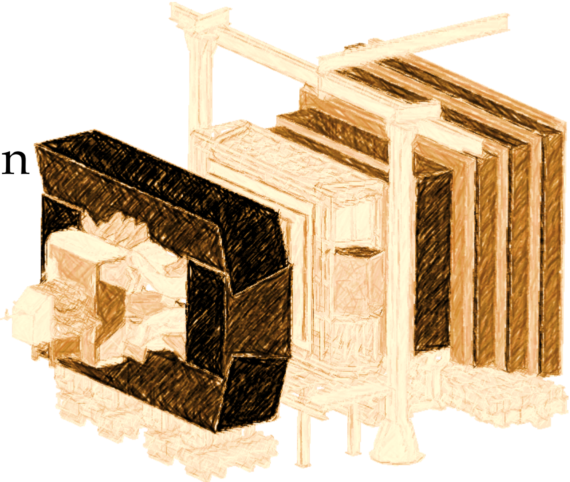
Kaons (& hyperons) at LHCb

Diego Martínez Santos

(on behalf of the LHCb Collaboration)

Introduction

- LHCb experiment at LHC
  - Designed mostly for **b** and **c** decays
    → ~zero trigger efficiency otherwise
  - But there is also an ~infinite **strangeness** production at LHC (kaon xs ~ 1.2 **barn**)
  - Run-I provided world best results in $K_S \rightarrow \mu\mu$ and $\Sigma \rightarrow p\mu\mu$
  - Major improvements in the trigger for **s** decays done for Run-II (2016-2018), and ongoing for Upgrade



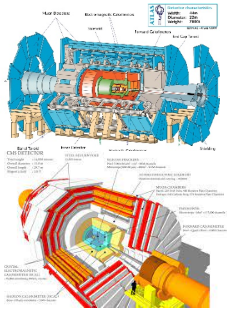
We speak about two upgrade phases:

Phase-I (2022-2030): Data taking started this year

Phase-II (2031->2035): Framework TDR published (CERN-LHCC-2021-012)

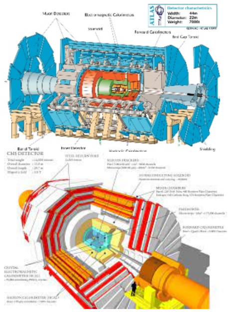
Transverse momentum

- Transverse momentum is a standard handle at LHC to separate signal events from generic pp collisions

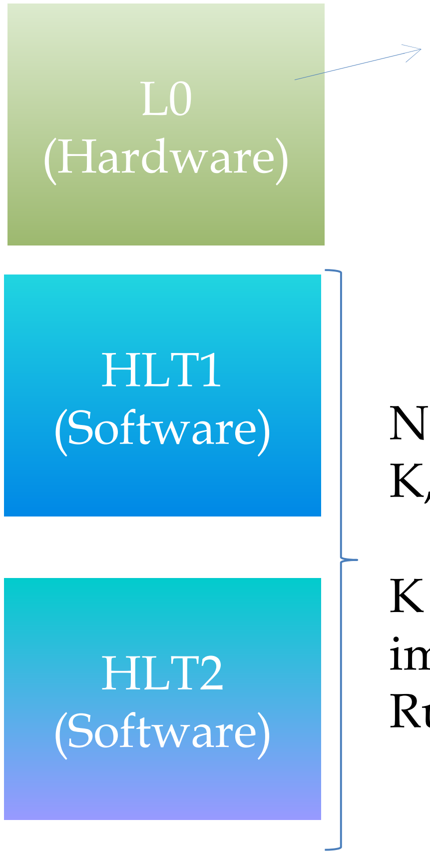
	Typical PT
	~30-40 GeV
B-physics	~ 1-2 GeV
s-physics	~0.08 GeV

Transverse momentum

- Transverse momentum is a standard handle at LHC to separate signal events from generic pp collisions
- Doesn't work at all for strangeness decays, which decay products have very low PT
- However this can be compensated by requiring large separation between the pp colision and the kaon decay point

	Typical PT
	~30-40 GeV
B-physics	~ 1-2 GeV
s-physics	~0.08 GeV

Trigger system: status and prospects



Main bottleneck for K (PT> O(GeV) . Can't be changed

Not designed for K, but flexible.

K triggers implemented in Run-II

LHCb Upgrade

(Note: This logo may not be official)

HLT
(Software)

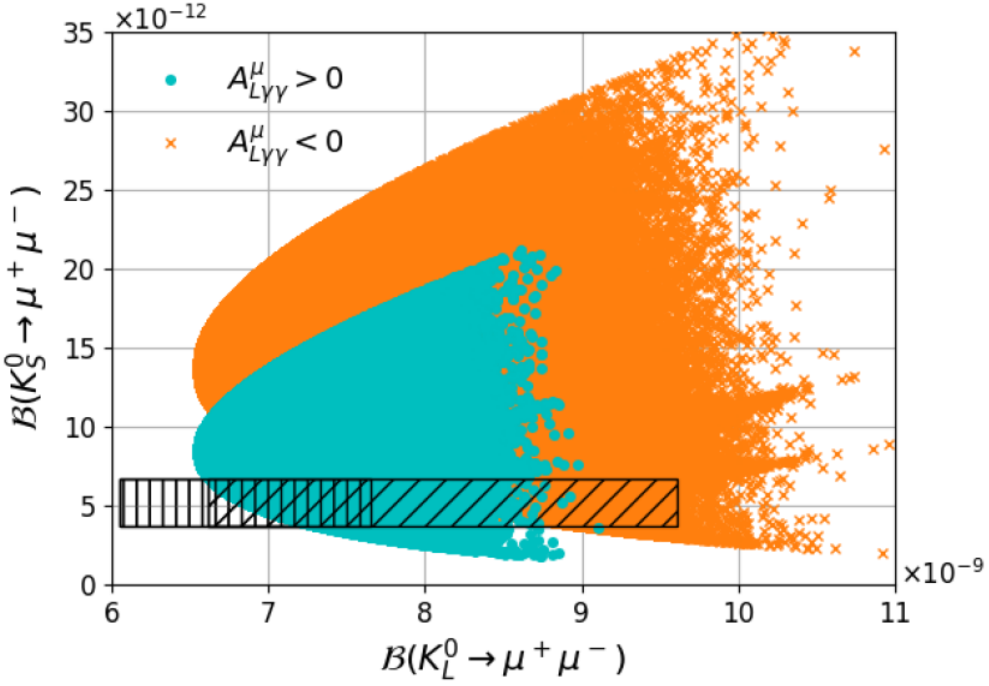
ε(2011-2012) ~ 1-2%
ε(Run-II) improved HLT ~ 18% (dimuons)
Maximum allowed by L0 ~30%

ε(Upgrade) ~ 100%

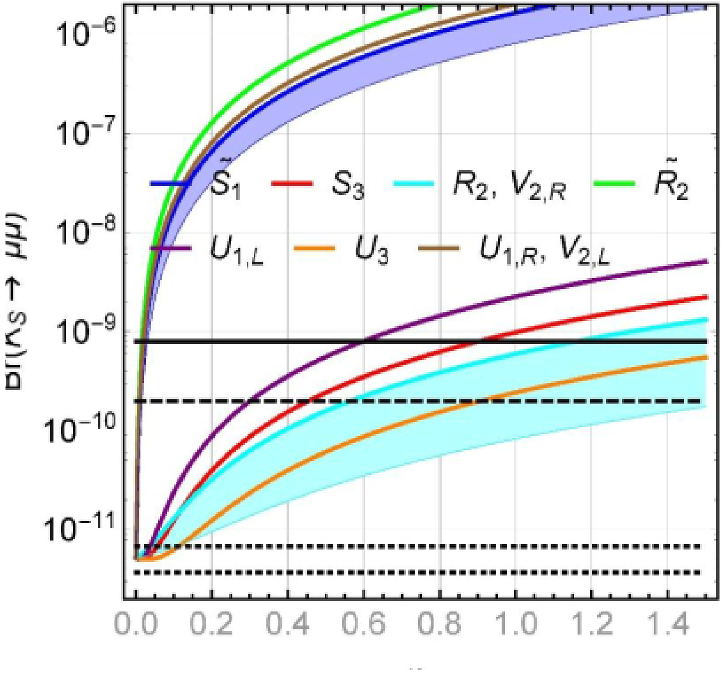
Available Results

$K_S \to \mu\mu$: motivation

- SM prediction: BR($K_S \to \mu\mu$) = $(5.18 \pm 1.50_{LD} \pm 0.02_{SD}) \times 10^{-12}$
  JHEP05(2018) 024 , JHEP 0401 (2004) 009, NPB 366 (1991) 189
- $K_S \to \mu\mu$ sensitive to different physics than $K_L \to \mu\mu$, NP can be bigger than SM by ~1 order of magnitude or even saturate current EXP limit



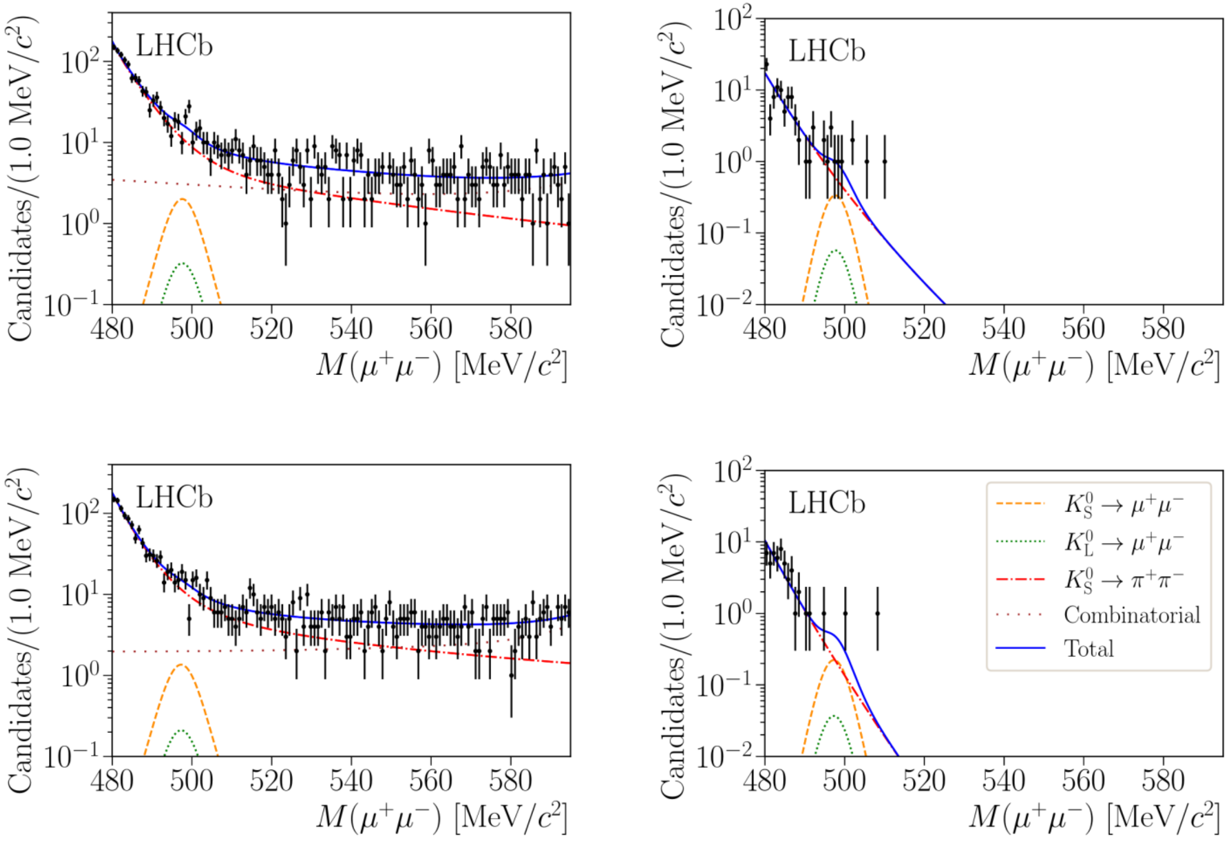
Example of a SUSY scenario from V.Chobanova et al., JHEP05(2018) 024



Leptoquark scenarios from Bobeth & Buras, JHEP02(2018)101

$K_S \to \mu\mu$ latest result

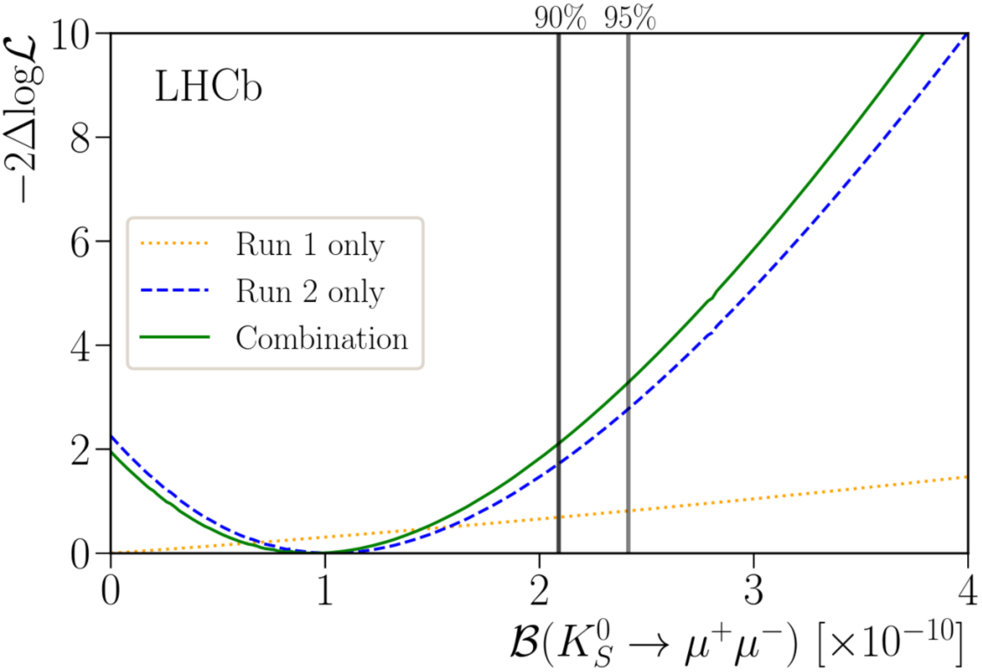
LHCb-PAPER-2019-038
arXiv: 2001.10354
PRL 125, 231801 (2020)



- Full dataset analysed (9 fb^{-1})
- No evidence for signal (1.4σ)

