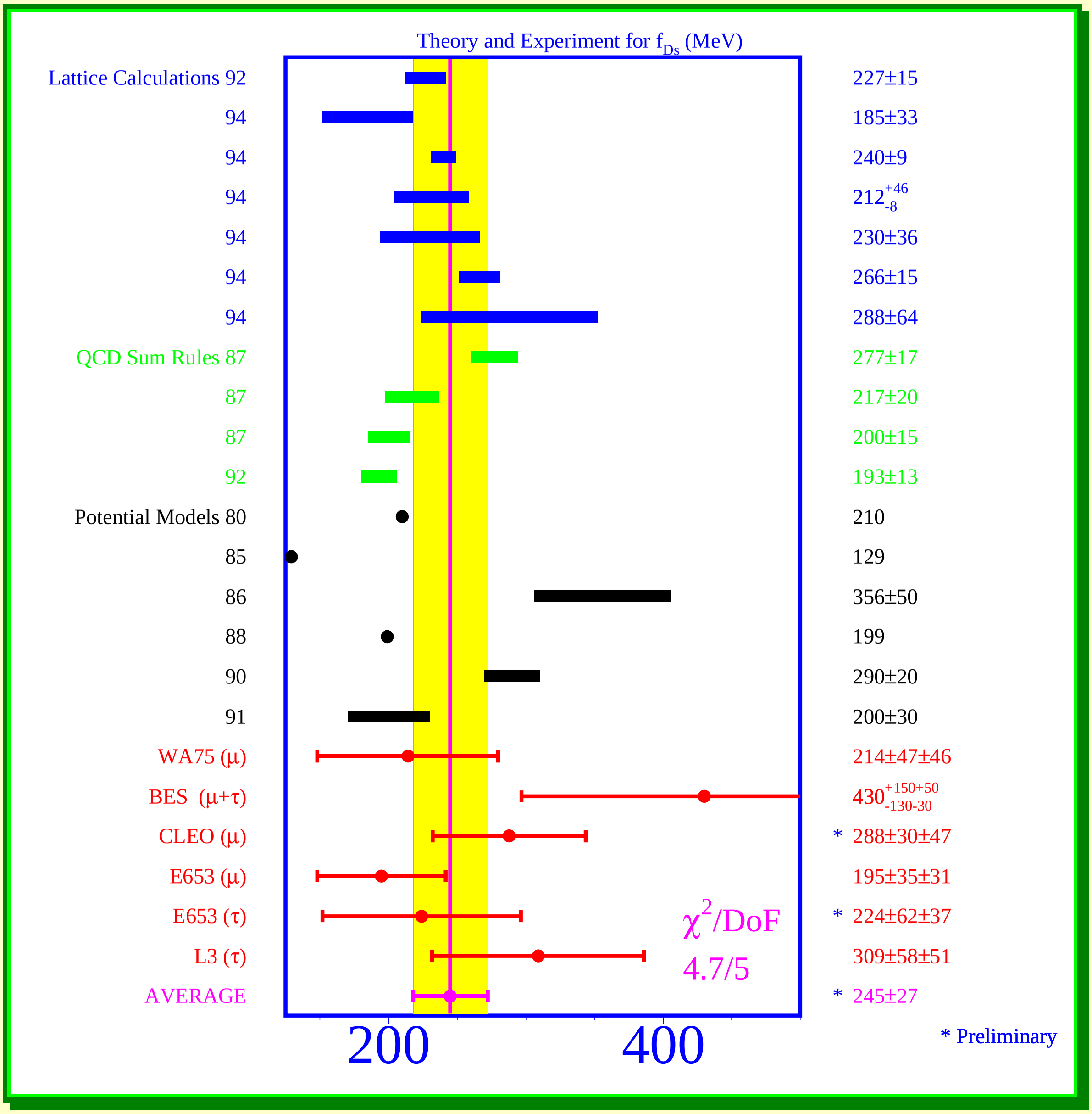
$$\mathcal{B}(D_S^+ \to \tau^+\nu_\tau) = (7.4 \pm 2.8 \pm 1.6 \pm 1.8)\%$$

Using the PDG values of τ_{D_S}, M_{D_S} and V_{cs}:

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

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

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.

$$\boxed{f_{D_S} = \mathbf{245 \pm 27}\ \mathrm{MeV}}$$

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	$7.4 \pm 2.8 \pm 1.6 \pm 1.8$

$D_S \to \mu\nu_\mu$

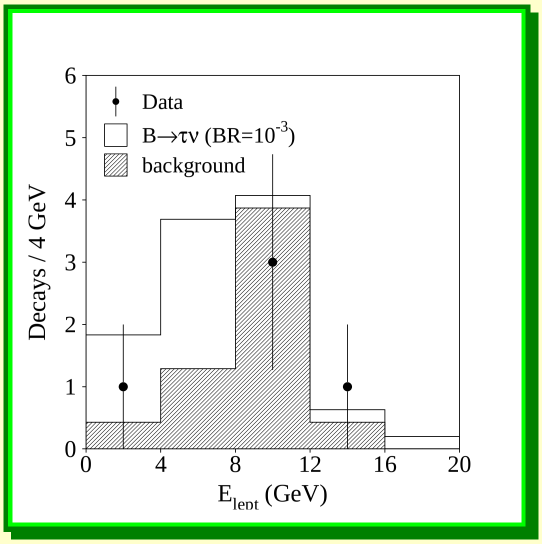
Experiment	Branching Fraction (%)
WA75	$0.37 \pm 0.16 \pm 0.07 \pm 0.19$
E653	$0.30 \pm 0.12 \pm 0.06 \pm 0.08$
CLEO	$0.66 \pm 0.14 \pm 0.14 \pm 0.17$
BES	$2.0^{+4.4}_{-1.7}$
BES combined	$1.5^{+1.3+0.3}_{-0.6-0.2}$

