$H \rightarrow \gamma\gamma$ @ 3 TeV

Discussion on the paper to be submitted CLICdp-Draft-2021-003

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Status and Open issues

- PhD analyses started 2015
- Results presented:
  - CLICdp AWG: 21 Feb 2017, 22 Aug 2017, 24 Feb 2020, 27 Jan 2020
  - CLIC WS 2017, 2021
  - ALPS 2019
  - LCWS21
- Paper submitted to the Pub. Com. 25th of January 2021
- Draft number CLICdp-Draft-2021-003 assigned
- Resolved issue of systematic uncertainty estimate from the reconstruction of the luminosity spectrum

(P. Roloff commented that our estimate based of fraction of selected signal events at various center-of-mass energies is too conservative – leads to overestimate)

Are we double-counting background by including mono-photon processes (eeγ, $\nu\nu\gamma$, qqγ)?

- A bit of a history…
  - These processes were considered in the same analysis at 1.4 TeV (published in the Higgs paper)
  - WHIZARD V1.95 used in both analyses
  - …under similar user's requirements

1.4 TeV   samples   3 TeV

Process	σ[fb][1]	Events in 1.5 ab^{-1}	Events Available[2]	Event Weights
$e^+e^- \to \nu\bar{\nu}\gamma$	30	44000	50000	0.9
$e^+e^- \to \nu\bar{\nu}\gamma\gamma$	17	26000	22000	1.2
$e^+e^- \to \gamma\gamma$	27	41000	32000	1.3
$e^+e^- \to e^+e^-\gamma$	290	430000	285000	1.5
$e^+e^- \to e^+e^-\gamma\gamma$	13	19000	5500	3.5
$e^+e^- \to q\bar{q}\gamma$	67	100000	92000	1.1
$e^+e^- \to q\bar{q}\gamma\gamma$	17	25000	16000	1.5

Signal process	$\sigma(fb)$	$N@5ab^{-1}$	$N_{simulated}$
$e^+e^- \to H\nu\nu, H \to \gamma\gamma$	0.95	4750	24550
Background processes	$\sigma(fb)$		
$e^+e^- \to \gamma\gamma$	19	$9.5 \cdot 10^5$	$3 \cdot 10^4$
$e^+e^- \to e^+e^-\gamma$	797	$4.0 \cdot 10^6$	$3 \cdot 10^6$
$e^+e^- \to e^+e^-\gamma\gamma$	56	$2.8 \cdot 10^5$	$1.5 \cdot 10^5$
$e^+e^- \to \nu\bar{\nu}\gamma$	47	$2.4 \cdot 10^5$	$2 \cdot 10^5$
$e^+e^- \to \nu\bar{\nu}\gamma\gamma$	49	$2.5 \cdot 10^5$	$1.6 \cdot 10^5$
$e^+e^- \to q\bar{q}\gamma$	363	$1.9 \cdot 10^6$	$1.2 \cdot 10^6$
$e^+e^- \to q\bar{q}\gamma\gamma$	59	$3.0 \cdot 10^5$	$3 \cdot 10^5$

Cuts on generated final states*:

- At least two photons with $E > 10\,\text{GeV}$, $p_T > 5\,\text{GeV}$ and $5° < \theta < 175°$
- At least one Higgs candidate with $110\,\text{GeV} < M(\gamma\gamma) < 140\,\text{GeV}$
- No visible lepton or quark with $10° < \theta < 170°$

**Second photon comes from ISR or FSR (background)*

Cuts on generated final states*:

1. di-photon invariant mass in the window (100-150) GeV
2. at least two photons in event with polar angle between 5 deg and 175 deg
3. p_T > 10 GeV of the photons
4. *We haven't restricted q or l in the tracker – can be refined*

