Future Higgs Factories and experimental challenges

Patrizia Azzi - INFN Padova

Higgs24, Uppsala, Nov 24

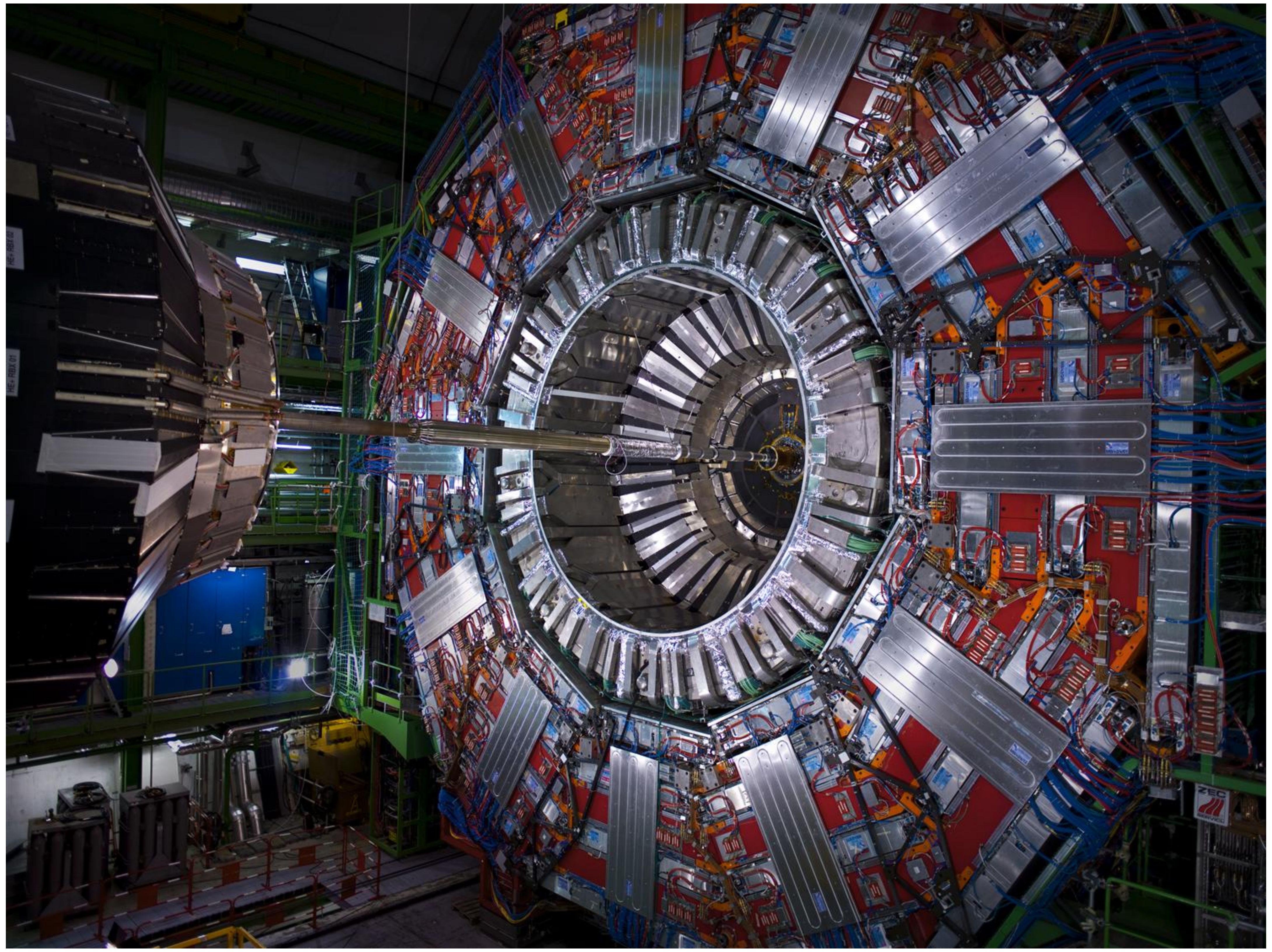
DISCLAIMER: most/all of the numbers for all machines are being updated for the European Strategy

Several talks on future ee factories at this conference:
- A. Sciandra, K. Asteriadis, M. Vukasinovic, G. Ripellino, R. Sengupta, J. Tian, M. Cepeda...

The LHC Legacy

So far…

- **Higgs boson discovered at the SM predicted** mass**
  - **by precision EWK measurements from LEP
- **Extraordinary precision beyond expectations**
- **SM confirmed to high accuracy up to the TeV scale**
- **No hints of new physics:**
  - Traditional models under siege
  - New approaches & strategies appearing



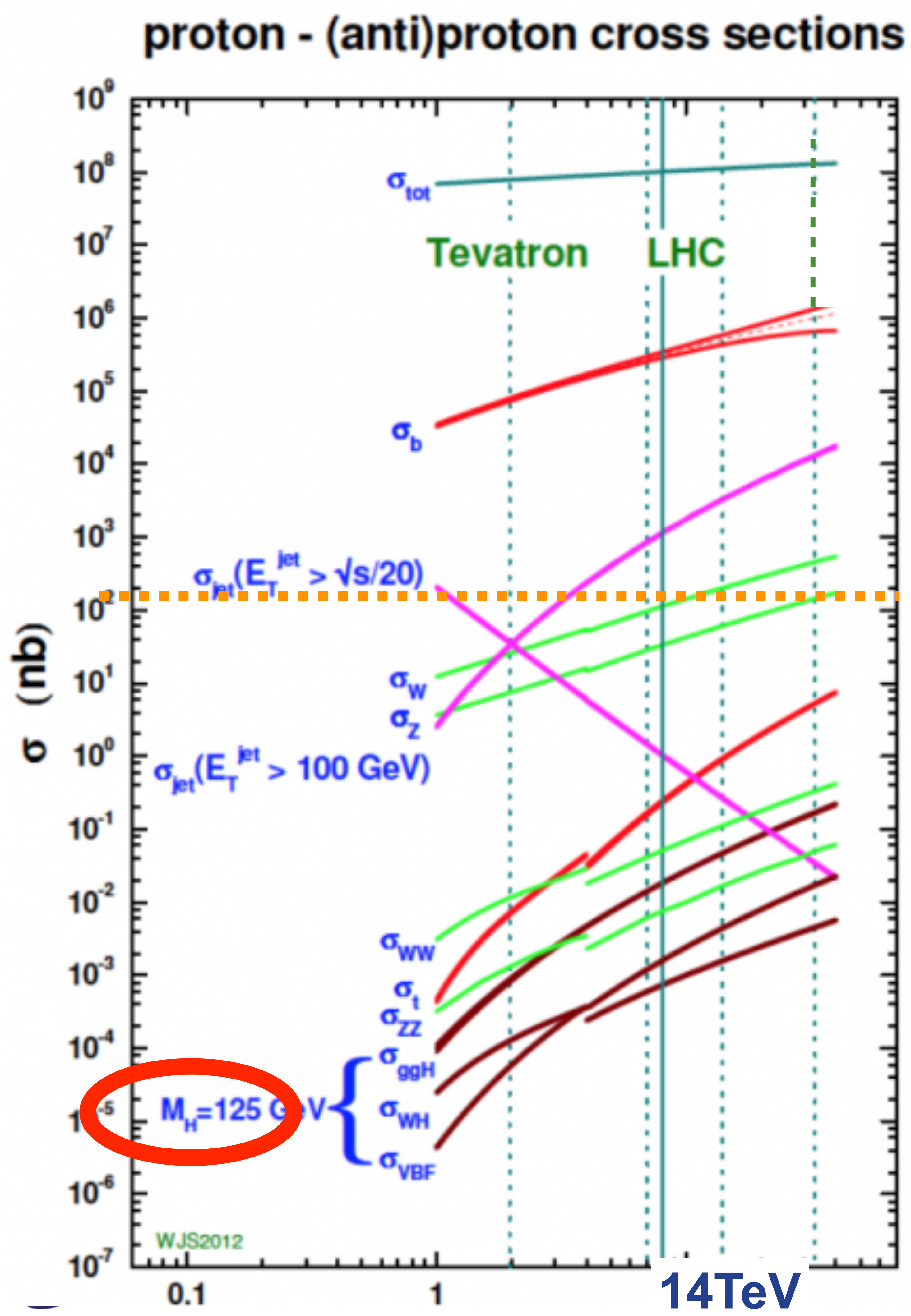
The Higgs after the HL-LHC

what is left?

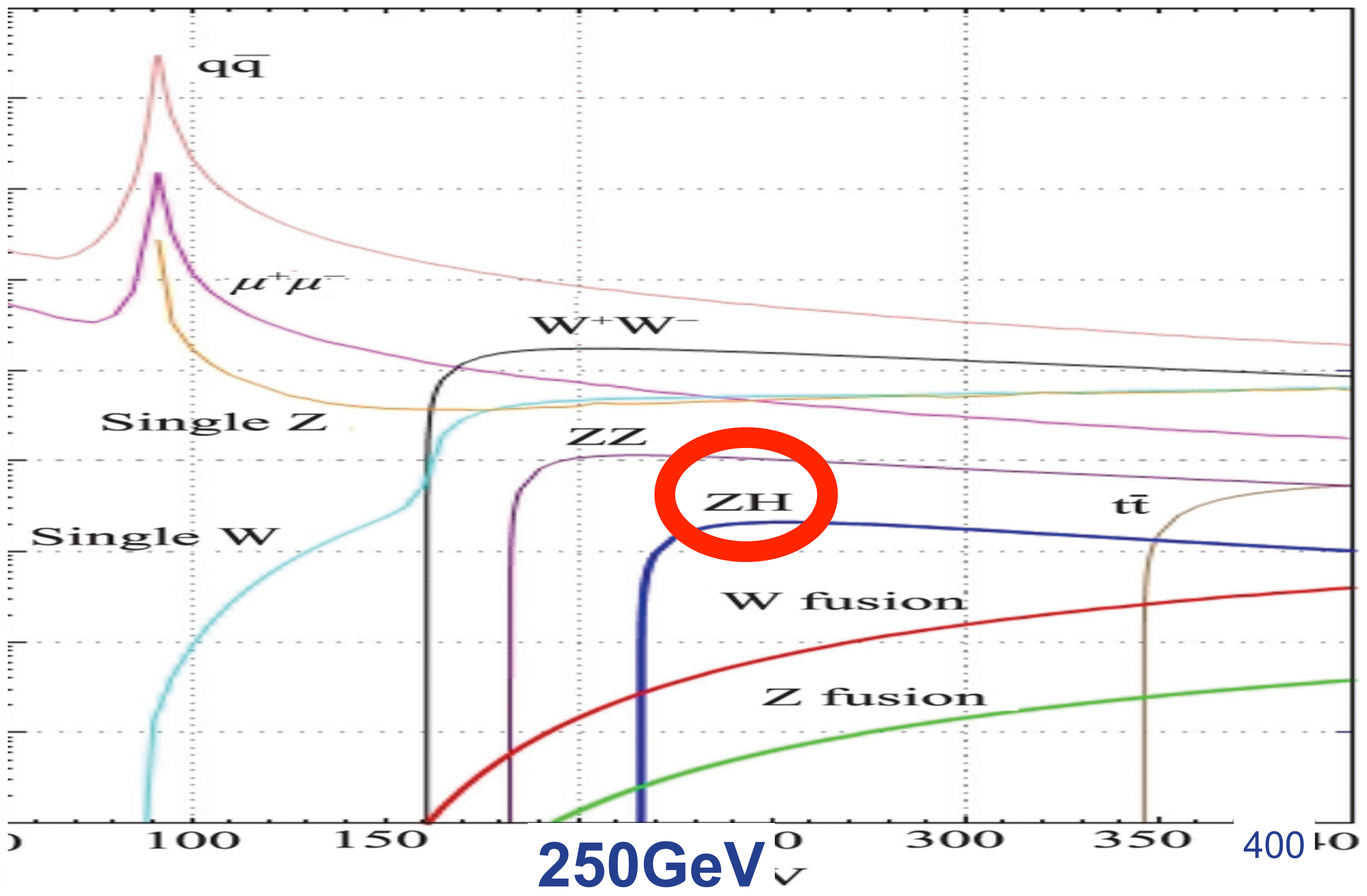
- **Comparing to the last European Strategy Update predictions for the HL-LHC phase, the LHC experiments have surpassed many expectation already with Run2 data.**
- **The HL-LHC is a true Higgs factory with ~10^8 H produced (and at least 1M in each production mode) but concerning the couplings:**
  - model dependent coupling determination
  - challenging S/B in several channels (pileup!)
  - (very) hard to measure second generation couplings
  - ~impossible to measure first generation couplings
- **Self-coupling prediction are being currently updated for the European Strategy and might change the role in this of future colliders proposed.**

Advantage of e^+e^-

elementary and colourless



- smaller backgrounds cross sections
- S/B ~1 for main decays



- no triggers needed (maybe)
- clean environment, extreme precision possible
- √s precisely known, model independent measurements possible
- complementary to hadron collider measurements
- some few-TeV reach possible

FUTURE CIRCULAR COLLIDER

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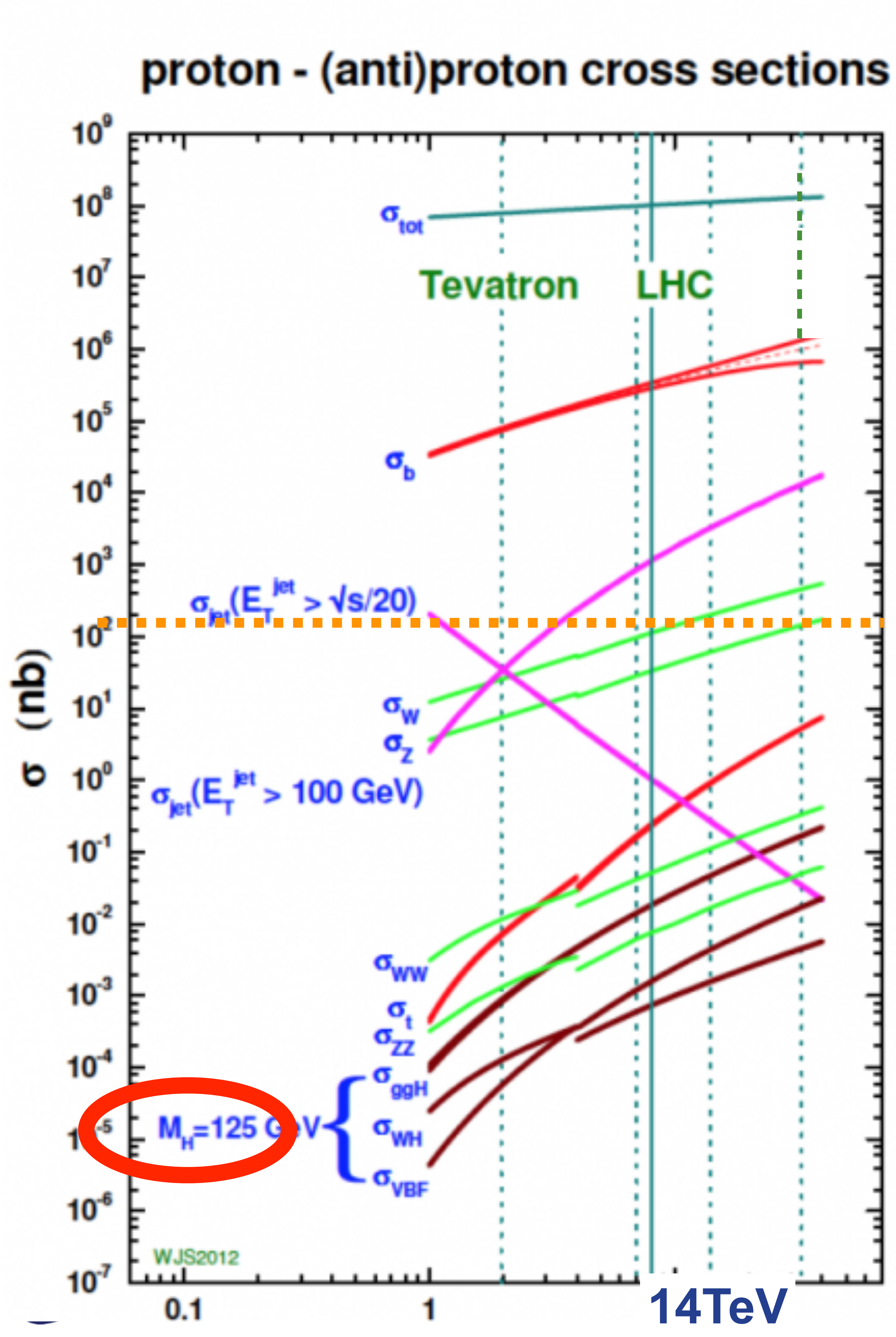

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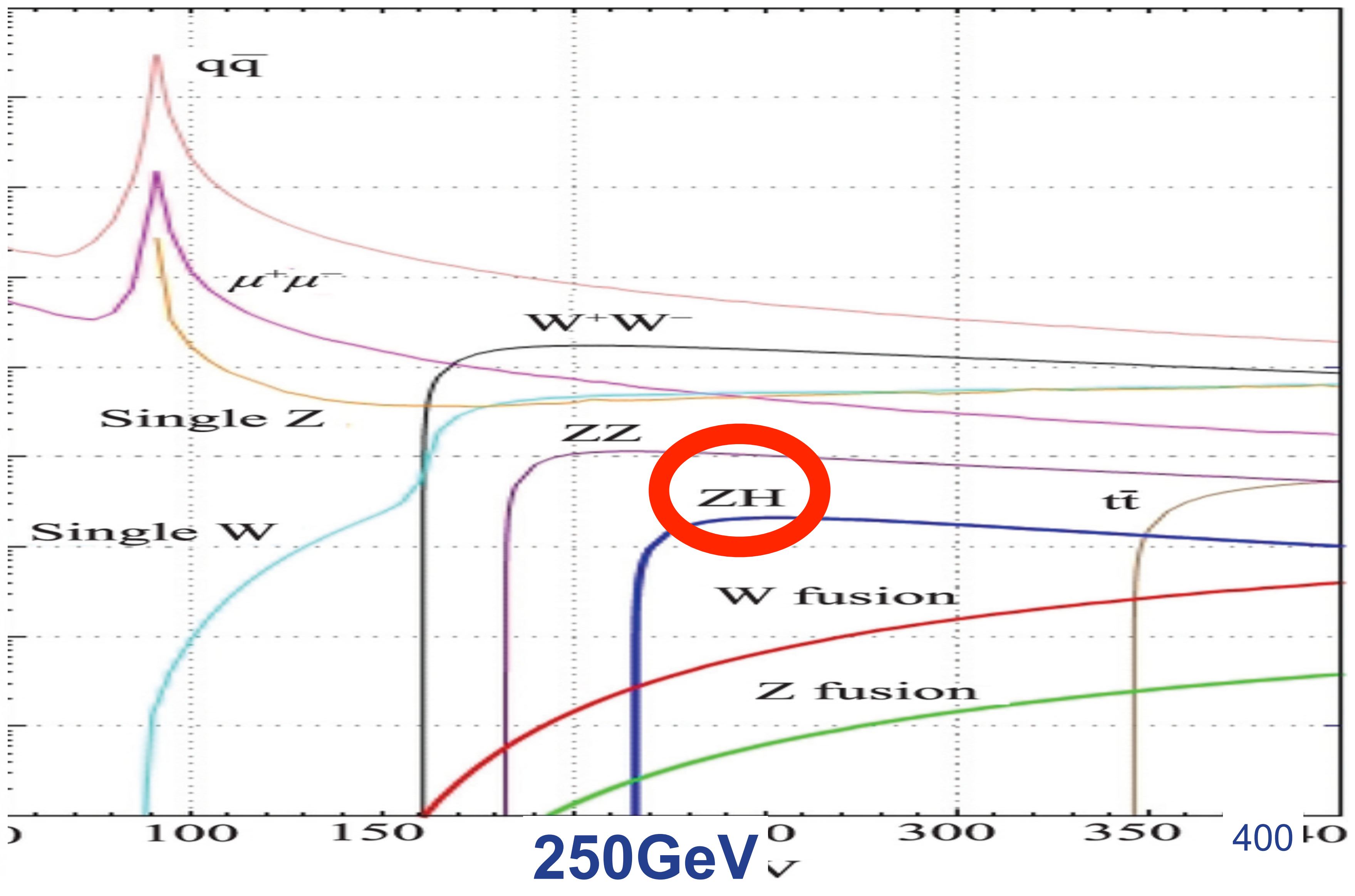

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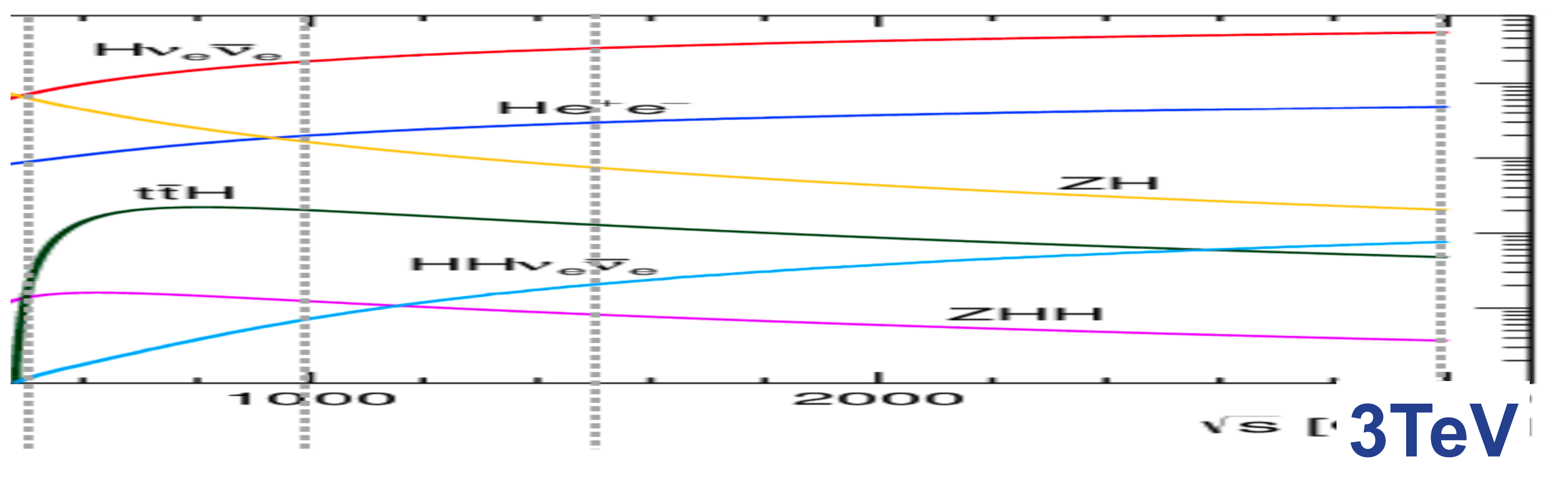

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Future e+e- colliders

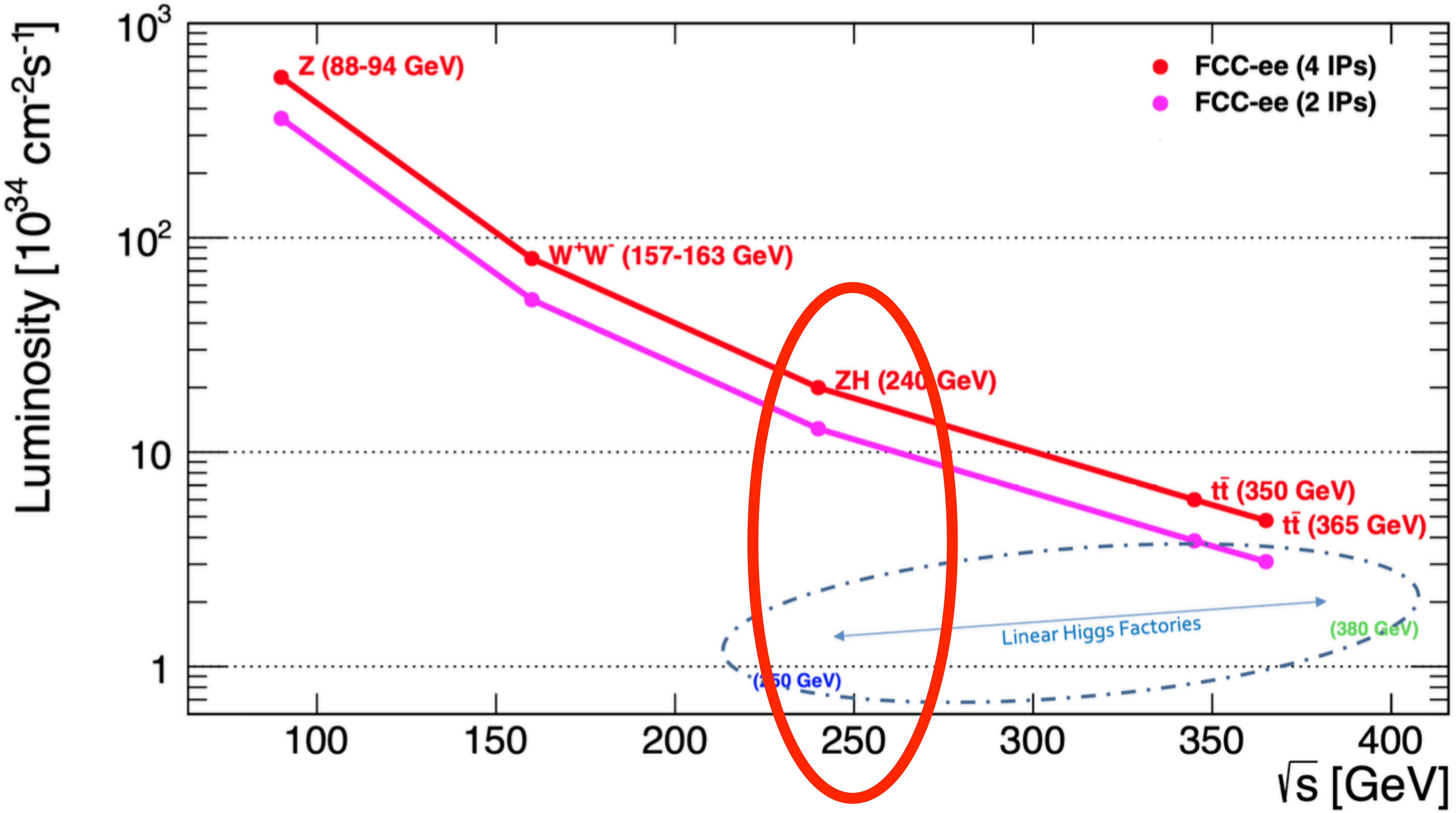
Various proposals: (CC) FCC-ee, CEPC;(LC) ILC, ILC@CERN, C3, HALHF

- **e+e- can be linear or circular**
- **"Higgs Factory" means running between 240/250GeV and a 365/380GeV**
  - Providing about millions of clean single Higgs events from ZH or VBF production
- **Physics production process is the same, but implementation is not.**
- **Main differences are:**
  - TIME: luminosity achievable (i.e. the speed of collecting the events & power consumption needed)
  - PRECISION: control of the machine parameters (precision on $\sqrt{s}$, beam polarization)
  - IPs: number of running experiments

Linear colliders can profit of longitudinally polarized beams, some studies in progress by CEPC as well recently

Energy range & luminosity

Producing in a clean environment all the heaviest SM particles



Lepton colliders are flexible

Example a possible FCC-ee run plan

- **Producing in a clean environment all the heaviest SM particle. Not just Higgses.**

LEP Data statistics accumulated every 2 minutes!

