LHCb meets the LHC Higgs WG

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On behalf of the LHCb Collaboration

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LHCb experiment
A General Purpose *Forward* Detector

- LHCb, originally designed for b- and c-hadron physics, is now considered a **general purpose forward detector**

- Study **complementary region** w.r.t. ATLAS and CMS

- **Lower pile-up** (~1 in Run 2) means **cleaner events**

- **Excellent track momentum resolution**: 0.4% at 5 GeV and 0.6% at 100 GeV

- **Excellent vertex reconstruction helps in jets identification**: tagging of b- and c-jets with reconstruction of secondary vertices

- **Muon ID efficiency**: 97% with 1-3% μ → π mis-identification

- Electron reconstruction with bremsstrahlung recovery

$(2 < \eta < 5)$

Int. J. Mod: Phys. A 30, 1530022 (2015)
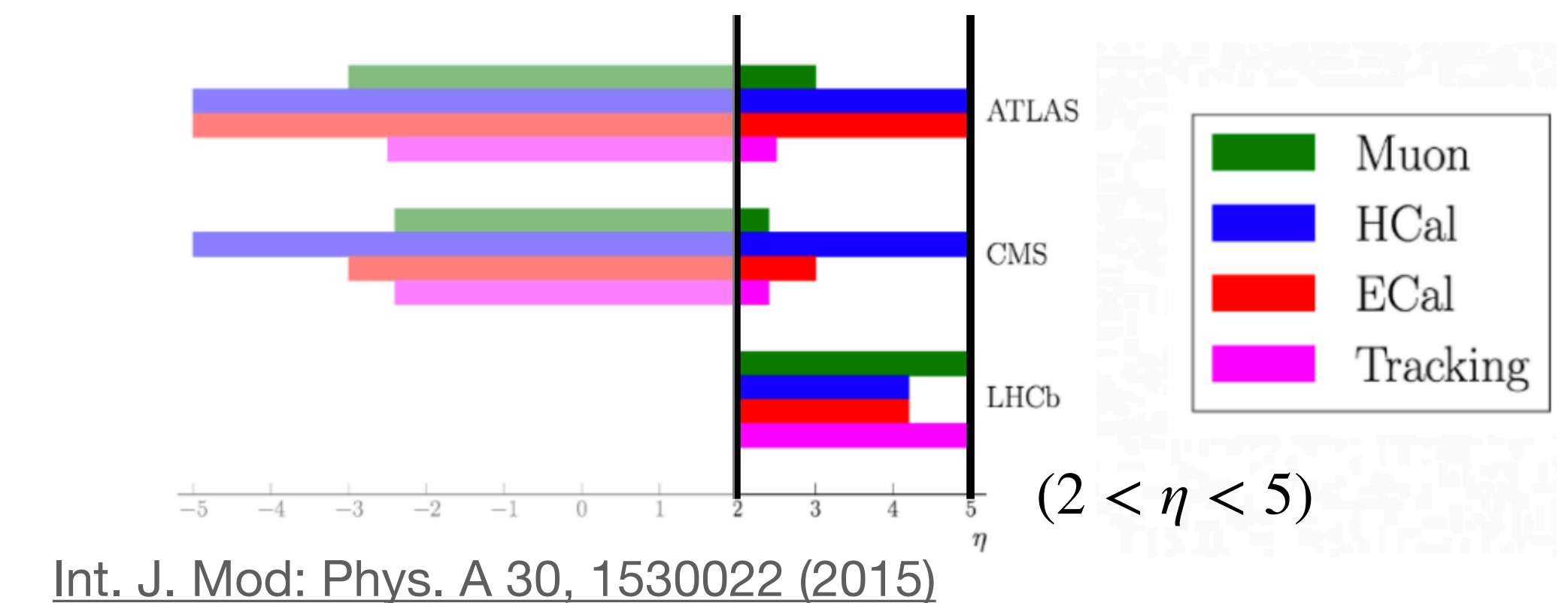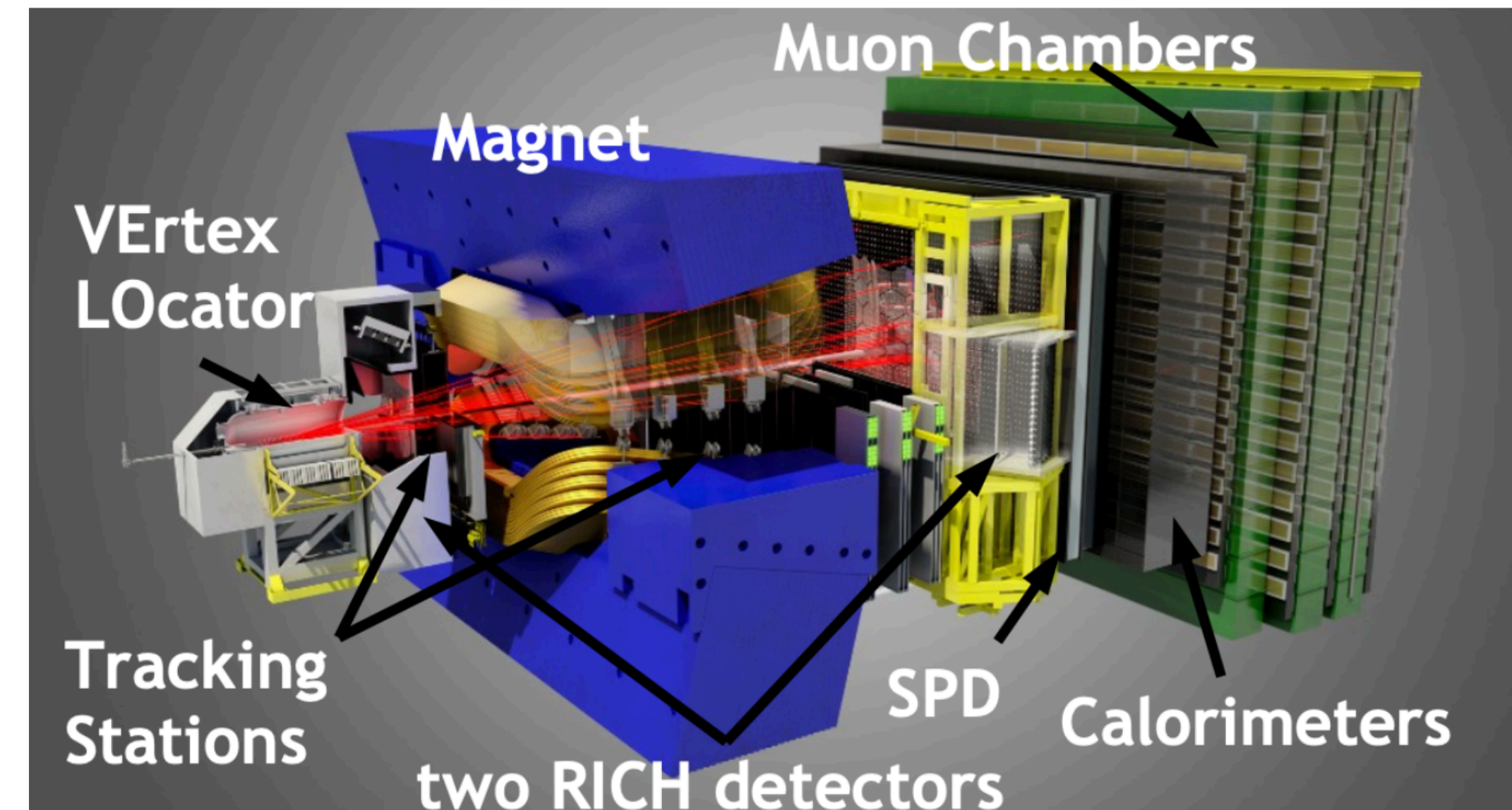
What has been studied so far?

