Proceeding to the LHC seminar talk “Update of the $B0 \to K{*}0$ μ+ μ− angular analysis at LHCb” held by Eluned Smith on behalf of the LHCb collaboration on 13th of March 2020

Summary of *Update of the $B^0 \to K^{*0}\ \mu^+\ \mu^-$ angular analysis at LHCb*

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Please write an abstract with the most important information

The stated Process is of such importance because the $b \to s\mu\mu$ transition is forbidden at tree level due to FCNC. A study of this is preferebly done with indirect searches because the energy scales can be set much larger than in in direct searches, therefore new Physics(NP)is more accesible.

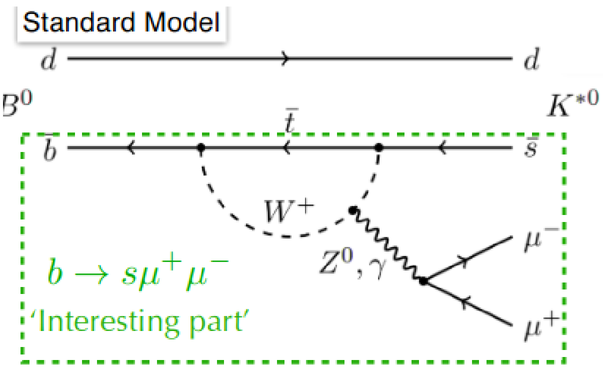

Fig. **Abbildung 1:** Process in standard model.

The whole discussion about leptoquarks is irrelevant for this proceeding! This measurement is model-independent! In b->sll we do not search for a particular new particle but for the type of new physics contributions (their structures, coupling strength and so on) It would be much more interesting to discuss the connection to other b->sll results like RK, RK*, Bs2mumu, …

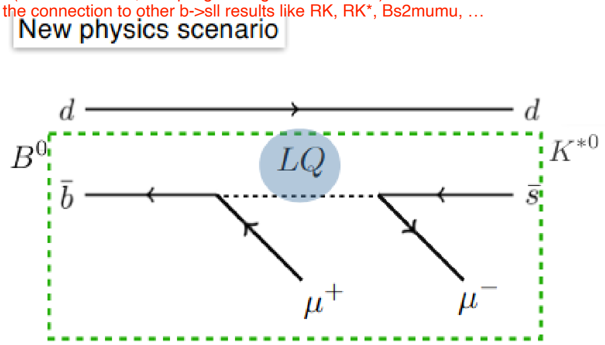

Fig. **Abbildung 2:** Process in new physics model.

In figure 2[1], instead of a suppressed loop via a W-boson which decays weak into a neutral gauge boson and then further into two muons, the NP model suggest a leptoquark as ”gauge boson”. Leptoquarks (mostly denoted as X- and Y-Boson) are particles postulate by the GIM model, which provides a way to change a quark into a lepton via the decay channel

$$X \to l^+ + \bar{\mathrm{D}}$$

1 transition in effective theory

Instead of calculating the well known transition via box diagram, we now factorize out the loops and replace them with an effective coupling ~~(analogous to 4f coupling)~~. This results in a 4-particle-vertex which is now described with Wilson coeffcients with are sensitive to NP.

You have the same problems there in the calculation.

an effective coupling

which

With these changes an effective Hamiltonian H_{eff} can be written as

The Wilson coefficients are not sensitive to NP. The difference of between total Wilson coefficient and the Wilson coefficient for the SM describe how large the NP contributions are

Which Wilson coefficients can be accessed with the angular analysis of B->K*mumu and how do they contribute?

$$H_{eff} = -\frac{4G_f}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i (C_i \cdot O_i + C_i{}' \cdot O_i{}')$$

What are the C_i’ and O_i’?

where C_i are the short ranged ilson coeffcients which we ant to study. The O_i are the long distance, low energy QCD operators which follow the formfactors.

They are not all QCD operators, but they incorporate non-pertubative QCD effects (like the form factors) that occur in the B meson

2 angular Analysis

This is not your work! Write from a neutral perspective.

With the angular analysis we want to measure the decay rate of a process as a function of the final state decay angles, which are schematically shown in figure 3.

The three important angles are θ_k, θ_l and ϕ. Because the two leptons and the Kaon and Pion are produced in sort of opposite directions, θ_k is the angle between the Kaon and the vector sum of the Kaon and the Pion, which is the general flight direction. For θ_l it is the same argumentation but for the positive lepton and the fligh direction of the leptons.

in which reference frame? I would claim that they fly in the same z-direction in the detector

Please read carefully the paper for the angle definitions!

Can you get a better resolved picture?

