Universität Zürich[UZH]

Test of lepton flavour universality in $B^+ \to K^+ l^+ l^-$ decays in high dilepton invariant mass squared region

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Speaker: Vadym Denysenko
vadym.denysenko@physik.uzh.ch
vadym.denysenko@cern.ch
University of Zurich
Zurich, Switzerland

R_K measurements

- Ratio of $B^+ \to K^+ l^+ l^-$ branching fractions (a theoretically clean observable):

$$R_K = \frac{\int_{q^2_{min}}^{q^2_{max}} \frac{d\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)}{dq^2} dq^2}{\int_{q^2_{min}}^{q^2_{max}} \frac{d\mathcal{B}(B^+ \to K^+ e^+ e^-)}{dq^2} dq^2}, \qquad q^2 \equiv \textit{dilepton invariant mass squared}$$

- In the Standard Model (SM) coupling of gauge bosons to leptons are independent of lepton flavour:

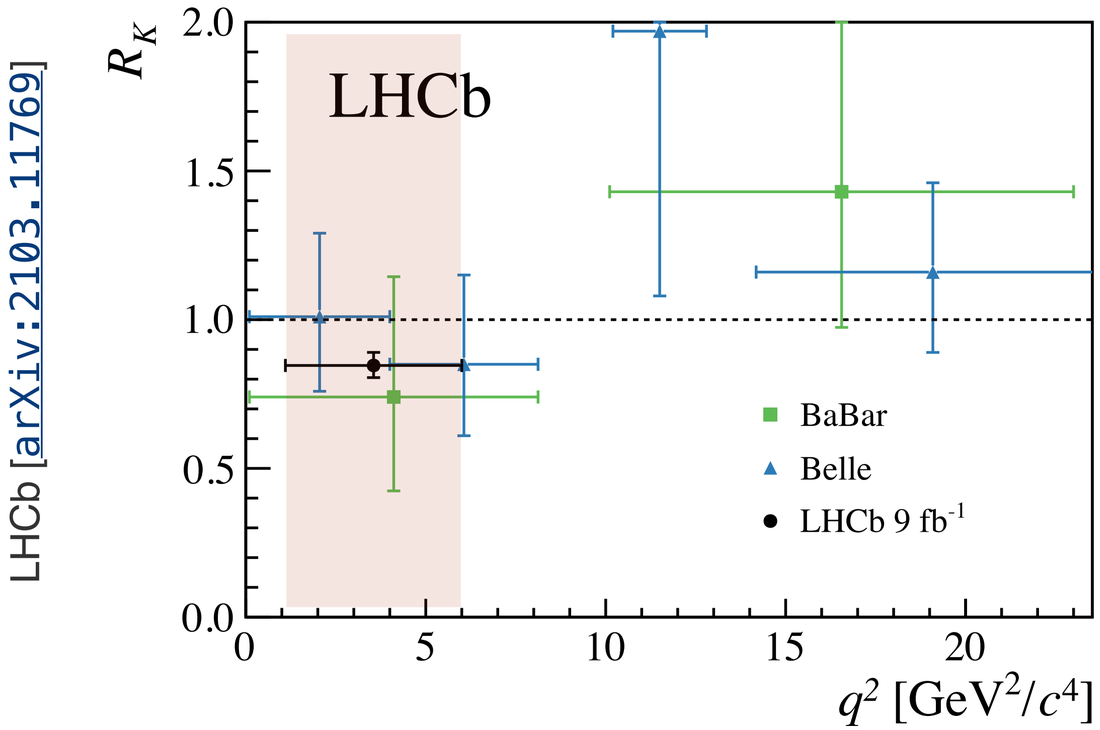
$$R_K \cong 1$$

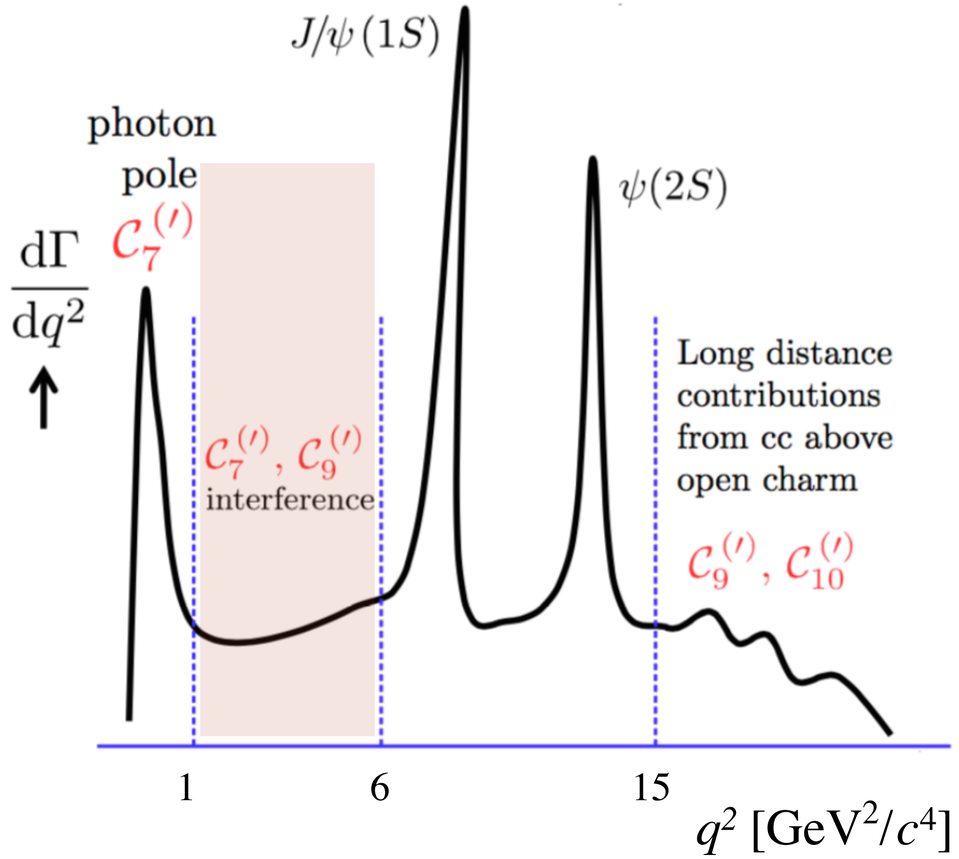
- Any significant deviation — hint of New Physics (NP):
  - Latest results show 3.1σ tension with SM [arXiv:2103.11769]

R_K measurements

'Central q^2' measurements ($q^2 \in [1.1\ \text{GeV}^2, 6.0\ \text{GeV}^2]$), see Davide's talk before:

- 3.1 σ tension with the Standard Model

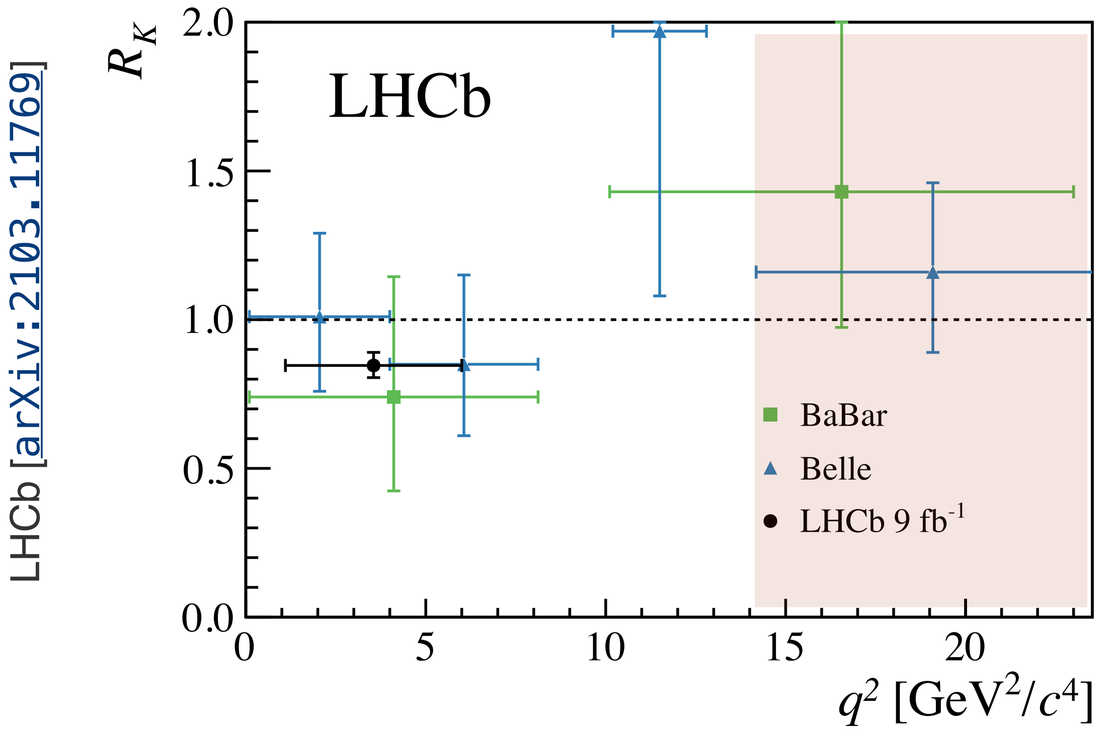


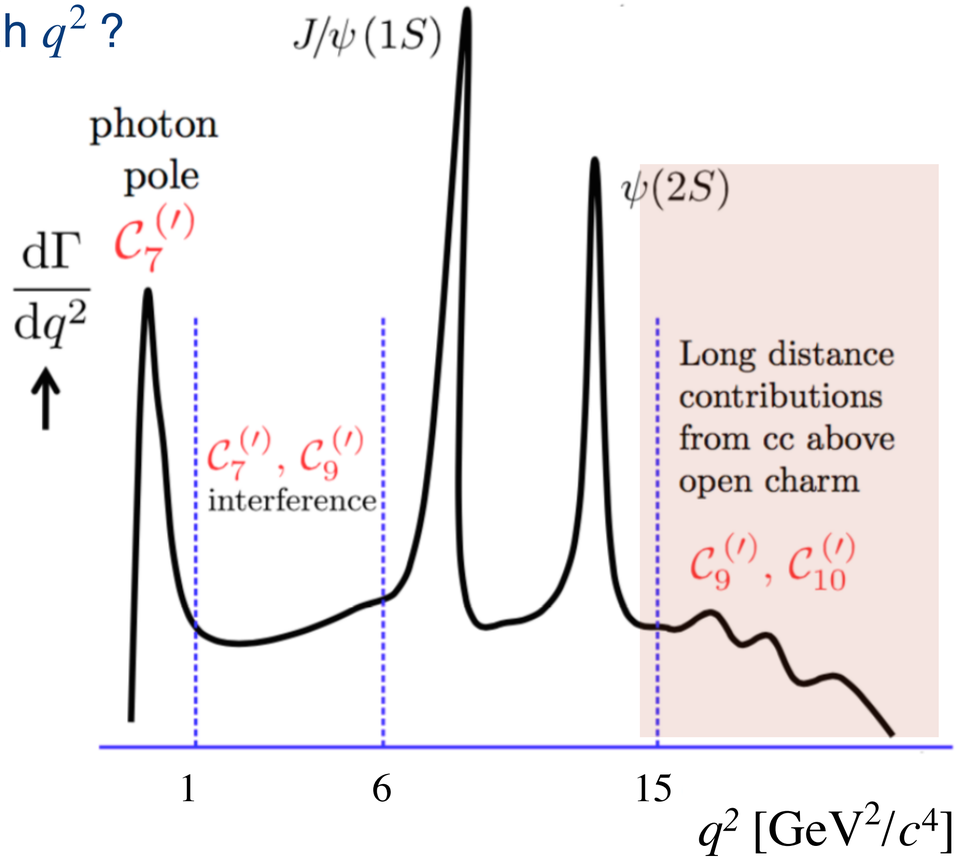


R_K measurements

Only have measurements from the *B*-factory experiments at high q^2

Question: Why hasn't LHCb made measurements of R_K at high q^2 ?



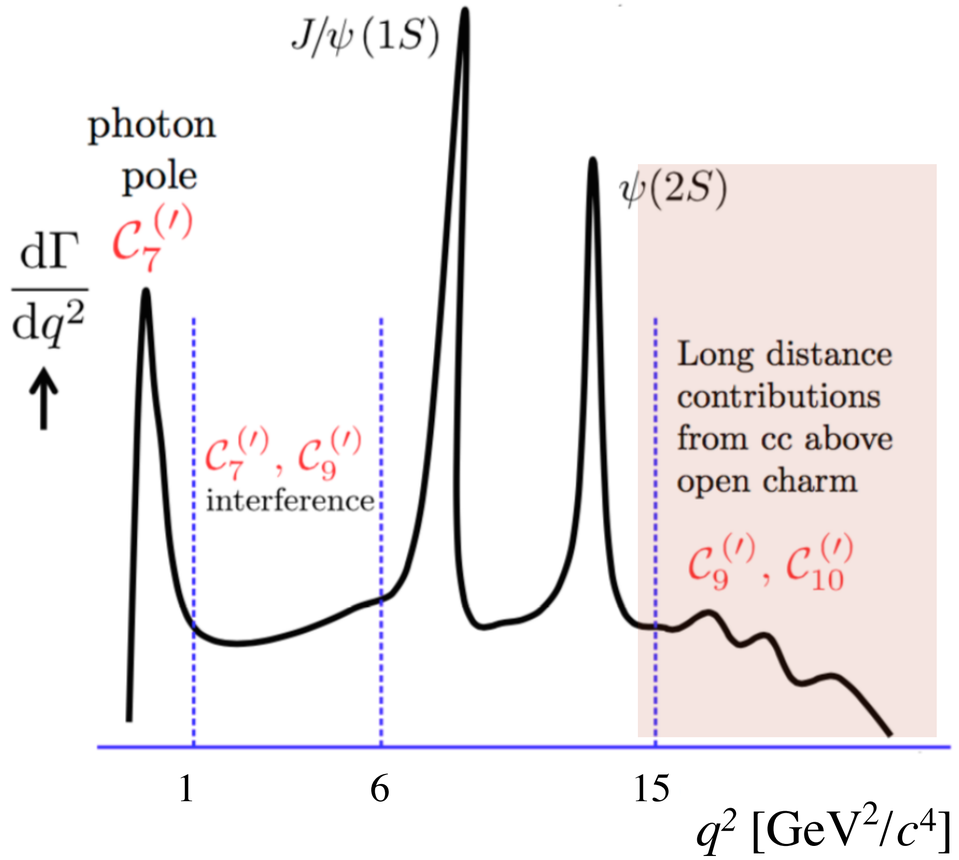


R_K measurements

'High q^2' measurements:

- Statistically **independent** measurements with a large yield;

Question: Why hasn't LHCb made measurements of R_K at high q^2 ?



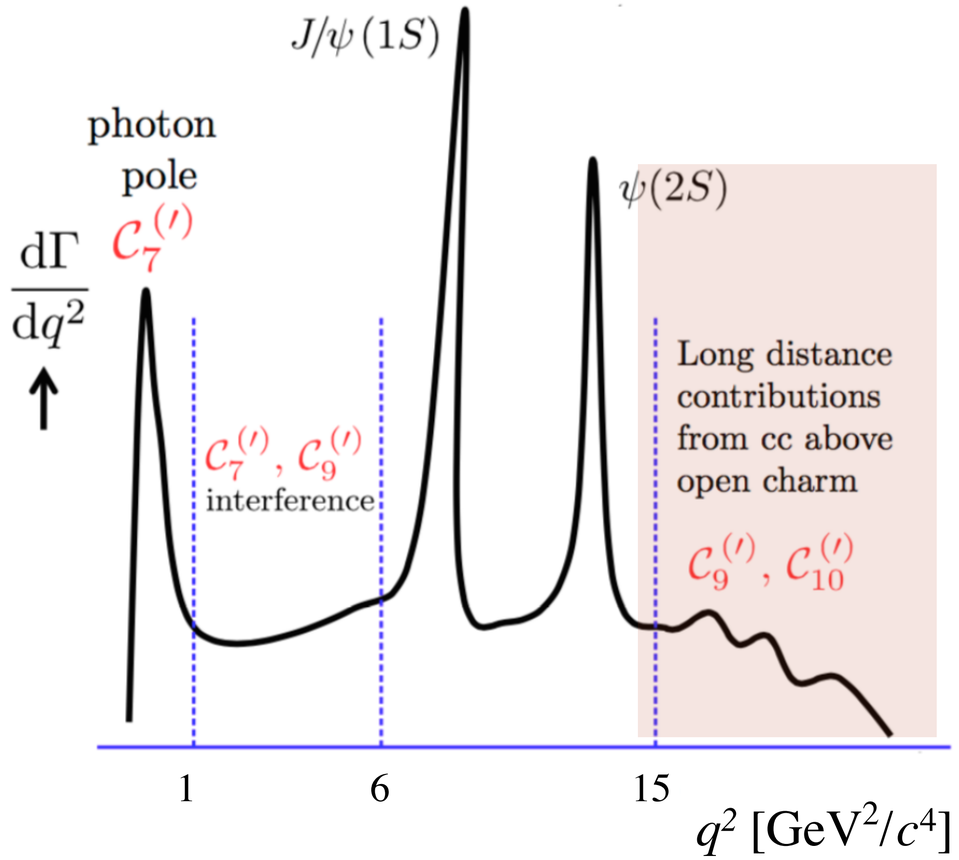
R_K measurements

'High q^2' measurements:

- Statistically **independent** measurements with a large yield;

