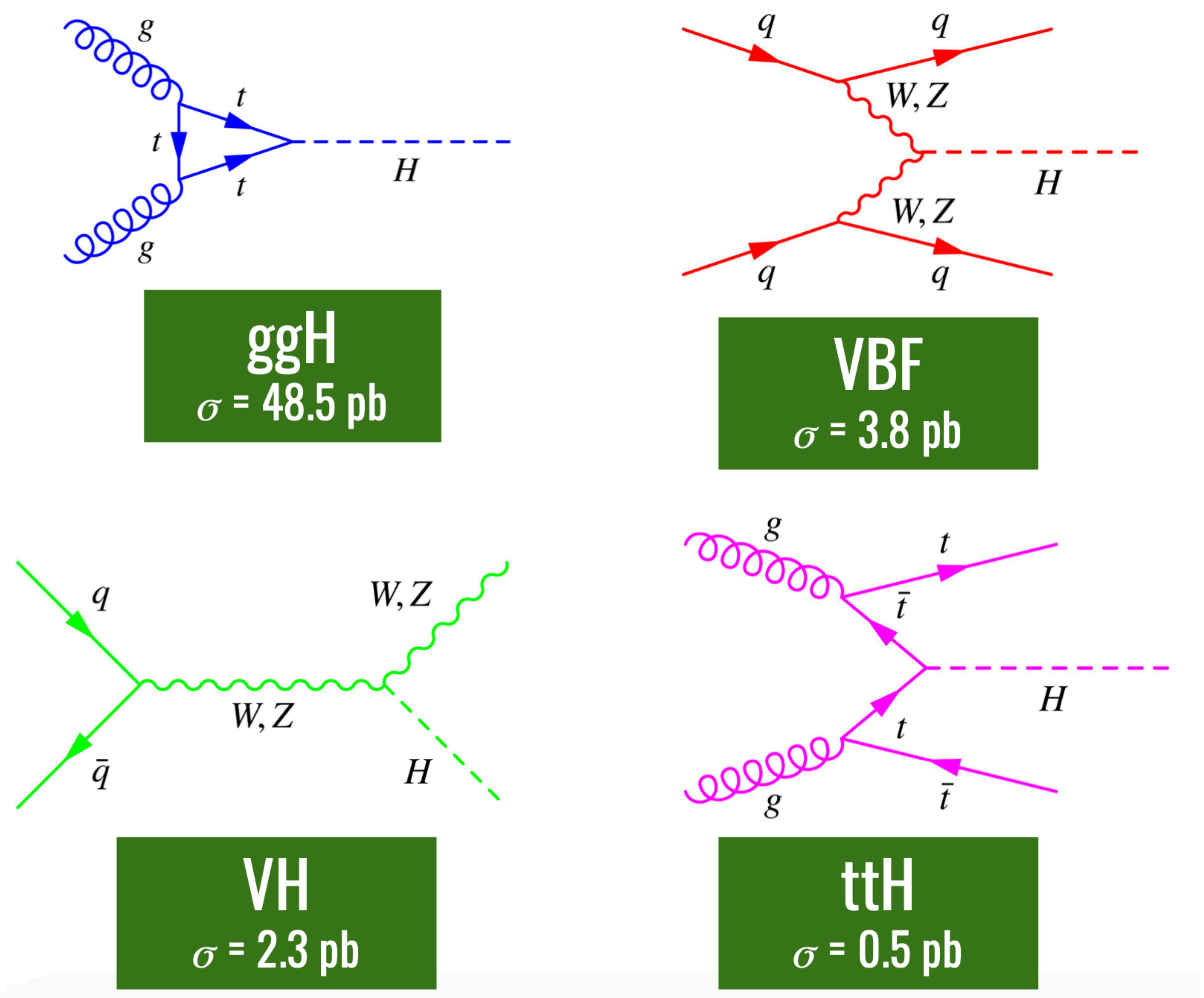
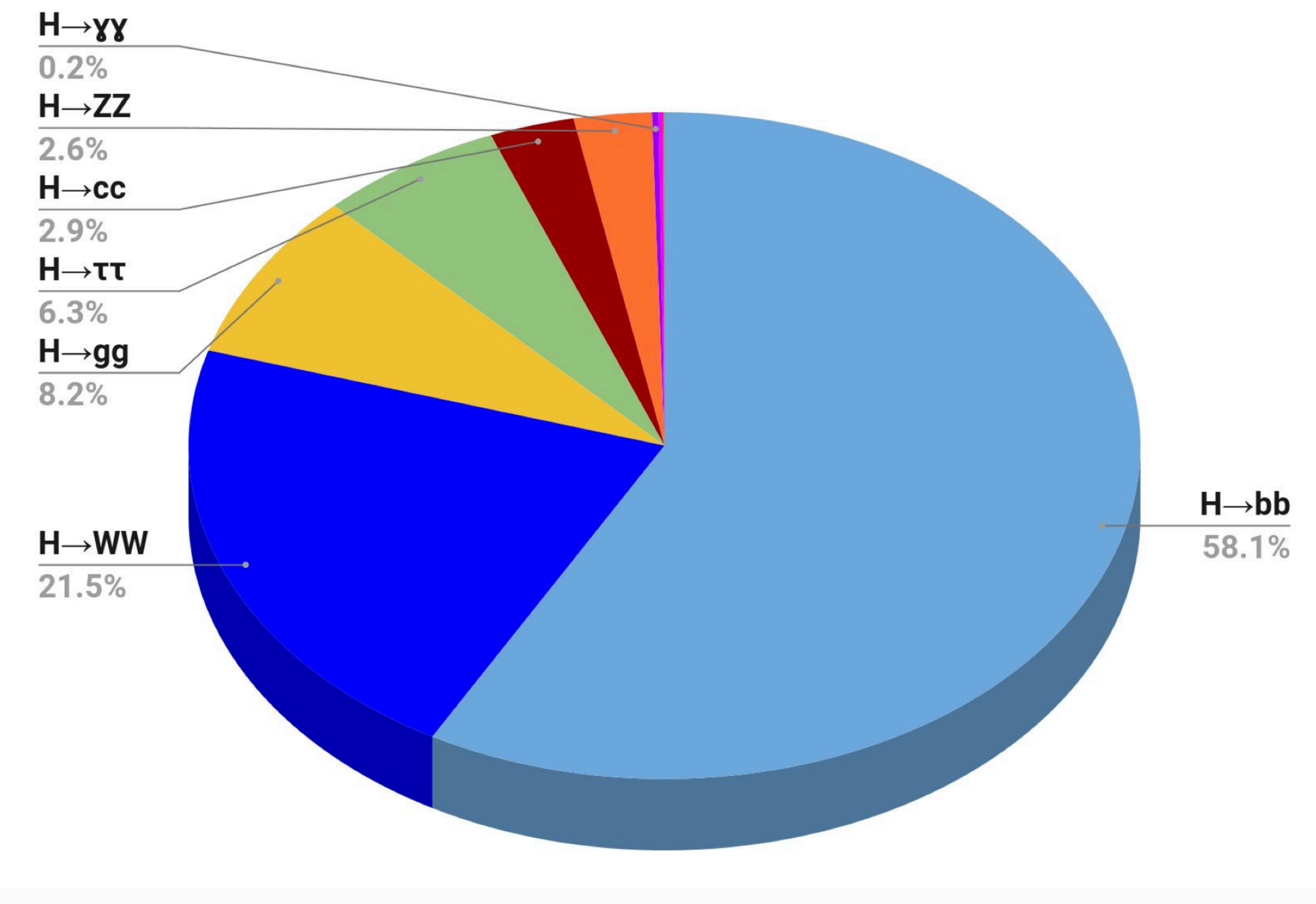
FCC-ee Higgs summary

CEPC workshop, Guangzhou
07.11.2025

Xunwu Zuo
on behalf of FCC Higgs study group

Why more than (HL-)LHC?





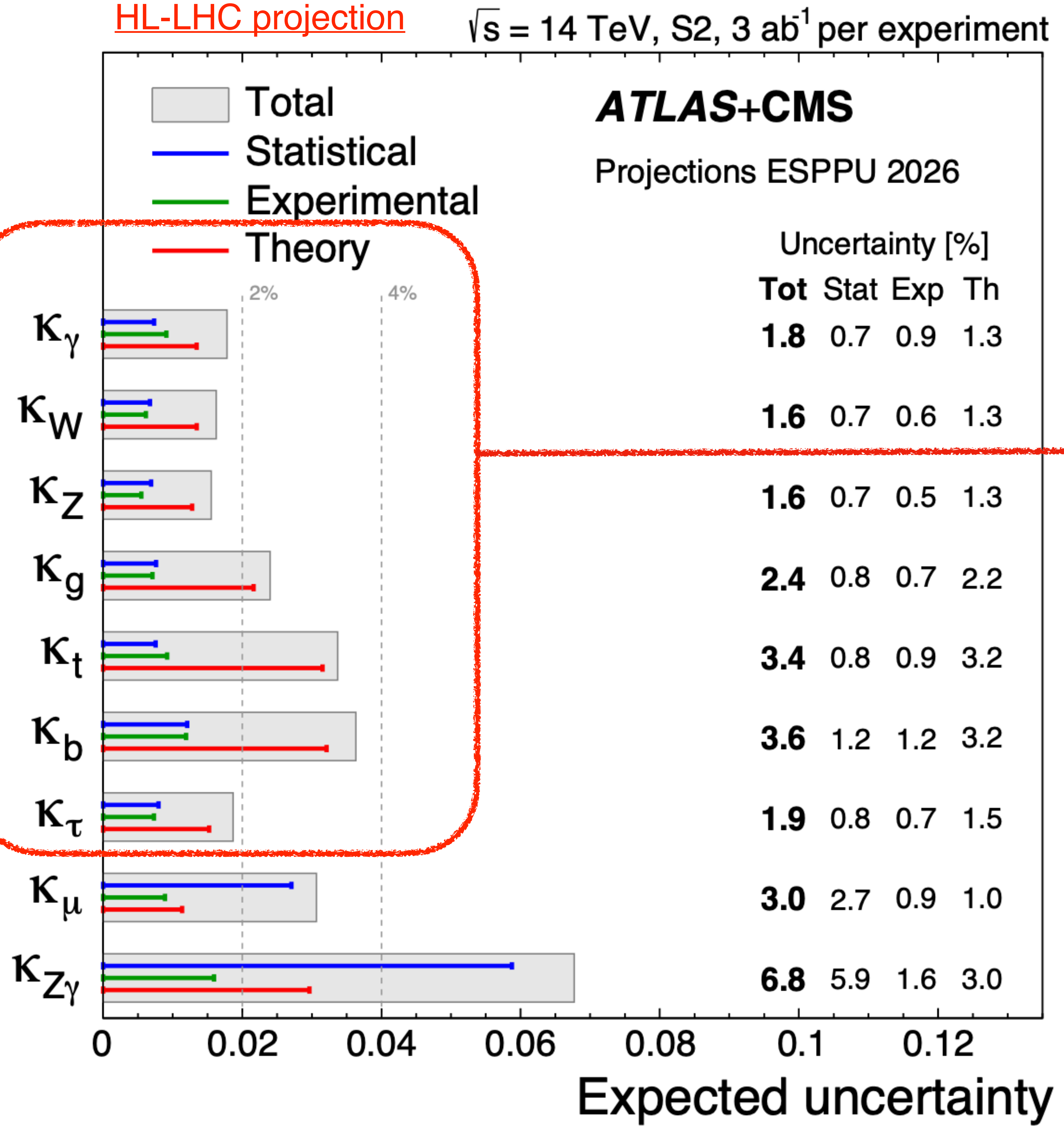
At LHC

- Only measure $\sigma \times \mathscr{B}$ (not total cross section or width)
- Not all decays accessible (e.g. many hadronic decays)

Interpretation only model-dependent

Why more than (HL-)LHC?

HL-LHC projection

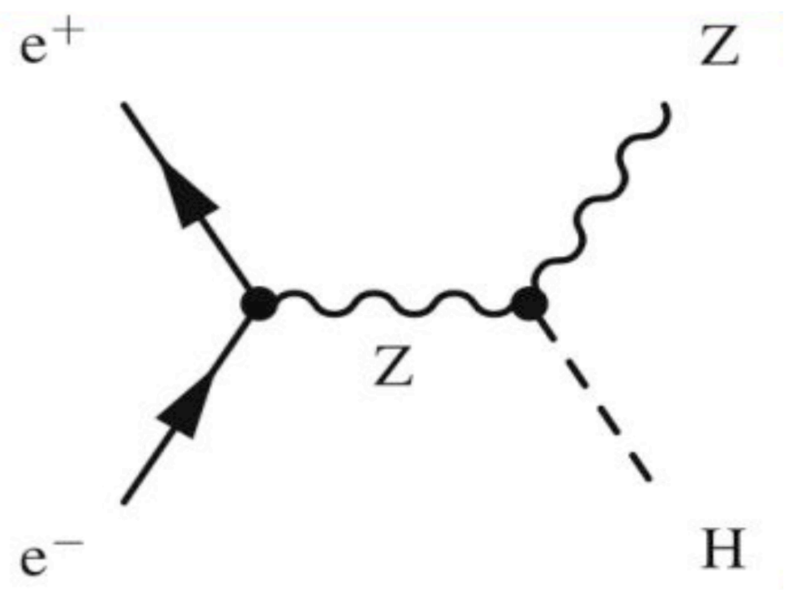


Theory uncertainty becomes dominant

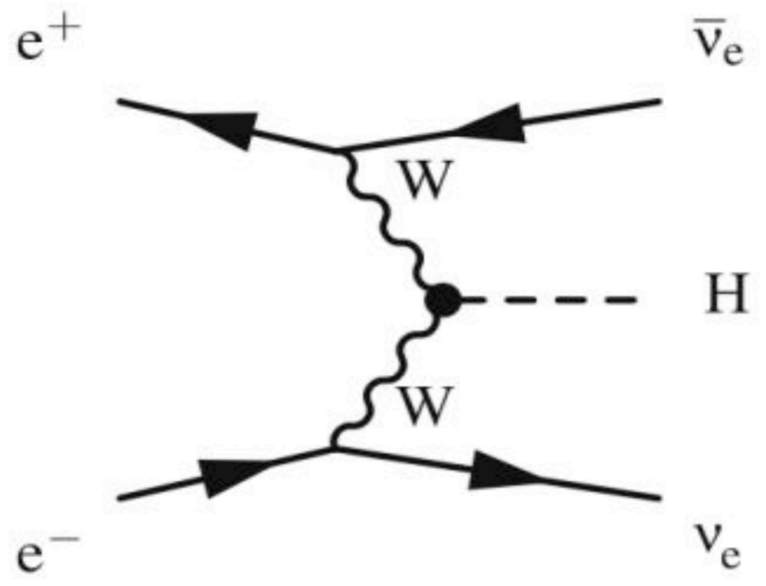
More in
talk by Chen Zhou

Overview of Higgs program

- Two main production modes



2.2M events at 240 GeV
379k events at 365 GeV



65k events at 240 GeV
92k events at 365 GeV

- ~ 20 dedicated analysis notes
  - public at CERN CDS
- Summary submitted to ESPPU
  - Comprehensive coverage of Higgs properties
  - Model-independent coupling determination
  - Unrivaled precision
  - Complementary to other experiments

relative precision on BR, in percent

$\sqrt{s}$	240 GeV		365 GeV	
channel	**ZH**	**WW → H**	**ZH**	**WW → H**
ZH → any	±0.31		±0.52	
γH → any	±150			
H → bb	±0.21	±1.9	±0.38	±0.66
H → cc	±1.6	±19	±2.9	±3.4
H → ss	±120	±990	±350	±280
H → gg	±0.80	±5.5	±2.1	±2.6
H → $\tau\tau$	±0.58		±1.2	±5.6 (*)
H → $\mu\mu$	±11		±25	
H → WW*	±0.80		±1.8 (*)	±2.1 (*)
H → ZZ*	±2.5		±8.3 (*)	±4.6 (*)
H → $\gamma\gamma$	±3.6		±13	±15
H → Zγ	±11.8		±22	±23
H → $\nu\nu\nu\nu$	±25		±77	
H → inv.	$< 5.5 \times 10^{-4}$		$< 1.6 \times 10^{-3}$	
H → dd	$< 1.2 \times 10^{-3}$			
H → uu	$< 1.2 \times 10^{-3}$			
H → bs	$< 3.1 \times 10^{-4}$			
H → bu	$< 2.2 \times 10^{-4}$			
H → sd	$< 2.0 \times 10^{-4}$			
H → cu	$< 6.5 \times 10^{-4}$			

HEWT summary

(*) analyses ongoing, results scaled from FCC CDR

Outline

Selected Higgs results

★ Cross section, Higgs mass, width More in talk by Chenguang Zhang

★ Self coupling

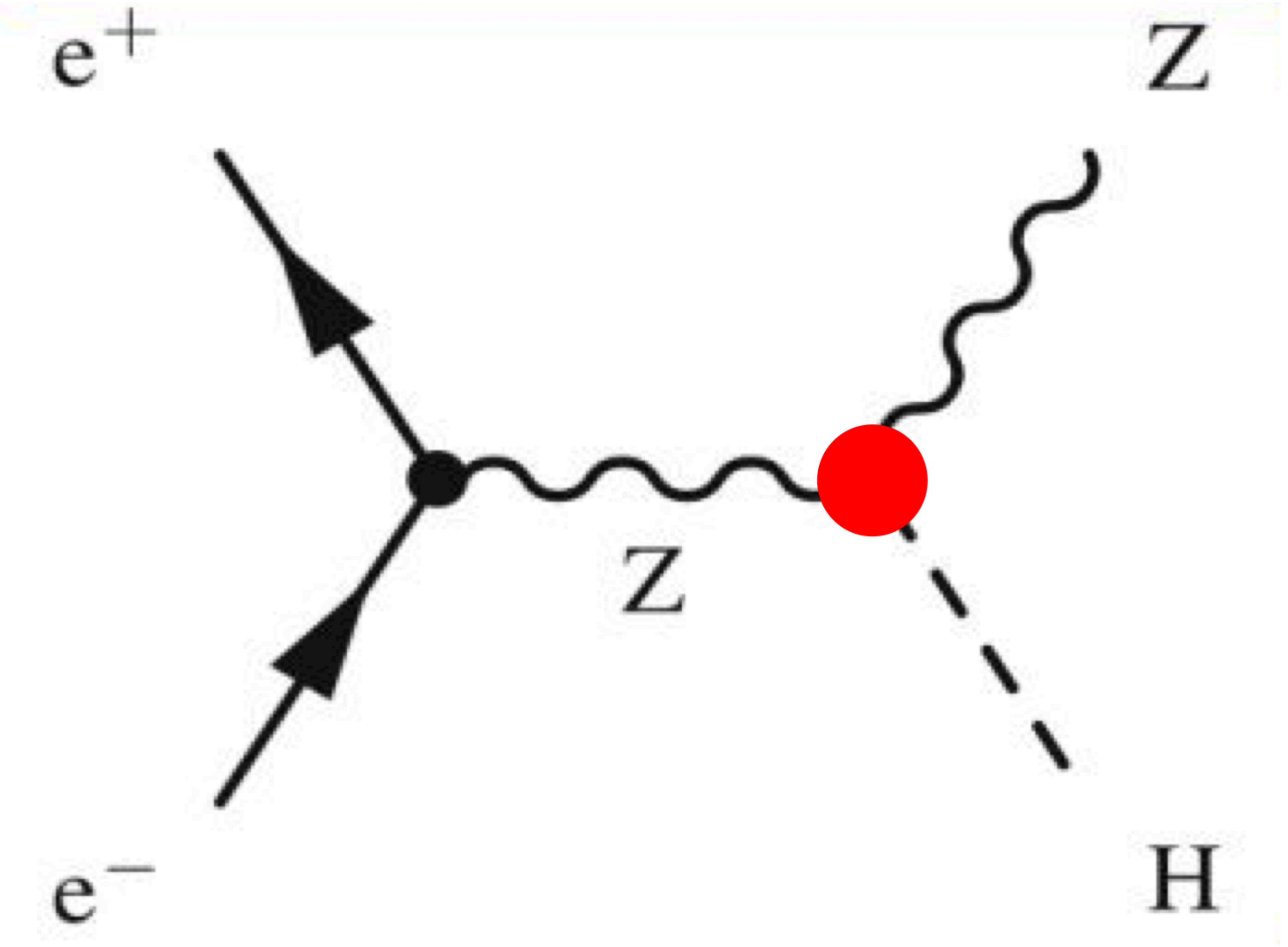
★ Higgs to invisible More in talk by Geliang Liu

★ Electron Yukawa through $e^+e^- \rightarrow H$

★ Higgs to hadrons (b,c,g,s)

ZH production

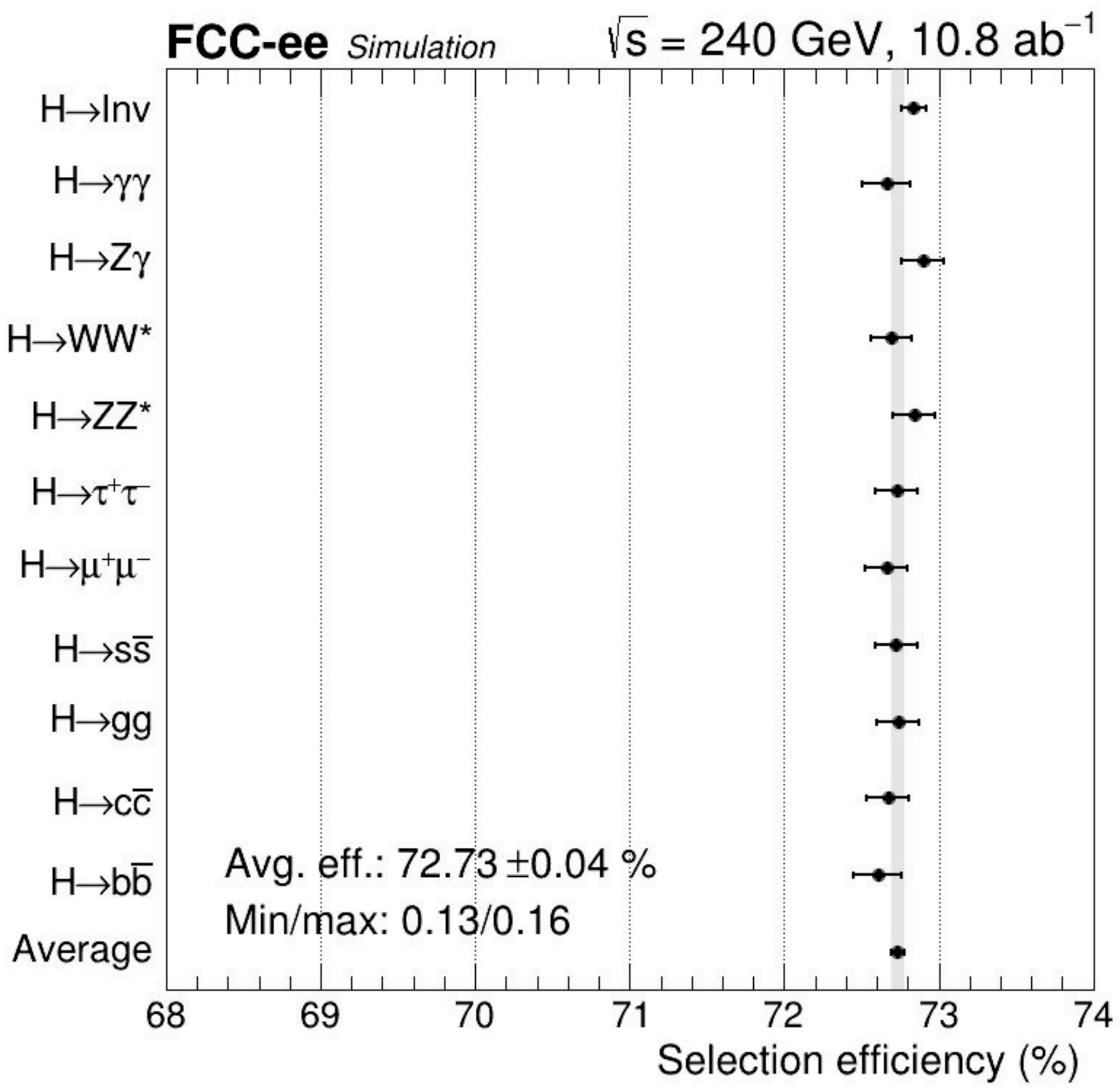
- Recoil from Z, $m^2_{recoil} = s + m^2_Z - 2E_Z\sqrt{s}$
- Inclusive Higgs decay
- Model-independence
- Basis for the self coupling, width, mass and many other measurements

