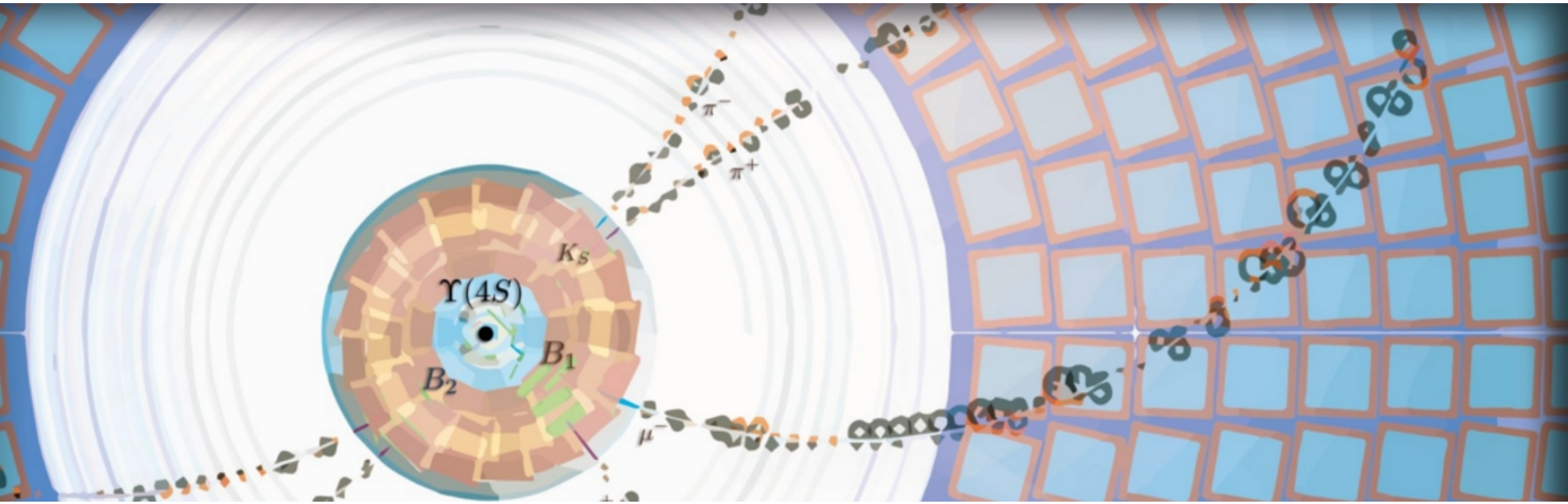
Angular Analysis $B \to K^{(*)}\ell^+\ell^-$.

Overview of the Analysis



Simon Wehle Sergey Yashchenko
Deutsches Elektronen-Synchrotron
9th Annual Helmholtz Alliance Workshop,
November 17, 2015

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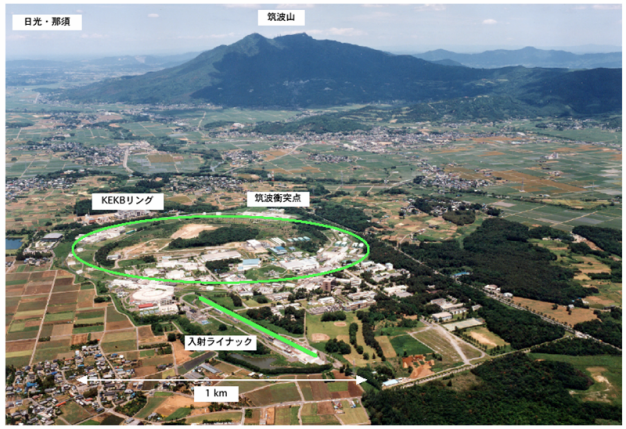
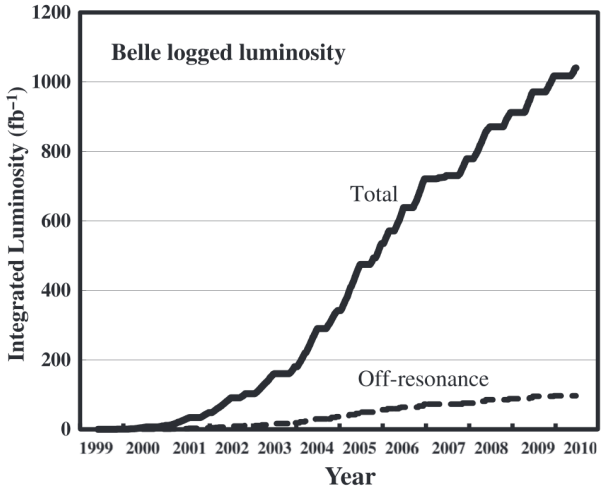
The Belle Experiment

