Exclusive Displaced Hadronic Signatures in the LHC Forward Region

Searching for LLPs at the LHC: 6th workshop
Ghent (Nov 27th 2019)

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Talk fully based on arXiv:1910.05225

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Introduction (I)

- Exotic Higgs decays are a well studied way to produce BSM scalars (h → SS)
- These scalars can be weakly coupled (so long-lived) and with an arbitrary mass, hence potentially much lower than the electroweak scale
- Depending on the specific scenario and flavor structure of the S couplings, S could decay predominantly to hadrons

From Higgs Physics at the HL-LHC and HE-LHC report

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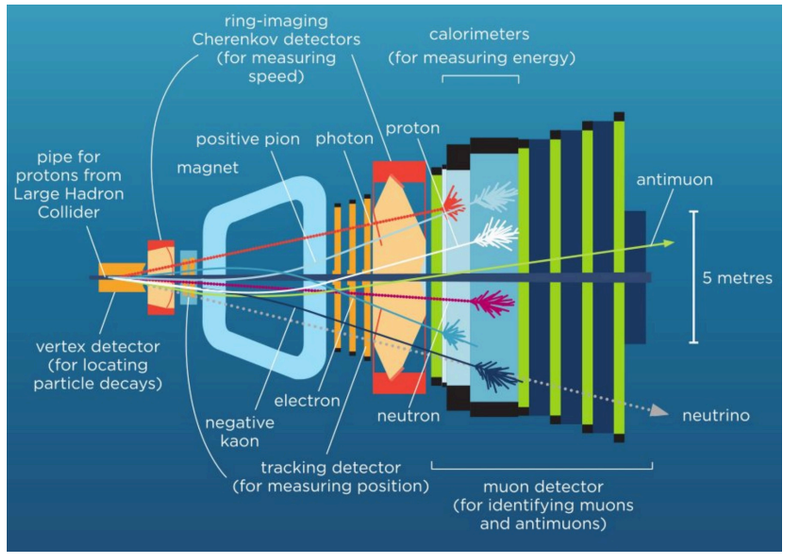
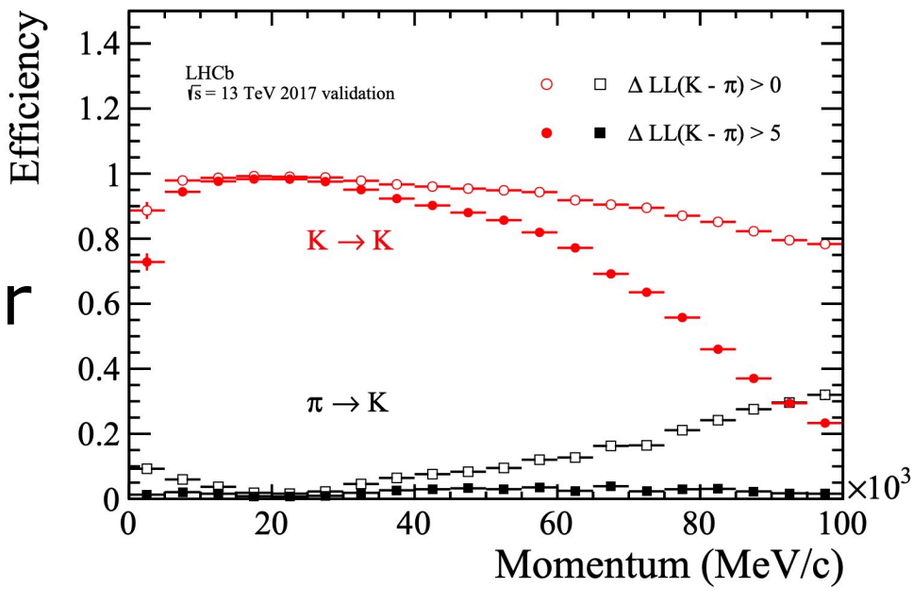
- ➡ How to study this case? Usual approach, **displaced jets**. However, with jets, even with jet substructure, hard to go in mass below ~10 GeV or so. Alternative, **invisible Higgs decays** (from fitting SM Higgs properties including an unknown decay fraction)
- ➡ Yet other alternative, HCAL decays (e.g. ATLAS), sensitive to masses above ~5 GeV.

Introduction (II)

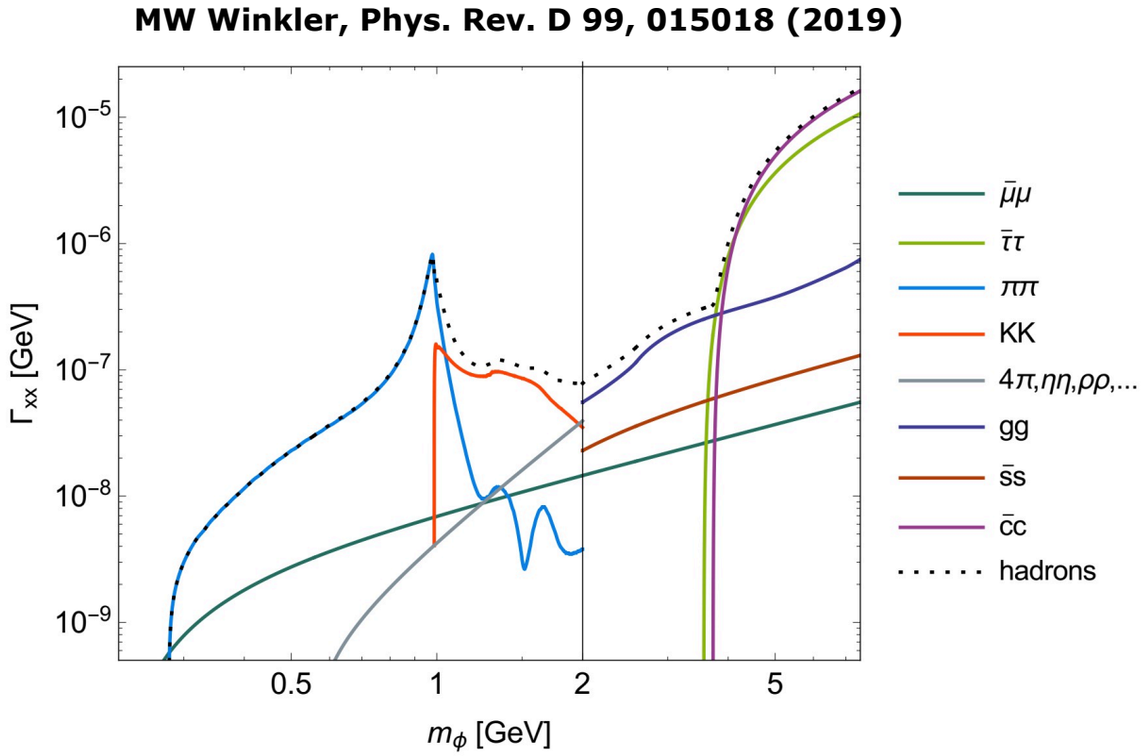
- Proposal: exclusive track reconstruction at LHCb
  - The RICH detector can determine the identity of charged hadrons, separating for instance, kaons from pions.
  - Moreover, triggering on light displaced vertices decaying to kaons is feasible at LHCb (more later)
  - Other important aspects, good invariant mass and IP resolution, vertexing
  - This together allows overcoming other disadvantages (worse acceptance, less integrated luminosity)