In each detector:
105 Z/sec, 104 W/hour,1500 Higgs/day, 1500 top/day

Working point	Z, years 1-2	Z, later	WW, years 1-2	WW, later	ZH	$t\bar{t}$	
$\sqrt{s}$ (GeV)	88, 91, 94		157, 163		240	340–350	365
Lumi/IP (10^{34} cm^{-2}s^{-1})	70	140	10	20	5.0	0.75	1.20
Lumi/year (ab^{-1})	34	68	4.8	9.6	2.4	0.36	0.58
Run time (year)	2	2	2	0	3	1	4
Number of events	6×10^{12} Z		2.4×10^{8} WW		1.45×10^{6} ZH + 45k WW $\rightarrow$ H	1.9×10^{6} $t\bar{t}$ +330k ZH +80k WW $\rightarrow$ H	

"Tera-Z"

Preliminary numbers (with new optics).
Up to 10.8/ab at √s=240GeV (3y)
and up to √s=3/ab at 365 GeV(5y)

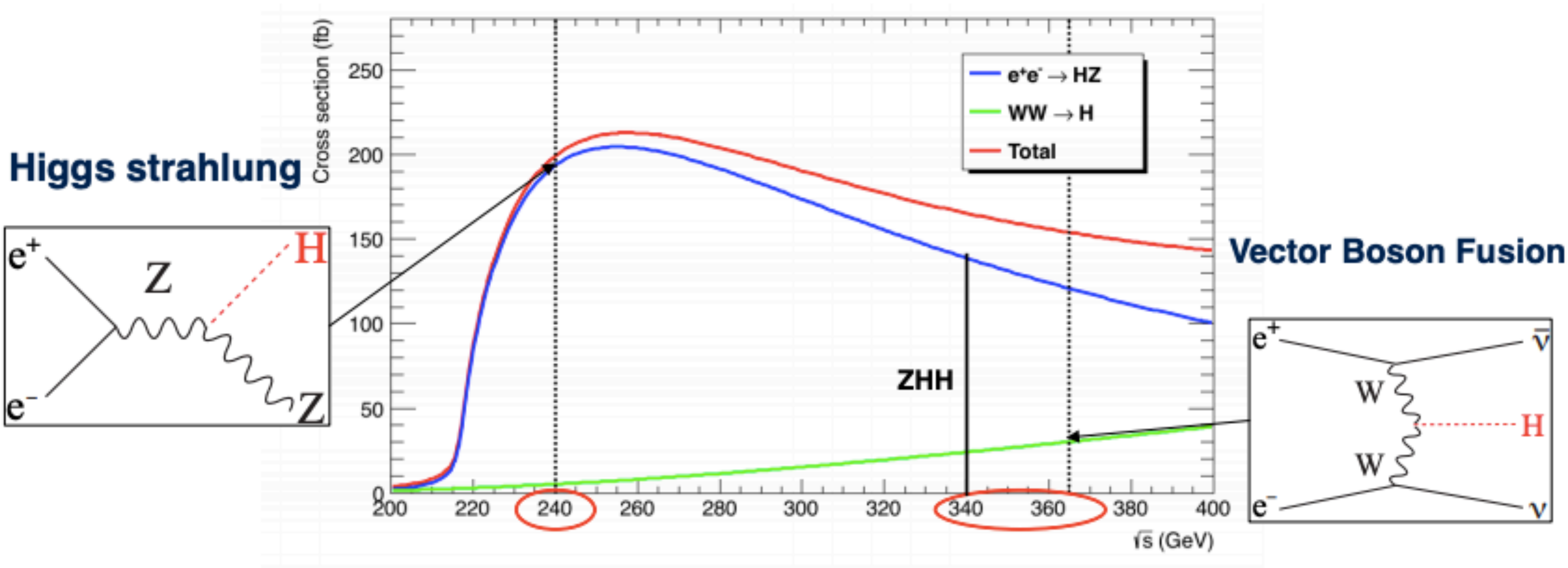
Never produced before at a lepton collider!

Even more Higgs-focused possibilities

- **Opportunities** beyond the baseline plan (√s below Z, 125GeV, 217GeV; larger integrated lumi…)
- **Opportunities** to exploit FCC facility differently (to be studied more carefully):
  - using the electrons from the injectors for beam-dump experiments,
  - extracting electron beams from the booster,
  - reusing the synchrotron radiation photons.

Higgs production in e+e- collisions

"Higgs Factory" mode

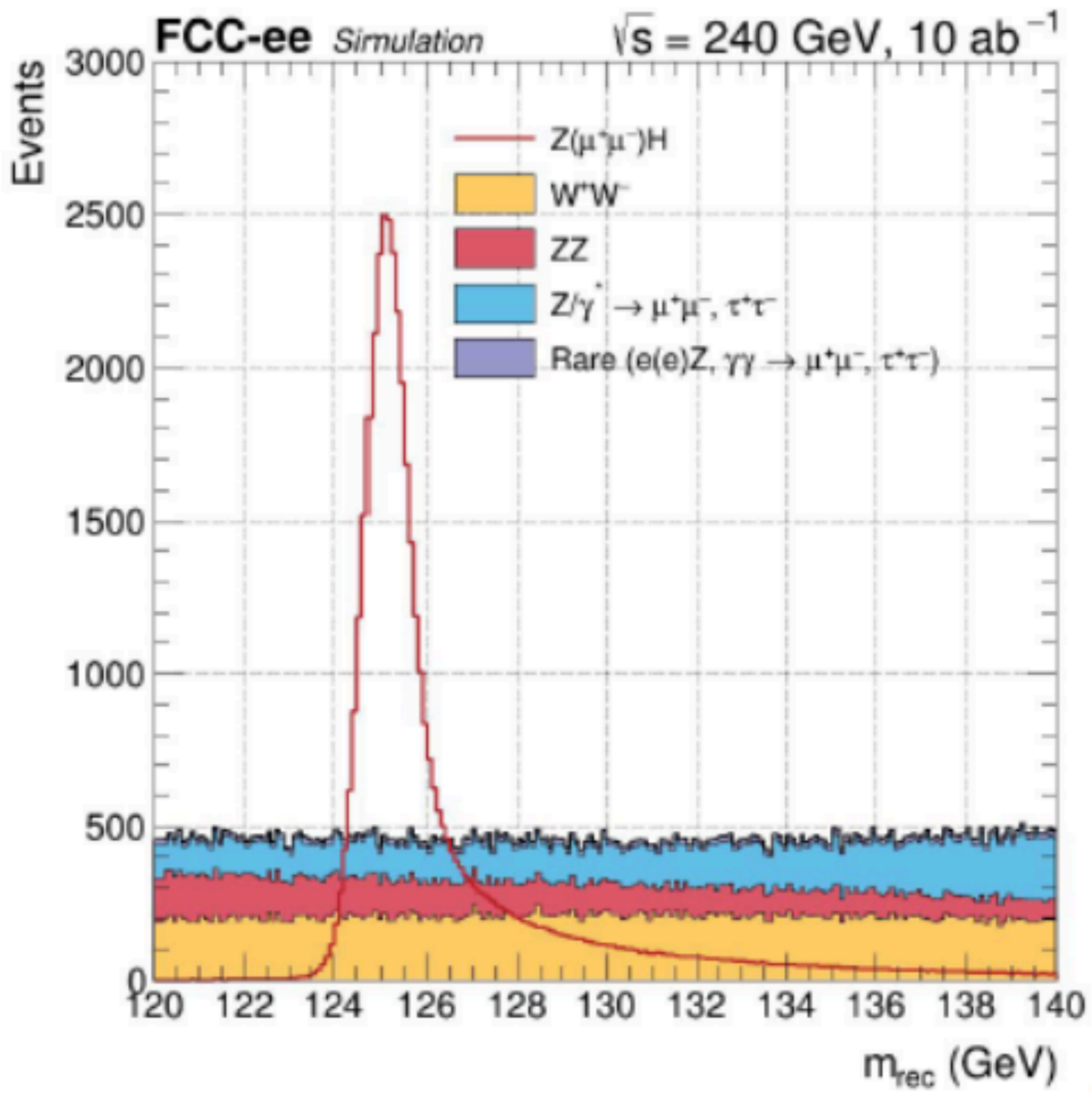


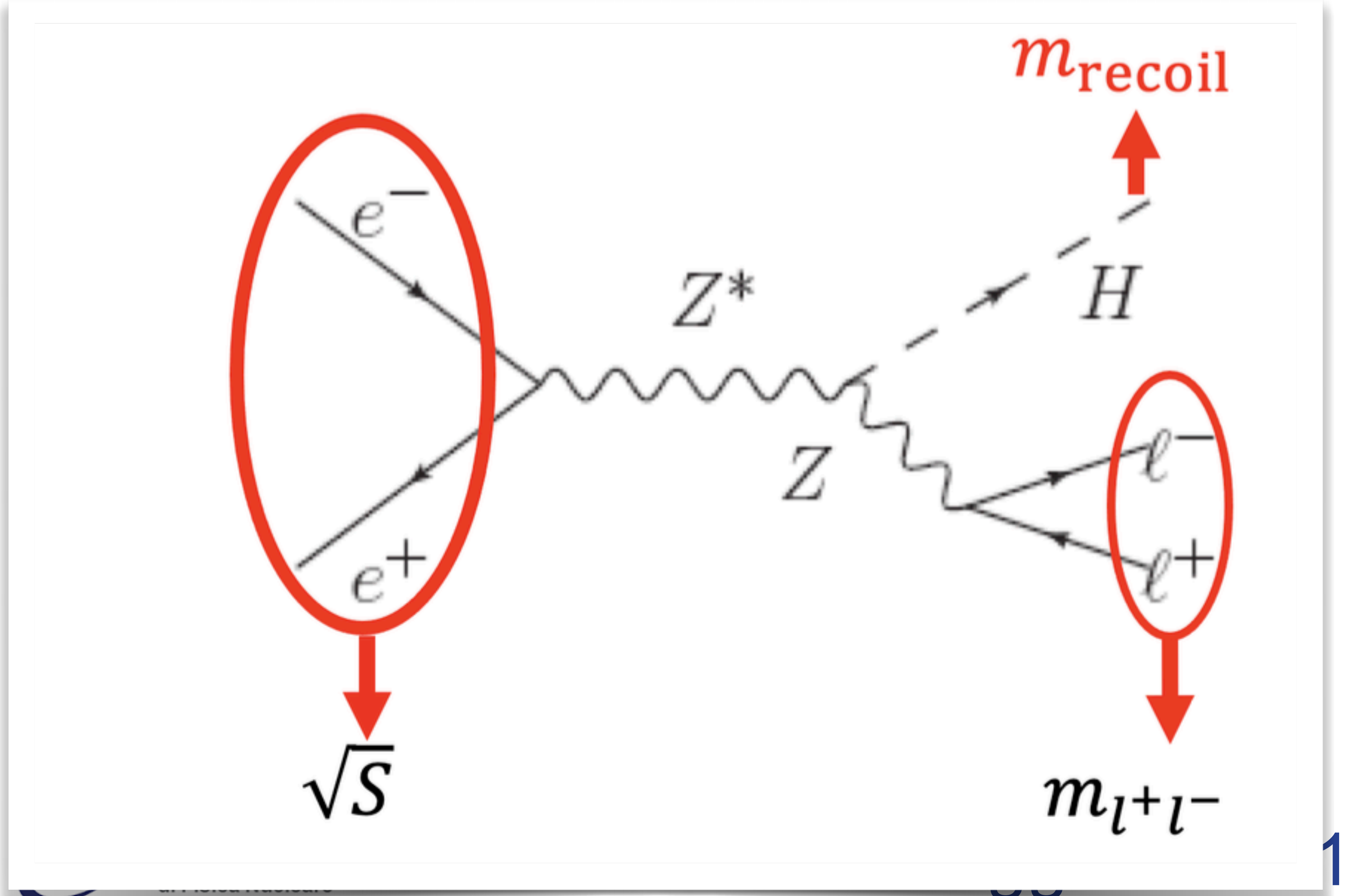
- Higgs-strahlung mode dominates at 240GeV

Recoil method

Unique to lepton colliders

- **Allows to tag Higgs event independently of decay mode:**
  - Precision measurements: couplings, mass, width
  - Searches for Exotic Higgs, invisible decays
- **Z « tagged » via its leptonic or hadronic decays**

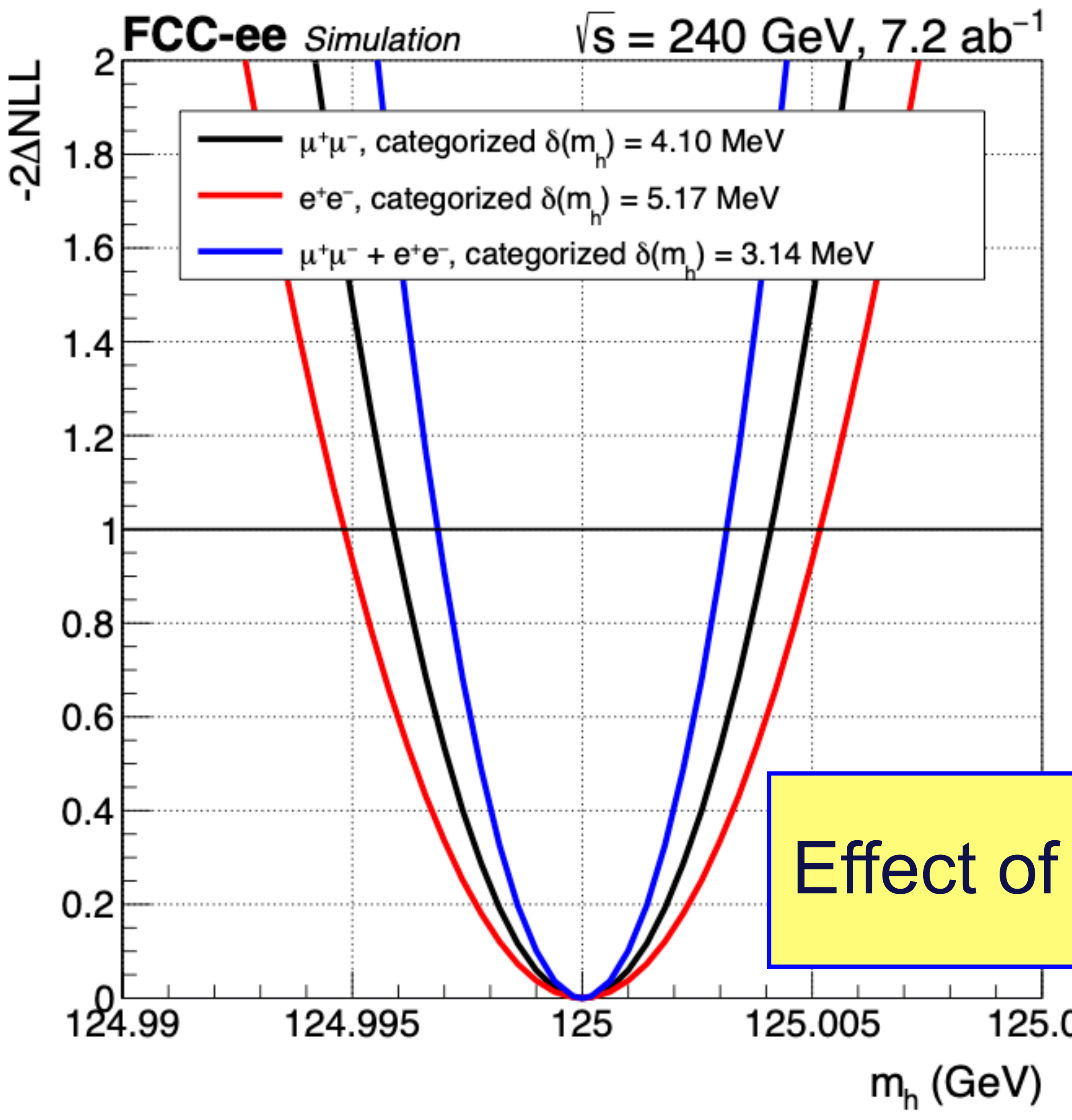




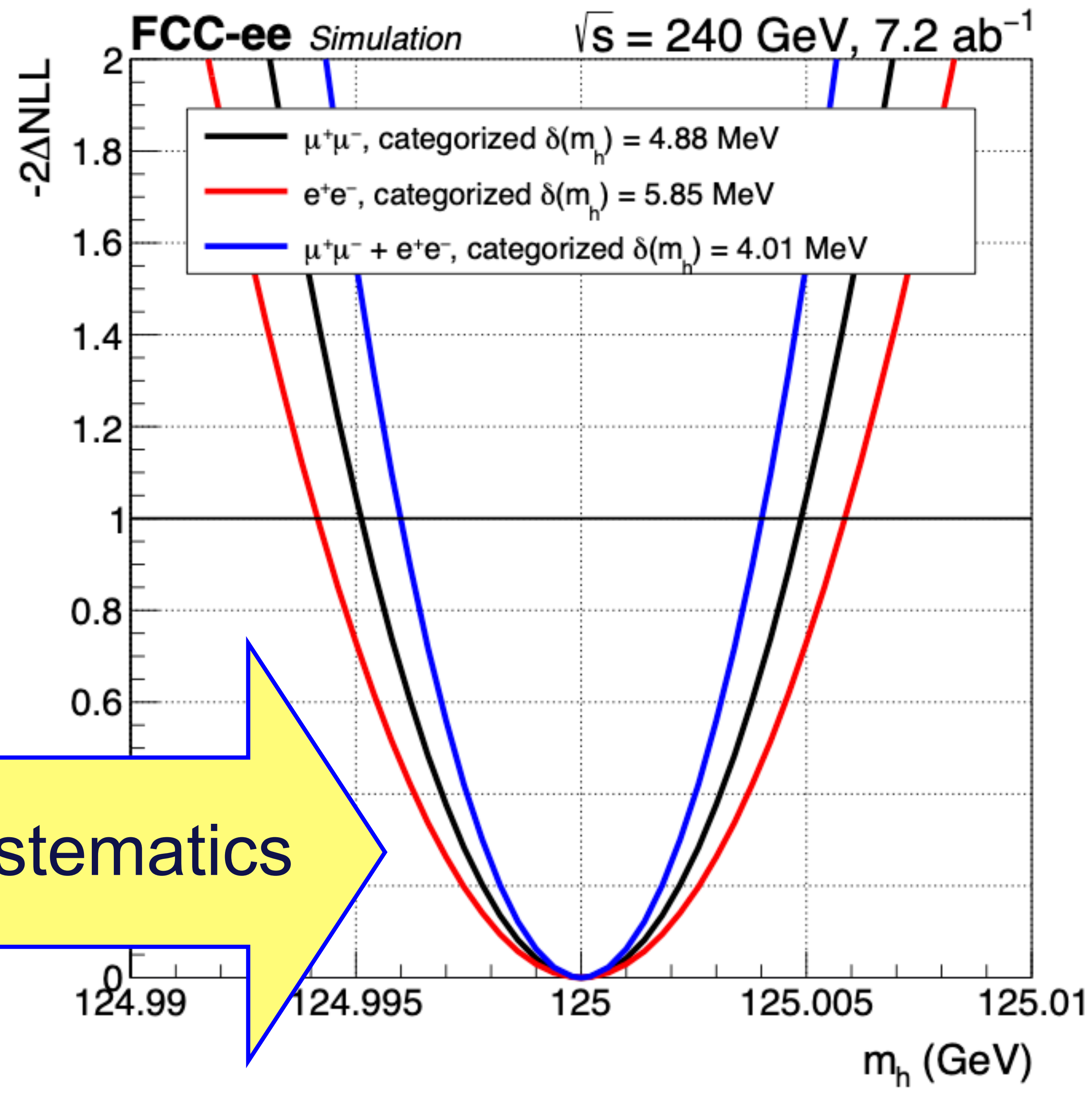
$$m_{\text{recoil}}^2 = (\sqrt{s} - E_{l\bar{l}})^2 - p_{l\bar{l}}^2 = s - 2E_{l\bar{l}}\sqrt{s} + m_{l\bar{l}}^2$$

Higgs mass

Precise m(H) measurement is also needed for a possible monochromatic run at $e^+e^- \rightarrow H$

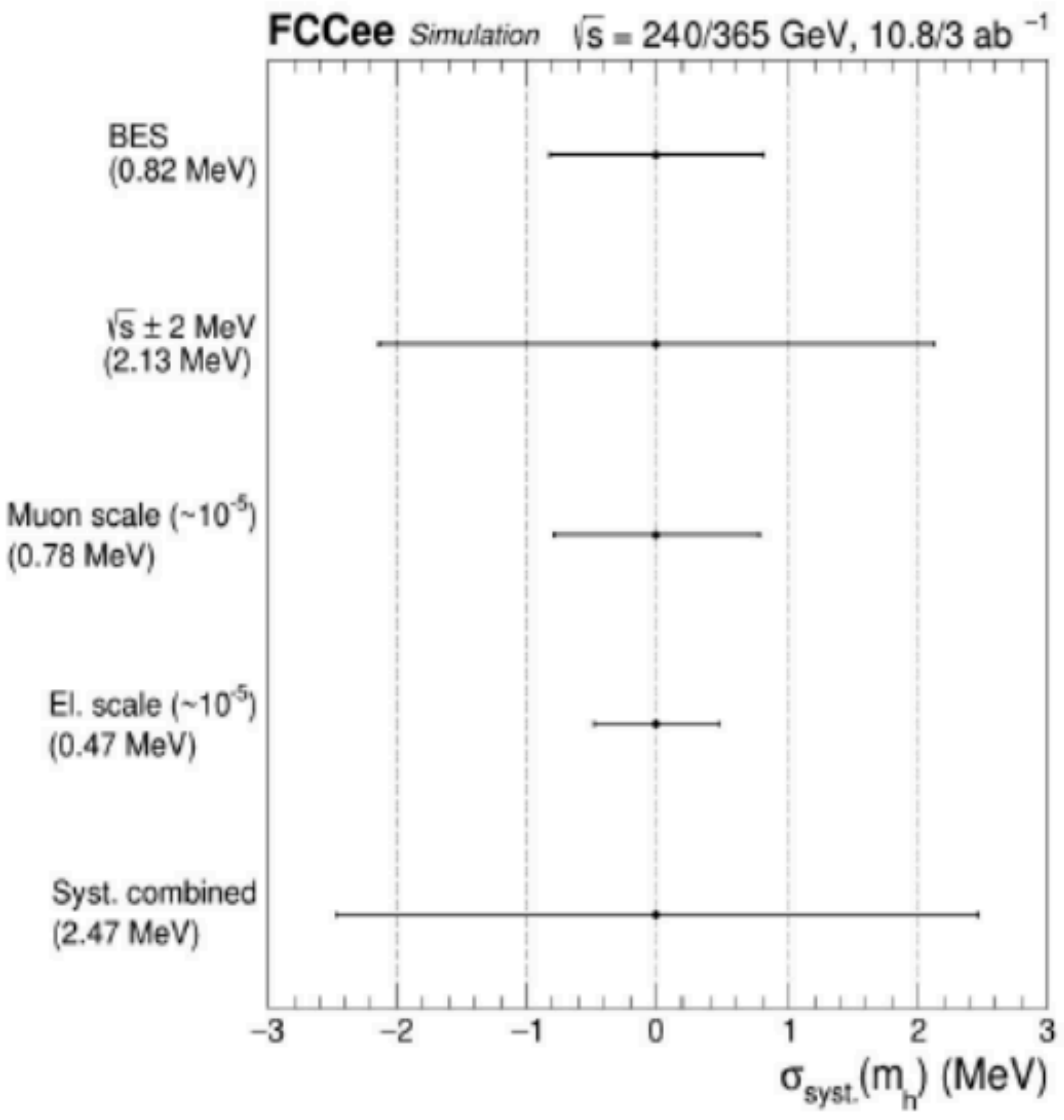


Effect of systematics



Systematics:

For the Higgs mass, the systematic uncertainty is dominated by the uncertainty on the c.o.m energy



Using 10.8 ab-1 (240 GeV) and 3 ab-1 (365 GeV)

- **Current combined uncertainty: 3.05(3.93) MeV**
- Systematics contribute ~2.5 MeV, ecm uncertainty dominant
- Improvement by adding 365 GeV ~ 1%

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Comparing different configuration

Example from Higgs mass analysis

- **Important to assess the major systematic effects, and the impact of different detector performance**

Table from study at 240GeV and 10.8ab-1

Nominal configuration → Nominal

Crystal ECAL to Dual Readout → Degradation electron resolution

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

IDEA drift chamber → CLD Si tracker → Silicon tracker

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

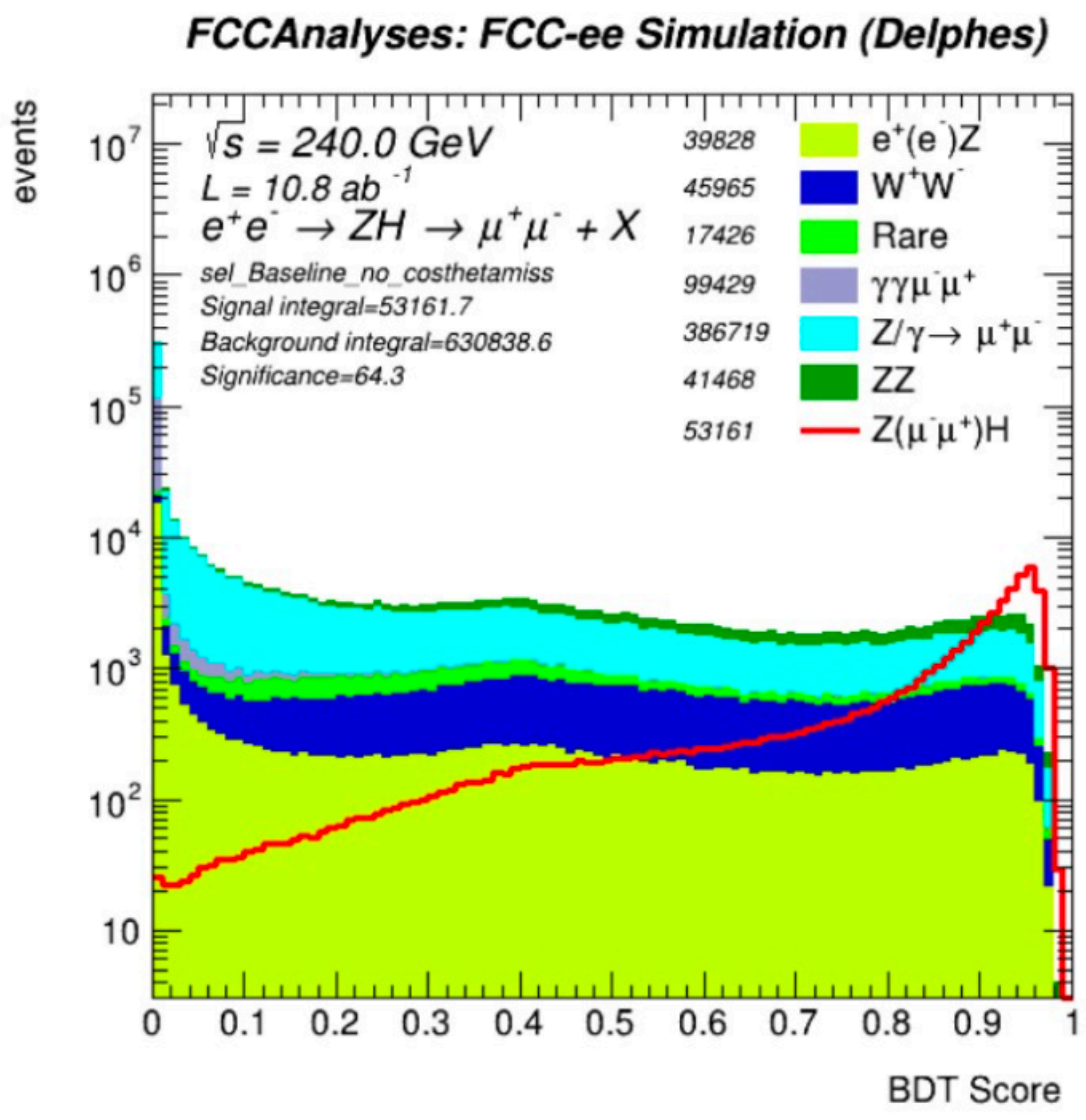
Perfect (=gen-level) momentum resolution → Ideal resolution

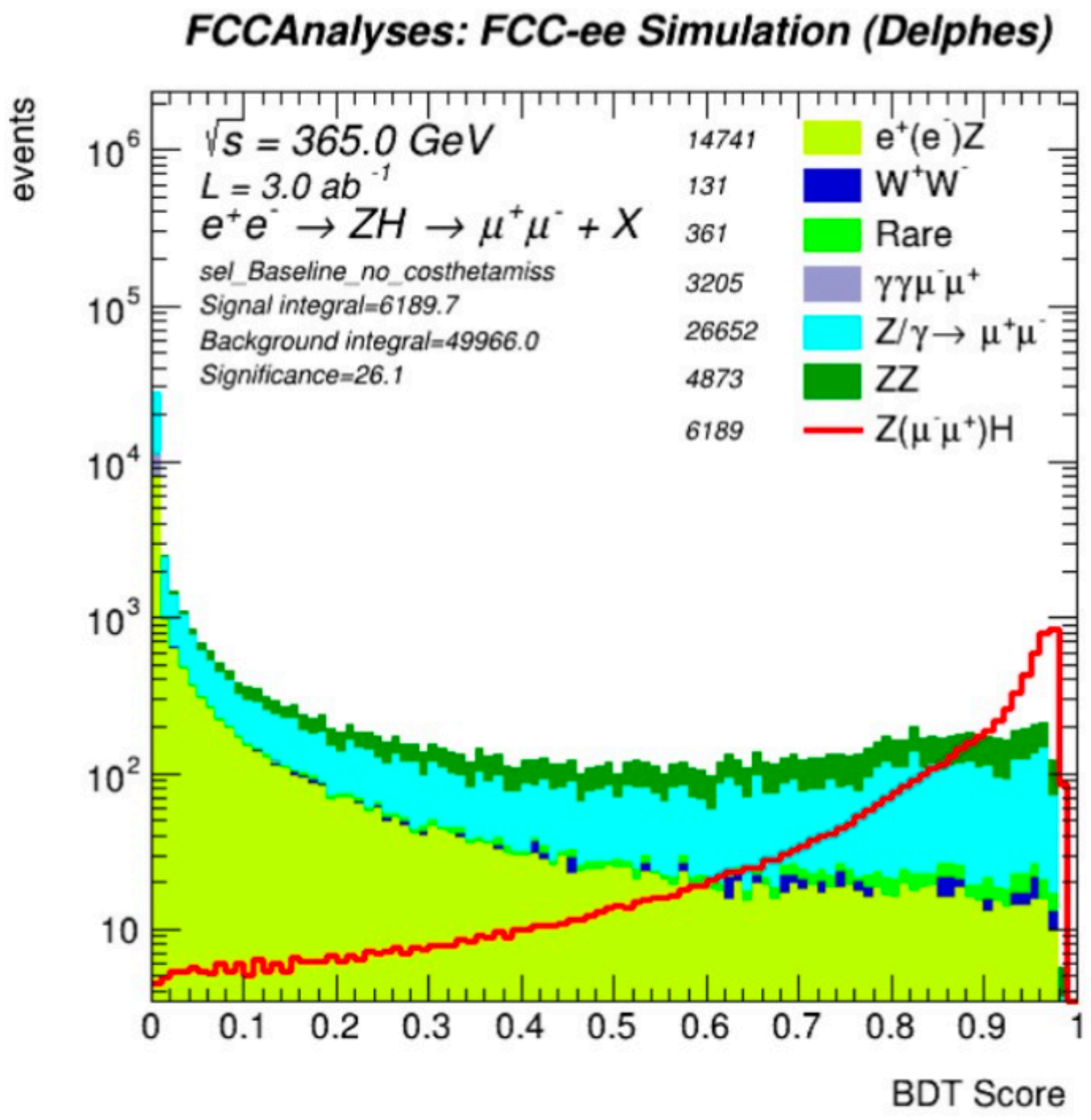
Final state	Muon	Electron	Combination
Nominal	3.92(4.74)	4.95(5.68)	3.07(3.97)
Categorized	3.92(4.74)	4.95(5.68)	3.10(3.97)
Degradation electron resolution			3.24(4.12)
Magnetic field 3T	3.22(4.14)	4.11(4.83)	2.54(3.52)
Silicon tracker	5.11(5.73)	5.89(6.42)	3.86(4.55)
BES 6% uncertainty	3.92(4.79)	4.95(5.92)	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)