$K_S \rightarrow \mu\mu$ latest result

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



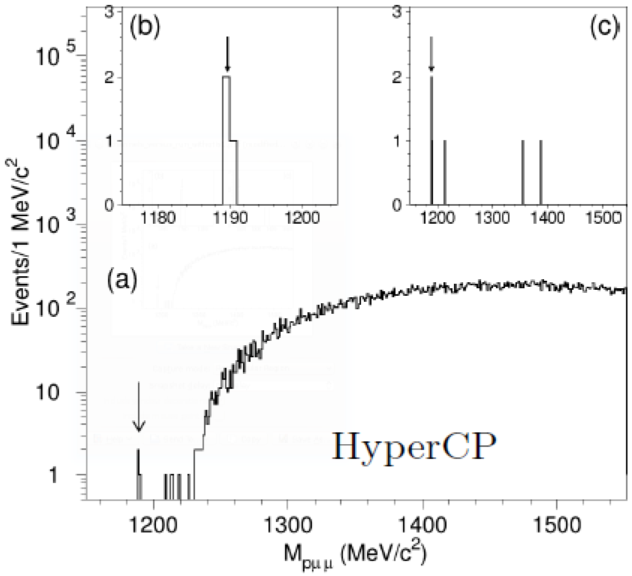
- Full dataset analysed (9 fb^{-1})
- No evidence for signal (1.4σ)

BR($K_S \rightarrow \mu\mu$) < 2.1x 10^{-10} @ 90% CL

At 1σ: $\mathcal{B}(K_S^0 \to \mu^+\mu^-) = 0.9^{+0.7}_{-0.6} \times 10^{-10}$

Expect to reach sensitivities very close to the SM prediction with the Phase-II Upgrade

The HyperCP evidence



- The HyperCP collaboration found evidence for $\Sigma \to p\mu\mu$ decays, and provided a BR:

$$B(\Sigma \to p\,\mu\,\mu) = \left(8.6^{+6.6}_{-5.4} \pm 5.5\right) \times 10^{-8}$$

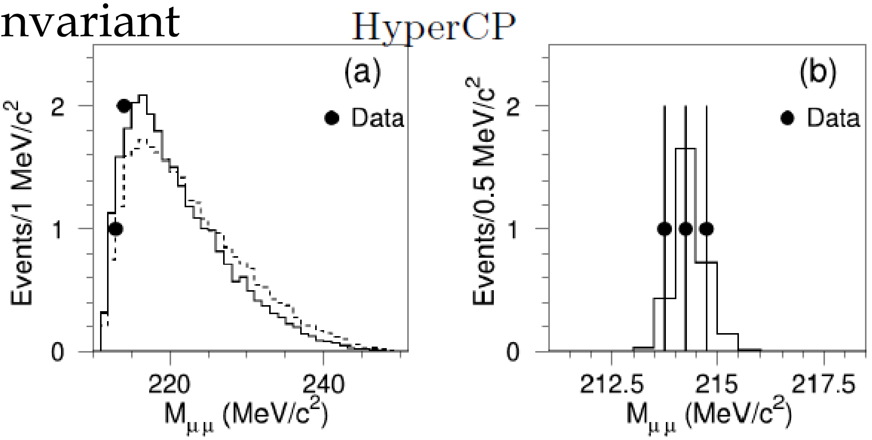
PRL 94 (2005) 021801

- Consistent w/ SM: 1.6 < BR[x10^{-8}] < 9

X G He et al, PRD 72 (2005) 074003

- This evidence had wide relevance since all 3 observed events had the same dimuon invariant mass (214 MeV)

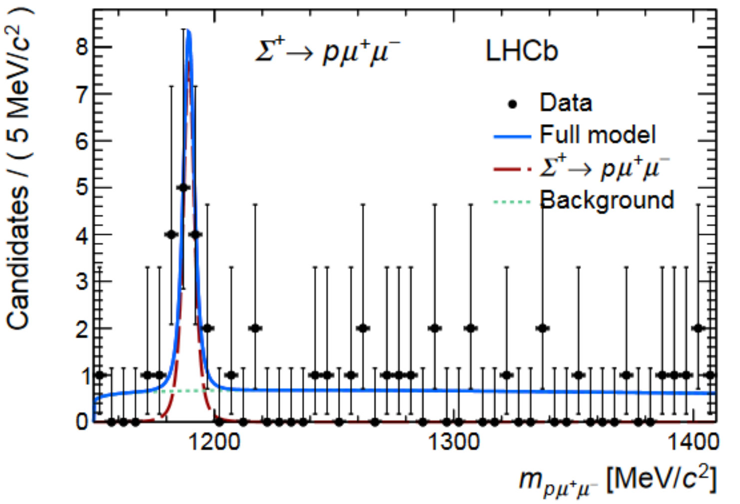
- Suggested the existence of a new neutral particle at that mass

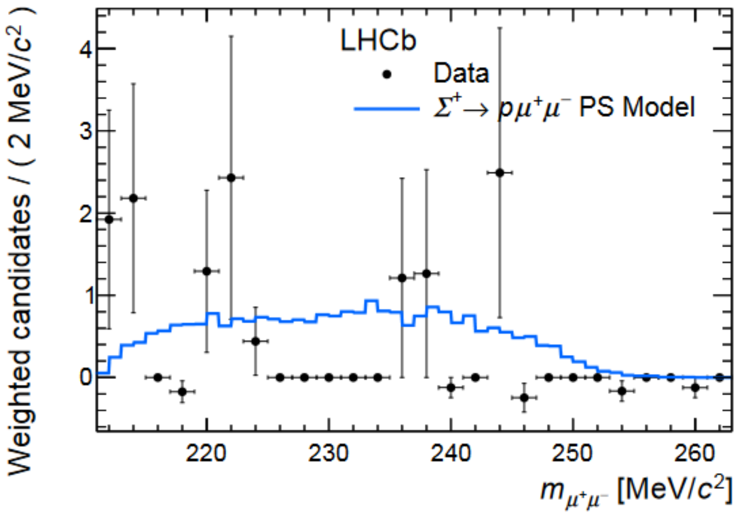


$\Sigma \to p\mu\mu$

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

- Current result $\Sigma \to p\mu\mu$. Run II : Found 4σ evidence BR($\Sigma \to p\mu\mu$) : x 10^{-8}, no evidence of resonant dilepton state
- Run-II: We expect ~150 signal events → measure AFB
- Upgrade(s): Full differential decay rate





10 years ago we thought this channel was ~impossible and instead now we are even thinking on an amplitude analysis….

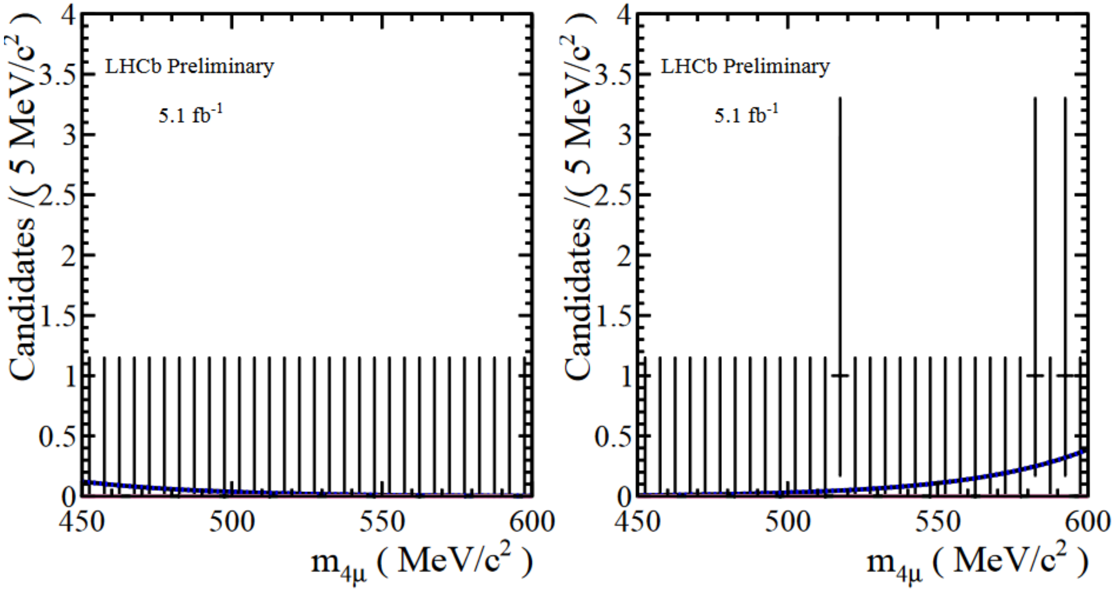
$K^0 \to \mu\mu\mu\mu$

NEW

LHCb-PAPER-2022-035

- Search for $K_{S(L)} \to \mu\mu\mu\mu$ (See Miguel's talk this morning), which are very suppressed in SM, 10^{-13} (KL) – 10^{-14} (KS)

- No events found in signal region, set world's best (first) upper limits on those decays



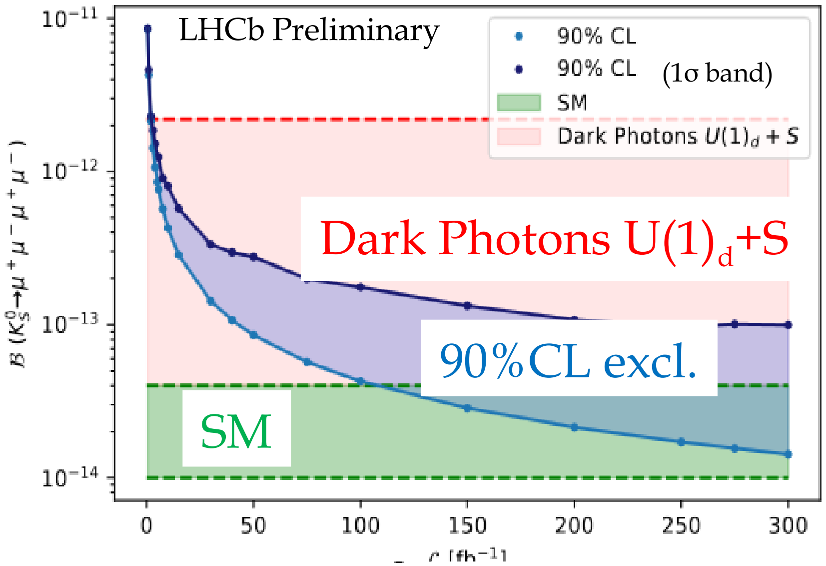
$$\boxed{\begin{aligned}&\mathcal{B}(K^0_S \to \mu^+\mu^-\mu^+\mu^-) < 5.1 \times 10^{-12},\\&\mathcal{B}(K^0_L \to \mu^+\mu^-\mu^+\mu^-) < 2.3 \times 10^{-9},\end{aligned}}$$

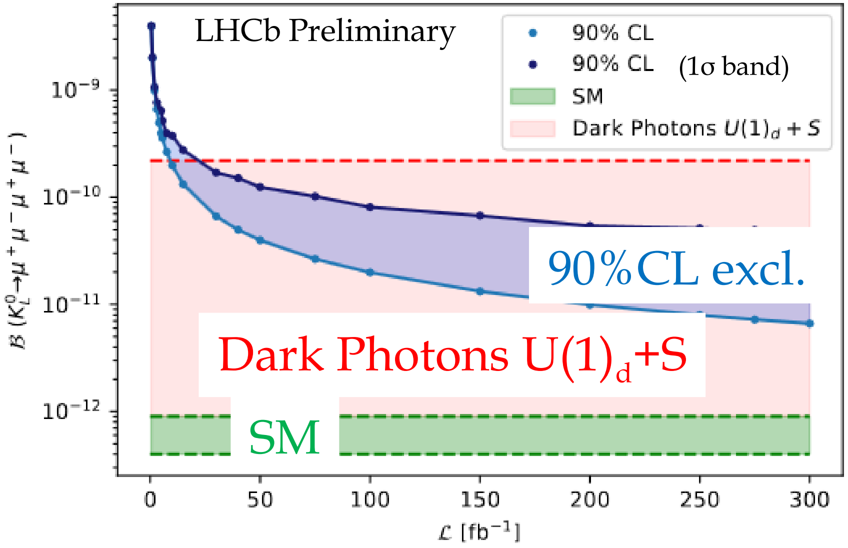
$K^0 \rightarrow \mu\mu\mu\mu$

NEW

LHCb-PAPER-2022-035

- Prospects for the Upgrade are excellent:
- Scan most of the allowed range in BSM models (such as Dark Photons)
- Get close to the SM values if no signal is found





Prospects for other strangeness decays

$K_S \to \pi^0 \mu\mu$ sensitivity study

$$\mathcal{B}(K_L \to \pi^0 \mu^+ \mu^-)_{\rm SM} = \{1.4 \pm 0.3, 0.9 \pm 0.2\} \cdot 10^{-11}$$

Sensitive to BSM, eg, ED

$$\mathcal{B}(K_L \to \pi^0 l^+ l^-) = \left(C^l_{\rm dir} \pm C^l_{\rm int}\,|a_S| + C^l_{\rm mix}\,|a_S|^2 + C^l_{\gamma\gamma} + C^l_S\right) \cdot 10^{-12}$$

$$|a_S| \;=\; 1.20 \pm 0.20$$

Dominant uncertainty, that makes difficult potential BSM interpretation of K_L → $\pi^0\mu\mu$

$$\begin{aligned}
C^e_{\rm dir} &= (4.62 \pm 0.24)\left[({\rm Im}\,Y_A)^2 + ({\rm Im}\,Y_V)^2\right], \\
C^e_{\rm int} &= (11.3 \pm 0.3)\,{\rm Im}\,Y_V\,, \\
C^e_{\rm mix} &= 14.5 \pm 0.5\,, \\
C^e_{\gamma\gamma} &\approx C^e_S \approx 0\,, \\
C^\mu_{\rm dir} &= (1.09 \pm 0.05)\left[2.32\,({\rm Im}\,Y_A)^2 + ({\rm Im}\,Y_V)^2\right] \\
C^\mu_{\rm int} &= (2.63 \pm 0.06)\,{\rm Im}\,Y_V\,, \\
C^\mu_{\rm mix} &= 3.36 \pm 0.20\,, \\
C^\mu_{\gamma\gamma} &= 5.2 \pm 1.6\,, \\
C^\mu_S &= (0.04 \pm 0.01)\,{\rm Re}\,Y_S + 0.0041\,({\rm Re}\,Y_S)^2\,.
\end{aligned}$$

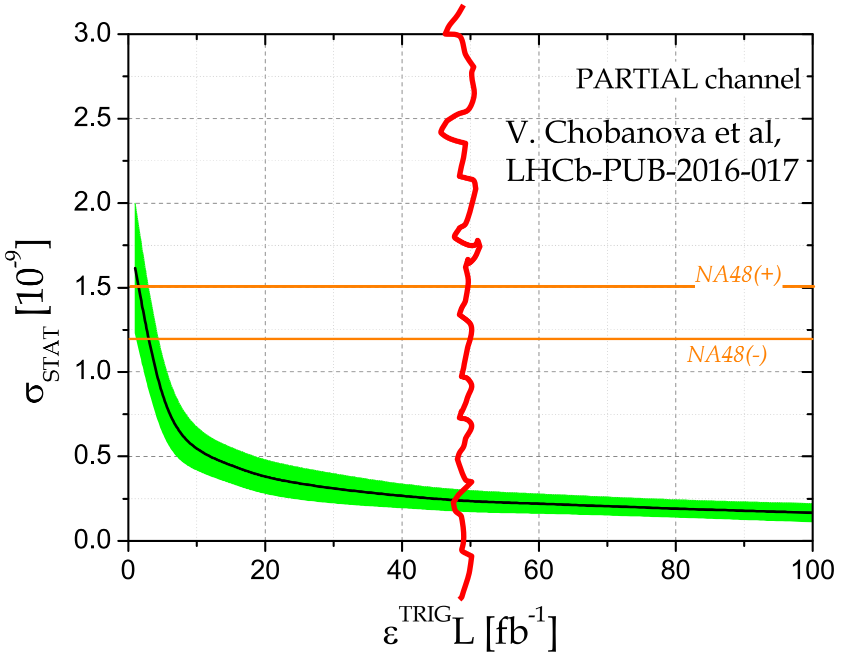
It comes from the **experimental uncertainty** on BR(K_S → $\pi^0\mu\mu$) measured by NA48

