Status Update

Pr.李数 group meeting

Khanh N. Vu

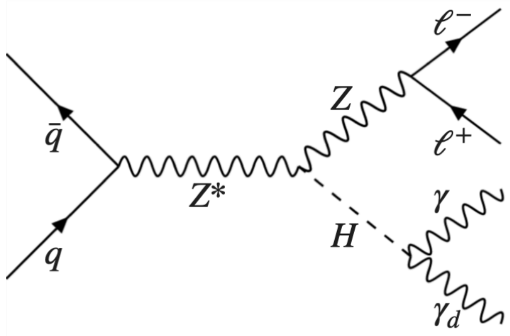
Dec 01st, 2023

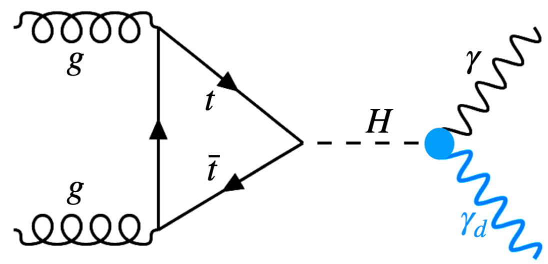
Run-2 Dark photon $H \rightarrow \gamma\gamma_{\mathrm{d}}$ combination

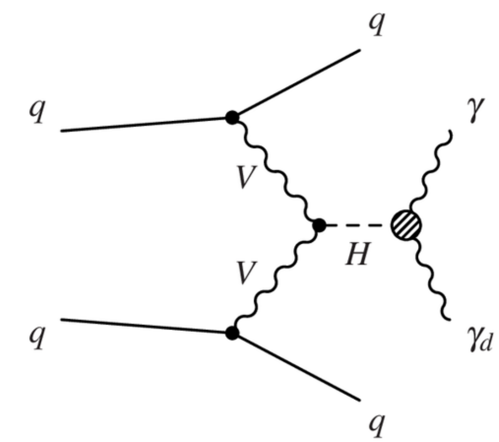
Khanh, Qibin, Changqiao, Shu

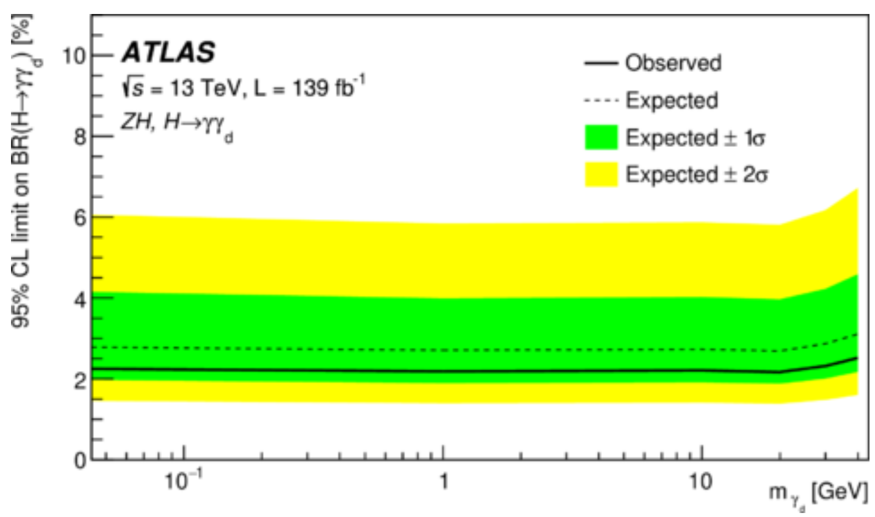
EB request in CDM meeting

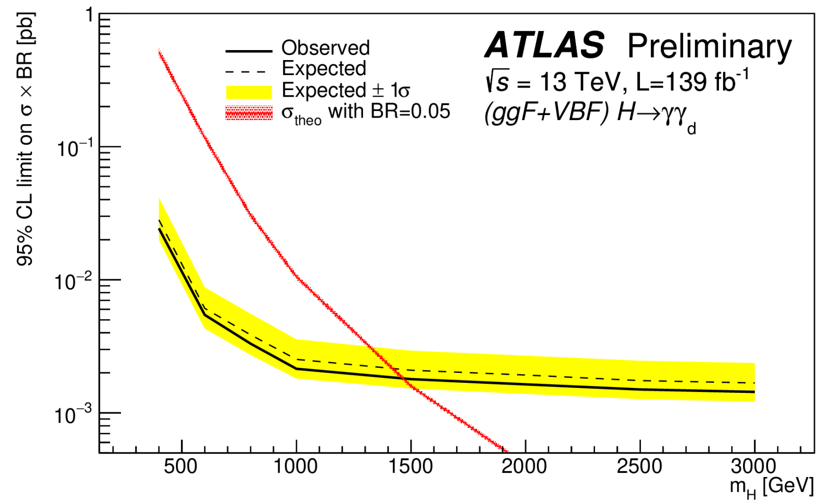
Scenarios of combination

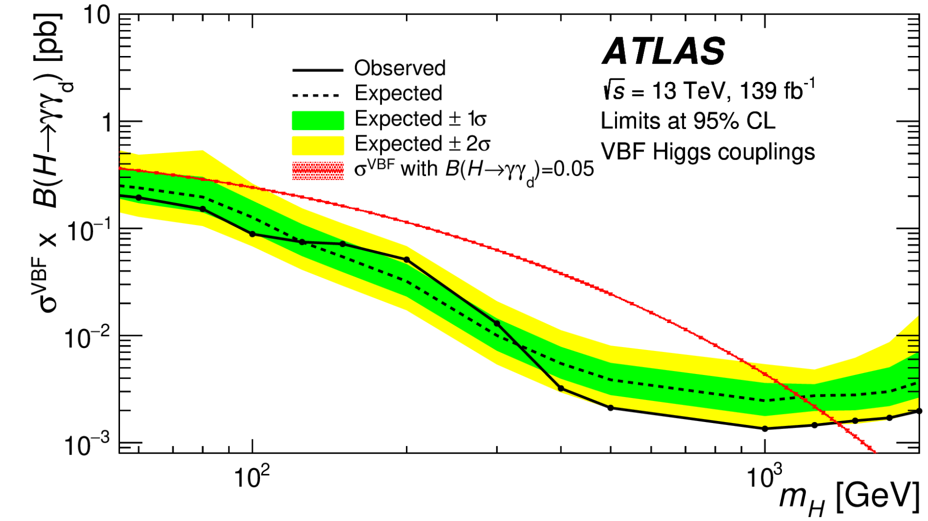












ZH analysis

$m_H = 125$ GeV

$m_{\gamma_d} = [0,\ 40]$ GeV

monophoton recast

$m_H = [400,\ 3000]$ GeV

massless γ_d

VBF analysis

$m_H = [60,\ 2000]$ GeV

massless γ_d

- Most straightforward and worthy scenarios for the stat. combination, based on available results from 3 input analyses
  - **ZH + VBF combination for mH = 125 GeV, myD = 0** ⟶ combined limits on BR($H125 \to \gamma\gamma_d$)
  - **Monophoton-recast + VBF combination for mH = 0.4 - 3 TeV, myD = 0** ⟶ combined limits on $\sigma \times \mathrm{BR}$ for (ggF+VBF) $H \to \gamma\gamma_d$
    - **preliminarily combined limits for up to 1 TeV so far.**

Preliminary results of VBF+ZH combination for SM Higgs, massless dark photon

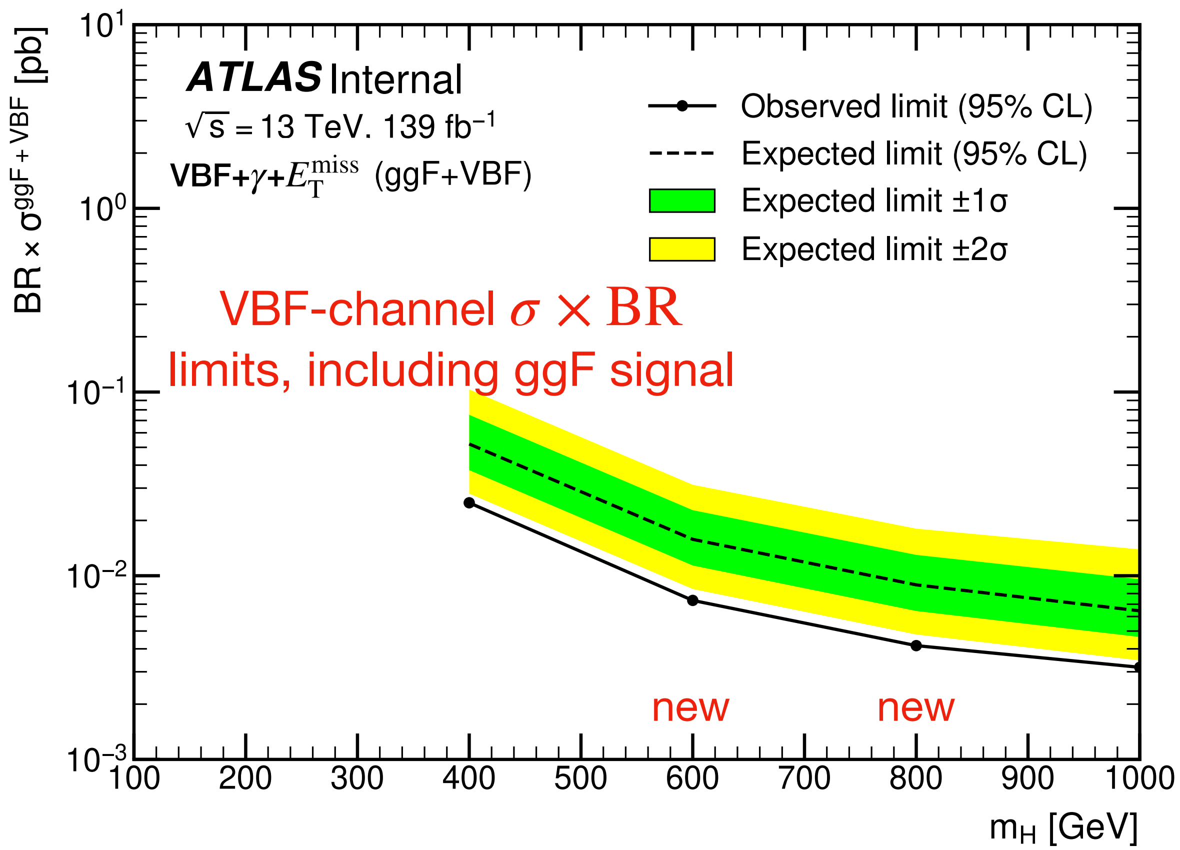
$m_H = 125\ \text{GeV},\ m_{\gamma_d} = 0$

