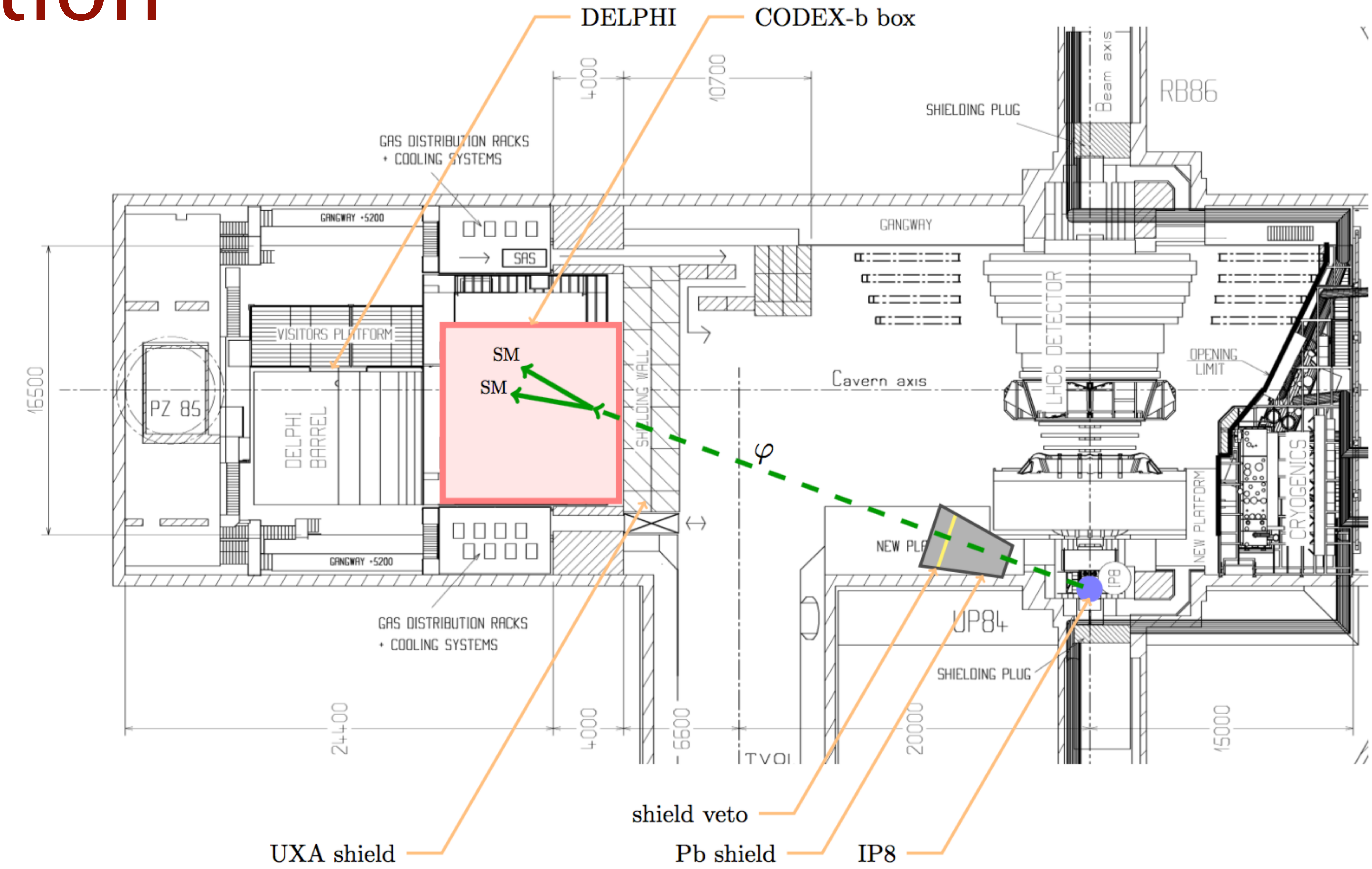
# CODEX-b : expanding LHCb's capabilities for long lived particle searches

