Searches for Exotic Higgs-like boson decays at LHCb

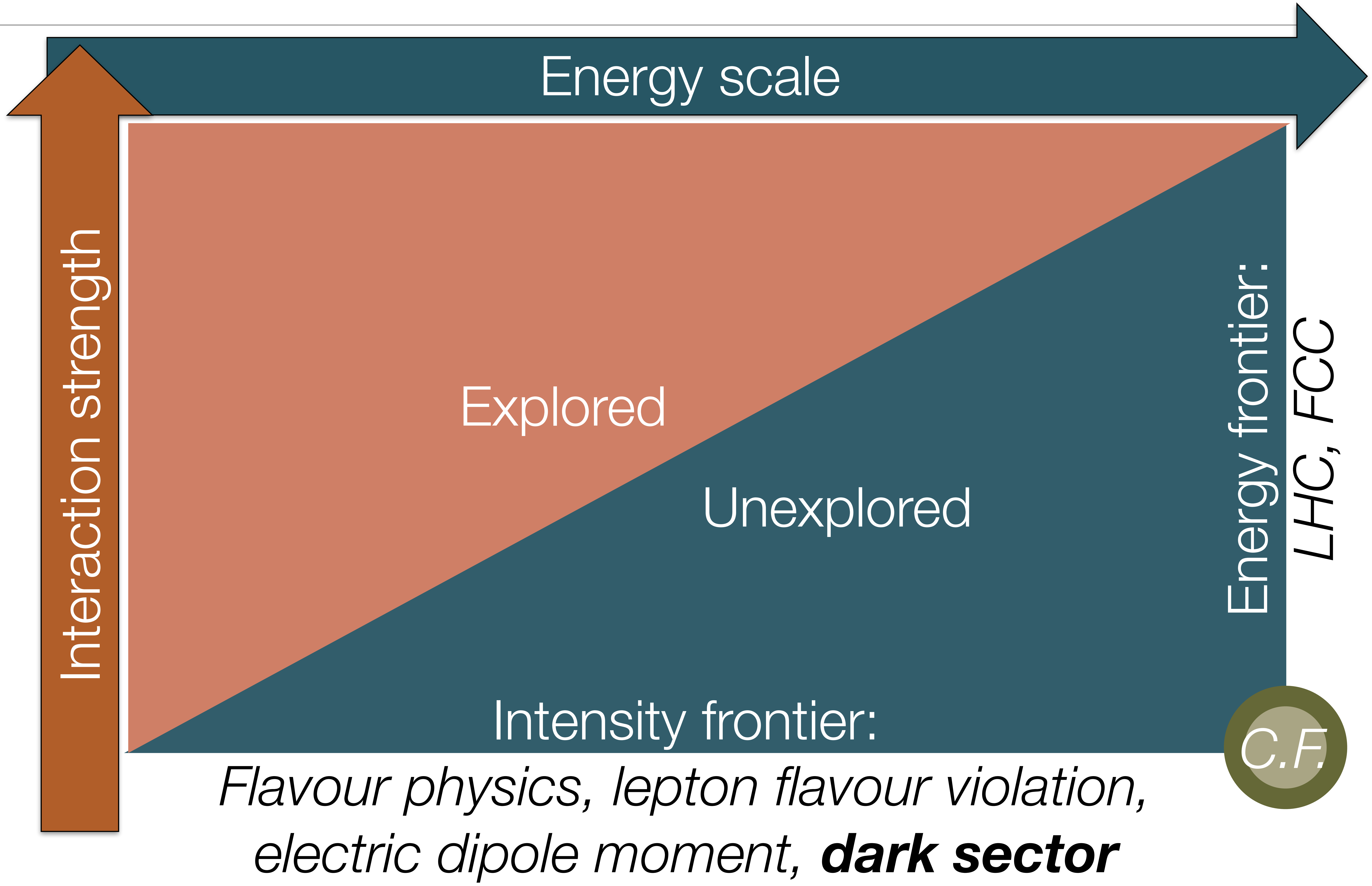
Federico Leo Redi on behalf of the LHCb collaboration

WIN2019 - Bari, Italia

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Introduction / 1

- Naturalness does not seem to be a **guiding principle** of Nature
- There are some **anomalies in flavour physics** which (if true) seem again to point out that our theory prejudice was wrong
- We should therefore not forget that **we have a 2D problem** (Mass VS Coupling)
- Low coupling → Long Lived
- *Thanks to X. Cid, C. Vazquez, and L. Sestini*

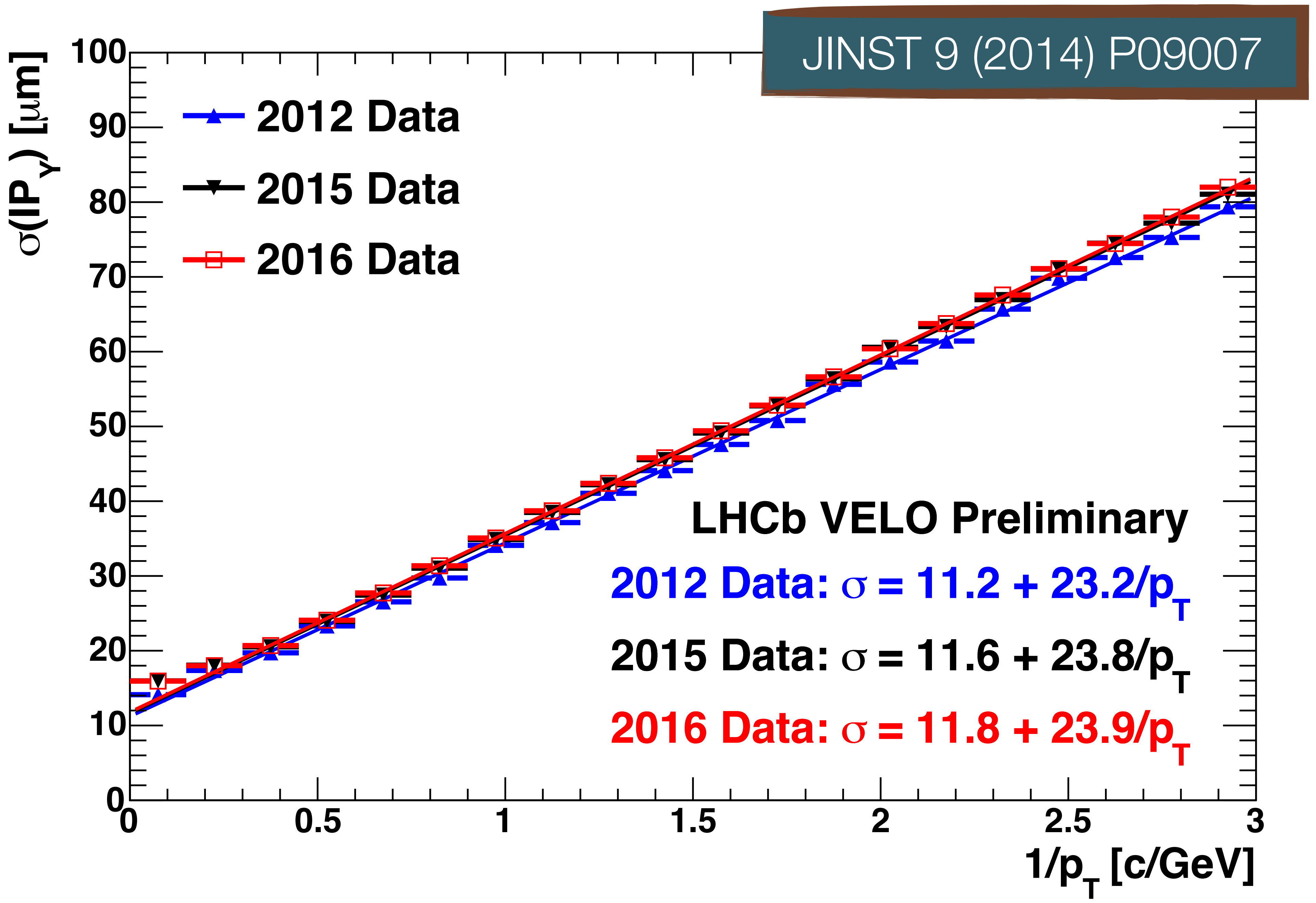


Landscape today / 1

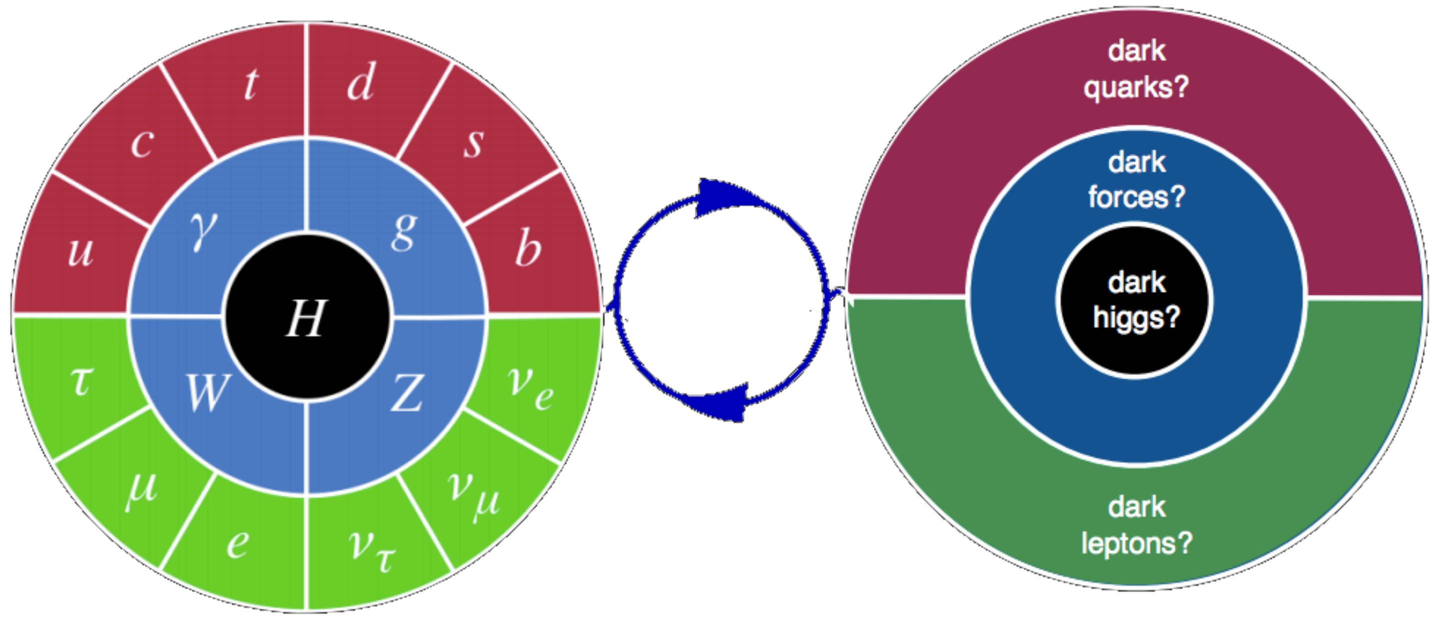
- The Intensity frontier is a **broad** and **diverse**, yet **connected**, set of science opportunities: heavy quarks, charged leptons, hidden sectors, neutrinos, nucleons and atoms, proton decay, etc...
- In this talk, I will concentrate on **dark sector** and **exotic Higgs-like boson**.
- **Landscape**: LHC results in brief:
  - Direct searches for **NP** by **ATLAS** and **CMS** have not been successful so far
    - Parameter space for popular **BSM** models is **decreasing rapidly**, but only < 5% of the complete HL-LHC data set has been delivered so far
    - NP discovery **still may happen**!
  - **LHCb** reported intriguing hints for the violation of lepton flavour universality
    - In $b \to c\mu\nu$ / $b \to c\tau\nu$, and in $b \to se^+e^-$ / $b \to s\mu^+\mu^-$ decays (see **Julián**'s 5 Jun 2019, 15:30 and **Cedric**'s 5 Jun 2019, 17:16 talks)
    - Possible evidence of **BSM** physics **if substantiated** with further studies (e.g. **BELLE II**)

Landscape today / 2

- In the dark sector: ***L = L$_{SM}$ + L$_{mediator}$ +L$_{HS}$***
  - Hidden Sector decay rates into SM final states is suppressed
  - Branching ratios of O(10^{-10})
  - Long-lived objects
  - Interact very weakly with matter
- Experimental challenge is **background suppression**
- **Full reconstruction**, **low pT** triggering, and **PID** are essential to minimise model dependence
  - **Two** strategies of searching for mediators at accelerators:
  - **Not decaying in the detector**
    - Missing energy technique
    - Scattering technique: electron or nuclei scattered by DM…
  - **Decaying in the detector**
    - Reconstruction of decay vertex



M. Williams



JINST3(2008)S08005
Int J Mod Phys A30(2015)1530022
JHEP 1511 (2015) 103

LHCb detector / 1

- **LHCb** is a dedicated flavour experiment in the **forward region** at the LHC ($1.9 < \eta < 4.9$) (~1°-15°)

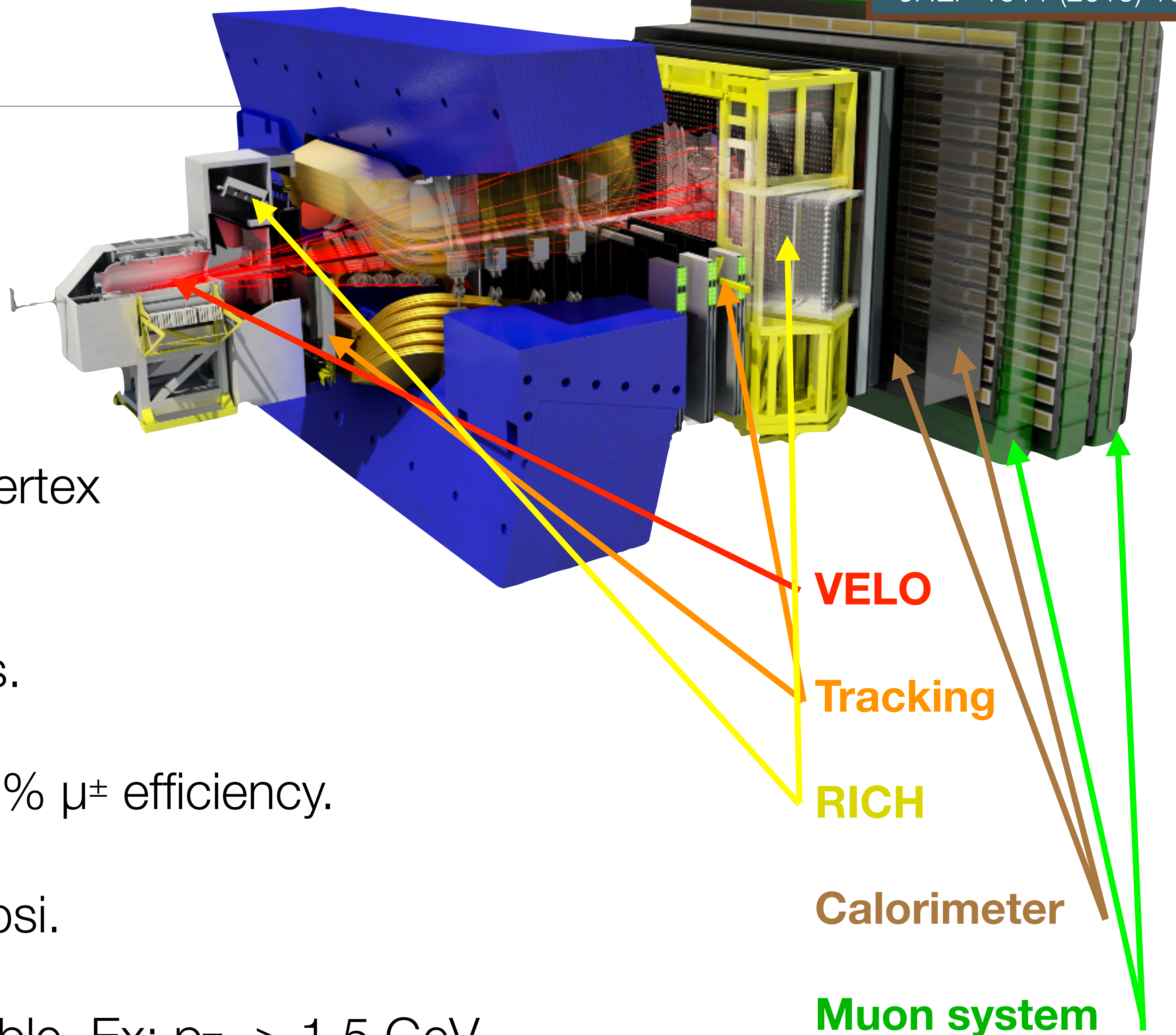
- **Precise vertex reconstruction** < 10 μm vertex resolution in transverse plane.

