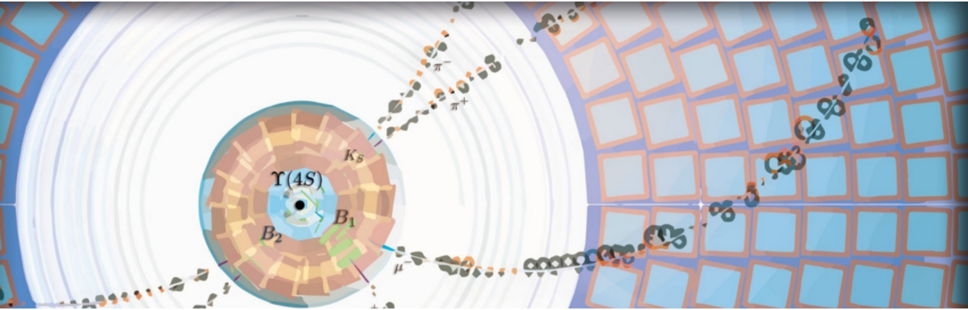
Angular Analysis of $B \to K^{(*)}\ell^+\ell^-$.

At the Belle Experiment



Simon Wehle
Deutsches Elektronen-Synchrotron

LHC Ski 2016,
Obergurgl, 14.04.2016

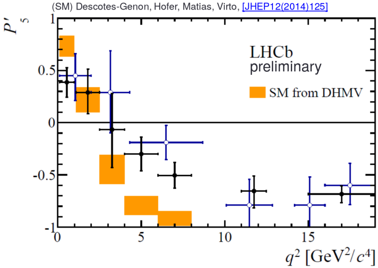
Can we find new physics in the $b \to s\ell\ell$ quark transition?

Flavor Changing Neutral Currents

Can we find new physics in the $b \to s\ell\ell$ quark transition?

$$R_K \equiv \frac{\mathcal{B}(B^+ \to K^+\mu\mu)}{\mathcal{B}(B^+ \to K^+ee)} \text{ by LHCb } \to 2.6\sigma$$

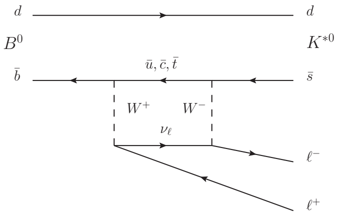
P_5-anomaly by LHCb Measuerements $\to 3.4\sigma$



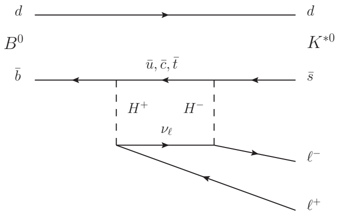
What about the *B*-factories?

The Decay Topology

How does this transition proceed?



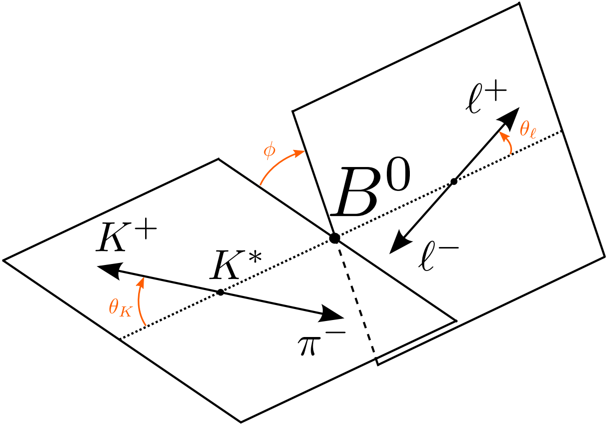
(a) SM example



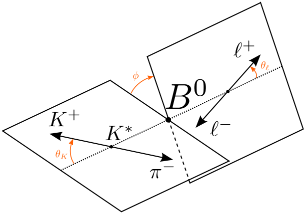
(b) NP example

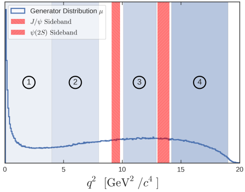
- We analyze $b \to s\ell\ell$ in the decay of $B^0 \to K^*(892)^0 \ell^+ \ell^-$
- The angular distributions might reveal physics beyond the Standard Model
- We reconstruct B mesons in the Belle dataset

