b->sll binning in LHCb

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on behalf of the LHCb Rare Decays group

LHC Heavy Flavour WG topical meeting: b->sll

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binning philosophy

- As many as possible within the limit of keeping the fits stable

- Prime example: $B^{0,+} \to K^{*0,+}\mu^+\mu^-$

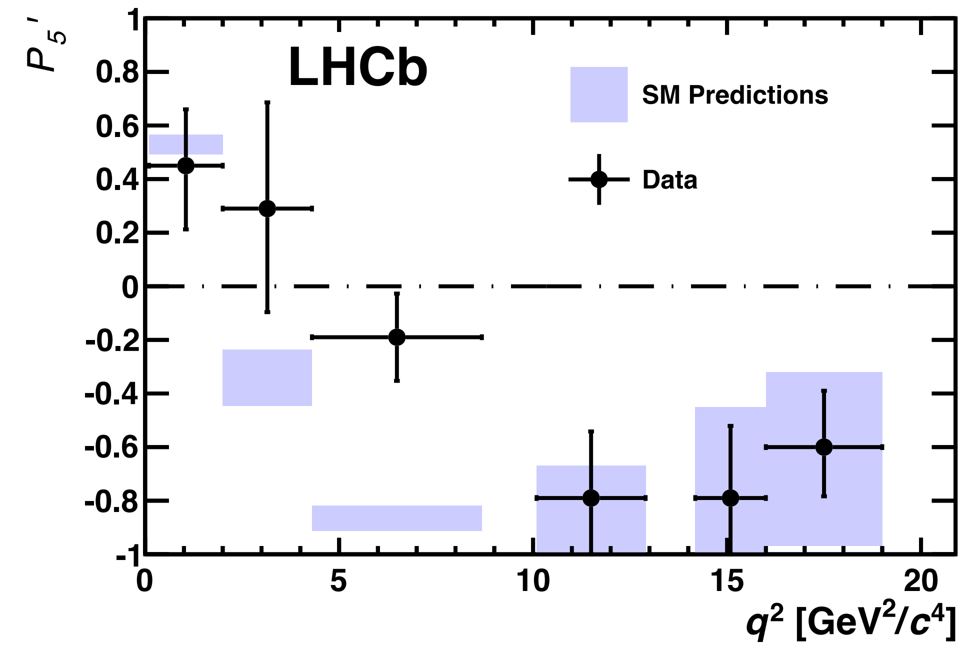
2 large bins	8 small bins
	[0.1, 0.98]
[1.1, 6.0]	[1.1, 2.5]
	[2.5, 4.0]
	[4.0, 6.0]
	[6.0, 8.0]
	[11.0, 12.5]
[15.0, 19.0]	[15.0, 17.0]
	[17.0, 19.0]

← $\phi(1020)$ gap

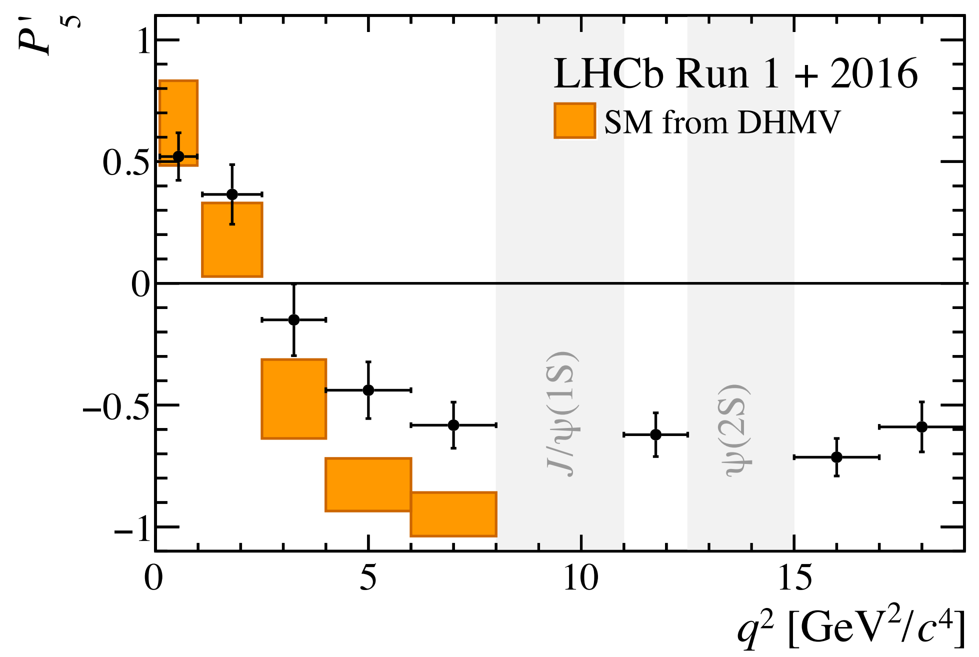
- finer binning always a sub-scheme of coarser binning

- $m_{\mu\mu}$ resolution is excellent
  - no limits to the narrowness of the bins

