Angular analysis of the $B^0 \rightarrow K^{*0}e^+e^-$ decay with the LHCb detector

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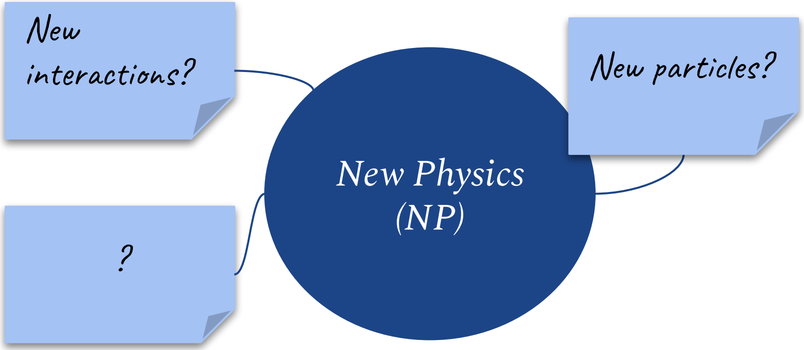
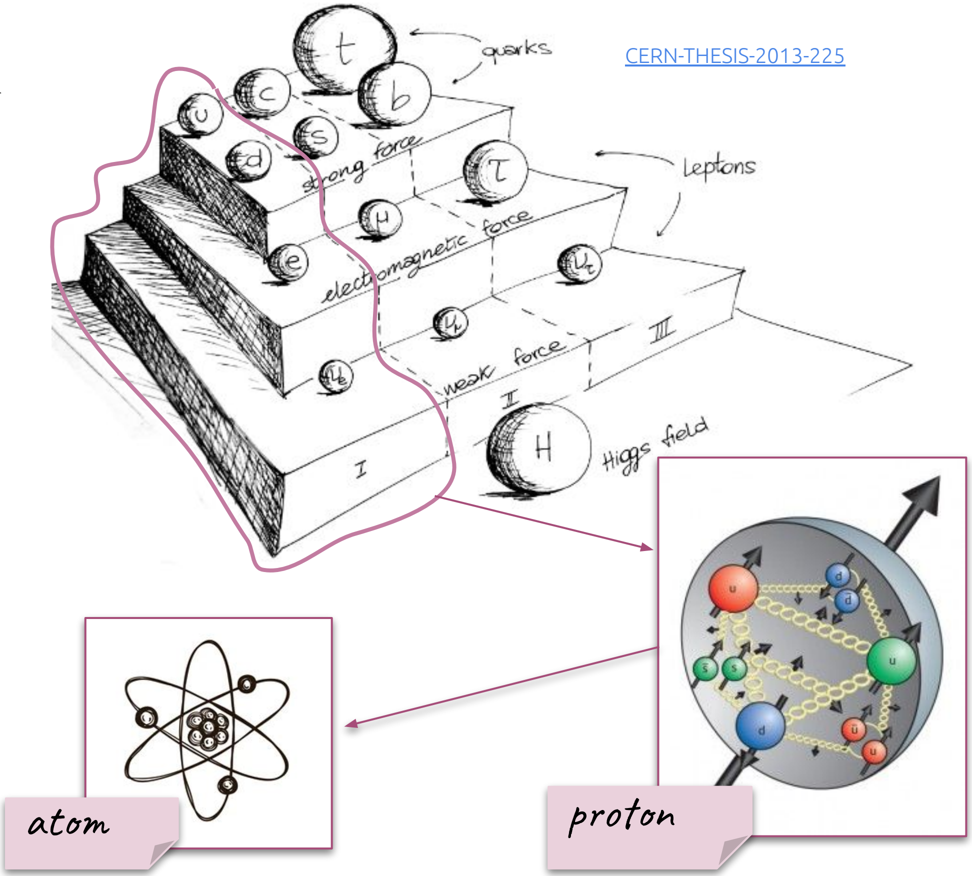
Standard Model (SM) of particle physics

- SM is an excellent theory describing particles and their interactions
- First generation particles are *stable* : they compose the matter of our world

- The SM still leaves a lot of open questions
- Test the SM is a way to search for clues of physics beyond the SM



