ZH and mH studies at FCC-ee

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On behalf of the FCC Collaboration

Higgs2021
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Outline

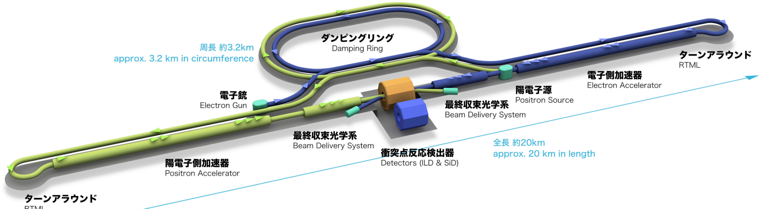
- **Overview of FCC**
- **Recoil mass technique**
- **Event selection**
- **Signal and background modelling**
- **Systematics**

Future Colliders

❑ Future Linear Colliders:

1. International Linear Collider (ILC)

1) e^+e^- at 250GeV, 500 GeV and 1000 GeV
2) 30-50 km



ILC加速器の構成模式図
Schematic illustration of ILC

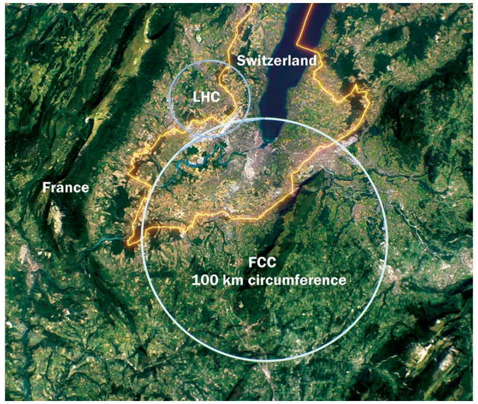
2. The Compact Linear Collider (CLIC)

1) e^+e^- at 380 GeV, 1.5 TeV and 3 TeV
2) 11-50 km

❑ Future Circular Colliders:

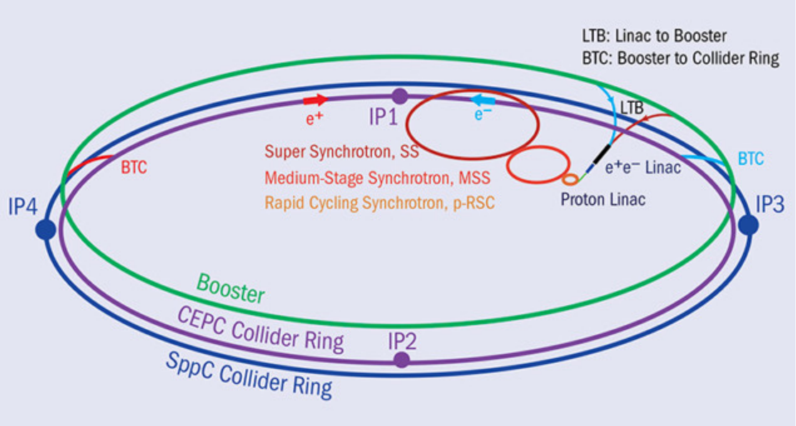
1. The Future Circular Collider (FCC)

1) FCC-ee: e^+e^- at ~125-365 GeV, as first-generation Z, Higgs and top factory at high luminosities
2) FCC-hh: $p-p$ at 100 TeV as natural continuation of LHC at energy frontier
3) Circumference ~90 km (LHC: ~27 KM)

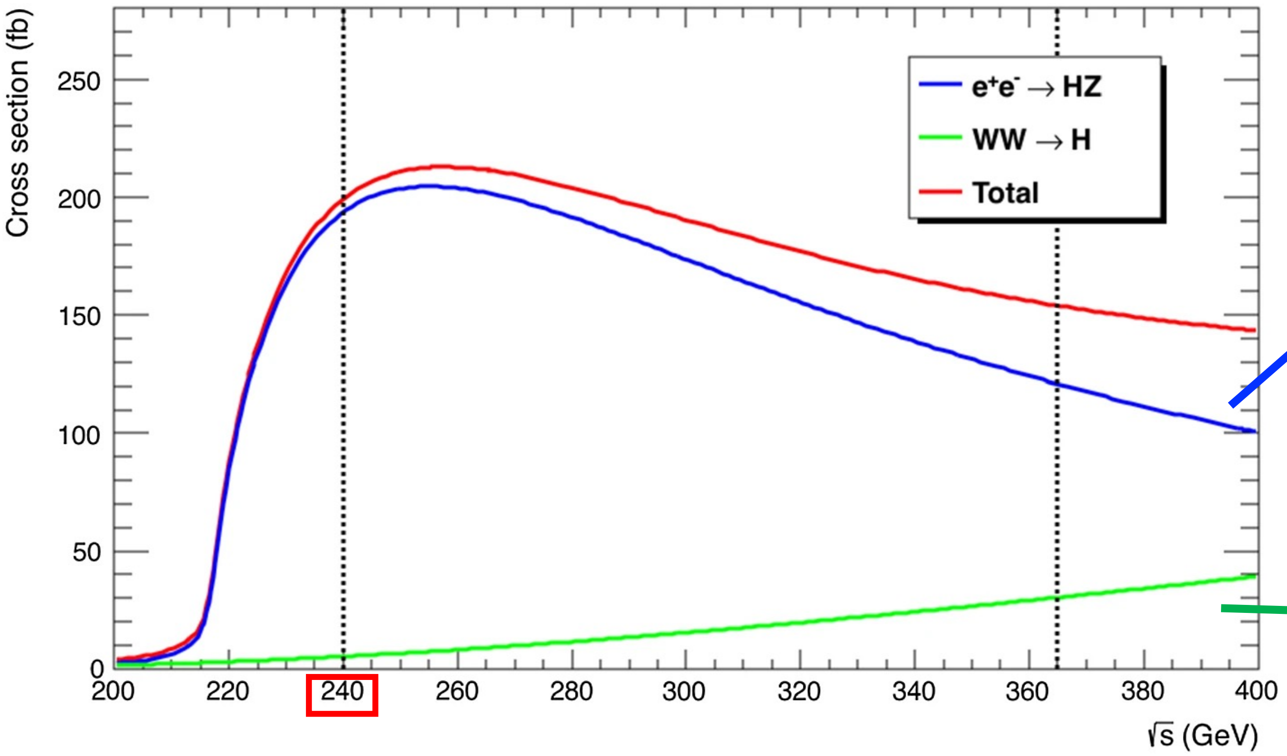


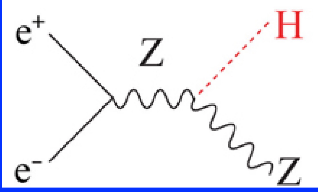
2. Circular Electron Positron Collider (CEPC)

1) e^+e^- with similar parameters as FCC-ee
2) Super Proton–Proton Collider (SppC)

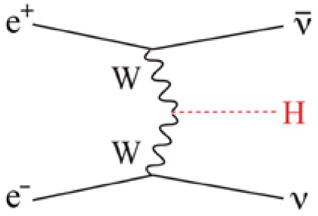


Higgs production at Future Circular Collider (FCC)





- s-channel, cross-section maximal above the threshold of the process



- t-channel, cross-section grows logarithmically with the centre-of-mass energy

❖FCC-ee as a Higgs factory

- ➢Total Cross-section maximizes at $\sqrt{s} \sim 260$ GeV
- ➢For the Higgs-strahlung $(e^+e^- \rightarrow ZH)$:
  1. ZH optimal event rate is at $\sqrt{s} \sim 240$ GeV : $\sigma \sim 200$ fb ~ 10^6 events (@ $L = 5\ ab^{-1}$)
  2. With data at $\sqrt{s} \sim 365$ GeV, 1.8×10^5 ZH and 0.45×10^5 WW-fusions (~30%) (@ $L = 1.5\ ab^{-1}$)
     (useful for measuring self-coupling and Γ_H precisely)

"Higgs recoil mass" technique at Future Circular Collider (FCC)

- Goal: precise measurements of ZH cross section (per mille) and Higgs mass ~ MeV

  Current best result: $m_H = 125.38 \pm 0.14(\pm 0.12)$ GeV @CMS

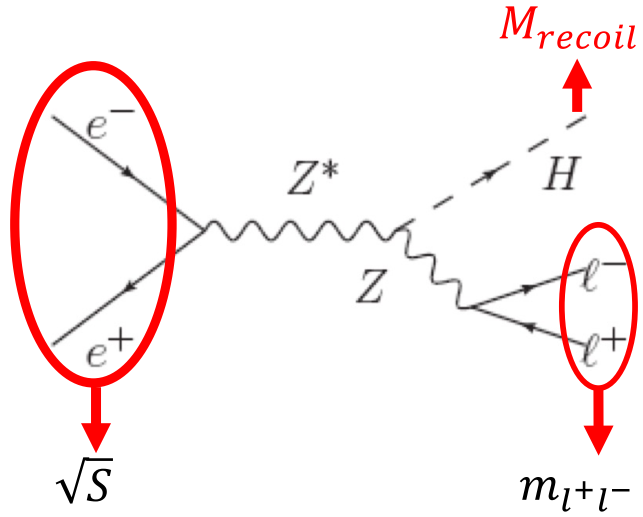
  The σ_{ZH} accuracy could reach 0.5%

  determine g_{HZZ} and Higgs width (Γ_H)

  Electron Yukawa coupling measurement via s-channel

  $e^+e^- \rightarrow H$ @$\sqrt{S} = m_H$ ($\Gamma_H = 4.2$ MeV)(details on talk of Davide d'Enterria)

  Trilinear Higgs-self coupling



- Signal: $e^+e^- \rightarrow ZH \rightarrow l\bar{l} + X$

  ZH is the dominant Higgs production process @ 240 GeV e^+e^-machine

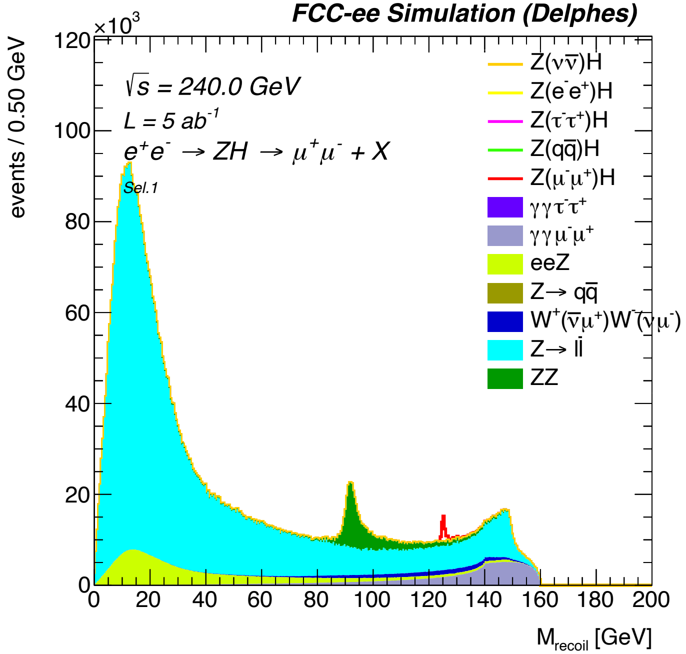
- M_{recoil} from the Z production without measuring the Higgs production final state

$$M_{recoil}^2 = (\sqrt{s} - E_{l\bar{l}})^2 - p_{l\bar{l}}^2 = s - 2E_{l\bar{l}}\sqrt{s} + m_{l\bar{l}}^2$$

- Sensitive to the precise knowledge of the centre-of-mass energy and ISR

- Model-independent study

- WW, ZZ and $Z/\gamma \rightarrow l\bar{l}$ Backgrounds @ 240 GeV

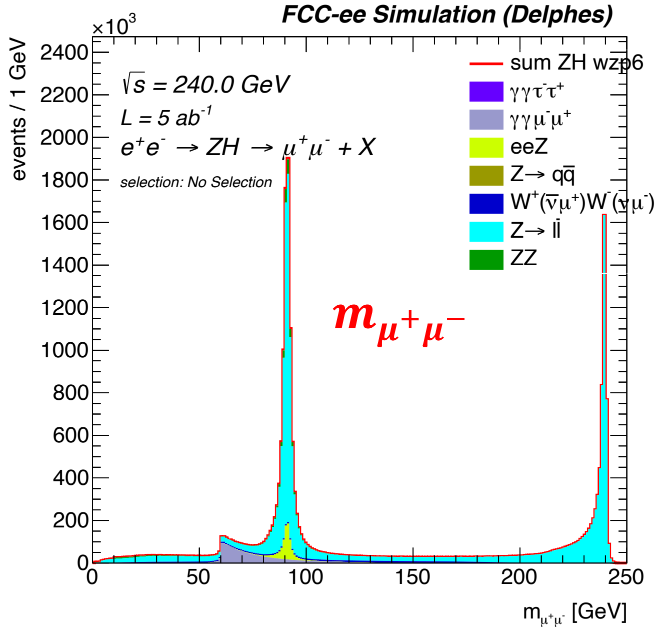


FUTURE CIRCULAR COLLIDER

Signal, Background and Selections

Monte-Carlo campaign ("Spring2021"):

- $\sqrt{s} = 240$ GeV
- Luminosity: $L = 5\ ab^{-1}$
- ISR and FSR on
- Beam Energy Spread (BES) sets to 0.165%= $\pm$ 198MeV
- IDEA detector; detector response modelled with Delphes

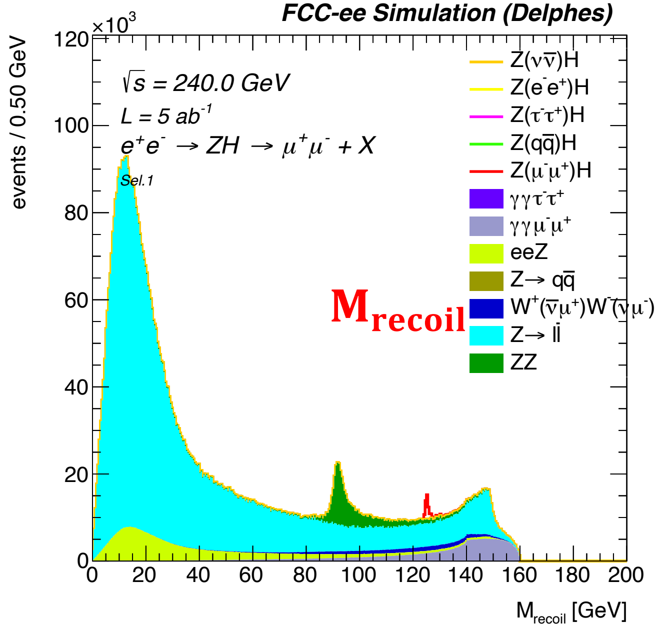


Signals:

1. $Z(\mu^+\mu^-)H$ (Whizard)
2. $Z(\tau^+\tau^-)H$ (Whizard)
3. $Z(q\bar{q})H$ (Whizard)
4. $Z(\nu\bar{\nu})H$ (Whizard)
5. $Z(e^+e^-)H$ (Whizard)

Backgrounds:

1. ZZ(inclusive), (Pythia)
2. $W^+(\nu\mu^+)W^-(\bar{\nu}\mu^-)$, (Pythia)
3. $Z \to l^+l^-$, (Pythia)
4. $Z \to q\bar{q}$, (Pythia)
5. eeZ, (Whizard)
6. $\gamma\gamma \to \mu^+\mu^-$, (Whizard)
7. $\gamma\gamma \to \tau^+\tau^-$ (Whizard)

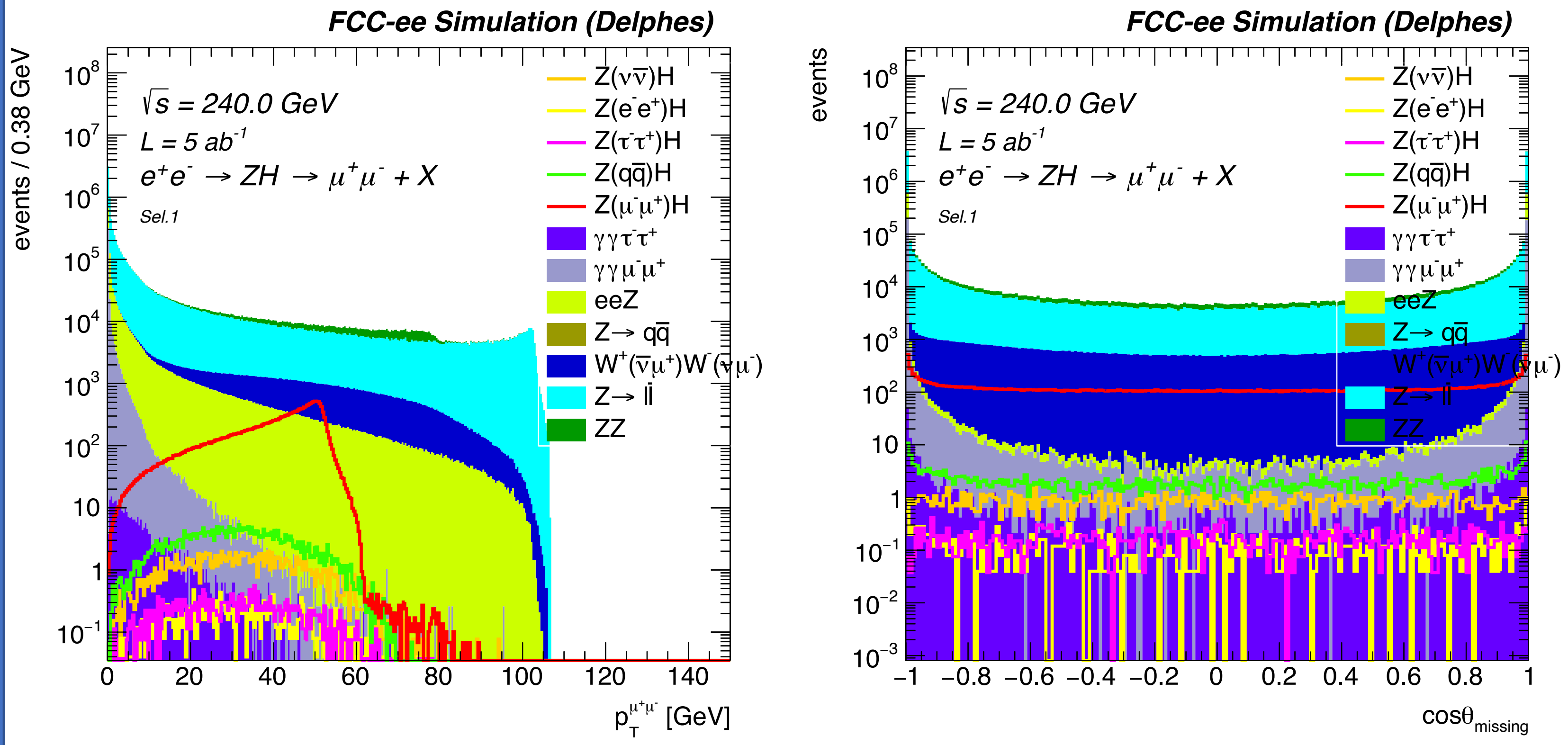


	mumuH	WW_mumu	ZZ(inclusive)	Zll
$\sigma \cdot L$	33822	1289600	6794950	68893500
NEVENTS	10^6	10^7	10^7	$0.99 \cdot 10^7$
NEVENTS/$\sigma \cdot L$	29.57	7.75	1.47	0.14

Event Selections

Event-Selection:

1. At least one Z boson from a $\mu^+\mu^-$ pair
2. $m_{\mu^+\mu^-} \in [86, 96]$ GeV → focus on Z resonance space
3. $M_{\text{recoil}} \in [120, 140]$ GeV → Signal exhibits sharp peak around ~ 125 GeV,
4. $p_T^{\mu^+\mu^-} \in [20, 70]$ GeV → Signal mainly within this region, Low $p_T^{\mu^+\mu^-}$ cuts back-to-back events ($Z/\gamma^* \to ll$)
5. $|\cos\theta_{missing}| < 0.98$ → Polar angle of missing momentum, reduce $\gamma\gamma$ processes. ISR emitted approximately collinear with the incoming beams escapes detection in the beam pipe



After Pre-Selection:

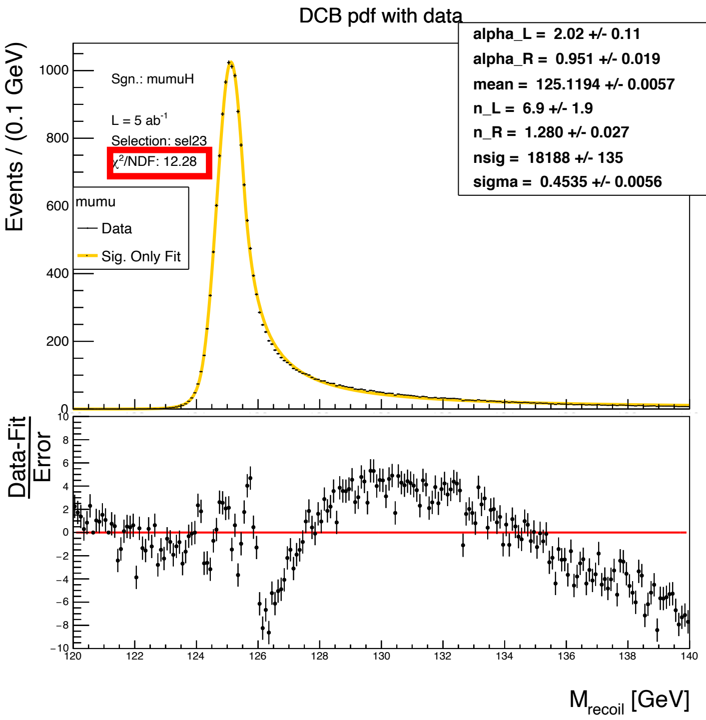
1. At least one Z boson from a $\mu^+\mu^-$ pair
2. $m_{\mu^+\mu^-} \in [80, 100]$ GeV

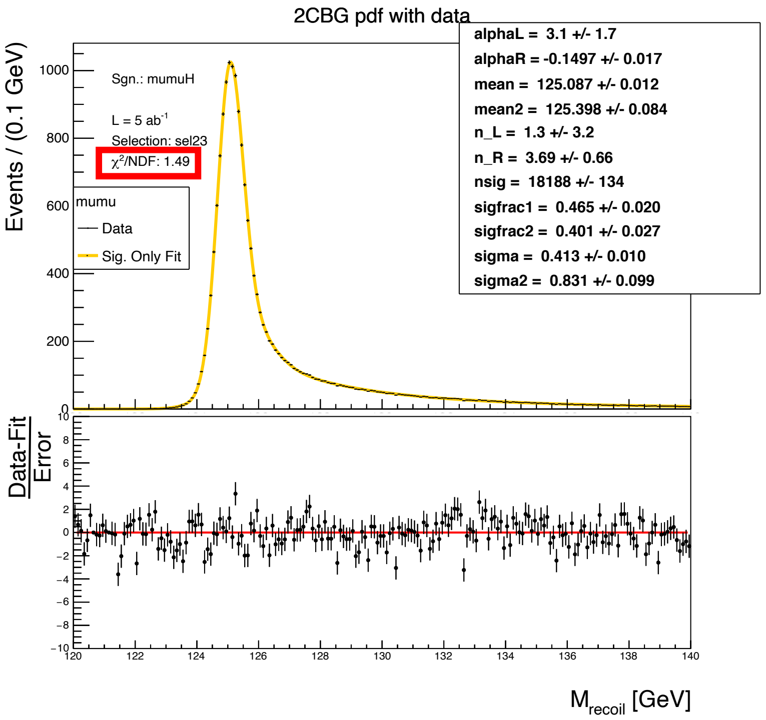
Signal Modelling

Customized p.d.f. 2CBG:

- Two crystal-ball functions (left and right), sharing mean and width
- Added Gaussian to cope with the high tails
- Gaussian suppressed in norm ($sigfrac1 + sigfrac2 > 0.8$)
- In total 10 “free” parameters (+1 normalization)

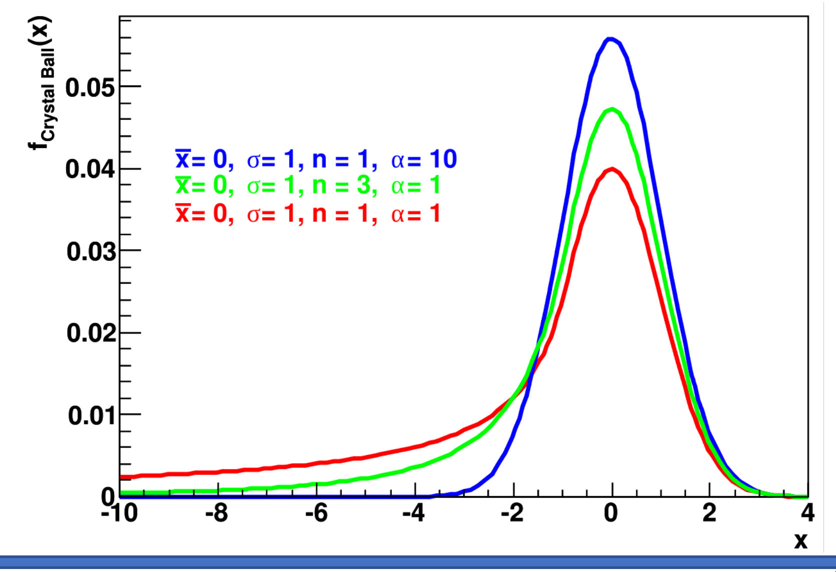
$$pdf(M_{recoil}) = sigfrac1 \cdot CB(M_{recoil}; \mu, \sigma, \alpha_L, n_L) + sigfrac2 \cdot CB(M_{recoil}; \mu, \sigma, \alpha_R, n_R) + (1 - sigfrac1 - sigfrac2) \cdot Gauss(M_{recoil}; \mu_2, \sigma_2)$$





Crystal-Ball function:

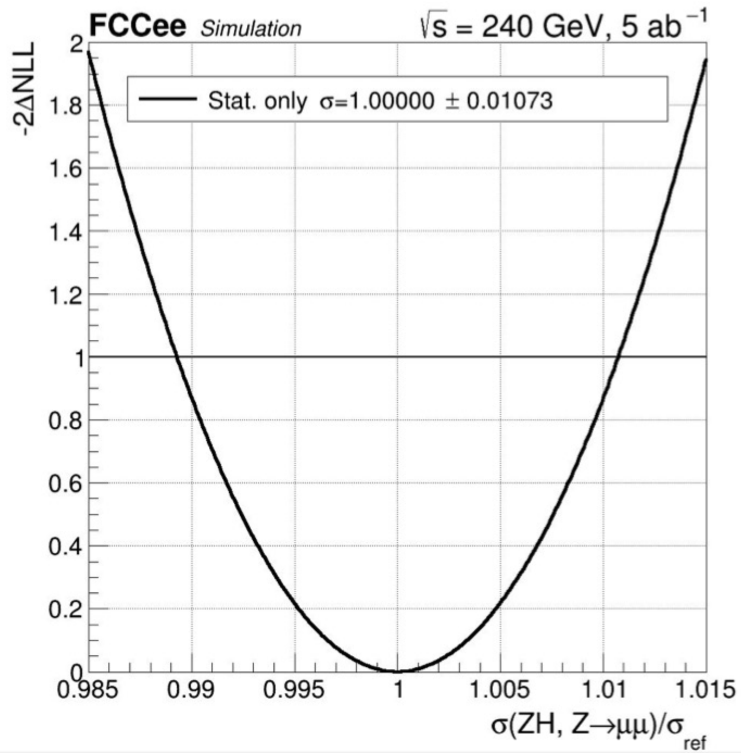
$$f(x;\alpha,n,\bar{x},\sigma) = N \cdot \begin{cases} \exp(-\frac{(x-\bar{x})^2}{2\sigma^2}), & \text{for } \frac{x-\bar{x}}{\sigma} > -\alpha \\ A \cdot (B - \frac{x-\bar{x}}{\sigma})^{-n}, & \text{for } \frac{x-\bar{x}}{\sigma} \leqslant -\alpha \end{cases}$$