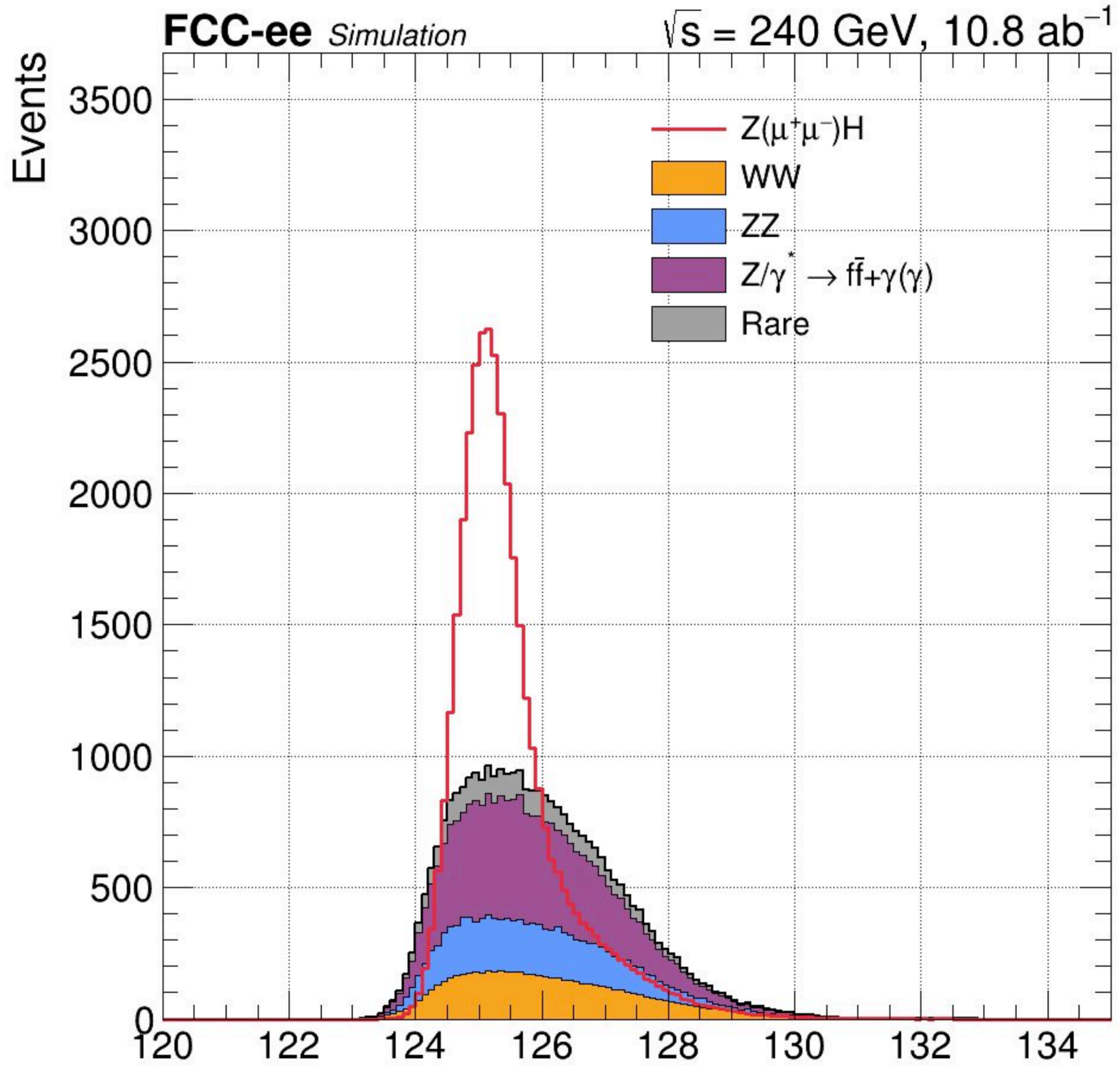


ZH cross section - leptonic channel

- Focus on kinematics of $Z \to ee, \mu\mu$
- Crucial to stay agnostic to Higgs decays
- Model-independence achieve at 0.2% level

- BDT based on $Z \to ee, \mu\mu$ kinematics to suppress backgrounds
- Fit recoil mass in 2 bins of MVA discriminator





FCC Note: ZH leptonic

Combined uncertainty of 0.52(1.35)% at 240(365) GeV

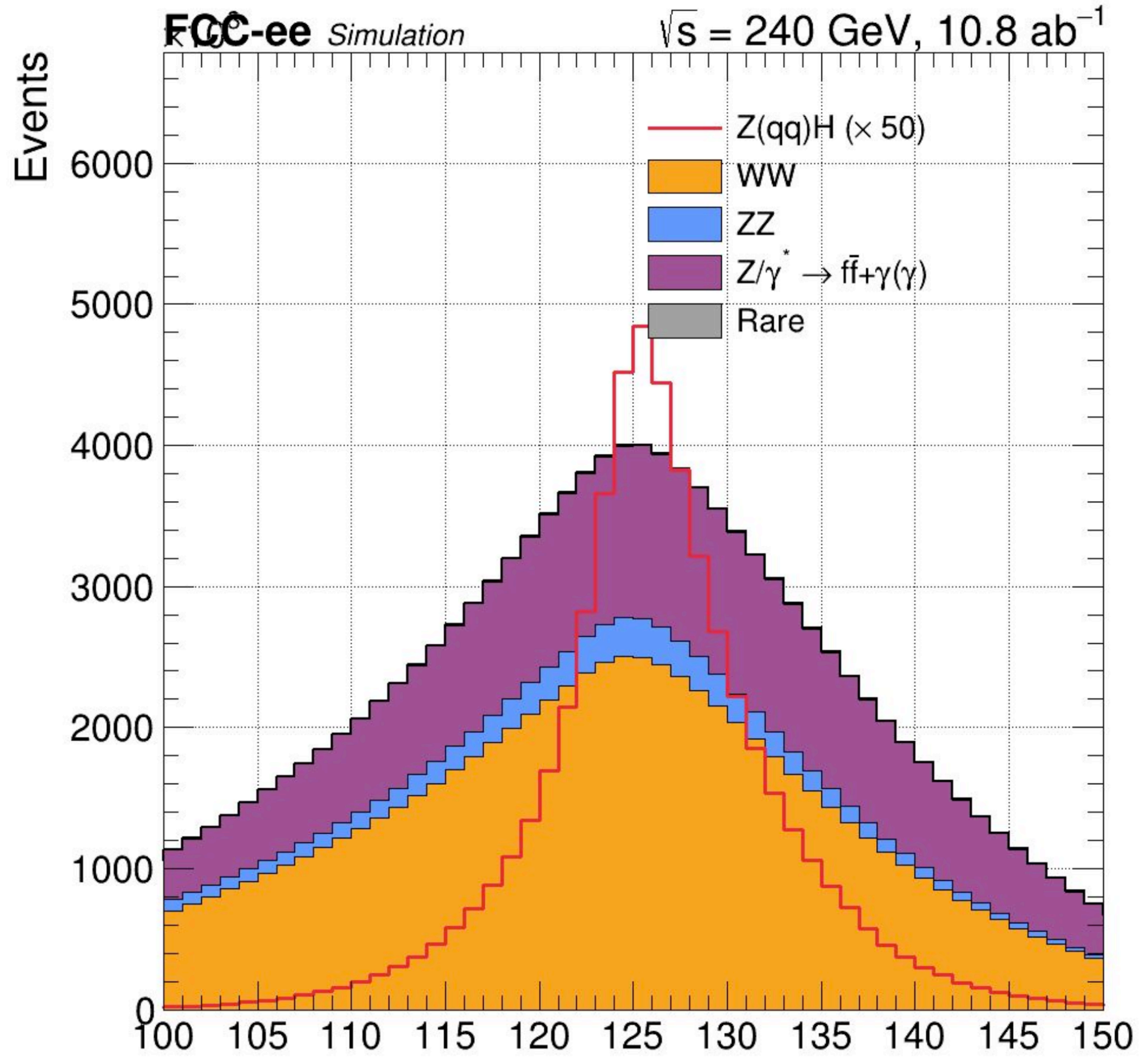
Uncertainty on ZH (%)		
√s (GeV)	240 GeV	365 GeV
Muon	0.68	1.83
Electron	0.81	1.95
Combination	0.52	1.35

ZH cross section - hadronic channel

Consider all $Z \rightarrow qq$ decay

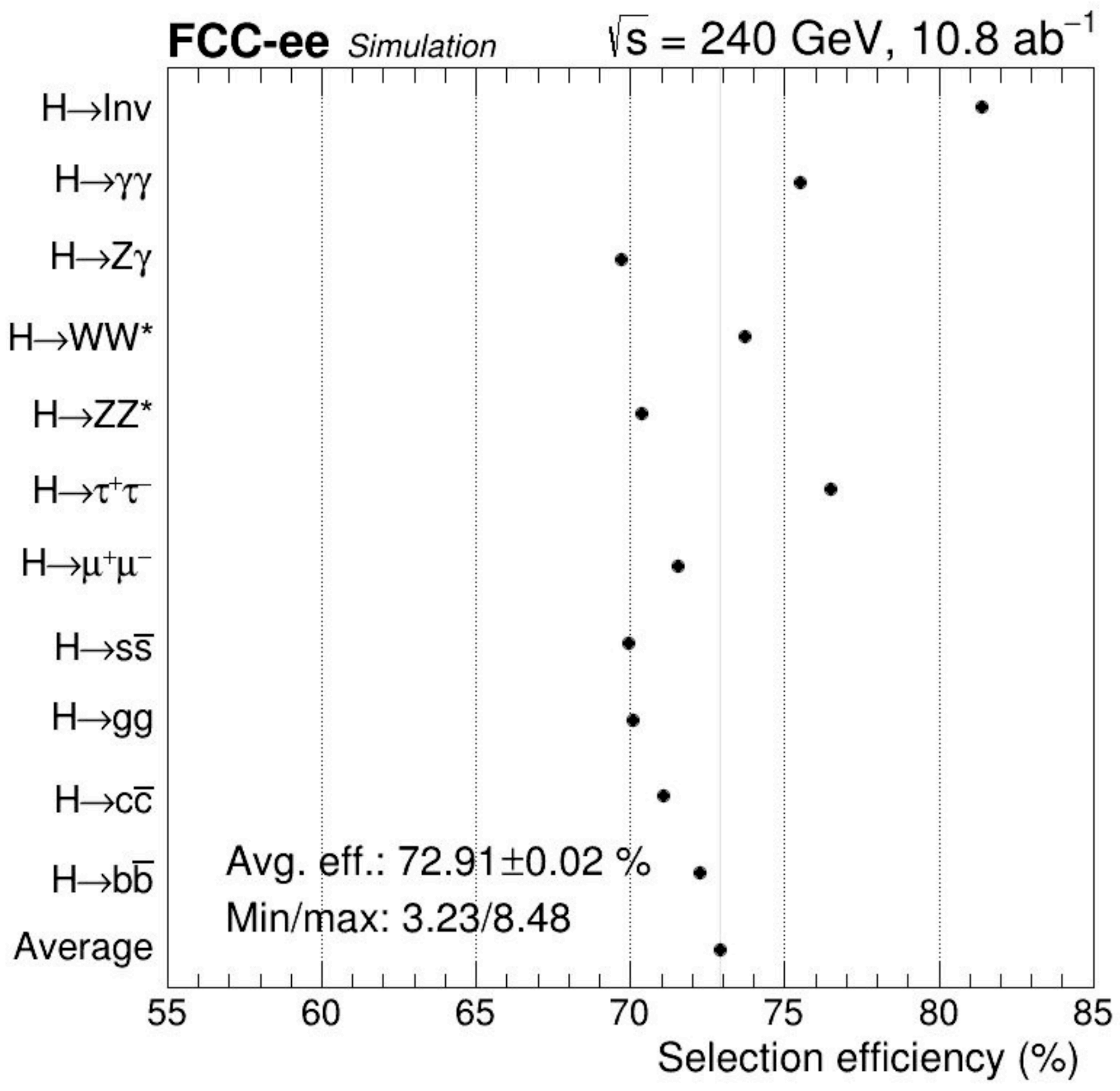
- High statistics: $\mathscr{B}(Z \rightarrow qq)$ = 70%, $\mathscr{B}(Z \rightarrow ee, \mu\mu)$ = 7%
- Multi-jet final state depends on Higgs decay (n_j = 2,4,6)
- Select pairing to match ZH, minimize $\chi^2 = (m_{jj} - m_Z)^2 + (m_{recoil} - m_H)^2$
- BDT to suppress WW and Z/γ backgrounds
  - Inputs: dijet kinematics, angular correlations
- 2D fit of $m_{recoil} - m_{jj}$ in 2 bins of MVA discriminator

Hard to achieve decay mode independence, need to evaluate impact



FCC Note: ZH hadronic

ZH cross section - hadronic channel



Selection efficiency ~10% spread

Bias test to evaluate impact (arXiv 1509.02853):

- Pseudo-data by perturbing each BR independently to yield a deviation δZH = x% (prior)
- Bias = μ^{fit} - 1 - x%, needs to be smaller than expected uncertainty

FCC Note: ZH hadronic

Bias on σ(ZH) (%)			
Channel	Leptonic	Hadronic	Combination
Bias prior	5%	1%	1%
bb	-0.011	0.027	0.02
cc	-0.013	-0.085	-0.063
gg	-0.013	-0.024	-0.018
ss	-0.016	-0.168	-0.124
$\mu\mu$	0.095	0.149	0.115
$\tau\tau$	-0.008	-0.072	-0.054
ZZ	0.487	0.023	0.042
WW	-0.023	-0.039	-0.03
$Z\gamma$	0.545	-0.132	-0.069
γ	-0.007	0.285	0.209
inv	0.002	0.362	0.267

Uncertainty of hadronic measurement: 0.38(0.57)% at 240(365) GeV

Higgs mass

Fundamental parameter in SM, connected to other measurements

- EWK radiative correction depends on m_H
- FCC-ee demands sub-percent precision on cross section and BRs
- Translates to $\delta(m_H)$ < O(10) MeV requirement

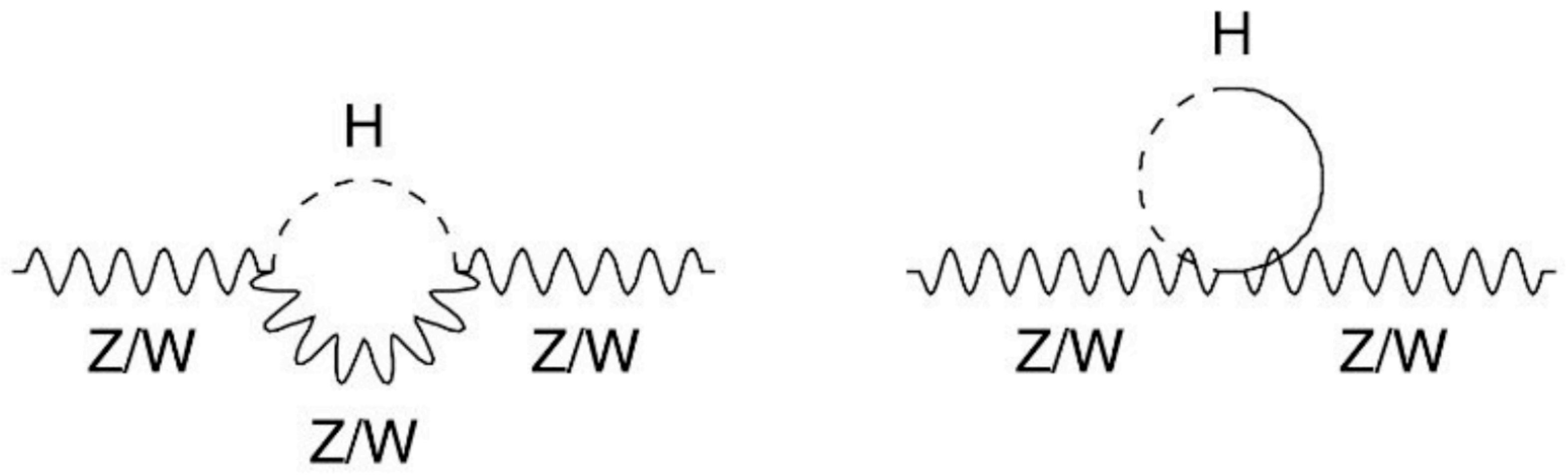
Higgs mass analysis

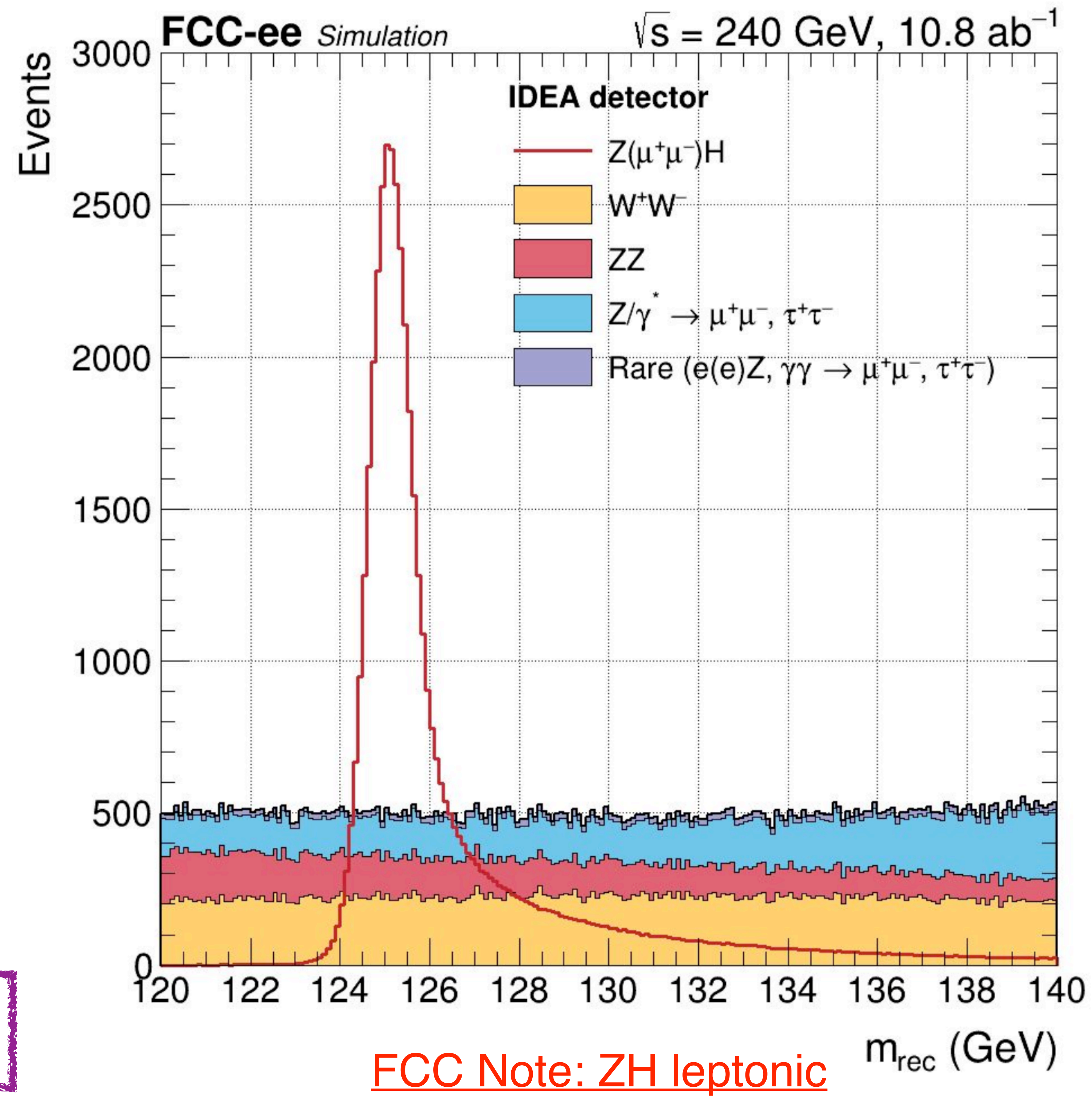
- Tight selection on $Z \to ee, \mu\mu$ decays, m_H from m_{recoil}
- Sensitivity driven by 240 GeV data
- Rely on excellent tracking resolution

Total uncertainty of 4 MeV, statistically dominated

- Systematic uncertainty of $\sqrt{s}$ taken as 2 MeV (but 1 MeV achievable)
- Foundation for potential $e^+e^- \to H$ study

Today ~150 MeV → HL-LHC ~20 MeV → FCC-ee ~4 MeV





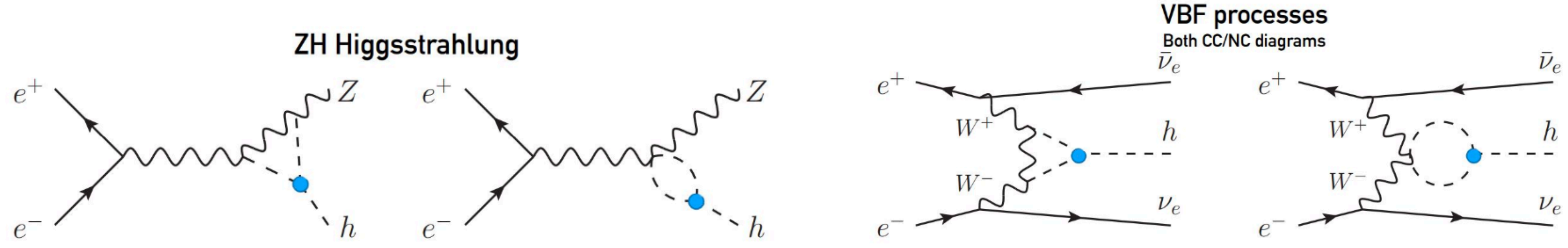
FCC Note: ZH leptonic

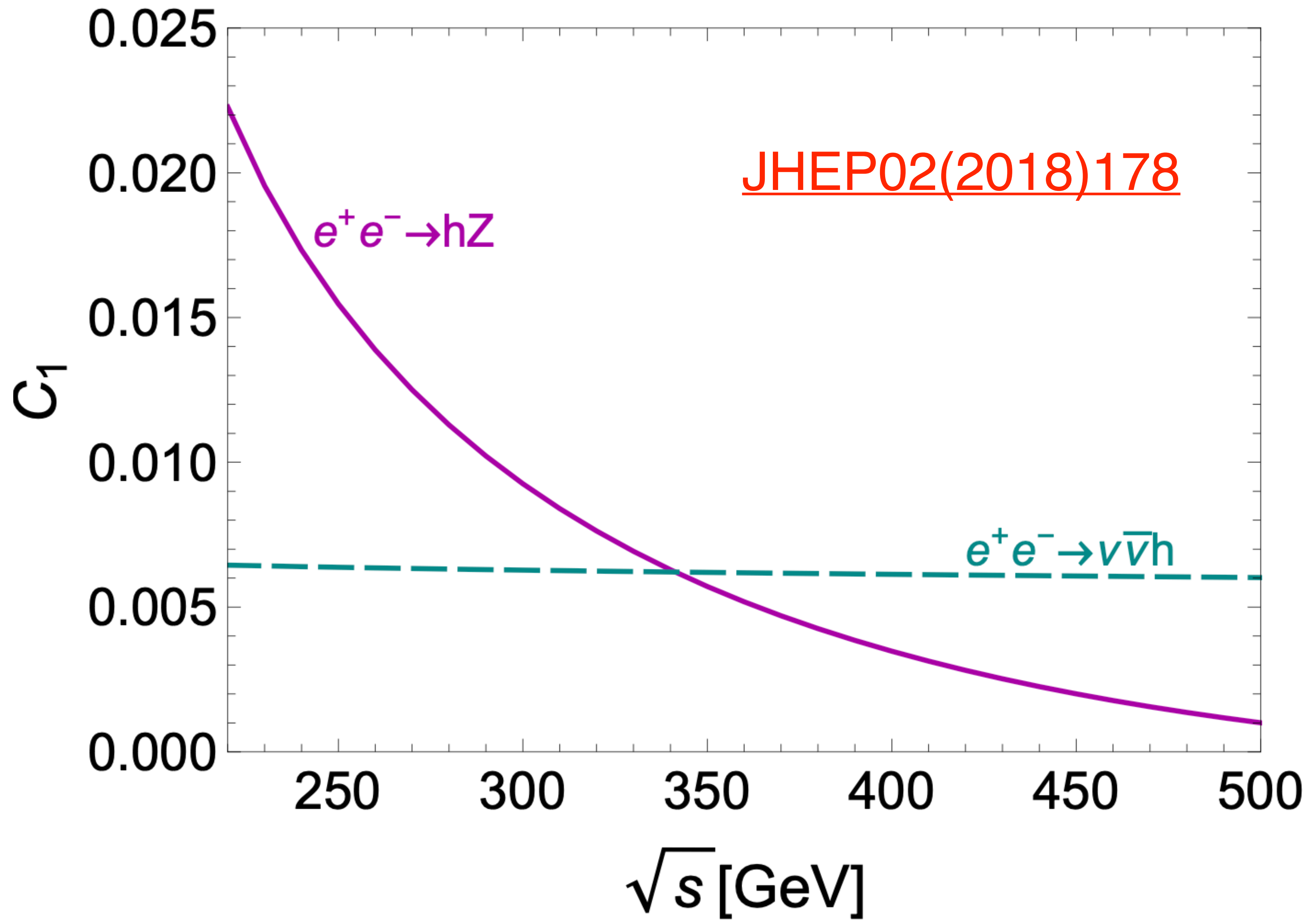
Higgs width

FCC Note: Higgs width

- Measurements of Higgs total width, and all Higgs couplings, at LHC are model-dependent
- Model-independent measurement at e^+e^- colliders
- Based on model-independent $\sigma(e^+e^- \to ZH)$ determination
  - $\sigma(ZH) \times \mathscr{B}(H \to XX) \propto g_{HZZ}^2 \times \frac{g_{HXX}^2}{\Gamma_H}$ $\Rightarrow$ $\Gamma_H \propto \frac{\sigma(ZH)^2}{\sigma(ZH, H \to ZZ)}$
- Similarly, for VBF mode
  - $\sigma(\nu_e\nu_e H) \times \mathscr{B}(H \to YY) \propto g_{HWW}^2 \times \frac{g_{HYY}^2}{\Gamma_H}$ $\Rightarrow$ $\Gamma_H \propto \frac{\sigma(ZH)^2\sigma(\nu_e\nu_e H, H \to YY)}{\sigma(ZH, H \to YY)\sigma(ZH, H \to WW)}$
- Combining these relations in kappa fit leads to **$\delta\Gamma_H$ = 0.78%**
  - Crucial to measure $H \to ZZ, WW$ to high precision
- With Γ_H determined, each $\mathscr{B}(H \to XX)$ measurement becomes a model-independent determination of g_{HXX} coupling.

