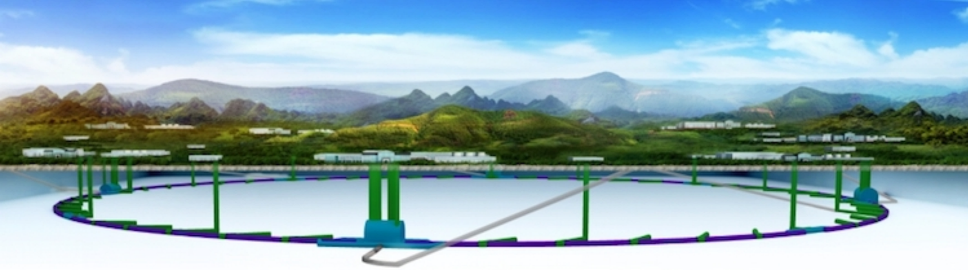


Kinematic reconstruction of the W mass and width at FCC-ee

Marina Béguin

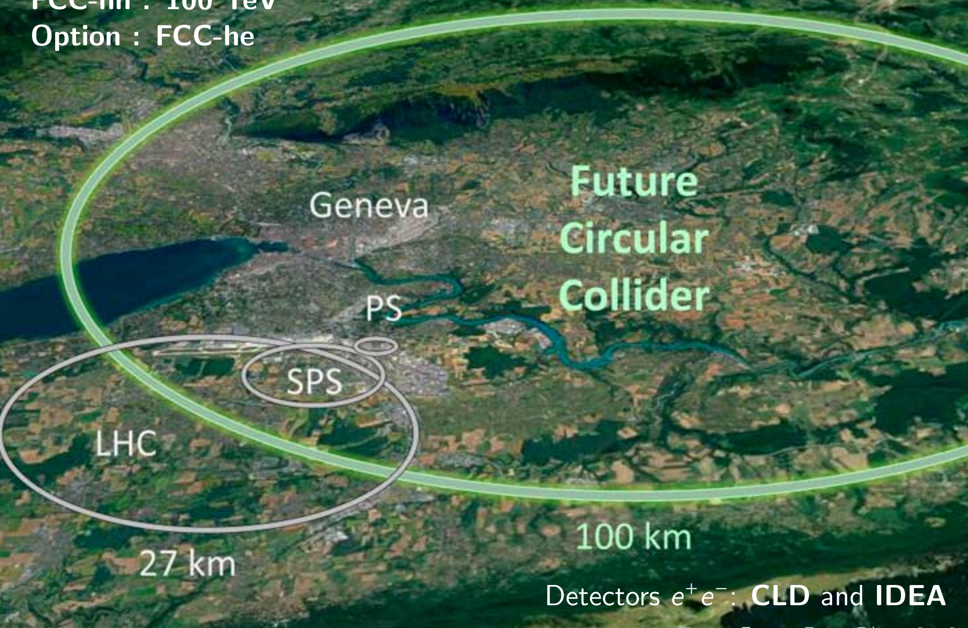
On behalf of the FCC-ee WG2 working group

