EW : Z pole & W pairs

Paolo Azzurri – INFN Pisa
CEPC workshop EU

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Outline

- Electroweak physics at the Z pole

  The Z lineshape, neutrino species

  Decay BR : Rb and Rc

  Asymmetries, $\sin^2\theta_{eff}$

  $\alpha_{QED}(m_Z^2)$

- Electroweak physics at the WW threshold and above

  Measurement of the W mass and width at threshold

  Measurement of W decay branching fractions

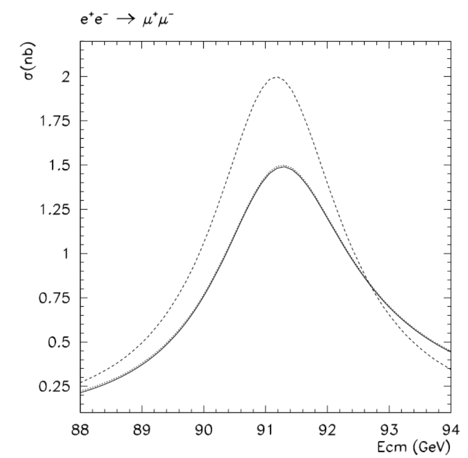
  Direct measurement of W mass and width

  Constraints on gauge couplings

  (mostly FCCee studies & projections)

the Giga/Tera Z pole precision

CEPC : 10^9-10^{11} Z decays : **LEP1 x $10^{2\text{-}4}$**
FCCee: 4 10^{12} Z decays : **LEP1 x 10^5**



Radiation function calculated up to $O(\alpha^3)$: 10^{-5} precision → $\Delta m_Z \approx 100$ KeV

continuous E_{CM} calibration (resonant depolarization)
➔ Z **mass** and **width** : 100-500 KeV (syst)

model (in) dependent (S-matrix) approach for γZ interference effects
off shell data needed for precise independent approach (reduced th assumptions)

beam spread (~60 MeV) and beams crossing angle (~30mrad) monitored with μ+μ-

Z pole

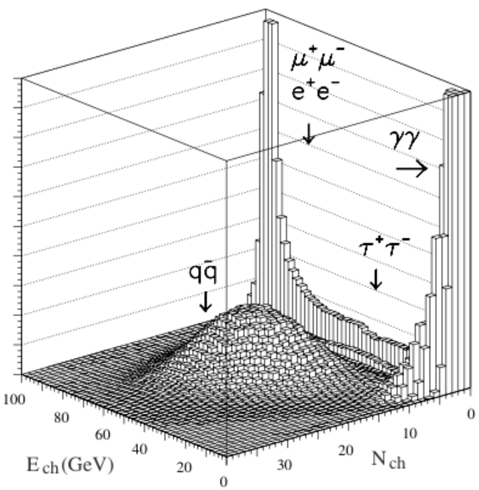
luminosity from Bhabha events

- th uncertainty now at 10-4 level
- det position accuracy at 2µm level

altenative using photon pairs ee→γγ

$$\sigma_{bh}^{th} \sim \frac{16\pi\alpha^2}{s}\left(\frac{1}{\theta_{min}^2} - \frac{1}{\theta_{max}^2}\right)$$

Partial widths



FCC ee relative precisions JHEP01(2014)164

R_l hadronic/leptonic width : $\mathbf{5\ 10^{-5}}$

R_b Zbb partial width : $\mathbf{5\ 10^{-5}}$

Invisible width : $\mathbf{10^{-3}}$ N_ν (Zγ)

Z pole acceptance

- @LEP acceptance effects at **10^{-4}** OK for cross sections at **10^{-3}** level. Main effects were due to track losses, angle mis-measurements and knowledge of boundaries.
- @CEPC/FCCee exploit a statistical uncertainty at **10^{-5}** !

Example from ALEPH, EPJC 14 (2000) 1

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)

@LEP detectors inner edge (**relevant boundary**) was known at the level of up to **20 µm**
The beam displacement (**vertical** and **horizontal**) becomes ineffective by choosing two fiducial regions (**loose and tight**) and **alternating them** in the two sides

@CEPC/FCCee can **use similar methods for cross sections** measurements (e.g. different and alternating forward and backward fiducial regions), but still need to identify and know well the relevant boundaries (~1µm level)

couplings and R_b

couplings measurements require asymmetry and width ratios

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

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

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

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

- R_b Very sensitive to rad. vertex corrections due to new particles
- 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 (vertex detectors) helps in reducing the correlation
- Correlations sources should be identified and studied with data (done at LEP)

$\Delta R_b \approx$ **5** (**30**) 10^{-5} **stat** (**syst**) $\Delta R_c \approx$ **15** (**150**) 10^{-5} **stat** (**syst**)

Z asymmetries

- Z boson decay to ff : 3 observables from the direction and decay of the outgoing fermion

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

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

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

Can measure for e,μ,τ,c,b

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

Can measure with τ' s

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

- Additional asymmetries with polarization of initial state :

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

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

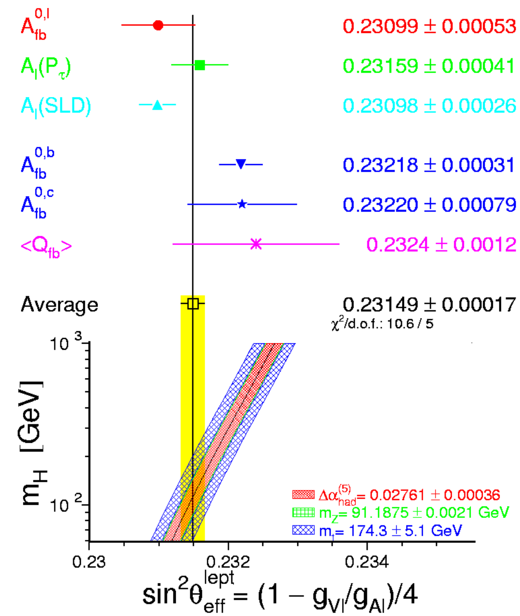
Z asymmetries

CEPC/FCCee can sizably improve **b asymmetry**

- use semileptonic b decays
- use weighted charge of particles in the hemisphere

•different systematic effects [QCD corrections to be improved]

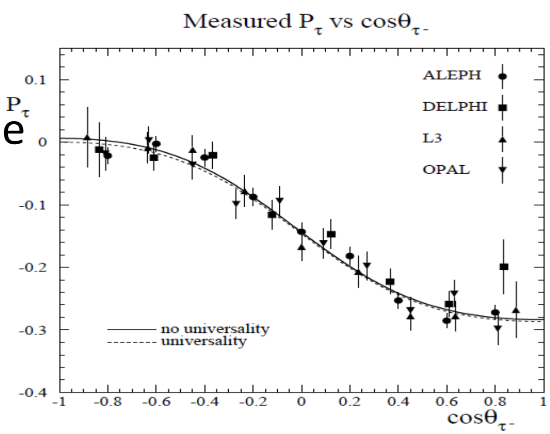
➔ $\Delta A_b \approx$ **2** (**30**) 10^{-4} **stat** (**syst**) $\Delta A_c \approx$ **3** (**80**) 10^{-4} **stat** (**syst**)



tau polarization A

Polarization vs the production angle allows A_e to be separated from A_τ : Universality test and $\sin^2\theta_W$

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



➔ $\Delta A_\tau \approx$ **4** (**30**) 10^{-5} **stat** (**syst**)

➔ $\Delta A_{e,\mu} \approx$ **5** (**10**) 10^{-5} **stat** (**syst**)

$A_{FB}(\mu^+\mu^-)$ and $A_{FB}(\tau^+\tau^-)$ can also be considerably improved.
$A_{FB}(e^+e^-)$ more difficult because of t-channel.

FCCee **projections** ➔ Δ_{rel} **$\sin^2\theta_{eff}$** ≈ **2 10^{-5}** (**syst**) ➔ x100 improvement wrt LEP !

