Physics
Institute III A

RWTH AACHEN
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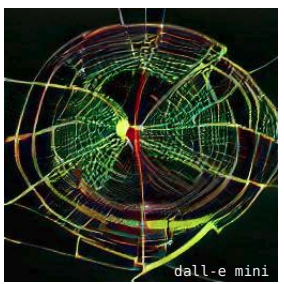
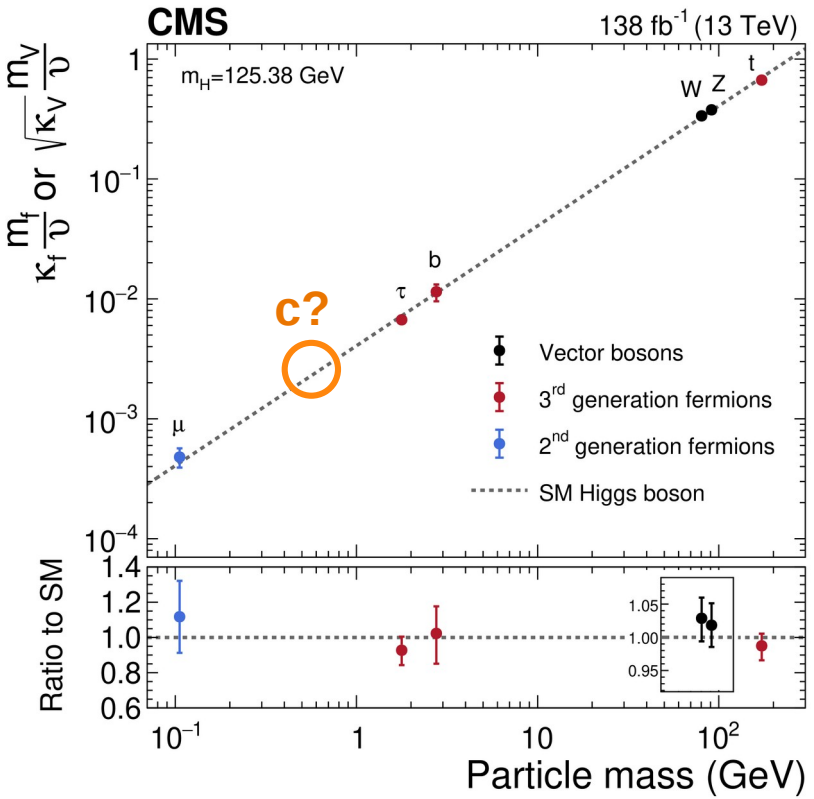
Constraints on the Higgs-charm coupling by CMS

Andrey Pozdnyakov
(RWTH Aachen)
on behalf of CMS Collaboration

ICHEP-2022,
Bologna, Italy
July 07, 2022



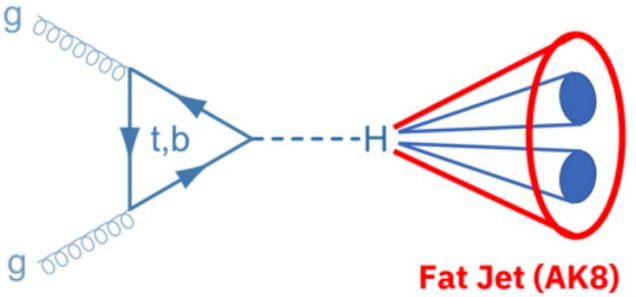
Introduction and outlook

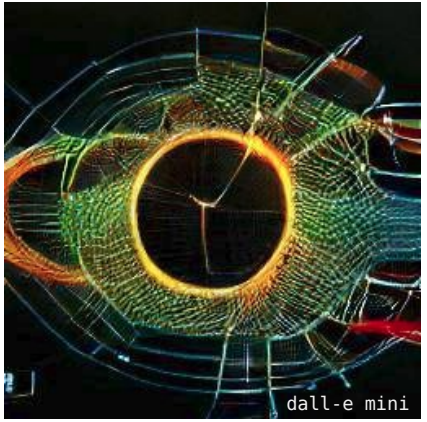


Nature 607 (2022) 60-68

- On the way to fully characterize the Higgs boson: coupling to charm
- Few ways to constrain Higgs charm coupling at CMS:
  - Direct search for $H \to c\bar{c}$ decay: in ggH and VH channels
  - Indirect constraints from Higgs kinematics
  - Rare $H \to J/\psi+\gamma$ decay
- What is the projection for HL-LHC?

ggH($c\bar{c}$)

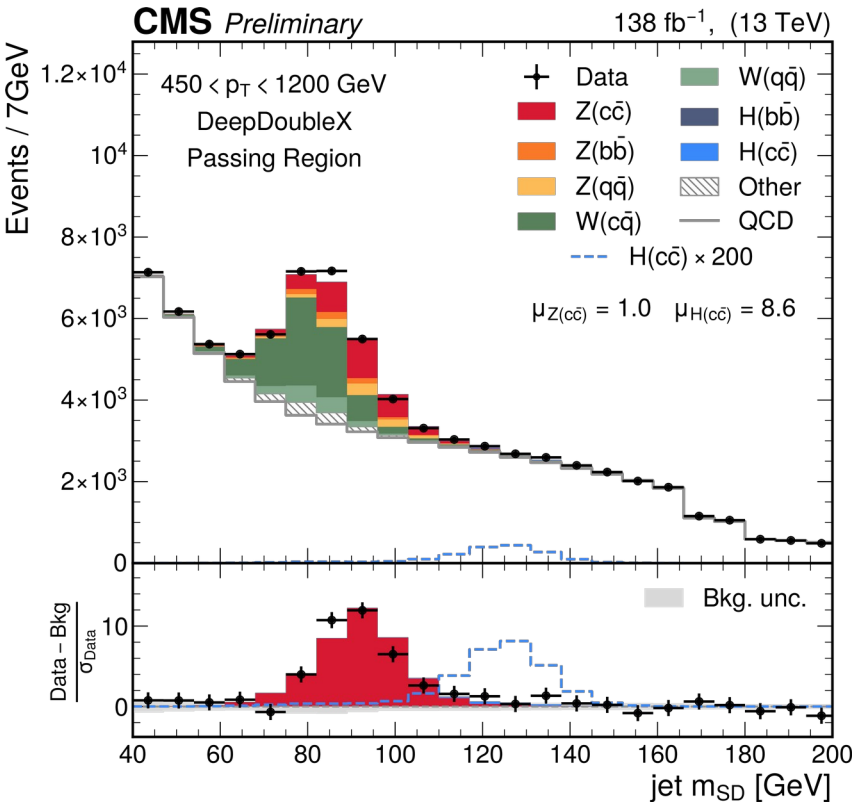




dall-e mini image based on phrase:
“Constraints on Higgs-charm coupling by CMS”
10.5281/zenodo.5146400