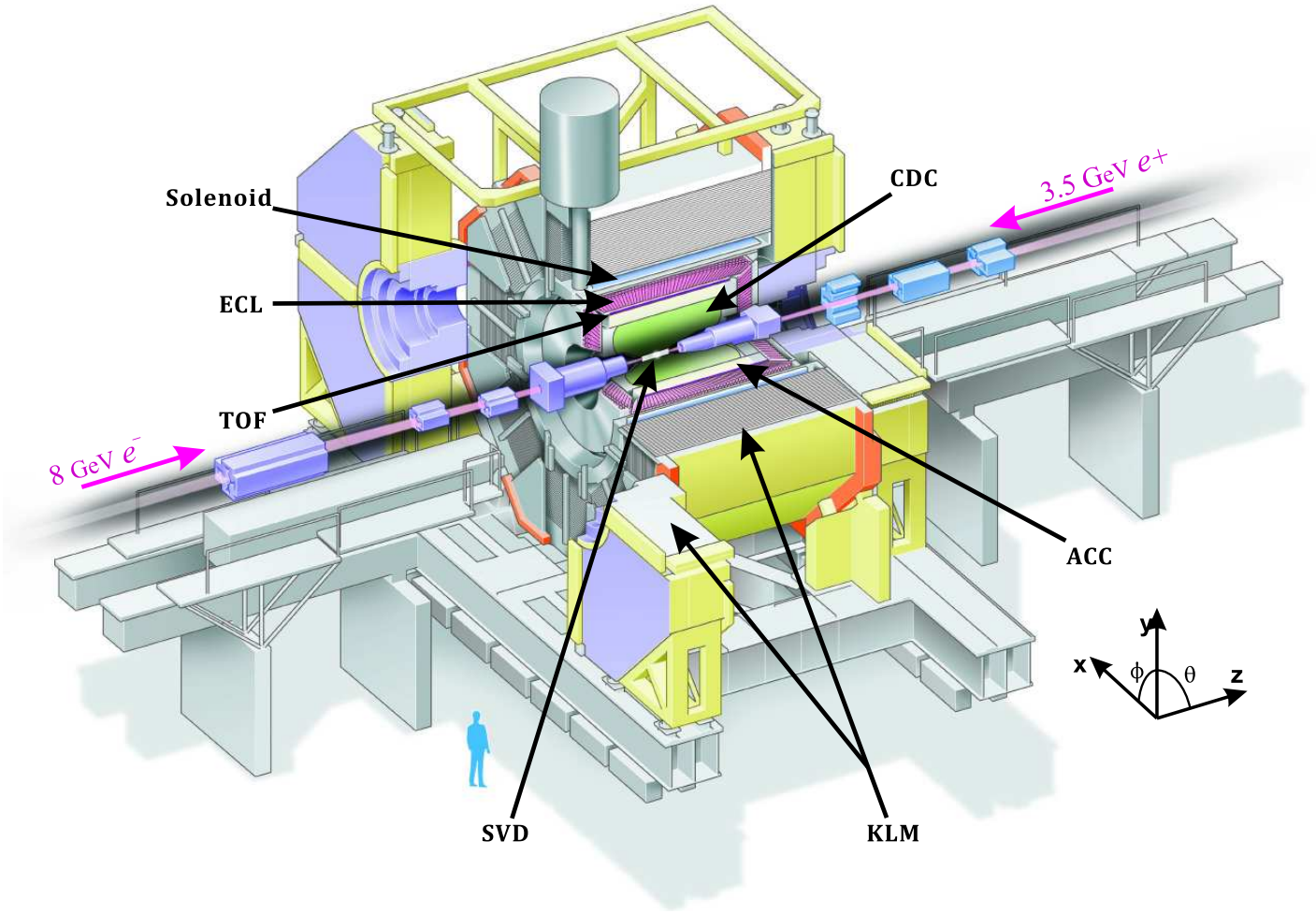




- The Belle Experiment is located at the KEKB accelerator in Tsukuba, Japan
- It is designed as a "B factory"
- 771 million $B\bar{B}$ meson pairs
- World record for integrated luminosity