Higgs physics @ LHCb
A good amount of studies so far
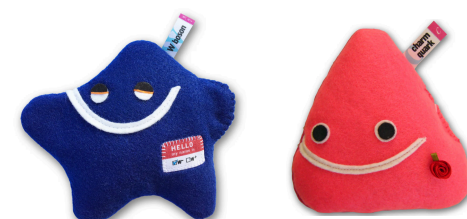
SM studies

- **ggF:**

  - Search for $H \to \tau\tau$

  - Inclusive search for $H \to b\bar{b}$ and $H \to c\bar{c}$ (in progress)

- **VH:**

  - Search for $H \to b\bar{b}$ and $H \to c\bar{c}$

BSM studies

- **Extended Higgs Sector:**

  - 2DHM into dimuons

- **NMSSM and MSSM:**

  - Higgs into neutralinos

  - NMSSM Higgs into dimuons

- **Exotic Higgs Decays:**

  - LFV Higgs-like bosons decays

  - Higgs into dark pions

$H \to b\bar{b}$ and $H \to c\bar{c}$

## VH and ggF

https://cds.cern.ch/record/2209531

- Leveraging **clean LHCb environment** to reconstruct **di-jets signatures**

- **Search for a** $b\bar{b}$ ($c\bar{c}$) **+ lepton signature** (both electron and muon), sensitive to WH and ZH signals

- **Efficiently tag jets** coming from b, c and light quarks

- Upper limits on Yukawa couplings: $y^b < 7y^b_{SM}$, $y^c < 80y^c_{SM}$

- Search for $H \to b\bar{b}$ and $H \to c\bar{c}$ in a **inclusive** final state:

  - **Directly triggering** on di-jets with an identified SV

  - **Model-independent approach** → no dependence on the Higgs production mechanism

