Energy calibration for W physics

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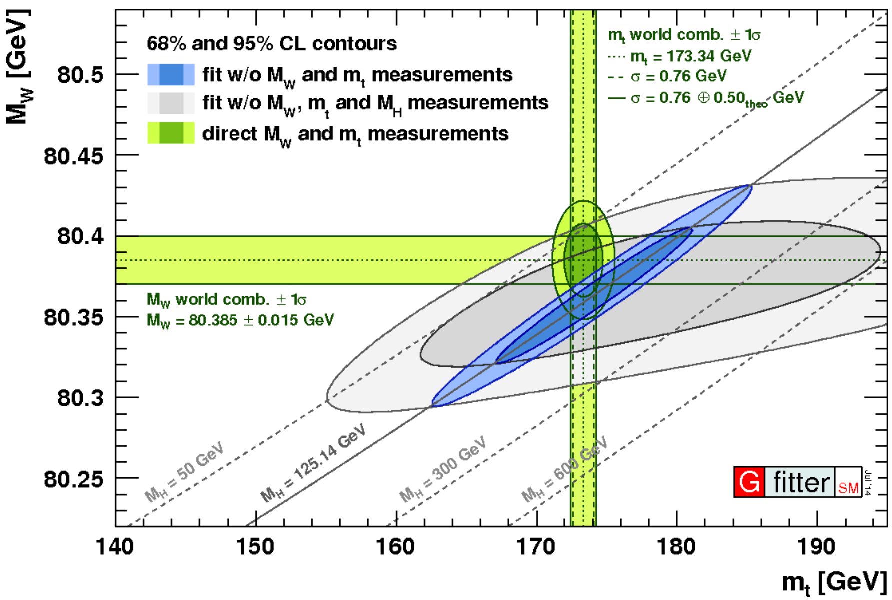
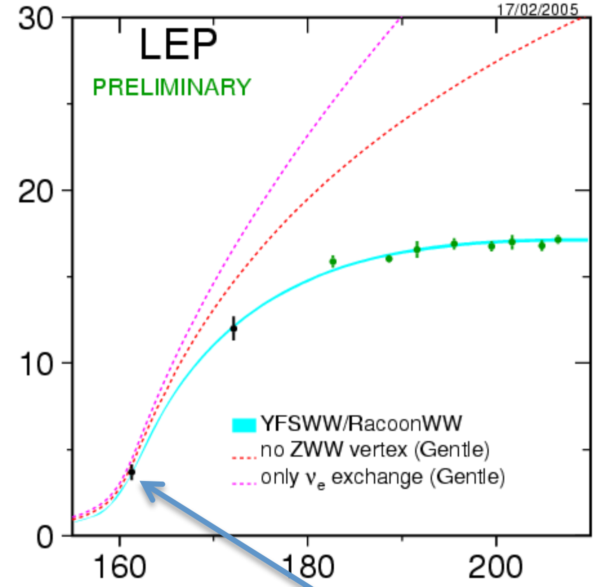
FCC-ee polarization workshop

October 18th 2017

WW threshold





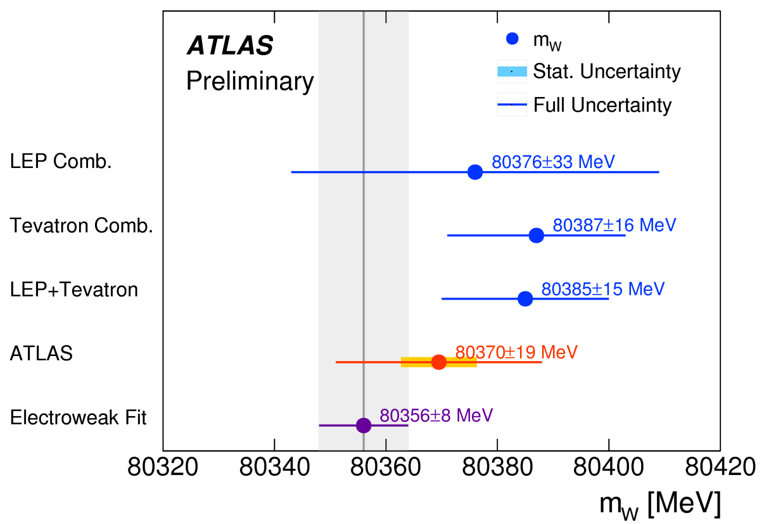
At LEP2 √s=161 GeV σ=4pb

ε=0.75, σ_B=300 fb

p=0.9 : εp≈0.68 (@161)

