Recent results on exotica searches at LHCb

Implications of LHCb measurements and future prospects workshop

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Outline

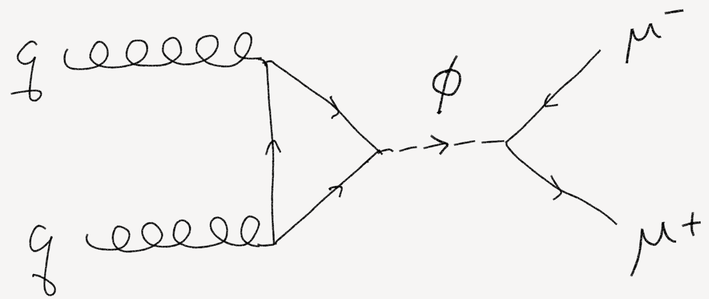
- Last public exotica searches at LHCb
  - Search for a dimuon resonance in the ϒ mass region
  - Search for lepton-flavour-violating decays of Higgs-like bosons
- Future prospects:
  - Dark Photons
  - Axion like particles
  - Displaced jets from hidden valley pions

} *Trigger studies*

Search for a dimuon resonance in the Υ mass region

JHEP 08 (2018) 147

- search for a spin-0 boson using Run I data (3 fb^{1})
- ϕ produced via gluon fusion
- looking for prompt $\phi \to \mu^+\mu^-$ decays
- mass window [5.5, 15] GeV/c^2

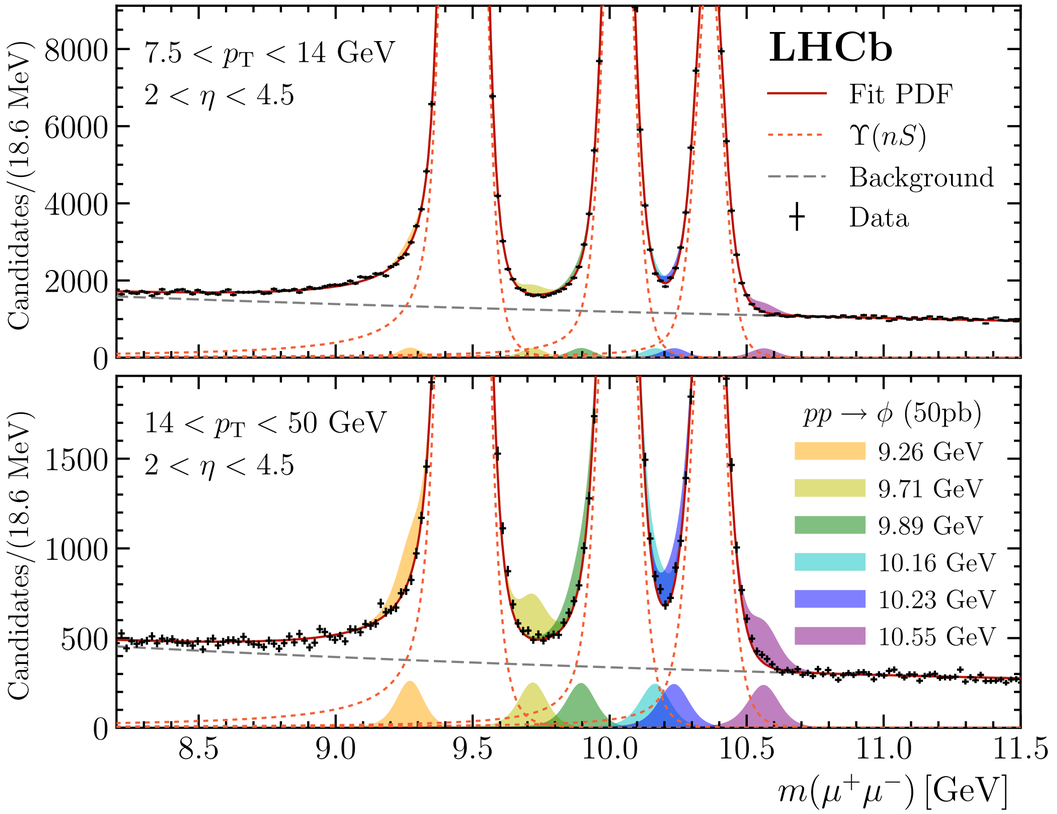


LHCb excellent mass resolution allows to explore regions near and between the Υ resonances for the first time in pp collisions

Search for a dimuon resonance in the ϒ mass region

- μμ candidate:
  - two oppositely charged tracks identified as muons, passing muon triggers (1 muon with p_T > 10 GeV/c or 2 muons p_T > 4.7 GeV/c and m(μμ) > 4.8 GeV/c²)
  - good vertex quality, consistent with the primary vertex
  - reconstructed proper time < 0.1 ps
- Backgrounds:
  - ϒ(nS) (n = 1, 2, 3) resonances
  - μμ from Drell-Yan
  - μμ from heavy flavour decays
  - μπ, prompt π misidentified as muon

reduced using a uBoost technique



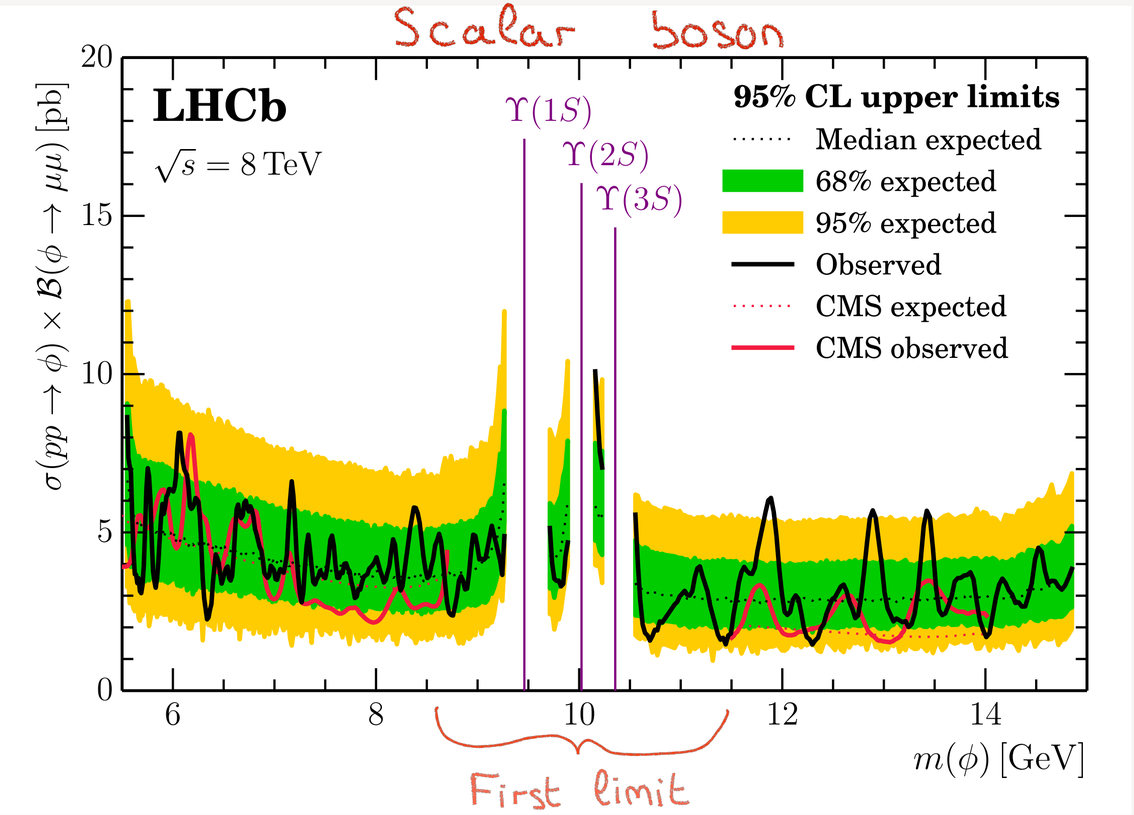
Look for μμ resonances from 5.5 to 15 GeV/c² in bins of $p_T(\phi)$ and $\eta(\phi)$ to provide **model independent** results.