The Decay Topology



The decay is completely described by:
θ_ℓ, θ_K, ϕ and $q^2 = M^2_{\ell^+\ell^-}$





The observables are depended on $q^2 = M^2_{\ell^+\ell^-}$

The differential decay rate can be expressed by measurable observables:

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

Experimental Challenges

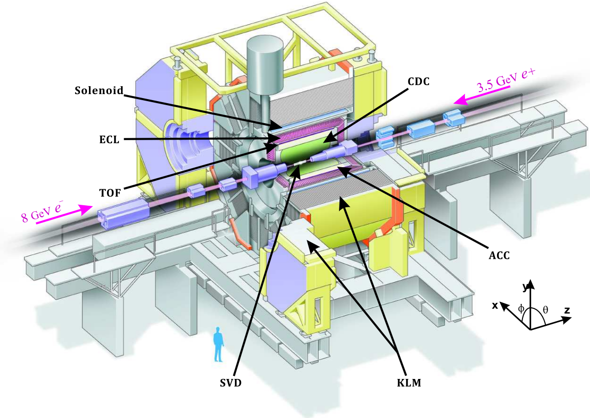
The reconstruction of $B \to K^{(*)}\ell^+\ell^-$ is challenging!

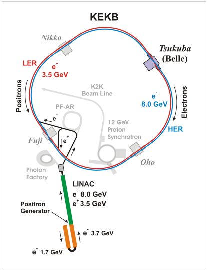
- The branching ratio for $B^0 \to K^*(892)^0\ell^+\ell^-$ is in the order of 10^{-7}
- There is irreducible background from $B \to K^* J/\psi$ and $B \to K^*\psi(2S)$
- We expect $\mathcal{O}(100)$ candidates in the Belle data-sample

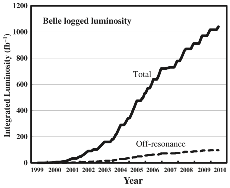
Solution:

- Highly efficient reconstruction algorithms to find as many candidates as possible
- Robust fitting technique – suitable for low statistics
  - $\to$ folding method introduced by LHCb in 2013 (arXiv:1308.1707)

The Belle Experiment







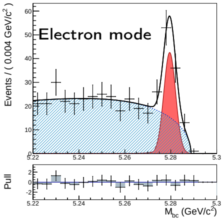
We use 772 million $B\bar{B}$ pairs recorded by the Belle detector

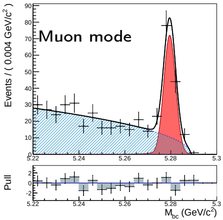
Multivariate approach

- Neural networks for identifying all primary particles and K^*
- K^* is reconstructed in $K^*(892)^0 \to K^+\pi^-$
- Neural networks for signal selection (one for each B decay channel)
- Signal is identified in the beam constrained mass

$$M_{\rm bc} \equiv \sqrt{E_{\rm Beam}^2 - |\vec{p}_B|^2}$$

We find:
117.6 ± 12.4 signal candidates for $B^0 \to K^*(892)^0\mu^+\mu^-$
69.4 ± 12.0 for $B^0 \to K^*(892)^0 e^+ e^-$





Reconstruction of $B^0 \to K^{*0}\ell^+\ell^-$

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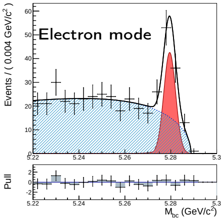

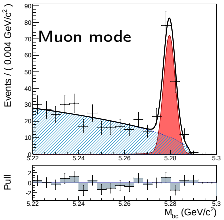

Reconstruction of $B^0 \to K^{*0}\ell^+\ell^-$

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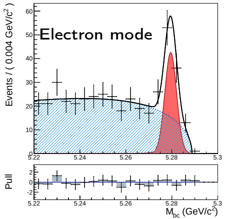
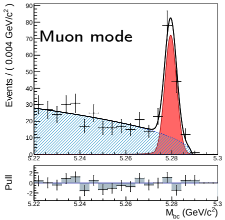
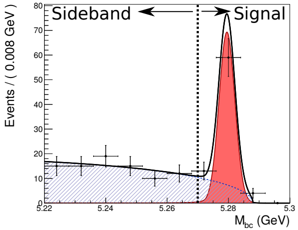




Fit Procedure



We extract in each fit:

- The longitudinal polarization of the K^*, F_L
- The observables

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

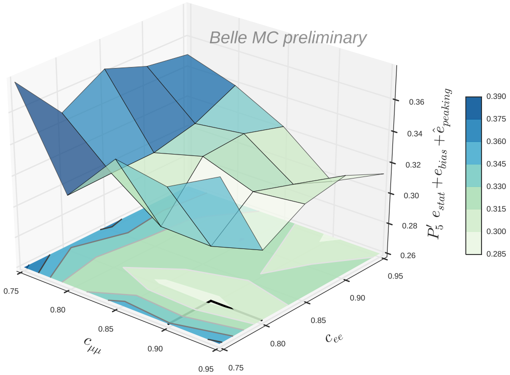
considered to be largely free from form-factor uncertainties (J. High Energy Phys. 05 (2013) 137).

- The transverse polarization asymmetry $A_T^{(2)}$

- The fit is performed in bins of q^2 in θ_L, θ_K and ϕ, each treated as an independent measurement
- We fit $M_{\rm bc}$ to determine the signal to background fraction
- We fit the shape of the background in the $M_{\rm bc}$ sideband with smoothed histograms

Optimization and Systematic uncertainties

- We perform toy studies with simulated events to evaluate and optimize all methods



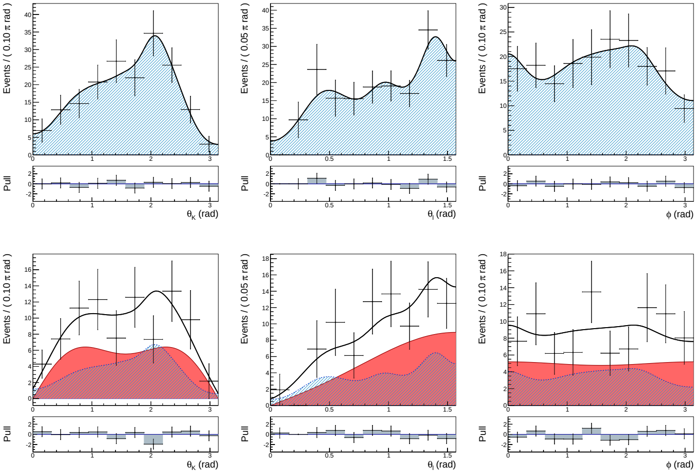
Systematic Uncertainties

- Fit bias (dominant systematic error)
- Data/MC discrepancy
- Acceptance correction
- Peaking Background
- K^* S-Wave contribution (negligible)
- $\mathcal{CP}$ Asymmetries (negligible)
- Cross-Feed (negligible)

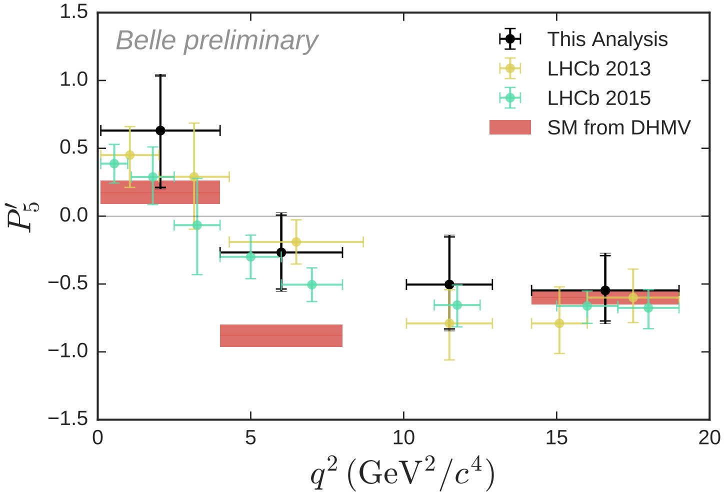
Neural network selection optimization.

Example Fit-Projections for P_5' in Bin 2

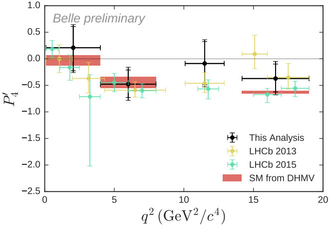
Background region (top) - Signal region (bottom)

