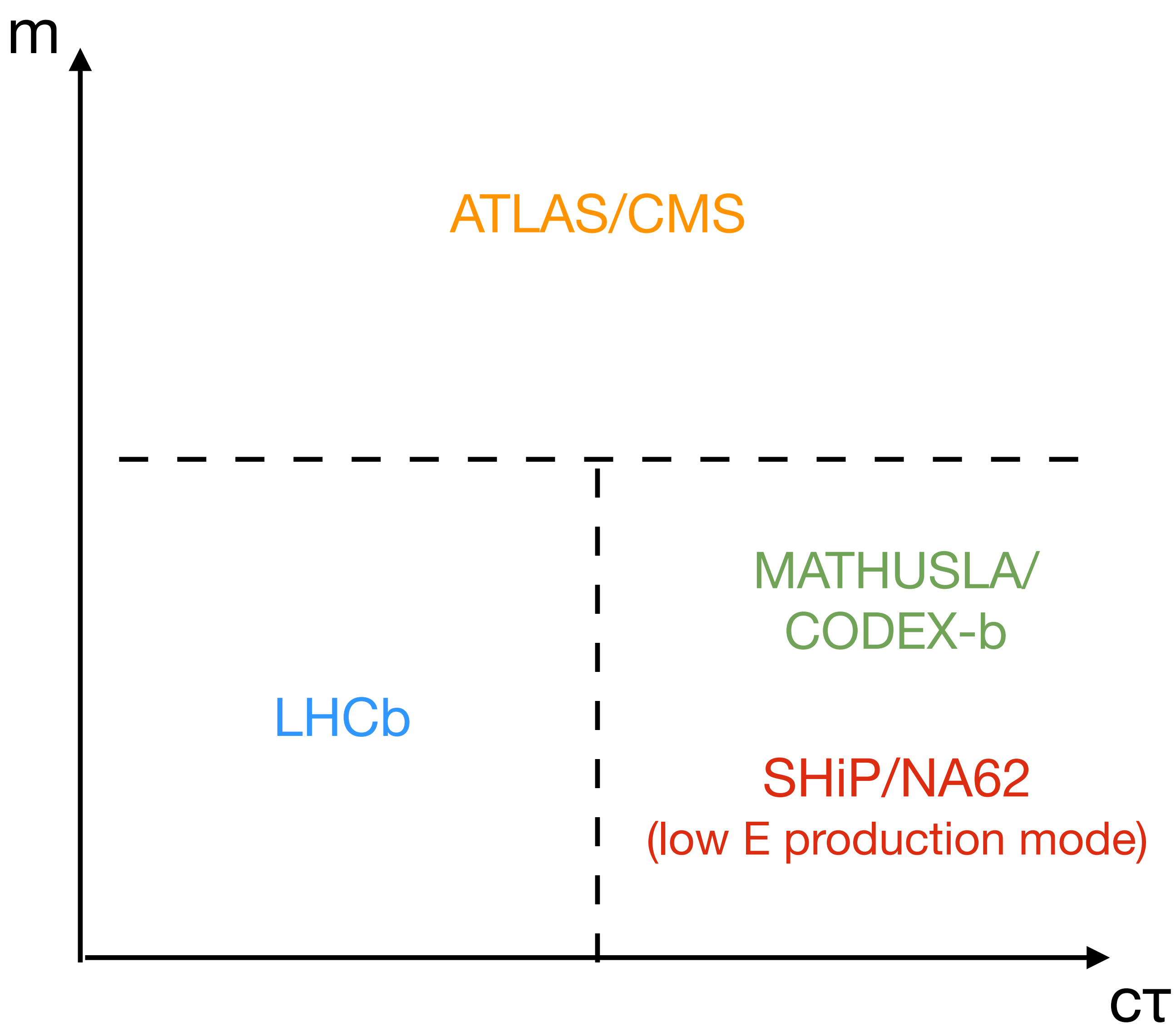
COmpact DEtector for eXotics at LHC-b (CODEX-b)

Vladimir Gligorov, Simon Knapen, Michele Papucci, Dean Robinson

1708.09395

The Long Lived Particle Program



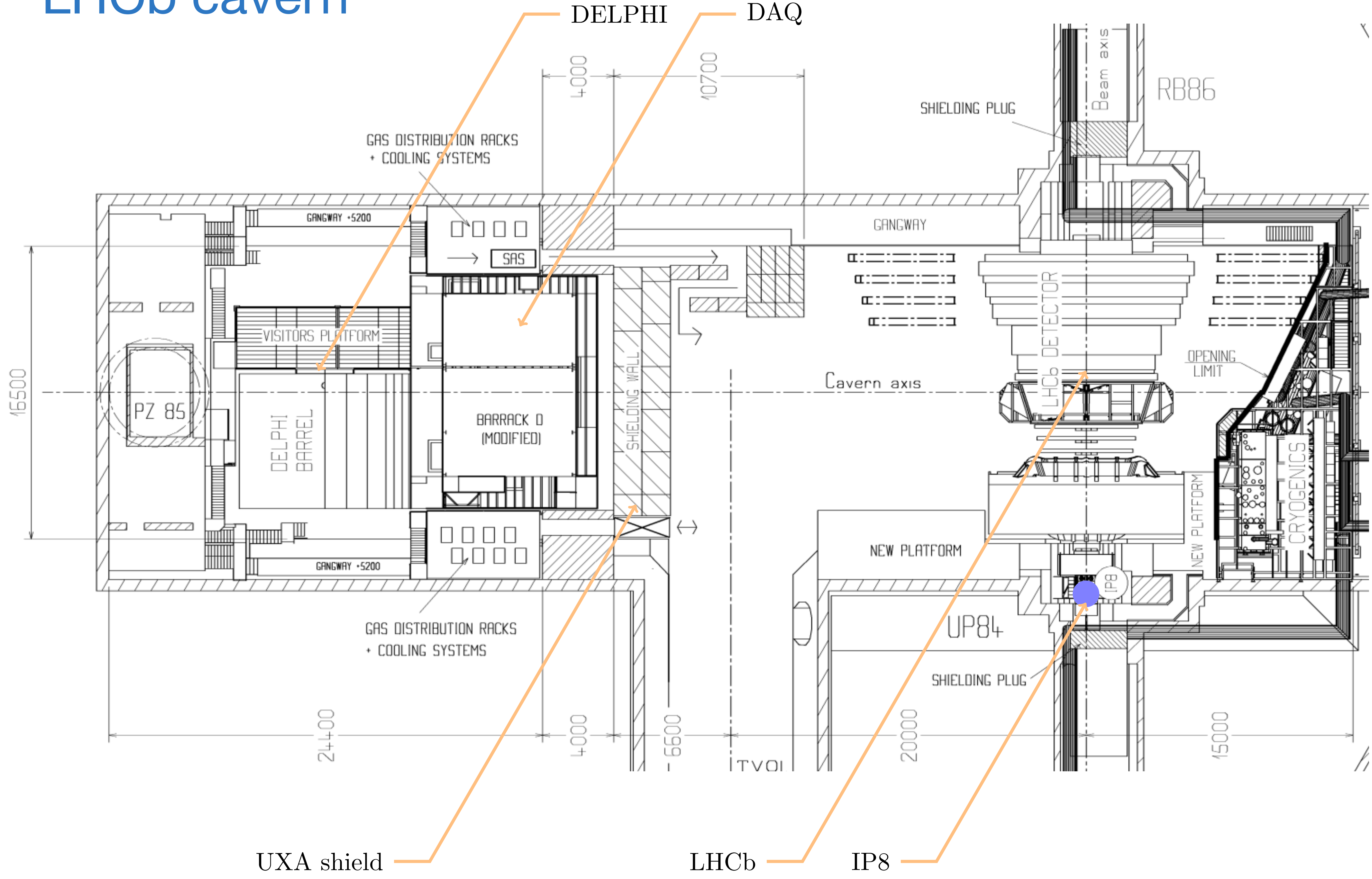
Low mass LLP's with large $c\tau$ only probed effectively by beam dump experiments

↓

At the energy frontier, would need a shielded detector like MATHUSLA or CODEX-b

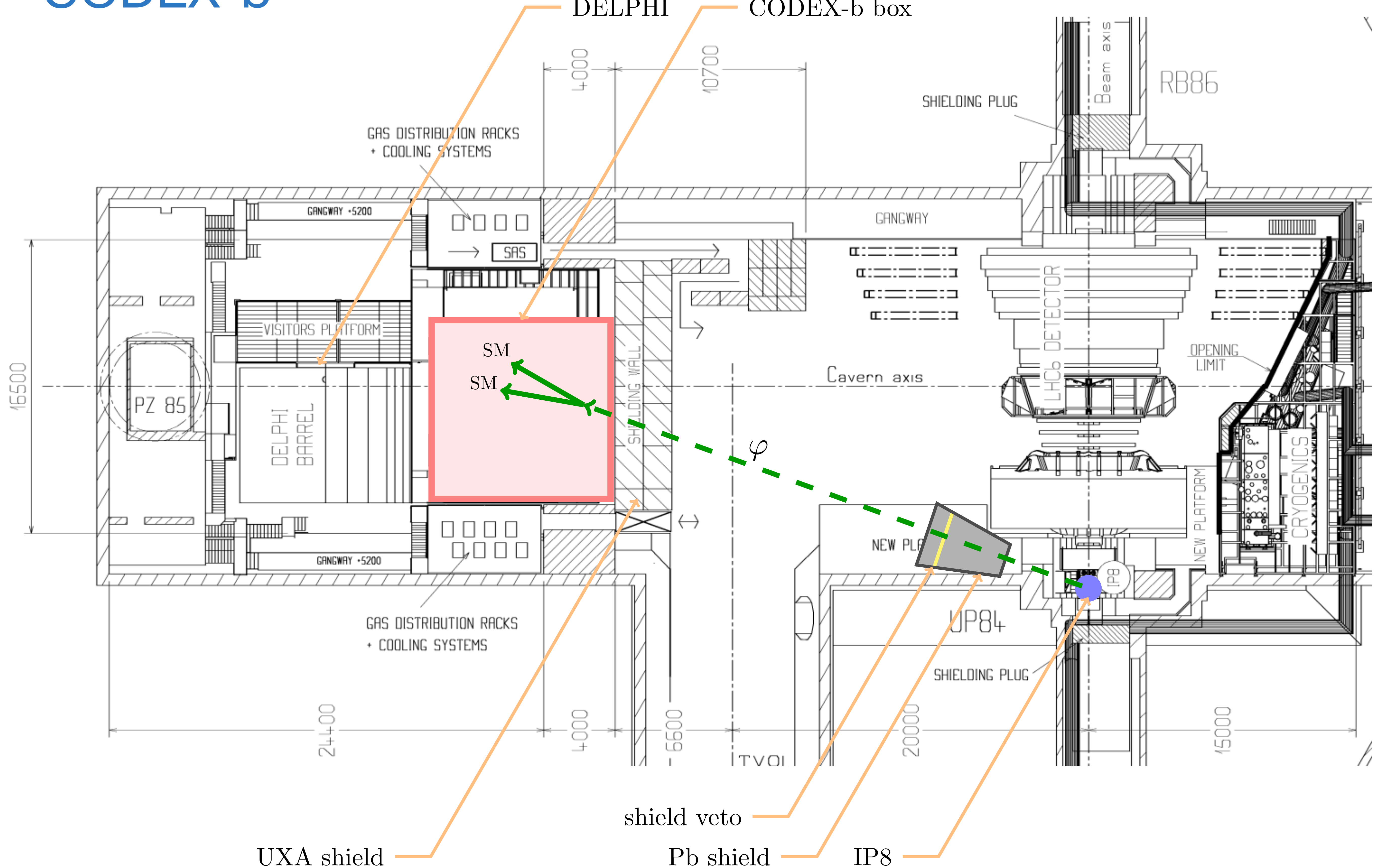
This is an oversimplification of course: final states, multiplicity, boost etc are crucial

