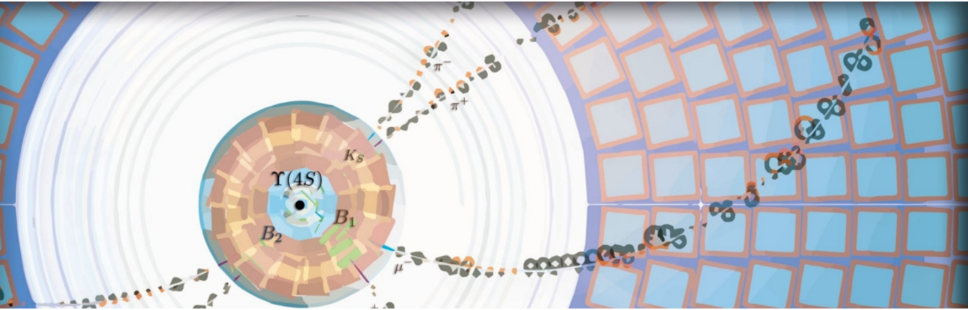
ANGULAR ANALYSIS OF THE DECAY $B \to K^* l^+ l^-$ AT THE BELLE EXPERIMENT.

Implementing the fit

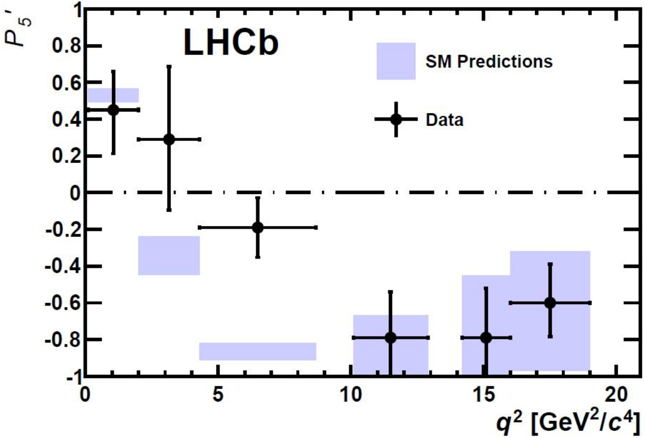


Leonard Koch
DESY summer student programme
Hamburg, 10.09.2014

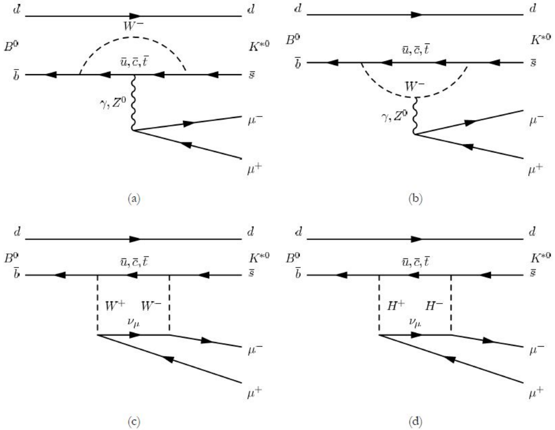
Motivation

LHCb (November 2013):
Phys. Rev. Lett. 111, 191801

3.7 σ deviation from Standard Model prediction



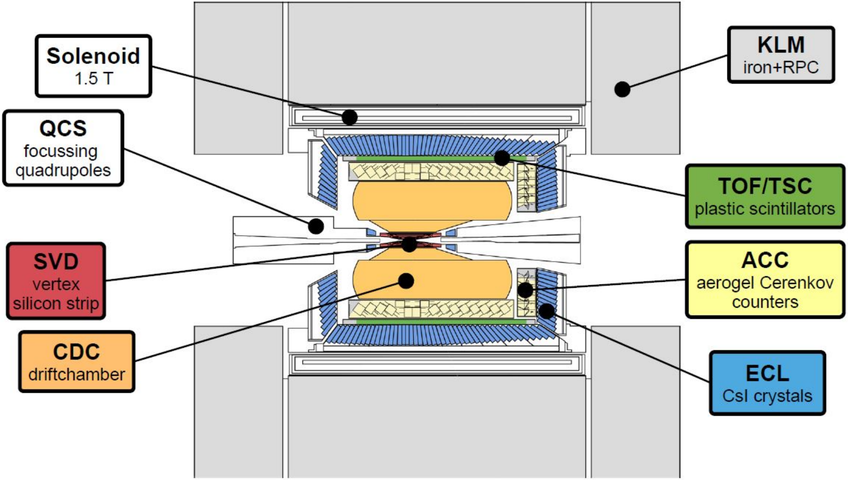
Flavour Changing Neutral Current (FCNC):
Sensitive to new physics