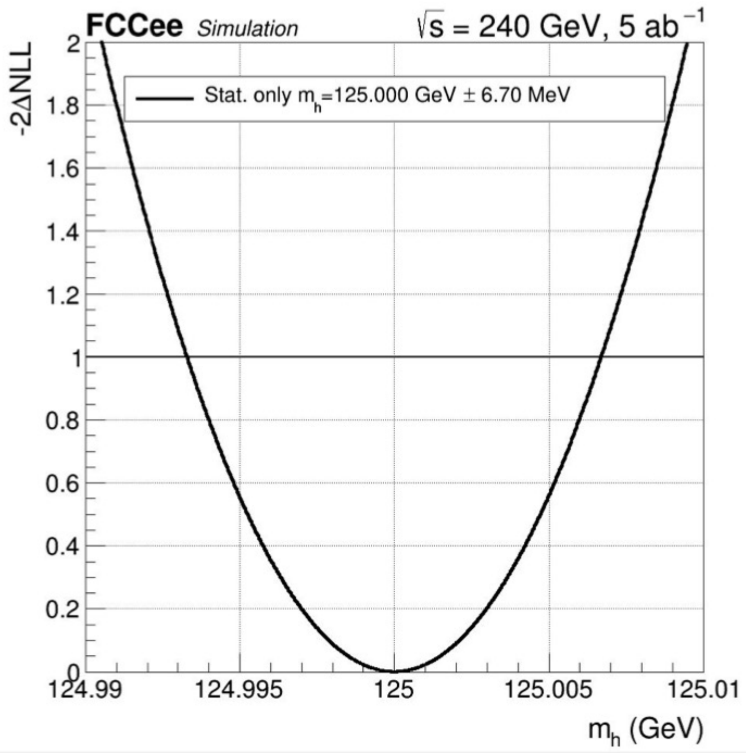


Statistical Analysis

Statistical analysis performed using Combine, the CMS statistical framework developed in context of Higgs analyses (*)

- Signal and background analytical shapes are fitted to pseudo-data Asimov dataset (= randomized with mean=signal+background)
  - Injected 125.0 GeV signal with cross-section of 0.0067656 pb (ref)
  - Free parameters: signal norm, background norm and mH floating
- Likelihood scans to extract cross-sections and Higgs mass with robust uncertainties
- First, w/o accounting for experimental uncertainties → **stat-only result**





Stat-only uncertainties:
→ Cross-section: ~ 1.1 %
→ Higgs mass: 6.70 MeV

(*) The ATLAS, CMS Collaborations, and LHC Higgs Combination Group. Procedure for the LHC Higgs boson search combination in Summer 2011. Technical Report CMS-NOTE-2011-005. ATL-PHYS-PUB-2011-11, CERN, Geneva, Aug 2011

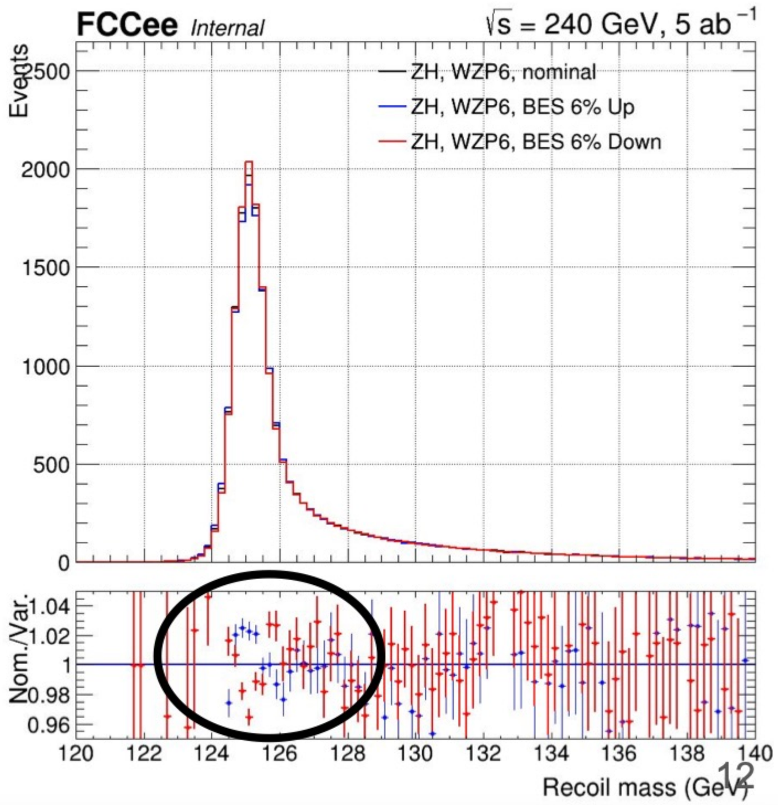
Systematic uncertainties

Study of systematic uncertainties to assess the impact on the Higgs mass and cross-section measurement

- Uncertainties directly alter the recoil distribution shape and/or normalization
- Can be constrained with data, depending on source of uncertainty
- Considered uncertainties: BES, ISR, center-of-mass, muon momentum scale

1) Beam energy spread uncertainty (nominal BES: ± 0.165% = ± 198 MeV)

- Uncertainty driven by accelerator instrumentation: bunch length measurement up to 0.3 mm accuracy or better → **6% BES uncertainty**
- Data-driven BES constraining possible ee→ ff(γ); e.g. longitudinal momentum imbalance of dimuon spectrum and/or Bhabha during fill → **estimated to be 1% BES uncertainty**



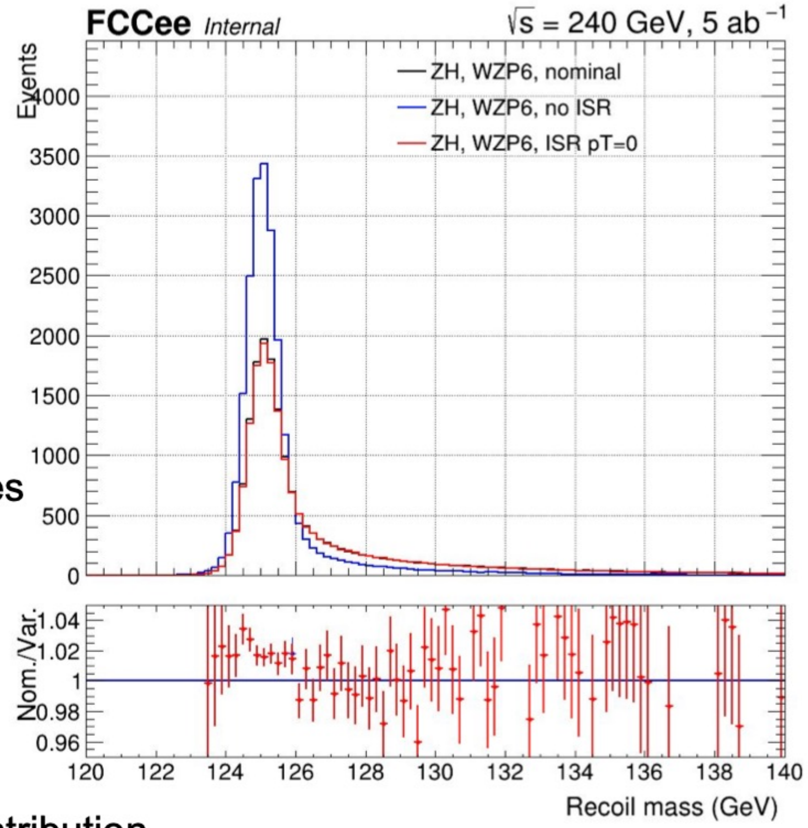
Generated perturbed signal samples @ 125.0 GeV with:

- 6% BES variation: 2-3 % shape effect observed at mass peak
- 1% BES variation: negligible variation ~ within statistical uncertainty

Systematic uncertainties

2) Initial State Radiation: ISR has impact on shape and normalization (xsec)

- ISR treatment in Whizard using structure function approach: photon p_T spectrum
  - either strict collinear approximation ($p_T = 0$)
  - or ad-hoc implementation of a physical spectrum (default sample)
- Generated perturbed sample in the strict collinear approximation
  - rather drastic → **very conservative estimation of ISR uncertainty !**
- Benchmarking against KKMC at Z-peak and/or Sherpa to obtain more realistic uncertainties for ISR treatment
- Can be constrained directly using data-driven techniques (including BES)



3) Center-of-mass: +/- 2 MeV

- $\sqrt{s}$ parameter in the recoil mass definition → uncertainty induces ~ linear shift the recoil distribution
- Precision estimated to be 2 MeV at 240 GeV using radiative return events Z → ll or Z → qq

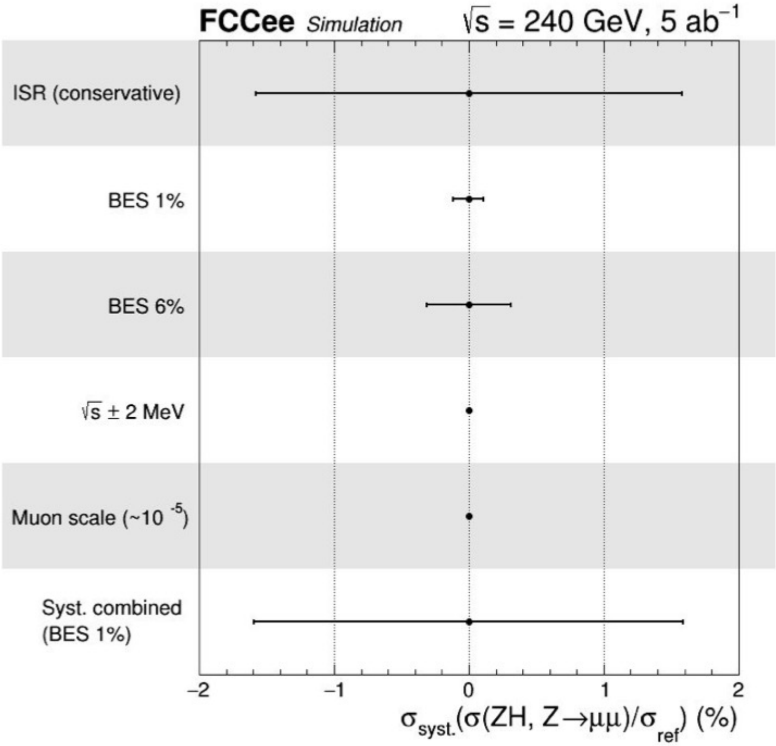
4) Muon momentum scale: relative scale uncertainty variation of 1e-5

- Directly affects m(μμ), hence shift in recoil mass
- Statistical potential to measure muon scale ~ 1e-6, but NMR probes so far limited to yield 1e-5 uncertainty

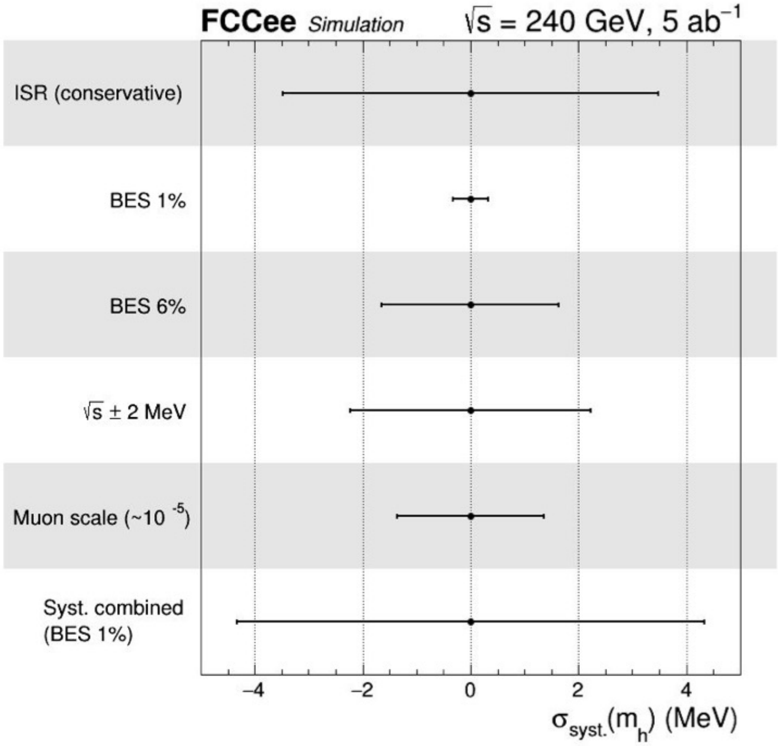
Systematic uncertainties

Systematic variations included in likelihood as Gaussian constraint terms

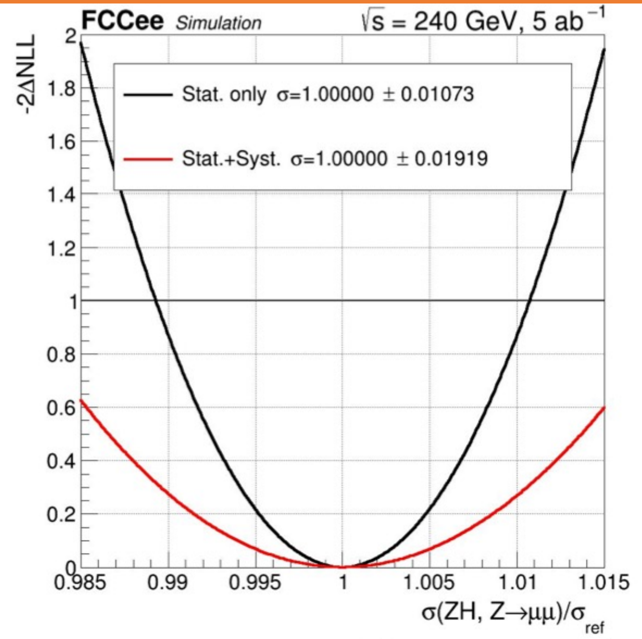
- Inclusion of all systematics: Δm_H = 7.98 MeV and $\Delta\sigma$ = 1.92 %
- Breakdown of uncertainties: vary systematics one by one, extract $\sigma^2_{syst} = \sigma^2_{tot} - \sigma^2_{stat}$
- ISR dominant (but conservatively estimated), muon scale/$\sqrt{s}$ accounts for ~ 2 MeV on Δm_H
- Impact on cross-section limited, except ISR

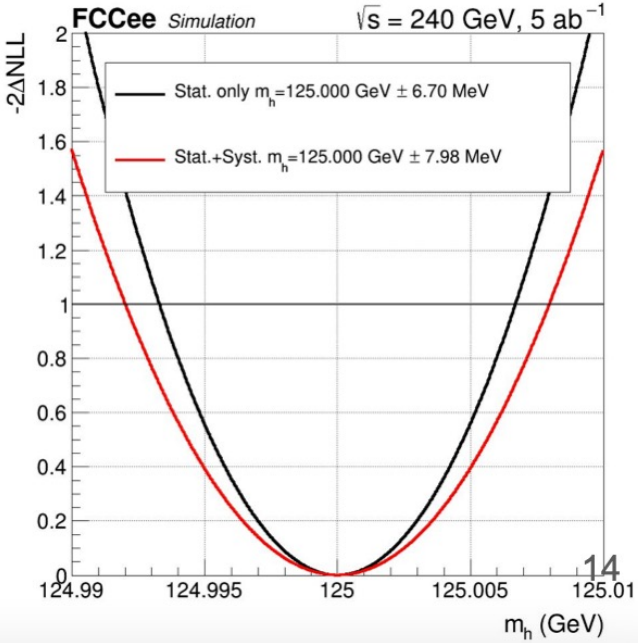


Cross section (%)



