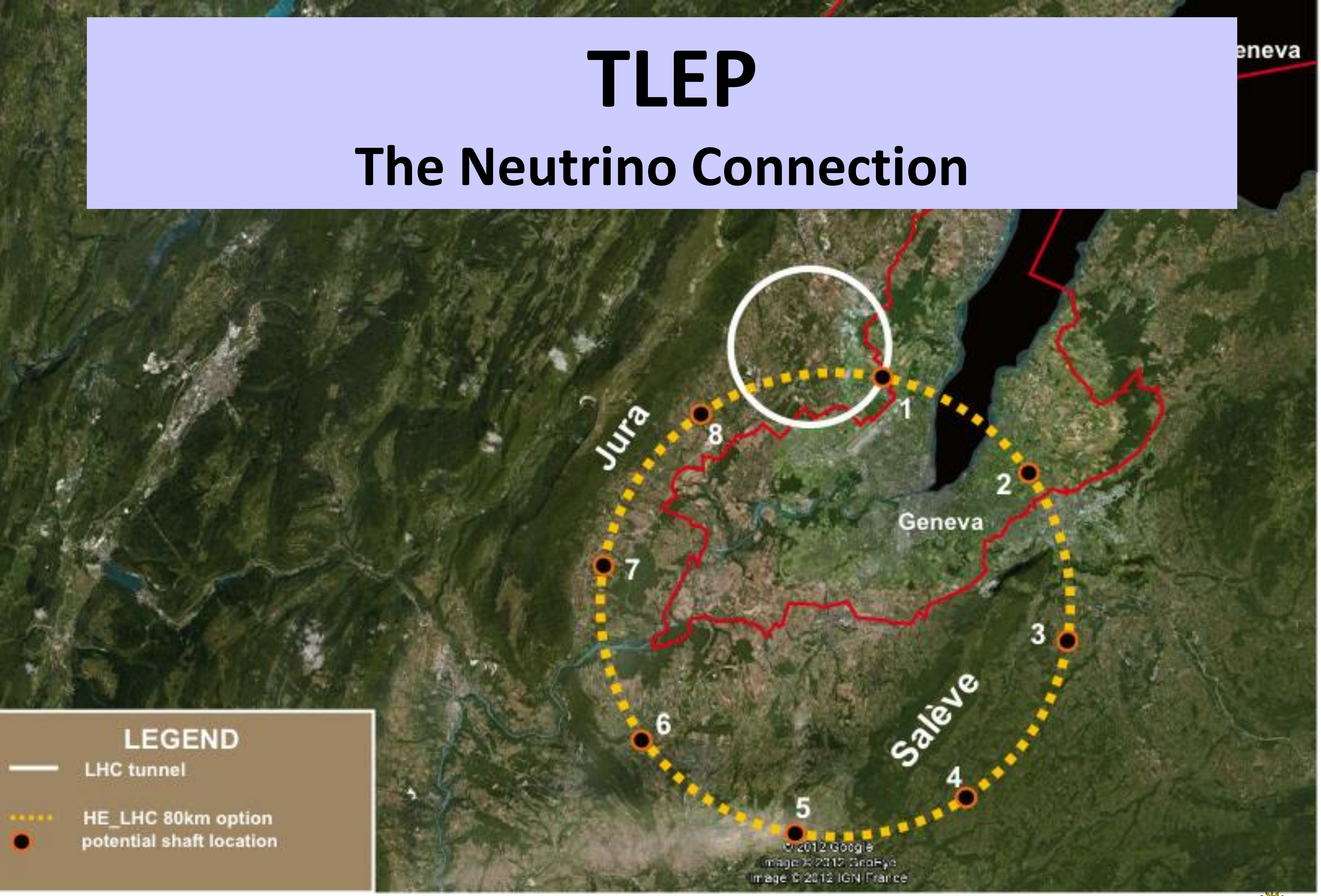
TLEP

The Neutrino Connection



NEUTRINO CONNECTIONS

The only known BSM physics at the particle physics level is the existence of neutrino masses

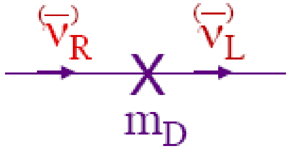
-- There is no unique solution for mass terms: Dirac only? Majorana only? Both?