$K^0_S \to \pi^0 \mu^+ \mu^-$	NA48	$(2.9\ ^{+1.5}_{-1.2}) \times 10^{-9}$

~50% relative error

Improved measurements of BR(K_S → $\pi^0\mu\mu$) will translate into improved BSM constraints from K_L → $\pi^0\mu\mu$

$K_S \rightarrow \pi^0 \mu\mu$ sensitivity study



V. Chobanova et al, LHCb-PUB-2016-017

LHCb-upgrade

Phase-II-upgrade? →

Much more bkg than $K_S \rightarrow \mu\mu$, but also 1000x more signal

$|a_S|=1.2\pm0.2$ from NA48 fixing b_S from VMD
PLB599 (2004) 197-211,

Projected statistical uncertainties on a_S under various analysis conditions

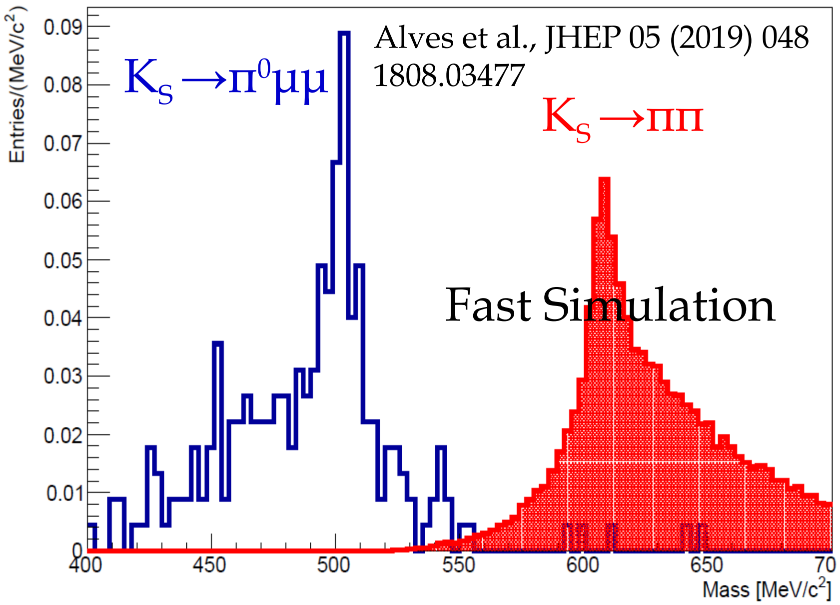
Configuration	Phase I	Phase II
BR & q^2 fit	0.25	0.10
BR & q^2 fit with NA48 constraint	0.19	0.10
BR & q^2 fit fixing b_S	0.06	0.024
a_S measurement from BR alone	0.06	0.024

(fixing b_S)

Alves et al., JHEP 05 (2019) 048
1808.03477

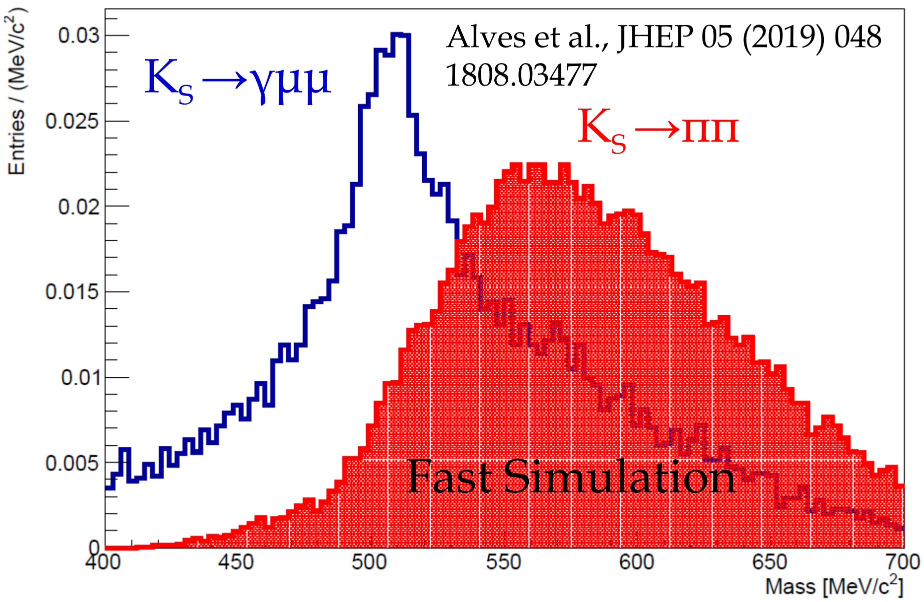
$K_S \rightarrow \gamma\mu\mu$, $K_S \rightarrow X\mu\mu$, $K_S \rightarrow X\pi\mu$,?

$K_S \rightarrow \pi^0\mu\mu$ analysis can also be extended to other neutrals, eg: $K_S \rightarrow \gamma\mu\mu$
But harder to separate from $K_S \rightarrow \pi\pi$ as the mass of the neutral gets lighter
(unless a cut on the energy is used)



Alves et al., JHEP 05 (2019) 048
1808.03477

Fast Simulation



Alves et al., JHEP 05 (2019) 048
1808.03477

Fast Simulation

Semileptonic decays

- Semileptonic Hyperon Decays (SHD)

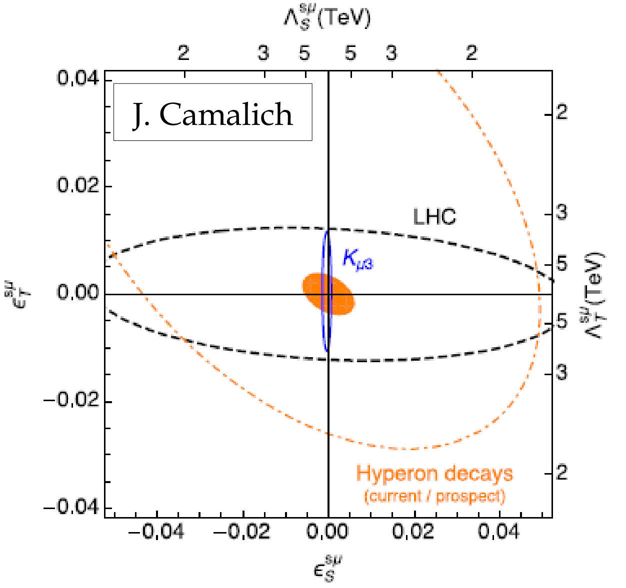
$$R_{B_1 B_2} = \frac{\Gamma(B_1 \to B_2\, \mu^- \,\bar{\nu}_\mu)}{\Gamma(B_1 \to B_2\, e^- \,\bar{\nu}_e)}$$

Very interesting in view of LUV hints in semileptonic B decays

Many muonic modes have still very poor precision (20%, 100%)

- ☺ High BR (10^{-4}): Massive yields in LHCb acceptance

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



(extrapolations from 1412.8484)

. Gonzalez-Alonso & JMC, NA62 Phyics Handbook

[Rare'N'Strange Workshop, 2017](https://indico.cern.ch/event/590880/contributions/2485320/)
https://indico.cern.ch/event/590880/contributions/2485320/

Semileptonic decays

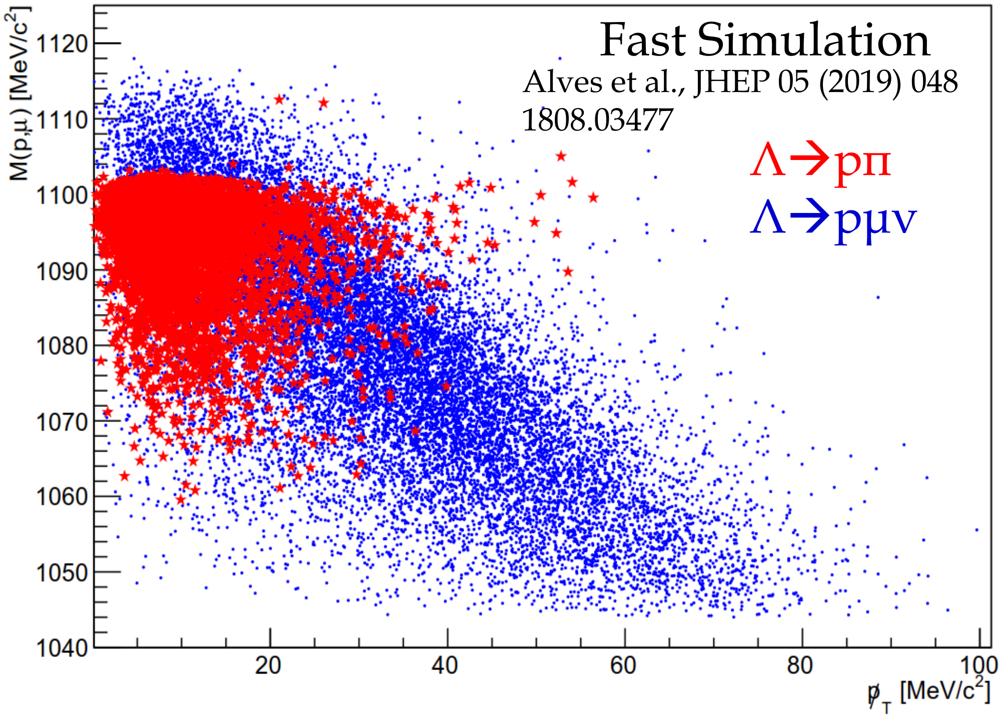
- Semileptonic Hyperon Decays (SHD)

Very interesting in view of LUV hints in semileptonic B decays

Many muonic modes have still very poor precision (20%, 100%)

- ☺ High BR (10^{-4}): Massive yields in LHCb acceptance

- ☹ Challenging peaking backgrounds:



Fast Simulation

Alves et al., JHEP 05 (2019) 048
1808.03477

For each
B1 → B2 μν there is always a
B1 → B2π (inc. →B2μν)
(misid rate O(1%))

☺ Can be separated in search planes

Lepton Flavour Violation

M. Borsato et al.,
Phys. Rev. D 99, 055017 (2019)
arXiv:1808.02006 [hep-ex]

- Lepton Flavour Violation is forbidden in SM, but allowed in BSM

LHCb can do:

$K_S \to e\mu$

No limit exits so far
$K_L \to e\mu < 4.7\times10^{-12}$ BNL, *PRL* **81** (1998) 5734–5737
$K_S \to e\mu$ is a LFV model discriminator

Lepton Flavour Violation

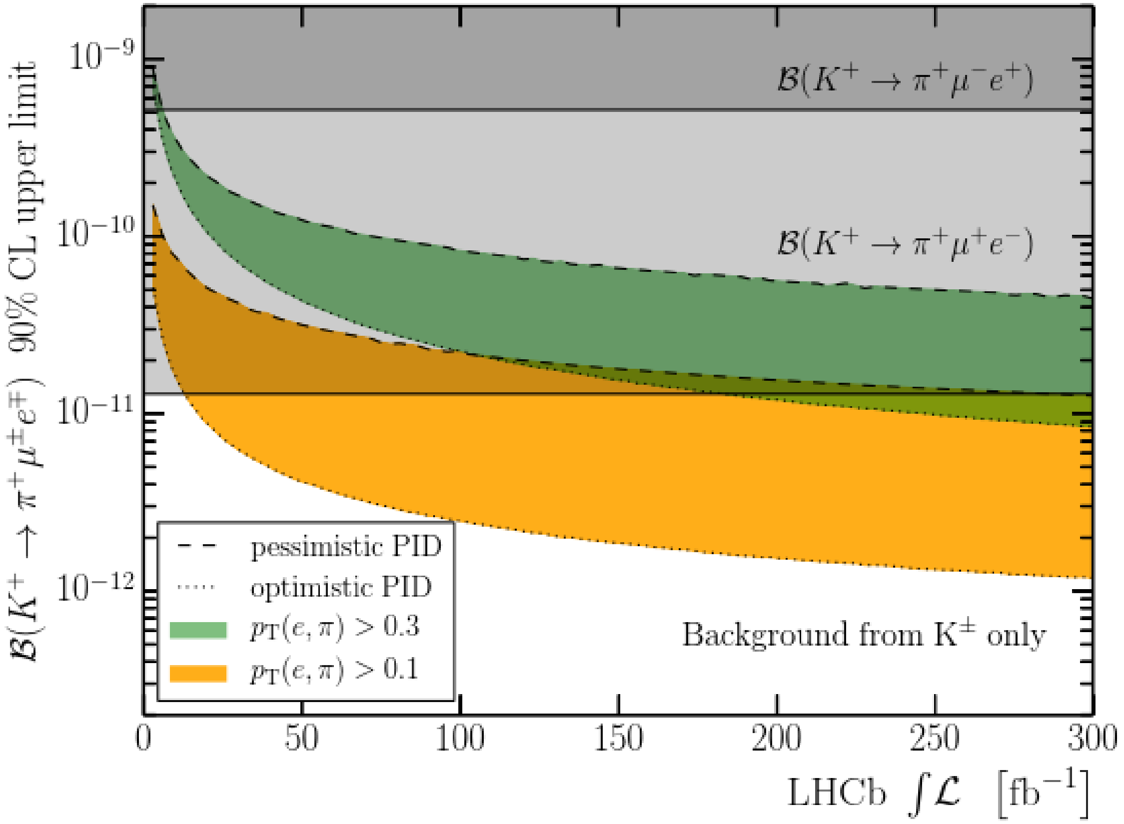
M. Borsato et al.,
Phys. Rev. D 99, 055017 (2019)
arXiv:1808.02006 [hep-ex]

- Lepton Flavour Violation is forbidden in SM, but allowed in BSM

LHCb can do:

$K_S \rightarrow e\mu$
$K^+ \rightarrow \pi^+\mu^-e^+$
Maybe $K^+ \rightarrow \pi^+\mu^+e^-$

