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 $\rightarrow$ ~zero trigger efficiency otherwise
  • But there is also an ~infinite strangeness production at LHC (kaon $\times s \sim 1.2$ 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

HLT1
(Software)

Not designed for K, but flexible.

HLT2
(Software)

K triggers being implemented

Typical PT

~30-40 GeV

~1-2 GeV

~0.08 GeV

B-physics

s-physics
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$\varepsilon(2011-2012) \sim 1\%-2\%$
$\varepsilon($Run-II$)$ improved HLT $\sim 18\%$ (dimuons)
Maximum allowed by L0 $\sim 30\%$

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$\sim 30\text{-}40$ GeV

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LHCb Upgrade

HLT (Software)

(Note: This logo may not be official)
Trigger system: status and prospects

- **L0** (Hardware)
  - Main bottleneck for K. Can’t be changed

- **HLT1** (Software)
  - Not designed for K, but flexible.
  - K triggers being implemented

- **HLT2** (Software)

**LHCb Upgrade**

- Simulation studies show that rate would be under control
  - $\varepsilon_{(2011-2012)} \sim 1-2\%$
  - $\varepsilon_{(Run-II)}$ improved HLT $\sim 18\%$ (dimuons)
  - Maximum allowed by L0 $\sim 30\%$

- $\varepsilon_{(Upgrade)} \sim 80-100\%$?
  - Simulation studies show that rate would be under control
  - V. Chobanova et al, CERN-LHCb-PUB-2016-017
**K_S→μμ: motivation**

- SM prediction: \( \text{BR}(K_S \rightarrow \mu\mu) = (5.18 \pm 1.50_{\text{LD}} \pm 0.02_{\text{SD}}) \times 10^{-12} \)
  

- \( K_S \rightarrow \mu\mu \) sensitive to different physics than \( K_L \rightarrow \mu\mu \), NP can be bigger than SM by \( \sim 1 \) order of magnitude or even saturate current EXP limit

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

Leptoquark scenarios from Bobeth & Buras, JHEP02(2018)101
$K_S \rightarrow \mu\mu$ latest result

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

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 (1.4$\sigma$)
**K_S → μμ latest result**

Full LHCb dataset analysed (9 fb⁻¹)

No evidence for signal (1.4σ)

**New world best upper limit**
(improved by a factor ~4)

\[ \text{BR}(K_S \to \mu\mu) < 2.1 \times 10^{-10} @ 90\% \text{ CL} \]

At 1σ: \[ \mathcal{B} \left( K_S^0 \to \mu^+\mu^- \right) = 0.94^{+0.72}_{-0.64} \times 10^{-10} \]

Sept. 2019
The HyperCP evidence

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

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


- Consistent w/ SM: $1.6 < \text{BR}[10^{-8}] < 9$

  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
\[ \Sigma \rightarrow \rho \mu \mu \]

- **Current result** \( \Sigma \rightarrow \rho \mu \mu \): Found 4\(\sigma\) evidence \( \text{BR}(\Sigma \rightarrow \rho \mu \mu) : 2.1 \pm 1.6 \times 10^{-8} \), no evidence of resonant dilepton state

- **Run-II:** We expect \(~150\) signal events \( \rightarrow \) measure AFB

- **Upgrade(s):** Full differential decay rate

10\(y\) ago we thought this channel was \(~impossible\) and instead now we are even thinking on an amplitude analysis…. 
$K_S \rightarrow \pi^0 \mu\mu$ sensitivity study

**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.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Phase I</th>
<th>Phase II</th>
</tr>
</thead>
<tbody>
<tr>
<td>BR &amp; $q^2$ fit</td>
<td>0.25</td>
<td>0.10</td>
</tr>
<tr>
<td>BR &amp; $q^2$ fit with NA48 constraint</td>
<td>0.19</td>
<td>0.10</td>
</tr>
<tr>
<td>BR &amp; $q^2$ fit fixing $b_S$</td>
<td>0.06</td>
<td>0.024</td>
</tr>
<tr>
<td>$a_S$ measurement from BR alone</td>
<td>0.06</td>
<td>0.024</td>
</tr>
<tr>
<td>(fixing $b_S$)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

