LHCb Phase II: experiment design and the Kaon-physics reach

Kaons @ CERN, September 11th– 14th, Geneva, Switzerland

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On behalf of the LHCb collaboration

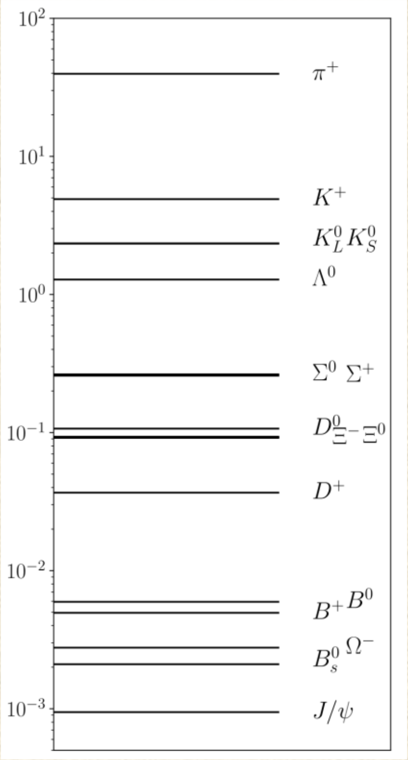
Content

- Introduction to LHCb and its reach for strange physics
- Recent strangeness measurements at LHCb
- Prospects for other strange decays at LHCb
- Summary and conclusions

Introduction to LHCb and its reach for strange physics

Introduction

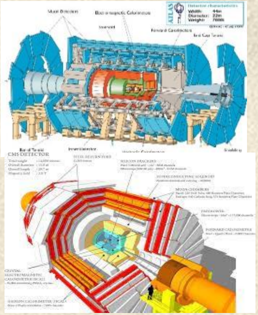
- LHCb experiment at the LHC
  - designed mostly to study **b** and **c** decays
  - trigger efficiency close to zero for **s** decays
- Very large strangeness production at the LHC ($\sigma_K^{prod} \sim \mathbf{1.2\ barn}$)
- World – best results on $K_S \to \mu^+\mu^-$(Run I + II) and $\Sigma^+ \to p\,\mu^+\mu^-$ (Run I)
- Major trigger improvements for **s** decays in Run-II (2016-18) and beyond
- <u>Two upgrade phases</u>
  - Upgrade 1 (2022 – 2030): Data taking has already started
  - Upgrade 2 (2031 – 2035): Framework TDR published (CERN-LHCC-2021-012)



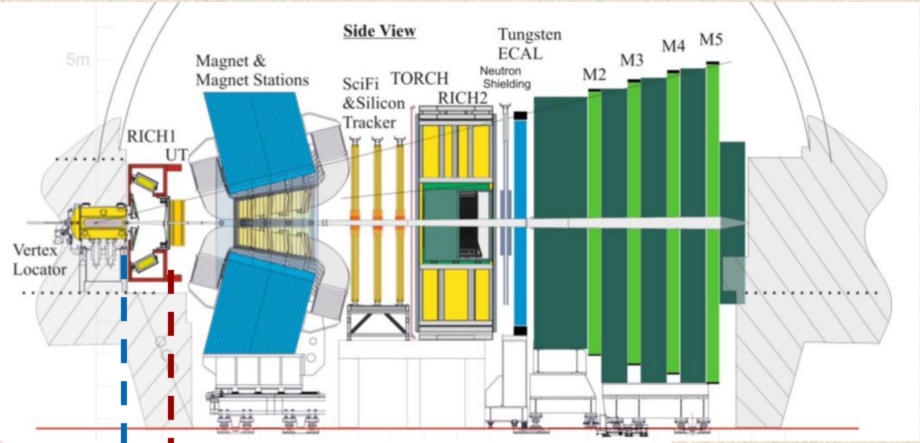
Exciting prospects for s physics at LHCb

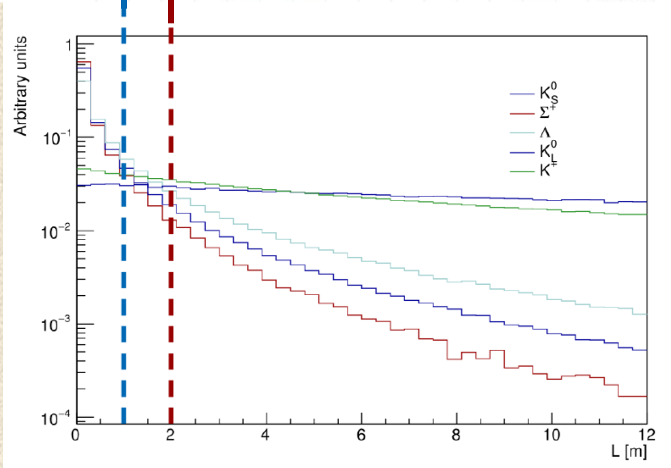
Strange physics at the LHC

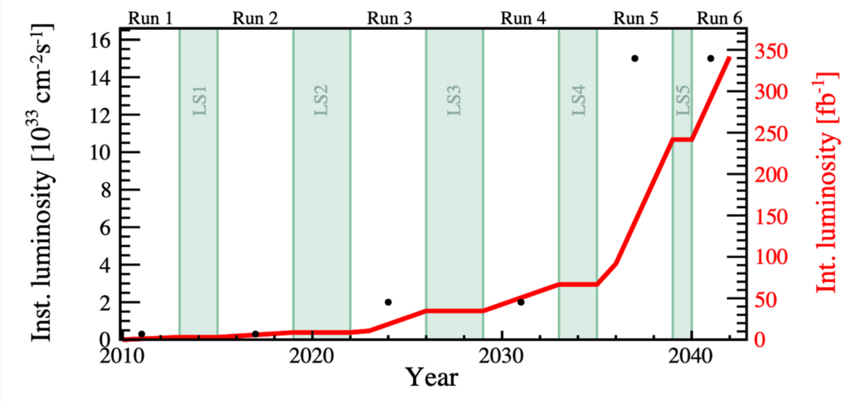
- Transverse momentum is a standard handle at the LHC to separate signal from generic pp collisions
- Doesn`t work for strange decays due to very low pT decay products
- Can be compensated by requiring large separation between the pp collision and the kaon decay point

	Typical pT
	**30 – 40 GeV**
***B* physics**	**~ 1 – 2 GeV**
***s* physics**	**0.08 GeV**

Upgraded LHCb detector







Upgrade 1 (U1)
$\mathcal{L}_{\text{peak}} = 2 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$
$\mathcal{L}_{\text{int}} = 50 \text{ fb}^{-1}$ (Run 3 & 4)

Upgrade 2 (U2)
$\mathcal{L}_{\text{peak}} = 1.5 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$
$\mathcal{L}_{\text{int}} = 300 \text{ fb}^{-1}$ (Run 5 & 6)

- Fully software trigger already available with U1 (Run 3)
- U2: same structure, major refurbishment of all LHCb subdetectors
- U2: maintain the same performance as in Run 3 at x7 more pileup
- Key ingredients: Granularity, Fast timing, Radiation hardness

Trigger system

L0
(Hardware)

Main bottleneck
for K physics:
pT > O(GeV)
irreversible

Run I + II

HLT1
(Software)

Not designed
for K physics
but flexible

HLT2
(Software)

Dedicated K
triggers
implemented in
Run II

Upgrade(s)

HLT
(Software)

