Measurements and questions to theorists

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The Pdf

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

$$P_1 = A_T^{(2)} = \frac{2S_3}{(1-F_L)} \qquad P_4' = \frac{S_4}{\sqrt{(1-F_L)F_L}} \qquad P_8' = \frac{S_8}{\sqrt{(1-F_L)F_L}}$$

$$P_2 = A_T^{Re} = \frac{S_6}{2(1-F_L)} \qquad P_5' = \frac{S_5}{\sqrt{(1-F_L)F_L}}$$

$$P_3 = \frac{S_9}{(1-F_L)} \qquad P_6' = \frac{S_7}{\sqrt{(1-F_L)F_L}}$$

The measurement

We use a folding technique to measure the observables

$\phi \to -\phi$ for $\phi < 0$

$$\frac{1}{\Gamma}\frac{d^3(\Gamma+\bar{\Gamma})}{d\cos\theta_\ell\, d\cos\theta_K\, d\phi} = \frac{9}{16\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + \frac{3}{4}(1-F_L)A_T^{Re}\sin^2\theta_K\cos\theta_\ell + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

The measurement

We use a folding technique to measure the observables

$$\phi \to -\phi \quad \text{if } \phi < 0$$
$$\theta_\ell \to \pi - \theta_\ell \quad \text{if } \theta < \pi/2$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\left[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell \right.$$
$$- F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi +$$
$$\left.\sqrt{F_L(1-F_L)}P_5'\sin 2\theta_K\sin\theta_\ell\cos\phi \right]$$

The measurement

We use a folding technique to measure the observables

$$\begin{gathered}\phi \to -\phi \text{ for } \phi < 0\\ \phi \to \pi - \phi \text{ for } \theta_\ell > \pi/2\\ \theta_l \to \pi - \theta_\ell \text{ for } \theta_\ell > \pi/2\end{gathered}$$

$$\begin{aligned}\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\Big[&\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - \\ &F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + \\ &\sqrt{F_L(1-F_L)}P_4'\sin 2\theta_K\sin 2\theta_\ell\cos\phi\ \Big]\end{aligned}$$

The measurement

We use a folding technique to measure the observables

$$\phi \to \pi - \phi \text{ for } \phi > \pi/2$$
$$\phi \to -\pi - \phi \text{ for } \phi < -\pi/2$$
$$\theta_\ell \to \pi - \theta_\ell \text{ for } \theta_\ell > \pi/2$$

$$\begin{aligned}\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\Bigg[&\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - \\ &F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + \\ &\sqrt{F_L(1-F_L)}P_6'\sin 2\theta_K\sin\theta_\ell\sin\phi\Bigg]\end{aligned}$$

