Higgs self-coupling measurement via ννHH (WW-fusion) @ 1 TeV ILC

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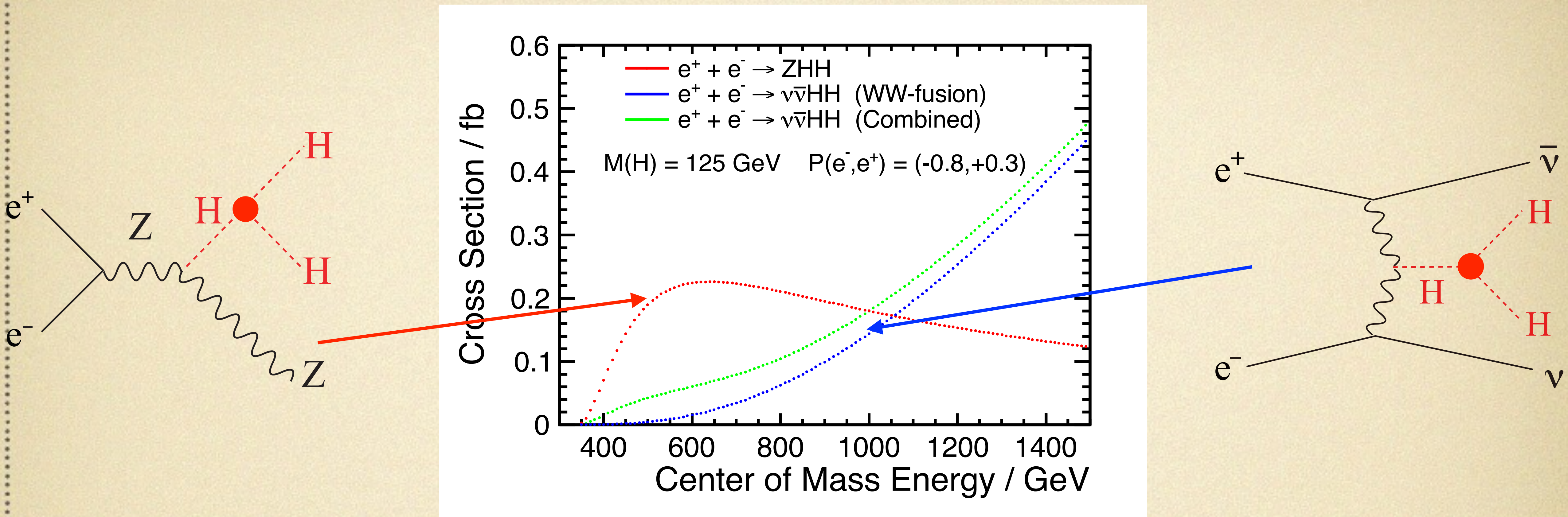
status of analysis



- ☑ DBD full simulation analyses (mH=120 GeV): ZHH @ 500 GeV, ννHH @ 1 TeV
- ☑ SGV fast simulation analysis: ννHH @ 1 TeV (consistent with full simulation)
- ☐ updating analysis of ZHH @ 500 GeV with mH=125 GeV and overlay: Claude, etc.
- ☐ updating analysis of ννHH @ 1 TeV: today's topic
- ☐ improvements of various analysis techniques and strategies; combine bb and WW* modes

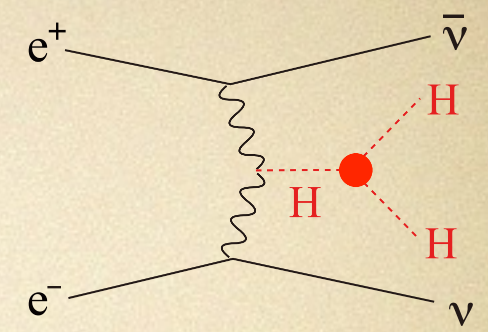
$\Delta\lambda_{HHH}/\lambda_{HHH}$	500 GeV	+ 1 TeV
Baseline	83%	21%
LumiUP	46%	13%

500 GeV: 500 (1600) fb^{-1}
1 TeV: 1000 (2500) fb^{-1}

including HH—>bbbb and HH—>bbWW*

LC-REP-2013-003 J. Tian @ LCWS14 C. Dürig @ AWLC14 M. Kurata @ ECFA2013

$$e^+ + e^- \to \nu\bar{\nu}HH \to \nu\bar{\nu}(b\bar{b})(b\bar{b})$$



(full simulation @ 1 TeV, mH = 125 GeV;
without γγ—>hadrons overlay case)

