Development of simulation workflows for BSM LLPs at LHCb.

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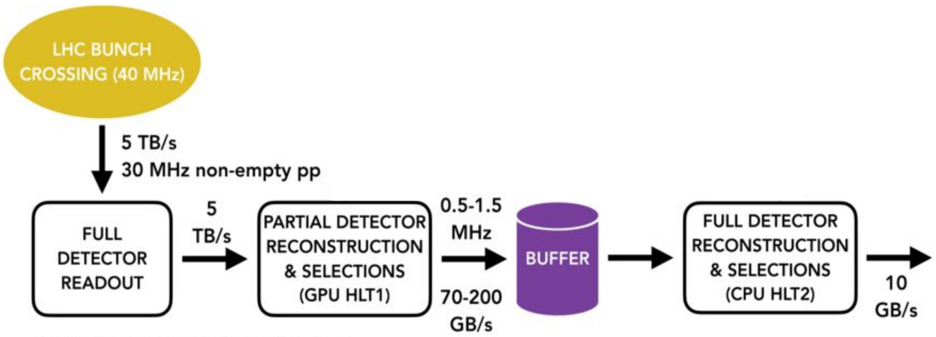
LHCb data flow

The Large Hadron Collider provides proton-proton collisions to LHCb 40 million times a second. This results in a huge generation of data, approx. 5 TB every second.

That’s too much data to be able to keep all of it, the price of storage is just too high, so instead data filtering is needed to keep only the events that contain interesting decays.

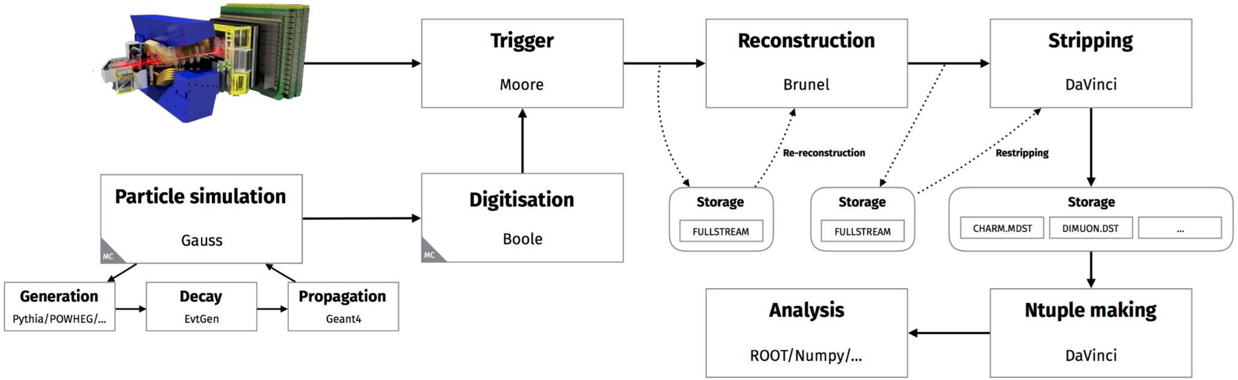


All numbers related to the dataflow are taken from the LHCb

[Upgrade Trigger and Online TDR]

Data from the detector are filtered through the trigger system, which consists of the two high-level triggers (HLT), implemented in the software.

LHCb data simulation flow



The next combination is used for simulation and further analysis

Gauss → Boole → (Moore) → DaVinci

↘ Allen (HLT1)

Gauss

The LHCb simulation framework that generates primary events and simulates the interaction with the detector by interfacing to different external applications.

Boole

Software which makes simulated hits in the virtual detector and converts them to signals that mimic the real detector. The output of Boole is designed to closely match the output of the real detector.

DaVinci

It is the analysis framework which supports selection of events proceeding from the further processing of data. It provides tools of general utilities for the manipulation and analysis.

