

Charm Yukawa Couplings

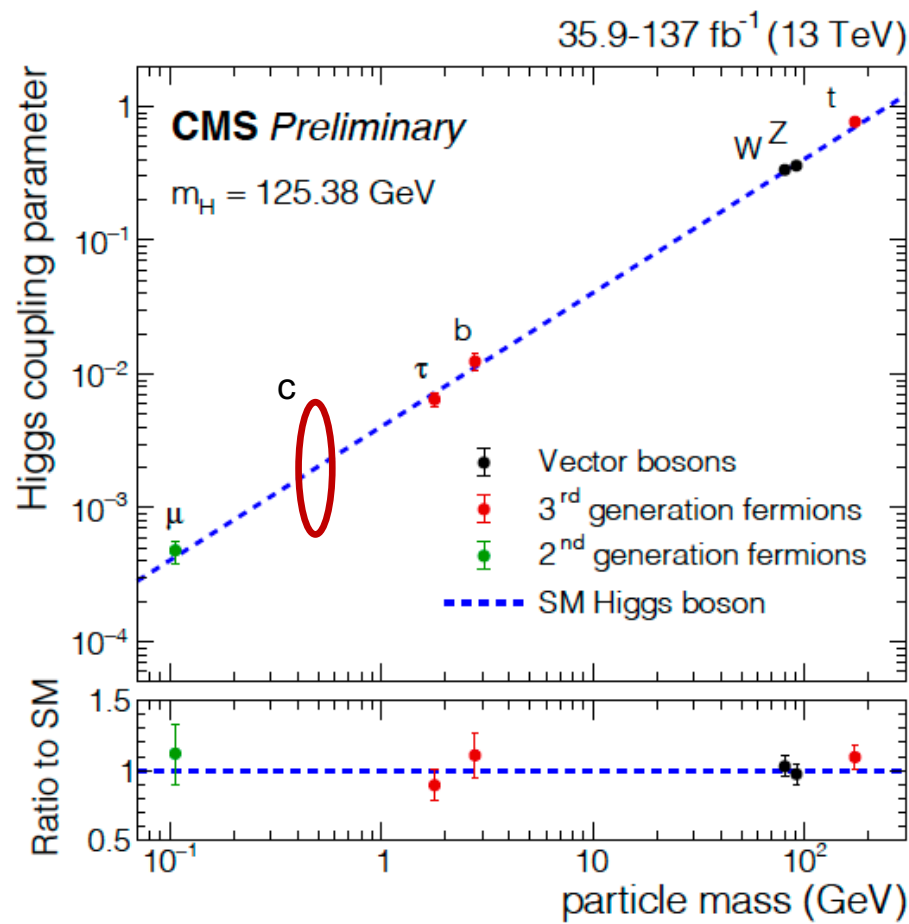
Experimental aspects

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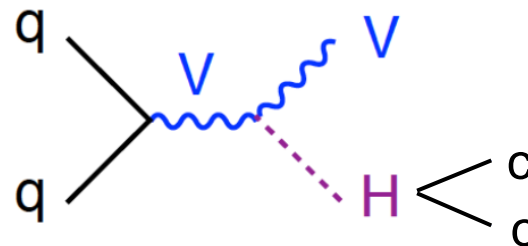
Higgs boson couplings

- Higgs boson has a unique role in the Standard Model
 - > Couplings to other particles are precisely predicted and proportional to particle mass
- LHC Run 1 (2010-2012)
~30 fb⁻¹ @ 7-8 TeV:
 - Higgs discovery ($H \rightarrow \gamma\gamma$, $H \rightarrow ZZ$)
 - Observation of $H \rightarrow WW$
- LHC Run 2 (2015-2018)
~160 fb⁻¹ @ 13 TeV:
 - Observation of $H \rightarrow \tau\tau$, $H \rightarrow bb$, ttH
 - Evidence for $H \rightarrow \mu\mu$
- Charm still missing
 - What are the prospects for Run 3 and HL-LHC?
 - Expected luminosity:
 - Run 3 (2022-2024) ~ 400 fb⁻¹
 - HL-LHC (from 2027) ~ 3000-4000 fb⁻¹



Higgs decay to charm quarks

- BR ($H \rightarrow cc$) $\sim 3\%$
- Experimental challenge is to discriminate charm-jets from multi-jet production \rightarrow exploit different Higgs boson production modes



- CMS Result**

[JHEP 03 (2020) 131]

$\sigma/\sigma_{SM} < 70(37)$ observed (expected)
at 95% C.L.

