Snowmass 2021 EF01:
Higgs Boson properties and couplings

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on behalf of CEPC EF01

Snowmass: a vision for the future of particle physics

- Goals of snowmass planning exercise in EF01:
  - identify key reference measurements of a precision Higgs program
    - provide compact summary of theoretical motivations
    - document the precision and physics potential
  - highlight the unique strengths of different future facilities
    - intrinsic advantages, unique capabilities to reconstructing particular decays etc.
    - complementary programs enhance the overall Higgs physics program

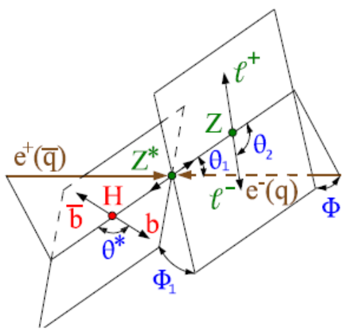
- Various machines to be considered for accelerator and physics studies during the Snowmass process
  - Snowmass 2013: CLIC, ILC, HL-LHC, VLHC, TLEP, muon collider etc.
  - Snowmass 2021: CEPC, FCC-ee, ILC, CLIC, EIC, LHeC, HE-LHC, SPPC, FCC-hh, etc.

- Timeline:
  - **Letters of Interest** (April 1 – August 31, 2020)
  - **Contributed Papers** (April 1 – July 31, 2021)

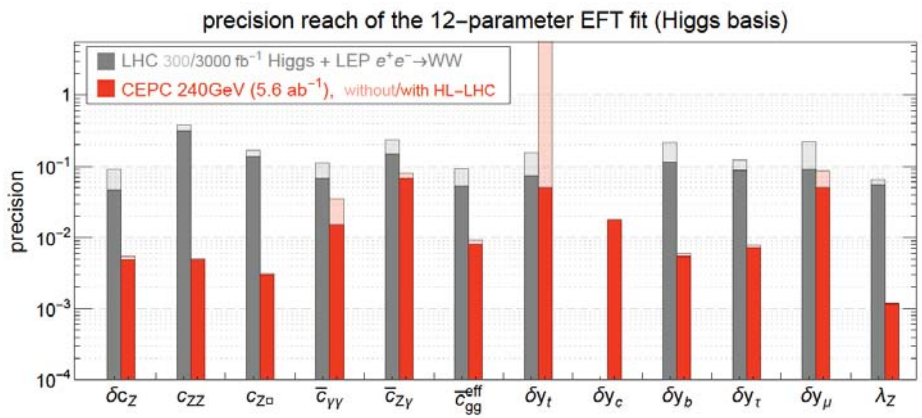
Studies done in CEPC-CDR

Property	Estimated Precision
m_H	5.9 MeV
Γ_H	3.1%
$\sigma(ZH)$	0.5%
$\sigma(\nu\bar{\nu}H)$	3.2%

Decay mode	$\sigma(ZH) \times$ BR	BR
$H \to b\bar{b}$	0.27%	0.56%
$H \to c\bar{c}$	3.3%	3.3%
$H \to gg$	1.3%	1.4%
$H \to WW^*$	1.0%	1.1%
$H \to ZZ^*$	5.1%	5.1%
$H \to \gamma\gamma$	6.8%	6.9%
$H \to Z\gamma$	15%	15%
$H \to \tau^+\tau^-$	0.8%	1.0%
$H \to \mu^+\mu^-$	17%	17%
$H \to$ inv	–	$< 0.30\%$



Higgs boson production and decay angles of the $e^+e^- \to Z^* \to ZH \to \mu^+\mu^- b\bar{b}$ process