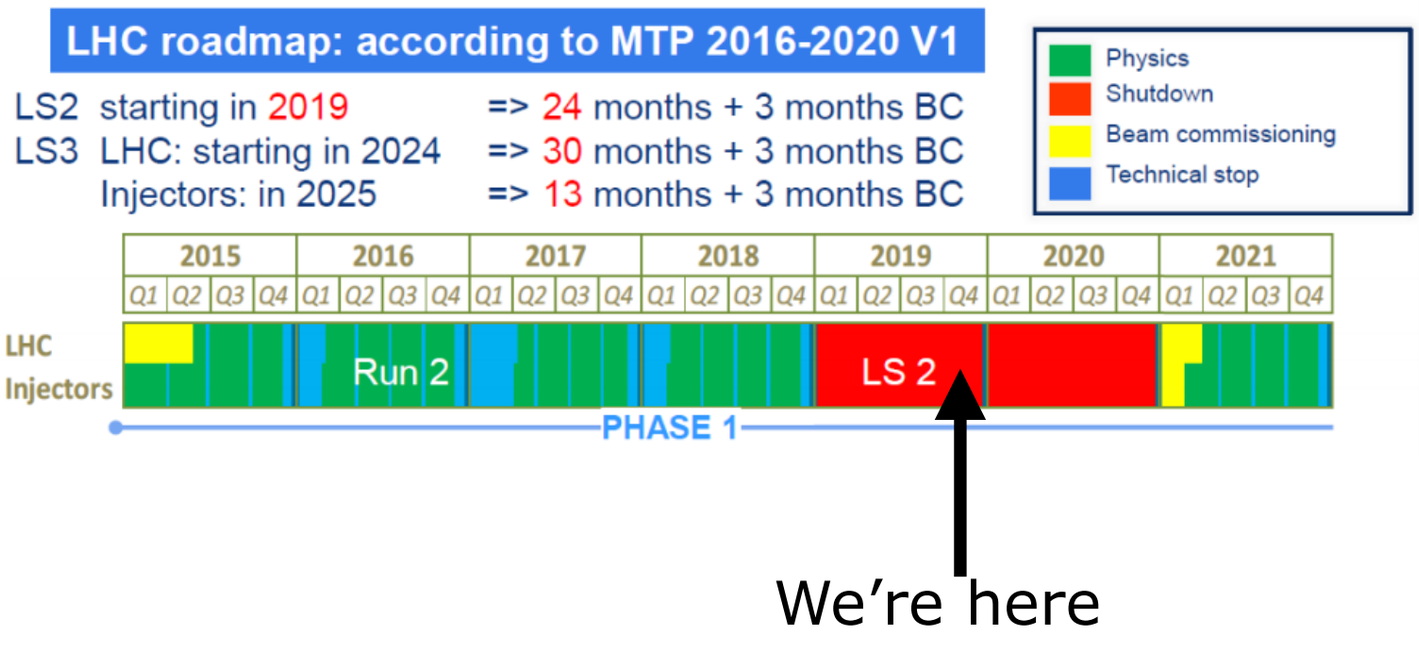
Introduction (III)

- LHCb would have great sensitivity to decays of the type h → S(KK)S(KK).
  - Almost no competition from other experiments if m_S ~ GeV.
  - Is a dominant S→KK decay possible?
  - For 1 GeV ≤ m_s ≤ 2 GeV, S dominantly decays into KK if the S coupling to quarks follows the flavor structure of Yukawa coupling!
  - Build full analysis example based on this and check sensitivity

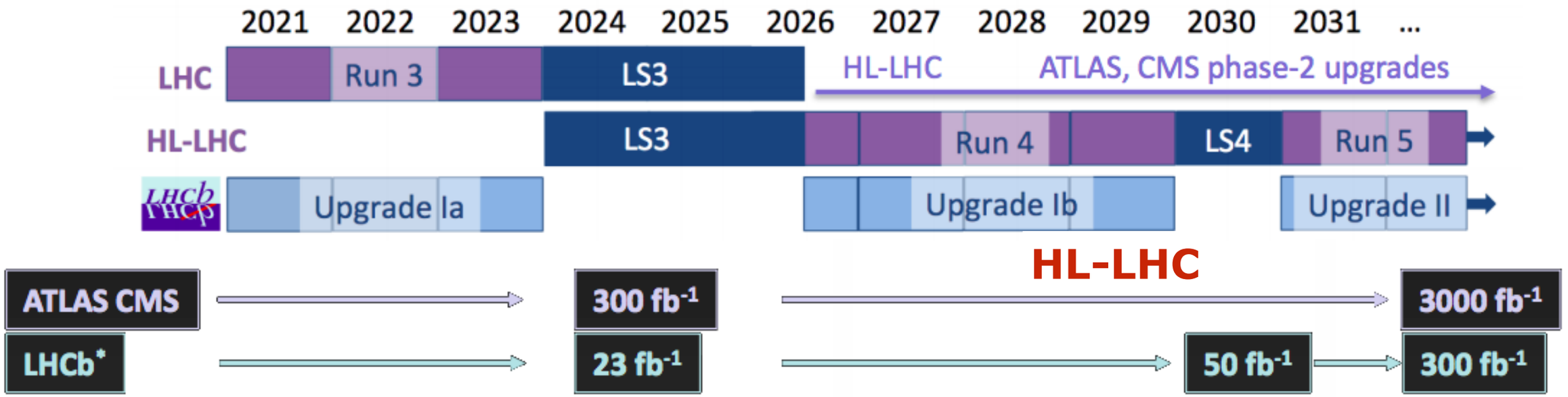


- This is an excellent example of LHCb capabilities to exclusive hadronic decays. Other hadronic decays (e.g., to protons, would work too!)

LHCb context



- LHCb currently has ~8 fb^{-1} of data in tape
- Run guaranteed till 2030, currently upgrading the detector
- Submitted LoI for LHCb Upgrade II, to run beyond 2030



15 fb^{-1} accounting just for Run 3!

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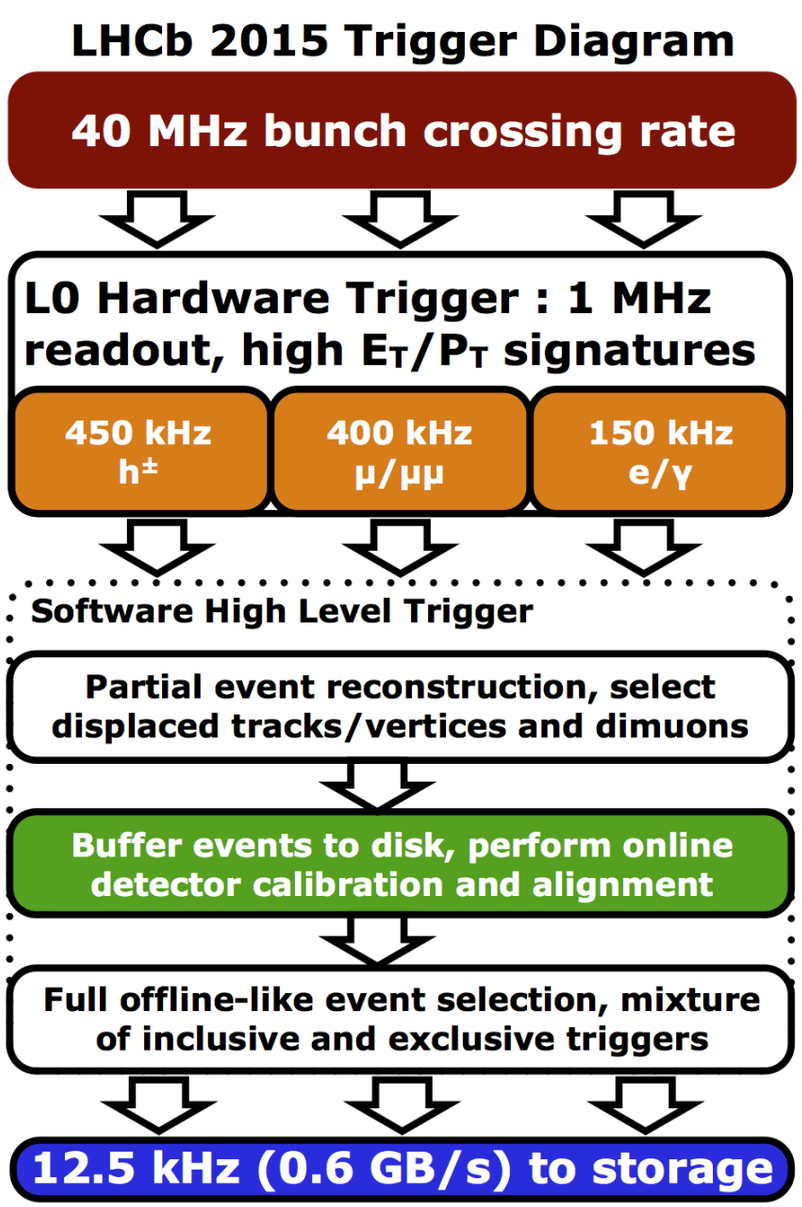
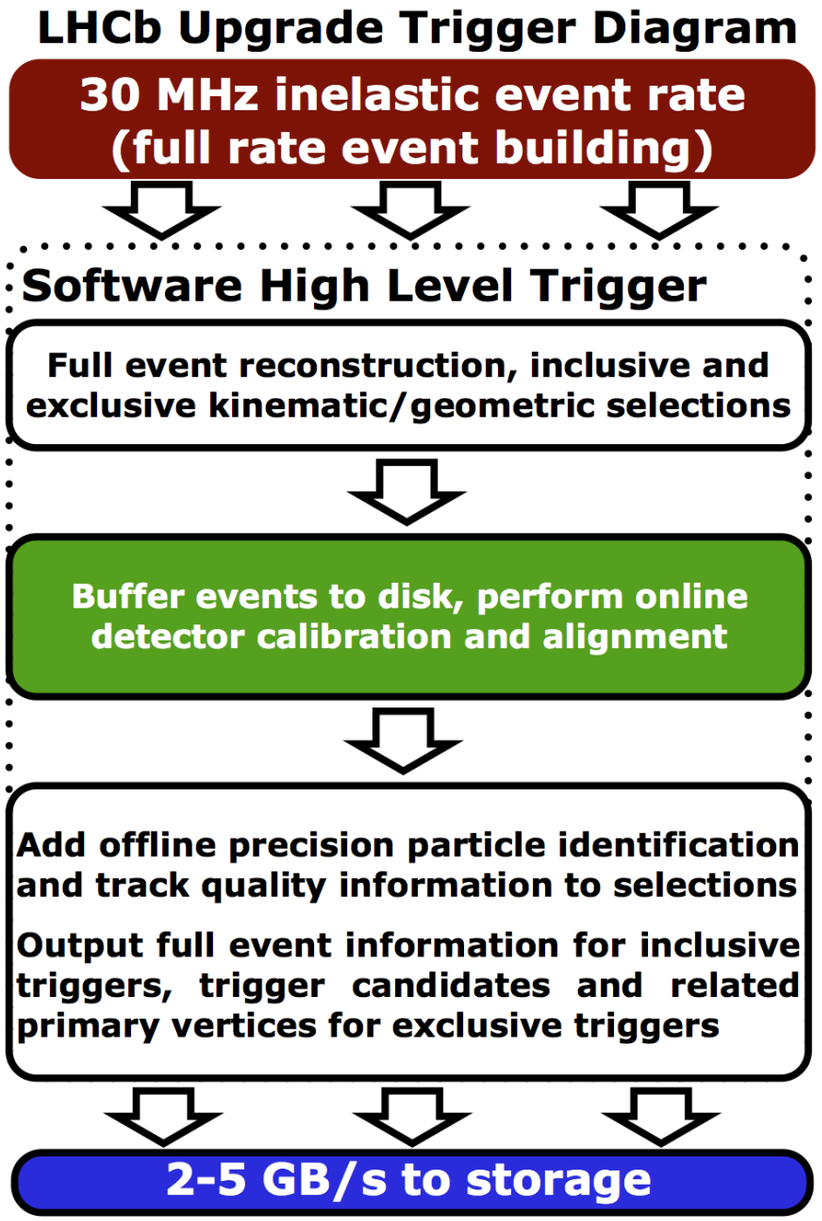
Run III trigger at LHCb

