(Update on) Higgs self-coupling determination at the FCC-hh

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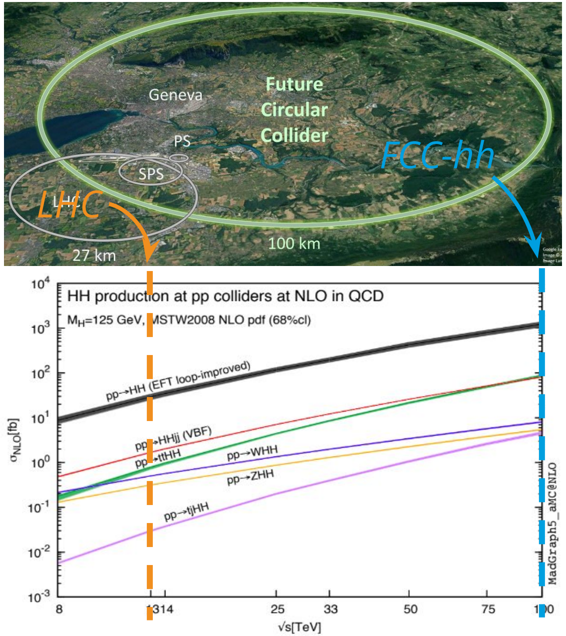
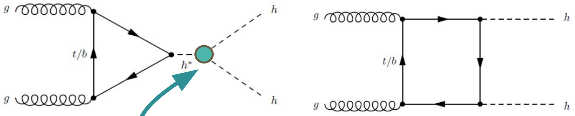
Higgs self-coupling @ FCC-hh: What & why?



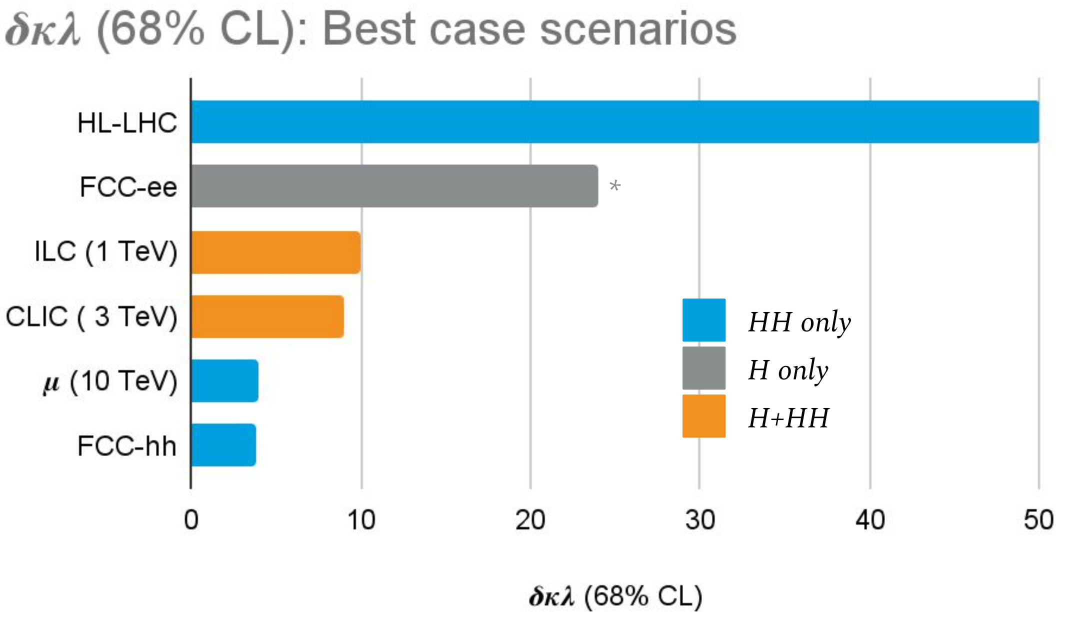


$\kappa_\lambda = \lambda^{meas} / \lambda^{SM}$

- Measuring the Higgs self-coupling allows us to gain insight into the nature of the Higgs potential and electroweak symmetry breaking
- **FCC-hh**: *pp*-collisions at 100 TeV, 30 ab^{-1} in ~25 years
- Measuring the **Higgs self-coupling via di-Higgs production** is key benchmark for FCC-hh
  - SM: $\sigma(ggHH) \sim O(1000)$ smaller than $\sigma(ggH)$
  - Large cross-section and data-set at FCC-hh
    - 20 x precision of HL-LHC

Overview of Higgs self-coupling limits & prospects

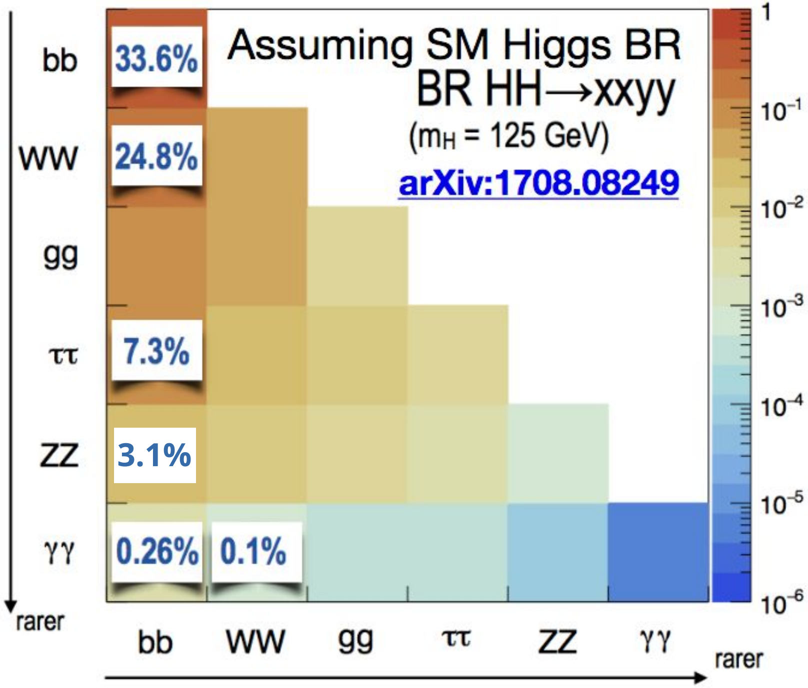
- At LHC we set limits: -0.4 < κ_λ < 6.3 (ATLAS-HDBS-2022-03)
- Only at future colliders we will reach a precision measurement



Details & references in back-up

** For FCC-ee the Higgs self-coupling is measured indirectly via one loop-effect in the ZH process*

Di-Higgs final states

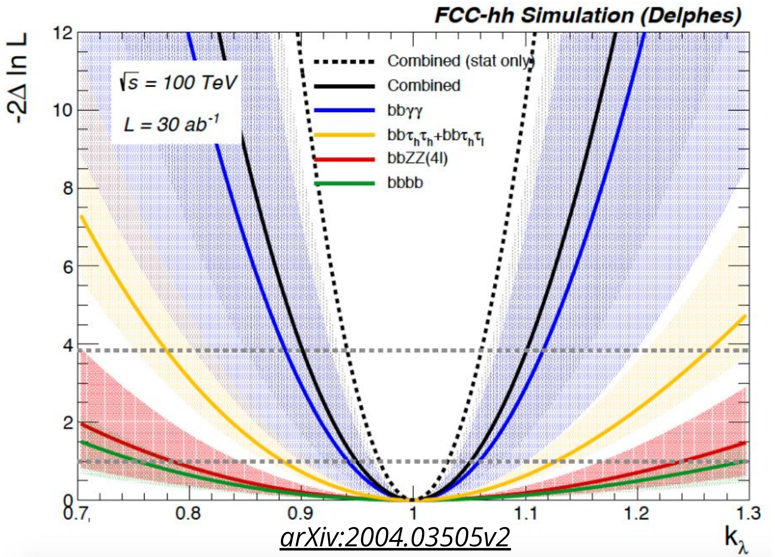


***HH* measurements**:

- Very low cross section
- Challenging final state
- Trade off between purity and high branching ratio

Higgs self-coupling projections for FCC-hh

M. Mangano, G. Ortona, M. Selvaggi



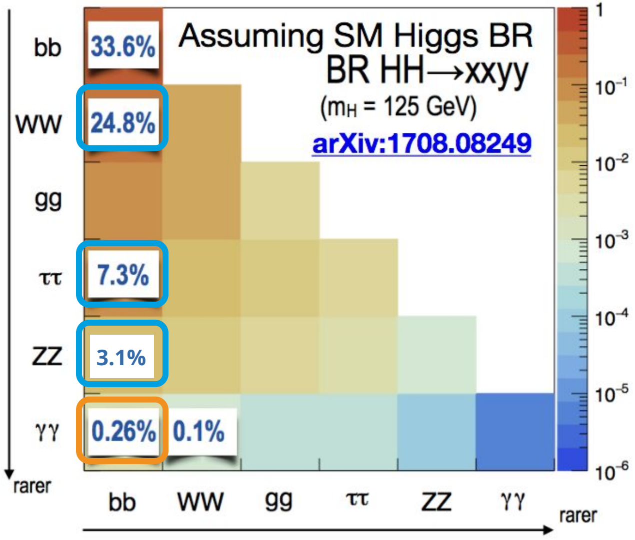
arXiv:2004.03505v2

	Combined precision
$\delta\kappa_\lambda$ (68% CL)	3.4% - 7.8%

- Previously published prospect studies combined ***bbyy***, ***bbττ(hh+lh)***, ***4b*** **and** ***bbZZ(4l)*** final states
- Considered three **different scenarios for detector performance** and systematic uncertainties by reweighting from main, detector scenario **based on LHC performance & FCC-hh CDR**

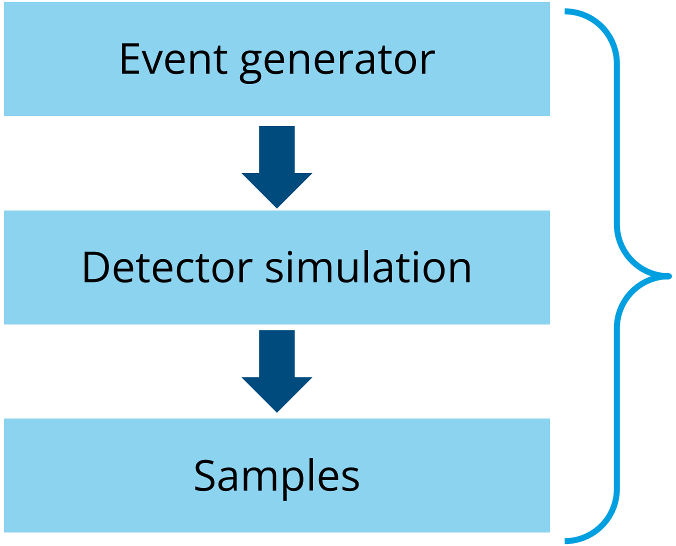
Our work: Update of $\bar{b}b\gamma\gamma$ and adding $\bar{b}bll+E_T^{miss}$

- Studying only $ggF\ HH$ production mode (so far)



Final state	$BR(HH\rightarrow X)$	Description
$\bar{b}b\gamma\gamma$	0.26%	• Rare, but high precision • DNN-based analysis • What is the ultimate precision that can be reached?
$\bar{b}bll+E_T^{miss}$	3.24%	• Summing contributions from $\bar{b}bWW(l\nu l\nu)+\bar{b}b\tau\tau(ll\nu l\nu)+\bar{b}bZZ(ll\nu\nu)$ • Larger BR, but more background contaminated, limited precision • Cut-based analysis • New for FCC-hh

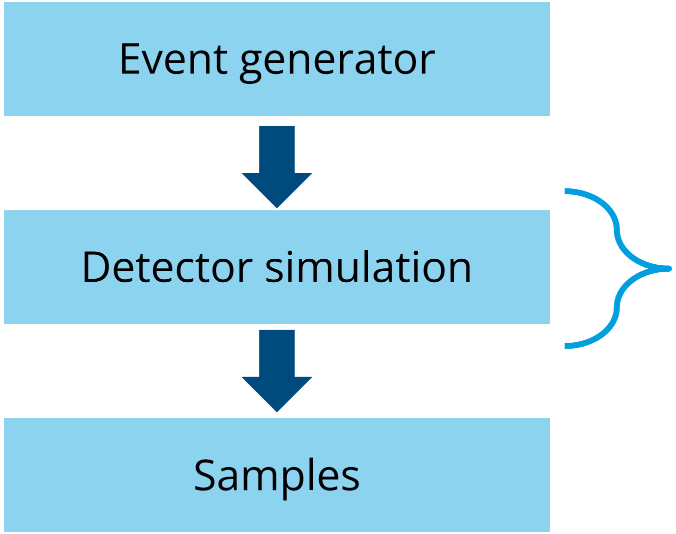
Common software stack for future facilities



All part of key4hep project: Consistent software stack for all future projects

- Fast, parametrized simulation in Delphes
- Using EventProducer framework (fork)
- Samples in EDM4HEP format

Common software stack for future facilities



- Our analyses employ two detector scenarios
  - Both implement fixes w.r.t the original FCC-hh Delphes card, e.g. bremsstrahlung for electrons, multiple scattering, resolutions in forward region

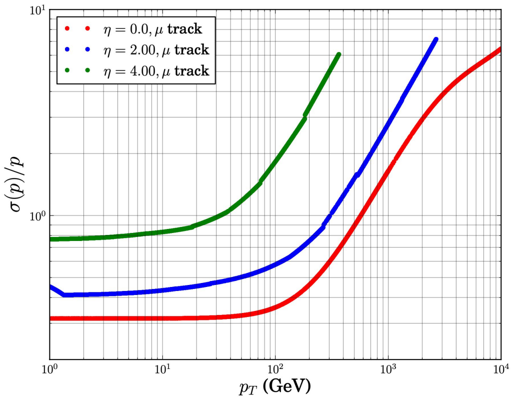
Common software stack for future facilities

