Exploring Higgs Physics: Past Achievements and Future Vision

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IHEP, Beijing

EPD Postdoc Interview
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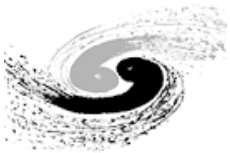


Institute of High Energy Physics
Chinese Academy of Sciences

ATLAS EXPERIMENT

Brief Biography

Education:

- Master's degrees from Quaid-e-Azam University, Islamabad (2016).
  Experimental High Energy Physics.
- PhD at Shandong University, China (2022)
  Particle and Nuclear Physics.

Early Experience:

- CMS experiment: Semiconductor strip detector noise modeling.
- Lecture Physics: University of Gujarat, Pakistan (2017)
- LHAASO Experiment: Performance study of the photomultiplier of the water Cherenkov detector array
- ATLAS Experiment:
  - Higgs in association with single top quark.
  - New Small Wheel Upgrade Project: sTGC detector test with X-rays.

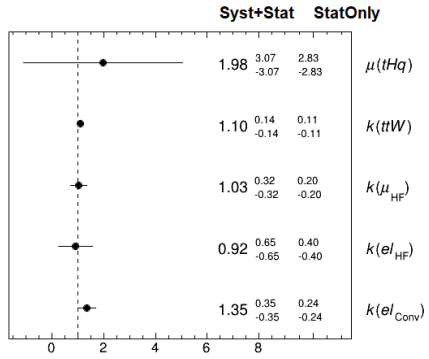
Current Role:

- Post Doctoral Researcher, IHEP Beijing
  ATLAS Experiment, CERN

PhD Research Work

Search for Higgs production associated with single top quark

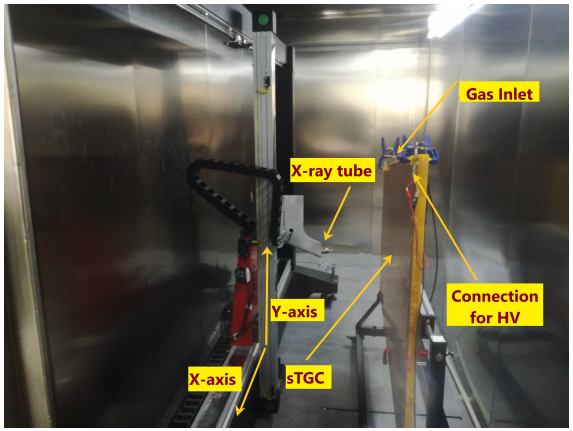
- First direct search of tHq performed in ATLAS using full Run-II data
- tHq vertex is sensitive to the magnitude and the sign of Higgs-top Yukawa coupling (y_t)
- For standard model–like Yukawa coupling ($y_t = 1$) there's no significant signal
- The biggest contribution to the μ(tHq) is given by the data statistical uncertainty
- The observed (expected) limit at 95% confidence level is found to be 8.3 (6.8) times the SM prediction
- **Contributions:** Main analyzer 2LSS channel, Single region optimization, Fake lepton background estimation, Charge-flip background estimation, Fit studies
- DIS2023: Measurements of the Higgs boson coupling properties to fermions with the ATLAS detector

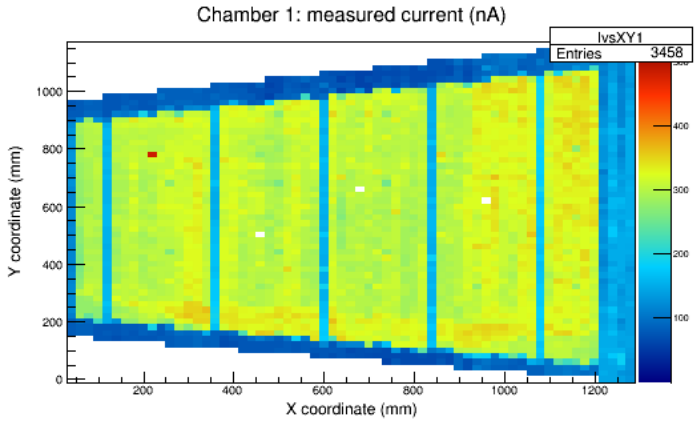


-2σ	-1σ	Upper Limit	+1σ	+2σ
3.62	4.86	**6.75**	9.68	13.71

ATLAS qualification task: New Small Wheel Upgrade Project: sTGC detector test with X-rays