Z pole

Parameter	Dominating source	expected uncertainty	improvement w.r.t. LEP
m_Z	beam energy	100 keV	20
Γ_Z	beam energy	100 keV	20
σ^0_{had}	luminosity	5×10^{-3} nb	20
R_ℓ	exp. acceptance	5×10^{-5}	8

	Statistical uncertainty	Systematic uncertainty	improvement w.r.t. LEP
R_μ (R_ℓ)	10^{-6}	5×10^{-5}	20
R_τ	1.5×10^{-6}	10^{-4}	20
R_e	1.5×10^{-6}	3×10^{-4}	20
R_b	5×10^{-5}	3×10^{-4}	10
R_c	1.5×10^{-4}	15×10^{-4}	10

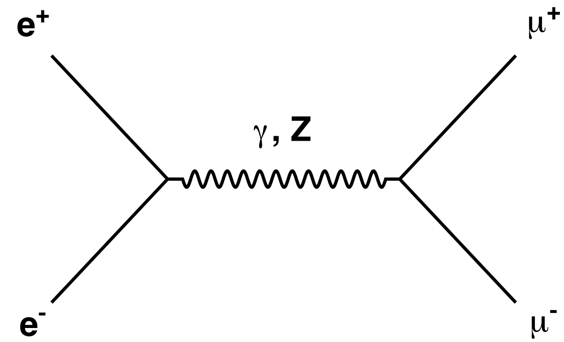
	Statistical uncertainty	Systematic uncertainty	improvement w.r.t. LEP
$\mathcal{A}_e$	$5. \times 10^{-5}$	$1. \times 10^{-4}$	50
$\mathcal{A}_\mu$	2.5×10^{-5}	1.5×10^{-4}	30
$\mathcal{A}_\tau$	$4. \times 10^{-5}$	$3. \times 10^{-4}$	15
$\mathcal{A}_b$	2×10^{-4}	30×10^{-4}	5
$\mathcal{A}_c$	3×10^{-4}	80×10^{-4}	4
$\sin^2\theta_{W,eff}$ (from muon FB)	10^{-7}	$5. \times 10^{-6}$	100
$\sin^2\theta_{W,eff}$ (from tau pol)	10^{-7}	6.6×10^{-6}	75

FCCee

Observable	LEP precision	CEPC precision	CEPC runs	$\int \mathcal{L}$ needed in CEPC
m_Z	2 MeV	0.5 MeV	Z lineshape	> 150 fb^{-1}
m_W	33 MeV	3 MeV	ZH (WW) thresholds	> 100 fb^{-1}
A^b_{FB}	1.7%	0.15%	Z pole	> 150 fb^{-1}
$\sin^2\theta^{\rm eff}_W$	0.07%	0.01%	Z pole	> 150 fb^{-1}
R_b	0.3%	0.08%	Z pole	> 100 fb^{-1}
N_ν (direct)	1.7%	0.2%	ZH threshold	> 100 fb^{-1}
N_ν (indirect)	0.27%	0.1%	Z lineshape	> 150 fb^{-1}
R_μ	0.2%	0.05%	Z pole	> 100 fb^{-1}
R_τ	0.2%	0.05%	Z pole	> 100 fb^{-1}

Direct measurement of $\alpha_{QED}(m_Z^2)$

Patrick Janot: arXiv:1512:05544, JHEP 2016(2) 1



High precision of FCCee will require higher order perturbative calculations : a **bottleneck** will be represented by the hadronic contributions to the vacuum polarization

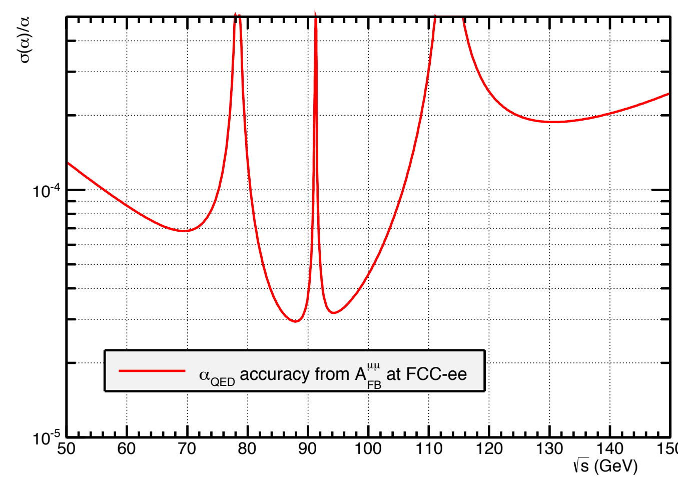
Rely of a self-normalizing quantity, the forward-backward asymmetry

$$A_{\rm FB}^{\mu\mu} = A_{\rm FB,0}^{\mu\mu} + \frac{3}{4}\frac{a^2}{v^2}\frac{\mathcal{I}}{\mathcal{G}+\mathcal{Z}}.$$

$$\sigma\left(A_{\rm FB}^{\mu\mu}\right) = \sqrt{\frac{1-A_{\rm FB}^{\mu\mu\,2}}{\mathcal{L}\sigma_{\mu\mu}}}.$$

$$\frac{\Delta\alpha}{\alpha} = \frac{\Delta A_{\rm FB}^{\mu\mu}}{A_{\rm FB}^{\mu\mu} - A_{\rm FB,0}^{\mu\mu}} \times \frac{\mathcal{Z}+\mathcal{G}}{\mathcal{Z}-\mathcal{G}} \simeq \frac{\Delta A_{\rm FB}^{\mu\mu}}{A_{\rm FB}^{\mu\mu}} \times \frac{\mathcal{Z}+\mathcal{G}}{\mathcal{Z}-\mathcal{G}},$$

$\sigma(\alpha)/\alpha$ plot, for a year of running at any √s



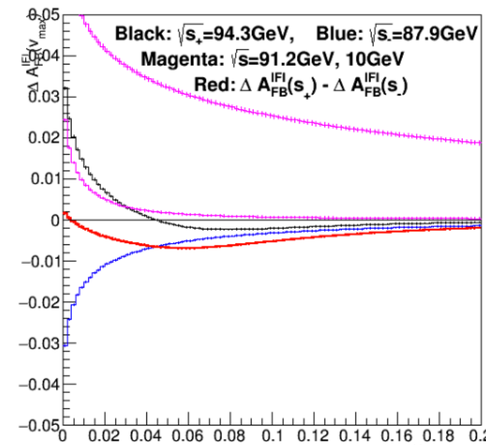
Optimal centre-of-mass energies for a 3×10^{-5} uncertainty on α_{QED} :
$\sqrt{s_-}$ = **87.9 GeV** and $\sqrt{s_+}$ = **94.3 GeV**

Determination of $\alpha_{QED}(m_Z^2)$

Two measurements : $\boxed{\alpha_- \equiv \alpha_{\rm QED}(s_-) \text{ and } \alpha_+ \equiv \alpha_{\rm QED}(s_+),}$

Solve for $\alpha_0 = \alpha_{QED}(m_Z^2)$ $\boxed{\dfrac{1}{\alpha_0} = \dfrac{1}{\alpha_\pm} + \beta \log \dfrac{s_\pm}{m_{\rm Z}^2}}$

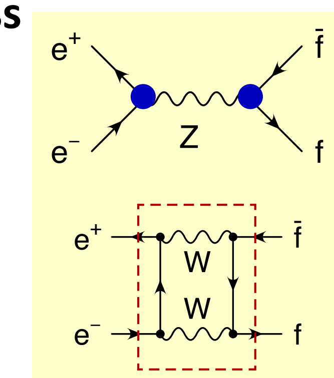
$$\frac{\Delta\alpha_0}{\alpha_0} \simeq \quad 0.528\frac{\Delta A_{\rm FB}}{A_{\rm FB}}(s_-) \quad + \quad 0.563\frac{\Delta A_{\rm FB}}{A_{\rm FB}}(s_+)$$



Type	Source	Uncertainty
Experimental	$E_{\rm beam}$ calibration	1×10^{-5}
	$E_{\rm beam}$ spread	$< 10^{-7}$
	Acceptance and efficiency	negl.
	Charge inversion	negl.
	Backgrounds	negl.
Parametric	$m_{\rm Z}$ and $\Gamma_{\rm Z}$	1×10^{-6}
	$\sin^2\theta_{\rm W}$	5×10^{-6}
	$G_{\rm F}$	5×10^{-7}
Theoretical	QED (ISR, FSR, IFI)	$< 10^{-6}$
	Missing EW higher orders	few 10^{-4}
	New physics in the running	0.0
Total (except missing EW higher orders)	Systematics	1.2×10^{-5}
	Statistics	3×10^{-5}

IFI at better than 1% to reach the required precision on $\alpha_{QED}(m_Z^2)$:
work in progress

Box + Vertex
EW correction



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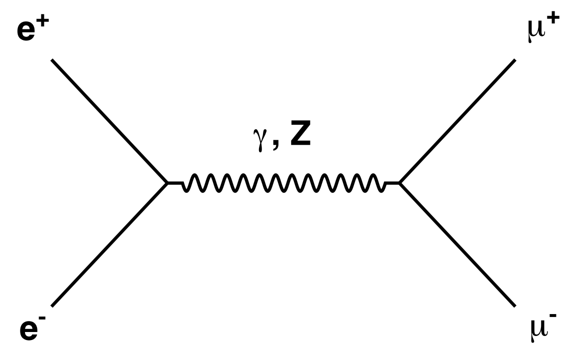