CEPC workshop

November 18, 2019

FCC-ee
FCC-hh : 100 TeV
Option : FCC-he

Z	WW	HZ	$t\bar{t}$
~ 91 GeV	~ 160 GeV	~ 240 GeV	~ 350-365 GeV



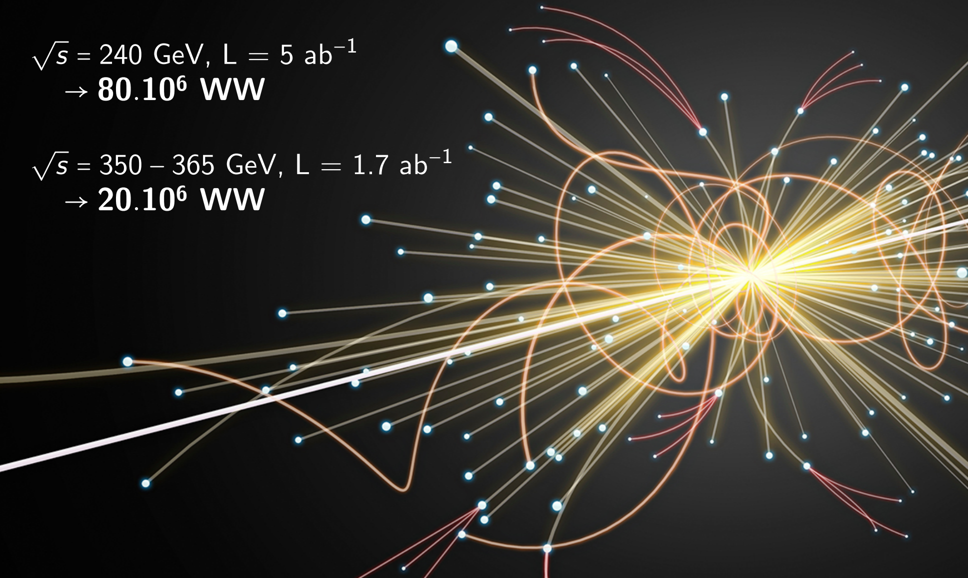
Detectors e^+e^-: **CLD** and **IDEA**

WW factory

$\sqrt{s} = 160$ GeV, L $= 12$ ab^{-1}
$\rightarrow$ **60.10^6 WW**

$\sqrt{s} = 240$ GeV, L $= 5$ ab^{-1}
$\rightarrow$ **80.10^6 WW**

$\sqrt{s} = 350 - 365$ GeV, L $= 1.7$ ab^{-1}
$\rightarrow$ **20.10^6 WW**

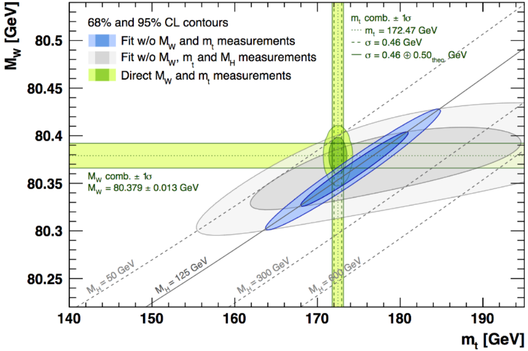


WW diboson physics at FCC-ee

- Measurements of the **W mass and width** directly and with threshold scan;
- W partial widths;
- Strong coupling constant;
- CKM matrix;
- Gauge self-couplings ...

... **with unprecedented accuracy**

W mass measurement

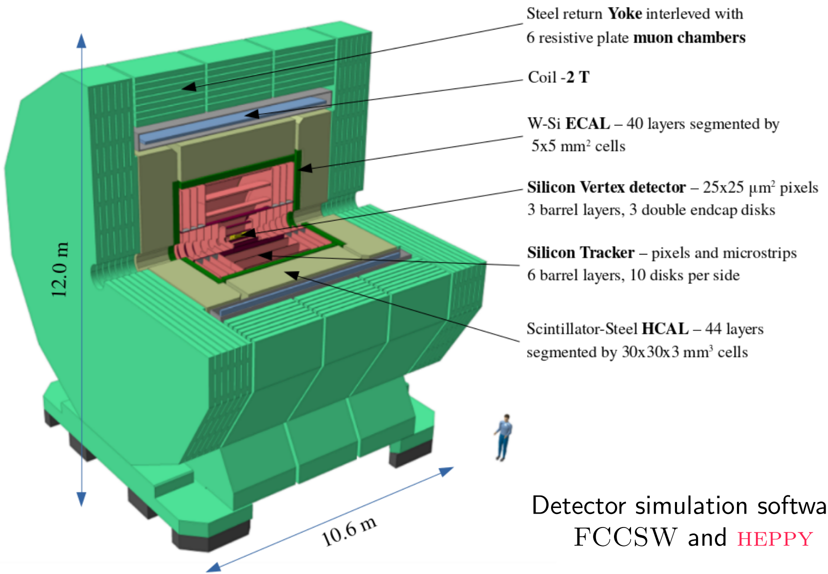


Precise relation between $\mathbf{M_W}$, M_H, M_t *is a* **crucial test** *of the internal consistency of SM and failure might reveal* **new physics**.