**Vladimir V. Gligorov, Simon Knapen,**
**Michele Papucci, Dean J. Robinson**

European Research Council
Established by the European Commission

# Location


DELPHI

CODEX-b box

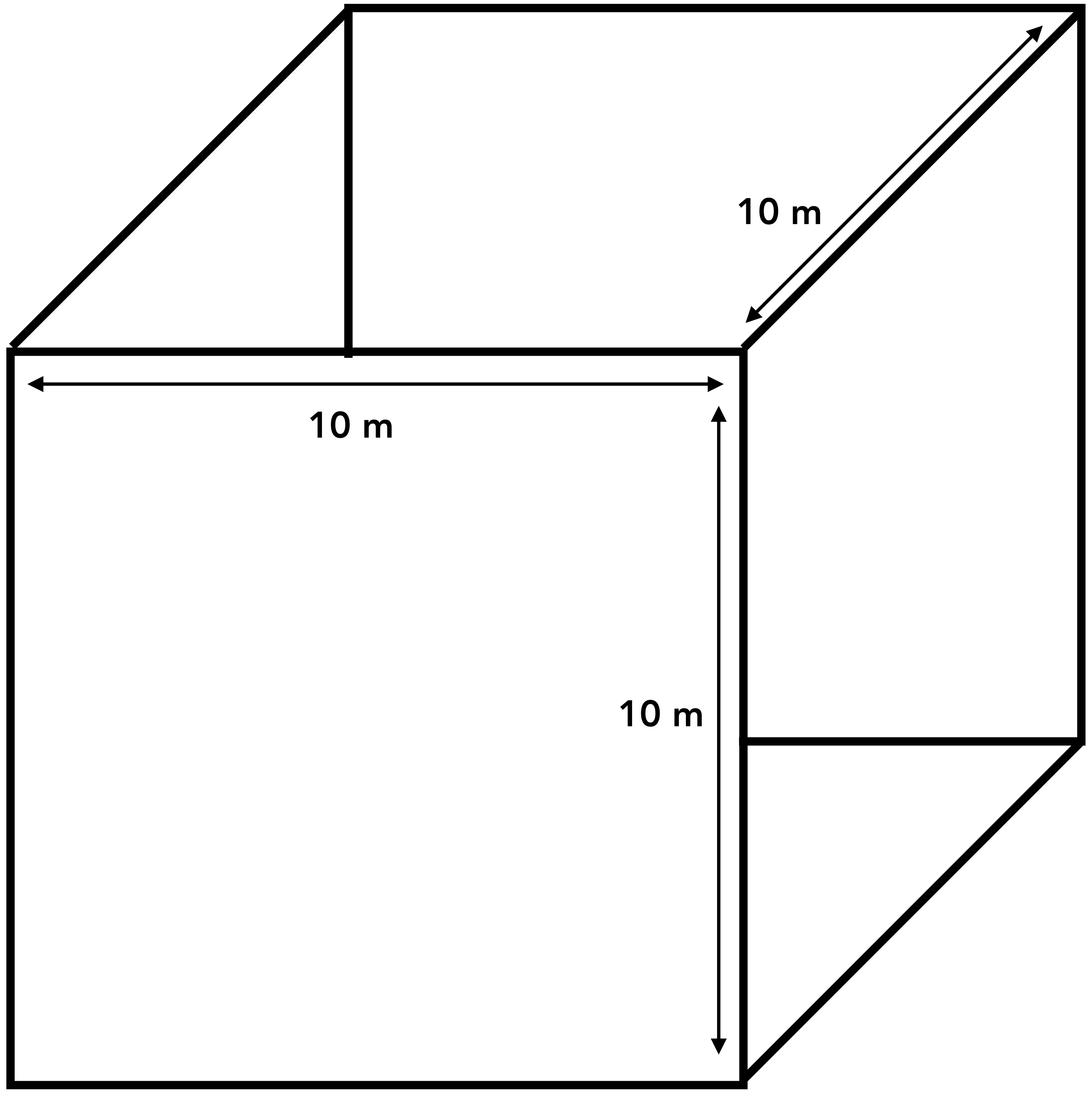
shield veto

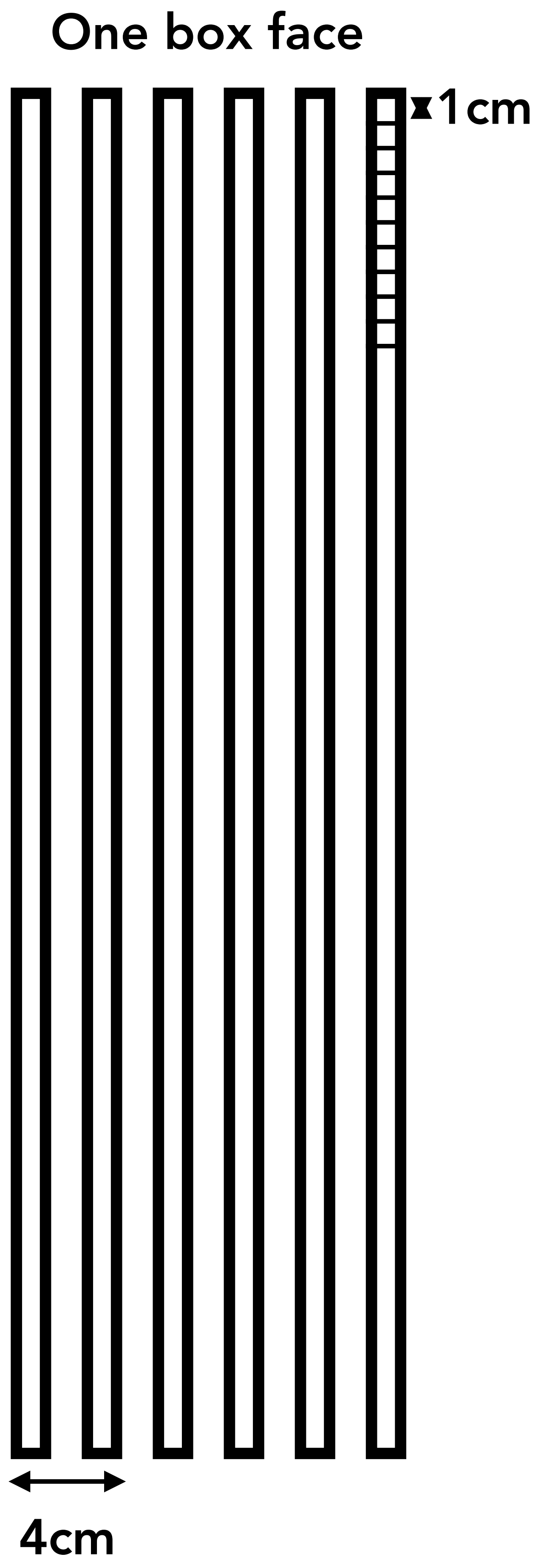
UXA shield

Pb shield

IP8

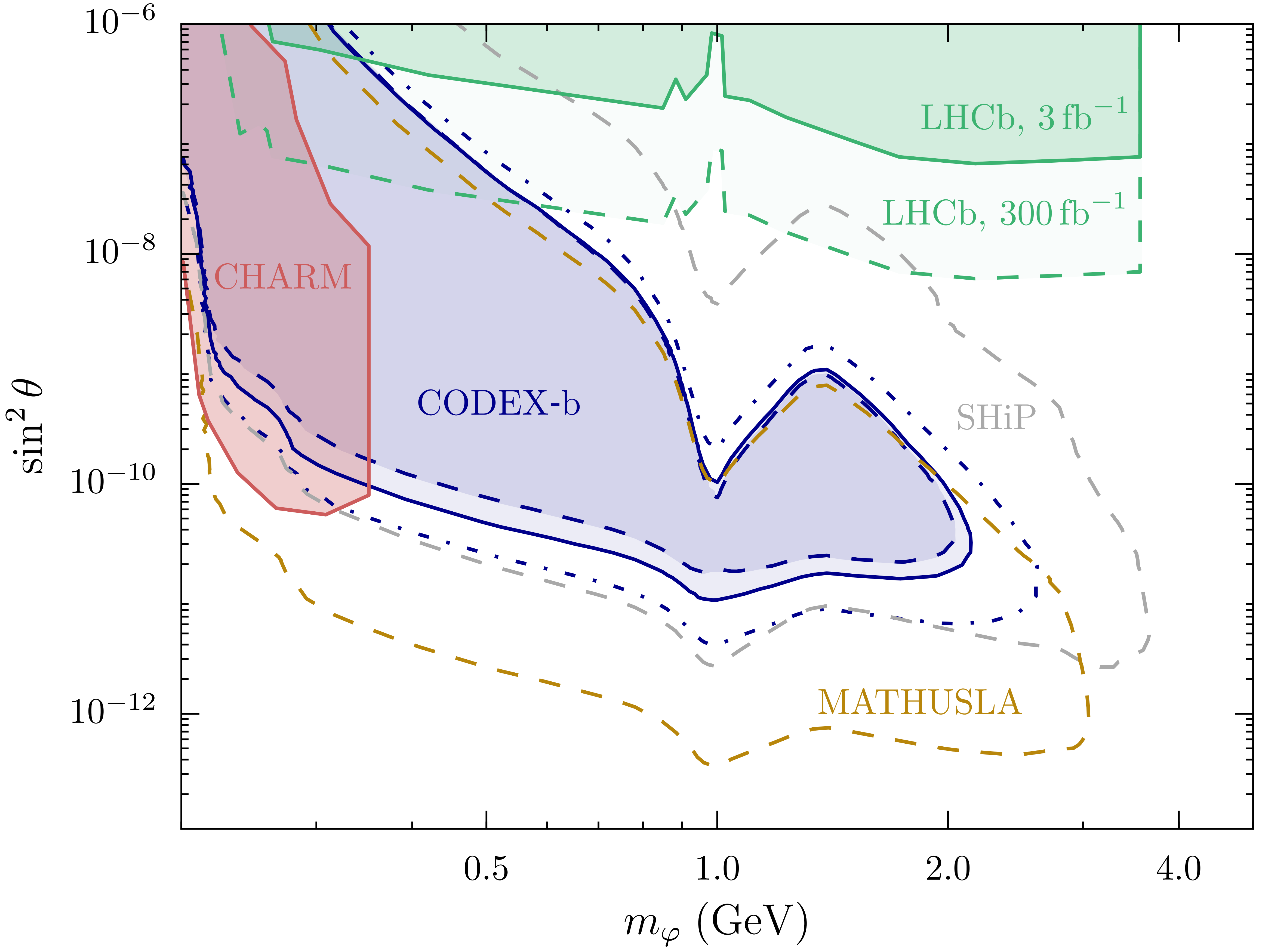
# Minimal proof-of-concept geometry

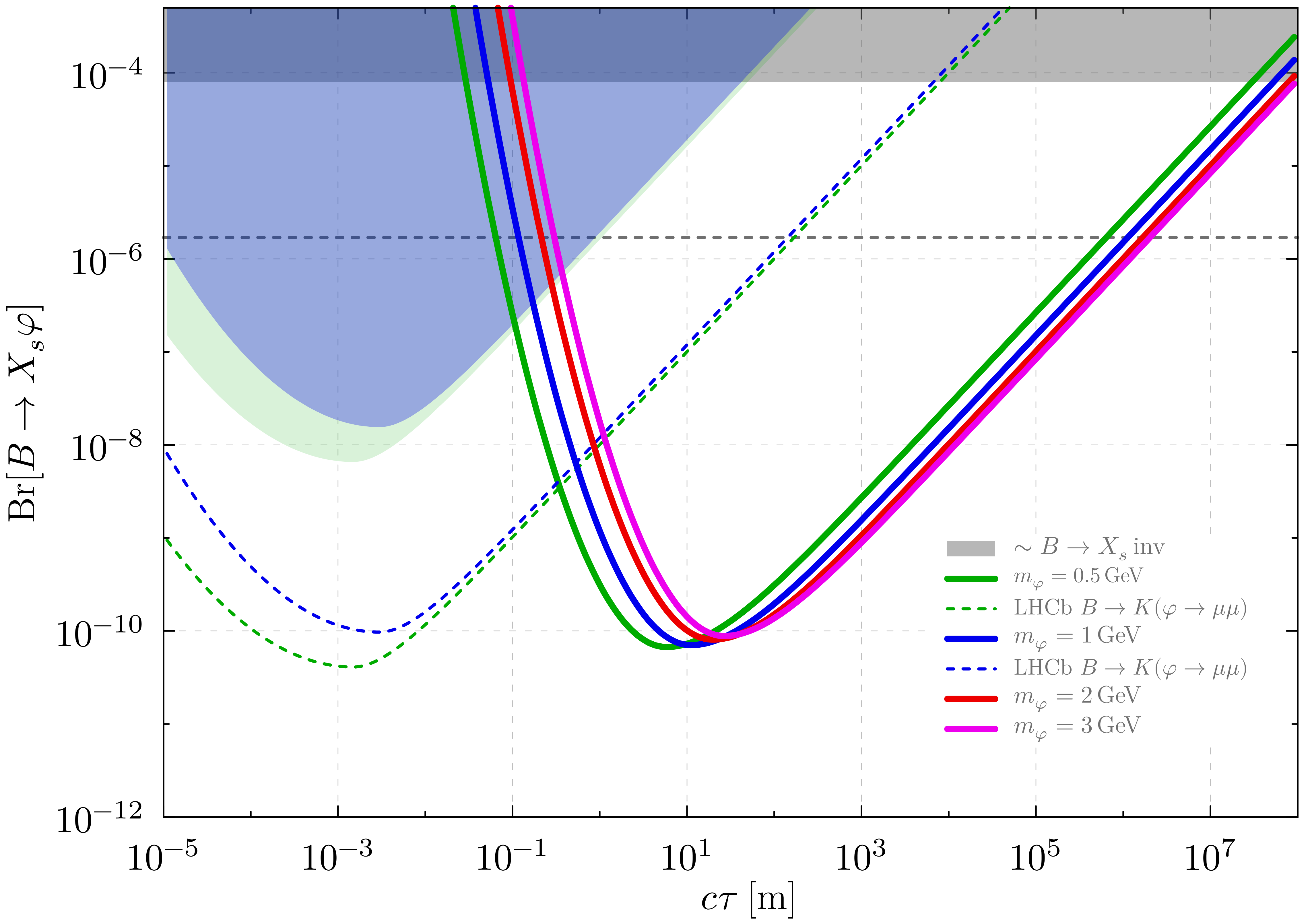




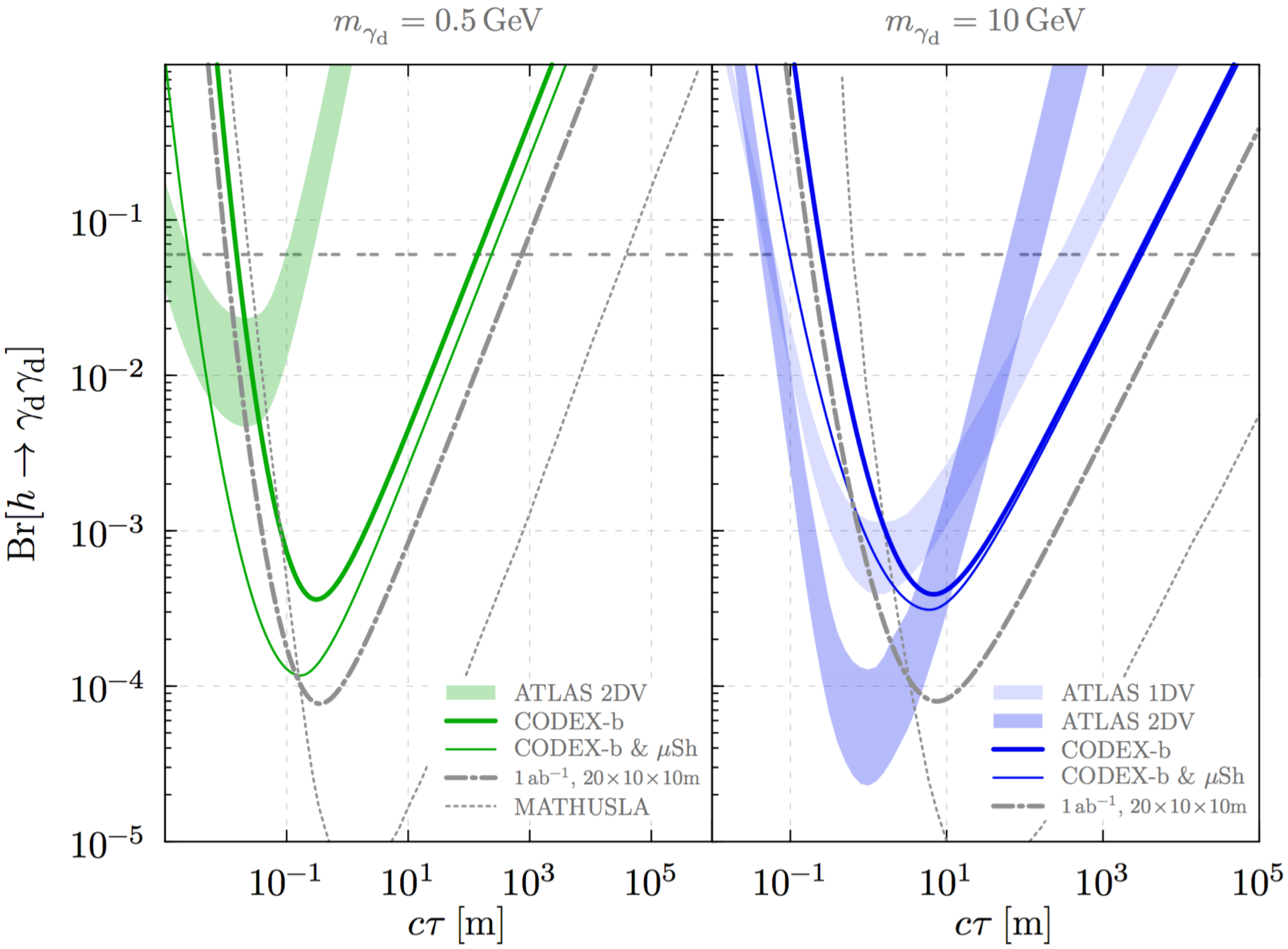