➔ m_W=80.40±0.21 GeV

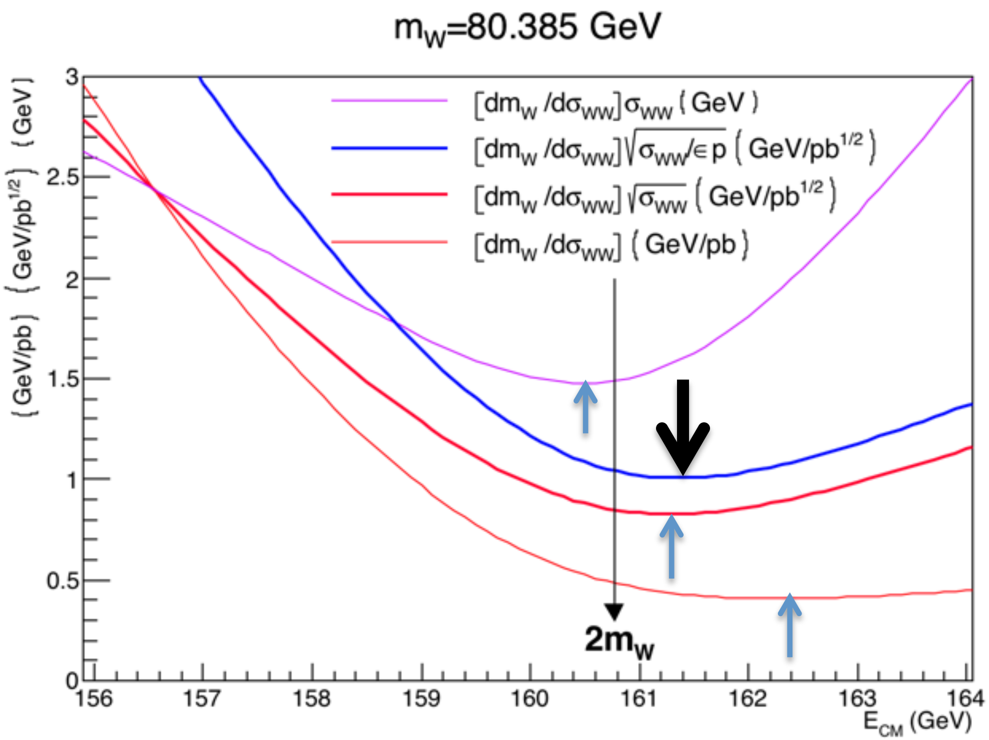
with 11/pb @E_{CM}=161 GeV



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

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

σ_{WW} with YFSWW3 1.18



Max stat sensitivity at √s~$2m_W$+600 MeV

√εp with fixed : ε=0.75 and σ_B=0.3pb

statistical precision
with L = 11/pb ➔ Δmw≈350MeV
with L= 8/ab ➔ Δmw≈0.40 MeV

need syst control on :
- Δε/ε, ΔL/L < **10^{-4}**
- $\Delta\sigma_B$<0.7 fb (2 **10^{-3}**)

and
ΔE(beam)<0.40 MeV (5×10^{-6})

WW threshold ΔM_W

$$\sigma = \left(\frac{N}{L} - \sigma_B\right)\frac{1}{\varepsilon}$$

$$\Delta m_W(stat) = \left(\frac{d\sigma}{dm_W}\right)^{-1}\frac{\sqrt{\sigma}}{\sqrt{L}}\frac{1}{\sqrt{\varepsilon p}}$$

$$\Delta\sigma_{WW} = \frac{\Delta\sigma_B}{\varepsilon}$$

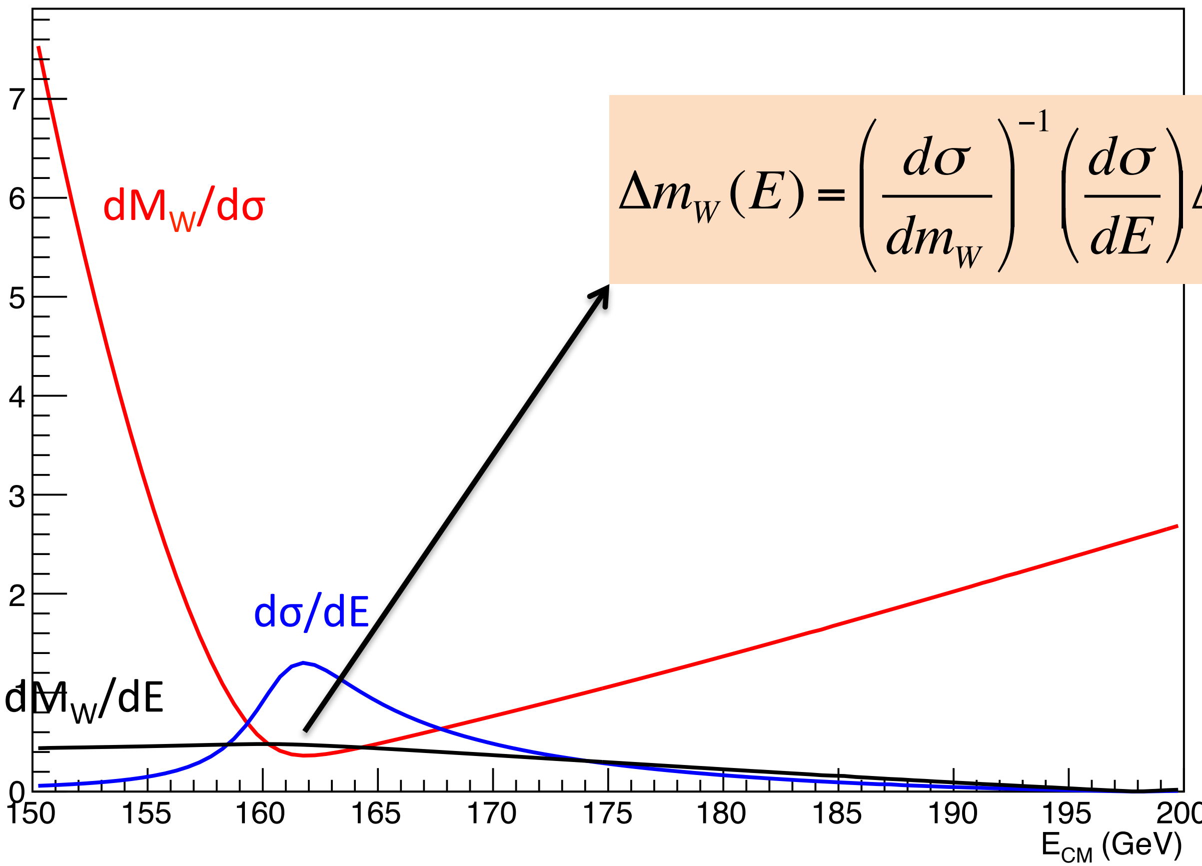
$$\Delta m_W(B) = \left(\frac{d\sigma}{dm_W}\right)^{-1}\frac{\Delta\sigma_B}{\varepsilon}$$