Methods

- At WW threshold;
- Direct determination

CLIC-Like Detector: CLD



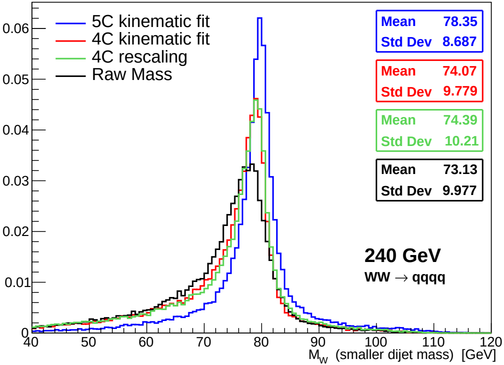
Detector simulation software:
FCCSW and HEPPY

More information in: FCC CDR v2

Direct reconstruction of M_W and Γ_W
Hadronic decay channel $WW \to q\bar{q}q\bar{q}$

Study at 162.6 GeV, 240 GeV and 365 GeV

- PYTHIA V8.24 simulation
- Reconstruction with HEPPY (CLD detector, DURHAM algorithm)



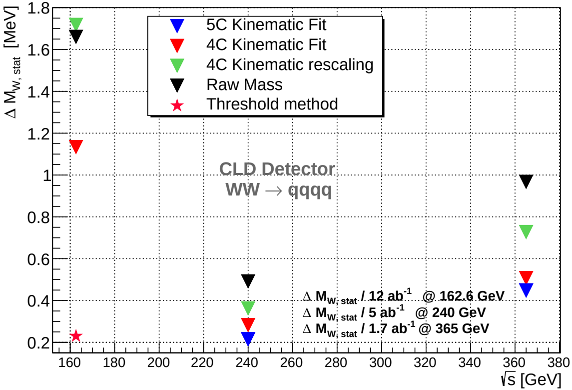
W mass estimators :

- **Raw mass**
- 4C **jets momenta rescaling**
- **Kinematic fit** with energy-momentum conservation (4C) and W masses equality (5C)

Direct reconstruction of M_W and Γ_W
Hadronic decay channel $WW \to q\bar{q}q\bar{q}$

Statistical uncertainty estimated with a **binned maximum likelihood fit** on the reconstructed M_W distributions, using **templates** with different nominal W mass (width) values.

Threshold measurement here



@162.6 GeV
$\Delta\Gamma_W(4C) = 1.1$ MeV
@240 GeV
$\Delta\Gamma_W(5C) = 0.47$ MeV
@365 GeV
$\Delta\Gamma_W(5C) = 1$ MeV

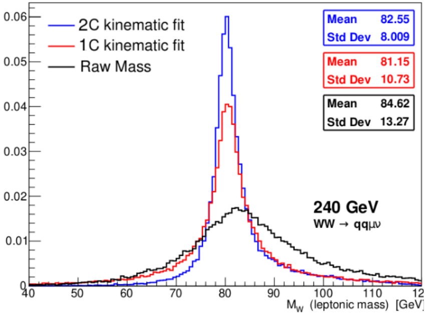
Mass and width uncertainties evaluated **independently**

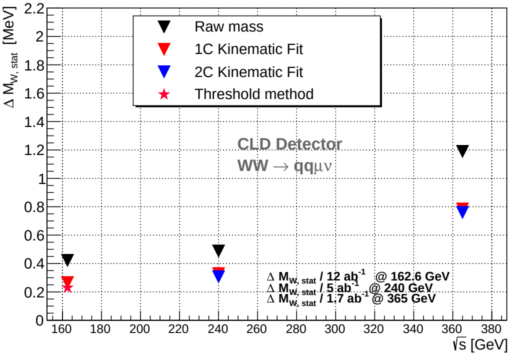
Full FCC-ee luminosity

Direct reconstruction of M_W and Γ_W
Semi-leptonic decay channel $WW \to q\bar{q}\ell\nu$

Study at 162.6 GeV, 240 GeV and 365 GeV

Only the muon decay





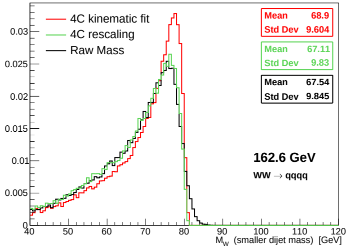
Threshold measurement here

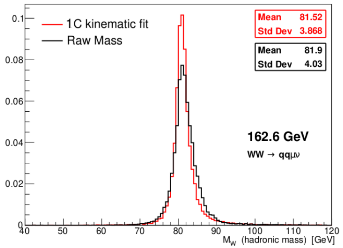
@162.6 GeV $\Delta\Gamma_W(1C) = 0.35$ MeV
@240 GeV $\Delta\Gamma_W(2C) = 0.68$ MeV
@365 GeV $\Delta\Gamma_W(2C) = 1.56$ MeV

