

# 11th Franco-Italian Meeting on B physics

*New Promising Flavour Physics Research Subjects in Theory and Experiment*

## Hadronic Uncertainties in B to $K^*ll$



M. Fedele



SAPIENZA  
UNIVERSITÀ DI ROMA

based on arXiv:1512.07157 in collaboration with:

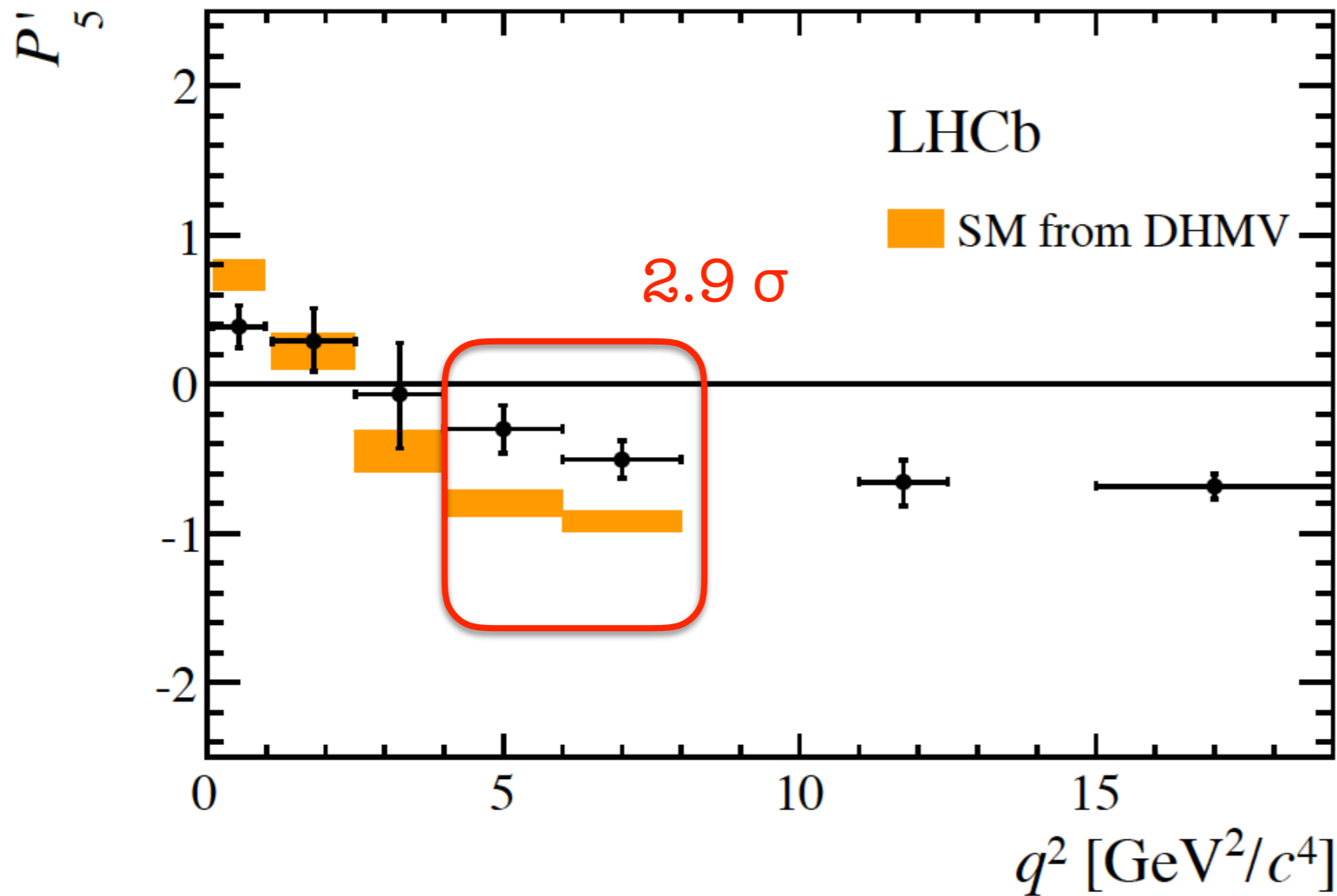
M.Ciuchini, E.Franco, S.Mishima, A.Paul, L.Silvestrini & M.Valli



Supported by:



# The $P'_5$ anomaly



LHCb

arXiv:1512.04442

Is NP the  
responsible for  
this anomaly?  
Many think so...

F. Beaujean et al. [arXiv:1310.2478](#) W. Altmannshofer, D.M. Straub [arXiv:1411.3161](#) S. Descotes-Genon et al. [arXiv:1510.04239](#) T. Hurt et al. [arXiv:1603.00865](#) A. Karan et al. [arXiv:1603.04355](#) ...

# The aim of my talk

Can we be **sure** that the anomaly **is due to NP**, or there is still a **chance that SM can reproduce** the experimental results? Is it even legit to ask...? **YES!**

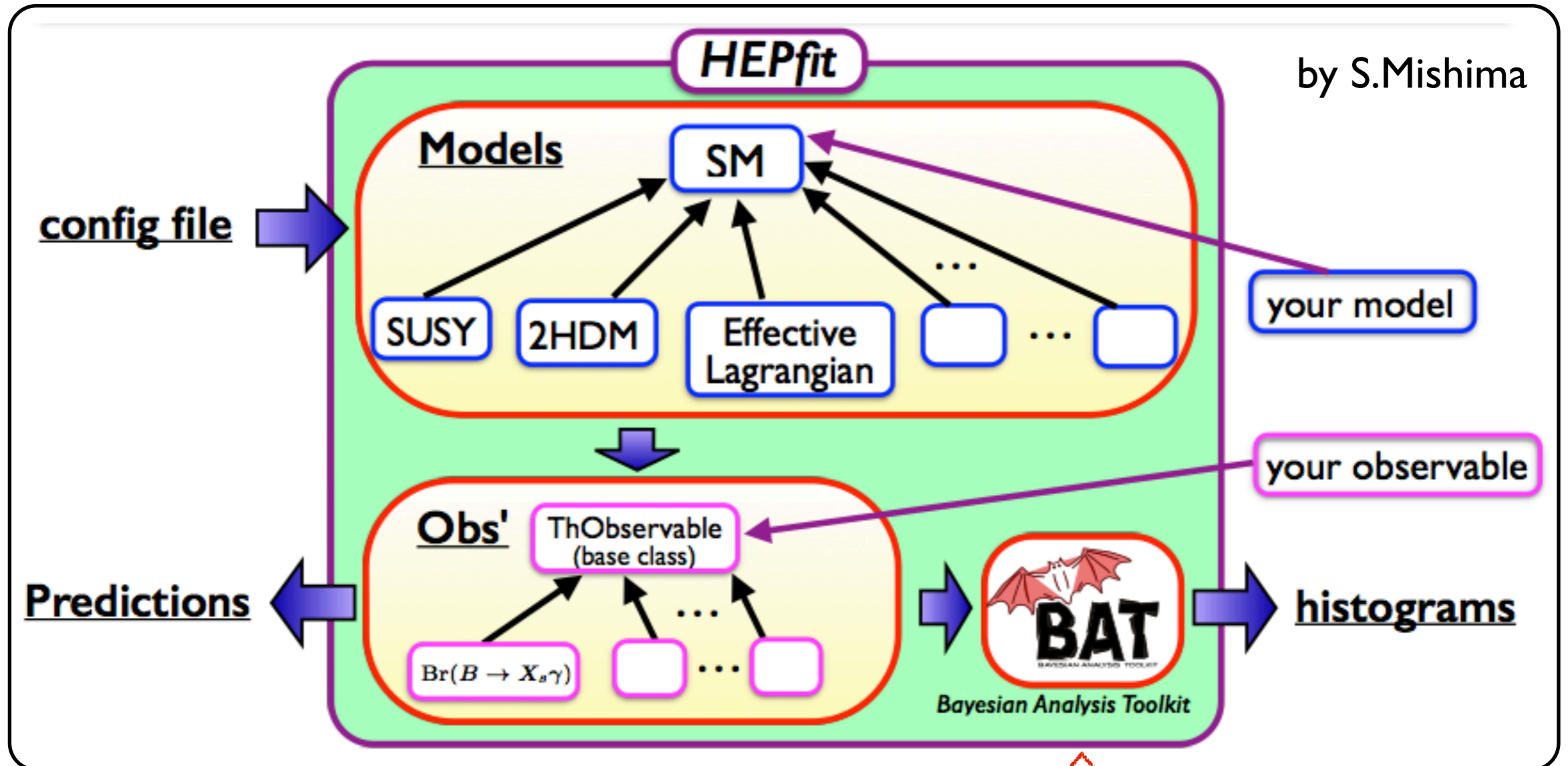
On the theoretical side, we still don't know how to properly take into account non-perturbative hadronic contributions in the whole phenomenological region

- Are the hadronic contributions **properly estimated** in the anomaly bins?
- How **sensitive** is the SM prediction **to hadronic contributions**?

To address this questions, we will **extract** by means of a **Bayesian analysis** the **hadronic contributions**

# HEPfit: a new tool for SM physics & Beyond

by S.Mishima

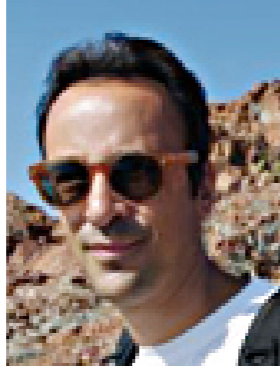


Full-fledged statistical data analysis **in this work** carried out by means of **Bayes Theorem**

$$P(\lambda | D) \propto P(D | \lambda) P_0(\lambda)$$

$\lambda$  posterior      likelihood       $\lambda$  prior

the HEPfit group:  
@present



L.Silvestrini



M.Ciuchini



S.Mishima



E.Franco



L.Reina



M.Pierini

+ 5 postdocs

+ 3 PhD students

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HEPfit is a framework for calculating observables (**Flavour**, **EWPT**, **Higgs**) in the SM and Beyond, constraining model parameter space with a global fit

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It is a **public code** written in C++, supporting MPI parallelization, with GSL, Boost, ROOT and Bayesian Analysis Toolkit (**BAT**) dependencies

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HEPfit v1.0 release candidate available @ <http://hepfit.roma1.infn.it/> with a user friendly cross-platform CMake + a detailed Doxygen documentation of the code (user manual coming out soon!)

Developer version available @ <https://github.com/silvest/HEPfit>

# The large- recoil region in HEPfit

$$\mathcal{H}_{\text{eff}}^{\Delta B=1} = \mathcal{H}_{\text{eff}}^{\text{sl}} + \mathcal{H}_{\text{eff}}^{\text{had}}$$

- NNLO matching and evolution of Wilson coefficients for  $Q_{1-10}$

- 7 Form Factors from LCSRs

$$F^{(i)}(q^2) = \sum_k \alpha_k^{(i)} \frac{[z(q^2) - z(0)]^k}{1 - (q/m_R^{(i)})^2}$$

+

19 x 19 correlation matrix

**A.Bharucha, D.M.Straub**  
and **R.Zwicky** arXiv:1503.05534

- Hard gluon exchanges from QCD factorization

**S.W.Bosch** and **G.Buchalla**  
arXiv:0106081

**M.Beneke, T.Feldmann**  
and **D.Seidel** arXiv:0106067

- Soft gluon exchanges ( $u\bar{u}$ ,  $c\bar{c}$  loops,  $Q_{8g}$  and WA)

$$h_\lambda(q^2) = h_\lambda^{(0)} + h_\lambda^{(1)} q^2 + \underline{h_\lambda^{(2)}} q^4$$

We followed the helicity amplitude formalism :

$$h_\lambda(q^2) = h_\lambda^{(0)} + h_\lambda^{(1)} q^2 + h_\lambda^{(2)} q^4$$

$$H_V(\lambda) \propto C_9 \tilde{V}_{L\lambda} + \frac{2m_b m_B}{q^2} C_7 \tilde{T}_{L\lambda} - \frac{16\pi^2 m_B^2}{q^2} h_\lambda \quad (\lambda = 0, \pm)$$

$$H_A(\lambda) \propto C_{10} \tilde{V}_{L\lambda} \quad , \quad H_P \propto \frac{2m_l m_B}{q^2} C_{10} \left( 1 + \frac{m_s}{m_B} \right) \tilde{S}$$

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## IN OUR BAYESIAN FIT

- LHCb binned angular observables (including correlations) and BRs for  $B \rightarrow K^* \mu^+ \mu^-$ ,  $K^* e^+ e^-$ ,  $K^* \gamma$

arXiv:1502.04442, 1304:6325

arXiv:1501.03038, 1304:3035

HFAG2014

- Half-normal distribution ( $\sigma=0.2$ ) for helicity amplitude suppression factor  
S.Jaeger and J.M.Camalich arXiv:1212.2263