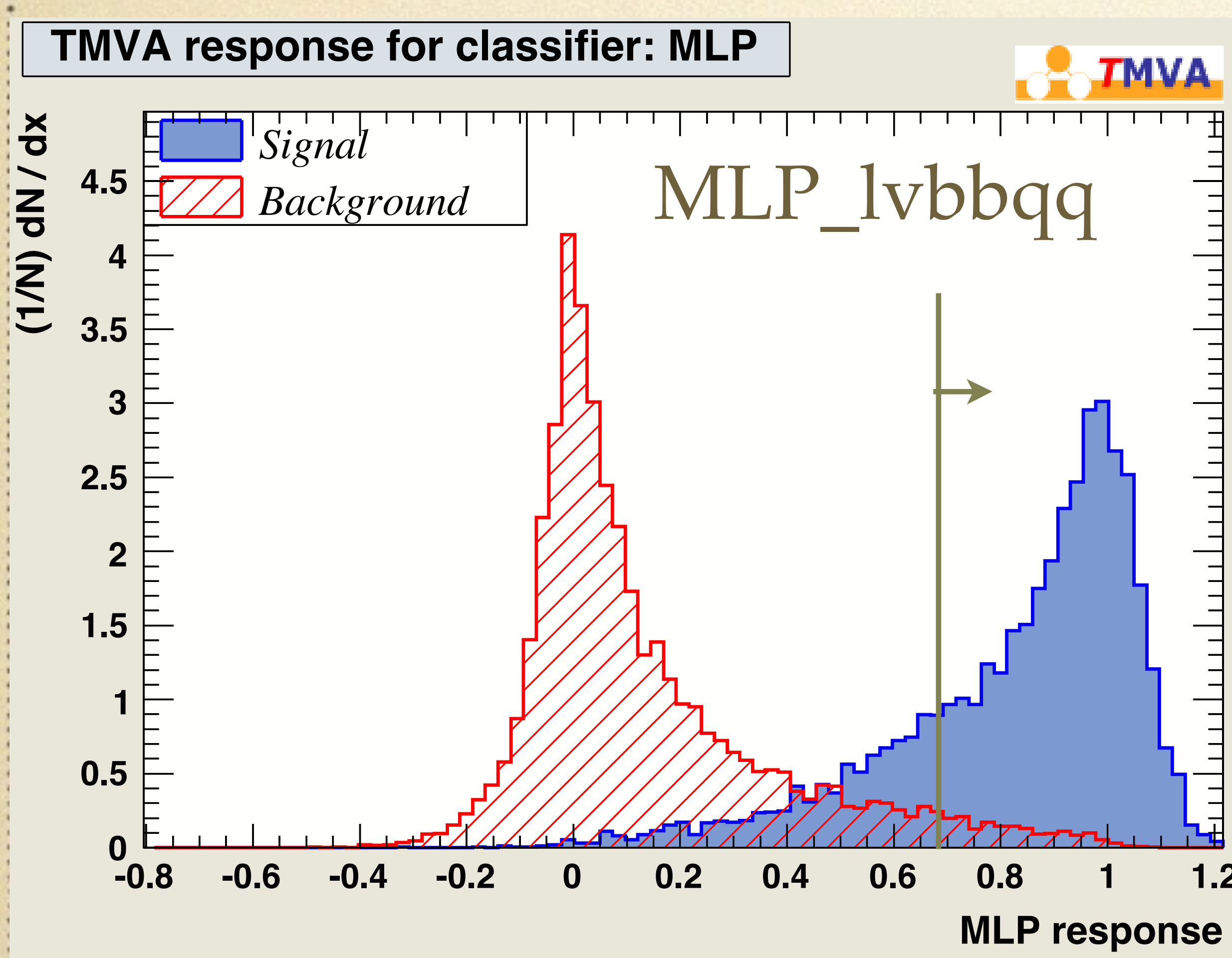
pre-selection:

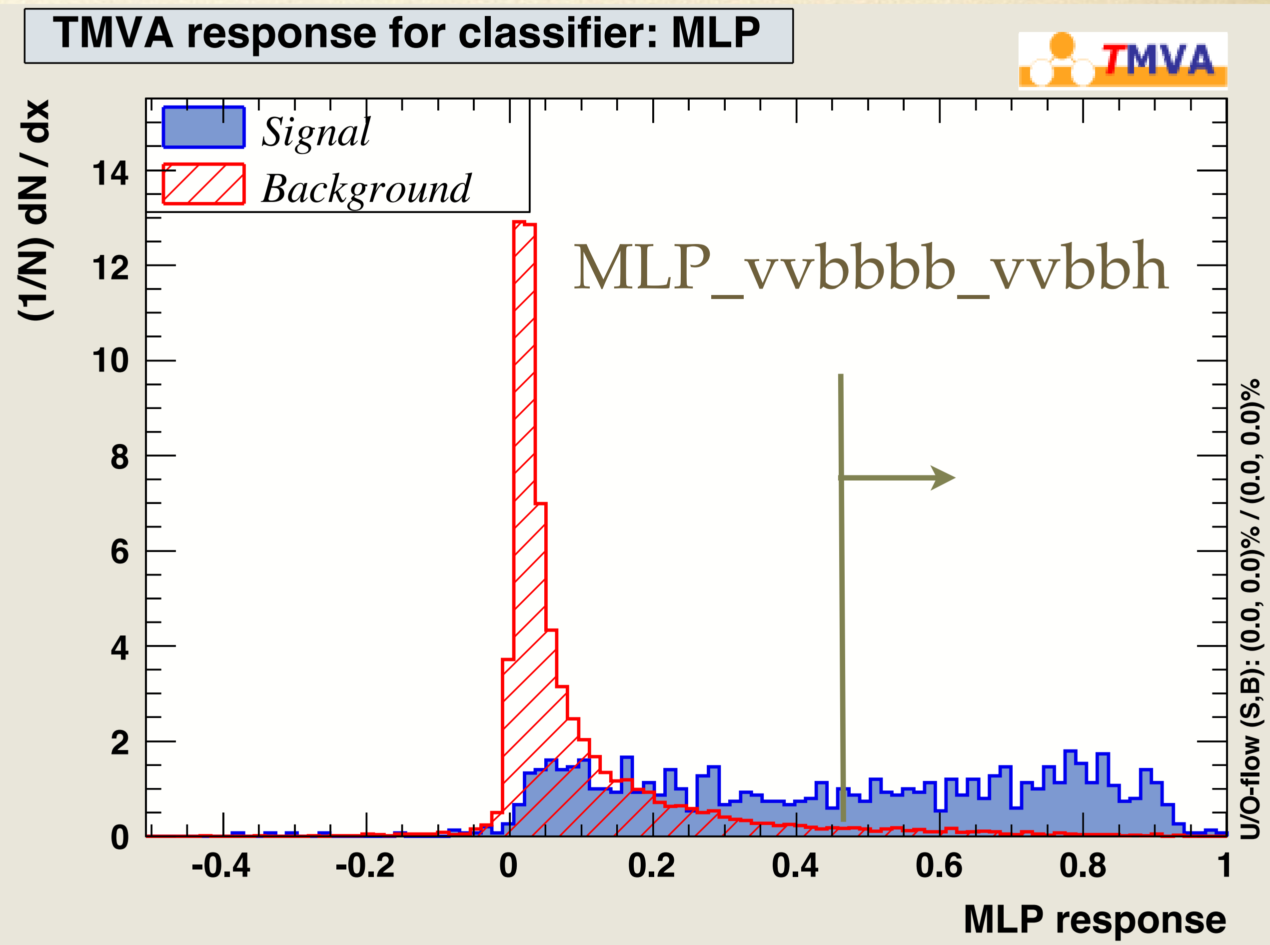
- reject events with isolated lepton (done with MVA based IsolatedLeptonTagging processor)
- cluster all particles to four jets (Durham), each with at least 7 particles, 3rd Btagging > 0.2 (done within LCFIPlus processors); pair those four jets to two Higgs by minimising χ2 defined by two pair masses.

