Higgs properties + Top at FCC-ee

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On behalf of the FCC Higgs/Top performance working group

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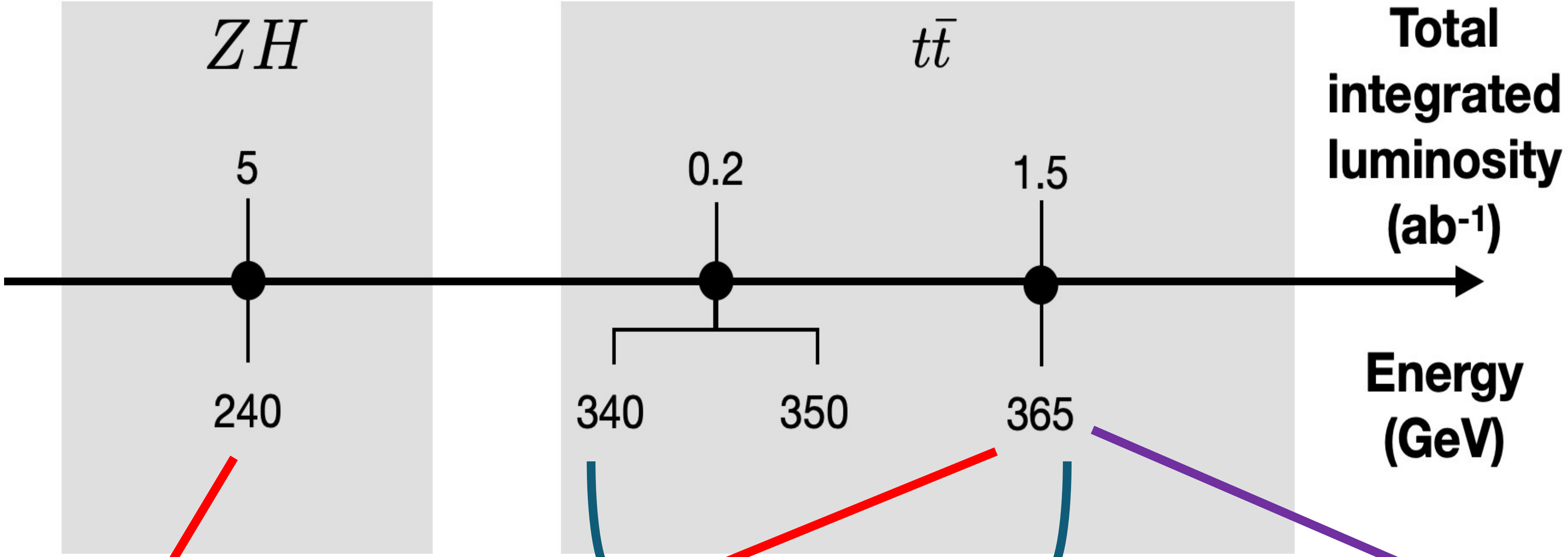
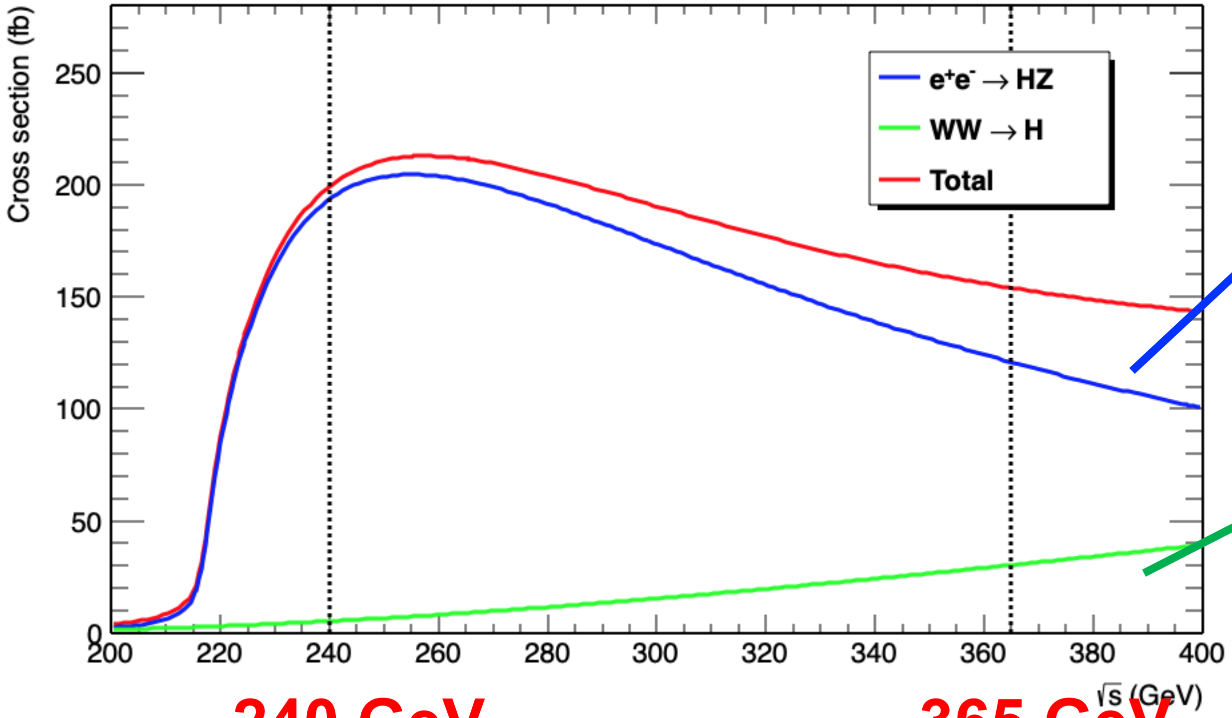
Outline

Plot from DOI 10.17181/224fq-qtf30



1. Higgs mass
2. ZH Cross-section
3. Higgs Width
4. Top mass/threshold scan
5. CKM Matrix V_{ts}

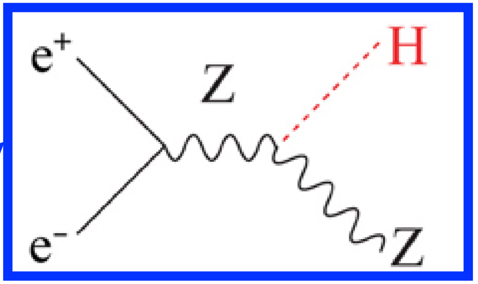
Higgs: Introduction



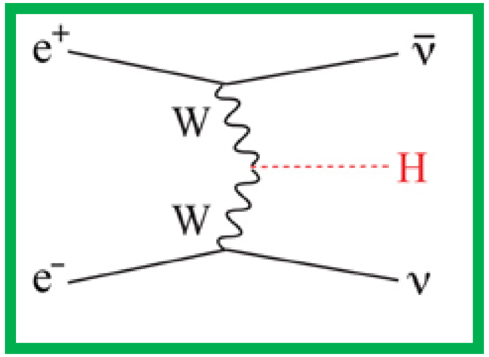
240 GeV **365 GeV**

Working point	ZH	$t\bar{t}$	
$\sqrt{s}$ (GeV)	240	340–350	365
Lumi/IP (10^{34} cm^{-2}s^{-1})	5.0	0.75	1.20
Lumi/year (ab^{-1})	2.4	0.36	0.58
Run time (year)	3	1	4
Number of events	$1.45\,10^6$ HZ + 45k WW → H	$1.9\,10^6$ $t\bar{t}$ +330k HZ +80k WW → H	