**10x10x10 metre box, with 6 RPC layers on each box face. Assume 1 cm granularity for the RPCs, and possibility of timing information (explored later in talk). Add 5 other triplets of RPC layers equally spaced in box to minimize the distance to the first measured point for the decay vertex determination.**

# Example model 1 — b→sX



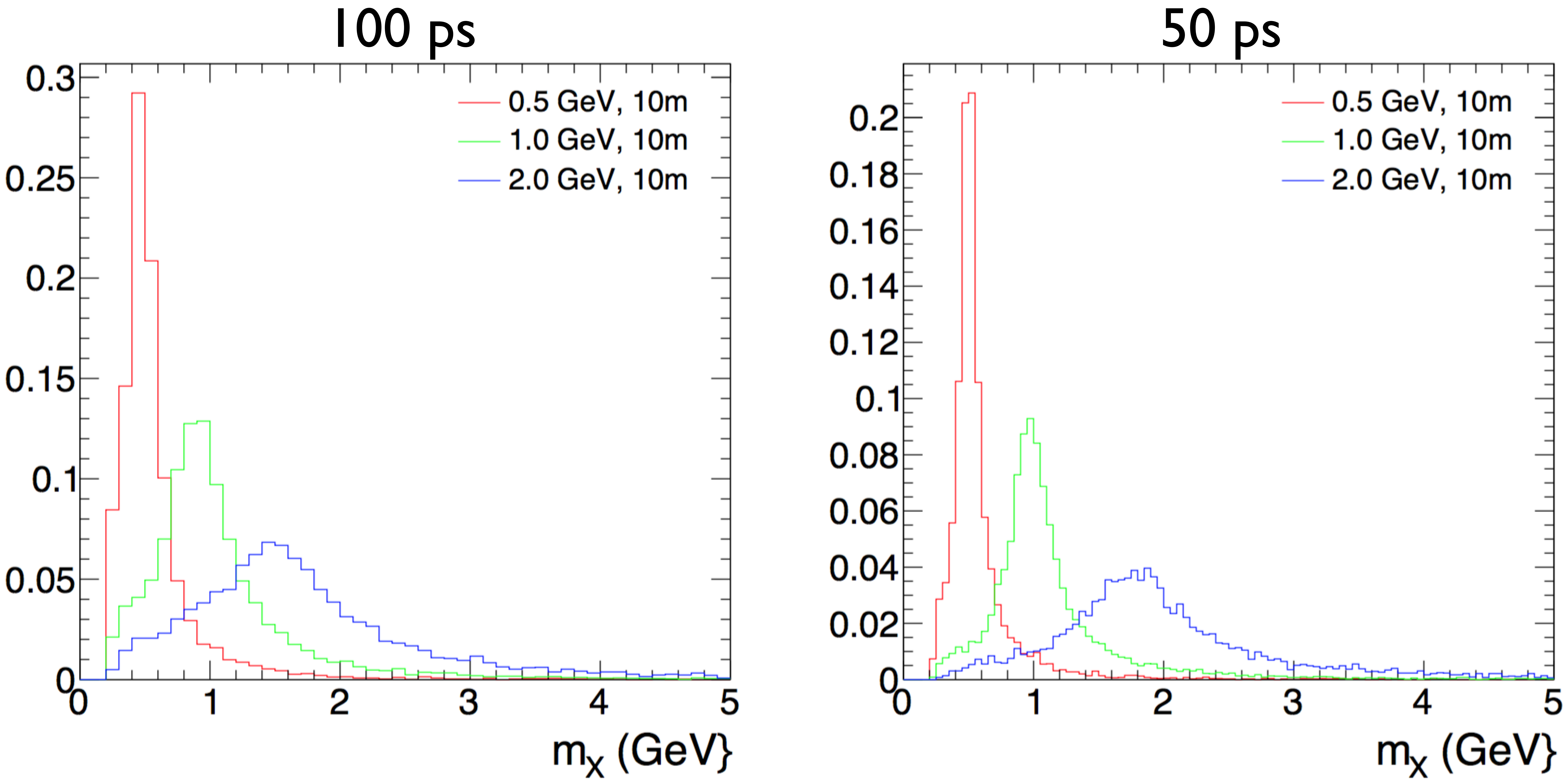


# Example model 2 — H→φφ



**Extends LHCb coverage far beyond ATLAS at low masses, competitive&complementary at higher ones. MATHUSLA has greater reach but backgrounds are uncorrelated.**