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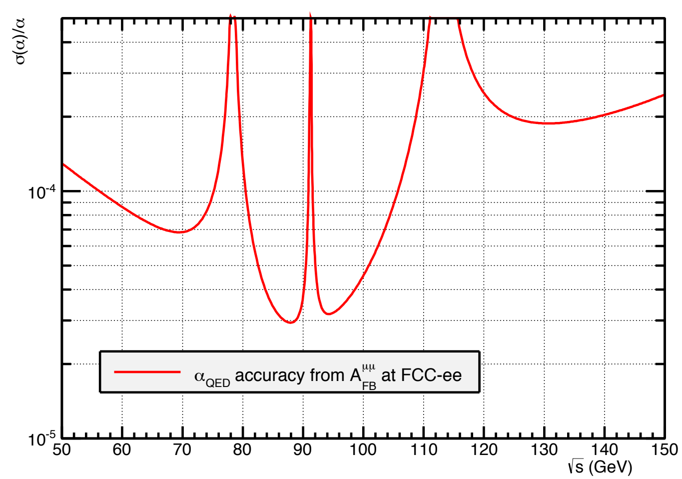

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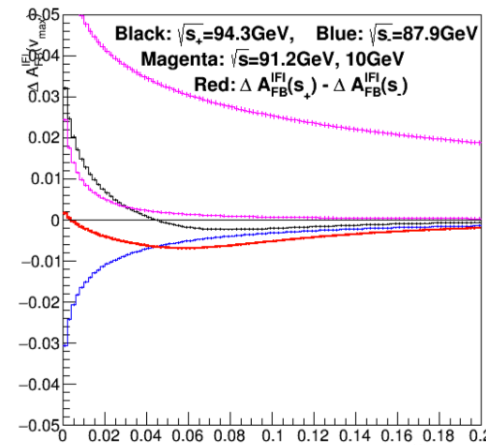

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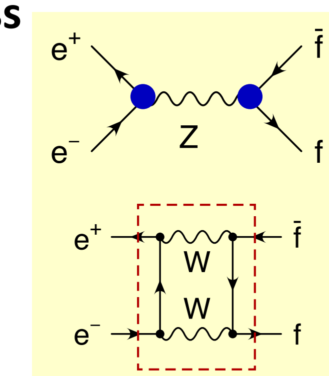
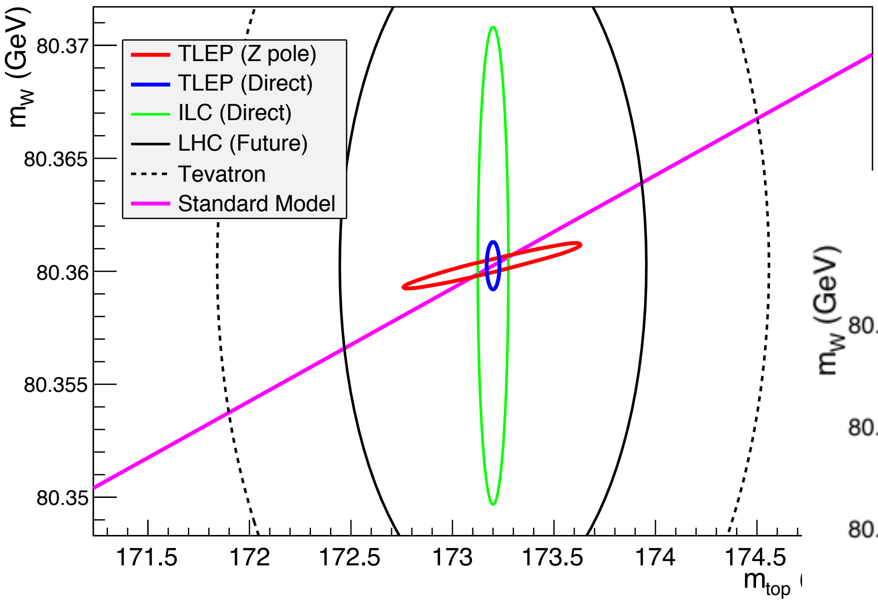
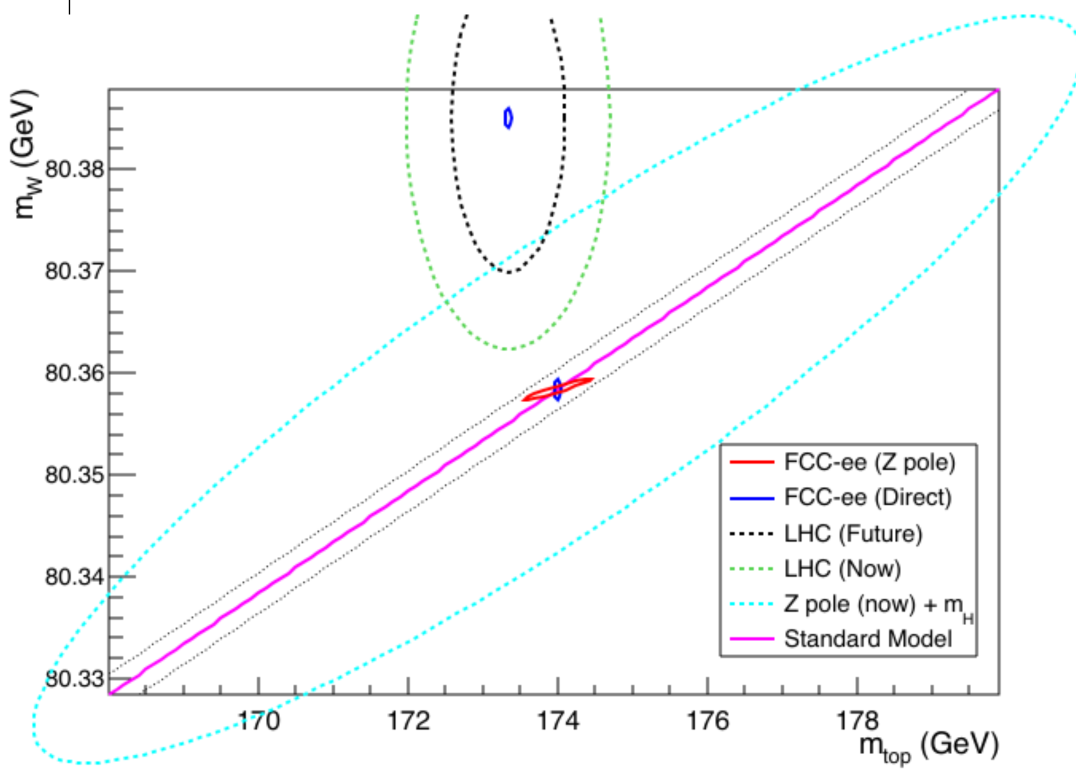


Z pole : effects on EW fit





Z pole detector requirements

The performance of a modern, general-purpose, e+e− detector are adequate for precision physics at the Z pole with FCCee/CEPC

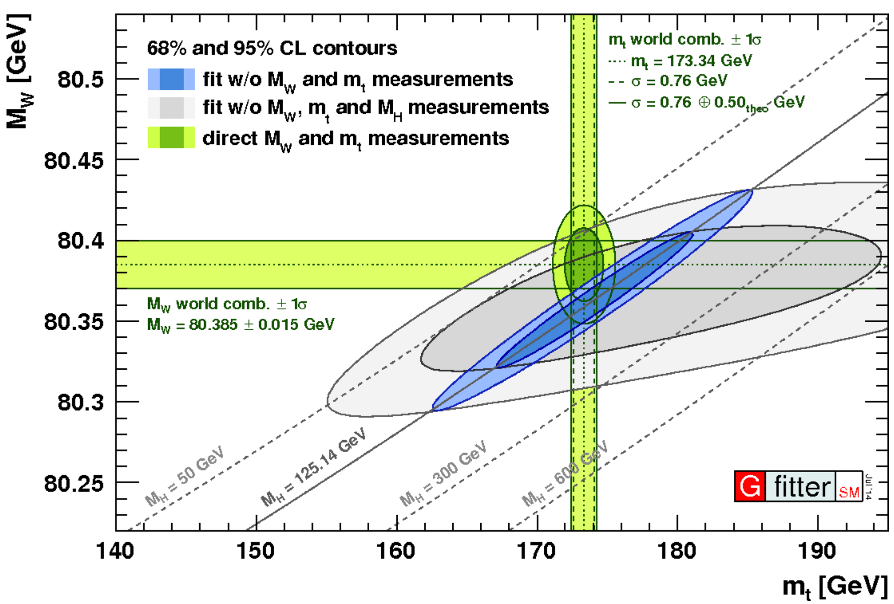
acceptance effects, related to the knowledge of large-**detector boundaries** and of **tracking efficiency** should be given special attention

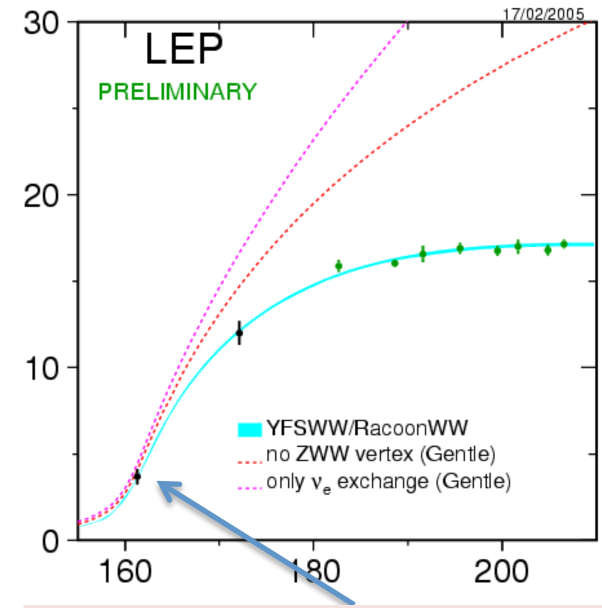
the mechanical stability of (luminosity) detectors should be improved, requiring an accuracy in detector position at the ≈ **2 μm level**

efficient detection of **photons** and excellent measurement of their **energy** is important, for tau polarization couplings and radiative events.