Run II



Run III



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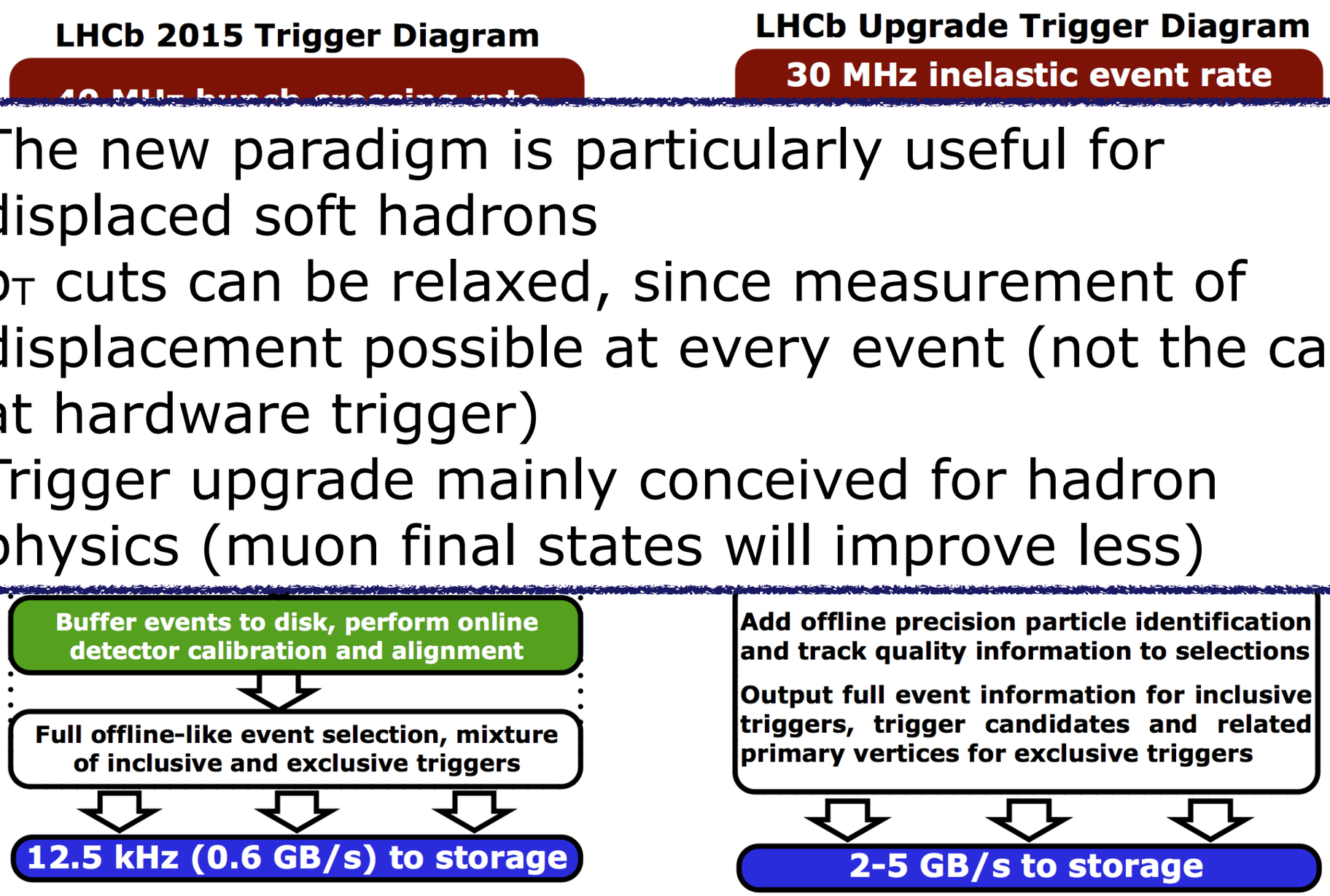
Run III trigger at LHCb

Run II

Run III



- The new paradigm is particularly useful for displaced soft hadrons
- p_T cuts can be relaxed, since measurement of displacement possible at every event (not the case at hardware trigger)
- Trigger upgrade mainly conceived for hadron physics (muon final states will improve less)

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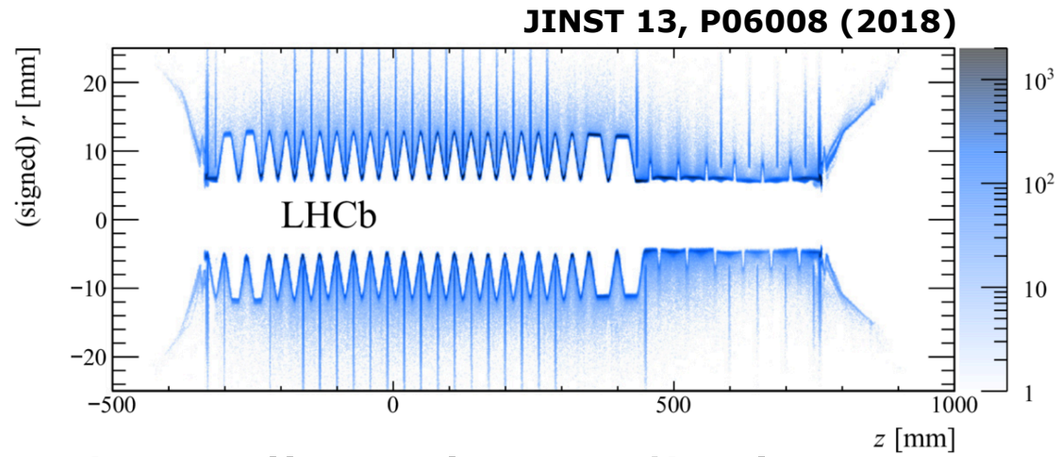
LHCb proposed selection