$$\Delta\sigma_{WW} = \sigma\left(\frac{\Delta\varepsilon}{\varepsilon}\oplus\frac{\Delta L}{L}\right)$$

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

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

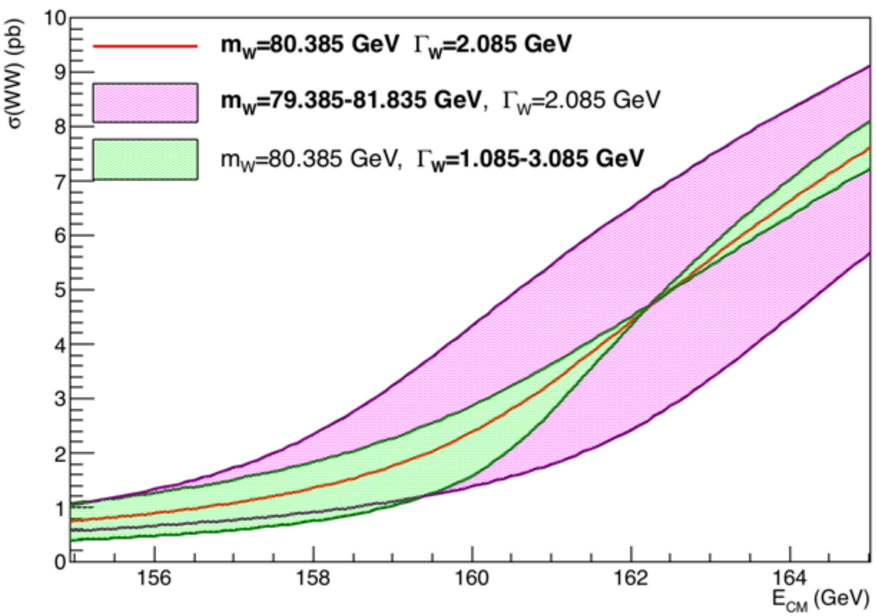
dM_W/dE_{CM}

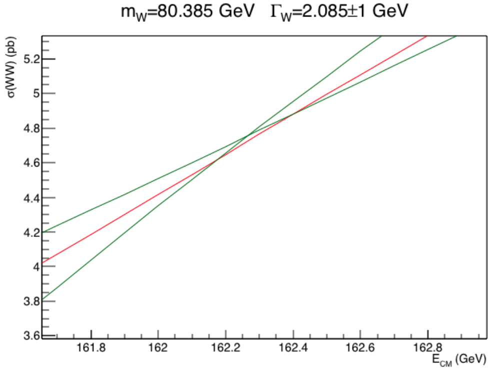


$$\Delta m_W(E) = \left(\frac{d\sigma}{dm_W}\right)^{-1}\left(\frac{d\sigma}{dE}\right)\Delta E \leq \frac{1}{2}\Delta E$$

