FCC Week 2015 (Washington)
26th March

EW precision measurements summary

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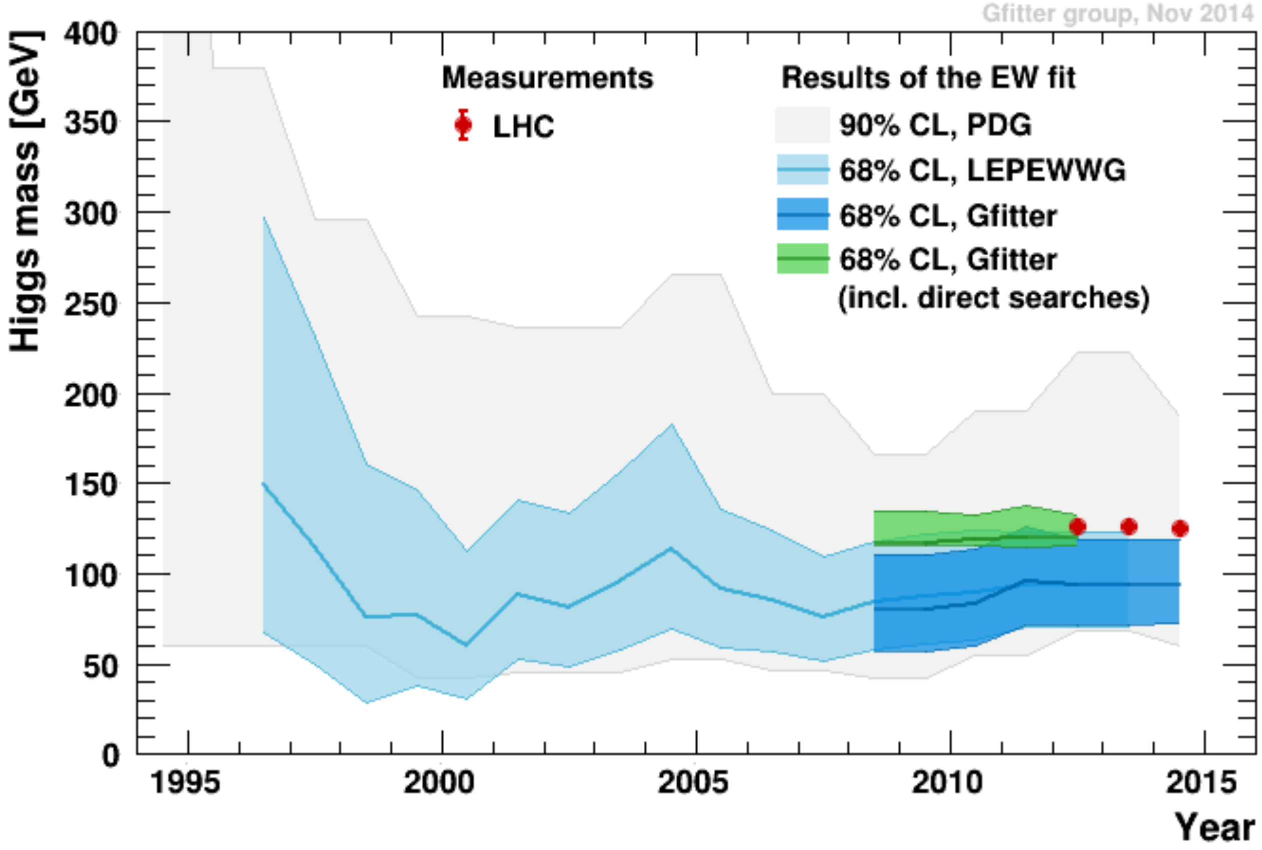
See also Doreen Wackeroth's talk on Tuesday

Acknowledgements: Patrizia Azzi, Martin Beneke, Alain Blondel, Roman Kogler, Michelangelo Mangano, Fulvio Piccinini

what are we up to ?

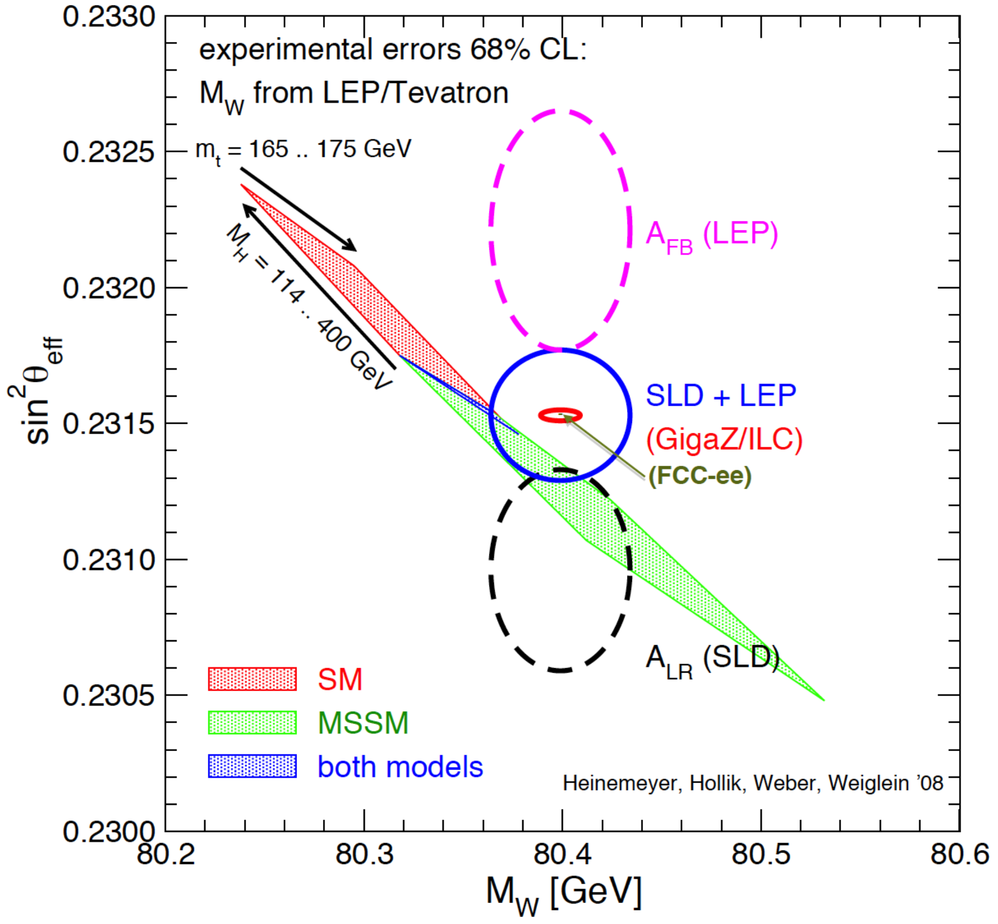
Time evolution of bounds on the SM Higgs boson mass from precision measurements



(courtesy of Roman Kogler)

Preparing next microscope

- Developing in important tools for indirect information on new physics:
  - discovery can be better prepared if we know where to look
  - once a new state is discovered need a framework to build the full picture (e.g. test the New Standard Model, give indications where other states could be)



(The FCC-ee "dot" is from the goals set by **JHEP 01 (2014) 164)**

The current experimental inputs to EW fits

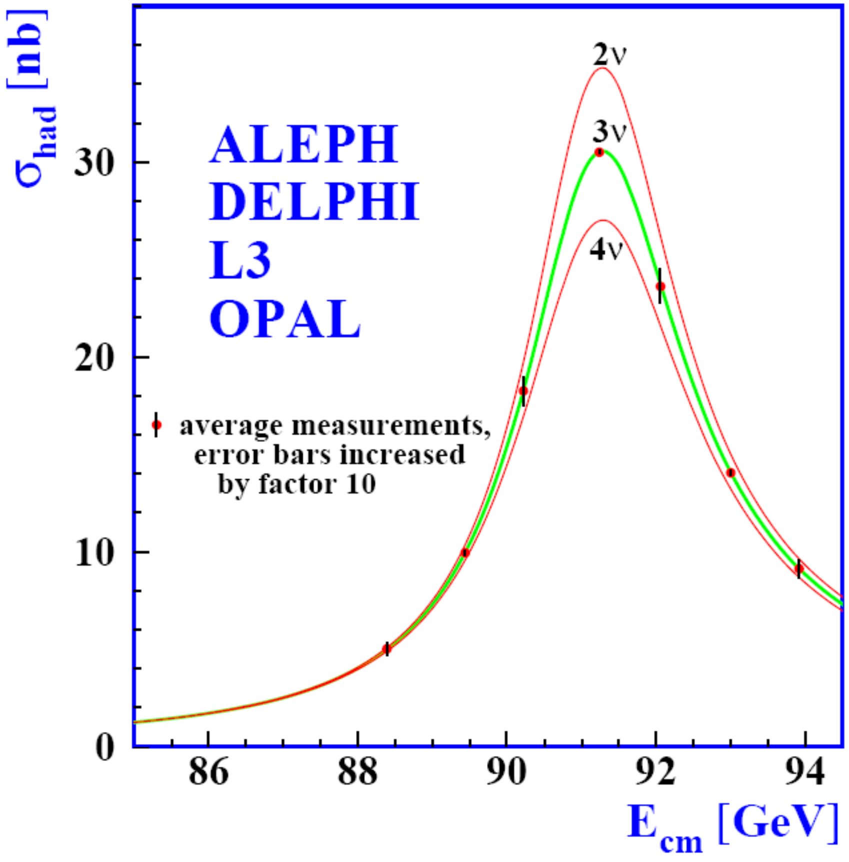
I will briefly discuss some of the challenges for FCC for the (pseudo)-observables on the right table (which typically means work to be done to exploit FCC potential)

The goals in precision for FCC-ee are given in JHEP 01 (2014) 164

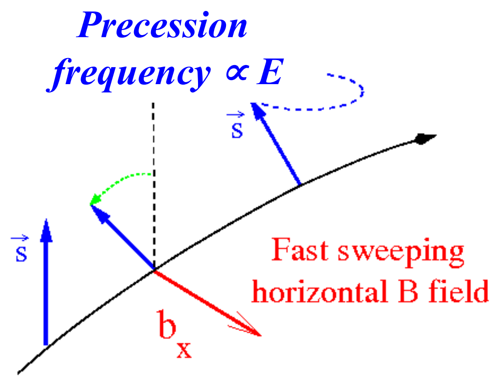
M_H [GeV]$^{(\circ)}$	125.14 ± 0.24	LHC
M_W [GeV]	80.385 ± 0.015	Tev.
Γ_W [GeV]	2.085 ± 0.042	
M_Z [GeV]	91.1875 ± 0.0021	
Γ_Z [GeV]	2.4952 ± 0.0023	
$\sigma^0_{\rm had}$ [nb]	41.540 ± 0.037	LEP
R^0_ℓ	20.767 ± 0.025	
$A^{0,\ell}_{\rm FB}$	0.0171 ± 0.0010	
A_ℓ $^{(\star)}$	0.1499 ± 0.0018	SLD
$\sin^2\theta^\ell_{\rm eff}(Q_{\rm FB})$	0.2324 ± 0.0012	
A_c	0.670 ± 0.027	SLD
A_b	0.923 ± 0.020	
$A^{0,c}_{\rm FB}$	0.0707 ± 0.0035	
$A^{0,b}_{\rm FB}$	0.0992 ± 0.0016	LEP
R^0_c	0.1721 ± 0.0030	
R^0_b	0.21629 ± 0.00066	
$\overline{m}_c$ [GeV]	$1.27^{+0.07}_{-0.11}$	
$\overline{m}_b$ [GeV]	$4.20^{+0.17}_{-0.07}$	
m_t [GeV]	173.34 ± 0.76	Tev.+LHC
$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$	2757 ± 10	

