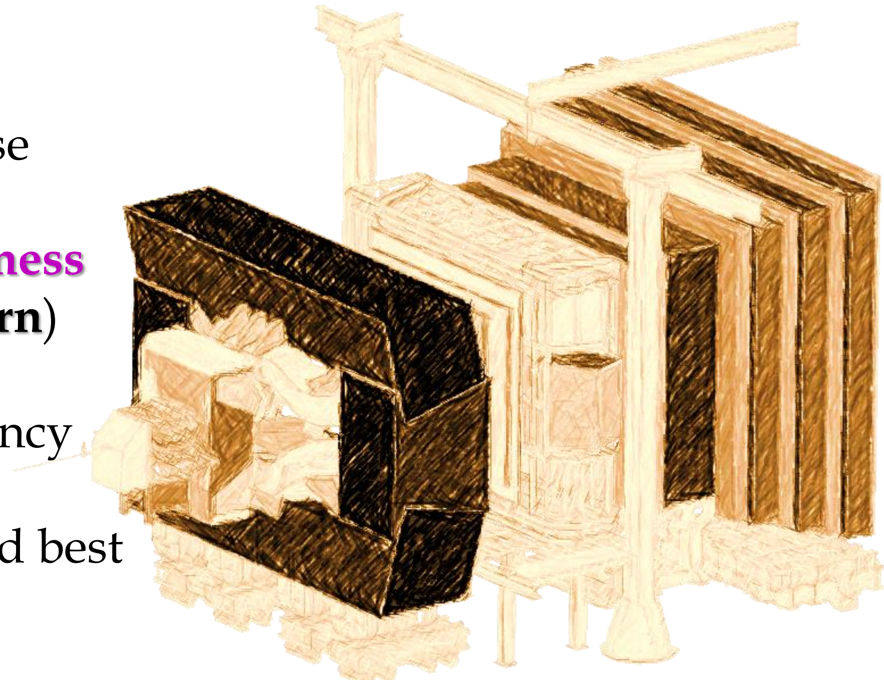
A strange program for the LHC

Diego Martínez Santos

Introduction

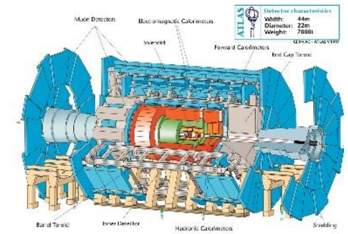
- LHCb experiment at LHC
  - Designed mostly for **b** and **c** decays
    → ~zero trigger efficiency otherwise
  - But there is also an ~infinite **strangeness** production at LHC (kaon xs ~ 1.2 **barn**)
  - Infinite production times zero efficiency requires L'Hopital
    - In 2011 we managed to get world best result in $K_S \to \mu\mu$
  - Major improvements in the trigger for **s** decays done for Run-II (2016-2018), and ongoing for Upgrade (>=2021)



Trigger system: status and prospects

L0
(Hardware)

Main bottleneck for K. Can't be changed



Typical PT

~30-40 GeV

HLT1
(Software)

HLT2
(Software)

Not designed for K, but flexible.

K triggers being implemented

B-physics ~ 1-2 GeV

s-physics ~0.08 GeV

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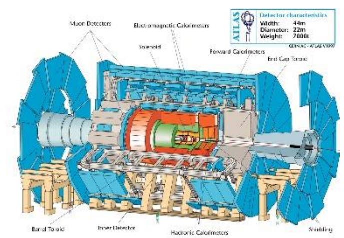

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ε(2011-2012) ~ 1-2%
ε(Run-II) improved HLT ~ 18% (dimuons)
Maximum allowed by L0 ~30%

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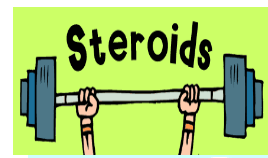
LHCb Upgrade



(Note: This logo may not be official)

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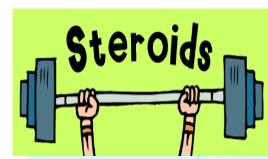

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HLT
(Software)

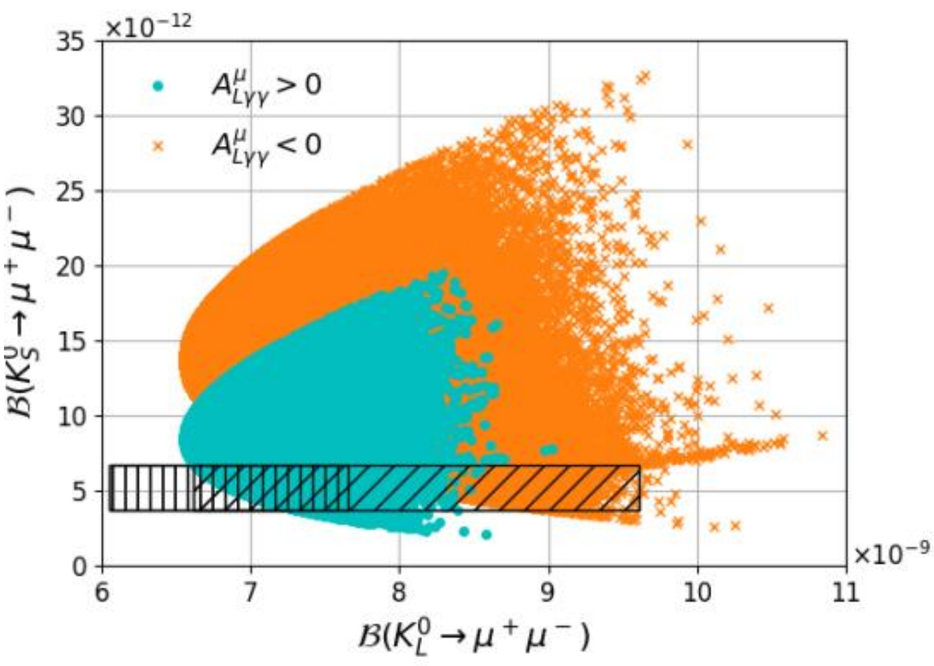
ε(2011-2012) ~ 1-2%
ε(Run-II) improved HLT ~ 18% (dimuons)
Maximum allowed by L0 ~30%

ε(Upgrade) ~ 80-100%

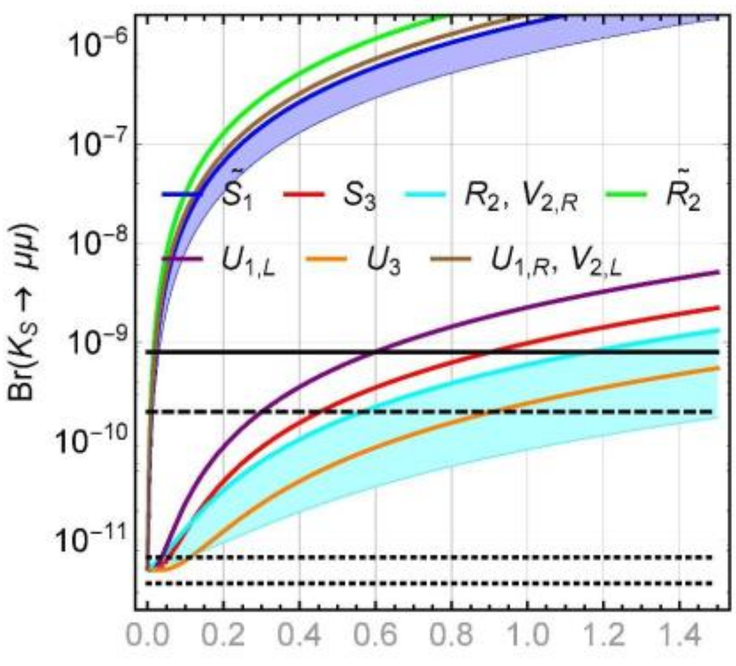
V. Chobanova et al, CERN-LHCb-PUB-2016-017

$K_S \to \mu\mu$: 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



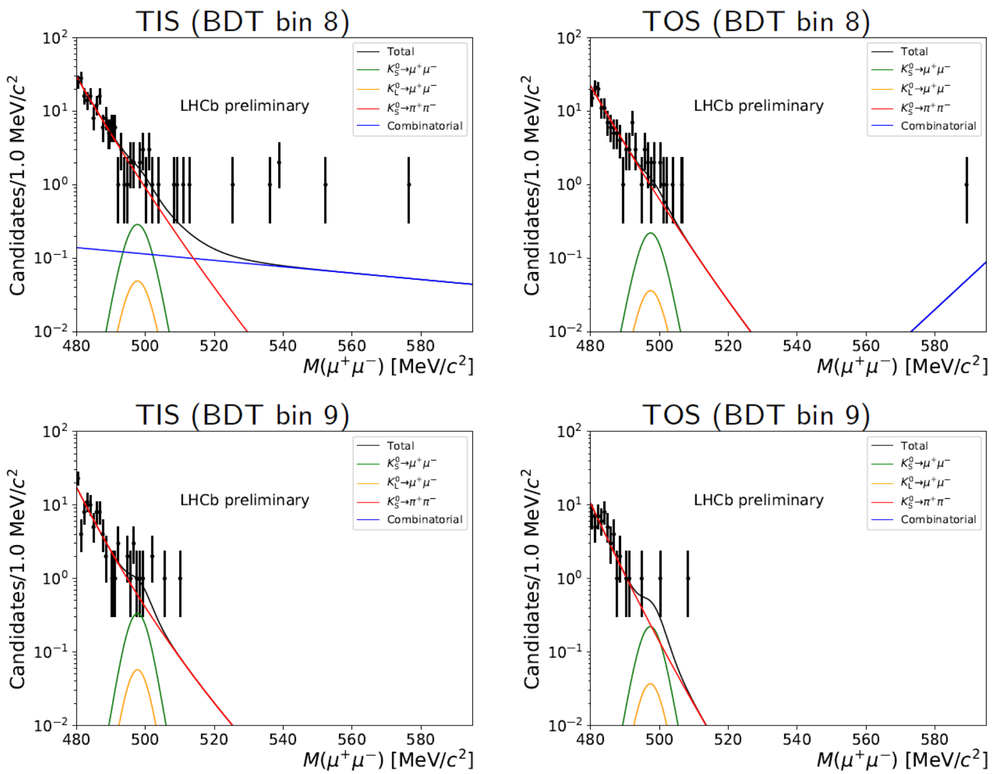
Example of a SUSY scenario from V.Chobanova et al., JHEP05(2018) 024



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

$K_S \to \mu\mu$ latest result

arxiv: 2001.10354



[LHCB-CONF-2019-002]

Full LHCb dataset analysed (9 fb^{-1})

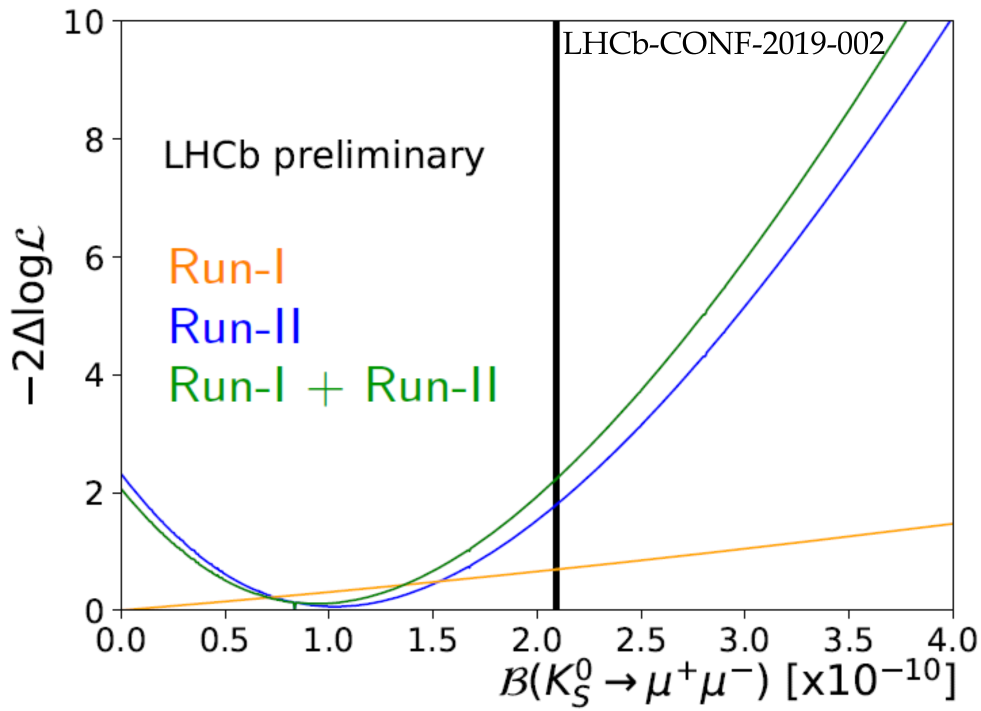
Benefits from huge (~1 order of magnitude) improvements in trigger for Run II

P_T muon thresholds at HLT: 80 MeV

No evidence for signal (1.4σ)

$K_S \rightarrow \mu\mu$ latest result

arxiv: 2001.10354



Full LHCb dataset analysed (9 fb^{-1})

No evidence for signal (1.4σ)

world best upper limit

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

At 1σ: $\mathcal{B}\left(K^0_S \rightarrow \mu^+\mu^-\right) = 0.94^{+0.72}_{-0.64} \times 10^{-10}$

