

Beyond the Standard Model in the Higgs sector at ATLAS

Kevin Sedlaczek on behalf of the ATLAS Collaboration
Phenomenology Symposium 2026, Pittsburgh



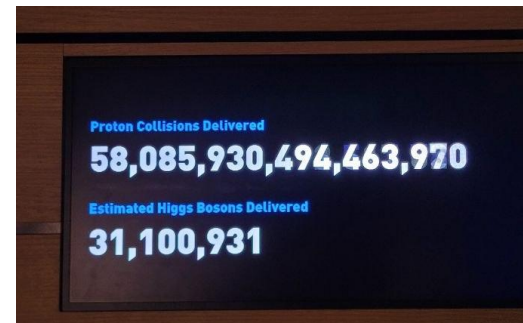
**Northern Illinois
University**

Looking beyond the SM in the Higgs sector

- Entering the precision era of Higgs physics at the LHC
- ~10% of potential BR into non-SM or exotic decays of the Higgs boson left by current constraints
- Higgs boson decays are particularly sensitive to new physics
 - small total width
 - strong coupling to massive particles

Why extend the EW sector?

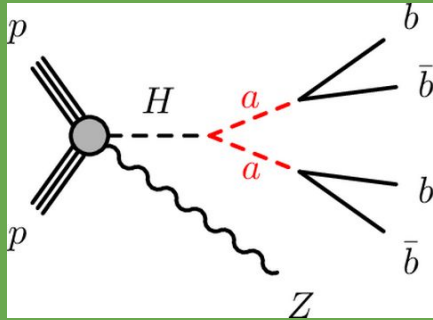
- DM models
- models with a first-order electroweak phase transition
- neutral naturalness
- pseudo-scalars a with masses below the electroweak scale



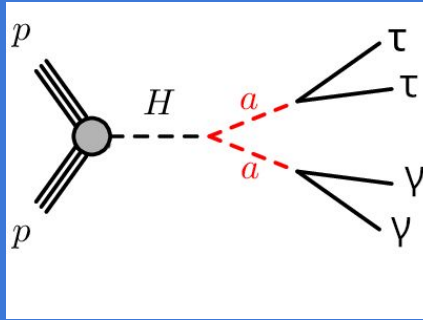
Measurements in this presentation

Full
Run-2

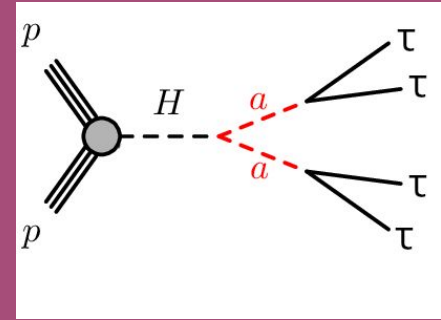
Search for decays of the Higgs boson into scalar particles decaying into four or six b-quarks



Search for Higgs boson decays into a pair of pseudoscalar particles in the $\gamma\gamma\tau_{\text{had}}\tau_{\text{had}}$ final state



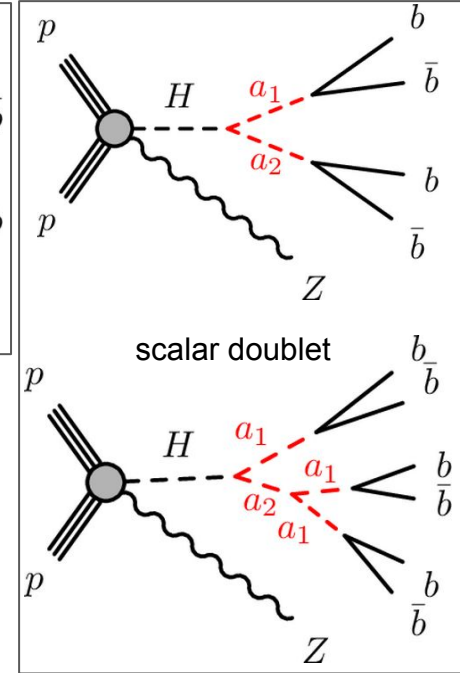
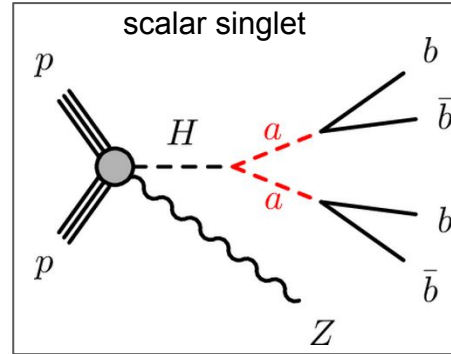
Search for decays of the Higgs boson into pair-produced pseudoscalar particles



Search for decays of the Higgs boson into scalar particles decaying into four or six b-quarks

