FCCee as a W factory

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FCC week Amsterdam

April 10th 2018

FCCe CDR

work in progress

- **Di-boson physics**
  - Measurement of the W mass and width at the WW threshold
  - Measurement of W partial widths
  - Direct determination of the W mass and width NEW!
  - Cross section measurements
  - Constraints on gauge self-couplings NEW!
  - Performance requirements

→ see poster by **Marina Béguin**

→ see poster by **Jiayin Gu**

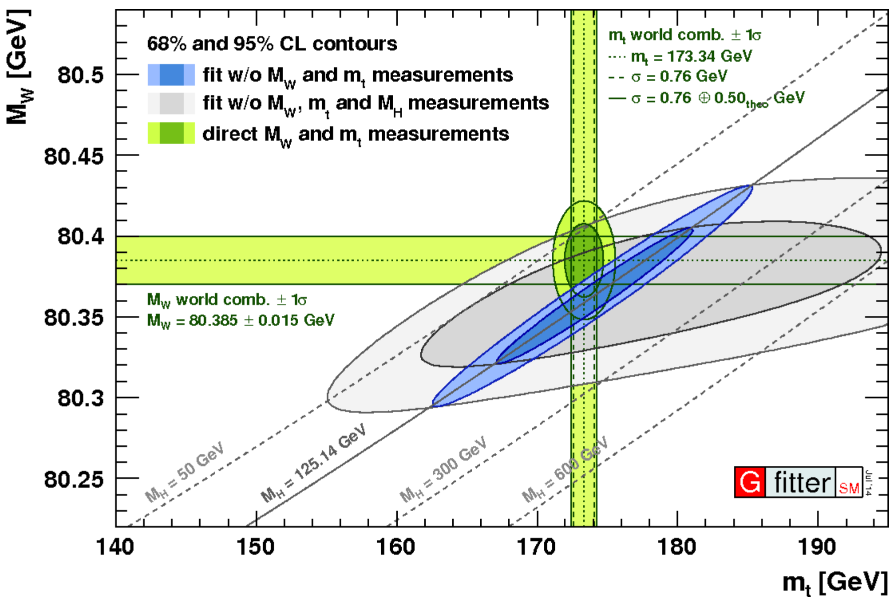
the FCCee OkuW factory

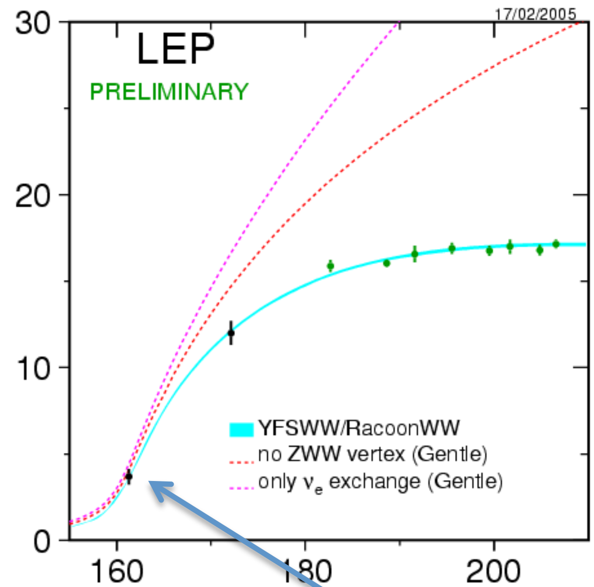
$\sqrt{s}$=160-162 GeV : σ_{WW}=3-5pb
L~4 $10^{35}/cm^2/s$: collect 8/ab in 1 year
30-40 10^6 WW decays

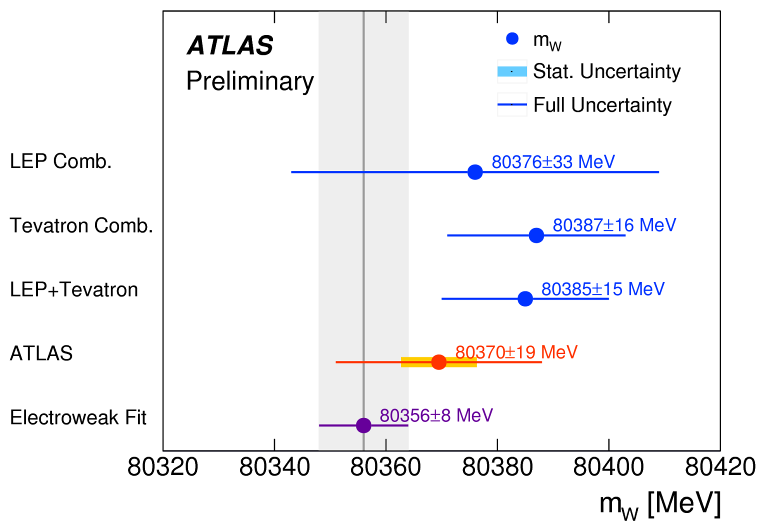
$\sqrt{s}$=240 GeV : σ_{WW}=16.7 pb
L~0.9 $10^{35}/cm^2/s$: collect 5/ab in 3 years
80 10^6 WW decays