Competition w/
NA62



Others: Dark Baryons, dielectrons…

- B-mesogenesis: G. Alonso-Alvarez et al, arXiv:2101.02706
- LHCb potential using b-hadrons: V. Chobanova et al. arXiv:2106.12870
- Using hyperons (arXiV: 2201.07805):
  - $\Xi0 \rightarrow \pi\pi X$
    - ~few x 10^{-6} , stat only (syst from bkg may be important)
  - $\Xi- \rightarrow \mu\mu\pi X$: Narrow peak near threshold, very high trigger efficiency and low bkg bcs muons
    → ~few x 10^{-10} – 10^{-11} stat only, but bkg syst expected to be small (peaking bkgs from $\Sigma \rightarrow p\mu\mu$, $K \rightarrow \pi\mu\mu$ are far away in mass)

- $K_S \rightarrow \mu\mu ee$, $K_S \rightarrow eeee$, $K_S \rightarrow \pi\pi ee$

Conclusions

- There is an LHC**s** community in the LHC**b** village
  - Trigger is constantly improving
  - From now on we expect to reach efficiencies **s** as high as for **b**'s
- Available measurements for: $\Sigma\to p\mu\mu$, BR($K_S \to \mu\mu$), BR($K_{S(L)} \to \mu\mu\mu\mu$)
  → First LHCb result with K_L was presented at this conference

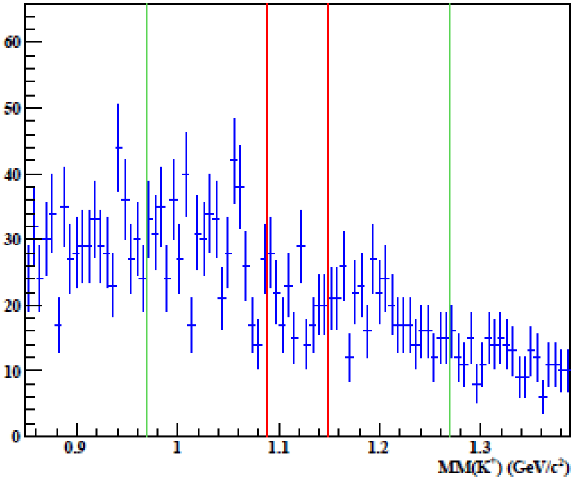
NEW

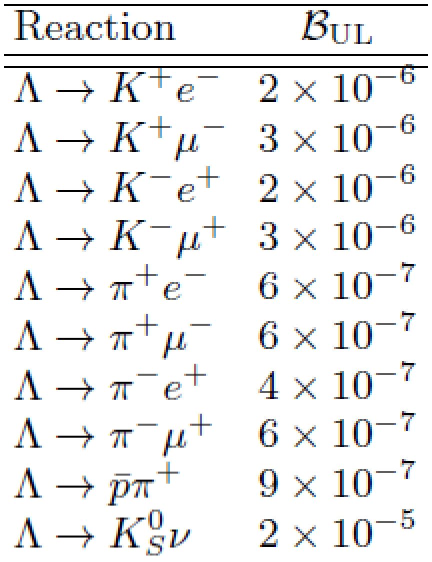
- Published prospects for $K_S\to\pi^0\mu\mu$, $K_S\to\pi^+\pi^-ee$
- Run-II (2016-2018) data analysis ongoing $\Sigma\to p\mu\mu$, $K_S \to (\gamma/\pi0)\mu\mu$, $\Lambda\to p\mu\nu$...
- Some more channels in our TODO list

Backup

B and L violation

CLAS collaboration (Jefferson Lab):
Limits on B and L violation





Reaction	$\mathcal{B}_{\rm UL}$
$\Lambda \to K^+ e^-$	2×10^{-6}
$\Lambda \to K^+ \mu^-$	3×10^{-6}
$\Lambda \to K^- e^+$	2×10^{-6}
$\Lambda \to K^- \mu^+$	3×10^{-6}
$\Lambda \to \pi^+ e^-$	6×10^{-7}
$\Lambda \to \pi^+ \mu^-$	6×10^{-7}
$\Lambda \to \pi^- e^+$	4×10^{-7}
$\Lambda \to \pi^- \mu^+$	6×10^{-7}
$\Lambda \to \bar{p} \pi^+$	9×10^{-7}
$\Lambda \to K^0_S \nu$	2×10^{-5}

arXiv:1507.03859 [hep-ex]

We can easily do many of CLAS' decays

…as well as others:

- Σ→ 3μ
- Λ→ π3μ

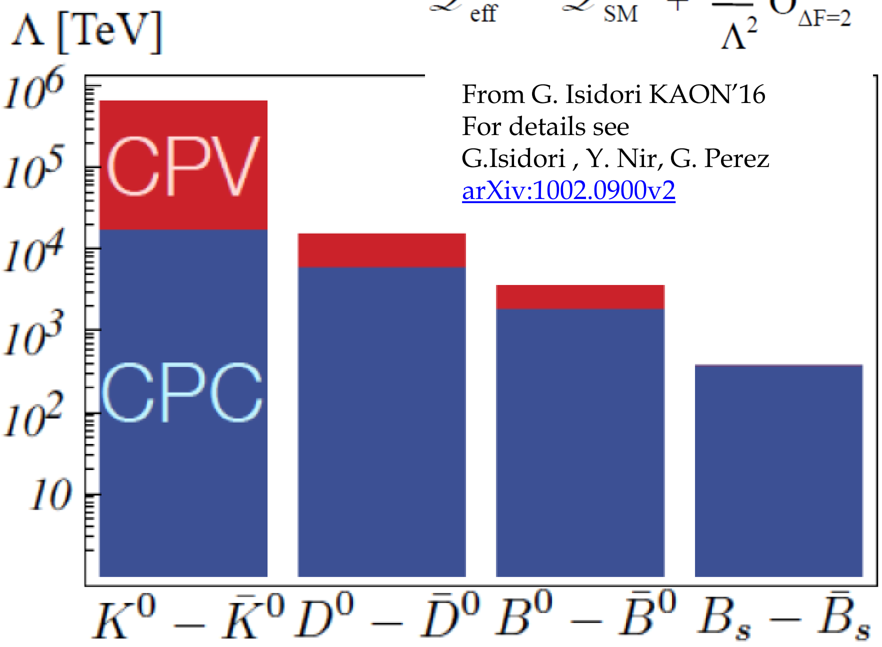
…and many other crazy (J conserving) combinations.

Currently very low priority, since we assume that BSM contributions can only be as much as BR ~10^{-56}

Strangeness decays

- So far a kaons showed great success on indirect searches: *c, b, t* , CKM …
- High theoretical interest, most notably to test departures from MFV paradigm (eg, flavor generic)

$$\mathscr{L}_{\rm eff} = \mathscr{L}_{\rm SM} + \frac{1}{\Lambda^2} O_{\Delta F=2}$$



From G. Isidori KAON'16
For details see
G.Isidori , Y. Nir, G. Perez
arXiv:1002.0900v2

- Useful to understand "Hints" for BSM in b sector
  - Eg: deviations in b→sμμ: are they replicated in s → dμμ?

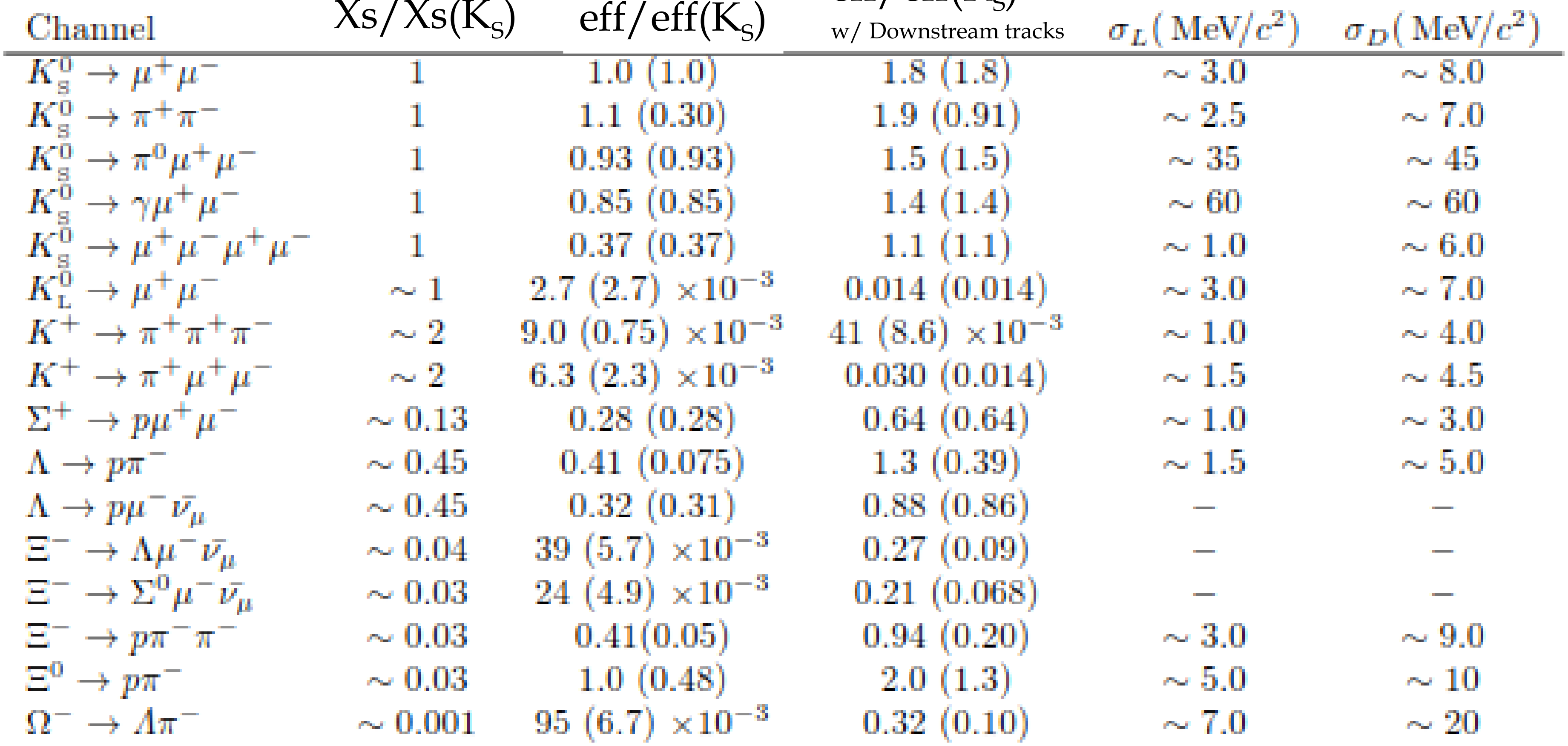
Y ➔ interesting

N ➔ interesting

- Potentially immense samples : high(est) ultimate experimental precision

Efficiencies

* More details in: arXiv:1808.03477 [hep-ex]



Channel	$Xs/Xs(K_S)$	$eff/eff(K_S)$	$eff/eff(K_S)$ w/ Downstream tracks	Mass resolution	
				σ_L (MeV/c^2)	σ_D (MeV/c^2)
$K^0_S \to \mu^+\mu^-$	1	1.0 (1.0)	1.8 (1.8)	~ 3.0	~ 8.0
$K^0_S \to \pi^+\pi^-$	1	1.1 (0.30)	1.9 (0.91)	~ 2.5	~ 7.0
$K^0_S \to \pi^0\mu^+\mu^-$	1	0.93 (0.93)	1.5 (1.5)	~ 35	~ 45
$K^0_S \to \gamma\mu^+\mu^-$	1	0.85 (0.85)	1.4 (1.4)	~ 60	~ 60
$K^0_S \to \mu^+\mu^-\mu^+\mu^-$	1	0.37 (0.37)	1.1 (1.1)	~ 1.0	~ 6.0
$K^0_L \to \mu^+\mu^-$	~ 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

Sensitivity of (semi)leptonic kaon decays in a nutshell

- $K_{\ell 3}$

$$\Gamma(K_{\ell 3(\gamma)}) = \frac{\overbrace{G_F^2}^{\text{Measured in } \mu \text{ decay}} m_K^5}{192\pi^3} \underbrace{|\tilde{V}^{\ell}_{us}|}_{\left(1 + \epsilon_L^{s\ell} + \epsilon_R^{s} - \tilde{v}_L\right) V_{us}^{\mathrm{SM}}}{}^2 f_+(0)^2 \overbrace{I_K^{\ell}(\lambda_{+,0},\, \epsilon_S^{s\ell},\, \epsilon_T^{s\ell})}^{\text{Phase-space Int.}} \underbrace{\left(1 + \delta^c + \delta^{c\ell}_{\mathrm{em}}\right)^2}_{\text{Rad. and isosp. corr.}}$$

- $K_{\ell 2}$

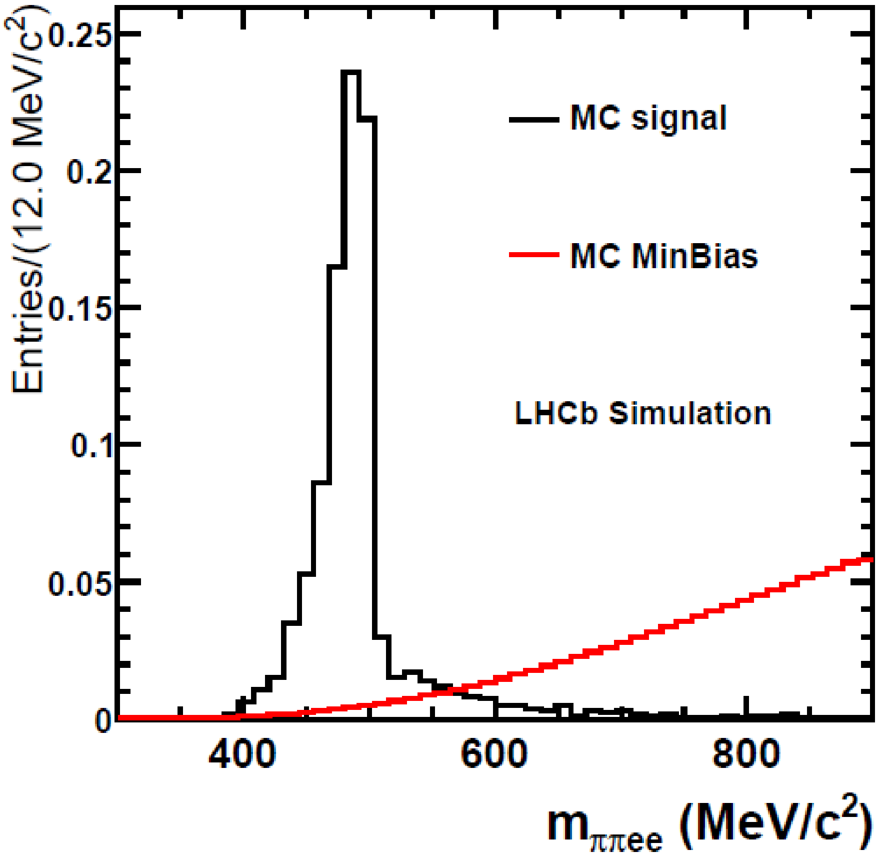
$$\Gamma_{K_{\ell 2(\gamma)}} = \frac{G_F^2 m_K\, m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_P^2}\right)^2 |\tilde{V}^{\ell}_{us}|^2 f_{K^\pm}^2 \left(1 - 4\epsilon_R^{s} - \underbrace{\frac{2B_0}{m_\ell}}_{\chi \text{ enh.}} \epsilon_P^{s\mu}\right)$$

