Effect of energy spread on the W mass and width determination

Paolo Azzurri – INFN Pisa
FCC-ee Energy Calibration and Polarization WG
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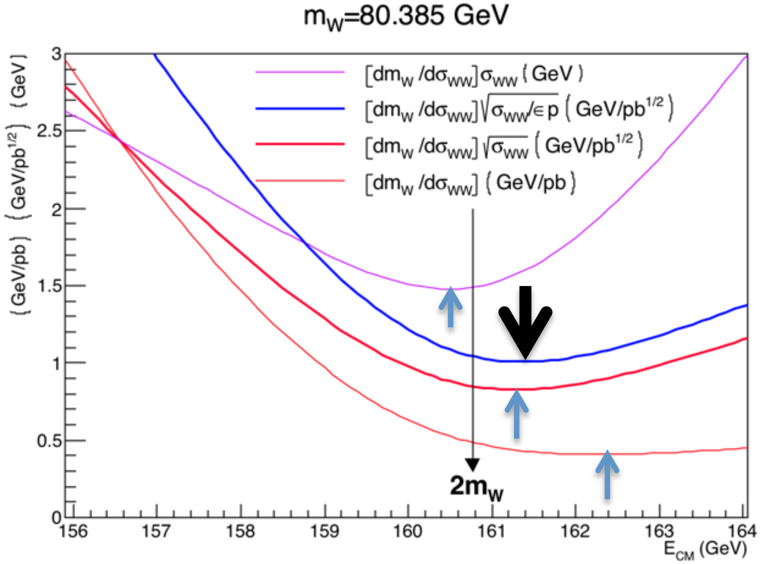
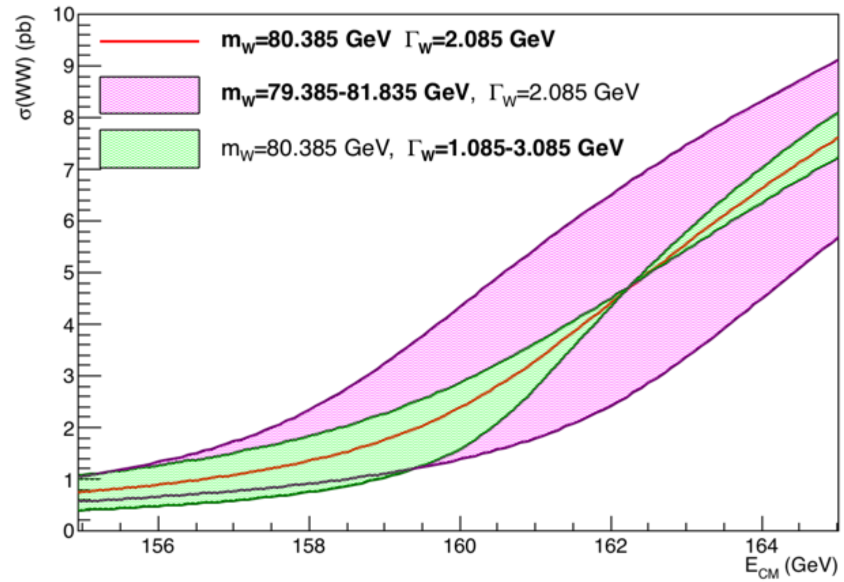
m_W and Γ_W from σ_{WW}