$B^0 \to K^*\mu\mu$



1 fb-1



4.7 fb-1

↓

2 large bins
8 small bins
+ 16 half bins

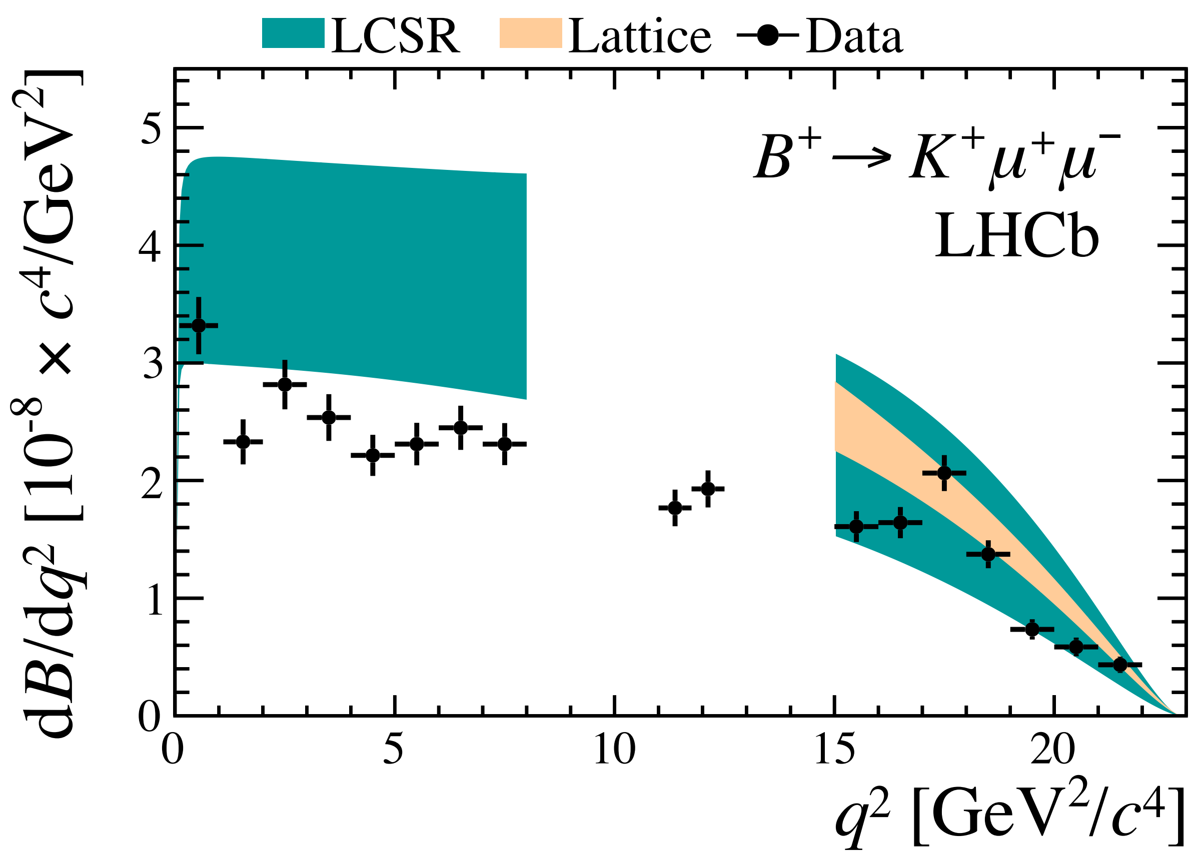
9 fb-1

Clearly depends on stats

- More bins

q^2 range (GeV^2/c^4)
$0.1 < q^2 < 0.98$
$1.1 < q^2 < 2.0$
$2.0 < q^2 < 3.0$
$3.0 < q^2 < 4.0$
$4.0 < q^2 < 5.0$
$5.0 < q^2 < 6.0$
$6.0 < q^2 < 7.0$
$7.0 < q^2 < 8.0$
$11.0 < q^2 < 11.8$
$11.8 < q^2 < 12.5$
$15.0 < q^2 < 16.0$
$16.0 < q^2 < 17.0$
$17.0 < q^2 < 18.0$
$18.0 < q^2 < 19.0$
$19.0 < q^2 < 20.0$
$20.0 < q^2 < 21.0$
$21.0 < q^2 < 22.0$
$1.1 < q^2 < 6.0$
$15.0 < q^2 < 22.0$