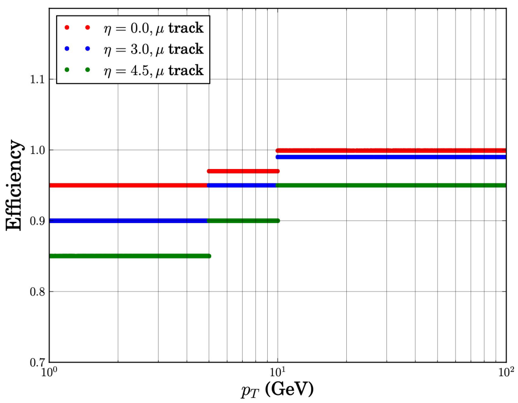
Event generator

Detector simulation

- Our analyses employ two detector scenarios
  - **Scenario I**: Optimistic case
    - LHC run 2 conditions with e.g. ideal crystal calorimeter, b-tagging (slightly) better than current CMS → This is the scenario to use for ultimate precision in $\bar{b}b\gamma\gamma$

Example parametrization for muons





CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

Common software stack for future facilities

Event generator

↓

Detector simulation

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Samples

Across all p_T and η bins, up to $|\eta| < 6$

- Our analyses employ two detector scenarios
  - Scenario I: Optimistic case
  - **Scenario II:** Baseline, more realistic
    - I.e. baseline LaR calorimeter from CDR, lower efficiencies, …

      → Use for new channel $\bar{b}bll{+}E_T^{miss}$

Relevant objects

	Relative p resolution		Efficiency	
	Scen I	Scen II	Scen I	Scen II
Electrons	0.4-1%	0.8-3%	76-95%	72-90%
Muons	0.5-3%	1-6%	90-99%	88-97%
Medium b-tagging			80-90%	76-86%

Common software stack for future facilities

Event generator

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Detector simulation

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Samples

↓

Physics analysis & statistical interpretation

All part of key4hep project: Consistent software stack for all future projects

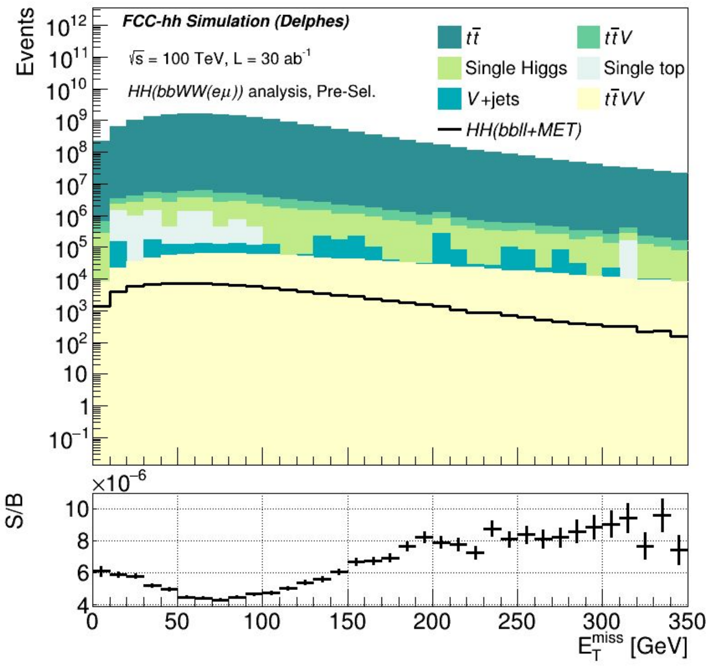
- Fast, parametrized simulation in Delphes
- Using EventProducer framework (fork)
- Samples in EDM4HEP format

Analysis with common framework FCCAnalyses

- Currently on fork with some new additions
  - E.g. getting tagged jets from Delphes
- Plan to integrate into main repo

$\bar{b}bll+E_T^{miss}$ analysis

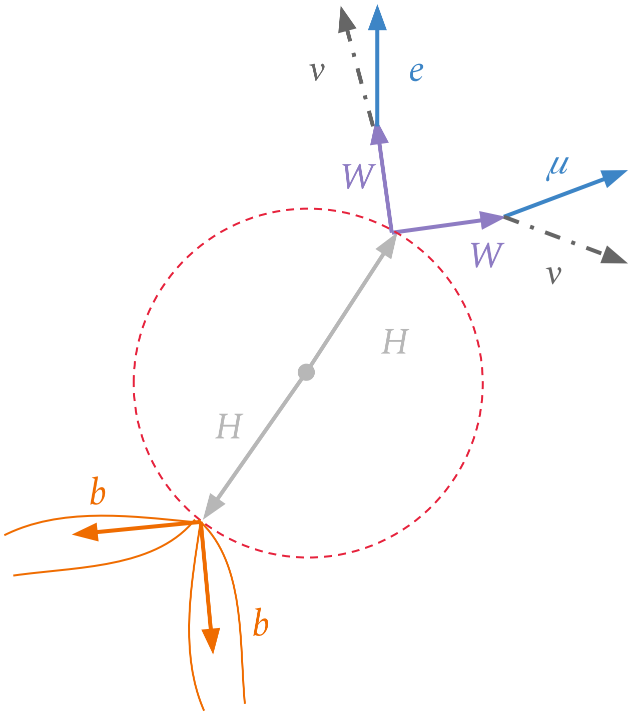
$b\bar{b}ll + E_T^{miss}$: Analysis strategy



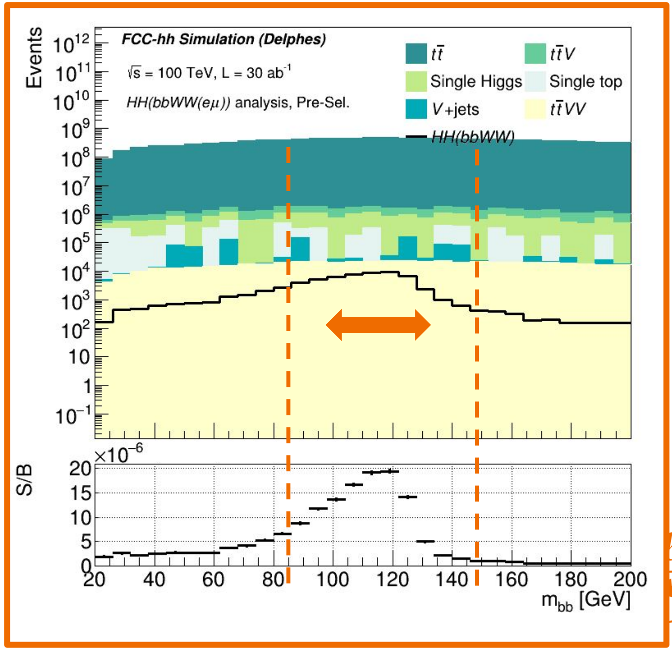
eμ-category

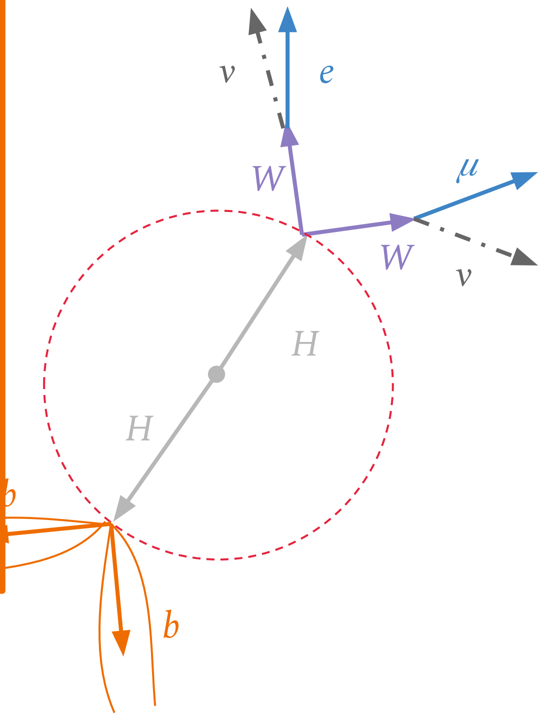
- Signal signature: Lepton pair + E_T^{Miss} + 2 b-jets
  - Leptons isolated from b-jets (ΔR > 0.4)
- Backgrounds from:
  - $\bar{t}t$ and single top
  - $\bar{t}tV$
  - Single Higgs (ggF, VBF, $\bar{t}tH$, VH)
  - V+jets
  - $\bar{t}tVV$
- Categorization of events based on lepton flavours and whether (on-shell) Z(ll) decay is present

$\bar{b}bll+E_T^{miss}$: Event kinematics & selection



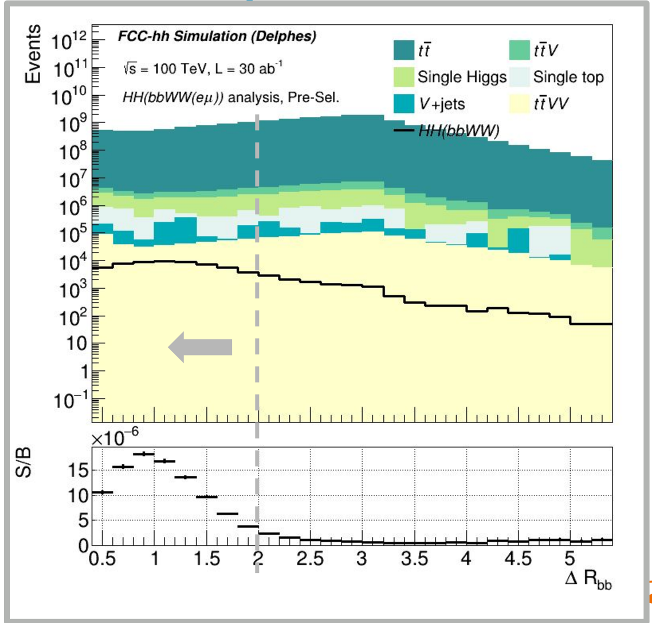
$\bar{b}bll+E_T^{miss}$: Event kinematics & selection

