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Unbinned angular analysis of $B^0 \rightarrow K^{*0} \mu^+ \mu^-$

Precision measurement of a fully parameterised rare decay

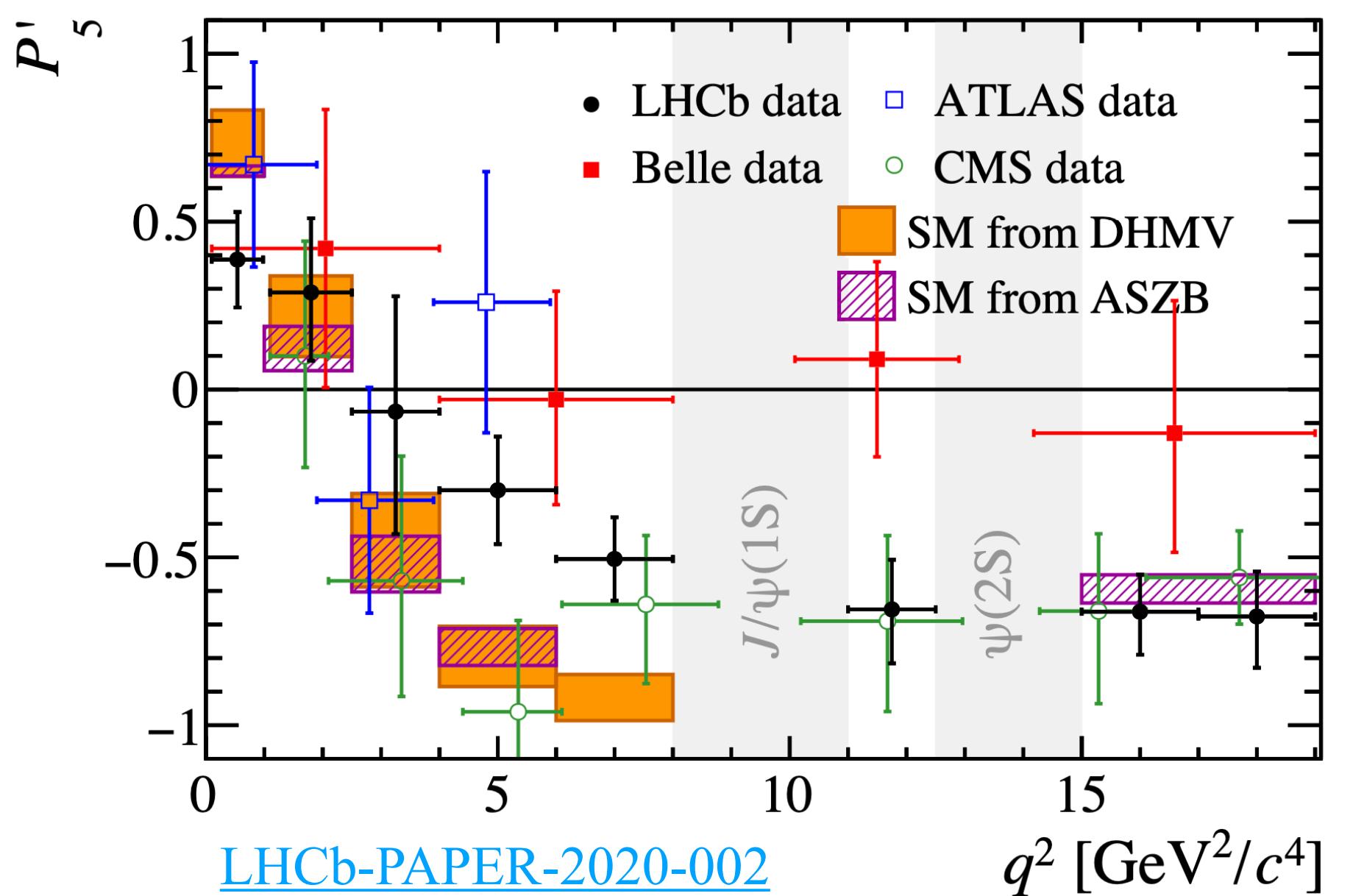
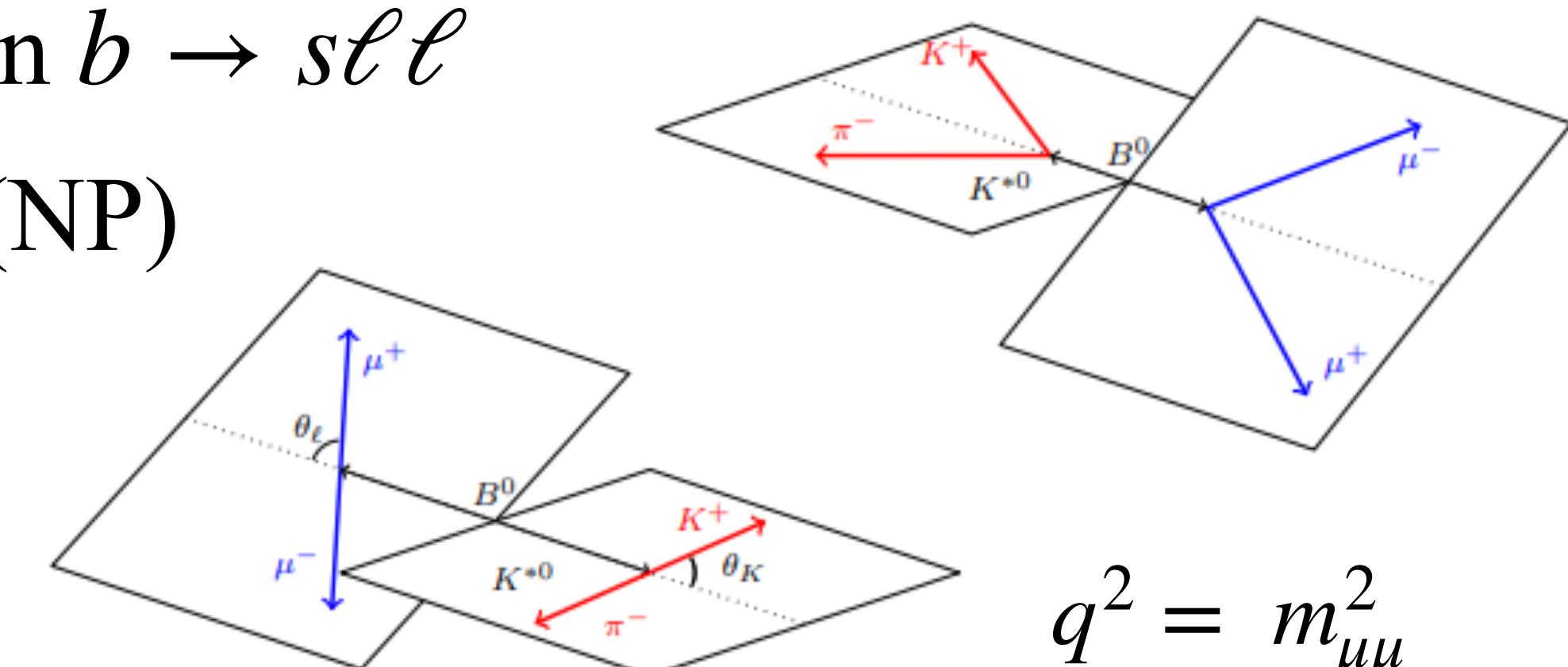
Martin Andersson

Leukerbad
19th January 2023

$B^0 \rightarrow K^{*0} \mu^+ \mu^-$

- ▶ Interesting part is the flavour changing neutral current in $b \rightarrow s\ell\ell$
- ▶ Suppressed in the SM \rightarrow sensitive to New Physics (NP)
- ▶ The phase space of the decay is fully described by five degrees of freedom: $q^2, \theta_\ell, \theta_K, \phi$ and $m_{K\pi}$
- ▶
$$\frac{d\Gamma[B^0 \rightarrow K^{*0} \mu^+ \mu^-]}{dq^2 d\Omega dm_{K\pi}^2} = \frac{9}{32\pi} \sum_i J_i(q^2) f_i(\cos \theta_\ell, \cos \theta_K, \phi) g_i(m_{K\pi}^2)$$

