A strange program for the LHC

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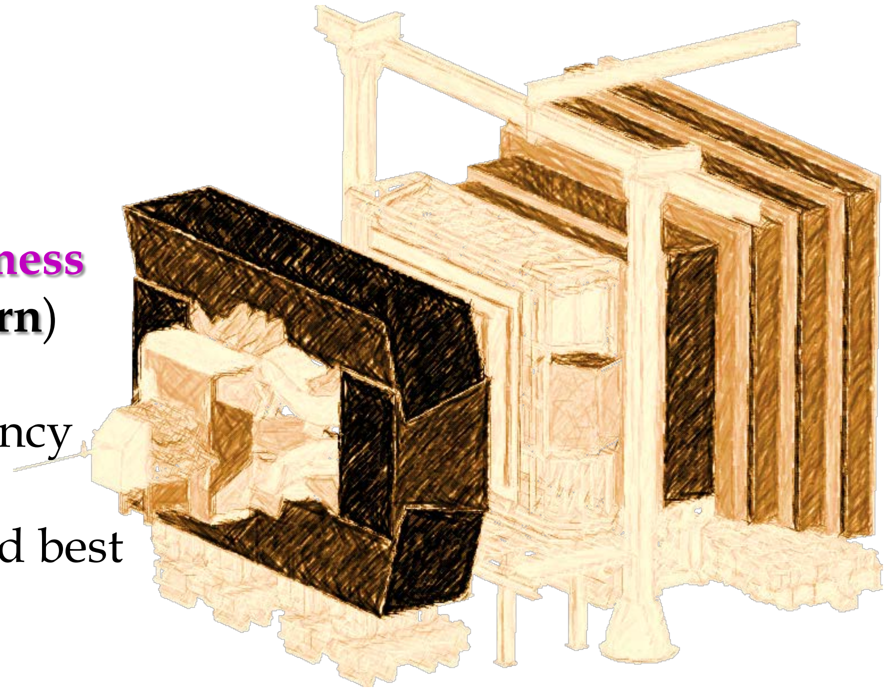
GAIN
(on behalf of the LHCb Collaboration)

Introduction

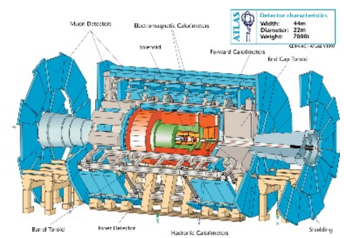
- LHCb experiment at LHC
  - Designed mostly for **b** and **c** decays
    → low trigger efficiency otherwise
  - But there is also an ~infinite **strangeness** production at LHC (kaon xs ~ 1.2 **barn**)
  - Infinite production times zero efficiency requires L'Hopital
    - In 2011 we managed to get world best result in $K_S \rightarrow \mu\mu$
  - 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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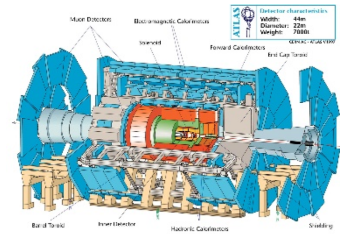

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ε(Run-II) improved HLT ~ 18% (dimuons)
Maximum allowed by L0 ~30%

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LHCb Upgrade

(Note: This logo may not be official)

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LHCb Upgrade

(Note: This logo may not be official)

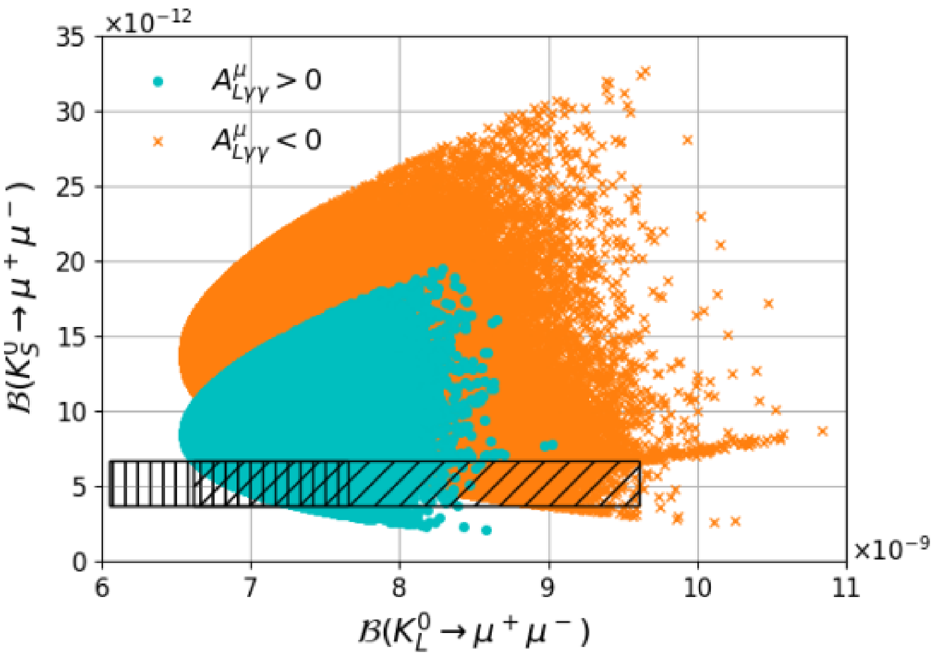
HLT (Software)

ε(Upgrade) ~ 80-100%?
Simulation studies show that rate would be under control

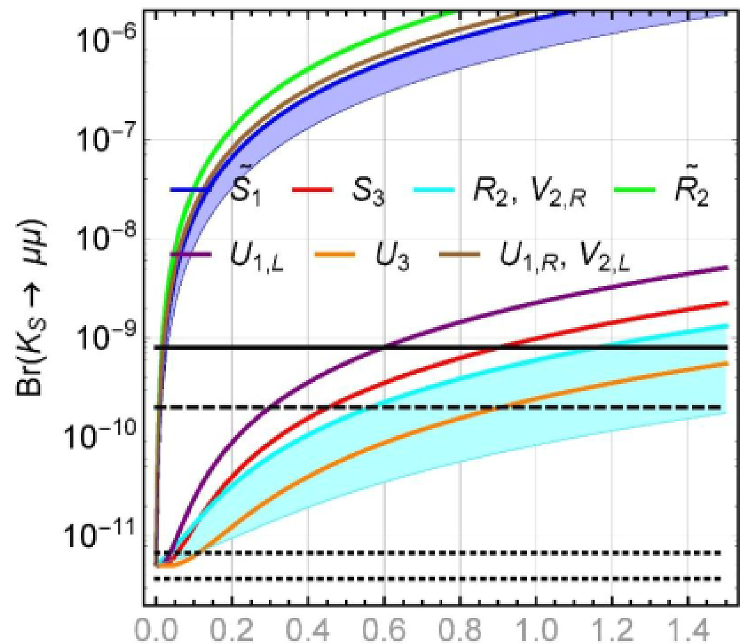
V. Chobanova et al, CERN-LHCb-PUB-2016-017

$K_S \to \mu\mu$: 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



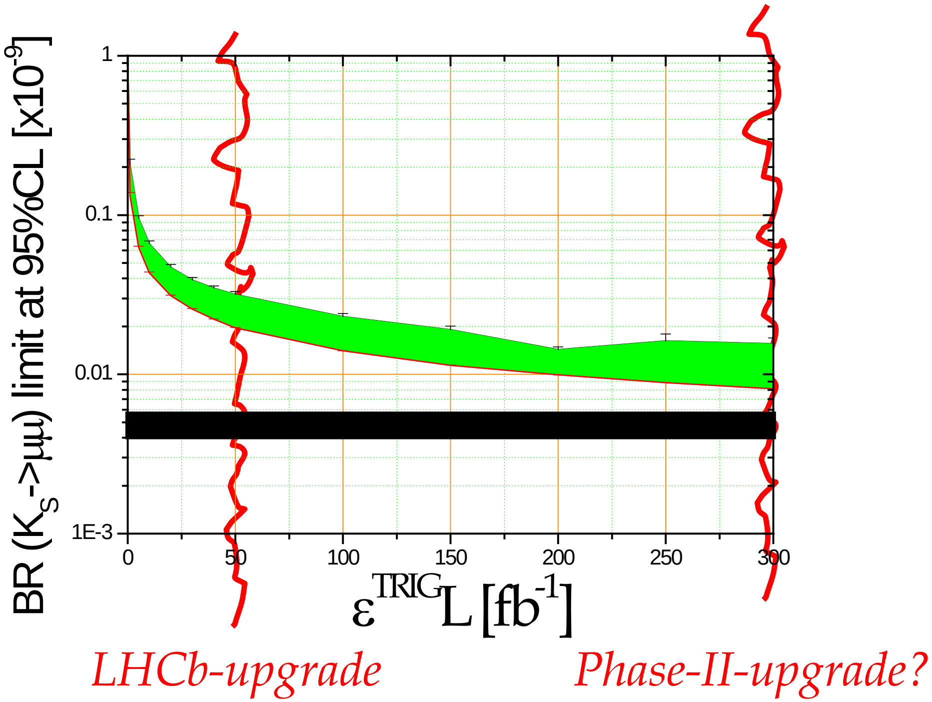
Example of a SUSY scenario from V.Chobanova et al., JHEP05(2018) 024



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

$K_S \to \mu\mu$ 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)]

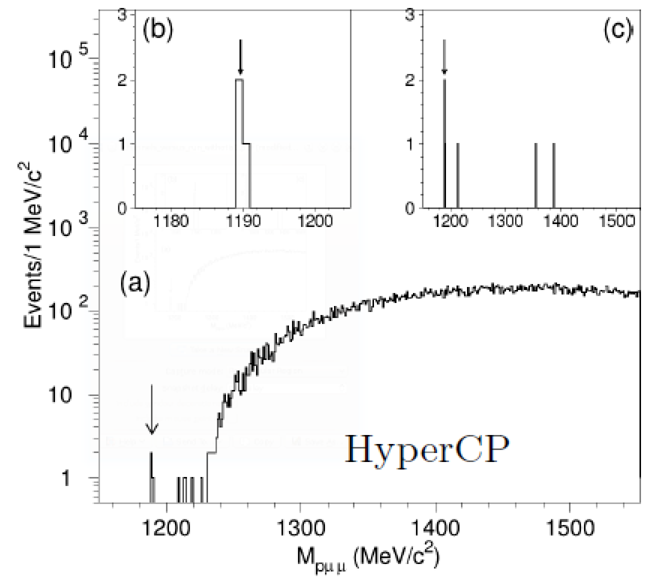
Could well become the strongest limit on a BR by an LHC experiment

The HyperCP evidence

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

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

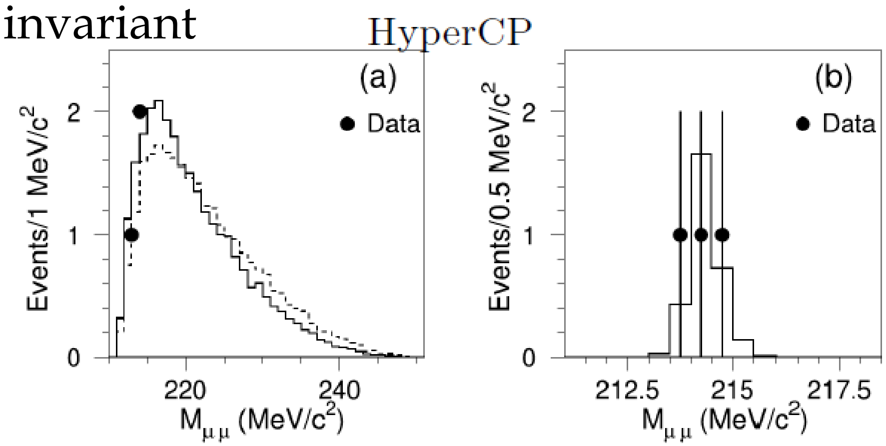
[Phys.Rev.Lett. 94 (2005) 021801]