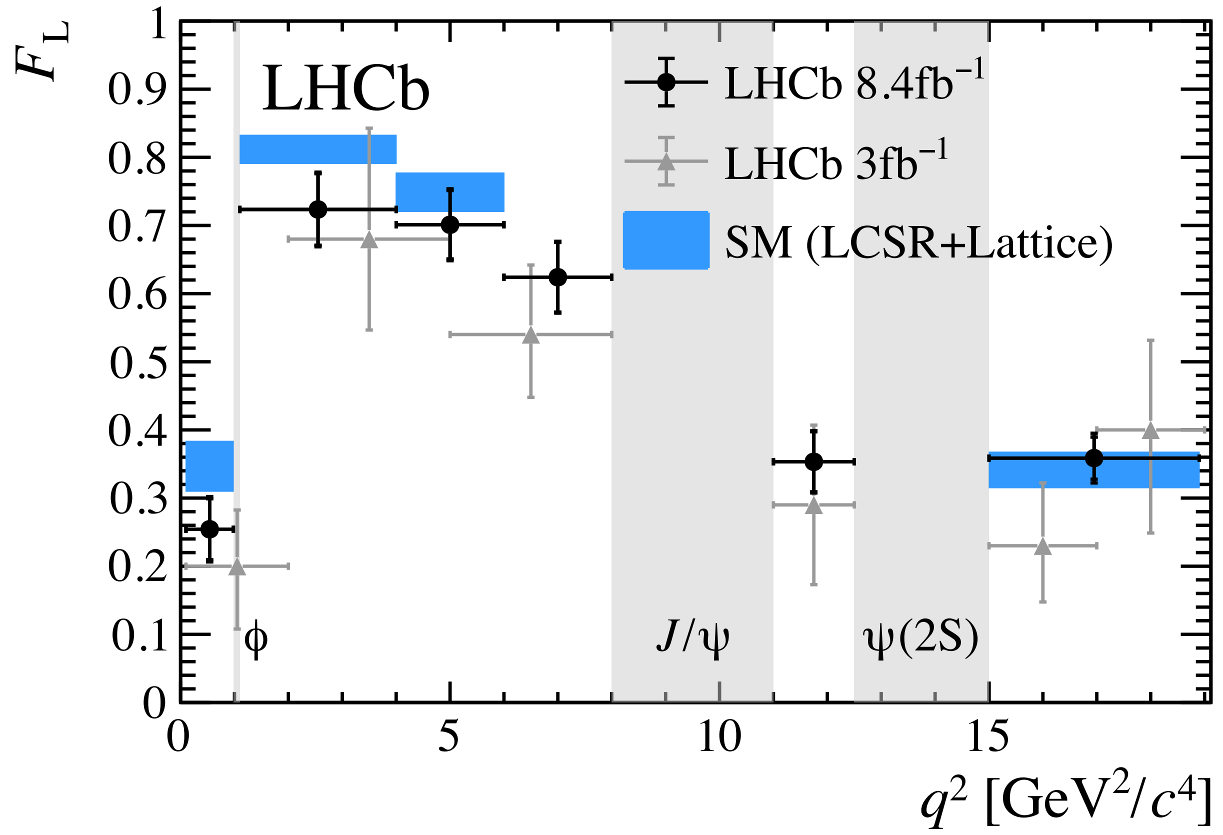
$B^+ \to K^+\mu\mu$



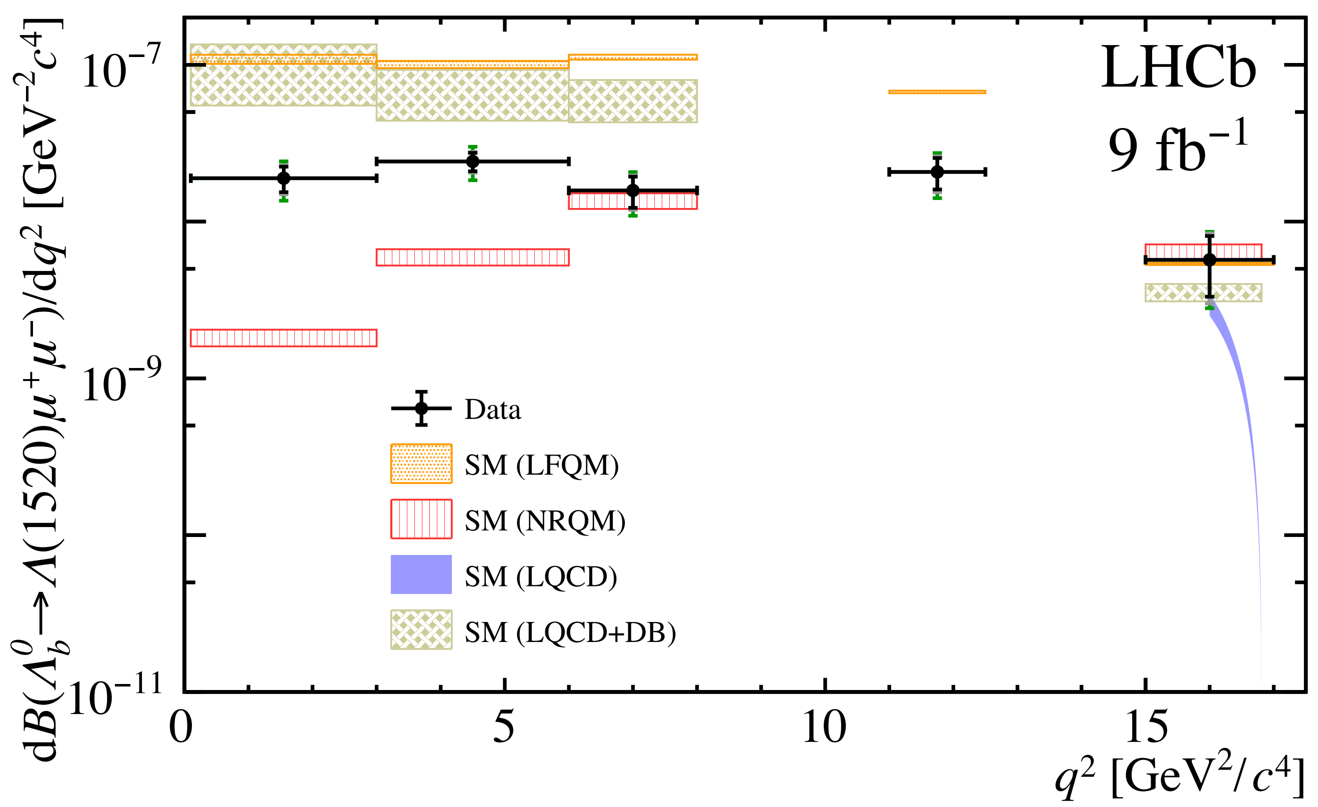
- Less bins

2 large bins	5 small bins
[1.1, 6.0]	[0.1, 0.98]
	[1.1, 4.0]
	[4.0, 6.0]
	[6.0, 8.0]
	[11.0, 12.5]
[15.0, 18.9]	

