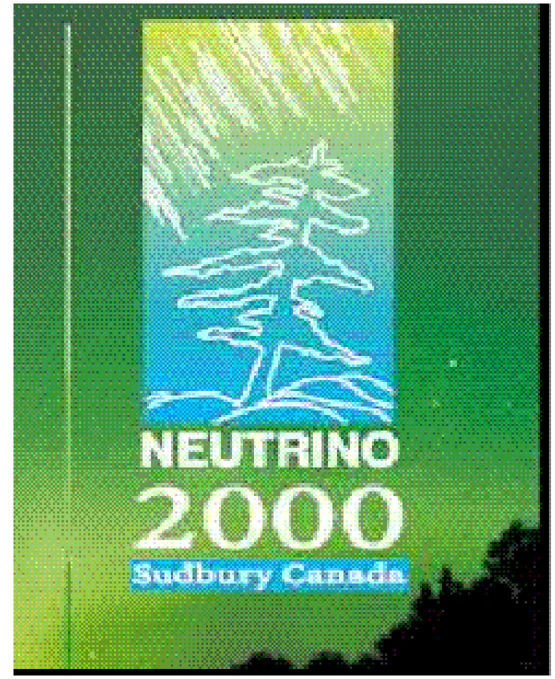
Tau Neutrino Mass



CLEO

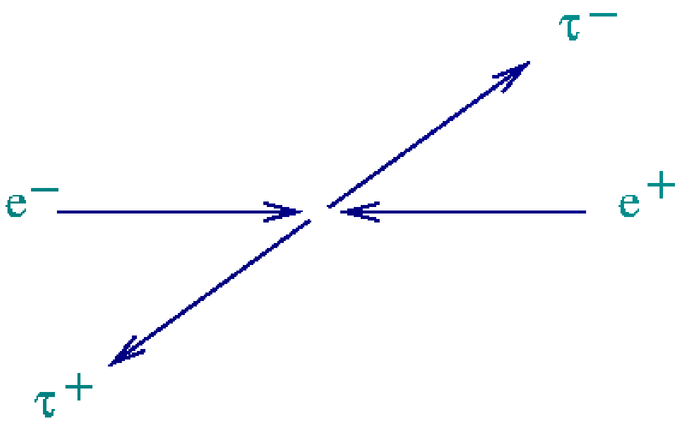
ALEPH

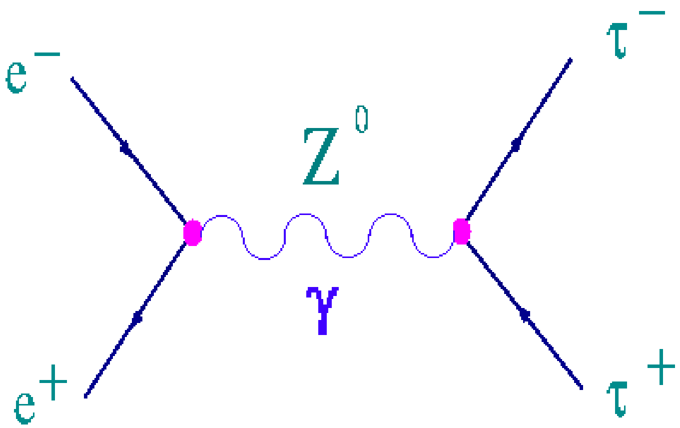
OPAL

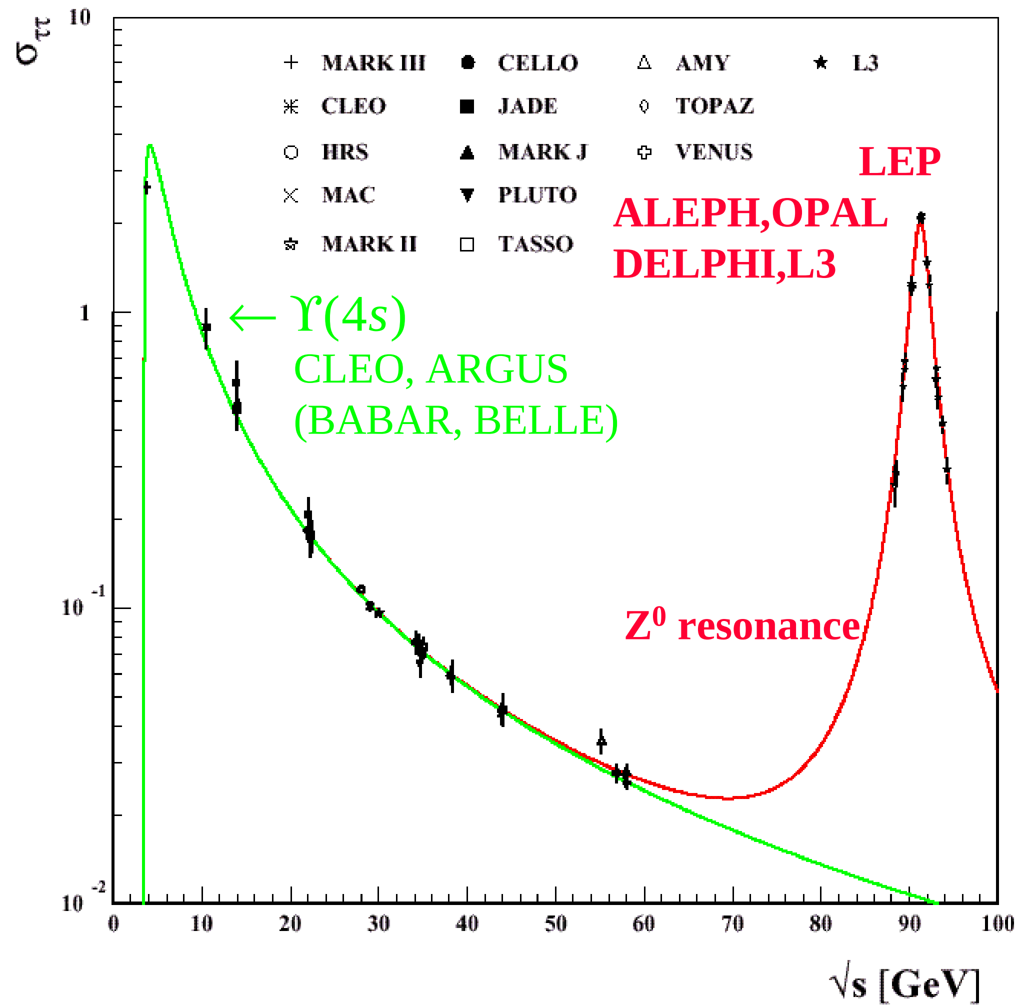
J.M. Roney

University of Victoria

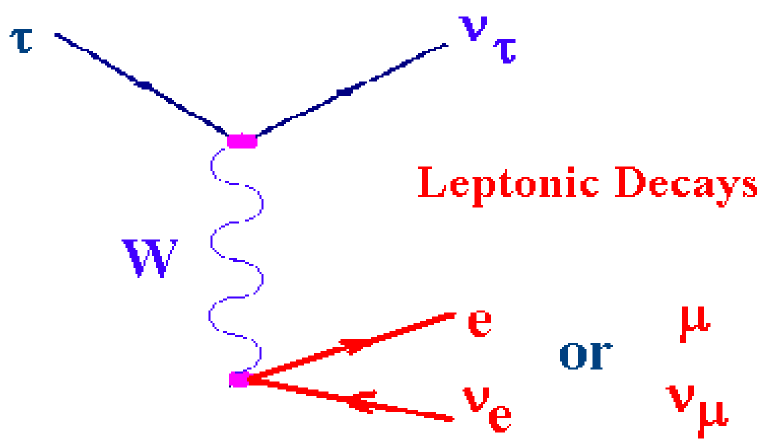
$e^+e^- \rightarrow t^+t^-$ Production

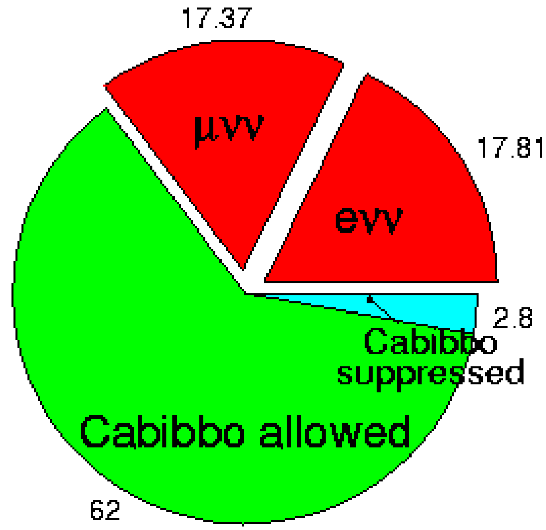




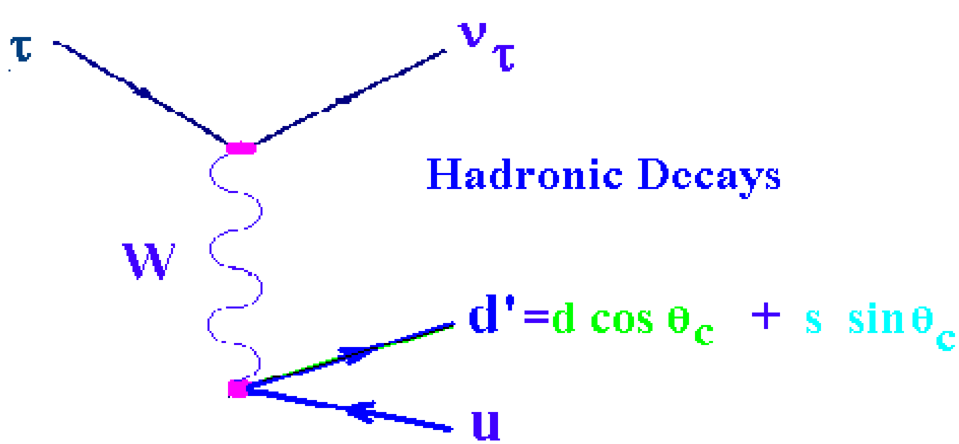


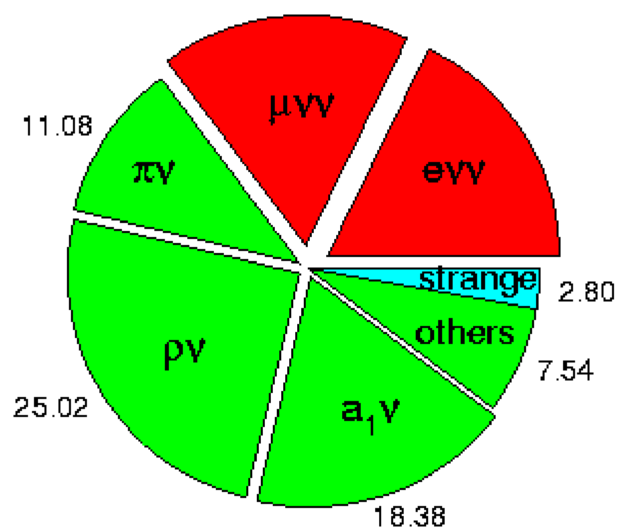
t Decay



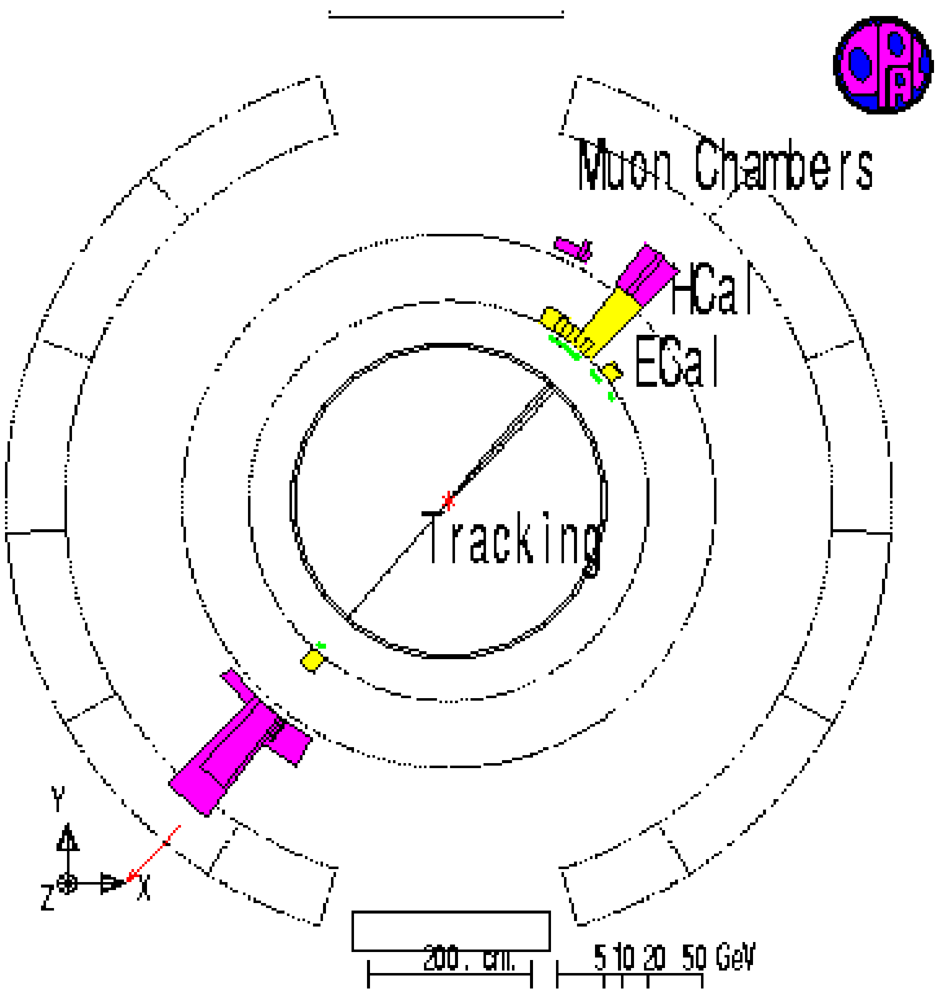


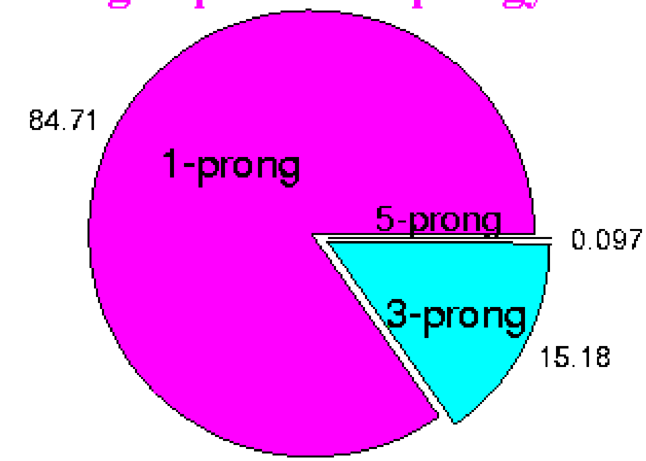
resonance decay modes

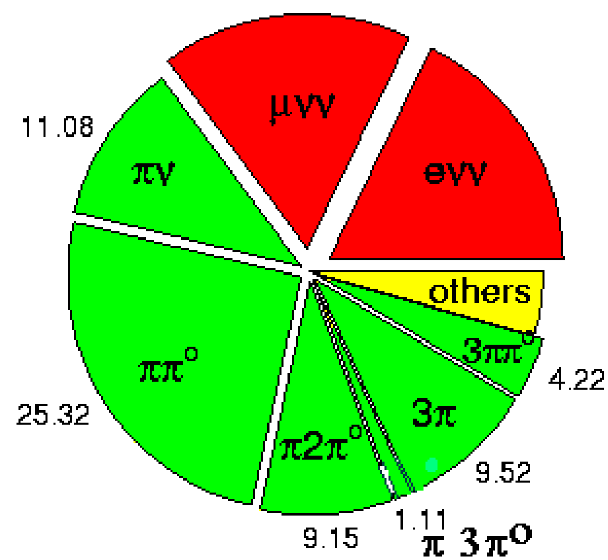




τ Detection







τ decays for m $_\nu$ measurement

- **high-multiplicity, high mass hadronic: single n & phase-space suppressed**