LHCb cavern



DELPHI
DAQ
UXA shield
LHCb
IP8
GAS DISTRIBUTION RACKS
+ COOLING SYSTEMS
GANGWAY +5200
SAS
VISITORS PLATFORM
PZ 85
DELPHI BARREL
BARRACK D (MODIFIED)
SHIELDING WALL
GANGWAY
SHIELDING PLUG
Beam axis
RB86
LHCb DETECTOR
Cavern axis
OPENING LIMIT
CRYOGENICS
NEW PLATFORM
UP84
4000
10700
16500
24400
6500
20000
15000

CODEX-b



DELPHI
CODEX-b box
SM
SM
φ
shield veto
UXA shield
Pb shield
IP8
GAS DISTRIBUTION RACKS
+ COOLING SYSTEMS
VISITORS PLATFORM
DELPHI BARREL
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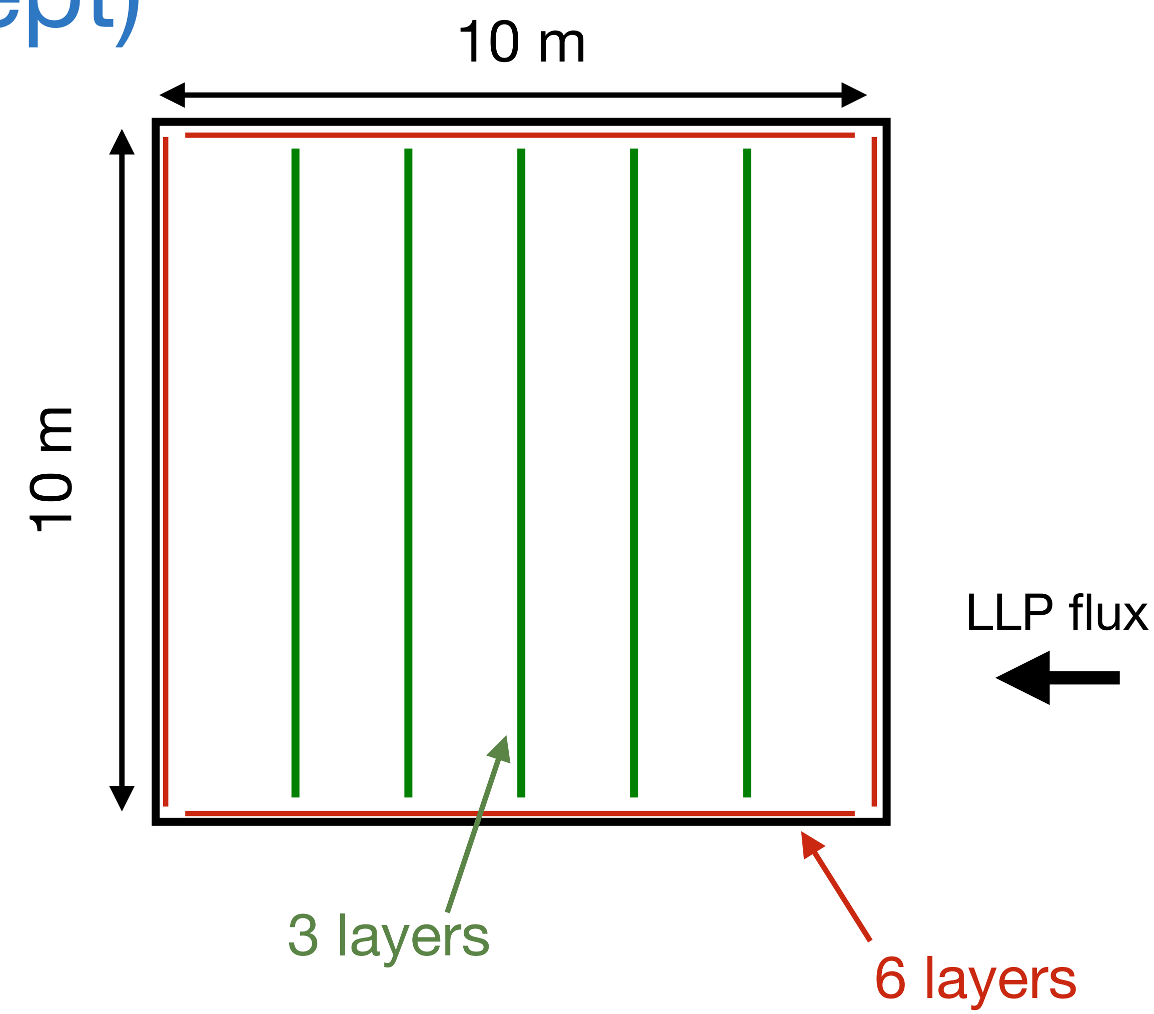
Fiducial volume (proof of concept)

- 10m x 10m x 10m fiducial volume
  → 1-2% geometric coverage
  (double if DELPHI is removed)

- 6 RPC layers on each surface

- 5 set of 3 vertical RPC layers in the volume

- 1 cm granularity



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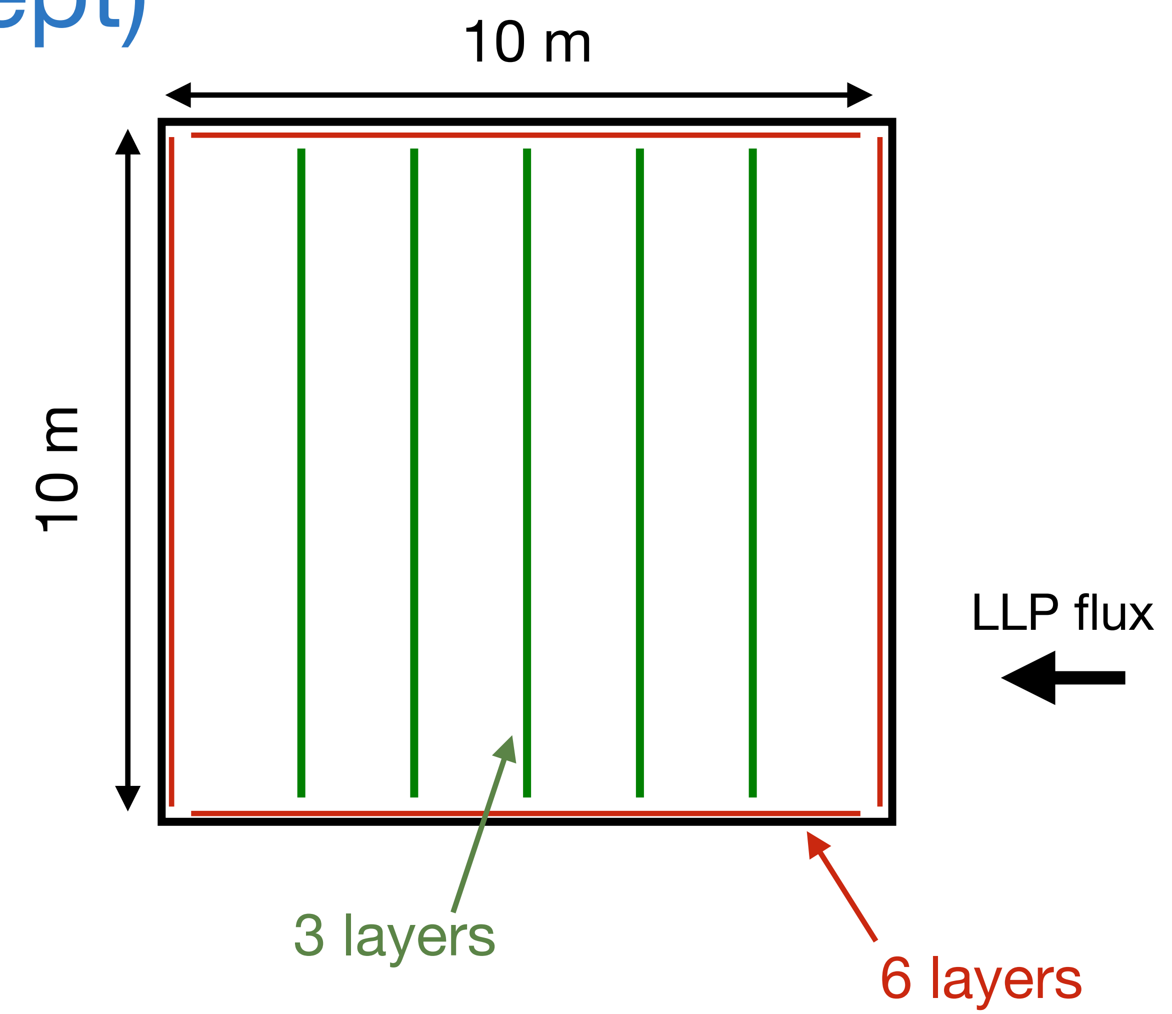