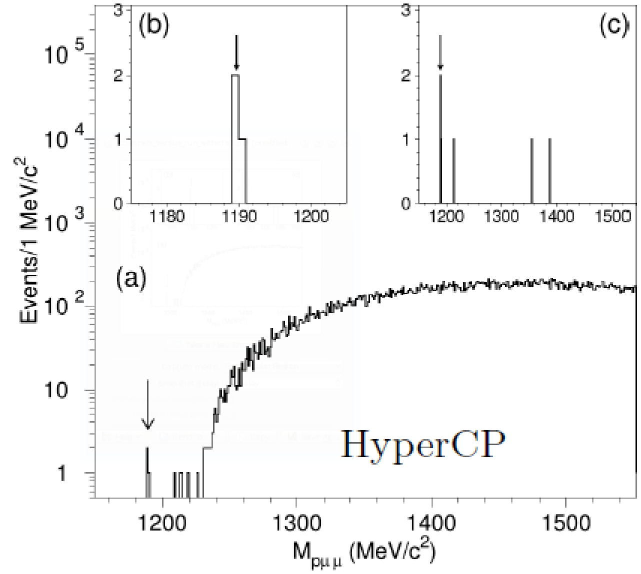
The HyperCP evidence

arxiv: 2001.10354

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

$$\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) = (8.6^{+6.6}_{-5.4} \pm 5.5) \cdot 10^{-8}$$

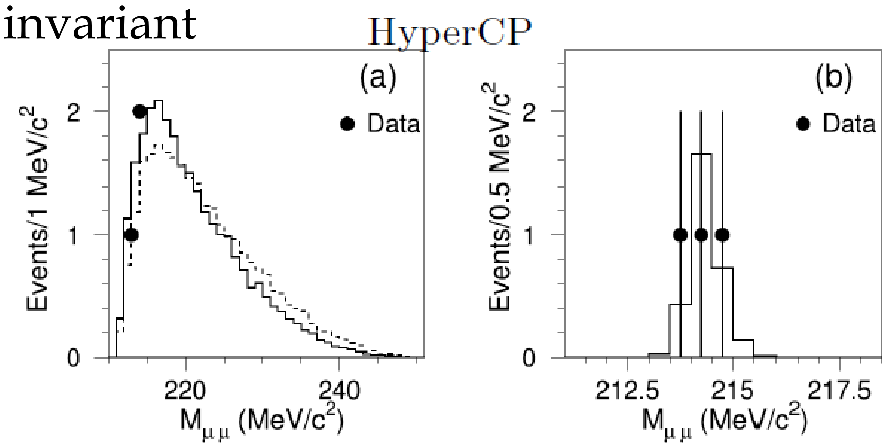
[Phys.Rev.Lett. 94 (2005) 021801]



- 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)

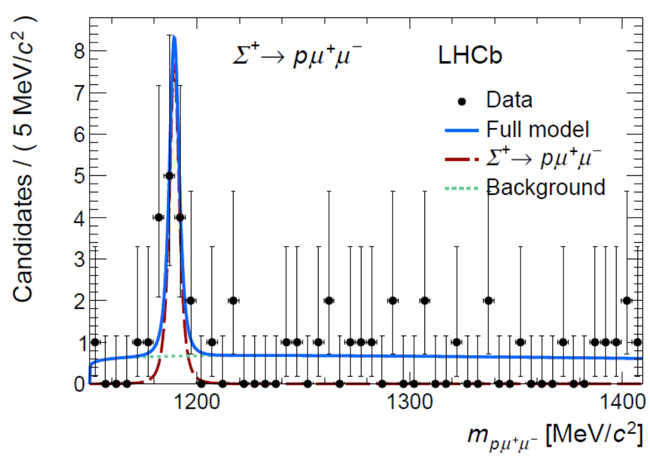


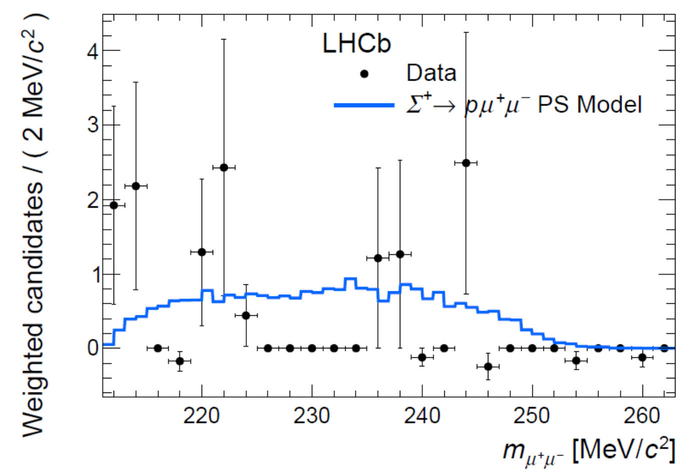
- Suggested the existence of a new neutral particle at that mass

Σ→pμμ

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

- Current result Σ→pμμ : Found 4σ evidence BR(Σ→pμμ) :$2.1^{+1.6}_{-1.2}$ x 10^{-8}, no evidence of resonant dilepton state
- Run-II: We expect ~150 signal events → measure AFB
- Upgrade(s): Full differential decay rate



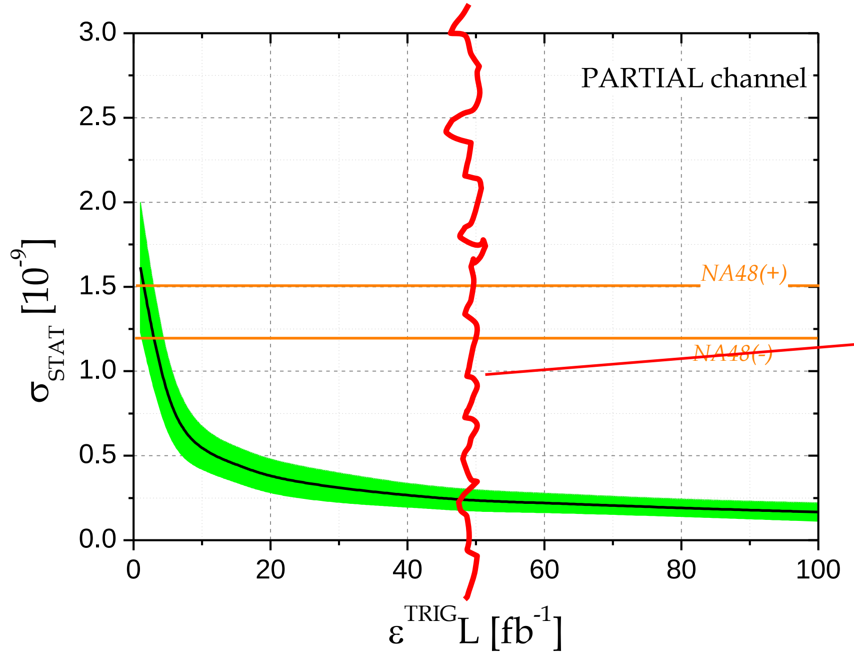


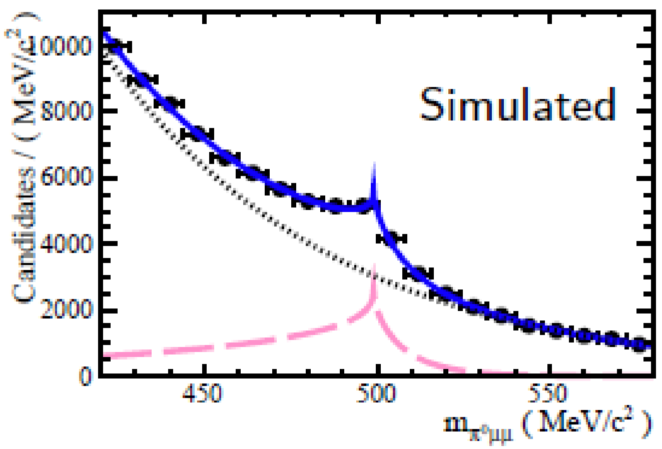
10y ago we thought this channel was ~impossible and instead now we are even thinking on an amplitude analysis….

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

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

arXiv:1808.03477 [hep-ex]





LHCb-upgrade

Phase-II-upgrade? →

$|a_S|$=1.2±0.2 from NA48 fixing b_S from VMD
PLB599 (2004) 197-211,

Table 4: Projected statistical uncertainties on a_S under various 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

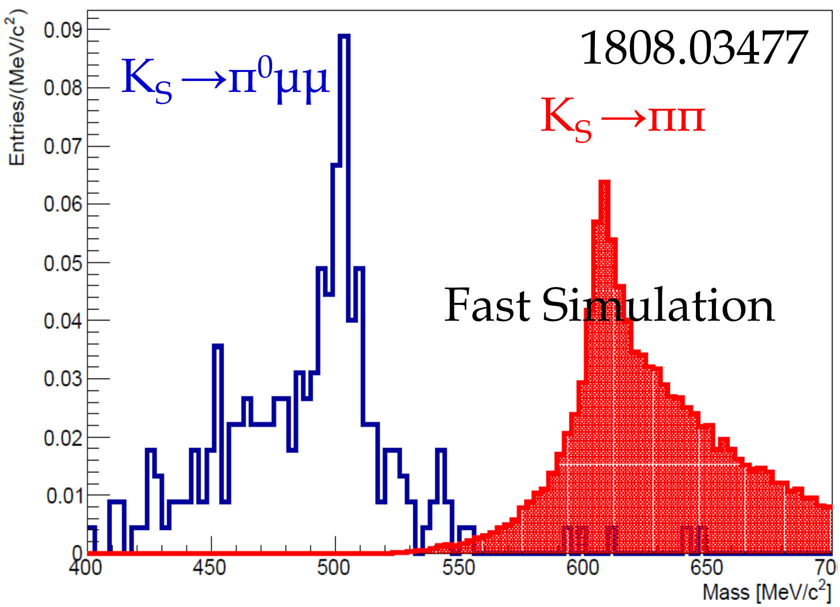
(fixing b_S)

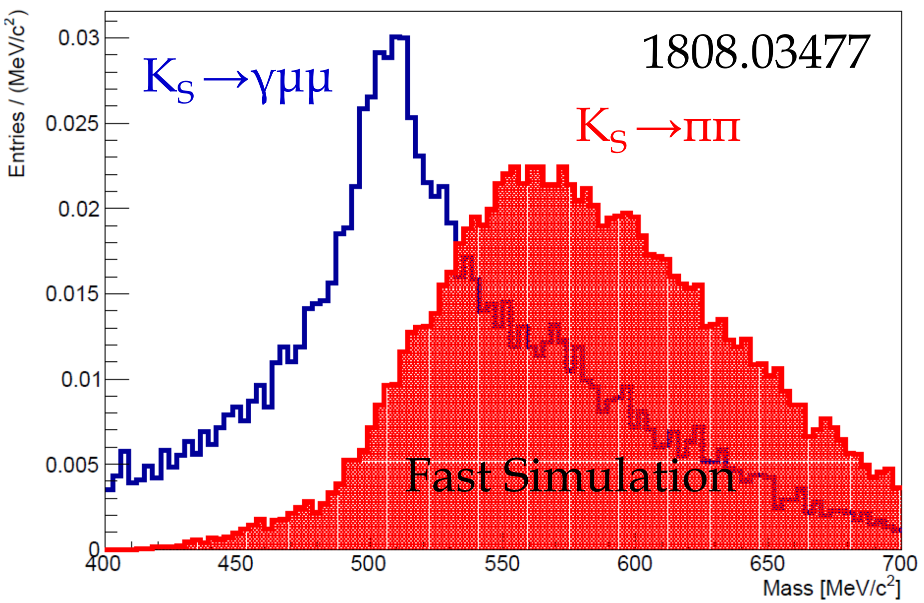
Much more bkg than $K_S \to \mu\mu$,
but also 1000x more signal

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

arXiv:1808.03477 [hep-ex]

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





Semileptonic decays

arXiv:1808.03477 [hep-ex]

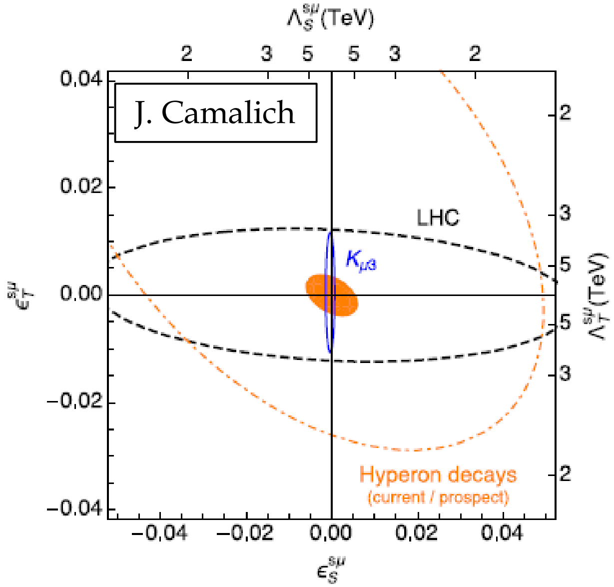
- Semileptonic Hyperon Decays (SHD)

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

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



(extrapolations from 1412.8484)

