[Recasting: CMS-HIG-18-011]

Search for an exotic decay of the **Higgs boson** to **a pair of light pseudoscalars** in the final state with **two muons and two b quarks** in pp collisions at 13 TeV

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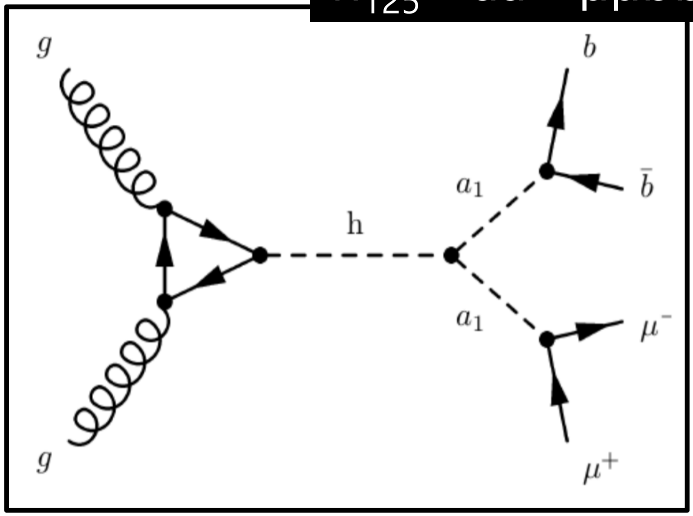
Introduction: Model

CMS-HIG-18_011: $h_{125} \to a_1 a_1 \to \mu\mu bb$

$h_{125} \to aa \to \mu\mu bb$



- **Reference model**:

  2HDM(type-III)**+S**

  Higgs doublets Φ_1, Φ_2 → H, $H^\pm$, A, h_{125}

  Complex scalar field $S_R + iS_I$ → a_1 (composed of S_I)

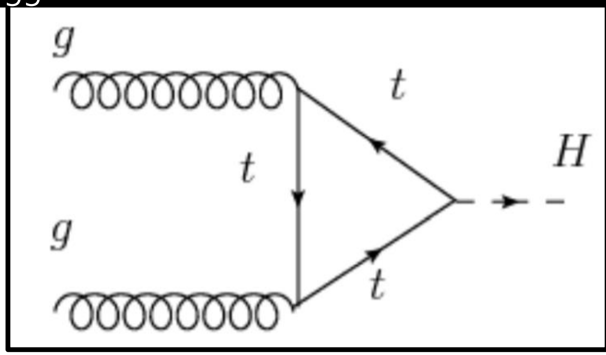
  (Additional **S** allows larger parametric space than 2HDM alone)

- **Motivations**: μμbb final state allows …
  (1) **a clear peak (μμ)** (2) **large branching ratio (bb)**

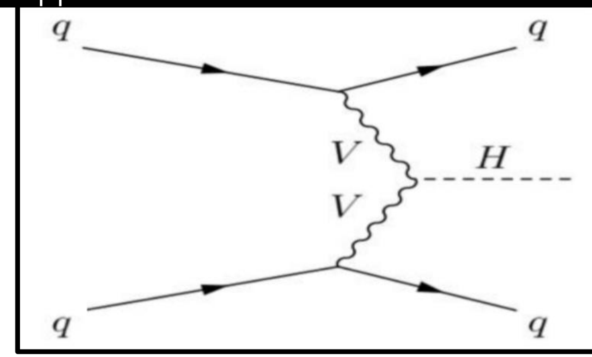
- **Previous works**
  h→aa→μμττ (CMS-HIG-17-029)
  h→aa→μμbb (CMS-HIG-17-024)

Higgs boson production process

σ_{ggF}(NNLO) = 48.58 ± 2.45 pb



σ_{qqh}(NNLO) = 3.78 ± 0.08 pb



ggF process is discussed

- **Branching ratios** (tan(β) = 2.0, M(a1) = 30 GeV)

Br(h→aa) = 10 %

h → aa → μμbb

⇒ BR(aa→μμbb) = 1.63 x 10^{-3}

BR(a→ττ) = 48.37 %
BR(a→bb) = 48.01 %
BR(a→μμ) = 0.17 %

❖ σ_{ggF} x Br(h→aa→μμbb) $_{expected}$ ∽ 0.79
❖ σ_{ggF} x Br(h→aa→μμbb) $_{simulated}$ ∽ 0.7