CERN-THESIS-2013-225

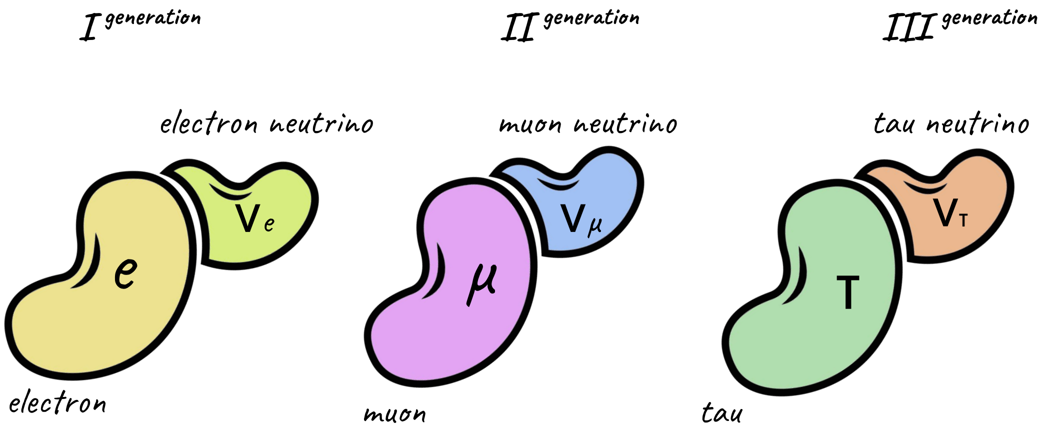


Nikhef

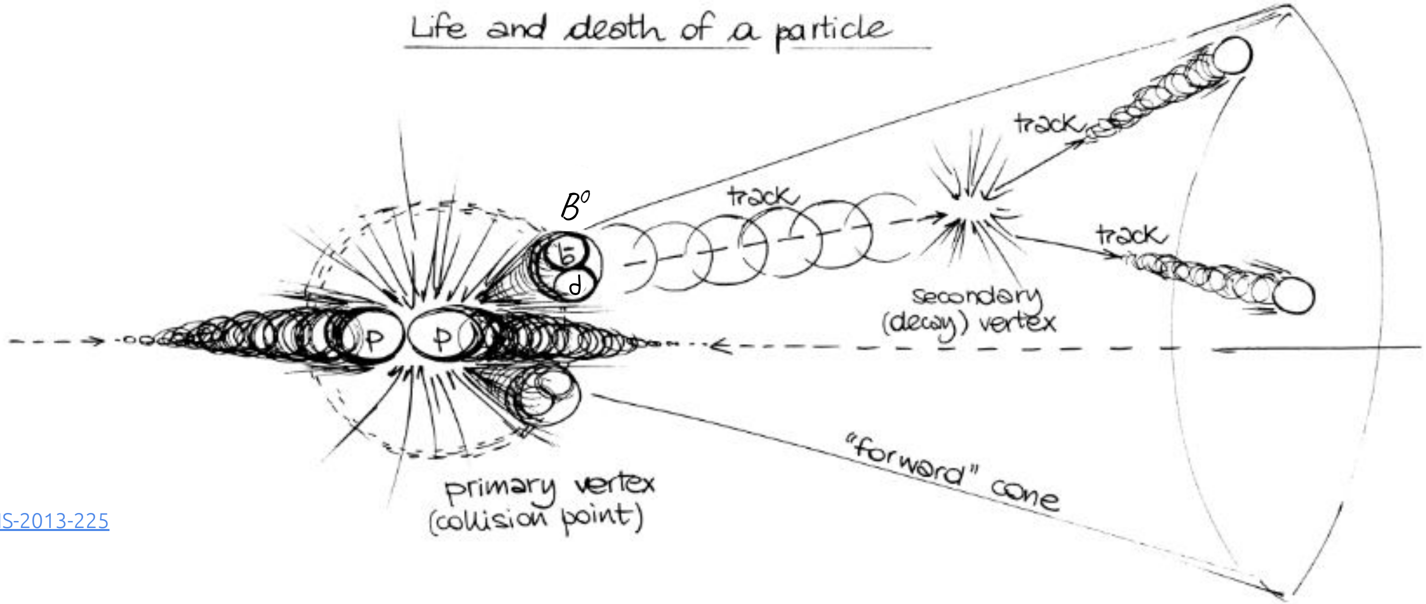
Lepton flavour universality in the SM

- Leptons are divided in 3 generations and 6 'flavours'
- Lepton flavour Universality (LFU):
  leptons behave in the same way under electroweak force

LFU
tested in this analysis



How do we probe the SM?



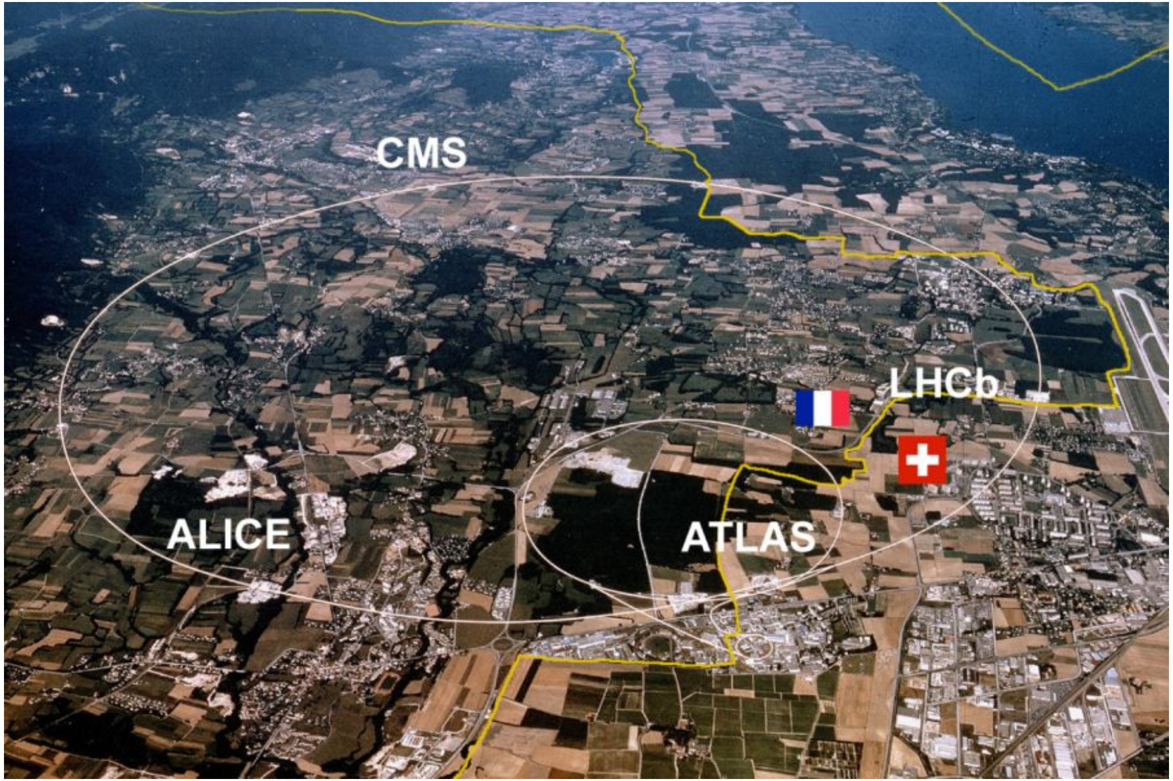
CERN-THESIS-2013-225

- Two beams of particles are accelerated and then made to collide
- At the collision point, beam constituents interact and other particles are generated from the energy transfer