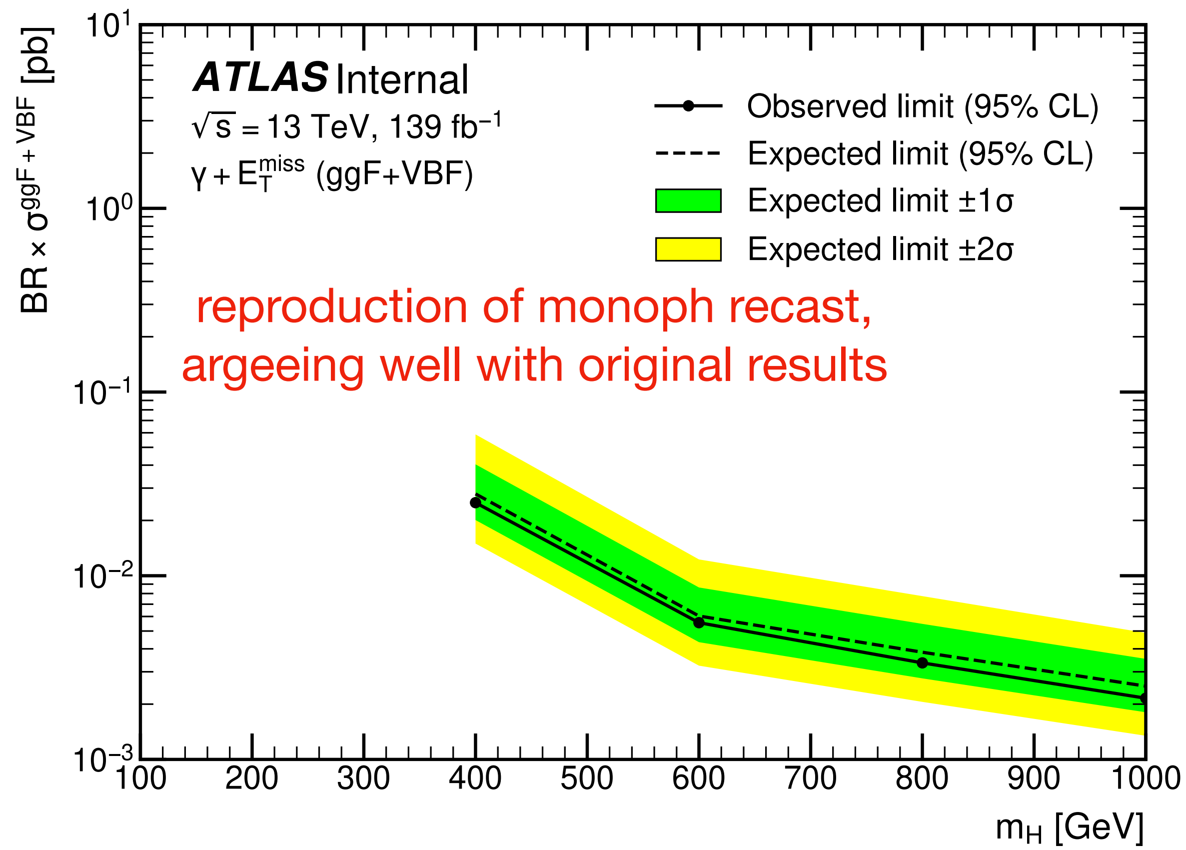
	Obs.	Exp.	-2σ	-1σ	$+1\sigma$	$+2\sigma$
VBF Reference	0.0180	0.0170		0.0120	0.0240	
VBF Reproduced	0.0185	0.0173	0.00929	0.0125	0.0251	0.0345
ZH Reference	0.0228	0.0282	0.0146	0.0198	0.0415	0.0606
ZH Reproduced	0.0228	0.0282	0.0152	0.0203	0.0400	0.0573
VBF-ZH Comb. Uncorr.	0.0135	0.0146	0.00782	0.0105	0.0208	0.0282
VBF-ZH Comb. Full Corr.	0.0132	0.0148	0.00794	0.0107	0.0212	0.0287

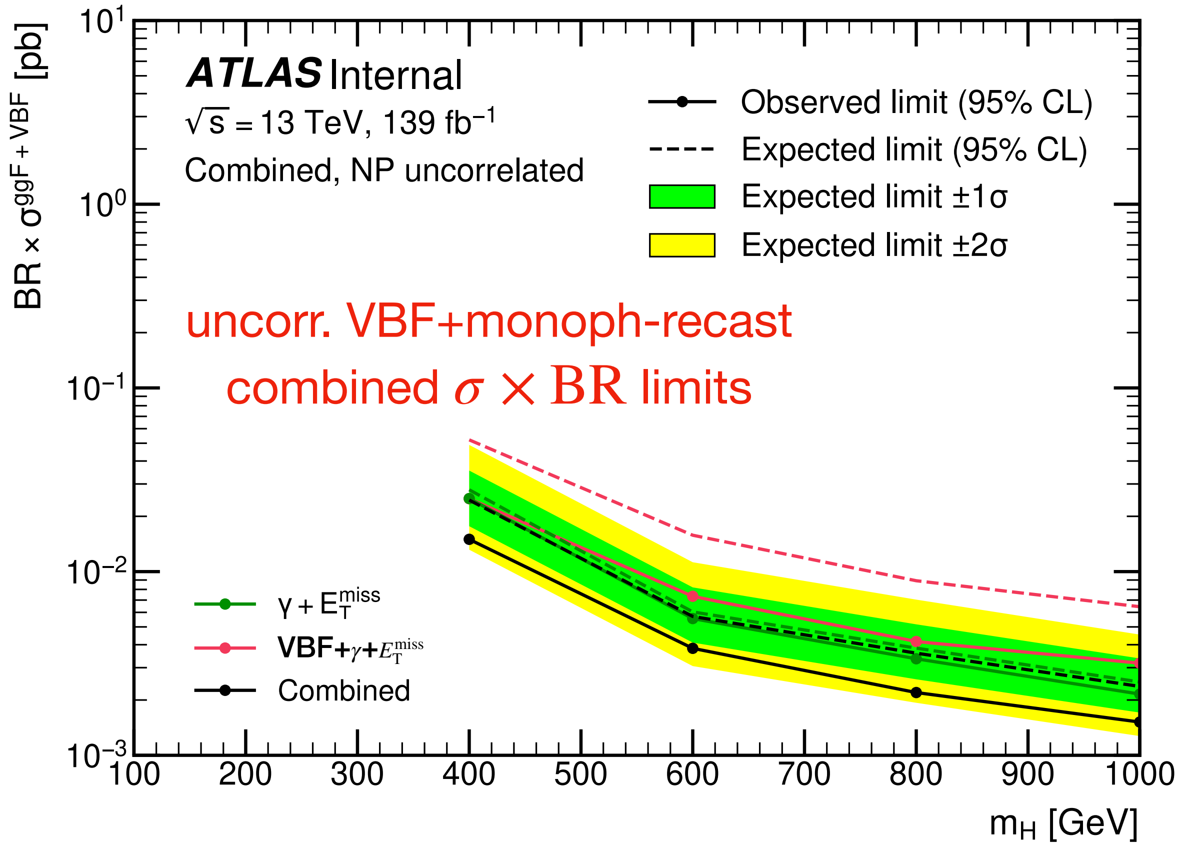
	ZH	VBF	Combined
ATLAS	2.3(2.8)%	1.8(1.7)%	1.3(1.5)%
CMS	4.6(3.6)%	3.5(2.8)%	2.9(2.1)%

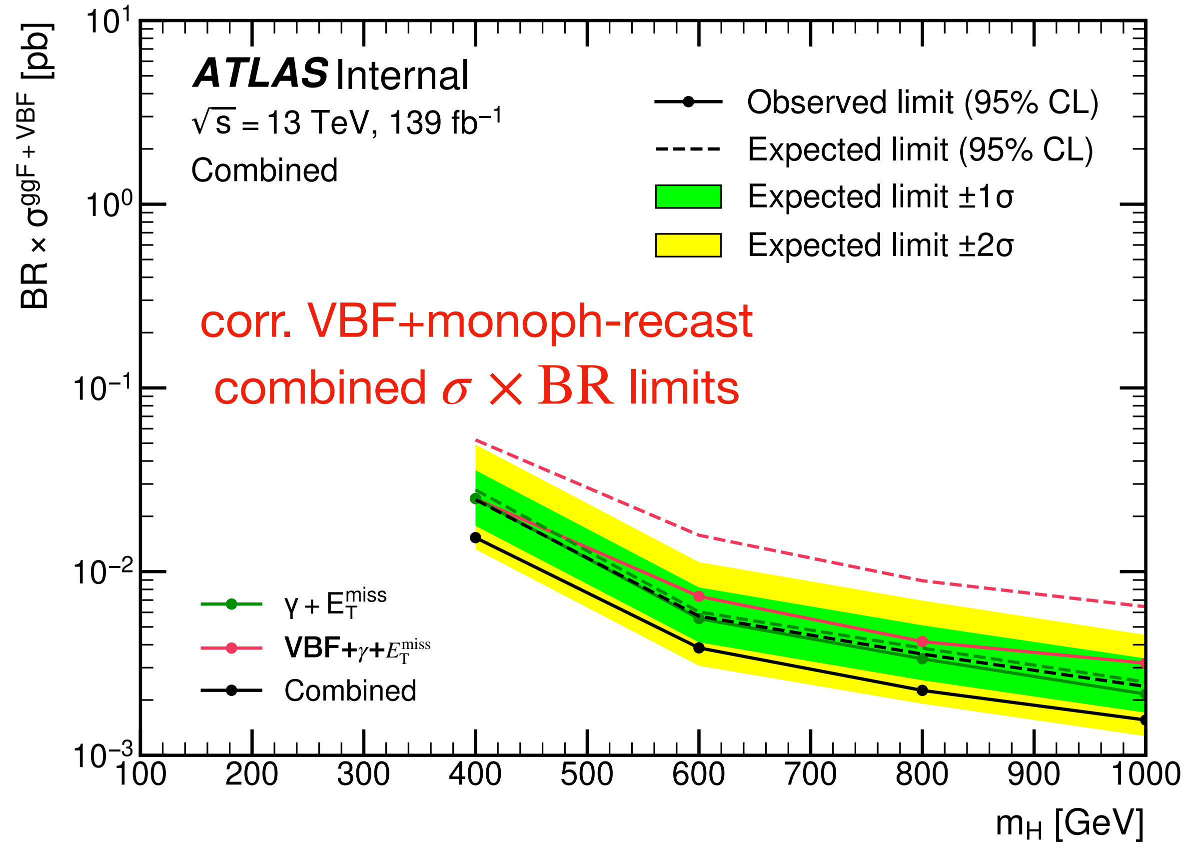
- **VBF limits on BR reproduced using Comb FW agree well with VBF ref. results.**
- **Preliminary VBF+ZH combined limits on BR($H \to \gamma\gamma_d$) (with correlation scheme) for SM H, massless dark photon is 1.3 (1.5)% $\Longrightarrow$ the most stringent constraint so far**