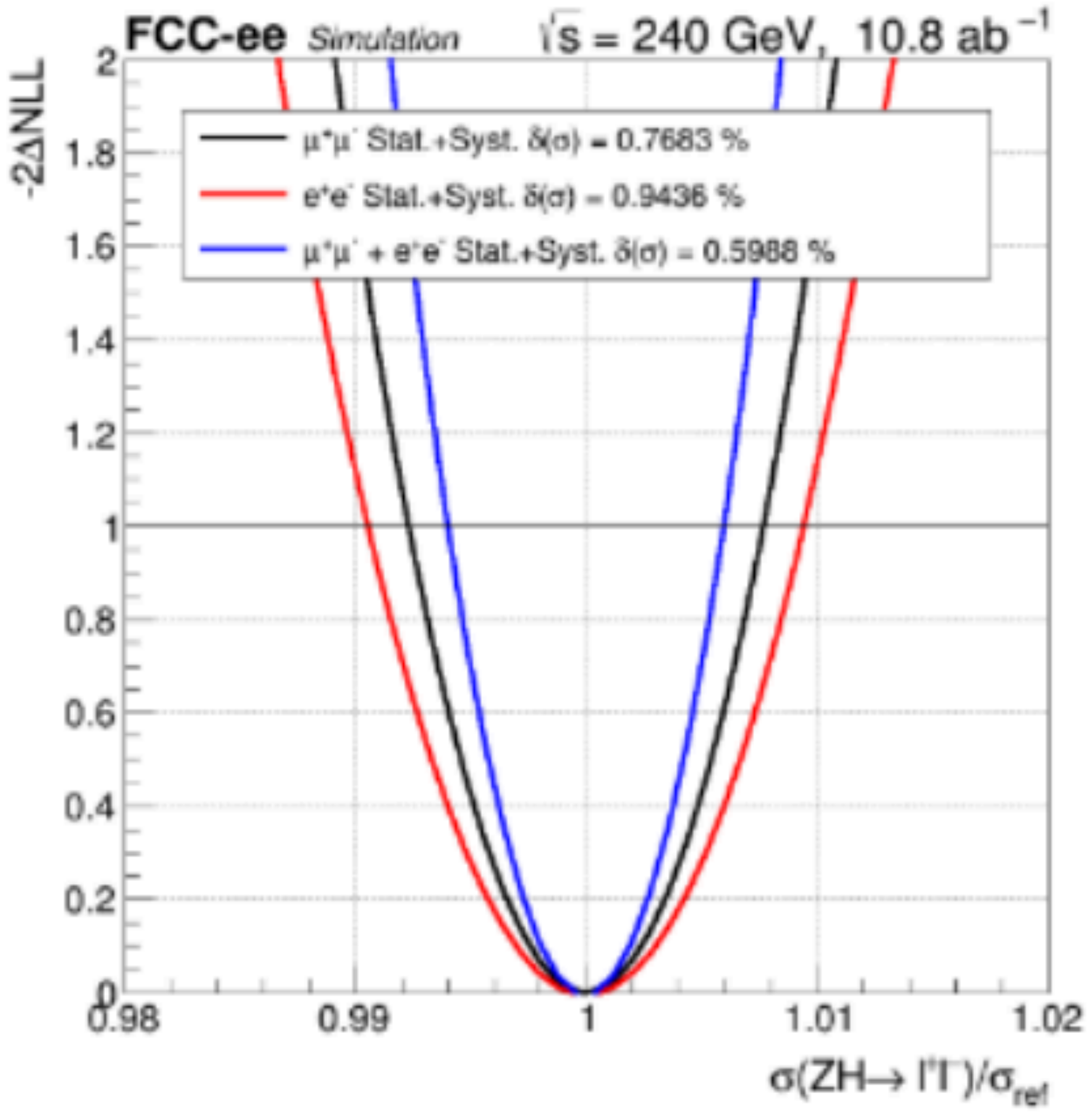
This is one example where a study done with a non-full simulation of the detector, manages to establish dependence on critical potential uncertainties

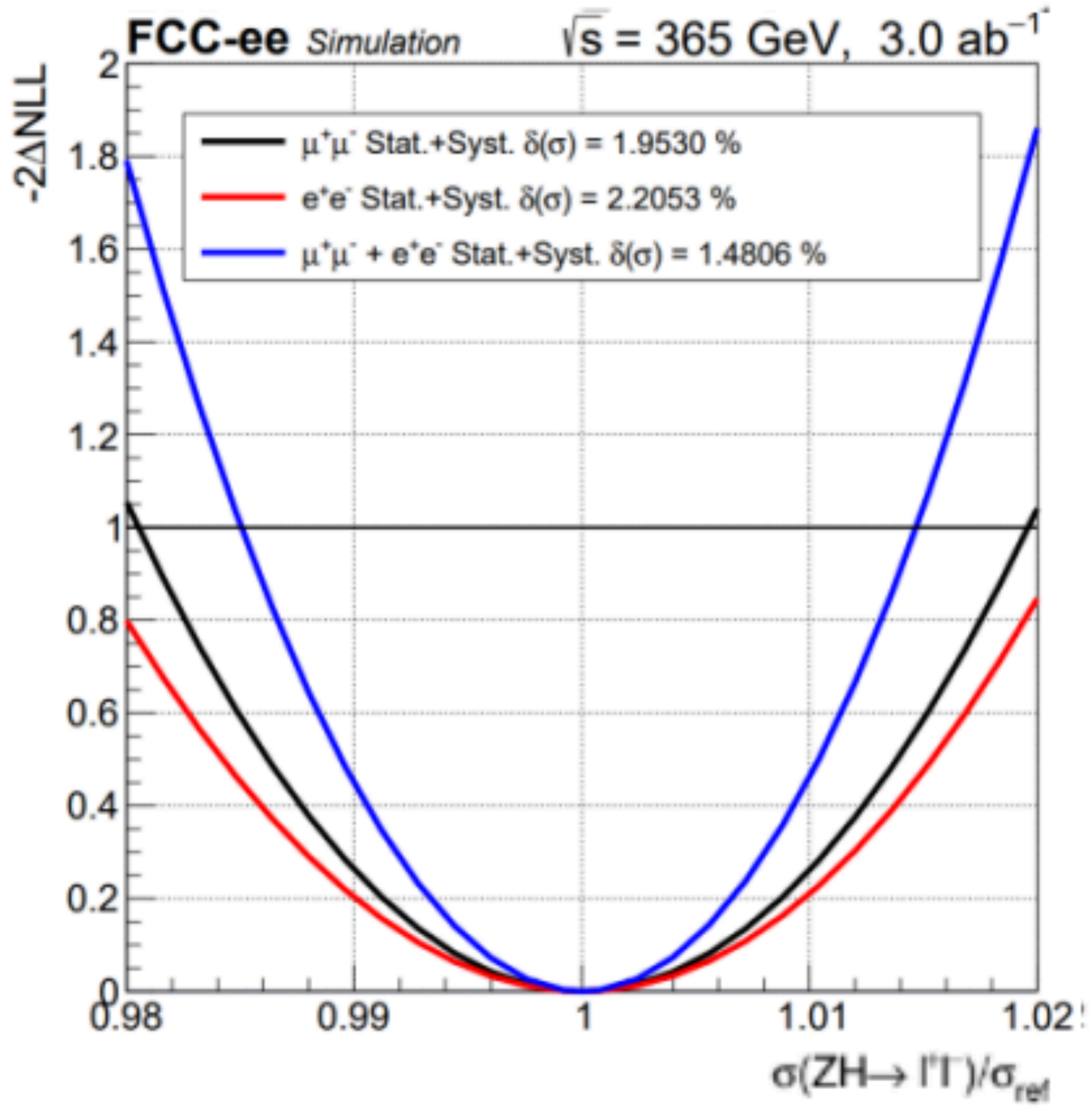
Total ZH production cross section

Essential piece for “model independent” Higgs couplings determination and more









- **Previously estimated sensitivity (CDR) ~0.5%**
- **Challenge to keep selection as much as possible decay-mode independent**
- **Systematics considered: BES, √s, lepton energy scale**

10.8/ab at √s=240 GeV : δσ = 0.599% (0.592% stat-only)
3.0/ab at √s=365 GeV : δσ = 1.48% (1.42% stat-only)

Systematics on the ZH cross-section

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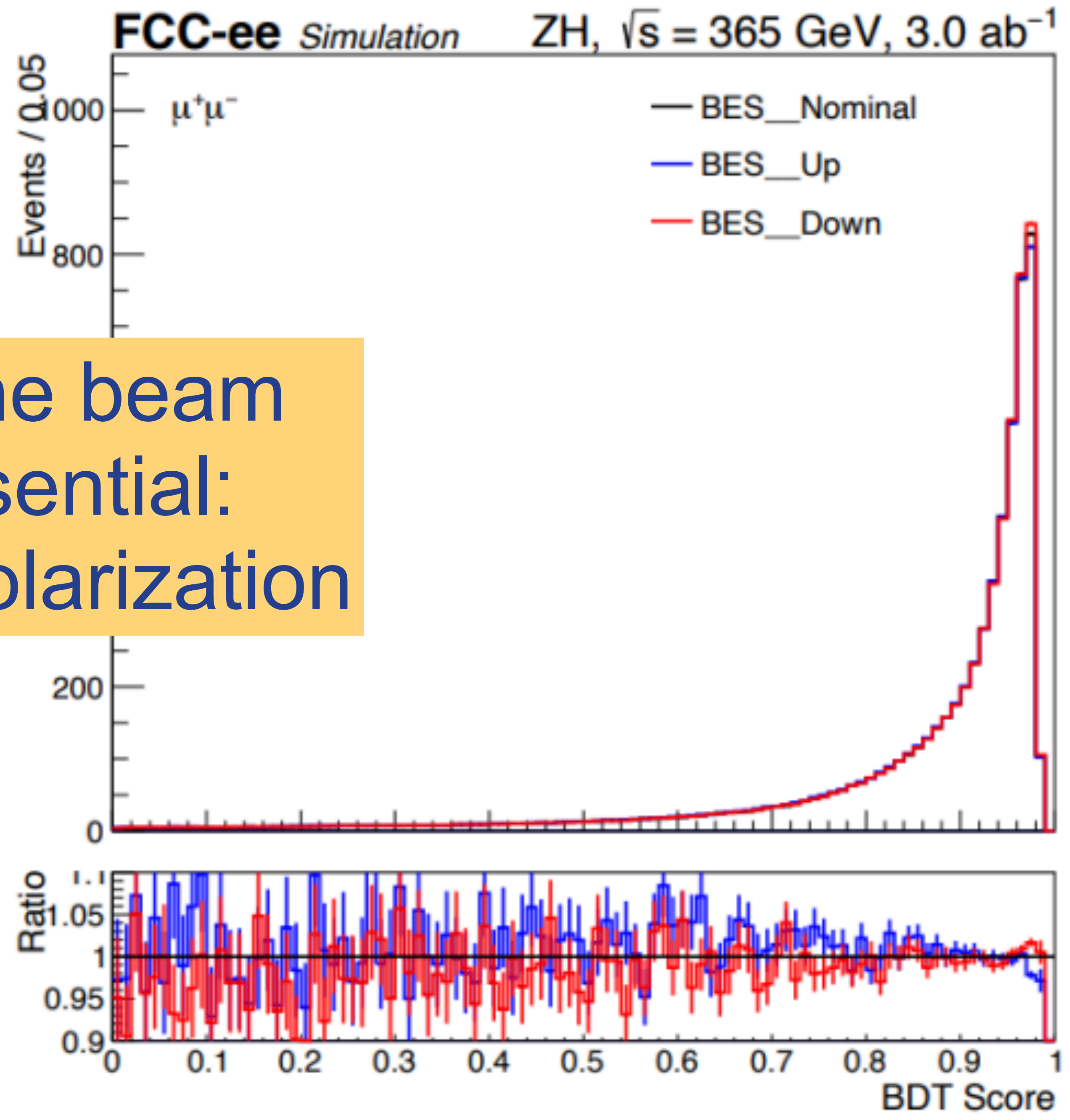


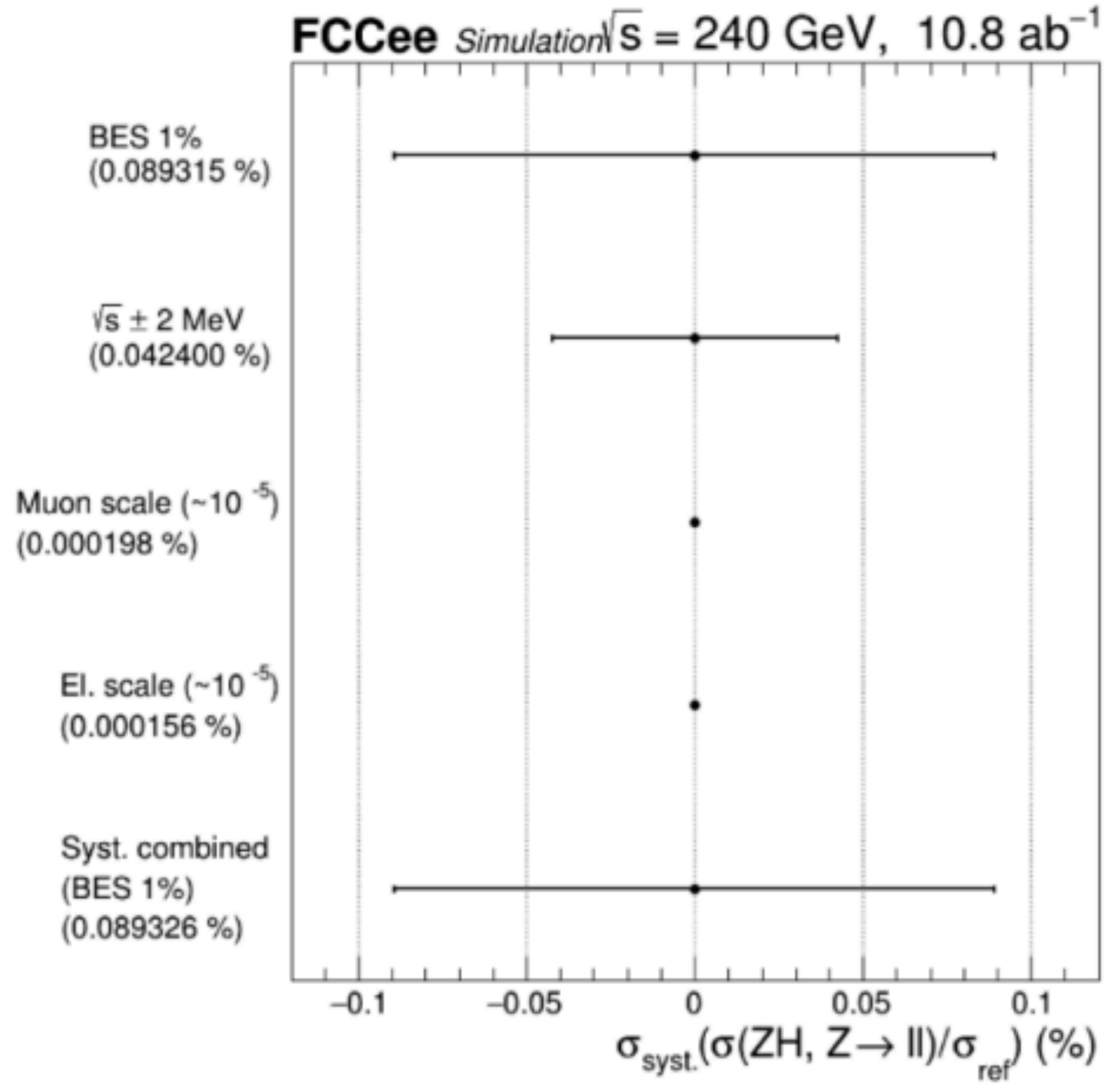
Control of the beam energy essential: resonant depolarization

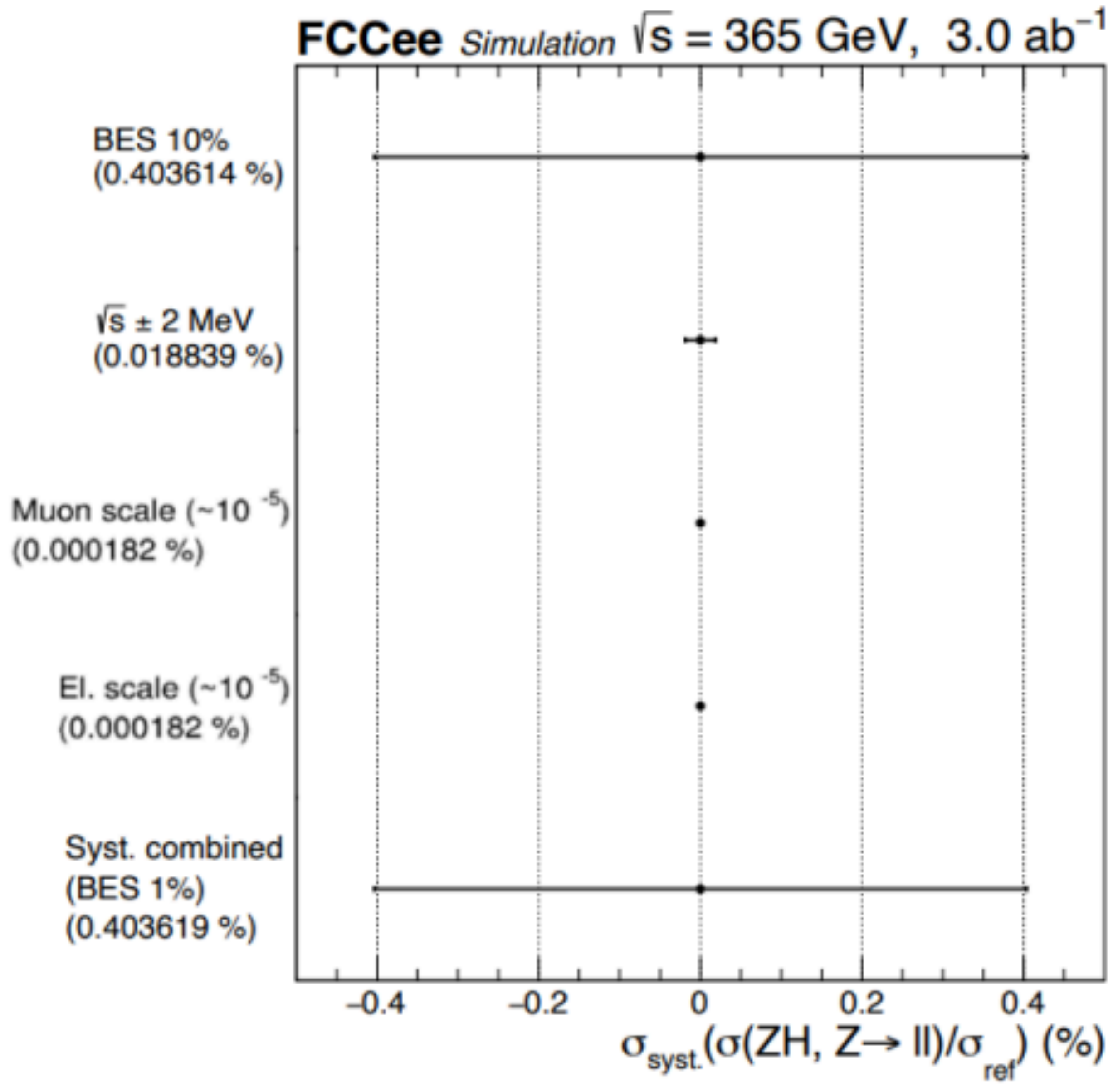
- **Beam energy spread, depends on the beam energy.**

  At a center-of-mass energy of 240 (365) GeV, the beam energy spread (BES) is ±0.185% (±0.221%) per beam, i.e. ±222 (±403) MeV.

  Uncertainty assumed on the BES value is **~1%** at 240 GeV and **~10%** at 365 GeV ➔Dominant systematic for ZH cross section measurement

- **ISR uncertainty** is not estimated precisely yet, but expected to be smaller





- **Centre-of-mass (√s)**: Uncertainty on the centre-of-mass energy which is expected to be known at the **~2 MeV** level for 240 and 365 GeV

- **Lepton momentum scale**: Uncertainty from the momentum of leptons assumed to be known at **10^{-5}** precision level both for 240 and 365 GeV

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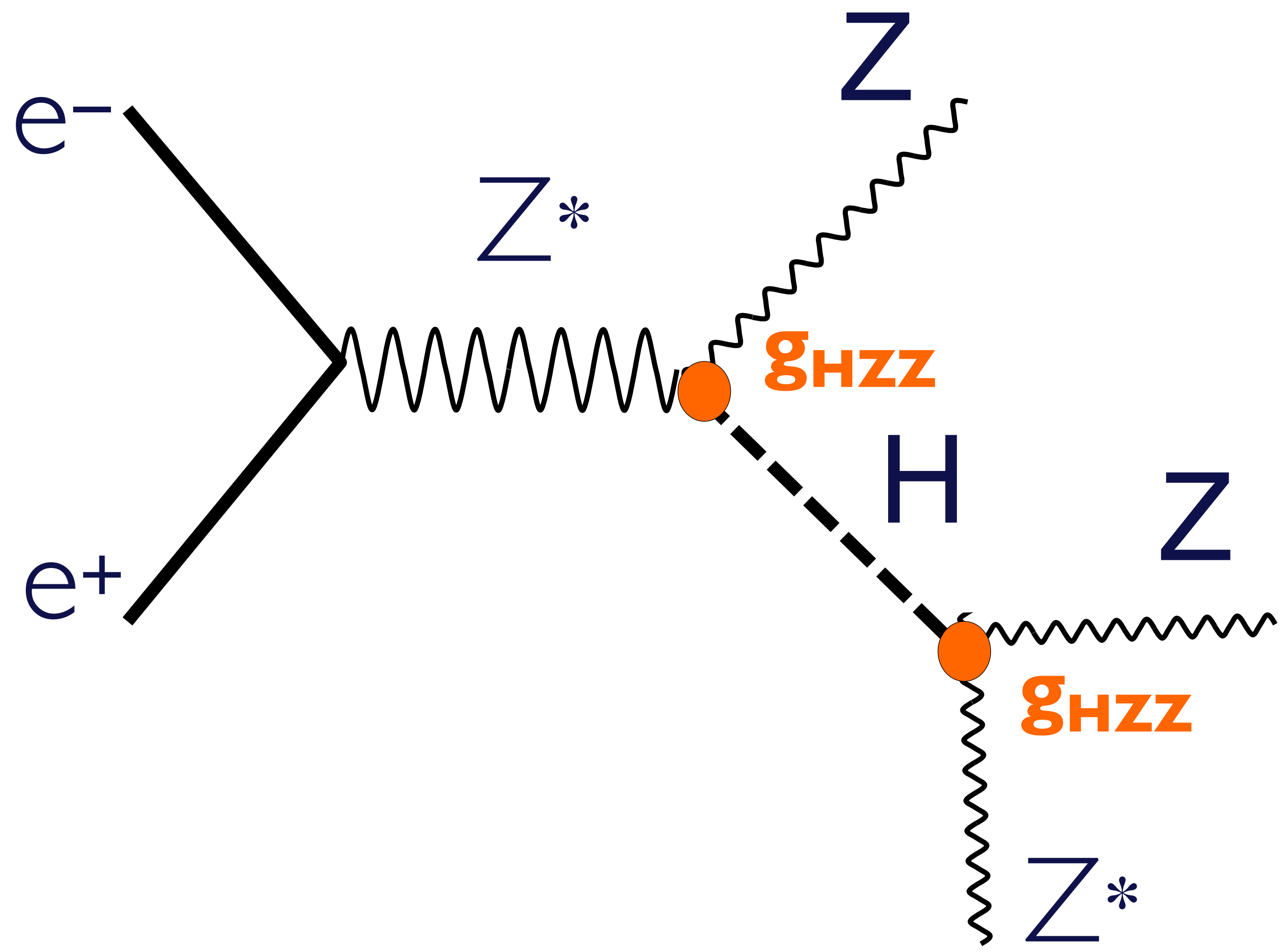
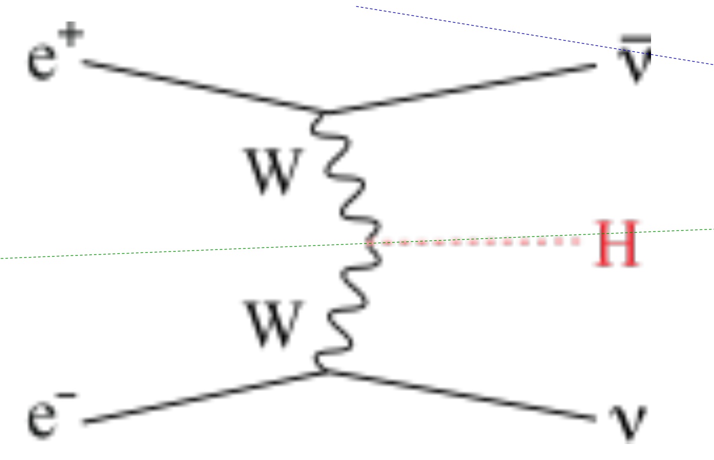
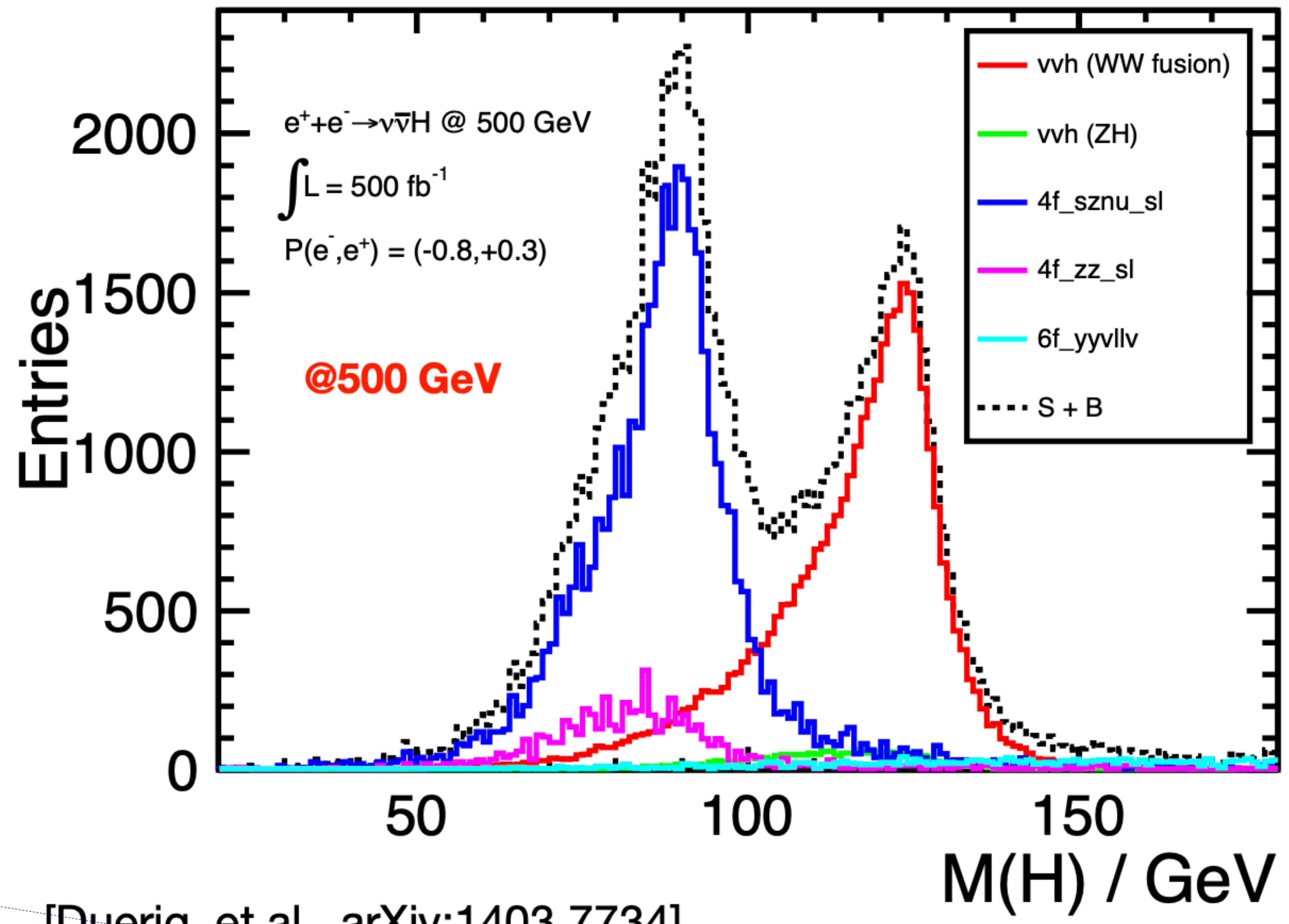
slide from Gregorio Bernardi