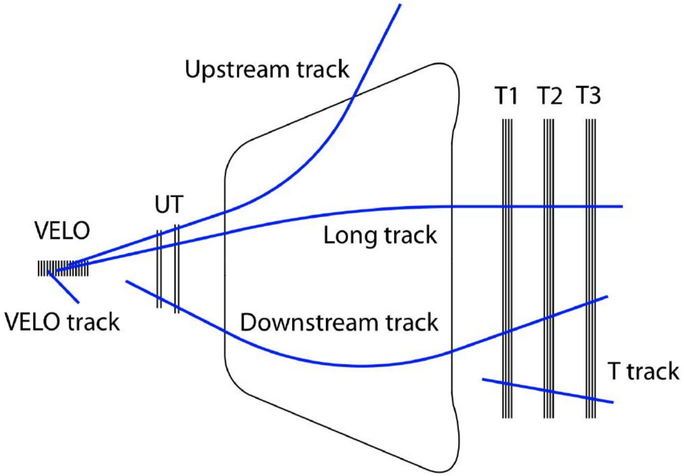
Track type definition

TT: has only SciFi track

DD: has SciFi and UT track

LL: has VELO, UT and SciFi track

We are interested specially in T-tracks and Downstream tracks which were not included in the trigger in Run 1 and Run 2



BSM Physics explanation

The hidden sector: scalar dark boson

One of the simplest and well-known models in this regard predicts the existence of a mixed state between a new scalar boson (S) and the SM Higgs (H), regulated by the mixing strength θ:

$$h = H \cdot \cos(\theta) - S \cdot \sin(\theta)$$

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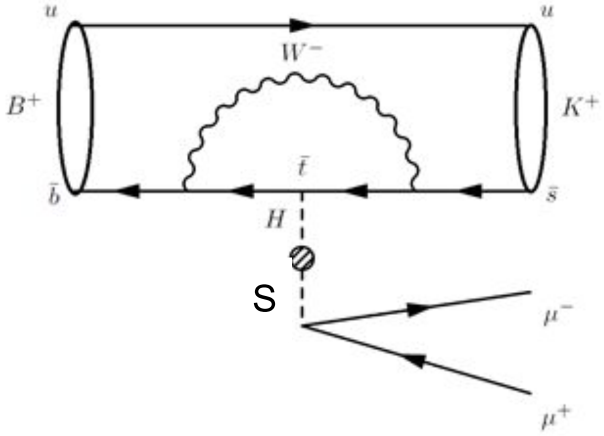


This model could be validated at LHCb through the experimental signature of the decay $B^+ \to S K^+$.

We are considering S decays into $\mu^+\mu^-$, $\pi^+\pi^-$, K^+K^- (and gluon gluon).

BSM Scalar Branching

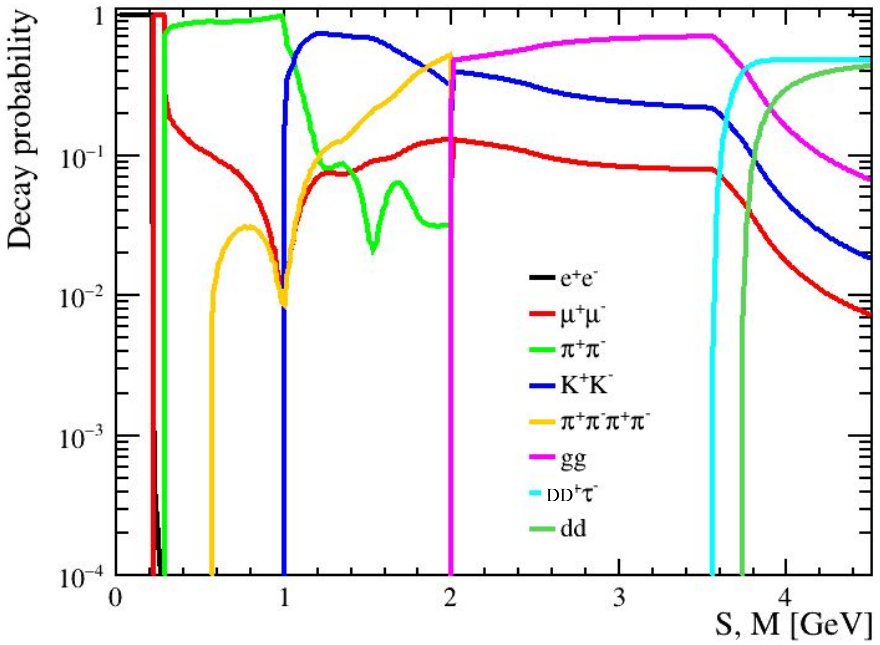
Main decay channels of a new scalar boson, S