Higgs self coupling





Probe of λ_3 through NLO contributions to single Higgs production

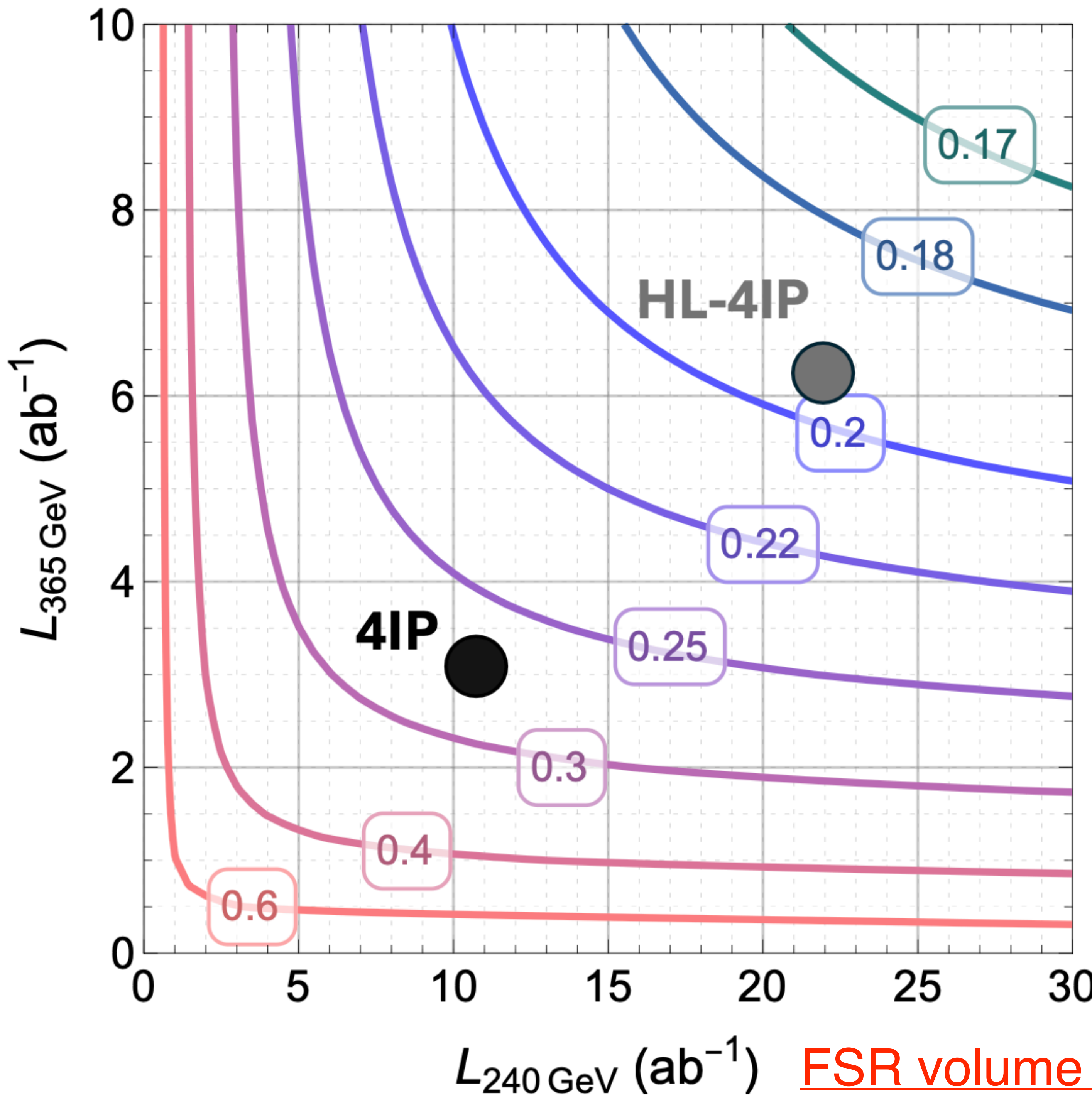
- $\Sigma_{NLO} = Z_H \Sigma_{LO}(1 + \kappa_\lambda C_1)$
- where $Z_H = 1/(1 - \kappa_\lambda^2 \delta Z_H)$, $\quad \delta Z_H \approx -0.00154$

C_1 shows dependence on $\sqrt{s}$

- Measure at both 240 GeV and 365 GeV to resolve correlation between κ_λ and other operators, like trilinear Z coupling λ_Z and correction to HZZ coupling δc_Z

With 0.3% precision on $\sigma(ZH)$, expect **27% precision on κ_λ**

- 18% if combined with HL-LHC
- Ultimate precision to be achieve at FCC-hh



FSR volume 1

Higgs to invisible

SM invisible decay via $H \to ZZ \to \nu\nu\nu\nu$

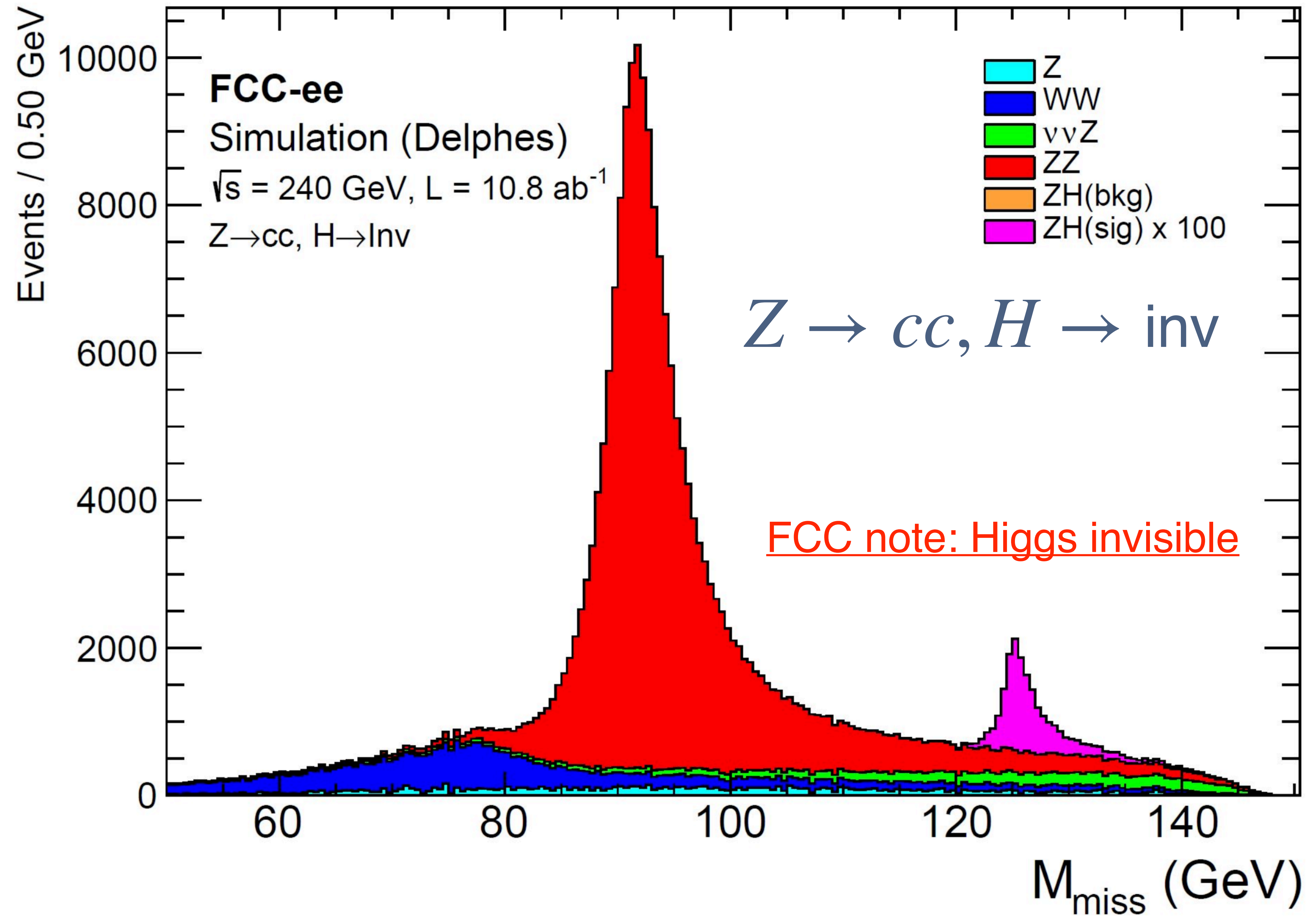
- SM branching ratio 0.106%
- Potential BSM couplings (e.g. dark matter) give rise to deviations

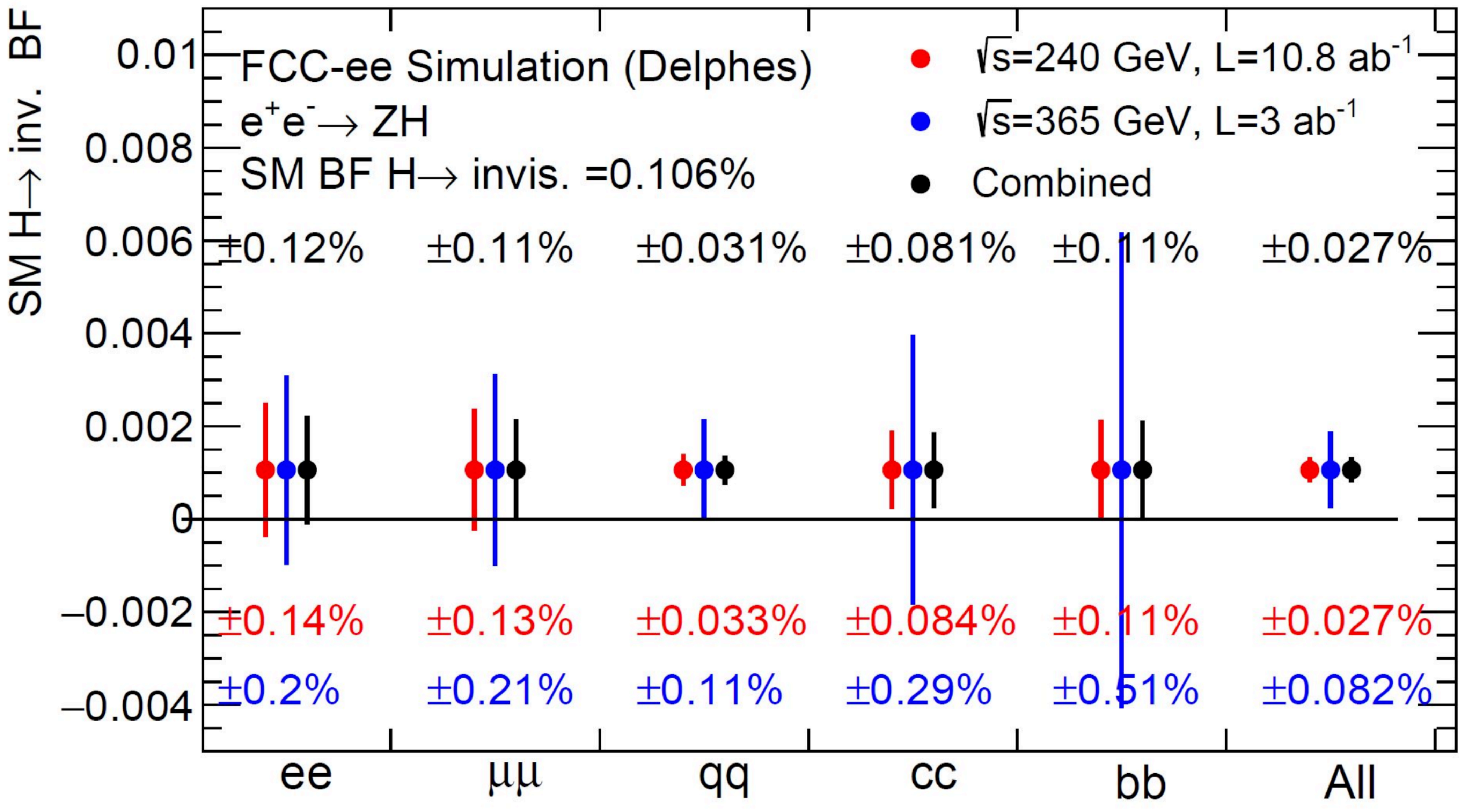
At FCC-ee, reconstruct invisible decay with recoil method

- Leptonic channels: $Z \to ee, Z \to \mu\mu$
- Hadronic channels: $Z \to$ light quarks, cc, bb
- Fit on missing mass

Combined result: ±0.027% uncertainty on $\mathscr{B}(H \to \text{inv})$

- 25% relative uncertainty on SM signal
- Upper limit of 0.055% at 95% CL
- Totally model-independent





Electron Yukawa

Resonant Higgs production at 125 GeV

- Only possibility to probe electron Yukawa, $\mathscr{B}(H \to ee) \sim O(10^{-9})$

Beam monochromotization is crucial

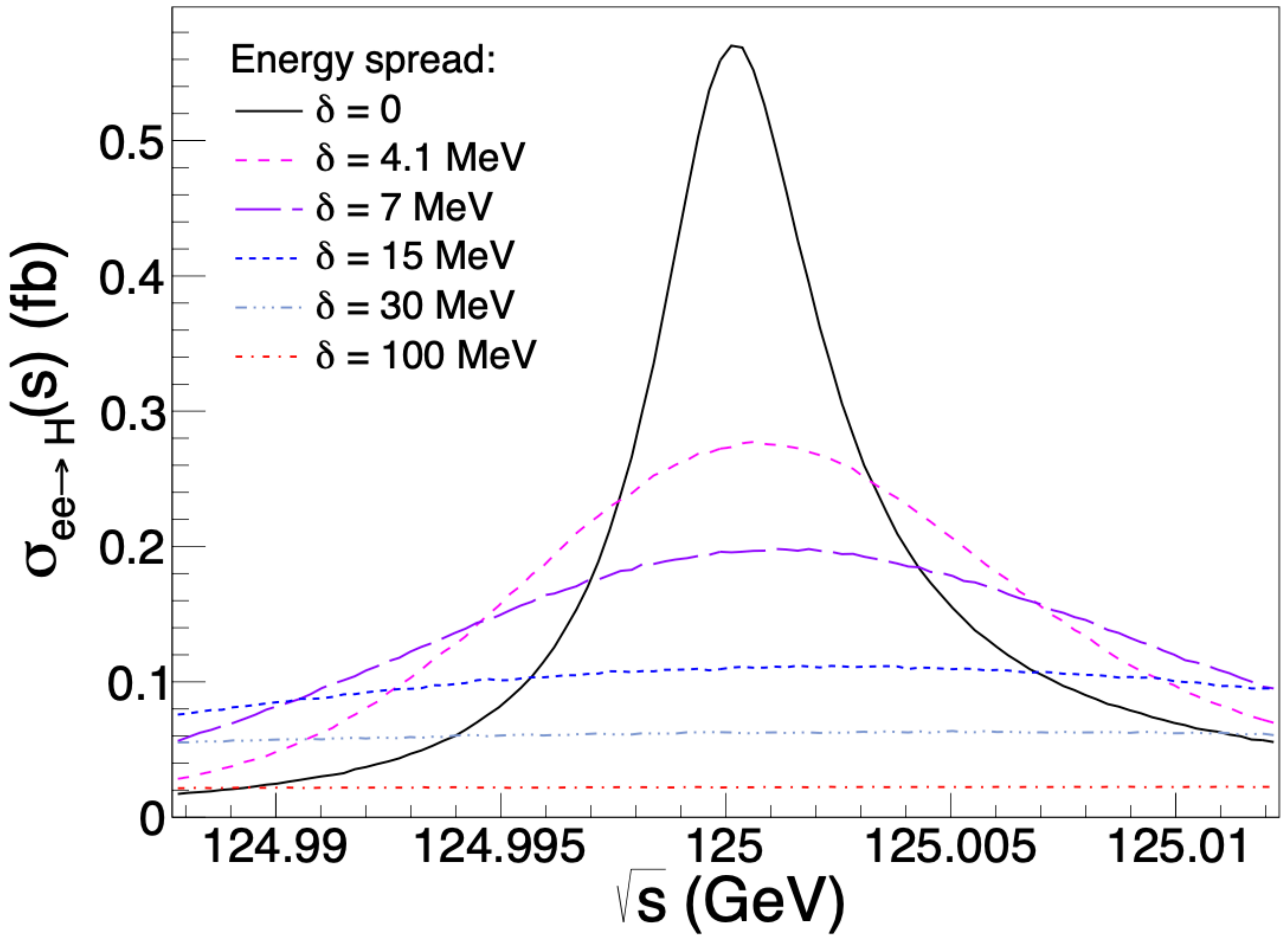
- $\sigma(ee \to H)$ = 1.64 fb (Born level) → 0.57 fb (consider ISR)
- Natural spread due to synchrotron radiation ~ 70 MeV (no peak shape)
- If beam energy spread ~ Γ_H (4 MeV), 0.28 fb
- No technology yet to achieve 4 MeV level spread

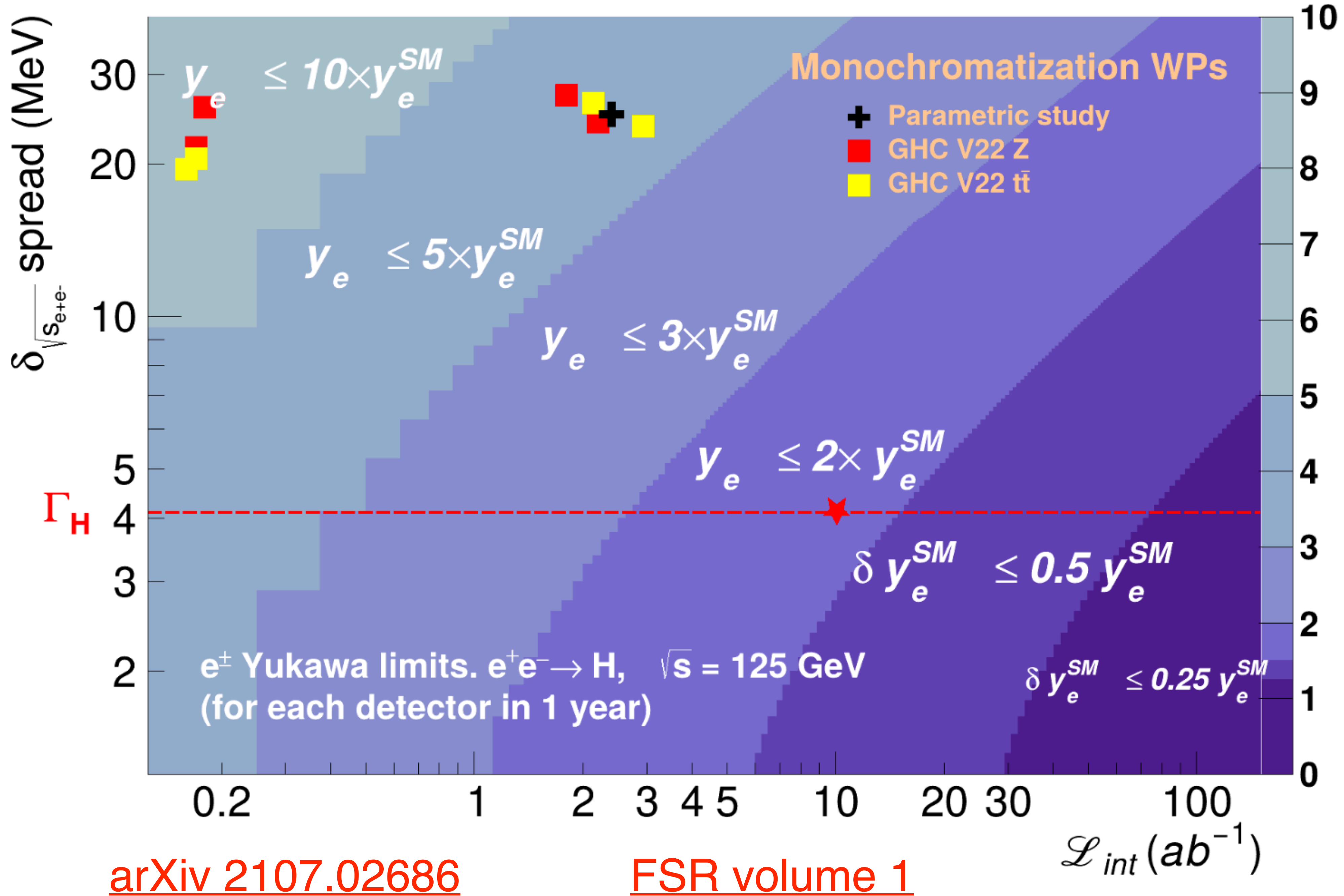
Very rare counting experiment

- $\sigma(e^+e^- \to H) \sim$ O(1) fb, $\sigma(e^+e^- \to Z) \sim$ O(10^5) fb
- $e^+e^- \to gg$ is golden channel (no $Z \to gg$)