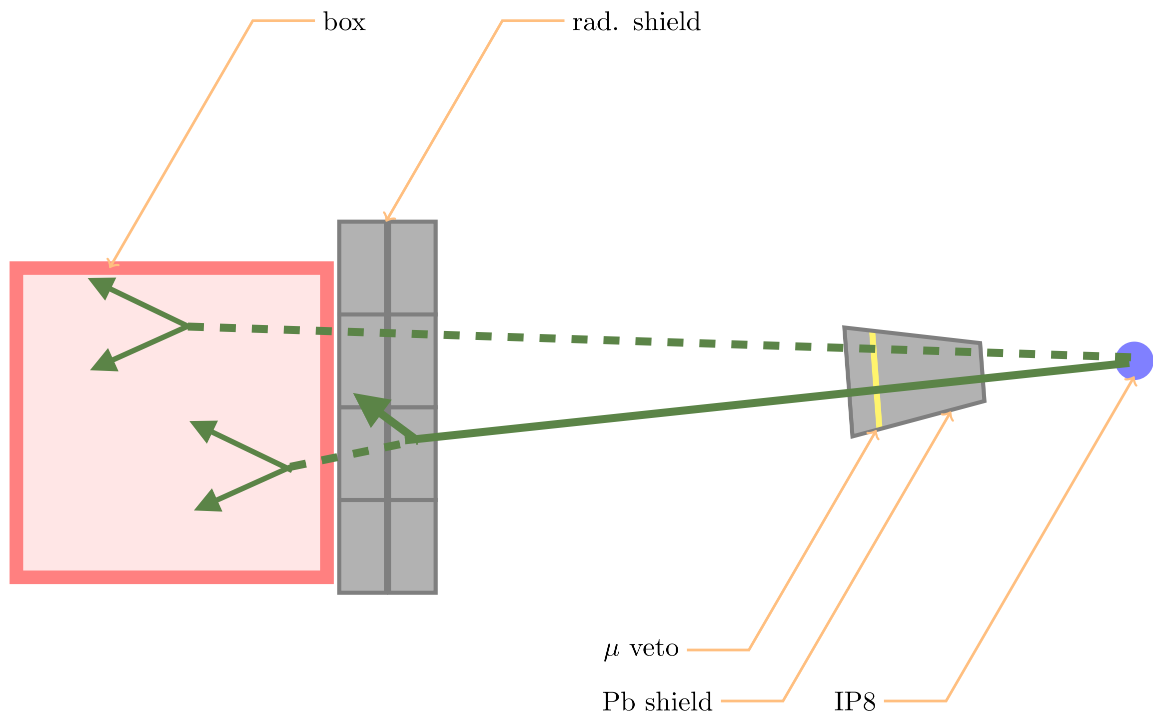
Key points:

- recover acceptance for particles with low boost

- minimize distance to first tracked point

Backgrounds

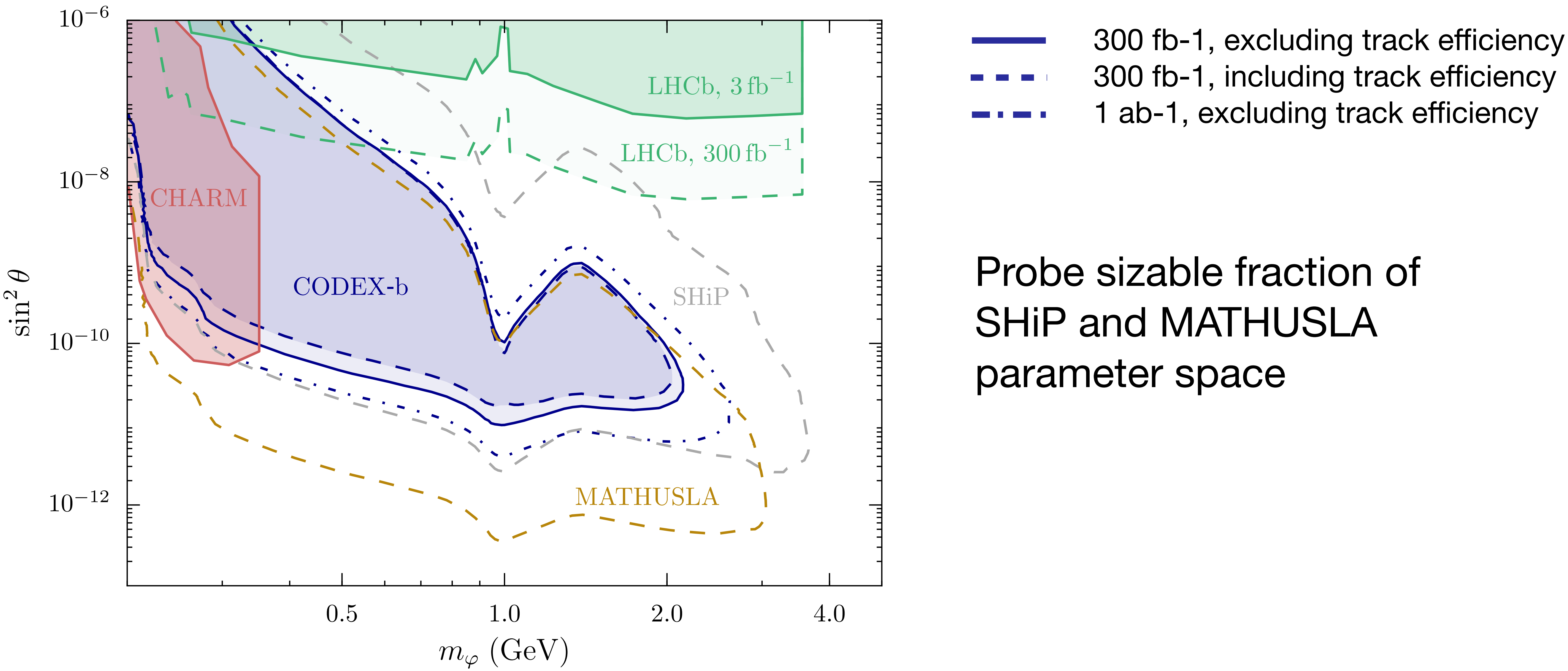
- Prompt muons can be veto-ed by front face of the box
- Prompt neutrons and K_L attenuated by shielding
- Secondary neutrons and K_L removed with muon veto
- Neutrinos are negligible



Quantitative estimates with GEANT4 in back-up slides and 1708.09395

Light scalar mixing with Higgs

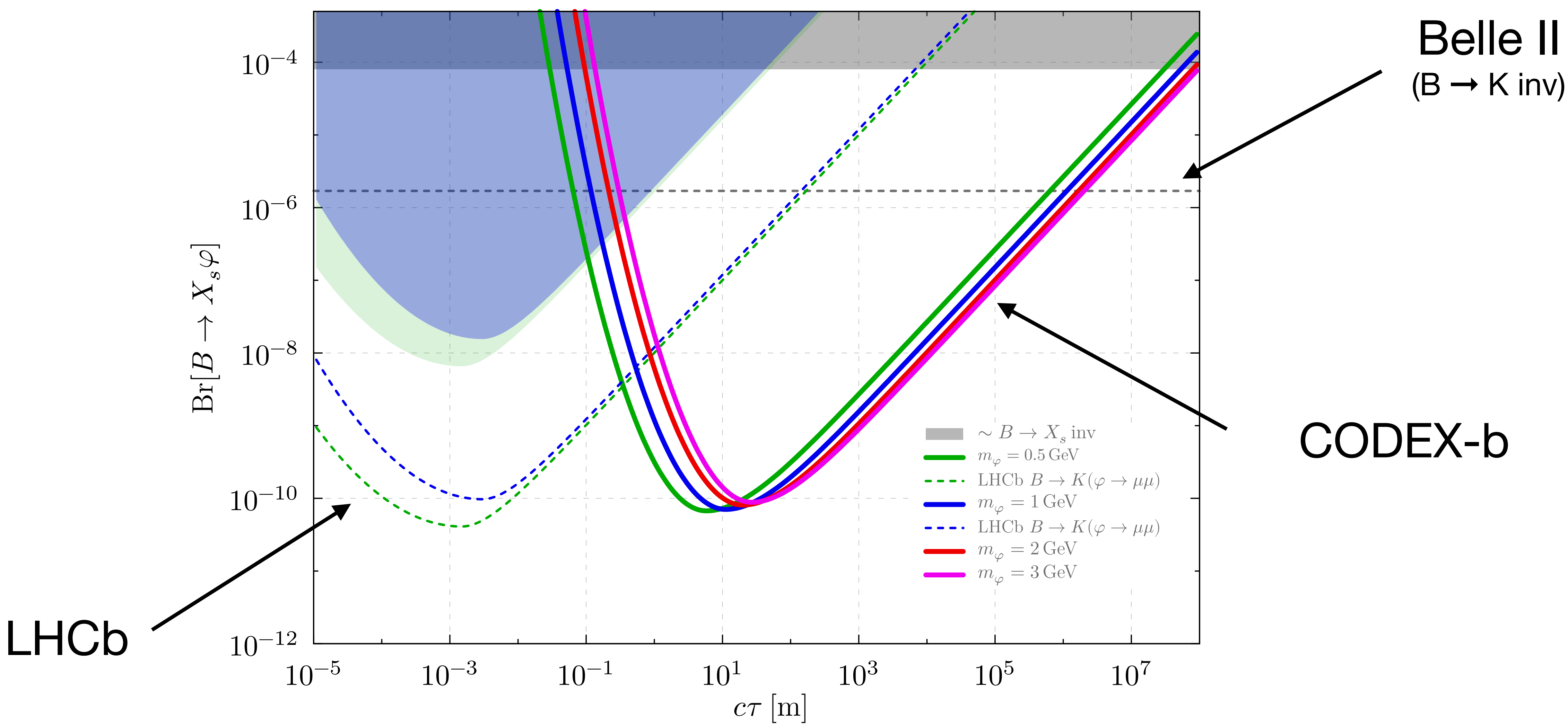
$B \to X_s \phi$



Probe sizable fraction of SHiP and MATHUSLA parameter space

(SHiP and MATHUSLA our recast to lifetime model used by LHCb and CODEX-b)