Available samples at MonteCarloSamplesForTheHiggsPaper

Type	Energy	Detector	ProdID	Events planned	Events produced	σ [fb]	Comments
ee -> qqγγ	3 TeV	CLIC_ILD	6966	250000	299600	72.3	WHIZARD V57, m(h) = 12 TeV
ee -> qqγ	3 TeV	CLIC_ILD	6969	1000000	1198600	583.6	WHIZARD V57, m(h) = 12 TeV
ee -> γνν	3 TeV	CLIC_ILD	6981	150000	194900	16806.4*	WHIZARD V57, m(h) = 12 TeV, preselection cuts for the H->gammagamma analysis ("cuts_h_gammagamma_3000.txt")
ee -> γγee	3 TeV	CLIC_ILD	6984	120000	144900	4244.7*	WHIZARD V57, m(h) = 12 TeV, preselection cuts for the H->gammagamma analysis ("cuts_h_gammagamma_3000.txt")
ee -> γγνν	3 TeV	CLIC_ILD	7014	120000	155500	2616.6*	WHIZARD V57, m(h) = 12 TeV, preselection cuts for the H->gammagamma analysis ("cuts_h_gammagamma_3000.txt")
ee -> γγ	3 TeV	CLIC_ILD	7017	20000	29900	866.9*	WHIZARD V57, m(h) = 12 TeV, preselection cuts for the H->gammagamma analysis ("cuts_h_gammagamma_3000.txt")
ee -> eeγ	3 TeV	CLIC_ILD	7020	3000000	3039000	185392.3*	WHIZARD V57, m(h) = 12 TeV, preselection cuts for the H->gammagamma analysis ("cuts_h_gammagamma_3000.txt")

Discussion

Are we double-counting background by including mono-photon processes (eeγ, ννγ, qqγ)?

- There are several questions that can be asked:

1) *Are cross-sections for processes with a single photon in the final state correctly reproduced in WHIZARD V1.95?*
2) *Is kinematics of the final state photon properly described?*

YES

If yes, than it is not justified to omit these processes because, apparently second photon can be found at the reconstruction level in a sufficient amount to mimic the signal

N_{BDT}, for integrated luminosity of 5 ab^{-1}

Process	$\varepsilon_{pre}(\%)$	$\varepsilon_{BDT}(\%)$	N_{BDT}
$e^+e^- \to H\nu\nu, H \to \gamma\gamma$	70	62.0	2062
$e^+e^- \to \gamma\gamma^*$	0.10	13.7	624
$e^+e^- \to e^+e^-\gamma^*$	0.03	9.8	26598
$e^+e^- \to e^+e^-\gamma\gamma^*$	0.05	7.4	788
$e^+e^- \to \nu\nu\gamma^*$	0.09	25.0	18585
$e^+e^- \to \nu\nu\gamma\gamma^*$	0.04	24.5	11628
$e^+e^- \to qq\gamma$	0.50	7.5	1089
$e^+e^- \to qq\gamma\gamma$	1	10.1	423

NO

If not, than it depends what is wrong:

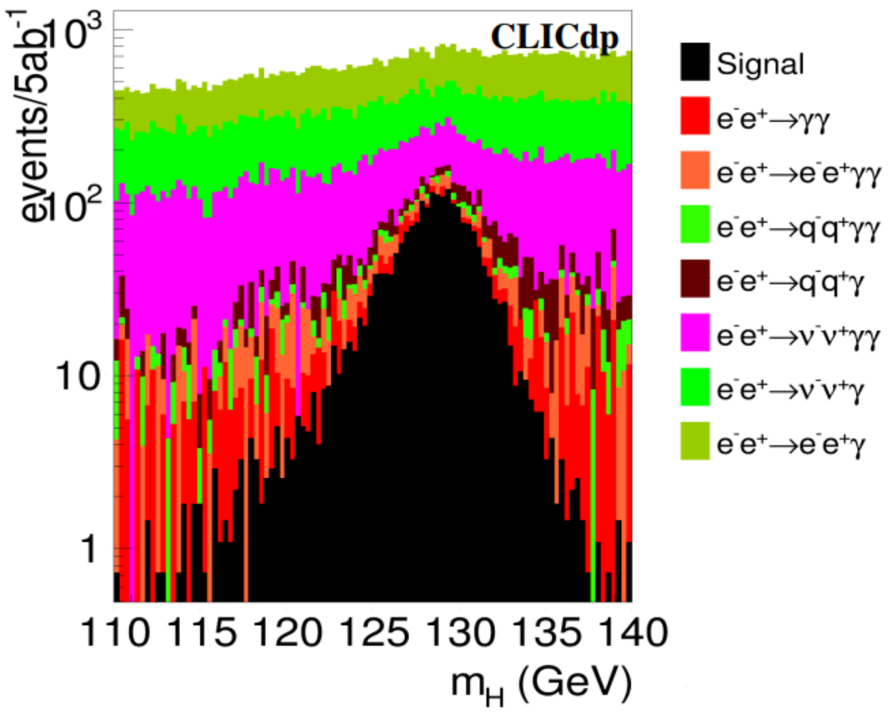
a) Only cross-section → can be cured with scaling (in MVA)
b) Kinematics → processes in question should be reprocessed in WHIZARD (2 ?)