$K_S \to \pi^0 \mu \mu$ analysis can also be extended to other neutrals, e.g: $K_S \to \gamma \mu \mu$

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)

--

1808.03477

Fast Simulation
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

$$R_{B_1 B_2}^{NP} \sim \frac{\epsilon_S^{SU} f_S(0) + 12 \epsilon_T^{SU} f_T(0)}{f_T(0) f_T(0)} \left(1 - \frac{3}{2} \delta \right) \left(1 + 3 \frac{g_T(0)}{f_T(0)} \right) \Pi(\Delta, m_{\mu})$$

(extrapolations from 1412.8484)

Gonzalez-Alonso & JMC, NA62 Physics Handbook

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

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

- 😞 Challenging peaking backgrounds:

For each $B_1 \rightarrow B_2 \mu \nu$ there is always a $B_1 \rightarrow B_2 \pi$ (inc. $\rightarrow B_2 \mu \nu$)

😊 Can be separated in search planes
Semileptonic decays

- Semileptonic Hyperon Decays (SHD)

Fast Simulation 1808.03477

\[ \Lambda \rightarrow p\pi \]
\[ \Lambda \rightarrow p\mu\nu \]

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

For each $B_1 \rightarrow B_2 \mu\nu$ there is always a $B_1 \rightarrow B_2\pi$ (inc. $\rightarrow B_2\mu\nu$)

Fast Simulation

1808.03477

$\Xi^- \rightarrow \Lambda\pi$

$\Xi^- \rightarrow \Lambda\mu\nu$

☺ Can be separated in search planes
Lepton Flavour Violation

- 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
\[ K_S \rightarrow e\mu \text{ is a LFV model discriminator} \]
Lepton Flavour Violation

• Lepton Flavour Violation is a hot topic nowadays

LHCb can do:

\(K_S \rightarrow e\mu\)
\(K^+ \rightarrow \pi^+\mu^-e^+\)
Lepton Flavour Violation

- Lepton Flavour Violation is a hot topic nowadays

LHCb can do:

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

Competition w/ NA62 to be clarified

Graph displaying the branching ratios for $\mathcal{B}(K^+ \rightarrow \pi^+\mu^-e^+)$ versus $LHCb \int \mathcal{L}$ [fb$^{-1}$].
Charged kaons

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

- Under study sensitivity to $K^+ \rightarrow \pi^+ \mu\mu$ vs NA62

- Benefits from the new dimuon triggers (the same way as $K_S \rightarrow \mu\mu$)
B and L violation (very low priority)

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

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 $\text{BR} \sim 10^{-56}$

**arXiv:1507.03859 [hep-ex]**
Conclusions

HIGH PT THRESHOLDS

I am inevitable

And I'm LHCB RHCP
Conclusions

• $s$ decays are awesome
  • High interest for BSM
  • Ultimate experimental precision $\sim 10^{-11} - 10^{-12}$

• 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

• Full LHCb dataset result: $K_S \rightarrow \mu\mu$

• Run-II (2016-2018) data analysis ongoing $\Sigma \rightarrow \rho\mu\mu$, $K_S \rightarrow (\gamma/\pi^0)\mu\mu...$
Backup
$\text{BR}(B_s \rightarrow \mu^+ \mu^-) = 2.65_{-0.39}^{+0.43} \times 10^{-9}, \quad \text{BR}(B_d \rightarrow \mu^+ \mu^-) = 1.09_{-0.68}^{+0.74} \times 10^{-10}$. 