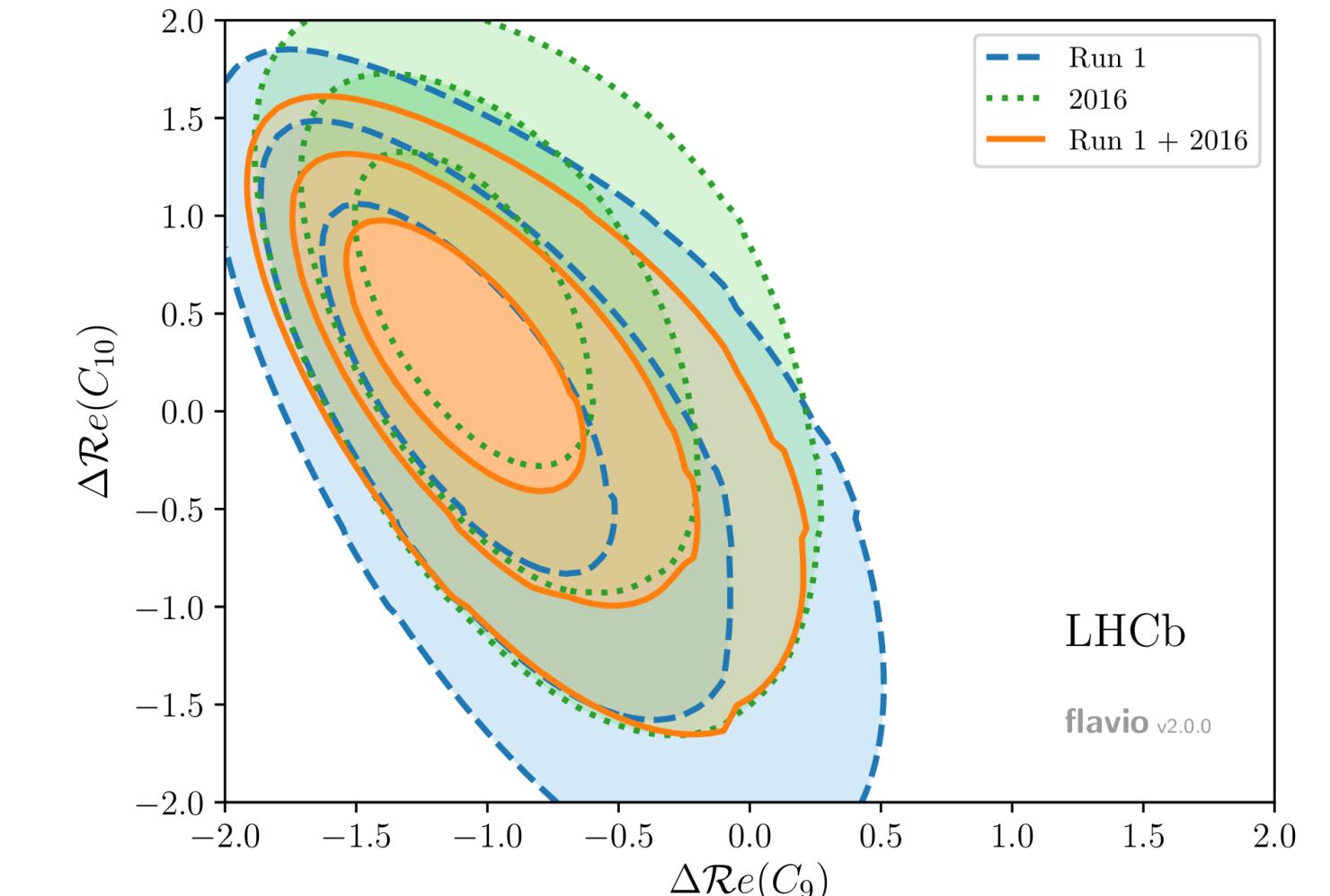
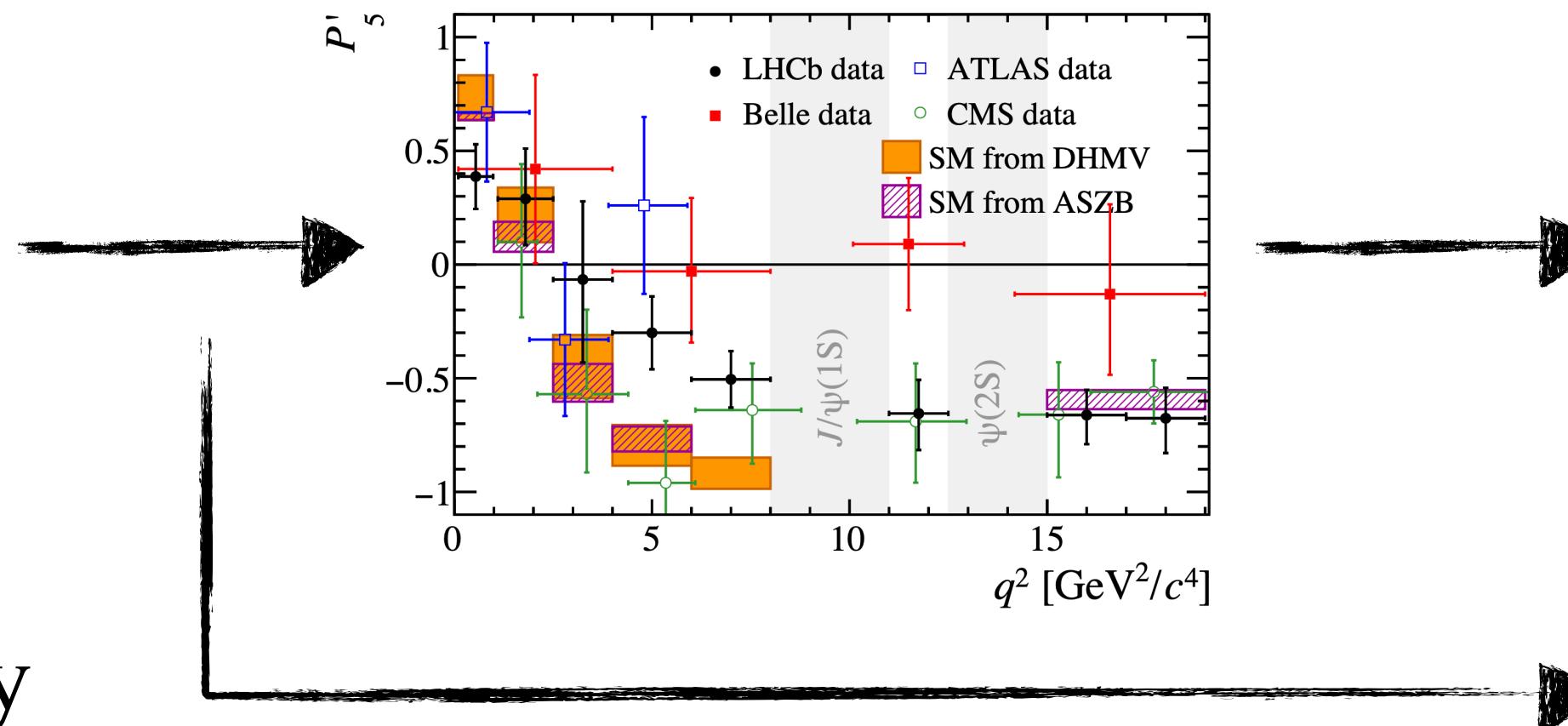
$J_i(q^2)$ Angular observables
 $f_i(\cos \theta_\ell, \cos \theta_K, \phi)$ Angular distributions
- ▶ Rich structure of K^{*0} gives particular sensitivity to NP
- ▶ Reduced theory uncertainties
- ▶ >3 sigma global anomaly observed in $K^{*0} \mu^+ \mu^-$
- ▶ Similar tensions seen in other $B \rightarrow V\ell\ell$ modes



Main motivation

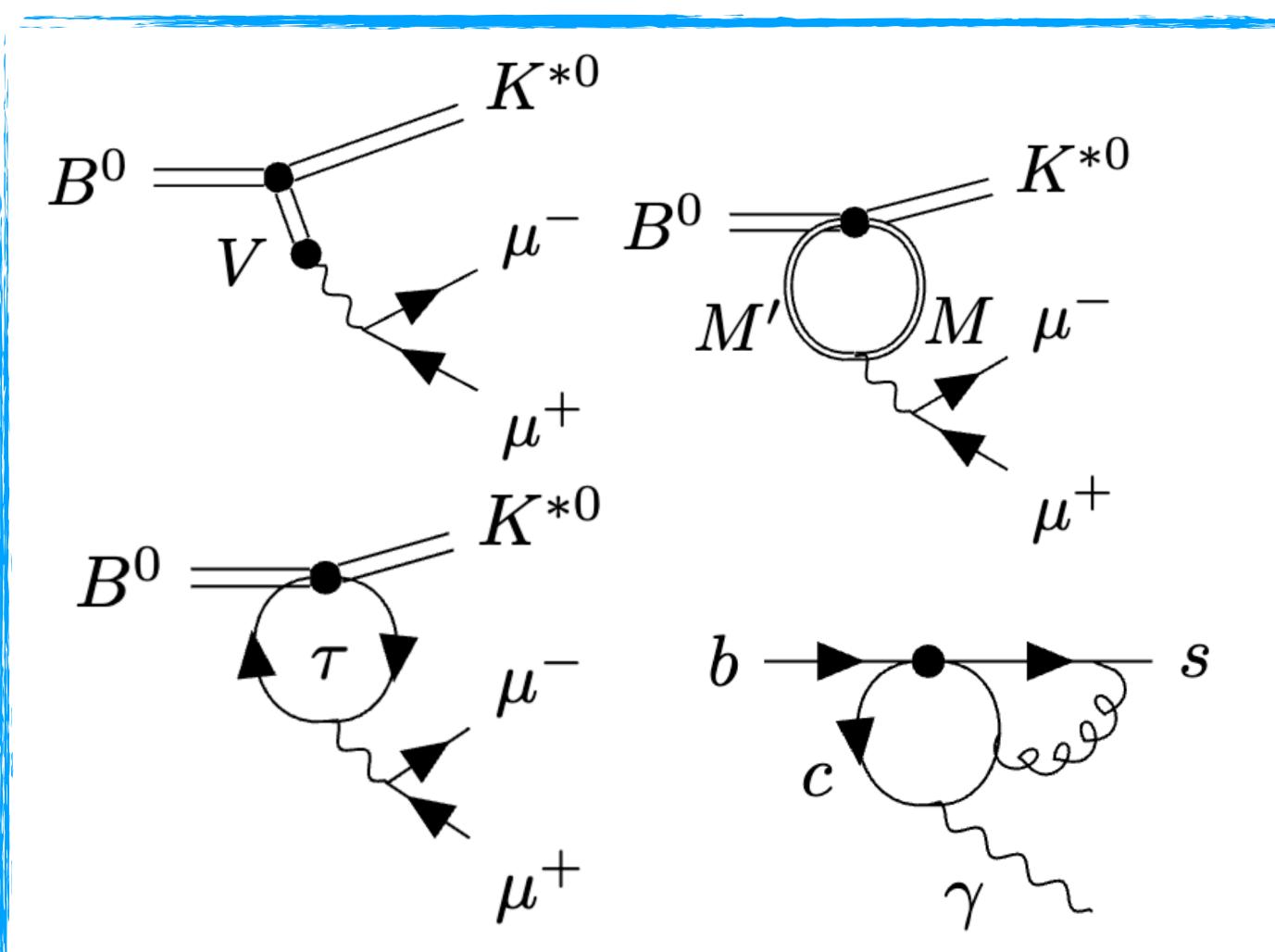
- ▶ Instead of the binned approach:

$$\frac{d\Gamma[B^0 \rightarrow K^{*0} \mu^+ \mu^-]}{dq^2 d\Omega dm_{K\pi}^2}$$

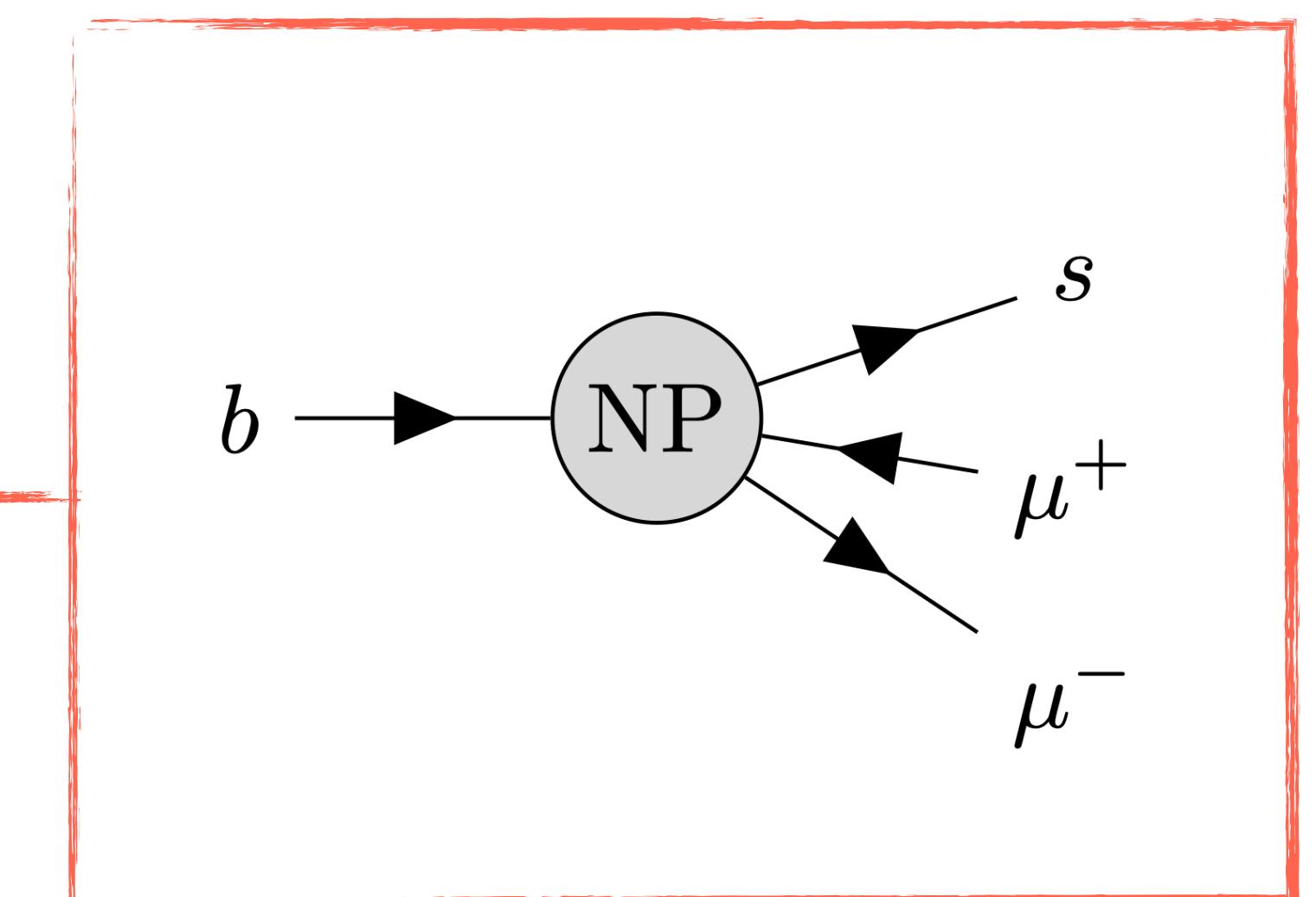


[LHCb-PAPER-2020-002](#)

