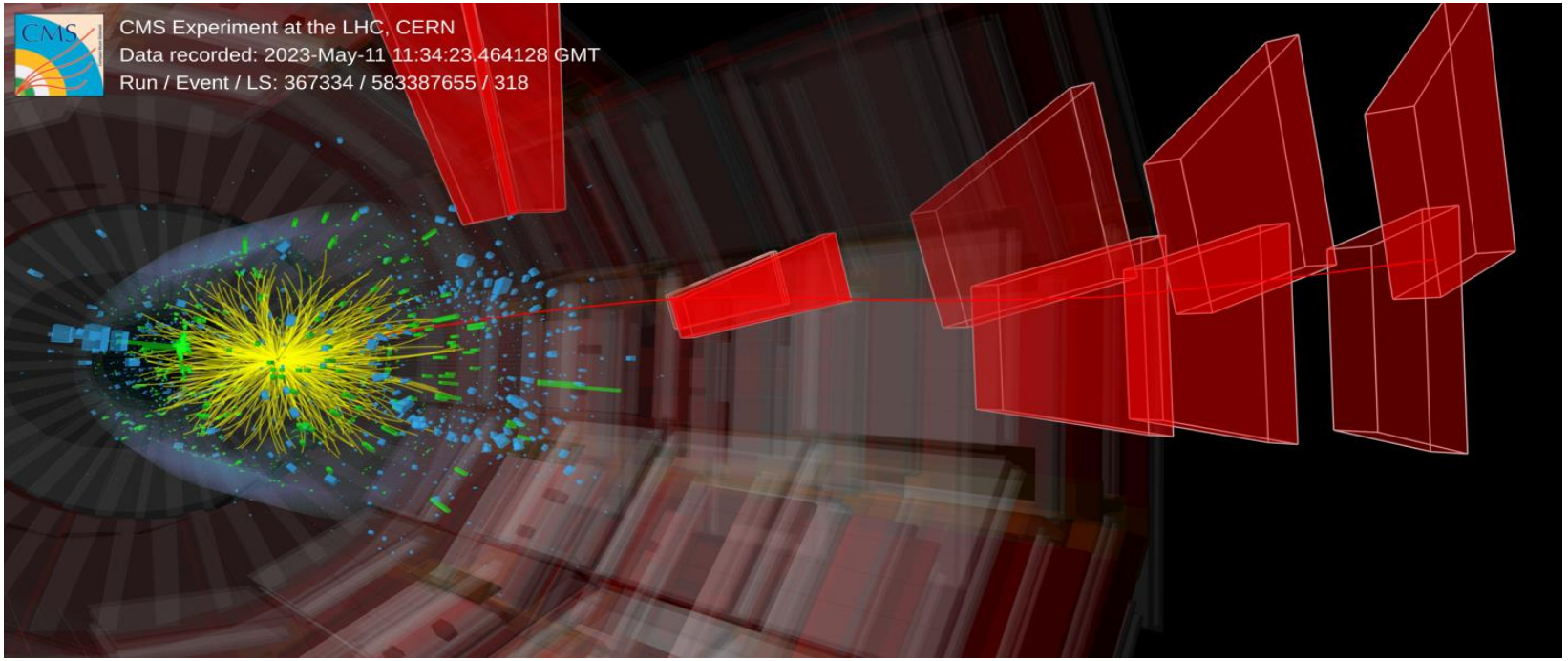
Higgs boson production in association with charm quarks at CMS



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LTP Seminar

October 29, 2024

University of Zurich[UZH]

PAUL SCHERRER INSTITUT PSI

Swiss National Science Foundation

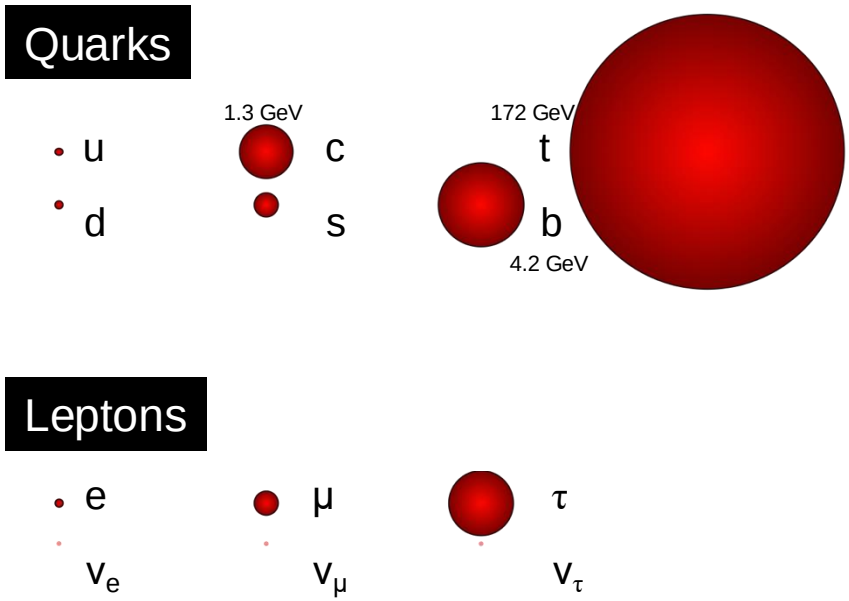
Outline

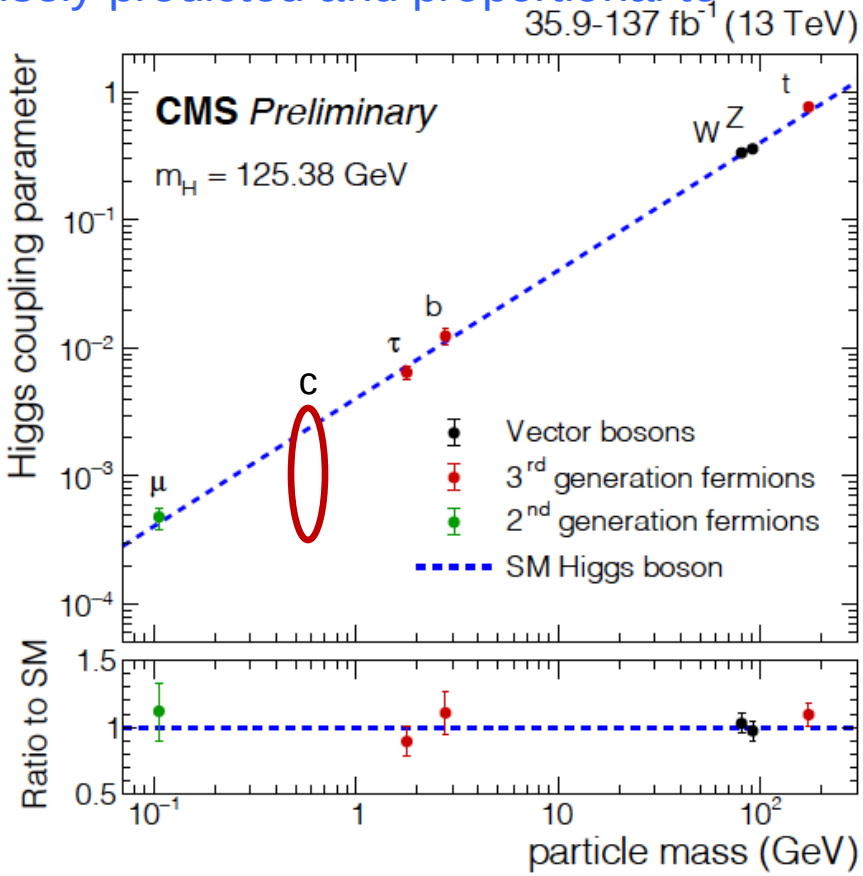
- Motivation
- Status of searches for Higgs boson coupling to charm quarks y_c (focus on CMS, similar results from ATLAS)
- Study of H+c production to constrain y_c
- Results of analysis with Run 2 data (2016-2018)
- Next steps
- Conclusion

