PROBING THE HIGGS SECTOR AT THE FCC-EE

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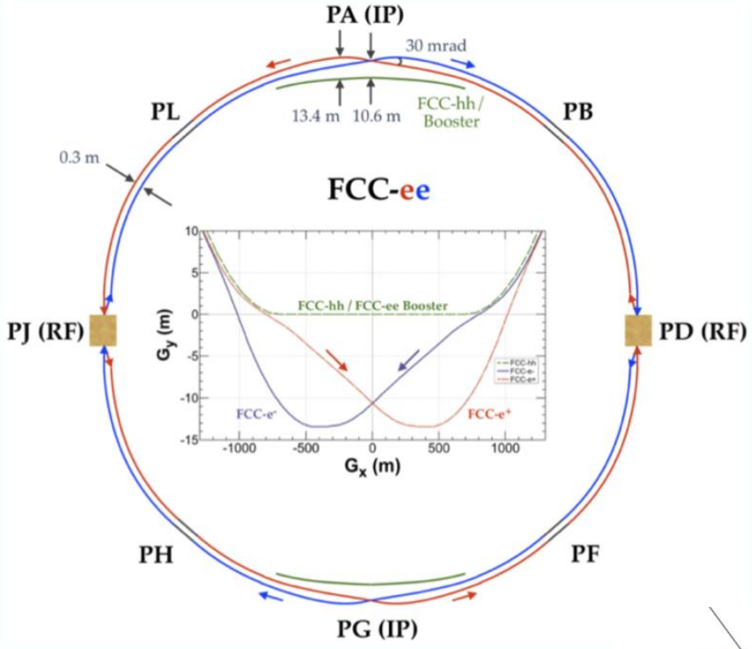
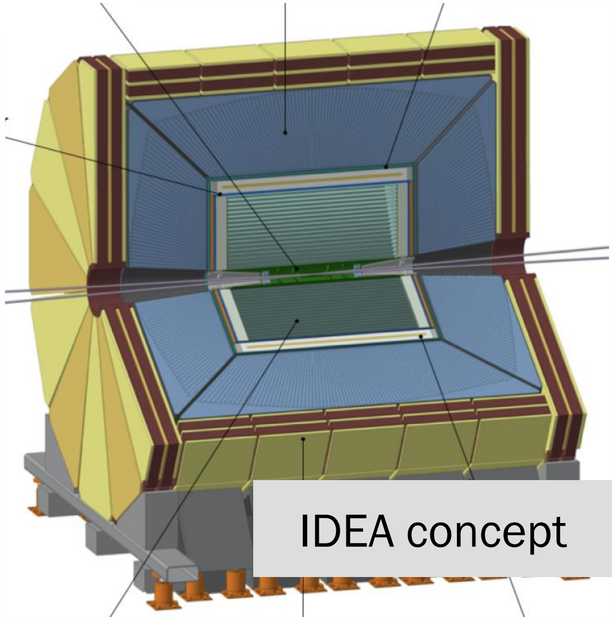
Exploring the Higgs sector

- Currently, only the first term of the SM Higgs potential is known $V^{\mathrm{SM}}(H) = \frac{m_H^2}{2} H^2 + \lambda v H^3 + \frac{\lambda}{4} H^4$
  - *How does it fully look like?*
  - *Small coefficients* $\lambda_{SM} \sim O(0.13)$
- But need the rest to check EWSB
- Other implications of fully known SM Higgs potential:
  - *Cosmology: Modifications of coefficients allows for 1st order electroweak transitions and could explain matter vs. anti-matter asymmetry (1711.00019)*
  - *BSM consequences and vacuum (in?)stability (Nat Rev Phys 3, 608–624 (2021))*
- Start with examining the Higgs boson self-coupling