Large Hadron Collider (LHC)

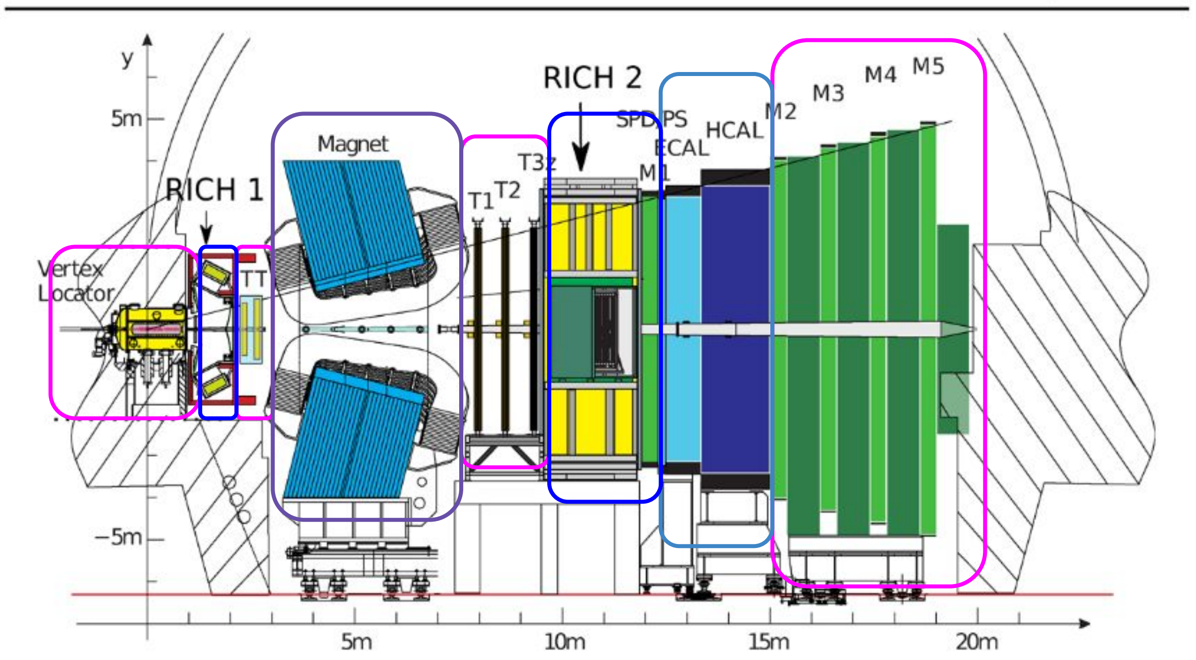
- The LHC is a circular particle accelerator operating at the laboratories of CERN
- Proton-proton collisions occur in a 27 km tunnel sited about 100 m underground

- So far 2 run periods (Runs 1 and 2)
- 4 interaction points, where experiments are located:
  - CMS
  - ATLAS
  - ALICE
  - LHCb



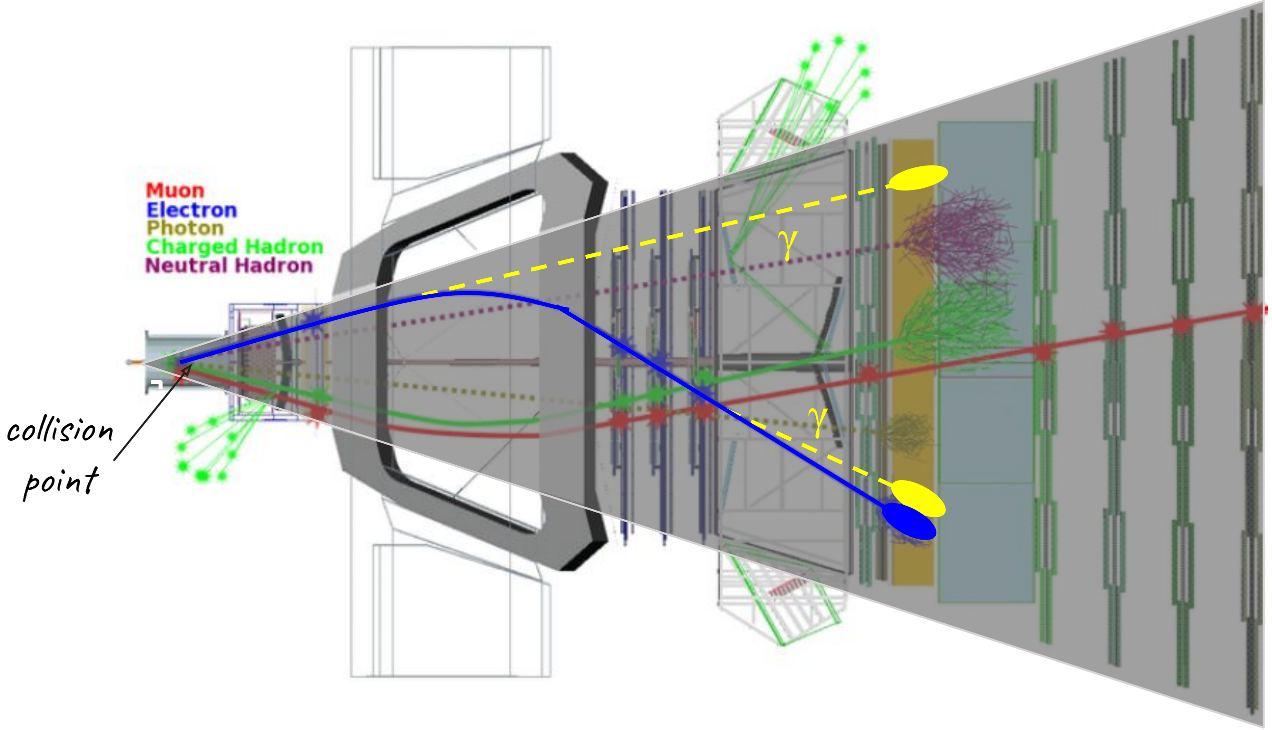
Large Hadron Collider beauty (LHCb) experiment