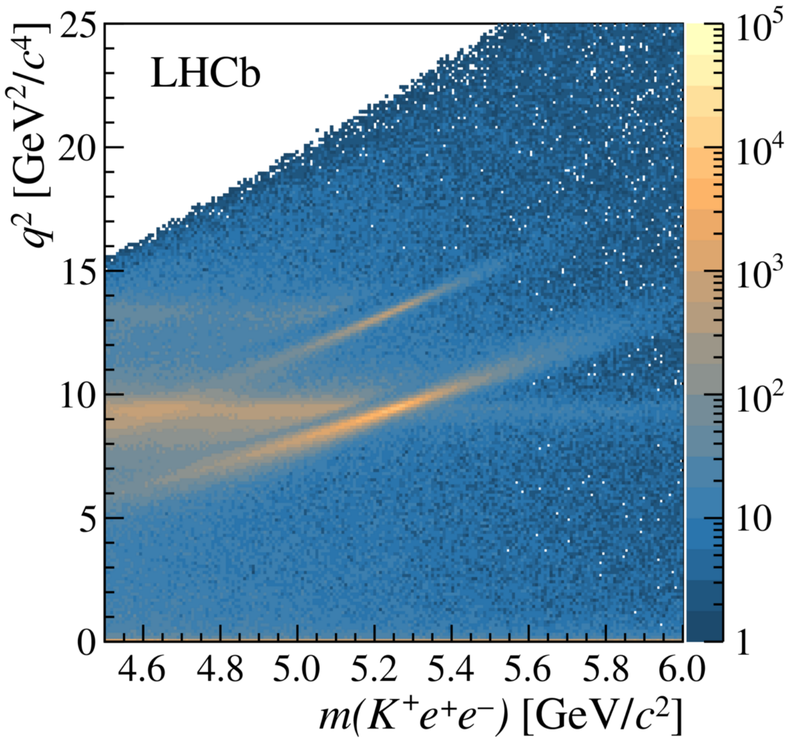
Question: Why hasn't LHCb made measurements of R_K at high q^2 ?

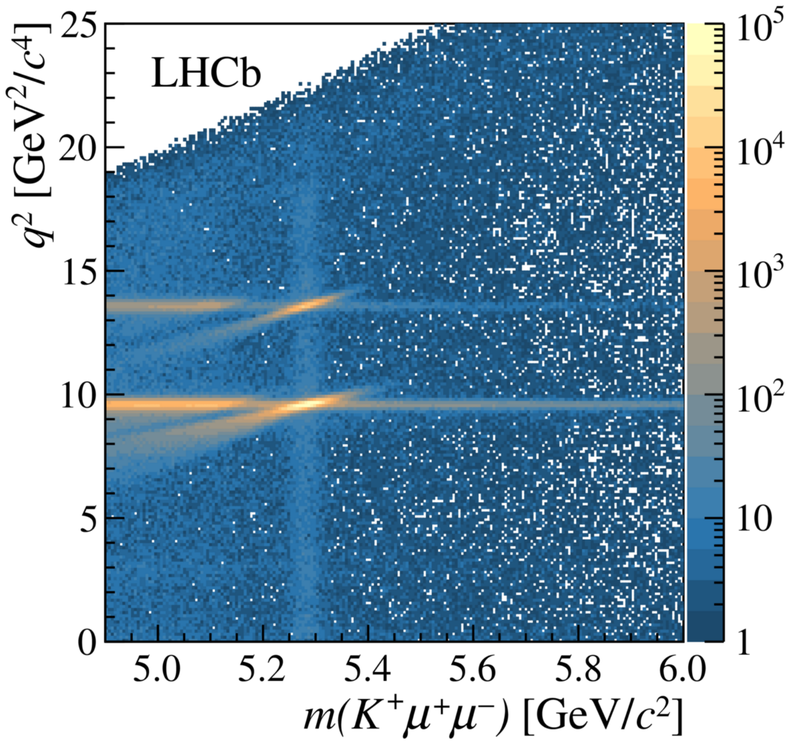
Answer: Bremsstrahlung effects are large thus the analysis become more difficult to perform.



Bremsstrahlung recovery

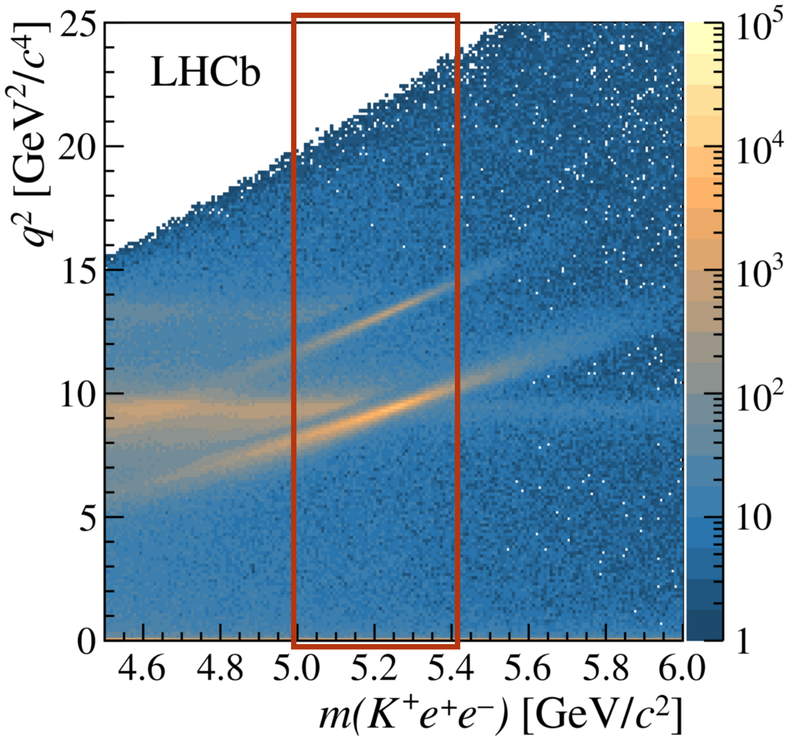
Even after Bremsstrahlung recovery, we see large differences between dielectron and dimuon final states:

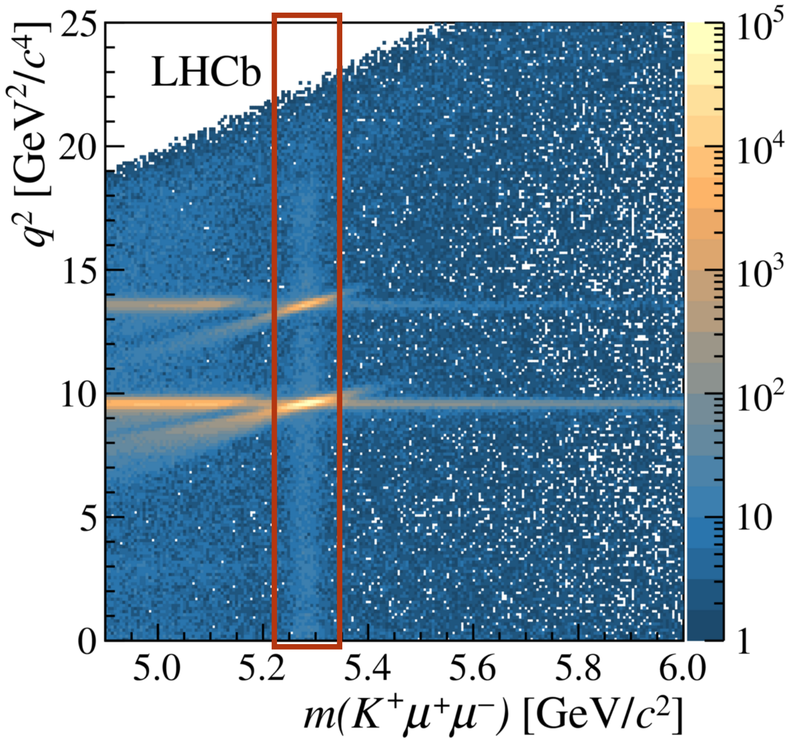




Bremsstrahlung recovery

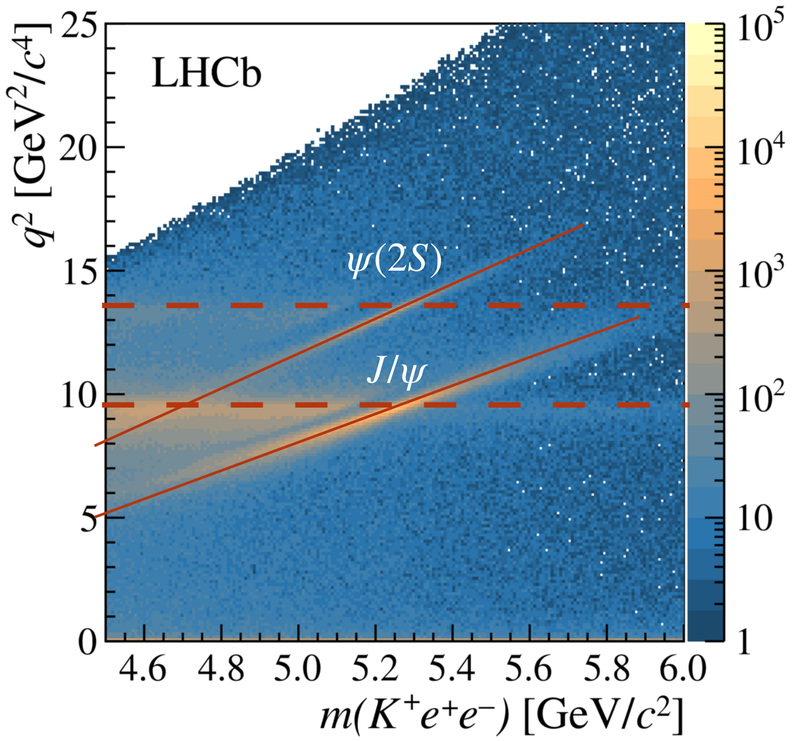
Due to imperfect Bremsstrahlung recovery signal is ‘washed out’ for electron channel.

