FCC-ee/TLEP physics workshop (TLEP7)
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FCC-ee precision measurements (WG1 & 2)

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FCC-ee and precision Z & W physics

- The great potential of FCC-ee for precision physics with beams at **~45 GeV** (Z pole) and at and above the WW threshold (**>80 GeV**) is well described in **arXiv:1308.617**
- Here I will mention a few points to progress on the work and remind about some measurement not included in the **arXiv** above
- Some items where useful work can start are marked as "**TODO**"

Typical EWK precision measurements at FCC-ee

The main effort should be directed to

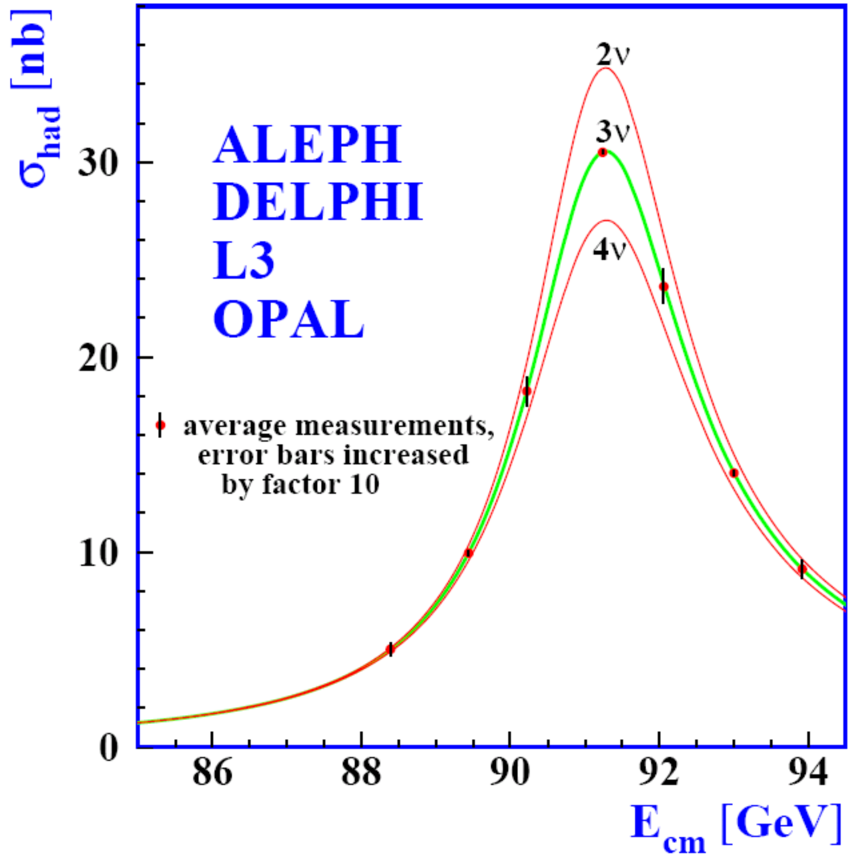
1. identify possible systematic uncertainties preventing such precisions
2. devise methods to overcome these uncertainties

Quantity	Physics	Present precision	Measured from	Statistical uncertainty	Systematic uncertainty	Key	Challenge
m_Z (keV)	Input	91187500 ± 2100	Z Line shape scan	5 (6) keV	< 100 keV	E_{beam} calibration	QED corrections
Γ_Z (keV)	$\Delta\rho$ (not $\Delta\alpha_{had}$)	2495200 ± 2300	Z Line shape scan	8 (10) keV	< 100 keV	E_{beam} calibration	QED corrections
R_ℓ	α_s, δ_b	20.767 ± 0.025	Z Peak	0.00010 (12)	< 0.001	Statistics	QED corrections
N_ν	PMNS Unitarity, ...	2.984 ± 0.008	Z Peak	0.00008 (10)	< 0.004		Bhabha scat.
N_ν	... and sterile ν's	2.92 ± 0.05	$Z\gamma$, 161 GeV	0.0010 (12)	< 0.001	Statistics	
R_b	δ_b	0.21629 ± 0.00066	Z Peak	0.000003 (4)	< 0.000060	Statistics, small IP	Hemisphere correlations
A_{LR}	$\Delta\rho, \epsilon_3, \Delta\alpha_{had}$	0.1514 ± 0.0022	Z peak, polarized	0.000015 (18)	< 0.000015	4 bunch scheme, 2exp	Design experiment
m_W (MeV)	$\Delta\rho$, $\epsilon_3, \epsilon_2, \Delta\alpha_{had}$	80385 ± 15	WW threshold scan	0.3 (0.4)MeV	< 0.5 MeV	E_{beam}, Statistics	QED corrections
m_{top} (MeV)	Input	173200 ± 900	$t\bar{t}$ threshold scan	10 (12) MeV	< 10 MeV	Statistics	Theory interpretation

