Measurements of R_K and R_{K^*} with the full LHCb Run 1 and 2 data

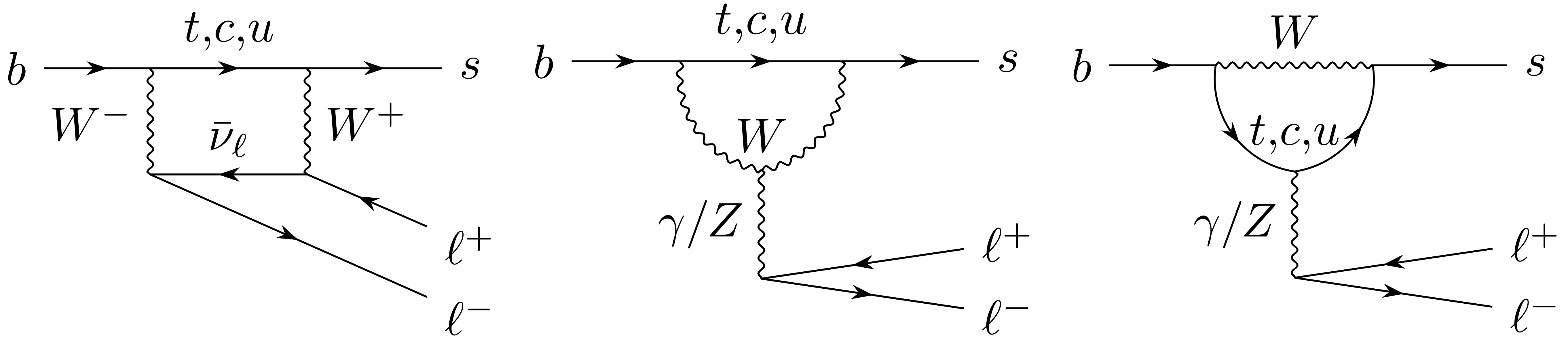
Renato Quagliani

École Polytechnique Fédérale de Lausanne (EPFL)

On behalf of the LHCb collaboration

LHCb-PAPER-2022-045
LHCb-PAPER-2022-046

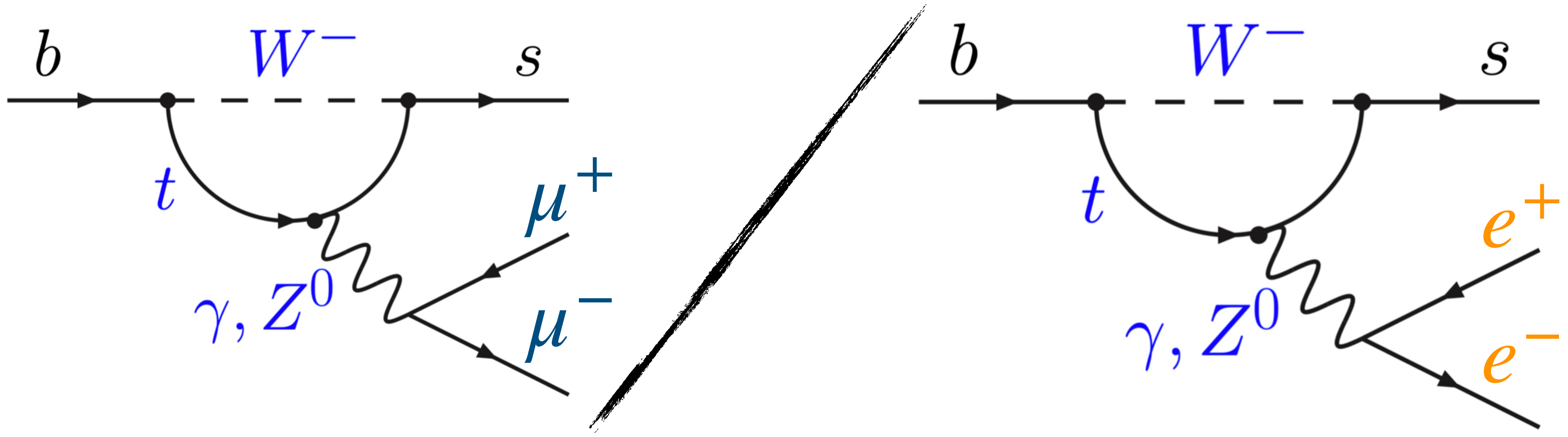
Introduction



- $b \to s\ell^+\ell^-$ and anomalies

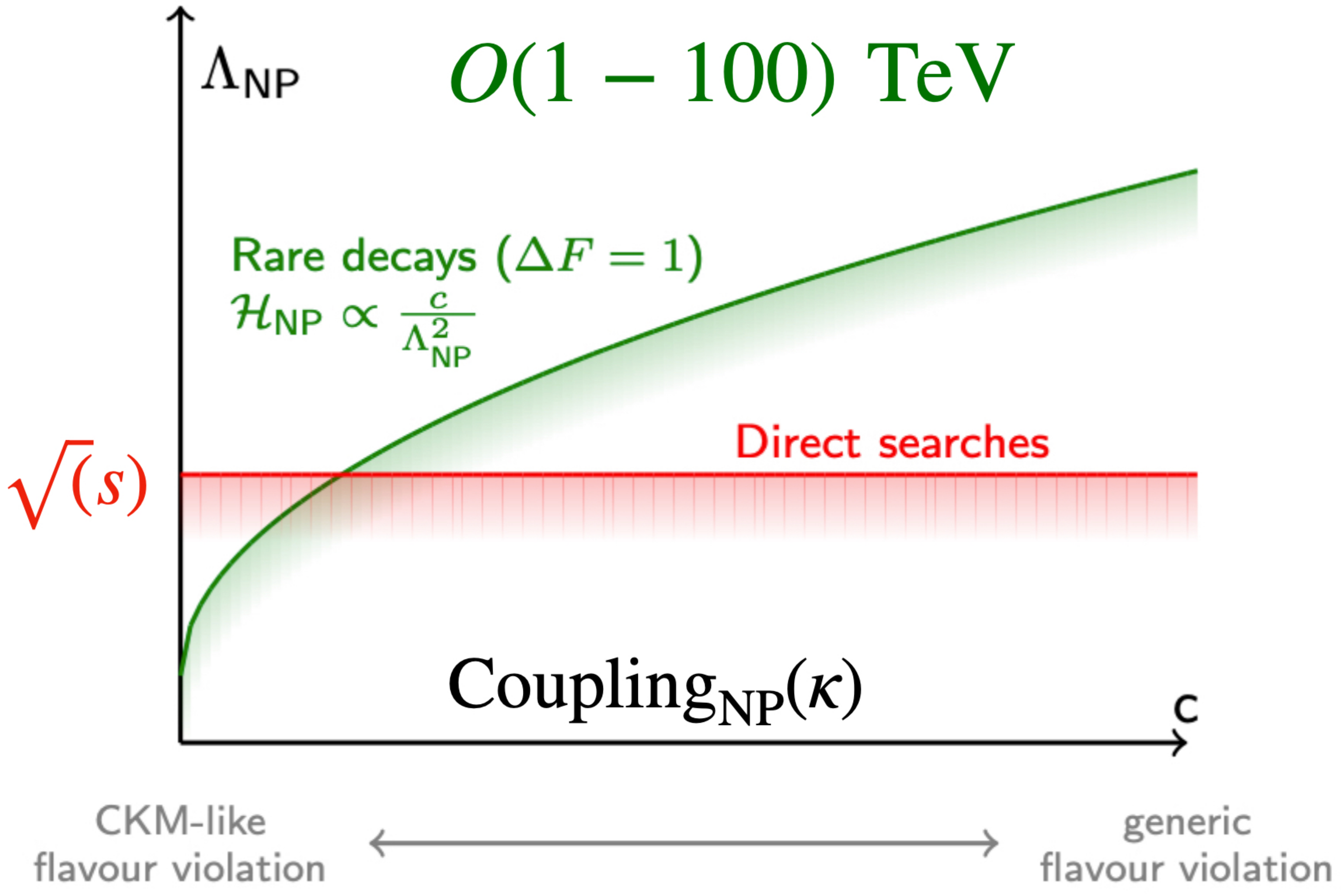
LFU test: R_{K,K^*} analysis

- Analysis strategy
- Selection and backgrounds
- Cross-checks
- Fits to data
- Results



Why $b \to s\ell^+\ell^-$ decays?

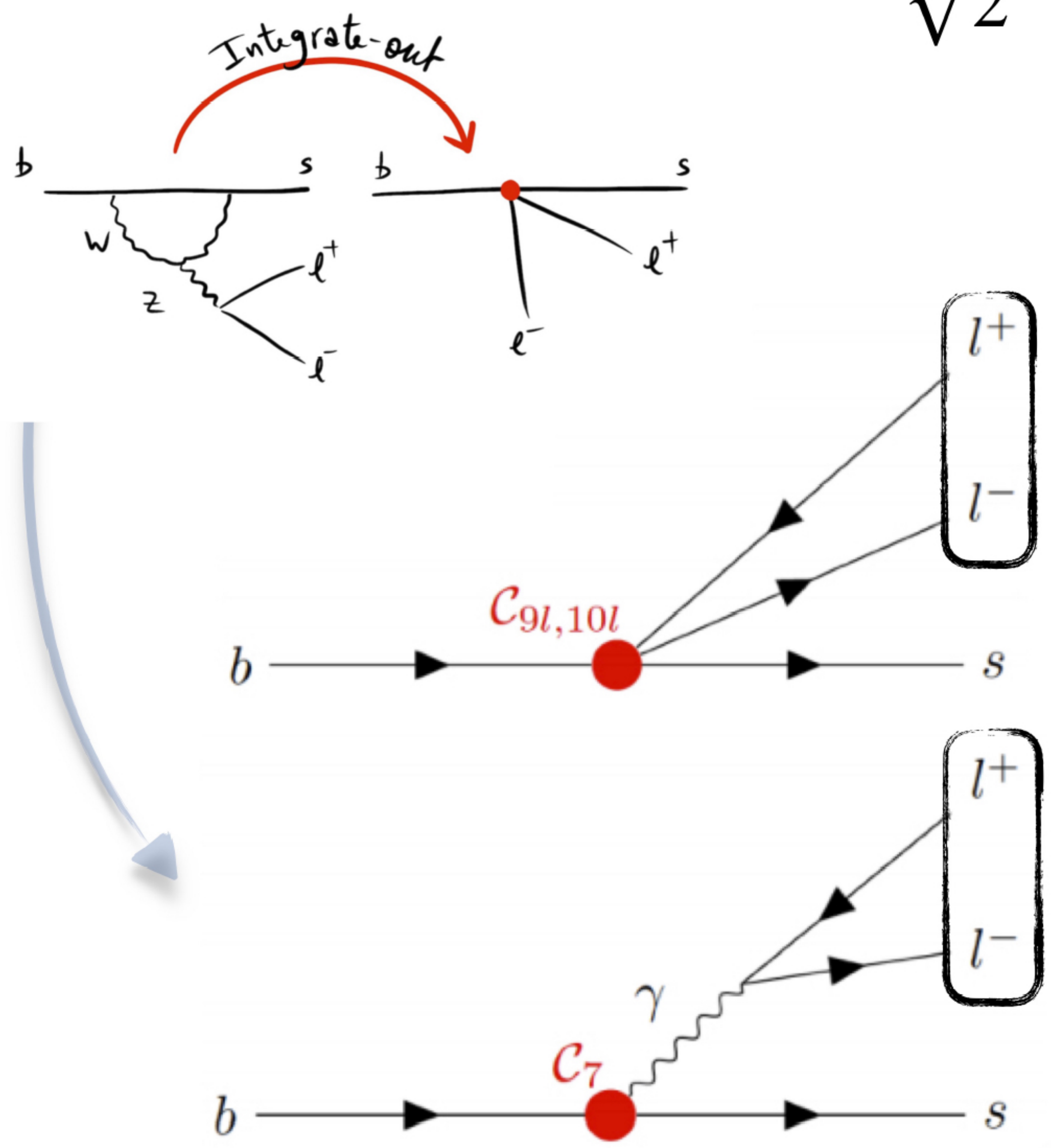
- **So far, no direct evidence of Beyond Standard Model (BSM) particles**
- Search of New Physics (NP) with indirect approach
  - EW gauge boson couplings to ℓ families universal in SM
  - Does it hold at higher energy scales?

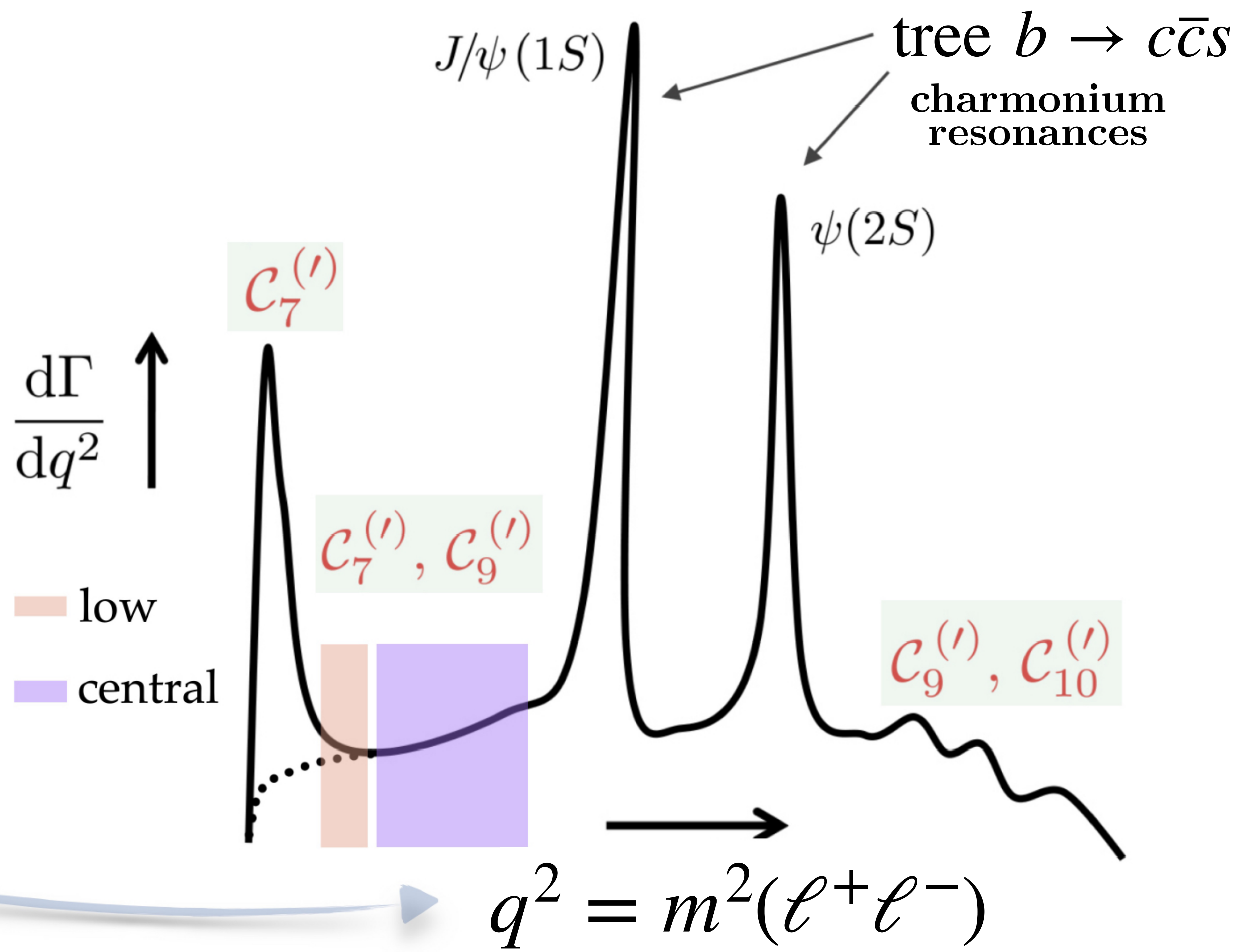


- **$b \to s\ell^+\ell^-$ to probe NP**
  - $\mathcal{B} \sim \mathcal{O}(10^{-6})$, suppressed at tree level
  - **Highly sensitive to NP** (TeV scale)
    - Λ_{NP} probed depends on NP structure
  - NP can affect decay rates and angular distributions
  - Is BSM physics hierarchical in lepton sector?

Why $b \to s\ell^+\ell^-$ decays?

$$H_{eff} = -\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \left(C_i^{SM} + \Delta_i^{NP} \right) O_i$$

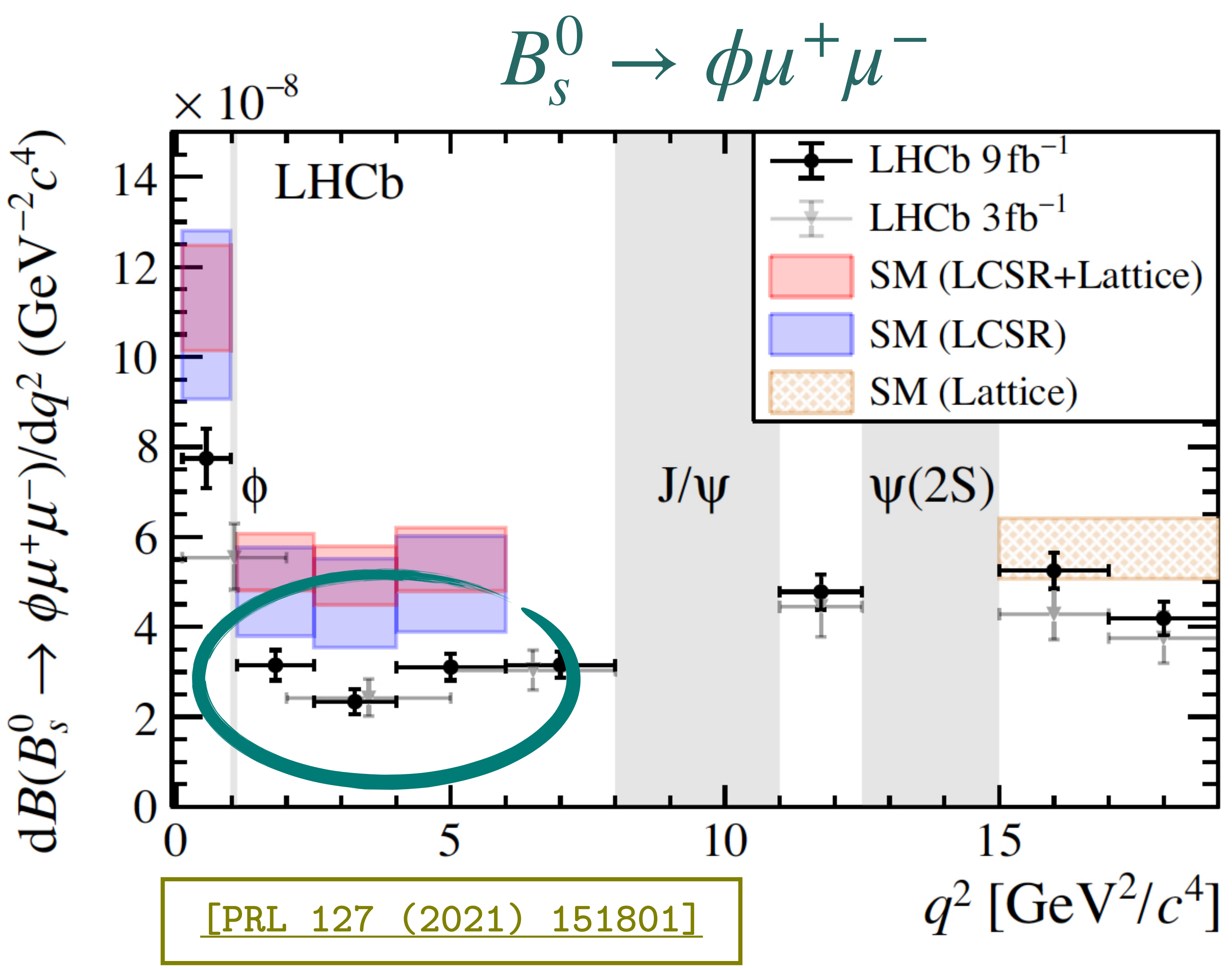




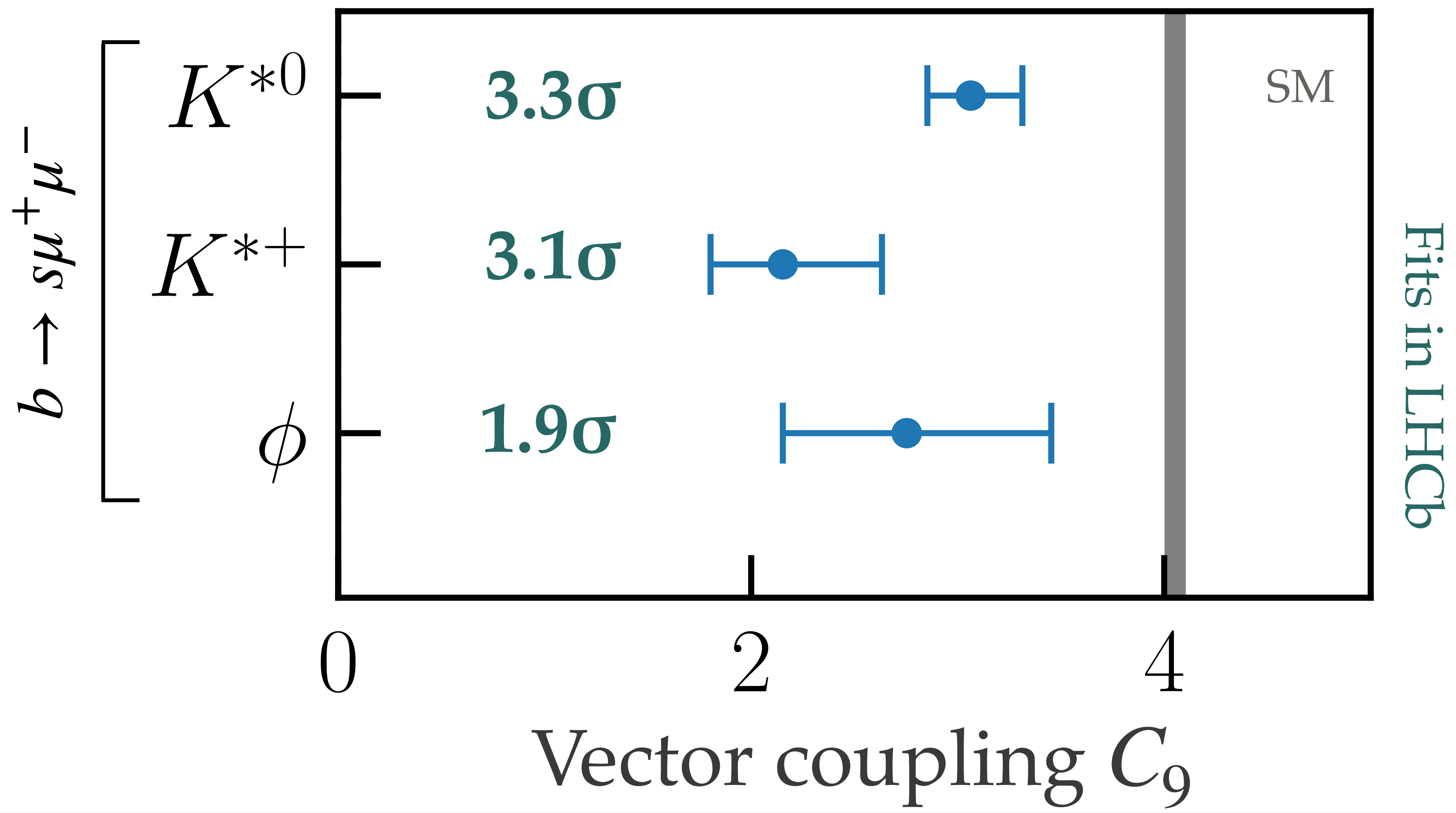
$\cdots$: with PseudoScalar H_s in final state, K_s^0, K^+

— : with Vector H_s in final state, $K^{*0}, K^{*+}, \phi, \ldots$

Anomalies in $b \to s\mu^+\mu^-$



[PRL 127 (2021) 151801]



$b \to s\mu^+\mu^-$ *differential decay rates*

- Similar behaviour in several decay (see backup)
- SM predictions heavily affected by hadronic form factor uncertainties $\sigma_{th} \sim \mathcal{O}$(20-30%)

Anomaly or common issue with form factors from SM?

$b \to s\mu^+\mu^-$ *angular analyses*

- Recent results (LHCb) ones:
  - $B^0 \to K^{*0}\mu^+\mu^-$ with 6 fb^{-1} (~ 4600 evts .) [PRL 125(2020)011802]
  - $B^+ \to K^{*+}\mu^+\mu^-$ with 9 fb^{-1} (~ 700 evts .) [PRL 126(2021)161802]
  - $B_s \to \phi\mu^+\mu^-$ with 9 fb^{-1}(~ 1900 evts .) [JHEP11(2021)043]
- Intriguing coherent and consistent pattern
  - However, *charm-loops* can mimic shift in C_9

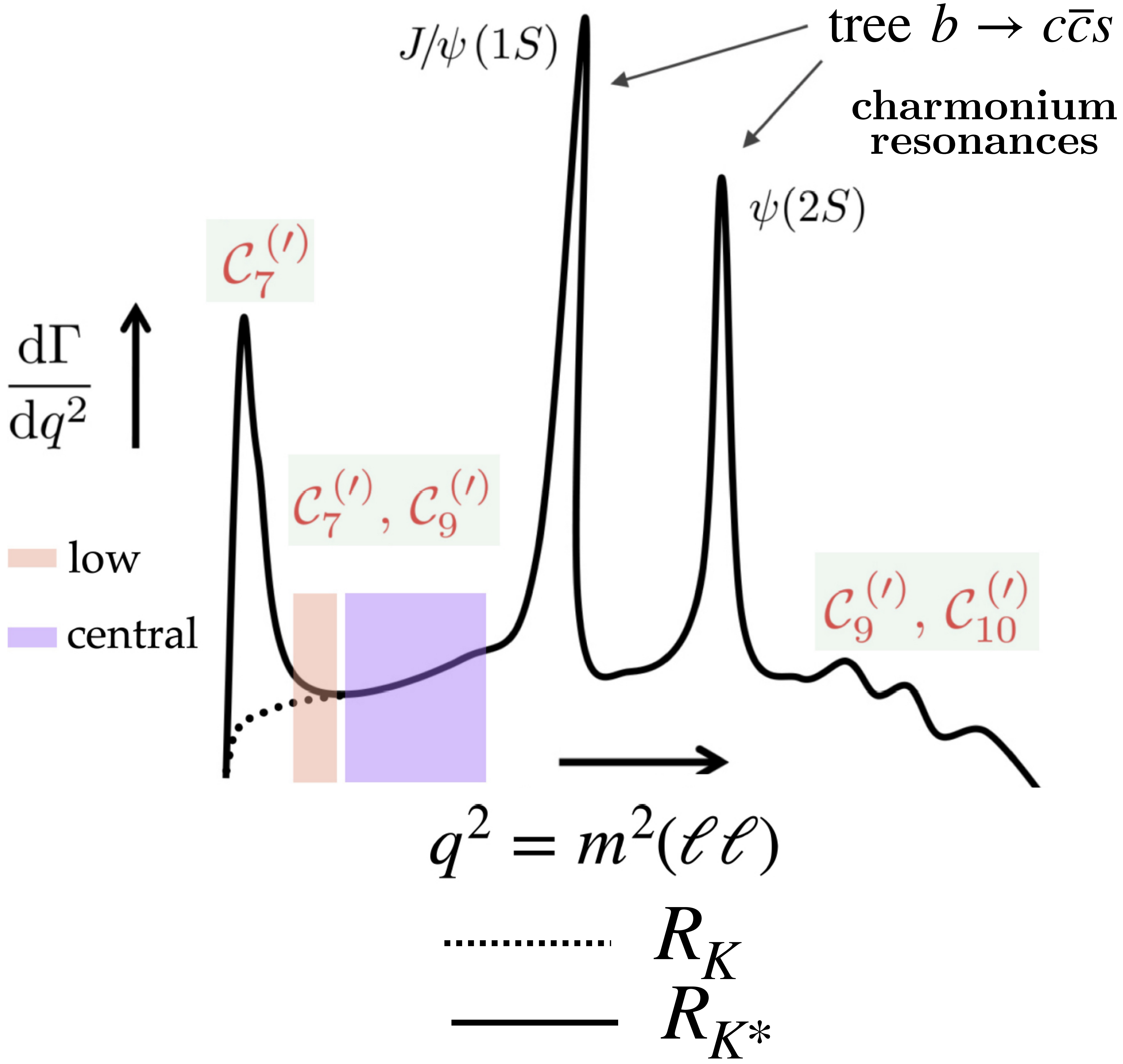
Today: lepton flavour universality test in $b \to s\ell^+\ell^-$

- **Full LHCb dataset ($9\,\mathrm{fb}^{-1}$), simultaneous measurement of R_K & R_{K^*}**

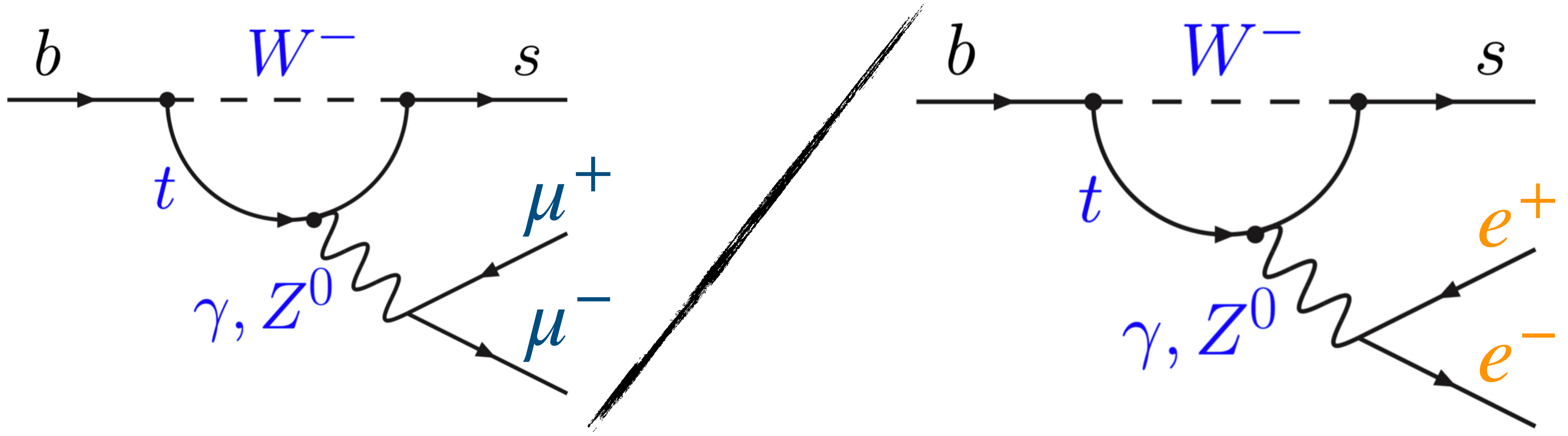
$$R_{K,K^*}(q_a^2, q_b^2) = \frac{\int_{q_a^2}^{q_b^2} \frac{\mathrm{d}\Gamma(B^{(+,0)} \to K^{(+,*0)}\mu^+\mu^-)}{\mathrm{d}q^2}\mathrm{d}q^2}{\int_{q_a^2}^{q_b^2} \frac{\mathrm{d}\Gamma(B^{(+,0)} \to K^{(+,*0)}e^+e^-)}{\mathrm{d}q^2}\mathrm{d}q^2}$$

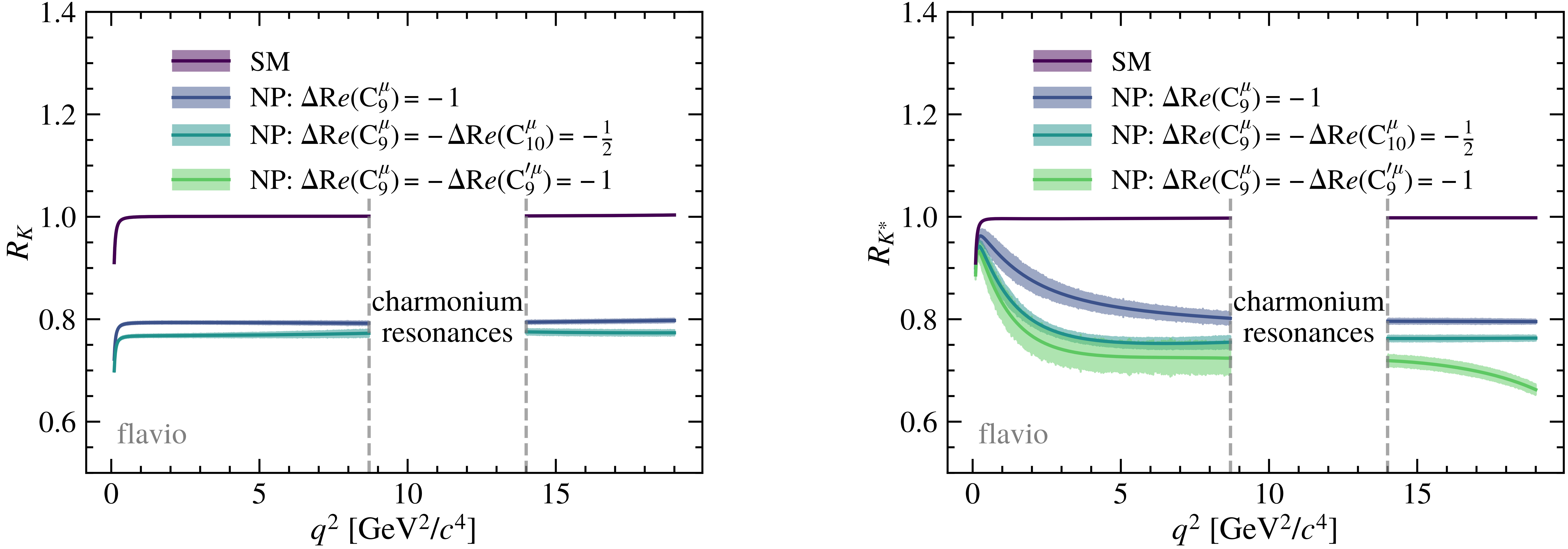
- **q^2 ranges:**
  - low-q^2 : $q^2 \in [0.1, 1.1]\,\mathrm{GeV}^2/c^4$
  - central-q^2 : $q^2 \in [1.1, 6.0]\,\mathrm{GeV}^2/c^4$
- **For R_{K^*}**

  K^{*0} : $m(K^+\pi^-) \in [792, 992]\,\mathrm{MeV/c}^2$



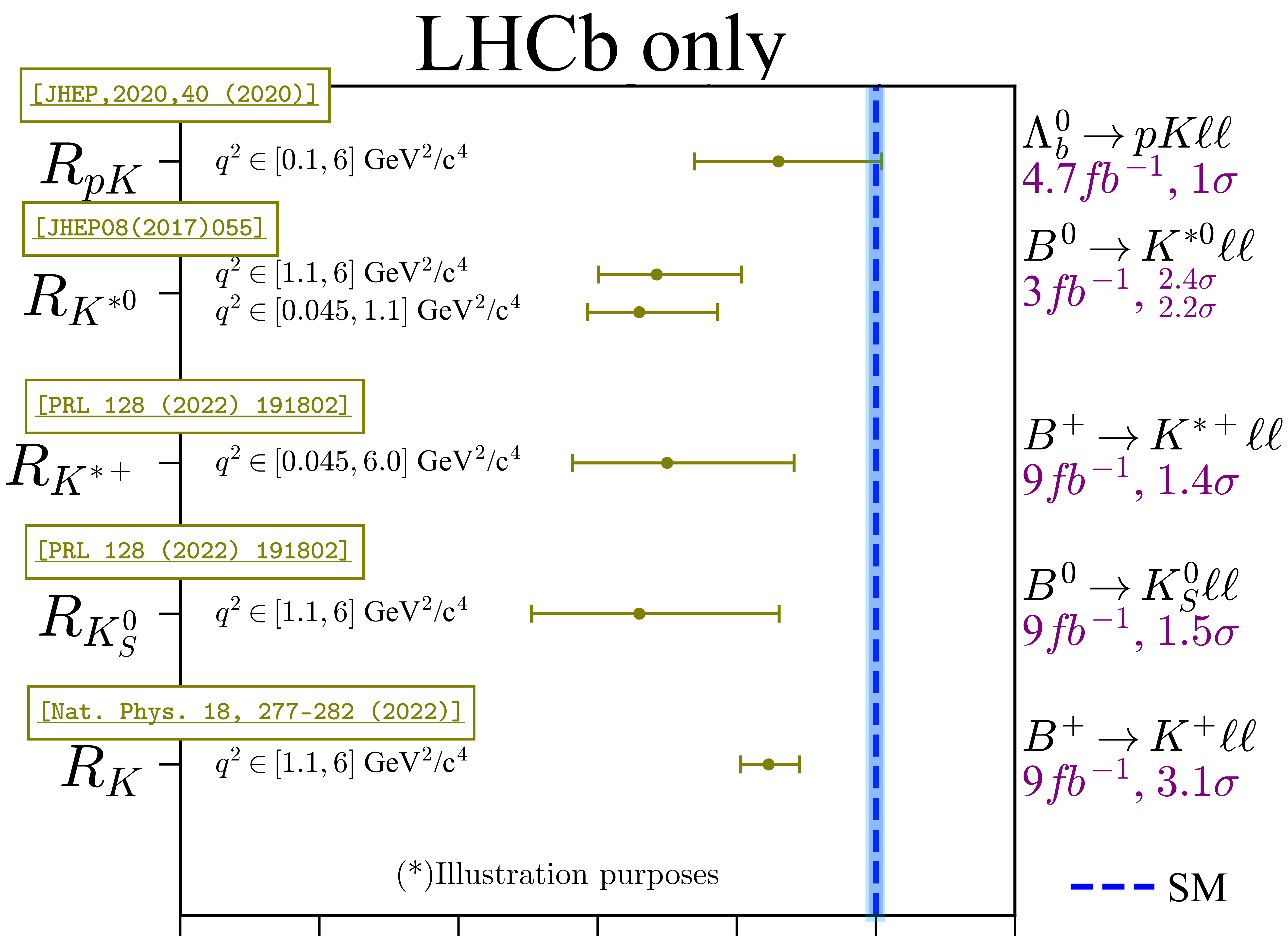
Sensitivity to NP in R_K and R_{K^*}





Lepton Flavour Universality (LFU) tests in $b \to s\ell^+\ell^-$

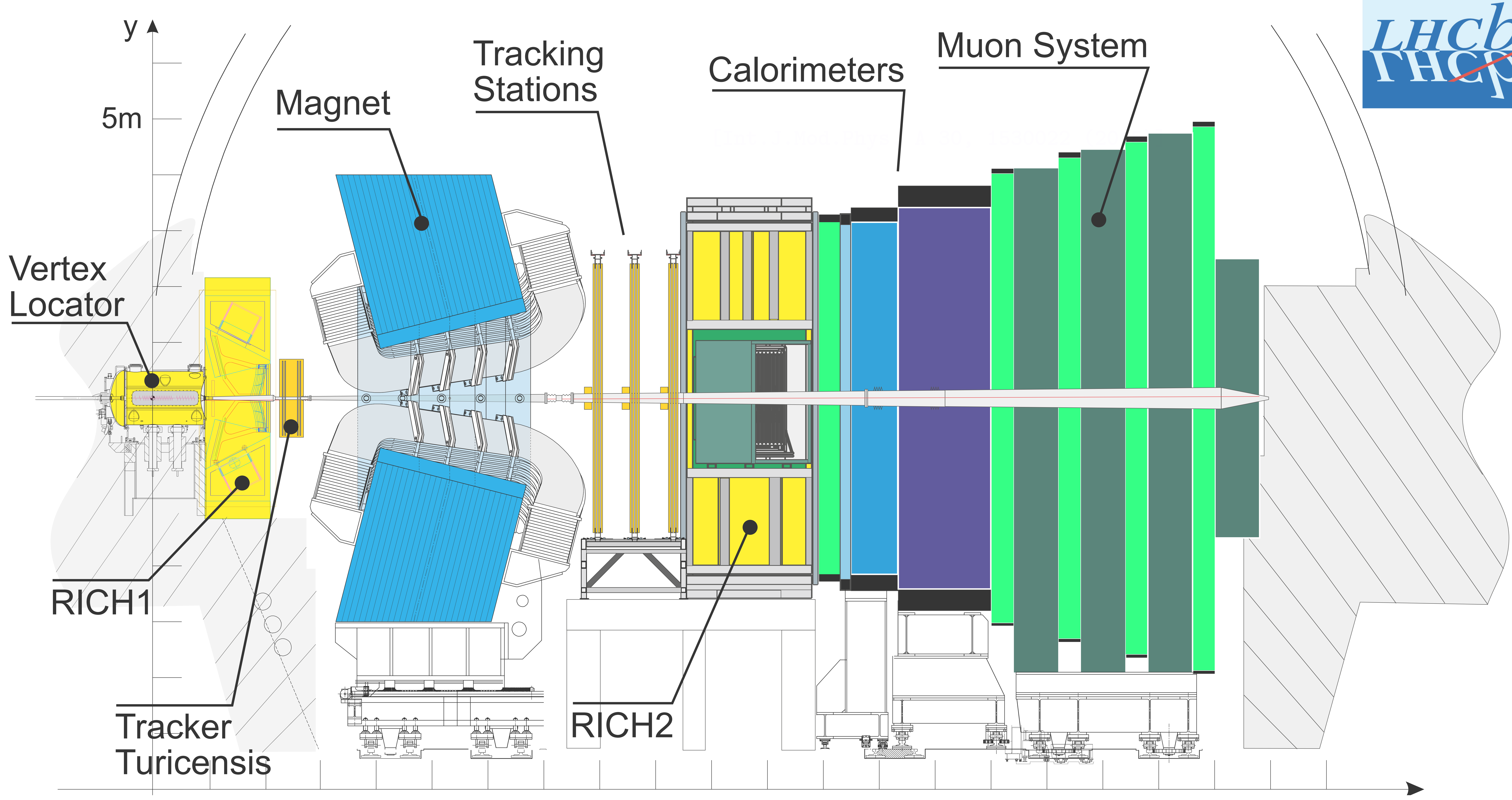
- Coherent pattern of tension to SM in LFU test with $b \to s\ell^+\ell^-$ transition:
- R_X ratio extremely well predicted in SM
  - Cancellation of hadronic uncertainties at 10^{-4}
  - $\mathcal{O}(1\%)$ QED correction [Eur.Phys.J.C 76 (2016) 8]
  - Statistically limited
- **Any departure from unity is a clear sign of New Physics**



$$R_X = \frac{\mathcal{B}(b \to s\mu^+\mu^-)}{\mathcal{B}(b \to se^+e^-)}$$

(*) Measurements from Belle not shown (larger statistical uncertainties)

The LHCb Detector



LFU test strategy

$$R_{K,K^*}(q_a^2, q_b^2) = \frac{\displaystyle\int_{q_a^2}^{q_b^2} \frac{\mathrm{d}\Gamma(B^{(+,0)} \to K^{(+,*0)}\mu^+\mu^-)}{\mathrm{d}q^2}\mathrm{d}q^2}{\displaystyle\int_{q_a^2}^{q_b^2} \frac{\mathrm{d}\Gamma(B^{(+,0)} \to K^{(+,*0)}e^+e^-)}{\mathrm{d}q^2}\mathrm{d}q^2}$$

$$R_{(K,K^*)} = \frac{\frac{\mathcal{N}}{\varepsilon}(B^{(+,0)} \to K^{(+,*0)}\mu^+\mu^-)}{\frac{\mathcal{N}}{\varepsilon}(B^{(+,0)} \to K^{(+,*0)}e^+e^-)}$$

- $\mathcal{N}$ **from mass fits,** ε **evaluated from data-driven corrected simulation**

LFU test strategy

$$R_{K,K^*}(q_a^2, q_b^2) = \frac{\int_{q_a^2}^{q_b^2} \frac{\mathrm{d}\Gamma(B^{(+,0)} \to K^{(+,*0)}\mu^+\mu^-)}{\mathrm{d}q^2}\mathrm{d}q^2}{\int_{q_a^2}^{q_b^2} \frac{\mathrm{d}\Gamma(B^{(+,0)} \to K^{(+,*0)}e^+e^-)}{\mathrm{d}q^2}\mathrm{d}q^2} \times \frac{\Gamma(J/\psi \to e^+e^-)}{\Gamma(J/\psi \to \mu^+\mu^-)}$$

Measured to be 1 Phys. Lett. B731, 227 (2014)

$r_{J/\psi}^{-1} = 1$

$$R_{(K,K^*)} = \frac{\frac{\mathcal{N}}{\varepsilon}(B^{(+,0)} \to K^{(+,*0)}\mu^+\mu^-)}{\frac{\mathcal{N}}{\varepsilon}(B^{(+,0)} \to K^{(+,*0)}e^+e^-)} \times \frac{\frac{\mathcal{N}}{\varepsilon}(B^{(+,0)} \to K^{(+,*0)}J/\psi(e^+e^-))}{\frac{\mathcal{N}}{\varepsilon}(B^{(+,0)} \to K^{(+,*0)}J/\psi(\mu^+\mu^-))}$$

- **$\mathcal{N}$ from mass fits, ε evaluated from data-driven corrected simulation**
- Use resonant-J/ψ mode as normalisation to cancel out most of ε systematics in e/μ differences. Resonant-J/ψ mode also used for ε calibration

LFU test strategy

$$R_{K,K^*}(q_a^2, q_b^2) = \frac{\int_{q_a^2}^{q_b^2} \frac{\mathrm{d}\Gamma(B^{(+,0)} \to K^{(+,*0)}\mu^+\mu^-)}{\mathrm{d}q^2}\mathrm{d}q^2}{\int_{q_a^2}^{q_b^2} \frac{\mathrm{d}\Gamma(B^{(+,0)} \to K^{(+,*0)}e^+e^-)}{\mathrm{d}q^2}\mathrm{d}q^2} \times \frac{\Gamma(J/\psi \to e^+e^-)}{\Gamma(J/\psi \to \mu^+\mu^-)}$$

Measured to be 1 Phys. Lett. B731, 227 (2014)

$r_{J/\psi}^{-1} = 1$

$$R_{(K,K^*)} = \frac{\frac{\mathcal{N}}{\varepsilon}(B^{(+,0)} \to K^{(+,*0)}\mu^+\mu^-)}{\frac{\mathcal{N}}{\varepsilon}(B^{(+,0)} \to K^{(+,*0)}e^+e^-)} \times \frac{\frac{\mathcal{N}}{\varepsilon}(B^{(+,0)} \to K^{(+,*0)}J/\psi(e^+e^-))}{\frac{\mathcal{N}}{\varepsilon}(B^{(+,0)} \to K^{(+,*0)}J/\psi(\mu^+\mu^-))}$$

- **$\mathcal{N}$ from mass fits, ε evaluated from data-driven corrected simulation**
- Use resonant-J/ψ mode as normalisation to cancel out most of ε systematics in e/μ differences. Resonant-J/ψ mode also used for ε calibration
- **Cross-check** goodness of calibration testing $r_{J/\psi}^{K,K^*} = 1$

LFU test strategy

Measured to be 1 PDG2022 | Measured to be 1 Phys. Lett. B731, 227 (2014)