- Lifetime resolution of ~ 0.2 ps for τ = 100 ps.

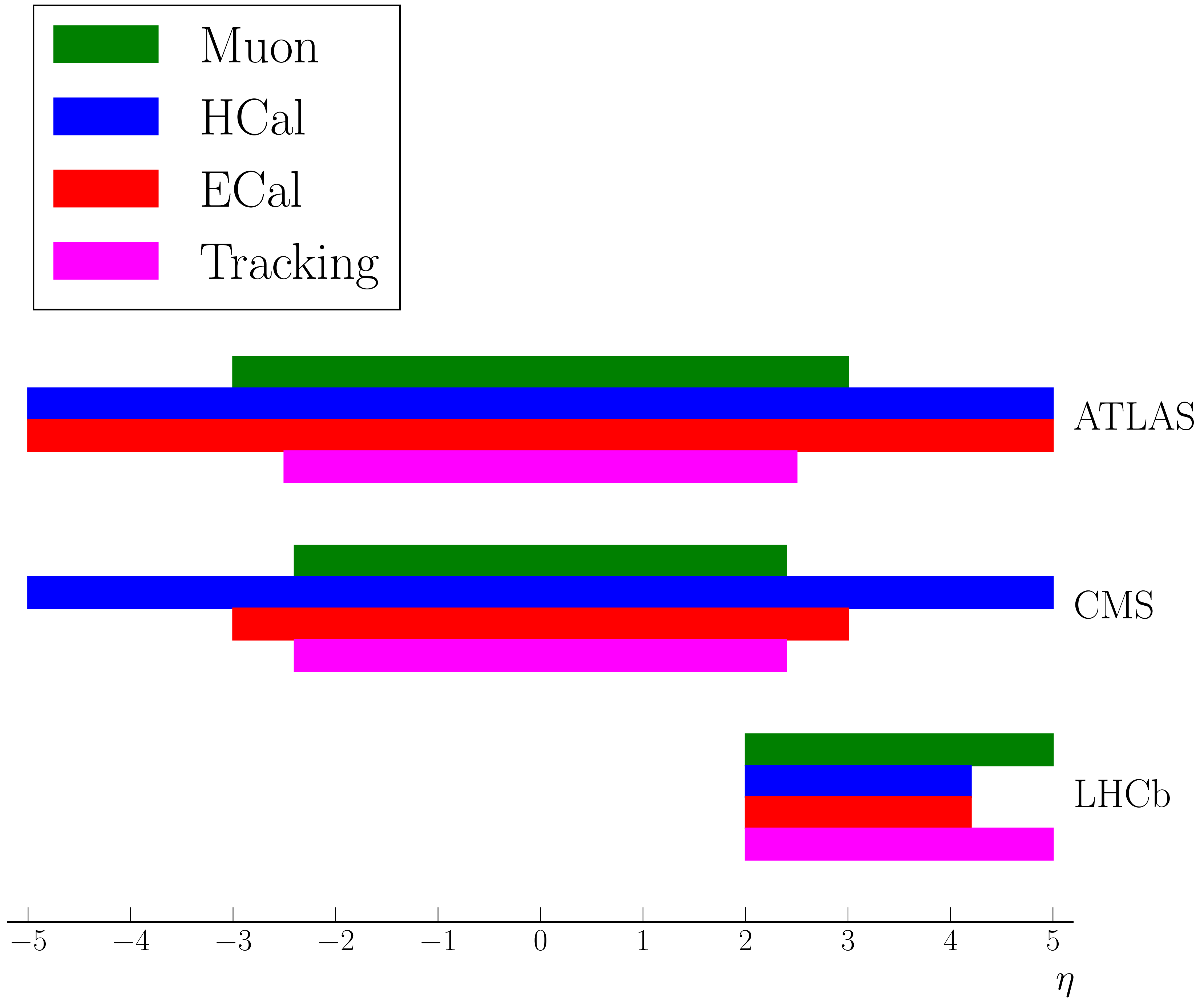
- **Muons** clearly identified and triggered: ~ 90% $\mu^{\pm}$ efficiency.

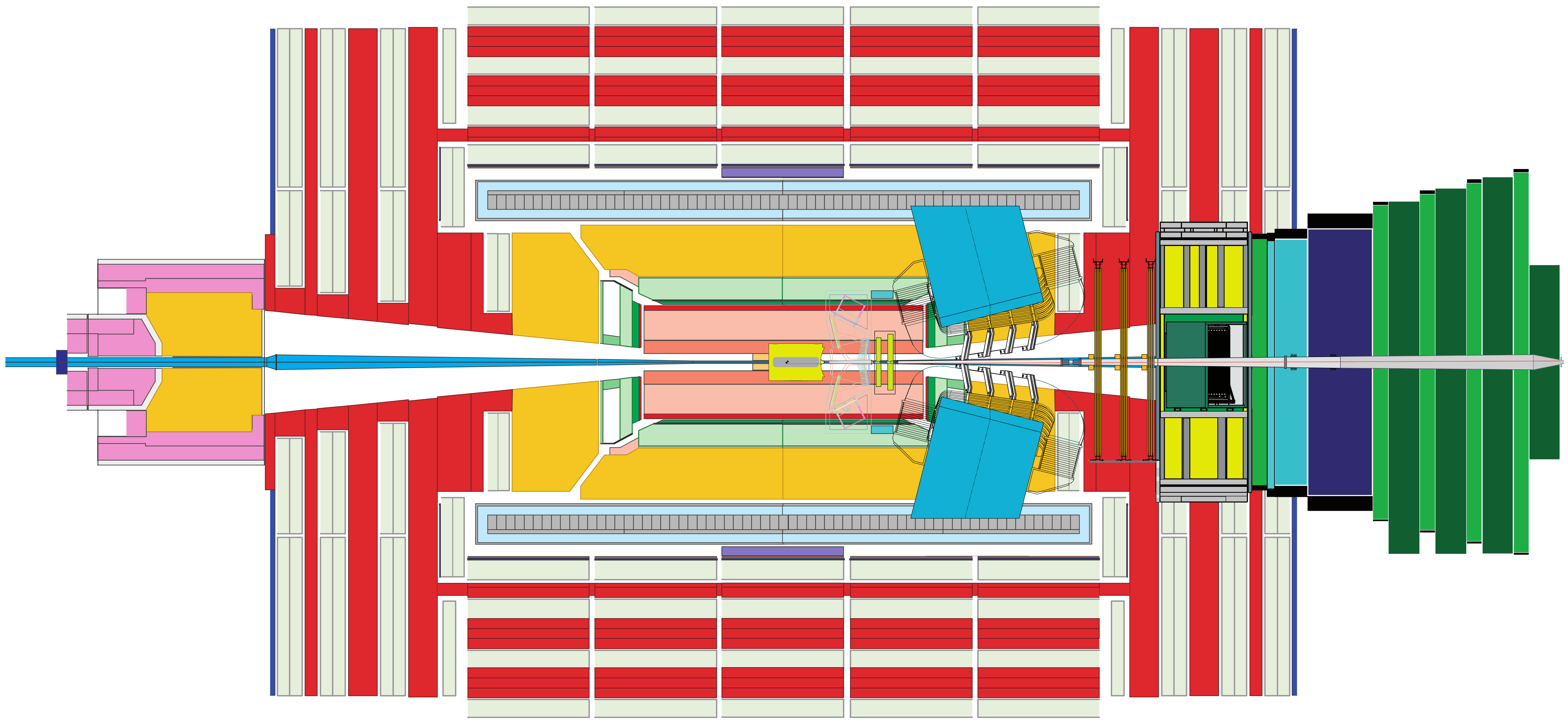
- Great **mass resolution**: e.g. 40 MeV for J/psi.

- **Low p_T trigger** means low masses accessible. Ex: $p_{T\mu} > 1.5$ GeV.



LHCb detector / 1 bis

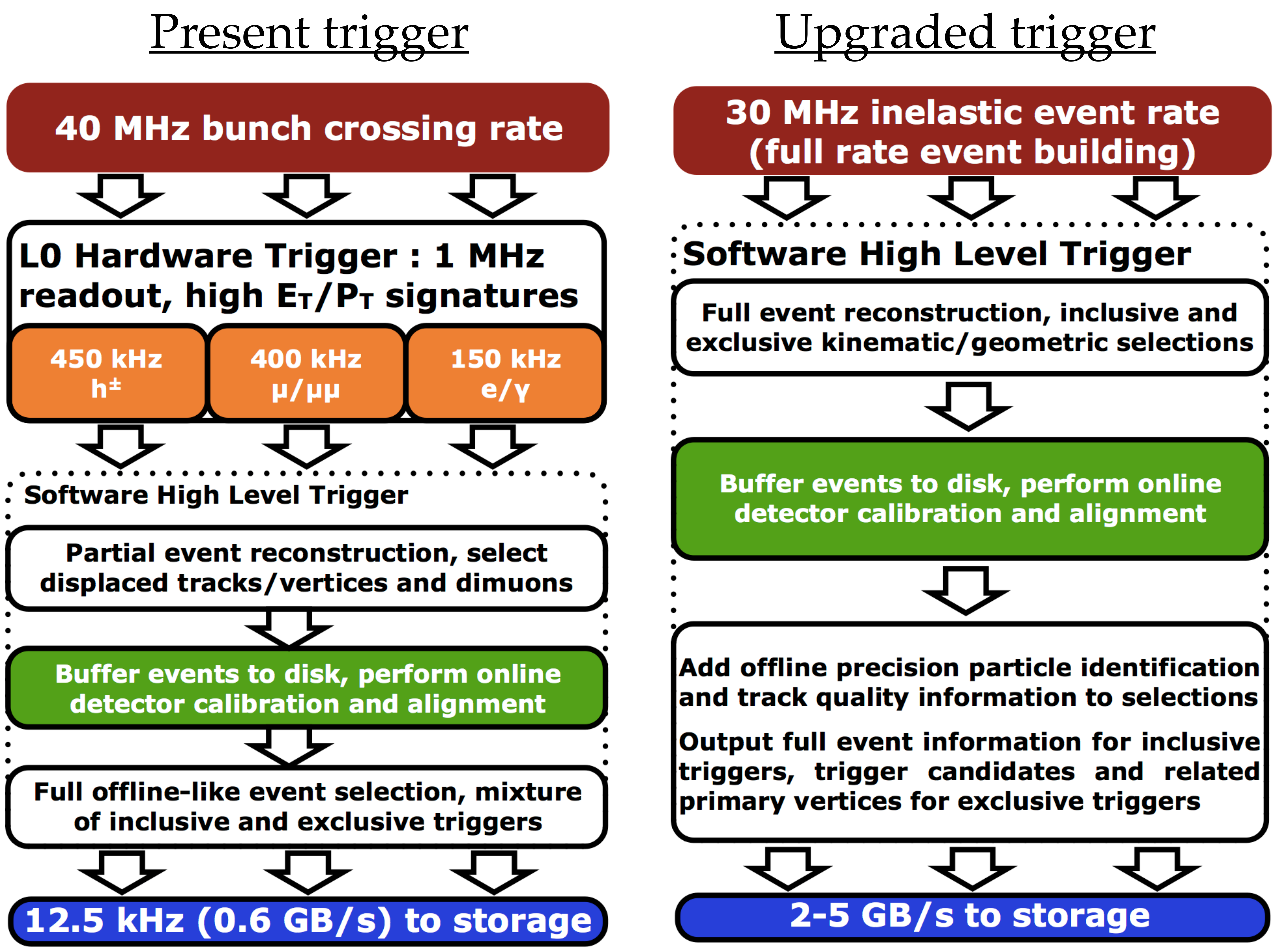




CERN-LHCC-2014-016
LHCB-TDR-016

LHCb detector / 2

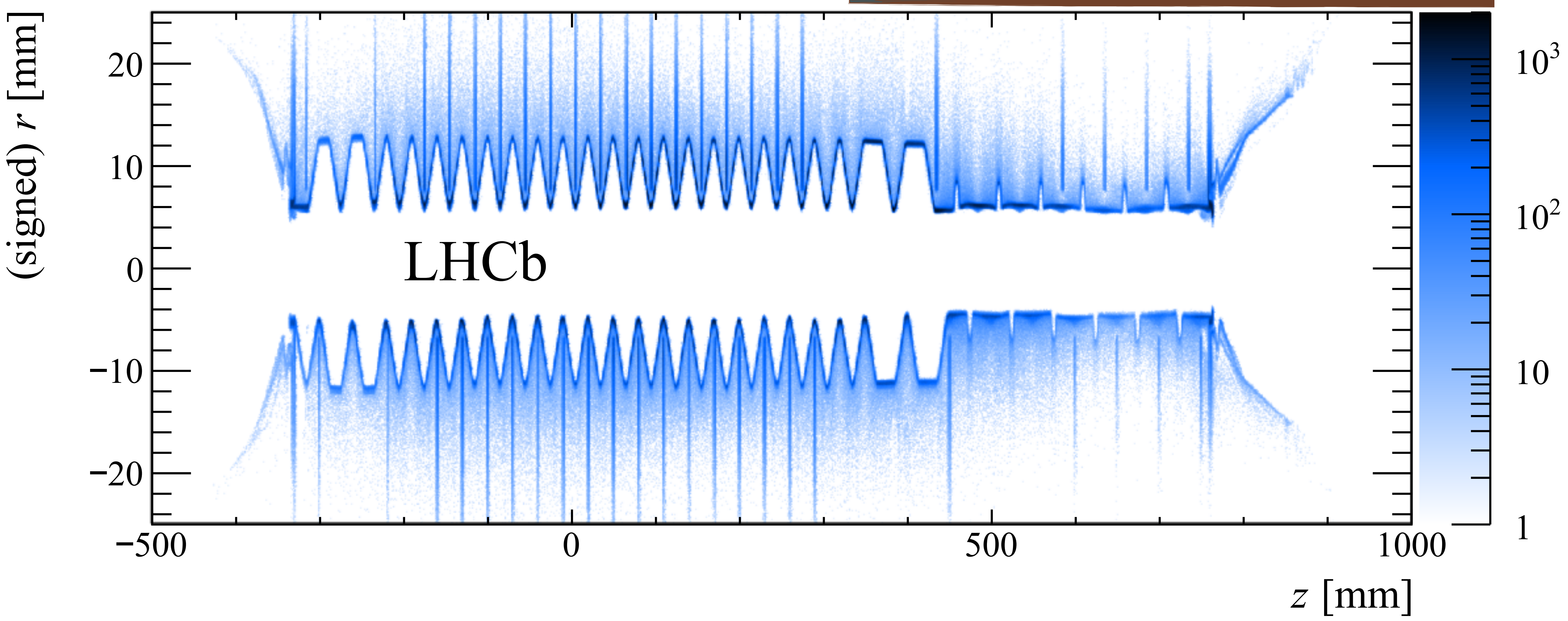
- Lower luminosity (and low pile-up)
  - **~1/8** of ATLAS/CMS in **Run 1**
  - **~1/20** of ATLAS/CMS in **Run 2**
- Hardware **L0 trigger** to be removed
- **Full real-time** reconstruction for all particles available to select events (since 2015)
  - **Real-time reconstruction** for all charged particles with $p_T > 0.5$ GeV
  - We go from 1 TB/s (post zero suppression to 0.7 GB/s (mix of full + partial events)
- LHCb will move to a **trigger-less readout system** for LHC Run 3 (2021-2023), and process
  5 TB/s in real time on the CPU farm

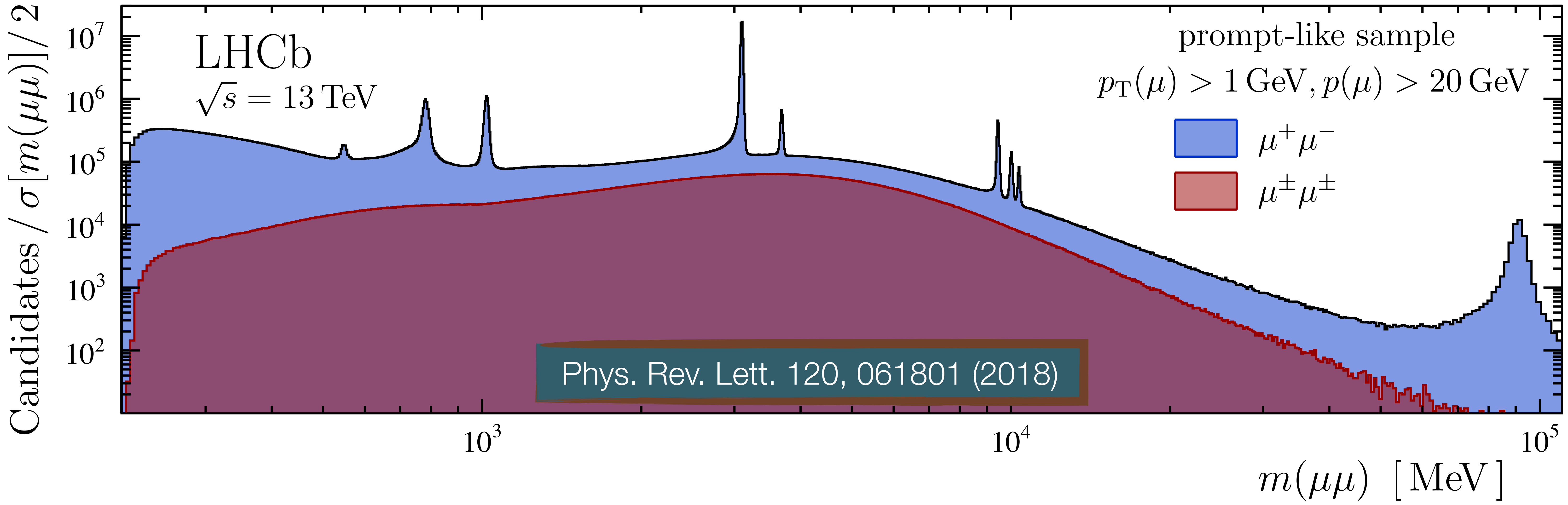


LHCb detector / 3

- Precise knowledge of the location of the material in the LHCb VELO is essential to reduce the background in searches for long-lived exotic particles
- LHCb data calibration process can align active sensor elements, an **alternative approach** is required to fully map the VELO material
- **Real-time calibration** in Run 2
- Hardware trigger is still there, and only ~10% efficient at low pT