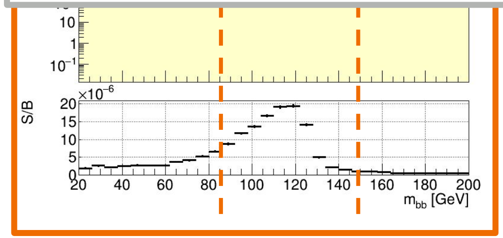


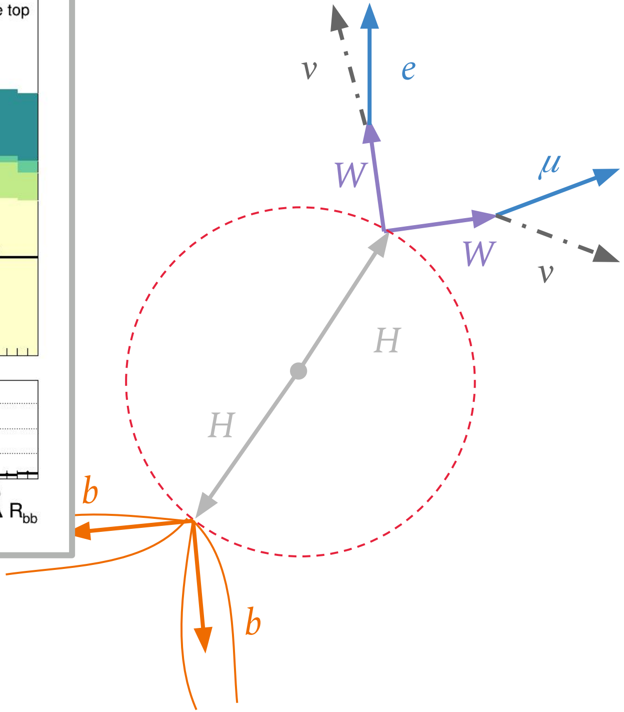


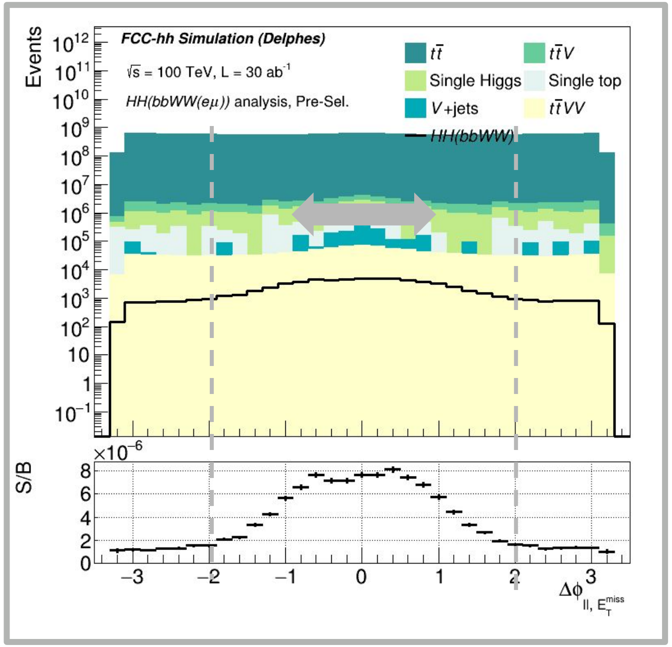
m_{bb}

$b\bar{b}ll+E_T^{miss}$: Event kinematics & selection



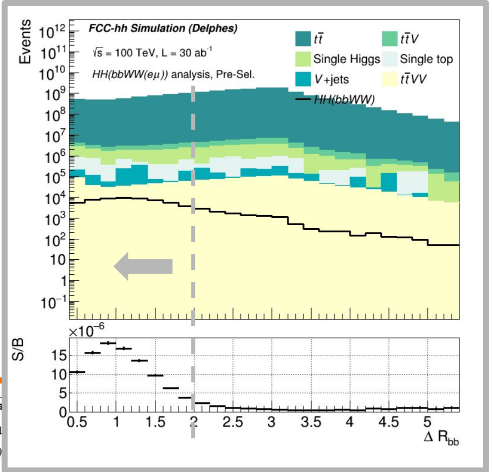


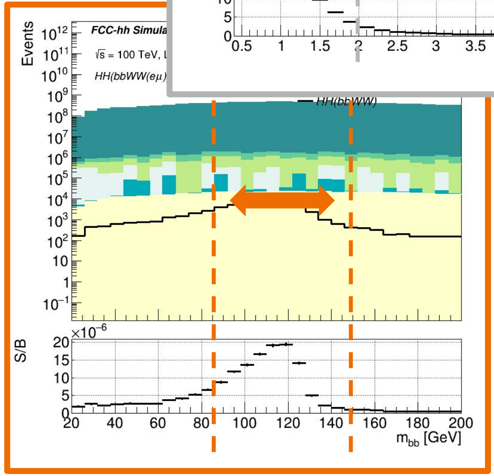


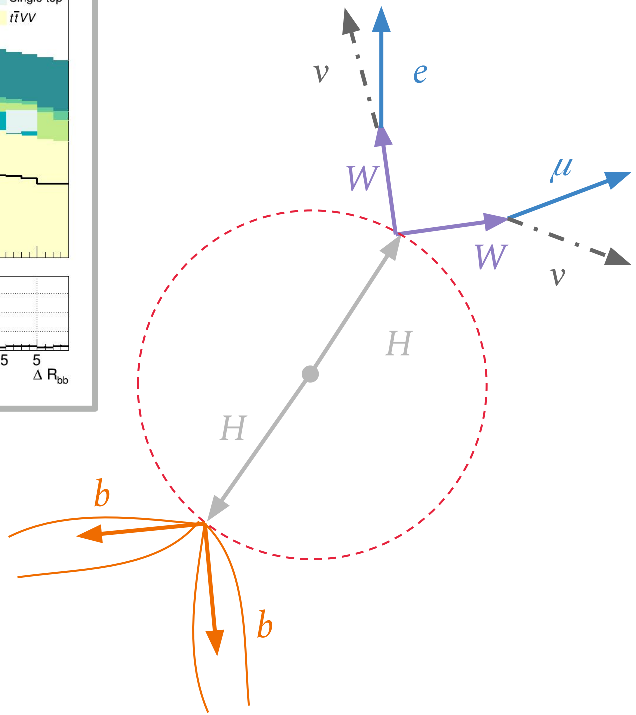


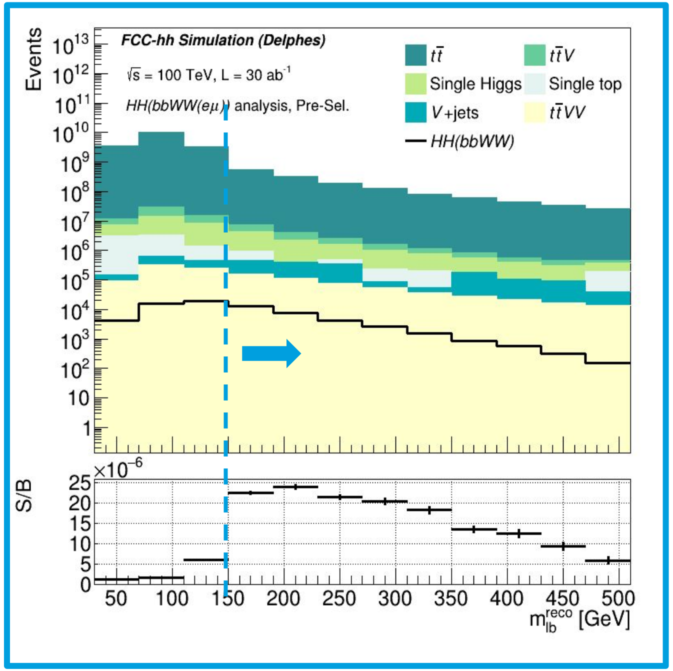
Higgses recoil against each other → Subsequent decays are boosted → Exploit angles!

$b\bar{b}ll+E_T^{miss}$: Event kinematics & selection





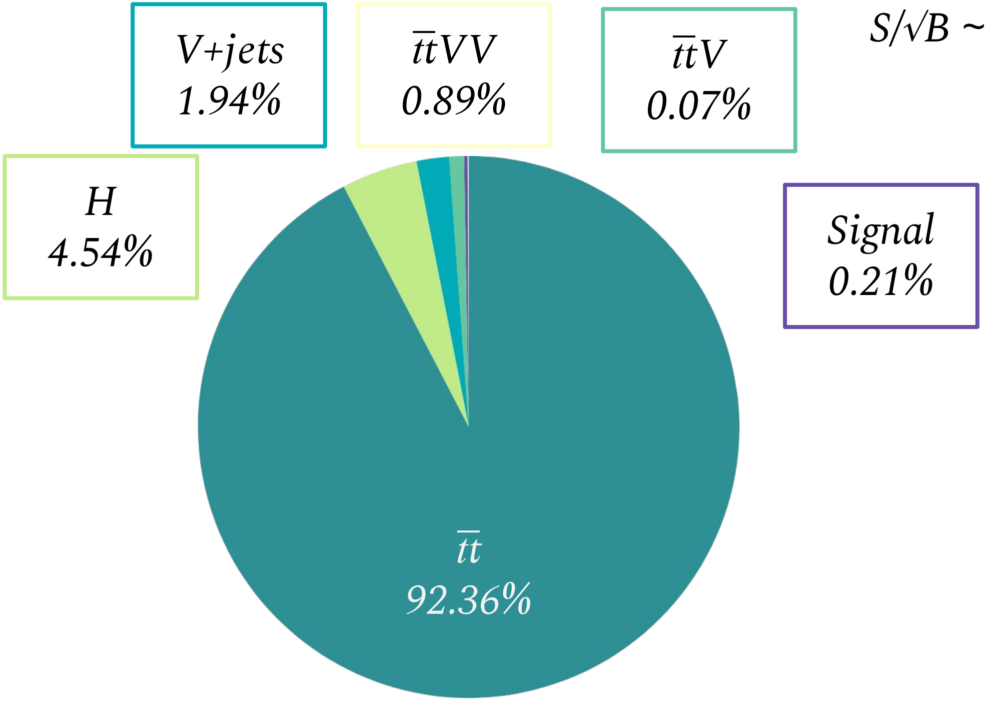




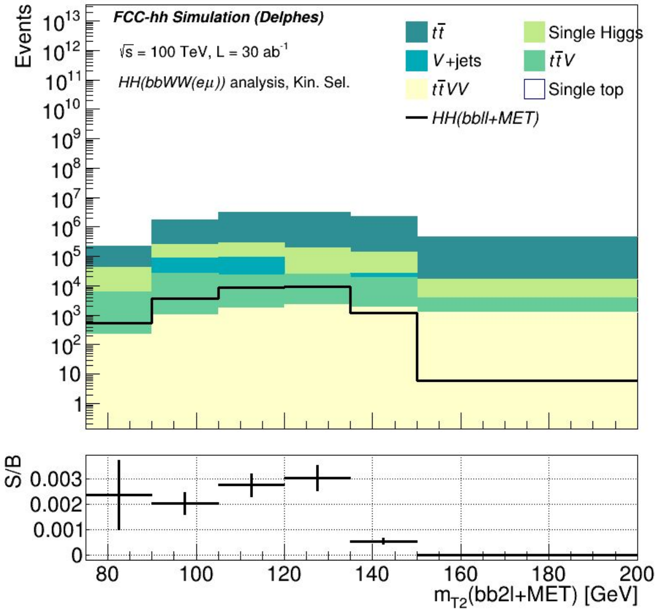
$$m_{lb}^{\text{reco}} = \min\left(\frac{m_{l_1b_1}+m_{l_2b_2}}{2}, \frac{m_{l_2b_1}+m_{l_1b_2}}{2}\right)$$

Targeted $t\bar{t}$ suppression

$b\bar{b}ll+E_T^{miss}$: Fit inputs



$S/\sqrt{B} \sim 7$



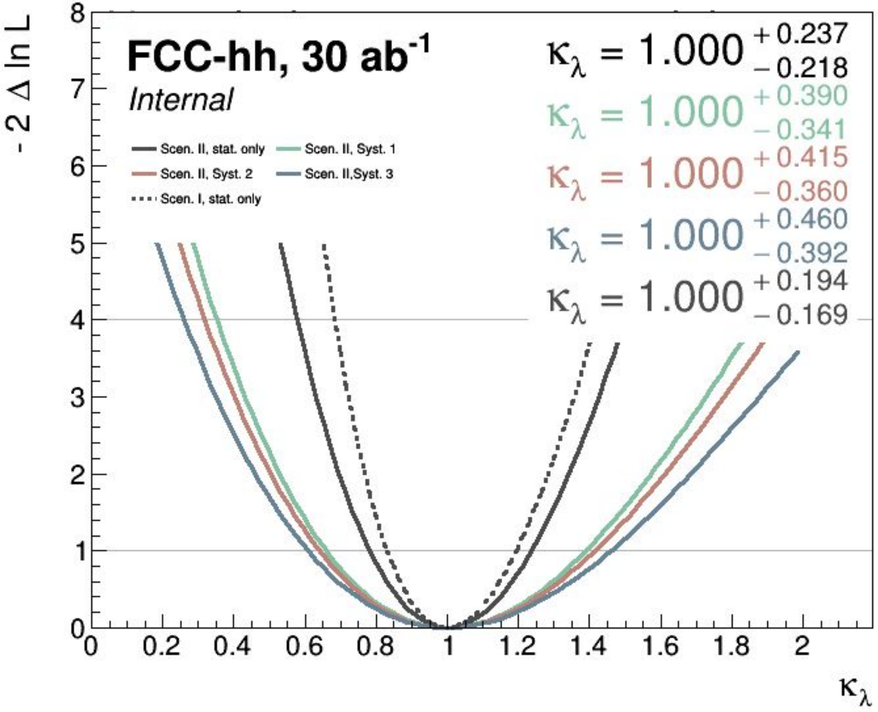
- Stransverse mass m_{T2} predicts invisible mass contribution
  - Capture the full HH decay

Results: Systematic uncertainties

Source of uncertainty	Syst. 1	Syst. 2	Syst. 3	Applies to	Correlated
Common systematics					
b-jet ID / b-jet	0.5%	1%	2%	Signals, MC bkgs.	✓
Luminosity	0.5%	1%	2%	Signals, MC bkgs.	✓
Signal cross-section	0.5%	1%	1.5%	Signals, MC bkgs.	✓
$b\bar{b}\gamma\gamma$ systematics					
γ ID / γ	0.5%	1%	2%	Signals, MC bkgs.	✗
$b\bar{b}\ell\ell + E_T^{miss}$ systematics					
Lepton ID / lepton	0.5%	1%	2%	Signals, MC bkgs.	✗
Data-driven bkg. est.	-	1%	1%	$V+$jets	✗
Data-driven bkg. est.	-	-	1%	$t\bar{t}$	✗

- Following previous di-Higgs studies@FCC-hh
- Applied as rate systematics only, no shape effect

$b\bar{b}ll+E_T^{miss}$: Results

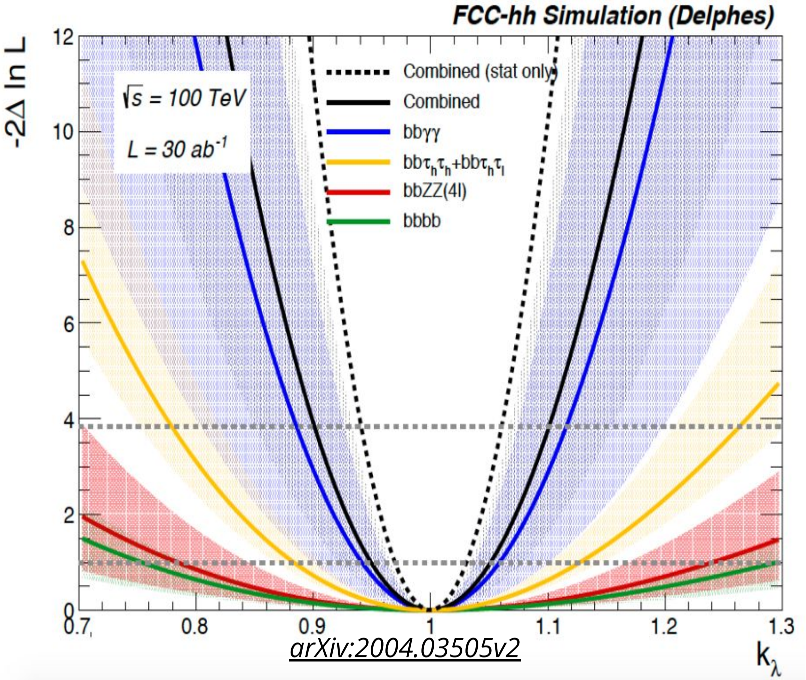


- Higgs self-coupling modifier κ_λ interpretation
  - Parametrized dependence of $\sigma(ggHH)$ on κ_λ
    - Inputs: κ_λ =1.0, 2.4, 3.0
  - All other couplings fixed to SM
  - NLO cross-sections at 100 TeV, with k-factor independent of κ_λ
  - No Higgs BR dependance on κ_λ and uncertainties or other additional theory uncertainties
- Preliminary results for scenario II $b\bar{b}ll+E_T^{miss}$
  - Neglecting V+jets and single top backgrounds

$\bar{b}byy$ analysis

$b\bar{b}\gamma\gamma$ analysis: Introduction

M. Mangano, G. Ortona, M. Selvaggi



arXiv:2004.03505v2

- The $b\bar{b}\gamma\gamma$ channel is the most sensitive one and it was already studied by previous paper achieving at best 3.8% (3.4% stat only) precision on the self coupling

$\bar{b}byy$ analysis: Introduction

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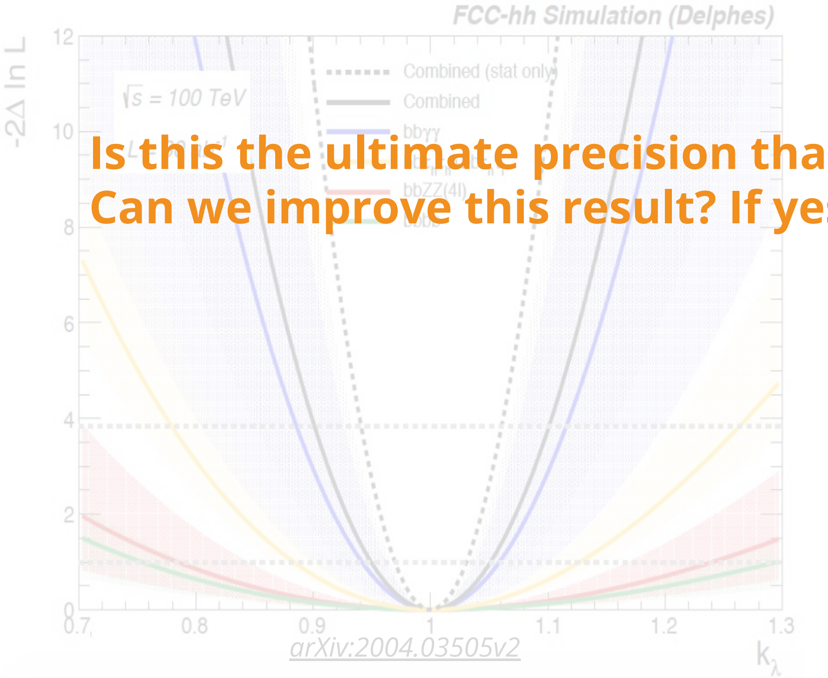

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- The $\bar{b}byy$ channel is the most sensitive one and it was already studied by previous paper achieving at best 3.8% (3.4% stat only) precision on the self coupling

Is this the ultimate precision that we can reach on the self coupling?
Can we improve this result? If yes how?