# Mass reconstruction using time-of-flight

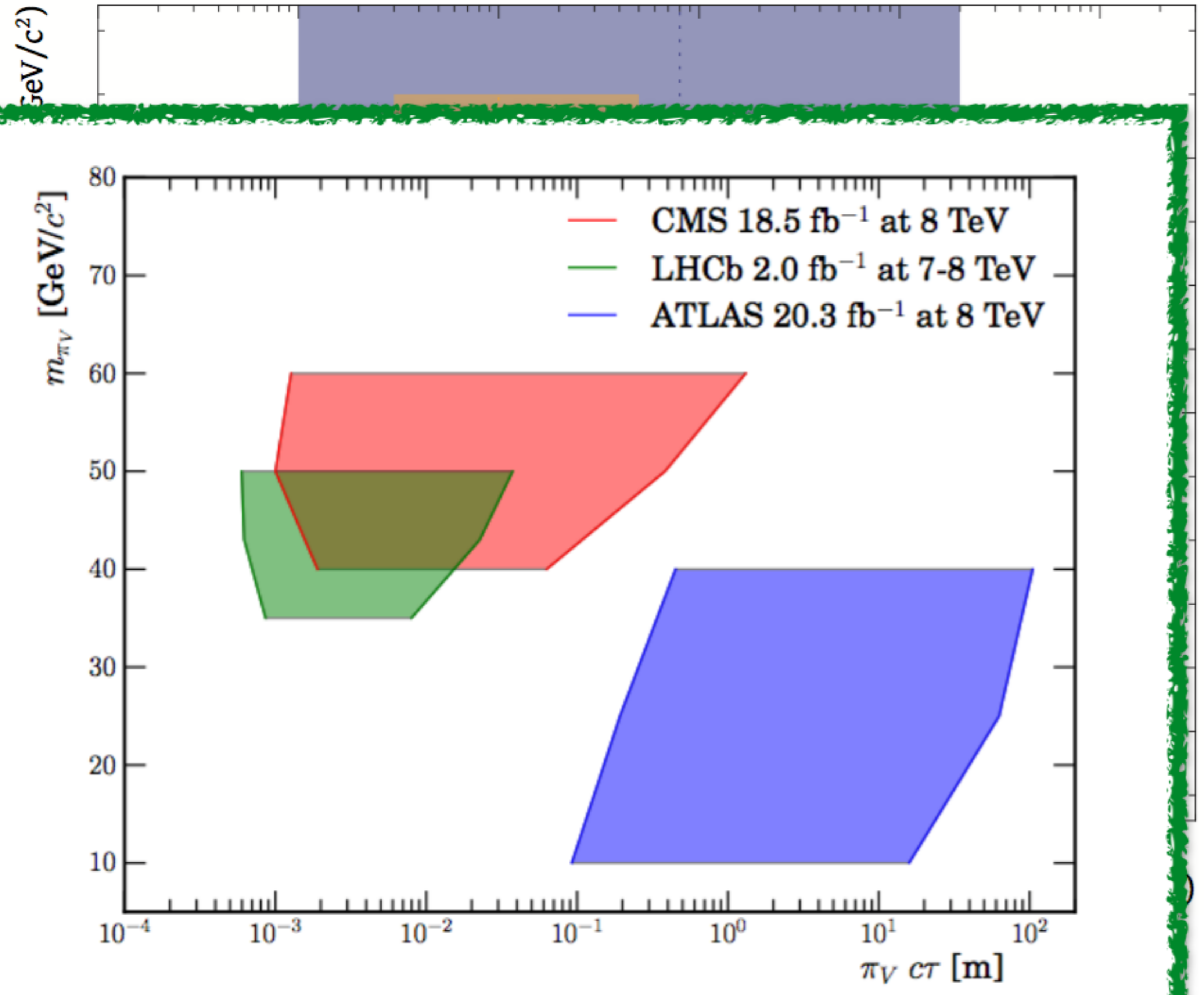


**Now assume 100/50 ps time resolution (per hit) in the tracking stations. The B→KX signals are actually slow enough that we can reconstruct the X mass…**

# BACKUP

# LHCb already complements ATLAS/CMS

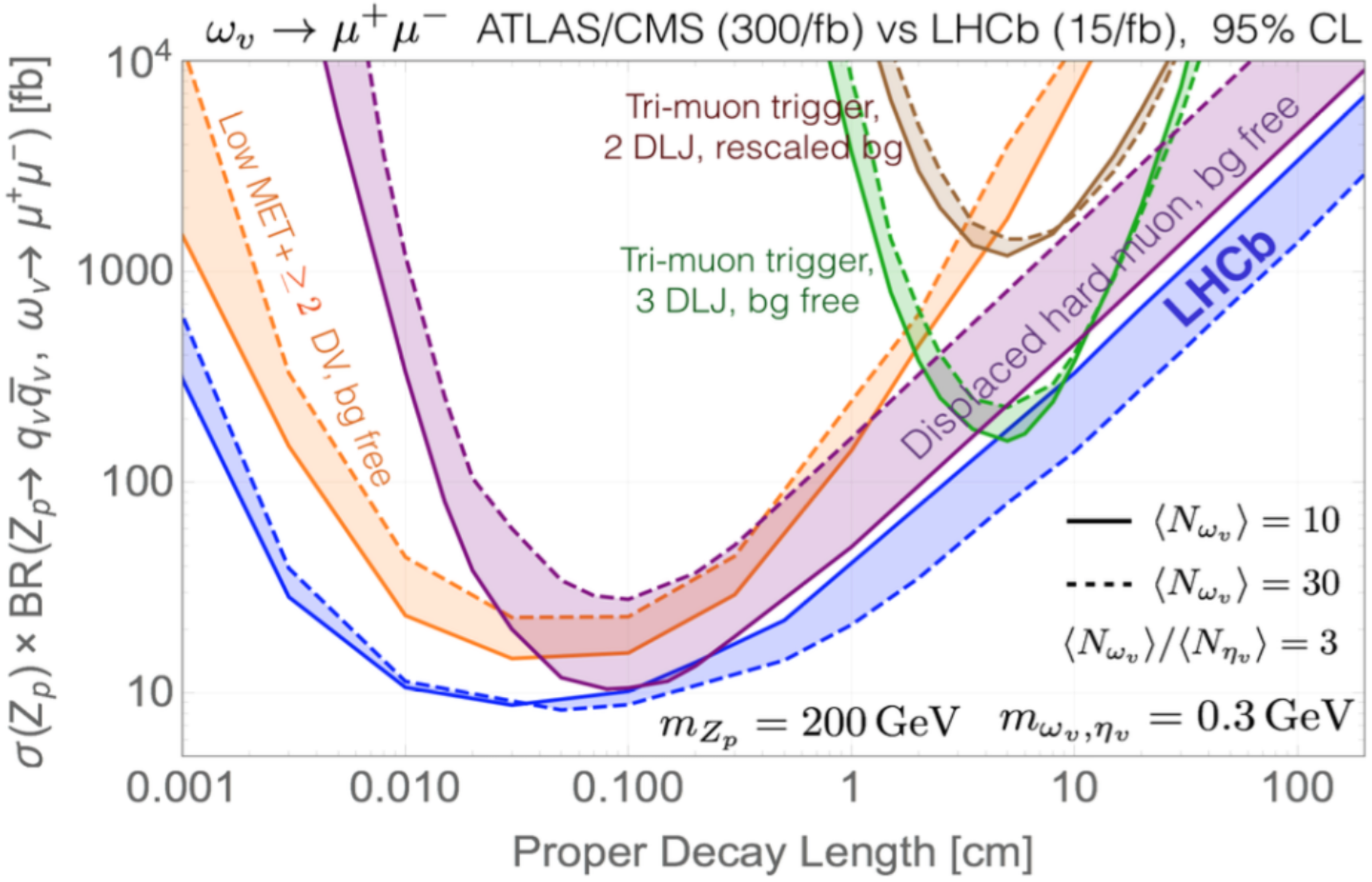
- Obvious disadvantage: LHCb collects less data than ATLAS/CMS and has worse acceptance for several searches
- But softer triggers (for instance, can trigger detached di-muons with $p_T \sim 1$ GeV/c), other advantages already mentioned
- In practice that means we can look into **complementary** phase space regions



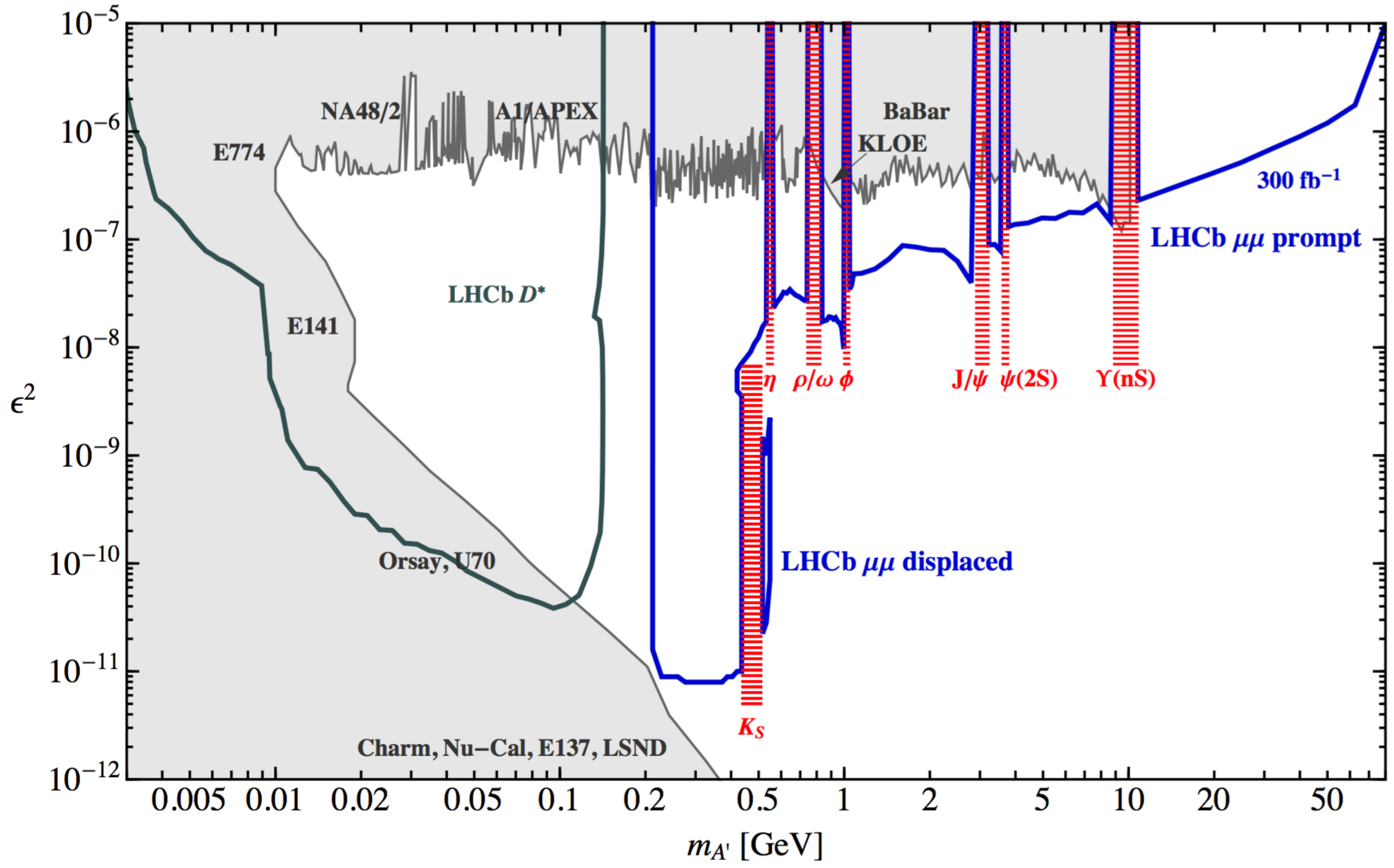
excluded areas where the limit set for $H \rightarrow \pi_V \pi_V$ is smaller than 50% the SM Higgs (plot by M. Borsato)

Many thanks to Xabier for the slide from our recent HL-LHC discussions!