final-selection:

- Visible energy < 900 GeV; Missing Mass > 0 (cut1)
- tt-bar suppression (MVA): MLP_lvbbqq > 0.67 (cut2)
- vvZZ and vvZH suppression (MVA): MLP_vvbbbb > 0.45 (cut3)
- B-tagging: Bmax3 + Bmax4 > 0.71 (cut4)

MVA output





inputs:

- Evis, MissPt, MissMass
- W mass case of tt4j and tt5j reconstruction
- tau mass in case of tt5j
- Pmax and Econe of leptons
- M(H1), M(H2)
- $Y_{5\text{-->}4}$

- two Z masses in case of ννZZ reconstruction
- Z and Higgs masses in case of ννZH reconstruction
- M(H1), M(H2)

see MVA details in LC-REP-2013-003

signal and backgrounds (reduction table)

P(e-,e+) = (-0.8,+0.2); Ecm = 1 TeV; mH = 125 GeV; w/o overlay $\int L = 2\ ab^{-1}$

(preliminary)

	ννHH - WWF (ννbbbb)	ννHH (ZHH)	ννZH	ννZZ	tt-bar	BG	significance
#expected	240	72.2	3.33E+03	1.72E+03	7.81E+05	7.86E+05	0.27
pre-selection	77.1(66)	23.3	472	781	2.97E+04	3.1E+04	0.44
cut1	75.2(64.4)	16	447	749	1.09E+04	1.21E+04	0.68
cut2	57.9(50.8)	5.48	260	227	397	890	1.9
cut3	33.5(29.4)	2.1	20.8	6.6	128	157	2.4
cut4	24.8(24.0)	1.57	12.1	3.34	6.86	23.9	3.6

