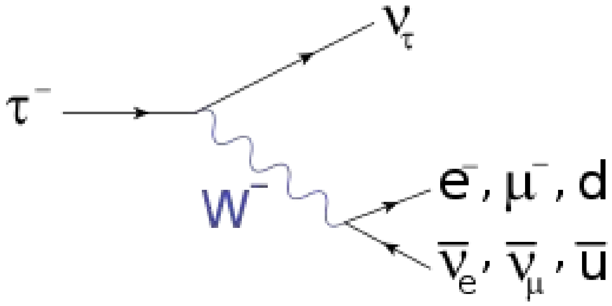
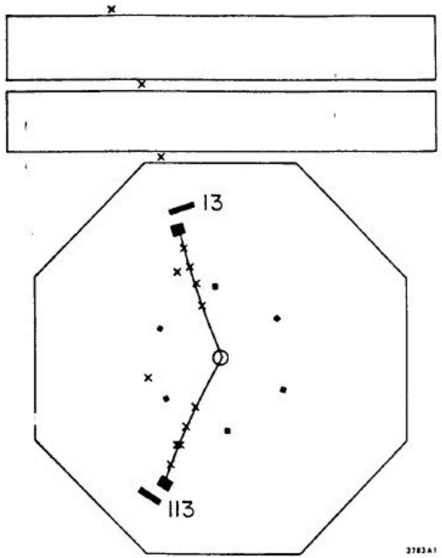
The University Of Sheffield.



The Discovery of the Tau lepton



Max Godsland and Samuel Sheldon

Some context

- Why were the electron and muon different?
- Perl believed an answer to the e-μ problem might be found by looking for a new heavy lepton
- Multiple lepton theories;
  - Sequential leptons,
  - Excited leptons,
  - Paraleptons,
  - Ortholeptons,
  - Long-lived leptons
  - Stable leptons