Higgs width determination

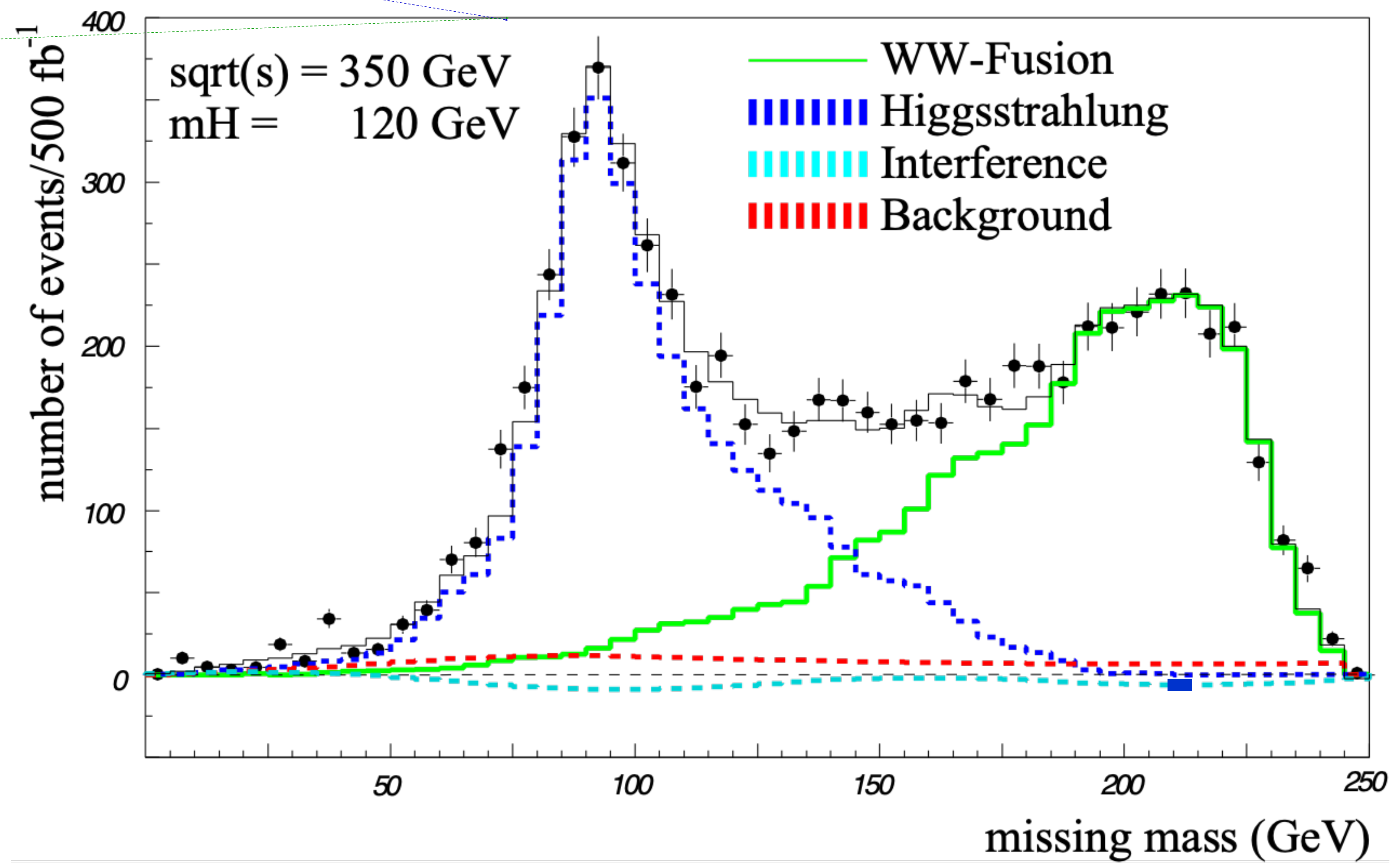
- **Model independent determination of the total Higgs decay width expected to be ~1%**







[Duerig, et al., arXiv:1403.7734]



ee →HZ & H → ZZ at √s = 240 GeV

- σ_{HZ} is proportional to g_{HZZ}^2
- BR(H → ZZ) = Γ(H → ZZ) / Γ_H is proportional to g_{HZZ}^2/Γ_H
  - σ_{HZ} × BR(H → ZZ) is proportional to g_{HZZ}^4/Γ_H
- Infer the total width Γ_H

WW → H νν→ bbνν at √s = 365/500 GeV

$$\Gamma_H \propto \frac{\sigma_{WW\to H}}{BR(H\to WW)} = \frac{\sigma_{WW\to H\to b\bar{b}}}{BR(H\to WW)\times BR(H\to b\bar{b})}$$

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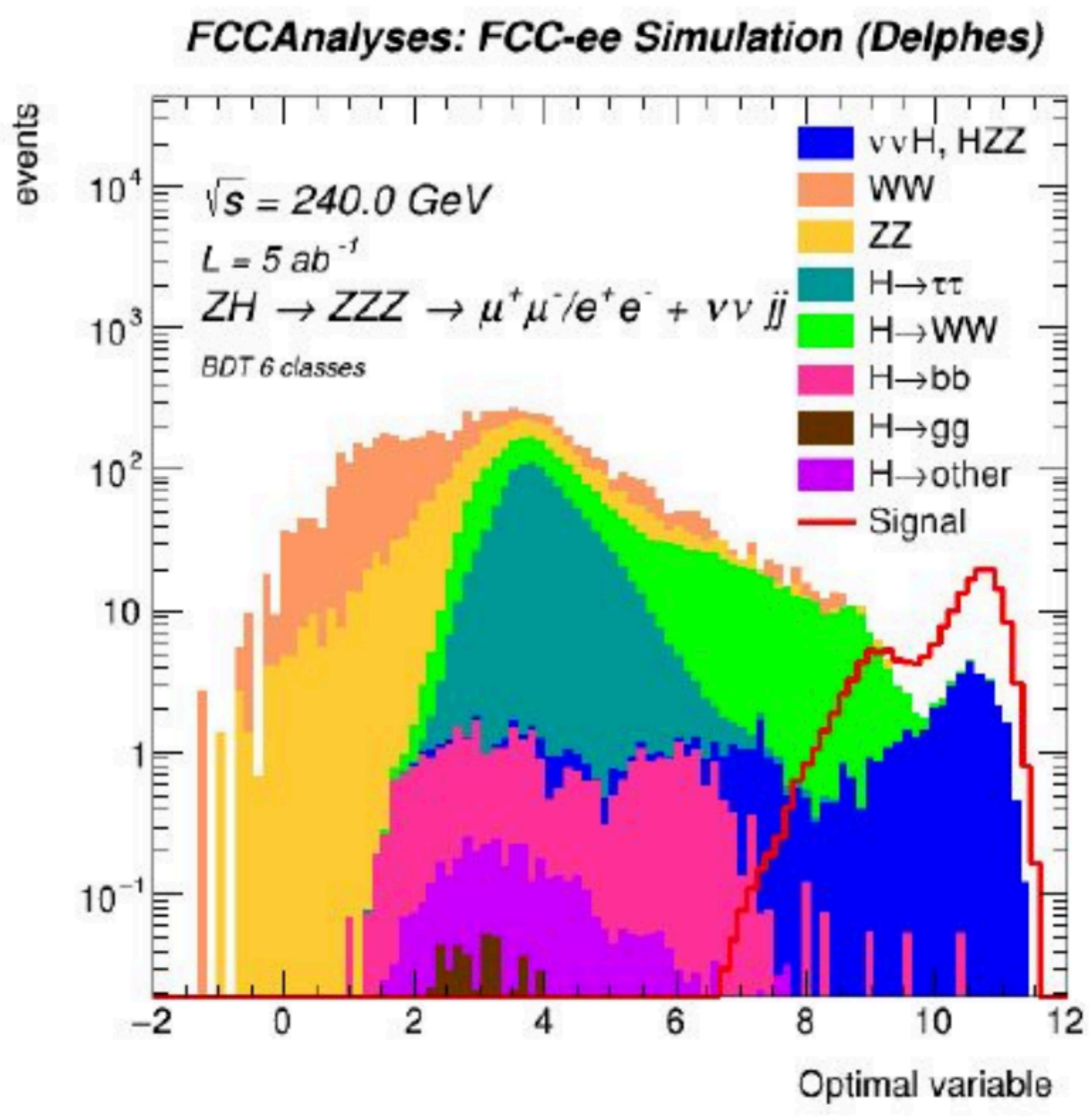
Example new Analysis with $H \rightarrow ZZ^*$

Many final states!



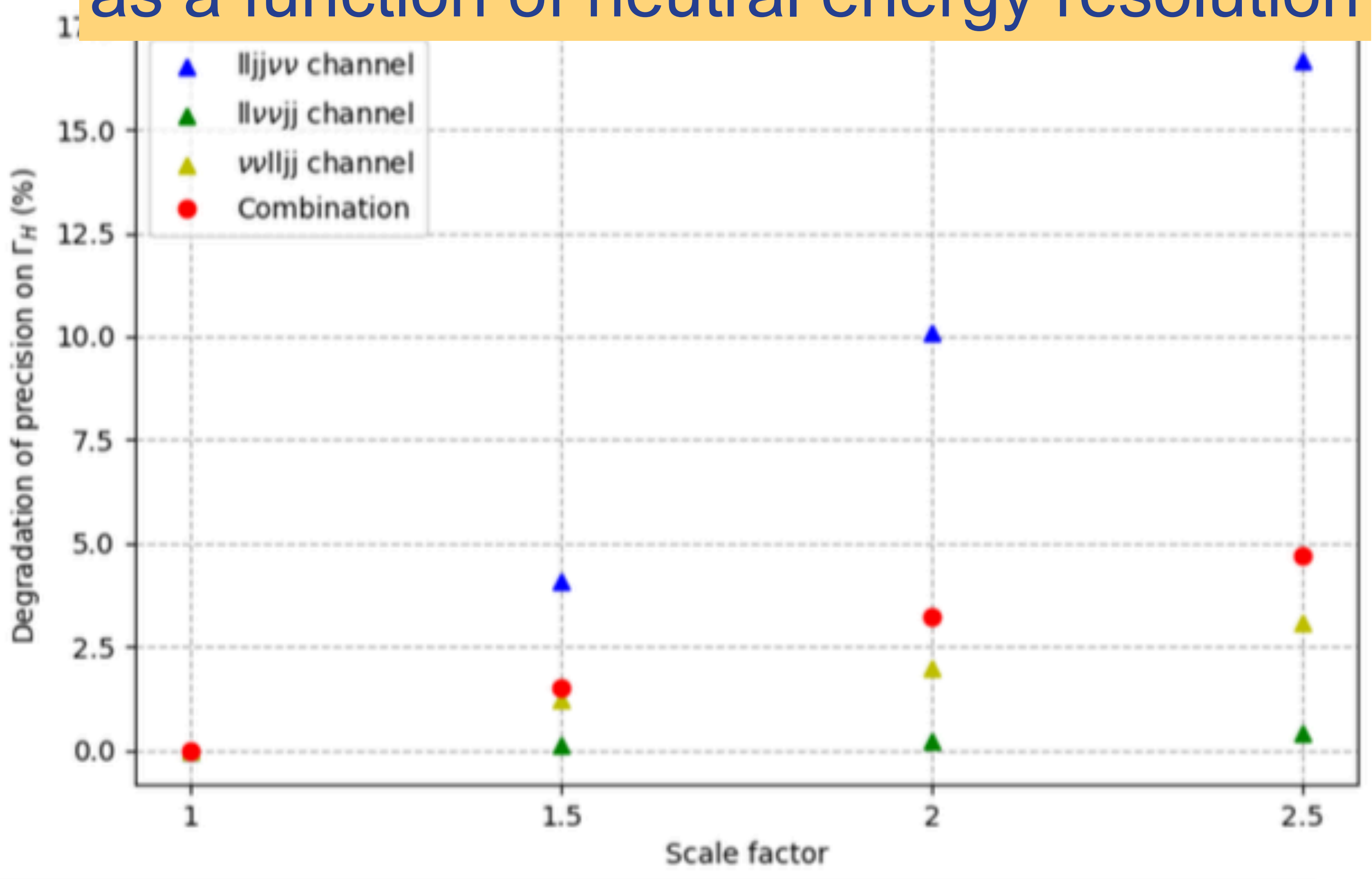
Uncertainties extrapolated to 10.8/ab at 240 GeV:

	ll + vvqq	ll + qqvv	vv + llqq	Combination
δσBR/σBR (%) Fit to BDT	5.0	7.3	4.7	3.1

	ll + qqqq
δσBR/σBR (%) Fit to BDT	8.4

	qqqqqq
δσBR/σBR (%) Cut & count	14

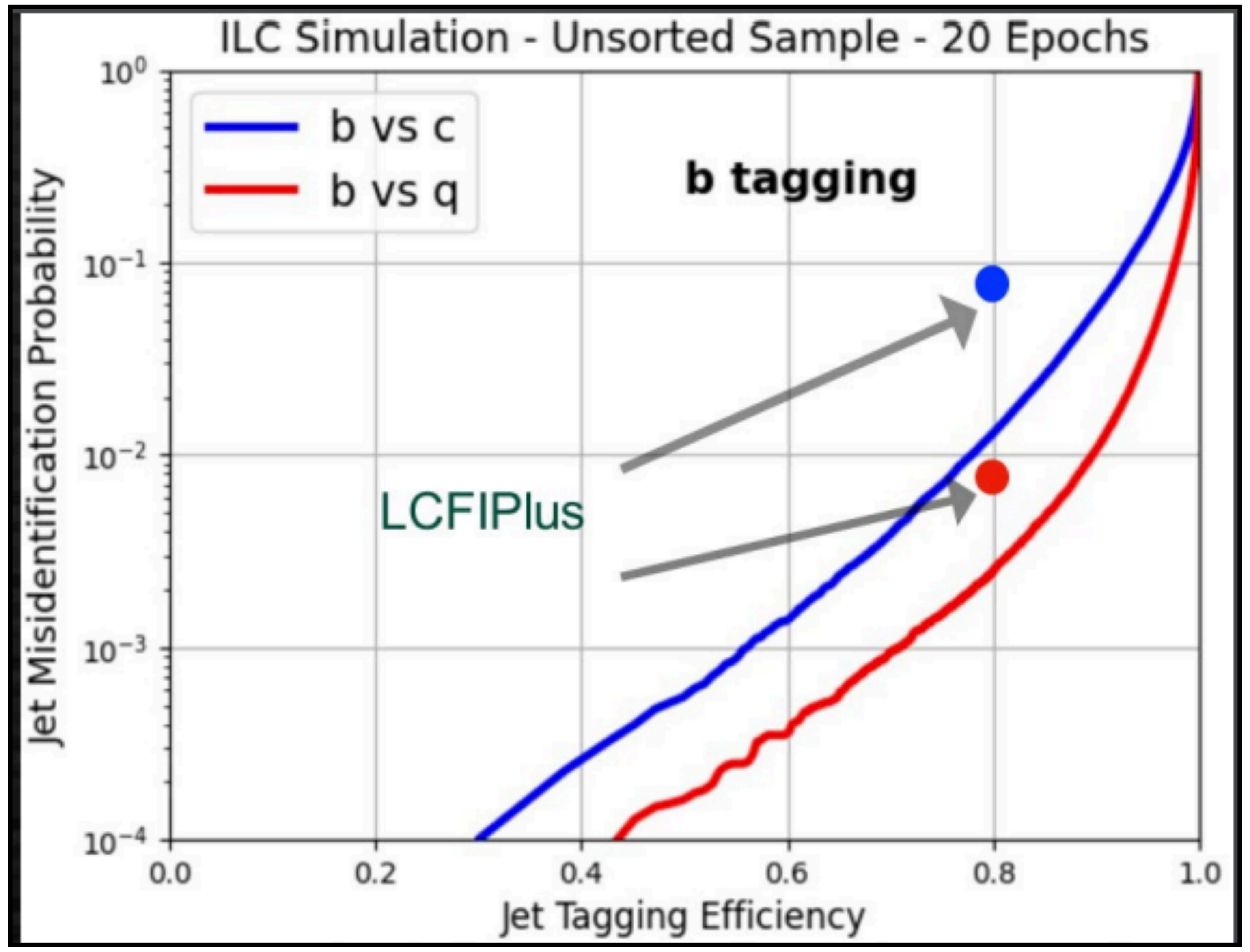
Degradation of precision on Γ_H as a function of neutral energy resolution



- Hadronic channels (WIP) instructive to understand needed detector performance and reconstruction capabilities

New flavor taggers have changed the game

Machine learning approach

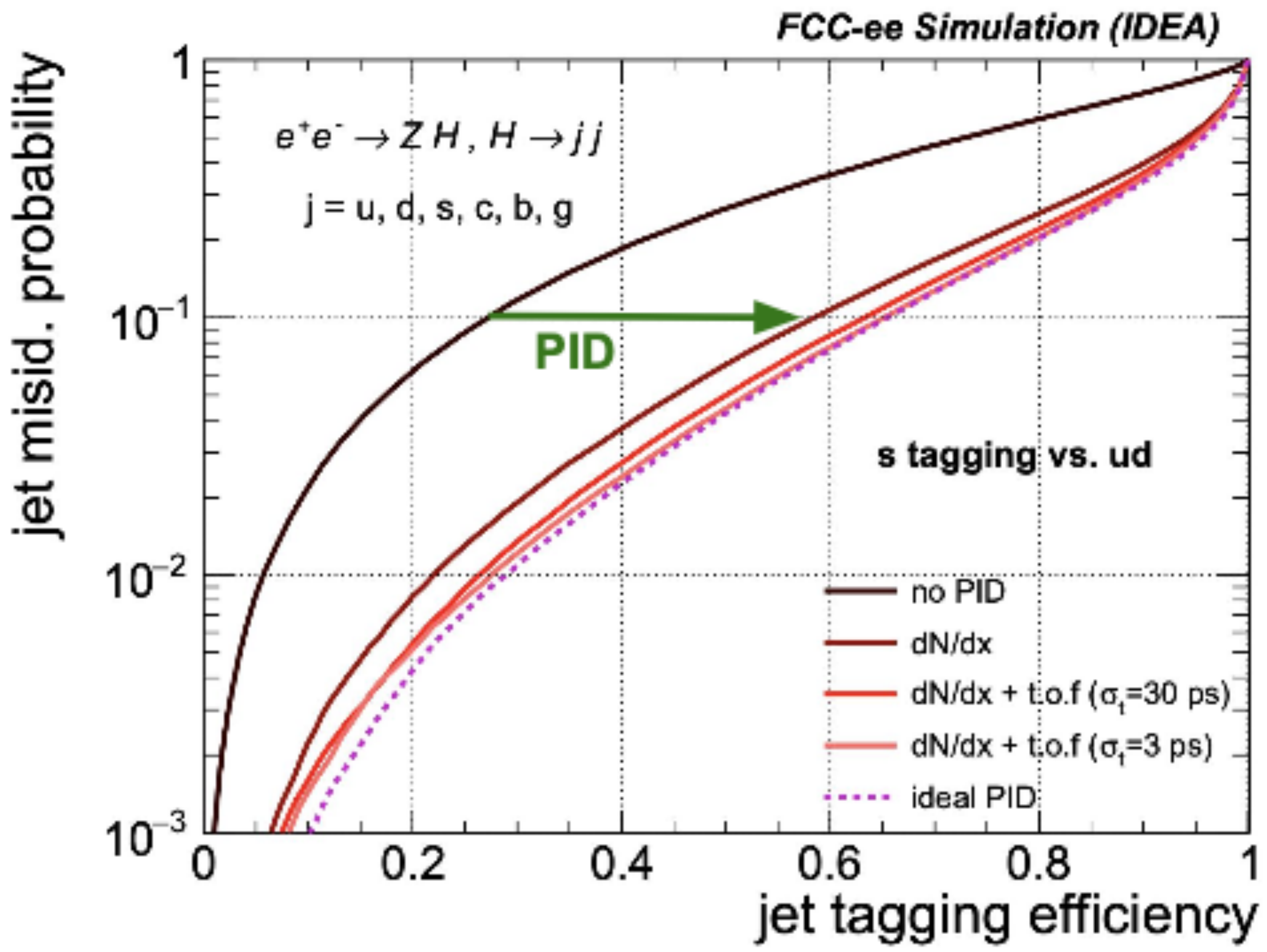


FCC ParticleNet

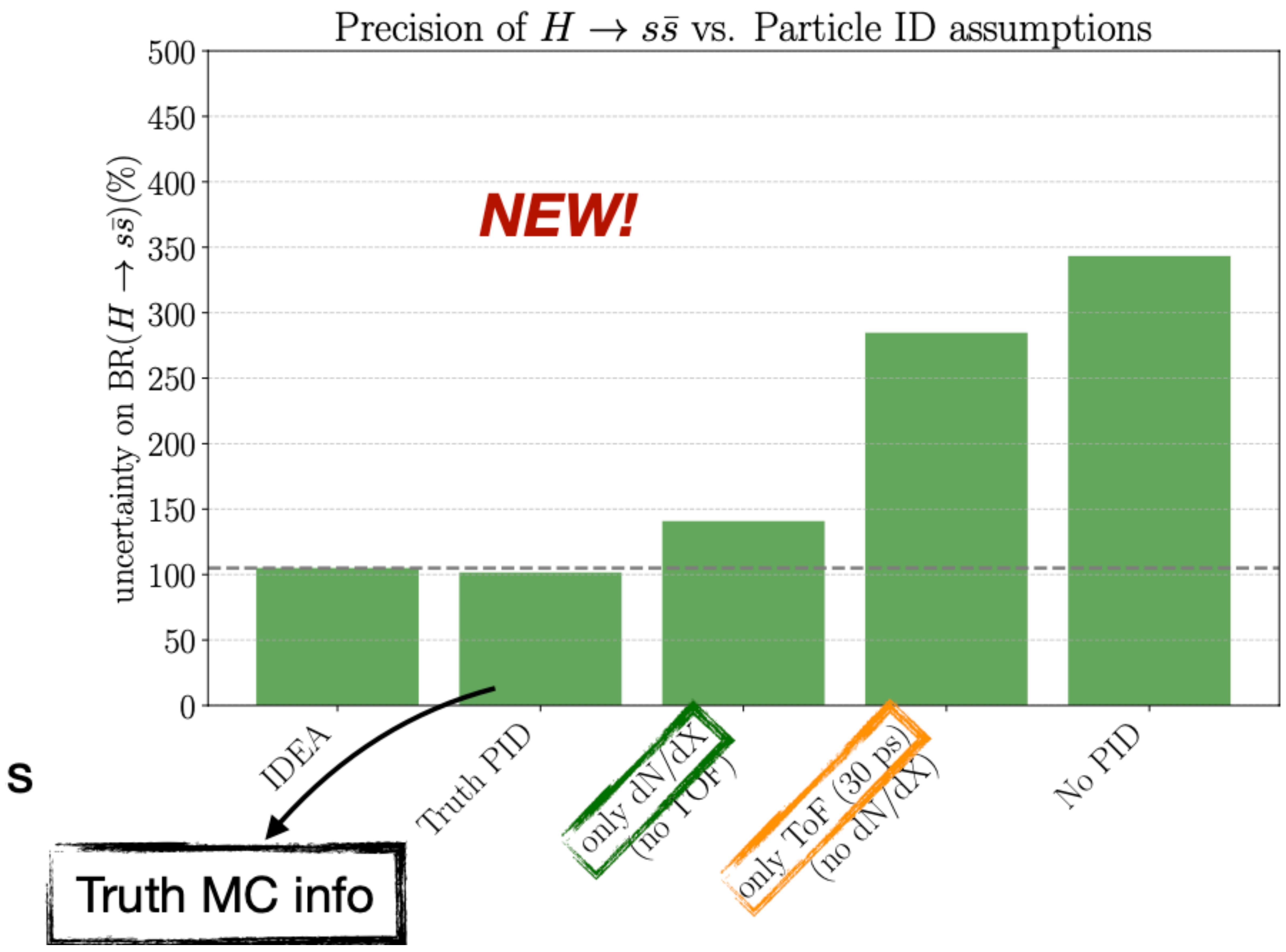
- **GNN approach has taken over from LHC experience to FCC, ILC, CEPC …with amazing improvements in performance which are still being explored.**
- **Studies ongoing to determine sensitivity to detector performance and parameters**

New opportunities: strange tagging

Particle ID capabilities



Training the ParticleNet with the additional information and comparing to ideal strange identification

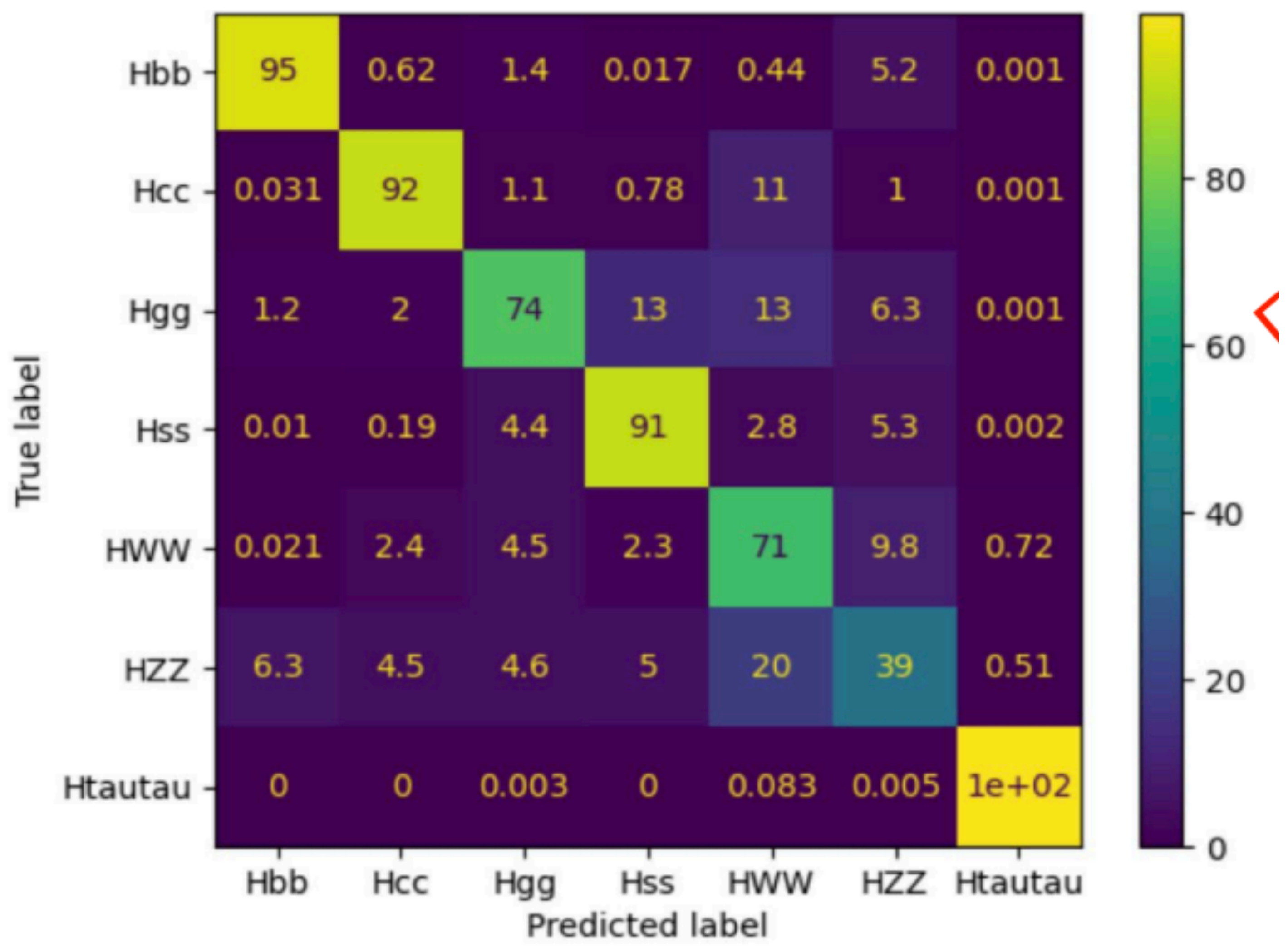


Interesting to study the dependence on the uncertainties on H->ss on the degradation of the detector performance

