A COmpact DEtector for eXotics at LHC-b (CODEX-b)

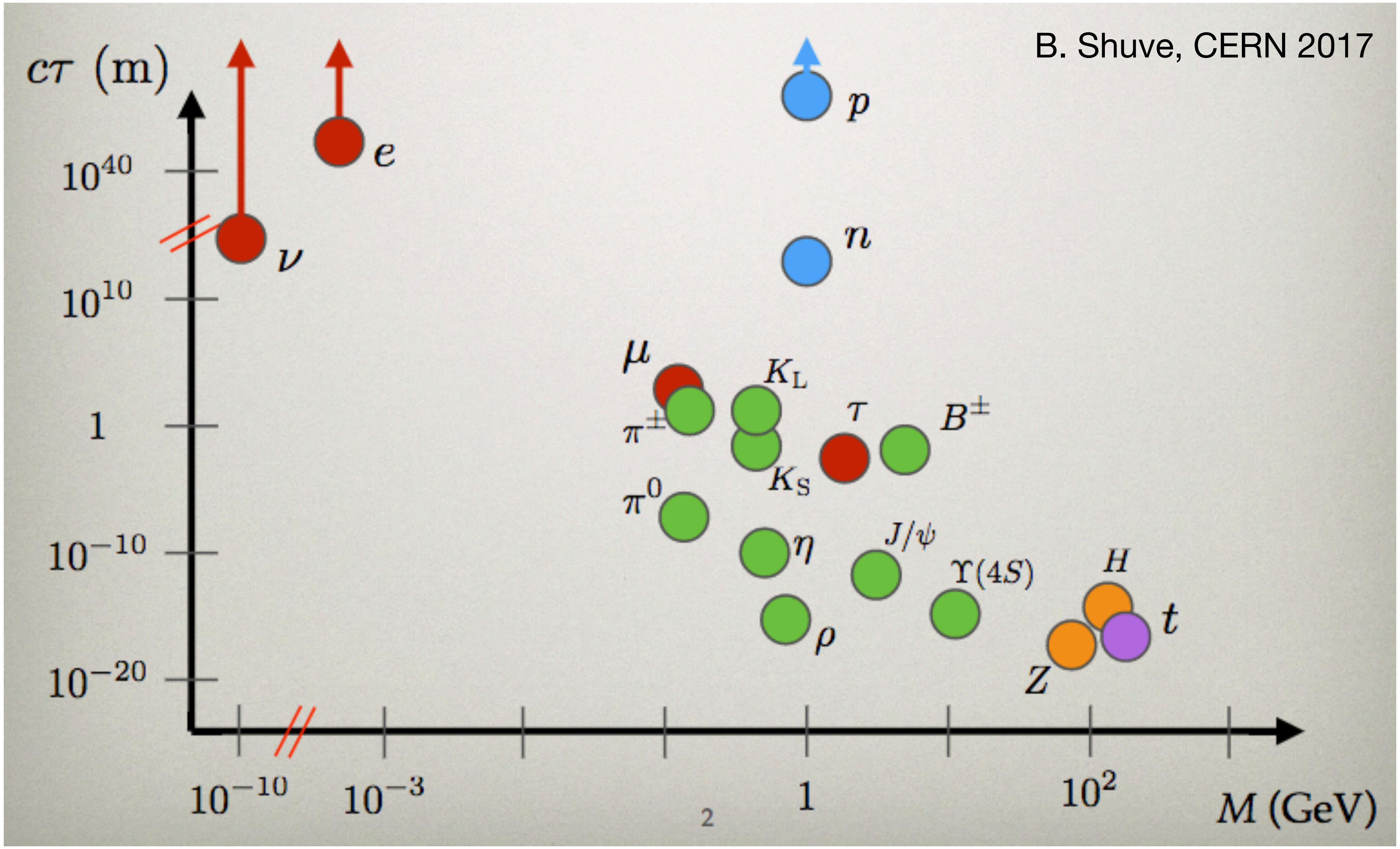
@ Winter Aspen, 03/26/2018

Simon Knapen

Lawrence Berkeley National Lab & UC Berkeley

based on 1708.09395 with V. Gligorov, M. Papucci, D. Robinson
18xx.xxxxx with J. Evans, M. Papucci, H. Ramani, D. Robinson

Long-Lived Particles are generic



Because $m_W >> \Lambda_{QCD}$

Whenever there are multiple mass scales, expect long-lived particles

Finding Long-Lived Particles

* LHCb is an important exception, see talk by M. Williams

ATLAS and CMS are very good at searching for high mass LLPs…

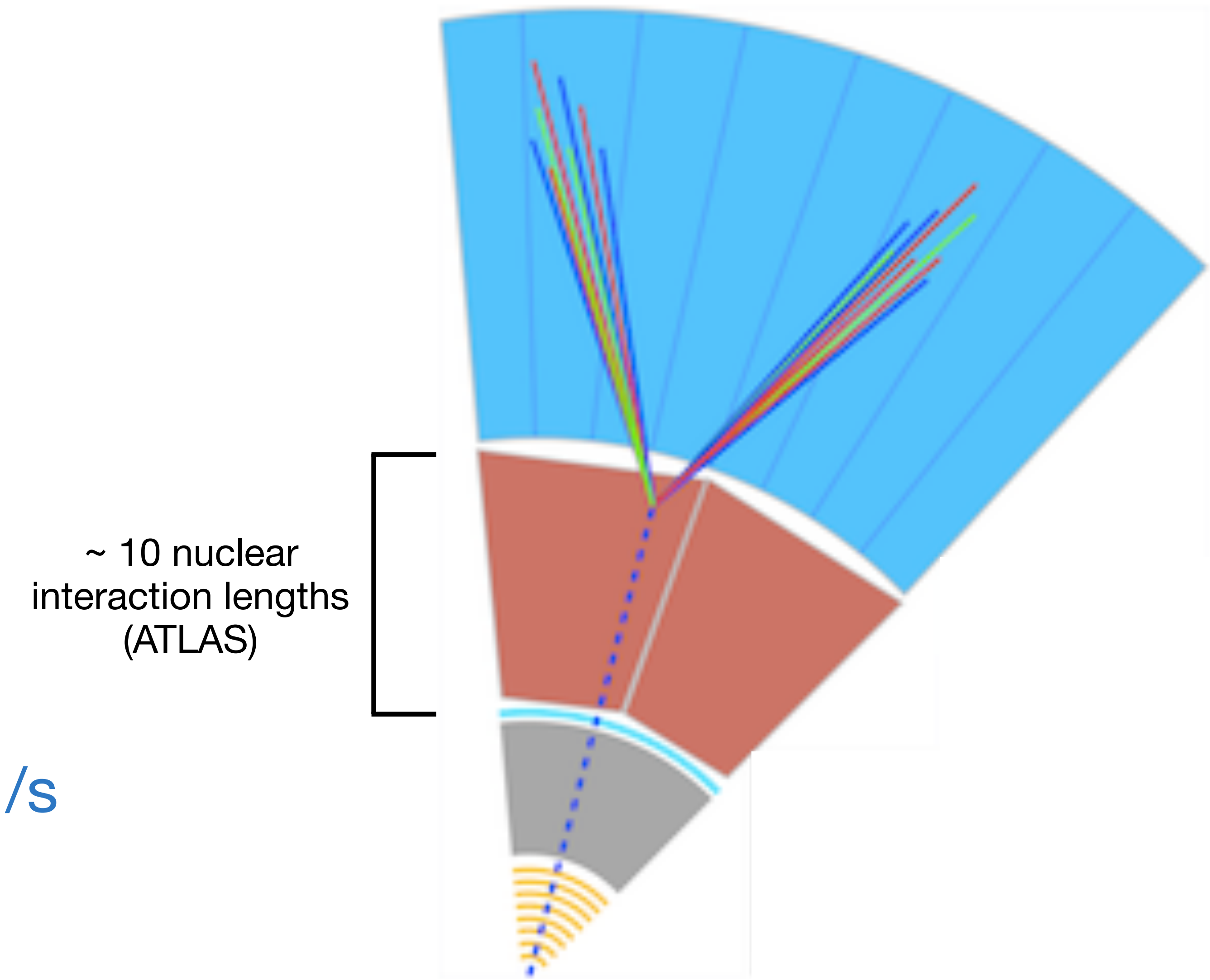
… but for low masses they suffer from*:

1. Tight trigger requirements
2. Backgrounds

A typical hadron has a chance of

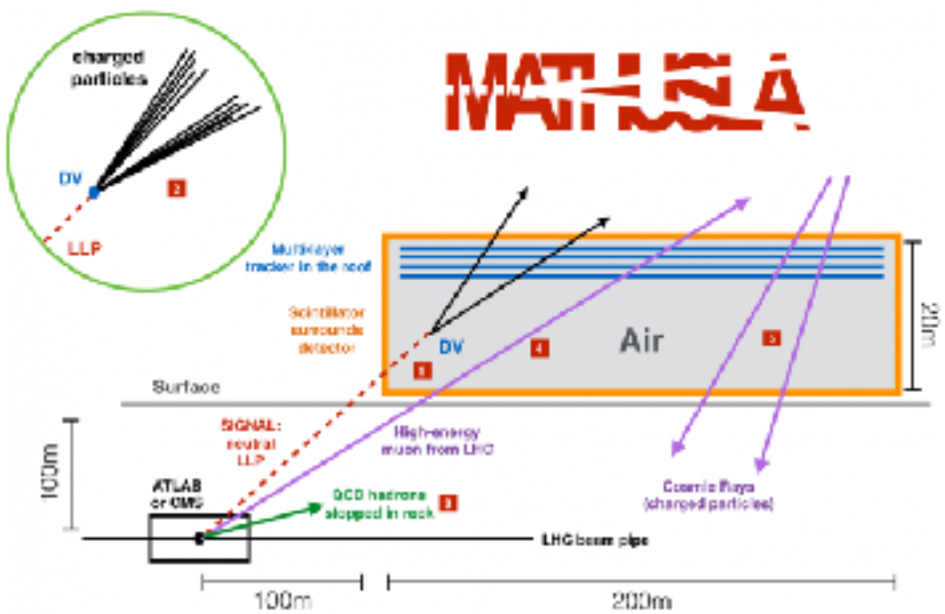
~ 10^{-5} to punch through the calorimeter…