↳ From 7,5 to 50 GeV/c

Search for a dimuon resonance in the ϒ mass region

No excess observed. Limits on production cross-section (8 TeV) for scalar boson:

Competitive limits w.r.t. CMS

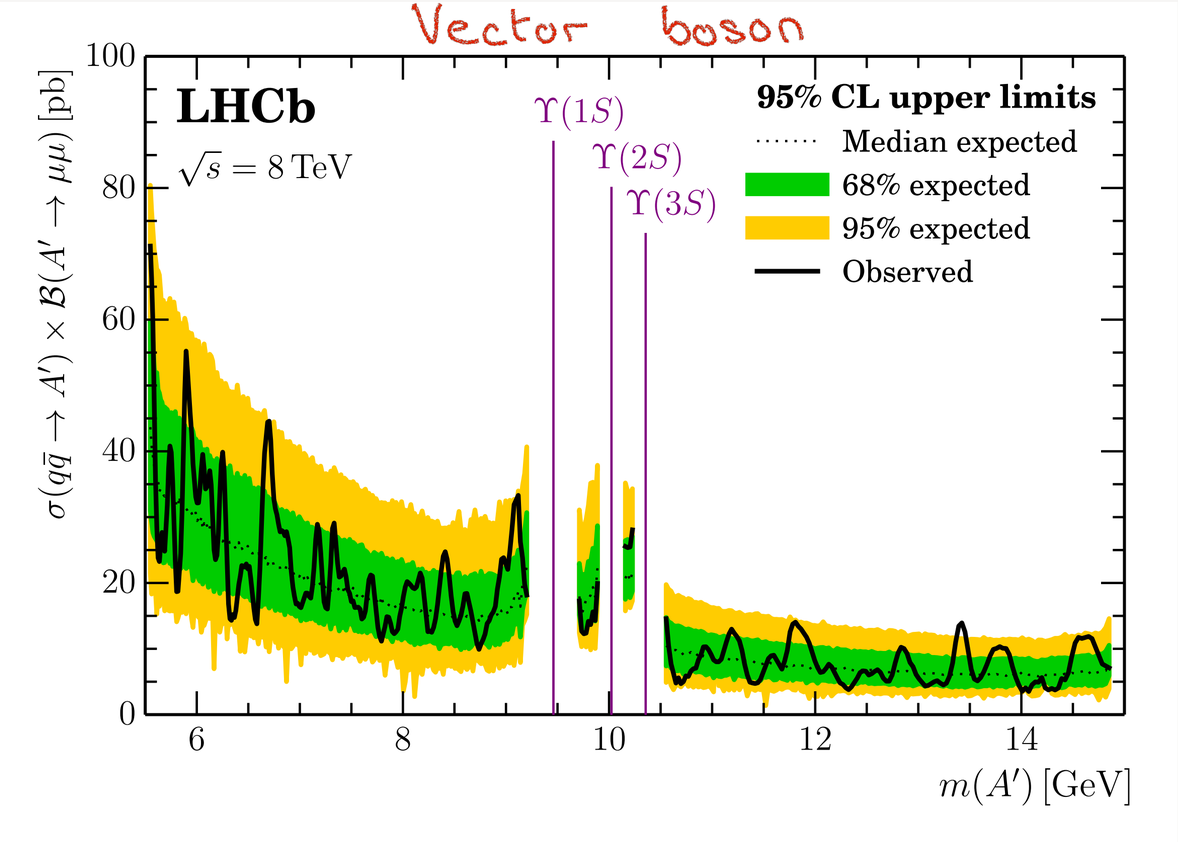


Model independent limits also provided for each p_T and η bin.

Search for a dimuon resonance in the ϒ mass region

Limits are also computed for the case of a vector boson produced via Drell-Yan.

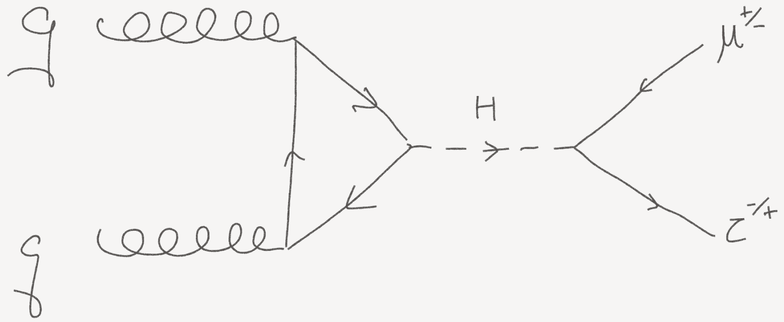
In other words limits for a prompt dark photon decaying to dimuon using Run I data.

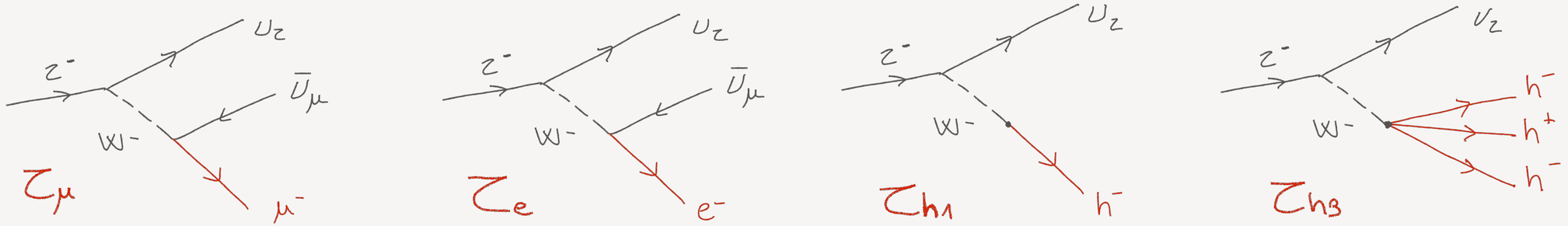


Search for lepton-flavour-violating decays of Higgs-like bosons

Submitted to EPJC

- search for a spin-0 boson using Run I data (2 fb^{1})
- H produced via gluon fusion
- looking for prompt $H \to \mu^{\pm}\tau^{\mp}$ decays
- mass window [45, 195] GeV/c^2
- τ reconstructed in 4 channels:





h± assumed to be pions

Search for lepton-flavour-violating decays of Higgs-like bosons

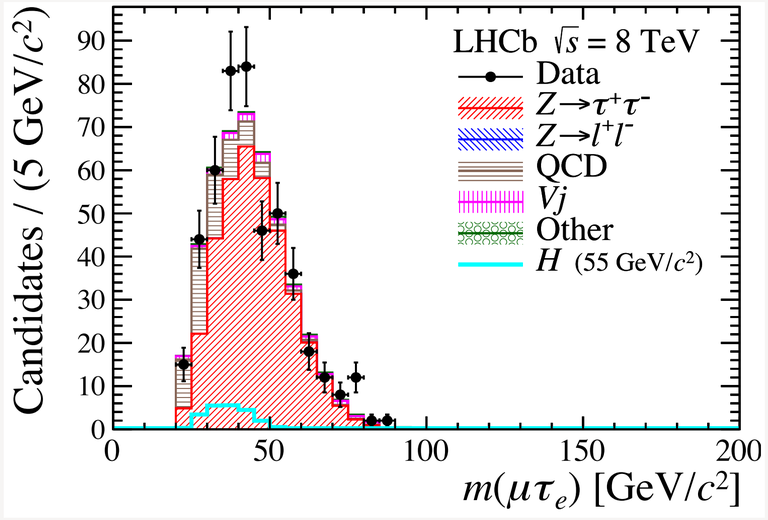
- Backgrounds: $Z \rightarrow \tau^+ \tau^-$, $Z \rightarrow l^+ l^-$ ($l = e,\mu$), heavy flavour production from QCD processes, electroweak boson production accompanied by jets (« Vj »)
- Selection:
  - trigger on muons or electrons $P_T > 15$ GeV/c
  - muons are required to be prompt, impact parameter < 50 μm
  - taus:
    - $\tau_e, \tau_{h1}, \tau_\mu$ track impact parameter > 10, 10, 50 μm, respectively
    - τ_{h3}, secondary vertex reconstructed, lifetime > 30 ps, mass < 3 GeV/c^2
  - muon and tau track required to originate from a common vertex and ~ back-to-back
  - optimized selections in three mass ranges, $\mathbf{m_H < m_Z}$, $\mathbf{m_H \sim m_Z}$ and $\mathbf{m_H > m_Z}$