JINST 13 (2018) no.06, P06008



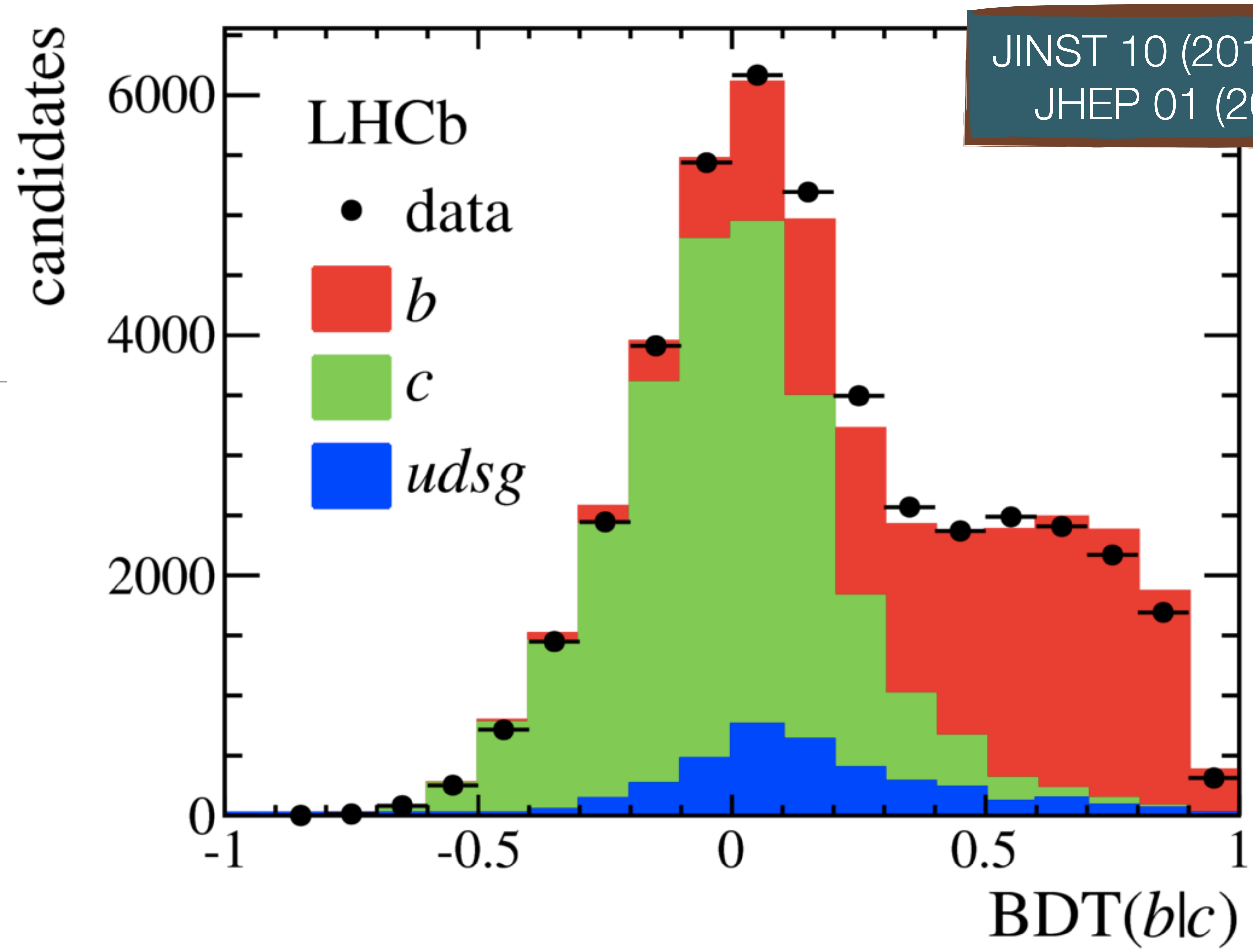


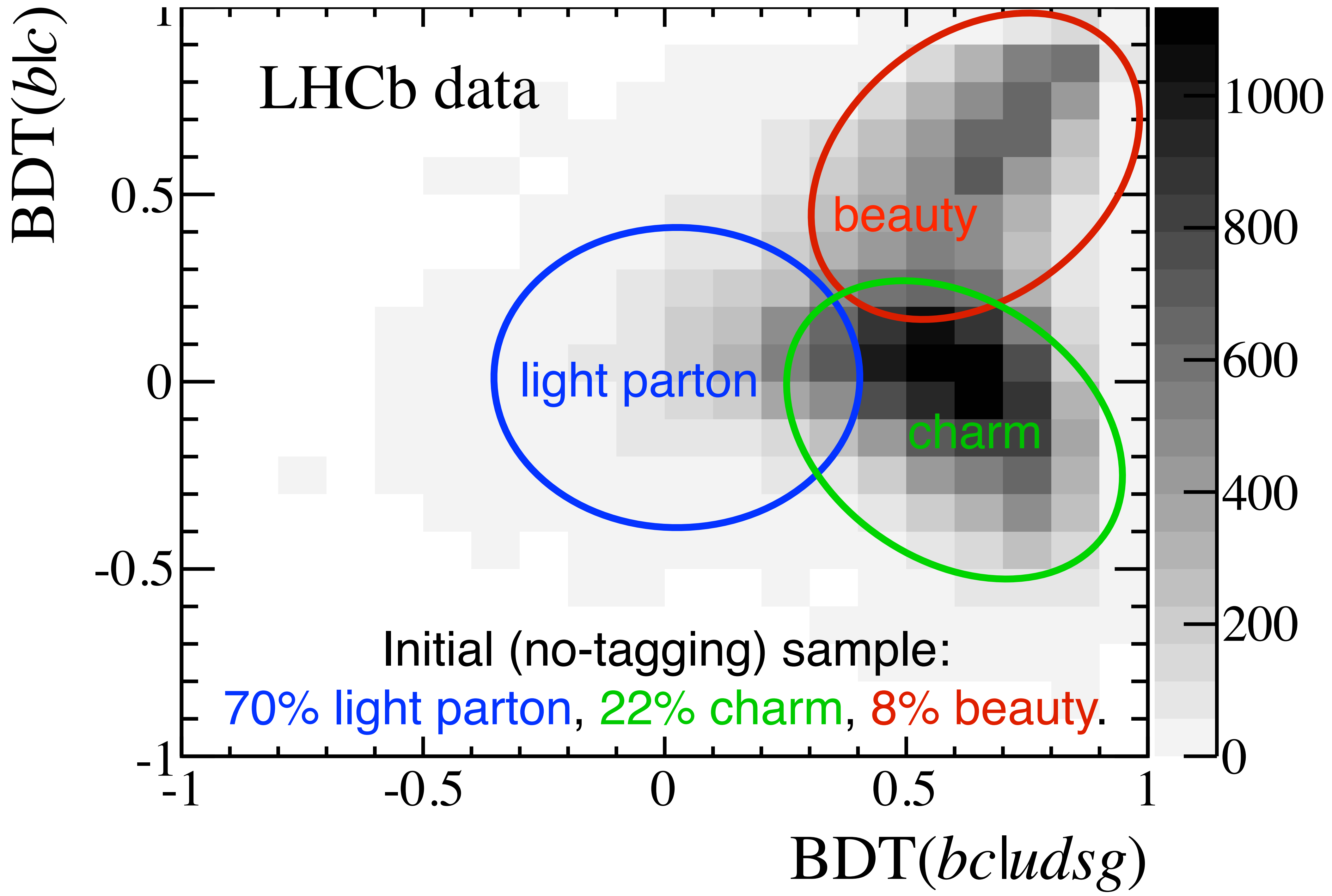
Phys. Rev. Lett. 120, 061801 (2018)

Jet physics at LHCb / 1

- Efficiency above 90% for jets with p_T above 20 GeV/c
- Jets reconstructed both online and offline!
- **b and c jet tagging**
- Require jets with a secondary vertex reconstructed close enough
- **Light jet** mistag rate < 1%, ε_b ~ 65%, ε_c ~ 25%
- SV properties (**displacement**, **kinematics**, **multiplicity**, etc) and jet properties combined in **two** BDTs
  - **$\mathbf{BDT_{bc|udsg}}$** optimised for heavy flavour versus light discrimination
  - **$\mathbf{BDT_{b|c}}$** optimised for b versus c discrimination