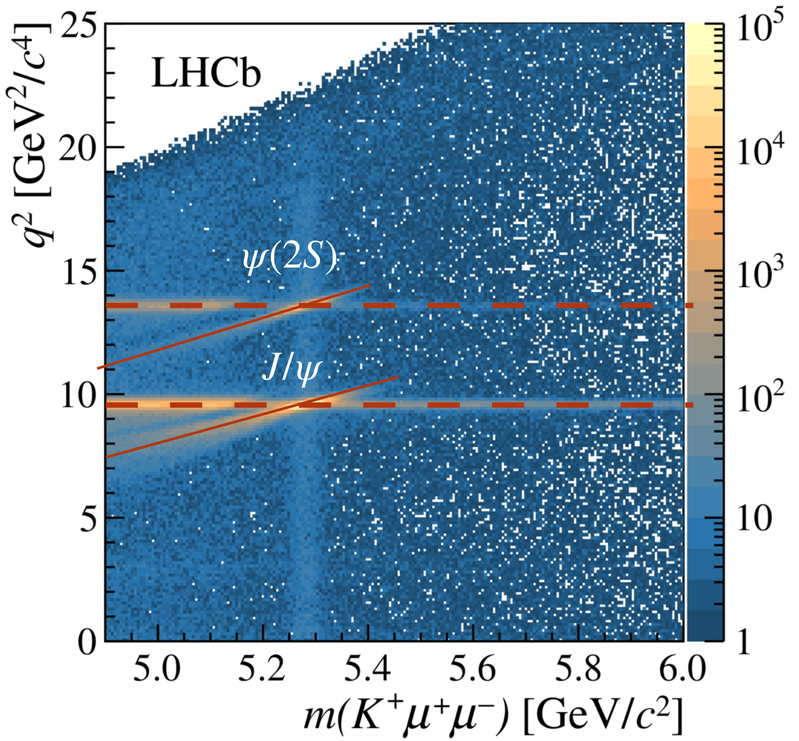




Bremsstrahlung recovery

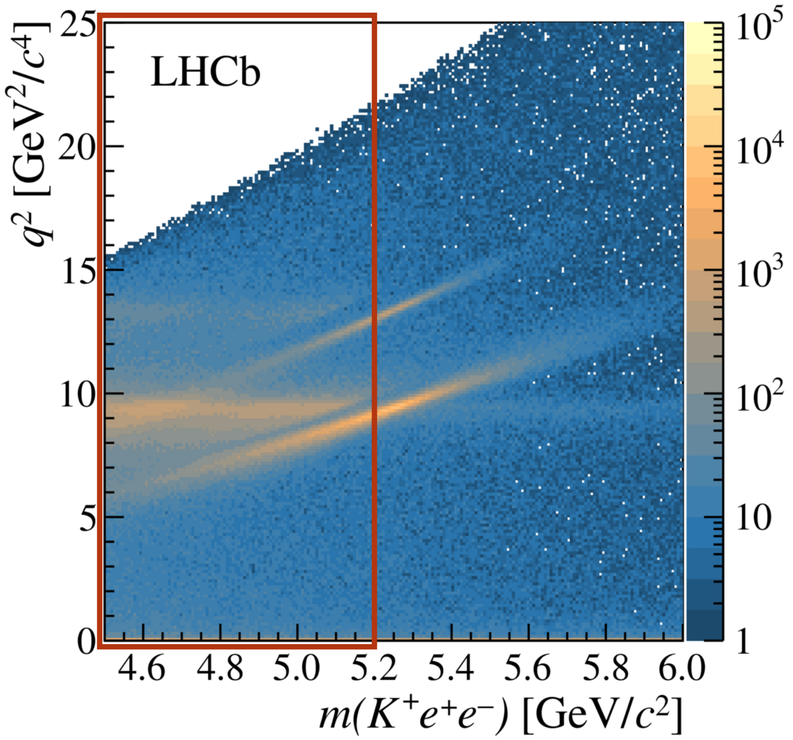
Narrow charmonium resonances have larger tails for the electron channel due to the imperfect Bremsstrahlung recovery and the energy resolution of the ECAL.

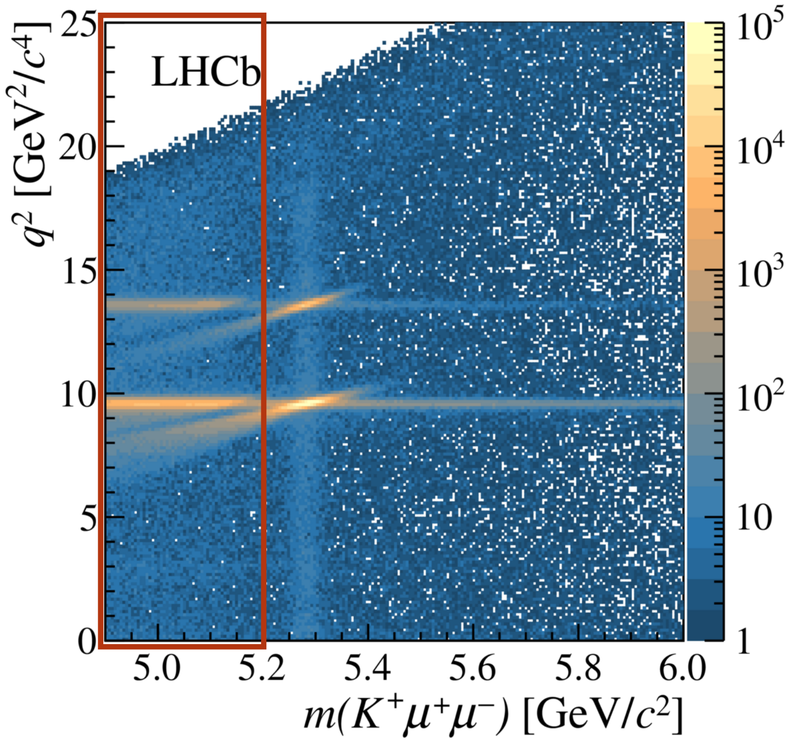




Bremsstrahlung recovery

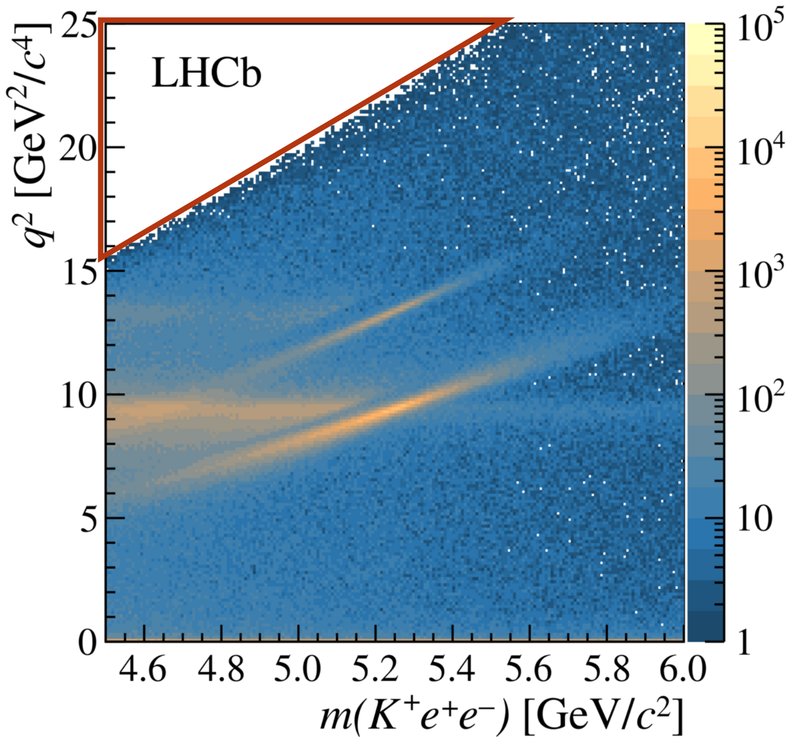
Partially reconstructed backgrounds are not well separated from the signal for the electron case.