More general models

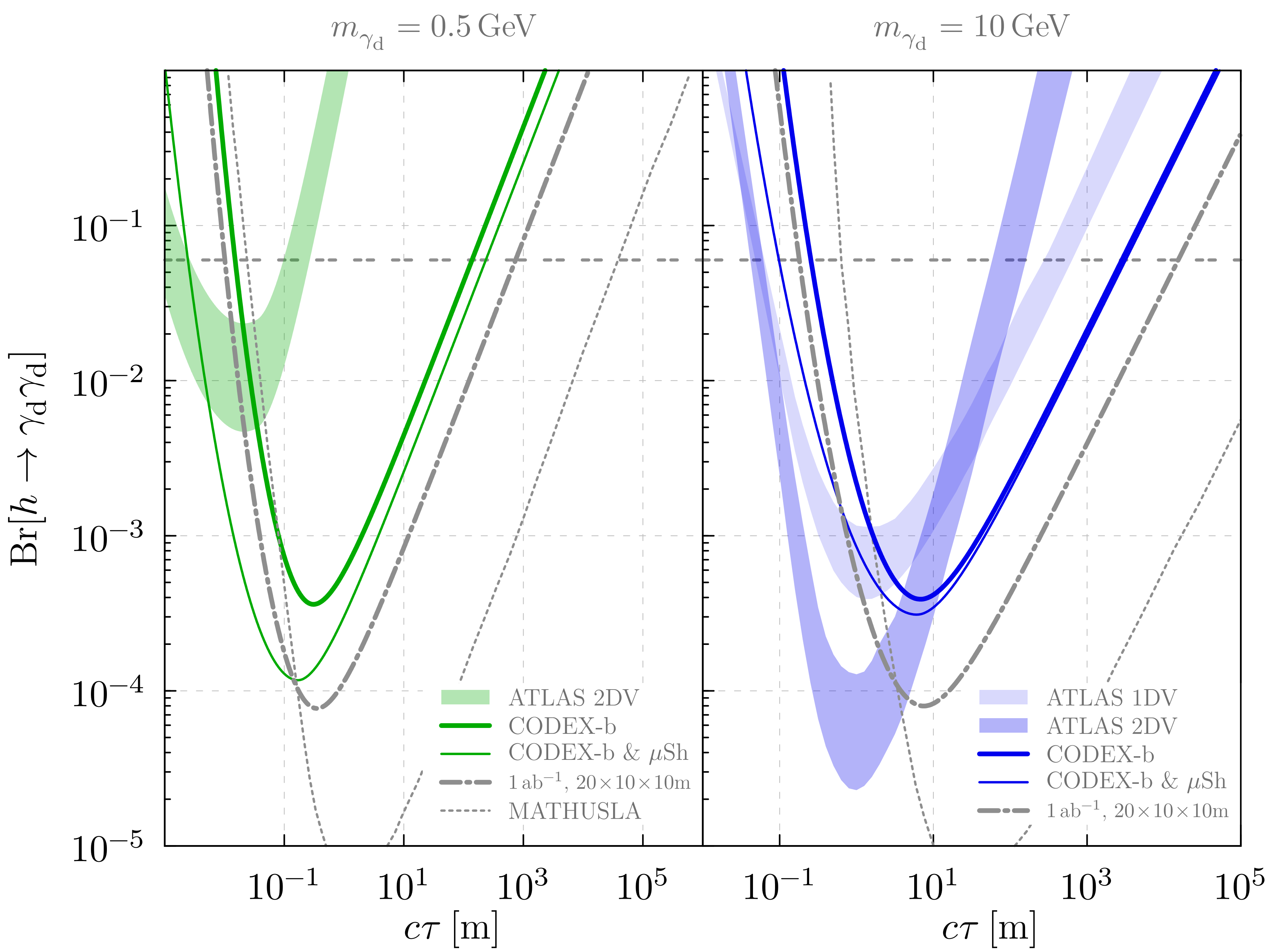


Complementary reach compared to main LHCb detector

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

Exotic Higgs decays

$h \to \gamma_d \gamma_d$

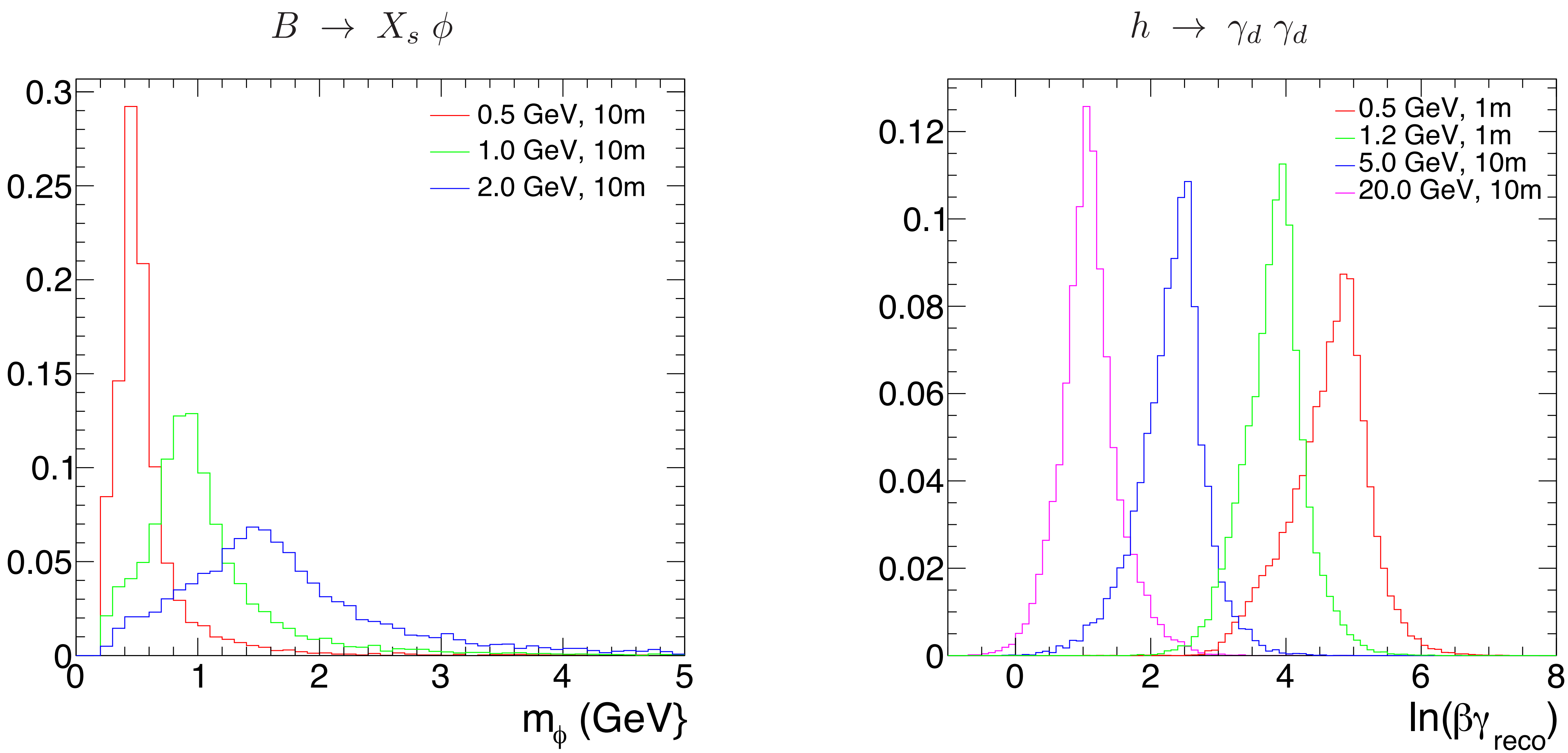


For low masses, ATLAS/CMS are background limited, CODEX-b and MATHUSLA have an edge

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

Mass measurement

With 100 ps timing



Rudimentary mass measurement possible even without calorimetry

Moving forward

Experiment

- Data driven background estimate, by installing a small telescope in the LHCb cavern
- Consider different tracking layout and/or technologies, to optimize momentum & vertex resolution vs cost
- Opportunity for synergy with R&D happening already on timing resolution for HL-LHC upgrade.

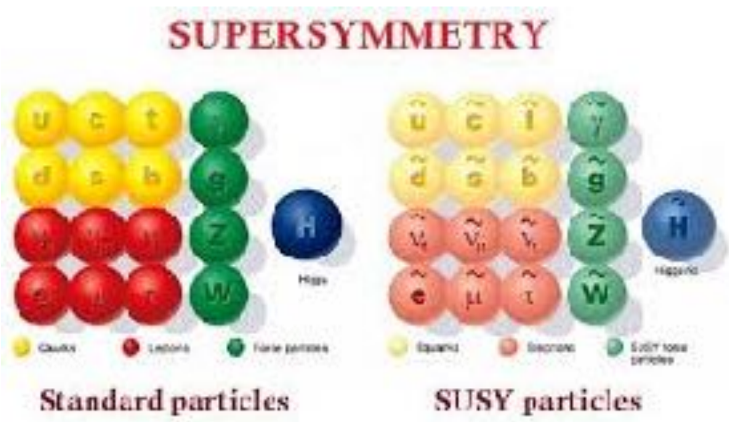
Theory

- Further strengthen physics case, benefit from lessons learned in the upcoming MATHUSLA white paper

Thanks!

More details about backgrounds, reconstruction efficiency & mass measurement in the back-up material

LLP's are generic



R-parity violation

Gauge mediation

(mini-)split SUSY

stealth SUSY

Asymmetric Dark Matter

Freeze-in

composite Dark Matter

…

Baryogenesis

Neutrino masses

Neutral Naturalness

Hidden Valleys

…

Wide range of masses & lifetimes ⟶ no single experiment has comprehensive coverage