- **reject non-♦ backgrounds: e^+e^- ✹ e^+e^-, e^+e^- ✹ hadrons, e^+e^- ✹ e^+e^- + hadrons**
- **reject ♦ decay backgrounds: ♑ convers'ns, mid-ID p^0 ✹ ♑♑ from hadronic interactions**
- **topology and experiment dependent purities (80%-99%) and efficiencies (0.5%- 50%)**

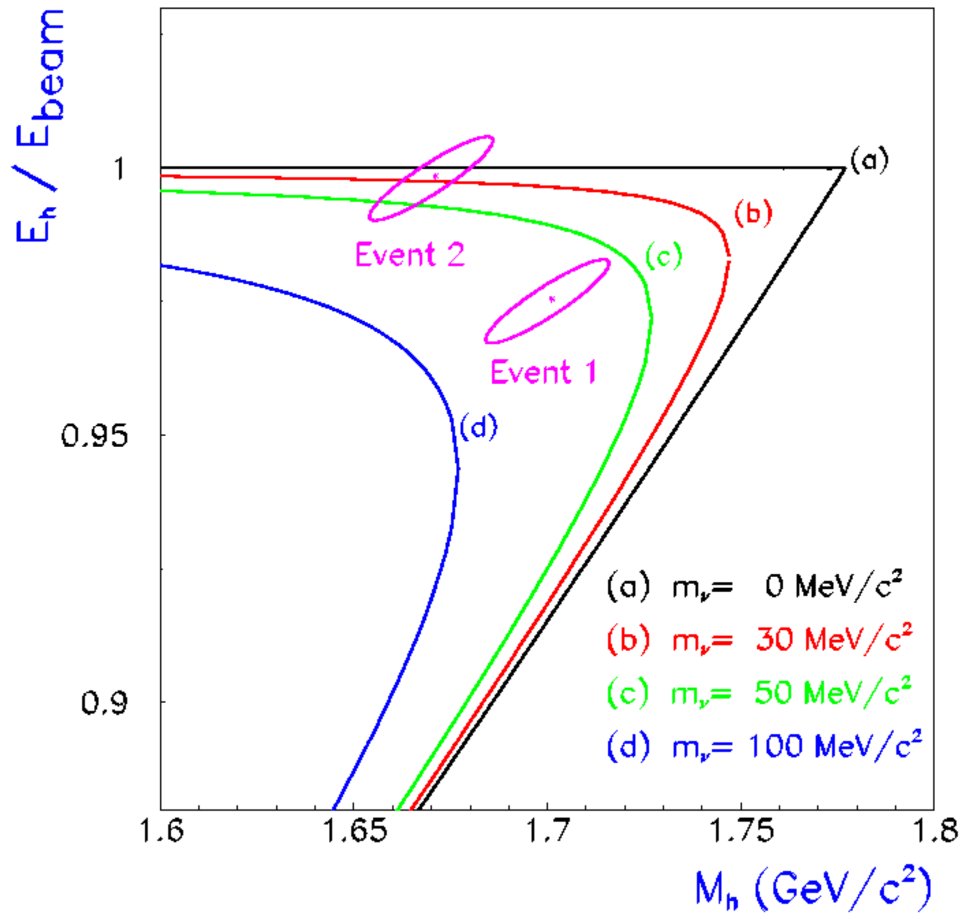
Measurement method

$$m_\nu^2 = (E_{beam} - E_h)^2 - (\vec{p}_\tau - \vec{p}_h)^2$$

$$= m_\tau^2 + M_h^2 - 2E_{beam}E_h + 2\sqrt{E_{beam}^2 - m_\tau^2}\,\sqrt{E_h^2 - M_h^2}\,\cos\theta_{h\tau}$$

For fixed m kinematic limit at $\cos\theta_{h\tau} = \pm 1$

Analysis in E_h/E_{beam} vs M_h plane



Fit method

Event-by-event probability:

$$\wp_i(m_\nu) = P(M_{hi}, E_{hi} \mid m_\nu) \otimes \Re(M_{hi}, E_{hi}, s_{M_i}, s_{E_i}, r_i) \otimes e(M_{hi}, E_{hi})$$