Introduction: Model

Higgs boson production process

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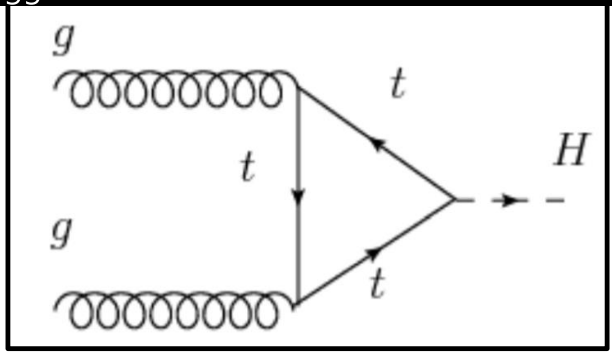

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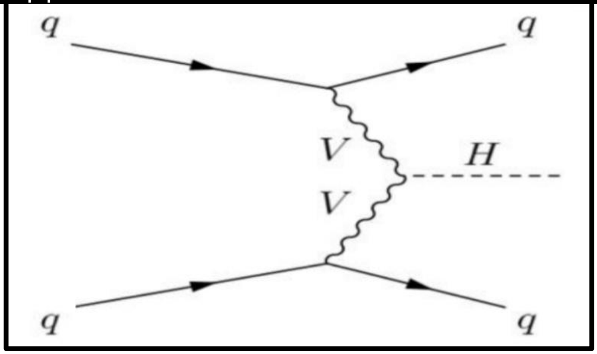

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σ_{ggF} x Br

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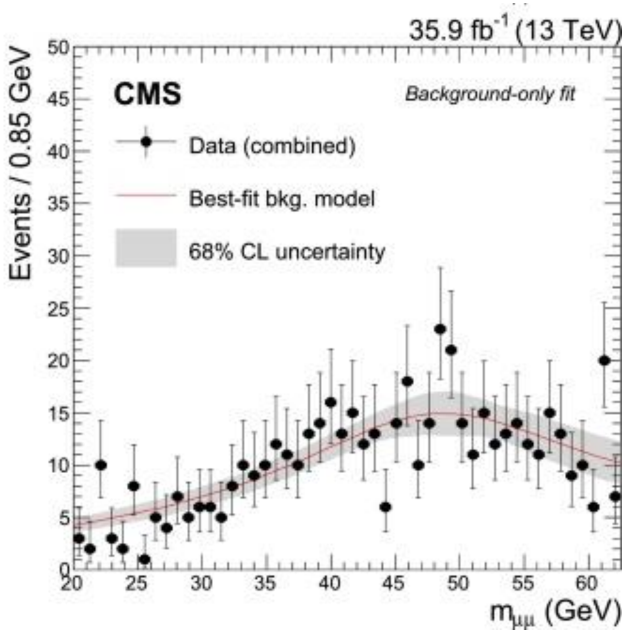
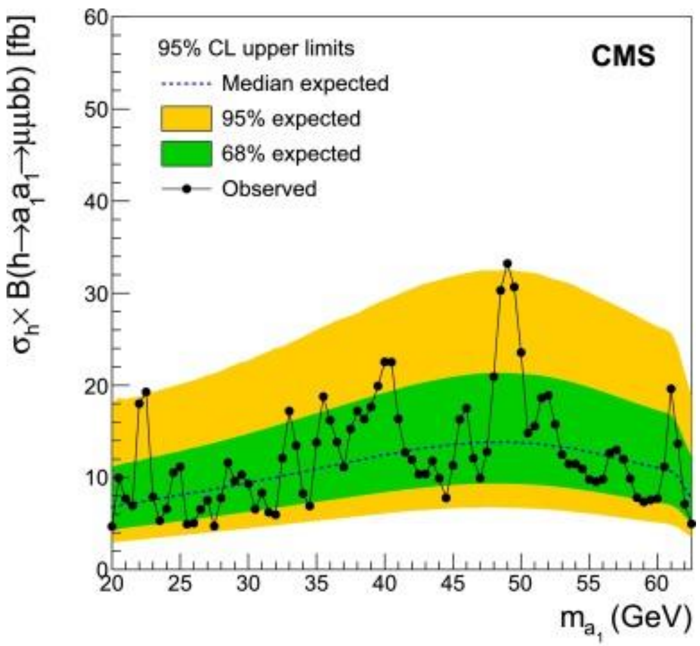
Introduction: Paper Results