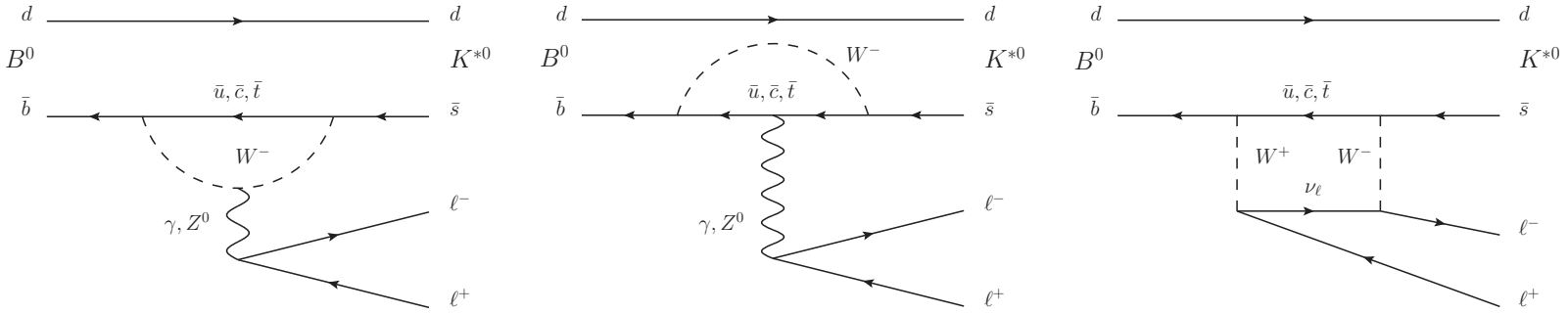
$$\int L dt = 1 \text{ ab}^{-1}$$

The Belle Detector



Motivation for $B \to K^{(*)}\ell^+\ell^-$

- Flavor Changing Neutral Currents are sensitive to new physics
- The interesting process in $B \to K^{(*)}\ell^+\ell^-$ contains the quark transition $b \to s\ell^+\ell^-$



- Small decay amplitudes $\mathcal{BR}(B \to K^*\ell\ell) \sim 10^{-6}$

$B \to K^* \ell\ell$ - Goals of the Analysis / Status

Goals of the analysis

- Full angular analysis, measurement of P'_i observables
  - The observables $P'_{4,5,6,8}$ can be extracted from the angular decay rate of $B^0 \to K^{0*}\ell^+\ell^-$
  - In 2013 the LHCb collaboration announced a local discrepancy of 3.7σ from Standard Model prediction in one of 24 measurements (Phys. Rev. Lett. 111, 191801)

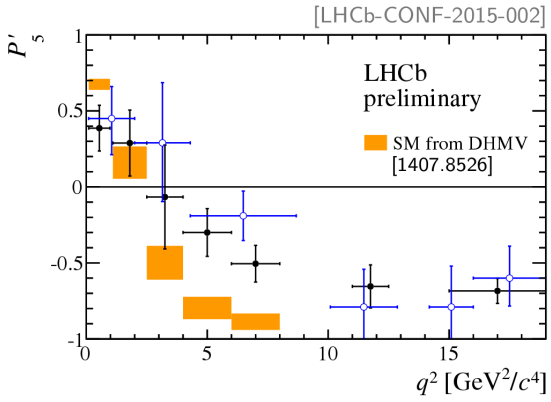


Figure : Result of LHCb for P'_5 (2015).

Current Status at Belle

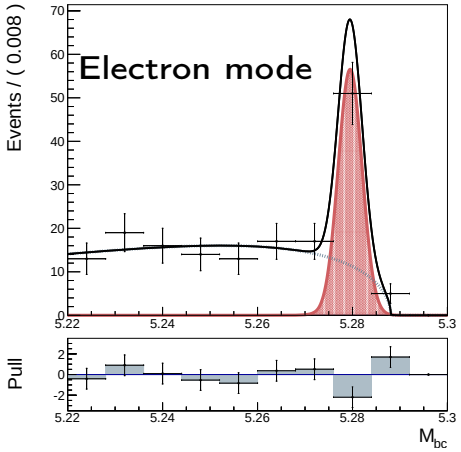
- We have determined our sensitivity in toy studies
- We can use a combination of the electron and muon channels
- The analysis waits for opening the box

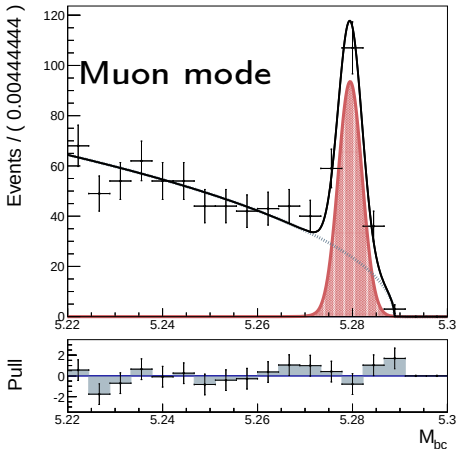
Reconstruction of $B^0 \to K^{*0}\ell^+\ell^-$

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

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





Full Angular Analysis

- This measurement uses the decay channels $B^0 \to K^*(892)^0(\to K^+\pi^-)\ell^+\ell^-$
- Difficult to measure with low statistics of ~ 150 events