Hadronic Higgs decays @ FCC-ee

quarks and gluons couplings "all in one"

- Three analyses targeting Z(ll), Z(νν) and Z(qq) + H→qq/gg
  - Split according to Z decay based on number and flavour of leptons, missing momentum
  - All particles except leptons from Z clustered into 2 or 4 jets depending on final state
  - GNN-based jet-flavour tagging (b/c/s/u/d/g/τ) + kinematic features to classify events into H→bb/cc/…
  - Simultaneous fit to m_{recoil} (Z→ll), m_{vis} vs m_{miss} (νν), m_{recoil} vs m_{jj} (qq) in the categories to extract the BRs
- Also determine BRs of Higgs to ττ, WW and ZZ as byproduct (fully hadronic decays) - but can do better with dedicated analyses



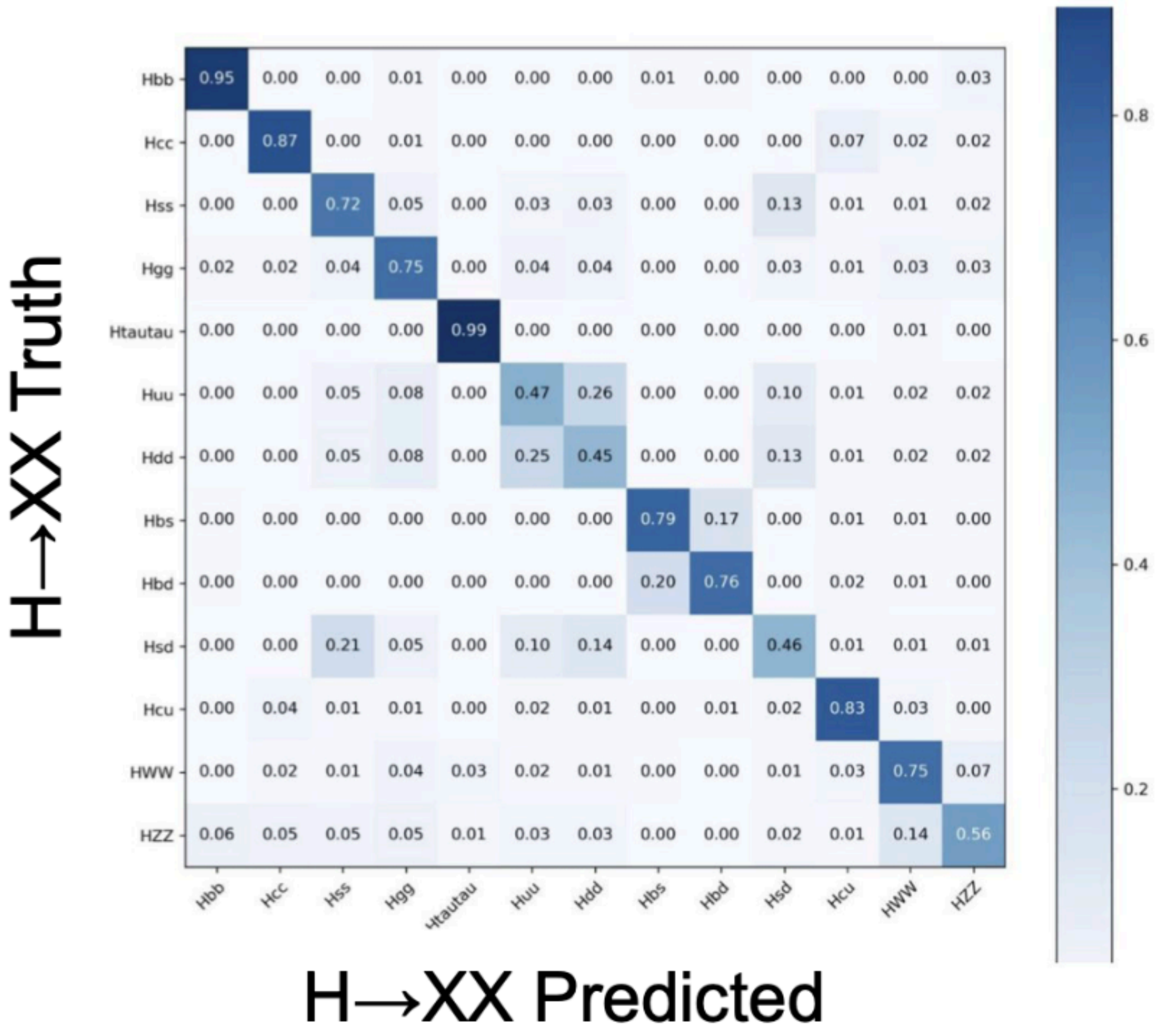
Analysis	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$	$H \to s\bar{s}$	$H \to ZZ$	$H \to WW$	$H \to \tau\tau$
$Z \to l^+l^-$	0.68	4.02	2.18	234	13.7	1.78	4.1
$Z \to q\bar{q}$	0.32	3.52	3.07	409	52.1	8.74	110
$Z \to \nu\bar{\nu}$	0.33	2.27	0.94	137	19.8	1.89	22
comb	0.21	1.66	0.80	105	10.1	1.16	4.0

Relative uncertainty (in %) at 68% CL on signal strengths in the various Higgs decay channels

Approaching the light quarks

new opportunities

- Extension of previous analysis using MVA with additional output classes (uu/dd/…) and floating freely in the final fit the normalisation of six additional Higgs decays



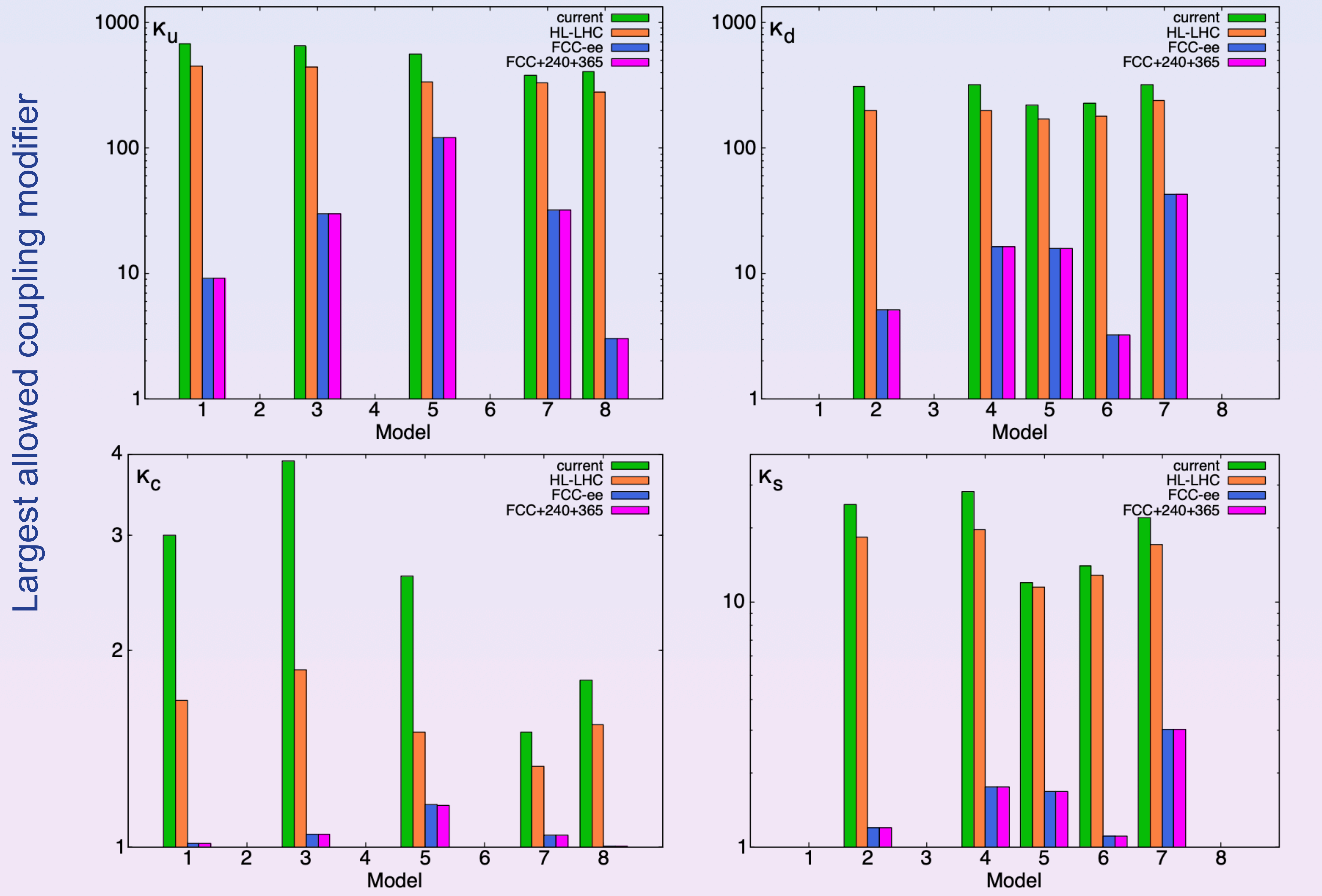
10.8/ab at 240 GeV, vvjj only

Final state	Upper limit on σBR @95% CL	BR(SM)
H→dd	1.4E-03	6E-07
H→uu	1.5E-03	1.4E-07
H→bs	3.7E-04	~1e-7
H→bd	2.7E-04	~1e-9
H→sd	7.7E-04	~1e-11
H→cu	2.5E-04	~1e-20

95% CL UL on σBR at 10^{-4} — 10^{-3} level with only vvjj final state at 240 GeV

Modification of Light Quark Yukawa from VLQ

In SMEFT operators that only modify the light quarks Yukawa



contact Barbara Erdelyi, RG, Nudžeim Selimović

- VLQ models that have no resonance and are constrainted by Higgs physics, flavor, EWK…
- Here we see the maximum deviations in various contexts

https://arxiv.org/abs/2410.08272v1

10.17181/7hbn8-3d233

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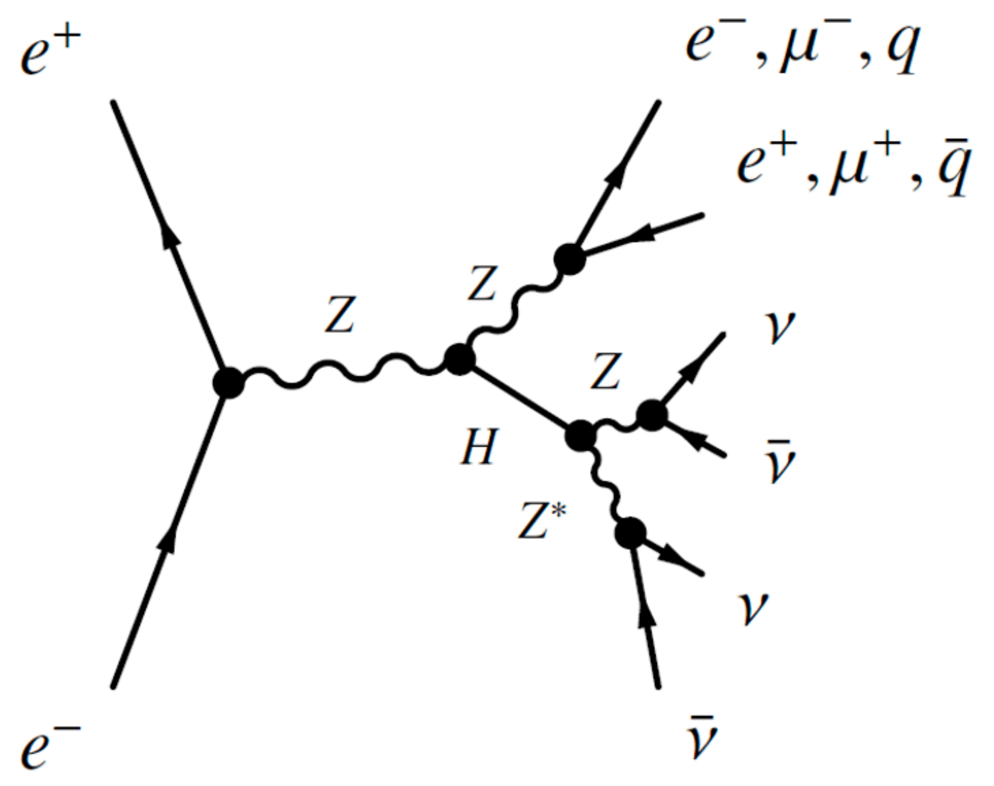
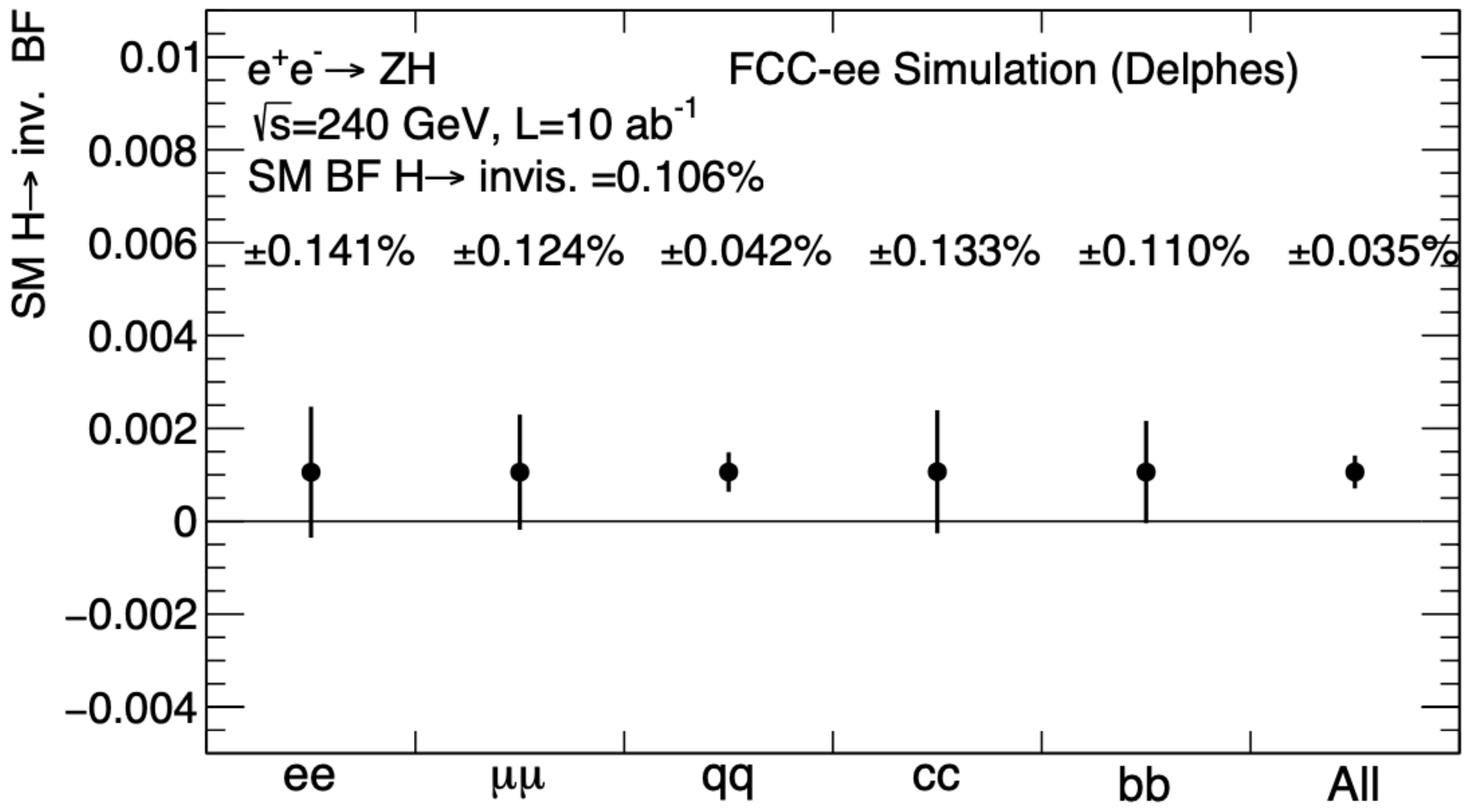
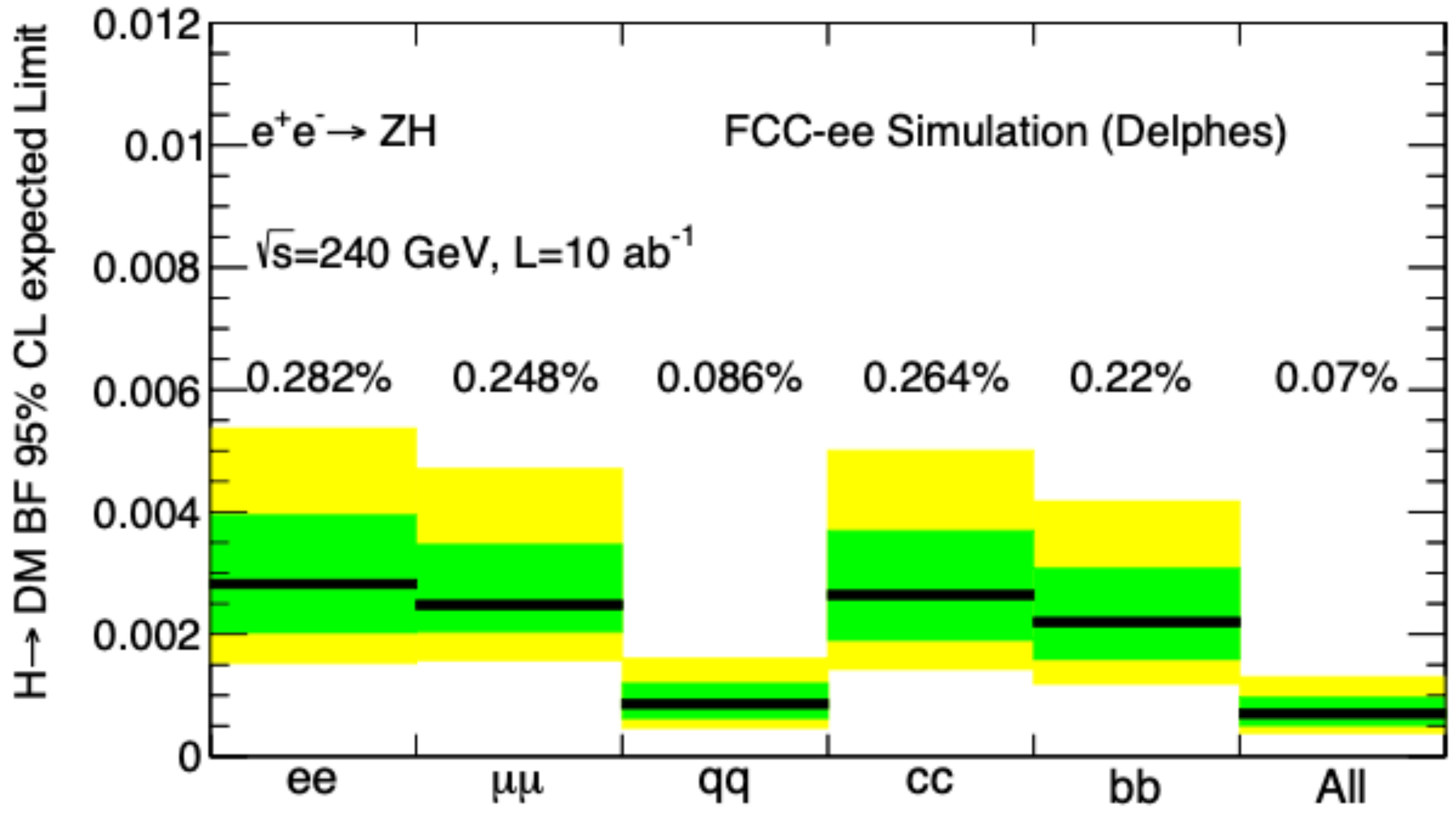
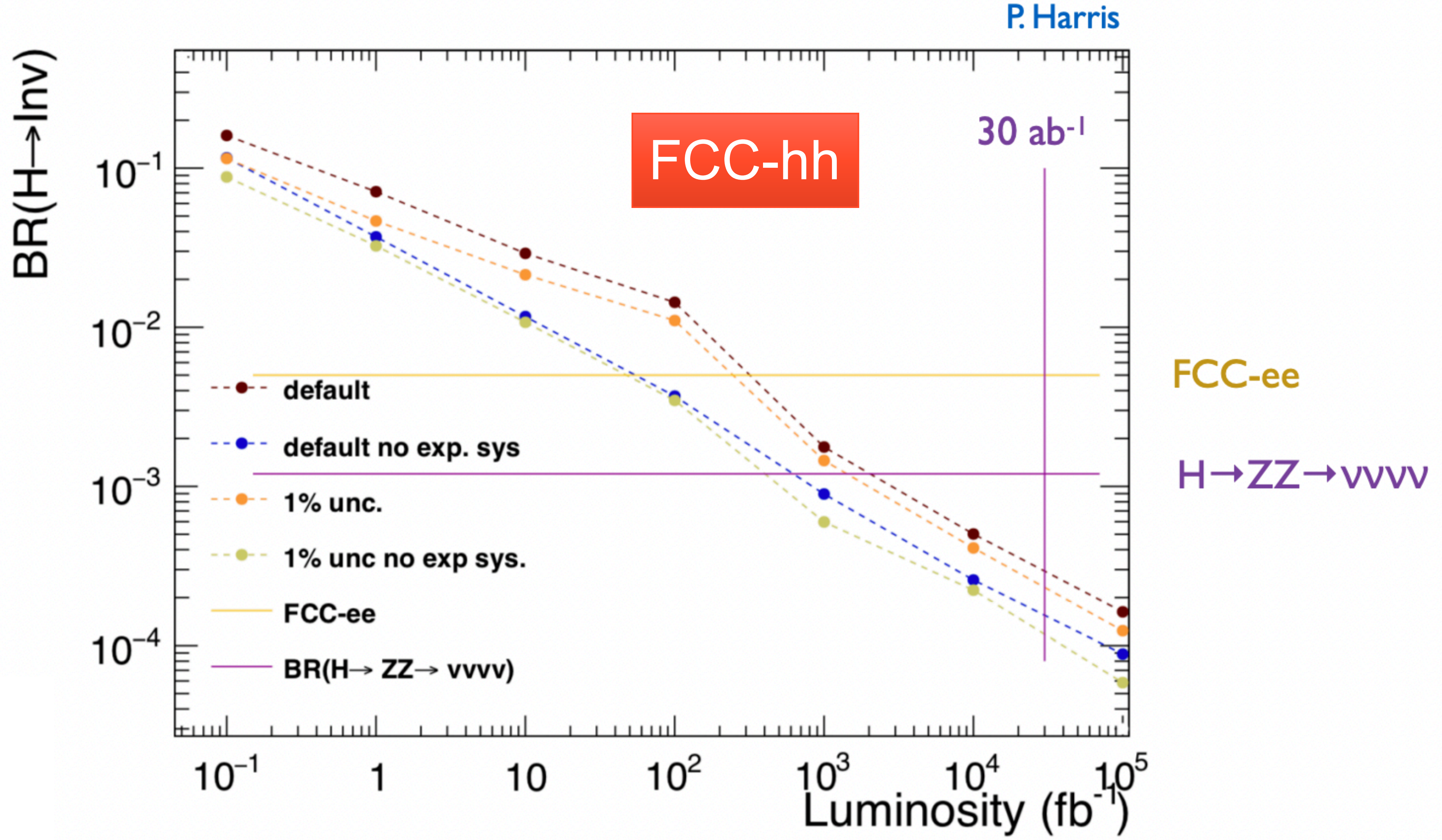
Higgs to invisible





BR(SM) with ~35% uncertainty





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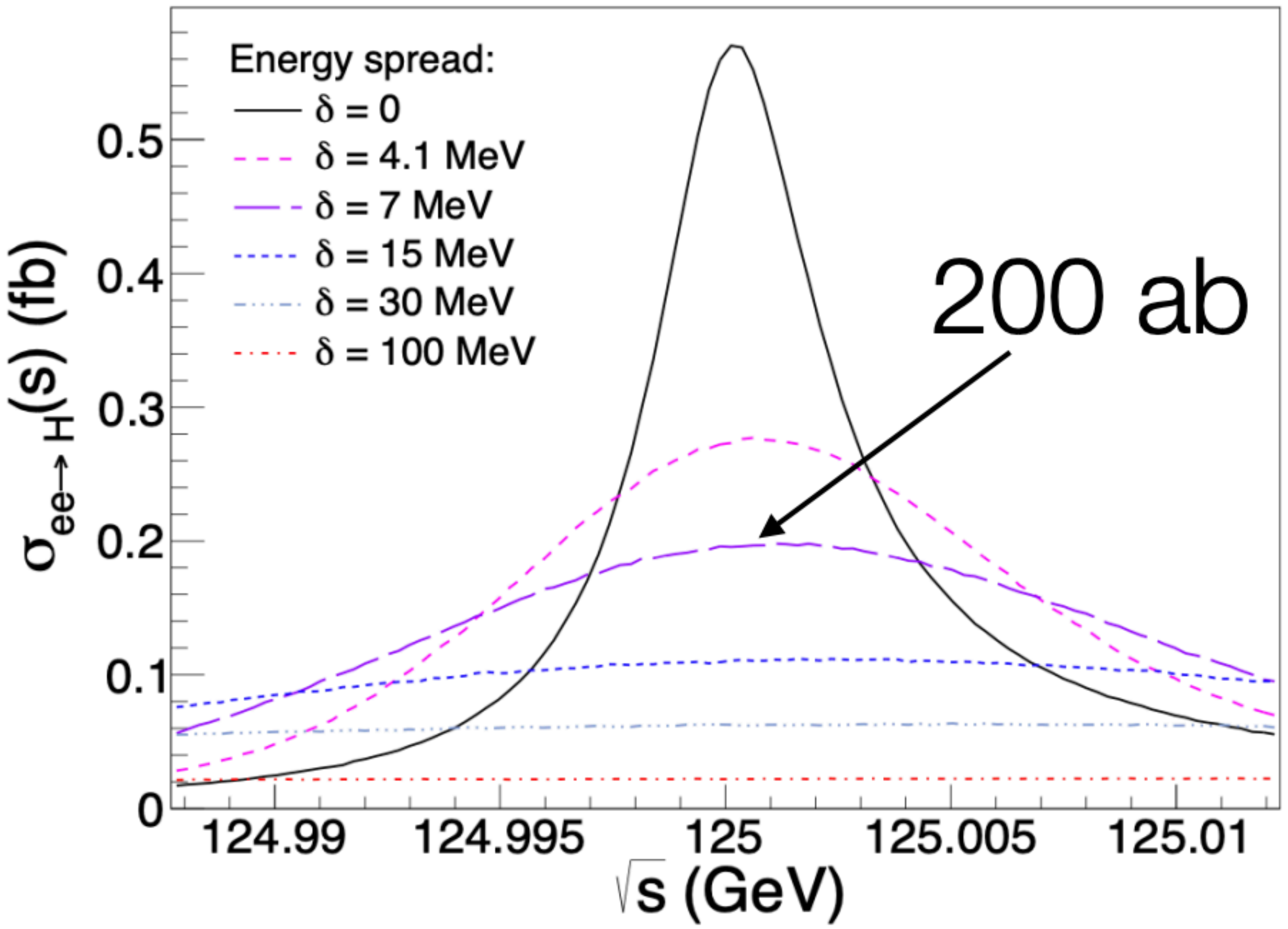
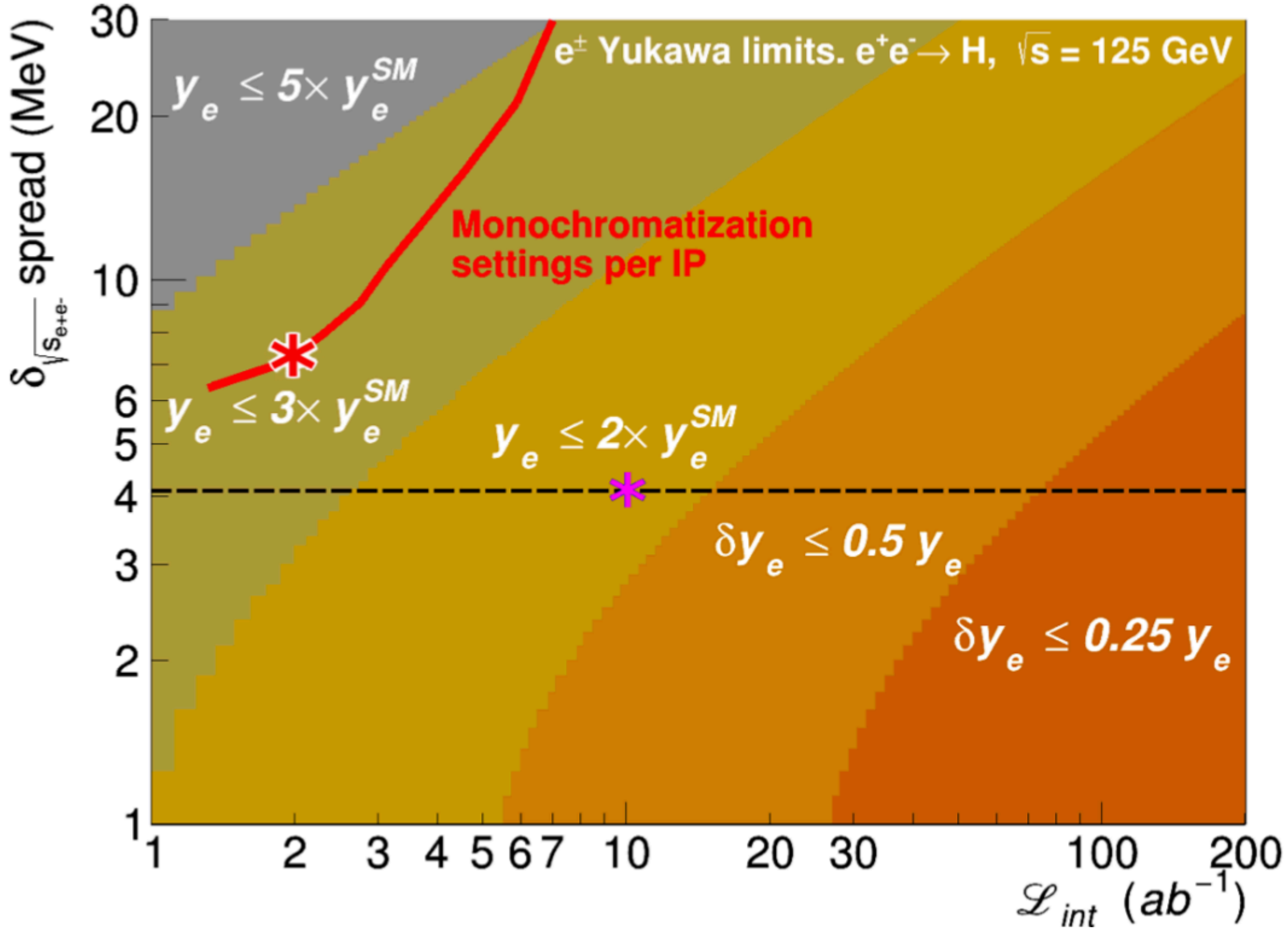
- If SM treated as background, sensitivity to EXO decays:
- **5σ for BR>0.18% and 95% exclusion if BR <0.07**