- See also presentation by Tiziano Bevilacqua in LTP seminar in November 2023

Motivation

- Higgs boson has a unique role in the Standard Model
  - > Couplings to other particles are precisely predicted and proportional to particle mass



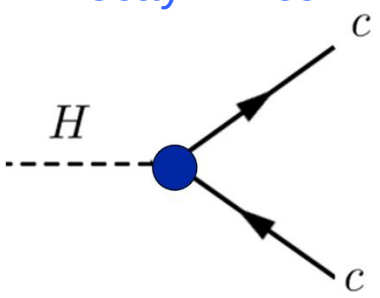


- SM is incomplete theory → new physics models introduce new particles and forces which alter predictions
- Precision measurements of Higgs boson couplings are crucial test of SM, second generation still largely unexplored

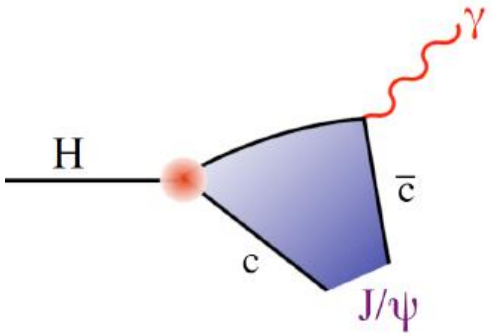
Higgs boson coupling to charm quarks at the LHC

- Challenging due to small coupling (rare processes) and experimental reconstruction of the c quark
- Different approaches to study the Higgs boson coupling to charm quarks