… but the LHC makes ~ 10^9 K_L mesons /s

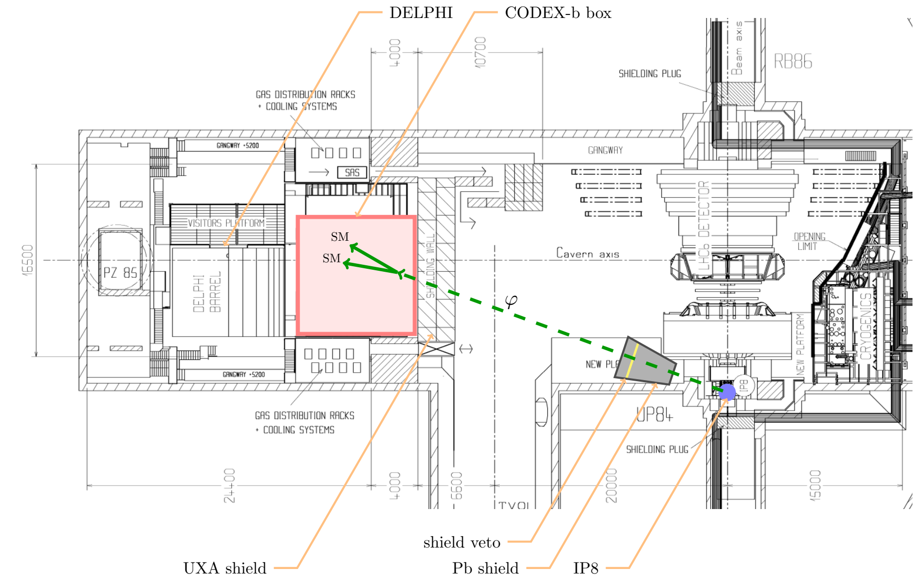


Solution:
Dedicated detector with more shielding

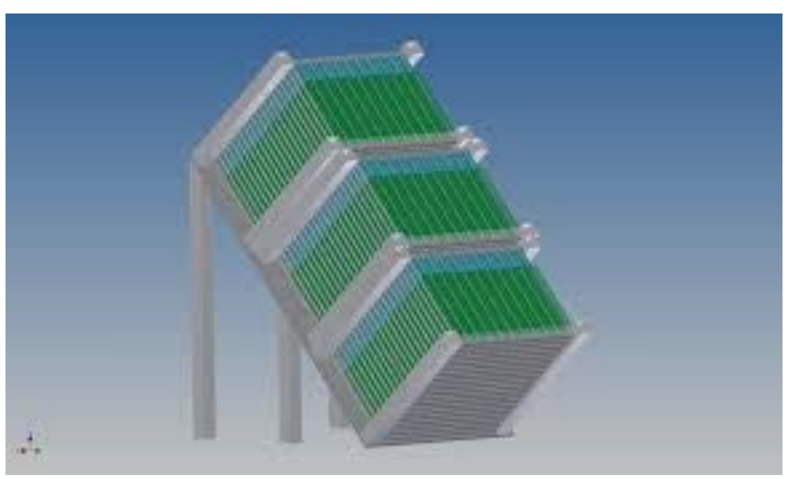
Proposals for shielded detectors



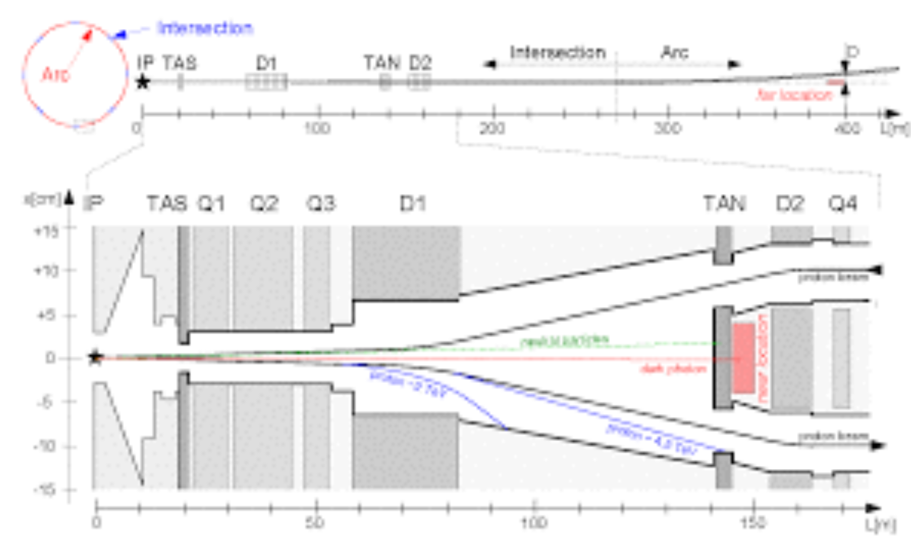
MATHUSLA



CODEX-b



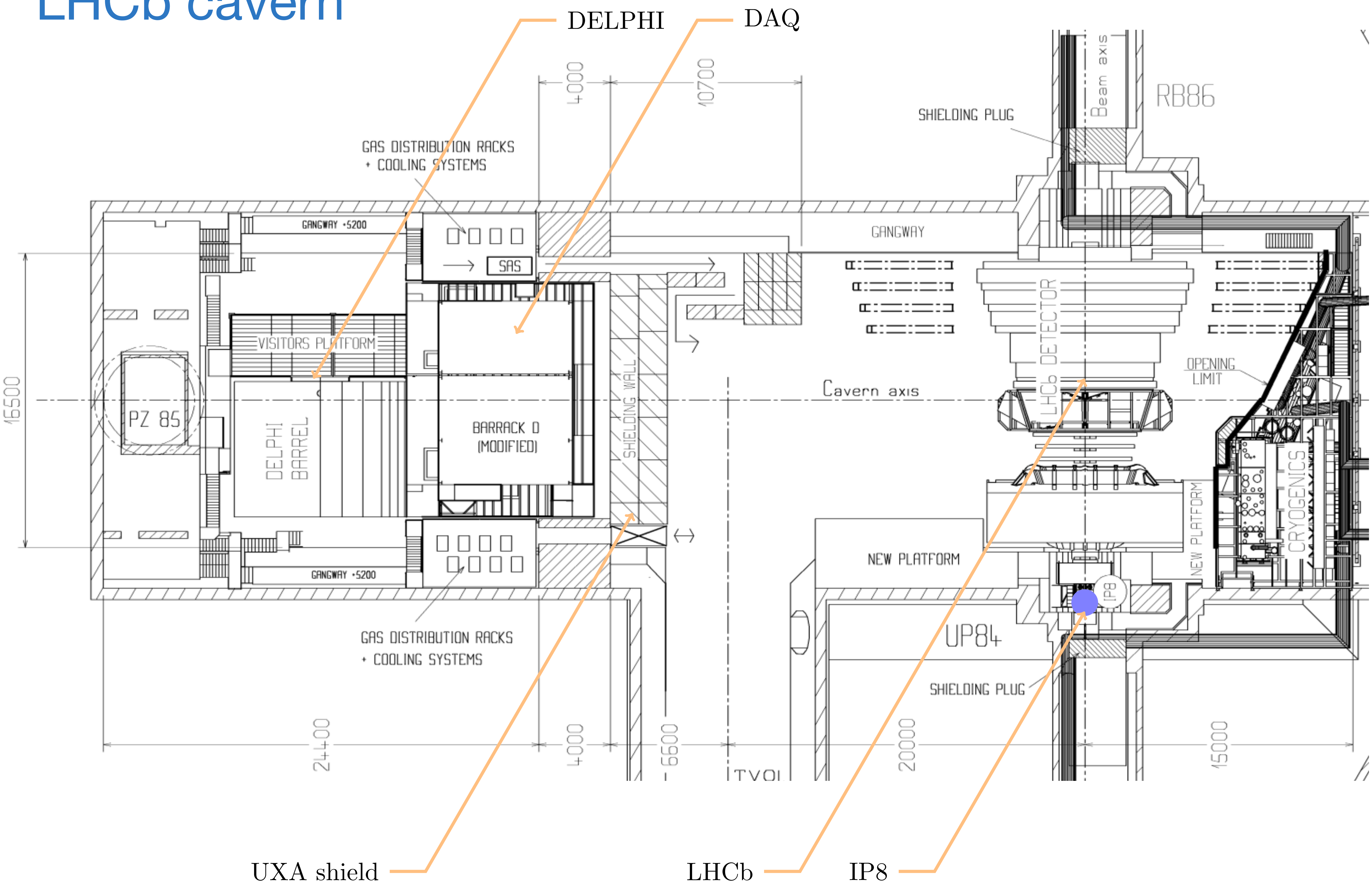
milliQan



FASER

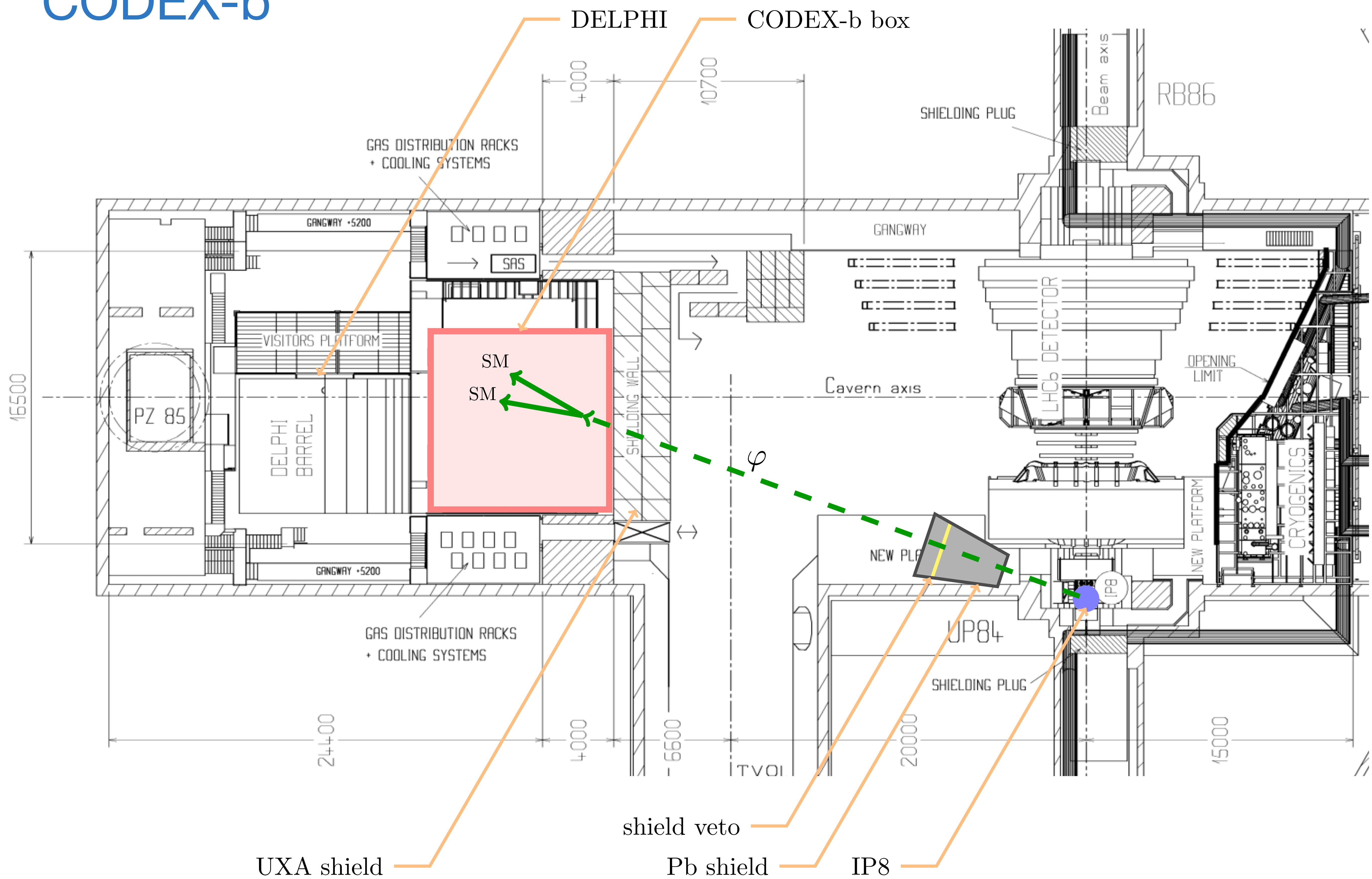
Discussion session after this talk

LHCb cavern



Data acquisition will be moved to surface for run 3

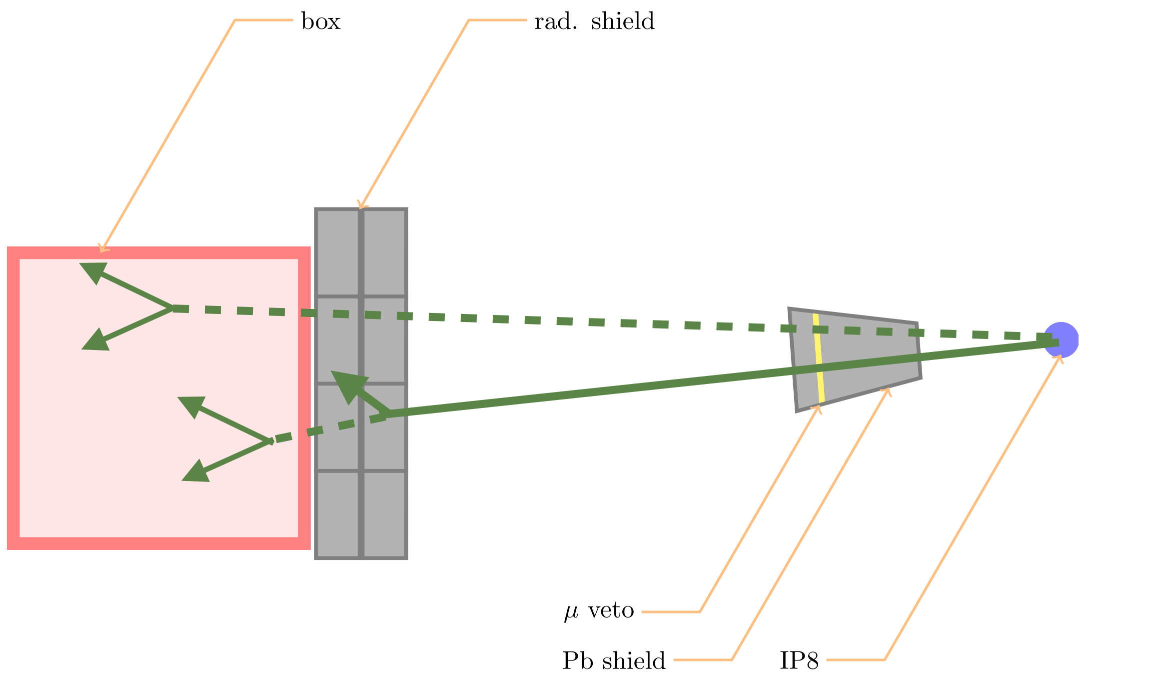
CODEX-b



Data acquisition will be moved to surface for run 3

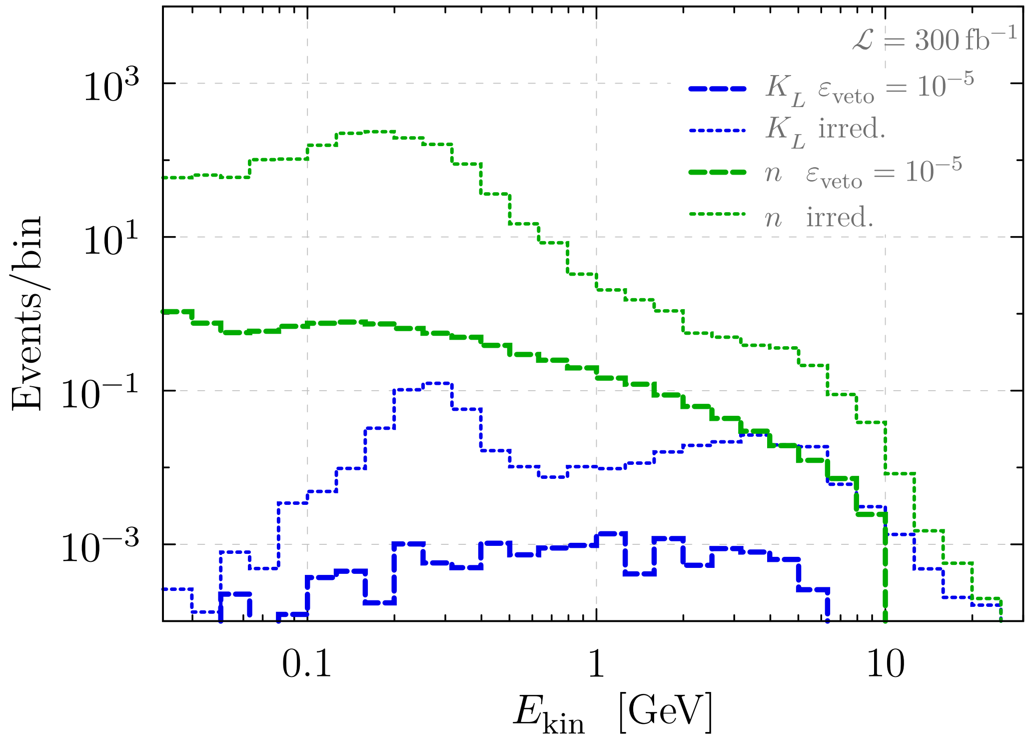
Backgrounds

- Absorb neutral hadrons in shield (irreducible background)
- Veto muon-induced backgrounds with muon veto + front face of the detector (reducible background)