The collider

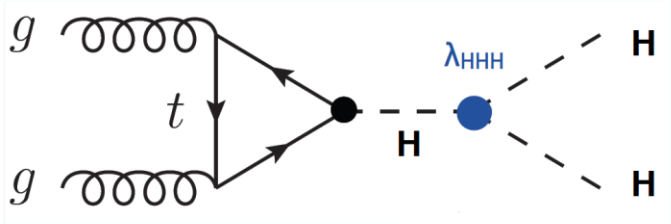


- FCC-ee facts:
  - e^+e^- *collider*
  - *91 km diameter*
  - $\sqrt{s} = 91, 160, 240, 365$ *GeV*
- Why FCC-ee?
  - *Clean final state => Excellent event reconstruction possible*
  - *Circular collider => Very high integrated luminosities*
  - *Big physics programme (Higgs, Precision EW, Heavy flavor and LLP)*


IDEA concept

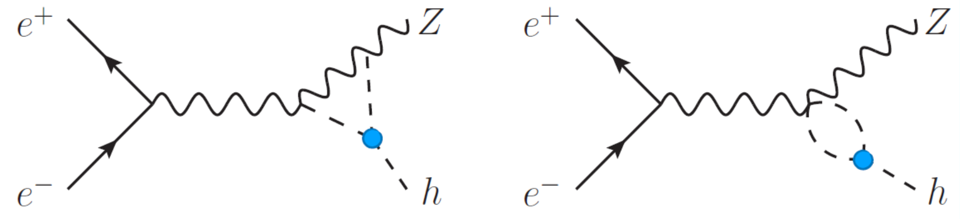
How to extract the Higgs self coupling

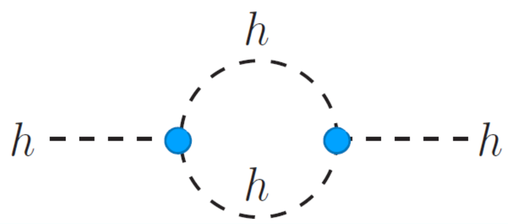
- With HL-LHC we could directly extract λ in di-Higgs production processes
  - *But cross section is quite low: 40fb at 14 TeV*
  - *Still, currently expect up to 50% precision (1902.00134)*