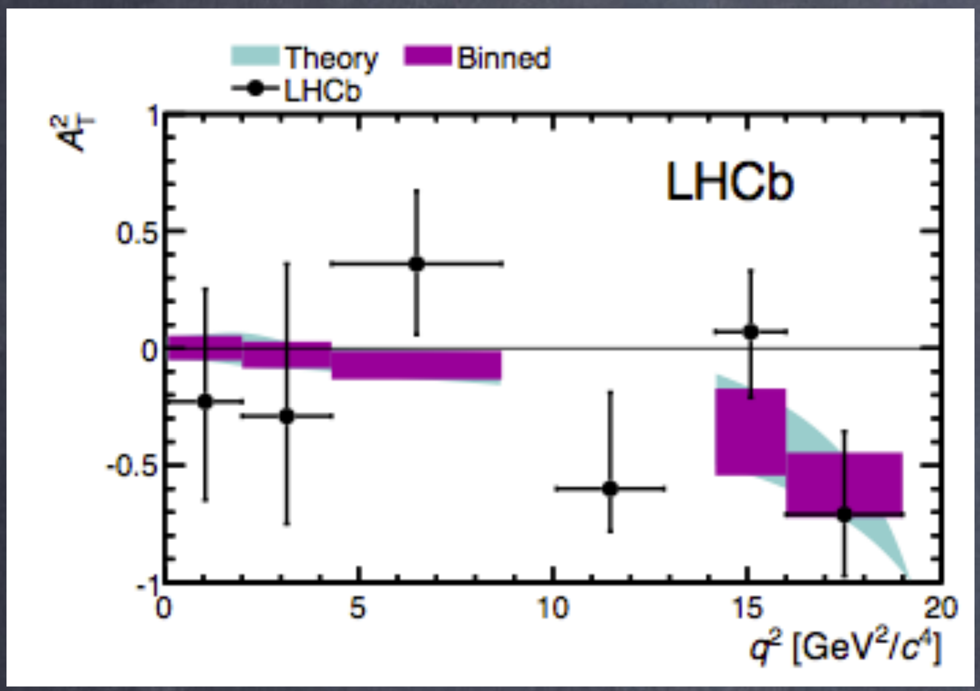
The measurement

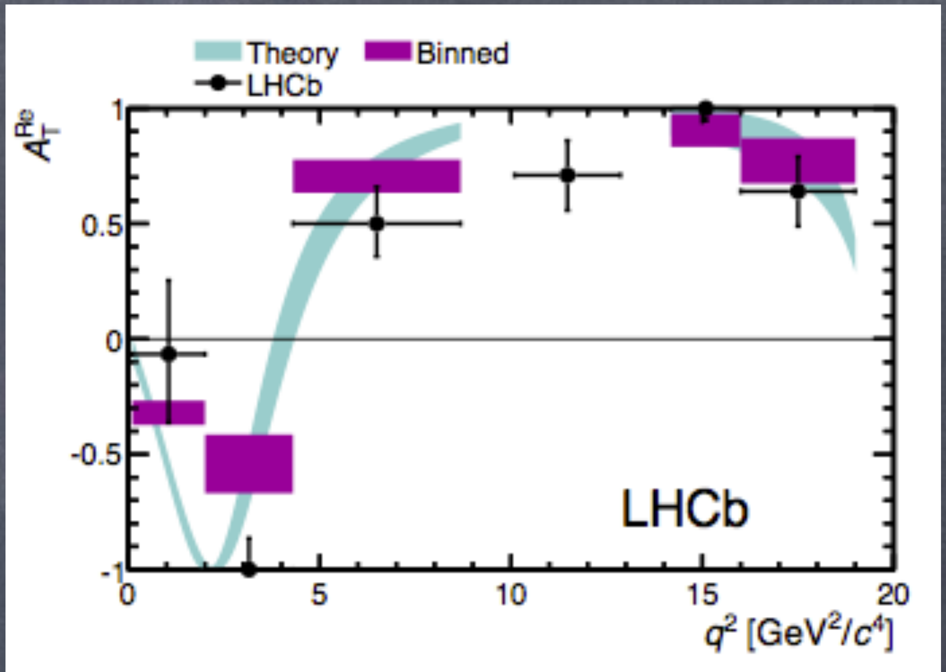
We use a folding technique to measure the observables

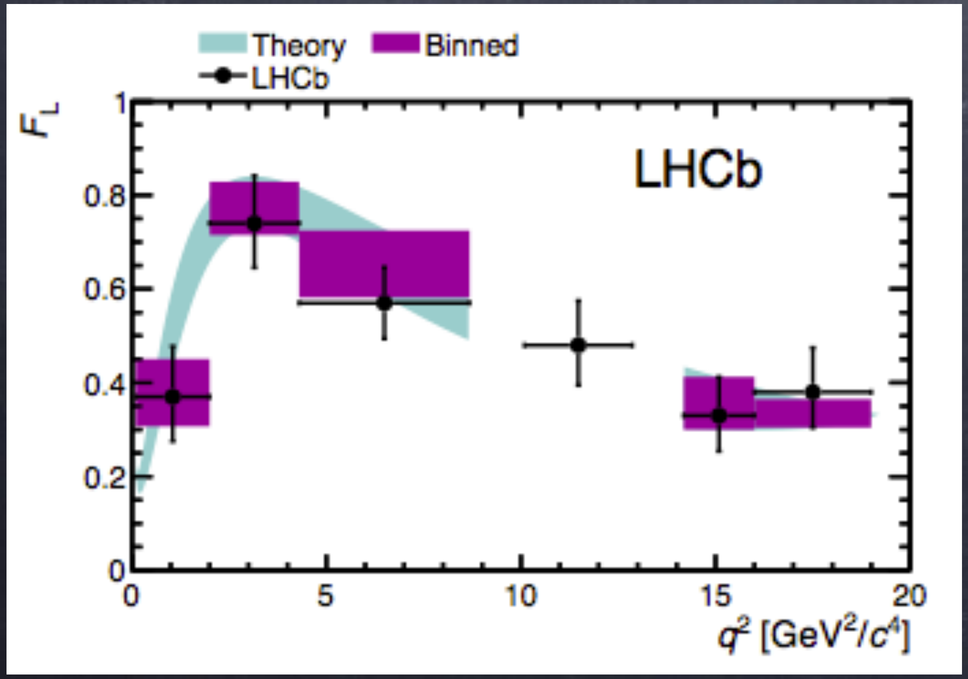
$$\phi \to \pi - \phi \text{ for } \phi > \pi/2$$
$$\phi \to -\pi - \phi \text{ for } \phi < -\pi/2$$