$$P(M_h, E_h | m_\nu) \propto \left[\left| M(M_h, E_h \mid m_\nu) \right|^2 \cdot PS(M_h, E_h \mid m_\nu) \right] \otimes \mathbf{ISR}(E_{beam}, E_t)$$

$$\mathbf{L} = \prod_{i=1}^{N} [\wp_i(m_\nu) + \wp_{backgd}(M_{hi}, E_{hi})]$$

$\wp_i(m_\nu)$ and $\wp_{backgd}(M_{hi}, E_{hi})$ determined with Monte Carlo or analytically

No. of decays in fits

	$\Upsilon(4s)$		Z^0	
	ARGUS	CLEO	ALEPH	OPAL
$N_{\tau\tau}$	$3-4\times10^5$	$4-5\times10^6$	2×10^5	2×10^5
Year published	(1992)	('98, '00)	(1998)	('96,'98)
$3p^{\pm}n_{t}$			2939	2514
$3p^{\pm}p^{0}n_{t}$		16577		
$5p^{\pm}(p^{0}*)n_{t}$	20	36	55^{*}	22
$3p^{\pm}2p^{0}n_{t}$		19		

CLEO $3p^{\pm}p^{0}n_{t}$

16577 decays in fit

543 within $m_h / m_t > 0.925$

Background:

3% $q\bar{q}$ and 7% t

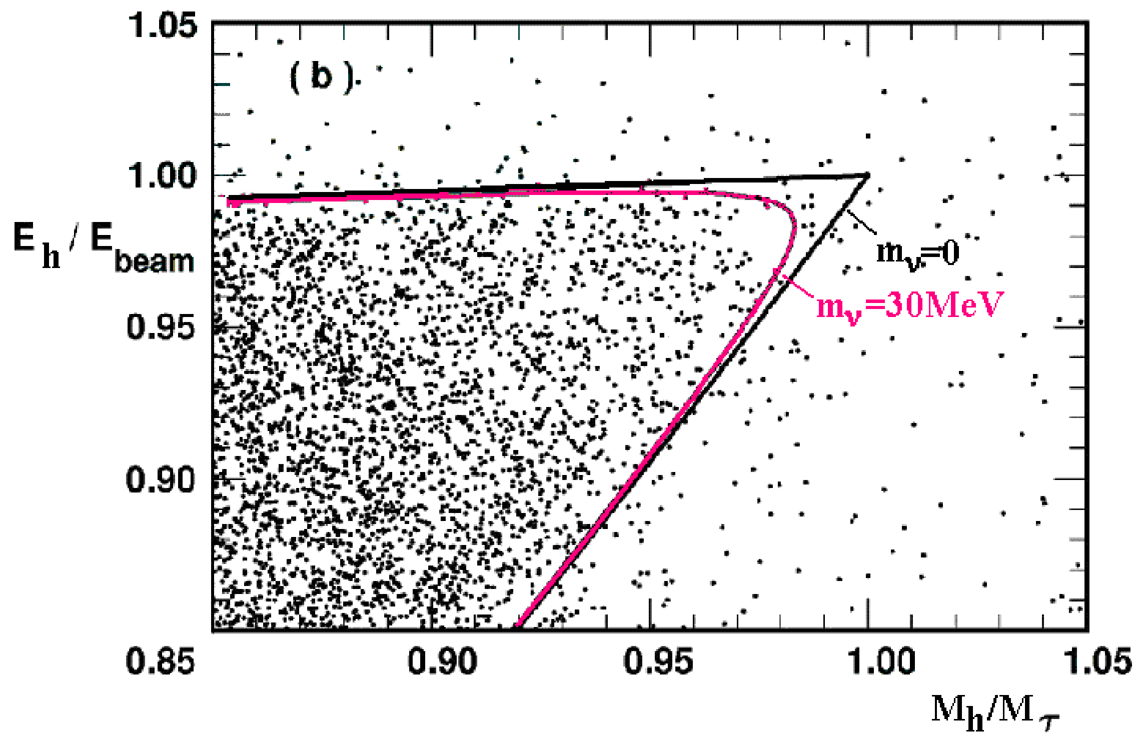
Dominant systematics:

p^{0} energy scale: 3.7MeV/c^2

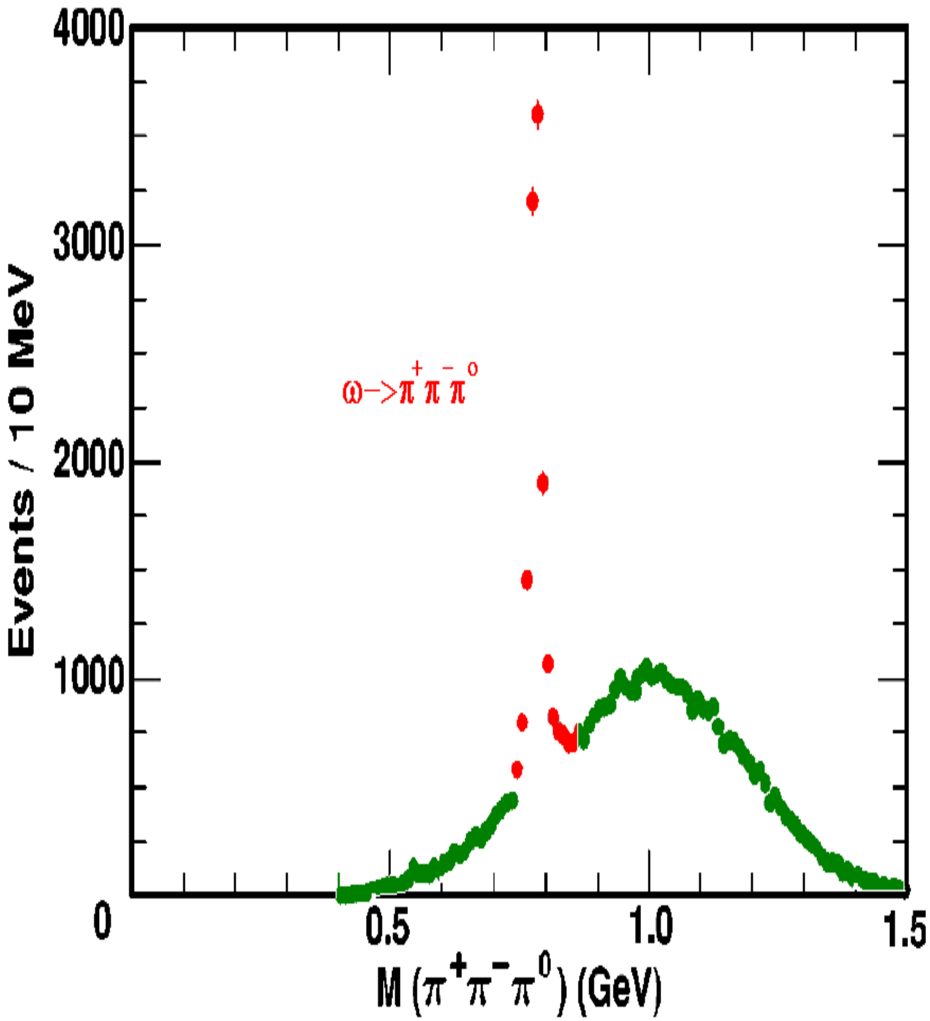
tracking p scale: 3.3MeV/c^2

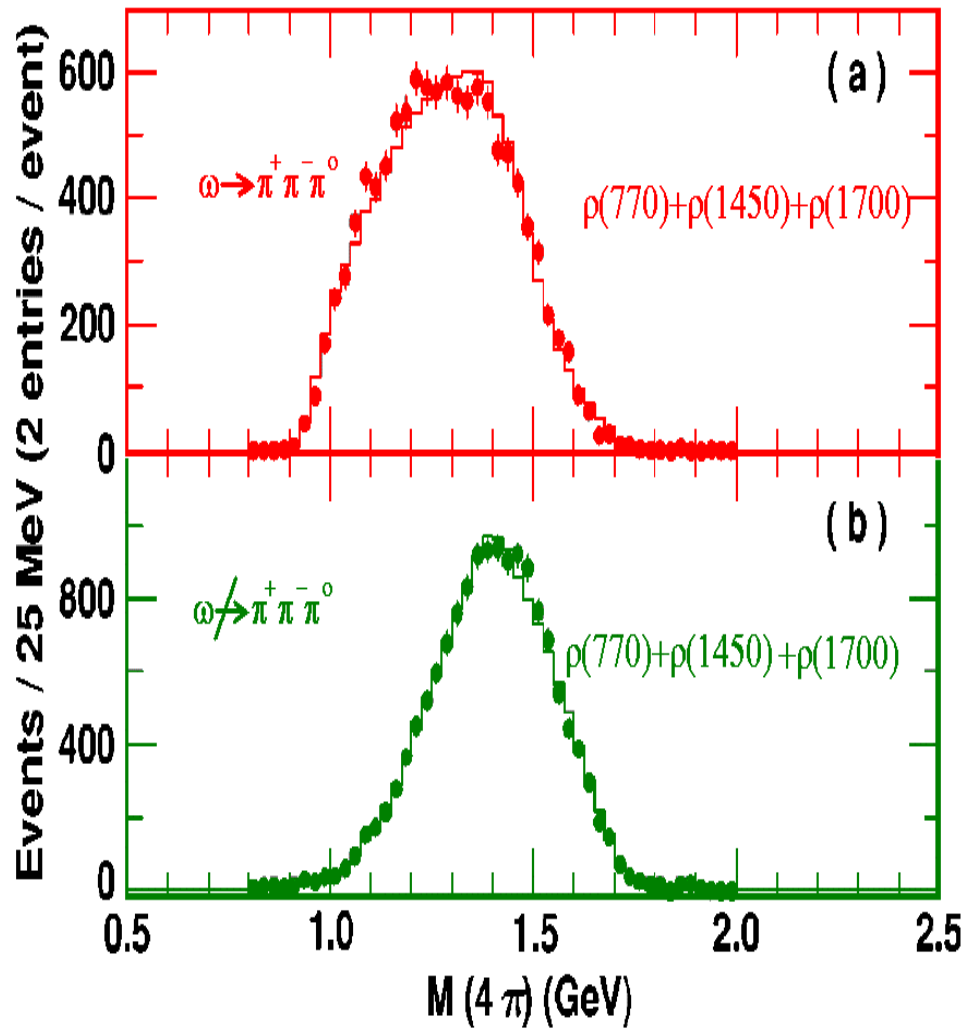
Spectral funct'n: 4.0MeV/c^2

[r(1700) M, Γ, amplitude]