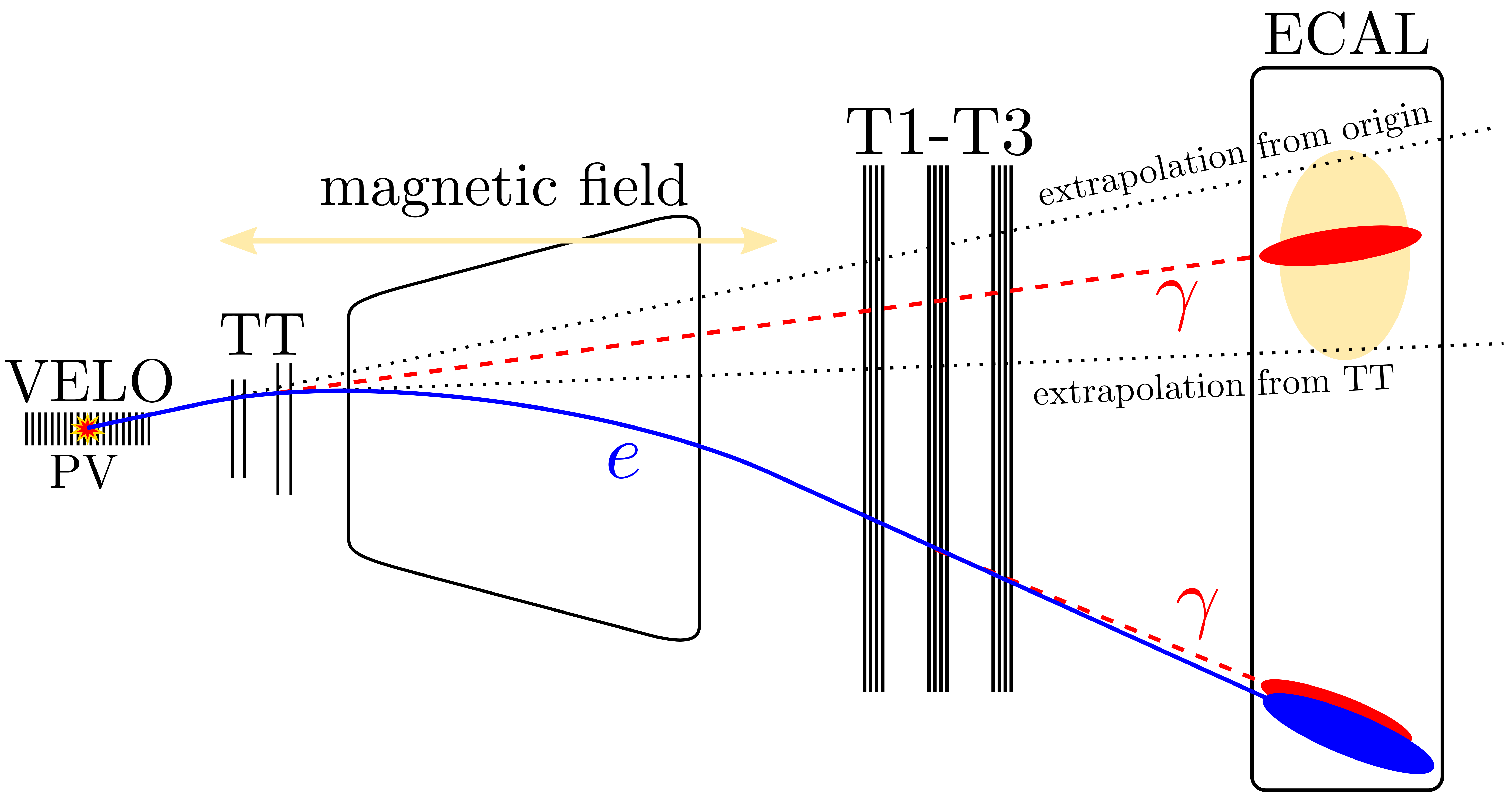
$$R_{\psi(2S)} = \frac{\Gamma(\psi(2S)\to\mu^+\mu^-)}{\Gamma(\psi(2S)\to e^+e^-)} \times \frac{\Gamma(J/\psi\to e^+e^-)}{\Gamma(J/\psi\to\mu^+\mu^-)}$$

$r^{-1}_{J/\psi} = 1$

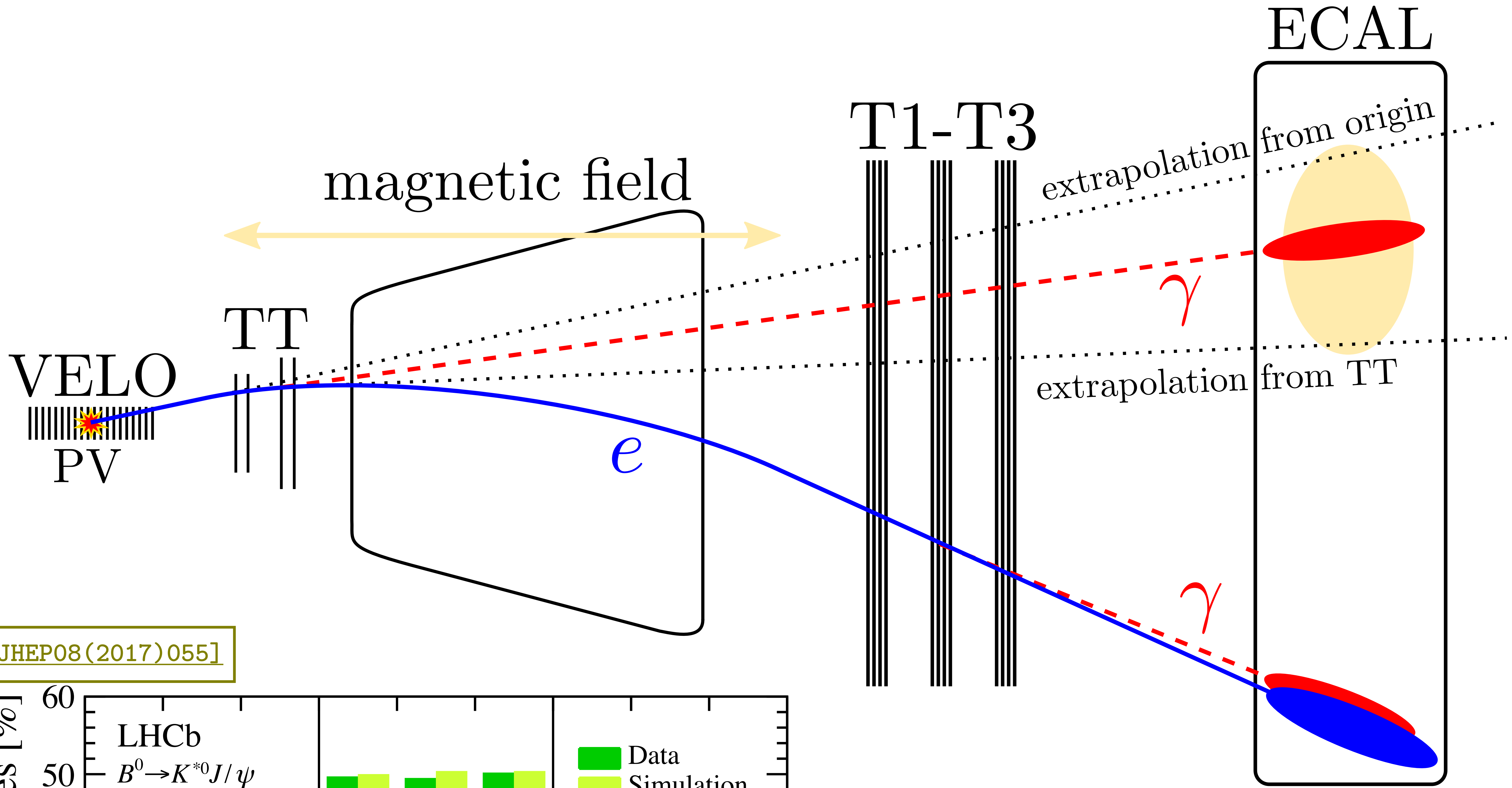
$$R^{(K,K^*)}_{\psi(2S)} = \frac{\frac{\mathcal{N}}{\varepsilon}(B^{(+,0)}\to K^{(+,*0)}\psi(2S)(\mu^+\mu^-))}{\frac{\mathcal{N}}{\varepsilon}(B^{(+,0)}\to K^{(+,*0)}\psi(2S)(e^+e^-))} \times \frac{\frac{\mathcal{N}}{\varepsilon}(B^{(+,0)}\to K^{(+,*0)}J/\psi(e^+e^-))}{\frac{\mathcal{N}}{\varepsilon}(B^{(+,0)}\to K^{(+,*0)}J/\psi(\mu^+\mu^-))}$$

- **$\mathcal{N}$ from mass fits, ε evaluated from data-driven corrected simulation**
- Use resonant-J/ψ mode as normalisation to cancel out most of ε systematics in e/μ differences. Resonant-J/ψ mode also used for ε calibration
- **Cross-check** goodness of calibration testing $r^{K,K^*}_{J/\psi} = 1$
- **Cross-check** goodness of method testing $R^{K,K^*}_{\psi(2S)} = 1$

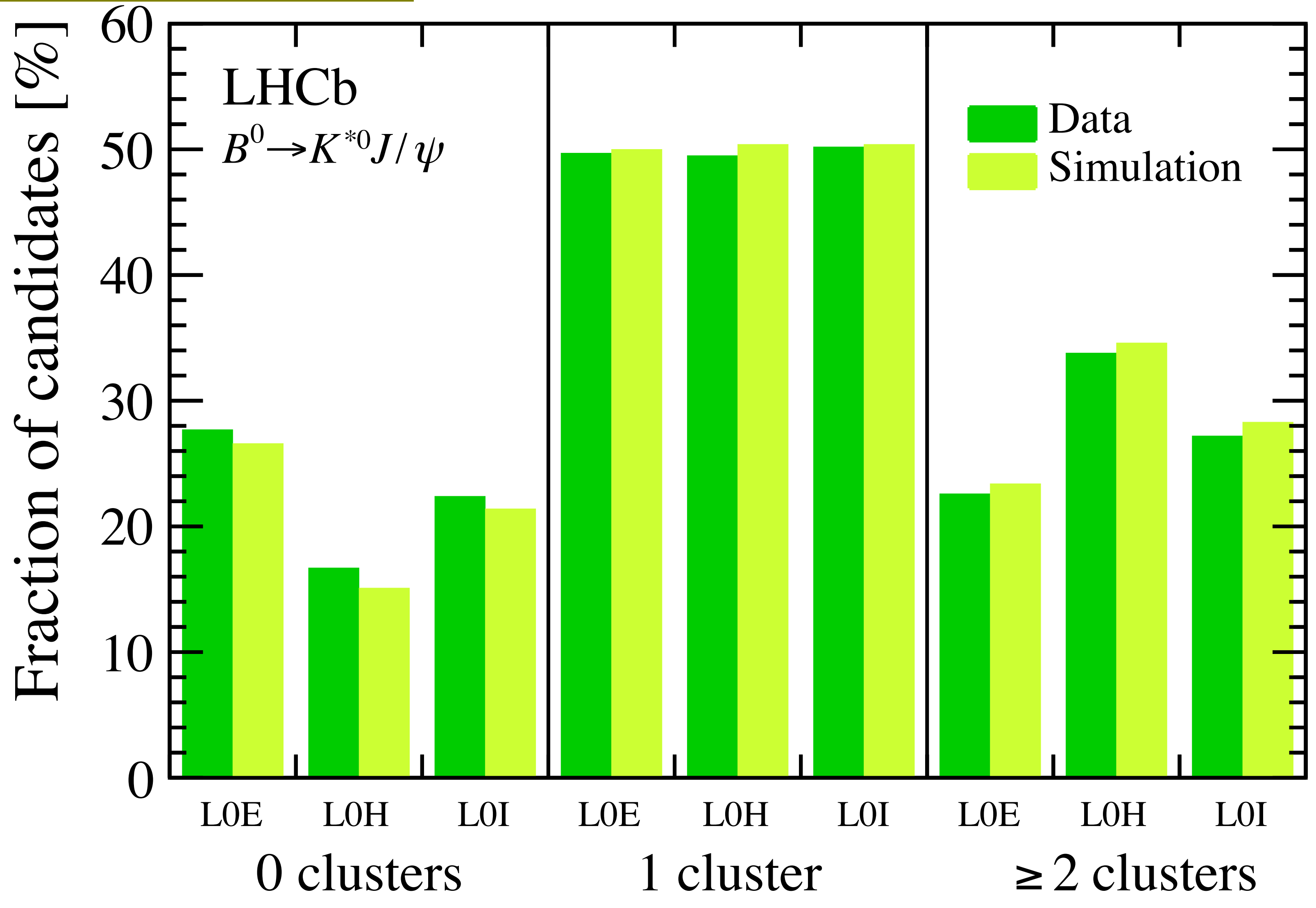
Challenges in LFU tests: electrons and energy losses



Challenges in LFU tests: electrons and energy losses



[JHEP08(2017)055]

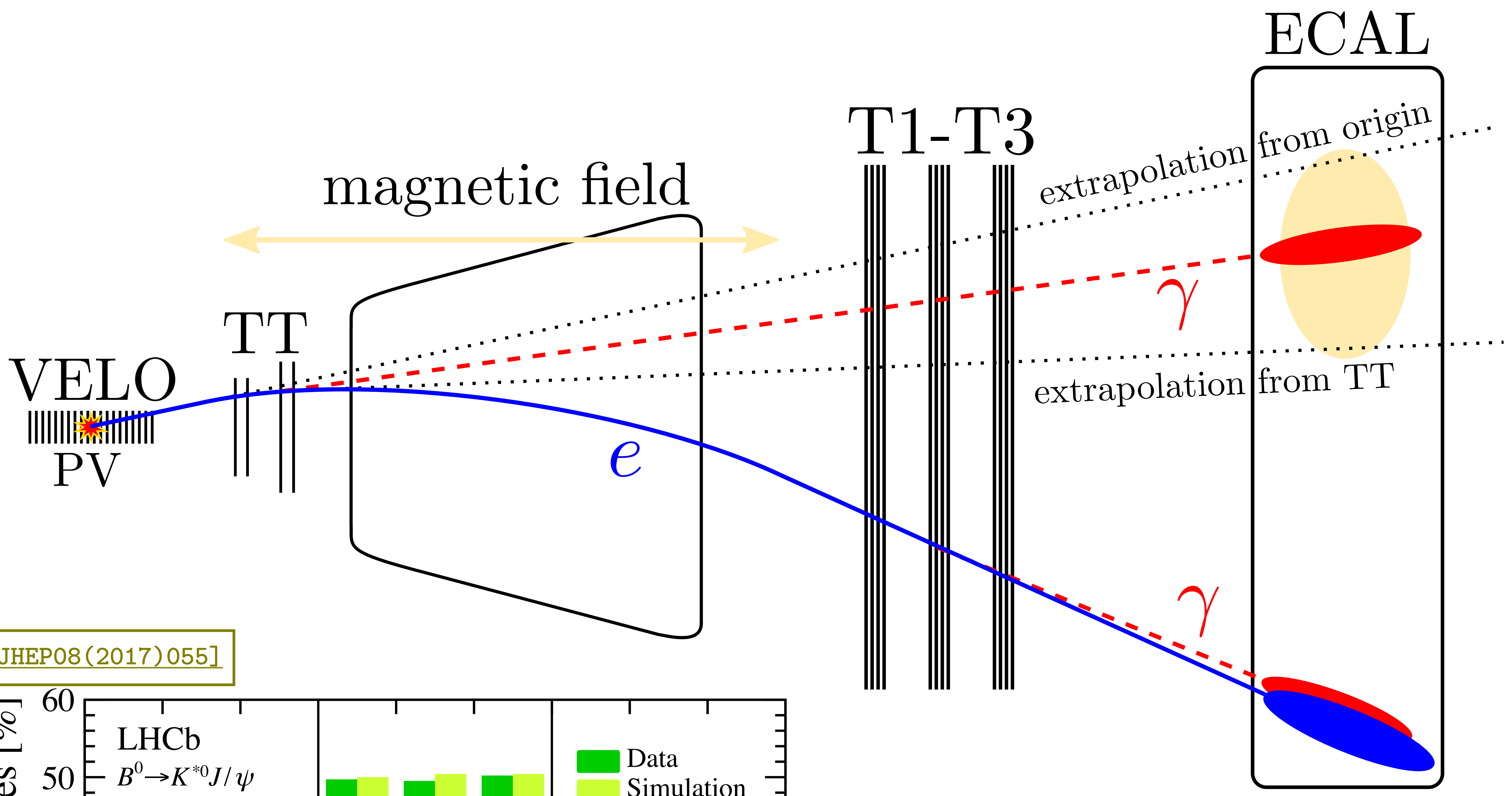


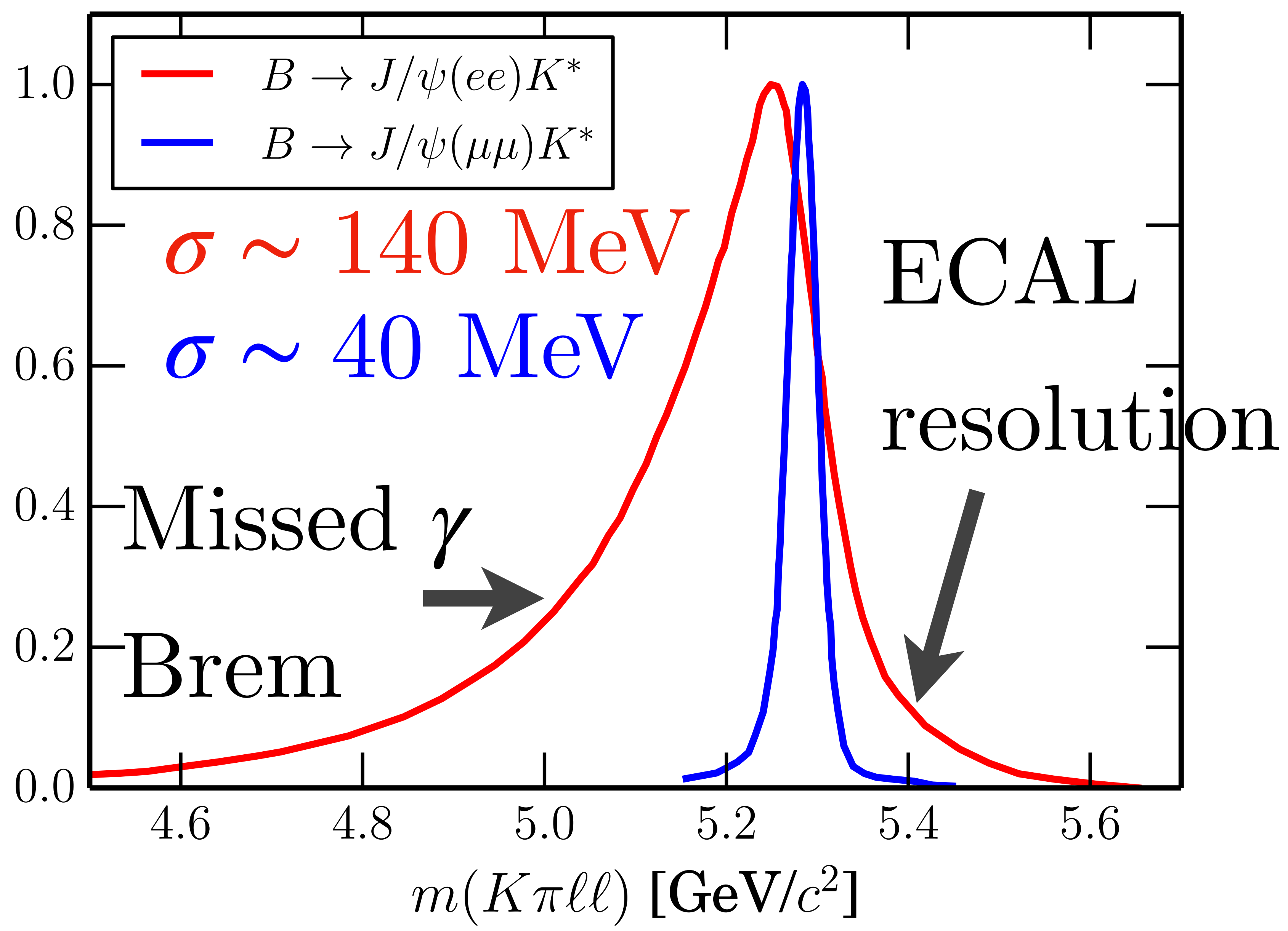
$\simeq$

- Brem recovery is O(50%) efficient
- Well described in simulation

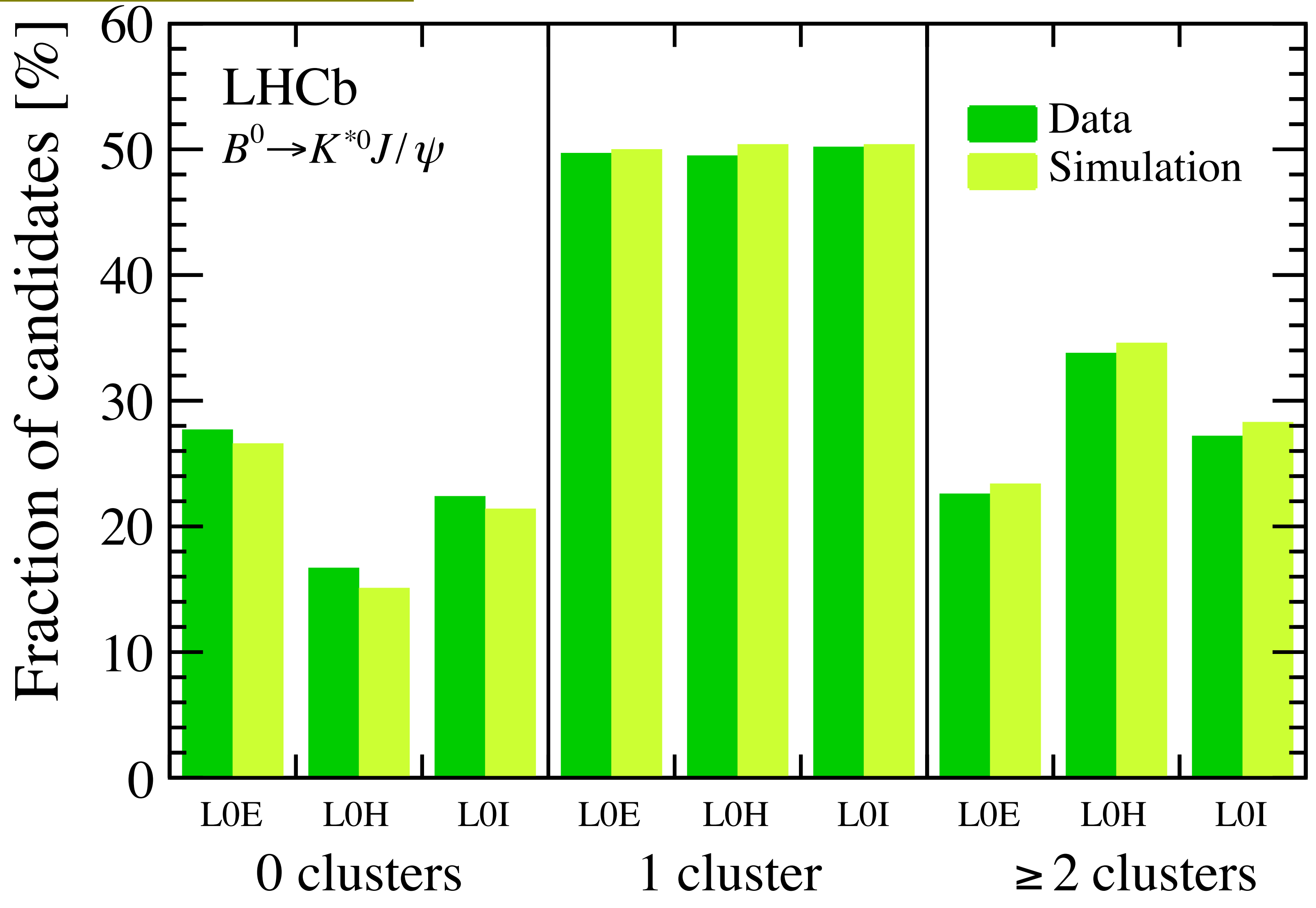
⇒ 3 "*Brem*" categories ($0/1/2\ \gamma$)

Challenges in LFU tests: electrons and energy losses





[JHEP08(2017)055]



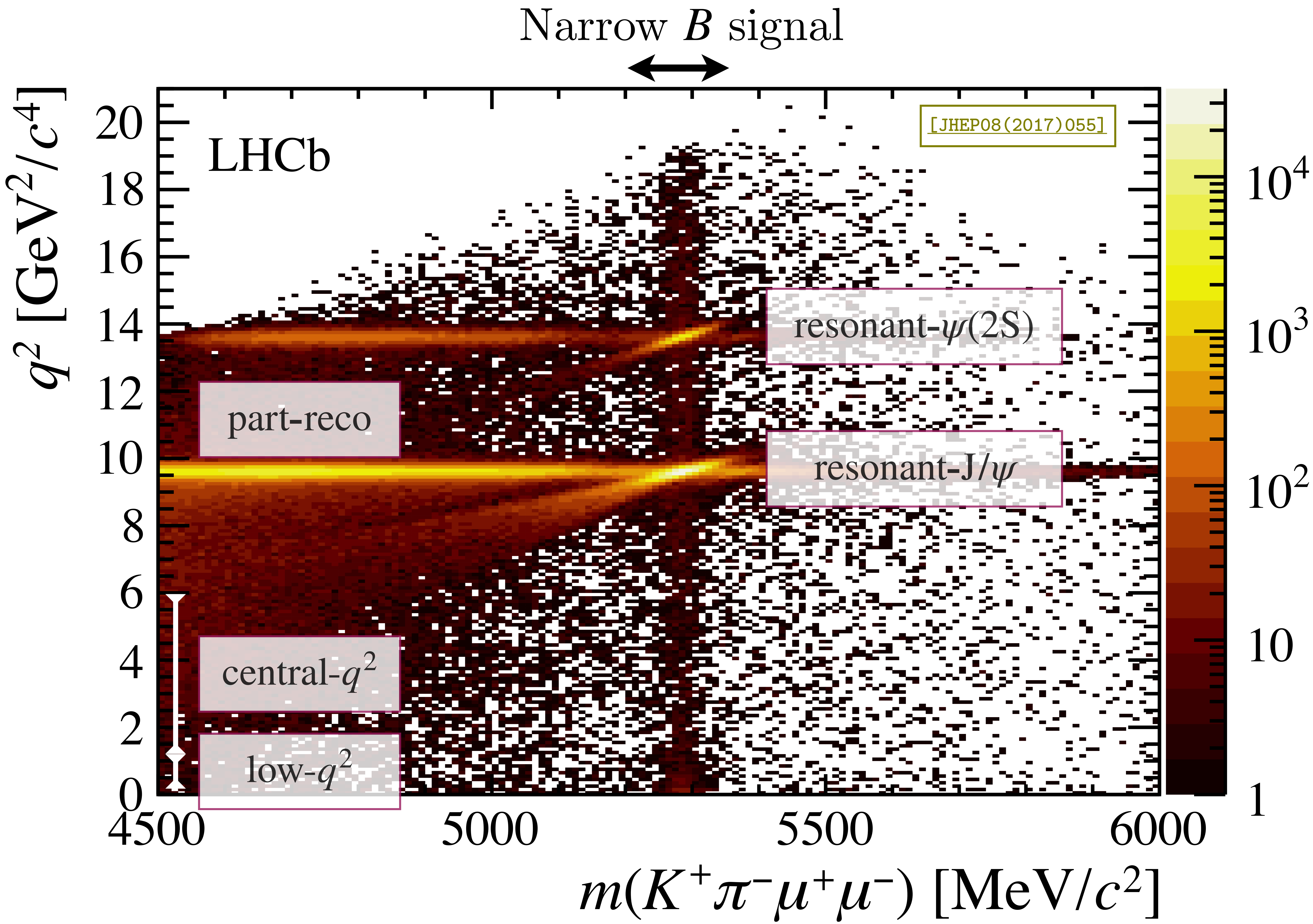
$\simeq$

- Brem recovery is O(50%) efficient
- Well described in simulation

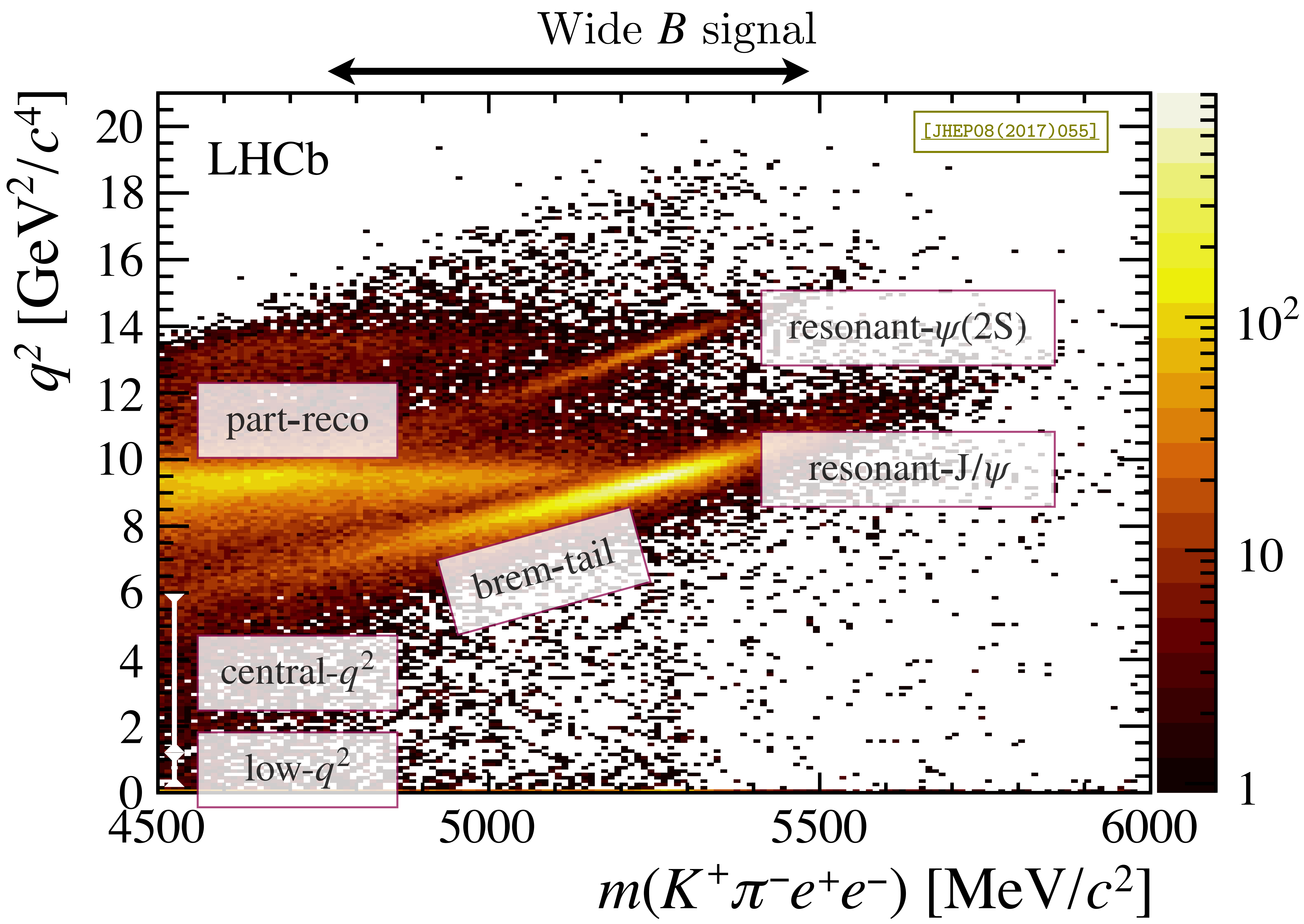
Wider fit range than muons

- more background,
- more sensitive to peaking structures
- lineshapes are brem-dependent

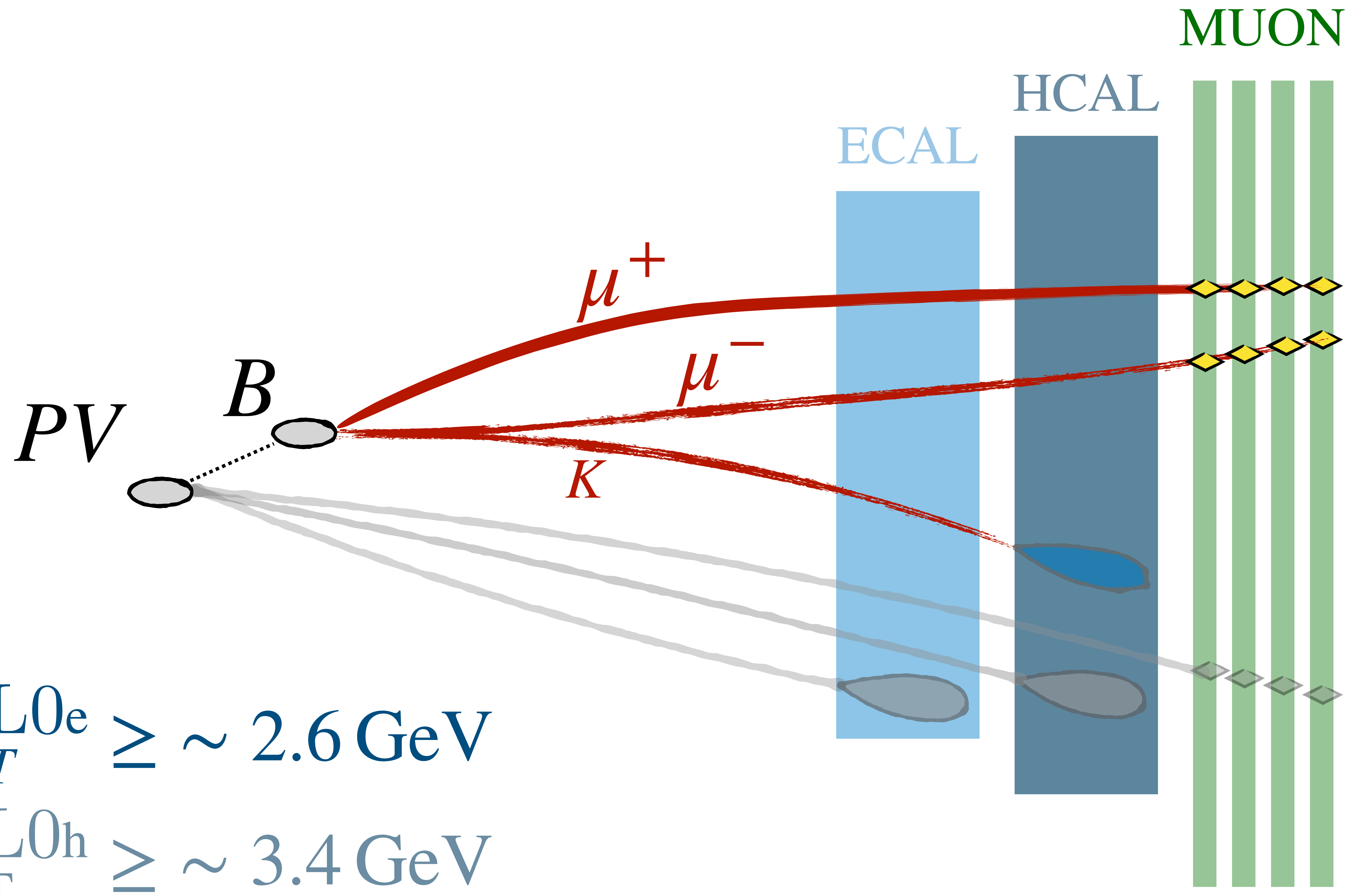
Net effect for LFU tests: muon modes

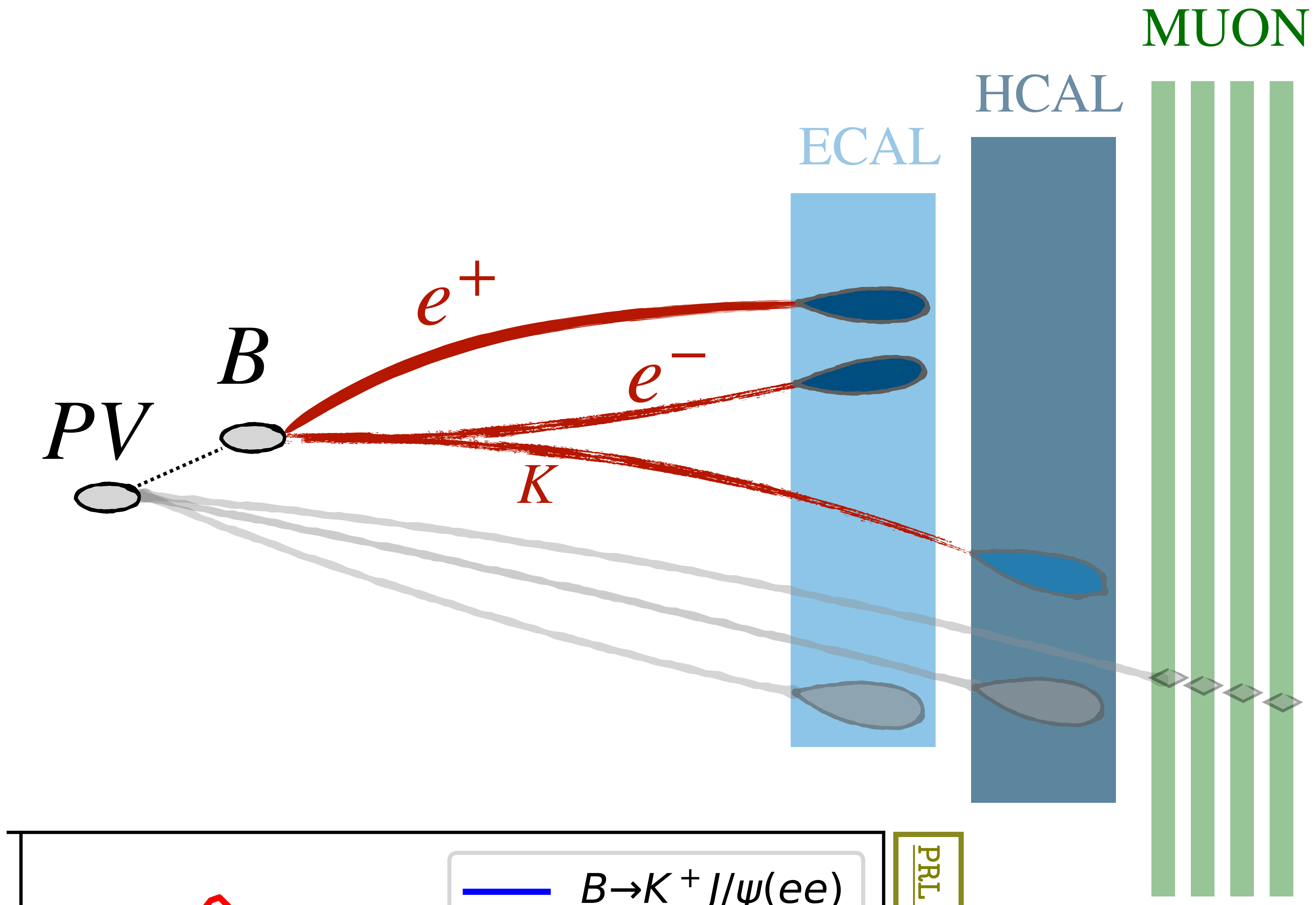


Net effect for LFU tests: electron modes



Hardware trigger: major effect on ε differences on μ/e



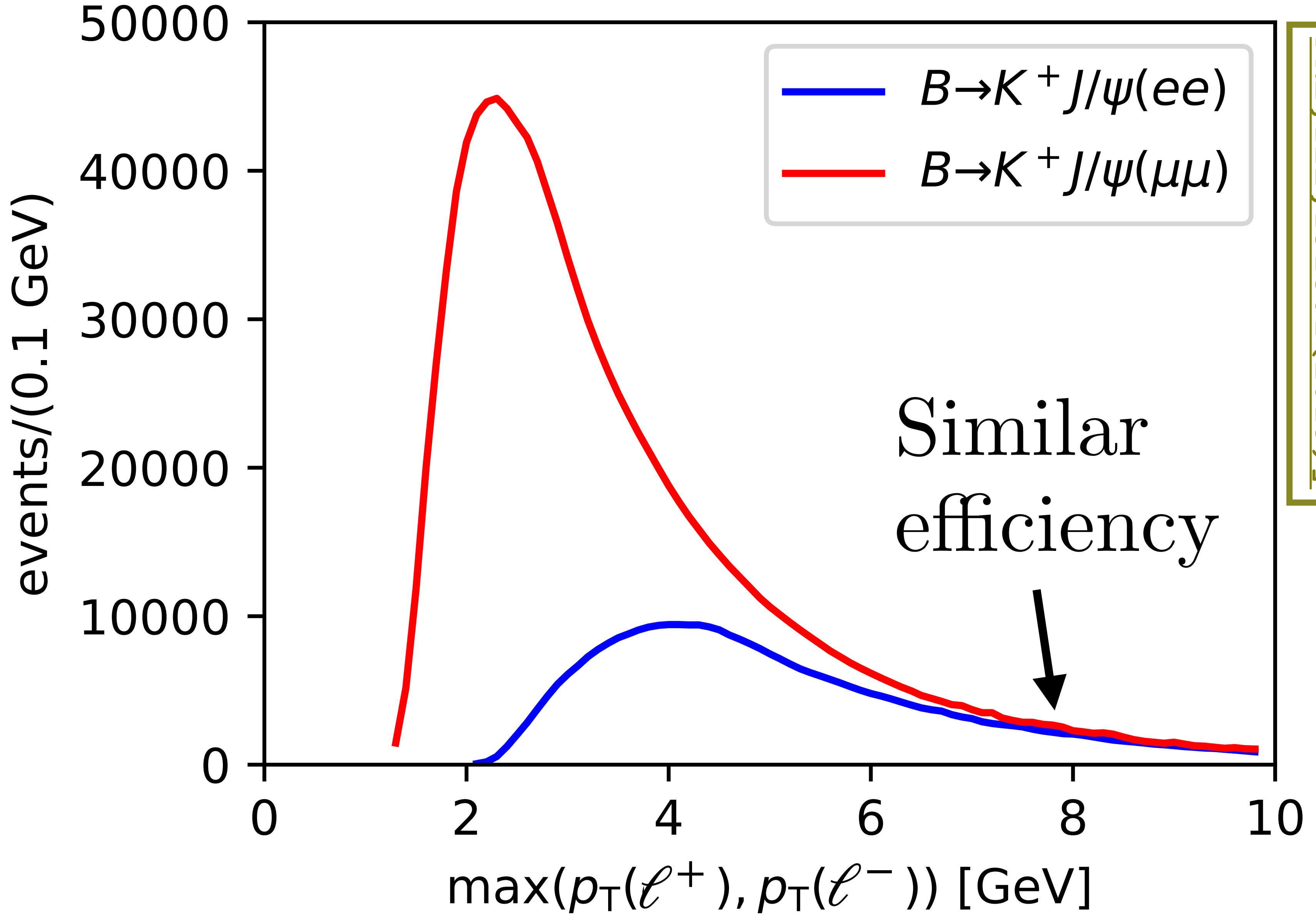


$E_T^{L0e} \geq \sim 2.6\,\mathrm{GeV}$

$E_T^{L0h} \geq \sim 3.4\,\mathrm{GeV}$

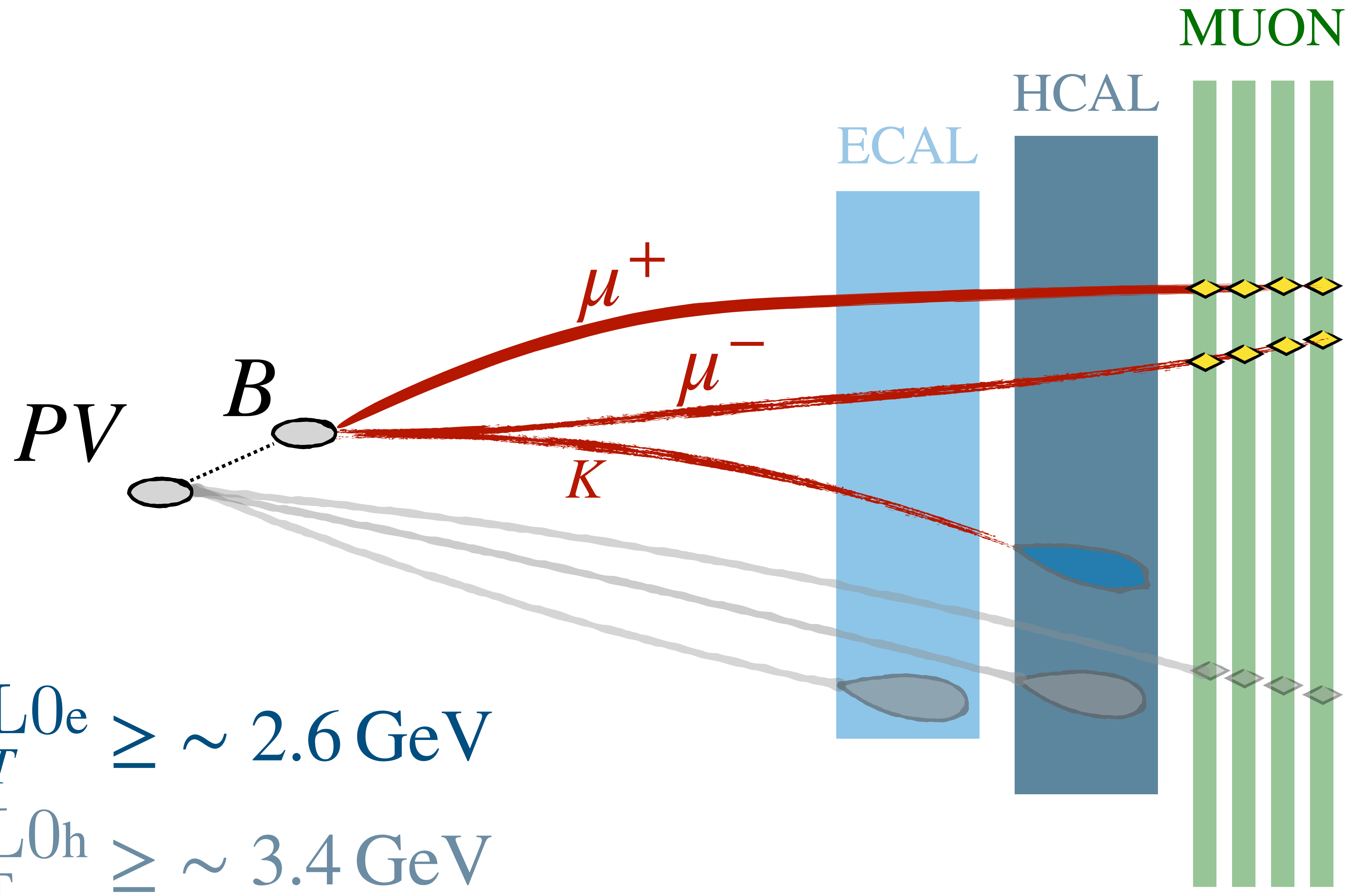
$p_T^{L0\mu} \geq \sim 1.4\,\mathrm{GeV}$