JINST 10 (2015) P06013
JHEP 01 (2014) 033

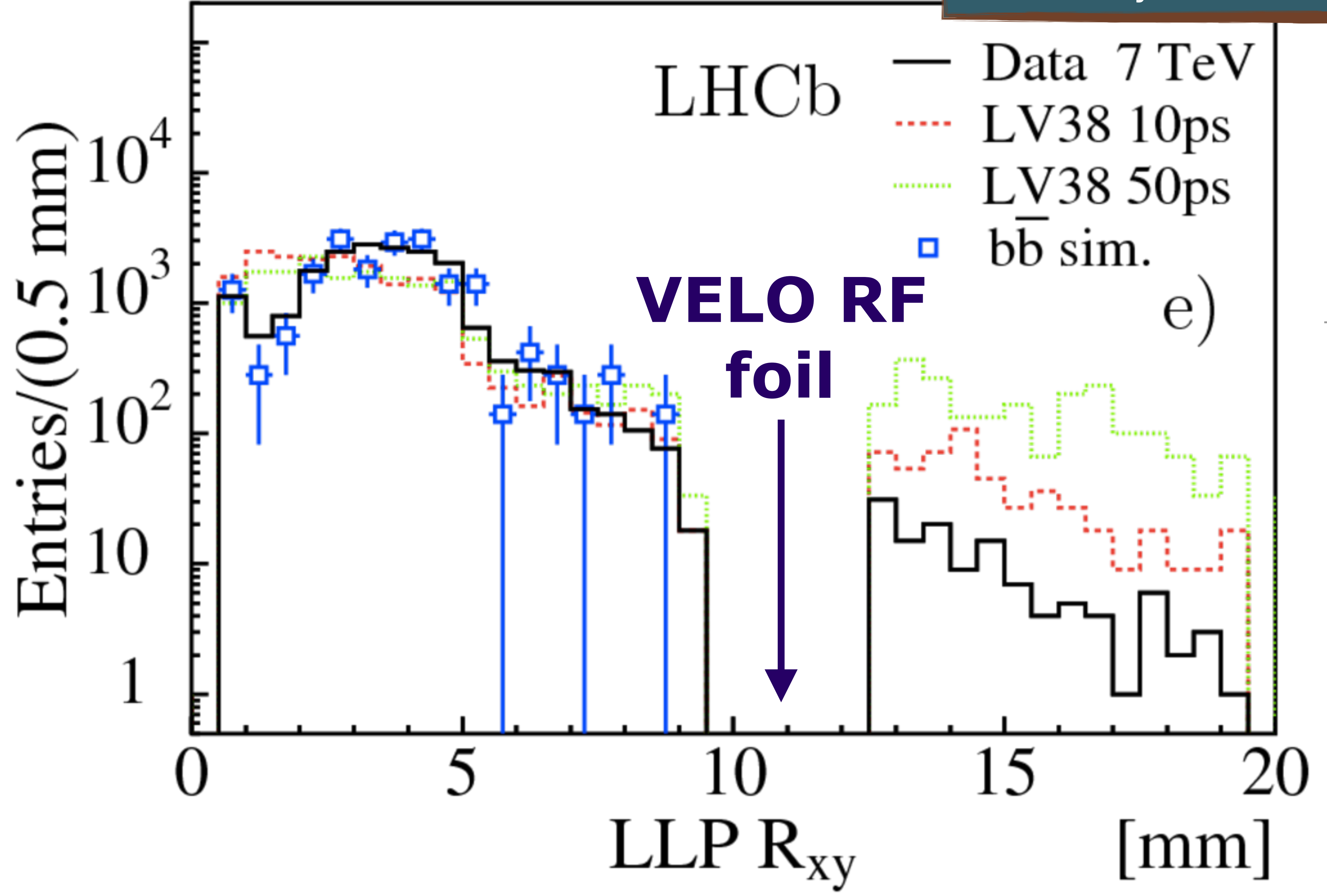


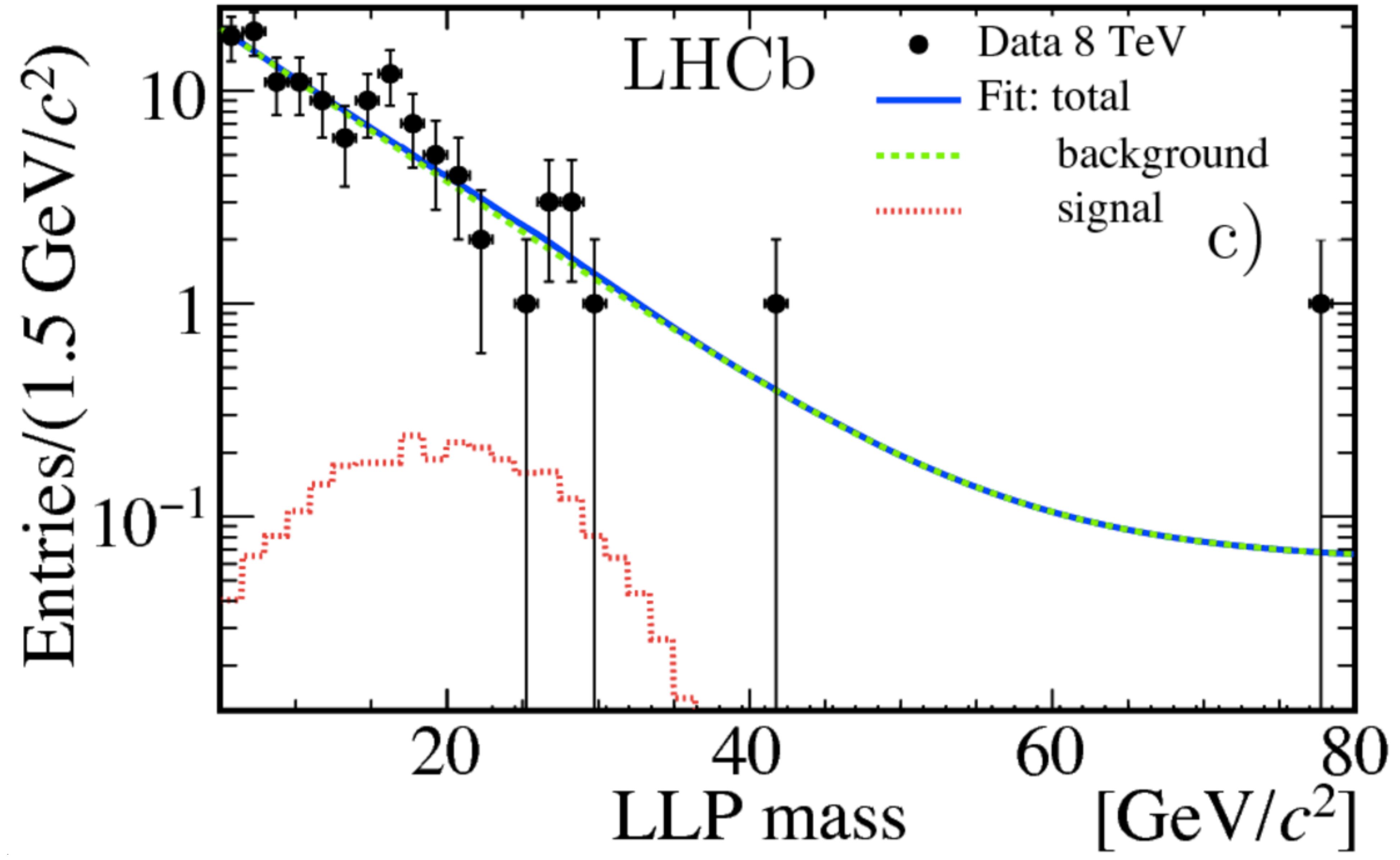


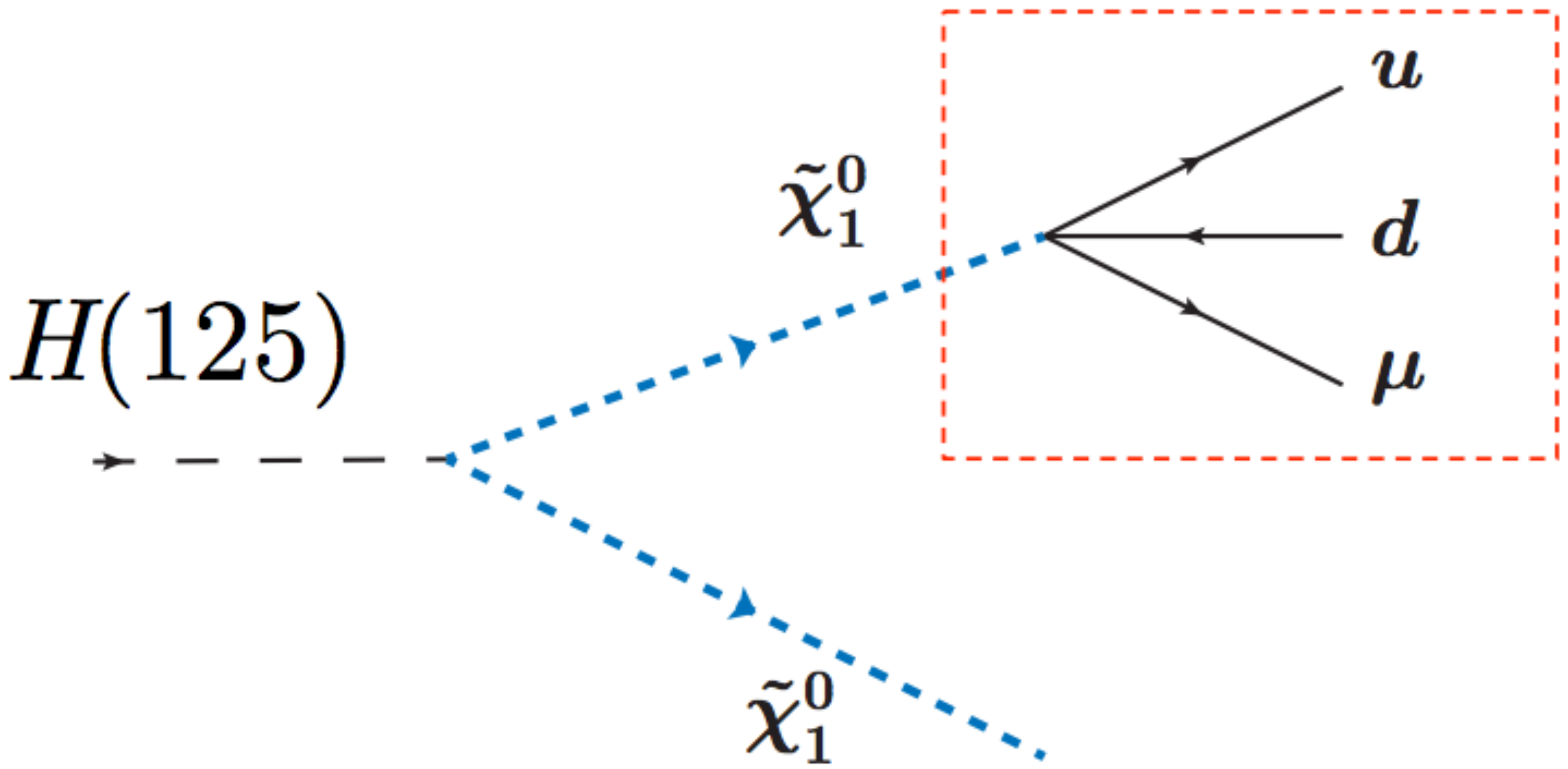
Eur. Phys. J. C 77 224

Higgs→LLP→μ+jets / 1

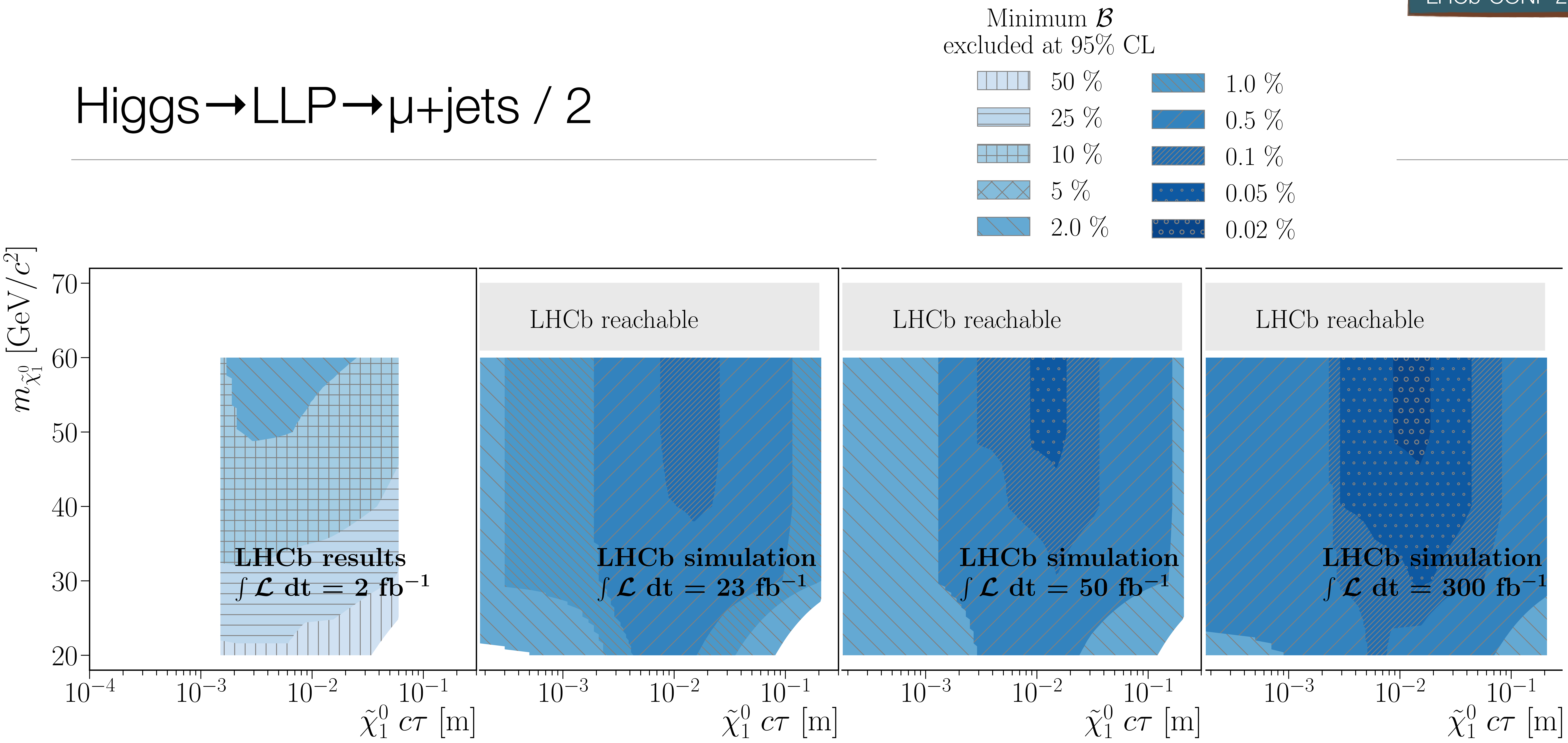
- Massive **LLP** decaying → **μ**+qq (→ **jets**)
- **Single displaced vertex** with several tracks and a high p_T muon; based on **Run-1** dataset
- Production of LLP could come e.g. from Higgs like particle decaying into pair of LLPs
- **m_{LLP}=[20; 80] GeV** and **τ_{LLP}=[5; 100] ps**
- Background dominated by **bb**
- No excess found: result interpreted in various models