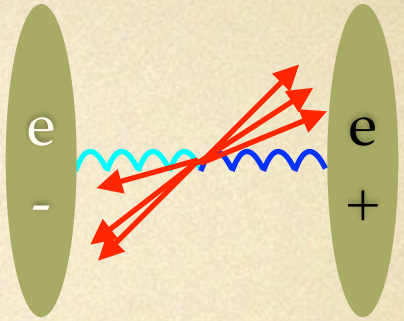
nS = 24.8, nB = 23.9 ~ 3.6σ

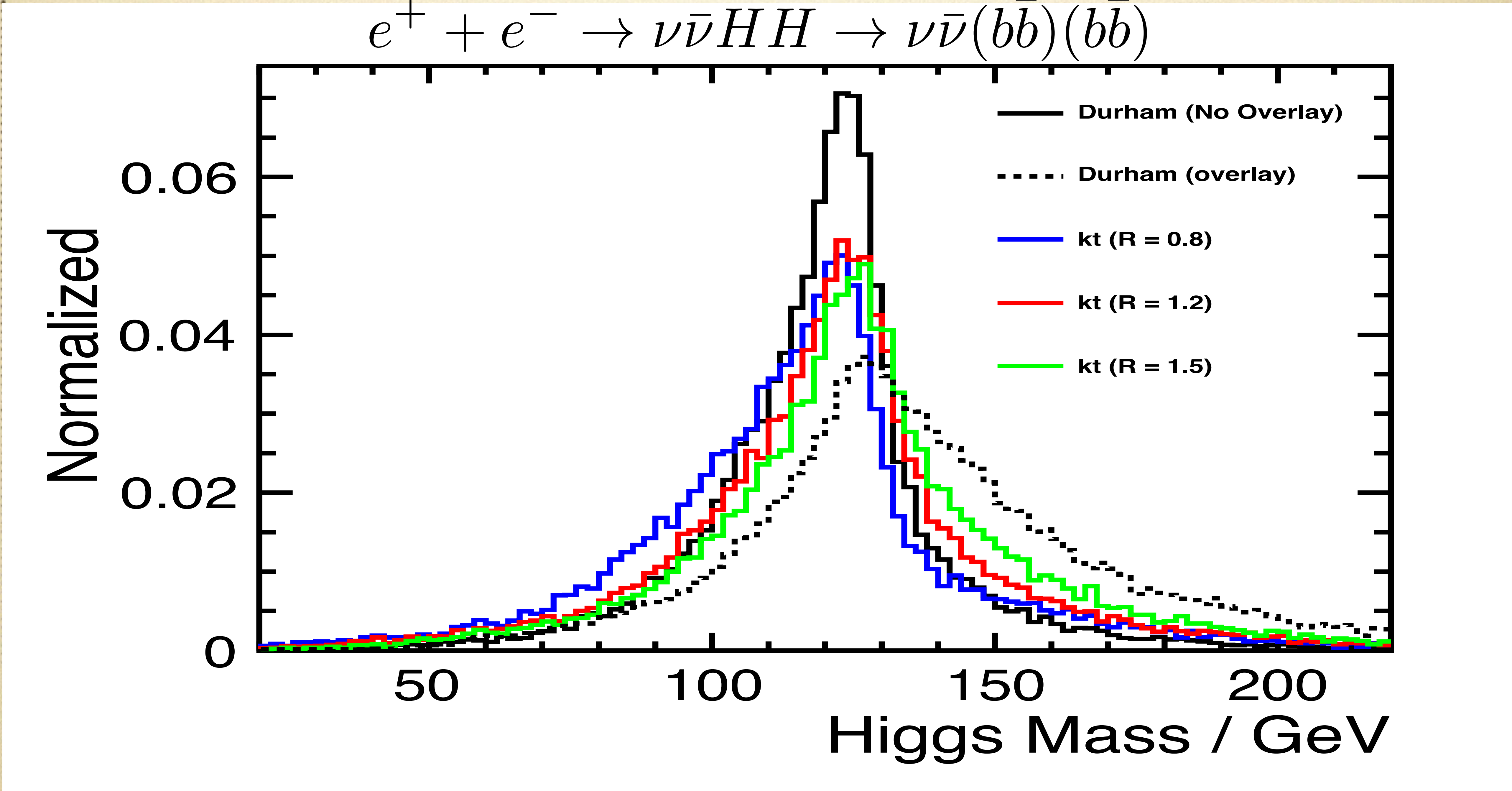
(3.7σ by previous extrapolation)