Expectations

- 10 ab^{-1}/y ~ 2.8k eeH events/y
- Potential to probe y_e at SM level





arXiv 2107.02686 FSR volume 1

Tagging performance

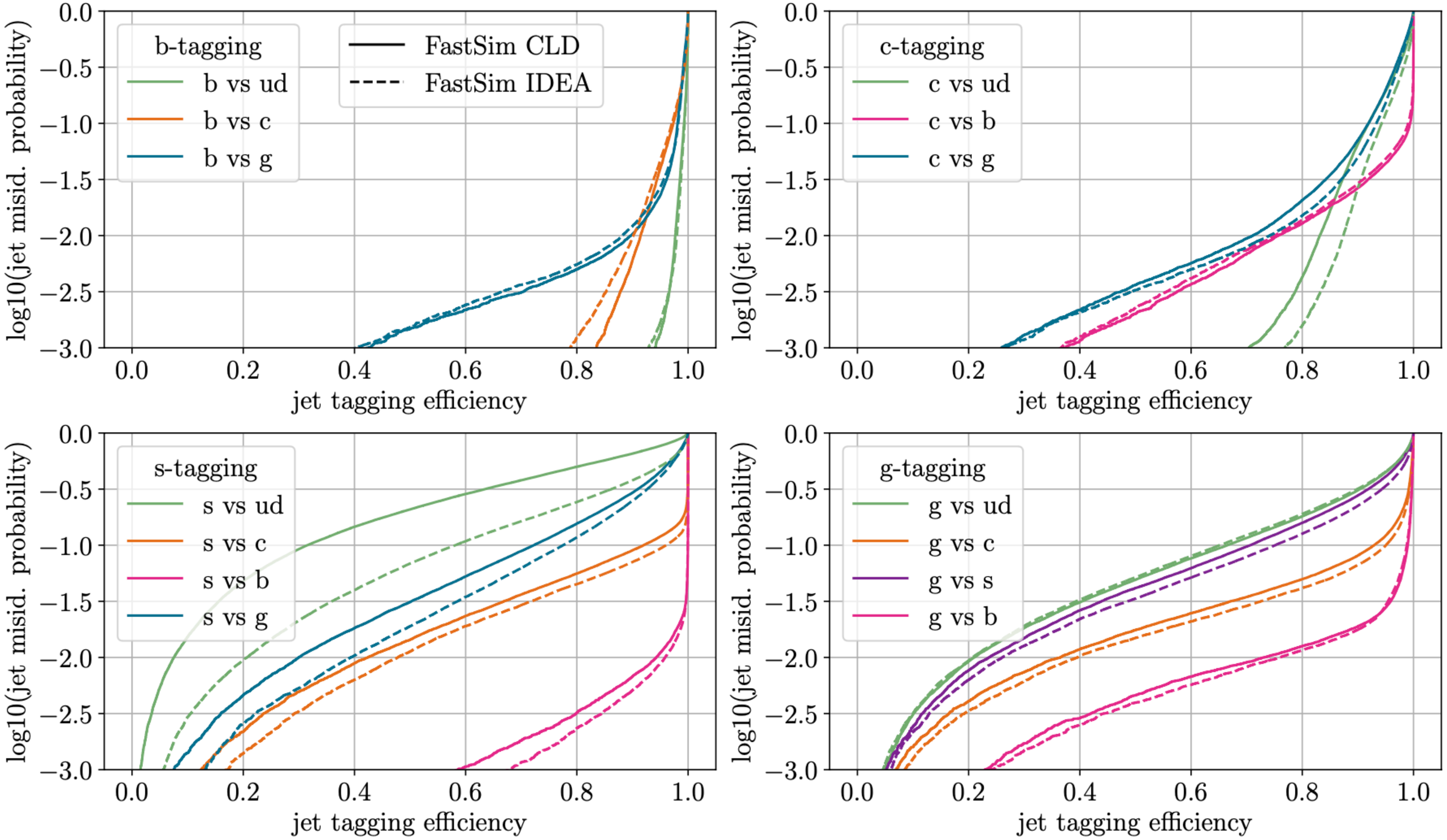
Well-separable, reconstructable jets in ZH events

Excellent jet tagging performance

- benefiting from energy resolution, vertexing, and PID

Large calibration datasets (Z, WW)

- uncertainty at O(10^{-4}-10^{-5})



FCC Note: jet tagging performance

Higgs to hadrons (b, c, s, g)

Consider $Z \to qq, ee, \mu\mu, \nu\nu$ decays

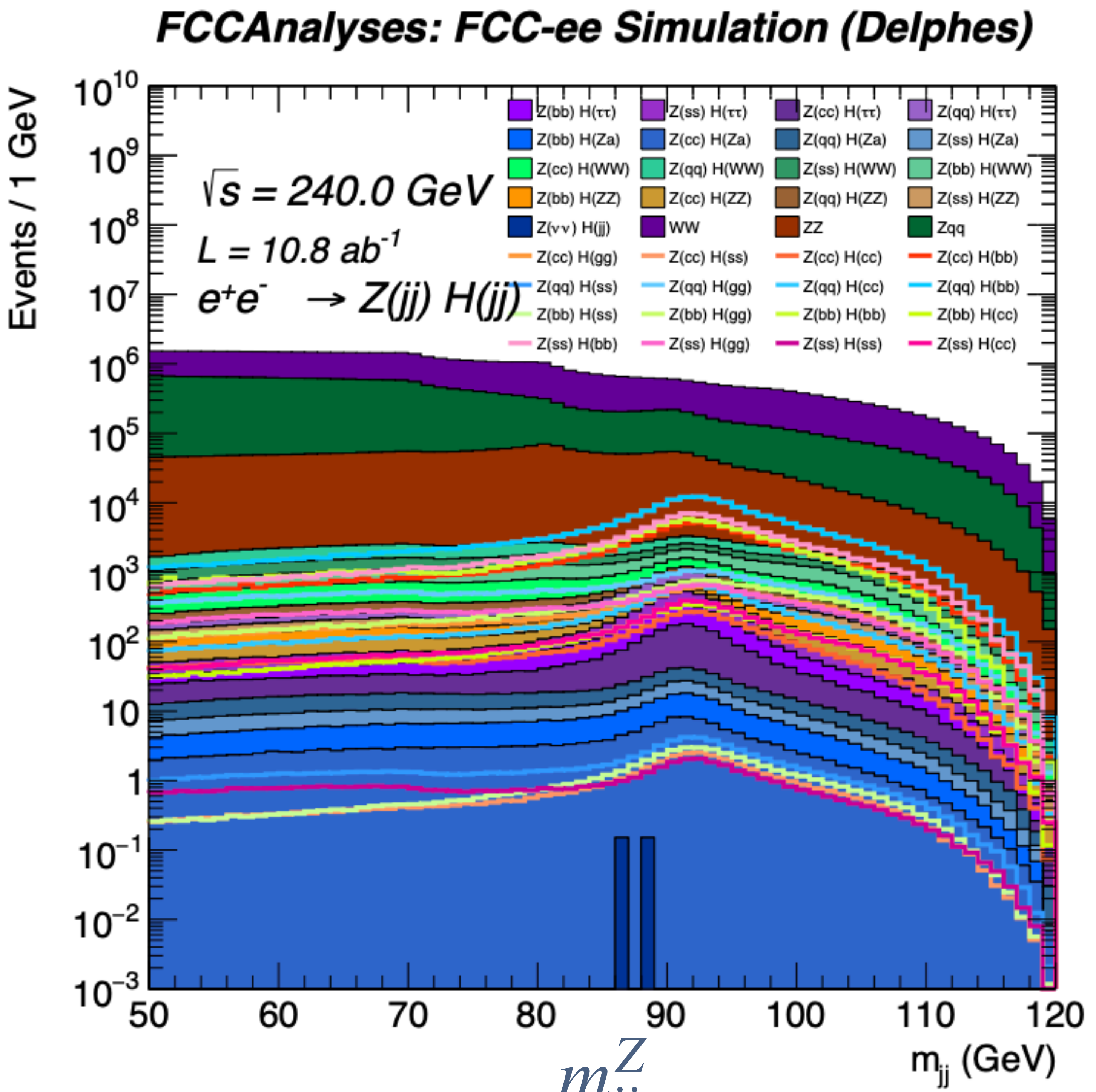
- $\mathscr{B}(Z \to qq)$ = 70%, high stats, limited by clustering
- $\mathscr{B}(Z \to ee, \mu\mu)$ = 7%, low stats, great resolution
- $\mathscr{B}(Z \to \nu\nu)$ = 20%, clean event, good tagging performance

Consider $H \to bb, cc, ss, gg, WW, ZZ, \tau\tau$ decays

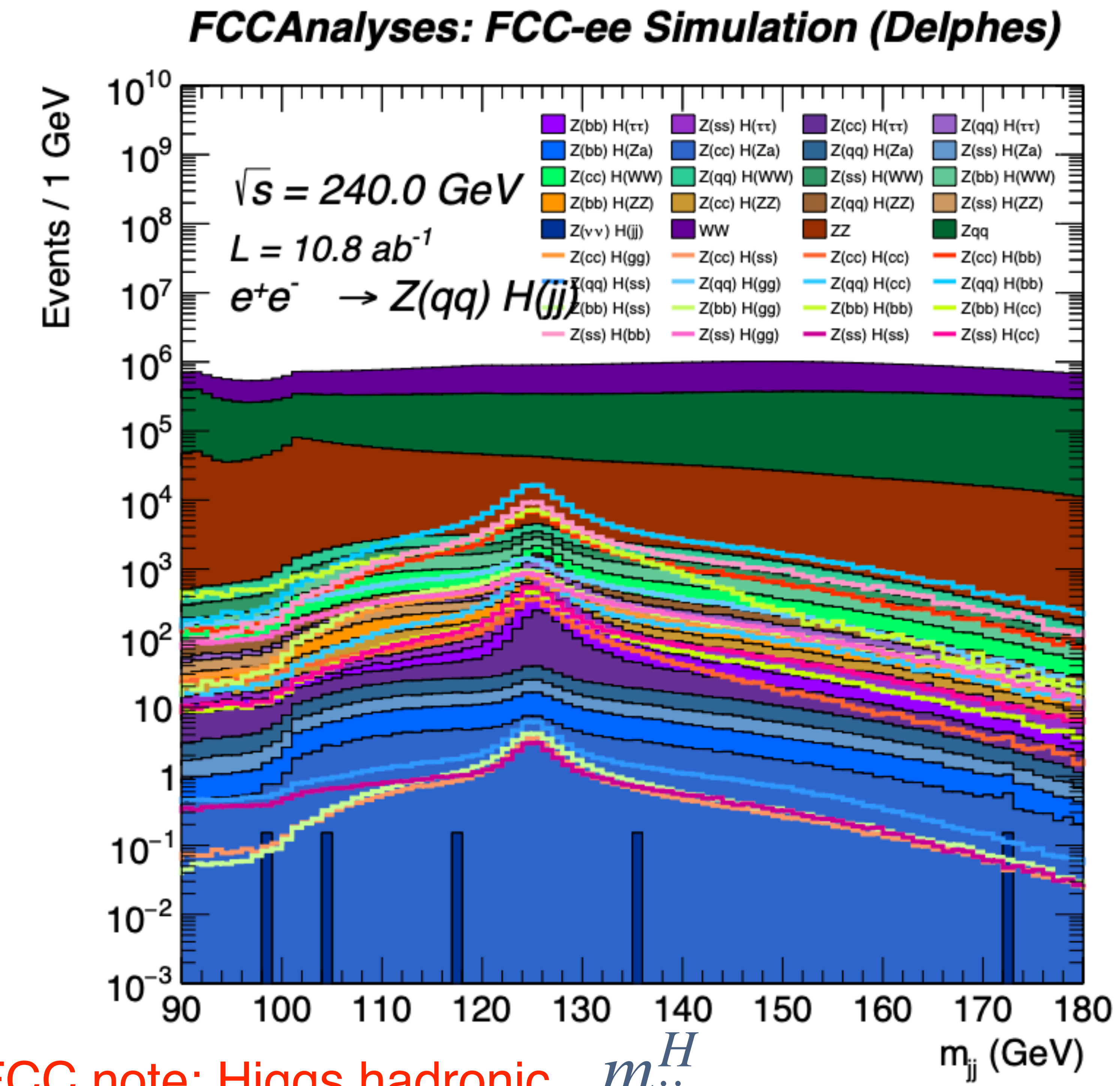
- All possible hadronic final states with same machinery
- $WW, ZZ, \tau\tau$ are byproducts (not optimized)

Event selection

- $Z \to \ell\ell$: 2 tight leptons, $N_j = 2$
- $Z \to \nu\nu$: $m_{vis} < 150$ GeV, $N_j = 2$
- $Z \to qq$: $m_{vis} > 150$ GeV, $N_j = 4$



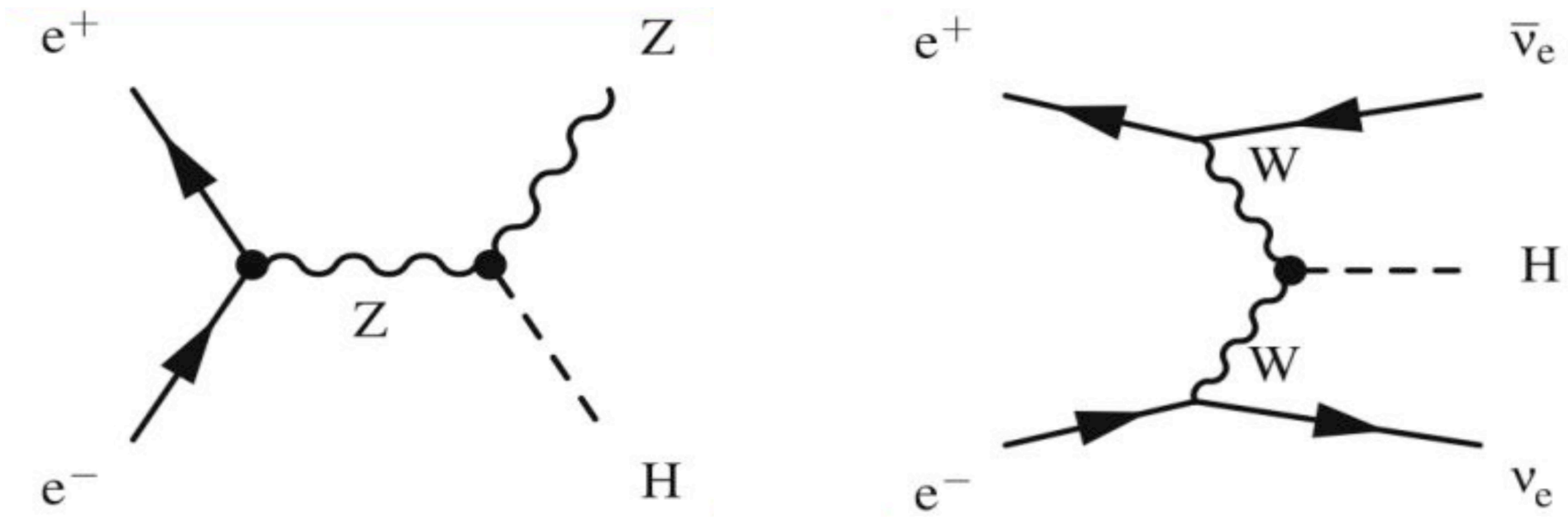
m_{jj}^{Z}



FCC note: Higgs hadronic

m_{jj}^{H}

$\nu\nu + H(jj)$



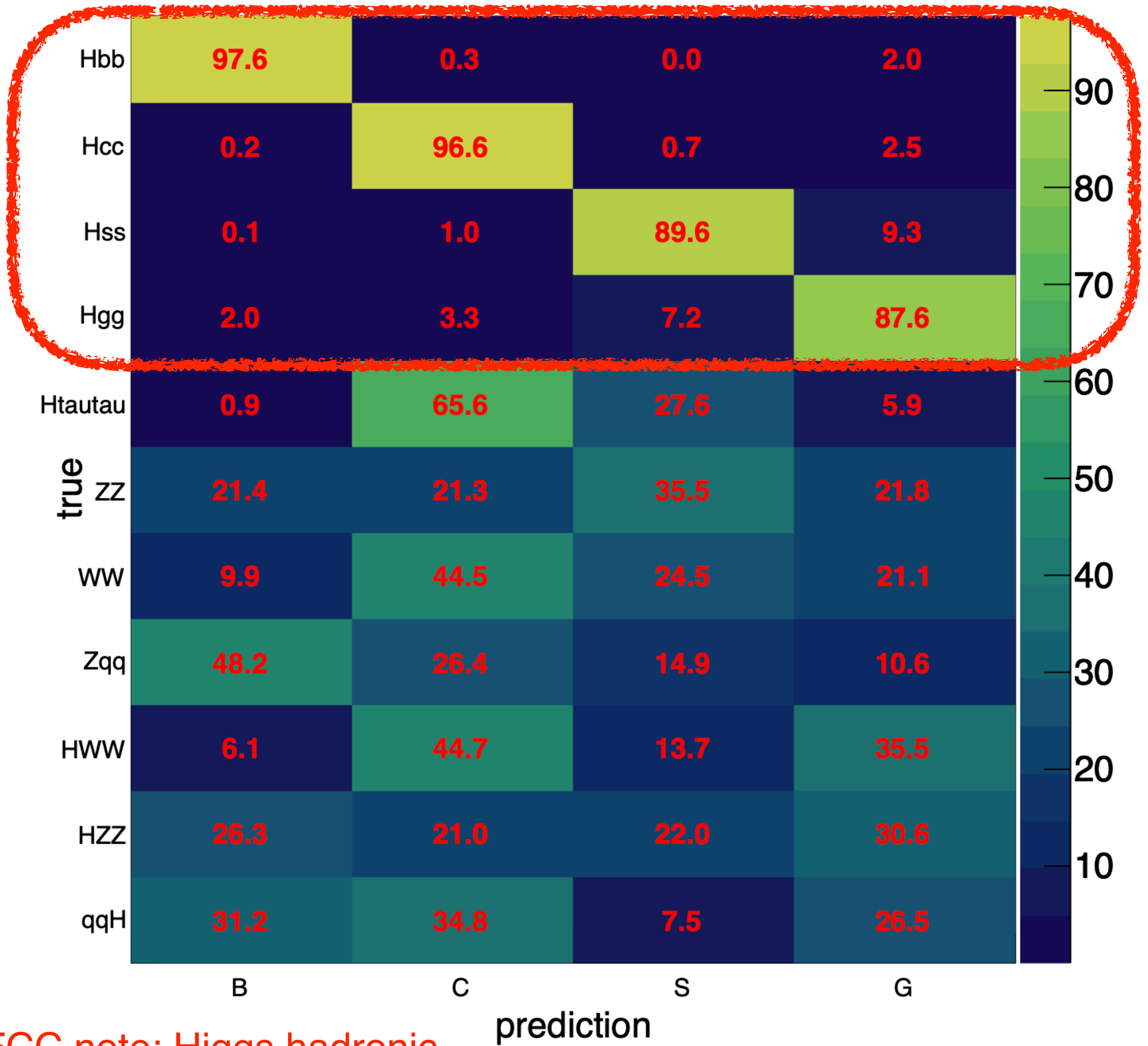
ZH/VBF separation

- ZH template: $e^+e^- \to \nu_\mu\nu_\mu H \times 3$
- VBF template: $e^+e^- \to \nu_e\nu_e H \ - \ e^+e^- \to \nu_\mu\nu_\mu H$

Categorization

- Based on sum of jet tagging score ($j = b, c, s, d, u, g, \tau$)
- Each tag further divided into 3 sub-categories based on purity
- 2-D fit on m_{jj} and m_{miss}

	B	C	S	G
L	< 1.1	< 1.0	< 1.1	< 1.2
M	$[1.1, 1.9]$	$[1.0, 1.8]$	$[1.1, 1.7]$	$[1.2, 1.5]$
H	> 1.9	> 1.8	> 1.7	> 1.5



FCC note: Higgs hadronic

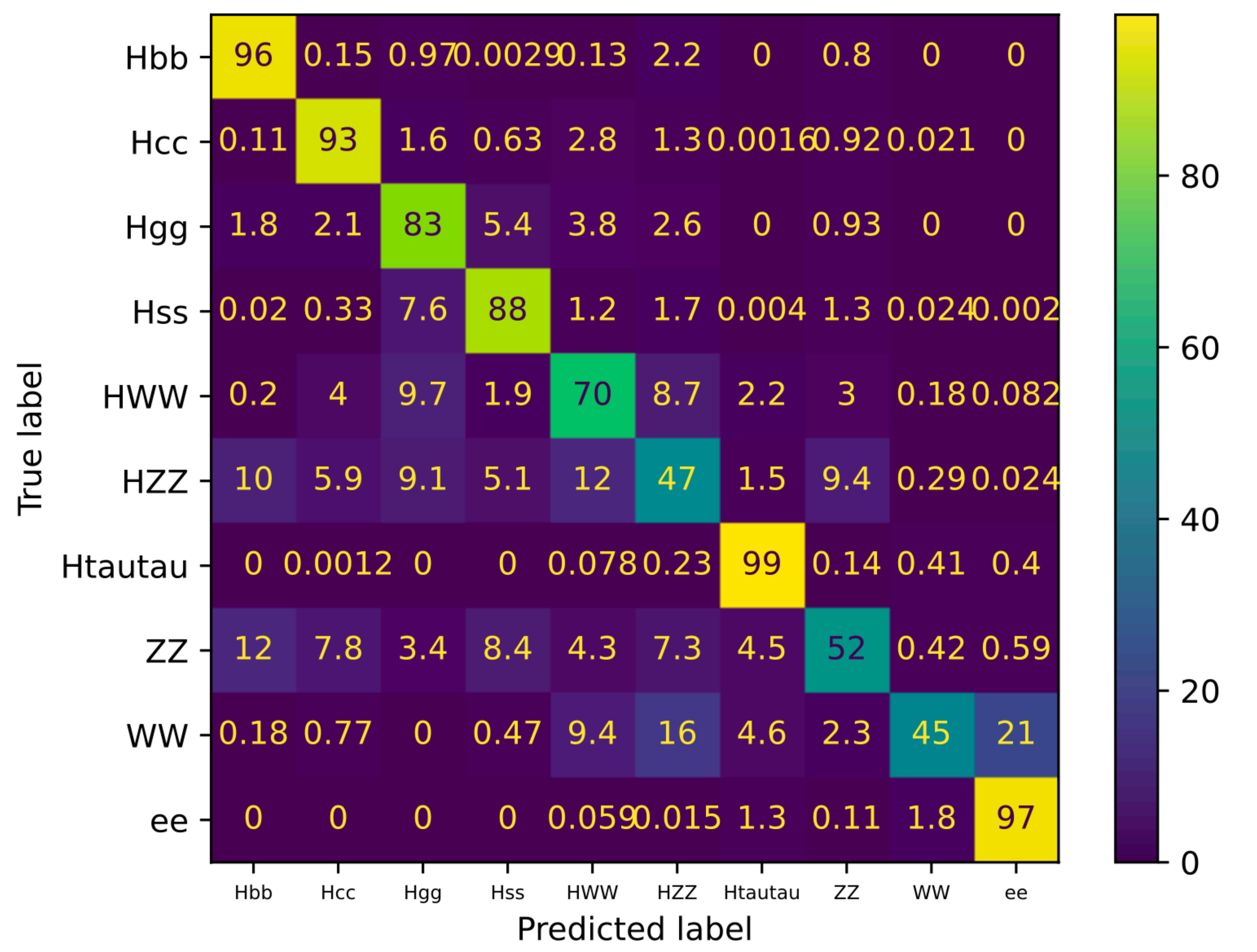
$Z(\ell\ell)H(jj)$ and $Z(jj)H(jj)$

$Z(\ell\ell)H(jj)$ analysis

- Fully connected NN to make 7 sig + 3 bkg categories
- Inputs: jet kinematics, tagging scores, missing energy
- Use NN to further divide 3 purity-based sub-categories
- 1-D fit on m_{recoil}

$Z(jj)H(jj)$

- Paring based on flavor tagging and dijet mass
- 16 flavor-based $\otimes$ 3 purity-based categories
- 2-D fit on m_{recoil} and m_{jj}



FCC note: Higgs hadronic

Higgs to hadrons - results

- Simultaneous fit across all categories
- $H \to WW, ZZ, \tau\tau$ as independent signal modes
- Precision driven by ZH at 240 GeV

Expected precision on σ×BR(Z(H→XX)) at √s=240 GeV				
Final state	**Z(νν)H(jj)**	**Z(ℓℓ)H(jj)**	**Z(jj)H(jj)**	**Combination**
H → bb	0.33	0.60	0.32	0.21
H → cc	2.27	3.47	3.52	1.61
H → gg	0.94	1.93	3.07	0.80
H → ss	140	220	410	120
H → WW*	1.28	1.49	8.74	1.17
H → ZZ*	11.4	7.65	50	9.94
H → $\tau\tau$	10.6	2.54	110	3.67