- At FCC-ee, we can indirectly access λ through NLO electroweak corrections

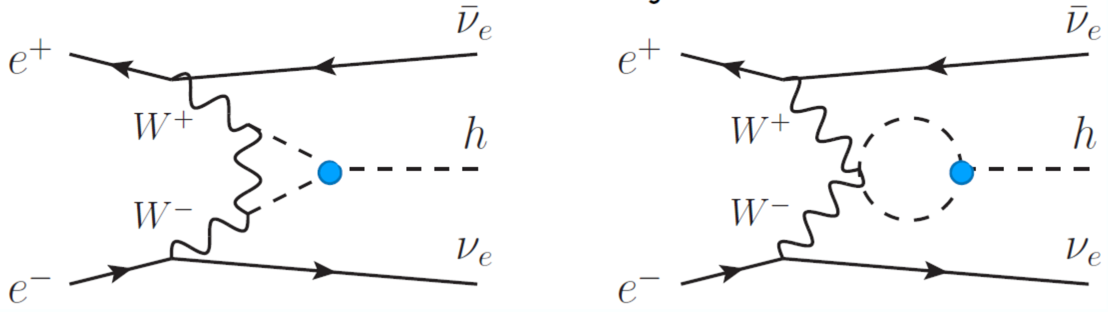
ZH Higgsstrahlung





VBF processes

Both CC/NC diagrams

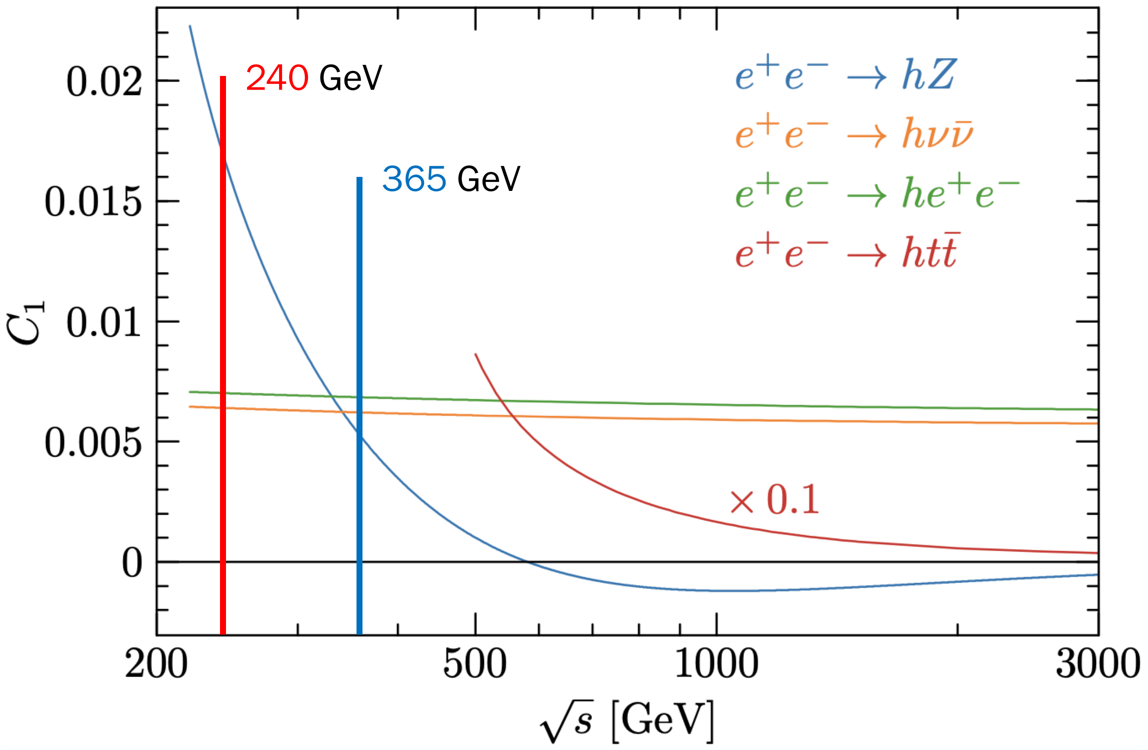


arXiv: 1711.03978
arXiv: 1607.04251

How to extract the Higgs self coupling

- Parametrize deviations from SM trilinear coupling with $\kappa_\lambda = {}^{\lambda}/_{\lambda_{SM}}$
- Can exploit high single Higgs cross sections at e+e- colliders (~200 fb for ZH at 240 GeV)
- Consider two energy points (240 and 365 GeV) to improve precision on the deviation of κ_λ from the SM value.

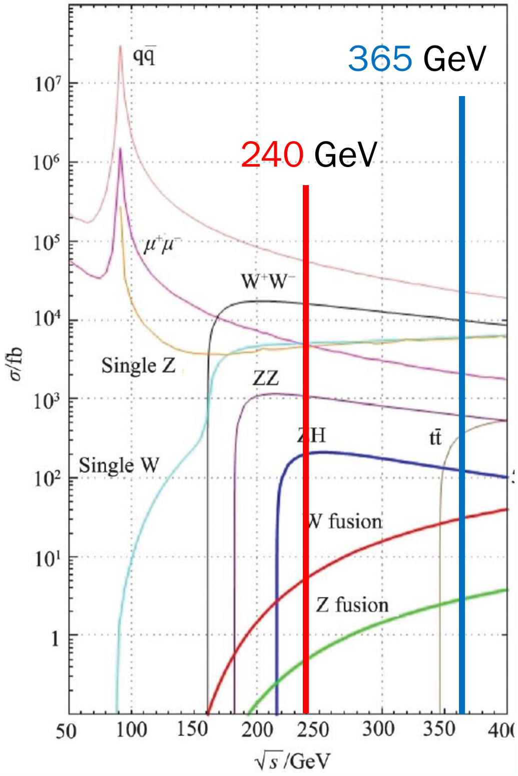
$$\Sigma_{\mathrm{NLO}} = Z_H \, \Sigma_{\mathrm{LO}} \left(1 + \kappa_\lambda C_1\right)$$