Tau decay

τ^- DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Modes with one charged particle				
particle$^-$ ≥ 0 neutrals $\geq 0 K^0 \nu_\tau$ ("1-prong")		(85.24 ± 0.06) %		–
particle$^-$ ≥ 0 neutrals $\geq 0 K^0_L \nu_\tau$		(84.58 ± 0.06) %		–
$\mu^- \overline{\nu}_\mu \nu_\tau$	[g]	(17.39 ± 0.04) %		885
$\mu^- \overline{\nu}_\mu \nu_\tau \gamma$	[e]	$(3.68 \pm 0.10) \times 10^{-3}$		885
$e^- \overline{\nu}_e \nu_\tau$	[g]	(17.82 ± 0.04) %		888
$e^- \overline{\nu}_e \nu_\tau \gamma$	[e]	(1.84 ± 0.05) %		888
$h^- \geq 0 K^0_L \nu_\tau$		(12.03 ± 0.05) %		883
$h^- \nu_\tau$		(11.51 ± 0.05) %		883
$\pi^- \nu_\tau$	[g]	(10.82 ± 0.05) %		883
$K^- \nu_\tau$	[g]	$(6.96 \pm 0.10) \times 10^{-3}$		820
$h^- \geq 1$ neutrals ν_τ		(37.00 ± 0.09) %		–
$h^- \geq 1\pi^0 \nu_\tau (\text{ex.} K^0)$		(36.51 ± 0.09) %		–
$h^- \pi^0 \nu_\tau$		(25.93 ± 0.09) %		878
$\pi^- \pi^0 \nu_\tau$	[g]	(25.49 ± 0.09) %		878
$\pi^- \pi^0$ non-$\rho(770)$ ν_τ		$(3.0 \pm 3.2) \times 10^{-3}$		878
$K^- \pi^0 \nu_\tau$	[g]	$(4.33 \pm 0.15) \times 10^{-3}$		814
$h^- \geq 2\pi^0 \nu_\tau$		(10.81 ± 0.09) %		–
$h^- 2\pi^0 \nu_\tau$		(9.48 ± 0.10) %		862
$h^- 2\pi^0 \nu_\tau (\text{ex.} K^0)$		(9.32 ± 0.10) %		862
$\pi^- 2\pi^0 \nu_\tau (\text{ex.} K^0)$	[g]	(9.26 ± 0.10) %		862
$\pi^- 2\pi^0 \nu_\tau (\text{ex.} K^0)$, scalar		$< 9 \times 10^{-3}$	CL=95%	862
$\pi^- 2\pi^0 \nu_\tau (\text{ex.} K^0)$, vector		$< 7 \times 10^{-3}$	CL=95%	862
$K^- 2\pi^0 \nu_\tau (\text{ex.} K^0)$	[g]	$(6.5 \pm 2.2) \times 10^{-4}$		796
$h^- \geq 3\pi^0 \nu_\tau$		(1.34 ± 0.07) %		–
$h^- \geq 3\pi^0 \nu_\tau (\text{ex.} K^0)$		(1.25 ± 0.07) %		–
$h^- 3\pi^0 \nu_\tau$		(1.18 ± 0.07) %		836
$\pi^- 3\pi^0 \nu_\tau (\text{ex.} K^0)$	[g]	(1.04 ± 0.07) %		836
$K^- 3\pi^0 \nu_\tau (\text{ex.} K^0, \eta)$	[g]	$(4.8 \pm 2.1) \times 10^{-4}$		765
$h^- 4\pi^0 \nu_\tau (\text{ex.} K^0)$		$(1.6 \pm 0.4) \times 10^{-3}$		800
$h^- 4\pi^0 \nu_\tau (\text{ex.} K^0, \eta)$	[g]	$(1.1 \pm 0.4) \times 10^{-3}$		800
$a_1(1260) \nu_\tau \to \pi^- \gamma \nu_\tau$		$(3.8 \pm 1.5) \times 10^{-4}$		–
$K^- \geq 0\pi^0 \geq 0 K^0 \geq 0\gamma \nu_\tau$		(1.552 ± 0.029) %		820
$K^- \geq 1 (\pi^0 \text{ or } K^0 \text{ or } \gamma) \nu_\tau$		$(8.59 \pm 0.28) \times 10^{-3}$		–
Modes with K^0's				
K^0_S (particles)$^- \nu_\tau$		$(9.44 \pm 0.28) \times 10^{-3}$		–
$h^- \overline{K}^0 \nu_\tau$		$(9.87 \pm 0.14) \times 10^{-3}$		812
$\pi^- \overline{K}^0 \nu_\tau$	[g]	$(8.40 \pm 0.14) \times 10^{-3}$		812
$\pi^- \overline{K}^0$ (non-$K^*(892)^-$) ν_τ		$(5.4 \pm 2.1) \times 10^{-4}$		812
$K^- K^0 \nu_\tau$	[g]	$(1.48 \pm 0.05) \times 10^{-3}$		737
$K^- K^0 \geq 0\pi^0 \nu_\tau$		$(2.98 \pm 0.08) \times 10^{-3}$		737
$h^- \overline{K}^0 \pi^0 \nu_\tau$		$(5.32 \pm 0.13) \times 10^{-3}$		794
$\pi^- \overline{K}^0 \pi^0 \nu_\tau$	[g]	$(3.82 \pm 0.13) \times 10^{-3}$		794
$\overline{K}^0 \rho^- \nu_\tau$		$(2.2 \pm 0.5) \times 10^{-3}$		612
$K^- K^0 \pi^0 \nu_\tau$	[g]	$(1.50 \pm 0.07) \times 10^{-3}$		685
$\pi^- \overline{K}^0 \geq 1\pi^0 \nu_\tau$		$(4.08 \pm 0.25) \times 10^{-3}$		–
$\pi^- \overline{K}^0 \pi^0 \pi^0 \nu_\tau (\text{ex.} K^0)$	[g]	$(2.6 \pm 2.3) \times 10^{-4}$		763
$K^- K^0 \pi^0 \pi^0 \nu_\tau$		$< 1.6 \times 10^{-4}$	CL=95%	619