- ATLAS results**

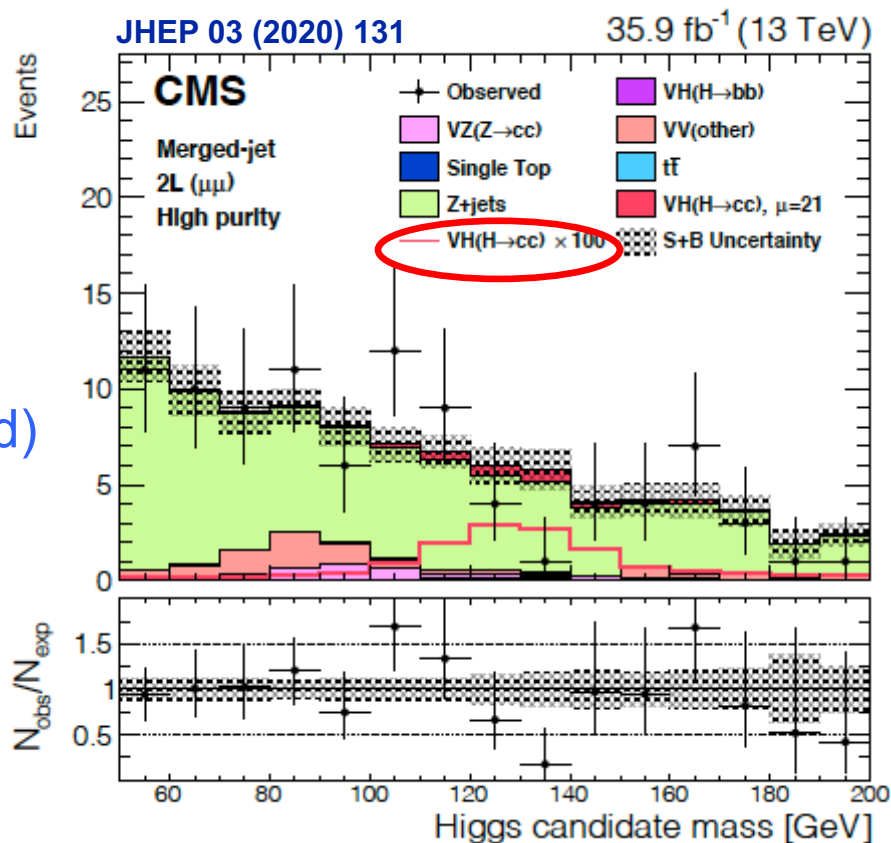
[Phys.Rev.Lett. 120, 211802]

$\sigma/\sigma_{SM} < 110(150)$ observed (expected)
at 95% C.L.

and projection for 3000 fb⁻¹:

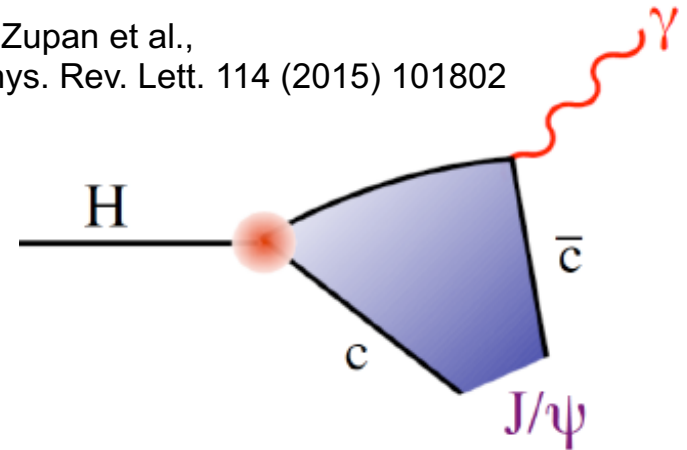
$\sigma/\sigma_{SM} < 6$ at 95% C.L.