From arXiv:1308.6176

TeraZ: high precision M_Z and Γ_Z

- Measure the Z lineshape by accumulating 10^{12} Z bosons in a energy scan
- At LEP reached ~$2\cdot10^{-5}$ and gained a lot of experience on **centre-of-mass energy determination with resonant depolarization**
- Could potentially reach ~10^{-6} (100 keV on M_Z)
- Clearly understanding how to exploit transverse polarization is an important **TODO**

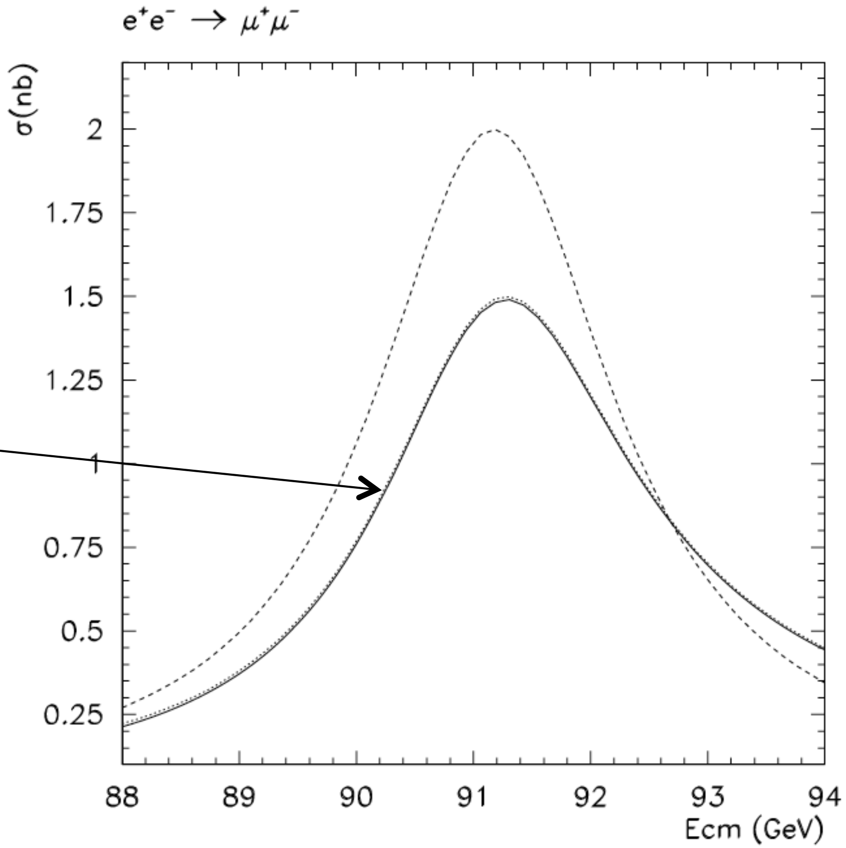


The Z lineshape

- The lineshape is highly asymmetric because of radiative effects
- At LEP the cross section was convolved with a radiator function H(s',s)

$$\sigma_{f\bar{f}}(s) = \int_{4m_f^2}^{s} ds' H(s,s')\hat{\sigma}_{f\bar{f}}(s')$$

- **(TODO)** is the radiator function used at LEP sufficient ? (probably not). How can it be improved ?



