

**New limits on $B_{(s)}^0 \rightarrow \mu^+ \mu^-$
and $K_S^0 \rightarrow \mu^+ \mu^-$**

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- LHCb: single-arm spectrometer with forward angular coverage from 10 mrad to 300 (250) mrad in the bending (non-bending) plane.
- Main physics goals: Search for New Physics through CP-violation studies and rare decays.
- Details about LHCb: follow **plenary talk by Hugo Ruiz!**

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- “Rare decays”: modes in which the branching fractions are suppressed in the SM and the rates or other experimental observables are sensitive to NP.
- Rare decays analysed at LHCb are all FCNC:
 - The access to NP is through new virtual particles entering in the loops
 - Indirect search for NP, access higher energy scales than direct searches!
- Rare decays, classified in:
 - electroweak penguin,
 - radiative decays,
 - **very rare decays**.

$$B_{(s)}^0 \rightarrow \mu^+ \mu^-$$

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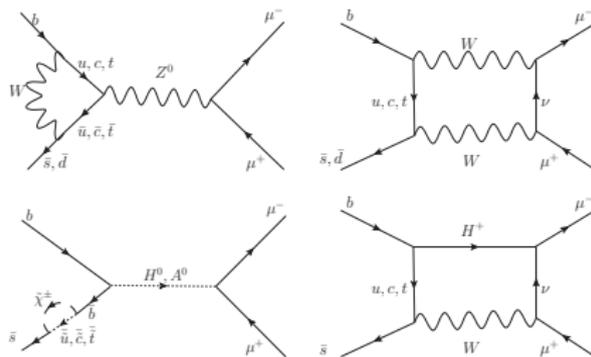
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- $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ decays (i.e $B^0 \rightarrow \mu^+ \mu^-$ and $B_s^0 \rightarrow \mu^+ \mu^-$) are FCNC which do not arise at tree level in SM.
- Feynman diagrams are boxes and penguins:



Examples of diagrams contributing to $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ decays in SM (top) and NP (bottom)

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- $\mathcal{B}(B_{(s)}^0 \rightarrow \mu^+ \mu^-)$ more sensitive to the scalar sector!
- In SM:

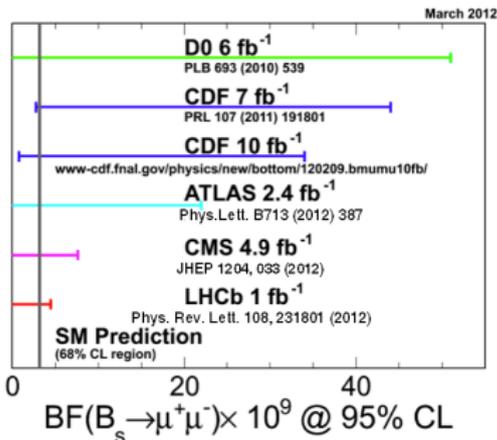
$$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-)|^{SM} = (1.1 \pm 0.1) \times 10^{-10}$$

$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)|^{SM} = (3.5 \pm 0.3) \times 10^{-9}$$

A. J. Buras *et. al.* *Eur.Phys.J.* **C72** (2012) 2172, [arXiv:1208.0934]

S. Descotes-Genon *et. al.* *Phys.Rev.* **D85** (2012) 034010, [arXiv:1111.4882]

K. De Bruyn *et. al.* *Phys.Rev.Lett.* **109** (2012) 041801, [arXiv:1204.1737]



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Dataset

- Analysis performed combining 2011 and 2012 data.
 - 1.1 fb⁻¹ of data at $\sqrt{s}=8$ TeV (2012)
 - 1.0 fb⁻¹ of data at $\sqrt{s}=7$ TeV (2011)

Analysis strategy

- Selection: apply cuts on $\mu^+ \mu^-$ candidates to remove most of the background.
- Classify each event using two variables (bins in a 2D parameter space).
 - **Geometrical properties** ($IP(B)$, $\tau(B)$, DOCA, $I(B)$, $I(\mu_1) + I(\mu_2)$, $minIP\chi^2(\mu)$, $p_T(B)$, $\cos P$, $p_{T,min}(\mu)$) combined in **Boosted Decision Tree**
 - **Invariant mass**

$$B_{(s)}^0 \rightarrow \mu^+ \mu^- \text{ and}$$

$$K_S^0 \rightarrow \mu^+ \mu^-$$

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Analysis strategy

- 2D space binned: treat each bin as an independent experiment \rightarrow compare expectations with observed data and combine results using **CL_s method** (Modified Frequentist Approach).
- Monitor specific backgrounds, such as $B_{(s)}^0 \rightarrow h^+ h'^-$ where both hadrons are misidentified as muons.
- Use of **control channels** to avoid dependence on simulation:
 - \rightarrow **Calibration of relevant variables** ($B_{(s)}^0 \rightarrow h^+ h'^-$, $D^0 \rightarrow K\pi, \dots$)
 - \rightarrow **Normalisation** ($B^+ \rightarrow J/\psi K^+$ and $B^0 \rightarrow K^+ \pi^-$). Around 25 (3) $B_S^0 \rightarrow \mu^+ \mu^-$ ($B^0 \rightarrow \mu^+ \mu^-$) SM candidates expected in the analysed dataset.
- Analysis is **blind**.

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- Combinatorial background

→ $b\bar{b} \rightarrow \mu\mu X$, two muons coming from different b quarks.

→ Fought against with BDT.

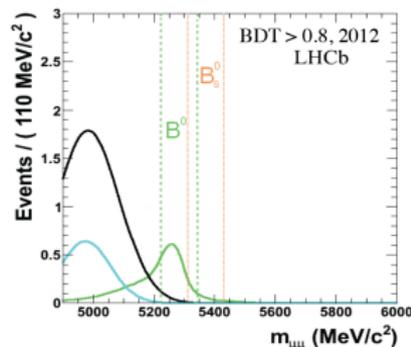
- $B_{(s)}^0 \rightarrow h^+ h^-$ ($B^0 \rightarrow K^+ \pi^-$, $B^0 \rightarrow \pi^+ \pi^-$, $B_S^0 \rightarrow \pi^+ K^-$ and $B_S^0 \rightarrow K^+ K^-$) in which both hadrons are misidentified as muons.

- Other specific backgrounds:

$$B^0 \rightarrow \pi^+ \mu^- \nu_\mu,$$

$$B \rightarrow \pi \mu^+ \mu^-.$$

Mass distribution of exclusive background candidates in the most sensitive BDT region (from MC)



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BDT

- Signal BDT calibration using $B_{(s)}^0 \rightarrow h^+ h'^-$ triggered independently of signal.

Mass

- The mass distributions for the signals are parameterised as two Crystal Ball functions.
 - Central extracted from exclusive $B_{(s)}^0 \rightarrow h^+ h'^-$ samples.
 - Resolutions extracted from interpolation of dimuon resonances and exclusive $B_{(s)}^0 \rightarrow h^+ h'^-$ samples.

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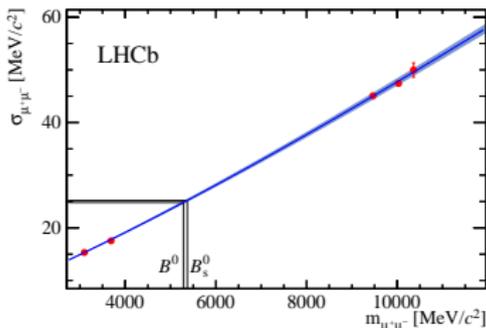
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Mass

- The mass distributions for the signals are parameterised as two Crystal Ball functions.
 - Resolutions extracted from interpolation of dimuon resonances and exclusive $B_{(s)}^0 \rightarrow h^+ h^-$ samples.



Channel	Peak position	Resolution
B^0	$(5284.36 \pm 0.26_{\text{stat}} \pm 0.13_{\text{syst}}) \text{ MeV}/c^2$	$(24.63 \pm 0.13_{\text{stat}} \pm 0.36_{\text{syst}}) \text{ MeV}/c^2$
B_s^0	$(5371.55 \pm 0.41_{\text{stat}} \pm 0.16_{\text{syst}}) \text{ MeV}/c^2$	$(25.04 \pm 0.18_{\text{stat}} \pm 0.36_{\text{syst}}) \text{ MeV}/c^2$

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- Background interpolated in bins of BDT using $B_{(s)}^0$ mass sidebands.
 - Interpolation fit includes combinatorial background and exclusive decays.
 - Only contribution in signal window: $B_{(s)}^0 \rightarrow h^+ h'^-$ double MisID and combinatorial background.
- Exclusive background parameters used as priors in the fit.
 - Yield from relative normalization to $B^+ \rightarrow J/\psi K^+$.
 - Mass and BDT shape from full MC.

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- Fits to determine the expected background on 2012 data (in bins of BDT).

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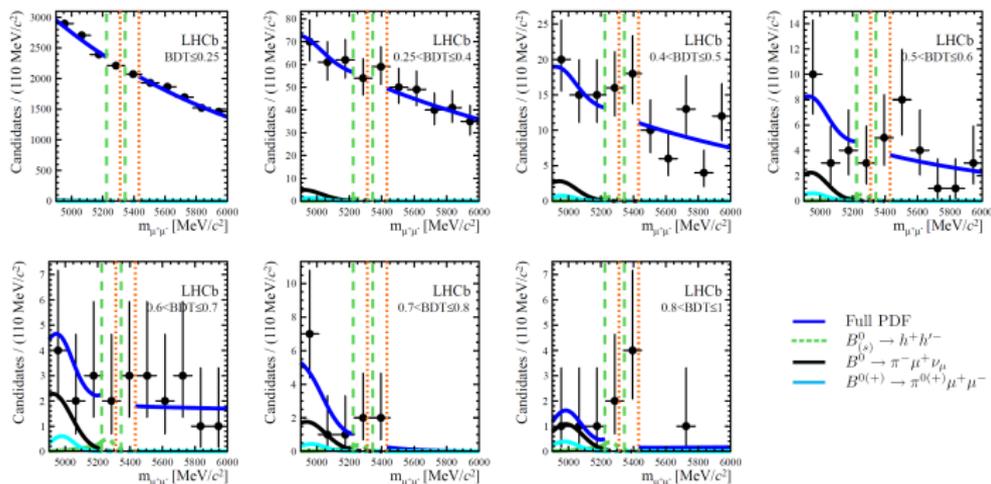
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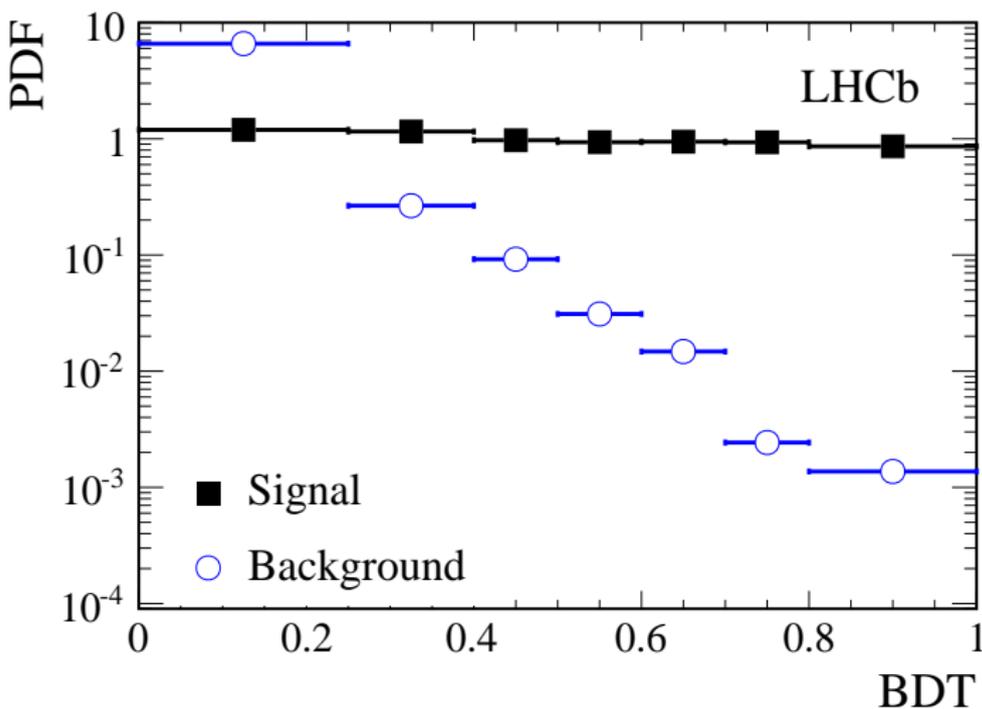
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- Final BDT shape for **signal** and **combinatorial background**:



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- Calculation of signal branching ratio:

→ normalise number of observed signal events to a calibration channel selected similarly and with a well known branching ratio ($B^+ \rightarrow J/\psi K^+$ and $B^0 \rightarrow K^+ \pi^-$)

$$\text{BR} = \text{BR}_{\text{cal}} \times \frac{\epsilon_{\text{cal}}^{\text{REC}} \epsilon_{\text{cal}}^{\text{SEL}} \epsilon_{\text{cal}}^{\text{TRIG}} \epsilon_{\text{cal}}^{\text{SEL}}}{\epsilon_{\text{sig}}^{\text{REC}} \epsilon_{\text{sig}}^{\text{SEL}} \epsilon_{\text{sig}}^{\text{TRIG}} \epsilon_{\text{sig}}^{\text{SEL}}} \times \frac{f_{\text{cal}}}{f_{B^0_q}} \times \frac{N_{B_{(s)}^0 \rightarrow \mu^+ \mu^-}}{N_{\text{cal}}} = \alpha_{\text{cal}} \times N_{B_{(s)}^0 \rightarrow \mu^+ \mu^-}$$

- Factors breakdown:

→ $f_{B^0}/f_{B^0_q} = f_{B^+}/f_{B^0_q}$: ratio of production fractions. From LHCb (semileptonic B decays and $B \rightarrow DX$): 0.256 ± 0.020 .

→ BR_{cal} : branching ratio of calibration channels (PDG).

→ N_{cal} : number of candidates in calibration channels.

→ $\frac{\epsilon_{\text{cal}}}{\epsilon_{\text{sig}}}$: ratios of efficiencies. Obtained with MC and/or data.

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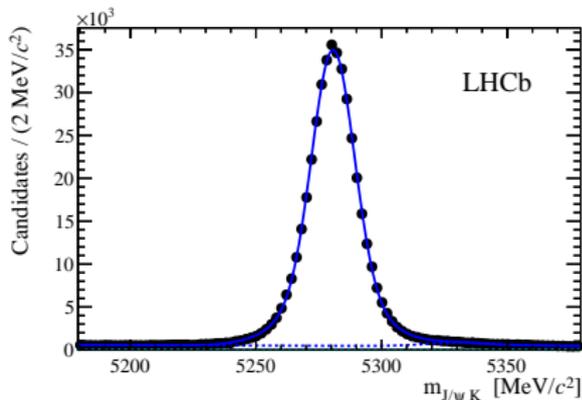
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- Normalisation factors driven by $B^+ \rightarrow J/\psi K^+$:



- In average (2012 data):

$$\alpha_{B_S^0 \rightarrow \mu^+ \mu^-} = (2.52 \pm 0.23) \times 10^{-10}$$

$$\alpha_{B^0 \rightarrow \mu^+ \mu^-} = (6.45 \pm 0.30) \times 10^{-11}$$

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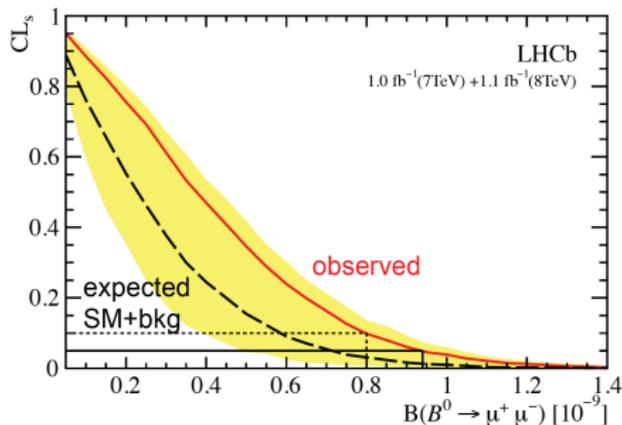
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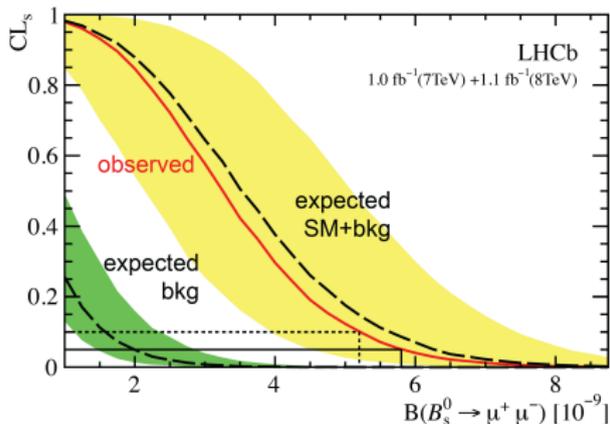
- Evaluate compatibility of observation with background only and signal+background hypotheses (CL_s method):



Limit	at 90 % C.L.	at 95 % C.L.
Exp. bkg+SM	5.8×10^{-10}	7.1×10^{-10}
Exp. bkg	5.0×10^{-10}	6.0×10^{-10}
Observed	8.0×10^{-10}	9.4×10^{-10}

→ Background **p-value: 16%**

- Evaluate compatibility of observation with background only and signal+background hypotheses (CL_s method):



→ Background **p-value**: $5 \times 10^{-4} \Rightarrow 3.5\sigma$

- Double sided limit (at 95% C.L.)

$$1.1 \times 10^{-9} < \mathcal{B}(B_S^0 \rightarrow \mu^+ \mu^-) < 6.4 \times 10^{-9}$$

- First evidence of the decay $B_S^0 \rightarrow \mu^+ \mu^-$!**

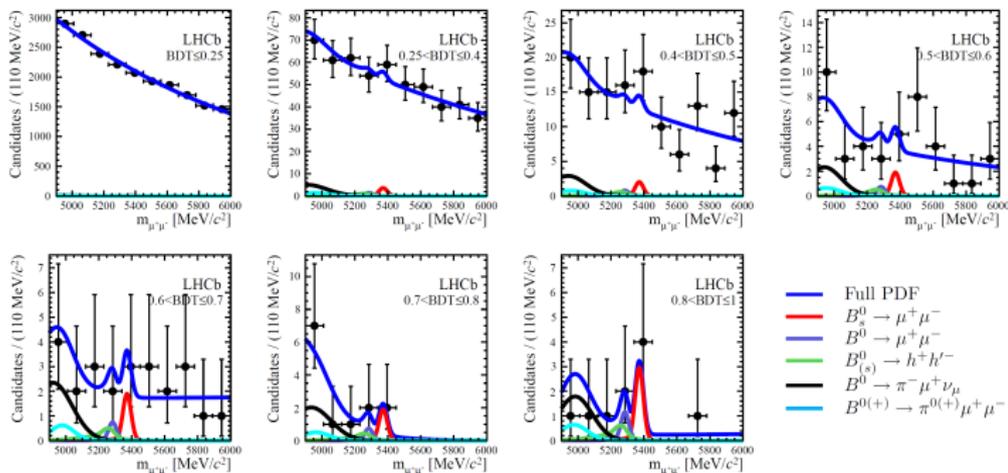
$B_S^0 \rightarrow \mu^+ \mu^-$ branching fraction fit

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- Simultaneous unbinned likelihood fit to 2011+2012 BDT bins.

→ Example: 2012 BDT bins.



- Fit result:

$$\mathcal{B}(B_S^0 \rightarrow \mu^+ \mu^-) = 3.2_{-1.2}^{+1.4}(\text{stat.})_{-0.3}^{+0.5}(\text{syst.}) \times 10^{-9}$$

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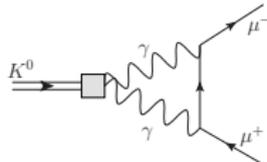
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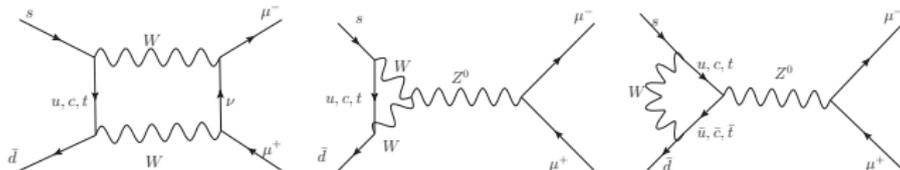
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- $K_S^0 \rightarrow \mu^+ \mu^-$ also FCNC: does not arise at tree level in SM.
- Two different components enter in the amplitude of $K^0 \rightarrow \mu^- \mu^+$. They gather
 → the long-distance (LD) contributions:



- the short-distance (SD) contributions:



$$\begin{aligned} &\text{New limits on} \\ B_{(s)}^0 &\rightarrow \mu^+ \mu^- \text{ and} \\ K_S^0 &\rightarrow \mu^+ \mu^- \end{aligned}$$

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- In the SM, the LD component of the amplitude completely dominates:

$$\rightarrow \mathcal{B}(K_S^0 \rightarrow \mu^+ \mu^-)|_{LD}^{SM} \sim 5 \times 10^{-12}$$

$$\rightarrow \mathcal{B}(K_S^0 \rightarrow \mu^+ \mu^-)|_{SD}^{SM} \sim 10^{-13}, \text{ being } \mathcal{B}(K_S^0 \rightarrow \mu^+ \mu^-)|_{SD}^{SM} \propto \bar{\eta}^2.$$

- Since constraints on $\bar{\eta}$ weak, NP scenarios where $\mathcal{B}(K_S^0 \rightarrow \mu^+ \mu^-)|_{SD}$ is at the 10^{-11} level allowed.

$$\rightarrow \mathcal{B}(K_L^0 \rightarrow \mu^+ \mu^-)|_{SD}^{SM} \propto \bar{\rho}.$$

- $\mathcal{B}(K_L^0 \rightarrow \mu^+ \mu^-)$ at the SM does not imply $\mathcal{B}(K_S^0 \rightarrow \mu^+ \mu^-)$ has to be at SM.