- **Main improvements**: **Regression technique** for jet energy correction and **Deep Neural Network** for jet identification
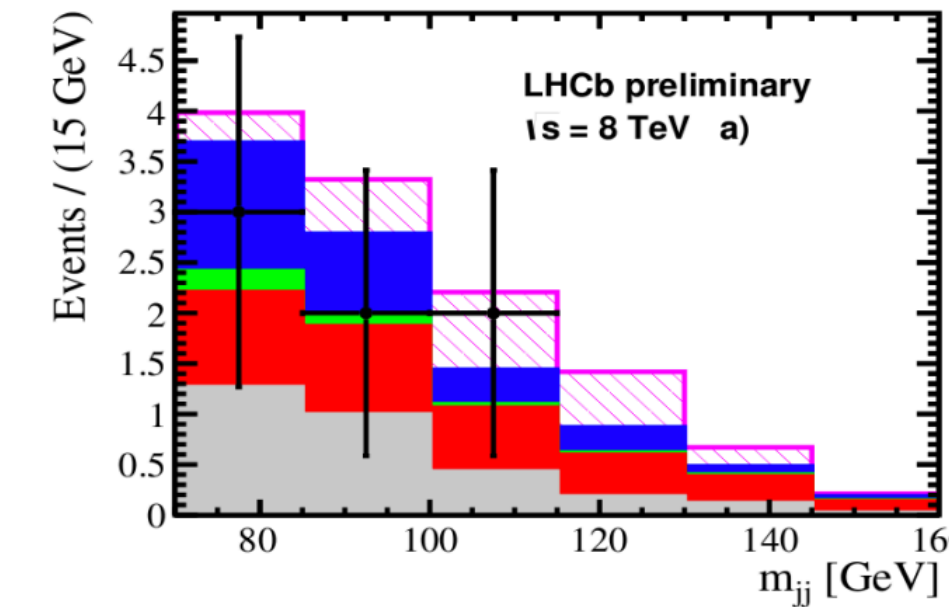