[ATL-PHYS-PUB-2018-016]



Higgs coupling to charm quarks through study of rare decays

Y. Zupan et al.,
Phys. Rev. Lett. 114 (2015) 101802



- Rare exclusive decays of the Higgs boson with mesons provide alternative approach for measurement of coupling to charm quark

– $BR(H \rightarrow J/\psi \gamma) = 2.5 \times 10^{-6}$

- Advantage is clean signature in the detector with $J/\psi \rightarrow \mu\mu$ or ee
- Search results at LHC:

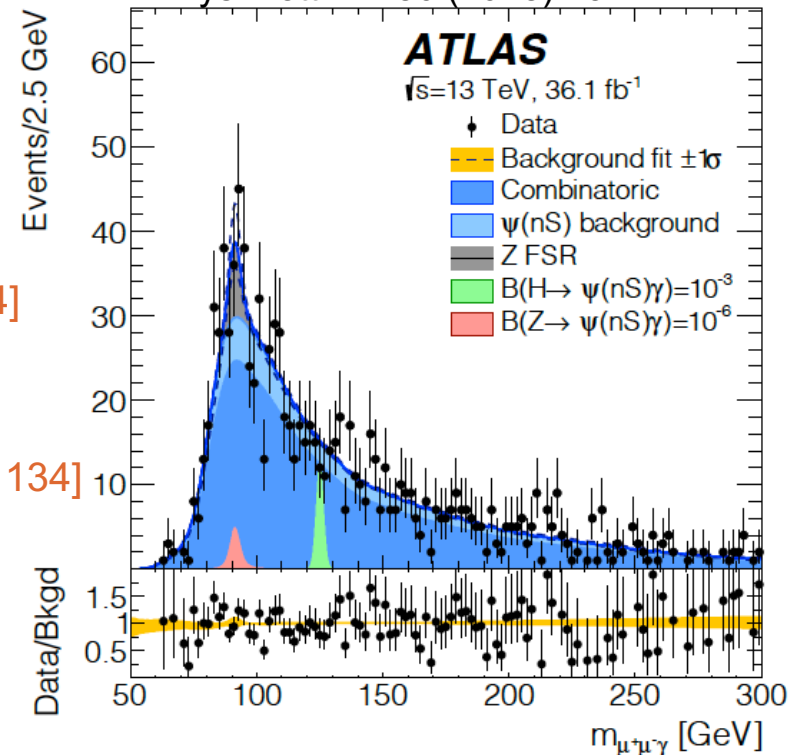
CMS $BR/BR_{SM} < 260(170)$ obs (exp) [EPJC 79 (2019) 94]
 ATLAS $BR/BR_{SM} < 117(100)$ obs (exp)
 at 95% C.L. [Phys. Lett. B 786 (2018) 134]

and projected to 3000 fb^{-1} :

$BR/BR_{SM} < 15$

[ATL-PHYS-PUB-2018-016]

Phys. Lett. B 786 (2018) 134



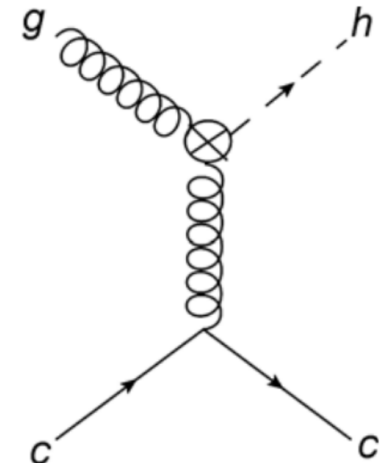
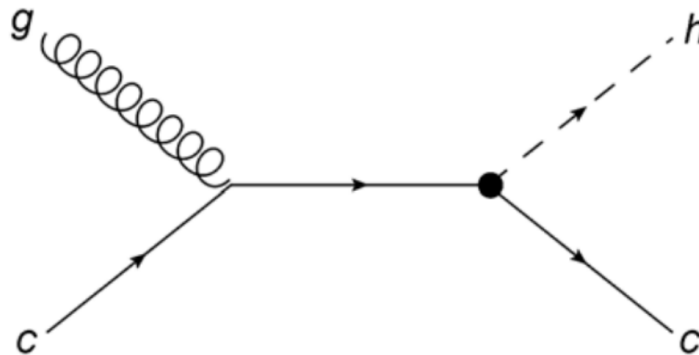
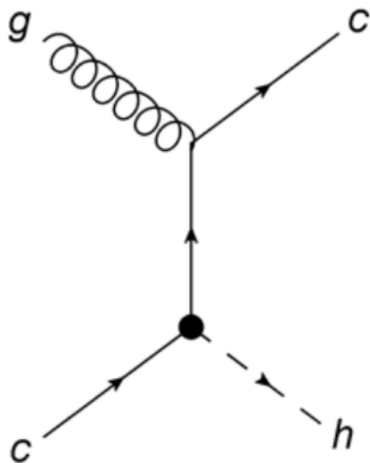
Higgs coupling to charm quarks through associated production