- ▶ Parameterise the decay amplitudes from WCs, FFs and non-local contributions



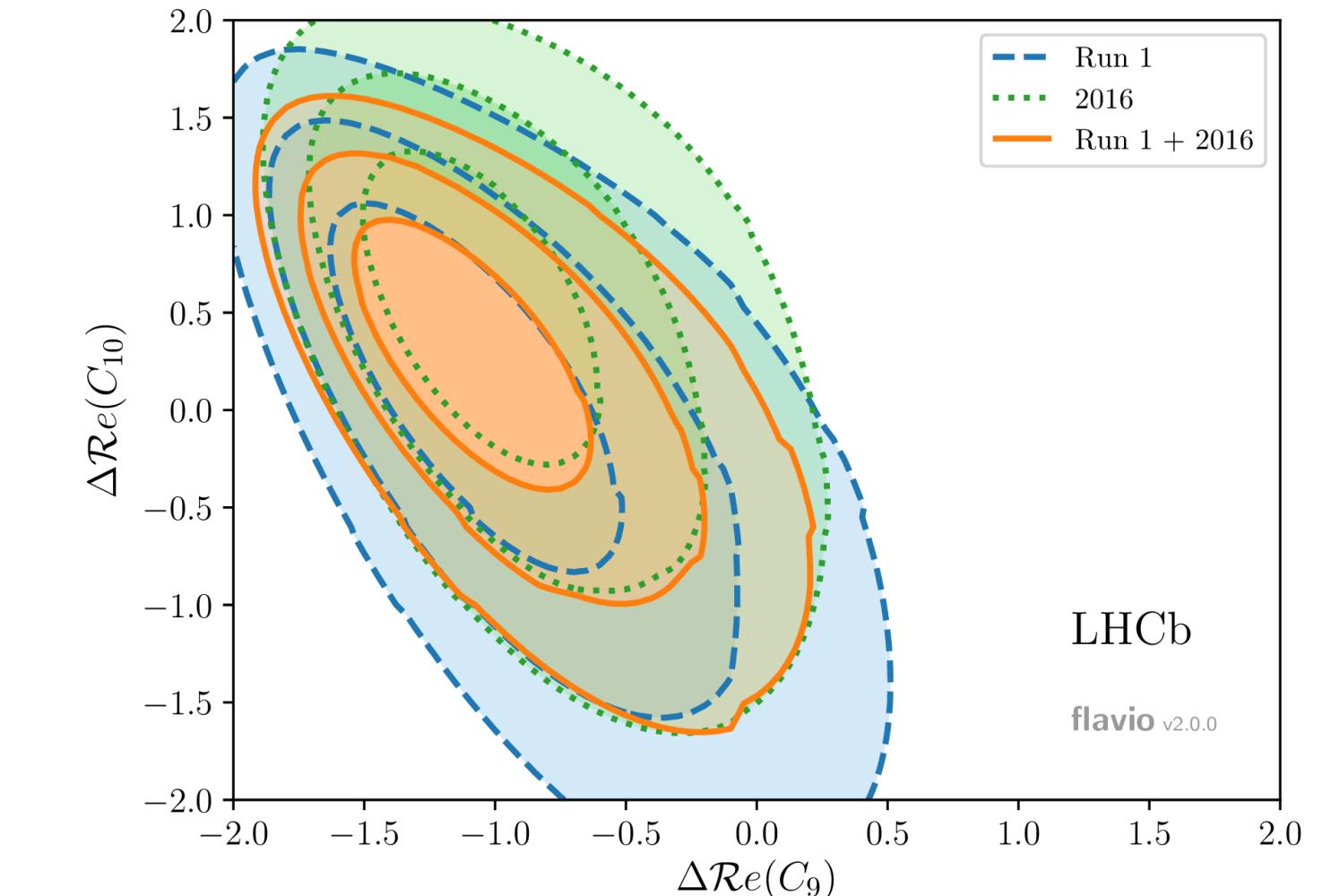
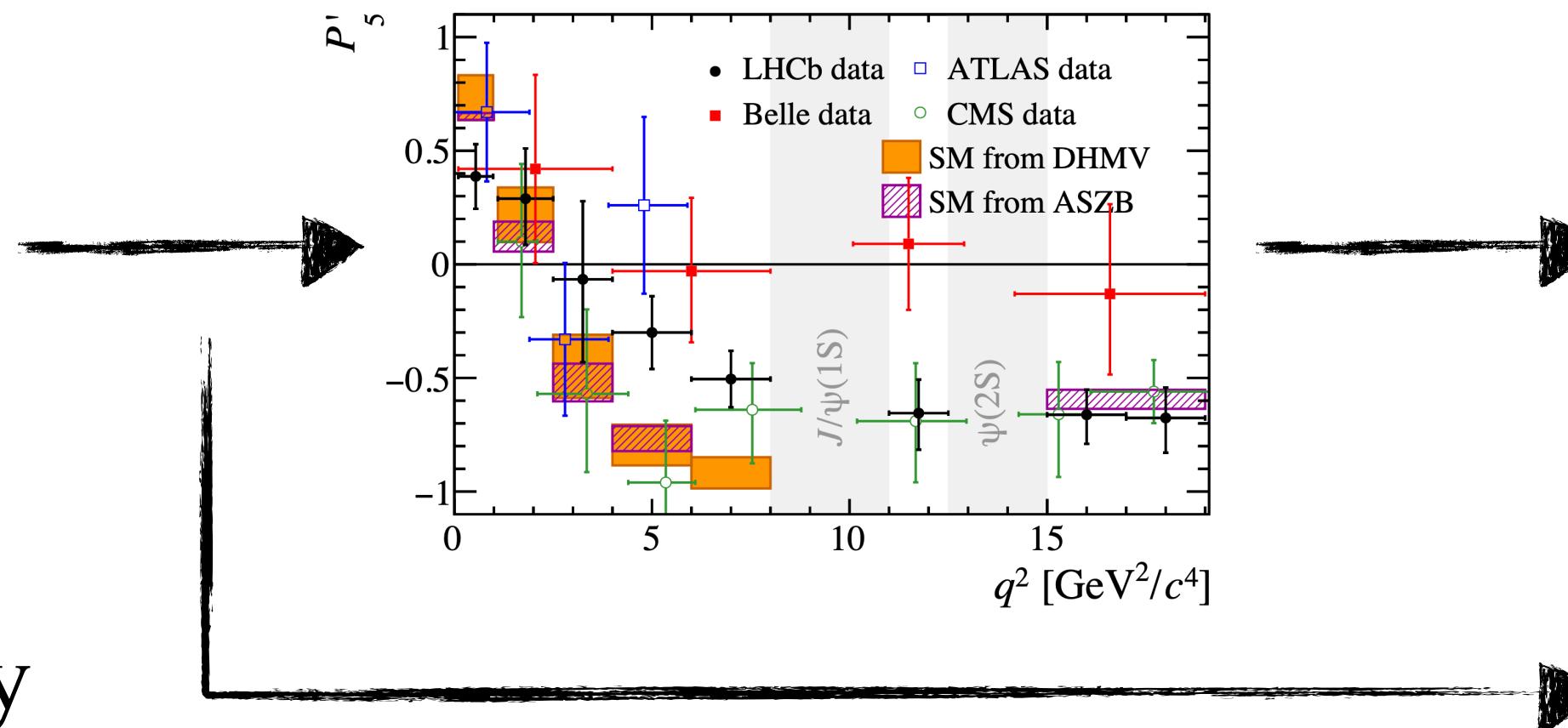
Interference with non-local contributions
OR
NP in the vector coupling
 C_9 ?