- Finally:

$$\mathcal{B}(K_S^0 \rightarrow \mu^+ \mu^-)|^{SM} = (5.1 \pm 1.5) \times 10^{-12}$$

G. Ecker and A. Pich *Nucl.Phys.* **B366** (1991) 189–208G. Isidori and R. Unterdorfer *JHEP* **0401** (2004) 009, [[hep-ph/0311084](https://arxiv.org/abs/hep-ph/0311084)]

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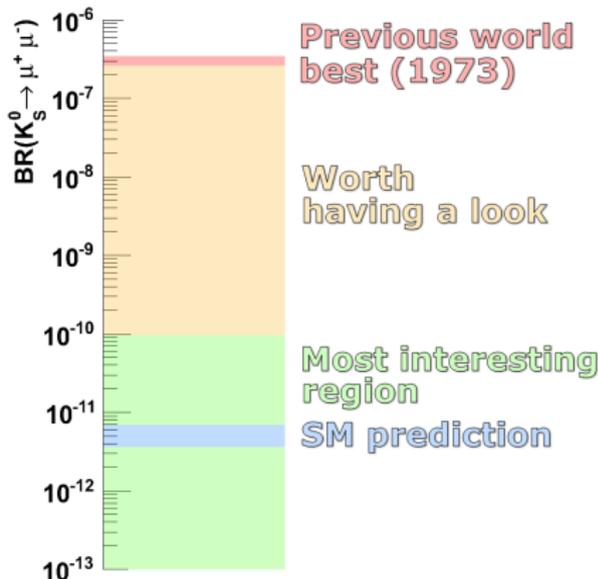
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- Best world upper limit, almost 40 years ago (1973)!

$$B(K_S^0 \rightarrow \mu^+ \mu^-) < 3.2 \times 10^{-7} \text{ at 90\% C.L.}$$

S. Gjesdal *et. al. Phys.Lett. B* **44** (1973) 217–220

→ Summary of the situation:



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Dataset

- Analysis performed using 1.0 fb^{-1} of 2011 data at $\sqrt{s}=7 \text{ TeV}$.

Analysis strategy

- Selection to reduce data size and get a clean $K_S^0 \rightarrow \pi^+ \pi^-$ control channel.
- Split sample **according to trigger category** because of discrepancies in event properties.
- Construction of BDTs based on geometrical and kinematical information. Train them on data.

$$B_{(s)}^0 \rightarrow \mu^+ \mu^- \text{ and}$$

$$K_S^0 \rightarrow \mu^+ \mu^-$$

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Analysis strategy

- **Bin-per-bin normalisation** to $K_S^0 \rightarrow \pi^+ \pi^-$, different strategies for different trigger categories. Not binning in mass.
- Determination of background per bin (combinatorial and contribution from $K_S^0 \rightarrow \pi^+ \pi^-$ double misID)
- Estimated background contribution from $K_S^0 \rightarrow \pi^+ \mu^- \bar{\nu}_\mu$, $K_S^0 \rightarrow \mu^+ \mu^- \gamma$, $K_L^0 \rightarrow \mu^+ \mu^-$, $K_L^0 \rightarrow \mu^+ \mu^- \gamma$, $K_L^0 \rightarrow \pi^+ \mu^- \bar{\nu}_\mu$, $K_L^0 \rightarrow \mu^+ \mu^- \gamma$. All negligible with current statistics.
- Use CL_s **method** to compare expectations with observed data and determine the upper limit on the branching fraction.
- Signal region also **blinded** until completion of the analysis.

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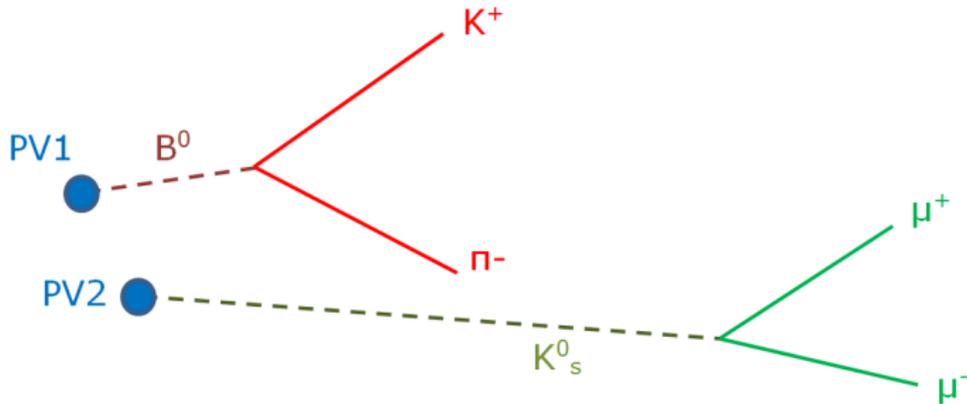
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- Signal properties very dependent on trigger behaviour:



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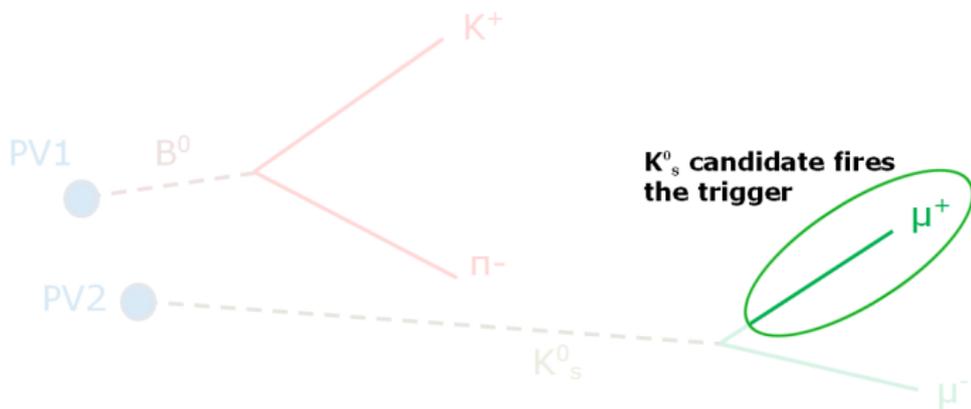
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- Signal properties very dependent on trigger behaviour:
 - Was the K_S^0 candidate responsible for the trigger at the three levels? (**Trigger On Signal, TOS**)



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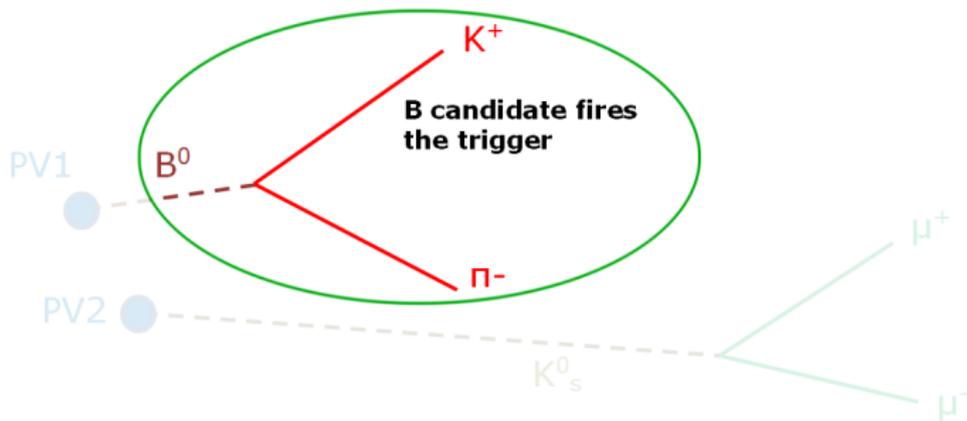
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- Signal properties very dependent on trigger behaviour:
 - Was the K_S^0 candidate responsible for the trigger at the three levels? (**Trigger On Signal, TOS**)
 - Was it some other particle in the underlying event? (**Trigger Independent of Signal, TIS**)



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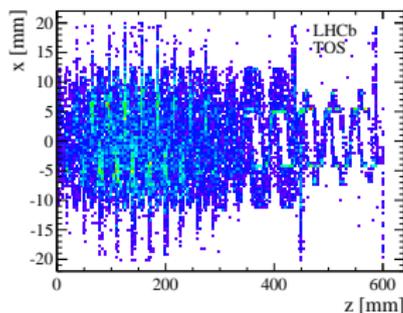
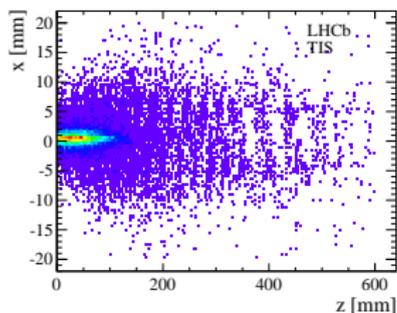
Conclusions

- Signal properties very dependent on trigger behaviour:
 - Was the K_S^0 candidate responsible for the trigger at the three levels? (**Trigger On Signal, TOS**)
 - Was it some other particle in the underlying event? (**Trigger Independent of Signal, TIS**)
- Use TOS and TIS samples for the analysis: different BDT discriminator and normalisation.

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

X. Cid Vidal

- Example of combinatorial background to fight against: Material interactions.



- Different discriminating variables for TIS and TOS analyses.
 - Lifetime of the K_S^0 candidate, Muon impact parameter significance, K_S^0 impact parameter significance, DOCA, Secondary vertex χ^2 , Decay angle of the daughters, 3D Coordinates of the secondary vertex, Boolean variable *IsMaterial*, $K_S^0 p_T$

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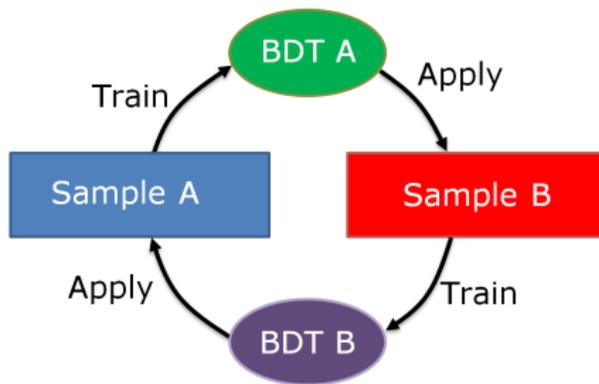
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- Due to lack of MC, BDT has to be trained on data.
- Avoid biasing the background estimation (same sidebands used for background interpolation), split in two samples of same size (**Sample A** and **Sample B**). Train BDT in opposite sample.

