Electroweak interaction The Glashow-Salam-Weinberg model

Particle Physics

Fabrice Couderc / Eli BenHaim

NPAC 2022/2023

Overview

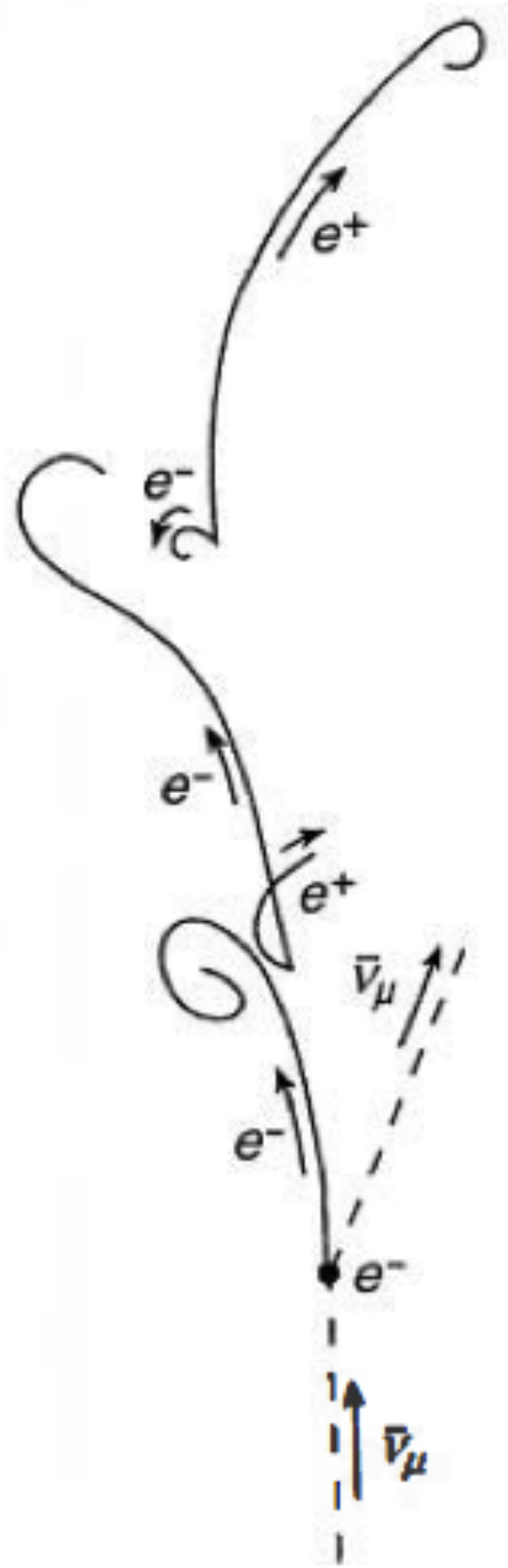
I. Introduction to $SU(2)_L$
   1. Charged weak current reminder
   2. Building a gauge theory of weak interaction
   3. Gauge bosons masses
   4. Discovery of neutral weak currents

II. Symmetry breaking and the BEH mechanism
   1. Scalar field and the abelian symmetry case

III. Electroweak symmetry and GSW model
   1. Electroweak symmetry $SU(2)_L \times U(1)$
   2. Breaking of EWK symmetry and gauge bosons masses
   3. Coupling to fermions, hypercharge and weak isospin
   4. W, Z boson couplings summary

IV. Experimental tests and exercises
   1. Z boson properties
   2. Lepton coupling universality
   3. Number of neutrino families
   4. Left-Right asymmetry at SLC and $\sin^2\theta_W$