Main Higgs Production Mechanisms at FCC-ee:



- ZH production
  "Higgs-strahlung"



- Vector Boson Fusion
  WW dominant

Include 365 GeV
Gain ~23% ZH events

Luminosity at 240 GeV is expected to be improved by 50%
Because of new proposed optics

Higgs mass

$\sqrt{s} = 240$ GeV
$L = 7.2 ab^{-1}$

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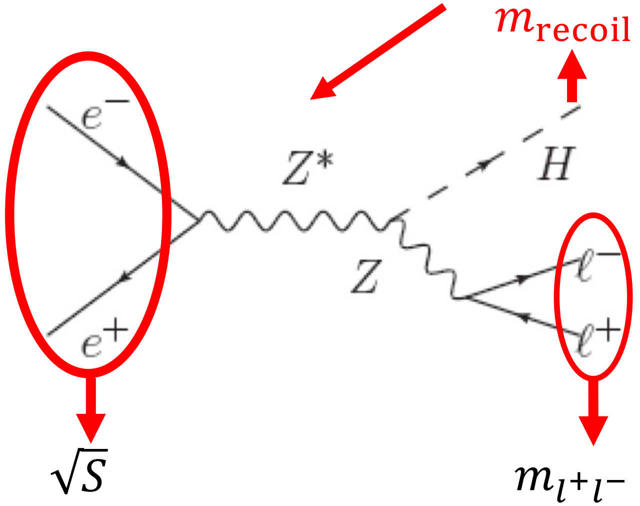
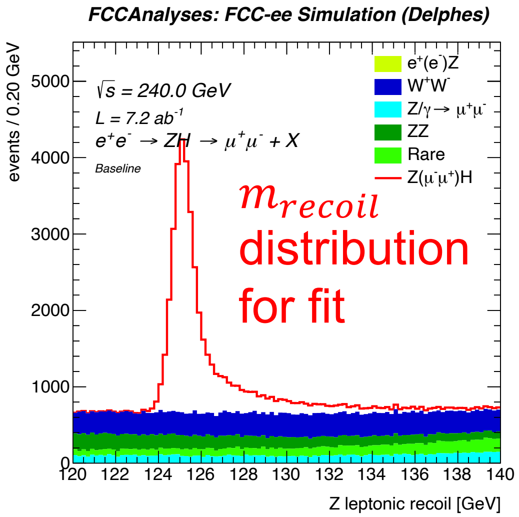
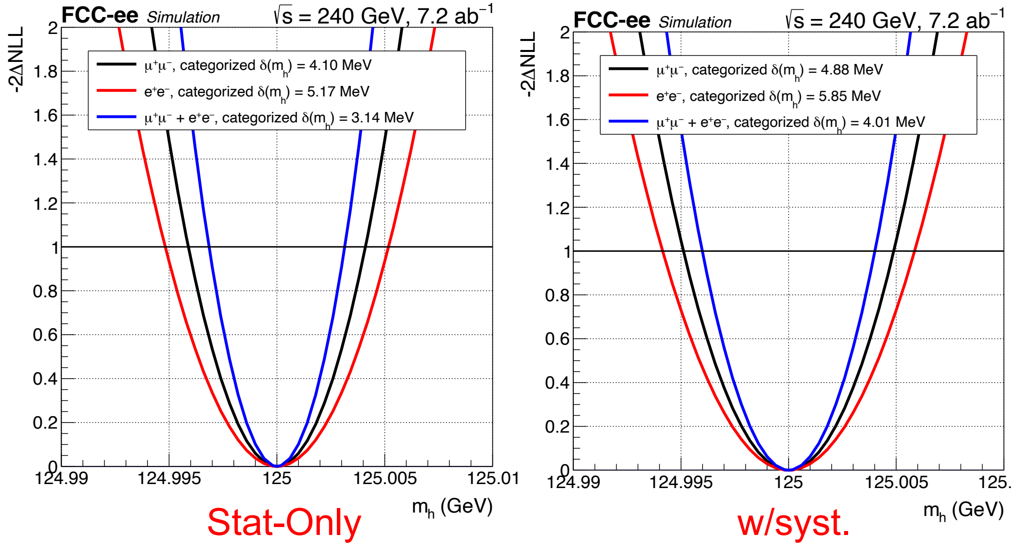
- Current best from LHC $\delta m_H \sim 100$ MeV
- At FCC-ee, Higgs mass will reach MeV level accuracy, ($\Gamma_H \sim 4.1$ MeV)
- Electron and Muons final states: $e^+e^- \rightarrow ZH \rightarrow l^+l^- + XX$, $(Z \rightarrow \mu^+\mu^-, e^+e^-)$
- M_{recoil} from the Z production without measuring the Higgs production final state

$$m^2_{\text{recoil}} = (\sqrt{s} - E_{l\bar{l}})^2 - p^2_{l\bar{l}} = s - 2E_{l\bar{l}}\sqrt{s} + m^2_{l\bar{l}}$$







Higgs mass, Fit with analytic shape

- Signal Shape: 2 Crystal-Ball with Gaussian core
- Backgrounds modelled as polynomial (3rd order)
- Signal and background injected in Combine, m_H as POI

Uncertainty Stat-Only, and w/ systematics:

- Higgs mass: 3.1 MeV → 4.0 MeV

Dominant Syst. Unc. :

Centre-of-mass with ~ 2 MeV

Higgs mass

$\sqrt{s} = 240$ GeV
$L = 7.2ab^{-1}$

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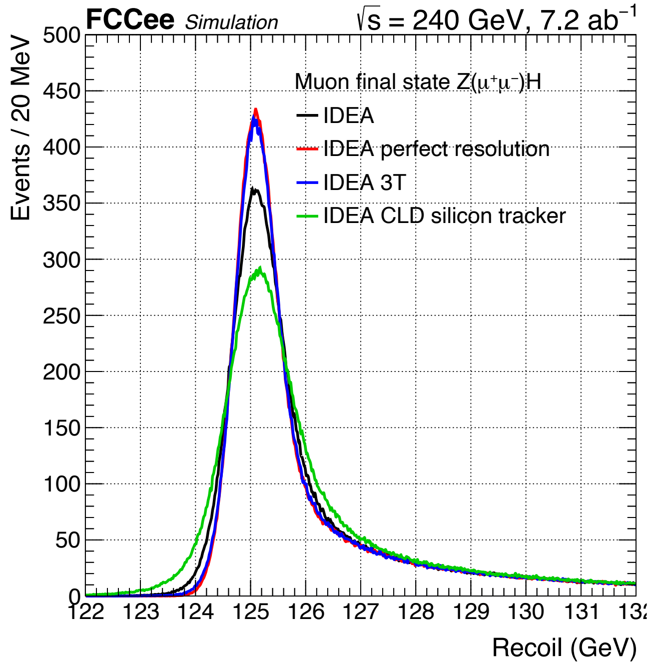
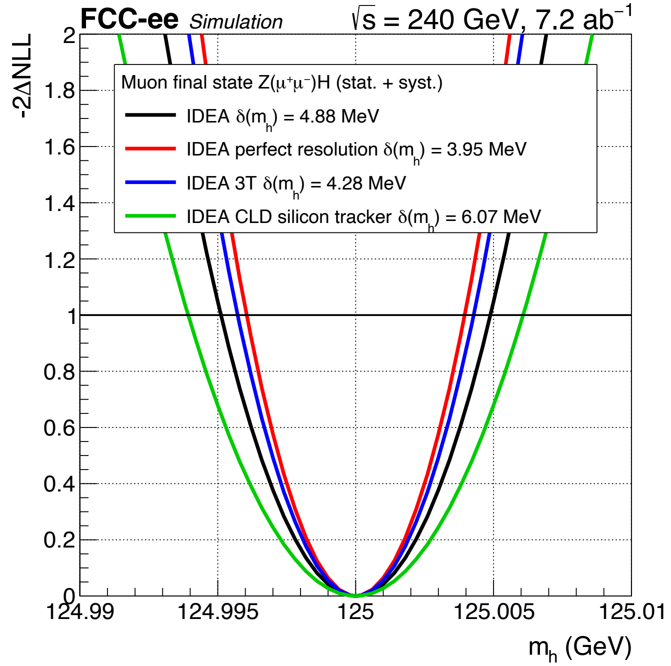
Some extended studies performed regarding detector effects