$\sqrt{s}$=350-365 GeV : σ_{WW}=12.0-11.5 pb
L~1.5 10^{34} $/cm^2/s$: collect 1.7/ab in 4.5 years
20 10^6 WW decays

WW threshold







At LEP2 $\sqrt{s}$=161 GeV σ=4pb

ε=0.75, σ_B=300 fb

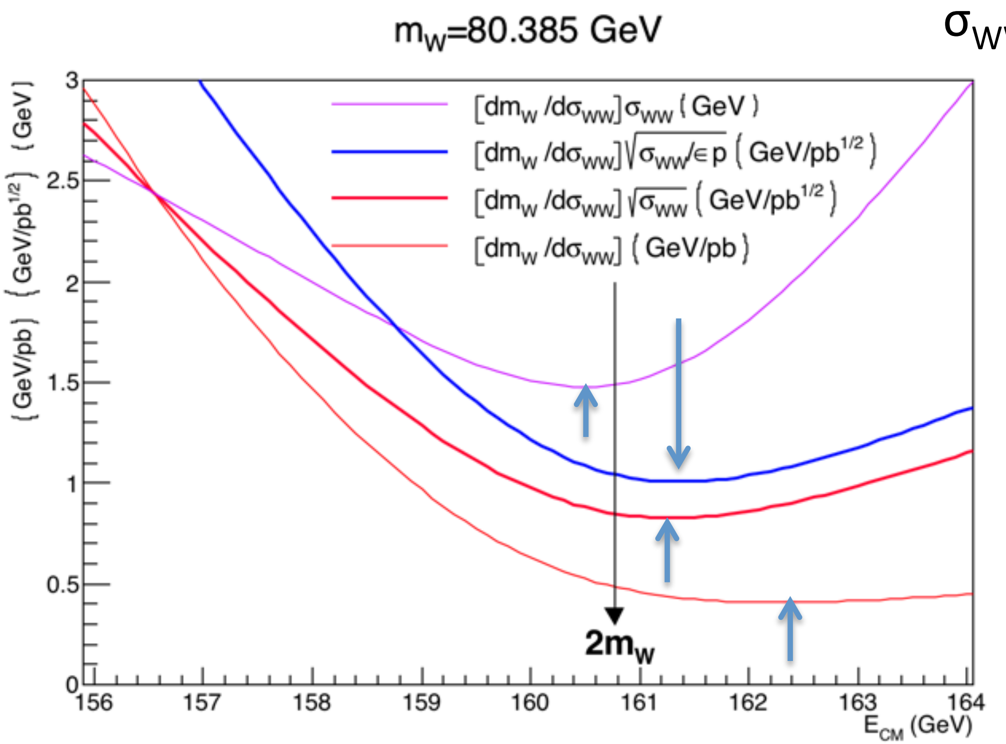
p=0.9 : εp≈0.68 (@161)

➔ 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

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

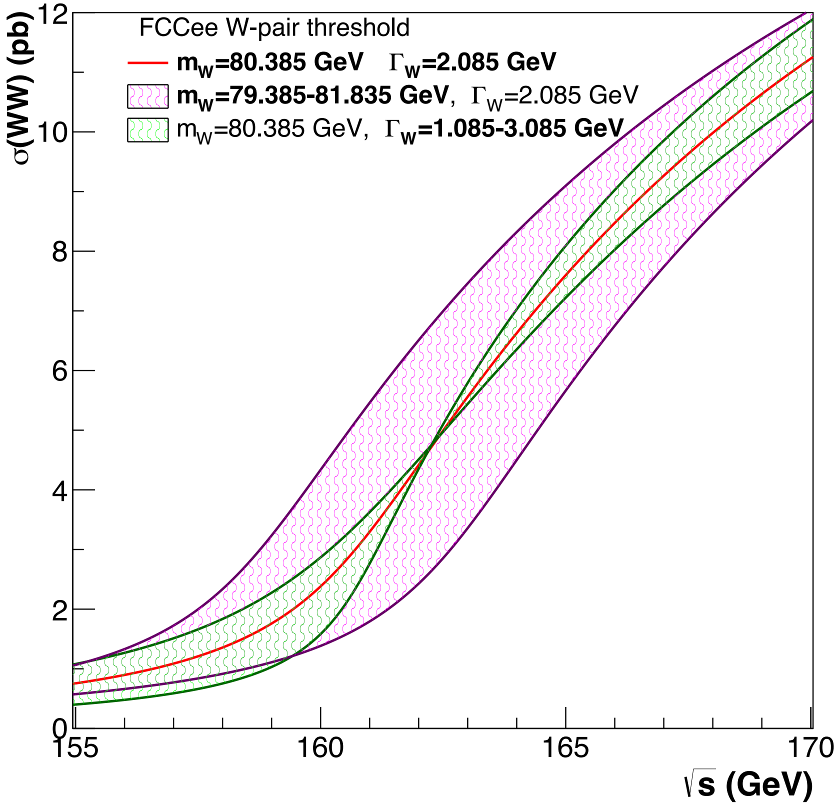
statistical precision
with L= 8/ab ➔ $\Delta m_W \approx 0.35$ MeV