Preliminary results of VBF+monophoton-recast combination for heavy Higgs, massless dark photon



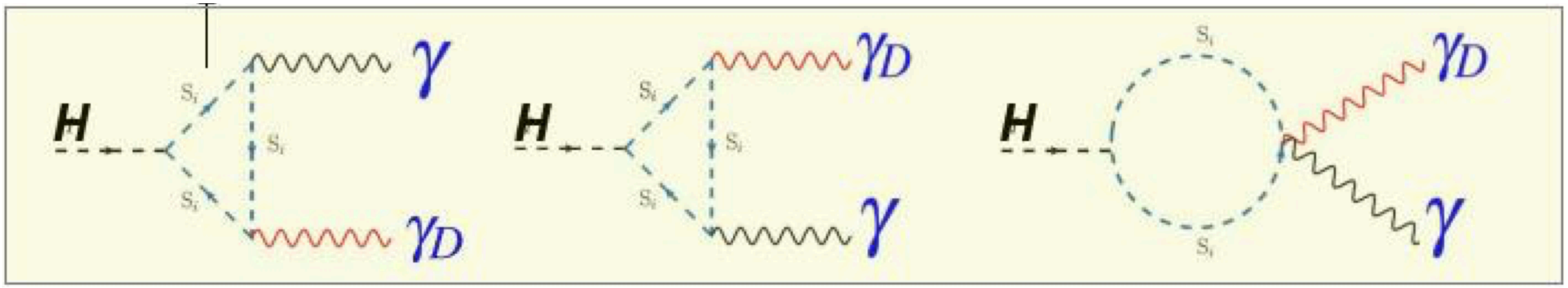






New interpretation for SM $H \to \gamma\gamma_d$ results

- In Minimal Model with 2 scalar messengers: one $\mathrm{SU(2)_L}$ doublet and one $\mathrm{SU(2)_L}$ scalar singlet, allowing to generate 1-loop $H \to \gamma\gamma_d$ vertex.



- In the Minimal Model, BR's of H → $\gamma\gamma_D$ / $\gamma_D\gamma_D$ / $\gamma\gamma$ can be expressed as:

$$\mathrm{BR}_{\gamma\gamma_D} = \mathrm{BR}^{\mathrm{SM}}_{\gamma\gamma}\frac{r_{\gamma\gamma_D}}{1+r_{\gamma_D\gamma_D}\mathrm{BR}^{\mathrm{SM}}_{\gamma\gamma}},$$

$$\mathrm{BR}_{\gamma_D\gamma_D} = \mathrm{BR}^{\mathrm{SM}}_{\gamma\gamma}\frac{r_{\gamma_D\gamma_D}}{1+r_{\gamma_D\gamma_D}\mathrm{BR}^{\mathrm{SM}}_{\gamma\gamma}},$$

$$\mathrm{BR}_{\gamma\gamma} = \mathrm{BR}^{\mathrm{SM}}_{\gamma\gamma}\frac{(1+\chi\sqrt{r_{\gamma\gamma}})^2}{1+r_{\gamma_D\gamma_D}\mathrm{BR}^{\mathrm{SM}}_{\gamma\gamma}},$$

With $r_{ij} \equiv \frac{\Gamma^{\mathrm{m}}_{ij}}{\Gamma^{\mathrm{SM}}_{\gamma\gamma}}$, generically indicating the pure messenger contribution to H → i j width

χ = ±1 in parametrizes the relative sign of the new physics and SM contributions in the amplitudes of the H → γγ

Simplifed Model: $r_{\gamma\gamma_D} = 2X^2\left(\frac{\alpha_D}{\alpha}\right), r_{\gamma_D\gamma_D} = X^2\left(\frac{\alpha_D}{\alpha}\right)^2, r_{\gamma\gamma} = X^2$

- With $X \equiv \frac{\xi^2}{3F(1-\xi^2)}$ and the mixing parameter $\xi = \frac{\Delta}{\bar{m}^2}$ depending on the mass difference of the 2 scalars. F from the SM H→γγ form factor (6.5). For a pair of mass-degenerate EW messengers, R~0.045
- More constraints could also be derived from H→γγ and H→inv BR's limits

- Resulting limits on BR from this analysis or other analyses (e.g Hinv Comb and Hyy measurements) can be used to constrain the 2 free parameters (α_D, ξ) in simplified model.

EB request

- EB request aiming **Moriond conferences** given in CDM meeting!

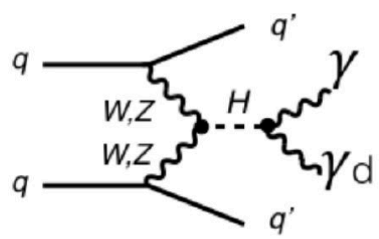
- Following the talk/discussion, **Action Items to trigger EB**:
    - ✓ **orthogonality checks with signal MC between monophoton-recast and VBF channel**
    - ✓ **Reply to questions/comments in CDS.**
    - **Produce combination results in 1 - 3 TeV.**
    - **Understand the 5% discrepancy between the VBF-recast vs raw results in high mass points.**
    - **Have draft version of new interpretation results**

Run-3 ggF $H \to \gamma\gamma_{\mathrm{d}}$ search

Khanh, Shu

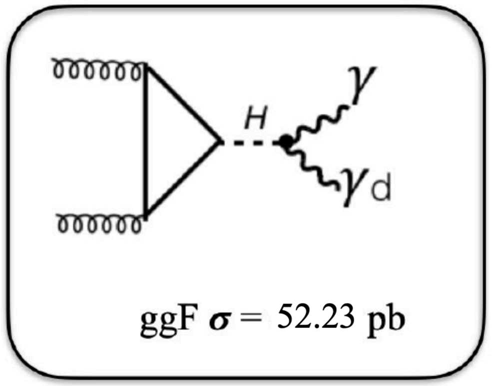
Recent update in HLRS meeting

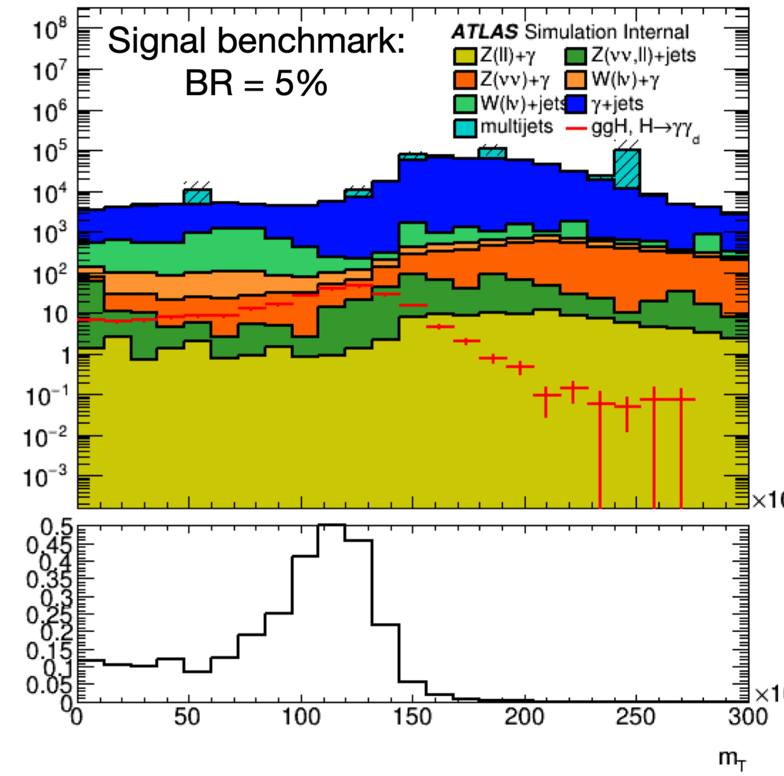
ggF $H \to \gamma\gamma_D$



VBF $\sigma = 4.08$ pb

<<





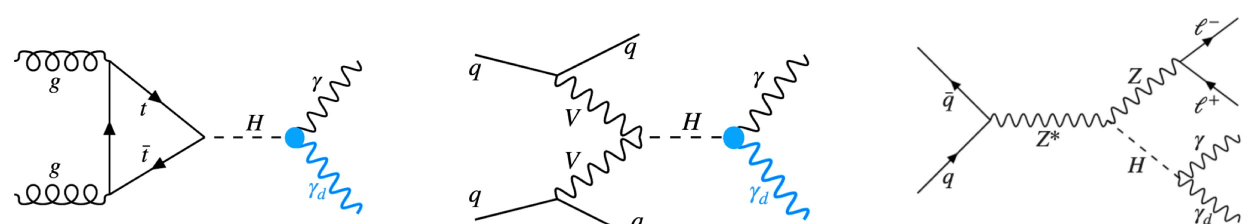
- ggF has significantly larger cross-section, BUT challenging signature:
  - Hard to define an efficient trigger while keeping reasonable rates
  - Mono-photon → primary vertex misidentification
  - low MET and low photon pT → overwhelmed by fake MET background

Signal generation

- Will consider also Z/W H and VBF production modes
  ➡ Expected contribution for MET > 100 GeV and photon PT > 50 GeV: 8.4% for ZH, WH, and 20% for VBF

- MC23c for all signals requested:
  - Signal requests at HLRS meetings: ggH (700k), VBF (300k), VH (WmH 250k, WpH 150k, qqZH 100k)
  - JIRA tickets: ggH, VBF, VH
  - Only VH not ready

- Generation release: AthGeneration,23.6.6

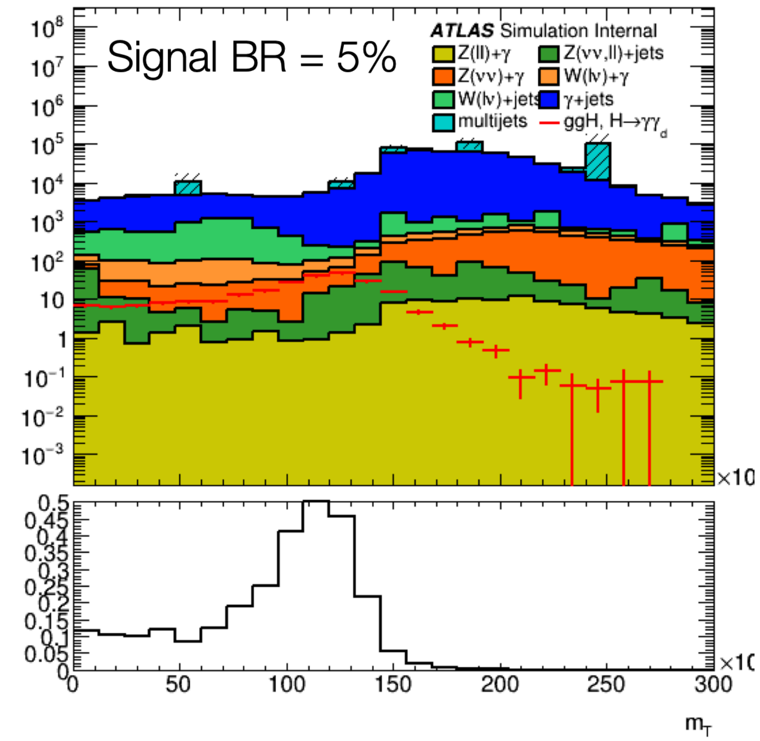


	ggF	VBF	WH ($W^+ + W^-$)	qqZH
Baseline cuts	705566	55580	18792	10490
Baseline cuts + lepton veto	705566	55580	11300	9448
Tight cuts	22407	5542	2456	1614
Tight cuts + lepton veto	22407	5542	1087 (+318 Wy, supp by 1y cut)	1464
Total contribution with tight cuts and a lepton veto (%)	73.47	18.17	3.56	4.8