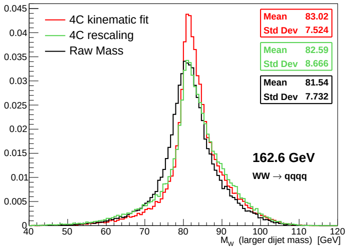
Full FCC-ee luminosity

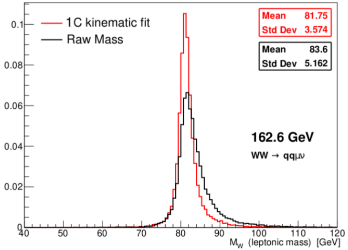
Direct reconstruction of M_W and Γ_W at threshold

Hadronic channel









Semi-leptonic channel

Direct reconstruction can be used to **extract W mass and width at threshold**

W mass and width statistical uncertainties

Table: Hadronic decay

	σ_{M_W} [MeV/c^2]			σ_{Γ_W} [MeV/c^2]		
$\sqrt{s}$ [GeV]	162.6	240	365	162.6	240	365
Luminosity (ab^{-1})	12	5	1.7	12	5	1.7
Raw Mass	1.66	0.49	0.97	1.44	1.10	1.71
4C rescaling	1.72	0.36	0.73	1.53	0.77	1.48
4C fit	1.13	0.28	0.5	1.1	0.58	0.95
5C fit		**0.21**	0.44		0.47	1.0

With threshold method $\sigma_{M_W} = \mathbf{0.23}$ MeV

Threshold measurement here

Full FCC-ee luminosity

Table: Semi-leptonic decay

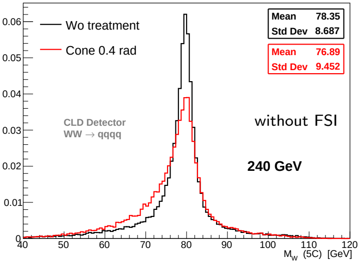
	σ_{M_W} [MeV/c^2]			σ_{Γ_W} [MeV/c^2]		
$\sqrt{s}$ [GeV]	162.6	240	365	162.6	240	365
Luminosity (ab^{-1})	12	5	1.7	12	5	1.7
Raw Mass	0.42	0.49	1.19	0.39	0.87	1.94
1C fit	**0.26**	0.33	0.78	0.35	0.59	1.36
2C fit		0.31	0.75		0.68	1.56

Systematic uncertainties

Main sources of systematic uncertainties at LEP2:
arXiv:1302.3415

Source	Systematic Uncertainty in MeV			
	on m_W			on Γ_W
	$q\bar{q}\ell\nu_\ell$	$q\bar{q}q\bar{q}$	Combined	
ISR/FSR	8	5	7	6
Hadronisation	13	19	14	40
Detector effects	10	8	9	23
LEP energy	9	9	9	5
Colour reconnection	–	35	8	27
Bose-Einstein Correlations	–	7	2	3
Other	3	10	3	12
Total systematic	21	44	22	55
Statistical	30	40	25	63
Statistical in absence of systematics	30	31	22	48
Total	36	59	34	83

FSI simulated with PYTHIA (SKI/SKII).
$\delta M_{W,FSI}$ reduced **using a cone (0.4 rad) on jets**



$\sqrt{s}$ [GeV]	162.6		240		365	
δM_{FSI} [MeV]	standard	cone	standard	cone	standard	cone
SKI	14.6	7.5	23.9	11.5	32.2	17.5
SKII	7.9	3.8	12.1	6.0	14.7	8.3
BEC	3.1	1.8	5.9	2.1	9.9	5.5

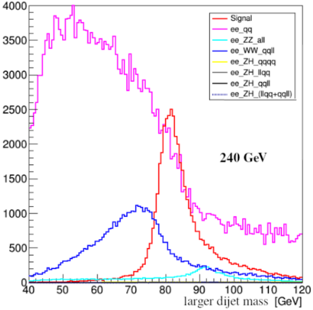
$\Delta M_{W,stat}$ is degraded with the cone by a few percents at threshold and 10-15% above.