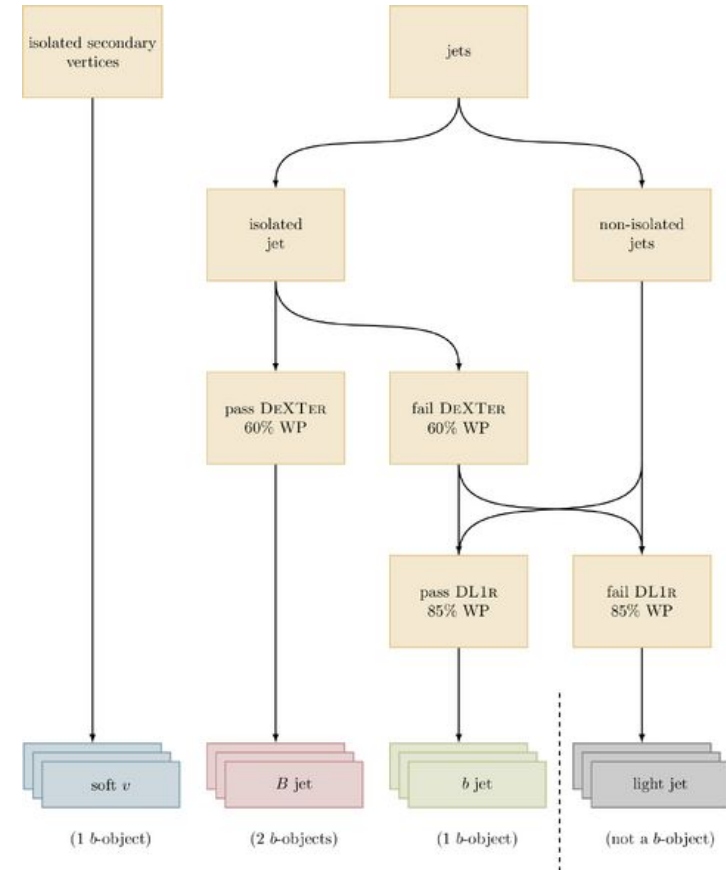
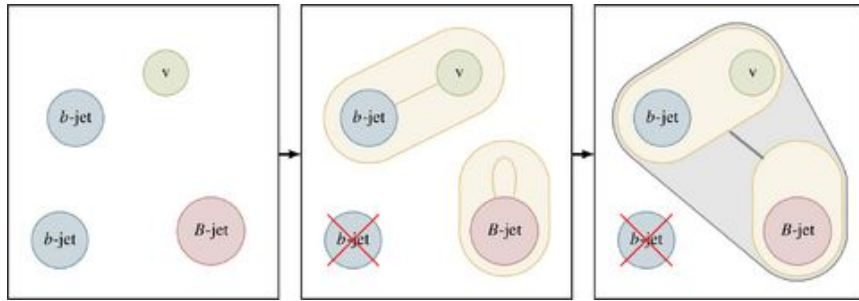
- Associated production of with a **Z boson** (**trigger** and bkg suppression)
- **4b** or **6b** final states
- Z decay defines channels (E_T^{miss} , **2lep**)
- m_a in [12, 60] GeV
- Strong coupling to heavy quarks for a 's with similar Yukawa structure

- Additional E_T^{miss} final state in 4b channel
- New techniques to identify collimated b-hadron decay products



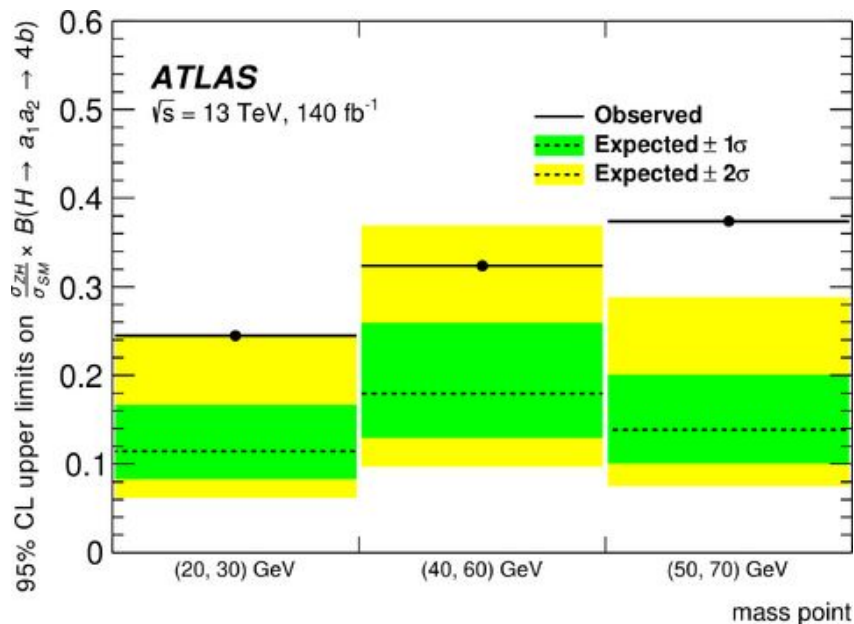
Final State Reconstruction

- **Overlap** and **softness**: challenging phase space for tagging b-objects
- DeXTER ML algorithm:
 - Identify jets from overlapping b-quarks (**B-jet**)
- DL1r b-tagging algorithm (**b-jets**)
- Encoder based b-object based signal reconstruction