Decay H→cc

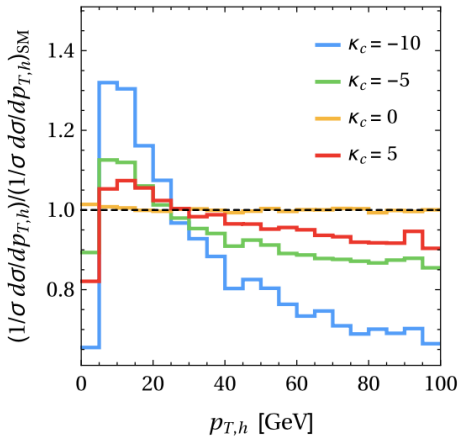


Rare exclusive decays

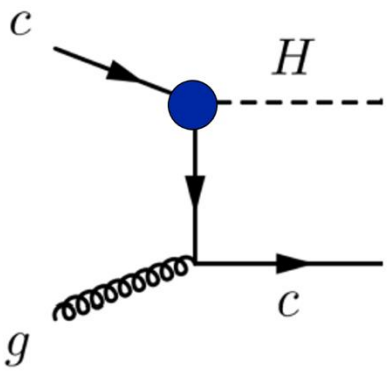


Higgs p_T spectrum

Phys. Rev. Lett. 118, 121801



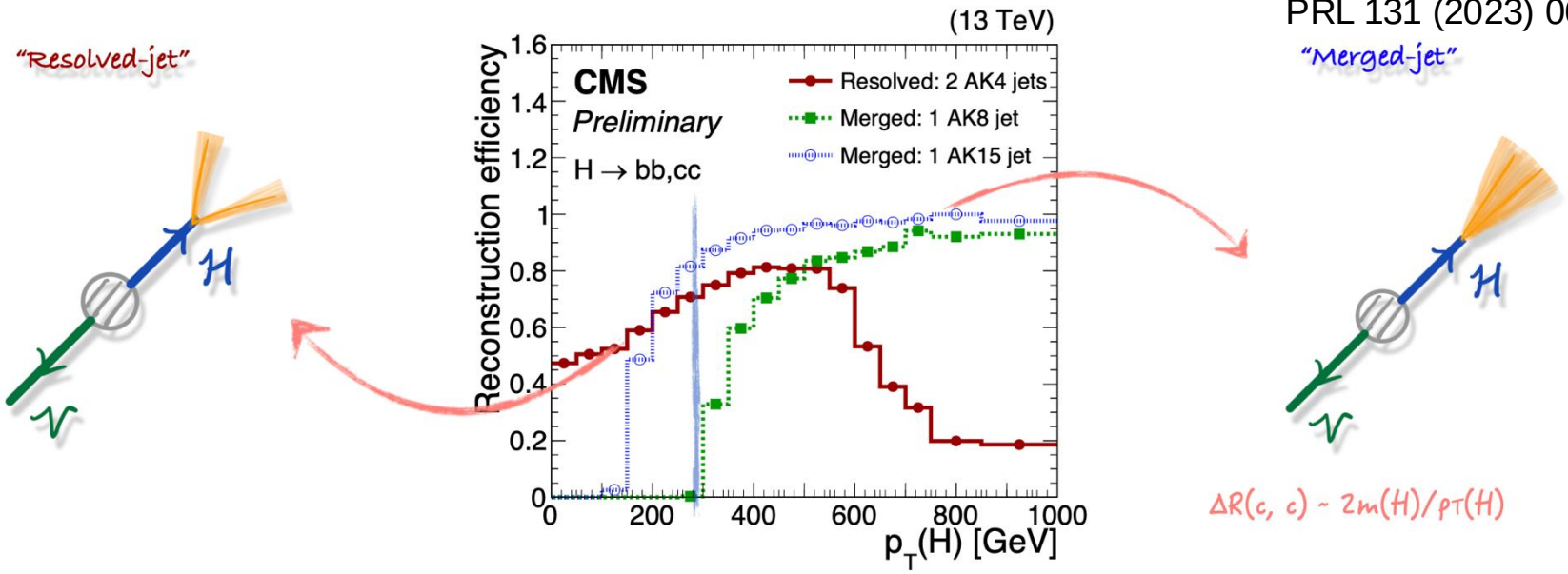
Production H+c



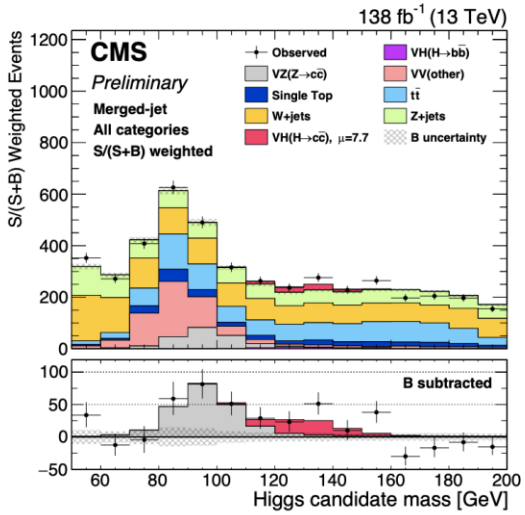
State of the art

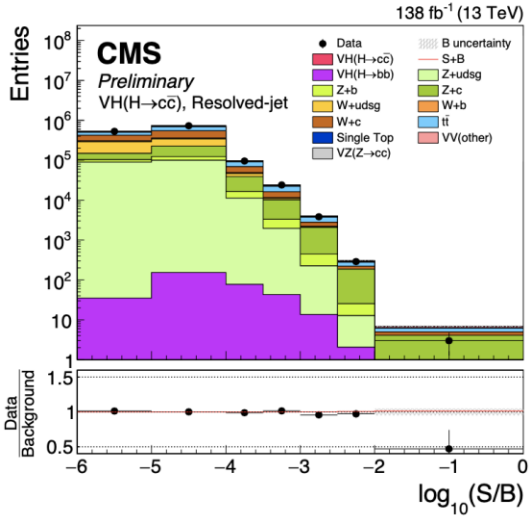
- Best sensitivity from H→cc in V(W/Z)H production