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)

- Useful to understand “Hints” for BSM in b sector
  - Eg: deviations in $b \rightarrow s\mu\mu$: are they replicated in $s \rightarrow d\mu\mu$?
  - Potentially immense samples: high(est) ultimate experimental precision

\[ \mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda^2} O_{\Delta F=2} \]
**Efficiencies**


<table>
<thead>
<tr>
<th>Channel</th>
<th>Xs/Xs(K_S)</th>
<th>eff/eff(K_S)</th>
<th>eff/eff(K_S) with Downstream tracks</th>
<th>Mass resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K^0 \rightarrow \mu^+\mu^- )</td>
<td>1</td>
<td>1.0 (1.0)</td>
<td>1.8 (1.8)</td>
<td>( \sim 3.0 )</td>
</tr>
<tr>
<td>( K^0 \rightarrow \pi^+\pi^- )</td>
<td>1</td>
<td>1.1 (0.30)</td>
<td>1.9 (0.91)</td>
<td>( \sim 2.5 )</td>
</tr>
<tr>
<td>( K^0 \rightarrow \pi^0\mu^+\mu^- )</td>
<td>1</td>
<td>0.93 (0.93)</td>
<td>1.5 (1.5)</td>
<td>( \sim 35 )</td>
</tr>
<tr>
<td>( K^0 \rightarrow \gamma\mu^+\mu^- )</td>
<td>1</td>
<td>0.85 (0.85)</td>
<td>1.4 (1.4)</td>
<td>( \sim 60 )</td>
</tr>
<tr>
<td>( K^0 \rightarrow \mu^+\mu^-\mu^+\mu^- )</td>
<td>1</td>
<td>0.37 (0.37)</td>
<td>1.1 (1.1)</td>
<td>( \sim 1.0 )</td>
</tr>
<tr>
<td>( K^0_L \rightarrow \mu^+\mu^- )</td>
<td>( \sim 1 )</td>
<td>2.7 (2.7) ( \times 10^{-3} )</td>
<td>0.014 (0.014)</td>
<td>( \sim 3.0 )</td>
</tr>
<tr>
<td>( K^+ \rightarrow \pi^+\pi^+\pi^- )</td>
<td>( \sim 2 )</td>
<td>9.0 (0.75) ( \times 10^{-3} )</td>
<td>41 (8.6) ( \times 10^{-3} )</td>
<td>( \sim 1.0 )</td>
</tr>
<tr>
<td>( K^+ \rightarrow \pi^+\mu^+\mu^- )</td>
<td>( \sim 2 )</td>
<td>6.3 (2.3) ( \times 10^{-3} )</td>
<td>0.030 (0.014)</td>
<td>( \sim 1.5 )</td>
</tr>
<tr>
<td>( \Sigma^+ \rightarrow p\mu^+\mu^- )</td>
<td>( \sim 0.13 )</td>
<td>0.28 (0.28)</td>
<td>0.64 (0.64)</td>
<td>( \sim 1.0 )</td>
</tr>
<tr>
<td>( \Lambda \rightarrow p\pi^- )</td>
<td>( \sim 0.45 )</td>
<td>0.41 (0.075)</td>
<td>1.3 (0.39)</td>
<td>( \sim 1.5 )</td>
</tr>
<tr>
<td>( \Lambda \rightarrow p\mu^-\bar{\nu}_\mu )</td>
<td>( \sim 0.45 )</td>
<td>0.32 (0.31)</td>
<td>0.88 (0.86)</td>
<td>( - )</td>
</tr>
<tr>
<td>( \Xi^- \rightarrow \Lambda\mu^-\bar{\nu}_\mu )</td>
<td>( \sim 0.04 )</td>
<td>39 (5.7) ( \times 10^{-3} )</td>
<td>0.27 (0.09)</td>
<td>( - )</td>
</tr>
<tr>
<td>( \Xi^- \rightarrow \Sigma^0\mu^-\bar{\nu}_\mu )</td>
<td>( \sim 0.03 )</td>
<td>24 (4.9) ( \times 10^{-3} )</td>
<td>0.21 (0.068)</td>
<td>( - )</td>
</tr>
<tr>
<td>( \Xi^- \rightarrow p\pi^-\pi^- )</td>
<td>( \sim 0.03 )</td>
<td>0.41 (0.05)</td>
<td>0.94 (0.20)</td>
<td>( \sim 3.0 )</td>
</tr>
<tr>
<td>( \Xi^0 \rightarrow p\pi^- )</td>
<td>( \sim 0.03 )</td>
<td>1.0 (0.48)</td>
<td>2.0 (1.3)</td>
<td>( \sim 5.0 )</td>
</tr>
<tr>
<td>( \Omega^- \rightarrow \Lambda\pi^- )</td>
<td>( \sim 0.001 )</td>
<td>95 (6.7) ( \times 10^{-3} )</td>
<td>0.32 (0.10)</td>
<td>( \sim 7.0 )</td>
</tr>
</tbody>
</table>
Sensitivity of (semi)leptonic kaon decays in a nutshell