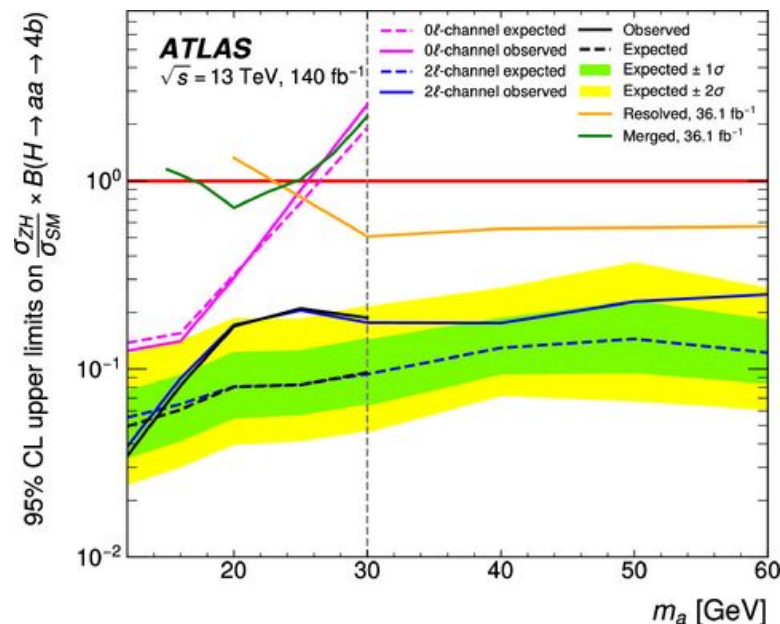


Results for 4b final state

$$H \rightarrow a_1 a_2 \rightarrow 4b$$



$$H \rightarrow aa \rightarrow 4b$$

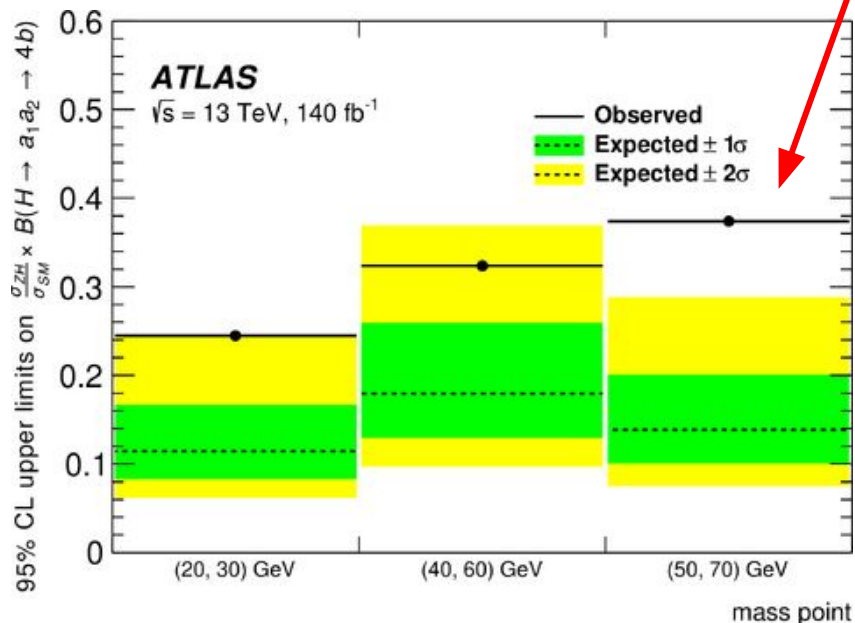


No significant excess over SM

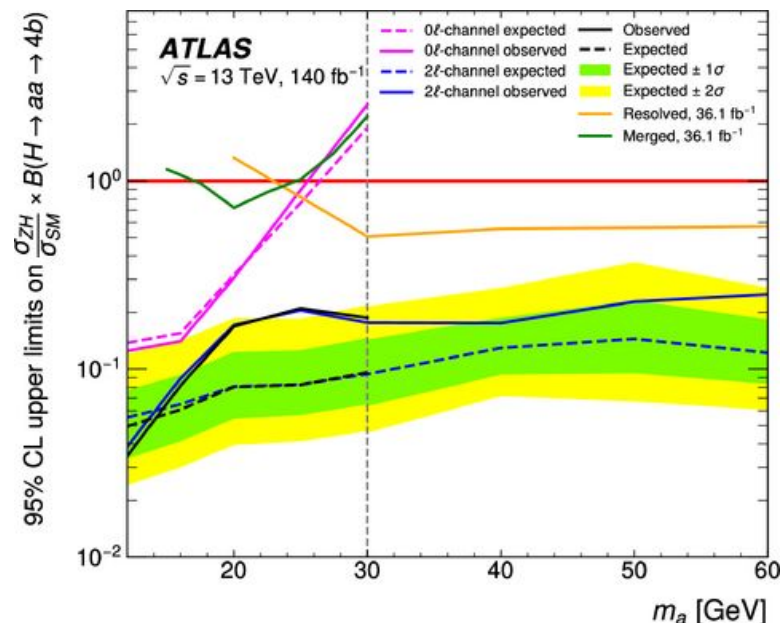
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$$H \rightarrow a_1 a_2 \rightarrow 4b$$

3.28 σ (2.57 σ)