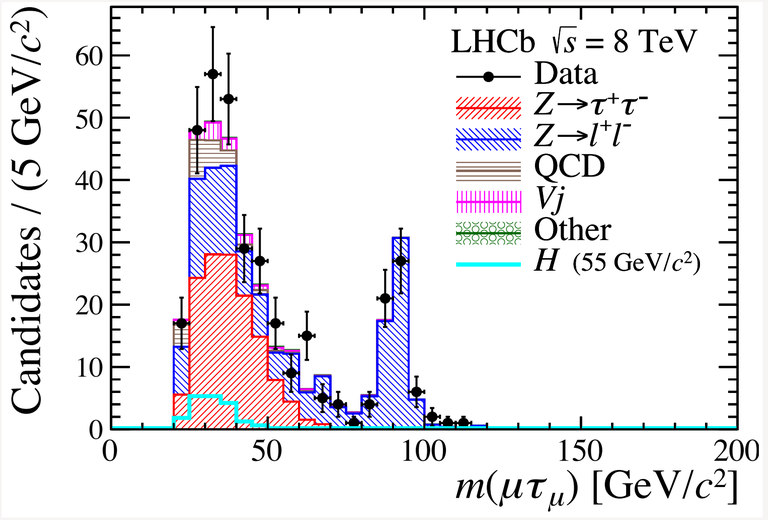
Search for lepton-flavour-violating decays of Higgs-like bosons

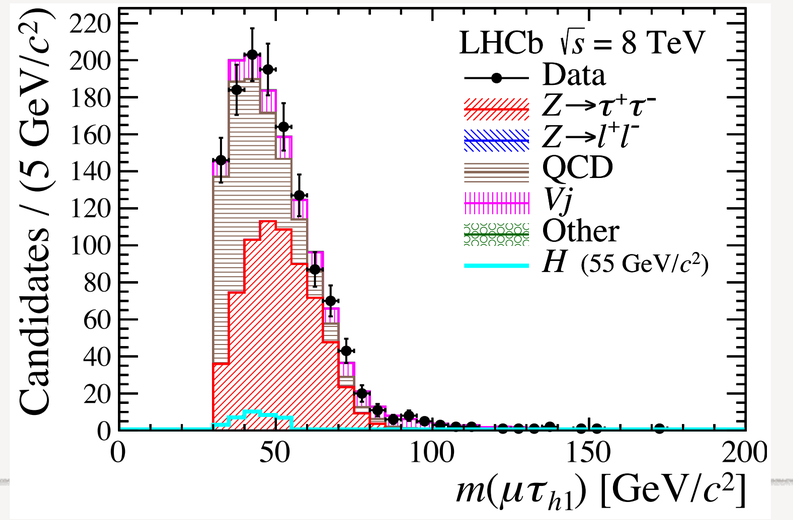
μτ invariant mass for the 4 τ channels.

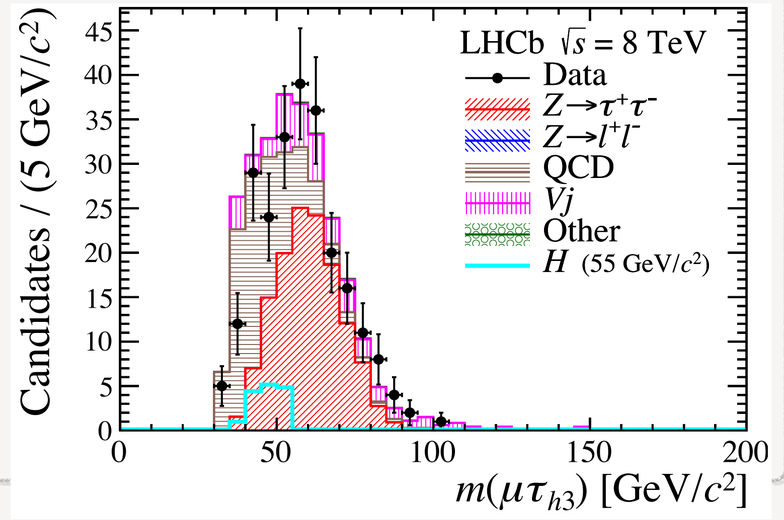
Example with m_H = 55 GeV/c^2 signal (normalized to √N)

Signal candidates are obtained from simultaneous fits of μτ invariant mass for the 4 τ channels.







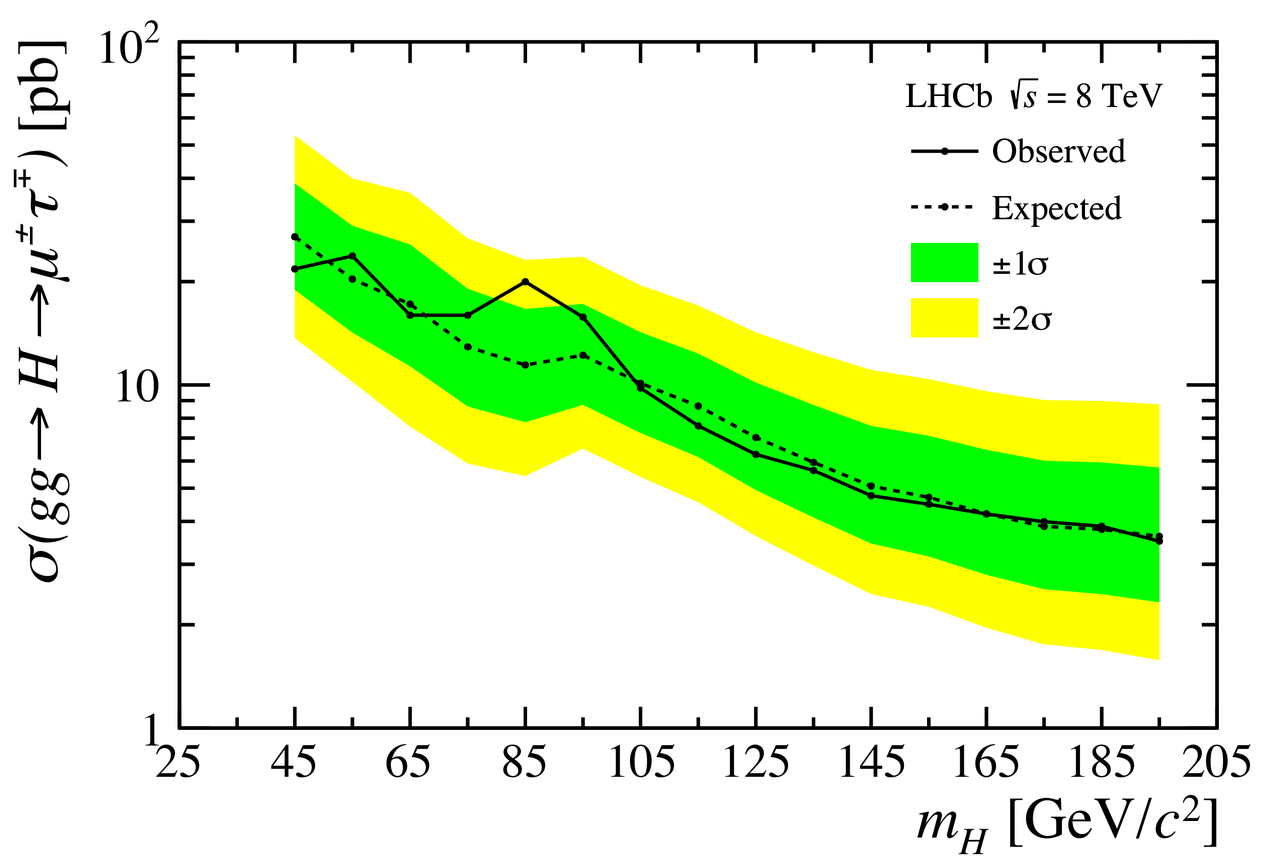


Search for lepton-flavour-violating decays of Higgs-like bosons

Results: fit results for all m_H are compatible with a null signal

95 % upper limits on:

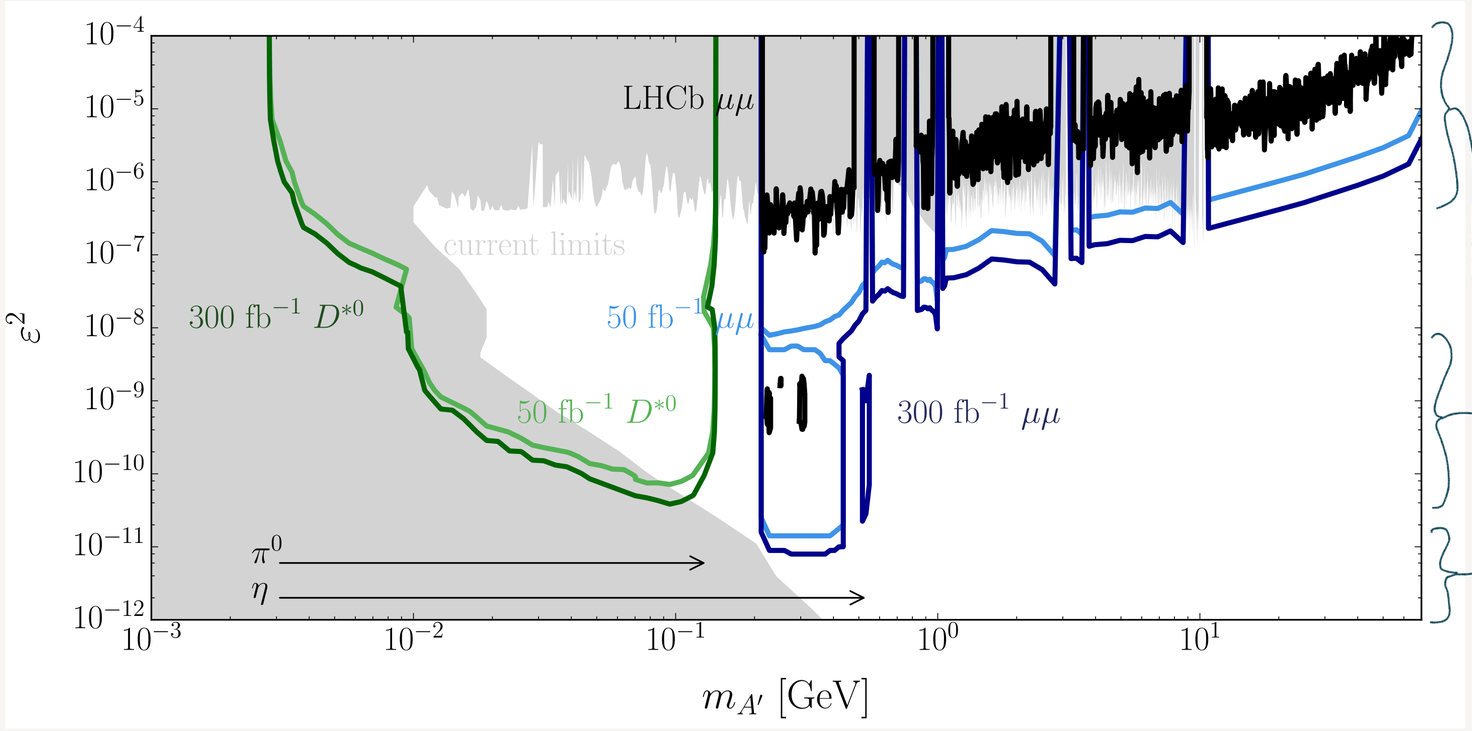
$$\sigma(gg \to H \to \mu^{\pm}\tau^{\mp})$$



Future prospects

Dark photons

Dark force U(1), analogous to EM force, involving a massive dark photon **A′** ($m_{A'}$) that mixes with the SM photon (ε) → 2 free parameters $\mathbf{m_{A'}}$ and $\boldsymbol{\varepsilon^2}$



Inclusive dark photons search using 1.6 fb^{-1} of 13 TeV pp collisions (black bands) **[PRL 120, 061801 (2018)]**

prompt A′ →μ⁺μ

displaced A′ →μ⁺μ

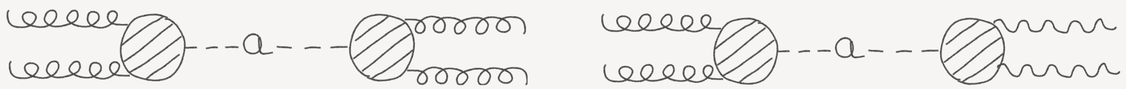
arrows: available mass ranges for dark photon produced in π⁰ → A′γ and η → A′γ decays, A′ →e⁺e.

Predicted discovery reach for 50/300 fb^{-1} for dark photons produced D*⁰ → D⁰A′, A′ →e⁺e⁻ decays, inclusive dimuons (A′ →μ⁺μ⁻).

Axion like particles: ALPs

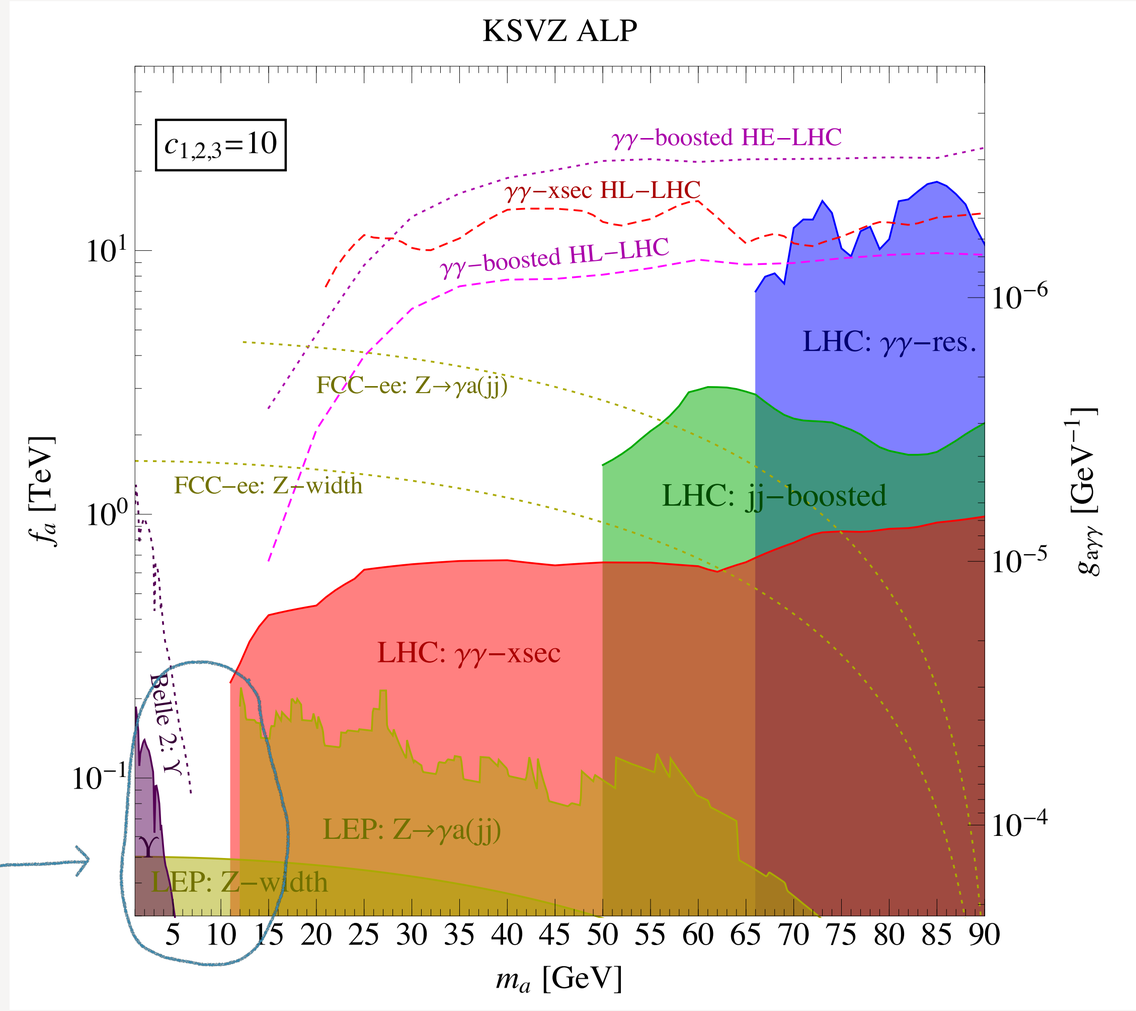
- Constraints from LHC resonance searches for $m_a \gtrsim 50$ GeV/c² for:

$a \to jj$ $\qquad$ $a \to \gamma\gamma$



- Poor limits for lower masses, computed from $\gamma\gamma$ cross-section measurements [PLB (2018) 06 039]

A LHCb search of $a \to \gamma\gamma$ could cover the region between 3 and 10 GeV/c² (see talk by K. Tobioka)



plot taken from Carlos Vazquez Sierra's talk at XIII meeting on B physics

ALPs to γγ at LHCb

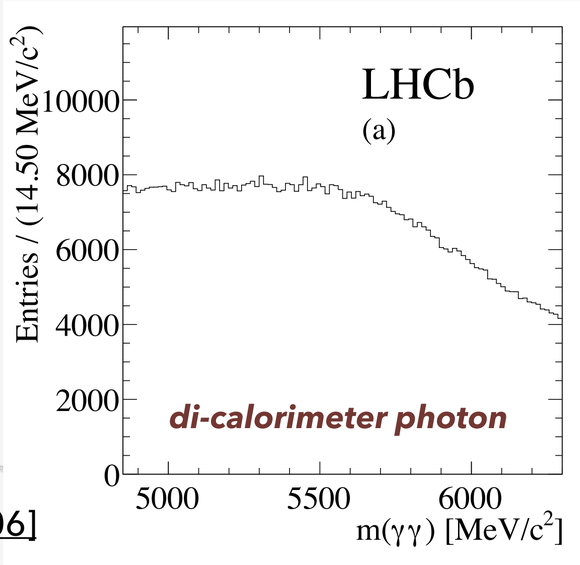
Can use the already existing trigger algorithm for $B_s^0 \to \gamma\gamma$

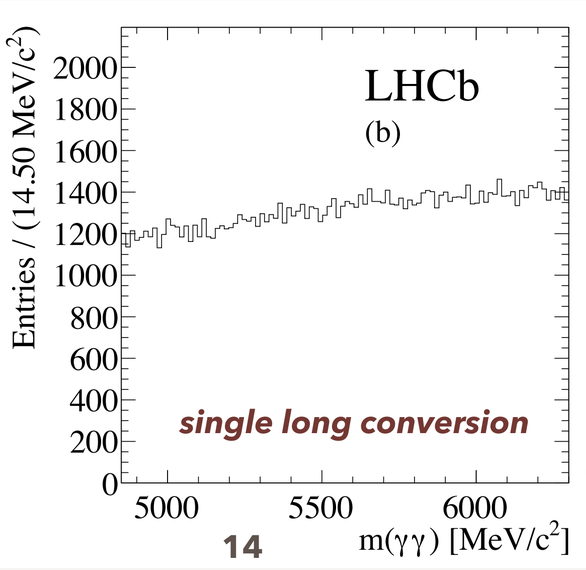
- Level 0 (L0) trigger: select converted and calorimeter γ
- High level trigger 1 (HLT1):
  - Pre-filters L0 candidates by E_T
  - Combine two candidates to form γγ and filter again by E_T, P_T and m(γγ)
- HLT2: BDT algorithm trained between simulated $B_s^0 \to \gamma\gamma$ and data

HLT1 requirements

Requirement	Value
$E_{\mathrm{T}}(\gamma)$ [GeV]	> 3.5
$E_{\mathrm{T}}(\gamma_1) + E_{\mathrm{T}}(\gamma_2)$ [GeV]	> 8
$M(\gamma_1\gamma_2)$ [GeV/c^2]	$[3.5, 6.0]$
$p_{\mathrm{T}}(\gamma_1\gamma_2)$ [GeV/c]	> 2

Trigger output:





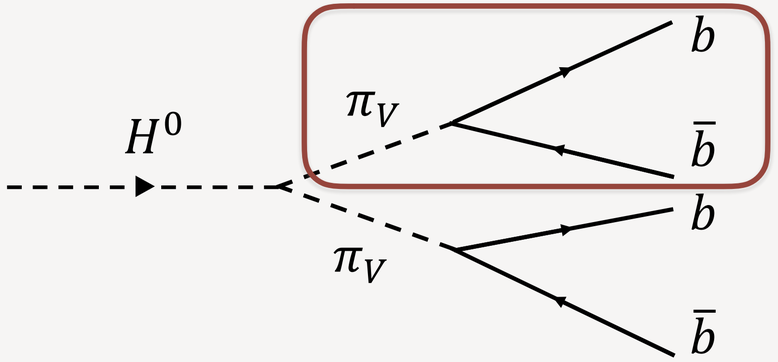
In **2018** the trigger selection is **adjusted for ALPs**, for instance mass range is extended to 12 GeV/c²

a → γγ Search planned using LHCb 2018 data

[LHCb-PUB-2018-006]