- 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)

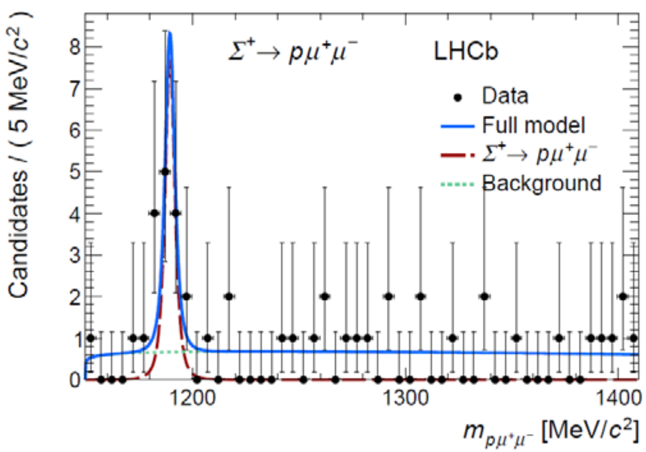


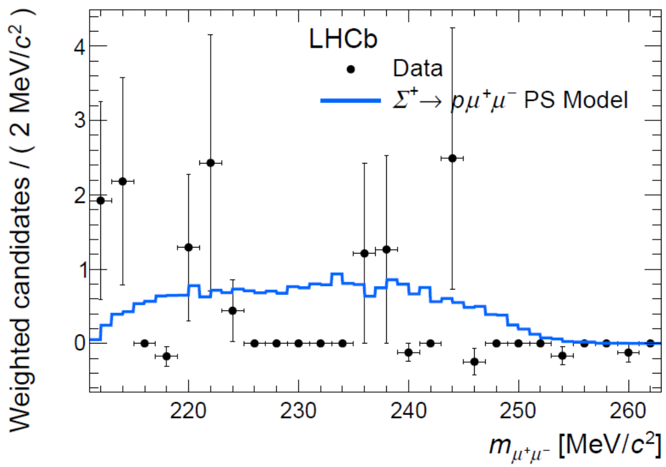
- Suggested the existence of a new neutral particle at that mass

$\Sigma \to p\mu\mu$

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

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



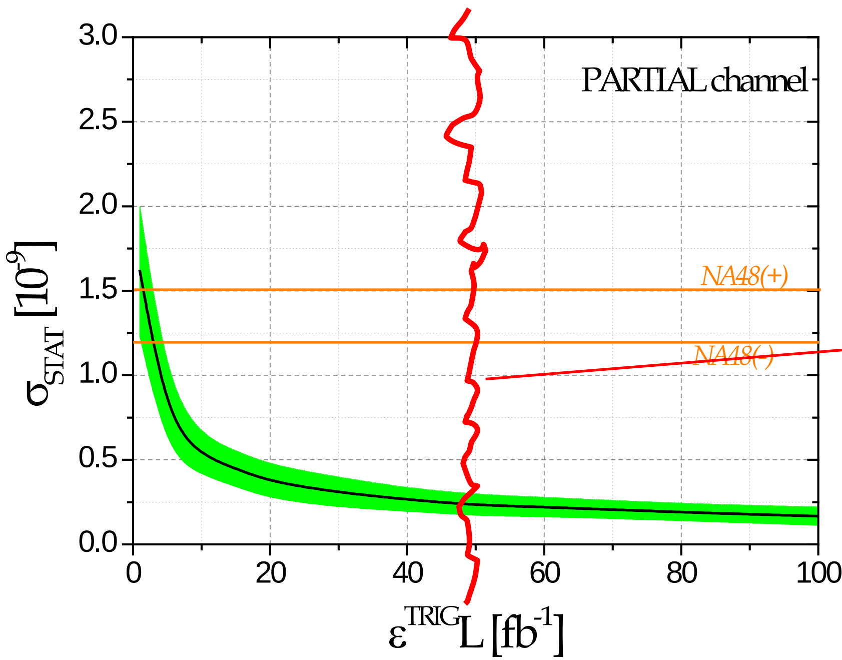


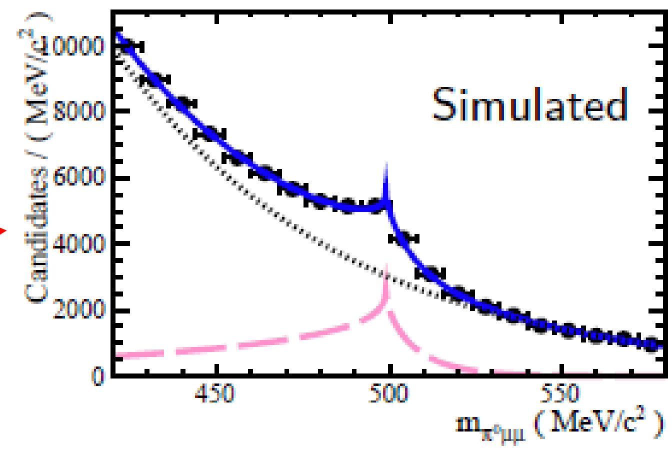
10y ago we thought this channel was ~impossible and instead now we are even thinking on an amplitude analysis….

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

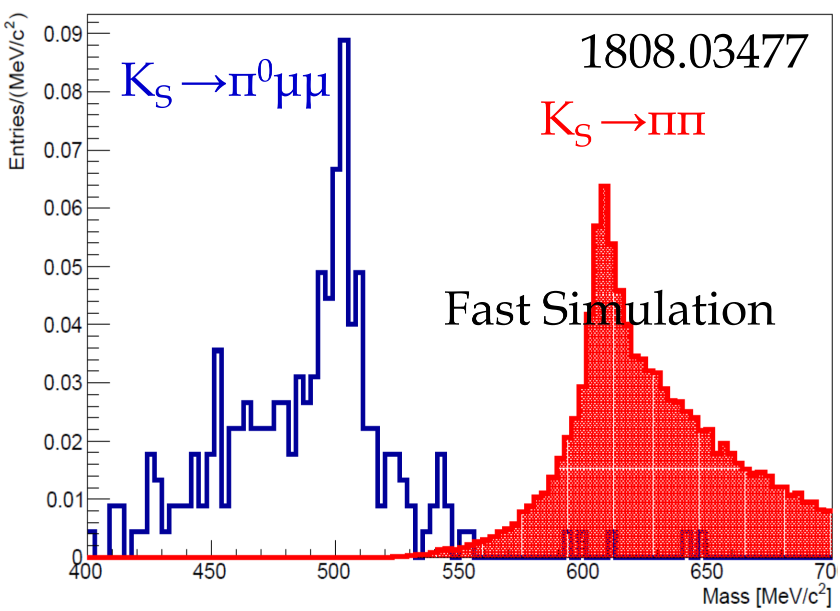
(fixing b_S)

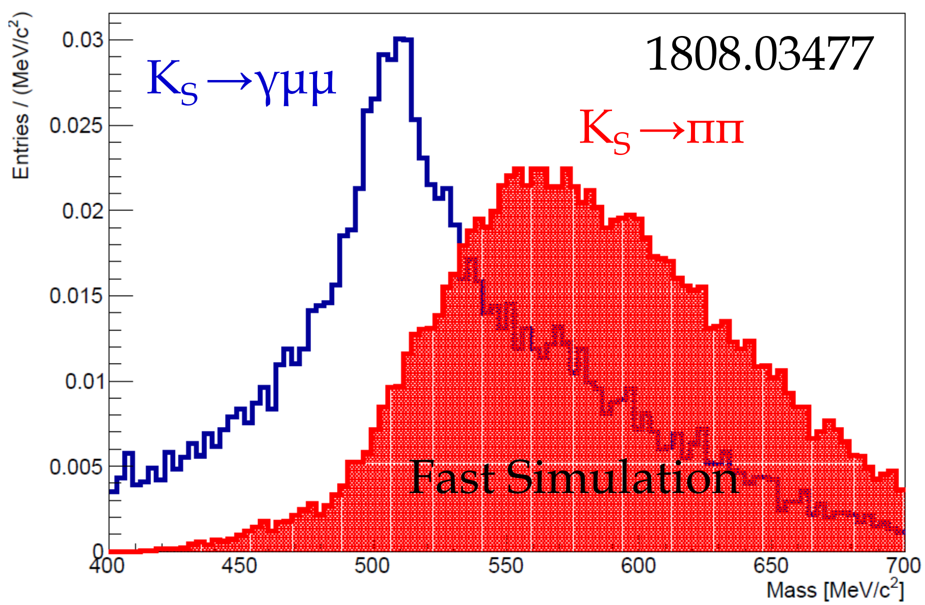
Much more bkg than $K_S \to \mu\mu$,
but also 1000x more signal

$K_S \to \gamma\mu\mu$?

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]

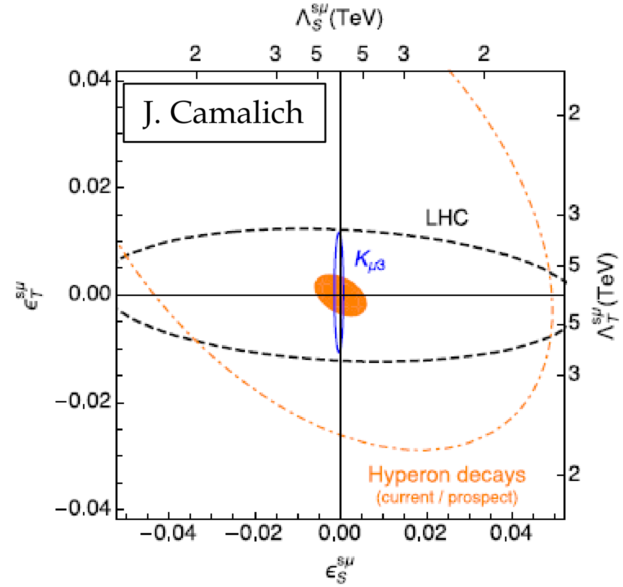
- Semileptonic Hyperon Decays (SHD)

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

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



(extrapolations from 1412.8484)

Gonzalez-Alonso & JMC, NA62 Phyics Handbook

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

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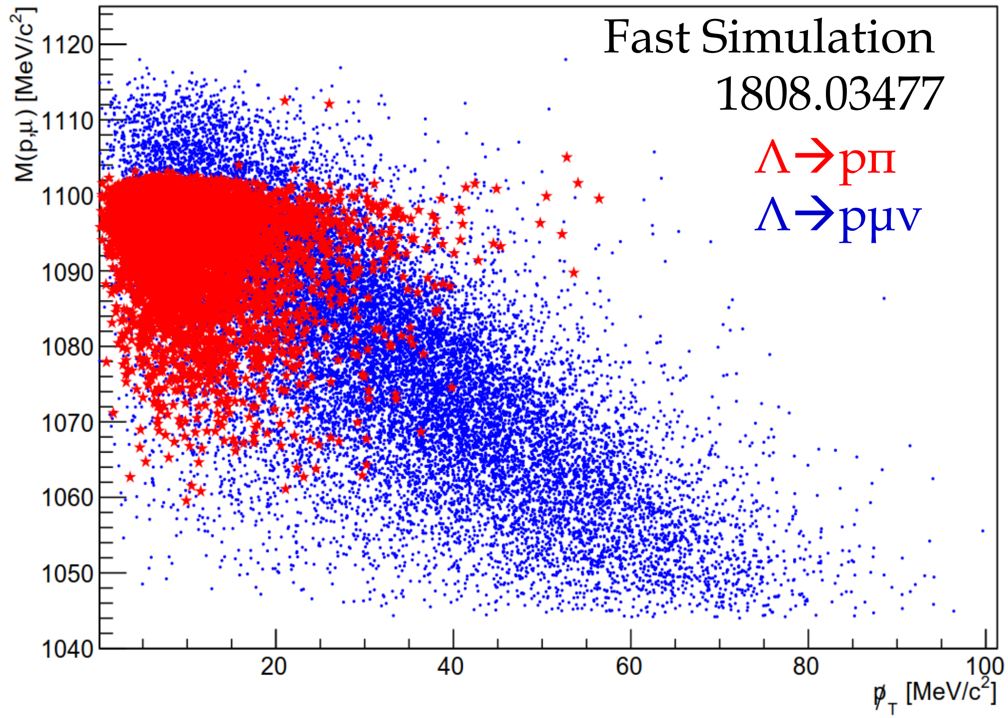