Mass (MeV)





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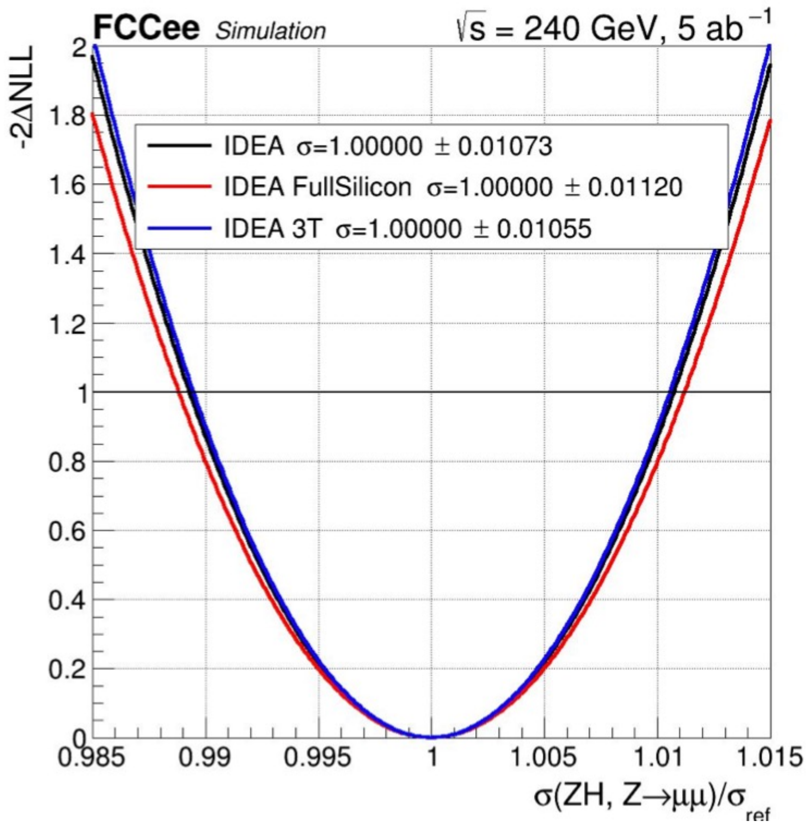
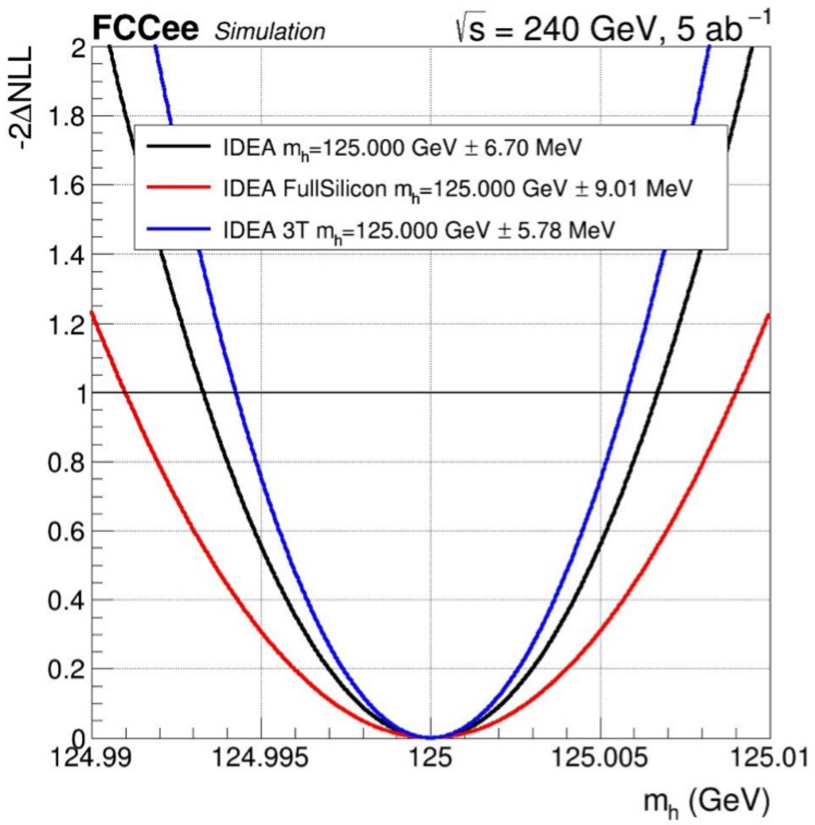
IDEA detector configurations

Different IDEA detector configurations studied:

- Magnetic field increased from 2T to 3T → expected better momentum resolution
- FullSilicon tracker instead of drift chamber → degraded resolution due to enhanced multiple scattering, especially at low p_T and in the range relevant for this analysis
- Effect on mass scales with resolution, impact on cross-section uncertainty limited





Stat-only results

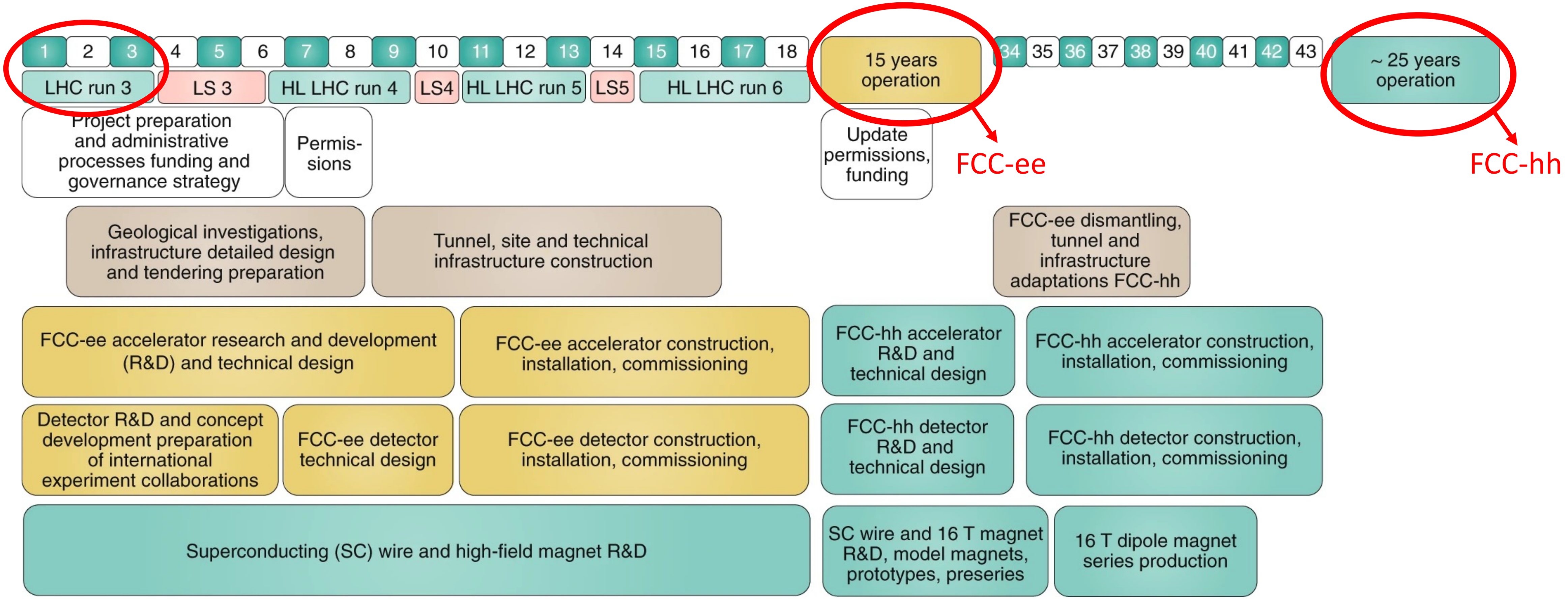
IDEA	Δm_H (MeV)	$\Delta\sigma$ (%)
Nominal	**6.70**	**1.07**
FullSilicon	**9.01**	**1.12**
3T	**5.78**	**1.06**

❖Conclusion:

- In the Higgs measurements at the e^+e^- colliders, the “ZH recoil mass” method will improve the uncertainty of $\mathrm{m_H}$ to several MeV level (while $\Gamma_\mathrm{H} = 4.1\ \mathrm{MeV}$) and measure the g_{HZZ} as a “candle” for other Higgs studies
- Optimized event selection to reject main backgrounds
- Signal modelling with customized p.d.f.
- Statistical analysis yields Higgs mass uncertainty 6.7MeV, cross-section 1.1% (stat-only)
- Inclusion of systematic uncertainties results into 8.0 MeV / 1.9% respectively, where ISR dominant but conservatively estimated

Backup

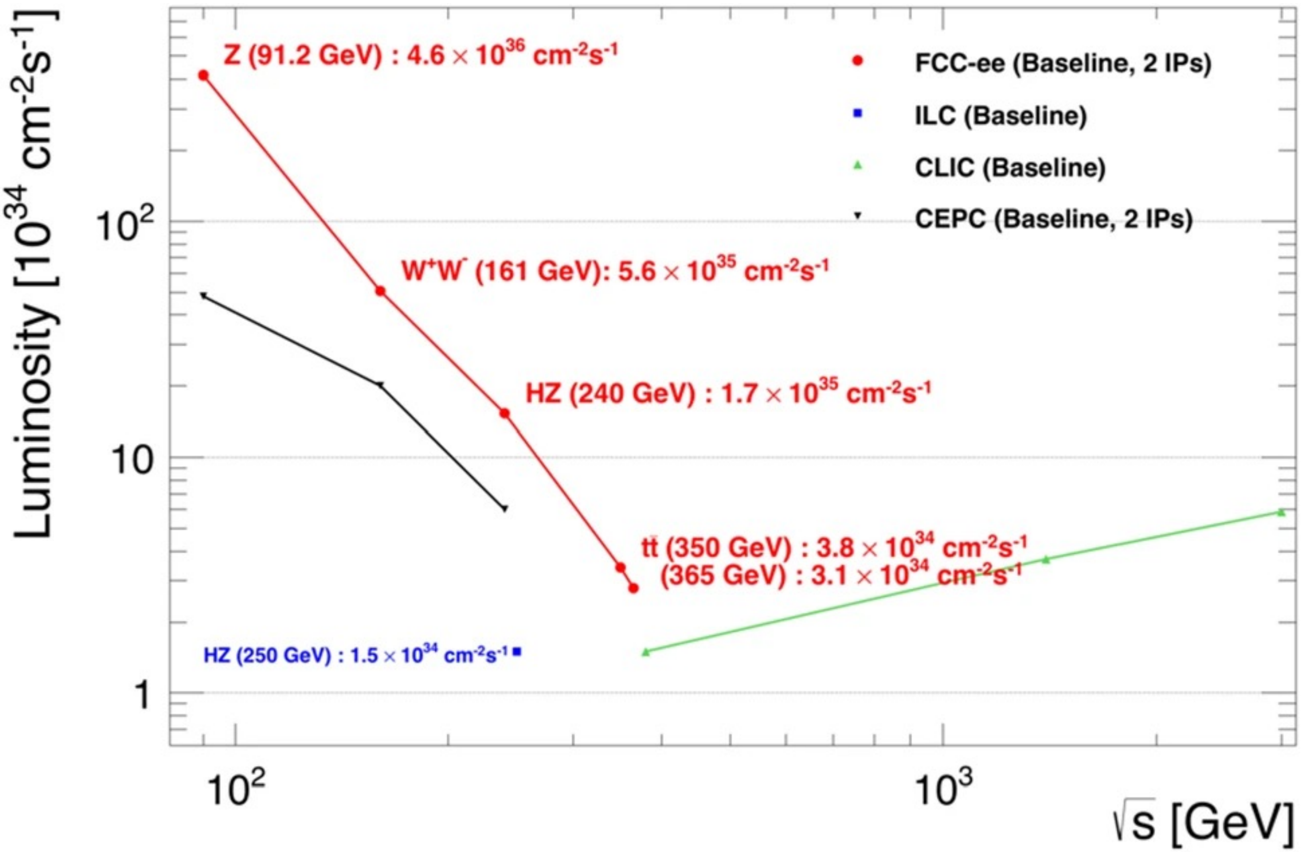
FCC integrated program



1. On the 18 years of preparation
   1) Feasibility study (5 year)
   2) then civil constructions
   3) then machine and detectors construction
2. 15 years of FCC-ee on different energy points
3. ~10 years to change the magnets between, and change the detectors
4. 25 years of FCC-hh

Future Circular Colliders succeeding the LHC

FCC-ee Luminosities



[FCC Physics Opportunities]

- 4 baseline working points
  - Z pole @91.2 MeV
  - W^+W^- threshold @ 161GeV
  - ZH threshold @ 240 GeV
  - $t\bar{t}$ threshold @ 365 GeV

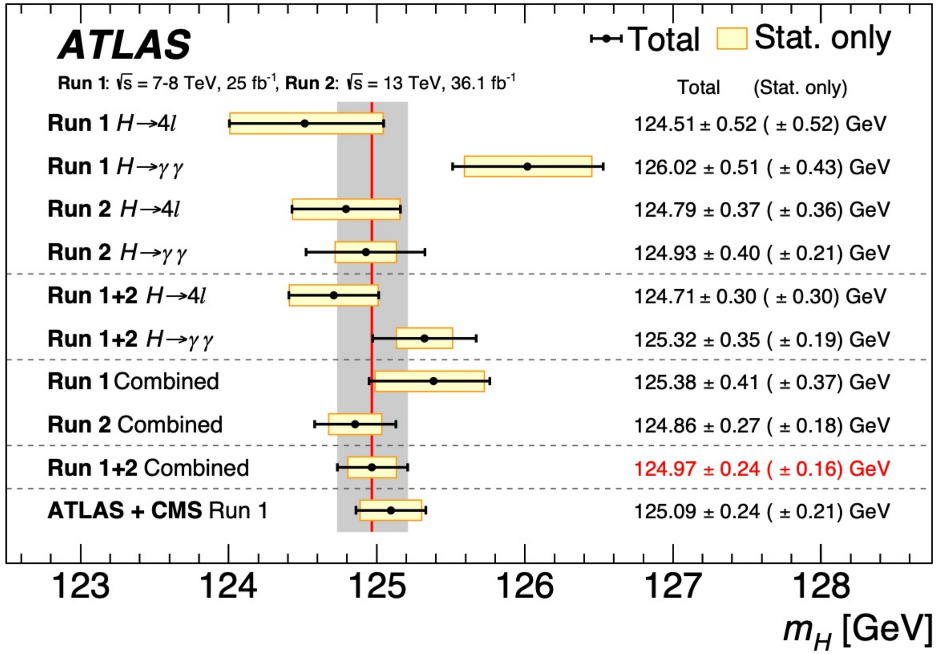
Phase	Run duration (years)	Centre-of-mass energies (GeV)	Integrated luminosity (ab^{-1})	Event statistics
FCC-ee-Z	4	88–95	150	3×10^{12} visible Z decays
FCC-ee-W	2	158–162	12	10^8 WW events
FCC-ee-H	3	240	5	10^6 ZH events
FCC-ee-tt(1)	1	340–350	0.2	$t\bar{t}$ threshold scan
FCC-ee-tt(2)	4	365	1.5	10^6 $t\bar{t}$ events