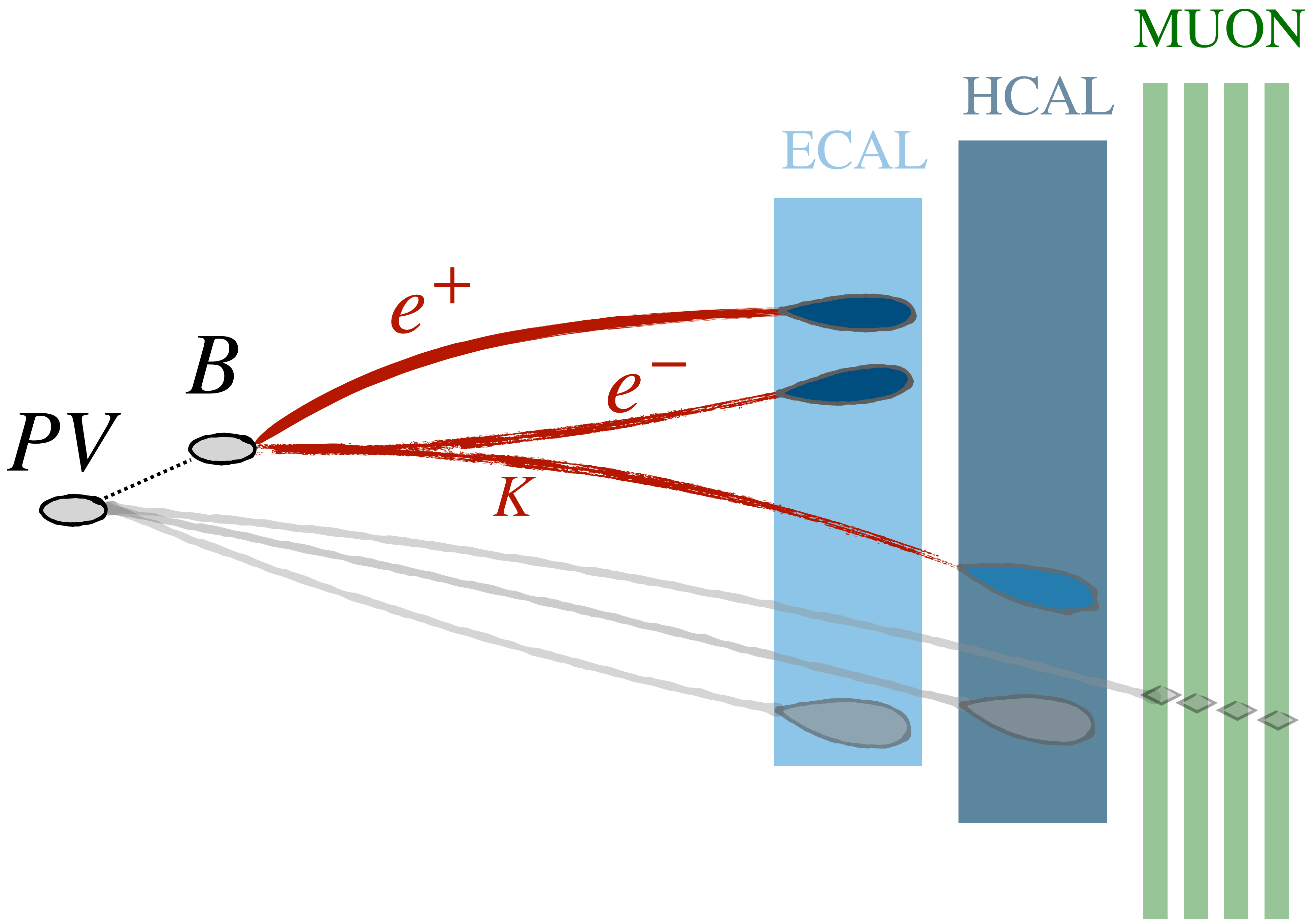
Selection effect from L0e vs L0μ $\sim \frac{1}{3}$



PRL, 122, 191801 (2019)]

Selection: hardware trigger choice in R_{K,K^*}





$E_T^{L0e} \geq \sim 2.6\,\text{GeV}$

$E_T^{L0h} \geq \sim 3.4\,\text{GeV}$

$p_T^{L0\mu} \geq \sim 1.4\,\text{GeV}$

Trigger-Independent-Signal (`TIS`)

- $\frac{\varepsilon(\text{L0}\mu,\text{h},\text{e})}{\varepsilon(\text{L0}\mu,\text{h},\text{e})}$ from underlying event

Trigger-On-Signal (`TOS`)

- $\frac{\varepsilon(\text{L0}\mu)}{\varepsilon(\text{L0e})}$ from tracks in B candidate

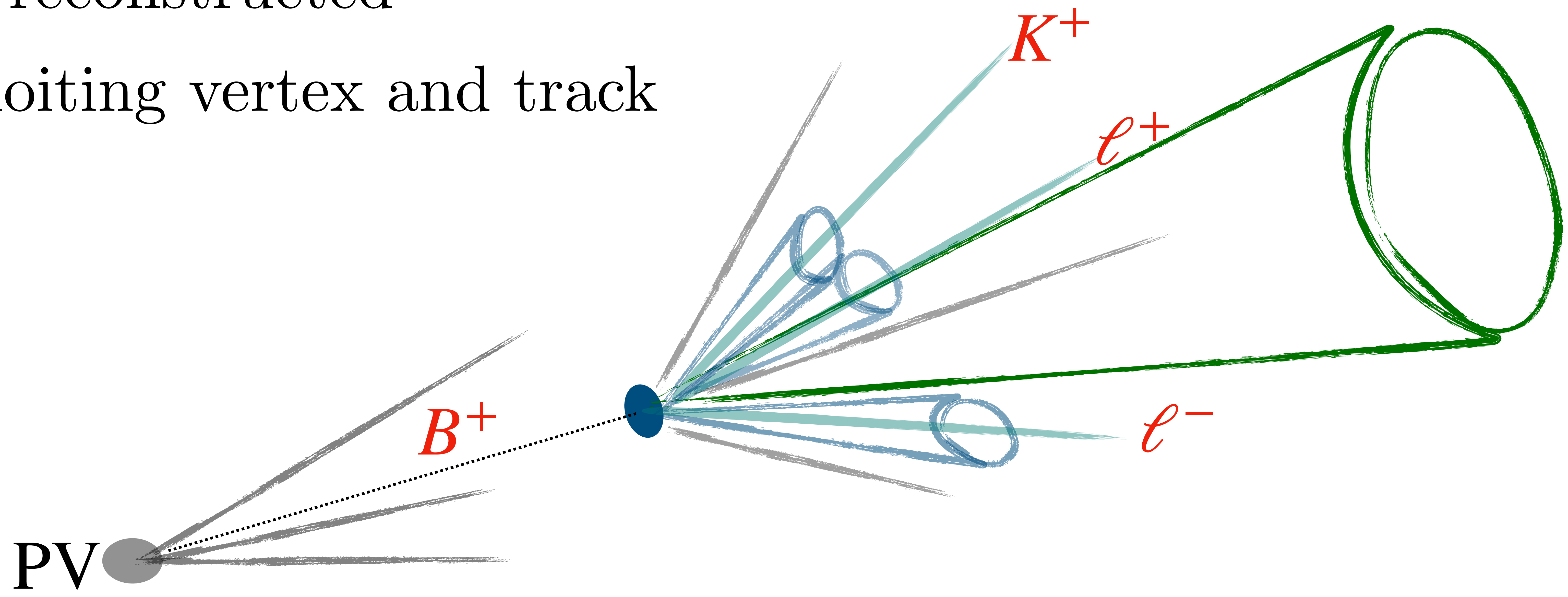
➡ R-ratio from $\left\langle \frac{\text{TIS}}{\text{TIS}}, \frac{\text{L0}\mu}{\text{L0e}} \right\rangle$

- ✦ Less $\varepsilon(e/\mu)$ differences to correct in `TIS`
- ✦ Previous R_{K,K^*} only L0μ in muon mode

Selection: multivariate classifiers

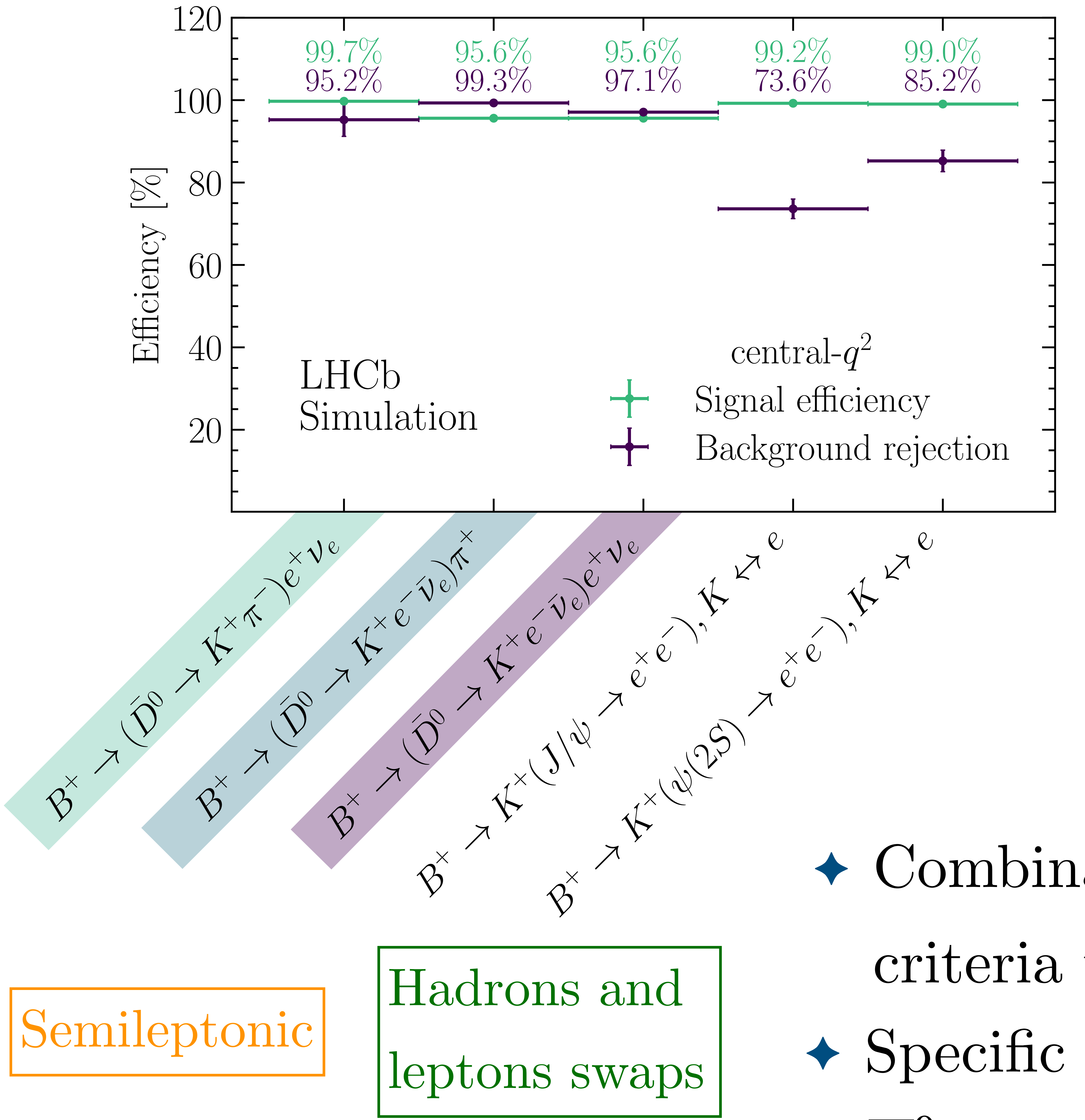
1. $B^{(+,0)} \to K^{(+,*0)}\mu^+\mu^-$ **and** $B^{(+,0)} \to K^{(+,*0)}e^+e^-$: suppress combinatorial with multivariate classifier using kinematic and vertex quality information.

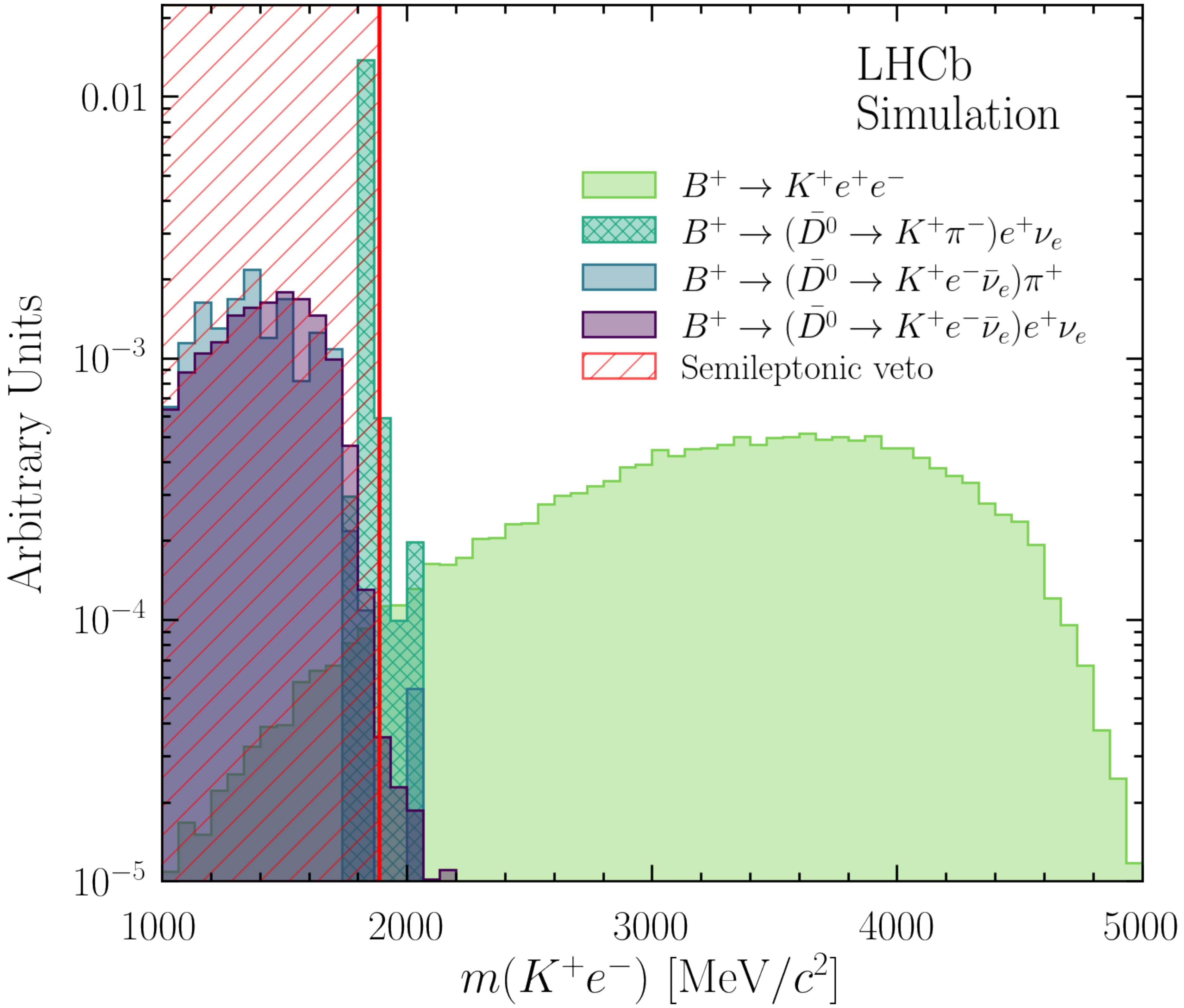
2. $B^{(+,0)} \to K^{(+,*0)}e^+e^-$: dedicated classifier to fight partially reconstructed background, exploiting vertex and track isolation



✦ Optimisation of significance for each mode/q^2 regions and data taking period

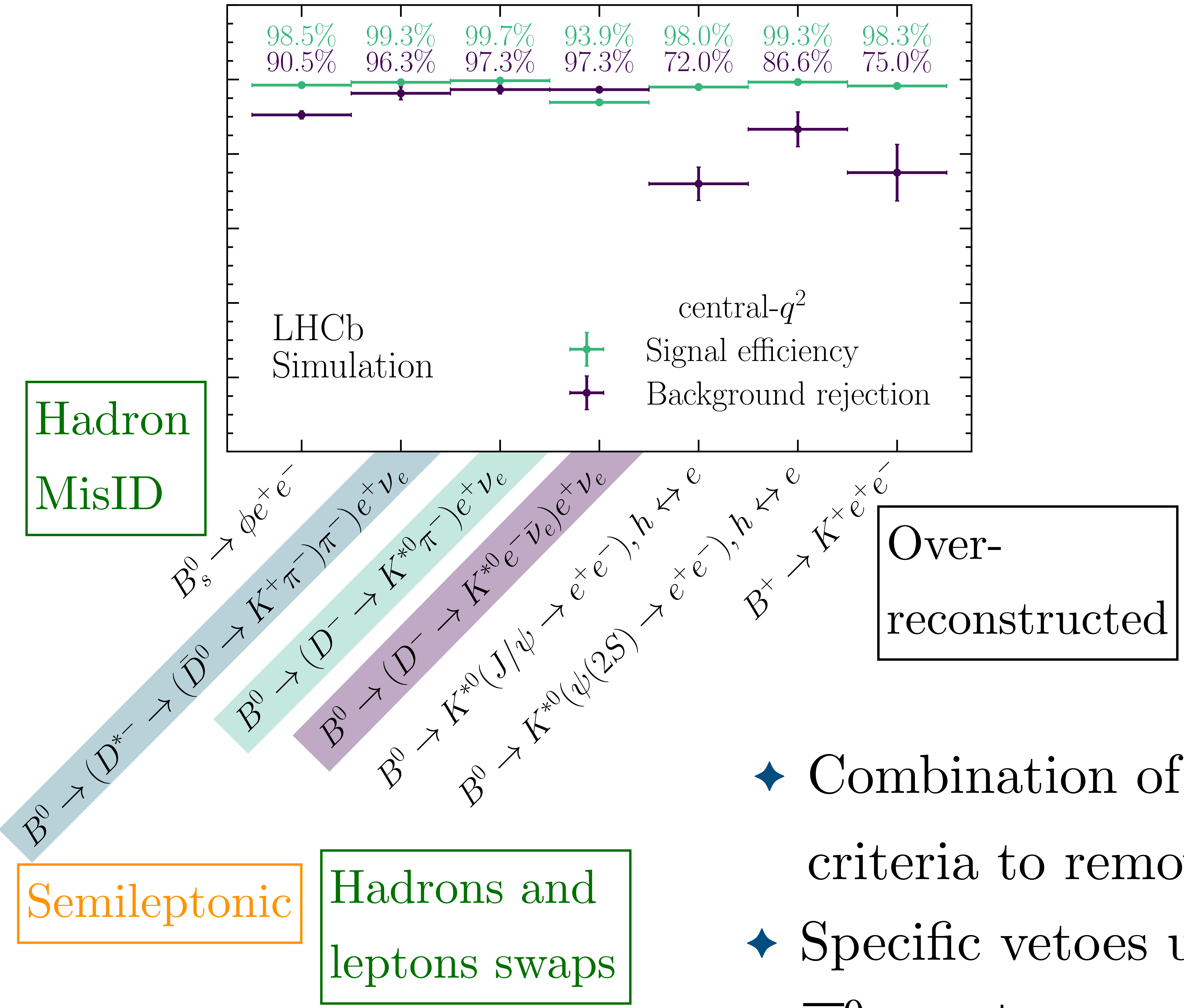
Selection: veto specific backgrounds B^+ mode

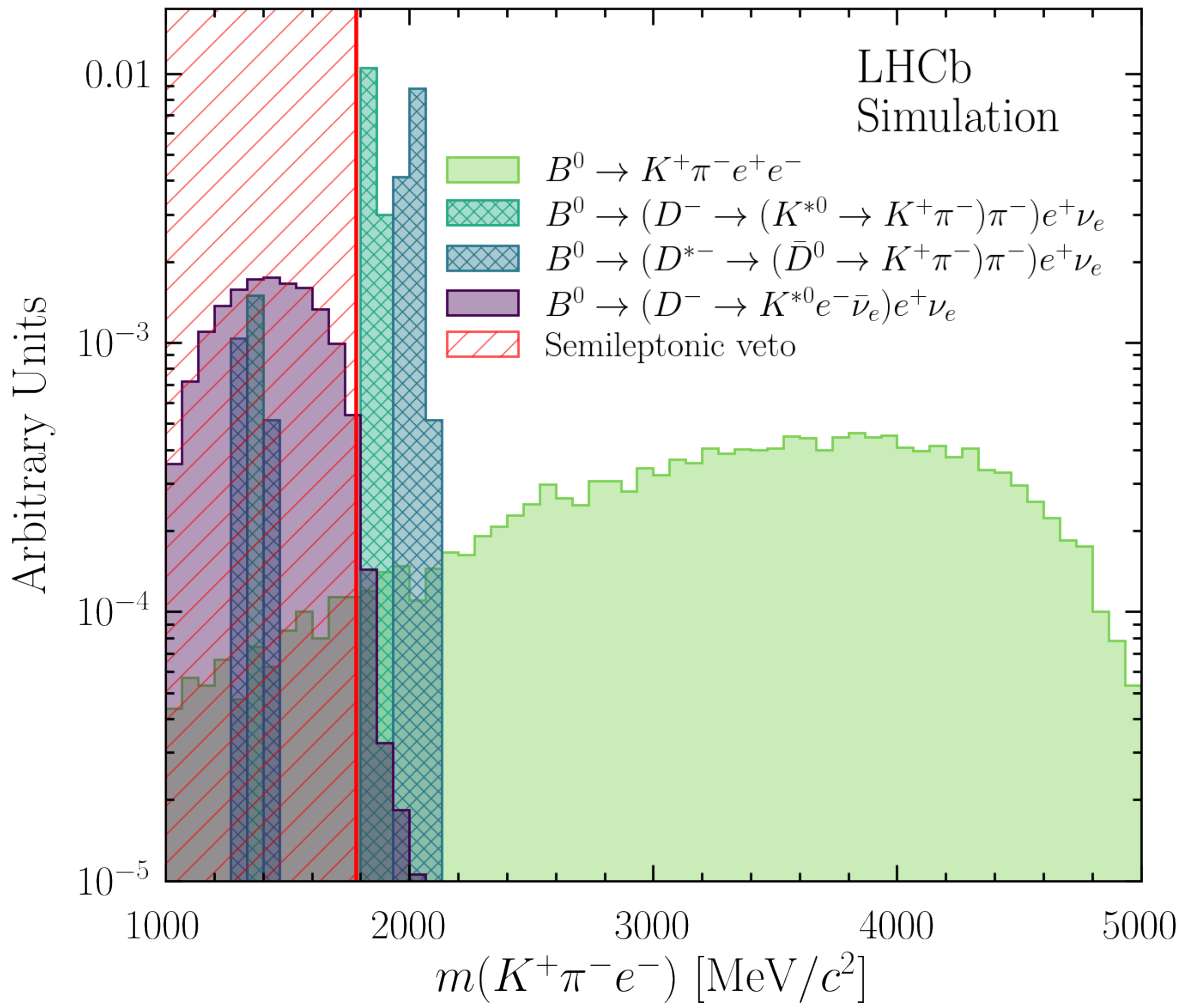




- Combination of efficient kinematic and particle identification criteria to remove background
- Specific vetoes under electron mis-ID hypothesis on $\overline{D}^0 \to K^+\pi^-_{\to e}$

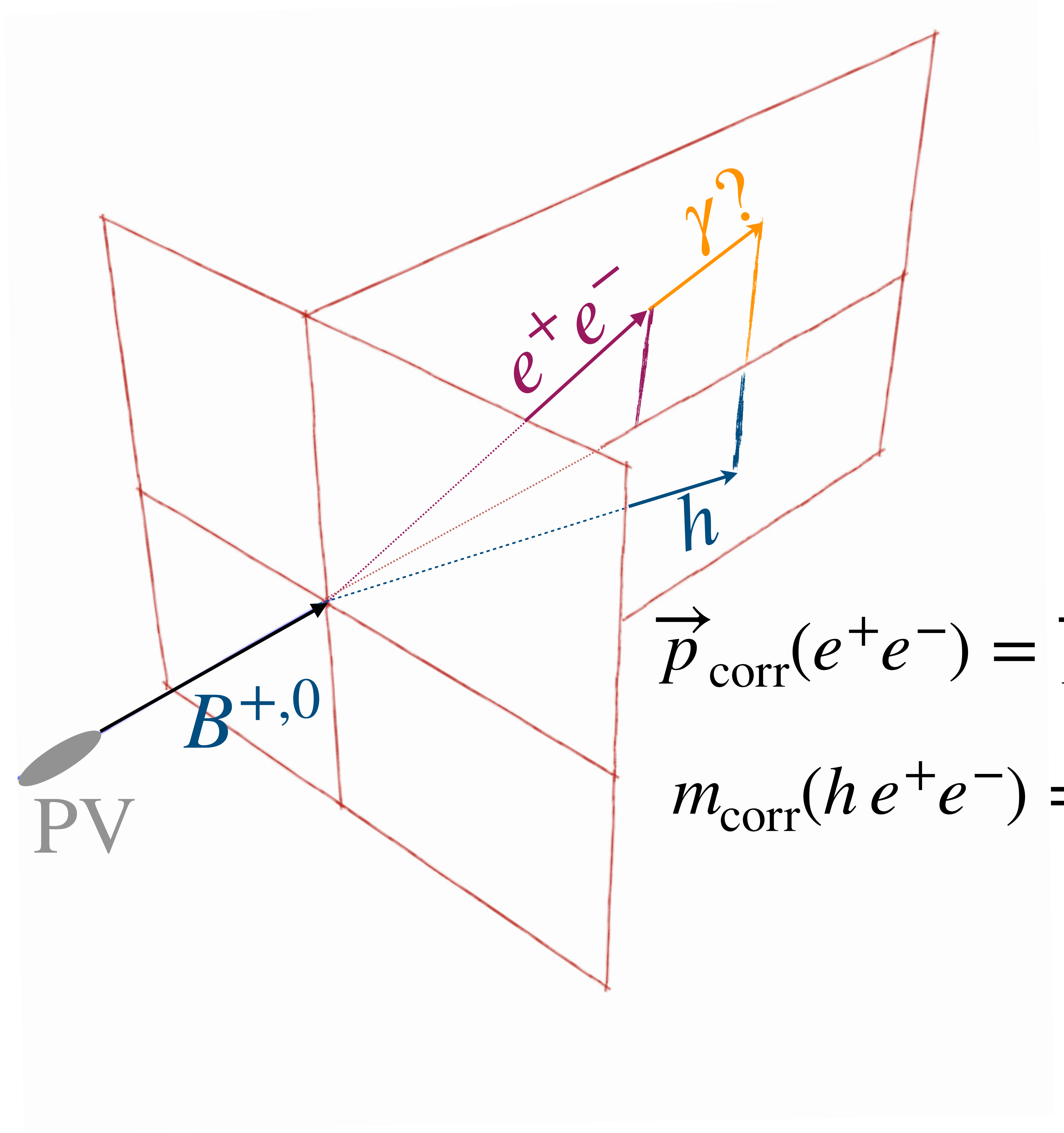
Selection: veto specific backgrounds B^0 mode





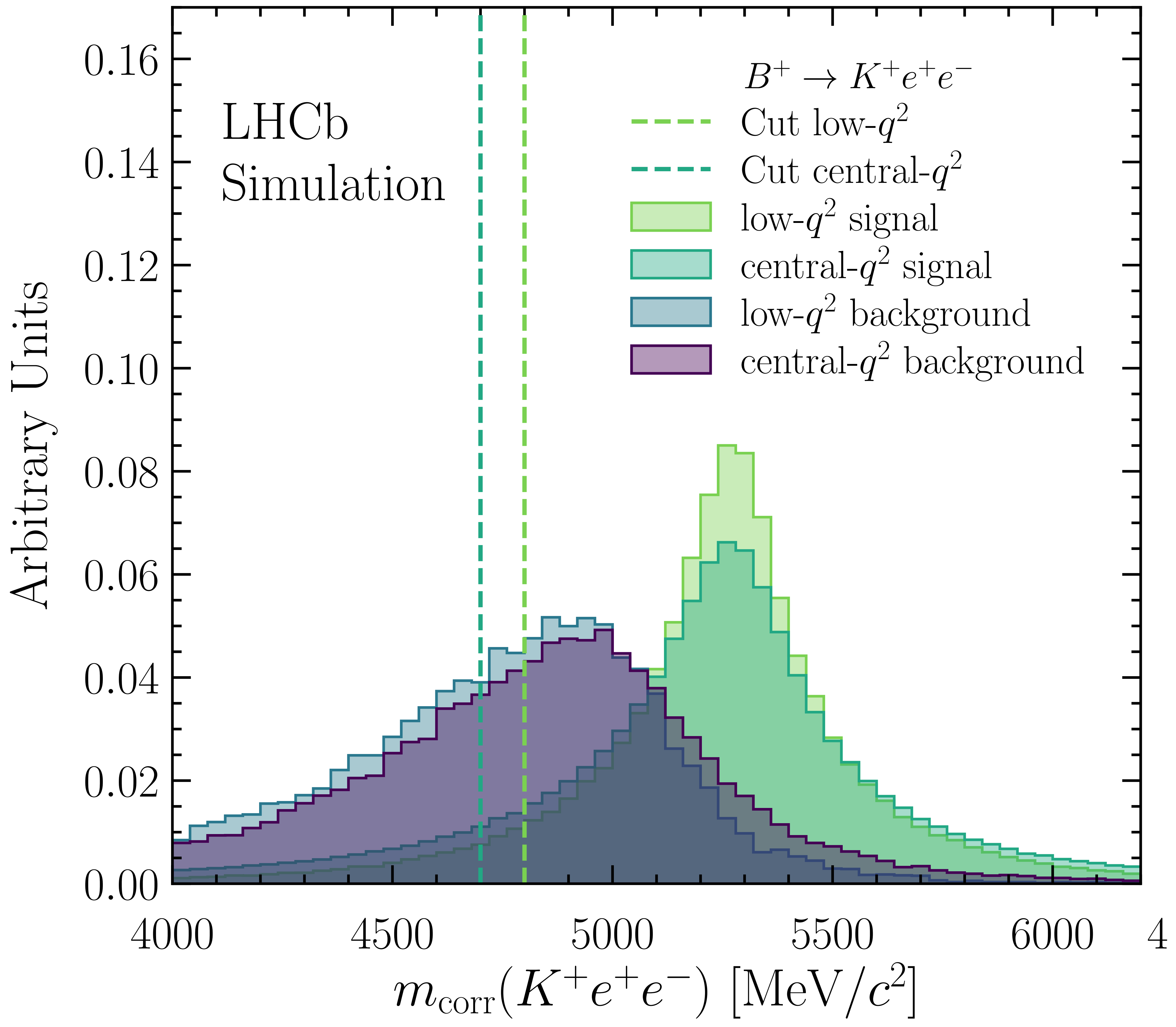
- Combination of efficient kinematic and particle identification criteria to remove background
- Specific vetoes under electron mis-ID hypothesis on $\overline{D}^0 \to K^+\pi^-_{\to e}$ and $D^- \to K^+\pi^-\pi^-_{\to e^-}$

Selection: partially reconstructed background



$$\vec{p}_{\mathrm{corr}}(e^+e^-) = \vec{p}(e^+e^-) \cdot \frac{p_{\mathrm{T}}(h)}{p_{\mathrm{T}}(e^+e^-)}$$

$$m_{\mathrm{corr}}(h\, e^+e^-) = |p_{\mathrm{corr}}(e^+e^-) + p_h|$$



- Small-correlation with combinatorial shape: modelled according to same-sign data $K^{+,*0}\ell^\pm\ell^\pm$
- After m_{corr} selection, **no** ≥ 2 missing hadron background expected in fit range.

Calibration of simulation to determine ε

Corrections for:

- Particle Identification (PID)
- Tracking (TRK)
- B kinematics and event multiplicity (BKIN&MULT)
- Hardware trigger (L0)
- High level software trigger (HLT)
- B decay vertex reconstruction (RECO)
- q^2 resolution and bin-migration (RES)

Calibration of simulation to determine ε

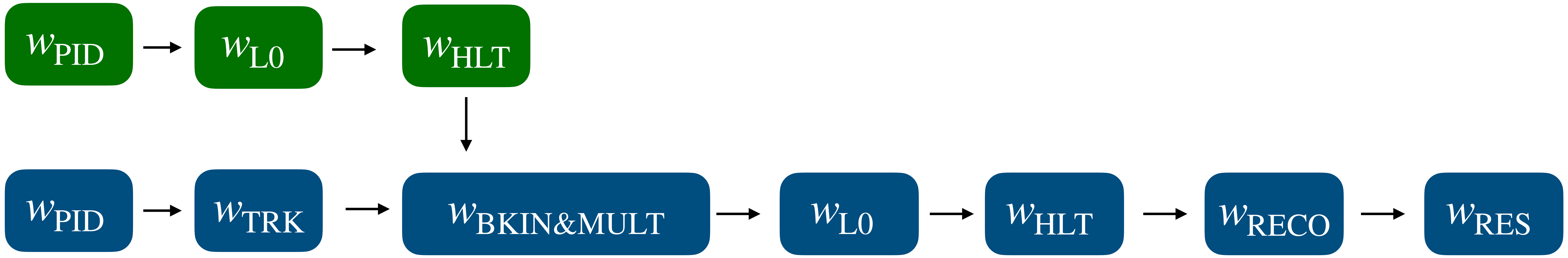
Corrections for:

- Particle Identification (PID)
- Tracking (TRK)
- B kinematics and event multiplicity (BKIN&MULT)
- Hardware trigger (L0)
- High level software trigger (HLT)
- B decay vertex reconstruction (RECO)
- q^2 resolution and bin-migration (RES)

Multi-step correction to simulation where $w_i = \frac{\varepsilon_{\text{Data}}}{\varepsilon_{\text{Simulation}}}$, where $\varepsilon_{\text{Simulation}}$ uses w_{i-1}

$B^{+,0} \to K^{+,*0} J/\psi(\mu^+\mu^-)$

$B^{+,0} \to K^{+,*0} J/\psi(\ell^+\ell^-)$

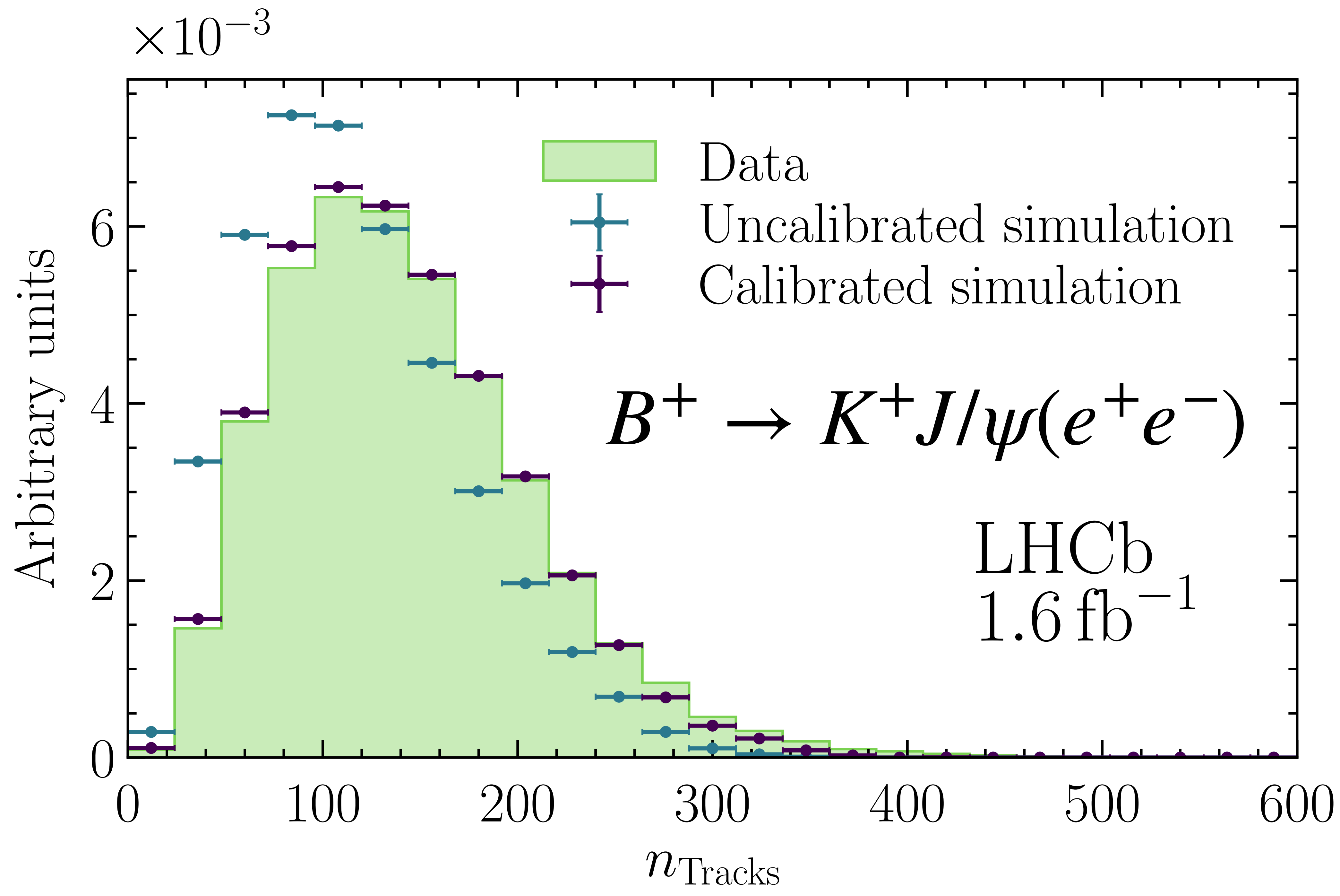


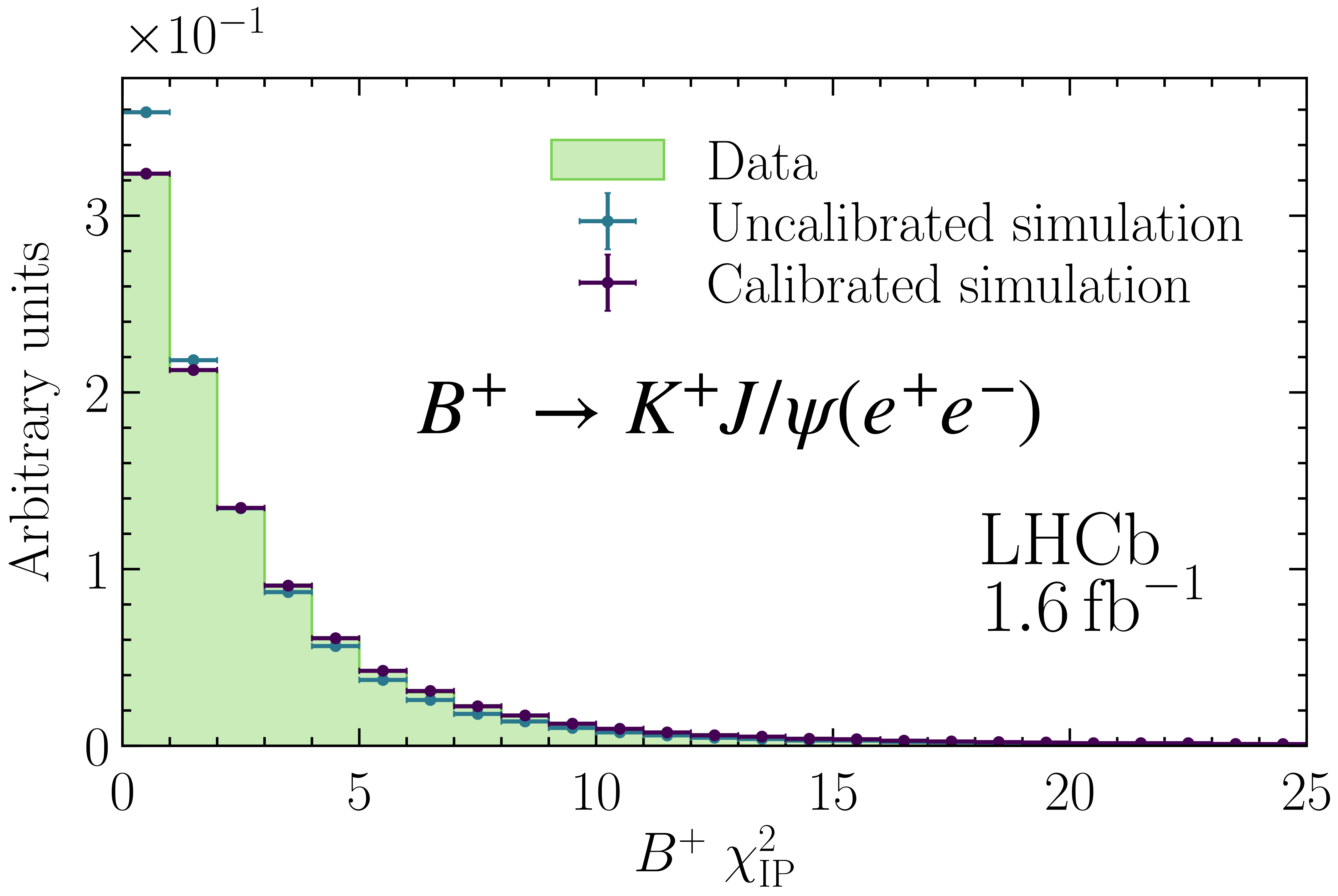
- Two weight chains evaluated: one using $B^+ \to K^+ J/\psi(\ell\ell)$ and one using $B^0 \to K^{*0} J/\psi(\ell\ell)$
- Results evaluated with both chains & shown to be compatible for the first time
- Nominal approach is to use the B^+ chain for B^0 decay channels and vice-versa

Calibration of simulation to determine ε

Corrections for:

- Particle Identification (PID)
- Tracking (TRK)
- **B kinematics and event multiplicity (BKIN&MULT)**
- Hardware trigger (L0)
- High level software trigger (HLT)
- **B decay vertex reconstruction (RECO)**
- q^2 resolution and bin-migration (RES)



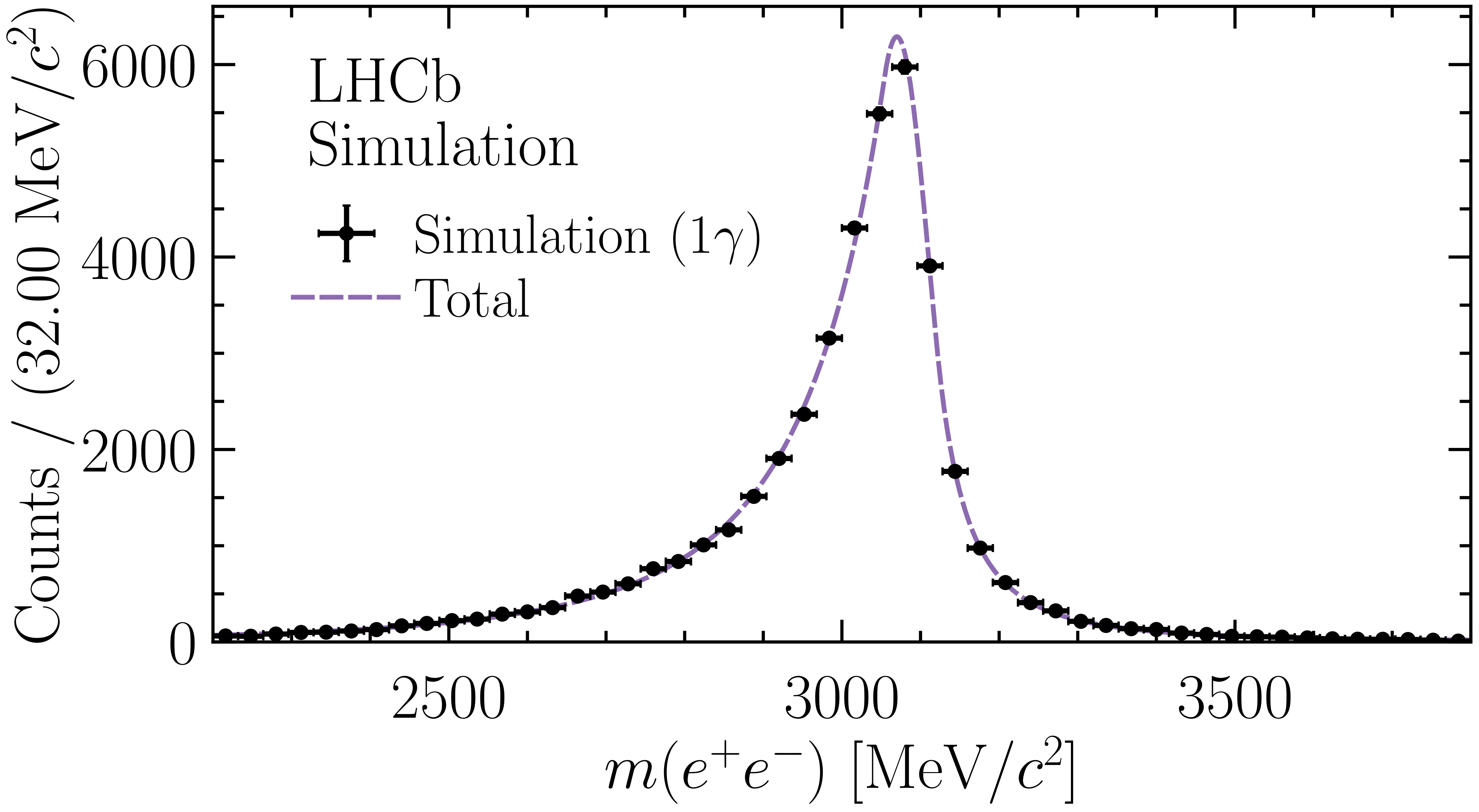


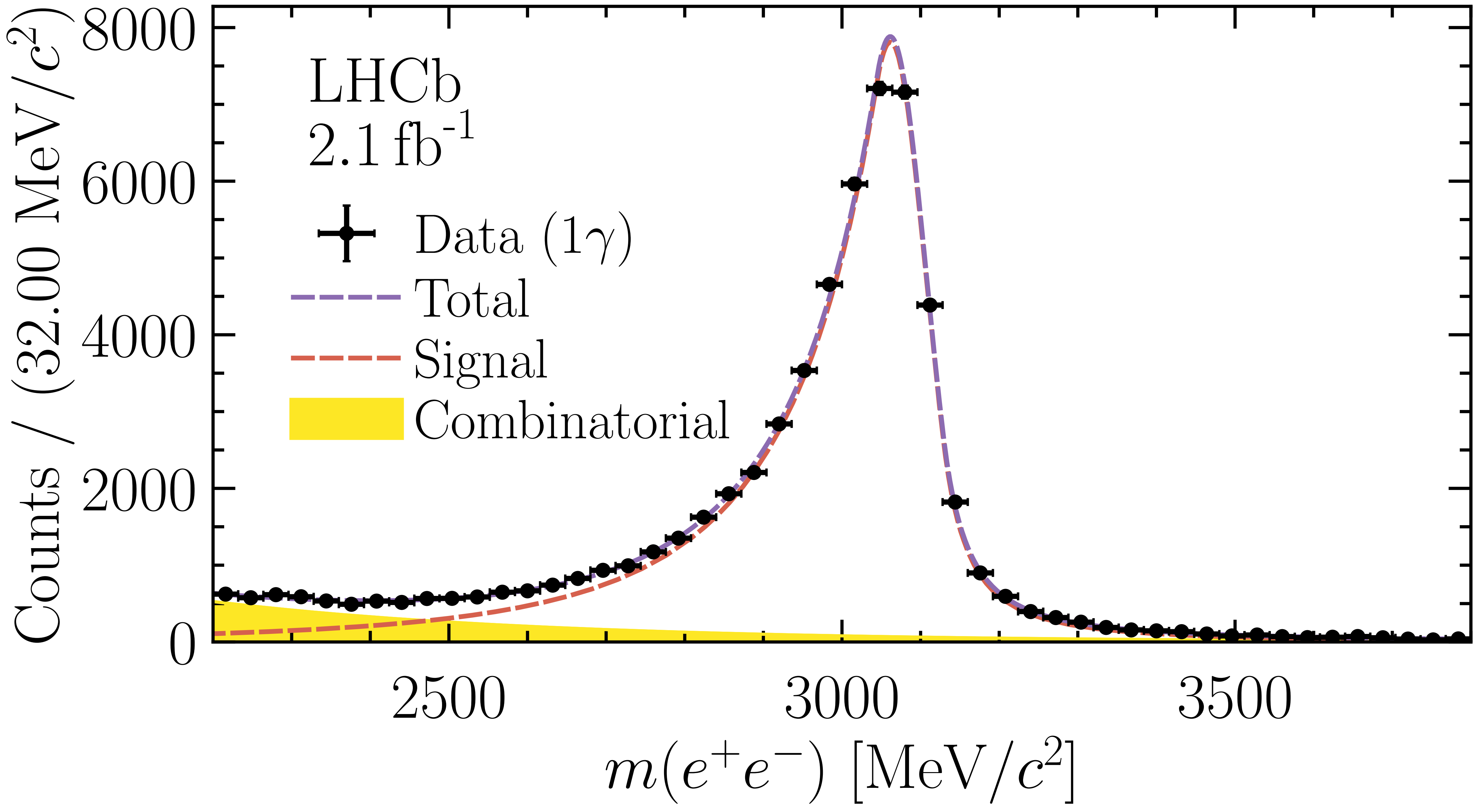
Excellent data/simulation agreement in each data taking period after all corrections

q^2 migration

Corrections for:

- Particle Identification (PID)
- Tracking (TRK)
- B kinematics and event multiplicity (BKIN&MULT)
- Hardware trigger (L0)
- High level software trigger (HLT)
- B decay vertex reconstruction (RECO)
- **q^2 resolution and bin-migration (RES)**

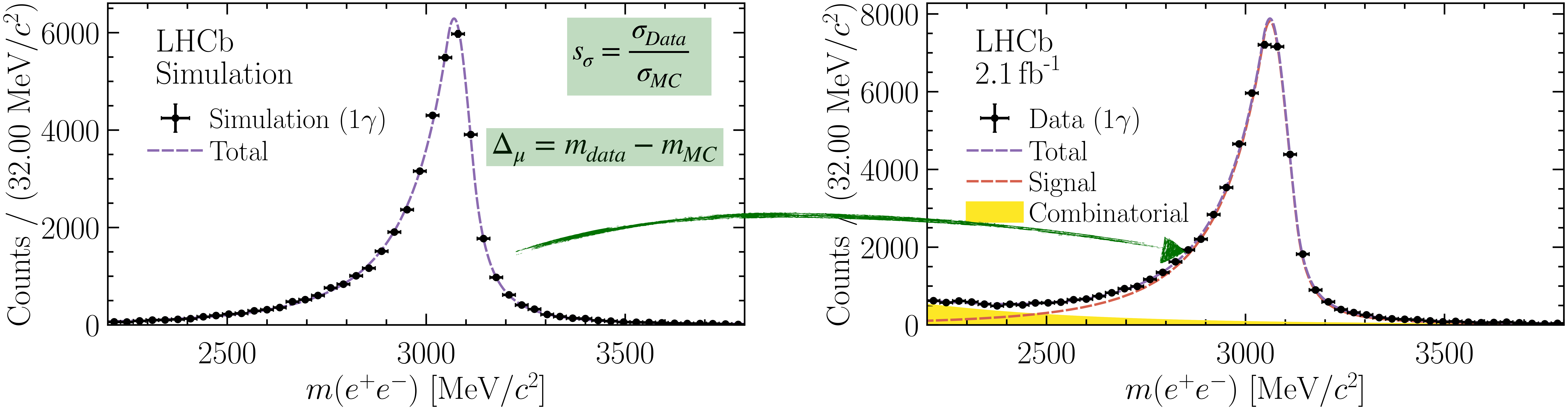




q^2 migration

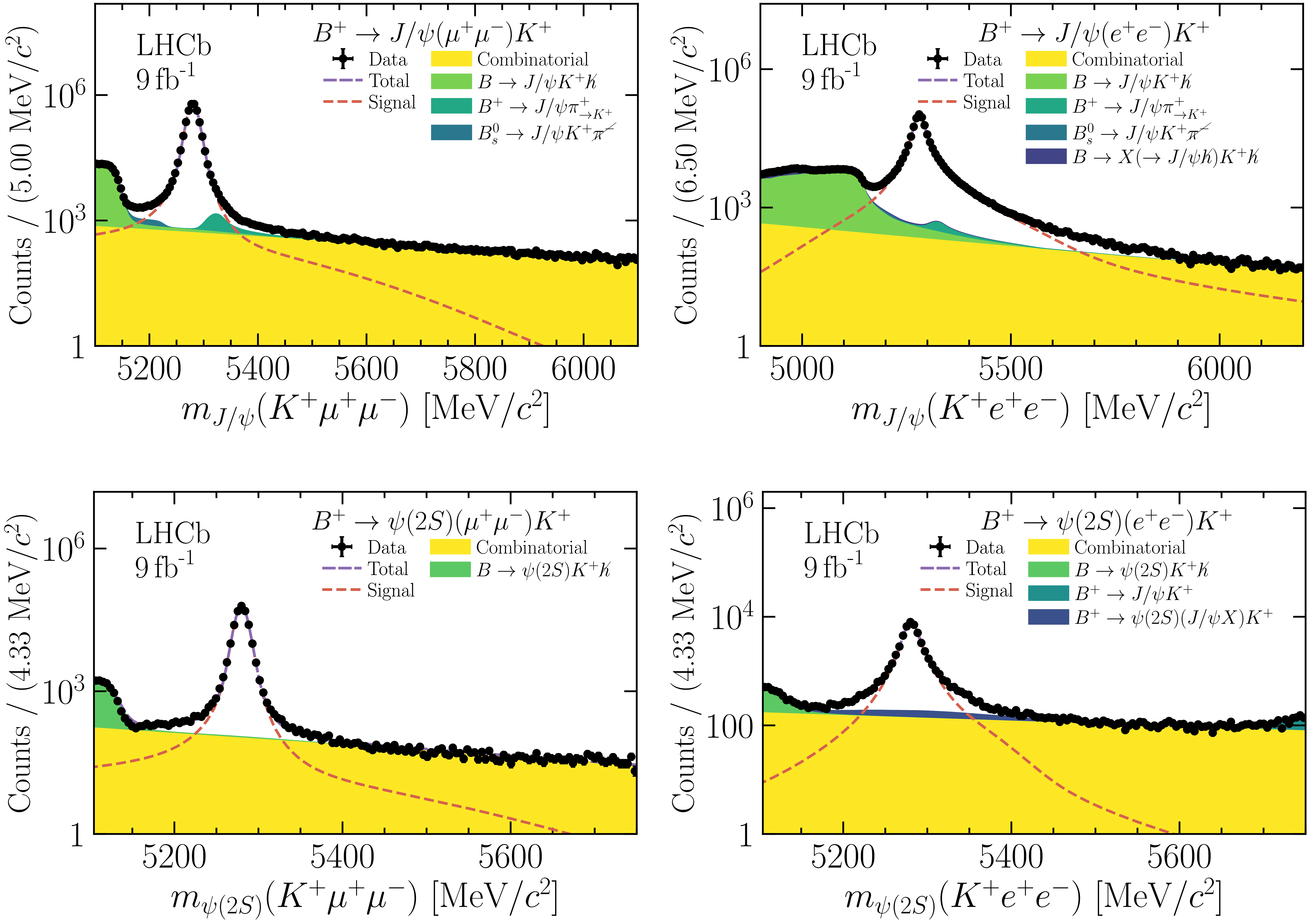
Corrections for:

- Particle Identification (PID)
- Tracking (TRK)
- B kinematics and event multiplicity (BKIN&MULT)
- Hardware trigger (L0)
- High level software trigger (HLT)
- B decay vertex reconstruction (RECO)
- **q^2 resolution and bin-migration (RES)**

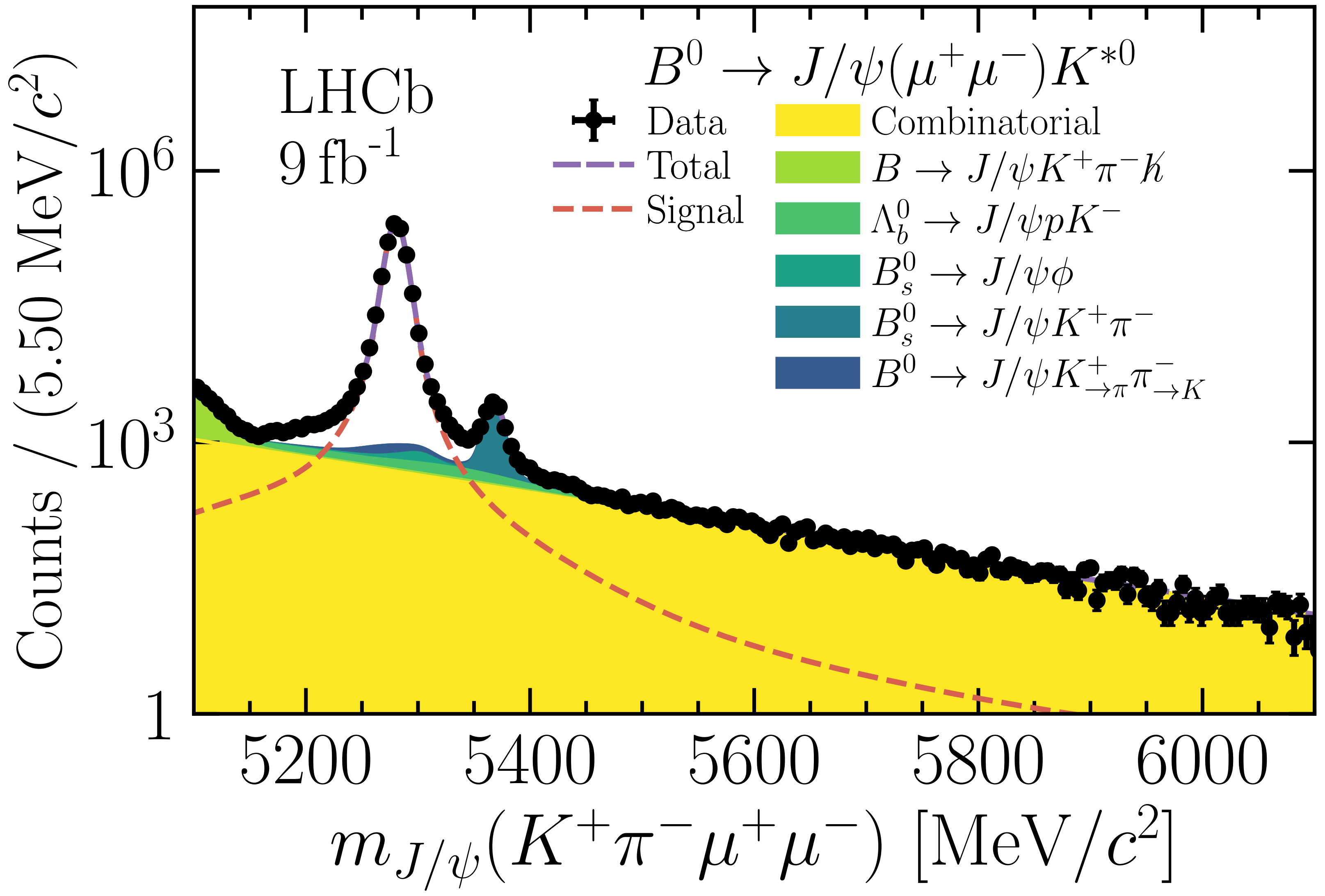


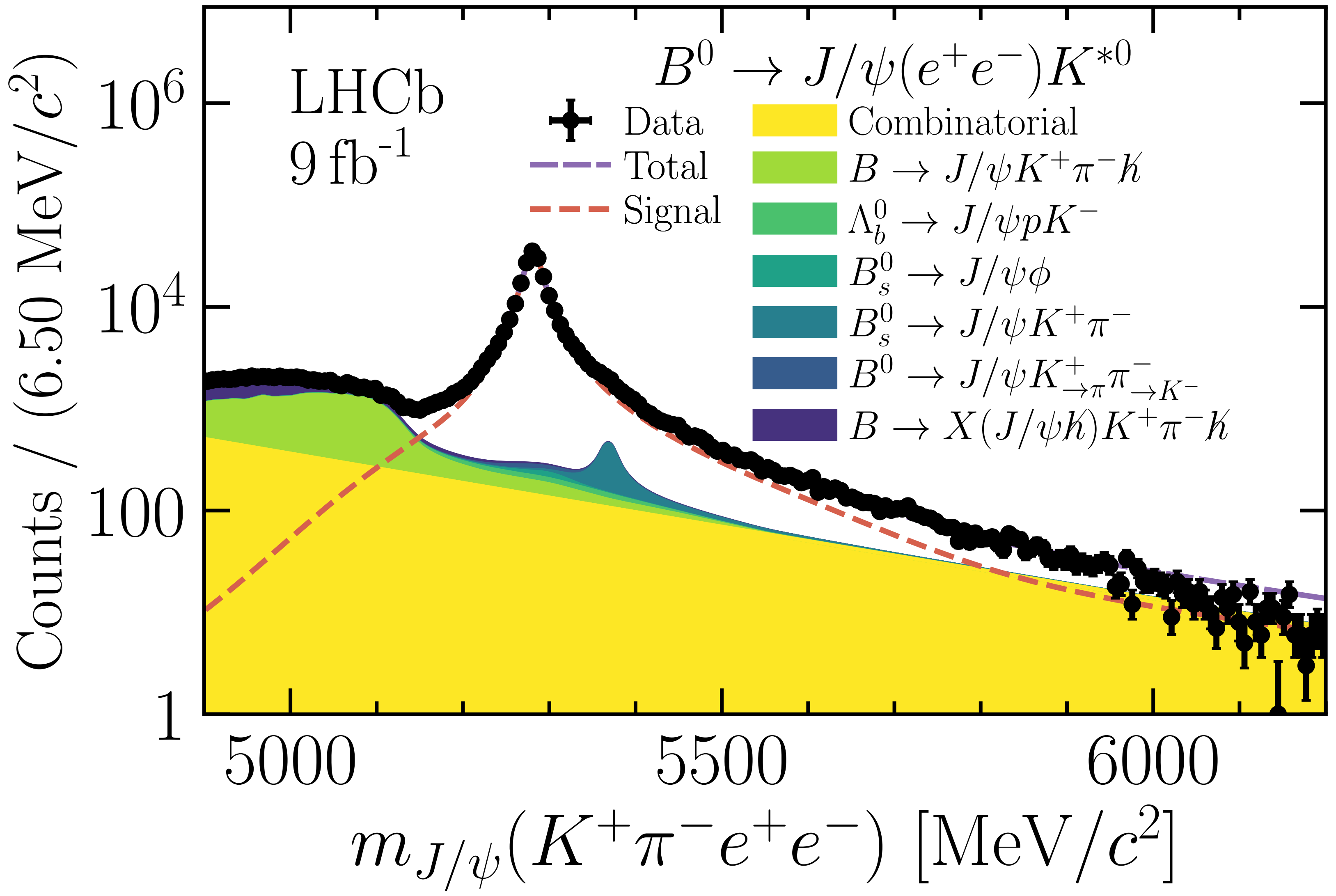
$$m^{\text{smeared}} = m^{\text{true}} + s_\sigma \cdot (m^{\text{reco}} - m^{\text{true}}) + \Delta\mu + (1 - s_\sigma) \cdot (\mu^{\text{MC}} - M^{\text{PDG}}_{J/\psi}).$$

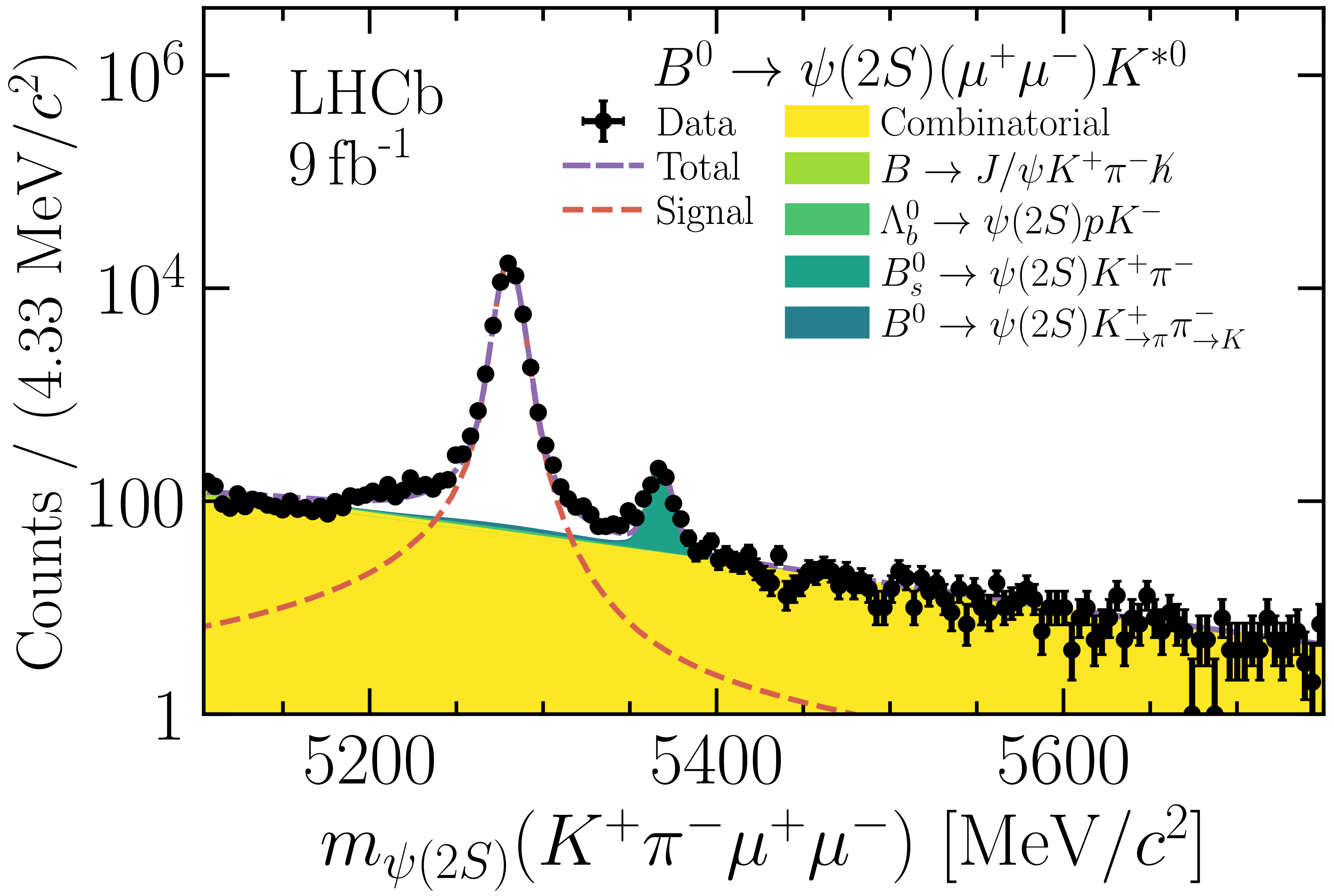
Cross-check resonant modes: mass fits (B^+)

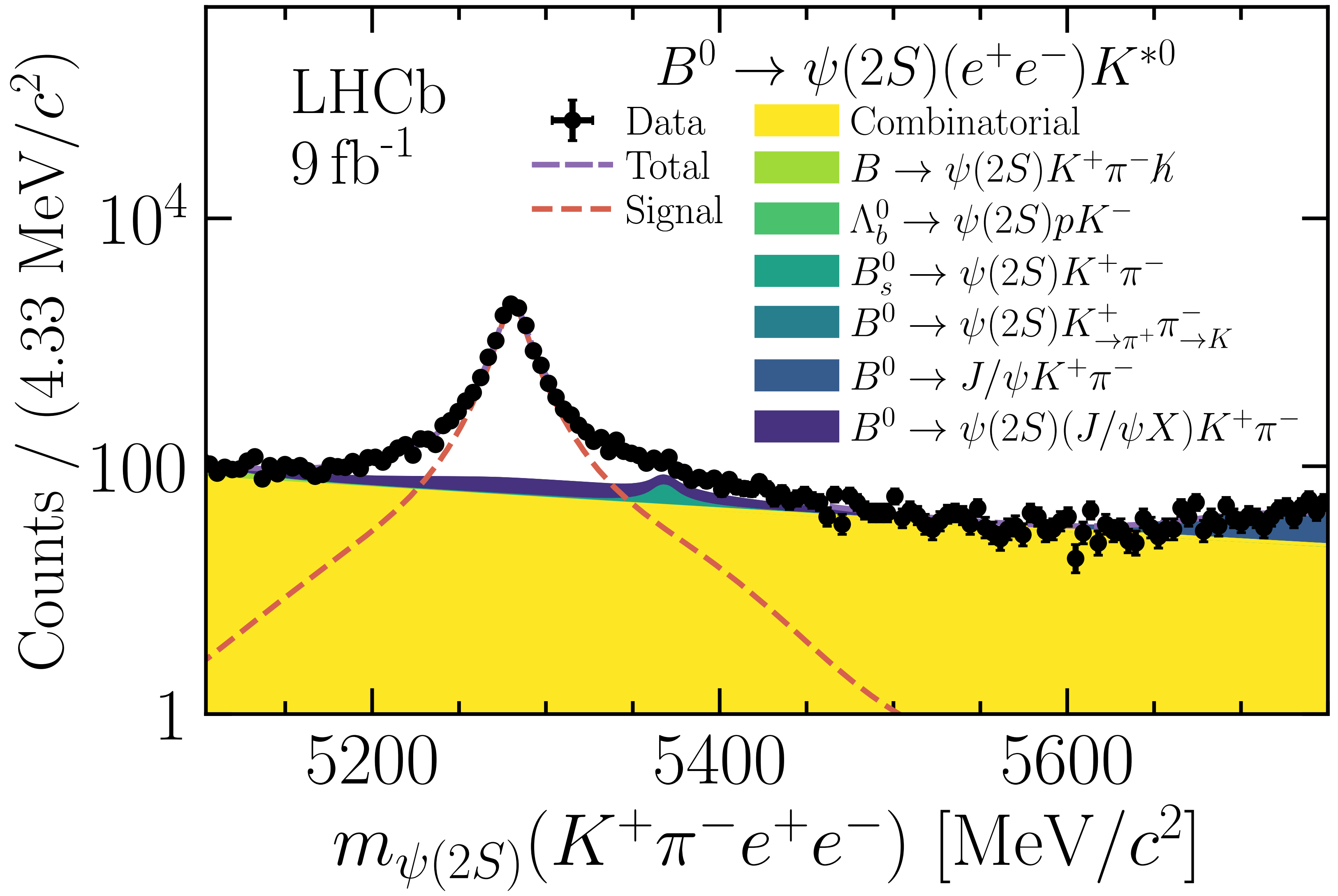


Cross-check resonant modes: mass fits (B^0)

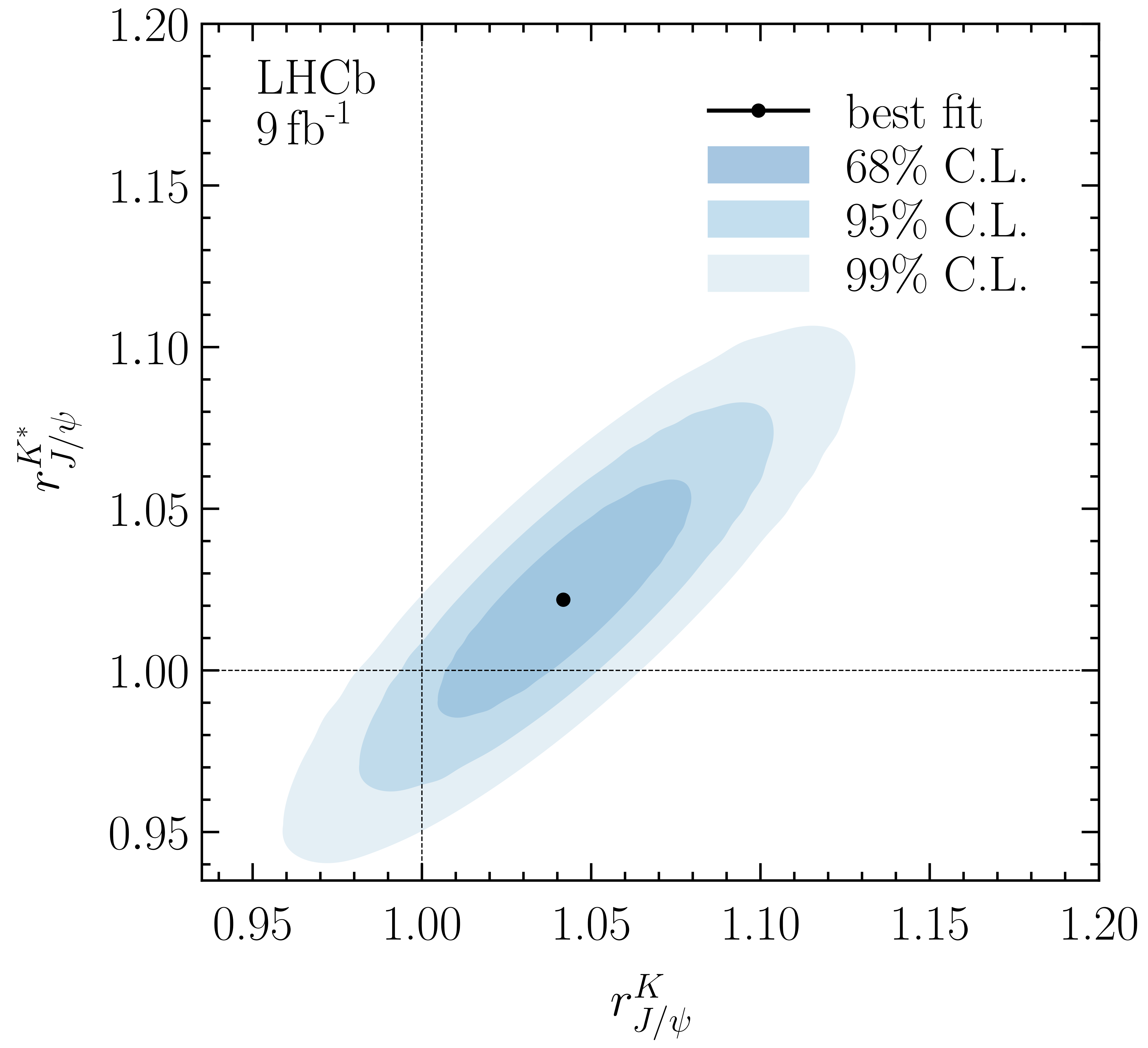


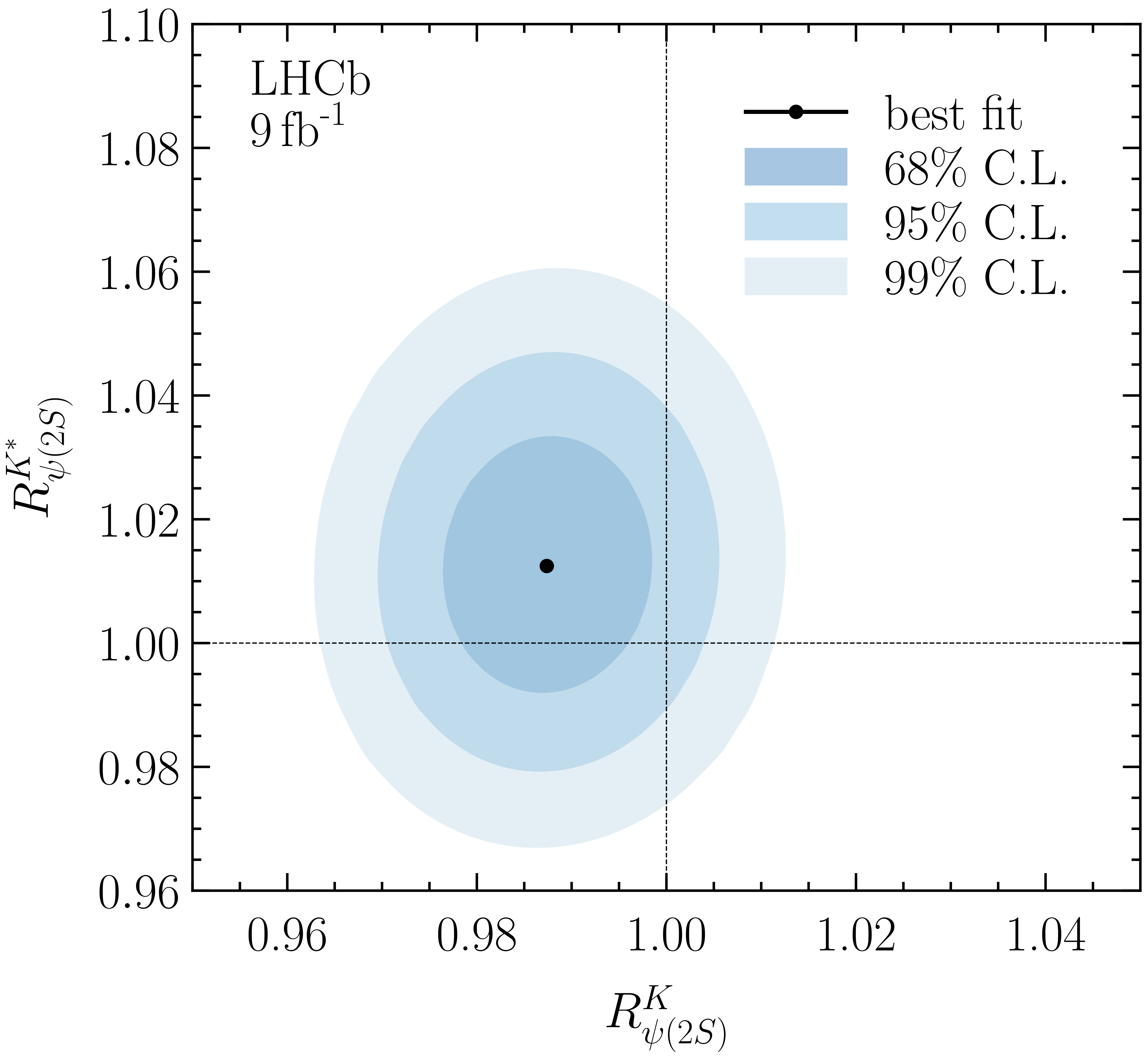






Cross-check resonant modes: $r_{J/\psi}$ & $R_{\psi(2S)}$



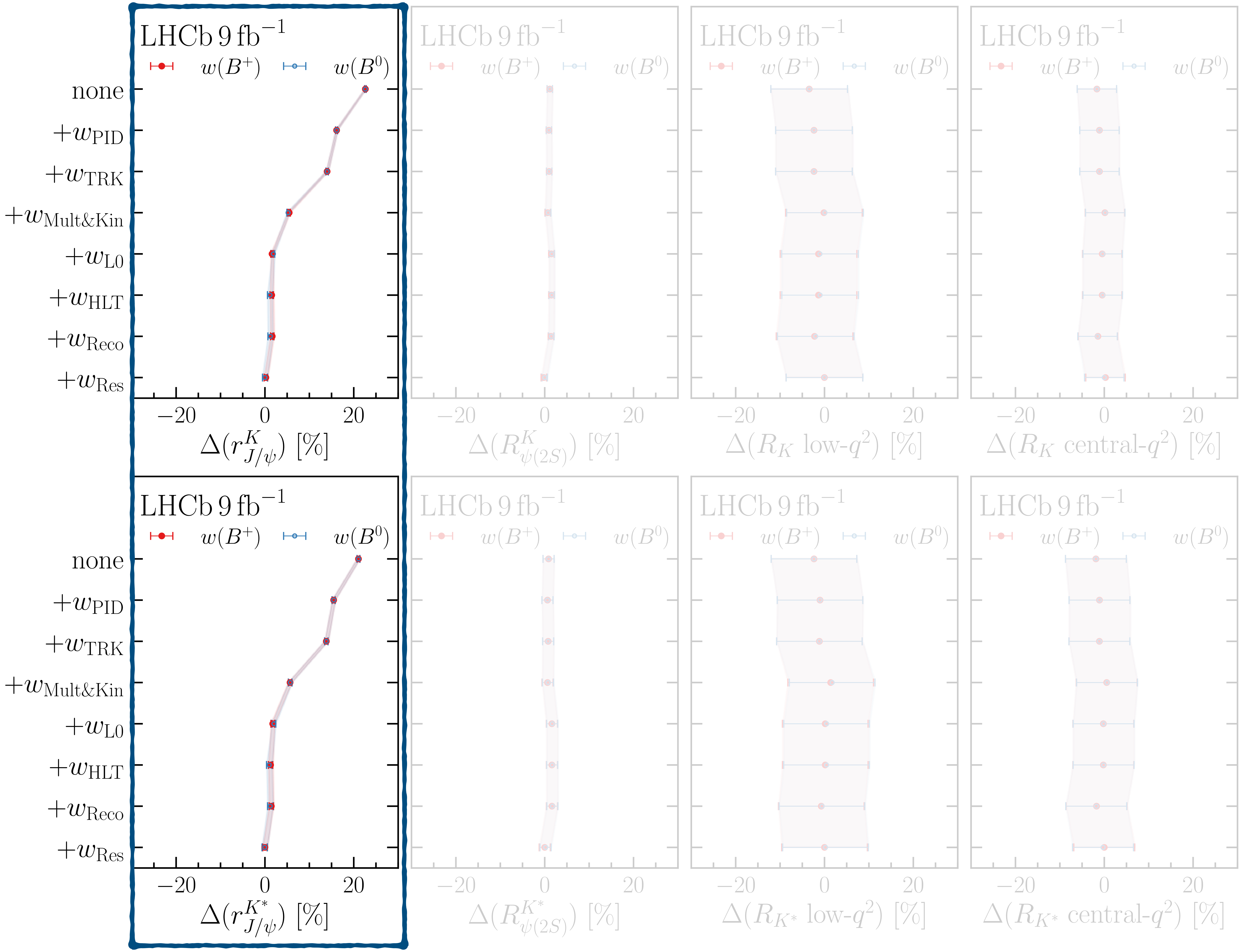


- σ_{syst} from J/ψ mass fit included
- σ_{syst} from ε single ratio included

- σ_{syst} from $\psi(2S)$ mass fit not included
- σ_{syst} from ε double ratio included

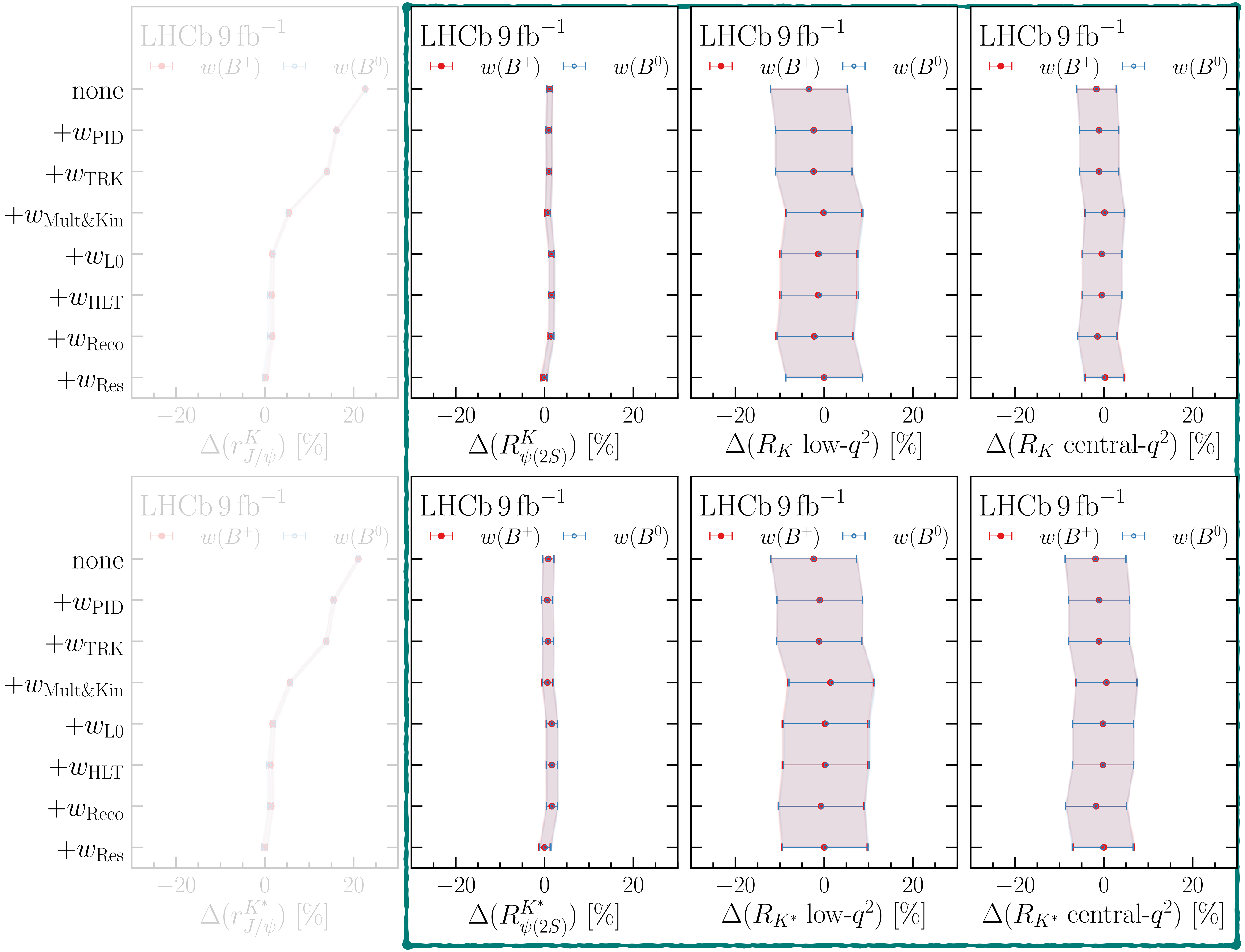
Efficiency ratios and double ratios

- On *single-ratios*, the calibration of efficiencies moves $r_{J/\psi}$ by 25%



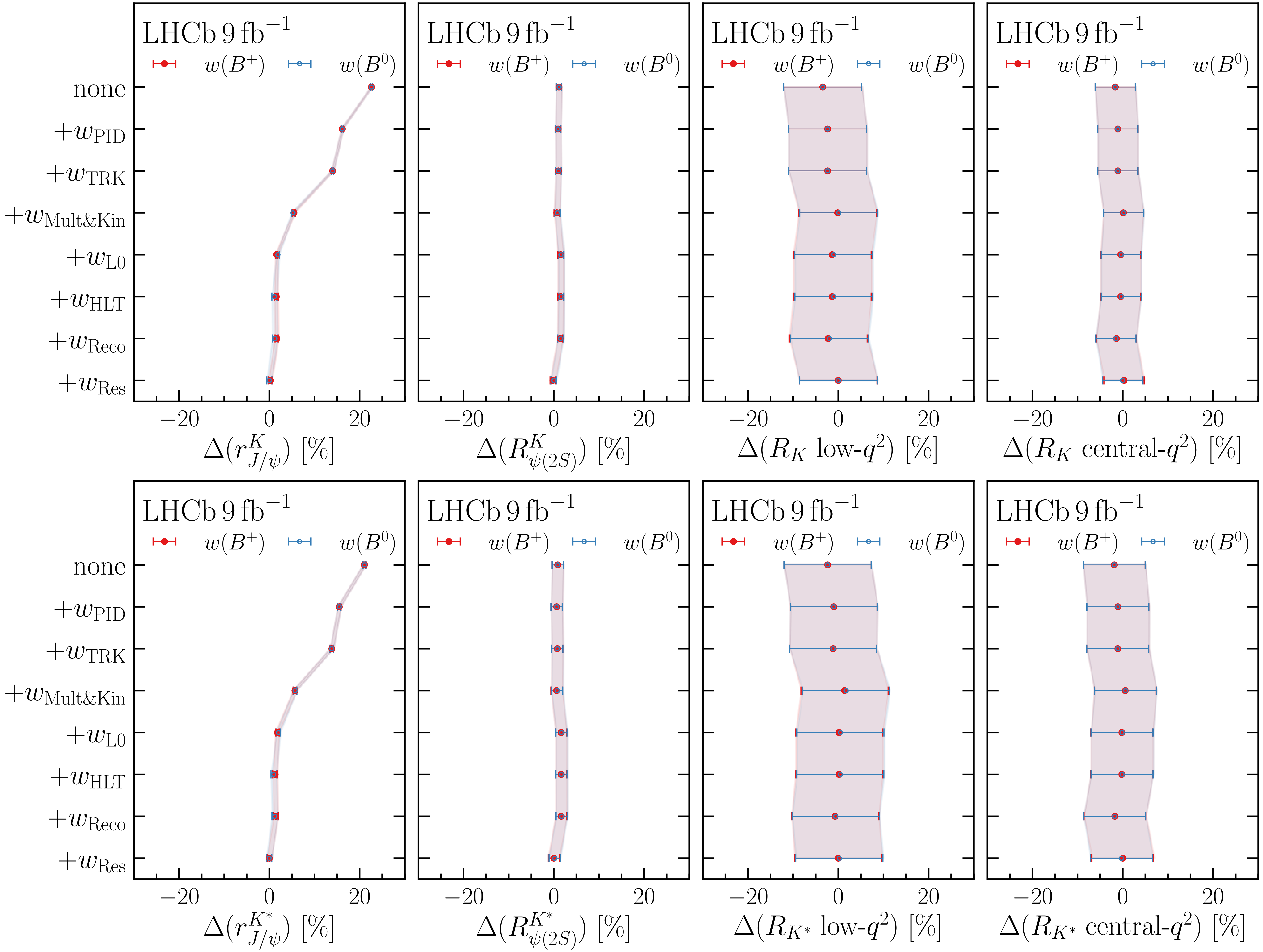
Efficiency ratios and double ratios

- On *single-ratios*, the calibration of efficiencies moves $r_{J/\psi}$ by 25%
- On all *double ratios*, the effect of corrections to simulation is moving the result by at most 5 %



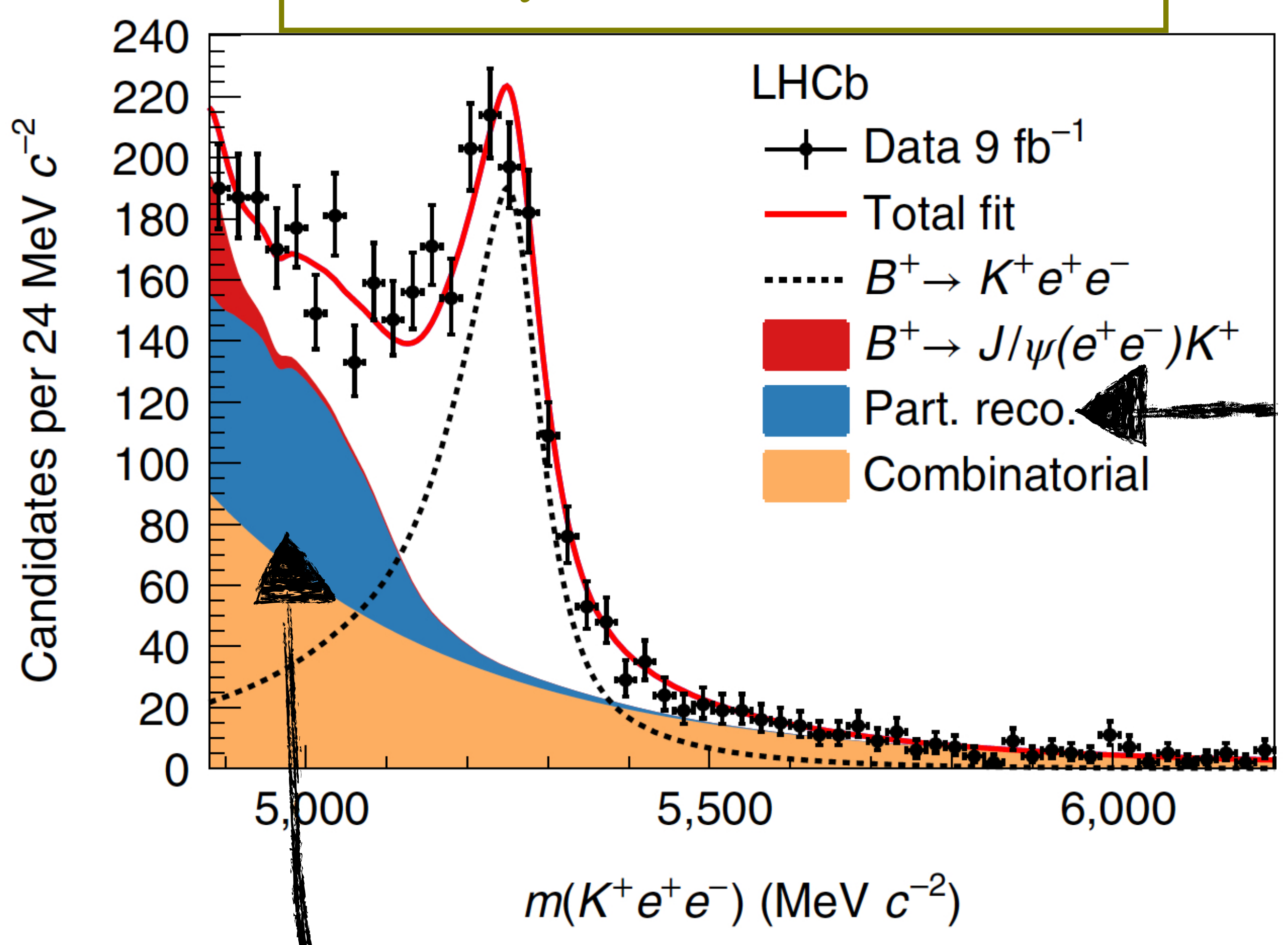
Efficiency ratios and double ratios

- On *single-ratios*, the calibration of efficiencies moves $r_{J/\psi}$ by 25%
- On all *double ratios*, the effect of corrections to simulation is moving the result by at most 5 %
- Demonstrate the strength of the double ratio method for ε



Cross-feed $R_{K^{*0}}$ & R_K in mass fit for electron mode

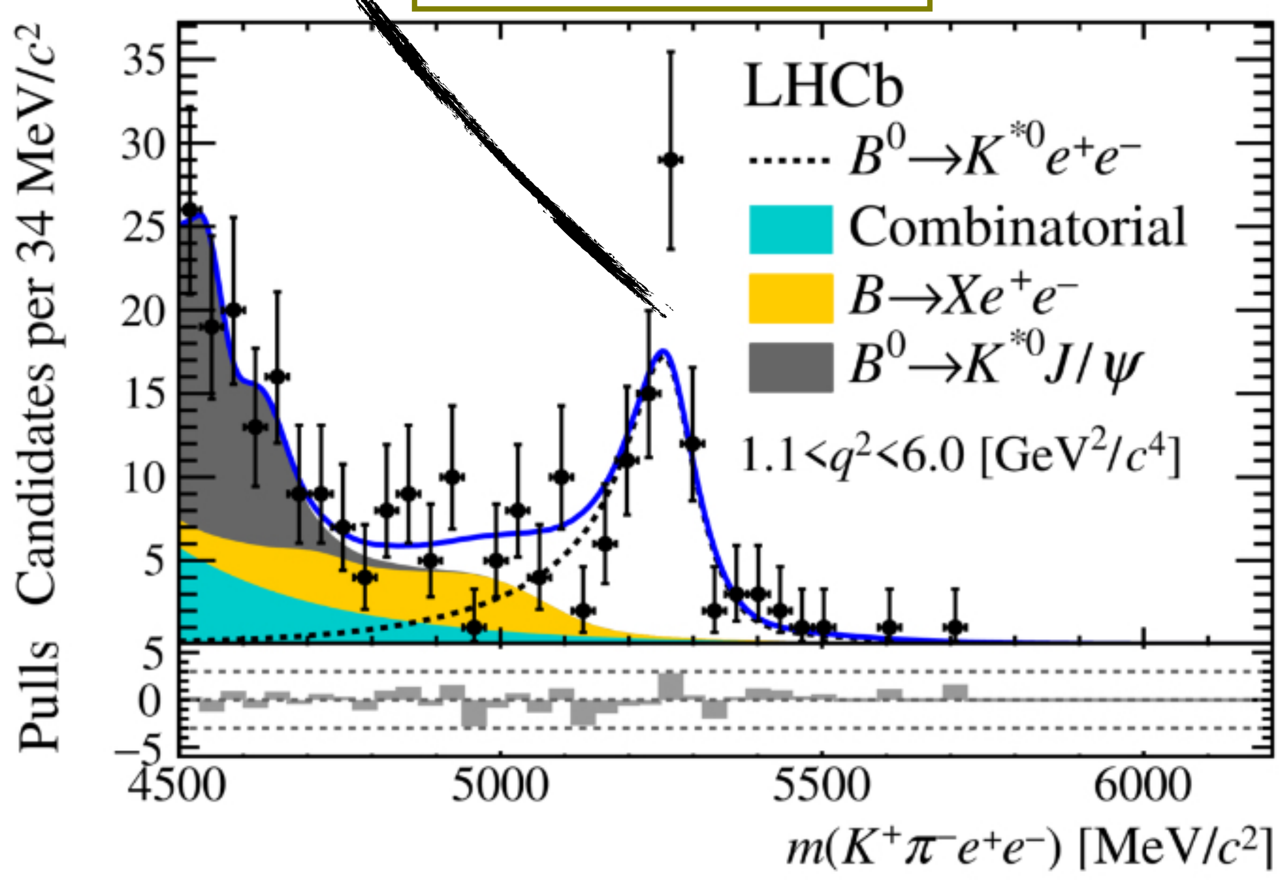
[Nat. Phys. 18, 277-282 (2022)]