Search in ggH channel

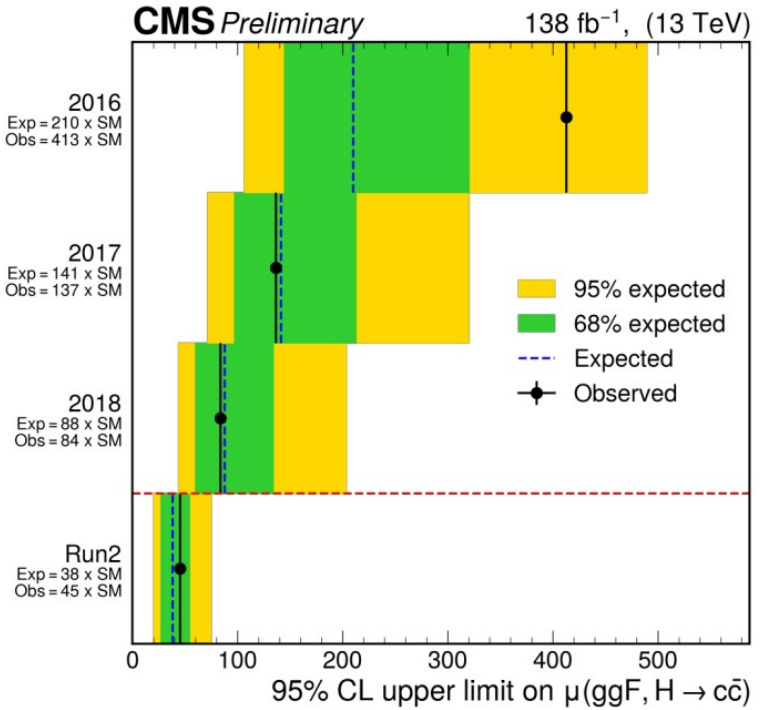
- Higgs candidate is a anti-kt jet with R=0.8 (AK8), p_T>450 GeV
  - not a pure ggH signal:
    - 50% ggF (ggH+jet)
    - 30% VBF
- Double-charm tagging with NN:
  - CNN/RNN with low level inputs
  - Mass independent using dedicated simulation samples



Recent! CMS-PAS-HIG-21-012

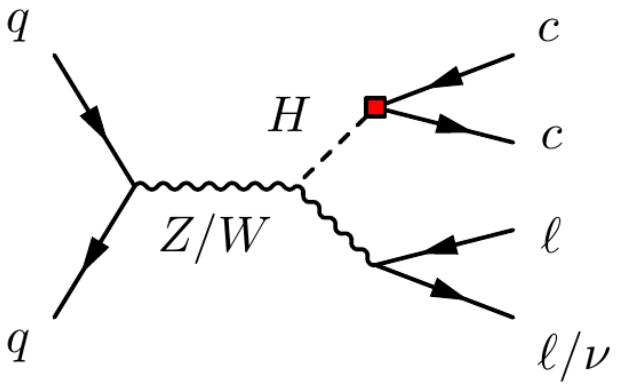
ggH(cc) results

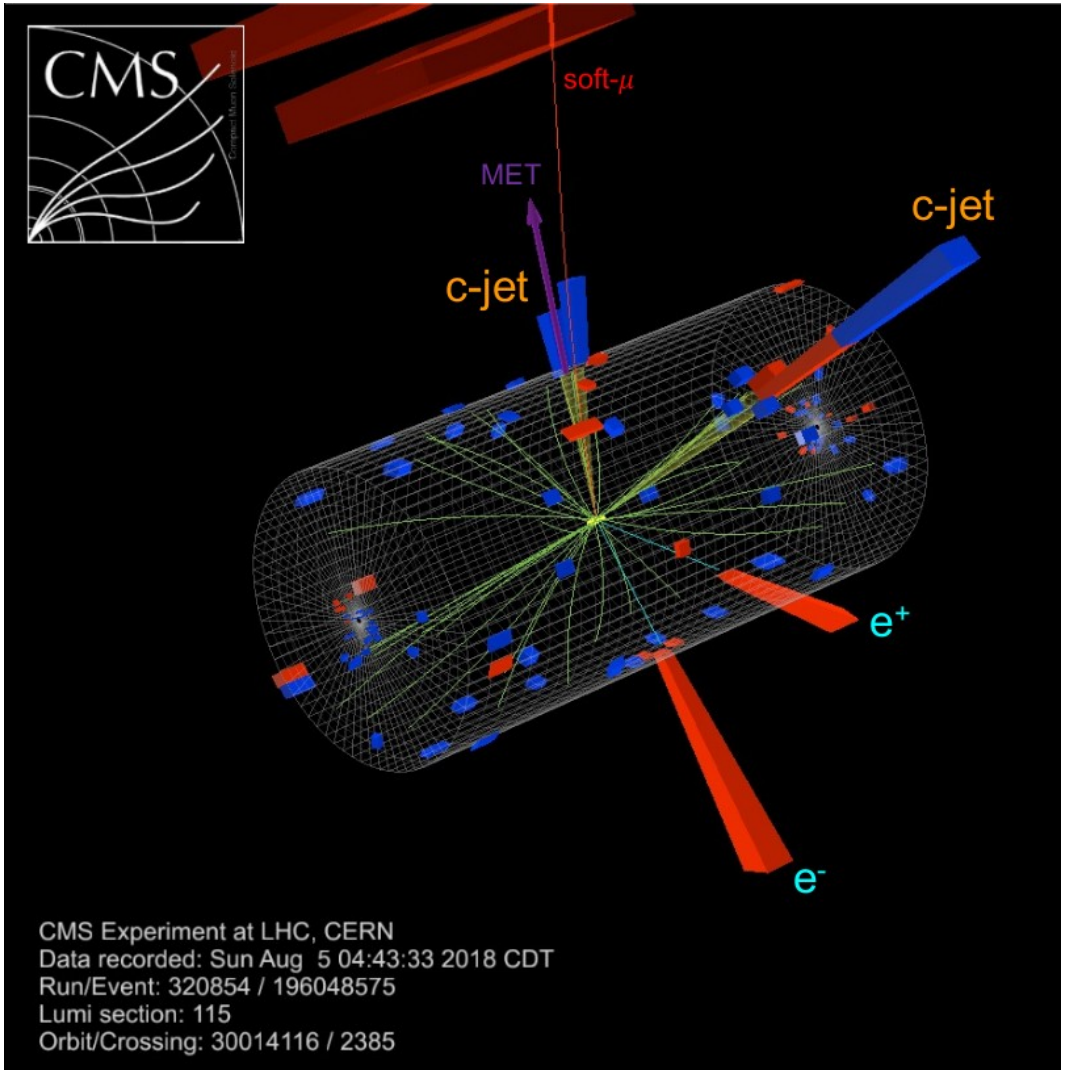
- Limit at 45 (38) x SM @95% CL
- Validation of techniques with $Z \to c\bar{c}$ candle
  - Observation with >> 5 sigma
- See poster by Andrzej Novak for more details