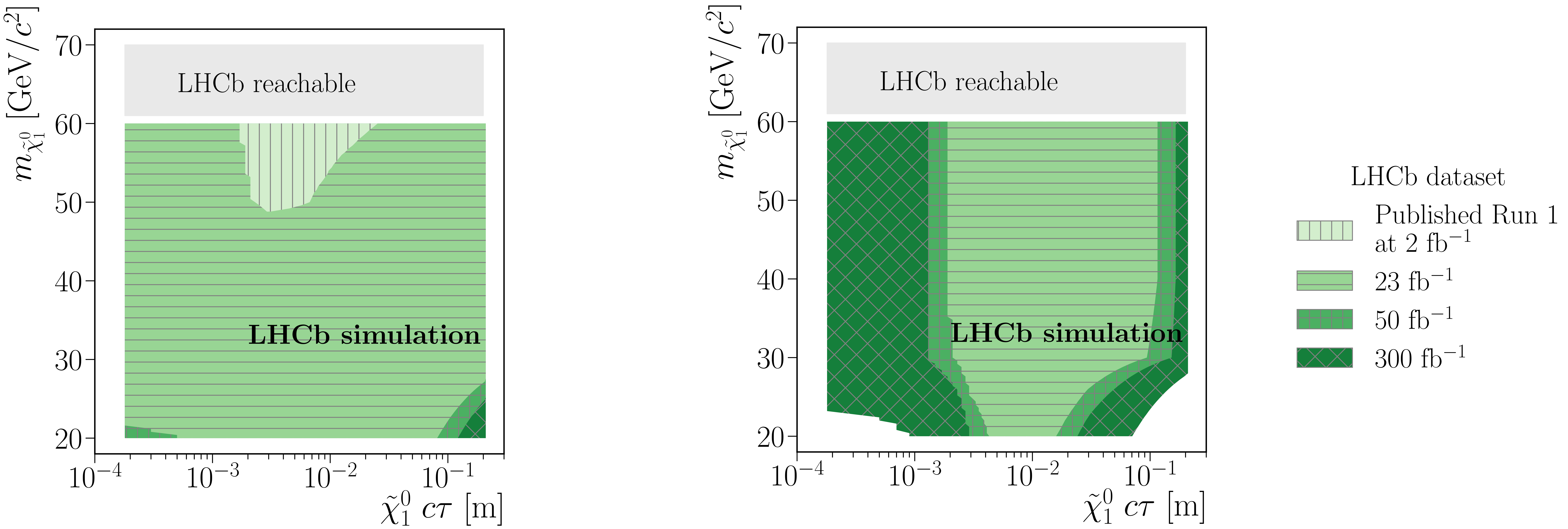




Higgs→LLP→μ+jets / 2



Higgs→LLP→μ+jets / 3

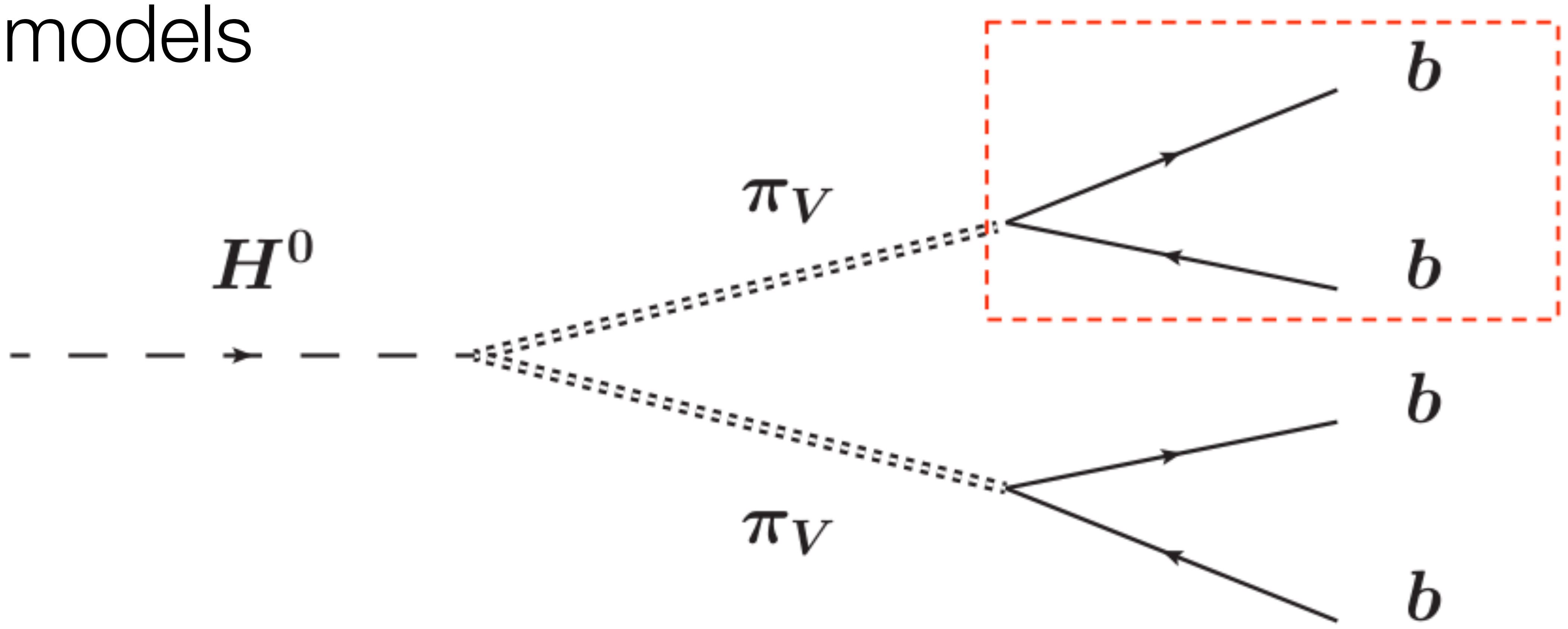


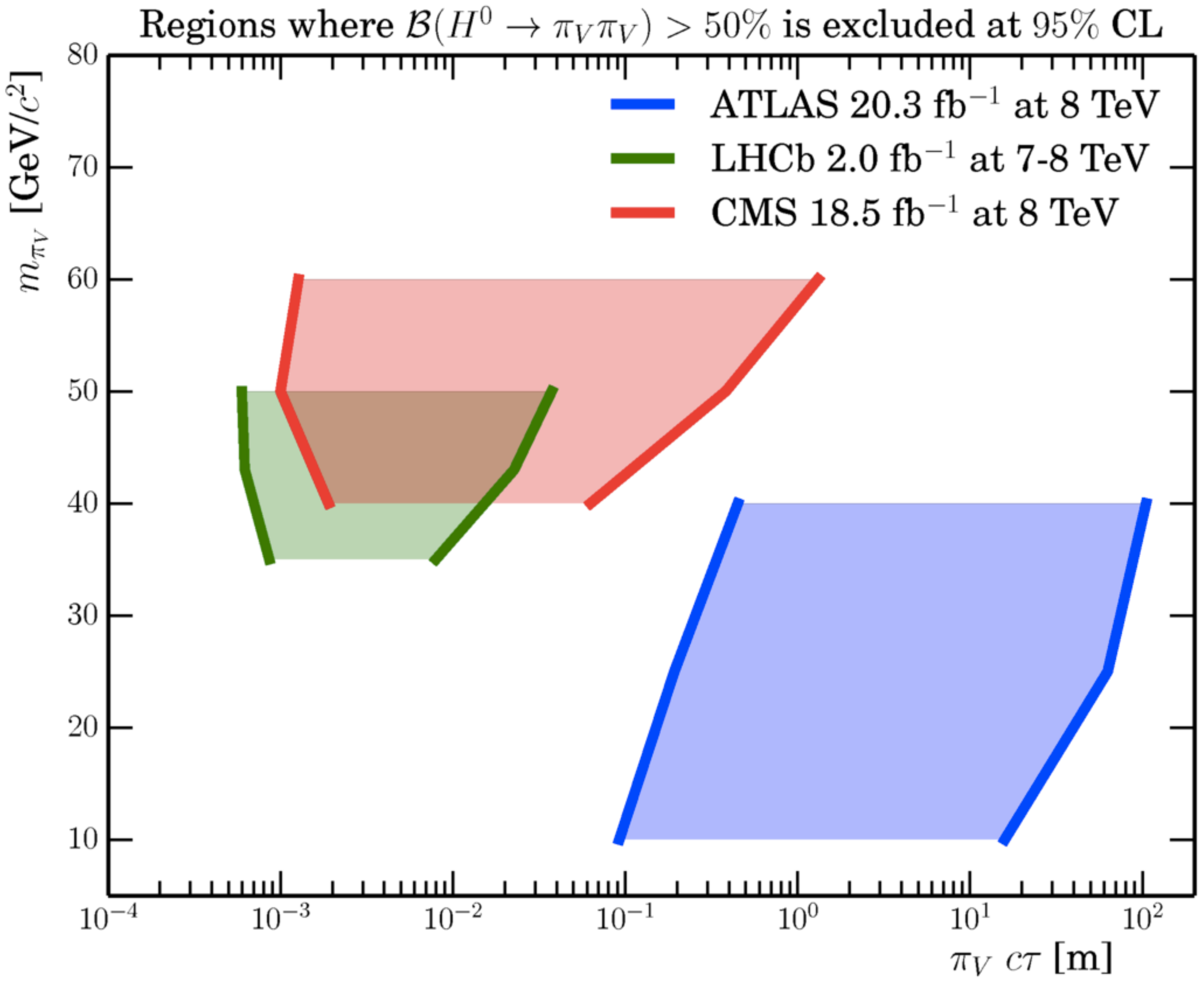
Bf(Higgs→LLP+LLP) < 2 %

Bf(Higgs→LLP+LLP) < 0.5 %

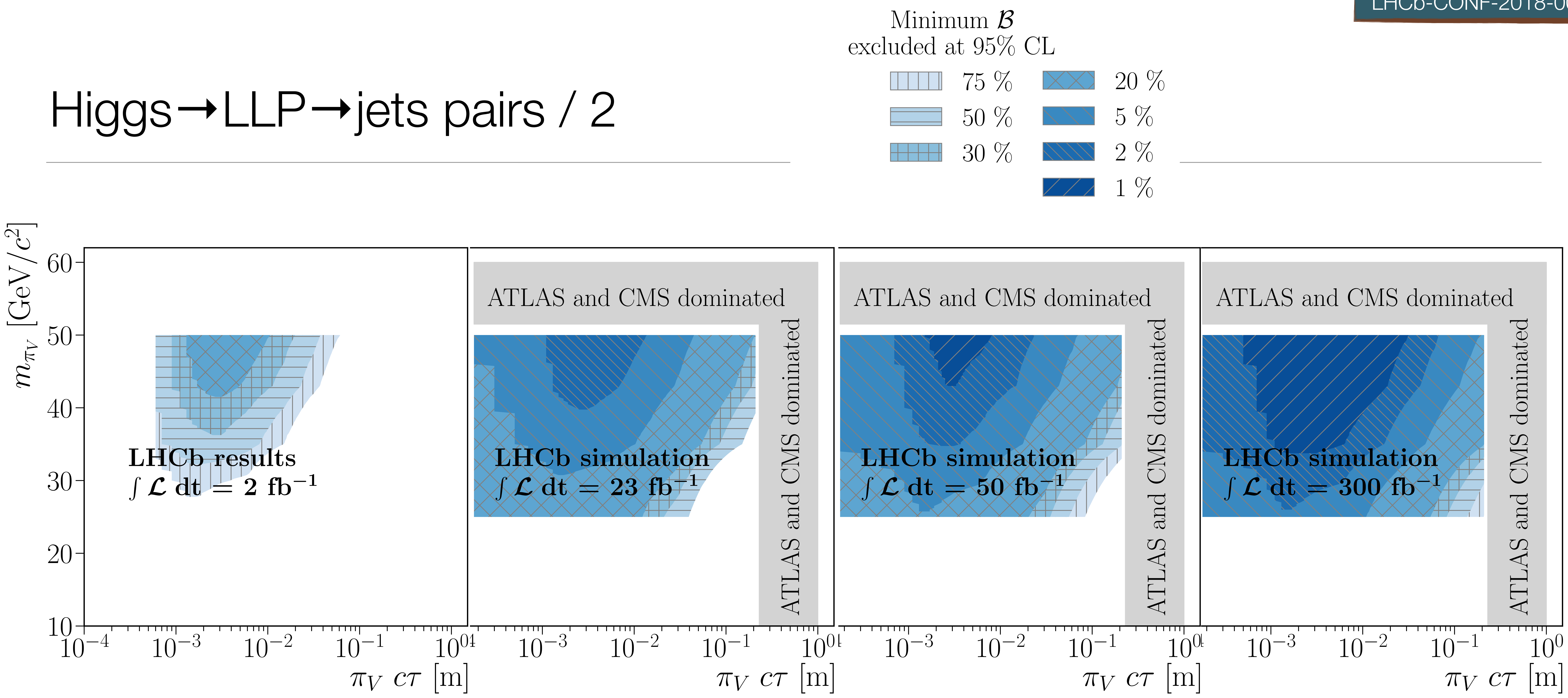
Higgs→LLP→jet pairs / 1

- Massive **LLP** decaying →bb+bb with bb → **jets**
- **Single displaced vertex** with two associated tracks; based on **Run-1** dataset
- Production of LLP could come e.g. from Higgs like particle decaying into pair of LLPs (e.g. π_V)
- **$m_{\pi V}$=[25; 50] GeV** and **$\tau_{\pi V}$=[2; 500] ps**
- Background dominated by **QCD**
- No excess found: result interpreted in various models