- Beauty (bottom) and charm quarks dedicated experiment
- Composed by several particle detectors that measure velocity, charge and lifetime of the particles



- Trackers: detect WHERE the particles passed by
- Magnet: not a detector, but it is necessary to bend particles and to measure their charge or velocity.
- Calorimeters: Energy deposit of the particles
- Cherenkov detectors (RICH): particle identification

Measuring leptons (LHCb detector)



muons

Quite easy:

- Stable particles
- No significant radiation
- Clean signature

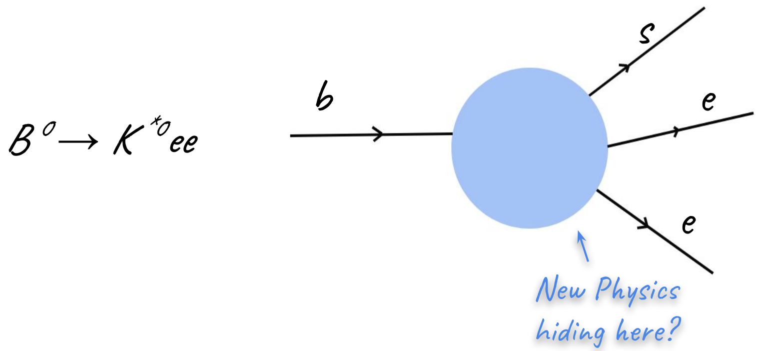
electrons

Harder

- Radiate at a rate 10^8 times greater than muons
  → complicating reconstruction
- PID and track reconstruction efficiencies lower

How do we test LFU in LHCb?

- Test the LFU comparing decay rates to electrons and muons
- Two main observables are used



- Comparison between SM prediction and precise measurement of these observables
- If discrepancies are observed → NP hints

Angular coefficients of the decay

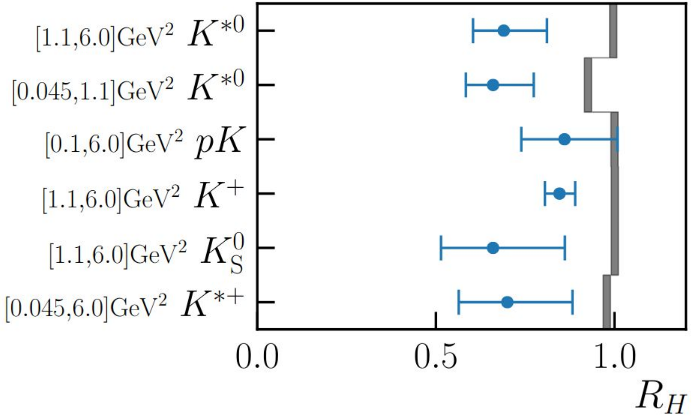
Branching Ratios

Branching Ratio is the 'decay frequency' of a certain decay channel:

$$BR(P \to l) = \frac{N(P \to l)}{N(Pdecaying)}$$

Why $B^o \rightarrow K^{*o}ee$ angular analysis

[credits to M. Borsato]

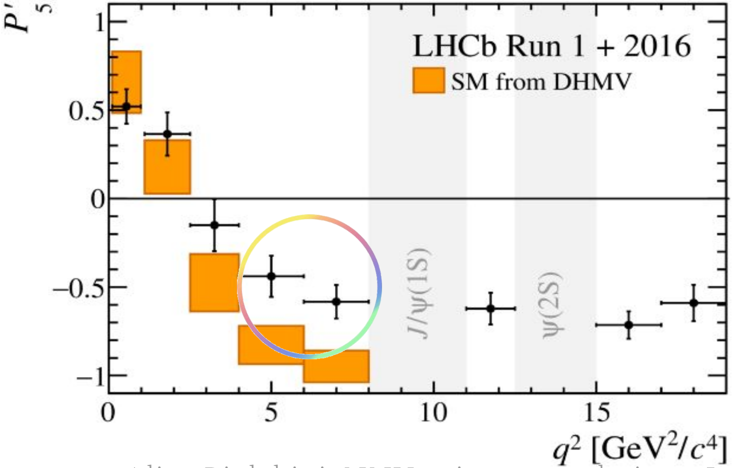


- SM predict equal BR between electron and muon

$$R(H) = \frac{\mathcal{B}(B \to H\mu^+\mu^-)}{\mathcal{B}(B \to He^+e^-)} = 1$$

- Angular analysis anomalies

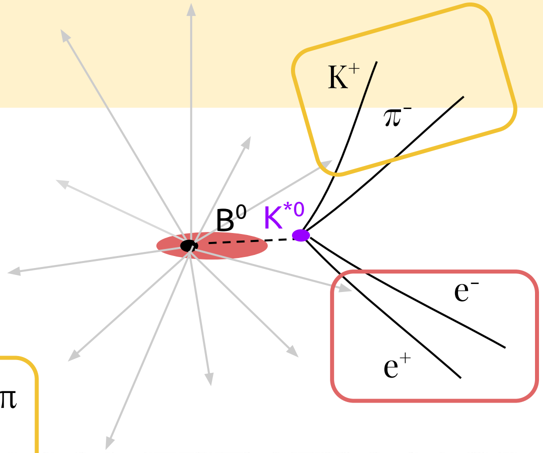
  i.e. $B^0 \rightarrow K^{*0}$ μμ angular analysis