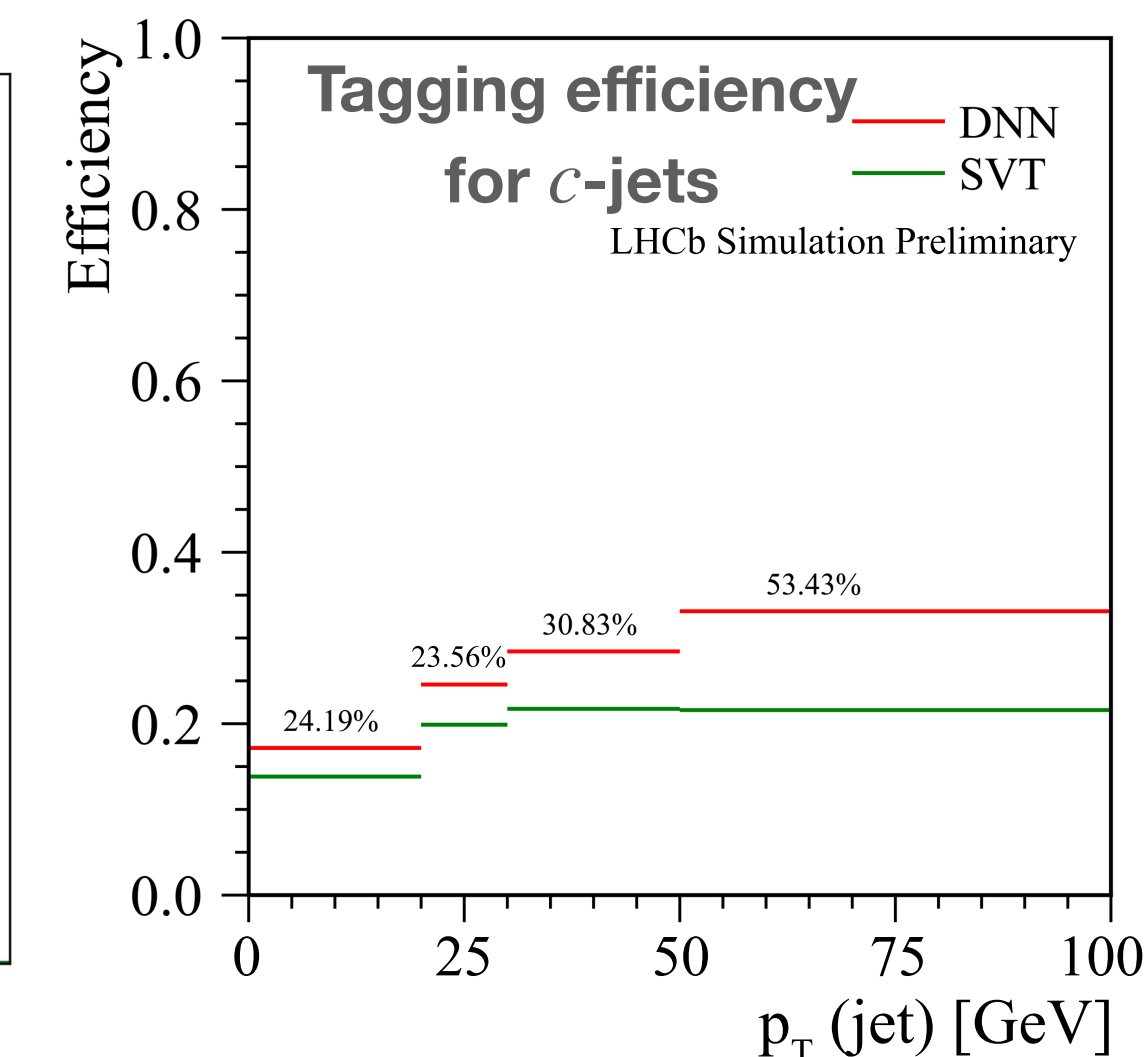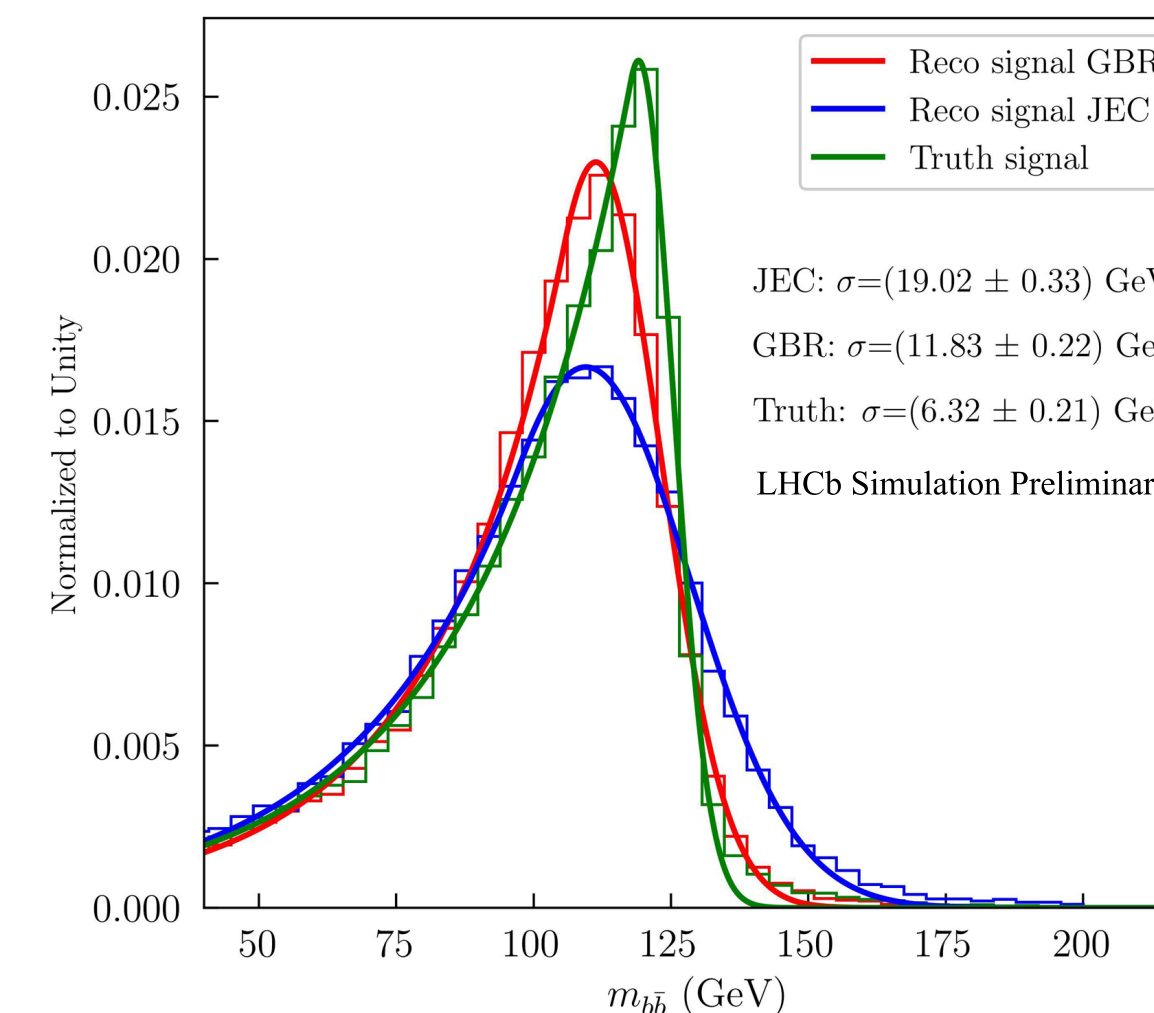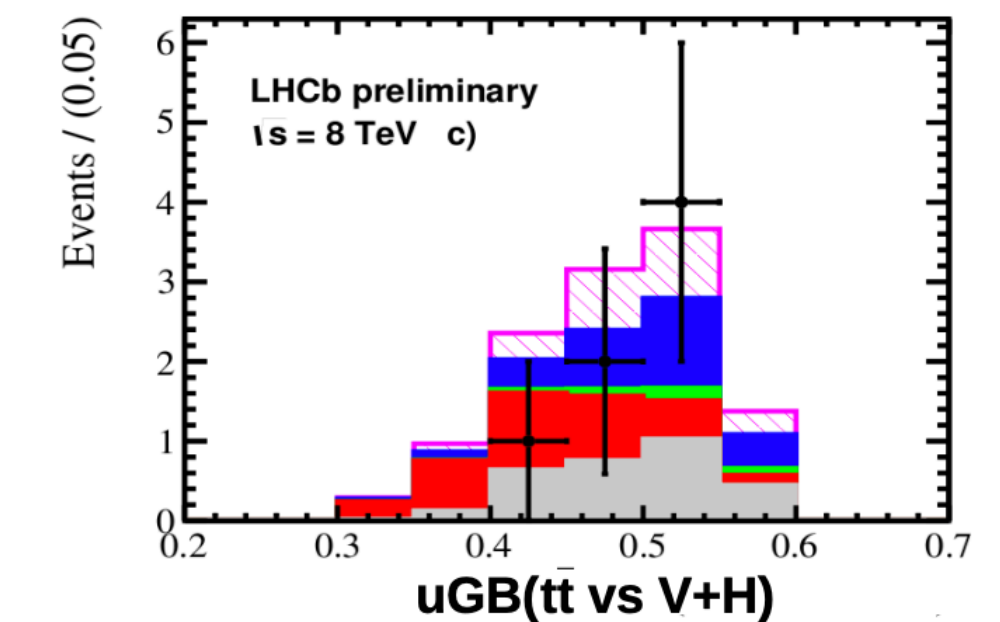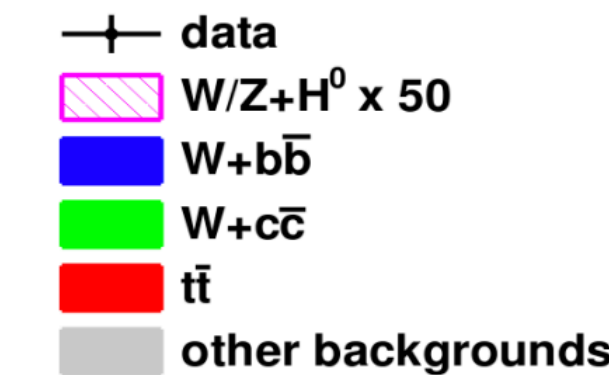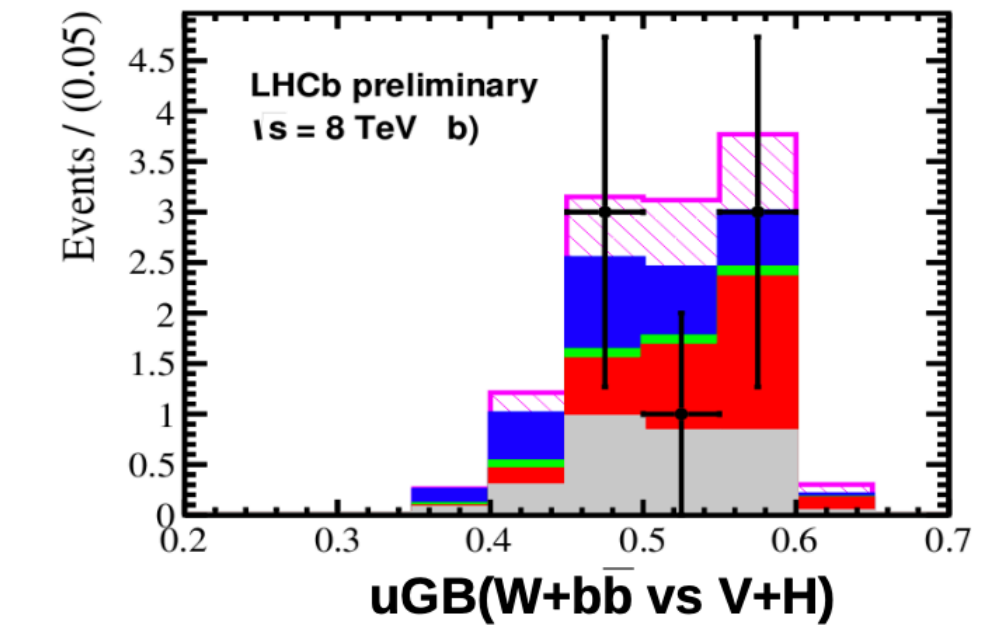