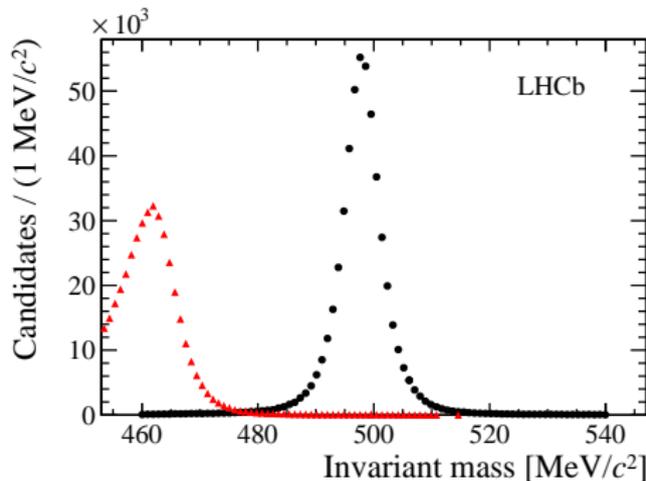


- Finally **4 samples for the analysis** (A and B for TIS and TOS categories).
- Define 10 BDT bins for each sample. 40 bins in total!

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

X. Cid Vidal

- Combinatorial and $K_S^0 \rightarrow \pi^+ \pi^-$ in which both pions are misidentified as muons, most relevant background.
 - Combinatorial background: right sideband of $K_S^0 \rightarrow \mu^+ \mu^-$. Fought against with BDT.
 - $K_S^0 \rightarrow \pi^+ \pi^-$ **double misID**: left sideband of $K_S^0 \rightarrow \mu^+ \mu^-$ (change of mass hypothesis $\pi \rightarrow \mu$). Fought against with PID cuts.



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- Normalisation strategy, independent for TIS and TOS analyses:

→ TIS: normalisation is done to $K_S^0 \rightarrow \pi^+ \pi^-$ TIS.

$$\mathcal{B}(K_S^0 \rightarrow \mu^+ \mu^-) = \frac{\epsilon_{\pi\pi}^{SEL/REC}}{\epsilon_{\mu\mu}^{SEL/REC}} \times \frac{1}{\epsilon_{\mu\mu}^{PID}} \times \frac{\mathcal{B}(K_S^0 \rightarrow \pi^+ \pi^-)}{N_{K_S^0 \rightarrow \pi^+ \pi^-}^{TIS}} \times N_{K_S^0 \rightarrow \mu^+ \mu^-}^{TIS}$$

$$\mathcal{B}(K_S^0 \rightarrow \mu^+ \mu^-) = \alpha_{TIS} \times N_{K_S^0 \rightarrow \mu^+ \mu^-}^{TIS}$$

→ TOS: normalisation is done to $K_S^0 \rightarrow \pi^+ \pi^-$ in minimum bias (MB)^a events.

$$\mathcal{B}(K_S^0 \rightarrow \mu^+ \mu^-) = \frac{\epsilon_{\pi\pi}^{SEL/REC}}{\epsilon_{\mu\mu}^{SEL/REC}} \times \frac{1}{\epsilon_{\mu\mu}^{PID}} \times \frac{s^{MB}}{\epsilon_{\mu\mu}^{TOS/SEL}} \times \frac{\mathcal{B}(K_S^0 \rightarrow \pi^+ \pi^-)}{N_{K_S^0 \rightarrow \pi^+ \pi^-}^{MB}} \times N_{K_S^0 \rightarrow \mu^+ \mu^-}^{TOS}$$

$$\mathcal{B}(K_S^0 \rightarrow \mu^+ \mu^-) = \alpha_{TOS} \times N_{K_S^0 \rightarrow \mu^+ \mu^-}^{TOS}$$

^afrom dedicated random trigger lines

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

X. Cid Vidal

$$\alpha_{TIS} = \frac{\epsilon_{\pi\pi}^{SEL/REC}}{\epsilon_{\mu\mu}^{SEL/REC}} \times \frac{1}{\epsilon_{\mu\mu}^{PID}} \times \frac{\mathcal{B}(K_S^0 \rightarrow \pi^+ \pi^-)}{N_{K_S^0 \rightarrow \pi^+ \pi^-}^{TIS}} \times N_{K_S^0 \rightarrow \mu^+ \mu^-}^{TIS}$$

$$\alpha_{TOS} = \frac{\epsilon_{\pi\pi}^{SEL/REC}}{\epsilon_{\mu\mu}^{SEL/REC}} \times \frac{1}{\epsilon_{\mu\mu}^{PID}} \times \frac{s^{MB}}{\epsilon_{\mu\mu}^{TOS/SEL}} \times \frac{\mathcal{B}(K_S^0 \rightarrow \pi^+ \pi^-)}{N_{K_S^0 \rightarrow \pi^+ \pi^-}^{MB}}$$

- Factors breakdown:

- $\rightarrow \mathcal{B}(K_S^0 \rightarrow \pi^+ \pi^-)$ (from PDG)

- $\rightarrow \epsilon_{\pi\pi}/\epsilon_{\mu\mu}$: selection, reconstruction, PID and TOS efficiencies (from data and/or MC)

- $\rightarrow s^{MB}$: efficiency of the MB trigger lines (from data).

- $\rightarrow N_{K_S^0 \rightarrow \pi^+ \pi^-}^{TIS/TOS/MB}$: number of $K_S^0 \rightarrow \pi^+ \pi^-$ events in different trigger lines.

- Normalisation factors at the level of 8×10^{-7} per BDT bin for TIS analysis and 2×10^{-8} per BDT bin for TOS analysis.

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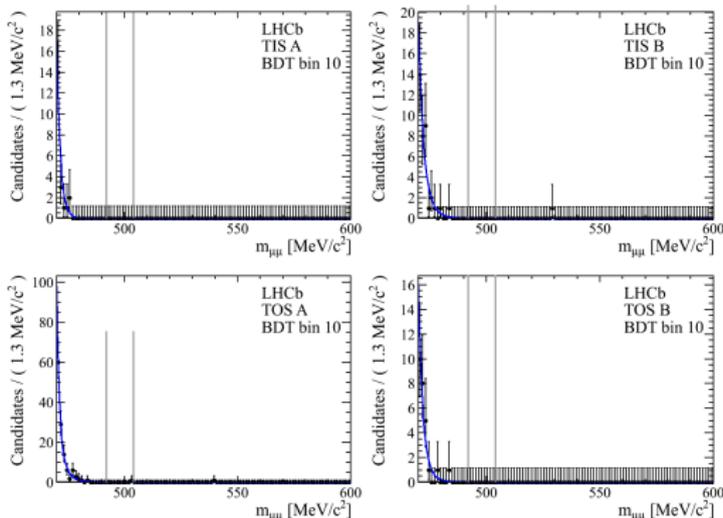
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- Background expected in signal region: fit to sidebands.

→ Model taking into account combinatorial background (exponential PDF) and $K_S^0 \rightarrow \pi^+ \pi^-$ double misID ($\rho \sim 1/(m - m_0)^n$ PDF).

Most sensitive bins for the analysis:



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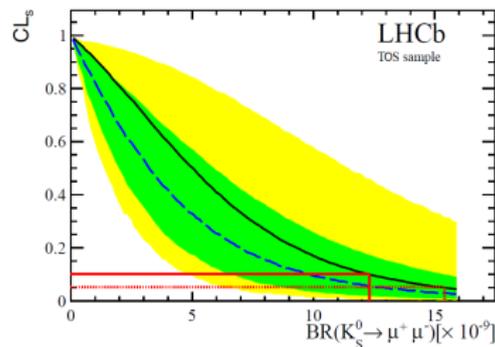
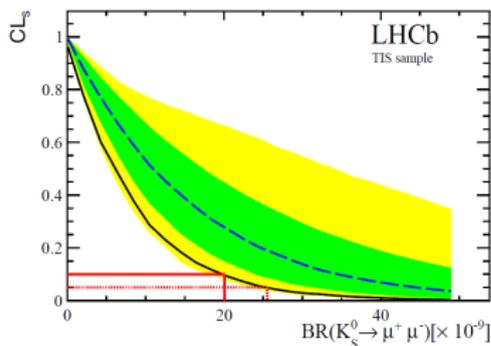
- Search did not produce any excess of signal over the expected background.
- Upper limits computed using the CL_s method.

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

X. Cid Vidal

- Search did not produce any excess of signal over the expected background.
- Upper limits computed using the CL_s method.

Expected limit in case only background was observed
Observation



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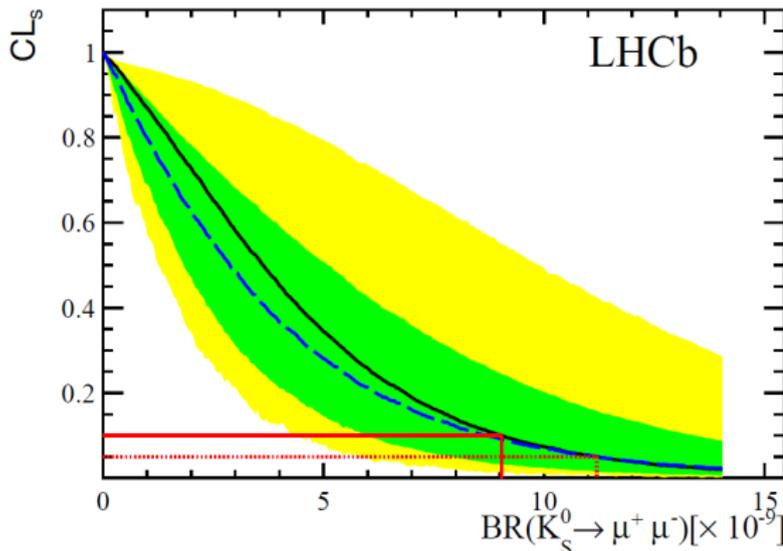
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New limits on
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X. Cid Vidal

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- Upper limits computed using the CL_s method.