Without clear answers to these questions can we be convinced that it is justified to neglect mono-photon processes?

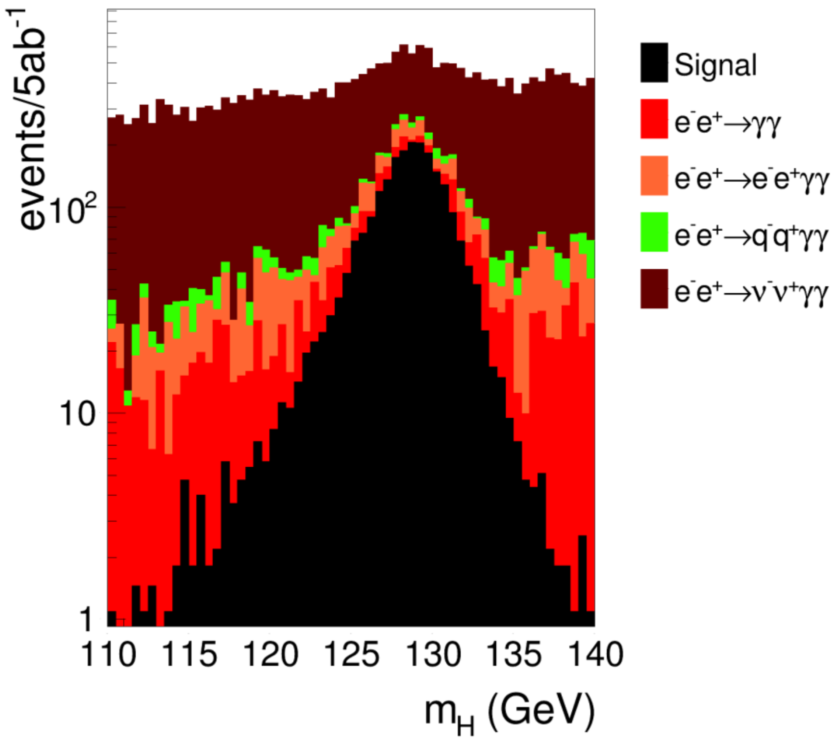
Result without mono-photon background

Di-photon mass distribution after MVA

