First Evidence for the Rare Decay

\[ B^0_s \rightarrow \mu^+\mu^- \]

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**Why rare?**

New physics (NP) is easiest to spot where according to the Standard Model (SM) an event is not likely to happen. In SM, \( B^0_{s,d} \rightarrow \mu^+ \mu^- \) decays are so rare because (i) only decays through loop diagrams are allowed (flavor-changing neutral current), and (ii) strong helicity suppression. The main SM diagrams contributing to \( BR(B^0_{s,d} \rightarrow \mu^+ \mu^-) \) are

\[ \frac{BR(B^0_{s,d} \rightarrow \mu^+ \mu^-)}{BR(B^0_{s,d} \rightarrow \mu^+ \mu^-)^{SM}} \approx \frac{\sigma(B^0_{s,d} \rightarrow \mu^+ \mu^-)}{\sigma(B^0_{s,d} \rightarrow \mu^+ \mu^-)^{SM}} \approx \frac{\sigma(B^0_{s,d} \rightarrow \mu^+ \mu^-)}{\sigma(B^0_{s,d} \rightarrow \mu^+ \mu^-)^{SM}} \]

LHCb measures a flavor-averaged and time-integrated branching ratio. For the same quantity, precise SM predictions read[2]:

\[ BR(B^0_s \rightarrow \mu^+ \mu^-) = (3.54 \pm 0.30) \times 10^{-9} \]
\[ BR(B^0_d \rightarrow \mu^+ \mu^-) = (1.07 \pm 0.10) \times 10^{-10} \]

**Why LHCb?**

The LHCb detector is well suited for measuring \( B^0_{s,d} \rightarrow \mu^+ \mu^- \) decays:

- **Abundant \( b \bar{b} \) pairs**
  \( \phi \rightarrow b \bar{b} \) – 300 pb at 7 TeV[2]
- **Outstanding muon ID performance**
  \( \mu^+ \rightarrow \mu^+ \nu \bar{\nu} \) (99.9% purity), \( \mu^- \rightarrow \mu^- \nu \bar{\nu} \) (99.9% purity)
- **Excellent mass and impact parameter resolution**
  \( \sigma_{m_{B^0}} \approx \sigma_{IP} \approx 2 \text{ MeV}/c^2 \)
- **Efficient trigger on low-\( p_t \) muons**

**How do we separate the signal candidates?**

After a loose pre-selection, we classify the events in two independent variables:

- Di-muon invariant mass (\( m_{\mu \mu} \))
- Boosted Decision Tree output (BDT)

We divide the BDT range into 8 bins. In each bin, we compare the number of observed events to the number of expected signal and background events.

**Impact on new physics**

Contributions from NP models to the \( BR(B^0_s \rightarrow \mu^+ \mu^-) \) and \( BR(B^0_d \rightarrow \mu^+ \mu^-) \) are strongly limited by the LHCb results[1]:

\[ BR(B^0_s \rightarrow \mu^+ \mu^-) = [3.2^{+1.3}_{-1.0} \text{ (stat)}^{+0.6}_{-0.5} \text{ (syst)}] \times 10^{-9} \]
\[ BR(B^0_d \rightarrow \mu^+ \mu^-) < 9.4 \times 10^{-10} \text{ at 95% CL}. \]

**References**