Weak neutral current discovery

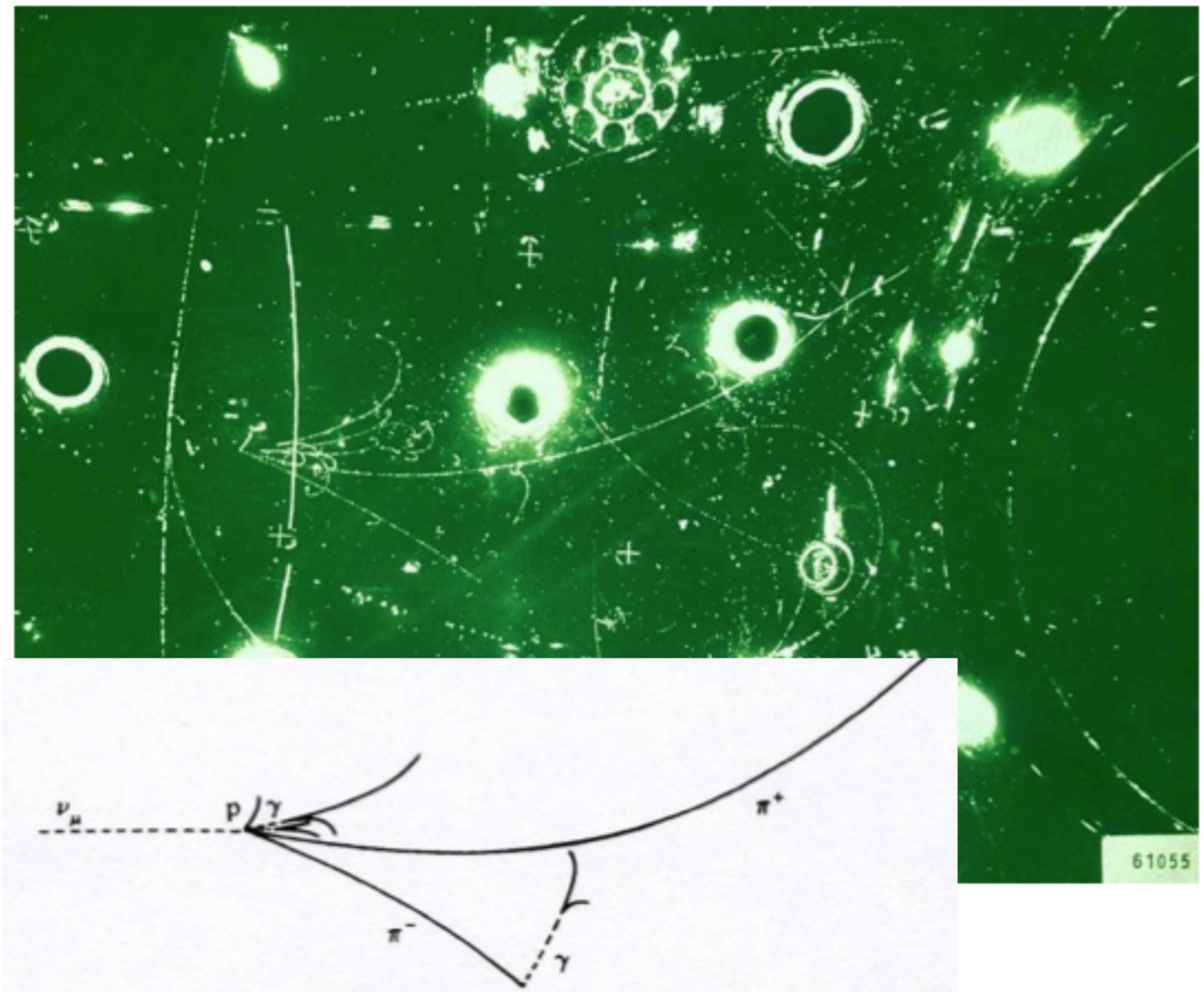


Gargamelle bubble chamber 1973

$$\nu_\mu\, e^- \rightarrow e^-\, \nu_\mu$$

Weak neutral current discovery

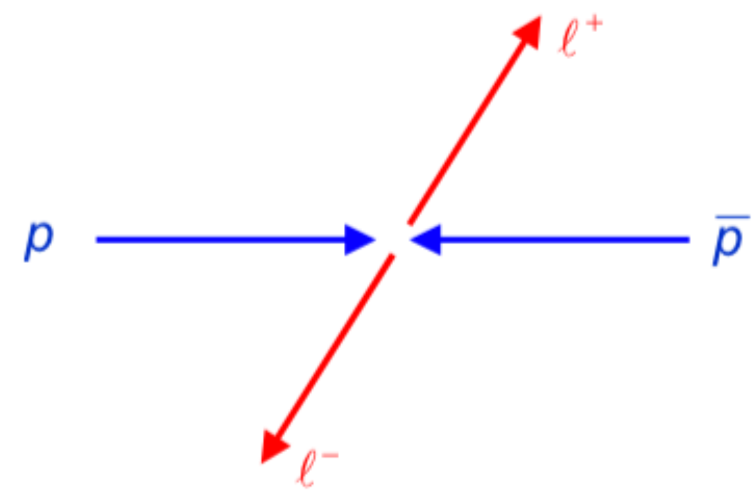
Gargamelle bubble chamber 1973