$\bar{b}byy$ analysis: Introduction

Is this the ultimate precision that we can reach on the self coupling?
Can we improve this result? If yes how?

- **New detector simulation**
  - **First time that we simulate an 'ideal' detector, in the previous studies it was reweighted from the main FCC-hh scenario**

$b\bar{b}\gamma\gamma$ analysis: Introduction

Is this the ultimate precision that we can reach on the self coupling?
Can we improve this result? If yes how?

- **New detector simulation**
- **New analysis strategy**
  - **We tried 2 main analysis strategy and compared the results**

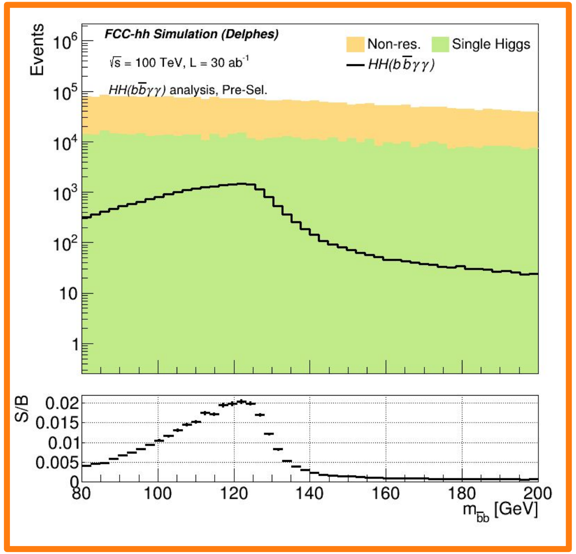
$b\bar{b}\gamma\gamma$ analysis: Introduction

Is this the ultimate precision that we can reach on the self coupling?
Can we improve this result? If yes how?

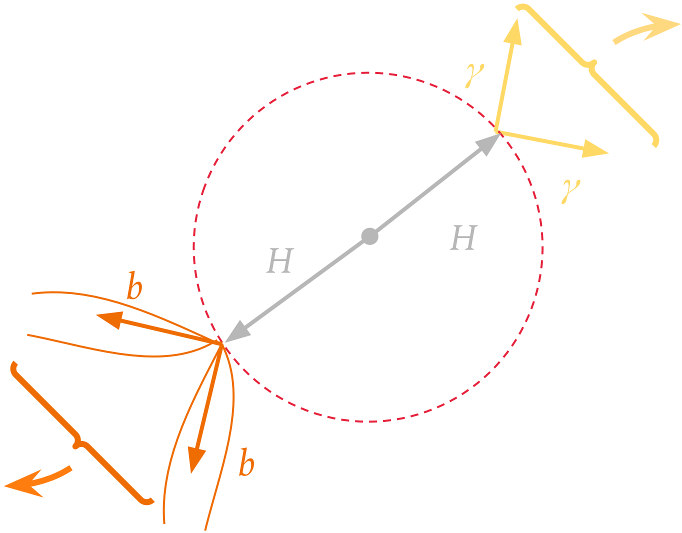
- **New detector simulation**
- **New analysis strategy**
- **Check which is the most sensitivity observable and try to improve it**
  - **Different assumptions on $m_{b\bar{b}}$ resolution**

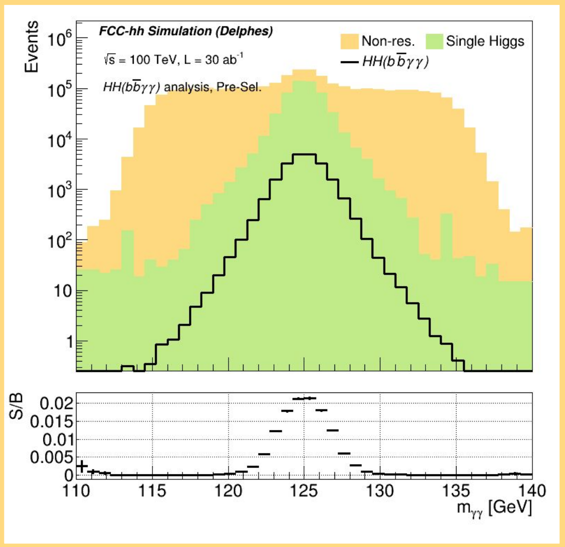
$b\bar{b}\gamma\gamma$ analysis: Strategy overview

Pre-selected events



Signal signature





- 2 b-jets & 2 photons with invariant masses near m_H

- Backgrounds:
  - Non-resonant QCD: $\gamma\gamma$+jets and γ+jets
  - Single Higgs production

$\bar{b}b\gamma\gamma$ analysis: Strategy 1 (Run2 like analysis)

3DNNs as for the baseline analysis:

- ‘ttH-killer’ trained signal vs ttH background (93% AUC)

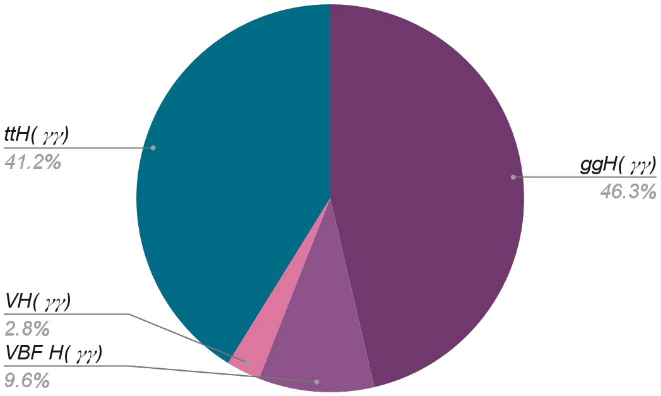
$\bar{b}b\gamma\gamma$ analysis: Strategy 1 (Run2 like analysis)

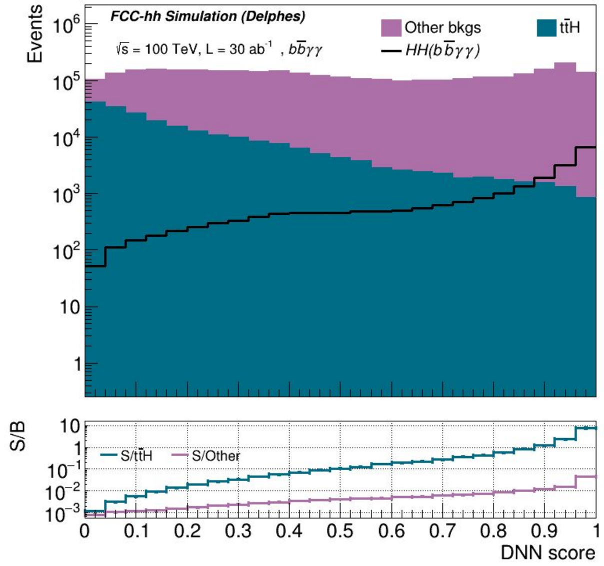
Pre-selected events

↓

DNN-based $t\bar{t}H$ tagger

Single Higgs bkg composition





- $t\bar{t}H$ enhanced - same final state as signal signature
  - $\boldsymbol{\sigma}(t\bar{t}H \rightarrow \boldsymbol{\gamma\gamma}) \sim 3\ \boldsymbol{\sigma}(ggHH \rightarrow bb\boldsymbol{\gamma\gamma})$
- Exploit expected differences in kinematics:
  - $t\bar{t}H$ more jets, but less energetic
  - $t\bar{t}H$ can contain high pT leptons

$b\bar{b}\gamma\gamma$ analysis: Strategy 1 (Run2 like analysis)

$$m_x = m_{\bar{b}b\gamma\gamma} - m_{\bar{b}b} - m_{\gamma\gamma} + 250\text{GeV}$$

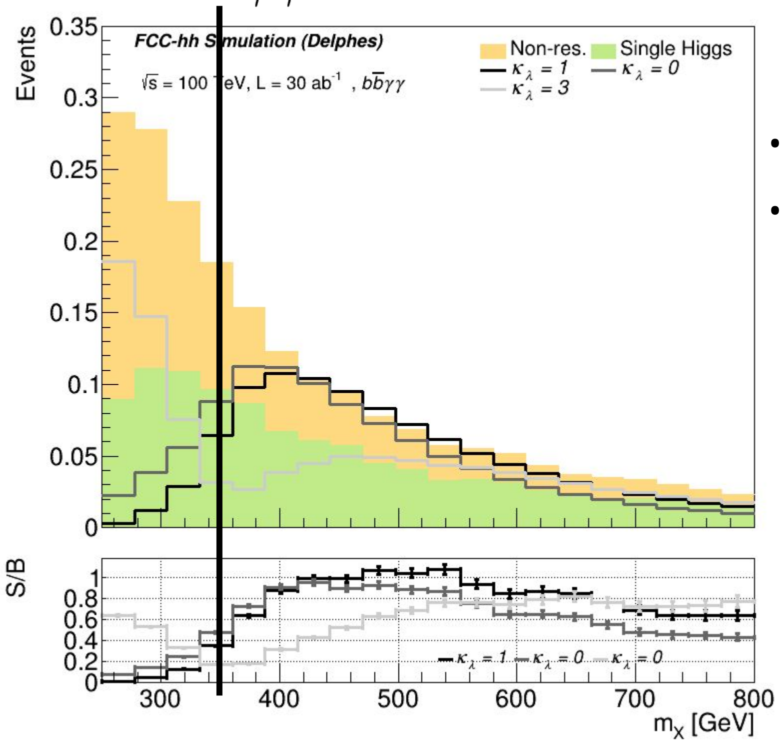
Pre-selected events

↓

DNN-based $\bar{t}tH$ tagger

↓

$m_x < 350$ GeV	$m_x > 350$ GeV



- Shape depends on κ_λ
- Region $m_x < 350$ GeV has low S/B for κ_λ=1 (SM) , but contributions from κ_λ≠1 (BSM) signals

$b\bar{b}\gamma\gamma$ analysis: Strategy 1 (Run2 like analysis)

3DNNs as for the baseline analysis:

- ‘ttH-killer’ trained signal vs ttH background (93% AUC)
- ‘High Mx region DNN’ trained signal vs all background but ttH (82% AUC)
- ‘Low Mx region DNN’ trained signal vs all background but ttH (74% AUC)

$b\bar{b}\gamma\gamma$ analysis: Strategy 1 (Run2 like analysis)

Pre-selected events

DNN-based $t\bar{t}H$ tagger

$m_x < 350$ GeV

$m_x > 350$ GeV

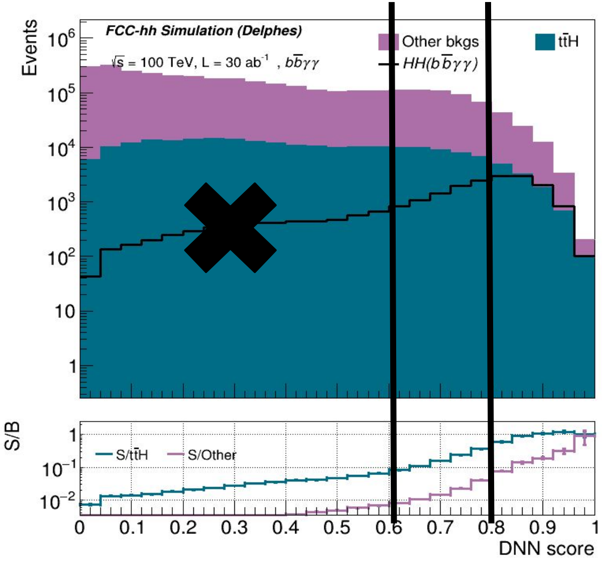
DNN to suppress non-$t\bar{t}H$ backgrounds

Optimization of DNN score cuts

Medium purity

High purity

- Separate DNNs for suppressing non- background, using same input variables as $t\bar{t}H$ tagger
- Optimization of cuts based on significance