Tentative analysis strategy

- Analysis strategy definition in progress. Plan to combine **Run2** (with MET > 150 GeV) and **Run3** (MET > 100 GeV)
- **Backgrounds:**

True photons $Z(\ell\ell/\nu\nu)+\gamma, W(\ell\nu)+\gamma$	1-lepton and 2-lepton CRs MET with leptons treated as invisible particles
Electrons-faking-photons $W(e\nu)+jets, Z(ee)+jets$	Standard rescaling of probe-e CR by fake-rates
Jets-faking-photons $dijets, W(\ell\nu)+jets, Z(\ell\ell/\nu\nu+jets)$	Need new data-driven method. ABCD based on photon ID and ISO probably not feasible due to tight photons in trigger
Fake MET $\gamma+jets$	Need to define data-driven method



- Plan to use BDT, but also interesting to exploit mT shape: fit mT template in bins of BDT (or the other way around) ?
- **Other future / ongoing studies:** improving mT resolution with ML, photon vertex identification, METNet

Preliminary cut-based SR

Preselections
- $E_T^{miss} > 100$ GeV, photon $p_T > 50$ GeV and $m_T > 80$ GeV
- 1 selected photon and no baseline leptons
- At most 3 jets

- E_T^{miss} significance > 6
- $\Delta\phi(E_T^{miss}, E_T^{\gamma}) \geq 1.25$
- $\Delta\phi(E_T^{miss}, E_T^{jet}) \leq 0.75$

to suppress events with wrong PV

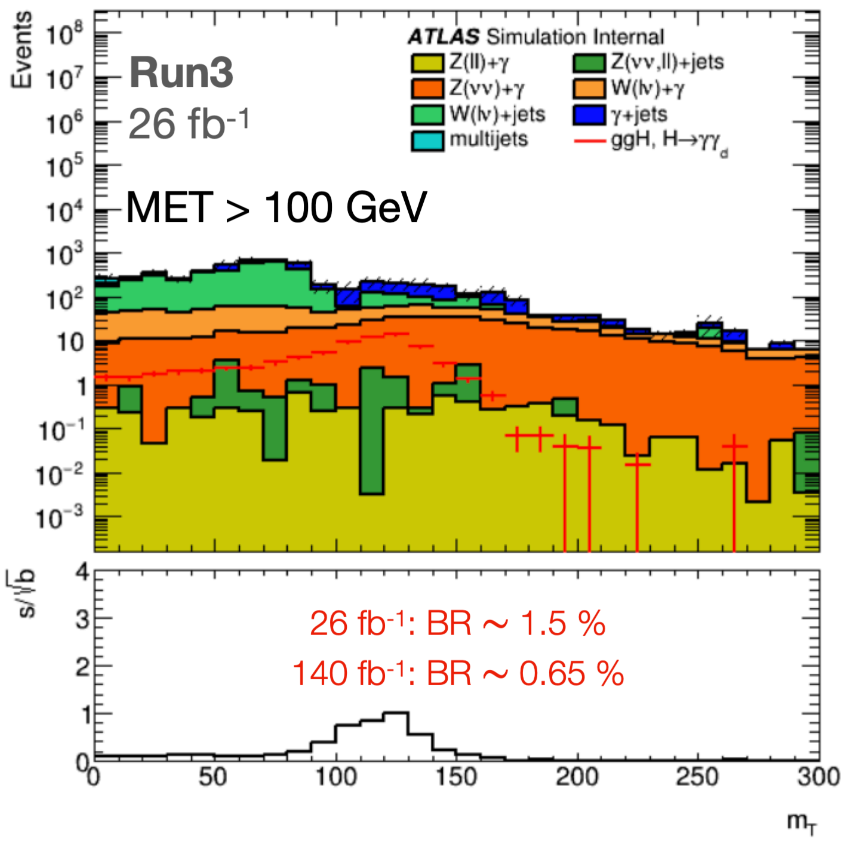
- $\Delta E_T^{miss} \geq -10$ GeV
- $p_T^{balance} \leq 2$
- $|\eta^{\gamma}| < 1.75$
- $\Delta\phi(j1,j2) < 2.5$

$$p_T^{balance} = \frac{E_T^{miss} + p_T^{\gamma}}{\sum p_T^{jets}}$$ (All scalars)

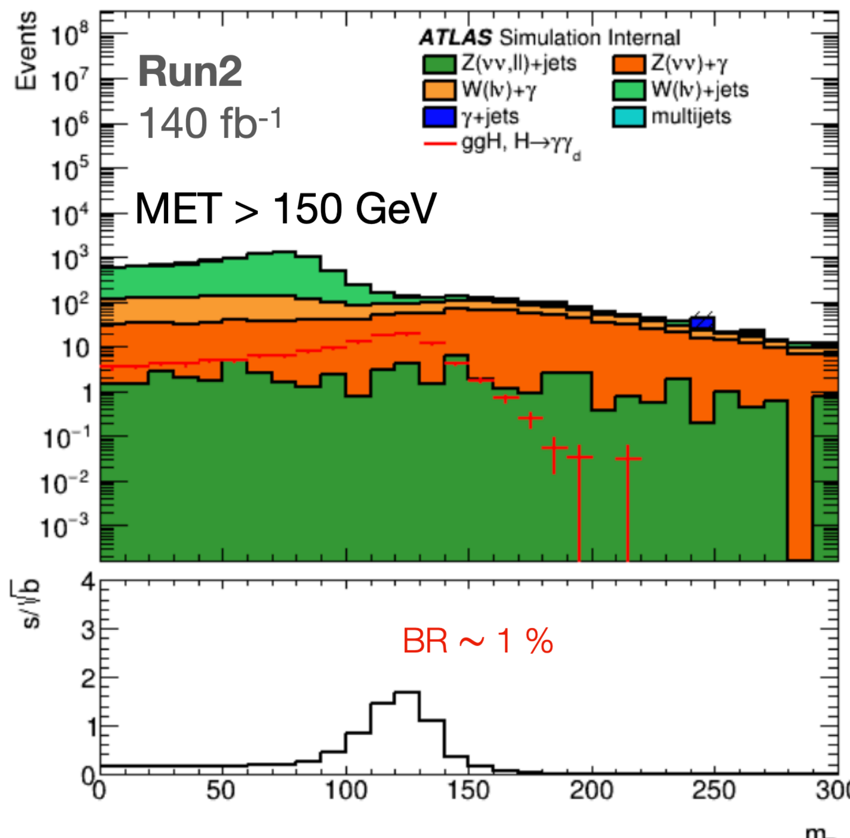
$$\Delta E_T^{miss} = E_{T,noJVT}^{miss} - E_T^{miss}$$

Cut-based SR

Run 3 vs Run 2 comparison



- Cross-section 52 pb and benchmark BR = 1%
- Signal acceptance:
  - wrt preselections: 56%
  - Total: 0.5%
- $s/\sqrt{b} \sim 1.3$



- Cross-section = 48 pb and benchmark BR = 1%
- Signal acceptance
  - wrt preselections: 20%
  - Total: 0.14%
- $s/\sqrt{b} \sim 2\,\%$

Comparable sensitivities between full Run2 and Run3 (2023)

Loss in signal acceptance compensated by much higher collected statistics and better suppression og y+jets background

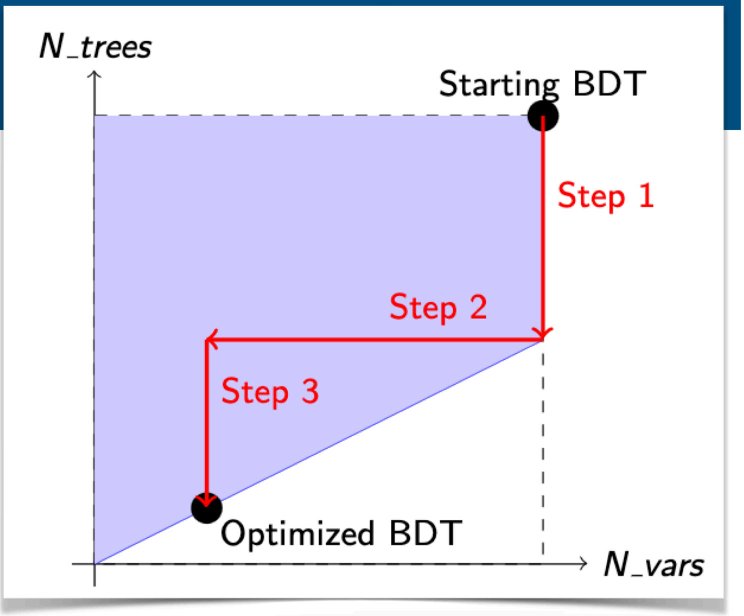
Total signal acceptance < 1%

Future plans: study backgrounds and lower MET, both for Run 3 and Run 2

TDLI team is getting involved in defining preliminary analysis strategy with stat only

Preliminary BDT studies

Michele Boldini (bachelor), Marcello Fanti, Silvia Resconi, Federica Piazza
(More details here)

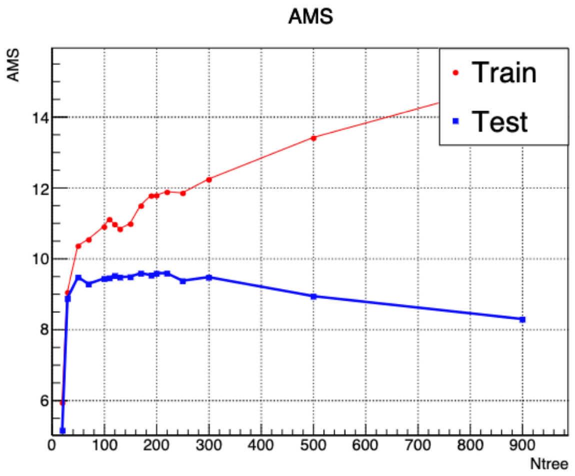


- Using TMVA
- Cut 80 < mT < 150 GeV prior to BDT, variable not in the training
- 3 steps optimization:
  - Preliminary optimization of Ntrees variable
  - Input variables: start from 18 and iteratively remove the variable whose removal reduces the AMS the less
  - Reoptimize Ntrees with final set of input variables

