Instituto Galego de Física de Altas Enerxías

UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

New approaches to find Dark Matter on the LHCb experiment

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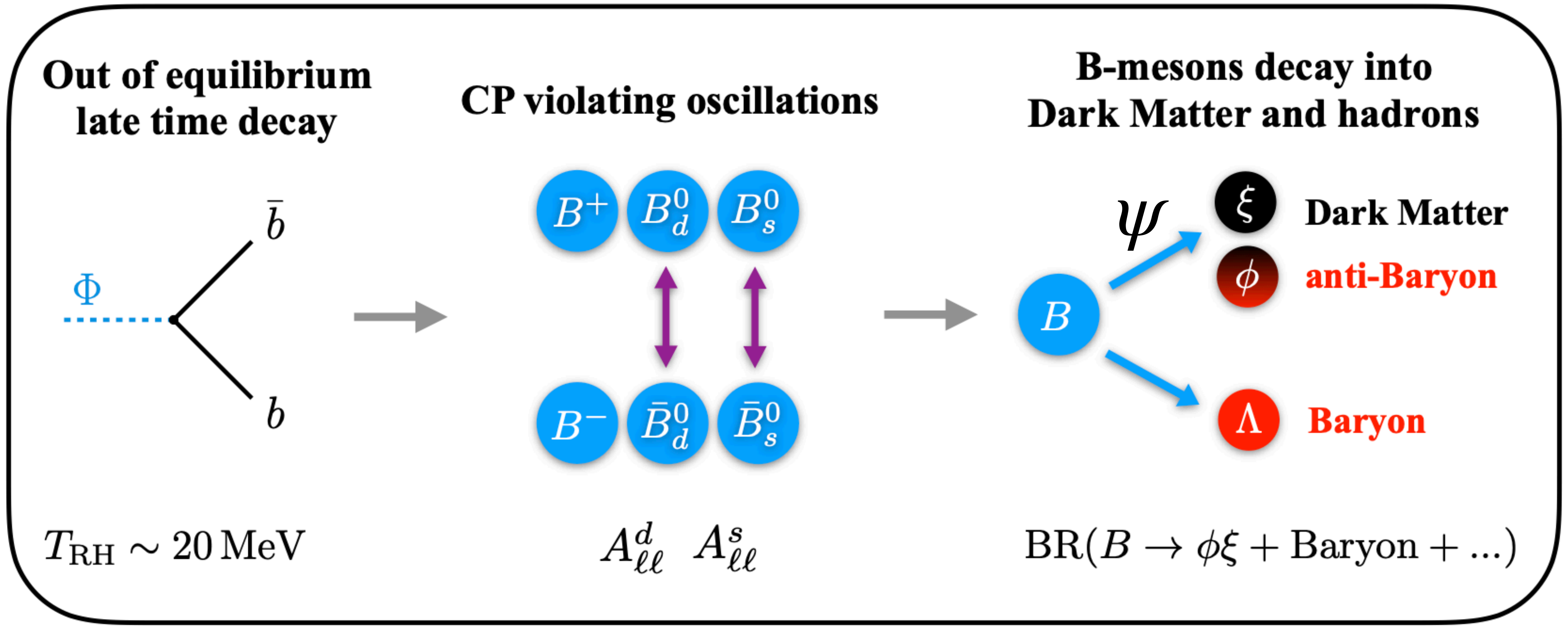
Outline

- Theoretical Background
- The LHCb experiment
- Available Channels for DM
- First Results
- WIP and Further Steps

Theoretical Background (I)

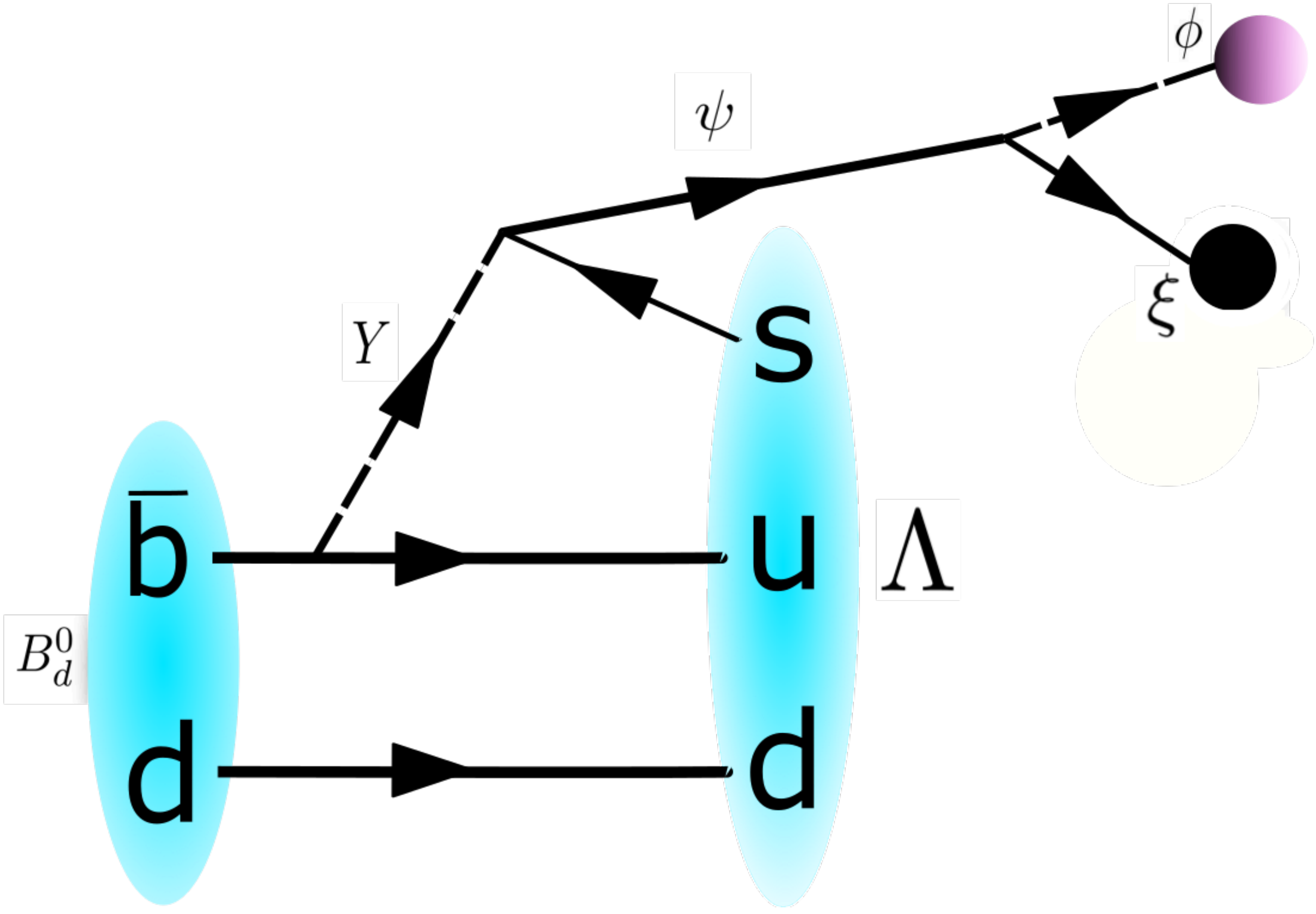
Baryogenesis and Dark Matter



- According to this theoretical model [Baryogenesis and Dark Matter from B Mesons, G. Elor et al. arXiv:1810.00880] both baryogenesis and dark matter can be explained from B-Mesons decays.
- Only three conditions must be required:
  - B-mesons out of thermal equilibrium in the early Universe
  - CP violation (would be enough with the SM one)
  - Baryon number violation
- We are looking for decays like: $B^0_{s,d} \to \psi + {\rm Baryon} + X$
- And Baryogenesis rate would be given by:

$$Y_B \propto \sum_{q=s,d} A^q_{ll} \times {\rm Br}(B^0_q \to \psi + {\rm Baryon} + X)$$