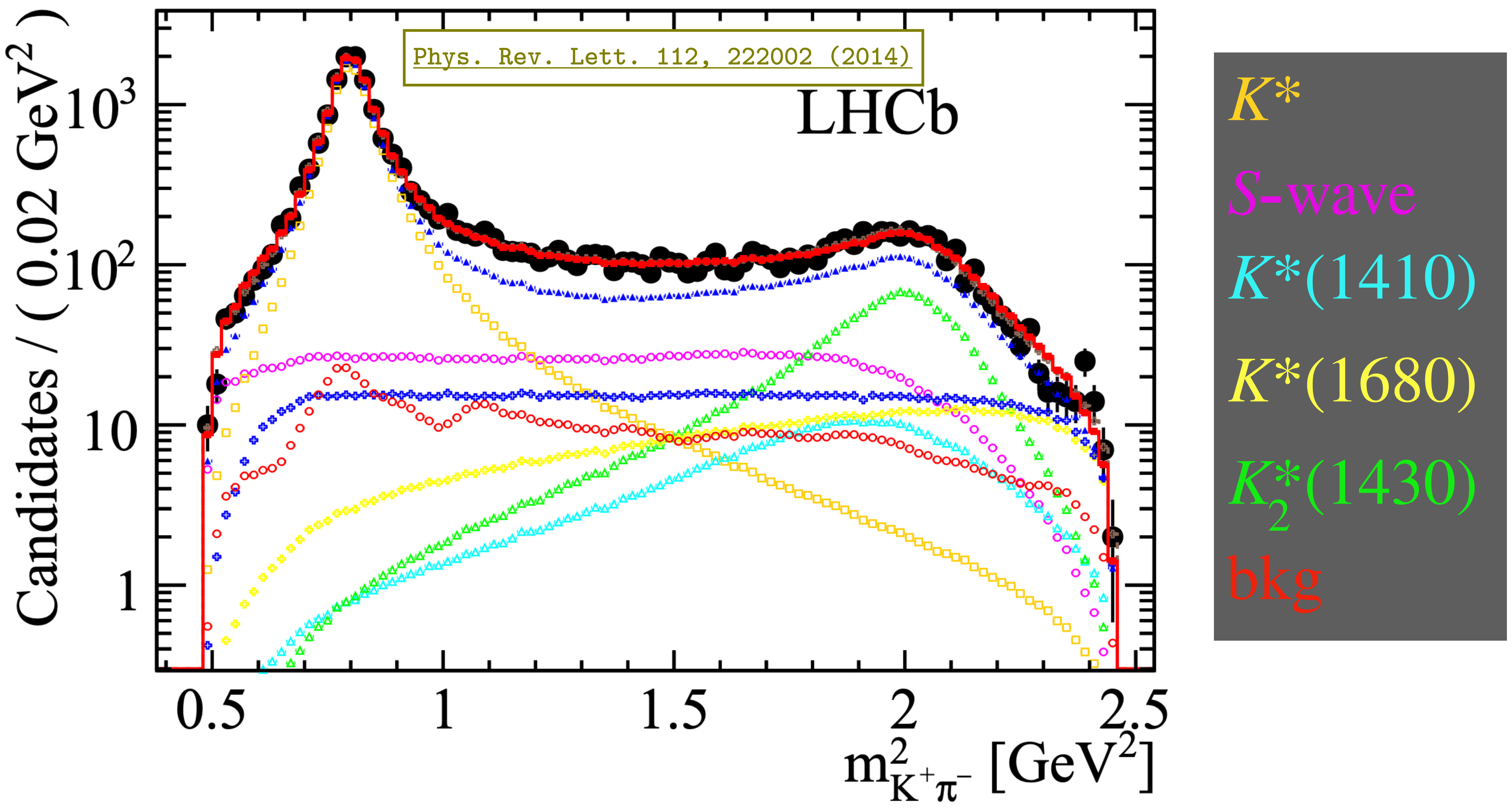
Was free

Improve per-event sensitivity constraining it from K mode*

[JHEP08(2017)055]



Phys. Rev. Lett. 112, 222002 (2014)



- Directly from $K^{*0}e^+e^-$
- Use F_S measurement in [JHEP 11 (2016) 047] [JHEP 04 (2017) 142] and Breit-Wigner tails
- Extrapolation factors / full amplitude from K^*J/ψ [Phys. Rev. Lett. 112, 222002 (2014)]

$K^+\not{\pi}^0$ accounting for isospin factors and ε corrections

Scan results in electron PID w/o treatment of misID bkg

LHCb

0.85 0.90 0.95 1.00 1.05 1.10 1.15

R_X

R_K low-q^2

DLL(e) \ ProbNN(e)	> 0.20	> 0.25	> 0.30	> 0.35	> 0.40	> 0.45	> 0.50	> 0.55	> 0.60
DLL(e) > 7	0.960 ± 0.097	0.971 ± 0.099	0.988 ± 0.102	0.997 ± 0.102	0.982 ± 0.100	0.973 ± 0.099	0.967 ± 0.099	0.967 ± 0.099	0.977 ± 0.102
DLL(e) > 5	0.961 ± 0.086	0.964 ± 0.086	0.969 ± 0.088	0.983 ± 0.090	0.973 ± 0.089	0.981 ± 0.091	0.979 ± 0.092	0.961 ± 0.090	0.985 ± 0.095
DLL(e) > 2	0.873 ± 0.073	0.904 ± 0.078	0.908 ± 0.079	0.958 ± 0.087	0.950 ± 0.086	0.954 ± 0.087	0.938 ± 0.086	0.940 ± 0.087	0.969 ± 0.093

R_K central-q^2

DLL(e) \ ProbNN(e)	> 0.20	> 0.25	> 0.30	> 0.35	> 0.40	> 0.45	> 0.50	> 0.55	> 0.60
DLL(e) > 7	0.948 ± 0.051	0.944 ± 0.051	0.944 ± 0.051	0.939 ± 0.051	0.939 ± 0.051	0.941 ± 0.051	0.934 ± 0.051	0.935 ± 0.051	0.937 ± 0.052
DLL(e) > 5	0.941 ± 0.044	0.938 ± 0.044	0.942 ± 0.044	0.933 ± 0.044	0.939 ± 0.045	0.951 ± 0.046	0.946 ± 0.046	0.953 ± 0.047	0.949 ± 0.048
DLL(e) > 2	0.906 ± 0.040	0.902 ± 0.040	0.907 ± 0.040	0.895 ± 0.040	0.904 ± 0.041	0.916 ± 0.042	0.920 ± 0.043	0.925 ± 0.044	0.919 ± 0.044

R_{K^*} low-q^2

DLL(e) \ ProbNN(e)	> 0.20	> 0.25	> 0.30	> 0.35	> 0.40	> 0.45	> 0.50	> 0.55	> 0.60
DLL(e) > 7	0.985 ± 0.112	0.982 ± 0.112	0.966 ± 0.109	0.952 ± 0.107	0.971 ± 0.111	0.975 ± 0.112	0.984 ± 0.114	0.970 ± 0.112	0.960 ± 0.111
DLL(e) > 5	0.980 ± 0.097	0.993 ± 0.100	0.978 ± 0.099	0.979 ± 0.100	1.007 ± 0.103	1.014 ± 0.105	1.010 ± 0.106	1.010 ± 0.108	1.019 ± 0.110
DLL(e) > 2	0.855 ± 0.080	0.848 ± 0.079	0.830 ± 0.076	0.847 ± 0.080	0.883 ± 0.086	0.901 ± 0.088	0.915 ± 0.089	0.925 ± 0.092	0.934 ± 0.117

R_{K^*} central-q^2

DLL(e) \ ProbNN(e)	> 0.20	> 0.25	> 0.30	> 0.35	> 0.40	> 0.45	> 0.50	> 0.55	> 0.60
DLL(e) > 7	1.127 ± 0.100	1.119 ± 0.099	1.116 ± 0.099	1.103 ± 0.098	1.097 ± 0.097	1.083 ± 0.095	1.097 ± 0.099	1.113 ± 0.101	1.119 ± 0.103
DLL(e) > 5	1.021 ± 0.074	1.016 ± 0.074	1.016 ± 0.075	0.997 ± 0.073	1.016 ± 0.076	1.001 ± 0.075	1.012 ± 0.077	1.035 ± 0.081	1.049 ± 0.084
DLL(e) > 2	0.965 ± 0.066	0.990 ± 0.069	0.986 ± 0.069	0.993 ± 0.071	1.024 ± 0.075	1.006 ± 0.073	1.014 ± 0.075	1.038 ± 0.079	1.039 ± 0.081

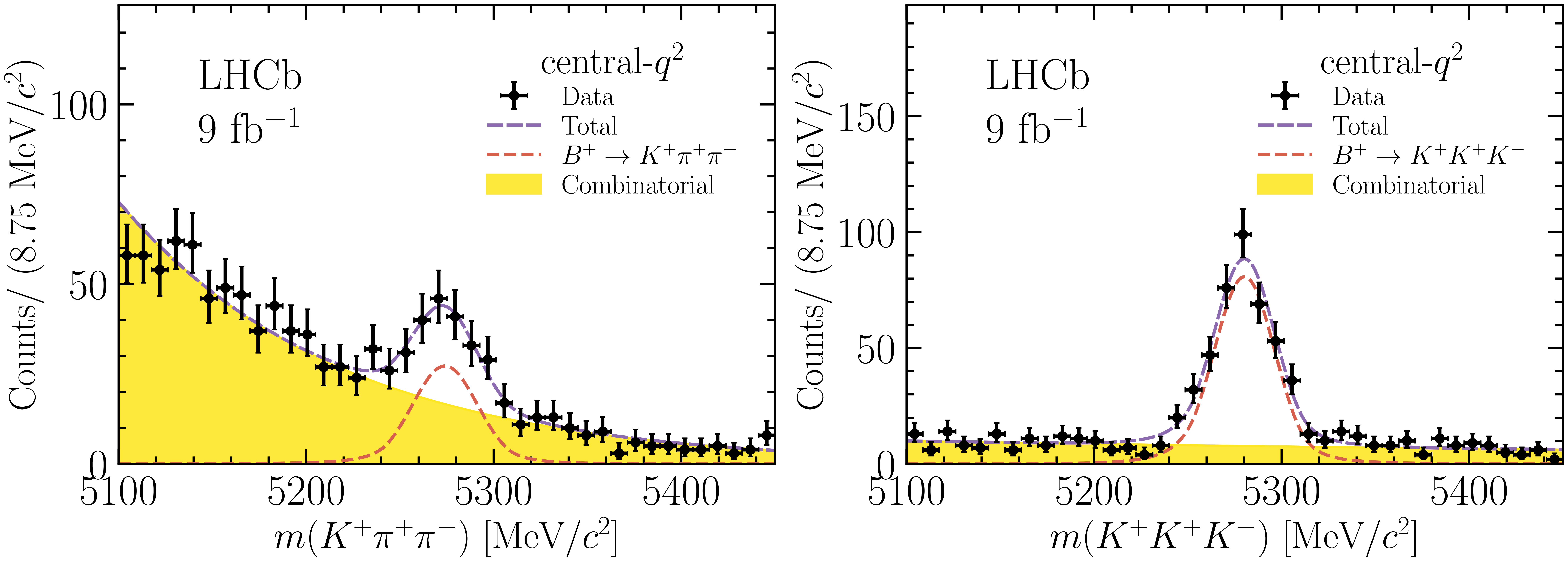
DLL(e): *combination of sub-detectors delta-log-likelihood for π/e*

ProbNN(e): *neural-net based e-ID score*

Tightening selection in electron PID without specific treatment of electron misidentified backgrounds exhibited a coherent pattern

Misidentified background in electron mode

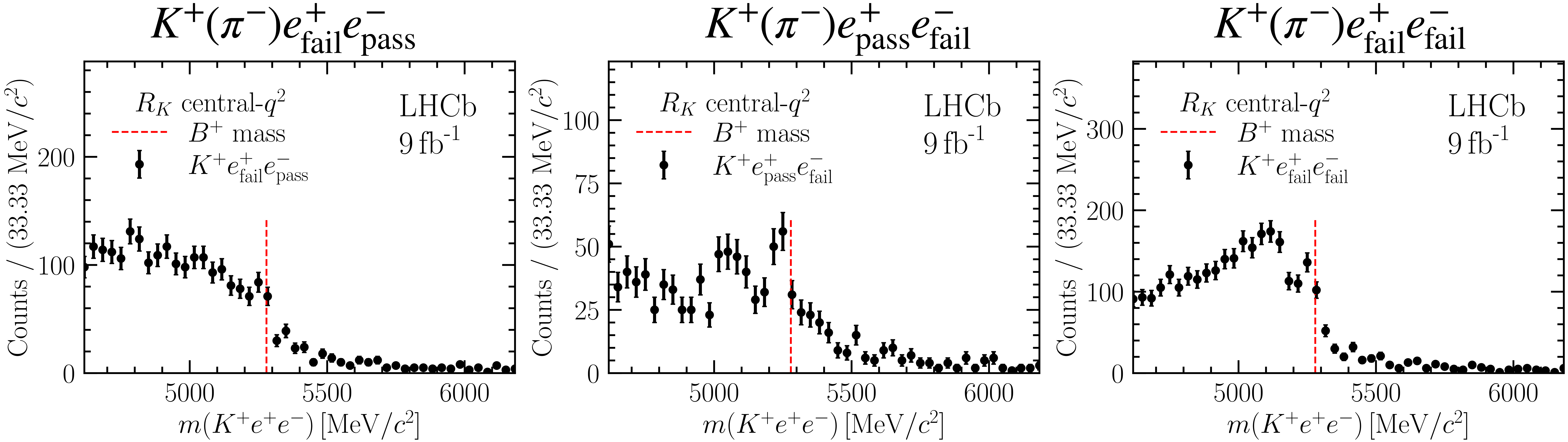
- Simple backgrounds from double-misidentification can be isolated inverting PID criteria (close to nominal selection) after full selection (i.e $K^{+,*0}h^+h^-$) on electron mode



- Similar structures (see *backup*) also for R_{K^*}, however unknown Dalitz for $K^{*0}h^+h^-$
- Single misidentification background as well, often unknown
- ***Developed a new inclusive data-driven treatment of misidentified background***

Misidentified background in electron mode

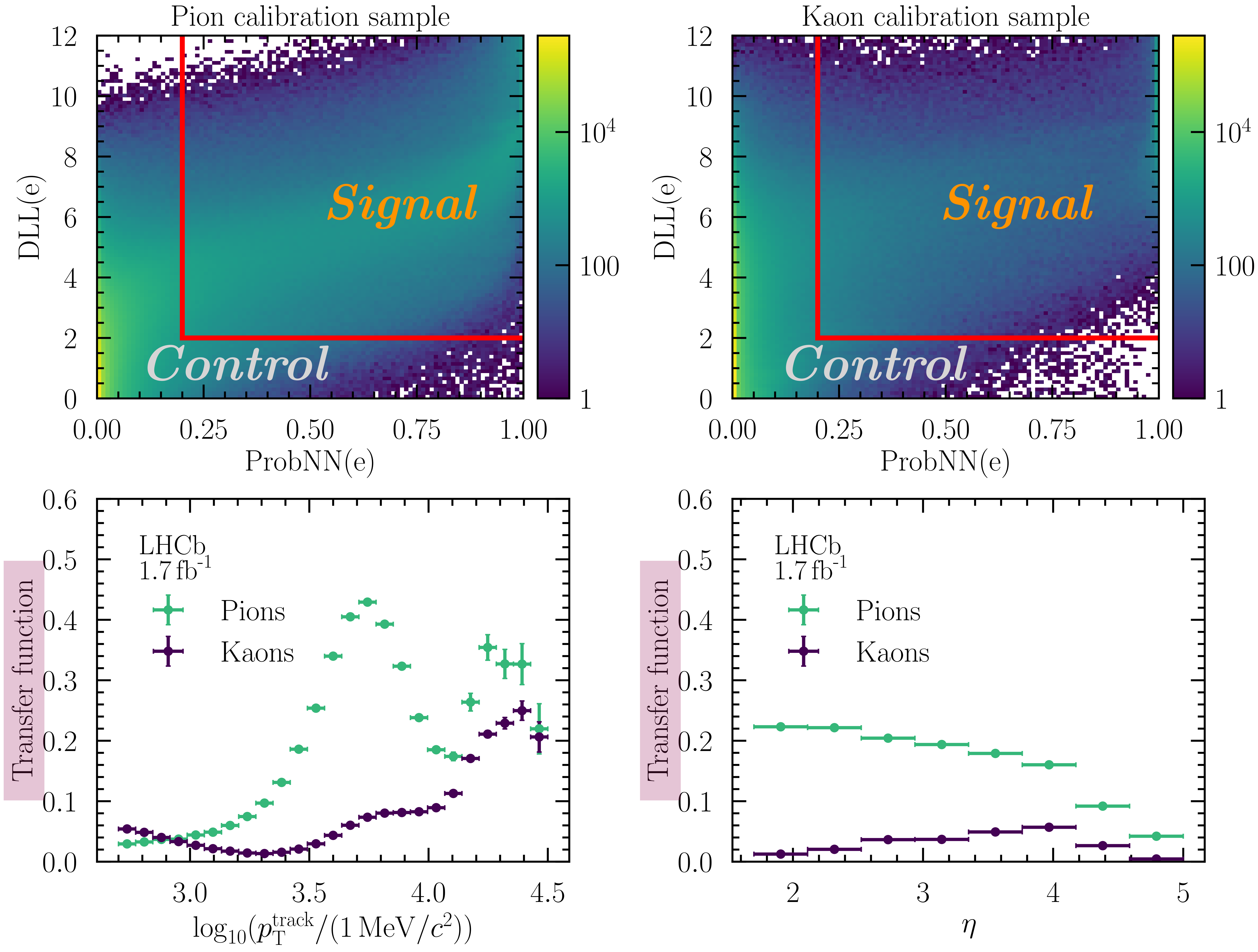
- Invert PID requirements on one or both e after full selection (*control region*)
- Subtract residual e^+e^- signal falling in the *control region*



- Categorise pion- and kaon-like electrons in *control region* based on neural-net kaon ID classifier
- Per-event/per-track weights on e_{fail} to predict background shape and normalisation for e_{pass}

Misidentified background in electron mode

- ***Control region*** choice:
  - not too far from signal, ensuring only pion/kaon misID is relevant
- $\frac{\text{pass}}{\text{fail}}$ (transfer function) from $D^{*-} \to \overline{D}^0(K^+\pi^-)\pi^-$ calibration data in p_T, η bins
  - $K/\pi \to e$: "control"→"signal"
- ***Validation:***
  - *Data*: use $\overline{D}^0(K^+\pi^-)$ in $K^+e^+e^-$ (no vetoes)
  - *Simulation*: $B^+ \to K^+K^+K^-$ and $B^+ \to K^+\pi^+\pi^-$
  - Prediction within 2% margin

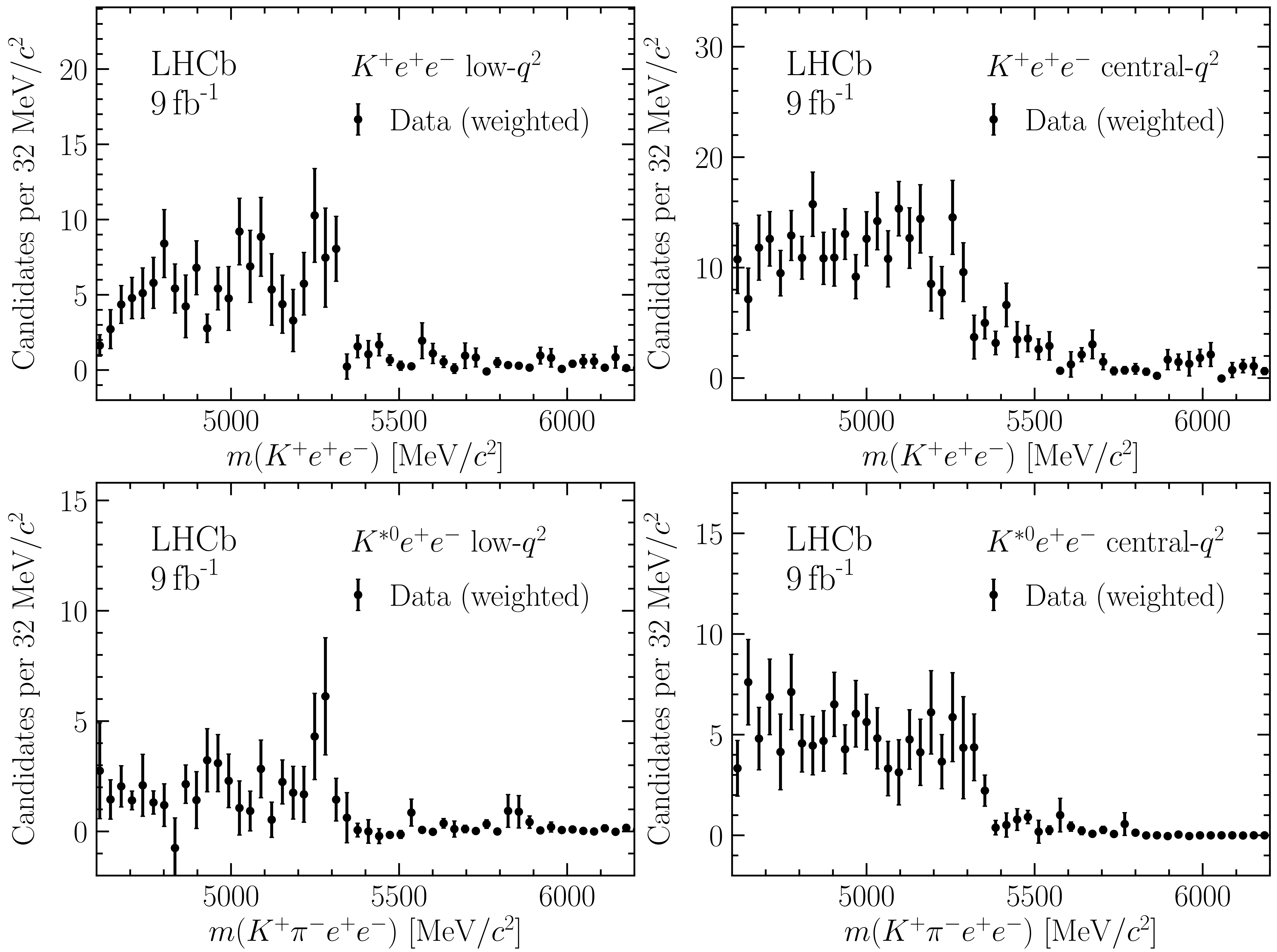


Misidentified background in electron mode

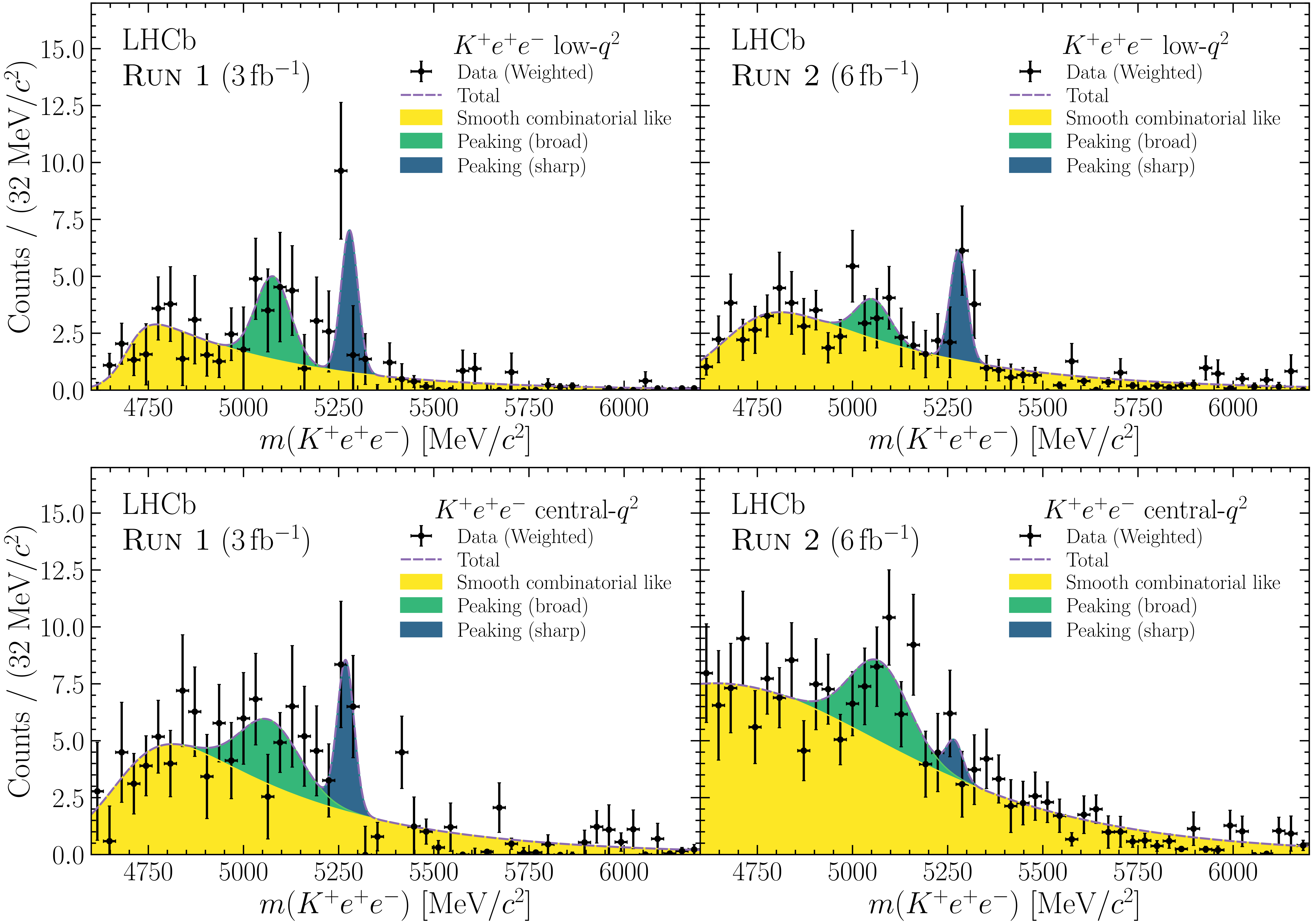
- ***Model them analytically***
  - Kernel density estimation for systematic
- ***Normalisation***
  - Gaussian constrained (stat. precision of prediction)
- ***Systematics***
  - Use alternative *"control"* regions
  - *Different kaon/pion ID tagging in control region*
  - *Trigger effects, binning transfer function*

NB: misidentified background not included in mass fit in previous analysis (see backup for comparison)

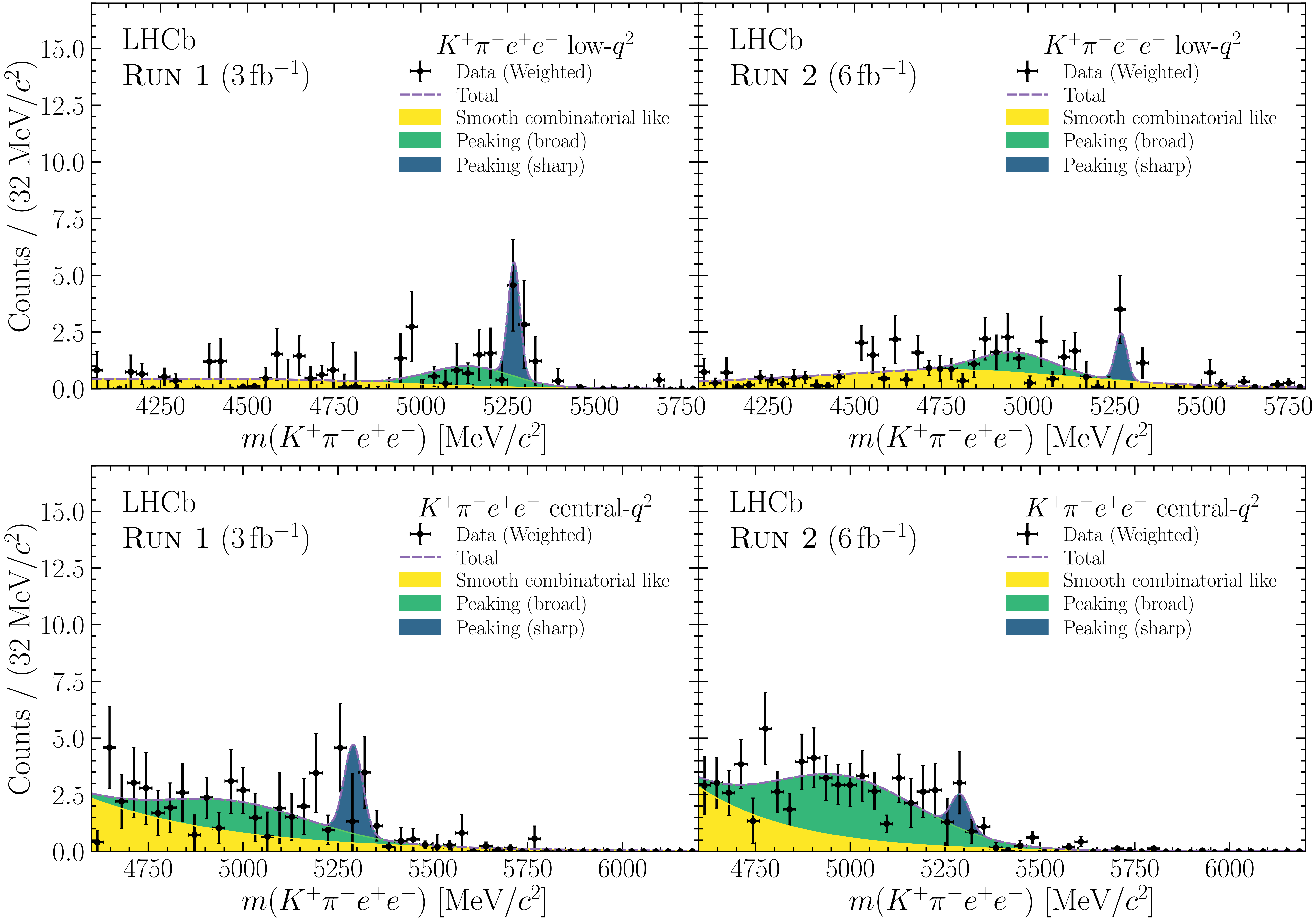
Predictions after per-track and per-event weighting (signal subtracted)



Misidentified background in electron mode (R_{K^+})



Misidentified background in electron mode (R_{K^*})



Mass fit to rare mode muons: simultaneous fit $R_{K,K^{*0}}$

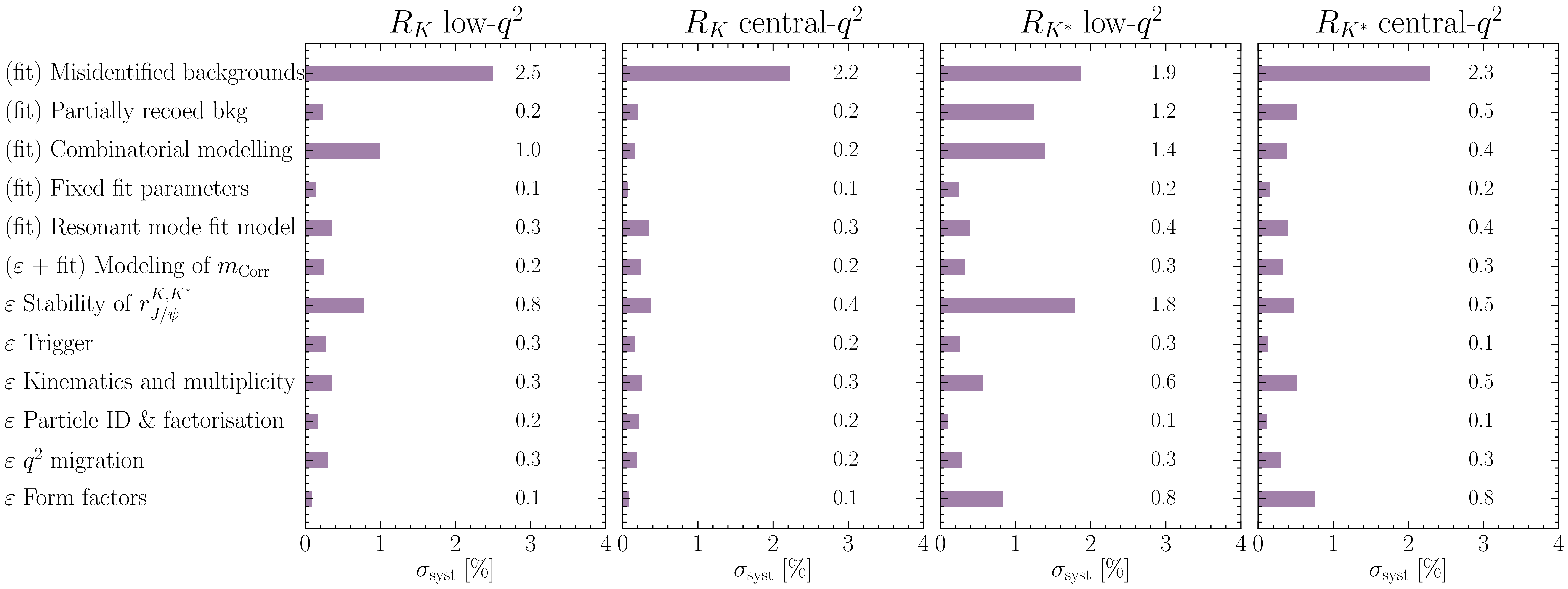
Mass fit to rare mode electrons: simultaneous fit $R_{K,K^{*0}}$

Mass fit to rare mode electrons: simultaneous fit $R_{K,K^{*0}}$

low-q^2 | central-q^2 | resonant-J/ψ

Mass fit to rare mode electrons: simultaneous fit $R_{K,K^{*0}}$

Systematics break down



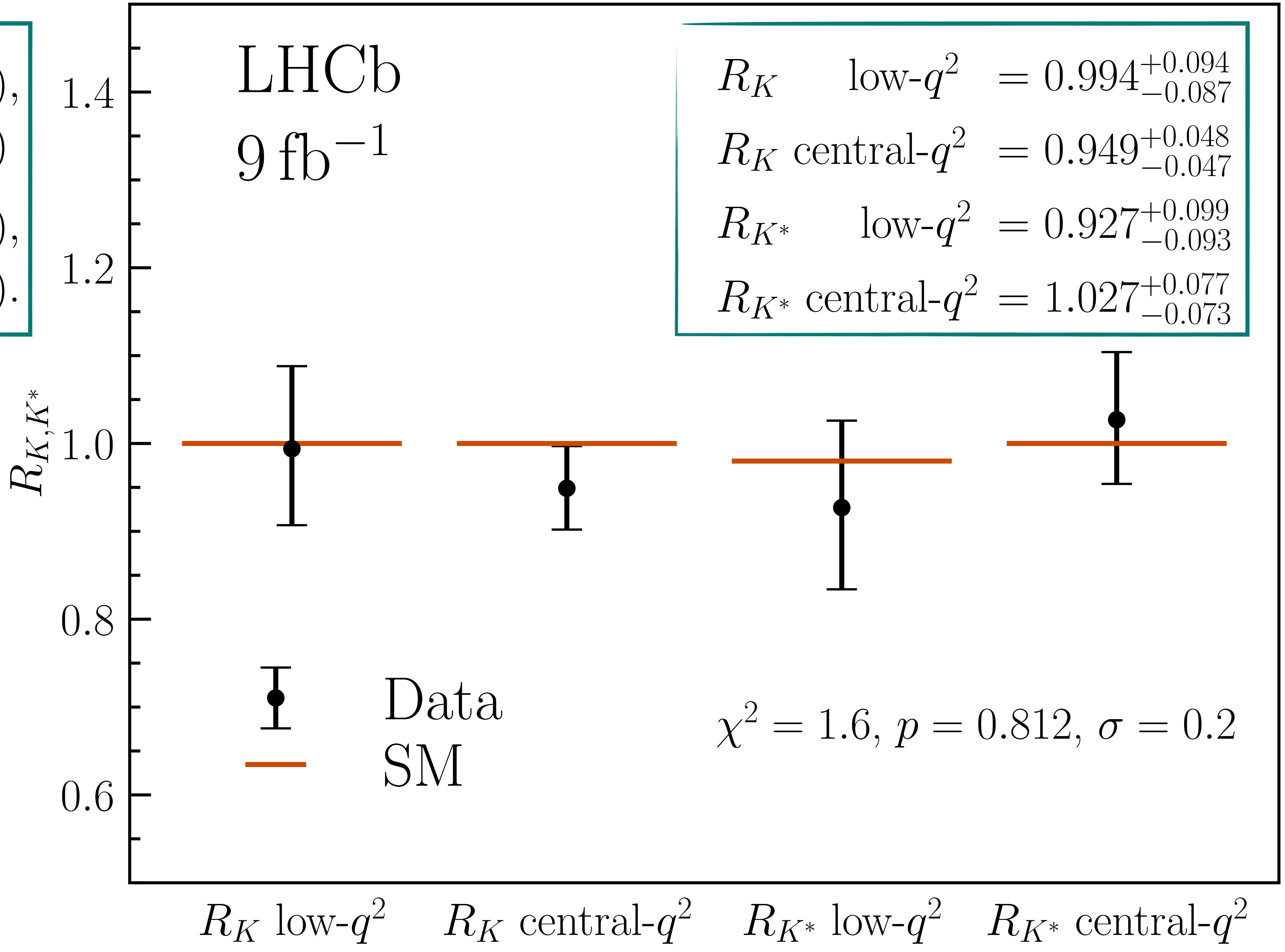
- Dominant systematic from misidentified backgrounds estimation from data driven method
- Measurement still statistically dominated

Results

$$\text{low-}q^2 \begin{cases} R_K & = 0.994\ ^{+0.090}_{-0.082}\ (\text{stat})\ ^{+0.027}_{-0.029}\ (\text{syst}), \\ R_{K^*} & = 0.927\ ^{+0.093}_{-0.087}\ (\text{stat})\ ^{+0.034}_{-0.033}\ (\text{syst}) \end{cases}$$

$$\text{central-}q^2 \begin{cases} R_K & = 0.949\ ^{+0.042}_{-0.041}\ (\text{stat})\ ^{+0.023}_{-0.023}\ (\text{syst}), \\ R_{K^*} & = 1.027\ ^{+0.072}_{-0.068}\ (\text{stat})\ ^{+0.027}_{-0.027}\ (\text{syst}). \end{cases}$$

- Most precise and accurate LFU test in $b \to s\ell\ell$ transition
- Compatible with SM with a simple χ^2 test on 4 measurement at 0.2 σ

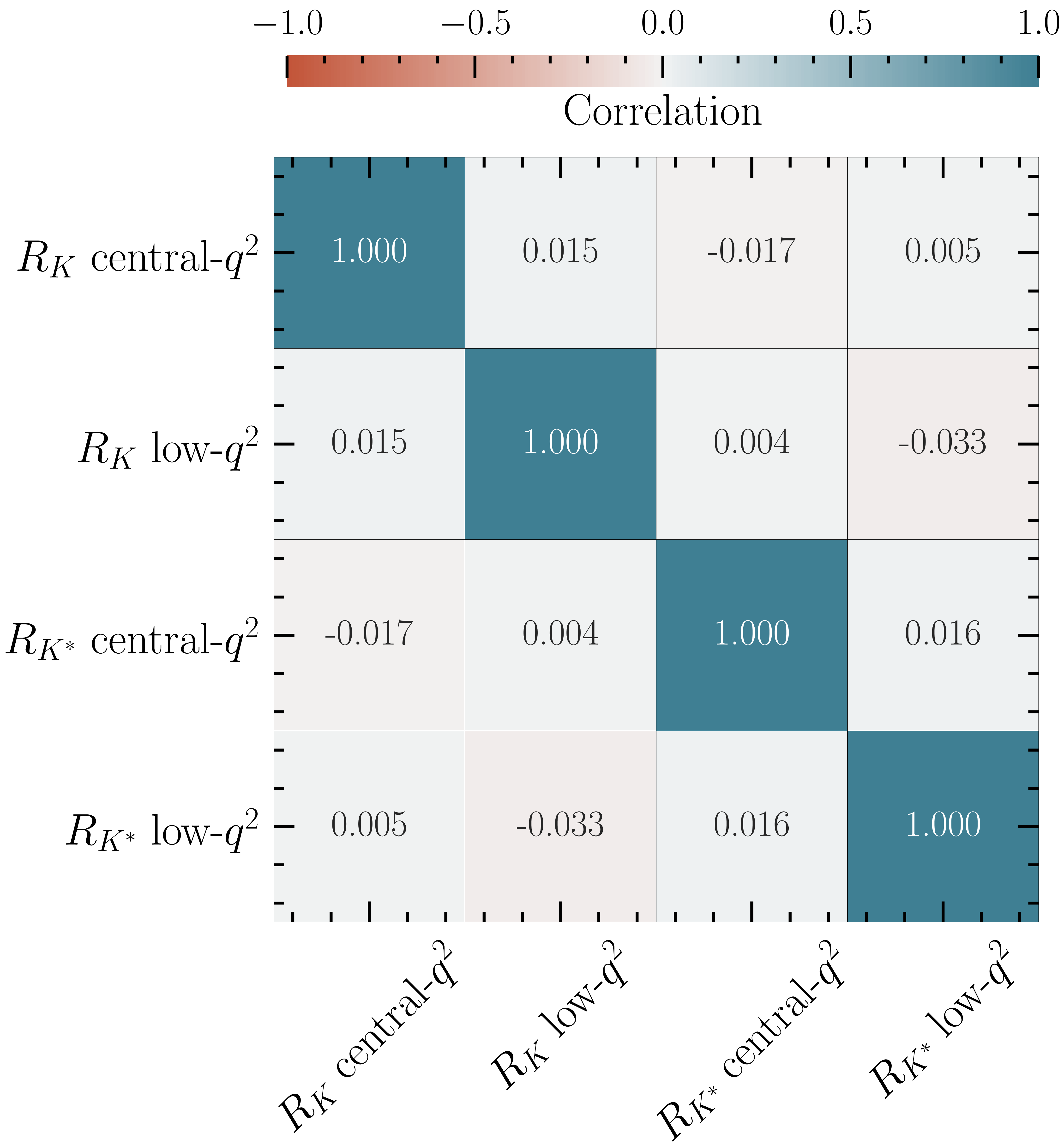


Results

$$
\text{low-}q^2 \begin{cases} R_K &= 0.994\ ^{+0.090}_{-0.082}\ (\text{stat})\ ^{+0.027}_{-0.029}\ (\text{syst}), \\ R_{K^*} &= 0.927\ ^{+0.093}_{-0.087}\ (\text{stat})\ ^{+0.034}_{-0.033}\ (\text{syst}) \end{cases}
$$

$$
\text{central-}q^2 \begin{cases} R_K &= 0.949\ ^{+0.042}_{-0.041}\ (\text{stat})\ ^{+0.023}_{-0.023}\ (\text{syst}), \\ R_{K^*} &= 1.027\ ^{+0.072}_{-0.068}\ (\text{stat})\ ^{+0.027}_{-0.027}\ (\text{syst}). \end{cases}
$$

- Correlation matrix from simultaneous fit between results



Results

$$\text{low-}q^2 \begin{cases} R_K = 0.994\ ^{+0.090}_{-0.082}\ (\text{stat})\ ^{+0.027}_{-0.029}\ (\text{syst}), \\ R_{K^*} = 0.927\ ^{+0.093}_{-0.087}\ (\text{stat})\ ^{+0.034}_{-0.033}\ (\text{syst}) \end{cases}$$

$$\text{central-}q^2 \begin{cases} R_K = 0.949\ ^{+0.042}_{-0.041}\ (\text{stat})\ ^{+0.023}_{-0.023}\ (\text{syst}), \\ R_{K^*} = 1.027\ ^{+0.072}_{-0.068}\ (\text{stat})\ ^{+0.027}_{-0.027}\ (\text{syst}). \end{cases}$$

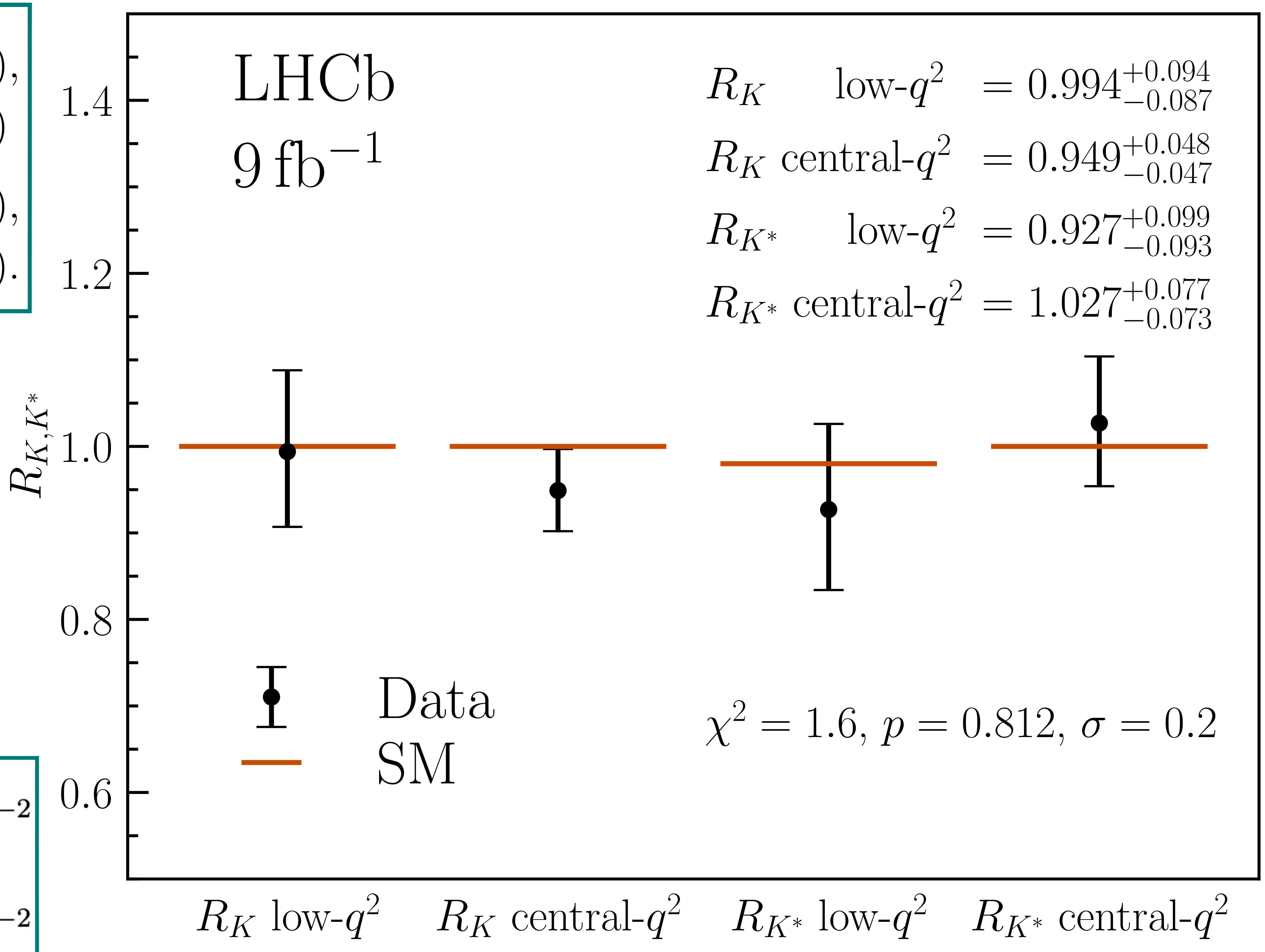
- Muon $\mathscr{B}$ agrees to published value within the analysis
- Scaling $R_{(K,K^*)}$ to measured branching ratios of muon mode in central q^2