σ_{WW} with YFSWW3 1.18





For mW determination only

max stat sensitivity at √s~2m_W+600 MeV

statistical precision

with L= 8/ab ➔ Δmw≈0.40 MeV

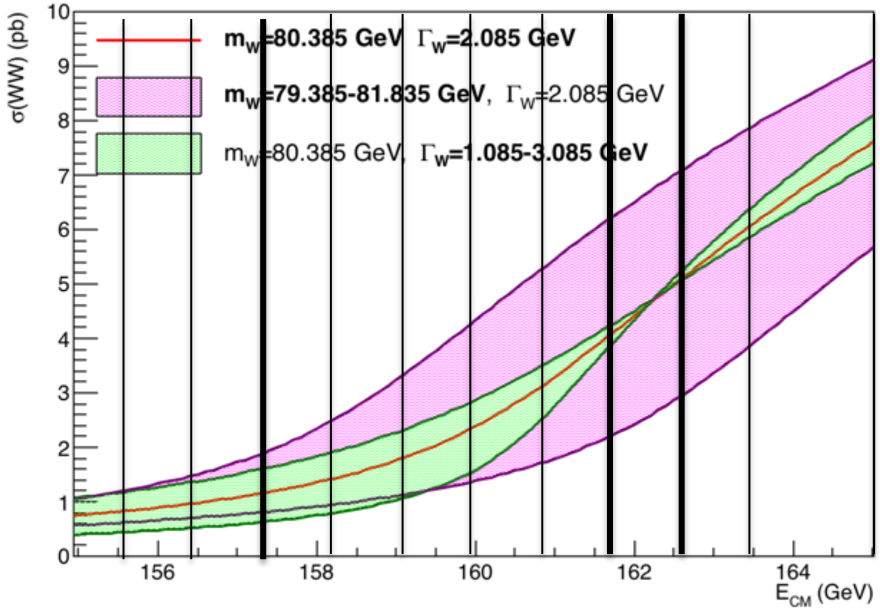
Measure σww in two energy points E_1, E_2 with a fraction f of lumi in E_1

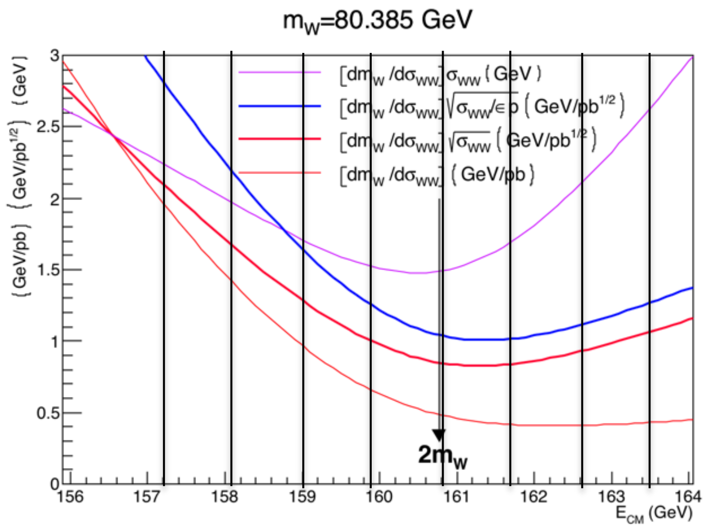
➔ determine both m_W & Γ_W

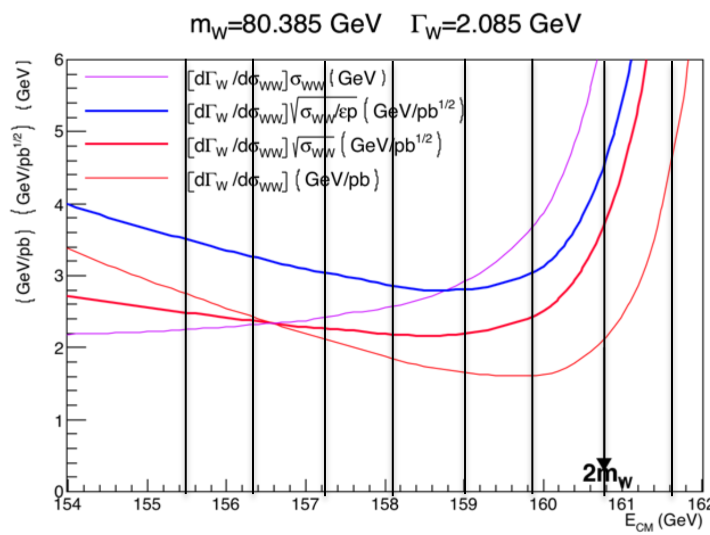
$d\sigma_{WW}/d\Gamma_W = 0$ at E_{CM}~**162.3 GeV** ~2m_W + 1.5 GeV

optimal energy points

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







min Δm_W with E_0=**161.7** GeV Δm_W=0.4 (MeV)

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=0.55 (MeV)

