Search for $b \to s\ell\ell$ Anomalies at the LHC

Les Rencontres de Physique de la Vallee d'Aoste

Yoav Afik

Technion: Israel Institute of Technology

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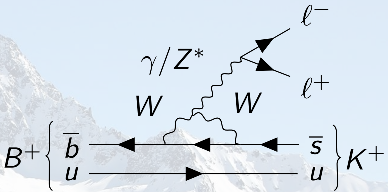
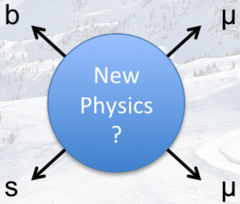
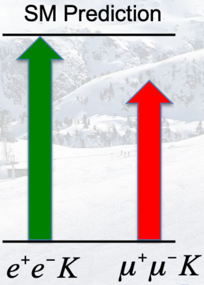
The $b \to s\ell\ell$ Anomalies

- Recent LHCb measurements present a pattern of deviations from the Standard Model prediction for rare B-meson decays ($R_{K^{(*)}}$).
- Possible Violation of Lepton Flavour Universality.
- New Physics may lay between the common initial and final state ($bs\ell\ell$).





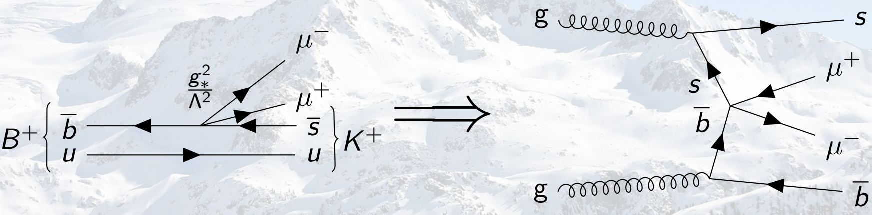


EFT Framework

- Taking a general model describing the anomalies (A. Greljo and D. Marzocca, Eur. Phys. J. C (2017) 77: 548):
  - $\mathcal{L}_{eff} = \frac{C^{U\mu}_{ij}}{v^2}(\bar{u}^i_L\gamma_\mu u^j_L)(\bar{\mu}_L\gamma^\mu\mu_L) + \frac{C^{D\mu}_{ij}}{v^2}(\bar{d}^i_L\gamma_\mu d^j_L)(\bar{\mu}_L\gamma^\mu\mu_L)$
  - $C^{U\mu}_{ij} = \begin{pmatrix} C_{u\mu} & 0 & 0 \\ 0 & C_{c\mu} & 0 \\ 0 & 0 & C_{t\mu} \end{pmatrix}, C^{D\mu}_{ij} = \begin{pmatrix} C_{d\mu} & 0 & 0 \\ 0 & C_{s\mu} & C^*_{bs\mu} \\ 0 & C_{bs\mu} & C_{t\mu} \end{pmatrix}$
- Non-diagonal term corresponds to the anomalies: $\mathcal{L}_{eff} \supset \frac{C_{bs\mu}}{v^2}(\bar{b}_L\gamma_\mu s_L)(\bar{\mu}_L\gamma^\mu\mu_L) + h.c.$
- Best fit corresponds to (B. Capdevila, A. Crivellin, S. Descotes-Genon, J. Matias and J. Virto, J. High Energ. Phys. (2018) 2018: 93):
  - $\frac{\pi}{\alpha V_{tb}V^*_{ts}} C_{bs\mu} = -0.62 \pm 0.13$
  - $C_{bs\mu} = g^2_* v^2/\Lambda^2$.
- Best fit corresponds New Physics scale of $\Lambda/g_* \approx 31^{+4}_{-3}$ TeV.

Low Energy to High Energy

- Generalizing the $bs\ell\ell$ interactions (4-fermion operator).
- Looking at direct production via *proton* − *proton* collisions:



- We can search for New Physics in final states contain two opposite sign muons and exactly one b-jet.
- Phenomenological framework detailed at: Y. A., J. Cohen, E. Gozani, E. Kajomovitz and Y. Rozen, J. High Energ. Phys. (2018) 2018: 56.

LHC Feasibility Study

- Simulating multi-purpose LHC detector.
- Basic selection:
  - Two opposite sign muons.
  - Exactly one b-tagged jet.
- New final state, not targeted in previous analyses.
- Dominant Standard Model background processes:
  - $t\bar{t}$: high missing transverse momentum (neutrinos).
  - $Z + jets, ZZ, WZ$ low invariant mass of the muon pair (Z-resonance).