$\sqrt{s}$	240 GeV		365 GeV	
Integrated luminosity	10.8 ab^{-1}		3.0 ab^{-1}	
Channel	ZH	$\nu_e\bar{\nu}_eH$	ZH	$\nu_e\bar{\nu}_eH$
$H \to b\bar{b}$	±0.21	±1.89	±0.41	±0.67
$H \to c\bar{c}$	±1.61	±19.4	±3.13	±3.49
$H \to s\bar{s}$	±120	±990	±360	±290
$H \to gg$	±0.80	±5.50	±2.21	±2.66
$H \to WW$	±1.17	±15.6	±3.18	±5.36
$H \to ZZ$	±9.94	±130	±26.0	±37.1
$H \to \tau^+\tau^-$	±3.67	∞	±11.0	±24.2

FCC note: Higgs hadronic

Summary

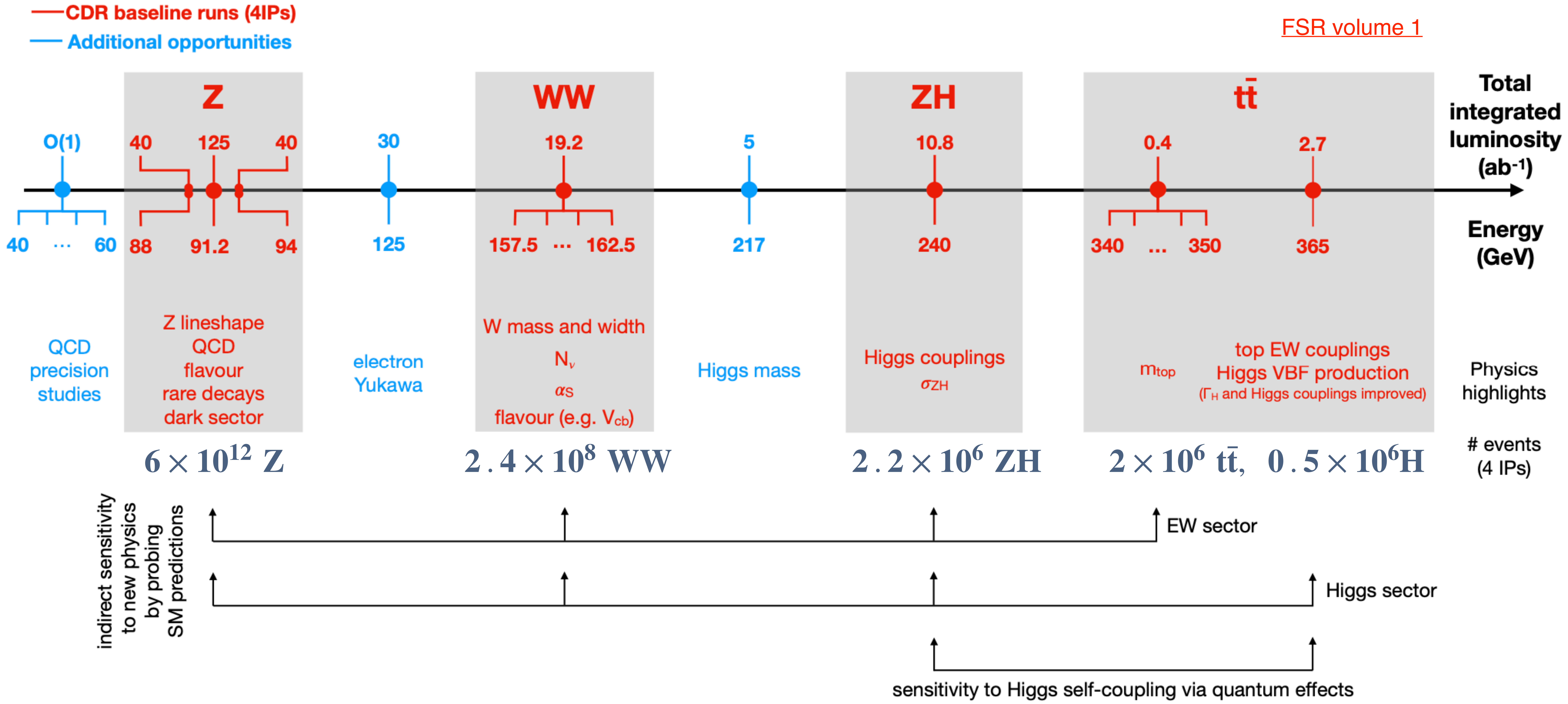
Future Higgs factories, like FCC-ee, can fully examine Higgs properties

- Highly complementary to pp colliders
- Model-independent measurements (cross section, width, and coupling strengths)
- Unique opportunities (electron Yukawa and invisible decay)
- Excellent precision (sub-percent for many measurements)

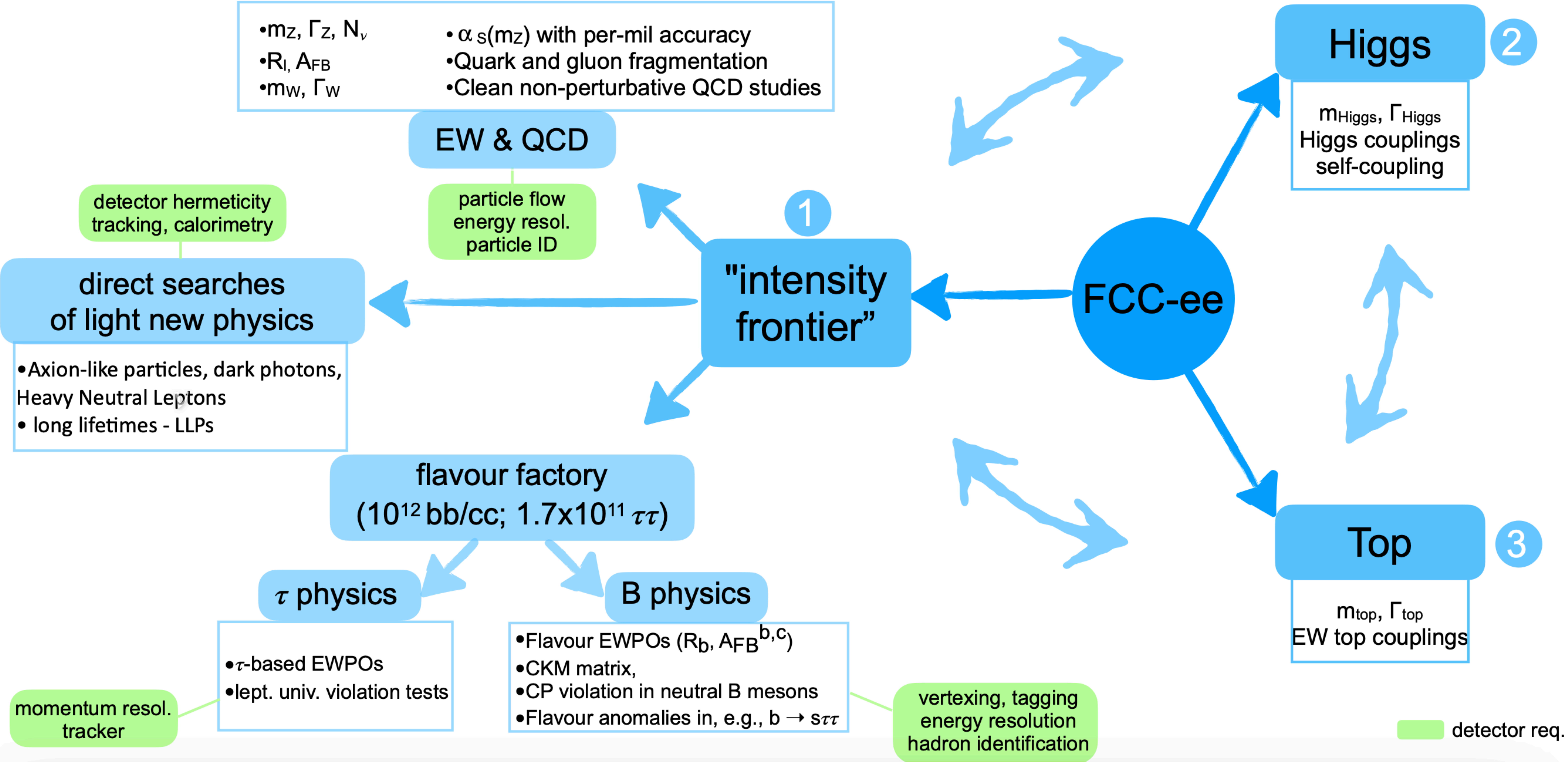
Backups

FCC-ee physics runs

FSR volume 1



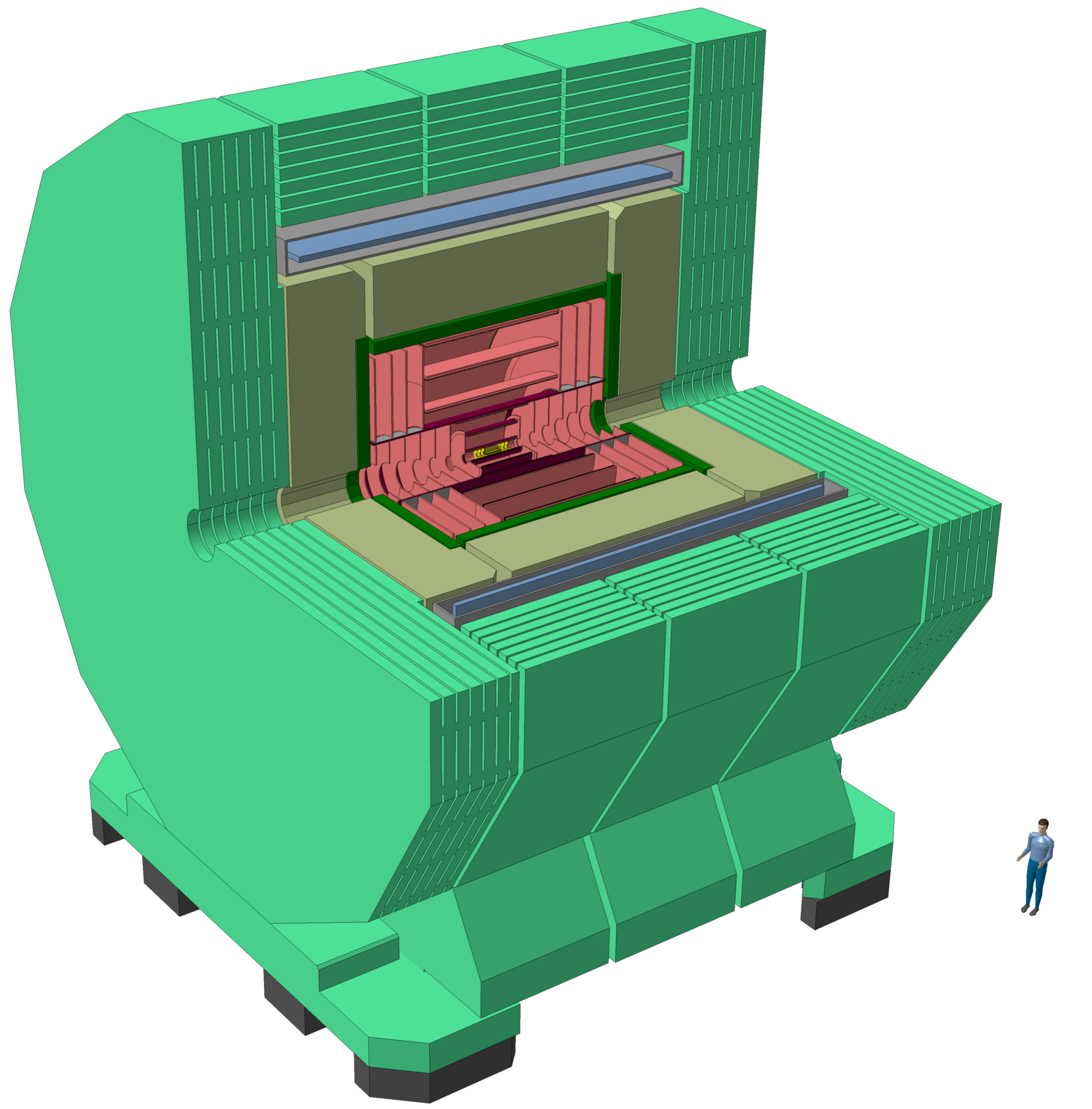
Physics program



Detector concepts

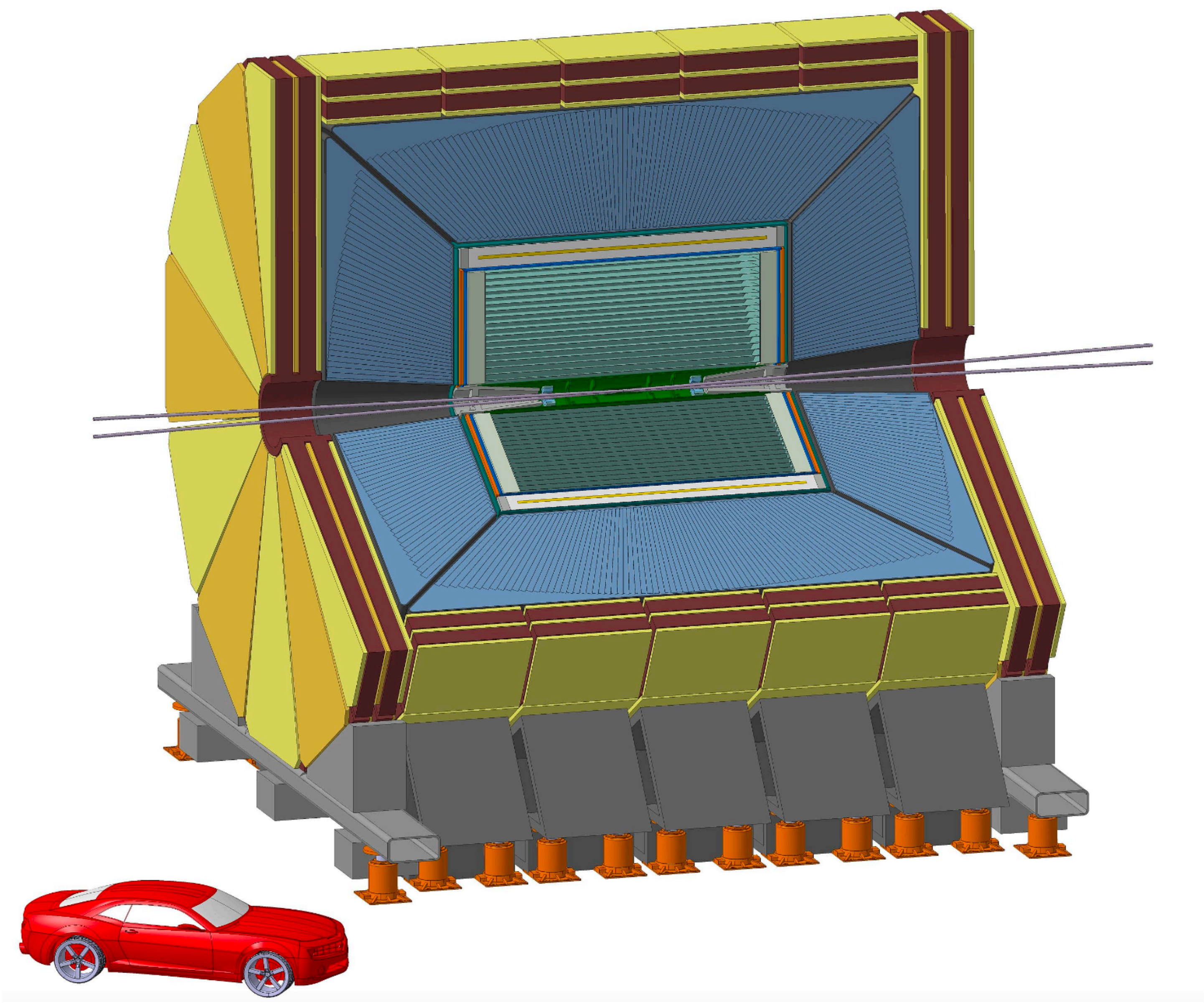
CLD (CLIC-like detector)

- Full silicon vertex detector and tracker
- High granularity silicon-tungsten ECAL + scintillator-steel HCAL
- Solenoid outside of calorimeter



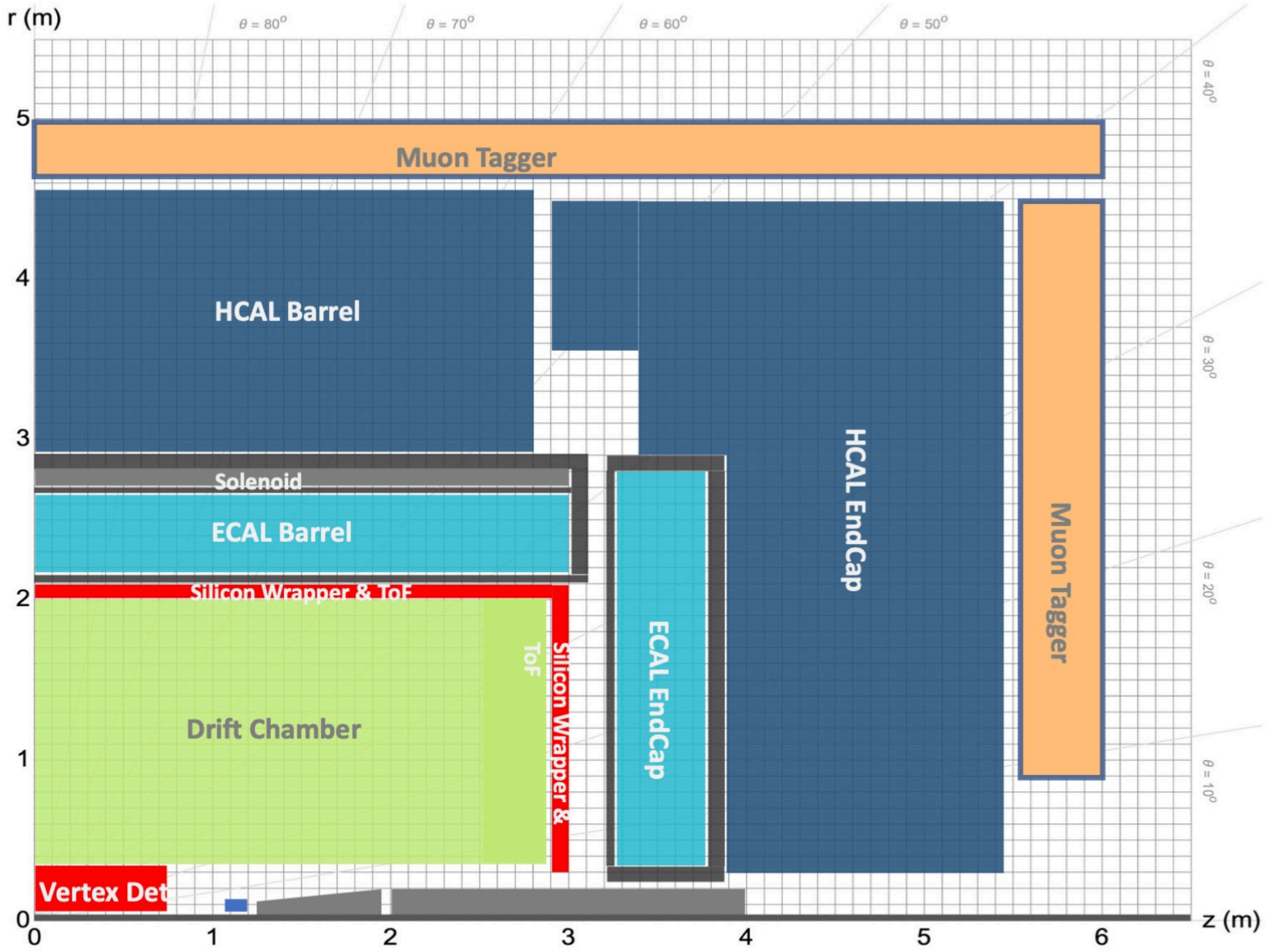
IDEA (Innovative detector for an electron-positron accelerator)

- Silicon vertex detector
- Low mass drift chamber
- Thin solenoid inside of duel-readout calorimeter (Cherenkov and scintillator)



ALLEGRO (A Lepton-Lepton collider Experiment with Granular Read-Out)

- Silicon vertex detector + silicon or gaseous tracker
- Noble liquid + Pb/W ECAL
- Solenoid between ECAL and HCAL



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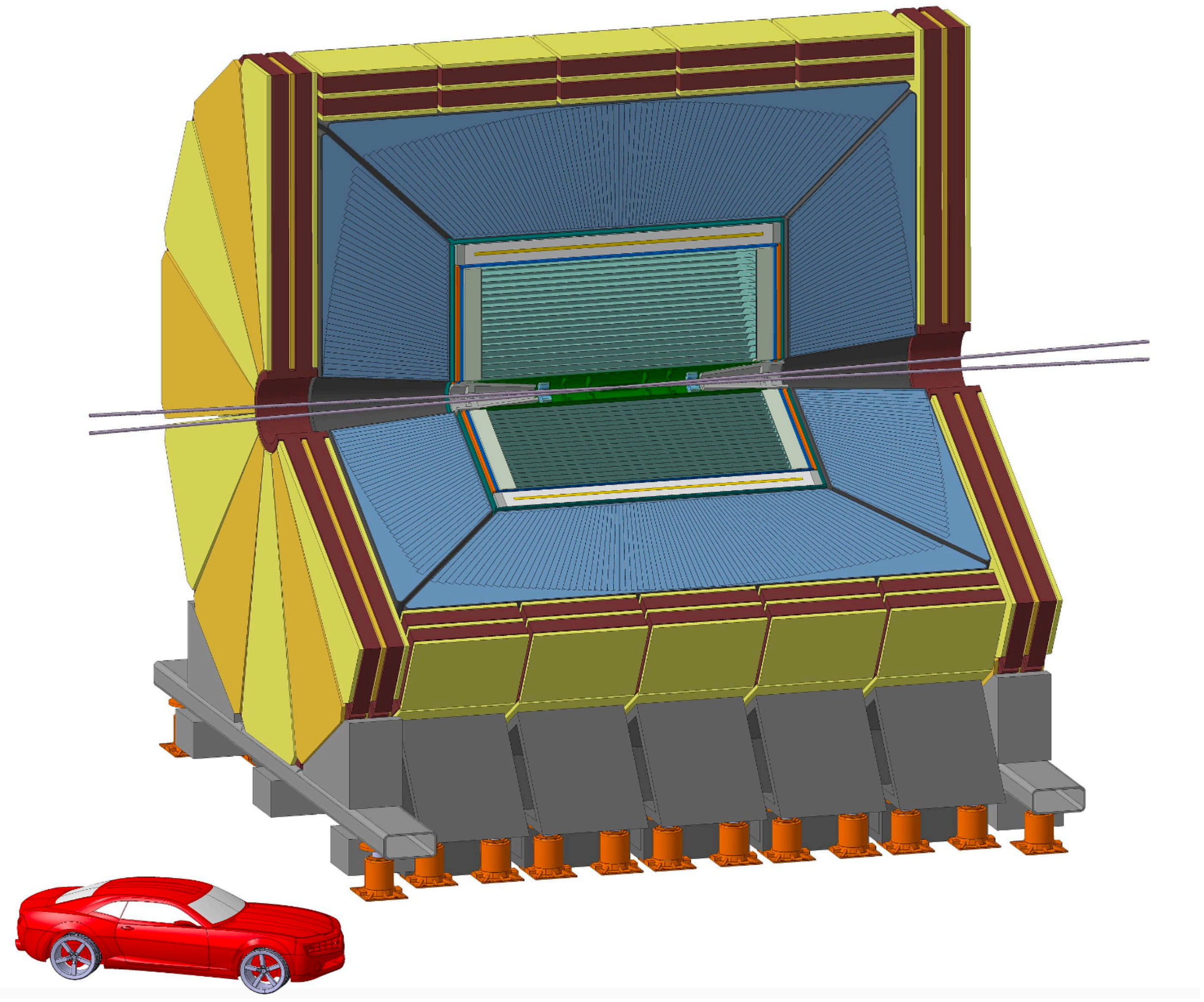
Analysis framework



Abundant centrally-produced simulation

- Generators: Pythia 8, Whizard + Pythia 6
- Simulation: Delphes fastsim based on IDEA concept
- 400+ MC samples, a few billion events (more than expected data)