E spread effects on σ_{WW}

Gaussian Energy spread smearing

$$\sigma'_{WW}(E_0) = \int \sigma_{WW}(E)\, G(E - E_0)\, dE$$

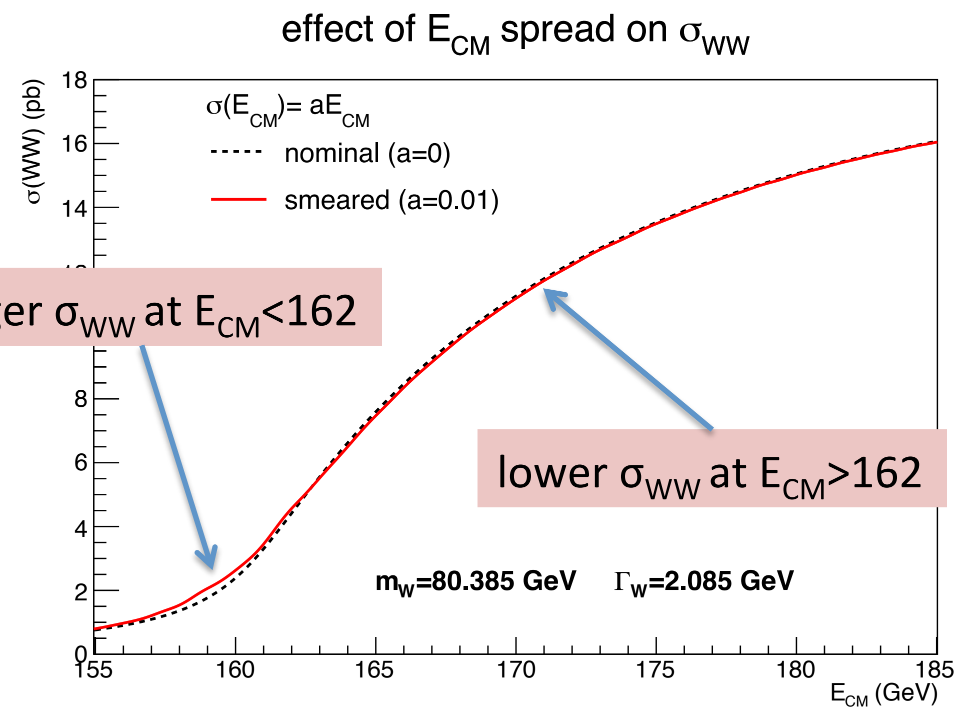
$$G(E) = \frac{1}{\sigma_E \sqrt{2\pi}} \exp\left(-\frac{E^2}{2\sigma_E^2}\right)$$

$$\sigma_E = aE$$

***a*=(0.47-1.10) 10^{-3}**

➔ σ_E=**75-180** MeV @E_{CM}=161 GeV

example with *a*=**10^{-2}**



larger σ_{WW} at E_{CM}<162

lower σ_{WW} at E_{CM}>162

crossing point near the $d\sigma_{WW}/\Gamma_W$=0 point

E spread effects on σ_{WW}

Gaussian Energy spread smearing : Taylor expansion

$$\sigma_{WW}(E) = \sigma_{WW}(E_0) + \frac{d\sigma_{WW}}{dE}(E-E_0) + \frac{1}{2!}\frac{d^2\sigma_{WW}}{dE^2}(E-E_0)^2 + \frac{1}{3!}\frac{d^3\sigma_{WW}}{dE^3}(E-E_0)^3 + \frac{1}{4!}\frac{d^4\sigma_{WW}}{dE^4}(E-E_0)^4 +$$

$$\sigma'_{WW}(E_0) = \int \sigma_{WW}(E)G(E-E_0)dE = \sigma_{WW}(E_0) + \frac{1}{2}\frac{d^2\sigma_{WW}}{dE^2}\sigma_E^2 + \frac{1}{8}\frac{d^4\sigma_{WW}}{dE^4}\sigma_E^4 +$$