JHEP 06 (2014) 133

JHEP 11 (2016) 047

$$\frac{d\mathcal{B}(B^+ \to K^+ e^+ e^-)}{dq^2} = (25.5^{+1.3}_{-1.2} \pm 1.1) \times 10^{-9}\ \text{GeV}^{-2}$$

$$\frac{d\mathcal{B}(B^0 \to K^{*0} e^+ e^-)}{dq^2} = (33.3^{+2.7}_{-2.6} \pm 2.2) \times 10^{-9}\ \text{GeV}^{-2}$$



Conclusion

$$\text{low-}q^2 \begin{cases} R_K = 0.994\ ^{+0.090}_{-0.082}\ (\text{stat})\ ^{+0.027}_{-0.029}\ (\text{syst}), \\ R_{K^*} = 0.927\ ^{+0.093}_{-0.087}\ (\text{stat})\ ^{+0.034}_{-0.033}\ (\text{syst}) \end{cases}$$

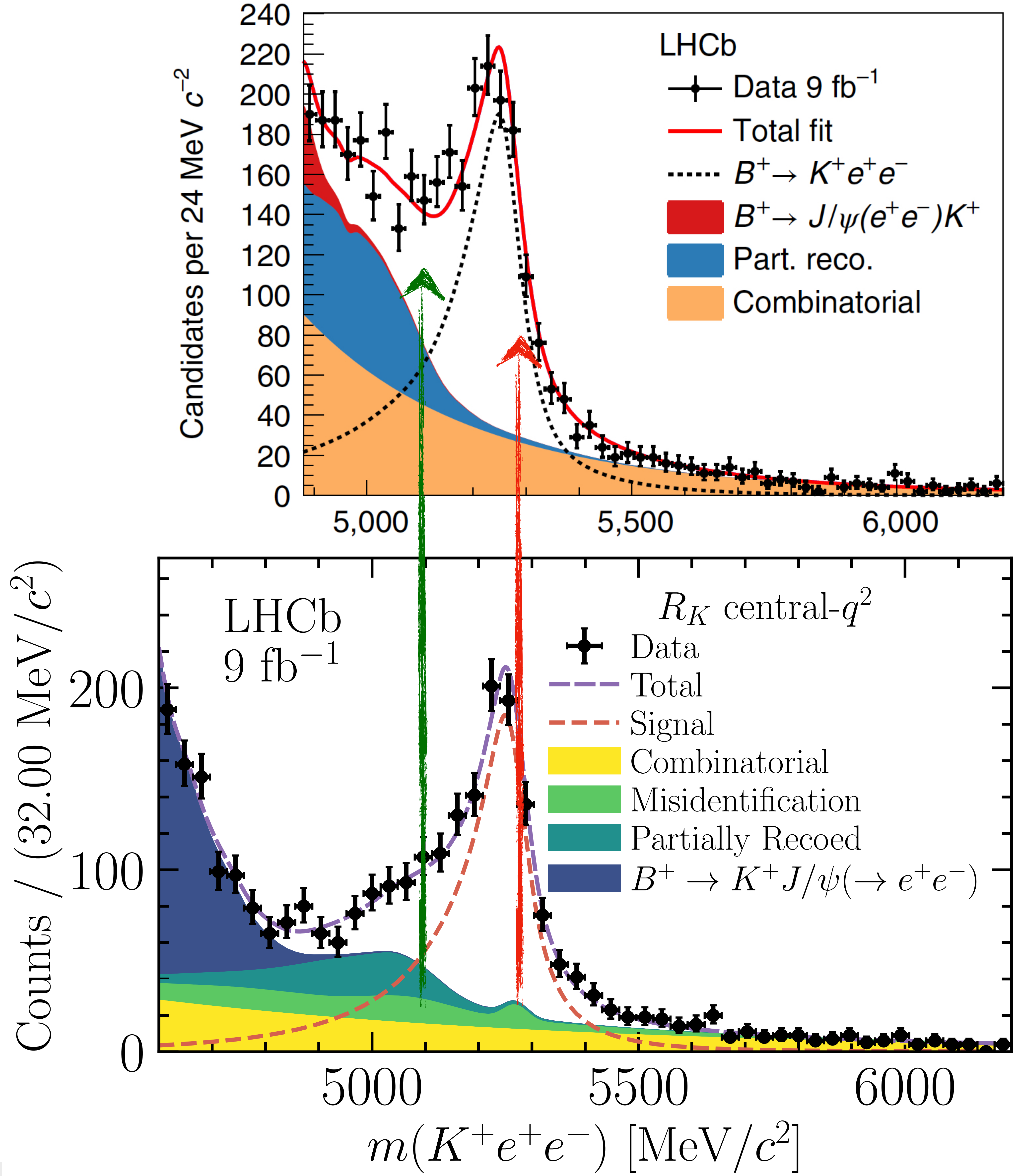
$$\text{central-}q^2 \begin{cases} R_K = 0.949\ ^{+0.042}_{-0.041}\ (\text{stat})\ ^{+0.023}_{-0.023}\ (\text{syst}), \\ R_{K^*} = 1.027\ ^{+0.072}_{-0.068}\ (\text{stat})\ ^{+0.027}_{-0.027}\ (\text{syst}). \end{cases}$$

- **Most precise and accurate LFU test to date**
- **The results are compatible with the SM at 0.2 σ level**
- In-depth revision and understanding of electron misidentification in this analysis
- Take all the knowledge acquired and bring it to the Run III data taking
- Brand new detector in Run III (a brand new detector)

Backup

Comparison to previous R_K measurement

[Nat. Phys. 18, 277-282 (2022)]



- Different PID cut used ➡ Allowed σ_{stat} : ± 0.033
- Mis-ID rate from $D^{*-} \to D^0(K\pi)\pi$
- With new(previous) analysis requirements

	Sample	$\pi \to e$	$K \to e$
(11+12)	Run 1	1.78 (1.70) %	0.69 (1.24) %
(15+16)	Run 2p1	0.83 (1.51) %	0.18 (1.25) %
(17+18)	Run 2p2	0.80 (1.50) %	0.16 (1.23) %

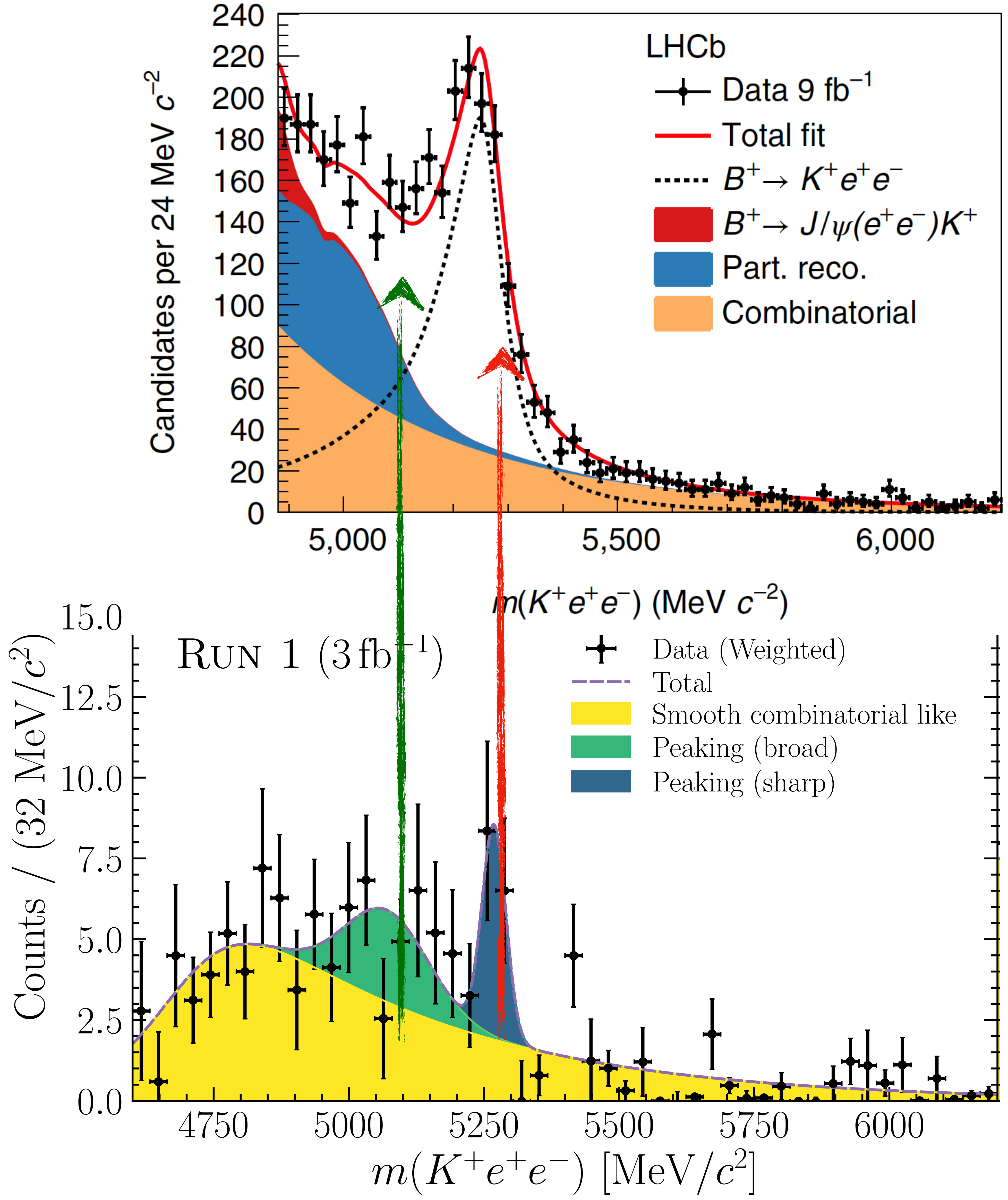
single-misID	× **1 (Run1)** × **2 (Run2)**	× **2 (Run1)** × **7 (Run2)**
double-misID	× **1² (Run1)** × **2² (Run2)**	× **2² (Run1)** × **7² (Run2)**

- Shift due to contamination at looser working point : $+\mathbf{0.064}$
- Shift due to not inclusion of background in mass fit: $+\mathbf{0.038}$

Adds linearly

Comparison to previous R_K measurement

[Nat. Phys. 18, 277-282 (2022)]



- Different PID cut used ➡ Allowed σ_{stat} : ±0.033
- Mis-ID rate from $D^{*-} \to D^0(K\pi)\pi$
- With new(previous) analysis requirements

	Sample	$\pi \to e$	$K \to e$
(11+12)	Run 1	1.78 (1.70) %	0.69 (1.24) %
(15+16)	Run 2p1	0.83 (1.51) %	0.18 (1.25) %
(17+18)	Run 2p2	0.80 (1.50) %	0.16 (1.23) %

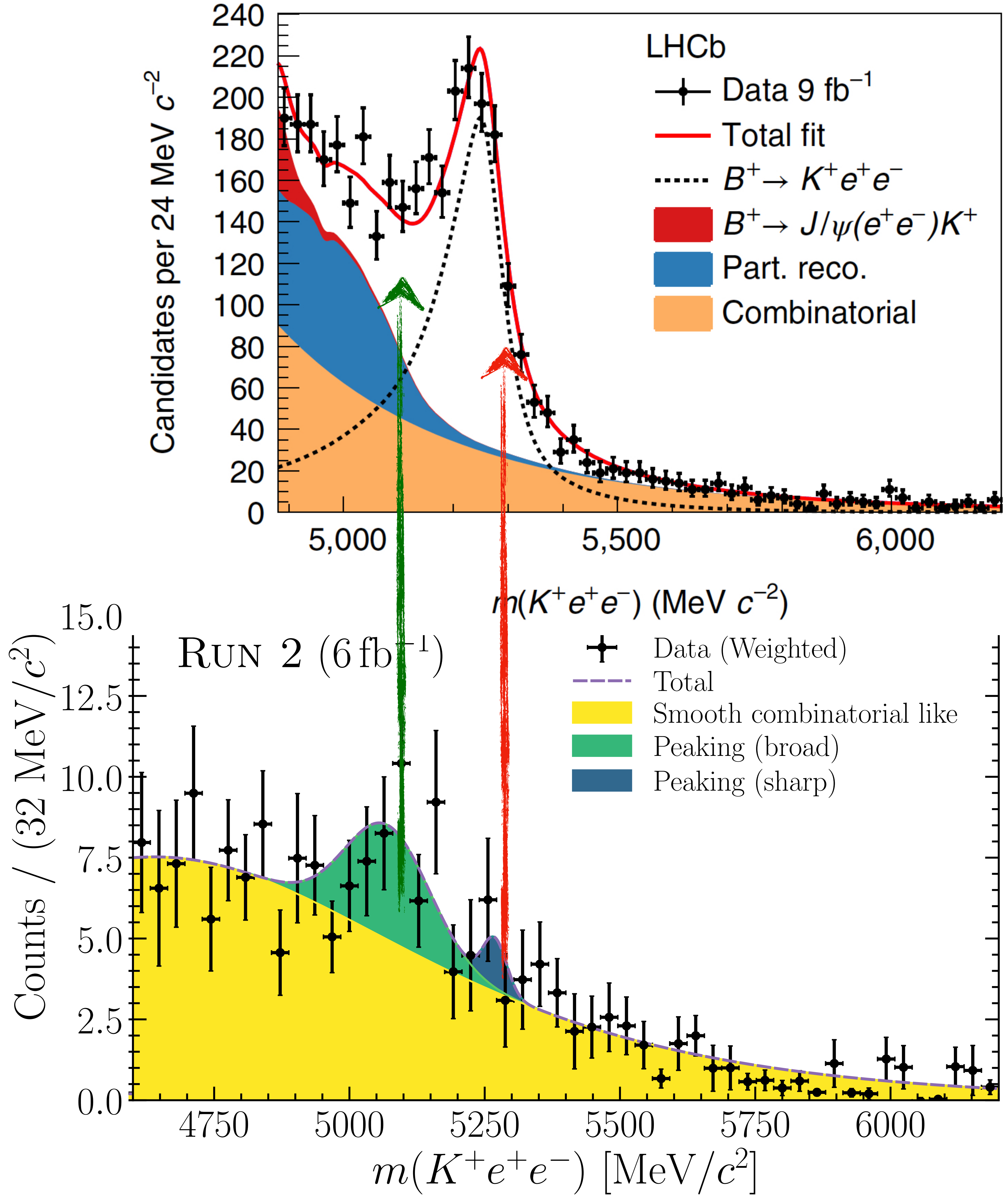
	$\pi \to e$	$K \to e$
single-misID	**× 1 (Run1)** **× 2 (Run2)**	**× 2 (Run1)** **× 7 (Run2)**
double-misID	**× 1^2 (Run1)** **× 2^2 (Run2)**	**× 2^2 (Run1)** **× 7^2 (Run2)**

- Shift due to contamination at looser working point : +**0.064**
- Shift due to not inclusion of background in mass fit: +**0.038**

Adds linearly

Comparison to previous R_K measurement

[Nat. Phys. 18, 277-282 (2022)]



- Different PID cut used ➡ Allowed σ_{stat} : ± 0.033
- Mis-ID rate from $D^{*-} \to D^0(K\pi)\pi$
- With new(previous) analysis requirements

	Sample	$\pi \to e$	$K \to e$
(11+12)	RUN 1	1.78 (1.70) %	0.69 (1.24) %
(15+16)	RUN 2P1	0.83 (1.51) %	0.18 (1.25) %
(17+18)	RUN 2P2	0.80 (1.50) %	0.16 (1.23) %

single-misID	**× 1 (Run1)** **× 2 (Run2)**	**× 2 (Run1)** **× 7 (Run2)**
double-misID	**× 1^2 (Run1)** **× 2^2 (Run2)**	**× 2^2 (Run1)** **× 7^2 (Run2)**

- Shift due to contamination at looser working point : $+\mathbf{0.064}$
- Shift due to not inclusion of background in mass fit: $+\mathbf{0.038}$

Adds linearly

q^2 regions

low-q^2 region:	$0.1 < q^2 < 1.1\,\mathrm{GeV}^2/c^4\,,$
central-q^2 region:	$1.1 < q^2 < 6.0\,\mathrm{GeV}^2/c^4\,,$
electron J/ψ region:	$6 < q^2 < 11\,\mathrm{GeV}^2/c^4\,,$
muon J/ψ region:	$\lvert m(\ell^+\ell^-) - M_{J/\psi}^{\mathrm{PDG}}\rvert < 100\,\mathrm{MeV}/c^2\,,$
electron $\psi(2S)$ region:	$11 < q^2 < 15\,\mathrm{GeV}^2/c^4\,,$
muon $\psi(2S)$ region:	$\lvert m(\ell^+\ell^-) - M_{\psi(2S)}^{\mathrm{PDG}}\rvert < 100\,\mathrm{MeV}/c^2\,,$

Fit ranges and observed yields

Fit ranges

Lepton	q^2 region	Fit type	Range (MeV/c^2)
Electron	low, central	unconstrained	4600–6200
	J/ψ	unconstrained	4600–6200
		constrained	4900–6200
	$\psi(2S)$	constrained	5100–5750
Muon	low, central	unconstrained	5150–5850
	J/ψ	unconstrained	5100–6100
		constrained	5100–6100
	$\psi(2S)$	constrained	5100–5750

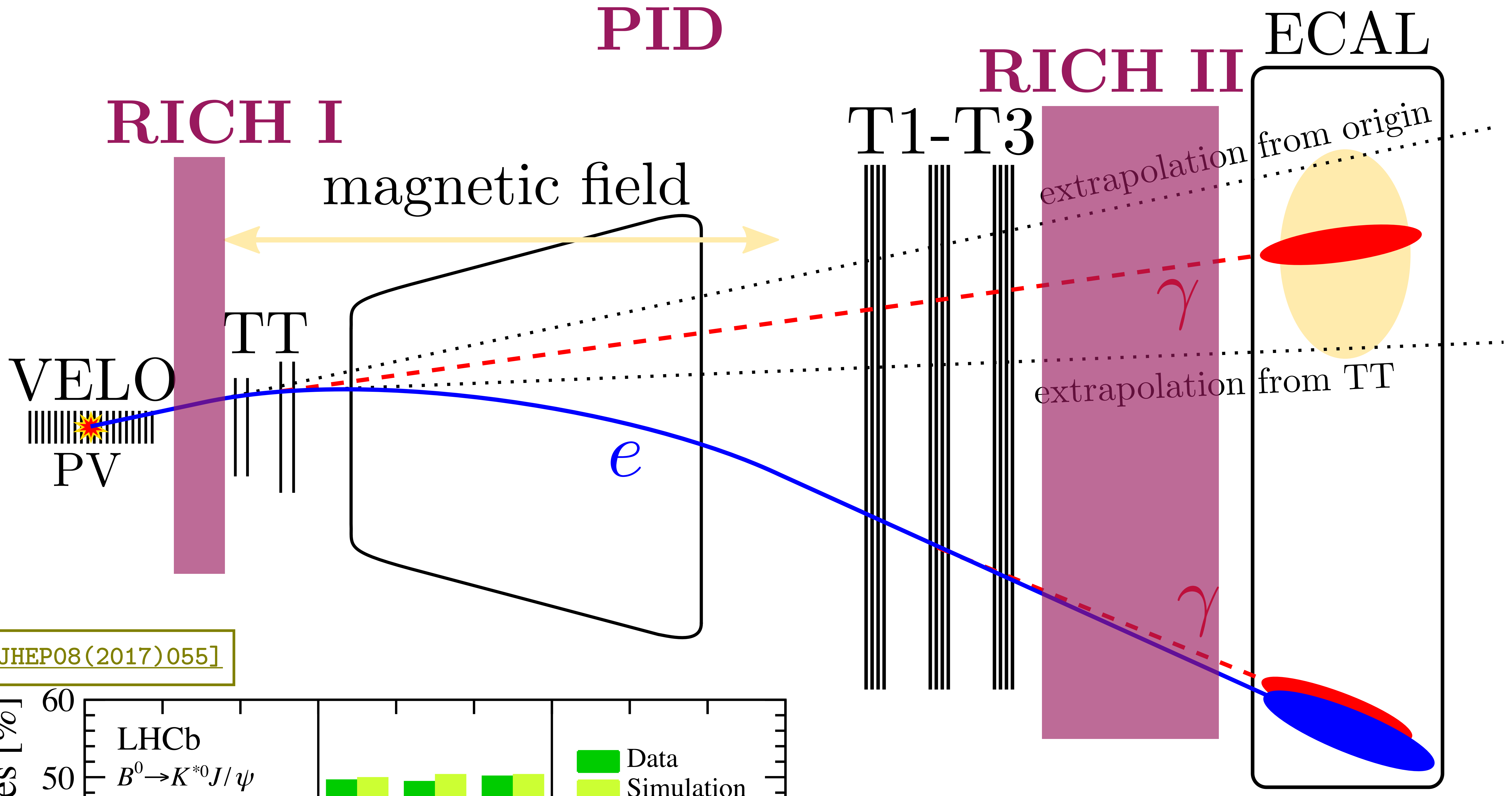
Measured yields from simultaneous fit to R_X

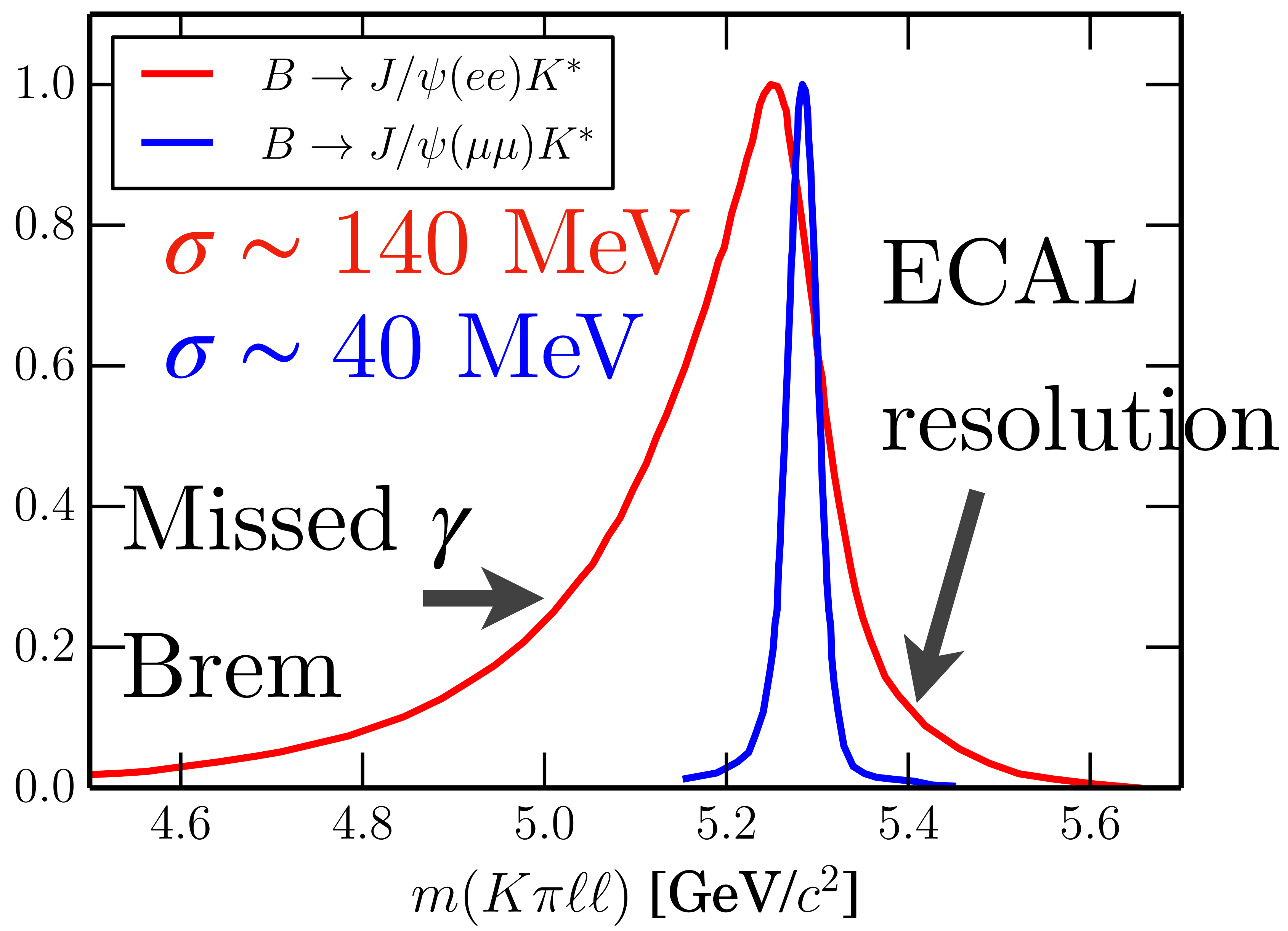
LU observable	Muon ($\times 10^3$)	Electron ($\times 10^3$)
low-q^2 R_K	1.25 ± 0.04	0.305 ± 0.024
low-q^2 R_{K^*}	1.001 ± 0.034	0.247 ± 0.022
central-q^2 R_K	4.69 ± 0.08	1.19 ± 0.05
central-q^2 R_{K^*}	1.74 ± 0.05	0.443 ± 0.028
J/ψ R_K	$(2.964 \pm 0.002) \times 10^3$	$(7.189 \pm 0.015) \times 10^2$
J/ψ R_{K^*}	$(9.733 \pm 0.010) \times 10^2$	$(2.517 \pm 0.009) \times 10^2$

"constrained" for cross-checks

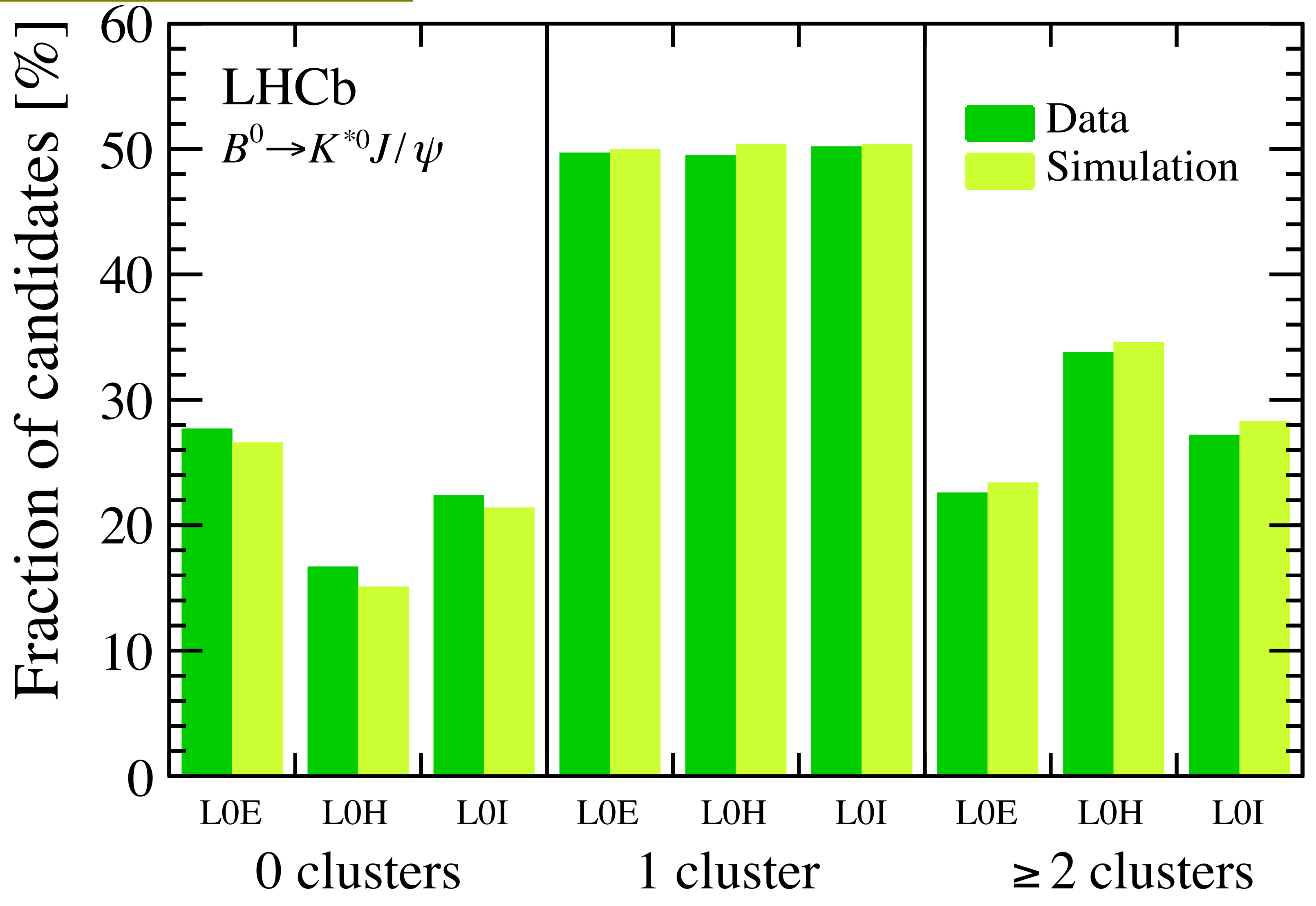
"unconstrained" for simultaneous fit to R_X

Challenges in LFU tests: electrons and energy losses





[JHEP08(2017)055]



Brem recovery is $\simeq$ O(50%) efficient
Well described in simulation

Wider fit range than muons:
more background,
more sensitive to peaking structures,
lineshapes are brem-dependent

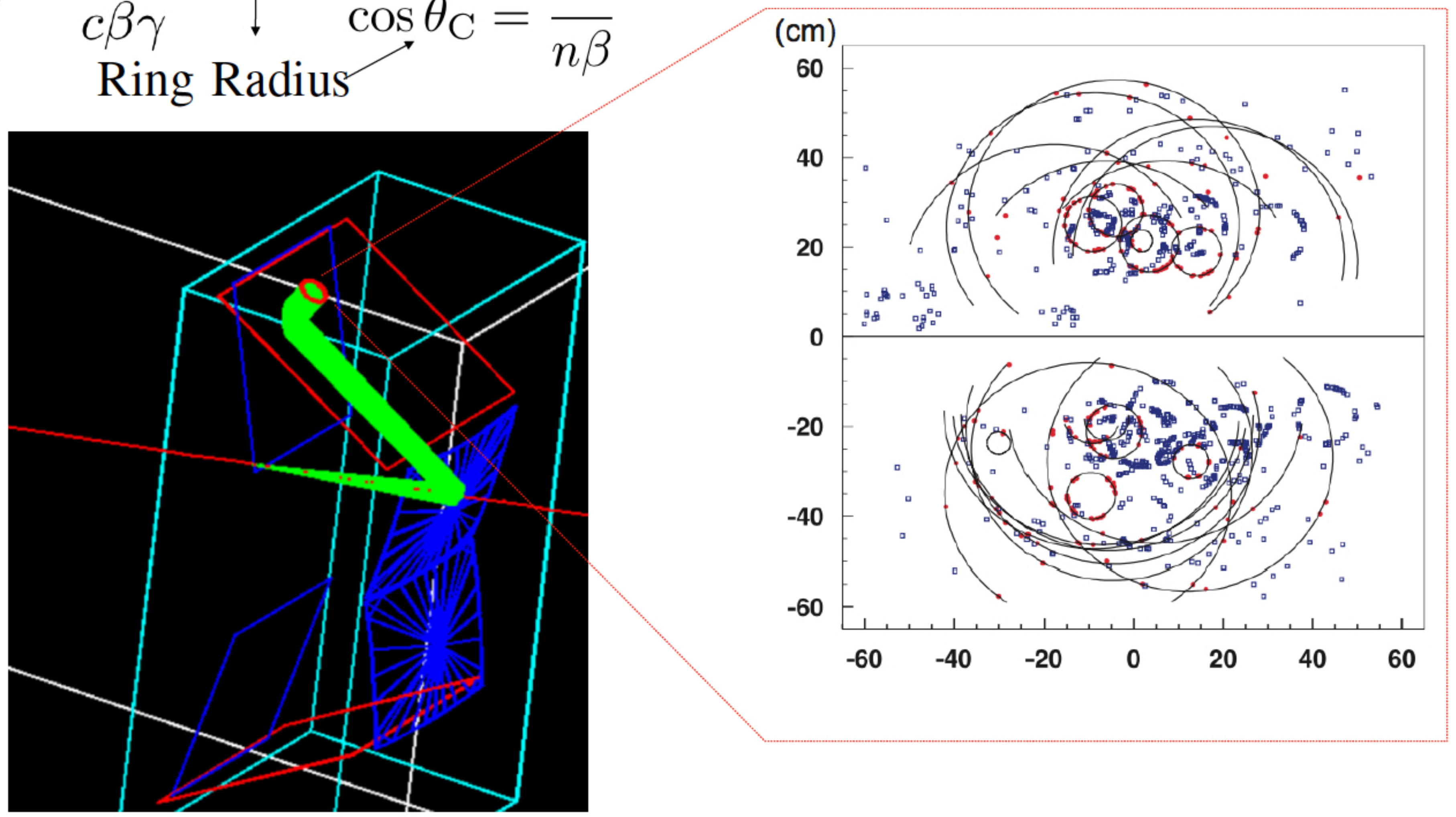
Challenges in LFU tests: electrons and PID

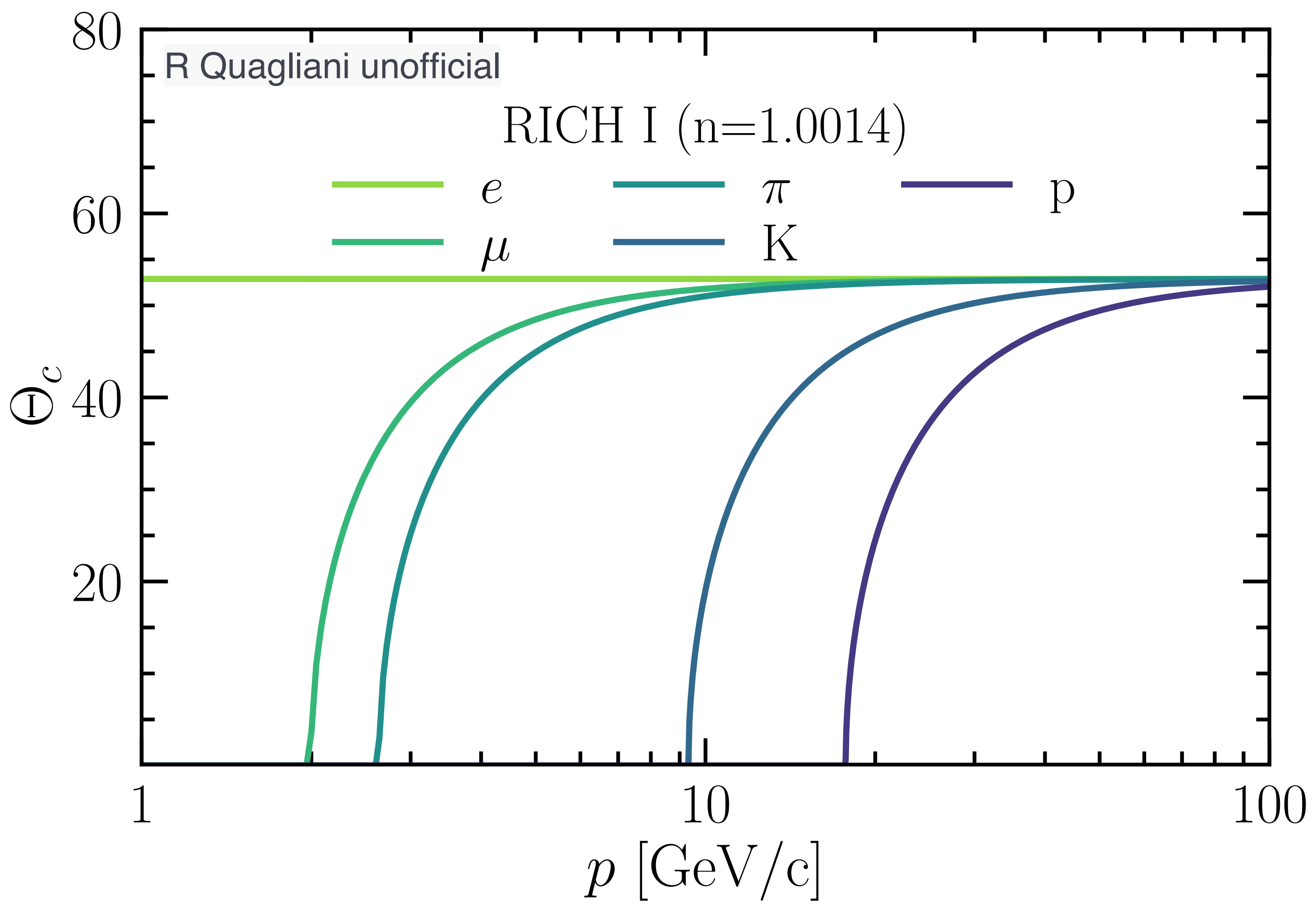
From RICH I (upstream) and RICH II (downstream) detector

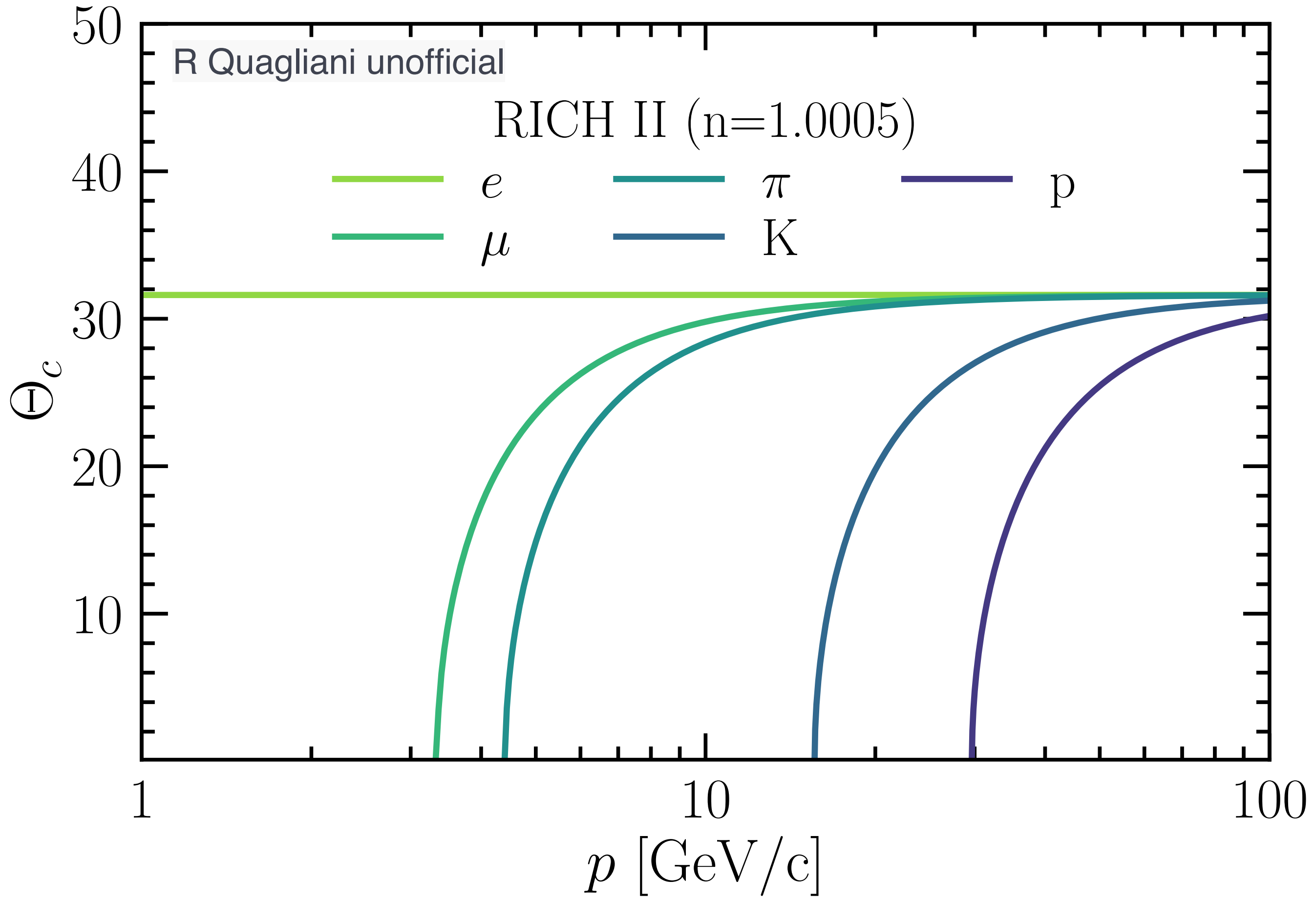
$$m = \frac{p}{c\beta\gamma} \qquad \cos\theta_C = \frac{1}{n\beta}$$

from tracking

Ring Radius







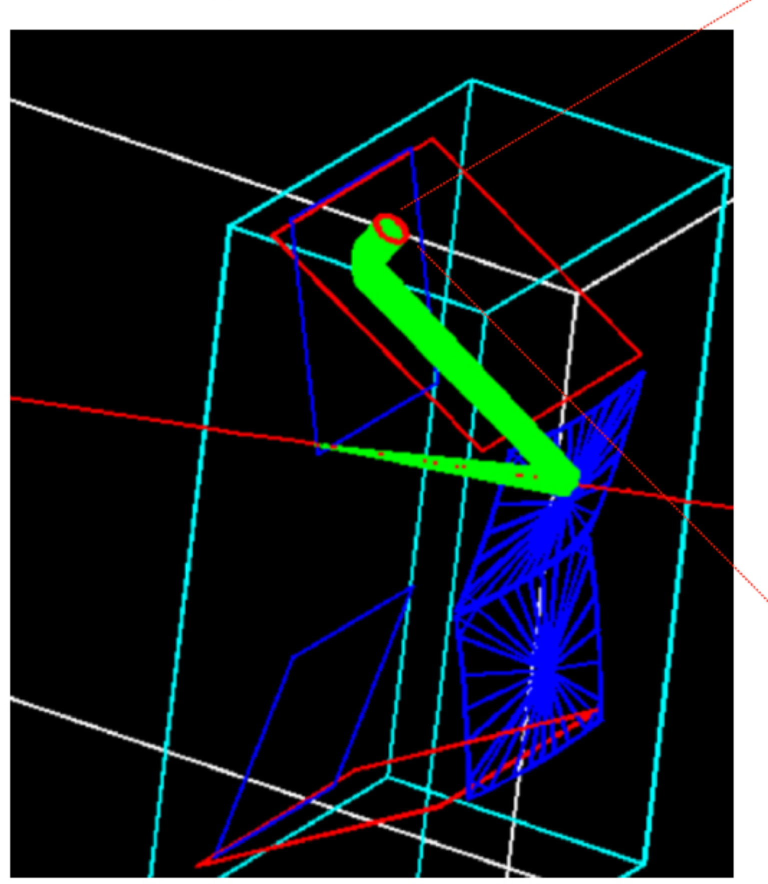
Challenges in LFU tests: electrons and PID

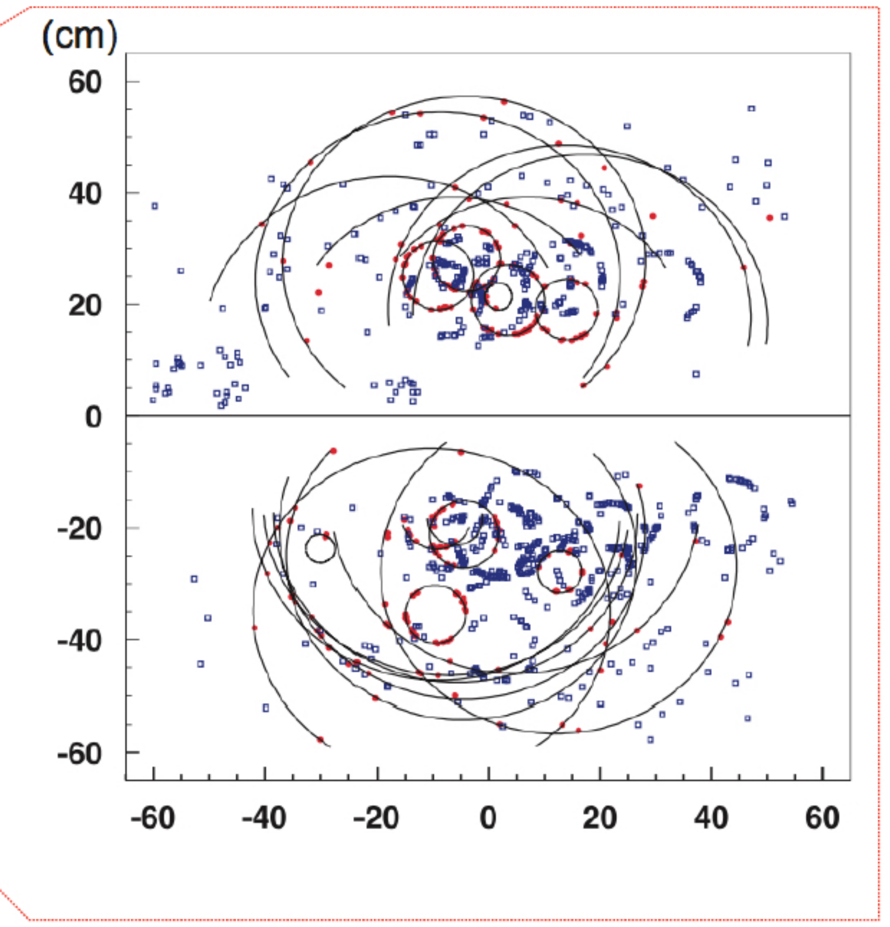
From RICH I (upstream) and RICH II (downstream) detector

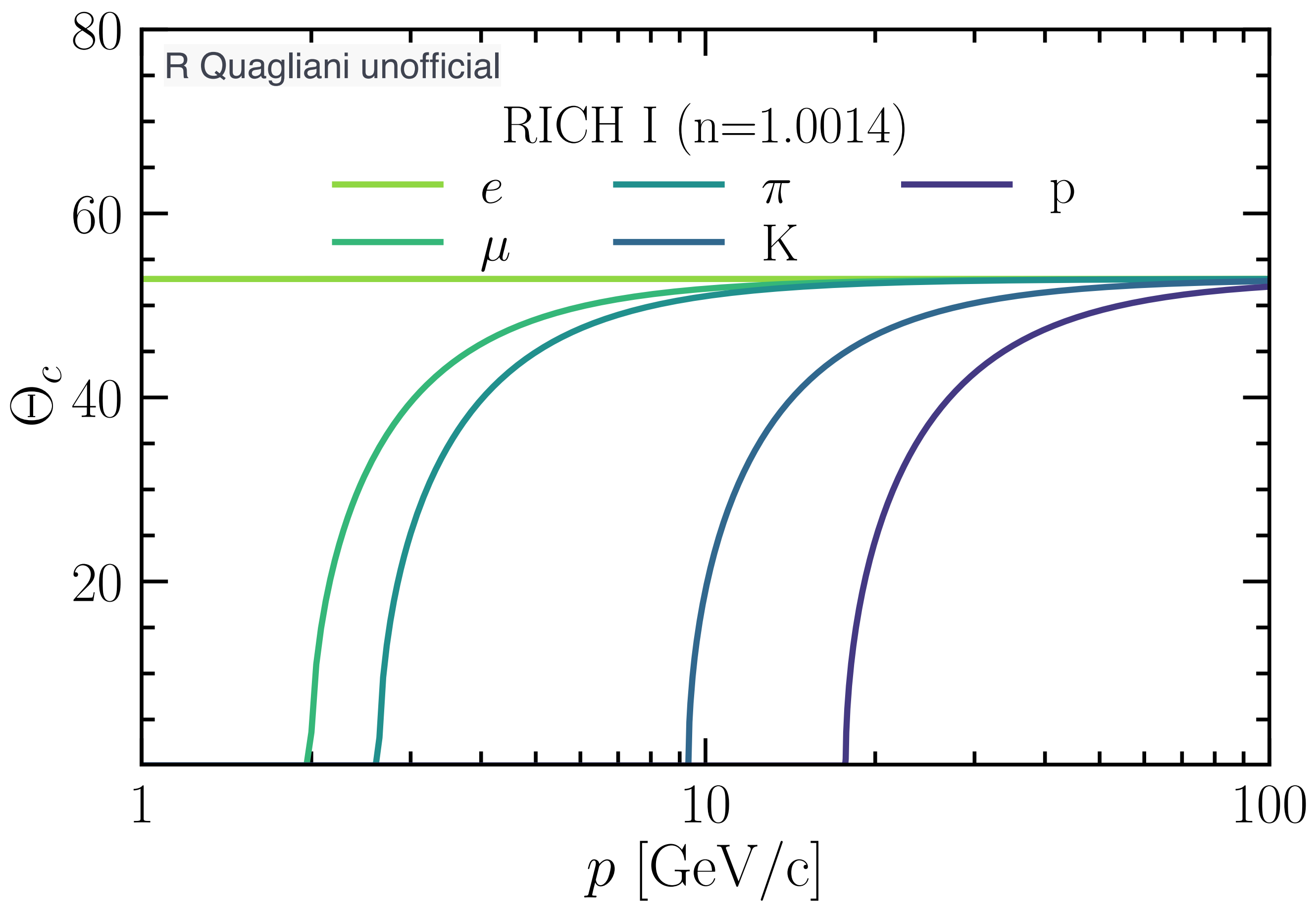
$m = \frac{p}{c\beta\gamma}$ $\cos\theta_C = \frac{1}{n\beta}$