$$\theta_\ell \to \pi - \theta_\ell \text{ for } \theta_\ell > \pi/2$$
$$\theta_K \to \pi - \theta_K \text{ for } \theta_\ell > \pi/2$$

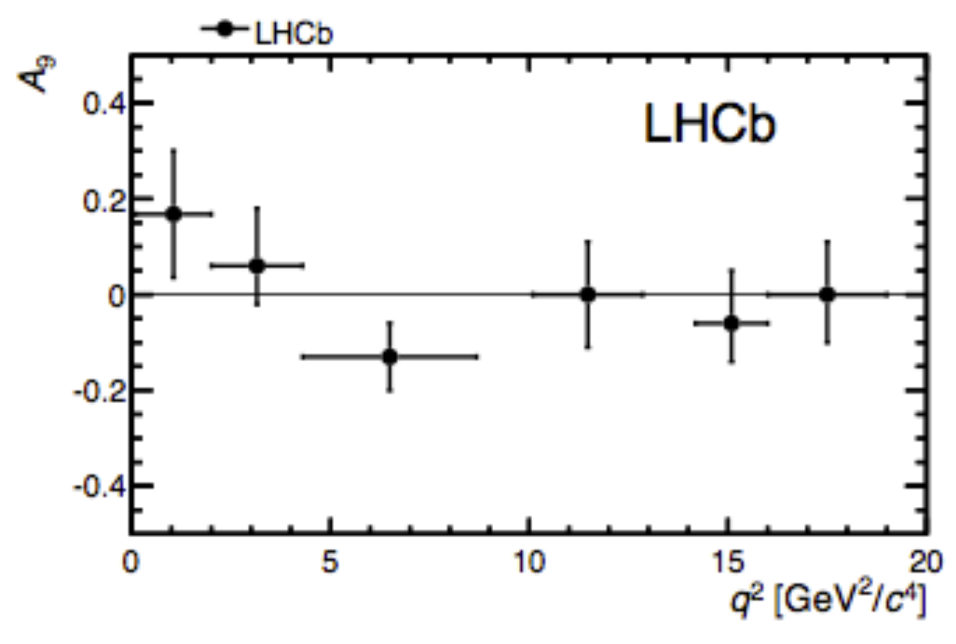
$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\Bigg[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + \sqrt{F_L(1-F_L)}P_8'\sin 2\theta_K\sin 2\theta_\ell\sin\phi\Bigg]$$

