Search for new resonance using the boosted Higgs pair production in the 4b final state

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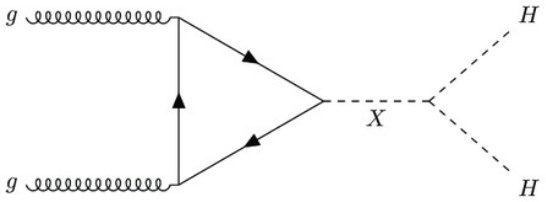
Search for Resonant di-Higgs Production

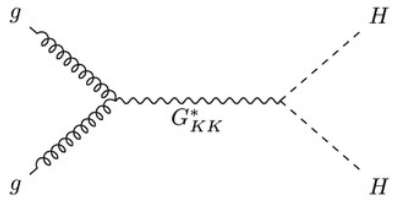
Resonant di-Higgs (HH) Production

- HH produced via gluon-gluon fusion (ggF)
- HH is sensitive to new resonances predicted by various BSM theories
  - Spin-0 boson X
    - e.g. predicted by two-Higgs-doublet models (2HDM)



SM Higgs + Scalar doublet
→ Supersymmetry, PQ symmetry, baryon asymmetry of the Universe …

  - Spin-2 Kaluza-Klein graviton G^*_{KK}
    - In bulk Randall–Sundrum (RS) model



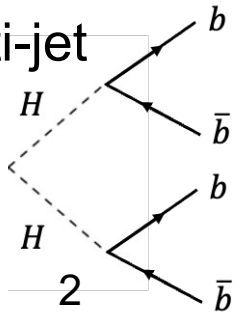
Add extra space-time dimensions to unify gravity and electromagnetism
→ Solving the hierarchy problem