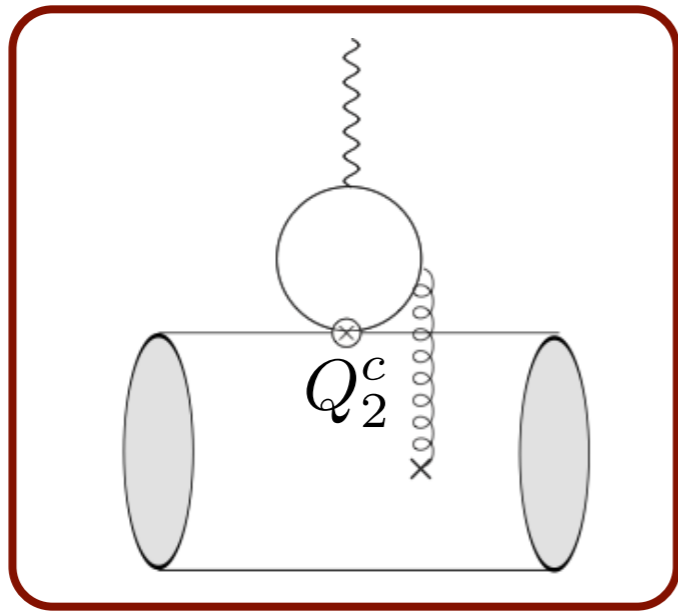
$$\left| \frac{h_+^{(0)}}{h_-^{(0)}} \right|$$

- Flat prior for the non-perturbative hadronic contribution :

$$\left| h_{0,\pm}^{(0,1,2)} \right| \in \left[ 0, 2 \cdot 10^{-3} \right] \quad , \quad \text{Arg} \left( h_{0,\pm}^{(0,1,2)} \right) \in \left[ 0, 2\pi \right]$$



Regarding soft-gluon emission, we can exploit an extra constraint in our fit taking into account the order of magnitude estimate from LCSR (A.Khodjamirian, T.Mannel, A.A.Pivovarov and Y.M.Wang arXiv: 1006.4945) as a gaussian weight on the absolute values of  $h_\lambda$



## DISCLAIMER

Effect estimated in the single-soft gluon approximation

Each additional soft-gluon exchange is suppressed by a factor  $1/(q^2 - 4m_c^2)$  hence this approximation holds only for very low  $q^2$  and worsens at higher  $q^2$  breaking down exactly where the “anomaly bins” sit

- Constraints (when applied) implemented only for  $q^2 \lesssim 1 \text{ GeV}^2$

***Results are different from the ones we put on arXiv due to a wrong factor in  $S_4$ . We thank Joaquim Matias to point us to an inconsistency in our results due to this wrong factor.***

# The SM@HEPfit analysis, case 1

## EXPERIMENTAL WEIGHTS :

$q^2$  experimental binning

$F_L, A_{FB}, S_{3,4,5,7,8,9}$   
*correlated in each bin of  $q^2$*

[0.1, 0.98], [1.1, 2.5], [2.5, 4.0]  
[4.0, 6.0], [6.0, 8.0]

$\mathcal{B}(B \rightarrow K^* \mu\mu)$

[0.1, 2], [2, 4.3], [4.3, 8.68]

$\mathcal{B}(B \rightarrow K^* \gamma)$

kinematical endpoint

$\mathcal{B}(B \rightarrow K^* ee), F_L, P_{1,2,3}$

[0.03, 1], [0.002, 1.12]

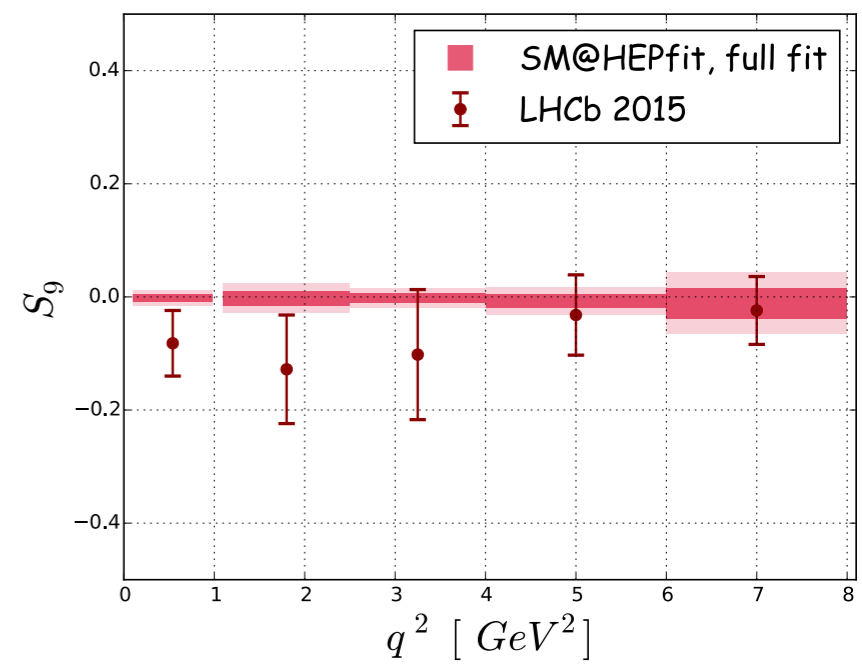
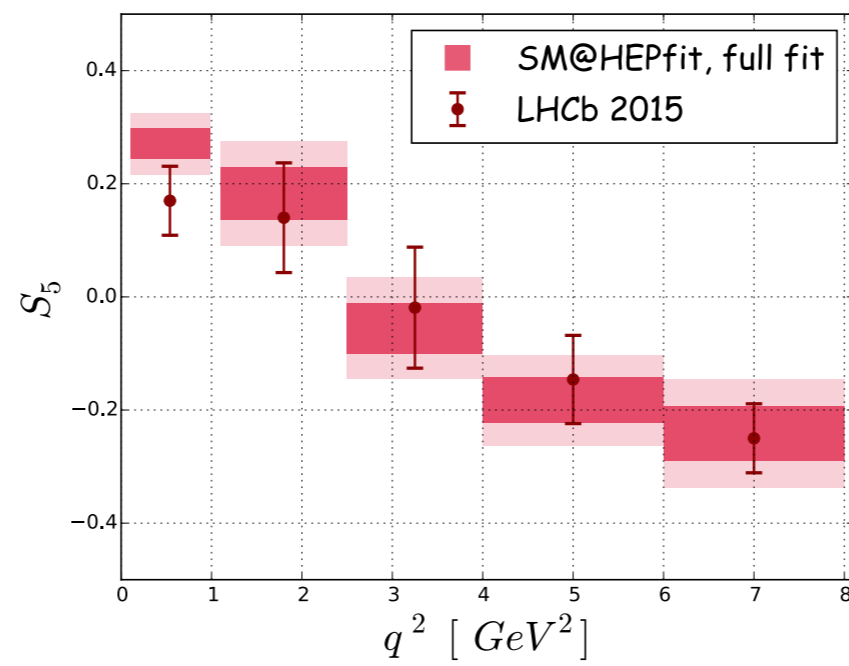
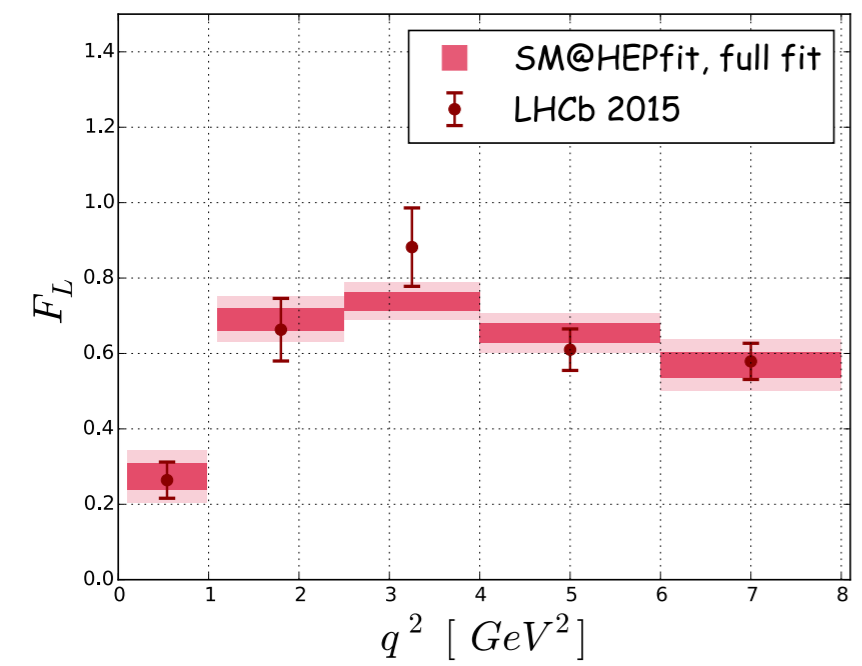
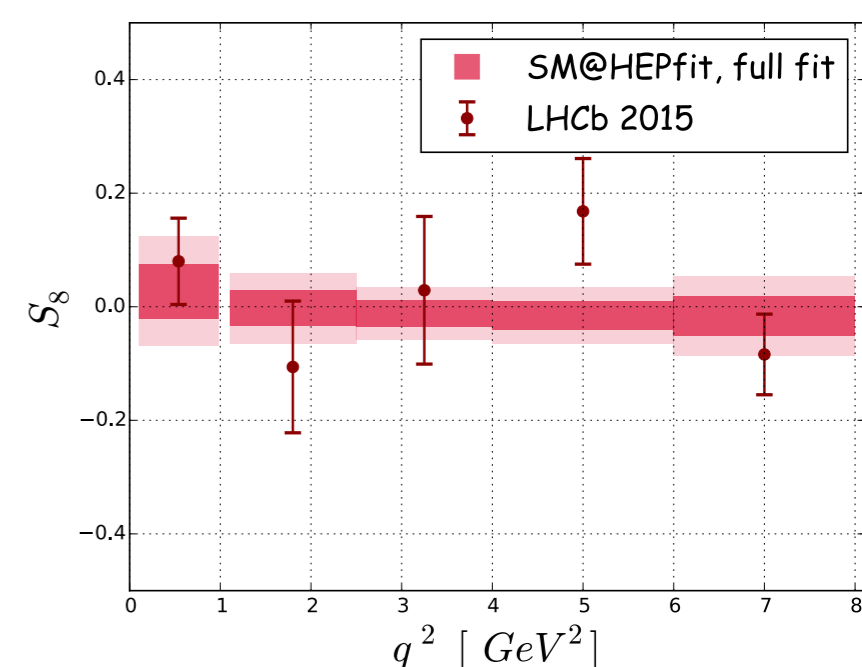
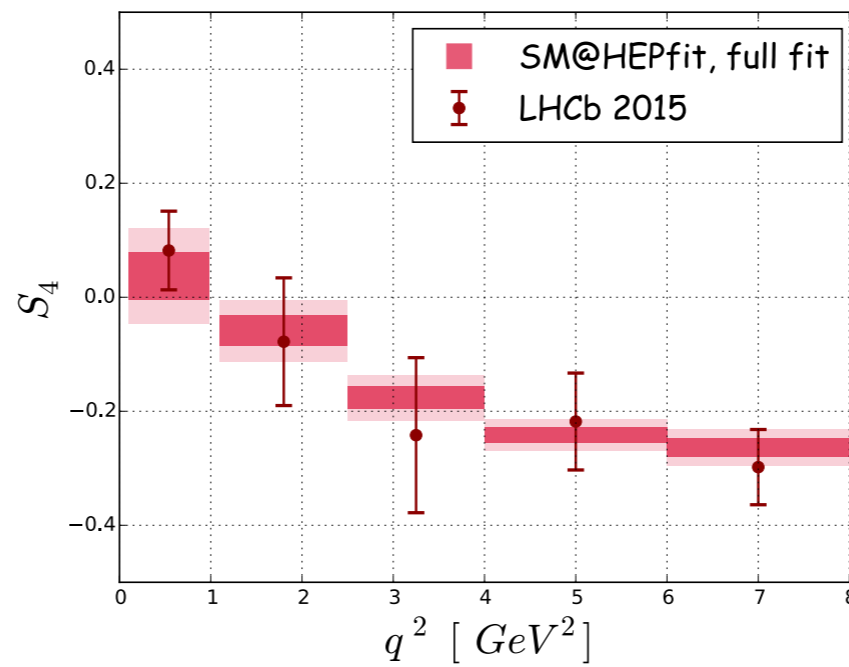
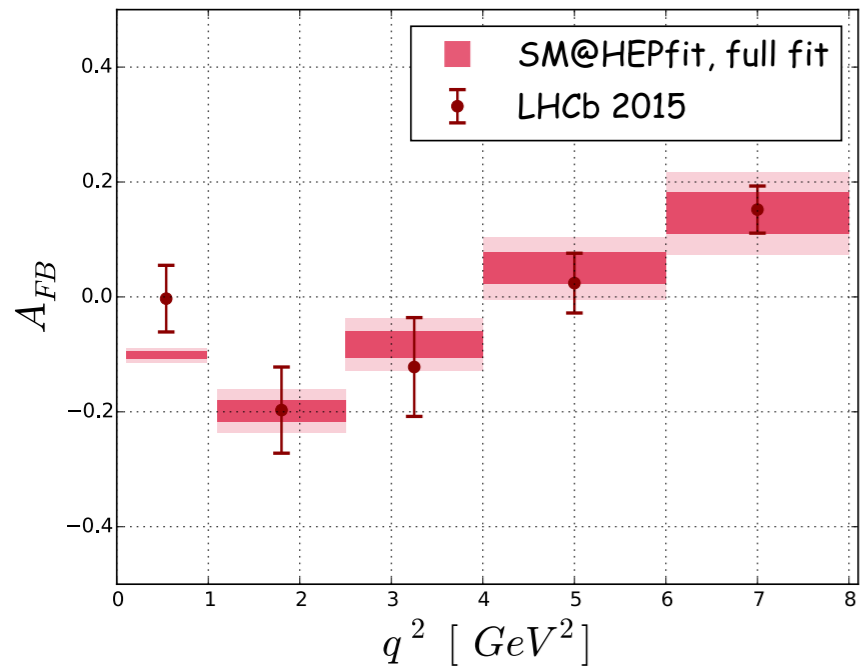
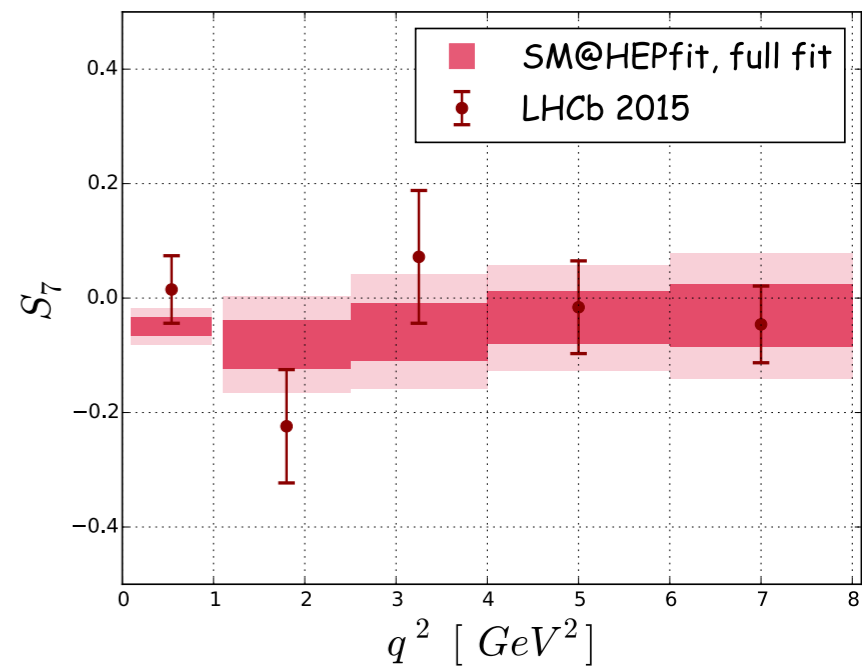
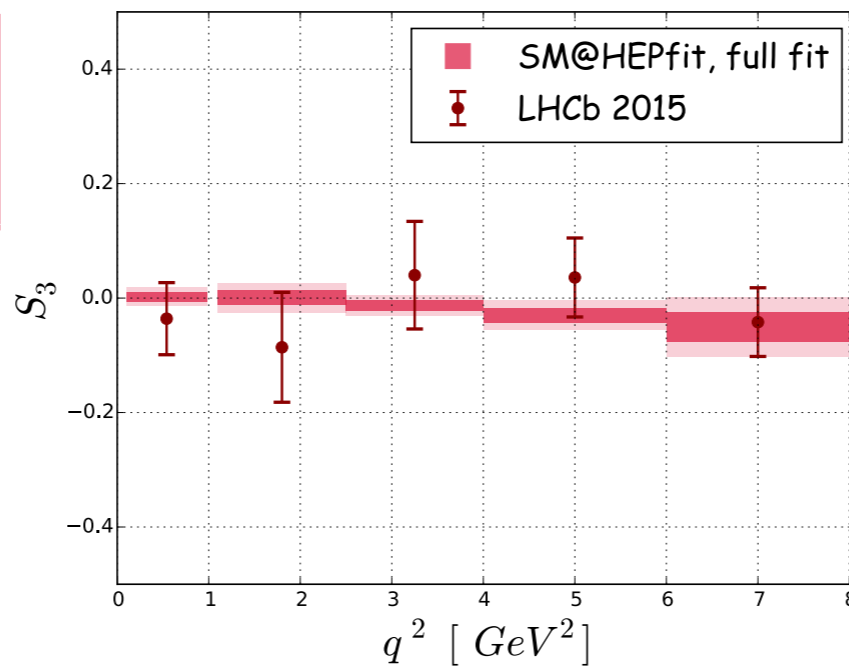
## THEORY WEIGHTS :