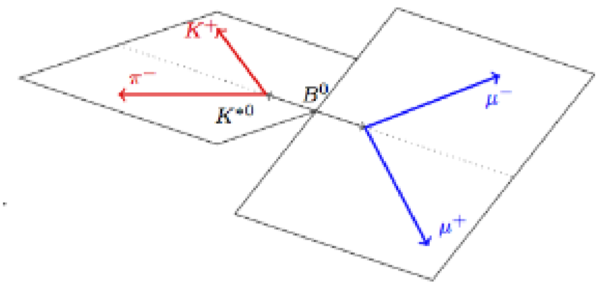

Fig
Abbildung 3: schematical image of decay angles.

The definition of the observables is missing. Also their connection to the decay rate

In general, the leptons do not fly in the exact same direction, so their dircetion vector span a plane. This is also true for the Pion and the Kaon. The angle ϕ is the the angle between the normalvector of the K-π-plane and the μ-μ-plane. This analysis can give access to more observables with reduced uncertainties.

What uncertainties? Which observables have these reduced uncertainties?

3 early LHCb Measurementsand local tension

The CMS measurement is actually very different compared to the LHCb, BELLE & ATLAS one

What is P5'? There is no definition so far

Angular analysis for local tension in P'_5 performed by other collaborations such as ATLAS and CMS show similar results but Data taken stops at roughly the J/Ψ Mass due to the resonant background. ~~Therefore the ATLAS measurement is not so good.~~ As seen in some global fits, the shift in the wilson coefficent $\mathrm{Re}\,(C_9)$, the deviations in these wilson coefficents or up to 3 - 5 σ. In general, these fits are a good tool to learn from the fits.

these measurements should be cited!

similar to what?

This is not really a sentence

4 the data set and Selection of Candidates

How large are the datasets in terms of integrated luminosities?

The data used comes from the years 2011, 2012, which was Run 1, and 2016. The center of mass energies were 7, 8 and 13 TeV respectively. The data taken in the later years is nearly double from what the have taken in 2011.

later years = 2016 & 2012?

twice the amount

For the stated process, it is required that the impact parameter for the daughters are quite large because they don't come from the primary vertex. Also the PID[1] is used to suppress the peaks in the background. Machine learning algorithms are used to reduce combinatorial background. For the probe regions in the q^2 plot, the signal regions muste be seperated fromm the background regions. Since there are decay modes which have the same final state as our wanted process, there are several peak regios which muste be cut out. This is for example the charmonium background of the J/Ψ and the ψ meson. The signal regions for the decay mode $b \to s\mu\mu$ can the be interpreted seperately. Also the photon pole at $q^2 = 0$. can be examined. The binning used is historically conditioned. The only cause for that is to compact the data. One boundary at 1,1 GeV is set to delete the $\phi(1020)$ resonance from the data.

do not

Where do the peaks come from?

[1]particle identification

How do they work? What datasets are used to train these? What variables are used for the signal-background separation?

Please go more into the details of the selection. This is a bit too superficial. Look into the paper for this

Please explain this with the plot of the q^2 spectrum of the decay rate

J\/\Psi, \psi(2S)

Can q2 really be 0?

What binning is used? Why are there two binning schemes?

5 angular fit model

To describe now the physics behind the angular analysis, instead of using the non-pertubative QCD form factors and the wilson coefficents, angular amplitudes A^{LR} are defined. Then we measure in the bins of $q^2 = m^2(\mu\mu)$ by firstly integrating over q^2 and secondly combining this with the B^0 and $\bar{B}^0$ decays. This results in a so called CP-averaged basis S_i. The resulting $\frac{d\Gamma}{dq^2}$ spectrum is then

Why are there different amplitudes? What does the spin of the K* have to do with this?

Mention that for a full analysis also the CP asymmetries have to be analysed as NP could contribute differently to CP-conjugated processes

$$\frac{1}{\frac{d(\Gamma+\bar{\Gamma})}{dq^2}} \cdot \frac{d\left(\Gamma+\bar{\Gamma}\right)}{d\cos\theta_l d\cos\theta_k d\phi}\Big|_P = \frac{9}{32\pi} \cdot f(F_L, \theta_k, \theta_l, A_{FB}, S_i)$$

dq^2

Here, the F_L describes the fraction of longitudinal polarisation of the K^{0*}. A_{FB} ist the forward/backward asymmetry of the dimuon system. In order the reduce uncertainties, the first basis of the S_i is transformed into a basis P_i which takes ratios of observables[1].

Which uncertainties?

Why do you put the citation here?

6 full fit model

In the full fit model the shape of the invariant mass plots are used to determine the amount of signal and background in the data.

Why is the dependence only in the signal PDF?

$$\mathrm{PDF}_{total} = f_{sig}\mathrm{PDF}_{sig}(\vec{\Omega}, m) + (1 - f_{sig})\mathrm{PDF}_{bkg}$$

The PDF function can be separated into an angular part and a massive part. After that a maximum likelihood fit is performed. As seen in figure 4 the massive part of the signal PDF is a gaussian fucntion with a radiative tail and

What is the bias correction?

the background PDF results in a exponential function.

