PAUL SCHERRER INSTITUT

HIGGS BR

Michael Spira (PSI)

Theory convenors: Ansgar Denner, Sven Heinemeyer, Alexander Mück

Experimental convenors: Ivica Puljak (CMS), Daniela Rebuzzi (ATLAS)

Group members: Ansgar Denner, Sven Heinemeyer, Alexander Mück, Ivica Puljak, Daniela Rebuzzi, Michael Spira, ...

Partial Width	QCD	Electroweak	Total	on-shell Higgs
$H \to b\bar{b}/c\bar{c}$	$\sim 0.1\%$	$\sim$ 1–2% for $M_H \lesssim 135$GeV	$\sim 2\%$	NNNNLO / NLO
$H \to \tau^+\tau^-/\mu^+\mu^-$		$\sim$ 1–2% for $M_H \lesssim 135$GeV	$\sim 2\%$	NLO
$H \to t\bar{t}$	$\lesssim 5\%$	$\lesssim$ 2–5% for $M_H < 500$GeV	$\sim 5\%$	(NNN)NLO / LO
		$\sim 0.1(\frac{M_H}{1\text{TeV}})^4$ for $M_H > 500$GeV	$\sim$ 5–10%	
$H \to gg$	$\sim 3\%$	$\sim 1\%$	$\sim 3\%$	NNNLO approx. / NLO
$H \to \gamma\gamma$	$< 1\%$	$< 1\%$	$\sim 1\%$	NLO / NLO
$H \to Z\gamma$	$< 1\%$	$\sim 5\%$	$\sim 5\%$	(N)LO / LO
$H \to WW/ZZ \to 4f$	$< 0.5\%$	$\sim 0.5\%$ for $M_H < 500$GeV	$\sim 0.5\%$	(N)NLO
		$\sim 0.17(\frac{M_H}{1\text{TeV}})^4$ for $M_H > 500$GeV	$\sim$ 0.5–15%	

- QCD: variation of Higgs widths for scale by factor 2 and 1/2
  elw: missing HO estimated from known structure at NLO
  $M_H \gtrsim 500$ GeV: Higgs self-interactions dominate error
  different uncertainties added linearly for each channel

- parametric uncertainties:
  $m_t = 172.5 \pm 2.5$ GeV $\qquad \alpha_s(M_Z) = 0.119 \pm 0.002$
  $m_b(m_b) = 4.16 \pm 0.06$ GeV $\qquad m_c(m_c) = 1.28 \pm 0.03$ GeV
  different uncertainties added quadratically for each channel

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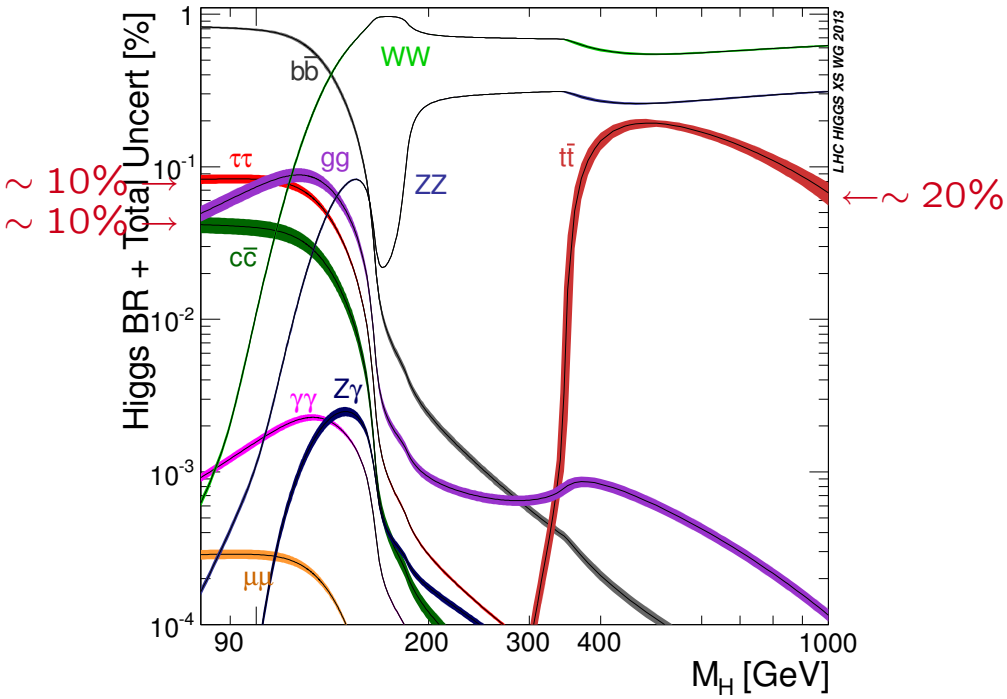
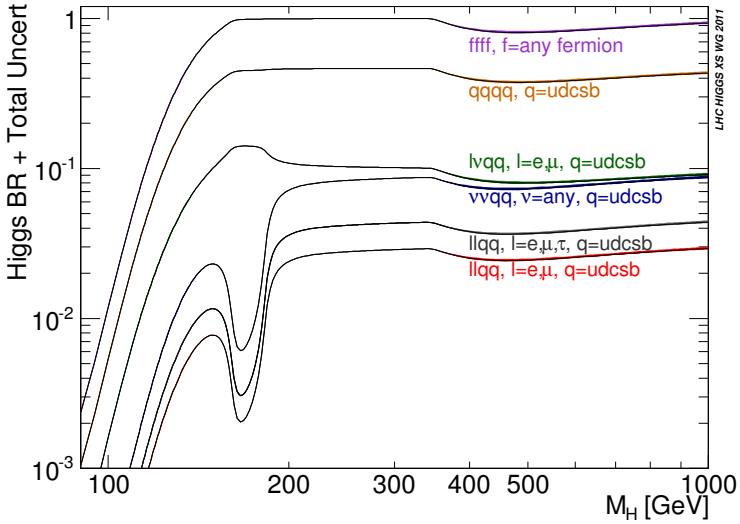
- QCD: variation of Higgs widths for scale by factor 2 and 1/2
  elw: missing HO estimated from known structure at NLO
  $M_H \gtrsim 500$ GeV: Higgs self-interactions dominate error
  different uncertainties added linearly for each channel