$\pi^- K^0 \overline{K}^0 \nu_\tau$		$(1.55 \pm 0.24) \times 10^{-3}$		682
$\pi^- K^0_S K^0_S \nu_\tau$	[g]	$(2.33 \pm 0.07) \times 10^{-4}$		682
$\pi^- K^0_S K^0_L \nu_\tau$	[g]	$(1.08 \pm 0.24) \times 10^{-3}$		682
$\pi^- K^0_L K^0_L \nu_\tau$		$(2.33 \pm 0.07) \times 10^{-4}$		682
$\pi^- K^0 \overline{K}^0 \pi^0 \nu_\tau$		$(3.6 \pm 1.2) \times 10^{-4}$		614
$\pi^- K^0_S K^0_S \pi^0 \nu_\tau$	[g]	$(1.82 \pm 0.21) \times 10^{-5}$		614
$K^{*-} K^0 \pi^0 \nu_\tau \to \pi^- K^0_S K^0_S \pi^0 \nu_\tau$		$(1.08 \pm 0.21) \times 10^{-5}$		–
$f_1(1285) \pi^- \nu_\tau \to \pi^- K^0_S K^0_S \pi^0 \nu_\tau$		$(6.8 \pm 1.5) \times 10^{-6}$		–
$f_1(1420) \pi^- \nu_\tau \to \pi^- K^0_S K^0_S \pi^0 \nu_\tau$		$(2.4 \pm 0.8) \times 10^{-6}$		–
$\pi^- K^0_S K^0_L \pi^0 \nu_\tau$	[g]	$(3.2 \pm 1.2) \times 10^{-4}$		614
$\pi^- K^0_L K^0_L \pi^0 \nu_\tau$		$(1.82 \pm 0.21) \times 10^{-5}$		614
$K^- K^0_S K^0_S \nu_\tau$		$< 6.3 \times 10^{-7}$	CL=90%	466
$K^- K^0_S K^0_S \pi^0 \nu_\tau$		$< 4.0 \times 10^{-7}$	CL=90%	337
$K^0 h^+ h^- h^- \geq 0$ neutrals ν_τ		$< 1.7 \times 10^{-3}$	CL=95%	760
$K^0 h^+ h^- h^- \nu_\tau$	[g]	$(2.5 \pm 2.0) \times 10^{-4}$		760
Modes with three charged particles				
$h^- h^- h^+ \geq 0$ neutrals $\geq 0 K^0_L \nu_\tau$		(15.21 ± 0.06) %		861
$h^- h^- h^+ \geq 0$ neutrals ν_τ (ex. $K^0_S \to \pi^+\pi^-$) ("3-prong")		(14.55 ± 0.06) %		861
$h^- h^- h^+ \nu_\tau$		(9.80 ± 0.05) %		861
$h^- h^- h^+ \nu_\tau (\text{ex.} K^0)$		(9.46 ± 0.05) %		861
$h^- h^- h^+ \nu_\tau (\text{ex.} K^0, \omega)$		(9.43 ± 0.05) %		861
$\pi^- \pi^+ \pi^- \nu_\tau$		(9.31 ± 0.05) %		861
$\pi^- \pi^+ \pi^- \nu_\tau (\text{ex.} K^0)$		(9.02 ± 0.05) %		861
$\pi^- \pi^+ \pi^- \nu_\tau (\text{ex.} K^0)$, non-axial vector		< 2.4 %	CL=95%	861
$\pi^- \pi^+ \pi^- \nu_\tau (\text{ex.} K^0, \omega)$	[g]	(8.99 ± 0.05) %		861
$h^- h^- h^+ \geq 1$ neutrals ν_τ		(5.29 ± 0.05) %		–
$h^- h^- h^+ \geq 1\pi^0 \nu_\tau (\text{ex.} K^0)$		(5.09 ± 0.05) %		–
$h^- h^- h^+ \pi^0 \nu_\tau$		(4.76 ± 0.05) %		834
$h^- h^- h^+ \pi^0 \nu_\tau (\text{ex.} K^0)$		(4.57 ± 0.05) %		834
$h^- h^- h^+ \pi^0 \nu_\tau (\text{ex.} K^0, \omega)$		(2.79 ± 0.07) %		834
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$		(4.62 ± 0.05) %		834
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau (\text{ex.} K^0)$		(4.49 ± 0.05) %		834
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau (\text{ex.} K^0, \omega)$	[g]	(2.74 ± 0.07) %		834
$h^- h^- h^+ \geq 2\pi^0 \nu_\tau (\text{ex.} K^0)$		$(5.17 \pm 0.31) \times 10^{-3}$		–
$h^- h^- h^+ 2\pi^0 \nu_\tau$		$(5.05 \pm 0.31) \times 10^{-3}$		797
$h^- h^- h^+ 2\pi^0 \nu_\tau (\text{ex.} K^0)$		$(4.95 \pm 0.31) \times 10^{-3}$		797
$h^- h^- h^+ 2\pi^0 \nu_\tau (\text{ex.} K^0, \omega, \eta)$	[g]	$(10 \pm 4) \times 10^{-4}$		797
$h^- h^- h^+ 3\pi^0 \nu_\tau$		$(2.12 \pm 0.30) \times 10^{-4}$		749
$2\pi^- \pi^+ 3\pi^0 \nu_\tau (\text{ex.} K^0)$		$(1.94 \pm 0.30) \times 10^{-4}$		749
$2\pi^- \pi^+ 3\pi^0 \nu_\tau (\text{ex.} K^0, \eta, f_1(1285))$		$(1.7 \pm 0.4) \times 10^{-4}$		–
$2\pi^- \pi^+ 3\pi^0 \nu_\tau (\text{ex.} K^0, \eta, \omega, f_1(1285))$	[g]	$(1.4 \pm 2.7) \times 10^{-5}$		–
