THW-BSM

The Top quark and the Higgs boson as Windows on Beyond the Standard Model physics

Benjamin Fuks

LPTHE / Sorbonne Université

14th Joint workshop of the FJPPN and FKPPN International Laboratories

14-16 May 2025, Nantes

A large and mixed teams of French and Korean fellows

French node – 2 institutes – CNRS and universities – staff and non-staff

- Staff members: G. Cacciapaglia, B. Fuks, M. Goodsell, H.S. Shao
- Students and postdocs: D. Agin (PhD), A. Chrysostomou (PD), M. Guicheneuy (PhD)

- Staff members: A. Deandrea, L. Darme
- Students: T. Alezraa (PhD), W. Isnard (PhD), A. Ncube (PhD)

Korean node – 3 institutes – KIAS and universities – staff and non-staff

- Staff members: S.J. Lee
- Postdocs: D.W. Kang (PD)

- Student: D. Kim (PhD)

- Staff members: S.C Park
- Students: T.-G. Kim (PhD), Y. Park (PhD), D.Y. Cheong (PhD), S.-C. Hyun (PhD)

Broad expertise in theoretical physics, beyond the Standard Model, collider physics, QCD calculations, machine learning methods, LHC physics, *etc.*

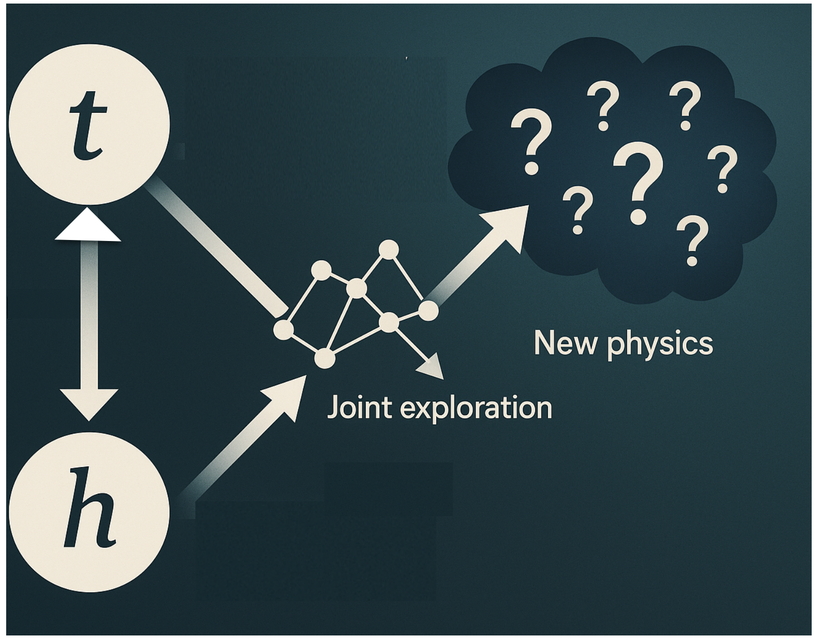
Scientific objectives of THW-BSM

Focus on drawbacks of the Standard Model

- The top quark portal to new physics
  - ➙ Large mass ≡ unique sensitivity to new phenomena
- The Higgs portal to new physics
  - ➙ Central to the electroweak symmetry breaking mechanism

Joint exploration of the top and Higgs sectors

- Better determination of the landscape of possible new physics setups
- Cutting-edge phenomenological methods including machine learning
- Connection with the experiment: proposing new searches and refine existing ones
- Final goal: maximisation of the discovery potential of the LHC Run 3



Work plans

General work plans

- Machine learning methods
  - ➙ Combining independent studies from the two nodes in the context of $t\bar{t}H$ production
- Precision predictions for BSM-induced top production
  - ➙ Combining the pheno/model building expertise of the two nodes with precision calculation techniques
  - ➙ Contribution to understanding the recent discovery by CMS of exotic effects in top-antitop production
- Effective approach to top physics
  - ➙ Deviations to the top-Higgs coupling with four-top probes
  - ➙ Connection with composite setups
- Compositeness as a tool to understanding inflation
  - ➙ Formal aspects to better corner composite models at the heart of our pheno studies