-- if Both, existence of (2 or 3) families of massive right-handed (~sterile) N_i , $\bar{N}_i$ neutrinos is predicted («see-saw» models) but masses are unknown (eV to 10^{10}GeV)

-- Arguably, sterile neutrinos are the most likely 'new physics' there is.

Adding masses to the Standard model neutrino 'simply' by adding a Dirac mass term

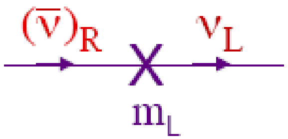
$$m_D \nu_L \overline{\nu_R} \qquad m_D \overline{\nu_L} \nu_R$$



implies adding a right-handed neutrino (new particle)

<u>No SM symmetry</u> prevents adding then a term like

$$m_M \overline{\nu_R{}^c}\, \nu_R$$



and this simply means that a neutrino turns into a antineutrino
(the charge conjugate of a right handed antineutrino is a left handed neutrino!)

See-saw in the most general way :

$$\mathcal{L} = \frac{1}{2}(\bar{\nu}_L,\, \bar{N}_R^c) \begin{pmatrix} 0 & m_D \\ m_D^T & M_R \end{pmatrix} \begin{pmatrix} \nu_L^c \\ N_R \end{pmatrix}$$

$M_R \neq 0$
$m_D \neq 0$
Dirac + Majorana

$$\tan 2\theta = \frac{2\, m_D}{M_R - 0} \qquad \ll 1$$

$$m_\nu = \tfrac{1}{2}\left[(0 + M_R) - \sqrt{(0 - M_R)^2 + 4\, m_D^2}\right] \qquad \simeq -m_D^2/M_R$$

$$M = \tfrac{1}{2}\left[(0 + M_R) + \sqrt{(0 - M_R)^2 + 4\, m_D^2}\right] \qquad \simeq M_R$$

general formula — if $m_D \ll M_R$

$M_R = 0$
$m_D \neq 0$
Dirac only, (like e- vs e+):

m ↑

ν_L ν_R $\bar{\nu}_R$ $\bar{\nu}_L$

$I_{weak}=$ ½ 0 ½ 0

4 states of equal masses

Some have I=1/2 (active)
Some have I=0 (sterile)

$M_R \neq 0$
$m_D = 0$
Majorana only

m ↑

ν_L $\bar{\nu}_R$

$I_{weak}=$ ½ ½

2 states of equal masses

All have I=1/2 (active)

$M_R \neq 0$
$m_D \neq 0$
Dirac + Majorana

m ↑

ν_L N_R $\bar{\nu}_R$ $\bar{N}_L$

$I_{weak}=$ ½ 0 ½ 0

4 states , 2 mass levels

m1 have I=1/2 (~active)
m2 have I=0 (~sterile)

$$\tan 2\theta = \frac{2\, m_D}{M_R - 0} \qquad \ll 1$$

$$m_\nu = \tfrac{1}{2}\left[(0 + M_R) - \sqrt{(0 - M_R)^2 + 4\, m_D^2}\right] \qquad \simeq -m_D^2/M_R$$

$$M = \tfrac{1}{2}\left[(0 + M_R) + \sqrt{(0 - M_R)^2 + 4\, m_D^2}\right] \qquad \simeq M_R$$