Electron Yukawa coupling (unique!)

arXiv:2107.02686

From resonant production $e^+e^- \rightarrow H$





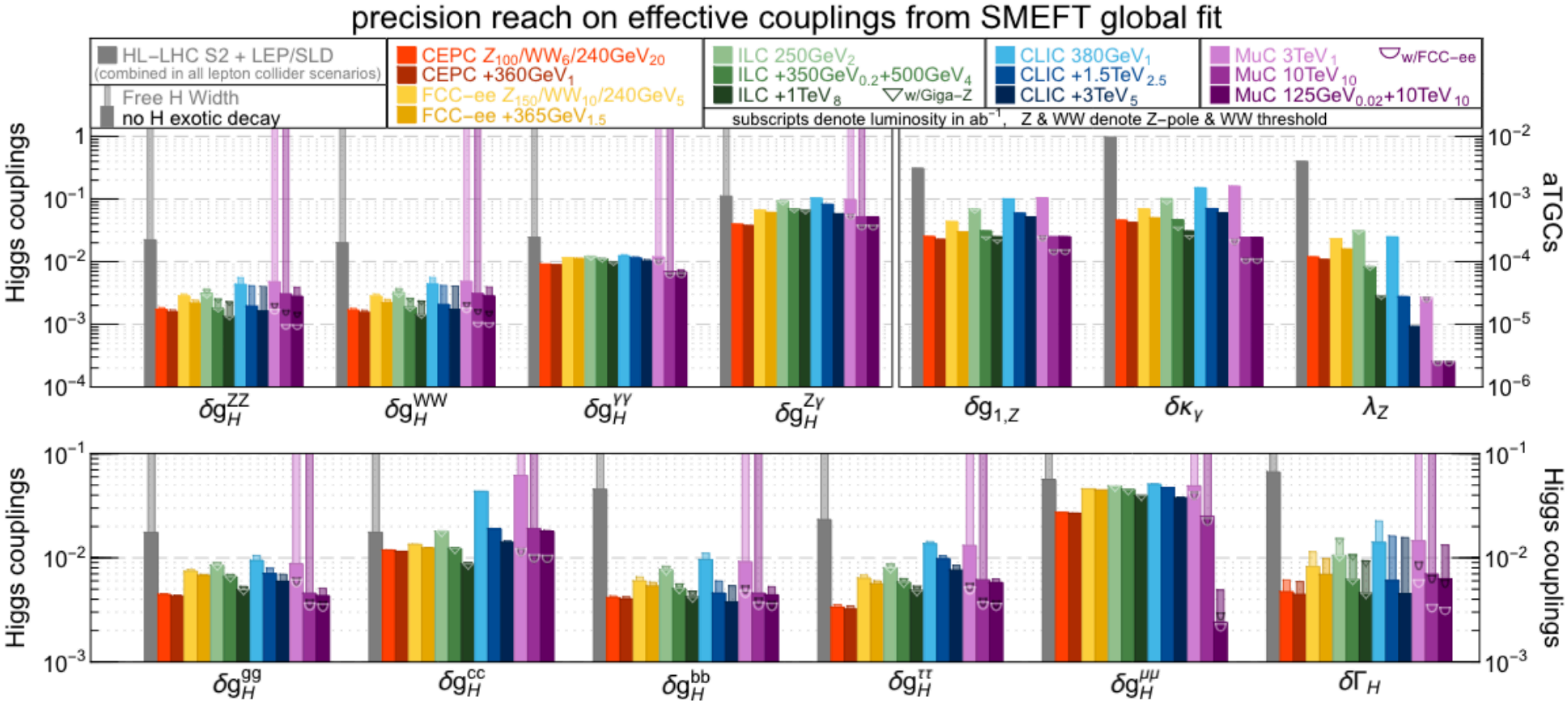
$$\sigma_{ee\rightarrow H} = \frac{4\pi \Gamma_H \Gamma(H \rightarrow e^+e^-)}{(s - m_H^2)^2 + m_H^2 \Gamma_H^2},$$

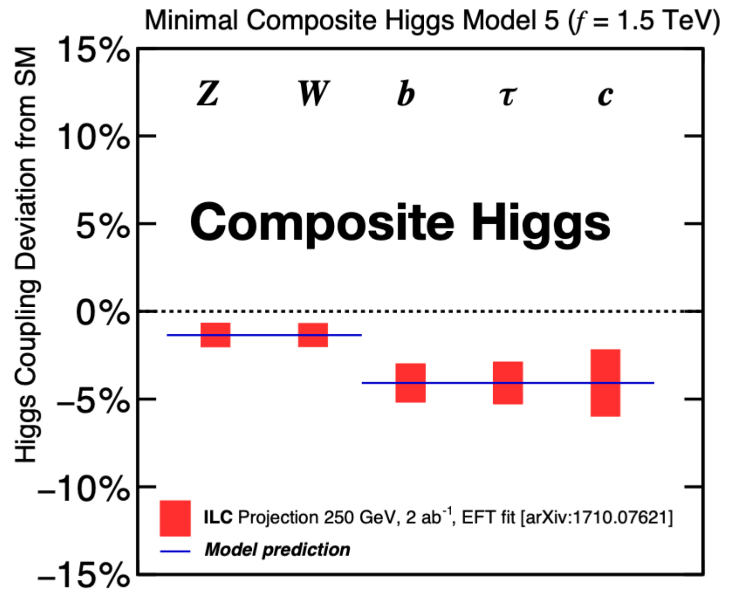
8/ab/yr (4 IP) with δ=7 MeV: 1600 ee→H/yr ⇒ $y_e < 1.6\, y_e^{SM}$ in 2 yrs
To reach sensitivity to SM need optics w/ excellent monochromatisation AND L_{inst}

Higgs couplings are crucial

Precision precision precision

- Why <1% ? to be sensitive to effects from BSM (EFT or concrete models)



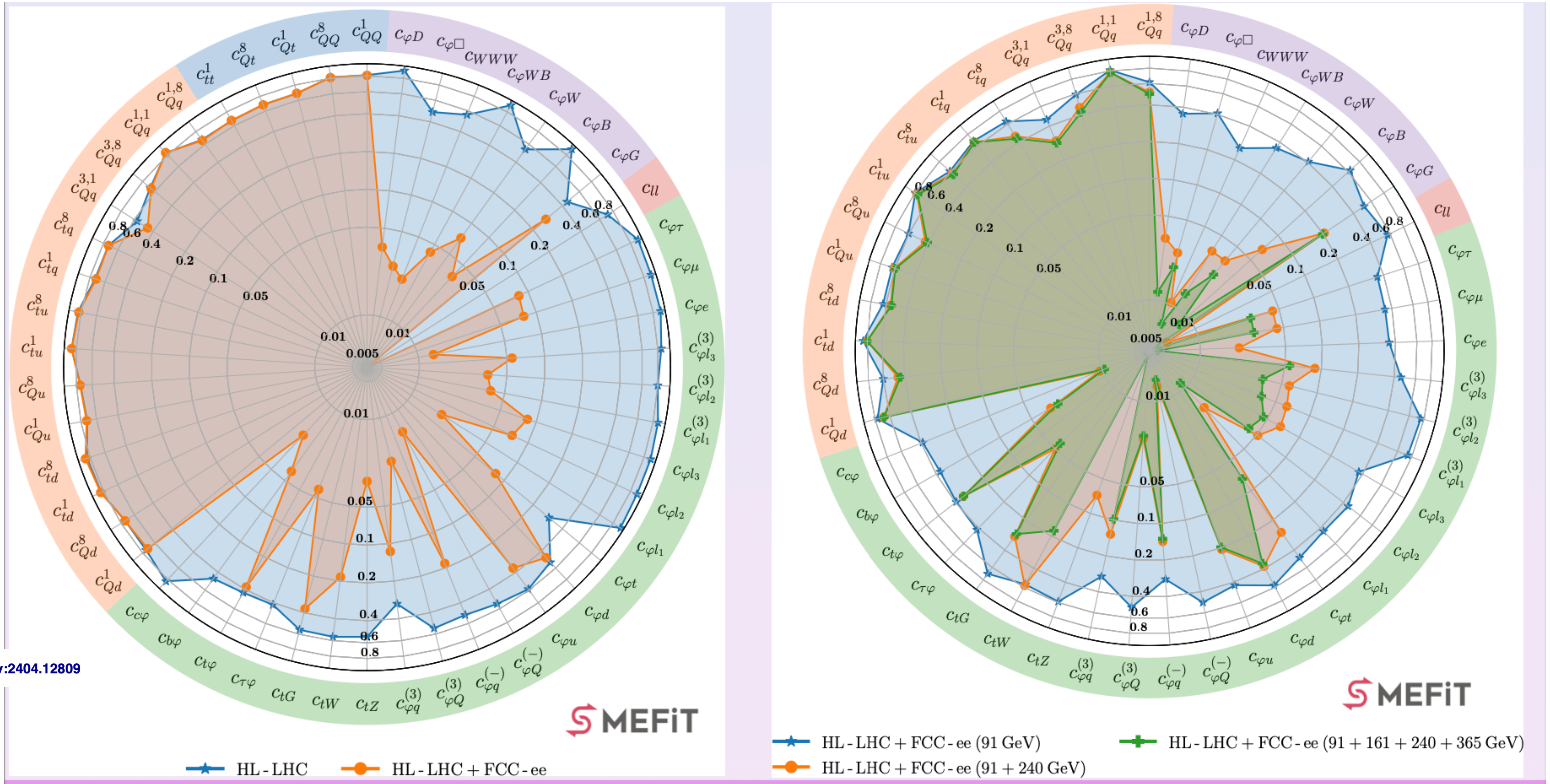


BUT there is more...

Predictions for the past EPPSU

The SMEFT at Future Colliders

Analysiing the contribution of runs at different √s



E. Celada *et al.* (smefit), arXiv:2404.12809

Higgs program NEEDS precision EWK measurements

J. de Blas, G. Durieux, C. Grojean, J. Gu, A. Paul https://arxiv.org/abs/1907.04311

$$\mathcal{L}_{\rm Eff} = \mathcal{L}_{\rm SM} + \sum_{d>4} \frac{1}{\Lambda^{d-4}} \mathcal{L}_d, \qquad \mathcal{L}_d = \sum_i c_i^{(d)} \mathcal{O}_i^{(d)} .$$

- **Fit to new physics effects parameterised by dimension 6 SMEFT operators**
- **The precision measurements of the Z pole run affect significantly Higgs operators: almost ideal if present, and a factor 2 worse if absent!**

Higgs couplings

aTGC couplings

Indirect BSM sensitivity from EWPO

FUTURE CIRCULAR COLLIDER

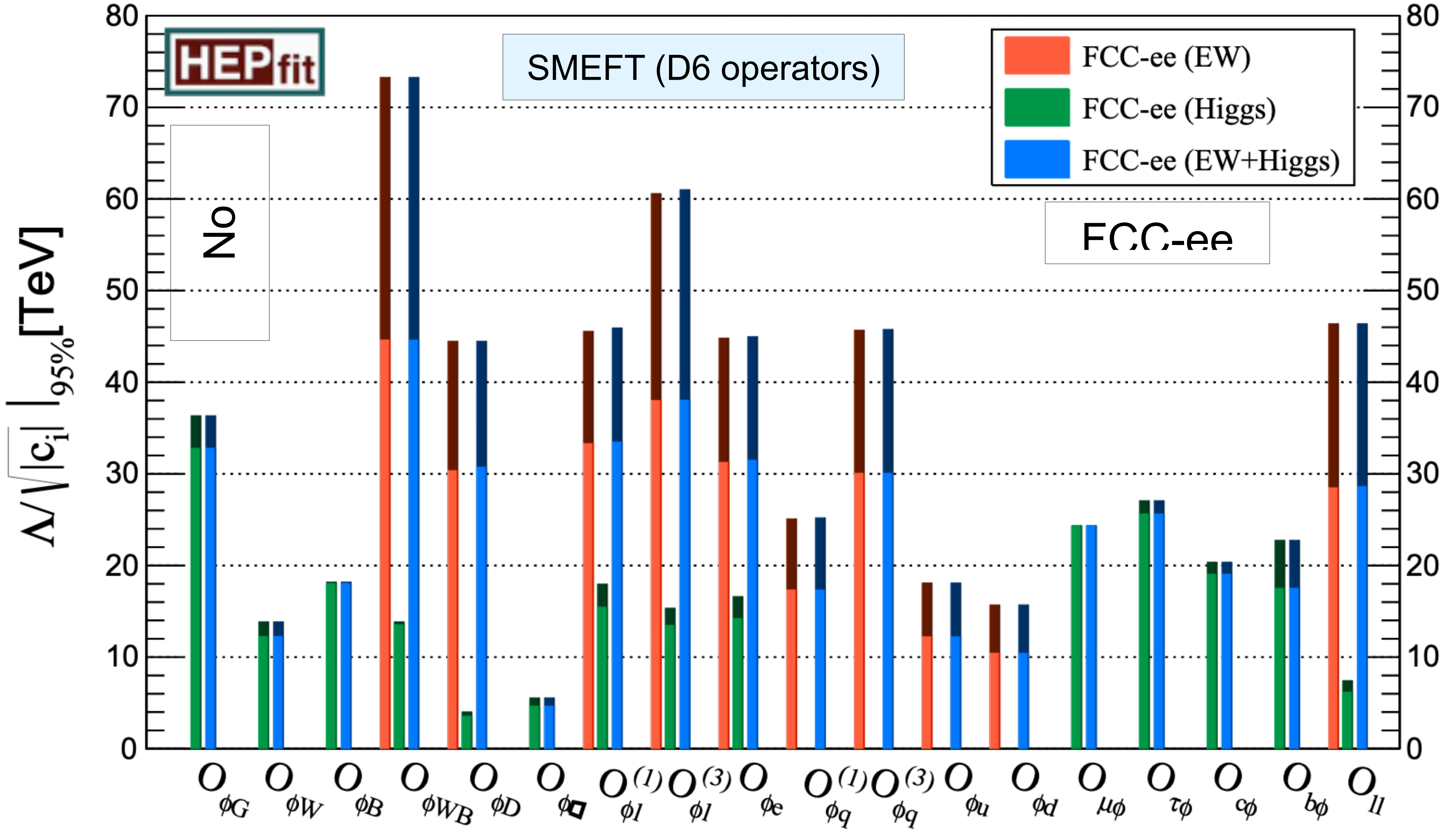
arXiv:2106.13885

- Target: reduce systematic uncertainties to the level of statistical
- Exquisite √s precision (100keV@Z, 300keV@WW)
- ~50 times better precision than LEP/LSD on EW precision observables

Need TH results to fully exploit Tera-Z

Quantity	Current precision	FCC-ee stat. (syst.) precision	Required theory input	Available calc. in 2019	Needed theory improvement†
m_Z Γ_Z $\sin^2\theta^{\ell}_{\rm eff}$	2.1 MeV 2.3 MeV 1.6×10^{-4}	0.004 (0.1) MeV 0.004 (0.025) MeV $2(2.4)\times10^{-6}$	non-resonant $e^+e^-\to f\bar{f}$, initial-state radiation (ISR)	NLO, ISR logarithms up to 6th order	NNLO for $e^+e^-\to f\bar{f}$
m_W	12 MeV	0.25 (0.3) MeV	lineshape of $e^+e^-\to WW$ near threshold	NLO ($ee\to 4f$ or EFT framework)	NNLO for $ee\to WW$, $W\to f\bar{f}$ in EFT setup
HZZ coupling	—	0.2%	cross-sect. for $e^+e^-\to ZH$	NLO + NNLO QCD	NNLO electroweak
$m_{\rm top}$	100 MeV	17 MeV	threshold scan $e^+e^-\to t\bar{t}$	N^{3}LO QCD, NNLO EW, resummations up to NNLL	Matching fixed orders with resummations, merging with MC, α_s (input)

†The listed needed theory calculations constitute a minimum baseline; additional partial higher-order contributions may also be required.

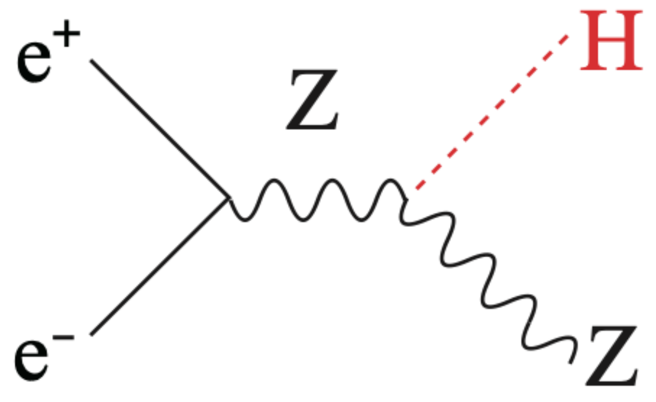


Indirect sensitivity to 70TeV-scale sector connected to EW/Higgs

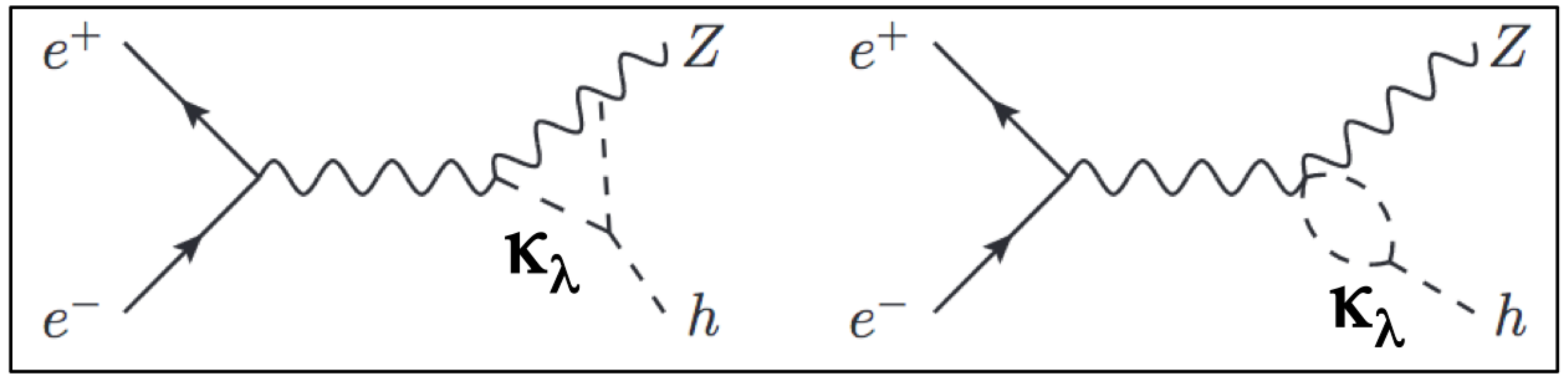
Higgs self-coupling with single Higgs

M. McCullough
arXiv:1312.3322

σ_{HZ}

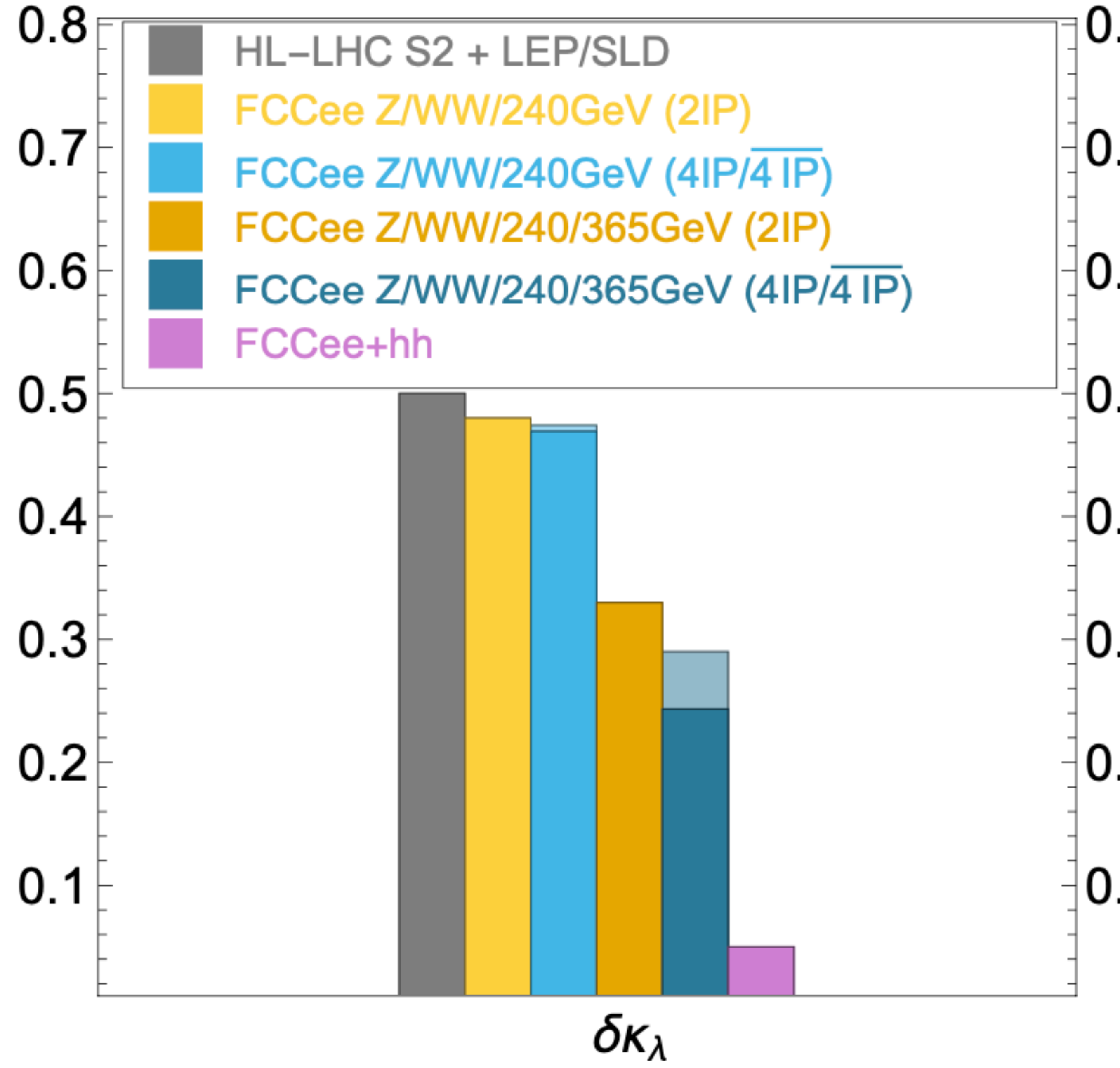


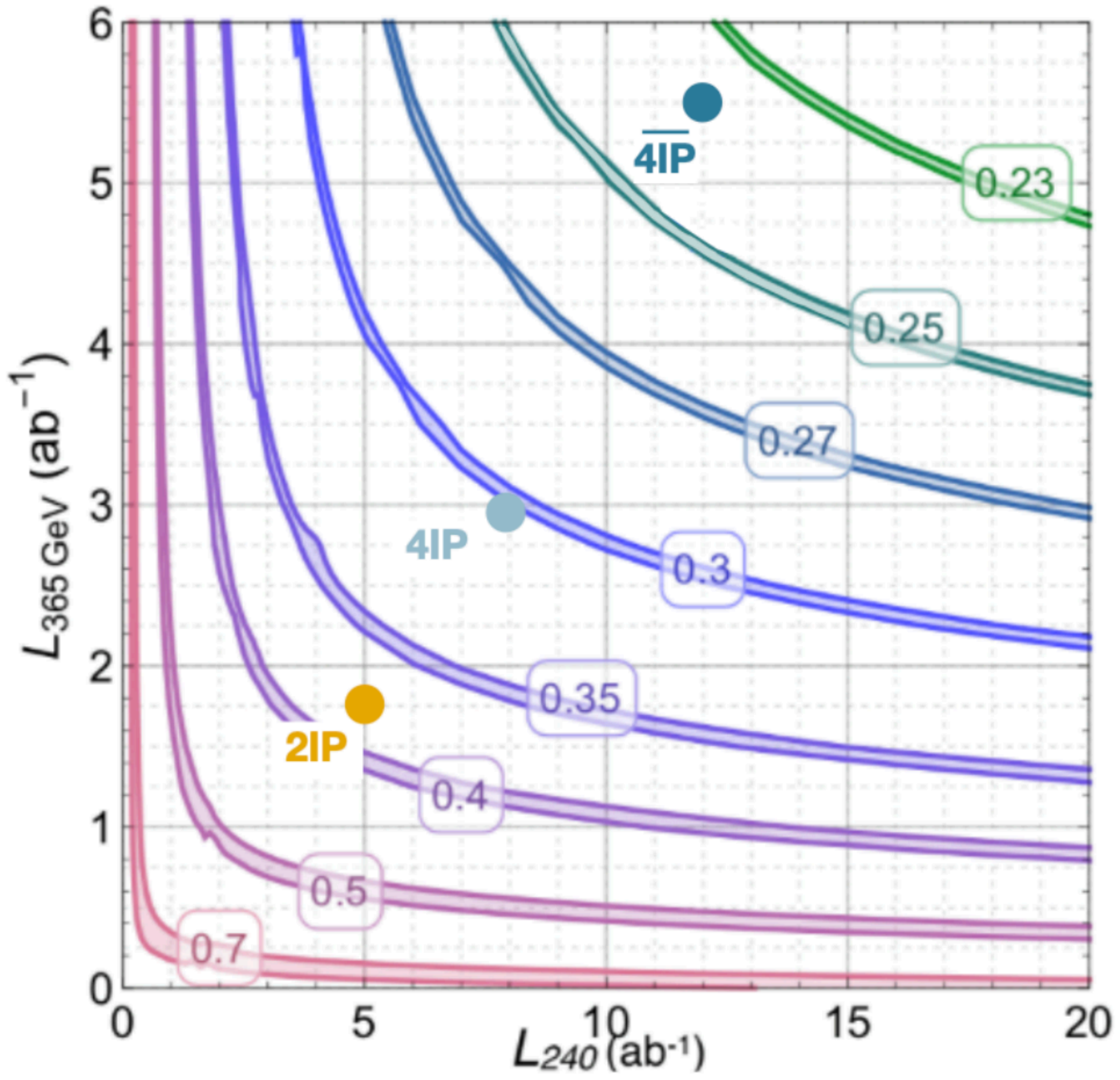
+



$$\Sigma_{\text{NLO}} = Z_H \Sigma_{\text{LO}}(1 + \kappa_\lambda C_1) \qquad \kappa_\lambda \equiv \frac{\lambda_3}{\lambda_3^{\text{SM}}}$$