- **Number of fold** = 2
- **Boost:** Adaboost
- $\beta = 0.2$
- **Min node size** = 5%
- **Max depth** = 3

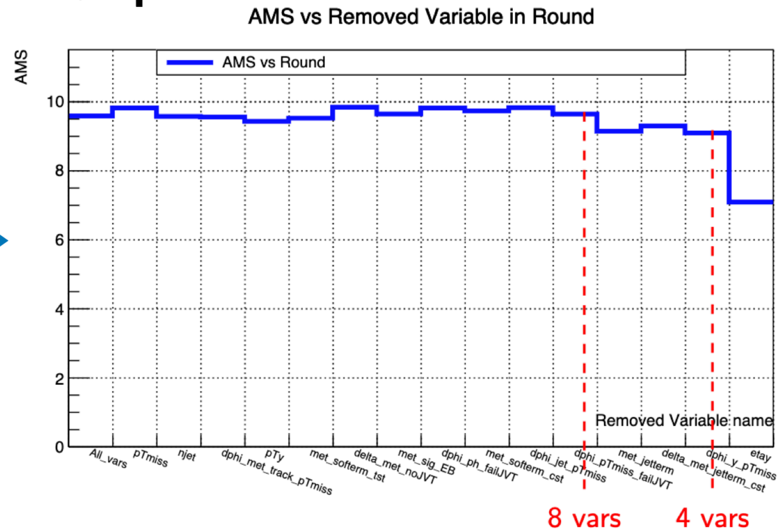
$$AMS = \sqrt{2\left(n \ln\left[\frac{n}{b}\right] - s\right)}$$

Step 1 Benchmark: BR = 5%



Ntrees = 200

Step 2 Benchmark: BR = 5%

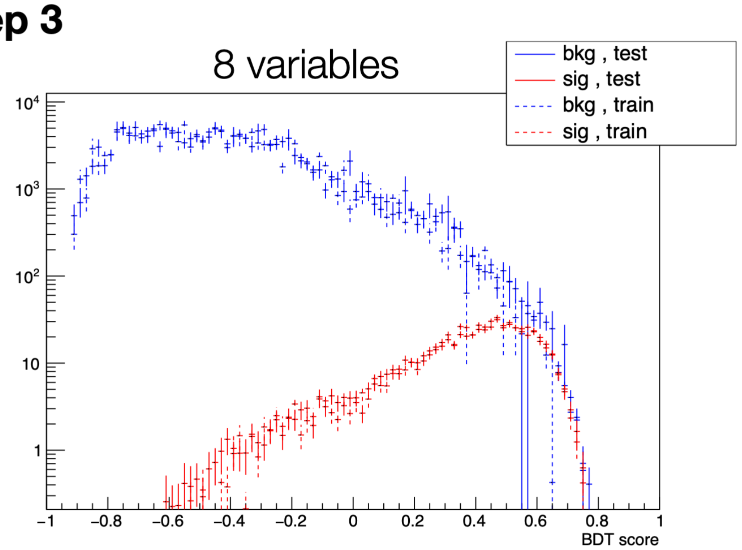


2 possibilities: 8 or 4 variables in final training

- MET_sig
- $\Delta\varphi(MET, \sum_{failJVT} p_T^{Jet})$
- $\Delta\varphi(p_T^{\gamma}, MET)$
- η_γ
- MET_cst
- $MET\_jetterm$
- MET_track_et
- MET with jetterm CST $-$ MET

- MET_sig
- η_γ
- MET_cst
- MET_track_et

Step 3



Conclusions:

- Preliminary studies, to test potentialities of BDT
- BDT approach seems promising (from BR∼2% exclusion cut.based to BR∼1% using BDT)
- BDT trained only for mH = 125 GeV for now ⟶ still ample room for our contribution to here.

R24 Xbb tagger $g \to bb$ calibration

Khanh, Changqiao

Recent update in FTAG plenary meeting

The GN2X tagger

Based on a Graph Neural Network algorithm and transformer architecture

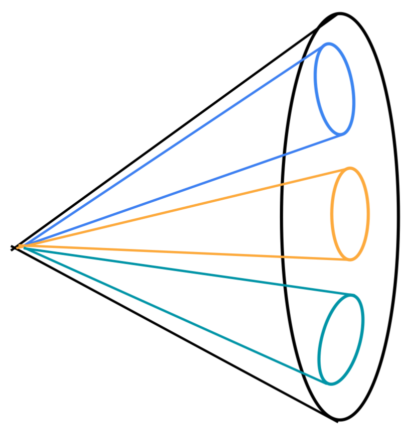
Input: large-R jet tracks

Output: $p_{hbb}, p_{hcc}, p_{top}, p_{qcd}$

Discriminant: $D_{GN2X} = \ln(\frac{p_{hbb}}{f_{cc} \cdot p_{hcc} + f_{top} \cdot p_{top} + (1 - f_{cc} - f_{top}) \cdot p_{qcd}})$

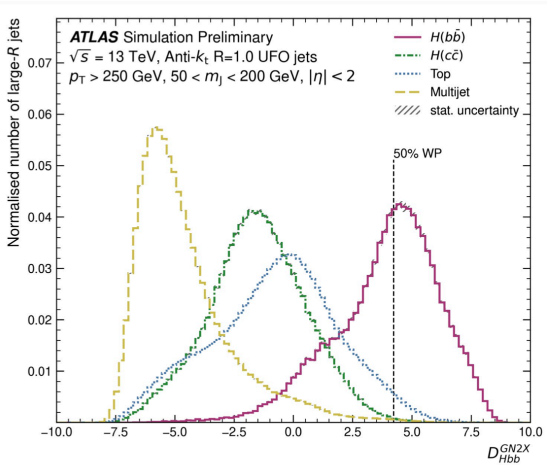
where $f_{cc} = 0.02$ and $f_{top} = 0.25$

Working Points					
50%	60%	70%	80%	85%	→ signal acceptance
4.20	3.65	3.04	2.25	1.72	→ discriminant value



The g→bb calibration

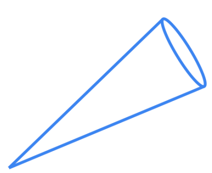
- The GN2X tagger is trained on simulated H(bb), H(cc), top and multijet jets.
- Performance of tagger in MC must be calibrated based on data.
- g→bb multijet events kinematically similar to H→bb and an important background.
- In-situ calibration of mistag efficiency is performed using gbb multijet events.
- Samples separated in p_T slices to increase statistics in high p_T range
- Scale factors derived in p_T bins for each tagger WP



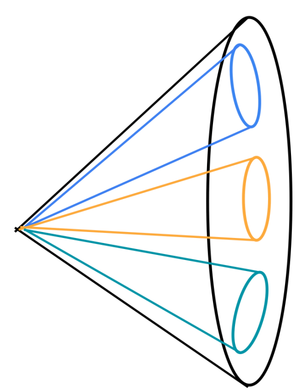
Code framework

- Ntuple production using AnalysisTop (R24) and custom event saver code — loose selections applied.
- Histogram files created with Ntuples Analyzers and further selections applied.
- Fit performed using TRexFitter — config file here.

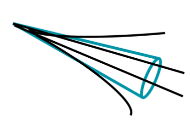
Object definition



- ❑ small-R jet (R = 0.4)
  - ❑ Jet collection: `AntiKt4EMPFlowJets`
  - ❑ p_T>20 GeV, |η|<2.5, Tight JVT WP



- ❑ large-R jet (R = 1.0)
  - ❑ Jet collection: `AntiKt10UFOCSSKSoftDropB100Zcut10Jets`
  - ❑ p_T>200 GeV, |η|<2, m>50 GeV.
- ❑ VR track-jet
  - ❑ Jet collection: `AntiKtVR30Rmax4Rmin02PV0TrackJets`
  - ❑ p_T>7 GeV, |η|<2.5



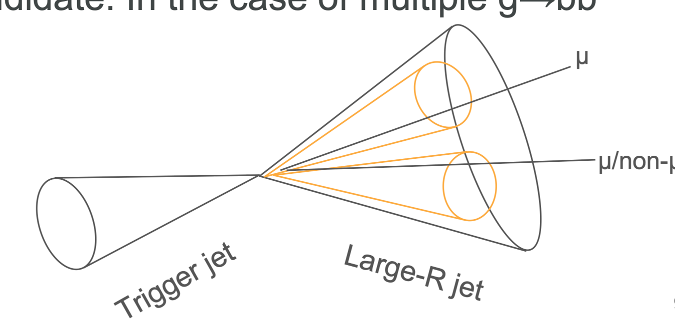
- ❑ soft muon
  - ❑ p_T>8 GeV; |η<2.4|, |d0|<2 mm, |z0sint|<2 mm