- Main background for this search QCD bb and material interactions (others checked to be subdominant). Handles against both:
  - Actual analysis can benefit from existing LHCb material mapping (veto secondary vertices)



  - Additional boost from Higgs production, allows large displacement even for moderate lifetimes. As a precaution, avoid detector region where most material interactions happen. Neglect material interactions in our analysis
  - Kaons must form a good displaced vertex, the S candidate must point back to the PV
  - Isolation of kaons (no other tracks with some displacement near by)
  - Reconstruct one or both S candidates
  - Veto well known resonances (e.g. $\phi \rightarrow KK$)

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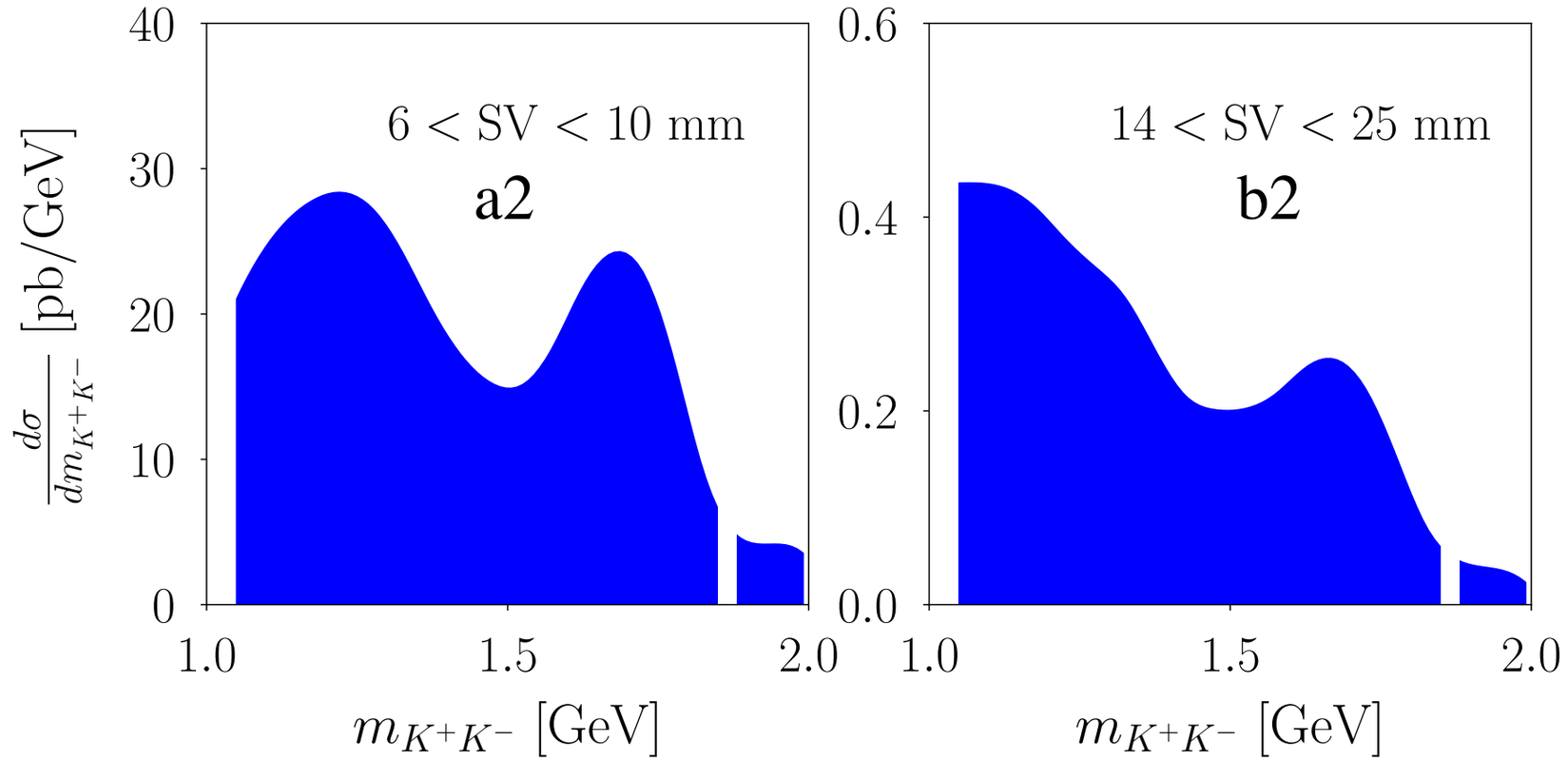
Background yields

- Different signal regions defined, providing different degree of sensitivity

Signal Region	ρ range (mm)	Isolation	Number of S	bg @ 15 fb^{-1} $m_S = [1, 2]$ GeV
a_1	$6 < \rho < 10$	no	1	7.85×10^6
a_2	$6 < \rho < 10$	yes	1	2.62×10^5
b_1	$14 < \rho < 25$	no	1	2.01×10^5
b_2	$14 < \rho < 25$	yes	1	3.43×10^3
c_1	both $6 < \rho < 10$	no	2	16.8
c_2	both $6 < \rho < 10$	yes	2	0.67
d_1	both $14 < \rho < 25$	no	2	$< 10^{-4}$
d_2	both $14 < \rho < 25$	yes	2	$< 10^{-6}$



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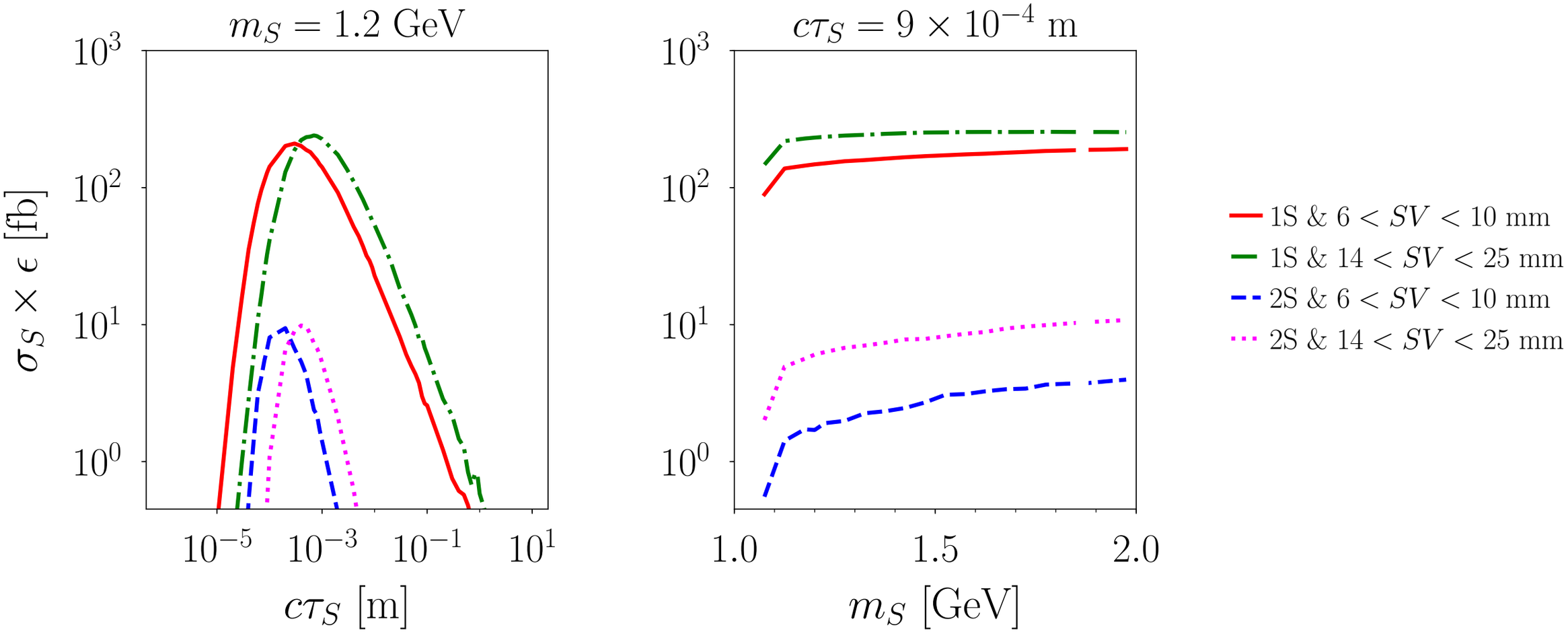
Signal efficiency