HH final state

- Large variety of decay modes

	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%

  - 4b final state
    - Largest BR
    - Large QCD multi-jet background



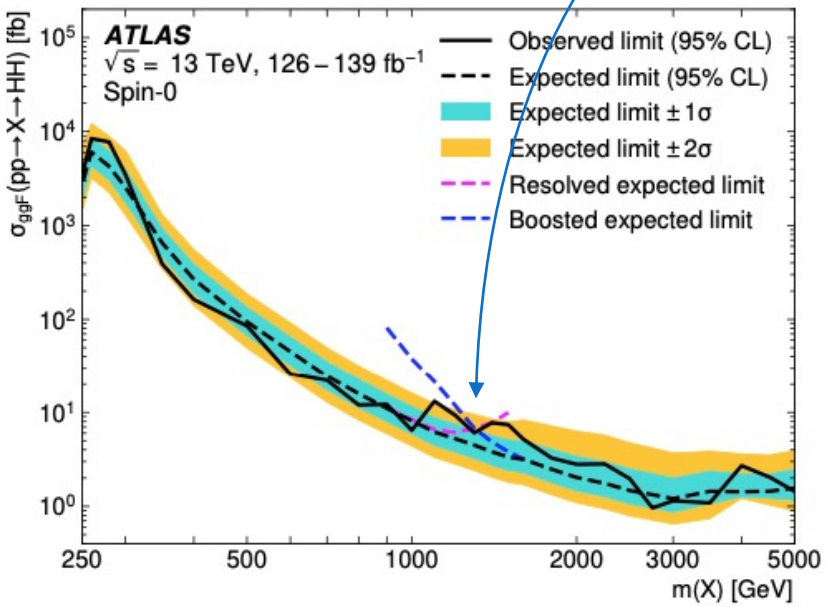
HH→4b Analysis in Run2

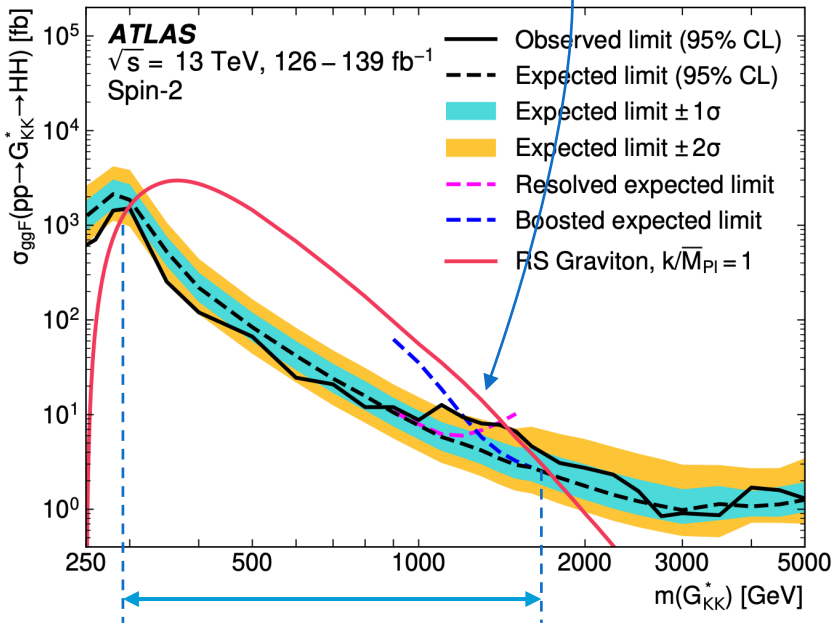
paper : CERN-EP-2021-229

Set upper limits (95% CL) on cross-section of resonant HH production

Largest excess @1100 GeV

- local significance : 2.3σ for spin-0 and 2.5σ for spin-2
- global significance : 0.4σ for spin-0 and 0.8σ for spin-2





Statistical uncertainties are dominant mostly from background modeling

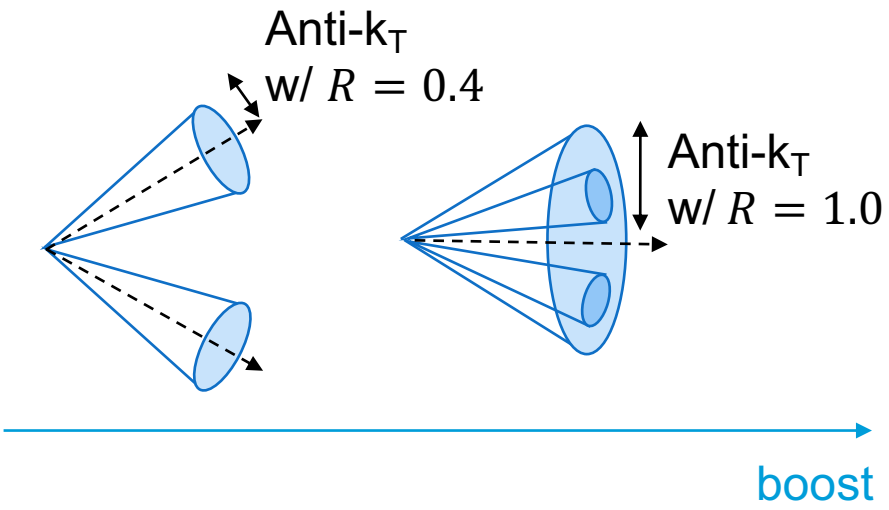
Randall-Sundrum（RS）model is excluded for graviton mass between 298 GeV and 1460 GeV

Analysis Channels

Jet reconstruction

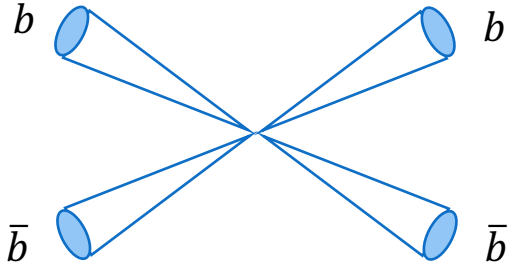
- Using topological cluster
- Clustered by anti-k_T algorithm