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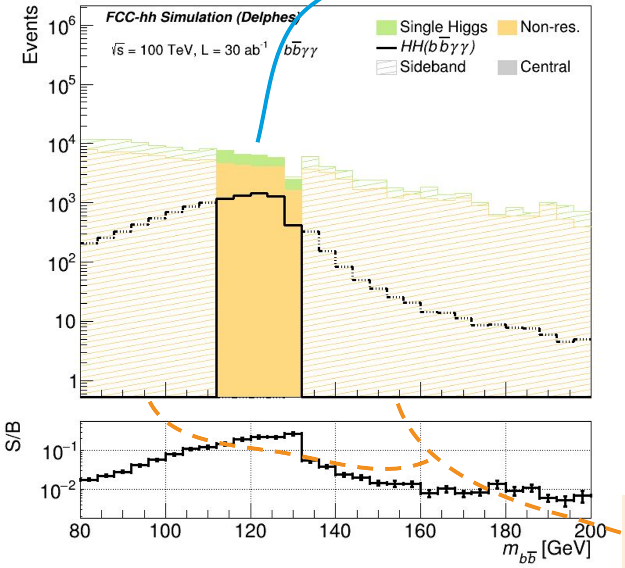
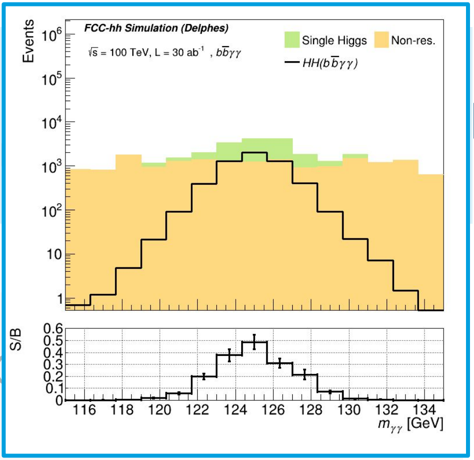
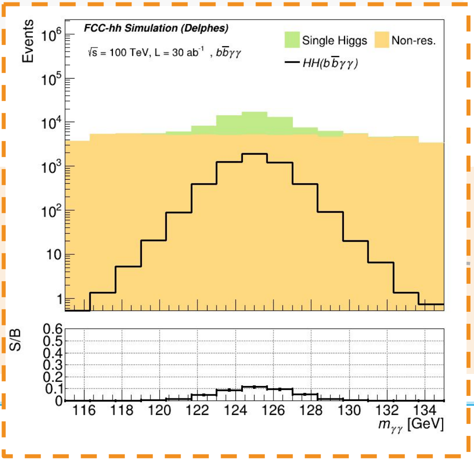
$m_{b\bar{b}}$ splitting:

- 1 $m_{b\bar{b}}$ bin (m$_{b\bar{b}}$ distribution not used)
- 2 $m_{b\bar{b}}$ bins (sideband + central region)
- optimal mbb binning ($m_{b\bar{b}}$ in bins that are determined by the significance)

$b\bar{b}\gamma\gamma$ analysis: Strategy 1 (Run2 like analysis 2 $m_{b\bar{b}}$ bins)







Categorize based on $m_{b\bar{b}}$

Sideband

Central region

Fit $m_{\gamma\gamma}$ in 8 categories

$\bar{b}by y$ analysis: Strategy 2

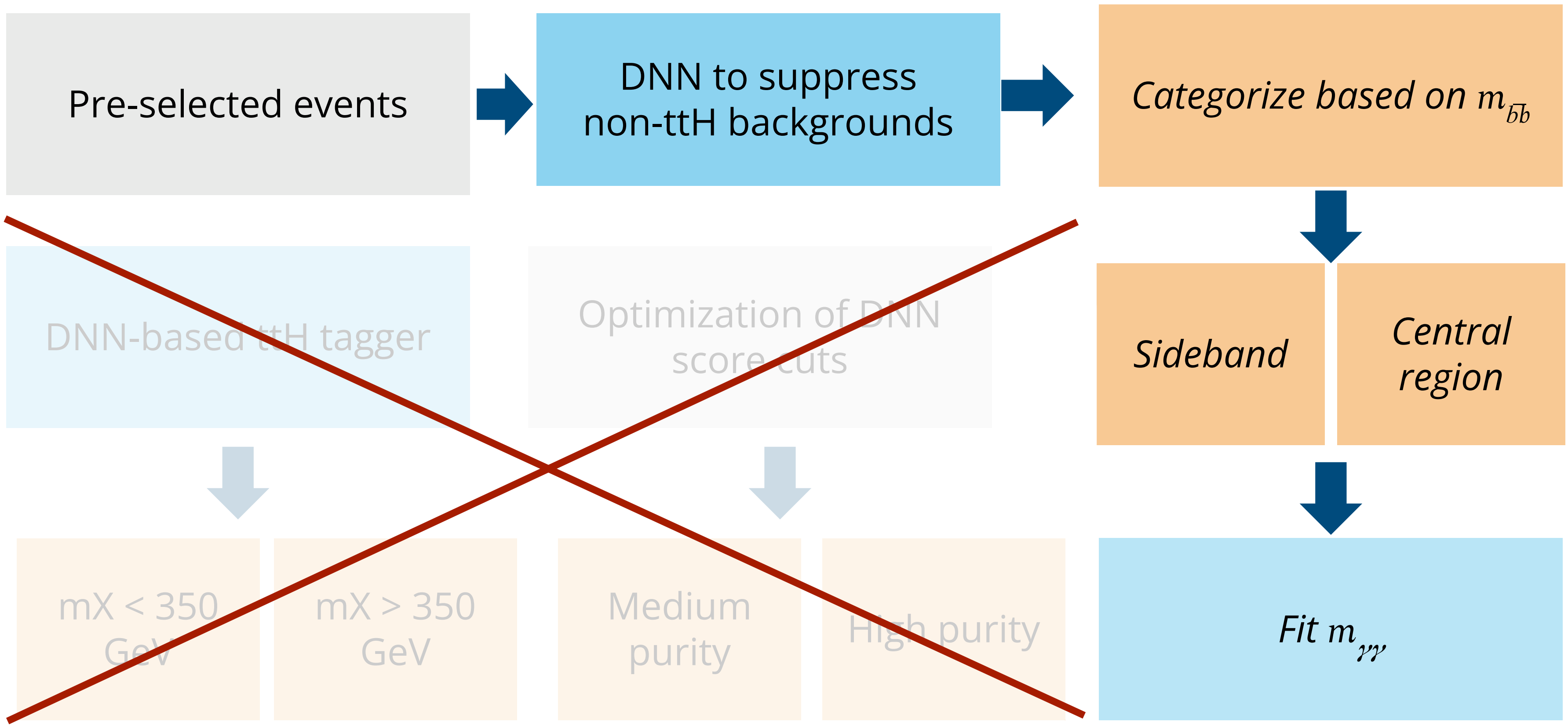
1DNN with all the backgrounds in (87% AUC)

- AUC is compatible with the mean of the AUCs used in strategy 1 → the sensitivity at the end should be the same

$m_{\bar{b}b}$ splitting:

- 1 $m_{\bar{b}b}$ bin (m$_{\bar{b}b}$ distribution not used)
- 2 $m_{\bar{b}b}$ bins (sideband + central region)
- optimal mbb binning ($m_{\bar{b}b}$ in bins that are determined by the significance)

$b\bar{b}\gamma\gamma$ analysis: Strategy 2 overview (2 $m_{b\bar{b}}$ bins splitting)



$\bar{b}byy$ analysis: Strategies comparison and results

Strategy 1 and strategy 2 gave the same results:

- Improve the DNN splitting doesn't really optimize the analysis

Does the $m_{\bar{b}b}$ splitting optimize the sensitivity?

$b\bar{b}\gamma\gamma$ analysis: Strategies comparison and results

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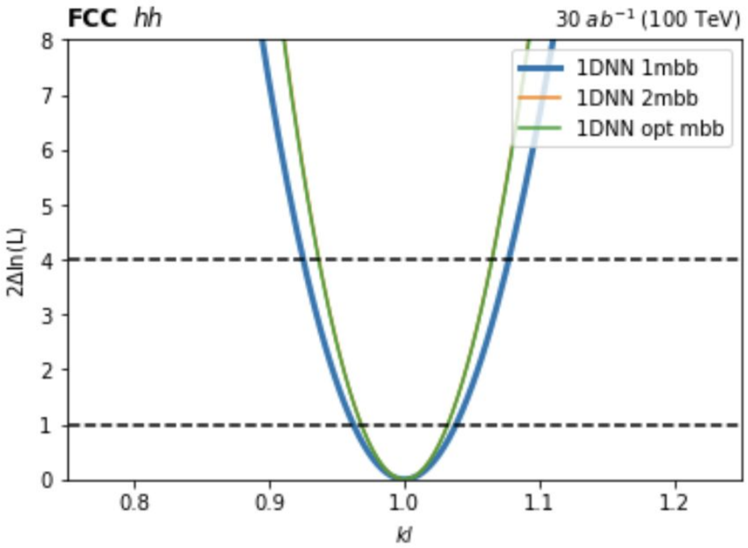
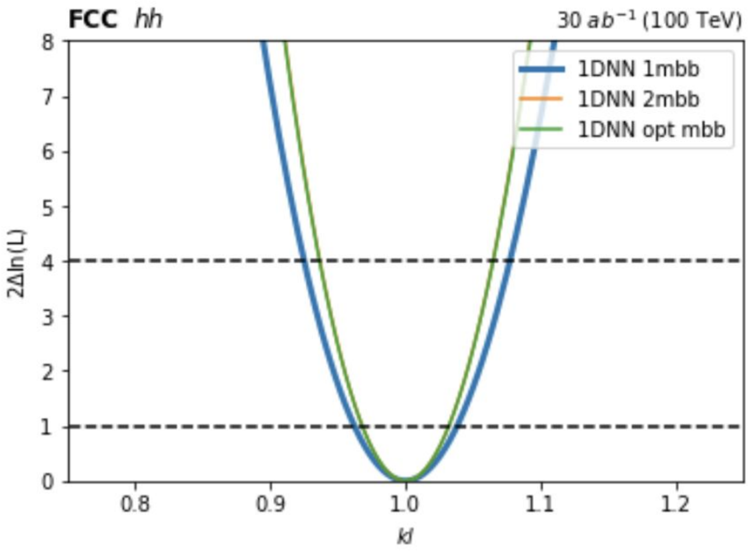


	$1\ m_{b\bar{b}}$
Stat only	3.8%
Syst I	4.4%

$\bar{b}byy$ analysis: Strategies comparison and results

Does the $m_{\bar{b}b}$ splitting optimize the sensitivity?



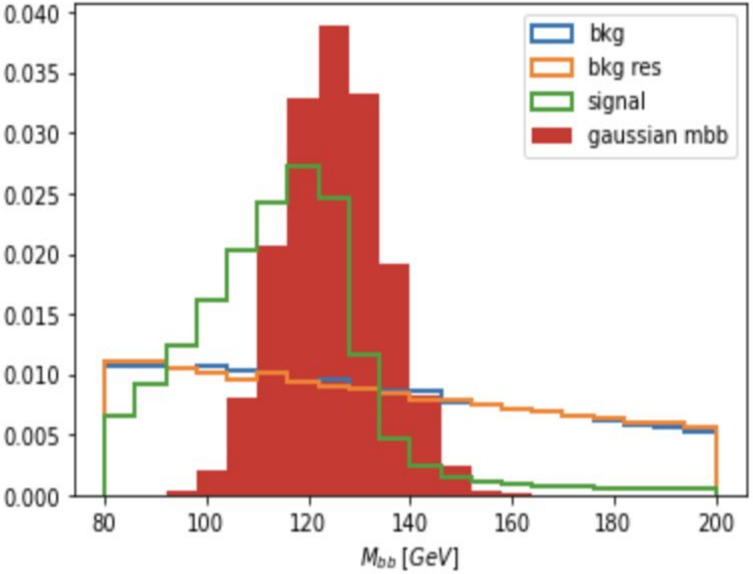
Why the solution with 2 $m_{\bar{b}b}$ binning or a $m_{\bar{b}b}$ optimize binning lead to the same precision on κ_{λ}?

	1 $m_{\bar{b}b}$	2 $m_{\bar{b}b}$	$m_{\bar{b}b}$ optBin
Stat only	3.8%	3.2%	3.2%
Syst I	4.4%	3.6%	3.6%

It's time to investigate properly the $m_{\bar{b}b}$ distribution

$b\bar{b}\gamma\gamma$ analysis: the road to 1% precision on self coupling

We assume a gaussian resolution of 10 GeV for the $m_{b\bar{b}}$ of the signal



	$m_{b\bar{b}}$ optBin	Old result
Stat only	**2.5%**	3.4%
Syst I	**2.7%**	3.8%

1.5x improvement versus the older results

Seems that the resolution on $m_{b\bar{b}}$ is the key to achieve better precision on k_λ

$b\bar{b}\gamma\gamma$ analysis: the road to 1% precision on self coupling

What happens if we assume better resolution for the $m_{b\bar{b}}$ mass?

	Stat only	Syst 1
No assumption on $m_{b\bar{b}}$ resolution	3.2%	3.6%
10 GeV $m_{b\bar{b}}$ res	2.5%	2.7%

Already better that what quoted in the documentation (3.8% syst 1)

$b\bar{b}\gamma\gamma$ analysis: the road to 1% precision on self coupling

What happens if we assume better resolution for the $m_{b\bar{b}}$ mass?

	Stat only	Syst 1
No assumption on $m_{b\bar{b}}$ resolution	3.2%	3.6%
10 GeV $m_{b\bar{b}}$ res	2.5%	2.7%
5 GeV $m_{b\bar{b}}$ res	2.0%	2.3%
3 GeV $m_{b\bar{b}}$ res	**1.8%**	**2.0%**

Already better that what quoted in the documentation (3.8% syst 1)

Conclusion

We restarted the effort of FCC-hh Higgs self-coupling studies:

- Common software tools, working on integration of our developments into the main repositories

$\bar{b}bll+E_T^{miss}$

- Cut-based analysis showing first estimates of precision 20-40% stand-alone
- Finalizing the analysis with realistic detector scenario II
- Potential further optimization/studies: Improve lepton isolation efficiencies, impact of higher levels of pile-up, MVA ...