❖ Di-muon mass distribution

- Good resolution → clear peak
- m_{bb} is not described due to the large jet p_T resolution
- **No significant difference** between data and MC





❖ Upper limits on $\sigma \times Br$

- Observed limits are **within 2 standard deviations** of expected limits

Recasting: Sample Generation

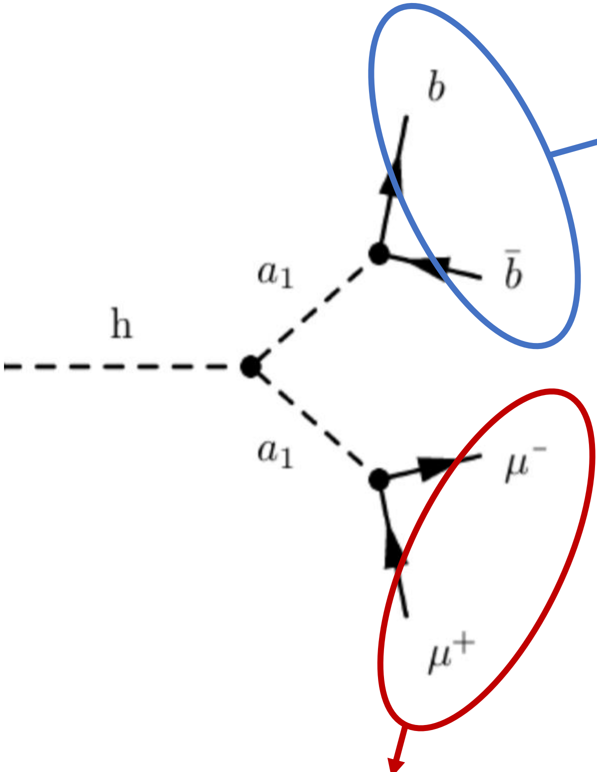
Generator (MadGraph)

- model card: NMSSMHET
- PDF: NNPDF60_nlo_as_0118
- PYTHIA8 is used for hadronization and parton showering
- **a_1 mass (GeV) $\supset$ [20, 40, 60]**
- 1K events are generated for each sample

Reconstruction (Delphes)

- Delphes default **b-tagging efficiency (loose working point)** is used
- CMS official b-tagging efficiency is described as a function of p_T, η
- We use **p_T^{jet} dependent efficiency** (Delphes default setting)

Recasting: Preselection



b-jet identification:

- p_T > 20, 15 GeV
- $|\eta|$ < 2.4
- $\Delta R(\text{jet}, \mu)$ > 0.4
- b-tagging:
  (CMS standard) 1 tight + 1 loose

Muon identification:

- p_T > 20, 9 GeV
- $|\eta|$ < 2.4
- (CMS standard) tight ID
- PF isolation[1] < 0.15
- $19.5 < M_{\mu\mu} < 63.5$ [2]

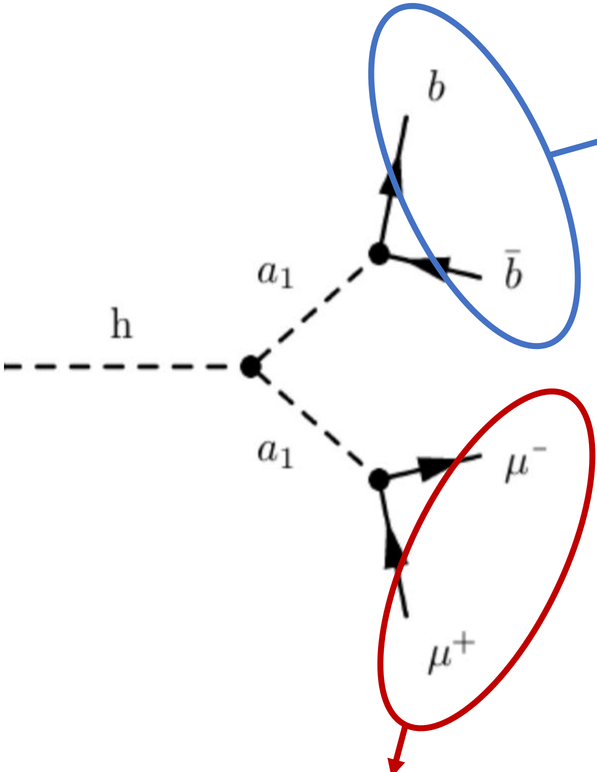
- **Particle-Flow(PF) isolation**[1]