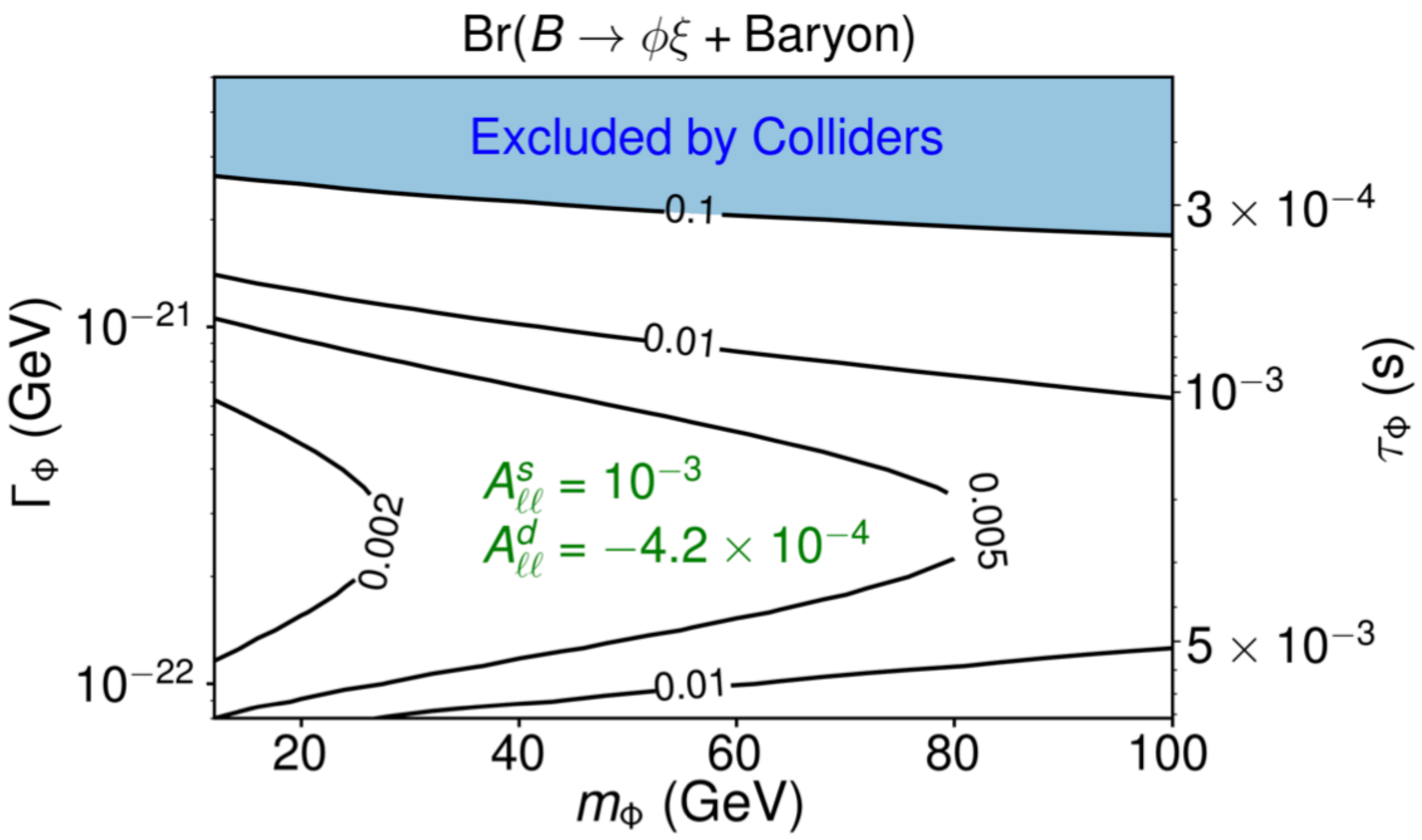
Theoretical Background (II)
Decays to Dark Matter



- An extension of the Standard Model is required, being the minimal one:

$$\mathcal{L} \supset -y_{ub} Y^* \bar{u} b^c - y_{\psi s} Y \bar{\psi} s^c + \text{h.c.}$$

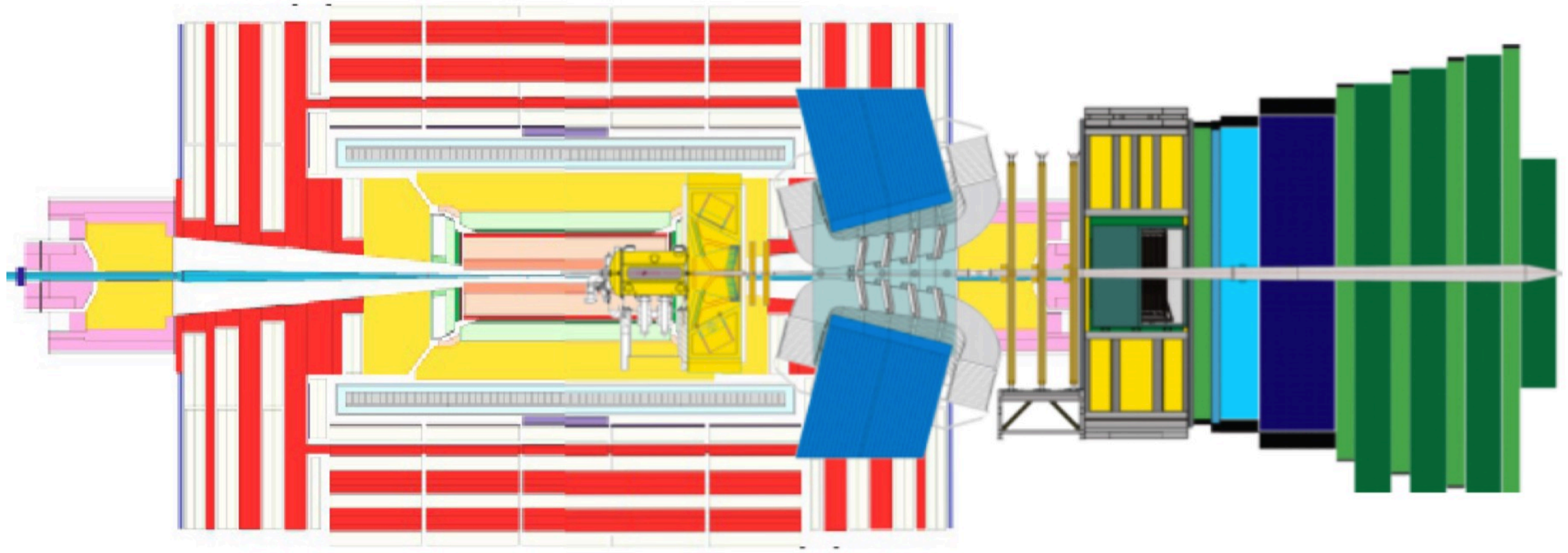
- Other flavour configurations are accepted.
- $1.2\text{GeV} < m_\psi < 4\text{GeV}$. Lower limit is given by neutron star stability, while the higher one by the energy available in a B-meson decay



Theoretical Background (III)

Branching ratios of the process

- For this model, high BR to DM are allowed, given certain values of lepton charge asymmetry.
- Many configurations of $A_{ll}^{s,d}$ are possible, even those predicted by the Standard Model.
- The values of $A_{ll}^{s,d}$ define the Branching Ratio plot.