LCSR FFs with correlation matrix for low  $q^2$  region only

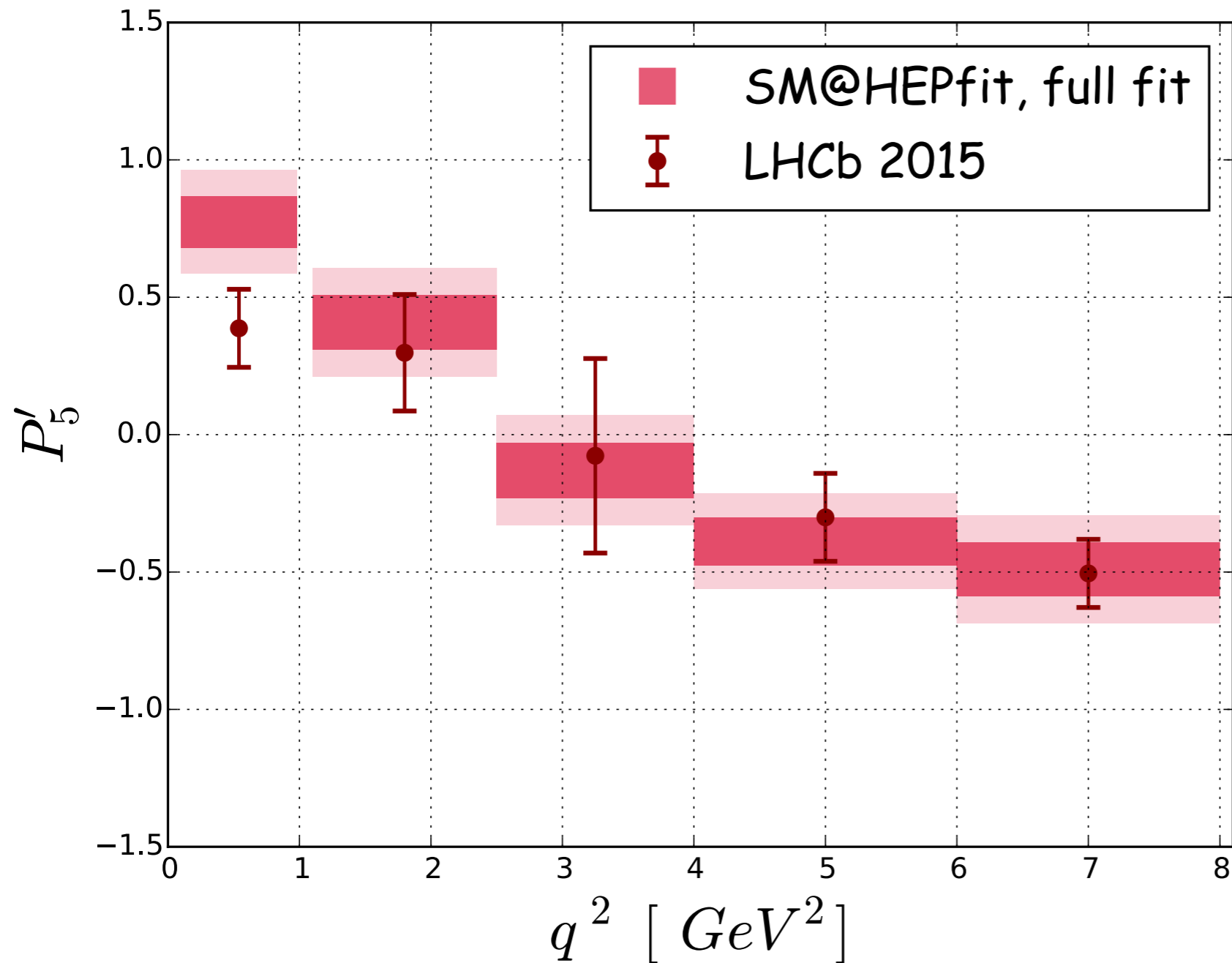
Amplitude helicity suppression at kinematical endpoint

Khodjamirian et al. constraint **ONLY** for  $q^2 \lesssim 1 \text{ GeV}^2$

# HEPfit full fit



# WHAT ABOUT THE OPTIMIZED OBSERVABLES ... ?



$$P'_5 = \frac{S_5}{\sqrt{F_L(1 - F_L)}}$$

No anomalies in  $P'_5$  ...!