- $\mathcal{B}(B \to K^* l^+ l^-) \sim 10^{-6}$

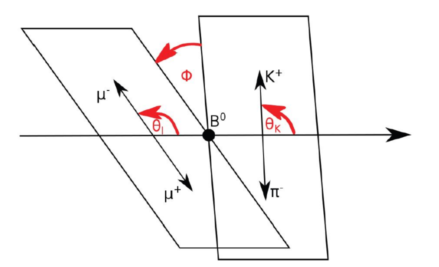
The Belle detector

- $e^+e^- \to \Upsilon(4S) \to B\overline{B}$ at $\sqrt{s} = 10.58\,\mathrm{GeV}$
- $\sim 800,000,000$ $B\overline{B}$ pairs $\to$ $\sim$ 300 signal events expected



Kinematic variables

- q^2 invariant mass squared of dilepton system
- θ_K angle between K and the opposite direction of B in K^* rest frame
- θ_l angle between B and l^- in dilepton rest frame
- ϕ angle between the K^* and dilepton decay planes in B rest frame



The probability density function (pdf)

Differential decay rate

$$
\begin{aligned}
\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_K\mathrm{d}\cos\theta_l\mathrm{d}\phi} = & \frac{9}{32\pi}[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K \\
& + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_l - F_L\cos^2\theta_K\cos 2\theta_l \\
& + S_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi \\
& + S_4\sin 2\theta_K\sin 2\theta_l\cos\phi \\
& + S_5\sin 2\theta_K\sin 2\theta_l\cos\phi \\
& + S_6\sin^2\theta_K\cos\theta_l \\
& + S_7\sin 2\theta_K\sin\theta_l\sin\phi \\
& + S_8\sin 2\theta_K\sin 2\theta_l\sin\phi \\
& + S_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi]
\end{aligned}
$$

The probability density function (pdf)

Differential decay rate

$$\frac{1}{d\Gamma/dq^2}\frac{d\Gamma}{dq^2 d\cos\theta_K d\cos\theta_l d\phi} = \frac{9}{32\pi}[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K$$
$$+\frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_l - F_L\cos^2\theta_K\cos 2\theta_l$$
$$+S_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi$$
$$+S_4\sin 2\theta_K\sin 2\theta_l\cos\phi$$
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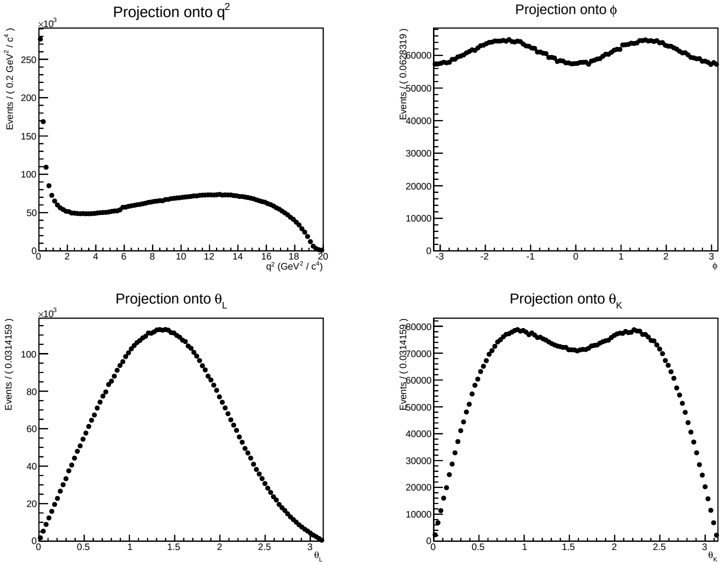
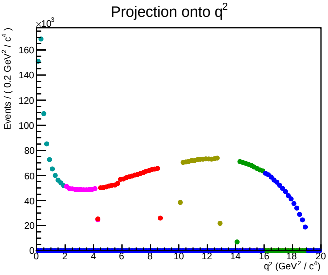
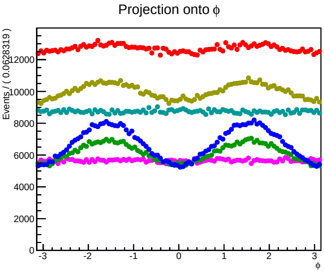
$$+S_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi]$$