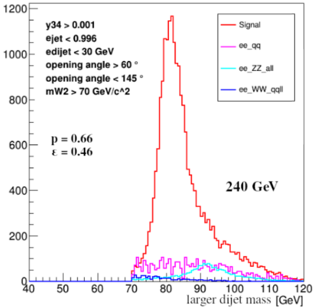
Background contamination in **hadronic** channel *Sofiane Lablack*

Background processes studied at **162.6 GeV, 240 GeV and 365 GeV** (if possible):

$$e^+e^- \to q\bar{q}(\gamma),$$
$$e^+e^- \to WW \to q\bar{q}\ell\ell,$$
$$e^+e^- \to ZZ \to 4f,$$

$$e^+e^- \to ZH \to q\bar{q}q\bar{q},$$
$$e^+e^- \to ZH \to q\bar{q}\ell\ell.$$





▷ Effective background rejection above threshold

▷ $\Delta M_W(5C) = 0.27$ MeV @240 GeV ($5ab^{-1}$) in presence of background (0.21 MeV without)

Bkg rejection increases with energy:
@162.6 GeV: $p = 0.41$, $\epsilon = 0.37$;
@365 GeV: $p = 0.85$, $\epsilon = 0.36$

Sofiane Lablack, Precise measurement of the W boson mass at the e^+e^- future circular collider (FCC-ee), Master Thesis, 2019

Conclusion

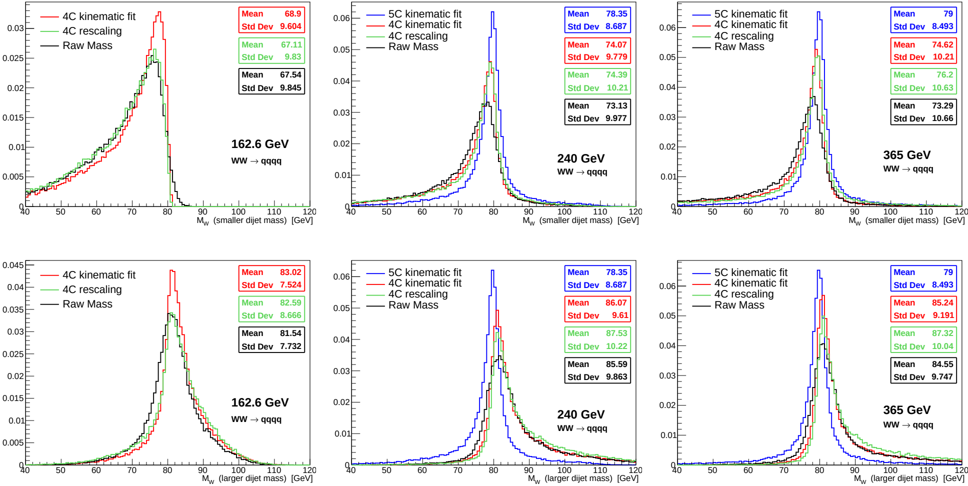
The **amount of W-pairs** at different centre-of-mass energies planned at **FCC-ee** presents a huge potential for the W physics measurements.

- Direct M_W and Γ_W measurements at threshold and above is possible at FCC-ee. Yielding to statistical **precision below MeV-level** ($\Delta M_W =$ **210 keV** @240 GeV for hadronic channel and $\Delta M_W =$ **260 keV** @162.6 GeV for semi-leptonic channel).
- Measurement of the centre-of-mass energy with **good precision** (2 MeV @365 GeV) for energies above the WW threshold, where the resonant depolarisation cannot be used (more information here).
- Ultimately a simultaneous fit of WW, ZZ and $Z\gamma$ events could be performed to extract m_W/m_Z with potential **large cancellations of systematic uncertainties**