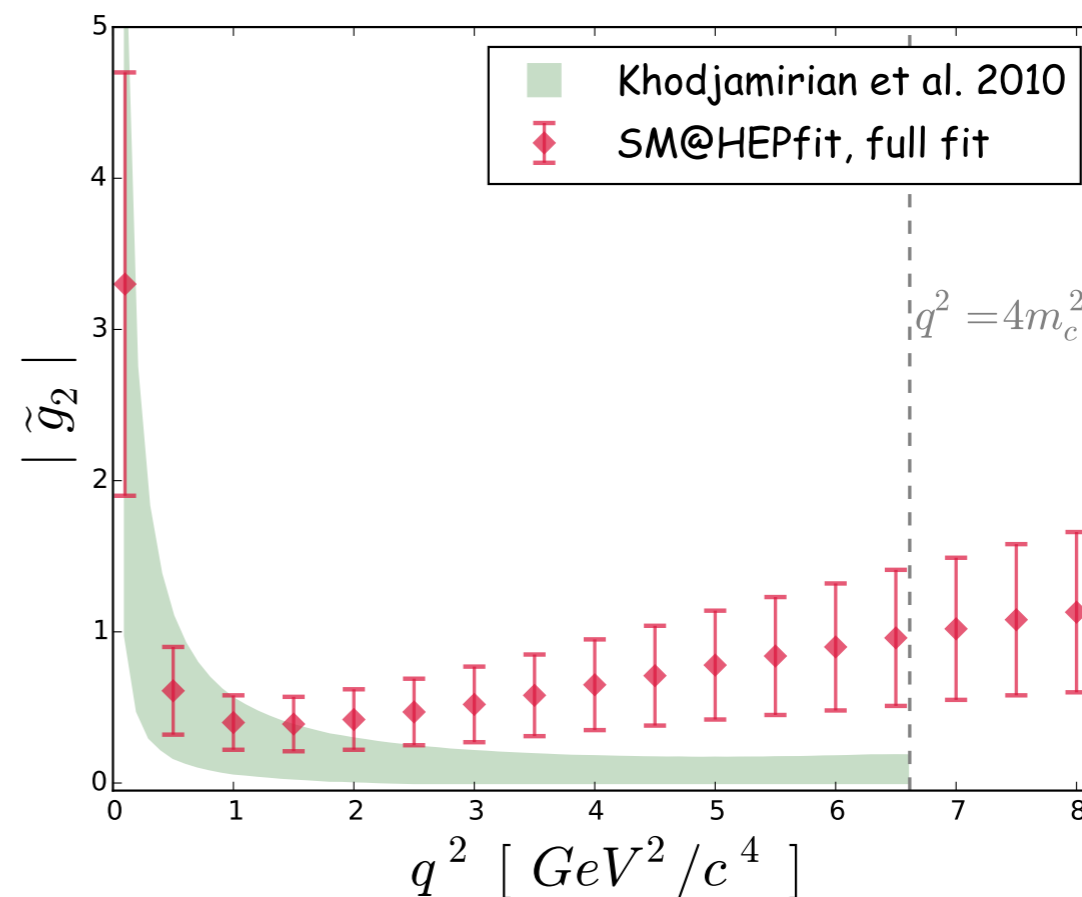
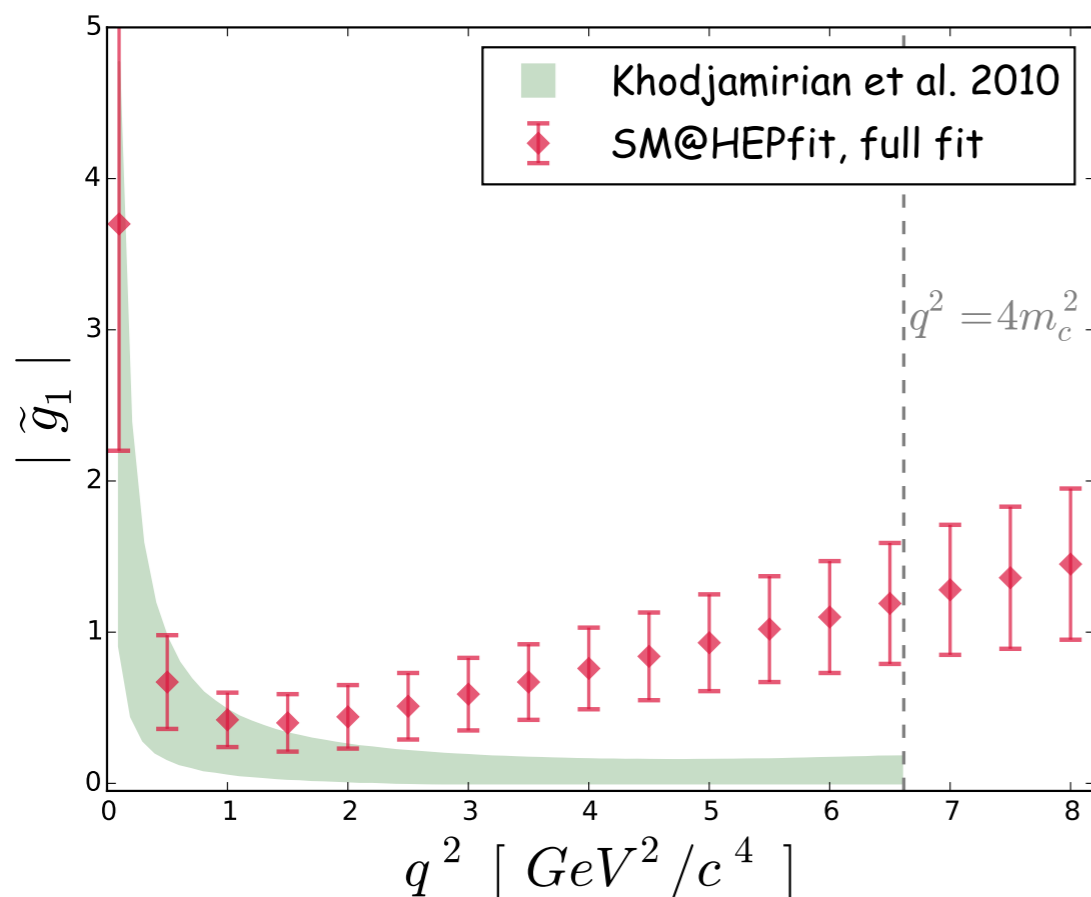
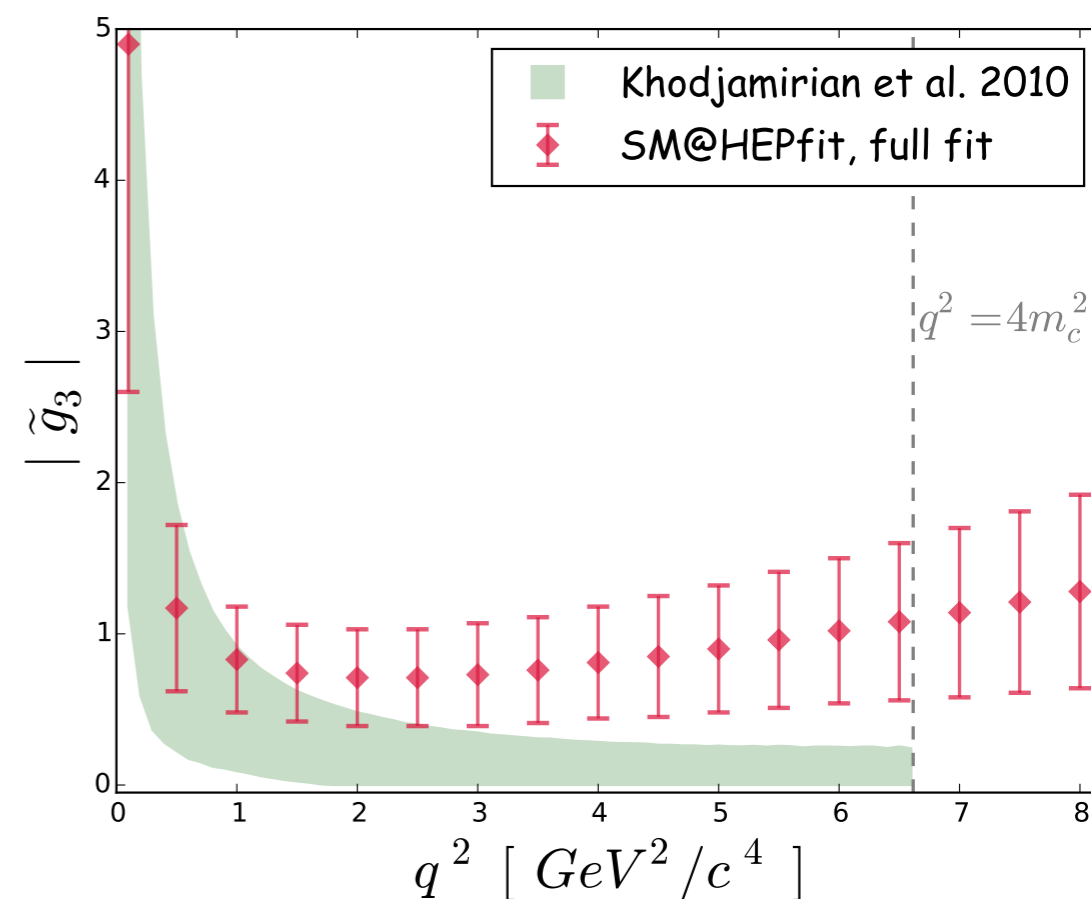
# EXTRACTING THE NON-PERTURBATIVE HADRONIC CONTRIBUTION

$$\tilde{g} \equiv \Delta C_9^{(\text{non pert.})} / (2C_1)$$

see *arXiv:1006.4945*

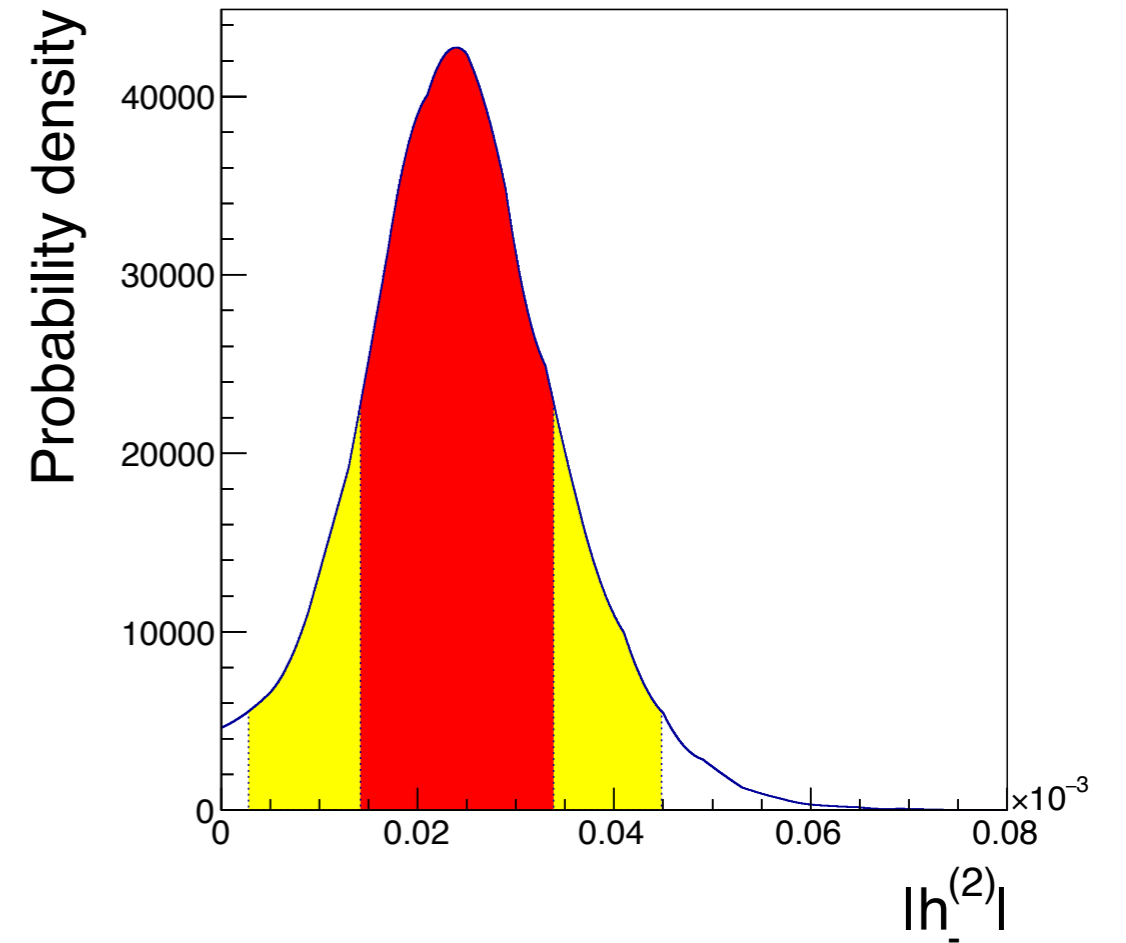
## DISCLAIMER

NP contribution in  $C_7$  and/or  $C_9$  cannot reproduce such a  $q^2$  behaviour



# RESULTS FOR THE HADRONIC PARAMETERS $h_\lambda$

Parameter	Absolute value	Phase (rad)
$h_0^{(0)}$	$(5.7 \pm 2.0) \cdot 10^{-4}$	$3.57 \pm 0.55$
$h_0^{(1)}$	$(2.3 \pm 1.6) \cdot 10^{-4}$	$0.1 \pm 1.1$
$h_0^{(2)}$	$(2.8 \pm 2.1) \cdot 10^{-5}$	$-0.2 \pm 1.7$
$h_+^{(0)}$	$(7.9 \pm 6.9) \cdot 10^{-6}$	$0.1 \pm 1.7$
$h_+^{(1)}$	$(3.8 \pm 2.8) \cdot 10^{-5}$	$-0.7 \pm 1.9$
$h_+^{(2)}$	$(1.4 \pm 1.0) \cdot 10^{-5}$	$3.5 \pm 1.6$
$h_-^{(0)}$	$(5.4 \pm 2.2) \cdot 10^{-5}$	$3.2 \pm 1.4$
$h_-^{(1)}$	$(5.2 \pm 3.8) \cdot 10^{-5}$	$0.0 \pm 1.7$
$h_-^{(2)}$	$(2.5 \pm 1.0) \cdot 10^{-5}$	$0.09 \pm 0.77$



$|h_-^{(2)}|$  differs from zero at more than **95.45%** probability,  
 thus **disfavouring** the interpretation of the hadronic correction  
 as **NP contributions in  $C_7$  and/or  $C_9$**

# The SM@HEPfit analysis, case II

## EXPERIMENTAL WEIGHTS :

$q^2$  experimental binning

$F_L, A_{FB}, S_{3,4,5,7,8,9}$   
*correlated in each bin of  $q^2$*

[0.1, 0.98], [1.1, 2.5], [2.5, 4.0]  
[4.0, 6.0], [6.0, 8.0]

$\mathcal{B}(B \rightarrow K^* \mu\mu)$

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kinematical endpoint

$\mathcal{B}(B \rightarrow K^* ee), F_L, P_{1,2,3}$

[0.03, 1], [0.002, 1.12]