- Assuming "perfect" (generator-level) momentum resolution
- Nominal 2 T magnetic field → 3 T (stronger field → better tracking)
- IDEA drift chamber → CLD silicon tracker

	Combined
Nominal	4.01
Ideal resolution	3.33
Magnetic Field 3T	3.54
CLD 2T (silicon tracker)	4.66





Feedbacks to the Detector Design from Analysis

Higgs mass at 365 GeV

$\sqrt{s} = 365\ \text{GeV}$
$L = 2.3\ ab^{-1}$

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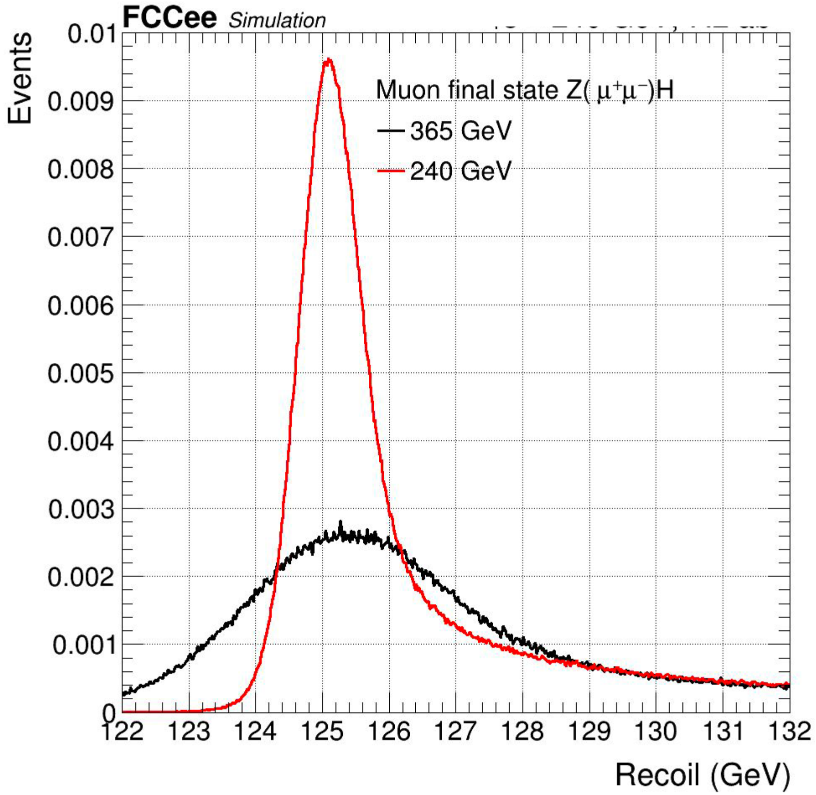
- **At $\sqrt{s} = 365\ \text{GeV}$**
  - Reduced statistics
  - Broadened recoil distribution
  - 365 GeV only: 24 MeV uncertainty on Higgs mass
  - Combined with 240 GeV brings it down from **3.13** MeV to **2.92** MeV (Stat-Only) **~7%** improvement



Preliminary

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Total ZH production cross-section

Measure the ZH cross-section in a Model-Independent way

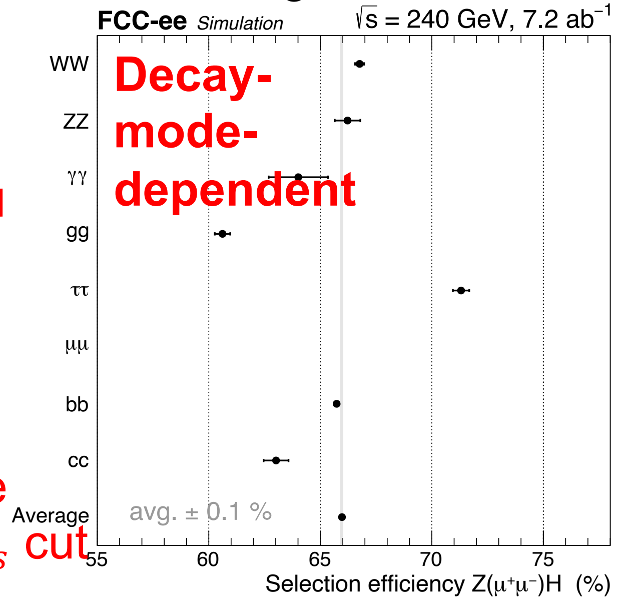
- Unique to electron-positron colliders because of known initial state
- Challenge to ensure model-independent
- Once know, determine couplings to $H \to XX$ in a model independent way

$$\sigma_{ZH} \times Br(H \to X\bar{X}) \propto \frac{g_{HZZ}^2 \times g_{HXX}^2}{\Gamma_H}$$

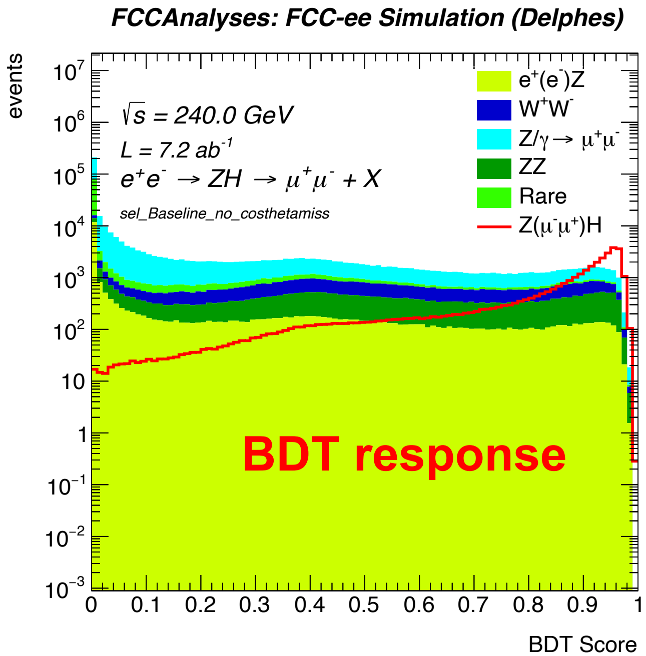
At FCC-ee ZH cross-section is expected to ~0.5 % accuracy