O(α^2) radiative corrections+soft photon correction+exponentiation

Precision cross section measurements: acceptance issues

- At LEP acceptance effects were at **10^{-4}** level, sufficient for cross sections measured at the **10^{-3}** level. At FCC-ee we have to exploit a statistical uncertainty at **10^{-5}** level… !
- The main effects were due to track losses, angle mis-measurements and knowledge of boundaries.

Table 13. Exclusive $\mu^+\mu^-$ selection: examples of relative systematic uncertainties (in %) for the 1994 (1995) peak points

Source	$\Delta\sigma/\sigma$ (%)
Acceptance	0.05
Momentum calibration	0.006 (0.009)
Momentum resolution	0.005
Photon energy	0.05
Radiative events	0.05
Muon identification	$\simeq$ 0.001 (0.02)
Monte Carlo statistics	0.06
Total	0.10 (0.11)

Example from ALEPH, EPJC 14 (2000) 1

(TODO) which requirements on the detector mechanical position ?

Again on acceptance issues

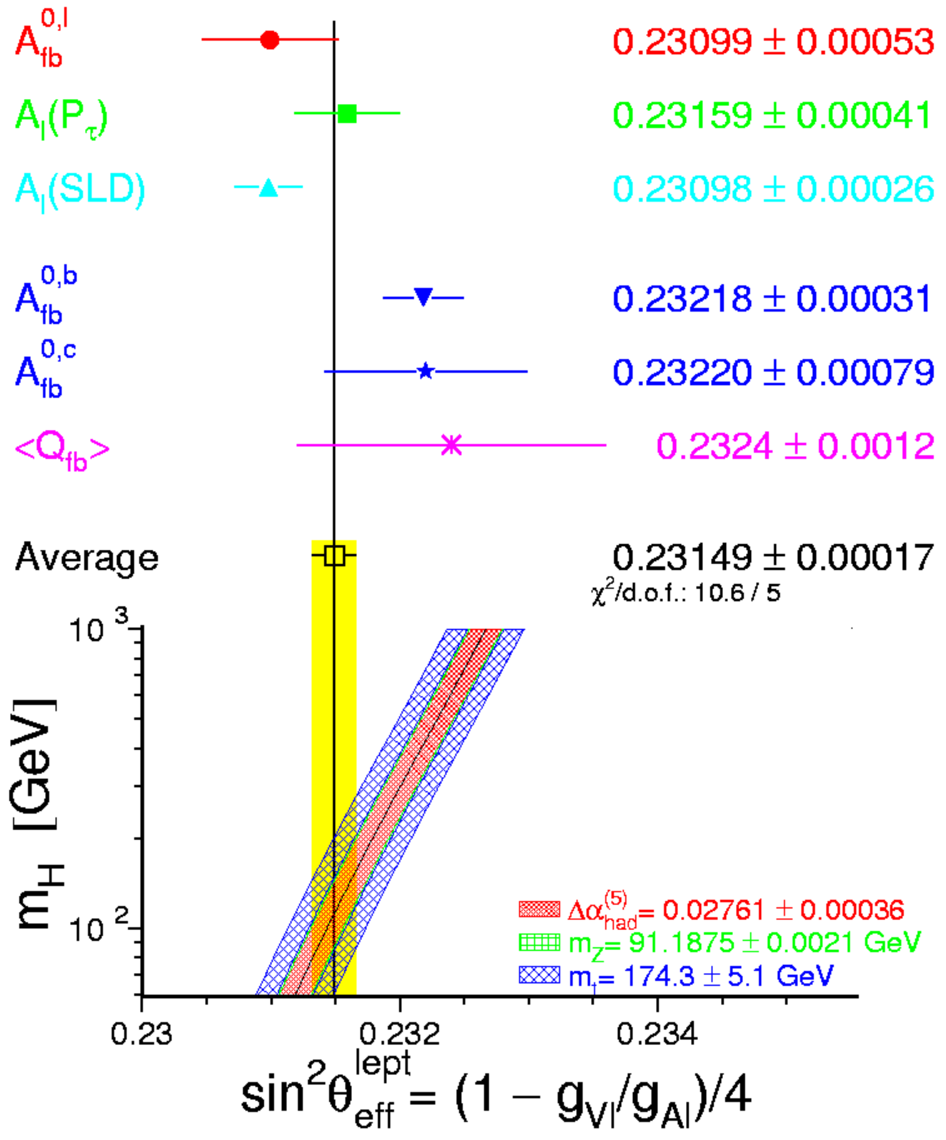
- At LEP the only detectors for which the mechanical precision was relevant were the luminometers.
- The inner edge of the detector (the **relevant boundary**) was known at the level of **20 μm**
- The beam displacement (**vertical** and **horizontal**) was made in-effective by choosing two different fiducial regions (**loose and tight**) and **alternating them** in the two sides (*)
- At **FCC-ee** we could **use similar methods for other cross sections** measurements (e.g. different and alternating forward and backward fiducial regions), <u>but still need to identify and know well the relevant boundaries</u>.