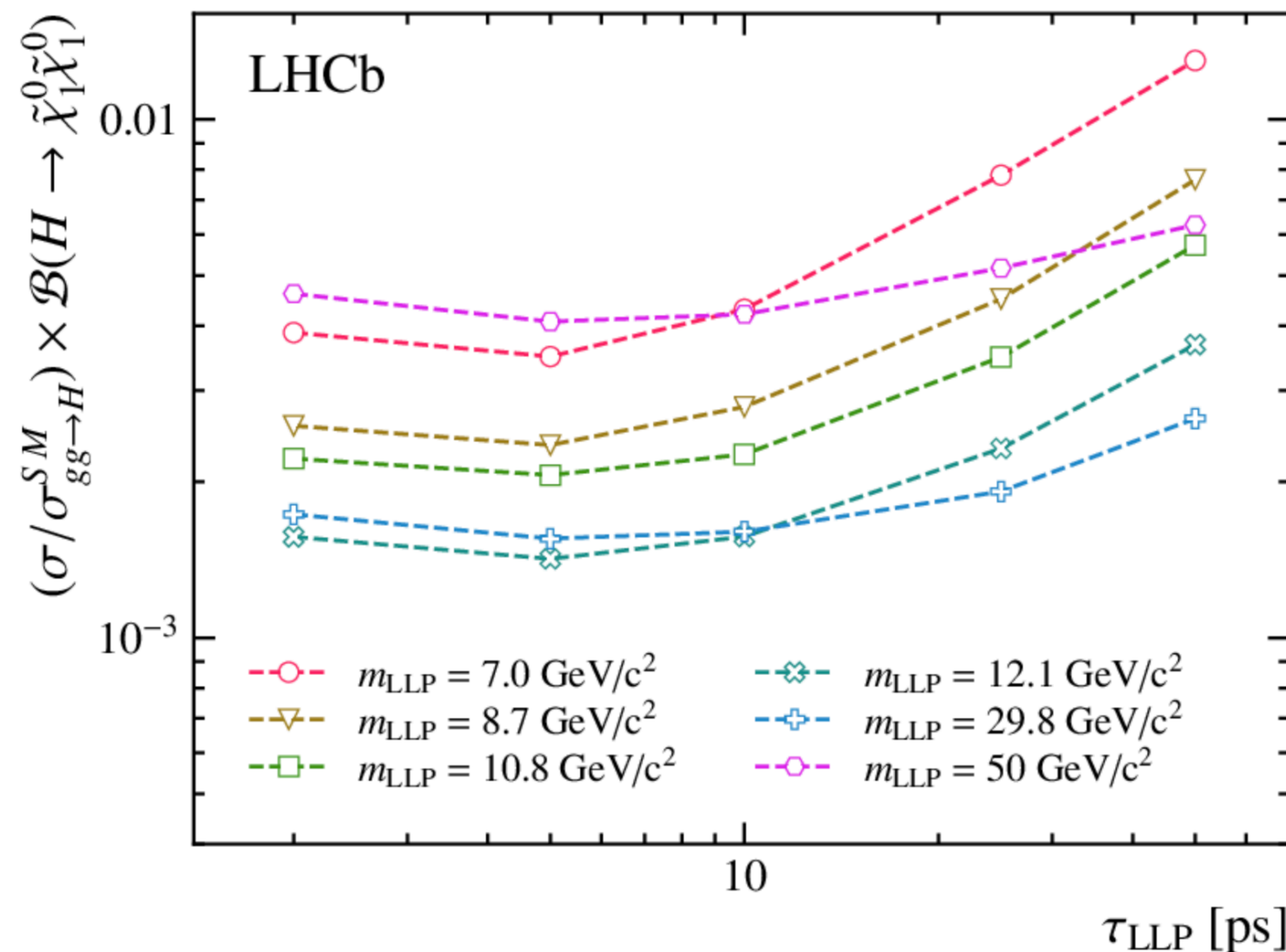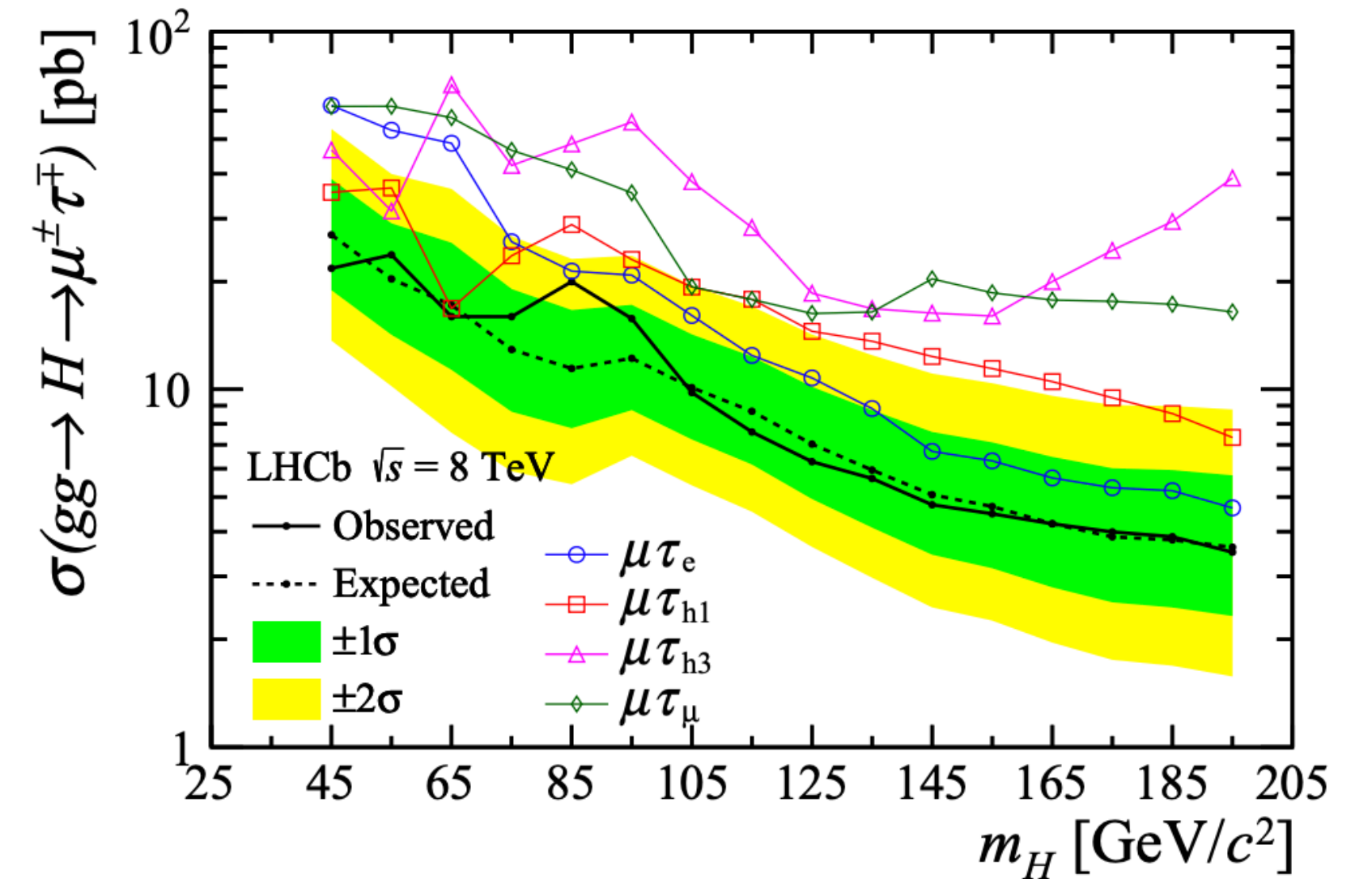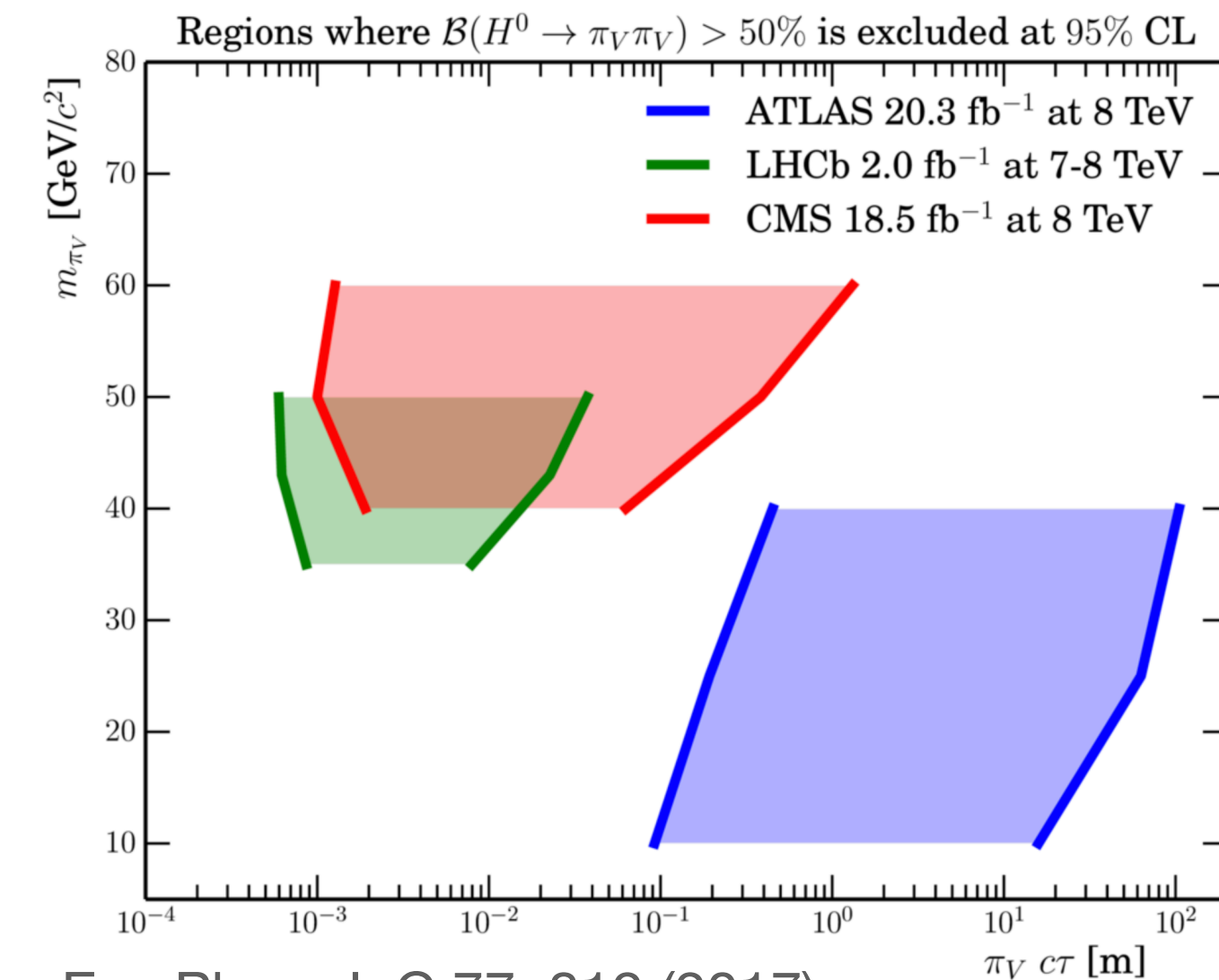# BSM searches
What can we do @ LHCb?