including overlay: γγ—>hadrons

- exclusive kt algorithm.
- optimization: R-value and Njets

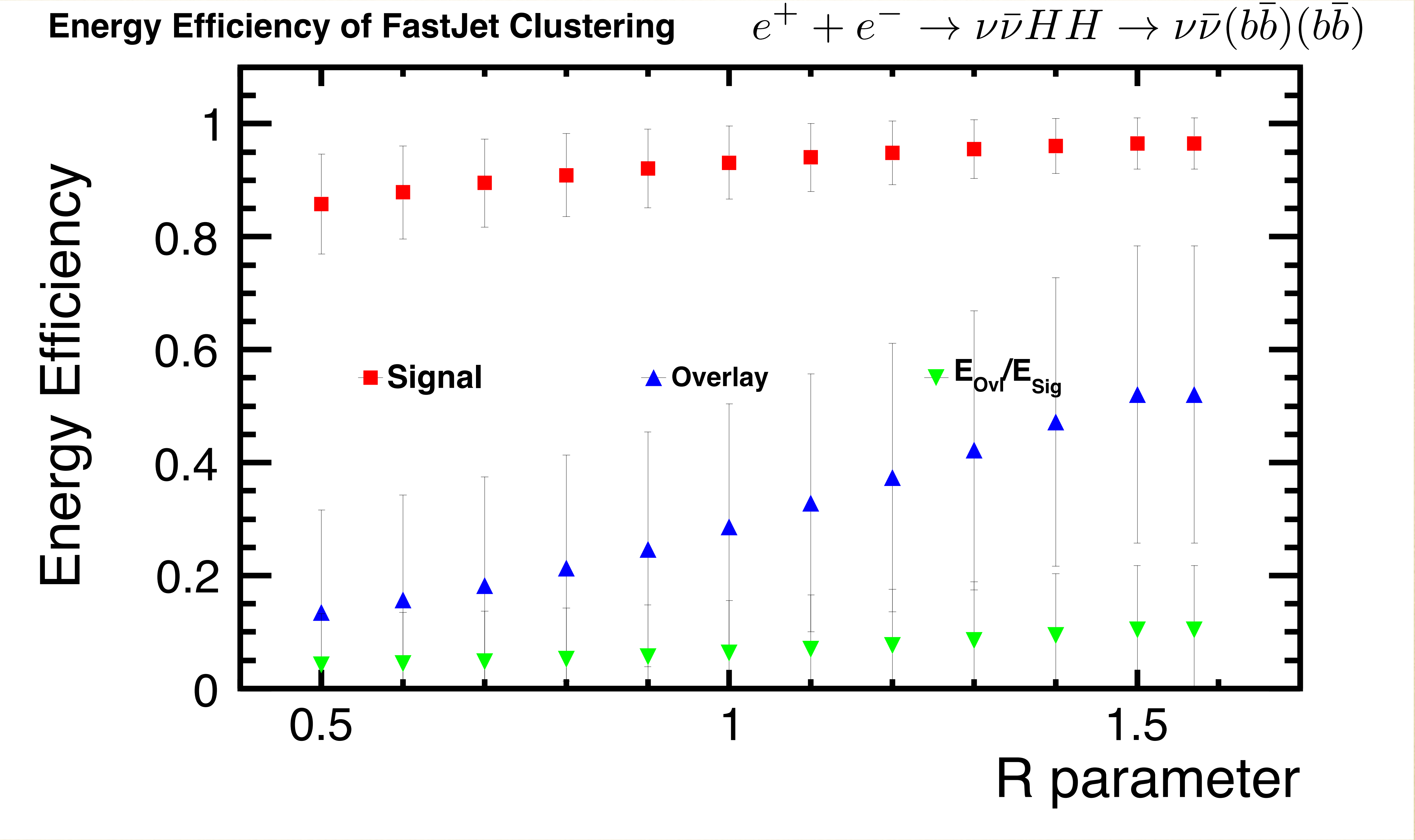
<N> = 4.1 @ 1 TeV





the overlay has a significant impact at 1 TeV!

impact of overlay



by traditional kt algorithm to remove overlay, for R=1.2, there are still ~40% (energy) of overlay remained, and having ~5-15% of remained signal particles' total energy

→ a big trouble for jet-clustering

signal and backgrounds (reduction table)

P(e-,e+) = (-0.8,+0.2); Ecm = 1 TeV; mH = 125 GeV; w/ overlay $\int L = 2\ ab^{-1}$

(very preliminary)

	ννHH - WWF (ννbbbb)	ννHH (ZHH)	ννZH	ννZZ	tt-bar	BG	significance
#expected	240	72.2	3.33E+03	1.72E+03	7.81E+05	7.86E+05	0.27
pre-selection	69.1(54.5)	19	473	600	2.94E+04	3.05E+04	0.4
cut1	66.2(52.4)	12.2	438	570	5.51E+03	6.53E+03	0.82
cut2	54.4(44.1)	4.09	322	392	759	1.48E+03	1.4
cut3	19.6(16.5)	0.445	19	6	109	134	1.6
cut4	12.6(12.2)	0.299	7.51	2.24	1.97	12.0	2.7

nS = 12.6, nB = 12.0 ~ 2.7σ

(25% degradation than case w/o overlay!)

impact of overlay: some hints from detailed comparison

- found by looking into the components of each jet: in ~18% of all events, there are jets which are dominated by overlay particles.
- this immediately lead two signal efficiencies drop: cut on #particles in each jet; cut on smallest b-likeness
- then caused wider Higgs mass —> again signal efficiency drop by mass cut to keep similar level of background
- possible healing 1: to force signal b-vertices not be merged by jet-clustering (one new feature provided by LCFIPlus)
- possible healing 2: to develop better overlay removal algorithm (start from previous study based on particle-by-particle overlay tagging algorithm, reported at LCWS13)

summary

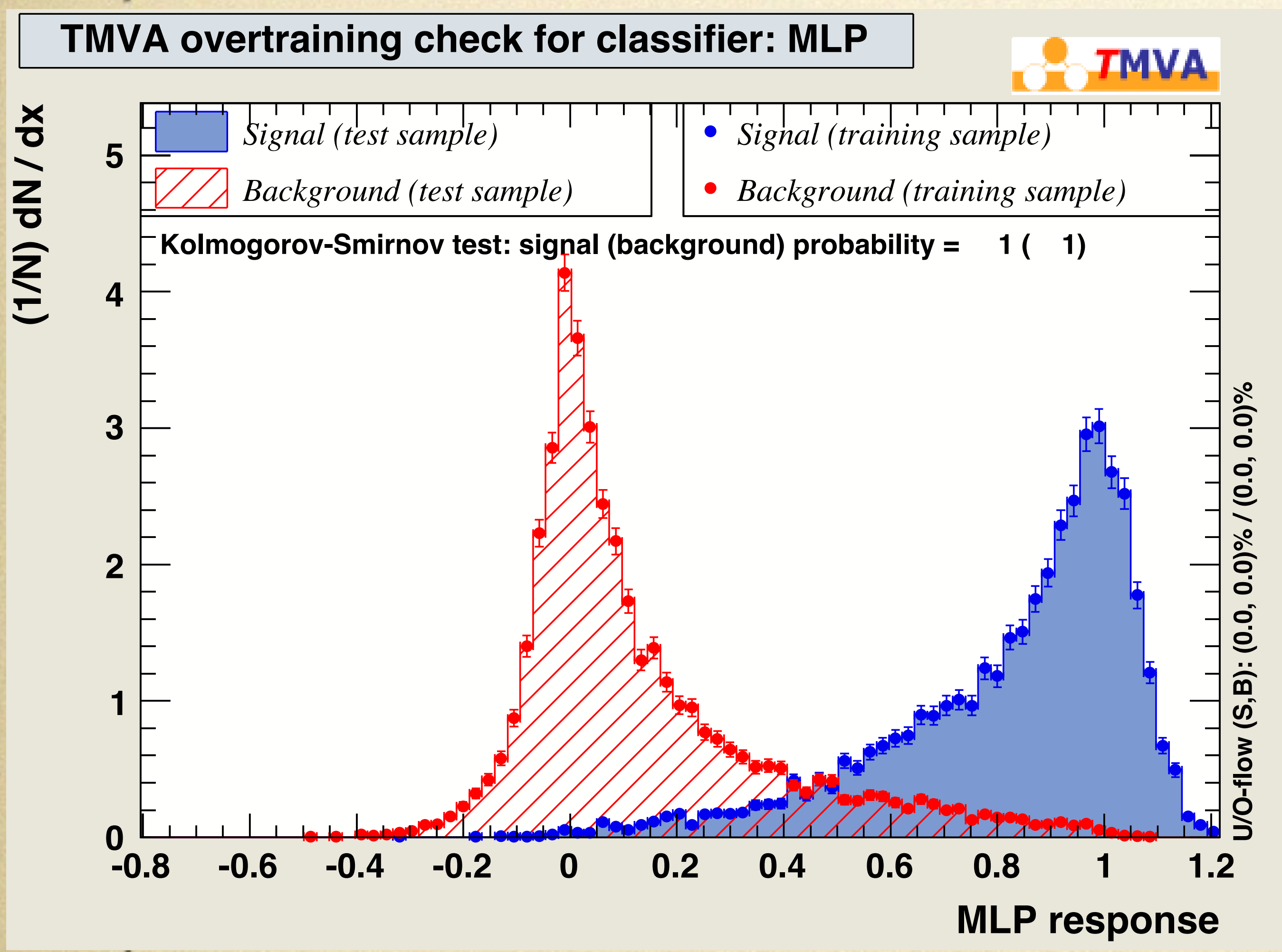
- analyses of ννHH @ 1 TeV are being updated with mH=125 GeV and γγ—>hadrons overlay, very preliminary results obtained.
- without overlay case, new results are very consistent with extrapolation from previous study done with mH=120 GeV.
- overlay <N>=4.1 at 1 TeV has a significant impact ~25% degradation; next step will focus on new strategies to heal this problem
- in addition to overlay, also think about improvements of other part of the analysis: new isolation; use tau finder to suppress further τνbbqq background; new jet clustering and pairing; cuts re-optimization for coupling instead of cross section, etc.