Measurements

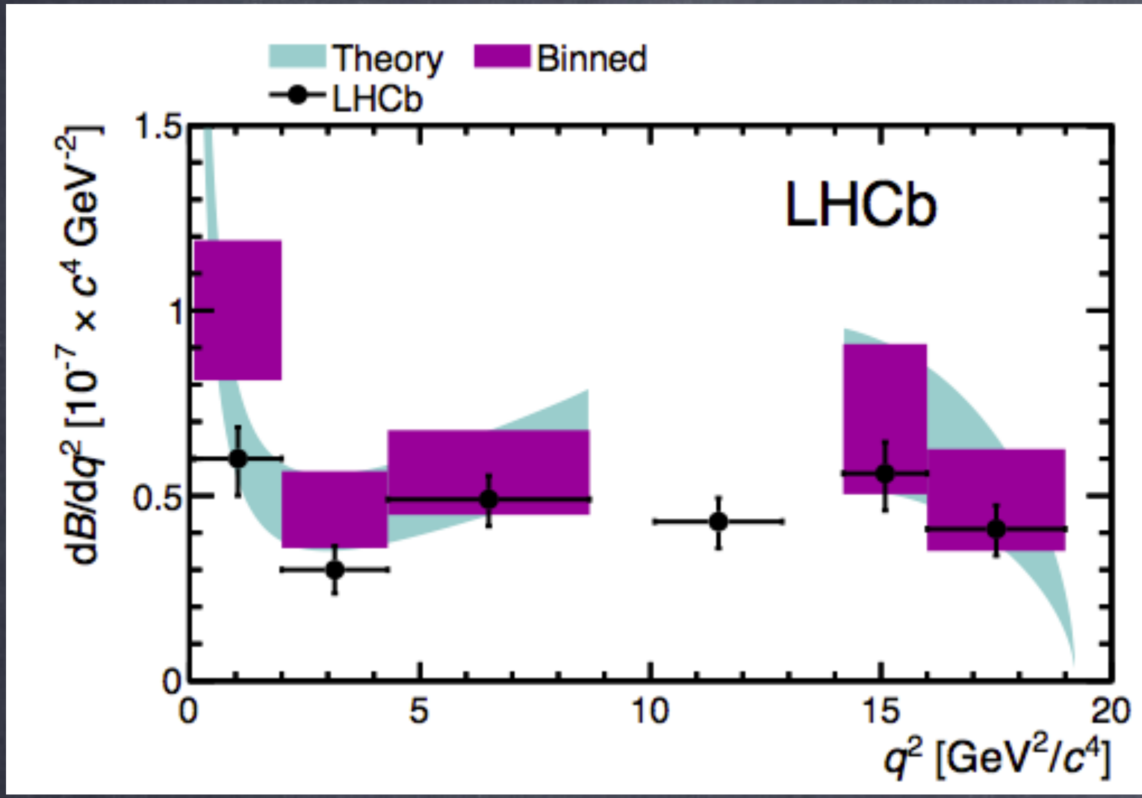


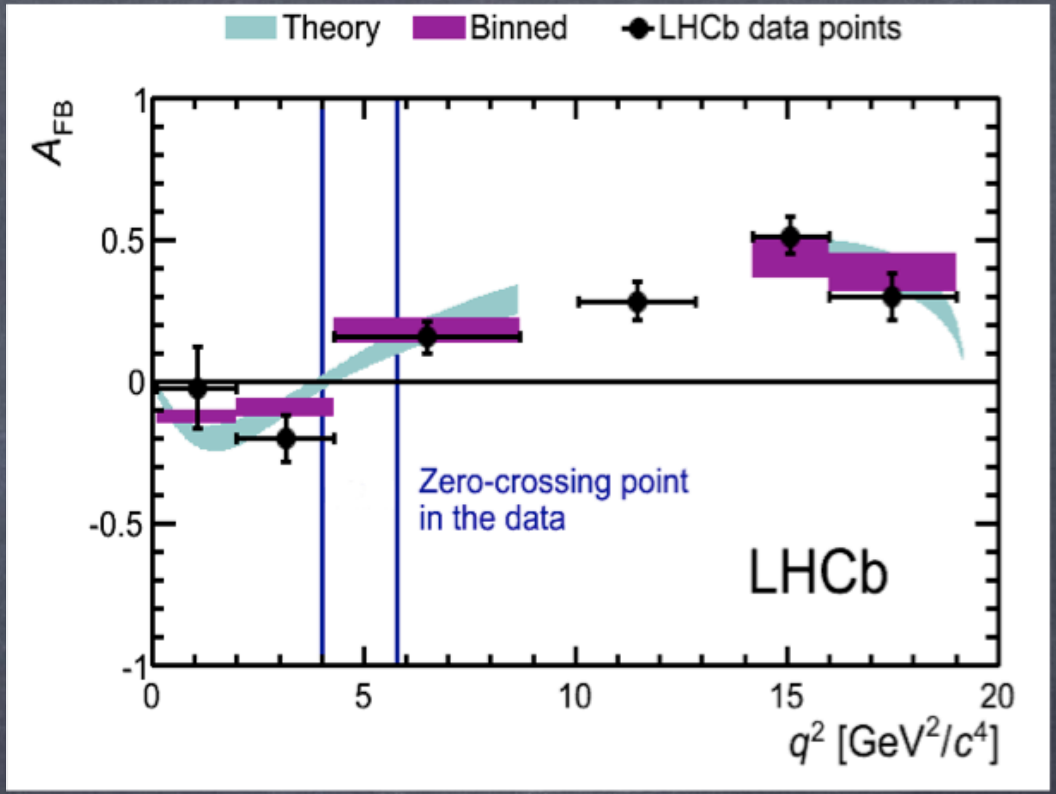






Measurements

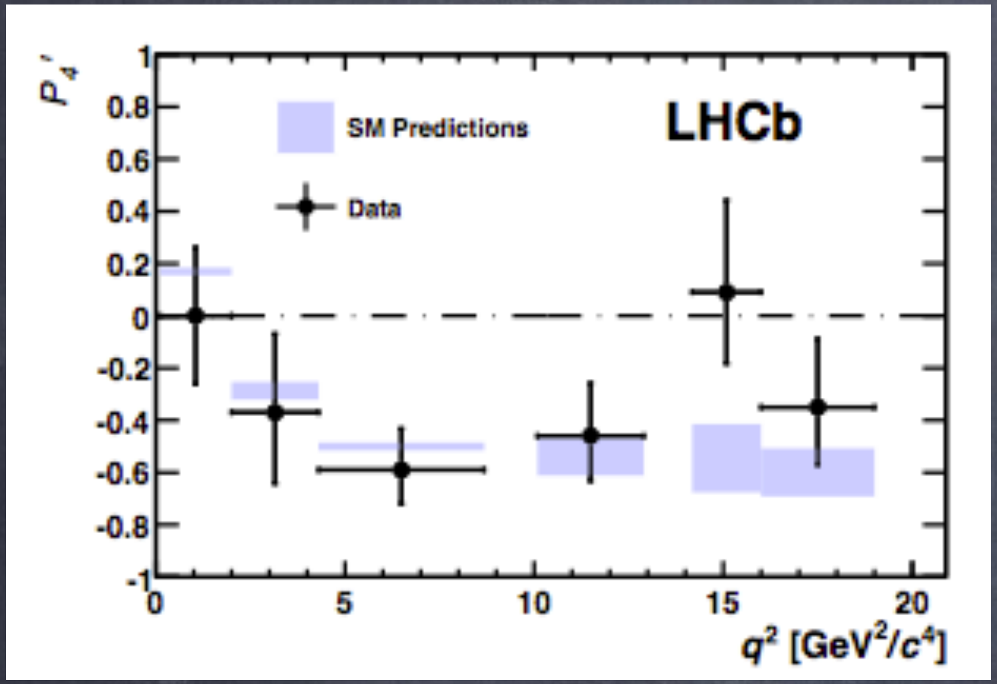