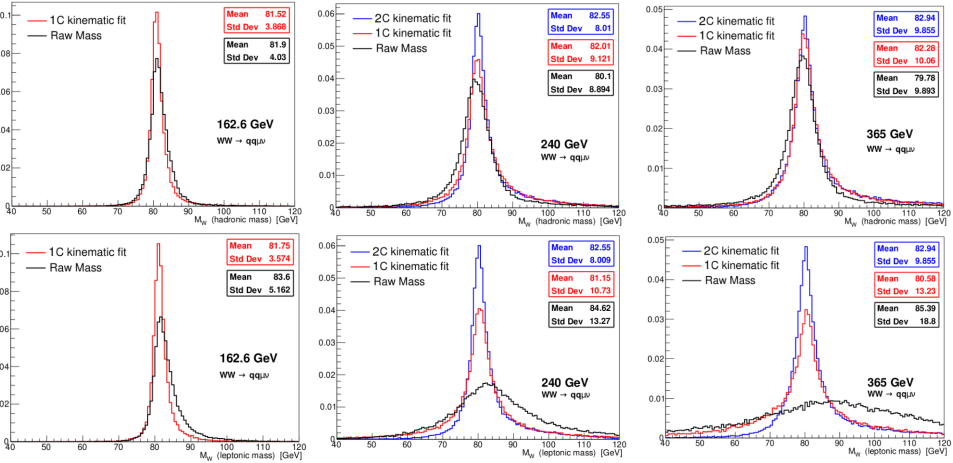
Thank you
谢谢


BACK-UP

W mass distributions - Hadronic channel

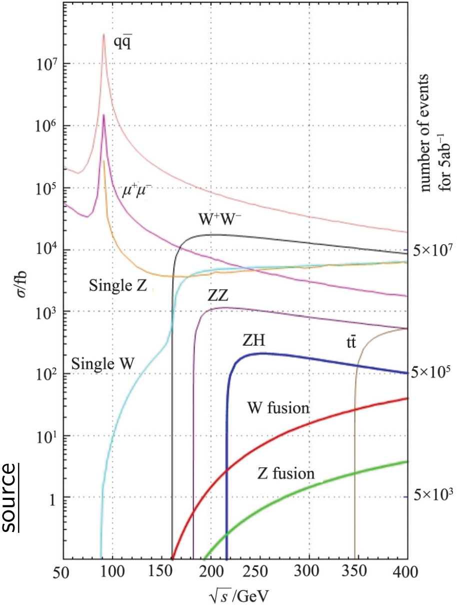


W mass distributions - Semi leptonic channel



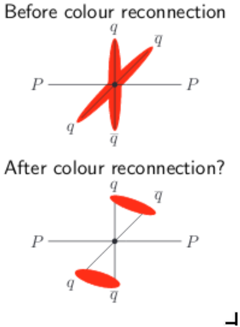
Cross-section for different processes in lepton collisions

source



All processes with larger or relatively close cross-section to the WW cross-section are potential backgrounds for the WW decay study.

Colour Reconnection - Models



Jesper Roy Christiansen, July 23, 2015, EPS HEP, Vienna

Color Reconnection (CR) : interaction between partons of the two Ws

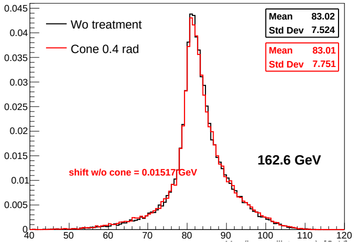
$$e^+e^- \rightarrow WW \rightarrow q_1\bar{q}_2 q_3\bar{q}_4$$

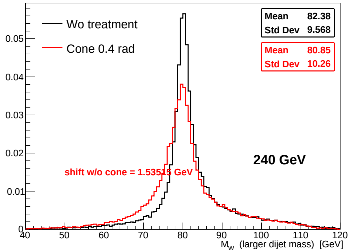
Because WW separation in phase-space is smaller than the typical distance scale of hadronisation: $(q_1\bar{q}_4)$ and $(q_3\bar{q}_2)$

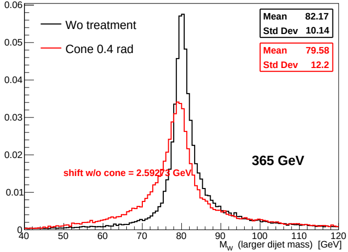
Models in PYTHIA for e^+e^- collisions are based on string hadronisation.

- SK1 : string = cylindrical bag. Colour reconnection probability proportional to the integrated overlap between cylinders.
- SK2 : string = vortex line. Colour reconnection if the cores are crossing.

Cone reconstruction effect on W mass resolution







The loss of particle information degrades the resolution by 2.9% at 162.6 GeV, 6.7% at 240 GeV and 16.9% at 365 GeV

Cone effect on $\Delta M_{W,stat}$

Full FCC-ee luminosity

$\sqrt{s}$ [GeV]	162.6		240		365	
$\Delta M_{W,stat}$ [MeV]	standard	cone	standard	cone	standard	cone
woFSI	1.14	1.18	0.215	0.228	0.463	0.564
SKI	1.18	1.21	0.225	0.244	0.478	0.55
SKII	1.17	1.19	0.218	0.237	0.467	0.539
BEC	1.17	1.18	0.224	0.236	0.461	0.58

$\Delta M_{W,stat}$ is degraded with the cone by few percent at threshold and 10-15% above.