$\varepsilon_{trig}(\text{Run I}) \sim 1-2\%$

$\varepsilon_{trig}(\text{Run II}) \sim 18\% \text{ (dimuons)}$

- improved HLT
- Maximum allowed by L0 ~30%

LHCb upgrade(s):
$\varepsilon_{trig}(\mathbf{2022+}) \sim \mathbf{100\%}$

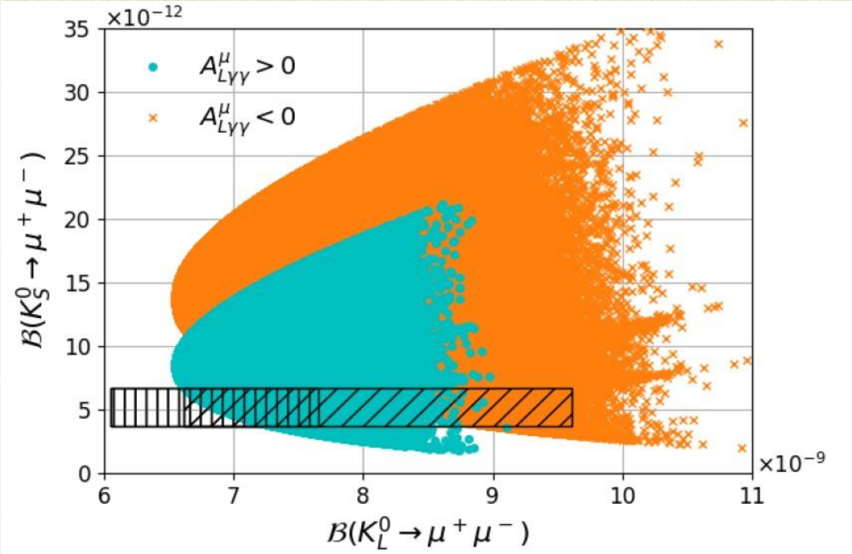
Recent strangeness measurements at LHCb

[PRL 125, 231801 (2020)], [PRL 120, 221803 (2018)], [arXiv:2212.04977v4]

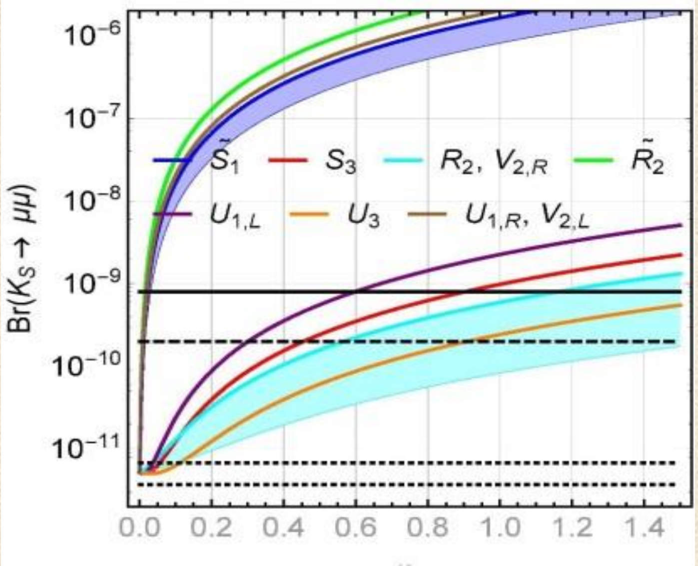
$K_S^0 \to \mu^+\mu^-$: motivation

JHEP 05 (2018) 024 , JHEP 0401 (2004) 009, NPB 366 (1991) 189

- SM prediction: $\text{BR}\left(K_S^0 \to \mu^+\mu^-\right)_{SM} = (5.18 \pm 1.50_{\text{LD}} \pm 0.02_{\text{SD}}) \times 10^{-12}$
- Sensitive to different physics than $K_L^0 \to \mu^+\mu^-$: NP contributions can be an order of magnitude higher than the SM value and can even saturate [JHEP03(2022)048] the current limits



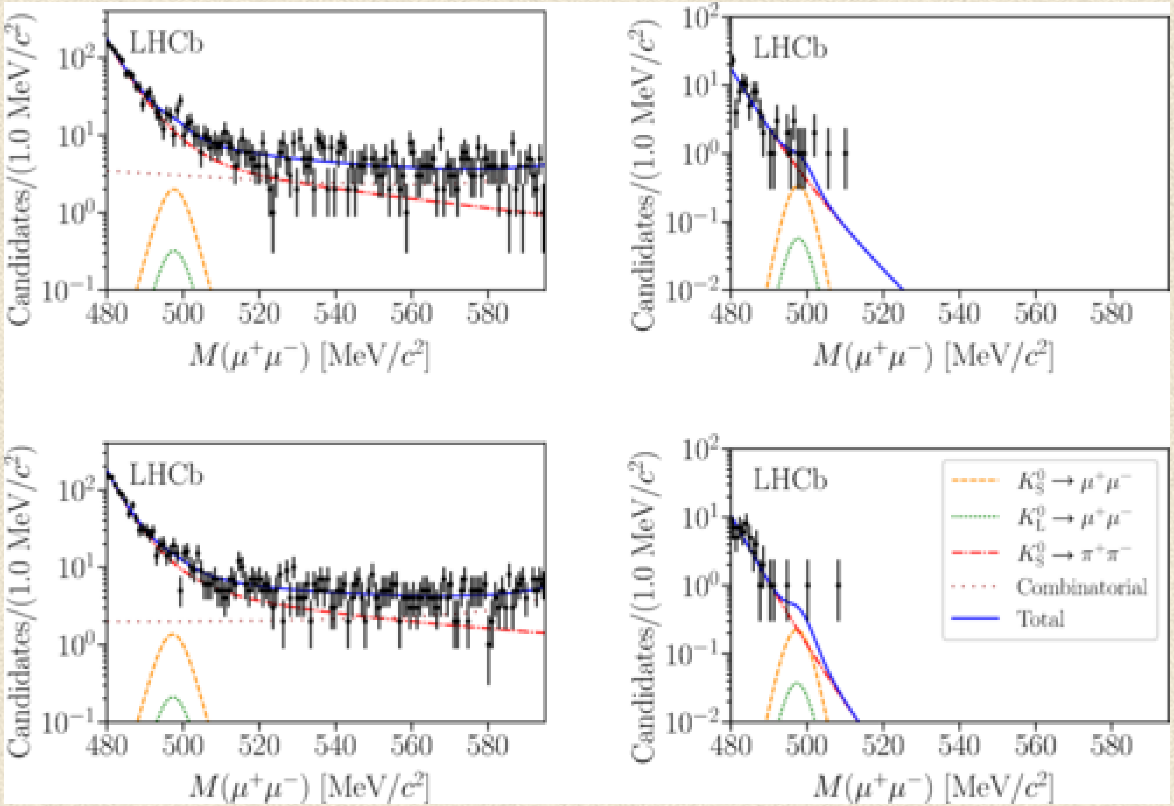
Example of a SUSY scenario JHEP 05 (2018) 024



Leptoquark scenarios from JHEP 02 (2018) 101

$K_S^0 \to \mu^+\mu^-$ latest results

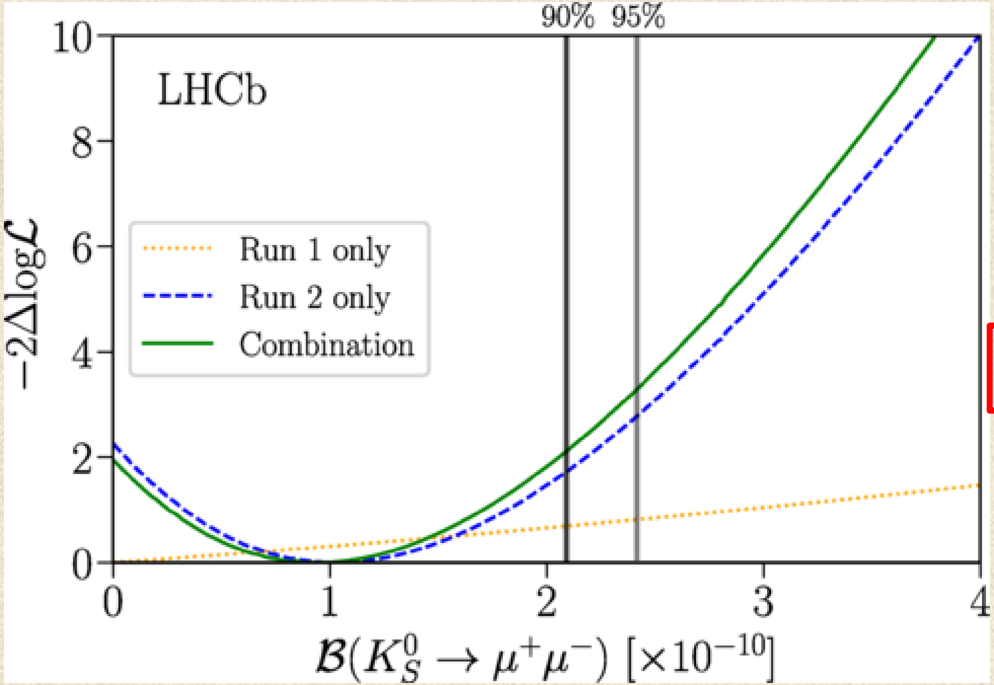
LHCb-PAPER-2019-038
arXiv: 2001.10354
PRL 125, 231801 (2020)