OLD - all background



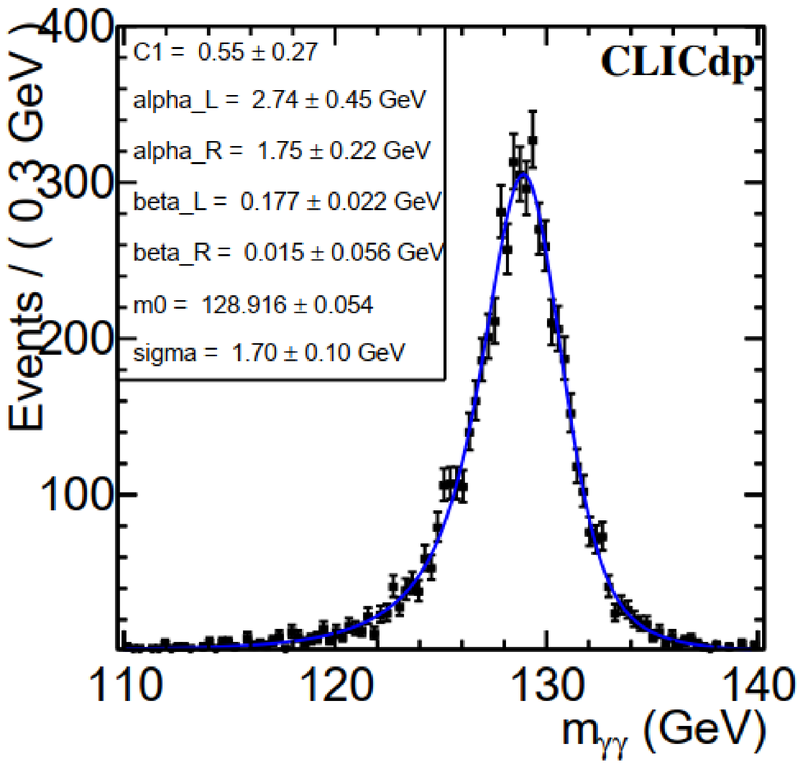
NEW – no mono-photon



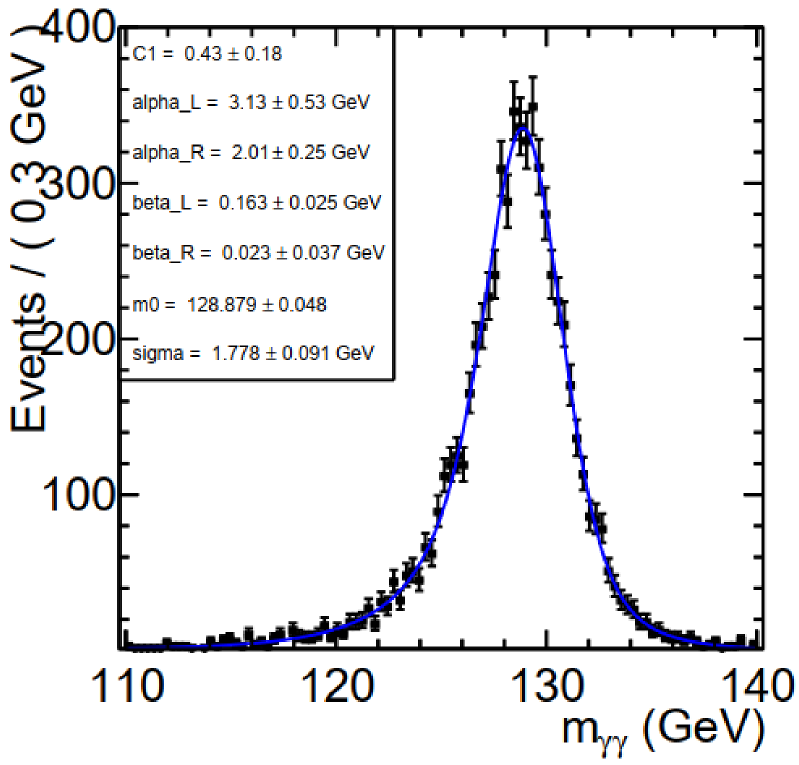
	N_s	N_b	Significance/δ(%)
Old	2060	63000	8.3/12
New	2360	17000	17/5.9