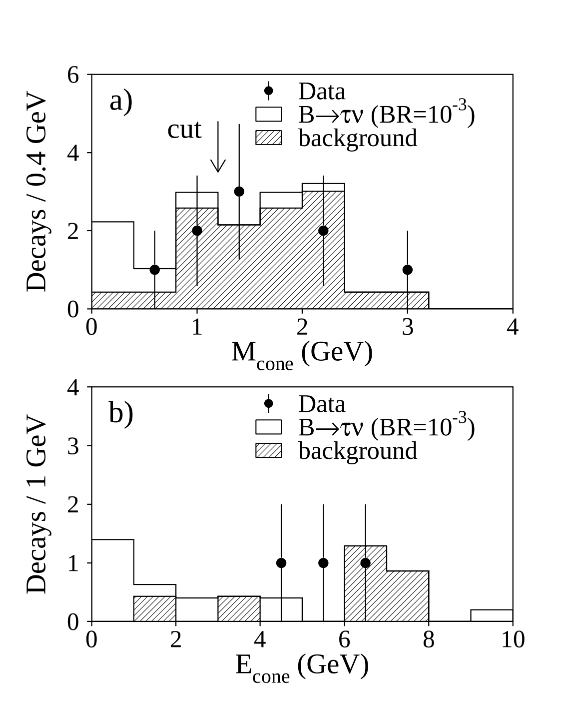
Branching for WA75,CLEO,E653 have been corrected for more recent measurements of the branching fractions used for normalization.

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

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

- Lepton or hadron with $E > 1\ \text{GeV}$ 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 $E_{B+} > 30\ \text{GeV}$.
- 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.

$\mathcal{B}(B^+ \to \tau^+\nu_\tau) < 5.7 \times 10^{-4}$ at $90\% C.L.$

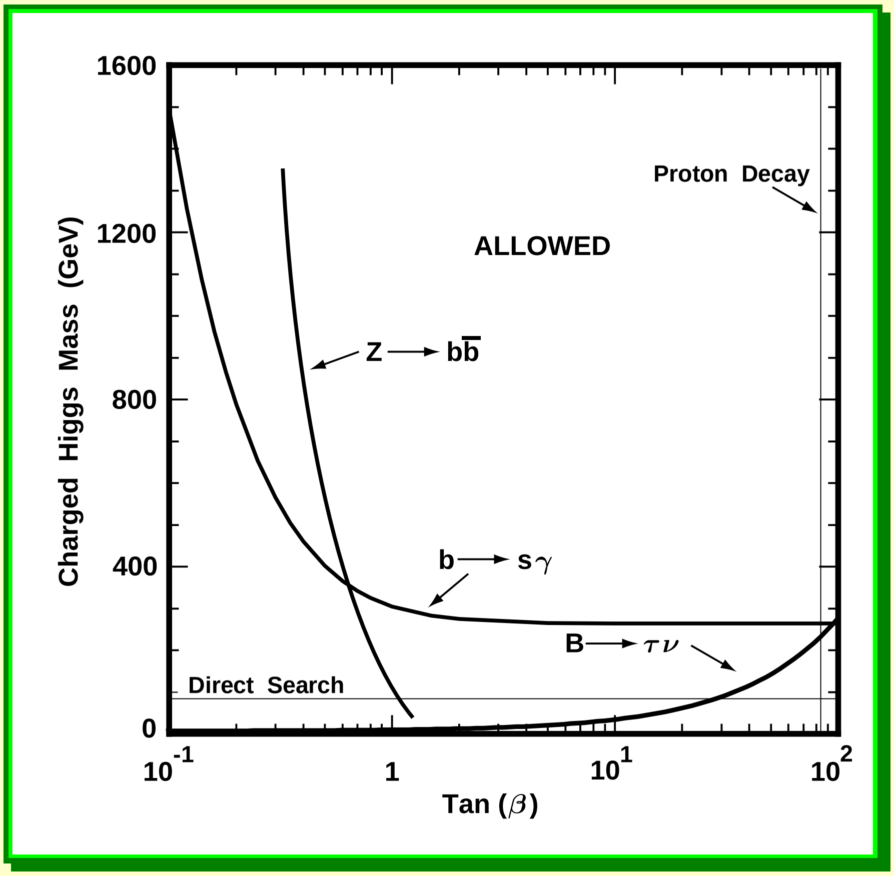
Limits on $H^{\pm}$

For models with Two Higgs doublets:

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

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

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



Summary

We have observed $\mathbf{15.6 \pm 6.0}$ $D_S \to \tau\nu$ events

- $\mathcal{B}(D_S \to \tau\nu) = \mathbf{7.4 \pm 2.8 \pm 1.6 \pm 1.8}$
- $f_{D_S} = \mathbf{309 \pm 58 \pm 33 \pm 38}$ MeV

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

- $\mathcal{B}(B \to \tau\nu) < \mathbf{5.6 \times 10^{-4}}$ is about an order of magnitude above predicted values.
- In two doublet Higgs models, $H^{\pm}$ could enhance this mode: At large $\tan\beta$ limit on $M_{H^{\pm}}$ comparable to $b \to s\gamma$
- Expect CLEO, BaBar, BELLE f_B measurement in the future.