- sTGC designed to provide fast trigger and high precision muon tracking under the high luminosity in Run-3 and HL-LHC
- Strict quality control procedures employed during chamber production: A technique based on the X-ray scanner with direct measurement of the chamber current
- The New Small Wheel Upgrade is installed in ATLAS and efficiently taking data for Run3

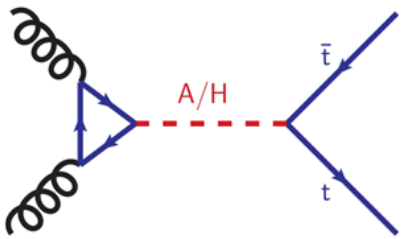


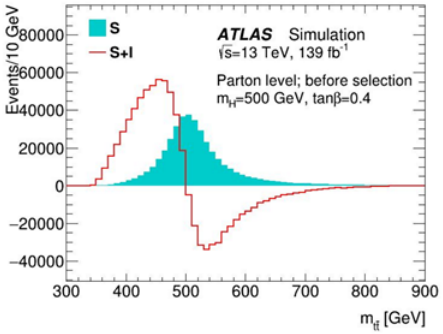


Work Achievement

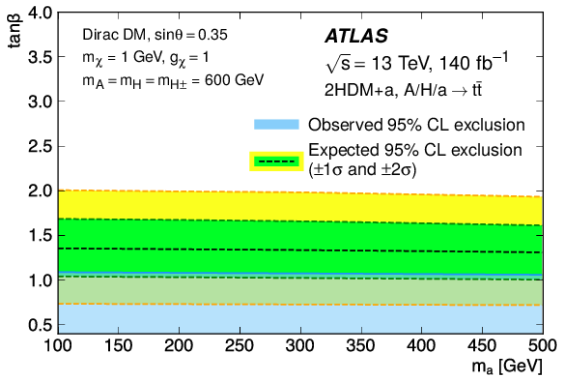
Search for a heavy nutral Higgs boson A/H decaying to a top quark-antiquark pair

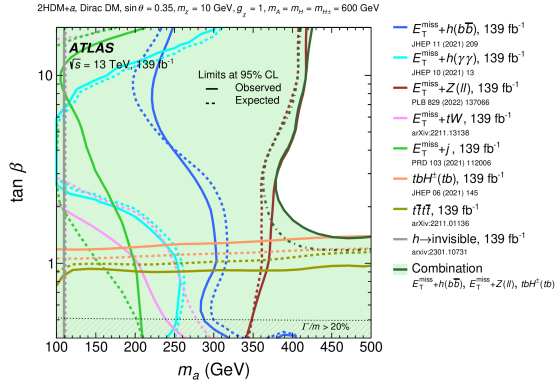
- Strong interference between signal process and irreducible background from SM ttbar production
- Interference pattern strongly dependent on signal parameters (model dependence!)
- Sensitive in general to (pseudo-)scalar predicted in BSM models
- Especially sensitive to low tanβ and high m_{ϕ} region for type-II 2HDMs





Contribution:
Developed and set exclusion limits for heavy neutral Higgs bosons within the framework of the Two-Higgs-Doublet Model with an additional pseudoscalar (2HDM+a).





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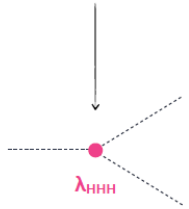
Current and Ongoing Research Work

Seeing double Higgs bosons at ATLAS

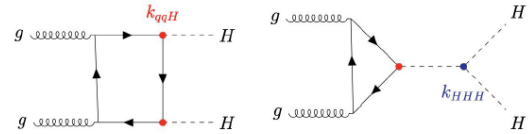
- SM Higgs mechanism demands a Higgs self-coupling
- Shape of the potential is closely related to the electroweak symmetry breaking
- Higgs self-coupling can be used to constrain the shape of the potential
- Expected to be directly accessible at the LHC through HH production

$$V(h) \simeq \frac{1}{2}m_H^2 h^2 + \lambda v h^3 + \frac{1}{4}\lambda h^4 + \dots$$