Gonzalez-Alonso & JMC, NA62 Phyics Handbook

https://indico.cern.ch/event/590880/contributions/2485320/

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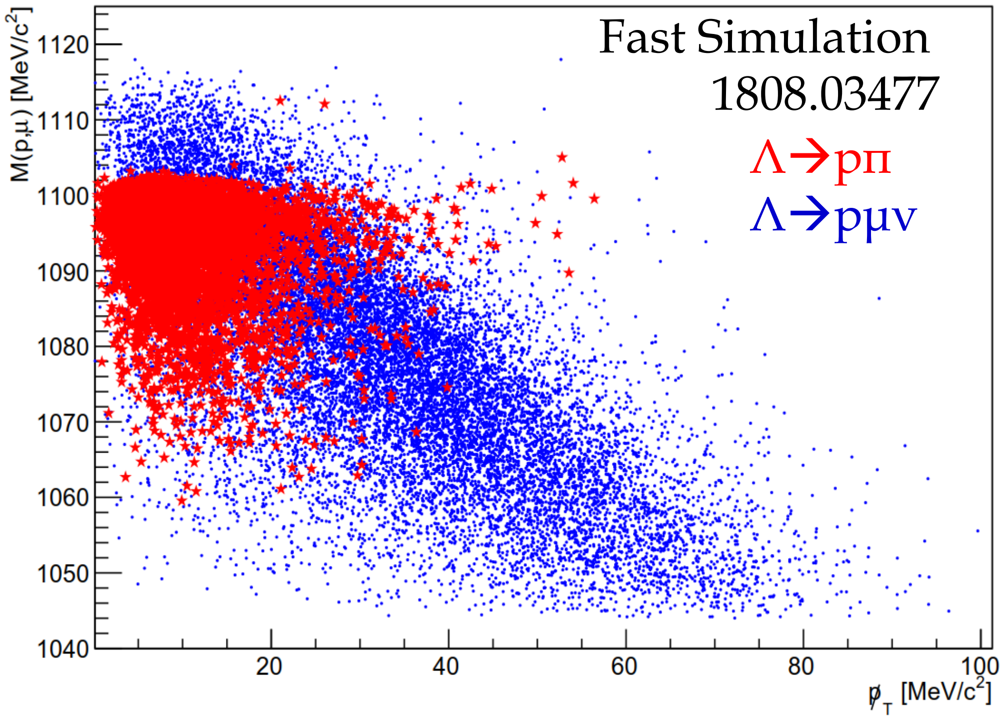
- ☹ Challenging peaking backgrounds:



For each
B1 → B2 μν there is always a
B1 → B2π (inc. →B2μν)

☺ Can be separated in search planes

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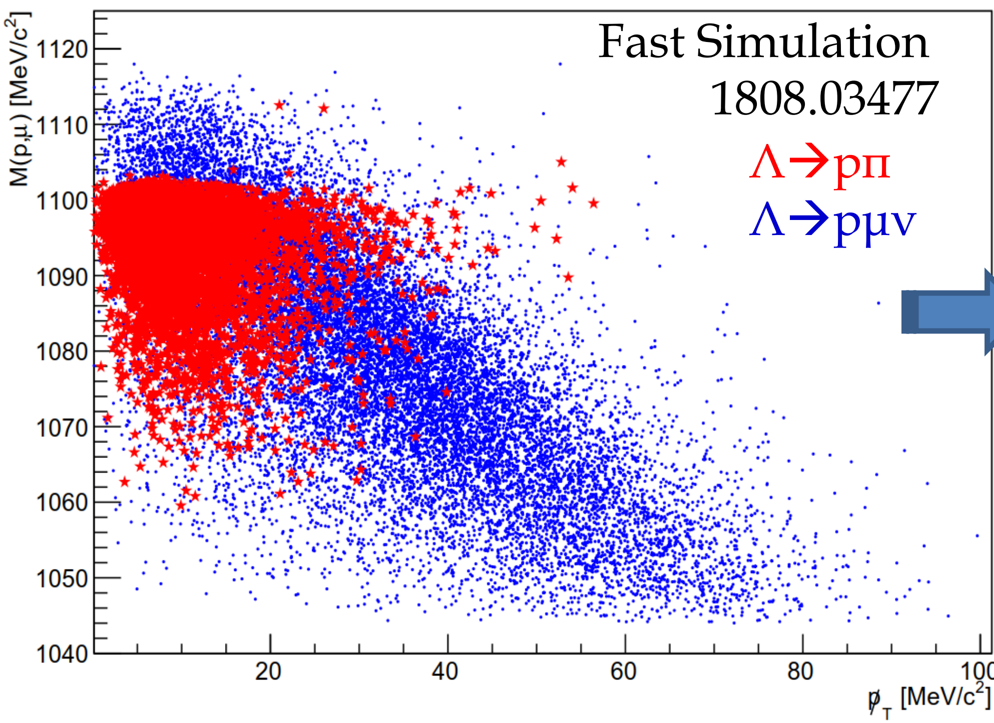

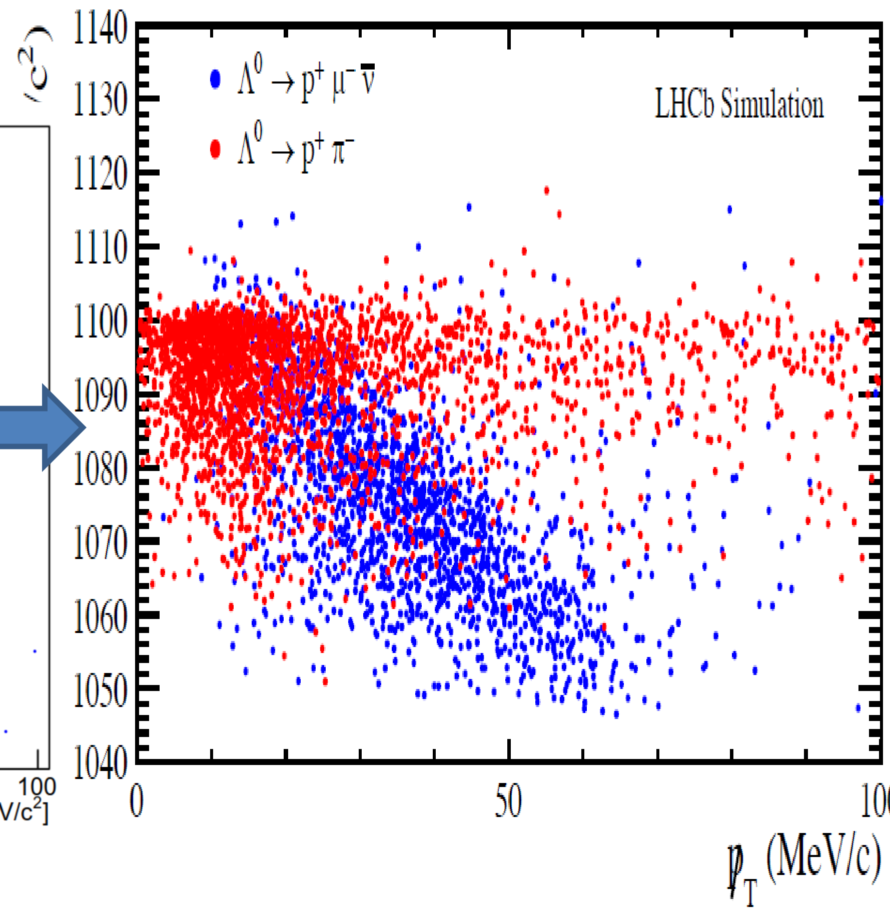

Expected O(7k) signal events per fb^{-1} → very good stat precision

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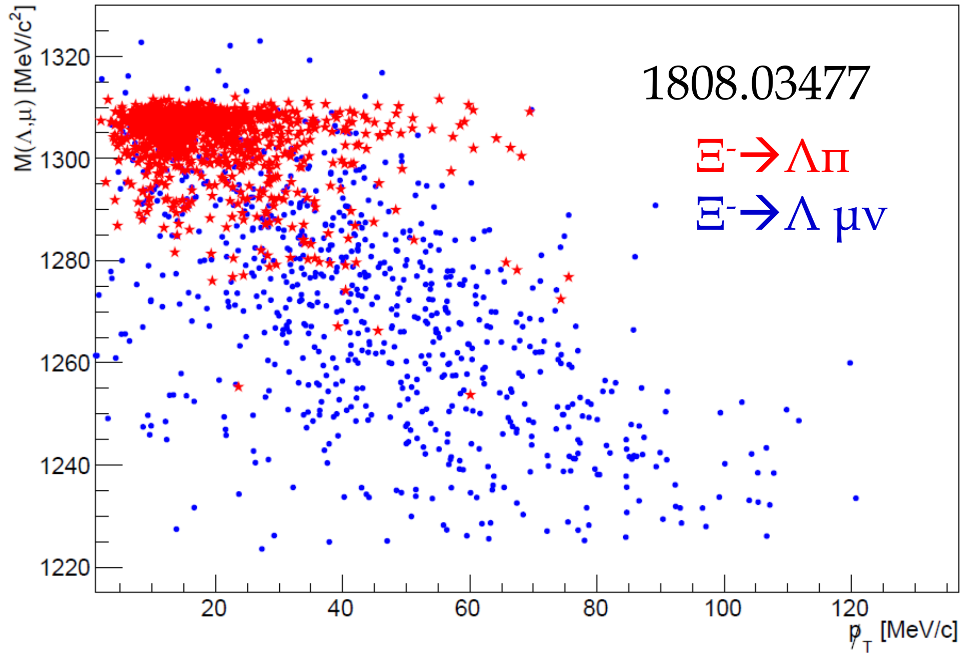
Fast Simulation



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Lepton Flavour Violation

arXiv:1808.02006 [hep-ex]

- Lepton Flavour Violation is a hot topic nowadays

LHCb can do:

$K_S \rightarrow e\mu$

No limit exits so far
$K_L \rightarrow e\mu < 4.7 \times 10^{-12}$ BNL, *PRL* **81** (1998) 5734–5737
$K_S \rightarrow e\mu$ is a LFV model discriminator

Lepton Flavour Violation

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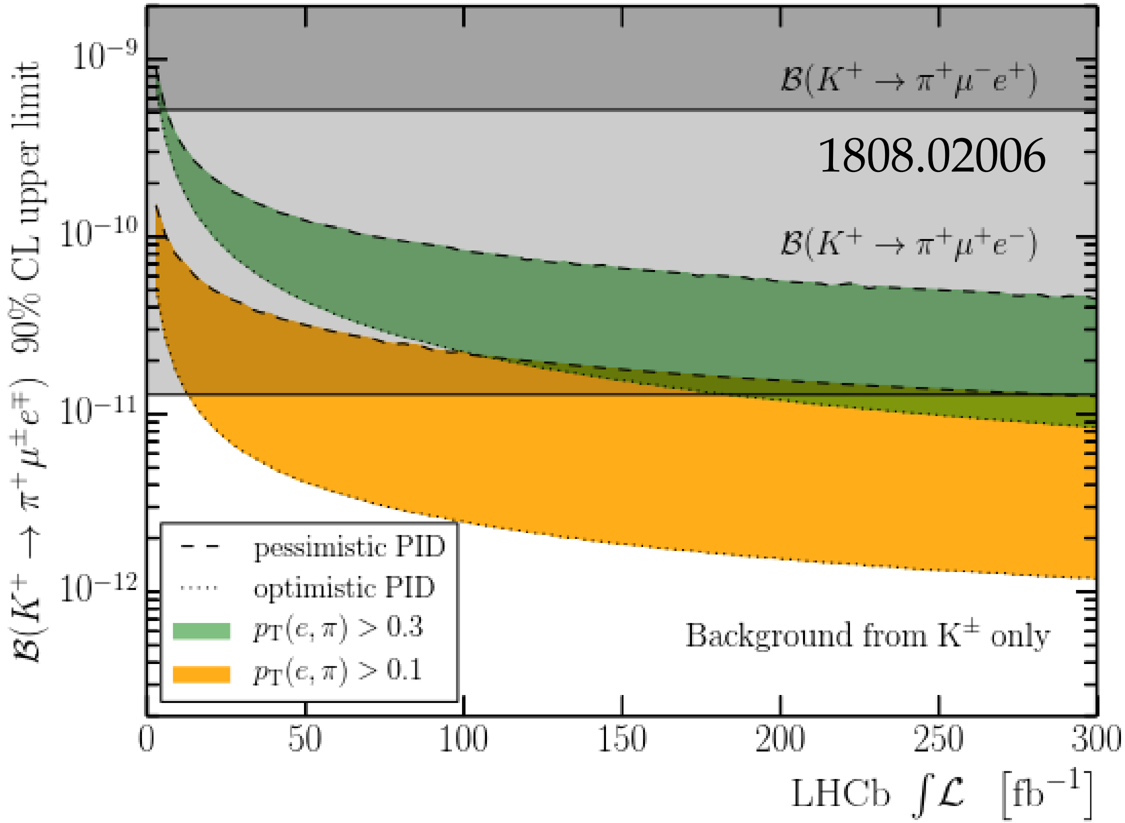
LHCb can do:

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



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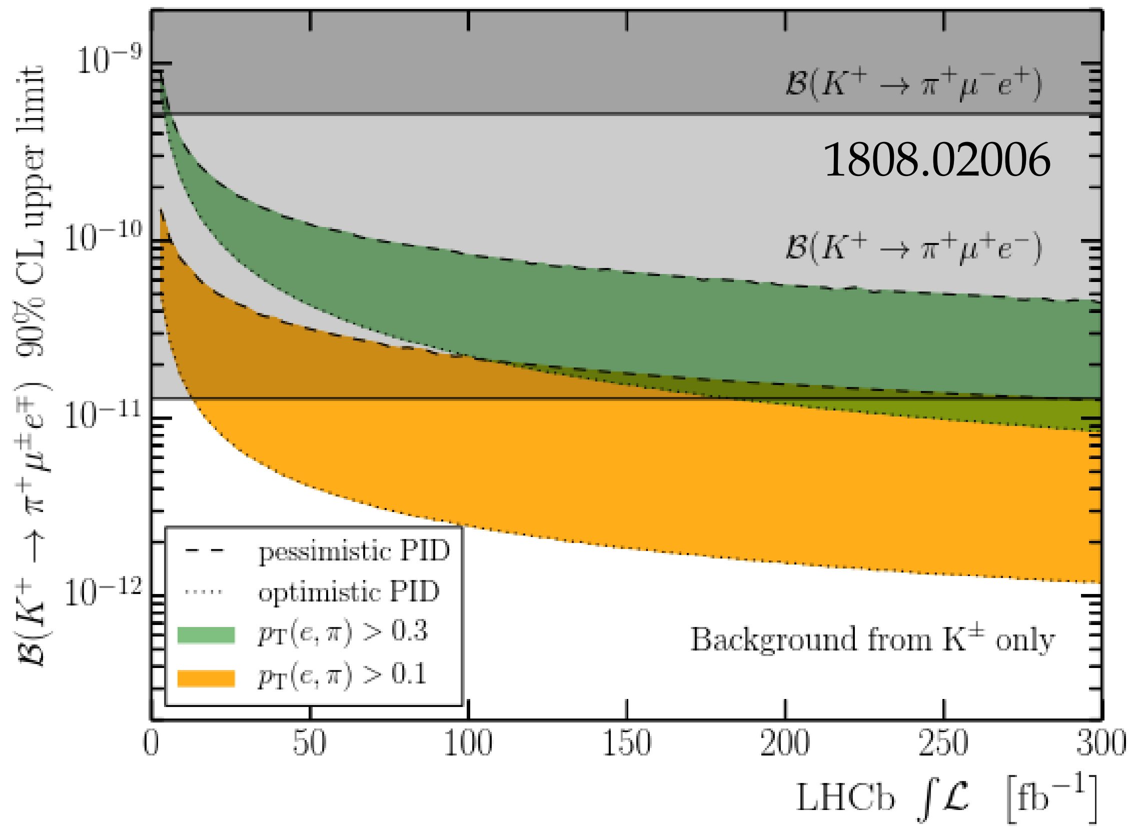
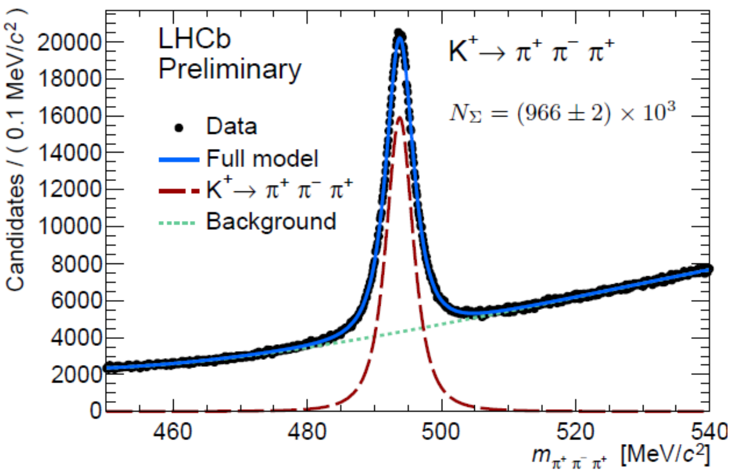
$K_S \to e\mu$
$K^+ \to \pi^+\mu^-e^+$
Maybe $K^+ \to \pi^+\mu^+e^-$

Competition w/ NA62 to be clarified

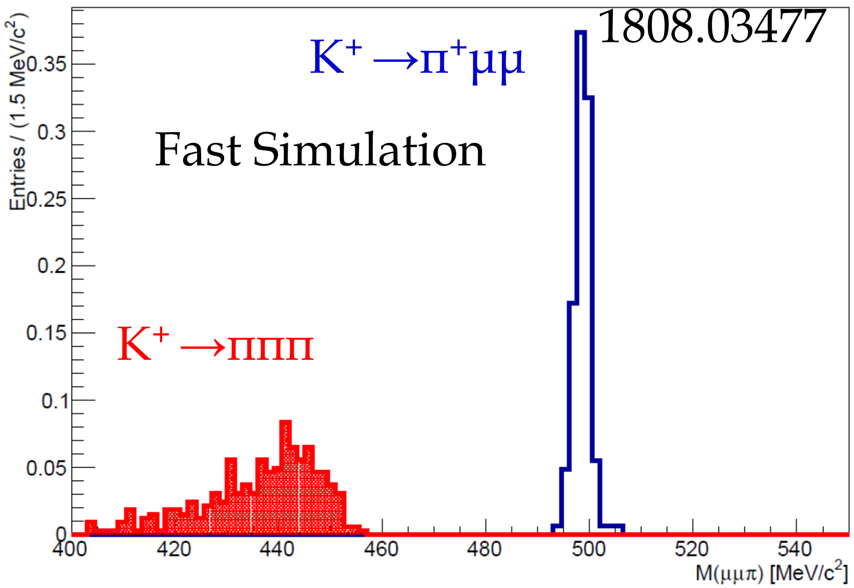


Charged kaons



- 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 $K_S \to \mu\mu$)



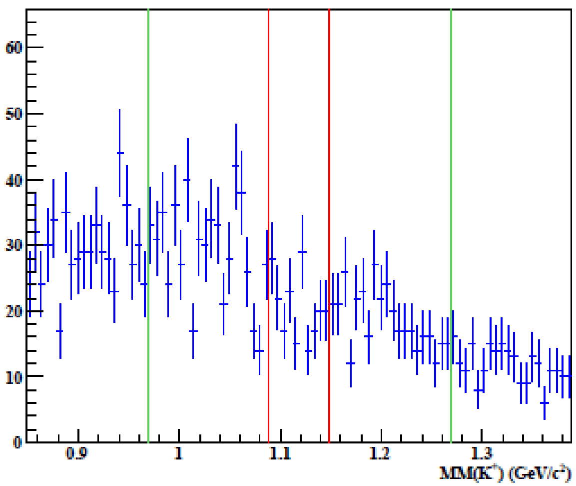
Others: Dark Baryons, 4 body kaon decays

- B-mesogenesis: G. Alonso-Alvarez et al, arXiv:2101.02706
- LHCb potential using b-hadrons: V. Chobanova et al. arXiv:2106.12870
- Using hyperons (follow same strategy as the arxiv above):
  - $\Xi 0 \rightarrow \pi\pi X$
    - ~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
    $\rightarrow$ ~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)

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

B and L violation

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



Reaction	$\mathcal{B}_{\mathrm{UL}}$
$\Lambda \to K^+ e^-$	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:

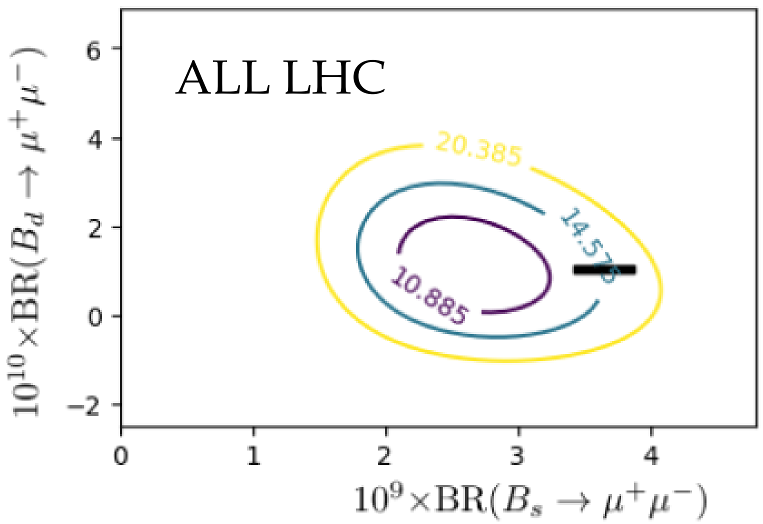
- $\Sigma \rightarrow 3\mu$
- $\Lambda \rightarrow \pi 3\mu$

…and many other crazy (J conserving) combinations.

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

Backup

$$\mathrm{BR}(B_s \to \mu^+\mu^-) = 2.65^{+0.43}_{-0.39} \times 10^{-9}, \qquad \mathrm{BR}(B_d \to \mu^+\mu^-) = 1.09^{+0.74}_{-0.68} \times 10^{-10}.$$

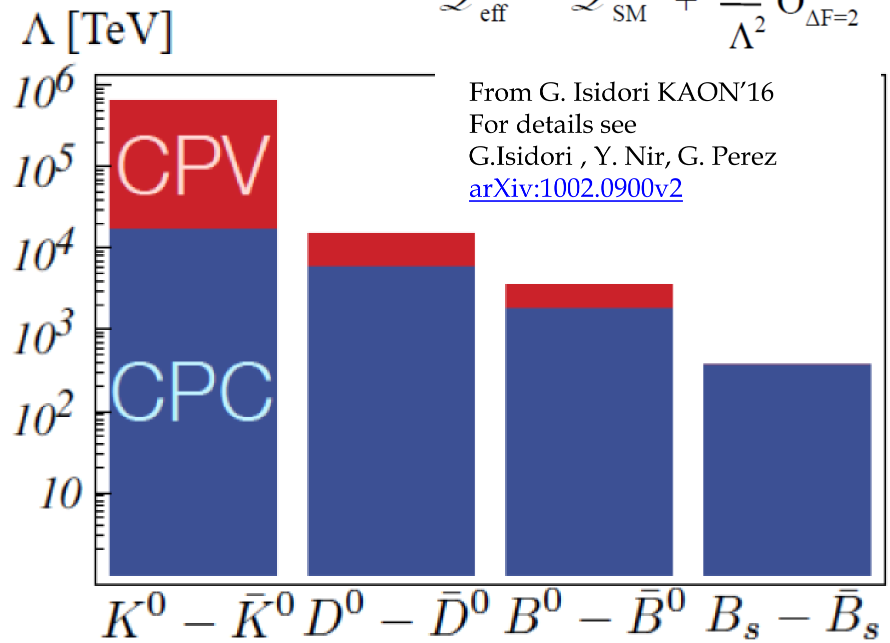


https://arxiv.org/pdf/1904.08399.pdf

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)

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



- 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

- $K_{\ell 3}$

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

- $K_{\ell 2}$

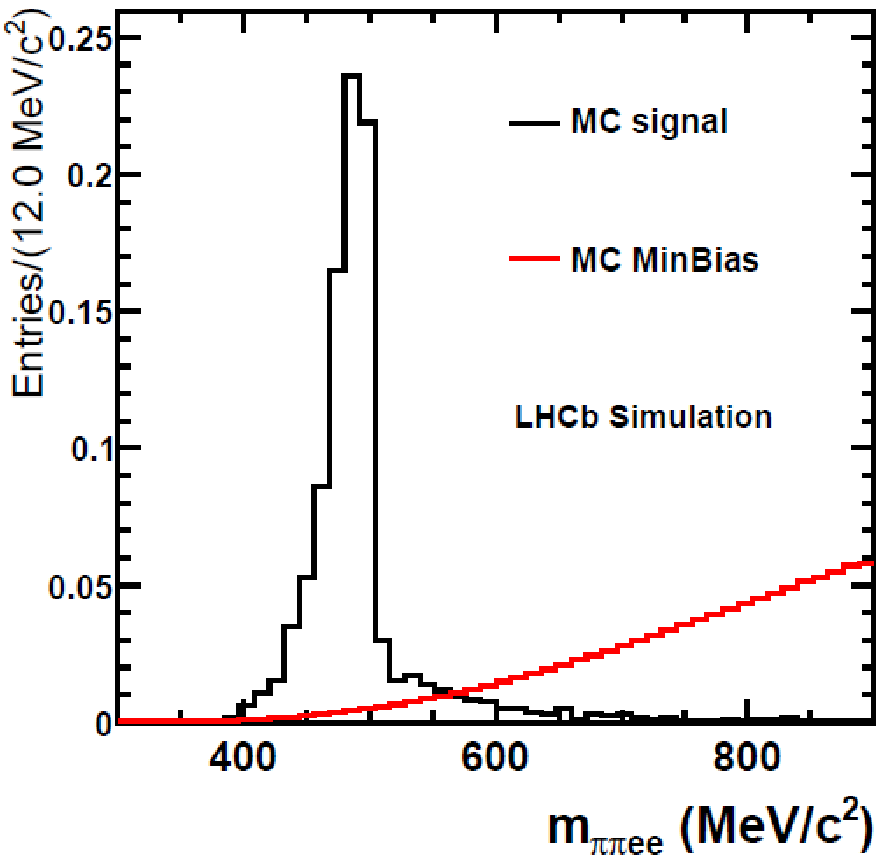
$$\Gamma_{K_{\ell 2(\gamma)}} = \frac{G_F^2 m_K\, m_\ell^2}{8\pi}\left(1-\frac{m_\ell^2}{m_P^2}\right)^2 |\tilde{V}_{us}^{\ell}|^2 f_{K^\pm}^2 \left(1-4\epsilon_R^{s}-\underbrace{\frac{2B_0}{m_\ell}}_{\chi \text{ enh.}}\epsilon_P^{s\mu}\right)$$

- $|\tilde{V}_{us}^{\ell}|$ 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