LHCb coverage for LLP's

- Higgs mixing portal

  LHCb: 1612.07818

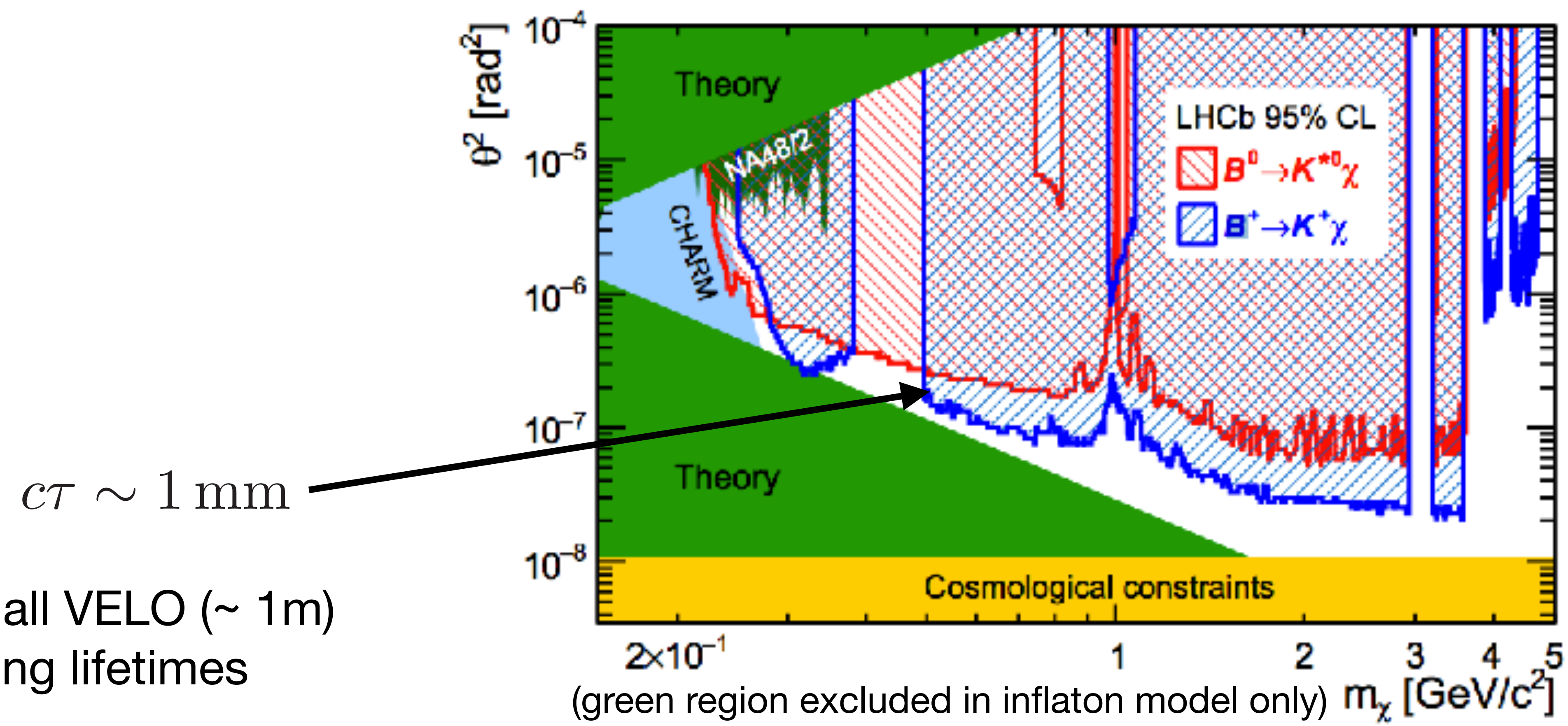
- Dark photon portal

  P. Ilten, J. Thaler, M. Williams, W. Xue: 1509.06765
  P. Ilten, Y. Soreq, J. Thaler, M. Williams, W. Xue: 1603.08926

- Hidden valleys

  A. Pierce, B. Shakya, Y. Tsai, Y. Zhao: 1708.05389

LHCb: 1612.07818



(green region excluded in inflaton model only)

Large boost and rather small VELO (~ 1m) reduce sensitivity to long lifetimes

Reconstruction efficiency (proof of concept)

- Require 6 hits per track
- Require minimum momentum of 600 MeV per track

$c\tau$ (m)	m_φ $[B \to X_s \varphi]$			m_{γ_d} $[h \to \gamma_d \gamma_d]$				
	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	–	–	–	–	–

low boost — high boost

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600 MeV cut

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low boost

600 MeV cut

high boost

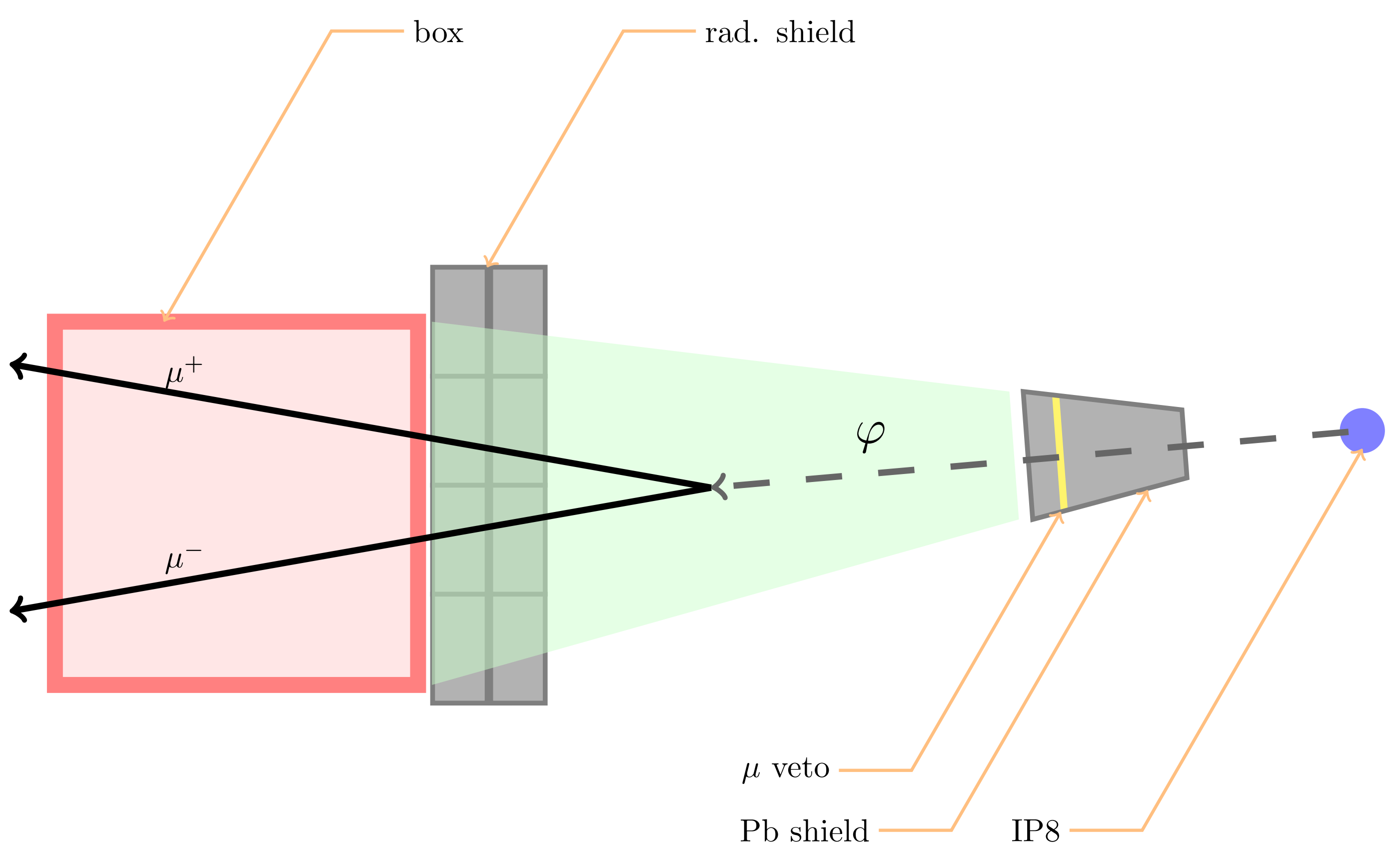
small opening angle,
overlapping decay products

Possible features

- Close to LHCb: ~ 4 bunch crossings for relativistic objects
  integrate CODEX-b in DAQ & readout as LHCb subdetector

- Relatively small, more ambitious design (timing, calorimetry, etc) may be possible (e.g. considering Time Projection Chamber)