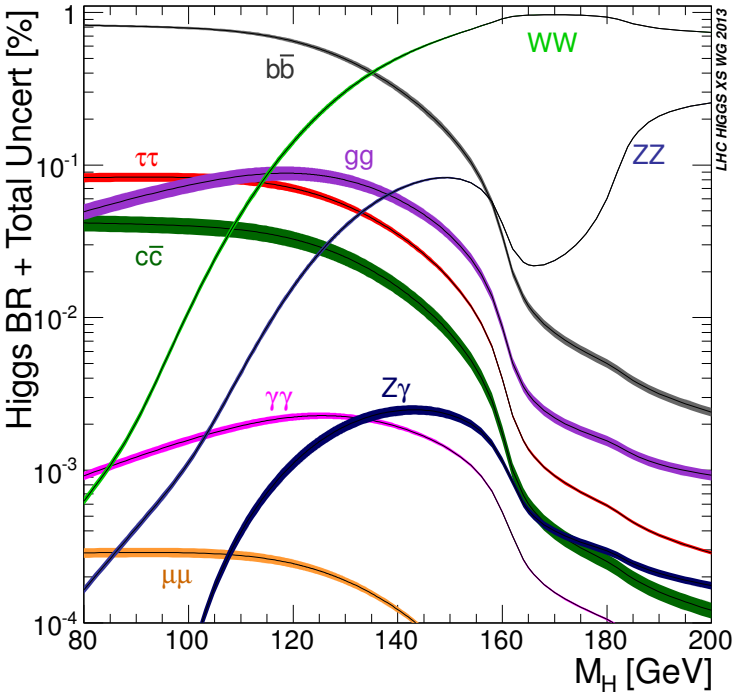
- parametric uncertainties: [→ discussions SM input parameters]
  $m_t = 173.2 \pm 0.9$ GeV $\alpha_s(M_Z) = 0.118 \pm 0.001$
  $m_b(m_b) = 4.18 \pm 0.03$ GeV $m_c(3\text{GeV}) = 0.986 \pm 0.025$ GeV
  different uncertainties added quadratically for each channel

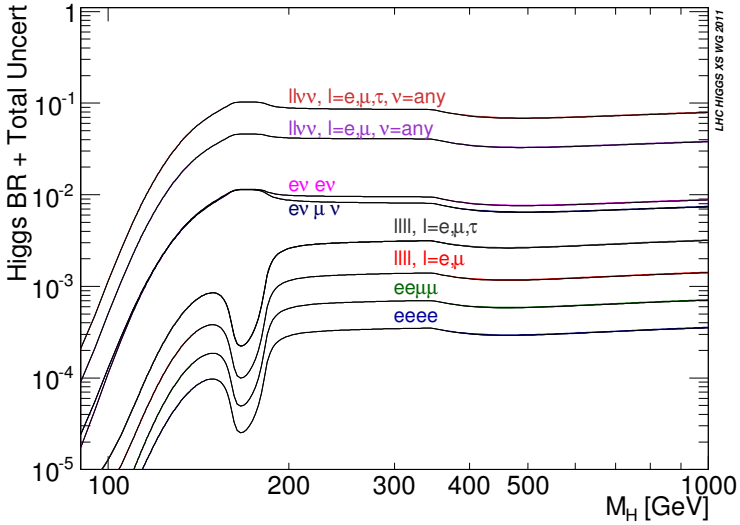
- total uncertainties: parametric & theor. uncertainties added linearly

HDECAY & Prophecy4f









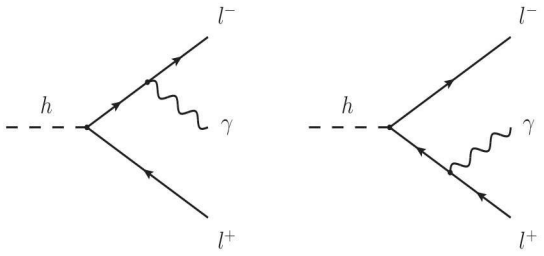
Denner, Heinemeyer, Puljak, Rebuzzi, S.

open issues in HDECAY:

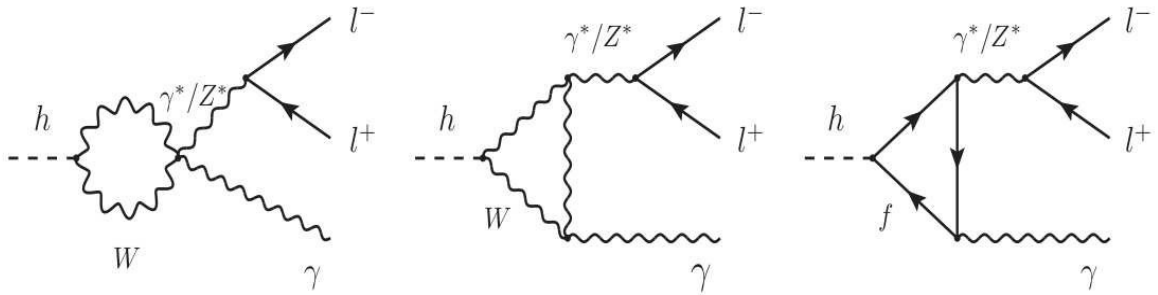
- Dalitz decays ($H \to Z\gamma \Leftrightarrow H \to \ell^+\ell^-\gamma$)
  [waiting for agreement ATLAS/CMS]