- Efficiency significantly better when reconstructing single S (2S suffers from acceptance)



* σ assumes BR(H→SS) = 19% and BR(S→KK) = 100%, where 19% is the current exclusion on Higgs → invisible by ATLAS/CMS

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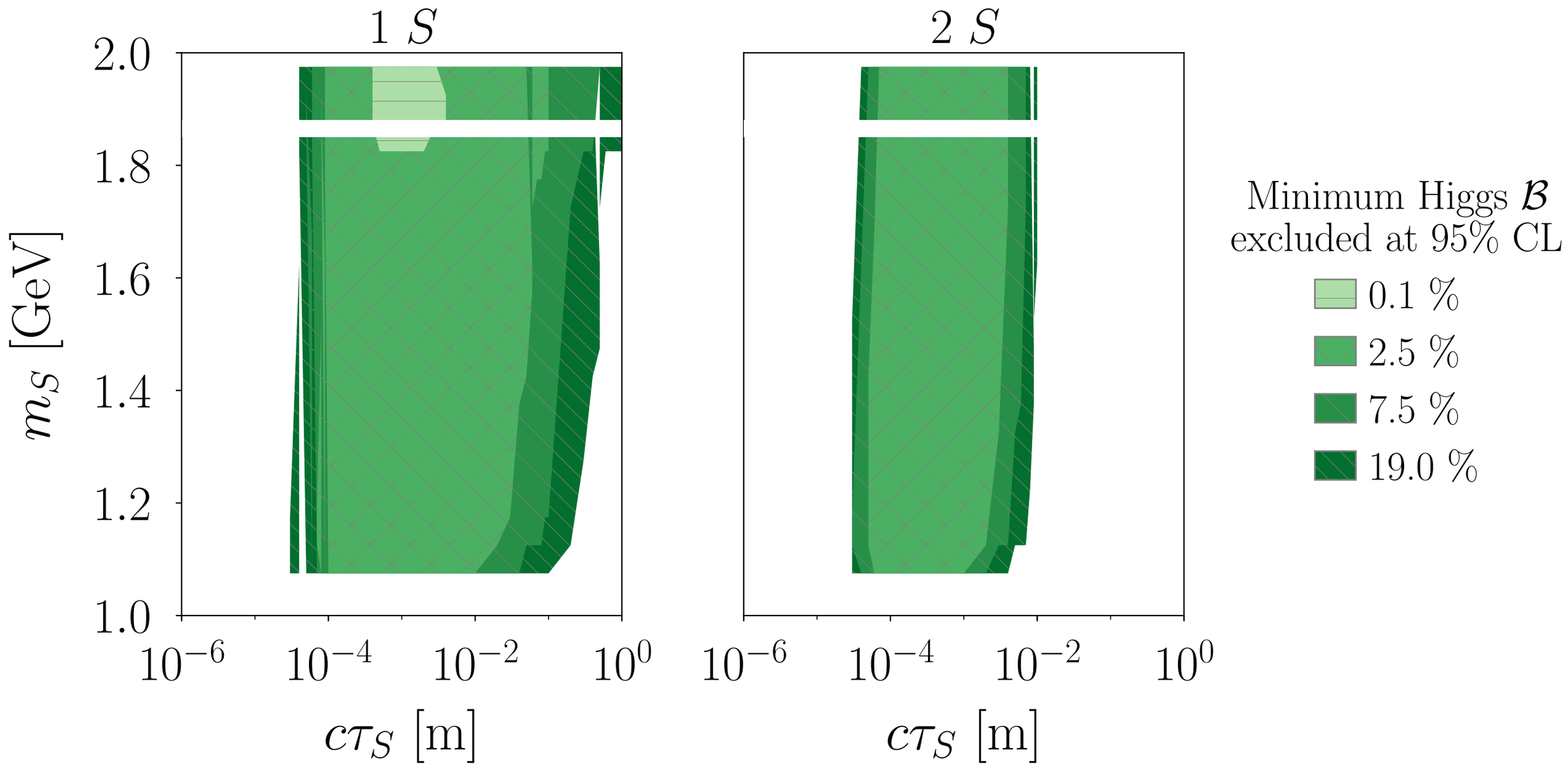
Branching ratio constraints (I)

- Model independent limits on BR(H→SS), assuming BR(S→KK) = 100%

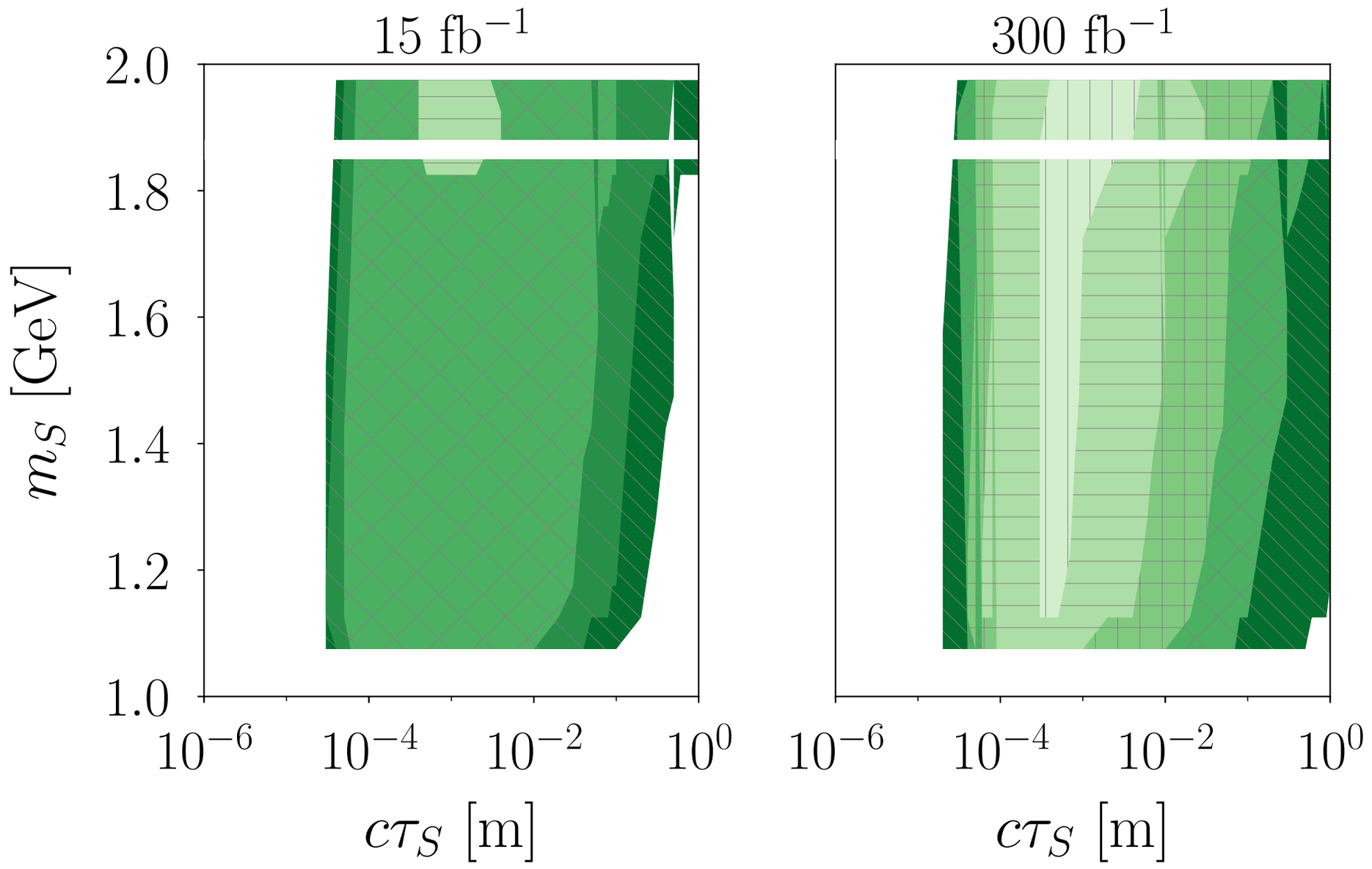
* LHCb limits @ 15 fb^{-1}



Branching ratio constraints (II)