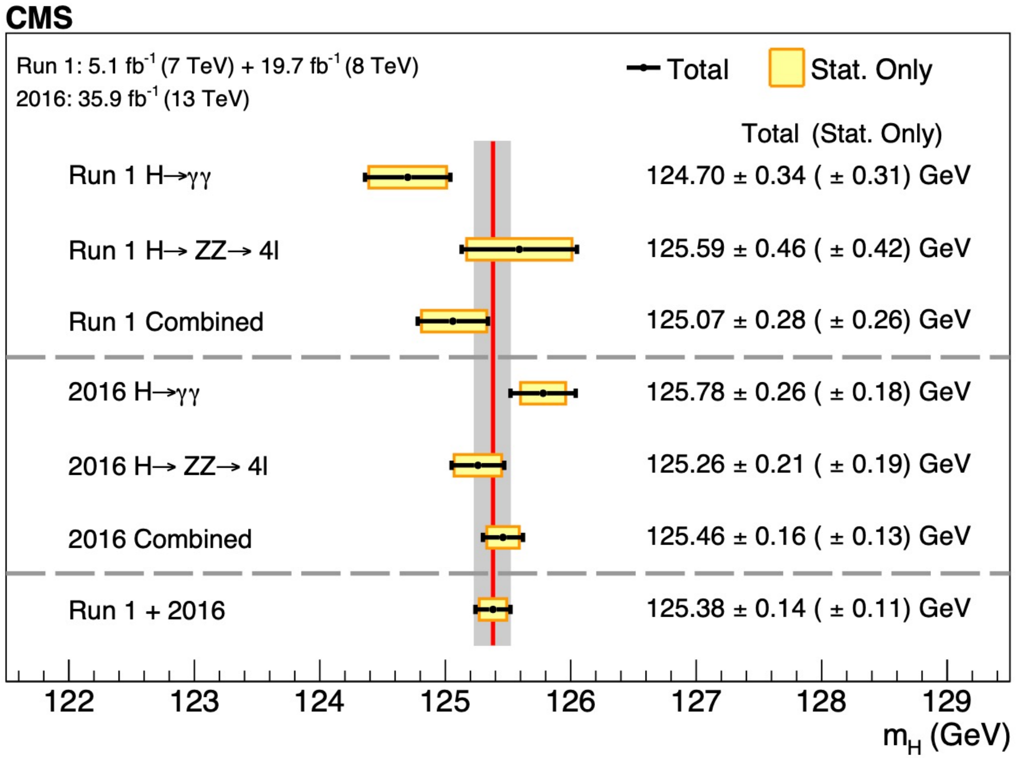
Where are we?

- Last ATLAS public m_H combined result includes 36 fb^{-1} Run 2 + Run 1 data

$$m_H = 124.97 \pm 0.24(\pm 0.16)\text{GeV}$$

Stefano's talk at ATALS WEEK





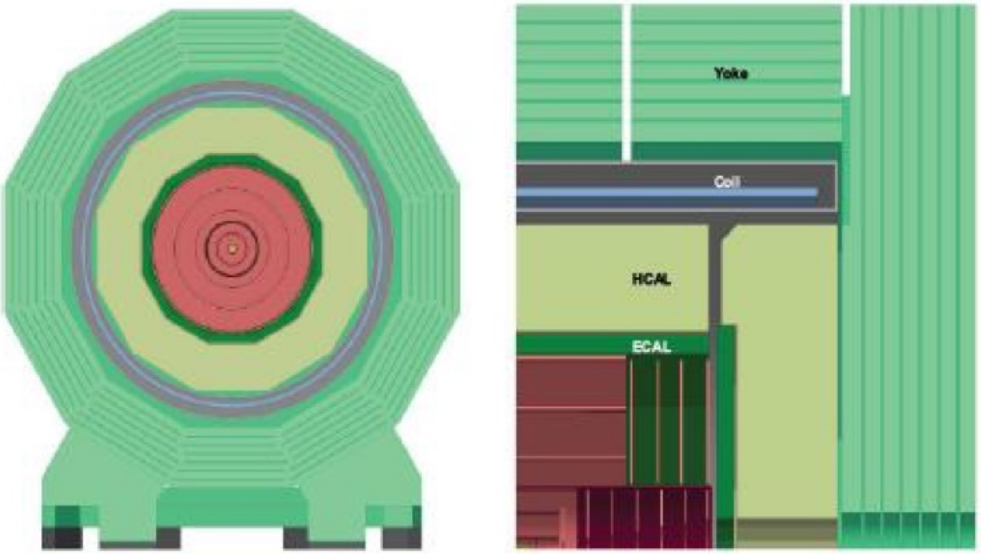
- Current LHC most precise measurement is from CMS

$$m_H = 125.38 \pm 0.14(\pm 0.12)\text{GeV}$$

FCC-ee is expected to reach ~ MeV uncertainty

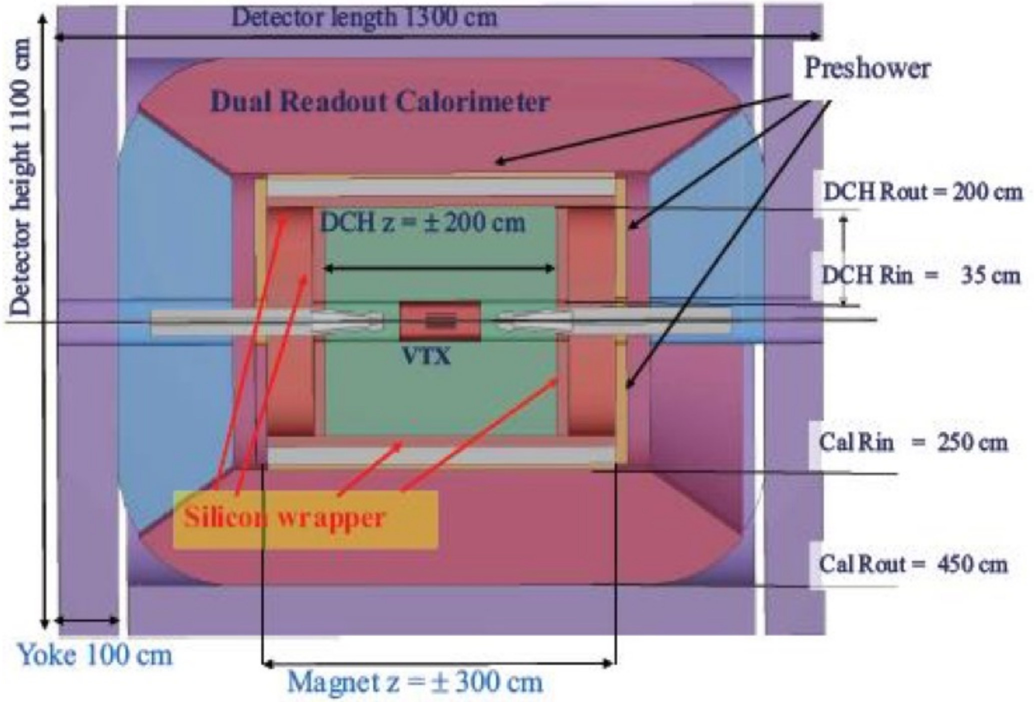
Detectors under study

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

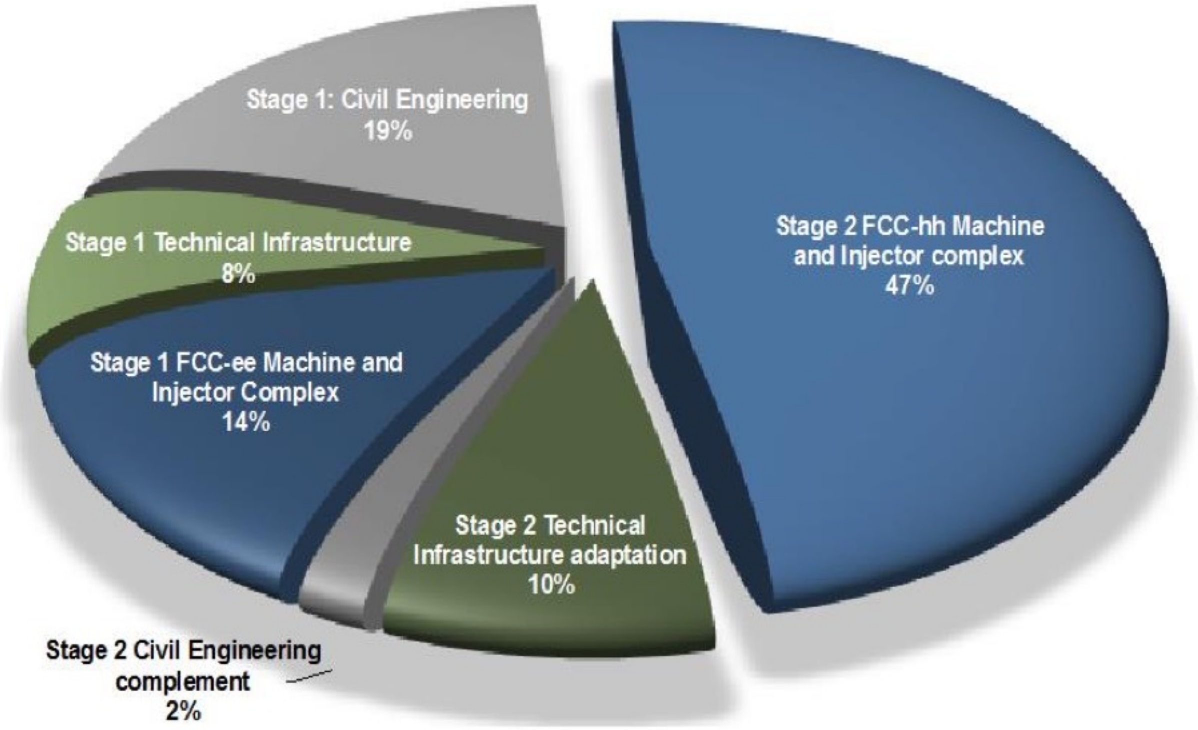
IDEA



- 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

Detectors under study

Domain	Cost in MCHF
Stage 1 - Civil Engineering	5,400
Stage 1 - Technical Infrastructure	2,200
Stage 1 - FCC-ee Machine and Injector Complex	4,000
Stage 2 - Civil Engineering complement	600
Stage 2 - Technical Infrastructure adaptation	2,800
Stage 2 - FCC-hh Machine and Injector complex	13,600
TOTAL construction cost for integral FCC project	**28,600**



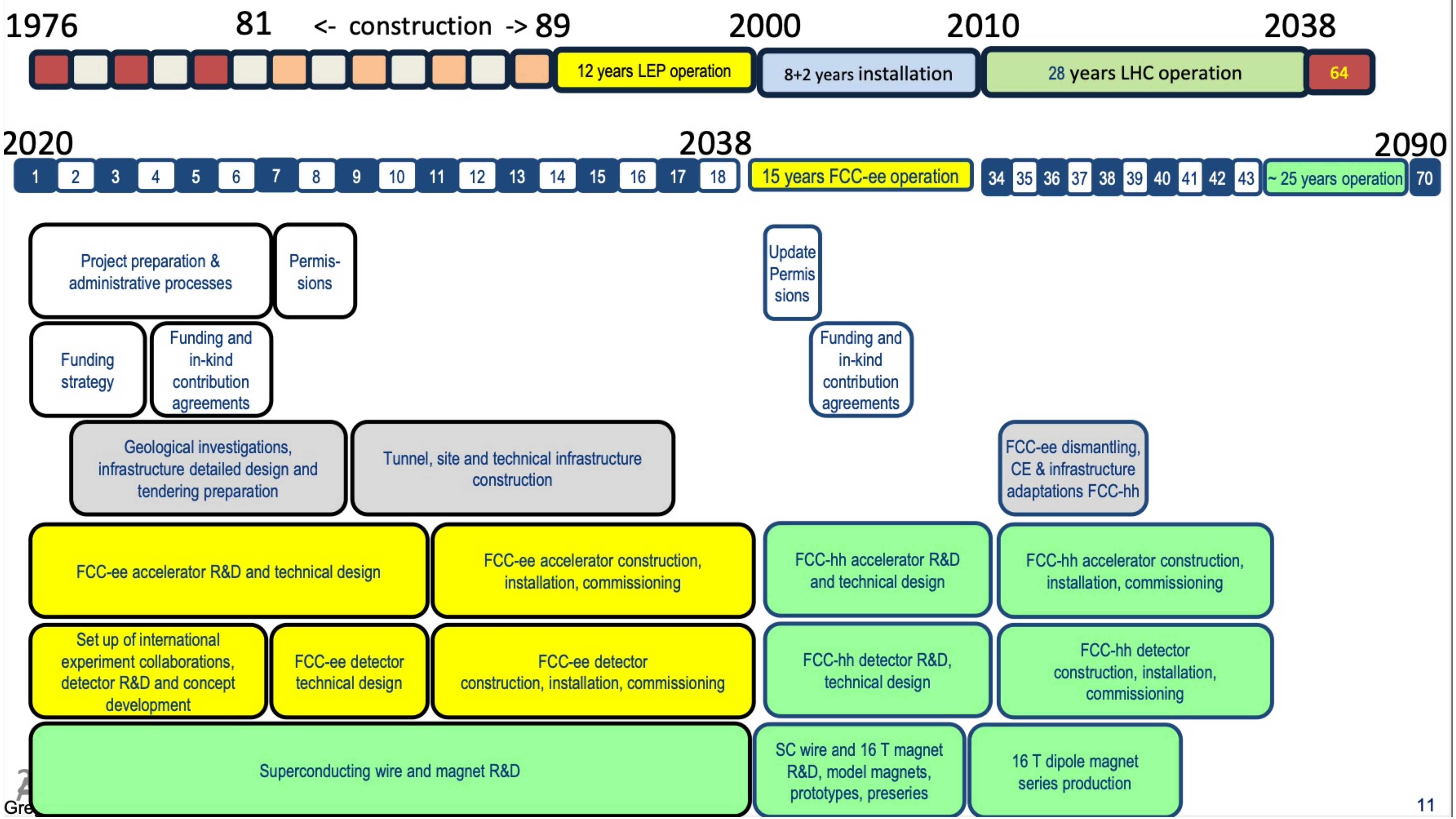
Total construction cost FCC-ee (Z, W, H) amounts to 10.5 BCHF + 1.1 BCHF (tt).