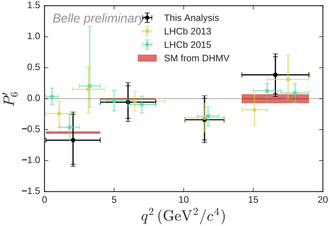


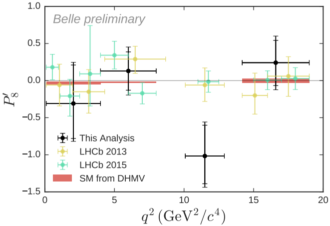
Result for the angular observable P'_5



Result for the angular observable $P'_{4,6,8}$







Perspective

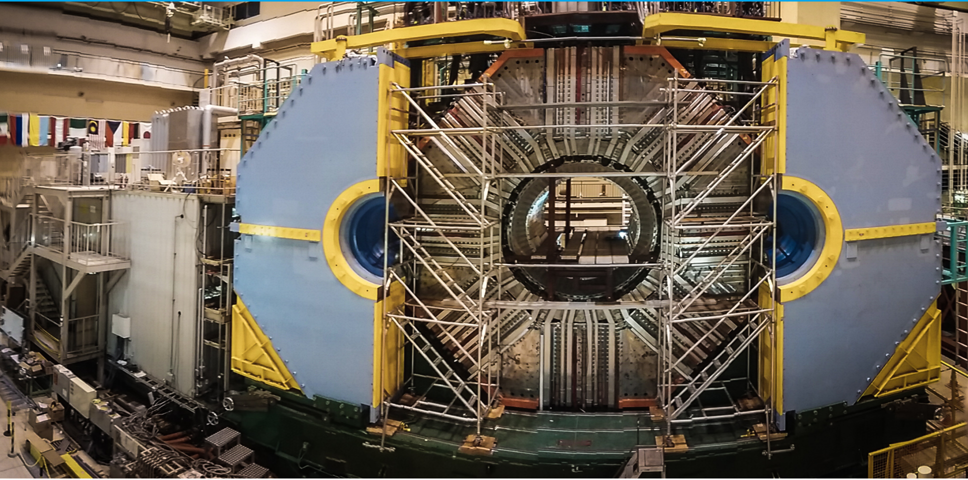
First Look

- The measurements are compatible with the SM predictions and LHCb measurements
- One measurement is found to deviate by 2.1σ from the predicted value into the same direction and in the same q^2 region where the LHCb collaboration reported the so-called P_5' anomaly

Outlook

- Results for the P' observables on arXiv: (Belle Conference Paper tomorrow on hep-ex).
- We will also look into A_{FB}, charged modes $B^+ \to K^{*+}\ell^+\ell^-$, R_K and $B^+ \to K^+\tau^+\tau^-$

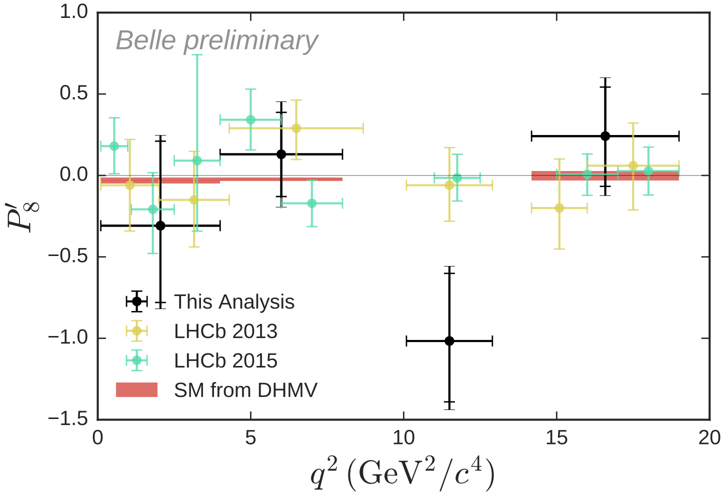
Thank you for your Attention!



Thank you!