status and plan for 2015

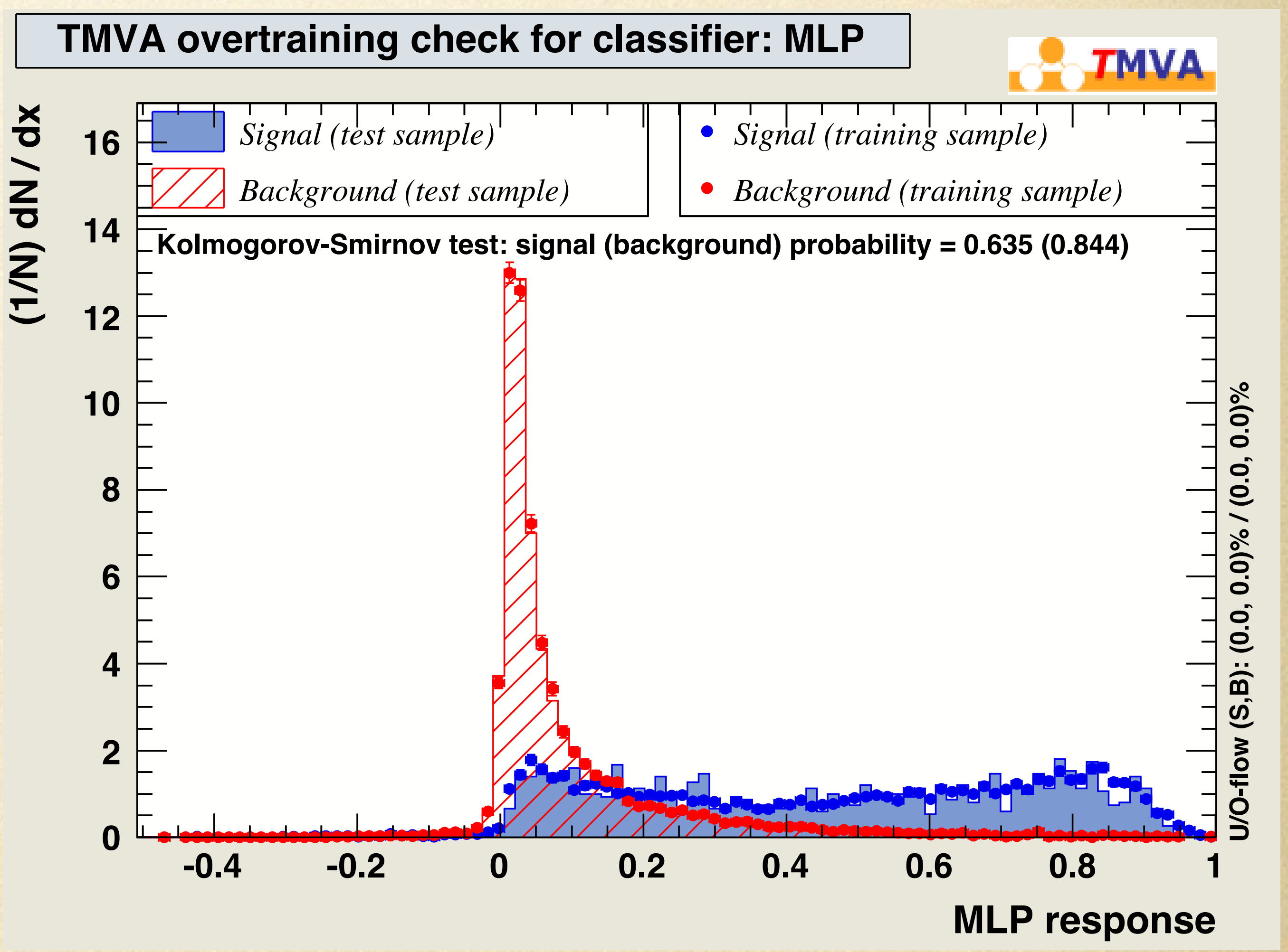
- Higgs self-coupling
  - collaboration with Claude and Masakazu
  - short-term: update ννHH @ 1 TeV analysis including overlay and mH=125 GeV, towards one publication
  - mid-term: improve ZHH @ 500 GeV with kinematic fitting, matrix element method, cut re-optimization, etc.
  - combine HH—>bbbb and HH—>bbWW*
- Matrix element method
  - continue development with more complement set of e+e- processes
  - try to implement detector transfer function and apply for analysis
- Color-singlet jet clustering
  - investigate the implementation of color correlation inside Pythia; to understand how color-singlet characteristics are implement in generator
  - combine the previous effort on Georgi Jet Clustering and Color-singlet Jet Clustering.