Small-R jet Large-R jet



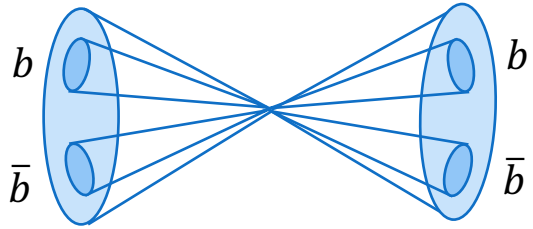
2 channels for HH→4b Analysis

- Resolved channel :
  Target low resonance mass $(251\ GeV \leq m_X \leq 1.5\ TeV)$



4 small-R jets

- Boosted channel :
  Target high resonance mass $(900\ GeV \leq m_X \leq 5\ TeV)$



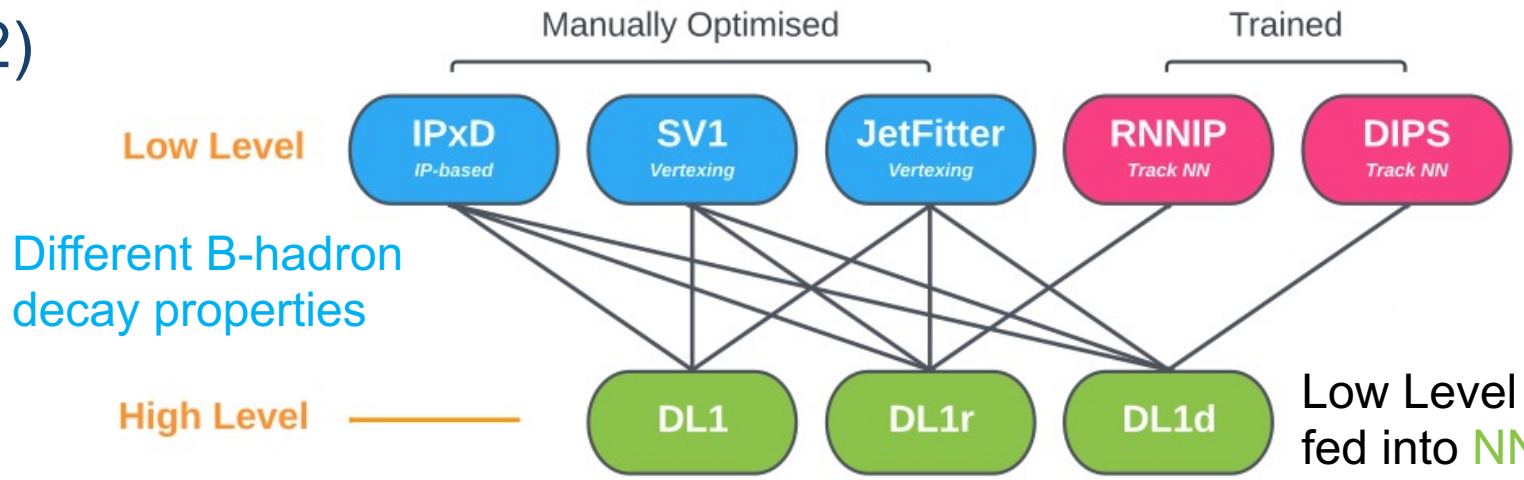
2 large-R jets

Focus on Boosted channel

b-tagging Algorithms

paper : ATL-PHYS-PUB-2022-226 (DL1r)
ATL-PHYS-PUB-2023-021 (GN2X)

DL1r (run2)