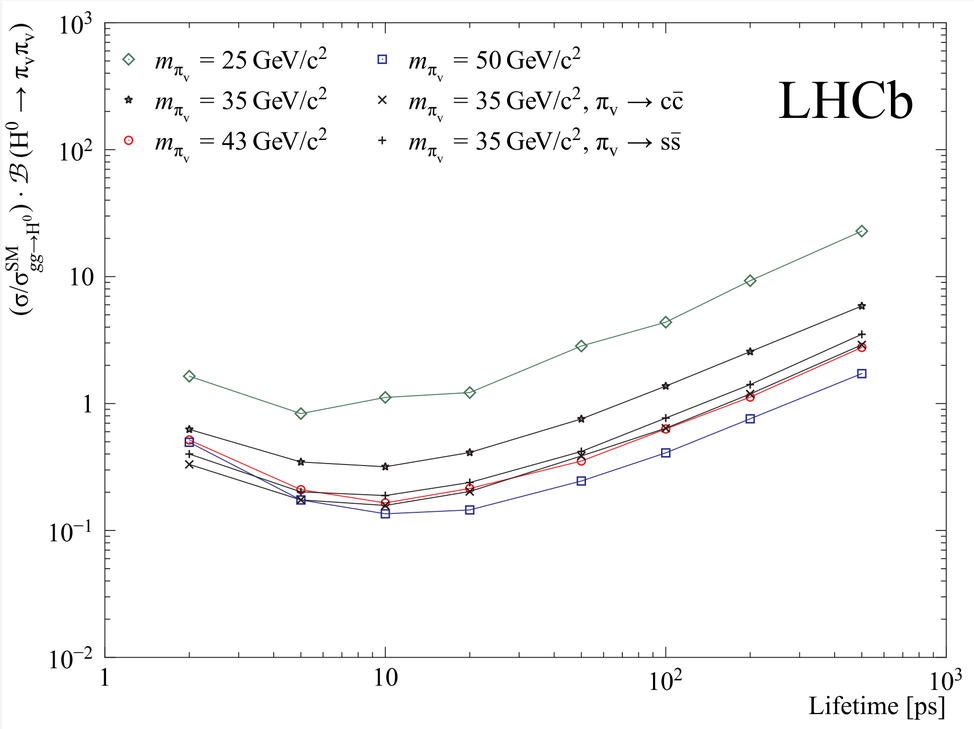
Displaced jets

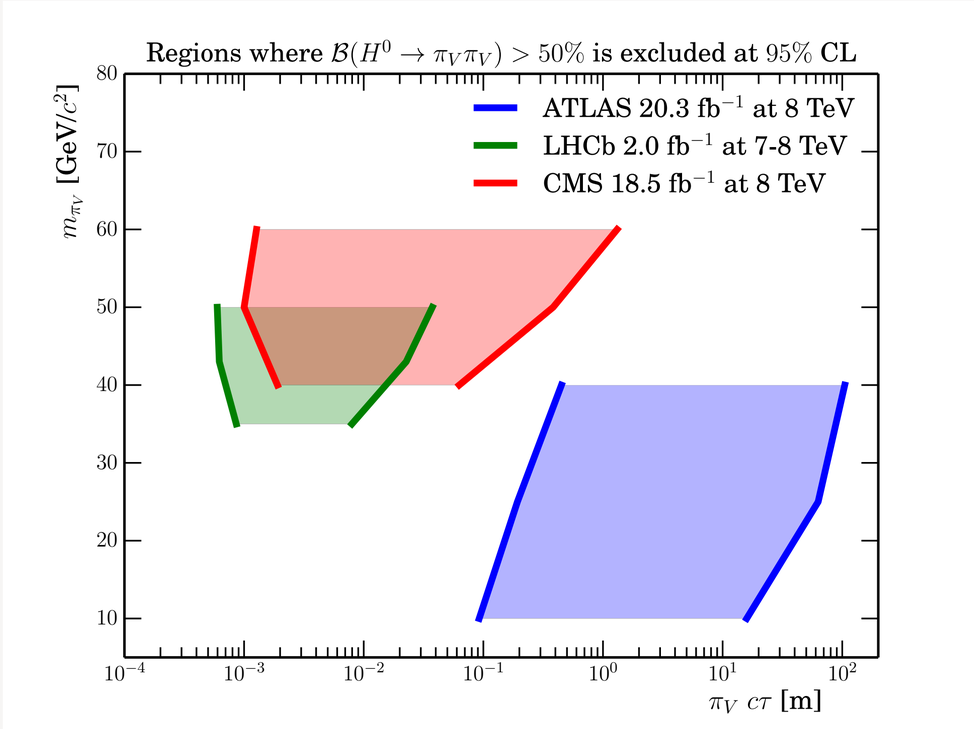
Signature: only one displaced dijet in acceptance



A search for long-lived dark pions decaying to two jets was done using 2 fb^{-1} Run I data of LHCb [EPJC (2017) 77 812]:

No excess found





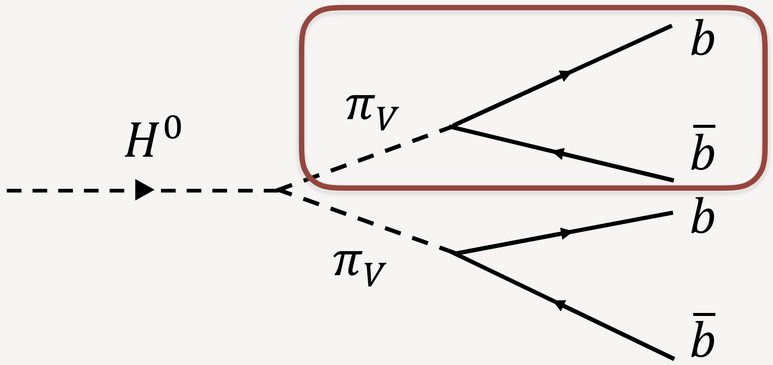
The strategy was to trigger on displaced vertices and to reconstruct the jets offline.

Displaced jets: new trigger strategy

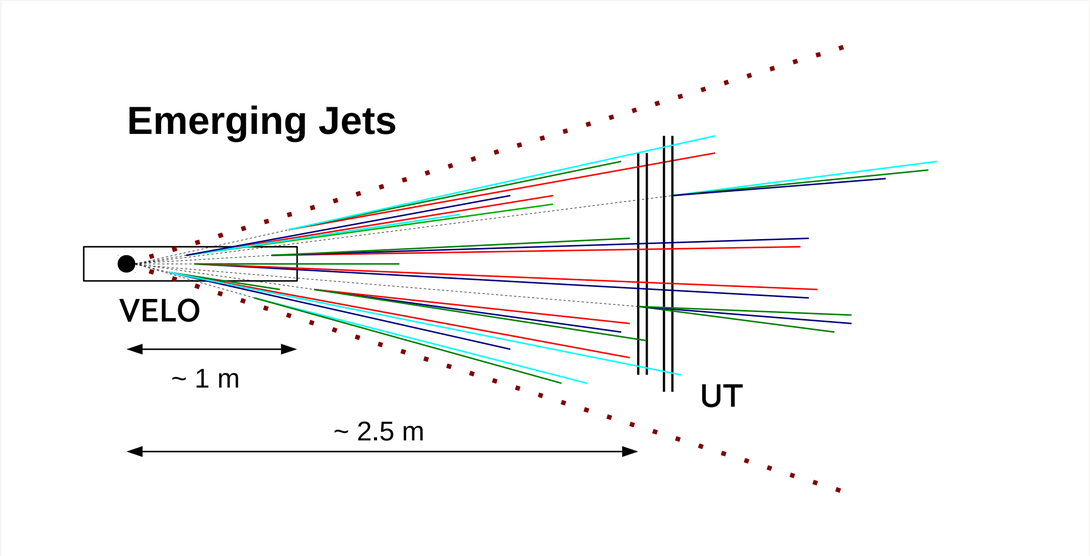
New strategy to **trigger directly on displaced jets.** This will allow to:

- Look for lower dark pion masses and lifetimes
- Study less simplistic scenario: emerging jet topology [arXiv:1708.05389]

Simplistic scenario



Less simplistic scenario: dark showers



Displaced jets: new trigger lines

Single jet:

- Jet P_T > 15 GeV/c
- P_T-weighted distance of closest approach to the beam line > 0.2 defined as:

$$\frac{\sum (p_T^{long} * DOCA_{BL})}{\sum p_T^{long}}$$

- Number of displaced long tracks > 5
- **No pre-scale**

We have already collected data →

DOCA = distance of closest approach

Displaced jets: new trigger lines

Single jet output in simulation:

Simulation samples: $Z'(125) \rightarrow q_v \sim q_v \rightarrow$ dark shower,
with $m(\pi_v) = 11, 20$ GeV/c^2 and $\tau(\pi_v) = 5, 10$ ps

At low dark pion masses we get a single merged jet:

- i.e for $m(\pi_v) = 11$GeV/c^2 the jet mass is also ~ 11GeV/c^2:
- more long tracks within the jet, i.e. part of the second jet reconstructed in the first one

↳ Improvement: a jet substructure tool for lower masses and increase the jet cone radius (currently 0.5).

