Constraining light-quark Yukawa couplings using Higgs distributions

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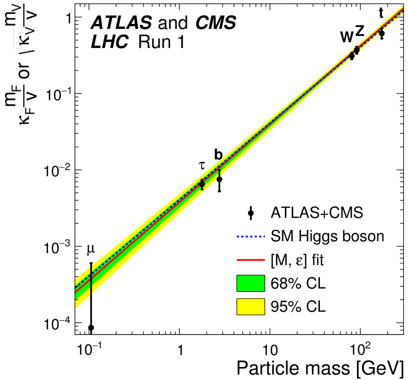
*in collaboration with F. Bishara, U. Haisch and P. Monni [1606.09253]

Higgs couplings



- we already know fairly well that the Higgs couples to gauge bosons and heavy fermions with strength similar to the Standard Model prediction
- measuring 2nd (and 1st) generation Yukawa couplings is notoriously difficult

probing light-quarks Yukawa couplings

$$\frac{y_q}{\sqrt{2}} = \kappa_q \frac{m_q}{v}$$

- no direct measurement for 1st and 2nd generation
- few ideas proposed in the past 2-3 years:

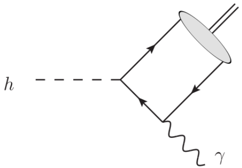
- rare exclusive decays: $h \to J/\psi + \gamma$, $h \to \Upsilon + \gamma$, ...

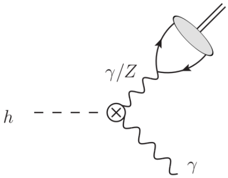
  [Bodwin et al. '13, Kagan et al. '14, Koenig,Neubert '15]

  . $|\kappa_c| < 430$, $|\kappa_b| < 78$ [Run-I]

  . $\sim$ 120 events @ 3 ab^{-1} (ATLAS+CMS, $e + \mu$)

  . $\kappa_c \sim 15$ [3 ab^{-1}] [previous talk]





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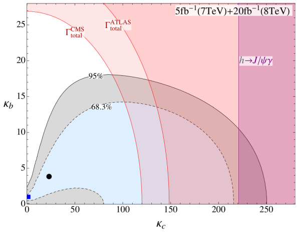
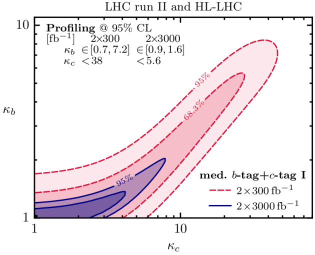


- recasting of $V + h(\to b\bar{b})$ production
  [Perez et al. '15 (+ Delaunay et al. '13)]
  - include charm mis-tagging into μ_b signal strength
  - $|\kappa_c| < 230$ [Run-I]



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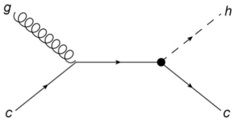

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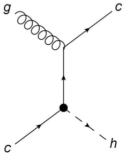
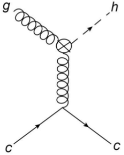


- $c + h$ production and flavour tagging

  [Brivio et al. '15]

  - y_c in production, only 1 c-tagging, clean Higgs decays
  - $|\kappa_c| < 3.9$ [3 ab^{-1}]



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- total width (direct measurement)
  - $|\kappa_c| < 120(150)$ [Run-I, CMS(ATLAS)]
  - stronger constraints from indirect width measurement

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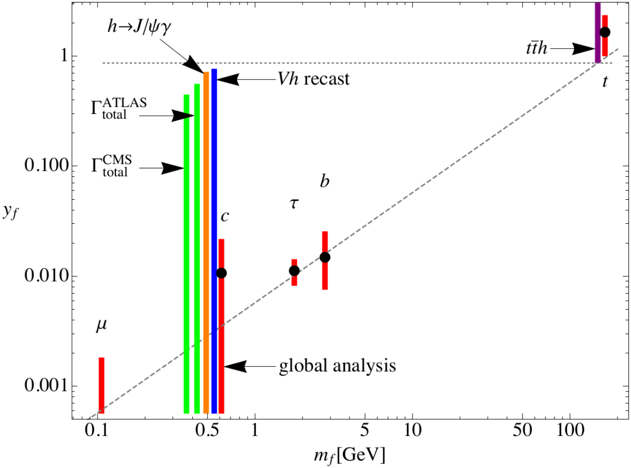
- total width (direct measurement)