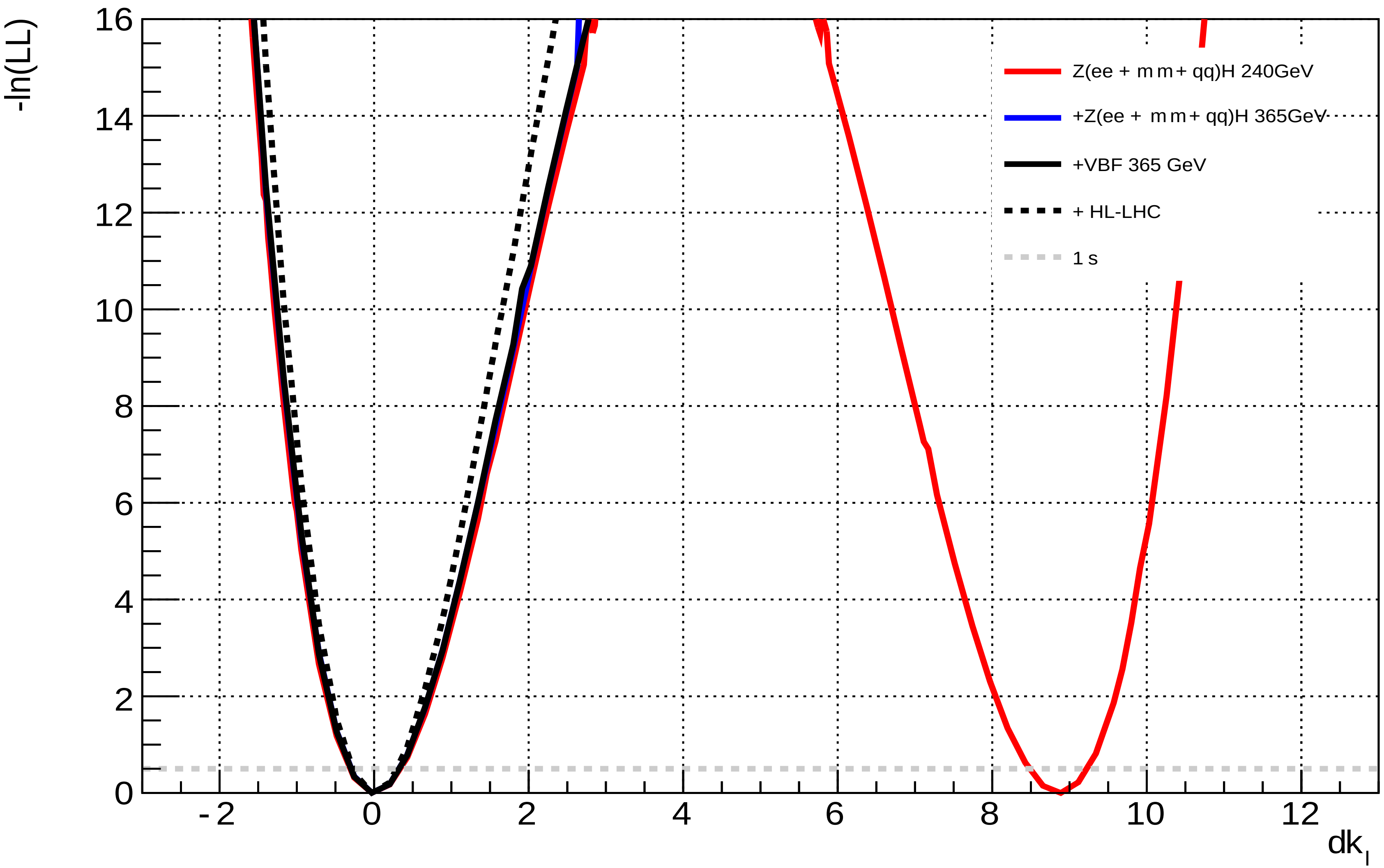
Considered processes

$$M^2_{\text{Rec}} = p^2_H = \left(E_{\text{ff}} - \sqrt{s}\right)^2 - |\vec{p_{\text{ff}}}|^2 = s - 2E_{\text{ff}}\sqrt{s} + M^2_{\text{ff}},$$