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

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}



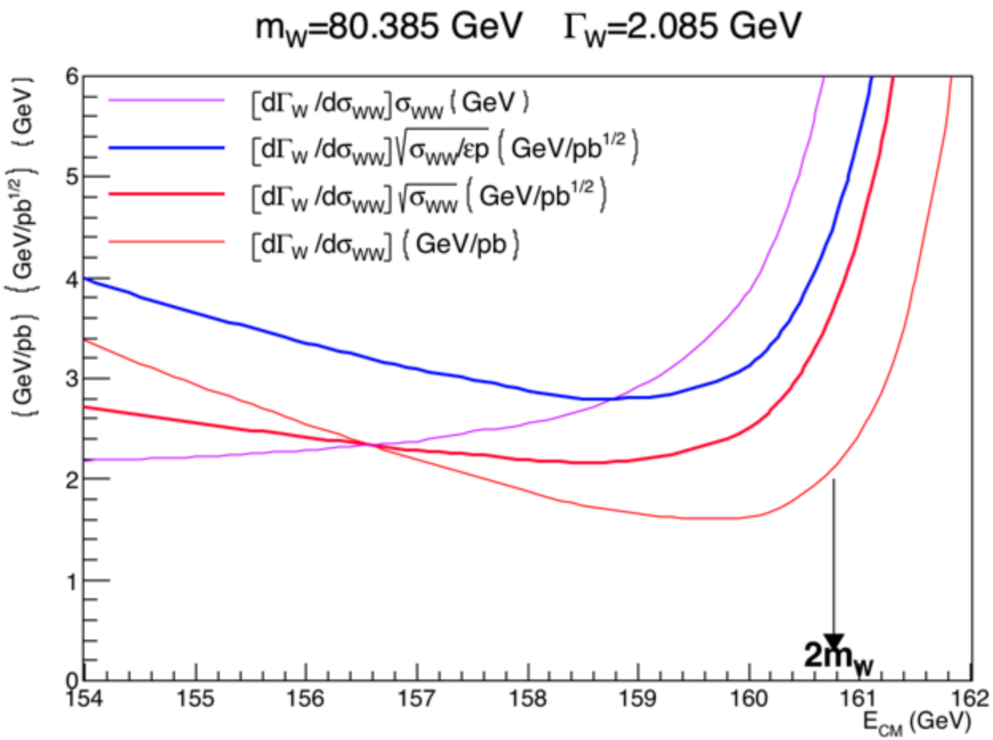
$d\sigma_{WW}/d\Gamma_W = 0$
at E_{CM}~**162.3 GeV**
~$2m_W$ + 1.5 GeV

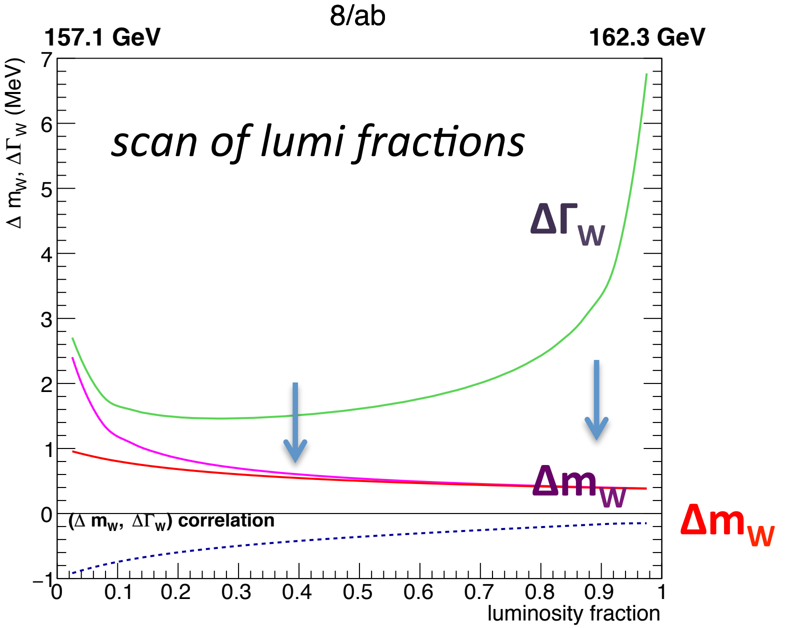
Measure σww in two energy points E_1, E_2 with a fraction f of lumi in E_1
➔ determine both m_W & Γ_W