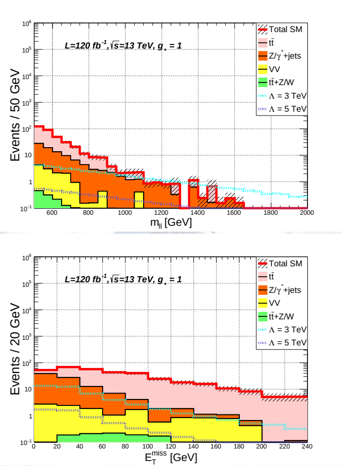


Figure: Kinematic distributions for the invariant mass of both muons (up) and the missing transverse energy (bottom).

Expected Sensitivity

- The signal and the background have differences in the kinematic distributions.
- Therefore, in addition to the basic selection, we apply the selection that maximize the sensitivity:
  - $E_T^{miss} < 180$ GeV.
  - $m_{\ell\ell} > 1700$ GeV.

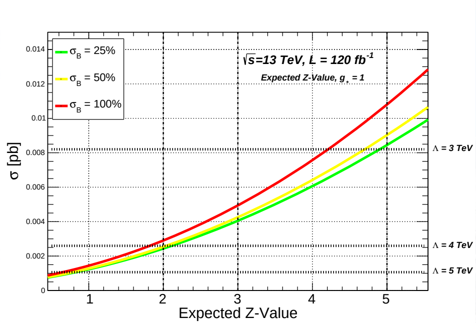


Figure: The signal cross-section as a function of the expected sensitivity (Z-value).

Expected Sensitivity

- Upper limit on the coefficient of the 4-fermion operator $(bs\ell\ell)$:

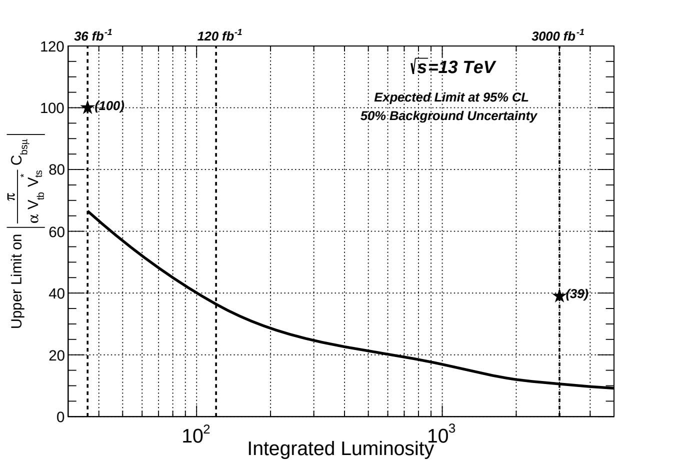


Figure: The predicted upper limit as a function of the total integrated luminosity.

Summary

- Several interesting measurements find deviations in B-meson decays into a pair of leptons and a Kaon.
- The deviations observed may indicate new physics in $bs\ell\ell$ interactions.
- Traditionally this type of interactions have been searched using B-meson decays.
- We propose a new approach to search for those interactions via the production mechanism in $proton - proton$ collisions.
- The new approach significantly improves to the sensitivity of ATLAS/CMS to new physics in $bs\ell\ell$ interactions.

Thank You

Backup Slides

Backup

B-meson Decay Anomalies

- The value of this ratio is stated within a given range of the lepton pair mass squared, $[q^2_{min}, q^2_{max}]$.
- 2.6σ discrepancy with respect to the SM in:

$$R_K = \frac{\int_{q^2_{min}}^{q^2_{max}} \frac{d\Gamma(B^+ \to K^+ \mu^+ \mu^-)}{dq^2} dq^2}{\int_{q^2_{min}}^{q^2_{max}} \frac{d\Gamma(B^+ \to K^+ e^+ e^-)}{dq^2} dq^2} \tag{1}$$

$$R_{K,[1.0,6.0]\mathrm{GeV}^2} = 0.745^{+0.090}_{-0.074} \pm 0.036$$

- $2.1 - 2.5\sigma$ discrepancy in the related mode with the vector meson:

$$R_{K^*} = \frac{\int_{q^2_{min}}^{q^2_{max}} \frac{d\Gamma(B^0 \to K^{0*} \mu^+ \mu^-)}{dq^2} dq^2}{\int_{q^2_{min}}^{q^2_{max}} \frac{d\Gamma(B^0 \to K^{0*} e^+ e^-)}{dq^2} dq^2} \tag{2}$$

$$R_{K^*,[0.045,1.1]\mathrm{GeV}^2} = 0.66^{+0.11}_{-0.07} \pm 0.03$$

$$R_{K^*,[1.1,6.0]\mathrm{GeV}^2} = 0.69^{+0.11}_{-0.07} \pm 0.05$$

The Detector

- Detecting products of *proton* − *proton* collisions.
- 4 main layers that can detect stable Standard Model particles (left to right):

Particle	$\mu^{\pm}$	$e^{\pm}$	γ	Hadrons	ν
Inner Detector	✓	✓	x	✓ / x	x
EM Calorimeter	✓	✓	✓	✓ / x	x
Hadronic Calorimeter	✓	x	x	✓	x
Muon Spectrometer	✓	x	x	x	x

- Particles originate from quarks appear as Hadron Jets.
- b-jets are identified by the Jet substructure.

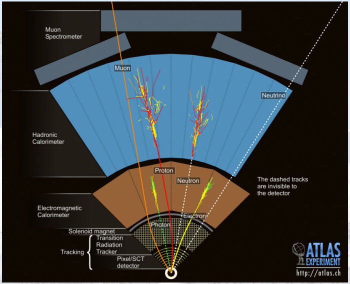


Figure: A schematic description of tracks at ATLAS for different particles.

Expected Sensitivity

- The upper limit:

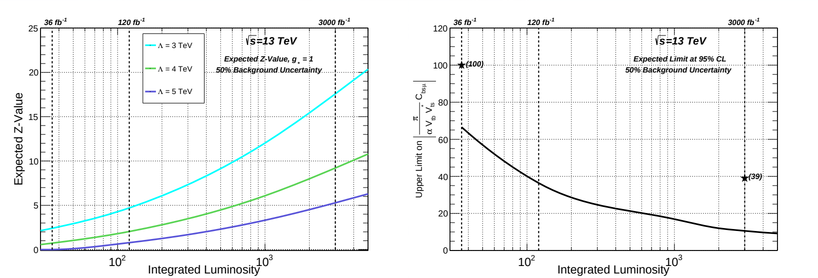


Figure: The predicted Z-value (left) and upper limit (right) as a function of the total integrated luminosity.

Expected Sensitivity

- Studies for the expected sensitivity at ATLAS were done.
- Figures are from: Y. Afik et. al. JHEP (2018) 2018: 56.

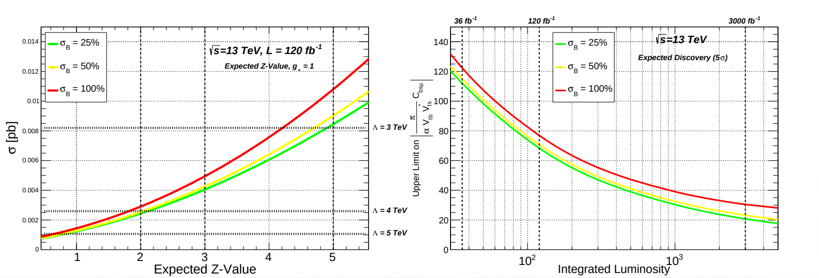


Figure: The expected Z-Value for $L = 120fb^{-1}$ (left) and the predicted discovery of 5σ (right) as a function of the total integrated luminosity.

How do we Reduce the Background?

- The signal and the background have differences in the kinematic distributions.
- We scan for different values of:
  - the missing transverse momentum.
  - the invariant mass of the muon pair.
- We choose the values with the maximum expected sensitivity, given the signal and background yields.

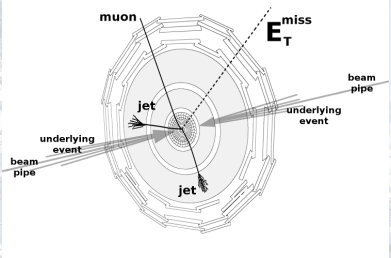


Figure: A schematic description of the missing transverse momentum.