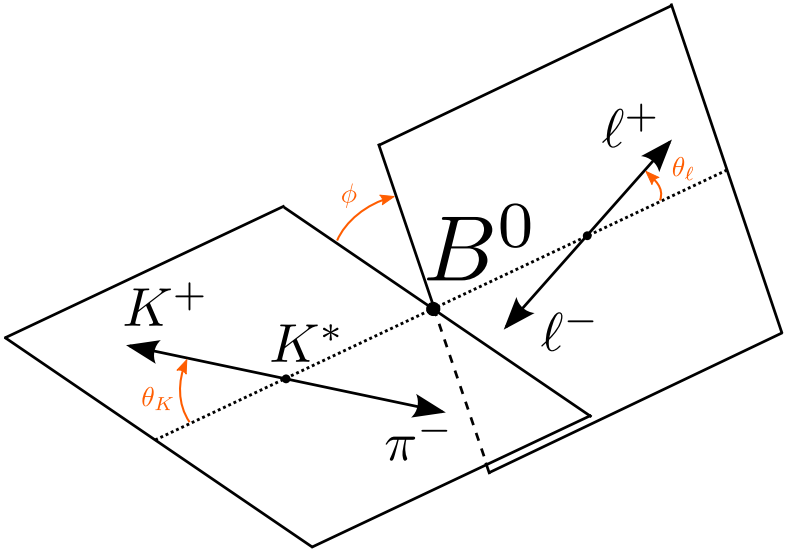


Figure : Definition of the angles in the decay $B^0 \to K^*\ell^+\ell^-$.

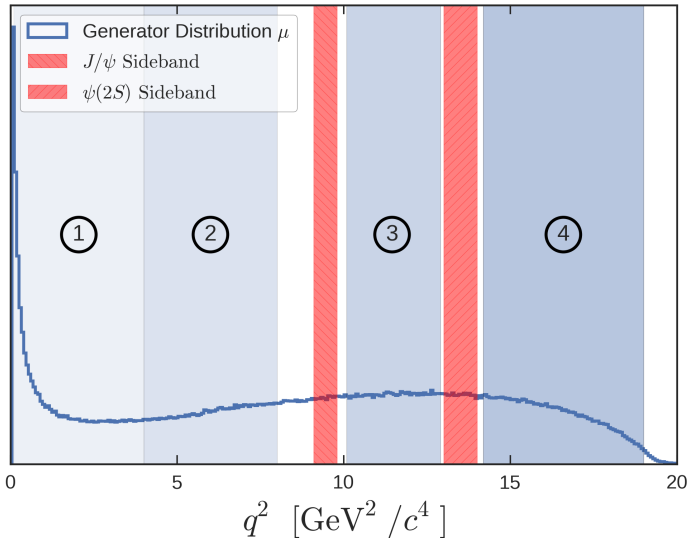


Figure : Binning in $q^2 \equiv M^2_{\ell^+\ell^-}$.

Full Angular Decay Rate

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

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

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

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

Full Angular Decay Rate

$$P_4', S_4 : \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \phi \to \pi - \phi & \text{for } \theta_L > \pi/2 \\ \theta_L \to \pi - \theta_L & \text{for } \theta_L > \pi/2, \end{cases}$$

$$P_5', S_5 : \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \theta_L \to \pi - \theta_L & \text{for } \theta_L > \pi/2, \end{cases}$$

$$P_6', S_7 : \begin{cases} \phi \to \pi - \phi & \text{for } \phi > \pi/2 \\ \phi \to -\pi - \phi & \text{for } \phi < -\pi/2 \\ \theta_L \to \pi - \theta_L & \text{for } \theta_L > \pi/2, \end{cases}$$

$$P_8', S_8 : \begin{cases} \phi \to \pi - \phi & \text{for } \phi > \pi/2 \\ \phi \to -\pi - \phi & \text{for } \phi < -\pi/2 \\ \theta_K \to \pi - \theta_K & \text{for } \theta_L > \pi/2 \\ \theta_L \to \pi - \theta_L & \text{for } \theta_L > \pi/2. \end{cases}$$

- 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).

Fit Procedure

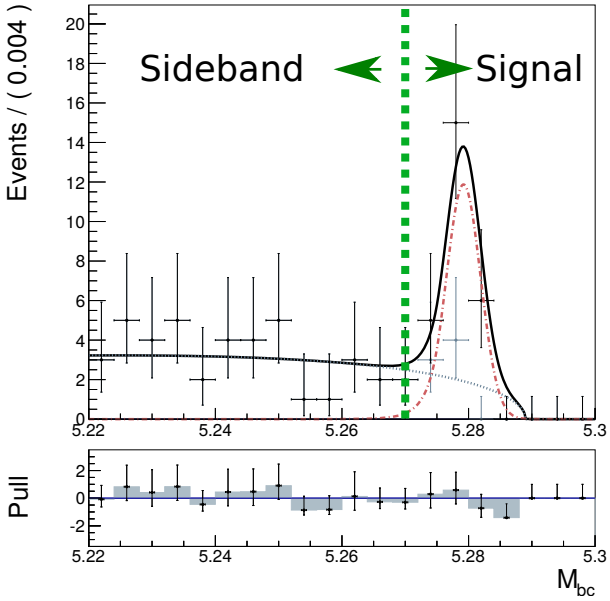


Table : Events in q^2 bins, MC predictions for n ($n^{\mu^+\mu^-} + n^{e^+e^-}$).