Main motivation

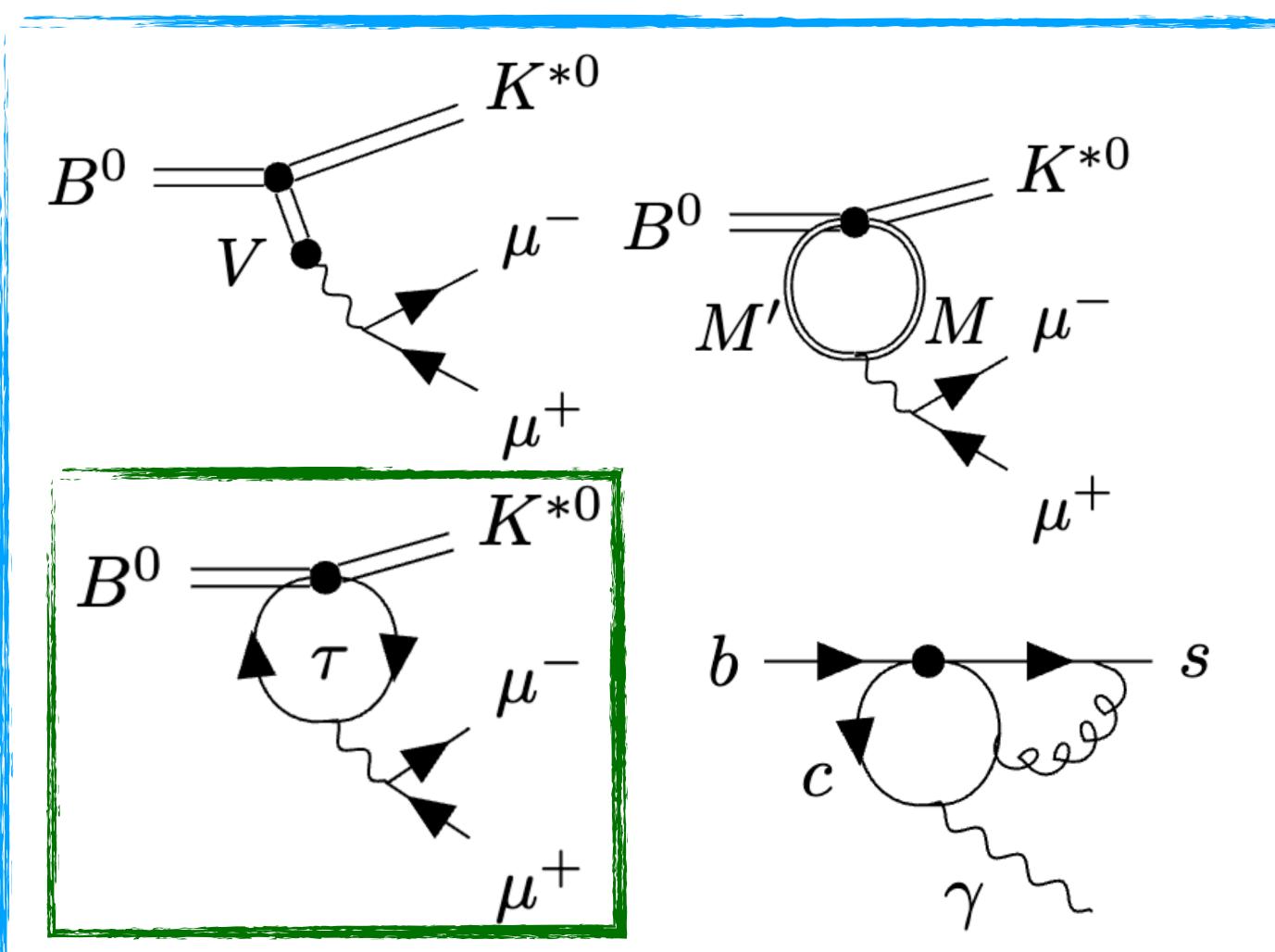
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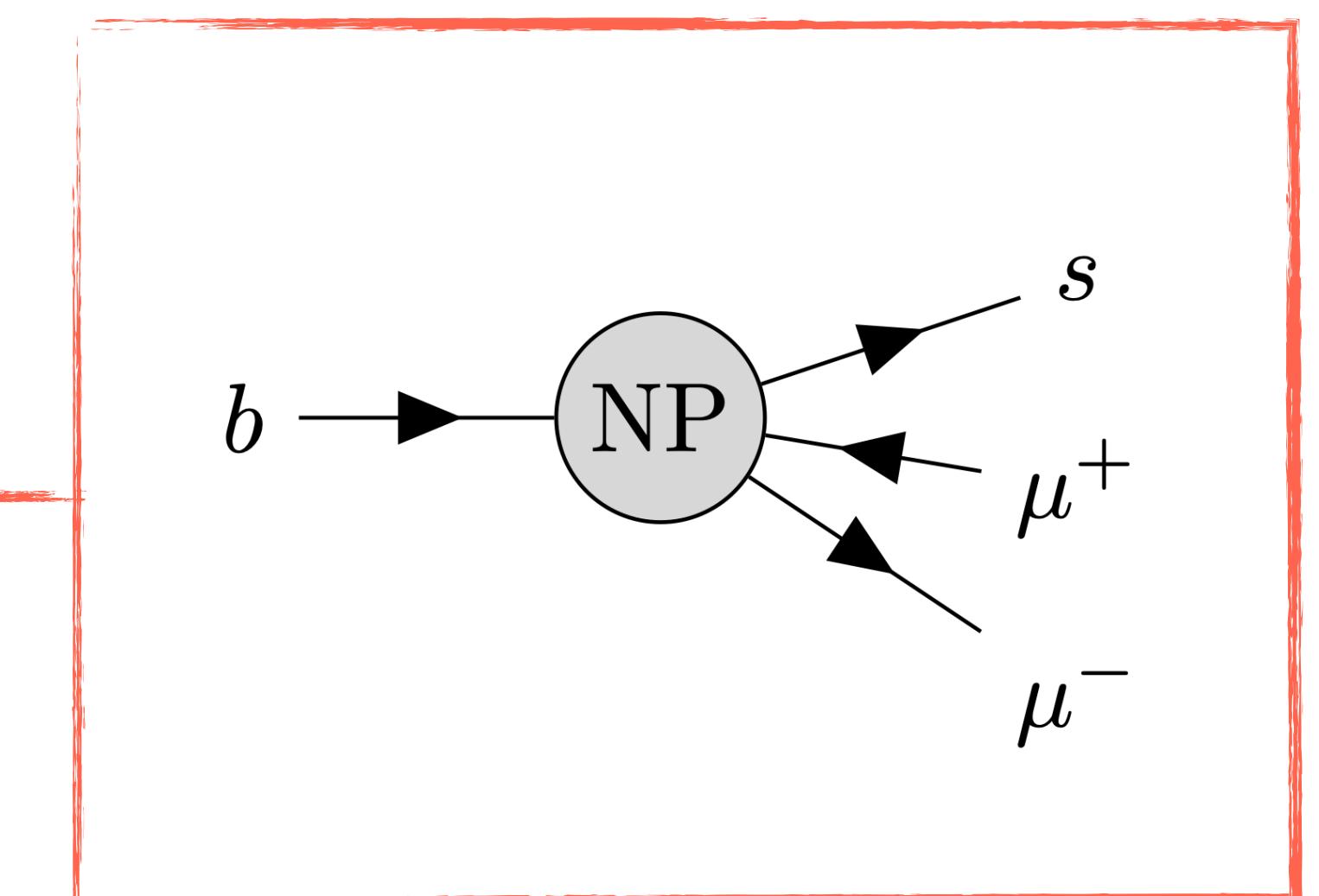
- ▶ Parameterise the decay amplitudes from WCs, FFs and non-local contributions



Interference with non-local contributions

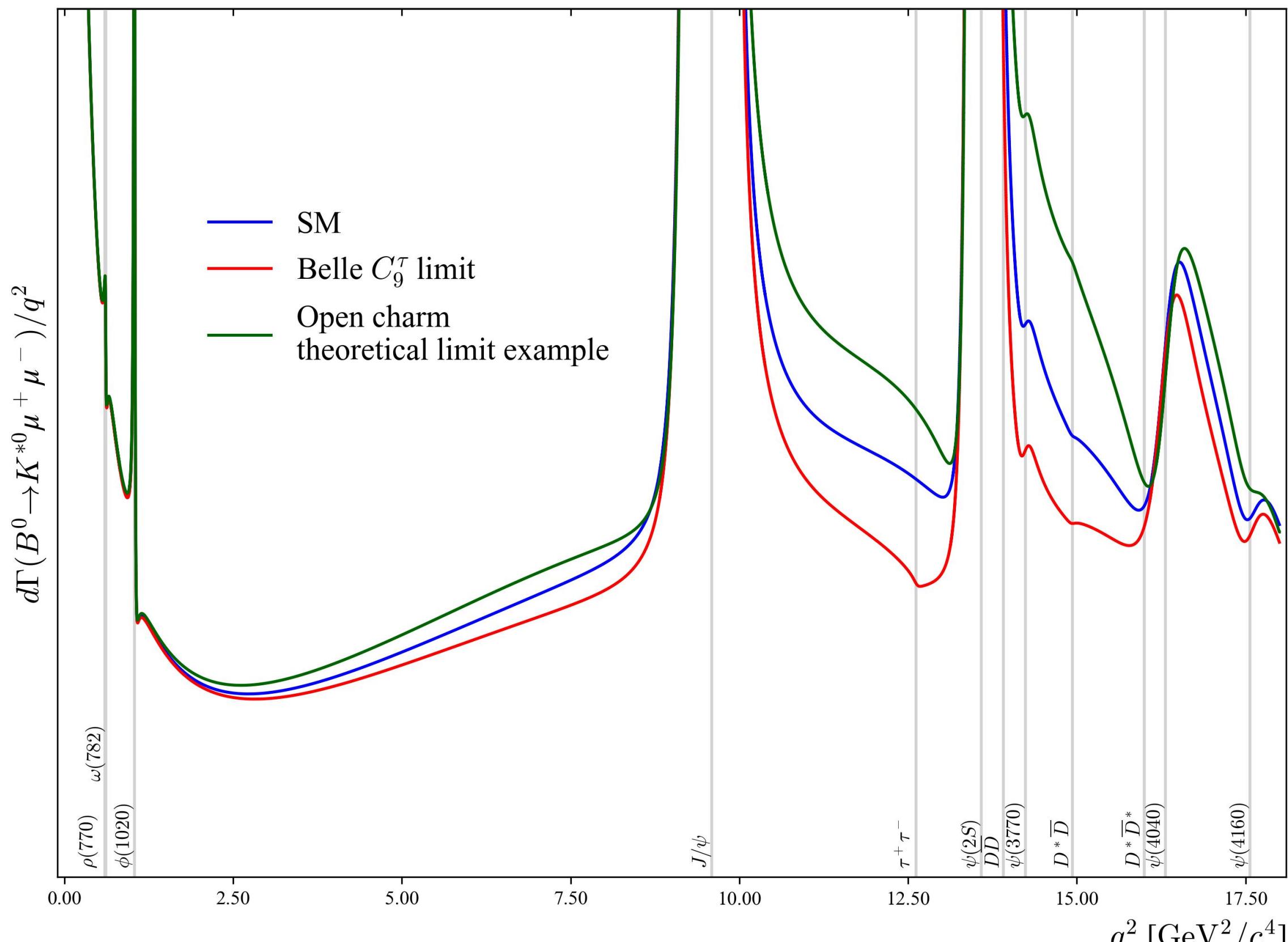
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NP in the vector coupling
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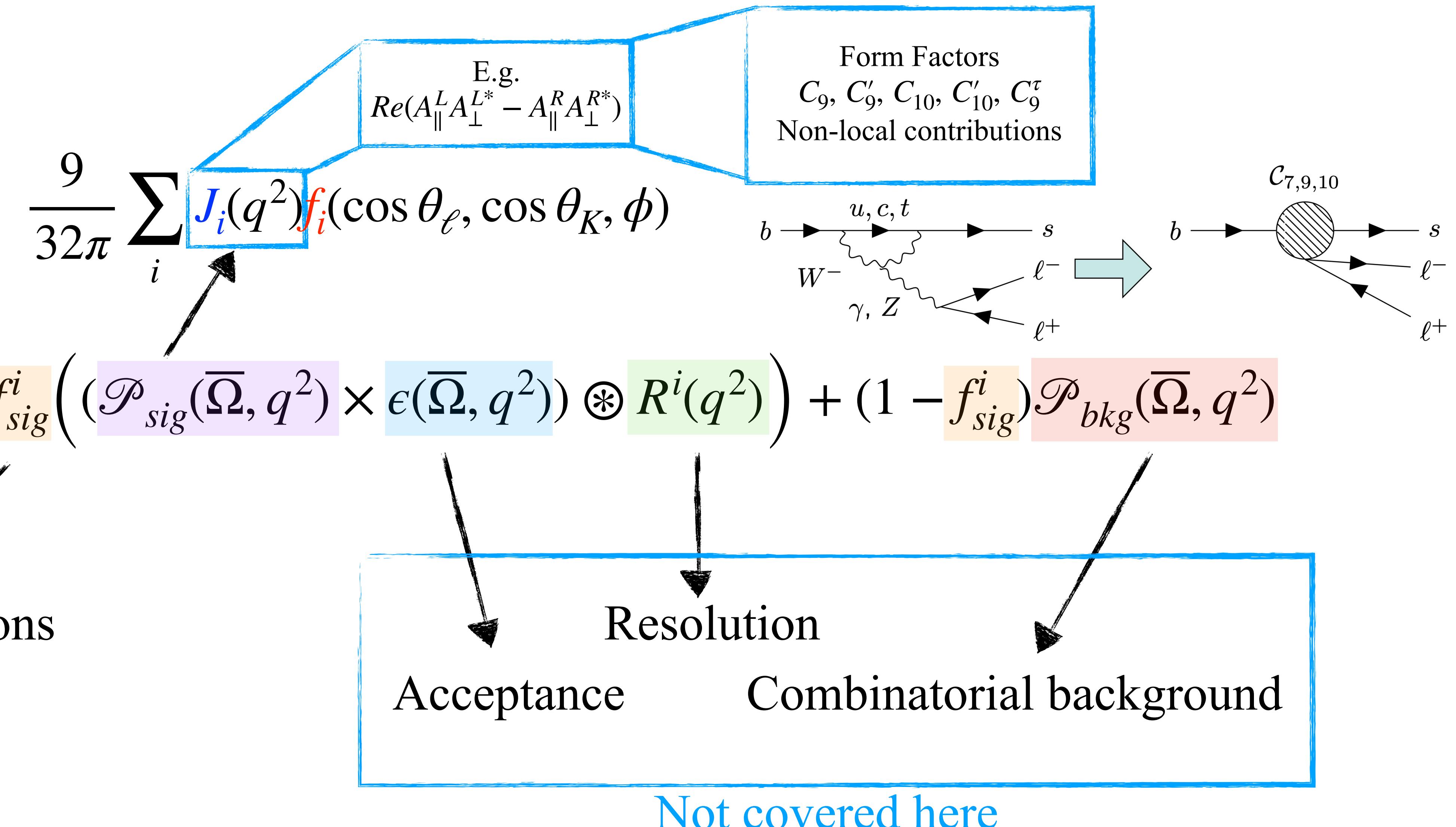
The $\tau^+\tau^- \rightarrow \mu^+\mu^-$ rescattering