- Several searches targeting **different final states**

- Study the **lepton-flavour-violating decay** $H \to \mu^{\pm}\tau^{\mp}$

  - τ leptons reconstructed both in leptonic and hadronic channels

- Search for **LLPs decaying to** $e\mu\nu$

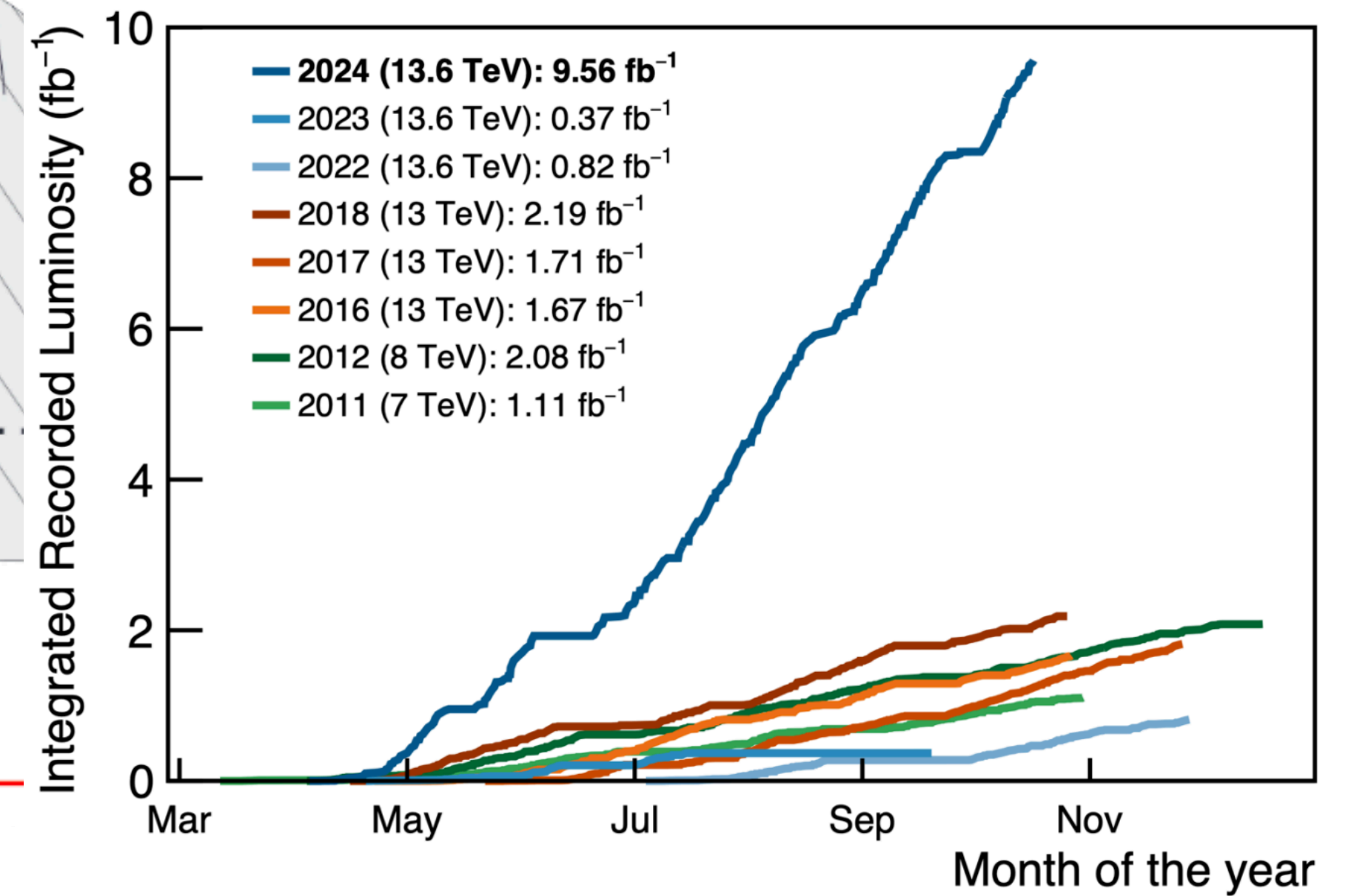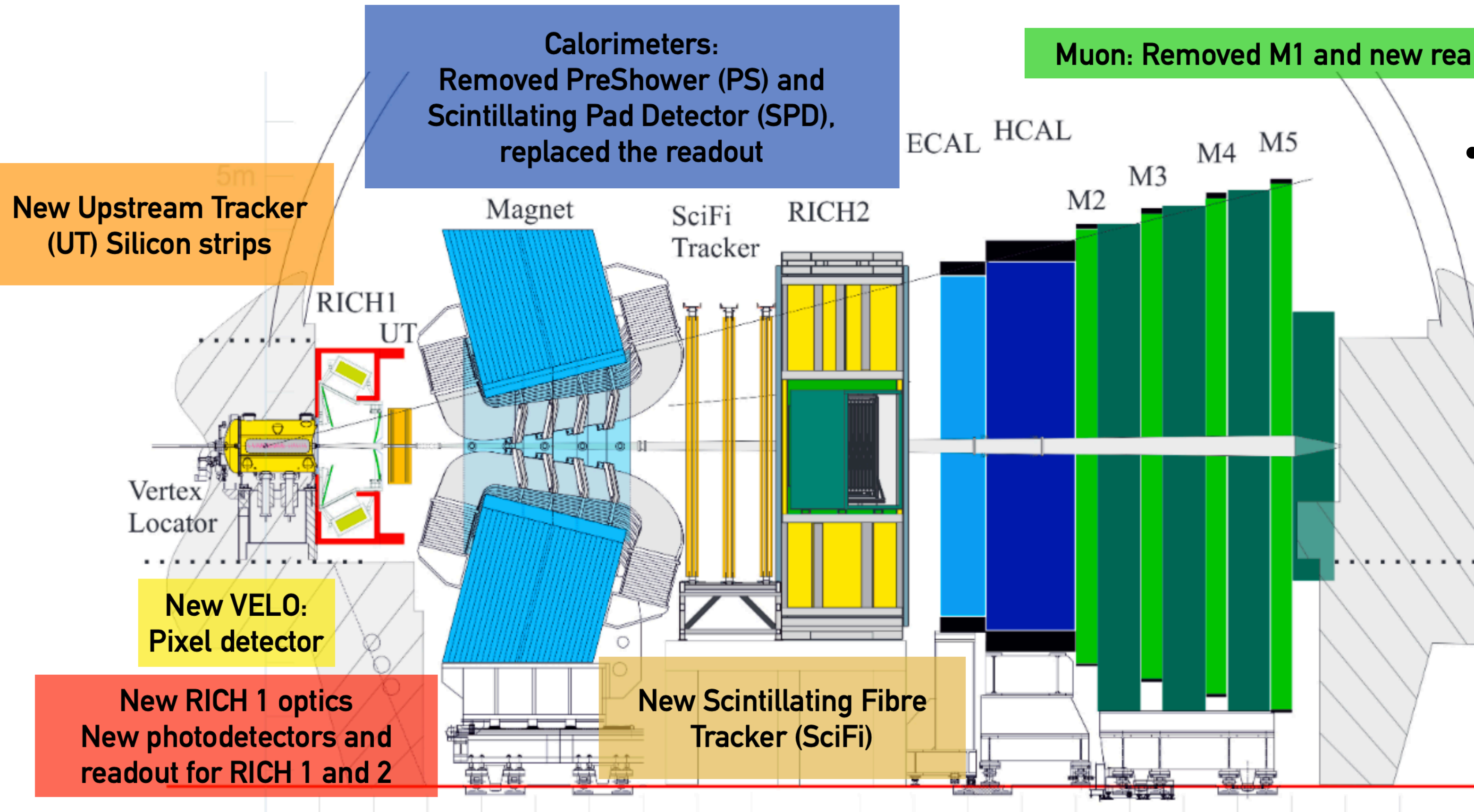Eur. Phys. J. C 78, 1008 (2018)

- Search for **LLPs decaying to jets**

Our plans for today and the future

LHCb today
Run 3 has kicked in

- We now have a **new detector**
- **Completely software trigger**
  - Several limitations on reconstructing objects in the past are now overcome

- **This year we have collected same data as Run 1 and Run 2 combined!**

New Upstream Tracker (UT) Silicon strips

Calorimeters:
Removed PreShower (PS) and Scintillating Pad Detector (SPD), replaced the readout

Muon: Removed M1 and new readout

New VELO: Pixel detector

New RICH 1 optics
New photodetectors and readout for RICH 1 and 2

New Scintillating Fibre Tracker (SciFi)

Integrated Recorded Luminosity (fb^{-1}) vs Month of the year

- 2024 (13.6 TeV): 9.56 fb^{-1}
- 2023 (13.6 TeV): 0.37 fb^{-1}
- 2022 (13.6 TeV): 0.82 fb^{-1}
- 2018 (13 TeV): 2.19 fb^{-1}
- 2017 (13 TeV): 1.71 fb^{-1}
- 2016 (13 TeV): 1.67 fb^{-1}
- 2012 (8 TeV): 2.08 fb^{-1}
- 2011 (7 TeV): 1.11 fb^{-1}

LHCb in the HL-LHC era

A completely new detector

- The LHCb Collaboration has proposed an **upgrade** for the **HL-LHC era**

- This will allow us to collect 300 fb^{-1} (or even more) of integrated luminosity

- The detector will come with **important improvements**:

  - Improved **VELO and tracker** to perform **4D reconstruction**

    $\rightarrow$ better SV reconstruction

  - **New ECAL** $\rightarrow$ similar jet energy resolution as for Run 2 and better electron reconstruction