- Associated to a total project duration of ~20 years (2025 – 2045)

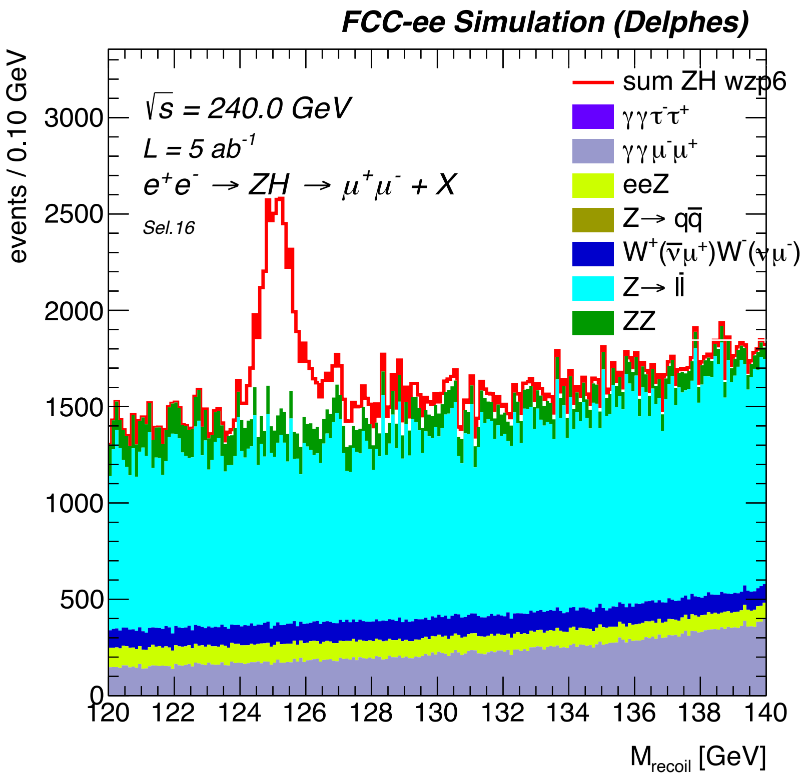
Total construction cost for subsequent FCC-hh amounts to 17 BCHF.

- Associated to a total project duration of ~25 years (2035 – 2060) (FCC-hh stand alone 25 BCHF)

FCC timeline with LEP-LHC



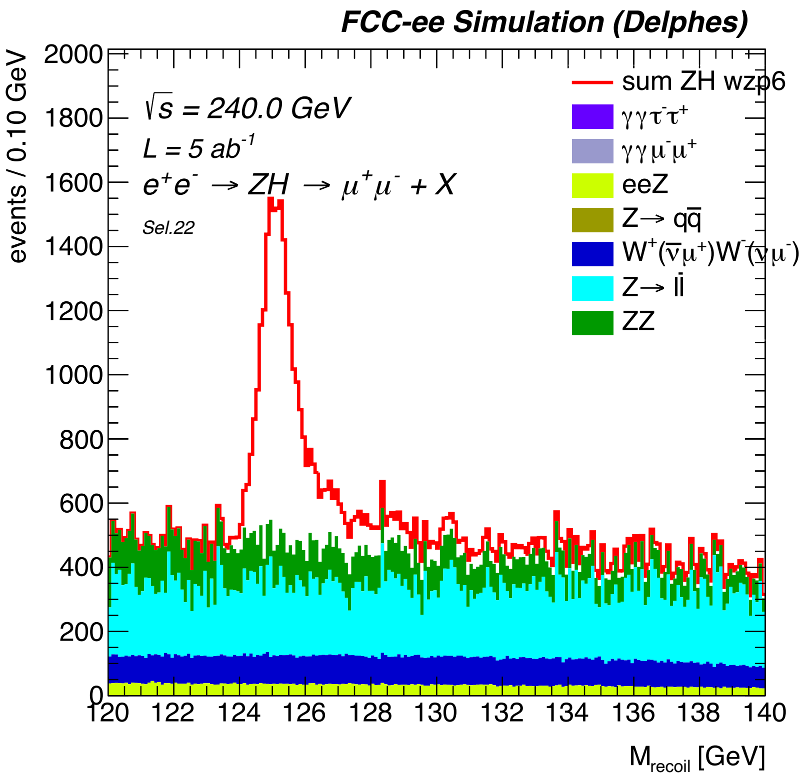
Evaluation of M_{recoil} distribution



APC-0-Selection:

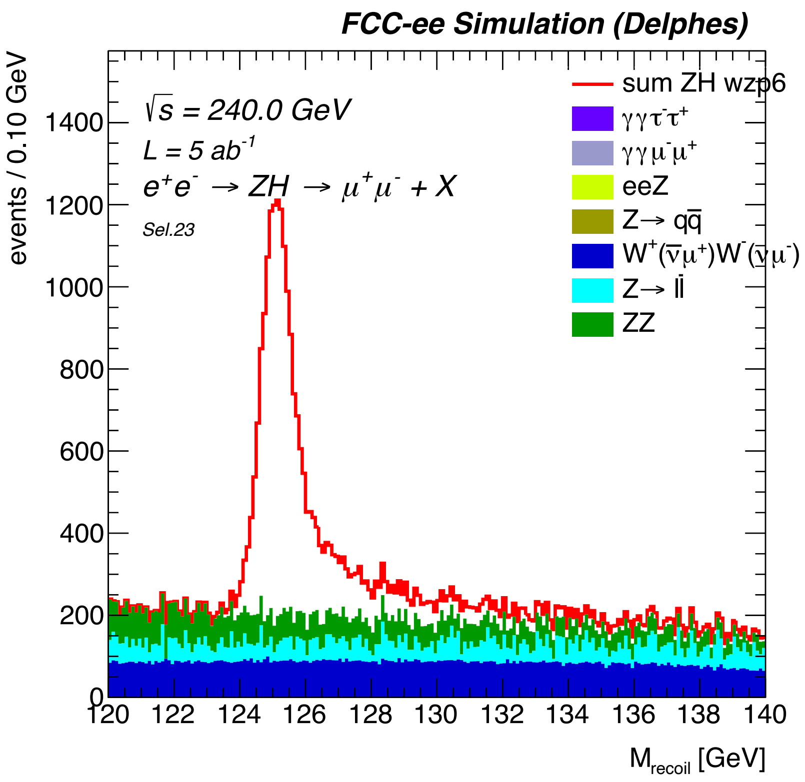
1. At least one Z boson from a $\mu^+\mu^-$ pair
2. $m_{\mu^+\mu^-} \in [86, 96]$ GeV
3. $M_{\text{recoil}} \in [120, 140]$ GeV

Reconstructed Particle



APC-1-Selection:

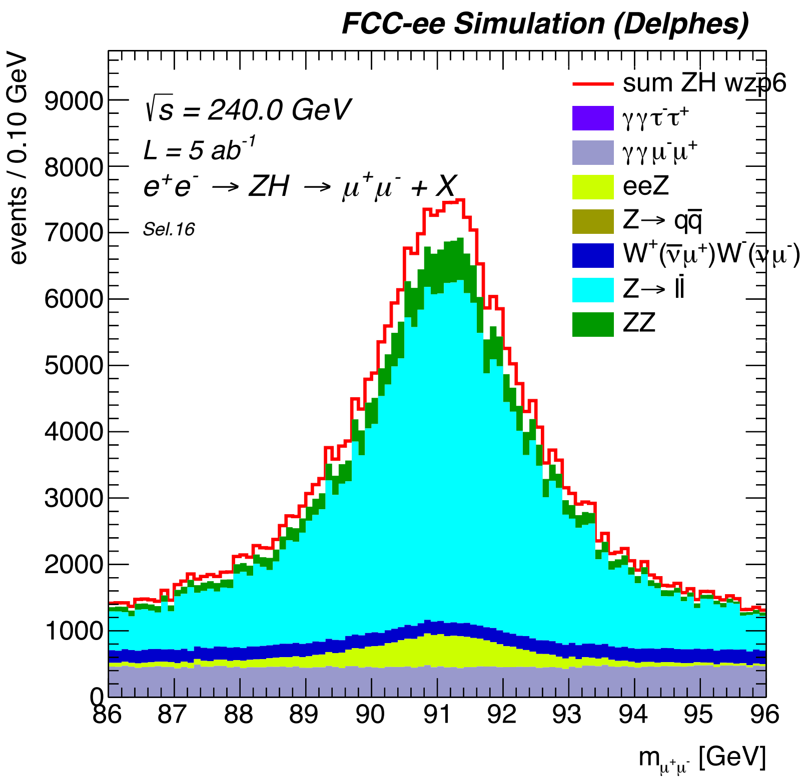
1. At least one Z boson from a $\mu^+\mu^-$ pair
2. $m_{\mu^+\mu^-} \in [86, 96]$ GeV
3. $M_{\text{recoil}} \in [120, 140]$ GeV
4. $p_T^{\mu^+\mu^-} \in [20, 70]$ GeV

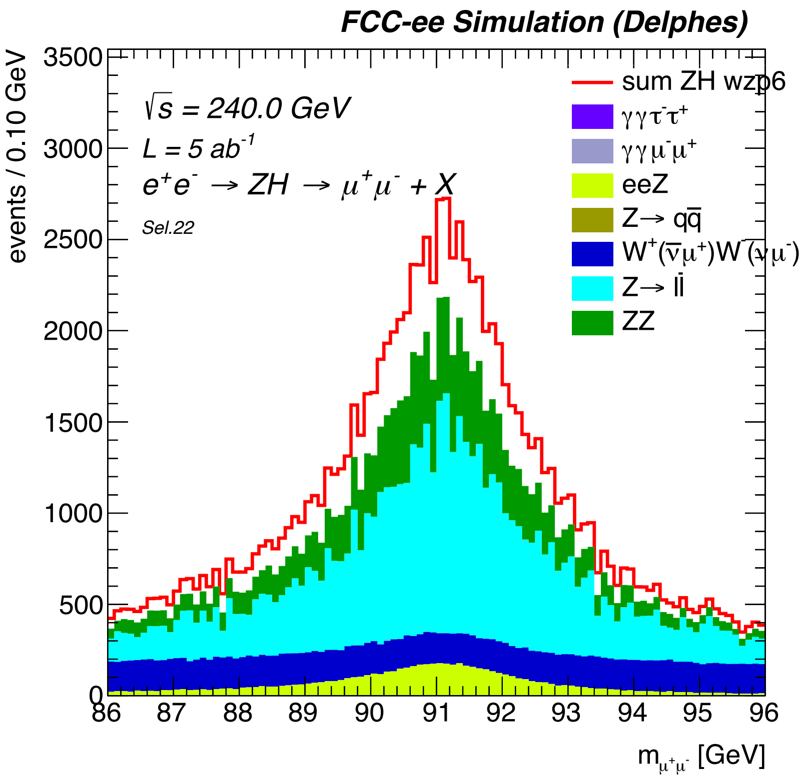


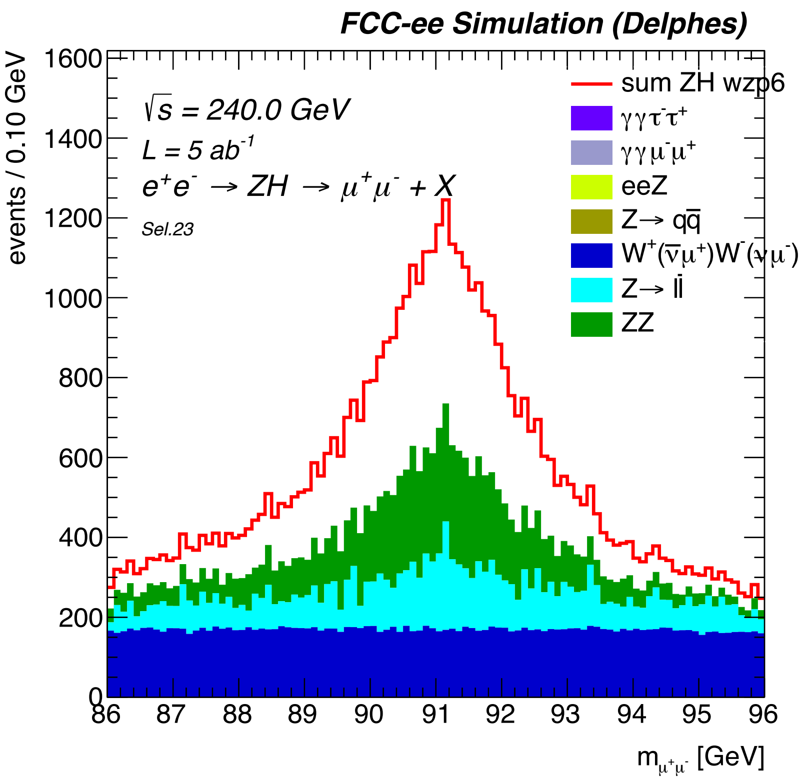
APC-2-Selection:

1. At least one Z boson from a $\mu^+\mu^-$ pair
2. $m_{\mu^+\mu^-} \in [86, 96]$ GeV
3. $M_{\text{recoil}} \in [120, 140]$ GeV
4. $p_T^{\mu^+\mu^-} \in [20, 70]$ GeV
5. $|\cos\theta_{missing}| < 0.98$

Evaluation of $m_{\mu^+\mu^-}$ distribution







APC-0-Selection:

1. At least one Z boson from a $\mu^+\mu^-$ pair
2. $m_{\mu^+\mu^-} \in [86, 96]$ GeV
3. $M_{\text{recoil}} \in [120, 140]$ GeV

APC-1-Selection:

1. At least one Z boson from a $\mu^+\mu^-$ pair
2. $m_{\mu^+\mu^-} \in [86, 96]$ GeV
3. $M_{\text{recoil}} \in [120, 140]$ GeV
4. $p_T^{\mu^+\mu^-} \in [20, 70]$ GeV