Displaced jets: new trigger lines

Jet p_T versus jet η in simulation (m = 11 GeV/c2):

Kinematic region of the background

Conclusion

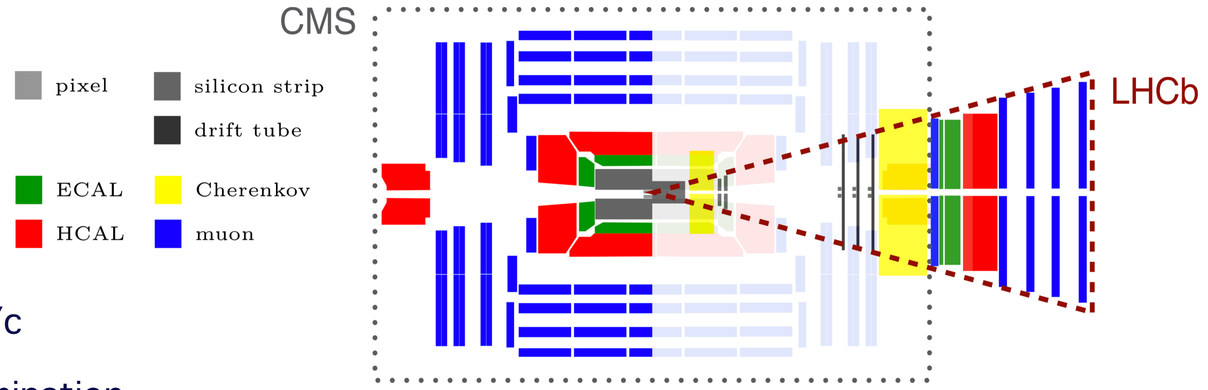
- First limit on scalar boson $\phi \rightarrow \mu^{\pm}\mu^{\mp}$ around and between the Υ resonances
- First limit of $H \rightarrow \mu^{\pm}\tau^{\mp}$ for Higgs-like bosons with low masses
- Promising/Exciting prospects for dark photons, ALPs, displaced jets, already with 2018 data and future runs, thanks to the new trigger developments. Other trigger abilities not shown is this talk such as:
    - trigger on a displaced di-jet (useful for higher $m(\pi_v)$);
    - trigger on 3/6 jets in order to study one or two gluinos decaying to 3 jets

Stay tuned. New ideas are welcome, don't hesitate to contact us. **Thank you for you attention**.

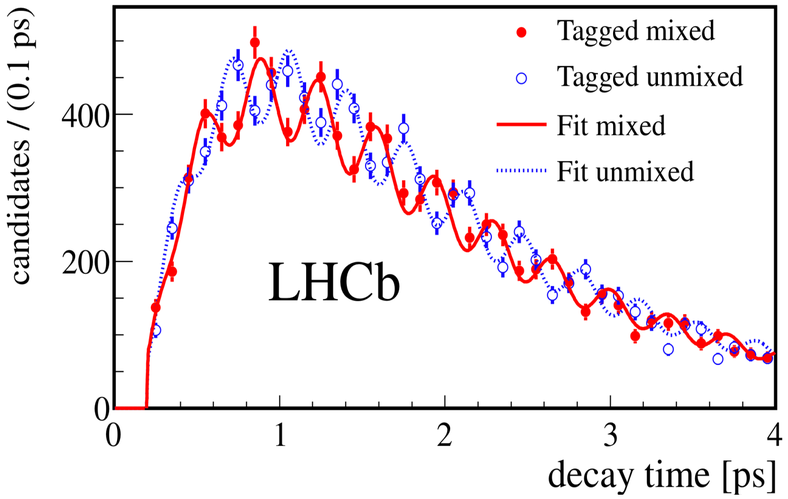
Backups

LHCb detector

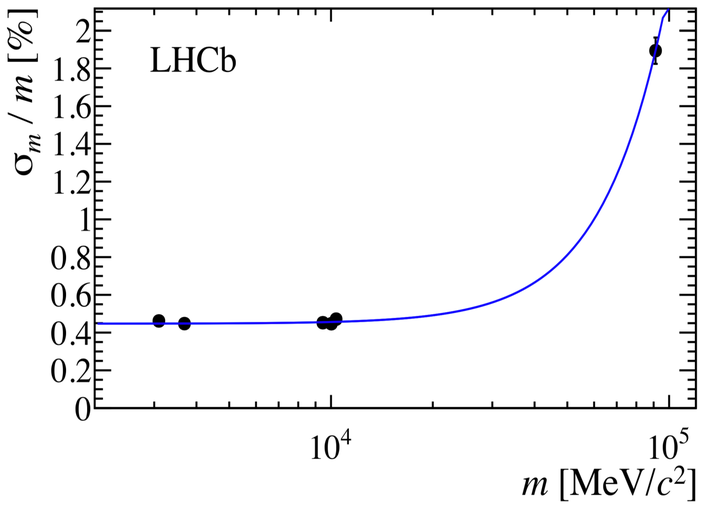
- fully instrumented in $2 < \eta < 5$
- excellent particle identification capabilities
- good jet reconstruction:
  - 10 to 20 % energy resolution for jets with $p_T > 10$ GeV/c
    [JHEP01 (2014) 033]
  - b(c) tagging efficiency of 65% (25%) with 0.3% contamination
    [JINST 10 (2015) P06013]



- excellent vertex resolution (B_s^0 decay time resolution ~40fs):