Z lineshape for high precision M_Z and Γ_Z

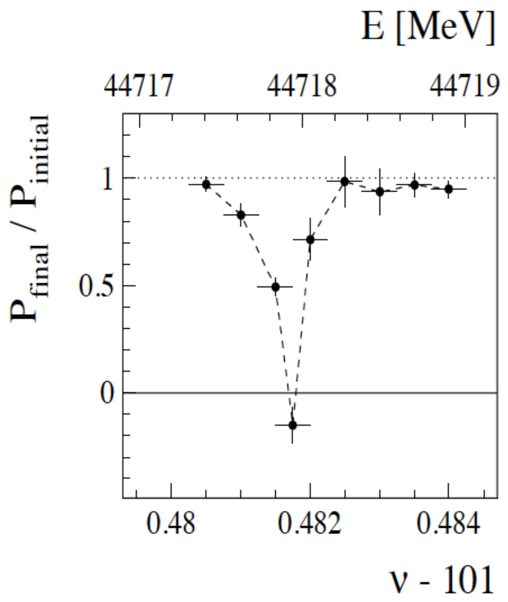
- Measure the Z lineshape by accumulating 10^{12} Z bosons in a energy scan
- At LEP reached ~$2\cdot10^{-5}$ and gained a lot of experience on **centre-of-mass energy determination with resonant depolarization**
- Could potentially reach ~10^{-6} (100 keV on M_Z and Γ_Z)
- Improve the knowledge of other observables, e.g. R_l and related $\alpha_s(M_Z)$ determination.



The key: beam energy calibration



- Resonant depolarization
    - use natural transverse polarization
    - add horizontal B field and Thomas precession



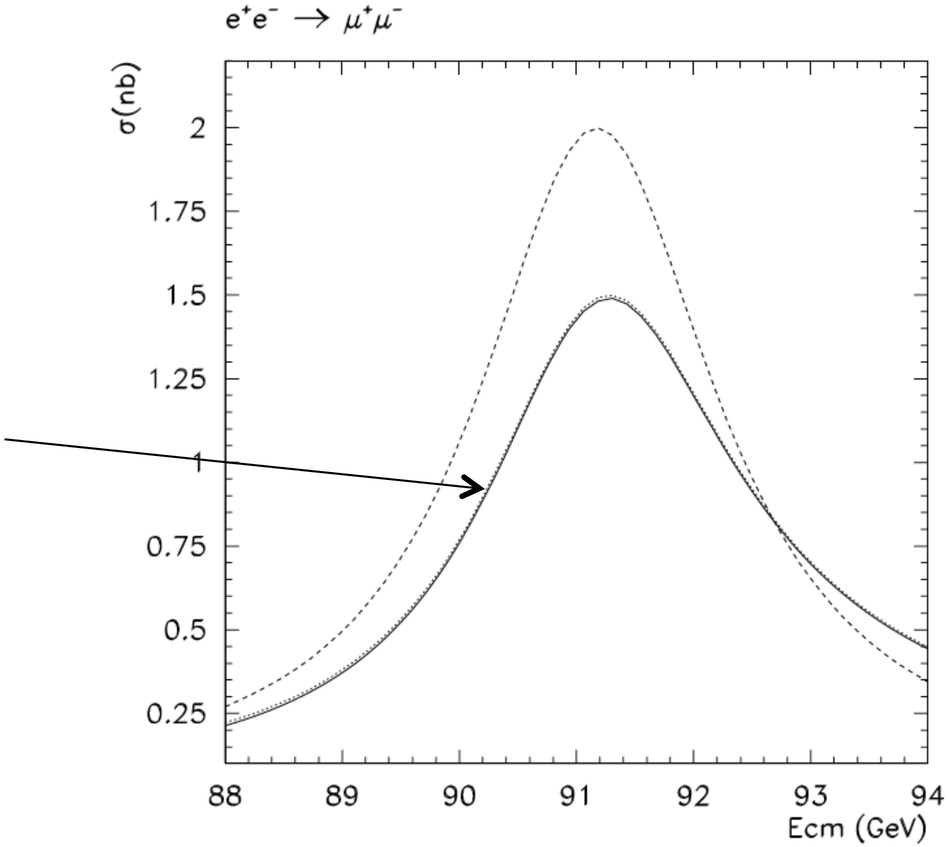
- The depolarizing resonance was very narrow at LEP (~ 100 keV), however the final systematic uncertainty was 1.5 MeV because of transport from polarization runs
- At **FCC-ee continuous calibration with dedicated bunches**

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)

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

- Current calculations gives a precision of 0.01%, sufficient for the 0.1% requirements at LEP times



Radiation function currently calculated up to O(α^3)

Uncertainty on the ISR deconvolution

- obtained through the comparison of additive and factorized form of the radiator function

	LEP 1 energy in GeV				
	$M_Z - 3$	$M_Z - 1$	M_Z	$M_Z + 1$	$M_Z + 3$
	$10^4 \times$ (fact/add-1)				
σ_μ	0.44	0.63	0.61	0.72	0.49
	0.88	0.63	0.68	0.72	0.49
$\sigma_{\rm had}$	0.58	0.58	0.64	0.73	0.59
	0.61	0.62	0.67	0.76	0.62
	fact-add [pb]				
σ_μ	0.01	0.03	0.09	0.05	0.02
	0.02	0.03	0.10	0.05	0.02
$\sigma_{\rm had}$	0.26	0.56	1.95	1.04	0.48
	0.27	0.60	2.04	1.08	0.51
	$10^5 \times$ (fact-add)				
A^μ_{FB}	1.00	1.00	0.00	0.00	-1.00
	-4.00	-2.00	0.00	1.00	1.00

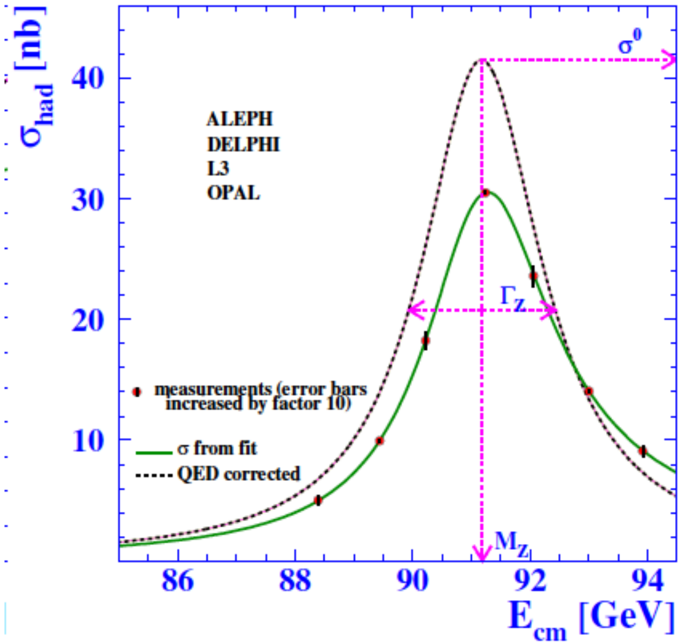
- The level of agreement between TOPAZ0 and ZFITTER around the Z peak is below the 0.01% level $\longrightarrow$ analysis at the 0.1% level on the derived observables are robust
- passing from 0.1% to 0.01% (or even more) precision requires an improvement of the deconvolution process

Lineshape: reduced cross sections

From ISR deconvolution the reduced cross section is obtained, for hadrons and for each lepton species

$$\sigma_{f\bar{f}}(s) = \sigma_{f\bar{f}}^{peak}(s)\frac{s\Gamma_Z^2}{(s-M_Z^2)^2+(\frac{s\Gamma_Z}{M_Z})^2} + "(\gamma - Z)" + "\gamma^2"$$

$$\sigma_{f\bar{f}}^{peak}(s) = \frac{12\pi}{M_Z^2}\frac{\Gamma_e\Gamma_\mu}{\Gamma_Z^2}$$



Interference term: zero at pole, in the standard LEP analysis is computed (*), alternatively can be measured off peak (S-matrix model independent approach).
(*) dependence on SM parameters less than 0.1%

Photon exchange, a few percent at the Z pole

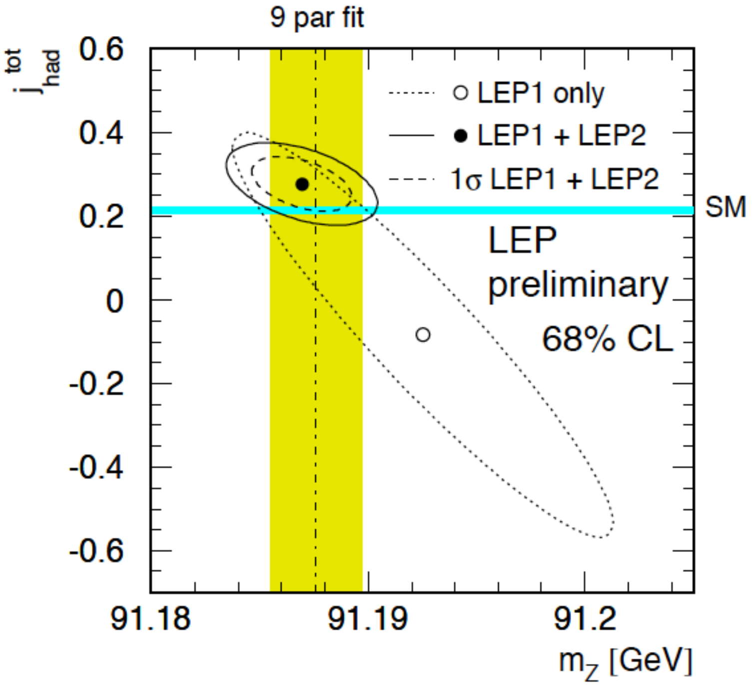
Lineshape at FCC-ee: requires model independent approach

A. Leike, T. Riemann, J. Rose, PLB273 (1991) 513

- General parameterization in terms of exchange of a massless and a massive vector boson

$$\sigma_T(s) = \frac{4}{3}\pi\alpha^2 \int \frac{ds'}{s}\left[\frac{r^\gamma}{s} + \frac{sr + (s - M_Z^2)j}{(s - M_Z^2)^2 + M_Z^2\Gamma_Z^2}\right]\rho_{ini}\left(\frac{s'}{s}\right)$$

- Leaves the contributions of Z exchange (r) and Z-γ interference (j) free
- Off-peak points greatly improve the measurement, adding LEP2 cross sections the M_Z precision obtained at LEP1 was recovered



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.