$$H \rightarrow aa \rightarrow 4b$$

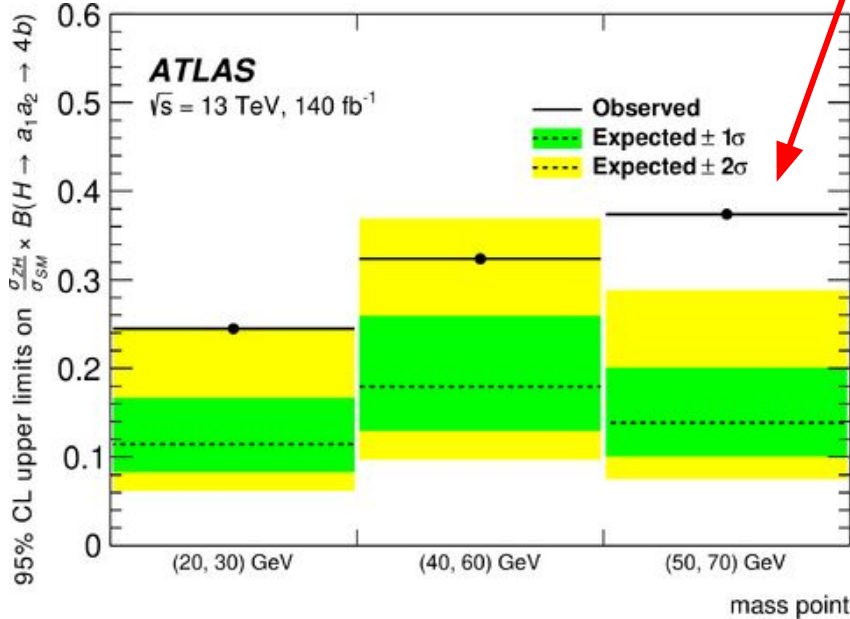


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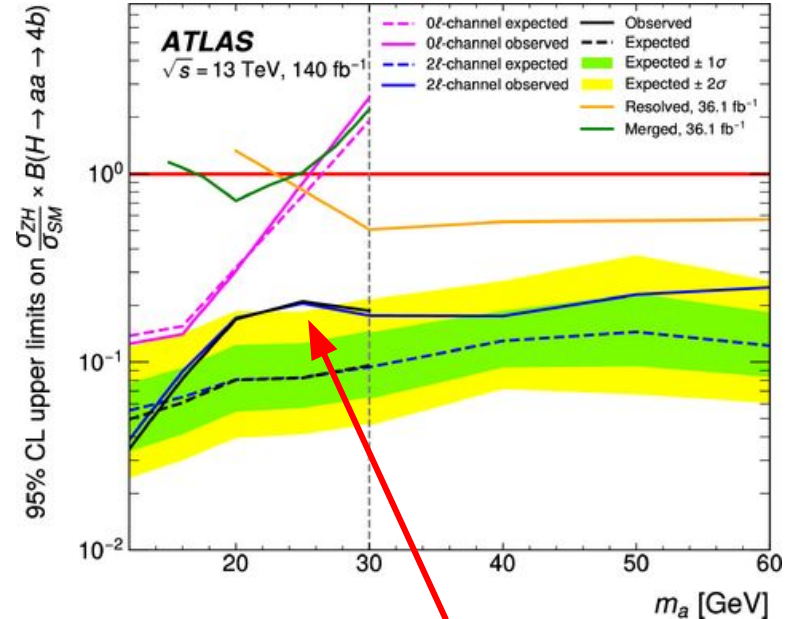
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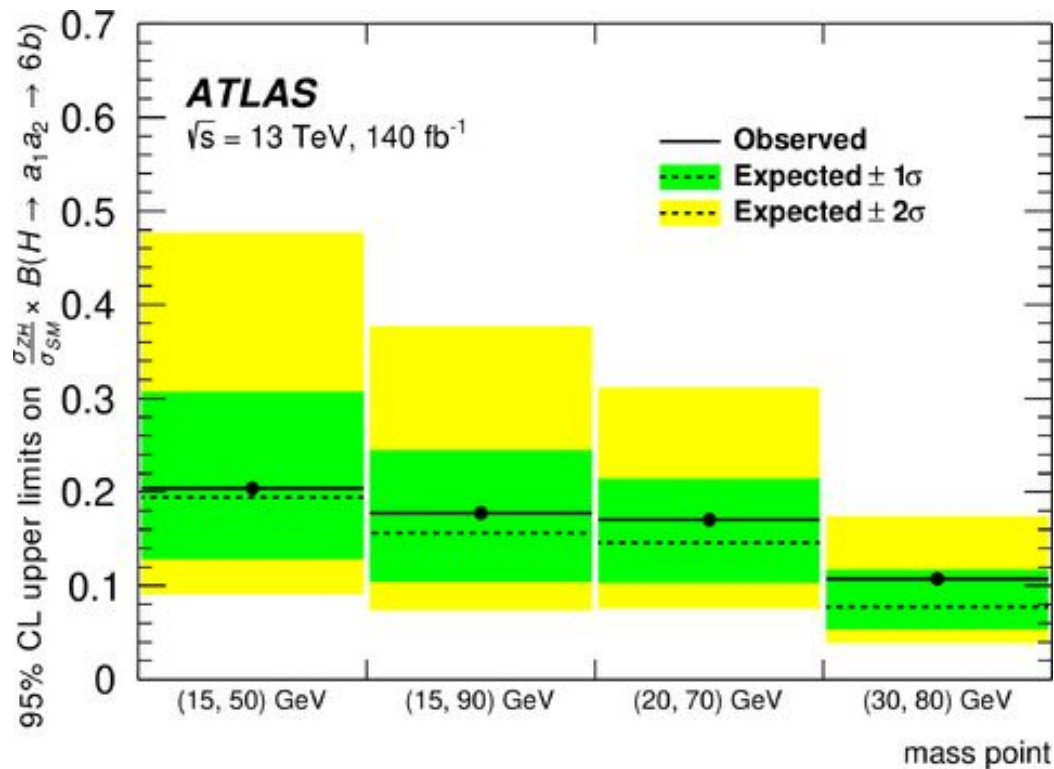
$H \rightarrow aa \rightarrow 4b$



No significant excess over SM

2.83 σ (2.04 σ)

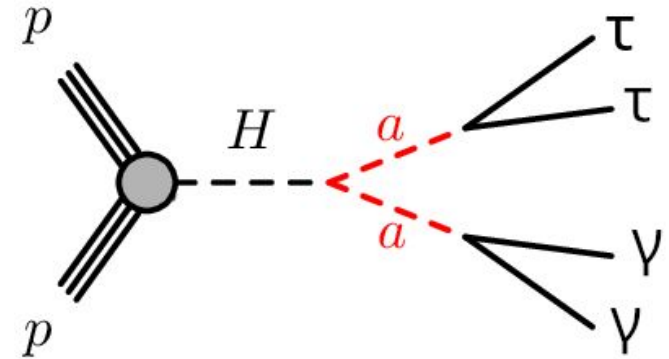
Results for 6b channel



No significant excess over SM

Search for Higgs boson decays into a pair of pseudoscalar particles in the $\gamma\gamma\tau_{\text{had}}\tau_{\text{had}}$ final state

- Good **trigger efficiency** and **mass resolution** using photons
- Large BR due to strong coupling with **massive taus**
- Previous measurements with either taus or photons, **first combination**
- mass range: m_a in [10, 60] GeV



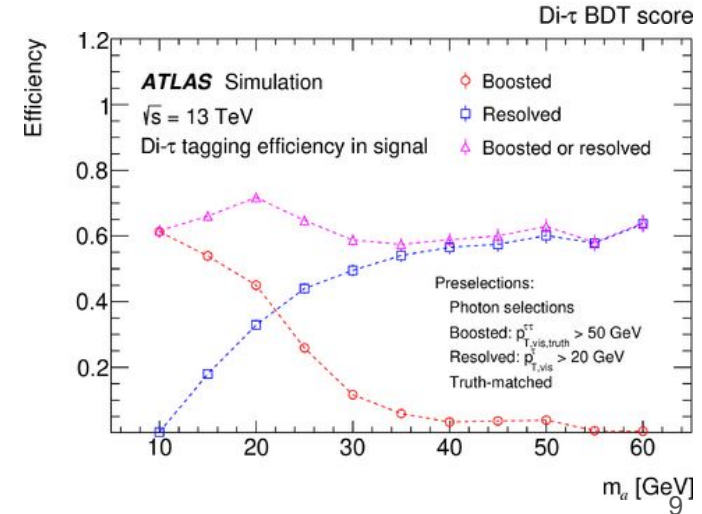
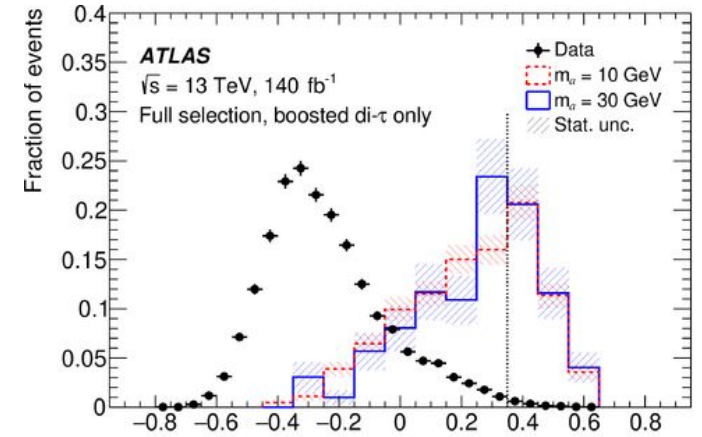
Analysis Strategy

- Trigger on photons, select two isolated photons, veto leptonic (e/mu) final states