(*) G. Barbiellini, M. Conversi et al. Atti Accad. Naz. Lincei 44 (1968) 233

TeraZ: final word on Asymmetries !

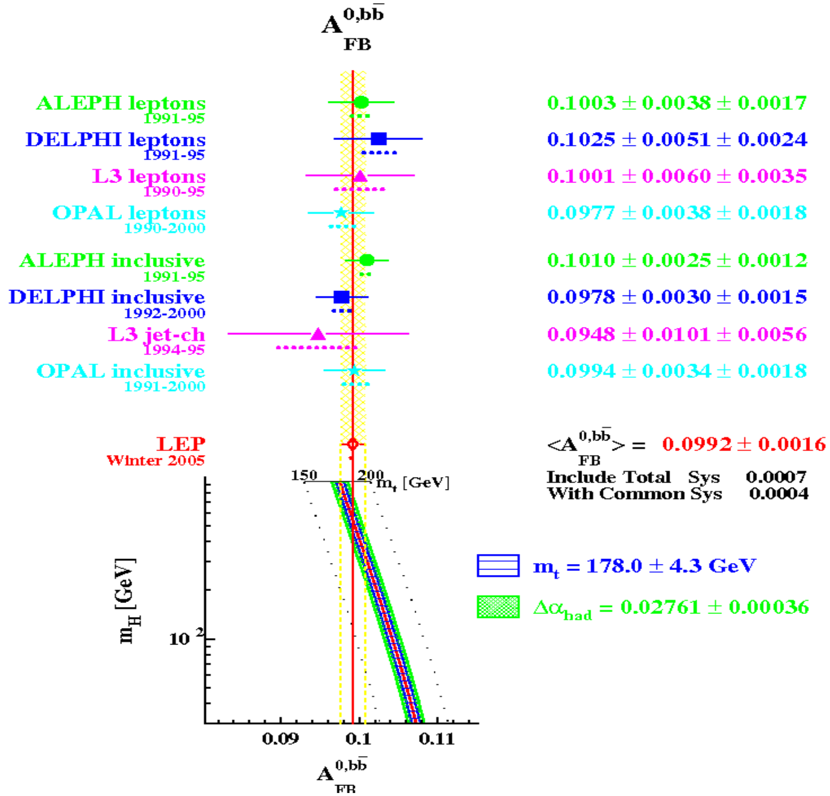
- Long standing difference between Alr and A_{FB}(b), **it must be sorted out**
- measurement of Alr with **polarized beams (TODO** study precision as a function of **two** beam polarization)
- direct **measurement of the b couplings** (again need polarization)
- Could potentially reach $\sim 10^{-6}$ on sin2theta

$\sin^2 \theta_{eff}^{l}$



At FCC-ee can sizably improve b asymmetry

- Two techniques
  - use semileptonic b decays
  - use weighted charge of particles in the hemisphere
- Very different systematic effects
- **LEP final combination statistically dominated**