$K^- h^+ h^- \geq 0$ neutrals ν_τ		$(6.29 \pm 0.14) \times 10^{-3}$		794
$K^- h^+ \pi^- \nu_\tau (\text{ex.} K^0)$		$(4.37 \pm 0.07) \times 10^{-3}$		794
$K^- h^+ \pi^- \pi^0 \nu_\tau (\text{ex.} K^0)$		$(8.6 \pm 1.2) \times 10^{-4}$		763
$K^- \pi^+ \pi^- \geq 0$ neutrals ν_τ		$(4.77 \pm 0.14) \times 10^{-3}$		794
$K^- \pi^+ \pi^- \geq 0\pi^0 \nu_\tau (\text{ex.} K^0)$		$(3.73 \pm 0.13) \times 10^{-3}$		794
$K^- \pi^+ \pi^- \nu_\tau$		$(3.45 \pm 0.07) \times 10^{-3}$		794
$K^- \pi^+ \pi^- \nu_\tau (\text{ex.} K^0)$		$(2.93 \pm 0.07) \times 10^{-3}$		794
$K^- \pi^+ \pi^- \nu_\tau (\text{ex.} K^0, \omega)$	[g]	$(2.93 \pm 0.07) \times 10^{-3}$		794
$K^- \rho^0 \nu_\tau \to K^- \pi^+ \pi^- \nu_\tau$		$(1.4 \pm 0.5) \times 10^{-3}$		–
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$		$(1.31 \pm 0.12) \times 10^{-3}$		763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau (\text{ex.} K^0)$		$(7.9 \pm 1.2) \times 10^{-4}$		763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau (\text{ex.} K^0, \eta)$		$(7.6 \pm 1.2) \times 10^{-4}$		763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau (\text{ex.} K^0, \omega)$		$(3.7 \pm 0.9) \times 10^{-4}$		763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau (\text{ex.} K^0, \omega, \eta)$	[g]	$(3.9 \pm 1.4) \times 10^{-4}$		763
$K^- \pi^+ K^- \geq 0$ neut. ν_τ		$< 9 \times 10^{-4}$	CL=95%	685
$K^- K^+ \pi^- \geq 0$ neut. ν_τ		$(1.496 \pm 0.033) \times 10^{-3}$		685
$K^- K^+ \pi^- \nu_\tau$	[g]	$(1.435 \pm 0.027) \times 10^{-3}$		685
$K^- K^+ \pi^- \pi^0 \nu_\tau$	[g]	$(6.1 \pm 1.8) \times 10^{-5}$		618
$K^- K^+ K^- \nu_\tau$		$(2.2 \pm 0.8) \times 10^{-5}$	S=5.4	472
$K^- K^+ K^- \nu_\tau$ (ex. ϕ)		$< 2.5 \times 10^{-6}$	CL=90%	–
$K^- K^+ K^- \pi^0 \nu_\tau$		$< 4.8 \times 10^{-6}$	CL=90%	345
$\pi^- K^+ \pi^- \geq 0$ neut. ν_τ		$< 2.5 \times 10^{-3}$	CL=95%	794
$e^- e^- e^+ \overline{\nu}_e \nu_\tau$		$(2.8 \pm 1.5) \times 10^{-5}$		888
$\mu^- e^- e^+ \overline{\nu}_\mu \nu_\tau$		$< 3.6 \times 10^{-5}$	CL=90%	885
Modes with five charged particles				
$3h^- 2h^+ \geq 0$ neutrals ν_τ (ex. $K^0_S \to \pi^- \pi^+$) ("5-prong")		$(9.9 \pm 0.4) \times 10^{-4}$		794
$3h^- 2h^+ \nu_\tau (\text{ex.} K^0)$		$(8.22 \pm 0.32) \times 10^{-4}$		794
$3\pi^- 2\pi^+ \nu_\tau (\text{ex.} K^0, \omega)$		$(8.21 \pm 0.31) \times 10^{-4}$		794
$3\pi^- 2\pi^+ \nu_\tau (\text{ex.} K^0, \omega, f_1(1285))$	[g]	$(7.69 \pm 0.30) \times 10^{-4}$		–
$K^- 2\pi^- 2\pi^+ \nu_\tau (\text{ex.} K^0)$	[g]	$(6 \pm 12) \times 10^{-7}$		716
$K^+ 3\pi^- \pi^+ \nu_\tau$		$< 5.0 \times 10^{-6}$	CL=90%	716
$K^+ K^- 2\pi^- \pi^+ \nu_\tau$		$< 4.5 \times 10^{-7}$	CL=90%	528
$3h^- 2h^+ \pi^0 \nu_\tau (\text{ex.} K^0)$		$(1.64 \pm 0.11) \times 10^{-4}$		746
$3\pi^- 2\pi^+ \pi^0 \nu_\tau (\text{ex.} K^0)$		$(1.62 \pm 0.11) \times 10^{-4}$		746
$3\pi^- 2\pi^+ \pi^0 \nu_\tau (\text{ex.} K^0, \eta, f_1(1285))$		$(1.11 \pm 0.10) \times 10^{-4}$		–
$3\pi^- 2\pi^+ \pi^0 \nu_\tau (\text{ex.} K^0, \eta, \omega, f_1(1285))$	[g]	$(3.8 \pm 0.9) \times 10^{-5}$		–
$K^- 2\pi^- 2\pi^+ \pi^0 \nu_\tau (\text{ex.} K^0)$	[g]	$(1.1 \pm 0.6) \times 10^{-6}$		657
$K^+ 3\pi^- \pi^+ \pi^0 \nu_\tau$		$< 8 \times 10^{-7}$	CL=90%	657
$3h^- 2h^+ 2\pi^0 \nu_\tau$		$< 3.4 \times 10^{-6}$	CL=90%	687