$$\nu_\mu \, p \rightarrow X \, \nu_\mu$$

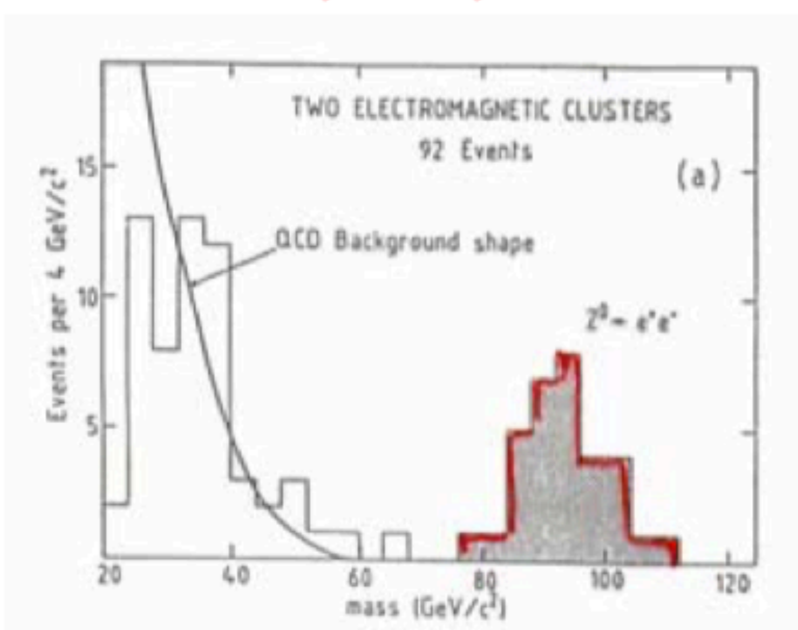
Z boson discovery

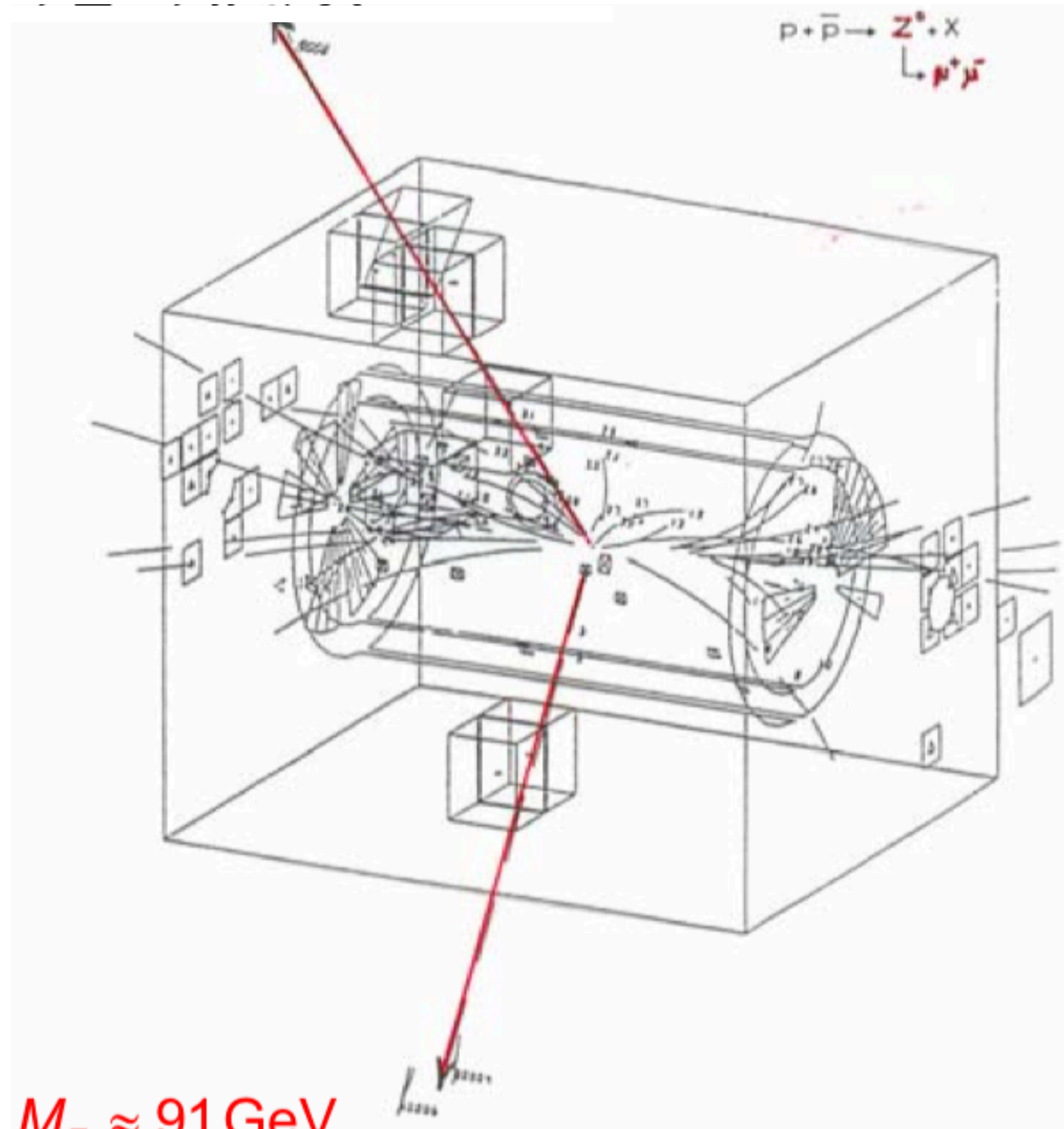
- CERN: UA1 and UA2 located on the SPS (Proton synchroton) ppbar collider with $\sqrt{s}$ = 540GeV - 1983