Quantity	TIS	xTOS	Combined
Expected 95 (90)% U.L.	44.4 (34.5)	12.7 (9.8)	11.2 (8.7)
Observed 95 (90)% U.L.	25.5 (20.1)	15.4 (12.3)	11.2 (9.0)
p -value	0.95	0.2	0.27

All limits shown are $\times 10^{-9}$

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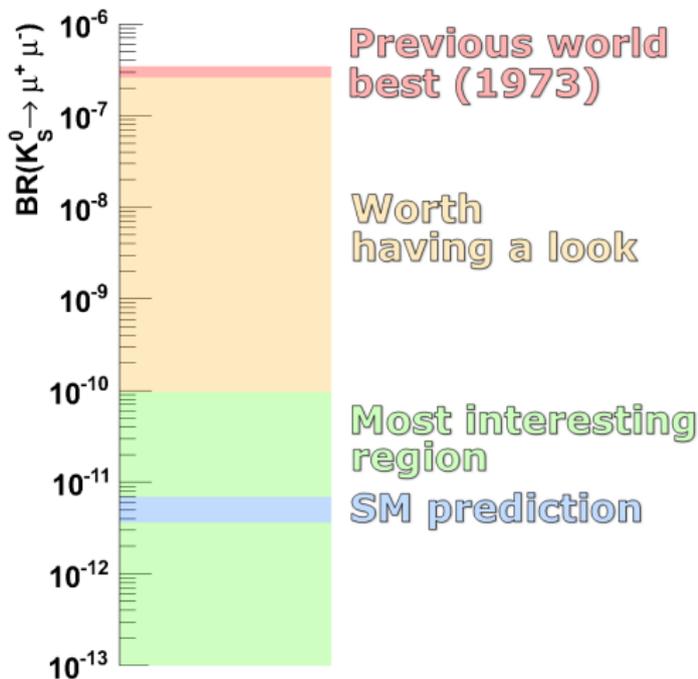
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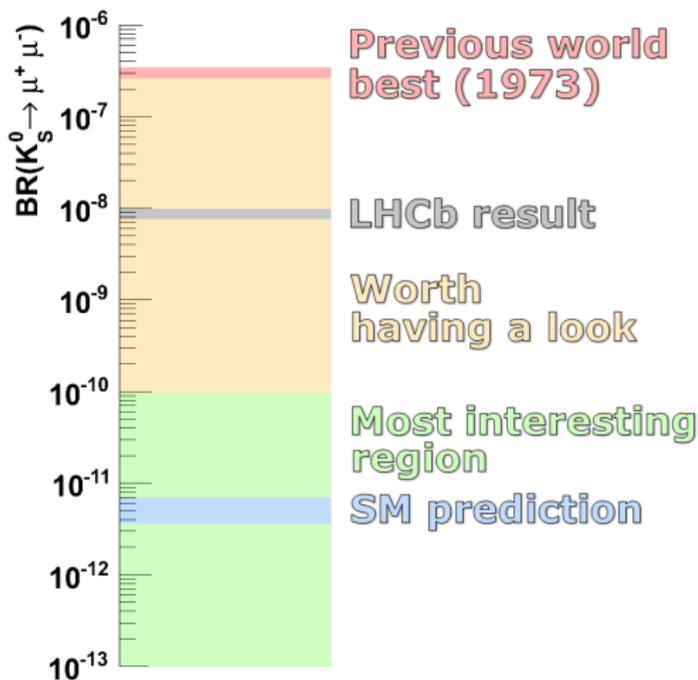
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New limits on
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X. Cid Vidal

- Neutral flavoured mesons dimuon decays are all sensitive to NP, FCNC.
- LHCb has world best results in 4 out of 5 decays.

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Limits at 95% C.L, except for $K_L^0 \rightarrow \mu^+ \mu^-$ and $B_S^0 \rightarrow \mu^+ \mu^-$ (measured \mathcal{B}). Values are all $\times 10^{-9}$.

$K_S^0 \rightarrow \mu^+ \mu^-$	$K_L^0 \rightarrow \mu^+ \mu^-$	$D^0 \rightarrow \mu^+ \mu^-$	$B^0 \rightarrow \mu^+ \mu^-$	$B_S^0 \rightarrow \mu^+ \mu^-$
11.2	(6.84 ± 0.11)	13	0.9	$(3.2_{-1.2}^{+1.5})$

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

X. Cid Vidal

- Neutral flavoured mesons dimuon decays are all sensitive to NP, FCNC.
- LHCb has world best results in 4 out of 5 decays.
- **Presented results of 3 of these decays.**

Limits at 95% C.L, except for $K_L^0 \rightarrow \mu^+ \mu^-$ and $B_S^0 \rightarrow \mu^+ \mu^-$ (measured \mathcal{B}). Values are all $\times 10^{-9}$.

$K_S^0 \rightarrow \mu^+ \mu^-$	$K_L^0 \rightarrow \mu^+ \mu^-$	$D^0 \rightarrow \mu^+ \mu^-$	$B^0 \rightarrow \mu^+ \mu^-$	$B_S^0 \rightarrow \mu^+ \mu^-$
11.2	(6.84 ± 0.11)	13	0.9	$(3.2^{+1.5}_{-1.2})$

→ First evidence for $B_S^0 \rightarrow \mu^+ \mu^-$ (3.5σ)!:

LHCb Collaboration Collaboration, R. Aaij *et. al.* arXiv:1211.2674

→ World best upper limit in $K_S^0 \rightarrow \mu^+ \mu^-$:

LHCb collaboration Collaboration, R. Aaij *et. al.* arXiv:1209.4029

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Thanks!

Backup

- $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)$ very sensitive to $\tan \beta$.
- Constrained fits to experimental data in certain SUSY models (CMSSM and NUHM1, realisations of MSSM), can provide expectations:

$$\frac{\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)_{CMSSM}}{\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)_{SM}} \approx 1.2_{-0.2}^{+0.8}$$

$$\frac{\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)_{NUHM1}}{\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)_{SM}} \approx 1.9_{-0.9}^{+1.0}$$

- Ratio of $\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-)$ and $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)$ also sensitive to NP. For instance, in certain MFV models (CMFV):

$$\frac{\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-)}{\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)} \Big|_{CMFV} \sim \frac{\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-)}{\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)} \Big|_{SM}$$

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

X. Cid Vidal

- Selection for signal and normalisation channels kept as similar as possible.

→ Example: $B_{(s)}^0 \rightarrow h^+ h'^-$ and $B_s^0 \rightarrow \mu^+ \mu^-$

	Cut	value
		$B_s^0 \rightarrow \mu^+ \mu^-$ and $B_{(s)}^0 \rightarrow h^+ h'^-$
μ / h	track $\chi^2 / ndof$	< 4
	IP χ^2	> 25
	p_T	> 0.25 and < 40 GeV/c
	p	< 500 GeV/c
	KL	< 5000
μ only	ISMUON	true
$B_{(s)}$	$ M_{hh} - M(B_{(s)}) $	< 600 MeV/c ²
	DOCA	< 0.3 mm
	vertex χ^2	< 9
	VDS	> 15
	IP χ^2	< 25
	t	$< 9 \cdot \tau(B_s^0)$
	BDS	> 0.05
	DLL($K - \pi$)	< 10
	DLL($\mu - \pi$)	> -5

Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

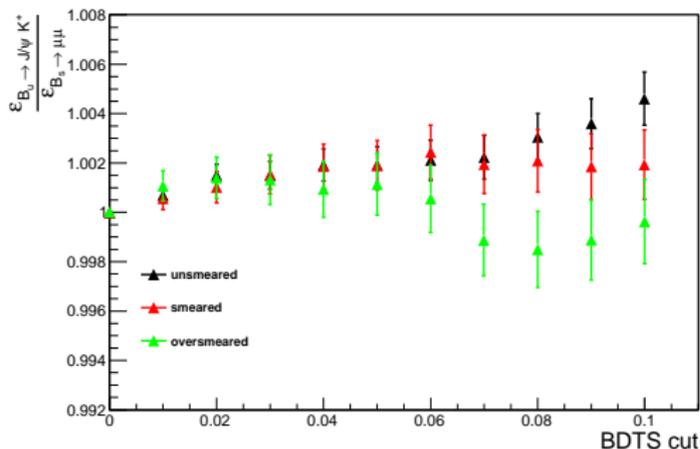
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$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

- On top of rectangular cuts, add a selection Boosted Decision Tree (BDTS).
 - Need to be applicable on signal and normalisation.
 - Use simple variables: $IP(B)$; $IP\chi^2(B)$; $SV(\chi^2)$; $DIRA^a$; B distance of flight; $DOCA^b$; $\min IP(\mu)$.



→ Apply BDTS cut on 0.05!

^a angle between p of the B and the difference between the SV and PV
^b min. distance between the two daughter tracks

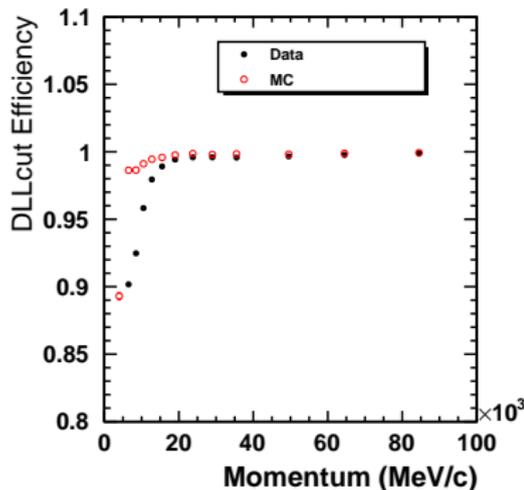
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$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

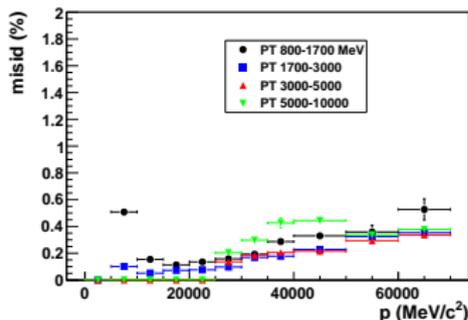
- MuonID cuts needed to separate signal from background ($B_{(s)}^0 \rightarrow h^+ h'^-$ with double misID $h \rightarrow \mu$)
- Efficiency of the cuts obtained using $B \rightarrow J/\psi (\rightarrow \mu^+ \mu^-) X$.
 - Tag a muon using muon system and use the second as *probe*.



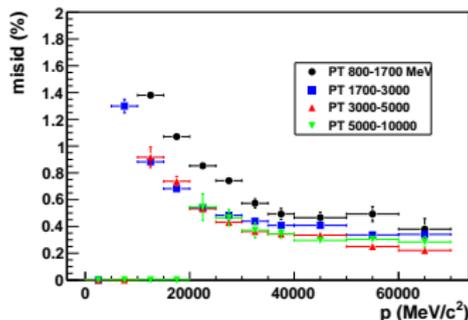
Pions and Kaons misID

- Use pions and kaons in $D^0 \rightarrow K\pi$ (from $D^* \rightarrow D^0\pi$) to determine $h \rightarrow \mu$ probability.
 - Different trigger lines and strategy to compute misID: systematic uncertainty.

Kaons



Pions



Double MisID

- $\epsilon_{hh \rightarrow \mu\mu}$ computed convoluting kaon and pion misID curves with the momentum and p_T spectrum of the two hadrons of Monte Carlo (MC) simulated $B_{(s)}^0 \rightarrow h^+ h'^-$.

$$\epsilon_{hh \rightarrow \mu\mu} = (1.52 \pm 0.07_{\text{stat}} \pm 0.07_{\text{syst}}) \times 10^{-5}$$

- Total $B_{(s)}^0 \rightarrow h^+ h'^-$ double misidentified events **5.4 ± 0.7**
- Mass and BDT shapes of $B_{(s)}^0 \rightarrow h^+ h'^- \rightarrow \mu\mu$ estimated with MC.