$B_s \to \phi\mu\mu$



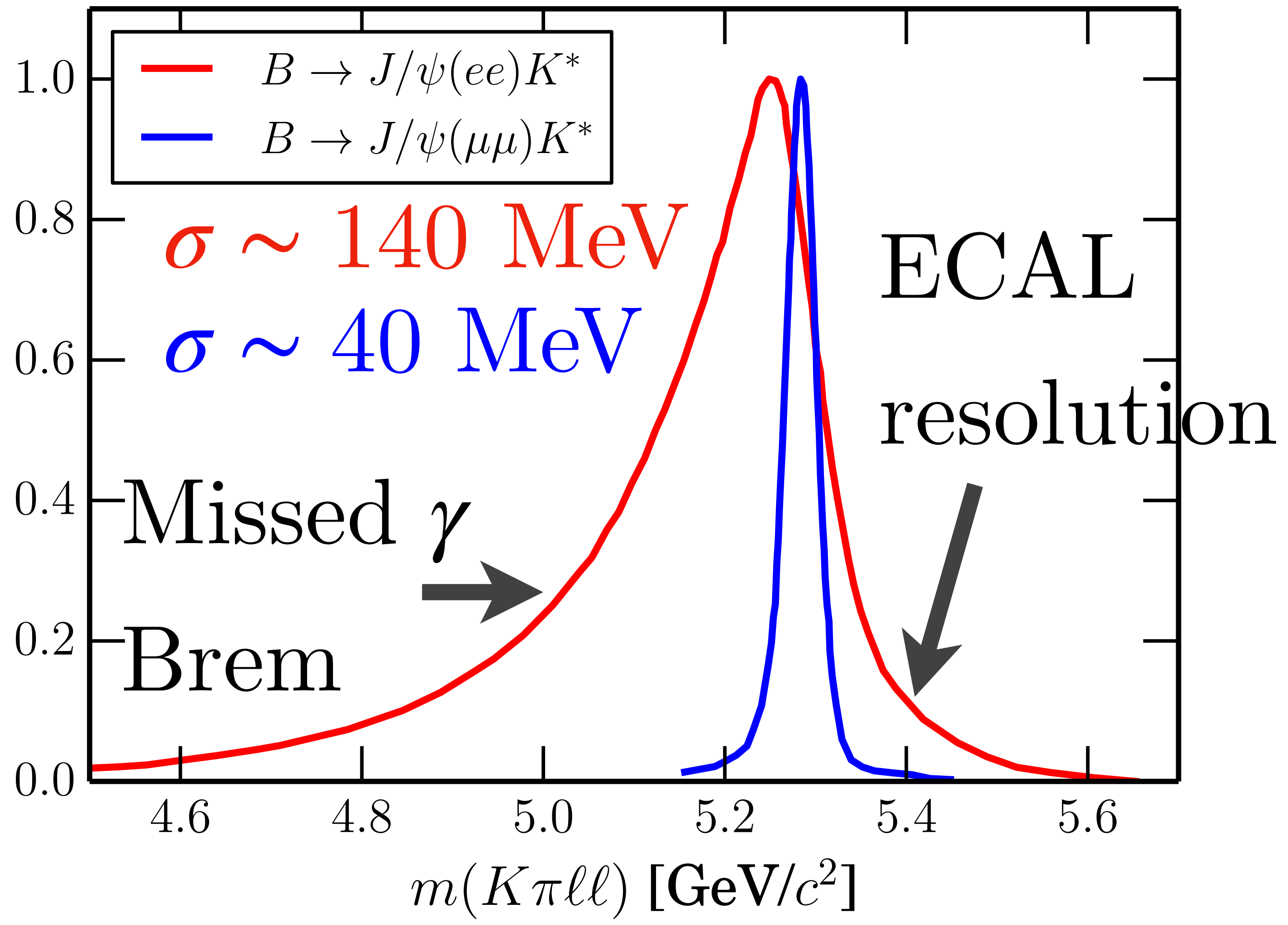
$\Lambda_b \to \Lambda(1520)\mu\mu$



- In both cases bin edges are part of the same set, e.g. 4.0, 6.0, 8.0, etc…

What about electrons?

- LFU test R_K, R_{K^*} { low-q2: [0.1*, 1.1] GeV^2 / central-q2: [1.1, 6.0] GeV^2



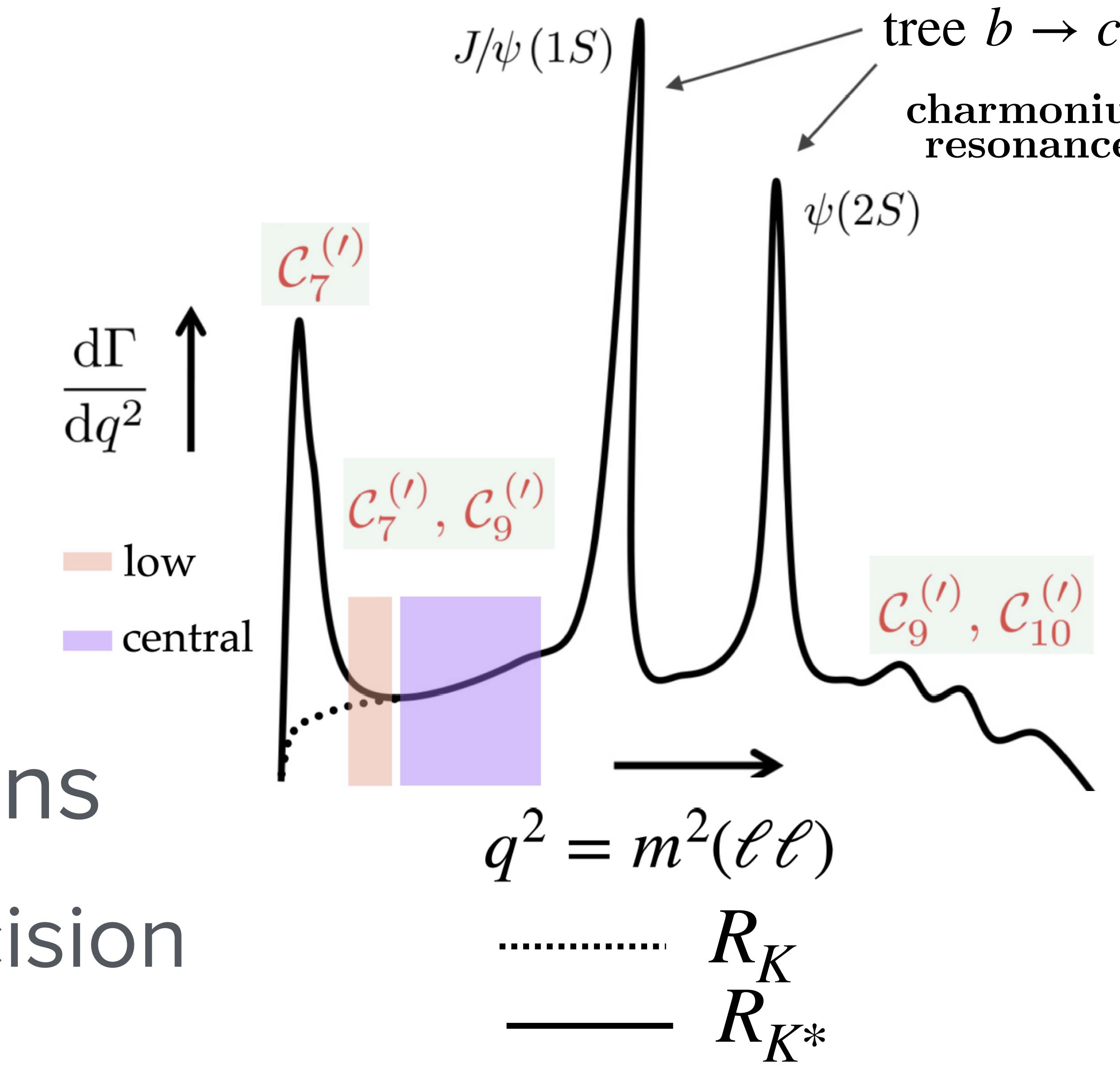
  - worse electron resolution prevent going closer to ψ resonances

  *first R_{K^*} went down to 0.045 GeV^2

    - lower limit increased to reduce theory syst. uncertainty due to photon pole + phase space closure ($R_{K^*}^{SM} \sim 0.9$)

    - R_K can go as low as you want without this issue

  - high-q^2 (q^2>14 GeV^2) more challenging…WIP



- With Run3 dataset expected to split central-q2 in at least 2 sub-bins
  - currently ~4% stat. uncert. in R_K central-q^2, can achieve the same precision in each sub-bin