- Full Run I + II dataset (9 fb^{-1})
- No evidence of signal (1.4 σ)
- Search performed in bins of the BDT output for different trigger categories

$K_S^0 \to \mu^+\mu^-$ latest results

LHCb-PAPER-2019-038
arXiv: 2001.10354
PRL 125, 231801 (2020)



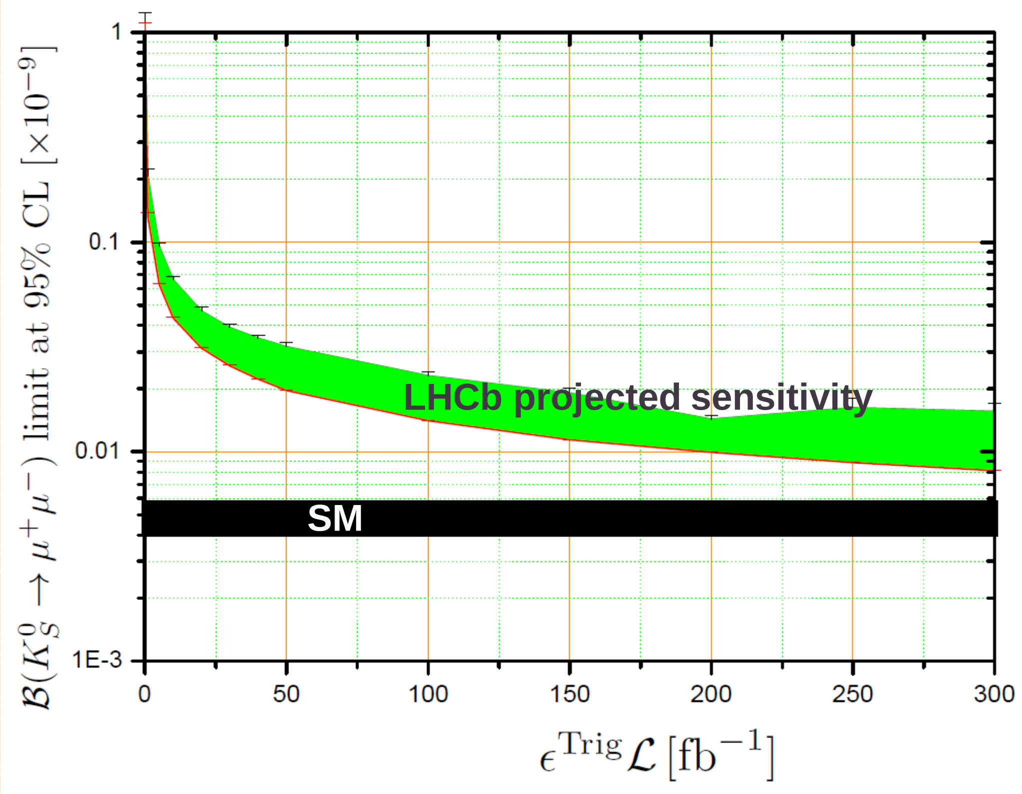
- Full Run I + II dataset (9 fb^{-1}) analyzed
- No evidence of signal (1.4 σ)

$BR(K_S^0 \to \mu^+\mu^-) < 2.1 \times 10^{-10}$ @ 90% CL

At 1σ: $BR(K_S \to \mu^+\mu^-) = 0.9^{+0.7}_{-0.6} \times 10^{-10}$

$K_S^0 \to \mu^+\mu^-$ prospects

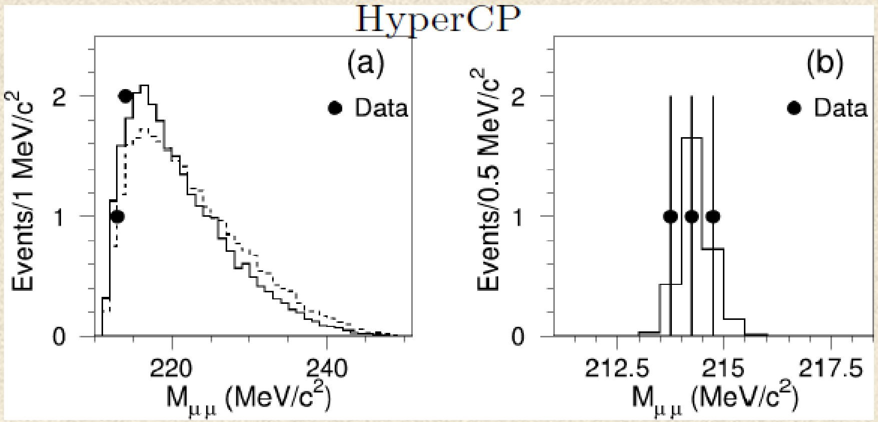
arXiv: 1808.03477
JHEP 05 (2019) 048

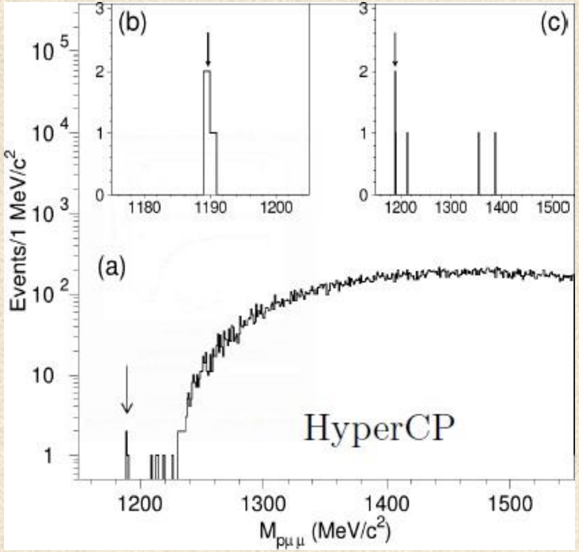


Expected to reach sensitivity close to the SM prediction with the Upgrade II

The $\Sigma^+ \to p\mu^+\mu^-$ decay: the HyperCP evidence

- The HyperCP collaboration (E871) at Fermilab found evidence for the $\Sigma^+ \to p\mu^+\mu^-$ decay
  - $BR(\Sigma^+ \to p\mu^+\mu^-) = \left(8.6^{+6.6}_{-5.4} \pm 5.5\right) \times 10^{-8}$ PRL 94 021801 (2005)
- Consistent with the SM expectation
  - $1.6 < BR(\Sigma^+ \to p\mu^+\mu^-)_{SM}\left[\times 10^{-8}\right] < 9$ PRD 72 074003 (2005)
- All three observed events had the same dimuon mass (214 MeV)
- Existence of a new neutral particle at that mass suggested