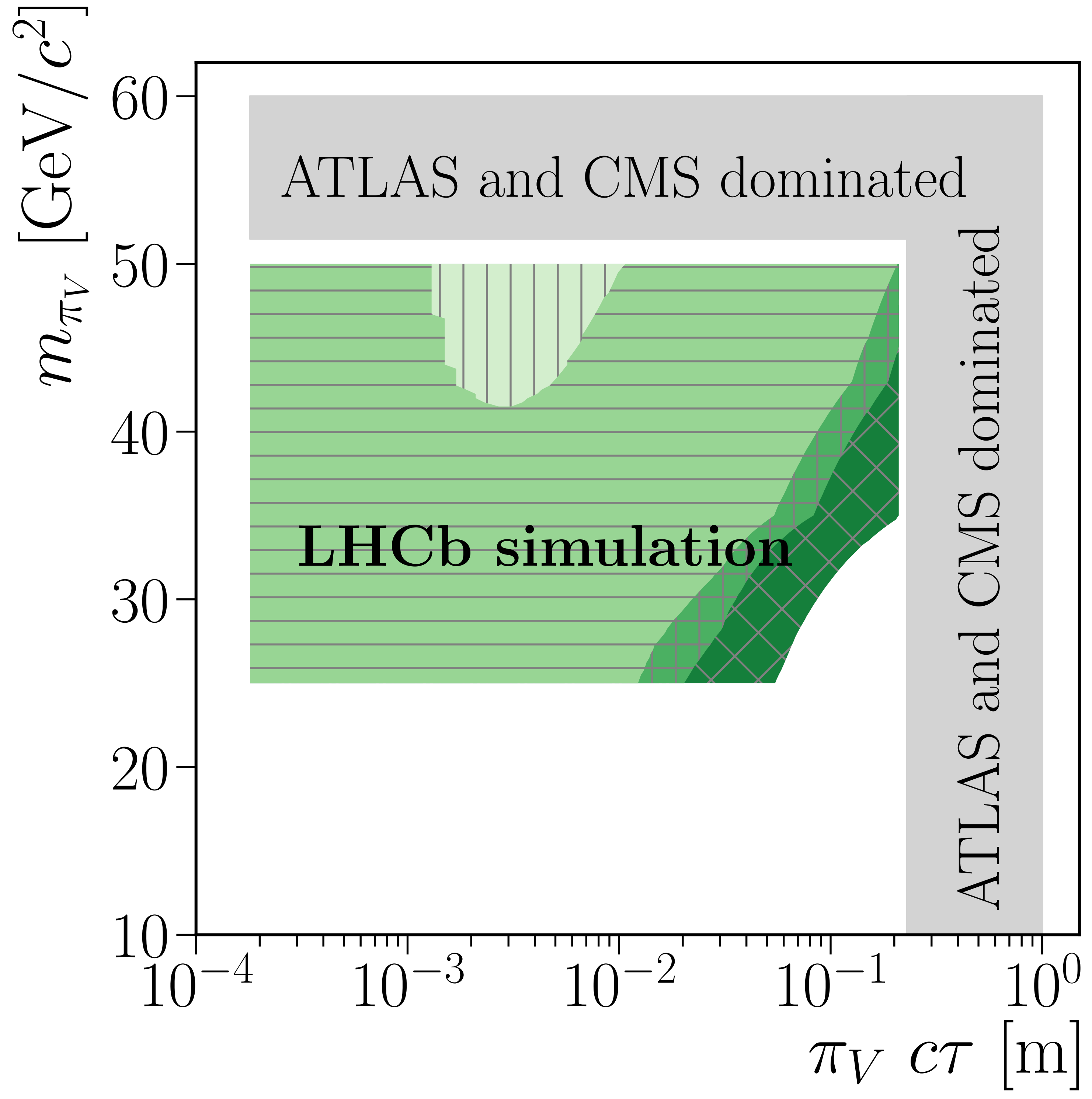


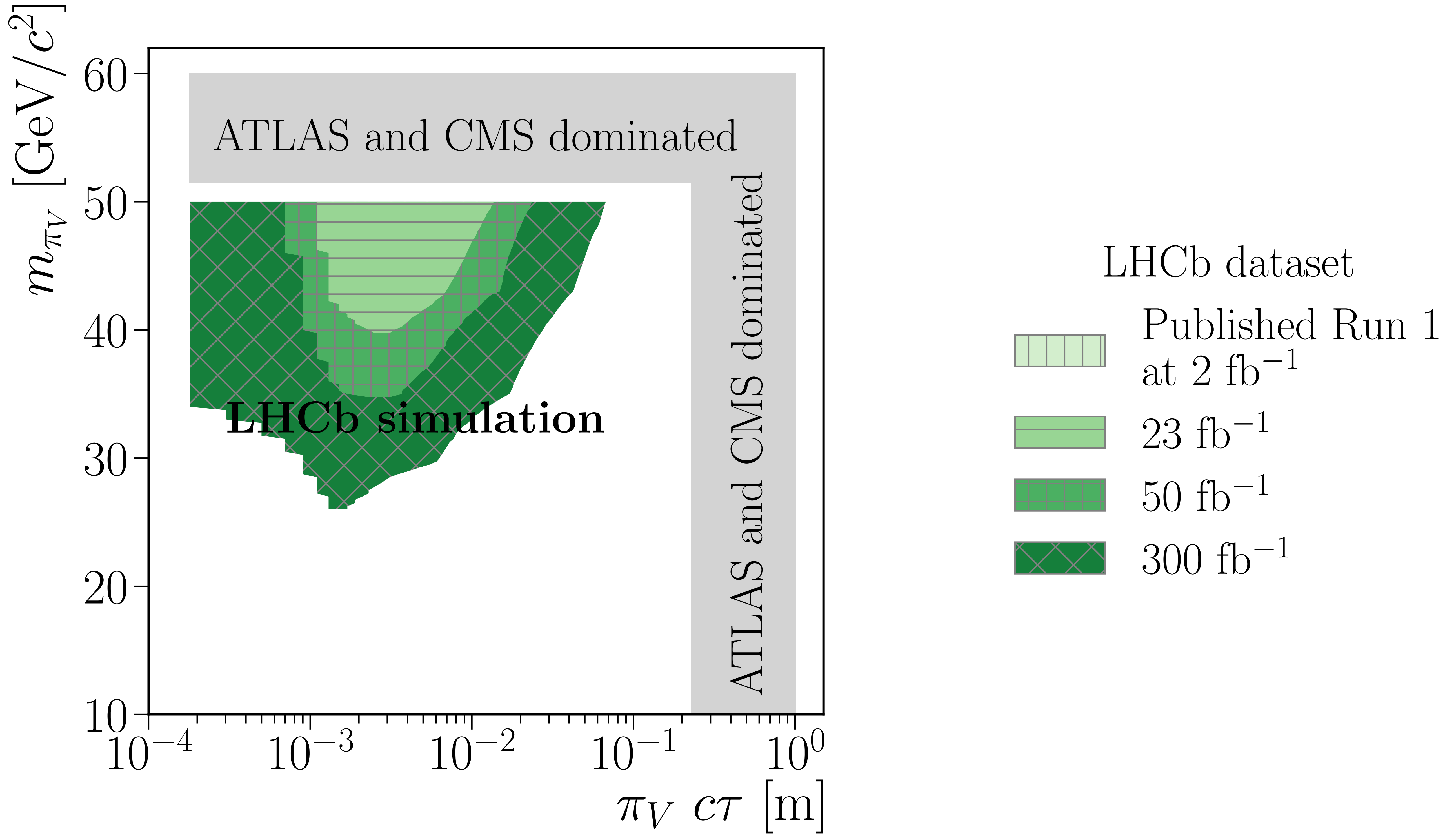


Higgs→LLP→jets pairs / 2



Higgs→LLP→jets pairs / 3





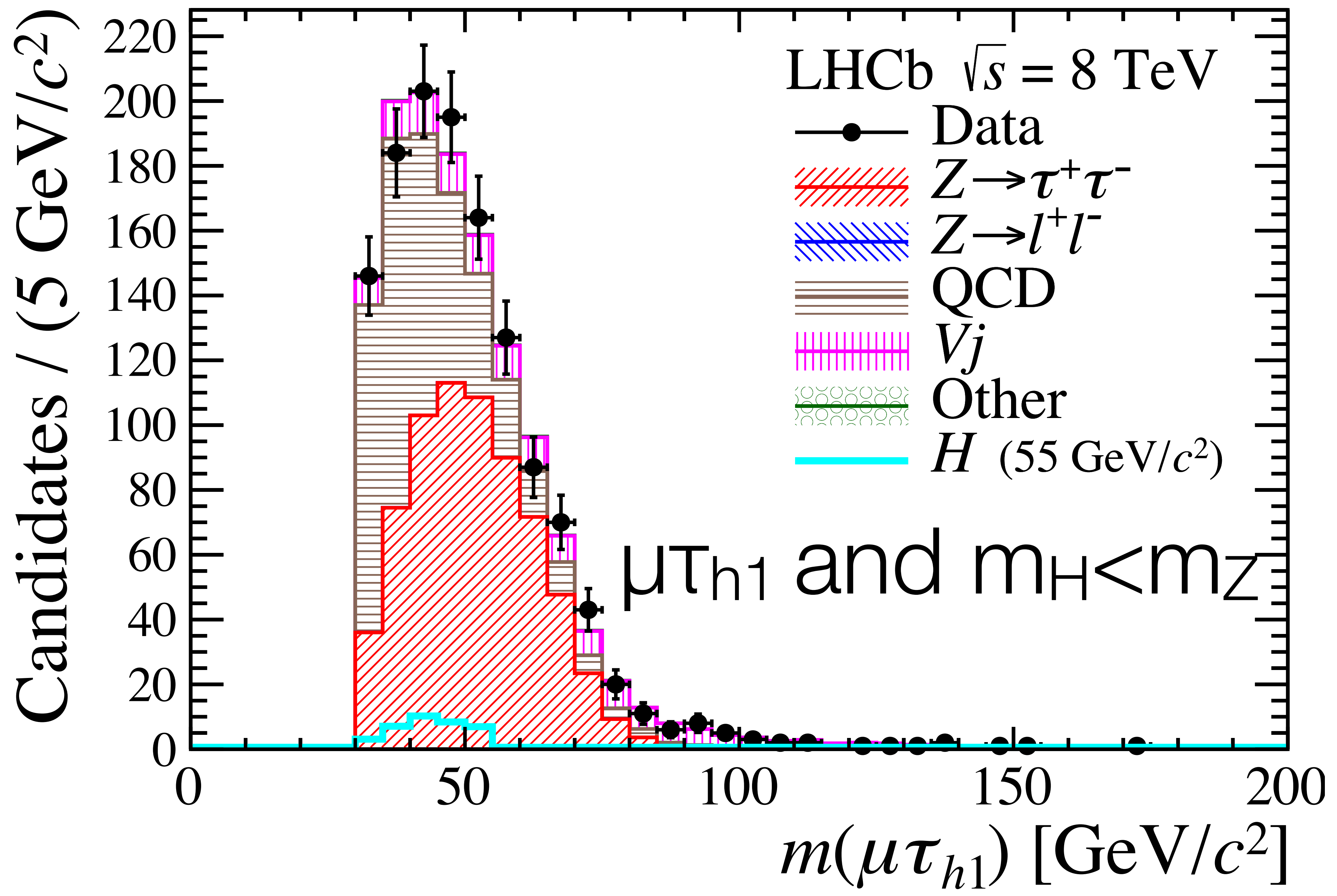
Bf(Higgs→π_V+π_V) < 20 %

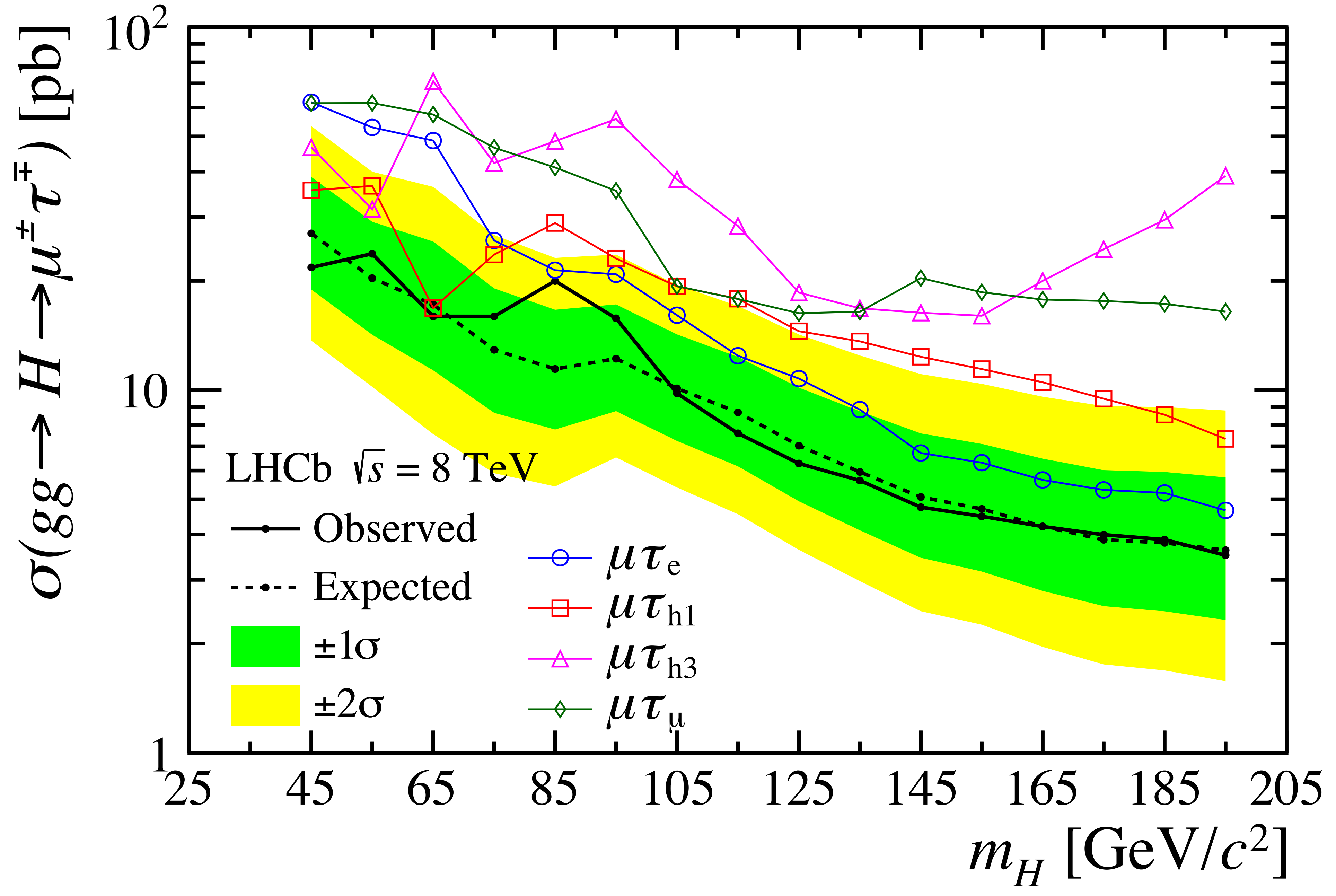
Bf(Higgs→π_V+π_V) < 2 %

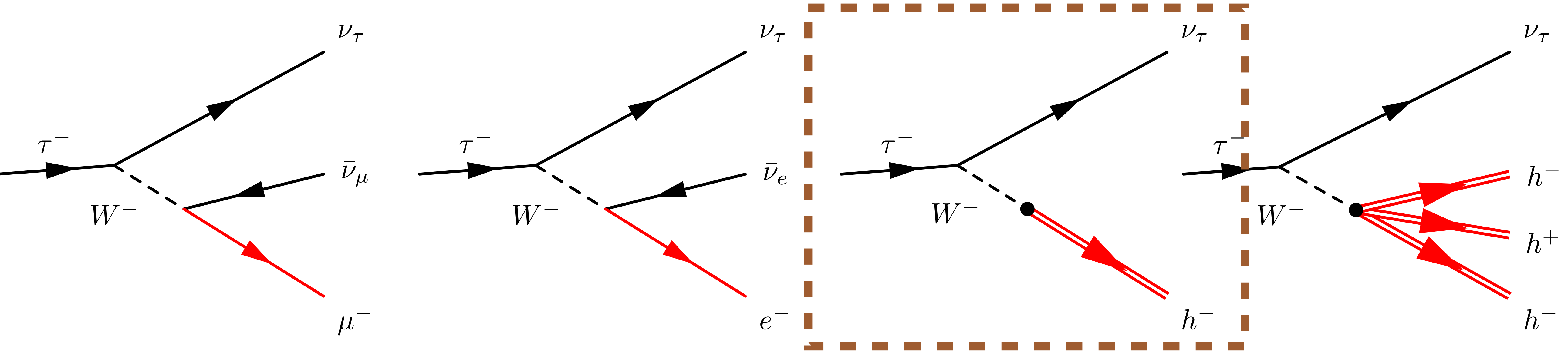
Eur.Phys.J. C78 (2018) no.12, 1008

H→μτ decays / 1

- Higgs-like boson decaying → μτ charged-lepton flavour-violating (CLFV)
- Analysis is separated into **four channels**
- **m_H=[45; 195] GeV** and **minimal flight distance** (impact parameter) of the reconstructed candidate is imposed
- Three different selections based on **m_H** w.r.t. **m_Z**
- Background dominated by **QCD**, **Z→ττ**, **Vj**
- No excess found



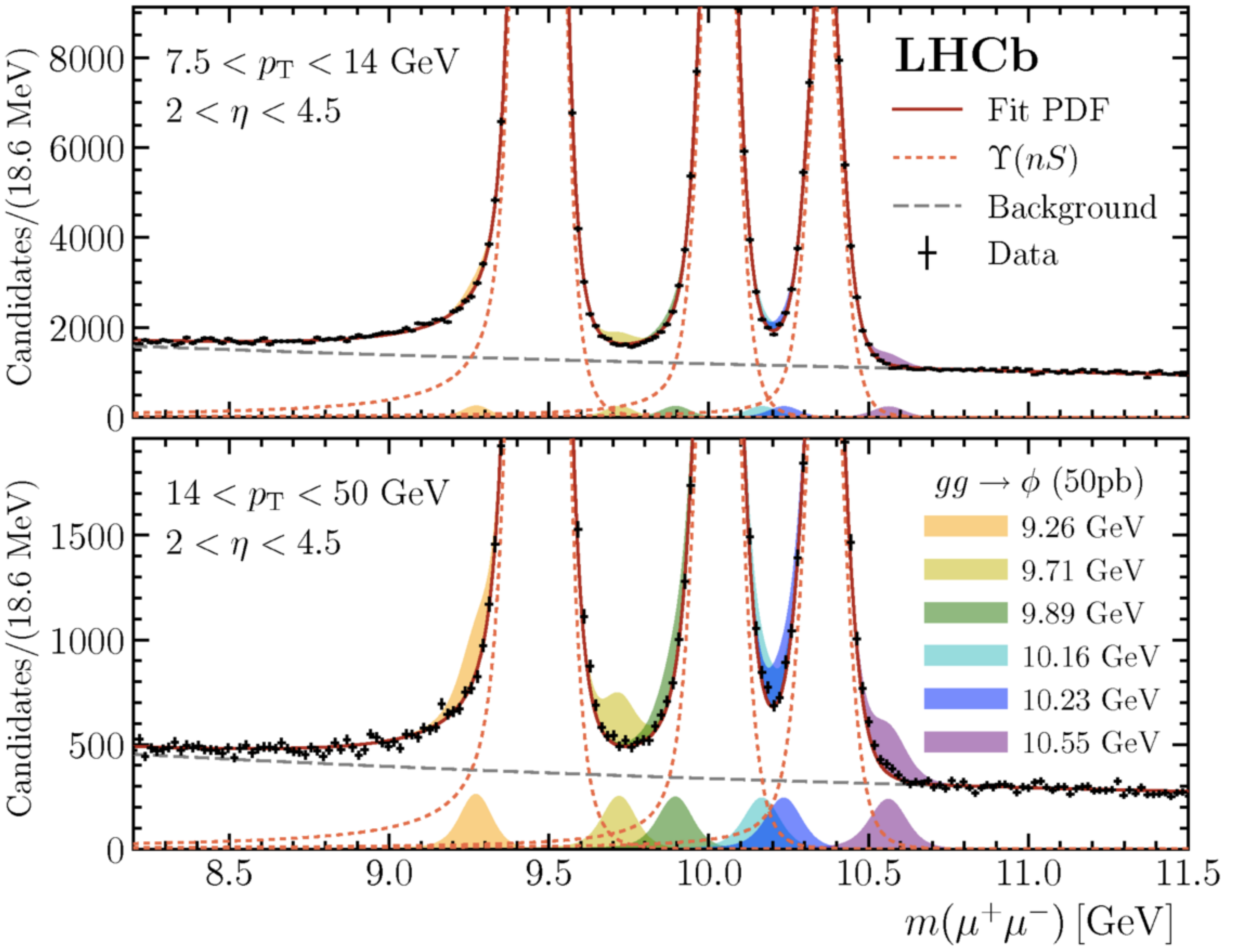




Searching in the Υ mass region / 1

JHEP 1809 (2018) 147

- Other light spin-0 particles in which LHCb can do well are light bosons from pp; **only Run 1**
- Spin-0 boson, ϕ, using Run 1 prompt $\phi \to \mu^+\mu^-$ decays, have been searched for
- Use **dimuon** final states:
  - Access to different mass window w.r.t $\gamma\gamma$ or $\tau\tau$ searches in 4π experiments
- Done in **bins of kinematics** ([p_T,η]) to maximise sensitivity
- Precise modelling of Υ(nS) tails to extend search range as much as possible
- **Mass independent** efficiency (uBDT)



Searching in the Y mass region / 2

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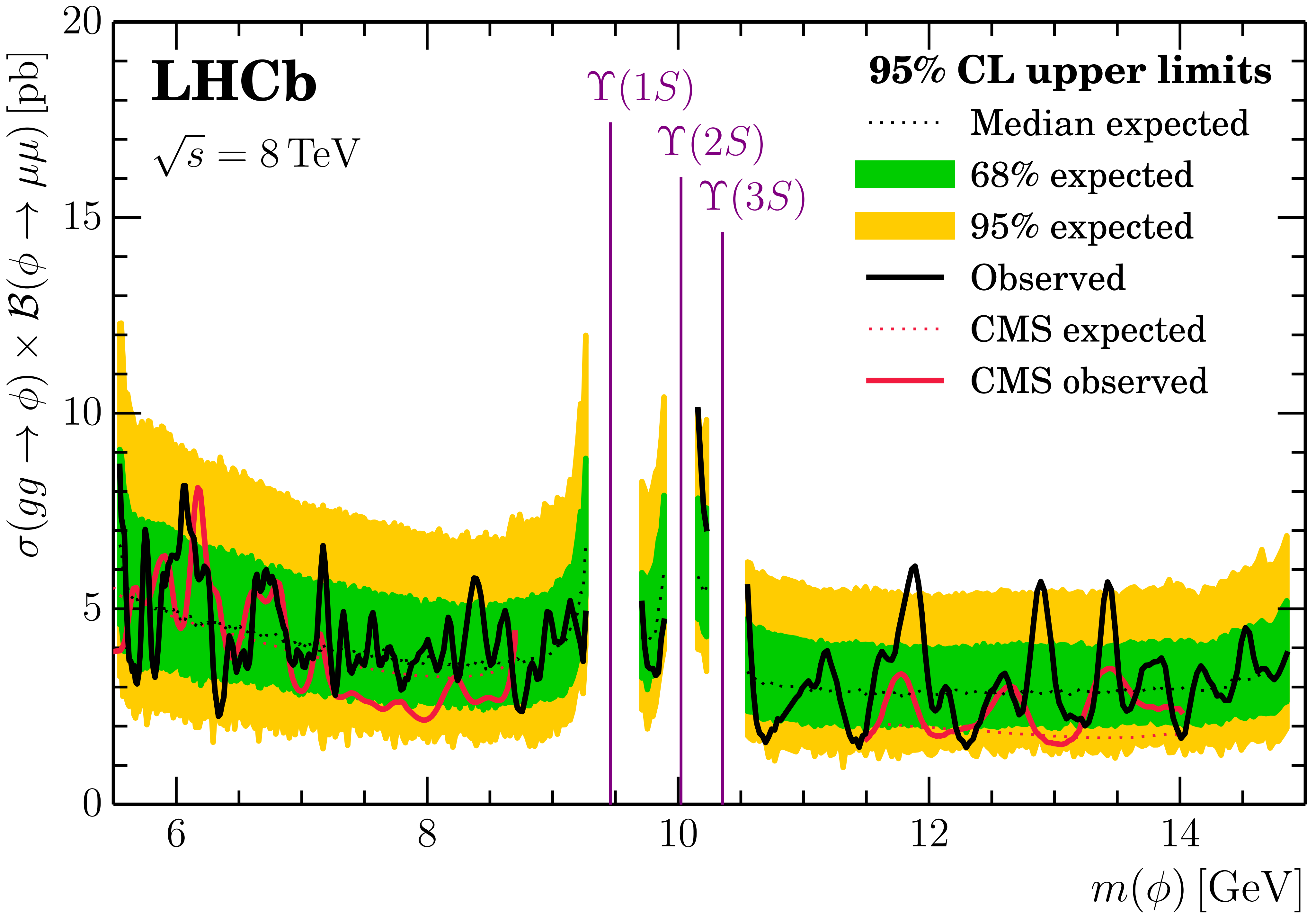
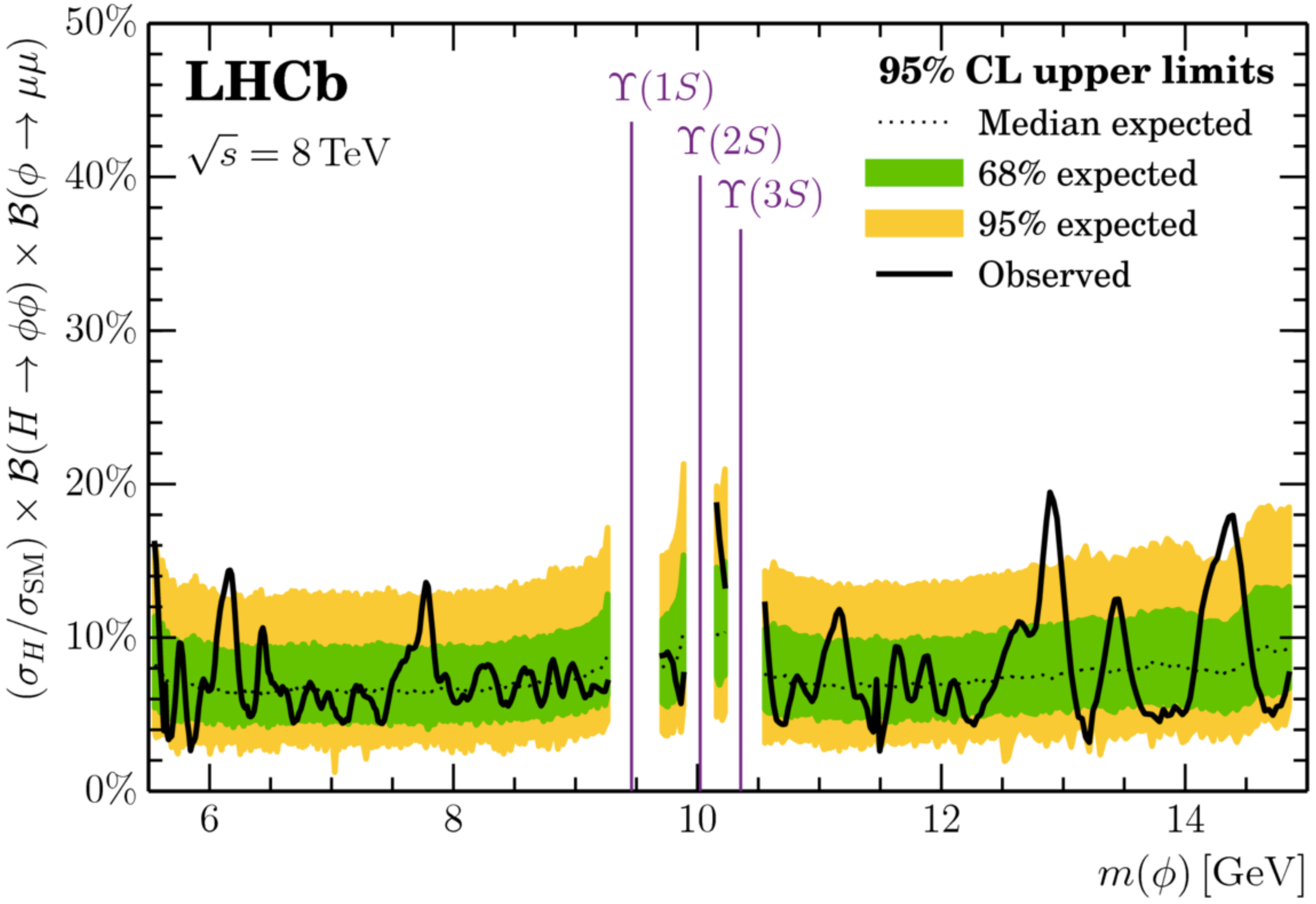
- Search for dimuon resonance in **$m_{\mu\mu}$ from 5.5 to 15 GeV** (also between Y(nS) peaks)
- No signal: limits on σ•BR set on (pseudo)scalars as proposed by **Haisch** & **Kamenik** [1601.05110]
- First limits in 8.7-11.5 GeV region - elsewhere competitive with CMS
- Interpreted as a search for a scalar produced through the SM Higgs decay