Conclusion

We restarted the effort of FCC-hh Higgs self-coupling studies:

- Common software tools, working on integration of our developments into the main repositories

$b\bar{b}\gamma\gamma$

- We studied several analysis configuration to test the stability of our results and the precision to which we are able to measure the self coupling
  - Not much difference in applying 3 or 1 DNN, but very sensitive to the $m_{b\bar{b}}$ resolution/splitting
- Reaching ~1% precision on κ_λ seems possible only if we are able to build a detector that can have a $m_{b\bar{b}}$ resolution of 3GeV
- We are happy to study different center of mass energy scenarios:
  - 80 TeV and 120 TeV

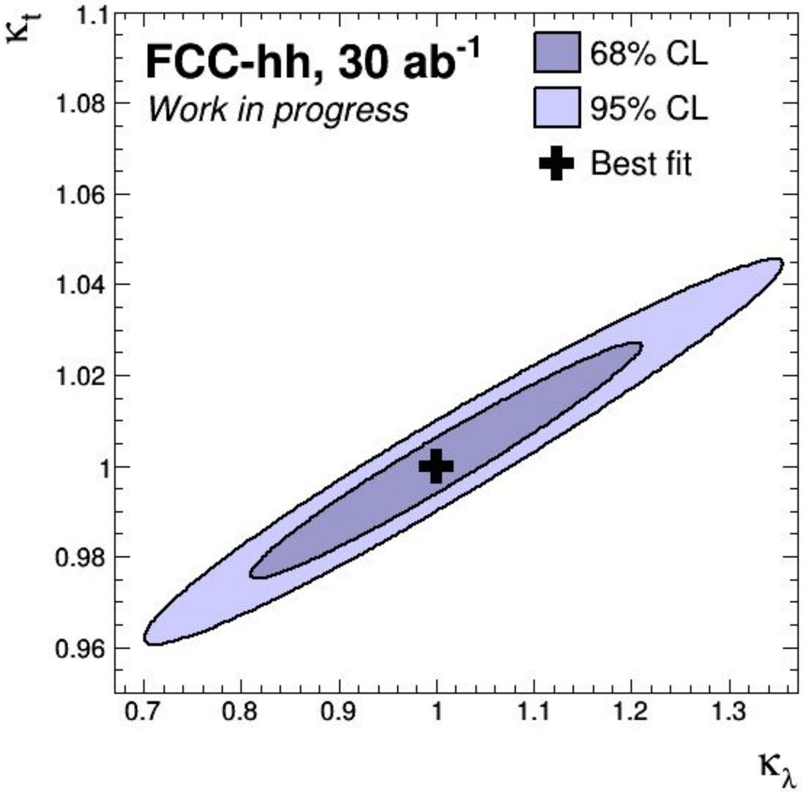
Bonus

Overview of Higgs self-coupling limits & prospects

Experiment	95% CL limit	Reference
ATLAS - *HH* - *H+HH*	$-0.6 < \kappa_\lambda < 6.6$ $-0.4 < \kappa_\lambda < 6.3$	ATLAS-HDBS-2022-03
CMS - *HH*	$-1.2 < \kappa_\lambda < 6.5$	Nature 607 (2022) 60
	$\delta\kappa_\lambda$ (68% CL)	
HL-LHC	~50%	e.g. ATL-PHYS-PUB-2022-005

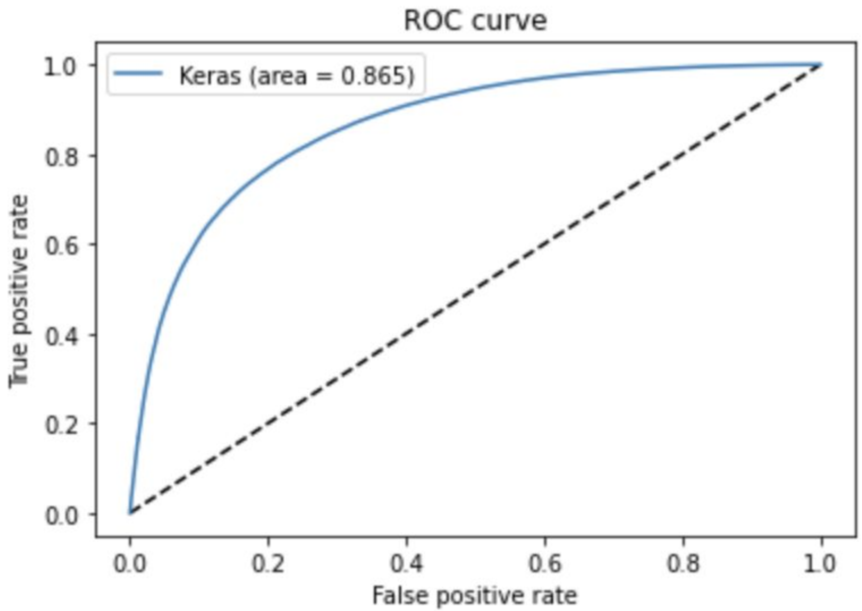
Best case scenarios for Future Colliders			
Experiment	$\delta\kappa_\lambda$ (68% CL)	Reference	
ILC (1 TeV)	10%	arXiv:2203.07622v2	*H+HH*
CLIC (3 TeV)	9%	arXiv:1812.01644v1	*H+HH*
FCC-ee	24%	JHEP01(2020)139	*H only*
μ (10 TeV)	~3.5%	arXiv:2203.07261v2	*HH*
FCC-hh	**3.4%**	***arXiv:2004.03505v2***	*HH*