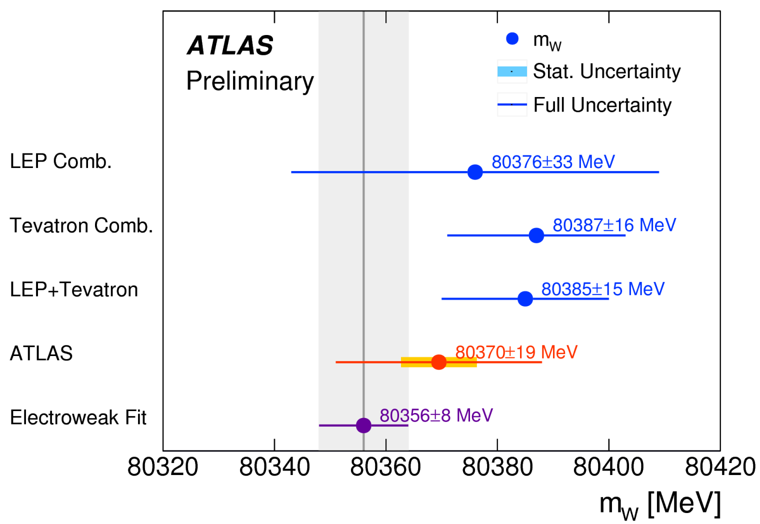
identification of **secondary vertexes** from B and C hadron decays is very relevant for HF quark couplings. A performance similar and better than modern LHC detectors should be the target (a factor 3 better than LEP detectors).

WW threshold



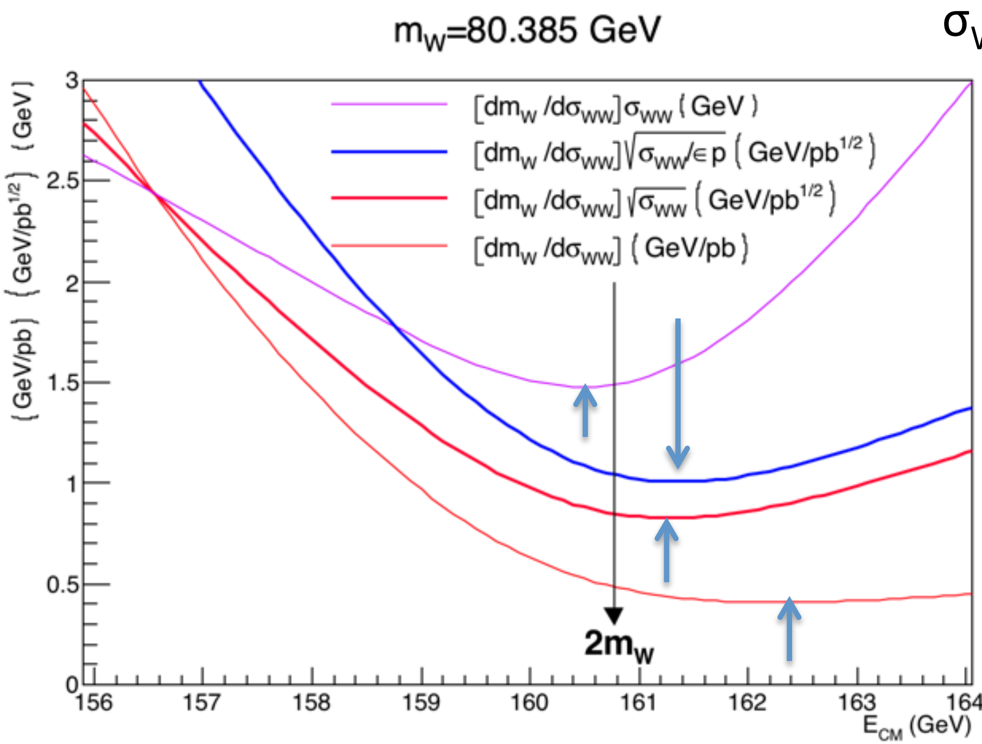


At LEP2 √s=161 GeV σ=4pb
ε=0.75, σ_B=300 fb
p=0.9 : εp≈0.68 (@161)
➔ m_W=80.40±0.21 GeV
with 11/pb @E_{CM}=161 GeV



$$\Delta m_W = \left(\frac{d\sigma}{dm_W} \right)^{-1} \Delta\sigma$$

m_W from σ_{WW}: sensitivity vs E_{CM}



Max stat sensitivity at $\sqrt{s}=2m_W$+600 MeV
= 161.4 GeV

σ_{WW} with YFSWW3 1.18

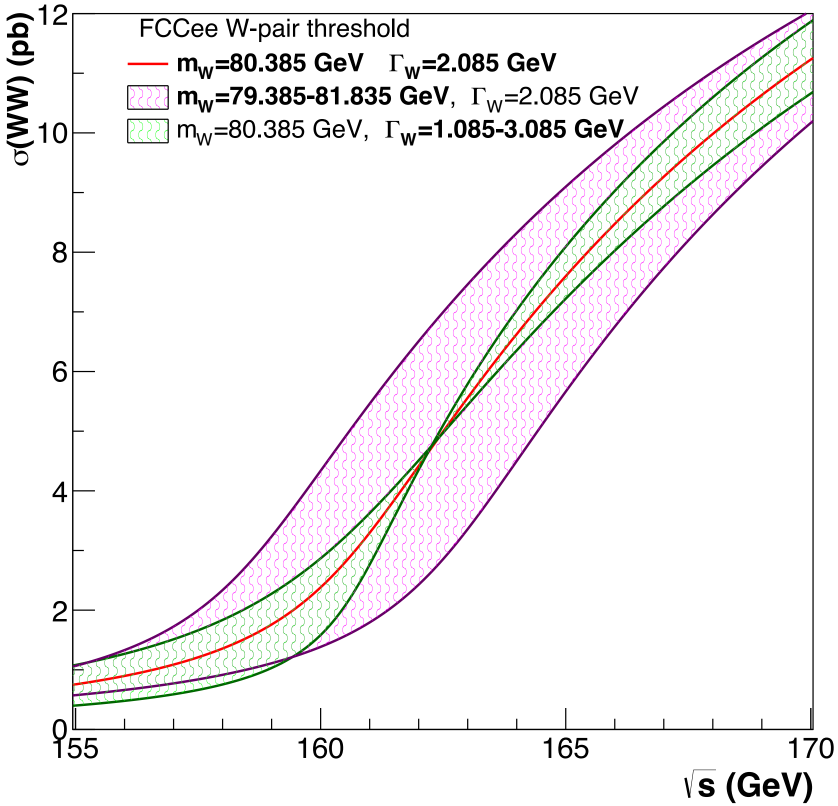
$\sqrt{\epsilon p}$ with fixed : ϵ=0.75 and σ_B=0.3pb

statistical precision
with L= 8/ab ➔ $\Delta m_W \approx 0.35$ MeV

need syst control on :

- ΔE(beam)<0.35 MeV (**4x10^{-6}**)
- $\Delta\epsilon/\epsilon$, $\Delta L/L$ < **2 10^{-4}**
- $\Delta\sigma_B$<0.7 fb (2 **10^{-3}**)