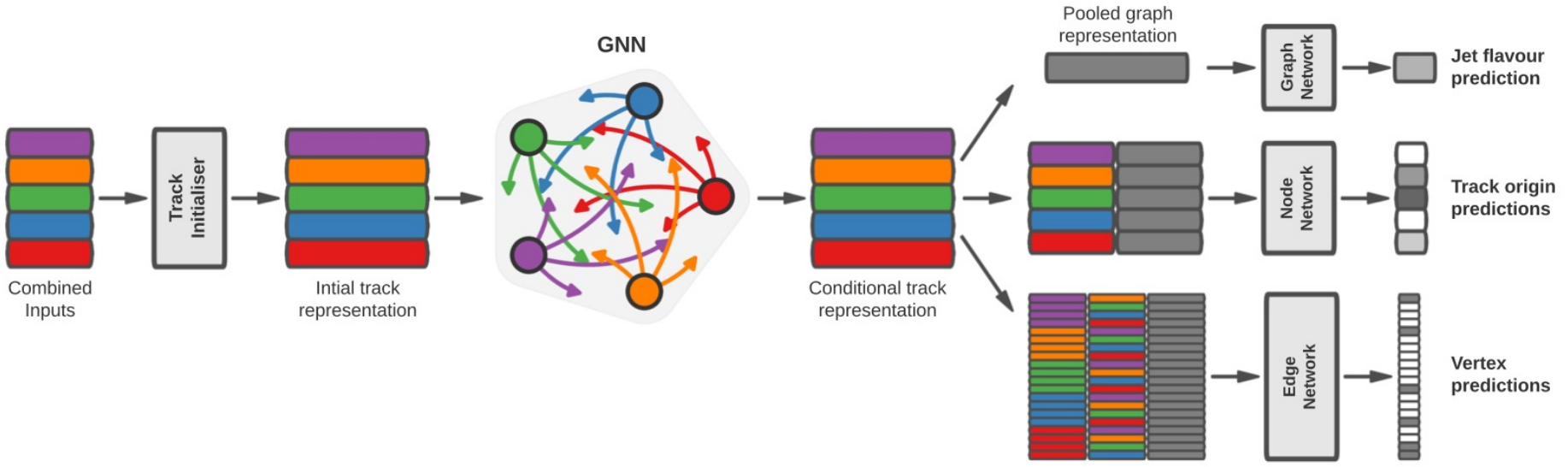


Track-based Machine Learning

Different B-hadron decay properties

Low Level outputs are fed into NNs

GN2X (run3) New Xbb tagger based on transformer



discriminate boosted $H(b\bar{b})$ and $H(c\bar{c})$ from top and QCD

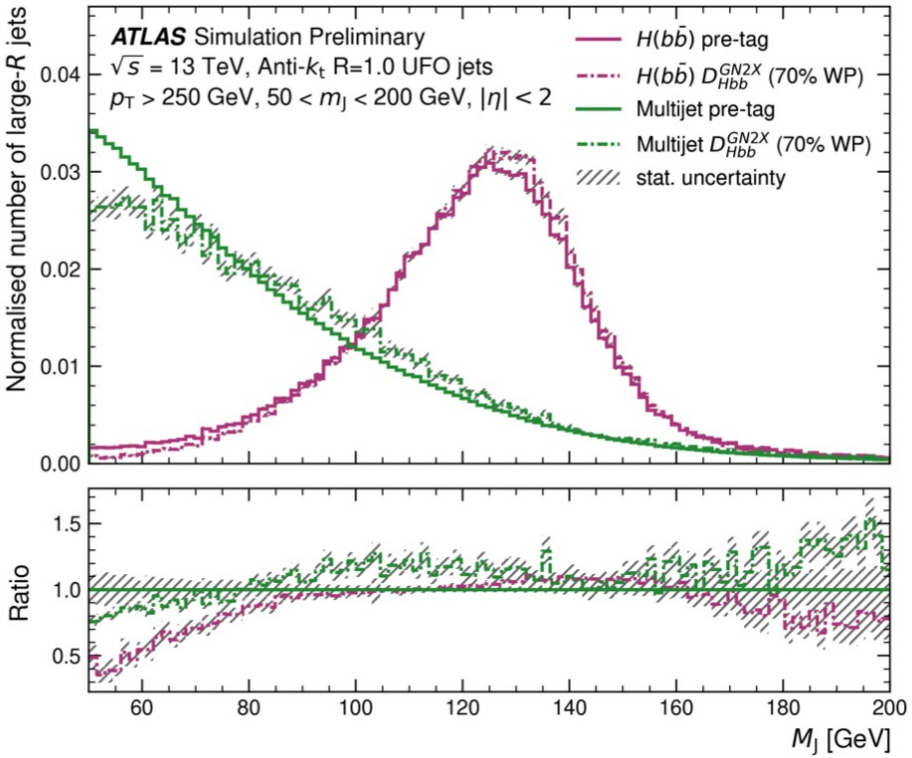
Auxiliary outputs → Improved performance and interpretability