- Higgsstrahlung ($e^+e^- \rightarrow$ ZH) @ 240 and 365 GeV
  - *<u>Inclusive</u> Higgs decays: $Z(\mu^+\mu^-)H$, $Z(e^+e^-)H$, $Z(q\bar{q})H$*
  - *Extracted recoil mass distribution* → M^2_{Rec}
- Exclusive VBF @ 365 GeV
  - *WW-Fusion: $e^+e^- \rightarrow \nu_e\bar{\nu}_e H(b\bar{b})$ and ZZ-Fusion: $e^+e^- \rightarrow e^+e^- H(b\bar{b})$*
  - *High background => <u>Exclusive</u> Higgs decays*
- Used centrally produced MC samples
  - *Involves a Delphes fast simulation of the proposed IDEA detector*
  - *Classified events into 18 orthogonal categories*



NLL in dk$_l$



	FCC-ee (This work)	+ HL-LHC
$\delta\kappa_\lambda$ (68% CL interval)	[-0.36, 0.40]	[-0.29, 0.31]

arXiv:1902.00134

Conclusions

- Analysis involving almost complete ZH and VBF
  - *Missing:* $Z(\nu\bar{\nu})H$ *(but small impact on analysis expected)*
- Summary
  - *From leptonic ZH only:* $\Delta m_H \sim 5.6$ *MeV*
  - *Sub-percent precision on* $\delta\mu_{ZH}$
  - *1D precision on* $\delta\kappa_\lambda$*: ~30% with HL-LHC measurement*

MY CURRENT WORK

CMS ECAL Barrel (EB) Upgrade

- HL-LHC changes things:
  - *More pileup: Improve timing resolution*
  - *Different Trigger system: Higher granularity for L1 calo trigger desired*
  - *APD dark current increases due to higher irradiation*
- Consequence: Have to redesign readout electronics and lower EB operating temp. from 18 to 9 °C to decrease APD dark current.
  - *Will let us keep Run-1 physics performance despite HL-LHC environment*
  - *Decreasing temp. requires precise temperature monitoring*