g→bb candidate selection

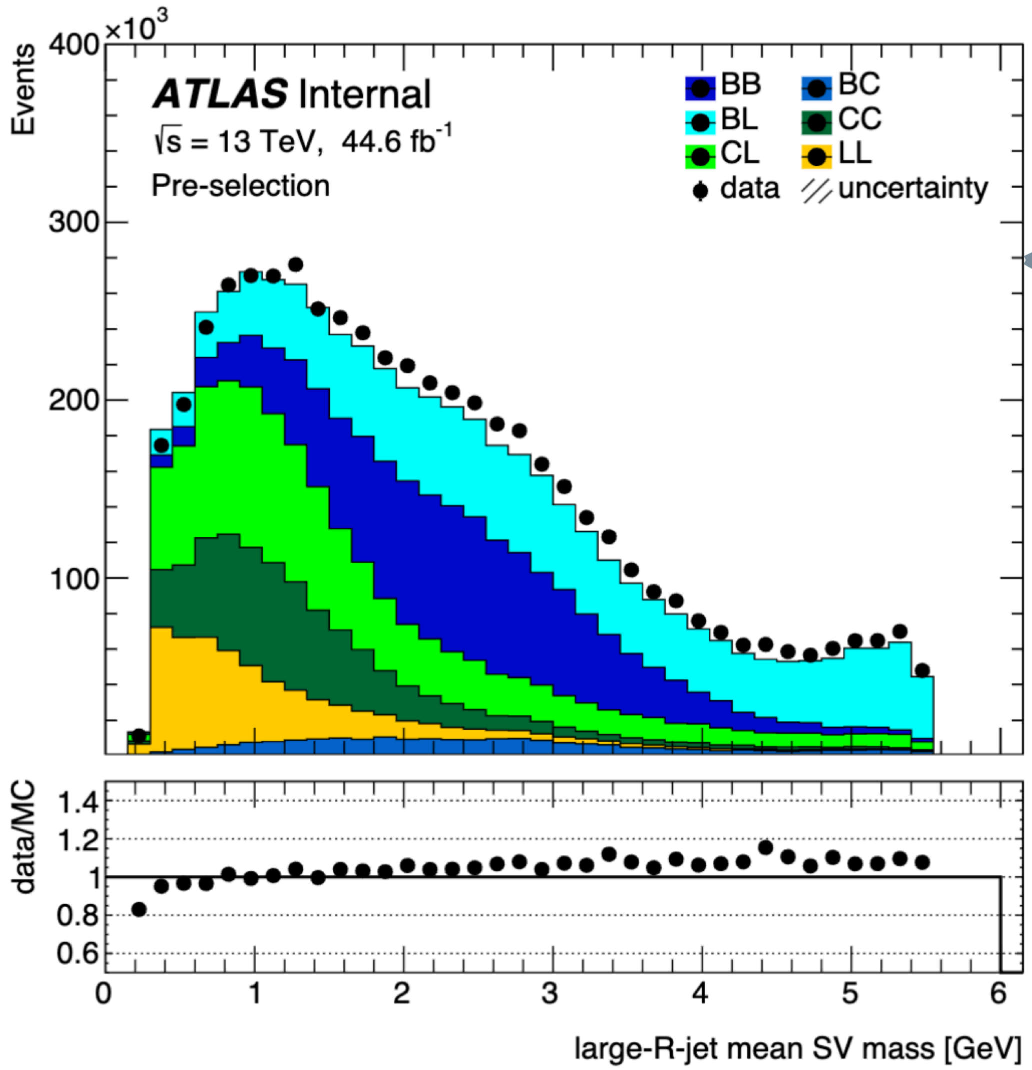
A g→bb candidate is defined as

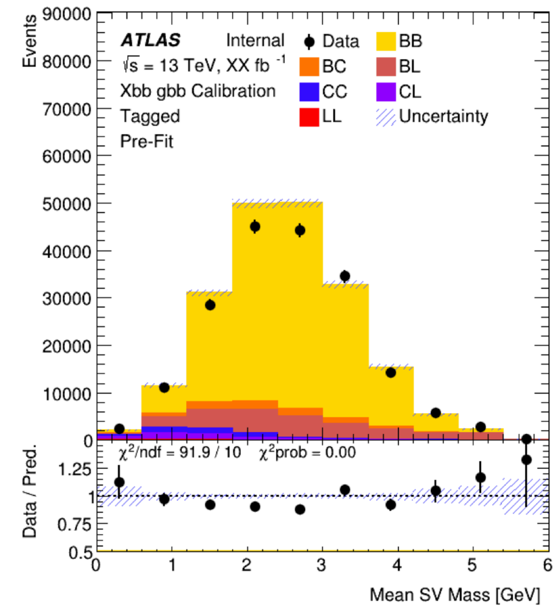
- a large-R jet with ≥ 2 ghost associated VR track-jets
- ≥ 1 VR track-jet is ΔR associated ($\Delta R < \max(0.2, \min(0.4, 30{*}p_T^{\text{track-jet}}))$ to a soft muon

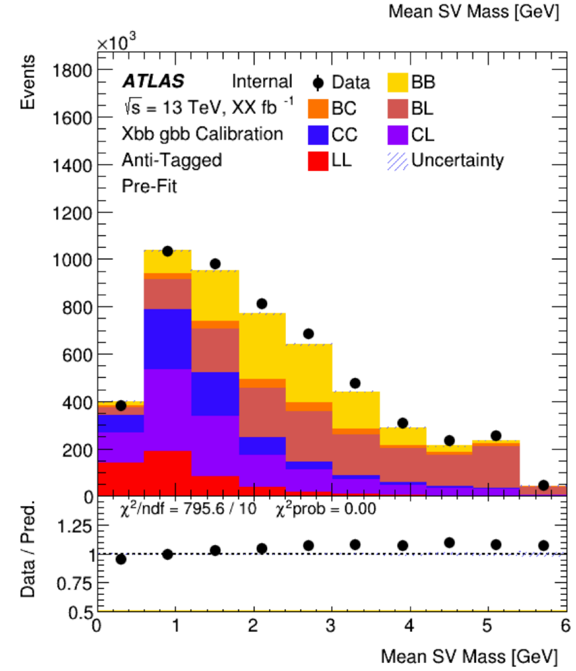
Events are required to have ≥1 g→bb candidate. In the case of multiple g→bb candidates, the highest p_T one is chosen.

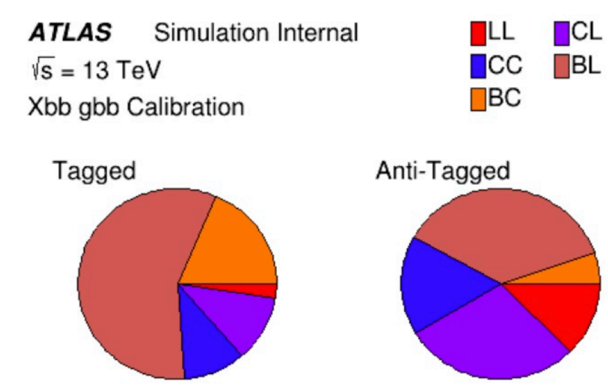


Apply the tagger





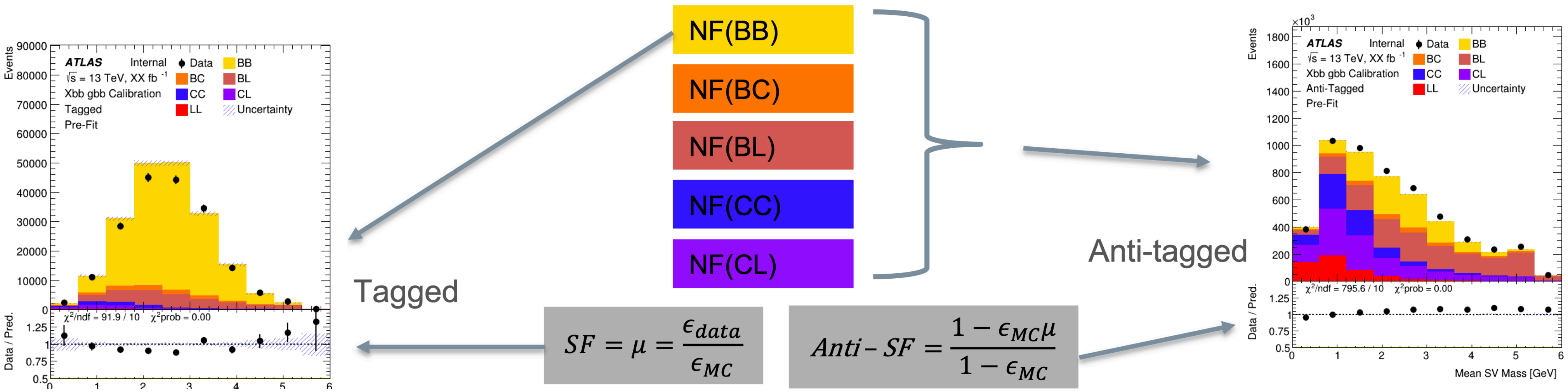




Apply GN2Xv00 at 80% WP (D_{GN2X} ≥ 2.25) to get tagged and anti-tagged regions

Fit procedure

- 6 flavour templates based on truth flavour label of VR track jets
→ fit MC flavour fractions
    - 5 normalisation factors (BB, BL, BC, CC, CL) to scale flavour components separately
- Calibrate efficiency of tagger on gbb events and extract SF