  Pile-up correction is not applied in this recasting (even though the paper uses it)

- **Dimuon mass cut** ($19.5 < M_{\mu\mu} < 63.5$)[2]

  Cover full $M(a_1)$ region, [20, 62.5], but veto Υ and Z boson

Recasting: Preselection



b-jet identification:

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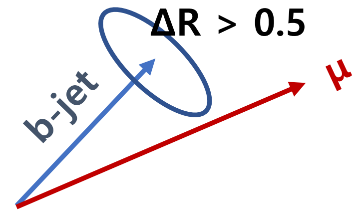

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- **b-tagging**

  - Delphes simulation does not provide variables for b-tagging
  → Cannot distinguish "tight" and "loose" working points
  → **"loose + loose" working point** is applied in Delphes and **re-weights it using tight/loose efficiency**

Recasting: Event Selection

Final (event) selection

- **MET < 60 GeV**
- $\boldsymbol{\chi_{bb}^2 + \chi_h^2 < 5}$, where $\chi_{bb} = \frac{m_{bb} - m_{\mu\mu}}{\sigma_{bb}}$ and $\chi_h = \frac{m_{\mu\mu bb} - m_h}{\sigma_h}$

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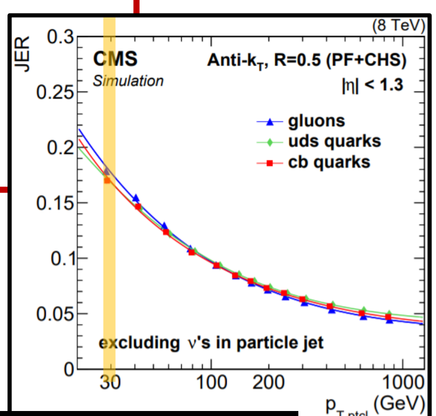
σ calculation

- **Original method** (paper):
  Fit the signal mass plot
- **Simplified method**:
  $\sigma(p_T^{jet} \sim 30) \sim 17\ \%$
  → $\sigma_{bb} \sim 17\ \%$ of $M(a_1)$



Jet p_T resolution

- **Simplified method**:

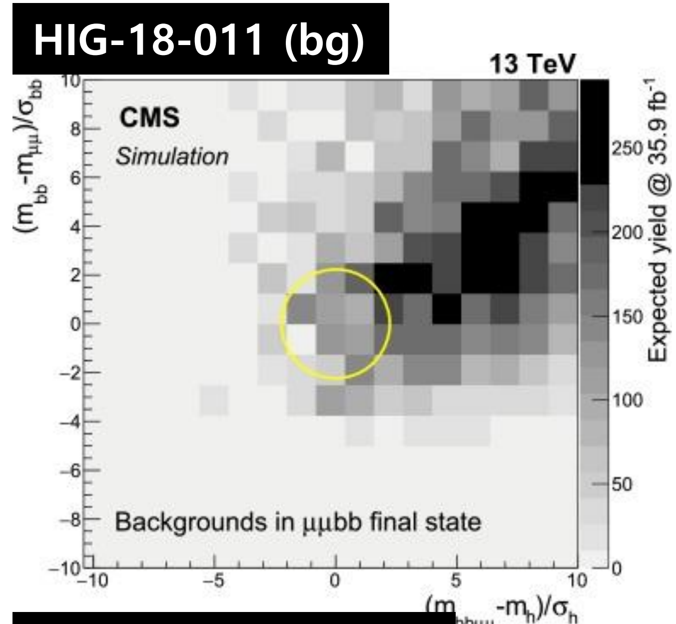
  $\sigma(p_T^{\mu} \sim 30) \sim 1\ \%$
  $\sigma(p_T^{jet} \sim 30) \sim 17\ \%$