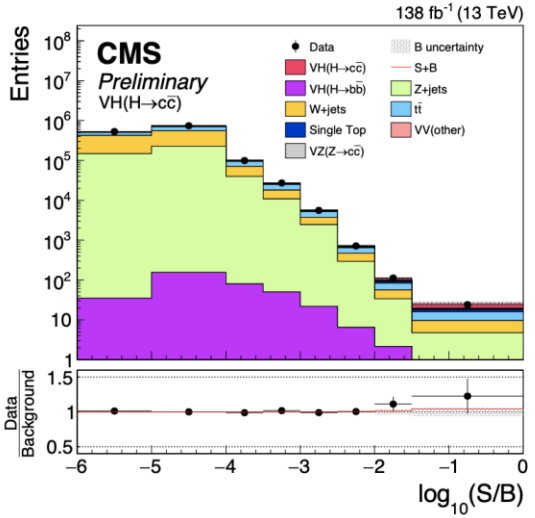
PRL 131 (2023) 061801



Merged-jet | Resolved-jet | Merged + Resolved

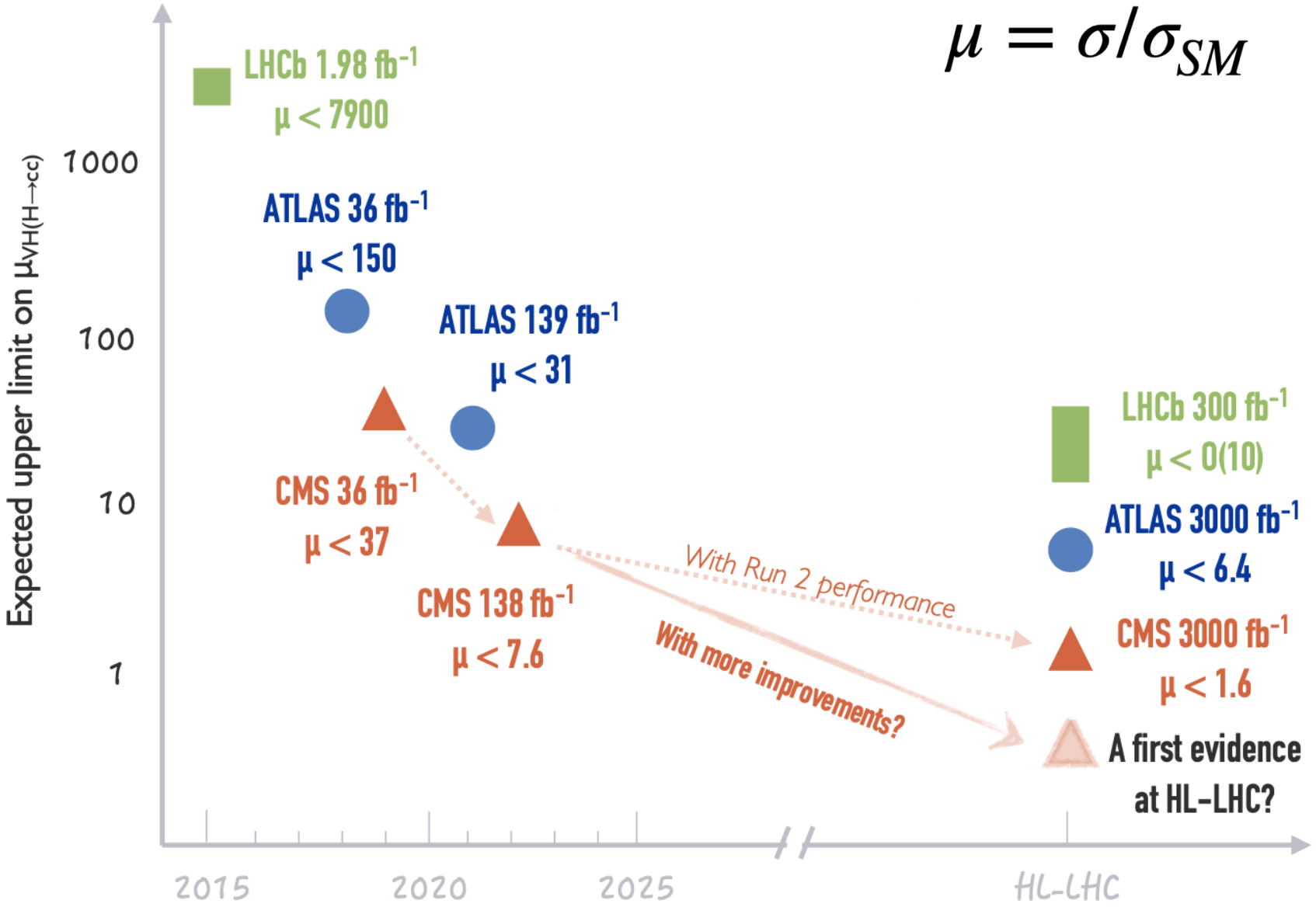






State of the art

- Lots of progress over the last years

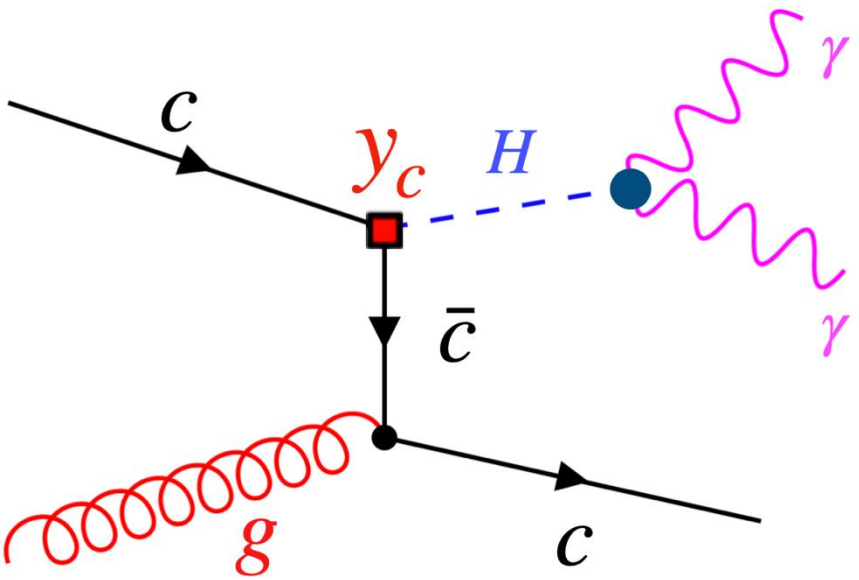


Higgs coupling to charm quarks through associated production

- Alternative approach to constrain y_c
- Advantages:
  - Higgs boson decay can be reconstructed from clean final state (H→γγ/WW/ττ)
  - Leading contribution requires only one charm to be tagged
  - Uncovered phase space, complementary to H→cc
- But also challenges:
  - Small cross section

~ 0.2 fb for $cH(H \to \gamma\gamma)$ vs 6.6 fb for $VH(H \to c\bar{c})$

  - Non-trivial signal simulation, large theory uncertainties
  - Soft c-quark spectrum



H+c production

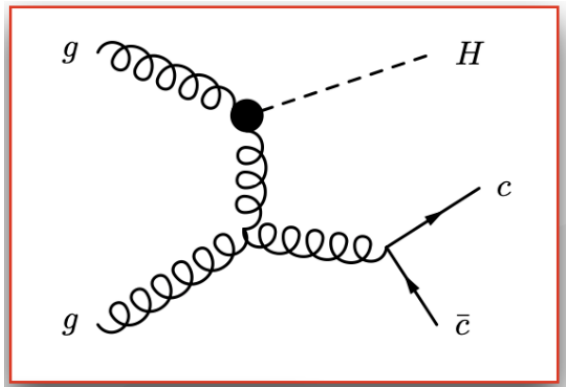
- Includes several contributions that do not depend on y_c
  - $H + g$ (fakes and $g \to c\bar{c}$)
  - $H + b(b \to c)$
  - $H + c$ not induced by y_c.

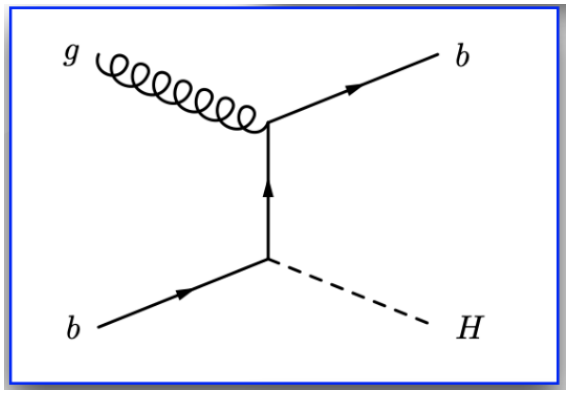
$$\sigma(hc) = A + B \cdot y_c + C \cdot y_c^2$$

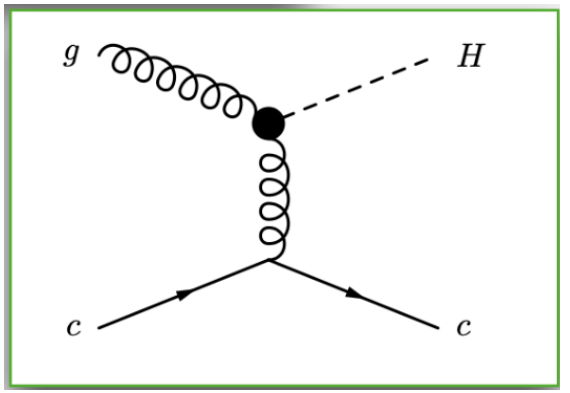
	σ [fb]
A	254.5
B	-3.5
C	34.5

$[y_c = y_c^{sm}]$

[GEN charm $p_T > 20$ GeV]