## THEORY WEIGHTS :

LCSR FFs with correlation matrix for low  $q^2$  region only

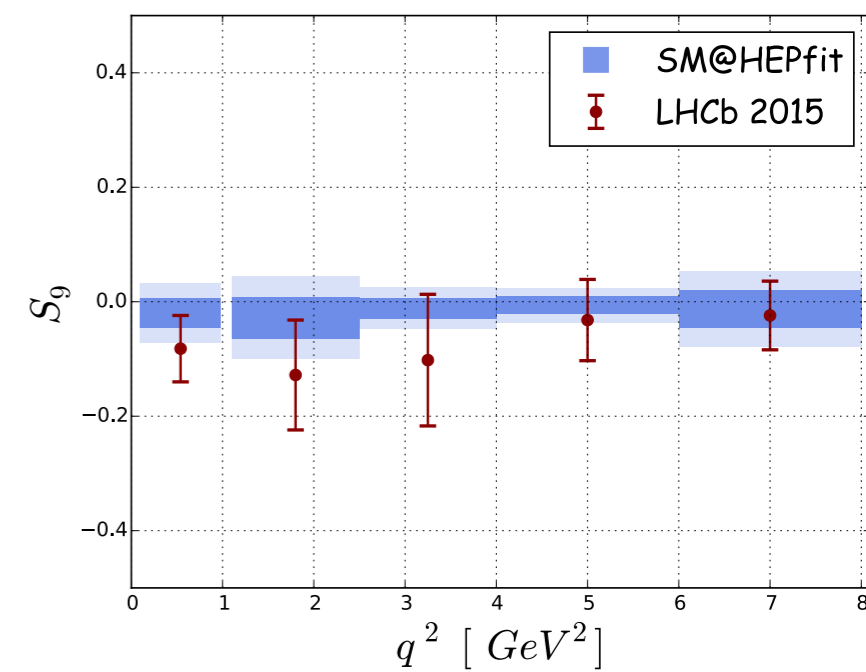
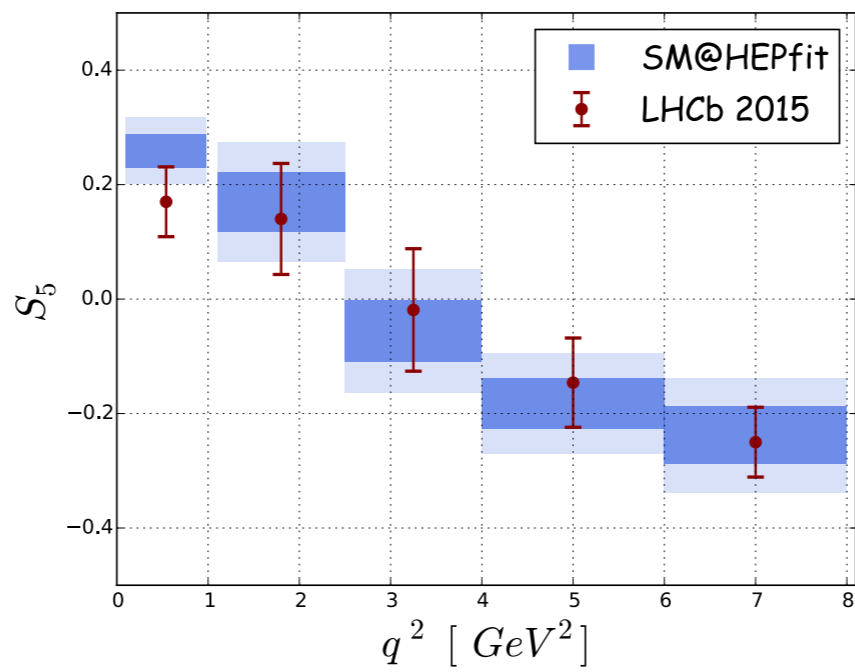
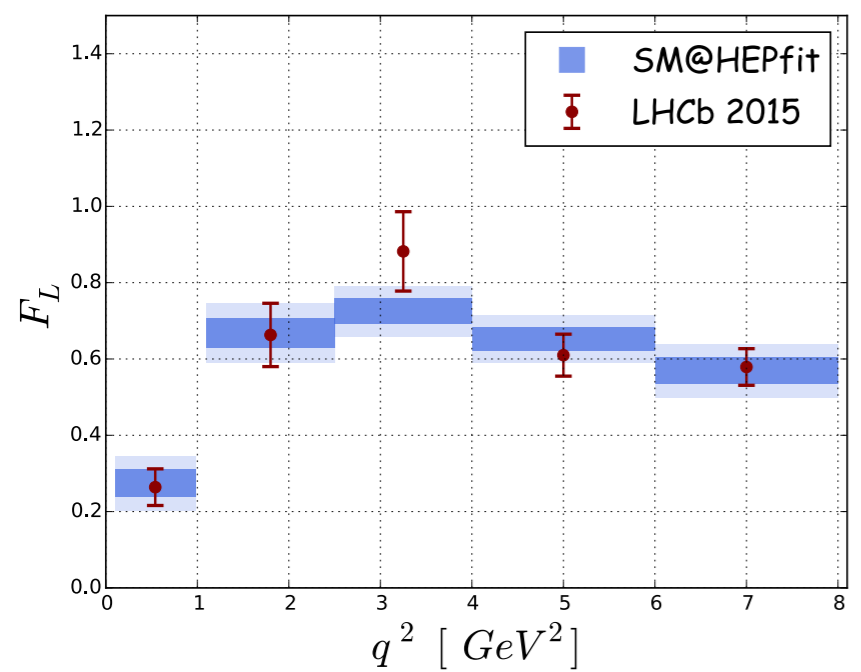
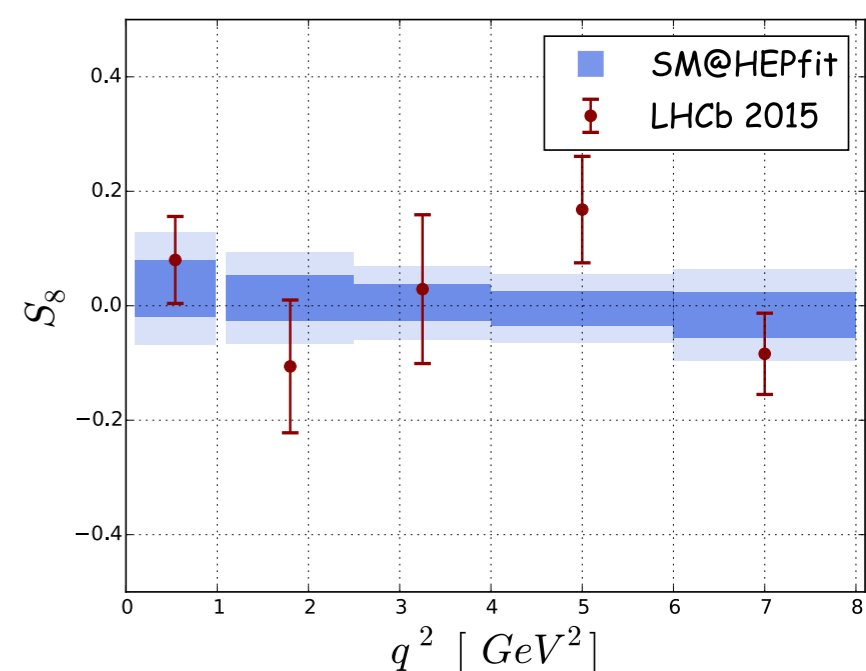
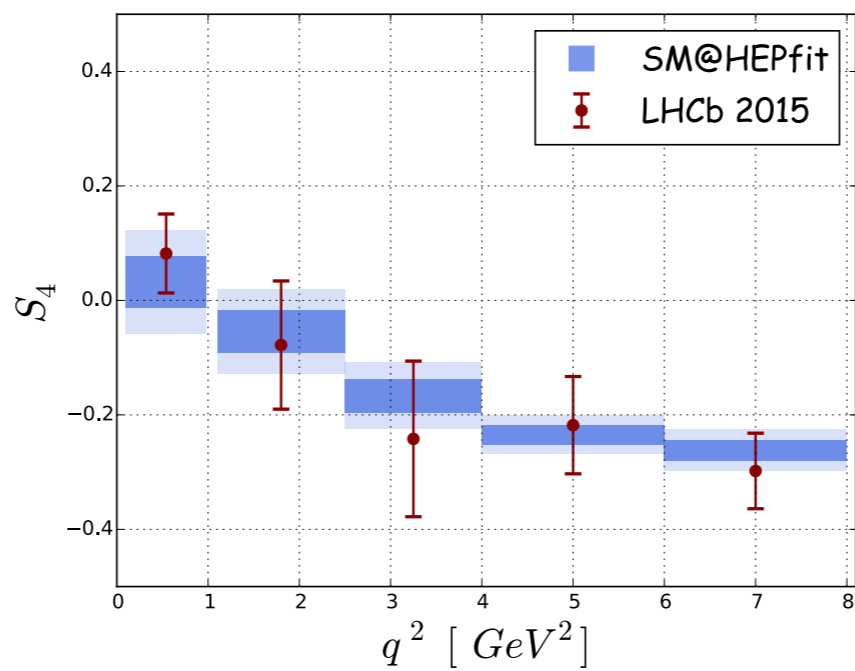
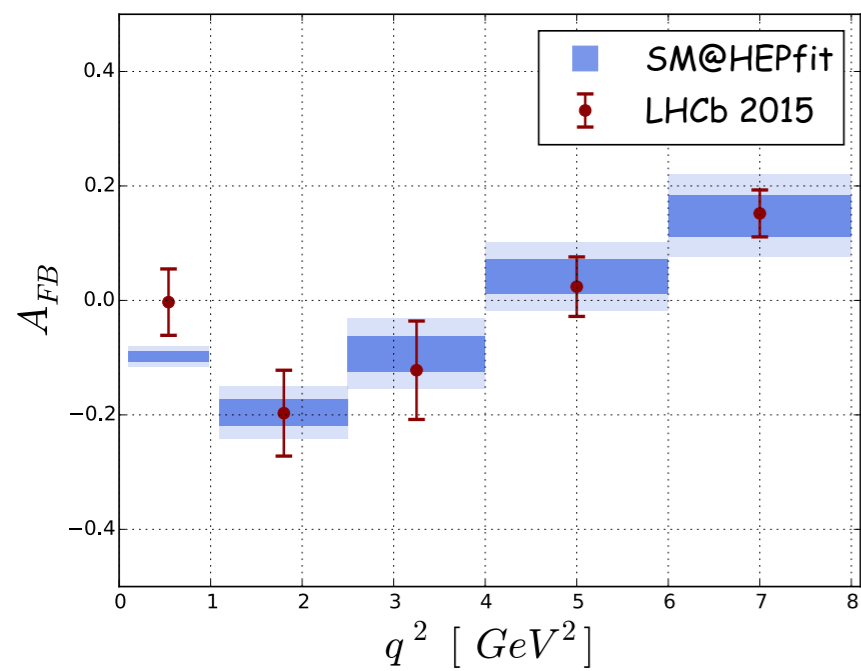
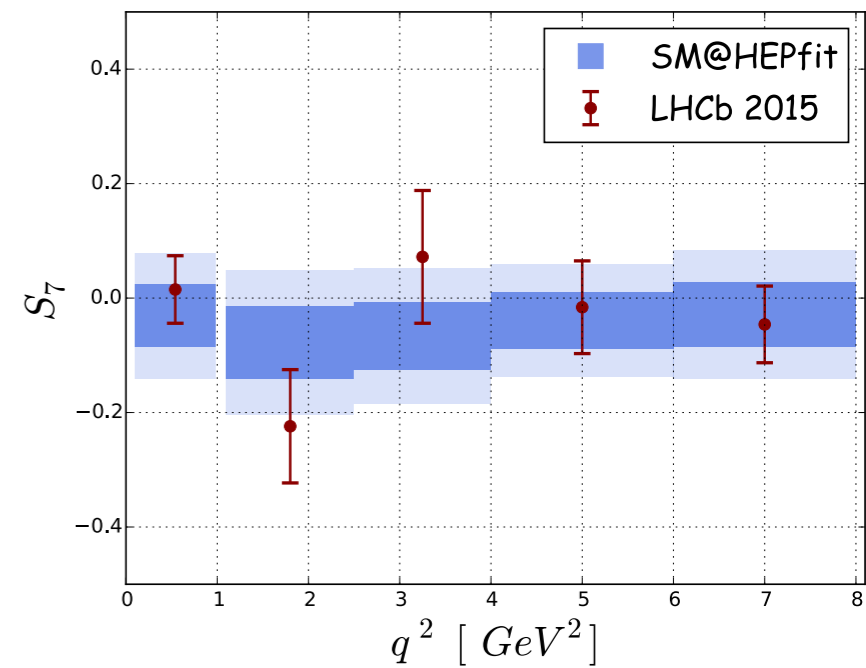
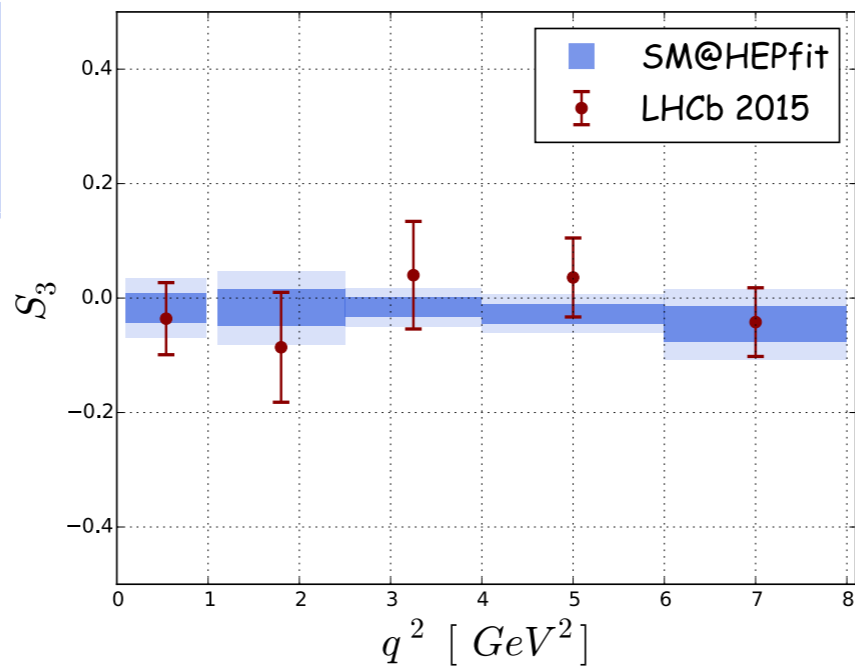
Amplitude helicity suppression at kinematical endpoint