Conclusions

- LHCb has an **extensive program** of searches even beyond flavour physics
  - Searches for **on-shell** and **off-shell** new physics from heavy flavour decays
  - Searches for **long-lived** particles with low mass and short lifetime
  - Searches for **dimuon resonances** in very broad parameter space
- Bright future ahead:
  - 3 fb^{-1} in Run 1, 7 fb^{-1} in Run 2 (with larger cross-sections); LHCb Upgrade II: 300 fb^{-1}
  - A lot of potential in the upgraded trigger (also 5x luminosity)

<table>
<tr><th>2019</th><th>2020</th><th>2021</th><th>2022</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th><th>2031</th><th>2032</th><th>203+</th></tr>
<tr><td colspan="2">LS2</td><td colspan="3">RUN III</td><td colspan="3">LS3</td><td colspan="3">RUN IV</td><td colspan="2">LS4</td><td colspan="2">RUN V</td></tr>
<tr><td colspan="2">LHCb 40 MHz Upgrade Ia</td><td colspan="3">L = 2e33</td><td colspan="3">LHCb Upgrade Ib</td><td colspan="3">L = 2e33; 50 fb^{-1}</td><td colspan="2">LHCb Upgrade II (proposed)</td><td colspan="2">L = 2e34; 300 fb^{-1} (proposed)</td></tr>
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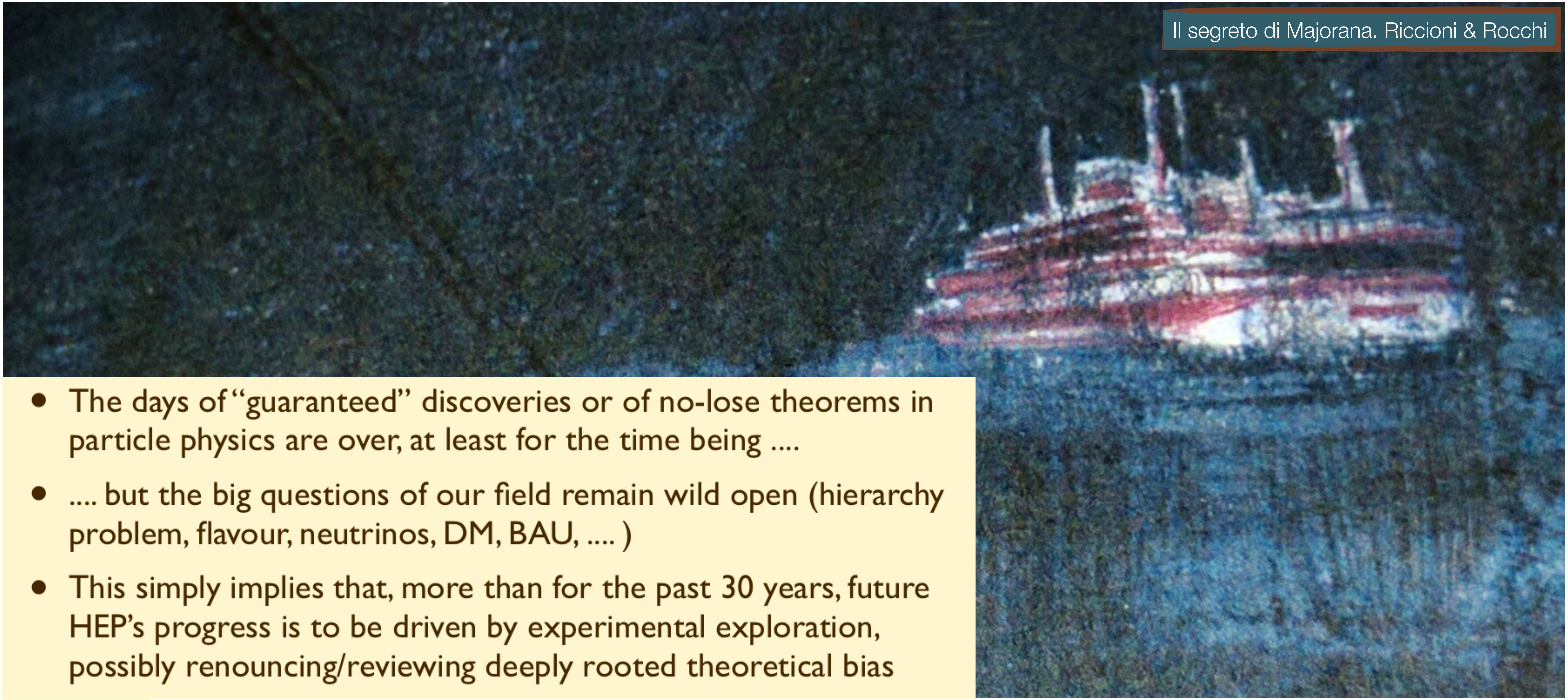


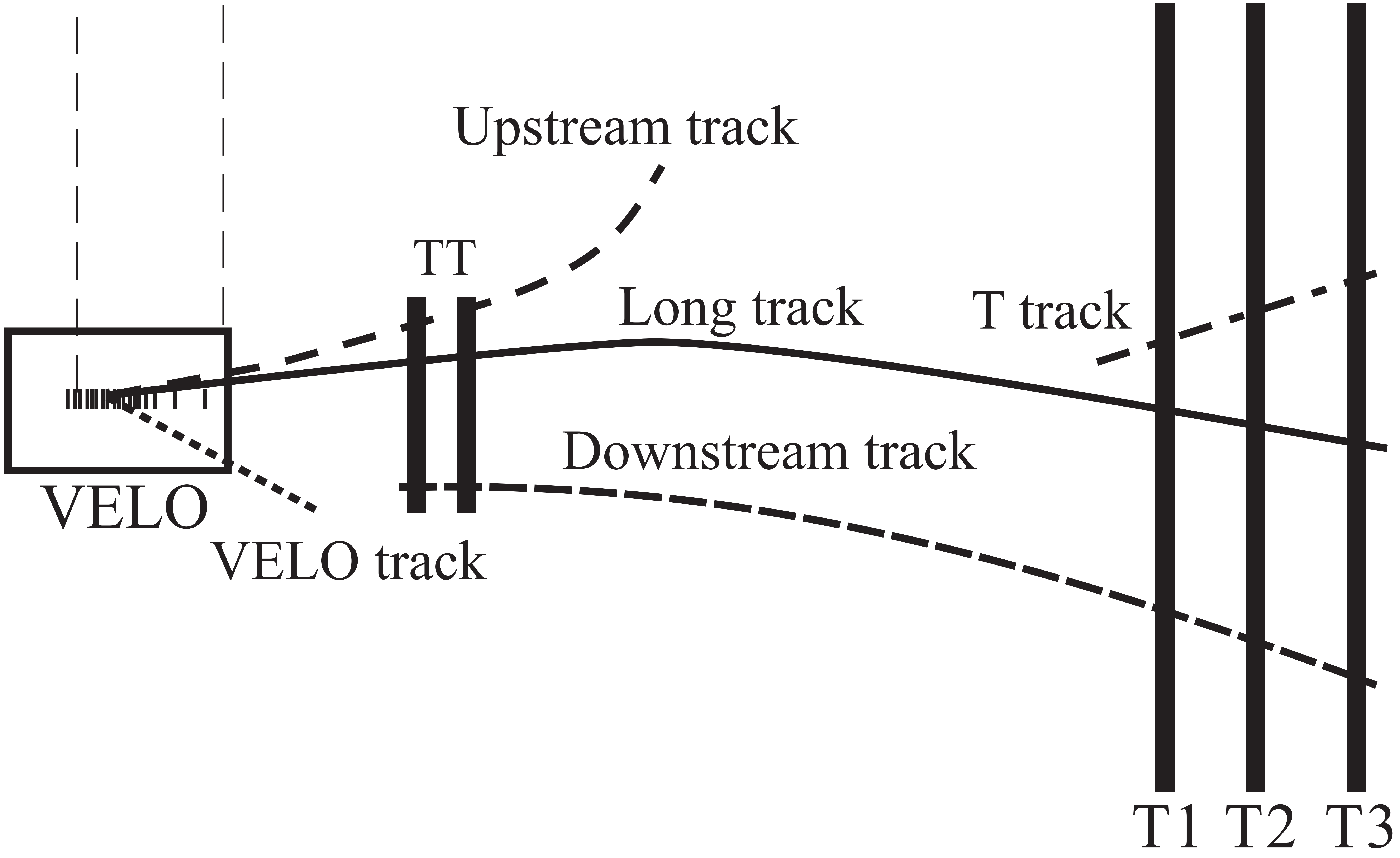
- The days of "guaranteed" discoveries or of no-lose theorems in particle physics are over, at least for the time being ....
- .... but the big questions of our field remain wild open (hierarchy problem, flavour, neutrinos, DM, BAU, ...)
- This simply implies that, more than for the past 30 years, future HEP's progress is to be driven by experimental exploration, possibly renouncing/reviewing deeply rooted theoretical bias

M. Mangano

Thanks

Federico Leo Redi

LHCb track types



Mass resolution

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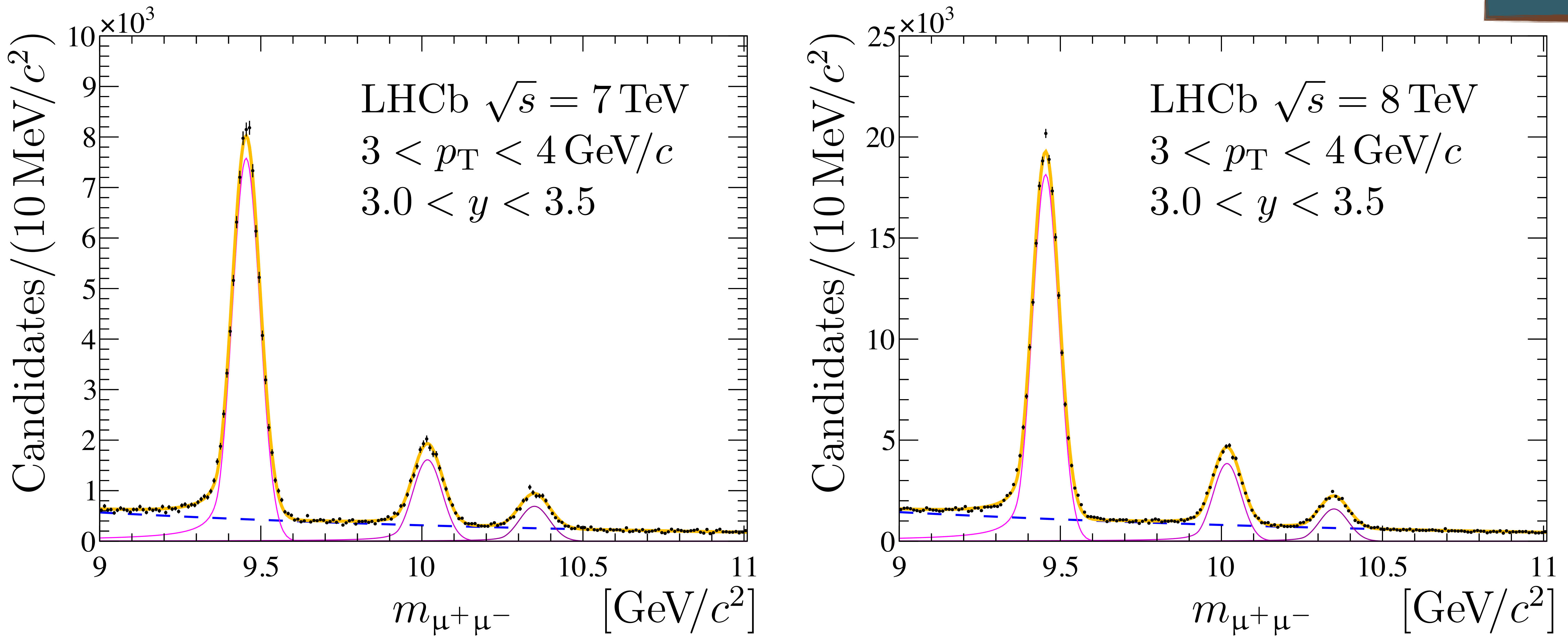


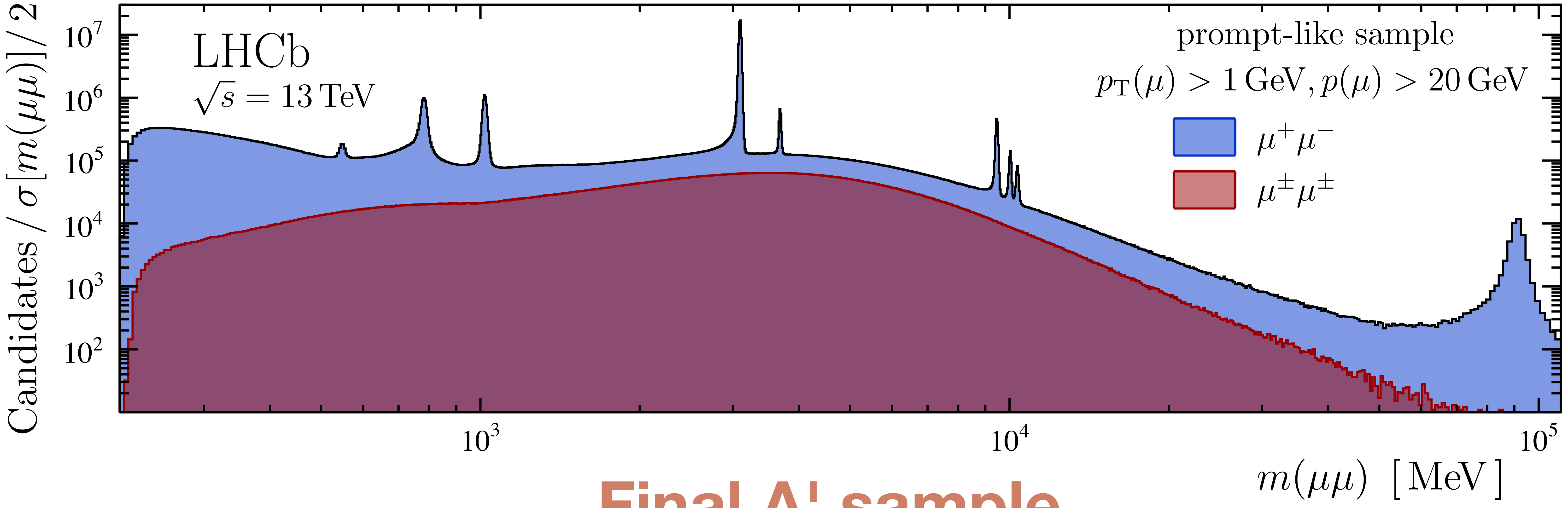
Figure 1: Efficiency-corrected dimuon mass distributions for (left) $\sqrt{s} = 7\,\text{TeV}$ and (right) $\sqrt{s} = 8\,\text{TeV}$ samples in the region $3 < p_T < 4\,\text{GeV}/c$, $3.0 < y < 3.5$. The thick dark yellow solid curves show the result of the fits, as described in the text. The three peaks, shown with thin magenta solid lines, correspond to the $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ signals (left to right). The background component is indicated with a blue dashed line. To show the signal peaks clearly, the range of the dimuon mass shown is narrower than that used in the fit.