Look for either **boosted di- τ** or **2 resolved taus**:

- RNN to identify tau candidates and final resolved τ
- Reconstruction algorithm for boosted di- τ signatures and BDT to remove quark or gluon jets
- Calibration in boosted $Z \rightarrow \tau\tau + \gamma$

BDT 70% WP: background rejection of ~ 240



Signal and Background Modeling

- Fitting $m_{\gamma\gamma}$ to an analytical model: agreement with simulation at 2.5%
- Additional systematic uncertainty due to spurious signal (up to 8% of exp. stat. uncertainty)

Double-sided Crystal-Ball with sigmoid:

$$f(m_{\gamma\gamma}; N, \delta_{\text{sgmd}}, \tau_{\text{sgmd}}, \lambda_{\text{exp}}) = N \times \frac{1}{1 + e^{-(m_{\gamma\gamma} - \delta_{\text{sgmd}})/\tau_{\text{sgmd}}}} \times e^{-\lambda_{\text{exp}} m_{\gamma\gamma}}$$

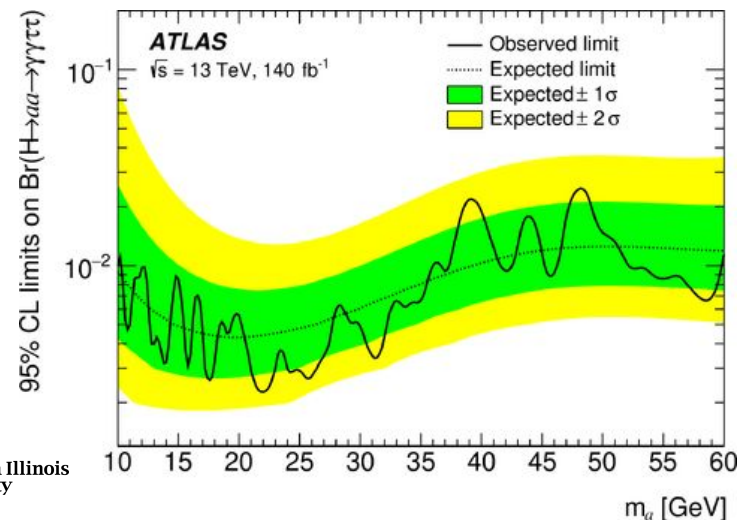
Backgrounds

1. **Continuum di-photon:** data-driven estimation using analytical description
2. **Photon + jets (fake photon):** control region inverting photon ID criteria
3. **Jets faking photons:** control region inverting photon ID criteria

Results

- Largest Uncertainties:
 - Statistical precision (di- τ uncertainty)
 - di- τ extrapolation uncertainty
- theory uncertainties
 - Renormalisation and factorisation scales
 - PDFs
- no significant excess over SM
- most significant excesses for $m_a = 39$ GeV (2.2σ) and $m_a = 48$ GeV (2.1σ)
- best sensitivity between 10 and 35 GeV

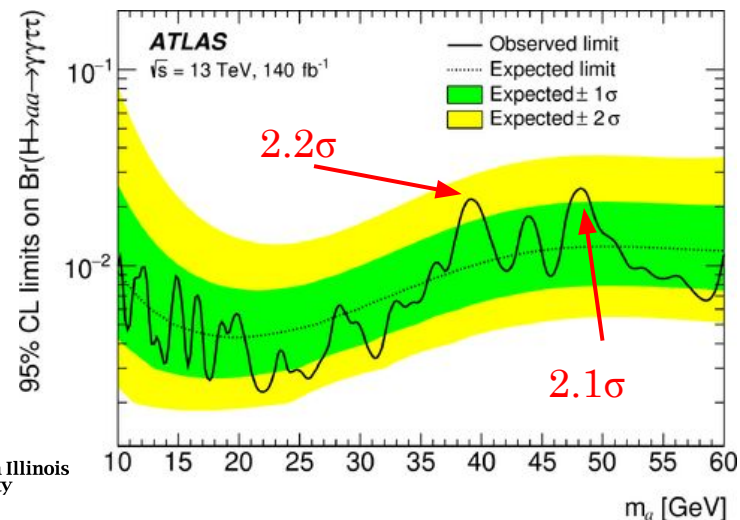
Source	Uncertainty	
	$\ln \mathcal{B}(H \rightarrow aa \rightarrow \gamma\gamma\tau\tau)$ [%]	
	$m_a = 10$ GeV	$m_a = 50$ GeV
Boosted di- τ object	63	0.8
Theory	9.9	27
Pile-up reweighting		4.5
Resolved τ reconstruction, identification and energy scale	0.3	4.0
Photon energy resolution		3.0
Photon identification efficiency		2.9
Signal shape modelling		2.5
Photon isolation efficiency		2.4
Photon trigger efficiency		1.1
Photon energy scale		< 1.0
Luminosity		0.8
Trigger on closely spaced photons	0.8	< 0.1
In background modelling		
Spurious signal	< $0.08 \sigma_{\text{stat}}$ 0.16 events	< $0.01 \sigma_{\text{stat}}$ 0.06 events



Results

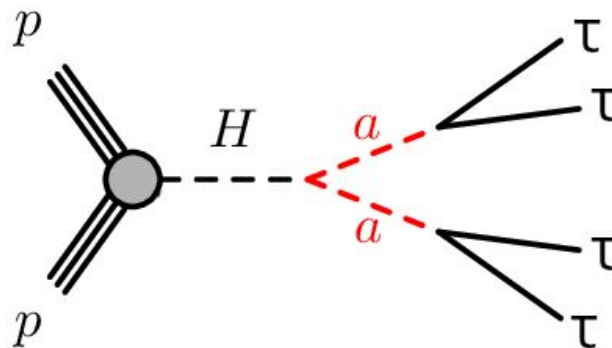
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	In background modelling	
Spurious signal	< $0.08 \sigma_{\text{stat}}$	< $0.01 \sigma_{\text{stat}}$
	0.16 events	0.06 events



Search for decays of the Higgs boson into pair-produced pseudoscalar particles

- Like the other singlet cases, this can be interpreted within 2HDM+S frameworks (MSSM + singlet field), especially sensitive to leptophilic models
- m_a in [15, 60] GeV (angular separation of taus)
- reconstructing 1-2 hadronic tau decays
- previous ATLAS measurement aimed at low m_a with boosted taus
- Two final states:
 1. $2\ell 2\tau_{\text{had}}$
 2. $3\ell 1\tau_{\text{had}}$