Γ_W from σ_{WW}



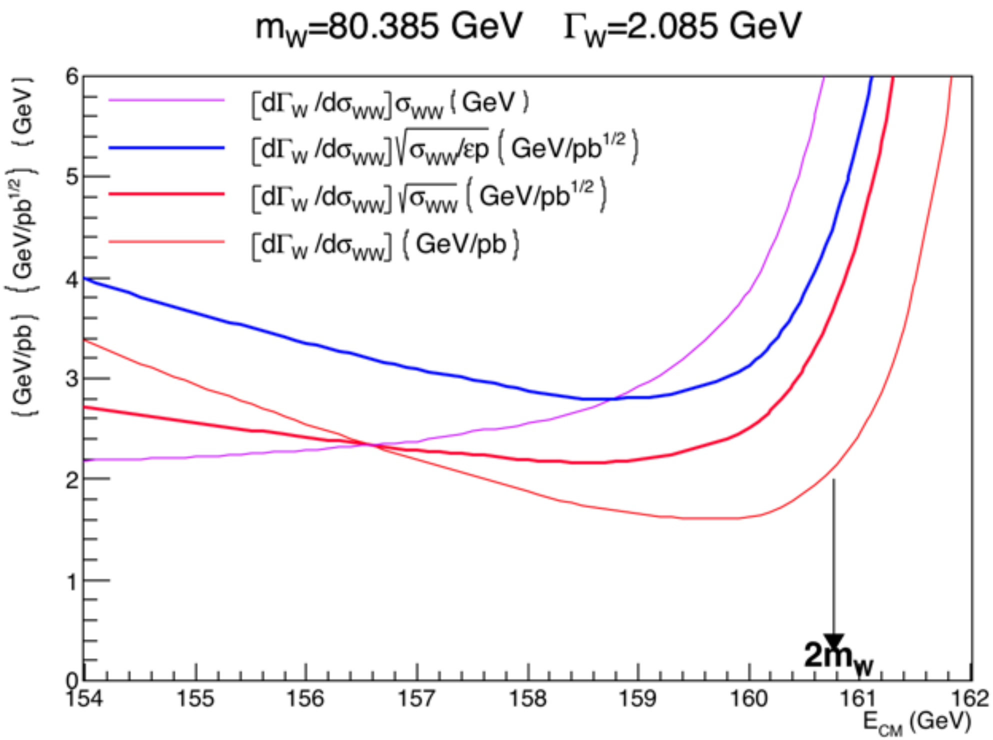
$d\sigma_{WW}/d\Gamma_W = 0$
at E_{CM}~**162.3 GeV**
~$2m_W$ + 1.5 GeV

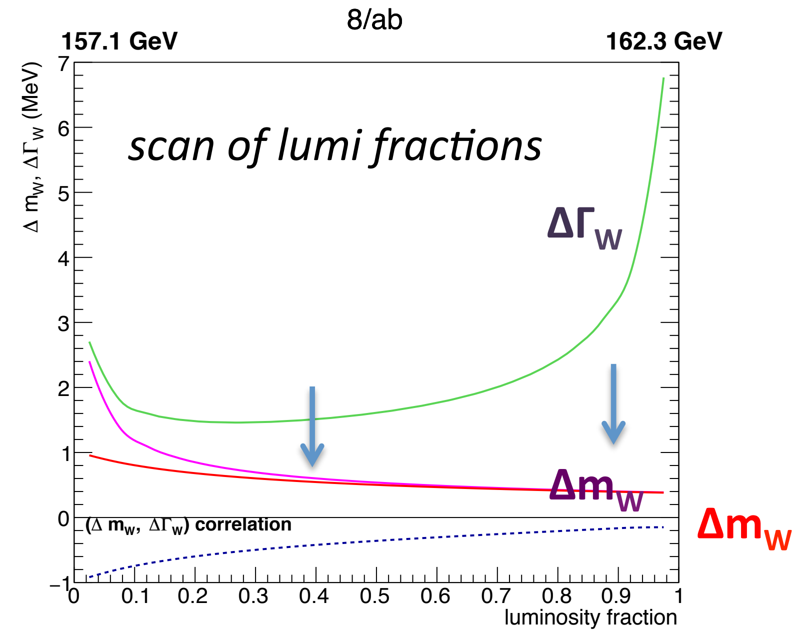
Measure σww in two energy points E_1, E_2 with a fraction f of lumi in E_1
➔ determine both m_W & Γ_W

Determine f, E_1, E_2 such to mimimise ($\Delta\Gamma_W$, Δm_W) with some target

Evaluate loss of Δm_W precision in the single parameter (m_W) determination
wrt scenario of running only at an optimal E_0=161 point

m_W & Γ_W from σ_{WW}





Δm_W , $\Delta\Gamma_W$: **from fitting both**

Δm_W : **from fitting only m_W**

with E_1=**157.1** GeV E_2=**162.3** GeV f=**0.4**

Δm_W=0.60 $\Delta\Gamma_W$=1.5 Δm_W=0.56 (MeV)

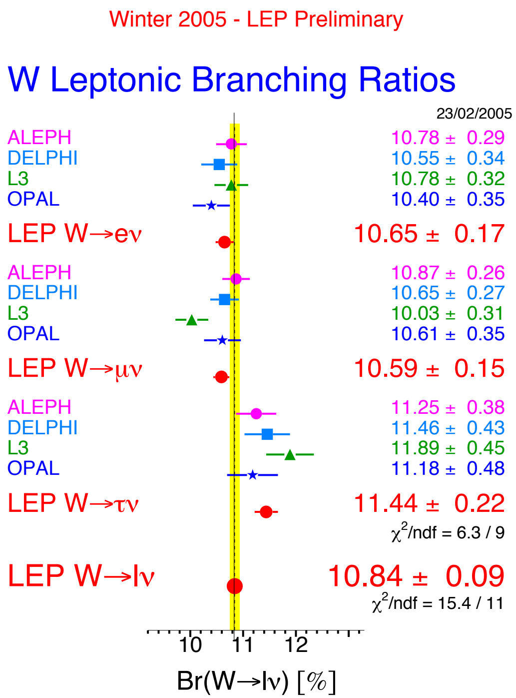
with resonant depolarization spin tune constraints

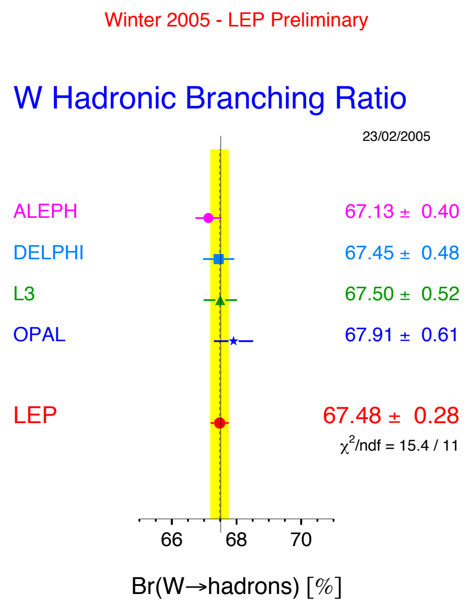
with E_1=**157.33** GeV E_2=**162.62** GeV f=**0.4**

Δm_W=0.65 $\Delta\Gamma_W$=1.6 Δm_W=0.60 (MeV)

$\rightarrow \Delta\alpha_S \approx (3\ \pi/2)\Delta\Gamma/\Gamma \approx\ 0.003$

W decay BR





8/ab@160GeV + 5/ab@240GeV

➔ 30M+ 80M W-pairs

➔ ΔBR(qq) (stat) =[1] 10^{-4} (rel)

➔ $\Delta\alpha_S \approx (9\ \pi/2)\Delta BR \approx 2\ 10^{-4}$

➔ ΔBR(e/μ/τν)(stat)=[4]10^{-4} (rel)

q/ l universality at 0.6%

➔ *FCCee @ 10^{-4} level*

Lept universality test at 2% level

tau BR ~2.7 σ larger than e/mu

➔ *FCCee @ 4 10^{-4} level*

will need excellent control of **lepton id**
i.e. cross contaminations in signal channels
(τ➔e,μ in the e,μ channels and v.v.)

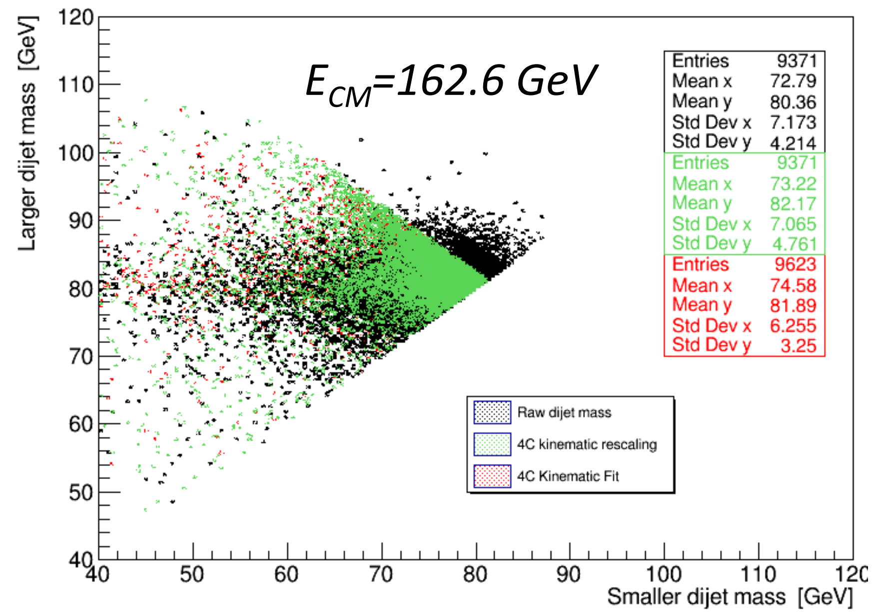
Flavor tagging would also allow to measure coupling to c & b-quarks (Vcs, Vcb,..)