For each
B1 → B2 μν there is always a
B1 → B2π (inc. →B2μν)

☺ Can be separated in search planes

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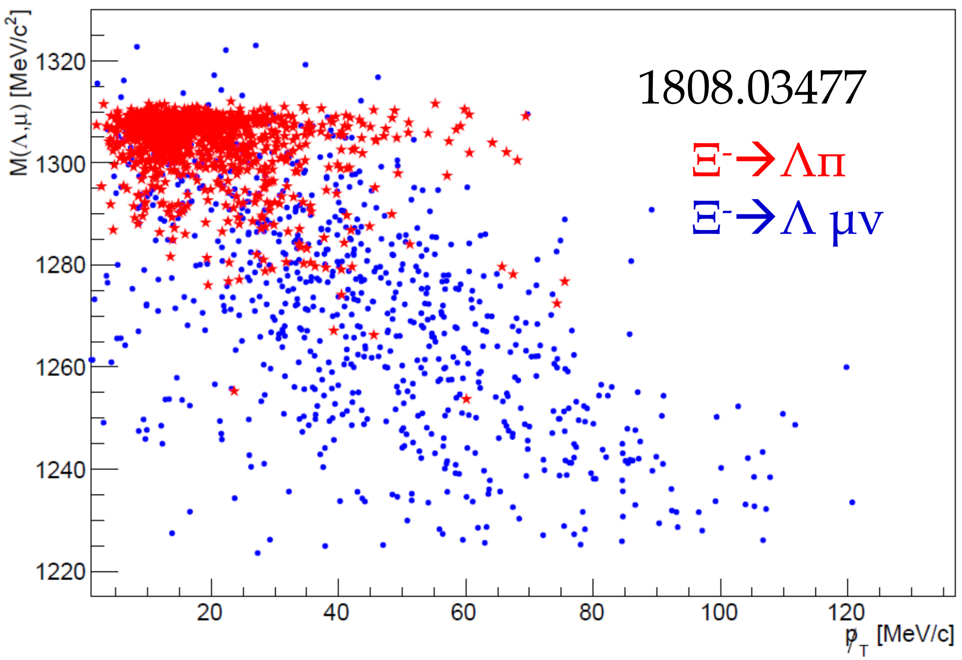
Fast Simulation



Lepton Flavour Violation

arXiv:1808.02006 [hep-ex]

- Lepton Flavour Violation is a hot topic nowadays

LHCb can do:

$K_S \to e\mu$

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

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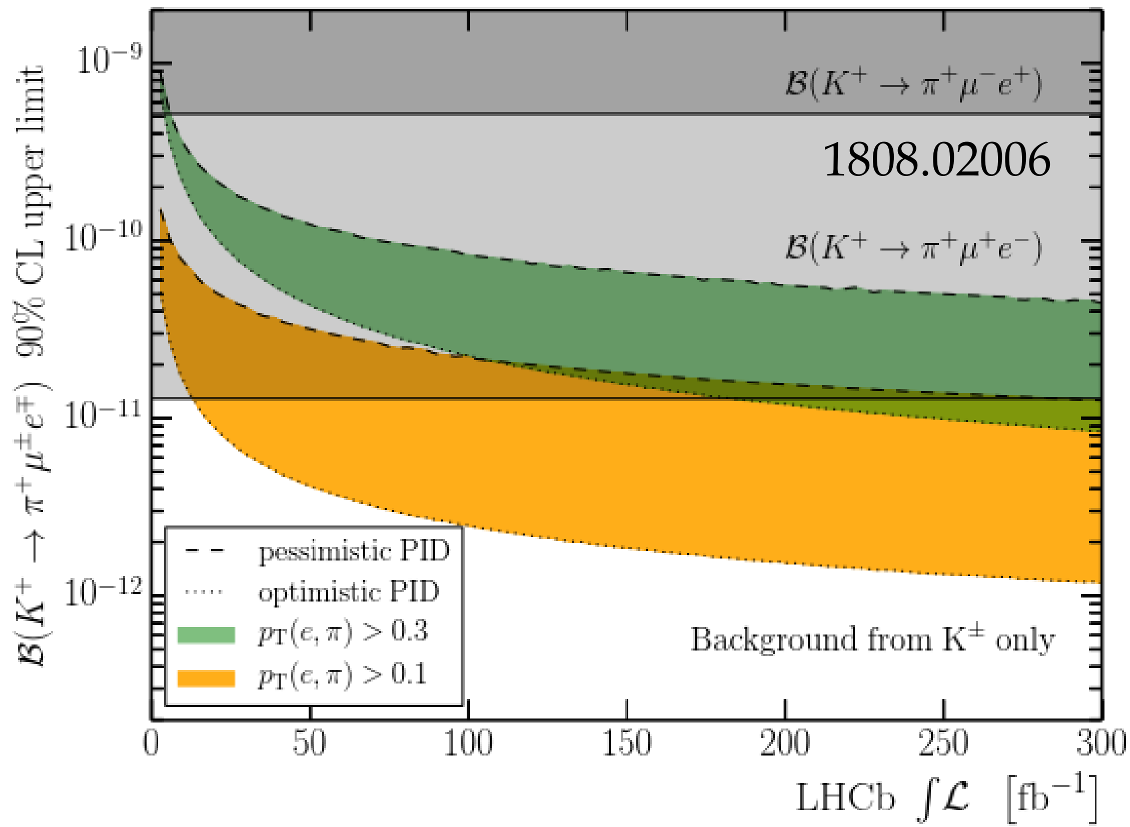
$K^+ \to \pi^+\mu^-e^+$



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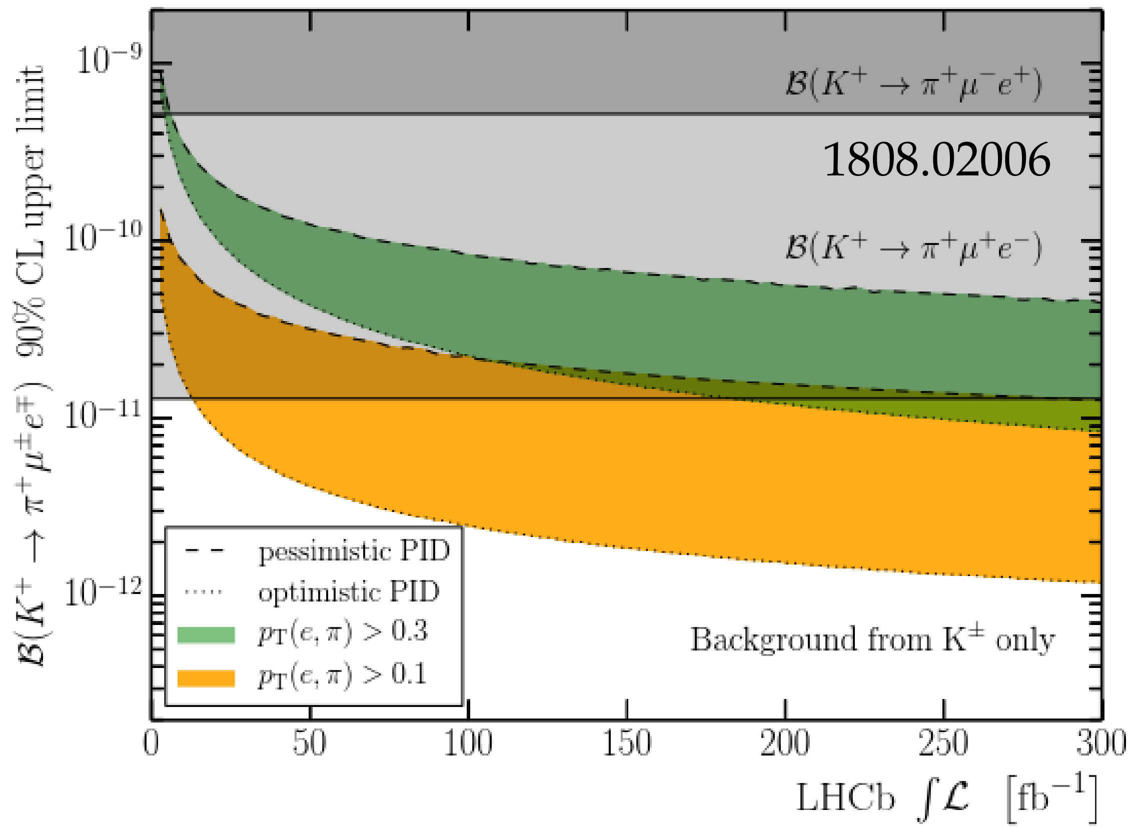
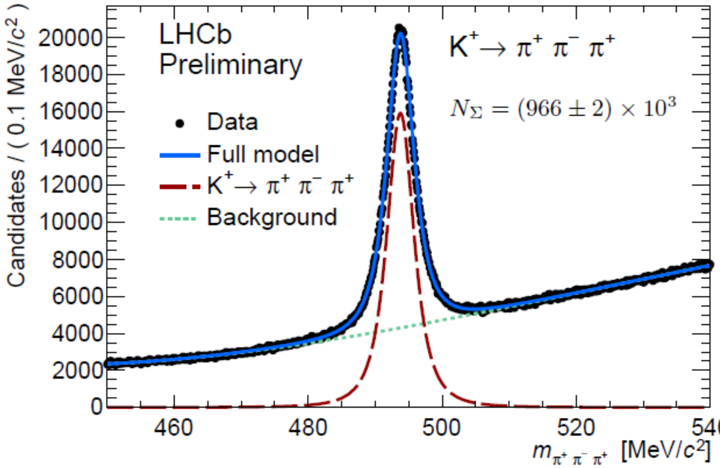
$K^+ \to \pi^+\mu^-e^+$
Maybe $K^+ \to \pi^+\mu^+e^-$

Competition w/
NA62 to be clarified

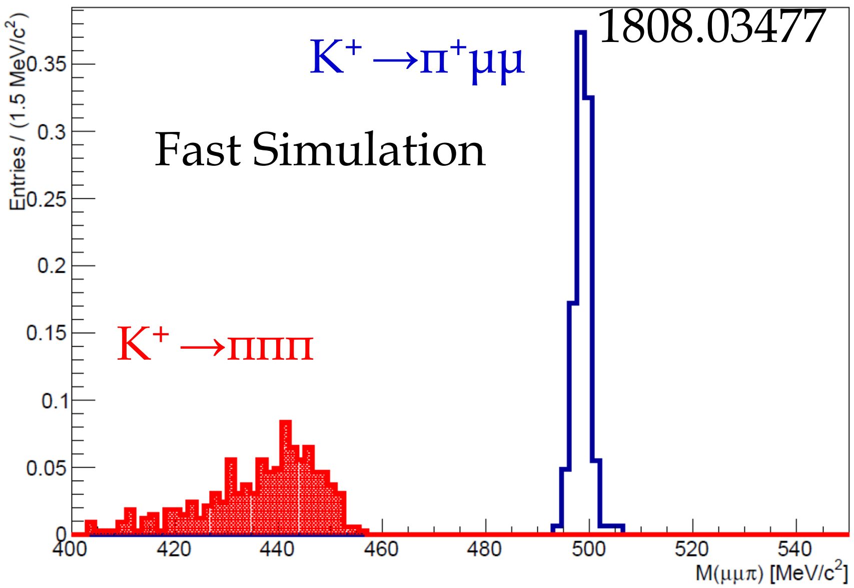


Charged kaons

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

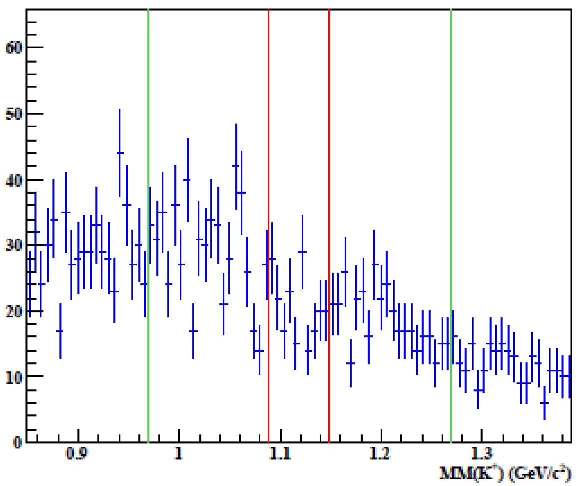


- Under study sensitivity to $K^+ \to \pi^+\mu\mu$ vs NA62
  - Benefits from the new dimuon triggers (the same way as $K_S \to \mu\mu$)