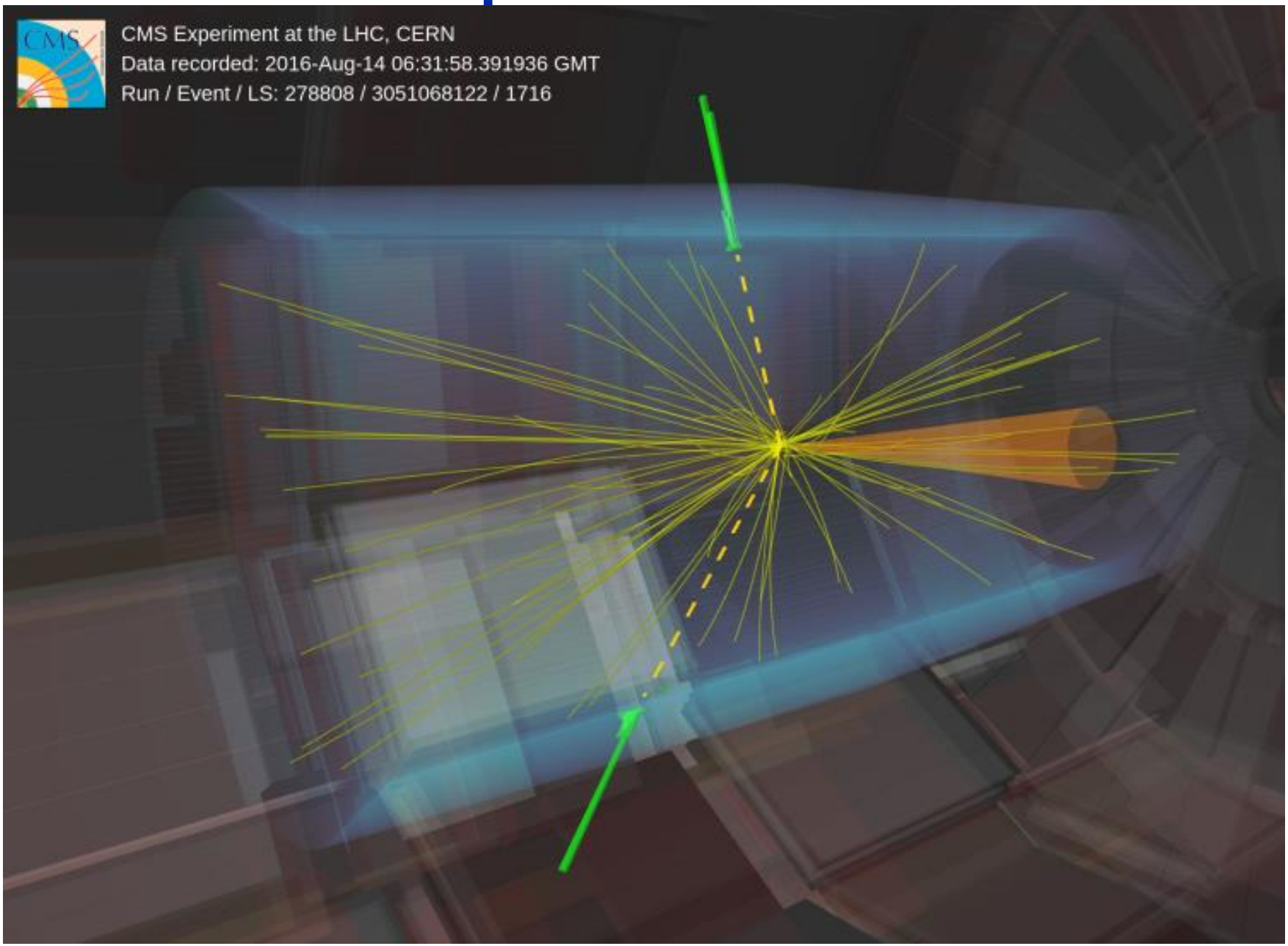






- Modelling of these contributions limits sensitivity on y_c
  - Largest contribution non-y_c dependent
  - Large theory uncertainties on y_c-dependent part

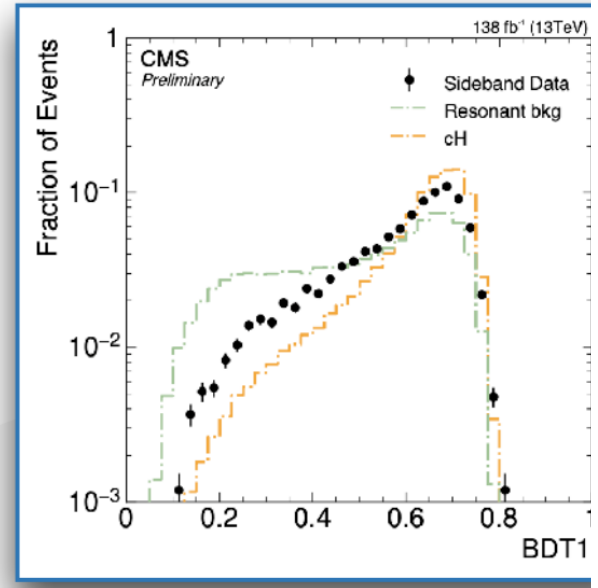
Search for H+c production at CMS



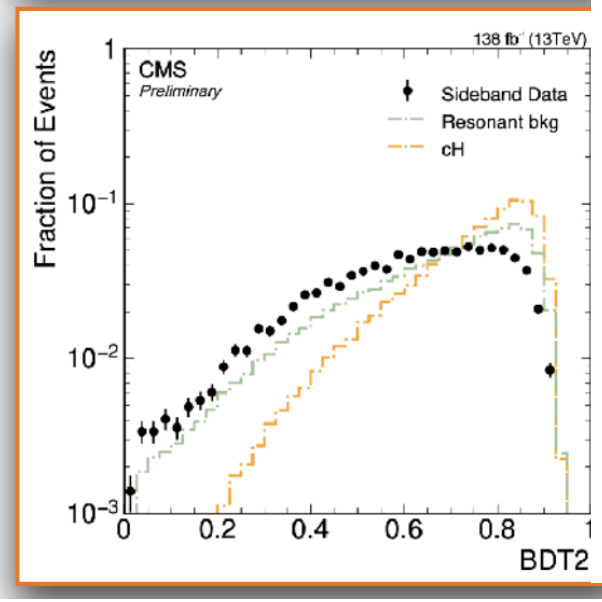
Search for H+c production at CMS

- Using Run 2 data (2016-2018) 136 fb^{-1}
- Analysis strategy
  - Use H→$\gamma\gamma$ decay channel (BR 0.2%)
  - Select events with 2 isolated photons associated with primary vertex
  - Require additional jet with p_T>20 GeV that passes charm jet identification
- Main backgrounds
  - Irreducible background from ggH events with ISR/FSR gluon splitting g→cc
  - Continuous $\gamma\gamma$ background
  - Train 2 BDTs based on kinematic variables to discriminate against these backgrounds