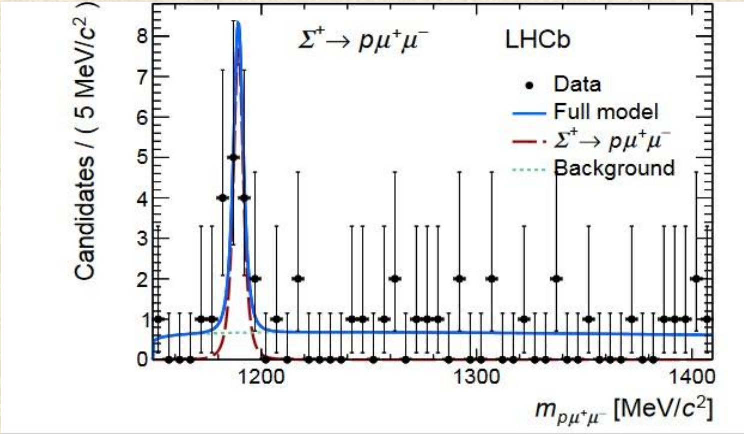


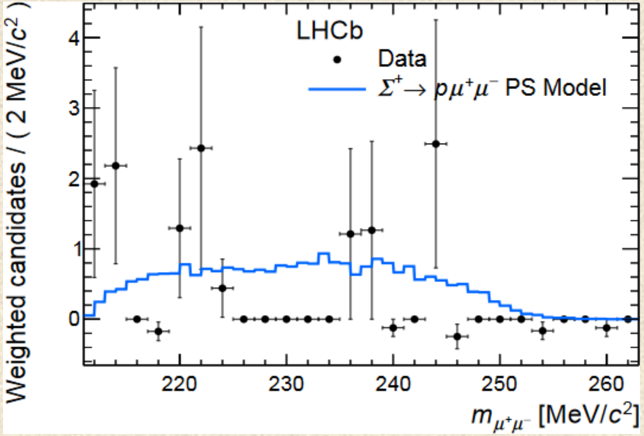


$\Sigma^+ \to p\mu^+\mu^-$ at LHCb

LHCb-PAPER-2017-049
arXiv:1712.08606
PRL 120, 221803 (2018)

- **4.1σ** evidence using Run I data ($3fb^{-1}$): $\boldsymbol{BR(\Sigma^+ \to p\mu^+\mu^-) = \left(2.2^{+1.8}_{-1.3}\right) \times 10^{-8}}$
- No evidence of resonant intermediate dilepton state
- Run II data: ~ 150 events expected allowing us to measure A_{FB} (analysis ongoing)
- Upgrade(s): differential decay rate measurement

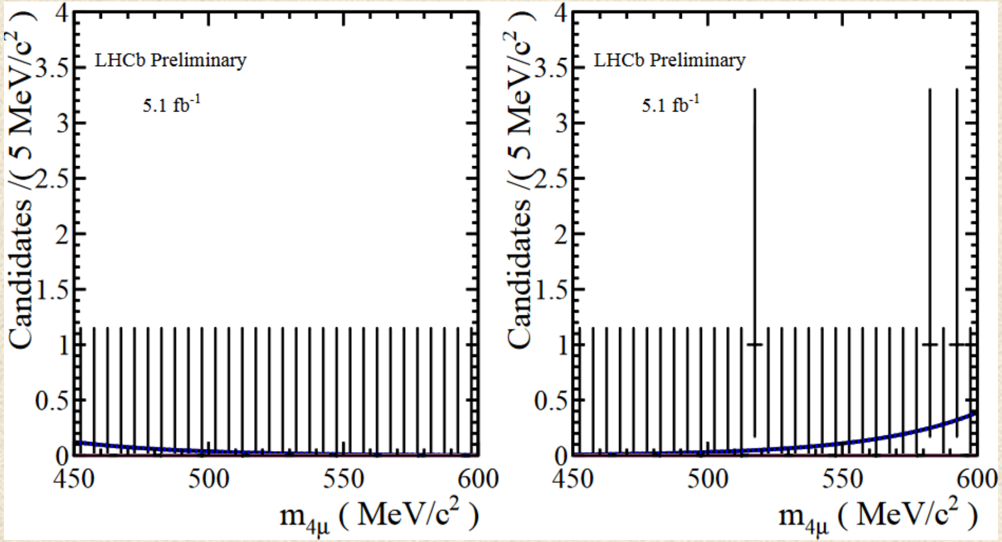




10 years ago this channel was considered impossible at LHCb. Now we are considering amplitude analysis

$K^0 \to \mu^+\mu^-\mu^+\mu^-$ at LHCb

- Search for $K^0_{S(L)} \to \mu\mu\mu\mu$ decays, heavily suppressed in the SM: $10^{-13}(K^0_L), 10^{-14}(K^0_S)$
- No events found in signal region (Run I + II): world's best (first) upper limits on these decays

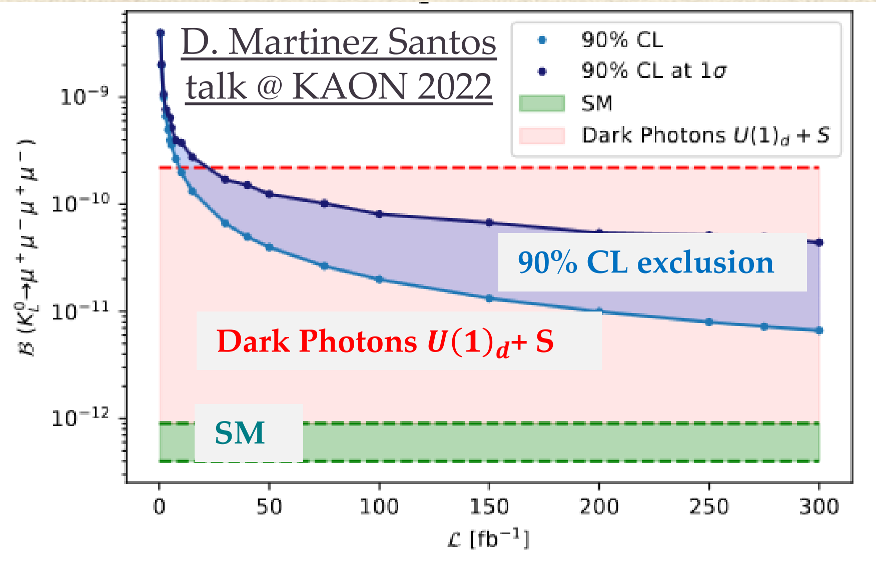


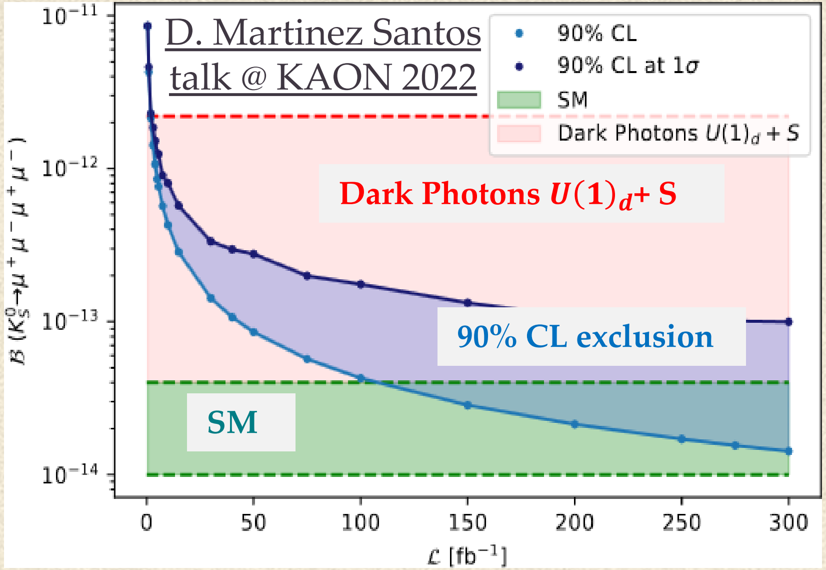
$$\boldsymbol{BR(K^0_S \to \mu^+\mu^-\mu^+\mu^-) < 5.1 \times 10^{-12}}$$
$$\boldsymbol{BR(K^0_L \to \mu^+\mu^-\mu^+\mu^-) < 2.3 \times 10^{-9}}$$

PRD 108 (2023) L031102

$K^0 \to \mu^+\mu^-\mu^+\mu^-$ at LHCb: prospects

- Prospects for the next LHCb Upgrade(s) are excellent
- Scan most of the allowed range in BSM models (e.g. dark photons)
- Get close to the SM sensitivity if no signal is found





Prospects for other strange decays at LHCb

[JHEP 05 (2019) 048], [LHCb-PUB-2016-017], [LHCb-PUB-2016-016], [PRD 99 (2019) 055017], [arXiv:2201.07805]