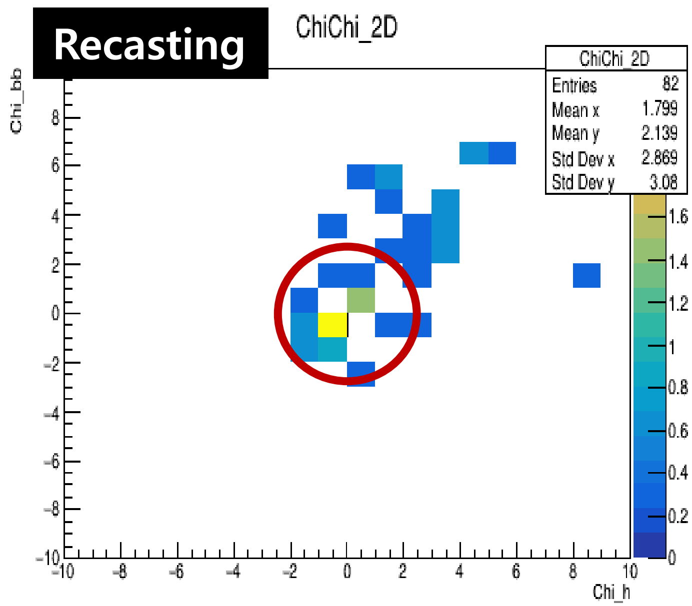
  → $\sigma_h \sim \sqrt{(2\sigma^{\mu} + 2\sigma^{jet})/4}$
  $= 9.3$ GeV

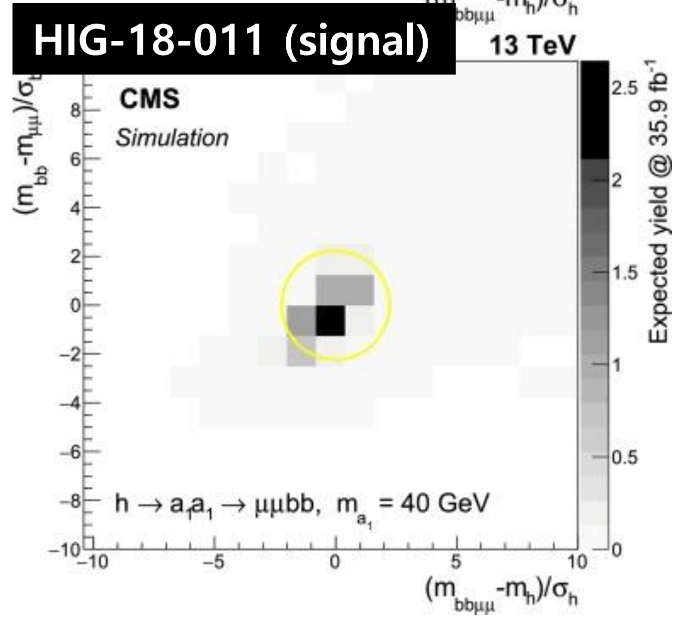
Recasting: χ_h - χ_{bb} plot

Chi2 discriminator

- $m(a_1)$ = 40 GeV results
- Chi2 discriminator can separate the signal very well (Right two plots)
- We've got almost similar results for the paper (Bottom two plots)







Results: Signal Yields

Object selection

	Preselection		Final selection	
	HIG-18-011	recasting	HIG-18-011	recasting
m_{a1} = 20 GeV	14.0	15.9	6.0	1.0
m_{a1} = 40 GeV	14.8	15.0	7.5	3.9
m_{a1} = 60 GeV	16.7	16.8	10.1	6.3

Preselection results are very good!

Results: Signal Yields

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- Final yields are much different for m_{a1} = 20 GeV sample, but it will recover for high mass a_1
- (We carefully expect) At low mass region, **boosted signature makes this kind of inefficiency**
  → Delphes cannot reconstruct boosted jet signature(?)

Summary

- **Exotic decay of h_{125} is studied** with "h125→a1a1→μμbb" decay channel
- **Signal yields** and **χ^2 distributions** are presented to compare with the paper, HIG-18-011
- **Preselection results are almost identical**, but final selection can make some inefficiency (probably due to the boosted signature)

Next Action Items

- Generate large sample
- Check boosted signature
- Recalculated $\sigma_{bb(h)}$ using a fit function

Th→aaank you ☺