- $|\tilde{V}^{\ell}_{us}|$ only accessible through CKM unitarity and LUV tests
- ϵ_R^{s} cannot be completely disentangled from $\epsilon_P^{s\ell}$
- $\epsilon_{S,T}^{s\ell}$ accessible through the spectra/angular distribution

Kaon decays alone cannot disentangle all NP possibilities

$K_S \to \pi^+\pi^- ee$ sensitivity study

C.Marin et al,
LHCb-PUB-2016-016



Based on simulation:

Expected a signal yield of

$$= 120^{+280}_{-100}$$

For the full Run-I dataset

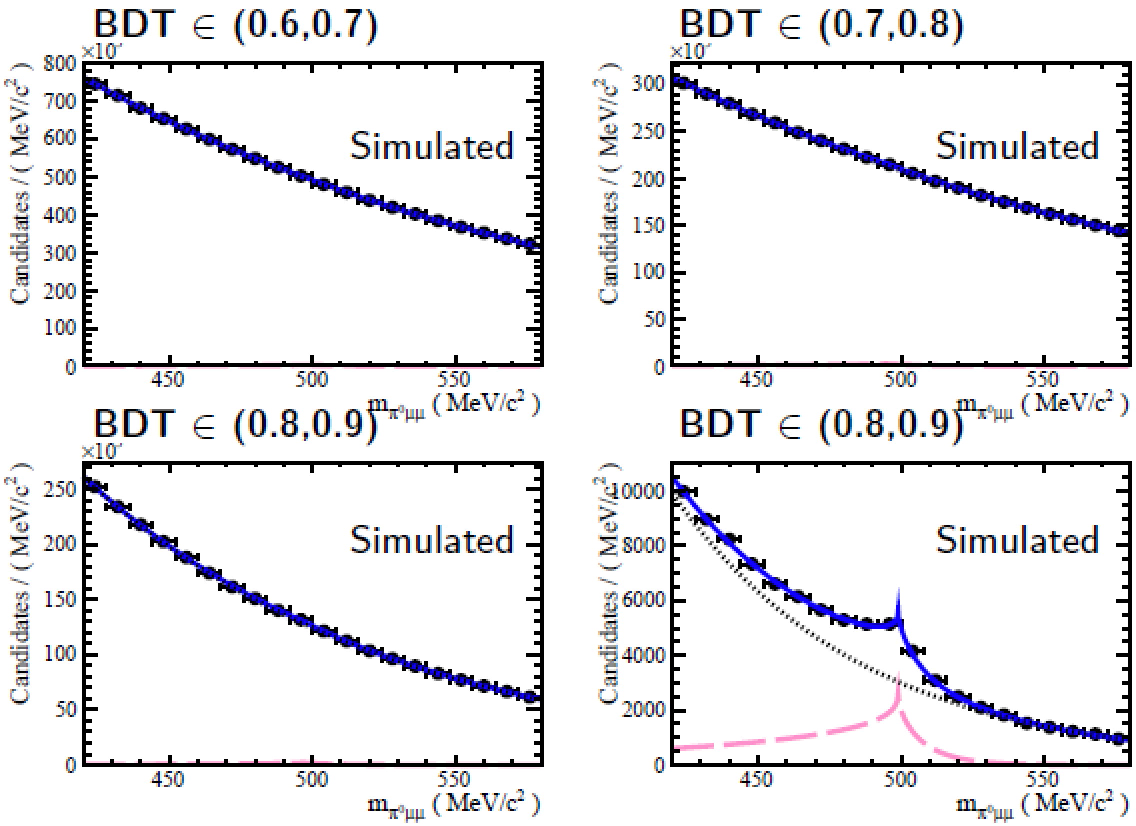
Expected background yield is not well known yet

K0 tagging?

arXiv:1808.03477 [hep-ex]

$$pp \to K^0 K^- X,\ pp \to K^{*+} X \to K^0 \pi^+ X \text{ and } pp \to K^0 \Lambda^0 X.$$

Toy MC for 50fb^{-1}



BDT ∈ (0.6,0.7)

BDT ∈ (0.7,0.8)

BDT ∈ (0.8,0.9)

BDT ∈ (0.8,0.9)

Lifetime acceptance and $K_L \rightarrow \mu\mu$ background

K_L and K_S are distinguishable only by the decaytime…
… and that is in theory. In practice, LHCb decaytime acceptance is not great for kaons

$\Big(\quad \Big) \quad ^{-}$ With β 5xΓs (>> Γ_L).

This makes the two lifetime distributions to look similar

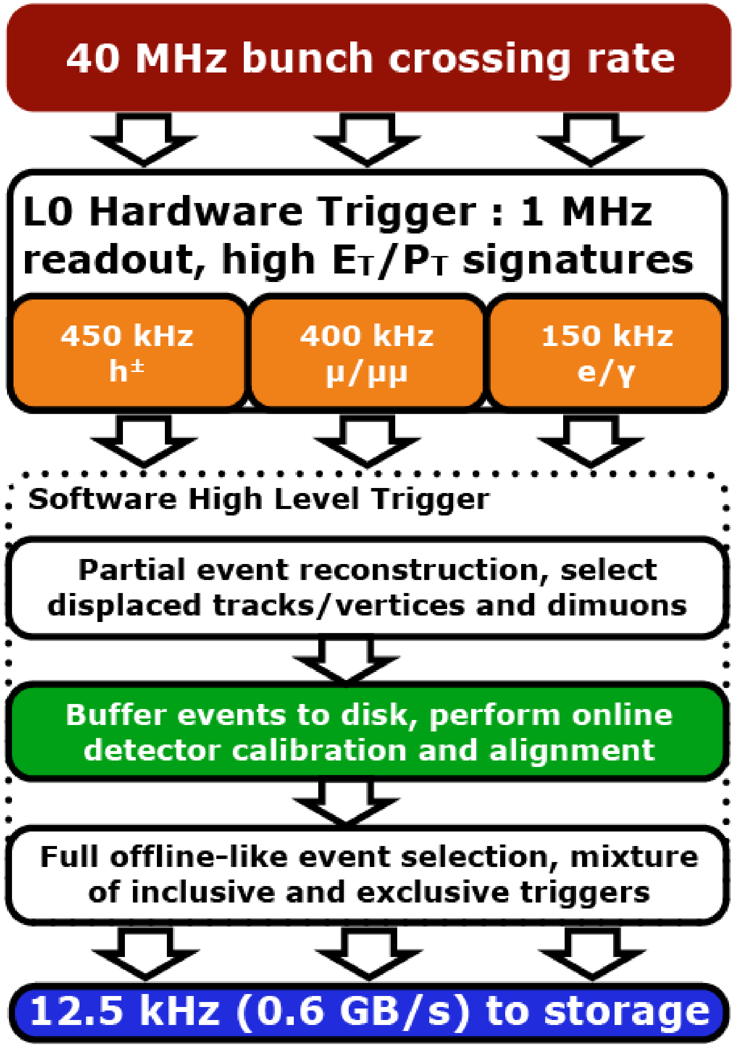
But the overall efficiency ratio is of course different

$$\frac{\epsilon_{K^0_{\rm L}}}{\epsilon_{K^0_{\rm S}}} = \frac{\Gamma_L \int_{0.1\tau_S}^{1.45\tau_S} e^{-t(\Gamma_S+\beta)} dt}{\Gamma_S \int_{0.1\tau_S}^{1.45\tau_S} e^{-t(\Gamma_L+\beta)} dt} \approx 2.2 \times 10^{-3}$$

And makes $K_L \rightarrow \mu\mu$ to become a negligible background for the current level of precision
But can be relevant when we approach the 10^{-11} level

$$\beta \sim 86\,\mathrm{ns}^{-1}$$

LHCb 2015 Trigger Diagram



40 MHz bunch crossing rate

L0 Hardware Trigger : 1 MHz readout, high E_T/P_T signatures

450 kHz $h^{\pm}$

400 kHz $\mu/\mu\mu$

150 kHz e/γ

Software High Level Trigger

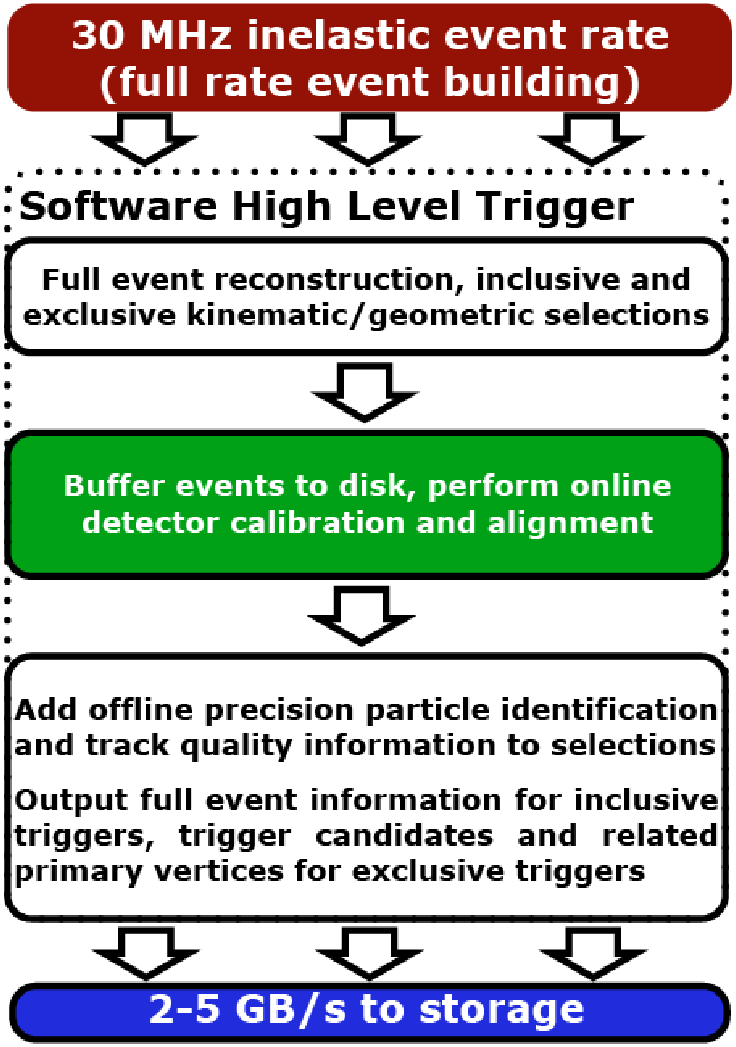
Partial event reconstruction, select displaced tracks/vertices and dimuons

Buffer events to disk, perform online detector calibration and alignment

Full offline-like event selection, mixture of inclusive and exclusive triggers

12.5 kHz (0.6 GB/s) to storage

LHCb Upgrade Trigger Diagram



30 MHz inelastic event rate (full rate event building)

Software High Level Trigger

Full event reconstruction, inclusive and exclusive kinematic/geometric selections

Buffer events to disk, perform online detector calibration and alignment

Add offline precision particle identification and track quality information to selections

Output full event information for inclusive triggers, trigger candidates and related primary vertices for exclusive triggers

2-5 GB/s to storage

Normalization of event yield

Converting a signal yield into a branching ratio

production crossection

Absolute efficiency

$$N\left(\ ^{0} \rightarrow \qquad\qquad \right) = \left(\ ^{0}\right) B \left(\ ^{0} \rightarrow \qquad \right)$$

Integrated luminosity

How? (normalization of event yield)

Converting a signal yield into a branching ratio

production crossection

Absolute efficiency

$$N({}^{0} \rightarrow \qquad) = ({}^{0}) B ({}^{0} \rightarrow \qquad)$$

Integrated luminosity

$$\frac{N({}^{0} \rightarrow \qquad)}{N({}^{0} \rightarrow \qquad)} = \frac{\cancel{({}^{0})} B ({}^{0} \rightarrow \qquad \cancel{)}}{\cancel{({}^{0})} B ({}^{0} \rightarrow \qquad \cancel{)}},$$

Introduce in the ntuples a decays counter

Very well known
(69.20±0.05)%

Dilepton mass distribution

Take formulae from hep-ph/9808289

$$\frac{d\Gamma}{dz} = \frac{\alpha^2 M_K}{12\pi(4\pi)^4}\,\lambda^{3/2}(1, z, r_\pi^2)\sqrt{1 - 4\frac{r_\ell^2}{z}}\left(1 + 2\frac{r_\ell^2}{z}\right)|W(z)|^2\,, \qquad (3)$$

z= m² ➔ dΓ/dm = 2m dΓ/dz

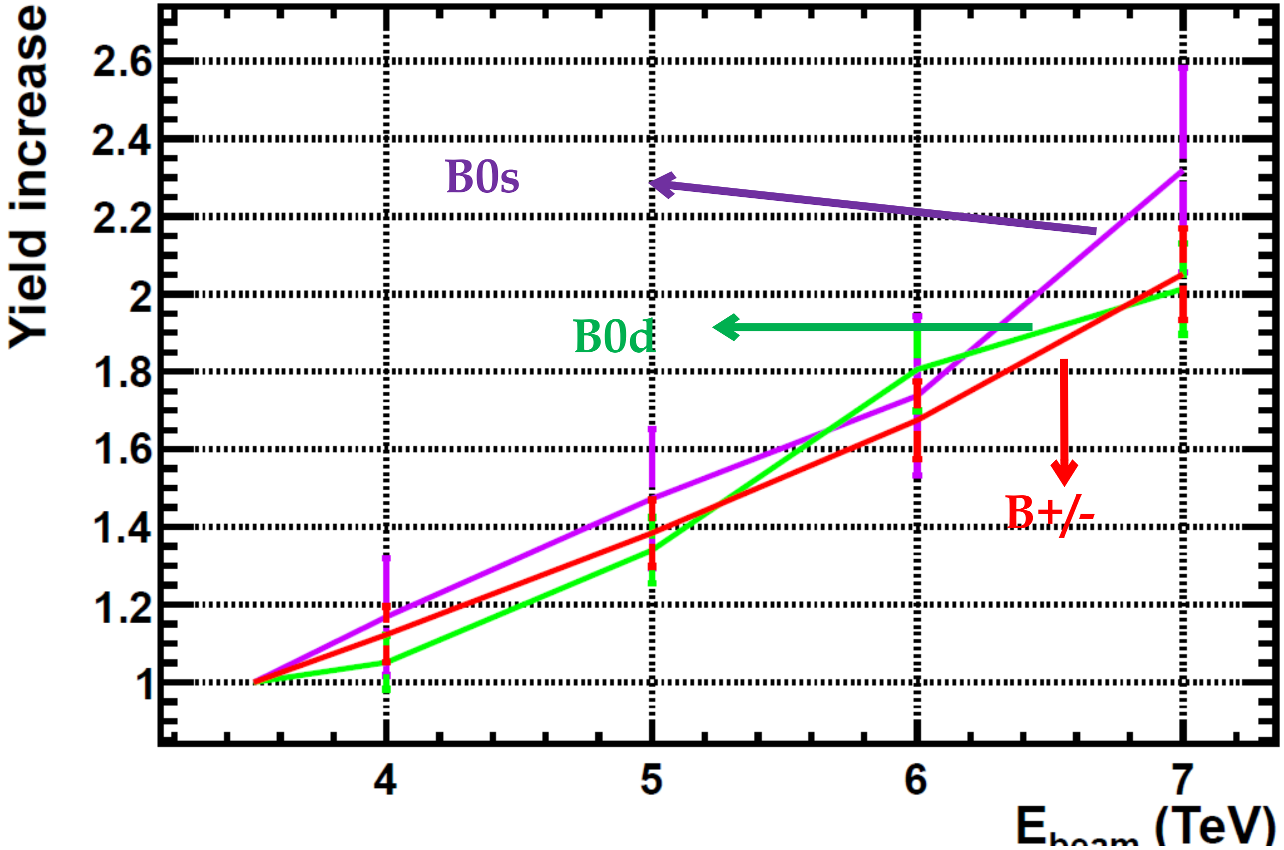
$$W_i(z) = G_F M_K^2 (a_i + b_i z) + W_i^{\pi\pi}(z)\;, \qquad (11)$$

$$W_i^{\pi\pi}(z) = \frac{1}{r_\pi^2}\left[\alpha_i + \beta_i \frac{z - z_0}{r_\pi^2}\right] F(z)\;\chi(z)\;,$$