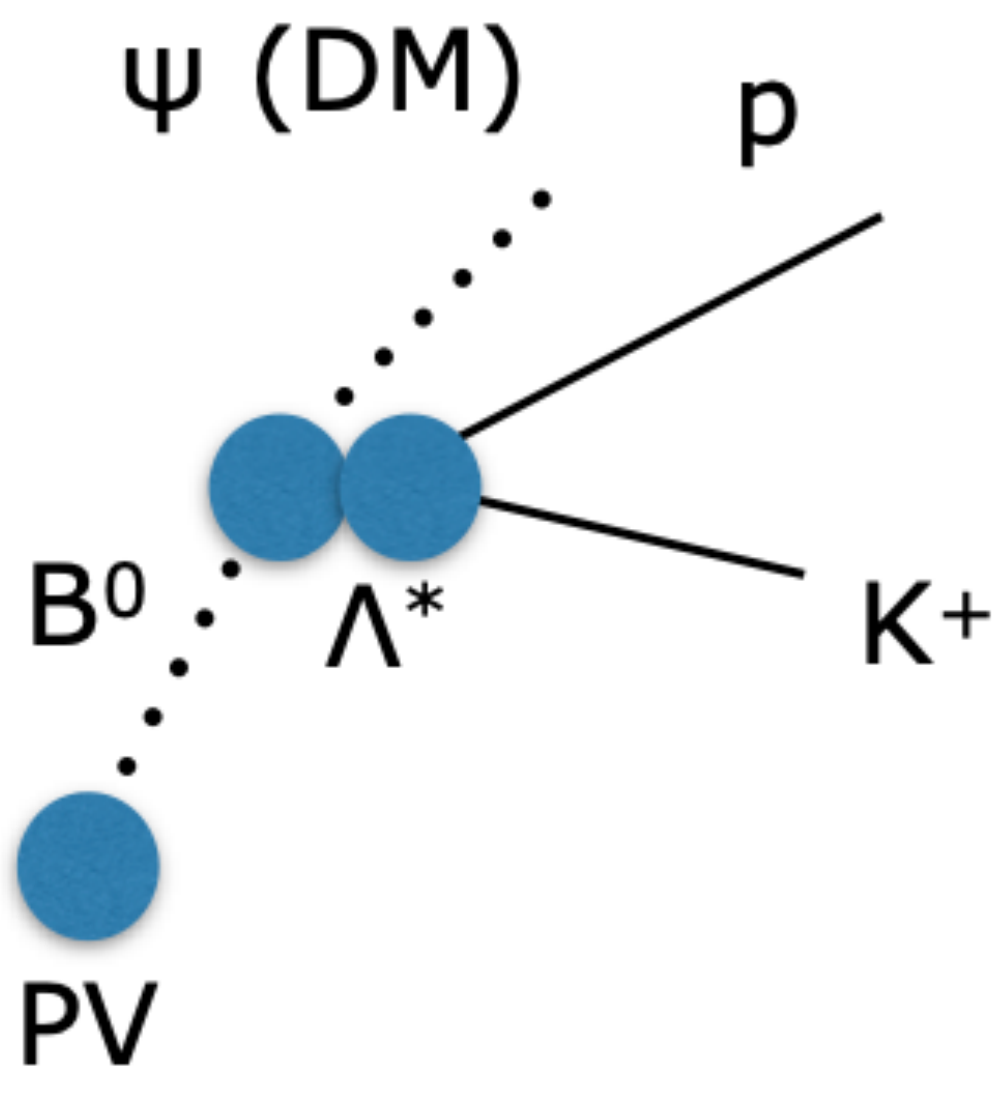


The LHCb experiment for DM

- We can't measure Missing Energy in LHCb, since it is not a closed detector, making our decays hard to study.
- BaBar and Belle are better suited experiment for this (BaBar already doing a paper on this).
- On the other hand, we have sensitivity for more modes, such as Λ_b, B_s decays or B_{s2}^{*0} resonances.