Mass sculpting

paper : ATL-PHYS-PUB-2023-021

- If $H(b\bar{b})$ tagging scores are correlated with large R jet masses, background mass distribution after tagging will be similar to the signal distribution
  → undesirable for data-driven background estimation

- GN2X is trained on mass decorrelated Higgs sample
- Modified Higgs samples are used to reduce background mass sculpting
  → Sculpting within 20%

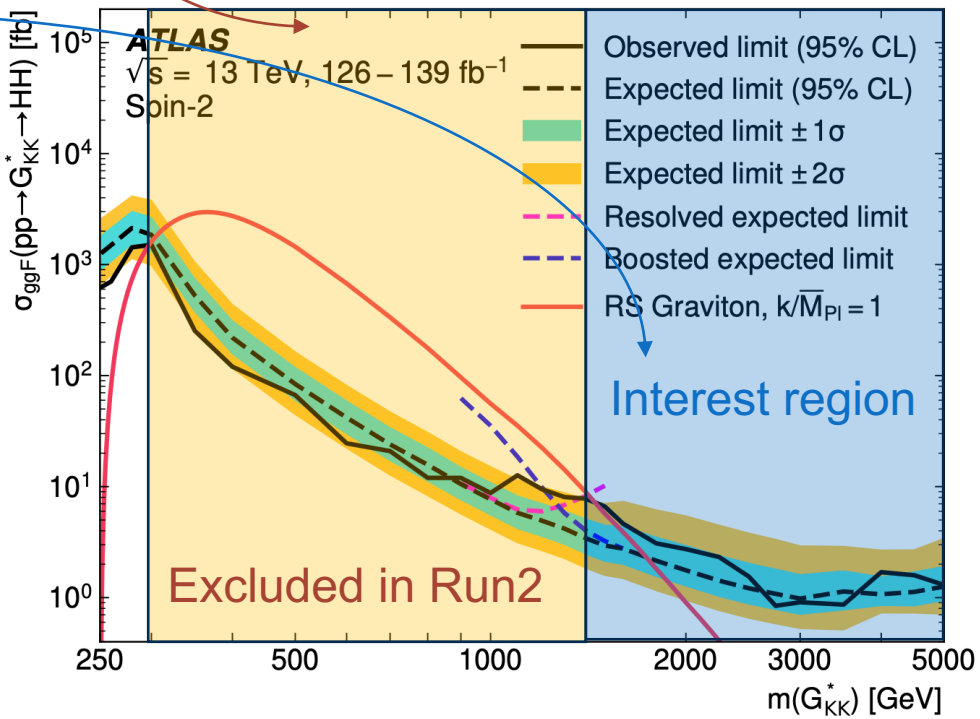


Motivation

- Search for Spin-2 Kaluza-Klein graviton G^*_{KK} In bulk Randall–Sundrum (RS) model via HH→4b analysis
- RS model is excluded for graviton mass between 298 GeV and 1460 GeV by Run2 Analysis
- Aiming to improve high mass region sensitivity
  - Using run2 + partial run3 data :