Focus of Snowmass 2021 in EF01

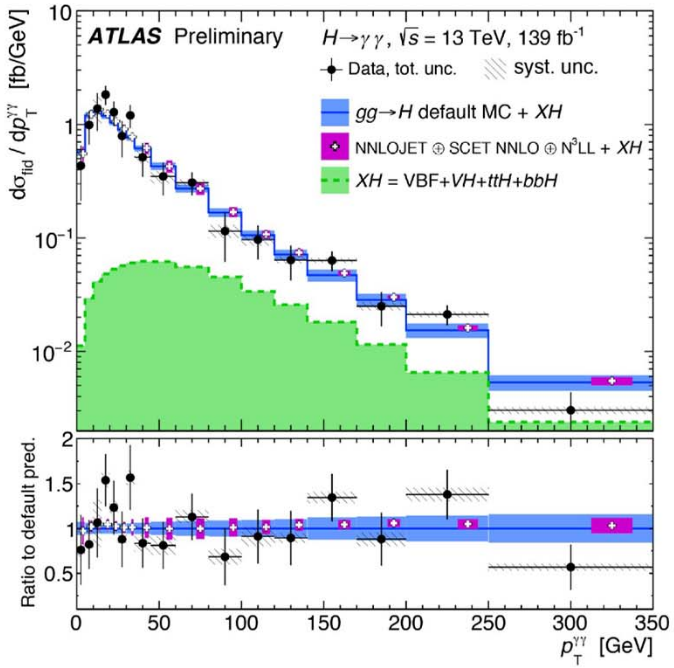
- Focus of Snowmass 2021 in EF01
  - fiducial differential cross sections: targeting phase space region matching experiment selections, in bins of interested variables
    - reduce sensitivity to SM modeling
    - isolate regions with higher BSM sensitivity
    - probe more precise theoretical corrections with finer SM measurements
  - CP violating Higgs couplings: targeting couplings sensitive to CP nature of Higgs with angular analyses or threshold scans
    - excellent null-test in SM
    - inputs to global EFT fits
    - different facilities have their unique features

Some typical reference differential analyses

p_T^H, N_{jets} Distributions

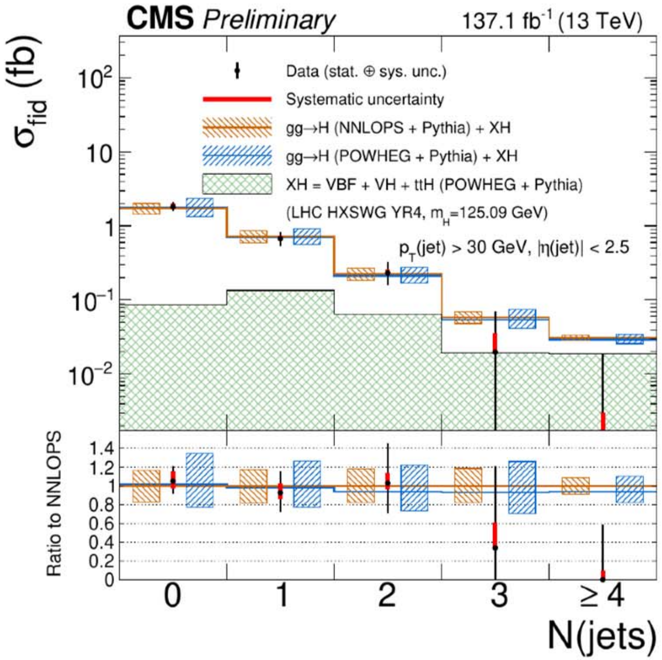
from Nicolas Berger

H→γγ
- 1-2% mass resolution
- S/B ~ 3% but $N_{reco\ H}$ ~ 7000



ATLAS-CONF-2019-029

H→ 4l
- 1-2% mass resolution
- S/B ~ 2 but $N_{reco\ H}$ ~ 200



CMS-PAS-HIG-19-001

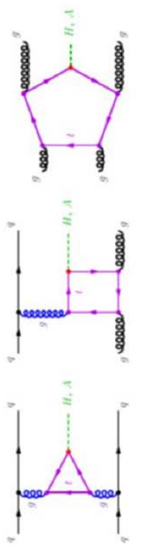
low-p_T^H: probe pQCD modeling, light-quark coupling
high-p_T^H: new particles in ggF loop, top coupling