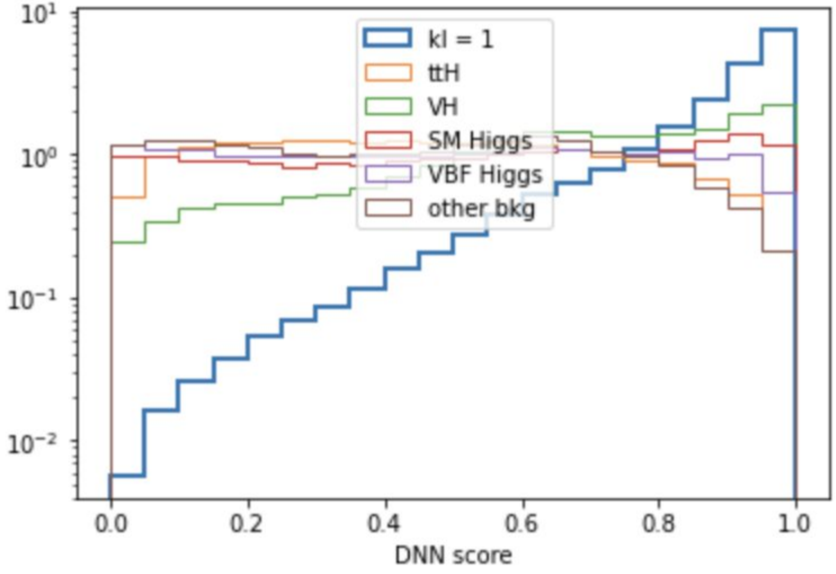
Results: Self-coupling precision



$b\bar{b}\gamma\gamma$ analysis: Strategy optimization

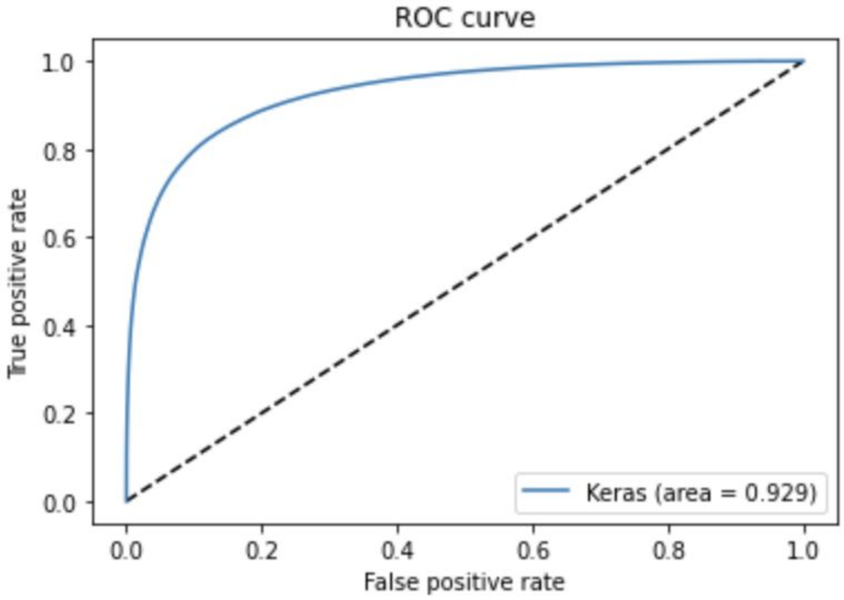
1 DNN performance

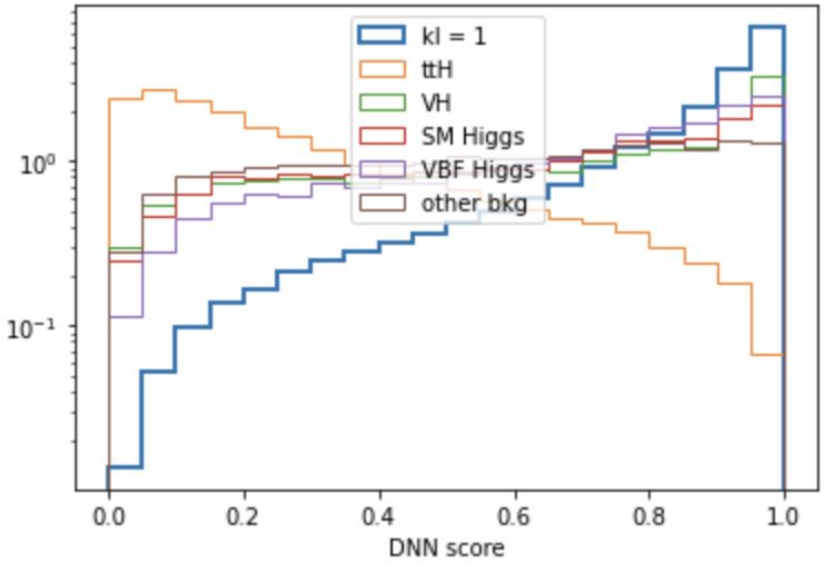




$b\bar{b}\gamma\gamma$ analysis: Strategy optimization

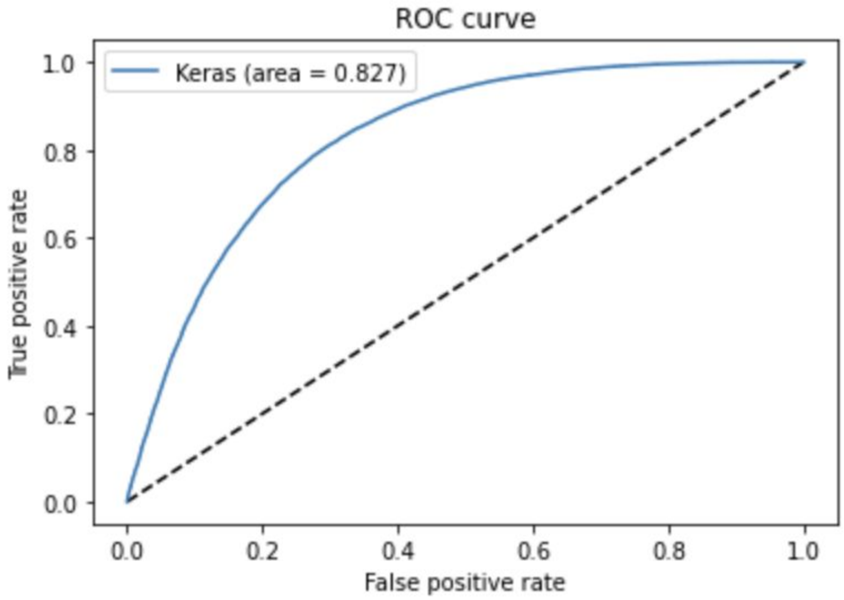
3 DNNs performances: ttH killer

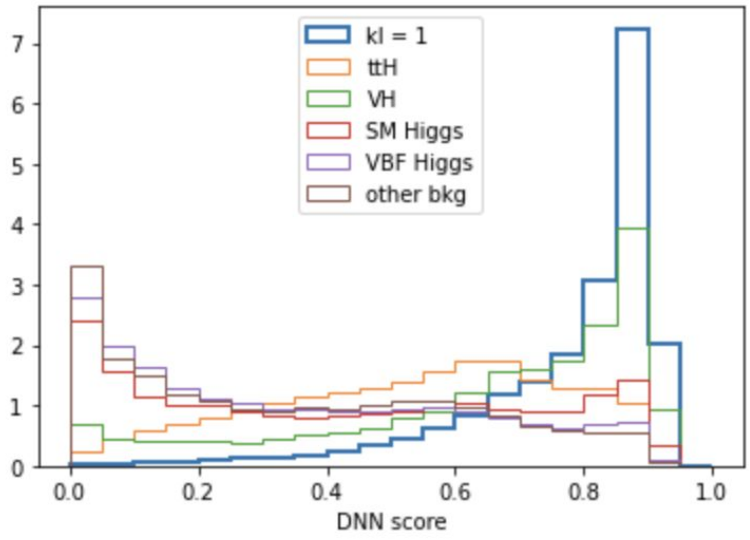




$b\bar{b}\gamma\gamma$ analysis: Strategy optimization

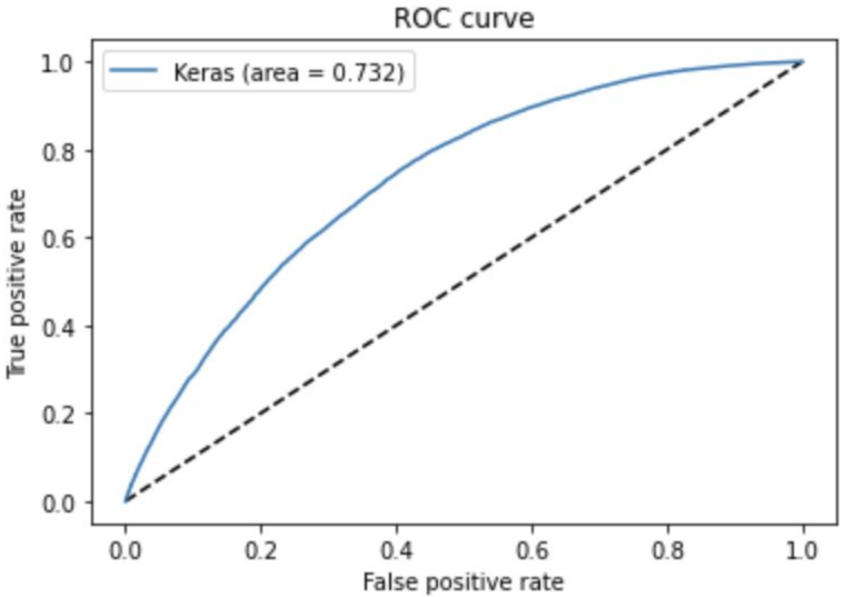
3 DNNs performances: Mx > 350

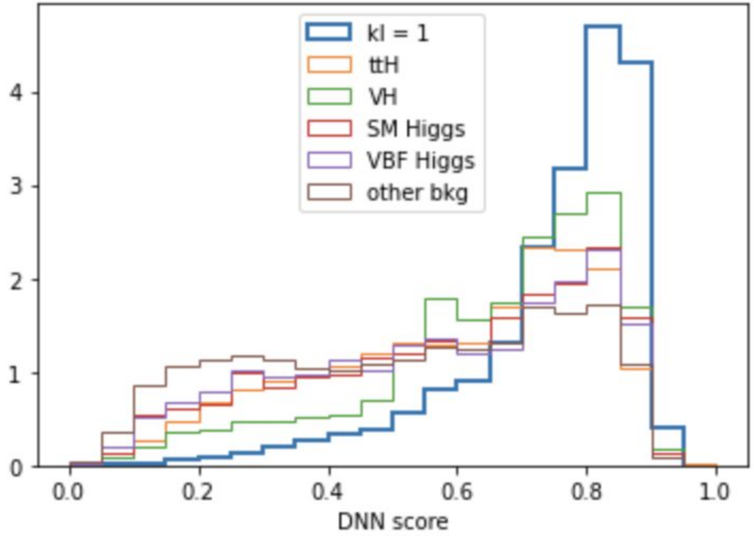




$b\bar{b}\gamma\gamma$ analysis: Strategy optimization

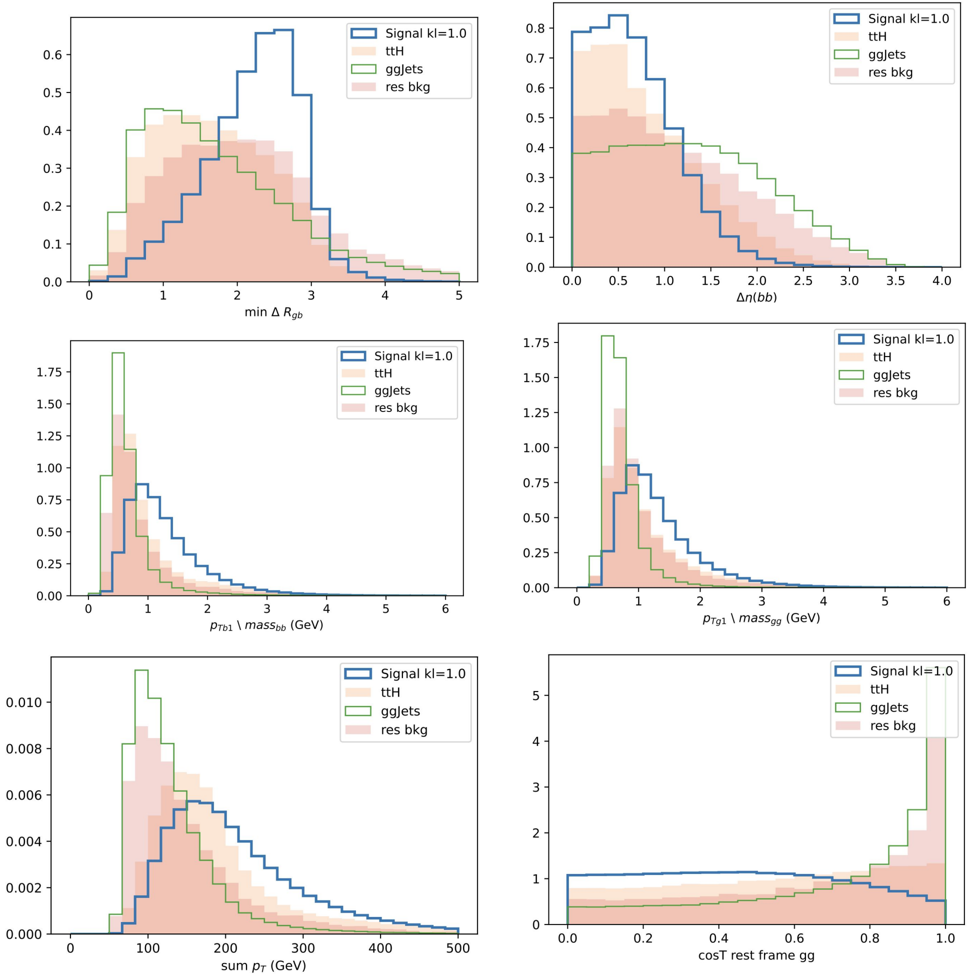
3 DNNs performances: Mx < 350





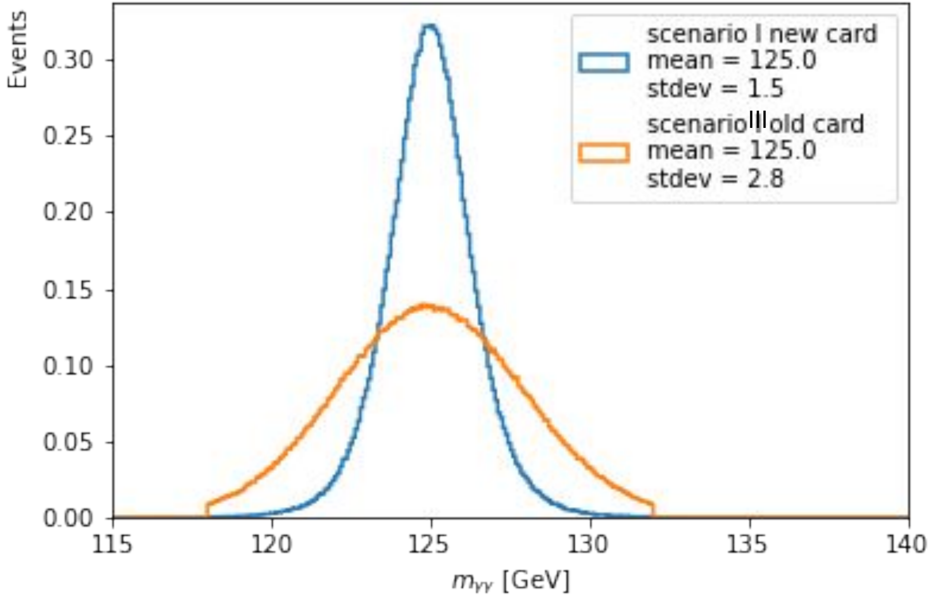
$\bar{b}b\gamma\gamma$ analysis: DNN input variables

- The number of jets (with no b tag requirement)
- The b tag of the leading and subleading jet;
- $p_T(j)/m(jj)$ of the leading and subleading jet,
- $p_T(jj)/m(jj)$ of the dijet object;
- $p_T(\gamma)/m(\gamma\gamma)$ of the leading and subleading photon;
- $p_T(\gamma\gamma)/m(\gamma\gamma)$ of the diphoton object;
- The scalar sum of the jet p_T;
- The ΔR between the closest photon-jet pair;
- The ΔR between the other photon-jet pair;
- The $\Delta\phi$ and $\Delta\eta$ between the leading and subleading photon;
- The $\Delta\phi$ and $\Delta\eta$ between the leading and subleading jet;
- The $\Delta\phi$ and $\Delta\eta$ between the diphoton and the dijet object,
- The angle between the diphoton object and the beam axis in the dijet rest frame;
- The angle between the leading jet and the beam axis in the dijet rest frame;
- The angle between the leading photon and the beam axis in the diphoton rest frame;
- Number of leptons, i.e. muons and electrons
- p_T of muons and electrons



Delphes parametrization update: m_{yy} resolution

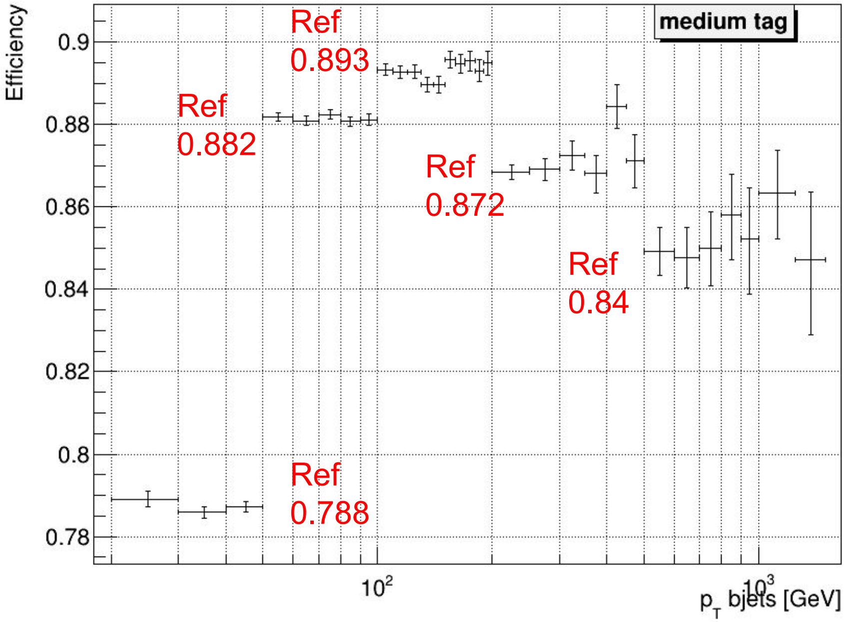
Reco level resolution obtained using $HH \rightarrow \bar{b}byy$ sample



- More aggressive resolution for m_{yy} compared to the baseline scenario

Delphes parametrization update: b-tagging

Checks were performed using 600k of $HH \rightarrow \bar{b}b\tau\tau$ events

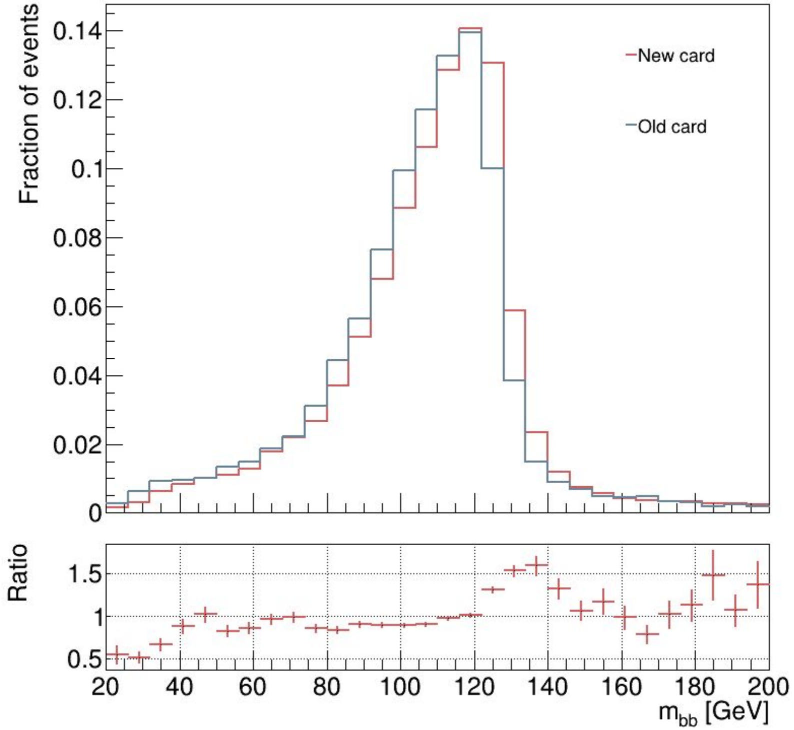


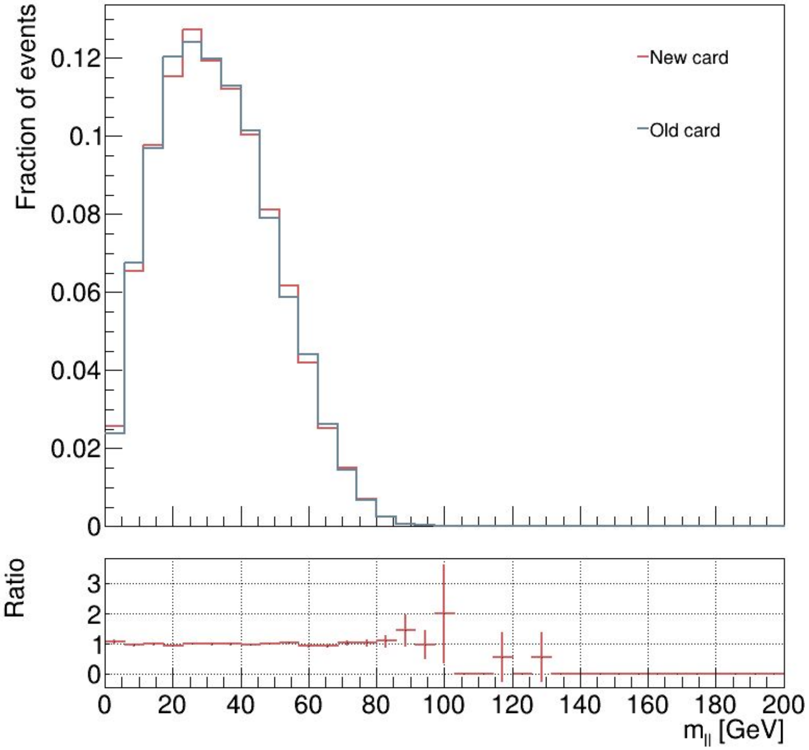
$$\text{eff.} = \frac{\text{pT reco-bjets medium, matched with a B had.}}{\text{pT reco-jet matched with a B had.}}$$