High-energy lepton pair:

$$m_{\ell\ell}^2 = (p_{\ell^+} + p_{\ell^-})^2 = M_Z^2$$





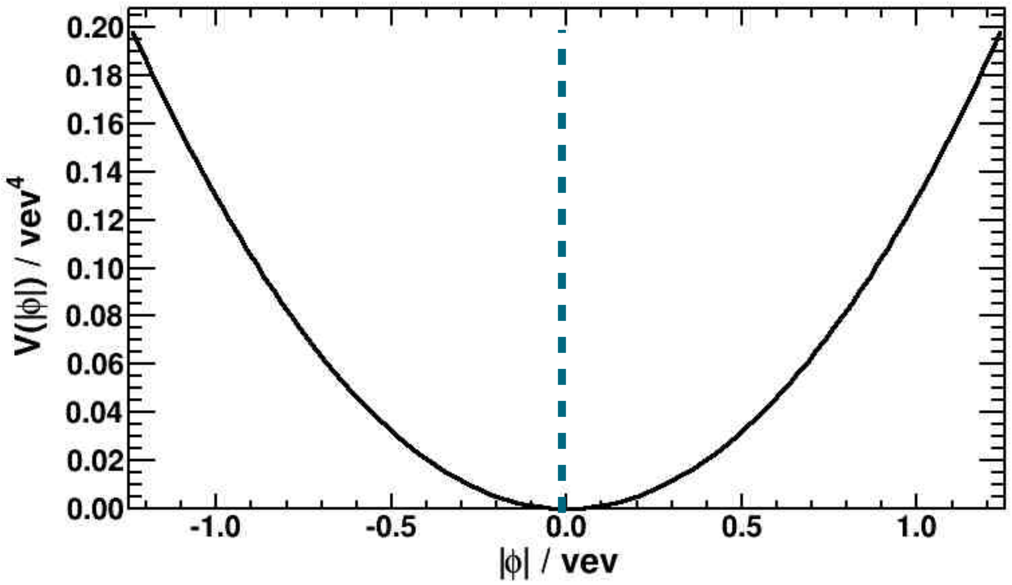
$M_Z \approx 91\,\mathrm{GeV}$

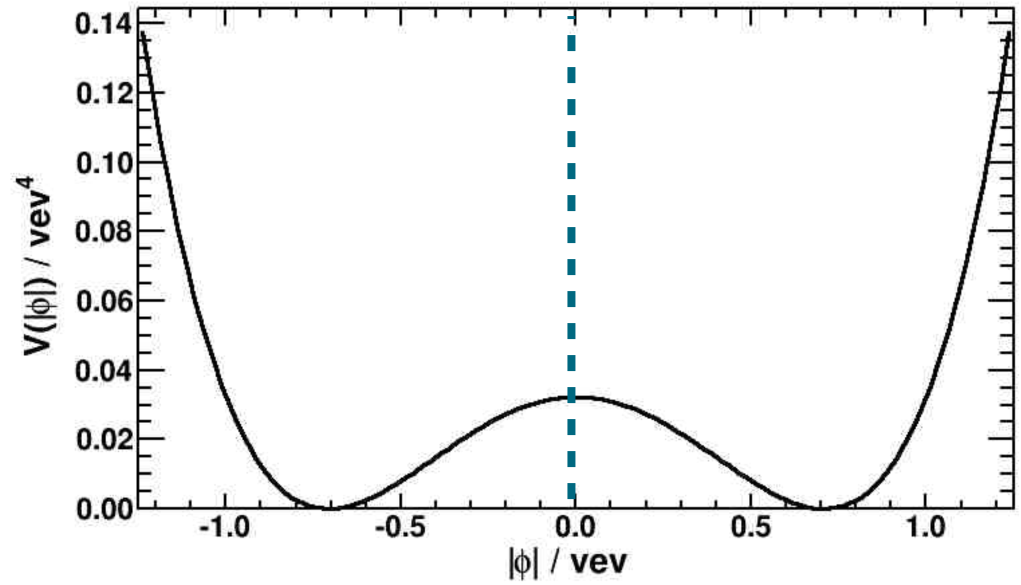
Higgs mechanism

- Break symmetry with an SU(2) doublet

$$V(\phi) = m^2|\phi|^2$$

$$V(\phi) = -\mu^2|\phi|^2 + \lambda|\phi|^4$$