CMS-PAS-HIG-21-012

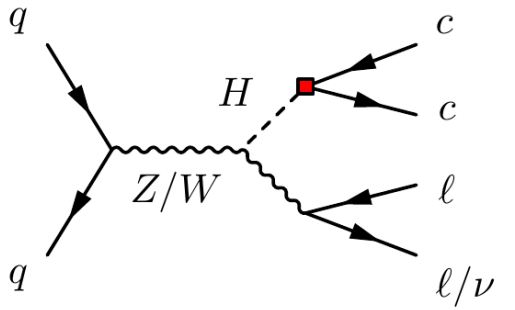
V+H($c\bar{c}$)


q
q
H
Z/W
c
c
ℓ
ℓ/ν


CMS
soft-μ
MET
c-jet
c-jet
e+
e-
CMS Experiment at LHC, CERN
Data recorded: Sun Aug 5 04:43:33 2018 CDT
Run/Event: 320854 / 196048575
Lumi section: 115
Orbit/Crossing: 30014116 / 2385

VH($c\bar{c}$) search at a glance

VH channel categories



$(Z \to l^+l^-) + H$

2L channel

- Cleanest

$(Z \to \nu\nu) + H$

0L channel

- Large E_T^{miss}

$(W \to l\nu) + H$

1L channel

- Larger production than ZH; larger BR of the W decay, compared to $Z \to l^+l^-$

$H \to c\bar{c}$

2 small-cone (AK4) charm-tagged jets ("2 jets topology")

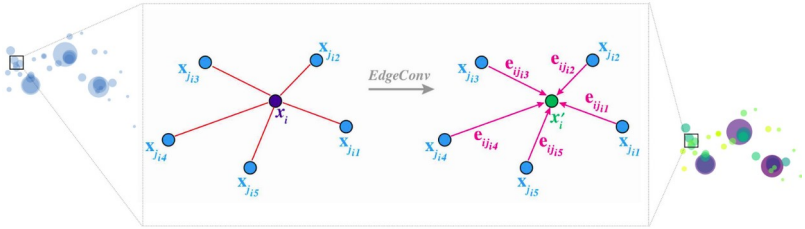
1 large cone (AK15) cc-tagged jet ("boosted topology")

Backgrounds: Z+jets, W+jets, $t\bar{t}$ (1L), VZ, QCD (0L)

ParticleNet: charm tagger for AK15 jets

Phys. Rev. D 101, 056019

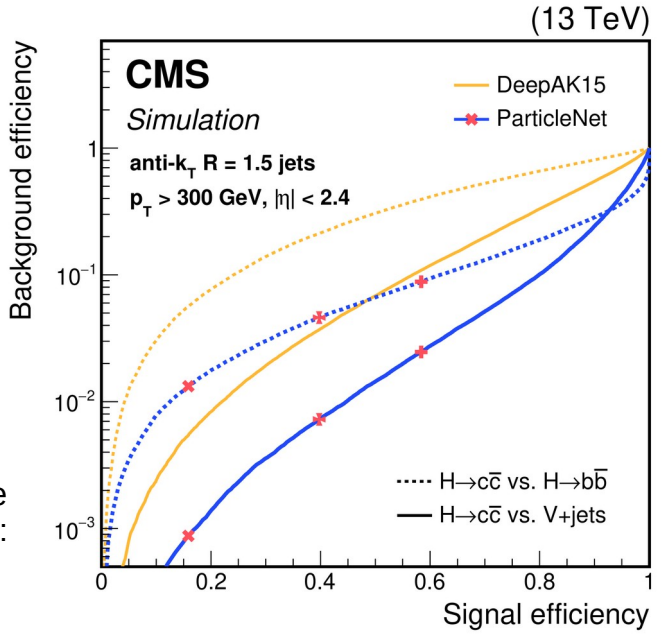
- ParticleNet: a multi-class jet classifier for t/H/W/Z tagging of fat jets
  - permutation-invariant GNN with EdgeConv
  - jet = unordered set of particles
- Use low-level jet features as inputs (PF candidates, SVs)
- Scores for: X→b$\bar{b}$, X→c$\bar{c}$, X→4q, QCD (b$\bar{b}$, c$\bar{c}$, b, c, others)



cc-tagging discriminant defined as

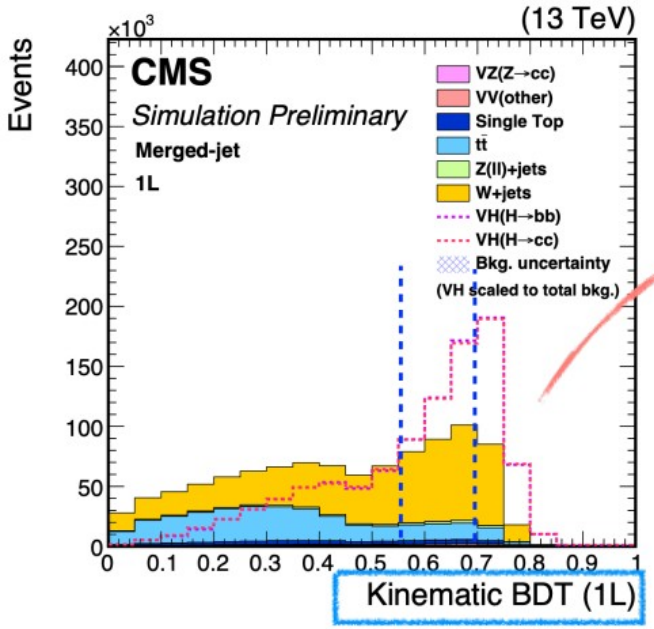
$P(X\to c\bar{c}) / [P(X\to c\bar{c})+P(QCD)]$