Activities in 2024 ; 2025 plans

Status report for 2024

- Continuous work on two research projects
  - ➙ New physics modelling via form-factors and four-top probes (LPTHE + KIAS + KoreaU)
  - ➙ Cosmology: composite inflation (IP2I + LPTHE + YonseiU)
- Organisation of a joint workshop (link)
  - ➙ Funding from a STAR grant (B. Fuks / S.J. Lee)
  - ➙ Four talks from French participants; dozens talks from Korean participants
  - ➙ Connection with researchers from China, Taiwan and Hong-Kong
  - ➙ Rich scientific exchanges, start of new projects

Plans for 2025

- Continuous work on the two existing research projects
  - ➙ Two papers planned!
- New project: constraints on composite models in light of the toponium discovery (LPTHE/KIAS)
  - ➙ Involvement of an M1 student from Paris and three new participants from KIAS
- Trip to Korea in light of the top 2025 conference (link)
  - ➙ Funding from a STAR grant (B. Fuks / S.J. Lee)
  - ➙ Trips for new French participants to our project (ATLAS experimentalists from LPNHE ⊕ CEA)
  - ➙ Two-day mini-workshop @ KIAS prior to the conference

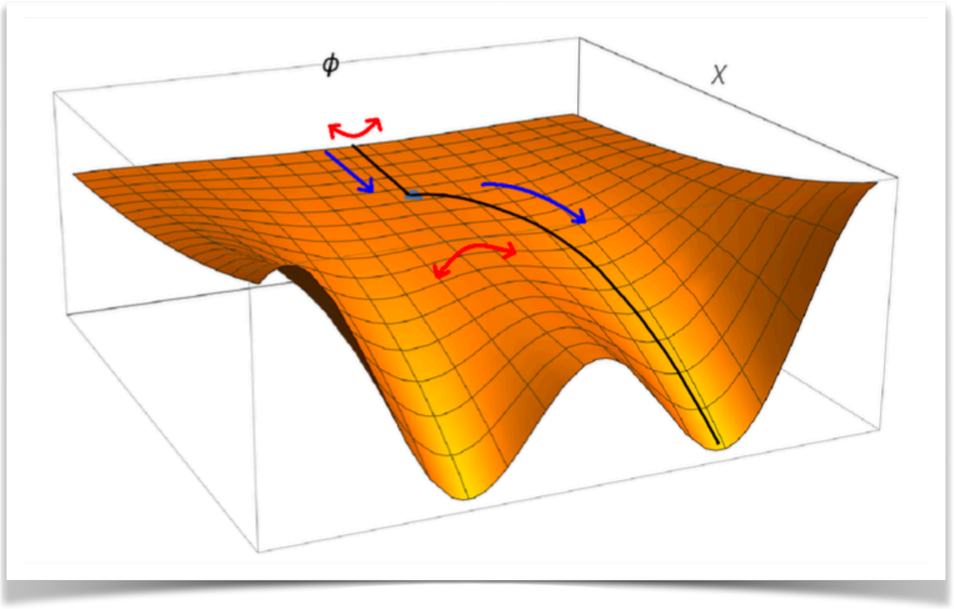
Samples of our results
1. Composite inflation

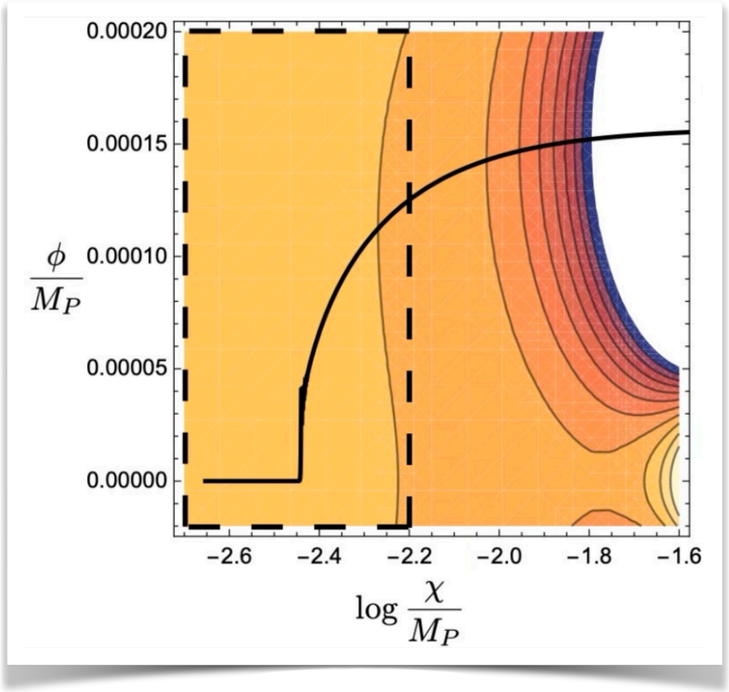
Composite inflation (LPTHE/IP2I/YonseiU)

[Cacciapaglia, Cheong, Deandrea, Isnard & Park (JCAP`23 + in preparation)]

Key idea: can inflation be driven by a composite particle (pNGB)?