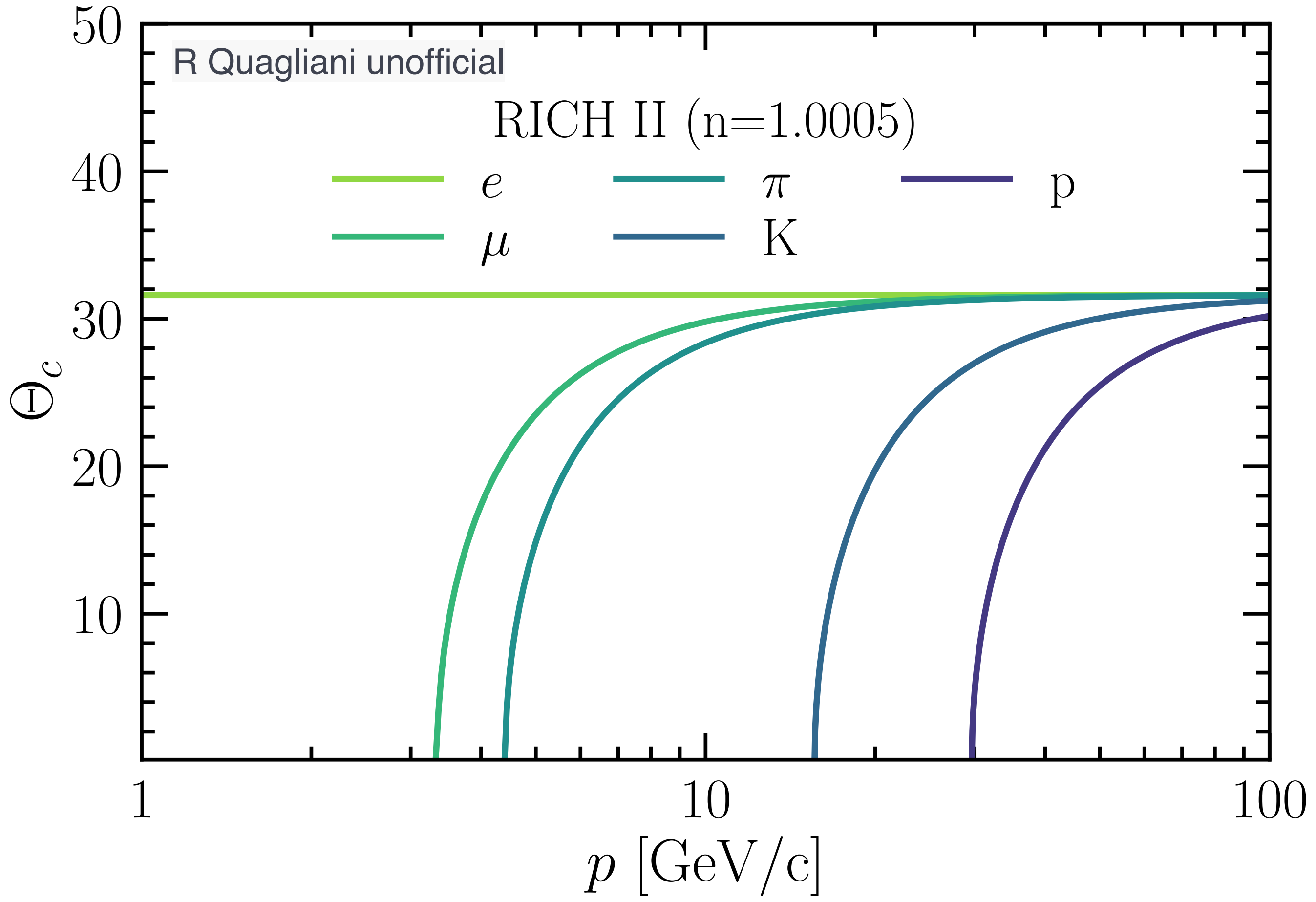
from tracking

Ring Radius

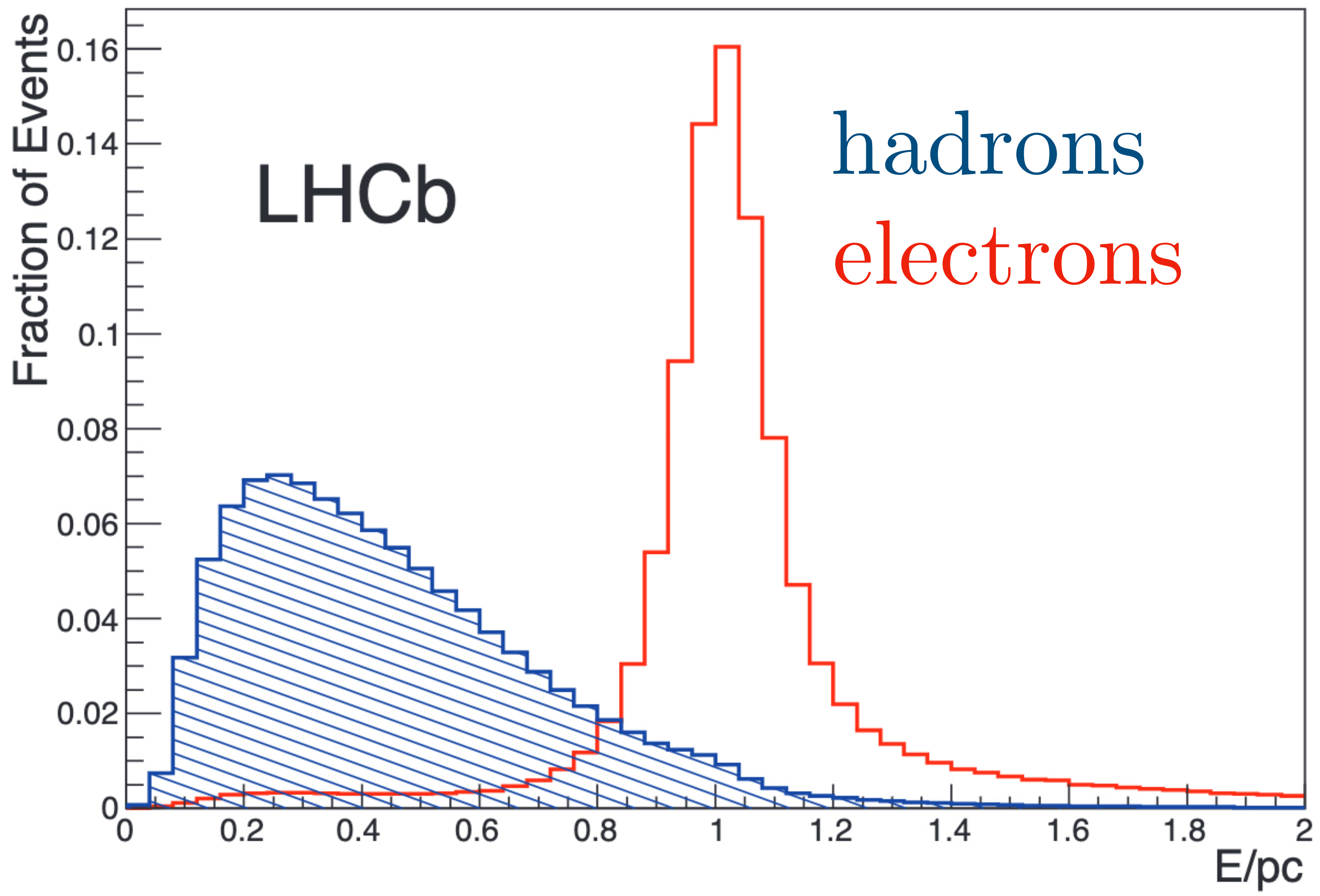








From ECAL



- $\text{DLL}(e) = \sum_{\text{ECAL,HCAL,RICH,MUON}} \Delta \log \mathscr{L}(e-\pi)$
- **ProbNNe**= Neural Net using tracking + PID of each detectors: e/h separation from simple sub-detectors greatly improved.

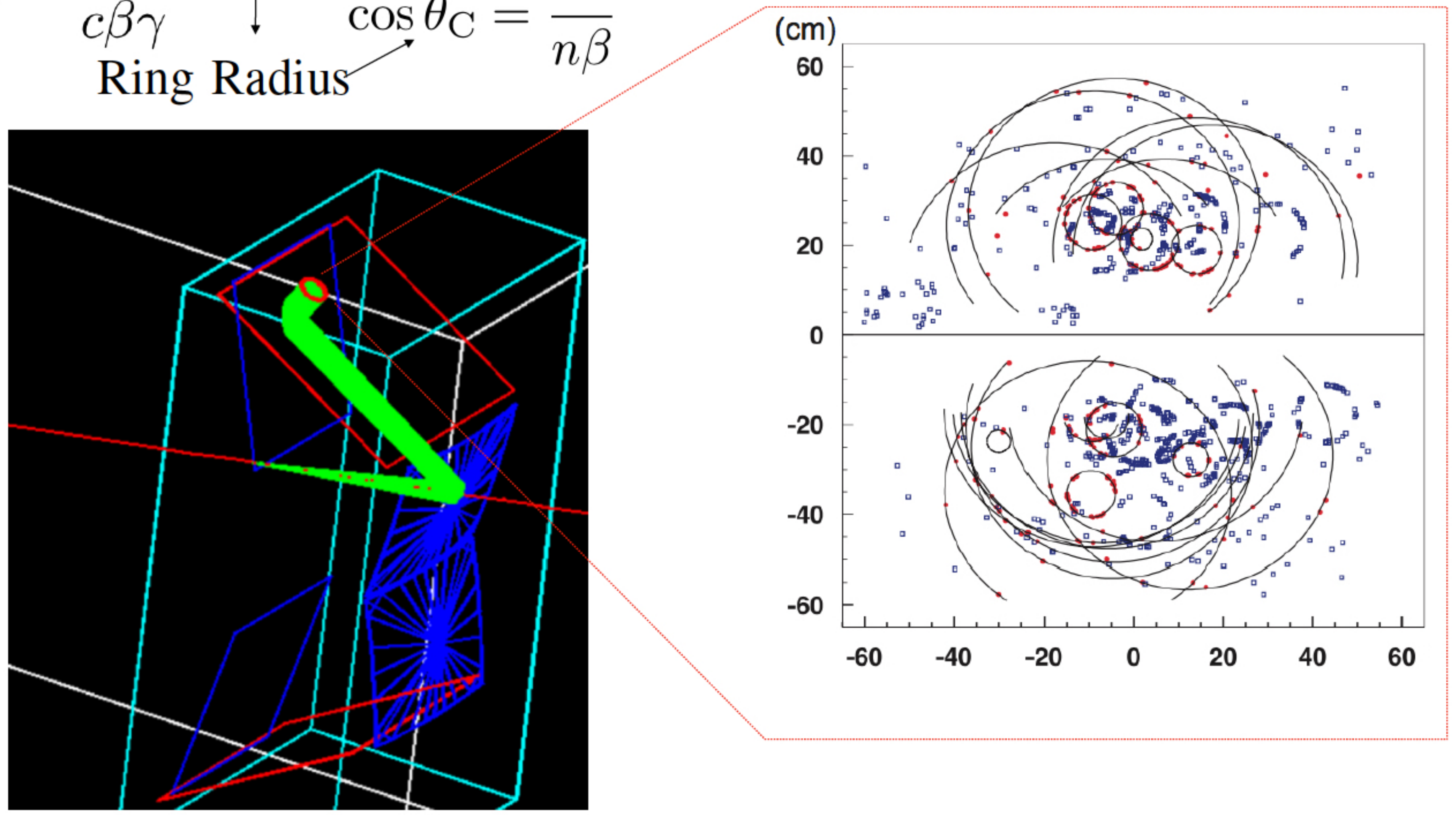
LFU tests: muons and PID

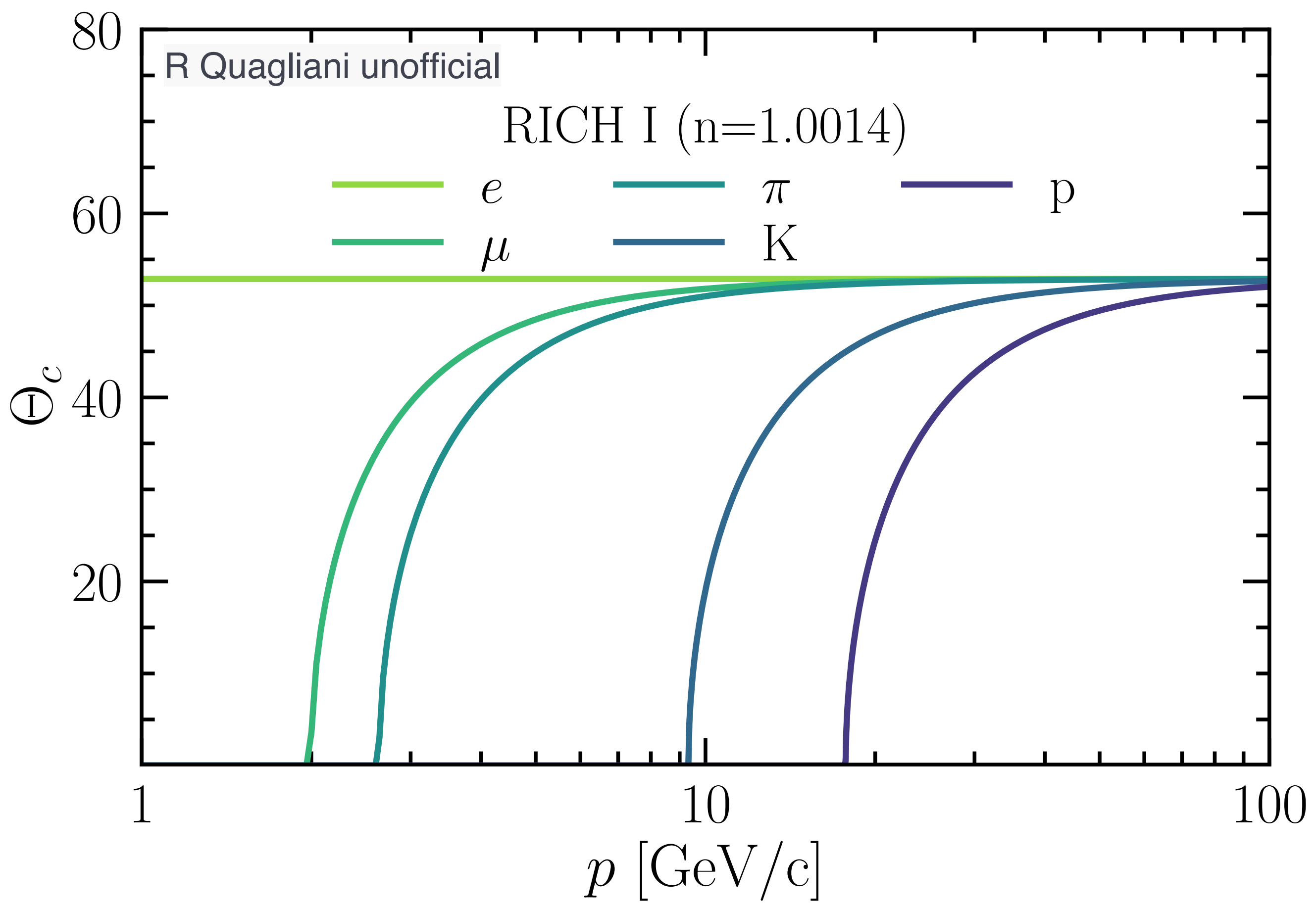
From RICH I (upstream) and RICH II (downstream) detector

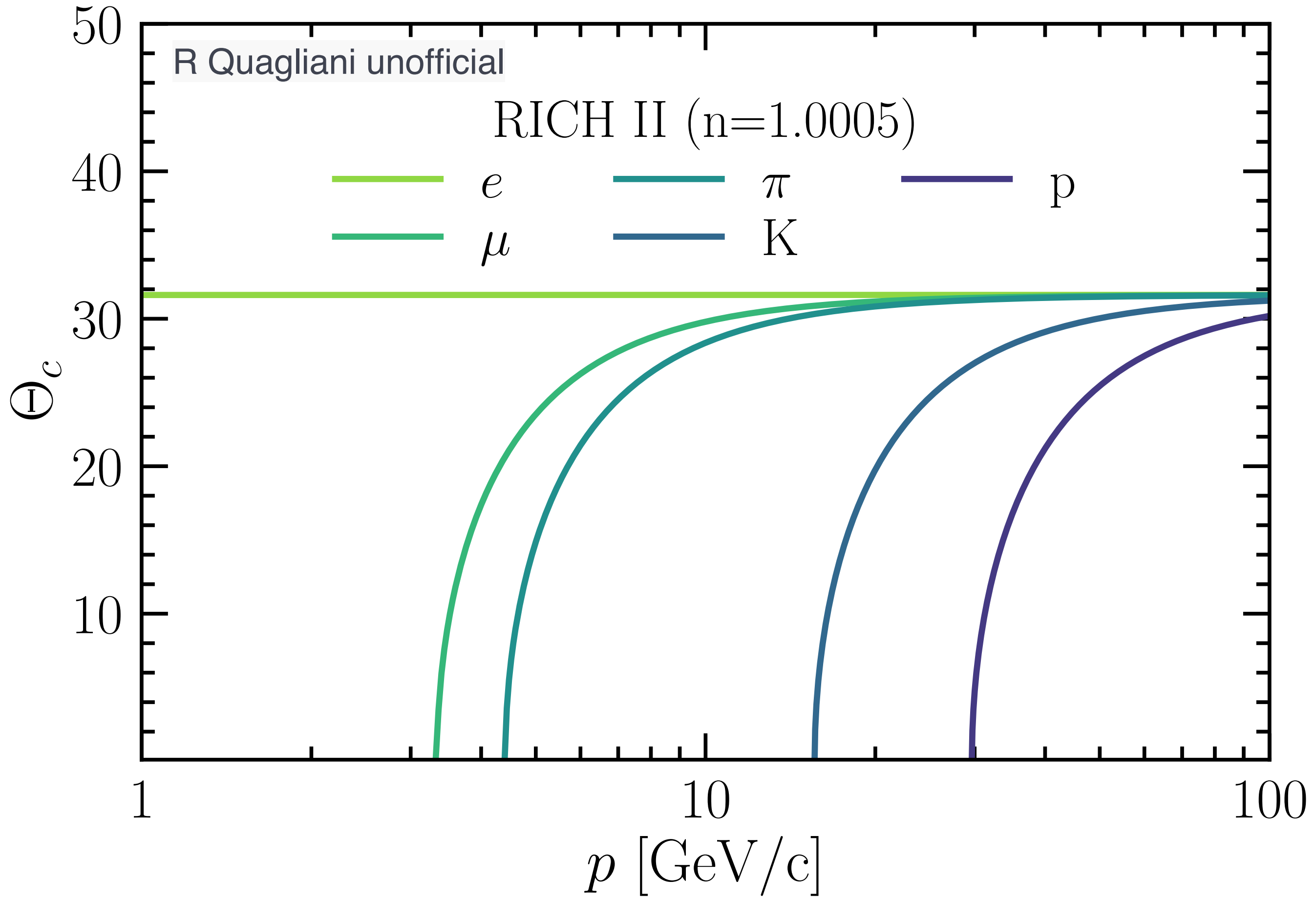
$$m = \frac{p}{c\beta\gamma} \qquad \cos\theta_C = \frac{1}{n\beta}$$

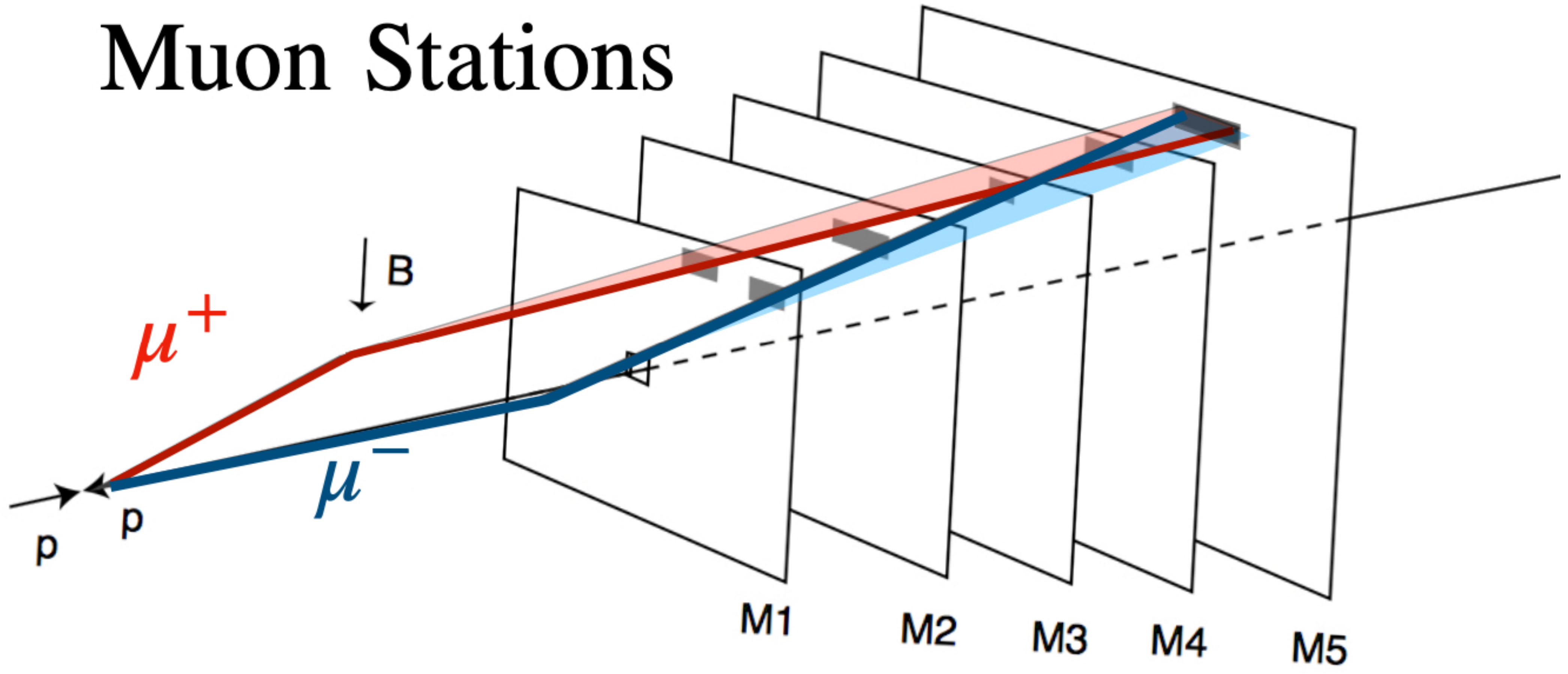
from tracking

Ring Radius





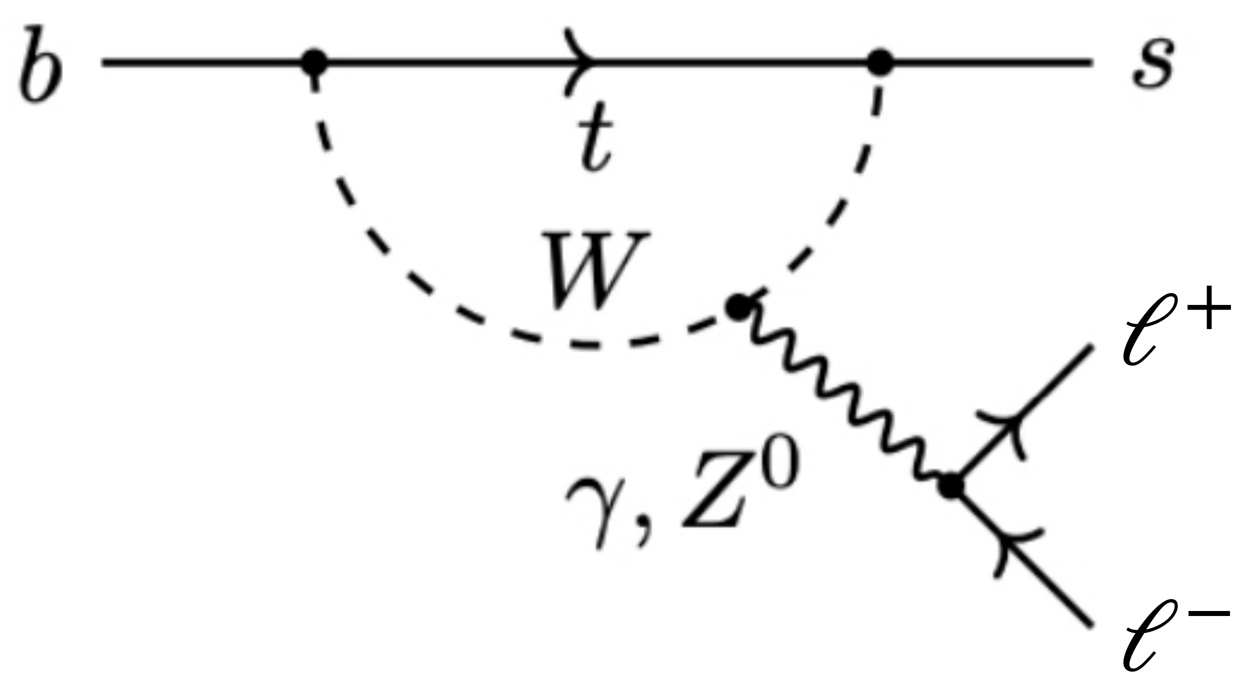




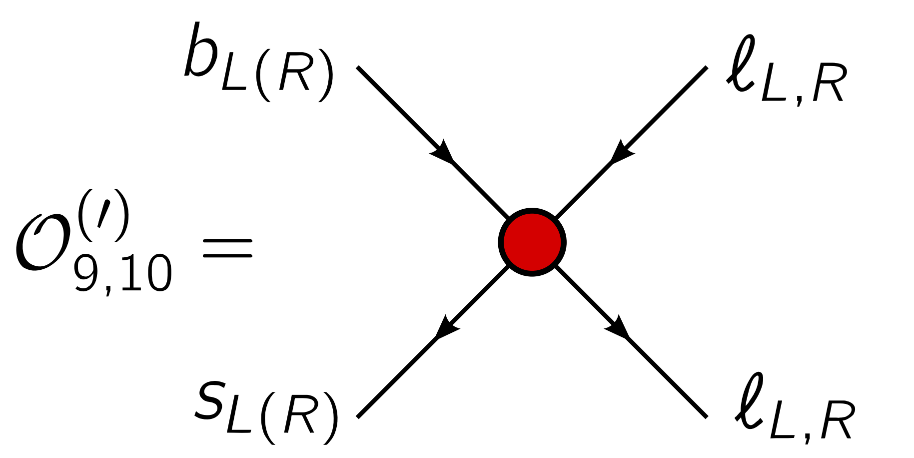
- Excellent **MuonID** and μ/h already with muon station coincidence
- Negligible brem losses at LHCb
- **Muon stations occupancy much lower than ECAL**

Why $b \to s\ell^+\ell^-$ decays?

Full theory



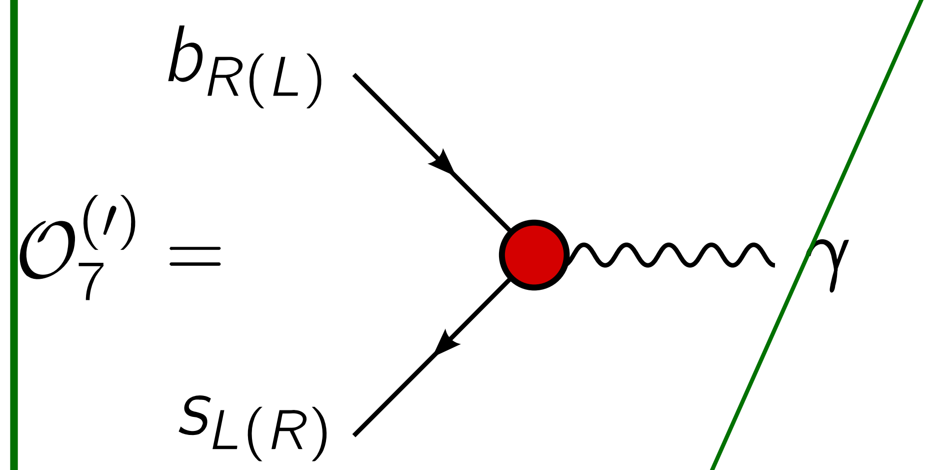
V-A (EW penguin)



$\mathcal{O}_9^{(\prime)} = (\bar{s}\gamma_\mu P_{\mathrm{L(R)}} b)(\bar{\ell}\gamma^\mu \ell)$

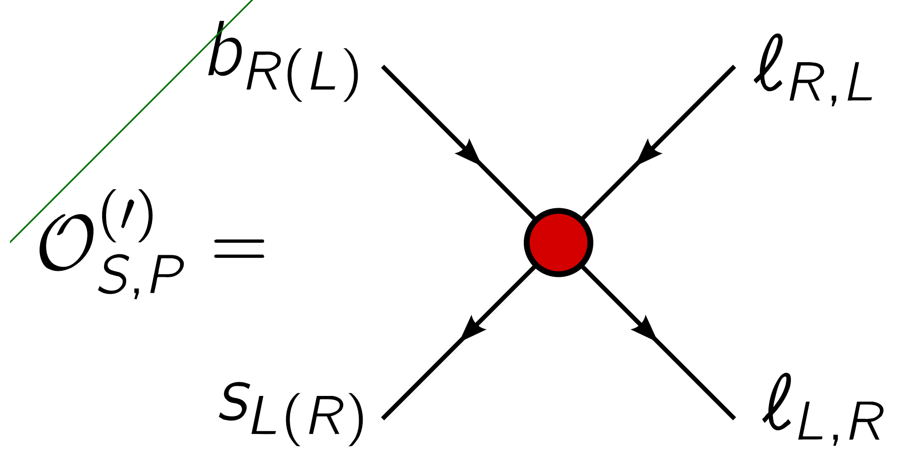
$\mathcal{O}_{10}^{(\prime)} = (\bar{s}\gamma_\mu P_{\mathrm{L(R)}} b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$

dipole (e.m. penguin)



$\mathcal{O}_7^{(\prime)} = \frac{m_b}{e}(\bar{s}\sigma_{\mu\nu} P_{\mathrm{R(L)}} b) F^{\mu\nu}$

scalar, pseudo-scalar



$\mathcal{O}_{\mathrm{S}}^{(\prime)} = \bar{s} P_{R(L)} b\, \bar{\ell}\ell$

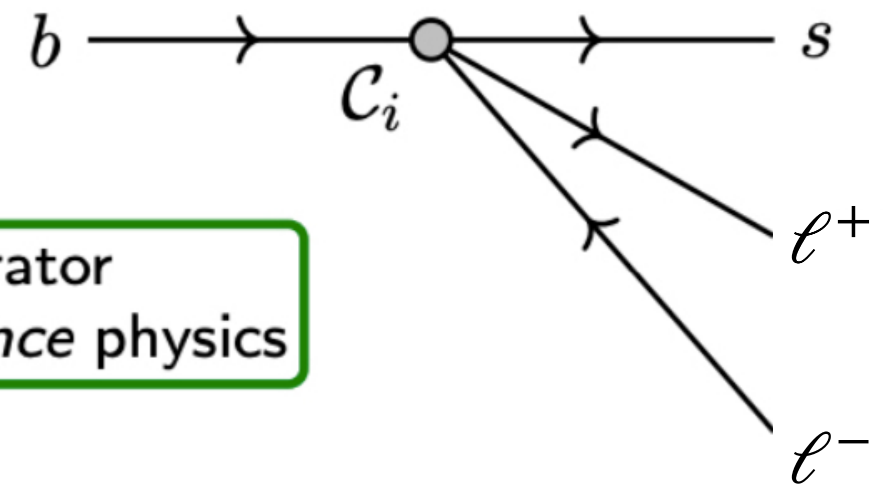
$\mathcal{O}_{\mathrm{P}}^{(\prime)} = \bar{s} P_{R(L)} b\, \bar{\ell}\gamma_5\ell$

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{\text{tb}} V_{\text{ts}}^* \sum_i \mathcal{C}_i \mathcal{O}_i$$

$\mathcal{C}_i$: Effective coupling "Wilson-coefficient" *short distance* physics

$\mathcal{O}_i$: Local operator *long distance* physics

Effective description



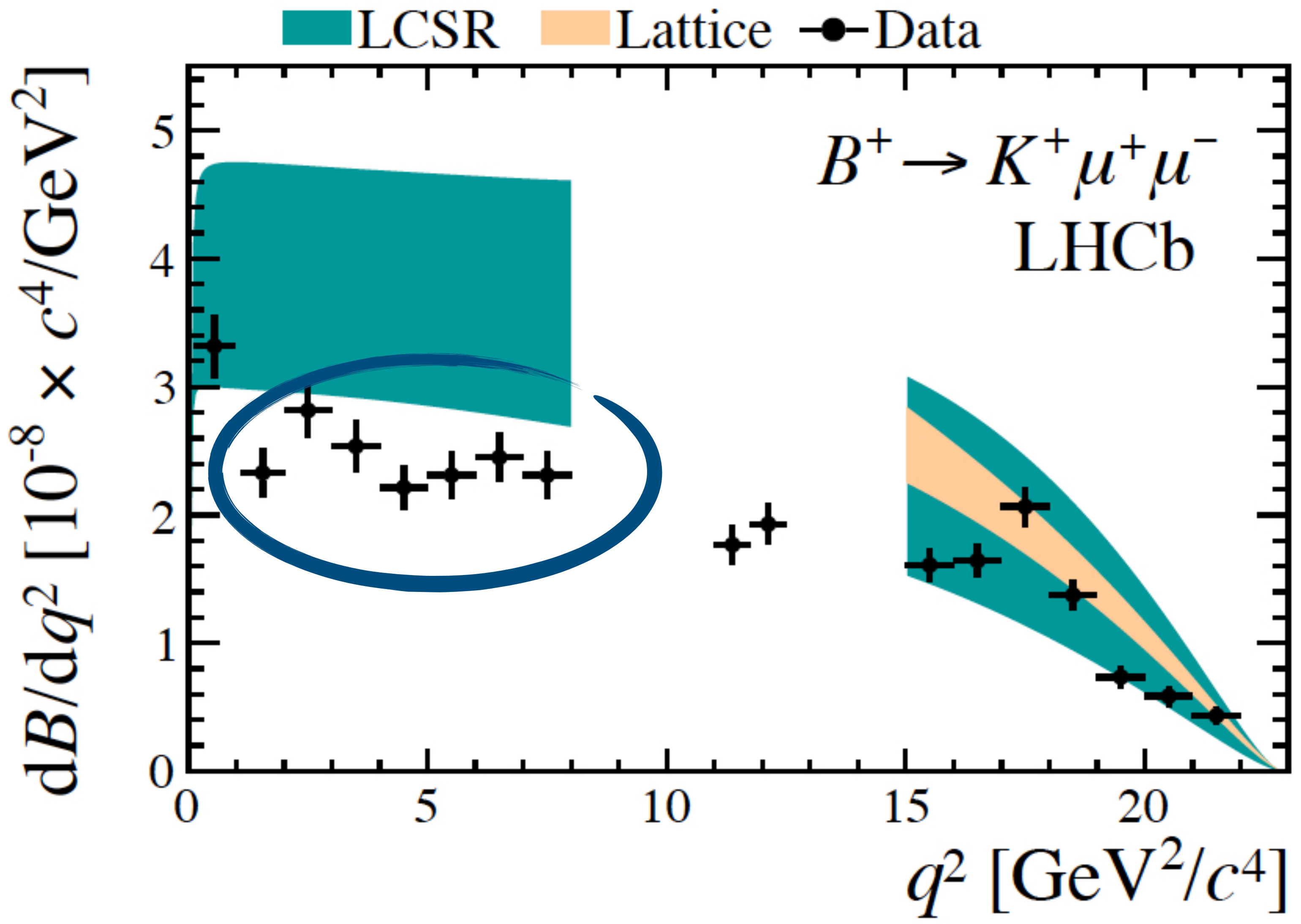
$$\Delta\mathcal{H}_{\text{NP}} = \frac{\mathcal{C}}{\Lambda^2_{\text{NP}}} \mathcal{O}_i$$

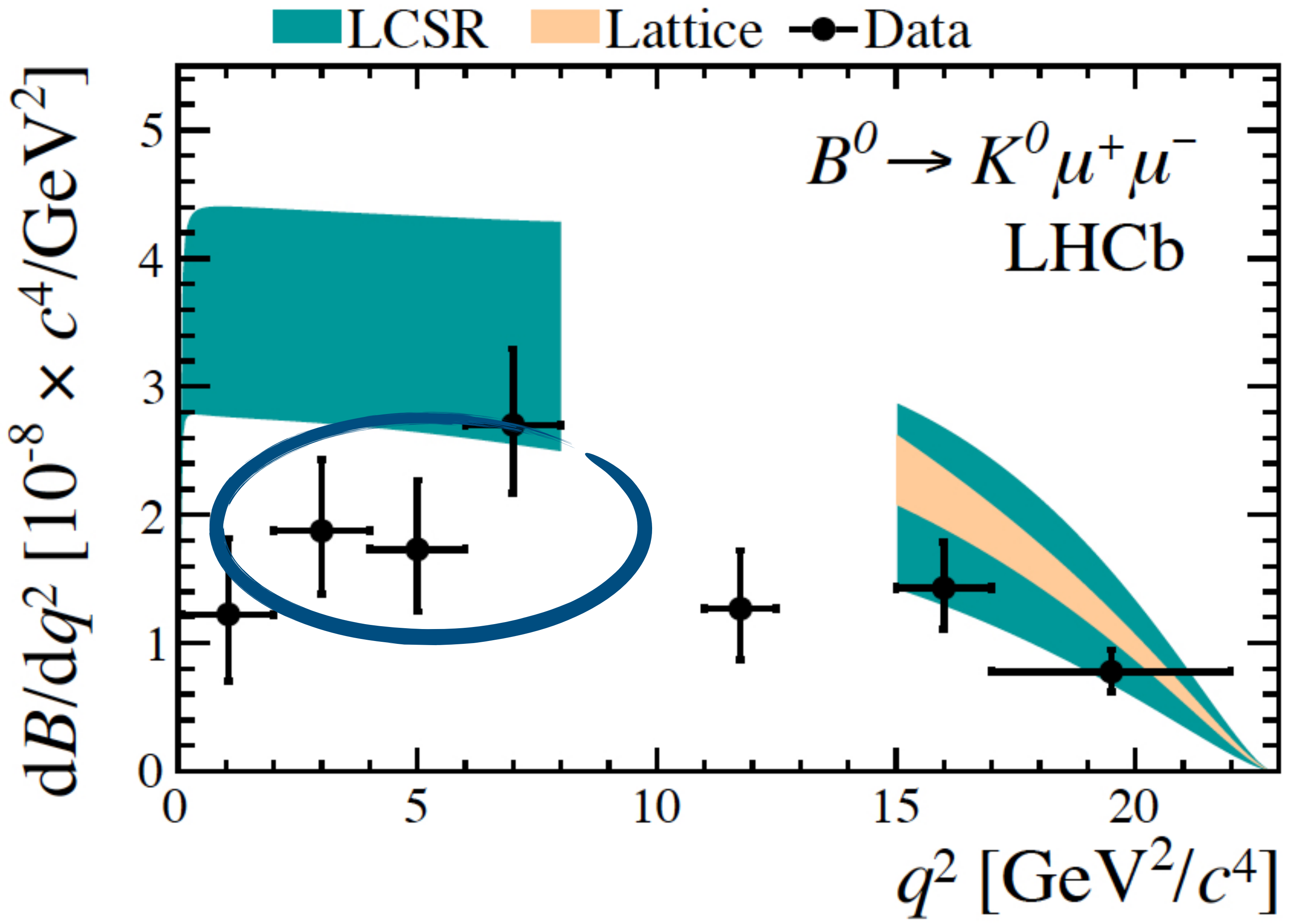
$\mathcal{C}$: Flavour-violating coupling

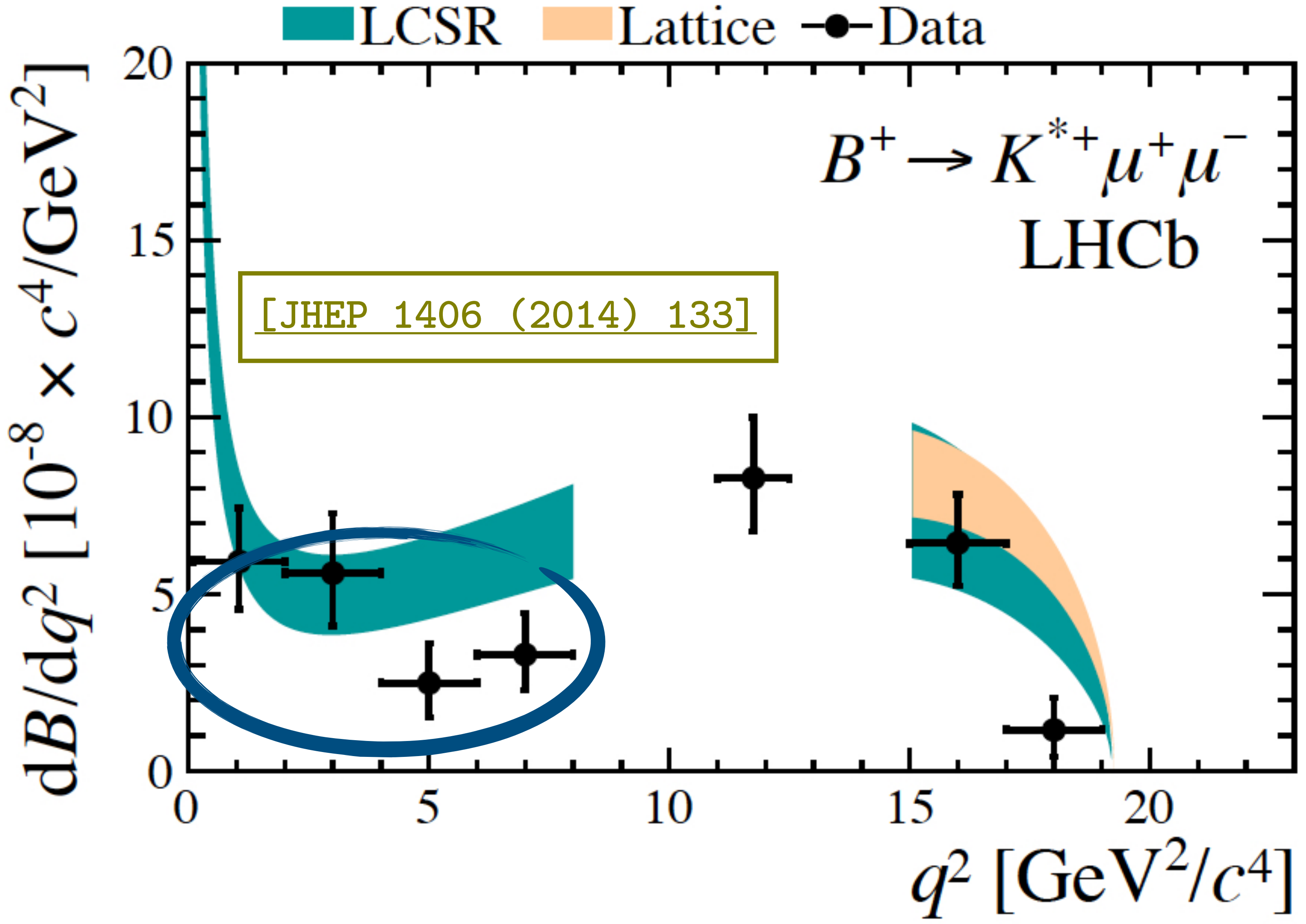
Λ^2_{NP}: NP scale

Coupling	$b \to s\gamma$	$B \to \mu\mu$	$b \to s\ell\ell$
$\mathcal{C}_7^{(\prime)}$	✓		✓
$\mathcal{C}_9^{(\prime)}$			✓
$\mathcal{C}_{10}^{(\prime)}$		✓	✓
$\mathcal{C}_S^{(\prime)}$		✓	
$\mathcal{C}_P^{(\prime)}$		✓	

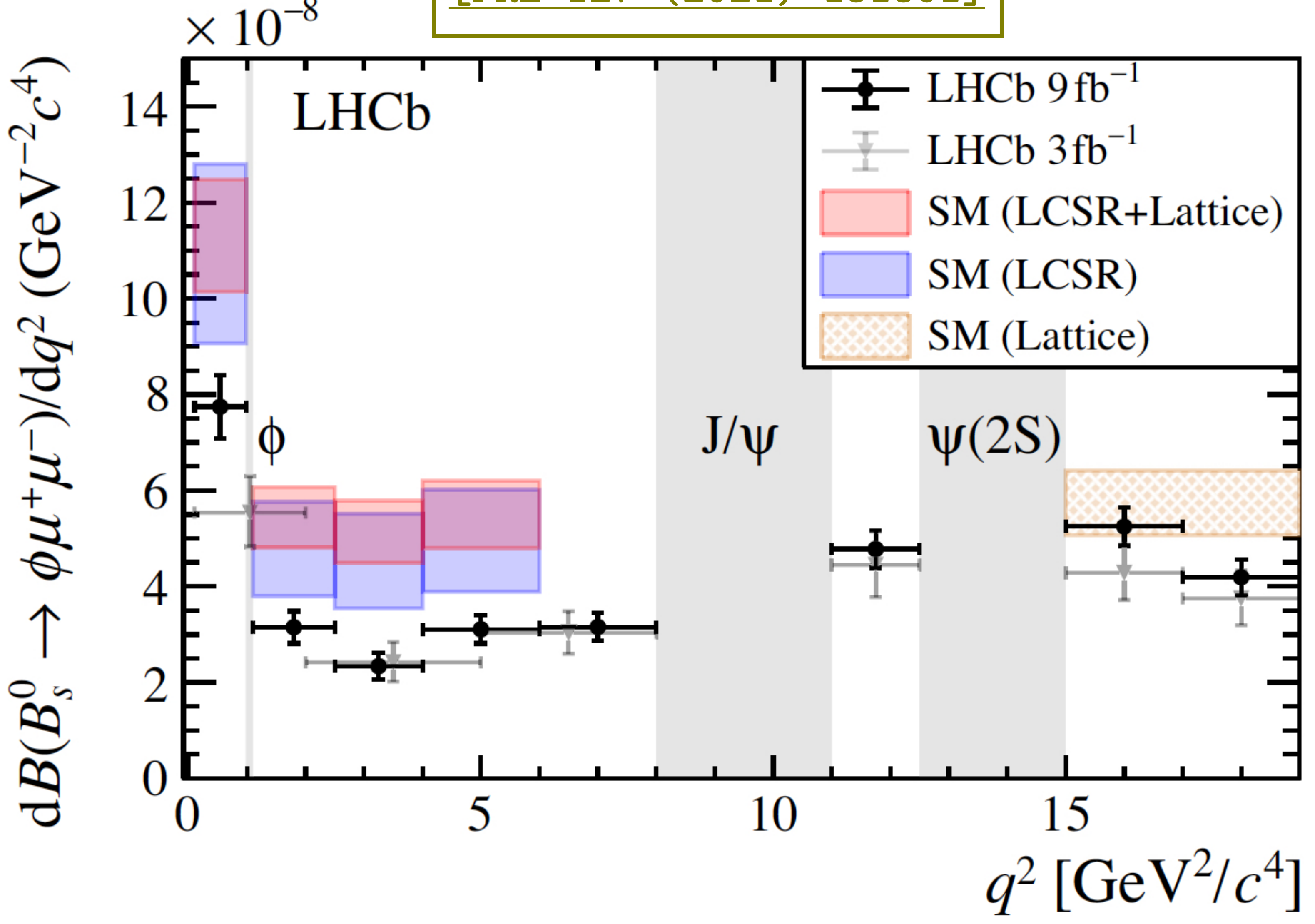
$b \to s\mu^+\mu^-$ differential decay rates







[PRL 127 (2021) 151801]



- SM predictions heavily affected by hadronic form factor uncertainties $\sigma_{th} \sim \mathcal{O}$(20-30%)
- dB/dq^2 in exclusive $b \to s\mu^+\mu^-$ seems to undershoot SM

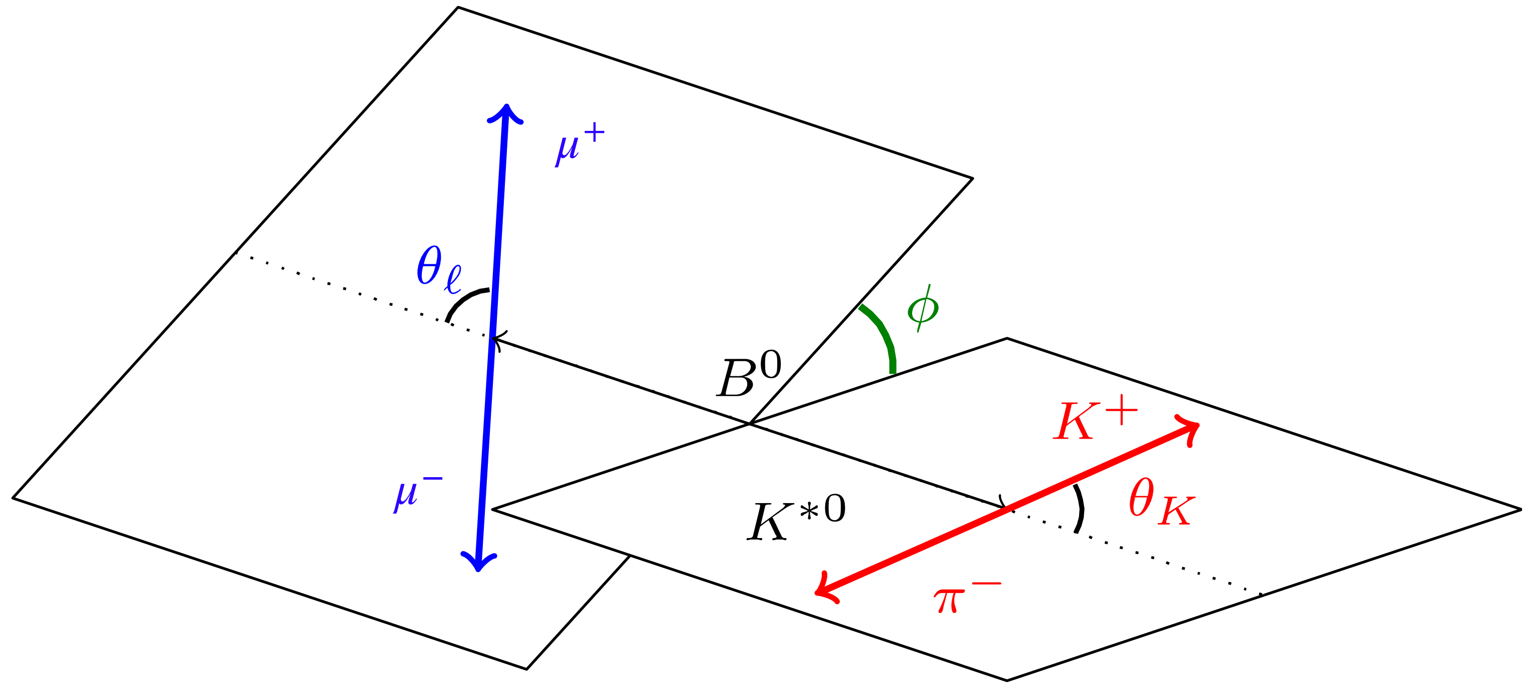
Anomaly or a common issue with form factors from SM?