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

X. Cid Vidal

- BDT used to classify $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ candidates according to their geometrical properties.
 - BDT built using the TMVA package.
 - BDT providing the best performance among several multivariate discriminants.
 - Variables entering in the BDT: $IP(B)$, $\tau(B)$, DOCA, $I(B)$, $I(\mu_1) + I(\mu_2)^a$, $minIP\chi^2(\mu)$, $p_T(B)$, $\cos P$, $p_{T,min}(\mu)$.
 - BDT built to be flat for signal and peaking at 0 for background.
 - BDT (and mass) binning optimized to give the better sensitivity.

^a/_/: Isolation variables, measuring how separated are the muons and B candidates from other particles

Backup slides

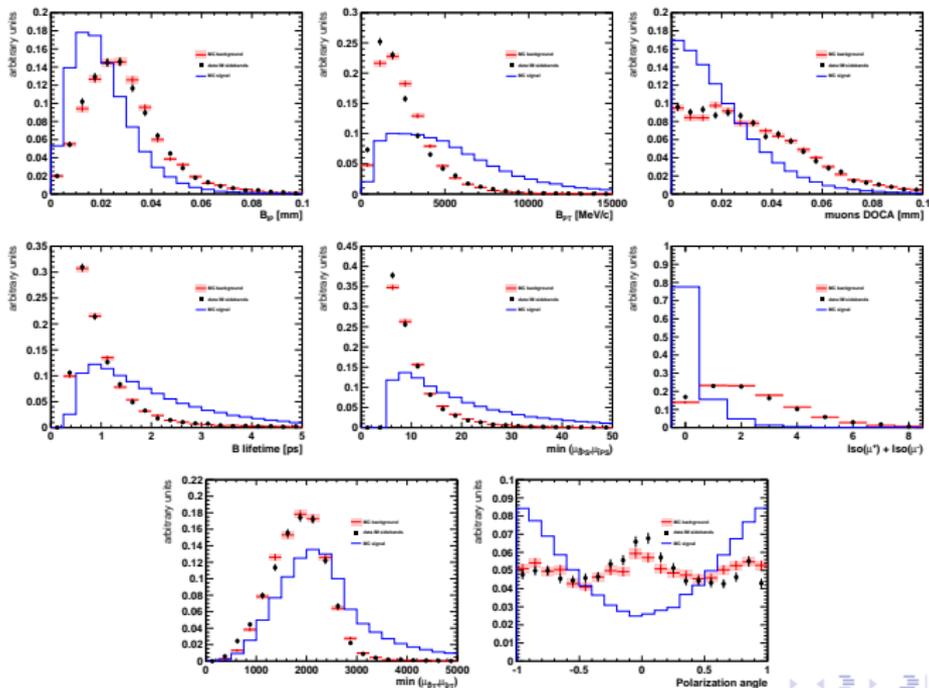
$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
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New limits on
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- BDT used to classify $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ candidates according to their geometrical properties.

→ Distribution of BDT variables on simulation **signal** and **background**, and on **data sidebands**:



Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

- Determine from MC:

$B_S^0 \rightarrow \mu^+ \mu^-$ 10.2%	$B^+ \rightarrow J/\psi K^+$ 5.9%	$B_S^0 \rightarrow J/\psi \phi$ 4.0%	$B_{(s)}^0 \rightarrow h^+ h'^-$ 7.9%
--	--------------------------------------	---	--

- Validate using data:

→ Use $\frac{\epsilon^{\text{REC}}(B^+ \rightarrow J/\psi K^+)}{\epsilon^{\text{REC}}(B_S^0 \rightarrow \mu^+ \mu^-)} \simeq \frac{\epsilon^{\text{REC}}(B^0 \rightarrow J/\psi K^{*0})}{\epsilon^{\text{REC}}(B^+ \rightarrow J/\psi K^+)}$

→ Ratio $\frac{\epsilon^{\text{REC}}(B^0 \rightarrow J/\psi K^{*0})}{\epsilon^{\text{REC}}(B^+ \rightarrow J/\psi K^+)}$: same in in data and MC.

- MuonID:

→ Correct MC using data 2D map in p and p_T and folding it into the p, p_T spectrum of the muons from reconstructed and selected MC $B_S^0 \rightarrow \mu^+ \mu^-$, $B^+ \rightarrow J/\psi K^+$ and $B_S^0 \rightarrow J/\psi \phi$.

New limits on
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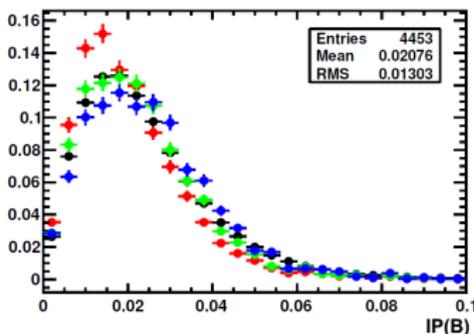
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Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

- Determine also from MC
 - Use “smearing” technique to reproduce in MC data IP resolutions (seen to be different!)

$B(IP)$ with different levels of smearing (colors), compared to data (black):



$$\frac{\epsilon_{B^+ \rightarrow J/\psi K^+}^{\text{SEL|REC}}}{\epsilon_{B_{(s)}^0 \rightarrow \mu^+ \mu^-}^{\text{SEL|REC}}} = 0.836 \pm 0.01$$

$$\frac{\epsilon_{B_S^0 \rightarrow J/\psi \phi}^{\text{SEL|REC}}}{\epsilon_{B_{(s)}^0 \rightarrow \mu^+ \mu^-}^{\text{SEL|REC}}} = 0.589 \pm 0.02$$

$$\frac{\epsilon_{B^0 \rightarrow K^+ \pi^-}^{\text{SEL|REC}}}{\epsilon_{B_{(s)}^0 \rightarrow \mu^+ \mu^-}^{\text{SEL|REC}}} = 1.11 \pm 0.01$$

New limits on
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X. Cid Vidal

Trigger efficiencies for $B \rightarrow J/\psi X$ channels

- Determine in data $B \rightarrow J/\psi X$ channels directly:

$$\epsilon^{\text{TRIG}} = \frac{N^{\text{TRIG\&SEL}}}{N^{\text{SEL}}} \quad ; \quad \epsilon^{\text{TIS}} = \frac{N^{\text{TIS\&SEL}}}{N^{\text{SEL}}}$$

$$\epsilon^{\text{TRIG}} = \epsilon^{\text{TIS}} \frac{N^{\text{TRIG\&SEL}}}{N^{\text{TIS\&SEL}}}$$

→ ϵ^{TIS} known, universal for B decays.

- This yields $\epsilon_{J/\psi}^{\text{TRIG|SEL}} = (87.2 \pm 0.4_{\text{stat}} \pm 3.8_{\text{syst}})\%$.

Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

New limits on
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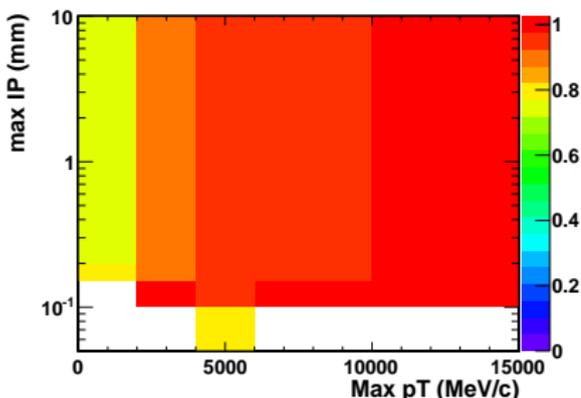
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$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

Trigger efficiencies for $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ channels

- Get trigger efficiency map using previous equation:



- Efficiency map applied to the muon spectrum of the $B_S^0 \rightarrow \mu^+ \mu^-$ MC sample.
 - The estimated trigger efficiency for $B_S^0 \rightarrow \mu^+ \mu^-$ events is $\epsilon_{B_S^0 \rightarrow \mu^+ \mu^-}^{\text{TRIG|SEL}} = (91.4 \pm 0.4_{\text{stat}} \pm 3.9_{\text{syst}})\%$

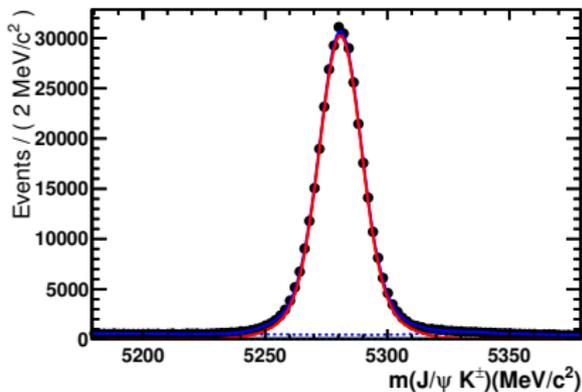
New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

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Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

- Obtain with unbinned fits to invariant mass spectra.
 → Example fit, $B^+ \rightarrow J/\psi K^+$:



$B^+ \rightarrow J/\psi K^+$	$B_S^0 \rightarrow J/\psi \phi$	$B^0 \rightarrow K^+ \pi^-$
340129 ± 640	19035 ± 139	10124 ± 916

- $\mathcal{B}(K_L^0 \rightarrow \mu^+ \mu^-)$ at the SM does not imply $\mathcal{B}(K_S^0 \rightarrow \mu^+ \mu^-)$ has to be at SM (orthogonal amplitudes!)
- $\mathcal{B}(K_S^0 \rightarrow \mu^+ \mu^-)_{SD}^{SM} \propto \bar{\eta}$, but constraints on $\bar{\eta}$ weak.
 - NP scenarios where $\mathcal{B}(K_S^0 \rightarrow \mu^+ \mu^-) |_{SD}$ is at the 10^{-11} level allowed,
 - enhancements above 10^{-10} less likely.
- Bounds on $\mathcal{B}(K_S^0 \rightarrow \mu^+ \mu^-)$ close to 10^{-11} could affect the CP-violating phase of the $s \rightarrow d\bar{l}\bar{l}$ amplitude (complementary to NA62 golden mode $K^+ \rightarrow \pi^+ \nu \bar{\nu}$).
- $K_S^0 \rightarrow \mu^+ \mu^-$ also suggested as a possible way to look for new light scalars.

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

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- Selection designed to be the same between signal and control channel, except for MuonID cuts and mass window.

→ In the case of $K_S^0 \rightarrow \pi^+ \pi^-$, apply “prescale” factor of 1000.