- $B^0 \rightarrow K^{*0}ee$ angular analysis plays a very important role in understanding the hypothetical NP

- ***Essential result to shed light on these flavour anomalies***

$B^0 \rightarrow K^{*0}ee$ topology



- The BR of this decay is ~ 1.03×10^{-6} [pdg], 1 B^0 every million decays into $K^{*0}ee$

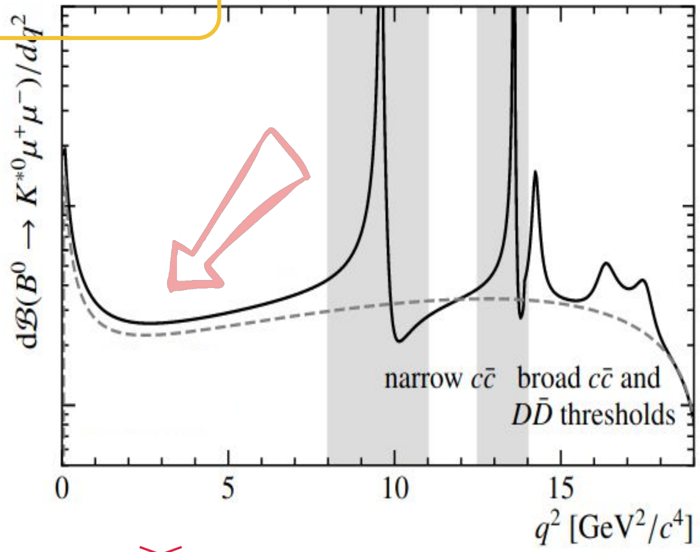
VERY RARE DECAY!

- K^{*0} is not a stable particle and immediately decays into a pair of K and π
  → laboratory decay channel is $B^0 \rightarrow K\pi e^+e^-$

- q^2 is the invariant mass of the system made by the two electrons

$$q^2 = (p_{e-} + p_{e+})^2$$

where p stands for the 4-momenta of the particles.



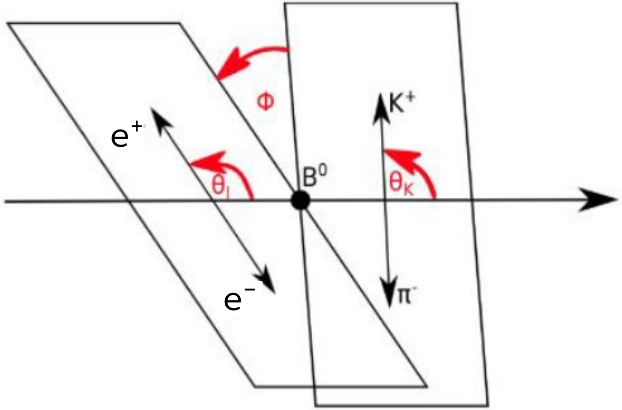
- The signal (our decay) q^2 is the gray dashed line.

Goal of the analysis

- The decay is described by 3 angles (θ_l, θ_K and ϕ)

Angular distribution

$$
\begin{aligned}
\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^4(\Gamma+\bar{\Gamma})}{\mathrm{d}q^2\mathrm{d}\vec{\Omega}} = \frac{9}{32\pi}\Big[&\tfrac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K \\
&+\tfrac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell \\
&-F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi \\
&+S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi \\
&+\tfrac{4}{3}A_{FB}\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi \\
&+S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]
\end{aligned}
$$



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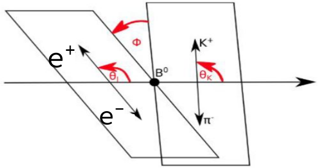

$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^4(\Gamma+\bar{\Gamma})}{\mathrm{d}q^2\mathrm{d}\vec{\Omega}} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \tfrac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + \tfrac{4}{3}A_{FB}\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi + S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

Angular distribution

- Goal of the analysis: Measure the coefficients describing the angular distribution and comparing them with SM predictions in each q^2 bin
- A 3D fit on the angular variables (θ_l, θ_K and ϕ) in several q^2 bins is performed

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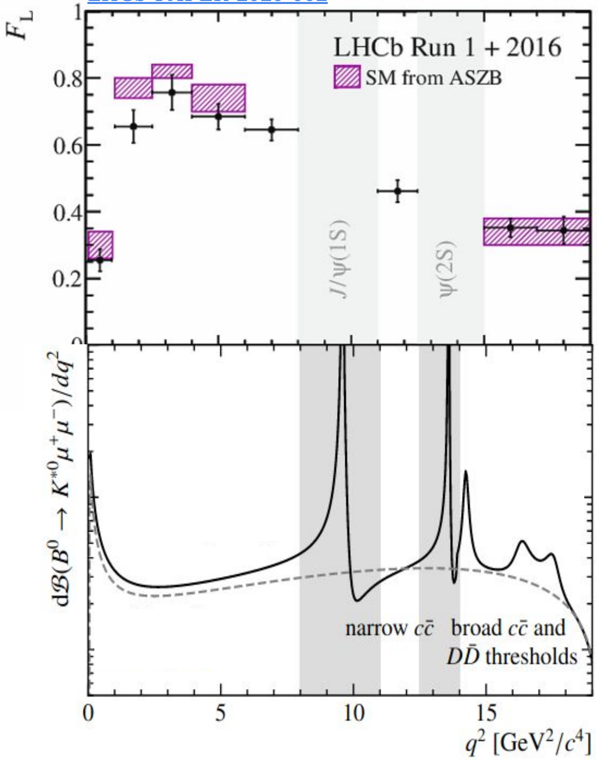
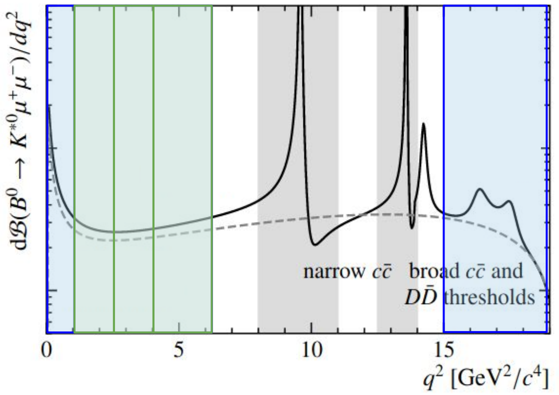
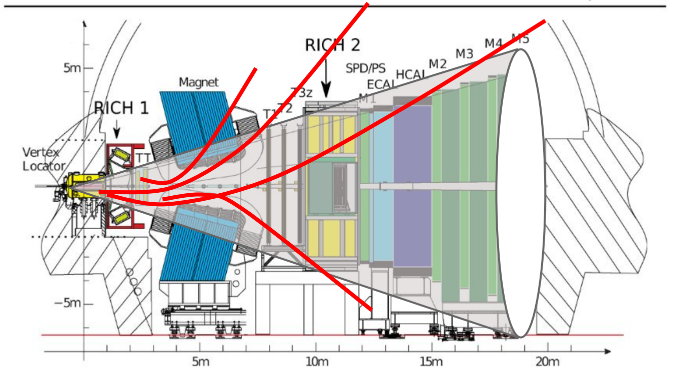