- Fundamental gauge theory with fermions
  - ➙ confinement at low scales
  - ➙ Spontaneous breaking of chiral and scale symmetry
  - ➙ Existence of pions and a dilaton ≡ tools to model inflation
- Hybrid inflation mechanism
  - ➙ Inflation driven by the dilaton
  - ➙ Pions ≡ waterfall fields ↔ end of inflation through a tachyonic instability





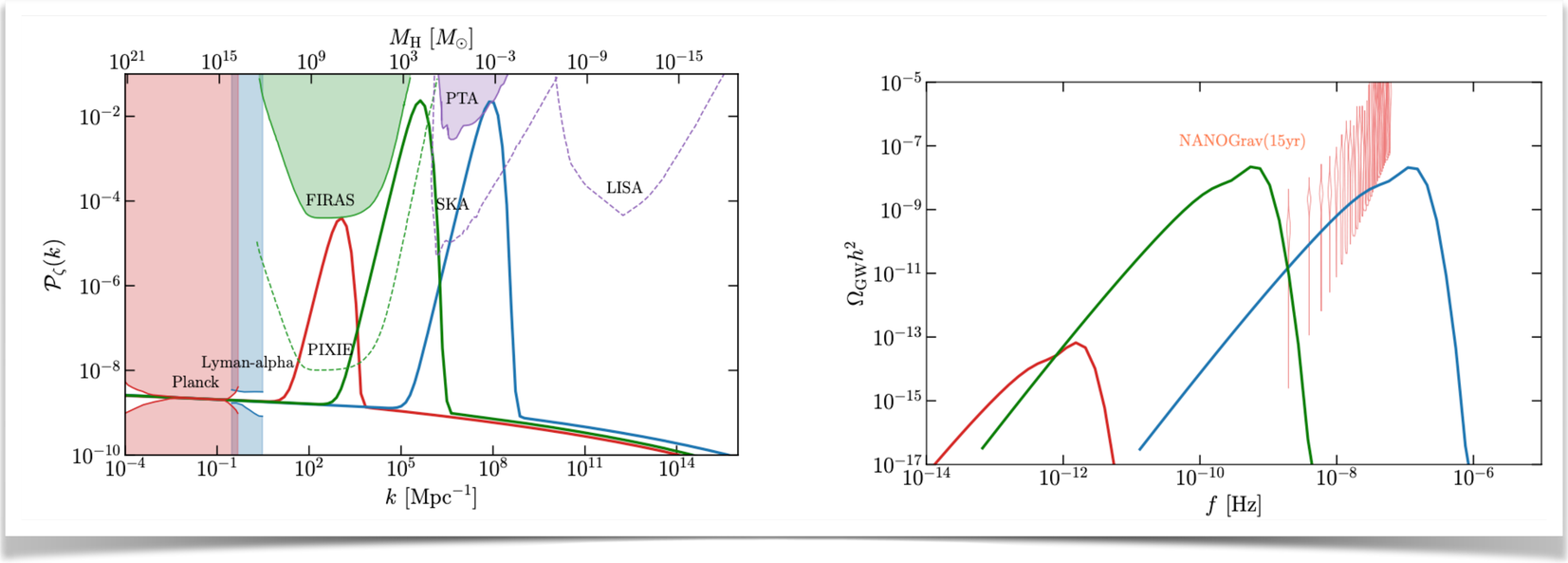
$$V(\phi,\chi) = -\lambda_\chi \delta_1 f_\chi^4 \left(\frac{\chi}{f_\chi}\right)^{3-\gamma_m} \cos\frac{\phi}{f_\phi} - \lambda_\chi \delta_2 f_\chi^4 \left(\frac{\chi}{f_\chi}\right)^{2(3-\gamma_{4f})} \sin^2\frac{\phi}{f_\phi} + \frac{\lambda_\chi}{4}\chi^4\left(\log\frac{\chi}{f_\chi} - A\right) + V_0\,.$$