No theoretical info on  $h_\lambda$

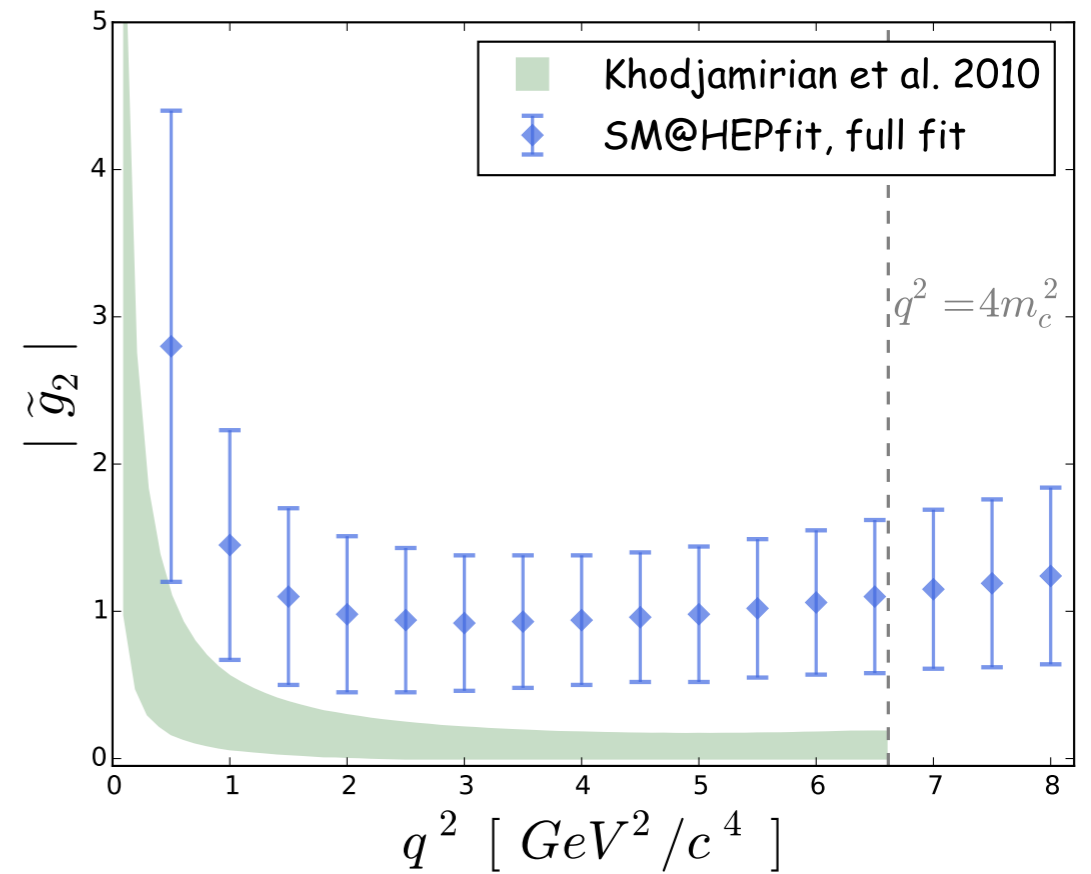
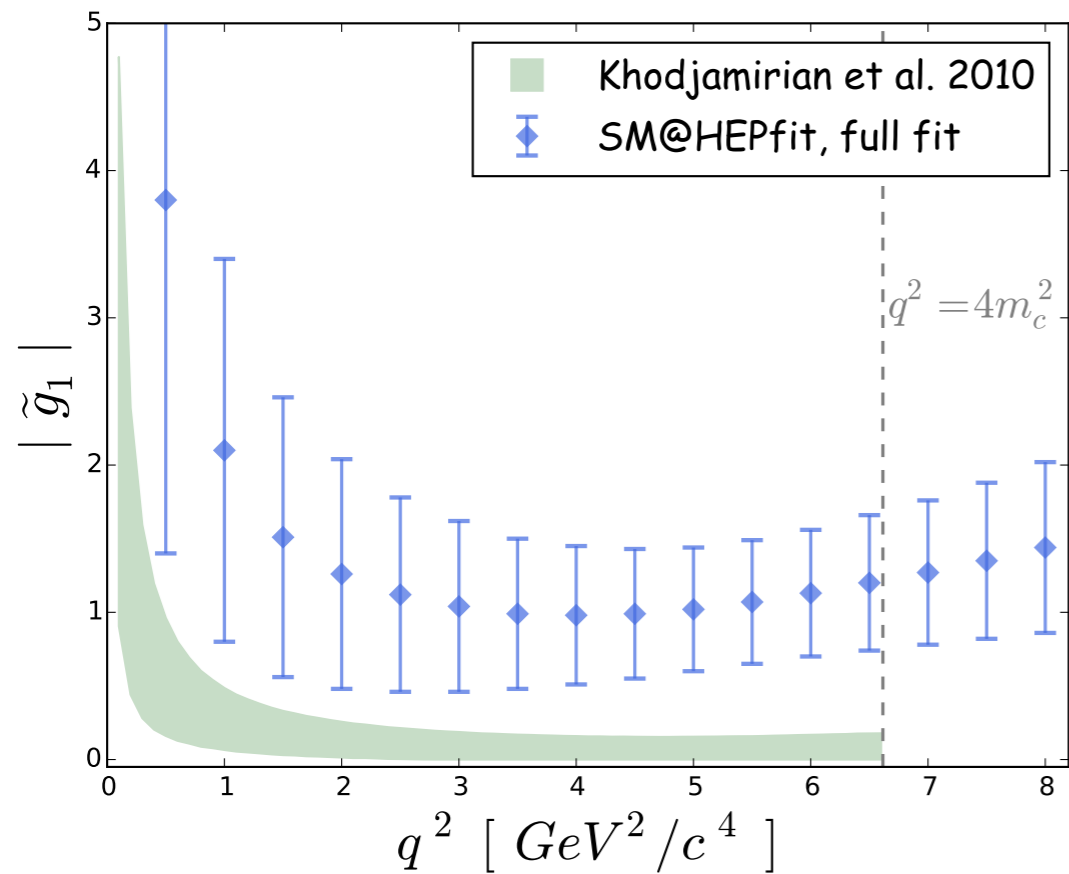
DATA-DRIVEN



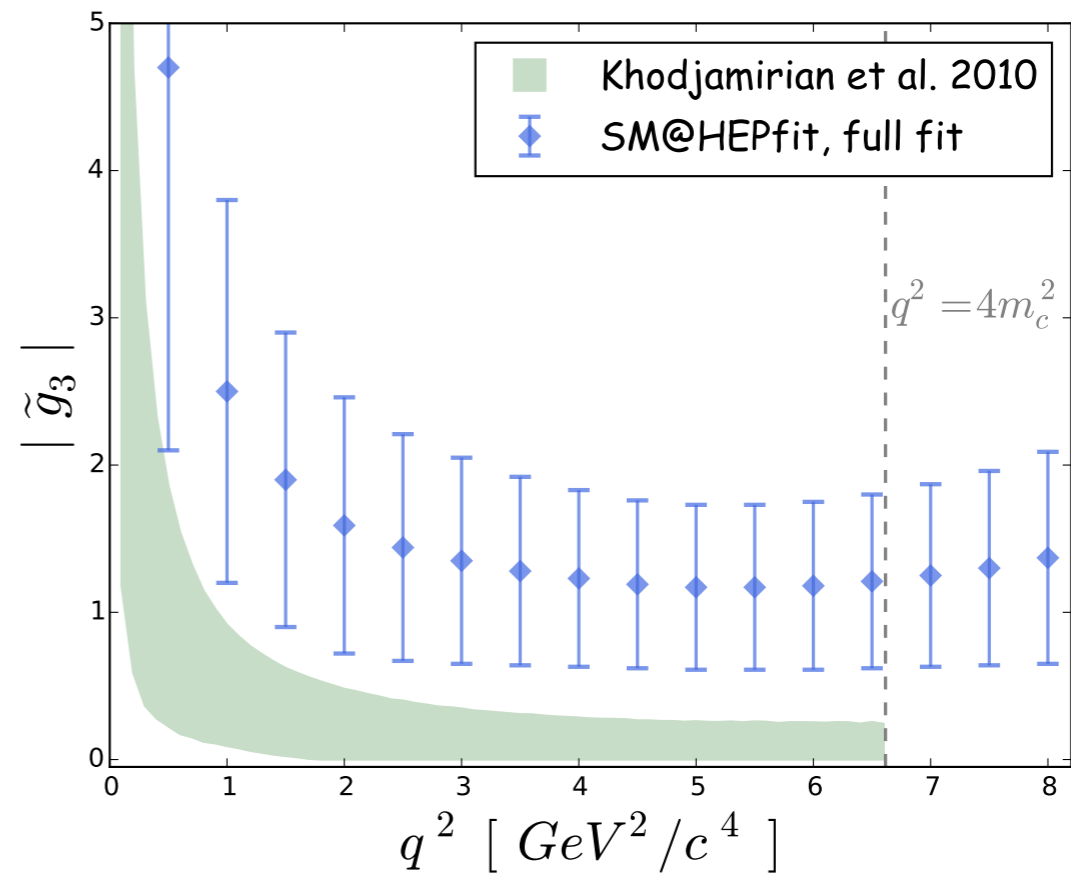
# HEPfit full fit



# EXTRACTING (again) THE NON-PERTURBATIVE HADRONIC CONTRIBUTION



A data-driven extraction leads to an inflated contribution with respect to LCSR estimate with unavoidable larger errors



No firm conclusions on  $q^2$  behaviour

# RESULTS FOR THE HADRONIC PARAMETERS $h_\lambda$ (again)

Parameter	Absolute value	Phase (rad)
$h_0^{(0)}$	$(5.8 \pm 2.1) \cdot 10^{-4}$	$3.54 \pm 0.56$
$h_0^{(1)}$	$(2.9 \pm 2.1) \cdot 10^{-4}$	$0.2 \pm 1.1$
$h_0^{(2)}$	$(3.4 \pm 2.8) \cdot 10^{-5}$	$-0.4 \pm 1.7$
$h_+^{(0)}$	$(4.0 \pm 4.0) \cdot 10^{-5}$	$0.2 \pm 1.5$
$h_+^{(1)}$	$(1.4 \pm 1.1) \cdot 10^{-4}$	$0.1 \pm 1.7$
$h_+^{(2)}$	$(2.6 \pm 2.0) \cdot 10^{-5}$	$3.8 \pm 1.3$
$h_-^{(0)}$	$(2.5 \pm 1.5) \cdot 10^{-4}$	$-1.53 \pm 0.75 \cup 1.85 \pm 0.45$
$h_-^{(1)}$	$(1.2 \pm 0.9) \cdot 10^{-4}$	$-0.90 \pm 0.70 \cup 0.80 \pm 0.80$
$h_-^{(2)}$	$(2.2 \pm 1.4) \cdot 10^{-5}$	$0.0 \pm 1.2$

$|h_-^{(2)}|$  differs from zero **at more than 68.3% probability**, thus **no firm conclusion** on the interpretation of the hadronic correction **can be drawn**

# COMPARING THE FITS

To **compare** different scenarios we used the **information criterion**, defined as

$$IC = -2\overline{\log L} + 4\sigma_{\log L}^2$$

The **first term** measures the **goodness of the fit**, while the **second** is a **penalty term** counting the number of **effective parameters**

Better models have smaller IC

<b>No constraints</b> on power corrections:	IC = 72
Khodjamirian et al. only for $q^2 \lesssim 1 \text{ GeV}^2$ :	IC = 78
Same as above, but <b>no <math>q^4</math> term</b> :	IC = 81
Khodjamirian et al. for <b>all <math>q^2</math></b> :	IC = 111