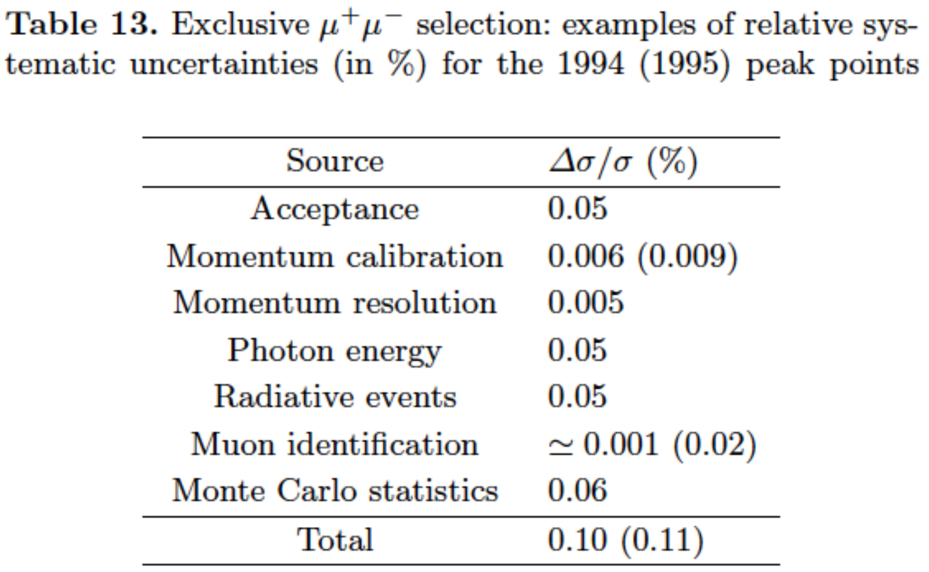


Table 13. Exclusive $\mu^+\mu^-$ selection: examples of relative systematic uncertainties (in %) for the 1994 (1995) peak points

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

which requirements on the detector mechanical position ?

Again on acceptance issues

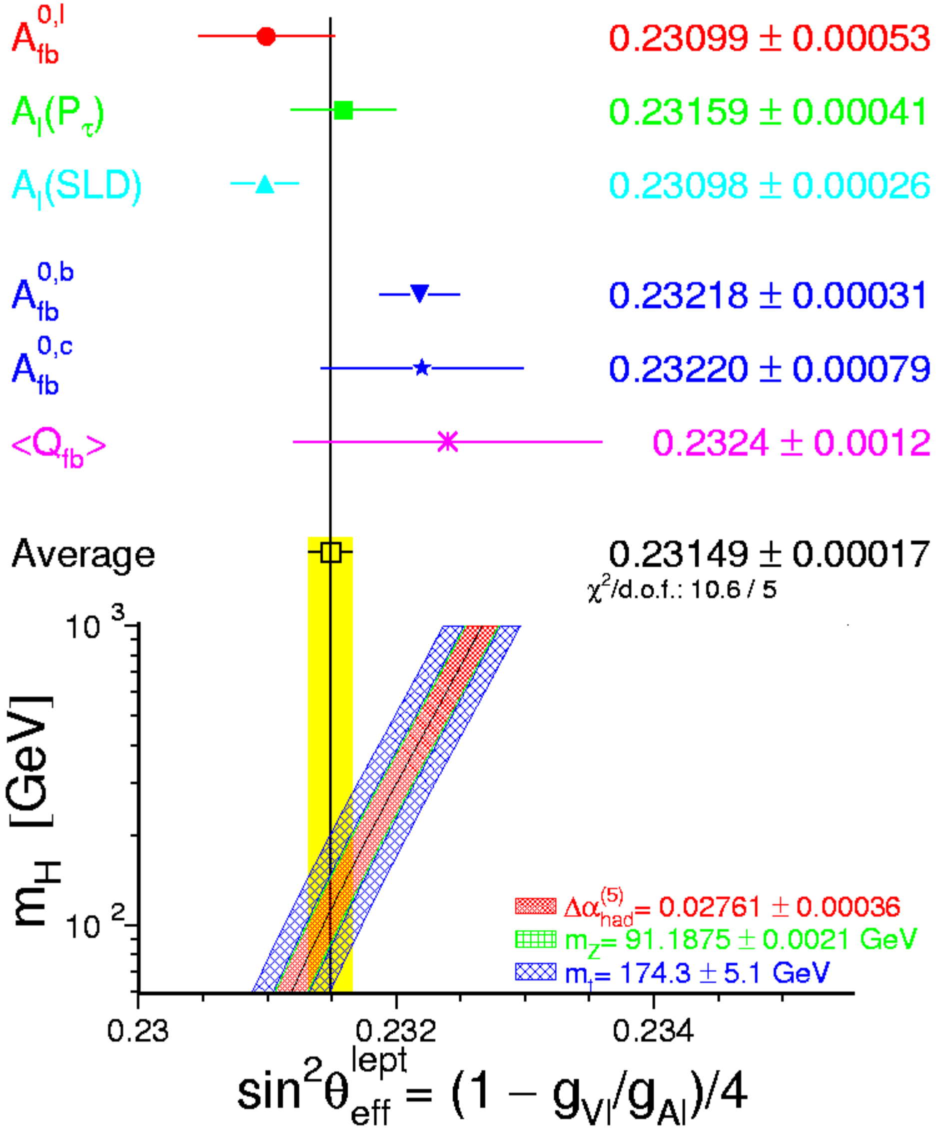
- At LEP the only detectors for which the mechanical precision was relevant were the luminometers.
- The inner edge of the detector (the **relevant boundary**) was known at the level of **20 μm**
- The beam displacement (**vertical** and **horizontal**) was made in-effective by choosing two different 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), but still need to identify and know well the relevant boundaries.

(*) 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 **long. polarized beams**
- direct **measurement of the b couplings** (again need long. polarization)
- Could potentially reach ~10^{-6} on sin2theta
- What can be done without long polarization ? (next slides)

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



Quick reminder on asymmetries

- Z boson decay to $f\bar{f}$: 3 observables from the direction and decay of the outgoing fermion

$$A_f = \frac{2 g_{Vf} g_{Af}}{(g_{Vf})^2 + (g_{Af})^2}$$

$$\sin^2 \theta_{eff}^{\,l} \equiv \frac{1}{4}\left(1 - \frac{g_{Vl}}{g_{Al}}\right)$$

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_{tot}} = \frac{3}{4} A_e A_f$$

Can measure for e,μ,τ,c,b

$$A_{pol} = \frac{\sigma_{F,R} + \sigma_{B,R} - \sigma_{F,L} - \sigma_{B,L}}{\sigma_{tot}} = -A_f$$

Can measure with τ's

$$A_{pol}^{FB} = \frac{\sigma_{F,R} - \sigma_{B,R} - \sigma_{F,L} + \sigma_{B,L}}{\sigma_{tot}} = -\frac{3}{4} A_e$$

- Additional asymmetries with polarization of initial state :

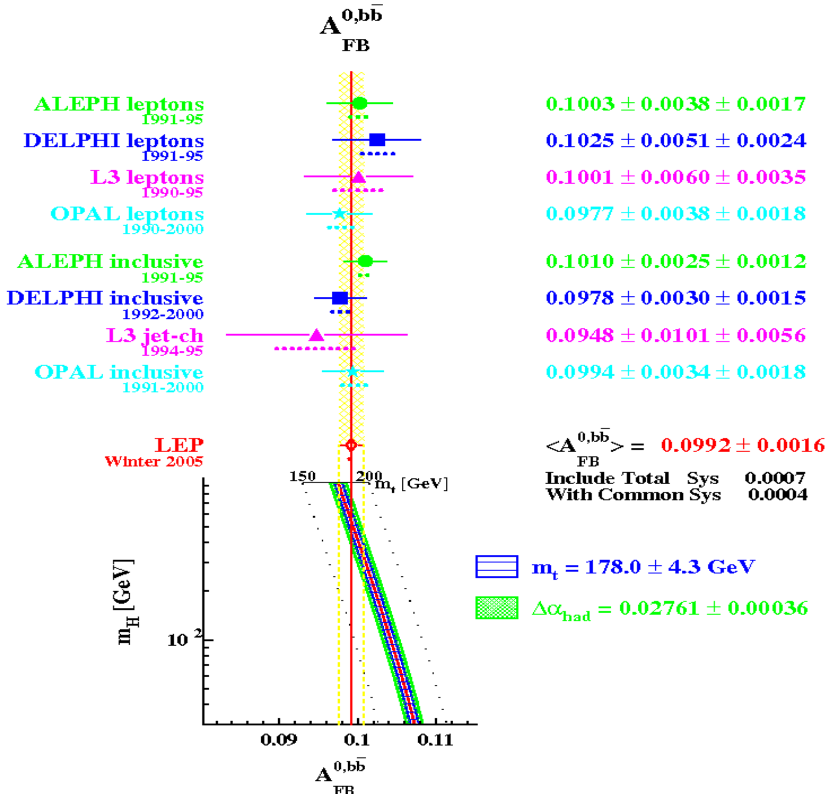
$$A_{LR} = \frac{\sigma_l - \sigma_r}{\sigma_{tot}} = A_e$$

$$A_{FB}^{pol} = \frac{\sigma_{F,l} - \sigma_{B,l} - \sigma_{F,r} + \sigma_{B,r}}{\sigma_{tot}} = \frac{3}{4} A_f$$