Common analysis tools

- RDataFrame-based common workflow
- Jet reconstruction: FastJet, exclusive Durham kT algorithm for most cases
- Flavor tagging: Particle Net, considering properties of all constituents (full track info, dN/dx, mTOF)
- Statistical analysis: CMS combine tool

Dedicated analyses to cover all Higgs properties

- ~ 20 dedicated analysis notes
- Centrally coordinated and reviewed

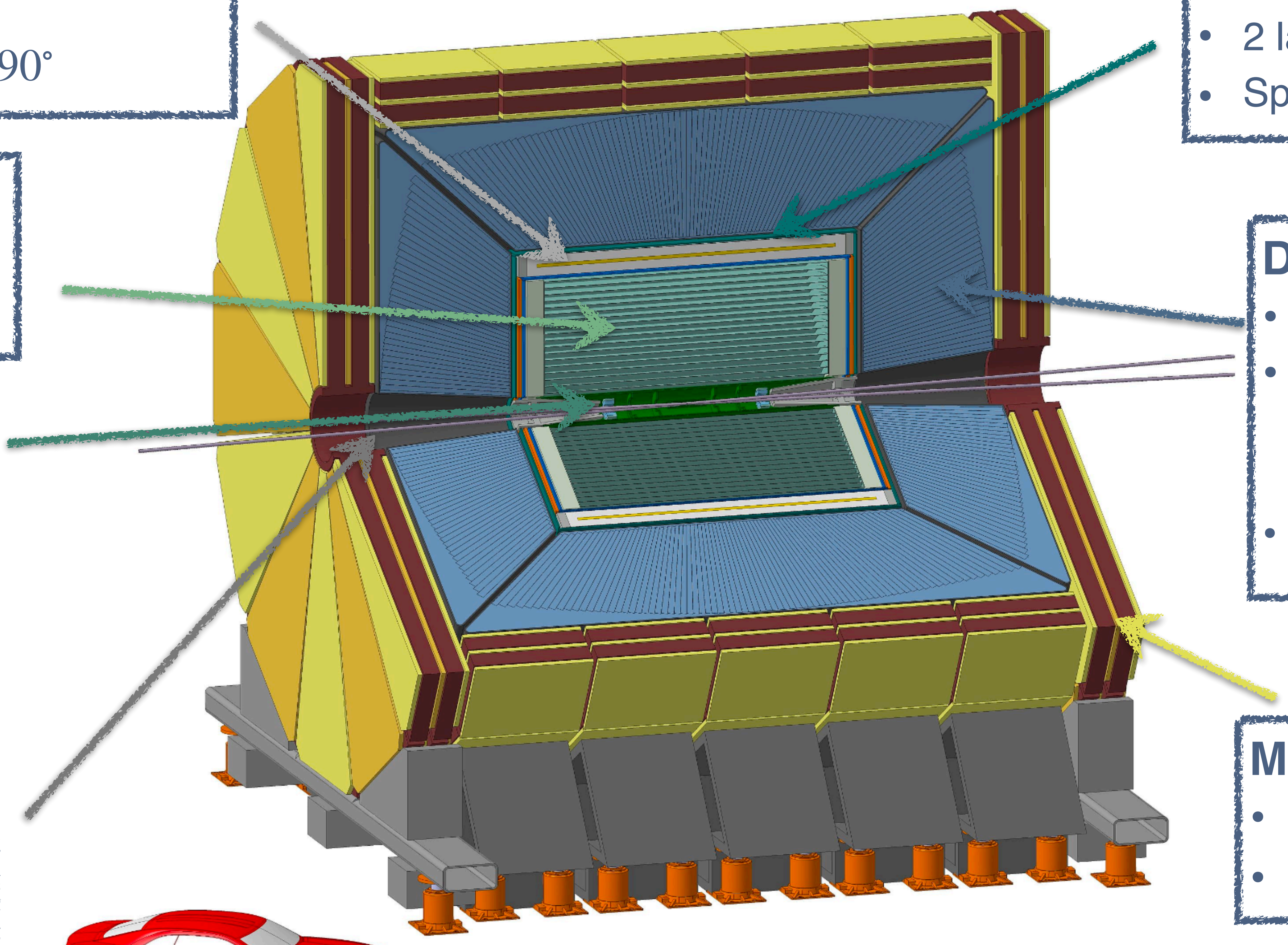
IDEA detector

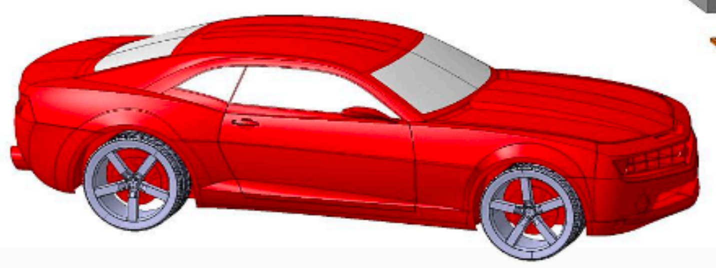
Superconducting solenoid
- 2 T, R = 2.0 - 2.4 m
- $0.74\ X_0,\ 0.16\ \lambda\ @90°$

Wire drift chamber
- 112 layers, R = 35 - 200 cm
- $0.016\ X_0 @ 90°$

Silicon vertex detector
- 5 layers, R = 1.7 - 34 cm
- Pixel $20 \times 20\ \mu m^2$

Beam pipe
- R ~ 1.5 cm



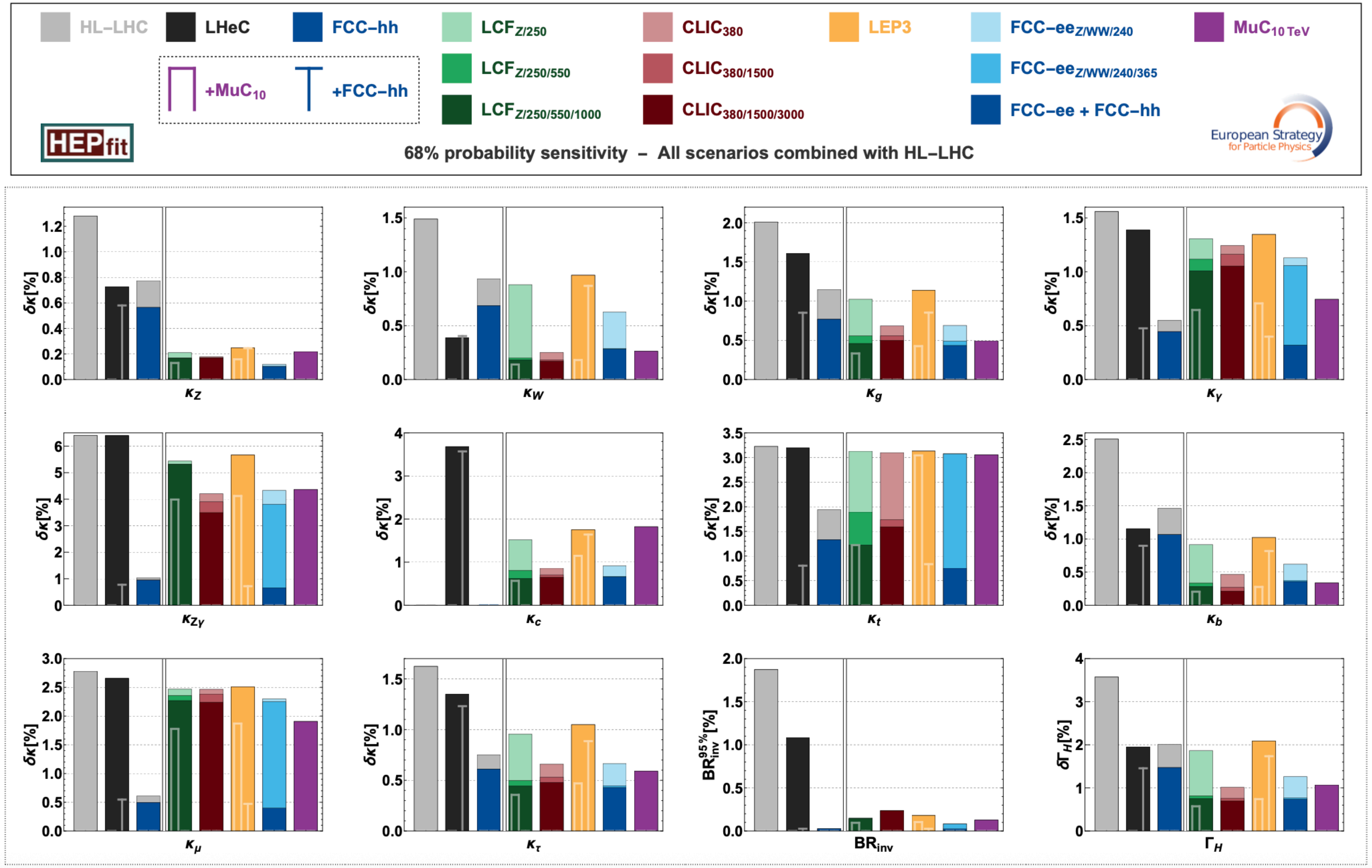


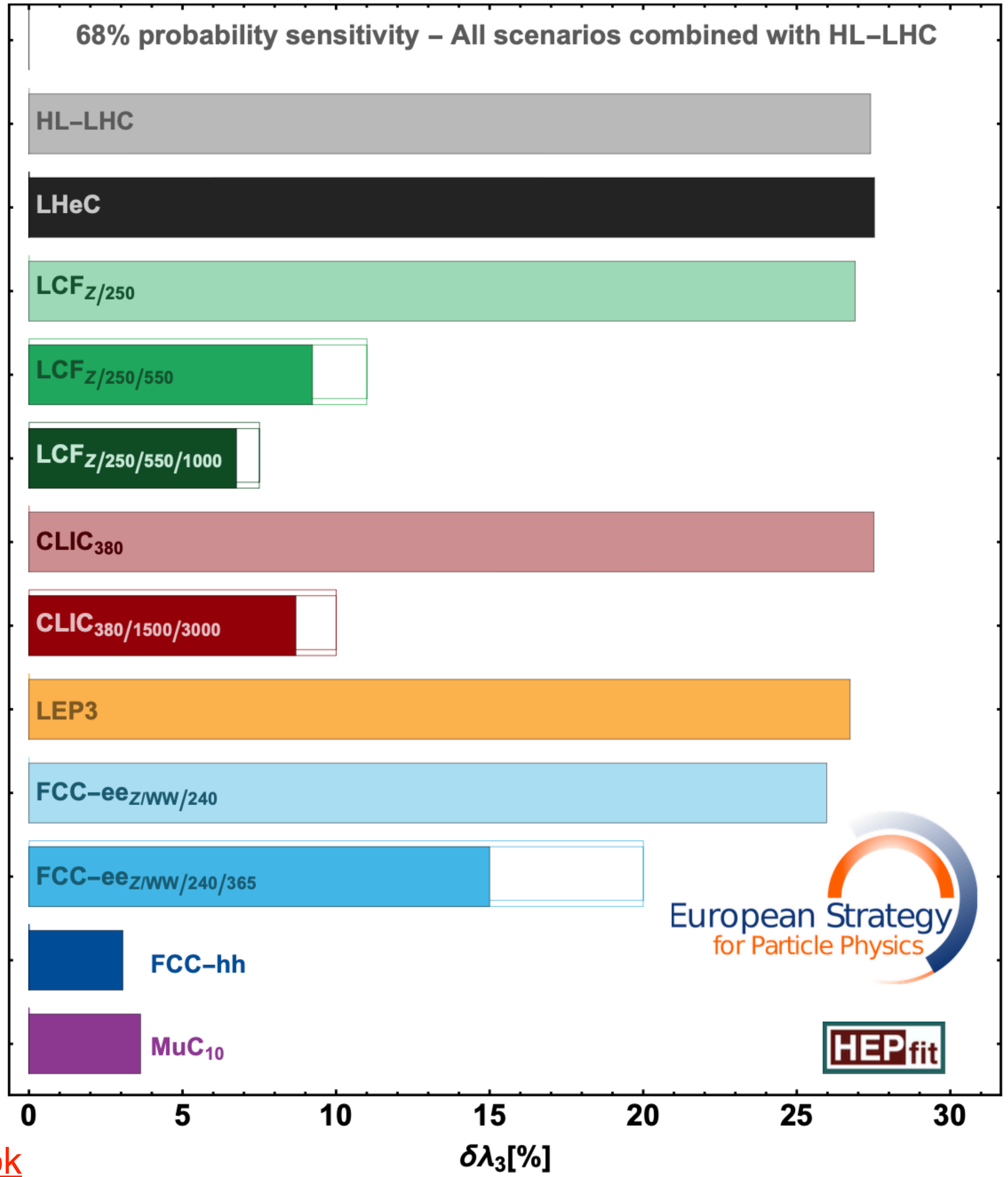
Preshower
- 2 layers, gas detector
- Spatial reso < 100 μm

Dual-readout calorimeter
- 2 m capillaries
- Alternate Cherenkov and scintillation fibers
- $\sigma_{EM} \approx \frac{10\,\%}{\sqrt{E}}$, $\sigma_{had} \approx \frac{30\,\%}{\sqrt{E}}$

Muon chambers
- 3 layers, gas detector
- Spatial reso < 400 μm

Comparison to collider options





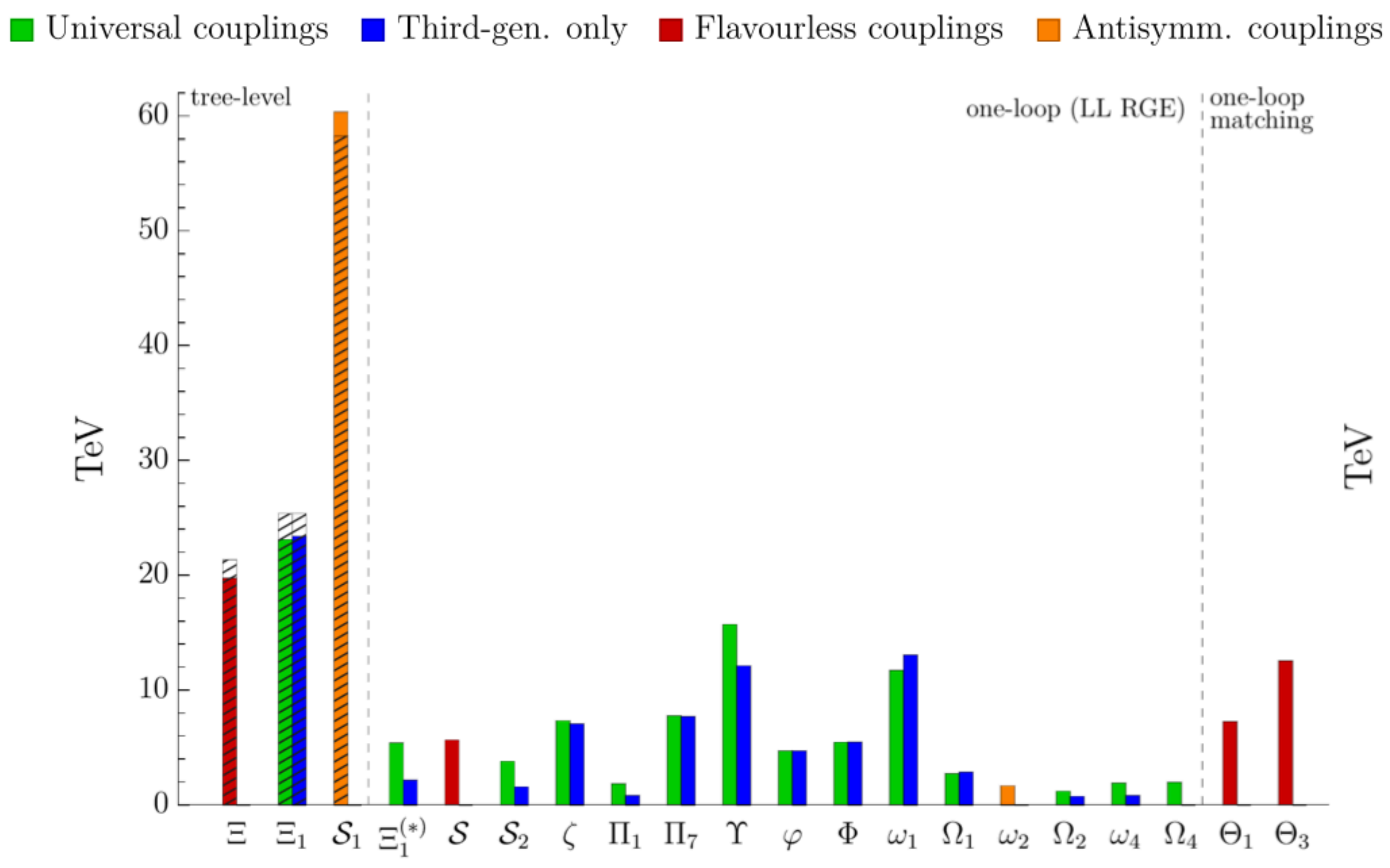
Physics briefing book

EFT probe

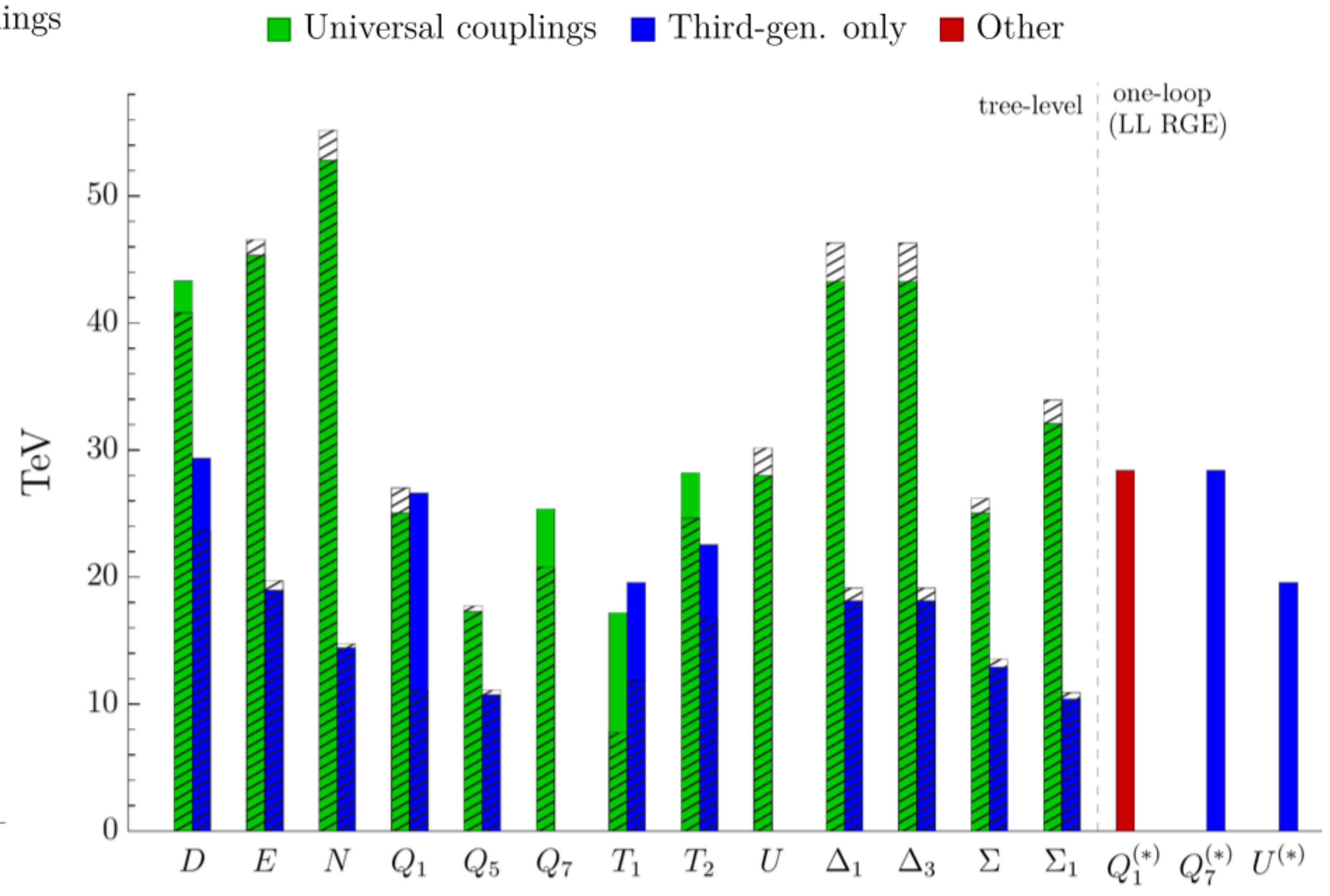
48 possible types of particles that can have tree-level linear interaction to SM, matched to Dim-6 SMEFT operators.