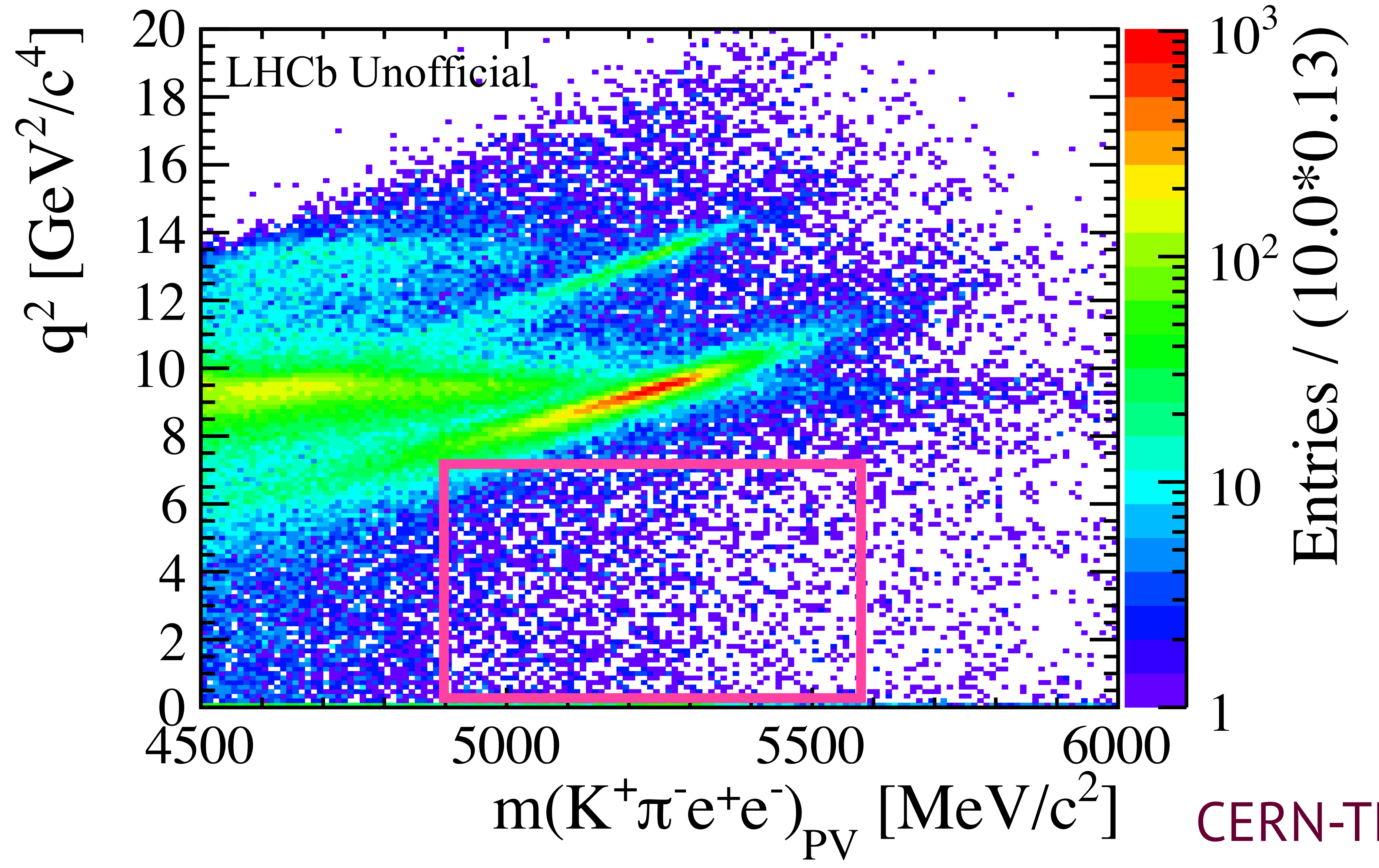
- For electrons, the finer the binning gets, the stronger the correlations between the bins

Electrons: q^2 constrained

- Upcoming $B^0 \to K^{*0}e^+e^-$ angular analysis

  In two wide ranges:

  - $q_c^2 \in$ [1.1, 6.0] GeV²
  - $q_c^2 \in$ [1.1, 7.0] GeV² ⟵ possible thanks to q^2 calculated by constraining reconstructed $m(K\pi ee)$ to PDG B^0 mass



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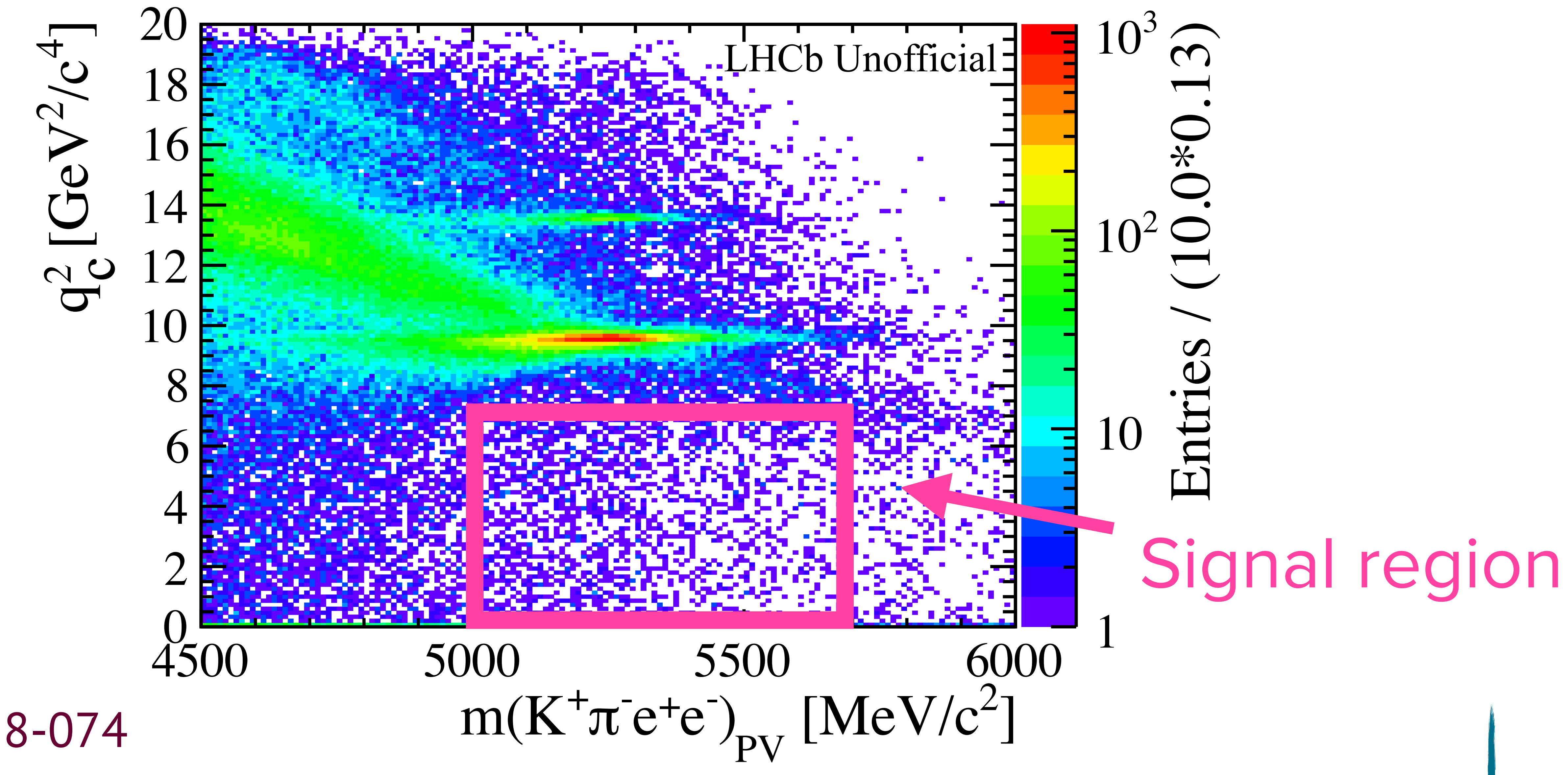