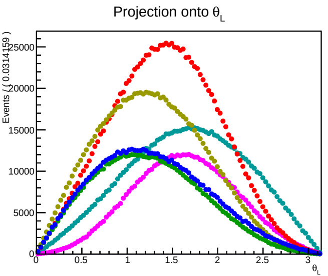
Monte Carlo data at generator level - q^2 binning

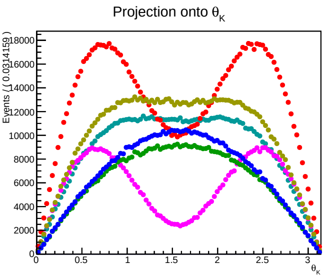


Monte Carlo data at generator level - q^2 binning









The probability density function (pdf)

Differential decay rate

$$
\begin{aligned}
\frac{1}{d\Gamma/dq^2}\frac{d\Gamma}{dq^2 d\cos\theta_K d\cos\theta_l d\phi} = \frac{9}{32\pi}\Big[& \frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K \\
& + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_l - F_L\cos^2\theta_K\cos 2\theta_l \\
& + S_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi \\
& + S_4\sin 2\theta_K\sin 2\theta_l\cos\phi \\
& + S_5\sin 2\theta_K\sin 2\theta_l\cos\phi \\
& + S_6\sin^2\theta_K\cos\theta_l \\
& + S_7\sin 2\theta_K\sin\theta_l\sin\phi \\
& + S_8\sin 2\theta_K\sin 2\theta_l\sin\phi \\
& + S_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi\Big]
\end{aligned}
$$

$$
P'_{4,5,6,8} = \frac{S_{4,5,7,8}}{\sqrt{F_L(1-F_L)}}
$$

Reducing the number of parameters

$$P'_4 \,/\, S_4 \;:\; \begin{cases} \phi \rightarrow -\phi & \text{for } \phi < 0 \\ \phi \rightarrow \pi - \phi & \text{for } \theta_l > \pi/2 \\ \theta_l \rightarrow \pi - \theta_l & \text{for } \theta_l > \pi/2, \end{cases}$$

$$P'_5 \,/\, S_5 \;:\; \begin{cases} \phi \rightarrow -\phi & \text{for } \phi < 0 \\ \theta_l \rightarrow \pi - \theta_l & \text{for } \theta_l > \pi/2, \end{cases}$$

$$P'_6 \,/\, S_7 \;:\; \begin{cases} \phi \rightarrow \pi - \phi & \text{for } \phi > \pi/2 \\ \phi \rightarrow -\pi - \phi & \text{for } \phi < -\pi/2 \\ \theta_l \rightarrow \pi - \theta_l & \text{for } \theta_l > \pi/2, \end{cases}$$

$$P'_8 \,/\, S_8 \;:\; \begin{cases} \phi \rightarrow \pi - \phi & \text{for } \phi > \pi/2 \\ \phi \rightarrow -\pi - \phi & \text{for } \phi < -\pi/2 \\ \theta_K \rightarrow \pi - \theta_K & \text{for } \theta_l > \pi/2 \\ \theta_l \rightarrow \pi - \theta_l & \text{for } \theta_l > \pi/2. \end{cases}$$

Transformation of angles

- Four different datasets
- Four different pdf's:
  - Each containing F_L, S_3 and one of $P'_{4,5,6,8}$
  - 8 $\rightarrow$ 3 parameters per fit $\rightarrow$ stability

Unbinned maximum likelihood fit:

Fitting techniques

Four different methods:

- $\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_K\mathrm{d}\cos\theta_l\mathrm{d}\phi}$
- $\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2\mathrm{d}\theta_K\mathrm{d}\theta_l\mathrm{d}\phi}$

- Fitting the four pdf's to the four datasets independently
- Fitting the four pdf's to the four datasets simultaniously

Monte Carlo Toy study

Which is the best fit? How sensitive?

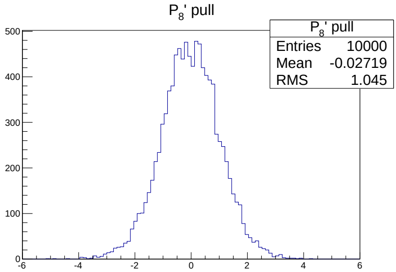
We expect 300 events distributed over the six q^2 bins: [59, 37, 77, 59, 34, 34].