Backup

MVA overtraining test



MLP_lvbbqq



MLP_vvbbbb_vvbbh

DBD full simulation

Higgs self-coupling @ 1 TeV

P(e-,e+)=(-0.8,+0.2) $e^+ + e^- \to \nu\bar{\nu}HH$ $M(H) = 120\text{GeV}$ $\int Ldt = 2\text{ab}^{-1}$

	Expected	After Cut
ννhh (WW F)	272	35.7
ννhh (ZHH)	74	3.88
BG (tt/ννZH)	7.86×10^5	33.7
significance	0.3	4.29

- better sensitive factor
- benefit more from beam polarisation
- BG tt x-section smaller
- more boosted b-jets

$$\frac{\Delta\sigma}{\sigma} \approx 23\% \qquad \frac{\Delta\lambda}{\lambda} \approx 18\%$$

Double Higgs excess significance: $> 7\sigma$

Higgs self-coupling significance: $> 5\sigma$

DBD analysis (no gam-gam overlay):

signal and backgrounds (reduction table)

Polarization: (e-,e+)=(-0.8,+0.2) $E_{\rm cm} = 1$ TeV, $M_H = 120$ GeV $\int L = 2\ {\rm ab}^{-1}$

	Expected	Generated	pre-selction	cut1	cut2	cut3	cut4
νvhh (WW F)	272	1.05×10⁵	127	107	77.2	47.6	35.7
νvhh (ZHH)	74	2.85×10⁵	32.7	19.7	6.68	4.88	3.88
ννbbbb	650	2.87×10⁵	553	505	146	6.21	4.62
ννccbb	1070	1.76×10⁵	269	242	63.3	2.69	0.19
yyxyyx	3.74×10⁵	1.64×10⁶	18951	4422	38.5	26.7	1.83
yyxyeν	1.50×10⁵	6.21×10⁵	812	424	44.4	11	0.73
yyxylν	2.57×10⁵	1.17×10⁶	13457	4975	202	84.5	4.86
ννZH	3125	7.56×10⁴	522	467	257	30.6	17.6
BG	7.86×10⁵		34597	11054	758	167	33.7
significance	0.3		0.68	1.01	2.67	3.25	4.29

$$\frac{\Delta\sigma}{\sigma} \approx 23\%$$

$$\frac{\Delta\lambda}{\lambda} \approx 20\%$$ (18%) (with weighting)

Double Higgs excess significance: 7.2σ

Preliminary results for 125 GeV without overlay

$P(e-,e+) = (-0.8,+0.3)$, $\int L dt = 2\ ab^{-1}$

- m_H = 120 GeV results extrapolated to 125 GeV give a precision of 53% on Higgs self-coupling
- preliminary results without overlay

modes	signal	background	significance excess	significance measurement
$ZHH \to l^-l^+HH$	3.0	4.3	1.16σ	0.91σ
	3.3	6.0	1.12σ	0.91σ
$ZHH \to \nu\bar{\nu}HH$	5.2	6.9	1.63σ	1.37σ
$ZHH \to q\bar{q}HH$	9.2	20.9	1.82σ	1.64σ
	7.7	23.5	1.45σ	1.31σ

cross section: $\frac{\Delta\sigma_{ZHH}}{\sigma_{ZHH}} = 32.6\%$

Higgs self-coupling: $\frac{\Delta\lambda}{\lambda} = 53\%$

	500 GeV at $\mathcal{L} = 2\ ab^{-1}$		
scenario	A	B	C
extrapolated	53%	42%	34%
full analysis	53%	42%	34%

Extrapolation works, slightly conservative

Scenario A: $HH \to bbbb$

Scenario B: with $HH \to bbWW^*$, $\approx$ 20% improvement

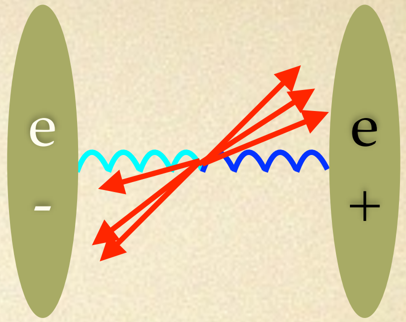
Scenario C: analysis improvement (kinematic fit, jet-clustering, etc.), expect 20% improvement

We achieve a precision of 53% on the Higgs self-coupling for $m_H = 125$ GeV!