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	

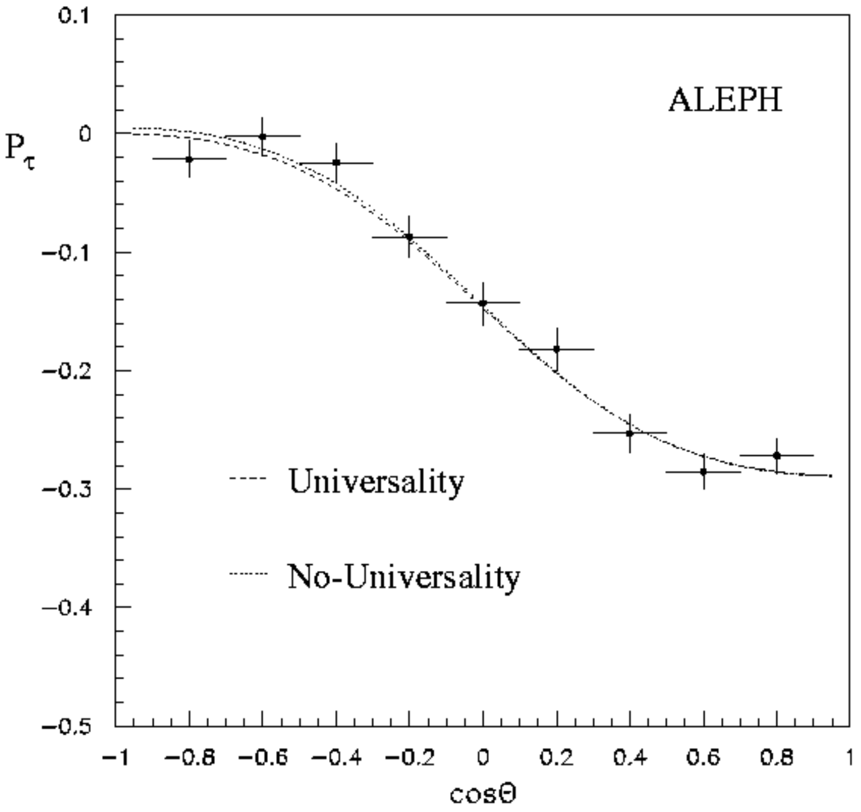


Can be reduced with improved calculations and proper choices of analysis methods

tau polarization

$$P_\tau(\cos\theta) = \frac{A_{pol}(1+\cos^2\theta) + \frac{8}{3}A_{pol}^{FB}\cos\theta}{(1+\cos^2\theta) + \frac{8}{3}A_{FB}\cos\theta}$$

- Polarization measurement as a function of the production angle allows A_e to be separated from A_τ
- Universality test and measurement of $\sin^2\theta_W$
- LEP combination was (again) statistically dominated



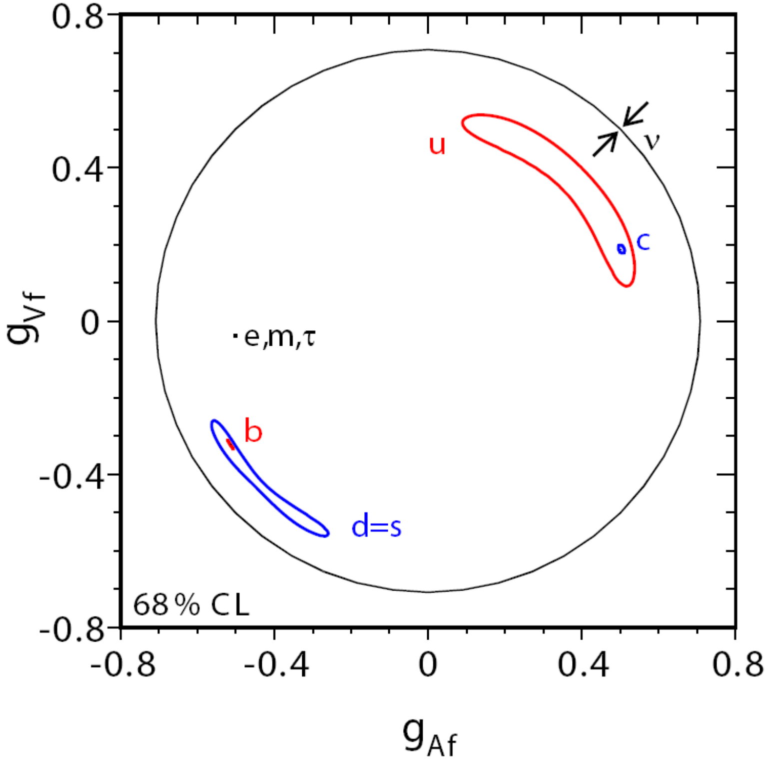
Again on FB asymmetries

- Also in this case a model independent approach (S-matrix) is desirable, the energy dependence was available, but was not tried at LEP.
  - trade statistical power for reduced theoretical assumptions
- $A_{FB}(\mu^+\mu^-)$ or $A_{FB}(\tau^+\tau^-)$ can also be considerably improved (currently largely dominated by statistics). $A_{FB}(e^+e^-)$ more difficult because of t-channel

Measuring the couplings

- Requires measurement of asymmetry and width (or width ratio as R_b)

$$R_b = \frac{\Gamma(Z \rightarrow b\bar{b})}{\Gamma_{had}}$$



$$A_{FB}(b) = \frac{\sigma_F - \sigma_B}{\sigma_{tot}} = \frac{3}{4} A_e A_b \text{ (LEP)} \longrightarrow \frac{g_{Vf}}{g_{Af}}$$

$$A_b = A_{FB}^{pol}(b) = 0.921 \pm 0.021 \text{ (SLC)} \nearrow$$

$$R_b = 0.21646 \pm 0.00065 \text{ (LEP+SLC)} \longrightarrow (g_{Af})^2 + (g_{Vf})^2$$

Improving on R_b

- Very sensitive to rad. vertex corrections due to new particles (e.g. stops or charginos)
- Important to sort out LEP b-couplings issue
- Measurement exploits the presence of two b hadrons and b-tagging.
- **Independent** from **b-tagging efficiency**, but **not** from **hemisphere correlations**
- Higher b-tagging performance (better vertex detectors) helps in reducing the correlation
- Correlations sources should be identified and studied with data (done at LEP)

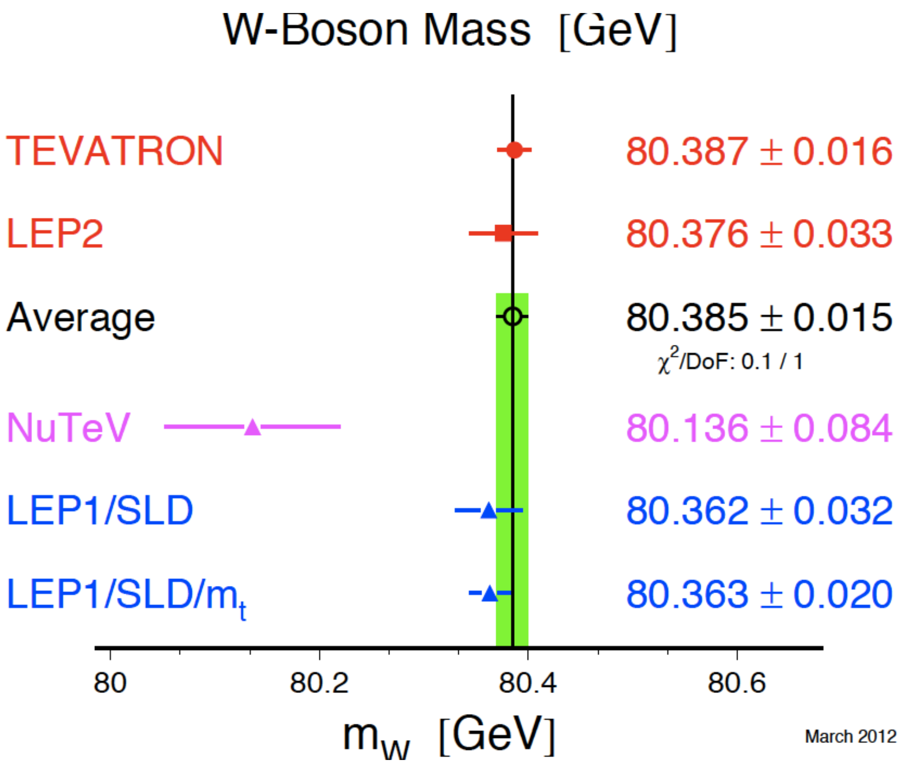
$$R_b \approx \frac{C_b F_1^2}{F_2}$$

$$\varepsilon_b \approx \frac{F_2}{C_b F_1}$$

- F_1 # single tag
- F_2 # double tag

160 GeV: Measurement of the W mass

- Here the Tevatron goal is 10 MeV and LHC goal 5 MeV. Will depend a lot on improvements of PDF.
- Perform a precise measurement from the WW threshold scan Could potentially reach ~ 0.5 MeV if resonant depolarization works at 80 GeV.



Also revisit the LEP2 method of direct reconstruction (there is room for improvement, e.g. beam energy, large statistics on semileptonic events, etc.)

The W mass from threshold scan

- Experimentally very clean, efficiencies and backgrounds from LEP →
  - $\mu^+\mu^-$ eff~70% bkg 10%
  - qq eff~90% bkg 20%
- The issue here is the theoretical description of the turn on shape (see talk of Doreen on Tuesday and comments on next slide)

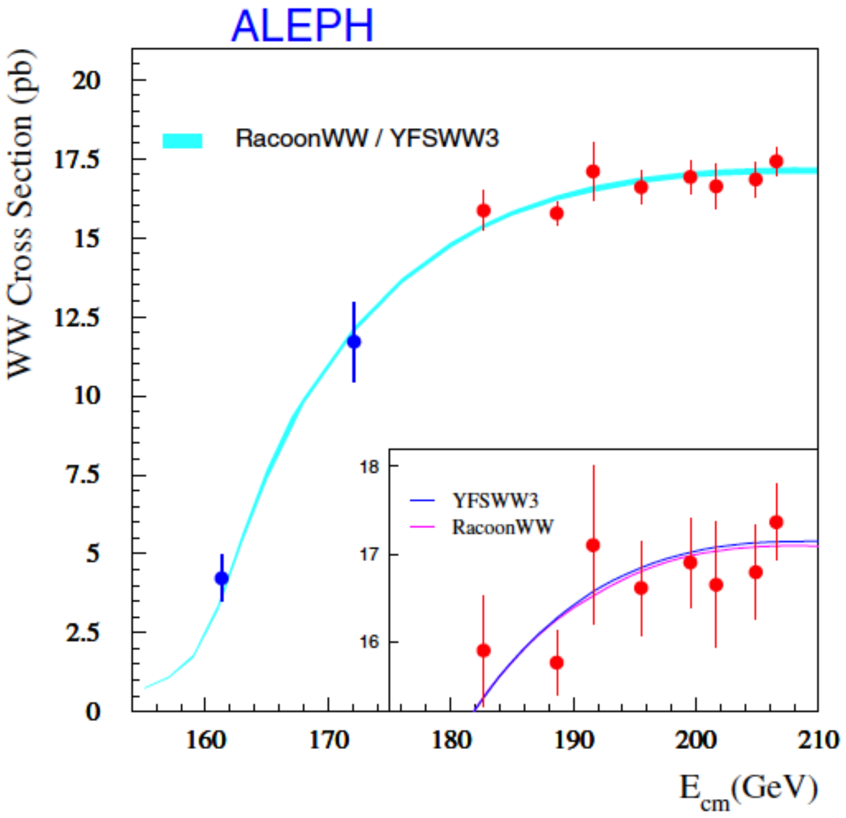


Fig. 4. Measurements of the W-pair production cross section at ten CM energies, compared to the Standard Model predictions from `YFSWW3` and `RacoonWW` for $m_W = 80.35\,\mathrm{GeV}/c^2$