$$\Delta m_W(E_b) = \leq \Delta E_b$$

Γ_W from σ_{WW}





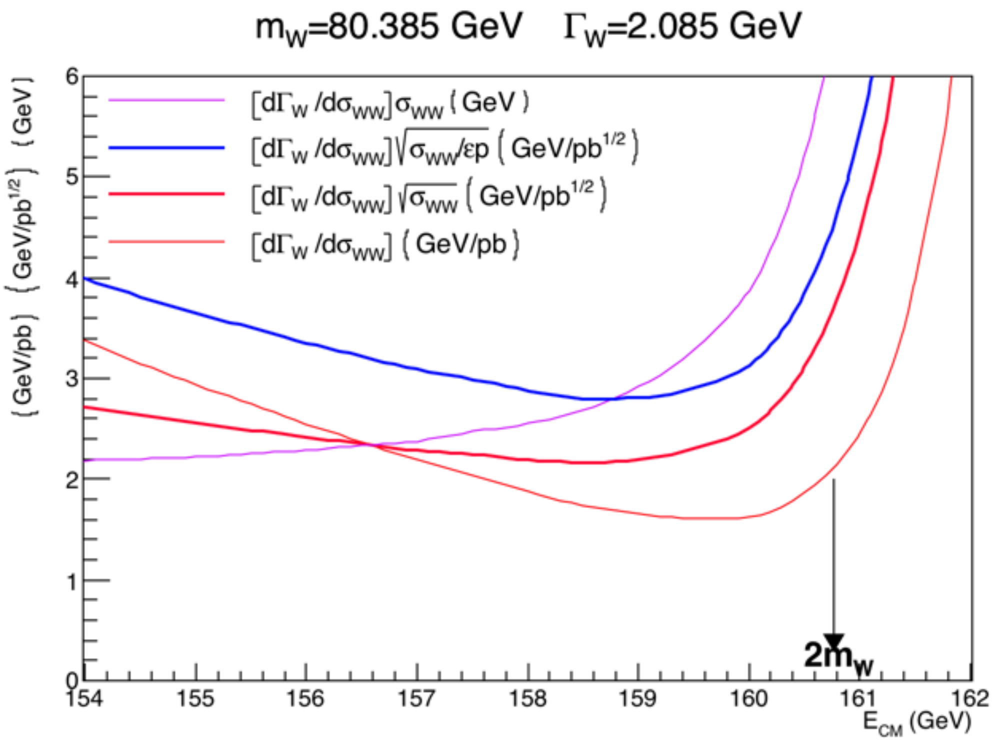
Measure σww in two energy points E_1, E_2 with a fraction f of lumi in E_1
➔ determine both m_W & Γ_W

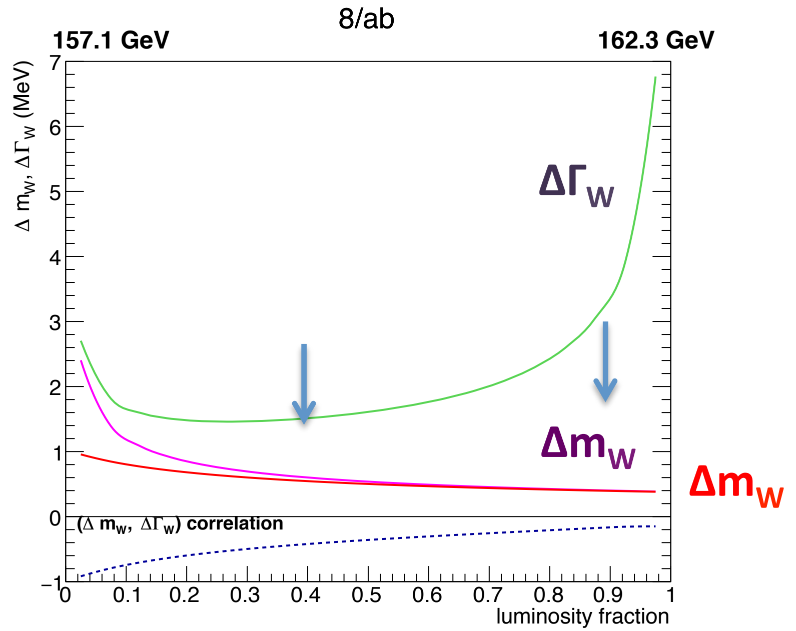
Determine f, E_1, E_2 such to mimimise ($\Delta\Gamma_W$, Δm_W) with some target