All, but a few, can be probed by W- and Z-pole observables

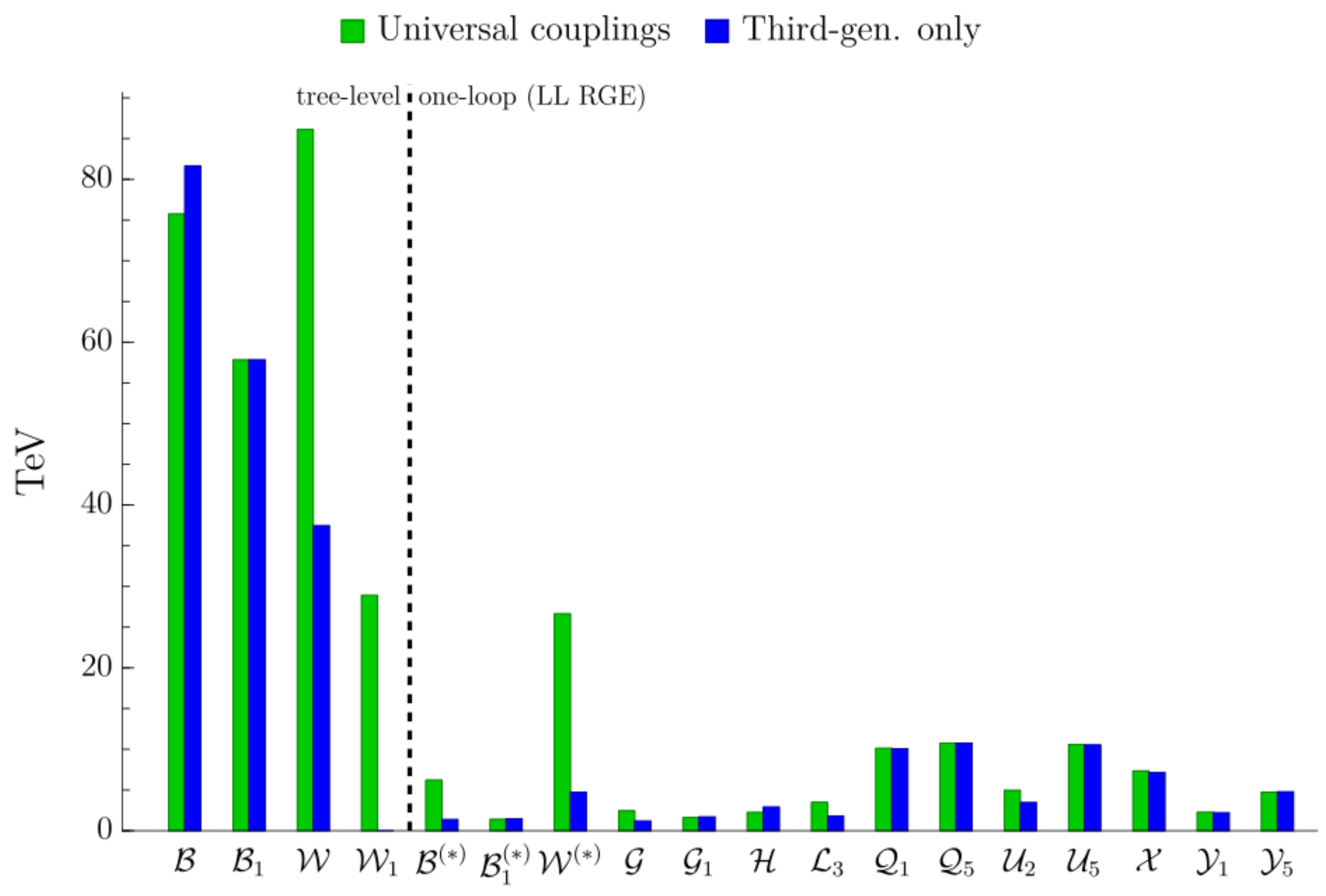
arXiv: 2408.03992



Scalar

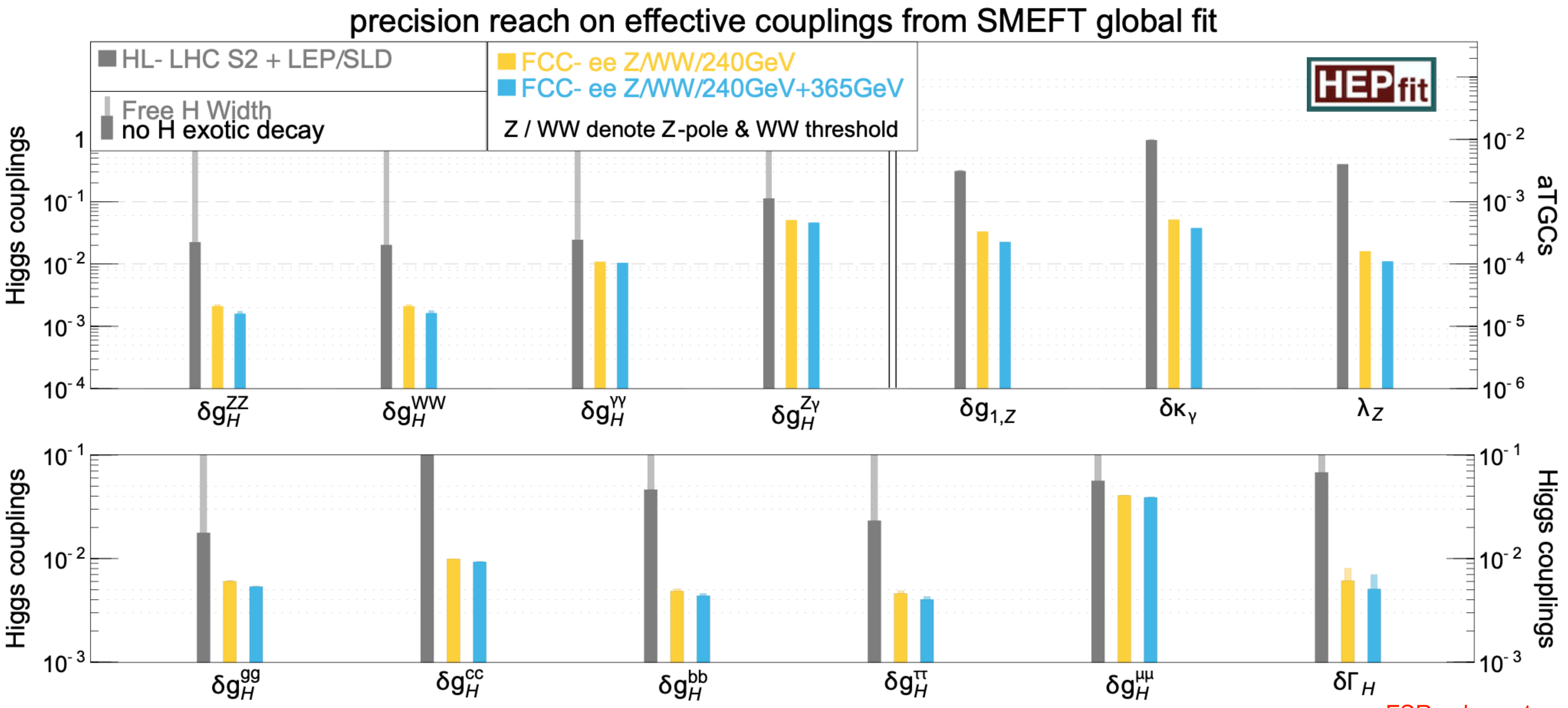


Fermion



Vector

Higgs SMEFT fit



FSR volume 1

kappa fit

Coupling	HL-LHC	FCC-ee	FCC-ee + FCC-hh
κ_Z (%)	1.3*	0.10	0.10
κ_W (%)	1.5*	0.29	0.25
κ_b (%)	2.5*	0.38 / 0.49	0.33 / 0.45
κ_g (%)	2*	0.49 / 0.54	0.41 / 0.44
κ_τ (%)	1.6*	0.46	0.40
κ_c (%)	–	0.70 / 0.87	0.68 / 0.85
κ_γ (%)	1.6*	1.1	0.30
$\kappa_{Z\gamma}$ (%)	10*	4.3	0.67
κ_t (%)	3.2*	3.1	0.75
κ_μ (%)	4.4*	3.3	0.42
$\lvert\kappa_s\rvert$ (%)	–	$^{+29}_{-67}$	$^{+29}_{-67}$
Γ_H (%)	–	0.78	0.69
$\mathcal{B}_{inv}$ (<, 95% CL)	1.9×10^{-2} *	5×10^{-4}	2.3×10^{-4}
$\mathcal{B}_{unt}$ (<, 95% CL)	4×10^{-2} *	6.8×10^{-3}	6.7×10^{-3}

FSR volume 1

Higgs mass and detector variation

stats (stats+syst)

Nominal configuration → Nominal

Crystal ECAL to Dual Readout → Degradation electron resolution

Nominal 2 T → field 3 T → Magnetic field 3T

IDEA drift chamber → Si tracker → Silicon tracker

Impact of Beam Energy Spread → BES 6% uncertainty, Disable BES

Perfect (=gen-level) momentum resolution → Ideal resolution

Final state	Muon	Electron	Combination
Nominal	3.92(4.74)	4.95(5.68)	3.07(3.97)
Degradation electron resolution	3.92(4.74)	5.79(6.33)	3.24(4.12)
Magnetic field 3T	3.22(4.14)	4.11(4.83)	2.54(3.52)
Silicon tracker	5.11(5.73)	5.89(6.42)	3.86(4.55)
BES 6% uncertainty	3.92(4.79)	4.95(5.92)	3.07(3.98)
Disable BES	2.11(3.31)	2.93(3.88)	1.71(2.92)
Ideal resolution	3.12(3.95)	3.58(4.52)	2.42(3.40)
Freeze backgrounds	3.91(4.74)	4.95(5.67)	3.07(3.96)
Remove backgrounds	3.08(4.13)	3.51(4.58)	2.31(3.45)

Explicit decay measurements

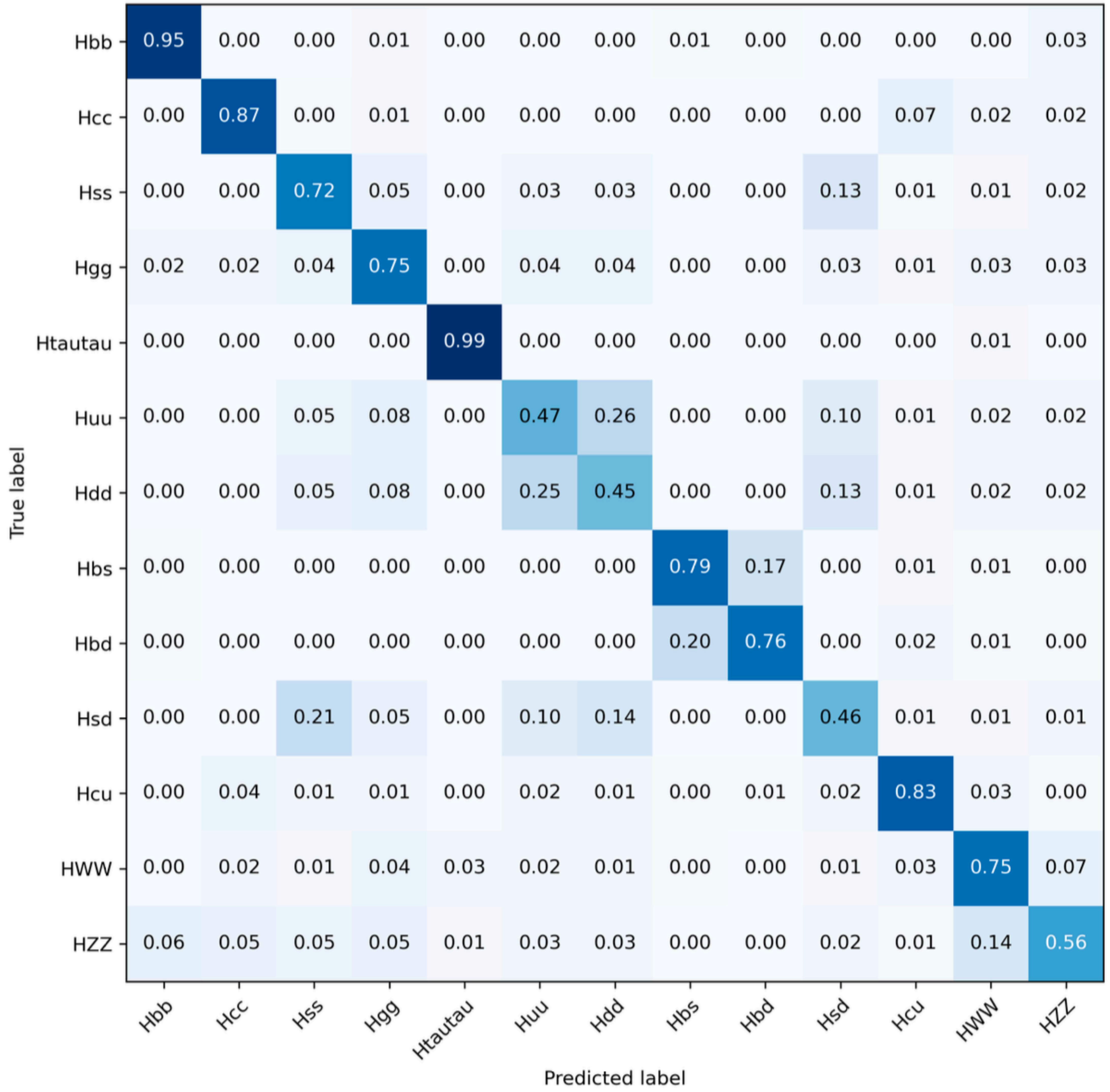
- Higgs to hadron final states
- Many modes inaccessible at LHC
- High precision on all decays channels

Light quark Yukawa and FCNC

Extension of $Z(\nu\nu)H(jj)$ analysis, with additional tags for light quarks or FCNC

Decay	SM Prediction	this work (95% CL)	current constraints
$H \to uu$	1.2×10^{-7}	$< 1.2 \times 10^{-3}$	3×10^{-2}
$H \to dd$	5.5×10^{-7}	$< 1.2 \times 10^{-3}$	7×10^{-3}
$H \to bs$	9×10^{-8}	$< 3.1 \times 10^{-4}$	$< 1.6 \times 10^{-3}$
$H \to bd$	4×10^{-9}	$< 2.2 \times 10^{-4}$	$< 10^{-3}$
$H \to cu$	3×10^{-20}	$< 2.0 \times 10^{-4}$	$< 2 \times 10^{-3}$
$H \to sd$	2×10^{-15}	$< 6.5 \times 10^{-4}$	—

FCC note: light & FCNC

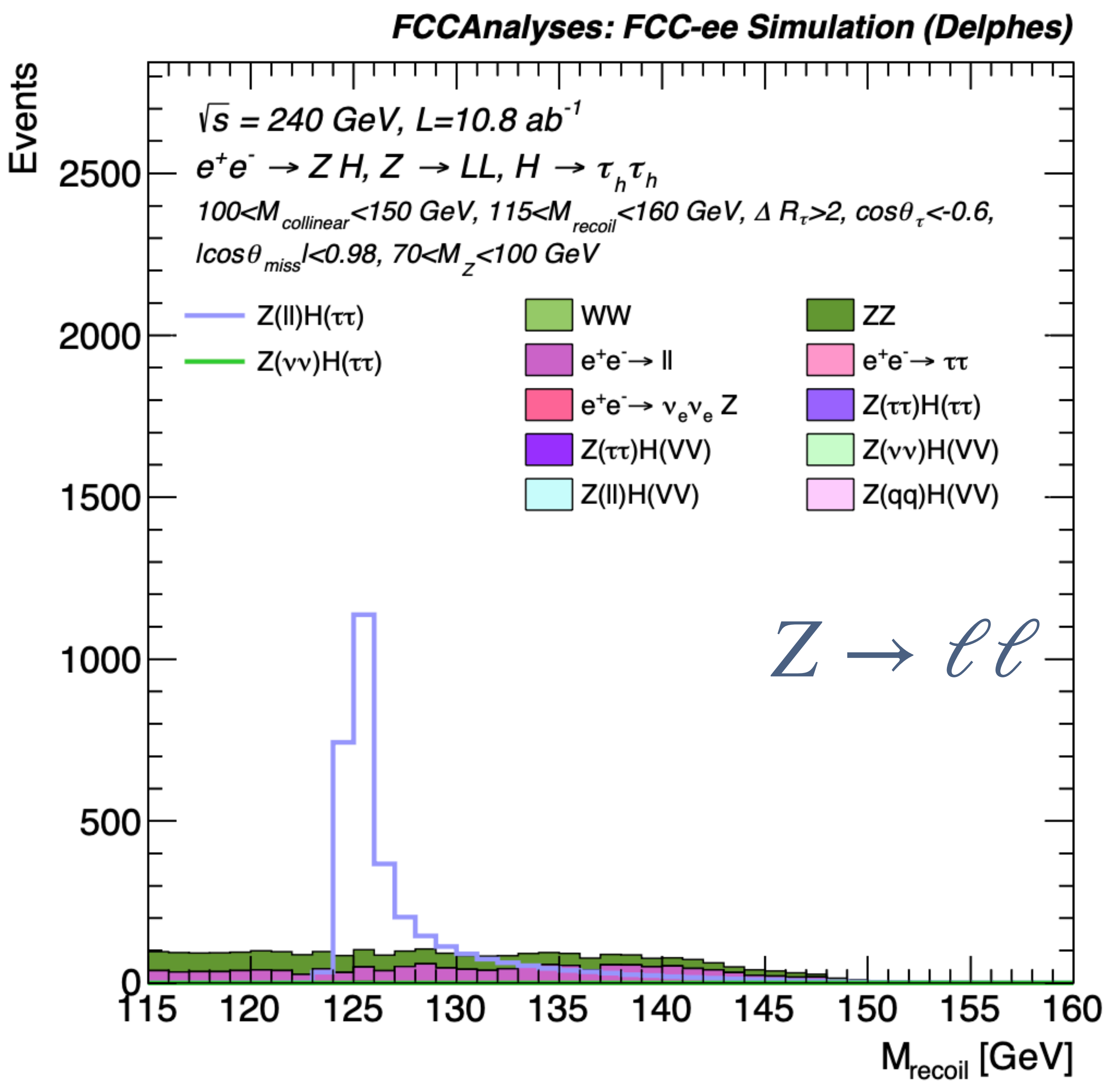


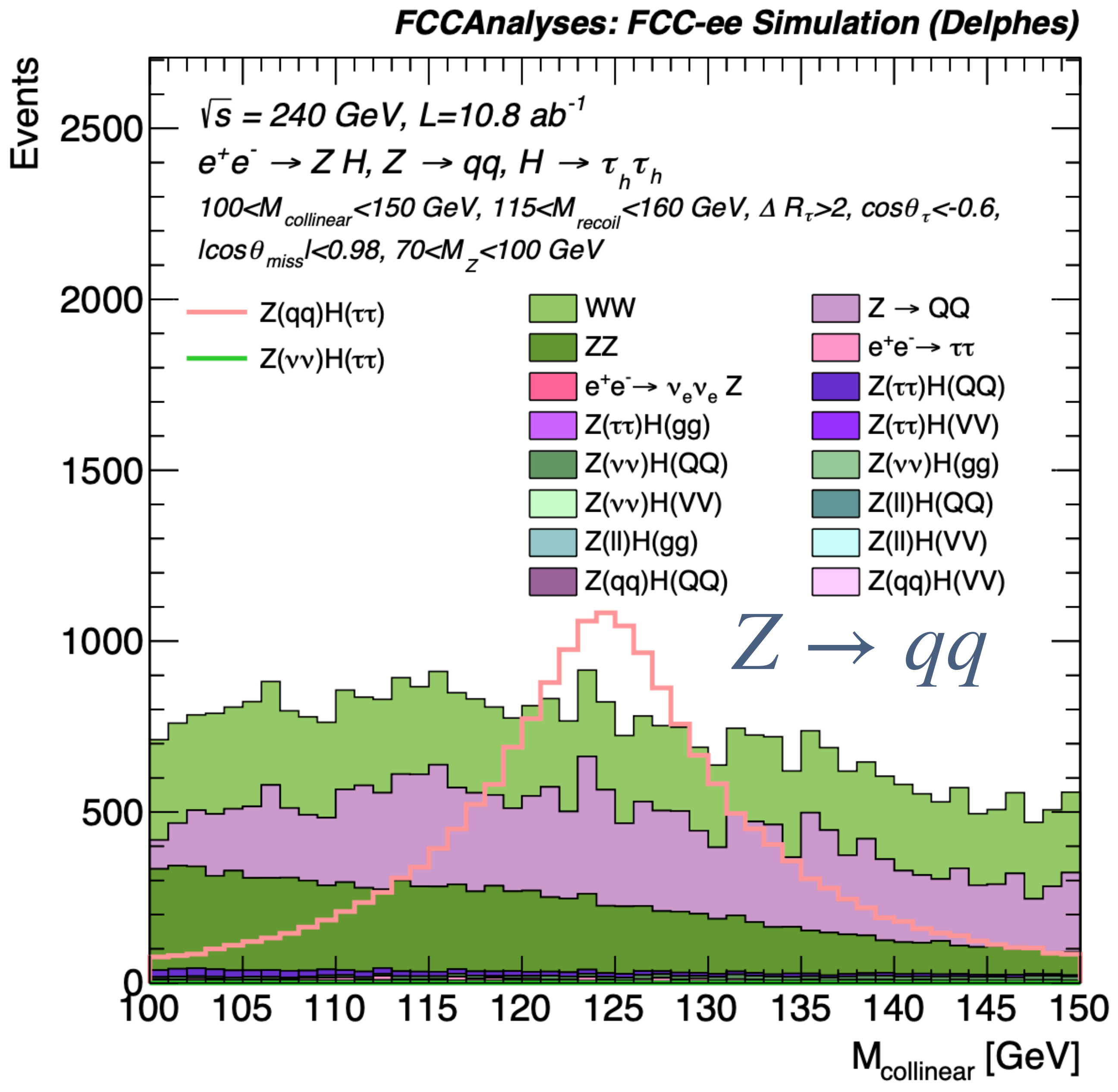
$H \to \tau\tau$

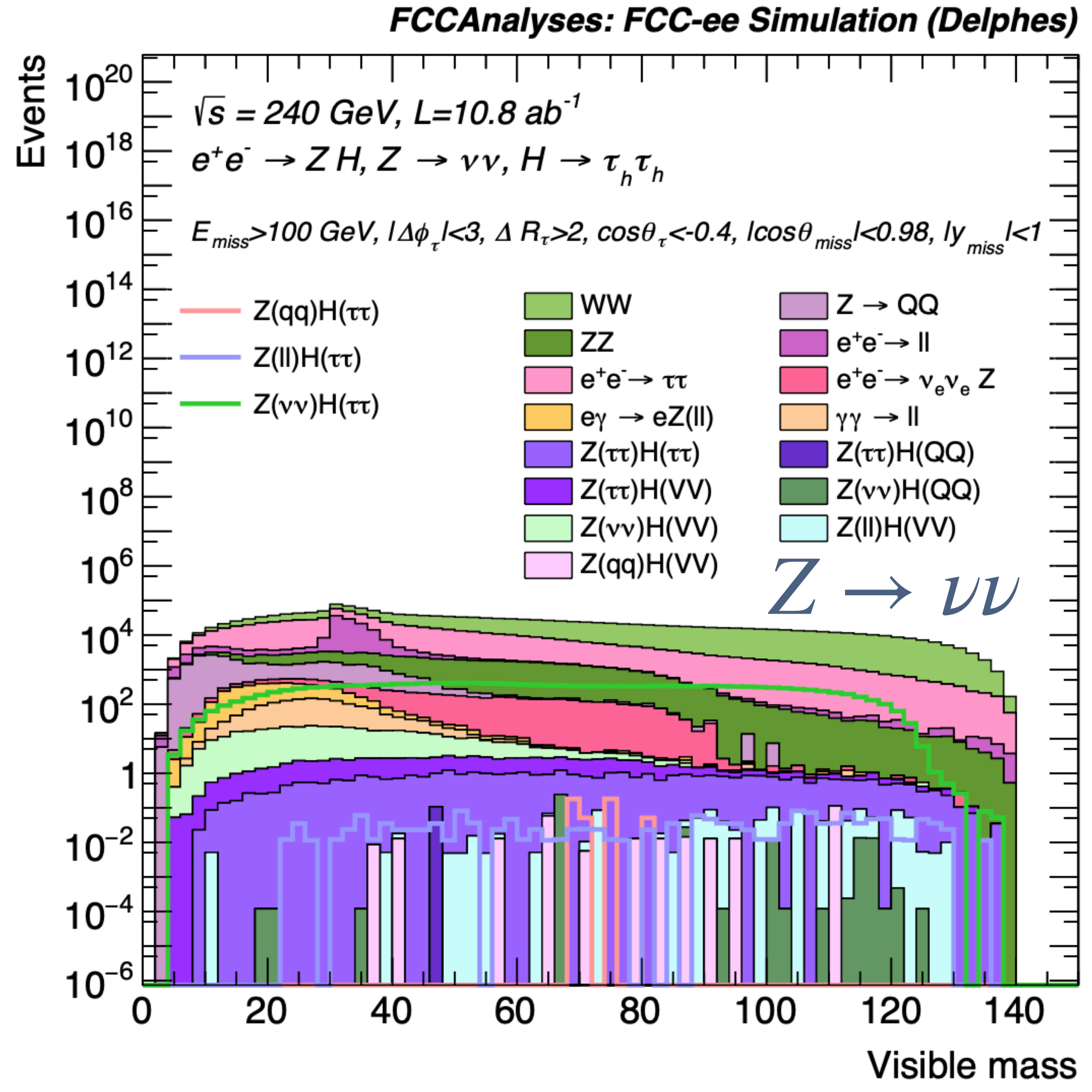
τ reconstruction from jets: PNet tagger or explicit tag based on constituents

Consider categories: $Z \to \ell\ell, jj, \nu\nu \otimes H \to \tau_\ell\tau_\ell, \tau_\ell\tau_h, \tau_h\tau_h$

[FCC note: Higgs tau tau]







BDT based on full event kinematics in $Z \to qq, \nu\nu$ cases

Fit of m_{recoil} for $Z \to \ell\ell$ and BDT score for $Z \to qq, \nu\nu$

$\sqrt{s}$	240 GeV	365 GeV	
$\mathcal{L}$	10.8 ab^{-1}	3 ab^{-1}	
	ZH	ZH	VBF
$H \to \tau\tau$	$\pm 0.58\%$	$\pm 1.27\%$	$\pm 13.54\%$

