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Vladimir Gligorov, Simon Knapen, Michele Papucci, Dean Robinson



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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

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• 1



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- 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
- box rad. shield μ veto μ veto μ veto μ Neto μ Neto

• Neutrinos are negligible

Quantitative estimates with GEANT4 in back-up slides and 1708.09395

 $B \rightarrow X_s \varphi$



(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)

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Exotic Higgs decays

 $h \rightarrow \gamma_d \gamma_d$



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

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

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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

SUPERSYMMETRY









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

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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



Reconstruction efficiency (proof of concept)

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

$c\tau$ (m)	m_arphi	$[B \rightarrow Z]$	$X_s arphi]$		$m_{\gamma_{ m d}}$	$[h \rightarrow \gamma]$	$\gamma_{ m d} \gamma_{ m d}]$	
	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
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Reconstruction efficiency (proof of concept)

Require 6 hits per track

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Require minimum momentum of 600 MeV per track

c au (m)	$m_{arphi} \ [B o X_s arphi]$			$m_{\gamma_{ m d}} \left[h ightarrow \gamma_{ m d} \gamma_{ m d} ight]$					
	0.5	1.0	2.0	0.5	1.2	5.0	10.0	20.0	
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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	_	<u>\ -</u>	_	_	_	
	lo	w boos	st		high boost				
600 MeV ci	MeV cut small opening angle, overlapping decay pr								
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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



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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



with mb crosssection, scattering probability is $\sim 10^{-3}$

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

neutrons / K_L + secondaries

prompt plus secondary from muons hitting shield



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

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neutrons / K_L + secondaries

pythia 8 + GEANT 4 simulation



- 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

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 $B \rightarrow X_s \varphi$ decays
 - Lifetime and production rate both set by mixing angle

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

Production

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

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



Production

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

Roughly ~ 10¹⁴ B-mesons with 300 fb⁻¹



Decay



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

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Production

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

Roughly ~ 10¹⁴ B-mesons with 300 fb⁻¹



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



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

J. Evans: 1708.08503

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Characterizing the signal

Parent boost reconstruction



Most important parameter is distance to first measured point

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Mass measurement

Include timing



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

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