Direct m_W reconstruction

(Marina Béguin)

Studies in the **four-jet channel**

PYTHIA + CLD simulation
Jet clustering with Durham algorithm
events constrained to form four jets
di-jet pairing : closest to the nominal m_W



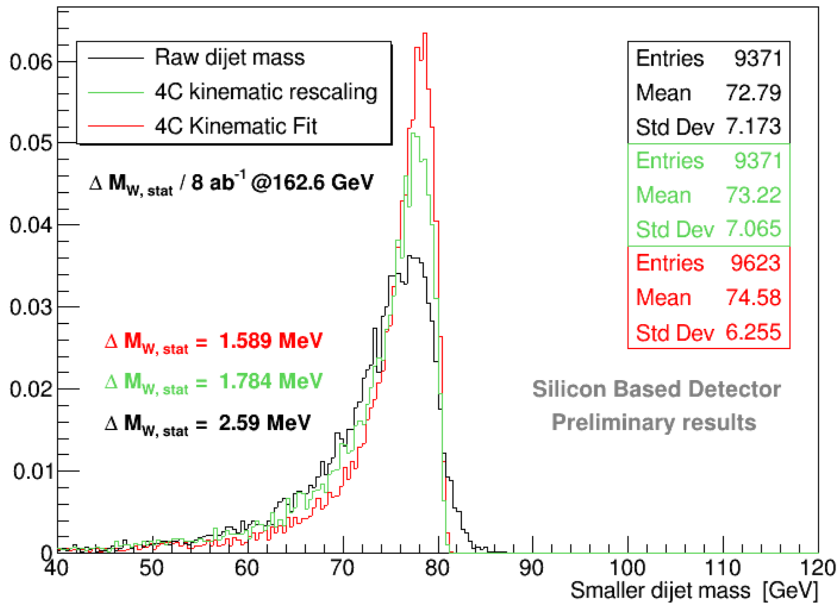
Three W mass estimators

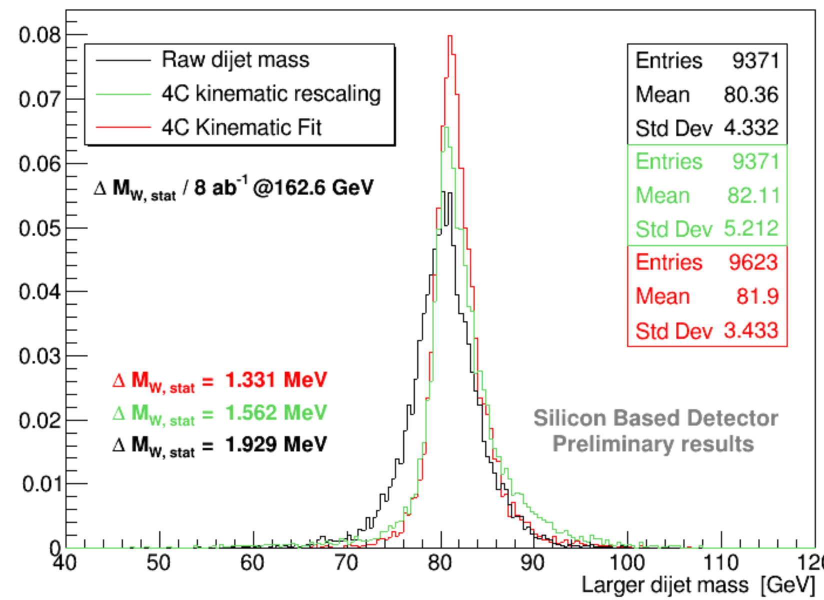
- **Raw** dijet mass
- 4C kinematic jets momenta **Rescaling**
- Kinematic **Fit** : minimising jets χ2

The expected statistical uncertainty on the W mass peak value (Δm_W,stat) is estimated with a **binned max likelihood fit** on the reconstructed m_W distributions, **using templates** with different nominal W mass values. The final expected uncertainty is the result of the combination of the measurements of the two reconstructed masses.

Direct m_W reconstruction

at the W-pair threshold



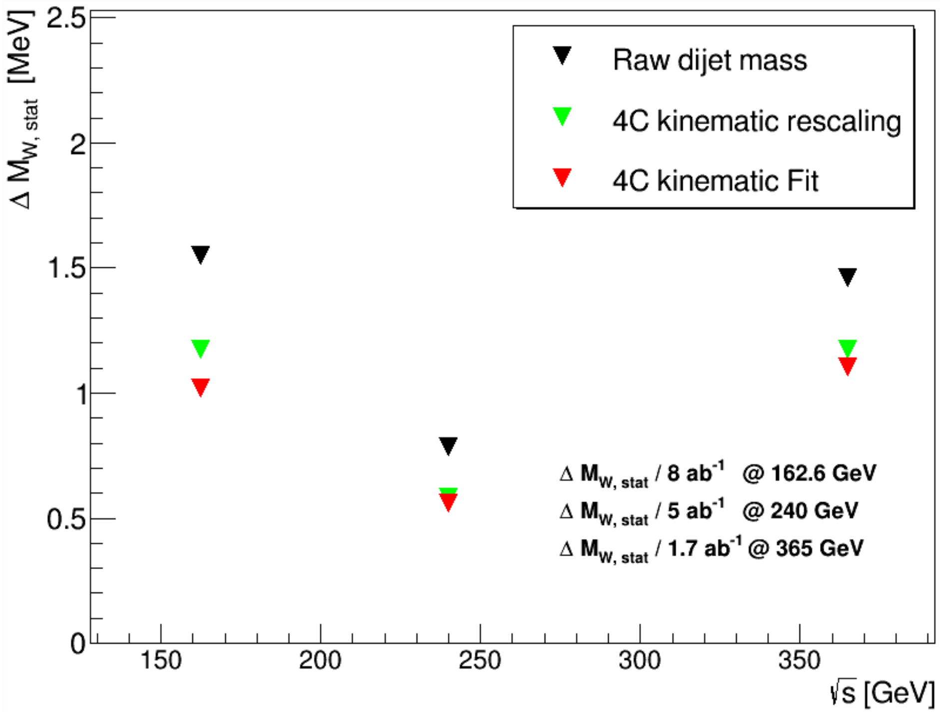


Smaller dijet mass tends to be off-shell
Larger dijet mass is on-shell

combined **statistical** uncertainties
ΔM_W (4C fit) = 1.02 MeV
ΔM_W (4C rescaling) = 1.18 MeV
ΔM_W (raw mass) = 1.55 MeV

Direct m_W reconstruction

ΔM_W (stat) summary with data at different E_{CM}



Optional possibility of using **cone** constraints on jets: the mass resolution is degraded ~20% because of the particle information loss.

This loss is expected to be compensated by a decrease of the FSI systematic uncertainty.

Coming soon:
- 5C kinematic fit with equality of the two dijet masses
- Study of the semi-leptonic WW decay channel

Direct m_W: systematics ?

5/ab@240GeV
➔ Δm_W (stat)= 0.5 MeV

$$M_Z^2 = s\frac{\beta_1 \sin\theta_1 + \beta_2 \sin\theta_2 - \beta_1\beta_2|\sin(\theta_1+\theta_2)|}{\beta_1 \sin\theta_1 + \beta_2 \sin\theta_2 + \beta_1\beta_2|\sin(\theta_1+\theta_2)|}$$

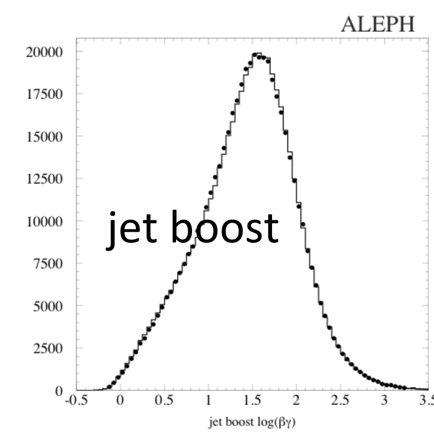
Is ΔE_{beam}~1MeV at E_{CM}=240-365 GeV possible ?
With radiative Z-returns (Zγ) events ? Maybe !