Binned vs unbinned

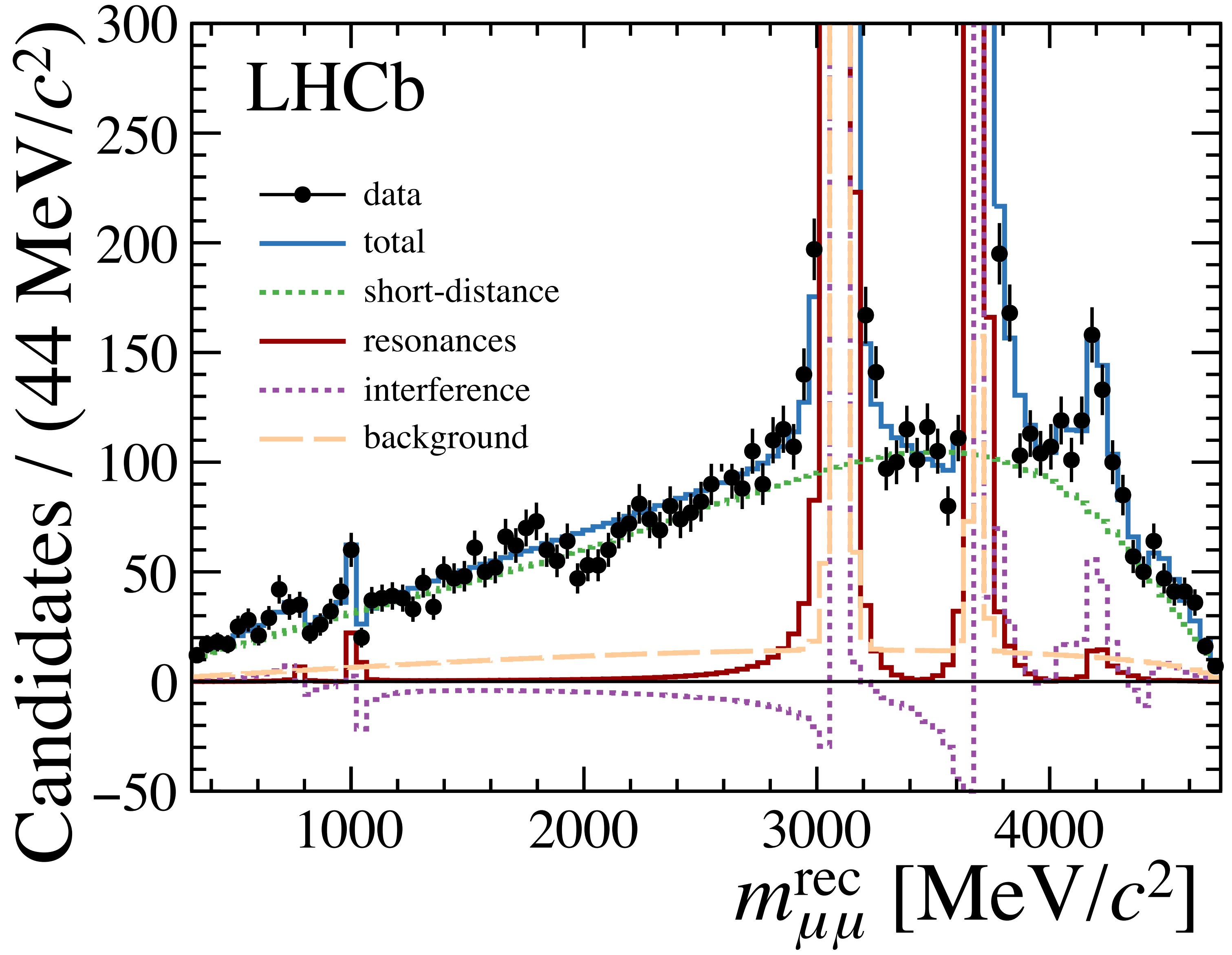
- LHCb is performing complementary q2-unbinned measurements
- Journey started in 2017 with (binned) phase difference determination in $B^+ \to K^+\mu\mu$
- Now 4D unbinned fit to $B^0 \to K^{*0}\mu\mu$
  - Complementary model assumptions
    - z-expansion [PRL 132 (2024) 131801, PRD 109 (2024) 052009]
    - dispersion relation [LHCb-PAPER-2024-011 in preparation]

Pro: more information

Cons: model-dependence (require external inputs from theory, e.g. FFs)