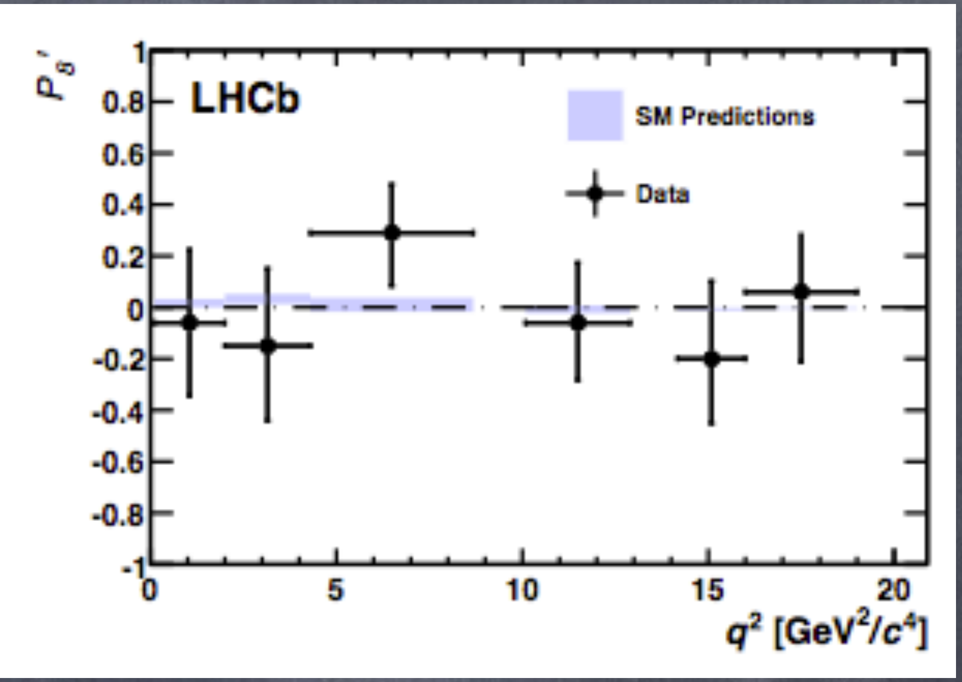


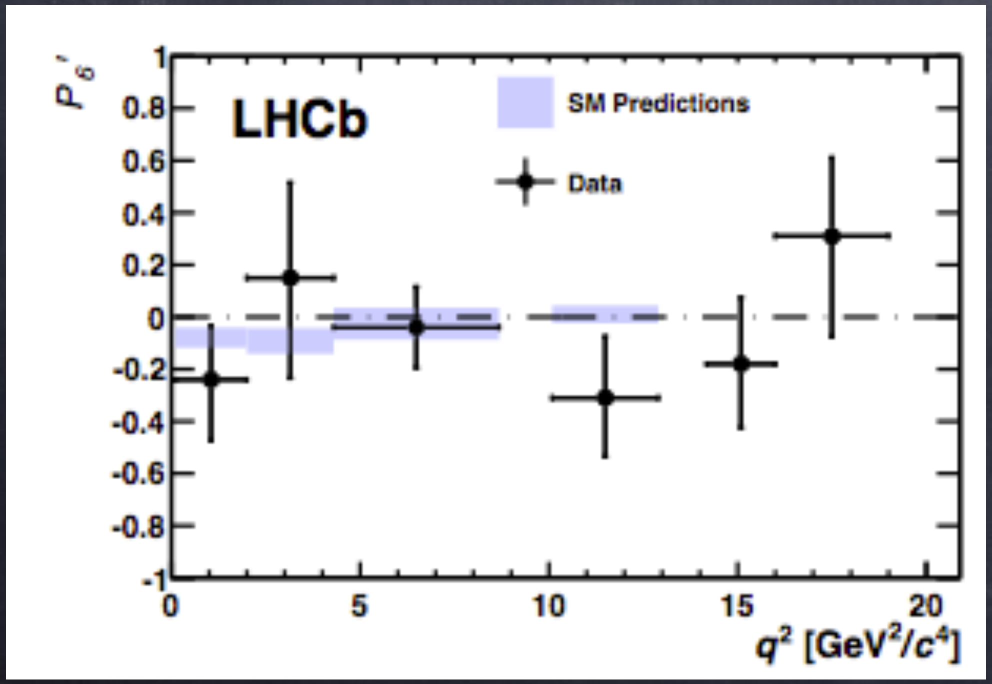
Also first measurement of the zero-crossing of A_{FB}