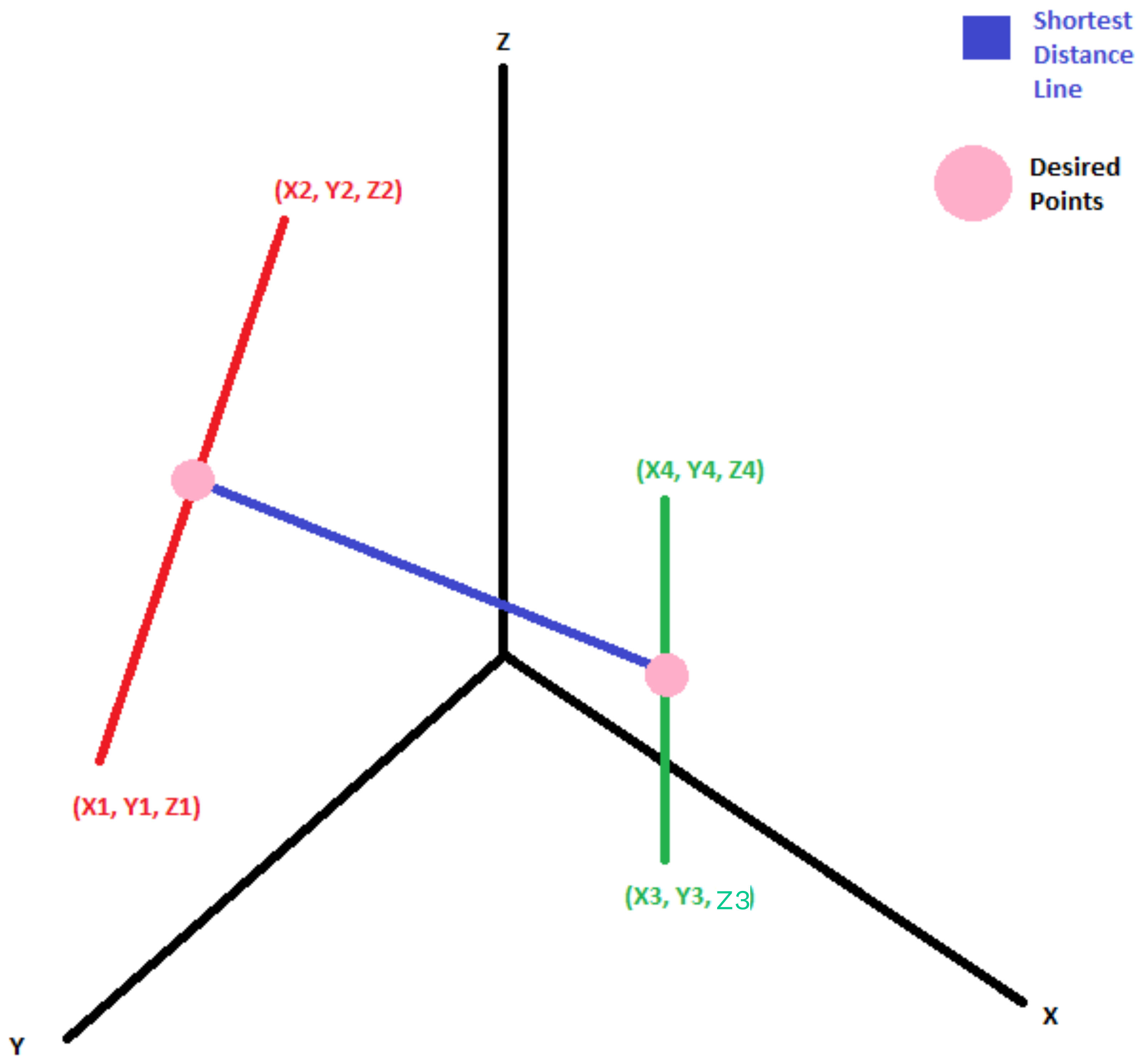
Available channels for DM

Decay Channel	Reconstruction Efficiency Signal
$B^0 \to \psi\Lambda^*,\ \Lambda^* \to pK^-$	39 %
$B^+ \to \psi\Lambda_c^+(2595), \Lambda_c^+(2595) \to \Lambda_c^+\pi^-\pi^+, \Lambda_c^+ \to pK^+\pi^-$	4.1%



- We can only reconstruct those events in which we detect every particle in the final state according to:
  - $p_T > 0.25 GeV$ and $\eta \in (2,5)$
  - $z(\Lambda_c^+)$<500mm and $\rho(\Lambda_c^+)$<30mm
- This is a standard configuration for LHCb because of the VELO.
- We chose these two flavour configurations of all the available ones by the Lagrangian because they are good candidate for LHCb.
- These kind of topologies are useful because we can obtain the decay point of the B-meson.

Some useful definitions (I)



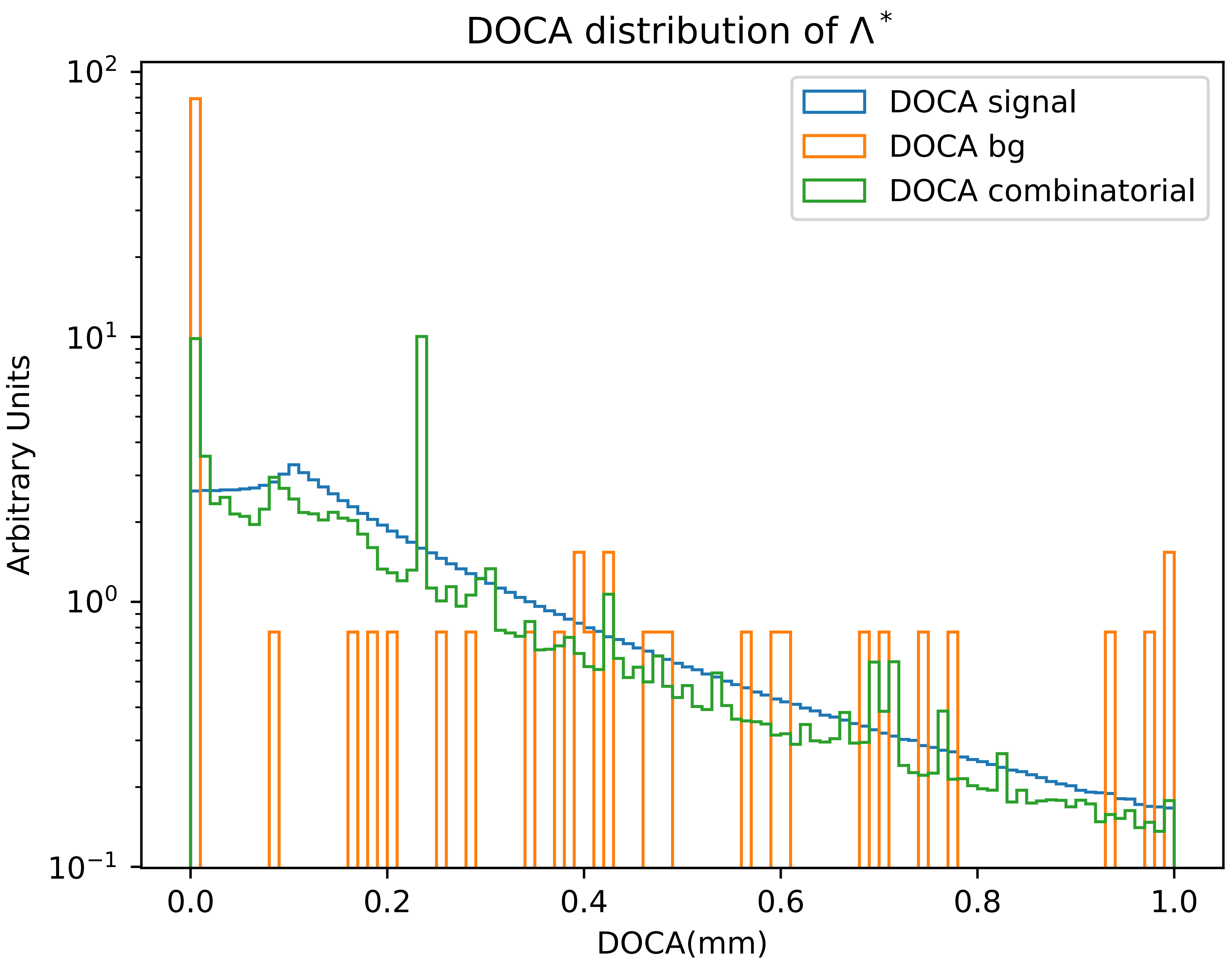
- Now we'd like to obtain somehow efficiencies for this processes and for theirs backgrounds.
- For this we study the DOCA (Distance Of Closest Approach) of the reconstructed baryons with the rest of p, K, π, e, μ in the LHCb acceptance. This is a way of measuring the isolation (expected higher for processes involving DM).
- Same goes for the IP (Impact Parameter) of the Baryons.