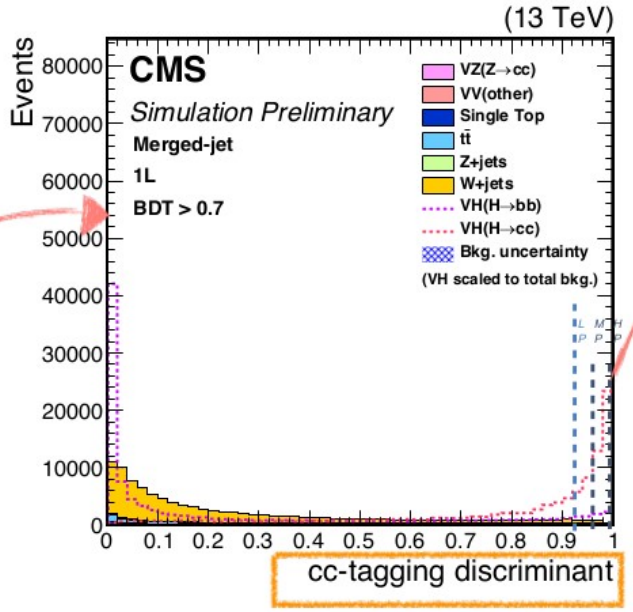
Great tagging performance for large-R jets:

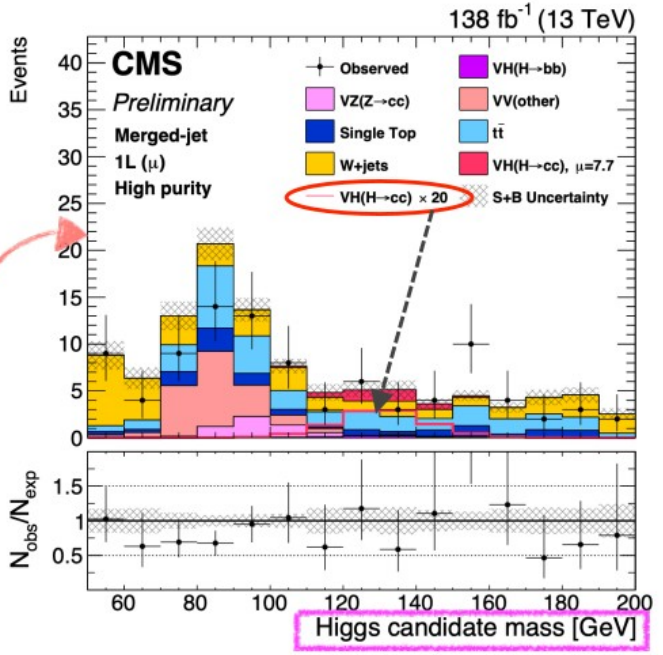


Analysis sketch: boosted topology

- Train BDT: signal vs (V+jets and $t\bar{t}$)
- Use cc-tagger score to define 3 regions (for high BDT score)
- Fit the jet mass (also using dedicated mass regression)
- Normalization of V+jets and $t\bar{t}$ bkg from CRs (low BDT, $N_{aj}>=2$)