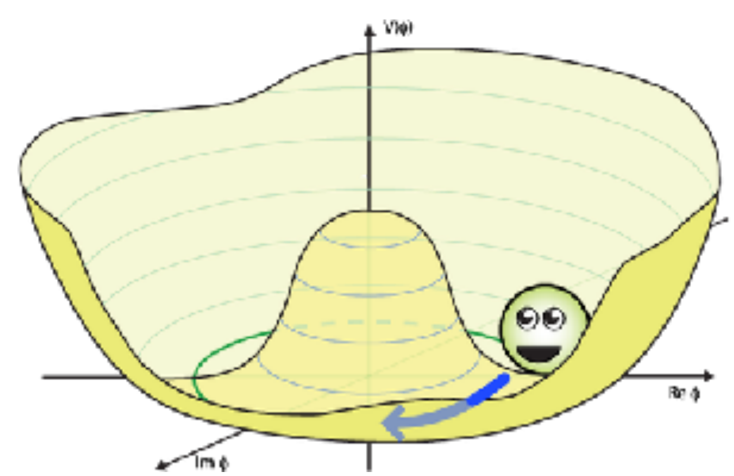




Developing ϕ around its minimum value $|\phi_{min}| = v^2/2$

$$v = \sqrt{\frac{\mu^2}{\lambda}}$$

= 246 GeV



Hypercharge and weak isospin

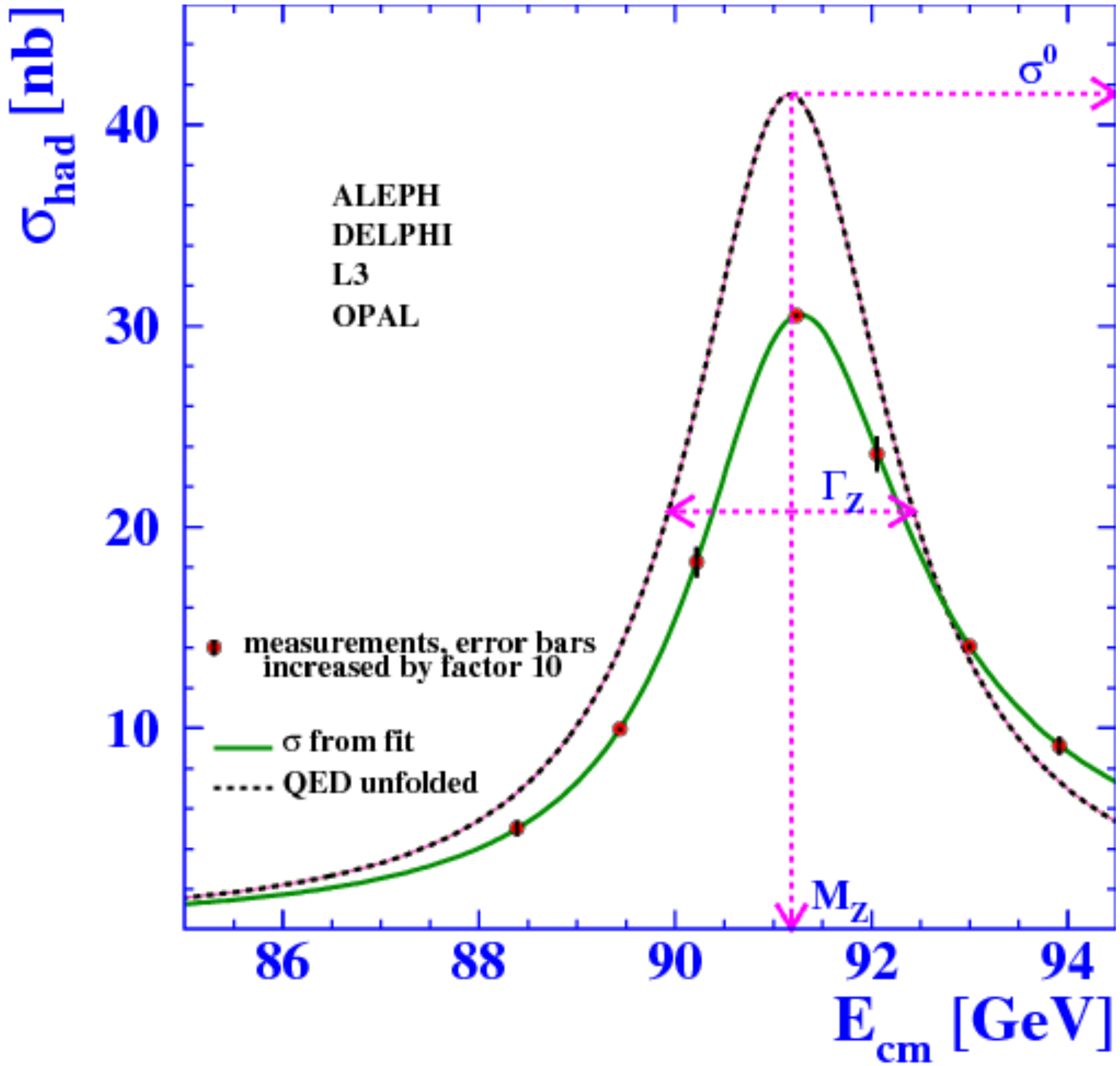
	Q	T_3 (left)	Y
U	+2/3	+1/2	1/6
D	-1/3	-1/2	1/6
nu	0	+1/2	-1/2
lep	-1	-1/2	-1/2