- ▶ Inspired by [Cornella et al. \(2020\)](#), measure the rescattering process $B^0 \rightarrow K^*\tau^+\tau^- \rightarrow K^*\mu^+\mu^-$
- ▶ Muons are well reconstructed and understood at LHCb
- ▶ Experimental challenges are orthogonal to direct searches
- ▶ Many explanations for $b \rightarrow c\ell\nu$ predict enhancements in $b \rightarrow s\tau\tau$
[\[arXiv:1712.01919\]](#)
- ▶ Current limit on $\mathcal{B}(B^0 \rightarrow K^{*0}\tau^+\tau^-)$ by [Belle \(2021\)](#) : 2.00×10^{-3} at 90% CL
- $C_9^\tau < 450$



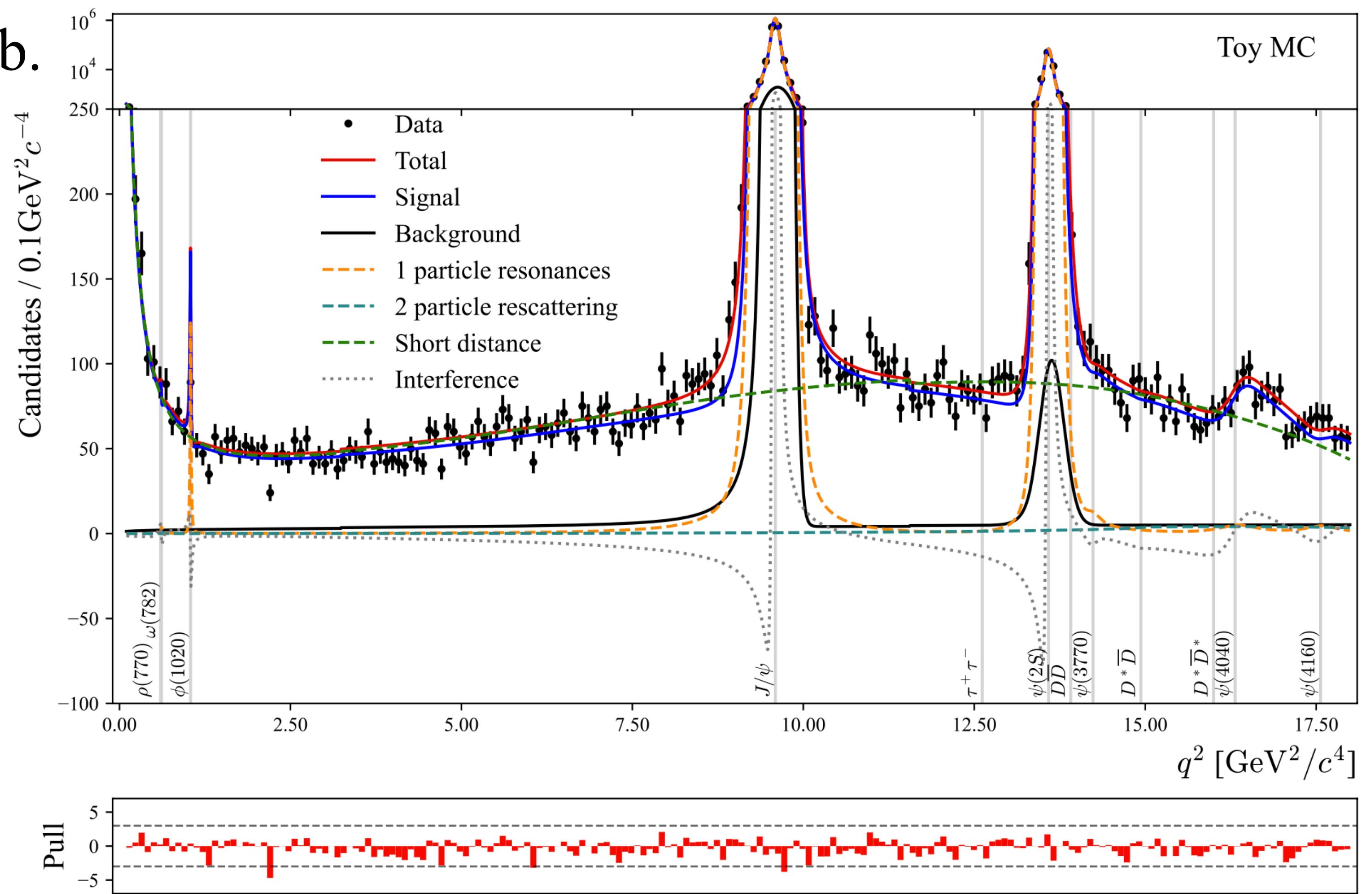
Full model

Total PDF in
 q^2 -region i



Fit strategy - q^2 projections

- ▶ Full q^2 spectrum unbinned ML fit to $B^0 \rightarrow K^{*0}(\rightarrow K^+\pi^-)\mu^+\mu^-$
- ▶ Crucial to correctly model the background in all dimensions
- ▶ High dimensionality, multiple comb. components, bias from vetoes
- ▶ Full fit is performed in 3 steps:
 - ▶ B mass fit to extract signal fractions
 - ▶ B mass sideband 5D bkg fit
 - ▶ Signal + background fit
- ▶ Nuisance parameters from data fit, and WCs set to SM



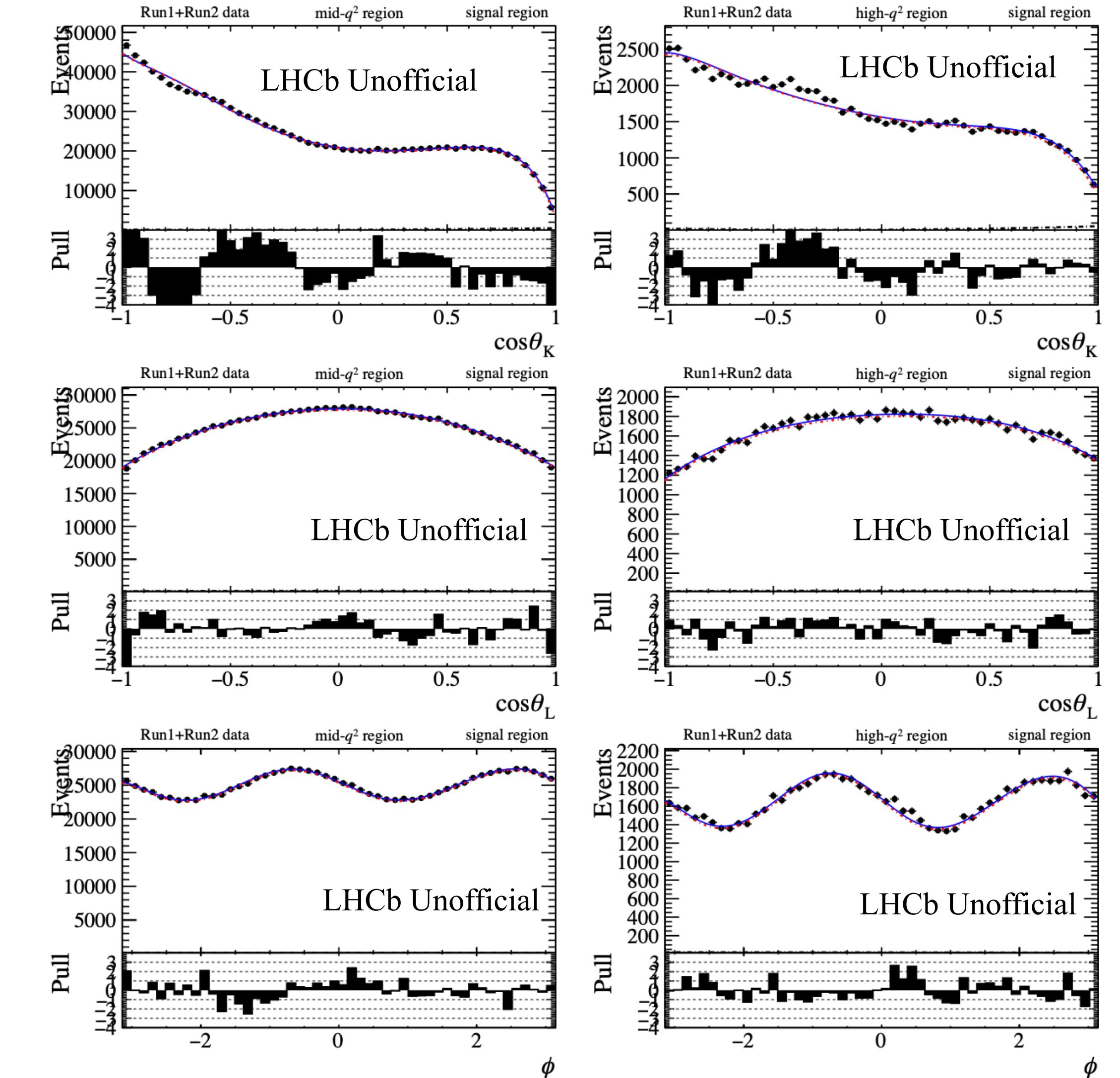
Fit strategy - angular projections

► Full q^2 spectrum unbinned ML fit to $B^0 \rightarrow K^{*0}(\rightarrow K^+\pi^-)\mu^+\mu^-$

► Showing Run1+Run2 data

► mid- q^2 ($3.24 - 11.56 \text{ GeV}^2/c^4$)
and high q^2 ($11.56 - 18.00 \text{ GeV}^2/c^4$)

► Systematic added for the pull seen in the $\cos(\theta_K)$ distribution



Conclusion

- Unbinned ML fit to $B^0 \rightarrow K^{*0} \mu^+ \mu^-$, fully parameterised in q^2 range $0.1\text{-}18.0 \text{ GeV}^2/c^4$
 - Fit WCs directly!
 - Data driven cross check of theory assumptions limiting the interpretation of the over 3 sigma anomaly
- As concluded at 2022 Implications:

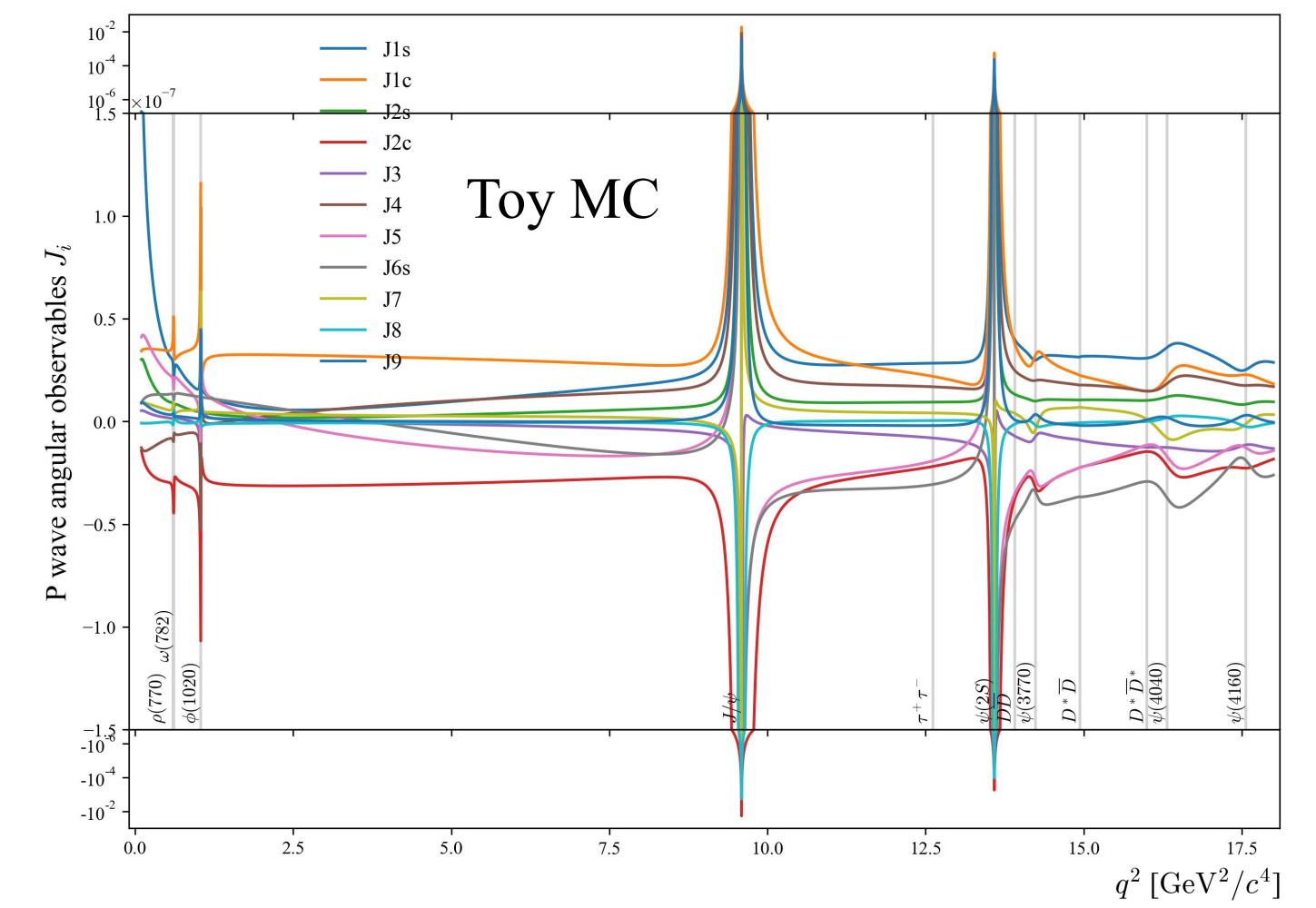
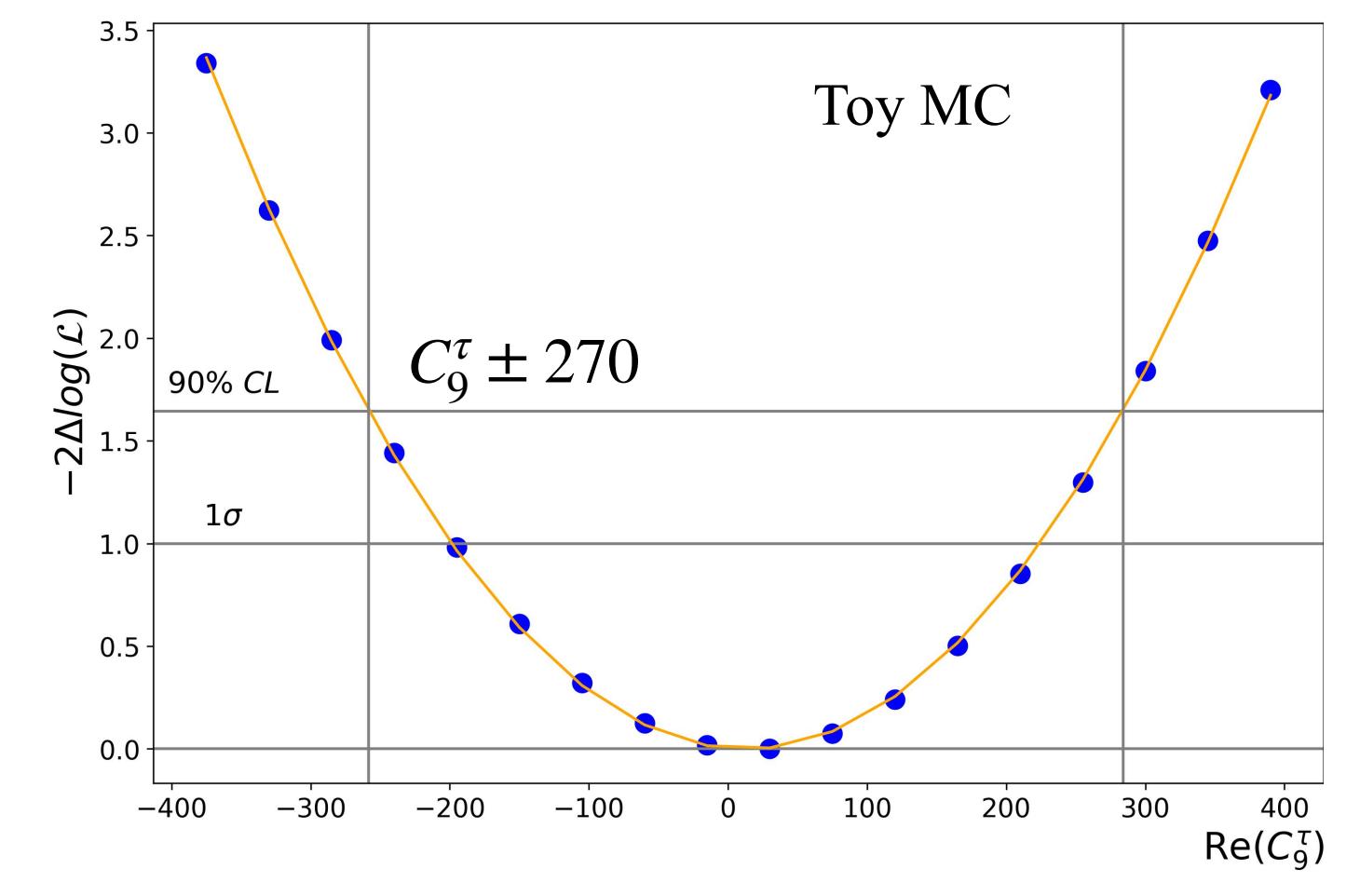
Take away message:

Non-local contributions cannot fully account for the “B anomalies”

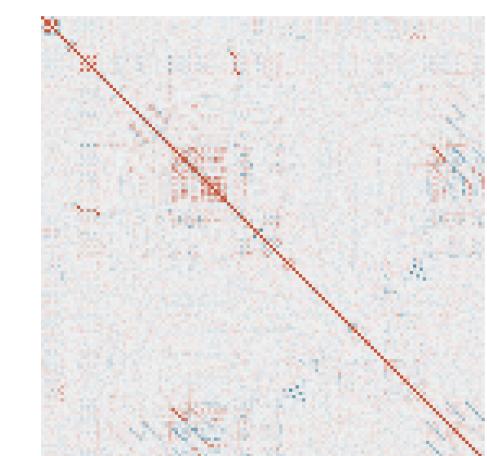
Méril Reboud - 20/10/2022

- Valuable comparison to binned analysis

- First indirect extraction of a $b \rightarrow s\tau\tau$ measurement - with world's best limit expected



Thank you for listening!