- global fit: $|\kappa_c| < 6.2$ [Run-I]

probing light-quarks Yukawa couplings

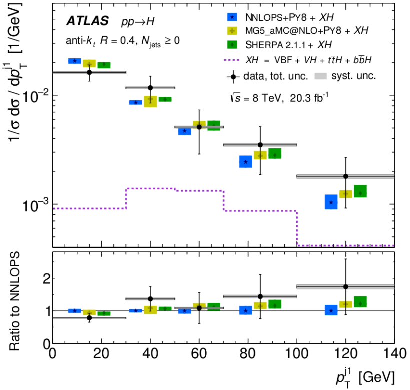
summary in one plot

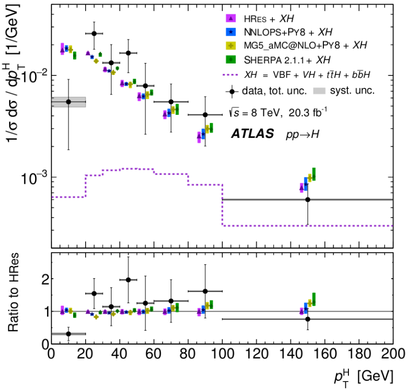
[Perez et al. '15]



differential distributions

- Higgs distributions have started to be measured. They will improve substantially in the future.
- Theoretical predictions are also nowadays under relatively good control (and they will continue improving)



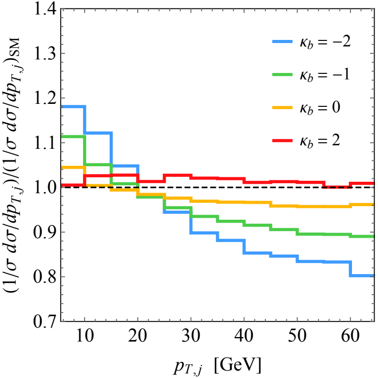


What is the sensitivity of Higgs differential distributions on Yukawa couplings?

Run I: shapes and bounds

$p_{T,j1}$

$p_{T,H}$



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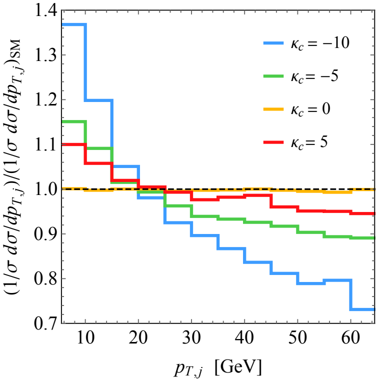

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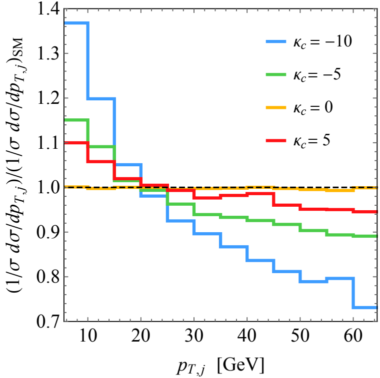

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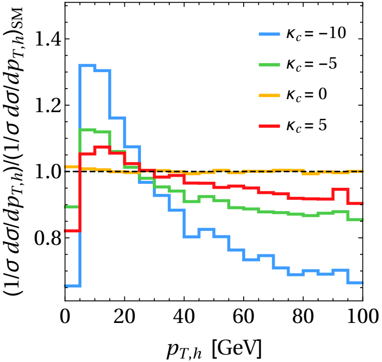

- used all EXP bins in $[0, 100]$ GeV, $h \to \gamma\gamma$ + $h \to 4\ell$
- normalized distributions: TH uncertainties reduced (e.g. PDF $\sim$ cancel out), no need to worry about new-physics effects in branching ratios.

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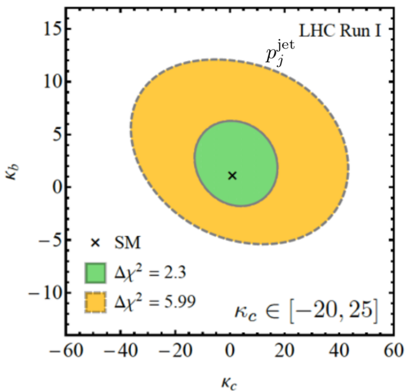

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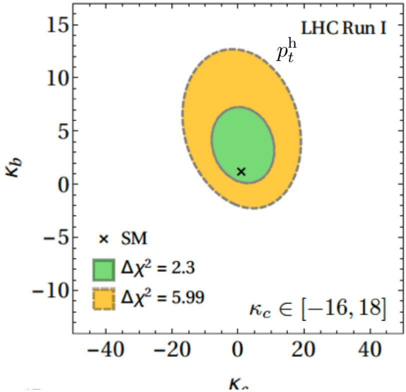

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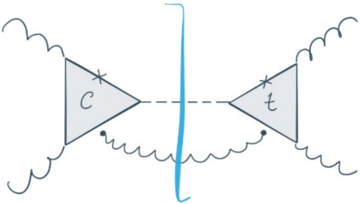
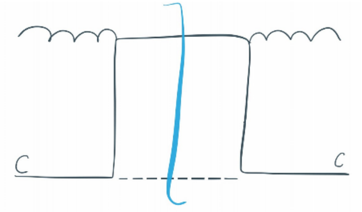
- normalized distributions: TH uncertainties reduced (e.g. PDF $\sim$ cancel out), no need to worry about new-physics effects in branching ratios.
- better bounds (order of magnitude) than all other strategies, except global fit

Contributions and scaling



$$\sim \alpha_S^3 \left(\kappa_c \frac{m_c}{m_h} \right) \frac{m_c}{m_h} \log^2 \left(\frac{p_T^2}{m_q^2} \right)$$