- **The precision of FCC-ee on the ZH cross section measurement (0.1%) allows to exploit the higher order effects from the Higgs self-coupling**
- **Measurements at $\sqrt{s}$=240 and 365GeV help lift degeneracy on C_1**
- $\delta k_\lambda \approx 28\,\%$ **with 4IPs (optimised scenario)**

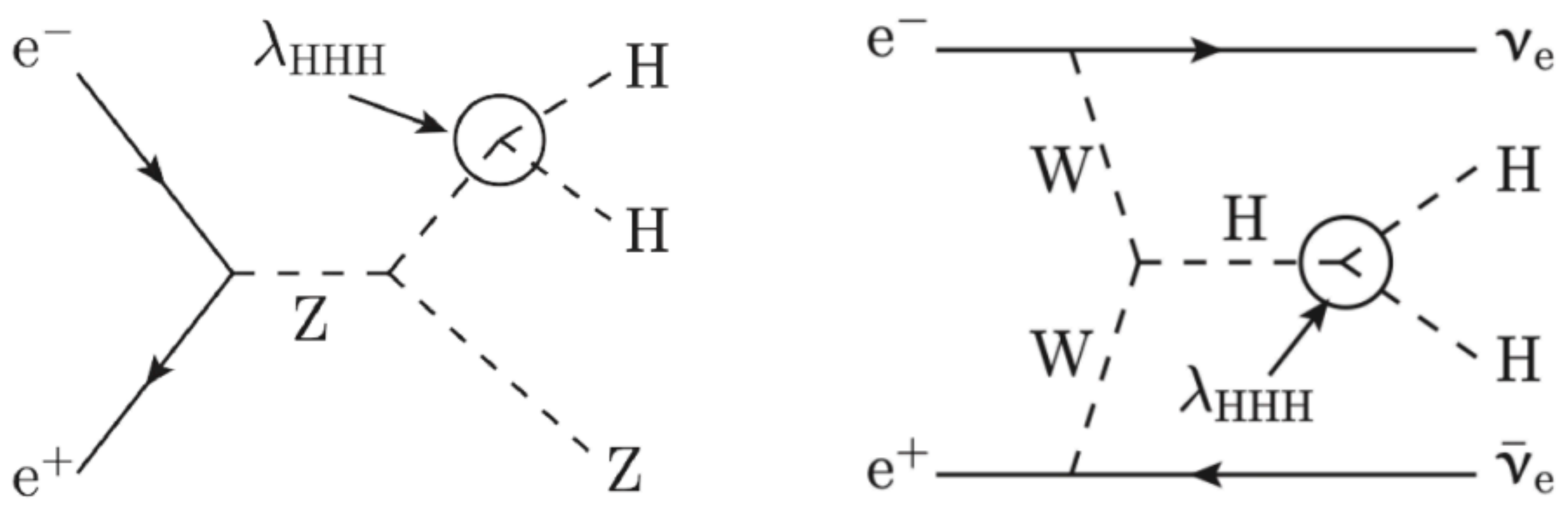




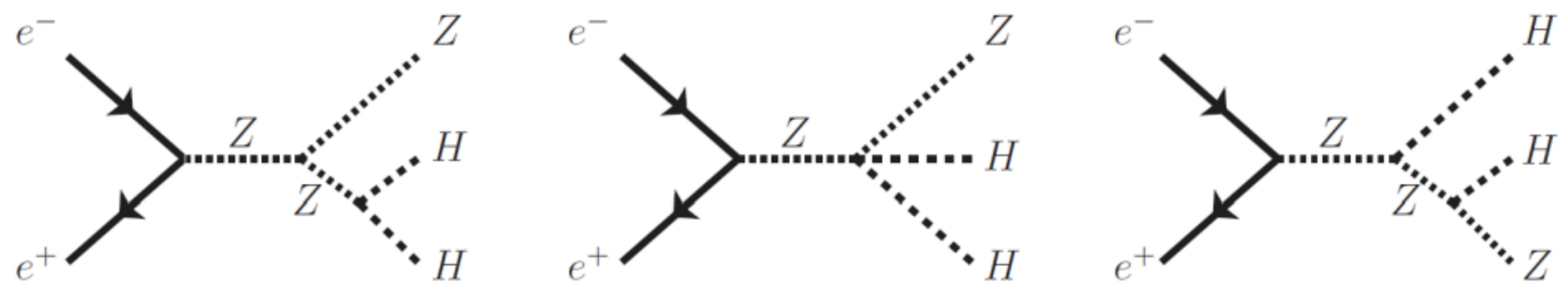
Higgs Self-Coupling with HH

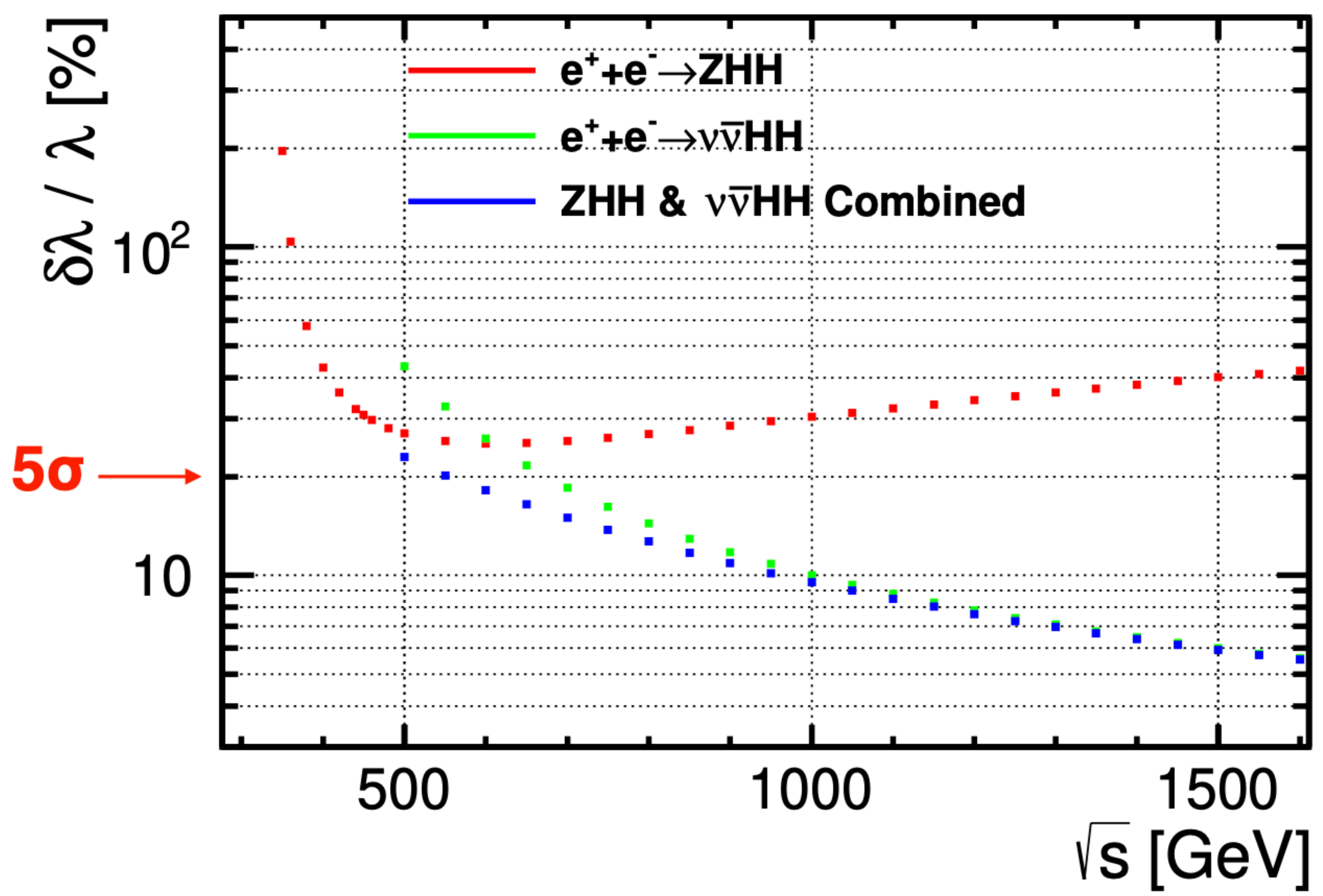
Need high energy for HH production & luminosity

- *direct access* to λ through double-Higgs production
  - Di-Higgs strahlung (**ZHH**; dominant < 1 TeV)
  - vector boson fusion (**$\nu\bar{\nu}$HH**; dominant > 1 TeV)



- degredation of sensitivity in ZHH by diagrams without λ





Discovery can be guaranteed

ILC500: 23%

ILC550: 20%

ILC600: 18%

Higher energy range >500GeV potentially reachable with linear collider upgrade

FUTURE CIRCULAR COLLIDER

Consideration on Higgs self-coupling at lepton colliders

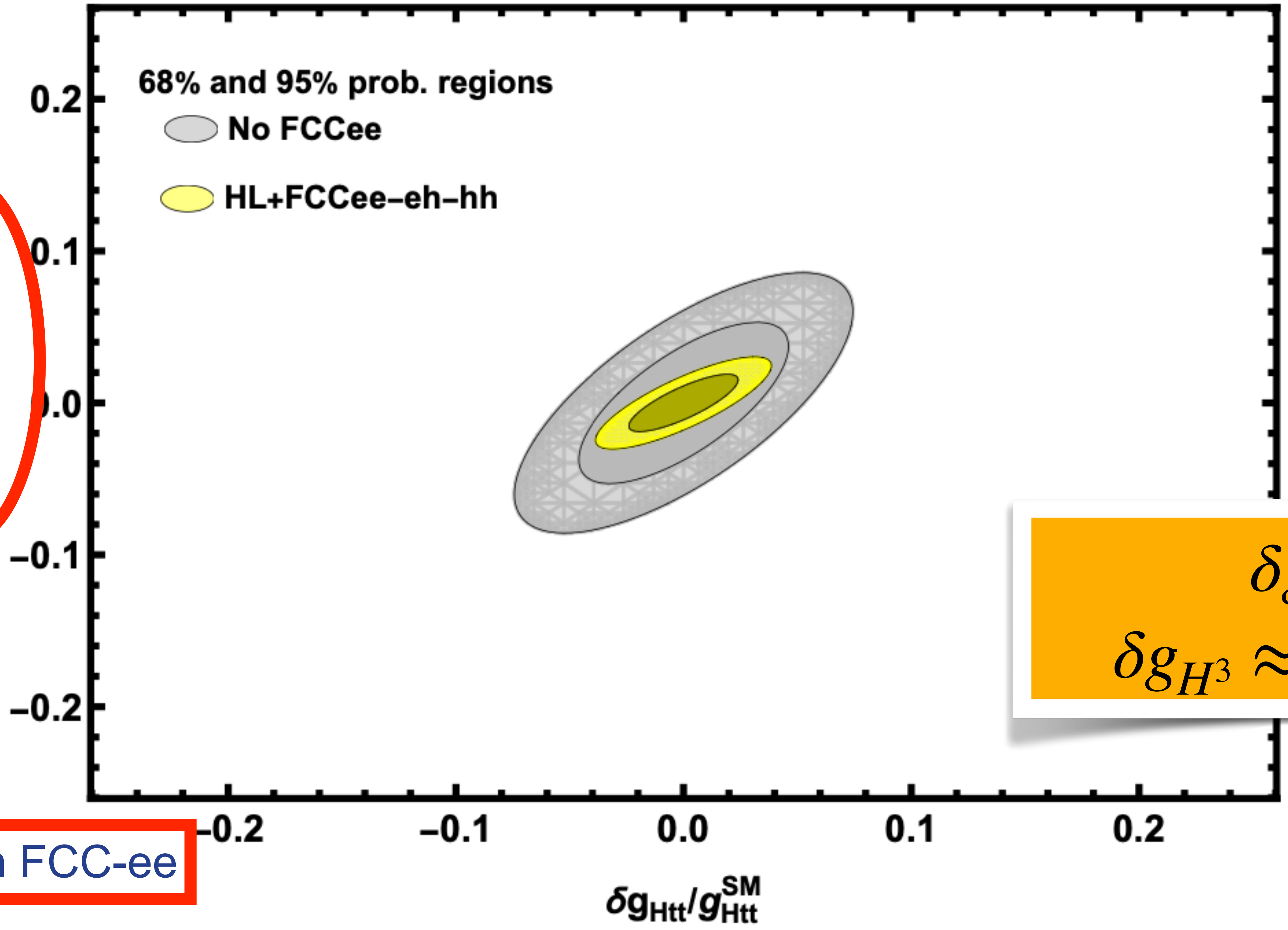
It is very difficult

- New HL-LHC predictions are not available yet, but will be much(!) better than the old ones.
- Determination via single-higgs production at FCC-ee is estimated at ~28%
- Determination via double-higgs production with $\sqrt{s}$>500GeV at ILC similar, to go below to 20% need to add the run at 1TeV.
  - but how much luminosity needed? how much time to get there with a LC?
- Higher order effects come into play too (and they affect both analyses)
- A ~100TeV hadron collider would achieve the same precision in the first few years of running, and few % precision with the full program.
  - and if preceded by an e+e- machine would allow model independent determination

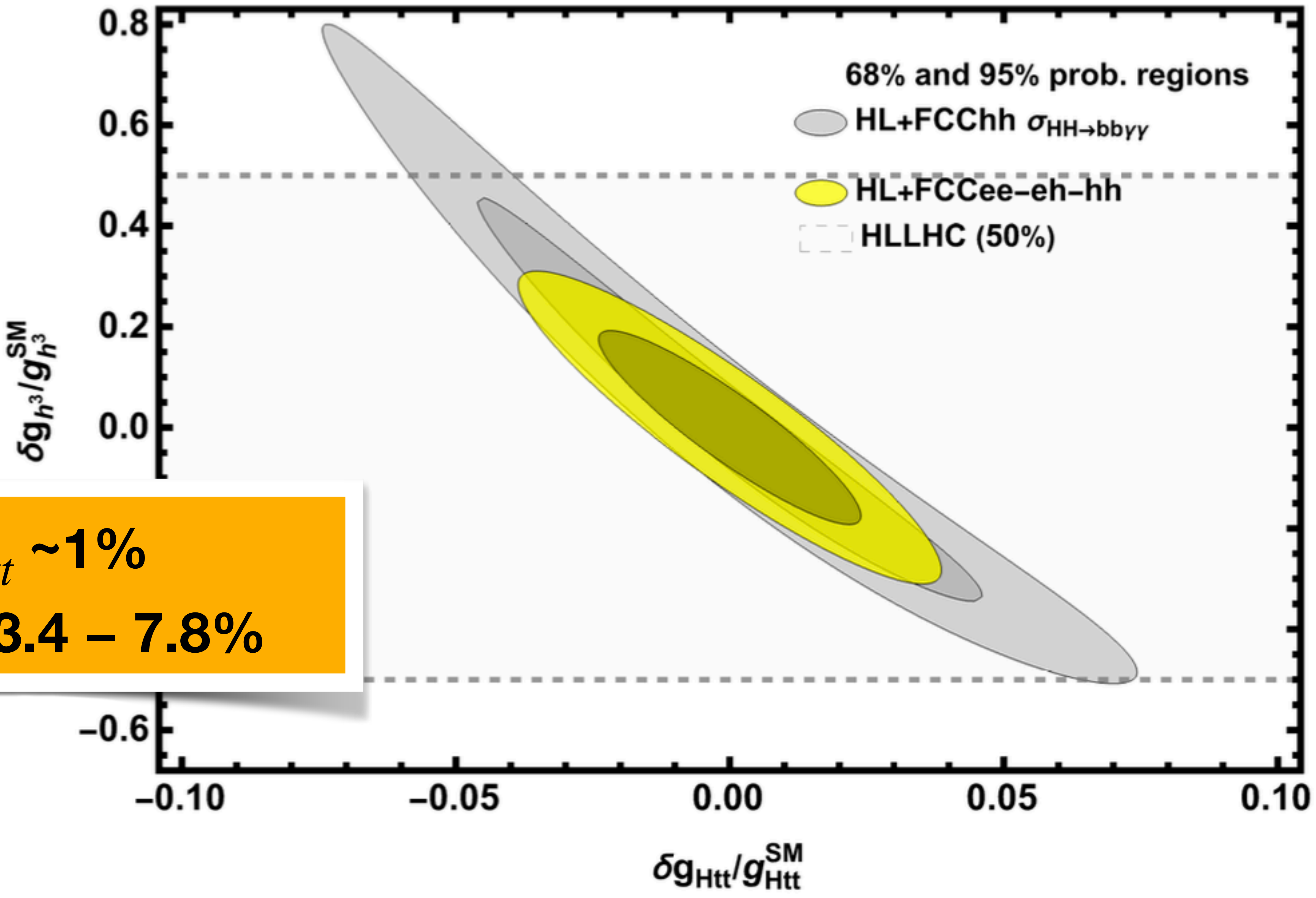
FUTURE CIRCULAR COLLIDER

FCC-ee & FCC-hh complementarity - k_t and k_λ

- The determination of the Ztt couplings from $e^+e^- \to t\bar{t}$ during the 365GeV run of the FCC-ee, in conjunction with the ttH/ttZ FCC-hh would help to **reduce the few per-cent uncertainty on δg_{tt} from the HL-LHC to ~1%.**
- Current estimates suggest that a precise determination of the self-coupling with an uncertainty of 3.4 − 7.8% would be within the reach of the 100 TeV pp collider



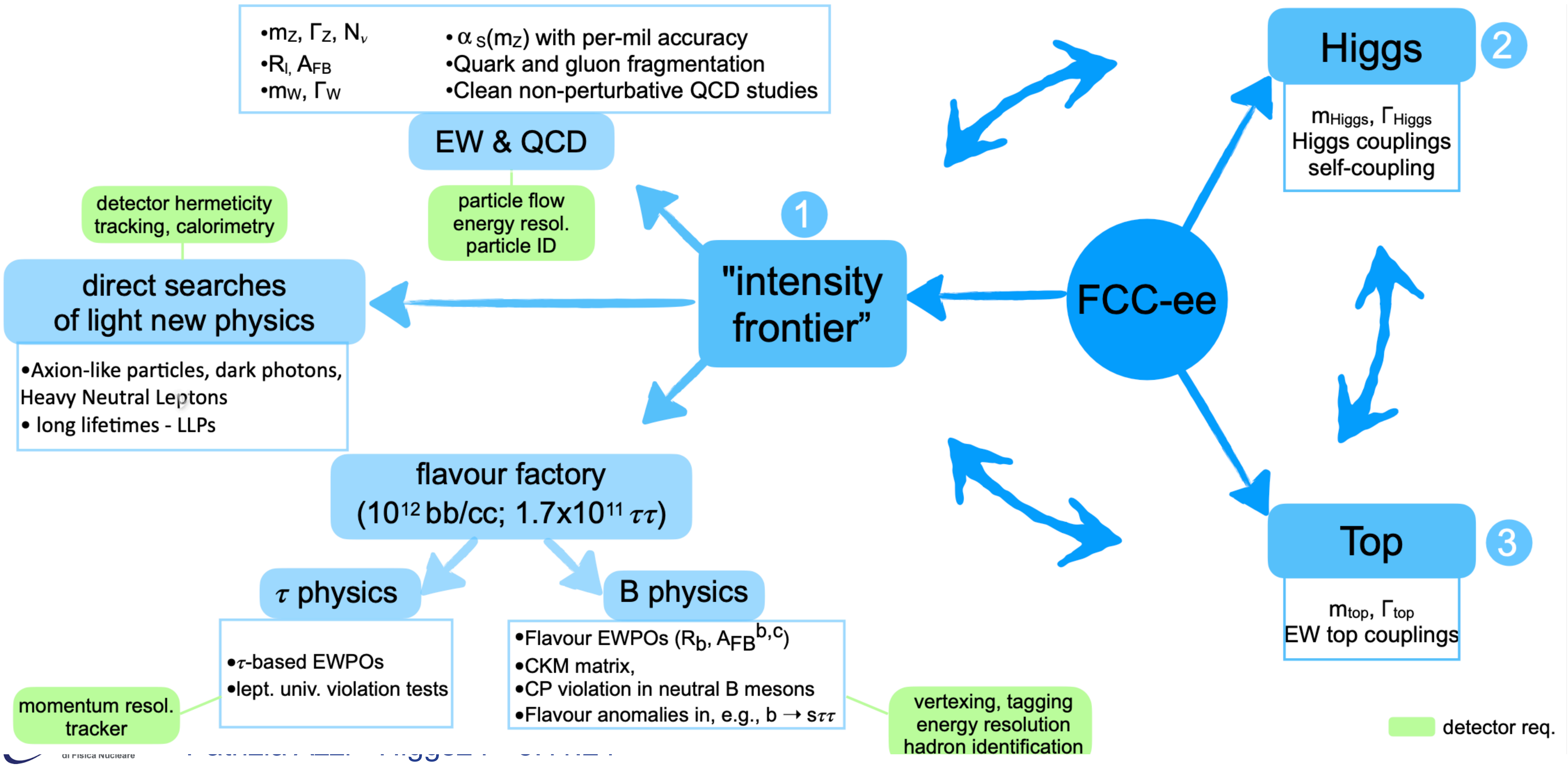
From FCC-ee



δg_{tt} ~1%

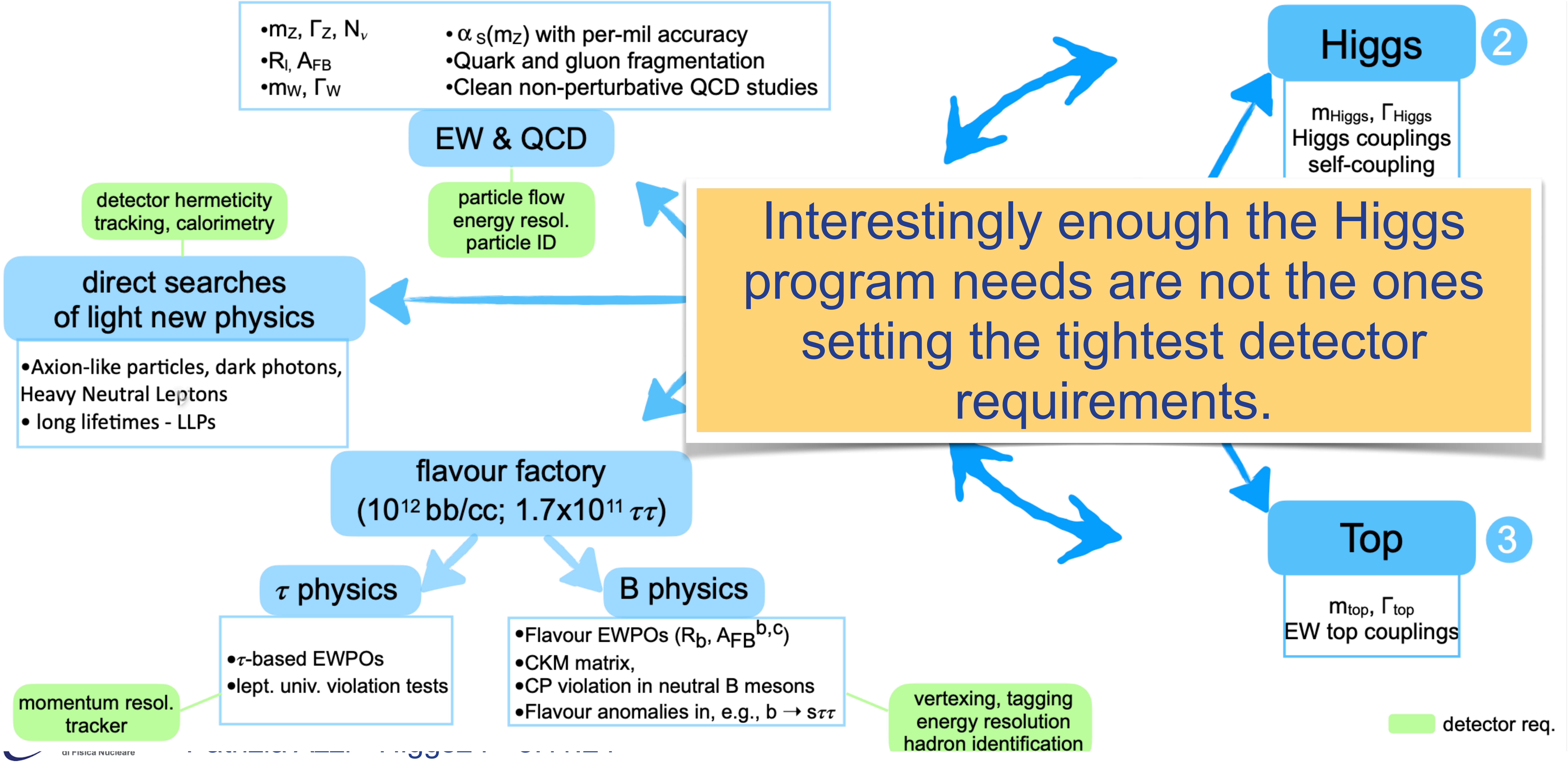
$\delta g_{H^3} \approx$ 3.4 – 7.8%

Setting strong detector requirements



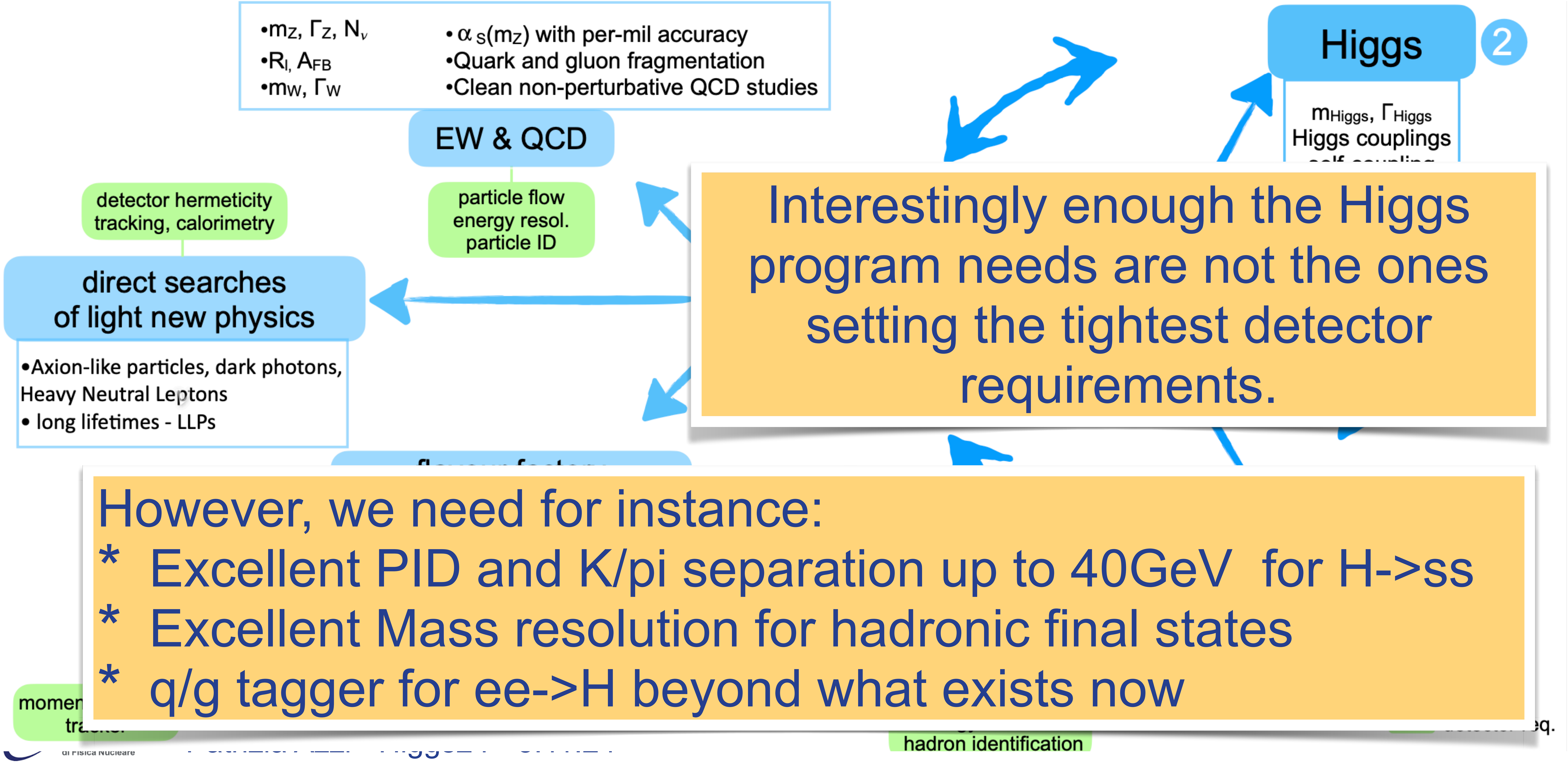
FUTURE CIRCULAR COLLIDER

Setting strong detector requirements



Setting strong detector requirements

FUTURE CIRCULAR COLLIDER



Interestingly enough the Higgs program needs are not the ones setting the tightest detector requirements.