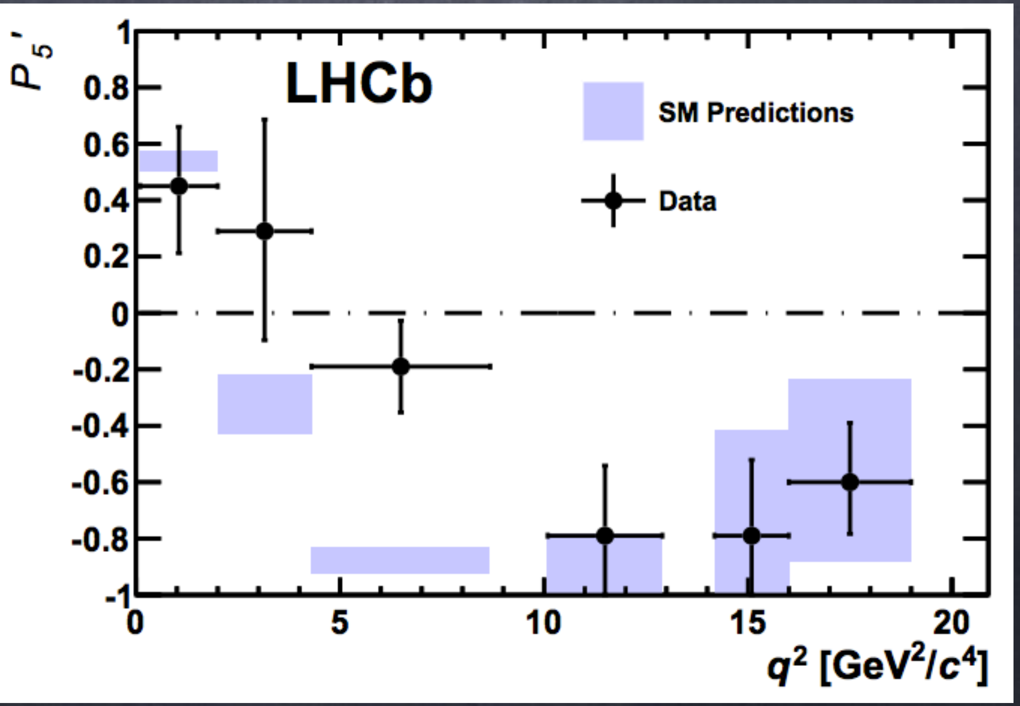
q_0^2 = 4.9±0.9 GeV^2

Measurements



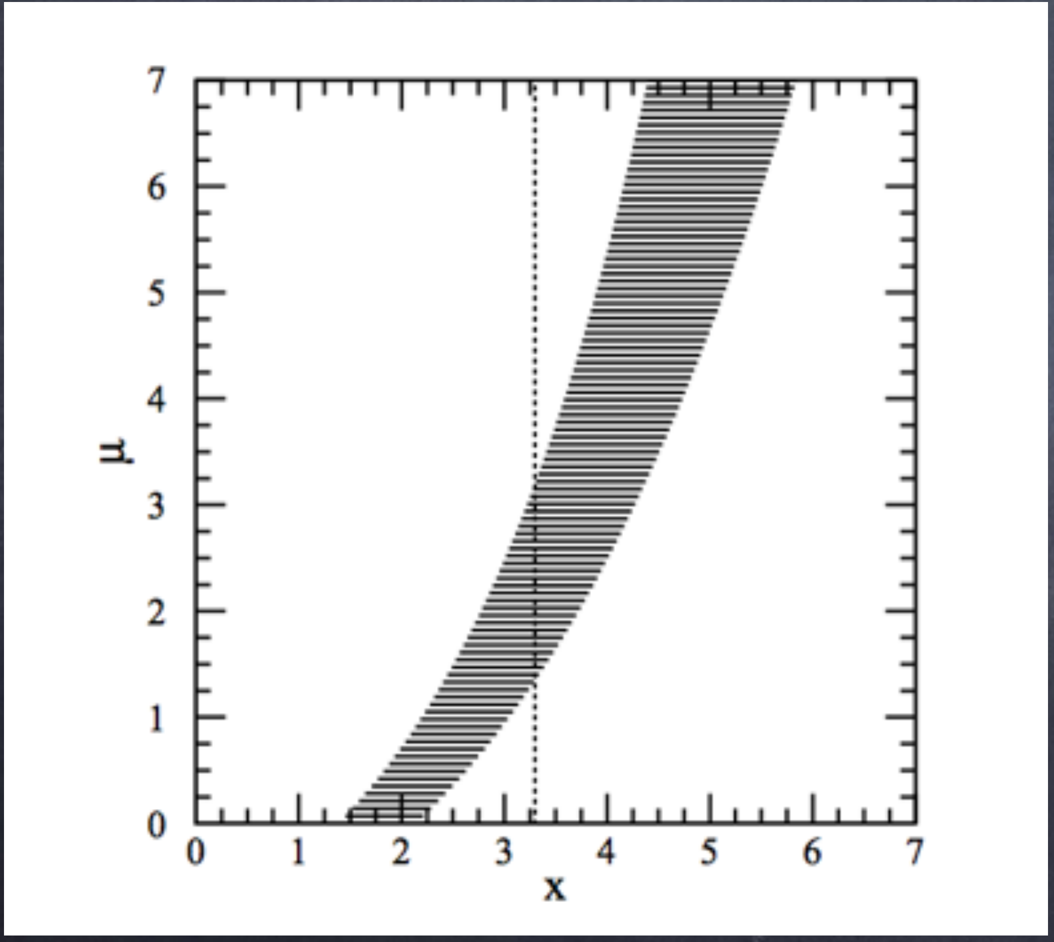






Errors

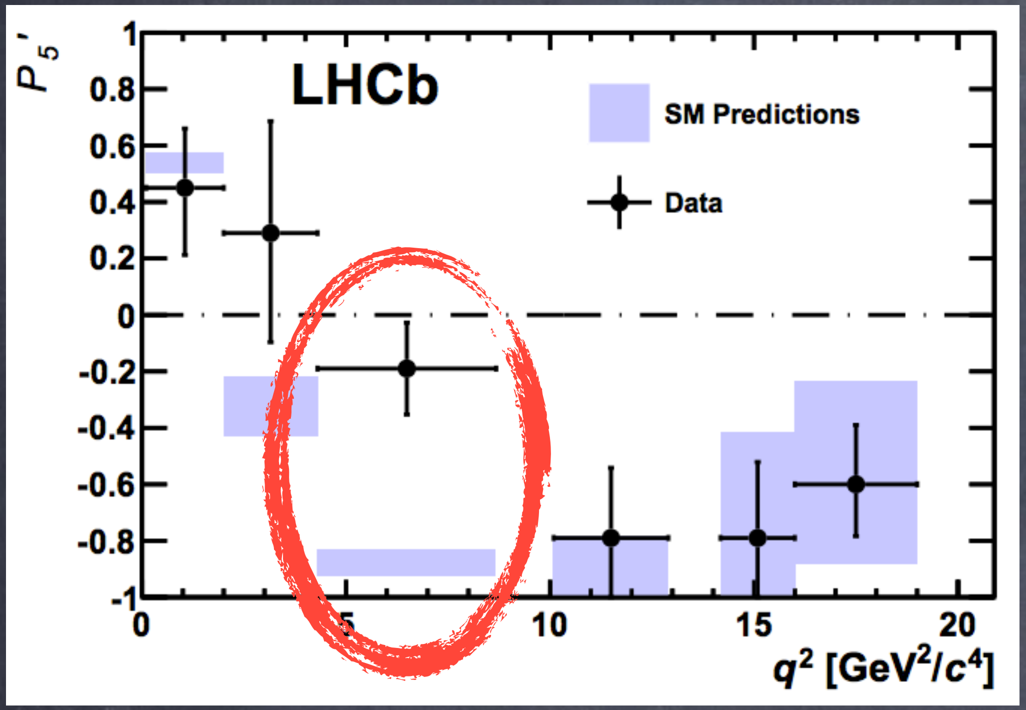
Errors are evaluated with the Feldman-Cousins construction



$$R = \frac{P(x|\mu)}{P(x|\hat{\mu})}$$

This is done for each observables independently, the other are considered nuisance parameters