Miscellaneous other allowed modes				
$(5\pi)^- \nu_\tau$		$(7.8 \pm 0.5) \times 10^{-3}$		800
$4h^- 3h^+ \geq 0$ neutrals ν_τ ("7-prong")		$< 3.0 \times 10^{-7}$	CL=90%	682
$4h^- 3h^+ \nu_\tau$		$< 4.3 \times 10^{-7}$	CL=90%	682
$4h^- 3h^+ \pi^0 \nu_\tau$		$< 2.5 \times 10^{-7}$	CL=90%	612
$X^-(S=-1) \nu_\tau$		(2.92 ± 0.04) %		–
$K^*(892)^- \geq 0$ neutrals $\geq 0 K^0_L \nu_\tau$		(1.42 ± 0.18) %	S=1.4	665
$K^*(892)^- \nu_\tau$		(1.20 ± 0.07) %	S=1.8	665
$K^*(892)^- \nu_\tau \to \pi^- \overline{K}^0 \nu_\tau$		$(7.83 \pm 0.26) \times 10^{-3}$		–
$K^*(892)^0 K^- \geq 0$ neutrals ν_τ		$(3.2 \pm 1.4) \times 10^{-3}$		542
$K^*(892)^0 K^- \nu_\tau$		$(2.1 \pm 0.4) \times 10^{-3}$		542
$\overline{K}^*(892)^0 \pi^- \geq 0$ neutrals ν_τ		$(3.8 \pm 1.7) \times 10^{-3}$		655
$\overline{K}^*(892)^0 \pi^- \nu_\tau$		$(2.2 \pm 0.5) \times 10^{-3}$		655
$(\overline{K}^*(892)\pi)^- \nu_\tau \to \pi^- \overline{K}^0 \pi^0 \nu_\tau$		$(1.0 \pm 0.4) \times 10^{-3}$		–
$K_1(1270)^- \nu_\tau$		$(4.7 \pm 1.1) \times 10^{-3}$		433
$K_1(1400)^- \nu_\tau$		$(1.7 \pm 2.6) \times 10^{-3}$	S=1.7	335
$K^*(1410)^- \nu_\tau$		$(1.5\ ^{+1.4}_{-1.0}) \times 10^{-3}$		326
$K^*_0(1430)^- \nu_\tau$		$< 5 \times 10^{-4}$	CL=95%	317
$K^*_2(1430)^- \nu_\tau$		$< 3 \times 10^{-3}$	CL=95%	317
$\eta \pi^- \nu_\tau$		$< 9.9 \times 10^{-5}$	CL=95%	797
$\eta \pi^- \pi^0 \nu_\tau$	[g]	$(1.39 \pm 0.07) \times 10^{-3}$		778
$\eta \pi^- \pi^0 \pi^0 \nu_\tau$	[g]	$(1.9 \pm 0.4) \times 10^{-4}$		746
$\eta K^- \nu_\tau$	[g]	$(1.55 \pm 0.08) \times 10^{-4}$		719
$\eta K^*(892)^- \nu_\tau$		$(1.38 \pm 0.15) \times 10^{-4}$		511
$\eta K^- \pi^0 \nu_\tau$	[g]	$(4.8 \pm 1.2) \times 10^{-5}$		665
$\eta K^- \pi^0 (\text{non-}K^*(892)) \nu_\tau$		$< 3.5 \times 10^{-5}$	CL=90%	–
$\eta \overline{K}^0 \pi^- \nu_\tau$	[g]	$(9.4 \pm 1.5) \times 10^{-5}$		661
$\eta \overline{K}^0 \pi^- \pi^0 \nu_\tau$		$< 5.0 \times 10^{-5}$	CL=90%	590
$\eta K^- K^0 \nu_\tau$		$< 9.0 \times 10^{-6}$	CL=90%	430
$\eta \pi^+ \pi^- \pi^- \geq 0$ neutrals ν_τ		$< 3 \times 10^{-3}$	CL=90%	744
$\eta \pi^- \pi^+ \pi^- \nu_\tau (\text{ex.} K^0)$	[g]	$(2.19 \pm 0.13) \times 10^{-4}$		744
$\eta \pi^- \pi^+ \pi^- \nu_\tau (\text{ex.} K^0, f_1(1285))$		$(9.9 \pm 1.6) \times 10^{-5}$		–
$\eta a_1(1260)^- \nu_\tau \to \eta \pi^- \rho^0 \nu_\tau$		$< 3.9 \times 10^{-4}$	CL=90%	–
$\eta \eta \pi^- \nu_\tau$		$< 7.4 \times 10^{-6}$	CL=90%	637
$\eta \eta \pi^- \pi^0 \nu_\tau$		$< 2.0 \times 10^{-4}$	CL=95%	559
$\eta \eta K^- \nu_\tau$		$< 3.0 \times 10^{-6}$	CL=90%	382
$\eta'(958) \pi^- \nu_\tau$		$< 4.0 \times 10^{-6}$	CL=90%	620
$\eta'(958) \pi^- \pi^0 \nu_\tau$		$< 1.2 \times 10^{-5}$	CL=90%	591
$\eta'(958) K^- \nu_\tau$		$< 2.4 \times 10^{-6}$	CL=90%	495
$\phi \pi^- \nu_\tau$		$(3.4 \pm 0.6) \times 10^{-5}$		585
$\phi K^- \nu_\tau$	[g]	$(4.4 \pm 1.6) \times 10^{-5}$		445
$f_1(1285) \pi^- \nu_\tau$		$(3.9 \pm 0.5) \times 10^{-4}$	S=1.9	408
$f_1(1285) \pi^- \nu_\tau \to \eta \pi^- \pi^+ \pi^- \nu_\tau$		$(1.18 \pm 0.07) \times 10^{-4}$	S=1.3	–
$f_1(1285) \pi^- \nu_\tau \to 3\pi^- 2\pi^+ \nu_\tau$	[g]	$(5.2 \pm 0.4) \times 10^{-5}$		–
$\pi(1300)^- \nu_\tau \to (\rho\pi)^- \nu_\tau \to (3\pi)^- \nu_\tau$		$< 1.0 \times 10^{-4}$	CL=90%	–