B and L violation (very low priority)

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:

- 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}

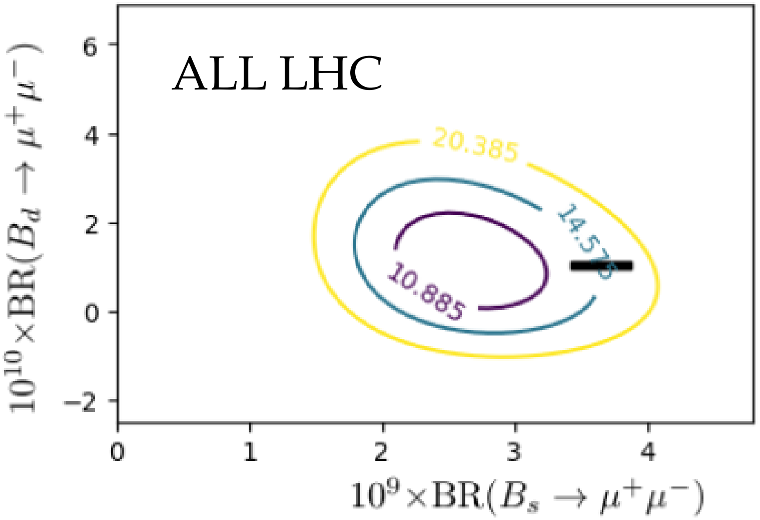
Conclusions

Conclusions

- **s** decays are awesome
  - High interest for BSM
  - Ultimate experimental precision ~ 10^{-11} -10^{-12}
- There is an LHC**s** community in the LHC**b** village
  - Trigger is constantly improving
  - We aim for LHCb upgrade to reach efficiencies **s** as high as for **b**'s
- Run-II (2016-2018) data analysis ongoing $\Sigma \to p\mu\mu$, $K_S \to \mu\mu$, $K_S \to (\gamma/\pi^0)\mu\mu$...

Backup

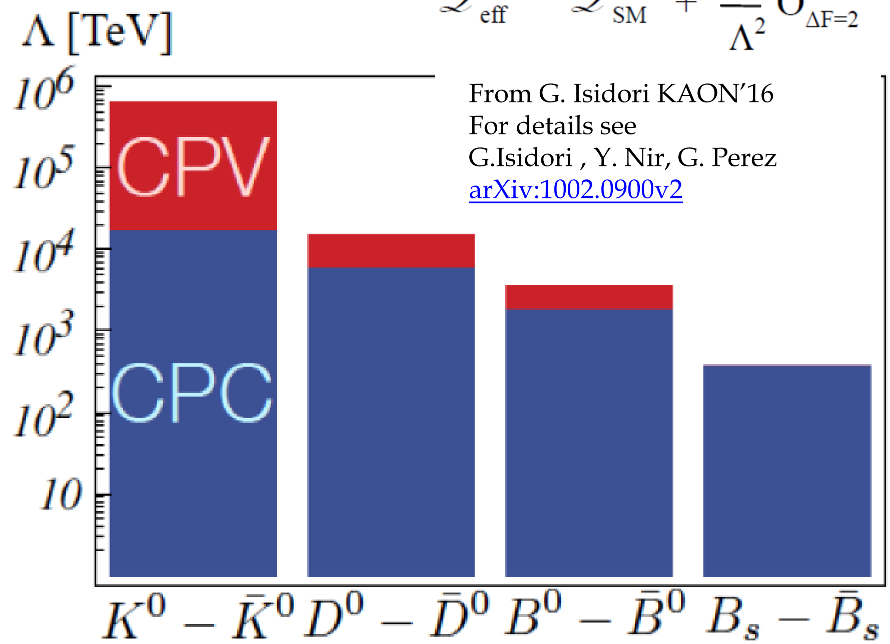
$$\mathrm{BR}(B_s \to \mu^+\mu^-) = 2.65^{+0.43}_{-0.39} \times 10^{-9}, \qquad \mathrm{BR}(B_d \to \mu^+\mu^-) = 1.09^{+0.74}_{-0.68} \times 10^{-10}.$$



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

Strangeness decays

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



- 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)

- 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

- $K_{\ell 3}$

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

- $K_{\ell 2}$

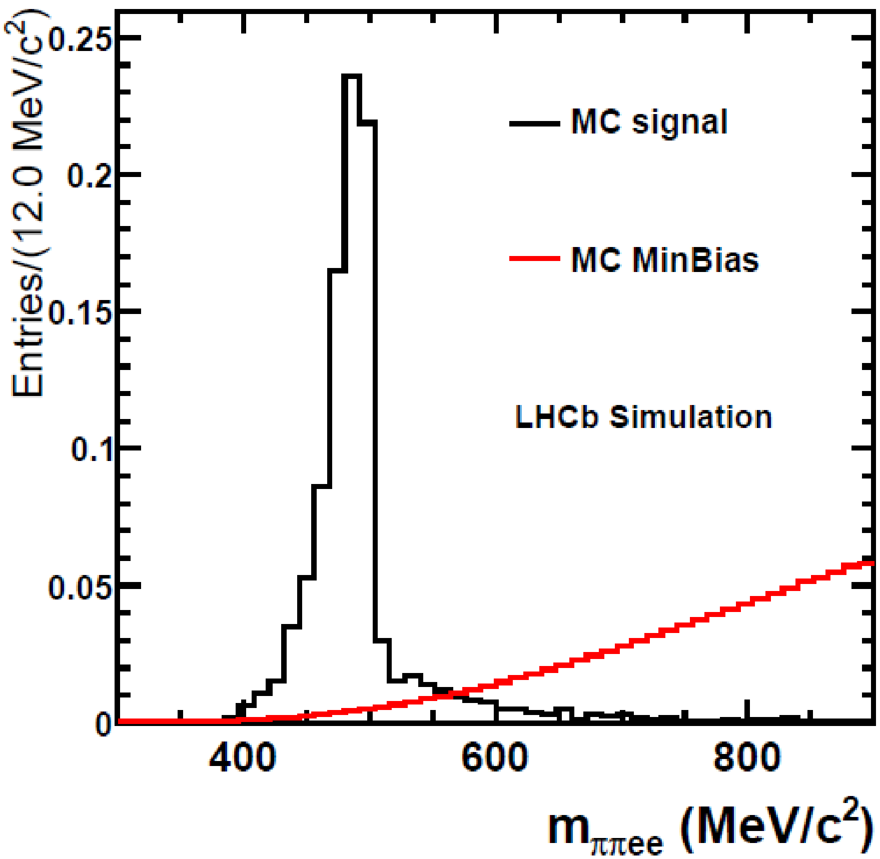
$$\Gamma_{K_{\ell 2(\gamma)}} = \frac{G_F^2 m_K\, m_\ell^2}{8\pi}\left(1-\frac{m_\ell^2}{m_P^2}\right)^2 |\tilde{V}_{us}^{\ell}|^2 f_{K^\pm}^2 \left(1-4\epsilon_R^{s} - \underbrace{\frac{2B_0}{m_\ell}}_{\chi \text{ enh.}}\epsilon_P^{s\mu}\right)$$

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

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

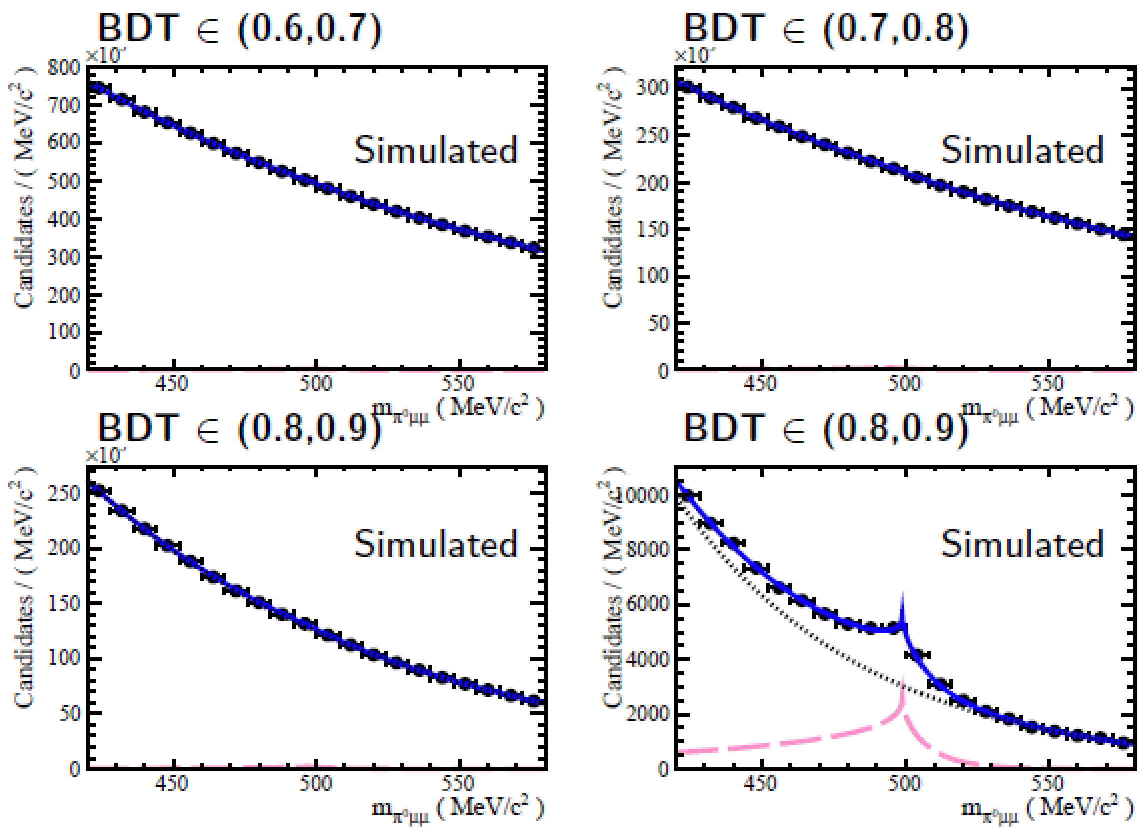
Expected background yield is not well known yet

K0 tagging?

arXiv:1808.03477 [hep-ex]

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

Toy MC for 50fb^{-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 $\beta \gtrsim 5\text{x}\Gamma_S$ ($\gg \Gamma_L$).