θ, β: jet polar angles and velocities in the CM frame

Table 9: Summary of the systematic errors on m_W and Γ_W in the standard analysis averaged ove 183-209 GeV for all semileptonic channels. The column labelled $\ell\nu q\bar{q}$ lists the uncertainties in m_W use in combining the semileptonic channels.

	Δm_W (MeV/c^2)				$\Delta\Gamma_W$ (MeV)			
Source	$e\nu q\bar{q}$	$\mu\nu q\bar{q}$	$\tau\nu q\bar{q}$	$\ell\nu q\bar{q}$	$e\nu q\bar{q}$	$\mu\nu q\bar{q}$	$\tau\nu q\bar{q}$	$\ell\nu q\bar{q}$
e+μ momentum	3	8	-	4	5	4	-	4
e+μ momentum resoln	7	4	-	4	65	55	-	50
Jet energy scale/linearity	5	5	9	6	4	4	16	6
Jet energy resoln	4	2	8	4	20	18	36	22
Jet angle	5	5	4	5	2	2	3	2
Jet angle resoln	3	2	3	3	6	7	8	7
Jet boost	17	17	20	17	3	3	3	3
Fragmentation	10	10	15	11	22	23	37	25
Radiative corrections	3	2	3	3	3	2	2	2
LEP energy	9	9	10	9	7	7	10	8
Calibration ($e\nu q\bar{q}$ only)	10	-	-	4	20	-	-	9
Ref MC Statistics	3	3	5	2	7	7	10	5
Bkgnd contamination	3	1	6	2	5	4	19	7

lepton and jet uncertainties from (Z) calibration data

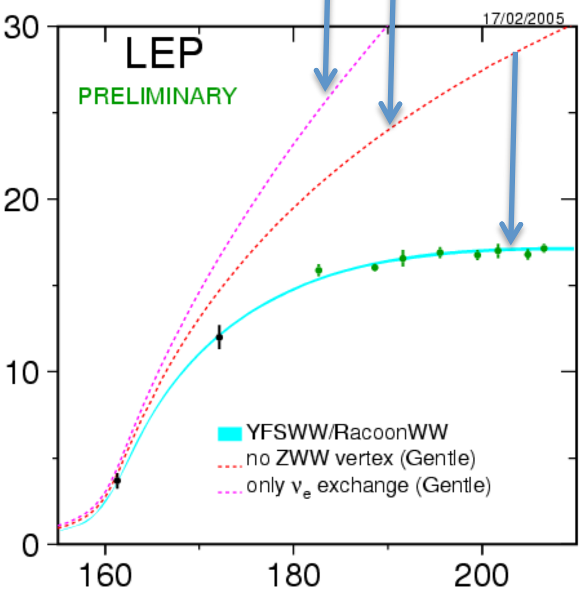


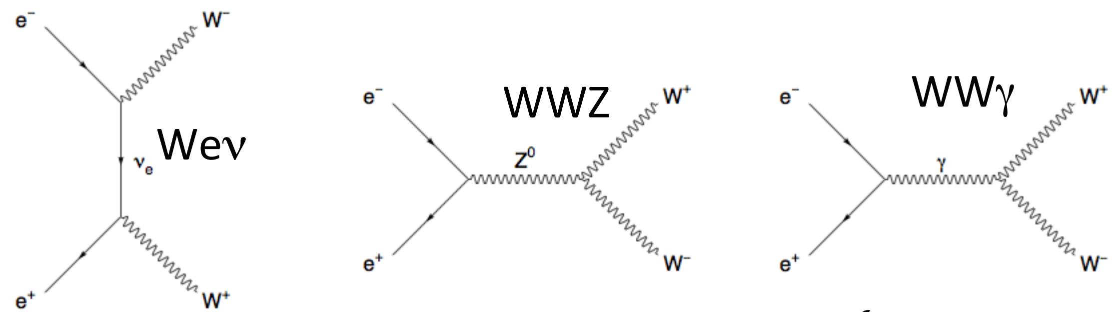
Detector PF capabilities

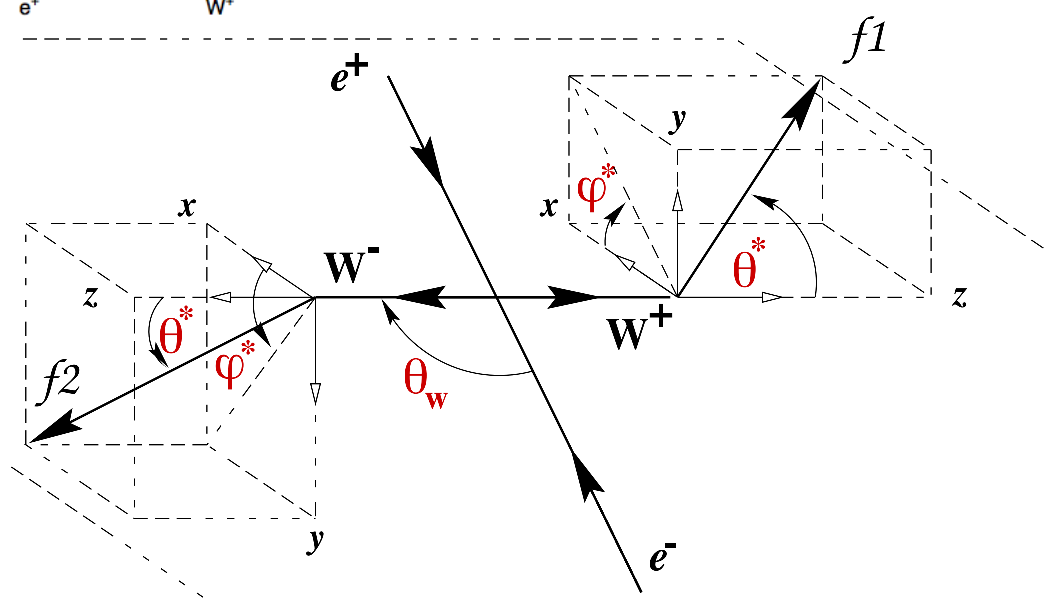
Triple gauge couplings

SU(2)⊗U(1) Gauge Cancellations

(Jiayin Gu)

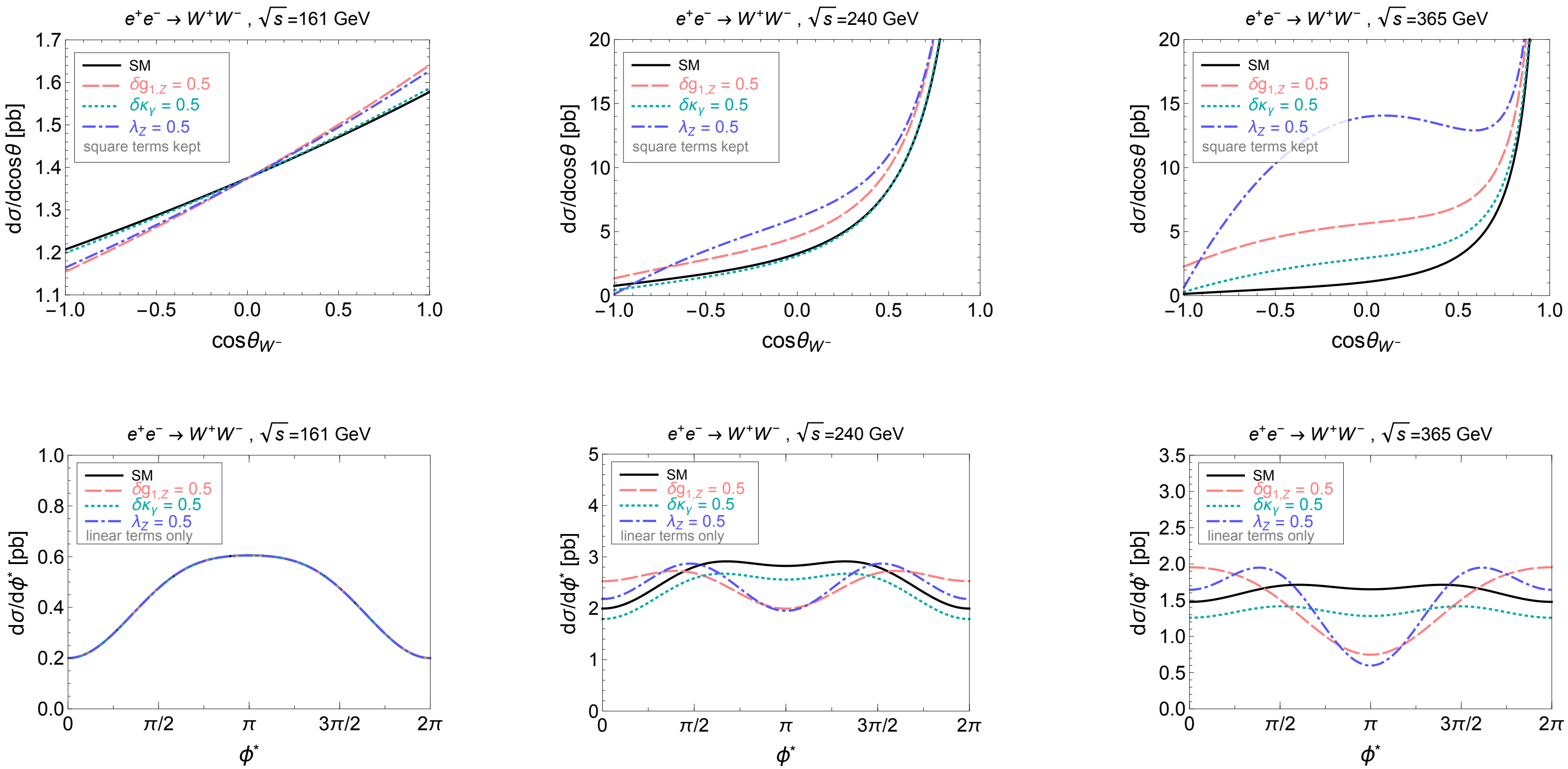






anomalies affect:
the **total rates** σ,
the **production angles** θ_W
the **decay angles** θ* ϕ*