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

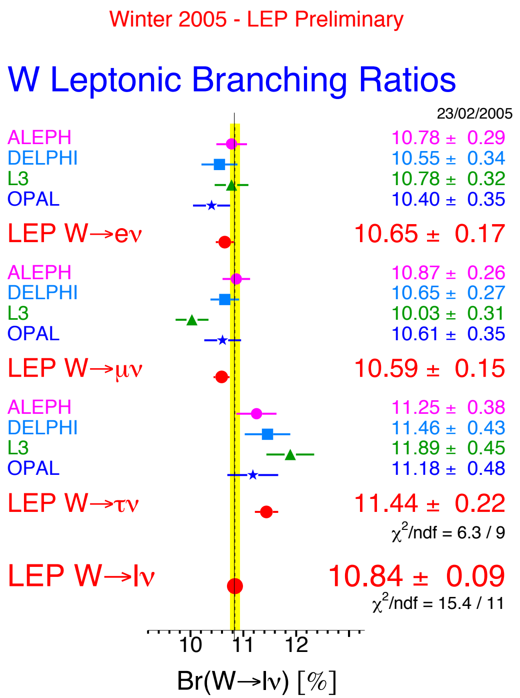
with E_1=**157.1** GeV E_2=**162.3** GeV f=**0.4**
Δm_W=0.60 $\Delta\Gamma_W$=1.5 Δm_W=0.56 (MeV)

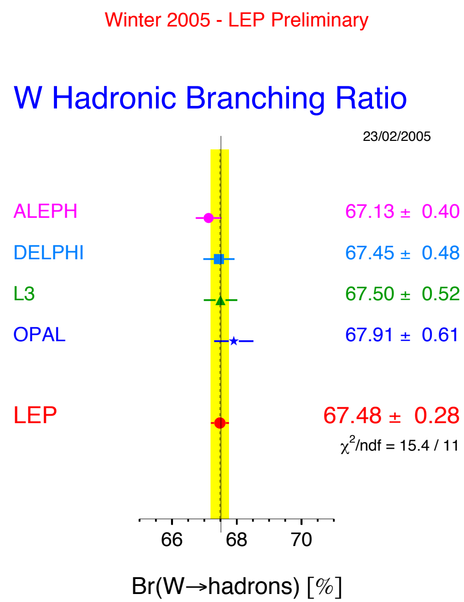
with resonant depolarization spin tune constraints

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)

➔ $\Delta\alpha_s \approx (3\pi/2)\Delta\Gamma/\Gamma \approx$ 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 much better control of lepton id
i.e. cross contaminations in signal channels
(τ➔e,μ in the e,μ channels and v.v.)

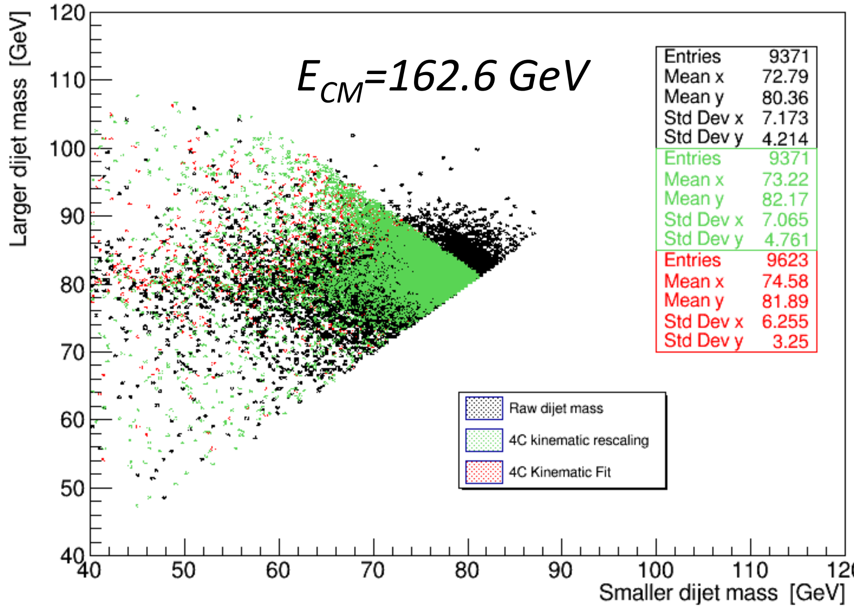
Flavor tagging would also allow to measure coupling to c & b-quarks (Vcs, Vcb,..)

Direct m_W reconstruction

➔ see details on poster by **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