N_{jets}: Probe pQCD modeling, production mode composition

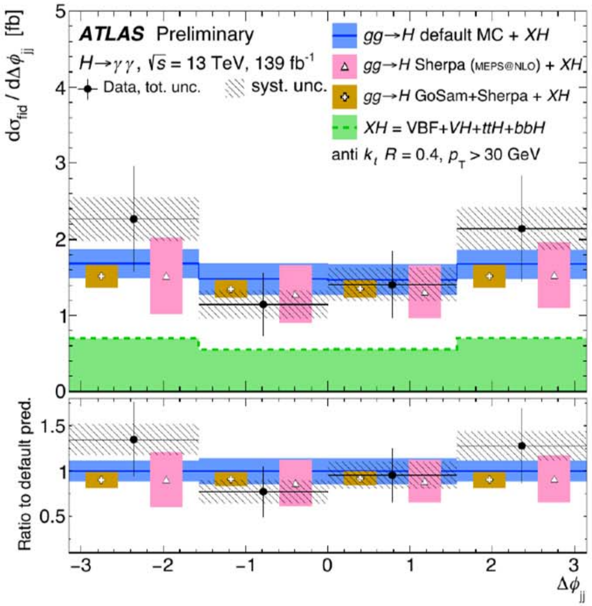
Some typical reference differential analyses

$\Delta\varphi_{jj}$, m_{34}

from Nicolas Berger



hep-ph/0703202



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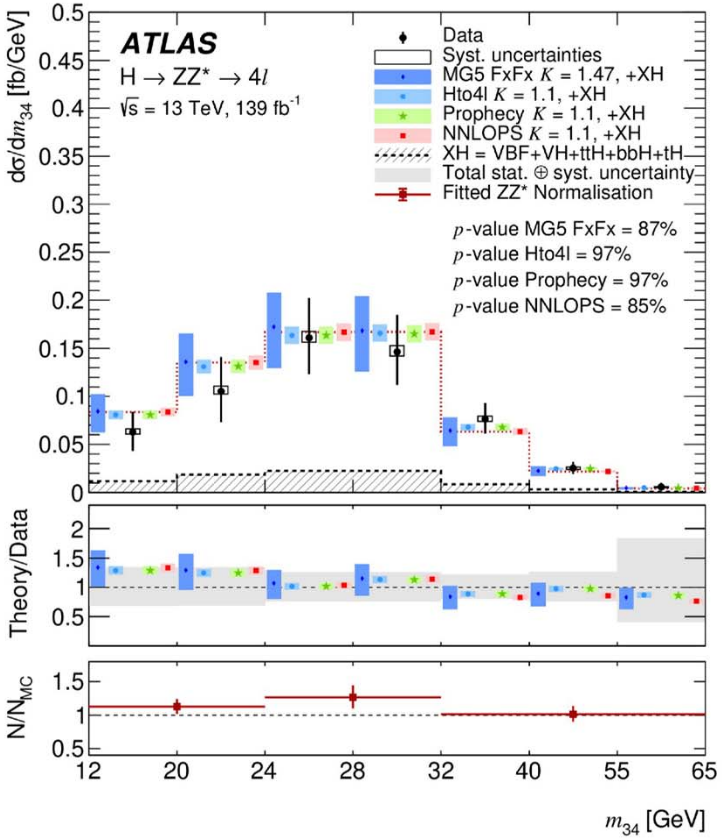


$\Delta\varphi_{jj}$: Sensitive to CP-odd Higgs admixtures

→ Small modulation in the SM, opposite sign for CP-odd components

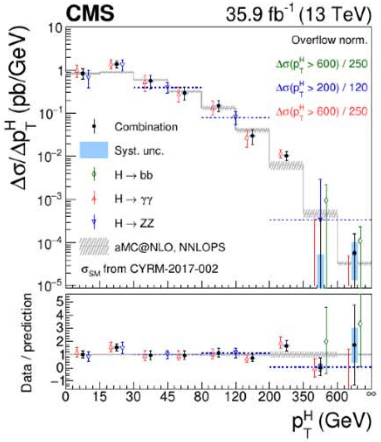
→ See also **ATL-PHYS-PUB-2019-008**: measure CP admixture @ HL-LHC from H→ ττ angular distributions

m_{34}: mass of subleading lepton pair (~m_{Z^*}), Probes H4l tensor structure (contact terms), light resonances