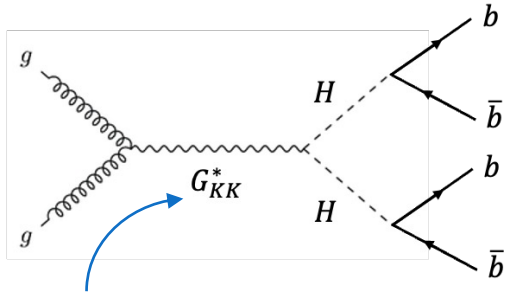
    High statistics due to increase in the luminosity
    - Run2 : 126~139 fb^{-1}
    - Run3 : 183 fb^{-1} (~2024) + ~150 fb^{-1} (2025~2026)
  - Using GN2X b-tagger :

    Improved $H(b\bar{b})$ tagging performance



MC Samples

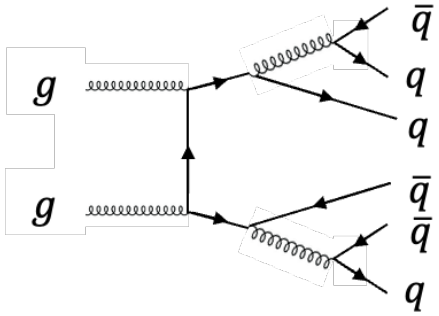
RS graviton signal sample



Spin-2 Kaluza-Klein graviton G^*_{KK}

- Passed ATLAS detector simulation and reconstruction
- Corresponds to run3 data in 2023
- 2 resonance mass points :
  - 1000GeV
  - 3000GeV

Dijet b-filtered background sample



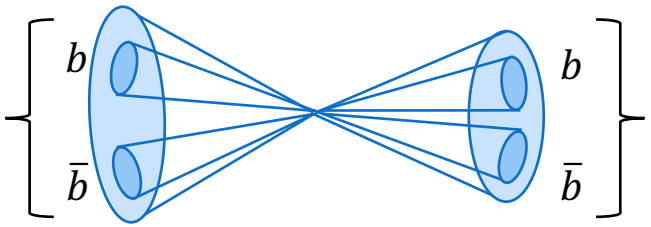
- Passed ATLAS detector simulation and reconstruction
- Corresponds to run3 data in 2023
- Multi b-jet filter applied during event generation :
  - Jet $p_T \geq 15$ GeV
  - ≥ 4 jets
  - ≥ 2 b-jets
- JZ filter applied during event generation :
  - Samples are split into several subsamples based on the leading truth jet pt
  - Use JZ3~JZ9+

Event selection

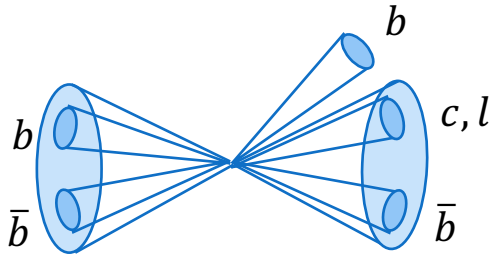
Event selection based on run2 analysis

1. At least 2 large R jets with $p_T > 250\ GeV$
2. 2 highest p_T jets are selected as the Higgs candidates
   - Leading (highest p_T) Higgs candidate : H_1
   - Subleading Higgs candidate : H_2
3. Each Higgs candidate is required to have $|\eta| < 2.0$, $m(H) > 50GeV$
4. At least 1 Higgs candidate must have $p_T > 450\ GeV$

$p_T > 450\ GeV$, $|\eta| < 2.0$, $m(H) > 50GeV$ — H_1 { b, $\bar{b}$ } H_2 — $p_T > 250\ GeV$, $|\eta| < 2.0$, $m(H) > 50GeV$