- mass effects and further HO corrections in MSSM

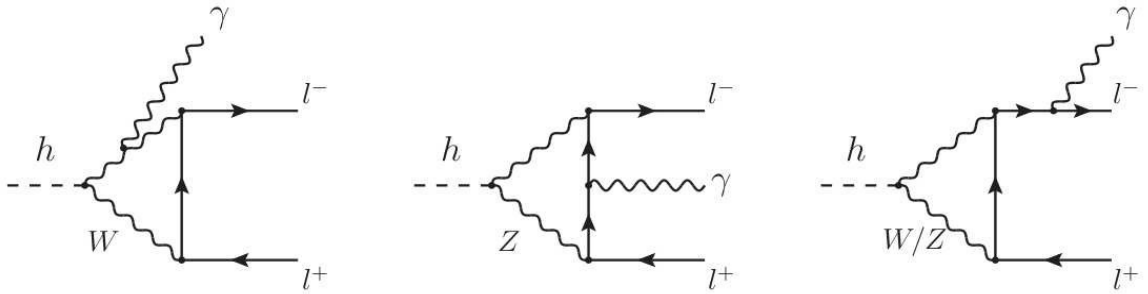
HIGGS DALITZ DECAYS



tree



off-shell



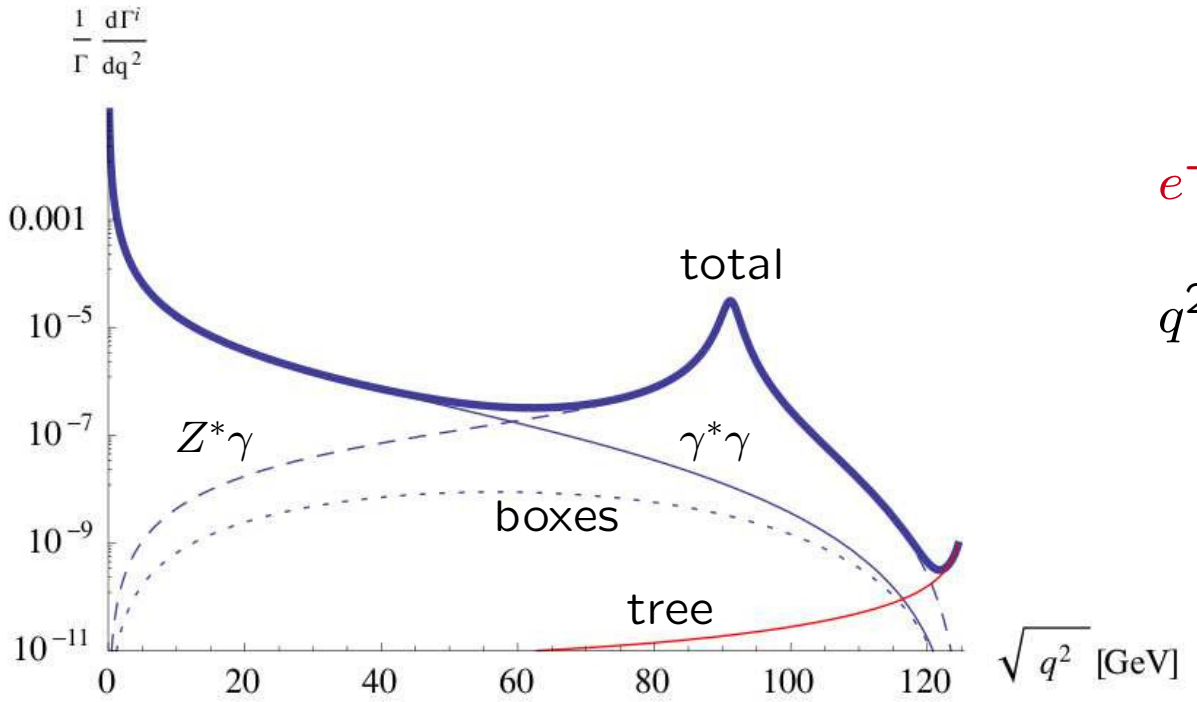
boxes

Abbasabadi, Bowser–Chao, Dicus, Repko
Sun, Chang, Gao
Passarino

$$\frac{\Gamma(h \to \gamma e^+ e^-)}{\Gamma(h \to \gamma\gamma)} = 5.7\%$$

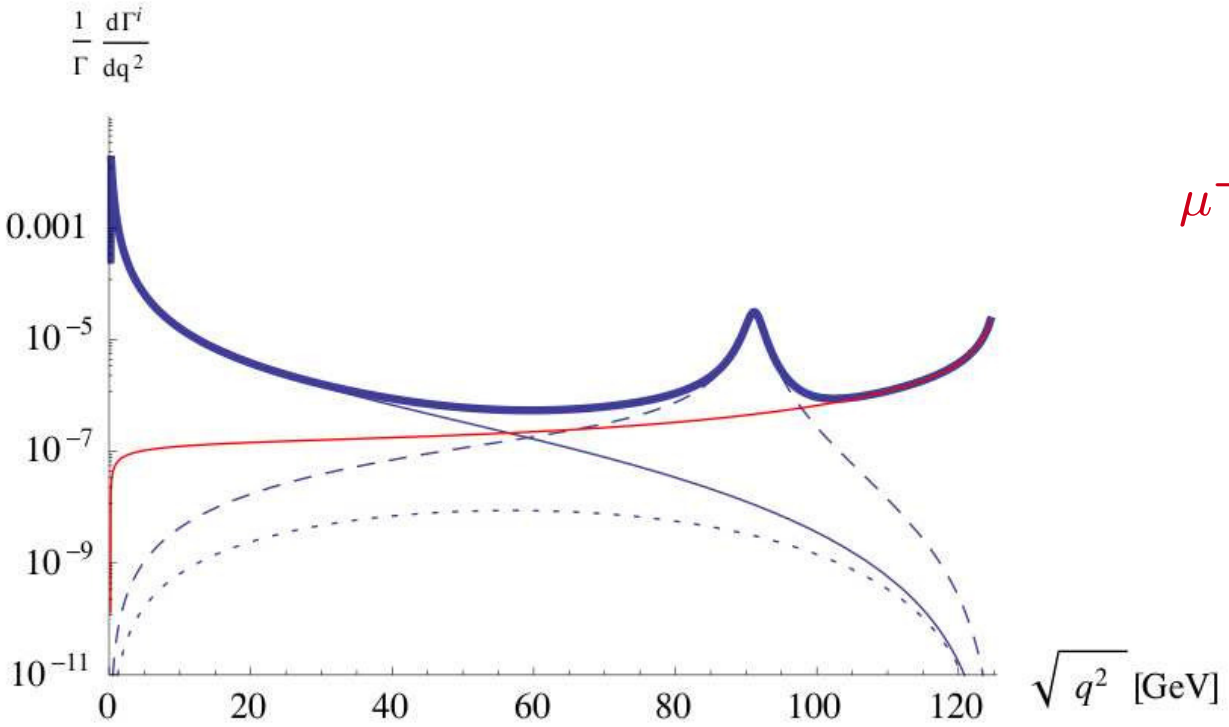
$$\frac{\Gamma(h \to \gamma \mu^+ \mu^-)}{\Gamma(h \to \gamma\gamma)} = 5.8\% \qquad (E_\gamma > 1 \text{ GeV})$$