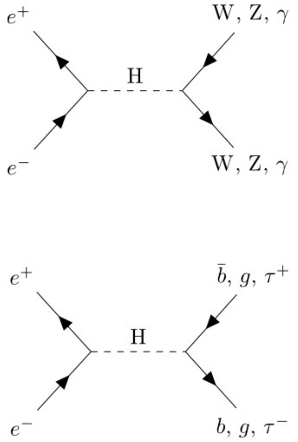
APC-2-Selection:

1. At least one Z boson from a $\mu^+\mu^-$ pair
2. $m_{\mu^+\mu^-} \in [86, 96]$ GeV
3. $M_{\text{recoil}} \in [120, 140]$ GeV
4. $p_T^{\mu^+\mu^-} \in [20, 70]$ GeV
5. $|\cos\theta_{missing}| < 0.98$

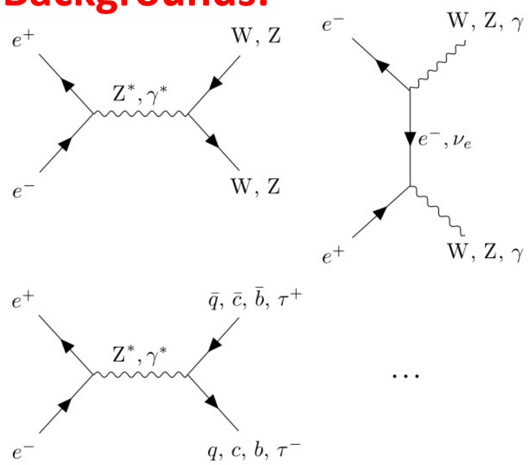
Reconstructed Particle

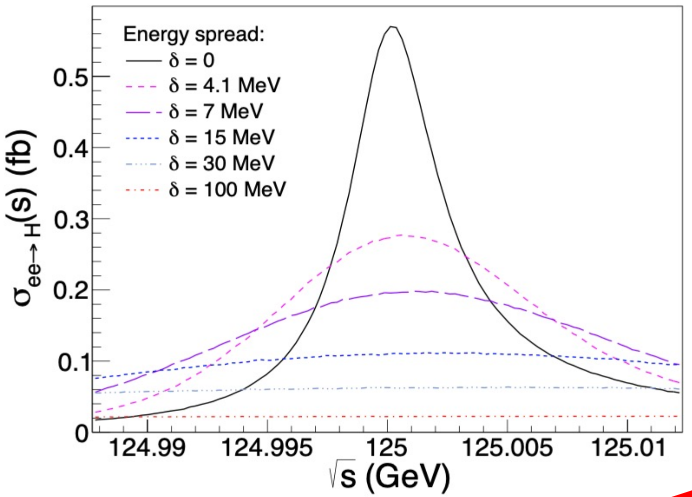
The electron Yukawa coupling via resonant s-channel $e^+e^- \to H$ production

Signals



Backgrounds:





arXiv:2107.02686

$$\sigma_{ee\to H} = \frac{4\pi\Gamma_H\Gamma(H\to e^+e^-)}{(s-m_H^2)^2 + m_H^2\Gamma_H^2},$$

- Yukawa couplings have been measured so far only for t, b and τ (μ, c after HL-LHC)
- Higgs decay to e^+e^- is unobservable: $BR(H \to e^+e^-) \propto m_e^2 \approx 5\times10^{-9}$
- Peak cross-section: $\sigma_{ee\to H} = 1.64$ fb ($m_H = 125$ GeV, $\Gamma_H = 4.2$ MeV)

Challenges:

1. Centre-of-mass energy at Higgs pole (Accurate knowledge of Higgs mass (~MeV)) → (feasible at FCC-ee with recoil method)
2. ISR and beam-energy spread (~MeV but still deliver large L_{int}) → If $(\delta_{\sqrt{s}}, L_{int}) = (4.1\text{ MeV}, 10\text{ab}^{-1})$ then $\sigma_{e^+e^-\to H} = 0.28$ fb
3. Existence of multiple backgrounds

Fundamental Physics motivations:

1. Electron Yukawa coupling is measurable
2. New particle that is quasi-degenerate with Higgs boson mass?

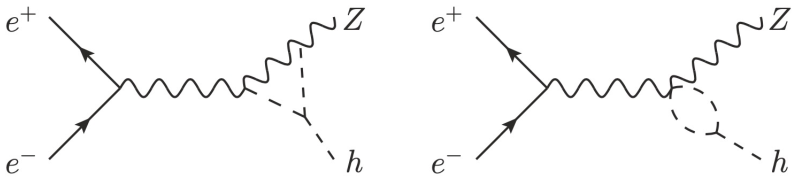
$H\to gg$	$H\to WW^* \to \ell\nu\,2j;\ 2\ell\,2\nu;\ 4j$	$H\to ZZ^* \to 2j\,2\nu;\ 2\ell\,2j;\ 2\ell\,2\nu$	$H\to b\bar{b}$	$H\to \tau_{had}\tau_{had};\ c\bar{c};\ \gamma\gamma$	Combined
1.1σ	$(0.53\otimes0.34\otimes0.13)\sigma$	$(0.32\otimes0.18\otimes0.05)\sigma$	0.13σ	$< 0.02\sigma$	1.3σ

Its feasibility study is still on going

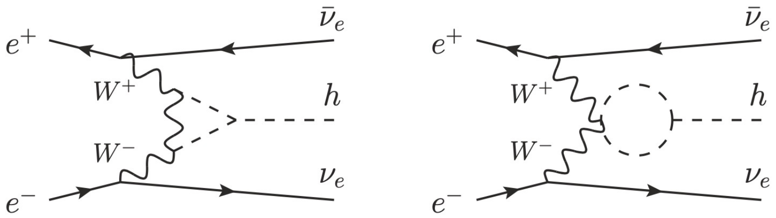
Trilinear Higgs Self-coupling

Trilinear coupling:

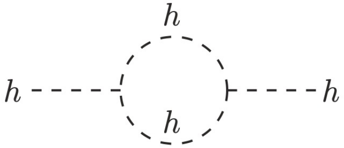
- Higgs strahlung: $e^+e^- \to ZH$



- WW-fusion: $e^+e^- \to \nu\bar{\nu}_e H$

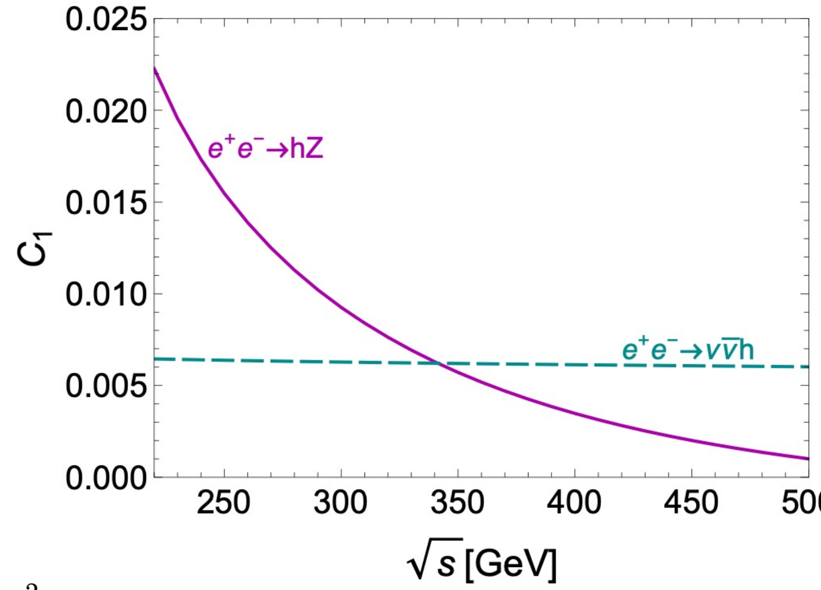


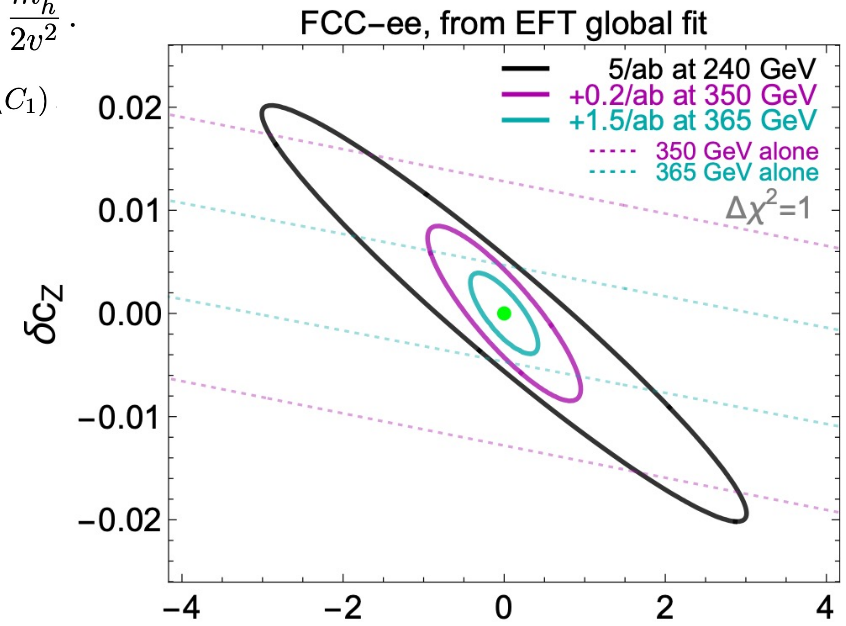
- Higgs self-energy



$$\kappa_\lambda \equiv \frac{\lambda_3}{\lambda_3^{\rm SM}}\,, \qquad \lambda_3^{\rm SM} = \frac{m_h^2}{2v^2}\,.$$

$$\Sigma_{\rm NLO} = Z_H \Sigma_{\rm LO}(1 + \kappa_\lambda C_1)$$





$\delta\kappa_\lambda$

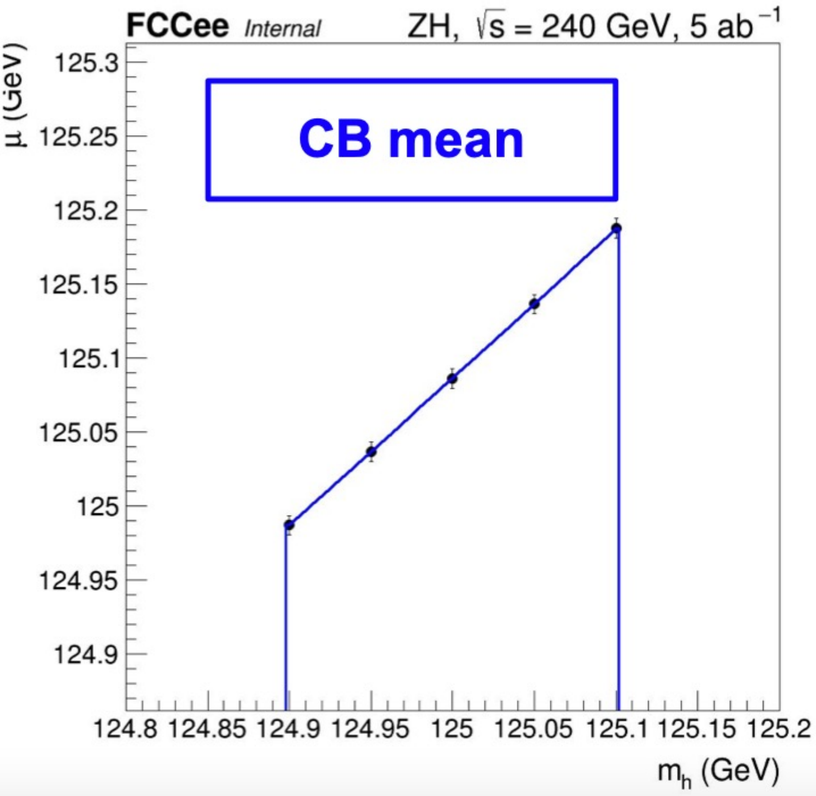
- Including all the FCC-ee running, a model-independent precision of ±42% can be achieved on $k_\lambda$reduced to ±34% in combination with HL-LHC, and to ±12% when only k_λ is allowed to vary
- FCC-hh has the potential to reach a precision of ~ 3-5% of λ_3 from di-Higgs production, in combination with the precise Higgs decay branching ratio measurements from the FCC-ee
- With four IPs, the first 5σ demonstration of the Higgs self-coupling is within reach in 15 years at FCC-ee

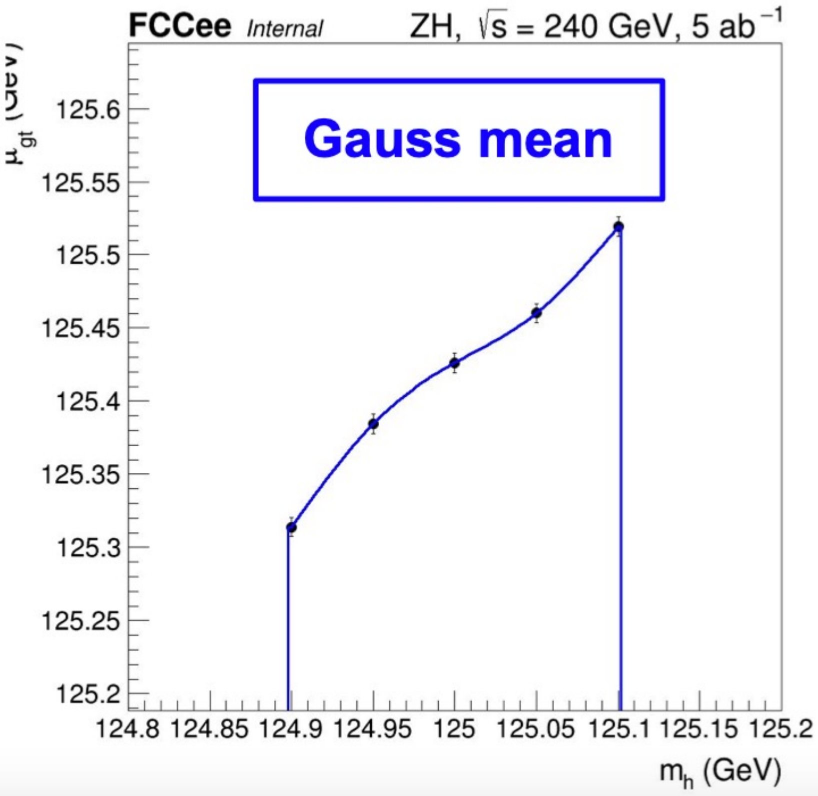
arXiv:1809.10041 arXiv:1711.03978

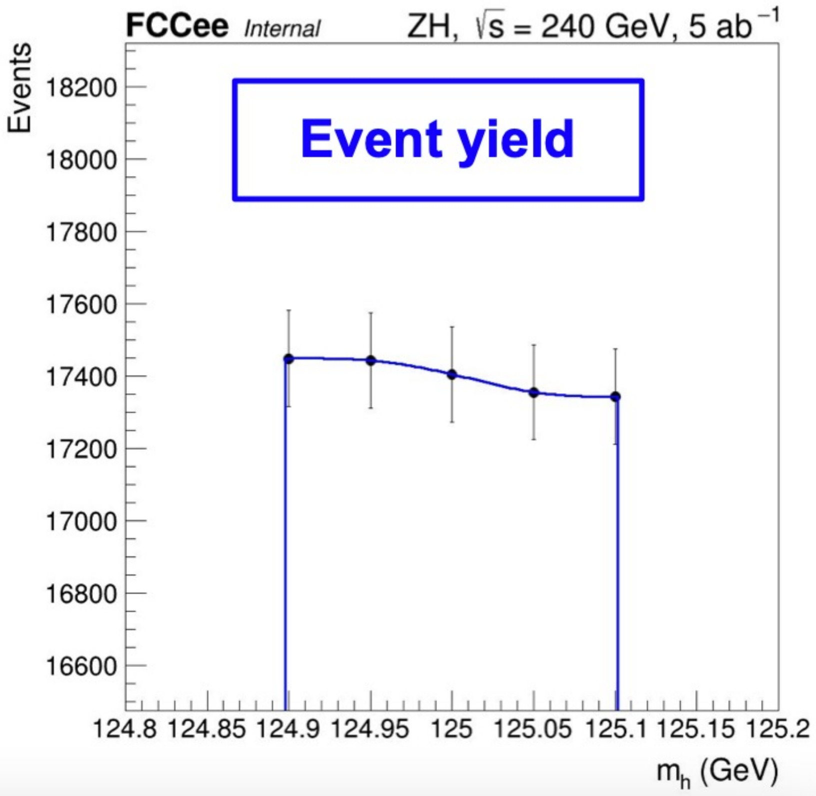
Fitting model and parameter settings

How does the signal shape change as function of (true) Higgs mass mH?