bin	q^2 bin range $[\mathrm{GeV}^2/c^4]$	$n_{\mathrm{sig}}/\mathrm{bin}$	$n_{\mathrm{bkg}}/\mathrm{bin}$
0	1.00 – 6.00	37 (24+13)	24 (18+6)
1	0.10 – 4.00	33 (21+12)	18 (11+2)
2	4.00 – 8.00	36 (24+12)	33 (20+13)
3	10.09 – 12.90	29 (23+6)	18 (16+2)
4	14.18 – 19.00	34 (26+8)	14 (12+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_{bc} to determine the signal to background fraction
- We fit the shape of the background in the M_{bc} sideband with smoothed histograms

Fit Example

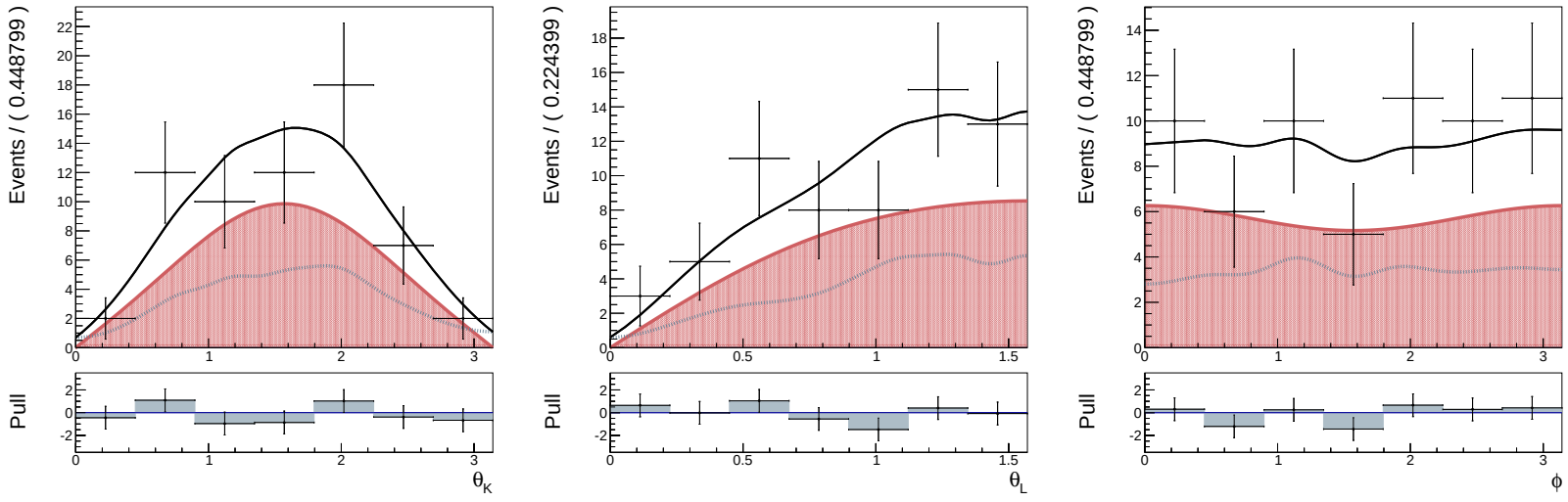


Figure : Fit example of the extraction of P_5' (q^2 bin 3) with components: signal, background and total pdf in solid-red, dashed blue and solid black line.

We estimate the efficiency in the angular variables with a spline fit on MC and weight the events by the inverse:

$$f_{eff}^{bin}(\cos\theta_L, \cos\theta_K, \phi, q^2) = f_{eff}^{\theta_L}(\cos\theta_L) \otimes f_{eff}^{\theta_K}(\cos\theta_K) \otimes f_{eff}^{\phi}(\phi) \otimes f_{eff}^{q^2}(q^2).$$

Toy Study - Results for P_5'