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

Simulation: pythia 8 + GEANT 4



Need about 4.5m of Pb shielding

V. Gligorov, SK, M. Papucci, D. Robinson: 1708.02243

Example models

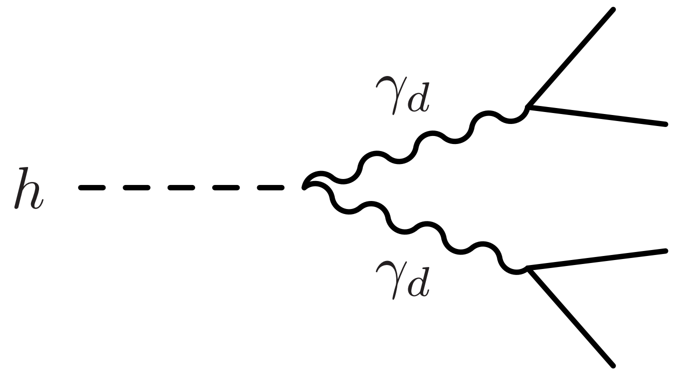
High energy portals

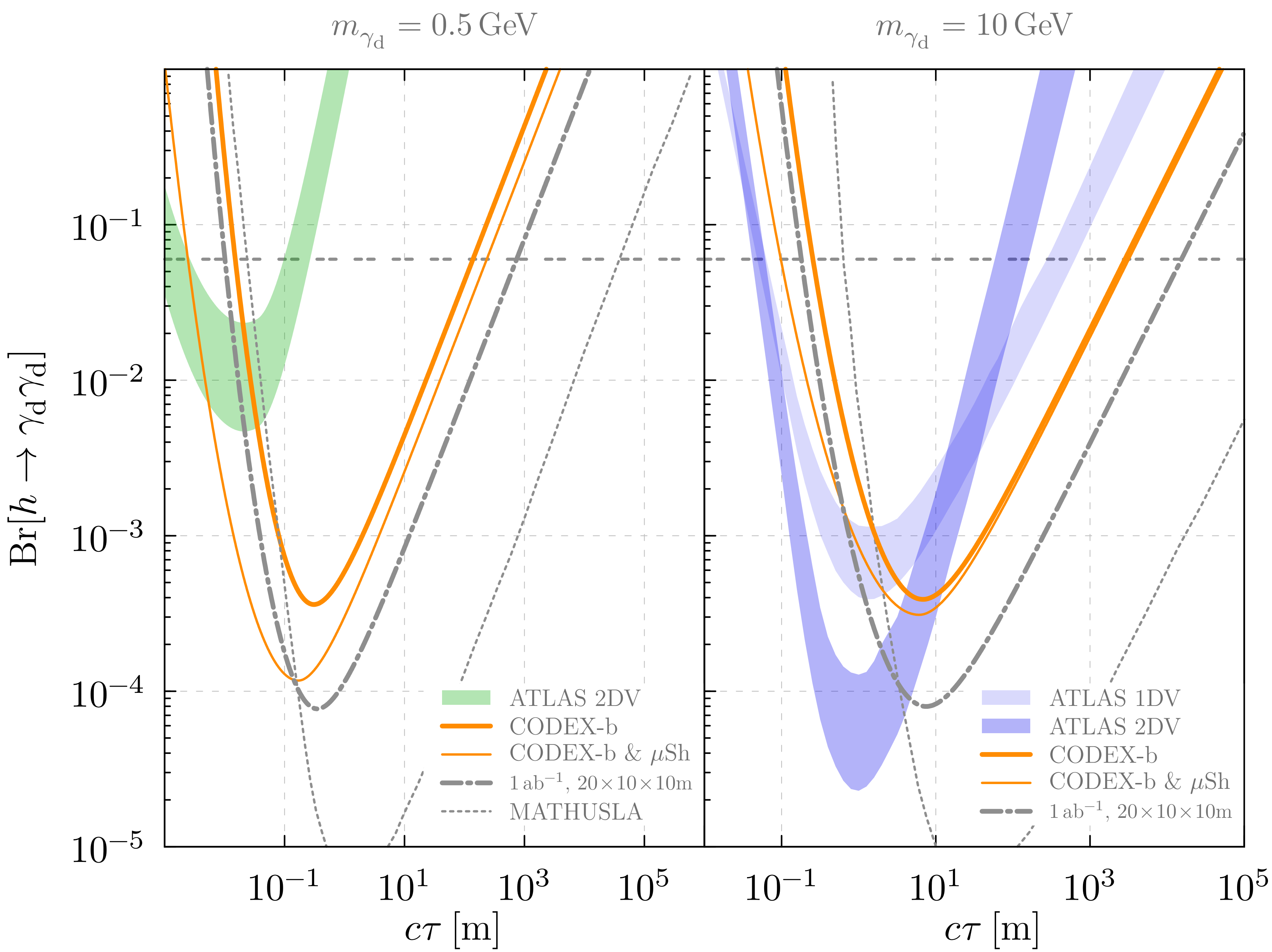
1. Exotic Higgs decays: $h \to A' A'$
2. Z decay to RPV neutralinos
3. Hidden sector glueballs as in Neutral Naturalness (back-up slides)

Low energy portals

1. Exotic B decays: $B \to K \varphi$
2. Heavy Neutral leptons
3. Axion-like particles (back-up slides)

Exotic Higgs decays





Application:
Neutral Naturalness
(See back-up material)

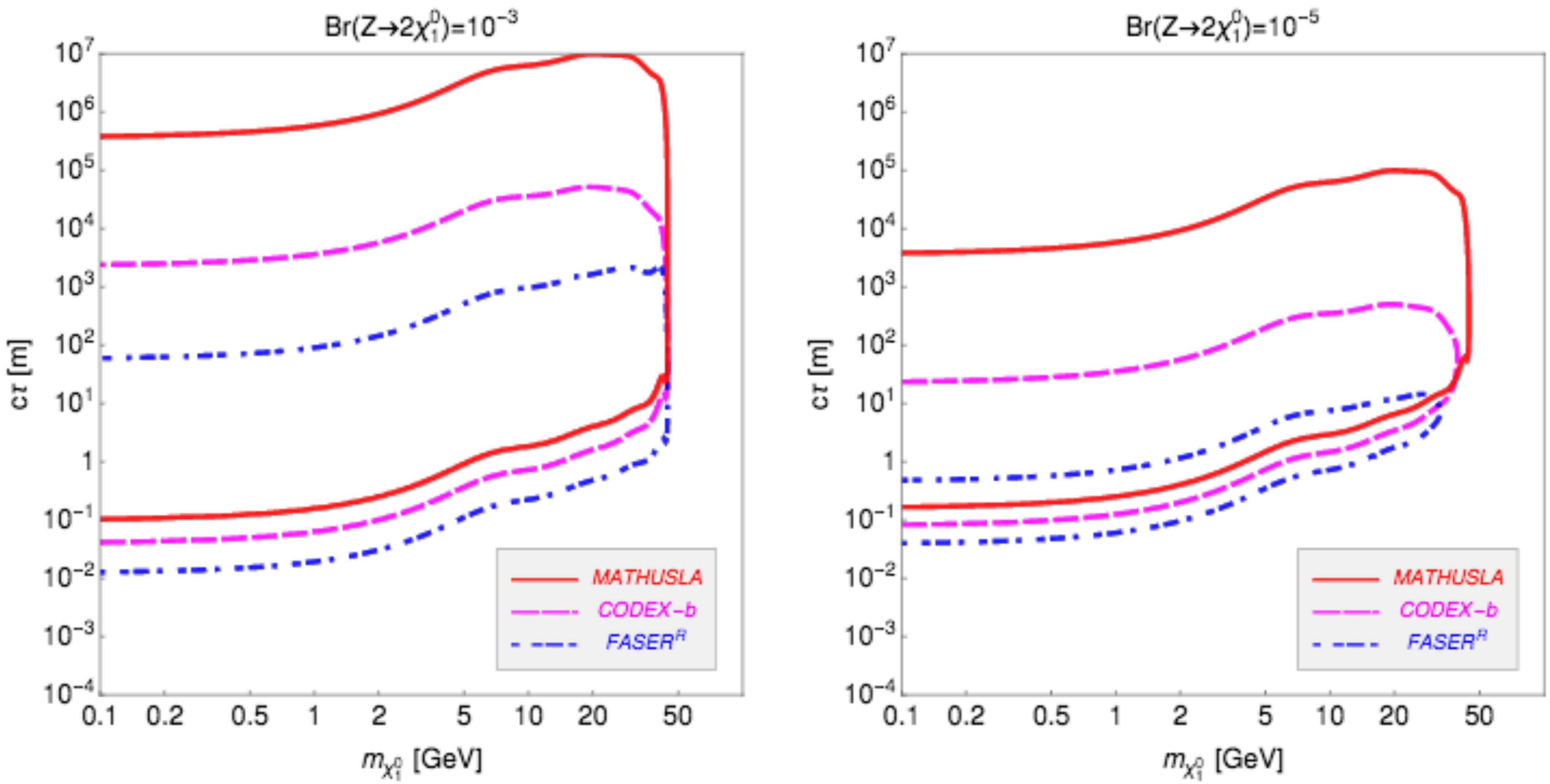
For low masses, ATLAS/CMS are background limited, CODEX-b & MATHUSLA have an edge