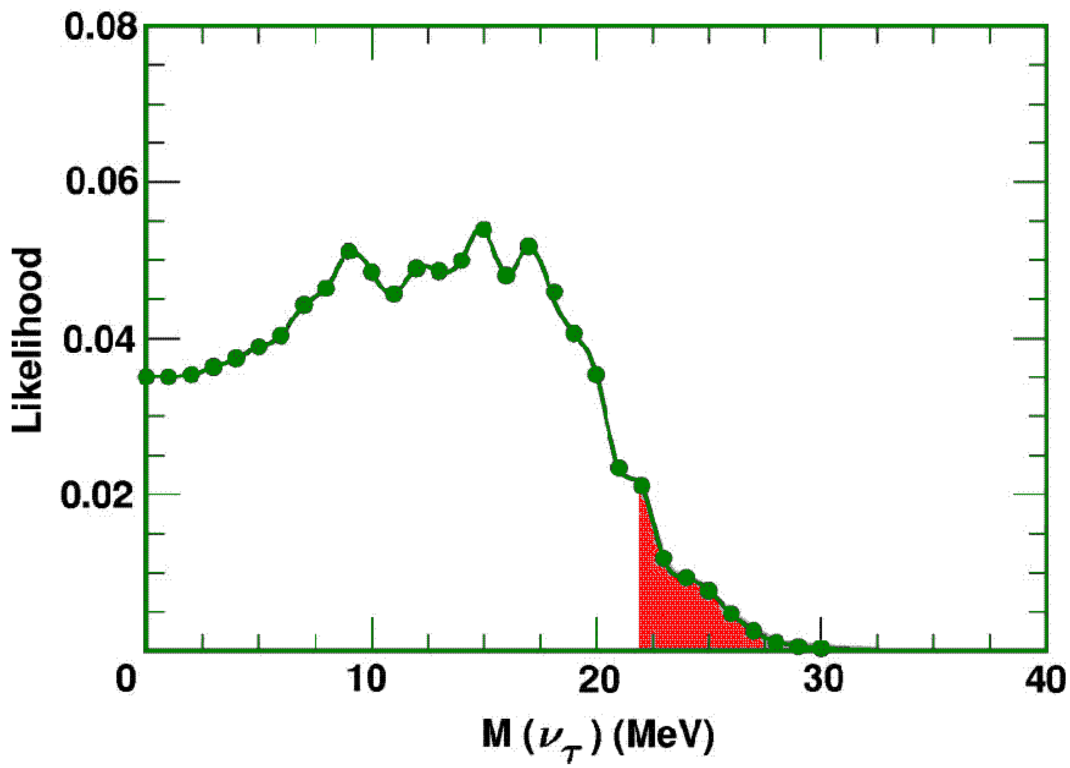


CLEO $3p^{\pm}p^{0}n_{t}$





CLEO $3\pi^{\pm}\pi^{0}\nu_{\tau}$



Limit excluding systematic errors:

$m_{\nu} < 22 \text{MeV}/c^2$

Limit including systematic errors:

$m_{\nu} < 28 \text{MeV}/c^2$ @95%CL

dependence on 543 event sample less sensitive to chance fluctuations

OPAL $\tau^- \to 3\pi^- 2\pi^+ \nu_\tau$

22 decays in fit

5 sensitive i.e.: $m_\nu < 100 MeV/c^2$

background events:

0.5 $q\bar{q}$ and 0.1 τ cf 22 obs

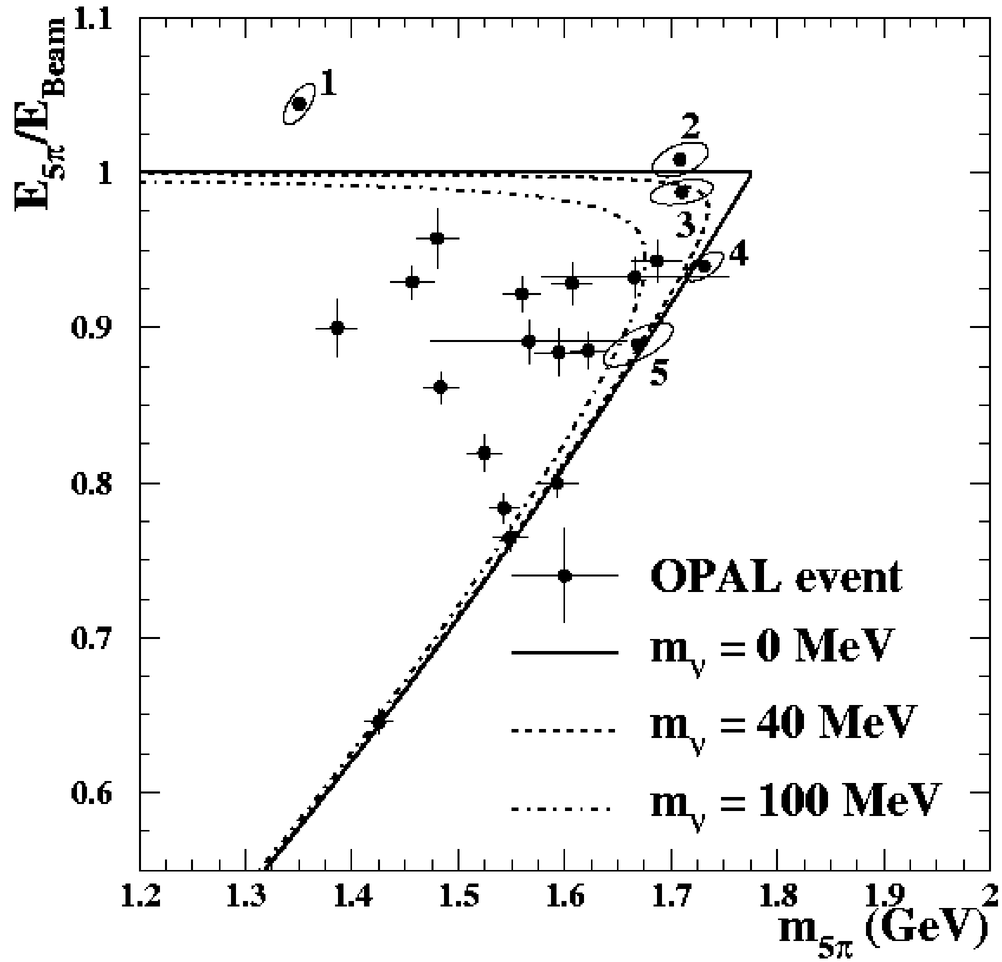
effective background events:

0.05 $q\bar{q}$ and 0.01 τ cf 5 obs

Dominant systematics:

non-Gaussian tails: $3.5 MeV/c^2$

resolution funct'n: $0.5 MeV/c^2$



OPAL $\tau^- \to 3\pi^- 2\pi^+ \nu_\tau$

Excluding systematic errors:

$m_\nu < 39.6 \mathrm{MeV}/c^2$

Including systematic errors:

dominated by resolution

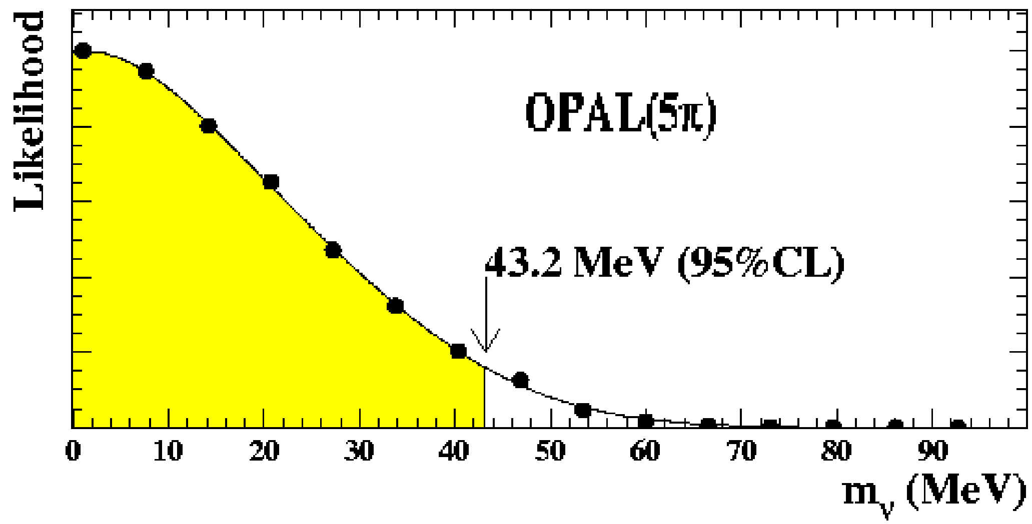
modelling ($3.5\mathrm{MeV}/c^2$)

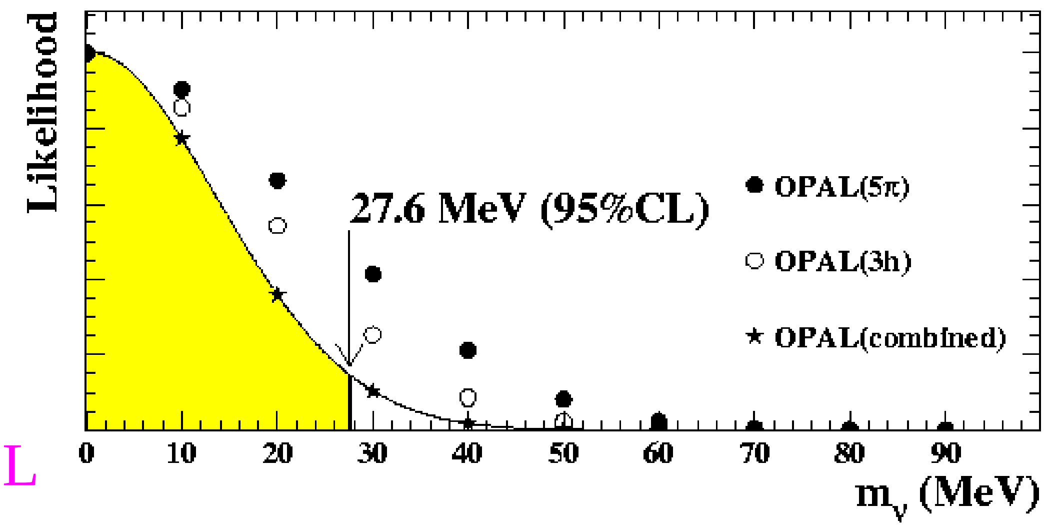
$m_\nu < 43.2 \mathrm{MeV}/c^2$

Combining with

3π analysis likelihood:

$m_\nu < 27.6 \mathrm{MeV}/c^2$ @95%CL





ALEPH $\tau^- \to 2\pi^-\pi^+\nu_\tau$

Excluding systematic errors:

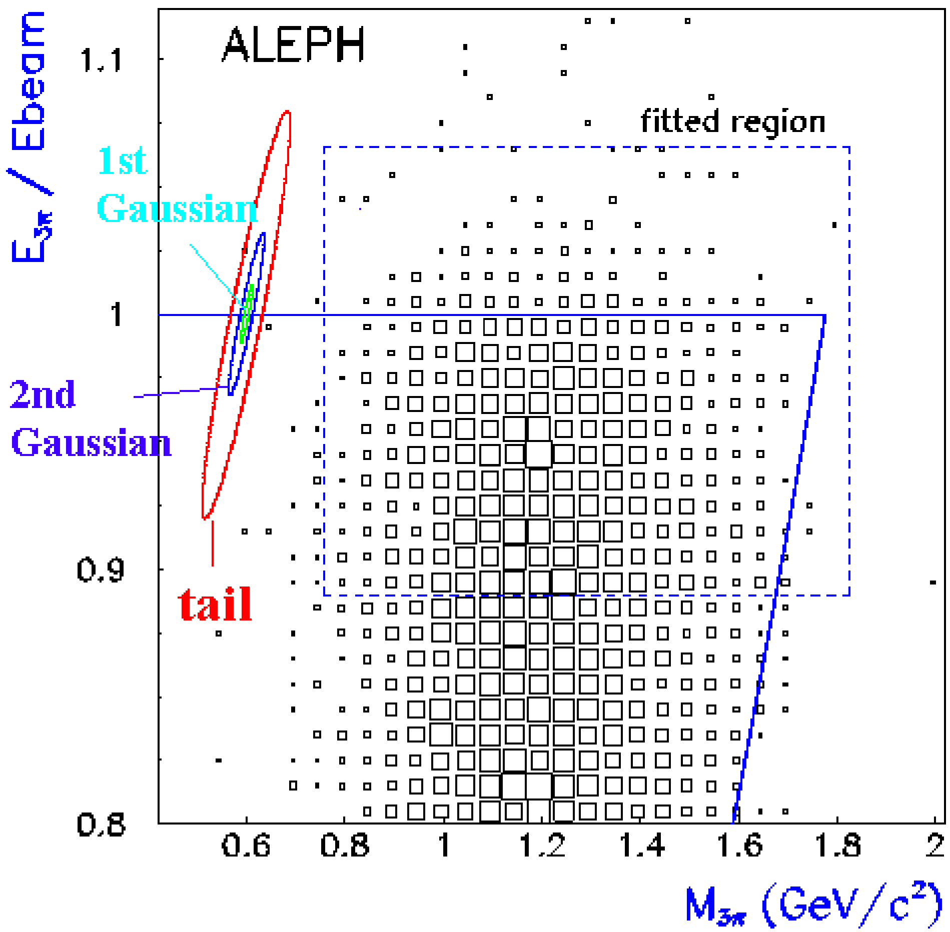
$m_\nu < 21.5 \mathrm{MeV/c^2}$

Including systematic errors:
Dominated by energy-mass resolution (3.1MeV) and calibration(2.6MeV)

$m_\nu < 25.7 \mathrm{MeV/c^2}$

Combining with ALEPH 5π analysis likelihood:

$m_\nu < 18.2 \mathrm{MeV/c^2}$ @95%CL

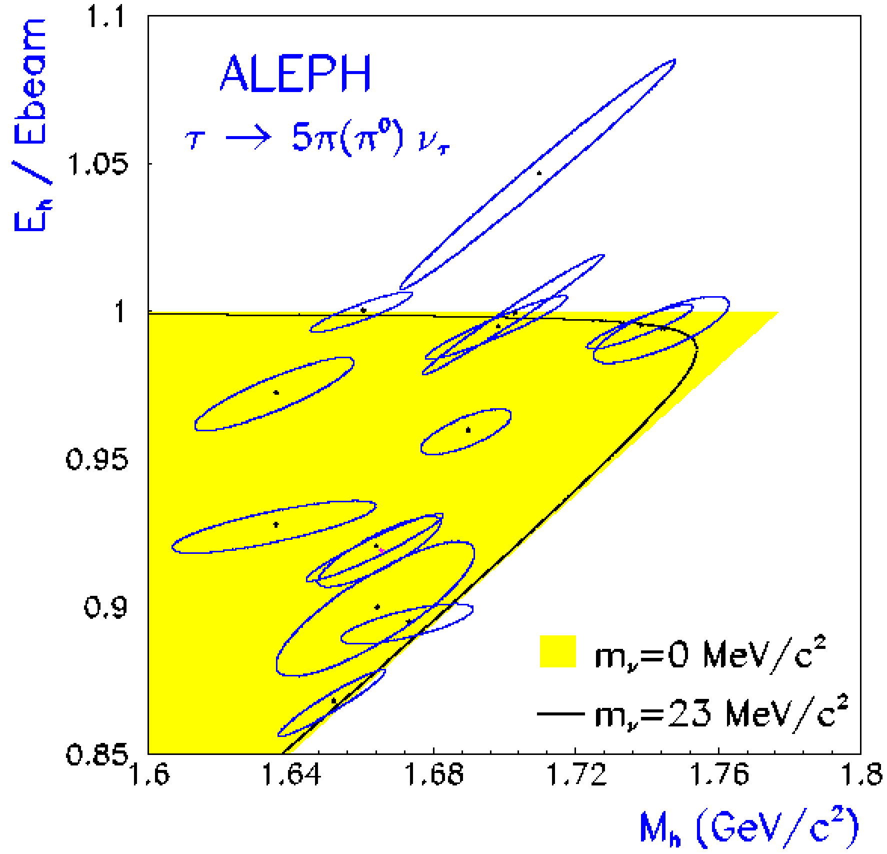


ALEPH

$t^{-} \rightarrow 3p^{-}2p^{+}(p^{0})n_{t}$

Excluding systematic errors:

$m_n < 22.3\text{MeV}/c^2$



Including systematic errors:
Dominated by modelling of resolution (0.6MeV);
t background (0.3MeV); and energy-mass calibration(0.3MeV)

$m_n < 23.1\text{MeV}/c^2$

Spectral function models

M_h description is model dependent (e.g. a_1), effects mitigated by high sensitivity to E_h

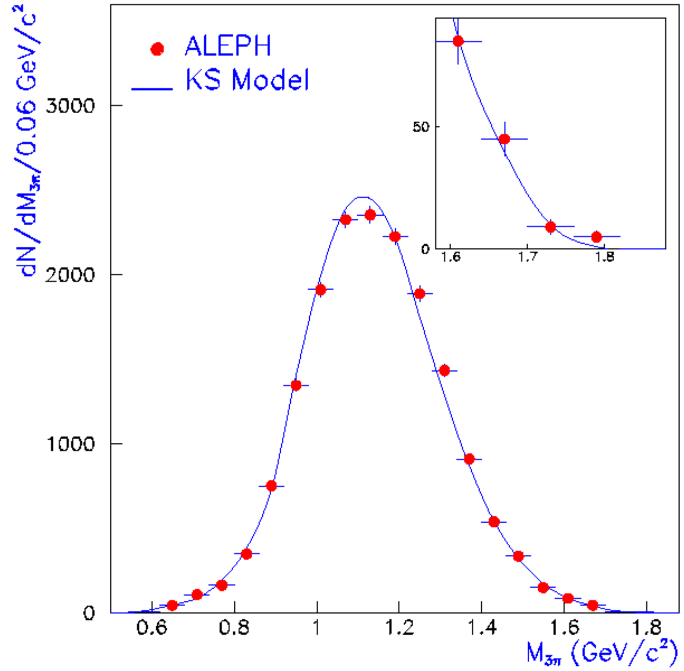
Systematic error in 3 *pn* from

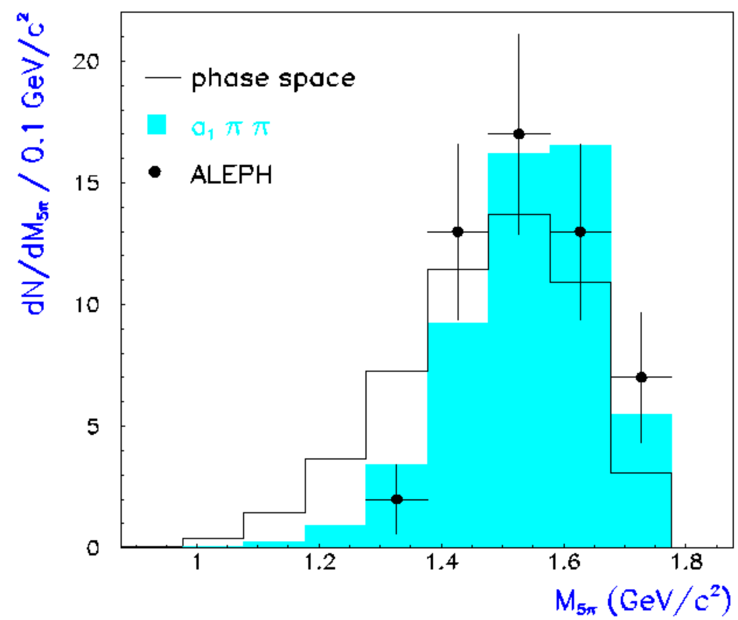
a_1, *r* and *r* ' M and Γ : 0.3MeV/c^2

Analogous concern in 5 *p* is less important.