1. Generate expected number of events according to the 'original' pdf with SM predicted parameters
2. Transform the angles
3. Perform the fit

> Repeat this procedure 10 000 times for each bin

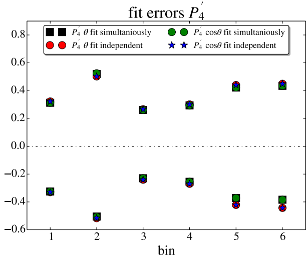
> Look into the error und pull distributions

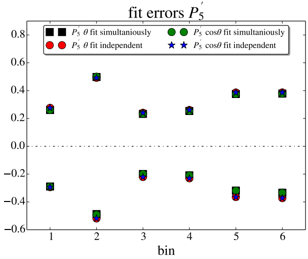
$$pull_{value} = \frac{value_{fitted} - value_{true}}{error_{value}}$$

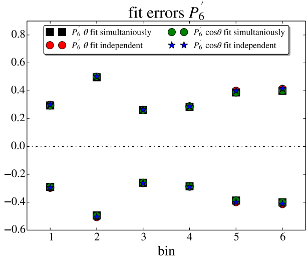


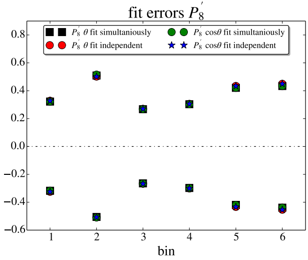
Monte Carlo Toy study

Fit errors



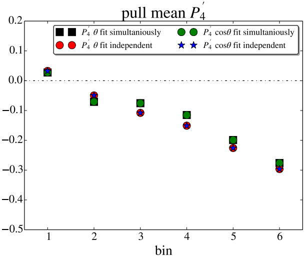


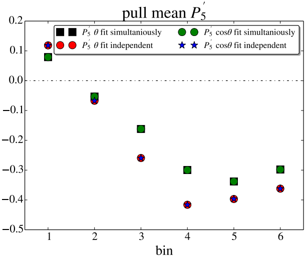


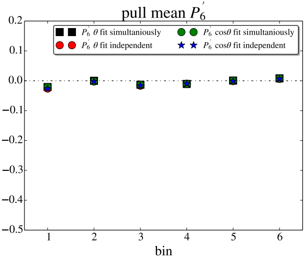


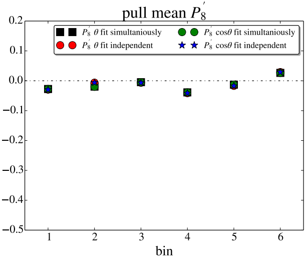
Monte Carlo Toy study

Pull mean



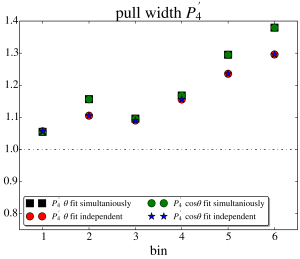


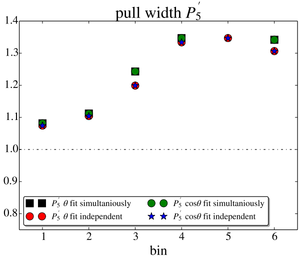


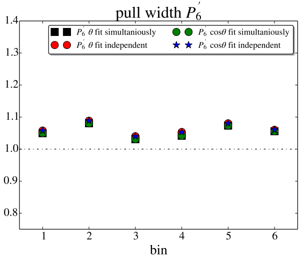


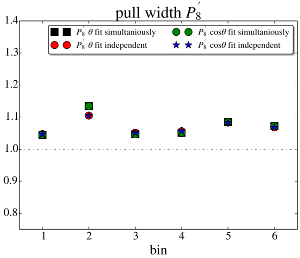
Monte Carlo Toy study

Pull width



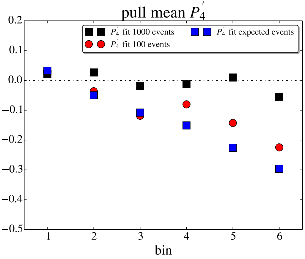


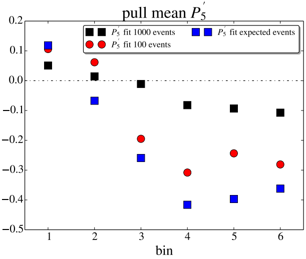


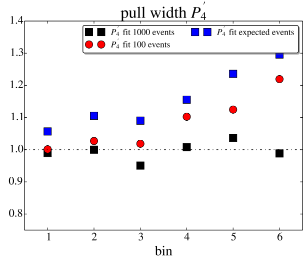


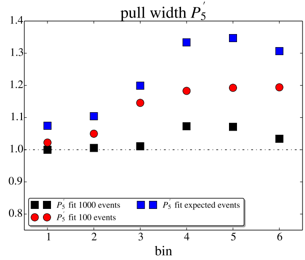
Monte Carlo Toy study

Higher statistics



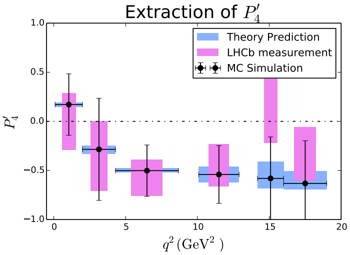


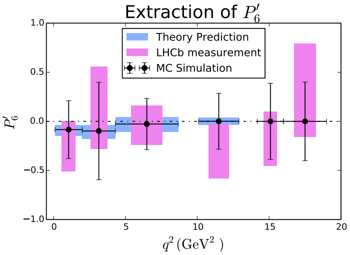