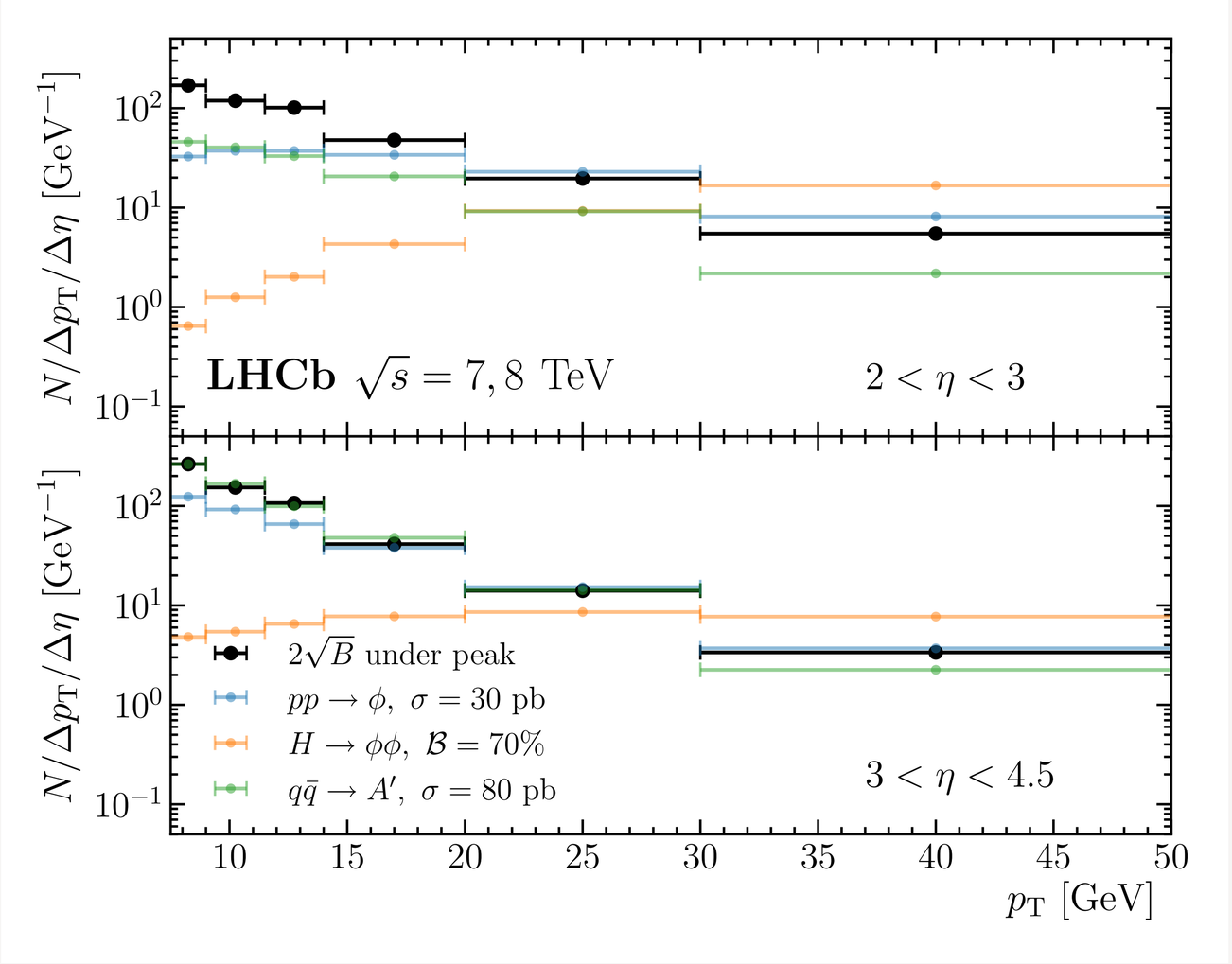


- excellent mass resolution (0.5 % for $J/\psi \to \mu\mu$, 2% for $Z \to \mu\mu$)



Search for a dimuon resonance in the Υ mass region

Expected sensitivity in each $p_T(\phi)$ and $\eta(\phi)$ bin



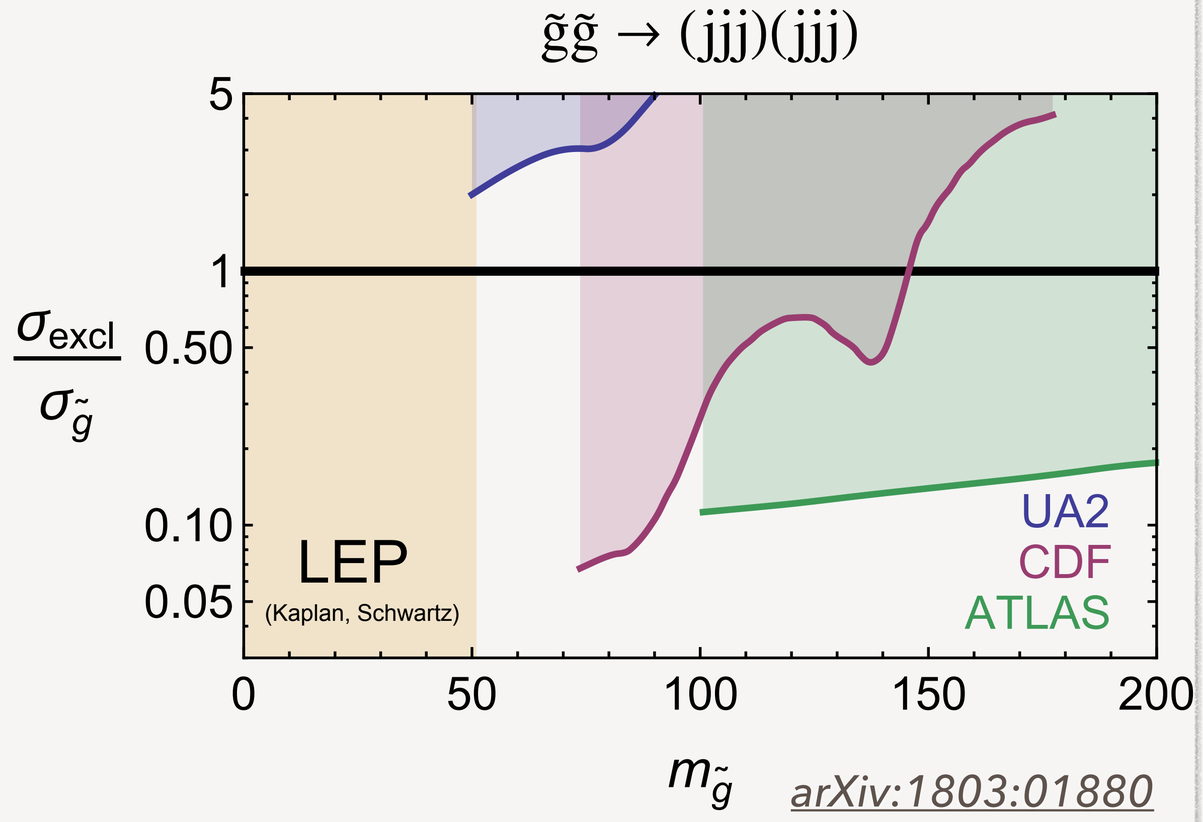
Search for lepton-flavour-violating decays of Higgs-like bosons

Selection for each decay channel:

Selection set	Variable	$\mu\tau_e$	$\mu\tau_{h1}$	$\mu\tau_{h3}$	$\mu\tau_\mu$
All	$p_{\mathrm{T}}(\tau)$ [GeV/c]	> 5	> 10	> 12	> 5
	$p_{\mathrm{T}}(\tau_{h3}^{\mathrm{prong1}})$ [GeV/c]	—	—	> 1	—
	$p_{\mathrm{T}}(\tau_{h3}^{\mathrm{prong2}})$ [GeV/c]	—	—	> 1	—
	$p_{\mathrm{T}}(\tau_{h3}^{\mathrm{prong3}})$ [GeV/c]	—	—	> 6	—
	$p_{\mathrm{T}}(\mu) - p_{\mathrm{T}}(\tau)$ [GeV/c]	> 0	—	—	—
	$m(\tau_{h3})$ [GeV/c^2]	—	—	0.7–1.5	—
	$m_{\mathrm{corr}}(\tau_{h3})$ [GeV/c^2]	—	—	> 3	—
	Time-of-flight (τ_{h3}) [fs]	—	—	> 30	—
	IP(τ) [μm]	> 10	> 10	—	> 50
	IP(μ) [μm]	< 50	< 50	< 50	< 50
	$\Delta\phi$ [rad]	> 2.7	> 2.7	> 2.7	> 2.7
	$\hat{I}_{p_{\mathrm{T}}}(\tau)$	> 0.9	> 0.9	> 0.9	> 0.9
	$\hat{I}_{p_{\mathrm{T}}}(\mu)$	> 0.9	> 0.9	> 0.9	> 0.9
L-selection	$p_{\mathrm{T}}(\mu)$ [GeV/c]	> 20	> 20	> 20	> 20
	$A_{p_{\mathrm{T}}}$	< 0.6	< 0.4	—	> 0.3
	$I_{p_{\mathrm{T}}}(\tau)$ [GeV/c]	< 2	< 2	< 2	< 2
	$I_{p_{\mathrm{T}}}(\mu)$ [GeV/c]	< 2	< 2	< 2	< 2
C-selection	$p_{\mathrm{T}}(\mu)$ [GeV/c]	> 30	> 30	> 30	> 30
	$A_{p_{\mathrm{T}}}$	—	< 0.5	—	> 0.3
H-selection	$p_{\mathrm{T}}(\tau)$ [GeV/c]	> 20	> 20	> 20	—
	$p_{\mathrm{T}}(\mu)$ [GeV/c]	> 40	> 40	> 40	> 50
	$A_{p_{\mathrm{T}}}$	—	—	—	> 0.4

Gluinos decaying to three jets

- **Motivation**: Filling the light gluino gap!
- Currently a light gluino (50-75 GeV/c^2) cannot be excluded by LEP, ATLAS or CDF.
- Best bound from UA2
- Cross sections < 2.6 pb are allowed in this gap
- LHCb could explore this region



arXiv:1803:01880

Final States:

Less signal, but way less background

- uds, dsc, usb, scb
- also possible to have two gluinos in the same event → uds + uds