Triple gauge couplings

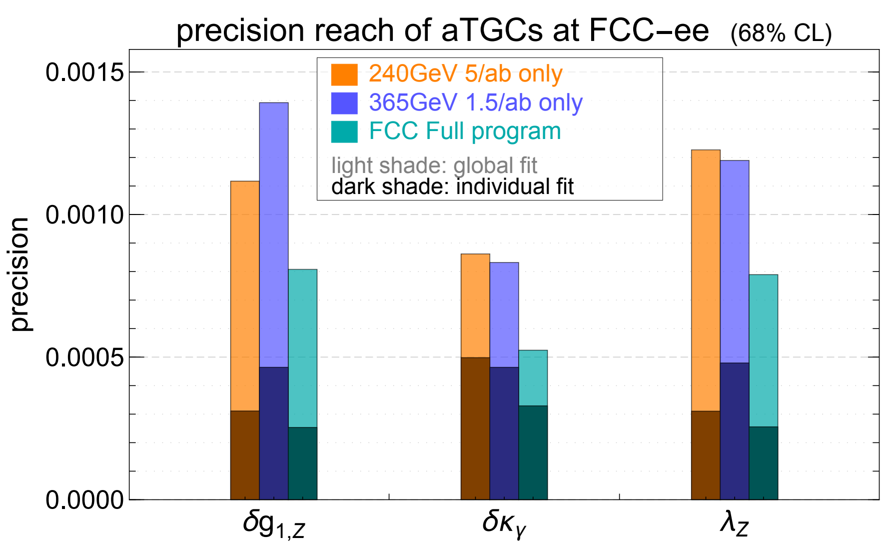


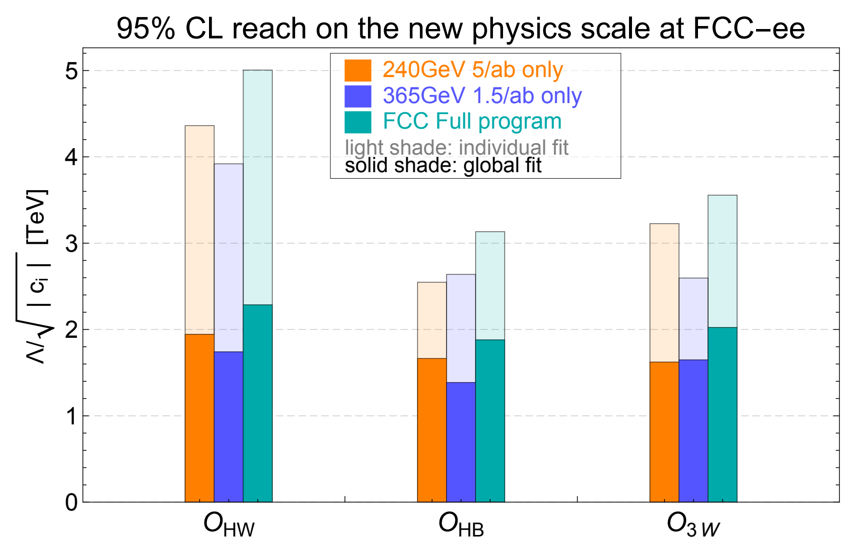
A large benchmark value (0.5) is shown to make the effects of the aTGCs visible. Since the precision reach of the aTGCs are at $O(10^{-3})$ or better, a linear approximation works very well for this analysis.

Triple gauge couplings

A binned chi-square fit is performed to estimate the precision reach of the three aTGCs at the FCCee.

Only the semileptonic channel, with one W decaying to e or μ is used.
The chi-square is summed over all bins of the five angles, considering only statistical uncertainties of signal events. The ambiguities in the reconstructions of the hadronic W decay angles (which are "folded") are taken into account.





LEP2 precision : 2-4 10^{-2}

current LHC limits $\Lambda/\sqrt{c}$<100-400 GeV

WW acceptance

how do we control acceptance at the 10^{-4} level (0.01%) ?
➔ aim for the highest possible acceptance and efficiency WP

- lepton **tracking** reco efficiency (was controlled at the 10^{-3} level at LEP2)
- lepton **identification** performances
  - @LEP2 10^{-3} level: (T&P with Z): effects on total $\Delta\sigma$ mitigated down to the 2-3 10^{-4} level thanks to $\tau \rightarrow e,u$ channel migrations recoveries
  - would need lepton-id at 10^{-4} level for max BR precision
- jet reconstruction and **energy calibration**
  - @LEP2 1-2% level ➔ 0.1% on $\Delta\varepsilon$:
  - FCCee would need calibration at 0.1% level (10x better) with control data ; best possible jet energy resolution helps
- **missing momentum** scale/resolution : similar to jet energy for qqlv
- lepton **isolation**
  - @LEP2 control at the $\Delta\varepsilon$~2 10^{-3} level: need to do 10x better
- jet **modeling** (signal & bkg)
  - was important syst on σ_{WW}@LEP2 (at the 2 10^{-3} level)

impact of theoretical uncertainties will hopefully not be limiting but work is needed to reach the target 0.2 10^{-3} precision level

WW background control

2-fermion : $\tau\tau$, qq
4-fermion : $\gamma\gamma \rightarrow \tau\tau$,ll$\nu\nu$, Zee, We$\nu$

some 4f bkg is identical to the signal final state → CC03-4f interferences

decay	efficiency	purity	bkg [LEP1996]
lνlν	70-80%	80-90%	**50fb** ($\tau\tau$,$\gamma\gamma \rightarrow \tau\tau$,Z$\gamma^*\rightarrow\nu\nu$ll)
eνqq	85%	~90%	**30fb** (qq, Zee, Zγ^*) **-10fb** (Weν)
$\mu\nu$qq	90%	~95%	**10fb** (Zγ^*,qq)
$\tau\nu$qq	50%	80-85%	**50fb** (qq, Zγ^*)
qqqq	90%	~90%	**~200fb** (qq (qqqq,qqgg))

measure directly the **backgrounds** with very different S/B levels **at different E_{CM} points**

concern is mostly on the four-jet background

measure forward electrons ($\theta \geq 0.1$ rad) for Zee Weν : determine forward pole dσ/dθ and WW interference effects

acceptance down to **θ=0.1 [cosθ= 0.995]** would also cover forward jets

limiting **correlated** systs can cancel out taking data at more E_{CM} points where

$$\left(\frac{d\sigma}{d\Gamma_W}\right)^{-1} \quad \left(\frac{d\sigma}{dm_W}\right)^{-1} \quad \left(\frac{d\sigma}{dm_W}\right)^{-1}\sigma \; \left(\frac{d\sigma}{d\Gamma_W}\right)^{-1}\sigma$$

differential factors are equal

Conclusions

- CEPC/FCCee will be a total game-changer for EW W/Z physics measurements
- No "a priori" walls on the road map to achieve the FCC goals for EW precision measurements but a lot of work, firstly on the theoretical calculations side
- At the Z, off peak data will play an important role (more than at LEP times)
  - can deliver $a_{QED}(m_Z^2)$ to 3×10^{-5}
- The WW threshold lineshape is a great opportunity to measure both m_W and Γ_W:
  - optimal points to take data are $\sqrt{s}=2m_w+1.5$ GeV (**Γ-insensitive**) and $\sqrt{s}=2mw-2-3$ GeV (-Γ**off shell**)
- Huge potential for other W physics measurements including higher energy data :
  - direct m_W , W BRs, TGCs
- Work from experimentalist needed to evaluate with care limiting systematics, study ways to overcome them, and reflect on the detector design consequences: opportunities to contribute