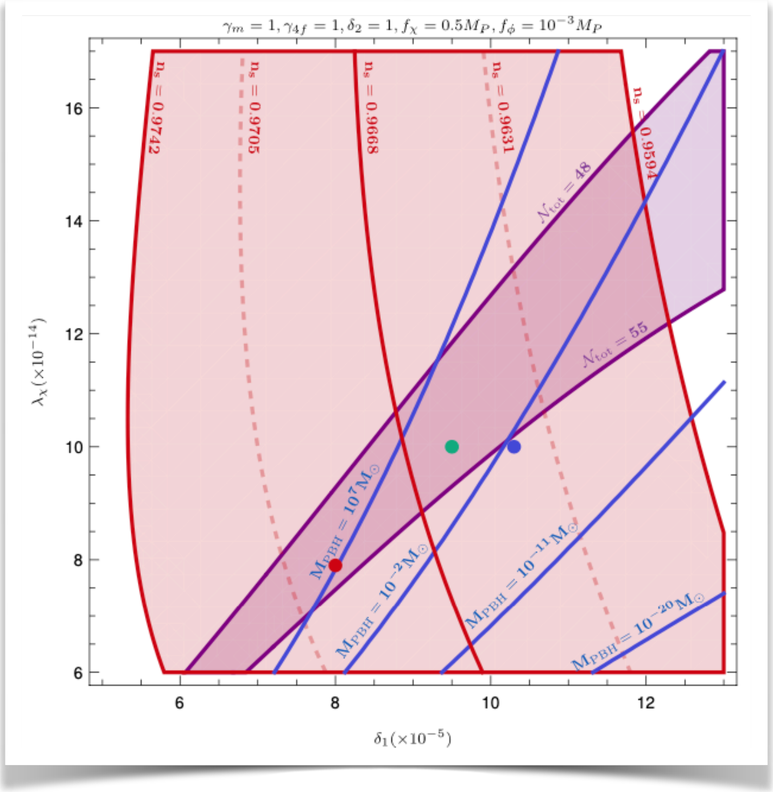
Composite inflation (LPTHE/IP2I/YonseiU)

[Cacciapaglia, Cheong, Deandrea, Isnard & Park (JCAP`23 + in preparation)]

Imprints of composite inflation in data?

- Planck observations ➥ constraints on the potential parameter space
  - ➙ Spectral index $n_s = 0.9668 \pm 0.0037$
  - ➙ Number of e-folds $\mathcal{N} \in [48,55]$
- Production of primordial back holes and gravitational waves during inflation
  - ➙ tachyonic pions ➥ enhanced curvature perturbations





Samples of our results
2. Four-top probes of new physics

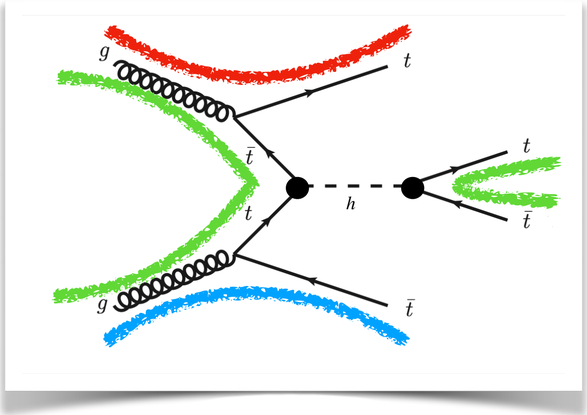
New physics through $t\bar{t}h$ form factors (LPTHE/KIAS/KoreaU)

[BF, Kang, Kim & Lee (in preparation)]