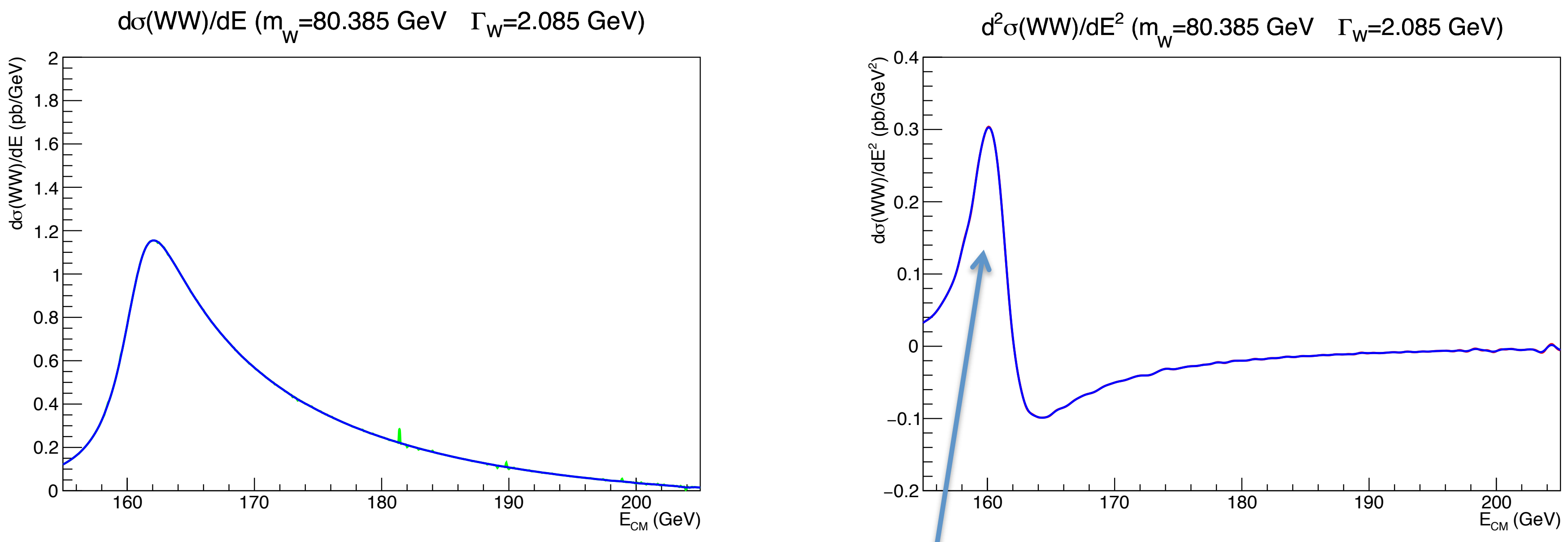
$$\int E^2 G(E)dE = \sigma_E^2$$

$$\int E^4 G(E)dE = 3\sigma_E^4$$

For E_{CM}=**161.7** GeV and a=10^{-3} spread
$d^2\sigma_{WW}/dE^2 \approx +0.07$ pb/GeV^2 ➔ $\Delta\sigma_{WW} \approx +0.9$ fb
$d^4\sigma_{WW}/dE^4 \approx +0.09$ pb/GeV^4 ➔ $\Delta\sigma_{WW} \approx +0.008$ fb (negligible)

effect on σ_{WW} is dominated by value of second derivative $d^2\sigma_{WW}/dE^2$

E spread effects on σ_{WW}



maximum effect at ECM=160.1 GeV

E spread effect on m_W & Γ_W

$\sigma(E_{CM})$=**(0.47-1.10) 10^{-3}** E_{CM}

Single point @E_{CM}=**161.7** GeV
➔ $\Delta\sigma_{WW}$ = +(0.2-1.1) fb
➔ **Δm_W = -(0.08-0.46) MeV**

Optimal m_W & Γ_W points @E_{CM}=**157.3 & 162.6** GeV
➔ $\Delta\sigma_{WW}$ = +(0.24-1.3) fb & = -(0.18-1.0) fb

➔ **Δm_W = -(0.09-0.48) MeV**
➔ **$\Delta\Gamma_W$ = +(0.6-3.3) MeV**

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 √s=2mw-2-3 GeV (-Γ**off shell**)
  - limiting data taking ECM points to half-integer spin tunes will bring a limited degradation to the optimal stat sensitivity.

- Beam energy spread effects at the level of $\Delta E_{CM}/E_{CM}$≈10-3 i.e. ΔE_{CM}≈160 MeV on the σ_{WW} lineshape are very small, yet they yield sizeable effects on the extracted m_W and Γ_W avalues, at the level of the expected statistical precision with L=8/ab of data.

- Maximum effects are at the level of Δm_W(stat) and 2x $\Delta\Gamma_W$ (stat) so that control on the beam energy RMS <50% is required to avoid additional syst contributions from this source

m_W & Γ_W from σ_{WW}

Uncertainty propagation

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

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

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

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

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

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

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