V. Gligorov, SK, M. Papucci, D. Robinson: 1708.02243

ATLAS reach: A. Coccaro, et al.: 1605.02742

RPV neutralinos

Take advantage of the large number of Z bosons

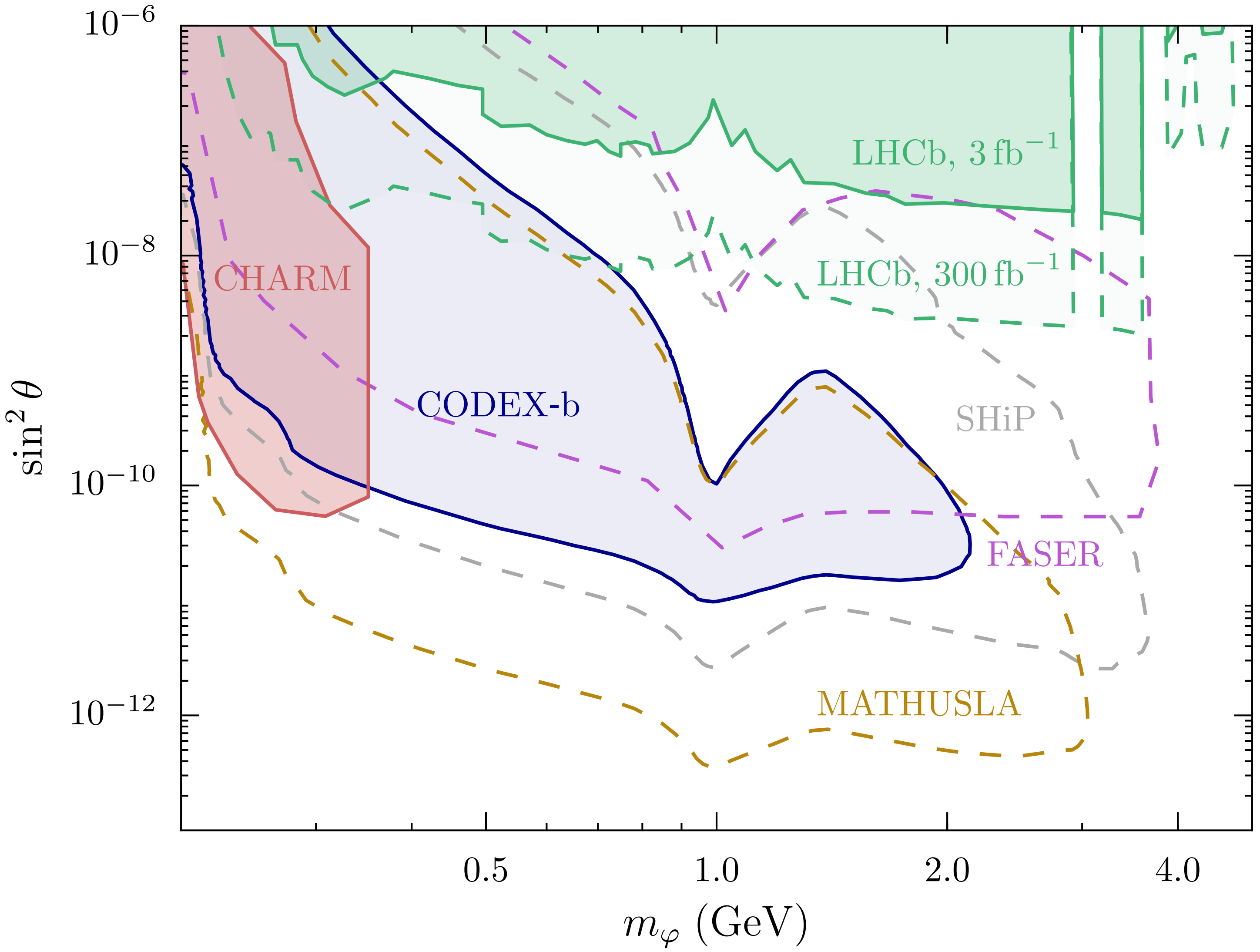


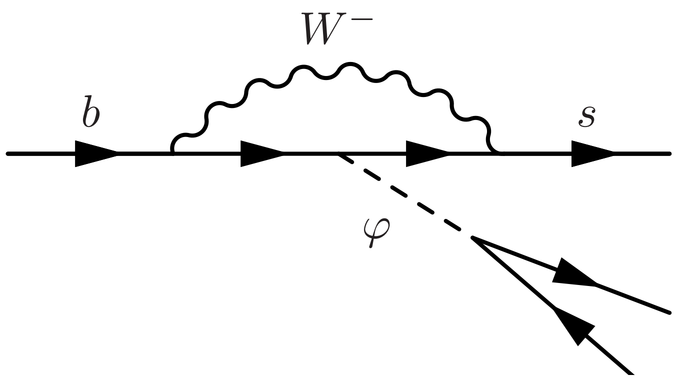
Maximum sensitivity:

	$\mathrm{Br}(Z \to \chi_1\chi_1)$
MATHUSLA	1×10^{-8}
CODEX-b	6×10^{-7}
FASER	5×10^{-6}

Heo, Hirsch, Wang: 1803.02212

Light scalar mixing with Higgs





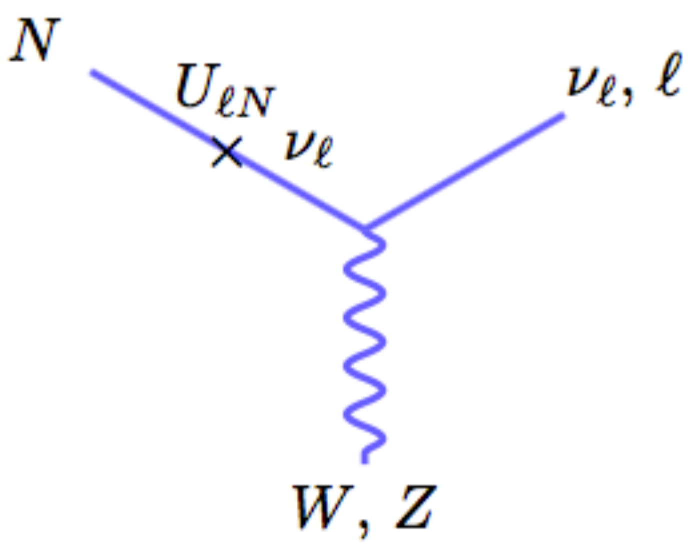
Beware of theory uncertainties on the lifetime!

V. Gligorov, SK, M. Papucci, D. Robinson: 1708.02243

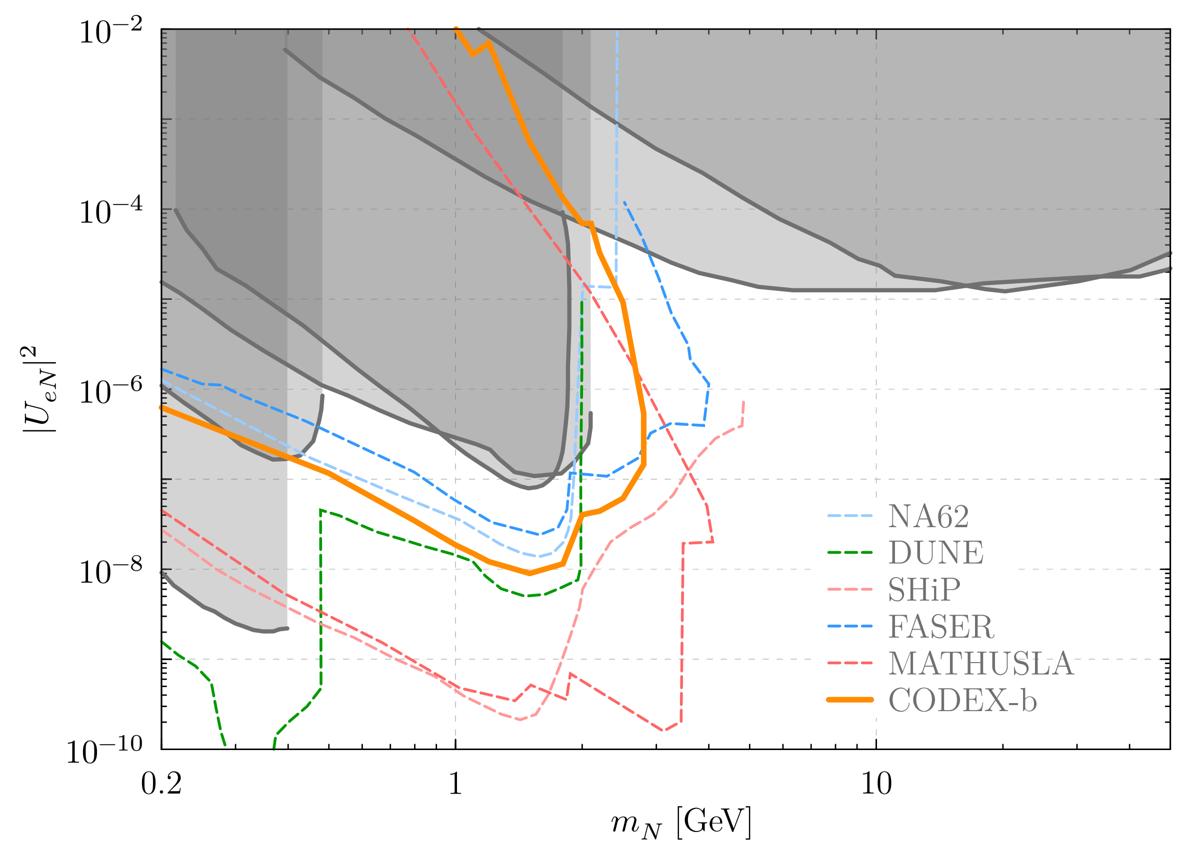
For application to coannihilating dark matter:
R. Tito D'Agnolo, C. Mondino, J. Ruderman. P. Wang: 1803.02901

Heavy neutral leptons

- Production: any SM decay with neutrinos
  (c, b, τ, W & Z decays)
- Decay: Mix back to off-shell SM neutrino
  (N→3ν, N→ℓ hadrons, N→νℓℓ)