- Muon shadow may be exploited for more energetic signals



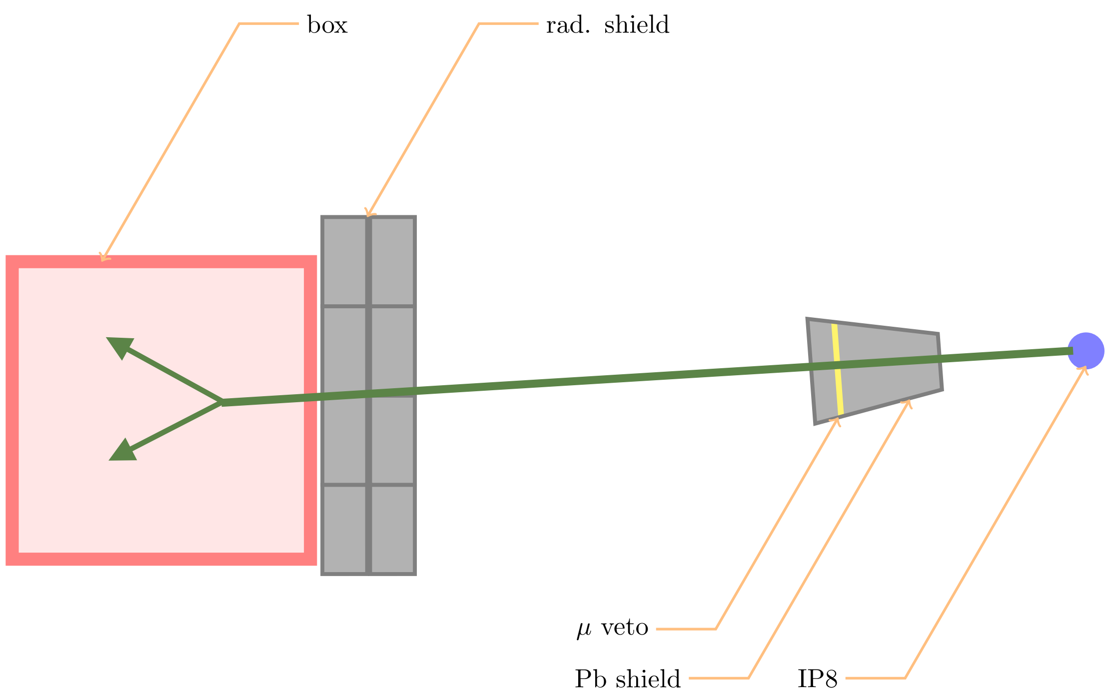
Backgrounds

Some comments

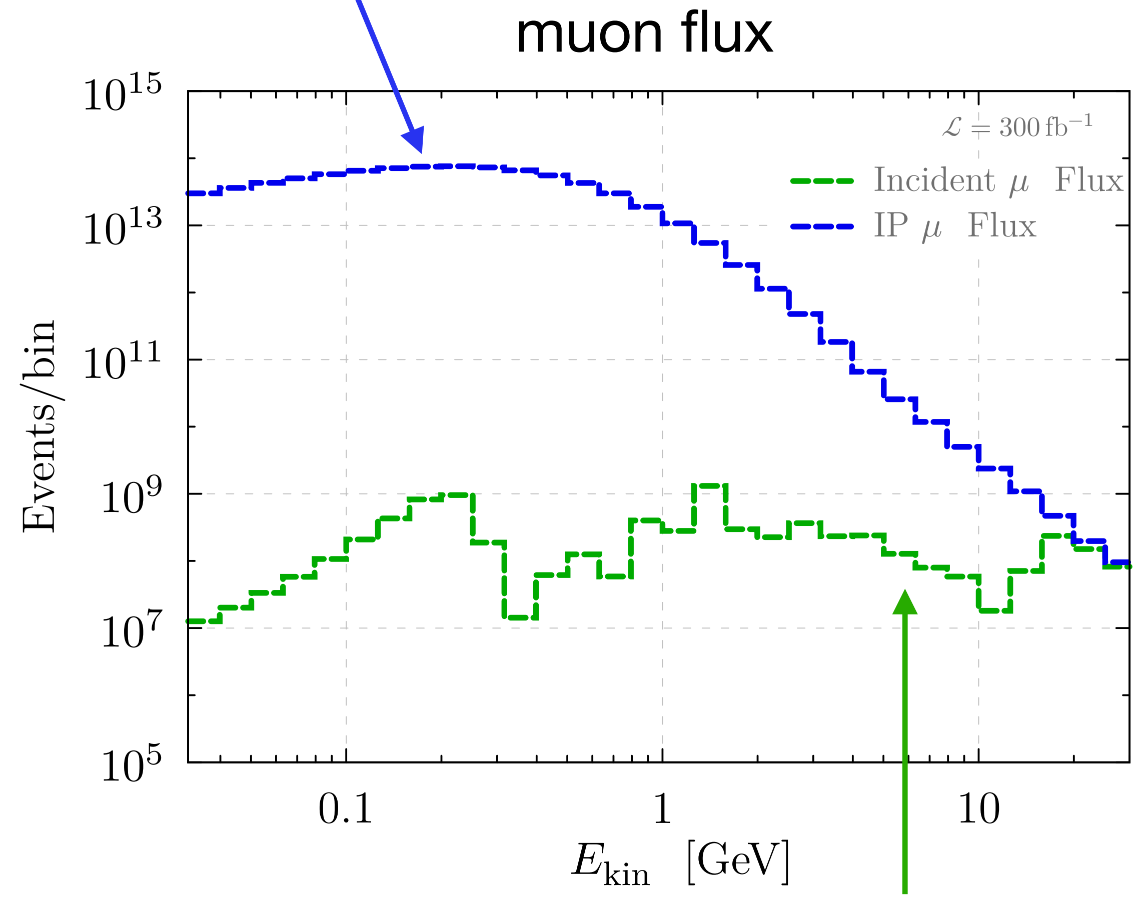
- Use cosmics for spatial and time alignment of the detector
- Backgrounds can be measured well ahead of construction, with different amounts of shielding
- Depending on particle ID capabilities neutrons and kaons may be veto-ed and less shielding may be needed

Backgrounds

muons scattering on air



pythia 8 + data



GEANT4

with mb crosssection, scattering probability is ~ 10^{-3}

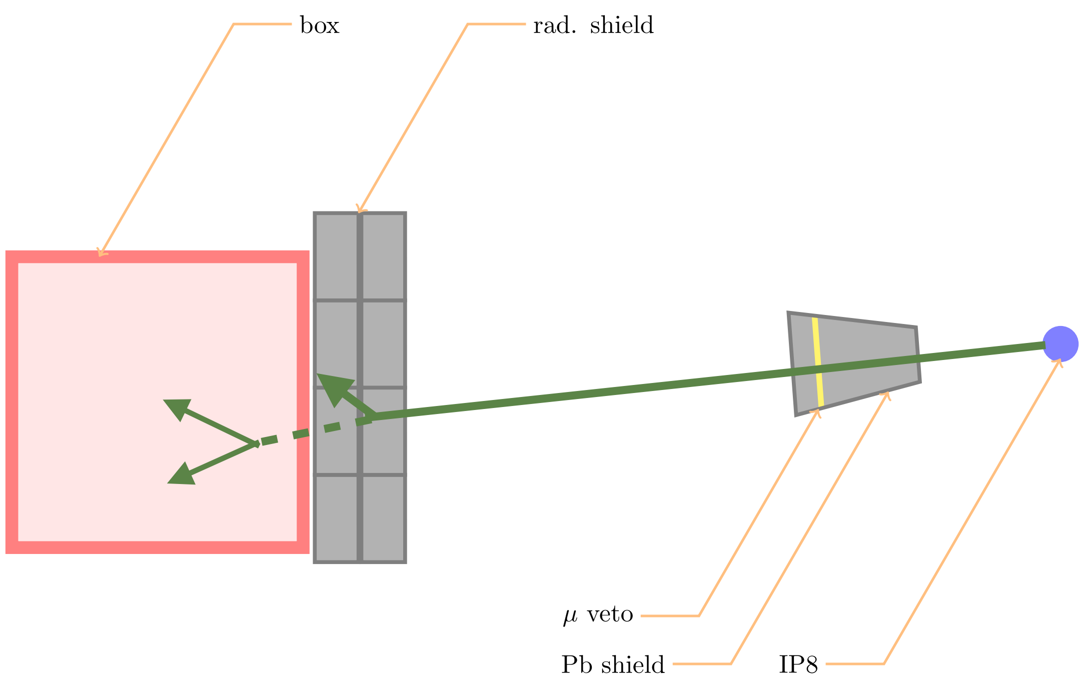
↓

~ 10^{7} events but can be veto-ed with shield veto + front face of the box

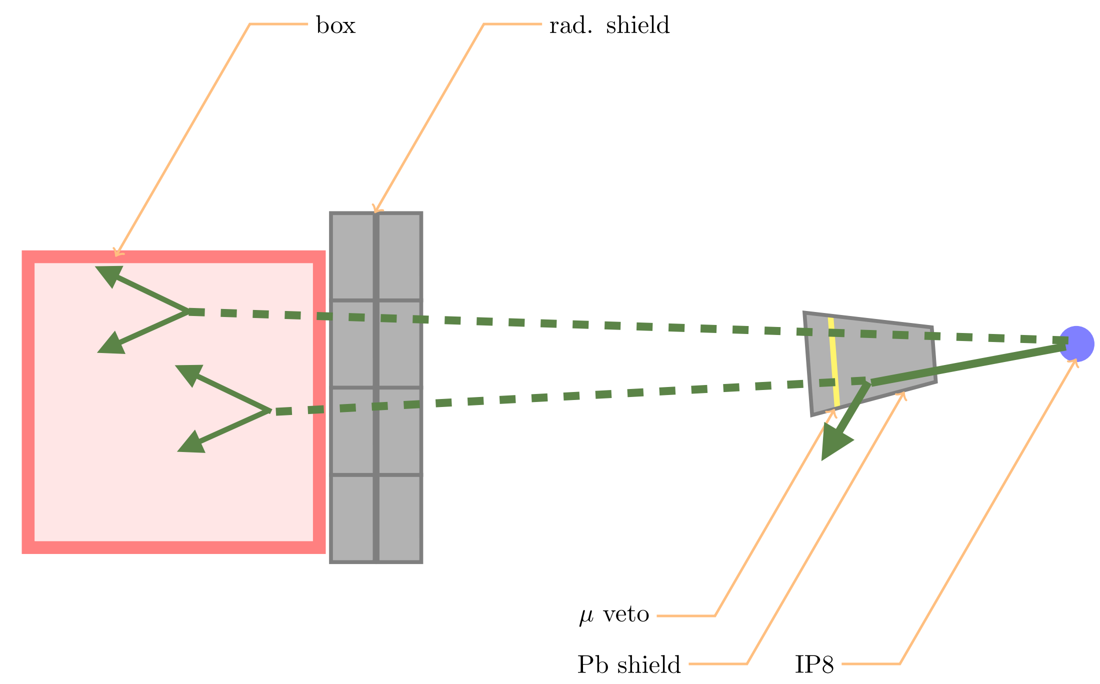
Backgrounds

neutrons / K_L + secondaries

prompt plus secondary from muons hitting shield



veto



irreducible

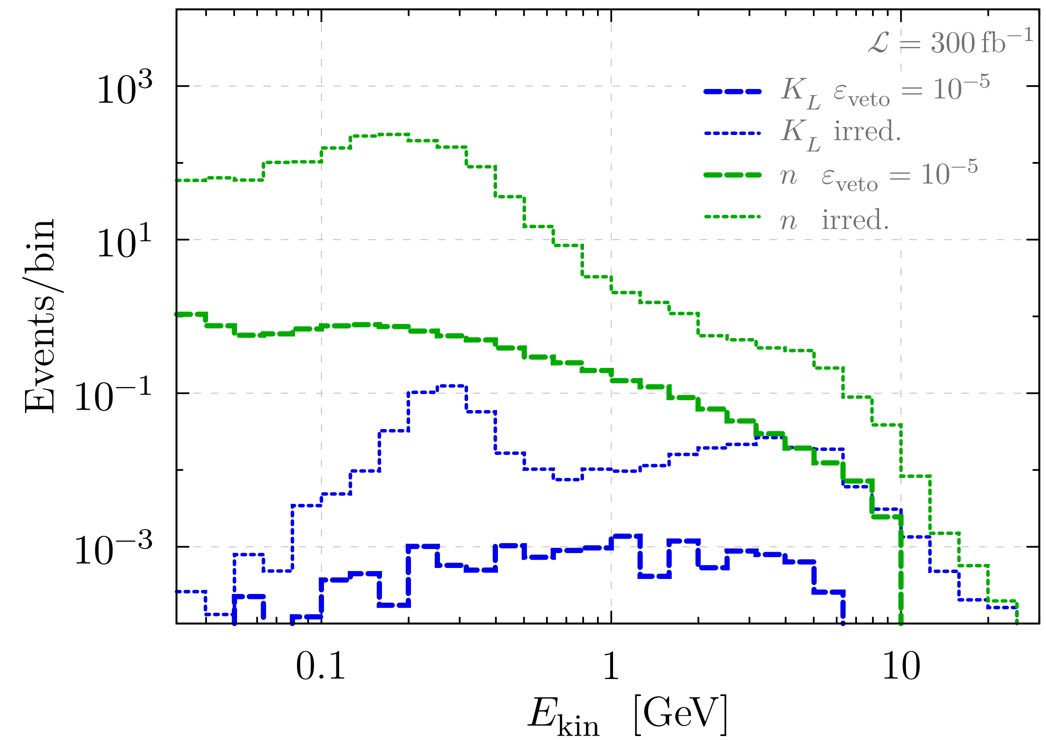
~ 32 interaction lengths (7 concrete + 25 Pb) → roughly 4.5 m of Pb