# So is something more needed?



Pierce et al. https://arxiv.org/abs/1708.05389



Ilten et al.
https://arxiv.org/abs/1509.06765
https://arxiv.org/abs/1603.08926

**LHCb reach worked out in certain scenarios, above showing two of them – you can see again that we can complement ATLAS/CMS for very light signals, up to a certain cτ region which is basically limited by the position of the TT where we need hits for a momentum measurement. Can we expand towards larger cτ values?**

# Integration with LHCb

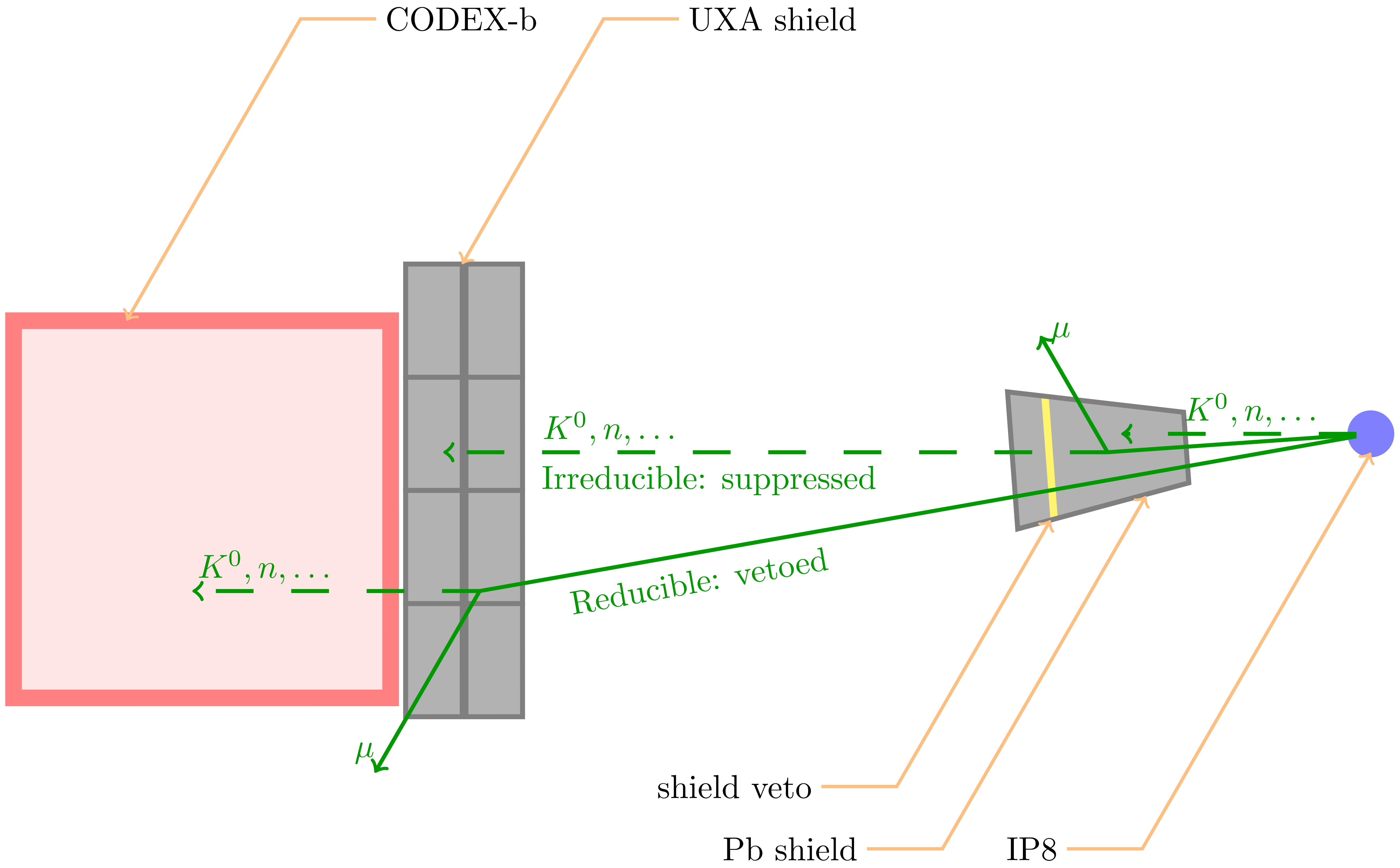
It is highly desirable to treat CODEX-b as an additional subdetector of LHCb, and to integrate it into the DAQ & readout.

Allows events which look interesting in CODEX-b (whose rate is low by definition) to be saved in LHCb as well. If we see a signal we could then look at the event in LHCb and see if an interesting tag exists there.

> You may think Phase II pileup would make this prohibitive, but that is not an immediate showstopper if both CODEX-b and LHCb give precise timing information.

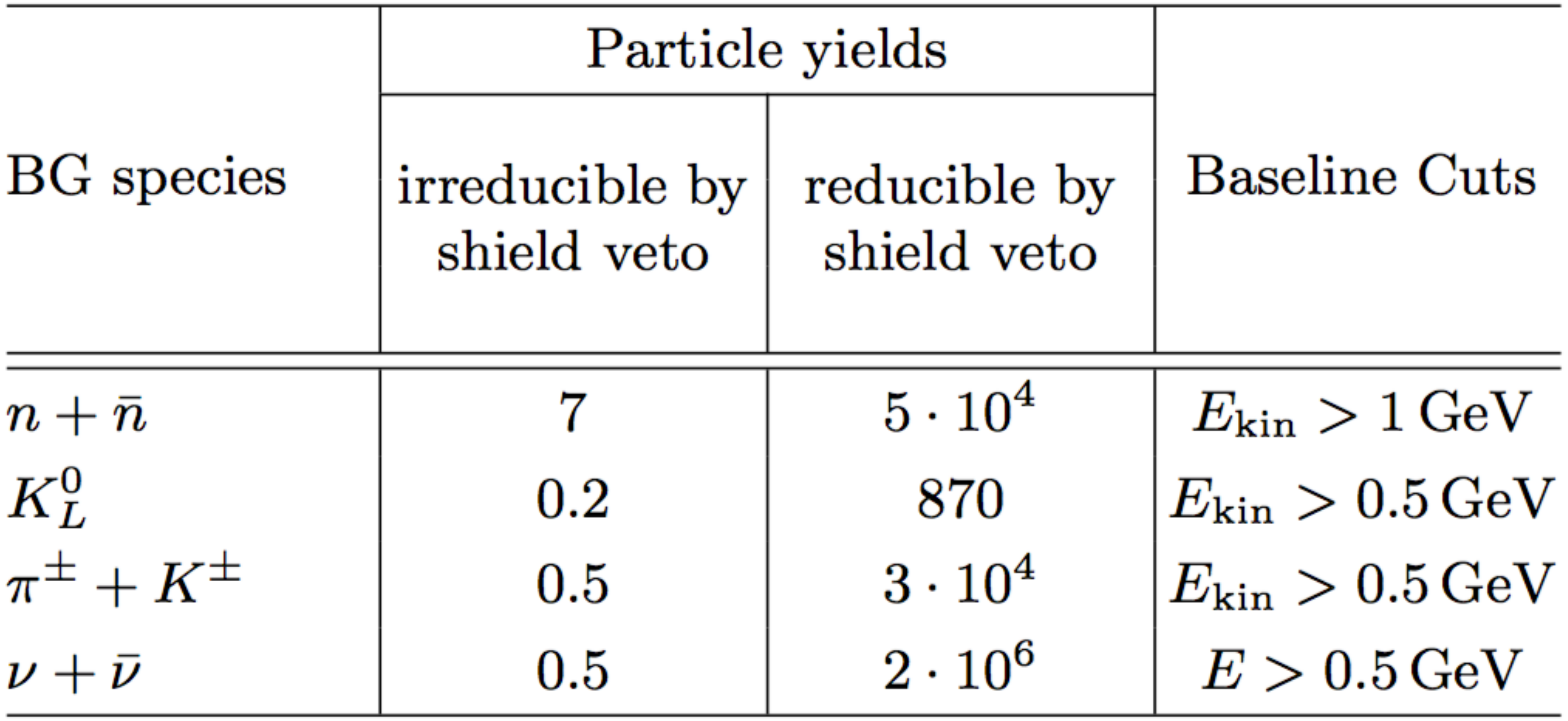
A tricky bit is that CODEX-b "events" are offset by around ~80 ns wrt. the LHC collision which produced them, but should be manageable.