Example: U_{eN}



$U_{\mu N}$ and $U_{\tau N}$ in the back-up material

18xx.xxxxx: J. Evans, SK, M. Papucci, H. Ramani D. Robinson

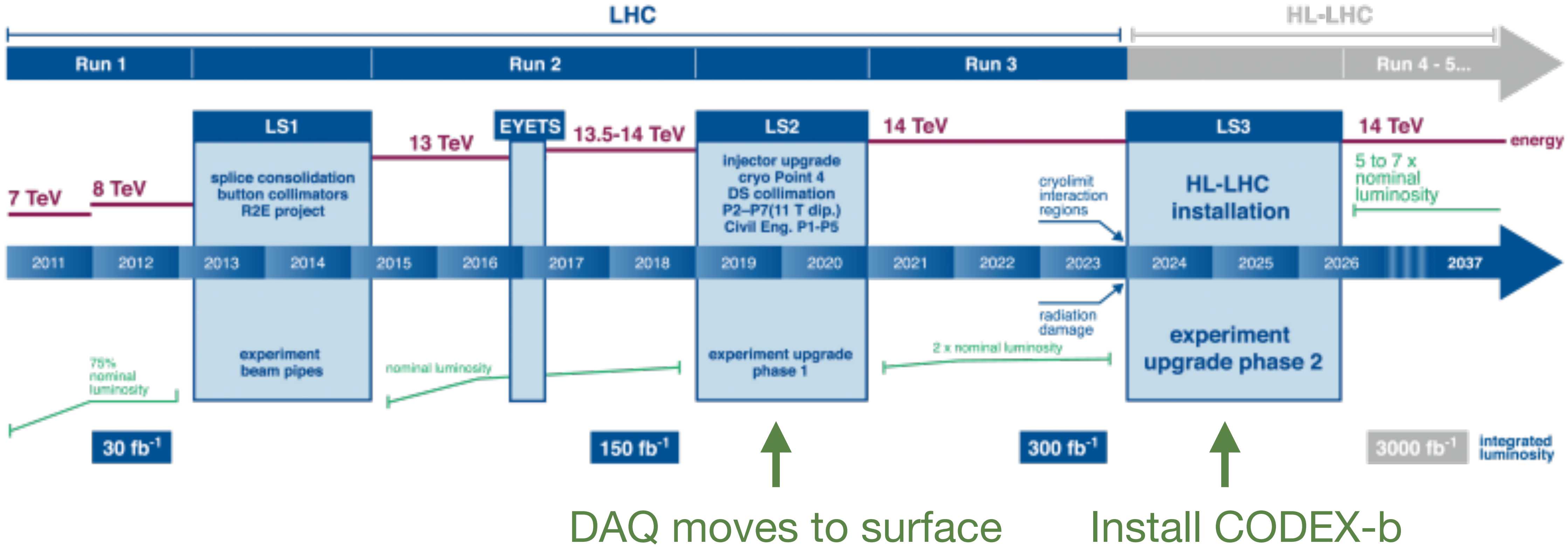
see also: Heo, Hirsch, Wang: 1803.02212

Moving forward

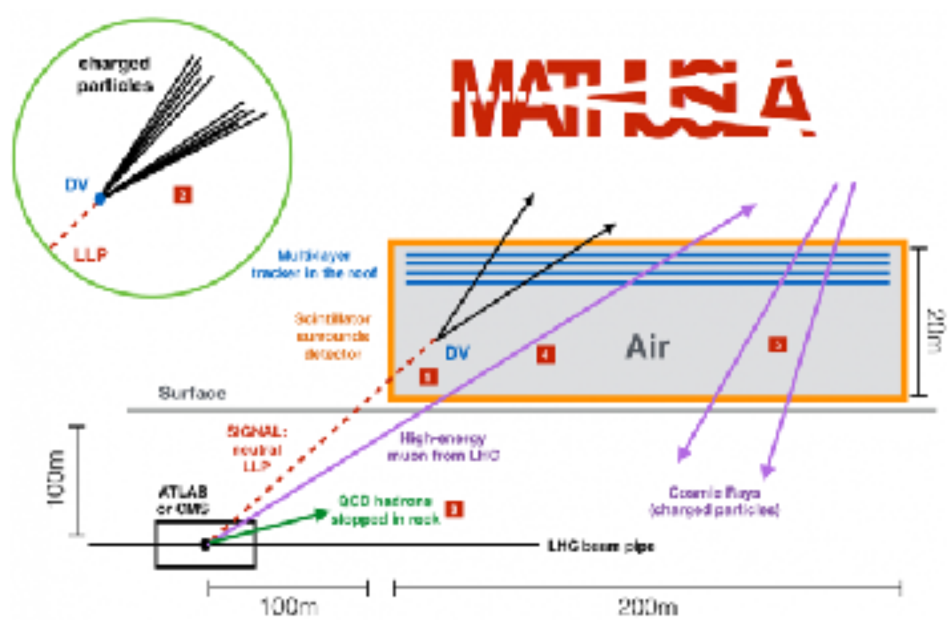
Ongoing work on theory side: more benchmark models

Ongoing work on the LHCb side

- Data driven background estimate →
- Considering different detector layouts
- Preparing a concrete proposal for the phase 2 upgrade

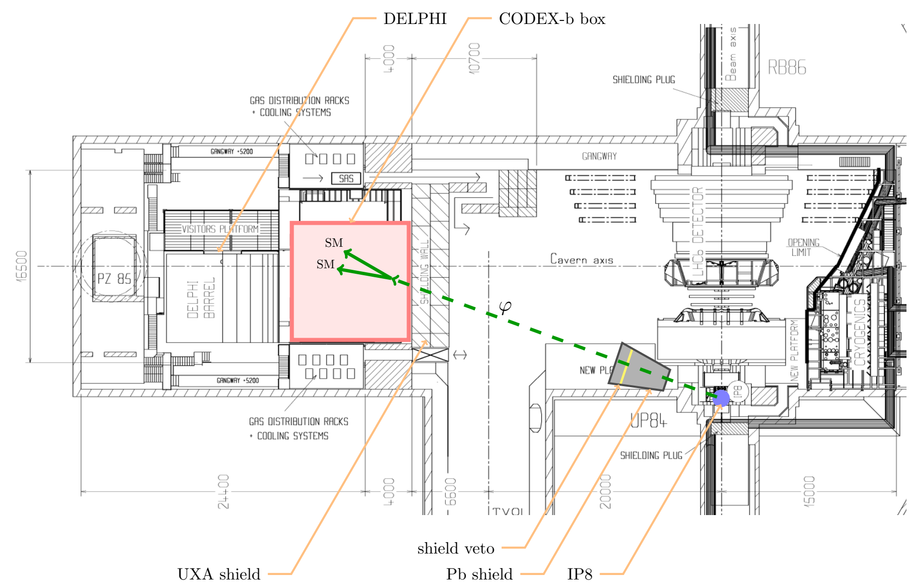


Discussion session



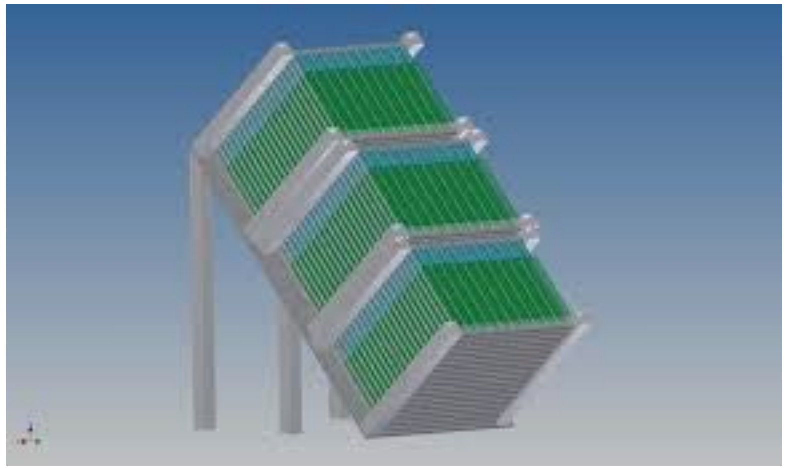
MATHUSLA

John Paul Chou



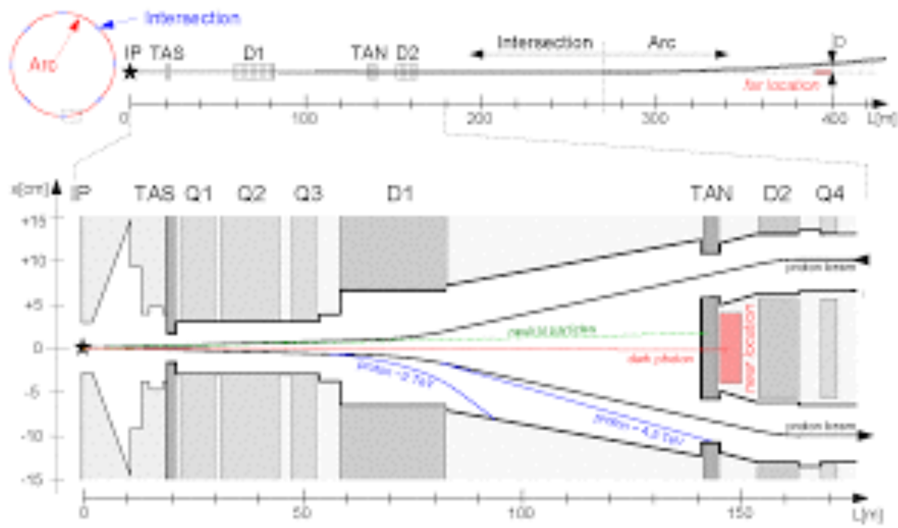
CODEX-b

SK



milliQan

Andy Haas



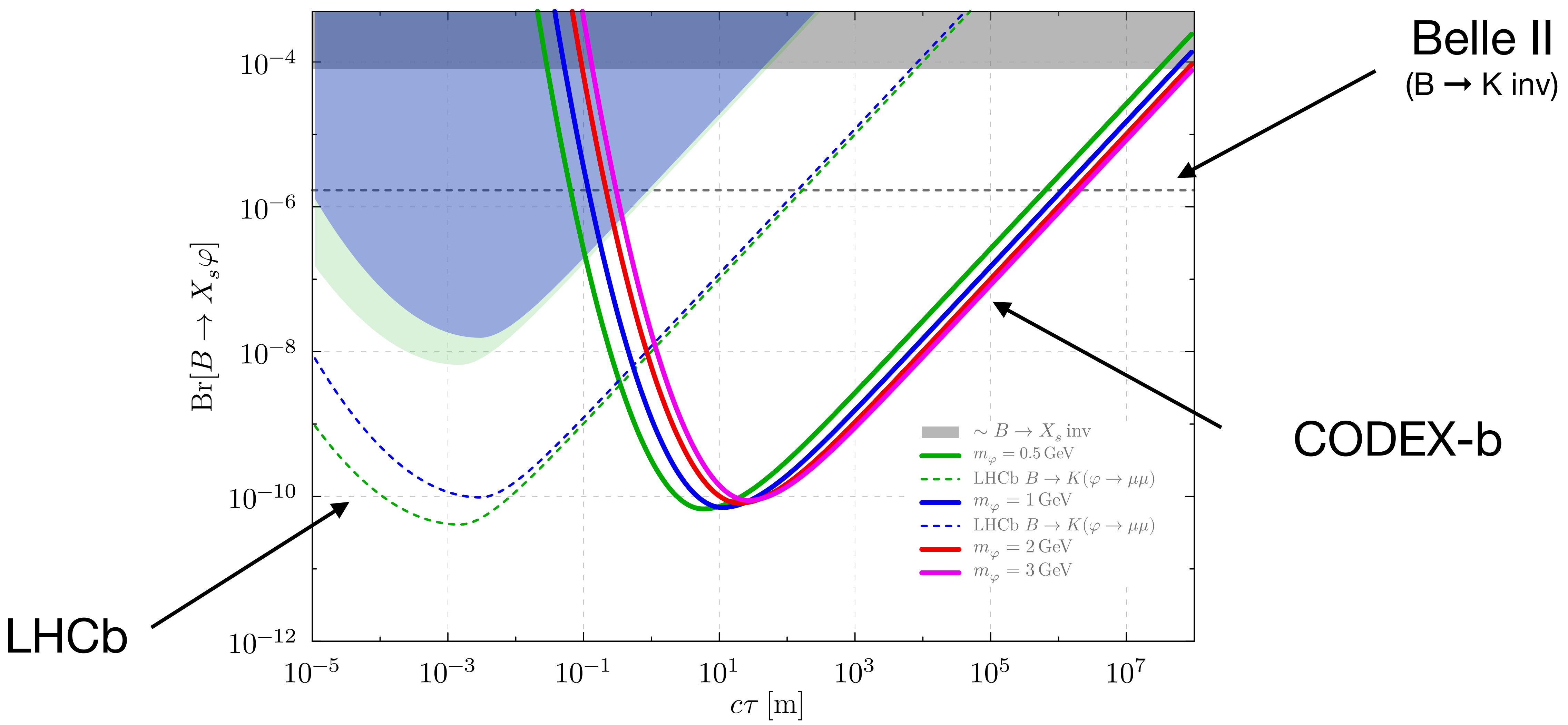
FASER

Felix Kling

Thanks!

Back-up

More general exotic B decays



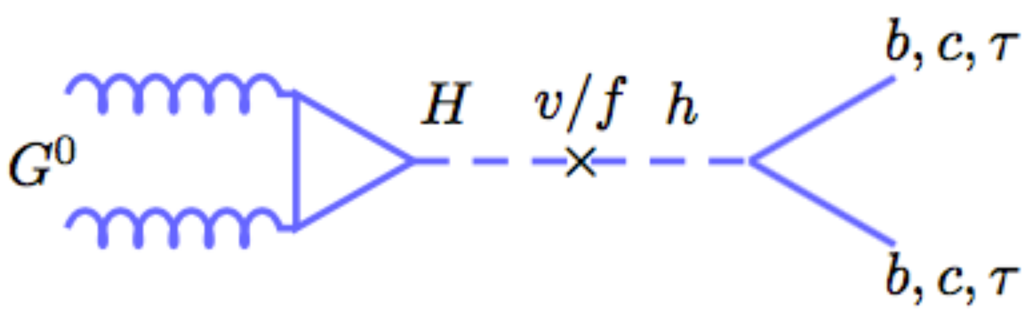
Complementary reach compared to main LHCb detector

(Branching ratio to muons is irrelevant for CODEX-b)