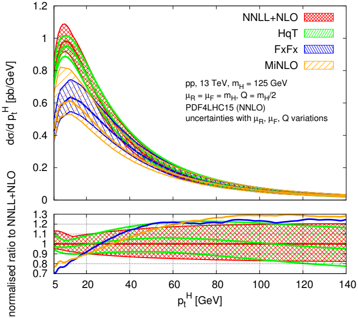
$$\sim \alpha_S^2 \left(\kappa_c \frac{m_c}{m_h} \right)^2$$

- one power of α_S from PDF

- shape distortion is not trivial because:
  - dynamical enhancement for $m_q < p_T < m_h$ (due to non-Sudakov double log)
  - scaling with κ_c is different

theoretical calculation and uncertainty

- ggF: NNLL + NLO (full mass dependence at LO, NLO corrections in HEFT)
  - for $p_{T,H}$ used new method for resummation in p_T space [Monni,ER,Torrielli '16]
  - validated against existing results
  - for $p_{T,j}$: `JetVHeto` [Banfi,Monni,Zanderighi (+Salam) '13]



- quark-initiated: `MG5_aMC@NLO`

☞ TH uncertainty: 5-10 %

How can this be improved (i.e. reach 5 % TH uncertainty)?

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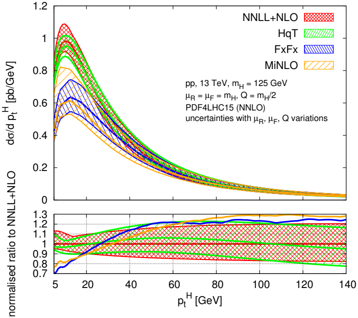

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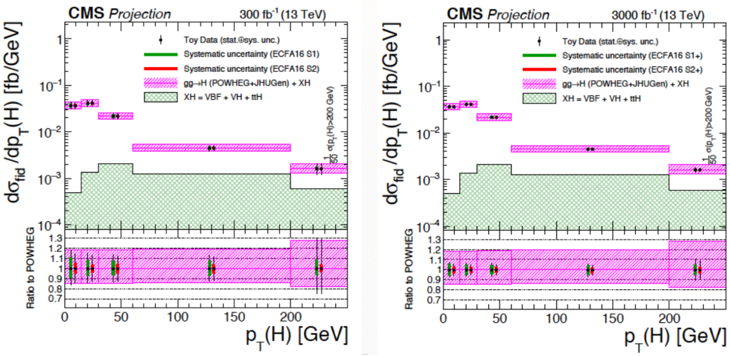
. NLO mass effects in Higgs spectrum not yet available partial results [Melnikov et al. '16]
. $\log(p_T/m_q)$ might not require resummation for bottom and charm partial results [Melnikov,Penin '16]
. N3LL Sudakov resummation in sight
. α_S uncertainty at most 2% for gg-induced; PDF errors mostly cancel

experimental accuracy

- statistics will not be a limitation here
- future projections for Run II and HL-LHC systematics: few %

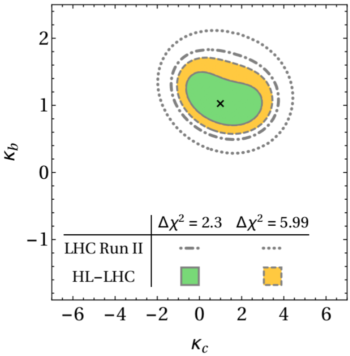


⇒ very likely, in the long run, TH precision will be the limiting factor

⇒ at least reaching 5% TH precision seems feasible

future projections

- use Higgs p_T: should be cleaner both experimentally and theoretically (non-perturbative effects expected to be small, $< 2\%$)
- assume combination of $\gamma\gamma$, ZZ, WW



1. Run-II [300 fb^{-1}, 5 GeV bins]
   - syst (exp) 3% ; theory 5%

   $\kappa_c \in [-1.4, 3.8]$

2. HL-LHC [3 ab^{-1}, 5 GeV bins]
   - syst (exp) 1.5% ; theory 2.5%

   $\kappa_c \in [-0.6, 3.0]$

- under these assumptions, at HL-LHC: $\kappa_b \in [0.7, 1.6]$, $|\kappa_s| \sim 30$ (assuming $\kappa_b = 1$ and profiling κ_c). This is a factor 100 better than $h \to \phi\gamma$

summary

- shown a new method to constrain light-quark Yukawas, based on exploiting Higgs differential distributions

  similar ideas proposed in [Soreq,Zhu,Zupan '16]

- transverse momentum distributions in Higgs production are sensitive to modifications of the Yukawas (notably y_c) due to the different functional dependence of different production modes

- limited by theory accuracy in the long run ($\rightarrow$ systematically improvable)

- relevant TH improvements are in sight: expect to probe $\mathcal{O}$(few) deviations in κ_c at Run II

- in all cases, it's an approach complementary to the others available, not limited by statistics, and with very little model dependence

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Thank you for your attention!