# Minimal shield & veto design



**Simple design : use first part of the shield to attenuate muon & neutral hadron backgrounds which could enter the detector volume and scatter or decay within it, faking a signal. Then use a thin veto layer to eliminate secondary production of backgrounds within the shield itself.**

# Basic GEANT background estimate



| BG species | Particle yields | | Baseline Cuts |
|---|---|---|---|
| | irreducible by shield veto | reducible by shield veto | |
| $n + \bar{n}$ | 7 | $5 \cdot 10^4$ | $E_{\rm kin} > 1\,{\rm GeV}$ |
| $K_L^0$ | 0.2 | 870 | $E_{\rm kin} > 0.5\,{\rm GeV}$ |
| $\pi^\pm + K^\pm$ | 0.5 | $3 \cdot 10^4$ | $E_{\rm kin} > 0.5\,{\rm GeV}$ |
| $\nu + \bar{\nu}$ | 0.5 | $2 \cdot 10^6$ | $E > 0.5\,{\rm GeV}$ |

**Simulate initial background flux with Pythia 8, propagate through shield, air, and detector using GEANT4. A few things to note :**

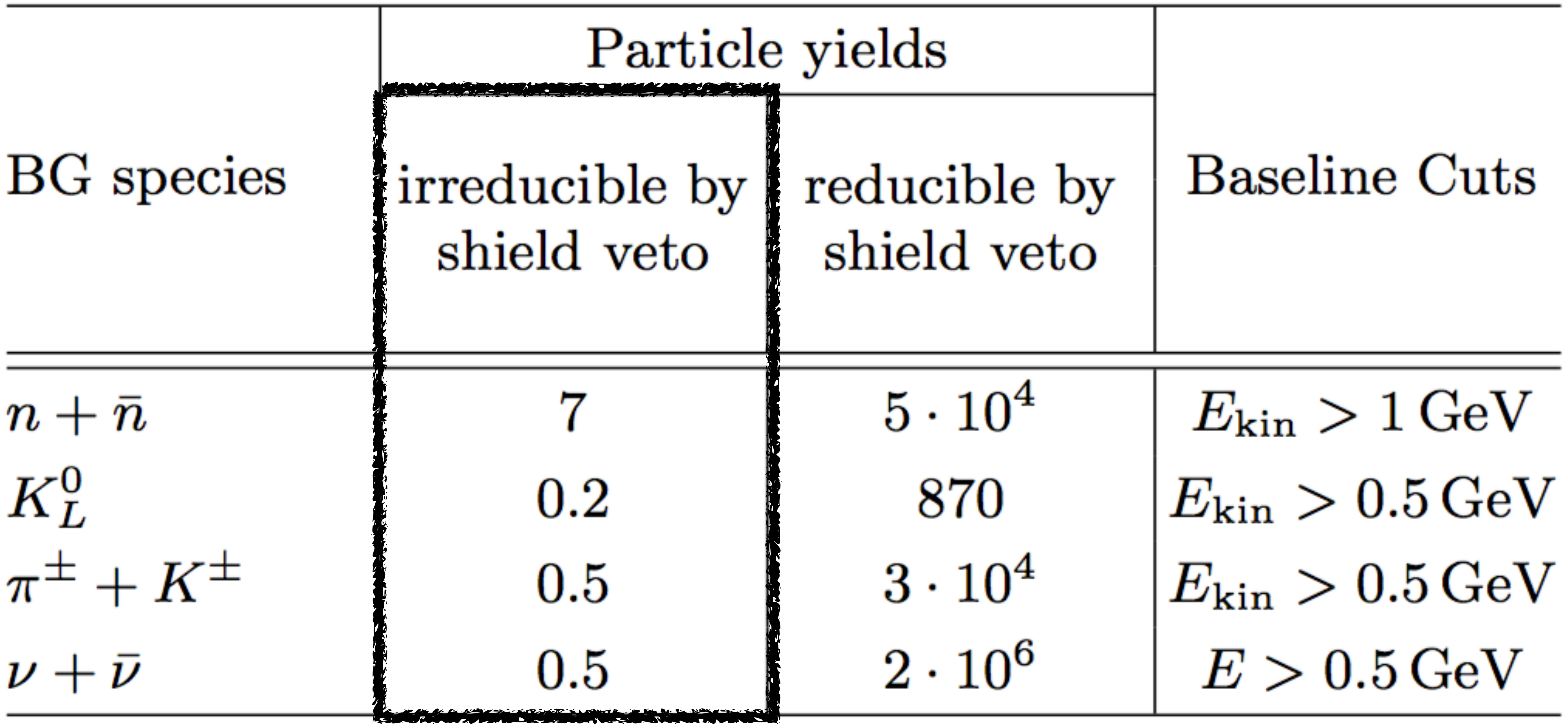
**— Nominally largest background is neutrons entering the box**

**— Muon-air interactions can be vetoed using front detector faces**

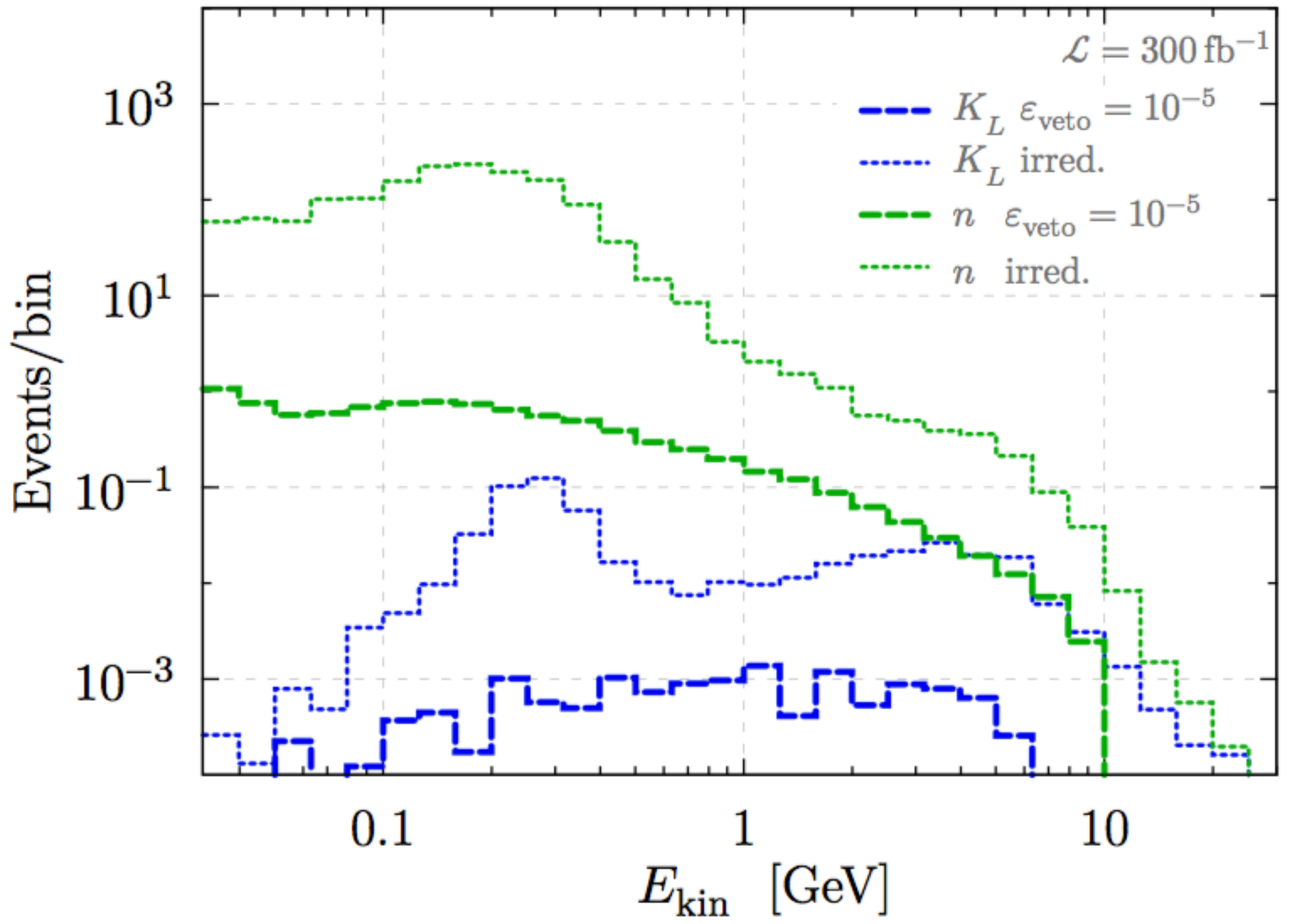
**— Neutrino backgrounds are entirely negligible.**

**No attempt yet to use any properties of reconstructed backgrounds to reject them, but timing + spatial information should help there.**