$$SF = \mu = \frac{\epsilon_{data}}{\epsilon_{MC}}$$

$$Anti\text{-}SF = \frac{1-\epsilon_{MC}\mu}{1-\epsilon_{MC}}$$

Fit performed using trex-fitter, example config file here

Regions: Tagged, anti-tagged

SF is fitted from BB template in tagged region

Anti-SF is fitted from BB template in anti-tagged region

NF(BB) is fitted from BB template in both regions

NF(BC, BL, CC, CL) are fitted from templates in anti-tagged regions

Signal: BB_{tagged}, $BB_{untagged}$

Background: $[BL, BC, CC, CL, LL]_{tagged,untagged}$

Variable: large-R jet mean SV mass

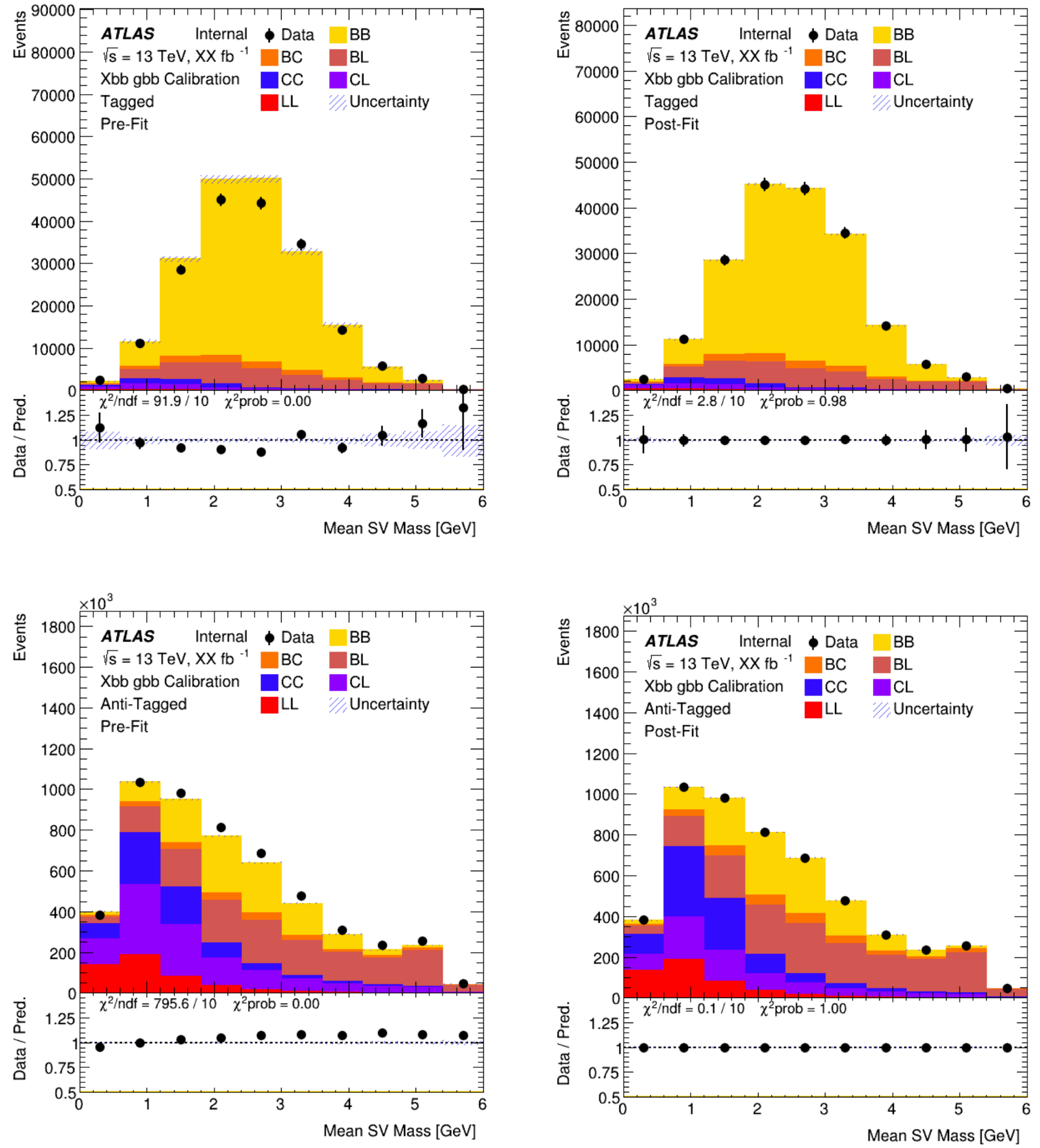
Preliminary fit results

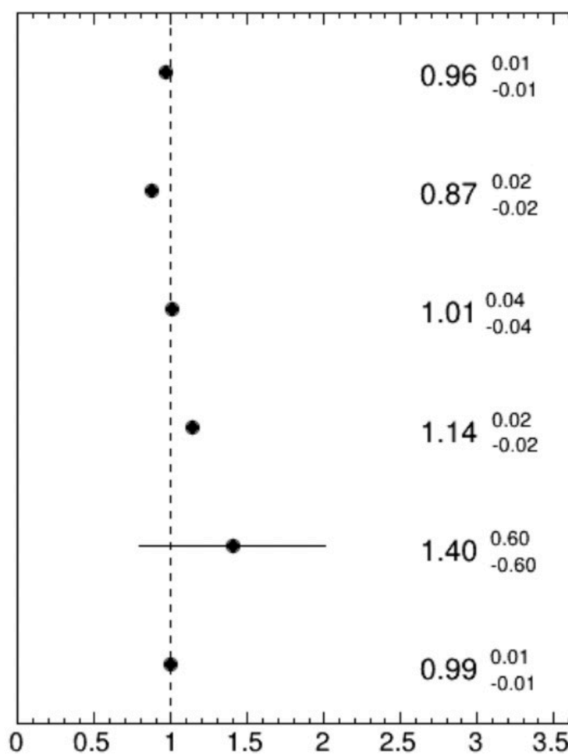
Stat. only

mc20d

All p_T bins (p_T>200 GeV)

GN2Xv00 (80% WP)





SF close to 1 and very small uncertainties – under investigation

CC and CL very anti-correlated

BC very low statistics, may remove/combine with another category

	NF(BB)	NF(BC)	NF(BL)	NF(CC)	NF(CL)	SF
NF(BB)	100.0	-18.3	-43.0	-19.3	-23.4	-85.6
NF(BC)	-18.3	100.0	-26.6	-3.0	-3.1	19.0
NF(BL)	-43.0	-26.6	100.0	15.4	-24.6	44.4
NF(CC)	-19.3	-3.0	15.4	100.0	-69.7	20.1
NF(CL)	-23.4	-3.1	-24.6	-69.7	100.0	24.4
SF	-85.6	19.0	44.4	20.1	24.4	100.0

Next steps

- Start new production with latest derivation p5835 (with GN2Xv01)
- Perform fit on full dataset
- Study other fit variables and optimise selection
- Perform full systematic fit
- Bin in p_T and repeat for other tagger WPs

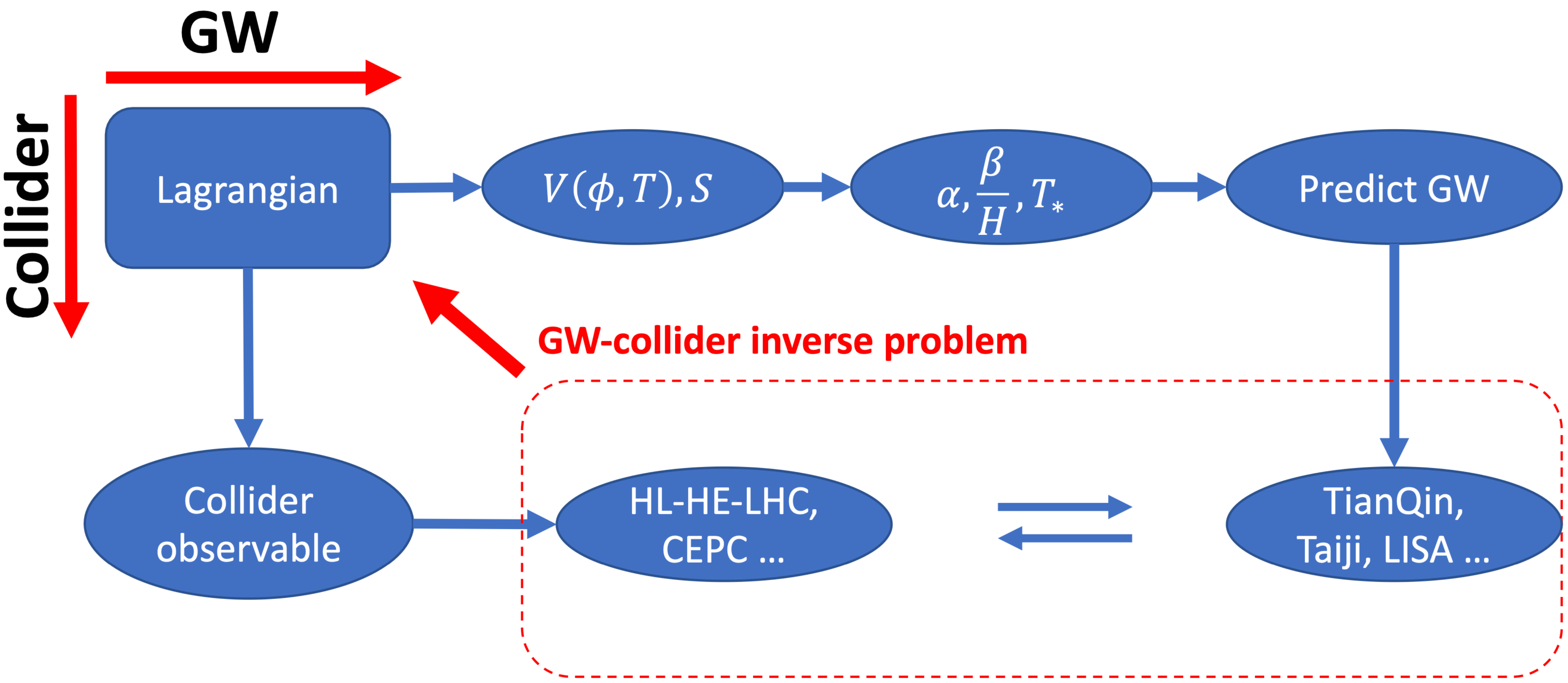
GW+collider inverse problem

Khanh, Shu in collaboration with VQ and Michael

to be honest, not much progress so far

General picture and key questions

李政道研究所 Tsung-Dao Lee Institute



❖ Q1: Can combination of **collider** and **GW** observations be used to determine the **BSM scenario** responsible for the observed signals?

Triplet scalar extension model

P. Fileviez Pérez, H.Patel, M.J. Ramsey-Musolf, K. Wang. PRD 79 (2009), 055024

Scalar field content:

$$H = \begin{pmatrix} \phi^+ \\ \frac{1}{\sqrt{2}}(v_0 + h + i\phi^0) \end{pmatrix}, \qquad \vec{\Sigma} = \begin{pmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 + x_0 \end{pmatrix},$$

Higgs doublet — SU(2) triplet

$$\Sigma^\pm = (\sigma_1 \mp i\sigma_2)/\sqrt{2} \quad \text{and} \quad \Sigma^0 = \sigma_3,$$

$$\Sigma = (1, \mathbf{3}, 0) = \vec{T} \cdot \vec{\Sigma} = \frac{1}{2} \begin{pmatrix} \Sigma^0 & \sqrt{2}\Sigma^+ \\ \sqrt{2}\Sigma^- & -\Sigma^0 \end{pmatrix}$$

Scalar potential:

Standard model — new particle mass + self coupling — Higgs portal interaction

$$V(H, \Sigma) = -\mu^2 H^\dagger H + \lambda (H^\dagger H)^4 \boxed{-\frac{1}{2}\mu_\Sigma^2 \vec{\Sigma}^2 + \frac{b_4}{4}(\vec{\Sigma}^2)^2} \boxed{+a_1 H^\dagger \Sigma H + \frac{a_2}{2} H^\dagger H \vec{\Sigma}^2}$$