Signal parameterisation

Angular distributions

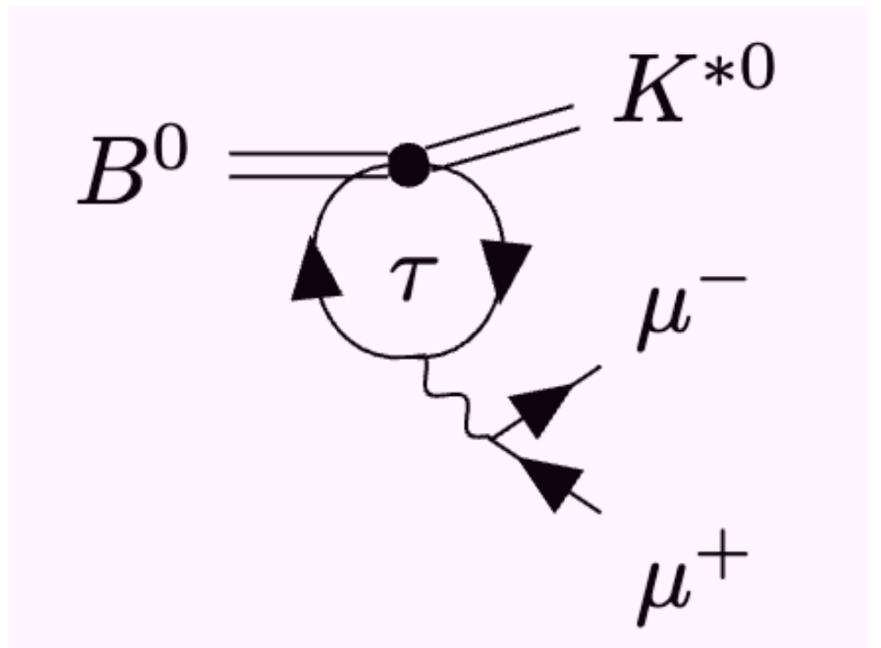
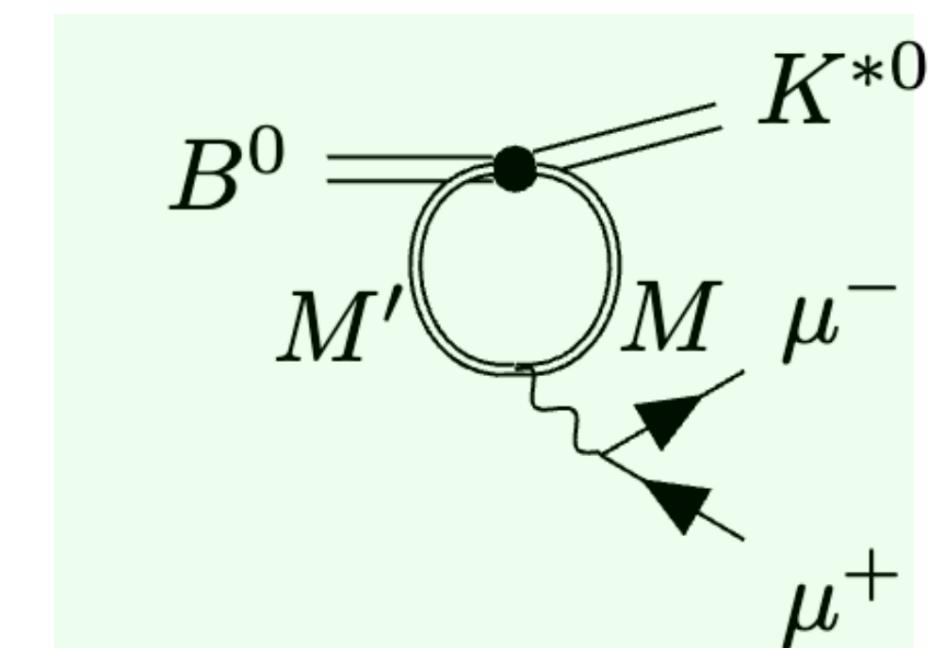
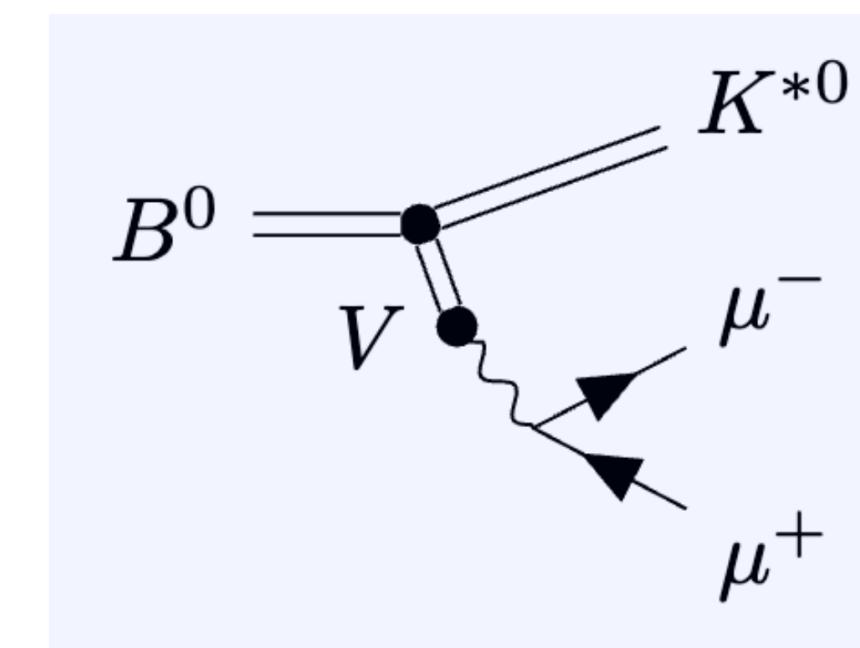
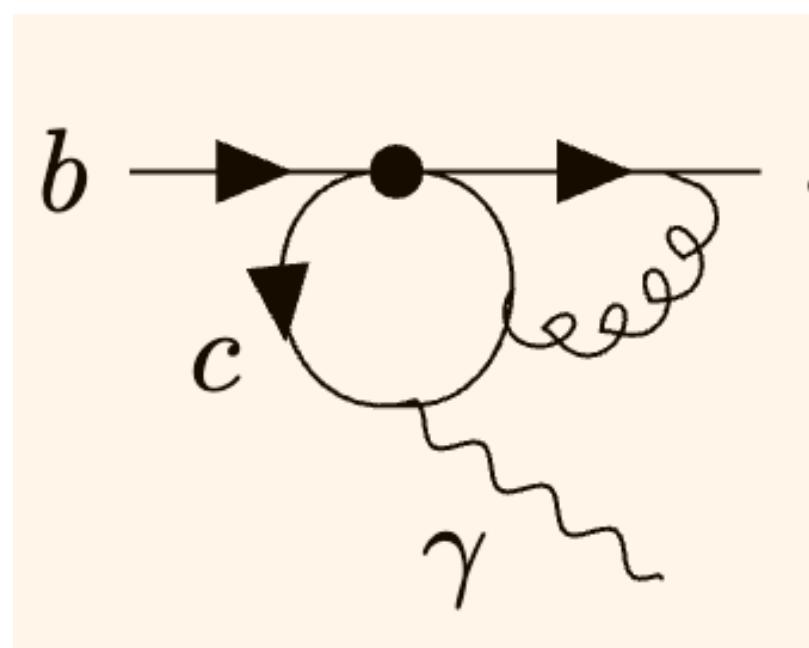
$$\blacktriangleright \frac{d\Gamma[B^0 \rightarrow K^{*0} \mu^+ \mu^-]}{dq^2 d\Omega} = \frac{9}{32\pi} \sum_i \mathbf{J}_i(q^2) \mathbf{f}_i(\cos \theta_\ell, \cos \theta_K, \phi) \int_{m_{K\pi}^2 = 0.796^2 GeV^2/c^4}^{m_{K\pi}^2 = 0.996^2 GeV^2/c^4} g_i(m_{K\pi}^2) dm_{K\pi}^2$$

Angular observables are bilinear combinations of the decay amplitudes

$$\mathcal{A}_\lambda^{L,R}(q^2) = N_\lambda \left\{ \left(C_9^{eff,\lambda}(q^2) \pm C'_9 \right) \mp (C_{10} \pm C'_{10}) F_\lambda^A(q^2) + M_\lambda C_7^{eff,\lambda} F_\lambda^T(q^2) \right\}$$

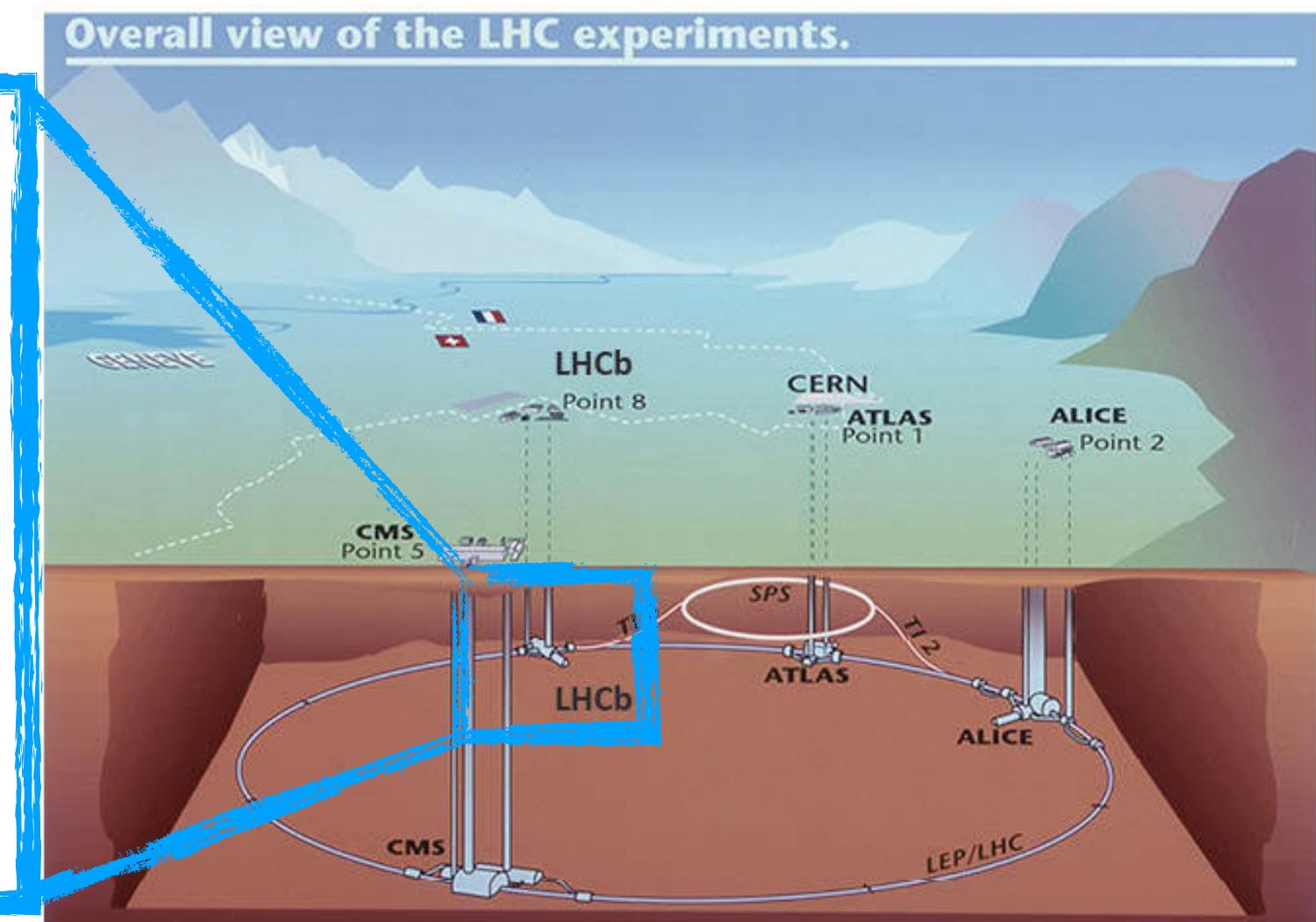
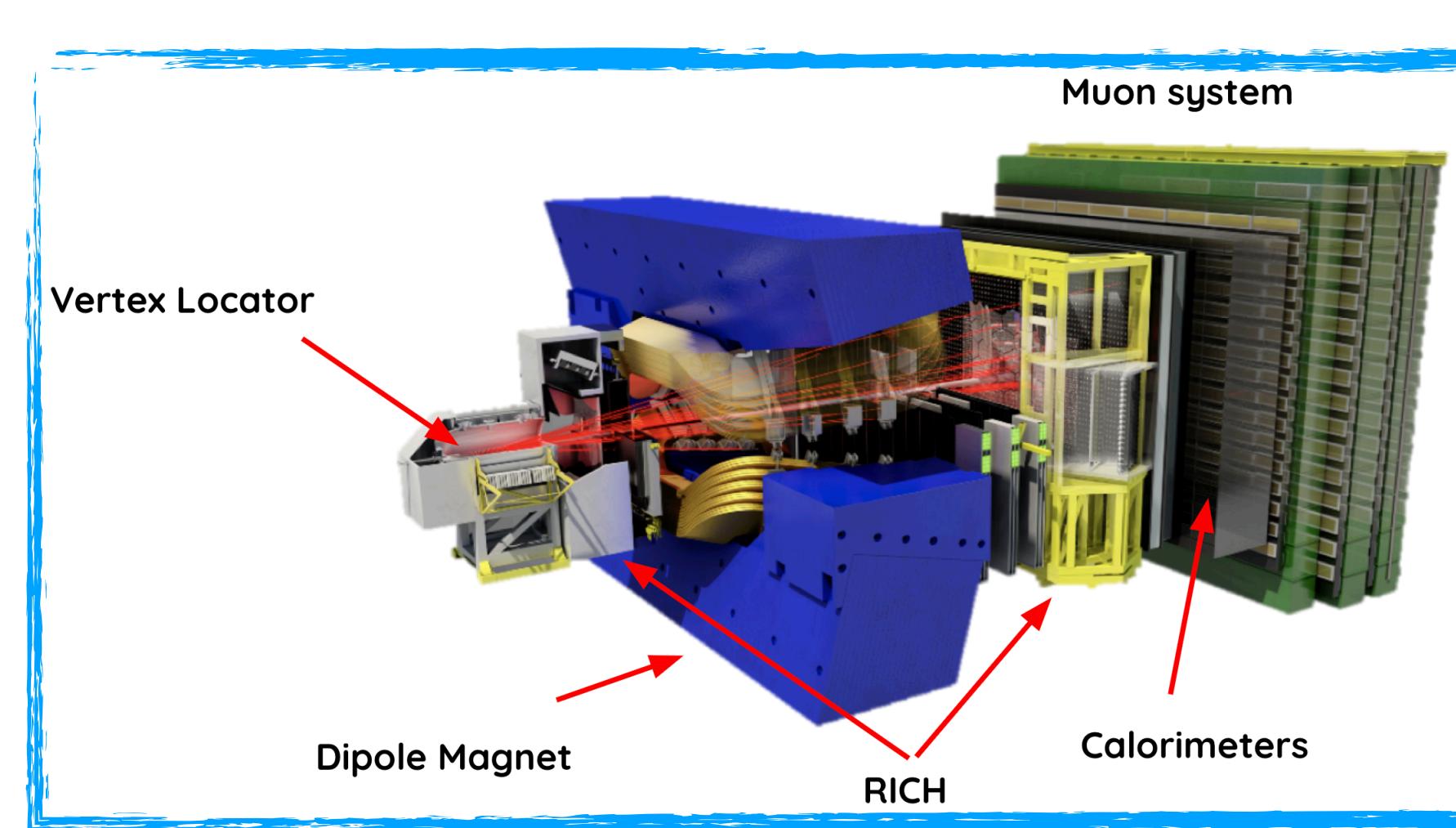
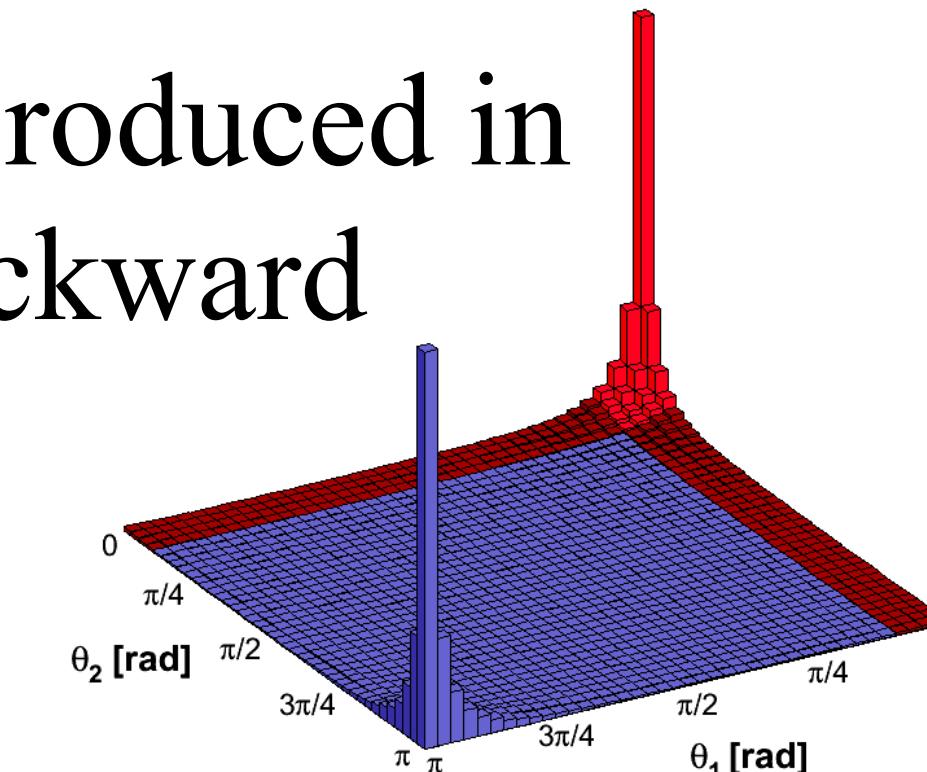
$$C_9^{eff,\lambda}(q^2) = C_9^\mu + \sum_{j=\rho..\psi_{4160}} \eta_j^\lambda e^{i\delta_j^\lambda} \frac{q^2}{m_j^2} A_j^{res}(q^2) + \sum_{k=D,D^*,D_{avg}} \eta_k^\lambda e^{i\delta_k^\lambda} h_k(q^2) + C_9^\tau \frac{-\alpha_{EM}}{2\pi} h_{PS}(q^2) + Y_{c\bar{c}}^{(0)0}$$