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

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

m_W & Γ_W from σ_{WW}





scan of lumi fraction at higher energy

Δm_W , $\Delta\Gamma_W$: error on W mass and width from fitting both

Δm_W : error on W mass from fitting only m_W

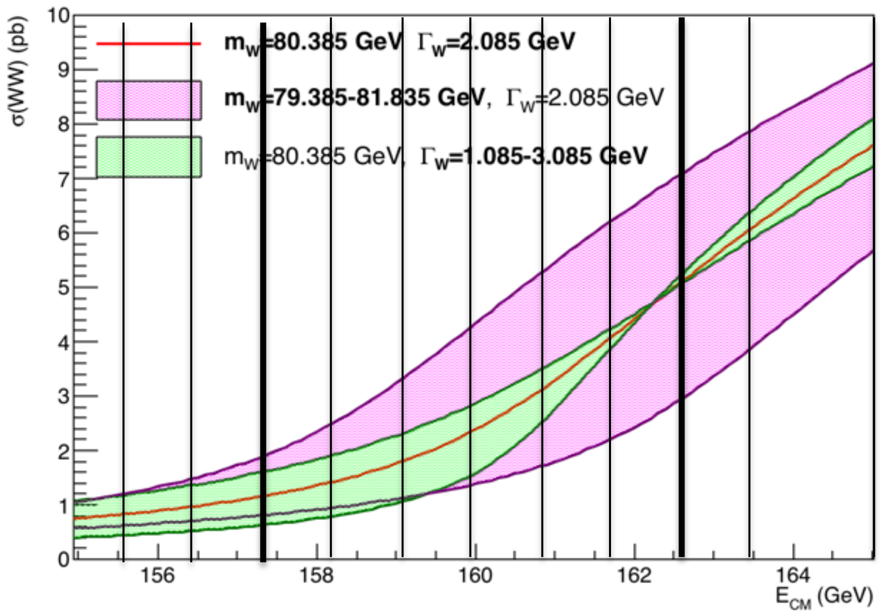
min Δm_W+$\Delta\Gamma_W$

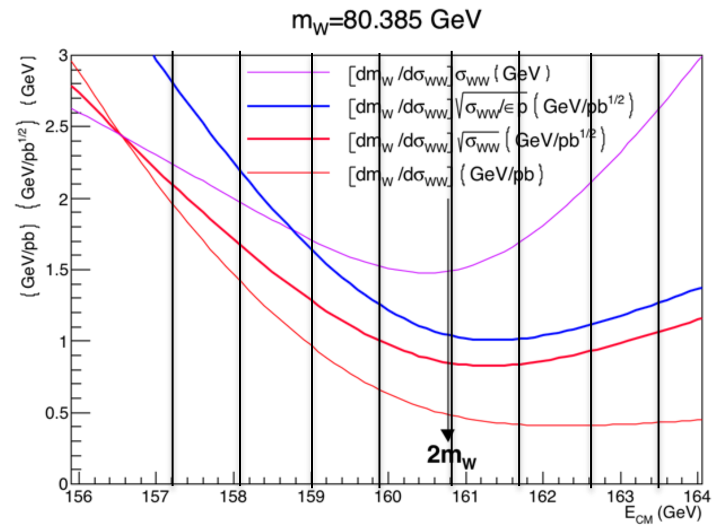
with E_1=157.1 GeV **E_2=162.3** GeV f=**0.4**
Δm_W=0.62 $\Delta\Gamma_W$=1.5 Δm_W=0.56 (MeV)

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

with half-integer spin tunes

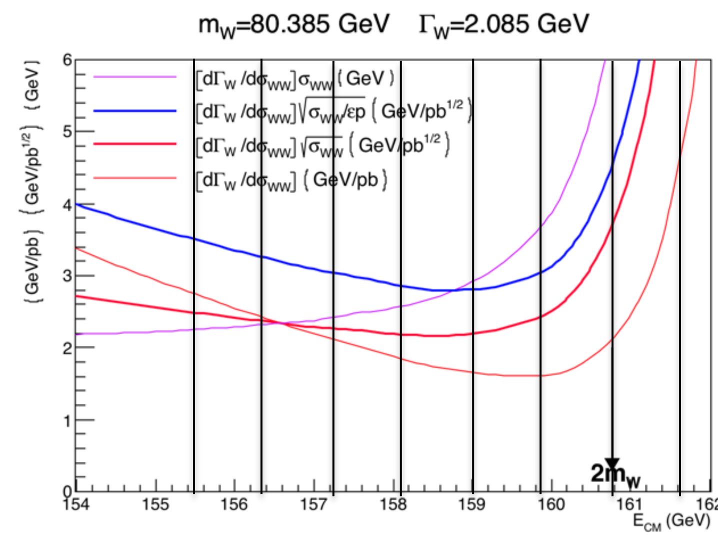
limiting data taking points to
$E_{CM} = (2n+1)*0.4406486$ GeV





min $\Delta m_W + \Delta\Gamma_W$

with E_1=157.3 GeV E_2=162.6 GeV f=0.4
Δm_W=0.65 $\Delta\Gamma_W$=1.6 Δm_W=0.60 (MeV)



~10% loss of stat precision

acc & bkg control

2-fermion : ττ, qq
4-fermion : γγ→ττ,llνν, Zee, Weν

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

decay	efficiency	purity	bkg [LEP1996]
lνlν	70-80%	80-90%	**50fb** (ττ,γγ→ττ,Zγ*→ννll)
eνqq	85%	~90%	**30fb** (qq, Zee, Zγ*) **-10fb** (Weν)
μνqq	90%	~95%	**10fb** (Zγ*,qq)
τνqq	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 (θ≥0.1 rad) for Zee Weν : determine forward pole dσ/d**θ** and WW interference effects