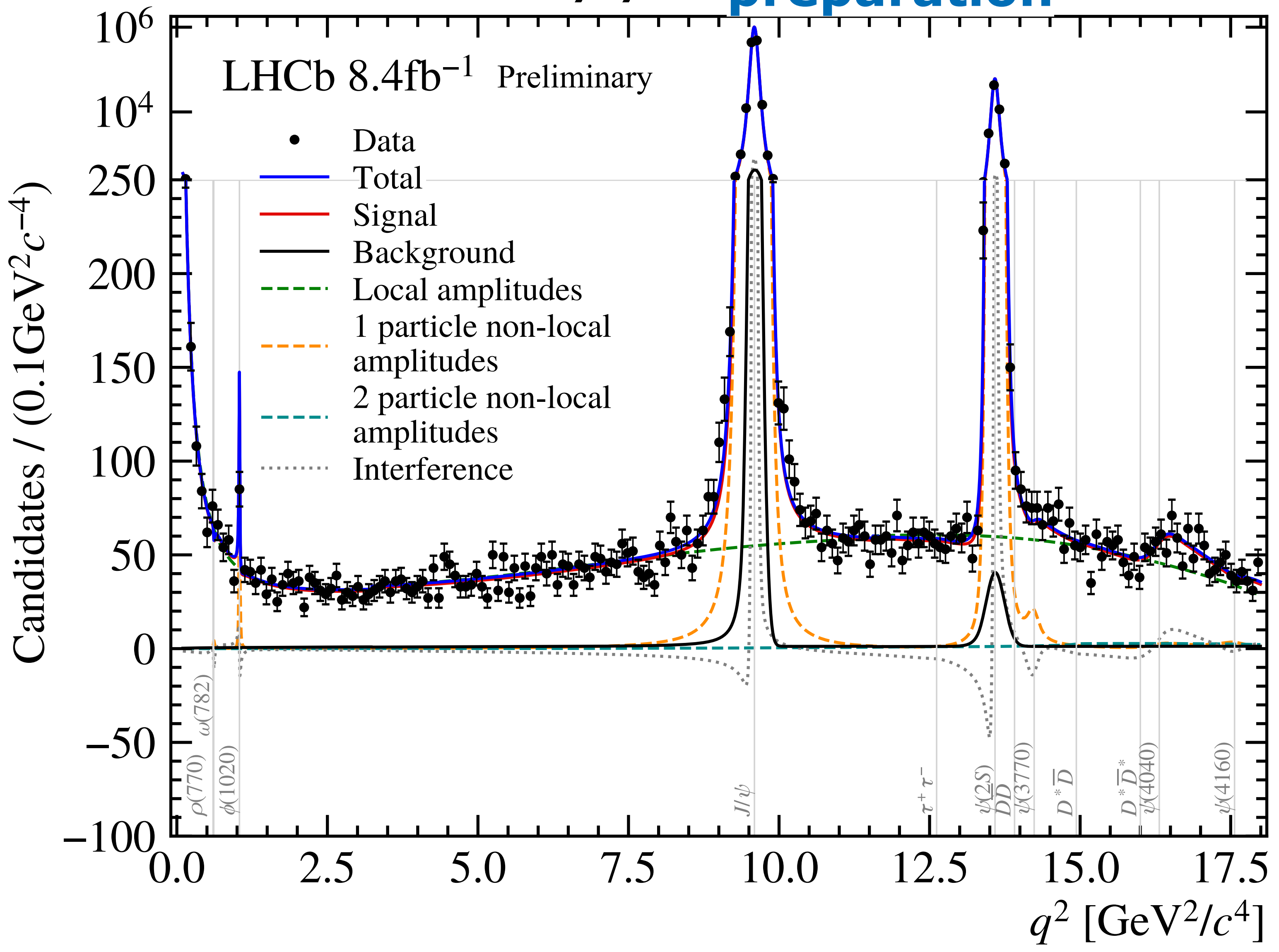
$B^+ \to K^+\mu\mu$

EUR. PHYS. J. C77 (2017) 161



$B^0 \to K^{*0}\mu\mu$

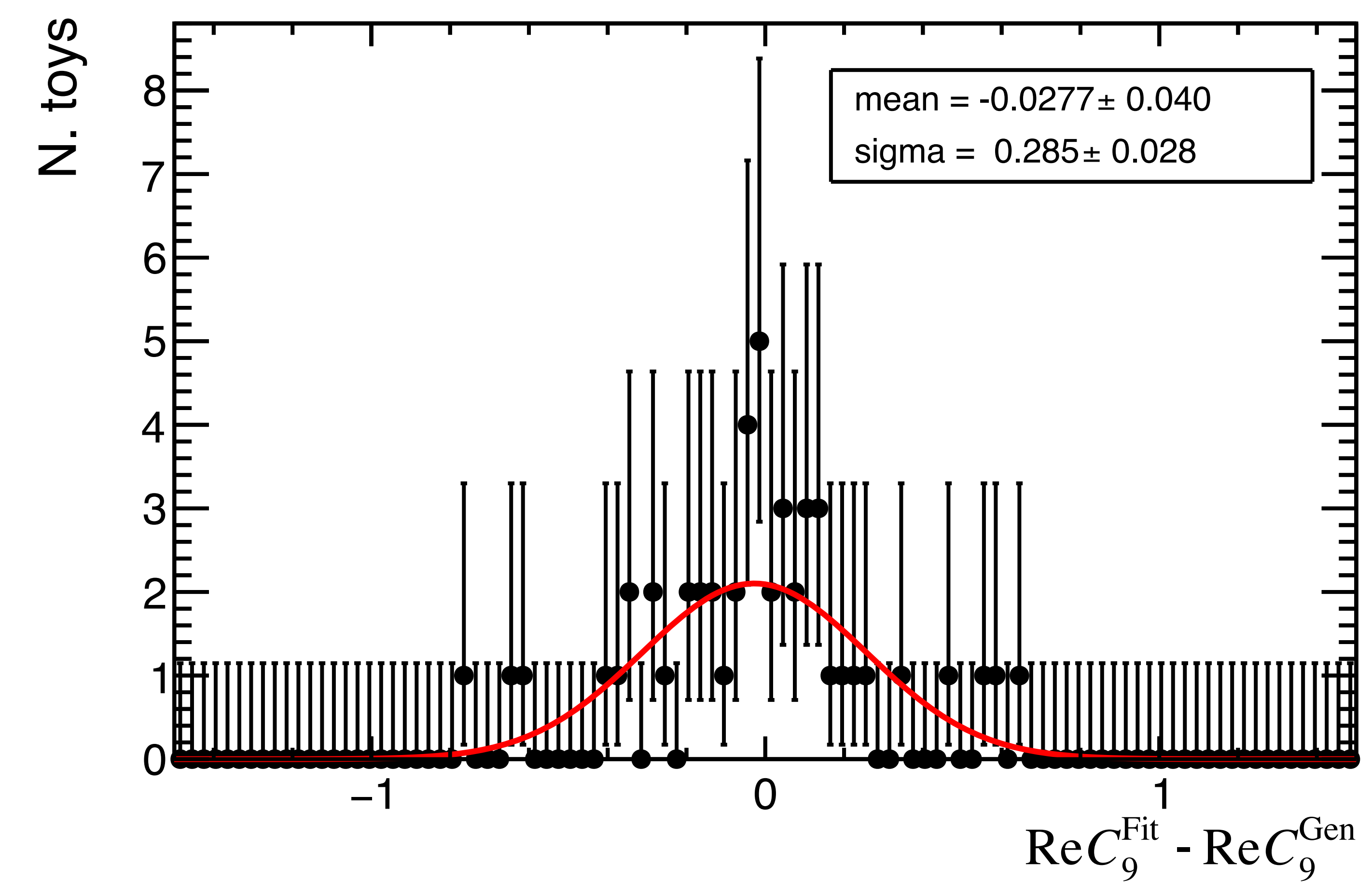
LHCb-PAPER-2024-011 in preparation



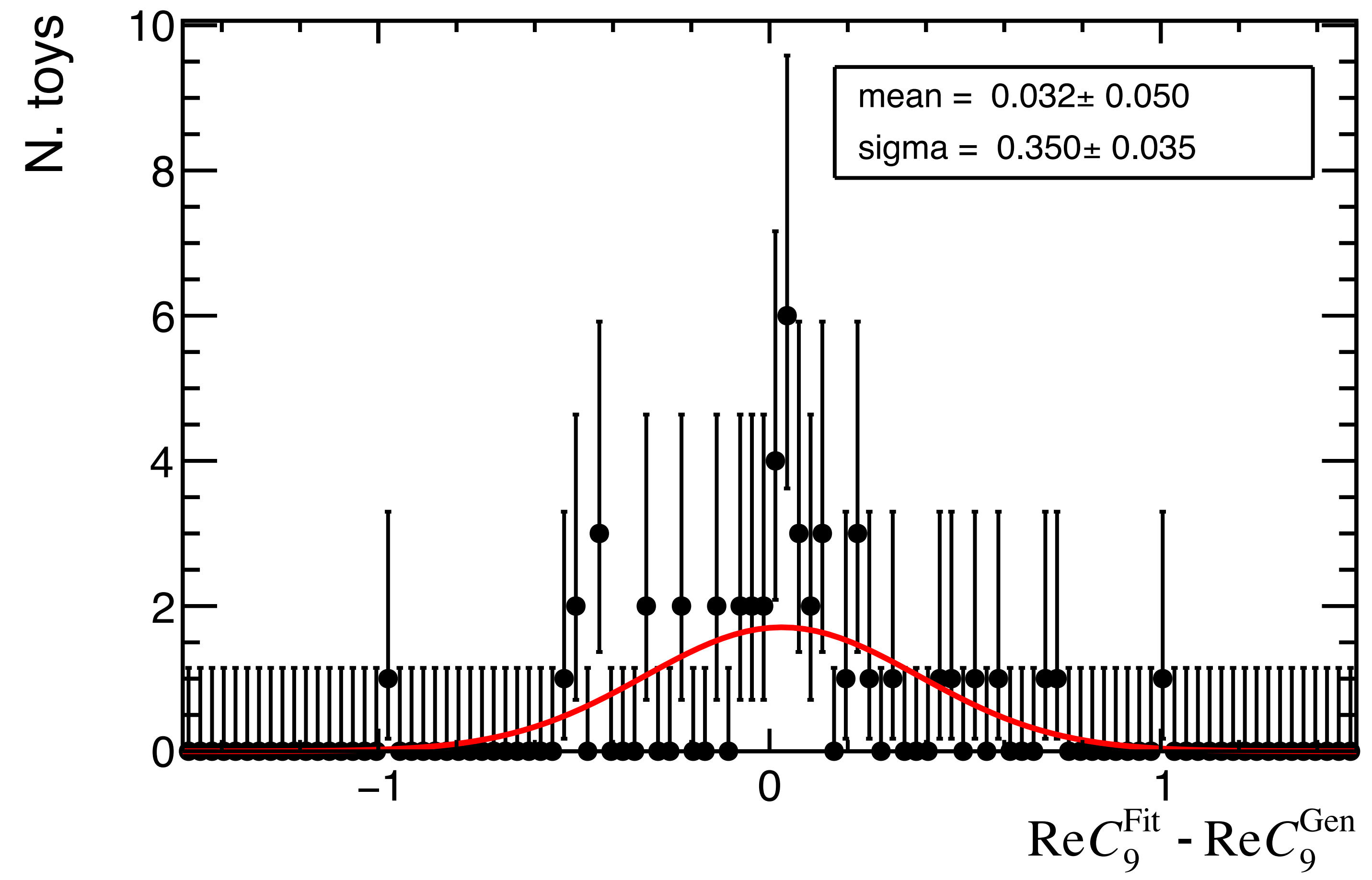
Unbinned analyses: pros

- Better sensitivity
  - Exact improvement depends on fit configuration, stats, etc.
  - Simple case with P-wave only toys, fit to C9, z-expansion model
- Fit extracts a lot of information: 100 signal parameters!!
  - What's the best way to pass this information to the community?

unbinned



binned



Reinterpretation of the result?

- z-expansion analysis provided bootstrapped set of coefficients
- Dispersion relation will provide synthetic datasets
  - large stat toys generated from fit result covariance matrix
  - can be refitted with different inputs/constraints

- A 3rd unbinned $B^0 \to K^{*0}\mu\mu$ analysis is on the way
  - minimal possible model dependency
  - amplitudes parametrised with 4th order polynomials in $q^2 \in [1.1, 8.0]$ GeV^2
    - no inputs required for FF, ect.

Summary and discussion points

- Muons: as many bins a possible
- Electrons: less stat and worse resolution, possibility to splitting bins in the short future
- Unbinned analyses: complementary information, different level of model dependency baked into the analysis
  - Can be extended to other decays, $\mathrm{e.g.}\ B^+ \to K^+\mu\mu$, CPV (split by $B^{0,+}$ vs $\overline{\mathrm{B}}^{0,+}$), $B^+ \to \pi^+\mu\mu$