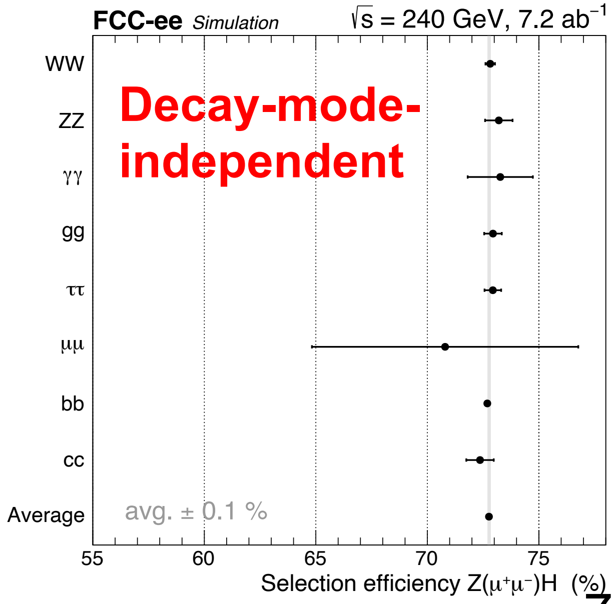
- $e^+e^- \to ZH \to l^+l^- + XX, (Z \to \mu^+\mu^-, e^+e^-)$

- Remove Decay-Mode dependent event selection → $\cos\theta_{miss}$
- Introduce BDT approach to keep decay-mode independency
- Fit BDT distribution



Remove $\cos\theta_{miss}$ cut





Total ZH production cross-section

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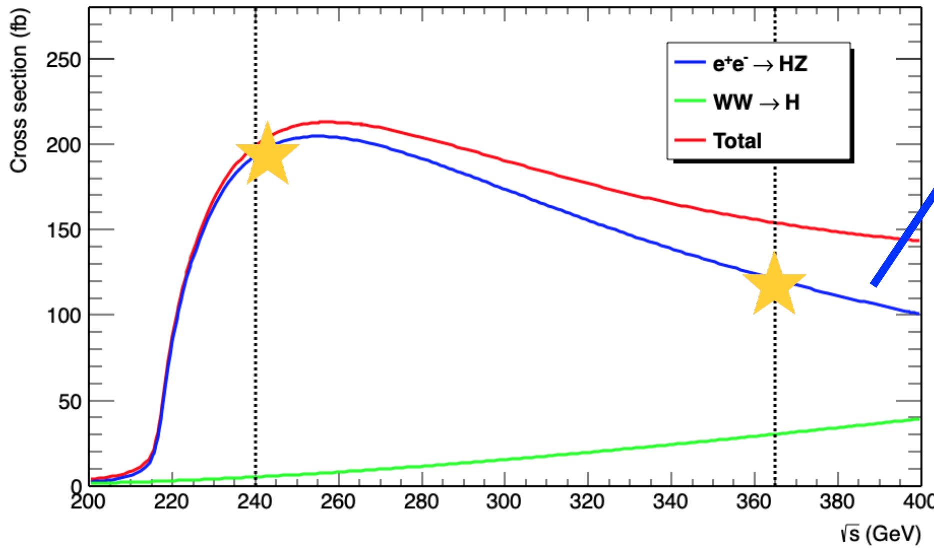
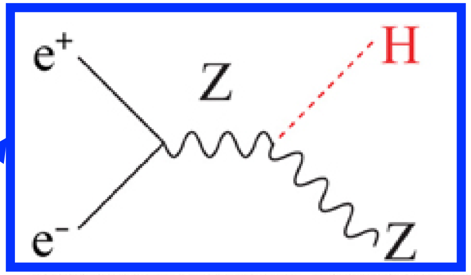
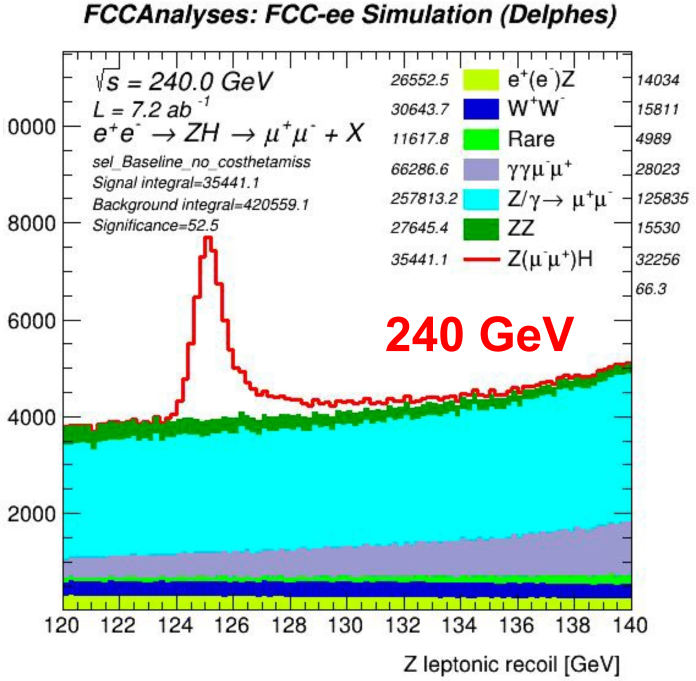
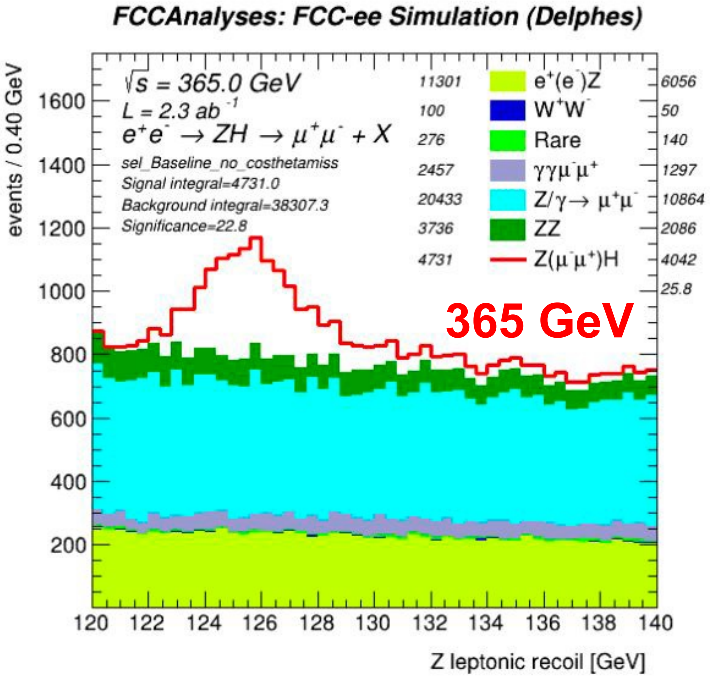
240 GeV 365 GeV









	$\delta\sigma_{ZH}/\sigma_{ZH}$
$\sqrt{s} = 240$ GeV, 7.2 ab^{-1}	0.69%
$\sqrt{s} = 365$ GeV, 2.3 ab^{-1}	1.10% (preliminary)

365 GeV has

- Worse resolution
- But Negligible WW background

Higgs width

L = 5 ab^{-1}

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Combes, Inès
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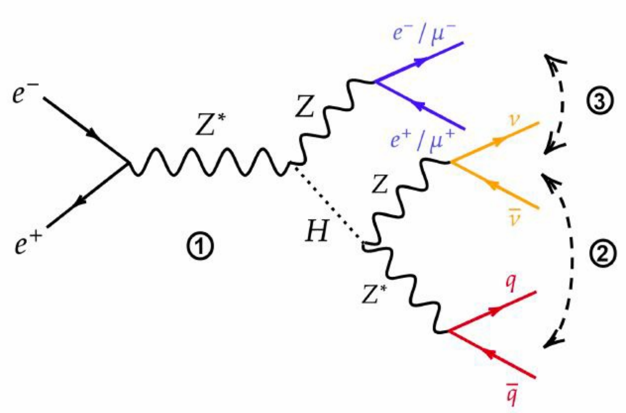
Michele Selvaggi
Aman Desai