Backgrounds

neutrons / K_L + secondaries

pythia 8 + GEANT 4 simulation

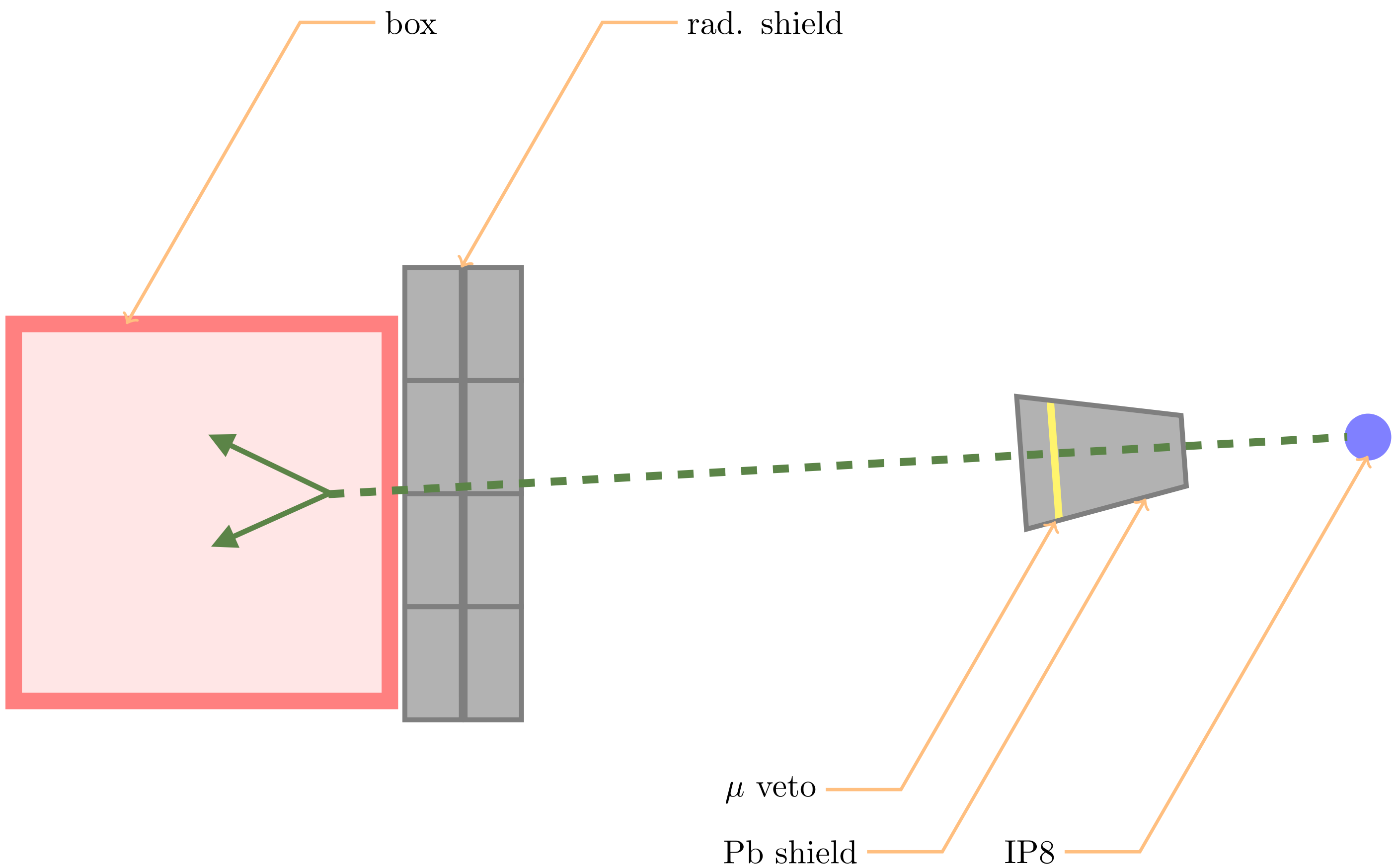
BG species	Particle yields: irreducible by shield veto	Particle yields: reducible by shield veto	Baseline Cuts
$n + \bar{n}$	7	$5 \cdot 10^4$	$E_{\rm kin} > 1\,{\rm GeV}$
K_L^0	0.2	870	$E_{\rm kin} > 0.5\,{\rm GeV}$
$\pi^\pm + K^\pm$	0.5	$3 \cdot 10^4$	$E_{\rm kin} > 0.5\,{\rm GeV}$
$\nu + \bar{\nu}$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



- need 10^{-4} - 10^{-5} muon veto, easily achieved with a few redundant layers
- neutrons dominate, with ~ 5% chance of scattering on air in the box
- secondary neutrinos completely negligible

Backgrounds

primary neutrinos



Very tricky to model, but with extremely conservative cuts, ~ 3 events

Likely to be overestimate with several orders of magnitude

Signal benchmarks

1. Light scalar mixing with Higgs
    - Produced in $B \to X_s \phi$ decays
    - Lifetime and production rate both set by mixing angle

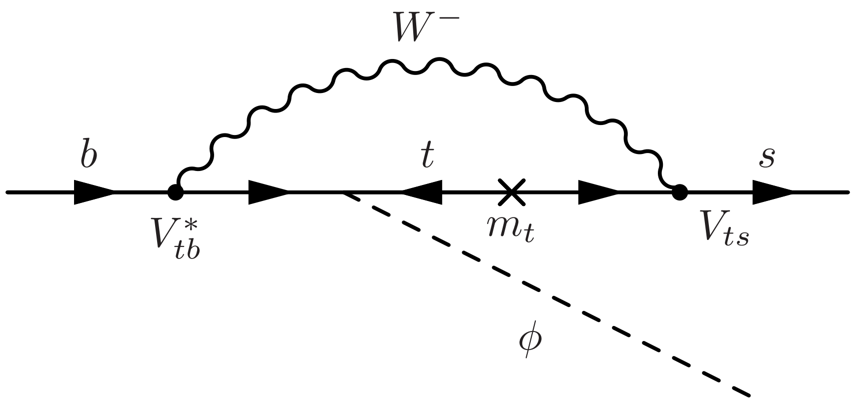
2. Dark photon
    - Produced in $h \to \gamma_d \gamma_d$ decays
    - Production rate and lifetime controlled by independent parameters

Light scalar mixing with Higgs

Production

$$\mathrm{Br}[B \to X_s \phi] \approx 6\, s_\theta^2\, (1 - m_\phi^2/m_B^2)^2$$

Roughly ~ 10^{14} B-mesons with 300 fb^{-1}



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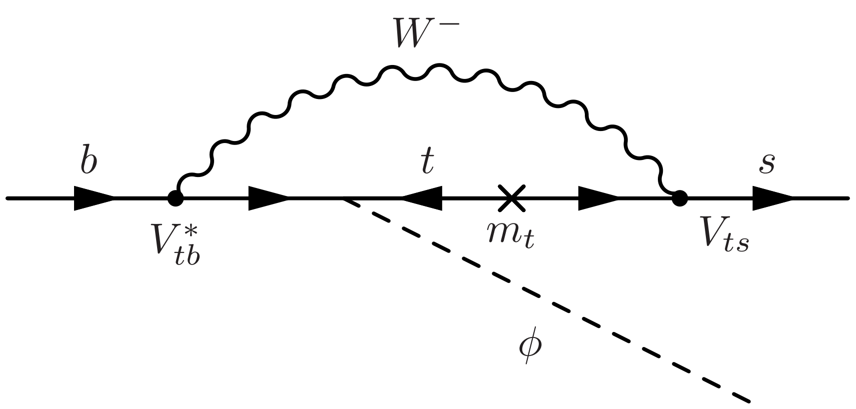
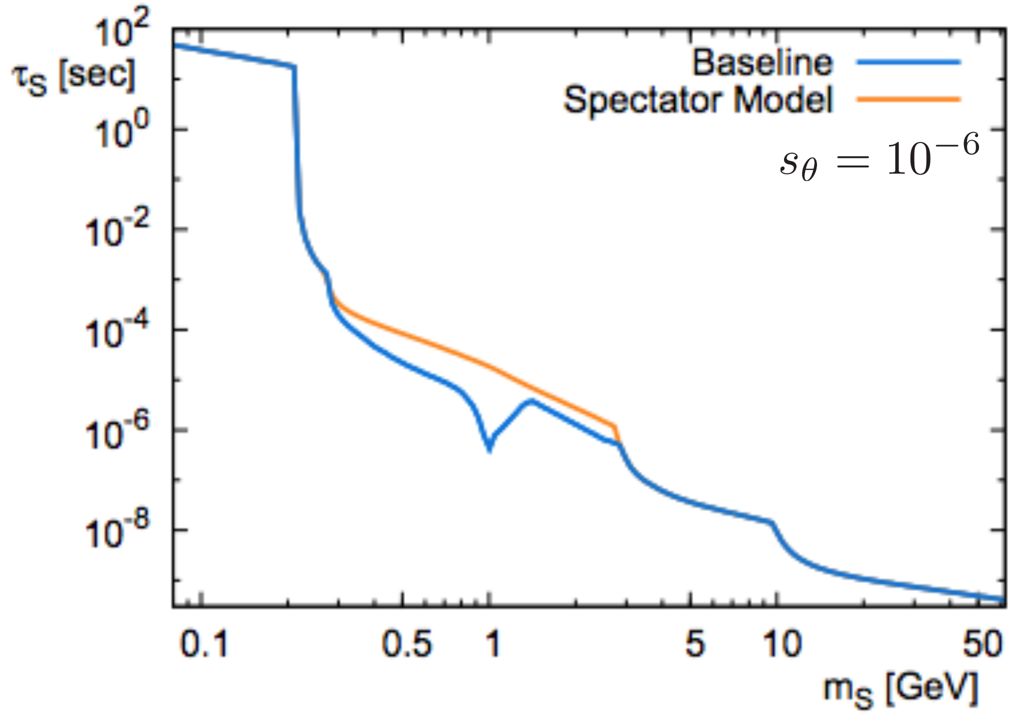


Decay



A. Fradette, M. Pospelov 1706.01920
J. F. Donoghue, et. al. , Nucl. Phys. B343, 341 (1990).

Light scalar mixing with Higgs

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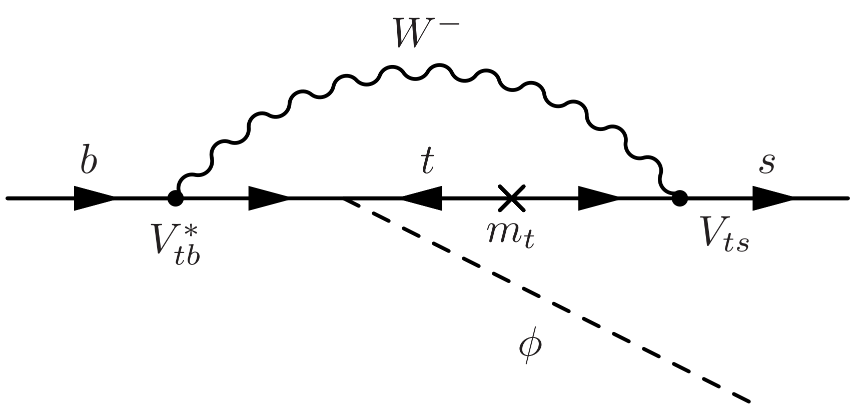