cH vs ggH



cH vs CB

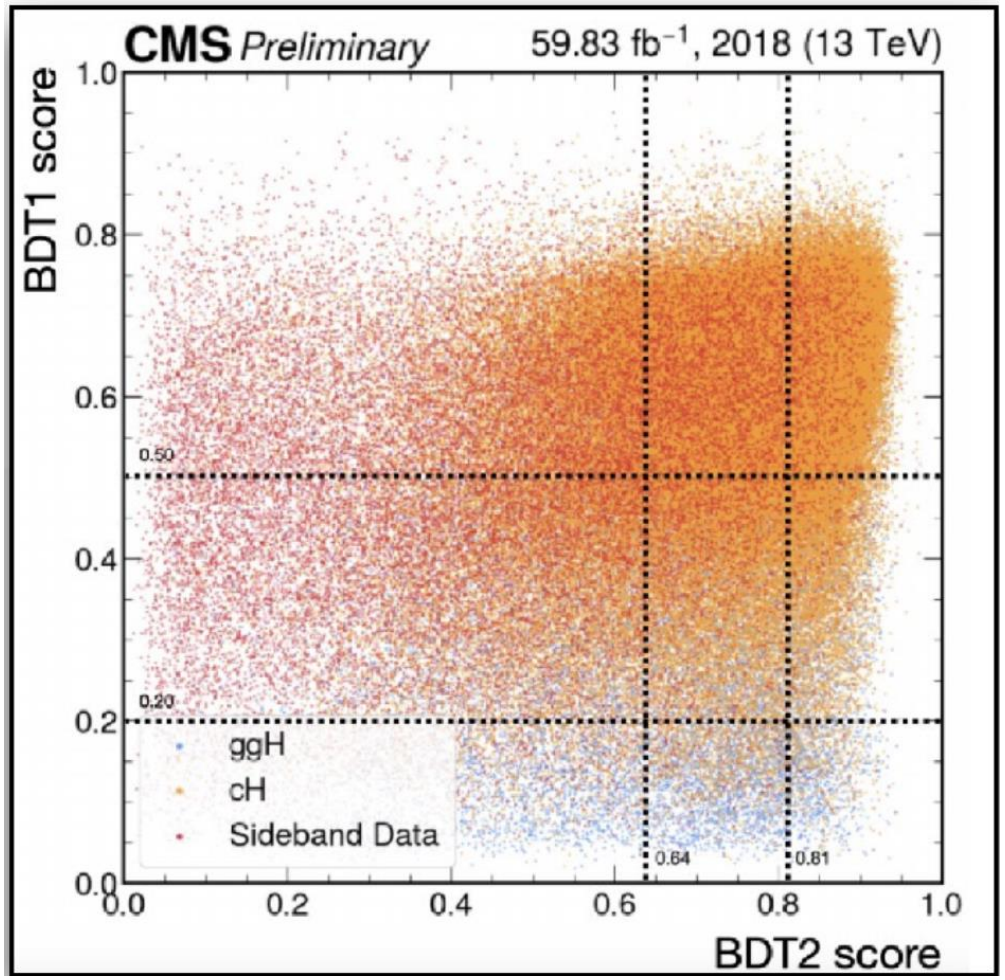


CMS-PAS-HIG-23-010

Signal extraction

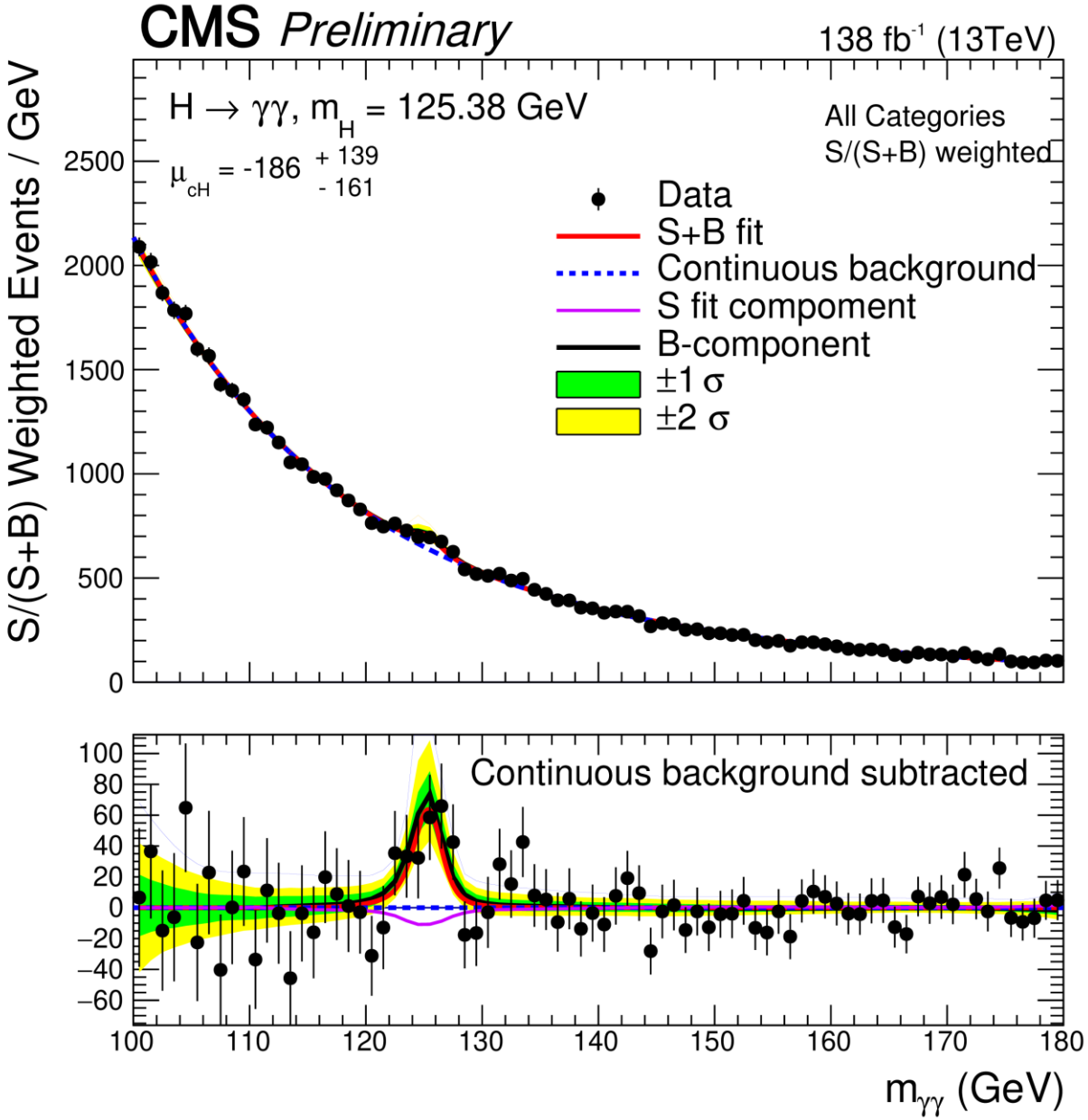
- Define 27 categories
  - 9 according to score of the two BDTs
  - For each of the 3 years
- Simultaneous maximum likelihood fit to the $m_{\gamma\gamma}$ distribution in the 27 categories
  - Signal shape modelled from MC
  - Background shape from fit to sidebands