A $t\bar{t}h$ interaction with momentum-dependent form factors

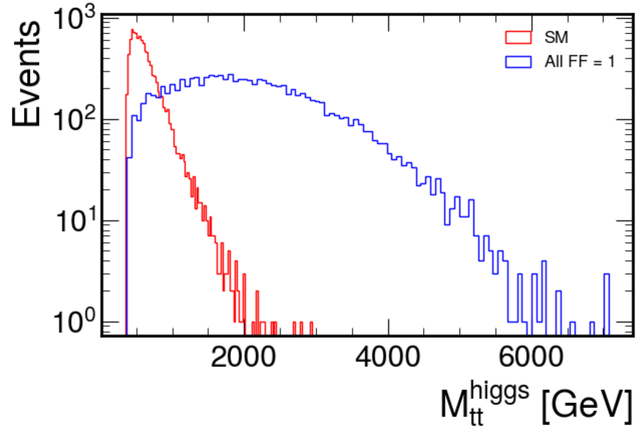
$$\mathscr{L}_{t\bar{t}h} = \bar{t}\Gamma t h \qquad \text{with} \qquad \Gamma = \left(1 + c_1\frac{p_1\cdot p_2}{\Lambda^2} + c_2\frac{p_h\cdot p_h}{\Lambda^2}\right) + \left(c_1'\frac{p_1\cdot p_2}{\Lambda^2} + c_2'\frac{p_h\cdot p_h}{\Lambda^2}\right)\gamma_5 + \Gamma_1\frac{v}{\Lambda^2}p_h^\mu\gamma_\mu + \Gamma_1'\frac{v}{\Lambda^2}p_h^\mu\gamma_\mu\gamma_5 + \frac{\Gamma_2}{\Lambda^2}p_1^\mu p_2^\nu\sigma_{\mu\nu}$$

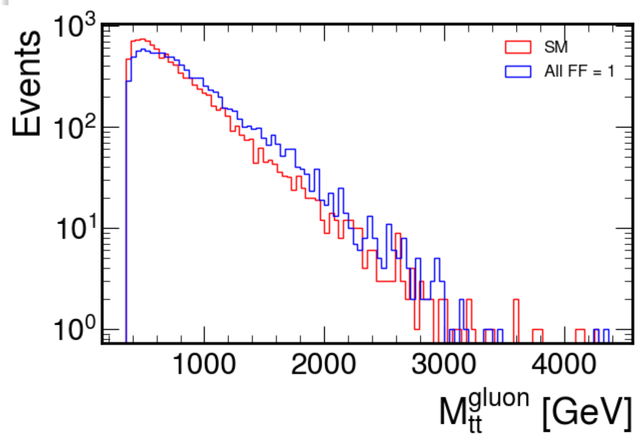
- Non trivial structure of the top-Higgs couplings encoded (as in composite models or loop-induced effects)
- Potential probe at current and future colliders



Four-top probes at the TeV scale (Λ = 1 TeV)

- 7-dimensional parameter space
- Two scenarios: SM (all $c_i, c_i' = 0$) and 'FF1' (all $c_i, c_i' = 1$)
- Deviations mostly driven by c_2, c_2'
  - ➙ $t\bar{t}$ pair related to the Higgs color connected and boosted
  - ➙ $t\bar{t}$ pair related to gluons are not color connected
  - ➙ Handles on new physics?