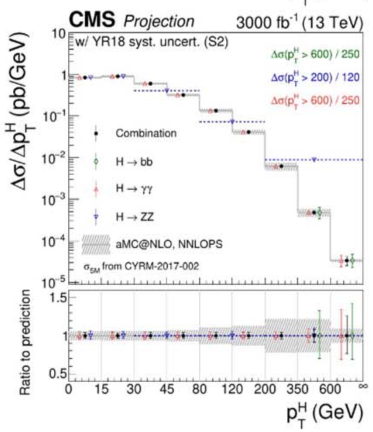
Interpretation of differential analyses

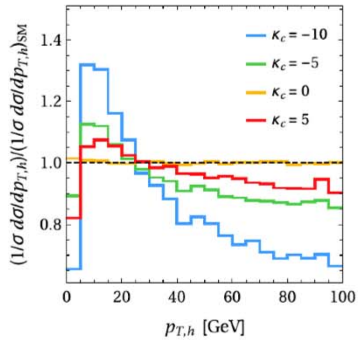
p_T^H Interpretation: Anomalous b,c couplings

Run 2



HL-LHC



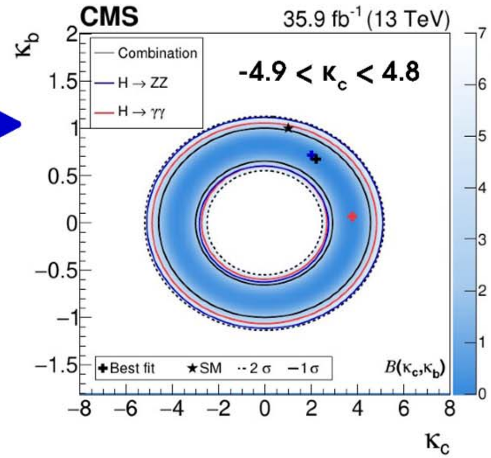


PRL 118, 121801 (2017)

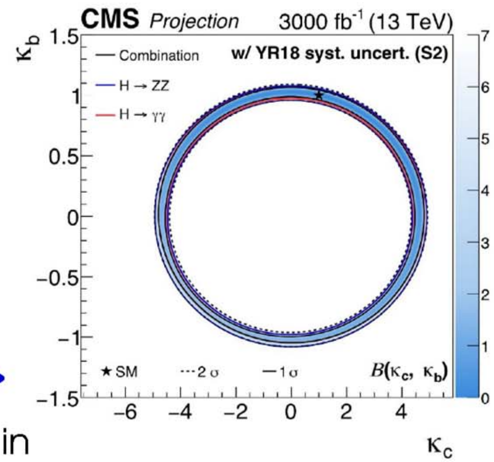
→ Anomalous $\kappa_{b,c}$ change p_T^H shape and normalization.

→ Parameterize cc→H, ggF and H→γγ loops with $\kappa_{b,c}$, assuming no other NP effects.

→ sensitivity mostly from norm.



PLB 792 (2019) 369



CMS-FTR-18-011

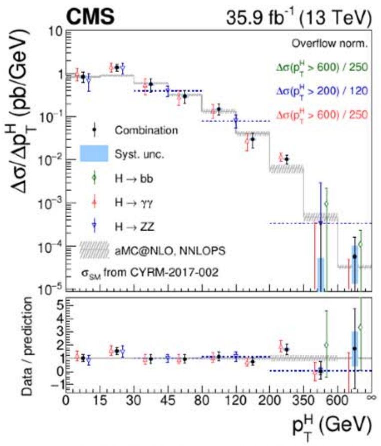
Similar sensitivity to direct measurement in VH→cc : μ(ZH→cc) ≲ 6 (ATL-PHYS-PUB-2018-016)