- Exploit rare production mechanism in which Higgs boson is produced in association with charm jets
- Advantages
 - Only one charm quark jet in the final state
 - Higgs boson decay can be reconstructed from clean final state ($H \rightarrow \gamma\gamma / WW / \tau\tau$)
 - Sensitive to sign of y_c
- Still to be explored at the LHC

Higgs charm associated production

$$\sigma(14 \text{ TeV}, cH) = 0.3 \text{ pb}$$

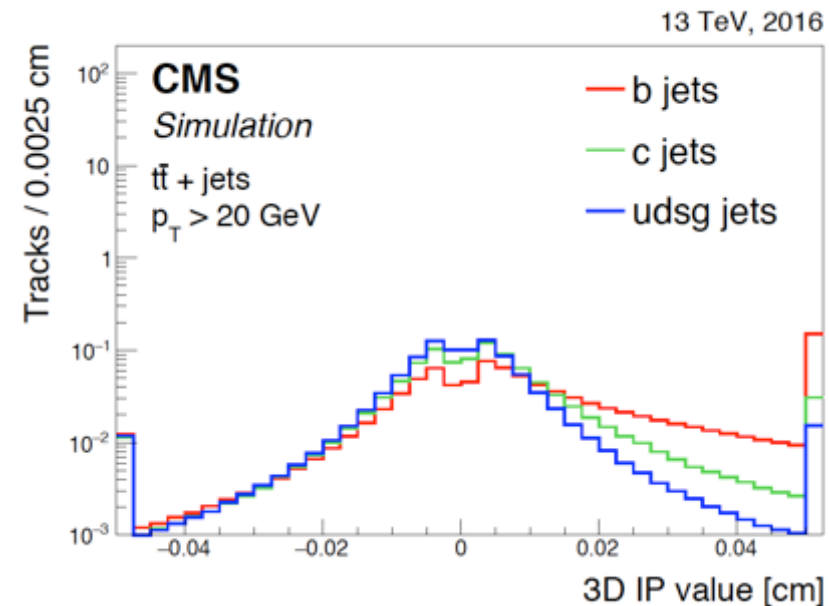
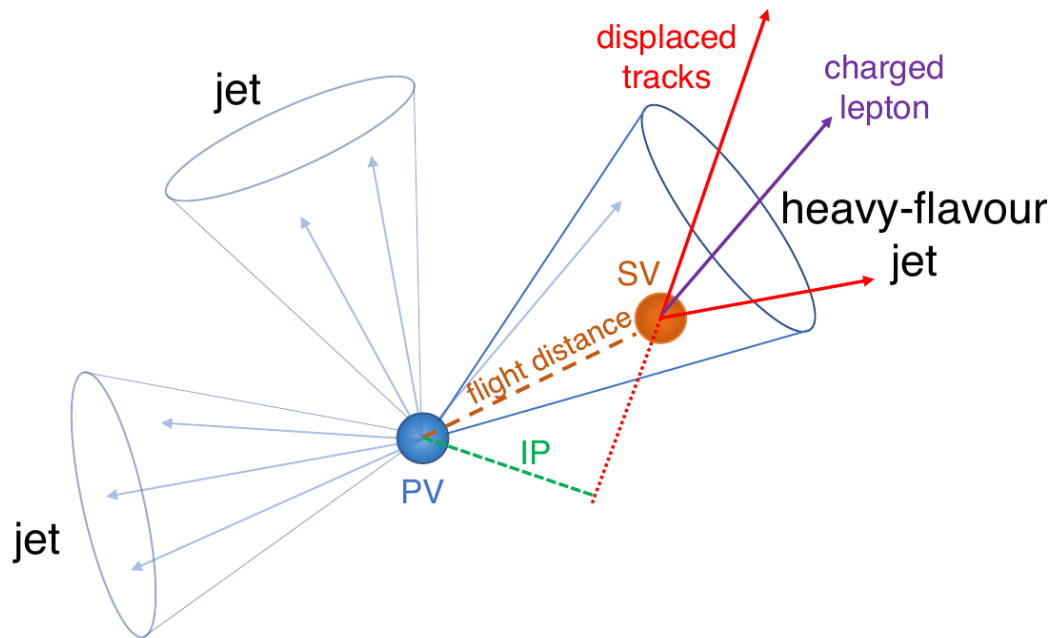
[I. Brivio, F. Goertz, G. Isidori, Phys. Rev. Lett. 115 (2015) 211801]



