

FJPPL (TYL) application 2024

Fiscal year April 1st 2024 – March 31th 2025

ID¹:	Title: A path toward the discovery of the Higgs-pair production in ATLAS (ATLAS HH)					
PIs: Members:	French Group			Japanese Group		
	name (Family name, First name)	title	lab.²	name (Family name, First name)	title	lab.³²
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	Nicolas Berger	Research Director	LAPP Annecy	Masubuchi, Tatsuya	Associate Professor	Osaka University
	Zhibo Wu	Post-doc	LAPP Annecy	(in hiring process)	Post-doc	KEK
	Djamel Boumediene	Research Director	LPCA Clermont	Vaslin, Louis	Post-doc	KEK
	Louis D'Eramo	Research Physicist	LPCA Clermont	Wickremasinghe, Lakmin	PhD	Osaka University
	Arthur Lafarge	PhD	LPCA Clermont			
Funding Request from France						
Description	€/unit	nb of units	total (€)	requested to⁴		
Visit to KEK	150/day	20 days (2 trips of 10 days)	3000	IN2P3		
Travel to Japan	1000	2 trips	2000	IN2P3		
Total			5000			
Funding Request from Japan						
Description	k¥/Unit	nb of units	total (k¥)	requested to⁵³		
Visit to LAPP	20/day	2 per. x 5 days/per.	200	KEK		
Travel to France	250	2 travels	500	KEK		
Total			700			
Additional Funding from France			Additional Funding from Japan			
provided by/requested to⁶⁴	Type	€	provided by/requested to⁷⁴	Type	k¥	
Total			Total			

¹ ID: If program continuation, use previous ID; if new project, ID will be set by the TYL directors;

² e.g. LAPP/IN2P3, Irfu/CEA, IPNS/KEK, etc.

³ IN2P3, Irfu or KEK

⁴ e.g. French Embassy, other CNRS or CEA programs, PICS, European grants, JSPS, RIKEN, Universities;

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Summary Of 2024 Project

The production of Higgs boson pairs (HH) at the Large Hadron Collider (LHC) provides a unique probe for measuring the strength of the Higgs self-interaction and constraining the shape of the Higgs potential, which are the nature of electroweak (EW) symmetry breaking in particle physics. This quantitative understanding reveals a multitude of fundamental phenomena, ranging from the nature of the EW phase transition in the early universe to the (meta-)stability of the EW vacuum.

Experimentally, HH production is a rare process in the Standard Model and has been originally considered as one of the primary physics targets in the scheduled High-Luminosity period of LHC (HL-LHC) in 2030's. On the other hand, our recent search efforts for the latest publications [1-4] using 140 fb^{-1} of proton-proton collisions at $\sqrt{s}=13 \text{ TeV}$ in the LHC Run 2 period have significantly improved the sensitivity to the HH production. **The search for HH production presently receives a lot of attention, and further search adding more collisions data in the Run 3 period (2022-2025) may bring us very close to the SM HH production in next four years.** The small HH cross-section means multiple final states must be used in order to gain statistics, and individual analyses should be much more harmonized since the initial design phase, considering complex statistical combinations with $O(10^4)$ nuisance parameters.

The aim of this project is to build up a new France-Japan collaboration toward the HH discovery and the measurement of the Higgs self-coupling, through a series of coherent ATLAS analyses with $bb\gamma\gamma$ and $bb\tau\tau$ final states with 400 fb^{-1} data in Run 2 and Run 3. The milestones are as follows:

- 2024: ramp-up and consolidate individual analyses; prepare harmonized analysis framework, study trigger usage, and, establish reconstructions of boosted or soft objects using novel machine learning;
- 2025: establish the methodology to measure the self-coupling constant, and make public results with a partial dataset;
- 2026: conclude the publications of individual analyses with the full dataset;
- 2027: combine the results of the ATLAS $bb\gamma\gamma$ and $bb\tau\tau$ analyses with the $bbbb$ one, and initiate the combination with corresponding results in CMS, to conclude on the Higgs self-coupling constraint at LHC Run 3.

Impacts by the project are not only on producing at least five publications on the search results with partial/full dataset, but also on establishing the methodology. This project benefits from the work of LAPP and LPCA on the $bb\gamma\gamma$ final state and combination, KEK on the $bb\tau\tau$ final state, and Osaka University on heavy-flavour-jet reconstruction and identification. The members of this small collaboration have been leading the Higgs physics program in the ATLAS experiment. Especially, Marco and Tatsuya had been the co-convenors of the ATLAS Higgs working group in 2020-2022 and 2021-2023, respectively; Tatsuya is currently the convenor of the LHC Higgs physics working group; Yu is locally leading the Higgs physics working group in the ATLAS Japan group; Louis has served as the Analysis Contact for the $HH \rightarrow b\bar{b}\gamma\gamma$ Run 2 legacy non-resonant analysis and is now coordinating the Higgs framework effort to develop a common analysis framework; and Djamel contributed to the Run 2 diHiggs multi-lepton analysis, and is currently the Analysis Contact for the $t\bar{t}HH$ analysis. Each group has complementary expertise in every important aspect of HH searches, including trigger strategy; reconstruction and identification of photons, heavy-flavor jets and tau leptons; Machine-Learning applications; and statistics treatments. As preparatory in-person interactions, Tatsuya and Nicolas organized the ATLAS Higgs workshop at Tokyo in 2023 autumn, where Yu presented the HH search strategy and Marco overviewed the role of Higgs physics in the wider particle physics landscape.

A support from FJPPL (TYL) in 2024 is critical for timely ramp-up of two harmonized analyses with EM and Hadronic final states, discussing together in-person to settle analysis details. Marco and Louis will visit KEK to work with Yu, Tatsuya and several early-career colleagues in Japan, and Tatsuya and Yu will visit LAPP and LPCA to work with Marco, Nicolas, Djamel, Louis and other experts.

References:

- [1] JHEP 01 (2024) 066 (HH- $\rightarrow b\bar{b}\gamma\gamma$)
- [2] ATLAS-CONF-2023-071 (HH- $\rightarrow b\bar{b}\tau\tau$)
- [3] Phys. Rev. D 108 (2023) 052003 (HH- $\rightarrow b\bar{b}b\bar{b}$)
- [4] Phys. Lett. B 843 (2023) 137745 (HH non-resonance search combination)

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Satellite meeting at annual workshop	
Articles, conference talks & posters related to the TYL project	
Jointly Supervised Students	
Comment related to IRL TYL & ILANCE	