Analysis strategy of the ongoing analysis

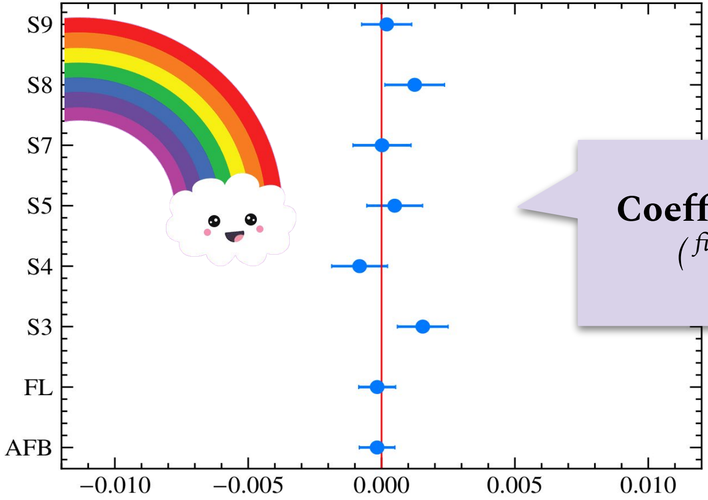
- Full Run1 and Run2 LHCb data are going to be used
- The analysis is planned to be performed in several q^2 bins
- The selection is the very first step in the analysis, it's important to separate signal from backgrounds
- A $B^0 \rightarrow K^{*0}ee$ Monte Carlo (MC) simulation is used in order to
  - study *detector efficiency*
  - irreducible backgrounds components
  - test our fitting strategy
- MC simulations are tricky we often need to correct them
- *How do we know that we have everything under control?*



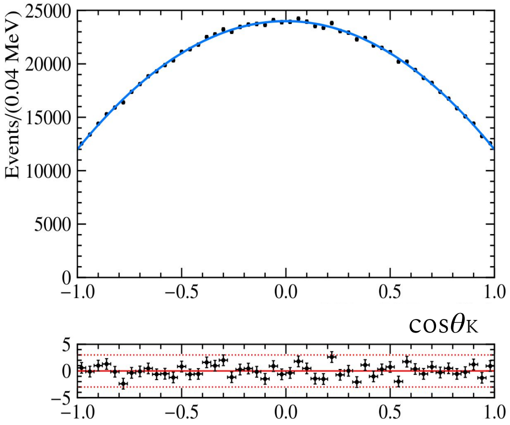


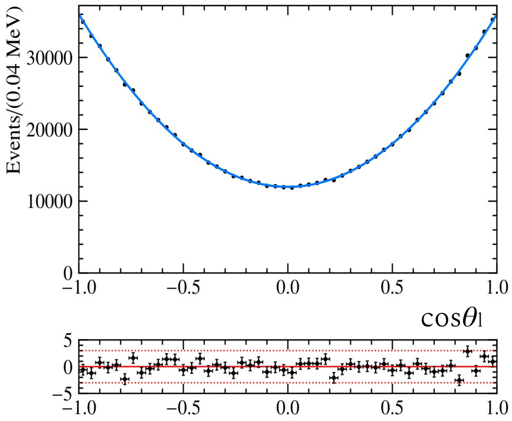
MC Generator level fit: before detector effects

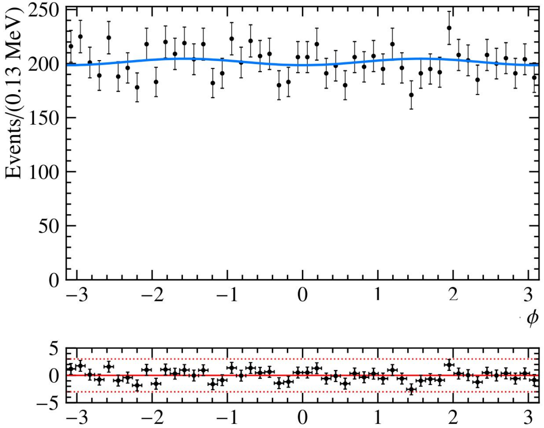
- A 3D fit to the complete MC Generator level sample is performed
- We retrieve the correct values of the coefficients