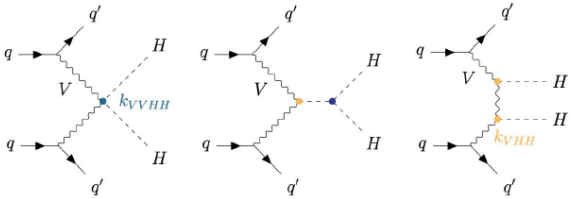


Directly measure λ_{HHH} via HH production
Strength of λ_{HHH} relative to SM prediction
$(\lambda_{HHH}/\lambda_{SM}) = \kappa_\lambda$

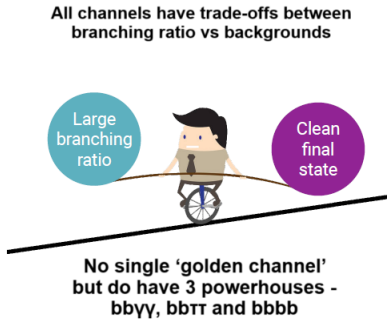
Non-resonant σ_{HH}^{ggF} = 30.77 fb at 13 TeV and 34.13 fb at 13.6 TeV for m_H = 125.00 GeV



Non-resonant σ_{HH}^{VBF} = 1.687 fb at 13 TeV and 1.874 fb at 13.6 TeV for m_H = 125.00 GeV



	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%

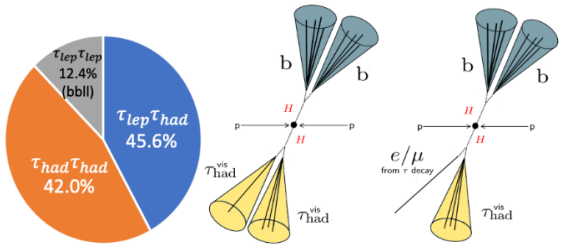


1- Search for the non-resonant production of Higgs boson pairs in the bb$\tau\tau$ final state (Run 2+3)
2- Search for non-resonant di-Higgs in the 4b final state (Run 2+3)

Current and Ongoing Research Work

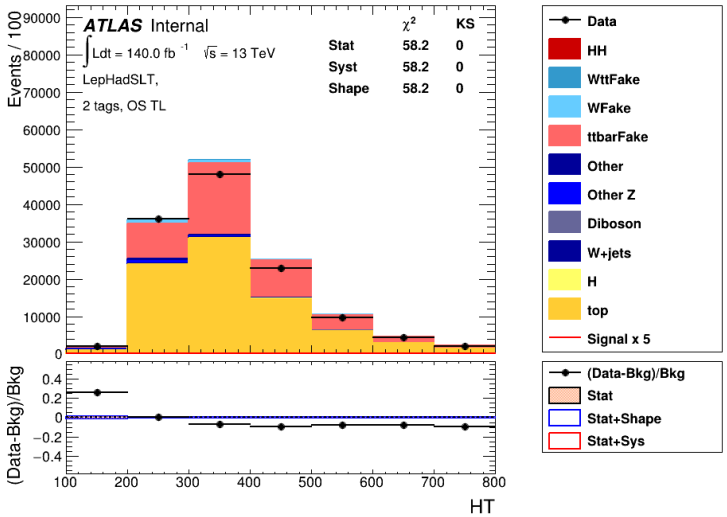
Search for the non-resonant production of Higgs boson pairs in the bb$\tau\tau$ final state (Run 2+3):

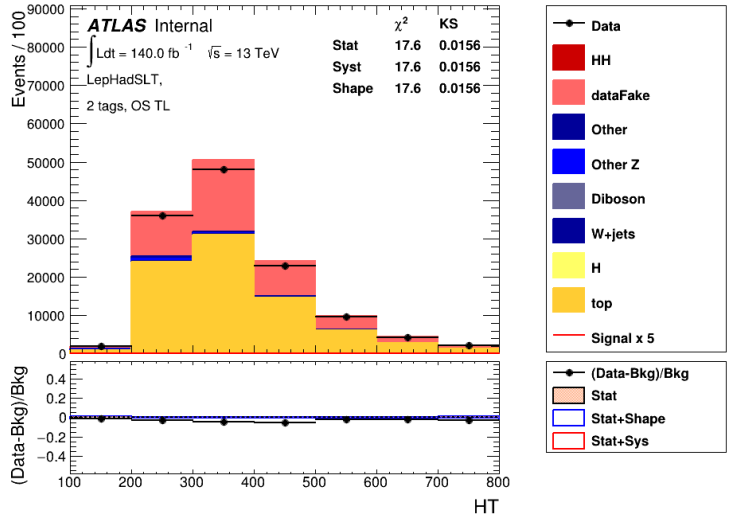
- Two b-jets + opposite-sign pair, Two main channels are HadHad and LepHad
- Combination of large branching fraction and clean signal
- Driving sensitivity on μ_{HH}