Remind of Bmm sensitivity

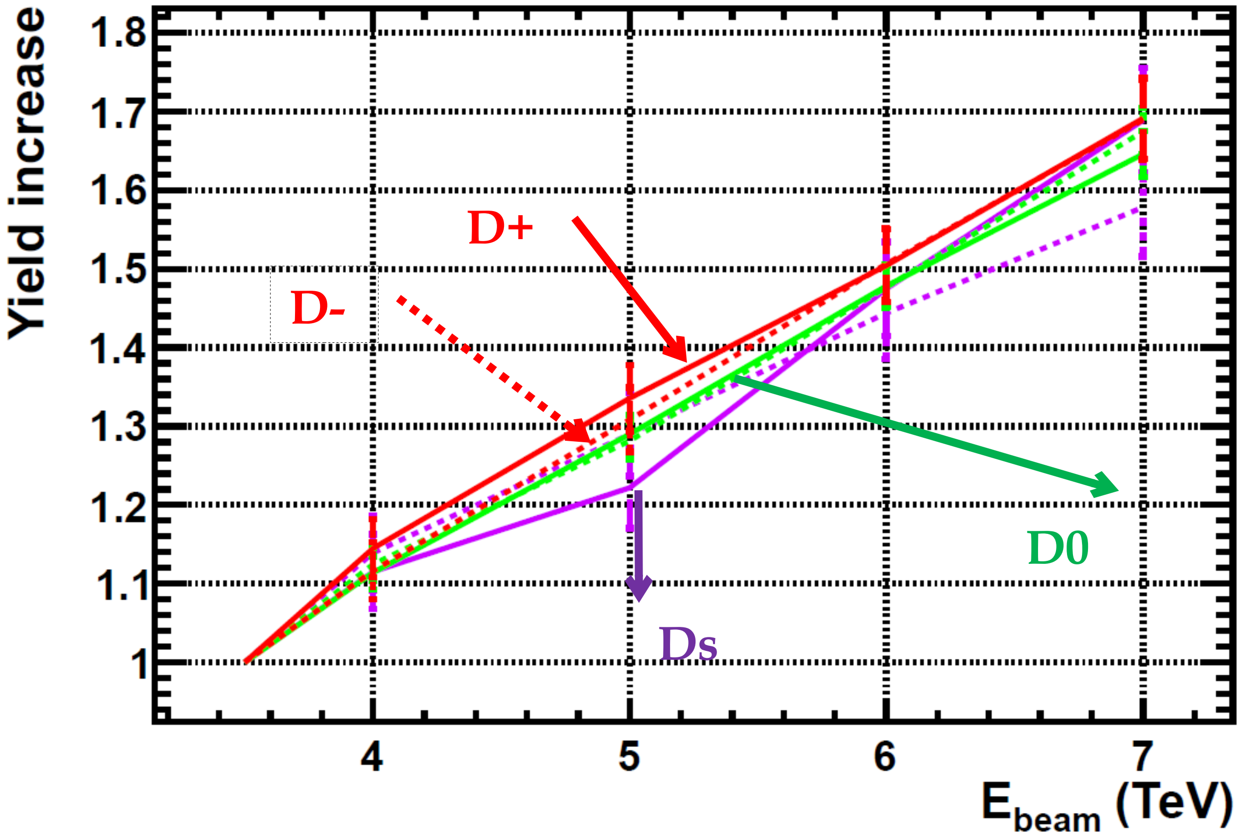
B mesons

We check that we get right the expected increase of B meson yields (i.e, a factor ~2)



D mesons

For D mesons the increase is slightly smaller (~1.6- 1.7)

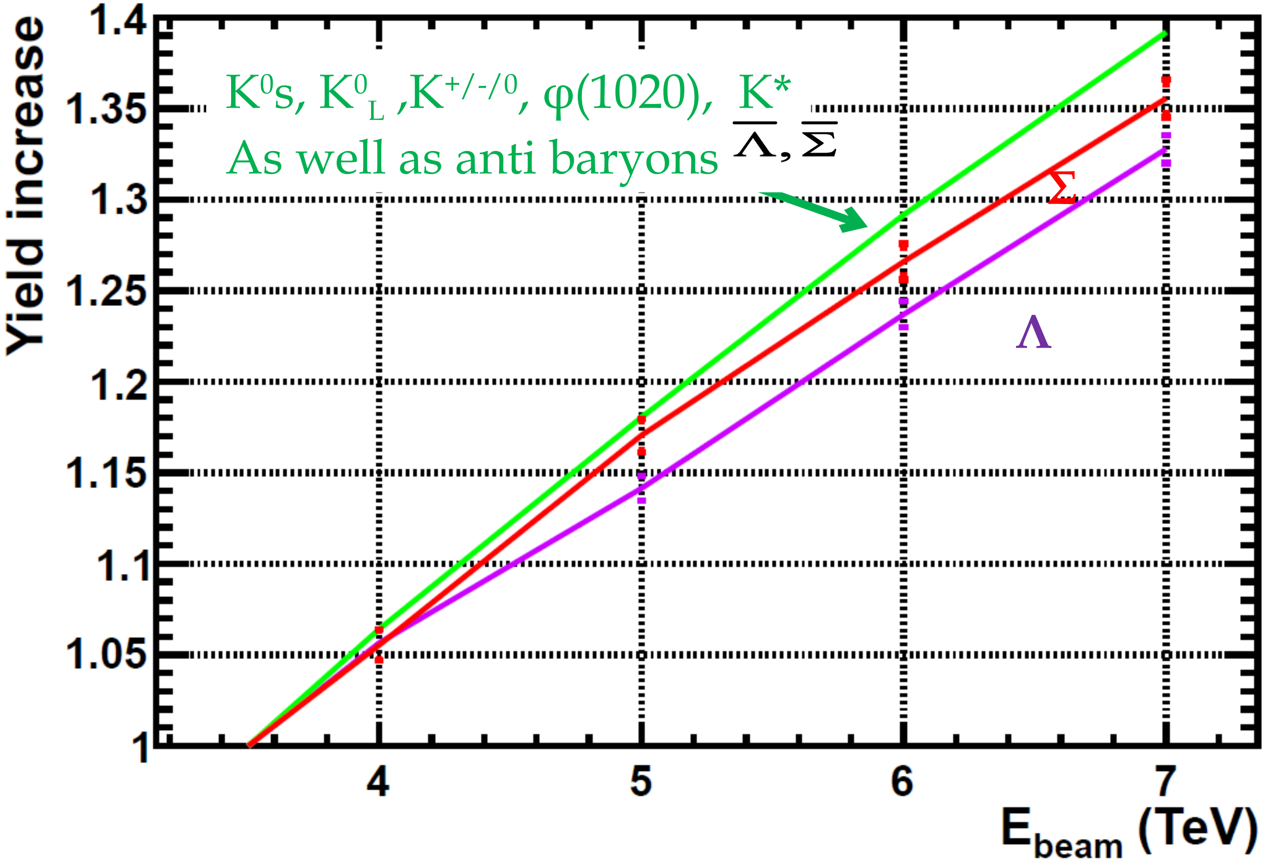


Strange particles

Increase for most of them is ~40%

A bit less for baryons (note: baryons, not anti-baryons)

However, the momentum is also different w.r.t 7 TeV.

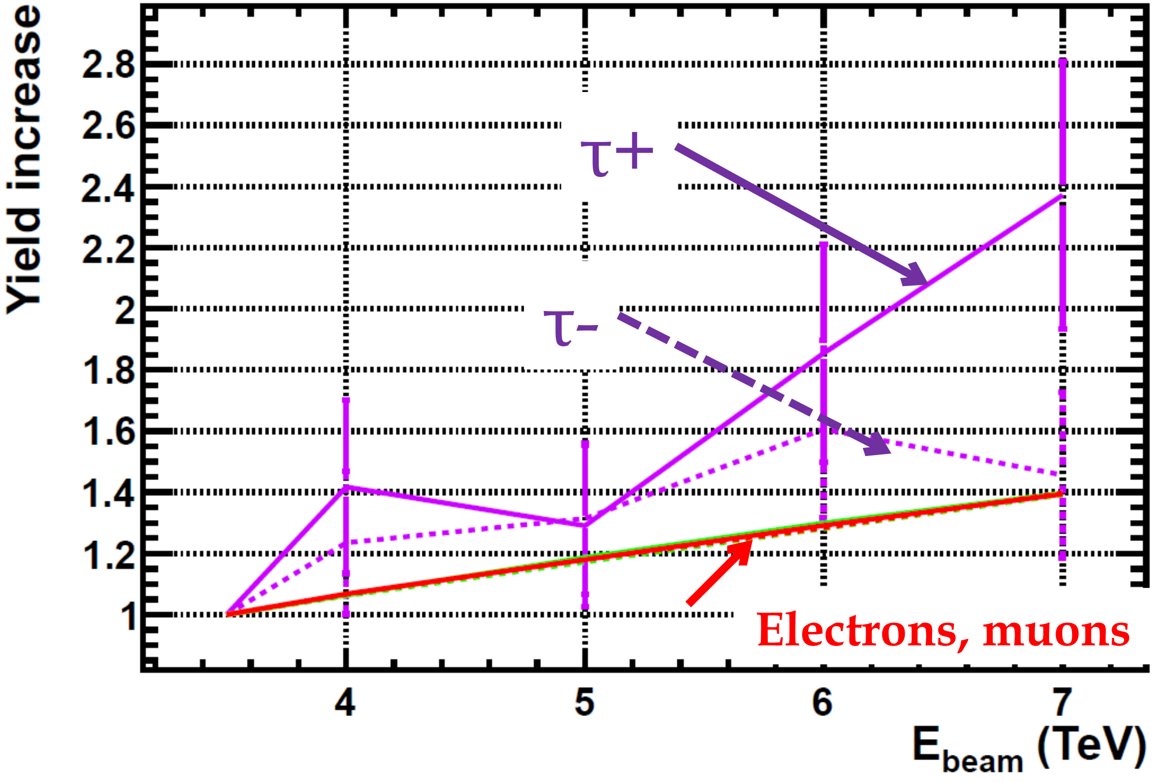


In particular, for the K0s decaying in the VELO the increase is "only" ~30% → This is the number we really care for Ks → μμ studies

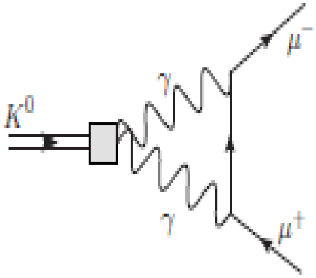
Leptons

Increase in tau yiled consistent with ~ 2 , expected by the fact that most of them come from b's and c's

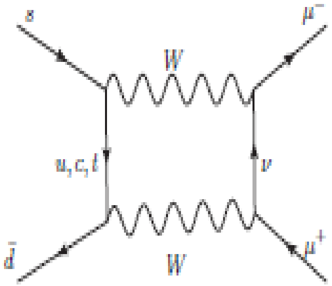
Check with more stats if the asymmetry +/- is still there

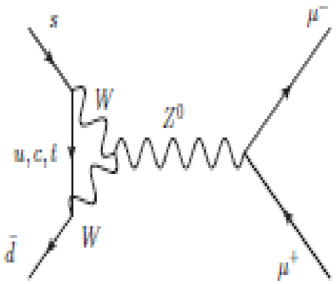


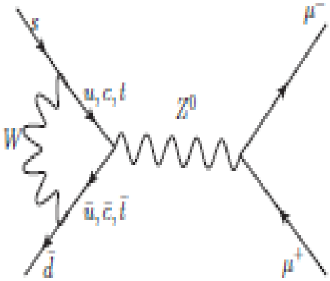
→ the long-distance (LD) contributions:

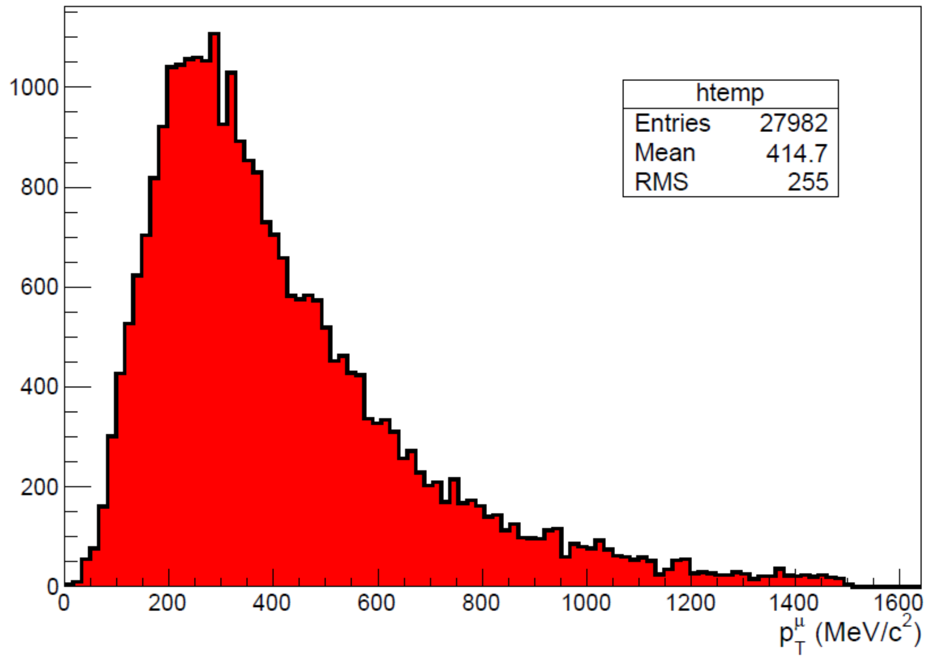


→ the short-distance (SD) contributions:





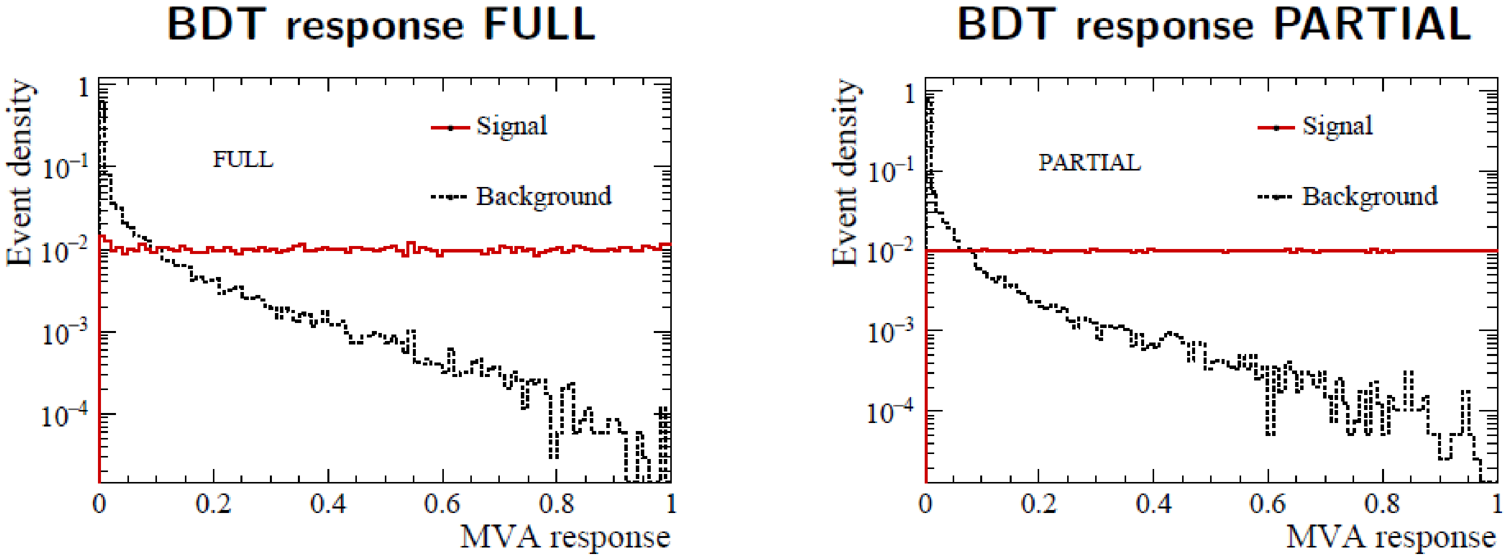



htemp
Entries 27982
Mean 414.7
RMS 255
1000
800
600
400
200
0
0
200
400
600
800
1000
1200
1400
1600
p_T^μ (MeV/c^2)

$K_S \to \pi^0\mu\mu$ sensitivity study

The background discrimination

V. Chobanova et al,
CERN-LHCb-PUB-2016-017



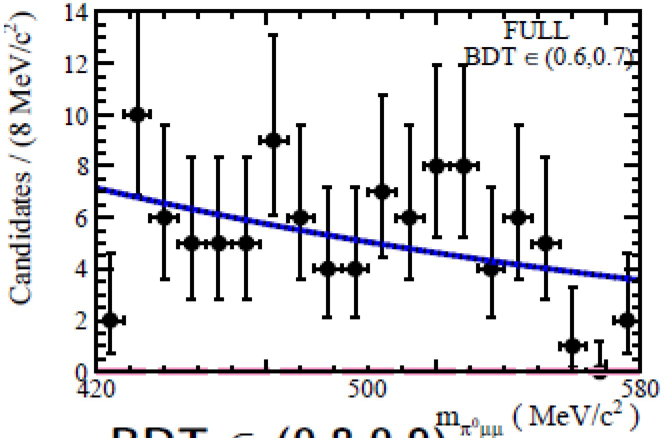
- As usual: BDT trained against combinatorial background
- Specific backgrounds: $\underbrace{K_S \to \pi\pi,\ K_L \to \pi\pi\pi}_{\text{Don't affect the sensitivity estimate}}$, $K_{S/L} \to \mu\mu\gamma\gamma$ (negligible)

$K_S \rightarrow \pi^0 \mu\mu$ sensitivity study

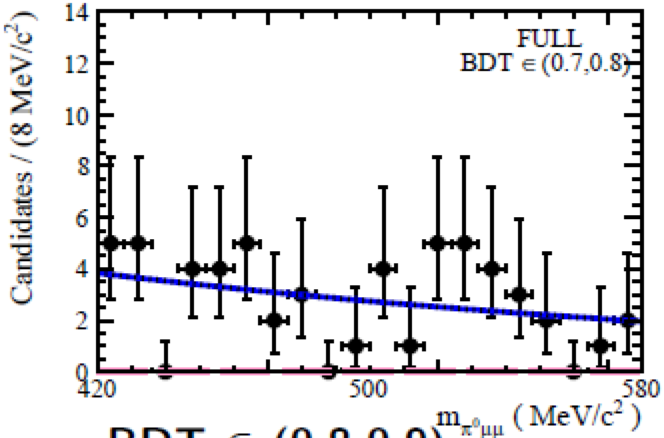
Fit, FULL

V. Chobanova et al,
CERN-LHCb-PUB-2016-017

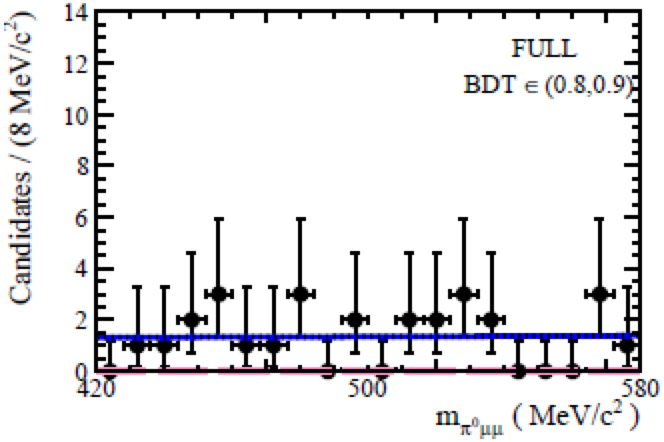
BDT ∈ (0.6,0.7)



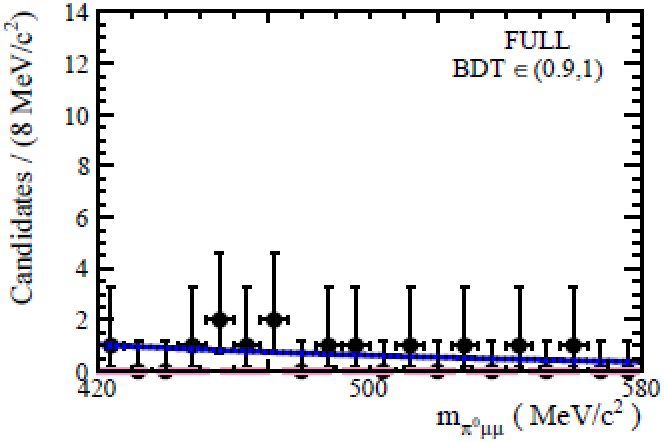
BDT ∈ (0.7,0.8)



BDT ∈ (0.8,0.9)



BDT ∈ (0.8,0.9)



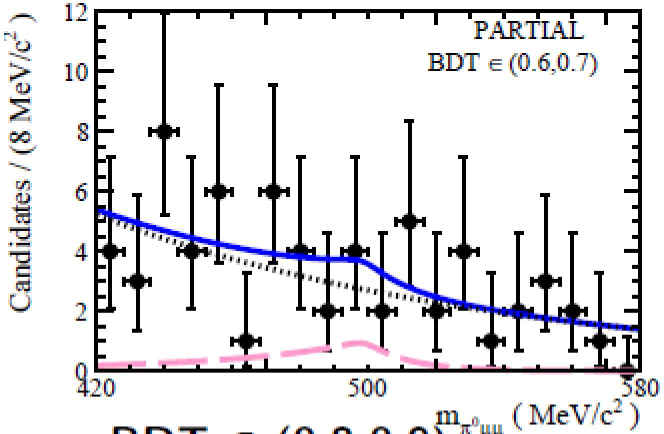
$K_S \to \pi^0 \mu\mu$ sensitivity study

Fit, PARTIAL

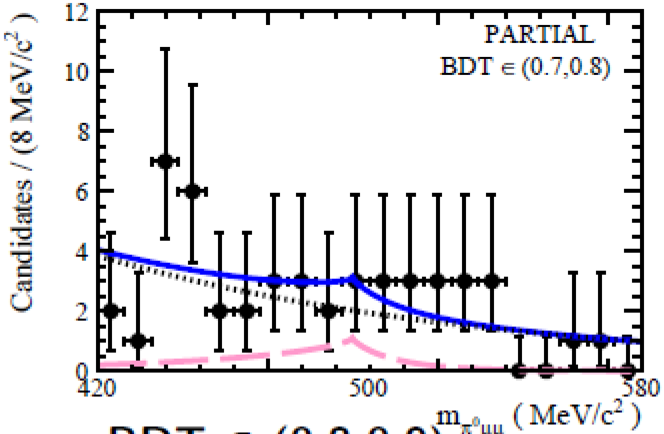
European Research Council

V. Chobanova et al,
CERN-LHCb-PUB-2016-017

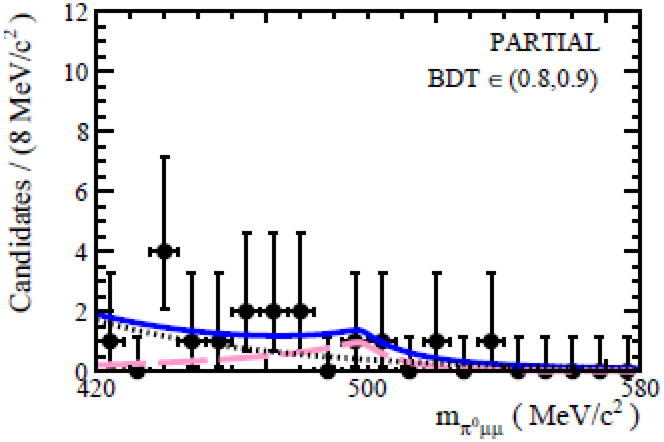
BDT ∈ (0.6,0.7)



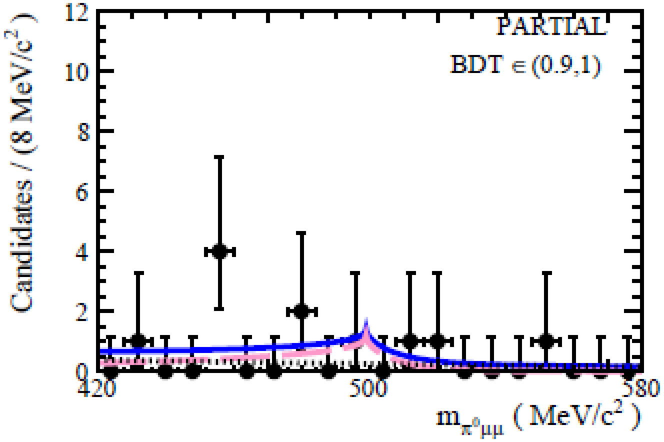
BDT ∈ (0.7,0.8)



BDT ∈ (0.8,0.9)

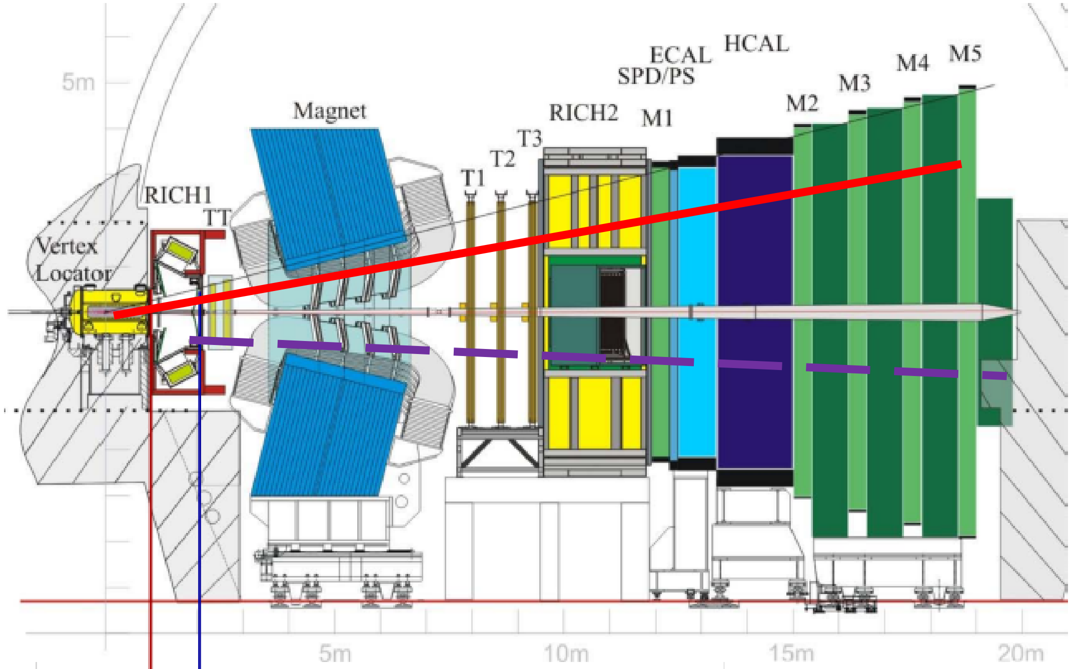


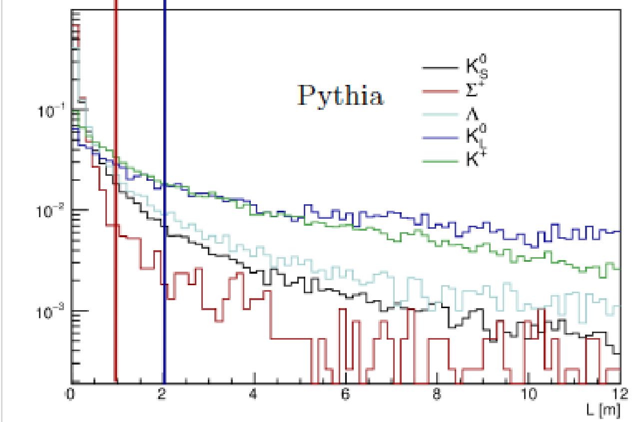
BDT ∈ (0.8,0.9)