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

For the full Run-I dataset

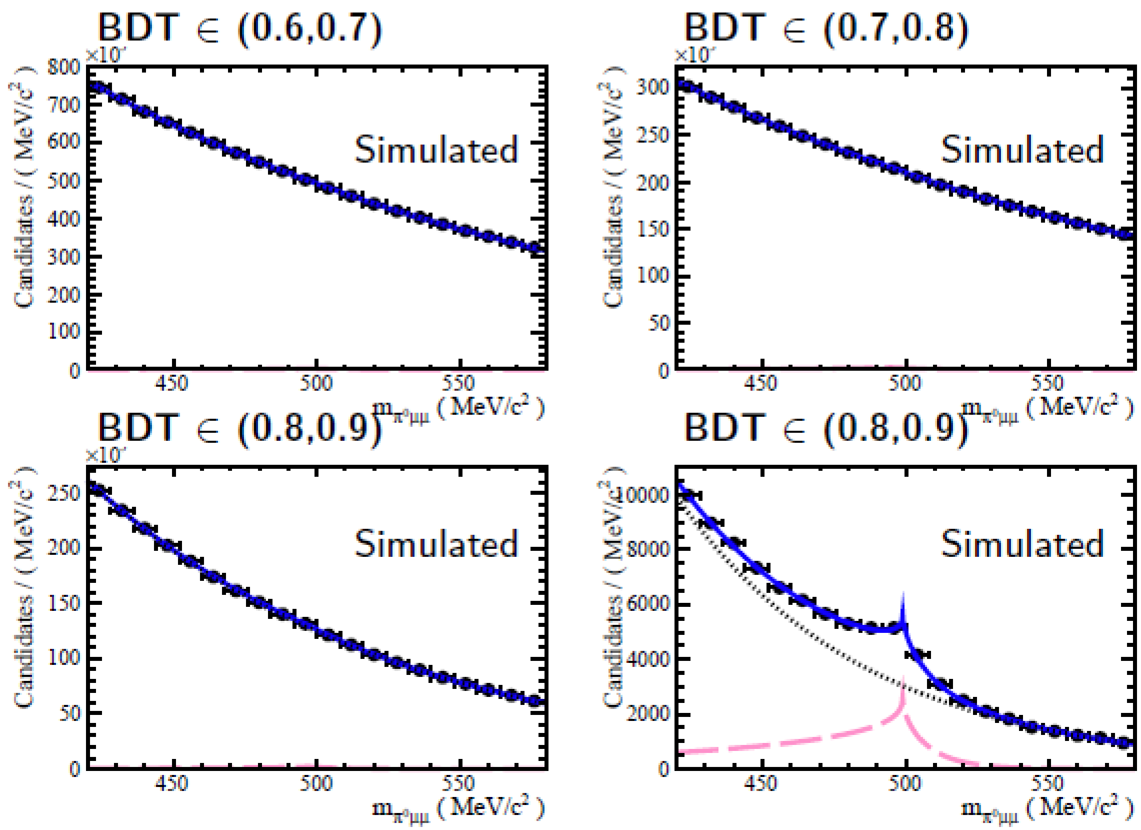
Expected background yield is not well known yet

K0 tagging?

arXiv:1808.03477 [hep-ex]

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

Toy MC for $50\mathrm{fb}^{-1}$



Lifetime acceptance and $K_L \to \mu\mu$ 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

$\epsilon(t) \sim e^{-\beta t}$ With $\beta \gtrsim 5 \mathrm{x} \Gamma_S$ ($\gg \Gamma_L$).

This makes the two lifetime distributions to look similar

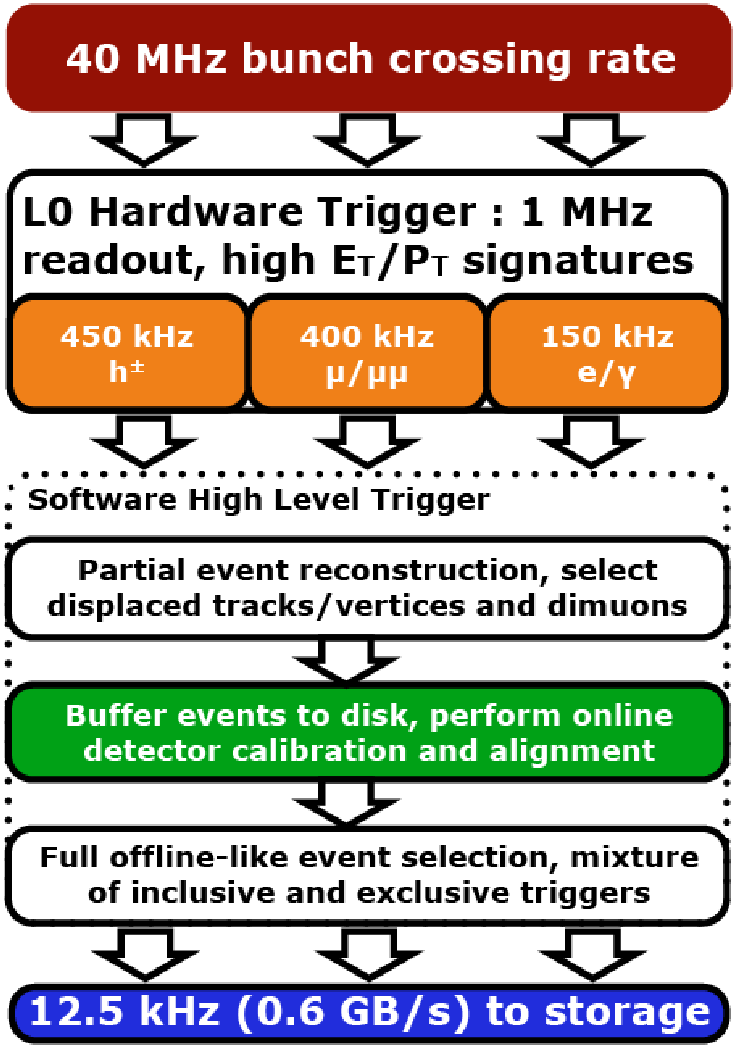
But the overall efficiency ratio is of course different

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

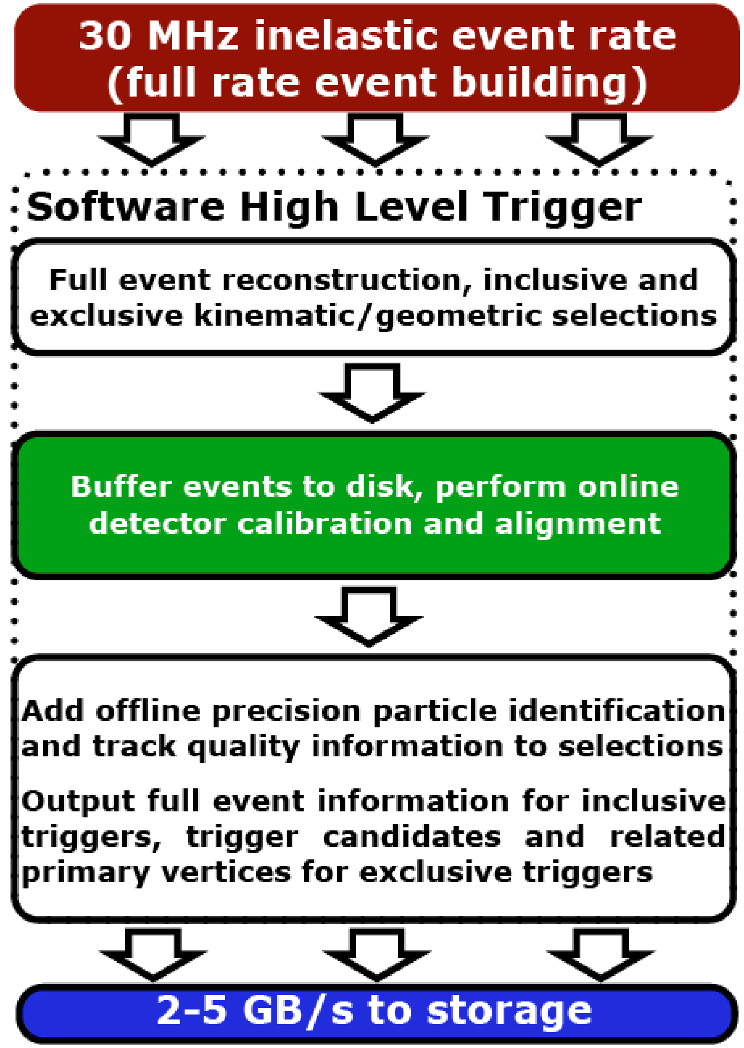
And makes $K_L \to \mu\mu$ to become a negligible background for the current level of precision
But can be relevant when we approach the 10^{-11} level

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

LHCb 2015 Trigger Diagram



LHCb Upgrade Trigger Diagram



Normalization of event yield

Converting a signal yield into a branching ratio

K_s^0 production crossection

Absolute efficiency

$$N(K_s^0 \to \pi\mu\mu) = \sigma(K_s^0) BR(K_s^0 \to \pi\mu\mu)\varepsilon L$$

Integrated luminosity

How? (normalization of event yield)

European Research Council

Converting a signal yield into a branching ratio

K_s^0 production crossection

Absolute efficiency

$$N(K_s^0 \to \pi\mu\mu) = \sigma(K_s^0)BR(K_s^0 \to \pi\mu\mu)\boldsymbol{\varepsilon}L$$

Integrated luminosity

$$\frac{N(K_s^0 \to \pi\mu\mu)}{N(K_s^0 \to \pi\pi)} = \frac{\sigma(K_s^0)BR(K_s^0 \to \pi\mu\mu)\boldsymbol{\varepsilon}L}{\sigma(K_s^0)BR(K_s^0 \to \pi\pi)\boldsymbol{\varepsilon}'L}$$

Introduce in the ntuples a $K_s^0 \to \pi\pi$ 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= m^2 ➔ dΓ/dm = 2m dΓ/dz

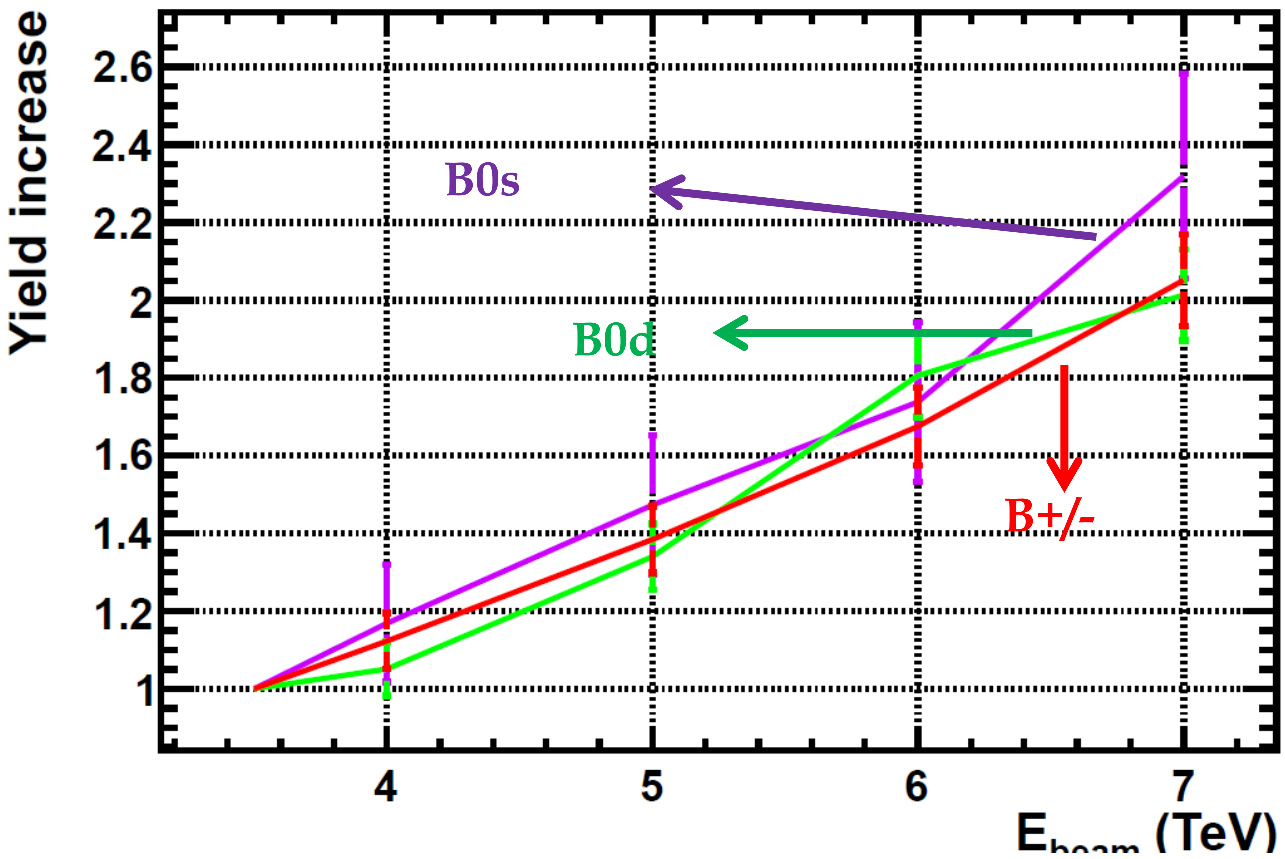
$$W_i(z) = G_F M_K^2 (a_i + b_i z) + W_i^{\pi\pi}(z) , \qquad (11)$$