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

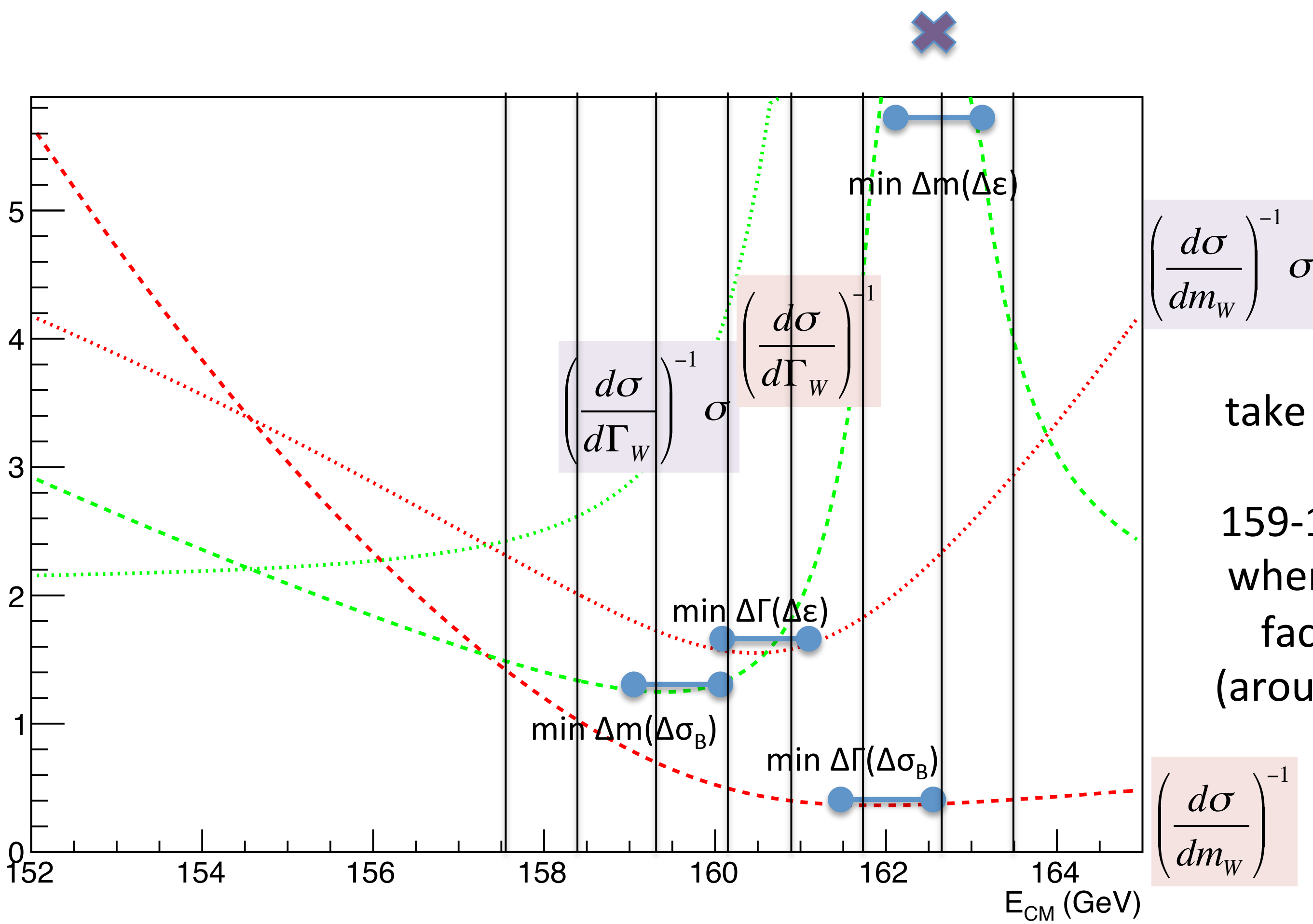
limiting **correlated** systs can cancel out taking data at more E_{CM} points where