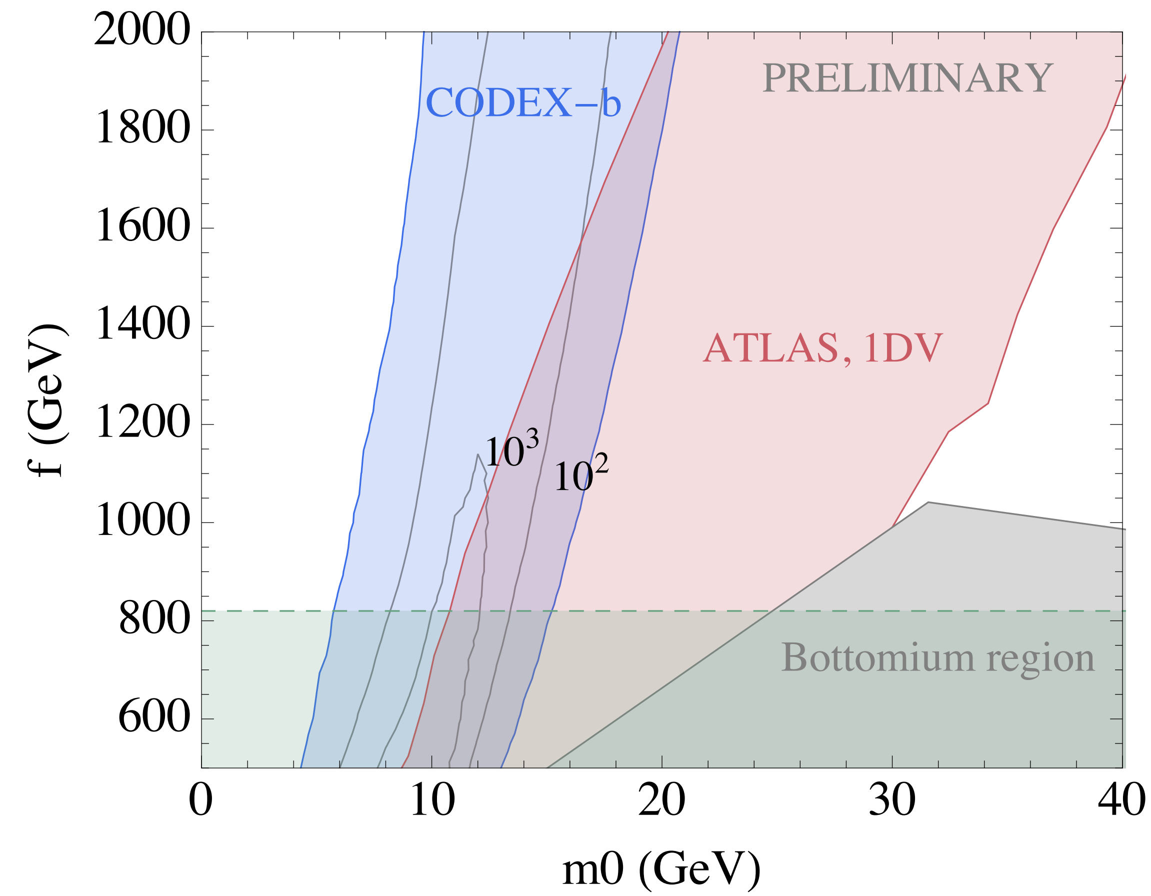
Hidden glueballs (Neutral Naturalness)

Production: exotic Higgs decay

Decay: through Higgs mixing:



Lifetime very strong function of glueball mass $c\tau \sim m_0^{-7}$



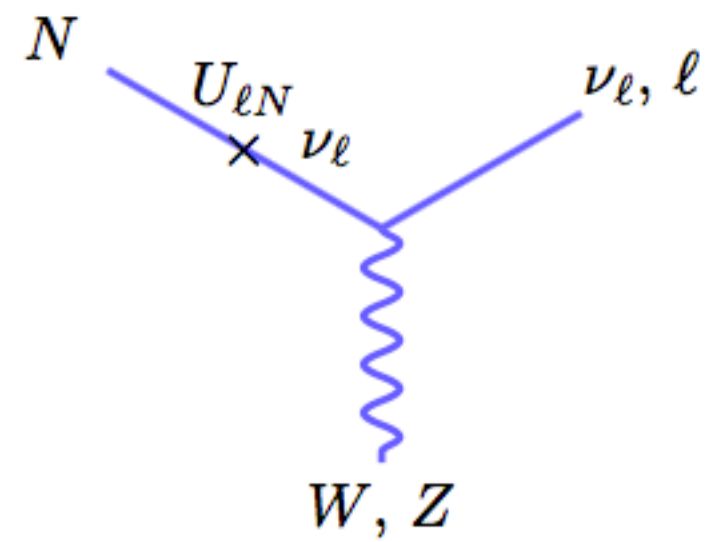
ATLAS / CMS pay double penalty at low mass:

- Backgrounds go up
- Requiring a second displaced vertex kills the signal rate

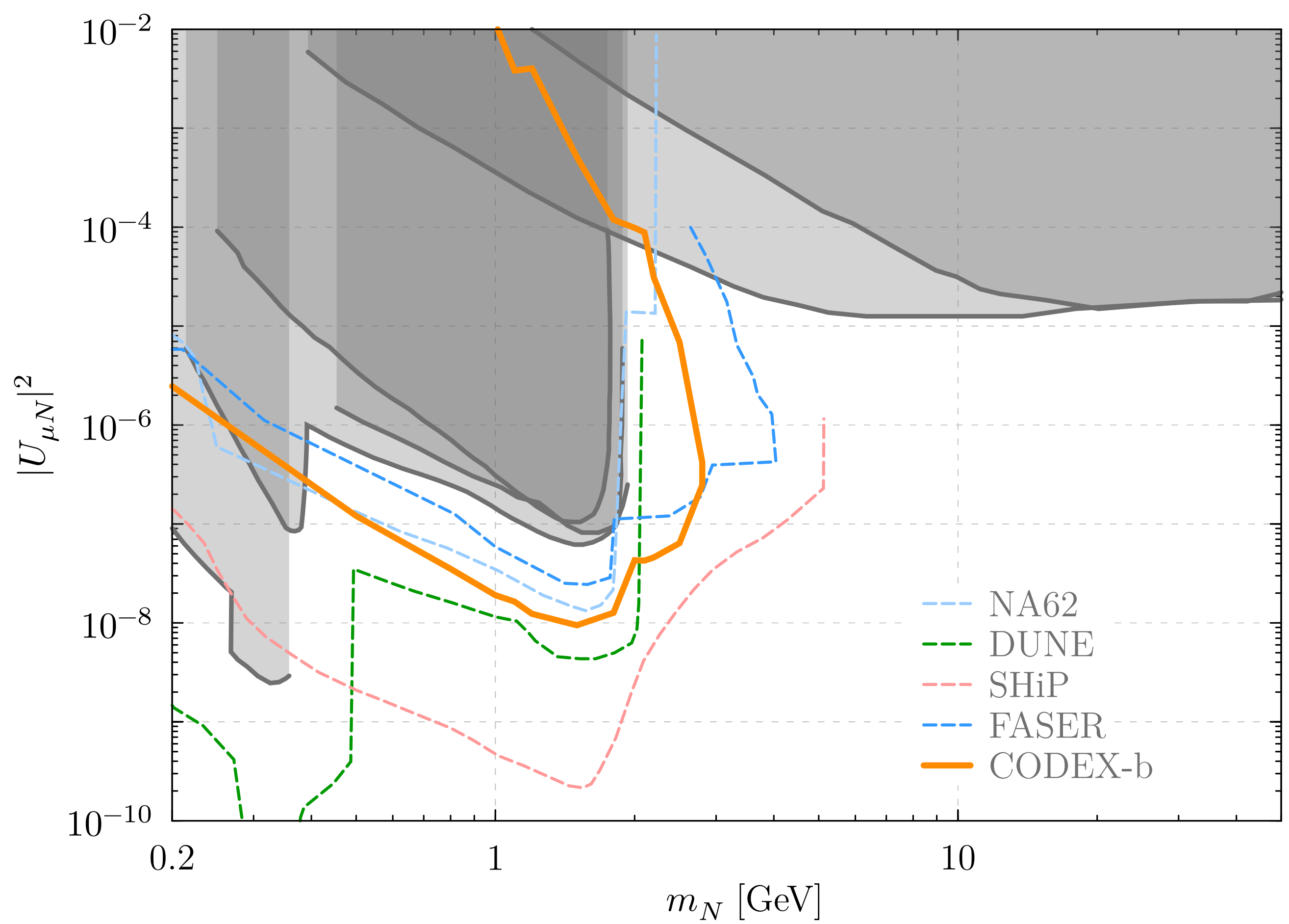
Heavy neutral leptons

- Production: any SM decay with neutrinos
  (c, b, τ, W & Z decays)

- Decay: Mix back to off-shell SM neutrino
  (N→3ν, N→ℓ hadrons, N→νℓℓ)



Example: $U_{\mu N}$

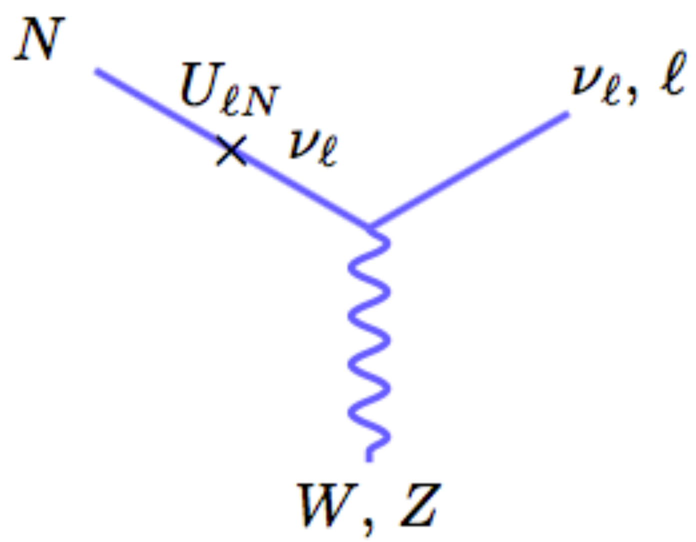


18xx.xxxxx: J. Evans, SK, M. Papucci, H. Ramani D. Robinson

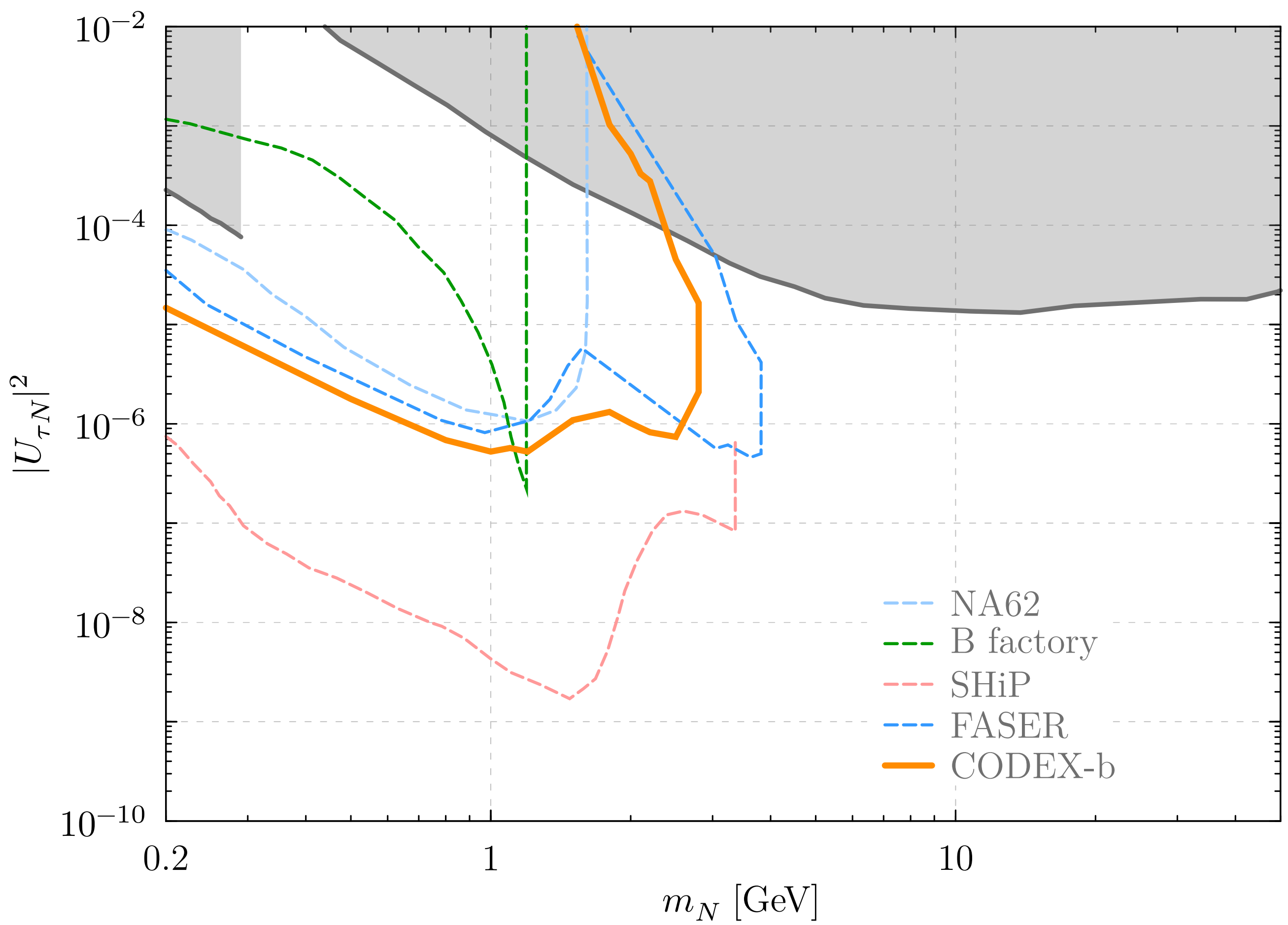
see also: Heo, Hirsch, Wang: 1803.02212

Heavy neutral leptons

- Production: any SM decay with neutrinos
  (c, b, τ, W & Z decays)
- Decay: Mix back to off-shell SM neutrino
  (N→3ν, N→ℓ hadrons, N→νℓℓ)