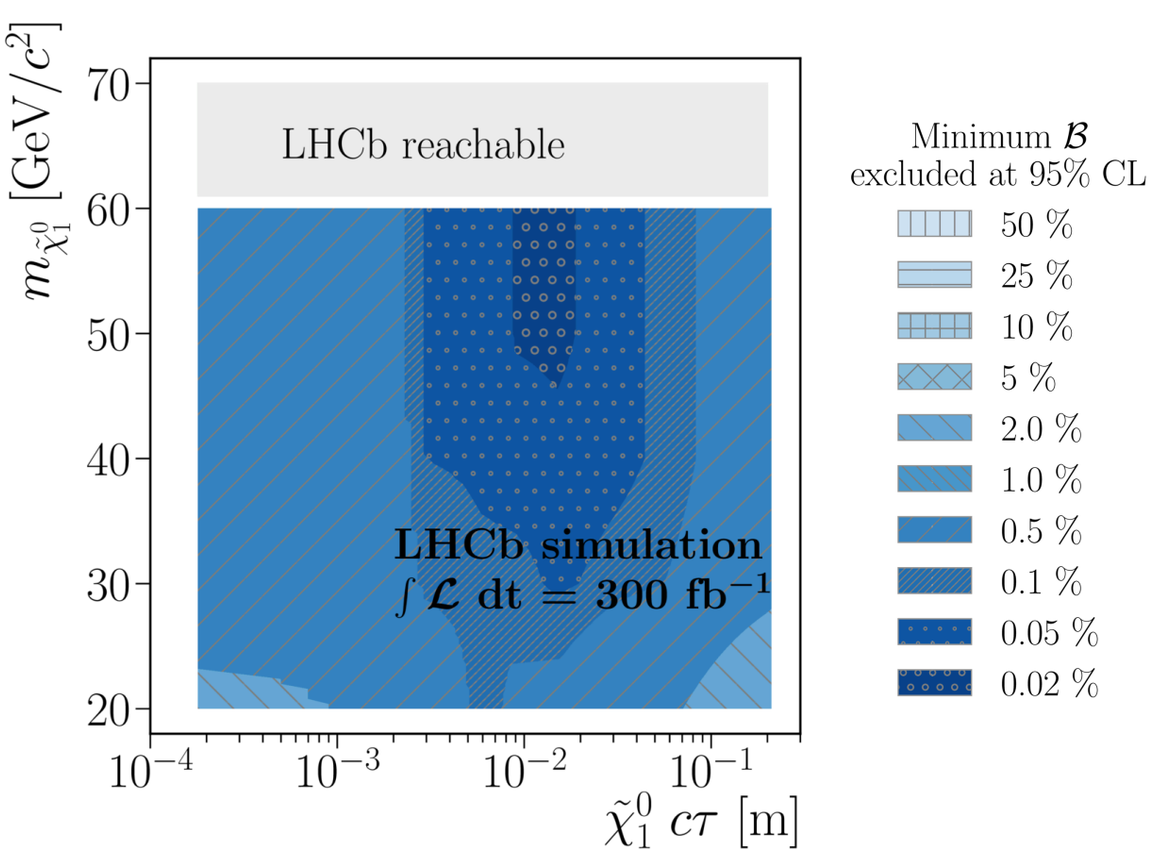
- Model independent limits on BR(H→SS), assuming BR(S→KK) = 100%

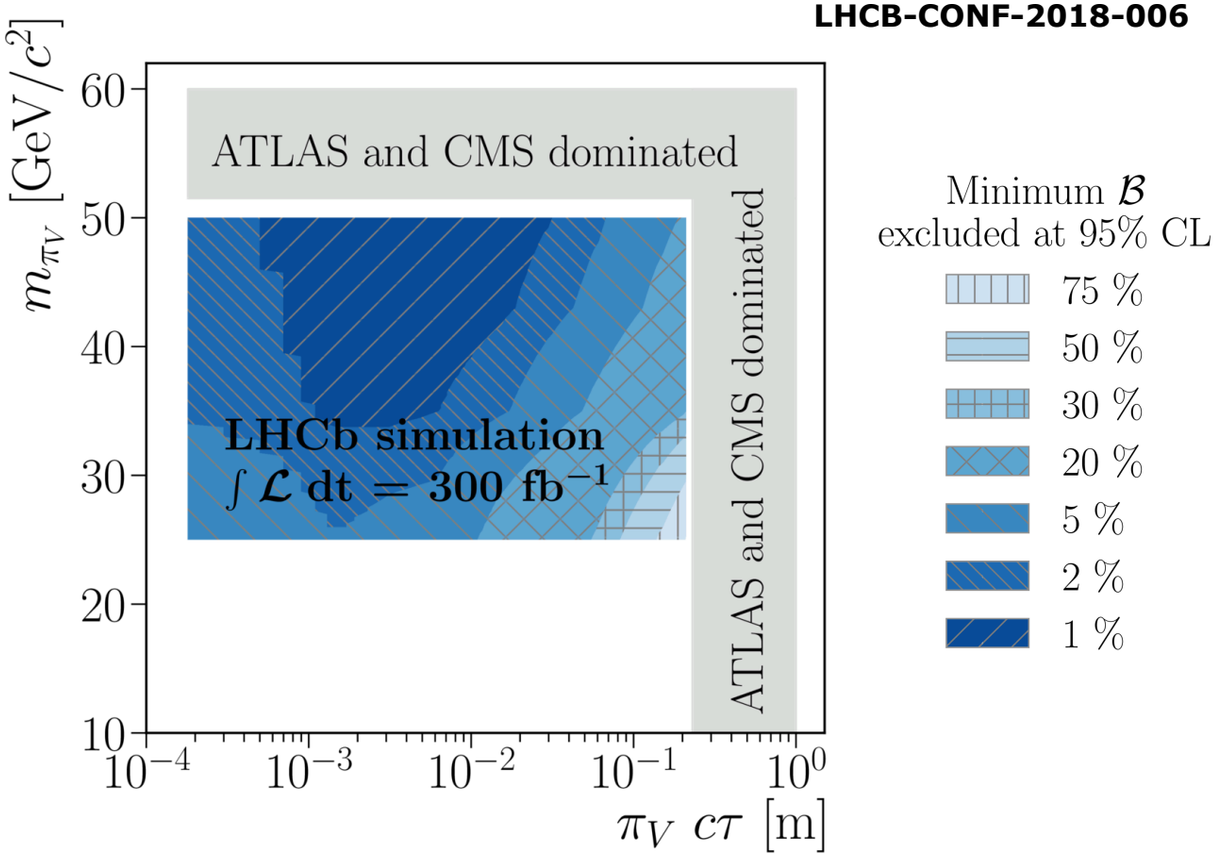
* Expected exclusion on Higgs → invisible by ATLAS/ CMS @ 3000 fb^{-1} is 2.5%



Comparison at LHCb

- Prospects at LHCb for other searches for LLPs in Higgs Exotic decays
  - Model: mSUGRA neutralino decaying to a lepton and two quarks
  - Model: Hidden valley V-pions decaying to jets