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

differential factors are equal

m_W & Γ_W from σ_{WW}

optimal E points with limiting **correlated** systs

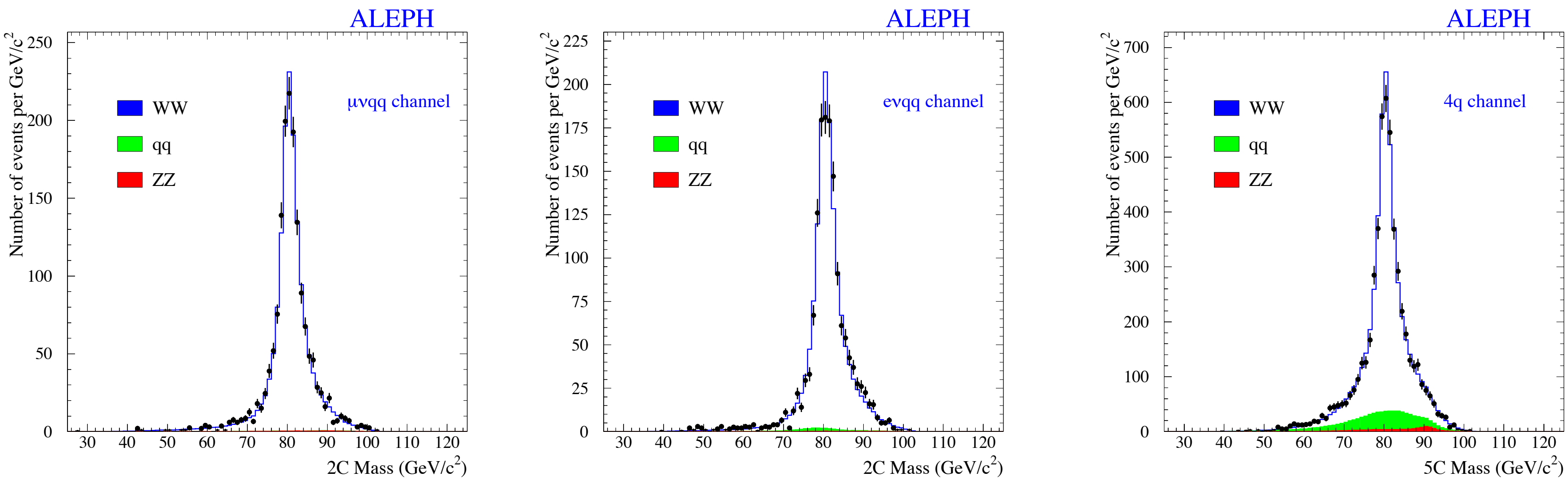


take data at different E_{CM} points 159-160-161-162-163 where the derivative factors are equal (around their minima)

reco mass of the W boson

full m_W reco with kinematic fit. main ingredients :
E_{CM} – jet/lepton angles – (jet boost)

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



ALEPH Eur.Phys.J.C47:309 (2006) : 683 /pb ~10k WW events

ignoring low energy particles in the qqqq channel

m_W = 80440±**43**(**stat.**)±24(syst.)±9(FSI)±9(LEP) MeV

Γ_W = 2140 ±**90**(**stat.**) ±45(syst.) ±46(FSI) ± 7(LEP) MeV

reco mass of the W boson

8/ab@160GeV + 5/ab@240GeV
➔ 30M+ 80M W-pairs
➔ Δm_W (stat)= 0.5 MeV

➔ Δm_W (syst) ≤ 1 MeV ?

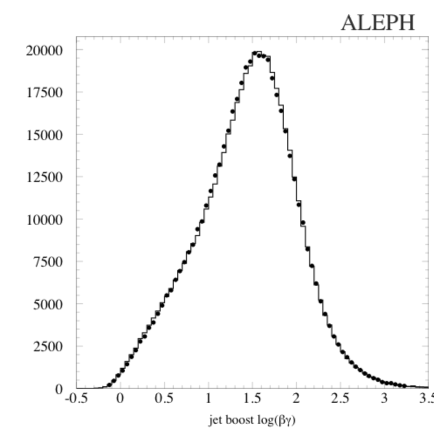
WW events produced near threshold also carry (reduced) kin information on m_W

Is ΔE_{beam}<1MeV at E_{CM}=240 GeV possible ?

With Zγ events ?
ΔE_{beam}~15MeV(stat) @LEP

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.