LHCb sensitivity to strange processes

Channel	$\mathcal{R}$	ϵ_L	ϵ_D	$\sigma_L(\text{MeV}/c^2)$	$\sigma_D(\text{MeV}/c^2)$
$K_S^0 \to \mu^+\mu^-$	1	1.0 (1.0)	1.8 (1.8)	~ 3.0	~ 8.0
$K_S^0 \to \pi^+\pi^-$	1	1.1 (0.30)	1.9 (0.91)	~ 2.5	~ 7.0
$K_S^0 \to \pi^0\mu^+\mu^-$	1	0.93 (0.93)	1.5 (1.5)	~ 35	~ 45
$K_S^0 \to \gamma\mu^+\mu^-$	1	0.85 (0.85)	1.4 (1.4)	~ 60	~ 60
$K_S^0 \to \mu^+\mu^-\mu^+\mu^-$	1	0.37 (0.37)	1.1 (1.1)	~ 1.0	~ 6.0
$K_L^0 \to \mu^+\mu^-$	~ 1	2.7 (2.7) $\times 10^{-3}$	0.014 (0.014)	~ 3.0	~ 7.0
$K^+ \to \pi^+\pi^+\pi^-$	~ 2	9.0 (0.75) $\times 10^{-3}$	41 (8.6) $\times 10^{-3}$	~ 1.0	~ 4.0
$K^+ \to \pi^+\mu^+\mu^-$	~ 2	6.3 (2.3) $\times 10^{-3}$	0.030 (0.014)	~ 1.5	~ 4.5
$\Sigma^+ \to p\mu^+\mu^-$	~ 0.13	0.28 (0.28)	0.64 (0.64)	~ 1.0	~ 3.0
$\Lambda \to p\pi^-$	~ 0.45	0.41 (0.075)	1.3 (0.39)	~ 1.5	~ 5.0
$\Lambda \to p\mu^-\bar{\nu}_\mu$	~ 0.45	0.32 (0.31)	0.88 (0.86)	–	–
$\Xi^- \to \Lambda\mu^-\bar{\nu}_\mu$	~ 0.04	39 (5.7) $\times 10^{-3}$	0.27 (0.09)	–	–
$\Xi^- \to \Sigma^0\mu^-\bar{\nu}_\mu$	~ 0.03	24 (4.9) $\times 10^{-3}$	0.21 (0.068)	–	–
$\Xi^- \to p\pi^-\pi^-$	~ 0.03	0.41(0.05)	0.94 (0.20)	~ 3.0	~ 9.0
$\Xi^0 \to p\pi^-$	~ 0.03	1.0 (0.48)	2.0 (1.3)	~ 5.0	~ 10
$\Omega^- \to \Lambda\pi^-$	~ 0.001	95 (6.7) $\times 10^{-3}$	0.32 (0.10)	~ 7.0	~ 20

Channel	$\mathcal{R}$	ϵ_L	ϵ_D	$\sigma_L(\text{MeV}/c^2)$	$\sigma_D(\text{MeV}/c^2)$
$K_S^0 \to \pi^+\pi^-e^+e^-$	1	1.0 (0.18)	2.83 (1.1)	~ 2.0	~ 10
$K_S^0 \to \mu^+\mu^-e^+e^-$	1	1.18 (0.48)	2.93 (1.4)	~ 2.0	~ 11
$K^+ \to \pi^+e^+e^-$	~ 2	0.04 (0.01)	0.17 (0.06)	~ 3.0	~ 13
$\Sigma^+ \to pe^+e^-$	~ 0.13	1.76 (0.56)	3.2 (1.3)	~ 3.5	~ 11
$\Lambda \to p\pi^-e^+e^-$	~ 0.45	$< 2.2 \times 10^{-4}$	~ 17 (< 2.2) $\times 10^{-4}$	–	–

Channel	$\mathcal{R}$	ϵ_L	ϵ_D	$\sigma_L(\text{MeV}/c^2)$	$\sigma_D(\text{MeV}/c^2)$
$K_S^0 \to \mu^+e^-$	1	1.0 (0.84)	1.5 (1.3)	~ 3.0	~ 8.0
$K_L^0 \to \mu^+e^-$	1	3.1 (2.6) $\times 10^{-3}$	13 (11) $\times 10^{-3}$	~ 3.0	~ 7.0
$K^+ \to \pi^+\mu^+e^-$	~ 2	3.1 (1.1) $\times 10^{-3}$	16 (8.5)$\times 10^{-3}$	~ 2.0	~ 8.0

$\mathcal{R}$ – ratio of production

ϵ – ratio of efficiencies

- Approximate simulations (validated with published ones) to get sensitivities
- Many channels to be probed
- In this talk I will focus on some of the more interesting channels where sensitivity studies are available

$K_S^0 \to \pi^0\mu^+\mu^-$ at LHCb: Sensitive study

$$BR(K_L^0 \to \pi^0 l^+ l^-)_{SM} = \left(C_{dir}^l \pm C_{int}^l \times |a_S| + C_{mix}^l \times |a_S|^2 + C_{\gamma\gamma}^l\right) \times 10^{-12}$$

Sensitive to BSM

VMD model assumption

NA48 results

$a_S = -1.6^{+2.1}_{-1.8}$, $b_S = +10.8^{+5.4}_{-7.7}$ PLB 576 (2003) 43-54

$a_S = +1.9^{+1.6}_{-2.4}$, $b_S = -11.3^{+8.8}_{-4.5}$ PLB 599 (2004) 197-201

$$BR\left(K_L^0 \to \pi^0\mu^+\mu^-\right)_{SM} = \{1.4 \pm 0.3, 1.0 \pm 0.2\} \times 10^{-11}$$

JHEP 08 (2006) 088

Theory

$|a_S| = 1.3 \pm 3.2$

$|b_S| = 18.0 \pm 11$

PLB 797 (2019) 134891

- $C_{dir}^e = (4.62 \pm 0.24) \times \left(w_{7V}^2 + w_{7A}^2\right)$
- $C_{int}^e = (11.3 \pm 0.3) \times w_{7V}$
- $C_{mix}^e = 14.5 \pm 0.5$
- $C_{mix}^e \approx 0$

- $C_{dir}^\mu = (1.09 \pm 0.05) \times \left(w_{7V}^2 + 2.32 \times w_{7A}^2\right)$
- $C_{int}^\mu = (2.63 \pm 0.06) \times w_{7V}$
- $C_{mix}^\mu = 3.36 \pm 0.20$
- $C_{mix}^\mu \approx 5.2 \pm 1.6$

- $w_{7A,7V} = \frac{\mathrm{Im}(\lambda_t \times y_{7A,7V})}{\mathrm{Im}\lambda_t}$, $y_{7V}(\mu \approx 1\mathrm{GeV}) = 0.73 \pm 0.04$, $y_{7A}(M_W) = -0.68 \pm 0.03$
- $\mathrm{Im}\lambda_t = (1.407 \pm 0.098) \times 10^{-4}$

$K_S^0 \to \pi^0\mu^+\mu^-$ at LHCb: Sensitivity study

$$BR(K_L^0 \to \pi^0 l^+ l^-)_{SM} = \left(C^l_{\rm dir} \pm C^l_{\rm int} \times |a_S| + C^l_{\rm mix} \times |a_S|^2 + C^l_{\gamma\gamma}\right) \times 10^{-12}$$

Sensitive to BSM

VMD model assumption

$$\mathrm{BR}\left(K_L^0 \to \pi^0\mu^+\mu^-\right)_{SM} = \{1.4 \pm 0.3, 1.0 \pm 0.2\} \times 10^{-11}$$