- Need important effort to push for **better performance** also at **analysis level** (e.g. **ML tools**)
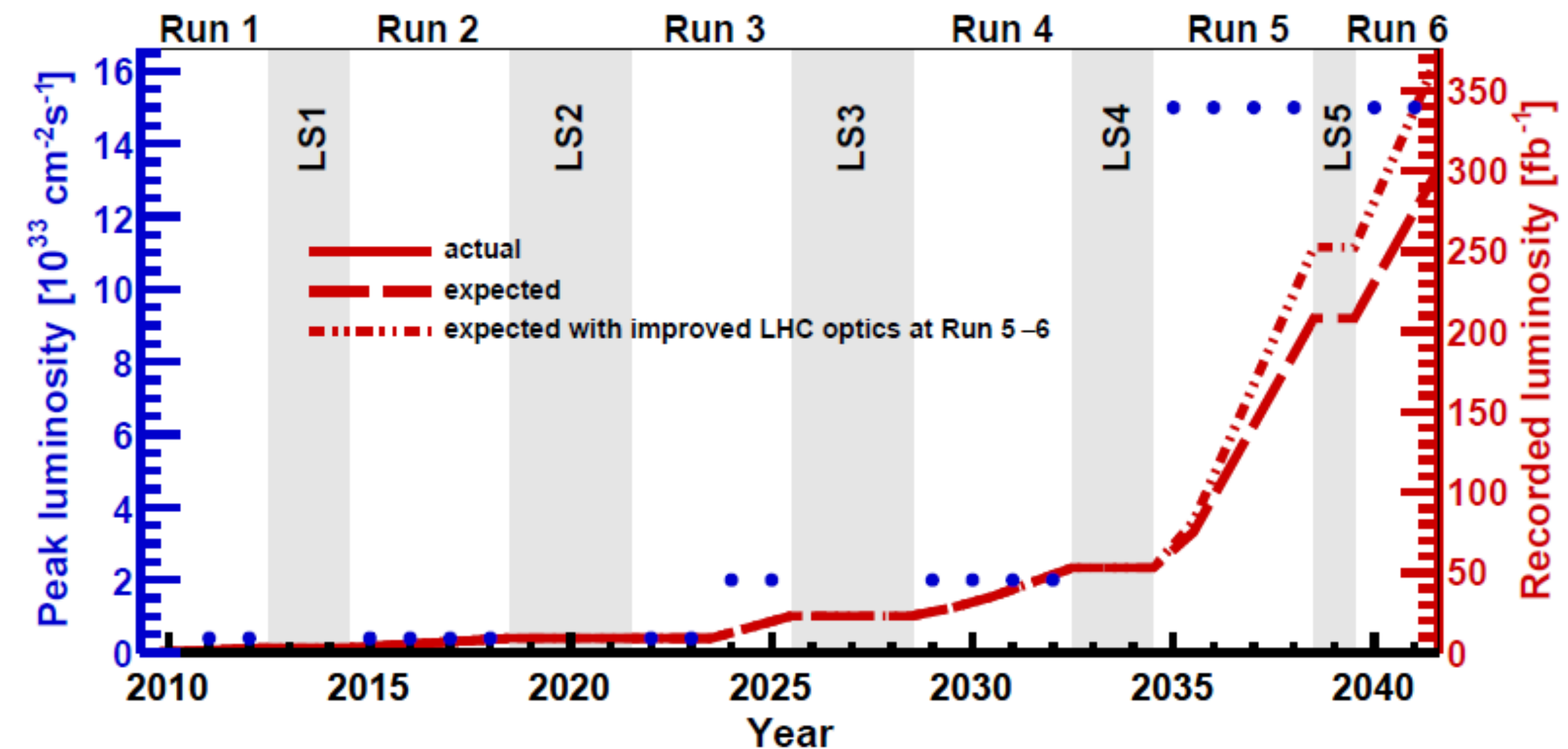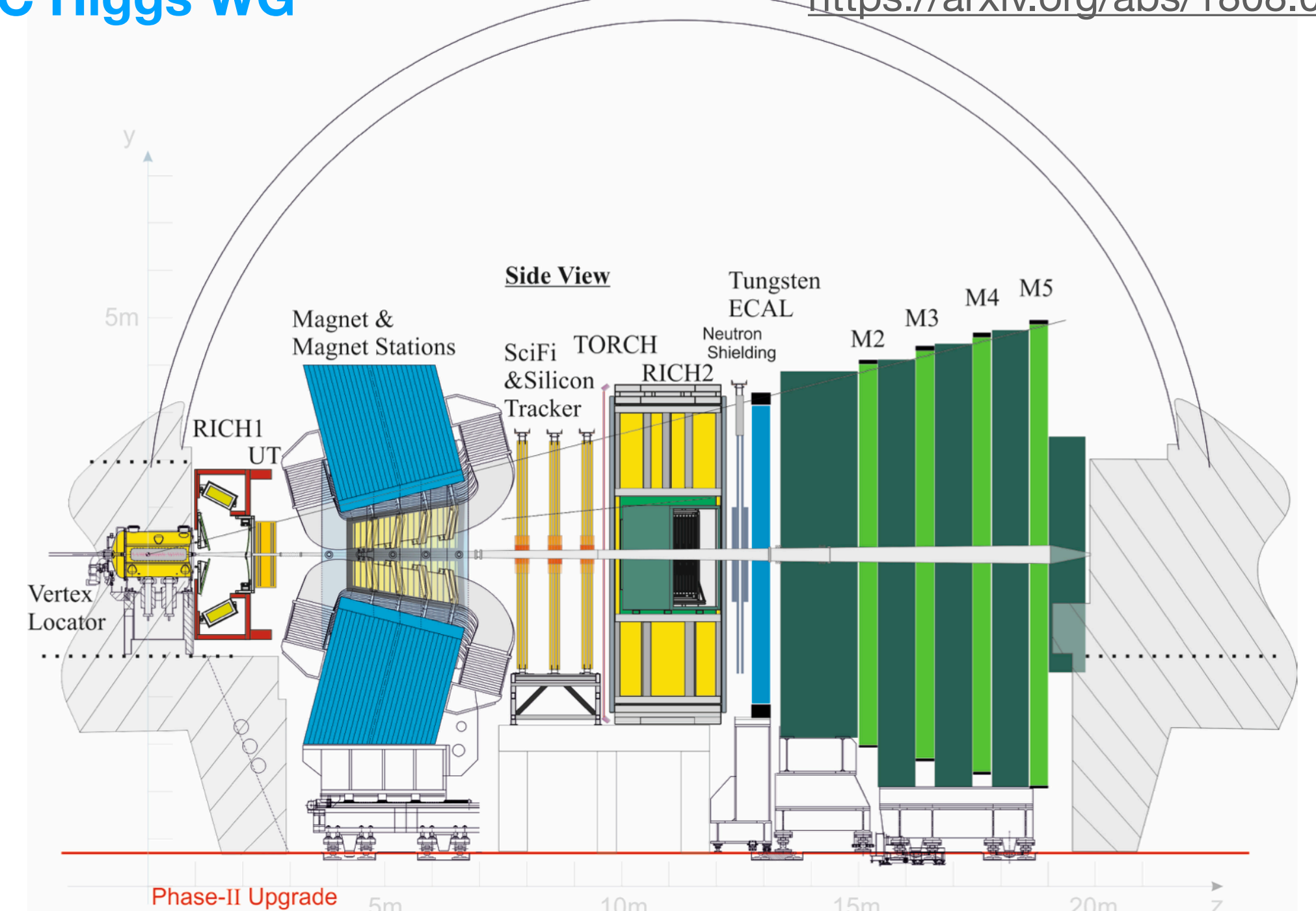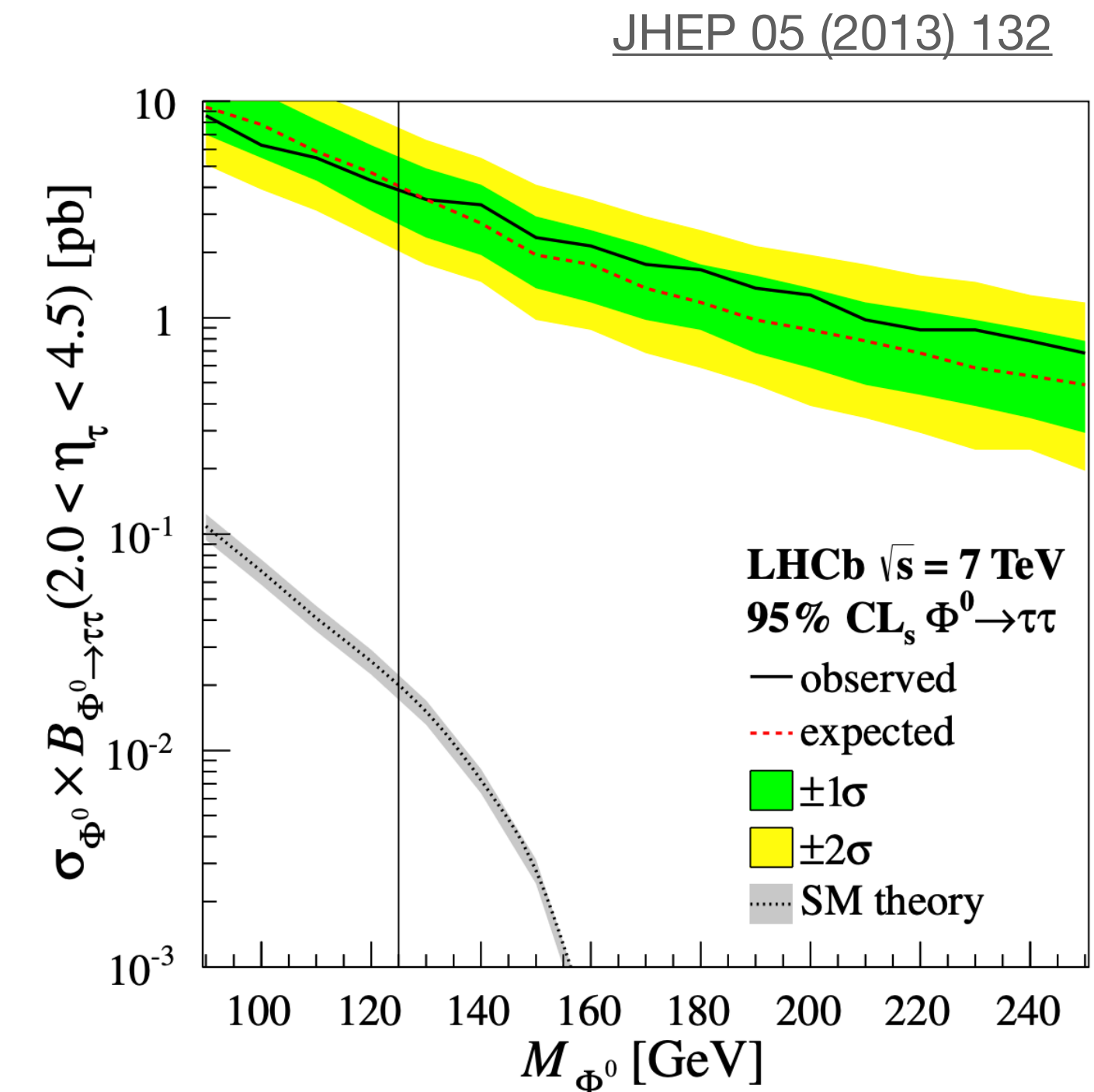
Higgs Physics @ LHCb in the future