Some comments about the errors



3.7sigmas from Quim predictions:

- generate the SM
- compute what is the probability to have such a bad agreement as the one we see

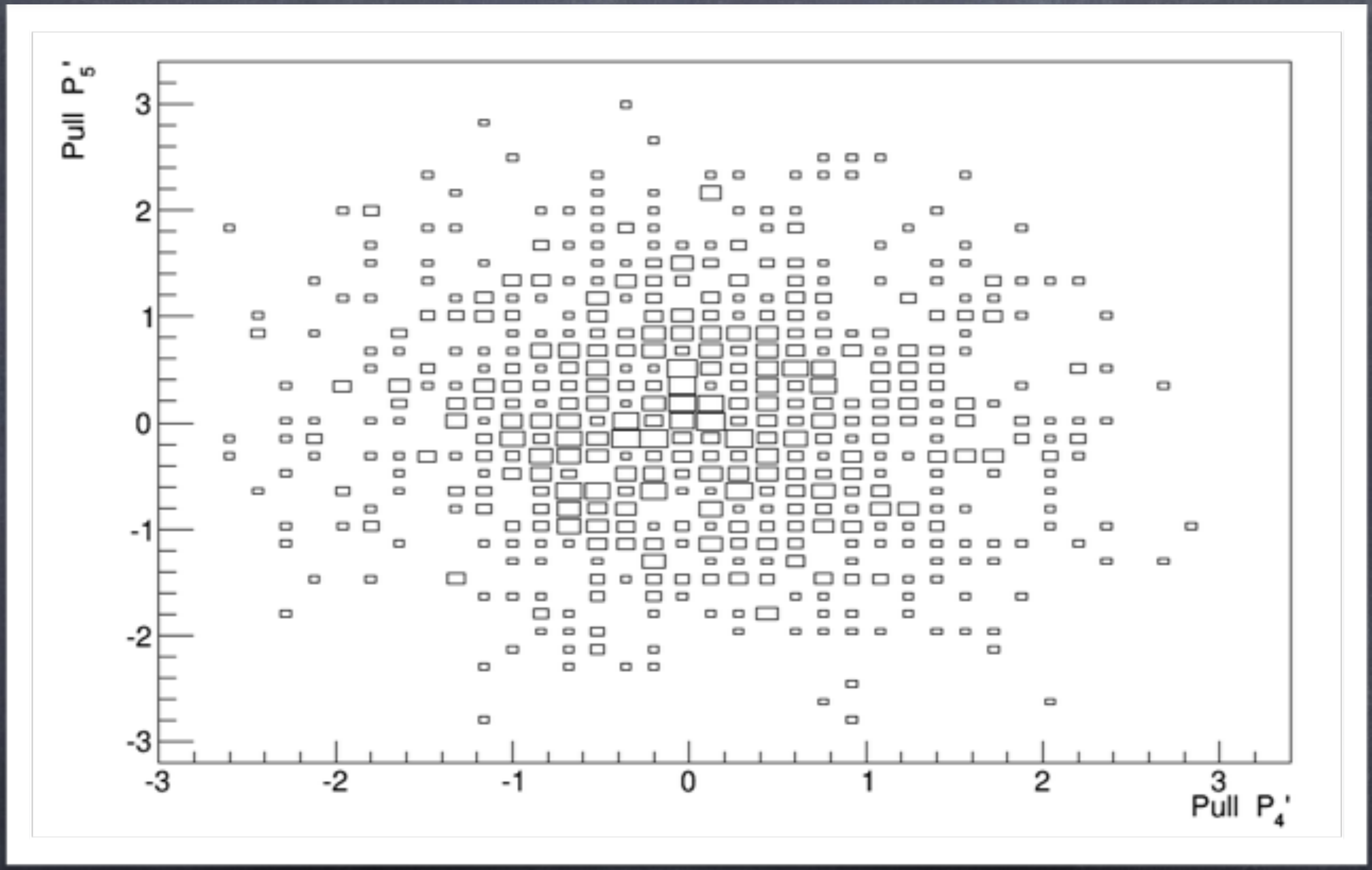
We get 2.8 sigmas considering 24 independent measurements... very conservative estimate

Correlations

LHCb did not give correlation matrix, so it is impossible to get the correlation associated to systematics and fit model and background… but the correlation due to the method can be extracted with a toy

Correlation due to physics you already take this into account!