CMS-PAS-HIG-23-010



Fit result

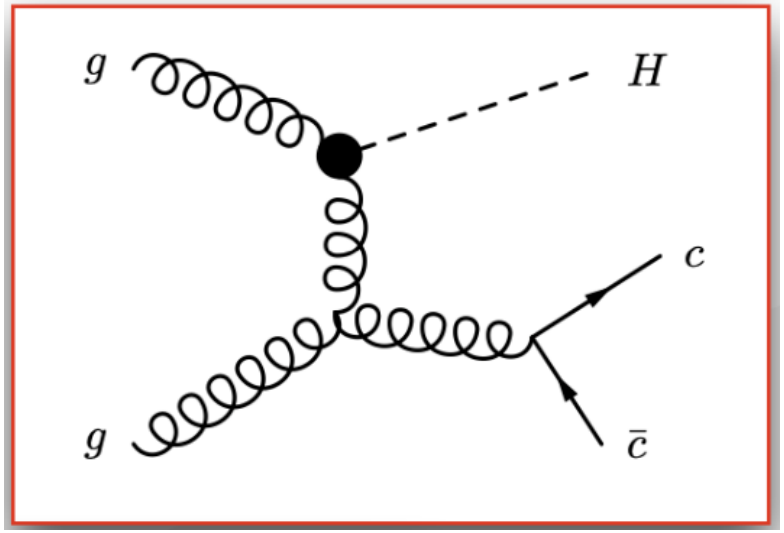
CMS-PAS-HIG-23-010



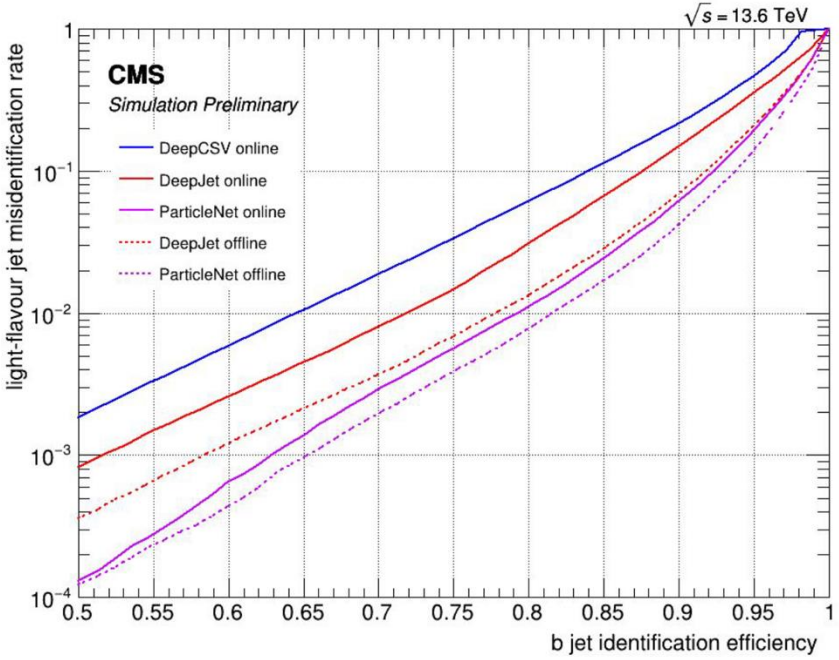
- Observed (expected) upper limit at 95% CL on the cH signal strength is 243 (355) times the SM prediction
- Result dominated by statistical uncertainty
- Main systematic uncertainty
  - Modelling of ggH background
  - Flavor scheme uncertainty on cH/bH production

Next steps

- Address main systematic uncertainty by measuring inclusive H+c production
  - Mainly, ggH+c, not y_c-dependent part
  - σ(ggH+c) is about 30x larger than σ(H+c, y_c)

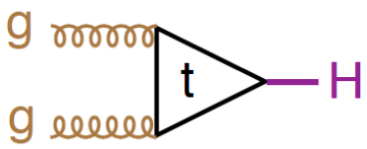


- Measure H+c and H+b simultaneously
- Include first part of Run 3 data (2022,2023) ~70 fb^{-1}
- Take advantage of new tools for charm tagging developed for Run 3



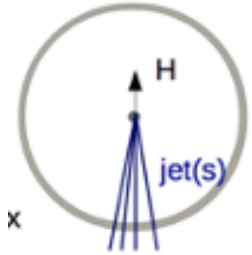
H+c production modes

"ggH"

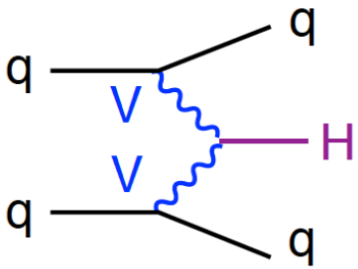


Gluon-gluon fusion

• Charm from gluon splitting in ISR/FSR

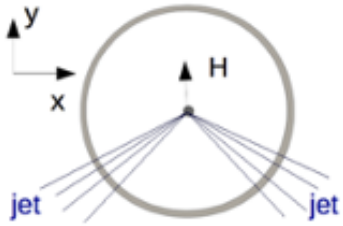


"VBF"
(10xlower than ggH)

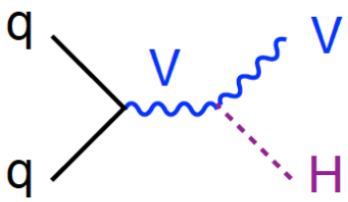


Vectorboson fusion

• Distinct experimental signature with two forward jets
• Charm in forward jets or g→cc



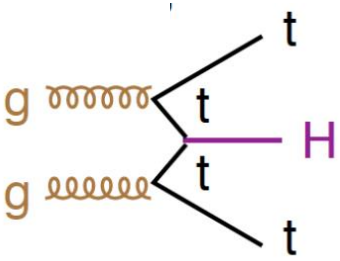
"VH"
(20xlower than ggH)



Associated production with W/Z

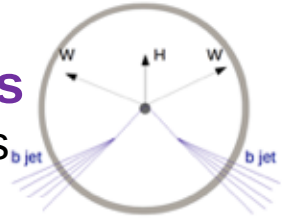
• W(Z) bosons in the final state
• Charm from V decay or g→cc

"ttH"
(90xlower than ggH)