# Energy spectrum of backgrounds

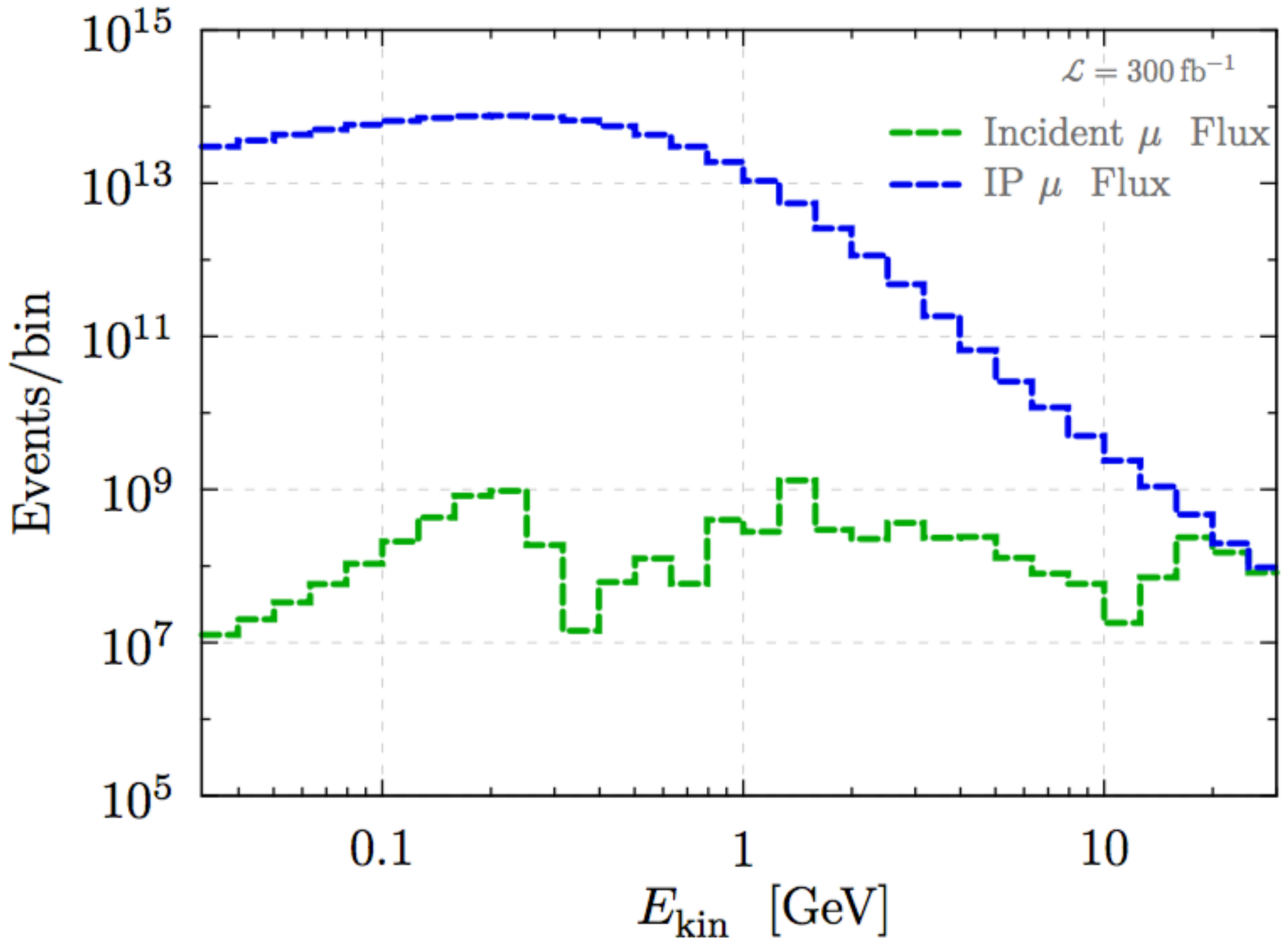


| BG species | Particle yields | | Baseline Cuts |
|---|---|---|---|
| | irreducible by shield veto | reducible by shield veto | |
| $n + \bar{n}$ | 7 | $5 \cdot 10^4$ | $E_{\mathrm{kin}} > 1\,\mathrm{GeV}$ |
| $K_L^0$ | 0.2 | 870 | $E_{\mathrm{kin}} > 0.5\,\mathrm{GeV}$ |
| $\pi^\pm + K^\pm$ | 0.5 | $3 \cdot 10^4$ | $E_{\mathrm{kin}} > 0.5\,\mathrm{GeV}$ |
| $\nu + \bar{\nu}$ | 0.5 | $2 \cdot 10^6$ | $E > 0.5\,\mathrm{GeV}$ |



These are the numbers of unvetoable particles entering the box, the estimated number of scatters in box is <1 for all particle species!

Also notice the energy spectrum of these particles : most of them, especially the neutrons, are very soft!

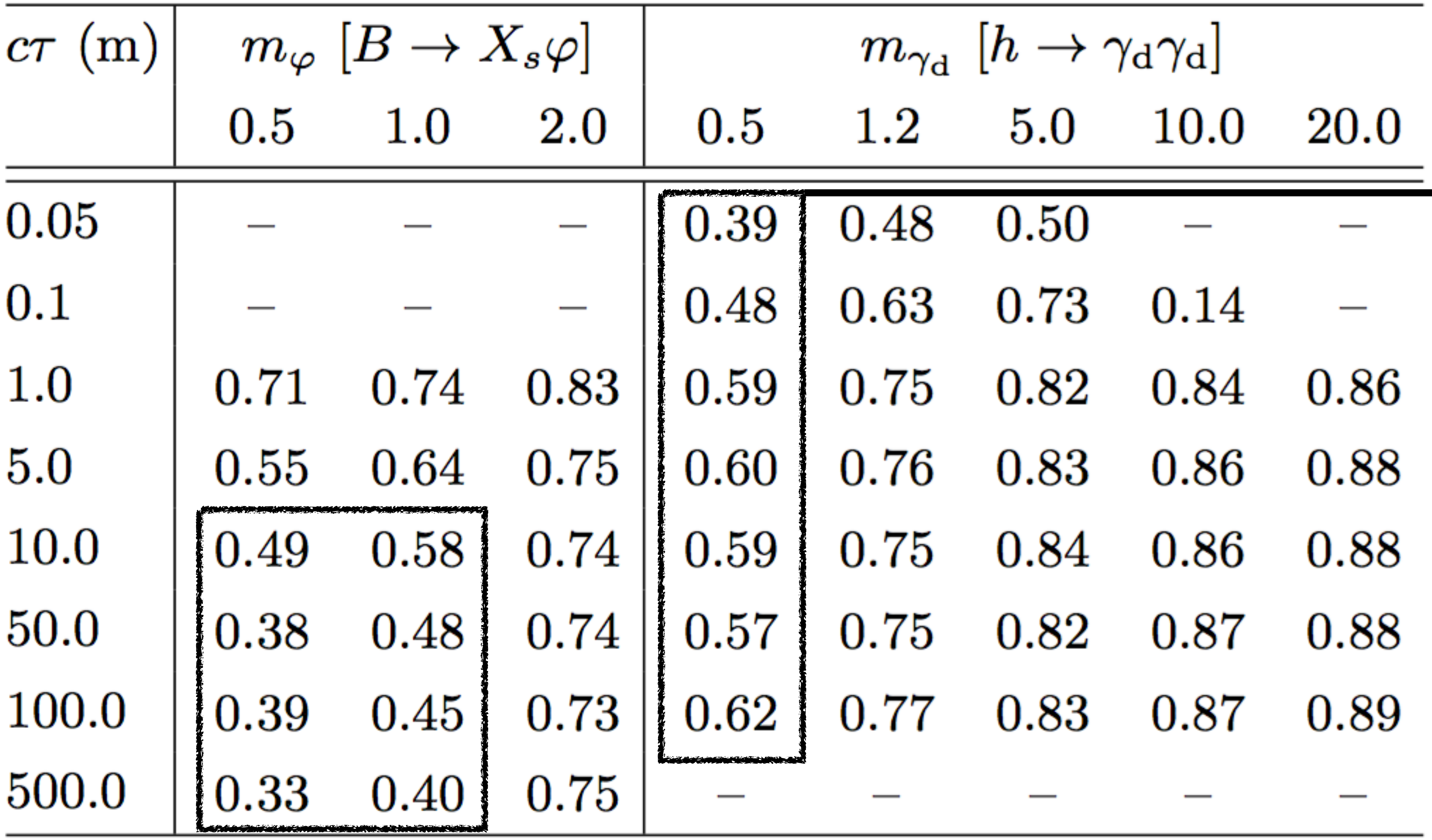


# Data driven background calibration

Cosmics will be used for spatial & time detector alignment and their negligible contribution can be calibrated from this.

Other backgrounds can be measured by putting a small telescope in the LHCb cavern and measuring background rates with different shield thicknesses. Could be done as an engineering run well ahead of full detector construction.