Considering only the leptonic decay mode $S \to \mu^+\mu^-$, the decay rate can be expressed by:

$$\Gamma(S \to \ell\ell) = \sin\theta^2 \frac{G_F m_S m_\ell^2}{4\sqrt{2}\pi}\left(1 - \frac{4m_\ell^2}{m_S^2}\right)^{3/2}$$

The Scalar Boson lifetime can be computed:

$$\tau_S = \frac{1}{\sum_l \Gamma(S \to \ell\ell)}$$



Simulation of the dark boson

- We have prepared official samples (after model validation with local samples)

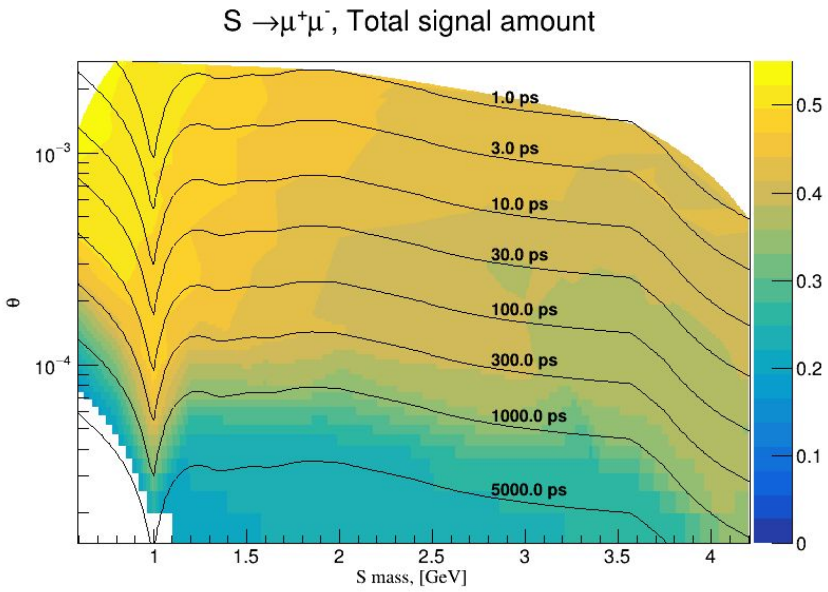
- Decay description and requirements:

- Mass and lifetime range of Dark Boson configuration:
  250 MeV/c² < m(S) < 4700 MeV/c² | 1 ps < τ(S) < 3000 ps
- Applied criteria: 2 < η(S) < 5
- Large official MC samples; (all links at slide 29) with chosen working points:
  Muon channel: $B^+ \to$ Dark Boson ($\to \mu^+\mu^-$) K^+ ; [2500MeV, 400ps], [3000MeV, 1000ps]
  Hadron channelsl: $B^+ \to$ Dark Boson ($\to \pi^+\pi^-$) K^+ ; [1000MeV, 400ps]
  $B^+ \to$ Dark Boson ($\to K^+K^-$) K^+ ; [2500MeV, 400ps]

- Ongoing: preparing simulations with Dark Boson → gluon gluon (important at high mass):

Sensitivity studies

Reconstructible S candidates (LL+DD+TT) as function of mass and lifetime/coupling



- Pseudorapidity: $2 < \eta(S) < 5$
- Mass from 0.5 - 4.7 GeV
- Lifetime from 1 to 3000 ps