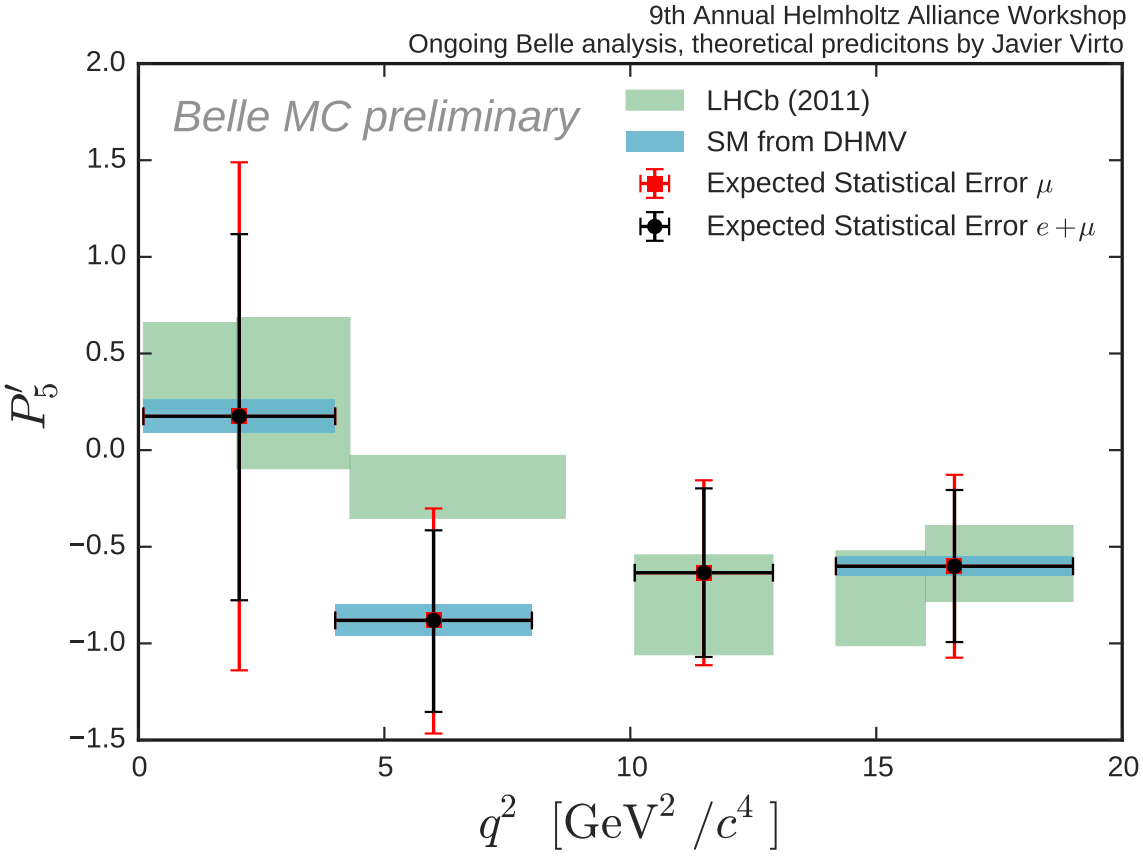


Figure : Result of the MC toy studies with the expected signal and background yields, each data point represents the averaged result of 10000 fits.

Sources for Systematic Uncertainties

For the angular analysis we consider sources of systematic uncertainty if they introduce an angular or q^2 dependent bias to the distribution of signal or background candidates.