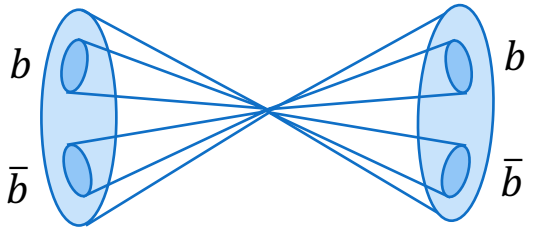
→ Reject large-R jet not originated from $b\bar{b}$



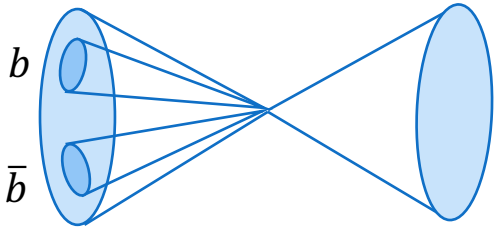
Categorization

Categorize events using parton truth label ID of small R jet

- SR (Almost 0 events)



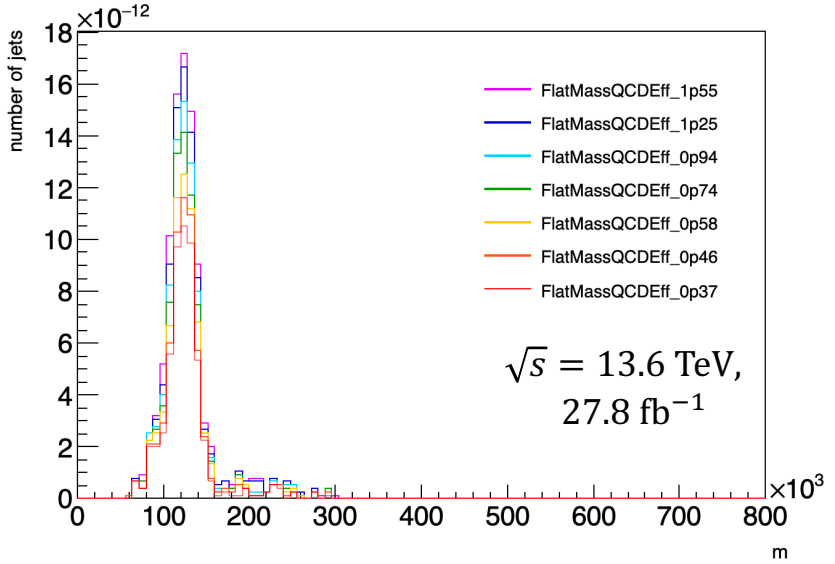
- CR



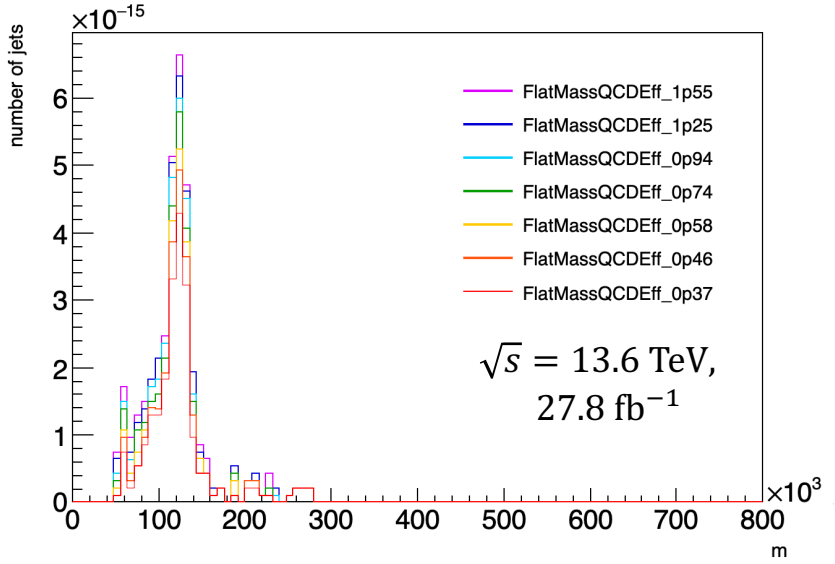
Large R jet mass distribution

FlatMassQCDEff :
working points designed to give a flat efficiency of the QCD dijet background