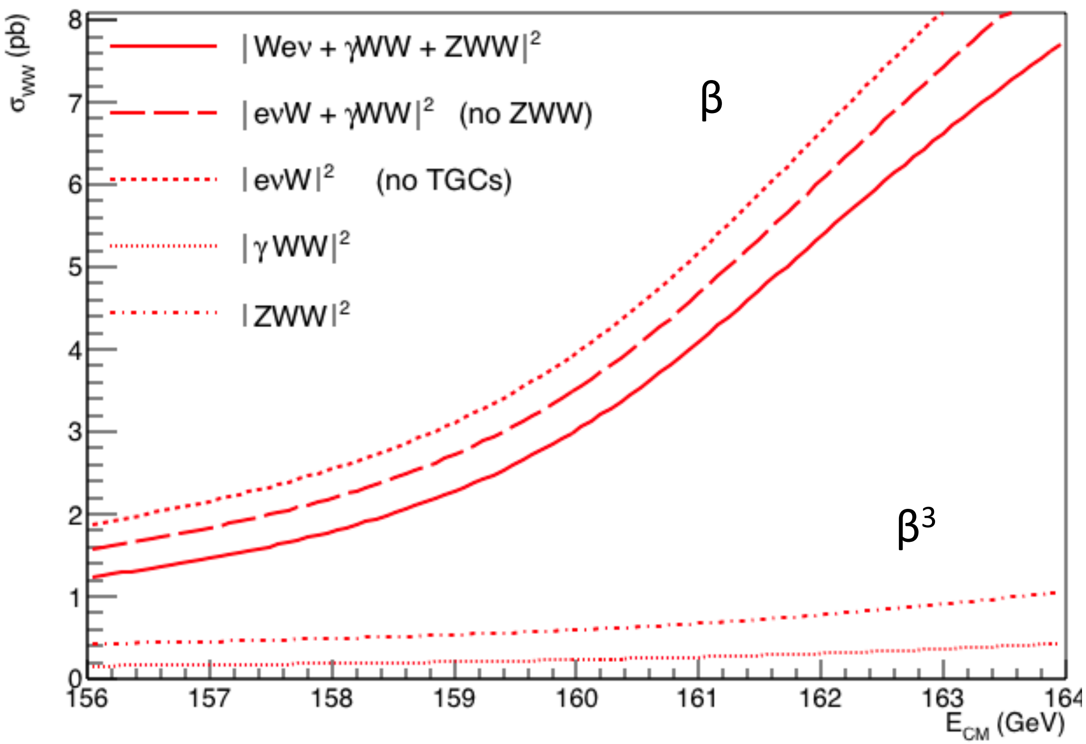
	Δm_W (MeV/c^2)				$\Delta\Gamma_W$ (MeV)			
Source	$e\nu q\bar{q}$	$\mu\nu q\bar{q}$	$\tau\nu q\bar{q}$	$\ell\nu q\bar{q}$	$e\nu q\bar{q}$	$\mu\nu q\bar{q}$	$\tau\nu q\bar{q}$	$\ell\nu q\bar{q}$
e+μ momentum	3	8	-	4	5	4	-	4
e+μ momentum resoln	7	4	-	4	65	55	-	50
Jet energy scale/linearity	5	5	9	6	4	4	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

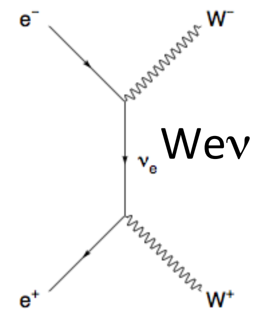


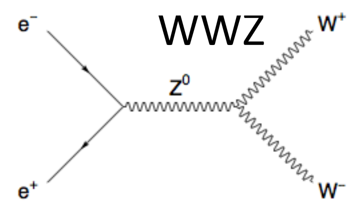
lepton and jet uncertainties from (Z) calibration data

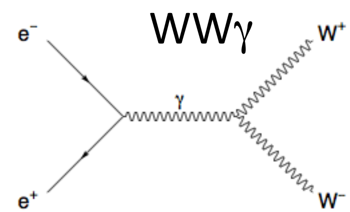
TGCs (also at threshold)

SU(2)⊗U(1) Gauge Cancellations









without TGCs

σ_{WW} +40% @157GeV +25%@162GeV

while $\Delta\sigma/\sigma \approx$ **0.5 10^{-3}**

LEP2 limts : κ, λ < 2-6 10^{-2}

Conclusions

- The WW threshold σ lineshape is a great opportunity to measure both m_W and Γ_W at the (sub)-MeV level with FCCee
  - 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**)
  - limiting data taking ECM points to half-integer spin tunes will bring a very limited degradation to the optimal stat sensitivity.

- Direct m_W reconstruction would also necessitate E_{beam} at the MeV level
  - making use of radiative Z-returns events can provide precise E_{beam} constraints (leading to an effective m_W/m_Z determination)
  - we can probably make use also of W-pairs collected near threshold to perform a direct reconstruction m_W measurement

Work in progress by **Marina Beguin**, stay tuned

- Many other W-physics topics (W BRs, TGCs …) should not have stringent E_{CM} requirements

m_W & Γ_W from σ_{WW}

Uncertainty propagation

$$\begin{cases} \Delta\sigma_1 = a_1\Delta m + b_1\Delta\Gamma \\ \Delta\sigma_2 = a_2\Delta m + b_2\Delta\Gamma \end{cases}$$

$$a_1 = \frac{d\sigma_1}{dm} \qquad b_1 = \frac{d\sigma_1}{d\Gamma}$$

$$a_2 = \frac{d\sigma_2}{dm} \qquad b_2 = \frac{d\sigma_2}{d\Gamma}$$

$$\Delta m = -\frac{b_2\Delta\sigma_1 - b_1\Delta\sigma_2}{a_2 b_1 - a_1 b_2}$$

$$\Delta\Gamma = \frac{a_2\Delta\sigma_1 - a_1\Delta\sigma_2}{a_2 b_1 - a_1 b_2}$$

Δm,$\Delta\Gamma$ linear correlation with uncorrelated $\Delta\sigma_1$,$\Delta\sigma_2$

$$r = -\frac{1}{\Delta m\Delta\Gamma}\frac{a_2 b_2\Delta\sigma_1^2 + a_1 b_1\Delta\sigma_2^2}{\left(a_2 b_1 - a_1 b_2\right)^2}$$