From Delphes card:

```
1.05 * (
(pt <= 20.0)                                         * (0.00) +
(abs(eta) < 4.0)            * (pt > 20.0 && pt < 50)     * (0.88) +
(abs(eta) < 4.0)            * (pt > 50.0 && pt < 100)    * (0.92) +
(abs(eta) < 4.0)            * (pt > 100.0 && pt < 200)   * (0.93) +
(abs(eta) < 4.0)            * (pt > 200.0 && pt < 500)   * (0.90) +
(abs(eta) < 4.0)            * (pt > 500.0 && pt < 1000)  * (0.87) +
(abs(eta) < 4.0)            * (pt > 1000.0)              * (0.85) +
(abs(eta) >= 4.0) * (0.00)
)
```

$\bar{b}bll+E_T^{miss}$: Mass resolution comparisons old and new Delphes card



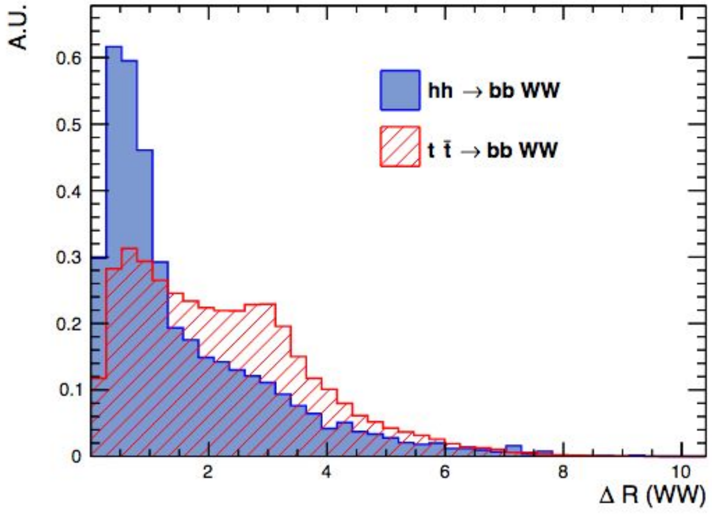


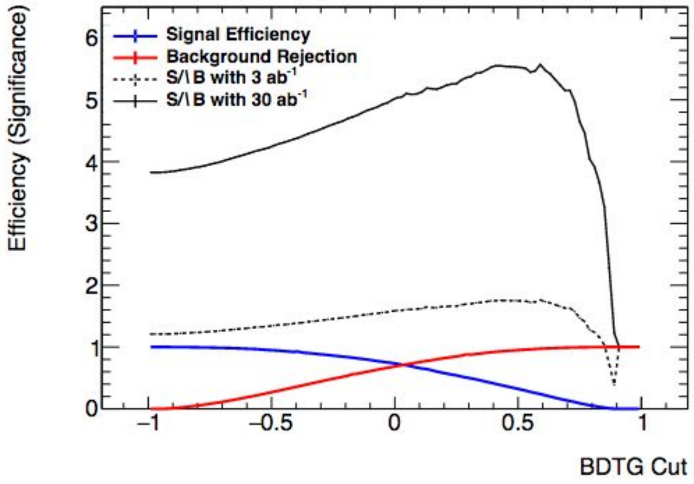
$b\bar{b}ll+E_T^{miss}$: Event selection & categorization

	DFOS	Analysis category SFOS, no Z-peak	SFOS, on Z-peak
Main signals	$b\bar{b}WW^*$, $b\bar{b}\tau\tau$	$b\bar{b}WW^*$, $b\bar{b}\tau\tau$	$b\bar{b}ZZ^*$, $b\bar{b}\tau\tau$
Selection variable		Criterion	
Lepton pair	$e\mu$	ee or $\mu\mu$	ee or $\mu\mu$
Number of b-jets		≥ 2	
m_{bb}		85 - 105 GeV	
ΔR_{bb}		< 2	
$\Delta R_{\ell\ell}$		< 1.8	
$H_{\mathrm{T2}}^{\mathrm{ratio}}$		> 0.8	
m_{lb}^{reco}		> 150 GeV	
$\Delta\phi(\ell\ell, E_T^{\mathrm{miss}})$	< 2		< 1.2
$m_{\ell\ell}$	10 - 80 GeV		81 - 101 GeV
$\Delta\phi(\ell\ell, E_T^{\mathrm{miss}})$-categories	< 1.2 ("low") and $1.2 - 2.0$ ("high")		-

Table 3.25.: Overview of the harmonized event selection and categorization.

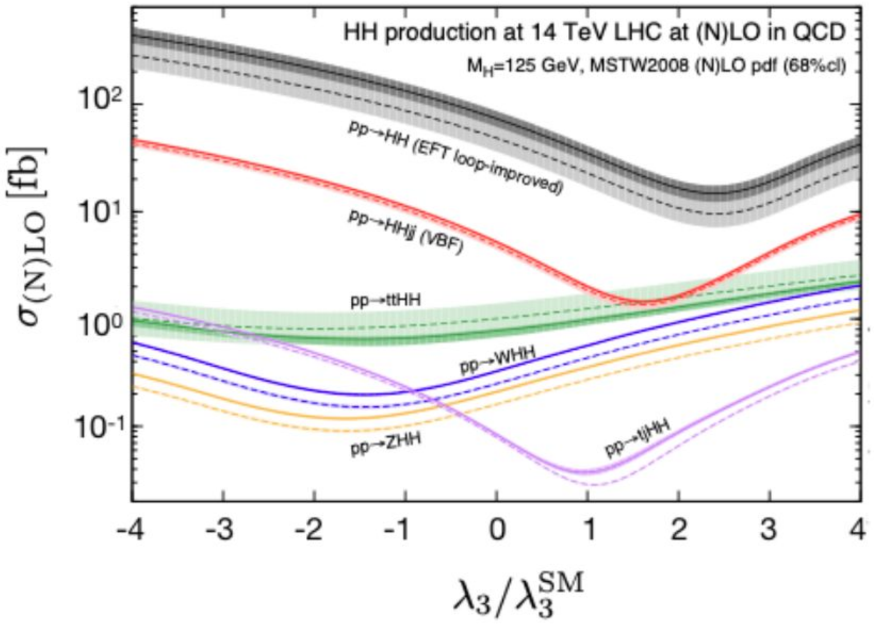
Previous projections for $\bar{b}bWW$ @ FCC-hh

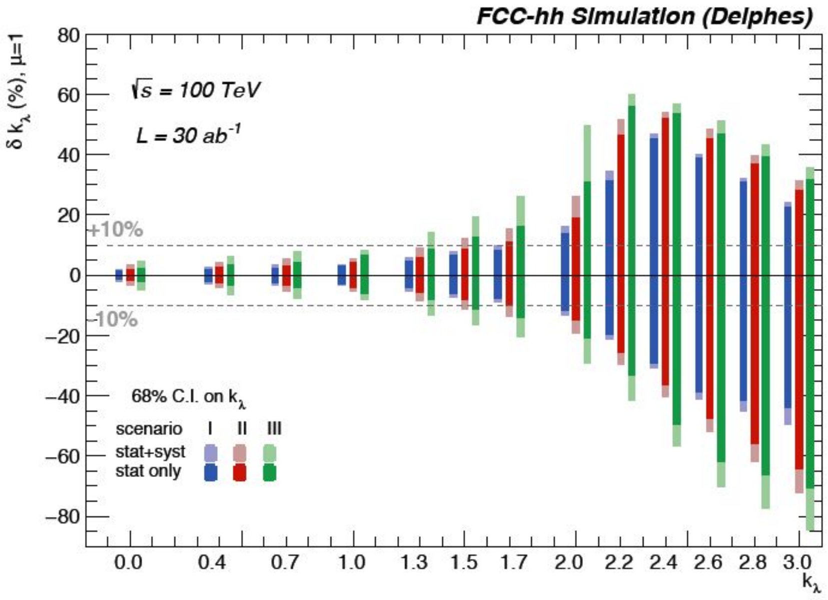




- $bbWW(2jl\nu)$ studied using BDT, with similar input variables as used here
- Achieved 40% precision (@68% CL) on κ

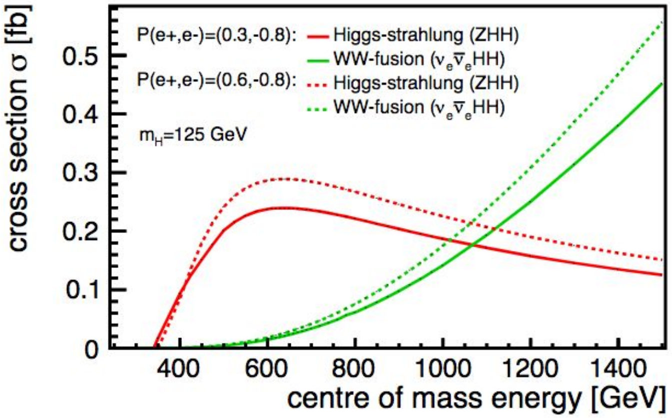
Di-Higgs cross-section dependance on κ_λ in pp-collisions

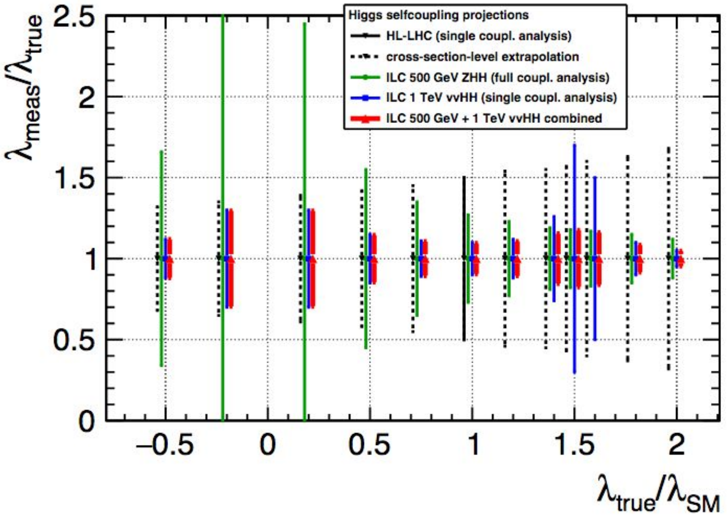




arXiv:2004.03505v2

Higgs self-coupling @ ILC





- Two production modes:
  - Higgsstrahlung, peaks ~500 GeV
  - WW-fusion, above ~1 TeV
  - → need runs at both energies for maximum κ_λ precision

- Studied dominant channels $4b$ and $bbWW$
- Advantage of ee-collider: ZHH cross-section increases with κ_λ, hence better constraints at values $\kappa_\lambda > 1$ than pp-colliders

arXiv:2203.07261v2

Higgs self-coupling @ muon collider

- Only $4b$

	3 TeV μ-coll. L≈ 1 ab^{-1}	10 TeV μ-coll. L= 10 ab^{-1}	14 TeV μ-coll. L≈ 20 ab^{-1}	30 TeV μ-coll. L= 90 ab^{-1}
	68% prob. interval			
$\delta\kappa_\lambda$	[-0.27,0.35] ∪ [0.85,0.94] →[-0.15,0.16] (2× L)	[-0.035, 0.037]	[-0.024, 0.025]	[-0.011, 0.012]

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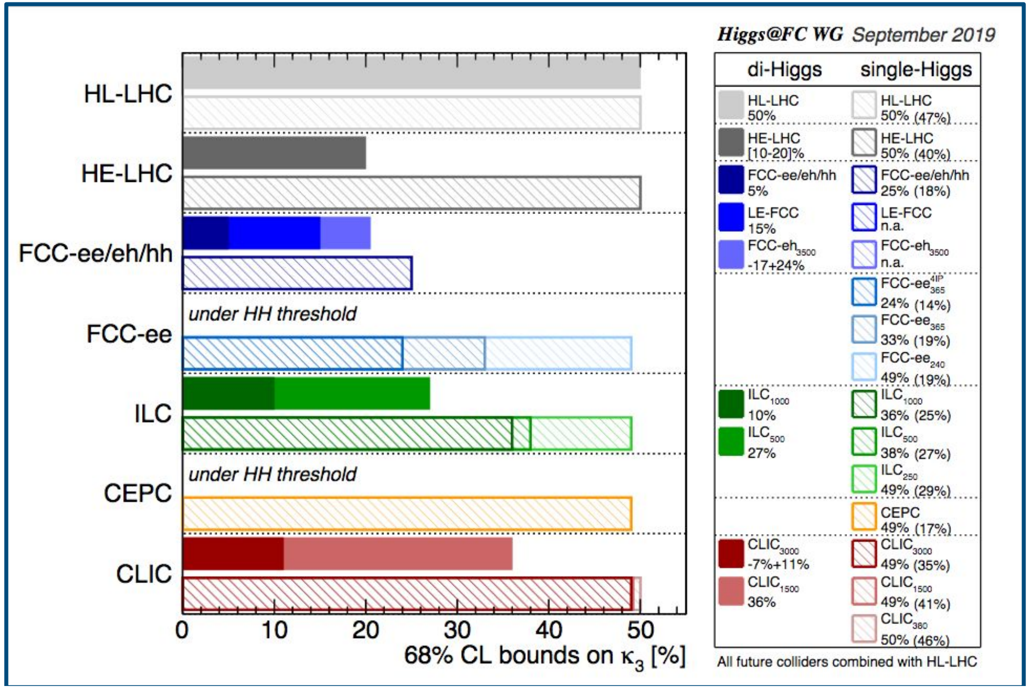
Why di-Higgs at FCC-hh?



[arXiv:1905.03764v2]

FCC-hh is the only perspective for a Higgs self-coupling precision measurement

↔

Higgs self-coupling measurement is a clear benchmark channel for the FCC-hh