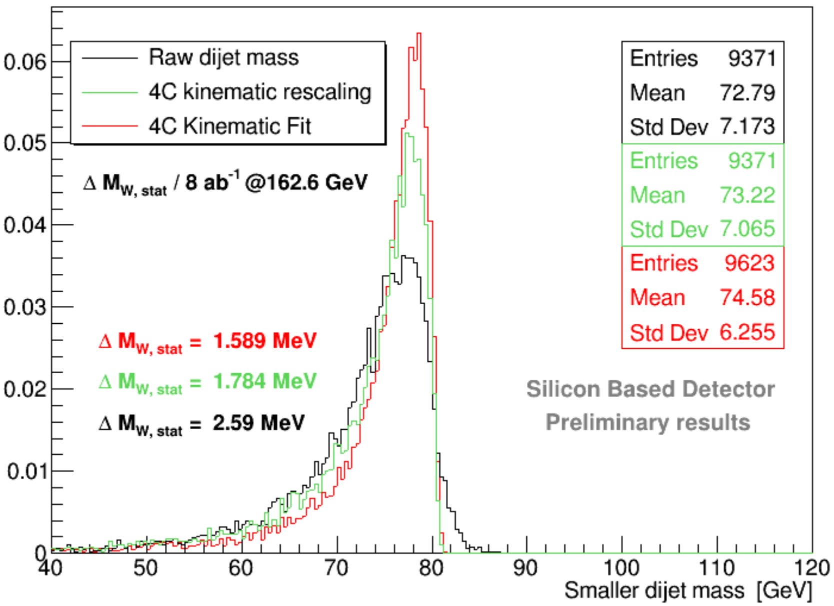
Three W mass estimators
- **Raw** dijet mass
- 4C kinematic jets momenta **Rescaling**
- Kinematic **Fit** : minimising jets χ2

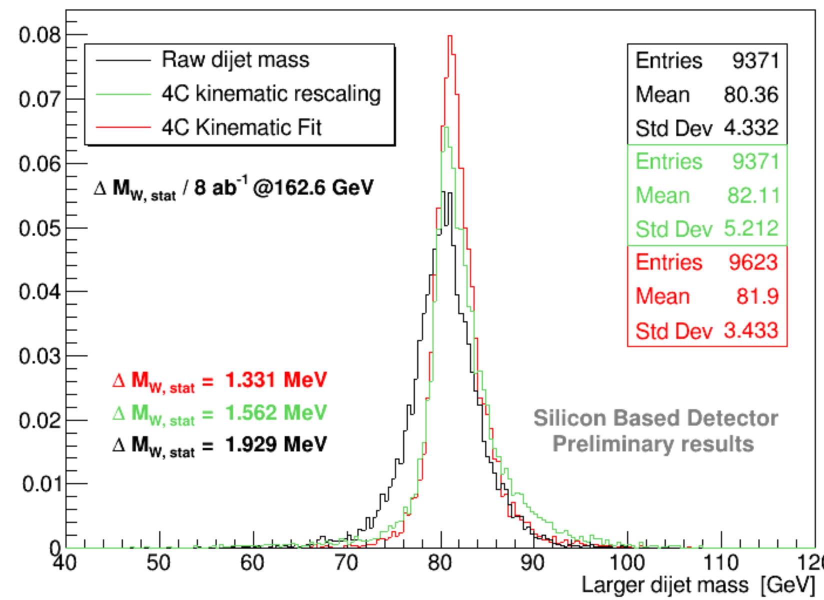
The expected statistical uncertainty on the W mass peak value (Δm_W,stat) is estimated with a **binned max likelihood fit** on the reconstructed m_W distributions, **using templates** with different nominal W mass values. The final expected uncertainty is the result of the combination of the measurements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

Direct m_W reconstruction

at the W-pair threshold

➔ details on poster by **Marina Béguin**





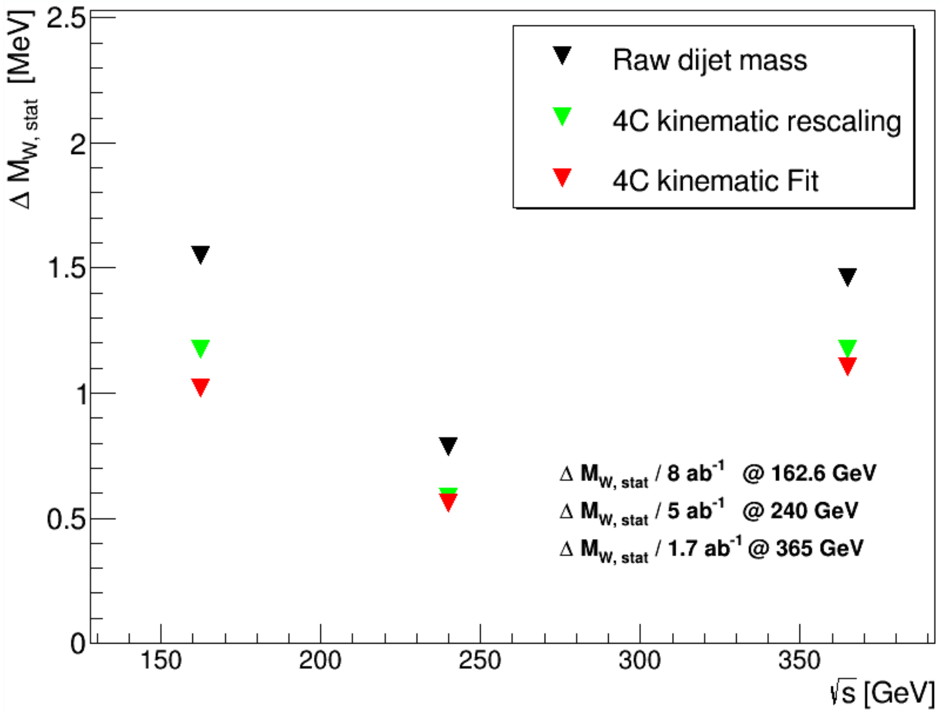
Smaller dijet mass tends to be off-shell
Larger dijet mass is on-shell