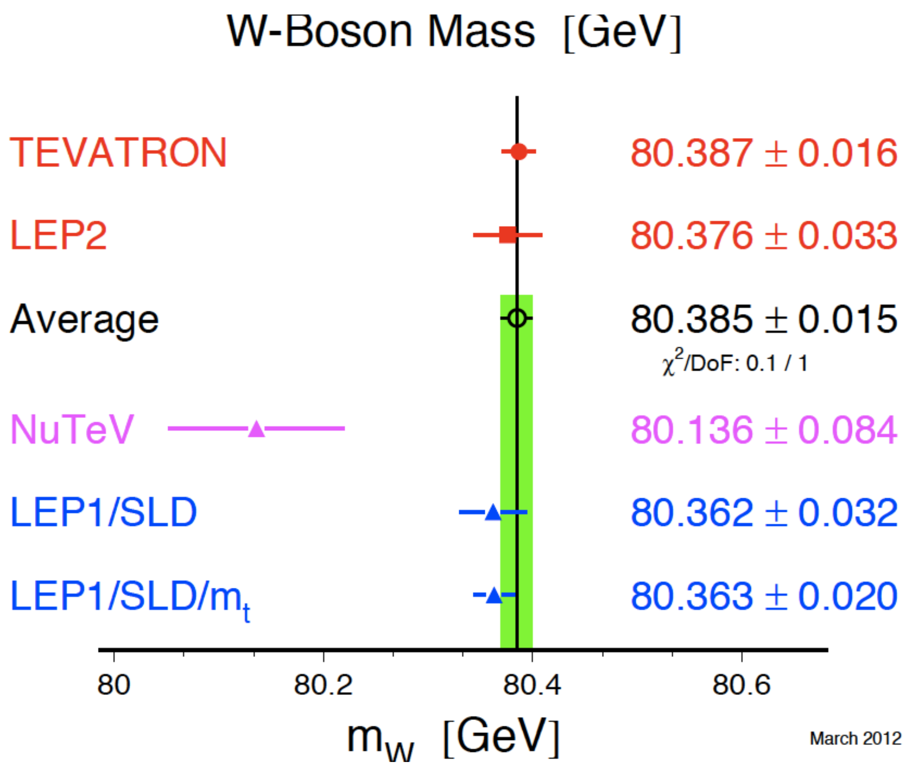


	ΔAFB(b)	
STATISTICS	0.00156	
UNCORRELATED SYSTEMATIC	0.00061	
QCD CORRECTION	0.00030	
LIGHT QUARK FRAGMENTATION	0.00013	
SEMILEPTONIC DECAYS MODELLING	0.00013	
CHARM FRAGMENTATION	0.00006	
BOTTOM FRAGMENTATION	0.00003	
TOTAL SYSTEMATIC ERROR	0.00073	

(TODO) Can be reduced with improved calculations and proper choices of analysis methods

160 GeV: Measurement of the W mass

- Perform a precise measurement from the WW threshold scan
  Could potentially reach ~ 0.5 MeV
- Revisit the LEP2 method of direct reconstruction (there is room for improvement, e.g. beam energy, large statistics on semileptonic events, etc. **TODO**)



The W mass from threshold scan

- **(TODO)** study sensitivity of the threshold scan to beam parameters
- Input to first study, efficiencies and backgrounds from LEP → next page
- Typical numbers:
  - $\mu^+\mu^-$ eff~70% bkg 10%
  - qq eff~90% bkg 20%