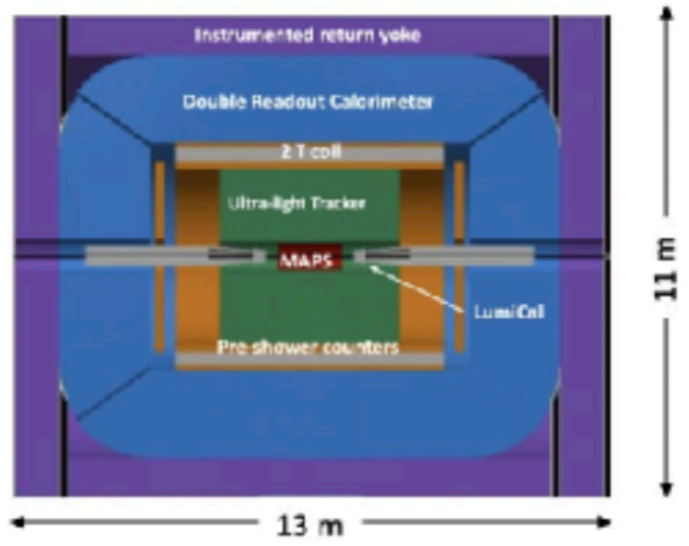
However, we need for instance:
* Excellent PID and K/pi separation up to 40GeV for H->ss
* Excellent Mass resolution for hadronic final states
* q/g tagger for ee->H beyond what exists now

Detectors for future Higgs factories

Need some concrete ideas to perform the analyses

- **LC studies based on detailed Full-Simulation of detector concepts (ILD, SID). Stable software framework ILCSOFT**
- **FCC-ee studies based on a Delphes description of a benchmark concept:**
  - with lots of variations applied to the various subdetector resolutions to study the dependence of the physics results
- **With new software (key4hep,edm4hep), new ML tools and experience from LHC the interplay between the hardware performance and the "added-one" from software is even stronger.**
- **Moreover, technologies of today won't be the ones we use to build detectors in 20 years from now!**
  - we should not be shy in pushing the limit of what we would like to achieve with an amazing machine such a e+e- collider EWK/Higgs/Top factory
  - *New ideas for detectors are welcome & needed!!!*

IDEA



- Silicon vertex detector
- Ultra light drift chamber with powerful particle identification
- Monolithic dual readout calorimeter
- Muon system

Baseline for studies shown in the following

Looking forward

Let's build it :-)

- A high luminosity e+e- collider is what particle physics needs.
- it is fantastic machine for extreme precision measurements of the Higgs physics properties complementing HL-LHC, and:
  - it can constrain the whole ElectroWeak sector and pave the way for whatever lies ahead, being sensitive to BSM effect at much higher scales
  - It would have sensitivity reach for the discovery of feebly interacting physics or dark matter candidates in a phase space not covered by any other experiment.
  - It would be an amazing flavor factory.
- For the precision measurement of the Higgs Self-Coupling a higher energy collider (hadron or muon) would be the most effective machine

European Particle Physics Update Process

Symposium in 24-27 June 2025, Lido of Venice

- **Last strategy proposed the start of the Feasibility study for the FCC project:**
  - Upcoming milestone for FCC is the completion of the Feasibility Study by March 2025 as input for the Update of the ESPP.
    - The following pre-TDR phase should prepare for a possible project approval by 2027-2028
    - Possible start of construction would then be 2032-33

- **While it is certainly important to evaluate other options, if compromises need to be made, it is even more important to unite the community behind the FCC-integrated project:**
  - is the one that provides the best and most needed physics outcome
  - in the most timely fashion

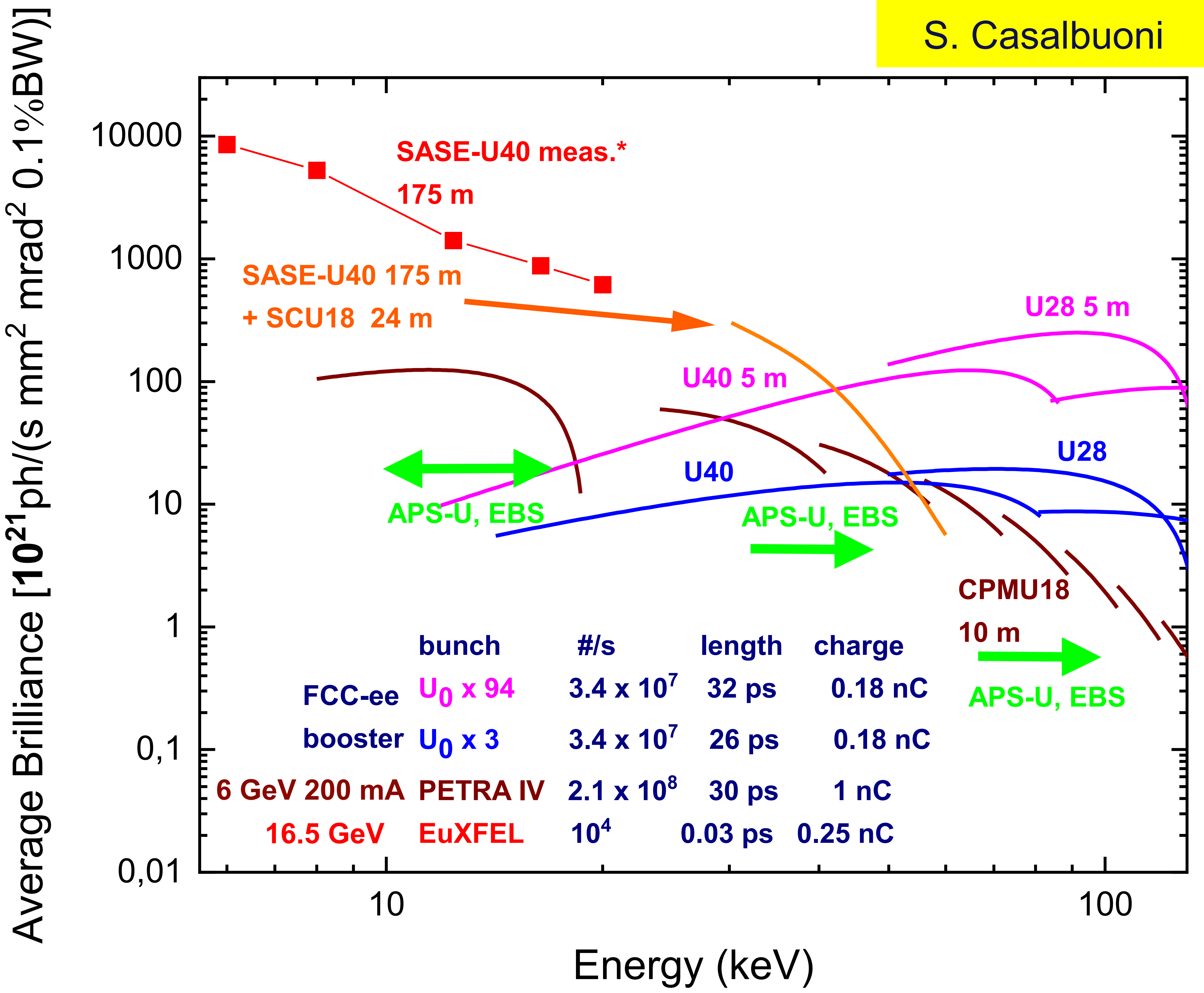
BACKUP

other FCC science applications under study

for example:

FCC-ee booster as diffraction limited storage ring with coherent synchrotron radiation down to 0.1 Å

S. Casalbuoni



FCC-ee injector as the world's **ultimate positron source** for material studies and paving a path towards the first **Bose-Einstein condensation of Ps** (511-keV gamma-ray laser)

M. Doser,
B. Rienäcker

using beamstrahlung for **radionuclide production**

e^- beam driven **neutron source**

M. Calviani,
C. Duchemin

etc.

"Other Science Opportunities at the FCC-ee" 28/29 November
https://indico.cern.ch/event/1454873/ .

Exotic Higgs Decays to LLPs

Gallen, Ripellino, Vande Voorde, Gonzalez-Suarez

- Higgs bosons could undergo **exotic decays** to e.g. **scalars that could be long-lived**
- New scalar could be a **portal between the SM and a dark sector (HAHM)** (arXiv:1312.4992, arXiv:1412.0018)
- Higgs boson (h) and the scalar (s) mix with a mixing angle sin θ
- **For sufficiently small mixing, the scalar can be long-lived**
  - cτ ~ meters if θ < 1e-6

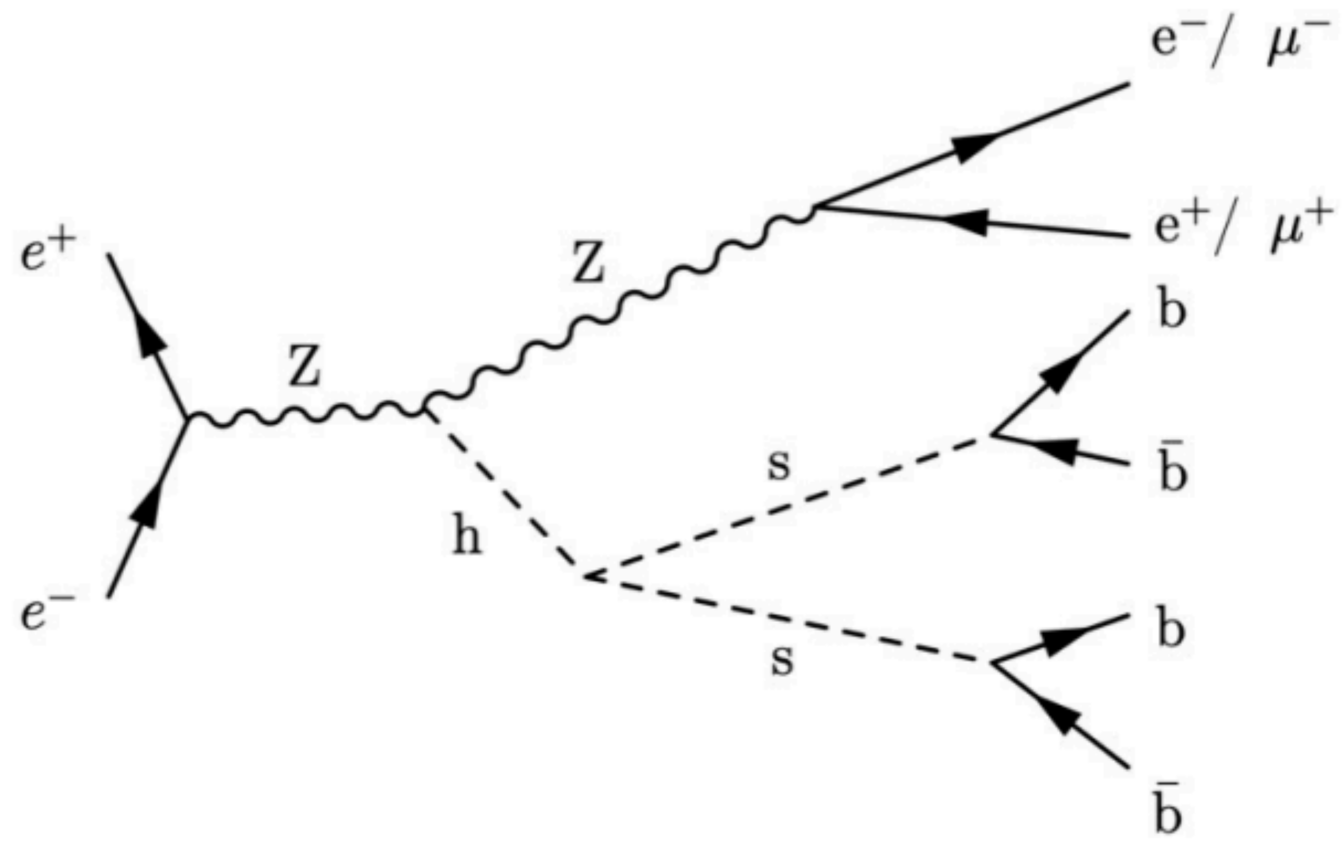
Magda's master thesis

FCC note under approval

Target FCC-ee **Zh stage** (240 GeV):

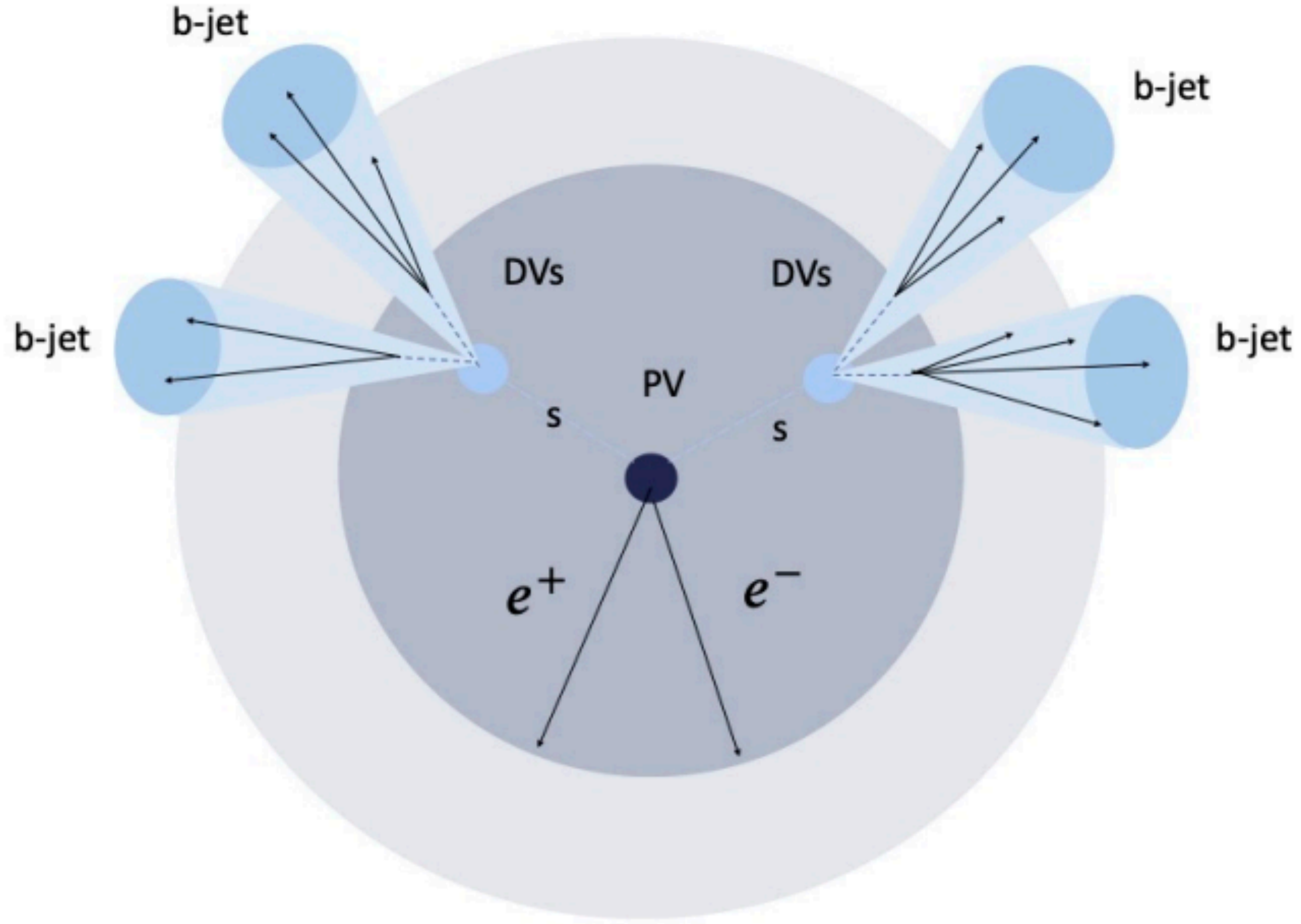
$e^+e^- \rightarrow Zh$ with $h \rightarrow ss \rightarrow b\bar{b}b\bar{b}$ and

$Z \rightarrow ll$ (2 electrons or 2 muons)



Experimental signature

2 displaced vertices (DVs) +
Z boson from ee or mumu



$H \to ss \to b\bar{b}b\bar{b}$ search summary

FUTURE CIRCULAR COLLIDER

- Basically alm
- Here IDEA ca
- Below a comp ... with less layers

Table 10: Normalized number of events for each signal sample, before and after each cut. The uncertainties are statistical.

m_s, sin θ	Before selection	Pre-selection	$70 < m_{ll} < 110$ GeV	n_DVs ≥ 2
20 GeV, 1e-5	55.2 ± 0.0413	37.3 ± 0.455	36.2 ± 0.448	4.45 ± 0.157
20 GeV, 1e-6	55.2 ± 0.0413	38.1 ± 0.460	37.2 ± 0.454	28.0 ± 0.394
20 GeV, 1e-7	55.2 ± 0.0413	45.4 ± 0.502	44.5 ± 0.497	0.665 ± 0.0607
60 GeV, 1e-5	18.9 ± 0.00813	12.0 ± 0.150	11.6 ± 0.148	0 (≤ 0.148)
60 GeV, 1e-6	18.9 ± 0.00813	12.0 ± 0.150	11.6 ± 0.147	9.21 ± 0.131
60 GeV, 1e-7	18.9 ± 0.00813	13.9 ± 0.161	13.5 ± 0.159	5.87 ± 0.105

M. Larson, LS

Mean proper lifetime cτ [mm]	3.4	341.7	34167.0	0.9	87.7	8769.1
$N_{DVs} \geq 2$ Events	20 GeV, 1e-5	20 GeV, 1e-6	20 GeV, 1e-7	60 GeV, 1e-5	60 GeV, 1e-6	60 GeV, 1e-7
IDEA	5.02	37.09	0.77	0.003	10.97	6.50
CLD (min. hits = 6)	5.08	6.02	0.11	0.003	10.67	0.82
CLD (min. hits = 5)	5.19	16.17	0.23	0.005	11.16	2.01
CLD (min. hits = 4)	5.30	24.34	0.31	0.003	11.21	2.99

Final # events selected

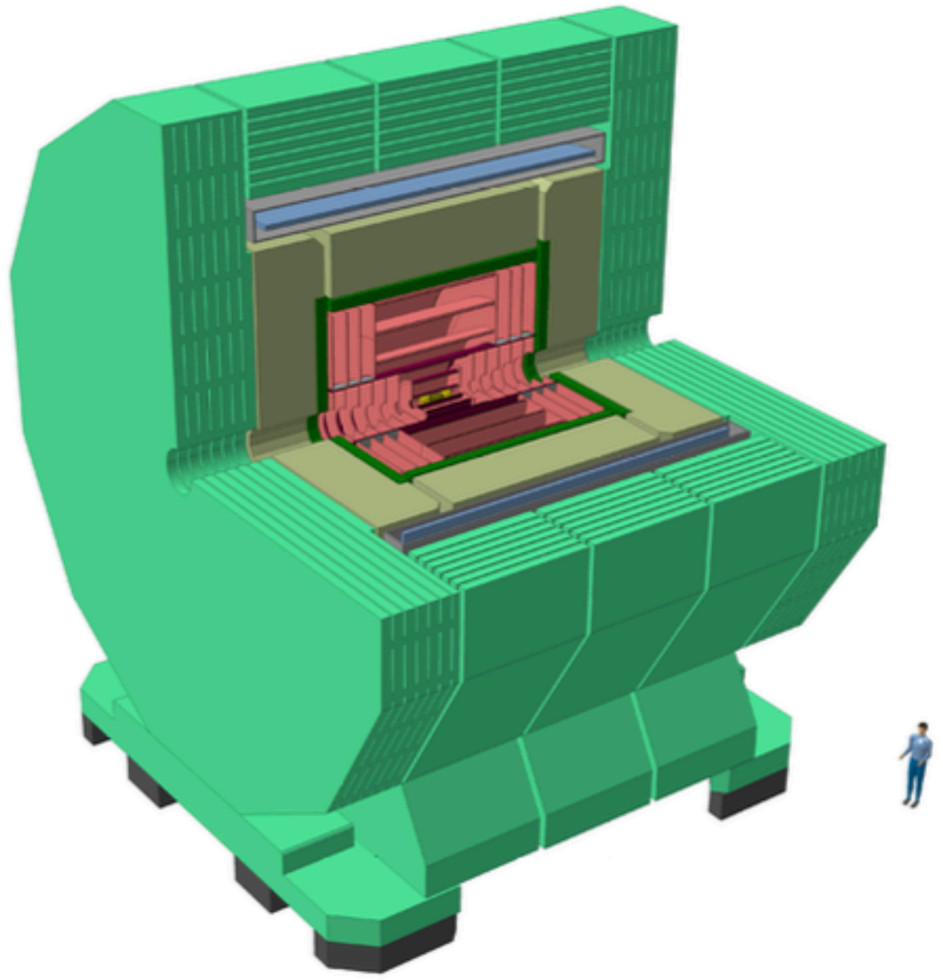
Currently new study started considering the final state: $H \to ss \to b\bar{b}\tau\tau$

Some preliminary detector benchmarks for FCC-ee

FUTURE CIRCULAR COLLIDER

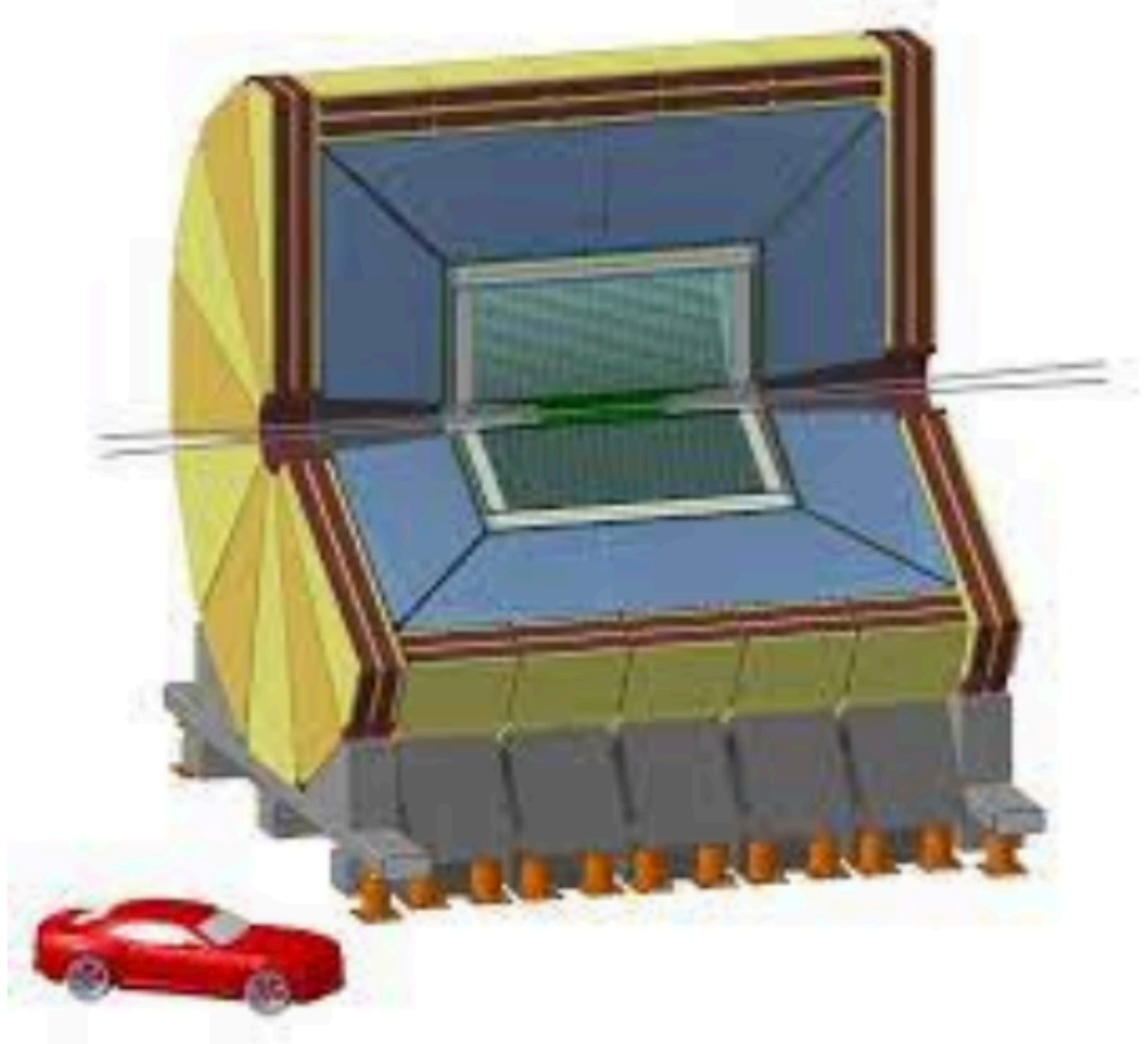
CLIC-like Detector (CLD)

- Full silicon vertex-detector + tracker
- 3D high-granularity calorimeter
- Solenoid outside calorimeter



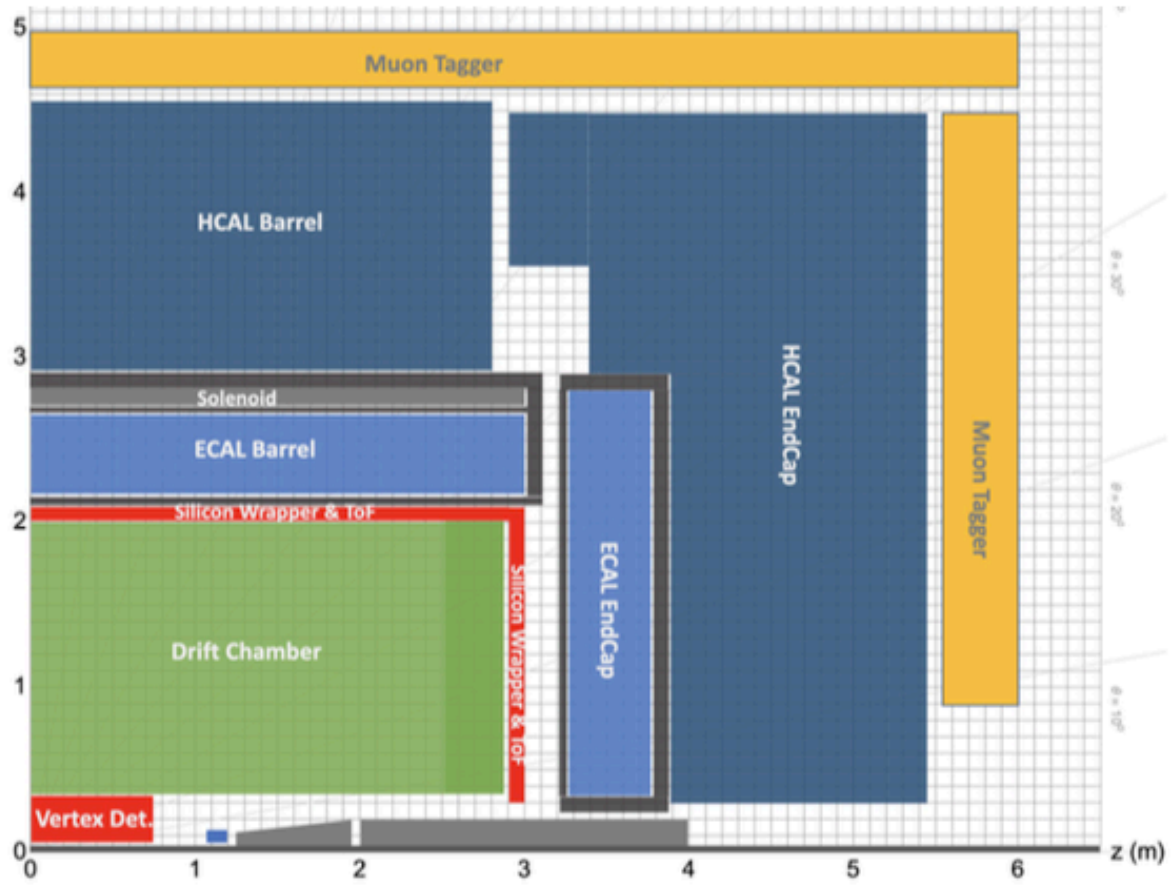
Innovative Detector for an Electron-Positron Accelerator (IDEA)

- Silicon vertex detector
- Short-drift chamber tracker
- Dual-readout calorimeter (solenoid inside)



Noble Liquid

- High-granularity noble liquid calorimeter
- LAr or Lar + Lead or Tungsten absorber
- Newest proposal



- In the process of extracting the requirement on the detector performance from the physics
  - With 4IP, opportunity to have detector optimised for specific processes
- Spoiler: "Higgs factory" requirements are not the most stringent

INFN Istituto Nazionale di Fisica Nucleare