Some useful definitions (II)

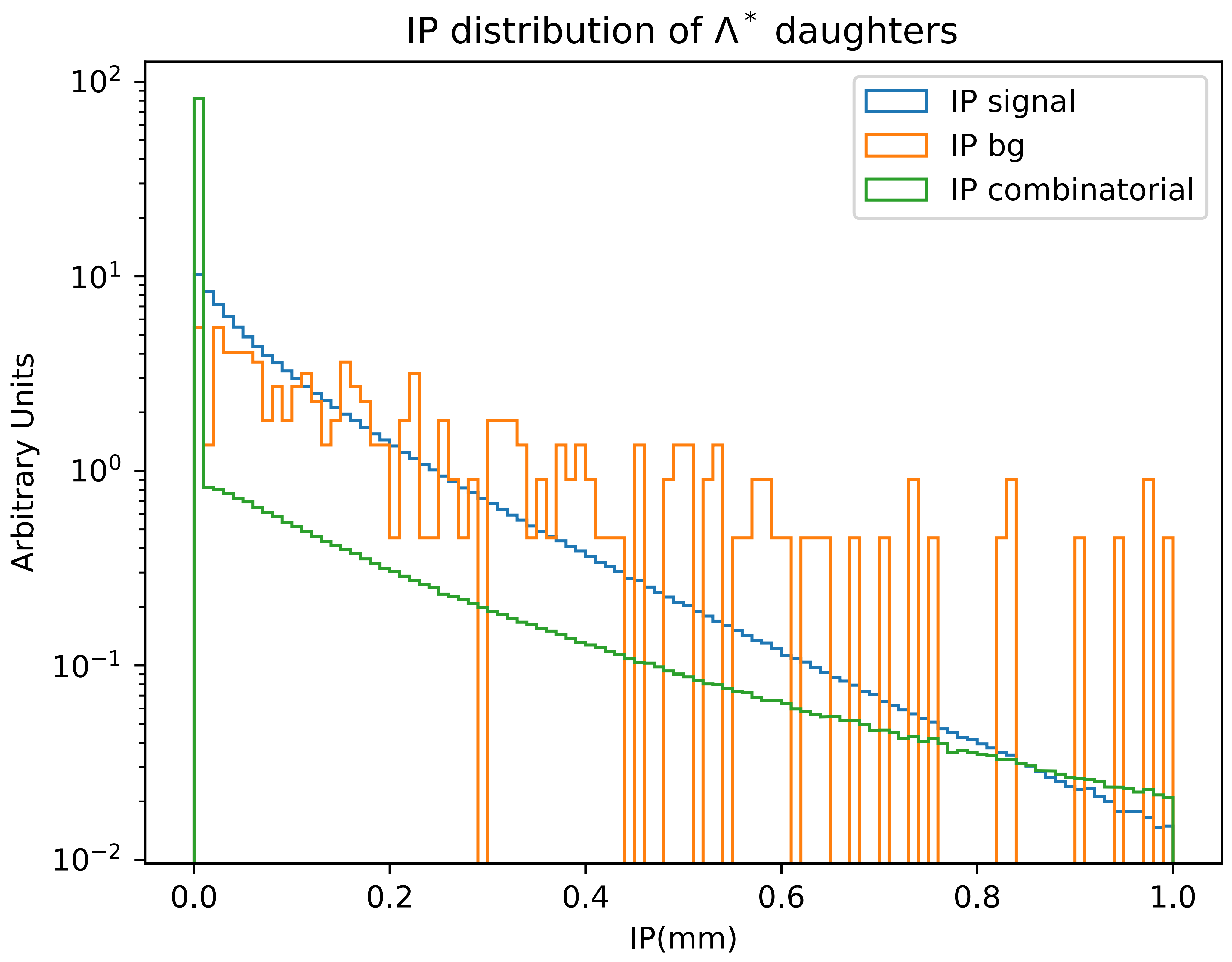
- Combinatorial Background: pK pairs coming from the same vertex with an invariant mass close (1.3 - 1.6GeV) to $\Lambda*$ mass (1.52 GeV). We exclude explicitly all of those pairs coming from an actual $\Lambda*$.
- Real Baryon Background: $\Lambda*, \Lambda_c^+$ that don't come from decays to Dark Matter.
- Signal: $\Lambda*, \Lambda_c^+$ that come from a decay involving Dark Matter.
- Every particle must be in the LHCb acceptance.
- For these concepts we can define the efficiencies:

$$\varepsilon_{B\bar{B}}^{\mathrm{BG}} = \frac{\#\Lambda^* \cdot \mathrm{BR}(\Lambda^* \to pK^-) \cdot \varepsilon}{\#\text{events}} \qquad \varepsilon_{B\bar{B}}^{\text{signal}} = \frac{\#\mathrm{Bs} \cdot \mathrm{BR}(B^0 \to \psi\Lambda^*) \cdot \mathrm{BR}(\Lambda^* \to pK^-) \cdot \varepsilon}{\#\text{events}}$$

First Results (I)