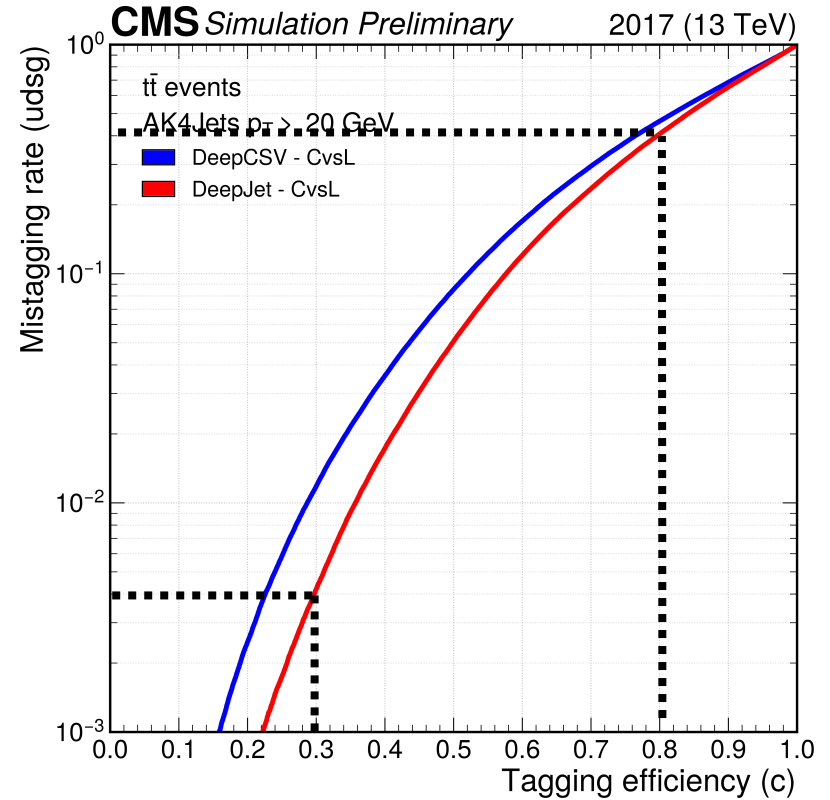
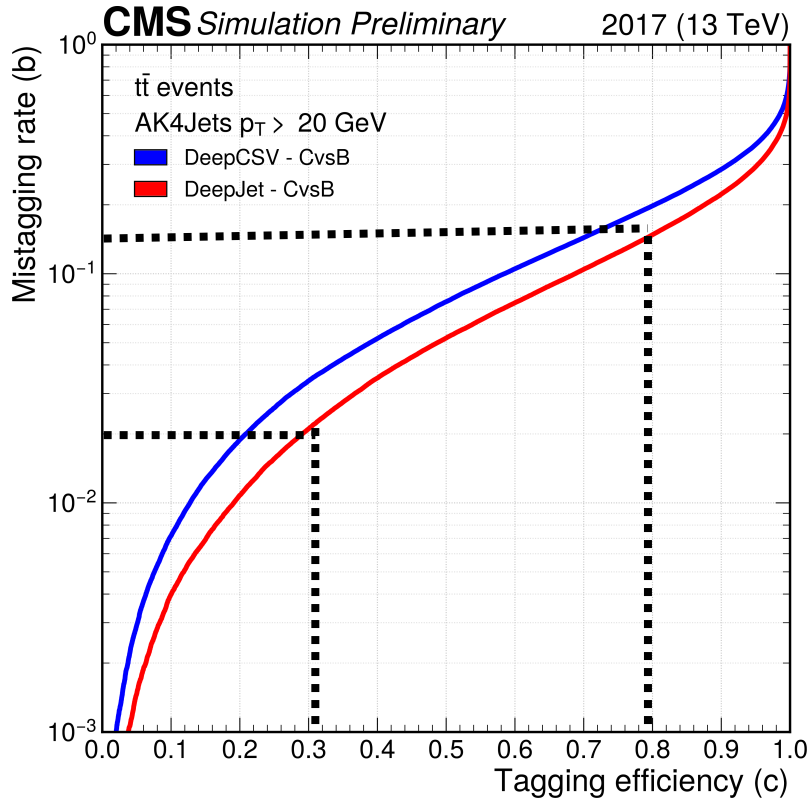
Heavy flavor tagging