Systematic error in 5 *pn* from

various models : <0.1MeV/c^2



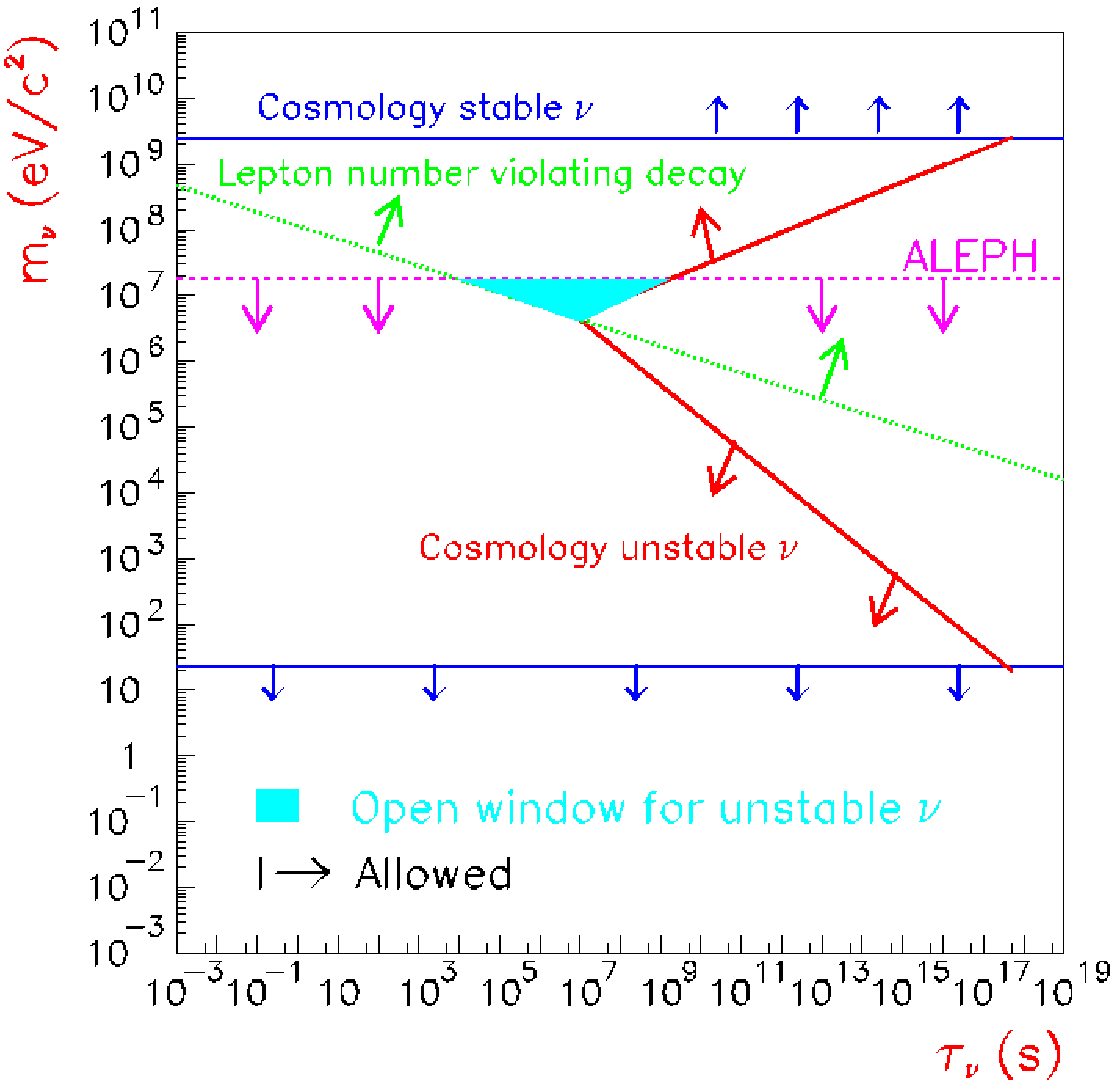


95% CL Limits (MeV/c^2)

	$\Upsilon(4s)$		Z^0	
	ARGUS	CLEO	ALEPH	OPAL
$3p^{\pm}n_t$			25.7	35.3
$3p^{\pm}p^{0}n_t$		28		
$5p^{\pm}(p^{0}\ *)n_t$	31	33.9	23.1*	43.2
$3p^{\pm}2p^{0}n_t$		35.9		
Combined	31	28&30	18.2	27.6

- **ARGUS used the M_h spectrum only**

Cosmological limits



Combining measurements

Each experiment provides the likelihood distributions which can be combined

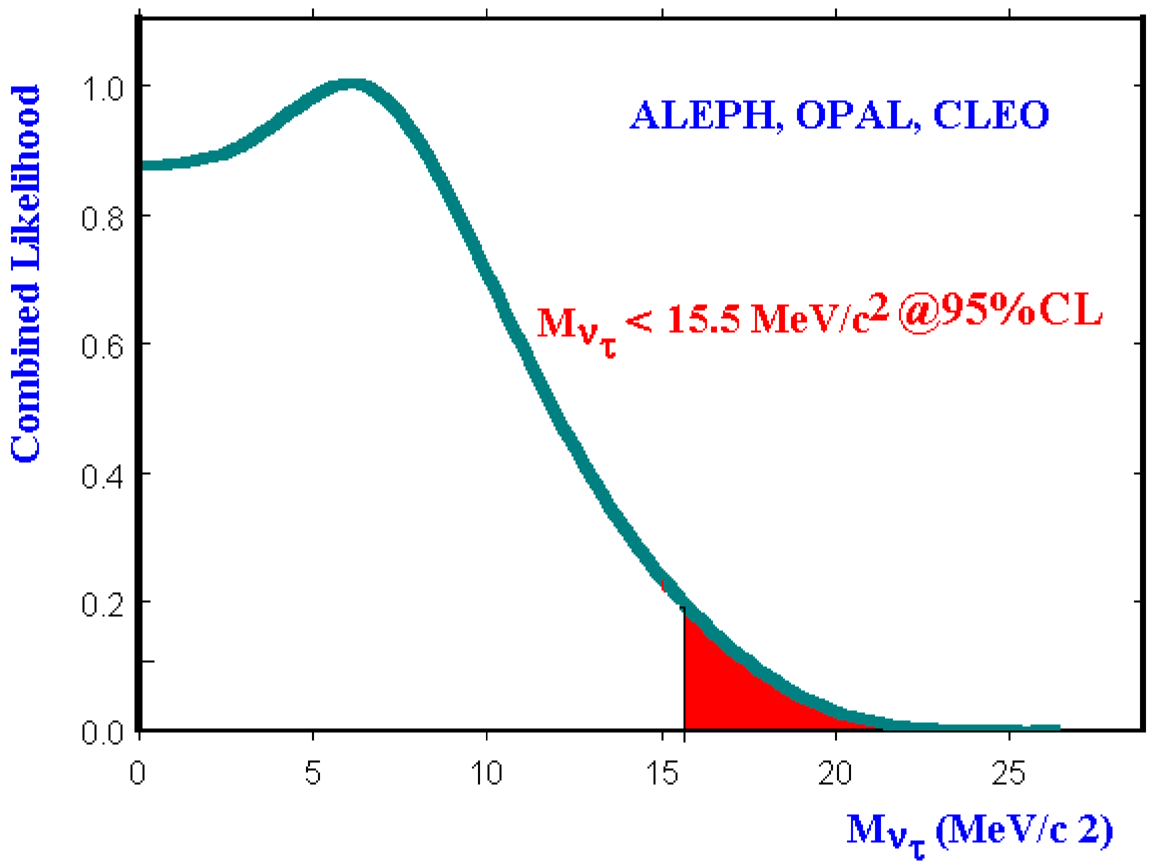
The dominant systematic errors in each are uncorrelated

Combining systematics-corrected likelihoods yields:

$m_{nt} <$ 15.5 MeV/c^2 @95%CL

long lifetime cosmological loophole is not closed

Combining measurements



Future prospects

- BABAR and BELLE are now taking data and each expect ~12/fb in 2000 and ~30/fb in 2001
- Repeat of CLEO $3\pi^{\pm}\ \pi^{0}$ measurement gives 7MeV/c^2 limit from statistics alone and 12MeV/c^2 with systematics, assuming $\rho(1700)$ parameters known
- To get to 3MeV/c^2 requires 300/fb (~1×10^{34}cm^{-2}s^{-1} luminosity machine) and smaller systematic errors

SUMMARY

- **Direct limit: m_{ν_τ}<18.2MeV/c^2 @95%CL from ALEPH**
- **New limit from CLEO m_{ν_τ}<28MeV/c^2 with new higher statistics channel**
- **Some improvement in limit when likelihoods combined, but loophole remains**
- **Reasonable prospects for reaching 3MeV/c^2 at BABAR and BELLE**