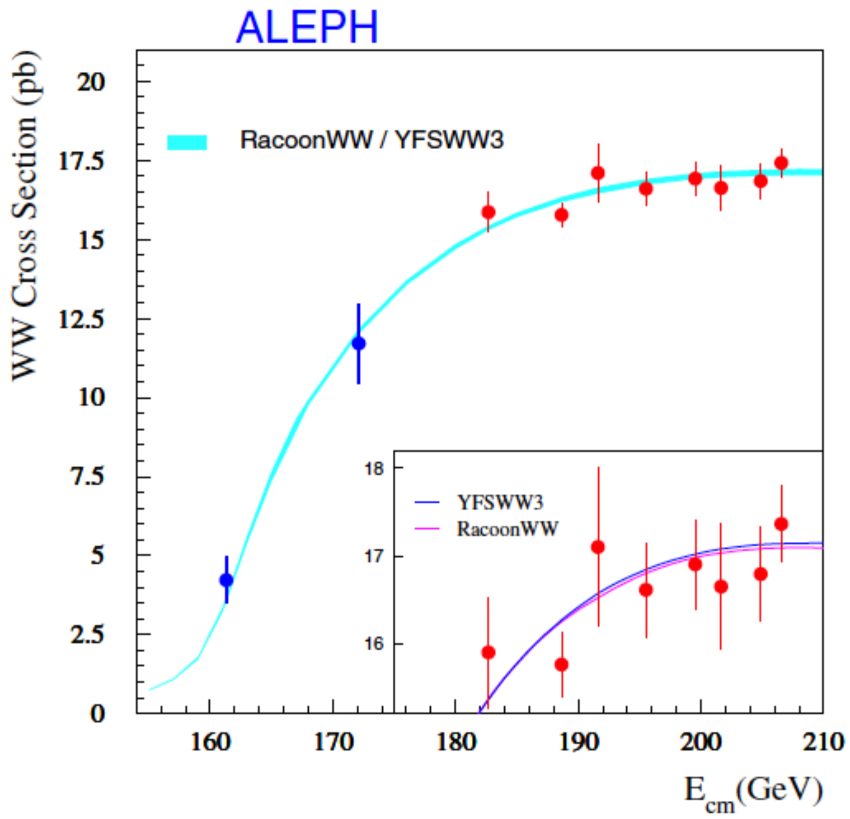


Fig. 4. Measurements of the W-pair production cross section at ten CM energies, compared to the Standard Model predictions from **YFSWW3** and **RacoonWW** for $m_W = 80.35\,\mathrm{GeV}/c^2$

Efficiency and Backgrounds for WW selection at LEP

Table 3. Summary of luminosity-weighted averaged results of the different event selections on Monte Carlo and data events. Efficiencies are given in percent for *CC03* processes. In the qqqq column only events with a NN output greater than 0.3 are considered; the backgrounds listed include non-qqqq WW decays

		Event selection and classification										
		ee	$e\mu$	$e\tau$	$\mu\mu$	$\mu\tau$	$\tau\tau$	eqq	μqq	τqq	qqqq	All
	$e\nu e\nu$	57.7	0	9.2	0	0	0.8	–	–	–	–	67.7
	$e\nu\mu\nu$	0	62.5	3.4	0	4.9	0.7	–	–	–	–	71.5
	$e\nu\tau\nu$	5.0	4.1	49.9	0	0.3	4.2	–	–	–	–	63.5
Eff. for	$\mu\nu\mu\nu$	0	0	0	64.7	7.2	0.6	–	–	–	–	72.5
WW $\rightarrow$	$\mu\nu\tau\nu$	0	5.4	0.3	4.1	53.6	3.2	–	–	–	–	66.6
(%)	$\tau\nu\tau\nu$	0.5	0.7	7.9	0.3	6.7	36.7	–	–	–	–	52.8
	$e\nu$qq	–	–	–	–	–	–	81.7	0.0	7.5	–	89.2
	$\mu\nu$qq	–	–	–	–	–	–	0.1	89.3	3.3	–	92.7
	$\tau\nu$qq	–	–	–	–	–	–	4.7	6.2	64.8	–	75.7
	qqqq	–	–	–	–	–	–	–	–	–	90.0	90.0
		Contribution (fb)										
$q\bar{q}$		0.	0.	0.	0.	0.	0.	57.2	12.7	123.3	1250.5	1443.7
ZZ		6.0	0.	3.5	6.6	3.4	5.0	8.3	19.9	63.0	196.3	312.0
$\gamma\gamma$		0.5	2.6	12.2	0.4	2.9	8.5	17.3	0.1	2.1	0.	46.6
Others		5.9	0.8	8.5	2.0	3.7	6.1	20.2	0.7	35.9	6.2	90.0
Total background		12.4	3.4	24.2	8.9	10.0	19.6	103.0	33.4	224.3	1453.1	1892.3
(*4f–CC03*)		11.4	7.9	12.6	3.6	3.7	4.8	58.9	3.0	88.6	177.3	371.8
		Number of events										
observed events		98	191	189	99	184	91	1566	1643	1515	5696	11272
expected background		16.3	7.7	25.1	8.6	9.4	16.7	110.5	24.8	213.6	1112.9	1545.3