We consider

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

Perspective

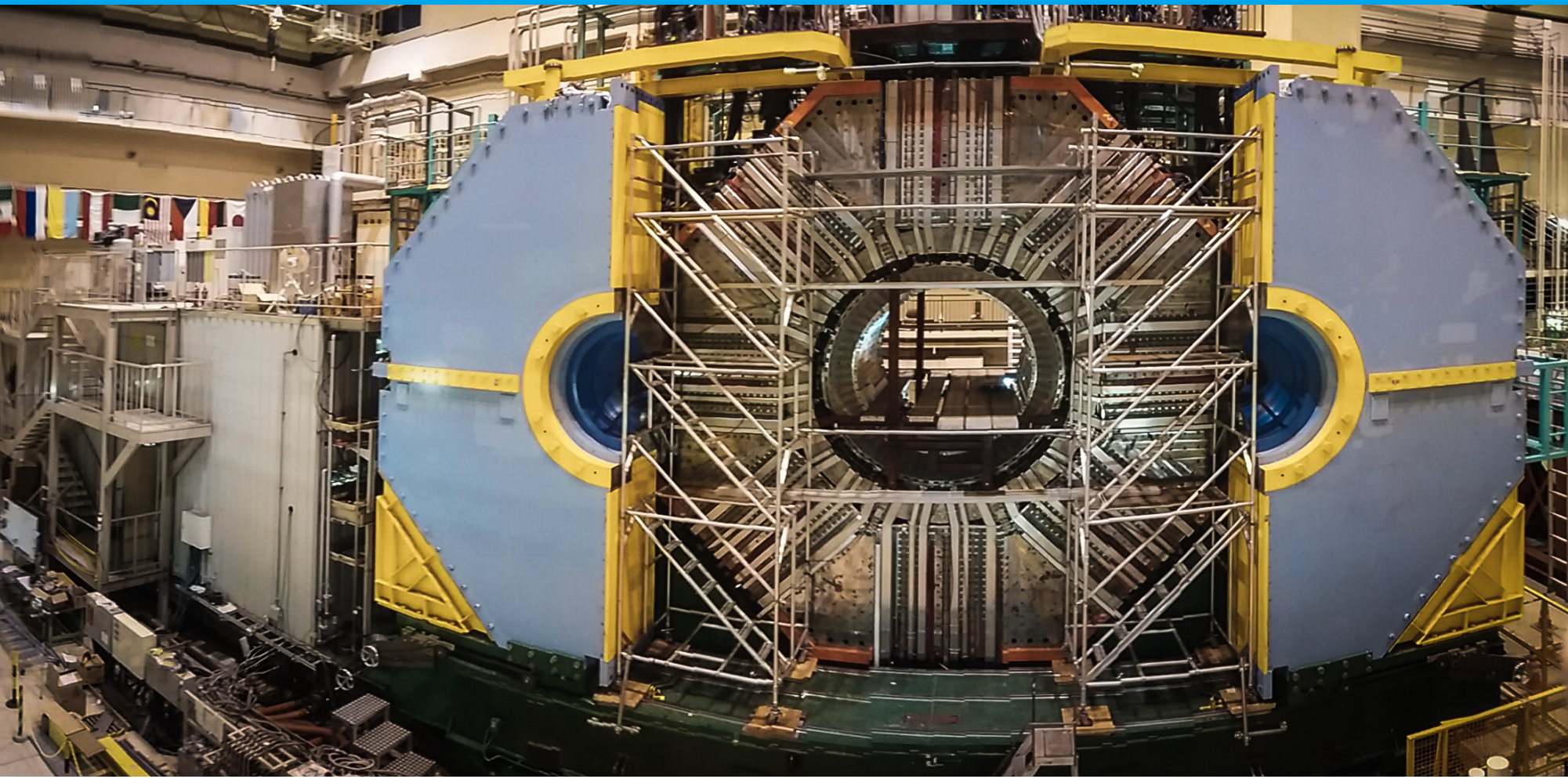
Resume

- We could show that we can perform the measurement
- Even with lower total signal yield than LHCb we might compare electron and muon channels

Outlook

- Will we also see a deviation in P_5'?
- We hope to get the permission for a box opening very soon
- The result is targeted to be shown at the winter conferences

Thank you for your Attention!



Thank you!

Toy Study - Results for P_4'

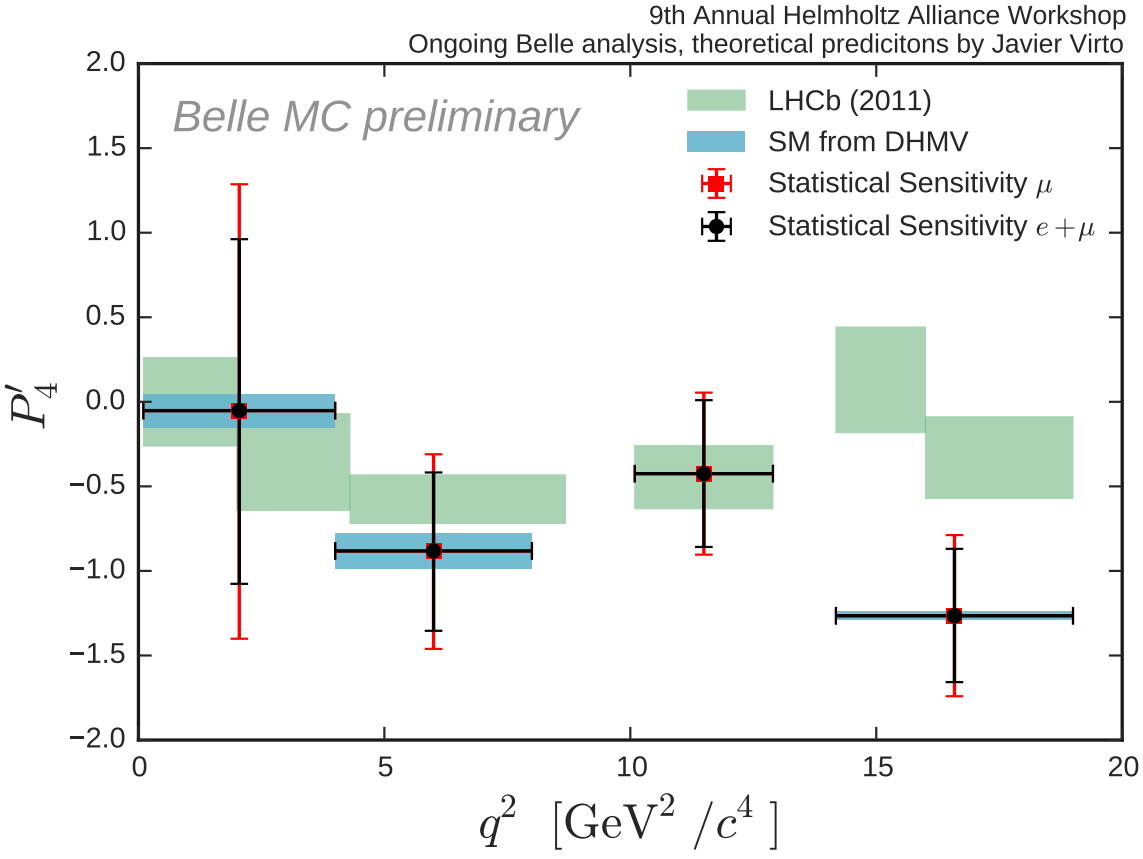
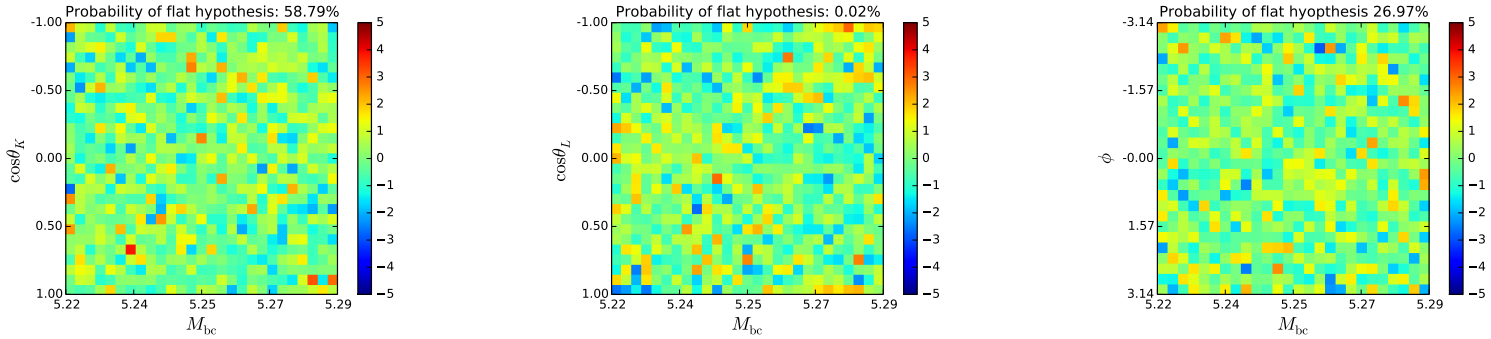


