[FJPPN-HEP_17] A path toward the discovery of the Higgs-pair production in ATLAS (ATLAS HH)

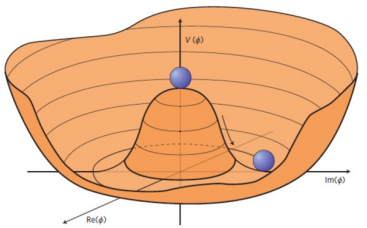
Japan: Yu Nakahama (KEK), Tatsuya Masubuchi (Osaka)
France: Marco Delmastro, Nicolas Berger (LAPP), Djamel Boumediene, Louis D'Eramo (LPC)

2024 Joint Workshop of FKPPN and TYL/FJPPN
at the KISTI, Daejeon, Korea, on 22-24 May 2024

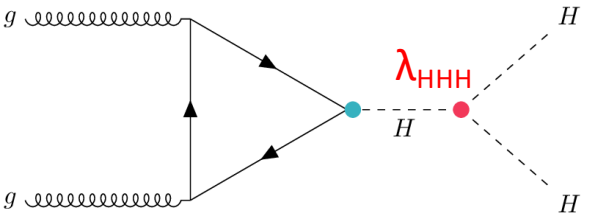
I wish I was there.

Scientific motivation

- In the Standard Model (SM), the Higgs boson self-coupling strength is related to the quartic term “shape” in the energy potential of the Higgs field, which is responsible for electroweak (EW) symmetry breaking.
  - 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.



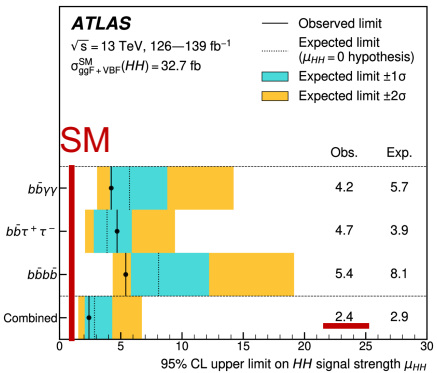
- The self coupling can be studied experimentally through the production of Higgs boson pairs (HH).



Time-wise motivation

- Experimentally, HH production is a rare process in the SM 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 TeV in Run 2 have significantly improved the sensitivity to the HH production.
  - Upper limit of SM HH signal strength $\mu_{HH(SM)}$<2.4 at 95% confidence level



Ref. [4]

References [1] JHEP 01 (2024) 066 (HH->bbγγ), [2] arXiv:2404.12660, submitted to Phys. Rev. D (HH->bbττ), [3] Phys. Rev. D 108 (2023) 052003 (HH->bbbb), [4] Phys. Lett. B 843 (2023) 137745 (HH non-resonance search combination)

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  - Upper limit of SM HH signal strength $\mu_{HH(SM)}$<2.4 at 95% confidence level
- HH search in Run 3 presently receives a lot of attention.
  - Further search adding more collisions data in Run 3 (2022-2025) might bring us very close to the SM HH production in next four years.

→ It is a time to establish a path toward the discovery with milestone results.

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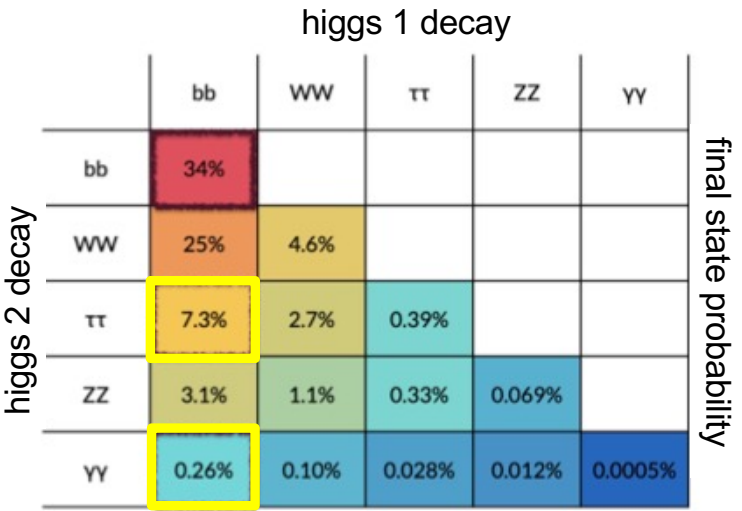
The aim of the project

- The small HH cross-section means that 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 bbγγ and bbττ final states using 400 fb^{-1} data in Run 2 and 3.



Research milestones in a path towards discovery

- JFY 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
- JFY 2025
  - establish the methodology to measure self-coupling, and make public results with a partial dataset
- JFY 2026
  - conclude the publications of individual analyses with the full dataset
- JFY 2027
  - combine the results of the ATLAS bbγγ and bbττ analyses with the bbbb one, and
  - initiate the combination with corresponding results in CMS, to conclude on the HH search and Higgs self-coupling constraint at LHC Run 3.

TYL HEP_17 project

- Partners
  - including 3 first PDs and 3 PhD students
  - good for joint training.