$$C_7^{eff,\lambda} = C_7 + \zeta^\lambda e^{i\omega^\lambda}$$

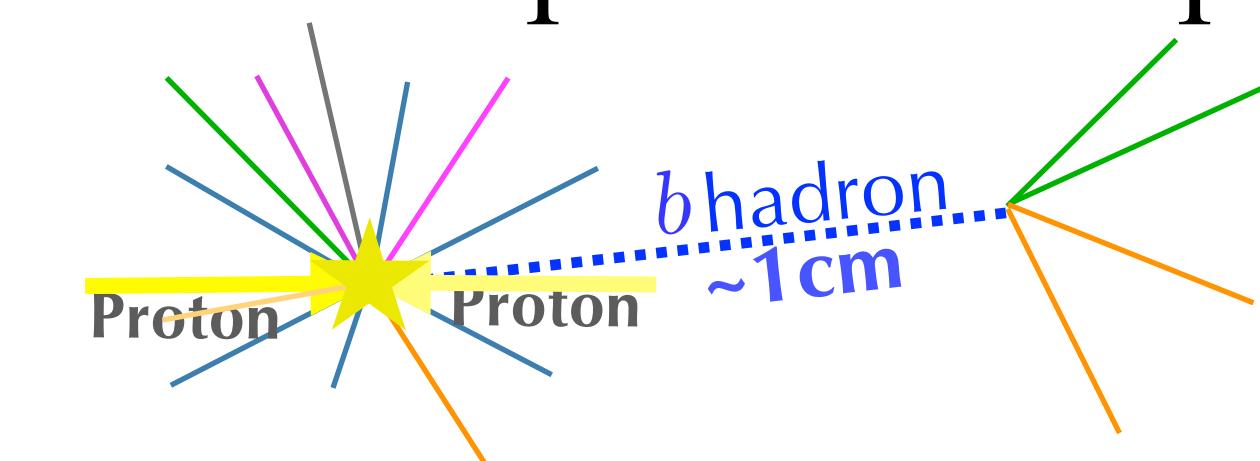


The LHCb experiment

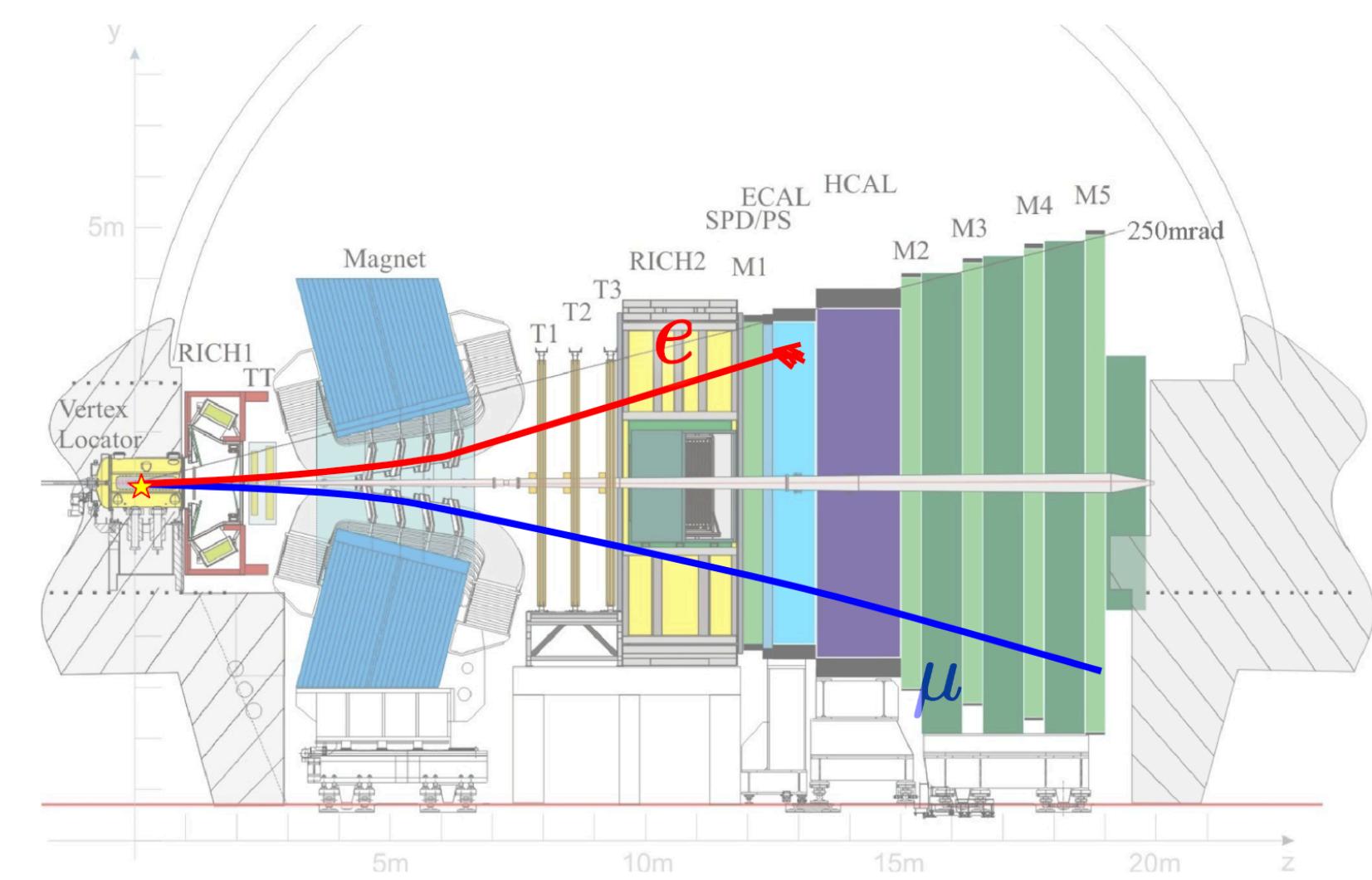
- ▶ General purpose detector in the forward region
- ▶ $b\bar{b}$ mostly produced in forward-backward region



- ▶ Boost of b -hadrons is exploited to separate signal and background



- ▶ Reconstruction of electrons is more difficult than that of muons



Int. J. Mod. Phys. A 30 (2015) 1530022