JHEP 08 (2006) 088

NA48 results

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Theory

$|a_S| = 1.3 \pm 3.2$

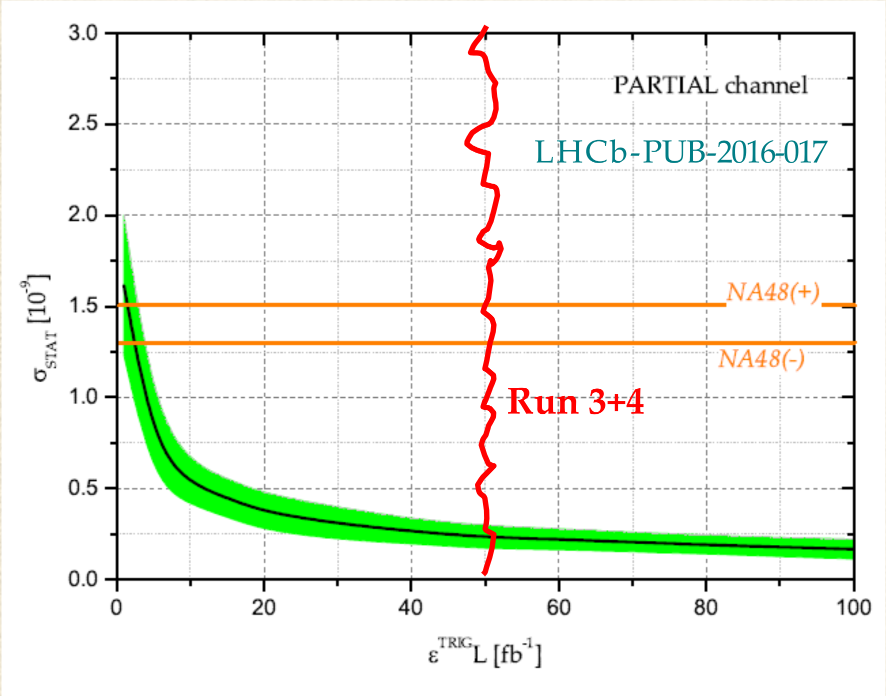
$|b_S| = 18.0 \pm 11$ PLB 797 (2019) 134891

- Significant $|a_S|$ uncertainty that makes BSM interpretations of $K_L^0 \to \pi^0\mu^+\mu^-$ difficult
- Comes from the experimental uncertainty on $\mathrm{BR}\left(K_S^0 \to \pi^0 l^+ l^-\right)$
  - $\mathrm{BR}\left(K_S^0 \to \pi^0\mu^+\mu^-\right)_{NA48} = \left(2.9^{+1.5}_{-1.2}\right) \times 10^{-9}$ PLB 599 (2004) 197-201
  - $\mathrm{BR}\left(K_S^0 \to \pi^0 e^+ e^-\right)_{NA48} = \left(3.0^{+1.5}_{-1.2}\right) \times 10^{-9}$ PLB 576 (2003) 43-54

Improved measurement of $K_S \to \pi^0\mu^+\mu^-$ will translate into improved BSM constraints from $K_L \to \pi^0\mu^+\mu^-$

$K_S^0 \to \pi^0\mu^+\mu^-$ at LHCb: Sensitivity study

- Much more background but **~ 1000 times more signal**



Phase II Upgrade → 300 fb^{-1}

NA48 results

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Theory

$|a_S| = 1.3 \pm 3.2$

$|b_S| = 18.0 \pm 11$ PLB 797 (2019) 134891

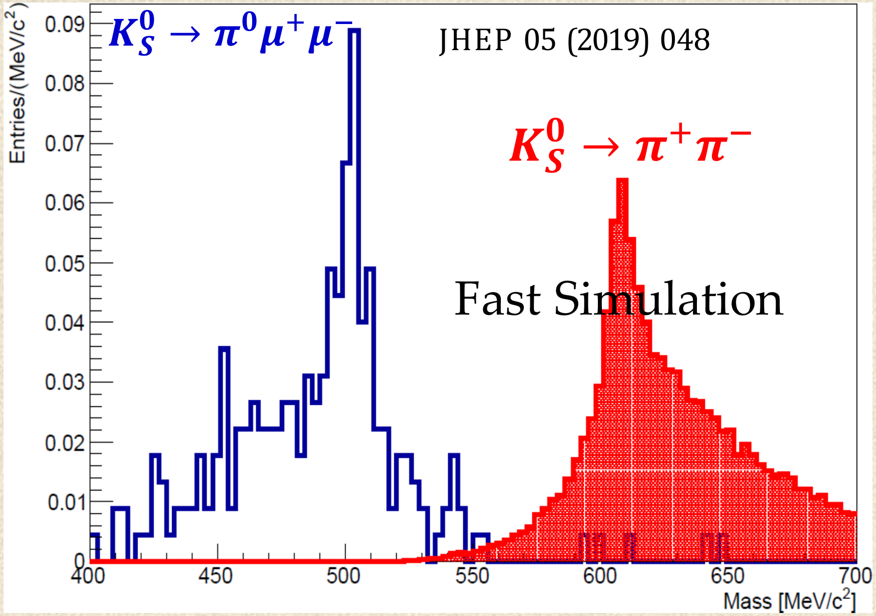
Projected statistical uncertainties on a_S under various analysis conditions

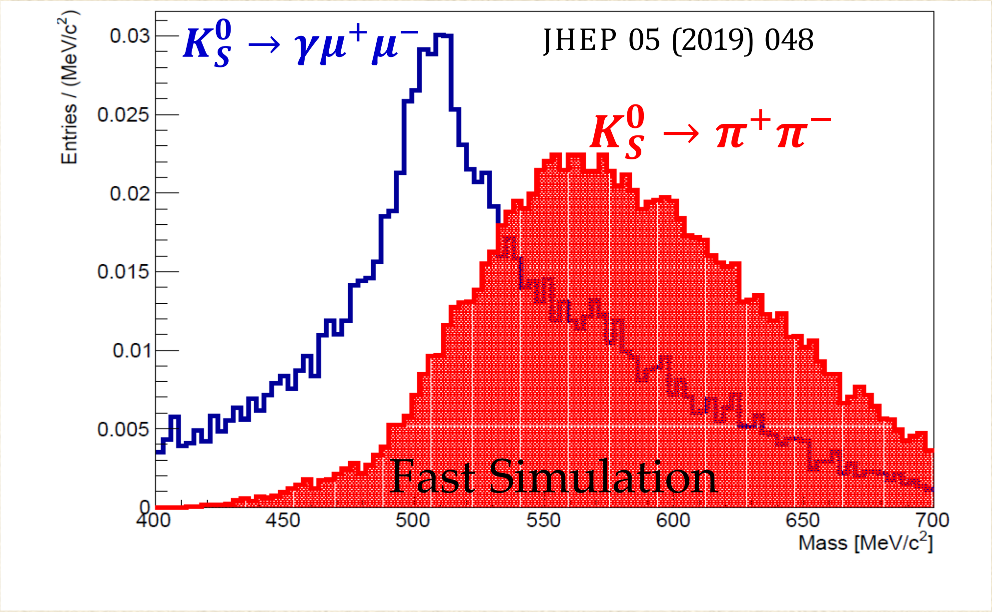
Configuration	Phase I	Phase II
BR & q^2 fit	0.25	0.10
BR & q^2 fit with NA48 constraint	0.19	0.10
BR & q^2 fit fixing b_S	0.06	0.024
a_S measurement from BR alone	0.06	0.024

JHEP 05 (2019) 048

What about $K_S^0 \to \gamma\mu^+\mu^-, K_S^0 \to X\mu^+\mu^-, K_S^0 \to X\pi\mu$?