Four-fermion production near WW threshold

- Theoretical calculations must refer to a final state of decayed W bosons and include non-resonant and off-shell effects.
- Roughly 1% error in the theoretical prediction of the total cross section results in a 15 MeV error on the mW measurement.
  - for 0.1% precision need to go to NNLO, dominant contribution calculated [arXiv:0807.0102], need to progress on this path
  - improvement of the presently available treatment of ISR [arXiv:0707.0773] is also required (it can be solved, but requires work)

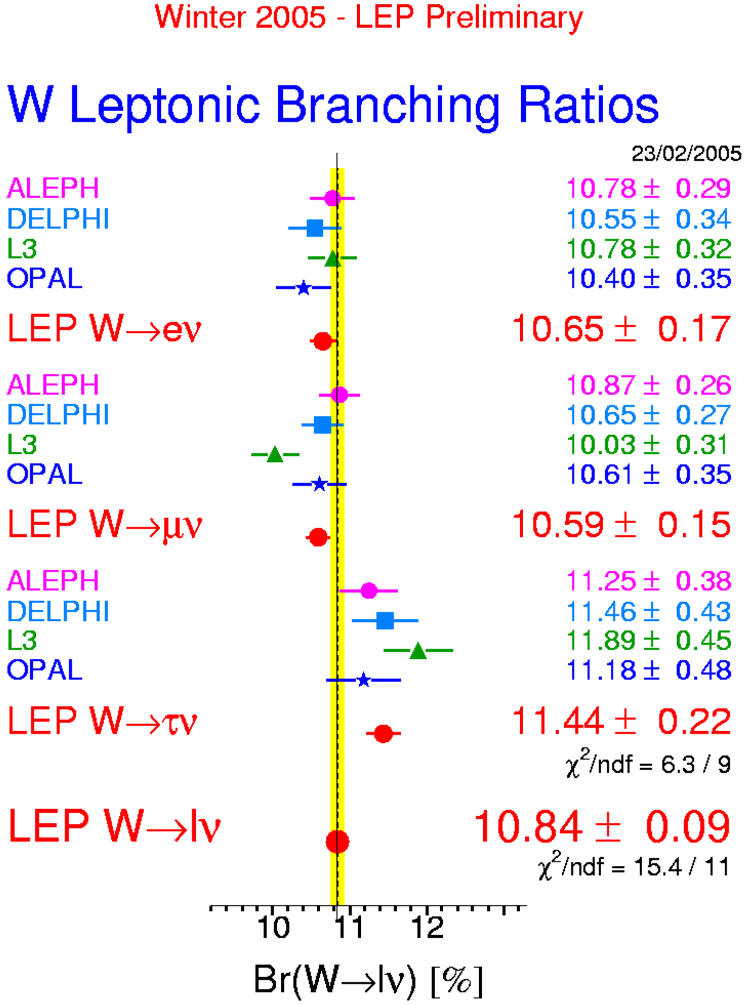
[comments from M. Beneke]

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) !!

Top quark mass

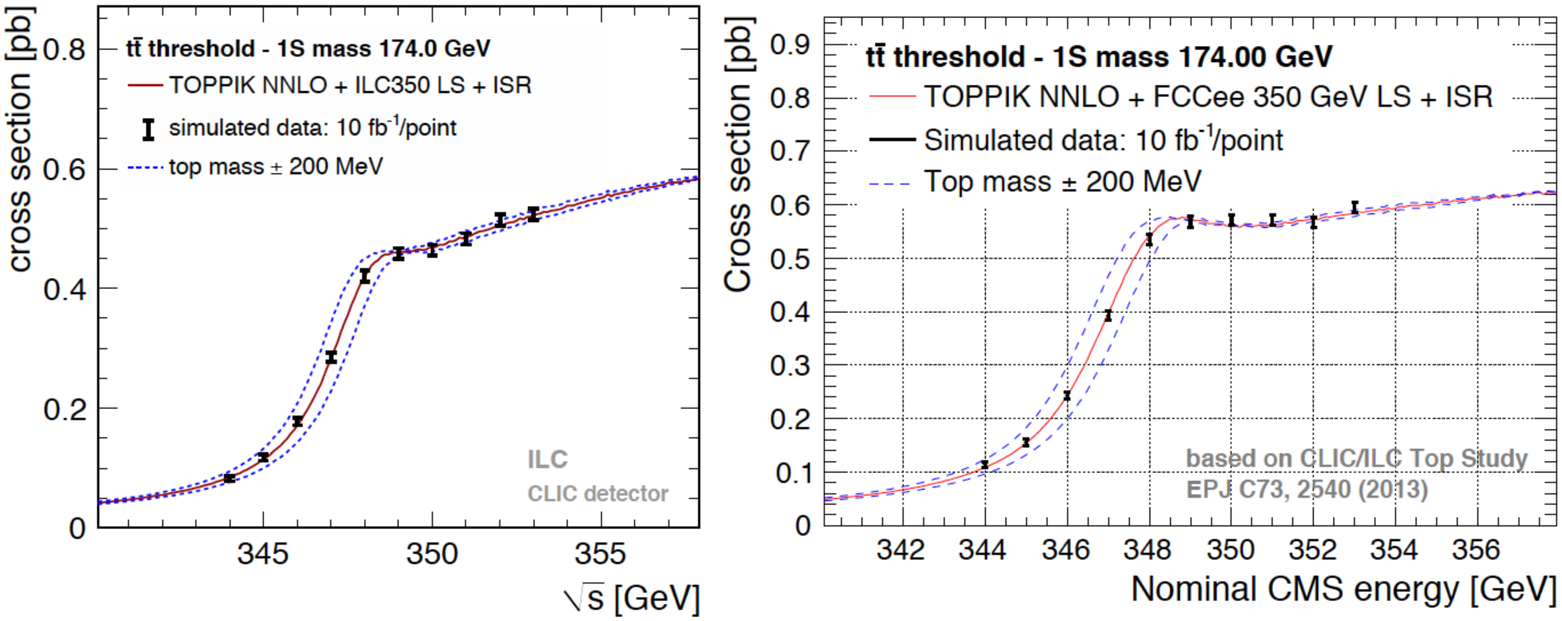
- The top quark mass is experimentally **measured at hadron colliders with a precision of ≈ 0.5 %**, however the **interpretation of the measurements in terms of pole mass is subject to many discussions**.
- Given the importance of this parameter in electroweak fits and given its connection to the stability of the electroweak vacuum, **any effort to shed light on measurement interpretations and to assess in a robust way systematic uncertainties at hadron colliders is worthwhile.**
- **Efforts in this direction have already started, with new analysis techniques, which will exploit the large top quark statistics to be collected in the next years at LHC**
- **Eventually, the top mass must be measured precisely at an e+e- colliders with a top pair production threshold scan**

e+e- at 350 GeV: threshold scan

see talk from Patrizia Azzi on Tuesday

- At FCC statistical uncertainty of 5 MeV with 1 ab^{-1}
- Theoretical *current* uncertainty from higher order QCD contribution ~ 100 MeV

- Comparing ILC and FCCee - assuming identical detector performance



Simulated data points - same integrated luminosity

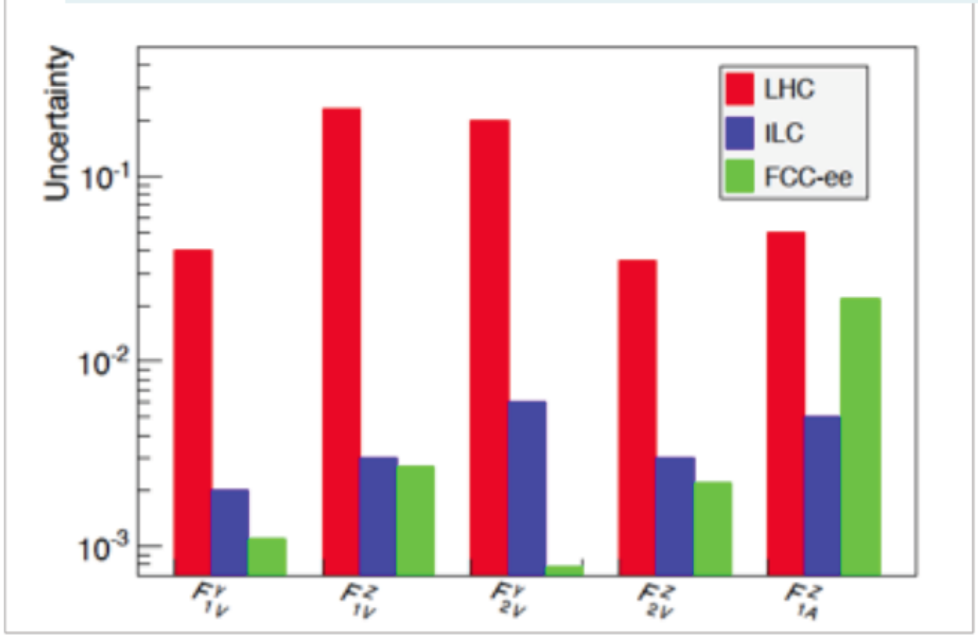
NB: Assuming unpolarized beams - LC beams can be polarized, increasing cross-sections / reducing backgrounds

From Frank Simon, TOP2014

Advantage of a very low level of beamstrahlung at FCC

Top couplings

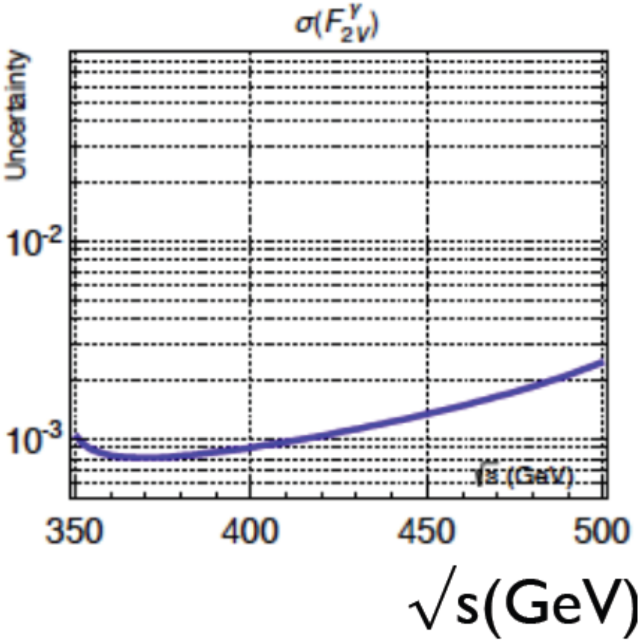
Statistical uncertainties for CP-conserving top quark form factors