Measuring the individual $H \to XX$ decay modes gives access to Higgs width (Γ_H)

- At 240 GeV, measuring $H \to ZZ$ (ZH)
- At 240+365 GeV, measuring $H \to b\bar{b}$ (VBF)
- Expected precision $\Gamma_H \sim 1\%$

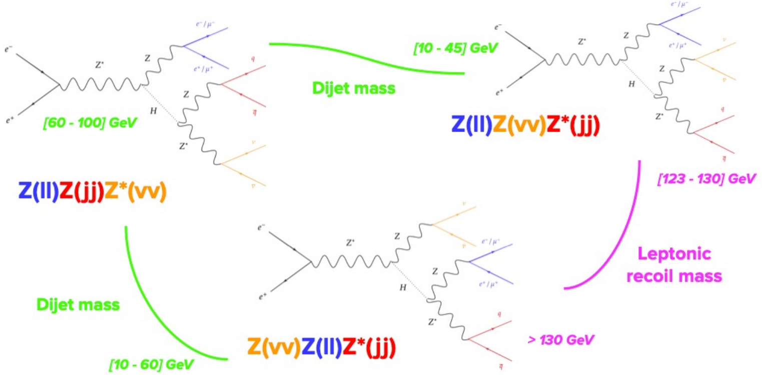
Inclusive ZH cross-section

$$\Gamma_H \propto \frac{\sigma(e^+e^- \to ZH)^2}{\sigma(e^+e^- \to ZH, H \to ZZ)}$$



$ZH \to ZZZ^*$ at 240 GeV:

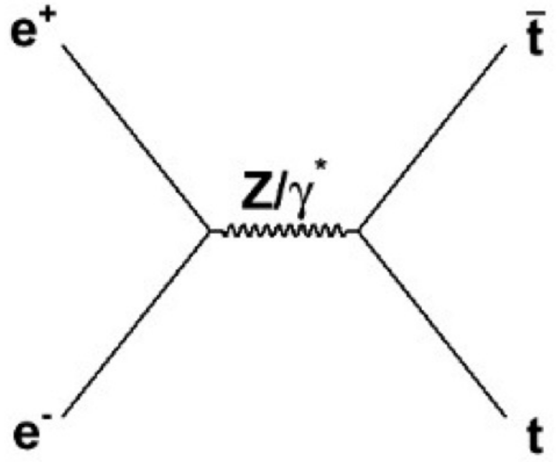
- $l\bar{l}\nu\bar{\nu}qq$,
  - 3 categories,
  - BDT for classification,
  - **4.6%** precision on Γ_H

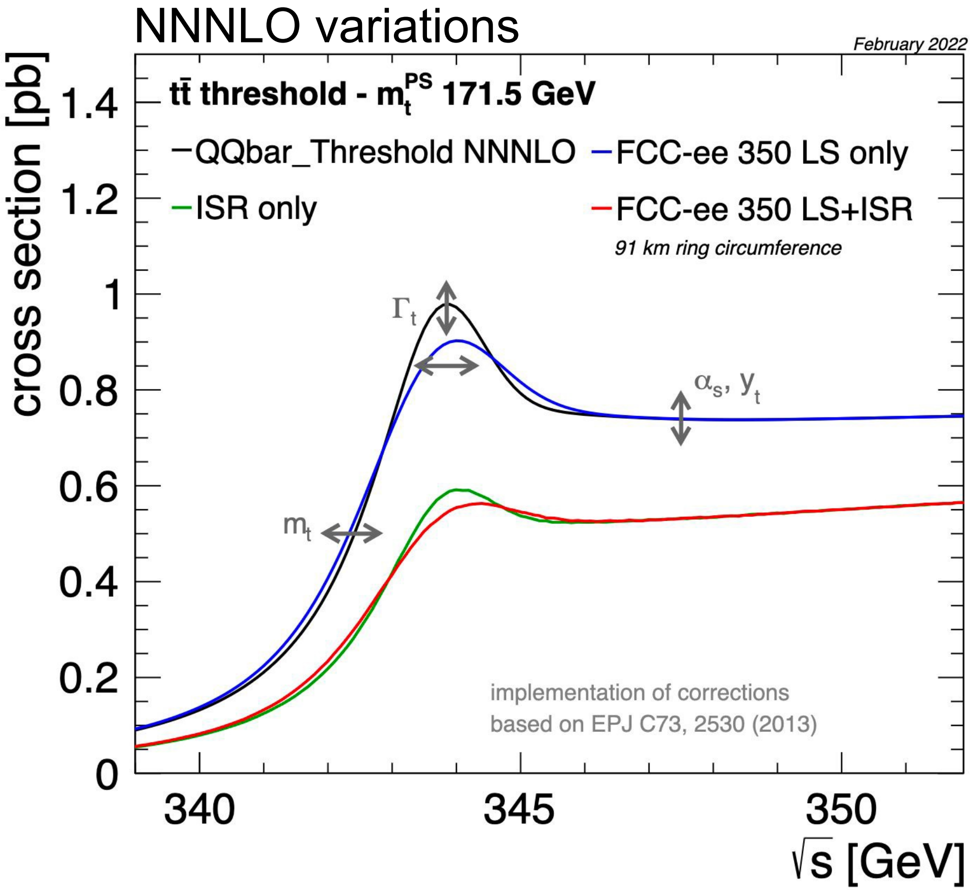


- $l\bar{l}qqqq$,
  - particles from the decay of (low energy) Z and Z* are mixed in the theta/phi plane
  - **12.4%** precision on Γ_H

- $qqqqqq$,
  - BDT to classify the events
  - Signal significance is 5.01

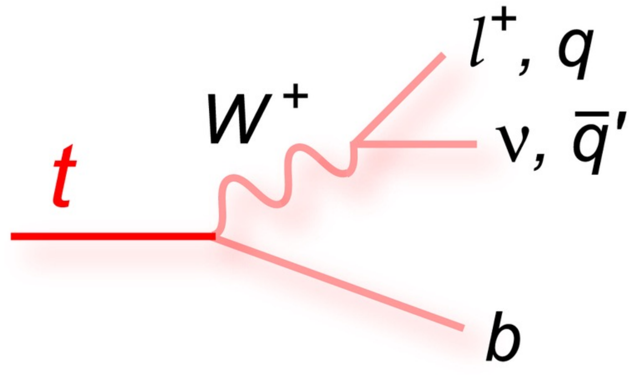
Top mass/threshold scan





- **Relative large uncertainty on top mass (+/- 0.5 GeV from HL-LHC)**
- **Baseline Run plan:**
  - 1 year threshold scan 340–350 GeV in 5 GeV window: total ~ 1.4 ab-1
  - 4 years at 365 GeV: total ~ 2.3 ab-1