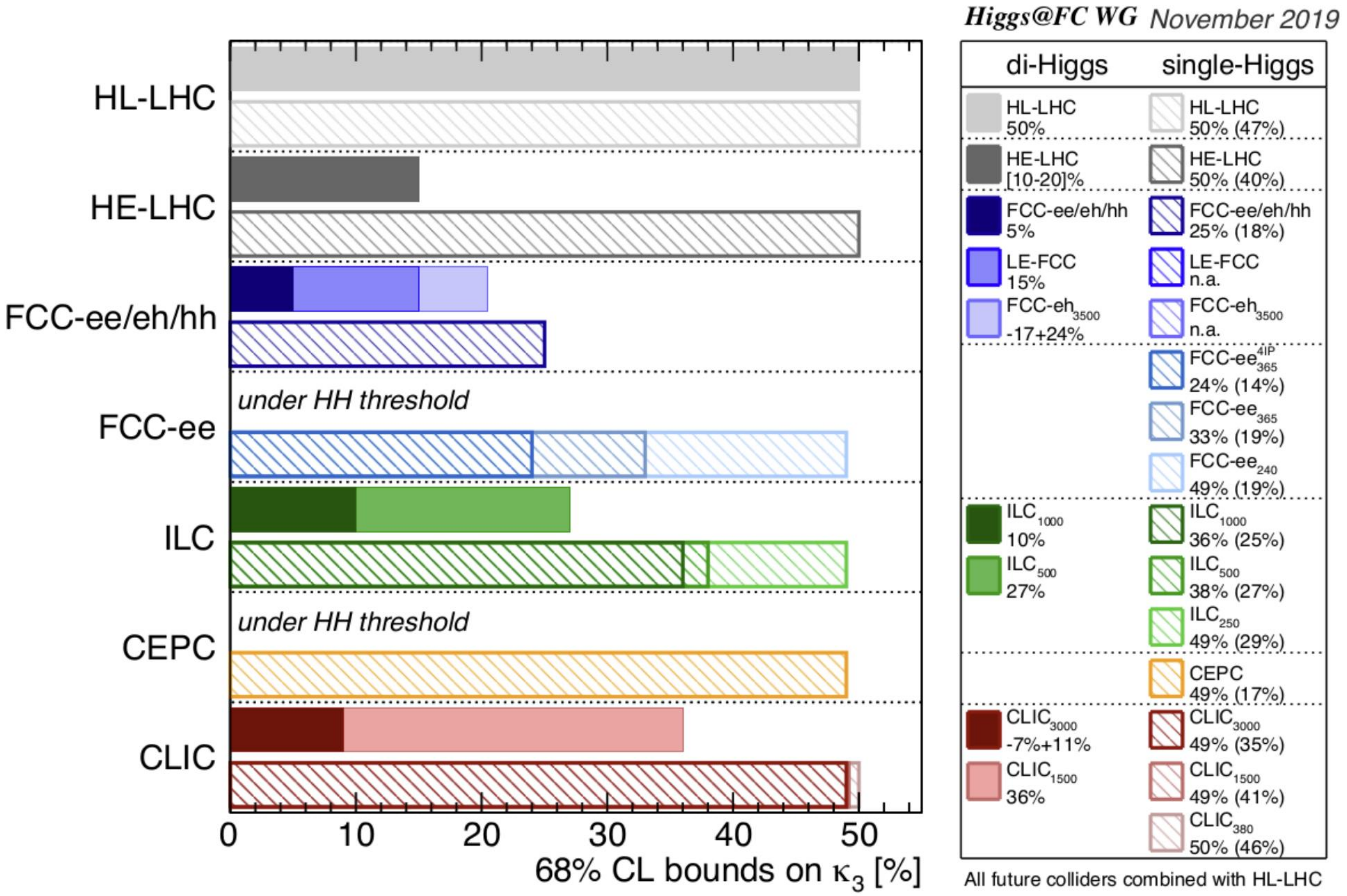
Precision temperature monitoring (PTM)

- Goal: 9.0 ± 0.05 °C, but why?
  - *Crystal light yield (-2.1%/°C) and APD gain (-2.4%/°C) are temperature dependent*
  - *Both affect the constant term of the ECAL energy resolution (relevant for high E)*
  - *Need precise cooling and monitoring system*

THANK YOU FOR YOUR ATTENTION

BACKUP SLIDES

κ_λ at FCC-hh and other colliders



Higgs boson mass measurement

- Precision Higgs boson mass measurements possible
  - *Exploit the clean leptonic final states of FCC-ee and excellent p_T and energy resolution of the IDEA detector*

Process / Δm_H [MeV]	FCC-ee (This work)
Z($\mu^+\mu^-$)H 240 GeV (365 GeV)	7.1 (120)
Z(e^+e^-)H 240 GeV (365 GeV)	9.2 (110)

	HL-LHC	ILC	CEPC	FCC-ee (This work)
Comparison Δm_H [MeV]	10-20	14	5.9	5.6

arXiv: 1905.03764

Higgs boson production cross section

- Deviations in measured Higgs boson production cross section
  - *Signal strength modifiers:* $\mu_i^f = \mu_i * \mu^f := \frac{\sigma_i}{\sigma_{i,SM}} * \frac{BR^f}{BR^f_{SM}}$
  - *Measured number of signal events:* $N_{sig} = \mu_i^f * \epsilon * L * (\sigma_i * BR^f)_{SM}$