Tau decay and $e^+ e^-$ annihilation

- Decays of interest were;

$$\tau^+ \to \mu^+ + \nu_\mu + \bar{\nu}_\tau$$

$$\tau^- \to \mu^- + \bar{\nu}_\mu + \nu_\tau$$

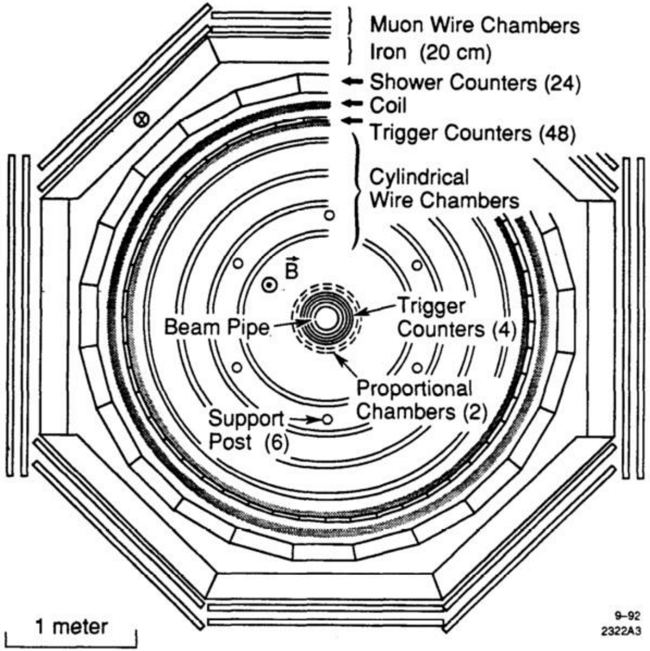
$$\tau^+ \to e^+ + \nu_e + \bar{\nu}_\tau$$

$$\tau^- \to e^- + \bar{\nu}_e + \nu_\tau$$

- The signature of these decays in the experiment were known as e-μ events; $e^+ + e^- \to e^\pm + \mu^\mp + \geq 2$ missing particles
- In the proposal for the Mark 1 detector at SLAC, searching for a new heavy lepton was given last three pages with a 10 page supplement
- A senior figure at SLAC stated “Ha, heavy leptons! If Martin discovers that we will let him publish it by himself”

Mark 1 detector (1975)

- “It was obsolete before it was built”
- Electron and photon detectors used 24 lead-scintillator shower counters- scratched during construction
- Electron identified by pulse height > 0.5 GeV
- Muon identified by (a) being detected in muon chamber and (b) small pulse height
- 95% photon detection efficiency at 200 MeV



The University Of Sheffield.

Initial results (1975)

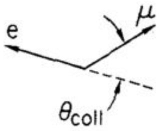
- Observed 3 prong and 2 prong events. **3 prong events defined as hadronic** so can be discarded. This left 25300 leptonic 2 prong events
- Requiring an **acoplanar angle > 20 degrees** reduced 25300 events to 2493
- Most reliable identification for particle with **momentum > 0.65 GeV/c** reducing number of events to 513
- Requirement of **no associated photons** reduced events to 24 so-called signature events
- Results rule out two-virtual photon events
- 4.7±1.2 misidentified e-μ events

$$\cos\theta_{copl} = -(\vec{n}_1 \times \vec{n}_{e^+})\cdot(\vec{n}_2 \times \vec{n}_{e^+}) / |\vec{n}_1 \times \vec{n}_{e^+}||\vec{n}_2 \times \vec{n}_{e^+}|$$