Top mass/threshold scan



Signal

$$e^+e^- \rightarrow WbWb$$

Background

$$e^+e^- \rightarrow WW$$

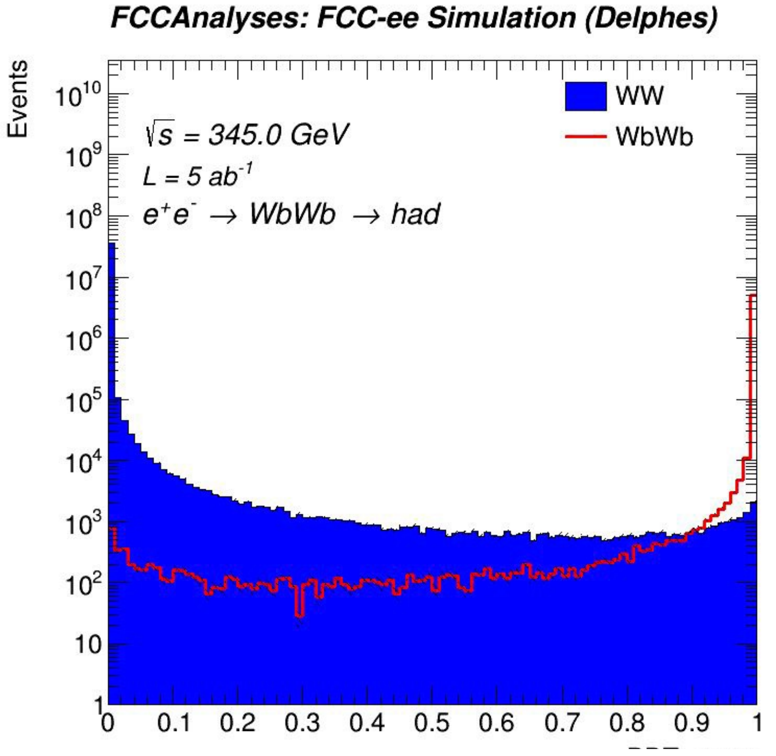
2 Categories

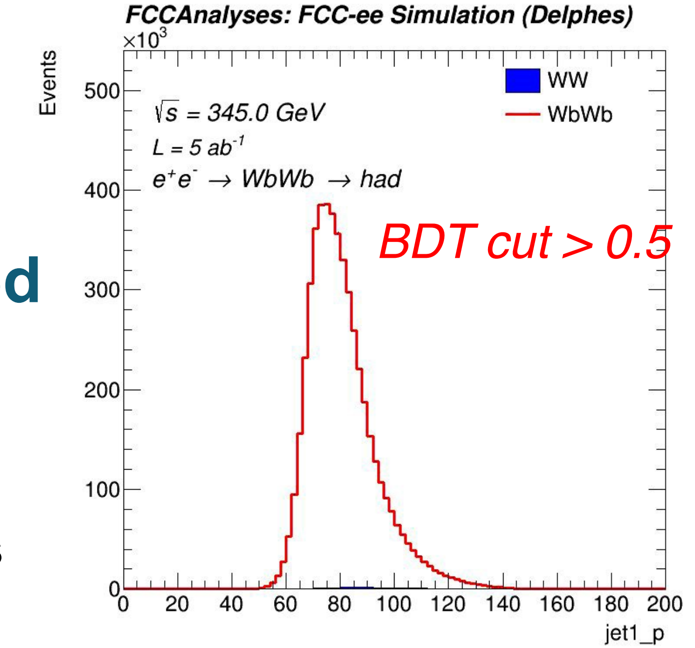
- Lepton + jets
- Full Hadronic

} ~80% of total branching ratio

BDT to separate Signal and background

- **Extremely pure $e^+e^- \rightarrow WbWb$ sample can be obtained**

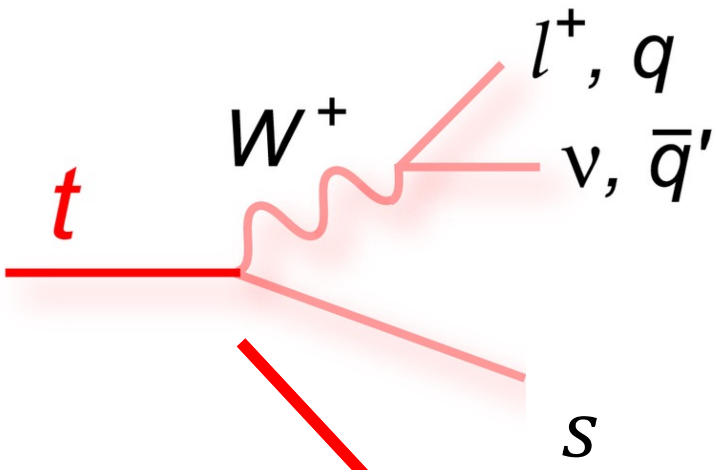




Ankita Mehta,
Matteo Defranchis

CKM matrix V_{ts}

Xunwu Zuo et al



$$\frac{-g}{\sqrt{2}}(\overline{u_L}, \overline{c_L}, \overline{t_L})\gamma^\mu W_\mu^+ V_{\text{CKM}} \begin{pmatrix} d_L \\ s_L \\ b_L \end{pmatrix}$$

$$V_{\text{CKM}} \equiv V_L^u V_L^{d\dagger} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- **From PDG, $|V_{ts}| = (41.5 \pm 0.9) \times 10^{-3}$**
  - Measured from B_s mixing
  - Dominated by theoretical uncertainties
- **Model independent at FCC-ee**
- **With 1.9×10^6 $t\bar{t}$ events**
  - $1.9\times10^6\times2\times|V_{ts}|^2 \sim$ **6400** $t \to Ws$ events
  - Assuming good s-tagging efficiency and correct reconstruction of W, still need b rejection below 0.1%

Summary

❖ Higgs physics

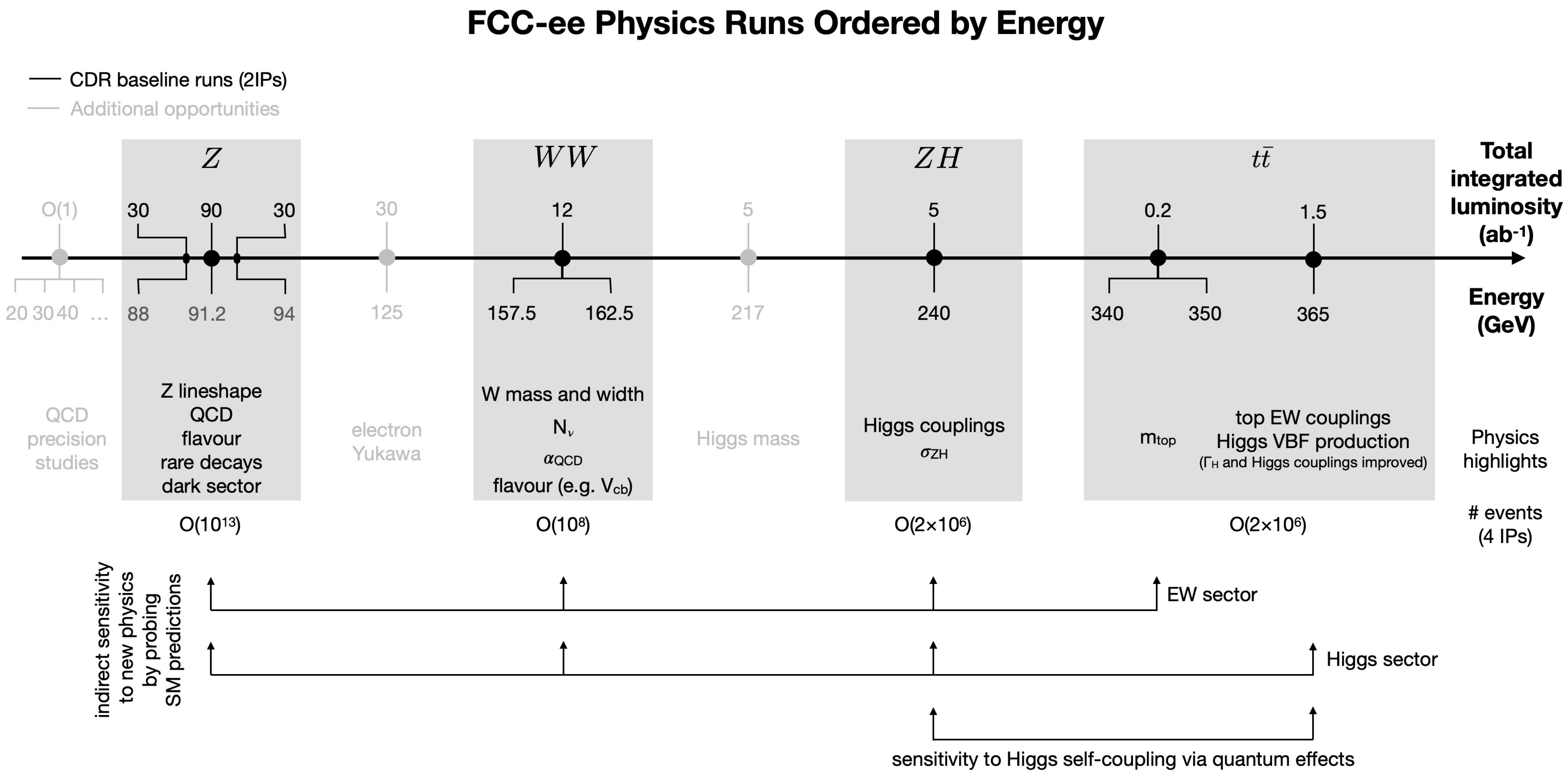
- ✓ Higgs studies mainly at $\sqrt{S} = 240\ \mathrm{GeV}$, 365 GeV as a complementary point
- ✓ Higgs mass uncertainty reach 4 MeV (at 240 GeV), ~24 MeV (at 365 GeV)
- ✓ ZH cross-section reach ~0.69% (at 240 GeV), ~1.10% (at 365 GeV)
- ✓ Higgs with has been done in different channels, Combining more channels
- ❑ More and more analysis start looking at 365 GeV opportunities