Expected background sources

Hadronic resonances

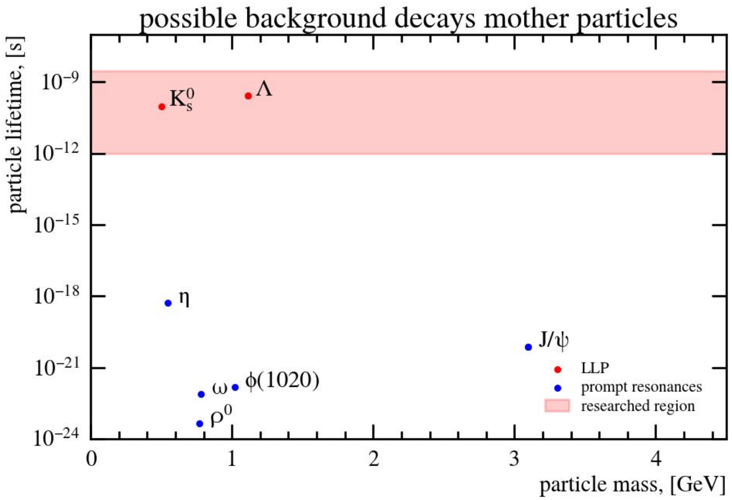
J/ψ, ψ, φ(1020), ψ(2S), ψ(3770), K**s**, ψ(4160), which were important in the Run1 analysis with *long* tracks

Strange candidates:

SM particles with large lifetimes: K**s**, **Λ0**

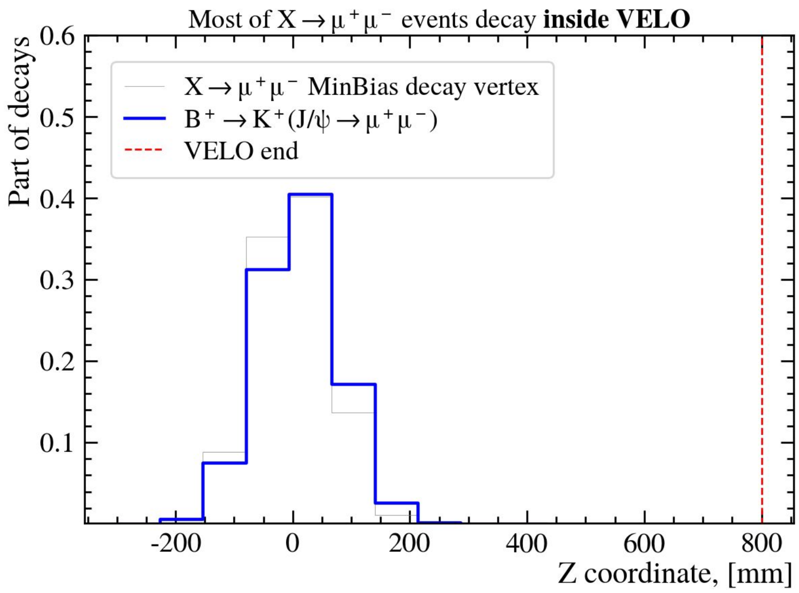
Combinatorial background:

Random pair combination of muons, coming from different *b*-hadron decays (semileptonic decays, etc…)



Background: hadronic resonances

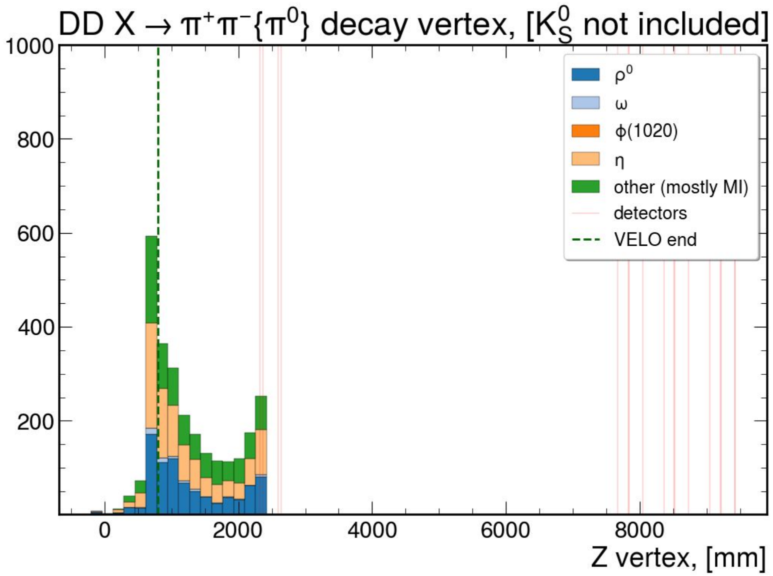
Decay vertices for hadronic resonances:



No *down-down* reconstructed tracks coming from J/ψ, both in case they are coming from prompt or from B decays

Background: hadronic resonances

Possible resonances after VELO:



For downstream region, except K_s, Λ_0, we can expect mostly eta, rho0 and material iterations pairs.

Those resonances can decay into μμ, but have very low rate.

$$\mathcal{B}\left(\rho^0 \to \mu^+\mu^-\right) = 4.55 \pm 0.28 \cdot 10^{-8}$$

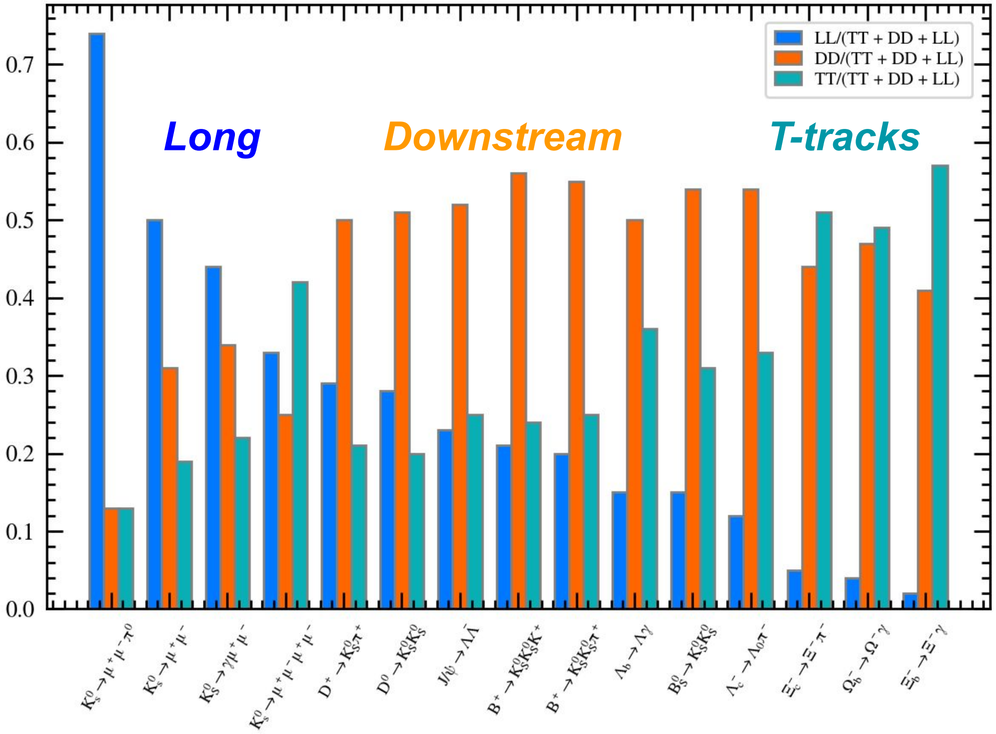
$$\mathcal{B}\left(\omega \to \mu^+\mu^-\right) = 7.4 \pm 1.8 \cdot 10^{-8}$$

$$\mathcal{B}\left(\eta \to \mu^+\mu^-\gamma\right) = 3.1 \pm 0.4 \cdot 10^{-4}$$

$$\mathcal{B}\left(\eta \to \mu^+\mu^-\right) = 5.8 \pm 0.8 \cdot 10^{-6}$$

Background: strange candidates

Reconstructed track categories as function of the decay channel:



Downstream tracks coming from b-/c-/-s hadron decays are expected from Λ and K_s candidates.