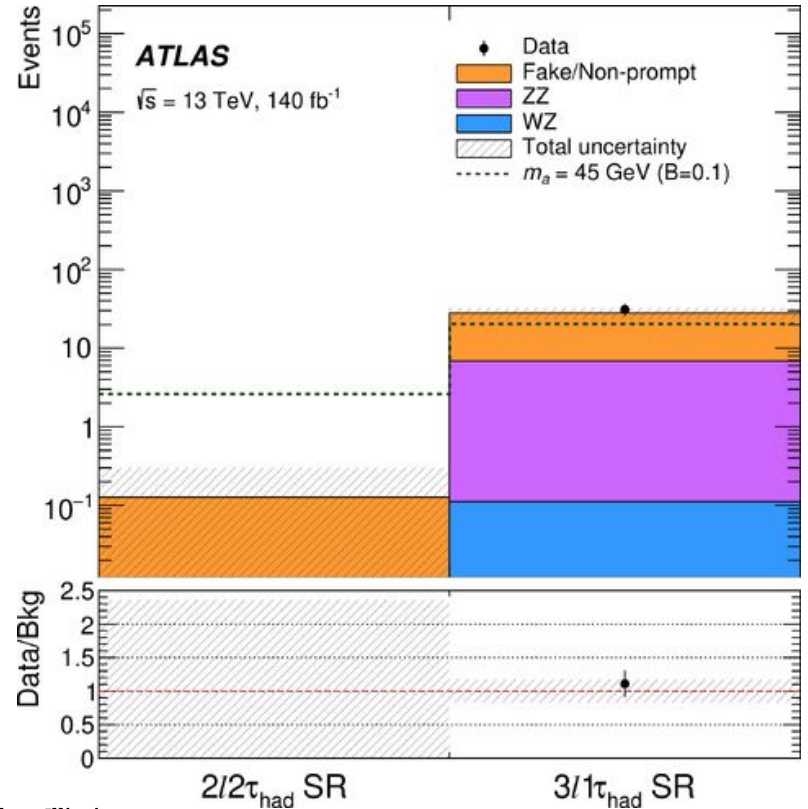
Signal Selection and Backgrounds

Signal:

- production via gluon-gluon fusion, normalised to full Higgs boson production cross-section
- SRs are combined in final statistical analysis

Backgrounds:

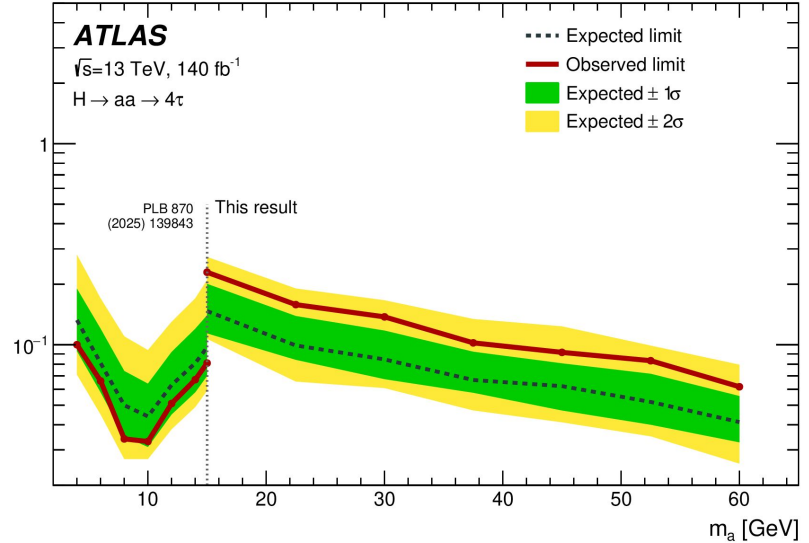
- fake and non-prompt leptons
 - heavy flavour hadrons
 - jets faking leptons
- WZ/ZZ , $Z/\gamma^* + \text{jets}$ and $t\bar{t}$



Results

Process	$2\ell 2\tau_{\text{had}}$ SR	$3\ell 1\tau_{\text{had}}$ SR
Data	0	31
Total background	$0.12^{+0.17}_{-0.12}$	28.0 ± 4.6
Fake/non-prompt	$0.12^{+0.17}_{-0.12}$	21.1 ± 4.7
WZ	< 0.01	0.11 ± 0.02
ZZ	0.01 ± 0.01	6.7 ± 0.7
$H \rightarrow aa \rightarrow 4\tau$ ($\mathcal{B} = 10\%$, $m_a = 45$ GeV)	2.6 ± 0.3	20.5 ± 2.4

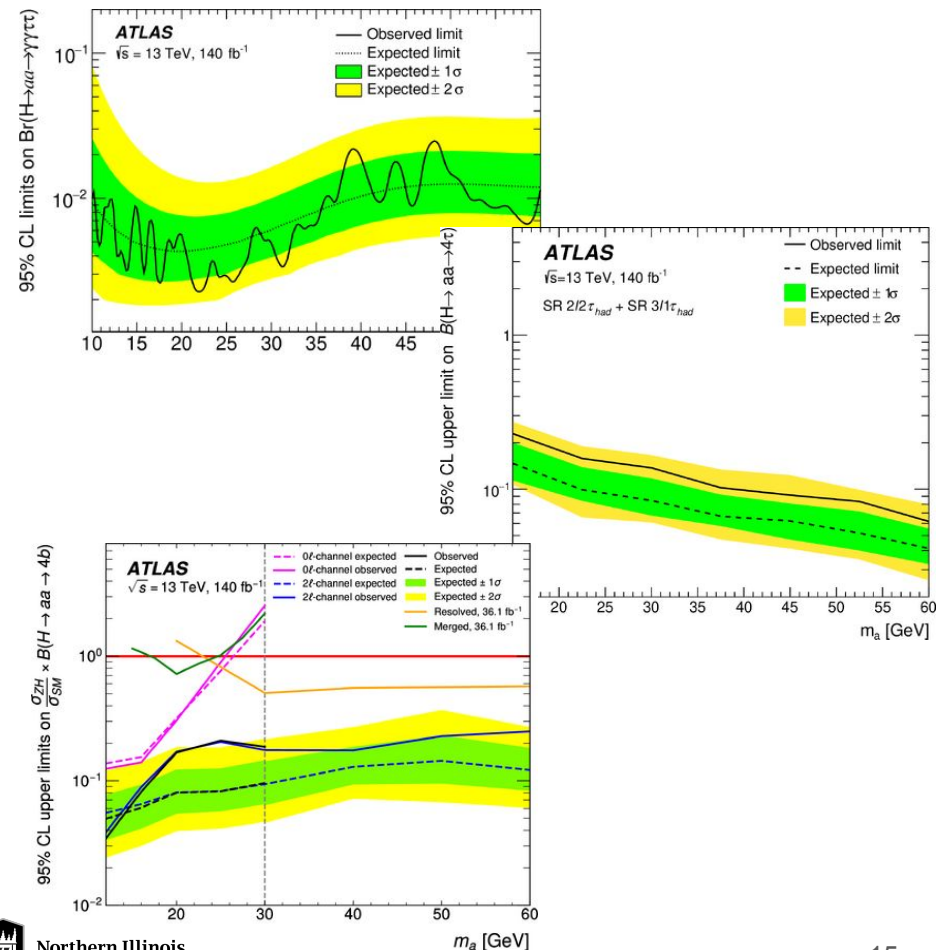
95% CL upper limit on $B(H \rightarrow aa \rightarrow 4\tau)$