Variable	$K_S^0 \rightarrow \mu^+ \mu^-$	$K_S^0 \rightarrow \pi^+ \pi^-$
K_S^0 mass	[450-1500] MeV/ c^2	[400-600] MeV/ c^2
K_S^0 DOCA	< 0.3 mm	< 0.3 mm
K_S^0 DIRA	> 0	> 0
K_S^0 τ	> 0.1 $\times \tau(K_S^0)$	> 0.1 $\times \tau(K_S^0)$
K_S^0 IP	< 0.4 mm	< 0.4 mm
Daughters IPS	> 10	> 10
Tracks $\chi^2/ndof$	< 5	< 5
Daughters PID	IsMuon=1	-

Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

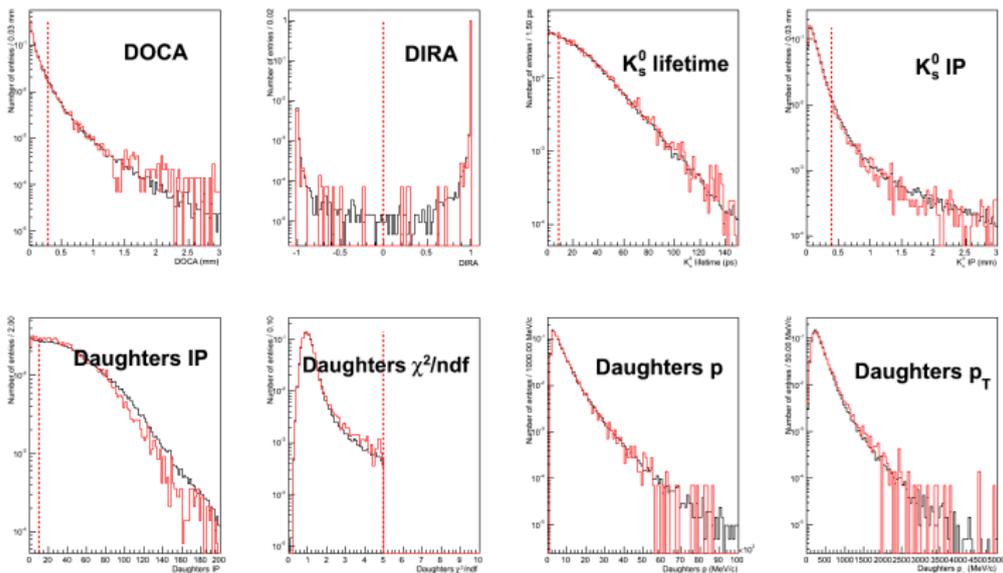
New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

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- Selection designed to be the same between signal and control channel, except for MUONID cuts and mass window.

→ In the case of $K_S^0 \rightarrow \pi^+ \pi^-$, apply “prescale” factor of 1000.

Selection variables in simulation for $K_S^0 \rightarrow \mu^+ \mu^-$ and $K_S^0 \rightarrow \pi^+ \pi^-$



Variables depending on trigger category

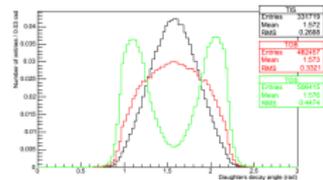
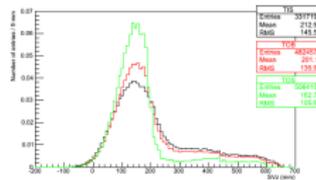
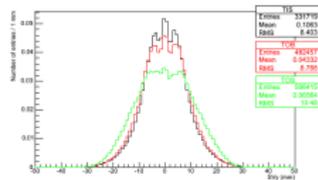
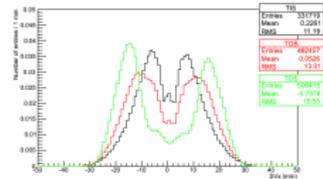
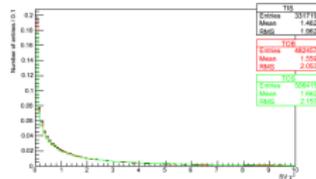
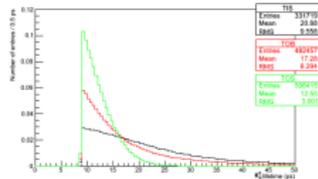
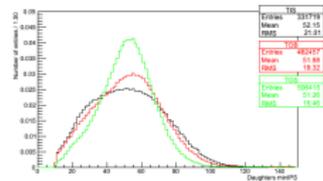
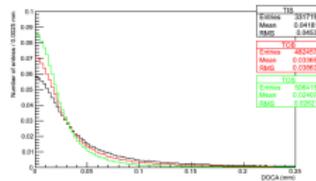
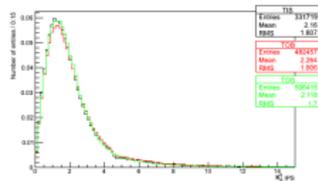
New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

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Discrimination variables in data for $K_S^0 \rightarrow \pi^+ \pi^-$ double misID
 for **TOS**, **TIS** or **neither TIS nor TOS**

Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$



New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

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Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

- Optimisation of variables for TIS and TOS analyses.
 Different sets of variables:

TIS	TOS
Lifetime of the K_S^0 candidate	Lifetime of the K_S^0 candidate
Muon impact parameter significance	Muon impact parameter significance
K_S^0 impact parameter significance	K_S^0 impact parameter significance
DOCA	DOCA
Secondary vertex χ^2	Secondary vertex χ^2
Decay angle of the daughters	Decay angle of the daughters
3D Coordinates of the secondary vertex	Boolean variable <i>IsMaterial</i>
	$K_S^0 p_T$

- Different MVA configurations trained, BDT providing the best performance!

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

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Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

- Due to lack of MC, BDT has to be trained on data.
 - Signal
 - TIS category: $K_S^0 \rightarrow \pi^+ \pi^-$ TIS;
 - TOS category: Use $K_S^0 \rightarrow \pi^+ \pi^-$ double misID TOS as signal proxy, select tight PID cuts (so $\mu \sim \pi$).
 - Background: corresponding TIS and TOS $K_S^0 \rightarrow \mu^+ \mu^-$ sidebands in the region below $1 \text{ GeV}/c^2$.

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

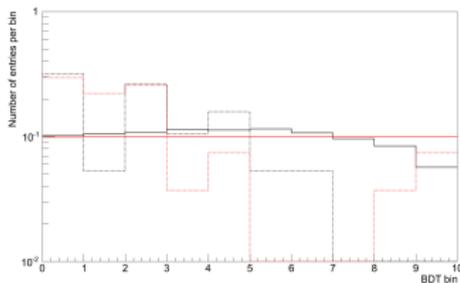
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BDT distribution for **Sample A** and **Sample B**. Straight lines: signal, dashed: background

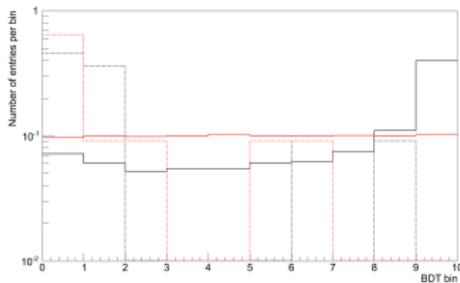
Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

TIS



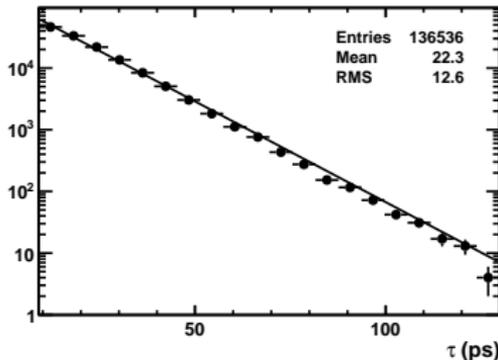
TOS



- $K_L^0 \rightarrow \mu^+ \mu^-$ events topologically equivalent to $K_S^0 \rightarrow \mu^+ \mu^-$ if the K_L^0 decays early enough.
- Determine effective contamination using only lifetimes of K_S^0 and K_L^0 , through the non-flat lifetime acceptance ($Acc[t]$):

$$\frac{\epsilon_{K_L^0 \rightarrow \mu^+ \mu^-}}{\epsilon_{K_S^0 \rightarrow \mu^+ \mu^-}} = \frac{\int_0^\infty Acc(t) e^{-\Gamma_L t} dt}{\int_0^\infty e^{-\Gamma_L t} dt} \frac{\int_0^\infty e^{-\Gamma_S t} dt}{\int_0^\infty Acc(t) e^{-\Gamma_S t} dt}$$

- $Acc[t]$ obtained using $K_S^0 \rightarrow \pi^+ \pi^-$ lifetime distributions on data:



- Using $\mathcal{B}(K_L^0 \rightarrow \mu^+ \mu^-) = (6.84 \pm 0.11) \times 10^{-9}$, the effective BR becomes:

$$\mathcal{B}(K_L^0 \rightarrow \mu^+ \mu^-)|_{eff} = 1.6 \times 10^{-11}$$

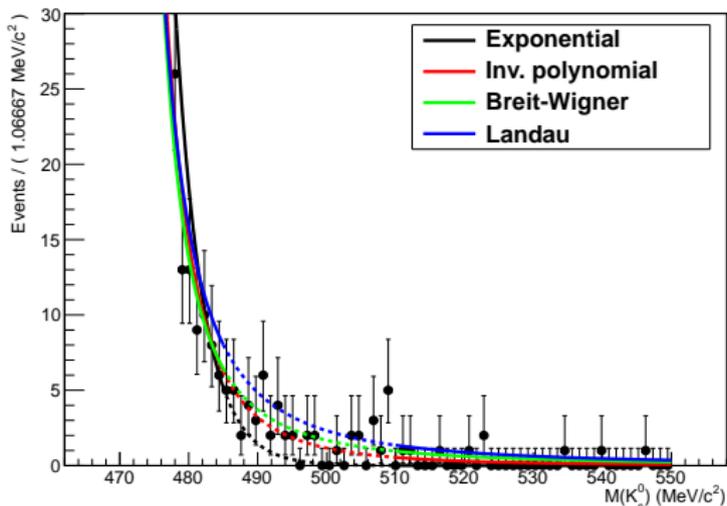
- Similar conclusions with $K_L^0 \rightarrow \mu^+ \mu^- \gamma$

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

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$K_S^0 \rightarrow \pi^+ \pi^-$ double misID parameterisation

- $K_S^0 \rightarrow \pi^+ \pi^-$ double misID, tail that needs to be parameterised. Use MC simulation.



- Inv. polynomial ($\rho \sim 1/(m - m_0)^n$) model selected.

Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

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Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

- Reconstruction and selection efficiencies evaluated using MC simulation.
 - Ratio of efficiencies is calculated in bins of transverse momentum (p_T) and rapidity.
 - Ratio reweighted according to the y , p_T of the K_S^0 in data.

BDT bin	$\frac{\epsilon_{\pi\pi\pi}^{SEL}}{\epsilon_{\mu\mu}^{SEL}} (TISB)$	$\frac{\epsilon_{\pi\pi\pi}^{SEL}}{\epsilon_{\mu\mu}^{SEL}} (TOSB)$
1	0.61 ± 0.02	0.69 ± 0.13
2	0.70 ± 0.03	1.31 ± 0.52
3	0.65 ± 0.03	0.67 ± 0.19
4	0.66 ± 0.04	0.49 ± 0.17
5	0.78 ± 0.06	0.85 ± 0.35
6	0.72 ± 0.09	1.49 ± 1.00
7	0.77 ± 0.06	0.56 ± 0.16
8	0.72 ± 0.06	1.14 ± 0.47
9	0.72 ± 0.07	1.09 ± 0.85
10	0.75 ± 0.06	1.63 ± 0.67

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

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Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

- Similar strategy to $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ case.
 - Get PID efficiency curves from data using $B \rightarrow J/\psi X$ decays.
 - Apply to $K_S^0 \rightarrow \mu^+ \mu^-$ p, p_T spectra. Instead of MC, use $K_S^0 \rightarrow \pi^+ \pi^-$ MB!