- $K_{\ell 3}$
  \[
  \Gamma(K_{\ell 3}(\gamma)) = \frac{G_F^2 m_K^5}{192\pi^3} \left| \tilde{V}_{us}^{\ell} \right|^2 f_+(0)^2 \left[ I_K(\lambda_{+0}, \epsilon_{s}, \epsilon_{c}) \left( 1 + \frac{\delta^c}{\delta^{c\ell}_{em}} \right)^2 \right] \left( 1 + \epsilon_{s}^{\ell} + \epsilon_{c}^{\ell} - \tilde{\nu}_L \right) V^{SM}_{us}
  \]

- $K_{\ell 2}$
  \[
  \Gamma(K_{\ell 2}(\gamma)) = \frac{G_F^2 m_K m_{\ell}^2}{8\pi} \left( 1 - \frac{m_{\ell}^2}{m_{P}^2} \right)^2 \left| \tilde{V}_{us}^{\ell} \right|^2 f_{K^\pm}^2 (1 - 4\epsilon_{c}) - \frac{2B_0}{m_{\ell}} \epsilon_{P}^{s\mu} \chi_{enh.}
  \]

- $|\tilde{V}_{us}^{\ell}|$ only accessible through CKM unitarity and LUV tests
- $\epsilon_{c}^{s}$ 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

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?

\[ pp \rightarrow K^0K^-X, \quad pp \rightarrow K^{*+}X \rightarrow K^0\pi^+X \quad \text{and} \quad pp \rightarrow K^0\Lambda^0X. \]
Toy MC for 50 fb$^{-1}$

- **BDT ∈ (0.6, 0.7)**
  - Simulated candidates ($\times 10^7$) as a function of $m_{\pi^0\mu\mu}$ (MeV/c$^2$)

- **BDT ∈ (0.7, 0.8)**
  - Simulated candidates ($\times 10^7$) as a function of $m_{\pi^0\mu\mu}$ (MeV/c$^2$)

- **BDT ∈ (0.8, 0.9)**
  - Simulated candidates ($\times 10^7$) as a function of $m_{\pi^0\mu\mu}$ (MeV/c$^2$)

- **BDT ∈ (0.8, 0.9)**
  - Simulated candidates ($\times 10^7$) as a function of $m_{\pi^0\mu\mu}$ (MeV/c$^2$) with additional data points.
**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

$$\epsilon(t) \sim e^{-\beta t} \quad \text{With } \beta \gtrsim 5\times \Gamma_s (\gg \Gamma_L).$$

This makes the two lifetime distributions to look similar.

But the overall efficiency ratio is of course different

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

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.

$$\beta \sim 86 \text{ ns}^{-1}$$
Normalization of event yield

Converting a signal yield into a branching ratio

\[ N(K_s^0 \rightarrow \pi\mu\mu) = \sigma(K_s^0)BR(K_s^0 \rightarrow \pi\mu\mu)\epsilon L \]

- **KS production crosssection**
- **Absolute efficiency**
- **Integrated luminosity**
How? (normalization of event yield)

Converting a signal yield into a branching ratio

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

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

Introduce in the ntuples a \( K_s^0 \to \pi\pi \) decays counter

Very well known 
\((69.20\pm0.05)\%\)
Dilepton mass distribution

Take formulae from hep-ph/9808289

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

\( z = m^2 \Rightarrow d\Gamma/dm = 2m \, d\Gamma/dz \)

\[ W_i(z) = G_F M_K^2 (a_i + b_i z) + W_{i\pi\pi}(z), \]  

\[ W_{i\pi\pi}(z) = \frac{1}{r_{\pi}^2} \left[ \alpha_i + \beta_i \frac{z - z_0}{r_{\pi}^2} \right] F(z) \chi(z), \]
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 yield 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:
$K_S \rightarrow \pi^0 \mu\mu$ sensitivity study