# FINAL REMARKS

In our **Bayesian analysis** of  $B$  to  $K^* \mu\mu$  we **do not hit the anomalies**, **provided we use the current LCSR estimates** for the non-factorizable hadronic contribution only in the reliable regime, i.e.  $q^2 \lesssim 1 \text{ GeV}^2$

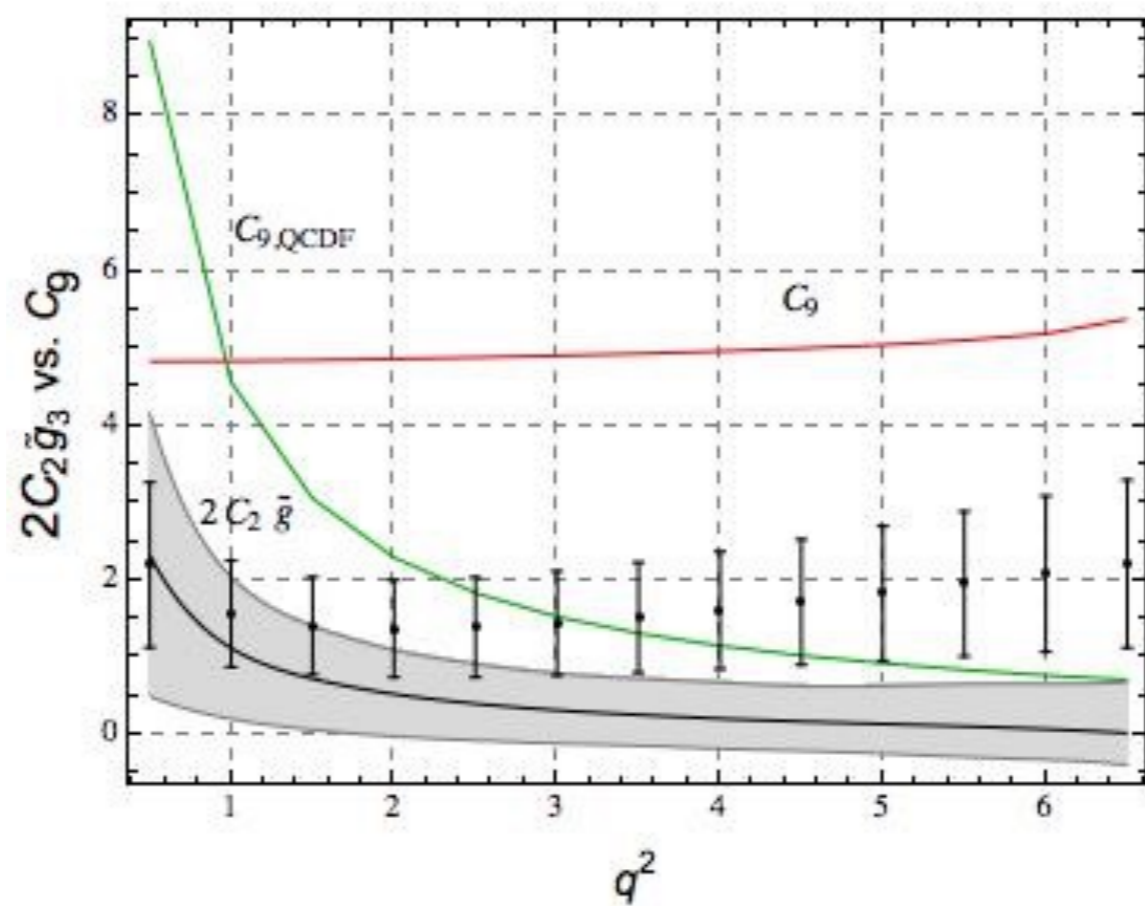
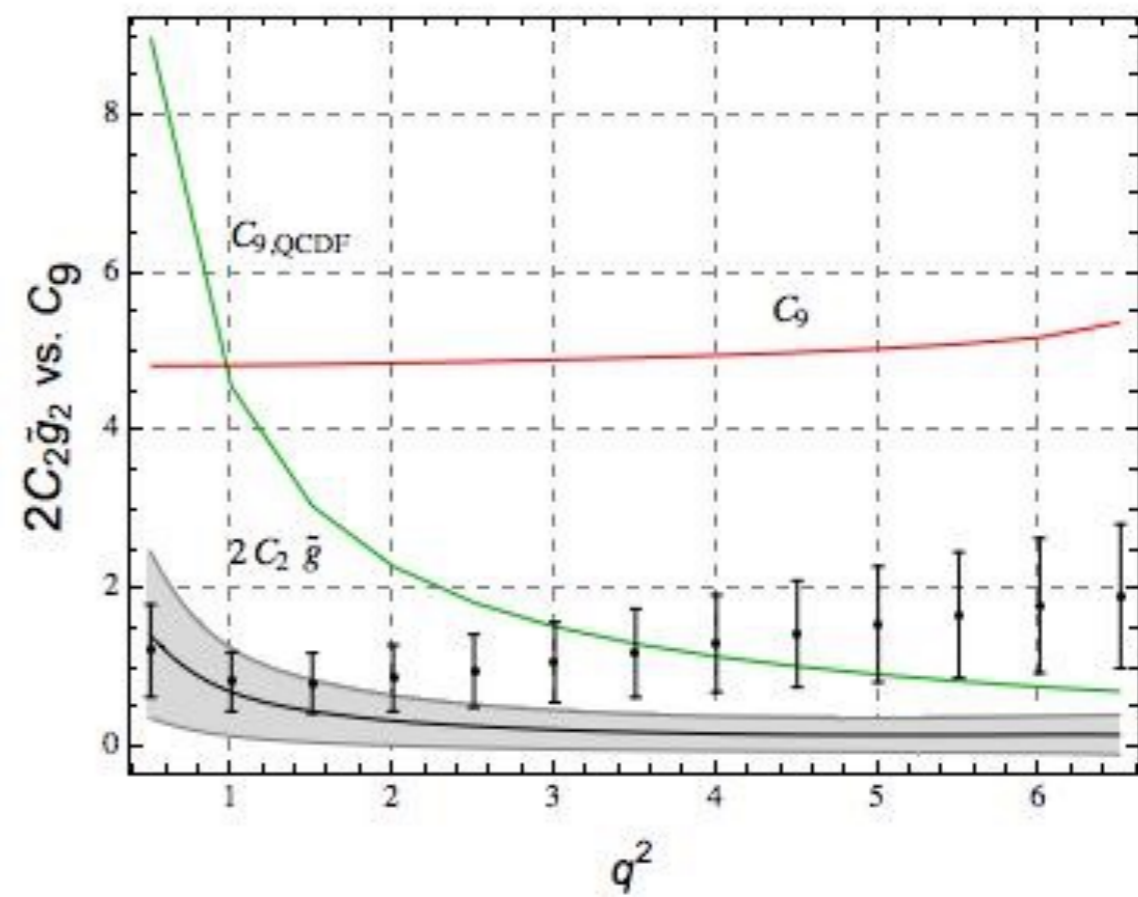
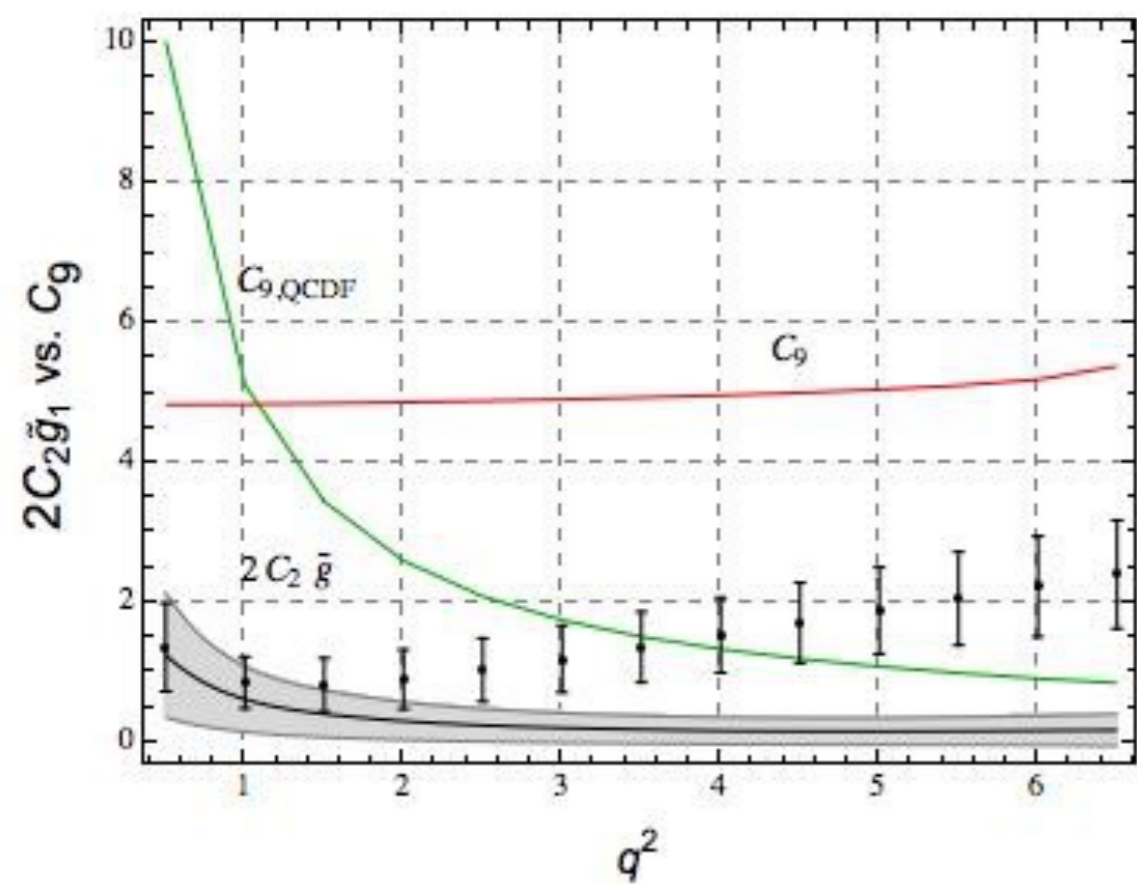
The extracted hadronic contribution displays an **expected growth** in respect to the current LCSR estimates for **higher  $q^2$** , showing a **behaviour that would hardly resemble** contribution mainly due to **NP**

The **Data-Driven** scenario shows that **experimental information** at hand is **not sufficient** to discriminate a definitive  $q^2$  behaviour

We need either **more statistics from LHCb data** or a **theoretical breakthrough** in the **estimate of non-factorizable hadronic contribution** before being able to probe NP looking at  $B$  to  $K^* \mu\mu$  alone