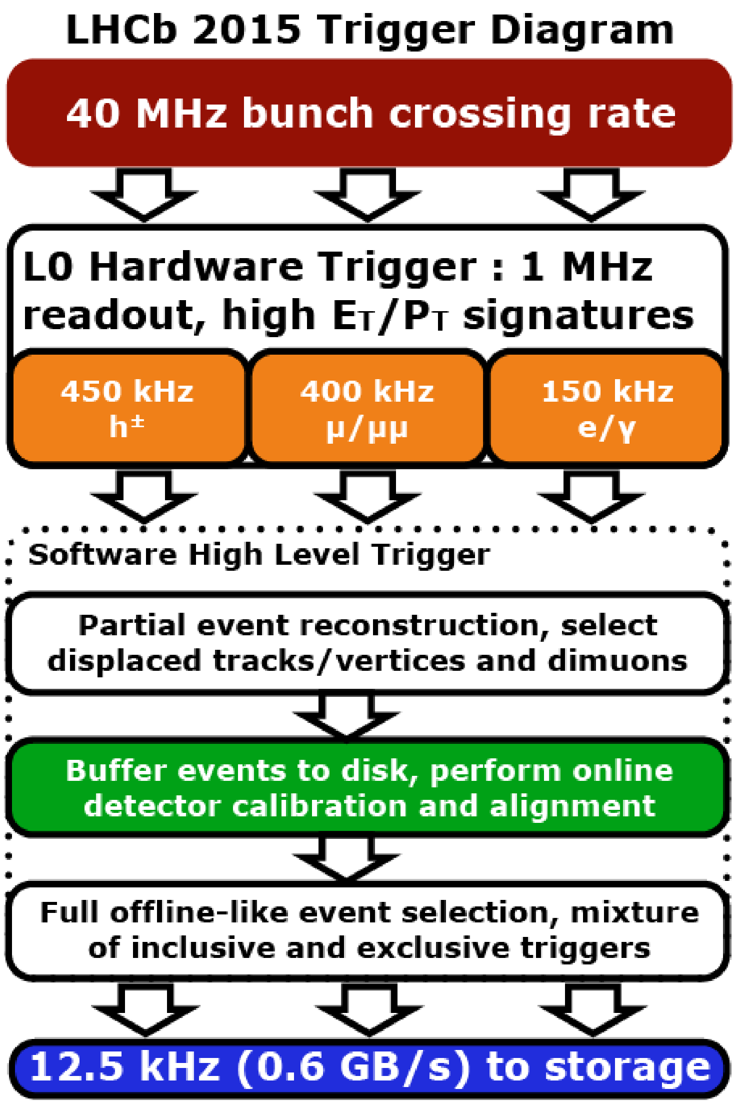
This makes the two lifetime distributions to look similar

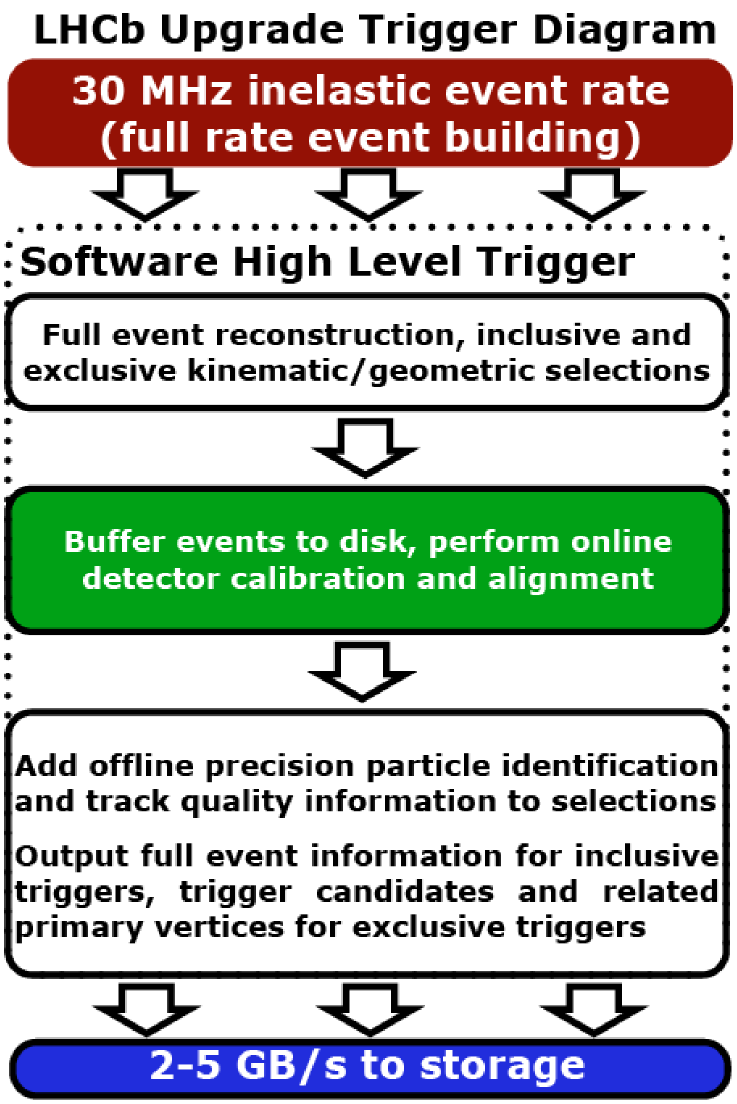
But the overall efficiency ratio is of course different

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

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

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


LHCb 2015 Trigger Diagram
40 MHz bunch crossing rate
L0 Hardware Trigger : 1 MHz readout, high ET/PT signatures
450 kHz h±
400 kHz μ/μμ
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

K_s^0 production crossection

Absolute efficiency

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

Integrated luminosity

How? (normalization of event yield)

Converting a signal yield into a branching ratio

K_s^0 production crossection

Absolute efficiency

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

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

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

$z = m^2$ ➔ $d\Gamma/dm = 2m\, d\Gamma/dz$

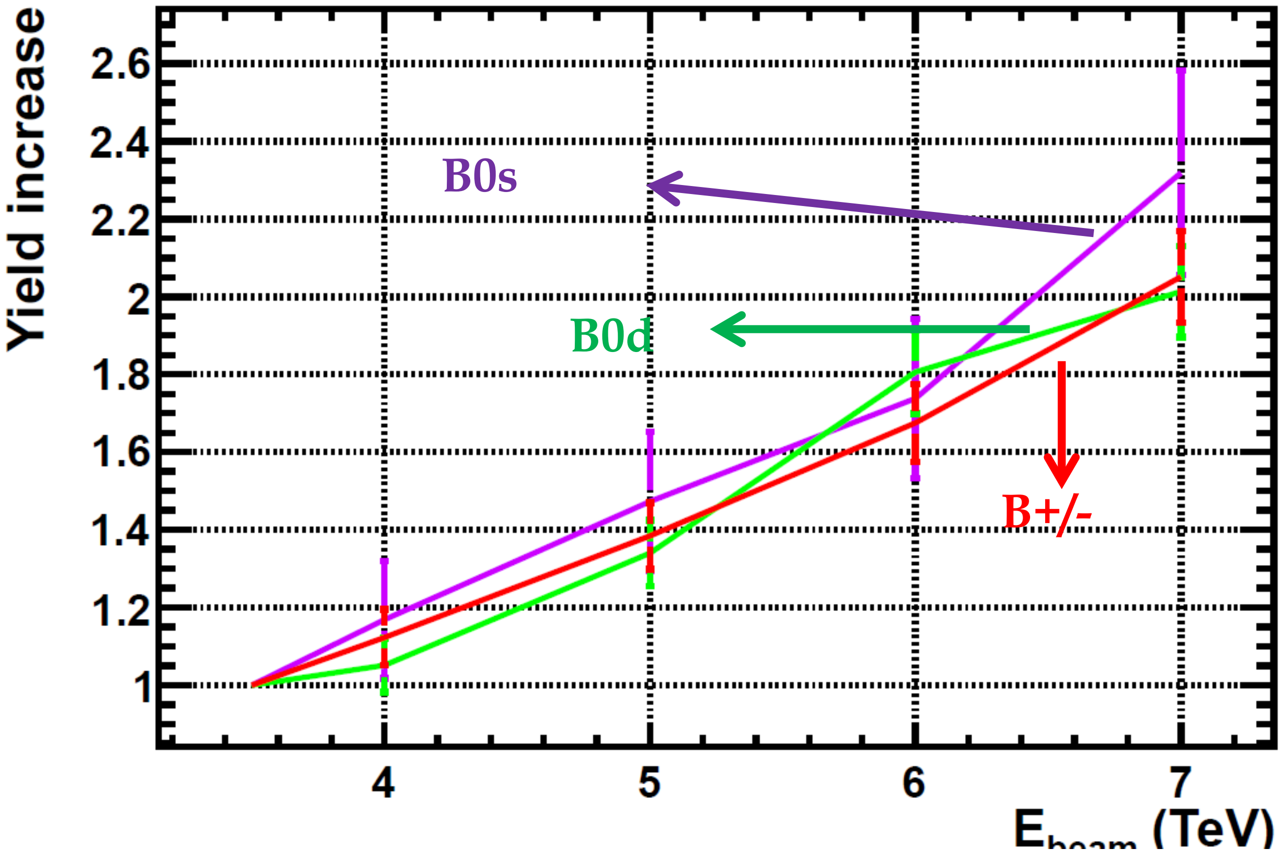
$$W_i(z) = G_F M_K^2 (a_i + b_i z) + W_i^{\pi\pi}(z) , \qquad (11)$$

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

Remind of Bmm sensitivity

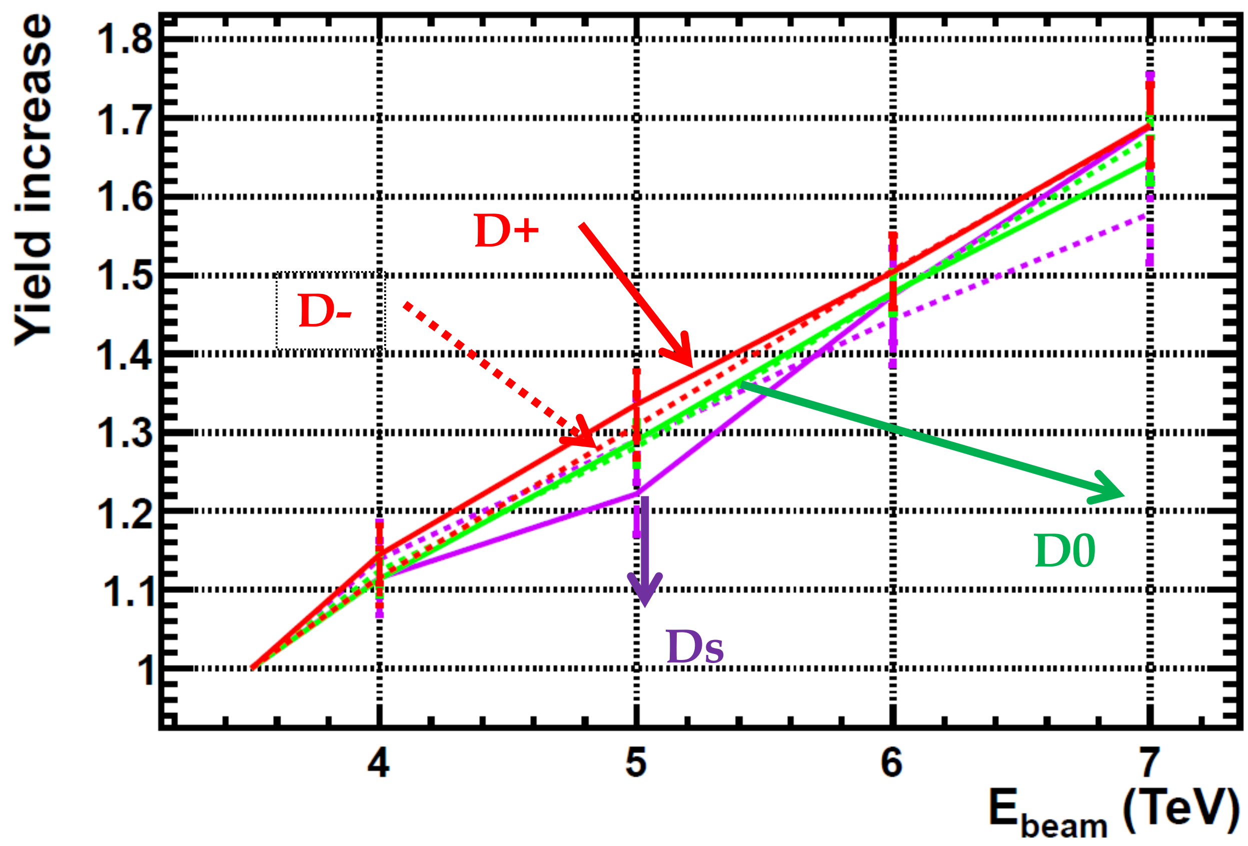
B mesons

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)