$$\frac{\Gamma(h \to \gamma \tau^+ \tau^-)}{\Gamma(h \to \gamma\gamma)} = 3.04$$



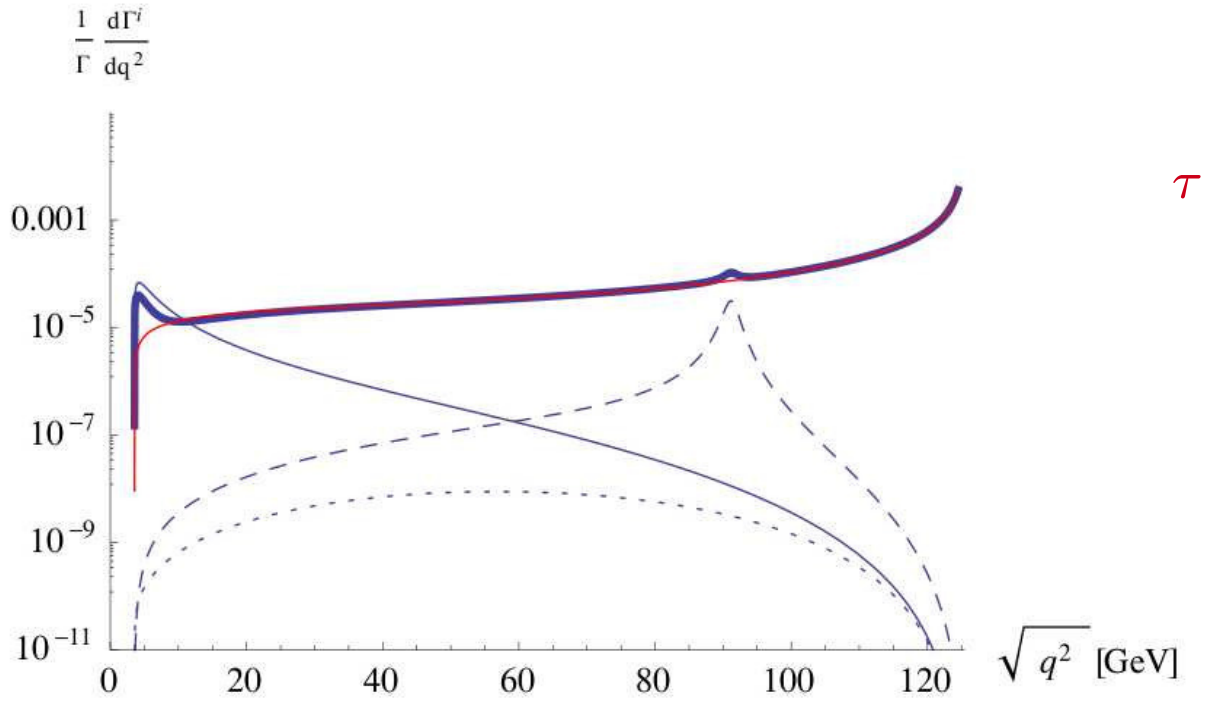
$e^+e^-\gamma$

$q^2 = M^2_{\ell^+\ell^-}$



Sun, Chang, Gao

$\mu^+\mu^-\gamma$



$\tau^+\tau^-\gamma$

Sun, Chang, Gao

$\rightarrow$ use programs by Dicus et al. and Passarino

Hto4l: a MC event generator for the Higgs decay into 4 charged leptons at NLOPS EW accuracy

Stefano Boselli, Carlo M. Carloni Calame,
Guido Montagna, Oreste Nicrosini, Fulvio Piccinini

University of Pavia and INFN Pavia

15/07/2015

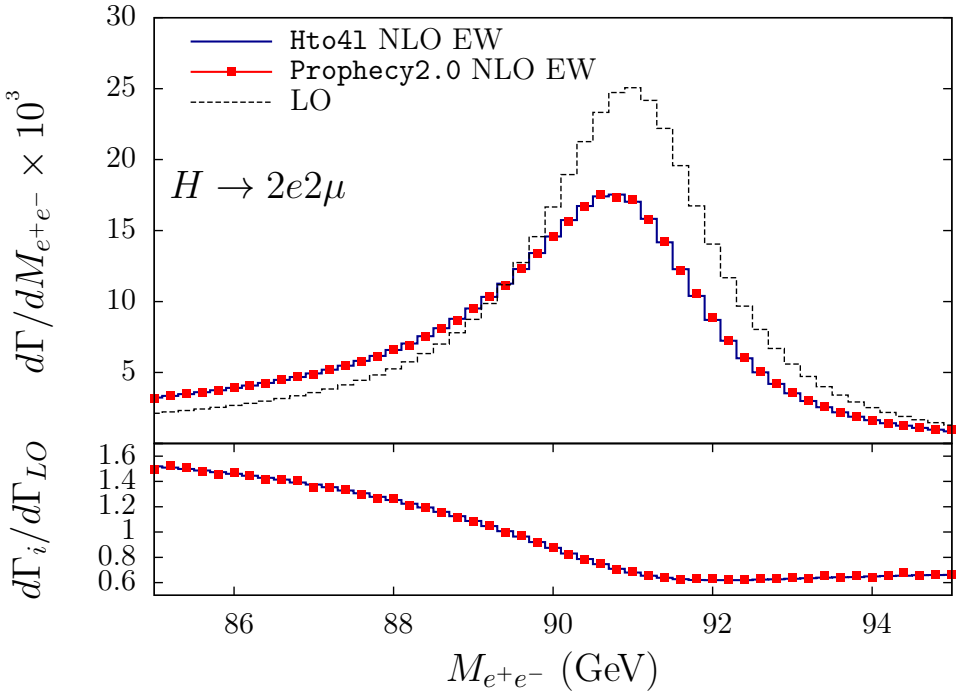
JHEP 1506 (2015) 023

http://www.pv.infn.it/hepcomplex/hto4l.html

Event generation

- **Hto4l** can be used both as integrator and as event generator;
- when used as event generator any Higgs production event file in LHE format can be fed to **Hto4l** (tested with **POWHEG** and **MC@NLO**);
- a LHE file with events including both Higgs production and decay is produced as output with full particle information (leptons and photons);
- the LHE file can be given as input to any Parton Shower code (switching off QED radiation from leptons in the shower);
- average rates for unweighted Higgs decays at NLOPS accuracy on lxplus:
  - 1.15 events/s in the $2e2\mu$ channel
  - 1.23 events/s in the $4e$ channel
  - 0.95 events/s in the 4μ channel