$+a_1 H^\dagger \Sigma H$ → Breaks Z_2 symmetry

Four unmeasured parameters: $\mu_\Sigma^2, a_1, a_2, b_4$

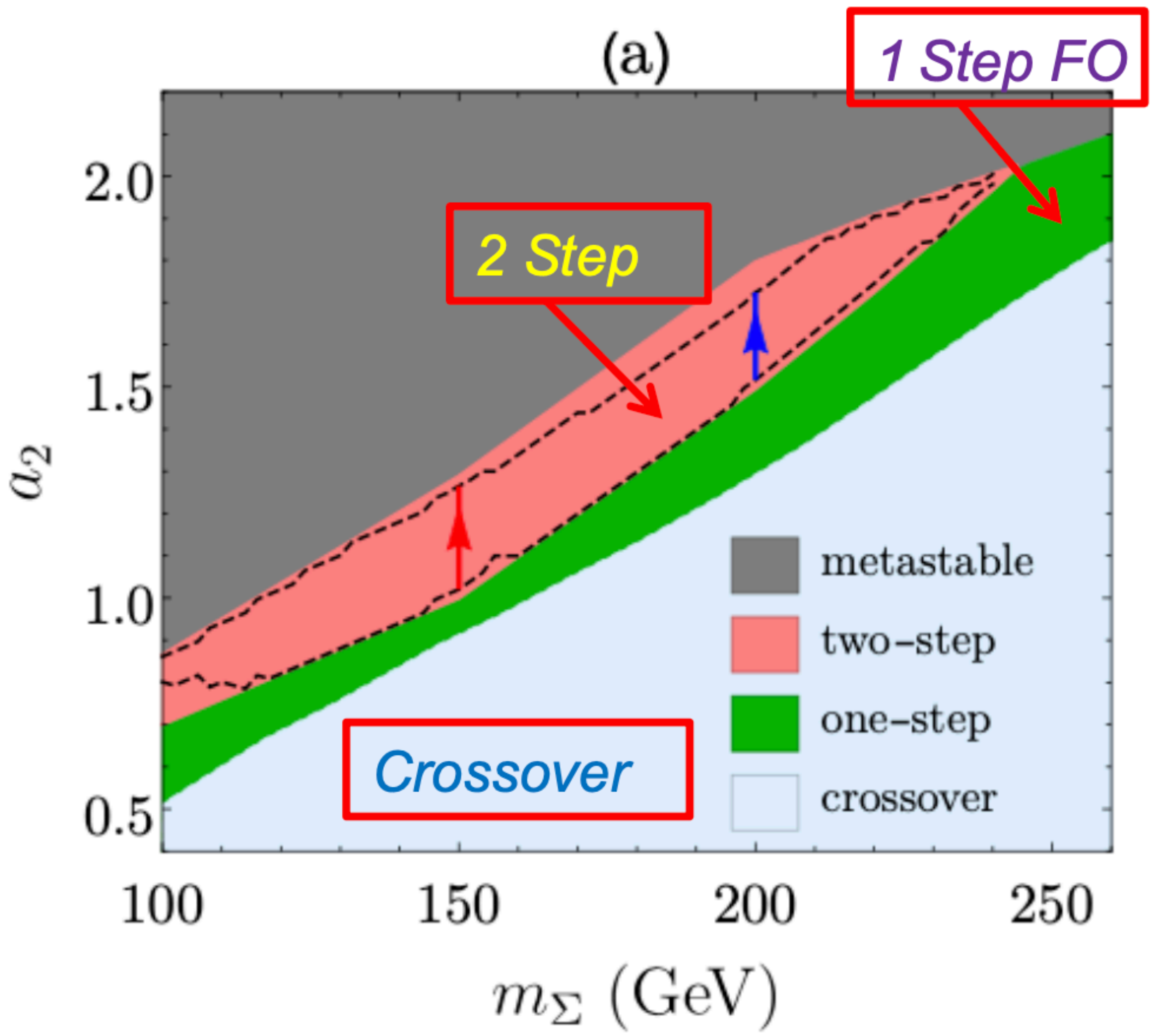
2-step phase transition with the 2nd step is 1st-order EWPT ⟶possible to generate GW via bubble collisions

Phase structure diagram

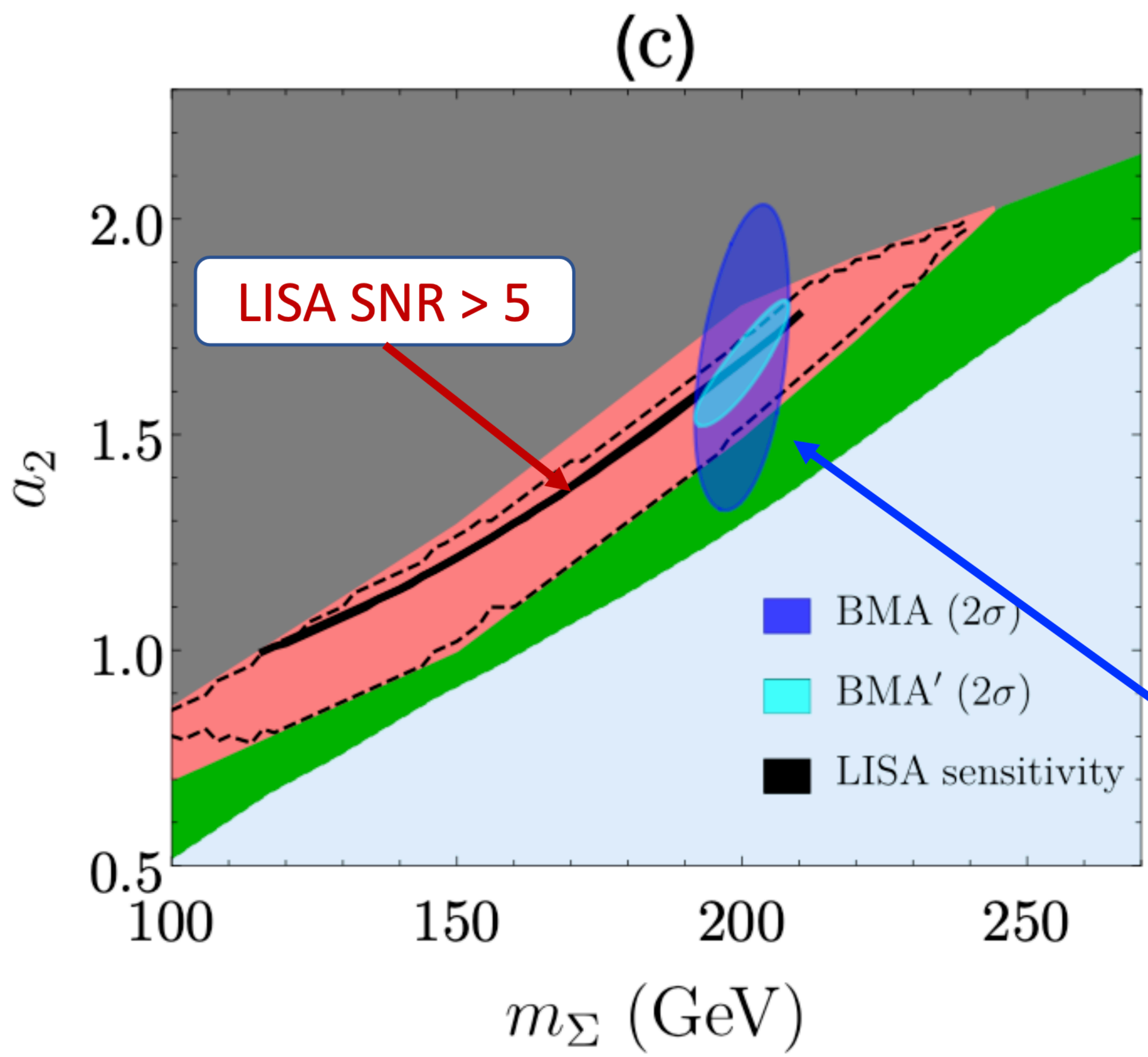
EFT+ Non-perturbative

Friedrich, MJRM, Tenkanen, Tran 2203.05889

$b_4 = 1.0$



Combination of GW-collider



Hypothetical set of measurements:

$$\delta_{\gamma\gamma} = -0.132 \pm 0.015,$$
$$m_\Sigma = (200 \pm 5)\ \text{GeV}$$
$$\text{BR}(\Sigma^0 \to ZZ) = 0.01 \pm 0.002\ ,$$

FCC-ee

BMA: $m_\Sigma + \delta_{\gamma\gamma}$

BMA' : BMA + $BR(\Sigma^0 \to ZZ)$

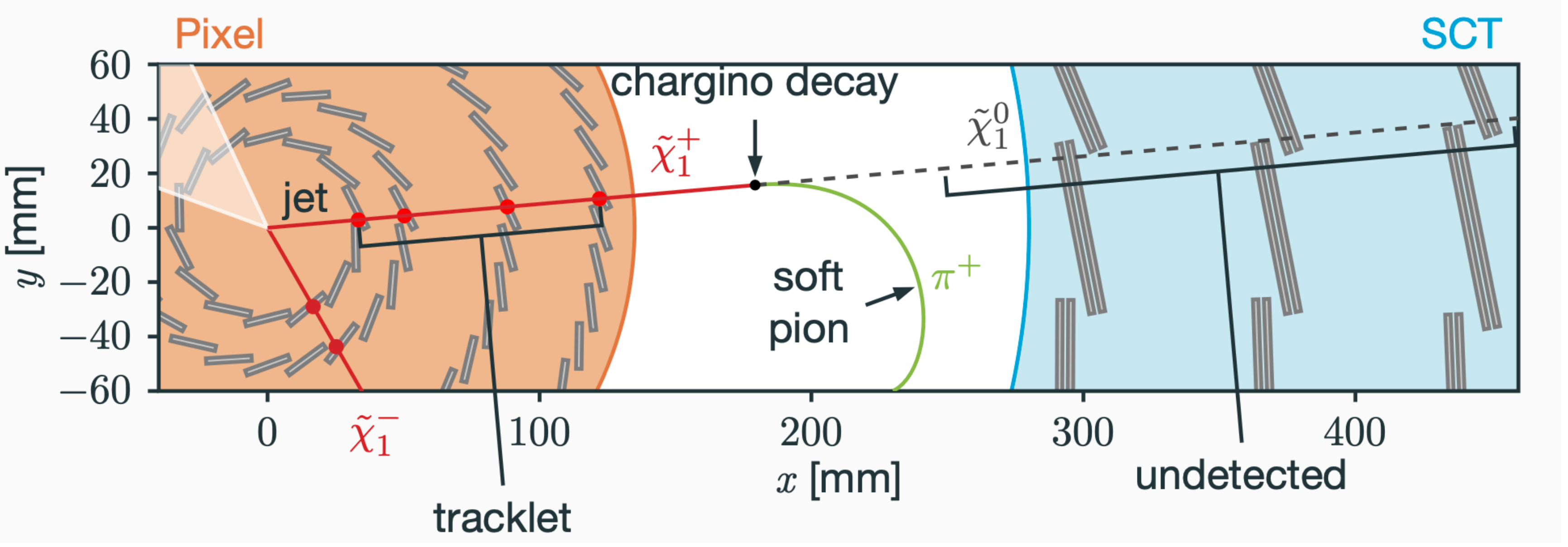
- GW-collider overlapped → model is responsible to both GW and collider signals
- If collider observed triplet scalar but the collider regions don't overlap with LISA region → model is not responsible to GW signal → another BSM is needed!

Important question under investigation: How to statistically combine measurements of LISA experiment and collider to find the overlapped region in parameter space?

From ATLAS point of view…

- Search for collider signatures in real scalar triplet extension model.
  - Precision measurements of H->yy ———> information on $\delta_{\gamma\gamma}$
  - **Z2-symmetry**: reinterpretation of long-lived chargino search with a disappearing track signature in the context of the triplet model ———> constraints in the model parameter space arxiv:2201.02472

$\Sigma^{\pm} \to \pi^{\pm}\Sigma^{0}$



  - **non Z2-symmetry**: $\Sigma^0 \to ZZ \to 4l$ reinterpretation of ATLAS search for Z boson pair in 4l final states ———> set limit on BR($\Sigma^0 \to ZZ$) arxiv:2009.14791

- Any model as long as it has 1st order EWPT, e.g singlet scalar model: h->aa->4b could be good candidate.