- Generated extra samples around 125 GeV: 124.9, 124.95, 125.05, 125.1 GeV
- Found only significant dependency on the mean (both CB and Gauss) and yields
  - Dependency as function of mH described using Spline
- Other parameters set as constant (best-fit parameters @ 125.0 GeV, see backup for all fits)







Number of events, error and number of entries

	Pre-Selection			APC-2-Selection		
Sample	#Events	Error	#Entries	#Events	Error	#Entries
$Z(\mu^+\mu^-)H$	24178.8	28.6	714893	18181.1	24.8	537560
$Z(\tau^+\tau^-)H$	32.7	1.1	873	12.4	0.7	330
$Z(q\bar{q})H$	425.5	5.4	6179	171.5	3.4	2491
Total Signal	**24637.0**	**35.1**	**721945**	**18365.0**	**28.9**	**540381**
$W^+(\nu\mu^+)W^-(\bar{\nu}\mu^-)$	133530.9	131.2	1035444	16927.3	46.7	131260
ZZ(inclusive)	315780.4	463.2	464728	11219.8	87.3	16512
$Z \rightarrow l\bar{l}$	7846308.6	7389.3	1127515	9471.1	256.7	1361
Total Main Bkgs.	**8295619.8**	**7983.8**	**2627687**	**37618.2**	**390.8**	**149133**
$\gamma\gamma\mu\mu$	384090.8	315.2	1484600	4.7	1.1	18
$\gamma\gamma\tau\tau$	304.3	8.0	1456	6.3	1.1	30
eeZ	793603.7	286.8	7654357	24.0	1.6	231
$Z \rightarrow q\bar{q}$	0.0	0.0	0	0.0	0.0	0
$Z(\nu\bar{\nu})H$	173.8	3.7	2257	69.3	2.3	900
$Z(e^+e^-)H$	23.4	1.0	587	9.3	0.6	234
Additional Bkgs	**1178195.9**	**614.7**	**9143257**	**113.5**	**6.7**	**1413**

- **Final-Selection**
  1. At least one Z boson from a $\mu^+\mu^-$ pair.
  2. $m_{\mu^+\mu^-} \in [86, 96]$ GeV
  3. $p_T^{\mu^+\mu^-} \in [20, 70]$ GeV
  4. $|\cos\theta_{missing}| < 0.98$
  5. $M_{\text{recoil}} \in [120, 140]$ GeV

Compared to Pre-Selection, Final-Selection keeps ~75% signals but rejects

- Main background:
  - ~87% WW
  - ~96% ZZ
  - ~99.88% $Z \rightarrow l\bar{l}$
- Additional background
  - ~99.99% $\gamma\gamma\mu\mu$,
  - ~99.93% eeZ

Expected value of the coupling constant

$$\sigma_{\mathrm{ZH}} \times \mathcal{B}(\mathrm{H} \to \mathrm{X\overline{X}}) \propto \frac{g^2_{\mathrm{HZZ}} \times g^2_{\mathrm{HXX}}}{\Gamma_{\mathrm{H}}} \quad \text{and} \quad \sigma_{\mathrm{H}\nu_e\bar{\nu}_e} \times \mathcal{B}(\mathrm{H} \to \mathrm{X\overline{X}}) \propto \frac{g^2_{\mathrm{HWW}} \times g^2_{\mathrm{HXX}}}{\Gamma_{\mathrm{H}}},$$

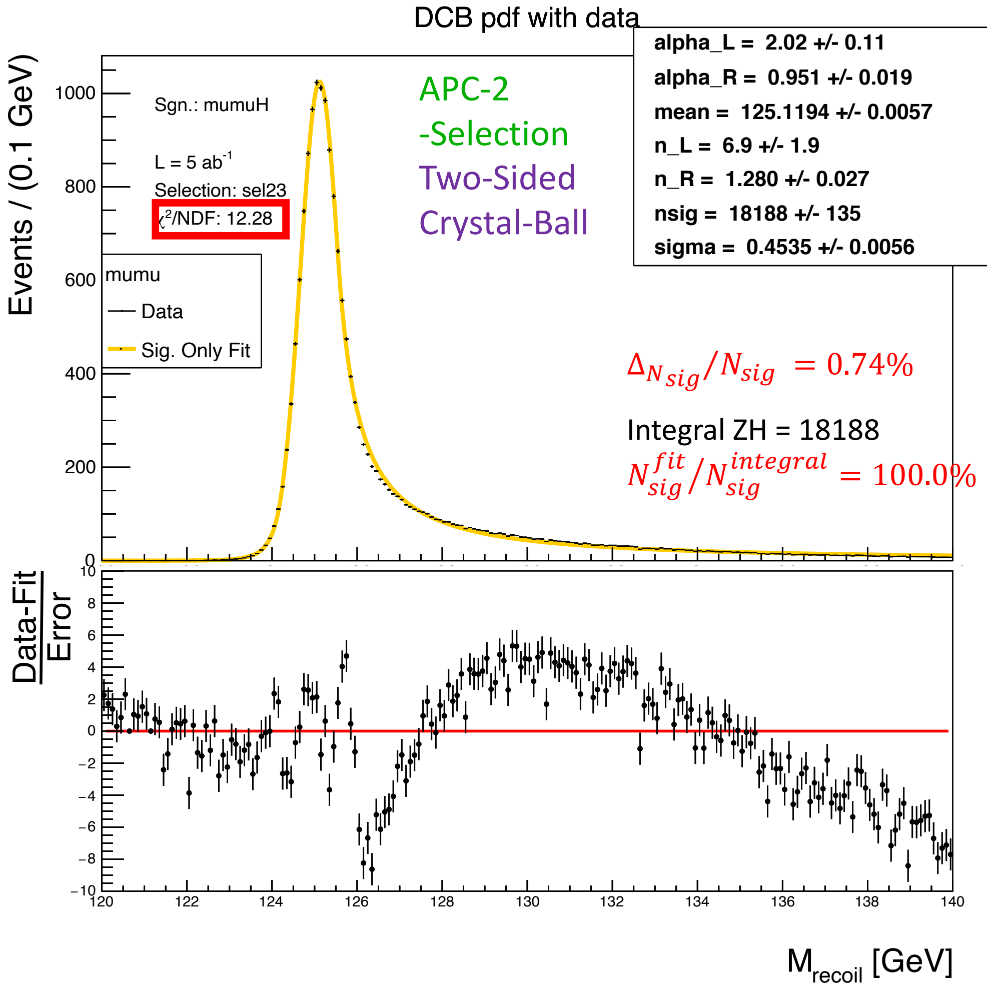
arXiv:2106.15438

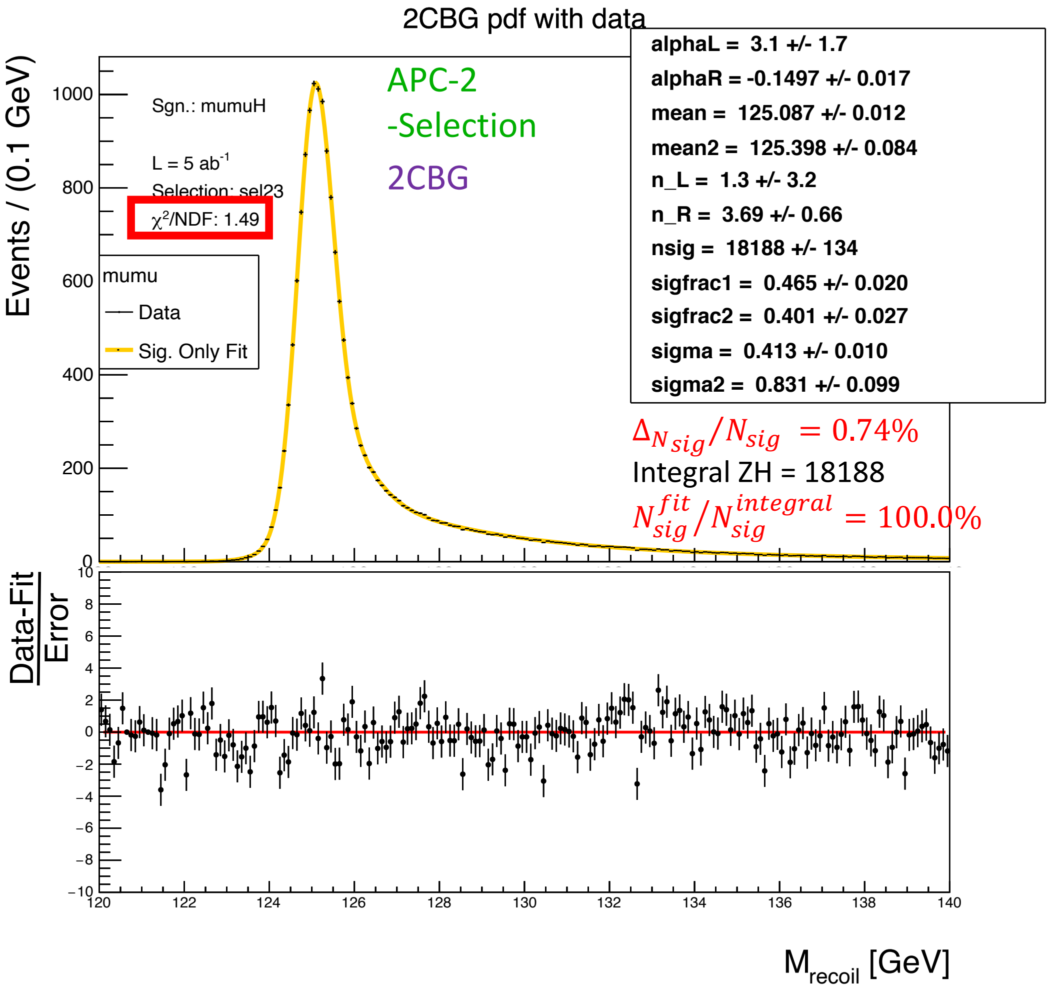
- The σ_{ZH} accuracy could reach 0.5%
- Obtaining the ZH cross section, one can determine g_{HZZ} and Higgs width (Γ_{H})
- g_{HZZ}, g_{HWW}, $g_{\mathrm{H}gg}$ and $g_{\mathrm{H}\tau\tau}$ are expected to reach per mille precision

$\sqrt{s}$	240 GeV		365 GeV	
Integrated luminosity	5 ab^{-1}		1.5 ab^{-1}	
$\delta(\sigma\mathcal{B})/\sigma\mathcal{B}$ (%)	ZH	$\nu_e\bar{\nu}_e$ H	ZH	$\nu_e\bar{\nu}_e$ H
$\mathrm{H} \to$ any	±0.5		±0.9	
$\mathrm{H} \to \mathrm{b\bar{b}}$	±0.3	±3.1	±0.5	±0.9
$\mathrm{H} \to \mathrm{c\bar{c}}$	±2.2		±6.5	±10
$\mathrm{H} \to \mathrm{gg}$	±1.9		±3.5	±4.5
$\mathrm{H} \to \mathrm{W^+W^-}$	±1.2		±2.6	±3.0
$\mathrm{H} \to \mathrm{ZZ}$	±4.4		±12	±10
$\mathrm{H} \to \tau^+\tau^-$	±0.9		±1.8	±8
$\mathrm{H} \to \gamma\gamma$	±9.0		±18	±22
$\mathrm{H} \to \mu^+\mu^-$	±19		±40	
$\mathrm{H} \to$ invisible	< 0.3		< 0.6	

Coupling	Precision (%) (κ framework / EFT)
g_{HZZ}	0.17 / 0.26
g_{HWW}	0.41 / 0.27
g_{Hbb}	0.64 / 0.56
g_{Hcc}	1.3 / 1.2
g_{Hgg}	0.89 / 0.82
$g_{\mathrm{H}\tau\tau}$	0.66 / 0.57
$g_{\mathrm{H}\mu\mu}$	3.9 / 3.8
$g_{\mathrm{H}\gamma\gamma}$	1.3 / 1.2
$g_{\mathrm{HZ}\gamma}$	10. / 9.3
g_{Htt}	3.1 / 3.1
Γ_{H}	1.1

Signal Only fit with different p.d.f. in the Higgs region (120-140 GeV)





$Z(\mu^+\mu^-)H$	σ_{CB}(GeV)	M_{CB}(GeV)	χ^2/NDF
DSCB	0.4535	125.1194	12.28
2CBG	0.4130	125.0870	1.49

- Compared to Two-Sided Crystal-Ball ($\chi^2/NDF \sim 12.3$), 2CBG function has better description of the signal χ^2/NDF decreases to ~ 1.5
- Still a little wiggle between 122-130 GeV