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

➔ details on poster by **Marina Béguin**

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

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

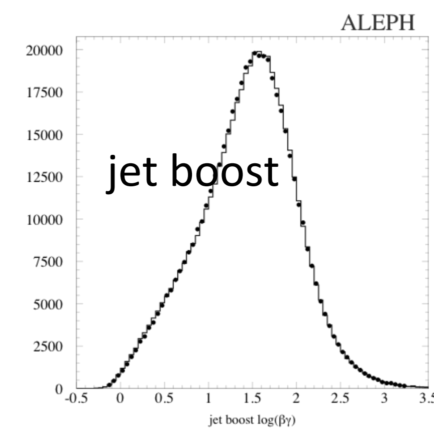
Is ΔE_{beam}~1MeV at E_{CM}=240-365 GeV possible ?
With radiative Z-returns (Zγ) events ? Maybe !

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

ALEPH 683 /pb
~10k WW events

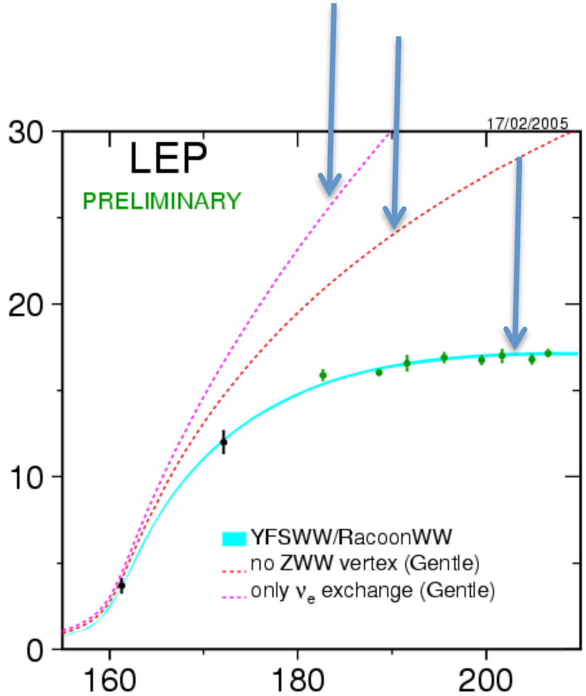


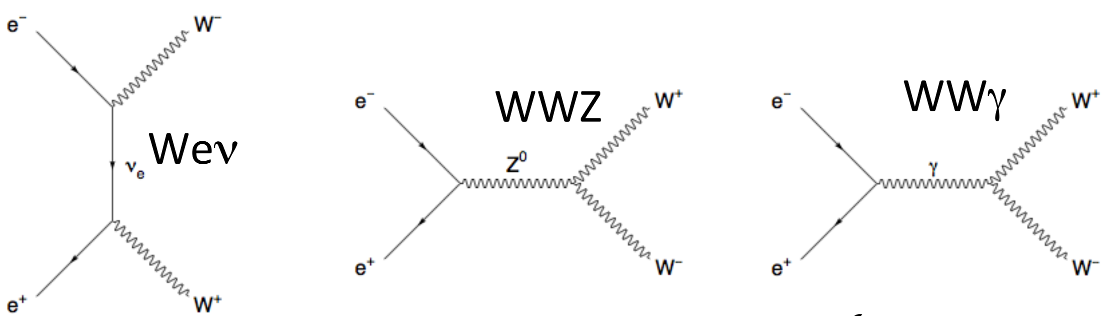
lepton and jet uncertainties from (Z) calibration data