Can be summarised with

$Q = T_3 + Y$

T_3 (U_L,D_L,right) = +1/2, -1/2, 0

Z boson property



Green curve includes radiative corrections

m_Z = 91.2 GeV
Γ_Z = 1.5 GeV

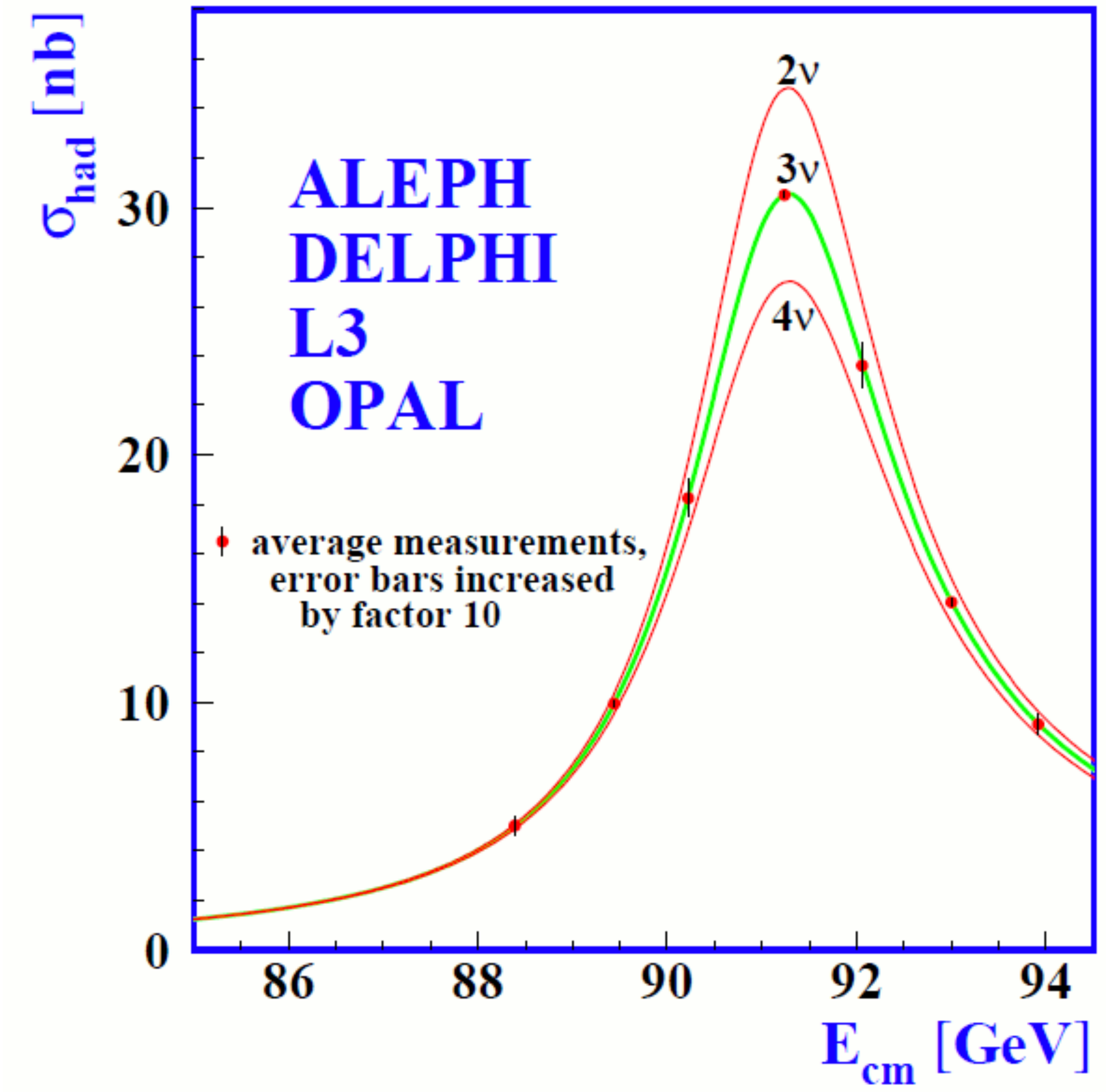
Z/W leptonic decays

- Do these couplings exist $A_\mu \bar{\psi}_L \gamma_\mu \psi_R$, $A_\mu \bar{\psi}_R \gamma_\mu \psi_L$?
  - ✓ and for Z_μ ? W_μ?

- Assuming leptons and quarks are massless,
  - Compute $B(W \to \ell \nu)$ at tree level neglecting phase space
  - Compute $\Gamma(Z \to \bar{\nu}\nu) / \Gamma(Z \to \bar{e} e)$
  - From $B(Z \to \ell\ell) = 3.3\%$, conclude that $B(Z \to \nu\nu) \simeq 20\%$
  - Use it to predict the number of neutrino family from Γ_{inv} measurement