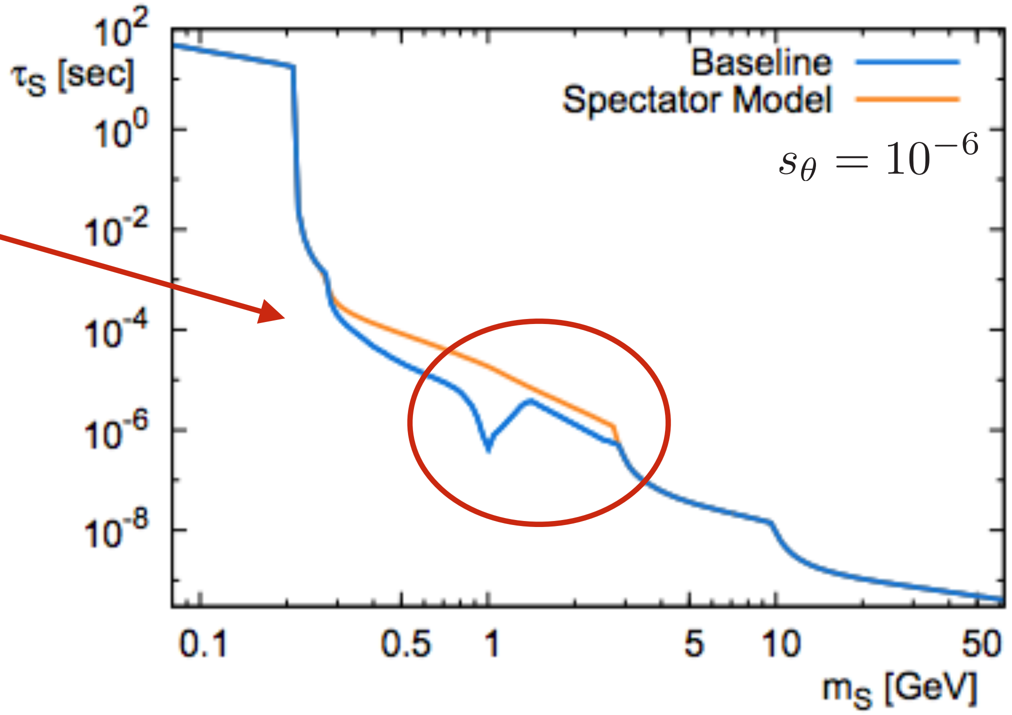
Decay

Large theory uncertainty

Different experiments make different assumptions to evaluate their reach

- LHCb, CODEX-b: "baseline" model
- SHiP: "spectator" model
- MATHUSLA: slight variation on "baseline" model

J. Evans: 1708.08503



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Characterizing the signal

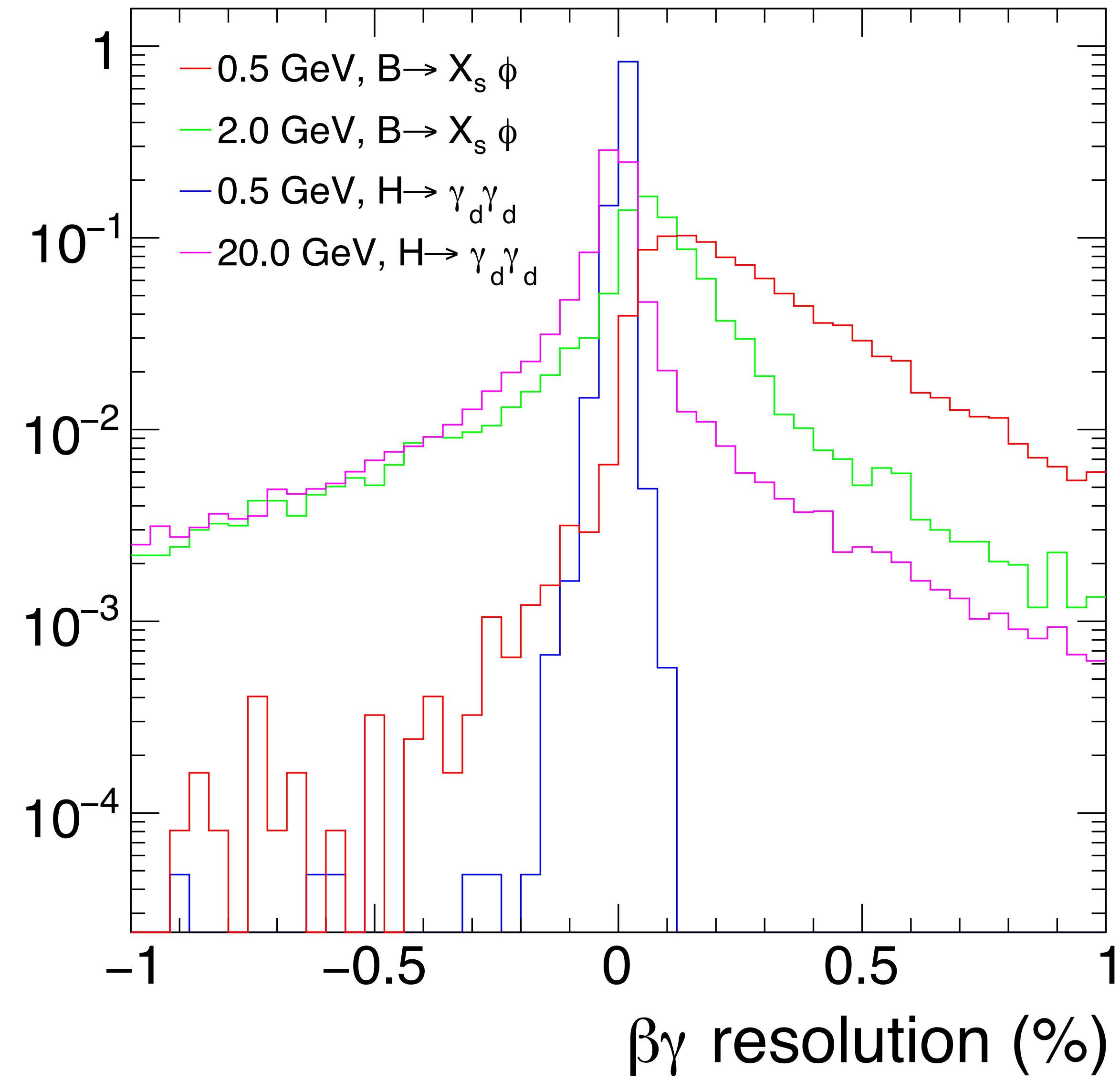
Parent boost reconstruction

Boost reconstruction

D. Curtin, M. Peskin: 1705.06327

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

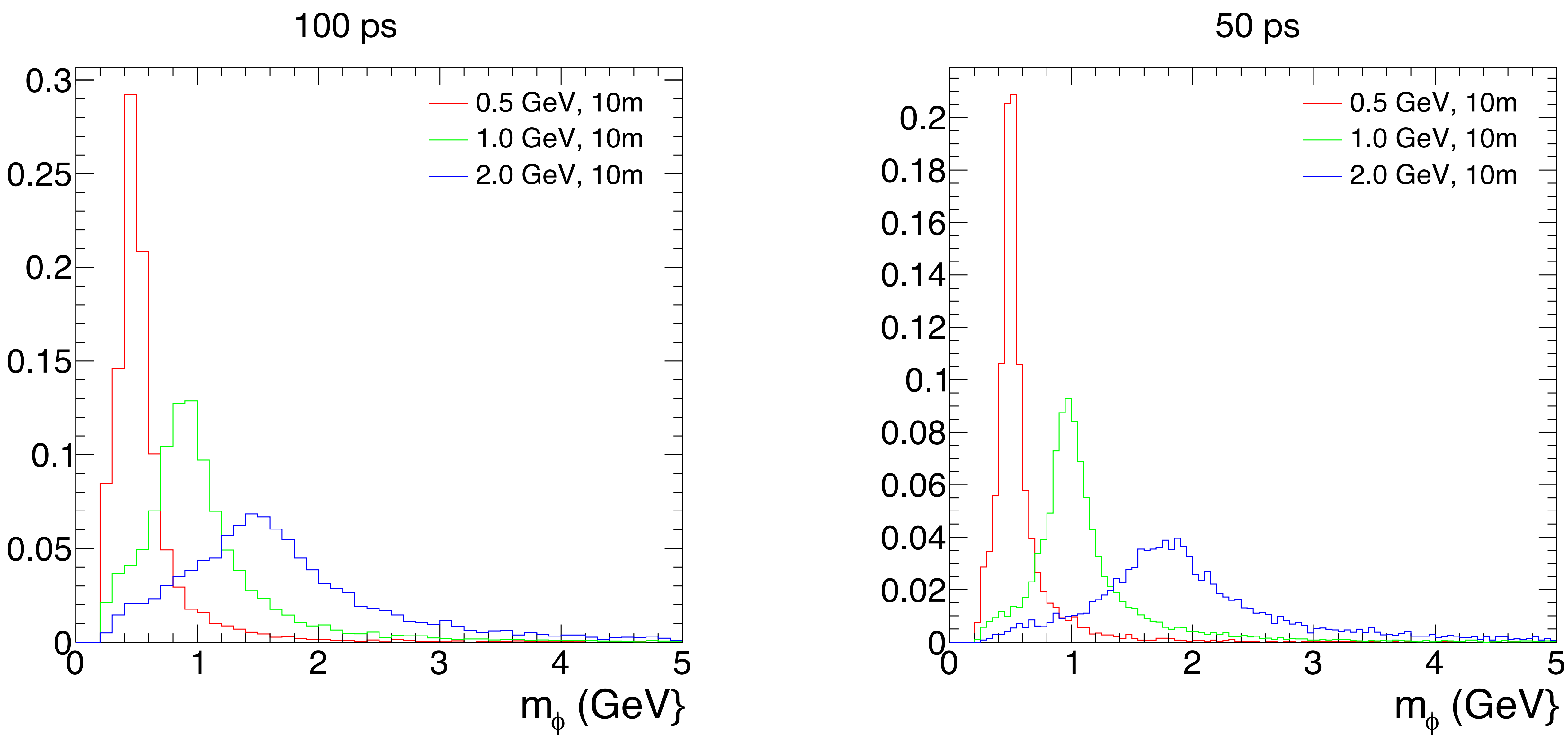
For relativistic decay products, only need spatial information



Most important parameter is distance to first measured point

Mass measurement

Include timing



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