general formula — if $m_D \ll M_R$

m_D associated with EWSB, part of SM, bounded by $v/\sqrt{2} = 174$ GeV

M_R is SM singlet, does whatever it wants: $\Rightarrow M_R \gg m_D$

Hence, $\theta \simeq m_D/M_R \ll 1$

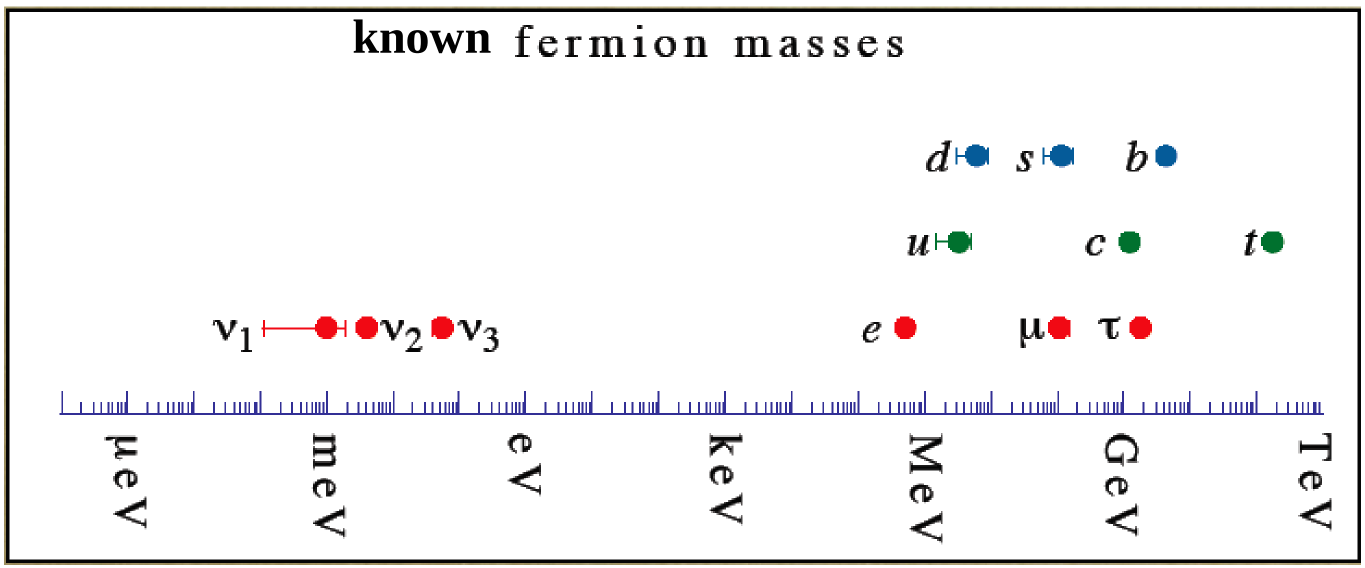
Note that this is not necessary as we have <u>no idea</u> of m_D and M_R !

$$\nu = \nu_L \cos\theta - N_R^c \sin\theta \simeq \nu_L \quad \text{with mass} \quad m_\nu \simeq -m_D^2/M_R$$

$$N = N_R \cos\theta + \nu_L^c \sin\theta \simeq N_R \quad \text{with mass} \quad M \simeq M_R$$

$$m_\nu = \frac{m_D^{\,2}}{M}$$

has been invoked to explain the smallness of active neutrino masses



Manifestations of sterile neutrinos

$$\nu = \nu L \cos\theta - N^{c}{}_{R} \sin\theta$$

$$N = N_R \cos\theta + \nu_L{}^{c} \sin\theta$$

ν = light mass eigenstate
N = heavy mass eigenstate
$\neq \nu_L$ which couples to weak interaction

-- mixing with active neutrinos leads to various observable consequences

-- if very light (eV) , possible effect on neutrino oscillations

-- if mixing in % or permil level, possibly measurable effects on

➔ PMNS matrix unitarity violation and deficit in Z invisible width ← today

➔ occurrence of Higgs invisible decays H→ $\nu_i \bar{N}_i$

➔ violation of unitarity and lepton universality in W or τ decays

next times!

-- etc etc..