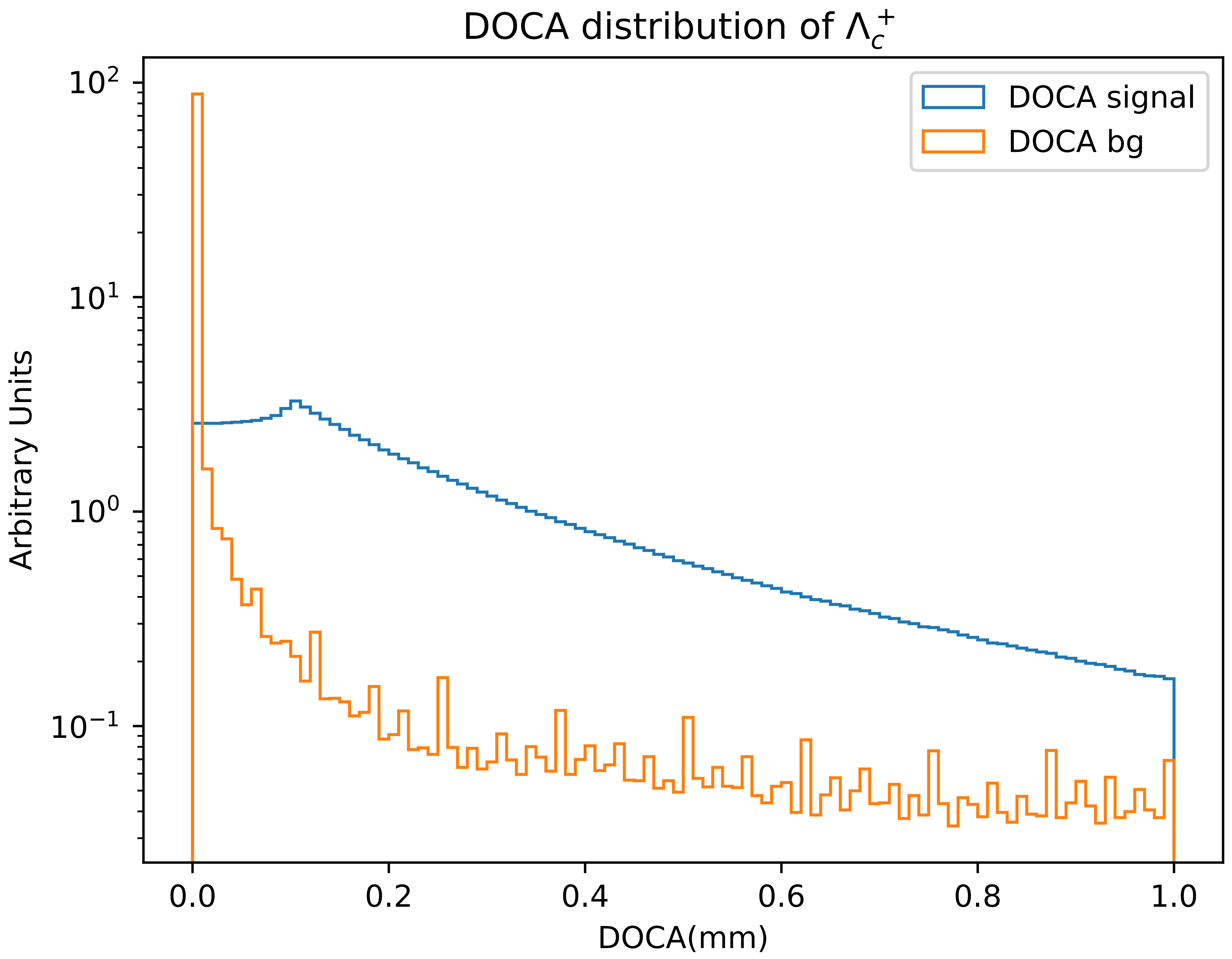


Cut: DOCA(Λ*)>0.02mm

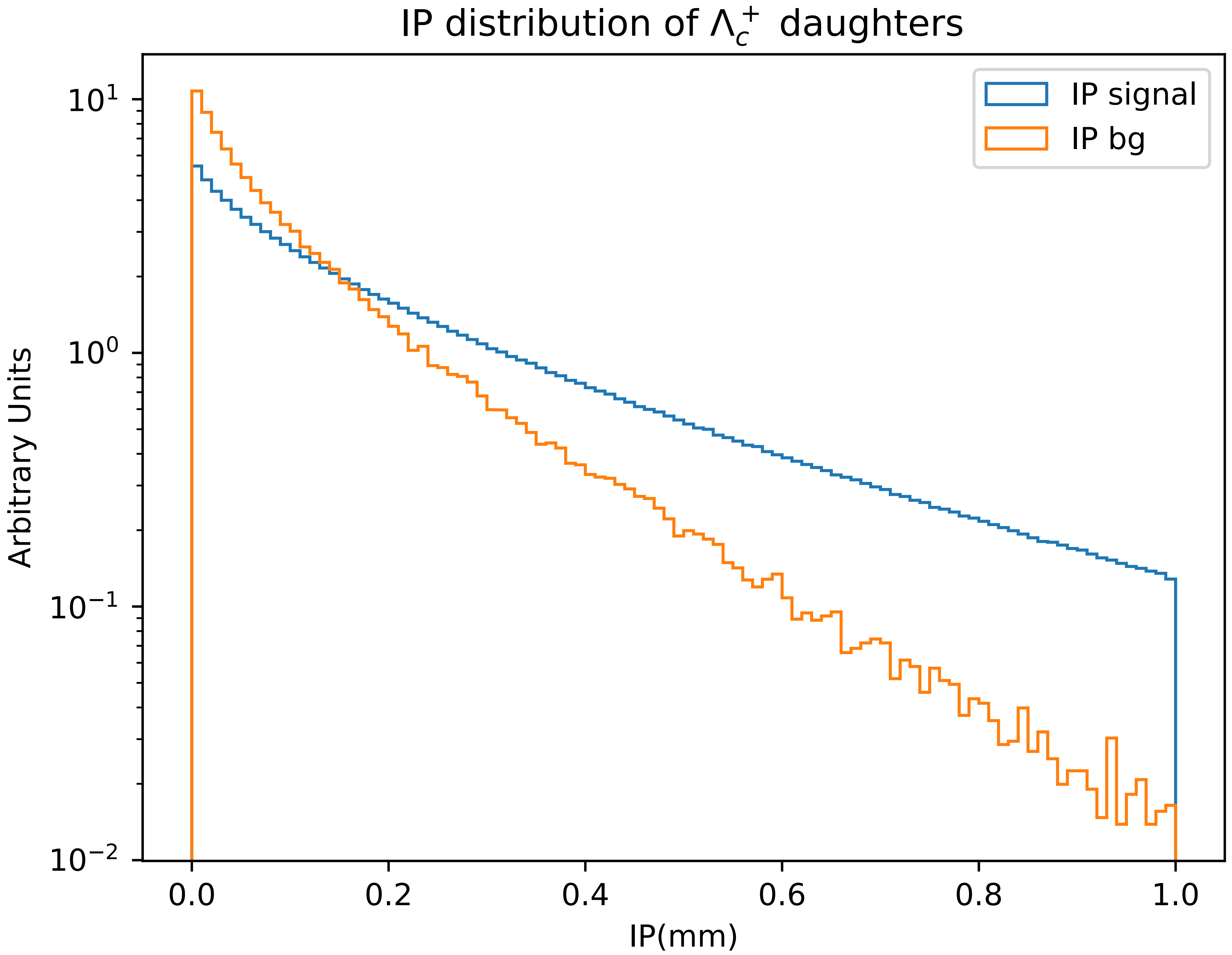


Cut: IP(Λ*)>0.0

First Results (II)



Cut: DOCA(Λ_c^+)>0.0



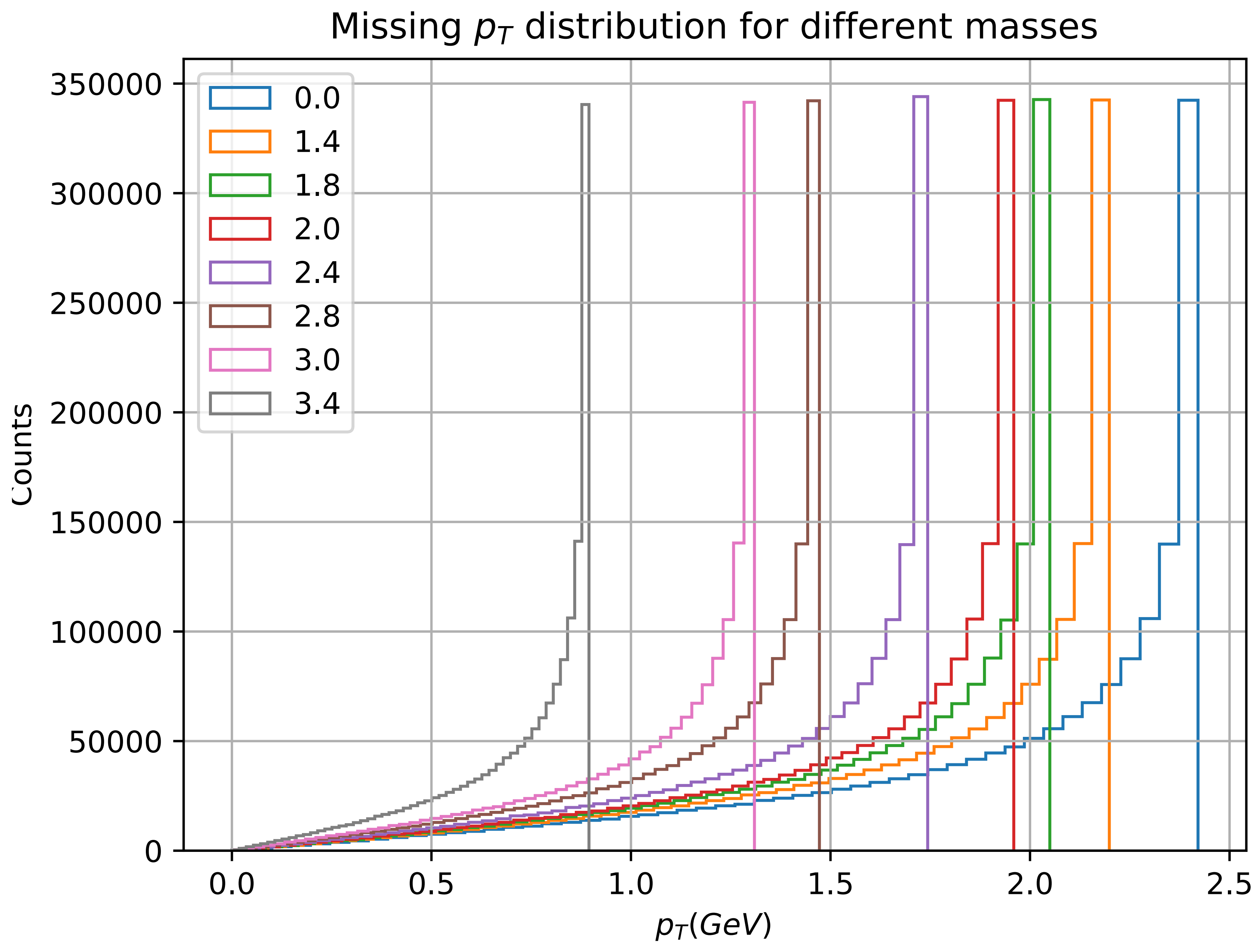
Cut: IP(Λ_c^+)>0.14mm

First Results (III)