Strangeness production/ detection at LHCb

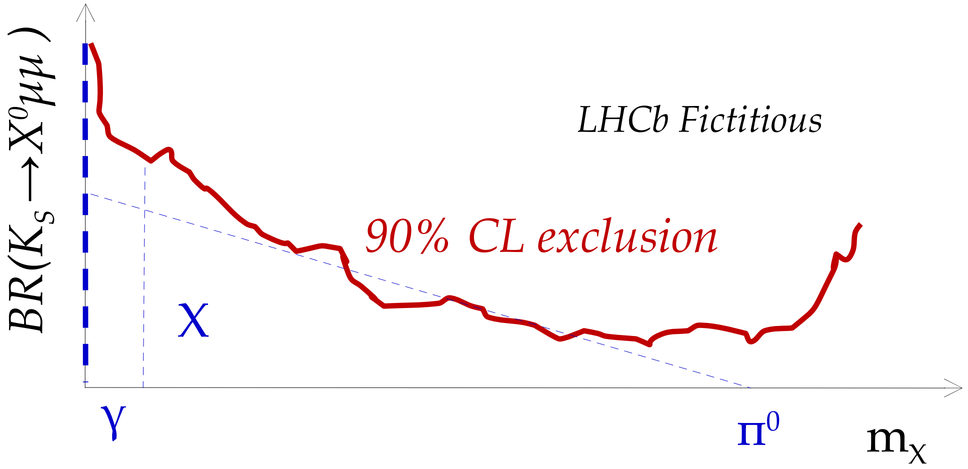
- The pp collisions @ LHC produce a ‘kaon flux’ of 10^{13} K_S per fb^{-1} of luminosity in the LHCb acceptance
- Charged decay products can be reconstructed using Long Tracks or Downstream Tracks
- We use Long Tracks for RnS
- Downstream will be investigated (extra yield, but worse reconstruction quality)



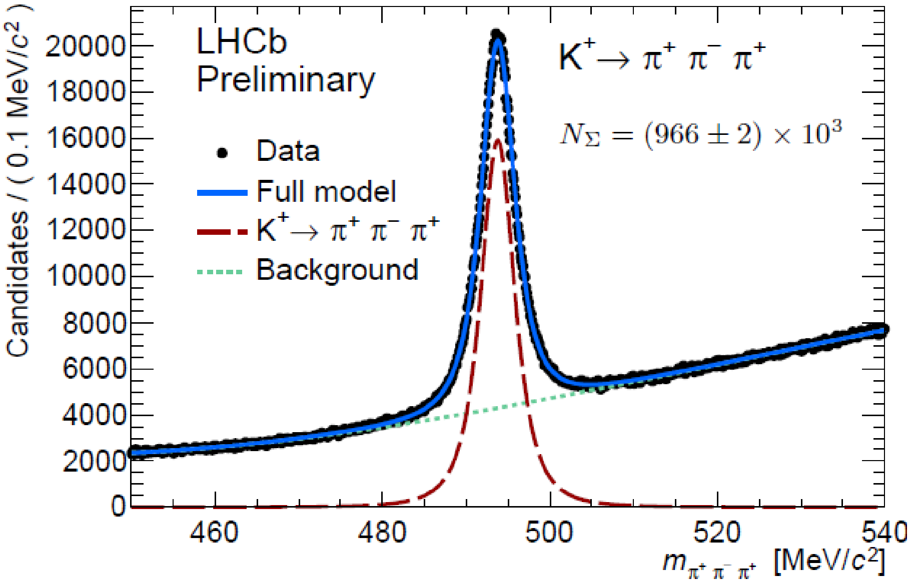


K_L , K_S produced in equal amounts. Acceptance ratio is ~$2\text{x}10^{-3}$ (for Long Tracks)

Ongoing stuff



K^+ studies



Large samples of charged kaon decays are available

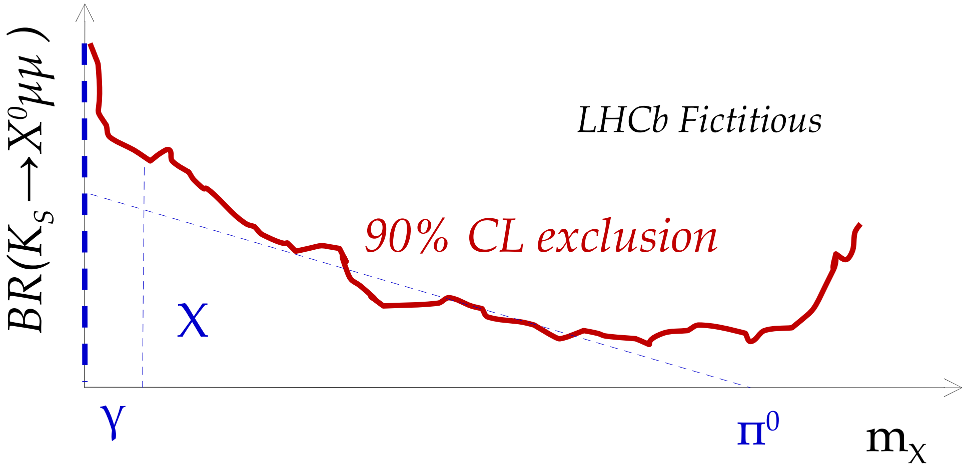
K^+ mass is not very well known

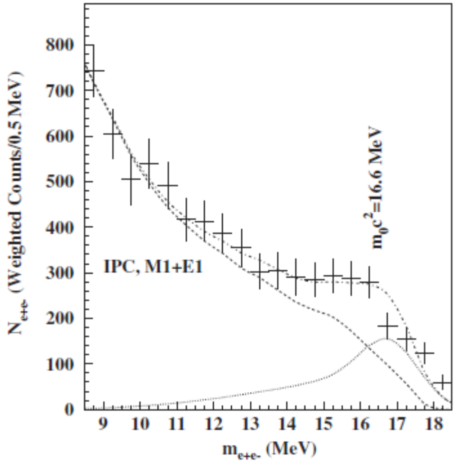
$K^+ \to \pi\mu\mu$?

$K_S \rightarrow X^0\mu\mu$

- The $K_S \rightarrow \pi^0\mu\mu$ PARTIAL analysis can be recasted for general/inclusive $K_S \rightarrow X^0\mu\mu$. With X being whatever neutral system:
    - $K_S \rightarrow \gamma\mu\mu$. Can also be completed with photon reconstruction
    - $K_S \rightarrow (l^+l^-)\mu\mu$. Some of them are also being searched for explicitly
    - Some exotic, eg, 17 MeV neutral boson of Phys. Rev. Lett. 116, 042501 (2016)

Limits can be provided as a function of X^0 mass

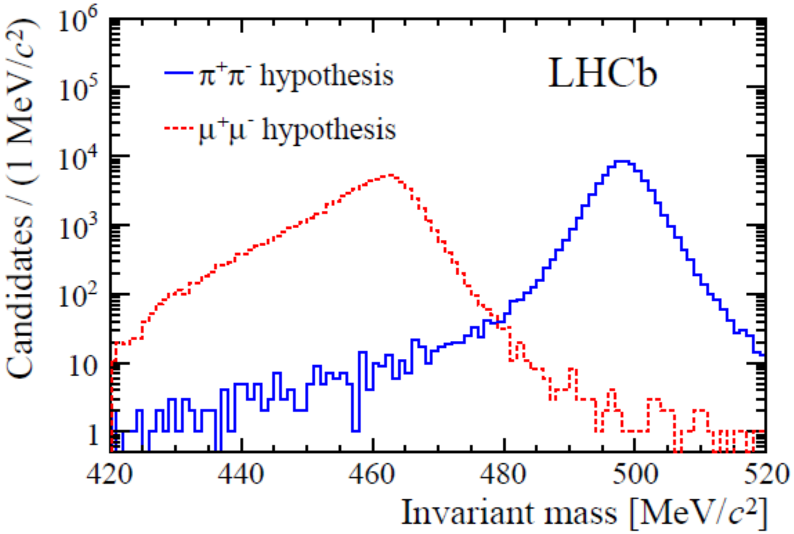




$K_S \rightarrow \mu\mu$ full Run-I analysis

arXiv:1706.00758 [hep-ex]

- Analysed full Run-I (2011-2012) data
- Events classified using a BDT trained against combinatorial background
- Dedicated muon identification algorithm trained against $K_S \rightarrow \pi\pi$
- Mass resolution 4 MeV



Background

$K_L \rightarrow \mu\mu$ negligible: (down to 10^{-11} precision)

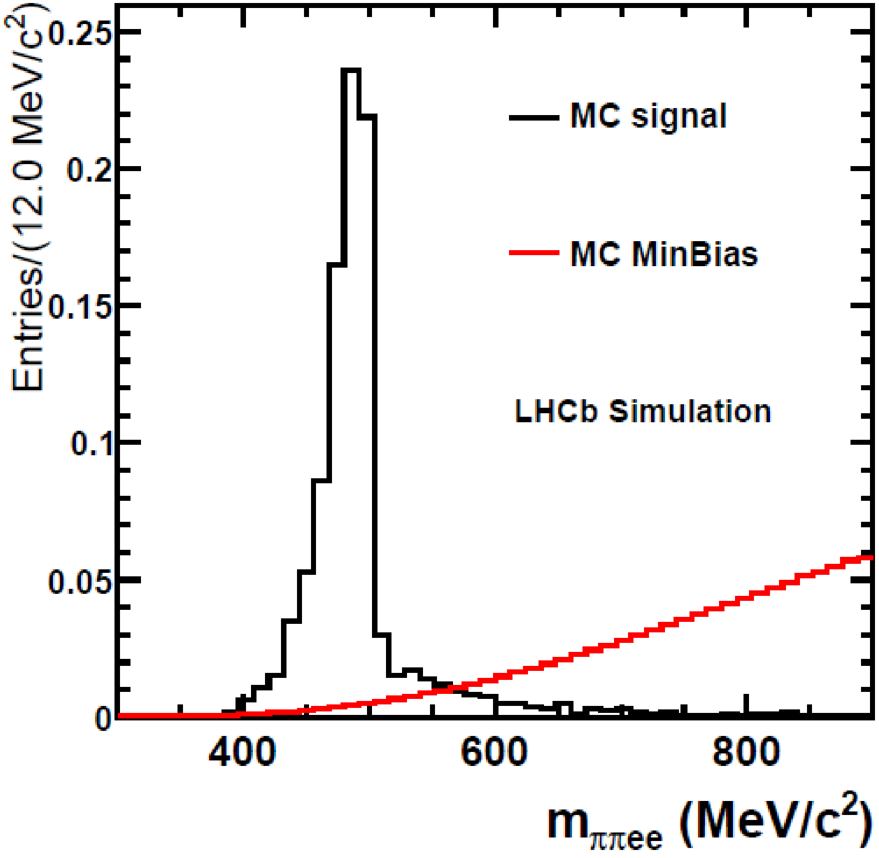
$K \rightarrow \pi\mu\nu$: negligible

$\Lambda \rightarrow p\pi$ removed by a cut in the Armenteros-Podolanski plot.

- **Combinatorial background**
- **$K_S \rightarrow \pi\pi$ double misid**

$K_S \to \pi^+\pi^- ee$ sensitivity study

C.Marin et al,
CERN-LHCb-PUB-2016-016



Based on simulation:

Expected a signal yield of

$$= 120^{+280}_{-100}$$

For the full Run-I dataset

Expected background yield is not well known yet

Why? ($K_S \to \pi^0\mu\mu$ and SM errors on $K_L \to \pi^0\mu\mu$)

$$\mathcal{B}(K_L \to \pi^0\mu^+\mu^-)_{\rm SM} = \{1.4 \pm 0.3, 0.9 \pm 0.2\} \cdot 10^{-11}$$

$$\mathcal{B}(K_L \to \pi^0 l^+ l^-) = \left(C^l_{\rm dir} \pm C^l_{\rm int}\,|a_S| + C^l_{\rm mix}\,|a_S|^2 + C^l_{\gamma\gamma} + C^l_S\right) \cdot 10^{-12}$$

$$|a_S| \;=\; 1.20 \pm 0.20$$

$$\begin{aligned}
C^e_{\rm dir} &= (4.62 \pm 0.24)\left[(\mathrm{Im}\,Y_A)^2 + (\mathrm{Im}\,Y_V)^2\right],\\
C^e_{\rm int} &= (11.3 \pm 0.3)\,\mathrm{Im}\,Y_V\,,\\
C^e_{\rm mix} &= 14.5 \pm 0.5\,,\\
C^e_{\gamma\gamma} &\approx C^e_S \approx 0\,,\\
C^\mu_{\rm dir} &= (1.09 \pm 0.05)\left[2.32\,(\mathrm{Im}\,Y_A)^2 + (\mathrm{Im}\,Y_V)^2\right]\\
C^\mu_{\rm int} &= (2.63 \pm 0.06)\,\mathrm{Im}\,Y_V\,,\\
C^\mu_{\rm mix} &= 3.36 \pm 0.20\,,\\
C^\mu_{\gamma\gamma} &= 5.2 \pm 1.6\,,\\
C^\mu_S &= (0.04 \pm 0.01)\,\mathrm{Re}\,Y_S + 0.0041\,(\mathrm{Re}\,Y_S)^2\,.
\end{aligned}$$

Dominant uncertainty, that makes difficult potential BSM interpretation of $K_L \to \pi^0\mu\mu$

It comes from the **experimental uncertainty** on BR($K_S \to \pi^0\mu\mu$) measured by NA48

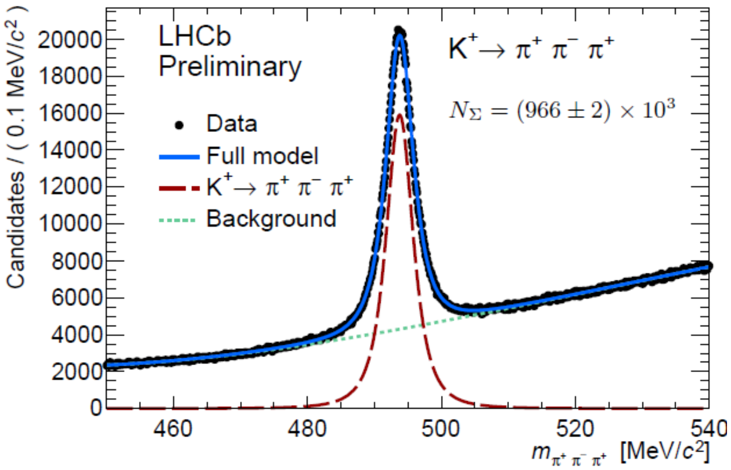
$K^0_S \to \pi^0\mu^+\mu^-$	NA48	$(2.9\,^{+1.5}_{-1.2}) \times 10^{-9}$

~50% relative error

Improved measurements of BR($K_S \to \pi^0\mu\mu$) will translate into improved BSM constraints from $K_L \to \pi^0\mu\mu$

Charged kaons

- K^+ mass in $K \to 3\pi$



- Under study sensitivity to $K^+ \to \pi^+\mu\mu$ vs NA62
  - Benefits from the new dimuon triggers (the same way as $K_S \to \mu\mu$)