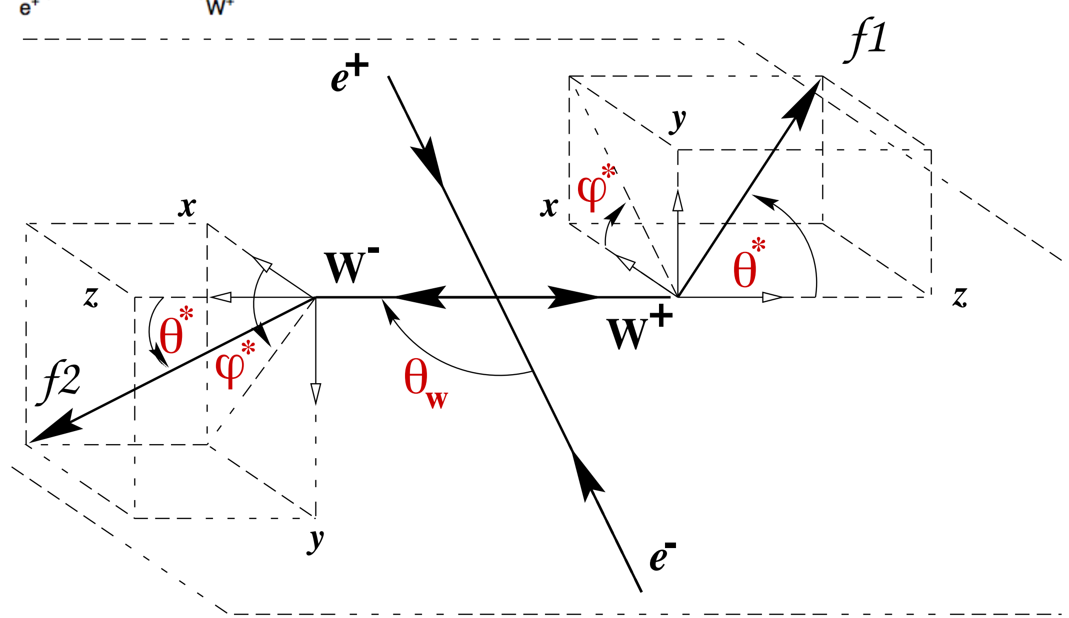
Triple gauge couplings

SU(2)⊗U(1) Gauge Cancellations

➔ see details on poster by **Jiayin Gu**



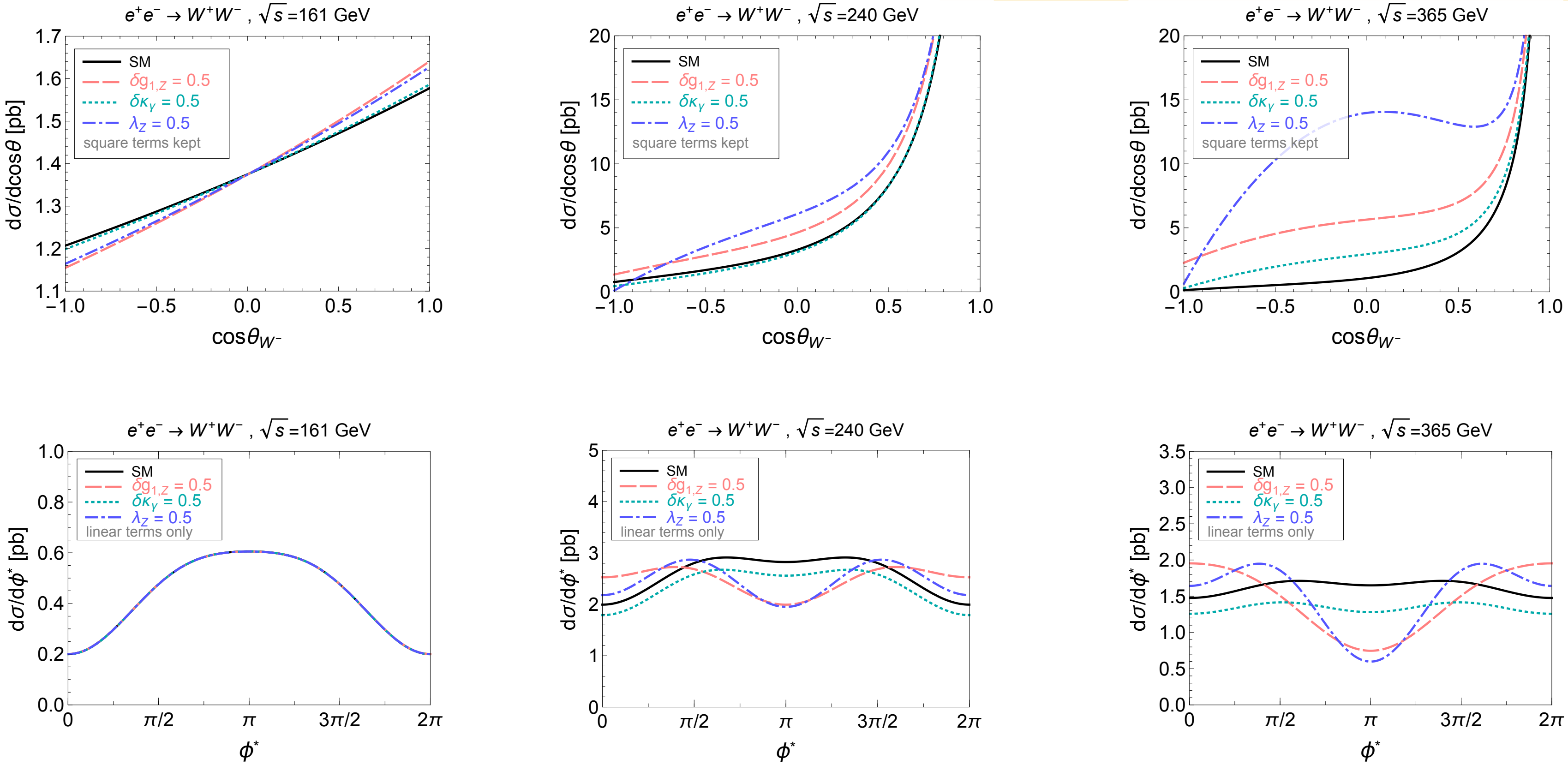




anomalies affect:
the **total rates** σ,
the **production angles** θ_W
the **decay angles** θ* ϕ*