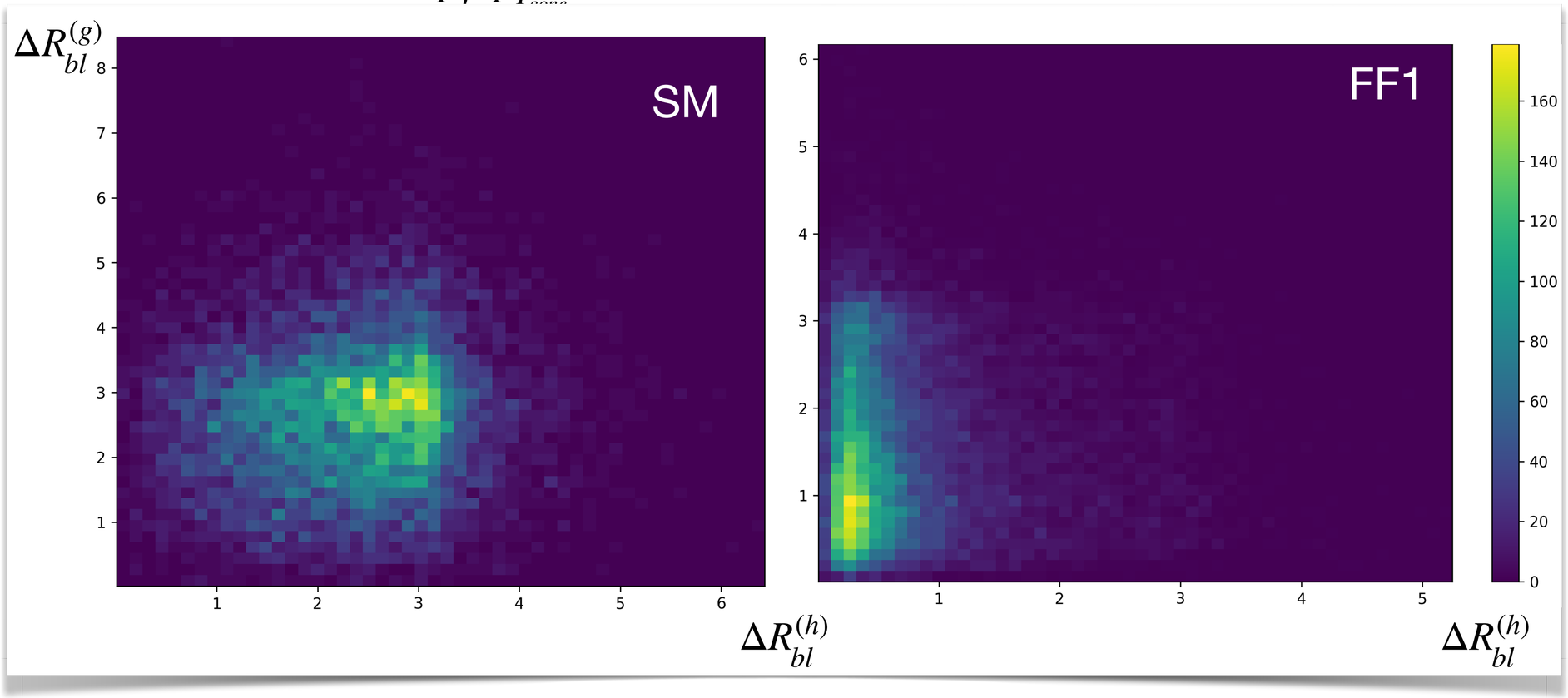


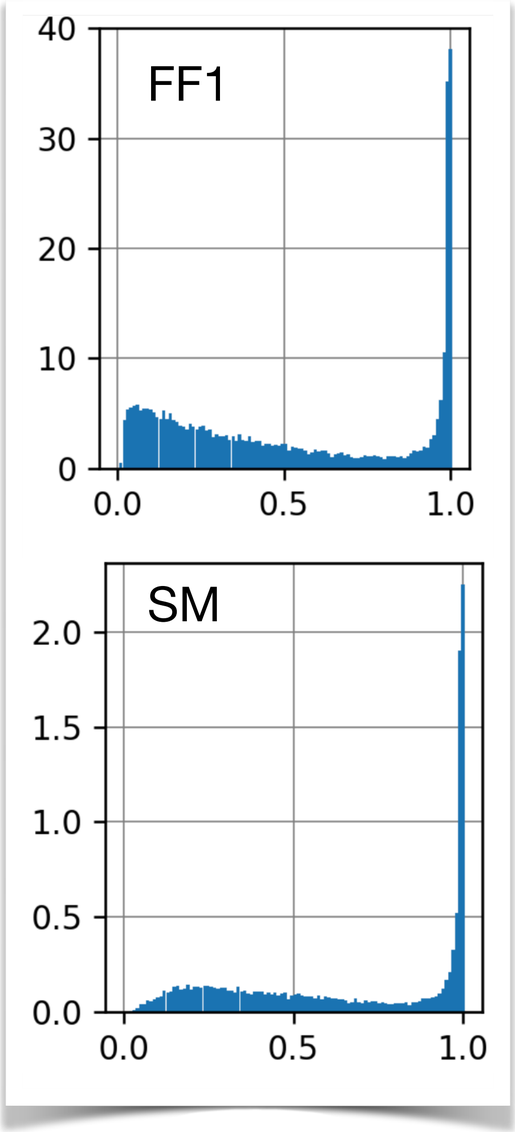
New physics through $t\bar{t}h$ form factors (LPTHE/KIAS/KoreaU)

Effects persist after decays

[BF, Kang, Kim & Lee (in preparation)]