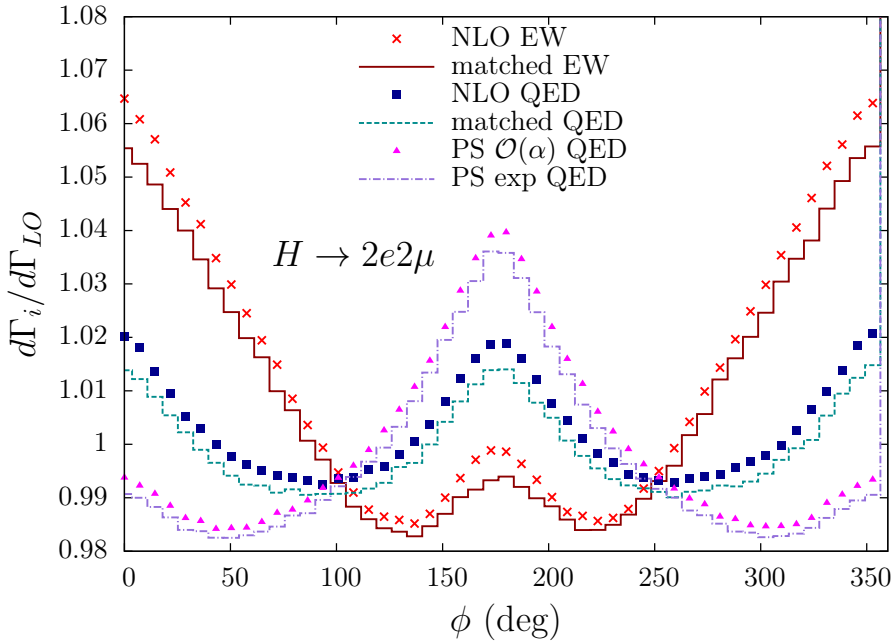
Comparison with **Prophecy4f** at NLO



Higgs partial width (KeV)		
M_H/Final State	**Prophecy4f**	**Hto4l**
125 GeV/$H \to ee\mu\mu$	0.24151(8)	0.24165(2)
140 GeV/$H \to ee\mu\mu$	1.2672(2)	1.2667(1)
125 GeV/$H \to 4\mu$	0.13324(2)	0.13325(2)
140 GeV/$H \to 4\mu$	0.6713(1)	0.6711(1)
200 GeV/$H \to 4\mu$	413.02(7)	412.98(2)

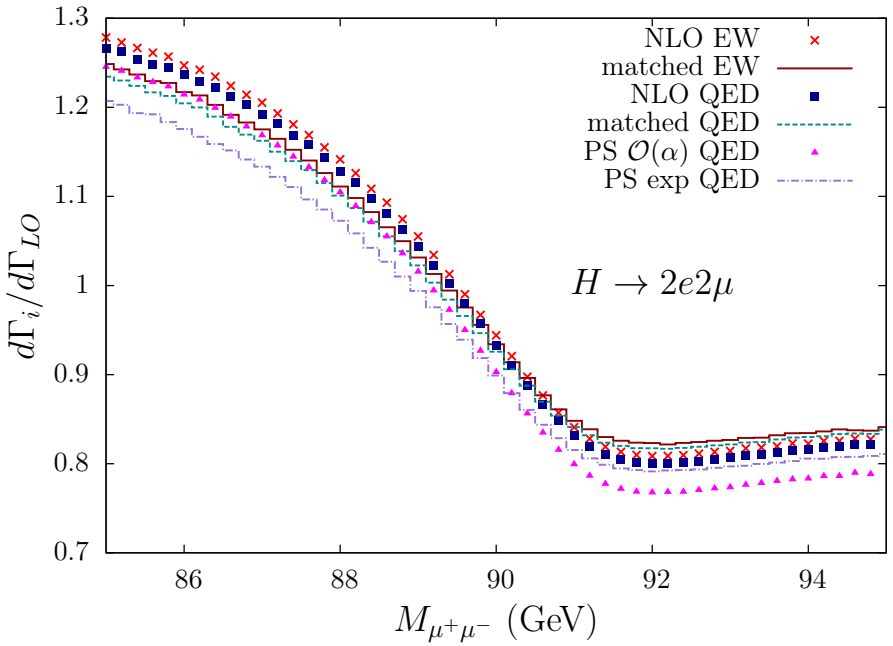
Predictions at NLOPS accuracy (in the Higgs rest frame)

Effects on the angle between the decay planes of the Z bosons



- pure weak corrections are important
- exact $\mathcal{O}(\alpha)$ QED corrections are important

Effects on the $\mu^+\mu^-$ pair invariant mass



- multiple photon effects are important

Higgs boson Dalitz decay in CMS

Ivica Puljak
with Andrey Pozdnyakov

For LHCHXS BR group internal consumption

14 July 2015

Higgs boson Dalitz decay in CMS

arXiv:1507.03031

Search for a Higgs boson decaying into $\gamma^*\gamma \to \ell\ell\gamma$ with low dilepton mass in pp collisions at $\sqrt{s} = 8\,\text{TeV}$