Contributing:

- Significantly contributed to EasyJet and HHARD Framework development.
- Performed fake-τ_{had} background estimation in LepHad channel.
- Applied an inclusive fake-factor method to estimate all fake-τ_{had} backgrounds from $t\bar{t}$ and multi-jet processes.

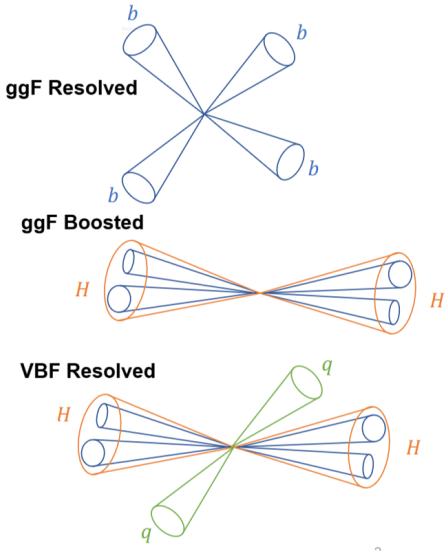




Current and Ongoing Research Work

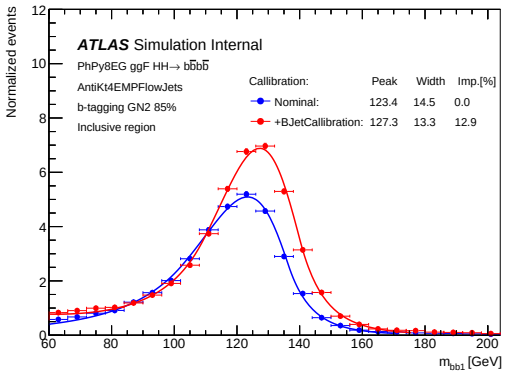
Search for non-resonant di-Higgs in the 4b final state (Run 2+3)

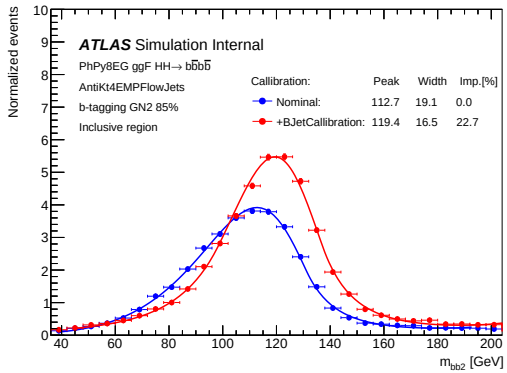
- The richest final state in HH production
- Considering ggF and VBF production modes: ggF resolved/boosted, VBF boosted
- Compared with previous Run-2 analysis
- Expect significant improvement from GN2 and GN2X
- Boosted ggF topology can help constrain HH signal strength

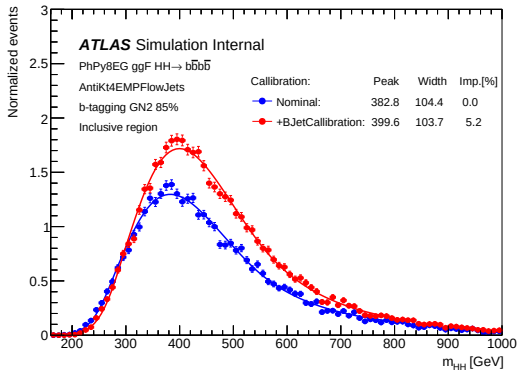


Contribution:

- b-jet energy correction.
- Applied a two-step approach to correct the b-jet energy:
- μ-in-jet correction targets the semi-leptonic decays of b-hadrons in reconstructed jets.
- p_T reco correction adjusts b-jets to account for out-of-cone and neutrino effects.