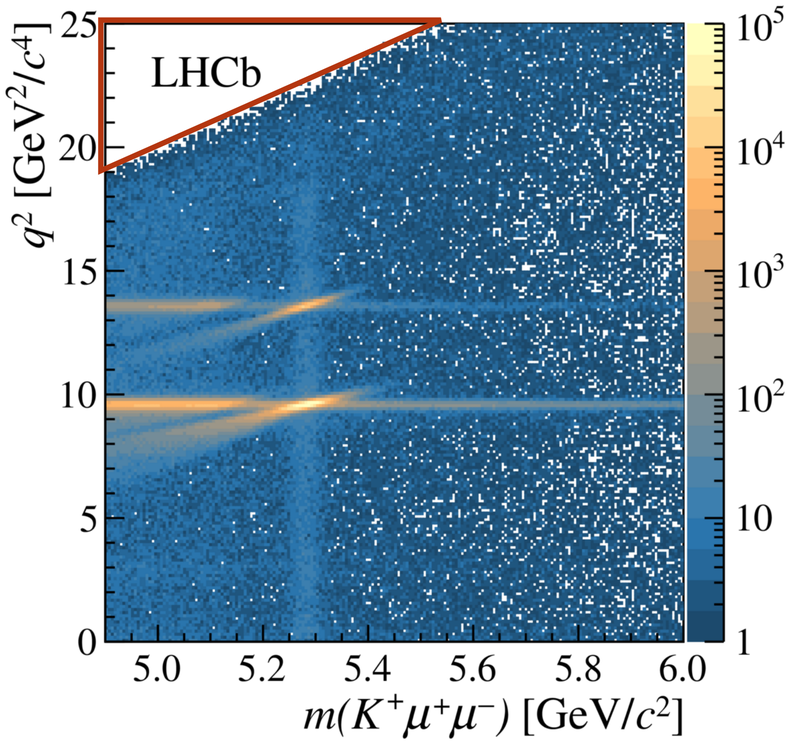




Bremsstrahlung recovery

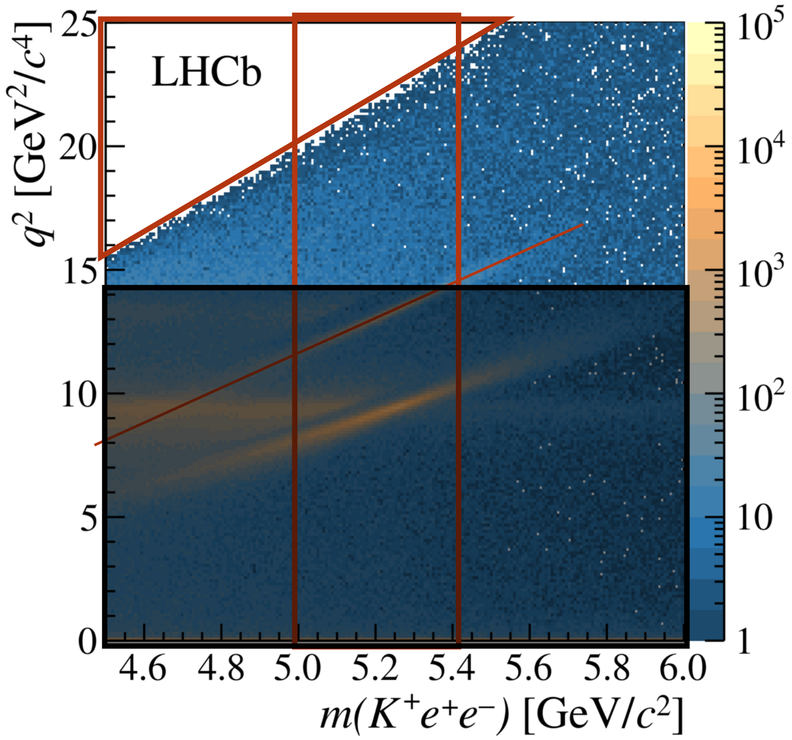
Combinatorial and partially reconstructed backgrounds are distorted by the available phase space.

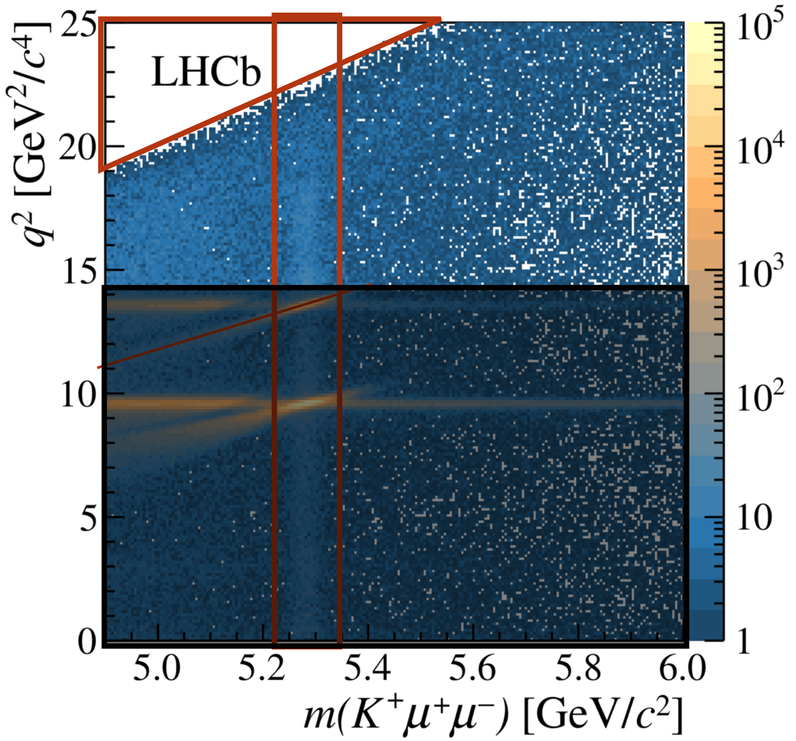




High q^2 problem

- Dielectron final state is difficult due to the $\psi(2S)$ resonance leakage (Bremsstrahlung recovery smears out resonances)
- Dimuon final state is less problematic