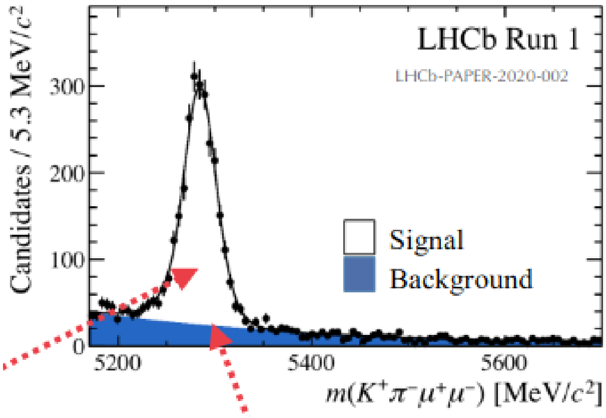

Fig
Abbildung 4: invariant B mass of Run 1 LHCb data.

Because of the factorization of the signal and background PDF

$$\mathrm{PDF}_{sig}(\vec{\Omega}, m) = \mathrm{PDF}_{sig}(\vec{\Omega}) \times \mathrm{PDF}_{sig}(m)$$

the angular part of the signal PDF of the Run 1 data and the data from 2016 can be shared What about the rest? in the analysis to perform a simultaneous fit $\sum_I S_{i,q^2_{bin}} f_i(\Omega)$. It is not clear why a fit should be done to this. Please make the relations to the decay width more clear previously!

7 modelling the efficiencies

Are the efficiencies treated equally between the years?

Why do we need a 4D parametrisation and cannot just take four acceptance functions, one for each variable?

Because the angular distribution and the q^2 distribution are influenced by the efficiencies, the parametrisation must be well known. This is done via an acceptance function, her the legendre polynomials. With 3 angles and q^2 a 4D parametrisation results in 4 coefficents

No! There are more depending on the order of Legendre polynomials you take for each dimension

Please put the formula for the acceptance function here

8 s-wave contribution

The vector-state is the K*0 which we want to look at, the problem are contribution from S-wave (spin 0) resonances in the Kpi spectrum

The $K\pi$ final state has more than one spin eigenstate. Therefore, additional terms are needed to differentiate between these states. Because $K\pi\mu\mu$ can be produced in a vector state which disturbs the angular distribution, the different structures of the spin 1 K^{0*} and the flat structure of the $K\pi$ state need to be analyzed.

Not the vector-state is the problem

How are they analyzed and what is done to deal with them?

9 uncertainties

The dominant systematic uncertainties across the q^2 bins are acceptance variation with q^2, peaking backgrounds and the bias correction. The whole table of uncertainties is shown in figure 5[1].

Source	F_L	S_3–S_9	P_1–P'_8
Acceptance stat. uncertainty	< 0.01	< 0.01	< 0.01
Acceptance polynomial order	< 0.01	< 0.01	< 0.02
Data-simulation differences	< 0.01	< 0.01	< 0.01
Acceptance variation with q^2	< 0.03	< 0.01	< 0.09
$m(K^+\pi^-)$ model	< 0.01	< 0.01	< 0.01
Background model	< 0.01	< 0.01	< 0.02
Peaking backgrounds	< 0.01	< 0.02	< 0.03
$m(K^+\pi^-\mu^+\mu^-)$ model	< 0.01	< 0.01	< 0.01
$K^+\mu^+\mu^-$ veto	< 0.01	< 0.01	< 0.01
Trigger	< 0.01	< 0.01	< 0.01
Bias correction	< 0.02	< 0.01	< 0.03

Dominant systematics in each observable category

Fig
Abbildung 5: table of systematic uncertainties.

Because of different decays in the same target finalstate, for example $\bar{\Lambda}^0_b \to \bar{p} \to \pi^- K^+\mu\mu$, (anti_p->pi) events that are drawn from distributions of these peaking backgrounds are not taken into the fit. Bias corrections come up if boundary effects like $F_S > 0$ are required.

What is FS?

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2}|_{S+P} = (1 - F_S)\ \frac{\mathrm{d}\Gamma}{\mathrm{d}q^2}|_P$$

For small F_S the bias towards higher values biases the P-wave and vice versa.

10 Results and conclusion

~~If the energy threshold is so big, that a $c\bar{c}$ pair can be produced in a loop which generates a J/Ψ, the would be a possibility to detect it.~~
The tension is confirmed with the 2016 data set. The significance of the discrepancy is nuisance parameter dependend and also depends on the q^2 bins.

What is the result of this analysis? What about the global fits? What about the Wilson coefficients? How do the results compare to the previous measurements?

Literatur

Eluned
[1] Elune Anne Smith. *Updated angular analysis of the decay $B^0 \to K^{*0}(\to K^+\pi^-)\mu^+\mu^-$*. ~~URL: https://indi.to/bMm9K (besucht am 17.07.2020).~~ LHC seminar, 13th of March 2020

cite the associated paper, the papers of previous measurements