Signal Fit

OLD



NEW – no mono-photon

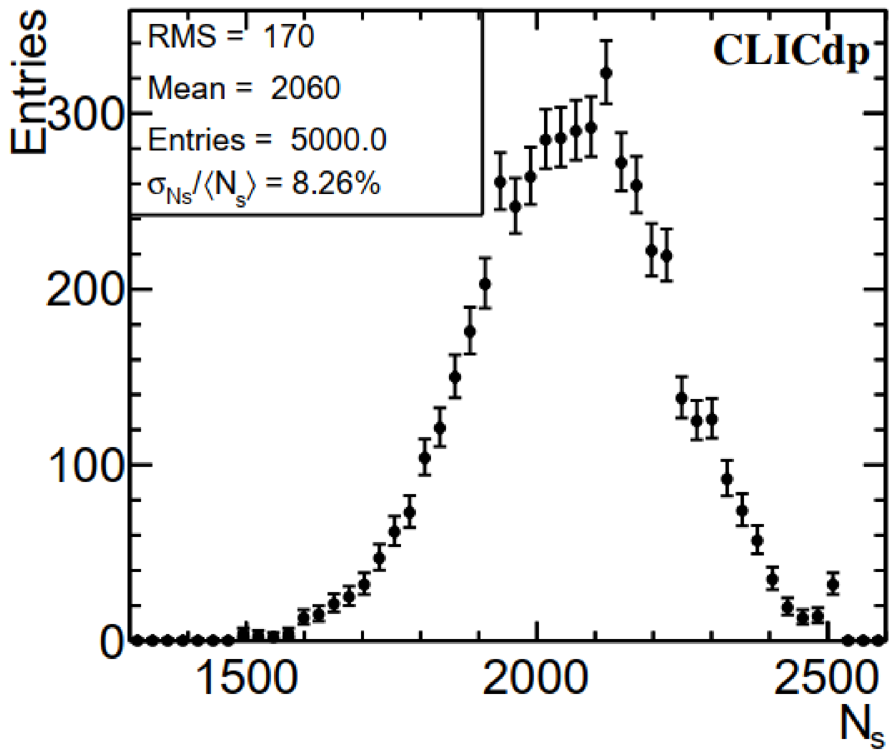


Signal is enriched by ~ 15%

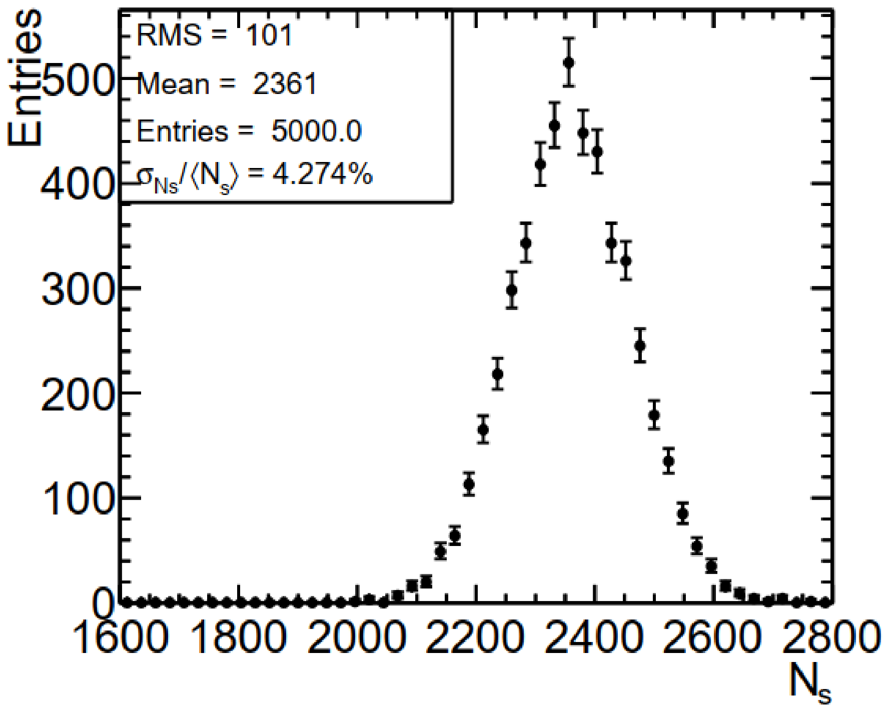
No relevant changes in mean and width

Pull Distribution

OLD - all background



NEW – no mono-photon



The width of the pull distribution is reduced by ~ ½, resulting in a drop of statistical uncertainty from 8.3% to 4.3%.

Kind of a current wisdom

Are we double-counting background by including mono-photon processes (eeγ, $\nu\nu\gamma$, qqγ)?

- There are several questions that can be asked:

1) *Are cross-sections for processes with a single photon in the final state correctly reproduced in WHIZARD V1.95? Or, in other words, can we just re-scale w.r.t. the cross-section from WHIZARD 2?*
2) *Is kinematics of the final state photon properly described? If not, new samples have to be produced, unless we are not convinced (how?) that chances to fake signal in the presence of photons (from FSR, BS background,…) in a detector are statistically insignificant.*

Without clear answers to these questions can we be convinced that it is justified to neglect mono-photon processes?

However,

- Omitting mono-photon background:
  - Improves signal statistics due to looser BDT output cut (from 0.3241 to 0.1064);
  - Boost statistical significance (from 8.2 to 17);
  - Halves the statistical dissipation of the measurement (from 8.3% to 4.3%).