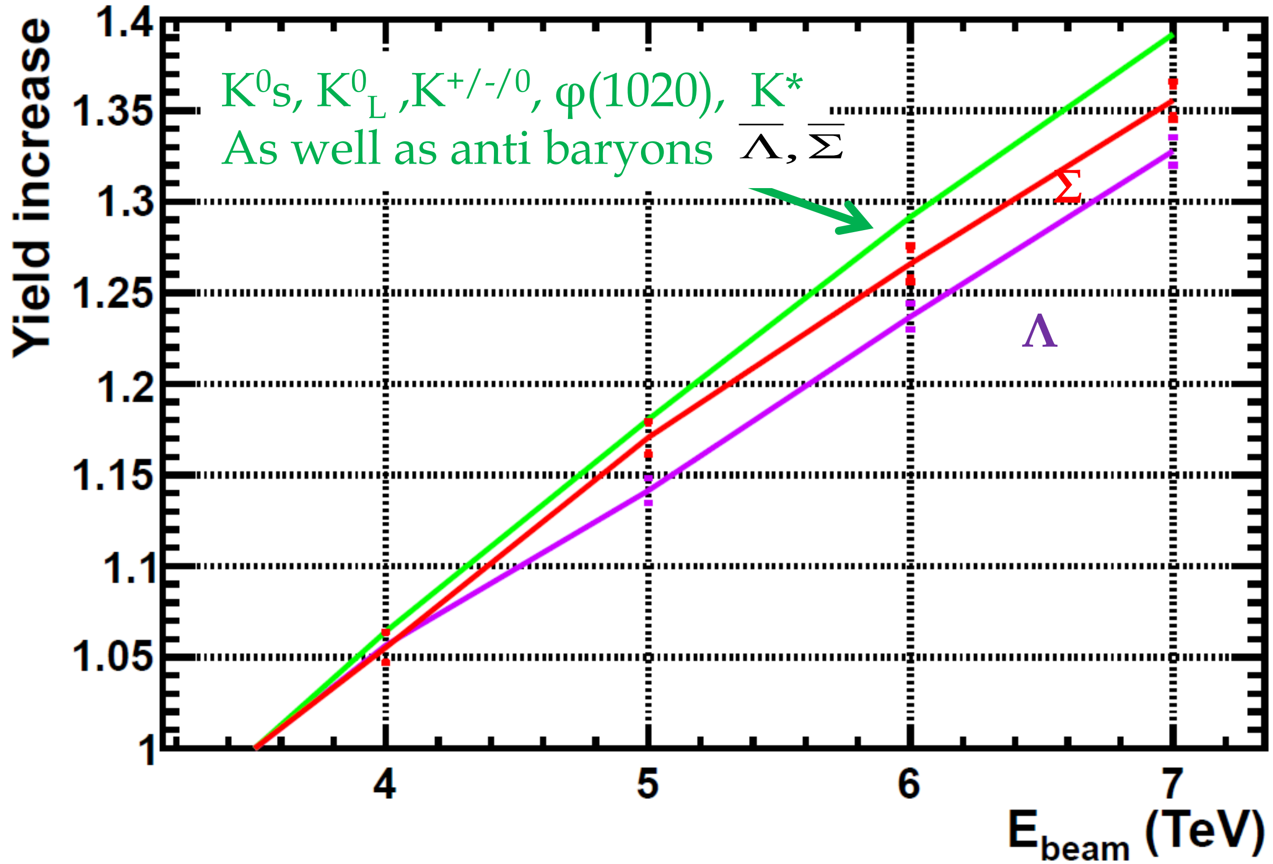


Strange particles

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.

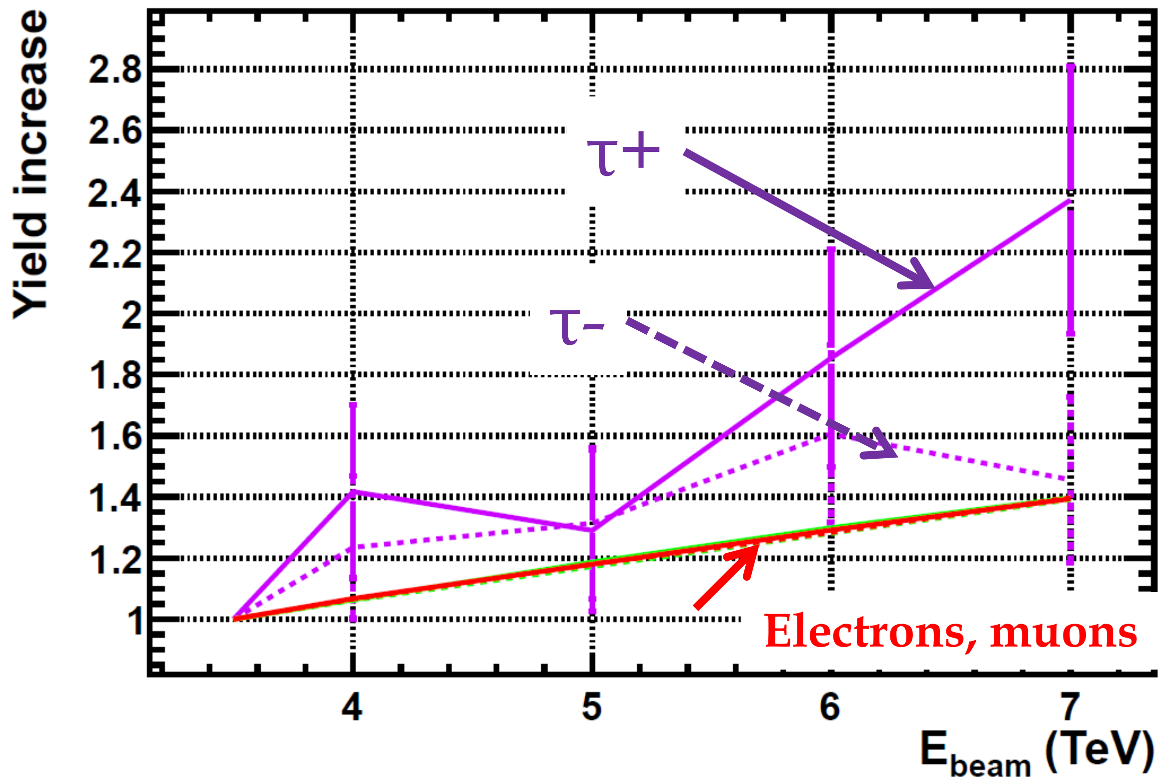


In particular, for the K0s decaying in the VELO the increase is "only" ~30% → This is the number we really care for Ks → μμ studies

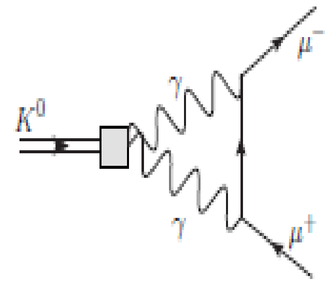
Leptons

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

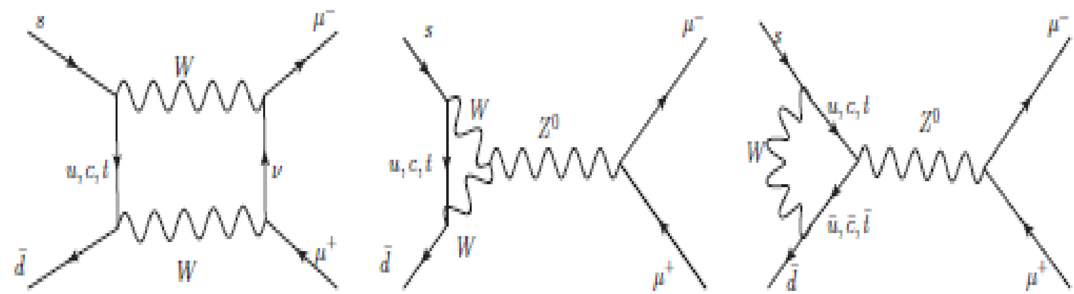
Check with more stats if the asymmetry +/- is still there

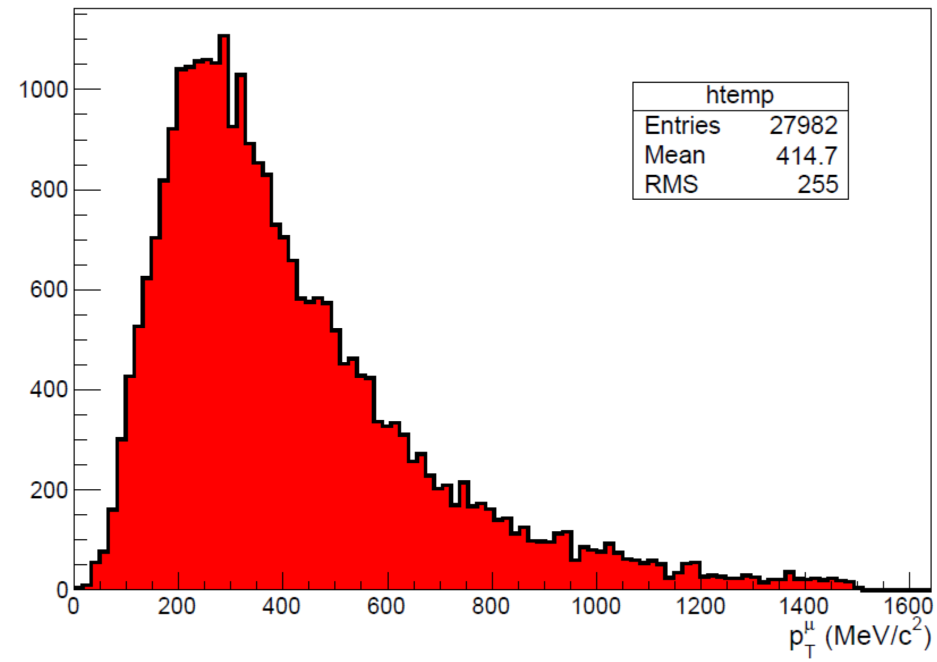


→ the long-distance (LD) contributions:



→ the short-distance (SD) contributions:

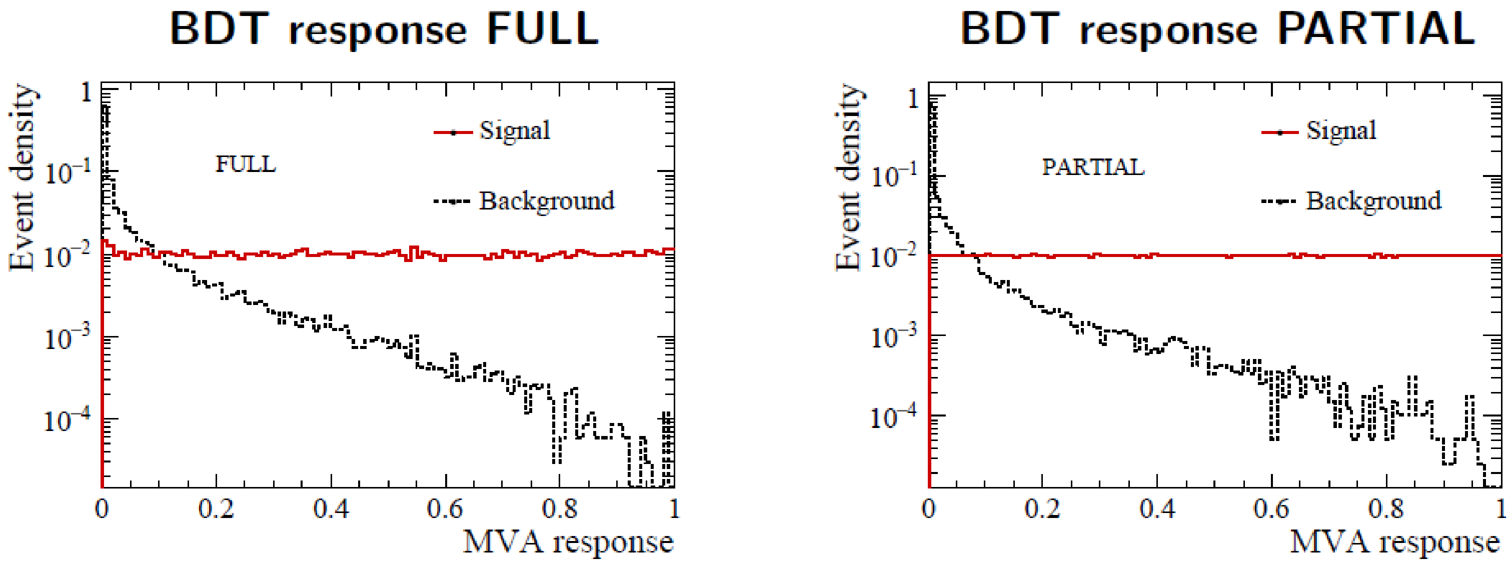



htemp
Entries 27982
Mean 414.7
RMS 255
1000
800
600
400
200
0
0
200
400
600
800
1000
1200
1400
1600
p_T^μ (MeV/c^2)

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

The background discrimination

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



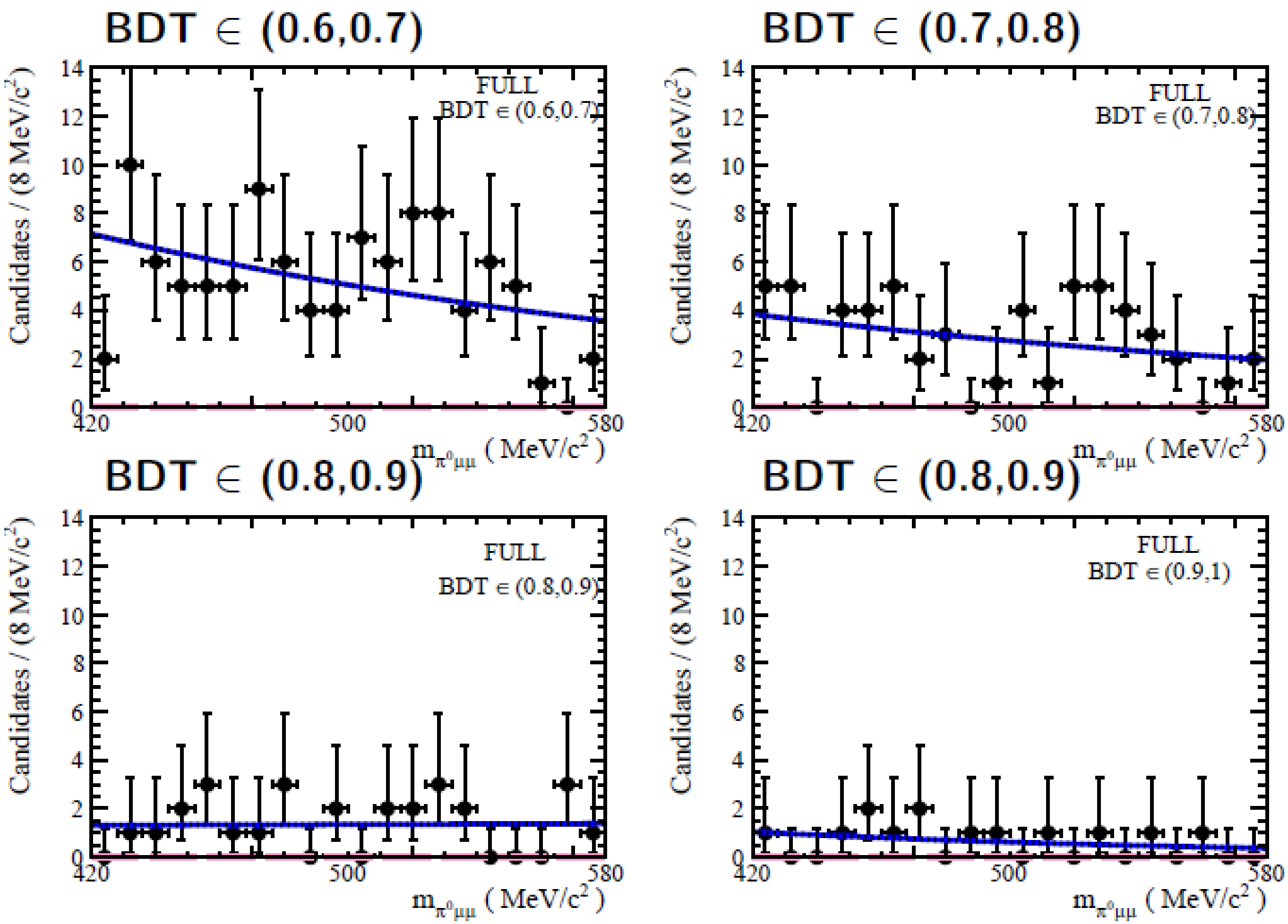
- As usual: BDT trained against combinatorial background
- Specific backgrounds: $K_S \to \pi\pi$, $K_L \to \pi\pi\pi$, $K_{S/L} \to \mu\mu\gamma\gamma$ (negligible)

Don't affect the sensitivity estimate

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

Fit, FULL

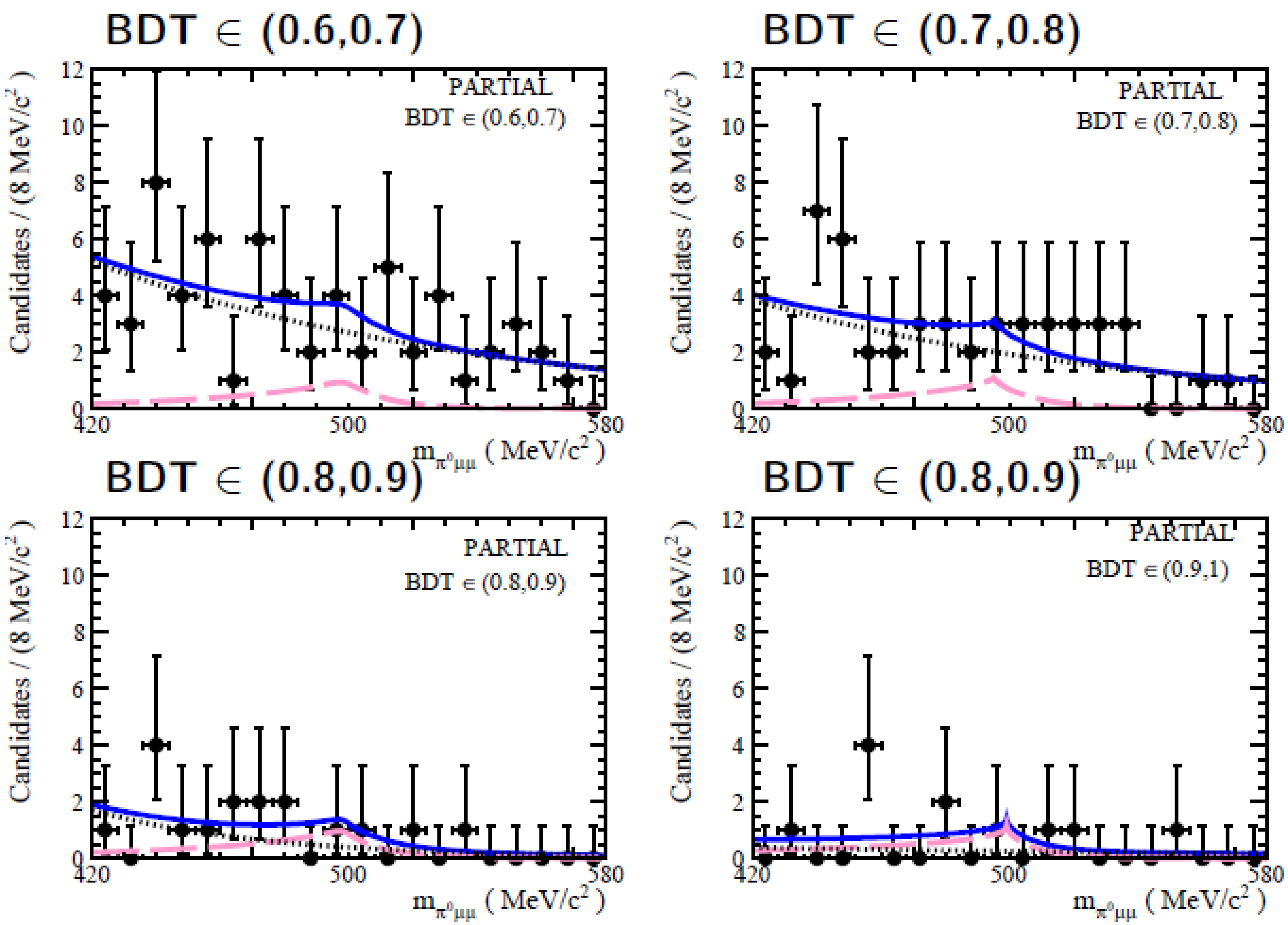
V. Chobanova et al,
CERN-LHCb-PUB-2016-017