❖ Top

✓Top mass/threshold scan, BDT has very good background rejection
✓CKM matrix V_{ts} measurement has started

Backup

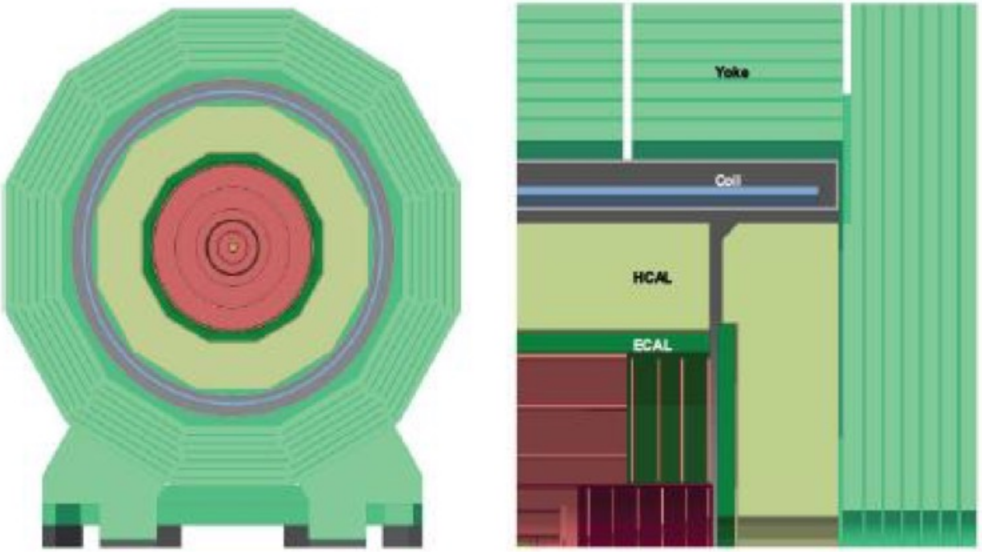
FCC-ee



FCC-ee Physics Runs Ordered by Energy
CDR baseline runs (2IPs)
Additional opportunities
Z
WW
ZH
tt̄
Total integrated luminosity (ab⁻¹)
O(1)
30
90
30
30
12
5
5
0.2
1.5
20 30 40 …
88
91.2
94
125
157.5
162.5
217
240
340
350
365
Energy (GeV)
QCD precision studies
Z lineshape
QCD
flavour
rare decays
dark sector
electron Yukawa
W mass and width
N_ν
α_{QCD}
flavour (e.g. V_{cb})
Higgs mass
Higgs couplings
σ_{ZH}
m_{top}
top EW couplings
Higgs VBF production
(Γ_H and Higgs couplings improved)
Physics highlights
O(10¹³)
O(10⁸)
O(2×10⁶)
O(2×10⁶)
# events (4 IPs)
indirect sensitivity to new physics by probing SM predictions
EW sector
Higgs sector
sensitivity to Higgs self-coupling via quantum effects