Figure : Result of the MC toy studies with the expected signal and background yields, each data point represents the averaged result of 10000 fits.

Background estimation on M_{bc} sideband

We check the correlation of the angular variables with the M_{bc} sideband:



(a) $\cos\theta_K$ vs. M_{bc} (b) $\cos\theta_L$ vs. M_{bc} (c) ϕ vs. M_{bc}

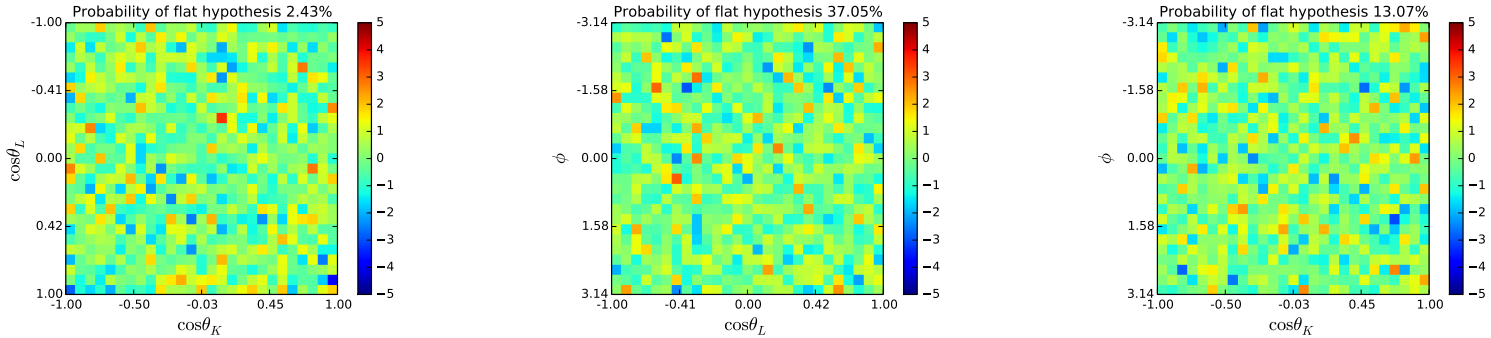
Figure : Flat correlation plot of M_{bc} with the angular variables and q^2. The color represents the deviation of the expected bin-content for a flat distribution in σ.

Efficiency estimation

We estimate the efficiency in the angular variables and weight the events by the inverse of the it:

$$f_{eff}^{bin}(\cos\theta_L, \cos\theta_K, \phi) = f_{eff}^{fit}(\cos\theta_L) \otimes f_{eff}^{fit}(\cos\theta_K) \otimes f_{eff}^{fit}(\phi).$$

This procedure is valid as there is no correlation in the efficiency among the angular variables.



(a) $\cos\theta_L$ vs. $\cos\theta_K$ (b) ϕ vs. $\cos\theta_L$ (c) ϕ vs. $\cos\theta_K$

Figure : Flat correlation plots of the reconstruction efficiency among the angular variables.