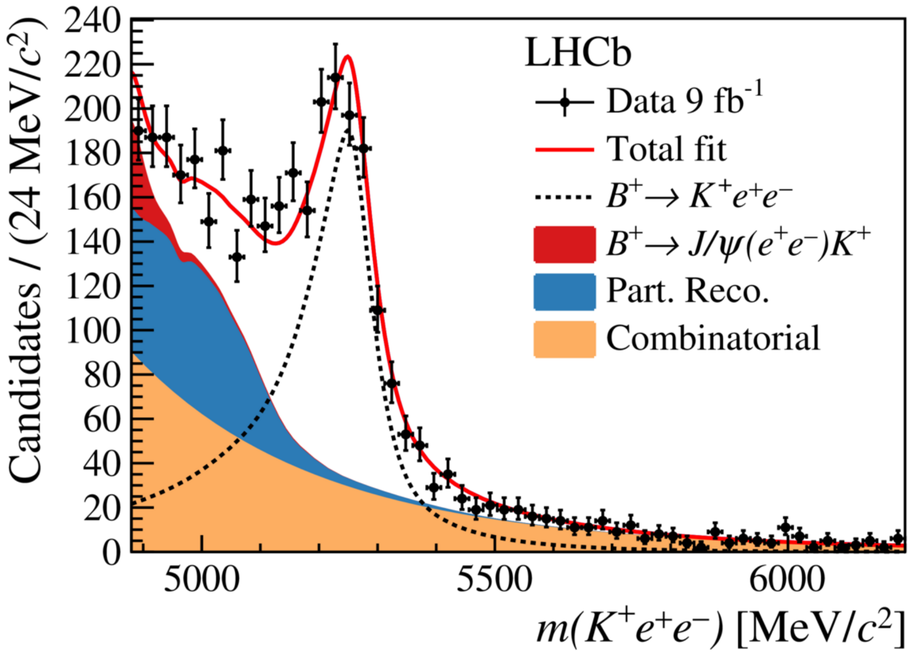




High q^2 problem

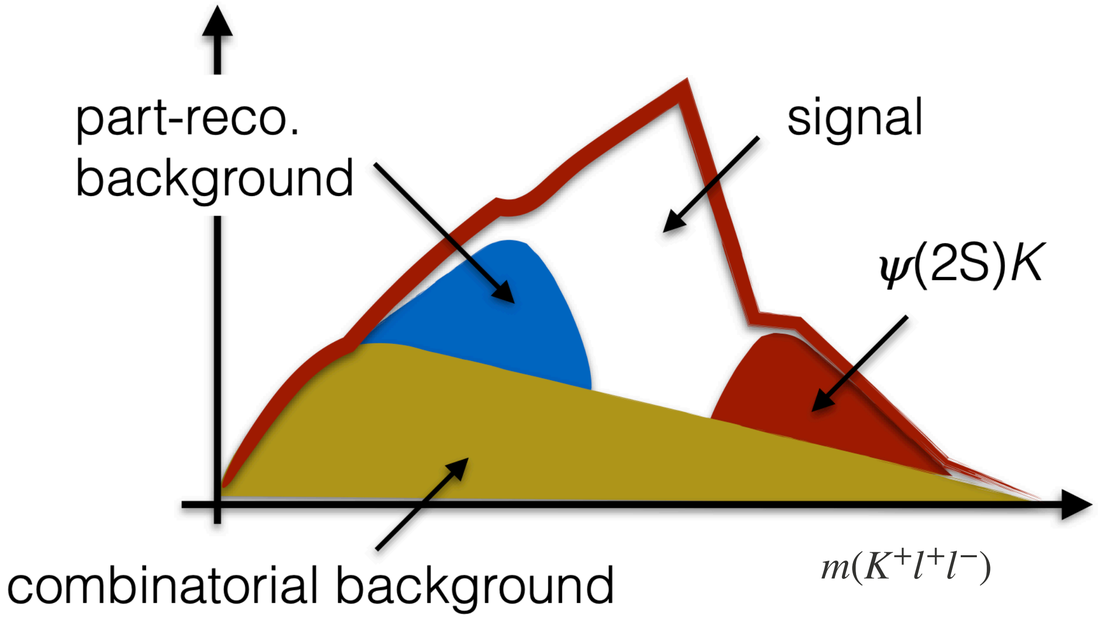
- ‘Central q^2’ measurements

LHCb [arXiv:2103.11769]



- ‘High q^2’ measurements:

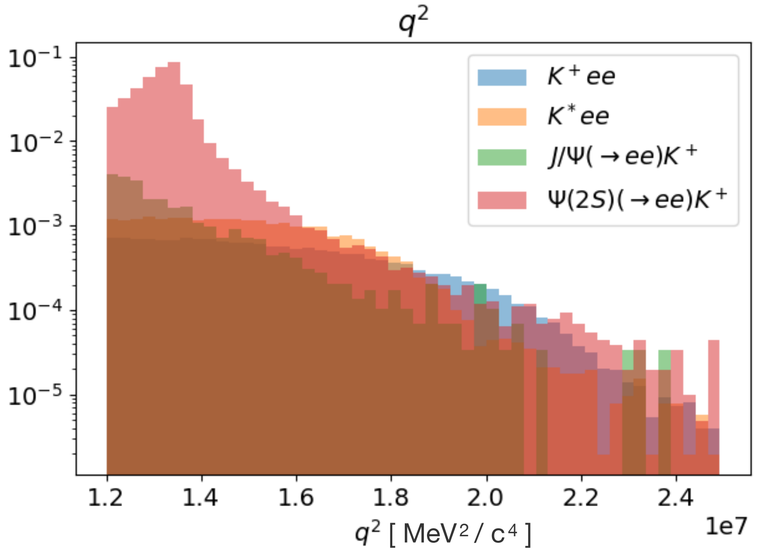
  It becomes challenging to statistically separate signal from background.



T. Blake talk

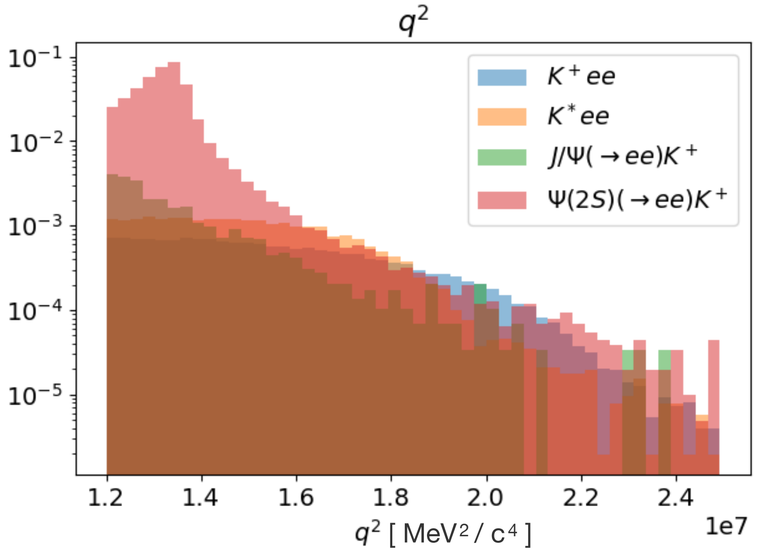
High q^2 problem

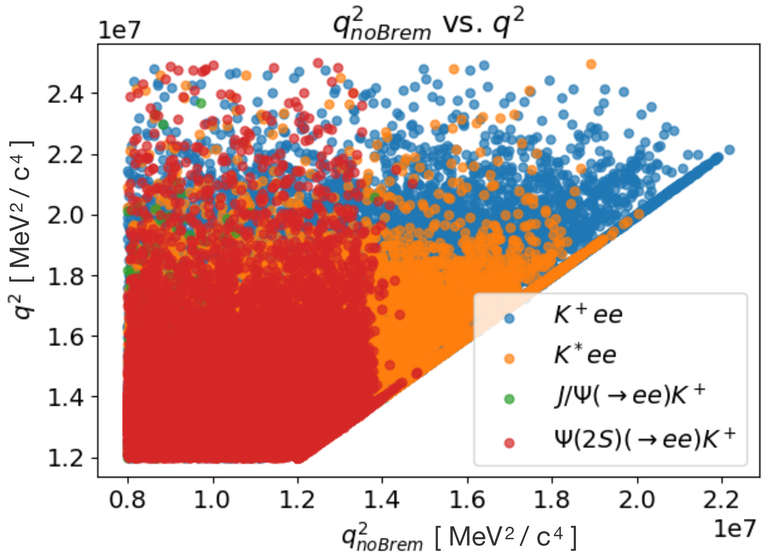
Resonances are smeared due to the wrong Bremsstrahlung recovery.



High q^2 solution

Since resonances are smeared due to the wrong Bremsstrahlung recovery:

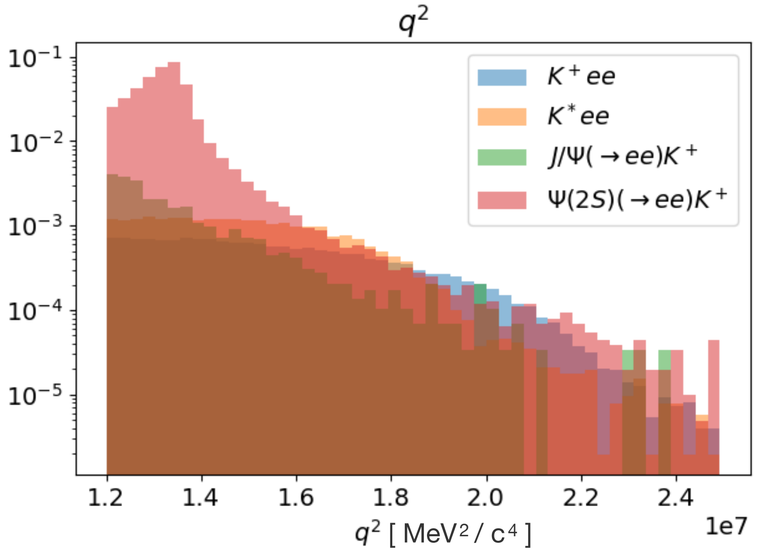


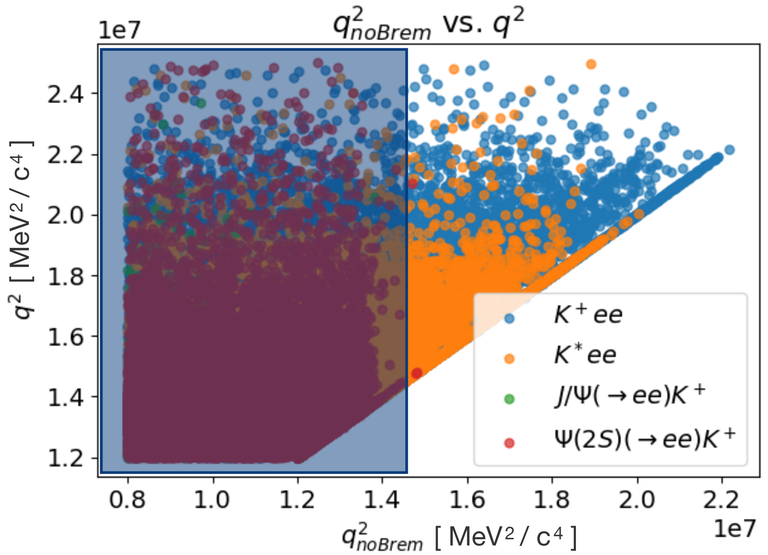


- $q^2_{no\ Brem.} \equiv$ *dilepton invariant mass (without adding Bremsstrashlung photons) squared*