- $K_S^0 \to \pi^0\mu^+\mu^-$analysis can be extended to other neutrals (e.g. $K_S^0 \to \gamma\mu^+\mu^-$)
- Harder to separate from $K_S^0 \to \pi^+\pi^-$ ($m_\gamma < m_{\pi^0}$): a cut on the energy could be used





$K^0 \rightarrow l^+l^+l^-l^-$

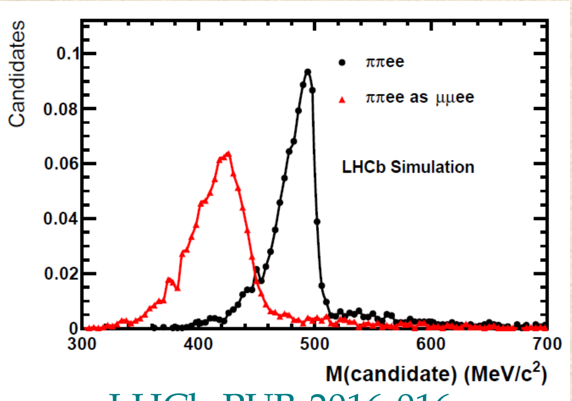
- $K^0 \rightarrow l^+l^+l^-l^-$
  - SD component sensitive to New Physics
  - dominated by LD uncertainties
- Interference between $\mathcal{A}(K_S^0 \rightarrow l^+l^+l^-l^-)$ and $\mathcal{A}(K_L^0 \rightarrow l^+l^+l^-l^-)$ would give a measurement of the sign of $\mathcal{A}(K_L^0 \rightarrow \gamma\gamma)$ [EPJC 73 (2013) 2678, JHEP 0401 (2004) 009]
- $K_L^0 \rightarrow l^+l^+l^-l^-$ studied by other experiments but no experimental constraints on the K_S^0 modes (except for the recent LHCb result on $K_S^0 \rightarrow \mu^+\mu^+\mu^-\mu^-$)

$$\boldsymbol{BR(K_S^0 \rightarrow e^+e^-e^+e^-) \sim 10^{-10}}$$
$$\boldsymbol{BR(K_S^0 \rightarrow \mu^+\mu^-e^+e^-) \sim 10^{-11}}$$
$$\boldsymbol{BR(K_S^0 \rightarrow \mu^+\mu^-\mu^+\mu^-) \sim 10^{-14}}$$

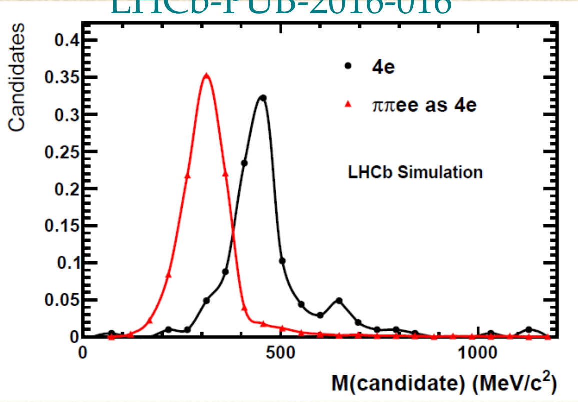
Sensitive to New Physics at the same order as the SM contribution

$K_S^0 \to \pi^+\pi^-e^+e^-$

- $K_S^0 \to \pi^+\pi^+e^+e^-$ can be used as a proxy to study the sensitivity to $K_S^0 \to l^+l^+l^-l^-$ decays
- Sensitivity study using LHCb simulations
- $BR\left(K_S^0 \to \pi^+\pi^+e^+e^-\right) = (4.79 \pm 0.15) \times 10^{-5}$
- $K_S^0 \to \pi^+\pi^+e^+e^-$ sensitivity with Run 1 conditions:
  - 120^{+280}_{-100} expected events per fb^{-1} of 8 TeV data
  - $\sim 3 \times 10^3$ expected background events (no multivariate selection)
- In Run 3 with ~100 % trigger efficiency: 5×10^4 events per fb^{-1}



LHCb-PUB-2016-016



- Similar efficiencies expected for the $K_S^0 \to l^+l^+l^-l^-$ rare channels
- Single Event Sensitivities of $\sim 9.6 \times 10^{-10}$ per fb^{-1} of collected data in Upgrade conditions

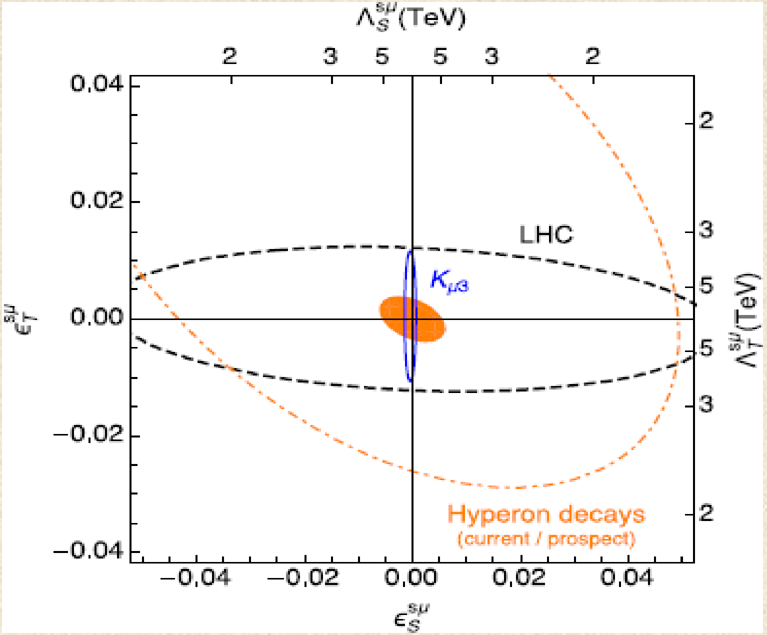
Semileptonic Hyperon Decays (SHD)

$$R_{B_1 B_2} = \frac{\Gamma(B_1 \to B_2\, \mu^- \,\bar{\nu}_\mu)}{\Gamma(B_1 \to B_2\, e^- \,\bar{\nu}_e)}$$

- Many muonic modes have still poor precision (15%-100%)
  - **Pro:** High BR(~10^{-4}) – huge yields at LHCb

- Sensitivity to helicity suppressed contributions $\epsilon_S^{S\mu}$ and $\epsilon_T^{S\mu}$

$$R_{B_1 B_2}^{\mathrm{NP}} \simeq \frac{\left(\epsilon_S^{s\mu}\,\frac{f_S(0)}{f_1(0)} + 12\,\epsilon_T^{s\mu}\,\frac{g_1(0)}{f_1(0)}\,\frac{f_T(0)}{f_1(0)}\right)}{(1-\frac{3}{2}\,\delta)\left(1+3\,\frac{g_1(0)^2}{f_1(0)^2}\right)}\,\Pi(\Delta, m_\mu)$$



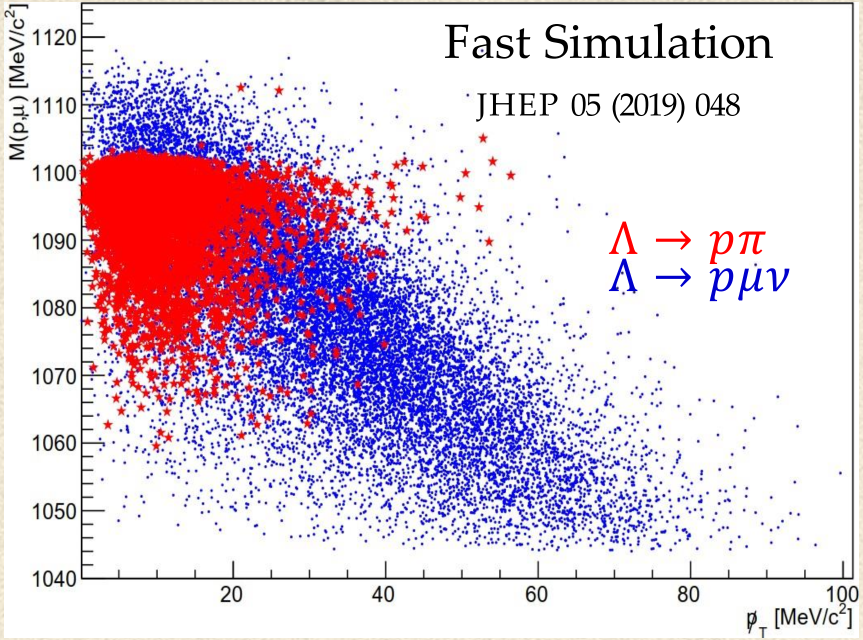
(extrapolations from 1412.8484)

Rare'N'Strange Workshop, 2017

Semileptonic Hyperon Decays (SHD)

$$R_{B_1 B_2} = \frac{\Gamma(B_1 \to B_2\, \mu^- \,\bar{\nu}_\mu)}{\Gamma(B_1 \to B_2\, e^- \,\bar{\nu}_e)}$$