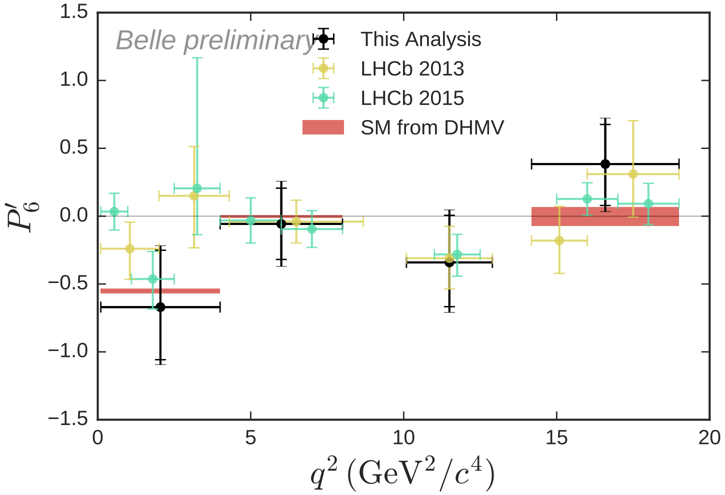
Appendix

Result P'_8



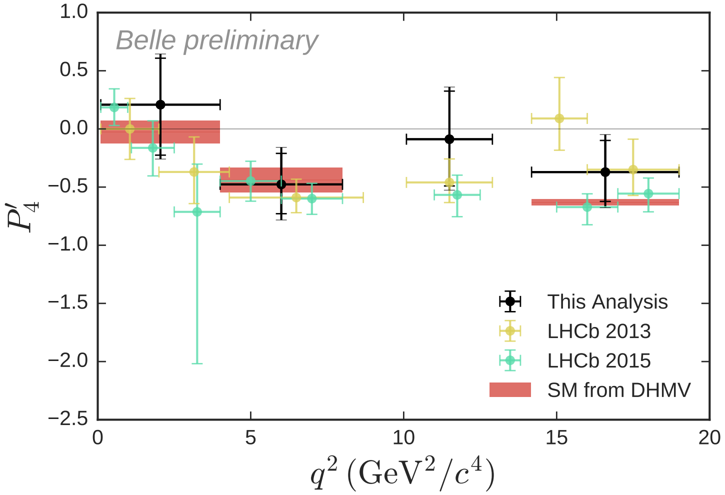
Belle preliminary
This Analysis
LHCb 2013
LHCb 2015
SM from DHMV
P'_8
$q^2\ (\mathrm{GeV}^2/c^4)$
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
5
10
15
20

Result P_6'



Belle preliminary
This Analysis
LHCb 2013
LHCb 2015
SM from DHMV
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
P_6'
0
5
10
15
20
$q^2\ (\mathrm{GeV}^2/c^4)$

Result P'_4

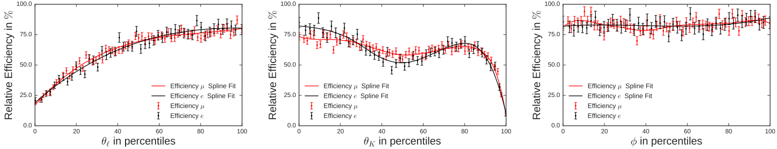


Belle preliminary
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
P'_4
0
5
10
15
20
$q^2\ (\mathrm{GeV}^2/c^4)$
This Analysis
LHCb 2013
LHCb 2015
SM from DHMV

Efficiency/Acceptance

- The reconstruction efficiency is not distributed equally across the angular variables
- We determine the efficiency on MC
- We assume that the reconstruction effieicny is uncorrelated in the 3D angular space

$$f_{eff}^{bin}(\cos\theta_\ell, \cos\theta_K, \phi, q^2) = f_{eff}^{fit}(\cos\theta_\ell) \otimes f_{eff}^{fit}(\cos\theta_K) \otimes f_{eff}^{fit}(\phi) \otimes f_{eff}^{fit}(q^2),$$



Systematics - Summary for optimized cut

Table : Summary of all considered systematic uncertainties for P_5'.

Bin	0	1	2	3	4
Peaking Background	0.0901	0.0636	0.0078	0.0498	0.0131
Data/MC Difference	0.0112	0.0067	0.0208	0.0142	0.0029
Efficiency Correction	0.0397	0.0205	0.0098	0.0215	0.0327
Fit Bias	0.0031	0.0061	0.0430	0.0127	0.0460
Total	0.0992	0.0675	0.0494	0.0575	0.0580

Full Angular Decay Rate

The full angular decay rate for $B^0 \to K^* \ell^+ \ell^-$ with 8 free parameters can be written as:

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

using definitions of J. High Energy Phys. 01 (2009) 019.

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Folding Procedure introduced by LHCb

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

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

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

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

- With a folding of the angles we reduce the dimension of free parameters
- We perform four measurements which are independently sensitive to three observable S_j, F_L and S_3
- The observables

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

are considered to be largely free from form-factor uncertainties (J. High Energy Phys. 05 (2013) 137).