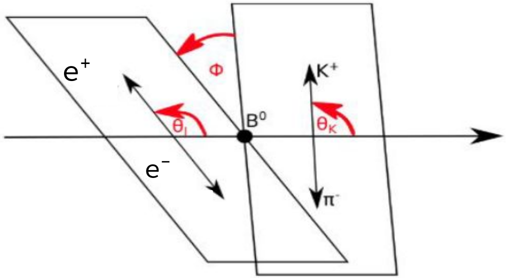
Coefficient residual:
$({}^{fit}Val - {}^{gen}Val)$





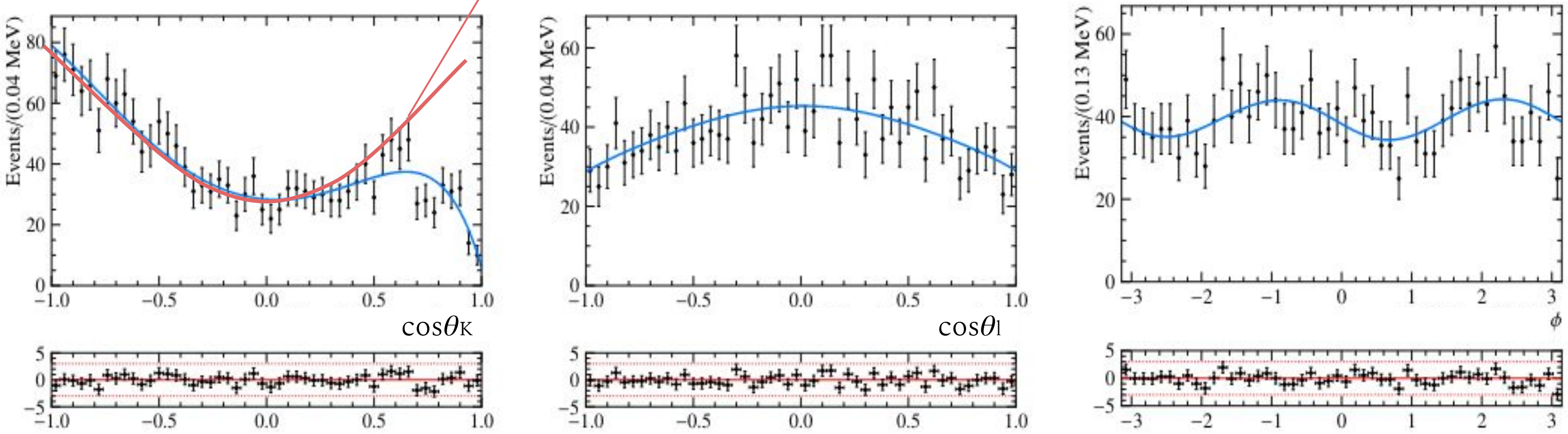


Detector efficiency



- The information of the detector efficiency has been added
- It changes the shape of the angular distributions, in particular cosθ_k shape.

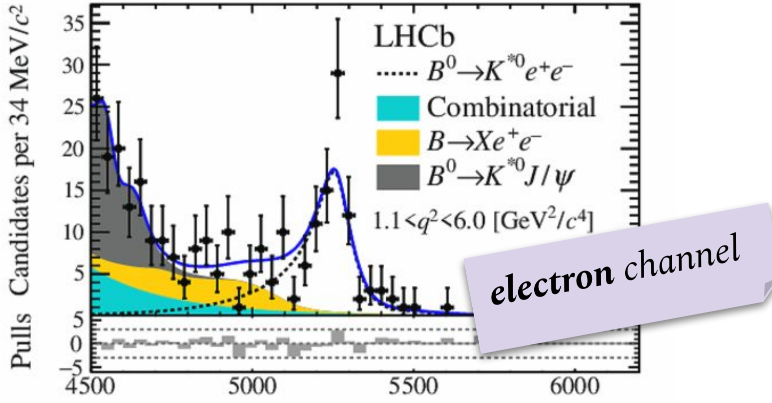
before



Low statistic available

- Low statistic = few events available
- Less than 500 events are expected in Run1 and Run2 data
- Perform an angular analysis with so few events is very challenging

- Final state invariant mass distribution (Run1 only)
  - Poor signal statistic
  - A lot of backgrounds
- Same decay channel but with muons → much cleaner



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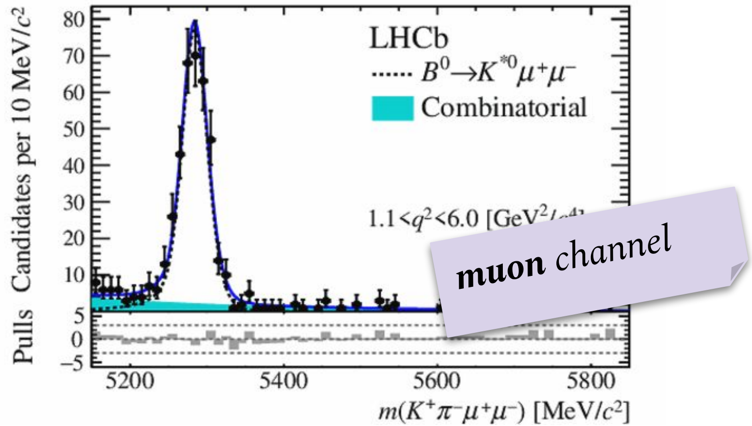
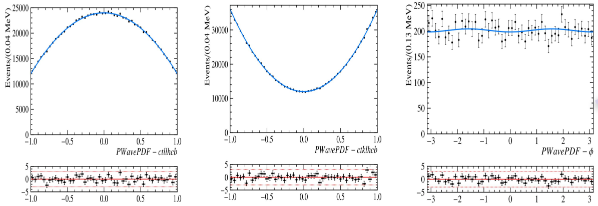