Triple gauge couplings

➔ see details on poster by **Jiayin Gu**



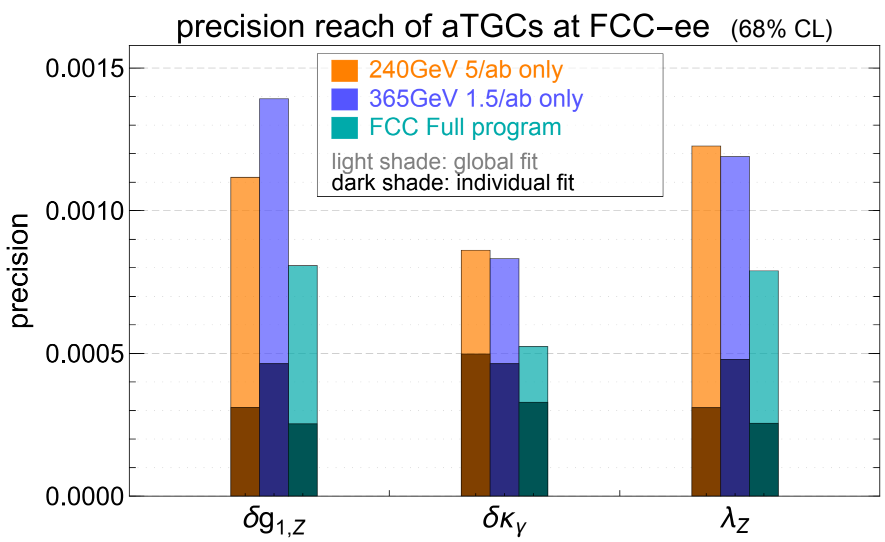
A large benchmark value (0.5) is shown to make the effects of the aTGCs visible. Since the precision reach of the aTGCs are at $O(10^{-3})$ or better, a linear approximation works very well for this analysis.

Triple gauge couplings

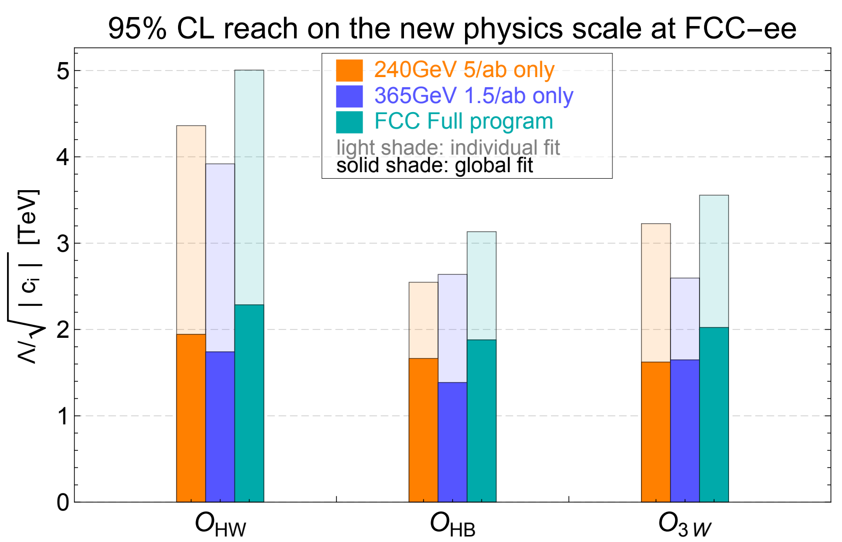
A binned chi-square fit is performed to estimate the precision reach of the three aTGCs at the FCCee.

→ see details on poster by **Jiayin Gu**

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

Conclusions

FCC ee is a total game-changer for W physics measurements

- No "a priori" walls on the road map to achieve the FCCee goals for W precision measurements but a lot of work, also on the theoretical calculations side
- The WW threshold lineshape is a great opportunity to measure both m_W and Γ_W:
  - take data at $\sqrt{s}=2m_w+1.5$ GeV (**Γ-insensitive**) and $\sqrt{s}$=2mw-2-3 GeV (-Γ**off shell**)
- Huge potential for other W physics measurements including higher energy data:
- W decay couplings at 10^{-4} level (solve eμ/τ diff, measure CKM & α_S)
- **Direct m_W measurements** shown to be possible also at threshold (ΔE_{beam}<1 MeV) and with better stats at higher energies (Δm_W(stat)what systematic limitations ?)
- Initial studies on **gauge couplings** indicate very vast (x100) improvements of the current sensitivities, specially using the higher energy W-pairs (@240-365 GeV)
- 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
- The potential of FCCee data for EW W measurements is still to be fully unraveled

Backup

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

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

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

differential factors are equal