-- Couplings are small (m_D/M) and generally out of reach of hadron colliders

-- Require high statistics e+e-

TLEP

IPAC'13 Shanghai

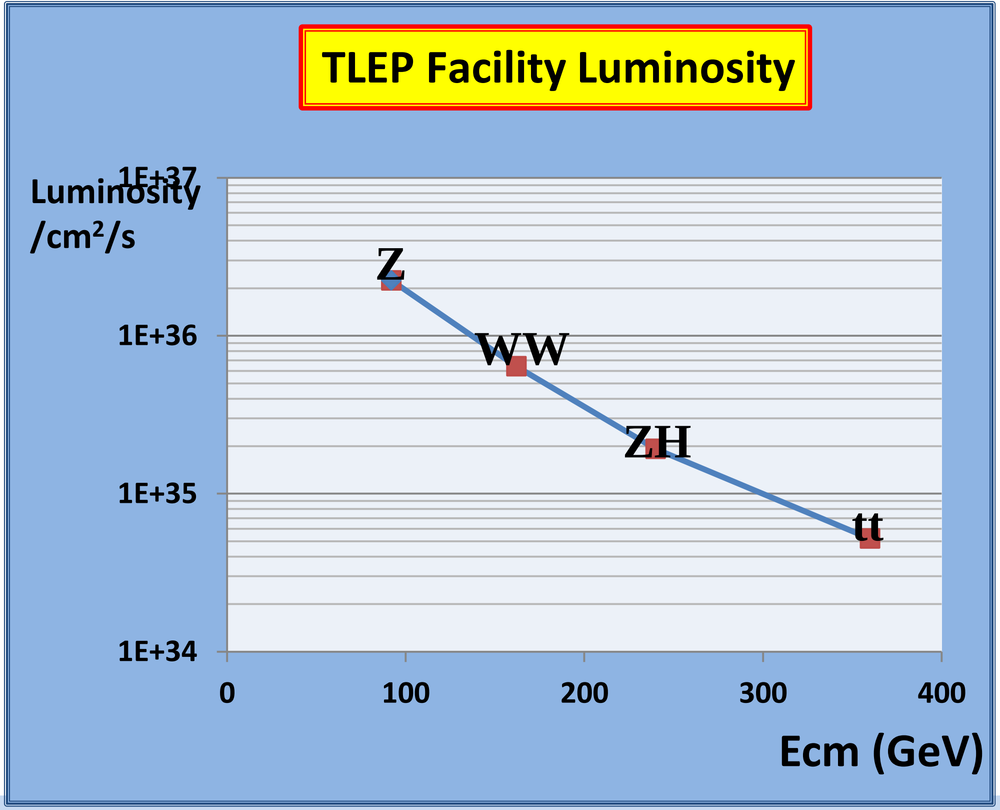
Table 1: TLEP parameters at different energies

	TLEP Z	TLEP W	TLEP H	TLEP t
E_{beam} [GeV]	45	80	120	175
circumf. [km]	80	80	80	80
beam current [mA]	1180	124	24.3	5.4
#bunches/beam	4400	600	80	12
#e−/beam [10^{12}]	1960	200	40.8	9.0
horiz. emit. [nm]	30.8	9.4	9.4	10
vert. emit. [nm]	0.07	0.02	0.02	0.01
bending rad. [km]	9.0	9.0	9.0	9.0
κ_ε	440	470	470	1000
mom. c. α_c [10^{-5}]	9.0	2.0	1.0	1.0
$P_{loss,SR}$/beam [MW]	50	50	50	50
β^*_x [m]	0.5	0.5	0.5	1
β^*_y [cm]	0.1	0.1	0.1	0.1
σ^*_x [μm]	124	78	68	100
σ^*_y [μm]	0.27	0.14	0.14	0.10
hourglass F_{hg}	0.71	0.75	0.75	0.65
E^{SR}_{loss}/turn [GeV]	0.04	0.4	2.0	9.2
V_{RF}, tot [GV]	2	2	6	12
$\delta_{max,RF}$ [%]	4.0	5.5	9.4	4.9
ξ_x/IP	0.07	0.10	0.10	0.10
ξ_y/IP	0.07	0.10	0.10	0.10
f_s [kHz]	1.29	0.45	0.44	0.43
E_{acc} [MV/m]	3	3	10	20
eff. RF length [m]	600	600	600	600
f_{RF} [MHz]	700	700	700	700
δ^{SR}_{rms} [%]	0.06	0.10	0.15	0.22
$\sigma^{SR}_{z,rms}$ [cm]	0.19	0.22	0.17	0.25
$\mathcal{L}$ /IP[10^{32}cm^{-2}s^{-1}]	5600	1600	480	130
number of IPs	4	4	4	4
beam lifet. [min]	67	25	16	20