⇒ change mass hypothesis and veto the Λ and K_s regions

Selection procedure: Neural Network

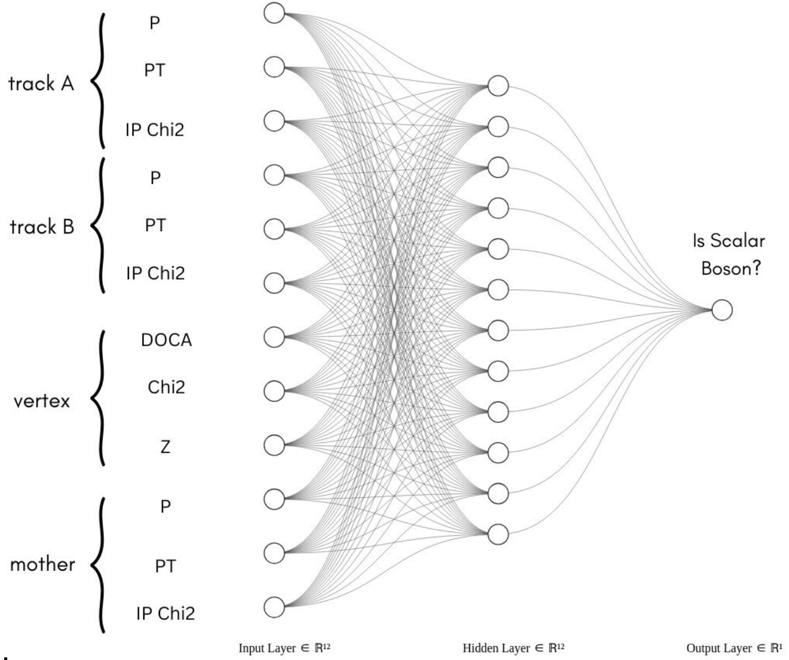
New HLT1 trigger lines in development (*Hlt1DownstreamMVADarkBoson2MuMu*)

Procedure:

- Pair *downstream* tracks

- NN selection: from each pair use a set of variables to decide if the pair corresponds to a scalar boson decay or not:

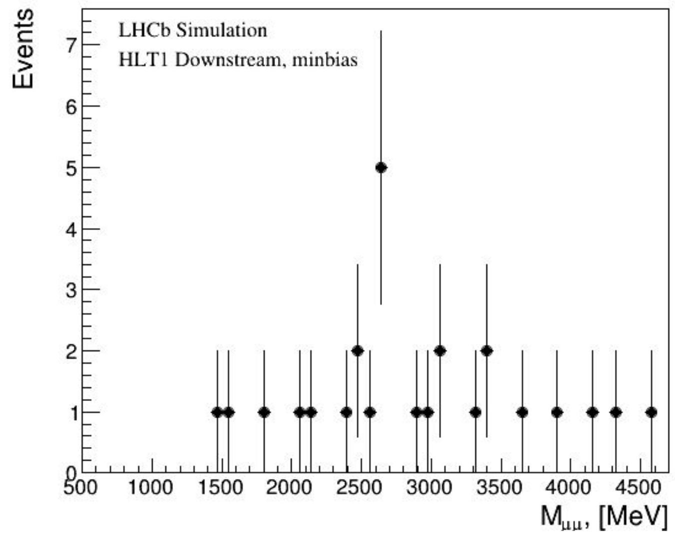
  - Both daughter particles momentum and track quality
  - Vertex quality and position
  - Mother particle momentum and quality



- Trained with signal simulated events and background MinBias

Background: combinatorial background

Random pair combination of muons are expected to come from different *b*-hadron decays (semileptonic decays, etc...)



Minbias sample, 100K events
NN threshold = 0.8

- MC simulations show that the amount of combinatorial background decreases with the mass of the scalar particle, being negligible for masses larger than 2 GeV.

Whats next?

- S -> gluon gluon
  - HLT1 downstream jets recognition
  - downstream hadronic resonances recognition
- Line implementation to HLT1
- Development of improvements for event selection NN

Thanks for attention!