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

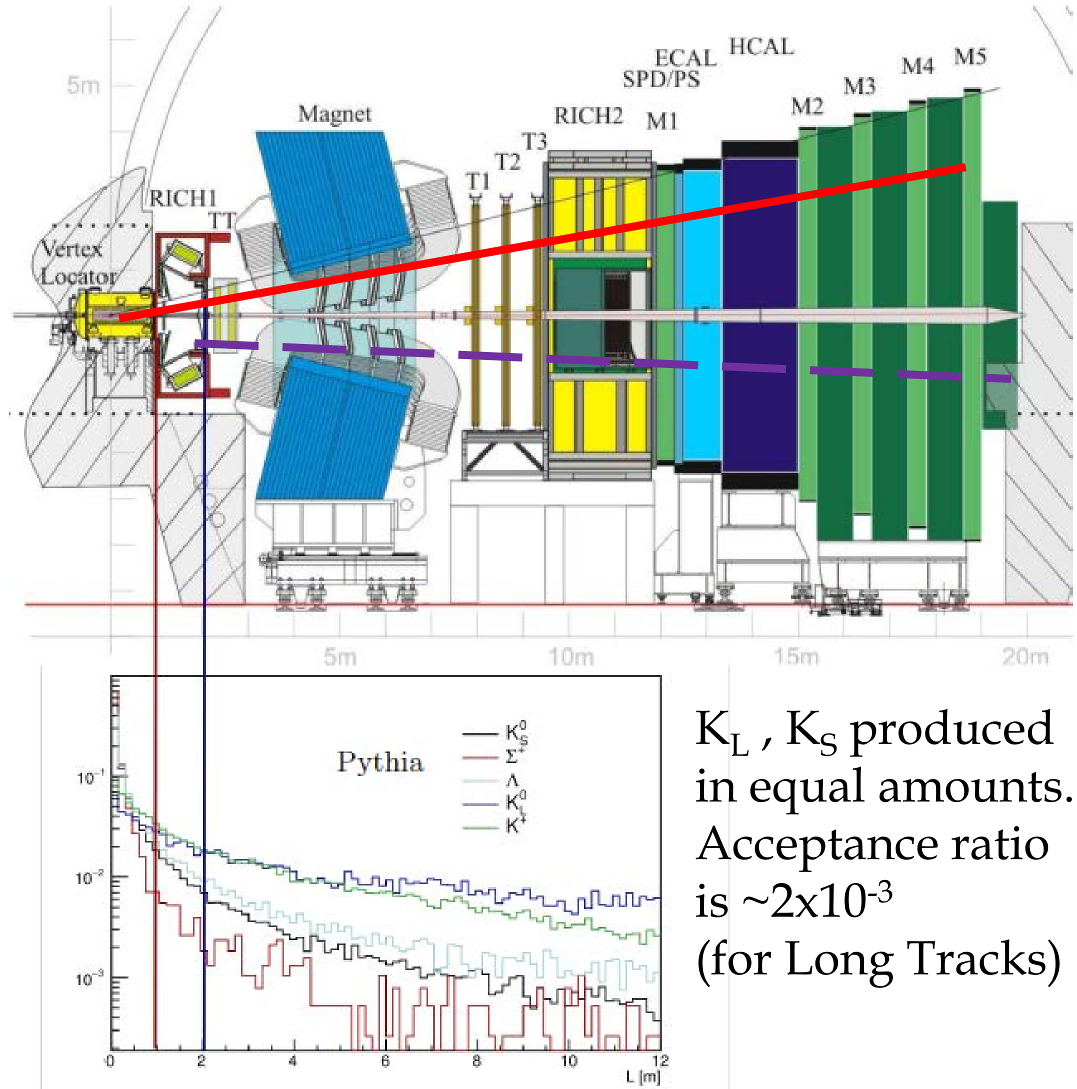
Fit, PARTIAL

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



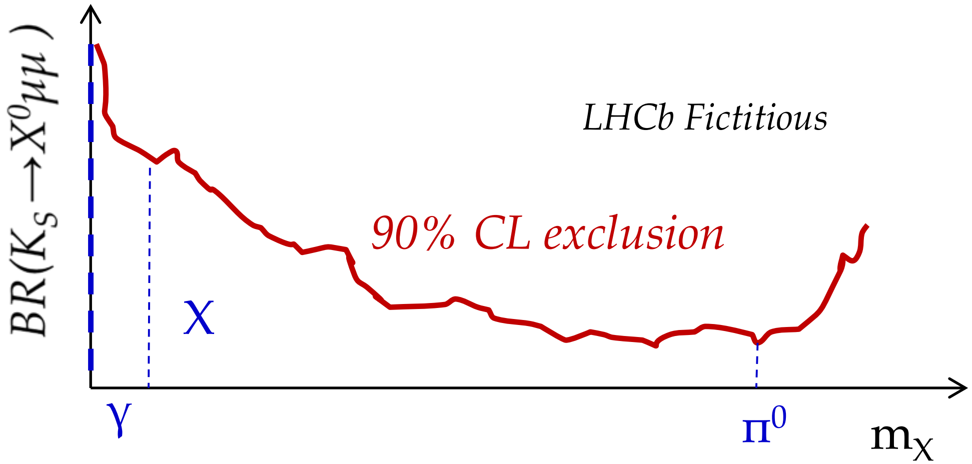
Strangeness production/detection at LHCb

- 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)

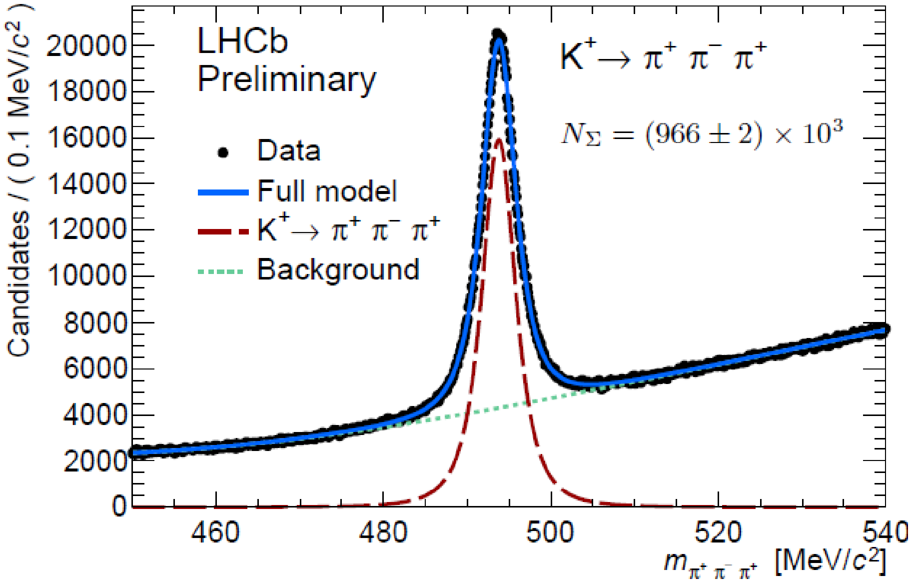


K_L , K_S produced in equal amounts. Acceptance ratio is ~$2x10^{-3}$ (for Long Tracks)

Ongoing stuff



K^+ studies



Large samples of charged kaon decays are available

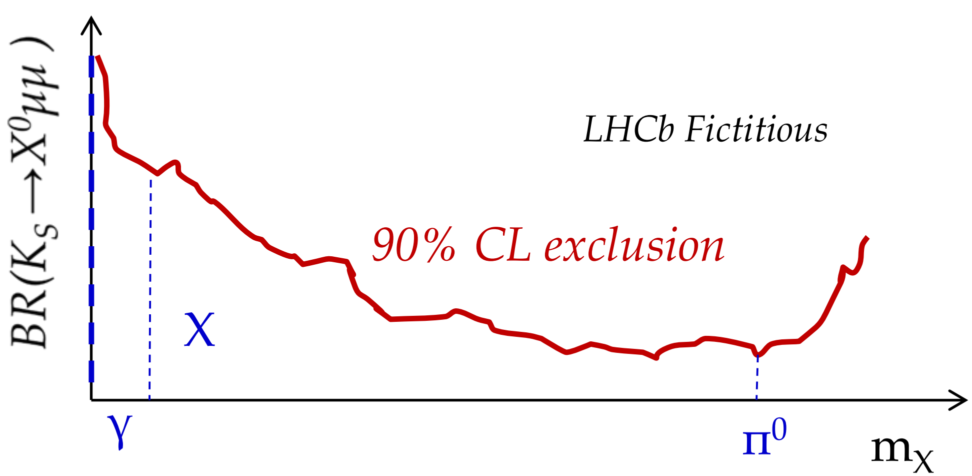
K^+ mass is not very well known

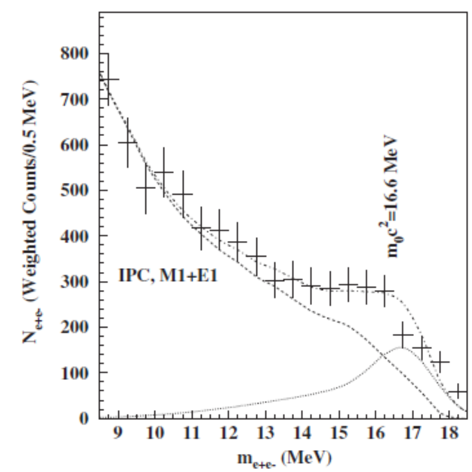
$K^+ \rightarrow \pi\mu\mu$?

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

- 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

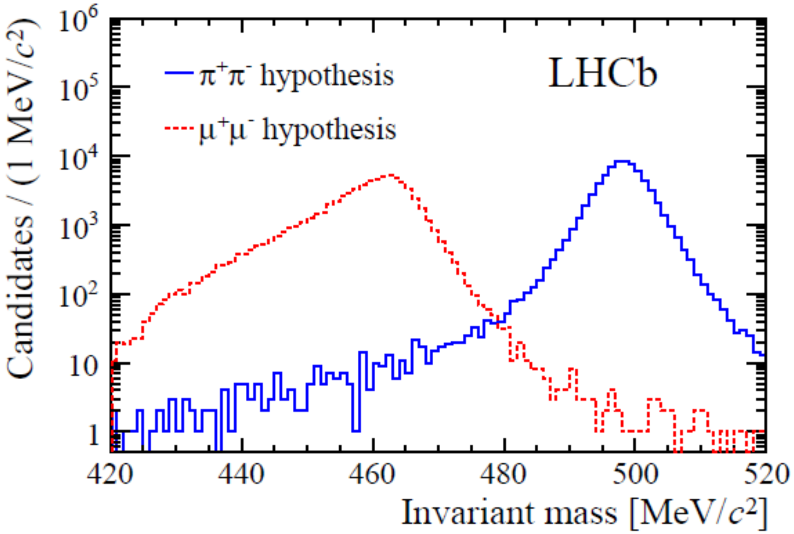




$K_S \to \mu\mu$ full Run-I analysis

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)

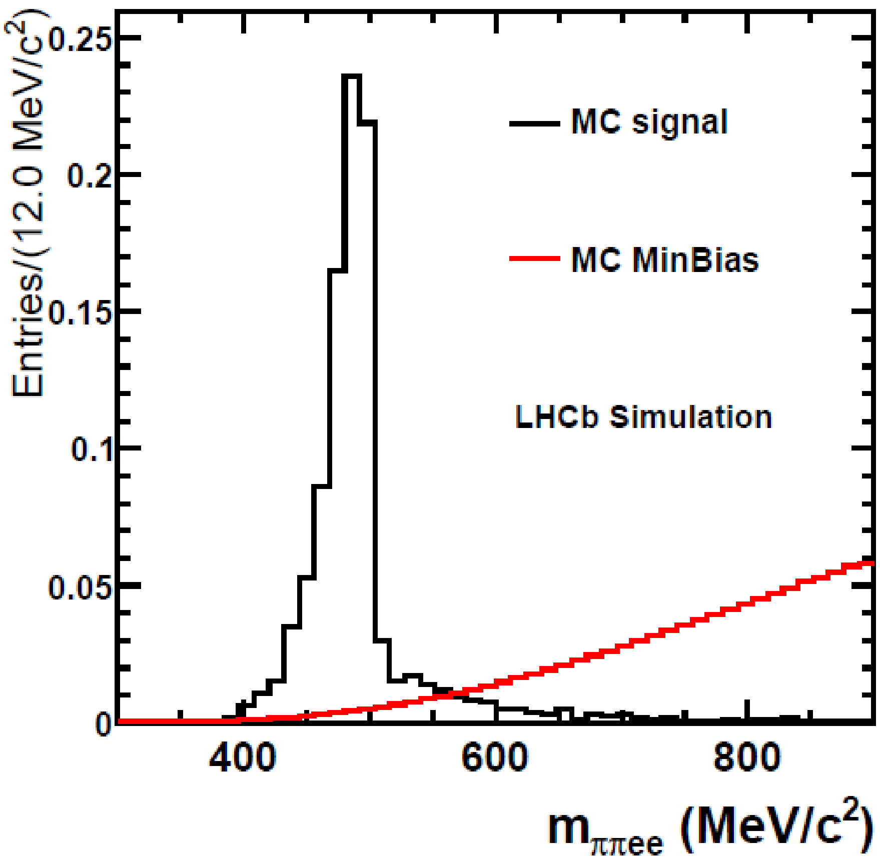
$K \to \pi\mu\nu$: negligible

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

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

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

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

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

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