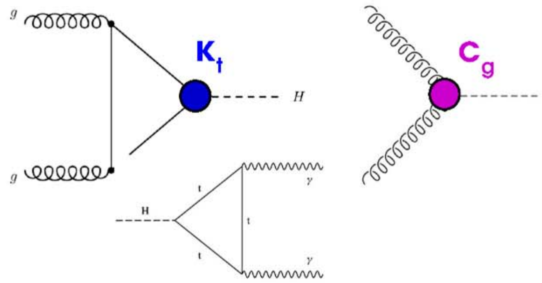
from Nicolas Berger

Interpretation of differential analyses

p_T^H Interpretation: Anomalous t,g couplings

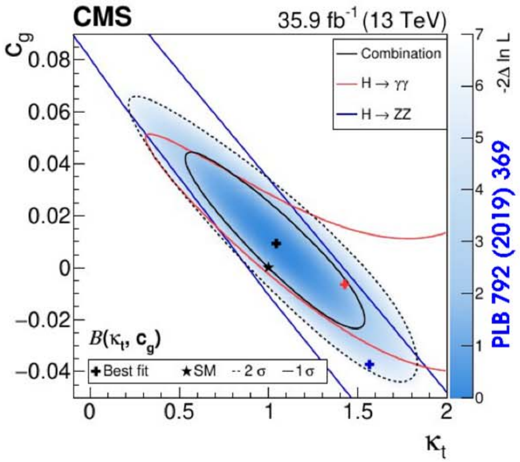
Run 2



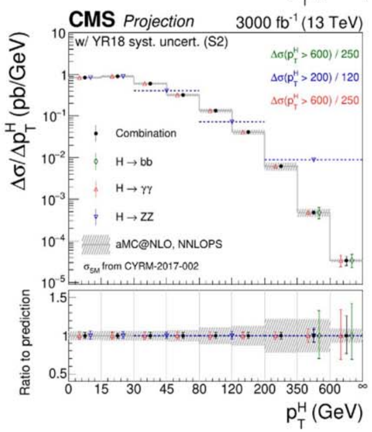


→ Disentangle contact gg→H interaction from top loop using p_T^H shape.

→ Also parameterize B(H→γγ), assuming no other NP effects.

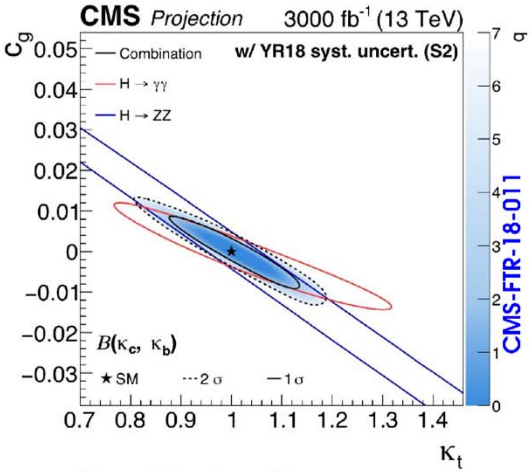


HL-LHC



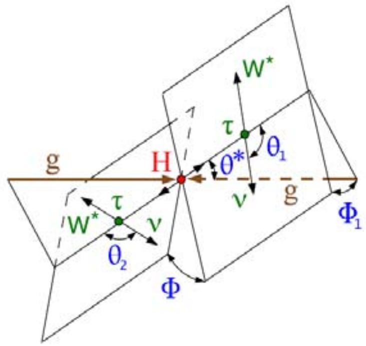
→ SM Normalization for $12c_g + \kappa_t \sim 1$

→ Shape and B(H→γγ) provide orthogonal constraints.



from Nicolas Berger

Some reference Higgs CP violating analyses



from Andrei Gritsan

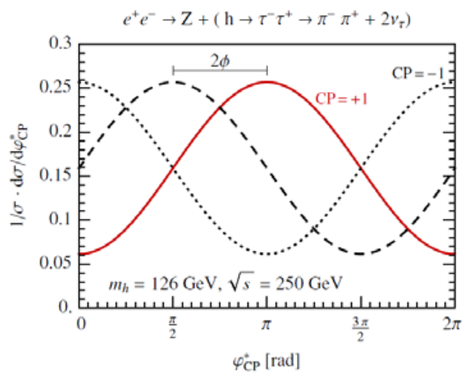
- Polarization in $H \to \tau^+\tau^-$ for CP in Hff