First contribution to the internal note documentation

Detector Upgrade

High-Granularity Timing Detector (HGTD)

- Will be installed in the ATLAS detector to mitigate pile-up effects during the High-Luminosity (HL) phase of the LHC
- Providing precision time measurements in the forward region.

HGTD test beam

- The design of the HGTD is based on the use of Low Gain Avalanche Detectors(LGADs)
- Performances of LGAD sensors from different vendors, and irradiated with high fluences have been measured in beam test campaigns
- Participated in test beam campaigns at SPS CERN and DESY
- Performed detailed test beam data analysis for charge collection, hit efficiency and time resolution of LGADs

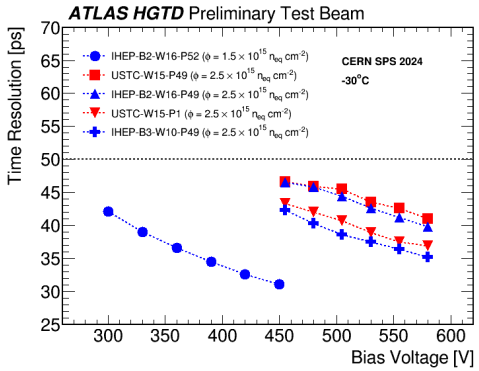
=> **CLHCP-2024:** ATLAS High Granularity Timing Detector: Test beam performance of LGAD sensors

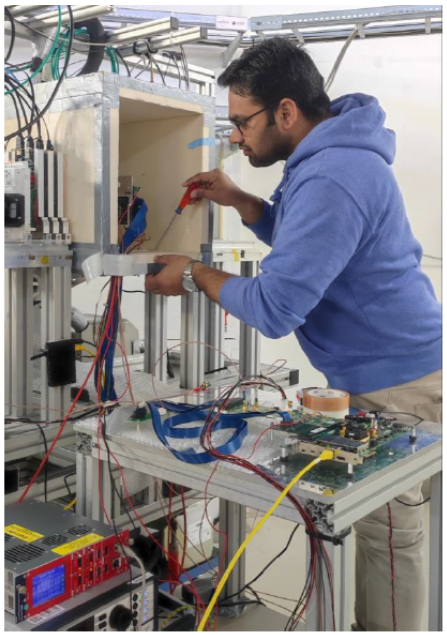
=> **Higgs Hunting 2024:** Nominated by ATLAS upgrade speakers committee for plenary talk ATLAS Phase 2 upgrade

=> **Pan for publication of HGTD pre-production LGAD sensors test during 2023-24 test beam:** Paper editor: Khuram Tariq and Giulia Di Gregorio

=> **Plan is to keep contributing as HGTD test beam expert and data analyzer**

ATL-COM-HGTD-2024-032





Changing the board during test beam @DESY

Detector Operation

Detector operation: ATLAS Run3 Data taking

- Started contribution as ID shifter in ATLAS Control room.
- I have contributed to ATLAS operations for Run 3 data taking as:
  - **Inner Detector (ID)** shifter, 29(2023) + 27(2024) shifts equivalent to 23.0 + 26.5 operational task points (OTPs).
  - **Pixel Run Manager (PRM)**, 2 weeks equivalent to 14.00 OTPs

Plan is to keep contributing as Pixel Run Manager => ITk Pixel DAQ/DCS Coordinator.

	Institute	Sum [Shifts]
1	Beijing IHEP	57.7
2	Siegen	37.2
3	Copenhagen	27.5
4	Wuppertal	27.15
5	Sheffield	24
	Marseille CPPM	19.3
	Göttingen	19.2
	Oregon	19.2
	Genova	19.15
	Nanjing	18.6

Pixel General Meeting

Conclusion and Vision

- HH is fundamental to our understanding the Higgs boson and electroweak symmetry breaking.
- The current focus is to build a strong foundation for future Run 3 and HL-LHC searches
- Advancing smoothly:
  - Improved CP tools, increased statistics and improved analysis techniques are expected to significantly enhance results:
  - E.g. 30 - 40% expected improved limits on HH$\rightarrow$bbtt and HH$\rightarrow$bbbb
  - Continuous improvements may lead to the first hints of evidence in Run 3!
- Supporting Run 3 data collection through active involvement in detector operations.
- Continue contributing to commissioning next-generation detectors like HGTD
- Alignment with the host institution's research goals.

Excited to see what the future holds in store for Run 3 and at the HL-LHC!

Thank You!