Efficiency per BB pair

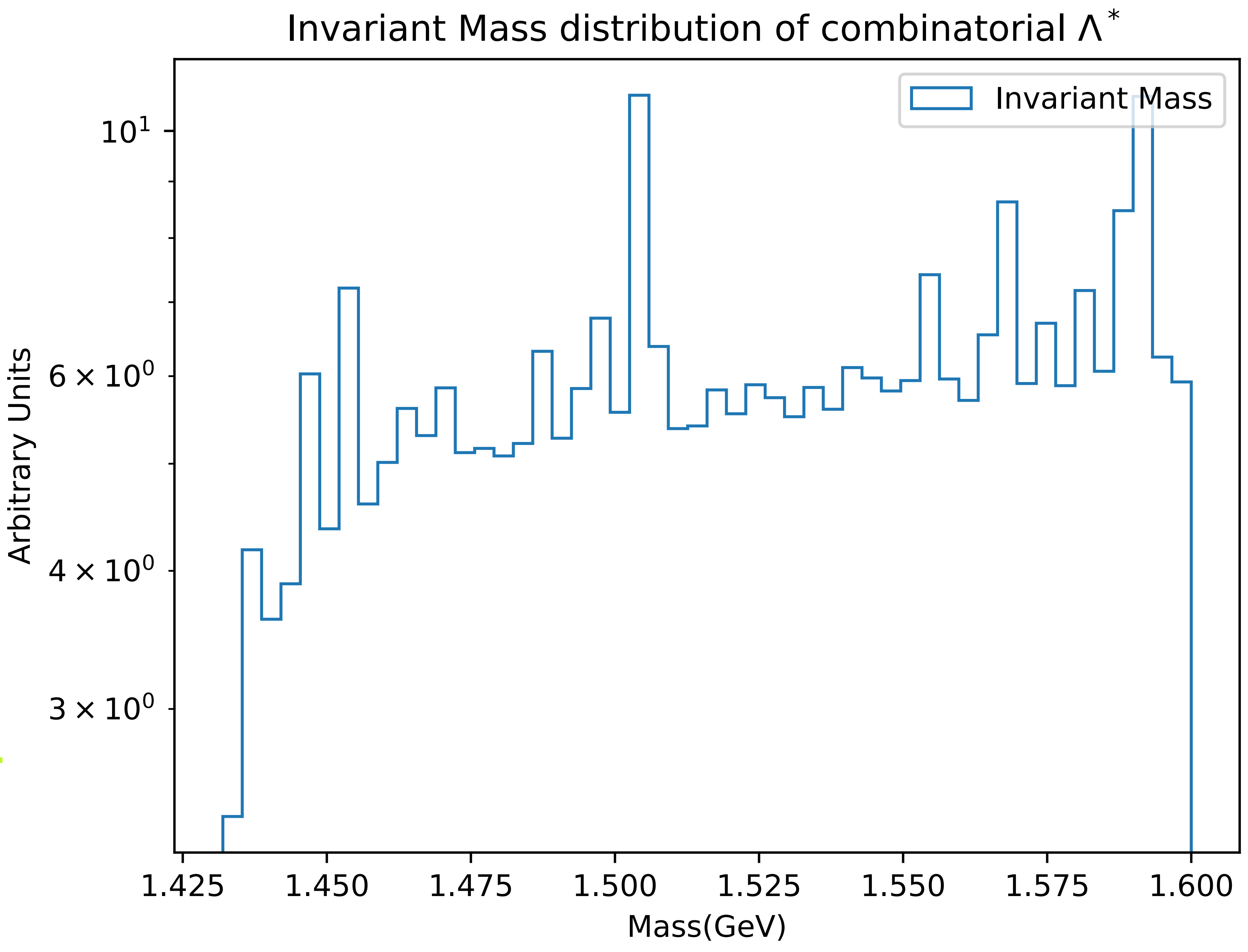
Baryon	Λ^*	Λ_c^+
Combinatorial Background	1.63(73)e-4	-
Real Baryon Background	1.82(91)e-7	1.47(78)e-7
Signal	0.00979(95) $\times \mathrm{Br}(\mathrm{B}^0 \to \psi\Lambda^*)$	0.25(11)e-4 $\times \mathrm{Br}(\mathrm{B}^+ \to \psi\Lambda_c^+)$
Combinatorial Yield	1.22e12	-
Real Baryon Yield	1-36e9	1.1e9
Signal Yield	7.34e13 $\times \mathrm{Br}(\mathrm{B}^0 \to \psi\Lambda^*)$	1.88e11 $\times \mathrm{Br}(\mathrm{B}^+ \to \psi\Lambda_c^+)$

- For the chosen decays we can estimate the efficiency per $B\bar{B}$ pair.
- This numbers have been calculated taken into account the previous cuts, based on the distributions that I showed. Keep in mind that these can be optimizable
- Yield (σ=500mb and L=15fb^{-1}): $N = \sigma L = 7.5 \times 10^{15}$
- For Branching Ratios in the order of 10^{-3} this decays could be found on Run 3.