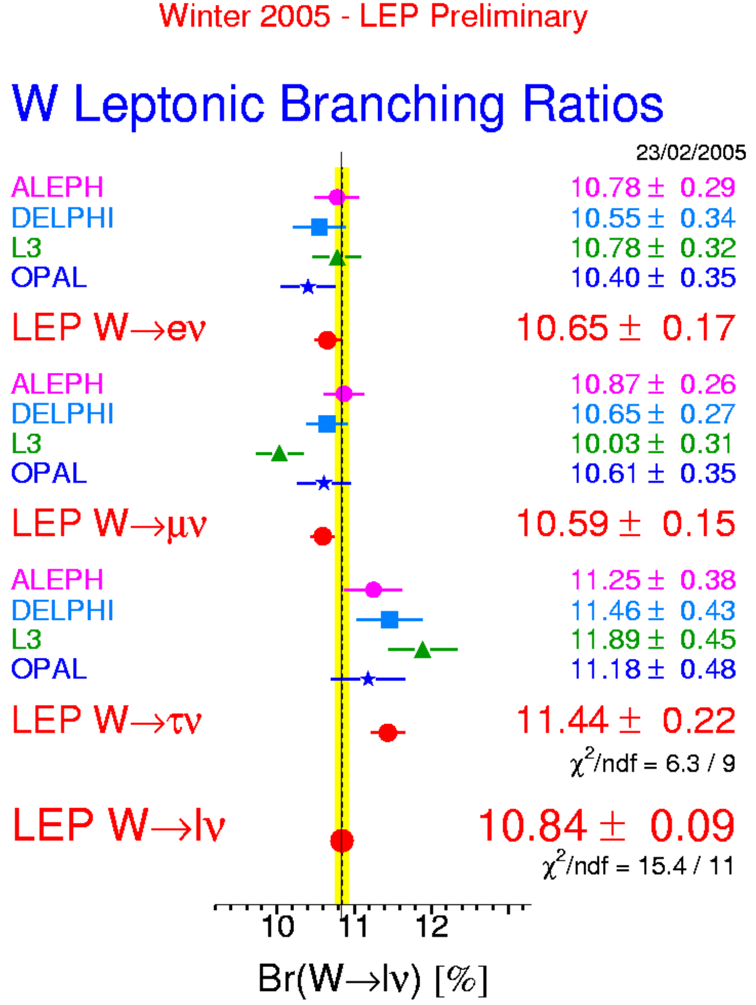
ALEPH, EPJC 38 (2004) 147

Improve W Branching Ratios with FCC-ee

Final results from LEP:

- combine electron and muon BR and compare to tau … a forgotten 3 σ effect !