Example: UτN



18xx.xxxxx: J. Evans, SK, M. Papucci, H. Ramani D. Robinson

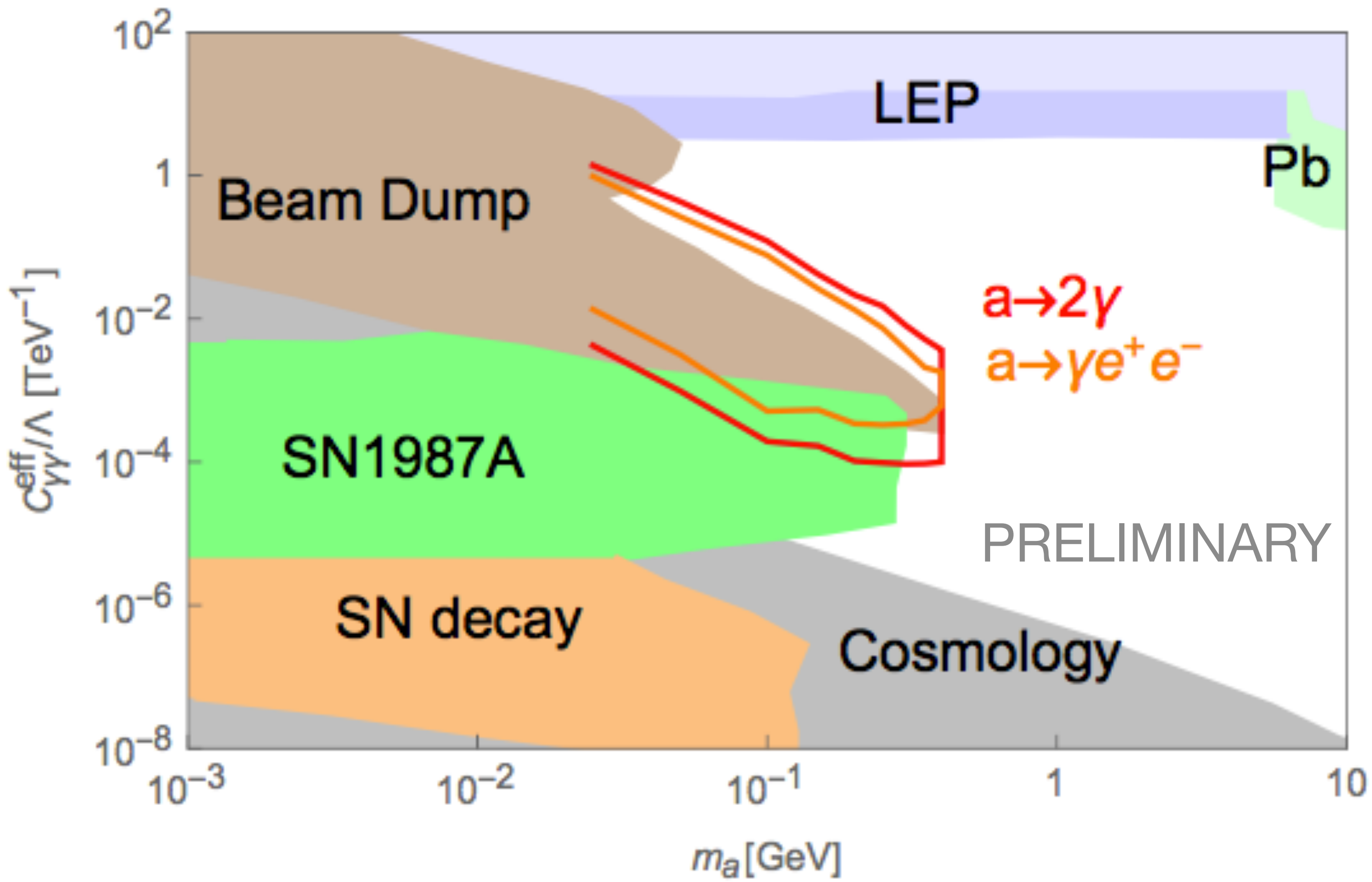
see also: Heo, Hirsch, Wang: 1803.02212

Axion-like particles

Assume only $aG\tilde{G}$ coupling in UV

↓

Induces $aF\tilde{F}$ coupling in IR
& mixing with SM π^0



Below the 3π threshold, the lifetime is enhanced

It is non-trivial but perhaps not impossible for CODEX-b to see the 2γ mode
(Will depend on final design choices.)

18xx.xxxxx: J. Evans, SK, M. Papucci, H. Ramani D. Robinson

Characterizing the signal

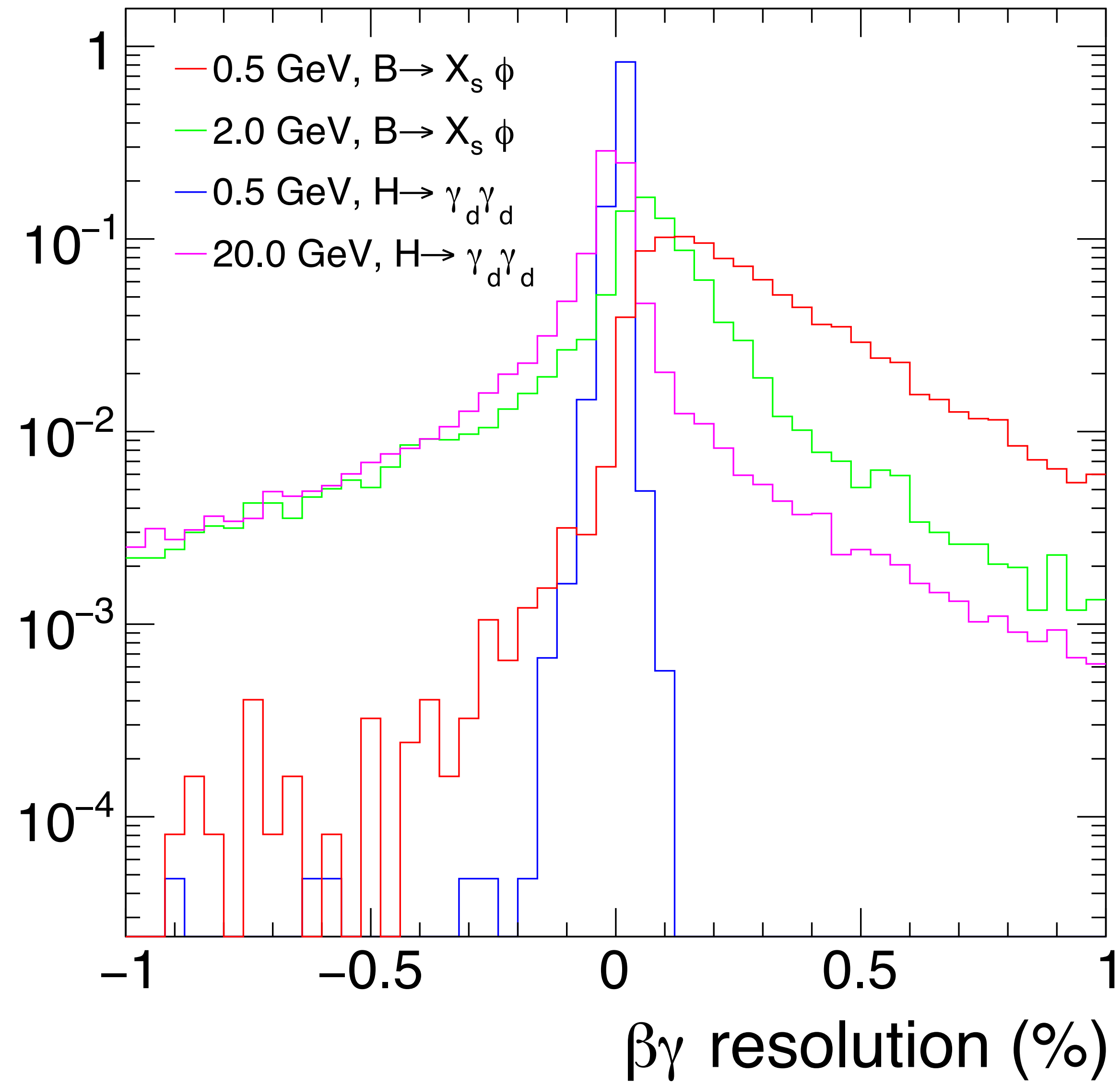
Parent boost reconstruction

Boost reconstruction

D. Curtin, M. Peskin: 1705.06327

$$\beta_X = \frac{\beta_1 \beta_2 \sin(\theta_1 + \theta_2)}{\beta_1 \sin\theta_1 + \beta_2 \sin\theta_1}$$

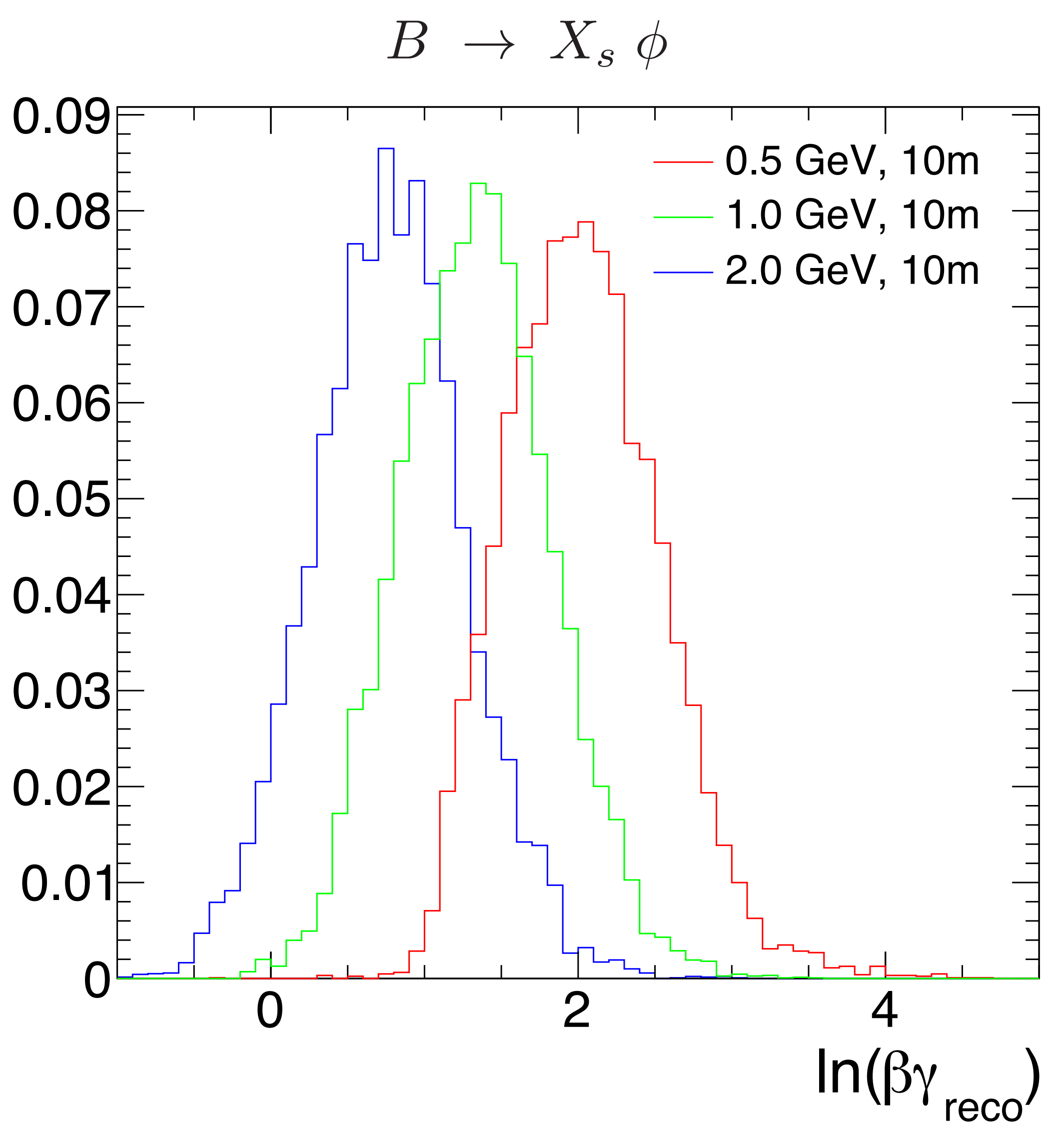
For relativistic decay products, only need spatial information