# Tracker efficiency estimate



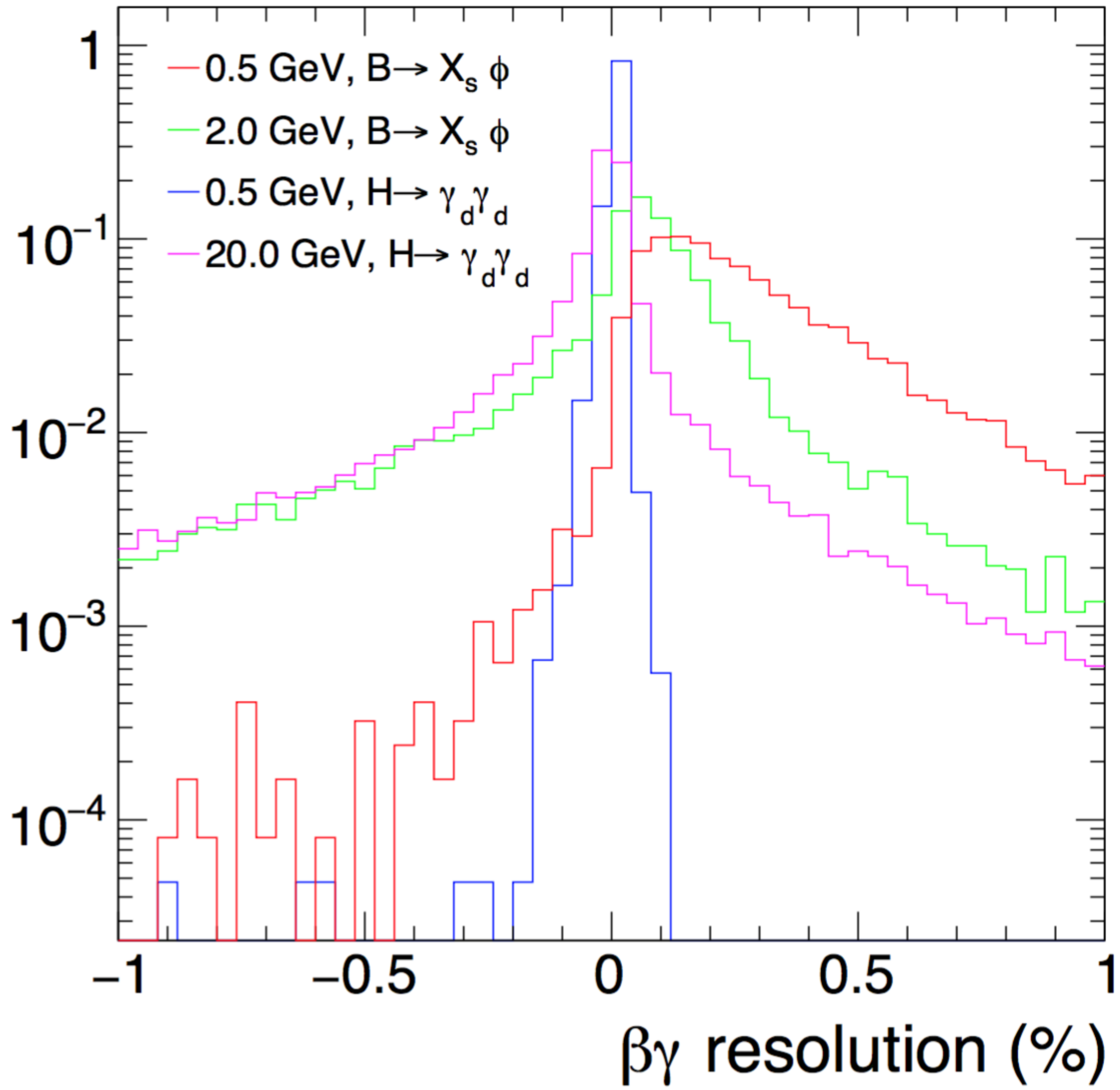
| $c\tau$ (m) | $m_\varphi$ $[B \to X_s\varphi]$ | | | $m_{\gamma_\mathrm{d}}$ $[h \to \gamma_\mathrm{d}\gamma_\mathrm{d}]$ | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.5 | 1.0 | 2.0 | 0.5 | 1.2 | 5.0 | 10.0 | 20.0 |
| 0.05 | – | – | – | 0.39 | 0.48 | 0.50 | – | – |
| 0.1 | – | – | – | 0.48 | 0.63 | 0.73 | 0.14 | – |
| 1.0 | 0.71 | 0.74 | 0.83 | 0.59 | 0.75 | 0.82 | 0.84 | 0.86 |
| 5.0 | 0.55 | 0.64 | 0.75 | 0.60 | 0.76 | 0.83 | 0.86 | 0.88 |
| 10.0 | 0.49 | 0.58 | 0.74 | 0.59 | 0.75 | 0.84 | 0.86 | 0.88 |
| 50.0 | 0.38 | 0.48 | 0.74 | 0.57 | 0.75 | 0.82 | 0.87 | 0.88 |
| 100.0 | 0.39 | 0.45 | 0.73 | 0.62 | 0.77 | 0.83 | 0.87 | 0.89 |
| 500.0 | 0.33 | 0.40 | 0.75 | – | – | – | – | – |

Dominated by partial overlap of decay products due to small opening angle, can be optimized using station spacing and granularity

Dominated by assumption that we don't track below 600 MeV of momentum, conservative since clearly we won't just fall off a cliff, but needs proper simulation

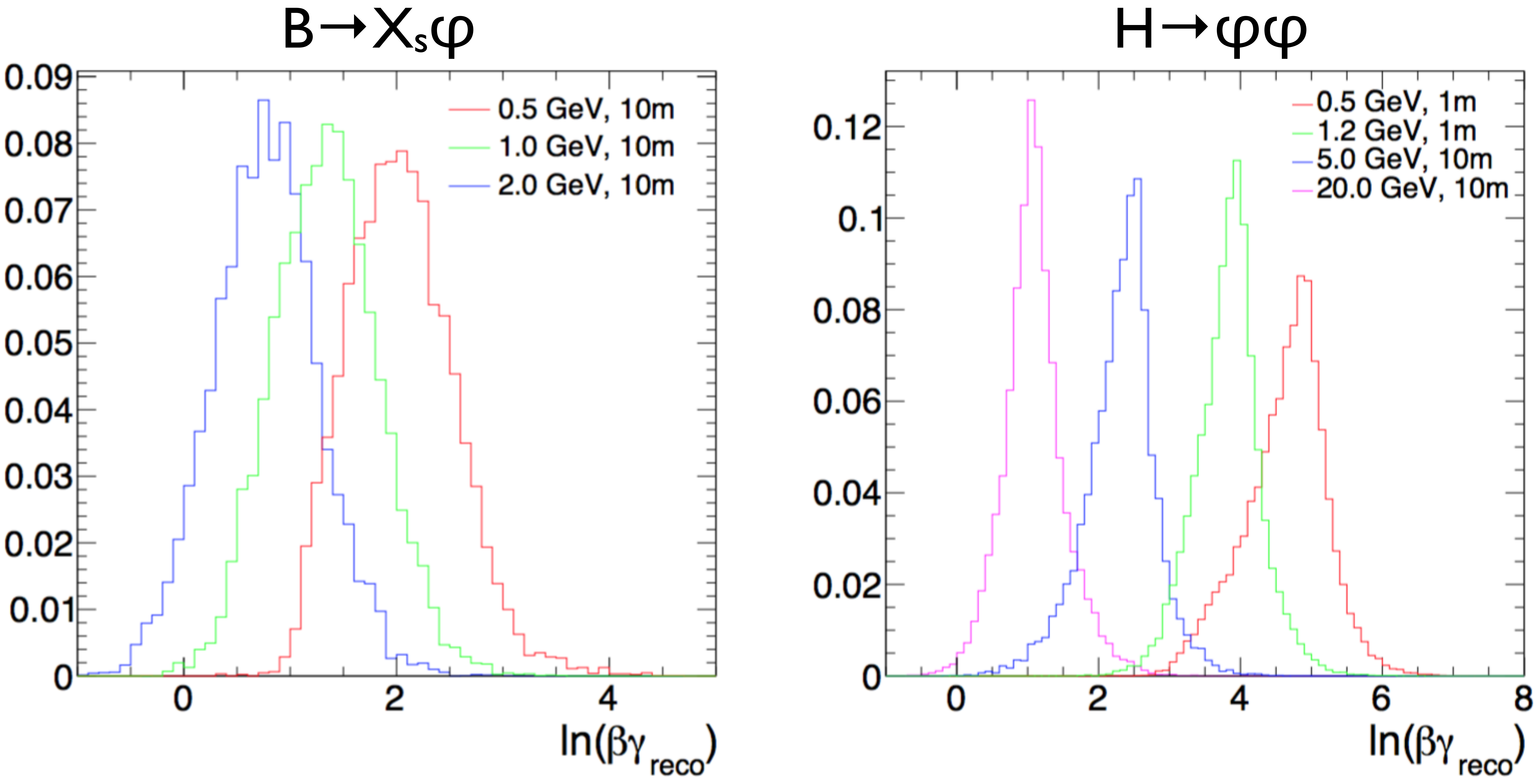
**Bottom line : these are O(1) numbers, not O(%), can be optimized further**

# Boost reconstruction



Reconstruct parent boost from the measured decay vertex (no timing!), assuming relativistic decay products. The resolution is < 1% (entirely dominated by distance to first measured point, not detector granularity) so the boost distribution is dominated by the generated spread of boosts, not resolution.

# Boost reconstruction



**Different intial states give different boost distributions; perhaps surprisingly we have some discriminating power between even the B→KX scenarios.**

# Complementarity with other searches

CODEX-b can cover a significant portion of parameter space for well-motivated, simple portals, and extend LHCb’s reach for long lived particles well beyond ATLAS/CMS.

CODEX-b has to cover around 1/100th of MATHUSLA’s tracking area (but of course does not have as large an absolute reach).

If you believe the physics case for LLP detection is worthwhile, allocating funds for a detector which is relatively simple to build, has complementary reach to more ambitious proposals, and has completely different backgrounds would seem prudent, particularly if someone sees a signal.

# Next steps

— Develop a more realistic proposal for the detector.

— Understand better how low we can realistically track in momentum.

— Work out the reach in some additional models of NP.

— Hopefully survive all these steps without a showstopper and contribute to the upcoming LLP physics white paper.

It is of course largely up to you : does this sound interesting? Would you like to collaborate on it?