Correlations



This can be used to compute a correlation coefficient

S-wave

Pollution from non-resonant Kπ in an S-wave state or from K*(1430) would change the angular distribution

$$\frac{d^3\Gamma}{d\cos\theta_\ell\, d\cos\theta_K\, d\phi} = \frac{9}{32\pi}\left[(1-F_S)PDF_{K^{*0}} + PDF_S\right]$$

$$F_S = \frac{|A_0^0|^2}{|A_0^0|^2 + |A_0|^2 + |A_\perp|^2 + |A_\parallel|^2}$$

$$\begin{aligned} PDF_S \;=\;& \frac{2}{3}F_S \sin^2\theta_\ell + \frac{4}{3}A_S \sin^2\theta_\ell \cos\theta_K + \\ & A_S^{(4)} \sin\theta_K \sin 2\theta_\ell \cos\phi + \\ & A_S^{(5)} \sin\theta_K \sin\theta_\ell \cos\phi + \\ & A_S^{(7)} \sin\theta_K \sin\theta_\ell \sin\phi + \\ & A_S^{(8)} \sin\theta_K \sin 2\theta_\ell \sin\phi. \end{aligned}$$

The terms $A_S^{(i)}$ are interference terms between the S-wave and P-wave

$$\begin{aligned} F_S &= \frac{A_{0,S}A_{0,S}^*}{\Gamma_{tot}} = \frac{\Gamma_S}{\Gamma_{K^*} + \Gamma_S} \\ A_S &= \sqrt{3}\frac{Re\left(A_0^{*L,R}A_0^{0(L,R)}\right)}{\Gamma_{tot}} \\ A_s^{(4)} &= \sqrt{\frac{2}{3}}\frac{Re\left(A_\parallel^{*L}A_0^{0(L)} + A_\parallel^{*R}A_0^{0(R)}\right)}{\Gamma_{tot}} \\ A_s^{(5)} &= \frac{2\sqrt{2}}{\sqrt{3}}\frac{Re\left(A_\perp^{*L}A_0^{0(L)} - A_\perp^{*R}A_0^{0(R)}\right)}{\Gamma_{tot}} \\ A_s^{(7)} &= \frac{2\sqrt{2}}{\sqrt{3}}\frac{Re\left(A_\parallel^{*L}A_0^{0(L)} - A_\parallel^{*R}A_0^{0(R)}\right)}{\Gamma_{tot}} \\ A_s^{(8)} &= \sqrt{\frac{2}{3}}\frac{Re\left(A_\perp^{*L}A_0^{0(L)} + A_\perp^{*R}A_0^{0(R)}\right)}{\Gamma_{tot}} \end{aligned}$$

Extraction of S-wave

Phase change in the Breit-Wigner used to measure F_s (assuming the S-wave is constant)

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_K} = \frac{F_S}{2} + A_S\cos\theta_K$$
$$\frac{3}{2}(1-F_S)F_L\cos^2\theta_K + \frac{3}{4}\left[(1-F_S)(1-F_L)\right]\left[1-\cos^2\theta_K\right]$$

$$< F_{\rm S} >= \frac{[(A_+ + A_-)^2/4 + (A_+ - A_-)^2/(4\times 1.23)]\times 3.24/(3F_{\rm L})}{1-[(A_+ + A_-)^2/4 + (A_+ - A_-)^2/(4\times 1.23)]\times 3.24/(3F_{\rm L})}$$

We got $F_s < 0.07$ at 68% C.L.
(Method cross checked with $B^0 \rightarrow J/\Psi K^*$)

S-wave ignored in the fit and added as a systematic

Theory uncertainty from our point of view

$$A_\perp^{L,R} = \mathcal{N}_\perp \left[\mathcal{C}^+_{9\mp10} V(q^2) + \mathcal{C}^+_7 T_1(q^2)\right] + \mathcal{O}(\alpha_s, \Lambda/m_b \cdots)$$

$$A_\parallel^{L,R} = \mathcal{N}_\parallel \left[\mathcal{C}^-_{9\mp10} A_1(q^2) + \mathcal{C}^-_7 T_2(q^2)\right] + \mathcal{O}(\alpha_s, \Lambda/m_b \cdots)$$

$$A_0^{L,R} = \mathcal{N}_0 \left[\mathcal{C}^-_{9\mp10} A_{12}(q^2) + \mathcal{C}^-_7 T_{23}(q^2)\right] + \mathcal{O}(\alpha_s, \Lambda/m_b \cdots)$$

naive factorizations?

$$A_\perp^{L,R} = X_\perp^{L,R} V(q^2) + \mathcal{O}(\alpha_s, \Lambda/m_b \cdots)$$

$$A_\parallel^{L,R} = X_\parallel^{L,R} A_1(q^2) + \mathcal{O}(\alpha_s, \Lambda/m_b \cdots)$$

$$A_0^{L,R} = X_0^{L,R} A_{12}(q^2) + \mathcal{O}(\alpha_s, \Lambda/m_b \cdots)$$

Form factors ralations

Theory uncertainty from our point of view

$$A_1(q^2) = \frac{2E}{m_B + m_{K^*}}\xi_\perp(q^2) + \Delta A_1 + \mathcal{O}(\Lambda/m_b)$$

$$A_2(q^2) = \frac{m_B}{m_B - m_{K^*}}[\xi_\perp(q^2) - \xi_\parallel(q^2)] + \frac{m_B}{2E}\frac{m_B + m_{K^*}}{m_B - m_{K^*}}\Delta A_1 + \mathcal{O}(\Lambda/m_b)$$

$$A_0(q^2) = \frac{E}{m_{K^*}}\frac{\xi_\parallel(q^2)}{\Delta_\parallel(q^2)} + \mathcal{O}(\Lambda/m_b)$$

How the uncertainty on this is computed?

Question about the resonances

For us the resonances J/psi and psi(2S) are very important for calibration and test of the analysis

We could measure the observables in the resonances in small invariant mass bins (left and right of the resonances)

Can you learn anything from there?