- Many muonic modes have still poor precision (15%-100%)
  - **Pro:** High BR(~10^{-4}) – huge yields at LHCb
  - Con: Challenging peaking backgrounds

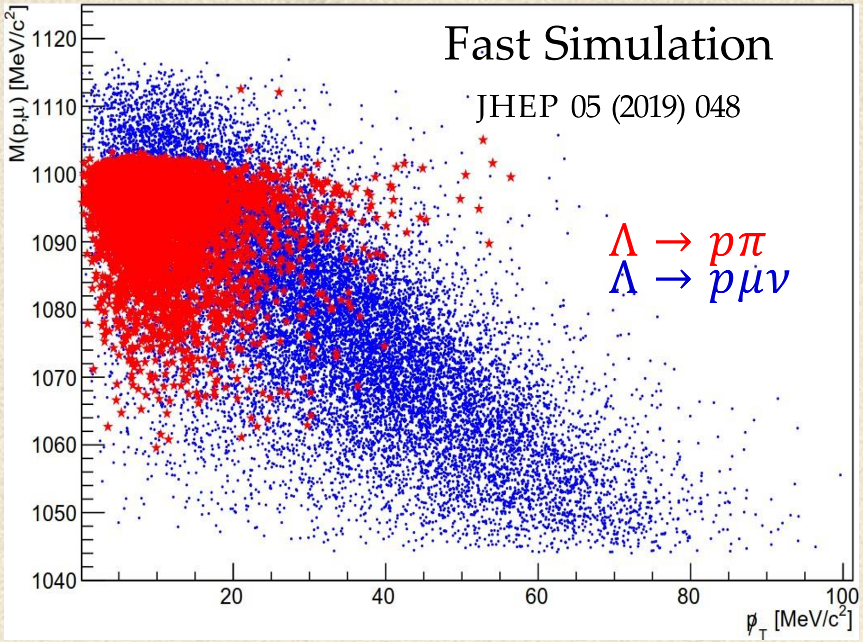


For each B1 → B2 μν there is always a B1 → B2 π (misid rate O(1%))

Semileptonic Hyperon Decays (SHD)

Λ DECAY MODES

	Mode		Fraction (Γ_i/Γ)	Confidence level
Γ_1	$p\pi^-$		(64.1 ± 0.5) %	
Γ_2	$n\pi^0$		(35.9 ± 0.5) %	
Γ_3	$n\gamma$		$(8.3 \pm 0.7) \times 10^{-4}$	
Γ_4	$p\pi^-\gamma$	[a]	$(8.5 \pm 1.4) \times 10^{-4}$	
Γ_5	$pe^-\overline{\nu}_e$		$(8.34 \pm 0.14) \times 10^{-4}$	
Γ_6	$p\mu^-\overline{\nu}_\mu$		$(1.51 \pm 0.19) \times 10^{-4}$	



- Most recent BES III result
  [PRL 127, 121802 (2021)]
  - $\mathcal{B}(\Lambda \to p\mu^-\bar{\nu}_\mu) = (1.48 \pm 0.21) \times 10^{-4}$
- LHCb measurement of $\mathcal{B}(\Lambda \to p\mu^-\nu_\mu)$ with Run 2 data ongoing
  - Improvements of at least factor 2 expected
  - Precision limited by systematic uncertainty

Lepton Flavour Violation

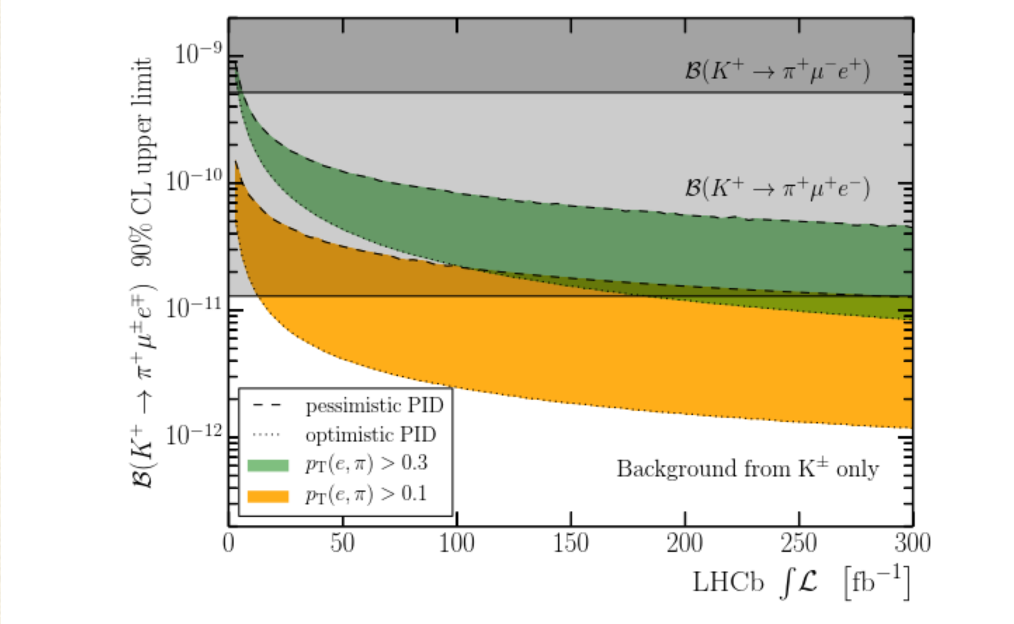
- Lepton Flavour Violation is forbidden in the Standard Model
- Allowed in various BSM scenarios predicting non-zero $K \to e\mu$ rates [PRD 99 (2019) 055017]
  - Measurement of both K_L and K_S modes can be used to discriminate between LFV models

- Present status
  - $K_L \to e\mu < 4.7 \times 10^{-12}$ at BNL [PRL 81 (1998) 5734-5737]
  - $K_S \to e\mu$ – no limit exist so far

- LHCb can do $K_S \to e\mu$

Lepton Flavour Violation

- Lepton Flavour Violation is forbidden in the Standard Model
- Allowed in various BSM scenarios predicting non-zero $K^+ \to \pi\mu e$ rates [PRD 99 (2019) 055017]



- Present status
  - $K^+ \to \pi^+\mu^-e^+ < 6.6 \times 10^{-11}$
  - $K^+ \to \pi^-\mu^+e^+ < 4.2 \times 10^{-11}$

PRL 127 (2021) 131802

- LHCb can do $K^+ \to \pi^+\mu^-e^+$
  - Maybe $K^+ \to \pi^+\mu^+e^-$

Same order of magnitude sensitivity as NA62/HIKE using optimistic PID projections

Others New Physics searches with hyperons

- Searches for NP using hyperons [arXiv:2201.07805]
- $\Xi^0 \to \pi^+\pi^- X$
  - Reach: few $\times 10^{-6}$ from statistics (systematics from backgrounds may be important)
- $\Xi^- \to \mu^+\mu^-\pi^- X$
  - Narrow peak near threshold, high trigger efficiency and low background due to the muons
  - Reach: few $\times 10^{-10} - 10^{-11}$from statistics, systematics from backgrounds expected to be small (peaking backgrounds $\Sigma \to p\mu\mu$ and $K \to \pi\mu\mu$ far away in mass)

Summary and conclusions

- There is a **s**trange physics community at LHC**b**
    - constant trigger improvements
    - already with Run III we should reach efficiencies for **s** as high as for b's
- Available measurement for $\Sigma^+ \to p\mu^+\mu^-, BR(K_S \to \mu^+\mu^-), K_{S(L)} \to \mu^+\mu^-\mu^+\mu^-$
- Published prospects for $K_S \to (\gamma/\pi^0)\mu^+\mu^-, K_S \to \pi^+\pi^-e^+e^-$
- Run II (2016-2018) data analyses ongoing: $\Sigma^+ \to p\mu^+\mu^-, K_S \to \pi^+\pi^-\mu^+\mu^-, \Lambda \to p\mu^-\nu$
- More channels in our TODO list (e.g. $K_S \to \mu\mu ee, K_S \to eeee$, LFV, other hyperon decays, etc …)

LHCb Upgrades offer an unique opportunity to study rare kaon and hyperon decays!