- The $t\bar{t}$ pair originating from the Higgs more boosted with non-vanishing form factors
  ➙ top decay products more collimated
- $\Delta R_{bl}^{(h)}$ much smaller than $\Delta R_{bl}^{(g)}$ ≡ potential handle on new physics
- Presence of non-isolated leptons
  ➙ mini-iso variable $p_T^{\ell}/p_{T_{\rm cone}}$ useful





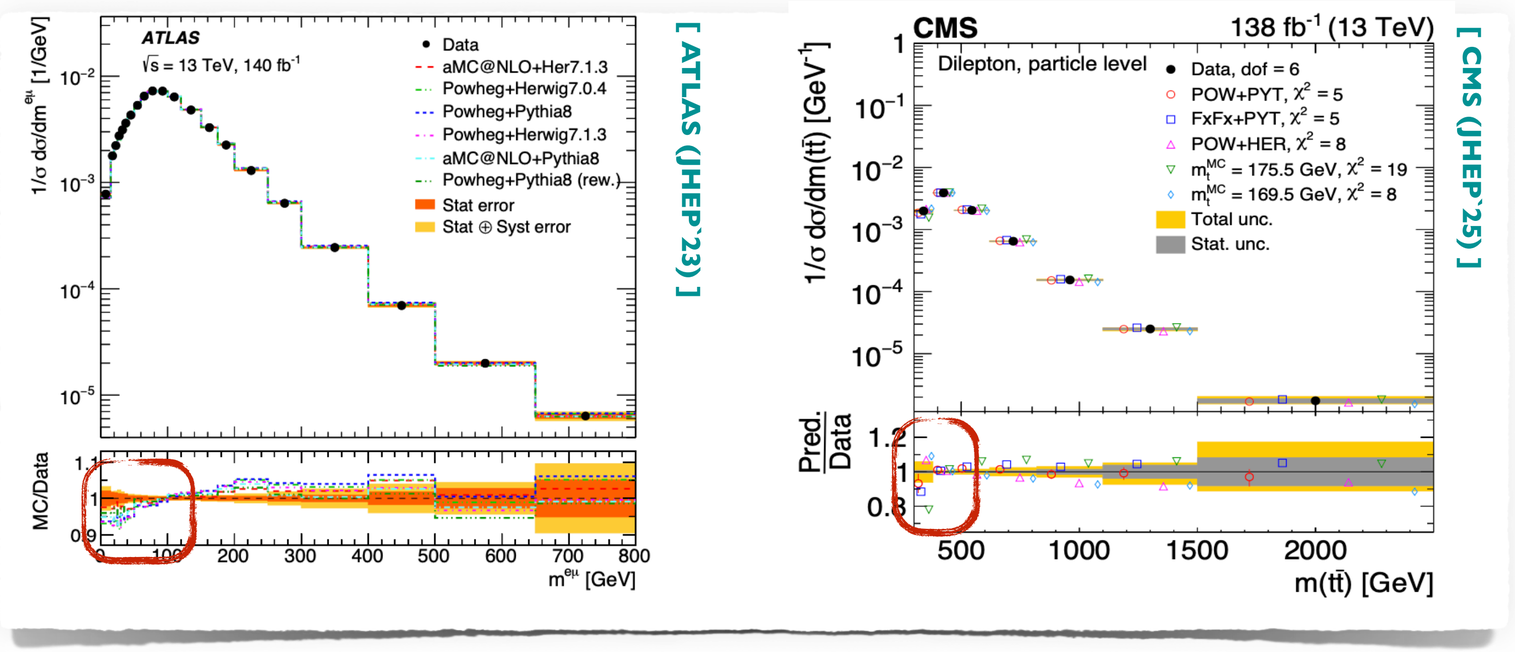
Samples of our results
3. New ideas in 2025