Standard Model measurements → WG1

- Main "limitation" = luminosity → increase luminosity while keeping good reconstruction performance

- Our main objective is to measure SM Higgs cross-section in the **forward region**

  - Leverage all possible production modes (ggF, VH and also VBF)

  - **Push further** on **jet reconstruction** and **identification performance** (GNNs, Particle transformers,…)

    - We can target the $H \to b\bar{b}$ cross section measurement at the end of Run 4

    - We can contribute to a global combination to measure the **charm Yukawa coupling**

  - Increase in statistics will open us to **more Higgs physics channels**

    - $H \to ZZ \to 4\mu, H \to WW, …$

    - Any deviation from SM prediction would indicate NP

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Higgs Physics @ LHCb in the future

BSM searches → WG3

- LHCb can leverage its cleaner environment and its peculiar phase-space to perform **several BSM searches**

- In particular, we can:

  - **Access objects with lower masses**

    - Complement measurements from ATLAS and CMS

  - Explore **new signatures**:

    - $H \to$ axions, …

  - Exploit **optimal PID performance**

  - e.g. using jet substructure informations

  - Develop **dedicated trigger** to select particular signatures

    - LLPs exclusive hadronic decay modes

    - Displaced (di-)muons and (di-)taus

https://arxiv.org/pdf/1910.05225
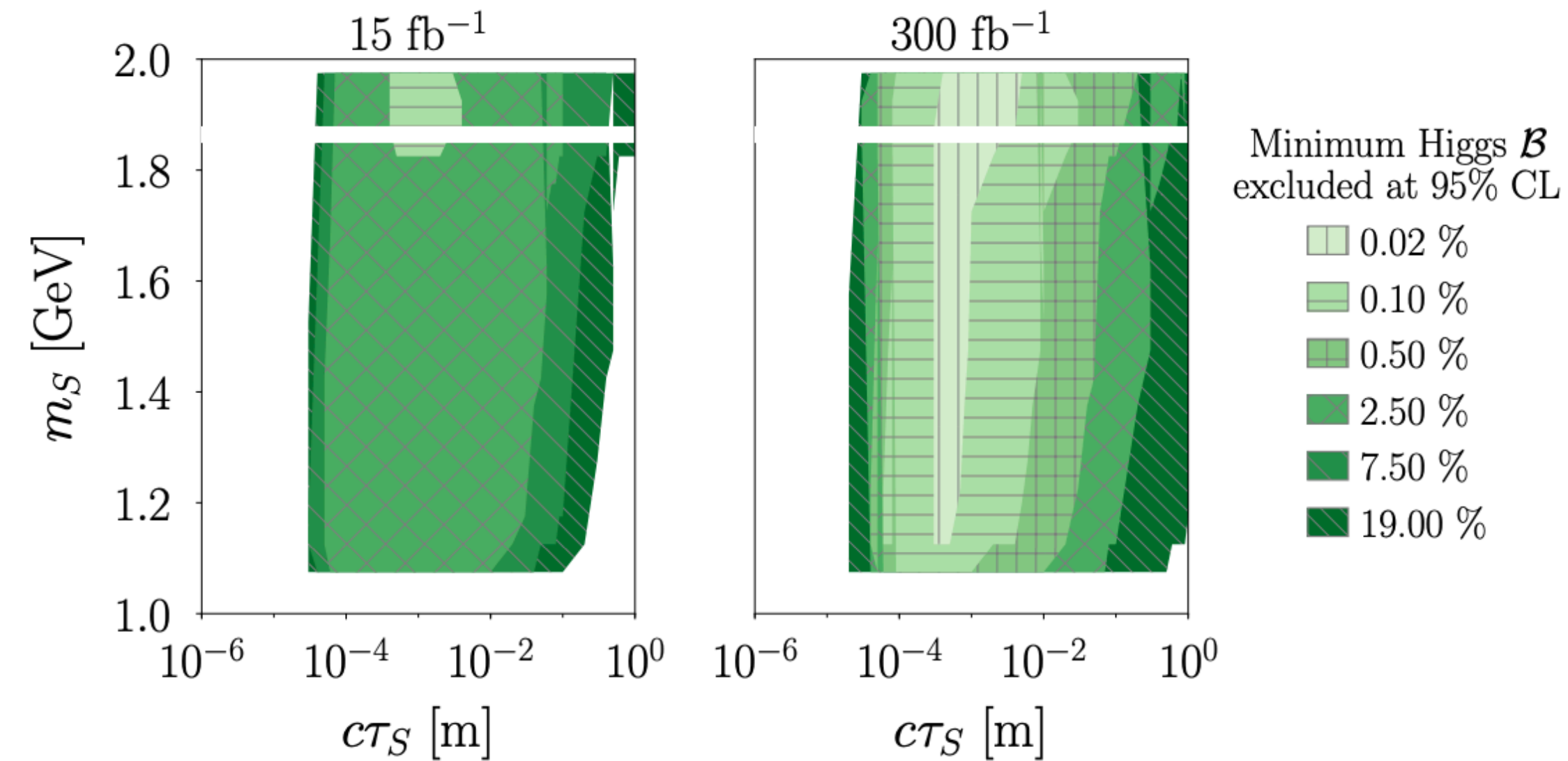
See talk by N. Grieser on
LLPs using muon shower signatures

Conclusions
Take-home messages

- LHCb has proven itself to be a **general purpose forward detector**

  - A lot of interesting and important measurements in the **QCD** and **EW** sectors
  - Able to perform studies on **several final states** with optimal performance

- Also, **LHCb interest in Higgs physics has increased over the years**

- Looking ahead of Run 3 and beyond, we plan to **get involved even more in these studies**

  - Unique possibility to **study Higgs physics in the forward region** of pp collisions
  - Unique possibility to **probe BSM theories in the forward region** of pp collisions

Thank you for your attention!