- Jets with heavy flavor quarks (b,c) identified based on distinct properties
 - Long lifetime, large mass, hard fragmentation, decays with leptons
 - Combine this information into neural network

Charm tagging needs to efficiently discriminate against b-jets as well as light-quark and gluon jets



Charm tagging performance



ϵ_c	ϵ_b	ϵ_{udsg}
30%	2%	0.4%
80%	14%	40%

Estimated sensitivity [I. Brivio, F. Goertz, G. Isidori, Phys. Rev. Lett. 115 (2015) 211801]

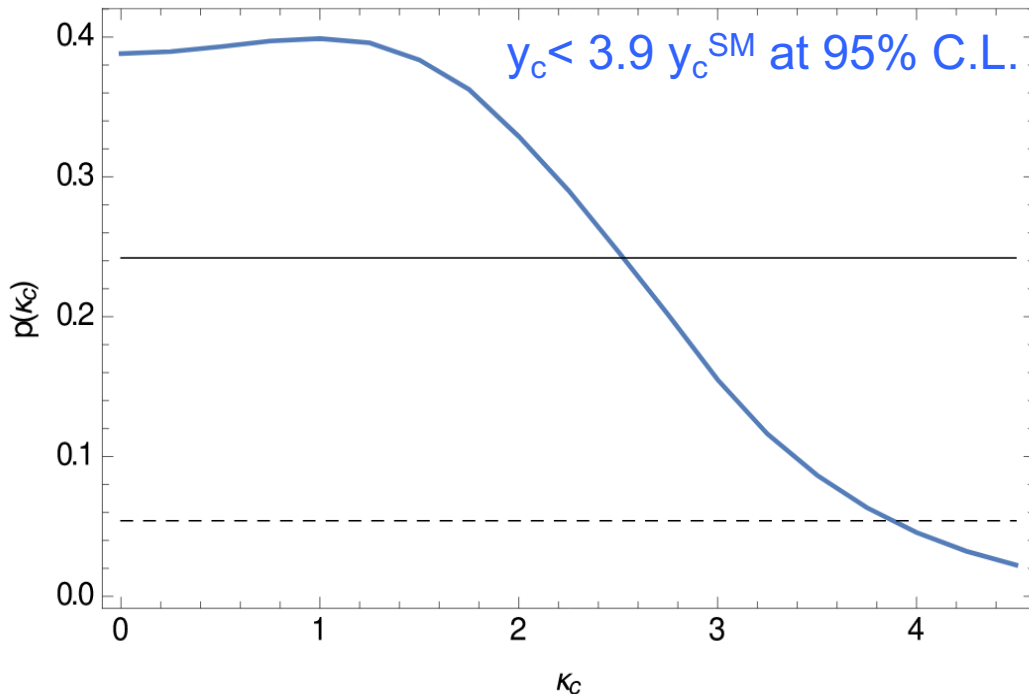
- Assuming low background from non-Higgs boson events when using clean final state ($H \rightarrow \gamma\gamma$)
- Main backgrounds:
 - $pp \rightarrow bH$ ($\sigma \sim 1.2x\sigma_c$)
 - $pp \rightarrow gH$ ($\sigma \sim 0.4x\sigma_c$)
 - $pp \rightarrow ccH$ ($\sigma \sim 0.2x\sigma_c$)

Luminosity 3000 fb⁻¹

Jet $p_T > 20$ GeV, $|h| < 5$, $\Delta R(j_1, j_2) > 0.4$

c-tagging efficiency 40%

c-tagging mistag rate 30% (b) and 1%(g)



- Sensitivity “comparable” to $H \rightarrow cc$
- More realistic estimate need
- Study potential of tagging lower p_T charm (only 25% of signal events have jet $p_T > 20$ GeV)
- Add additional Higgs boson decays