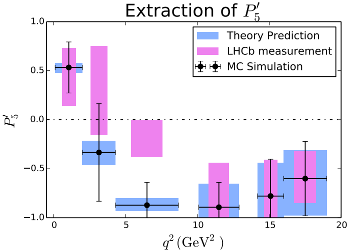


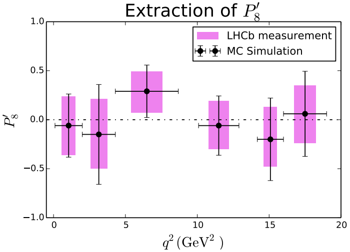
Monte Carlo Toy study

Sensitivity







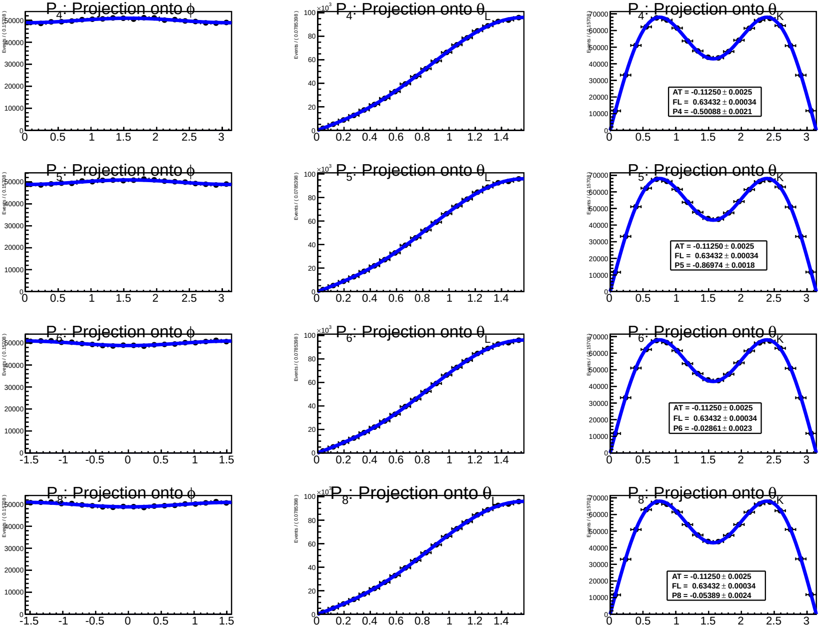


Conclusion and outlook

- Belle ($\sim$ 300) has lower statistics as LHCb ($\sim$ 880) has, but is still sensitive and can perform an independent measurement of $P'_{4,5,6,8}$
- Background and efficiency correction has to be included in the fit
- In the near future LHCb will analyze a larger data sample
  - clarify the nature of the 3.7 σ discrepancy
- Belle II will have $\times$ 50 higher statistics than Belle...

Thanks for your attention!

And special thanks to my supervisors Simon Wehle and Sergey Yashchenko


P4: Projection onto ϕ
P4: Projection onto θL
P4: Projection onto θK
AT = -0.11250 ± 0.0025
FL = 0.63432 ± 0.00034
P4 = -0.50088 ± 0.0021
P5: Projection onto ϕ
P5: Projection onto θL
P5: Projection onto θK
AT = -0.11250 ± 0.0025
FL = 0.63432 ± 0.00034
P5 = -0.86974 ± 0.0018
P6: Projection onto ϕ
P6: Projection onto θL
P6: Projection onto θK
AT = -0.11250 ± 0.0025
FL = 0.63432 ± 0.00034
P6 = -0.02861 ± 0.0023
P8: Projection onto ϕ
P8: Projection onto θL
P8: Projection onto θK
AT = -0.11250 ± 0.0025
FL = 0.63432 ± 0.00034
P8 = -0.05389 ± 0.0024