e^+e^- pheno studies at Snowmass-2013: arXiv:1308.2674

— the only CP in Hff at e^+e^- $\sqrt{s} < 500$ GeV

— reach $f_{CP} \sim 0.008$ $(\alpha \sim 5^\circ)$ at e^+e^- ref. lumi

— e^+e^- benefits from clean environment



$\tau \to l + \nu_l + \nu_\tau, \quad l = e, \mu,$

$\tau \to \pi + \nu_\tau,$

$\tau \to \rho + \nu_\tau \to \pi + \pi^0 + \nu_\tau,$

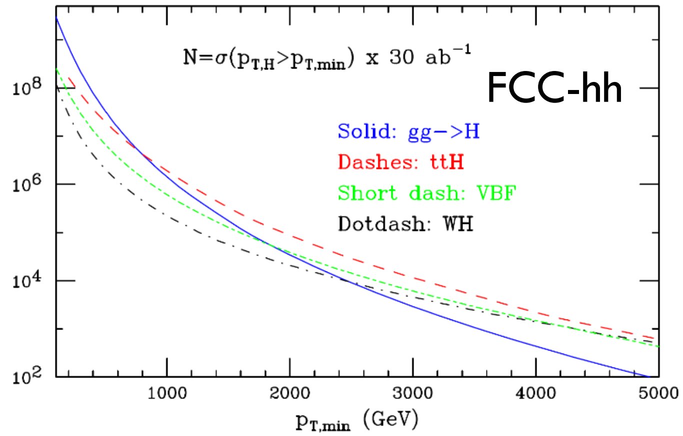
$\tau \to a_1 + \nu_\tau \to \pi + 2\pi^0 + \nu_\tau,$

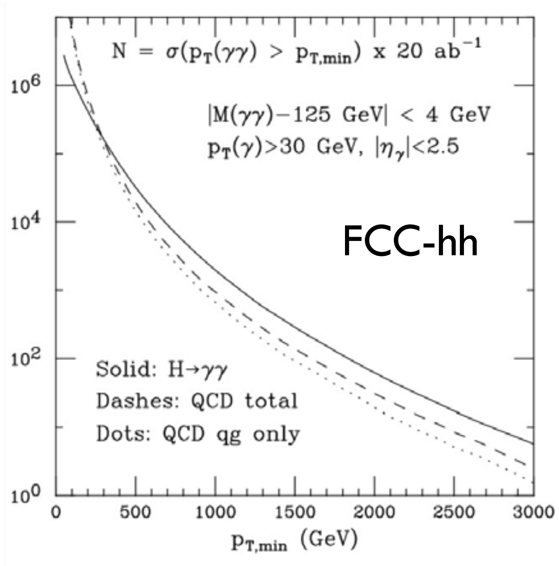
$\tau \to a_1^{L,T} + \nu_\tau \to 2\pi^\pm + \pi^\mp + \nu_\tau.$

- Other featured channels in CEPC
  - e+e− → ZH ⇒ HZZ,HZγ,Hγγ couplings
  - Current ZH->mumubb results could also be improved by exploring the kinematic distributions

About SPPC and FCC-hh

- Complementary Higgs precision measurements to lepton collider
  - specially interesting in large Higgs pT regions
    - different hierarchy of production channels
    - improved S/B, reduced pile-up effects
    - potentially accurate probe of the H pt spectrum up to large pt
  - standalone precise “ratios-of-BRs" measurements
    - independent of α_S, m_b, m_c, Γ_{inv} systematics
    - sensitive to BSM effects that typically influence BRs in different ways
  - probe top Yukawa coupling where ttH/Z contributions are subdominant





Summary

- A set of reference analyses will be established in EF01

- Currently focus on differential measurements and Higgs CP violating couplings

- CEPC should propose and work on channels that highlight our strengths – collaborate between theorists and experimentalists
  - pT(H) differential analyses
  - CP violation studies in HZZ and other channels
  - running of Higgs mass measurements?
  - other ideas are very welcome

- SPPC initiatives?