The CMS Collaboration*

Abstract

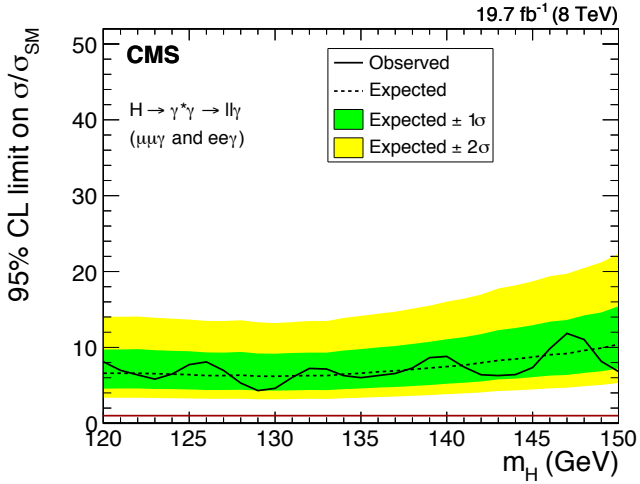
A search is described for a Higgs boson decaying into two photons, one of which has an internal conversion to a muon or an electron pair ($\ell\ell\gamma$). The analysis is performed using proton-proton collision data recorded with the CMS detector at the LHC at a centre-of-mass energy of 8 TeV, corresponding to an integrated luminosity of 19.7 fb^{-1}. The events selected have an opposite-sign muon or electron pair and a high transverse momentum photon. No excess above background has been found in the three-body invariant mass range $120 < m_{\ell\ell\gamma} < 150\,\text{GeV}$, and limits have been derived for the Higgs boson production cross section times branching fraction for the decay $\text{H} \to \gamma^*\gamma \to \ell\ell\gamma$, where the dilepton invariant mass is less than 20 GeV. For a Higgs boson with $m_{\text{H}} = 125\,\text{GeV}$, a 95% confidence level (CL) exclusion observed (expected) limit is 7.7 ($6.4^{+3.1}_{-2.0}$) times the standard model prediction. Additionally, an upper limit at 95% CL on the branching fraction of $\text{H} \to (\text{J}/\psi)\gamma$ for the 125 GeV Higgs boson is set at 1.5×10^{-3}.

Submitted to Physics Letters B

Higgs boson Dalitz decay in CMS

arXiv:1507.03031

- The search is performed for a Higgs-like particle within the mass range between 120 and 150 GeV
- In order to select the contribution from the Dalitz decay, we require $m_{ll} < 20$ GeV
- The samples for the Dalitz signal are produced at leading-order using
  - the MADGRAPH 5 matrix-element generator with the ANO-HEFT model, interfaced with PYTHIA 6.426

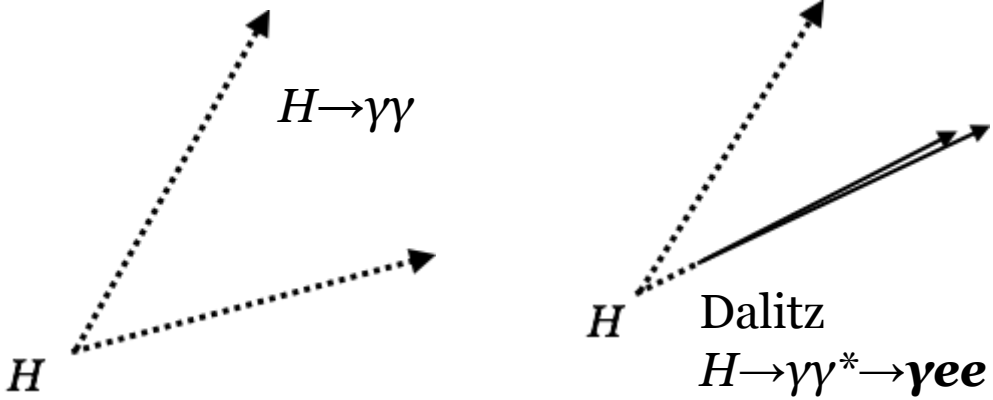


- The branching fractions for H → $\gamma^*\gamma$ are estimated using MCFM
  - For the SM Higgs boson in the mass range of 120–150 GeV, the H → $\gamma^*\gamma$ → $\mu\mu\gamma$ (eeγ) branching fraction is expected to be between 2.1 (2.9) × 10^{-5} and 3.3 (4.7) × 10^{-5} for m_{ll} below 20 GeV
- Some input from CMS to the BR group:
  - Generally, we just need to agree on what we call the Dalitz decay
  - It is H → llg, but the phase space for m(ll) could be selected differently
  - In our paper we use m(ll) < 20 GeV selection
    - though the MC signal samples we generated up to m(ll)<50 GeV
  - So, perhaps that could be our request: **to have numbers for m(ll) < 20 (50) GeV.**
    - **Even better if the full differential cross section for m(ll) is provided in some form**

Dalitz decays in ATLAS H→γγ

Dag Gillberg, Elisabeth Petit

Dalitz in $H\to\gamma\gamma$



Dalitz decays: $H\to\gamma ff$ can be mis-reconstructed as $H\to\gamma\gamma$.
In particular for $\boldsymbol{H\to\gamma ee}$ when ee-pair have **small separation**.

$H\to\gamma qq\to\gamma$+hadrons can also fake H→γγ, but this is very rare (less than ~10% of $H\to\gamma ee$)

$m_{\gamma ee}$ also peak at the Higgs mass
(the only "$H\to\gamma\gamma$ background" that has a resonance shape)

After full selection, we estimate: $N(H\to\gamma ff) / N(H\to\gamma\gamma) = 0.3\%$

This is taken straight from Pythia8 (see next slide).

In the analysis, we subtract this contribution and assign a 100% uncertainty on this it (i.e. 0.3% on the $H\to\gamma\gamma$ rate)

It is likely possible to tighten the photon reconstruction to reduce the Dalitz contribution (much) more at the expense of signal eff.