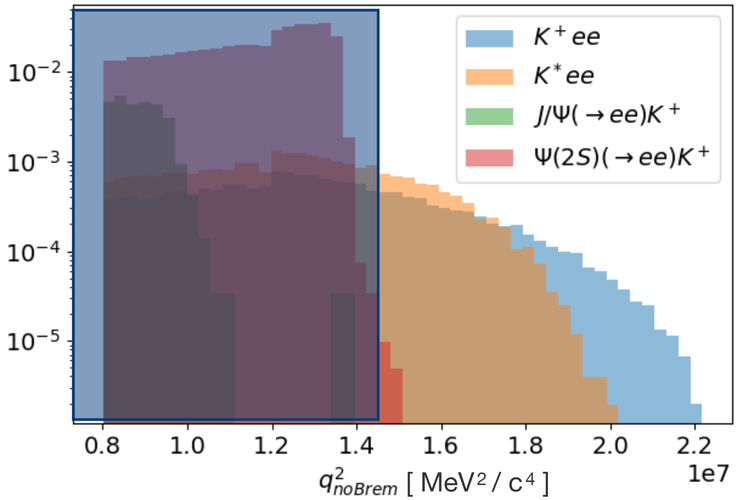
High q^2 solution

Since resonances are smeared due to the wrong Bremsstrahlung recovery:





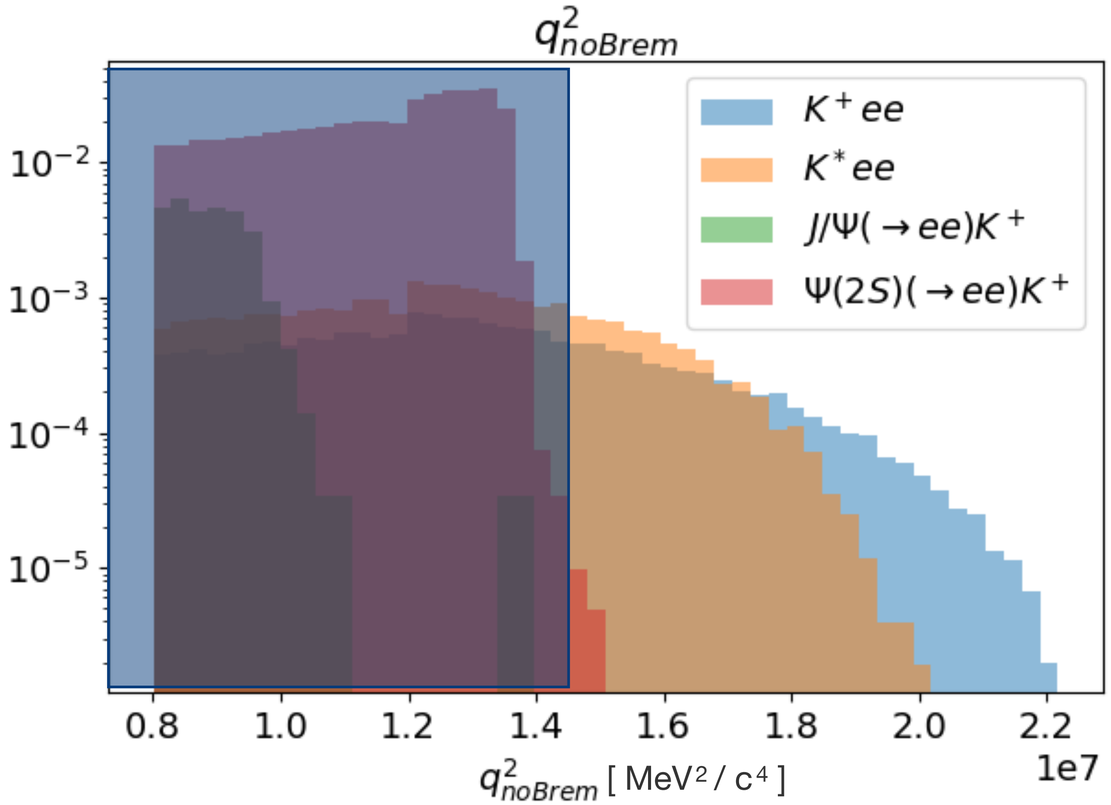
- $q^2_{no\ Brem.}$ is used in order to get rid of the resonance(s)

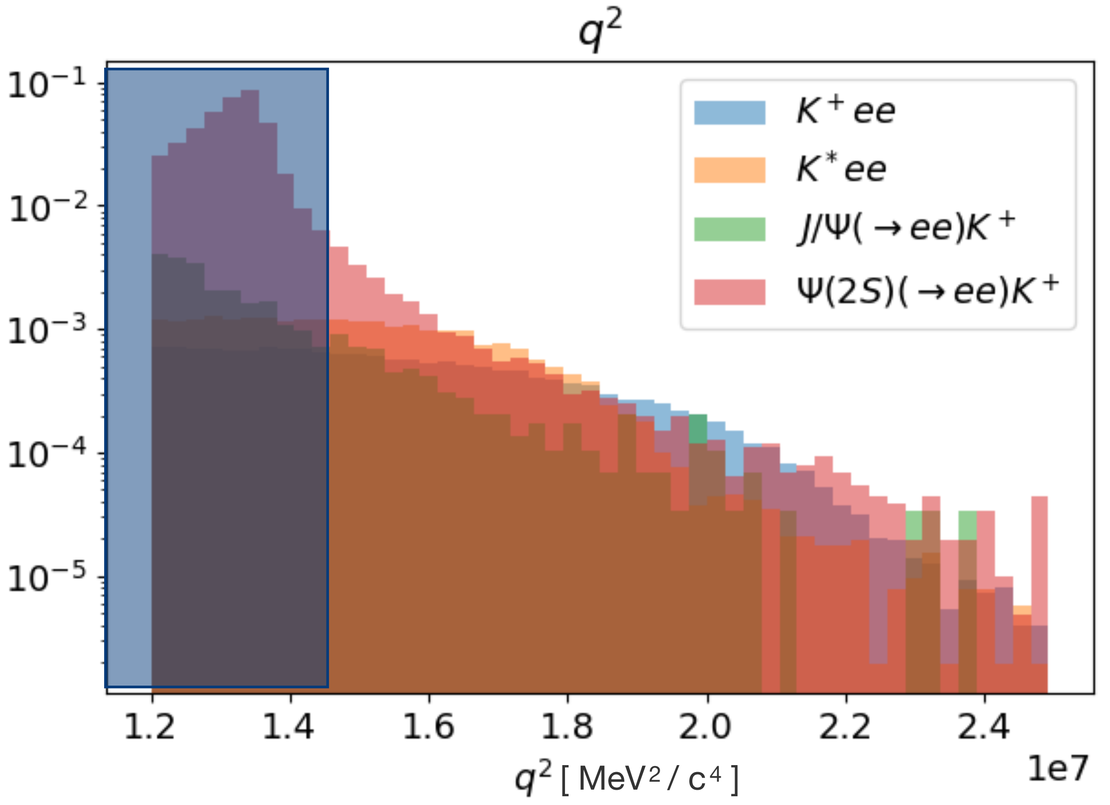


High q^2 solution

$q^2_{no\ Brem.}$ cut based signal selection:

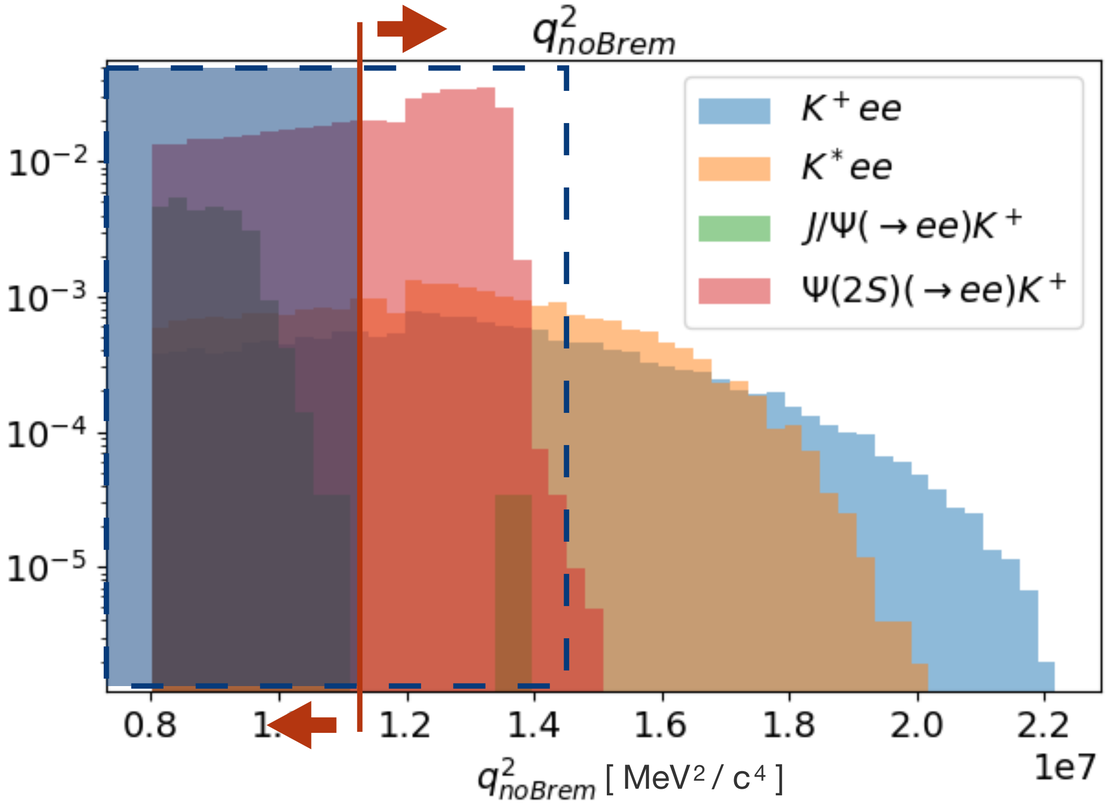
- Loose **~ 50%** of signal compared to q^2 cut.