Searching for Dark Photons / 1

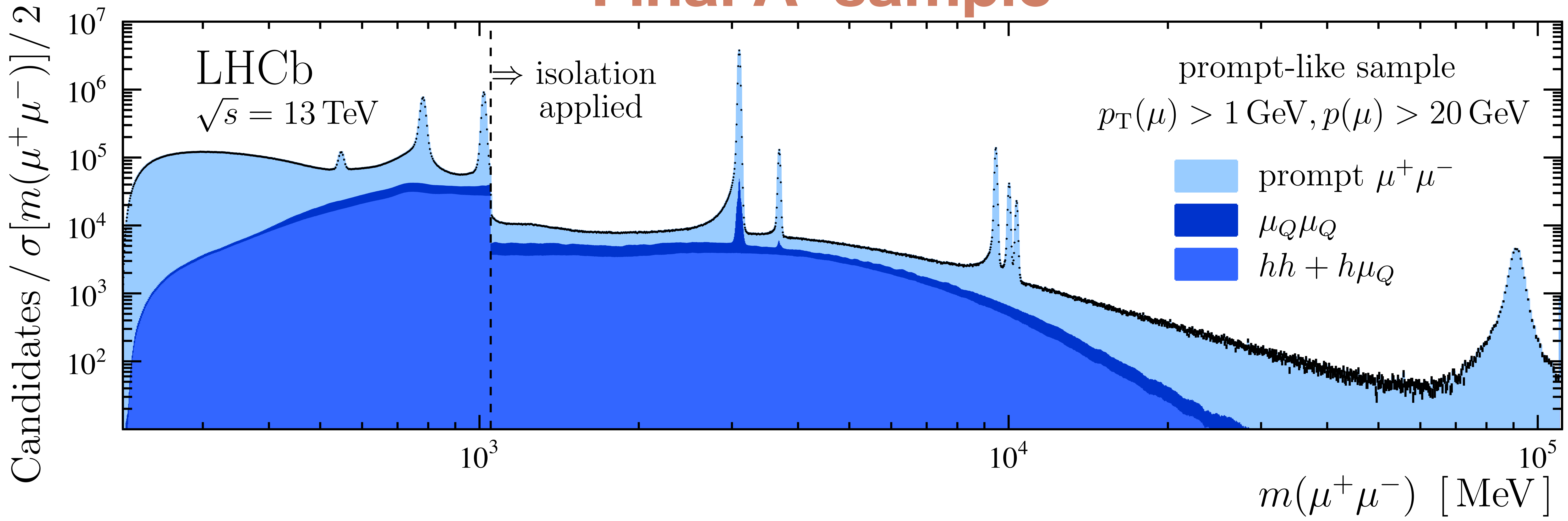
Phys. Rev. Lett. 120, 061801 (2018)

- Suppressing misidentified (non-muon) backgrounds and reducing the event size enough to record the **prompt-dimuon sample**
- Accomplished these by moving to **real-time calibration** in Run 2
- Hardware trigger is still there, and only ~10% efficient at low pT

Trigger output



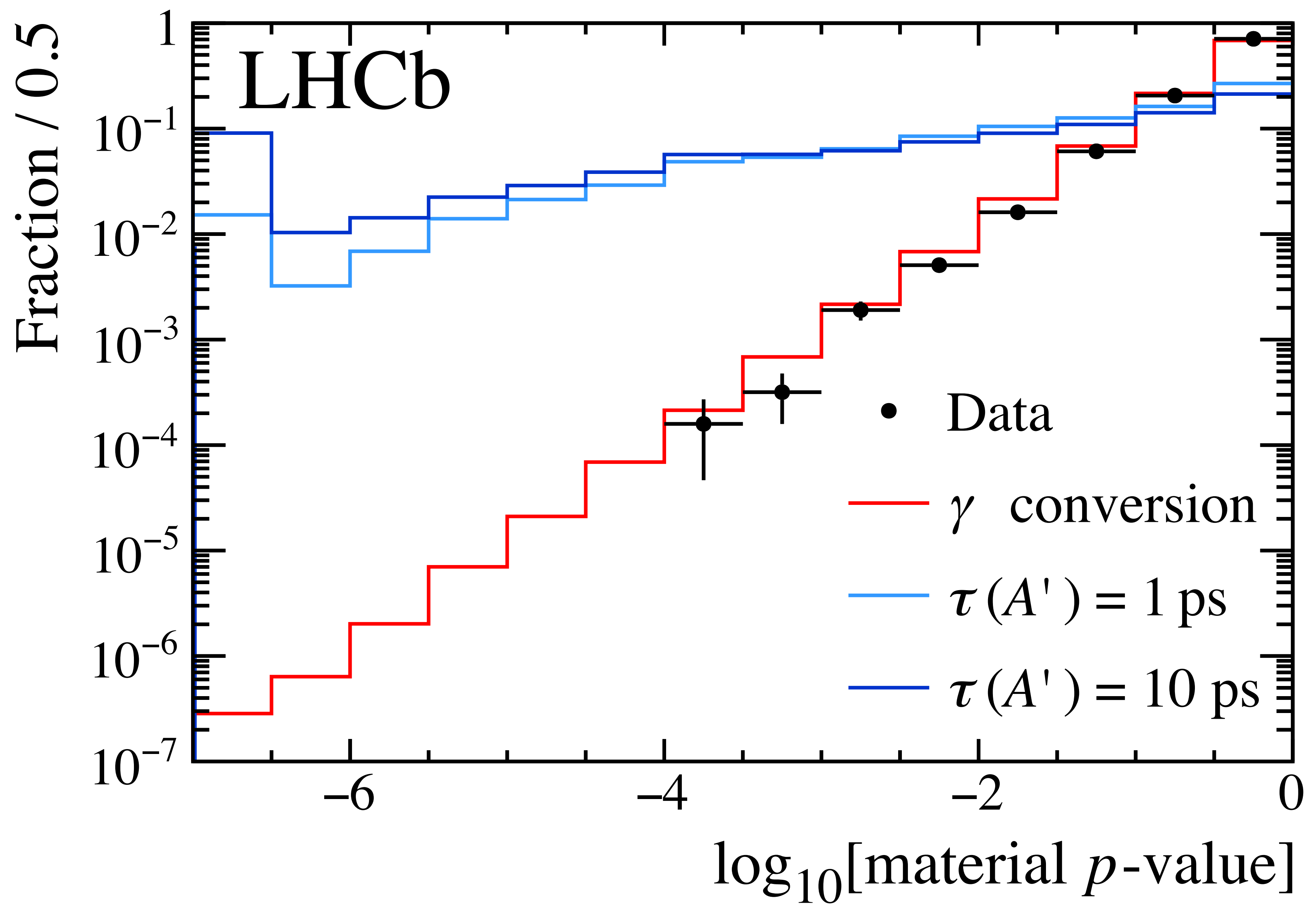
Final A' sample

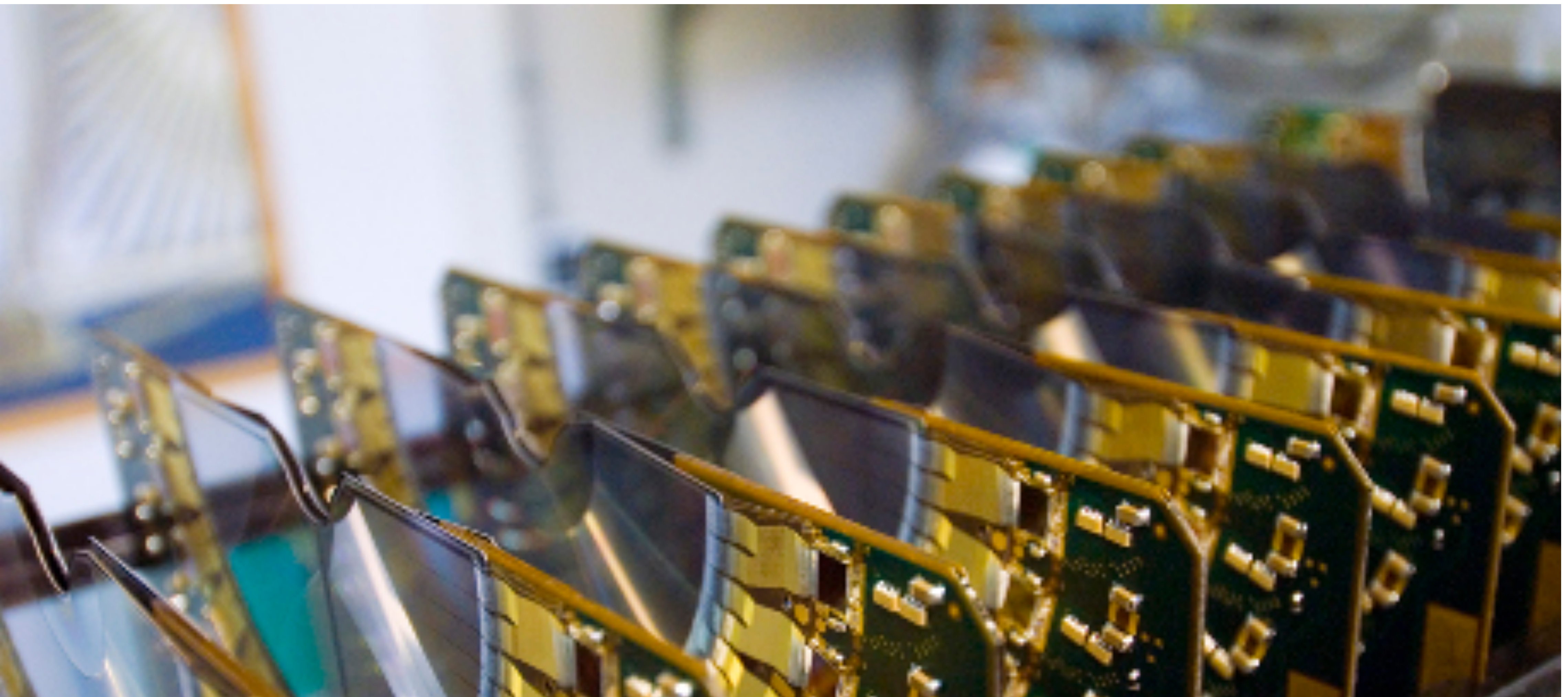


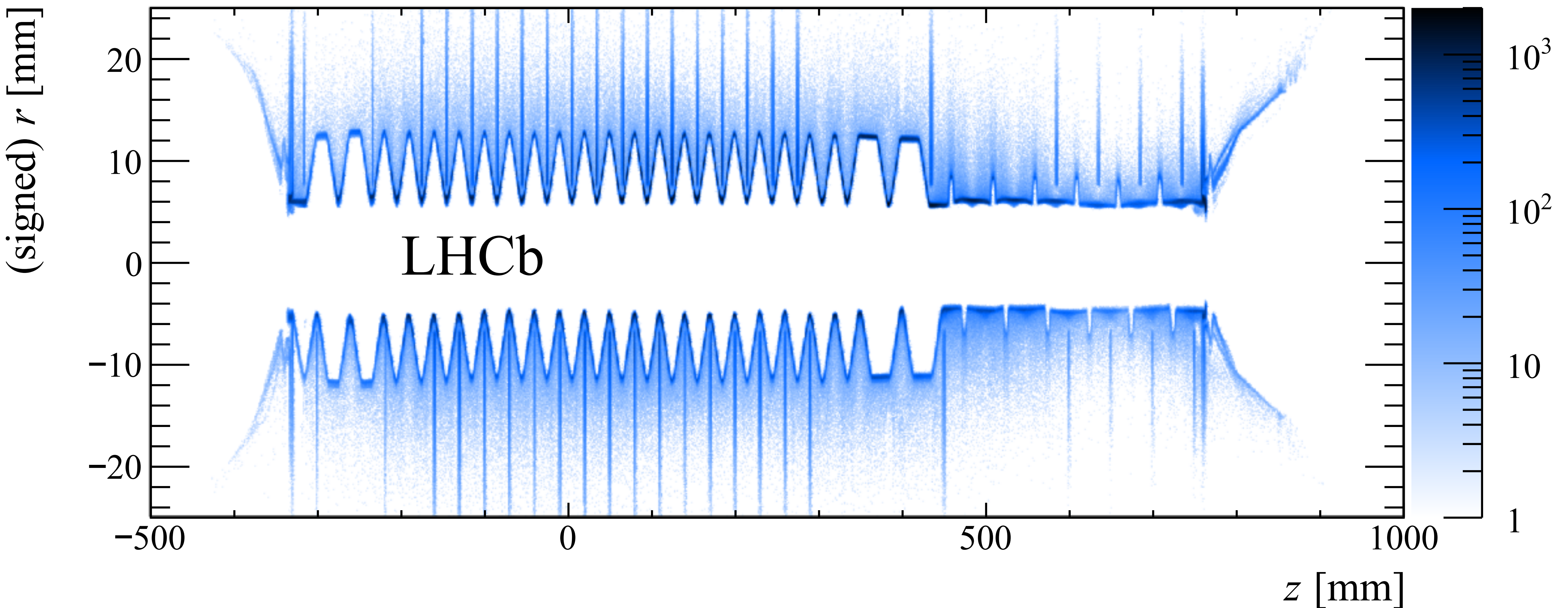
Searching for Dark Photons / 2

arXiv:[1803.07466]

- Background dominated by **material interactions** for displaced searches at LHCb
- Precise knowledge of the location of the material in the LHCb VELO is essential to reduce the background in searches for long-lived exotic particles
- LHCb data calibration process can align active sensor elements, an **alternative approach** is required to fully map the VELO material



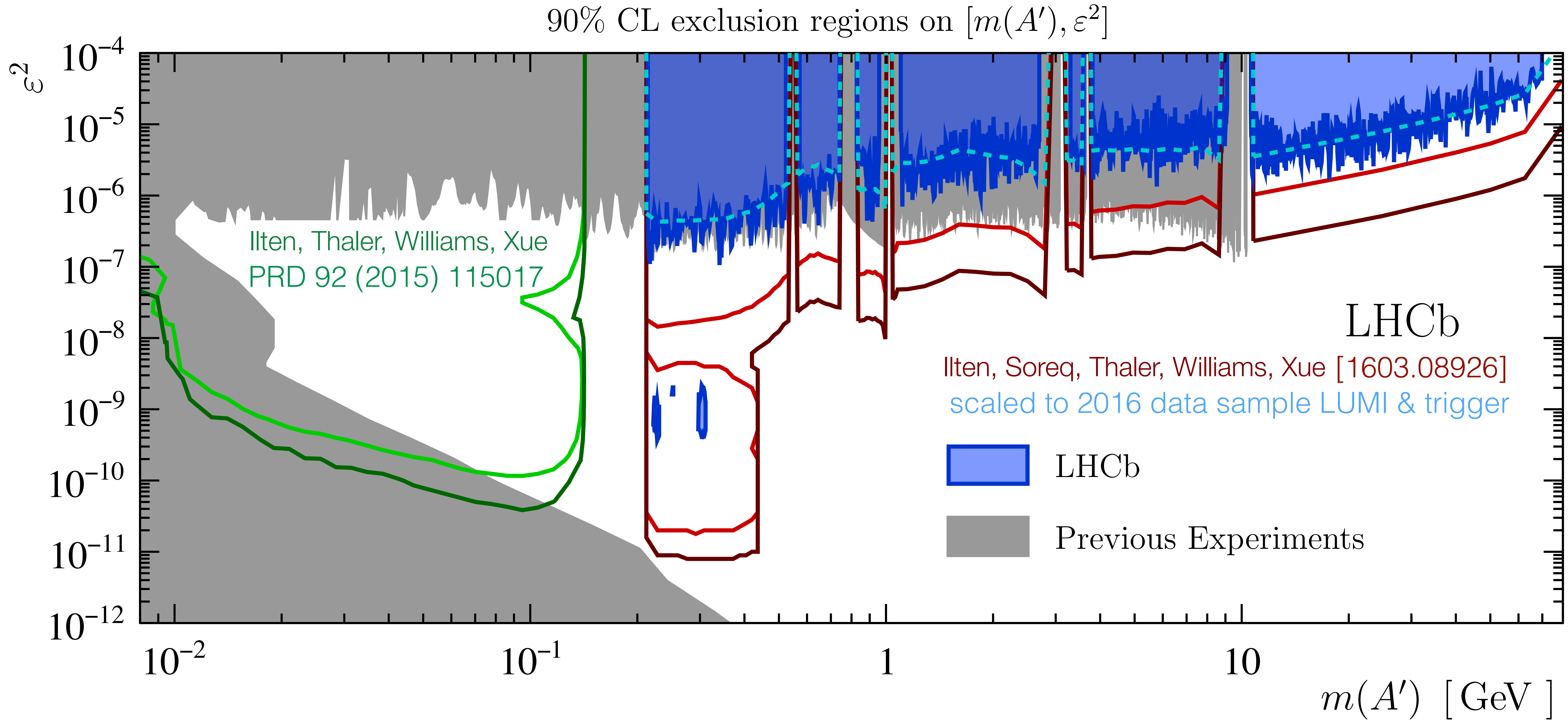




Search for Dark Photons / Results

Phys. Rev. Lett. 120, 061801 (2018)

- The 2016 dimuon results are consistent with (better than) predictions for prompt (long-lived) dark photons as discussed in [1603.08926]. We implemented huge improvements in the 2017 triggers for low masses, so plan quick turn around on 2017 dimuon search - then onto electrons.



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$H \to \mu\tau$ decays / 1bis

from top to bottom: $\mu\tau_e$, $\mu\tau_{h1}$, $\mu\tau_{h3}$, $\mu\tau_\mu$

from L to R: $\mu\tau_\mu$, $\mu\tau_e$, $\mu\tau_{h1}$, $\mu\tau_{h3}$,