Associated production with quarks

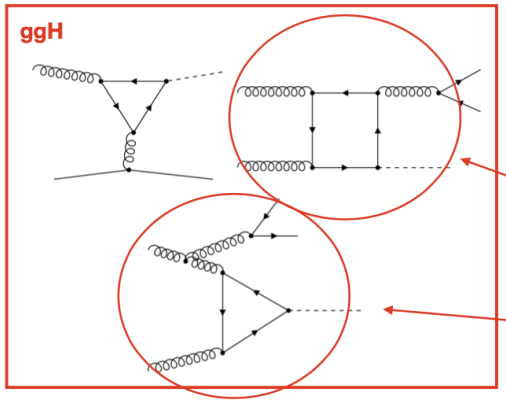
• Complex final state with at least two b-jets
• Charm from W and b-decay or g→cc



H+c production in ggH, VH, ttH, VBF

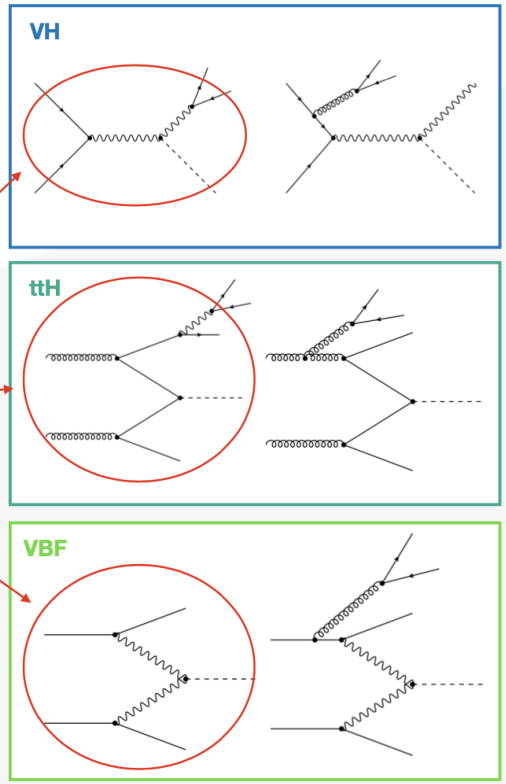
- How to define the signal?

H+c & H+b inclusive:



Dominant HF contribution:

- ME or V couplings (VH, ttH)
- PDFs (VBF)



Dominant

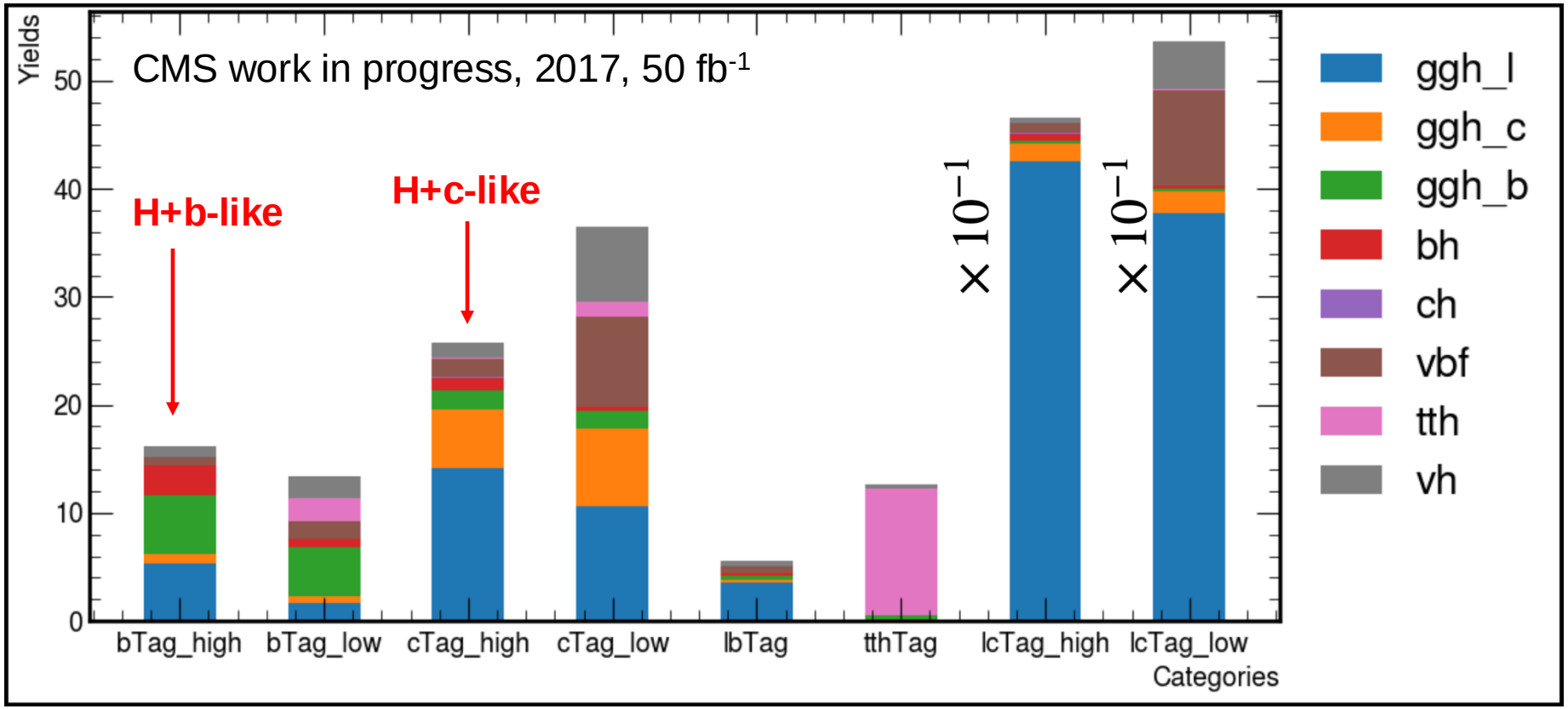
- All HF contributions coming from PDFs and PS.
- PS contribution 10 x PDF initiated one for ggH.

⇒ **Ideally we would like to isolate ggH+HF from the rest of the resonant H + HF production**

- Use distinct experimental signatures (e.g. number of jets, b-jets and leptons, angular separation) for discrimination

Event categorization

- Improved event selection and event classification
- Dominant background to ggh+c/b production from ggh+light-jet production → expect improvement from moving to new tagger
- Established control region for ttH, might be possible also for VH, VBF production



Summary

- Measurement of Higgs boson couplings to second generation quarks are a priority of the physics program at CMS
- Different approaches to constrain y_c, best sensitivity from V(H→cc)
- Search for c+H production provides an alternative approach
- First analysis carried out with Run 2 data
  - Using H→$\gamma\gamma$ decay channel
  - Results limited by statistics and theoretical uncertainty on resonant Higgs background
- Work ongoing to measure inclusive H+c production with Run 2 and Run 3 data