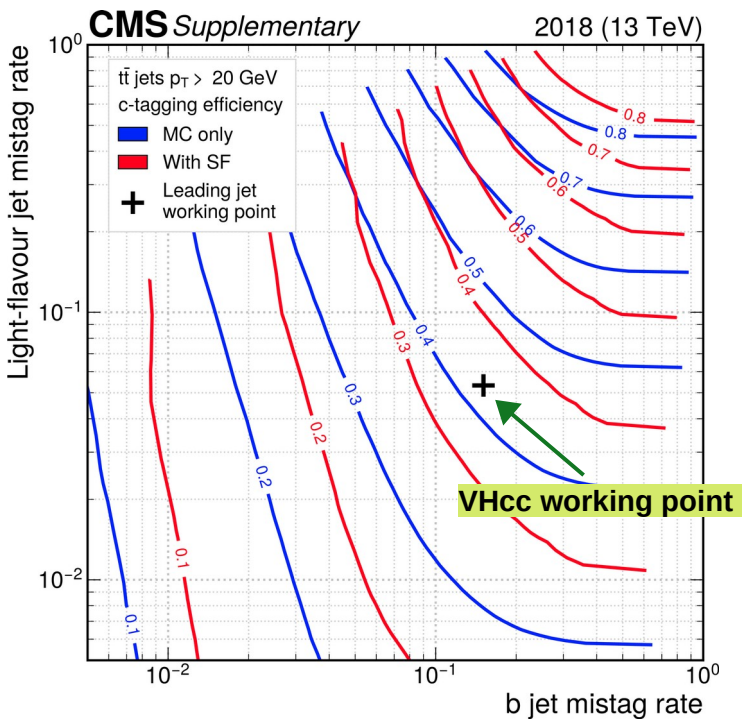




DeepJet: charm tagger for AK4 jets

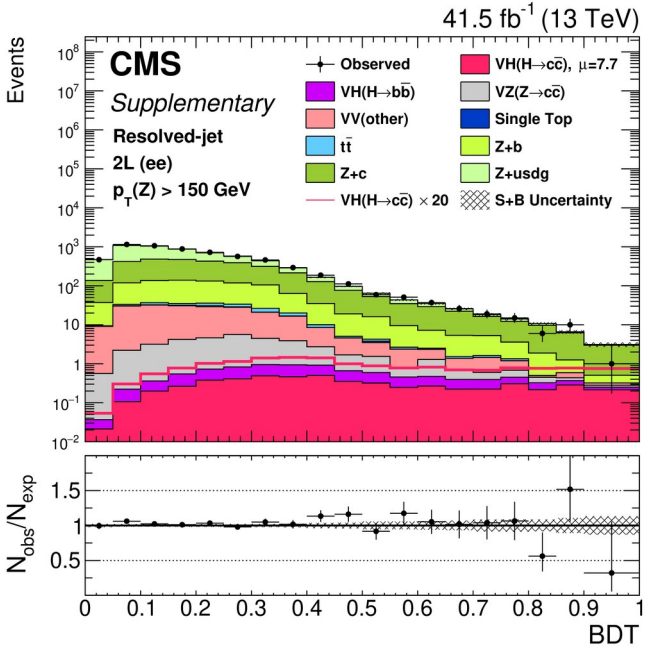
- Charm jet properties are in-between udsg and b-jets
- DNN multiclasifier is used to tag the AK4 jets: **DeepJet**
- Efficiencies of the Working Point (for jet with highest charm-tag score):
  - 42% c-jet eff
  - 15% b-jet mistag rate
  - 4% light jet mistag rate

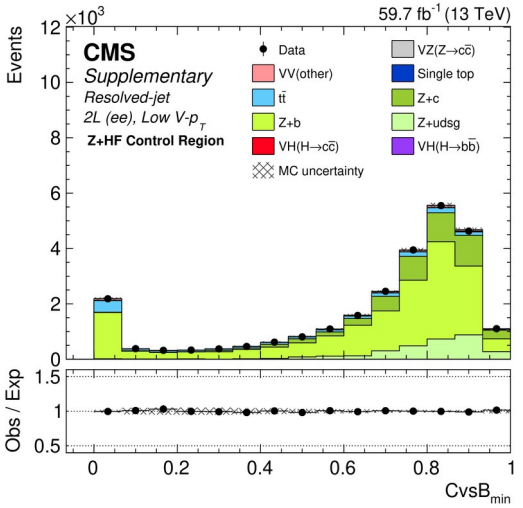
2022 JINST 17 P03014

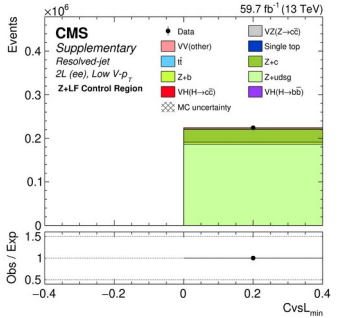


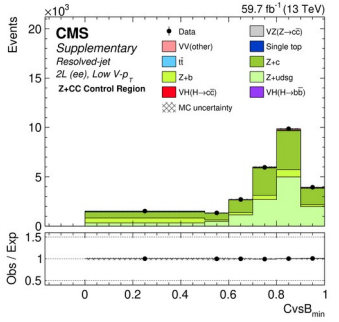
Analysis sketch: 2 jets topology

- Train BDT (signal vs all backgrounds), including the mass of the H candidate as input
  - Fit the BDT distributions to set the limit
- Constrain background normalization from CRs (V+LFj, V+HFj, V+CC, tt)