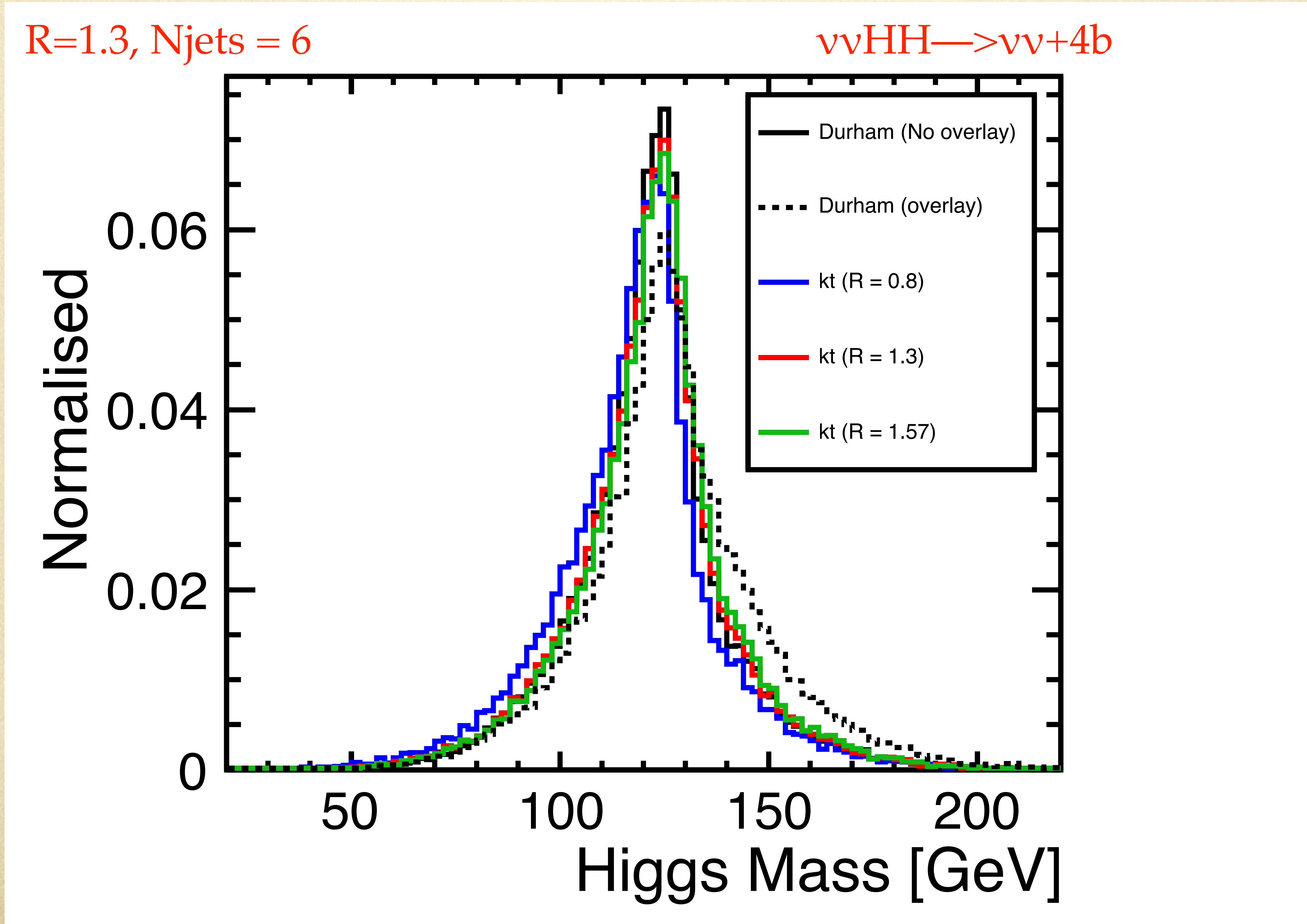
Effect of $\gamma\gamma$-overlay?

effect of overlay and strategy of removal: γγ—>hadrons

- exclusive kt algorithm.
- optimization: R-value and Njets



<N> = 1.7 (1.2) @ 500 GeV



impact of overlay on self-coupling

Preliminary results for 125 GeV with overlay

modes	signal	background	significance excess	significance measurement
$ZHH \to l^- l^+ HH$	2.7	5.9	0.91σ	0.72σ
	3.4	8.0	1.01σ	0.85σ
$ZHH \to \nu\bar{\nu}HH$	5.6	9.0	1.45σ	1.23σ
$ZHH \to q\bar{q}HH$	8.3	21.8	1.61σ	1.45σ
	8.7	38.2	1.31σ	1.21σ

cross section: $\frac{\Delta\sigma_{ZHH}}{\sigma_{ZHH}} = 35.4\%$

Higgs self-coupling: $\frac{\Delta\lambda}{\lambda} = 58.1\%$

500 GeV at $\mathcal{L} = 2\ ab^{-1}$			
scenario	A	B	C
w/o overlay	53%	42%	34%
w/ overlay	58%	47%	37%

Scenario A: $HH \to bbbb$
Scenario B: with $HH \to bbWW^*$, $\approx$ 20% improvement
Scenario C: analysis improvement (kinematic fit, jet-clustering, etc.), expect 20% improvement

Considering $\gamma\gamma$-overlay, we achieve a precision of 58% on the Higgs self-coupling

1 TeV at $\mathcal{L} = 2.5\ ab^{-1}$		
A	B	C
16%	13%	10%

arXiv:1310.0763v3[hep-ph]

Using additional WW-fusion data at 1 TeV we can achieve a precision of 10% on the Higgs self-coupling (w/o overlay)

it has a significant impact (8% worse); with few more overlaid particles, some background can be more like signal; we still need look into some detail to improve this; on the other hand, <N> of overlay is currently over estimated.