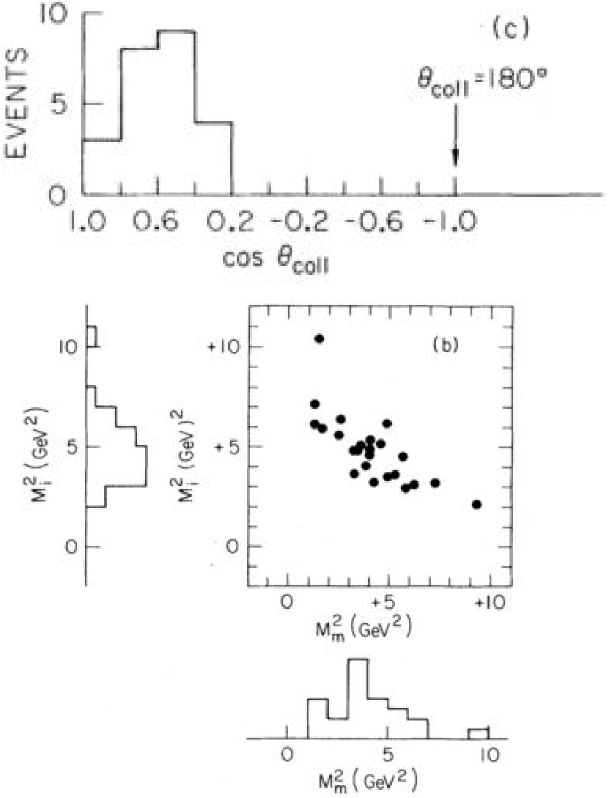
Particles \ N_γ	0	1	>1	0	1	>1
	Total charge = 0			Total charge = ±2		
e-e	40	111	55	0	1	0
e-μ	24	8	8	0	0	3
μ-μ	16	15	6	0	0	0
e-h	20	21	32	2	3	3
μ-h	17	14	31	4	0	5
h-h	14	10	30	10	4	6

Initial Results

- Low collinear angles, characteristic of decay of pair of particles



- At least two particles escaped detection
- Measured mass to be 1.6-2.0 GeV/c^2



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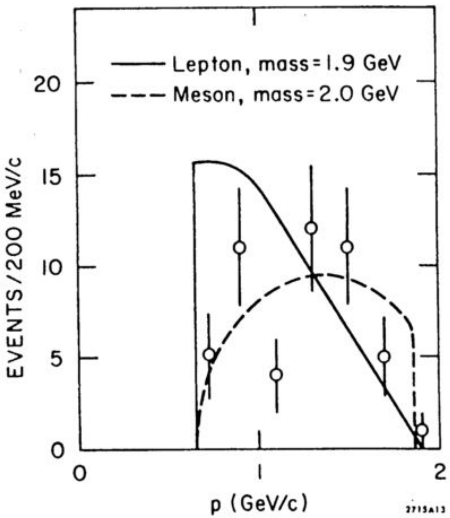
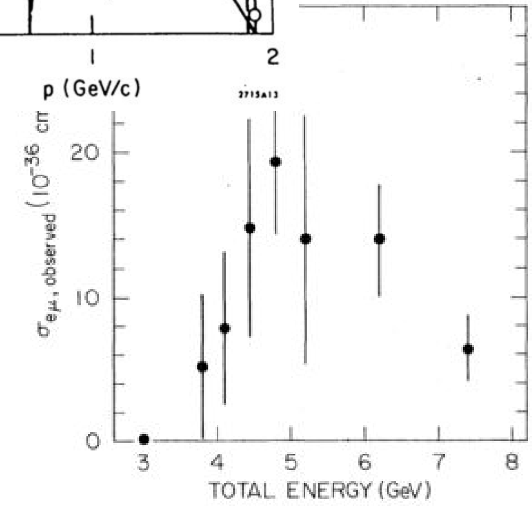
Initial results (problems)

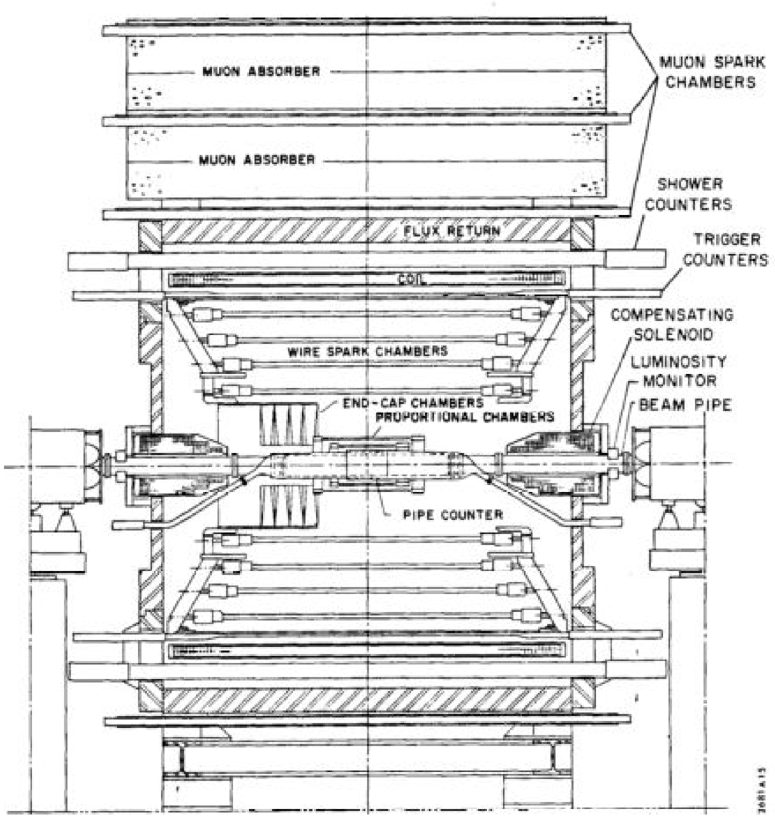
- Data seemed to suggest meson decay rather than heavy lepton decay
- Particle misidentification couldn't be ruled out totally (were the missing particles n, K^0_L?)
- The recently discovered D meson has a similar mass and production threshold
- Theories absolutely required a 4th quark, there was no such requirement for a third lepton