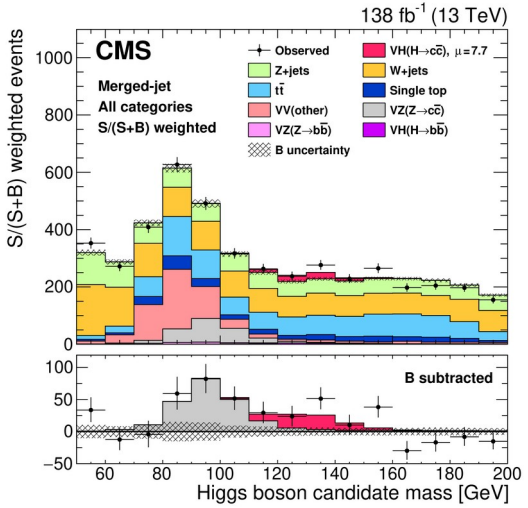


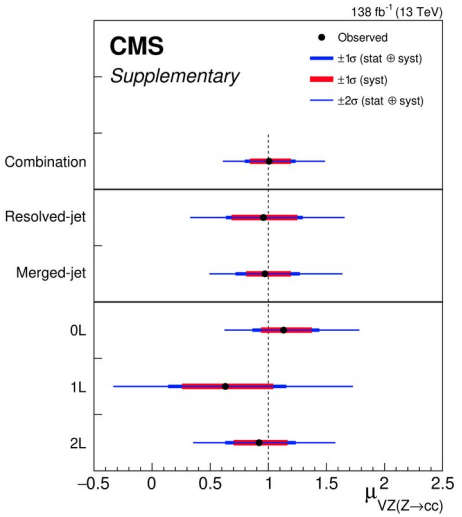


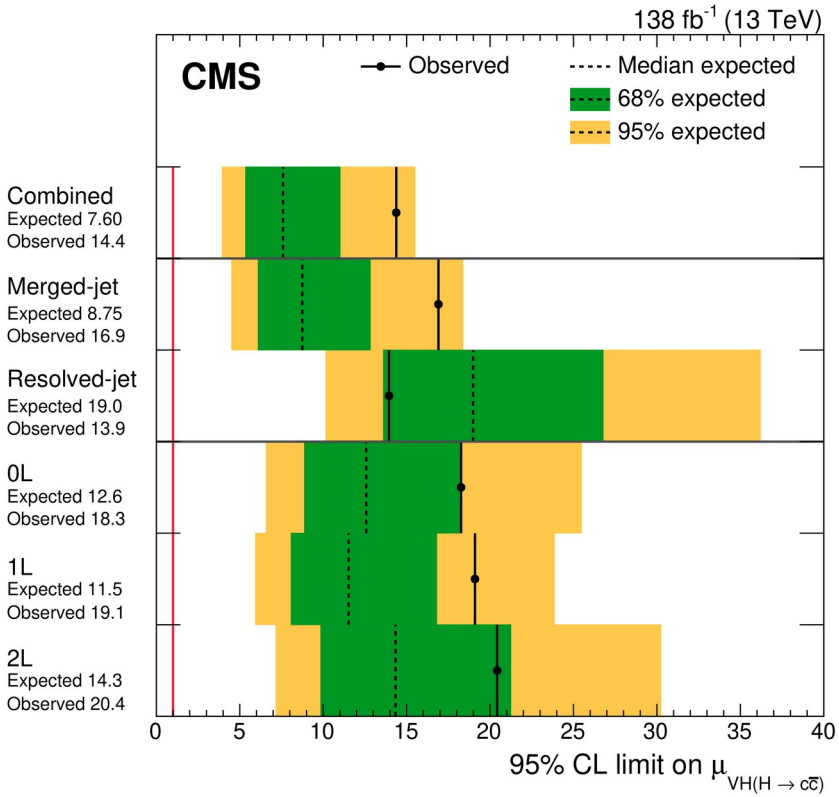


Expected limits and Z(cc) validation

- Final result combines merged and resolved analyses (separation on AK15 jet p_T=300)
- Observed (expected) UL on VH(cc) signal strength at 95% CL: $\mu_{VH(cc)} < 14\ (7.6)$
  - Strongest limit on VH(cc) process to date
  - Analysis validated with $Z \to c\bar{c}$ candle:
    - $\mu_{VZ(cc)} = 1.01 +/- 0.21$







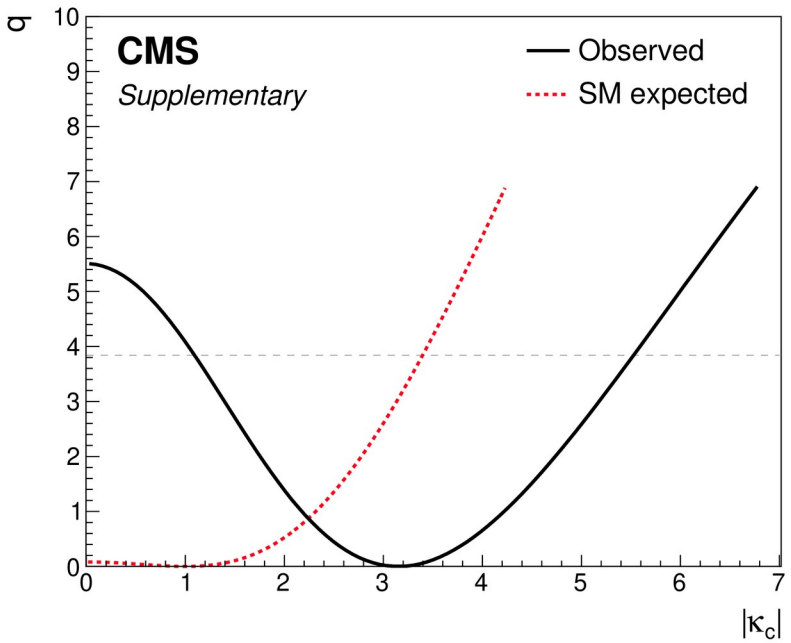
CMS-HIG-21-008

Constraint on k_c

- Constraint on $\mathbf{k_c}$ can be placed under assumption that all other H couplings fixed to SM values

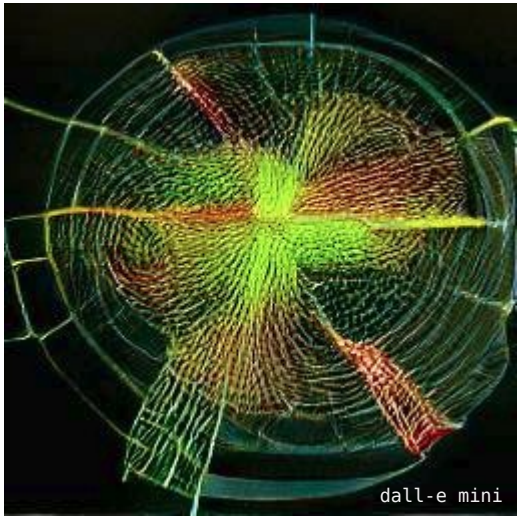
$$\mu_{VH(H\to cc)} = \frac{\kappa_c^2}{1+\mathcal{B}_{SM}(H\to cc)\times(\kappa_c^2-1)}$$

  - The 95% CL intervals obtained with likelihood scans
    - Observed: $1.1 < |k_c| < 5.5$
    - Expected: $|k_c| < 3.4$
  - Strongest constraint on $|k_c|$ from CMS (and HEP)



CMS-HIG-21-008

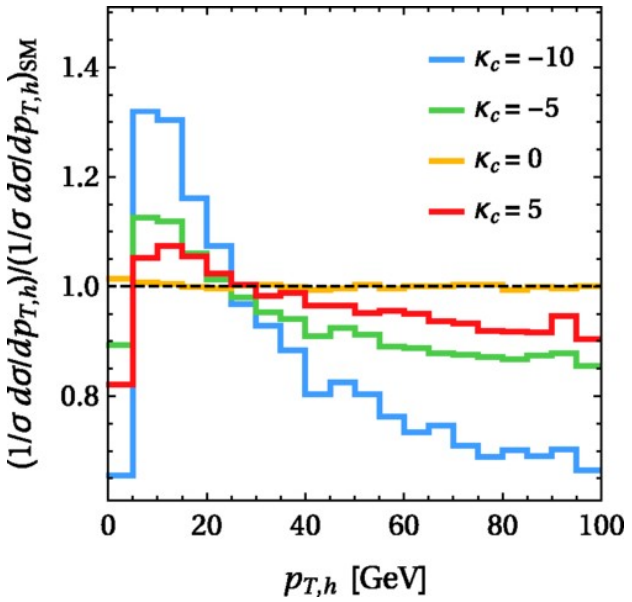
Indirect constraints from Higgs boson kinematics