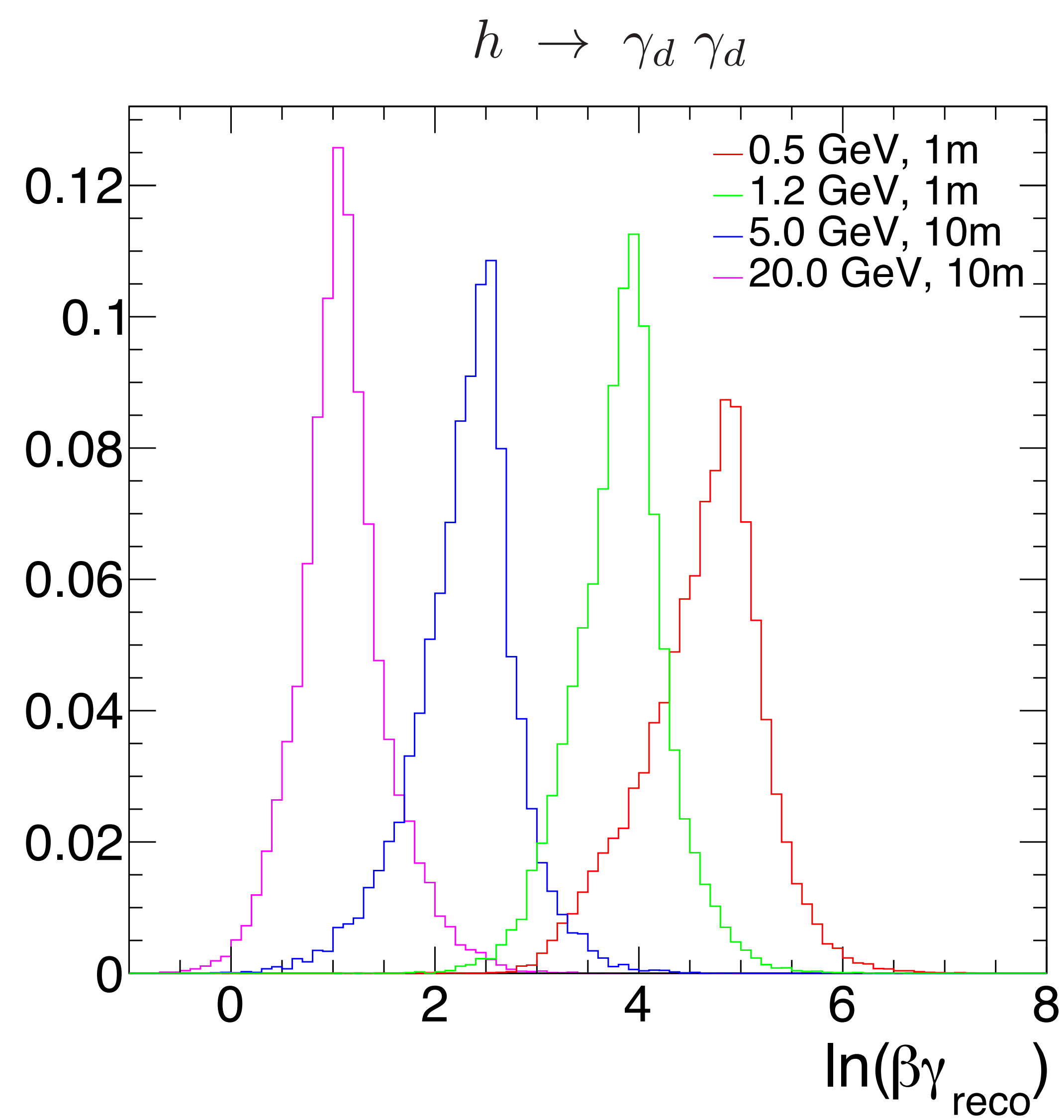


Most important parameter is distance to first measured point

Mass measurement

Only spatial information

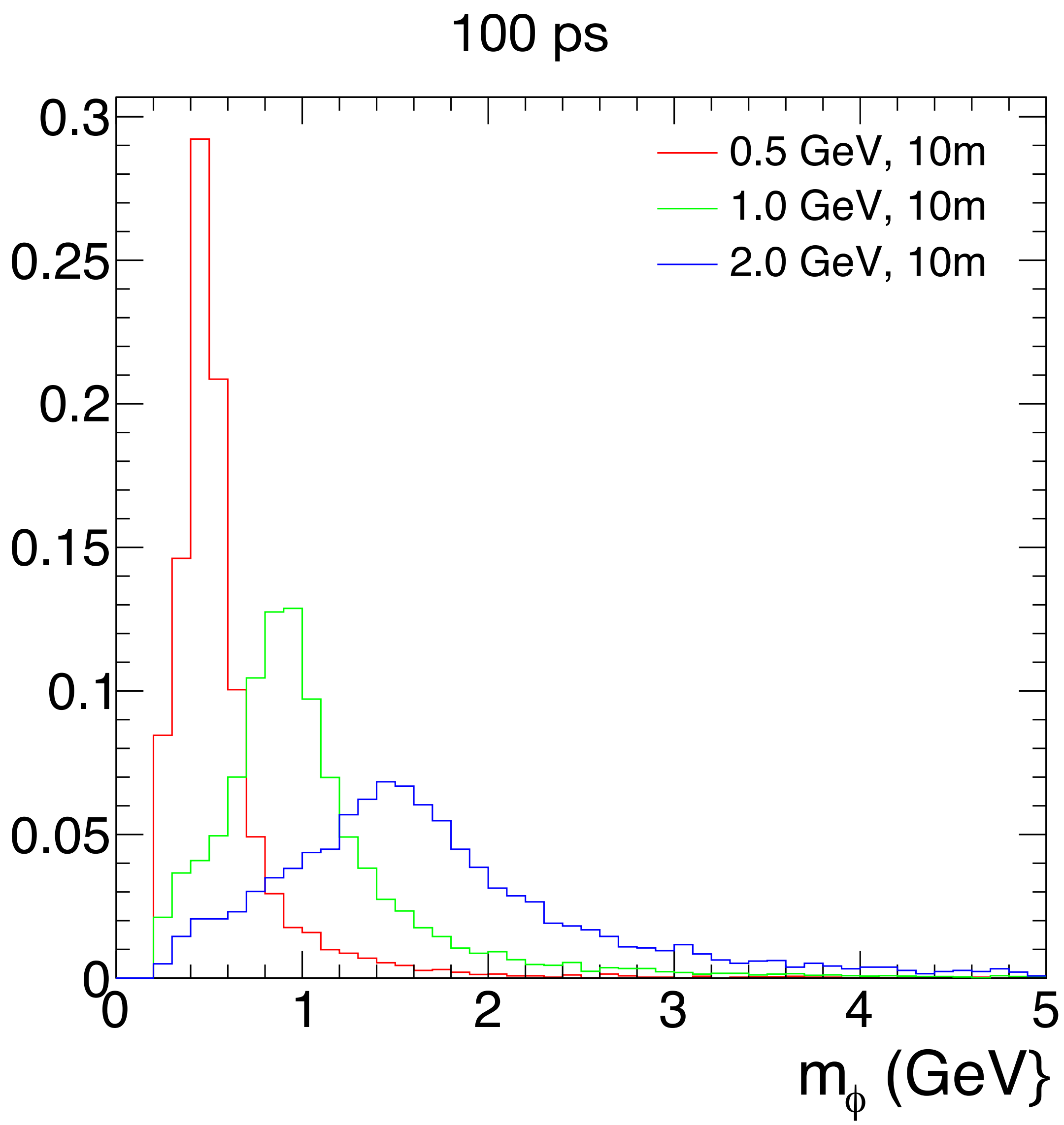


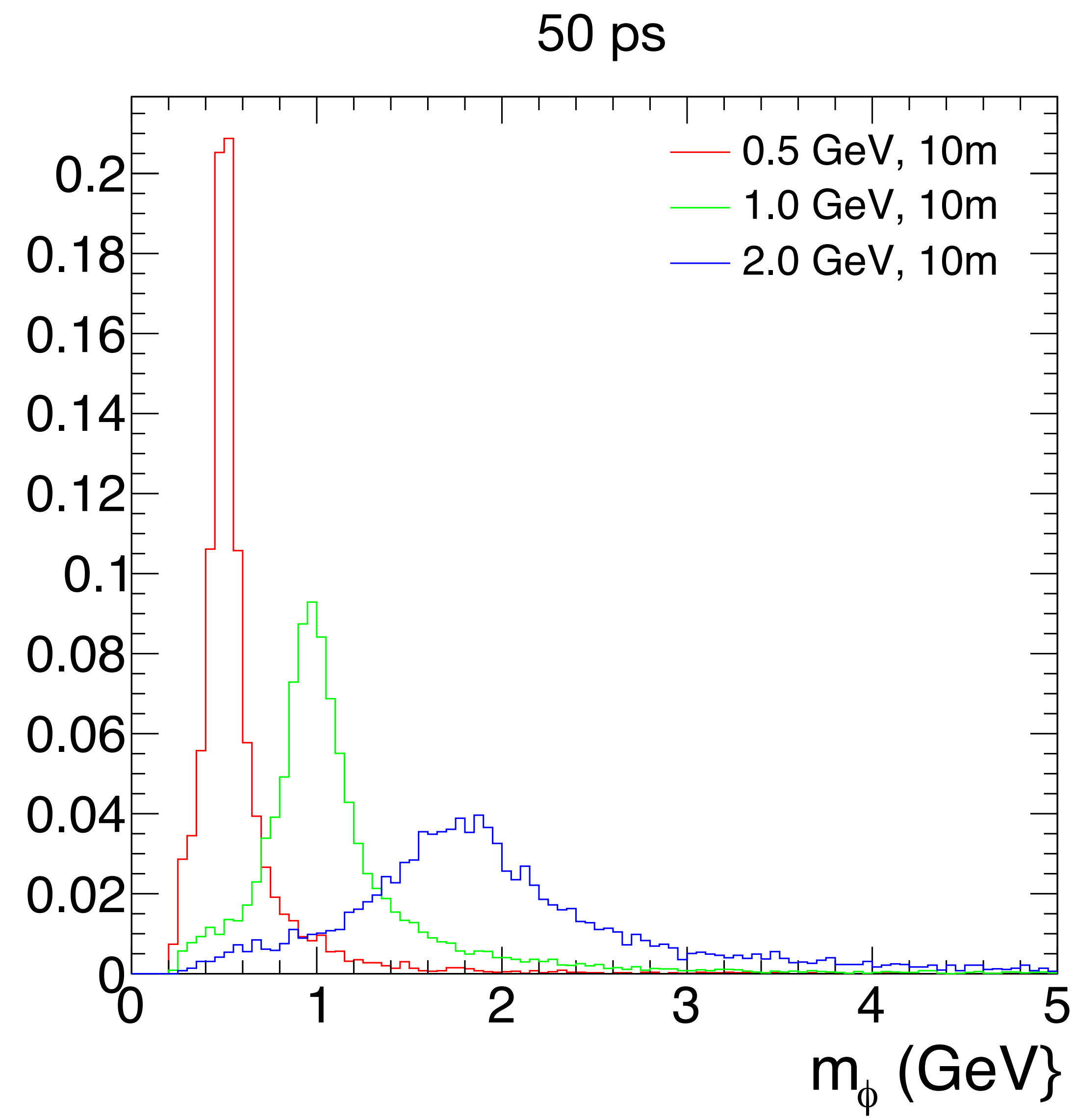


Rudimentary mass measurement possible even without calorimetry

Mass measurement

Include timing





For exotic B decays, mass separation can be improved by including time-of-flight information