LHC: Snowmass study 2005 $\sqrt{s}$=14TeV,300

ILC: $\sqrt{s}$=500GeV, 500fb^{-1}polarized beams

FCC-ee = $\sqrt{s}$=365 GeV, 2.4 ab^{-1}

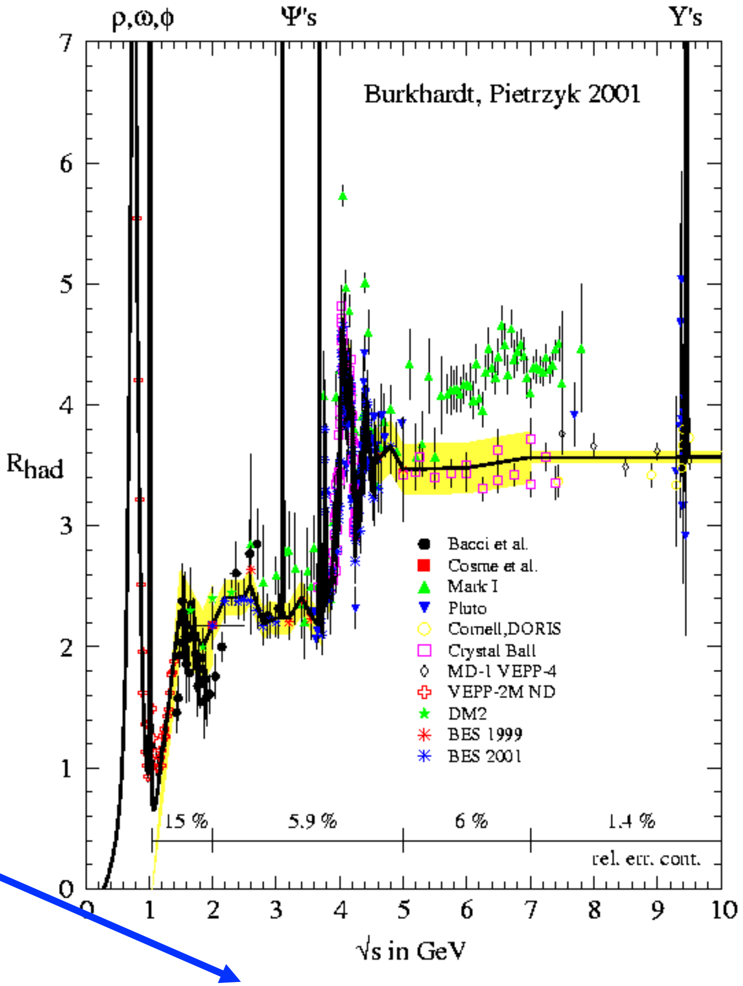


- can reach a precision at the per-mil level
- ttZ and ttγ can be disentangled without the need of polarization in the initial state
- no need for high energy runs, far above the threshold ($\sqrt{s}$=365 optimal)

P. Janot. arXiv:1503.01325v2

Running of α QED: $\alpha(M_Z)$

- The traditional way to compute $\alpha(M_Z)$ is to compute hadronic loops with dispersion relations by using low energy e^+e^- data.
- Precision should be improved at least a factor 3 to profit of FCC-ee precision



$$\alpha(s) = \frac{\alpha(0)}{1-\Delta\alpha_l(s)-\Delta\alpha^{(5)}_{had}(s)-\Delta\alpha_{top}(s)}$$

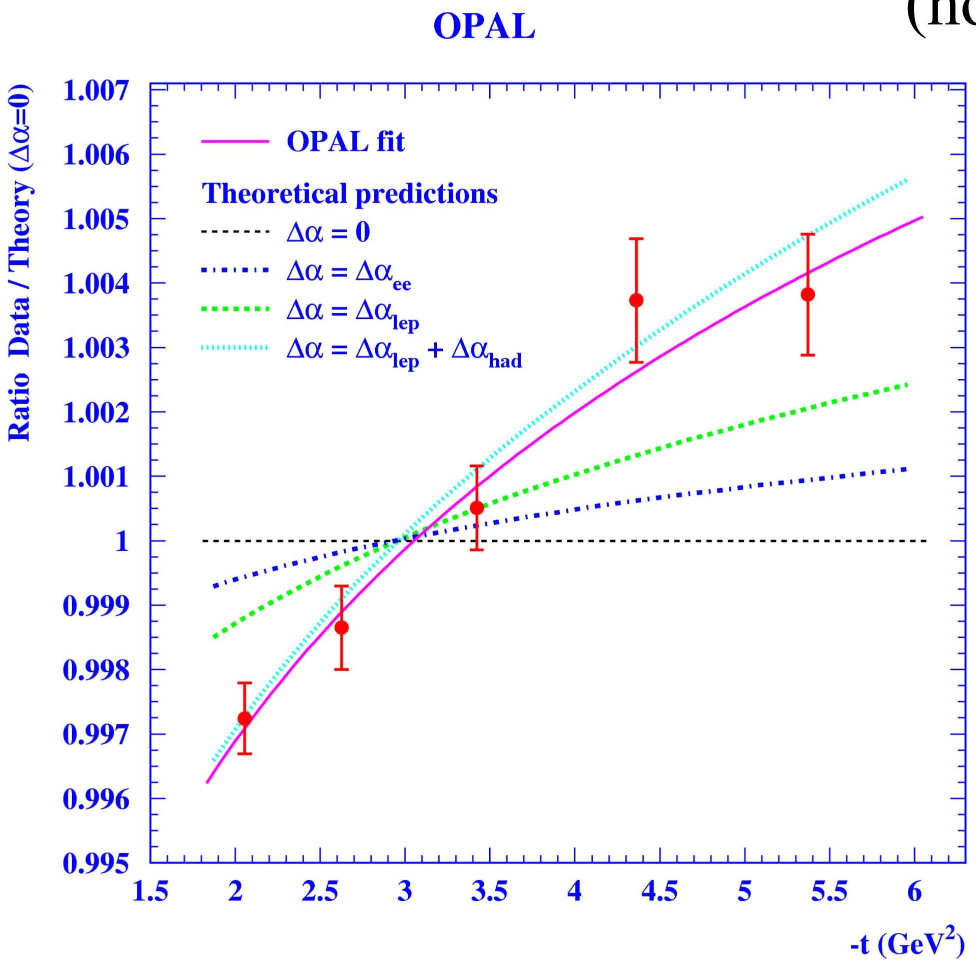
$$\Delta\alpha^{(5)}_{had}(s) = -\frac{\alpha s}{3\pi}\int_{4m_\pi^2}^{\infty}\frac{R_{had}(s')}{s'(s'-s)}ds'$$

$$\alpha(s) = \frac{1}{128.936 \pm 0.046}$$

Are there other ways ?

From low angle Bhabha Scattering : Evidence of α running and hadron contribution

(however it is low q^2)



$\Delta\chi^2 = 0.8$

$\chi^2/d.o.f. = 1.9/3$ **OPAL** fit

$\Delta\chi^2 = 18$

$\Delta\chi^2 = 37$

$\Delta\chi^2 = 60$

incompatible

OPAL fit

$$f(t) = \frac{N_{data}(t)}{N^0_{MC}(t)} = a + b \cdot \ln\left(\frac{t}{t_0}\right)$$

$$b = (726 \pm 96 \pm 70) \times 10^{-5}$$

$$\cong 2\frac{\delta\,\Delta\alpha}{\delta\,\ln t}$$

From large angle μ+μ- scattering at sqrt(s) < M_Z (see talk of Sbyszek WAS on Tuesday)

- Requires careful computation of higher order QED corrections and subtraction of Z component and interference
  - – best way is probably include in S-matrix common fit
- One additional motivation to take data off peak

Electroweak (pseudo) observables themselves have different dependence on $\Delta\alpha^{(5)}_{\mathrm{had}}$

- Could compute some interesting radiative correction by combinations of two (pseudo)observables and eliminate $\Delta\alpha^{(5)}_{\mathrm{had}}$ at first order (e.g. W mass, Z mass and $\sin^2\theta_W$)

$$1 - \sin^2\theta_{weff} = \frac{1}{\rho}\frac{m_W^2}{m_Z^2}$$

$$\rho = \left[1 + \varepsilon_1 - \varepsilon_2 - 0.3\ \varepsilon_3\right]$$

For the ε prameterization see
G. Altarelli, R. Barbieri, S. Jadach, Nucl. Phys. B369 (1992) 3.

Other topics non covered

- Neutrino counting
- Triple and quartic gauge couplings
- Measurements of α_s from lineshape and W hadronic decays
- Potential of FCC-hh for, e.g., dibosons

Conclusions

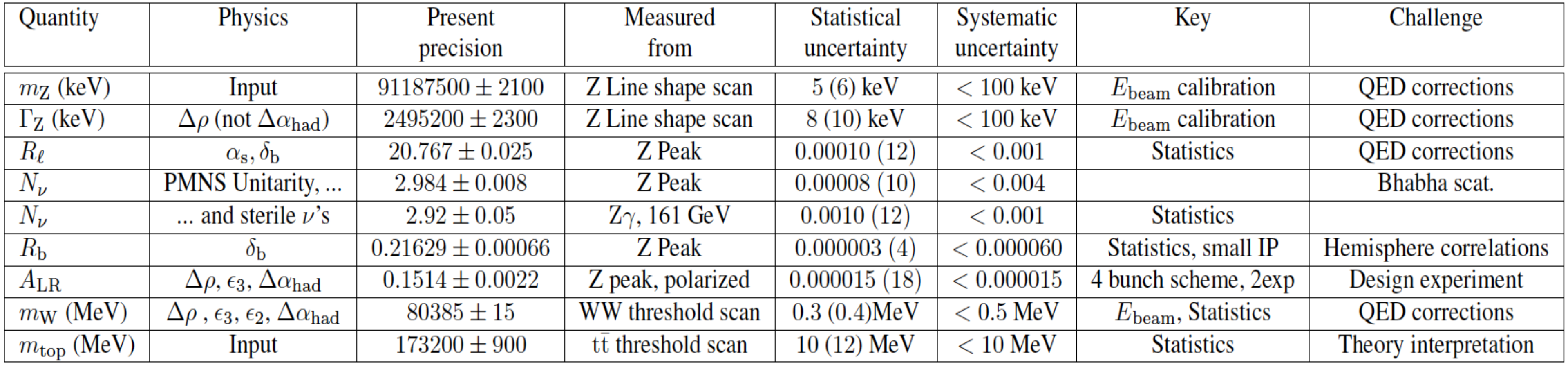
- There are no “a priori” walls on the road map to achieve the FCC goals for EW precision measurements
- Only a lot of work, especially on the theoretical calculations side: an opportunity to contribute
- At the Z, off peak data will play an important role (more than at LEP times)