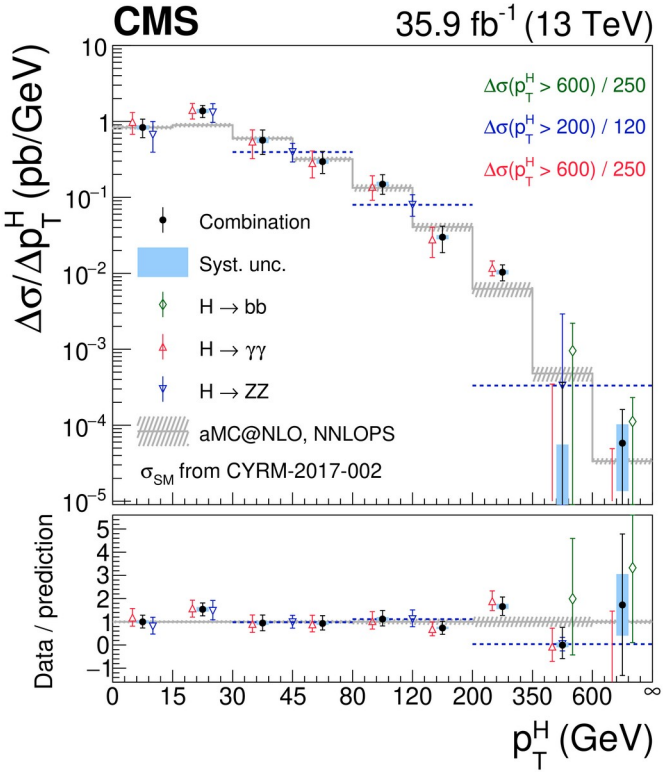


Indirect constraints from H kinematics

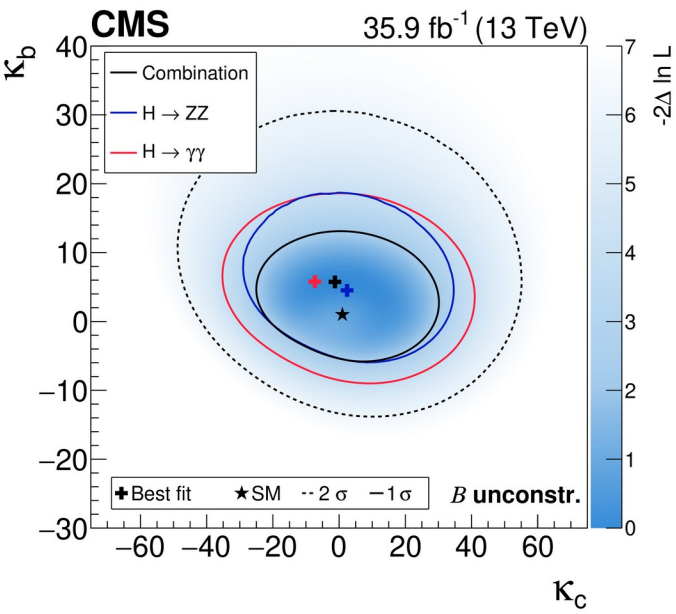
- Differential distributions (p_T, $|y|$, N_{jets} of the H) are sensitive to H couplings

Phys. Rev. Lett. 118, 121801



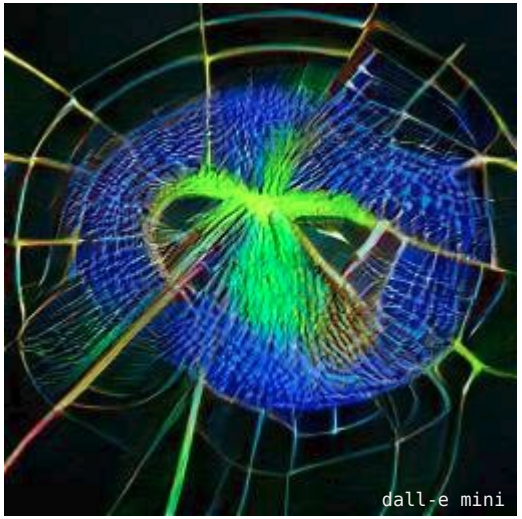


Phys. Lett. B 792 (2019) 369

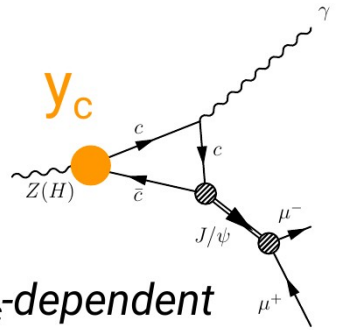


-33 < k_c < 38 (obs)

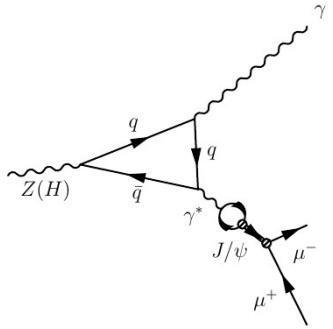
$H \to J/\psi + \gamma$



Search for H → J/ψ+γ decays



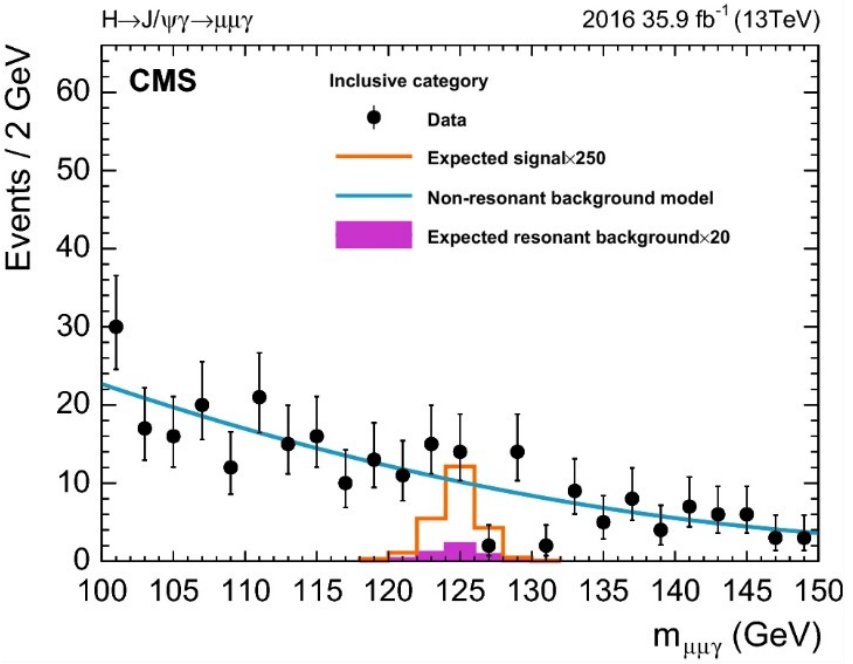
y_c-dependent



y_c-independent
(dominant contribution)