TLEP: A HIGH-PERFORMANCE CIRCULAR e^+e^- COLLIDER TO STUDY THE HIGGS BOSON

M. Koratzinos, A.P. Blondel, U. Geneva, Switzerland; R. Aleksan, CEA/Saclay, France; O. Brunner, A. Butterworth, P. Janot, E. Jensen, J. Osborne, F. Zimmermann, CERN, Geneva, Switzerland; J. R. Ellis, King's College, London; M. Zanetti, MIT, Cambridge, USA.

http://arxiv.org/abs/1305.6498.



CONSISTENT SET OF PARAMETERS FOR TLEP TAKING INTO ACCOUNT BEAMSTRAHLUNG

Will consider also : x10 upgrade with e.g. charge compensation? (suppresses beamstrahlung and beam-beam blow up)

In October 1989 LEP determined that the number of neutrino families was 3.11±0.15

In Feb 1990 Cecilia Jarlskog commented that this number could smaller than 3 if the left handed neutrino(s) has a component of (a) heavy sterile neutrino(s) which is kinematically suppressed or forbidden

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NEUTRINO COUNTING AT THE Z-PEAK AND RIGHT-HANDED NEUTRINOS

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Received 20 February 1990

We consider the implications of extending the minimal standard model, with n families of quarks and leptons, by introducing an arbitrary number of right-handed neutrinos, for neutrino-counting via the "invisible width" of the Z. It is shown that the effective number of neutrinos, $\langle n \rangle$, satisfies, the inequality $\langle n \rangle \leqslant n$, where $\langle n \rangle$ is defined by $\Gamma(\mathrm{Z} \to \text{neutrinos}) \equiv \langle n \rangle \Gamma_0$ and Γ_0 is the standard width for one massless neutrino. Thus, in the case of three families, the neutrino-counting can give a result which is less than three, if there are right-handed neutrinos.

Theorem.

In the standard model, with n left-handed lepton doublets and $N-n$ right-handed neutrinos, the effective number of neutrinos, $\langle n \rangle$, defined by

$$\Gamma(\mathrm{Z} \to \text{neutrinos}) \equiv \langle n \rangle \Gamma_0 ,$$

where Γ_0 is the standard width for one massless neutrino, satisfies the inequality

$$\langle n \rangle \leqslant n . \qquad (15)$$

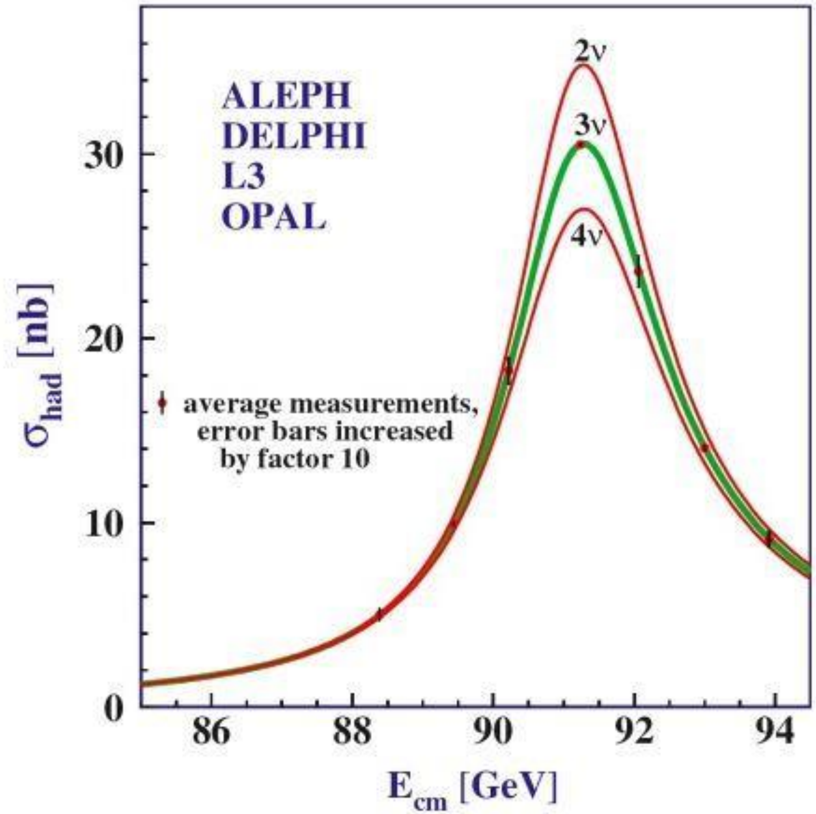
At the end of LEP:

Phys.Rept.427:257-454,2006

N_ν = 2.984 ±0.008

- 2 σ :^) !!

This is determined from the Z line shape scan and dominated by the measurement of the hadronic cross-section at the Z peak maximum ➔



The dominant systematic error is the theoretical uncertainty on the Bhabha cross-section (0.06%) which represents an error of ±0.0046 on N_ν

Improving on N_ν by more than a factor 2 would require a large effort to improve on the Bhabha cross-section calculation!

TLEP
$HZ^0W^-W^+t\bar{t}$

Another solution:
determine the number of neutrinos from the radiative returns

$$e^+e^- \rightarrow \gamma\ Z\ (\rightarrow \nu\ \bar{\nu})$$

CERN-TH.5528/8

NEUTRINO COUNTING

G. Barbiellini[1], X. Berdugo[2], G. Bonvicini[3], P. Colas[4], L. Mirabito[4], C. Dionisi[5], D. Karlen[6], F. Linde[7], C. Luci[8], C. Mana[8], C. Matteuzzi[9], O. Nicrosini[10], R. Ragazzon[1], D. Schaile[11], F. Scuri[1] and L. Trentadue*),[12]

in its original form (Karlen) the method only counts the 'single photon' events and is actually less sensitive than claimed. It has poorer statistics and requires running ~10 GeV above the Z pole. Systematics on photon selection are not small.

present result: N_ν = 2.92±0.05

TLEP HZ⁰W⁻W⁺tt̄

Neutrino counting at TLEP

given the very high luminosity, the following measurement can be performed

$$N_\nu = \frac{\dfrac{\gamma Z(inv)}{\gamma Z \to ee, \mu\mu}}{\dfrac{\Gamma_\nu}{\Gamma e, \mu}(SM)}$$

The common γ tag allows cancellation of systematics due to photon selection, luminosity etc. The others are extremely well known due to the availanbility of O(10^{12}) Z decays.

The full sensitivity to the number of neutrinos is restored , and the theory uncertainty on $\frac{\Gamma_\nu}{\Gamma e}(SM)$ is very very small.

A good measurement can be made from the data accumulated at the WW threshold where σ (γ Z(inv)) ~4 pb for |cosθ_γ| <0.95

161 GeV (10^7 s) running at 1.6×10^{35}/cm²/s x 4 exp → 3×10^7 γ Z(inv) evts, ΔN_ν =0.0011
adding 5 yrs data at 240 and 350 GeV .... ΔN_ν =0.0008

A better point may be 105 GeV (20pb and higher luminosity) may allow ΔN_ν =0.0004?

Conclusions

Given the high statistics (and if the detectors are designed appropriately) the measurement of the Z invisible width at TLEP should allow a powerful search for sterile neutrinos (or other invisible or exotic final states in Z decays)

The most powerful technique is the radiative returns $e+e- \rightarrow \gamma\ Z$ with a tag on the photon.

A sensitivity of $\Delta N_\nu = 0.001$ should be achievable and perhaps better

To do:

-- confirm numbers and check selection backgrounds etc..

-- optimize the experiment ('guess' is optimum around 105 GeV)

-- this is exciting.