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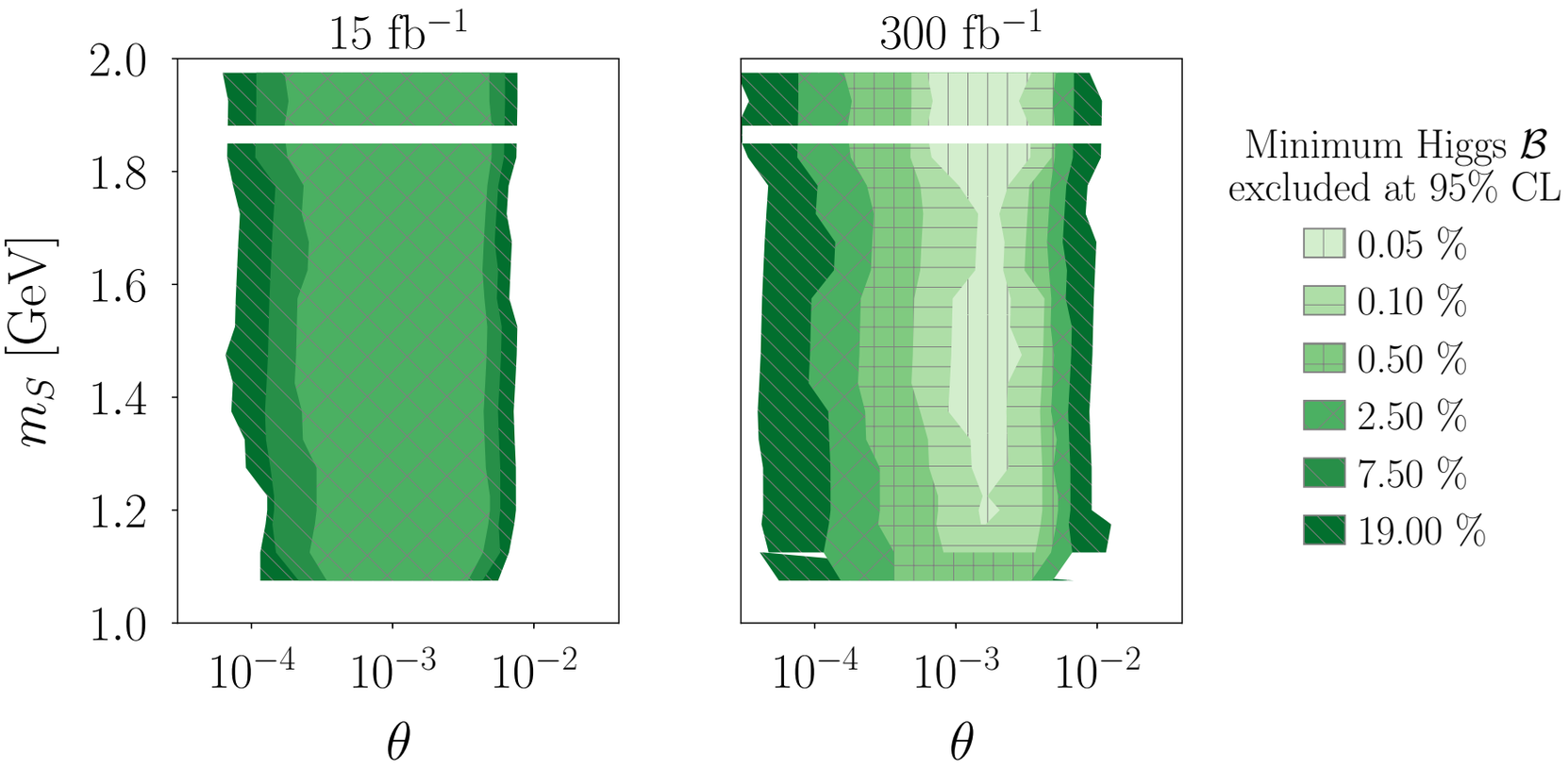
Hadrophilic interpretation

- Hadrophilic Higgs portal scenario, with minimal flavor violation and suppressed leptonic couplings to S
  - For BR(S→KK) and τ_S we take as reference Phys. Rev. D 99, 015018 (2019)
  - Given a mixing angle θ between S and the Higgs boson



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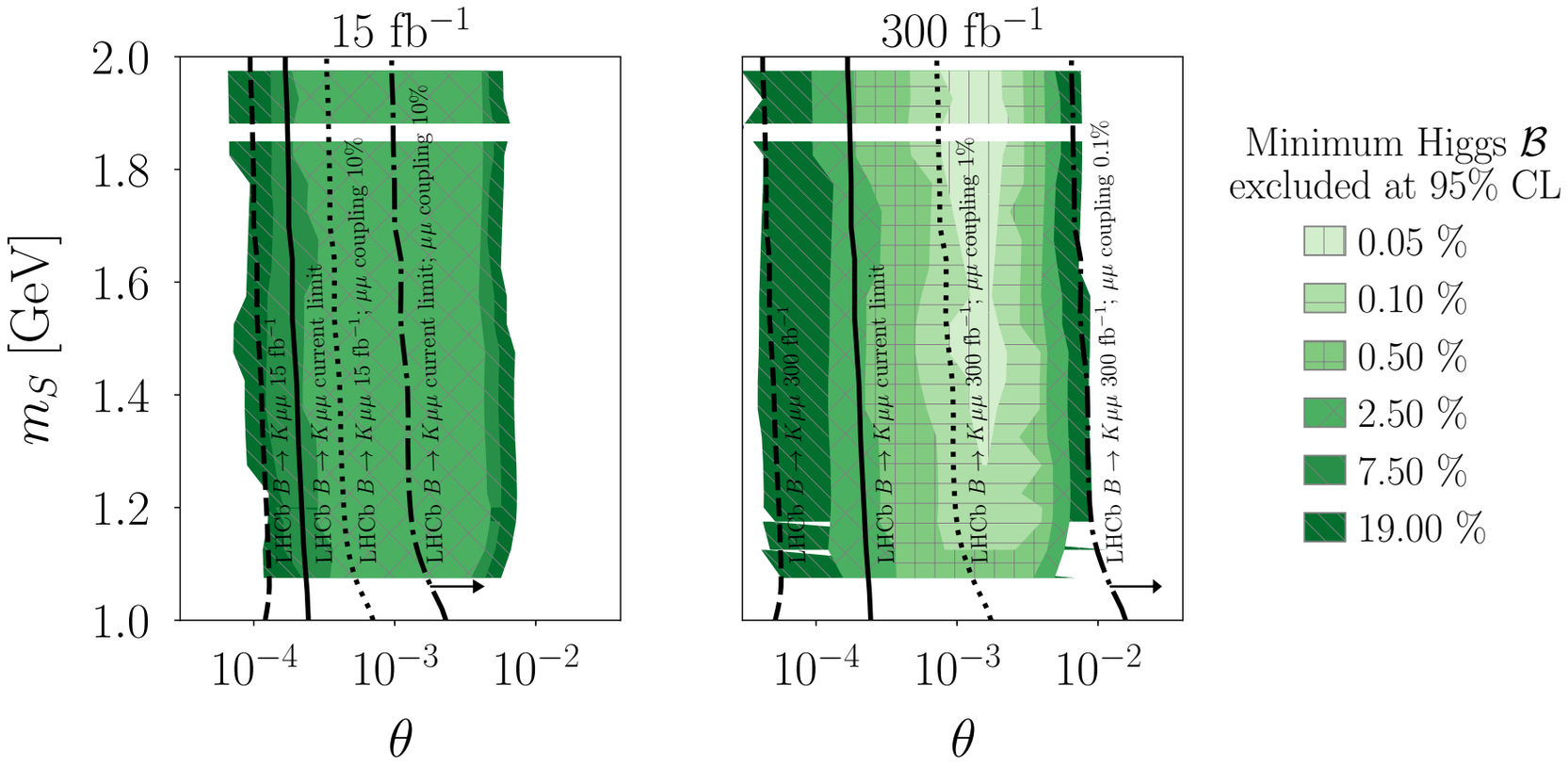
Higgs Portal through mixing

- Similar Higgs portal scenario as before, but now BR(S→μμ)~8%
  - In this case, important constraints from LHCb in *B* meson decays, e.g., $B^+ \to K^+ S(\mu\mu)$, or neutral decay $B^0 \to K^* S(\mu\mu)$
  - Limit in *B* decays dominates, but S→KK search important for on-shell Higgs searches or if μ coupling reduced