France	Japan
Marco Delmastro (LAPP, PI)	**Yu Nakahama (KEK, PI)**
Nicolas Berger (LAPP)	Tatsuya Masubuchi (Osaka)
Zhibo Wu (LAPP, PD)	Louis Vaslin (KEK, PD)
Djamel Boumediene (LPC)	Newly recruited (KEK, PD)
Louis D'Eramo (LPC)	Lakmin Wickremasinghe (Osaka, PhD st.)
Arthur Lafarge (LPC, PhD st.)	Newly recruited (Osaka, PhD st.)

- Program in JFY2024
  - Current work on HH→ bbyy and combination (LAPP, LPC) and HH→bbtautau (KEK, Osaka).
  - Coherent developments for timely ramp-up of two harmonized analyses with EM and Hadronic final states, discussing together in-person to settle analysis details with complementary expertise.
    - analysis framework (LPC), trigger strategy, tau reconstruction (KEK), photon reconstruction, statistics treatments (LAPP), and heavy-flavour-jet tagging (Osaka).
  - A few Zoom meetings, and two face-to-face meetings and student/PD stays in partner group.
- Request of TYL support: 2 travels/stays to KEK & 2 travels/stays to LAPP & LPC.

Three preparatory in-person interactions

(1) In TYL HEP_12 project on “Combined search for new heavy resonances in ATLAS”, several KEK and LAPP & LPC researchers research exchanges in 2022-2023.

- The initial idea of this project came across during one of informal meetings at KEK.

(2) Actual personnel exchange happened in 2023. Louis Vaslin (a PhD student at LPC in TYL HEP_12) became KEK PD, contributing to this project from the Japan team.

(3) Tatsuya and Nicolas successfully organized the ATLAS Higgs workshop at Tokyo in 2023 Oct, where Yu presented HH search strategy and Marco overviewed the role of Higgs physics in the wider particle physics landscape.

- Confirmed common interests with complementary approaches
- A few times of remote discussions for proposal details and R&D studies

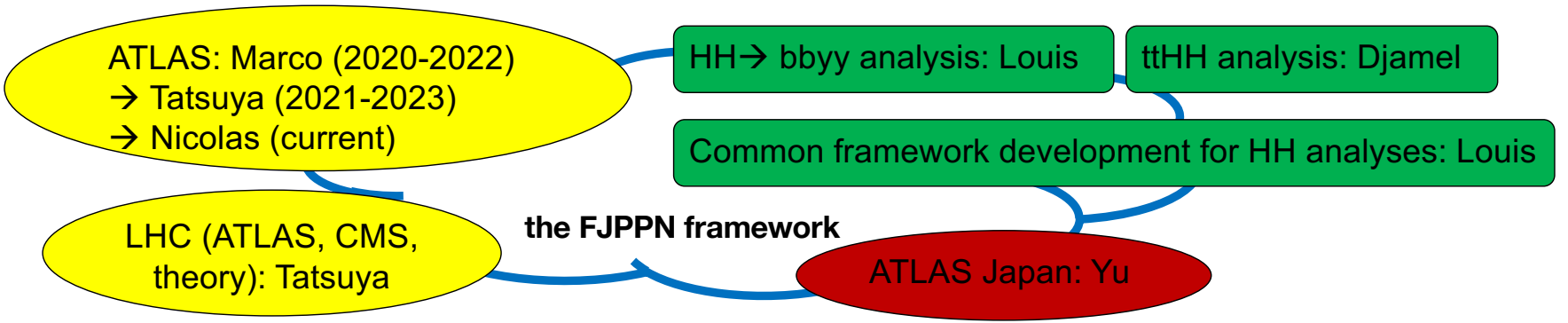

186 people in Higgs workshop

Marco’s Higgs talk in the wider particle physics landscape

Expected impact of the FJPPN framework

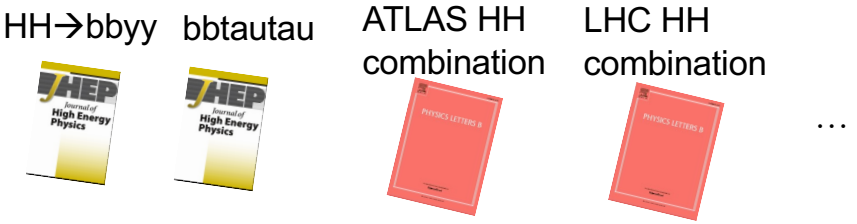
- Impacts by the project are not only on producing at least four publications on the search results with partial/full dataset, but also on establishing the methodology.

- All the six staff members of this small collaboration have been leading the Higgs physics program in the energy-frontier ATLAS experiment.
  - e.g. Marco and Tatsuya had been the co-convenors of the ATLAS Higgs working group in recent few years, followed by Nicolas currently.



Expected outcomes

- Four journal papers and maybe more if we publish with a partial dataset



- Three PhDs to be received.
  Three first PDs to be jointly trained.

→Main players in the current analysis period. We believe this is important for the HEP community's future as well.

- The first collaboration on HH studies in the FJPPN framework, which should be getting critical for coming several years.
  Our results are already getting close to SM.

Thank you for your attention

- Backup slides

Funding request

Funding Request from France				
Description	**€/unit**	**nb of units**	**total (€)**	**requested to[4]**
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 to[53]**
Visit to LAPP	20/day	20 days (2 trips of 10 days)	400	KEK
Travel to France	250	2 travels	500	KEK
Total			900	