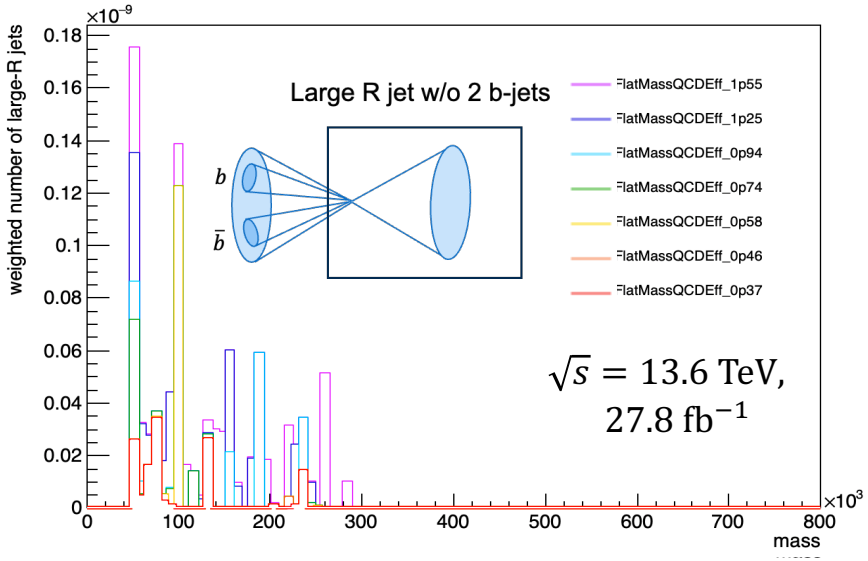
RS graviton (M1000)

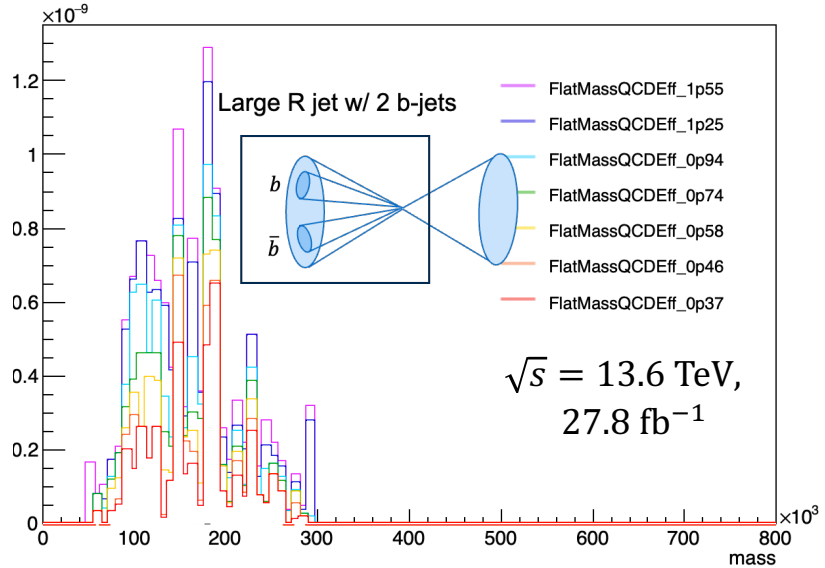


RS graviton (M3000)



Dijet b-filtered bkg





2025/2/24

Summary

Summary

- Aiming to discover new resonance via Higgs boson pair production in the 4b final state
- Performing boosted analysis on RS graviton MC signal sample and dijet b-filtered background sample using GN2X tagger