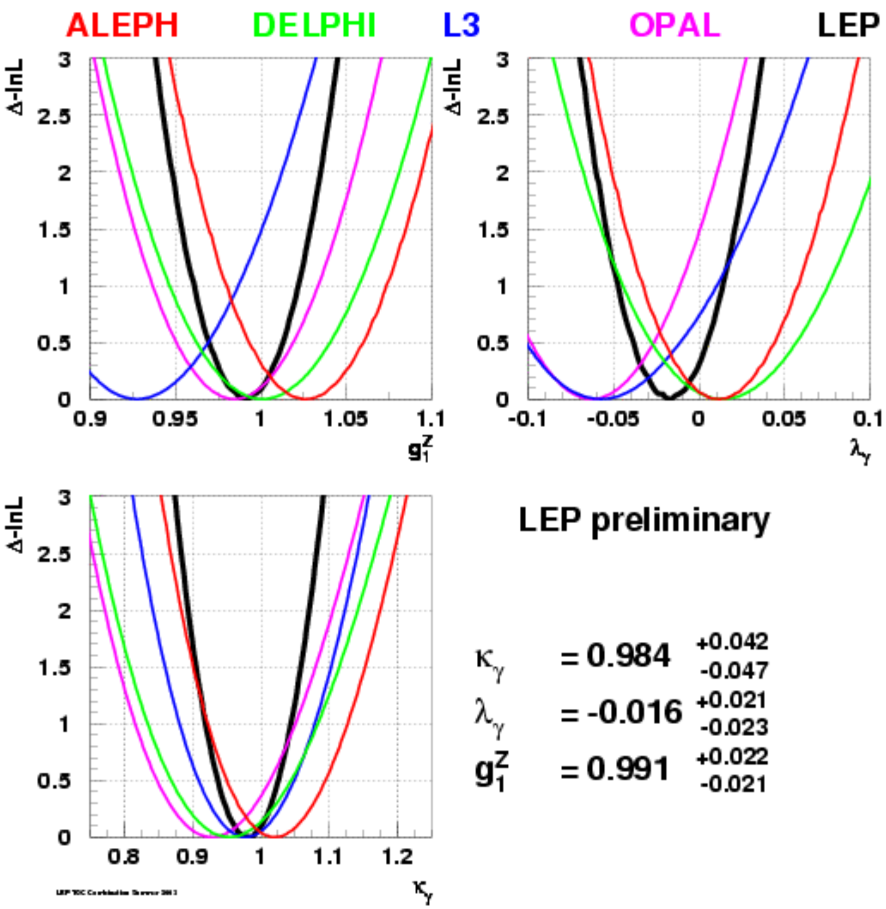
With 4 order of magnitues more W can do precise test of lepton universality …



Interesting to improve BR(W -> tau nu) !!

triple and quartic boson couplings

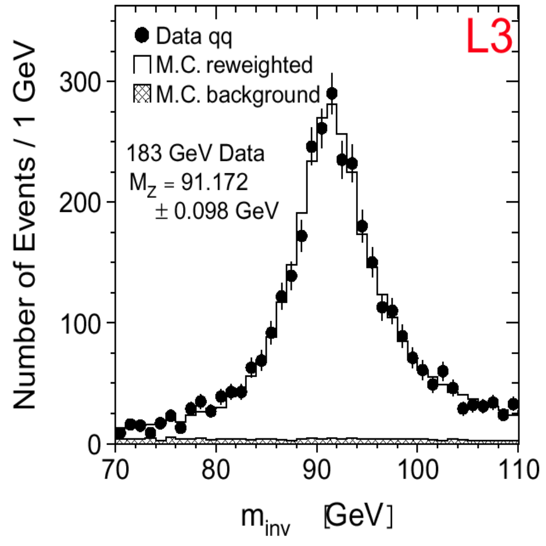
- Great potential for multi-gauge-boson production (di-boson WW, ZZ, Zγ or γγ production, but also tri-boson production like WWγ, WWZ, γγγ, WWH, etc.)
- **(TODO)** study the potential of FCC-ee in this sector



The Z invisible width and Z radiative returns

- Number of neutrino families from LEP N_ν=2.984±0.008
- Potential to improve the measurement to ±0.001 with $e^+e^- \rightarrow Z\gamma$
- Include study of sterile neutrinos
- **See talk of Serguei Ganjour later today**

Radiative return



Important: which generators ?

- Z pole results: for the signal used KoralZ 4.0 and KK 4.14
- WW events: used KoralW 1.51 and re-weighted to YFSWW3, compare with RacoonWW
- **(TODO)** Need to produce events for our studies !
- See previous talk of Staszek Jadach

Organization of WG1 – WG2

- Initial subgroups added to web pages
    - https://tlep.web.cern.ch/content/wg1-exp
    - https://tlep.web.cern.ch/content/wg2-exp
- Need several subgroup conveners !!

→ Advertized recently on the e-mail list, don't be shy and contact me !!

THANK YOU to **Elizabeth Locci** new subgroup convener for W mass & properties