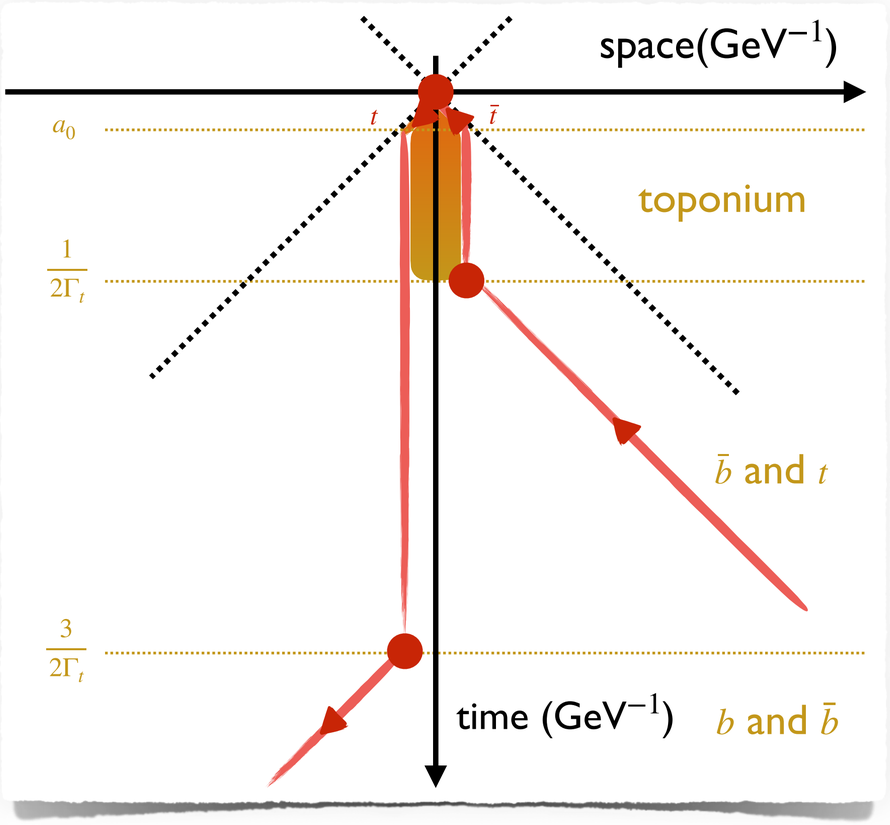
Top-philic BSM & the toponium discovery (LPTHE/KIAS)

[BF, Flacke, Kim, Kim, Lee & Munoz-Aillaud (in preparation)]

Copious top quark production at the LHC [$\sigma(13\,\text{TeV}) \sim 810$ pb]

- Precision measurements revealing anomalies close to the $t\bar{t}$ threshold
  - ➙ Bound state effects
  - ➙ Room for new physics?
- Impact of (pseudo-)scalar and fermionic composite resonances
- New project in 2025
  - ➙ Connection with ATLAS experimentalists from CEA and LPNHE (STAR-funded)





Making the best of the LHC!

- Exploitation of the full potential of the LHC (for BSM)
  - ➙ Designing new analyses ≡ probing new ideas
  - ➙ Recasting existing analyses ≡ viability of models
- Data preservation in beyond raw data
  - ➙ Analyses and their results ≡ the LHC legacy

Recasting developments

- Embedding new measurements and searches for LHC recasting
- Tackling machine-learning analyses
- Third MADANALYSIS 5 workshop in Korea in 2026
  - ➙ Recasting as an excuse for a vibrant school on BSM physics
  - ➙ Crucial for extending the database of recast analyses
- Well-cited proceedings

Proceedings of the second MadAnalysis 5 workshop on LHC recasting in Korea #1

Benjamin Fuks (Paris, LPTHE and IUF, Paris), Pyungwon Ko (Korea Inst. Advanced Study, Seoul), Seung J. Lee (Korea U.), Jack Y. Araz (Durham U., IPPP), Eric Conte (Strasbourg, IPHC and Haute Alsace U.) et al. (Jan 6, 2021)

Published in: *Mod.Phys.Lett.A* 36 (2021) 01, 2102001 • Contribution to: 2nd MadAnalysis 5 workshop on LHC recasting @ Korea • e-Print: 2101.02245 [hep-ph]

pdf DOI cite claim reference search 14 citations

Conclusions - 2025 in a nutshell

Physics explorations

- New physics modelling via form-factors and four-top probes (LPTHE/KIAS/KoreaU) ➙ one paper in preparation
- Composite inflation (IP2I/LPTHE/YonseiU) ➙ one paper published in 2023, another one in preparation
- Composite partners in light of the toponium discovery (LPTHE/KIAS)

Events

- Organisation of a joint workshop in 2024 ➙ funding from a STAR grant (B. Fuks / S.J. Lee)
- Participation to the Top 2025 International Conference ➙ funding from a STAR grant (B. Fuks / S.J. Lee)
- Preparation of the third MadAnalysis5 workshop in Korea (2026)