The background discrimination

- As usual: BDT trained against combinatorial background
- Specific backgrounds: $K_S \rightarrow \pi\pi$, $K_L \rightarrow \pi\pi\pi$, $K_{S/L} \rightarrow \mu\mu\gamma\gamma$ (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
$K_S \rightarrow \pi^0 \mu\mu$ 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 $\sim 2 \times 10^{-3}$ (for Long Tracks).
Ongoing stuff

BR($K_S \rightarrow X^0\mu\mu$)

$\chi$

$LHCb$ Fictitious

90% CL exclusion

$Y$

$\pi^0$

$m_\chi$
K$^+$ studies

Large samples of charged kaon decays are available

K$^+$ mass is not very well known

K$^+$→πμμ?
$K_S \rightarrow X^0 \mu \mu$

- 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

Limits can be provided as a function of $X^0$ mass
K_S → μμ full Run-I analysis

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

Background

K_L → μμ negligible: (down to 10^{-11} precision)

K → πμν : negligible

Λ → pπ removed by a cut in the Armenteros-Podolanski plot.

- Combinatorial background
- K_S → ππ double misid
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? \((K_S \rightarrow \pi^0 \mu \mu \text{ and SM errors on } K_L \rightarrow \pi^0 \mu \mu)\)

\[
\mathcal{B}(K_L \rightarrow \pi^0 \mu^+ \mu^-)_{\text{SM}} = \{1.4 \pm 0.3, 0.9 \pm 0.2\} \cdot 10^{-11}
\]

\[
\mathcal{B}(K_L \rightarrow \pi^0 l^+ l^-) = (C_{\text{dir}}^l \pm C_{\text{int}}^l |a_S| + C_{\text{mix}}^l |a_S|^2 + C_{\gamma \gamma}^l + C_S^l) \cdot 10^{-12}
\]

\[
|a_S| = 1.20 \pm 0.20
\]

\[
C_{\text{dir}} = (4.62 \pm 0.24) \left[ (\text{Im } Y_A)^2 + (\text{Im } Y_V)^2 \right],
\]

\[
C_{\text{int}} = (11.3 \pm 0.3) \text{ Im } Y_V,
\]

\[
C_{\text{mix}} = 14.5 \pm 0.5,
\]

\[
C_{\gamma \gamma} \approx C_S \approx 0,
\]

\[
C_{\text{dir}}^\mu = (1.09 \pm 0.05) \left[ 2.32 (\text{Im } Y_A)^2 + (\text{Im } Y_V)^2 \right],
\]

\[
C_{\text{int}}^\mu = (2.63 \pm 0.06) \text{ Im } Y_V,
\]

\[
C_{\text{mix}}^\mu = 3.36 \pm 0.20,
\]

\[
C_{\gamma \gamma}^\mu = 5.2 \pm 1.6,
\]

\[
C_S^\mu = (0.04 \pm 0.01) \text{ Re } Y_S + 0.0041 (\text{Re } Y_S)^2.
\]

Dominant uncertainty, that makes difficult potential BSM interpretation of \(K_L \rightarrow \pi^0 \mu \mu\)

It comes from the \textbf{experimental uncertainty} on \(\text{BR}(K_S \rightarrow \pi^0 \mu \mu)\)
measured by NA48

\[
K_S^0 \rightarrow \pi^0 \mu^+ \mu^- \quad \text{NA48} \quad (2.9^{+1.5}_{-1.2}) \times 10^{-9}
\]

\(~50\% \text{ relative error}\)

\textbf{Improved measurements of } \text{BR}(K_S \rightarrow \pi^0 \mu \mu) \text{ will translate into improved BSM constraints from } K_L \rightarrow \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