Fit behaviour at low statistic

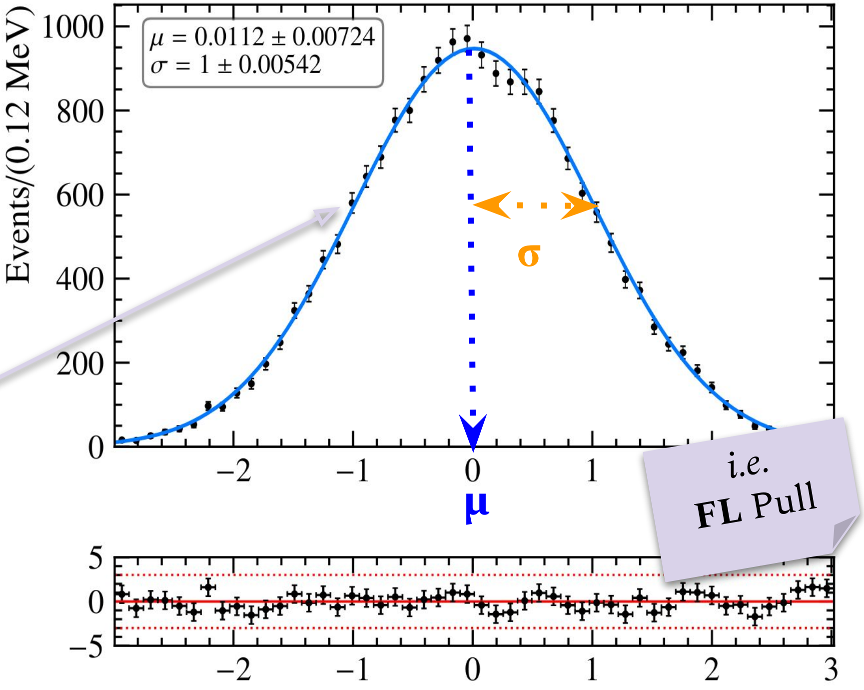
- Pseudo-experiments are performed

Samples are generated from the angular distribution with known coefficients values

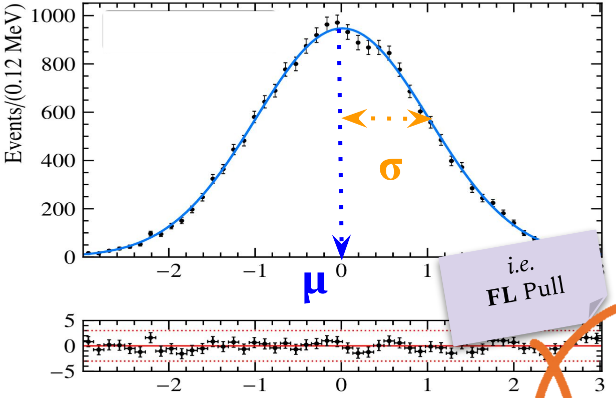
- A fit to each sample is performed:

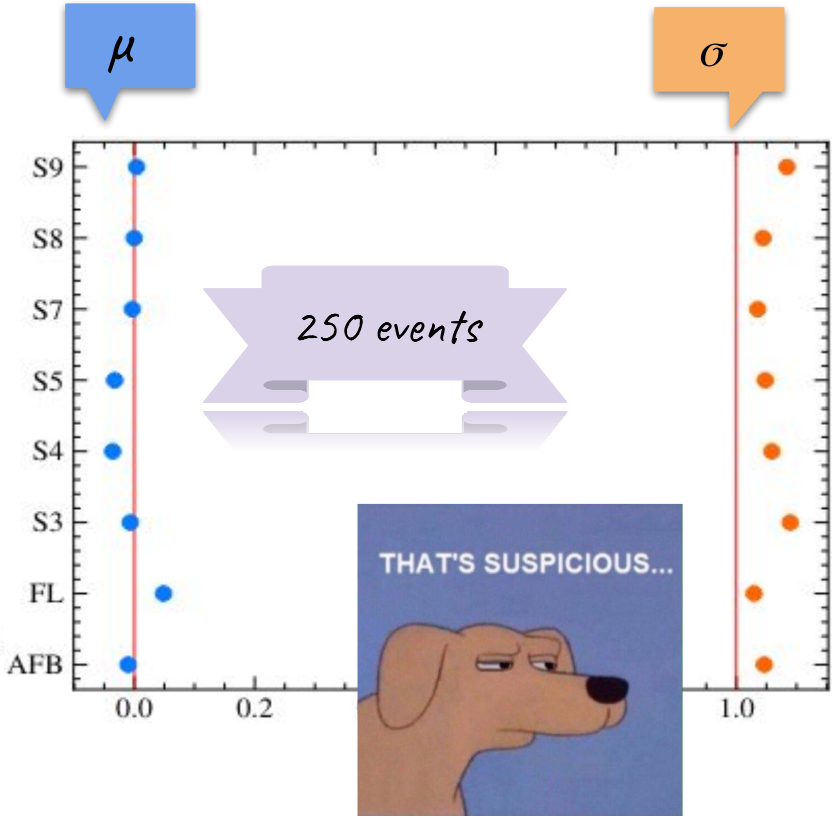


- The pull distributions $[(^{fit}Val - {}^{gen}Val) / {}^{fit}Error]$ must be Normal distributed → **μ = 0**, **σ = 1**



Fit behaviour at low statistic (cont'd)





- We are investigating this behaviour of the fit at low statistic
- So unfortunate that we are studying a rare decay!!
- *work in progress*

Conclusions

- We will perform an angular analysis of the $B^0 \rightarrow K^{*0}ee$ decay using the full available statistical power (LHCb Run1 and Run2 data)

  Main challenges
  - ★ The presence of electrons
  - ★ The very low statistic of this channel
  - ★ Multiple backgrounds need to be modeled

- We aim at reaching high accuracy to compare our results with that of the $B^0 \rightarrow K^{*0}\mu\mu$ analysis

This will be a very important result given the latest LFU tensions

Thanks for the attention