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

Remind of Bmm sensitivity

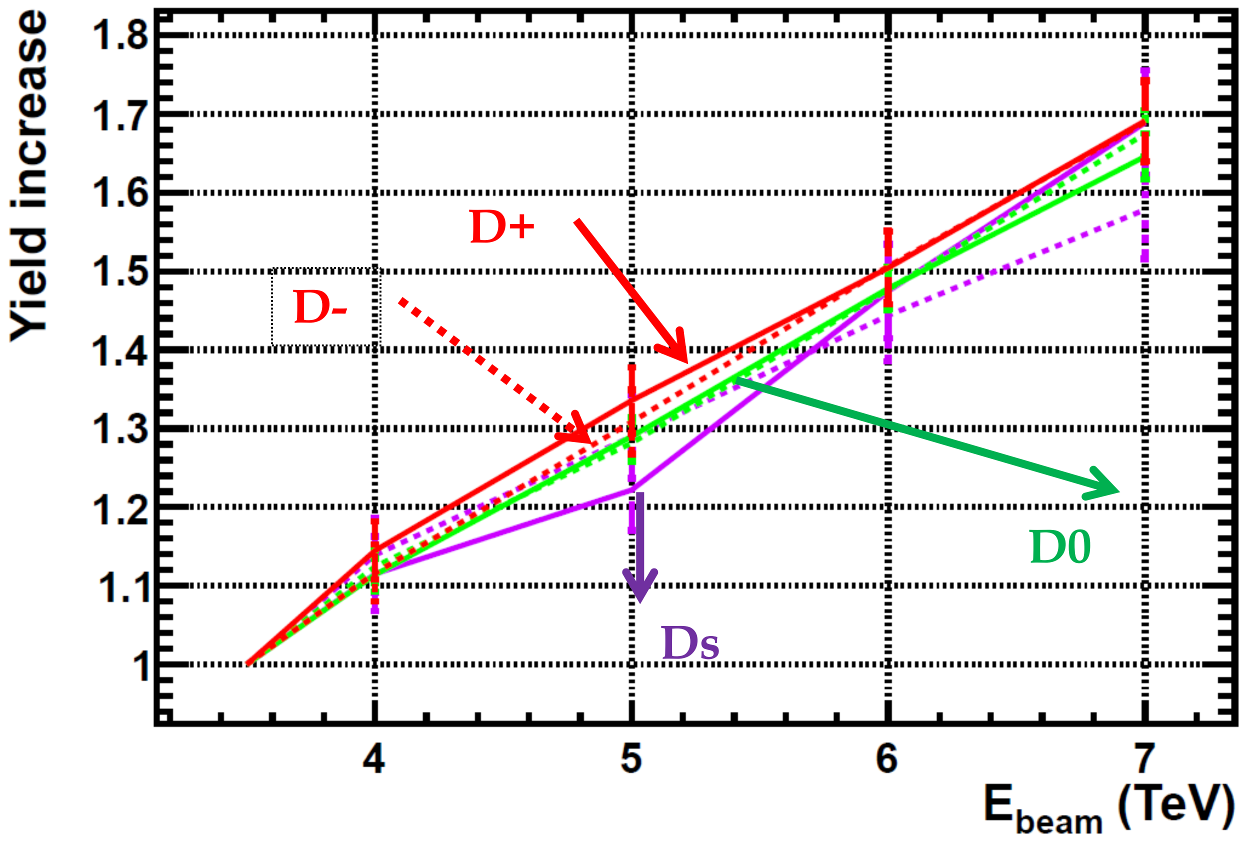
B mesons

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)

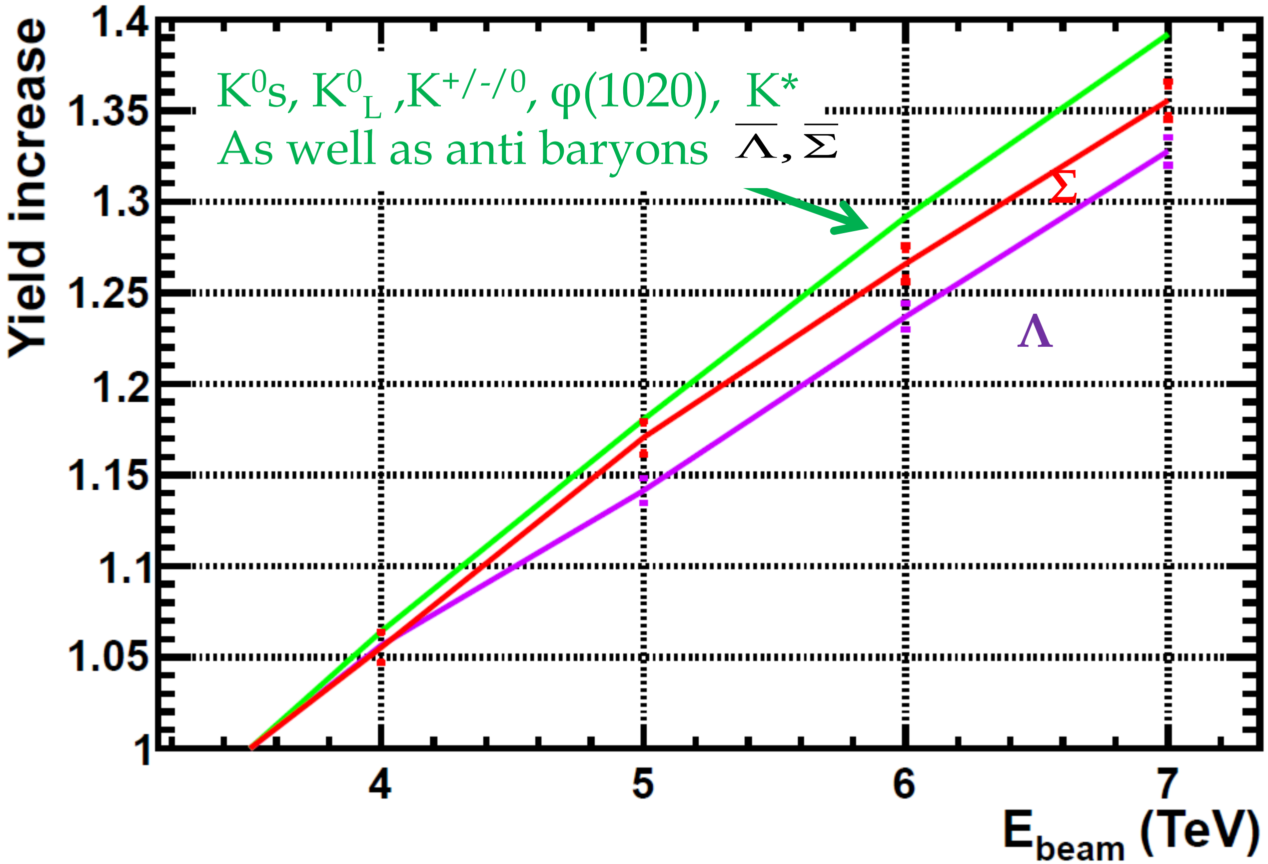


Strange particles

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.

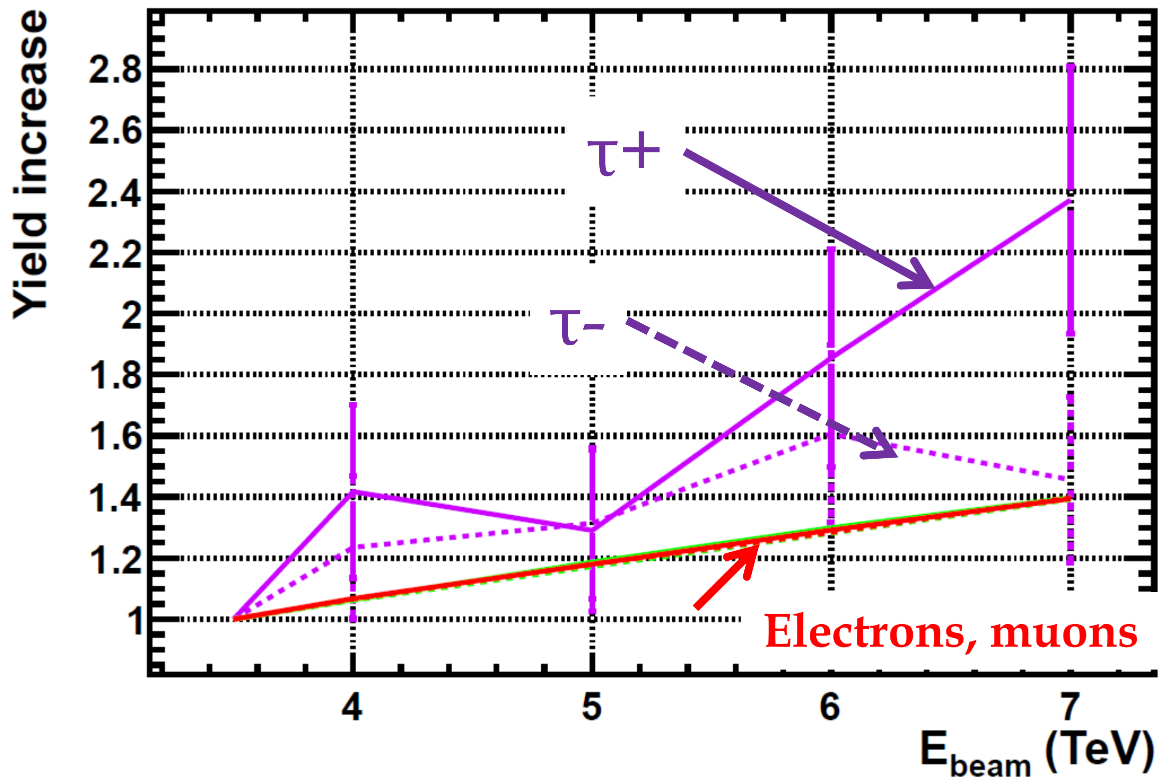


In particular, for the K0s decaying in the VELO the increase is "only" ~30% → This is the number we really care for Ks → μμ studies

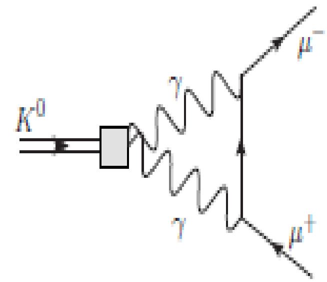
Leptons

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

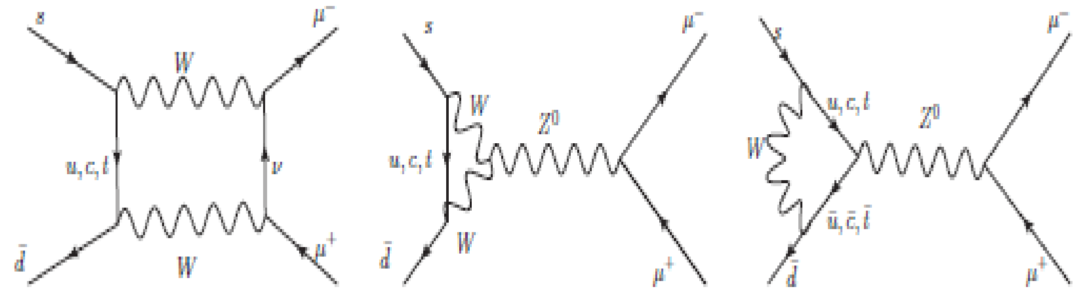
Check with more stats if the asymmetry +/- is still there

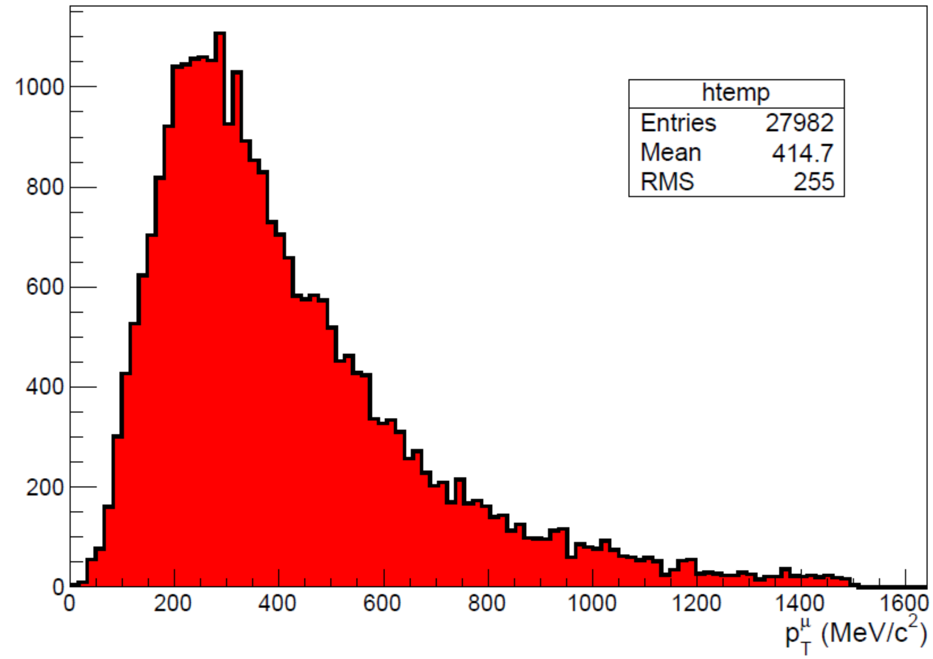


→ the long-distance (LD) contributions:



→ the short-distance (SD) contributions:

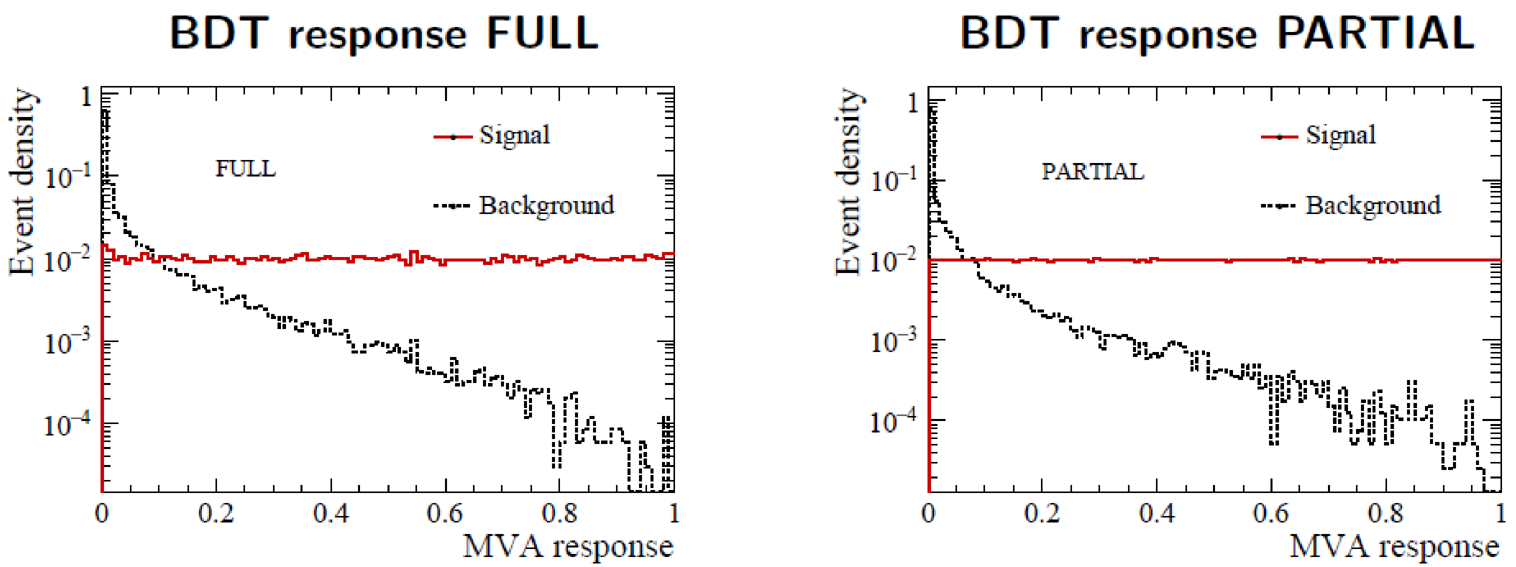



htemp
Entries 27982
Mean 414.7
RMS 255
1000
800
600
400
200
0
0
200
400
600
800
1000
1200
1400
1600
p_T^μ (MeV/c^2)

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

The background discrimination

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



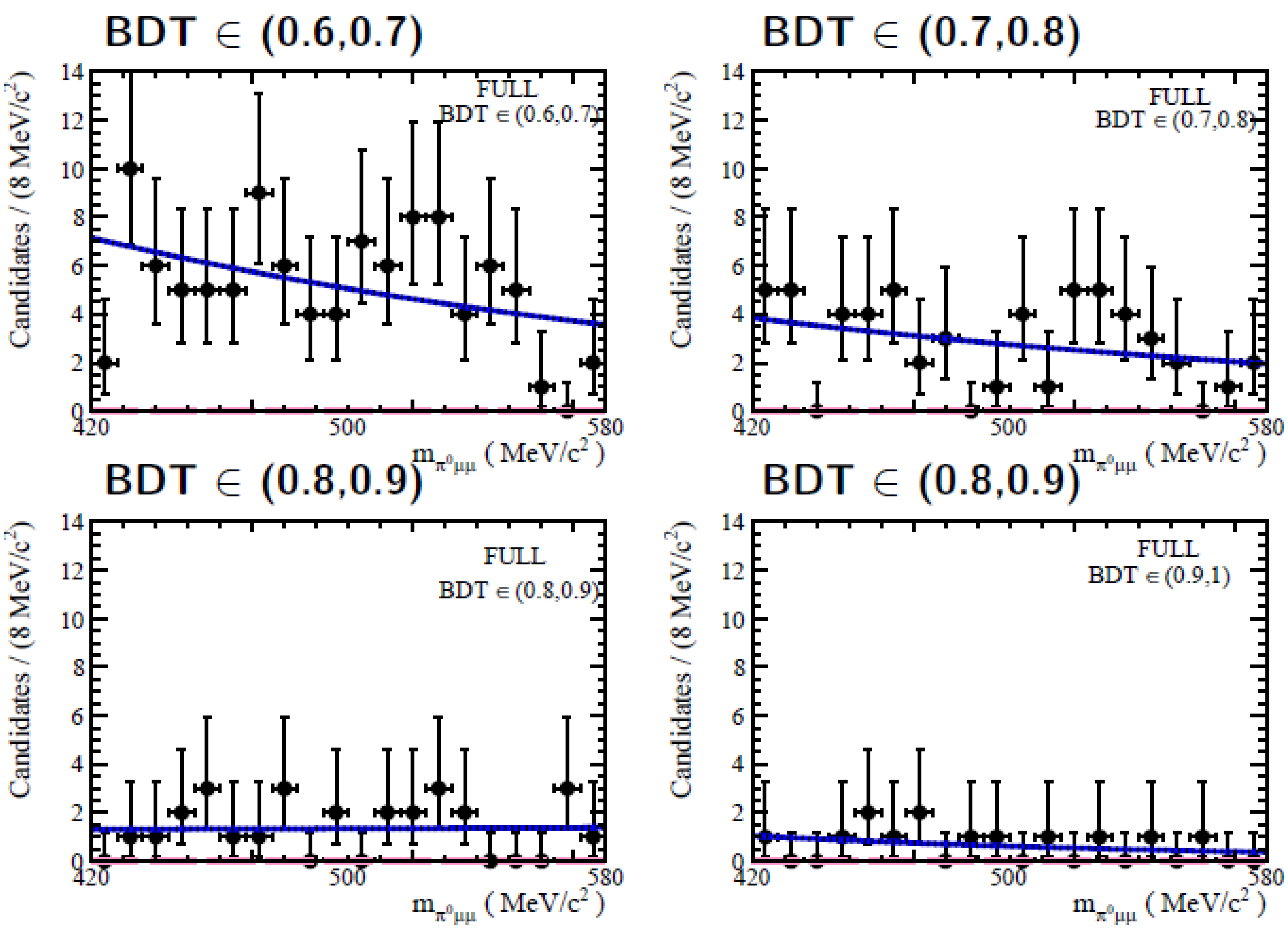
- As usual: BDT trained against combinatorial background
- Specific backgrounds: $K_S \to \pi\pi$, $K_L \to \pi\pi\pi$, $K_{S/L} \to \mu\mu\gamma\gamma$ (negligible)

Don't affect the sensitivity estimate

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

Fit, FULL

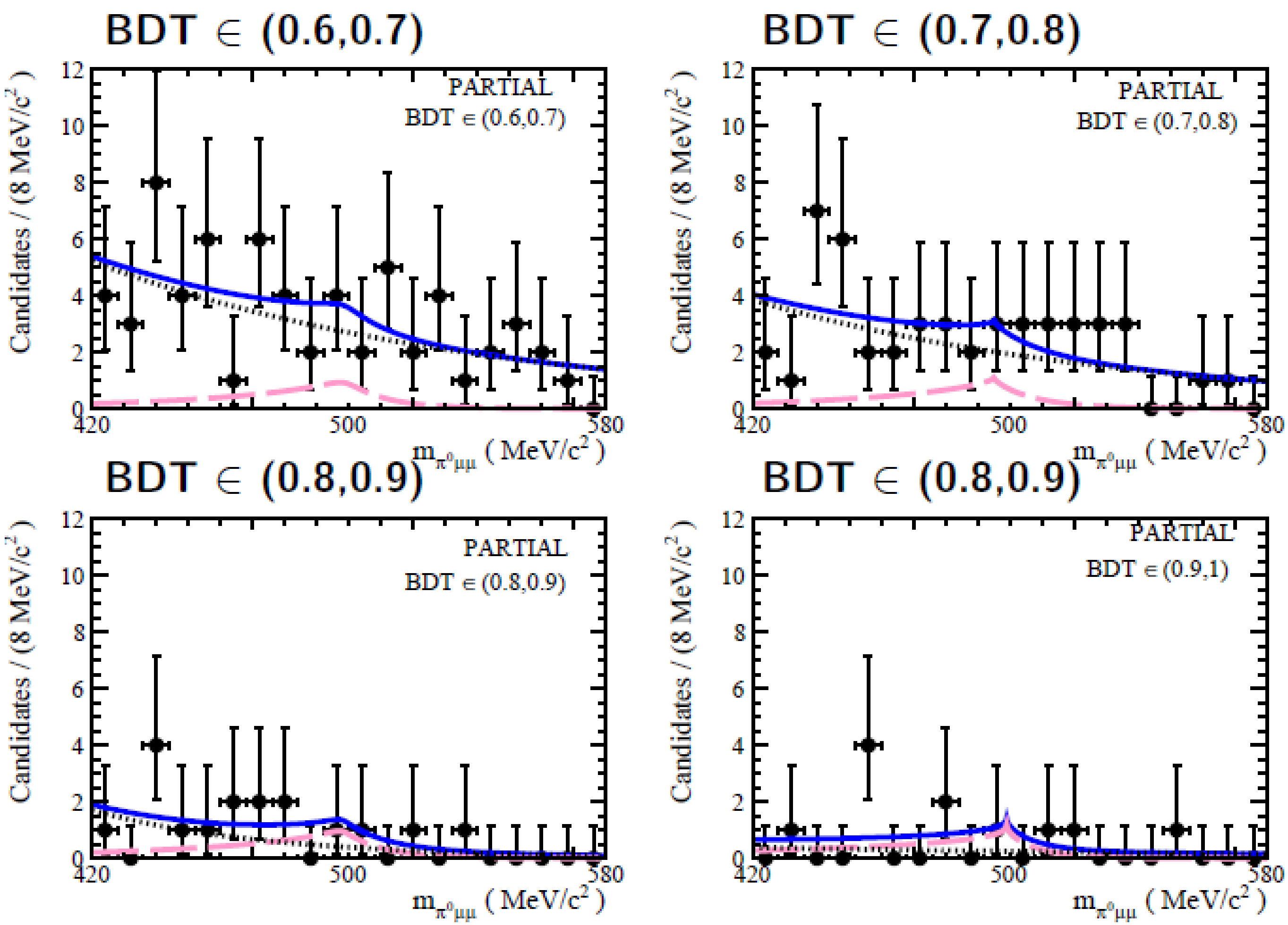
V. Chobanova et al,
CERN-LHCb-PUB-2016-017



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

Fit, PARTIAL

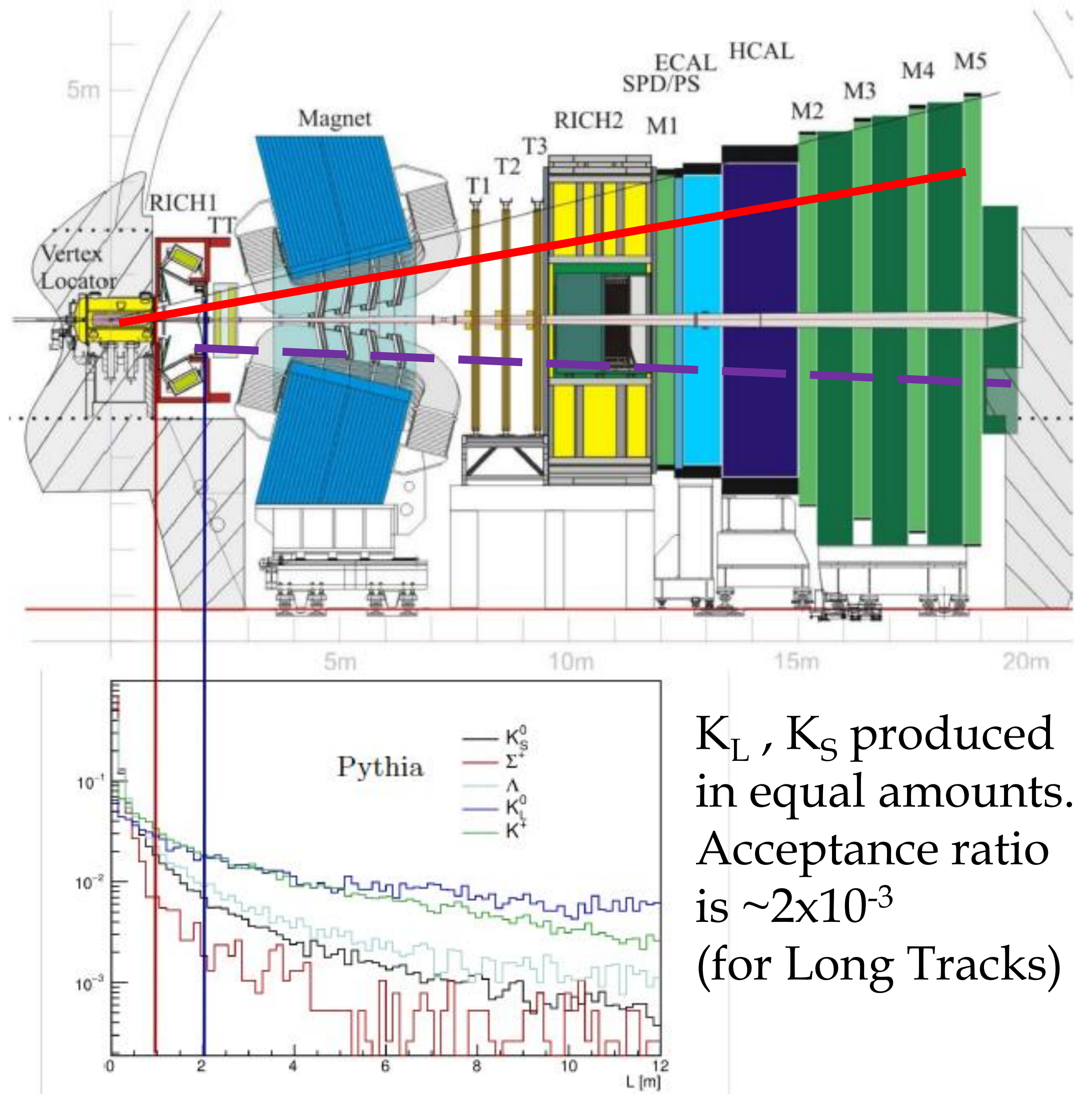
V. Chobanova et al,
CERN-LHCb-PUB-2016-017