Detector upgrade (Tower of Power)

- Charm particles could decay to muons
- Identifying the decaying particles required better muon detection
- Muon identification improved by adding barium-loaded concrete to the top of the detector
- Located on top of the detector as that was the only place with the necessary room

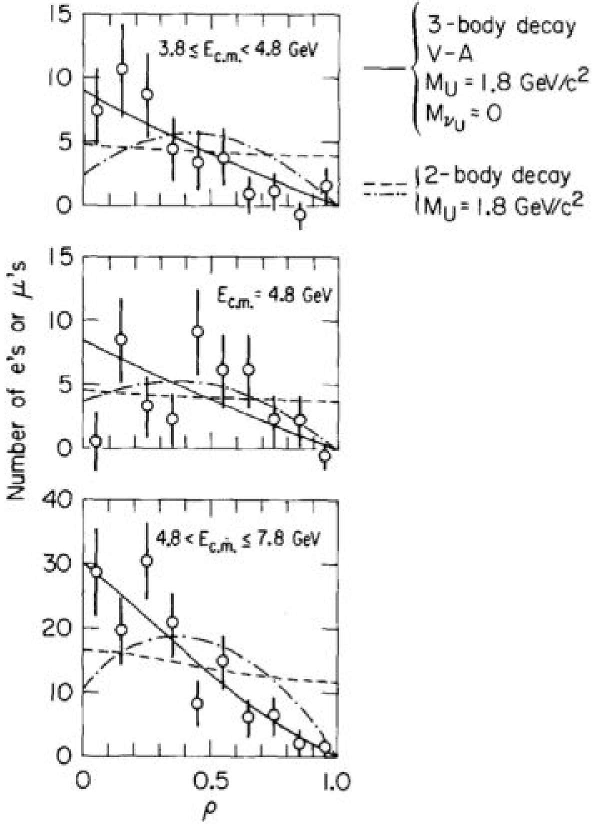


Further work

- Published confirmation of three body decay by looking at momentum distribution

$$\rho = \frac{p - 0.65}{p_{max} - 0.65}$$

- Best fit for three body lepton decay
- Now needed to confirm what the missing particles were



What were the missing particles?

- Not neutron
- Not kaon
- Looked at ALL events with $e^{\pm} + \mu^{\mp}$
- Did not observe enough ɣ, π^0, or other charged particles in general to conclude that these escaped detection in signature events.

Undetected particle(s)	90% confidence upper limit
K^0	0.09
π^0 or γ	0.18
Charged particle	0.09
Charged particle + π^0 or γ	0.11
TOTAL	0.39

- What else can’t you detect? Concluded they must be **neutrinos**
- Further evidence for a new lepton

From 1976 to present

- Outside confirmation from PLUTO at DORIS and DASP in 1977 definitively proved the existence of the tau and separated it from the D meson
- Mass estimates were revised from 1807±20 MeV/c^2 to 1776.9±0.5 MeV/c^2
- Lifetime was measured (around the time of discovery) to be $4.6 \pm 1.9 \times 10^{-13}$ s
- Experimental results agreed with theory that the tau was a point particle
- Upper limit of mass of tau neutrino estimated to be 600 MeV/c^2

Property	**Present value**
Tau mass	(1776.86±0.12)MeV/c^2
Tau lifetime	$2.903 \pm 0.005 \times 10^{-13}$s
Tau spin	½
Tau neutrino mass	<2eV/c^2

Summary

- Doubts about existence of the tau started before the SLAC Mark 1 was built
- Accurately removing events due to background was key to discovering tau
- Biggest uncertainty was identification of missing particles as neutrinos and not other candidates (as the detector used was poor) not overcoming statistical uncertainties
- Events rejected using thresholds that minimised background while still retaining a detectable signal
- The Charm particle has a similar mass and decay modes and was confused with the tau in experiments for a number of years
- Won the nobel prize in physics in 1995 along with discovery of neutrinos
- Today we know the tau has many decay modes, both leptonic and hadronic

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