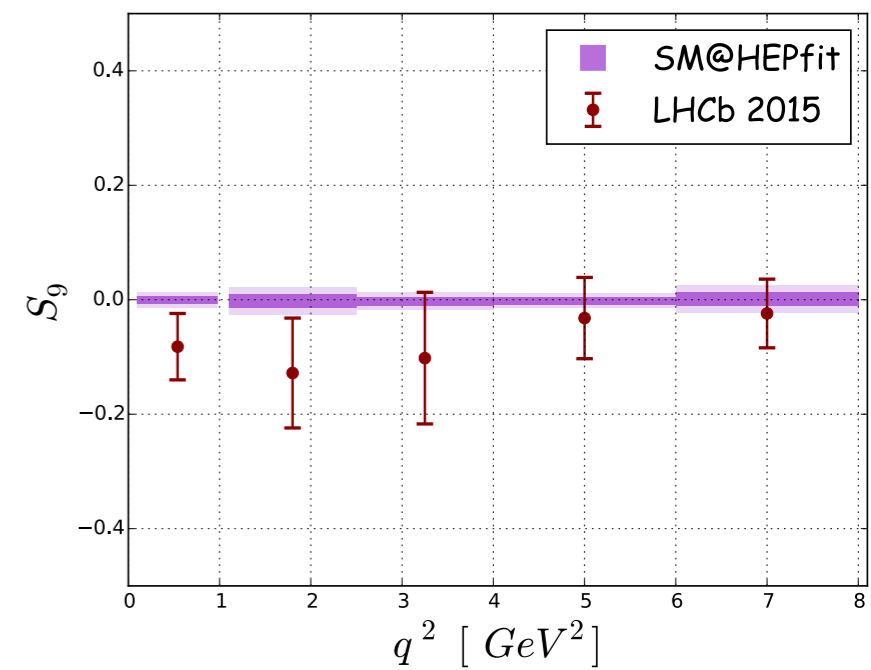
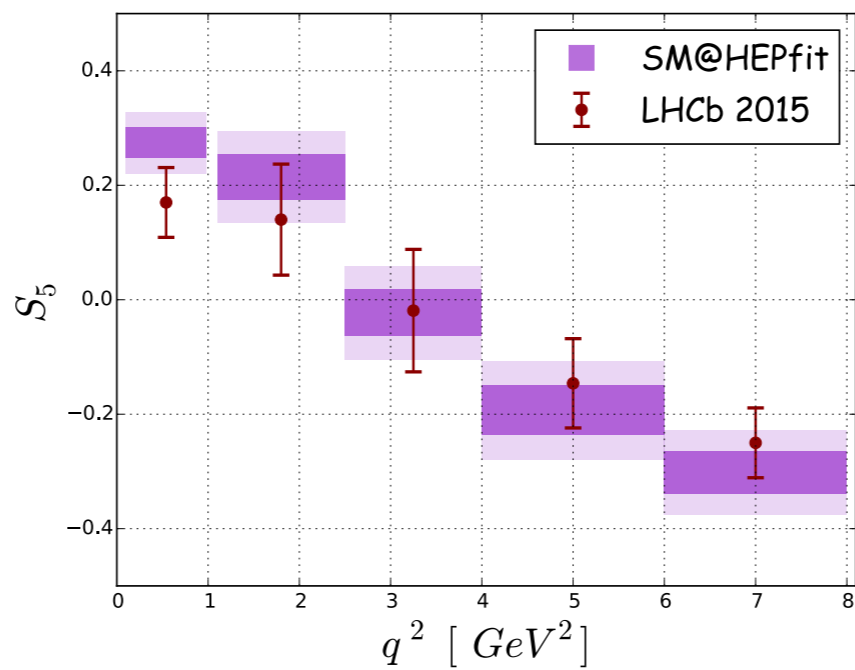
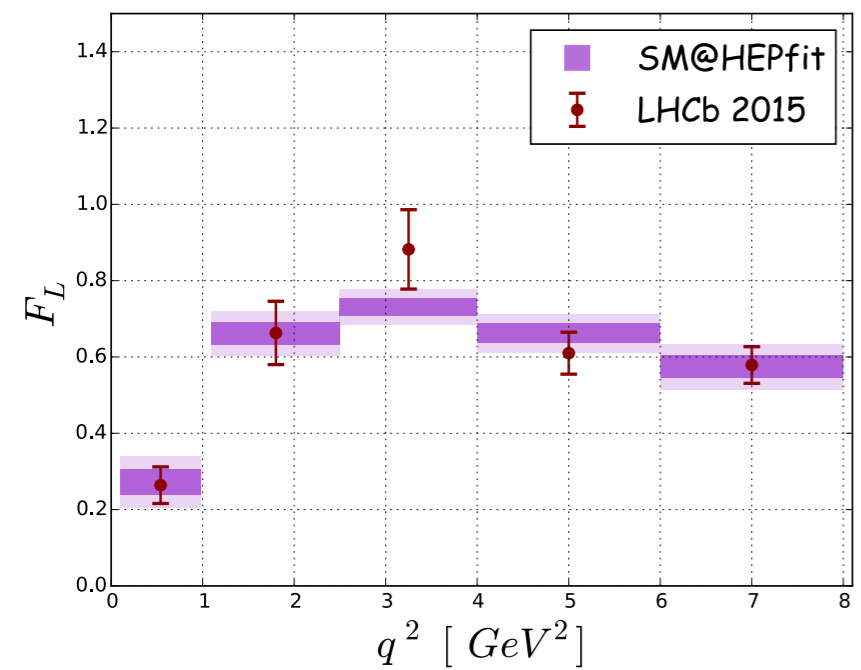
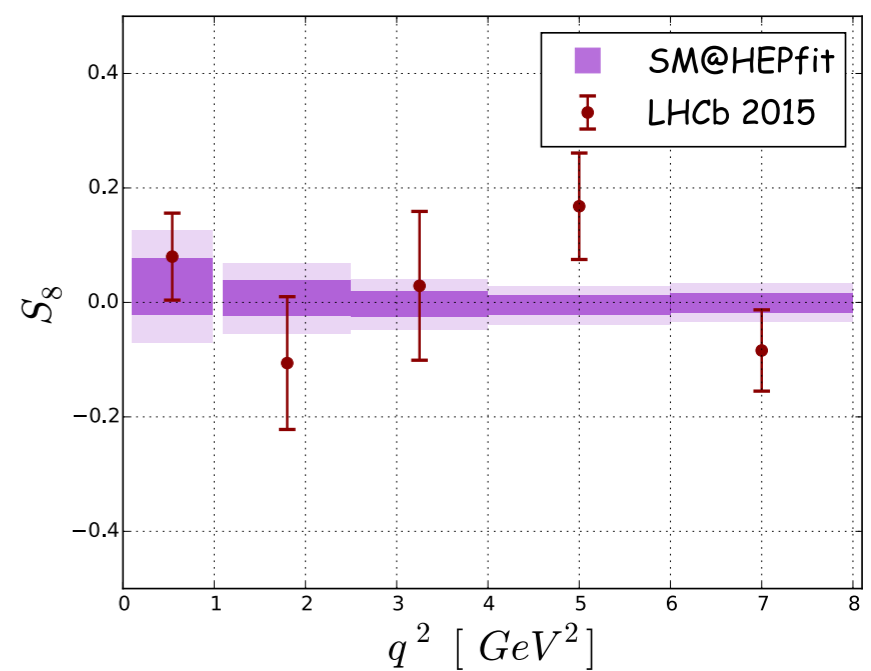
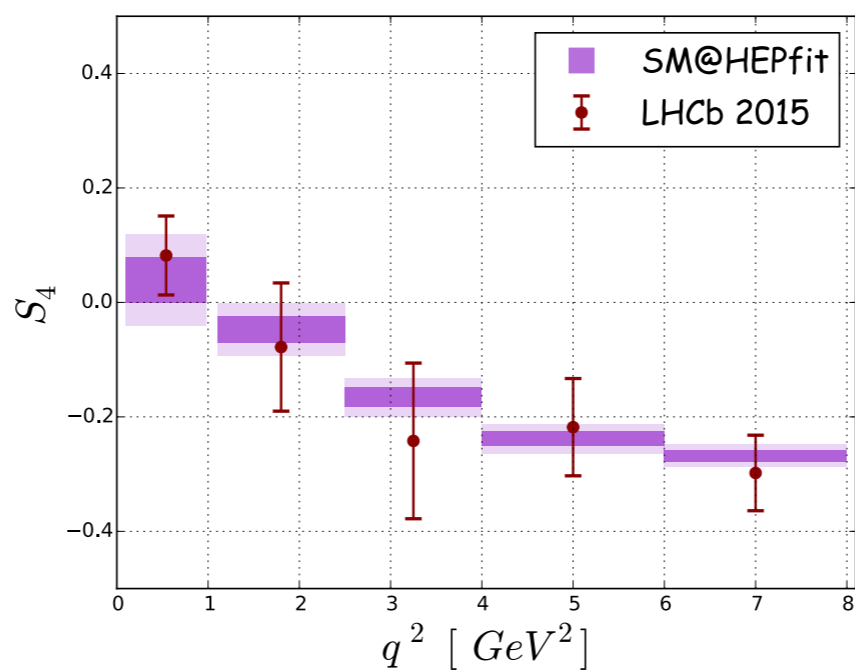
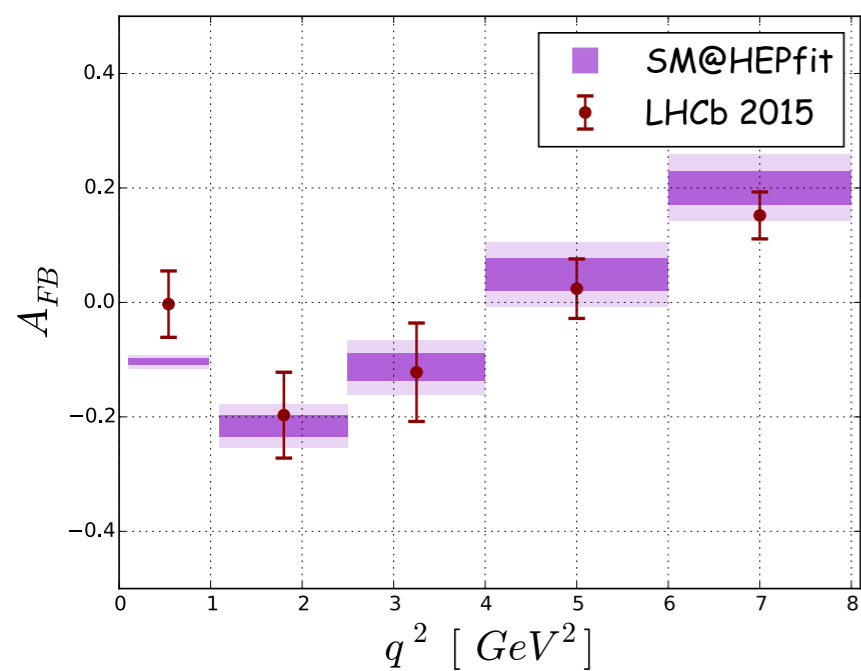
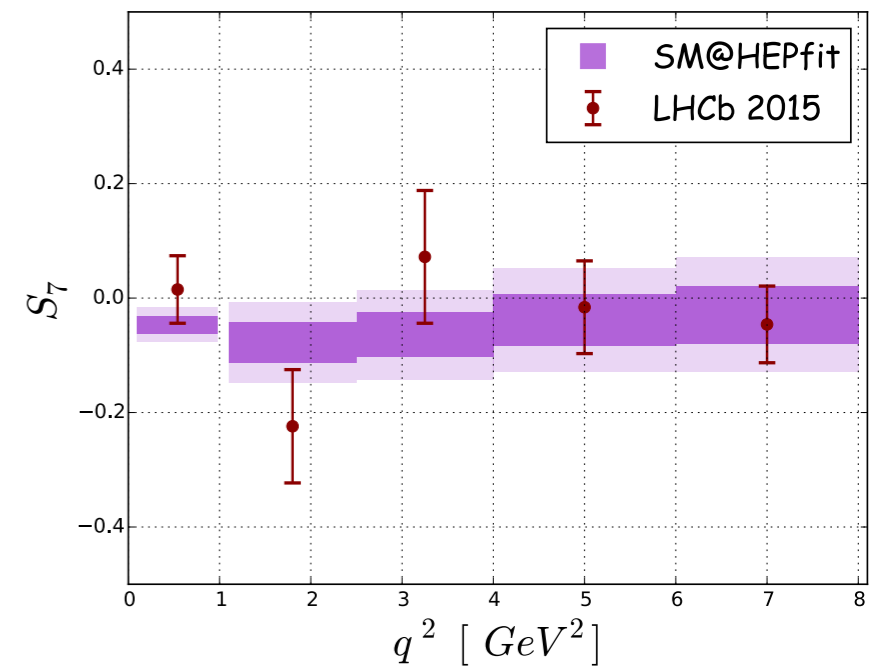
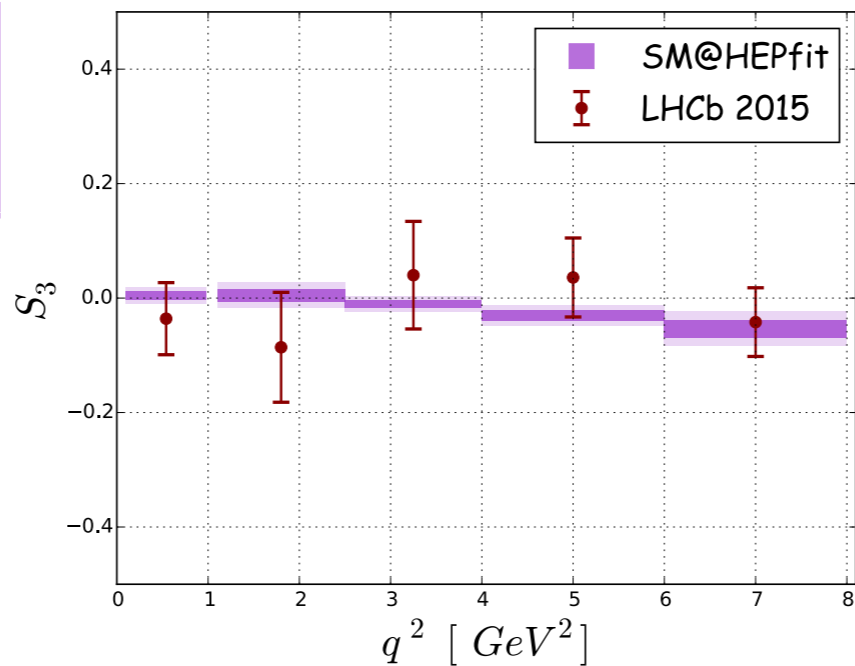
**Thank You!**

**Backup  
slides**





HEPfit  
no  $h_{\Lambda}^{(2)}$



# HEPfit

“Full” Khodj.