No significant excess over the SM

Conclusions

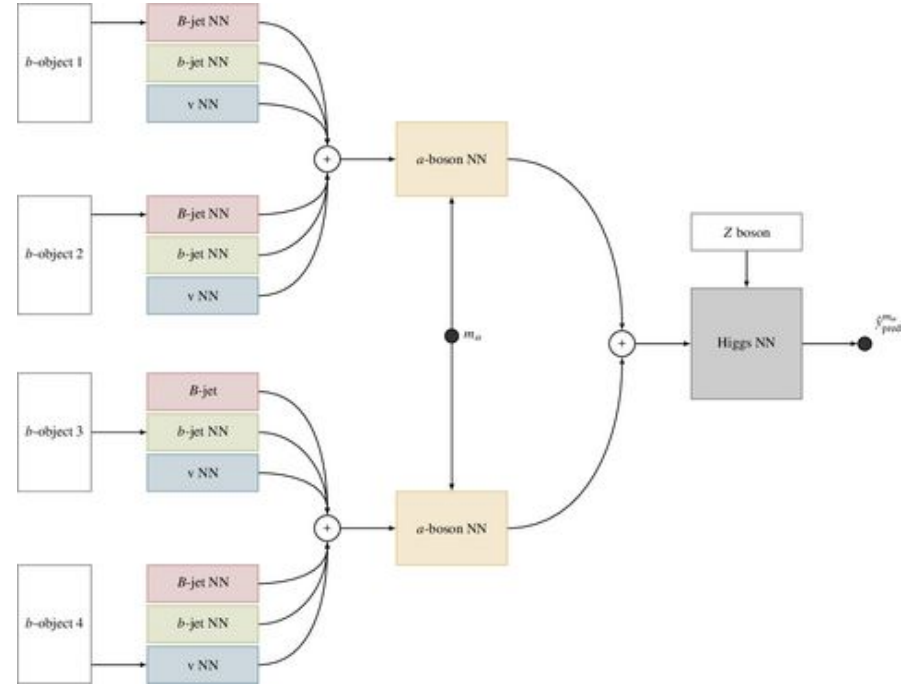
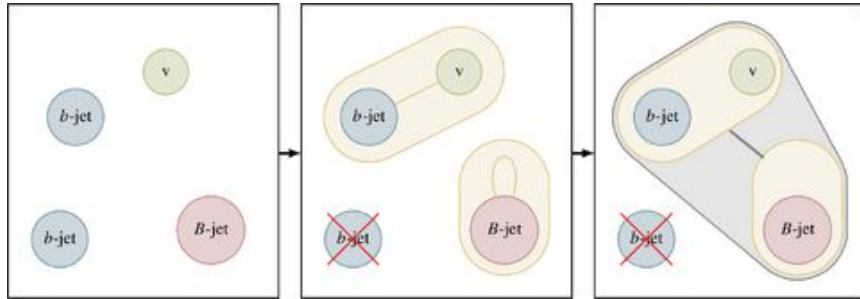
- Rich search program for BSM effects in the Higgs sector
- No significant excess found
- Increasing precision with more data and improved measurement techniques
- Soon to come analyses using Run 3 data



BACKUP

Final State Reconstruction (4b channel)

- Find most likely b-object configuration under signal hypothesis
- invariant under exchange of a's and b-objects
- separate encoder NN's for b-objects
- Accuracy of associating b-objects between 60% and 98%



Signal and backgrounds

Backgrounds

- Drell-Yan production of charged leptons or neutrinos in assoc. with HF jets
- $Z/\gamma^* \rightarrow \ell\ell/\nu\nu$
- $t\bar{t}$ and single top semi-leptonic + HF
- diboson and $t\bar{t}+V$
- 0lep: additionally QCD multijet bkg

Signal

1. $H \rightarrow 2a \rightarrow 4b$
 - a. E_T : ($m_a = 12, 16, 20, 25, 30$ GeV)
 - b. 2lep: s.a. + ($m_a = 40, 50, 60$ GeV)
2. $H \rightarrow a_1 a_2 \rightarrow 4b$ 2lep
 - a. (m_{a_1}, m_{a_2}) = (20, 30), (40, 60), (50, 70) GeV
3. $H \rightarrow a_1 a_2 \rightarrow 3a_1 \rightarrow 6b$ 2lep
 - a. (m_{a_1}, m_{a_2}) = (15, 50), (15, 90), (20, 70) and (30, 80) GeV

Results

- For $H \rightarrow 2a \rightarrow 4b$ the two channels are combined
- B-jet ID efficiency is important source of syst at low masses