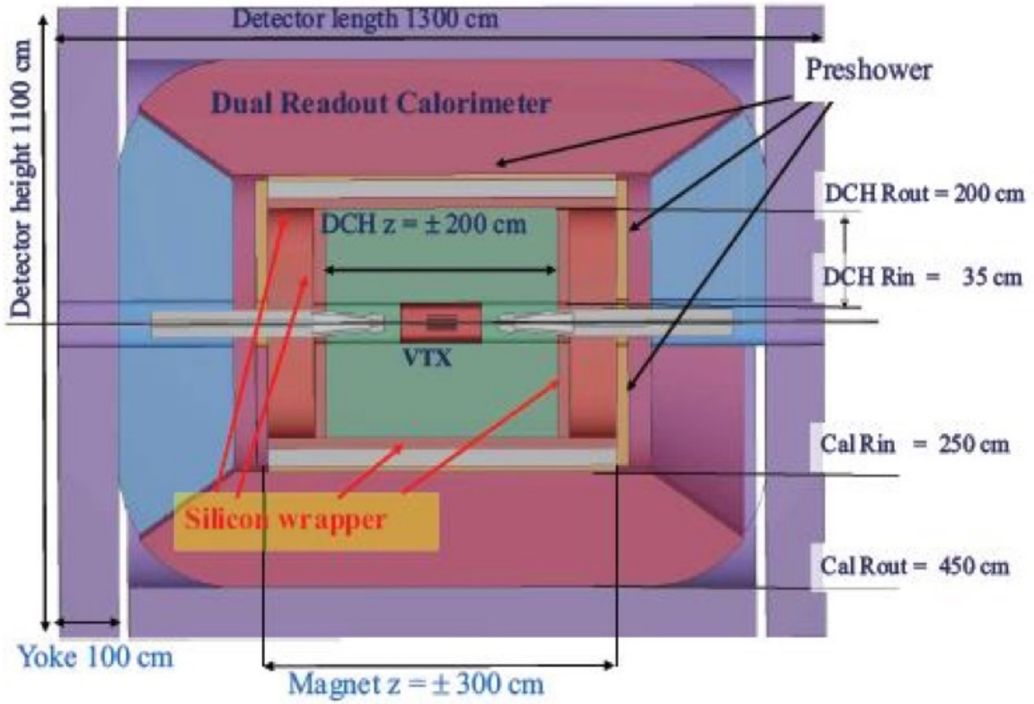
Detectors

CLD



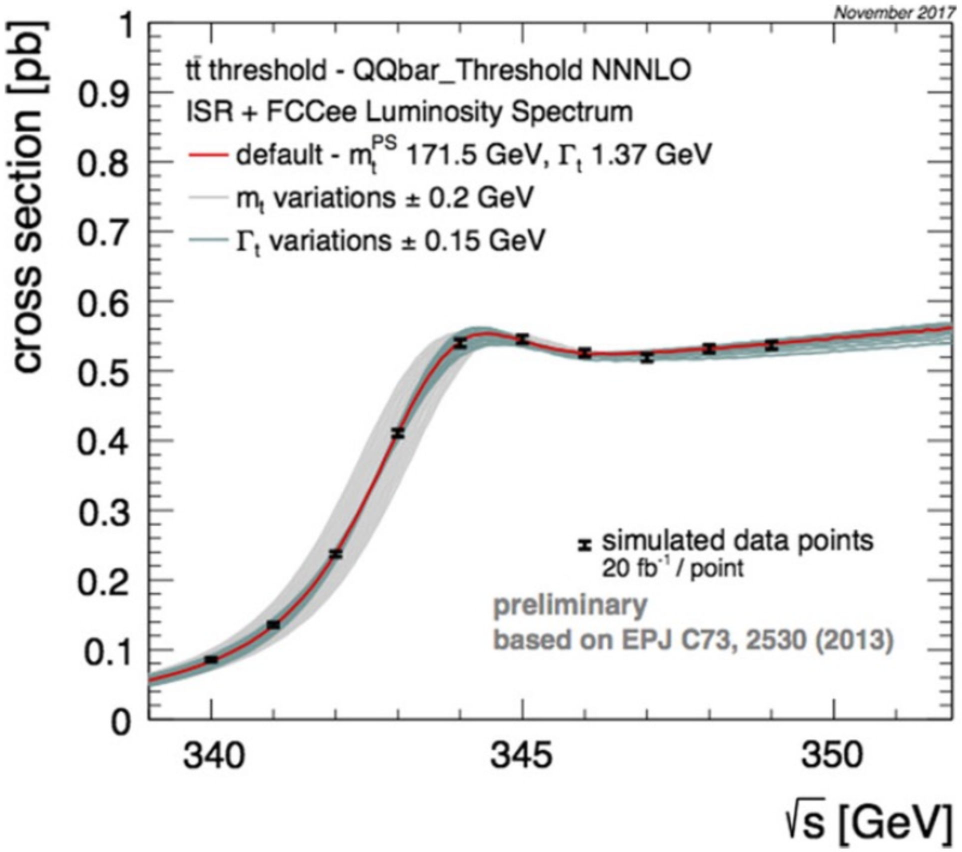
- conceptually extended from the CLIC detector design
  - full silicon tracker
  - 2T magnetic field
  - high granular silicon-tungsten ECAL
  - high granular scintillator-steel HCAL
  - instrumented steel-yoke with RPC for muon detection

IDEA

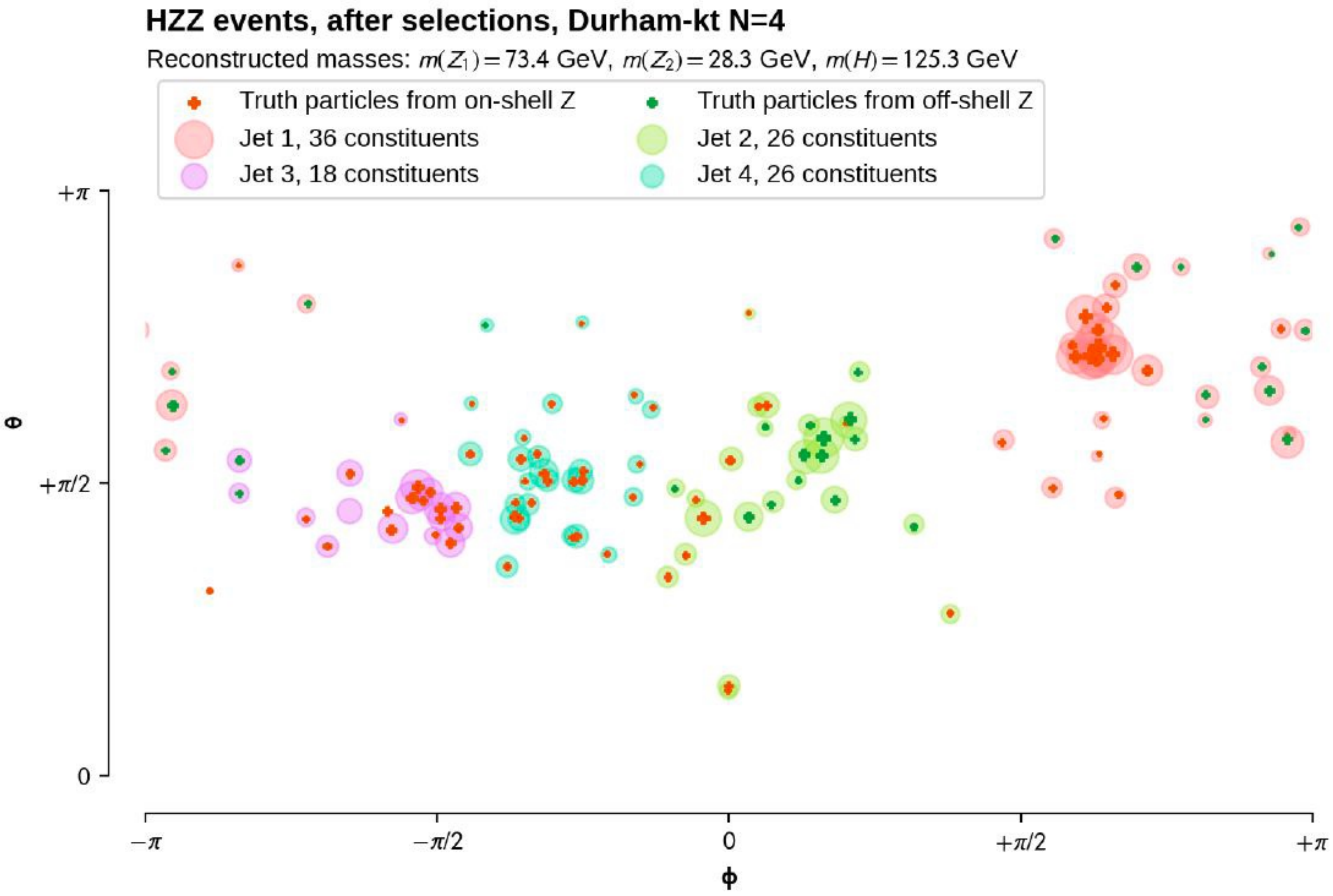


- explicitly designed for FCC-ee/CepC
  - silicon vertex
  - low X_0 drift chamber
  - drift-chamber silicon wrapper
  - MPGD/magnet coil/lead preshower
  - dual-readout calorimeter: lead-scintillating/ cerenkhov fibers
- µRwell for muon detection

Top mass/threshold scan



Higgs Width


HZZ events, after selections, Durham-kt N=4
Reconstructed masses: $m(Z_1) = 73.4$ GeV, $m(Z_2) = 28.3$ GeV, $m(H) = 125.3$ GeV
Truth particles from on-shell Z
Truth particles from off-shell Z
Jet 1, 36 constituents
Jet 2, 26 constituents
Jet 3, 18 constituents
Jet 4, 26 constituents
$+\pi$
$+\pi/2$
0
θ
$-\pi$
$-\pi/2$
0
$+\pi/2$
$+\pi$
ϕ