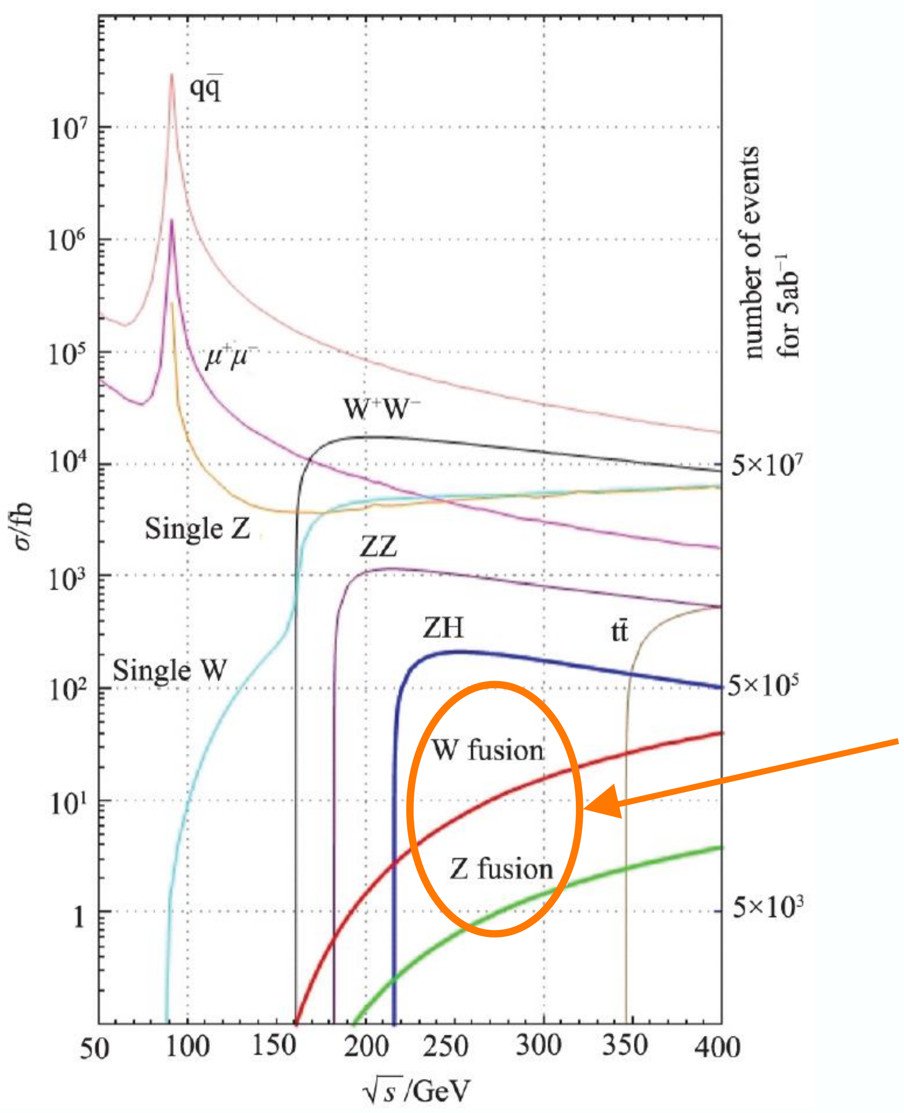
Process $\delta\mu_i$	FCC-ee (This work)
ZH	0.41 %
Charged VBF	4.8 %
Neutral VBF	7.4 %