Uncertainty source	Upper limit on $\sigma(ZH)/\sigma_{SM}(ZH) \times \mathcal{B}(H \rightarrow 2a \rightarrow 4b)$					
	$m_a = 12 \text{ GeV}$			$m_a = 25 \text{ GeV}$		
	0ℓ	2ℓ	$0\ell \ \& \ 2\ell$	0ℓ	2ℓ	$0\ell \ \& \ 2\ell$
Stat-only limit	0.060	0.029	0.025	0.35	0.19	0.19
Observed limit	0.12	0.039	0.034	0.89	0.21	0.21
MC statistics	0.065	0.030	0.026	0.37	–	0.19
Systematics	0.12	0.038	0.033	0.88	0.21	0.21
Experimental	0.076	0.032	0.028	0.51	0.20	0.20
Luminosity and pileup	0.062	–	–	0.36	–	–
DL1R tagging	–	–	–	0.35	0.20	0.20
DEXTer tagging	0.067	0.030	0.026	0.39	–	–
Electrons	–	–	–	–	–	–
Muons	–	–	–	–	–	–
Jets	0.063	0.029	0.025	0.39	–	–
E_T^{miss}	0.063	–	0.025	0.37	–	–
Tracks	0.066	0.029	0.026	0.42	–	0.20
Soft- v	–	–	–	–	–	–
Modeling	0.088	0.034	0.030	0.60	0.20	0.20
Top ($t\bar{t}$ and single top)	0.065	–	0.025	0.41	–	0.20
W/Z + jets	0.071	0.033	0.029	0.45	0.19	0.20
Signal	0.066	0.029	0.026	0.37	0.20	0.20
QCD	0.063	–	–	0.35	–	–

Region definitions and samples

- NLO (QCD) Powheg, NNPDF3.0nlo PDF set and $m_H = 125\text{GeV}$, normalized to NNLO (QCD) and NLO (EW)

Analysis channels	0 ℓ		2 ℓ	
	$H \rightarrow 2a \rightarrow 4b$		$H \rightarrow 2a/a_1a_2 \rightarrow 4b$	$H \rightarrow a_1a_2 \rightarrow 6b$
Common selection				
Triggers	$E_T^{\text{miss}} > 7\text{ GeV}$		Single lepton	
Leptons	$p_T > 7\text{ GeV}$		lead $p_T > 27\text{ GeV}$, sublead $p_T > 10\text{ GeV}$	
b -object multiplicity	$n_b = 2, n_B = 1$ or $n_B = 2$		$n_b + 2n_B + n_\nu \geq 4$	
Signal regions				
Leptons	0 leptons	2 SFOS leptons	2 SFOS leptons	2 SFOS leptons
E_T^{miss}	$E_T^{\text{miss}} > 150\text{ GeV}$	–	–	–
Z boson selection	–	$ m_{\ell\ell} - m_Z < 20\text{ GeV}$	$ m_{\ell\ell} - m_Z < 20\text{ GeV}$	$ m_{\ell\ell} - m_Z < 20\text{ GeV}$
Higgs boson selection	$ m_{aa} - m_H < 50\text{ GeV}$	High quadruplet NN score	–	–
Multijet rejection	$\min \Delta\phi(E_T^{\text{miss}}, a \text{ cand.}) > 60^\circ$	–	–	–
Categorization	n_j, n_b, n_B, n_{B_j}	Quadruplet NN prediction	Loose, Medium, Tight BDT bins	n_ν, n_b, n_B, n_{B_j}
Binning	–	Loose, Medium, Tight BDT bins	Loose, Medium, Tight BDT bins	Medium, Tight BDT bins
Control regions				
Multijet	<i>ABCD method</i> $150 < m_{aa} - m_H < 250\text{ GeV}$ $\min \Delta\phi(E_T^{\text{miss}}, a \text{ cand.}) < 30^\circ$		–	–
Lost lepton	Signal veto $ m_{aa} - m_H > 50\text{ GeV}$		–	–
Leptons	1 lepton, $p_T > 27\text{ GeV}$, $\Delta R(\ell, B) > 0.8$		–	–
E_T^{miss}	$E_T^{\text{miss,eff}} > 150\text{ GeV}$		–	–
Categorization	n_b, n_B, n_{B_j}		–	–
Z+jets enriched	Signal veto $ m_{aa} - m_H > 50\text{ GeV}$		Low quadruplet NN score	Loose BDT bins
Leptons	2 SFOS leptons, lead $p_T > 27\text{ GeV}$		2 SFOS leptons	2 SFOS leptons
E_T^{miss}	$E_T^{\text{miss}} < 50\text{ GeV}$, $E_T^{\text{miss,eff}} > 30\text{ GeV}$		$E_T^{\text{miss}} < 60\text{ GeV}$	$E_T^{\text{miss}} < 60\text{ GeV}$
Z boson selection	$ m_{\ell\ell} - m_Z < 10\text{ GeV}$		$ m_{\ell\ell} - m_Z < 10\text{ GeV}$	$ m_{\ell\ell} - m_Z < 10\text{ GeV}$
Categorization	n_b, n_B, n_{B_j}		n_ν, n_b, n_B, n_{B_j}	n_ν, n_b, n_B, n_{B_j}
$t\bar{t}$ enriched	–		–	–
Leptons	–		2 DFOS leptons	
Categorization	–		n_ν, n_b, n_B, n_{B_j}	

Signal Selection and Backgrounds

- ggF production of Higgs and normalized to inclusive Higgs production xsec
- $2\ell 2\tau_{\text{had}}$: 2 same charge e/mu and 2 same charge τ_{had} , total sum of charges = 0
- $3\ell 1\tau_{\text{had}}$: 3 e/mu and one τ_{had} , three leptons sum to +1 charge, all sum to 0
 - The two SRs are combined in profile likelihood fit for mass hypotheses between 15 and 60 GeV
- b-jet veto and Z veto using OC m_{ll}

Tau Reconstruction

- efficiency: 80% at $m_{\gamma\gamma} = 10\text{GeV}$, 90% at $m_{\gamma\gamma} = 90\text{GeV}$
- RNN using calorimeter and high-level event information to reconstruct tau candidates
- boosted di- τ : τ s within $R=0.4$ of each other
 - then reconstruct as large radius jet with $R=1.0$, $p_T > 50\text{ GeV}$
 - then reclustering constituents into at least 2 sub-jets with $p_T > 10\text{ GeV}$, $R=0.2$, and 1 or 3 subjets
- Efficiency of tagging is measured using tag-and-probe setup, using boosted $Z \rightarrow \tau\tau + \gamma$
- Scale factors for calibration of BDT around 1.00 ± 0.35 (stat.) ± 0.13 (syst.), but introducing systematic uncertainty due to different energy scales between calibration and signal processes