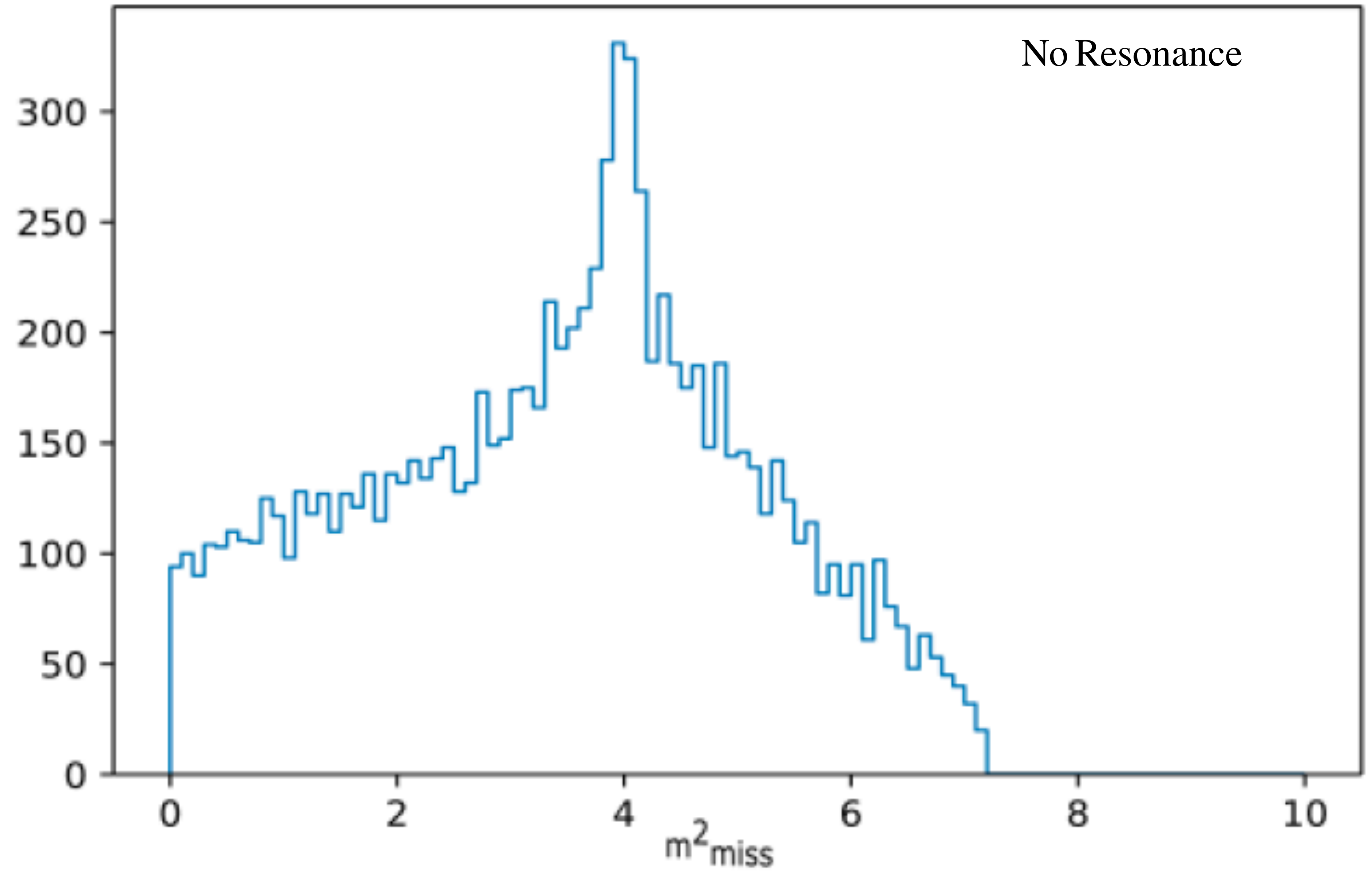


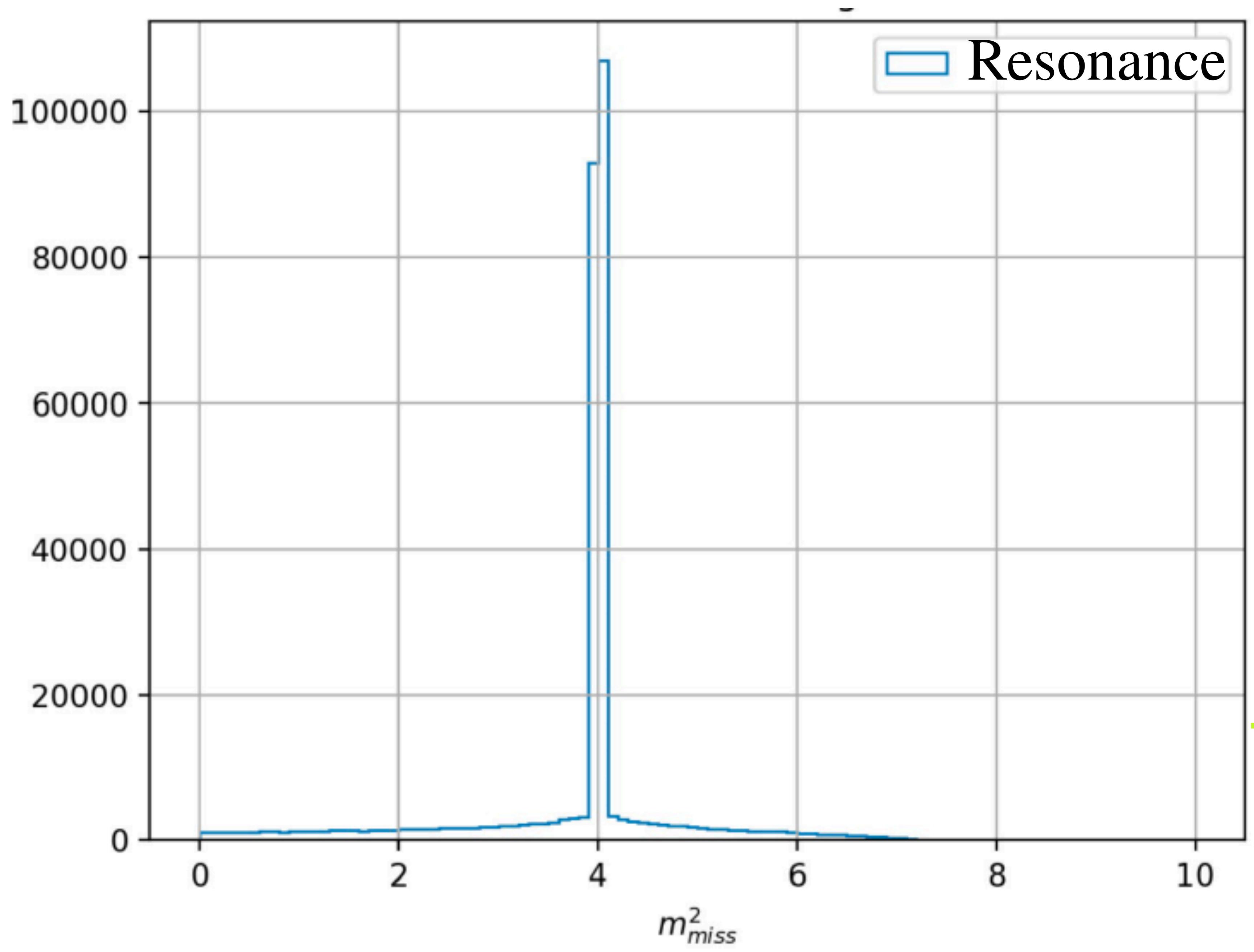
WIP and Further Steps (I)

- We now want to improve these numbers as much as we can. For this we have thought:
  - BDT (or another MVA technique) with additional variables, such as missing p_T.
  - Identifying the invariant mass resonances in the combinatorial background.



WIP and Further Steps (II)





- We now want to improve these numbers as much as we can. For this we have thought:
  - Using the B^*_{s2} resonance to improve background - signal discrimination [Search for the lepton flavour violating decay $B^+ \to K^+\mu^-\tau^+$ using B^{*0}_{s2} decays, LHCb Collaboration arXiv:1409.8548]
- Where $m^2_{\text{miss}} = m^2_\psi$ assuming a 2GeV mass.

Conclusions

- One of the key design objectives of the LHCb experiment is to search for B-meson decays.
- This makes the experiment an excellent candidate to search for these signatures, even with invisible particles in the final state (i.e. $\Lambda_b \to p\mu\nu$).
- For the SM predictions of A_{ll}^{q} the DM could be found on LHCb!
- Relatively low branching ratios are measurable from signal-background discrimination, below those allowed by the model.