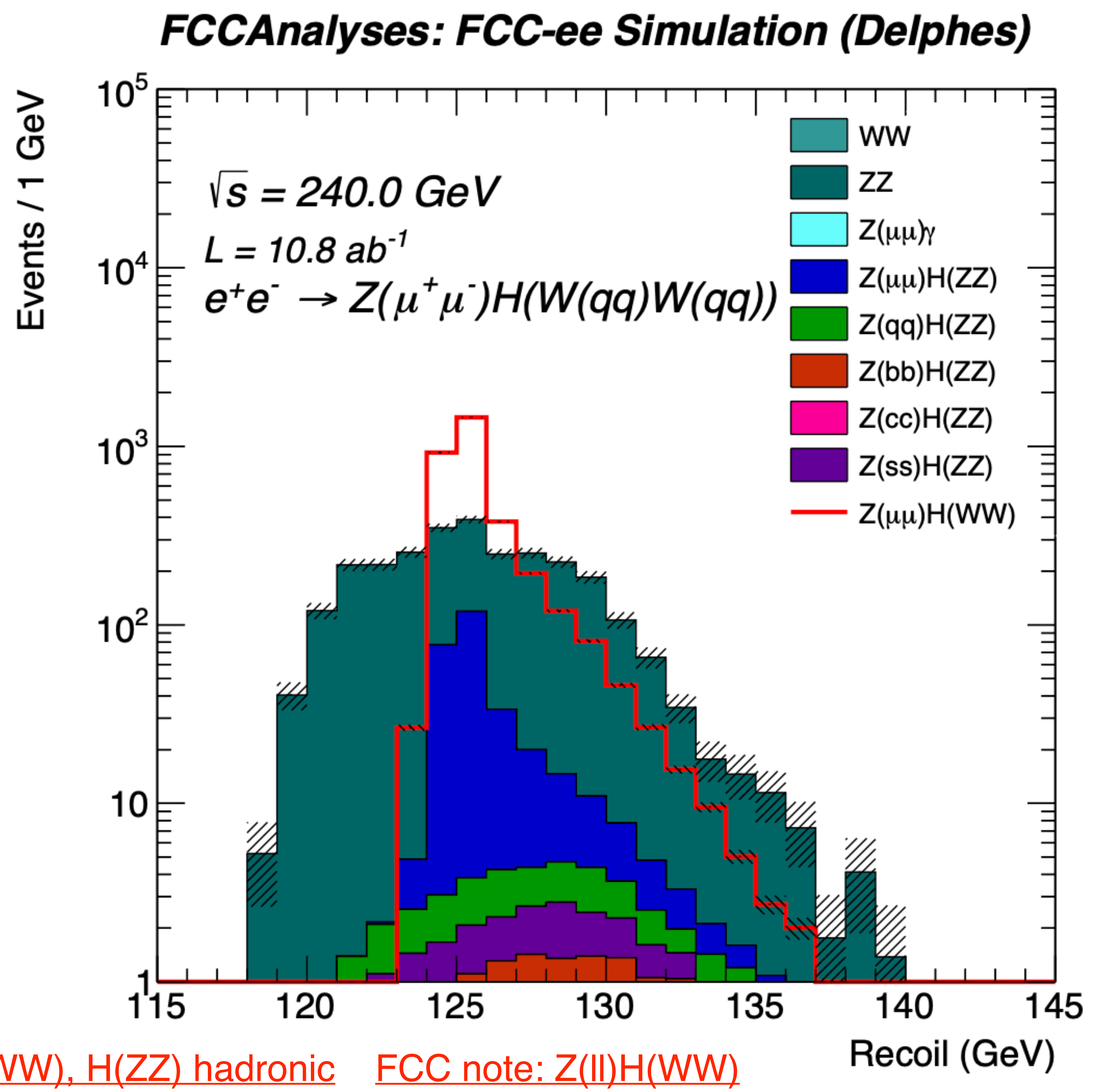
$H \to WW$

Critical input to model-independent Γ_H determination

Only considered hadronic final states for this result

- $Z(\nu\nu)H(WW)$: taken from the byproduct of $H(jj)$ analysis
- $Z(\ell\ell)H(WW)$: dedicated analysis
  - Use jet variables for selection, fit on m_{recoil}
- $Z(qq)H(WW)$: 6-jet final state, analyzed together with $Z(jj)H(ZZ)$
  - BDT to separate $H(WW)$ and $H(ZZ)$

Channel	Uncertainty (%)
vvjjjj	1.3%
lljjjj	1.6%
6j	1.48%
Combination	0.8%



A limiting factor for Γ_H precision in this round

- Can be improved by including other final states

FCC note: H(WW), H(ZZ) hadronic   FCC note: Z(ll)H(WW)

$H \to ZZ$

Critical input to model-independent Γ_H determination

Many final states for ZZZ decays

- 6ℓ case highly stats-limited
- $6j$ case combined with the $Z(qq)H(WW)$ analysis
- $2\nu 4j, 2\ell 4j$ results taken from the byproduct of $H(jj)$ analysis
- $2\nu 4\ell, 2j4\ell$ with simple selection, high purity, stats-limited
- $2\nu 2j 2\ell$ with permutations
  - Categorized based on $m_{\ell\ell}, m_{jj}, m_{\ell\ell jj}, m_{recoil}, m_{miss}$, etc.

Combined precision of 2.5%

- All statistically limited
- Simple cut-and-count results, room for improvement

Channel	Uncertainty on (%)
vvjjjj	11%
lljjjj	7.6%
vvlljj	4.7%
llvvjj	5.0%
lljjvv	7.3%
jjllvv	13%
jjvvll	19%
jj/vv 4l	10 %
6l	30 %
6j	8.2%
Combination	2.5%

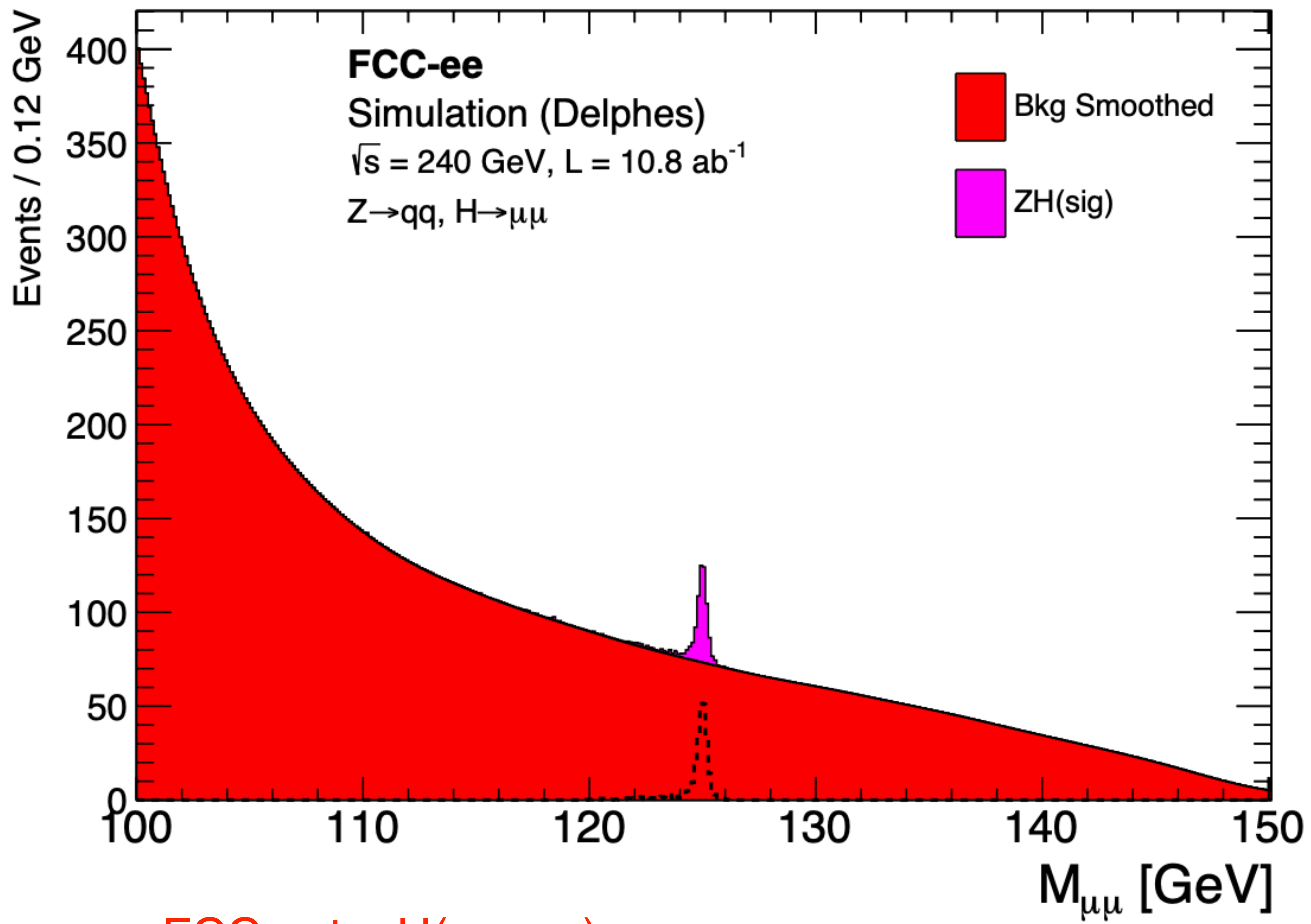
FCC note: H(WW), H(ZZ) hadronic

FCC note: H(ZZ) nnjjll FCC note: H(ZZ) 4lep

$H \to \mu\mu, \gamma\gamma, Z\gamma$

$H \to \mu\mu$

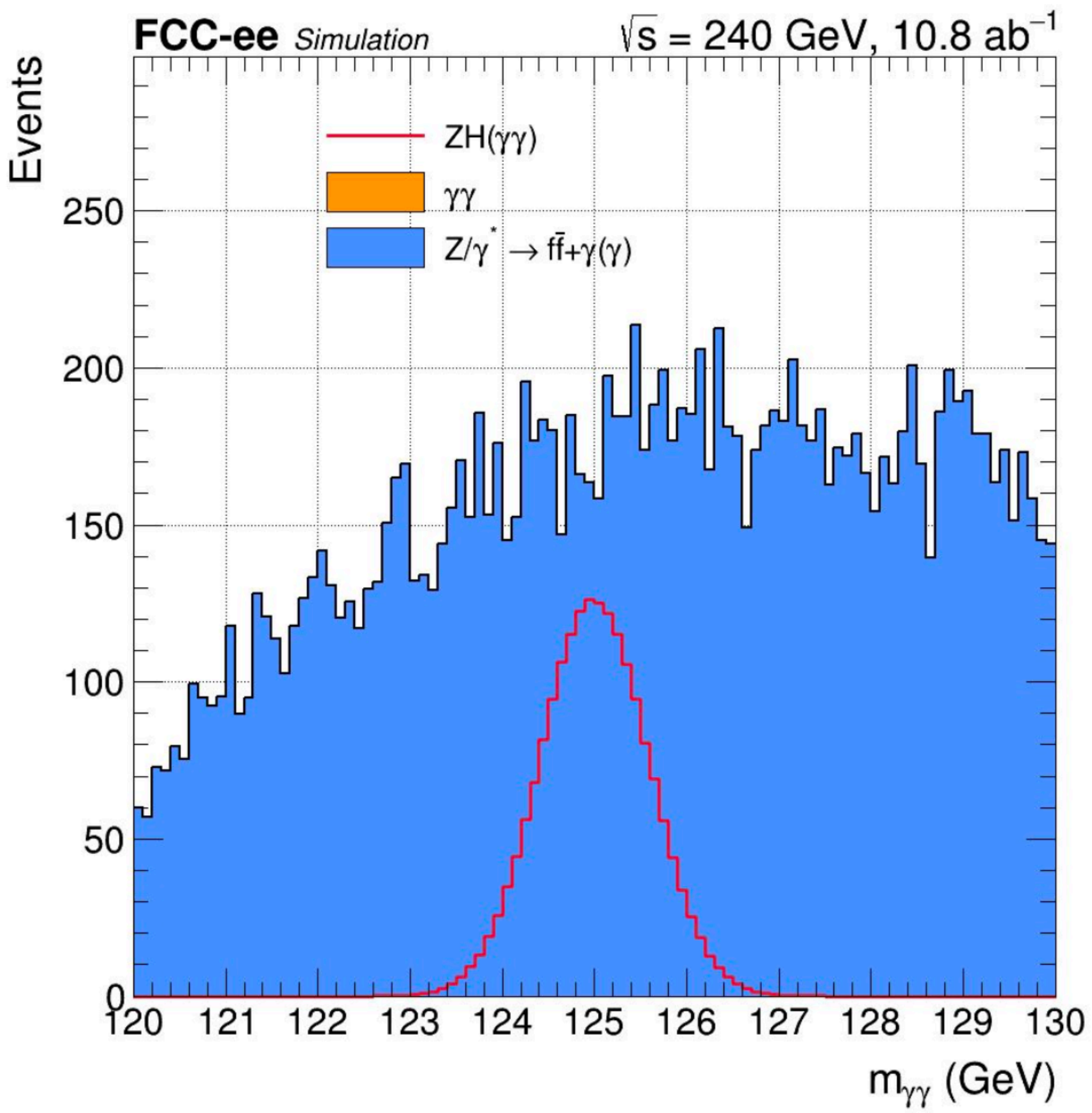
- Cut-and-count analysis in $Z \to qq, ee, \mu\mu, \nu\nu$ channels
- Combined precision 11%



FCC note: H(mumu)

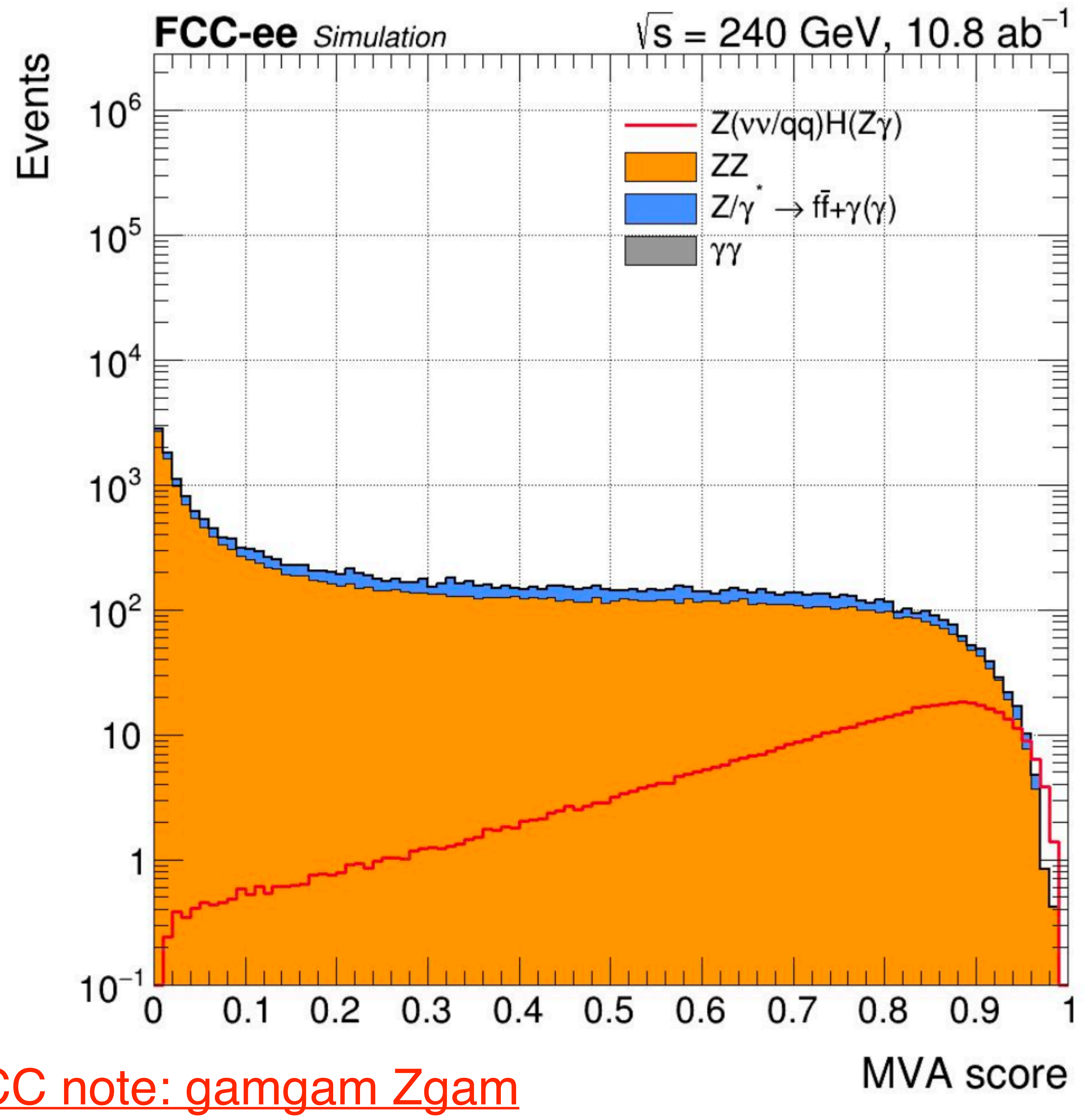
$H \to \gamma\gamma$

- Cut-and-count analysis in $Z \to qq, ee, \mu\mu, \nu\nu$ channels
- Combined precision 3.6%

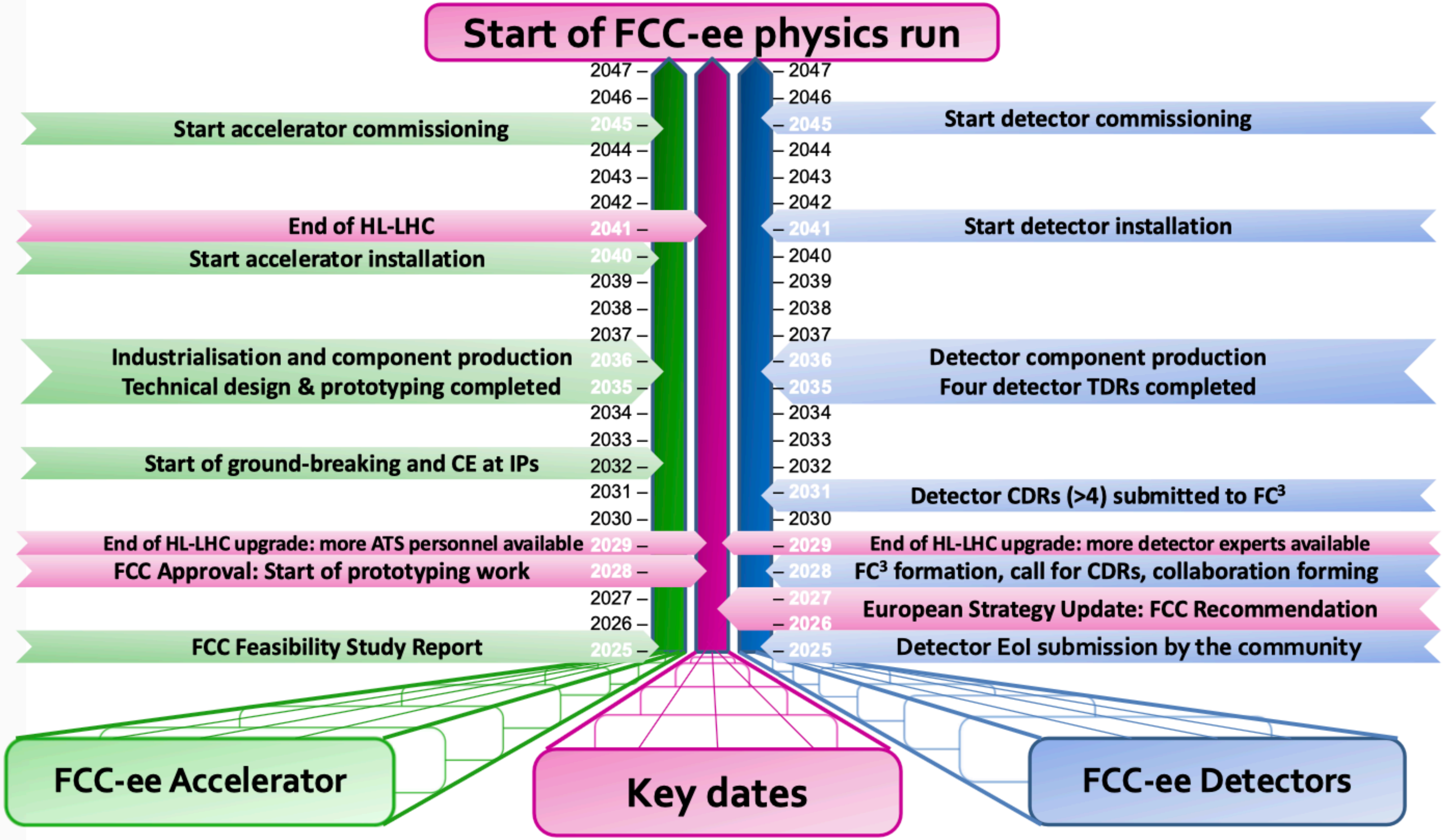


$H \to Z\gamma$

- Focus on $2j2\nu + \gamma$ final state
- Fit BDT output
- Combined precision 11.8%



FCC note: gamgam Zgam


Start of FCC-ee physics run
Start accelerator commissioning
End of HL-LHC
Start accelerator installation
Industrialisation and component production
Technical design & prototyping completed
Start of ground-breaking and CE at IPs
End of HL-LHC upgrade: more ATS personnel available
FCC Approval: Start of prototyping work
FCC Feasibility Study Report
2047
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Start detector commissioning
Start detector installation
Detector component production
Four detector TDRs completed
Detector CDRs (>4) submitted to FC³
End of HL-LHC upgrade: more detector experts available
FC³ formation, call for CDRs, collaboration forming
European Strategy Update: FCC Recommendation
Detector EoI submission by the community
FCC-ee Accelerator
Key dates
FCC-ee Detectors

Updated project cost for FCC-ee up to and including operation at ZH and 4 experiments
t-tbar upgrade requires additional 1.3 BCHF

Domain	Cost [MCHF]
Civil engineering	6160
Technical infrastructures	2840
Injectors and transfer lines	590
Booster and collider	4140
CERN contribution to four experiments	290
FCC-ee total	**14 020**
+ Four experiments (non-CERN part)	1300
FCC-ee total, including four experiments	**15 320**

Funding of FCC (and any other major future collider project) will come from two main sources:

- ❑ CERN Budget (i.e. revenues from Member and Associate Member States): would cover more than 50% of FCC investment cost
- ❑ External contributions:
  - additional voluntary contributions (in-cash or in-kind) from Member and Associate Member States
  - contributions from non-Member States
  - exploring possible contributions from the European Union in the next Multiannual Financial Framework (MFF 2028-2034)
  - exploring possible contributions of private donors (→ in Dec 2024, Council approved "*Policy for fundraising from private donors for scientific activities at CERN*")

Several funding models developed, based on different assumptions (e.g. constant or slightly increased CERN Budget)
→ final report will be submitted to Council and its subordinate bodies in August

Gianotti at FCC week 2025

FCC-ee cost estimate (FSR 2025)

Capital cost (2024 CHF) for construction of the FCC-ee is summarised below. This cost includes construction of the entire new infrastructure and all equipment for operation at the Z, WW and ZH working points.

FCC-ee

Domain	Cost [MCHF]
Civil engineering	6,160
Technical infrastructures	2,840
Injectors and transfer lines	590
Booster and collider	4,140
CERN contribution to four experiments	290
FCC-ee total	**14,020**
+ four experiments (non-CERN part)	1,300
FCC-ee total incl. four experiments	**15,320**

Note: Upgrade of SRF (800 MHz) & cryogenics for ttbar operation corresponds to additional cost of 1,260 MCHF

LCF CLIC

Unit: MCHF	LCF 250 (LP)	Δ LCF 550 (FP)	CLIC 380	Δ CLIC 1500
Collider	3864	4204	2471	4684
Main Beam inj./transfer	1181	86	1046	23
Drivebeam inj./transfer	-	-	1060	302
Civil Engineering	2338	0	1403	703
Technical Infrastructure	1109	1174	1361	1404
Sum	**8492**	**5464**	**7341**	**7116**

LEP3

Cost Element	2 new Xpts	2 Exist Xpts
Accelerator	2705	2705
Injectors and Transfer Lines	295	295
Technical Infrastructures	435	435
Experiments	130	60
Civil Engineering	165	165
LHC Removal/LEP3 Installation	140	140
Total CERN (MCHF)	**3870**	**3800**
Experiments non-CERN part	900	270

FCC-hh (after FCC-ee)

Cost summary table in 2024 MCHF for the construction of FCC-hh.

Domain	FCC-hh Cost [MCHF]
FCC-ee dismantling	200
Collider*	13400
Injectors and transfer linear	1000
Civil Engineering	520
Technical infrastructures	3960
Experiments	N/A
Total	**19080**

*target price of 2.0 MCHF per 14.3 m long magnet with 1.0 MCHF of conductor, 0.5 MCHF for assembly, and 0.5 MCHF for components

Muon Collider

LHeC (cost estimate 2018, 60 GeV e-)

Budget Item	Cost
SRF System	805MCHF
SRF R&D and Proto Typing	31MCHF
Injector	40MCHF
Magnet and Vacuum System	215MCHF
SC IR magnets	105MCHF
Dump System and Source	5MCHF
Cryogenic Infrastructure	100MCHF
General Infrastructure and installation	69MCHF
Civil Engineering	386MCHF
Total	1756MCHF

→ ~2 BCHF (2025)