q^2 BDT

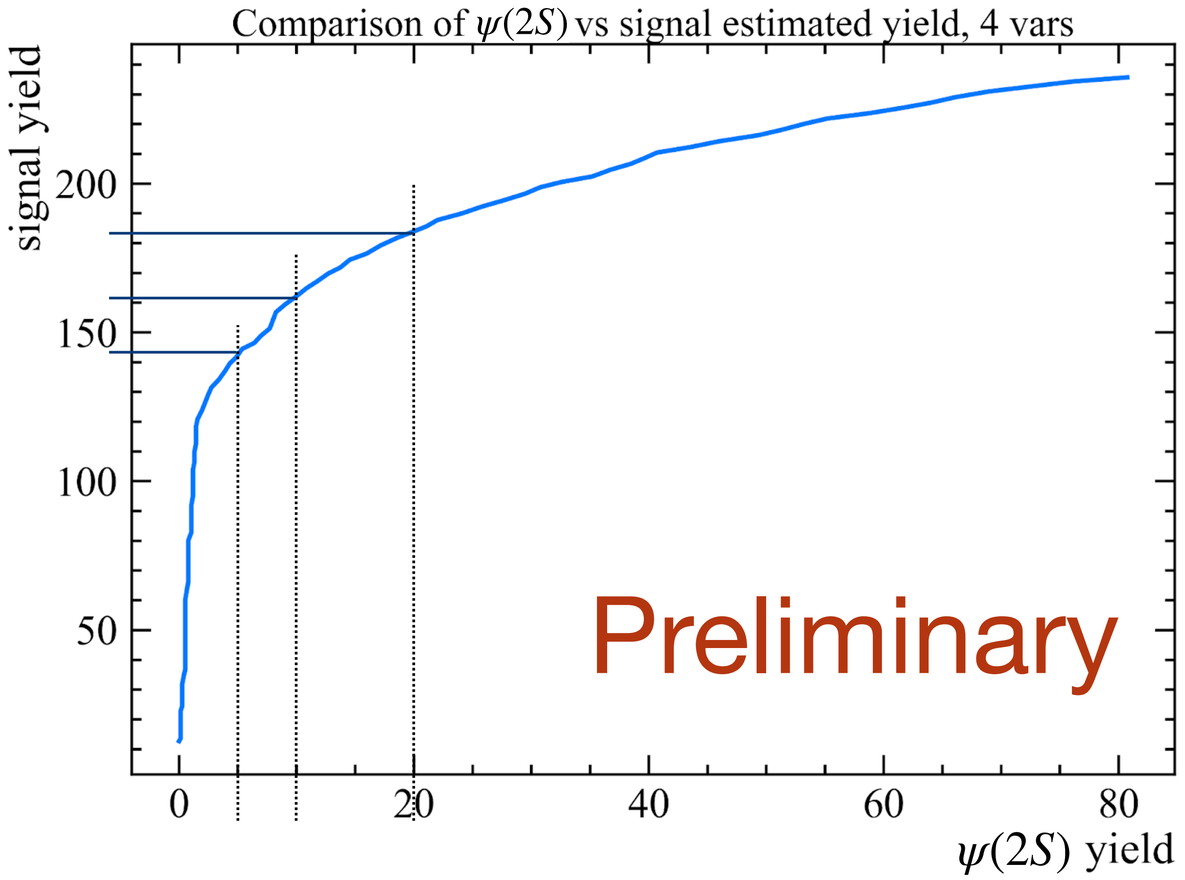
Purpose: Recover signal (discriminate against $\psi(2S)$)



q^2 BDT

Purpose: Recover signal (discriminate against $\psi(2S)$)

- Signal sample ($B \to Kee$):
  - $q^2_{no\ Brem.} < 14\ \mathrm{GeV}^2$
  - $q^2_{true} > 14\ \mathrm{GeV}^2$
  - $q^2 > 10\ \mathrm{GeV}^2$
- Background sample:
  - $B \to \psi(2S)(\to ee)K$
- Variables:
  - q^2 , $q^2_{no\ Brem.}$
  - Lepton momenta
  - Investigating addition of other variables



Electron Sensitivity studies

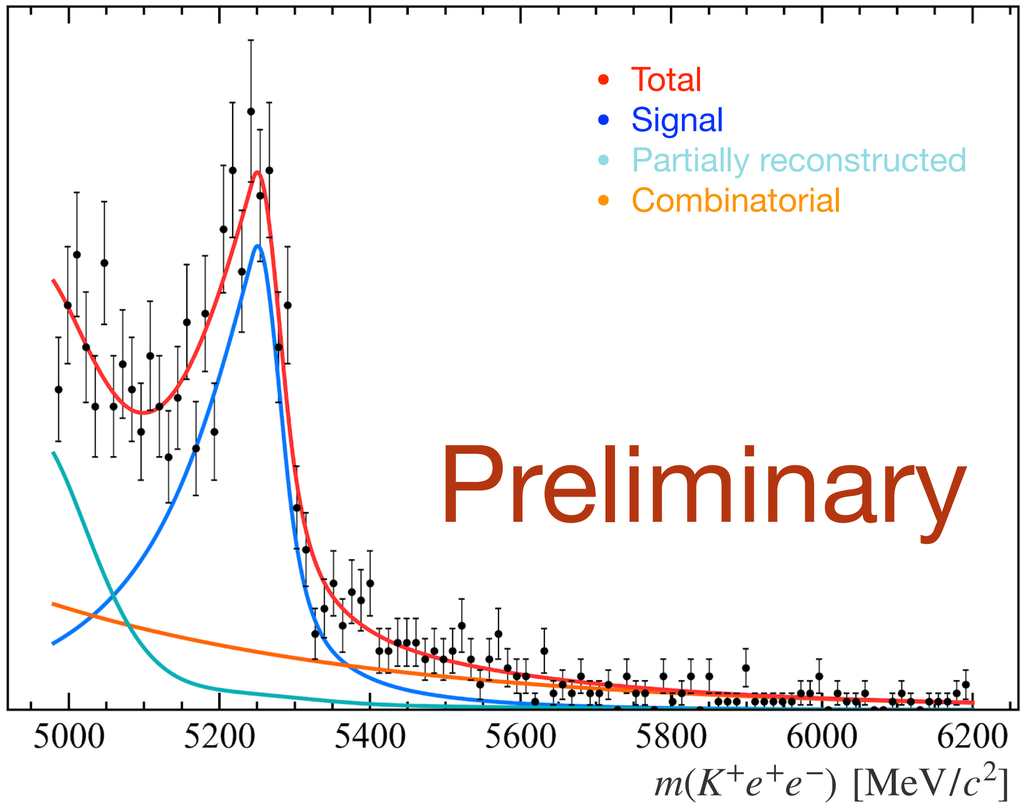
Status: Starting to put different components together

Expect around 800 signal (~ ½ of Central q^2)

- Signal: sum of 3 DCBs
  - Signal shape parameters fixed from simulation
  - Brem. fractions are gaussian constrained to the fraction observed in MC
  - Mean shift and scales are fixed from simulation
- Part. Reco.: KDE
- Comb.: Exponential (shape to be studied)

Total model obtained by summing the PDFs with the relative fraction obtained from simulation

Fit to toy model. Run1 + Run2 stats (9 fb^{-1}).



- Full selection and $q^2_{no\ Brem.} > 14\ \text{GeV}^2$
- Hlt and L0 eTOS
- PID cut corrected with weights (DLLe > 4)
- Combinatorial BDT cut and fit range

Summary

First **evidence of LFU violation** in $B^+ \to K^+ l^+ l^-$ decays has been **seen** by LHCb with 3.1σ deviation from Standard Model. To further investigate the problem **more studies** are **required**.

- Measurement of the **LFU ratio** R_K in **'high** q^2**'** region:
  - **first** LHCb measurement;
  - using the **full** available dataset (9 fb^{-1});
  - statistically **independent** result;
  - **high** yield;
  - **complementary** phase space;

Work in progress. Stay tuned for further updates :)

Thanks for your attention