Strangeness production/detection at LHCb

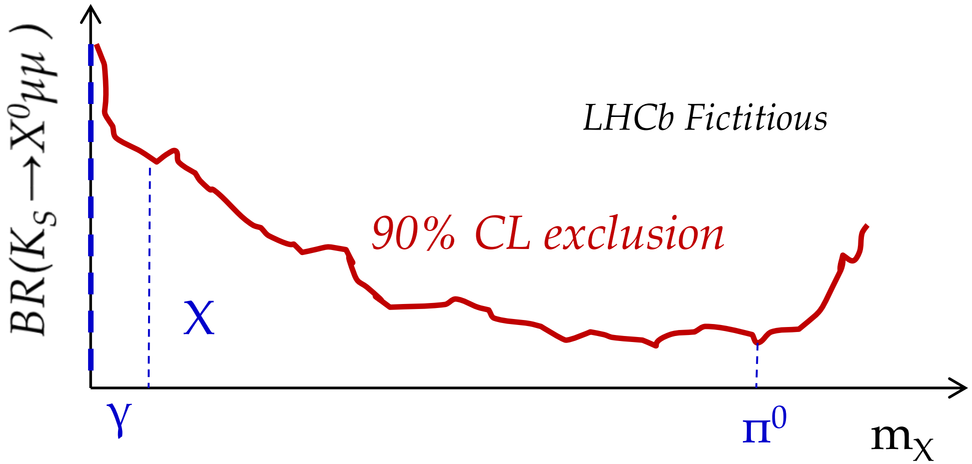
European Research Council

- 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)

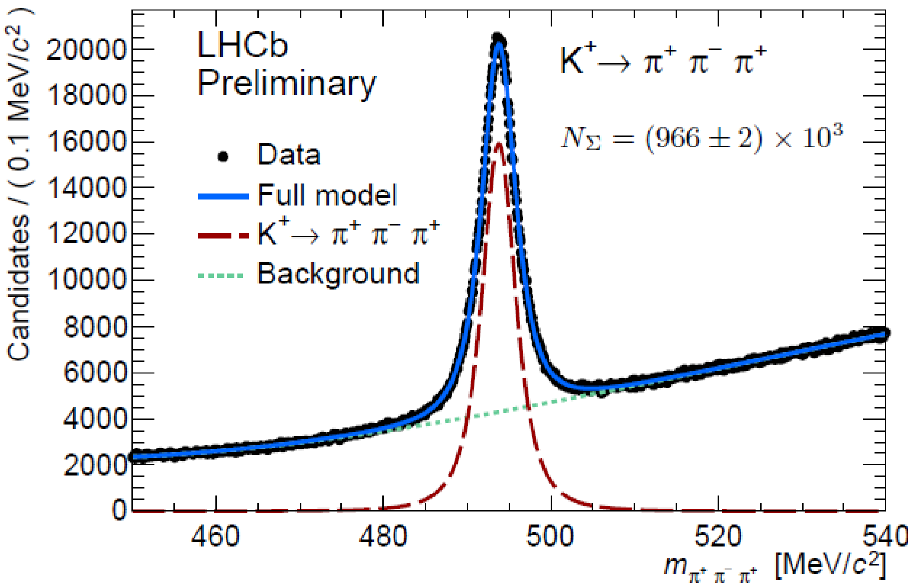


K_L , K_S produced in equal amounts. Acceptance ratio is ~$2x10^{-3}$ (for Long Tracks)

Ongoing stuff



K^+ studies



Large samples of charged kaon decays are available

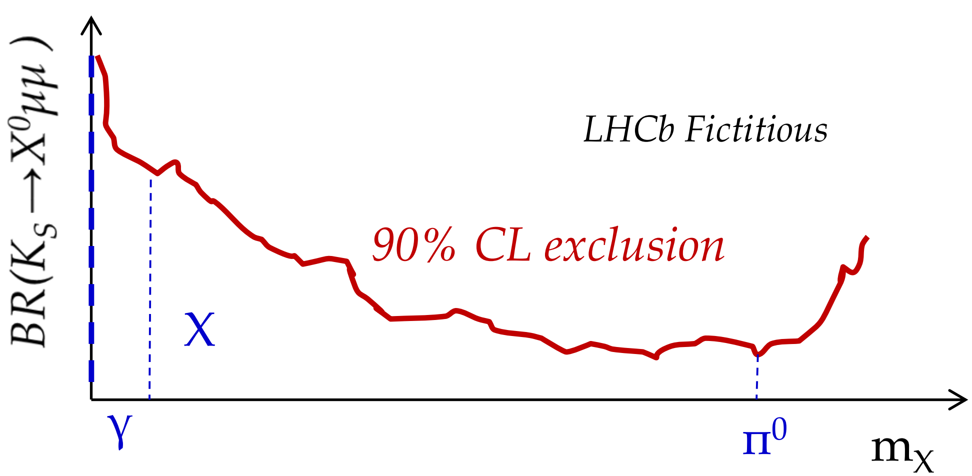
K^+ mass is not very well known

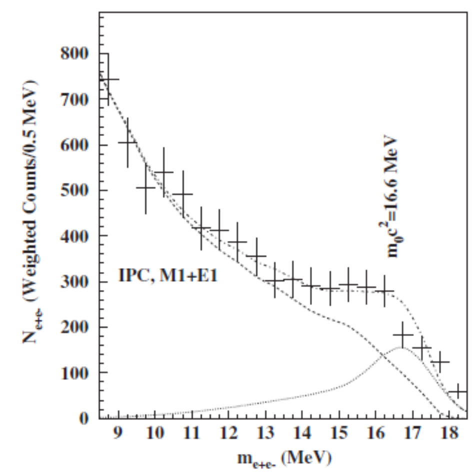
$K^+ \rightarrow \pi\mu\mu$?

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

- 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

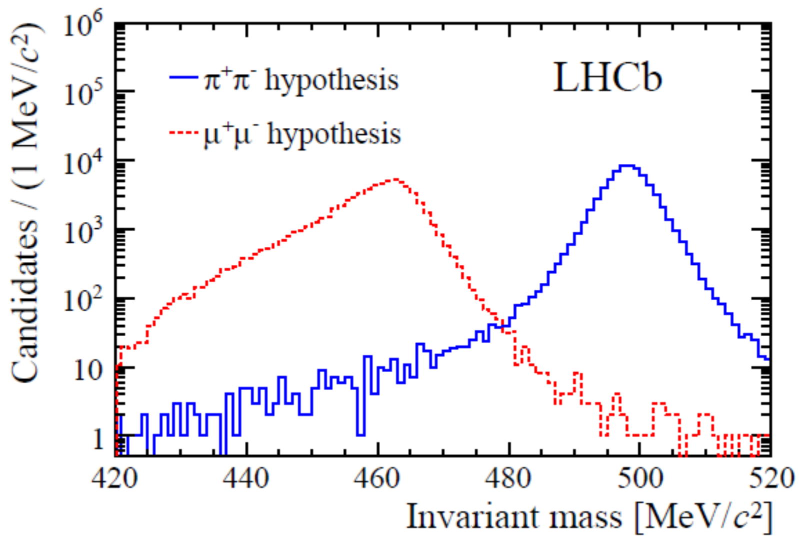




$K_S \to \mu\mu$ full Run-I analysis

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 $K_S \to \pi\pi$
- Mass resolution 4 MeV



Background

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

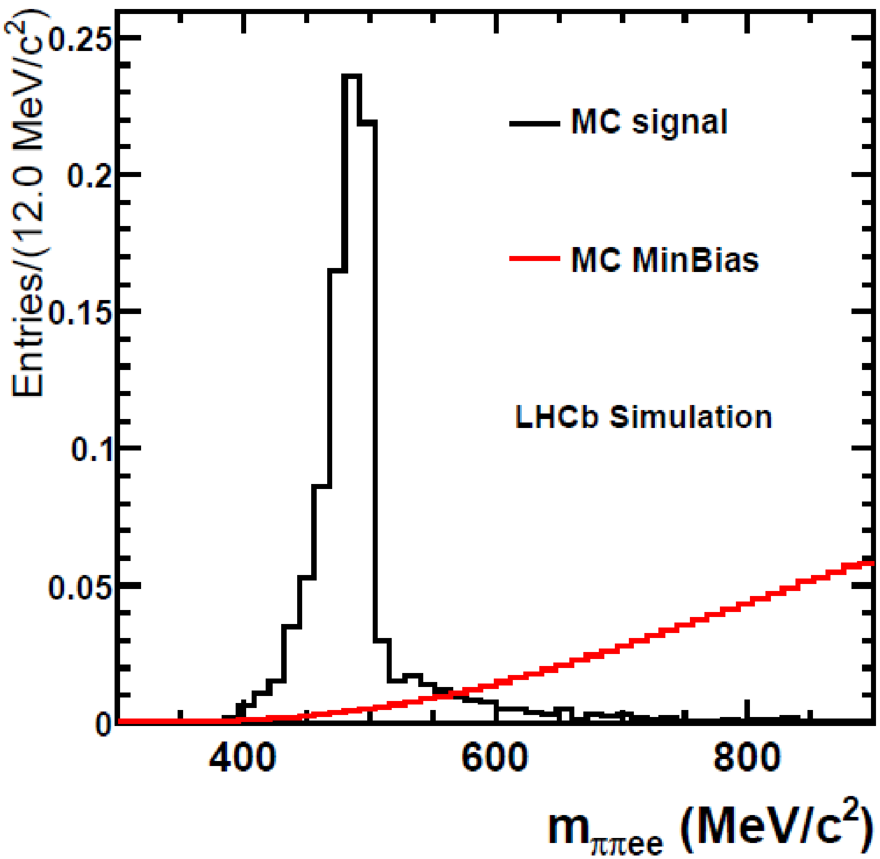
$K \to \pi\mu\nu$: negligible

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

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

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

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



Based on simulation:

Expected a signal yield of

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

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 $K_L \to \pi^0\mu\mu$)

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

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

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

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

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

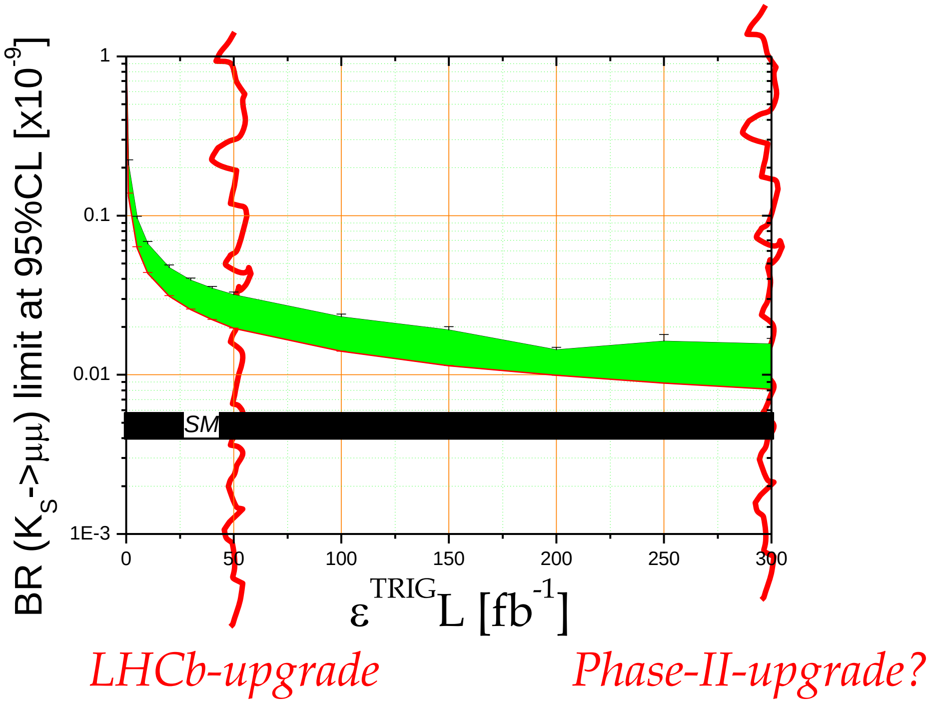
$K^0_S \to \pi^0\mu^+\mu^-$	NA48	$(2.9\,^{+1.5}_{-1.2}) \times 10^{-9}$

~50% relative error

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

$K_S \to \mu\mu$ prospects

Run- I: BR< 8 (10)x10^{-10} @90(95)%CL



- Extrapolating from Run-I result
- Full Run-II analysis ongoing: expected to improve by a **factor 4 to 10** Run-I's sensitivity
  - Better trigger
  - Better reco/selection
- Future: start to investigate tagged decays, which would allow to access NP in the K_S-K_L interference [D'Ambrosio&Kitahara PRL 119, 201802 (2017)]

Could well become the strongest limit on a BR by an LHC experiment