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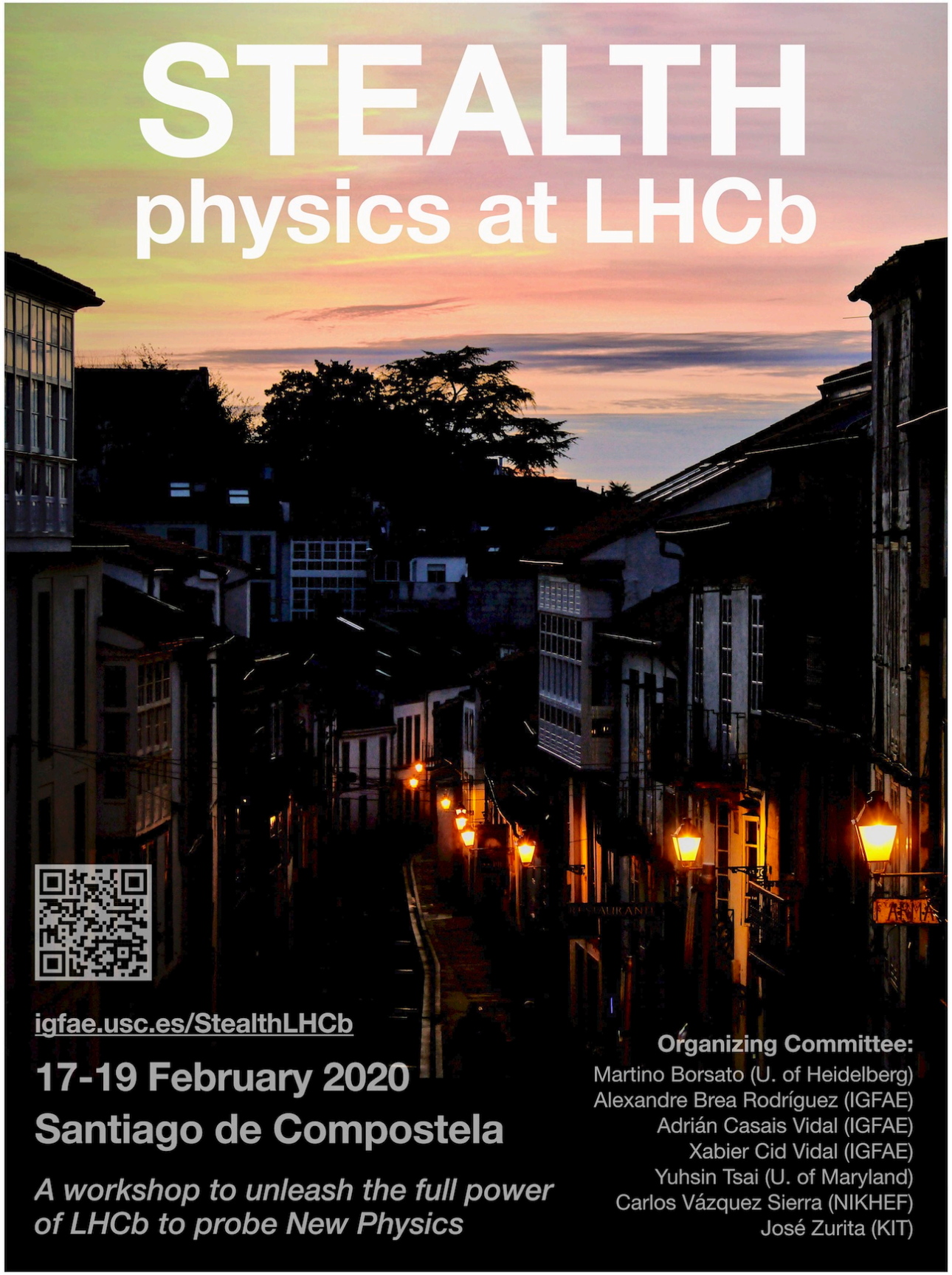
Conclusions

- Exclusive searches for LLPs decaying to hadrons can cover unique chunks of parameter space at LHCb
  - New hadronic triggers at LHCb in Run 3 provide new opportunities!

- Kaons offer an excellent example, but we recommend searching for as many hadronic final states as possible (e.g. π or p)

- Potential extension, similar searches in *B* hadron decays, cover smaller lifetimes

STEALTH
physics at LHCb



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A workshop to unleash the full power of LHCb to probe New Physics

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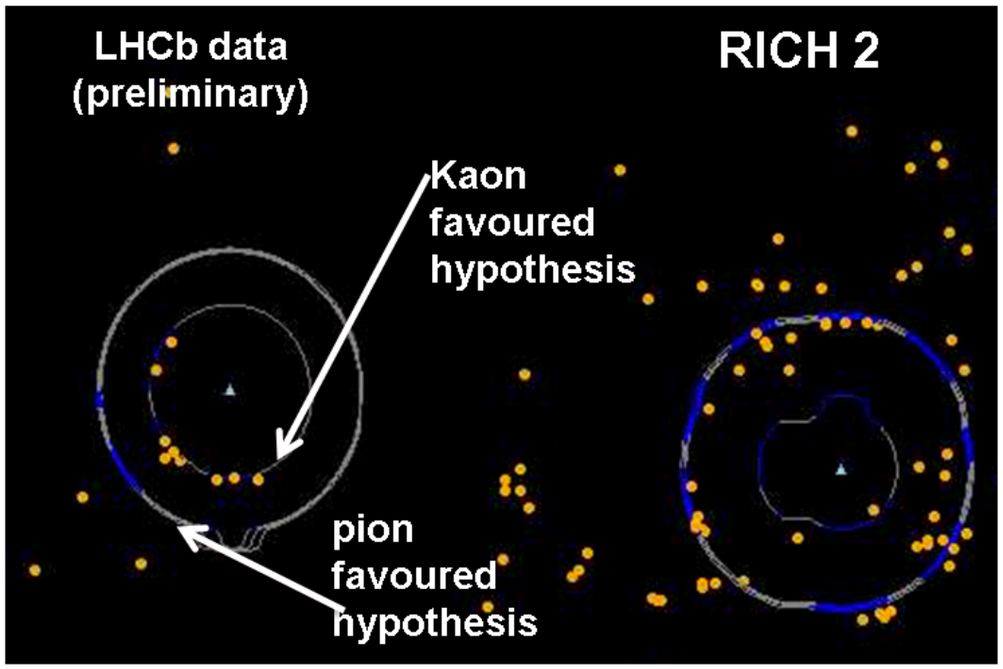
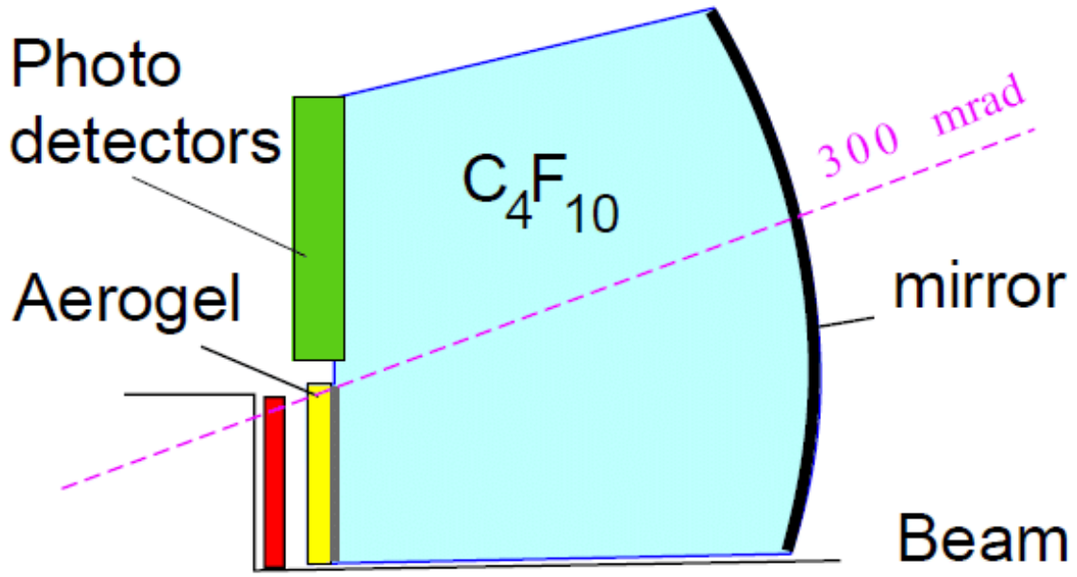
LHCb RICH





Hybrid photon detectors (HPDs)

ATLAS/CMS Higgs mixing

When reinterpreting the existing displaced muon searches at ATLAS and CMS [13, 45] from Higgs decaying into two dark photons ($2\gamma_d$) to the $h \to SS$ process, we get a bound BR($h \to SS$) $\lesssim 10\%$ (95% C.L.) for the (m_S, θ) of our interest. The bound excludes a small part of the sensitivity region in our 15 fb^{-1} projection. We set BR($\gamma_d \to \mu\mu$) $= 30\%$ [59] when rescaling the bound and requiring both S's to decay into muons in the ATLAS/CMS searches. ATLAS/CMS will have 300 fb^{-1} integrated luminosity when LHCb collects 15 fb^{-1} of data. Take the CMS study [45] as an example. When rescaling the 10 background in their 36 fb^{-1} search according to the luminosity, a similar CMS search can exclude BR($h \to SS$) $\gtrsim 4\%$ in the Higgs mixing model. At that time, the LHCb $S \to K^+K^-$ search will set a comparable (or even better) bound to the Higgs decay in this scenario.