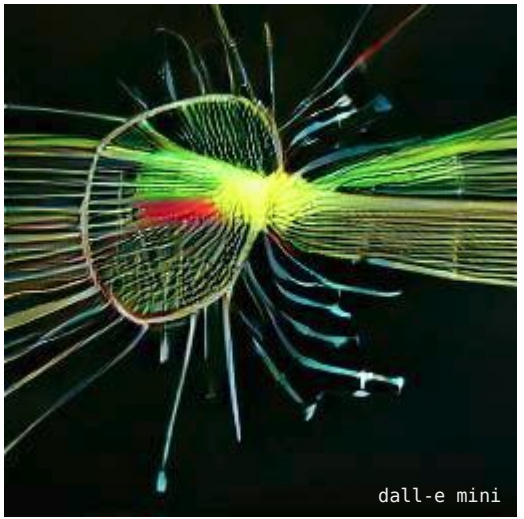
Phys. Rev. D 90, 113010
JHEP 08 (2015) 012
Phys. Rev. D 95, 054018
Phys. Rev. D 100, 054038

Eur. Phys. J. C 79, 94 (2019)

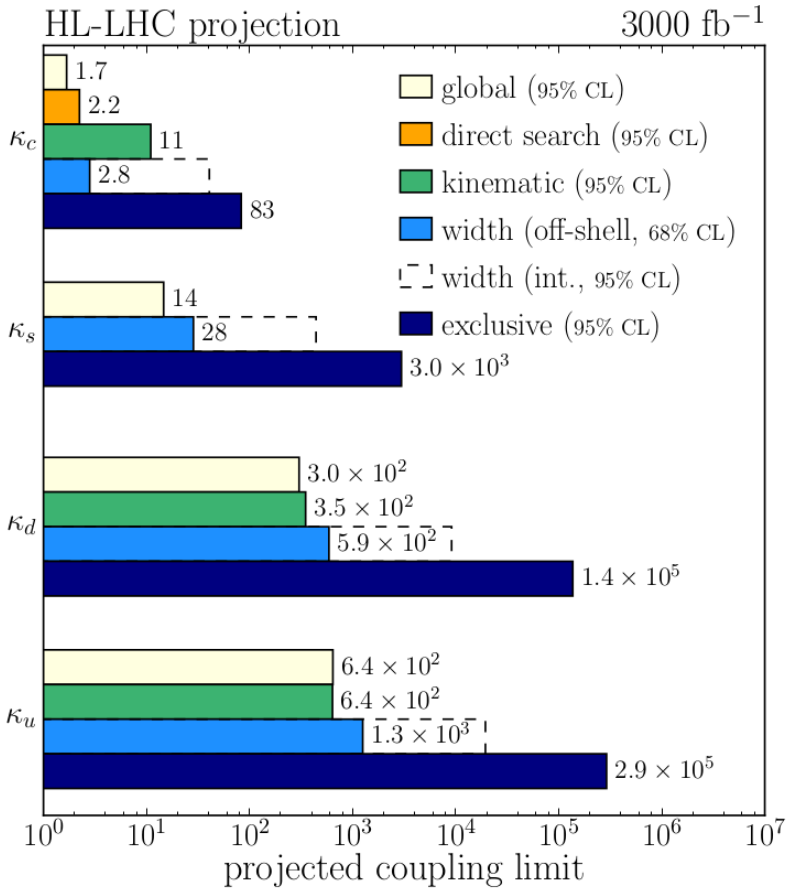


B(H → J/ψ+γ) < 220xSM (obs)

Projections to HL-LHC



Projection to HL-LHC

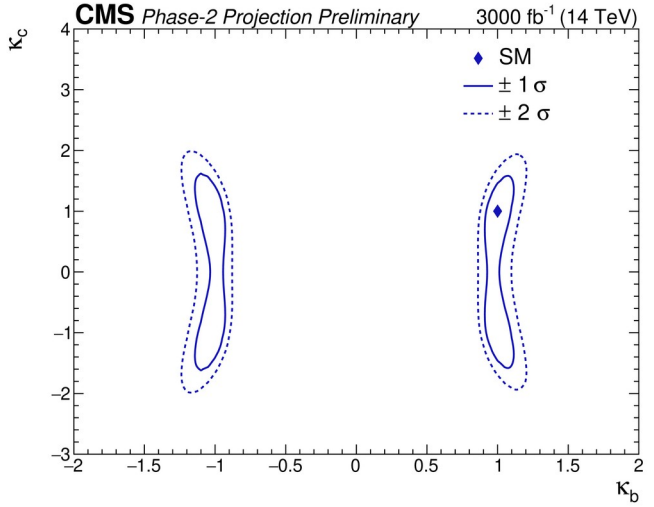


arXiv:1902.00134

- From VH(cc) boosted analysis alone: simultaneous extraction of H → b$\bar{b}$ and H → c$\bar{c}$ signal strengths:

$\mu_{VH(H \to bb)} = 1.00 \pm 0.03\,(stat.) \pm 0.04\,(syst.) = 1.00 \pm 0.05\,(total)$

$\mu_{VH(H \to cc)} = 1.0 \pm 0.6\,(stat.) \pm 0.5\,(syst.) = 1.0 \pm 0.8\,(total)$



CMS-HIG-21-008

Summary

- CMS has released two $H \to c\bar{c}$ analysis with full Run-2 dataset
  - ggH($c\bar{c}$):
    - Exploring H+jet topology with boosted large-cone jets
    - Limit set at 45xSM
  - VH($c\bar{c}$)
    - Using two complementary approaches to fully explore the VH($H \to c\bar{c}$) decay topology (AK4/AK15 jets).
    - Limit set at 14xSM; $1.1 < |k_c| < 5.5$ (95%CL interval)
      - Most stringent limit to date
  - The analyses are validated by measuring $Z \to cc$ process rate
- Constraints on $|k_c|$ from kinematics in $H \to \gamma\gamma$ and $H \to ZZ$
  - $|k_c| < 35$ (partial dataset)
- Limit on $H \to J/\psi+\gamma$ process: < 220xSM

The End