BACKUP

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



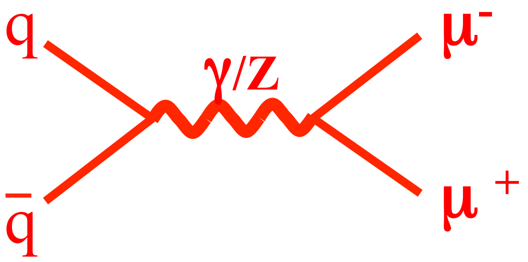
Quantity	Physics	Present precision	Measured from	Statistical uncertainty	Systematic uncertainty	Key	Challenge
m_Z (keV)	Input	91187500 ± 2100	Z Line shape scan	5 (6) keV	< 100 keV	$E_{\rm beam}$ calibration	QED corrections
Γ_Z (keV)	$\Delta\rho$ (not $\Delta\alpha_{\rm had}$)	2495200 ± 2300	Z Line shape scan	8 (10) keV	< 100 keV	$E_{\rm beam}$ 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	Zγ, 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}	$\Delta\rho$, ϵ_3, $\Delta\alpha_{\rm had}$	0.1514 ± 0.0022	Z peak, polarized	0.000015 (18)	< 0.000015	4 bunch scheme, 2exp	Design experiment
m_W (MeV)	$\Delta\rho$, ϵ_3, ϵ_2, $\Delta\alpha_{\rm had}$	80385 ± 15	WW threshold scan	0.3 (0.4)MeV	< 0.5 MeV	$E_{\rm beam}$, Statistics	QED corrections
$m_{\rm top}$ (MeV)	Input	173200 ± 900	$t\bar{t}$ threshold scan	10 (12) MeV	< 10 MeV	Statistics	Theory interpretation

From arXiv:1308.6176

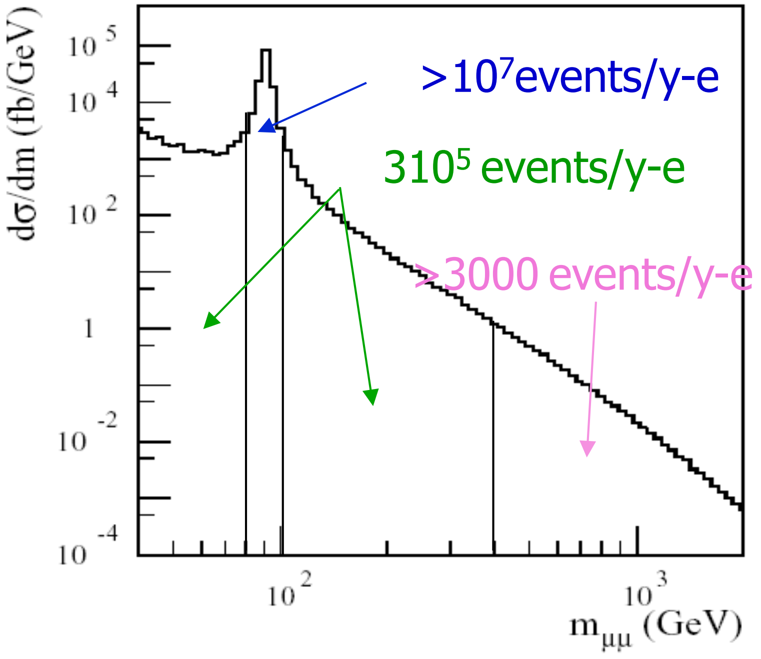
Parameter	Input value	Free in fit	Fit Result	w/o exp. input in line	w/o exp. input in line, no theo. unc
M_H [GeV]$^{(\circ)}$	125.14 ± 0.24	yes	125.14 ± 0.24	93^{+25}_{-21}	93^{+24}_{-20}
M_W [GeV]	80.385 ± 0.015	–	80.364 ± 0.007	80.358 ± 0.008	80.358 ± 0.006
Γ_W [GeV]	2.085 ± 0.042	–	2.091 ± 0.001	2.091 ± 0.001	2.091 ± 0.001
M_Z [GeV]	91.1875 ± 0.0021	yes	91.1880 ± 0.0021	91.200 ± 0.011	91.2000 ± 0.010
Γ_Z [GeV]	2.4952 ± 0.0023	–	2.4950 ± 0.0014	2.4946 ± 0.0016	2.4945 ± 0.0016
σ^0_{had} [nb]	41.540 ± 0.037	–	41.484 ± 0.015	41.475 ± 0.016	41.474 ± 0.015
R^0_ℓ	20.767 ± 0.025	–	20.743 ± 0.017	20.722 ± 0.026	20.721 ± 0.026
$A^{0,\ell}_{\mathrm{FB}}$	0.0171 ± 0.0010	–	0.01626 ± 0.0001	0.01625 ± 0.0001	0.01625 ± 0.0001
$A_\ell\ ^{(\star)}$	0.1499 ± 0.0018	–	0.1472 ± 0.0005	0.1472 ± 0.0005	0.1472 ± 0.0004
$\sin^2\theta^\ell_{\mathrm{eff}}(Q_{\mathrm{FB}})$	0.2324 ± 0.0012	–	0.23150 ± 0.00006	0.23149 ± 0.00007	0.23150 ± 0.00005
A_c	0.670 ± 0.027	–	0.6680 ± 0.00022	0.6680 ± 0.00022	0.6680 ± 0.00016
A_b	0.923 ± 0.020	–	0.93463 ± 0.00004	0.93463 ± 0.00004	0.93463 ± 0.00003
$A^{0,c}_{\mathrm{FB}}$	0.0707 ± 0.0035	–	0.0738 ± 0.0003	0.0738 ± 0.0003	0.0738 ± 0.0002
$A^{0,b}_{\mathrm{FB}}$	0.0992 ± 0.0016	–	0.1032 ± 0.0004	0.1034 ± 0.0004	0.1033 ± 0.0003
R^0_c	0.1721 ± 0.0030	–	$0.17226\ ^{+0.00009}_{-0.00008}$	0.17226 ± 0.00008	0.17226 ± 0.00006
R^0_b	0.21629 ± 0.00066	–	0.21578 ± 0.00011	0.21577 ± 0.00011	0.21577 ± 0.00004
$\overline{m}_c$ [GeV]	$1.27\ ^{+0.07}_{-0.11}$	yes	$1.27\ ^{+0.07}_{-0.11}$	–	–
$\overline{m}_b$ [GeV]	$4.20\ ^{+0.17}_{-0.07}$	yes	$4.20\ ^{+0.17}_{-0.07}$	–	–
m_t [GeV]	173.34 ± 0.76	yes	173.81 ± 0.85	$177.0\ ^{+2.3}_{-2.4}{}^{(\triangledown)}$	$177.0 \pm 2.3^{(\triangledown)}$
$\Delta\alpha^{(5)}_{\mathrm{had}}(M_Z^2)^{(\dagger\triangle)}$	2757 ± 10	yes	2756 ± 10	2723 ± 44	2722 ± 42
$\alpha_s(M_Z^2)$	–	yes	0.1196 ± 0.0030	0.1196 ± 0.0030	0.1196 ± 0.0028

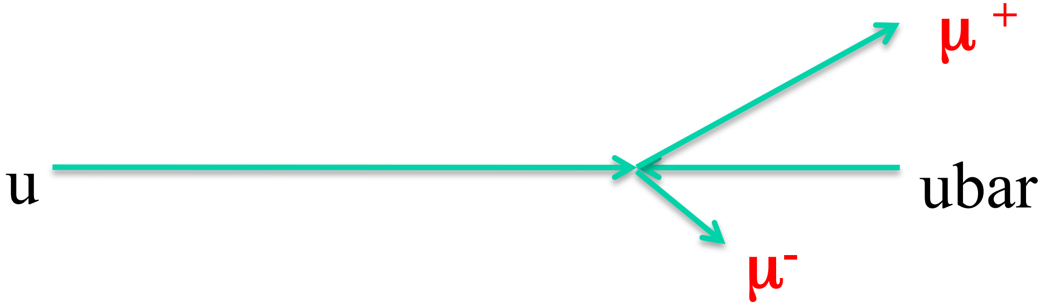
[Gfitter group, EPJC 74, 3046 (2014)]

Asymmetry from Drell-Yan events at LHC



- Signature is clear and background is low, however →
- forward-backward asymmetry: need to know quark direction
- at LO easy at Tevatron (p – pbar)
- at LHC study DY cross section as a function of invariant mass and
- assume that at high rapidity direction gives information on direction of valence quark