Dalitz background

The fraction of Dalitz to "total including Dalitz" is defined by the below expression and is denoted "ρ" and "ε_{ff}"in the tables below

From HXSWG:
0.228% ⟶ $\dfrac{\mathcal{B}(H \to f\bar{f}\gamma)}{\mathcal{B}(H \to \gamma\gamma) + \mathcal{B}(H \to f\bar{f}\gamma)}$

Stroynowski et al

$HiggsMass$	m_H=120GeV	
$Channel$	ρ	$BranchingFraction$
$H \to e^+e^-\gamma$	0.0333	71.38×10^{-6}
$H \to \mu^+\mu^-\gamma$	0.0167	35.90×10^{-6}
$H \to \tau^+\tau^-\gamma$	0.0078	16.77×10^{-6}
$H \to u\bar{u}\gamma$	0.0211	45.36×10^{-6}
$H \to d\bar{d}\gamma$	0.0053	11.39×10^{-6}
$H \to s\bar{s}\gamma$	0.0040	8.38×10^{-6}
$H \to c\bar{c}\gamma$	0.0123	26.44×10^{-6}
$H \to b\bar{b}\gamma$	0.0018	3.87×10^{-6}
$Total$	0.1022	219×10^{-6}

http://arxiv.org/abs/0704.3987

Pythia8

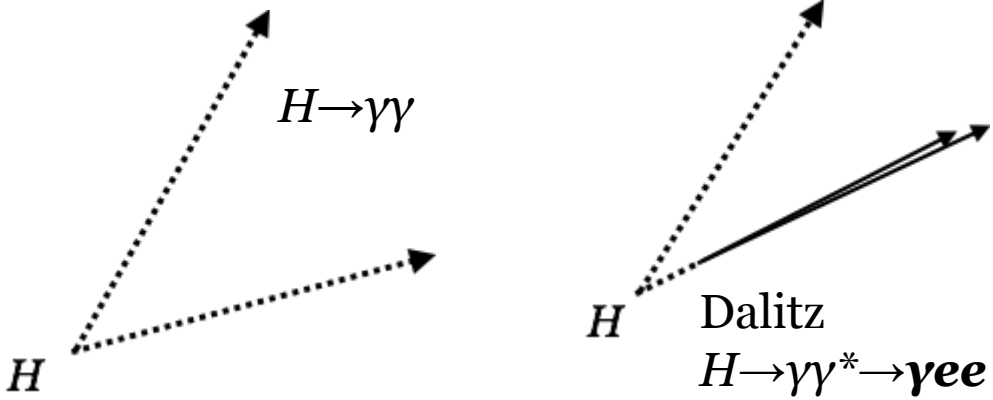
ee	2.60%
μμ	1.1%
ττ	0.25%
uu	1.00%
dd	0.25%
ss	0.21%
cc	0.38%
Total	5.75%

Discus+Repko

$f\bar{f}$	$\varepsilon_{f\bar{f}}$
$e\bar{e}$	2.90
$\mu\bar{\mu}$	1.14
$\tau\bar{\tau}$	0.23
$u\bar{u}$	1.71
$d\bar{d}$	0.42
$s\bar{s}$	0.21
$c\bar{c}$	0.45
Total	7.06

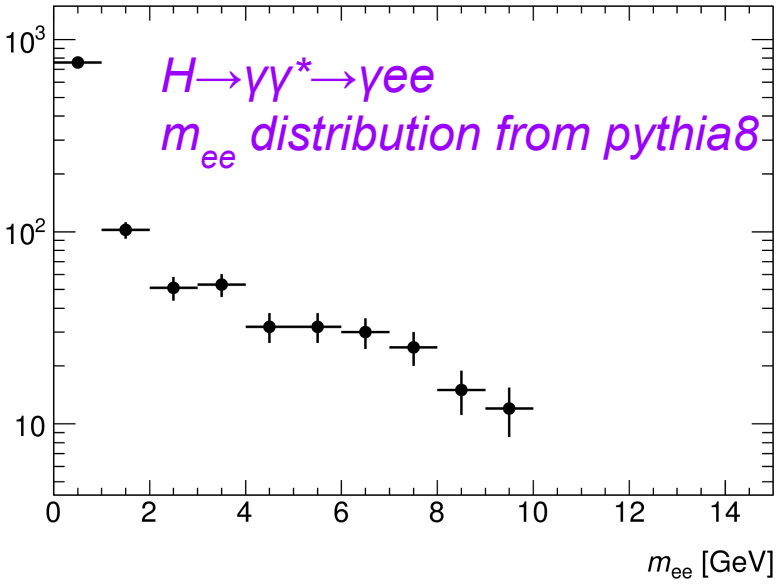
Although total rate is a bit different, the most important component: *H→γee*, is similar (~3% of H→γγ)

Summary



Dalitz decays: $H \to \gamma ff$ can be mis-reconstructed as $H \to \gamma\gamma$.
In particular for $\boldsymbol{H \to \gamma ee}$ when ee-pair have **small separation**.

=> interested in BR($H \to \gamma ee$) for mee < few GeV



Pythia 8 doesn't simulate γ→γff with m_{ff} > 10 GeV*