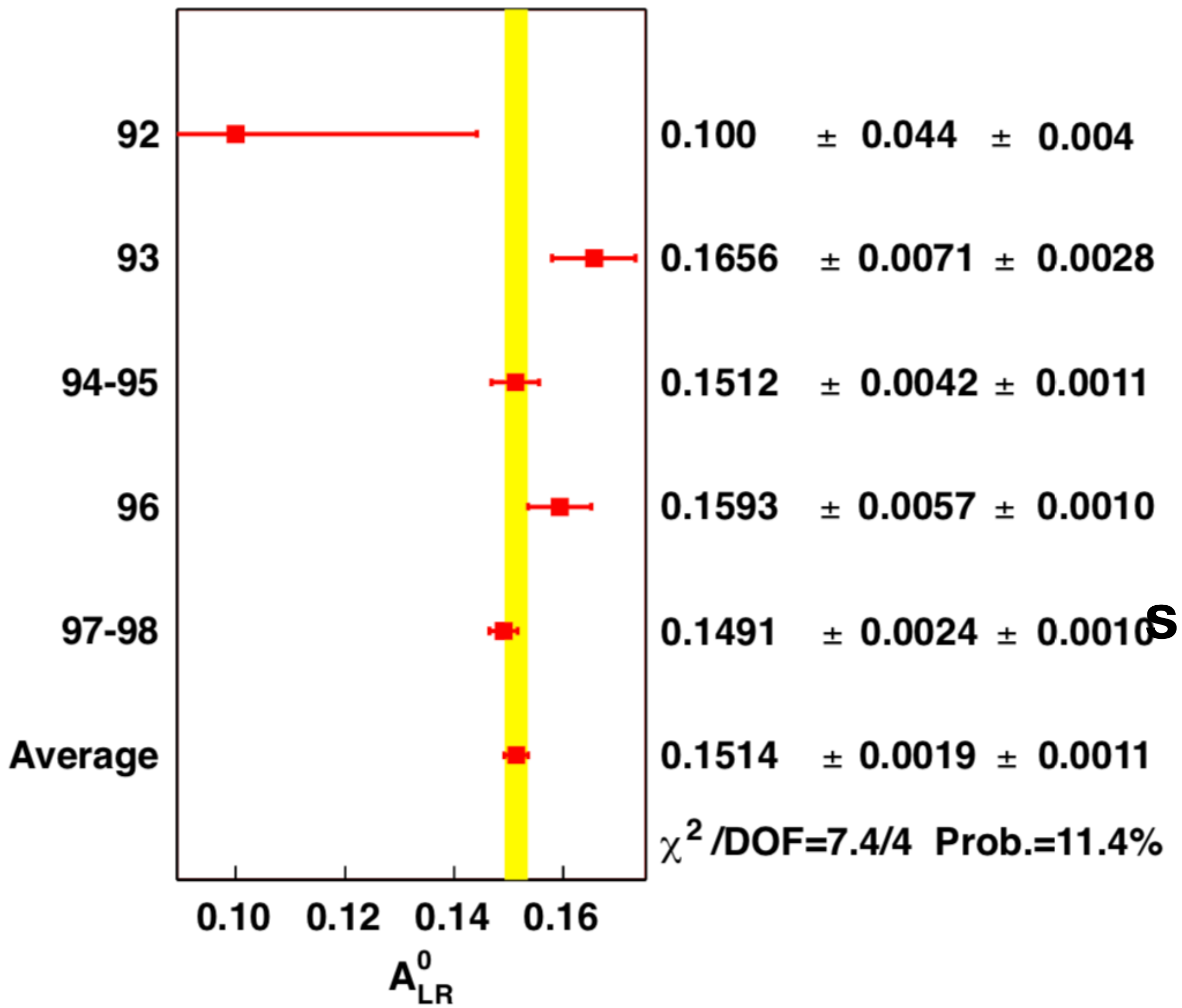
Note: $\sin^2\theta_W \simeq 0.23$

Number of neutrino family

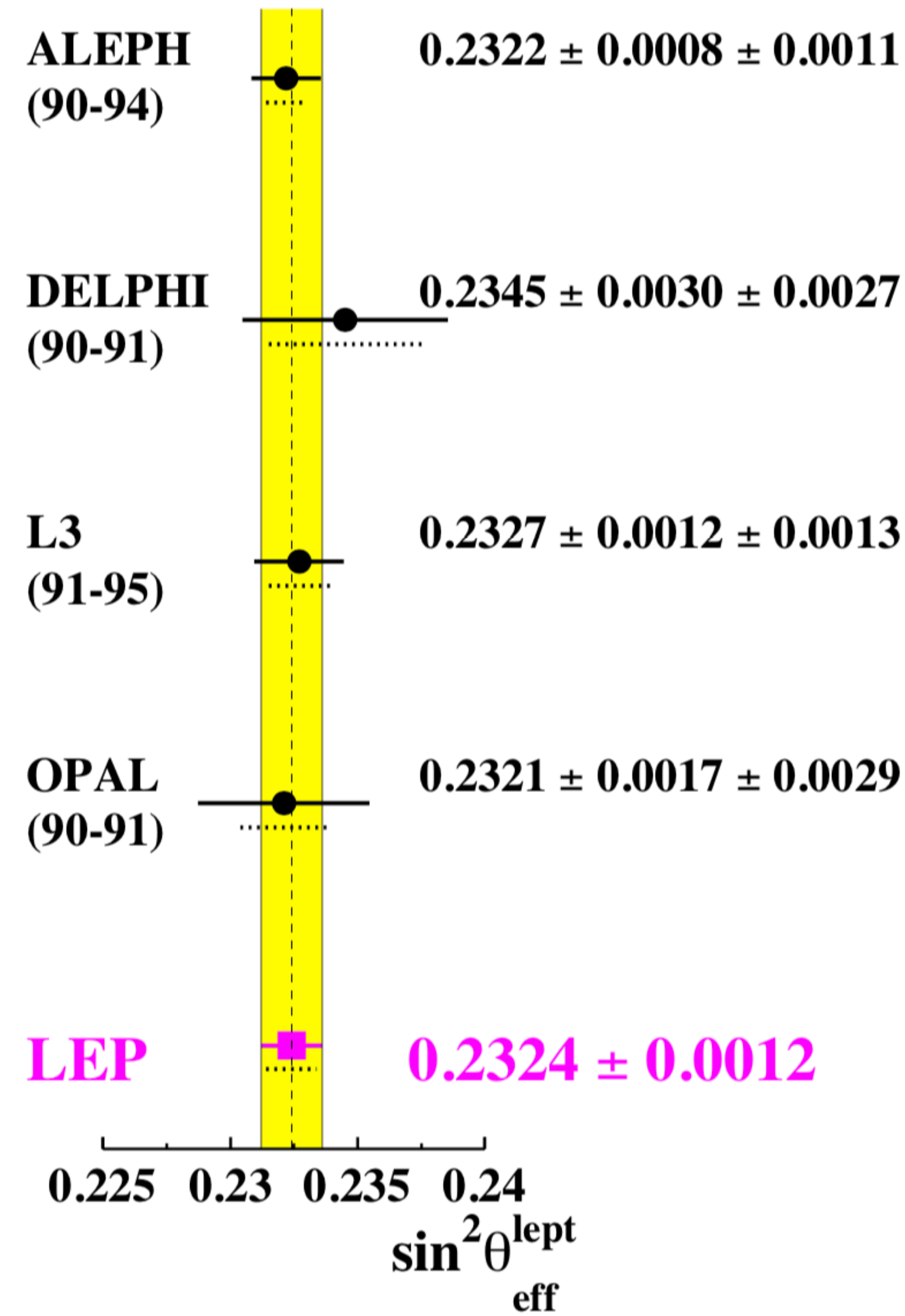


$N_\nu = 2.984 \pm 0.008$

Asymmetry A_{LR} and $\sin^2\theta_W$



sin



$\sin^2\theta_{eff} = 0.23097 \pm 0.00027$

NB: $1 - (m_W/m_Z)^2 = 0.22$