BDT bin	Sample A TIS	Sample B TIS
1	$(70.22 \pm 0.71) \%$	$(69.93 \pm 3.06) \%$
2	$(70.28 \pm 0.95) \%$	$(70.41 \pm 1.09) \%$
3	$(70.48 \pm 0.19) \%$	$(70.27 \pm 0.79) \%$
4	$(70.39 \pm 2.19) \%$	$(70.52 \pm 0.83) \%$
5	$(69.58 \pm 2.78) \%$	$(70.46 \pm 1.83) \%$
6	$(70.17 \pm 3.63) \%$	$(70.55 \pm 2.45) \%$
7	$(70.62 \pm 4.25) \%$	$(70.35 \pm 1.96) \%$
8	$(70.74 \pm 3.61) \%$	$(70.90 \pm 4.63) \%$
9	$(69.98 \pm 6.19) \%$	$(70.86 \pm 8.02) \%$
10	$(68.77 \pm 3.04) \%$	$(70.20 \pm 3.71) \%$

- Since TOS comes from *Single Muon* triggers: Similar strategy to MuonID case.
 - Get efficiency curves from data using $B^+ \rightarrow J/\psi K^+$ decays.
 - Apply to $K_S^0 \rightarrow \mu^+ \mu^-$ p, p_T spectra from $K_S^0 \rightarrow \pi^+ \pi^-$ MB!
- For the TOS case, consider together MuonID and TOS efficiencies.

BDT bin	Sample A TOS	Sample B TOS
1	$(17.13 \pm 2.74) \%$	$(16.02 \pm 2.82) \%$
2	$(16.88 \pm 2.70) \%$	$(15.58 \pm 2.74) \%$
3	$(17.24 \pm 2.76) \%$	$(16.26 \pm 2.86) \%$
4	$(16.63 \pm 2.66) \%$	$(16.33 \pm 2.87) \%$
5	$(16.11 \pm 2.58) \%$	$(16.78 \pm 2.95) \%$
6	$(15.47 \pm 2.48) \%$	$(16.33 \pm 2.88) \%$
7	$(15.62 \pm 2.50) \%$	$(15.85 \pm 2.79) \%$
8	$(15.57 \pm 2.49) \%$	$(15.83 \pm 2.79) \%$
9	$(15.49 \pm 2.48) \%$	$(16.23 \pm 2.86) \%$
10	$(14.78 \pm 2.37) \%$	$(15.23 \pm 2.68) \%$

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

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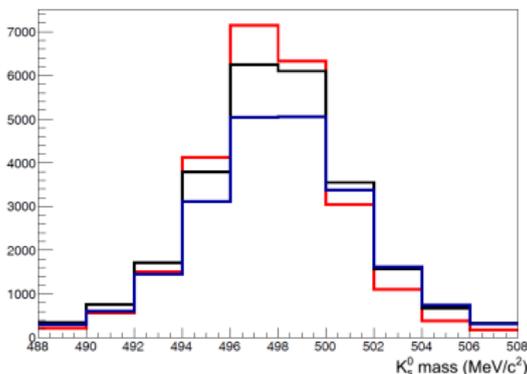
Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

- Mass resolution differs significantly between $K_S^0 \rightarrow \mu^+ \mu^-$ and $K_S^0 \rightarrow \pi^+ \pi^-$.

→ For this analysis, use a single mass bin.

Invariant mass distribution of $K_S^0 \rightarrow \pi^+ \pi^-$ and $K_S^0 \rightarrow \mu^+ \mu^-$ (MC simulation) and $K_S^0 \rightarrow \pi^+ \pi^-$ in MB data.



→ Include global factor $\epsilon_{\pi\pi}^M / \epsilon_{\mu\mu}^M = 1.08 \pm 0.04$ accounting for different efficiencies of the mass cut (492–504 MeV/c²).

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

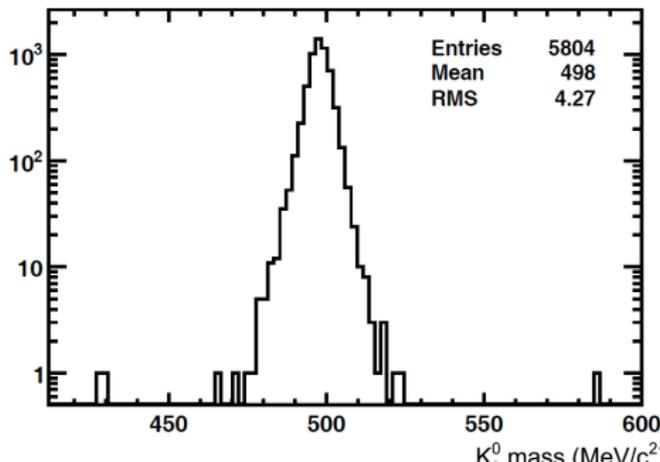
$K_S^0 \rightarrow \pi^+ \pi^-$ TIS yields and normalisation factors for TIS analysis

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Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

- Final normalisation TIS factor, add number of observed $K_S^0 \rightarrow \pi^+ \pi^-$ (TIS) per BDT bin and ratio of TIS efficiencies.
 - Ratio of TIS efficiencies, 1, checked on MC (adding systematic error of 18%)
 - Number calculated counting events (negligible background)



$K_S^0 \rightarrow \pi^+ \pi^-$ TIS yields and normalisation factors for TIS analysis

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- Final TIS normalisation factors

BDT bin	$\alpha_{TIS}^A (\times 10^{-8})$	$\alpha_{TIS}^B (\times 10^{-8})$
1	8.12 ± 0.39	7.40 ± 0.48
2	8.68 ± 0.53	8.21 ± 0.52
3	8.11 ± 0.55	7.46 ± 0.46
4	8.26 ± 0.68	7.41 ± 0.50
5	8.12 ± 0.81	8.65 ± 0.77
6	6.63 ± 0.60	7.80 ± 1.10
7	8.41 ± 0.97	8.18 ± 0.75
8	10.30 ± 1.70	7.55 ± 0.89
9	11.50 ± 2.00	7.60 ± 1.20
10	16.20 ± 1.50	7.98 ± 0.81

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

$K_S^0 \rightarrow \pi^+ \pi^-$ MB yields and normalisation factors for TOS analysis

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

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Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

- For TOS normalisation, use amount of $K_S^0 \rightarrow \pi^+ \pi^-$ that would have been selected if there were no prescale factors at any level to determine s^{MB} .
 - Make use of MB to determine trigger efficiency and consider the prescale factor of the $K_S^0 \rightarrow \pi^+ \pi^-$ stripping selection (1000):

$$\epsilon^{TRIG} = \frac{N_{K_S^0 \rightarrow \pi^+ \pi^-}^{MB \& TRIG}}{N_{K_S^0 \rightarrow \pi^+ \pi^-}^{MB}}$$

$$N_{K_S^0 \rightarrow \pi^+ \pi^-}^{SEL} = 1000 \times \frac{N_{K_S^0 \rightarrow \pi^+ \pi^-}^{TRIG}}{\epsilon^{TRIG}}$$

$$N_{K_S^0 \rightarrow \pi^+ \pi^-}^{SEL} = 1000 \times N_{K_S^0 \rightarrow \pi^+ \pi^-}^{TRIG} \times \frac{N_{K_S^0 \rightarrow \pi^+ \pi^-}^{MB}}{N_{K_S^0 \rightarrow \pi^+ \pi^-}^{MB \& TRIG}}$$

$$s^{MB} = \frac{N_{K_S^0 \rightarrow \pi^+ \pi^-}^{MB}}{N_{K_S^0 \rightarrow \pi^+ \pi^-}^{SEL}}$$

$K_S^0 \rightarrow \pi^+ \pi^-$ MB yields and normalisation factors for TOS analysis

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

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Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

- Check using MB trigger line (selects random events with a given rate, 70% corresponding to beam-beam, bb , crossings). Using 14.9 MHz as input rate of bb :

$$s^{MB} = Lumi \times 0.7 \times \frac{Rate^{MB}}{14.9 \text{ MHz}}$$

- Use difference between both methods to obtain systematic error. $s^{MB} = (2.70 \pm 0.76) \times 10^{-6}$

New limits on
 $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ and
 $K_S^0 \rightarrow \mu^+ \mu^-$

$K_S^0 \rightarrow \pi^+ \pi^-$ MB yields and normalisation factors for TOS analysis

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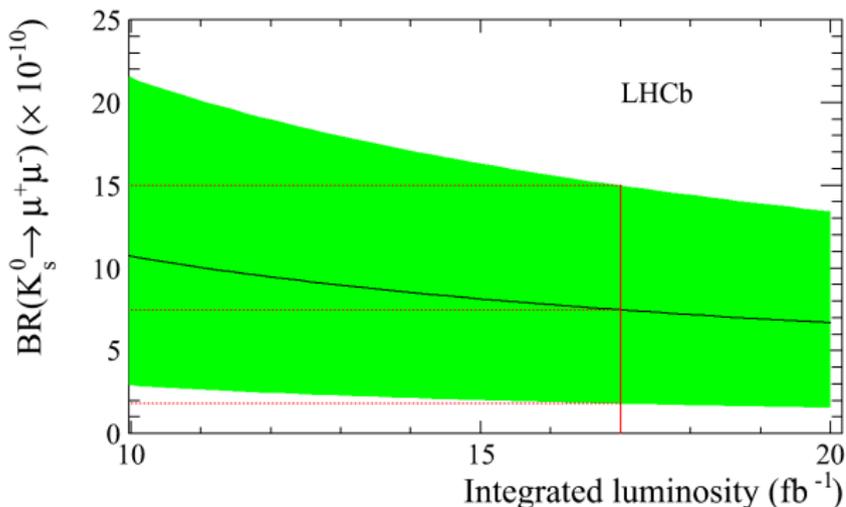
- Final TOS normalisation factors:

BDT bin	$\alpha_{TOS}^A (\times 10^{-8})$	$\alpha_{TOS}^B (\times 10^{-8})$
1	1.94 ± 0.70	0.92 ± 0.24
2	1.84 ± 0.65	2.40 ± 1.00
3	3.40 ± 1.40	1.61 ± 0.54
4	5.50 ± 2.20	1.24 ± 0.48
5	2.50 ± 1.00	2.50 ± 1.10
6	3.90 ± 1.60	4.60 ± 3.20
7	7.80 ± 4.80	2.01 ± 0.69
8	2.41 ± 0.97	4.20 ± 1.90
9	2.30 ± 0.99	4.20 ± 3.30
10	0.94 ± 0.22	7.10 ± 3.20

Backup slides

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$
 $K_S^0 \rightarrow \mu^+ \mu^-$

Expectations using 2011+2012 dataset



Most interesting region, hopefully at reach for LHCb upgrade ($\sim 50 fb^{-1}$ recorded)