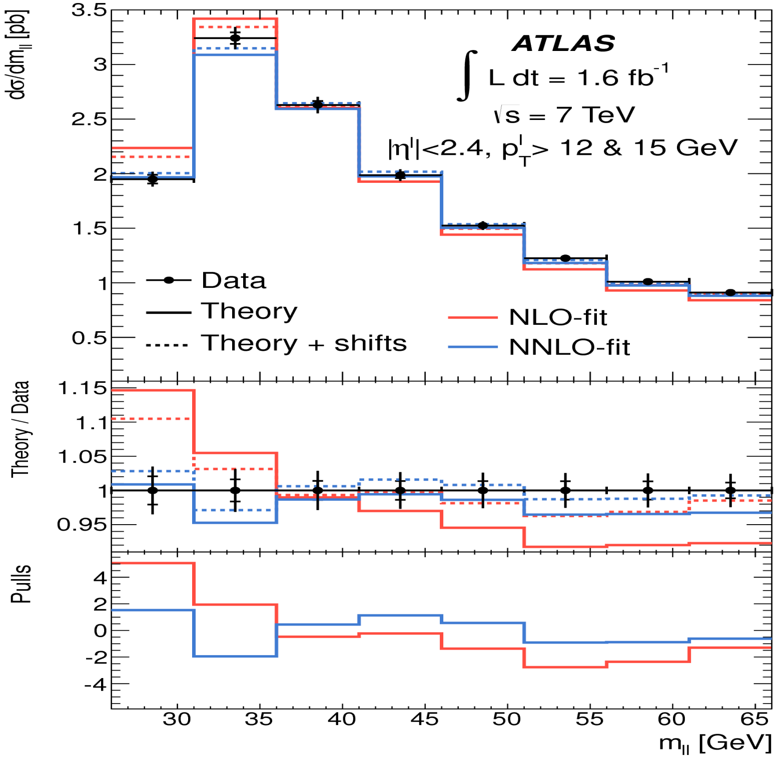


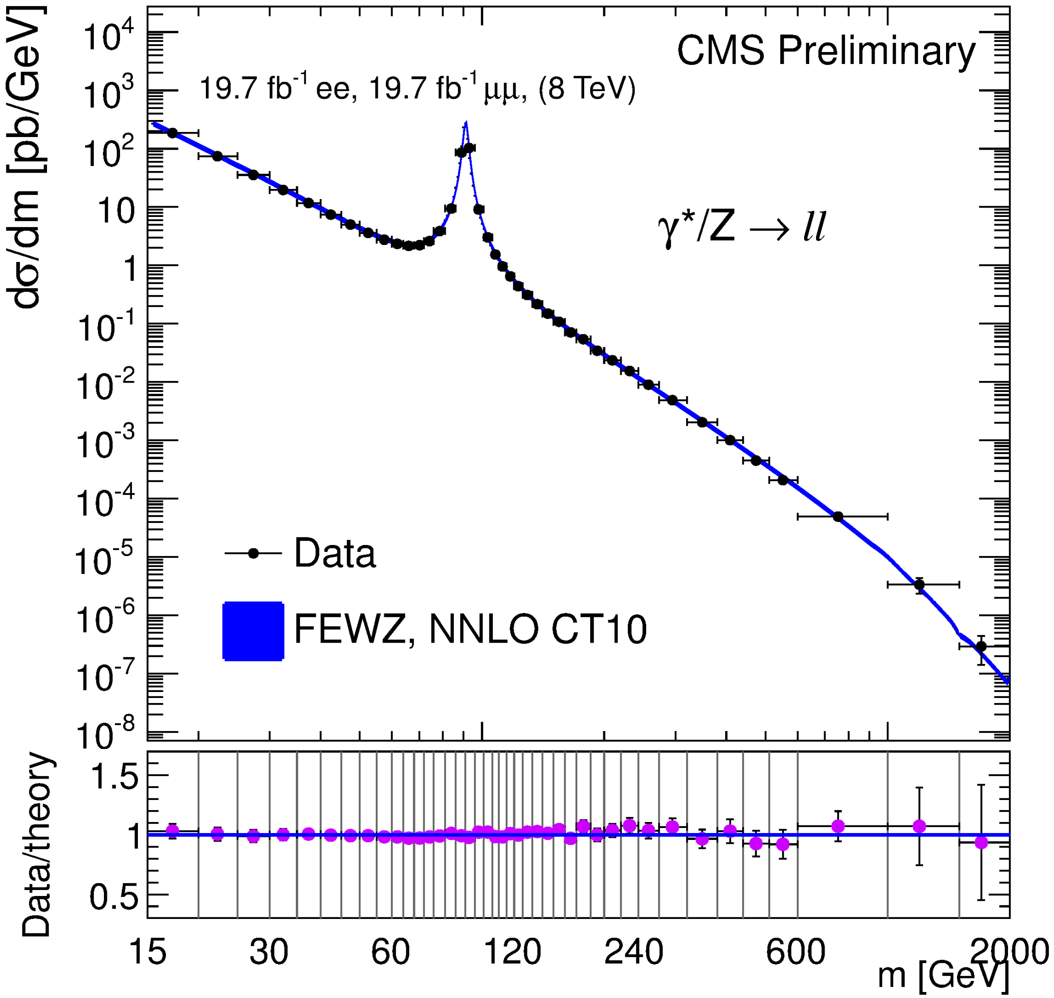


JHEP 12 (2013) 030 | CMS-PAS-SMP-1403 | JHEP 06 (2014) 112

Dilepton Drell Yan cross section

Impressive test of the Standard Model from 15 GeV to 2000 GeV !

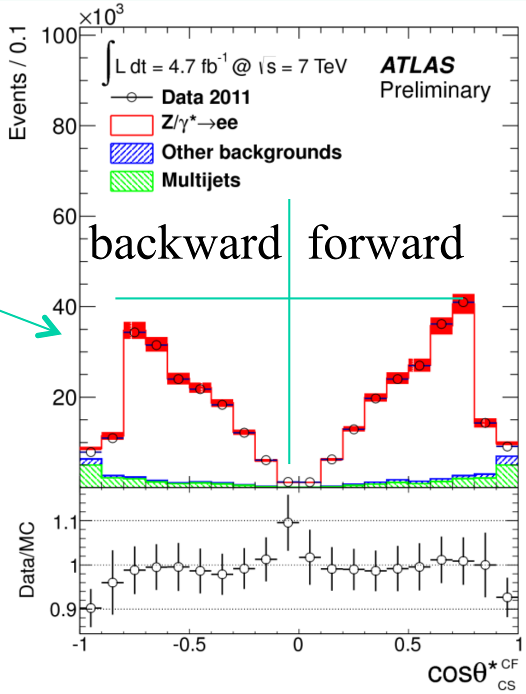


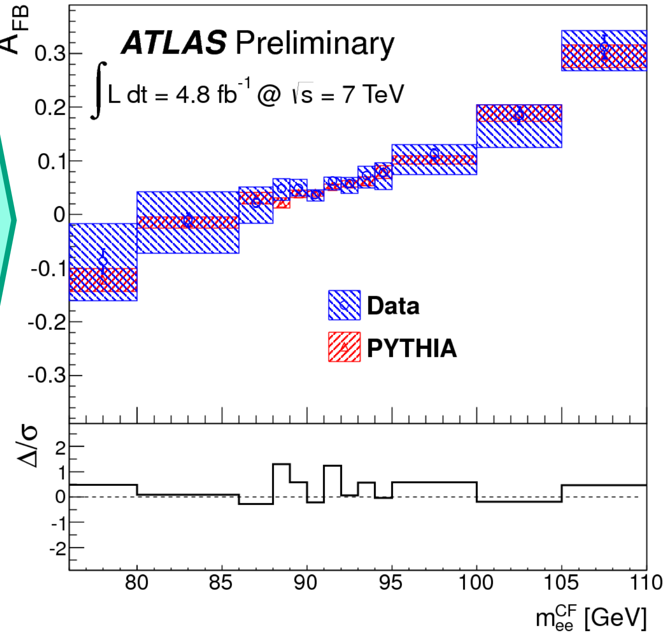


Weak mixing angle at LHC

ATLAS-CONF-2013-043

- Select central dilepton pairs, **and also central-forward electrons** with full 7 TeV dataset
- Raw AFB = Count forward/ backward abundance in CS frame
- AFB in good agreement with PYTHIA * PHOZPR NNLO K-factor (MSTWNNLO2008)
- 1.8σ lower angle than LEP +SLD average



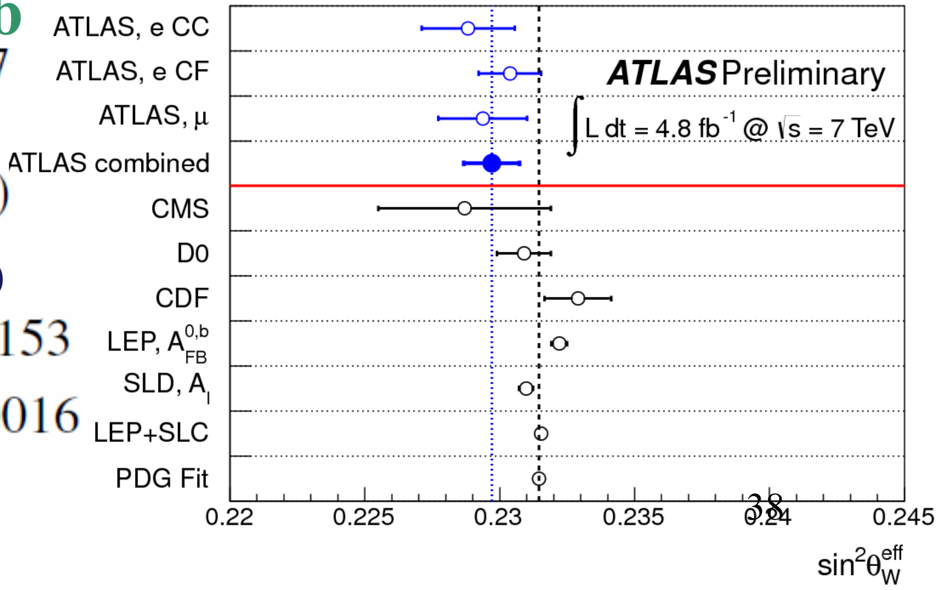


ATLAS 5/fb

$$\sin^2\theta_W^{\mathrm{eff}} = 0.2297 \pm 0.0004(\mathrm{stat.}) \pm 0.0009(\mathrm{syst.})$$

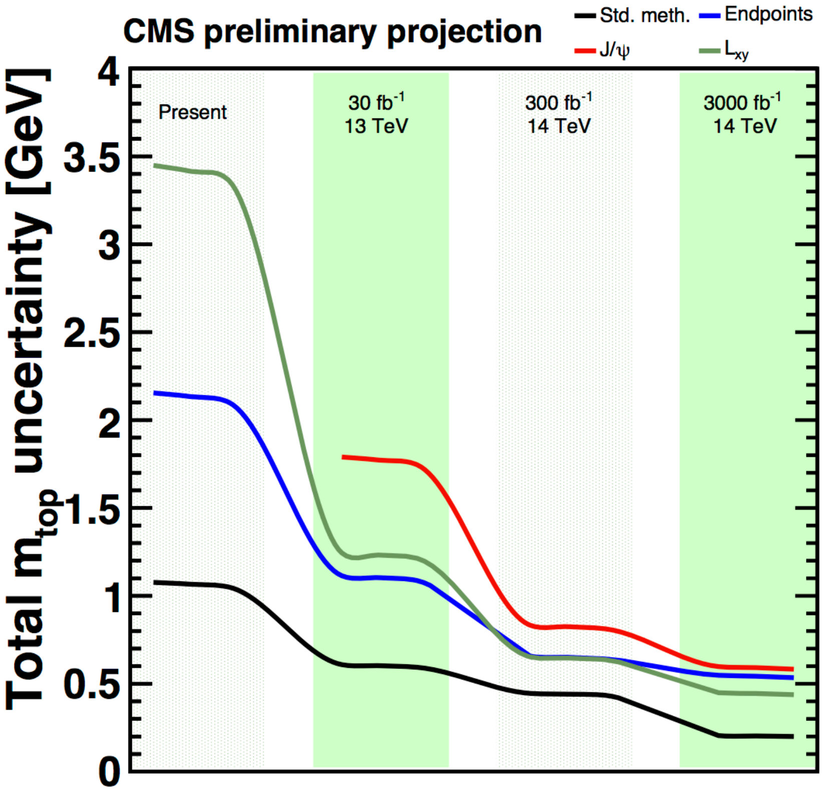
LEP + SLD

$$\sin^2\theta_W^{\mathrm{eff}} = 0.23153 \pm 0.00016$$



Prospects for top mass at the LHC

- There is potential to improve standard methods, taking advantage of the high statistics for, e.g., in-situ JES calibration, constraining models from differential studies, etc.
- There is even greater potential for alternative methods, most of the current systematic uncertainties can be reduced with higher statistics, e.g. top pt modeling, in-situ JES again
- Improvements on the cross section method are linked to improvements in the luminosity and beam energy uncertainties at LHC
- A optimistic view (maybe realistic give past experience at colliders !) of the evolution in precision is given in the picture



From CMS PAS FTR-13-017, prepared for the "European Strategy for particle physics" discussions