$\delta\mu^f := 0$ assumed

	ILC	CEPC	FCC-ee (This work)
ZH $\delta\mu_{ZH}$ [%]	2.1 – 2.2	0.50	0.41

arXiv: 1810.09037
arXiv: 2002.06371

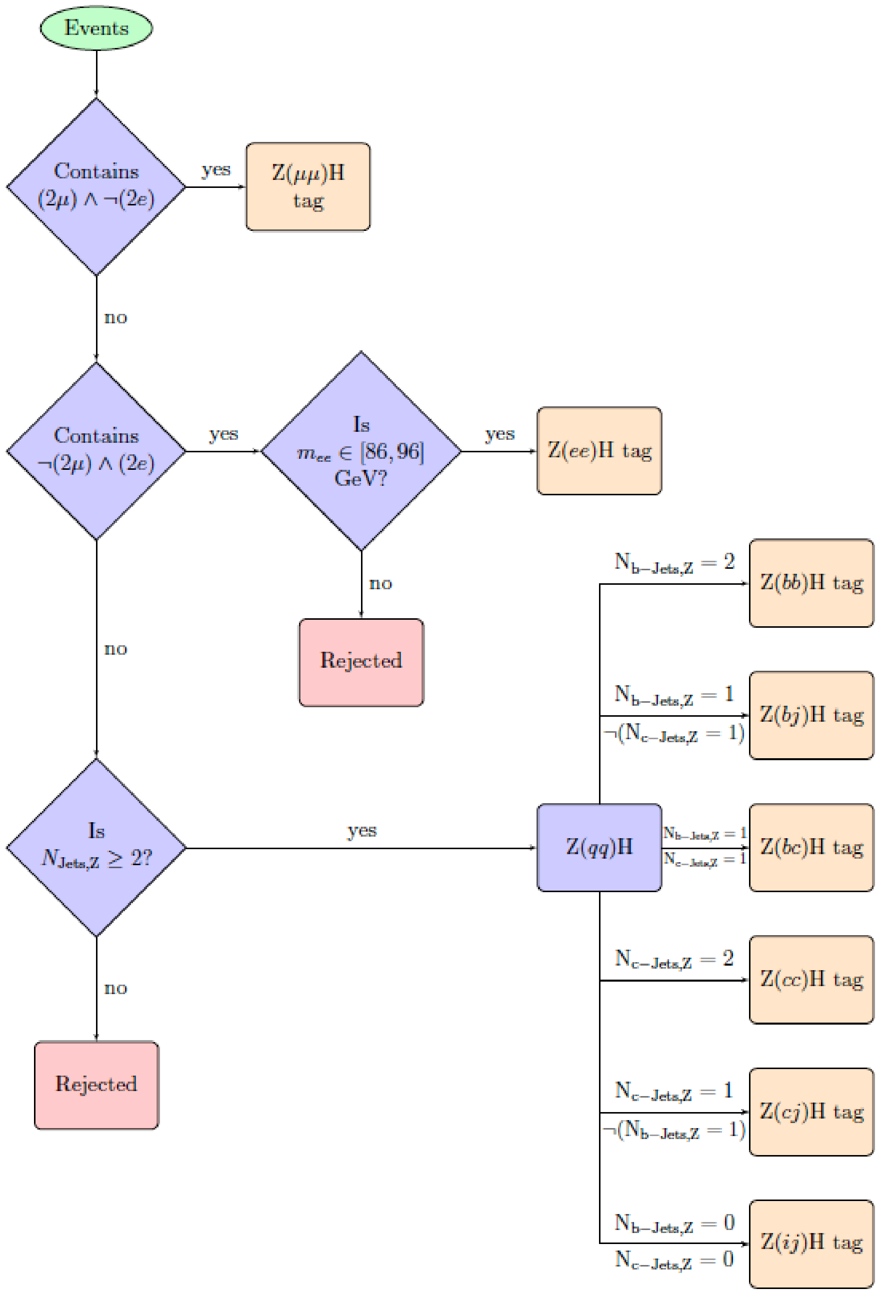
Production cross sections



VBF cross sections goes with $\ln(s/M_V^2)$

Categorization flowchart

- 240 GeV



Categorization flowchart

- 365 GeV