Flavor anomalies in $b \to s\ell^+\ell^-$: angular $b \to s\mu^+\mu^-$

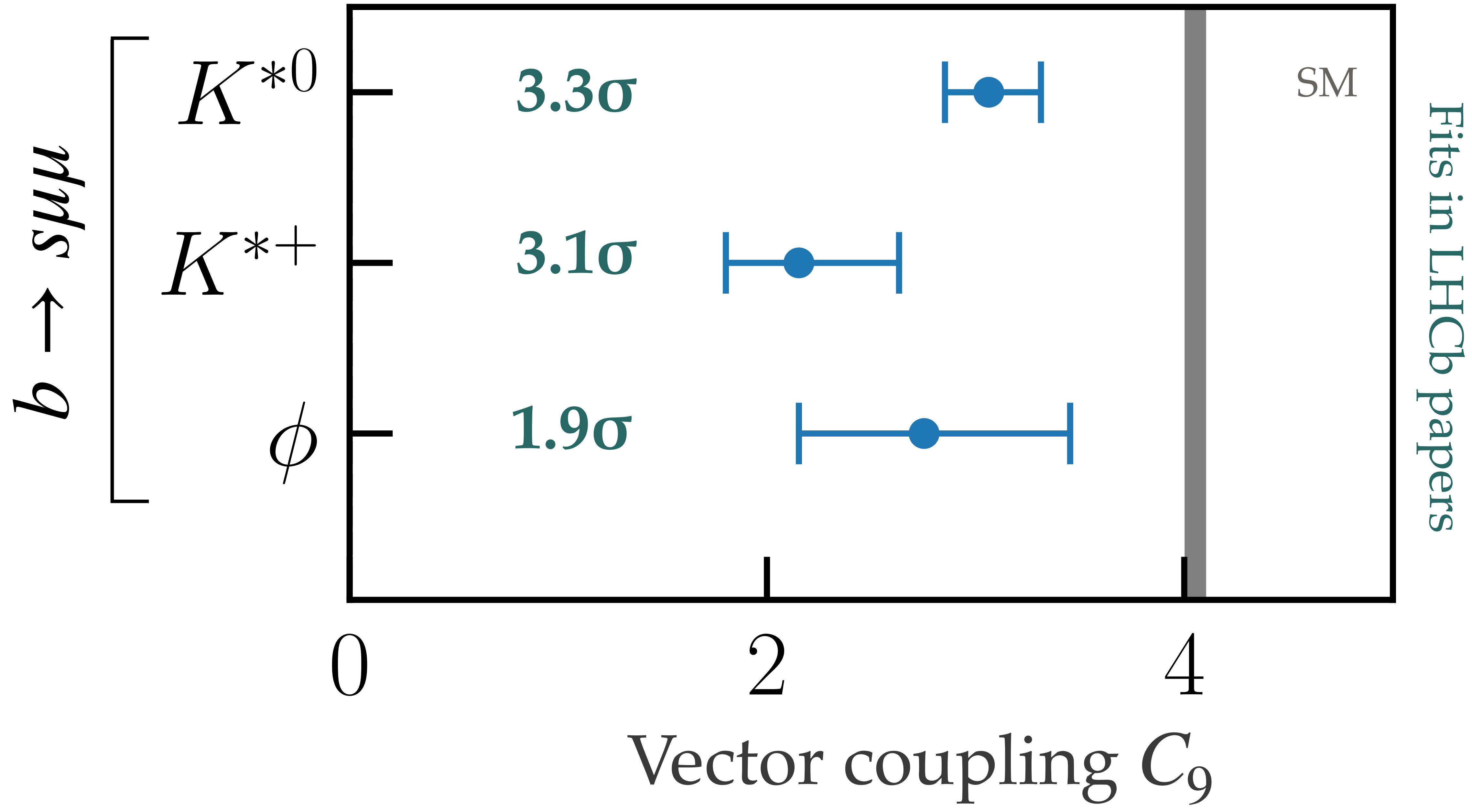
- **$B \to V\mu^+\mu^-$: vector in final state has rich kinematic structure → characterise NP**
- Described by 3 angles and q^2

$$\frac{\mathrm{d}^4\bar{\Gamma}[B^0 \to K^{*0}\mu^+\mu^-]}{\mathrm{d}q^2\,\mathrm{d}\vec{\Omega}} = \frac{9}{32\pi}\sum_i \bar{I}_i(q^2) f_i(\vec{\Omega})$$

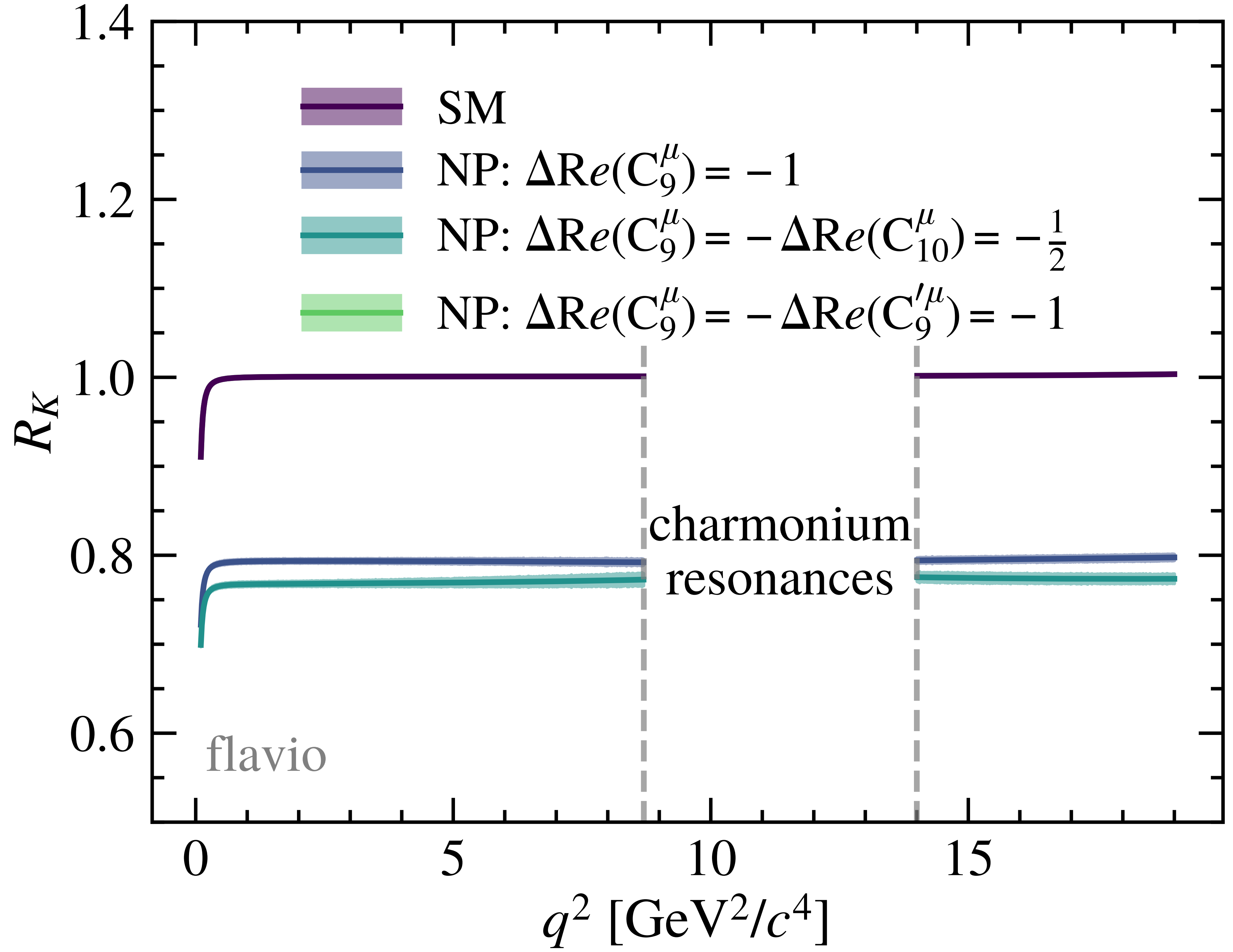
Wilson Coefficients   Angular moments

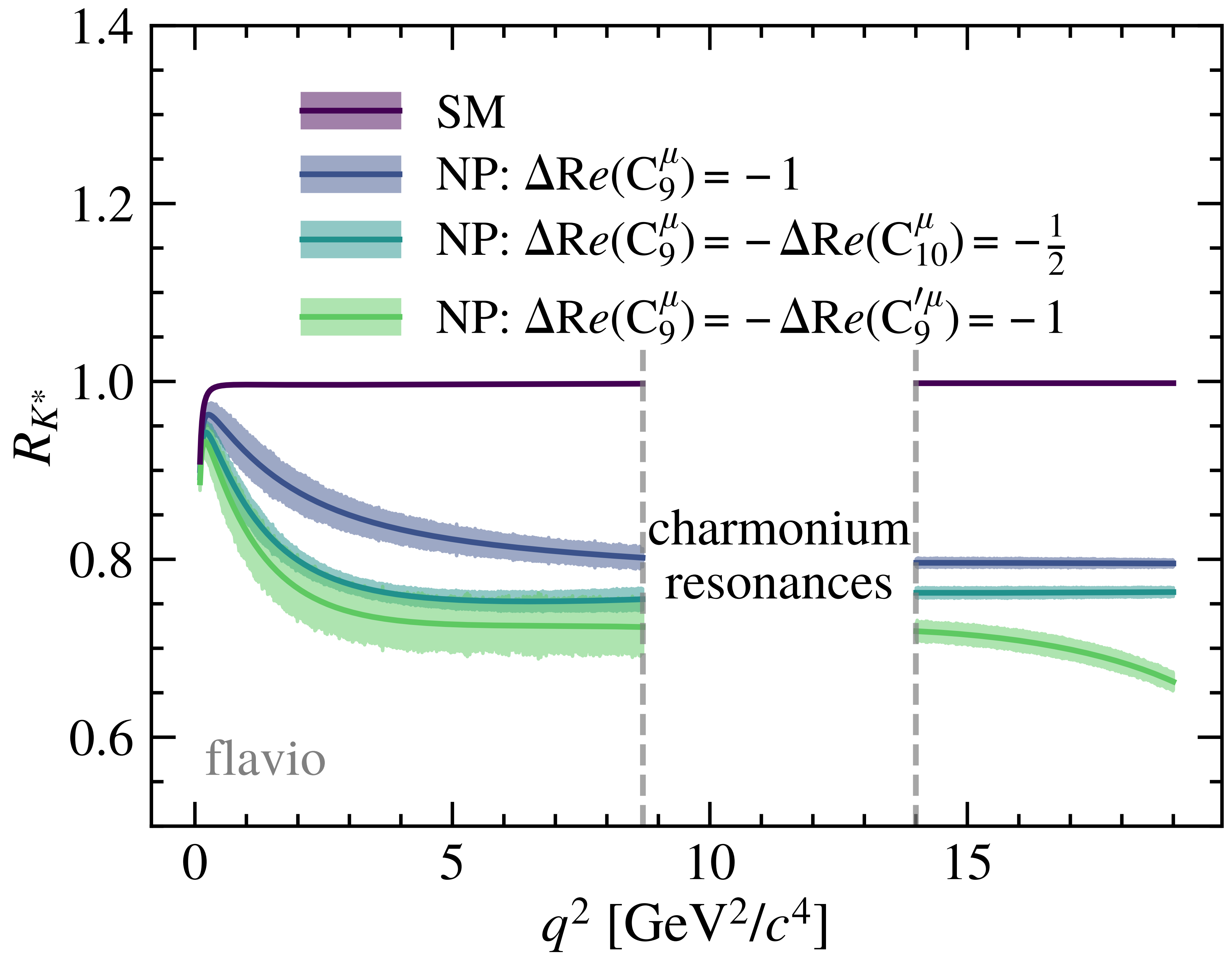


- Recent results (LHCb) ones:
  - $B^0 \to K^{*0}\mu^+\mu^-$ with 6 fb^{-1} (~ 4600 evts .) [PRL 125(2020)011802]
  - $B^+ \to K^{*+}\mu^+\mu^-$ with 9 fb^{-1} (~ 700 evts .) [PRL 126(2021)161802]
  - $B_s \to \phi\mu^+\mu^-$ with 9 fb^{-1}(~ 1900 evts .) [JHEP11(2021)043]
- Intriguing coherent and consistent pattern
  - However, charm-loops can mimic shift in C_9



BSM scenarios





Standard Model : only lepton mass differences

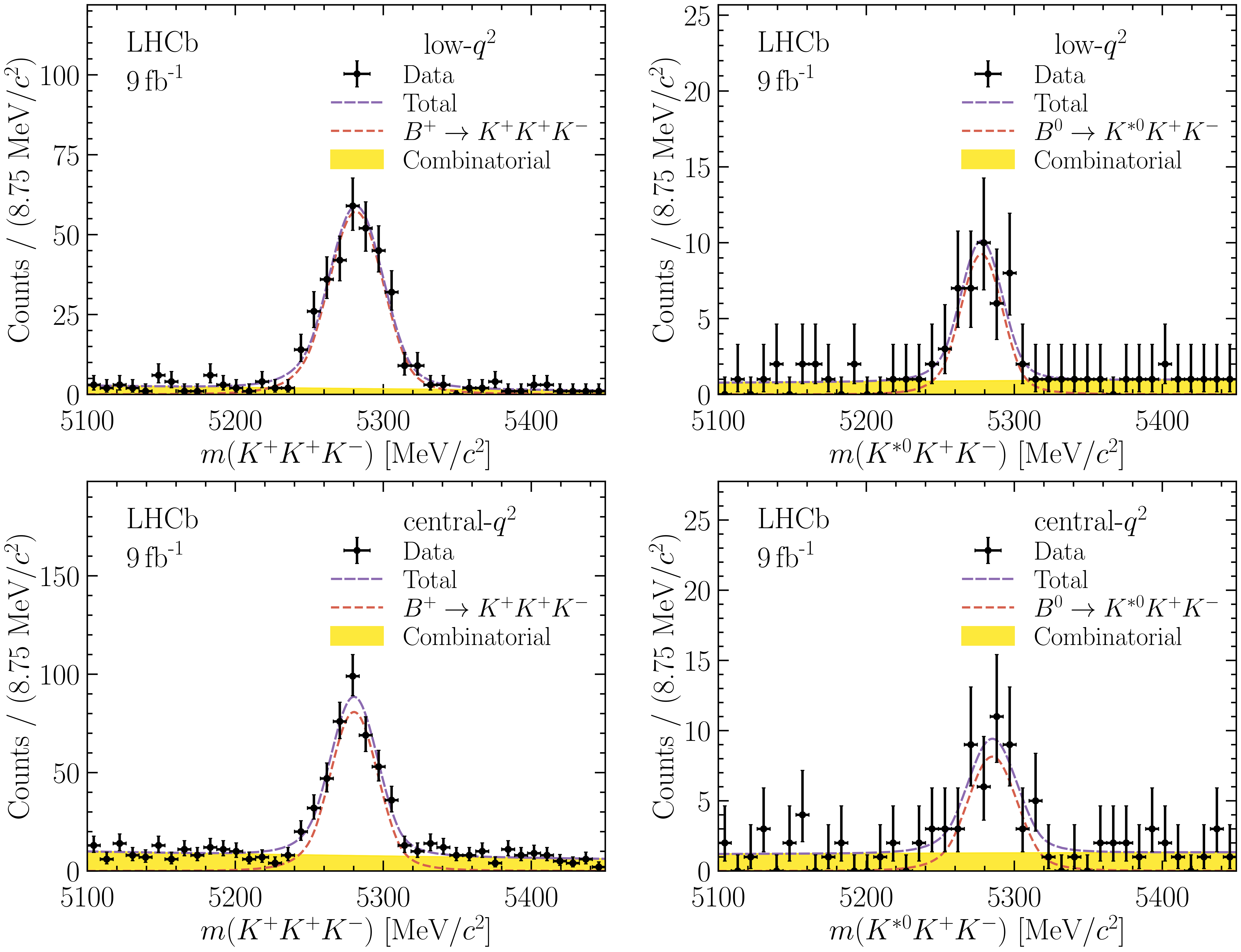
NP in muon vector coupling only

NP in muon vector and axial coupling, e.g. LQ

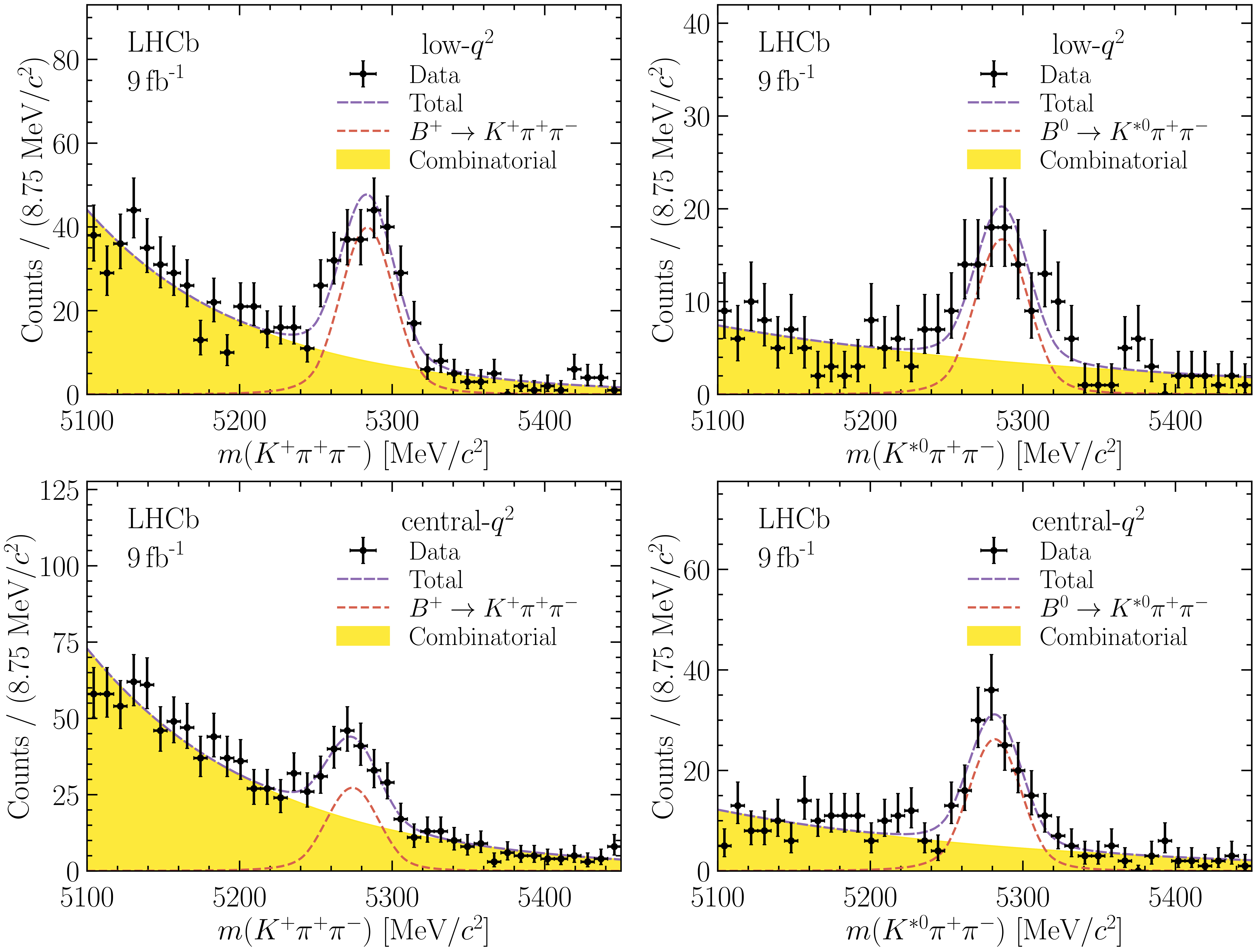
NP in muon left and right handed vector coupling

Scenarios preferred by global fits

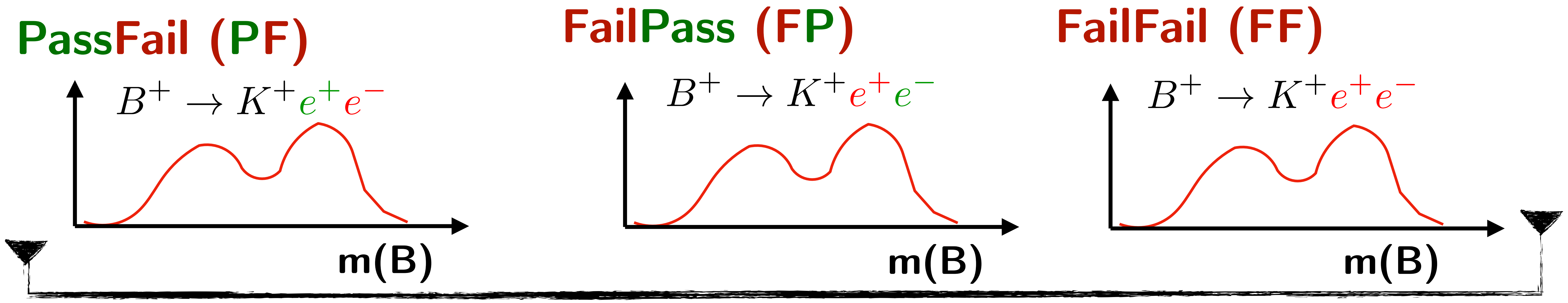
K^+K^- double mis-ID in '*control*' region



$\pi^+\pi^-$ double mis-ID in '*control*' region



Pass-fail method for electron misidentified backgrounds



- ✦ Data with inverted PID cuts is enhanced in misID content

$$N(PF) : N(B^+ \to K^+ e^+ h^-) + N(B^+ \to K^+ h^+ h'^-) + N(B^+ \to K^+ e^+ e^-) + N(B^+ \to K^+ J/\psi(\to e^+ e^-))$$

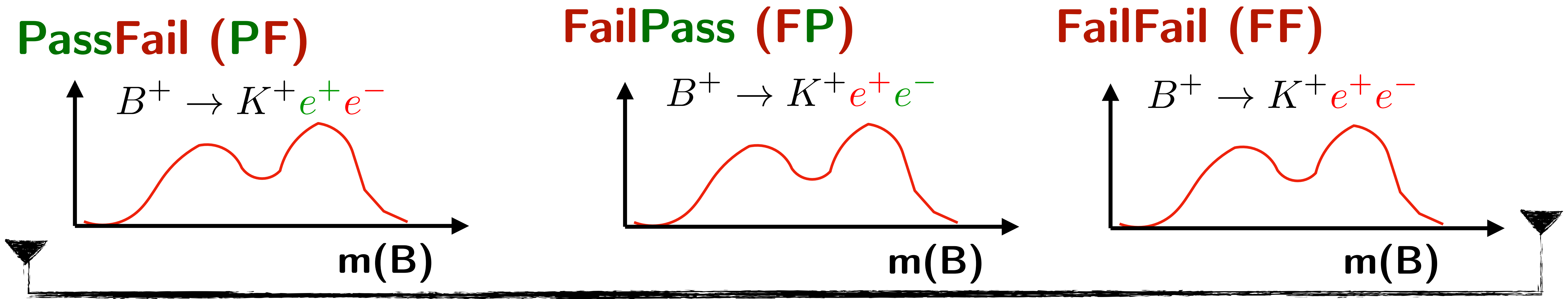
$$N(FP) : N(B^+ \to K^+ e^- h^+) + N(B^+ \to K^+ h^+ h'^-) + N(B^+ \to K^+ e^+ e^-) + N(B^+ \to K^+ J/\psi(\to e^+ e^-))$$

$$N(FF) : N(B^+ \to K^+ h^+ h'^-)$$

Residual double mis-id

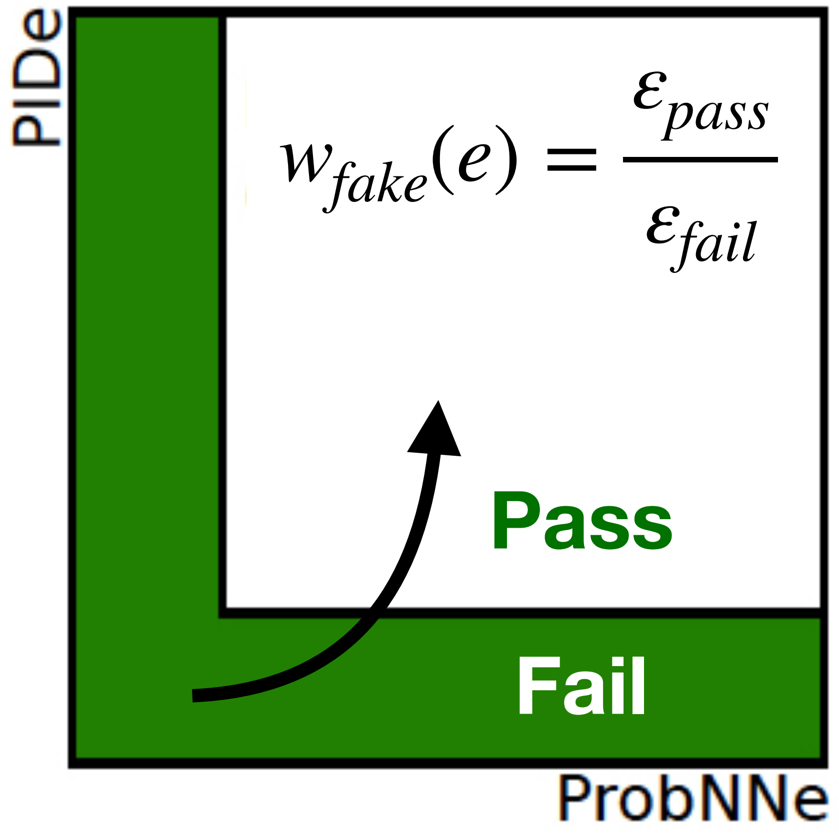
Residual signal contribution - subtract using simulation

Pass-fail method for electron misidentified backgrounds

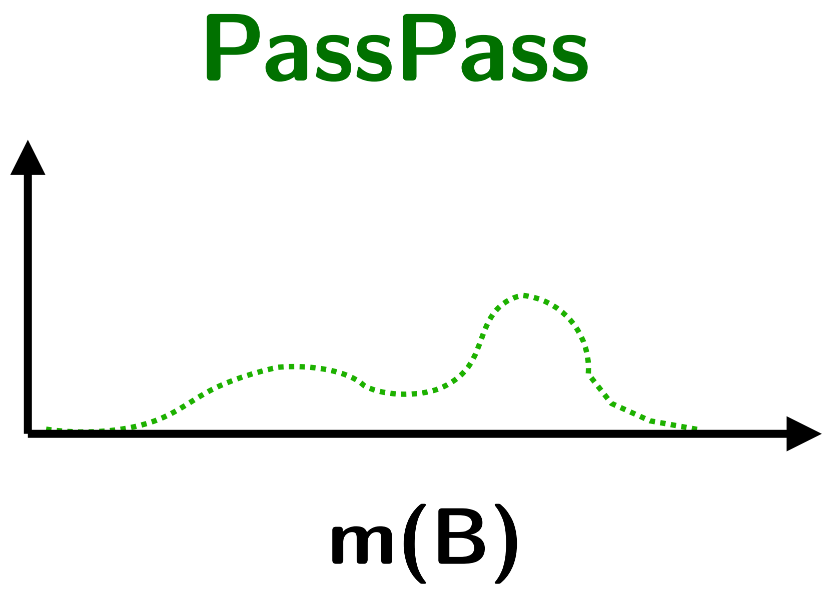


- Data with inverted PID cuts is enhanced in misID content

Transfer Function (From π/K calibration data samples)



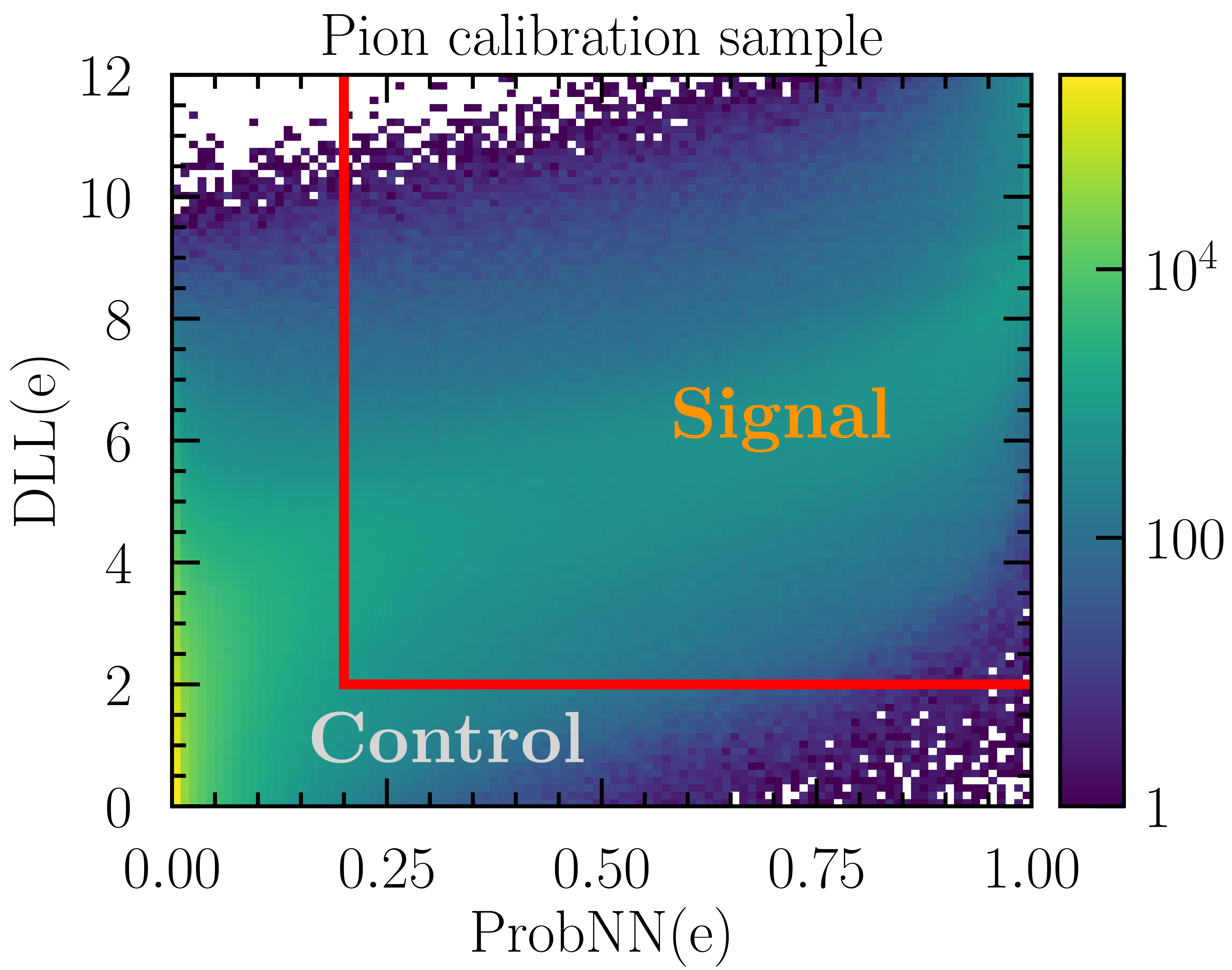
- Transfer from fail to pass region evaluated in bins of p_T and η



Shape + Prediction

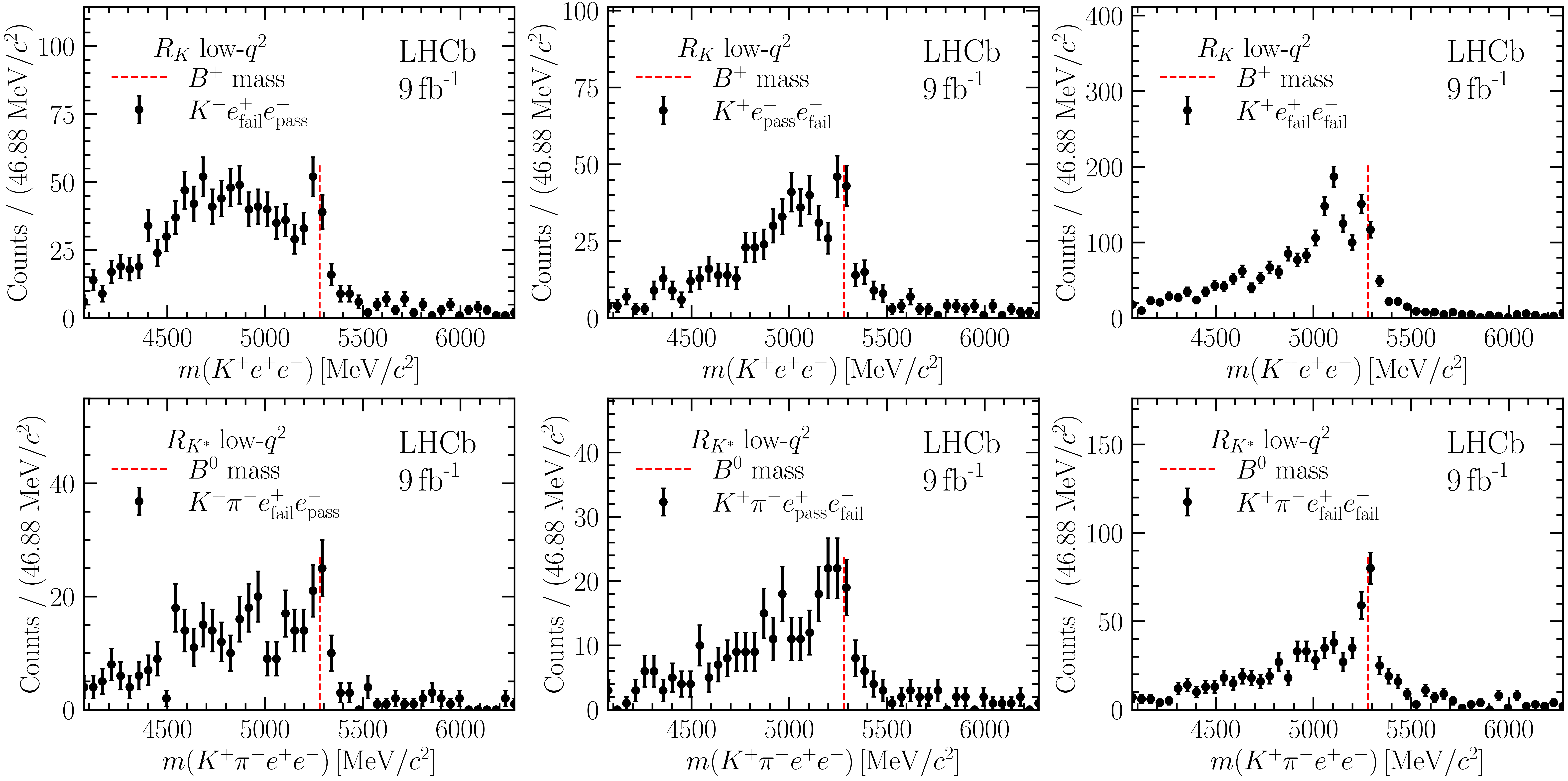
$$N(FP) + N(PF) - N(FF) = N(B^+ \to K^+ e^+ h^-) + N(B^+ \to K^+ h^+ e^-) + N(B^+ \to K^+ h^+ h'^-)$$

Choice of fail region

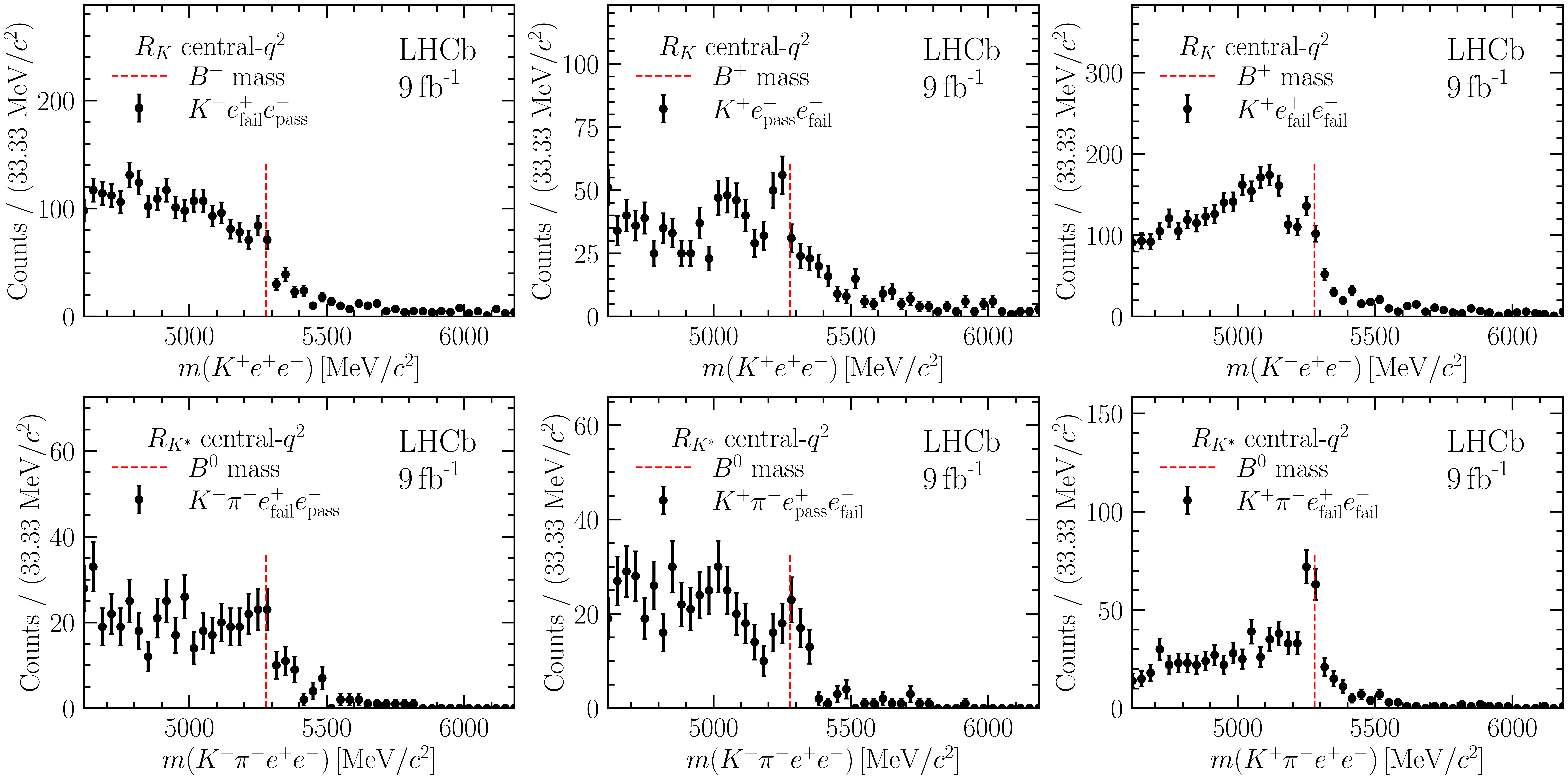


- Control region next to signal region
- Choose available region (`DLL(e) < 2 || ProbNNe < 0.2`) while `DLL(e)>0`.
- Other choices for a systematic uncertainty

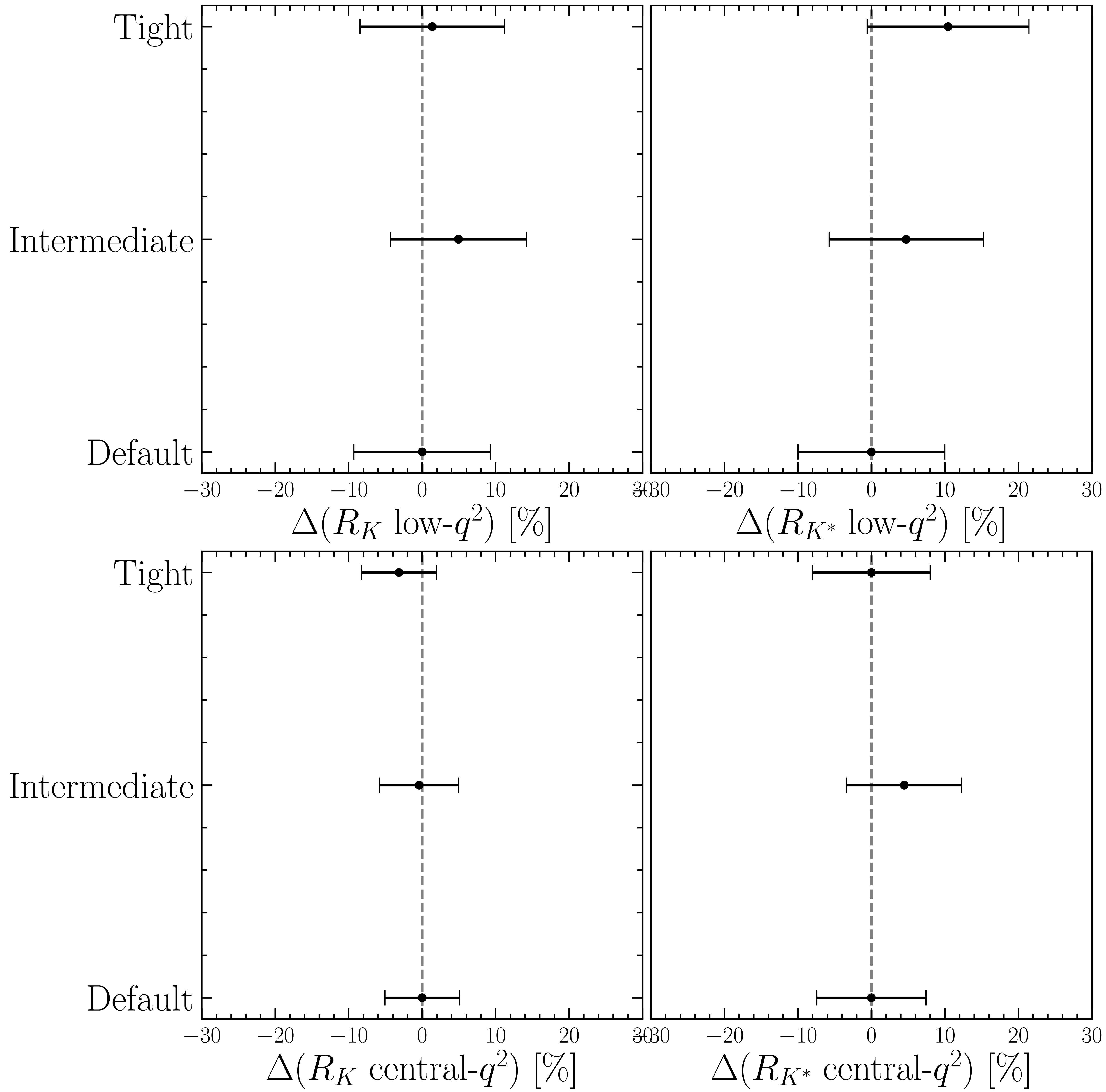
Data fully selected in "*control*" regions ($B^+ \to K^+e^+e^-$) [before weights]



Data fully selected in "*control*" regions ($B^0 \to K^{*0}e^+e^-$) [before weights]



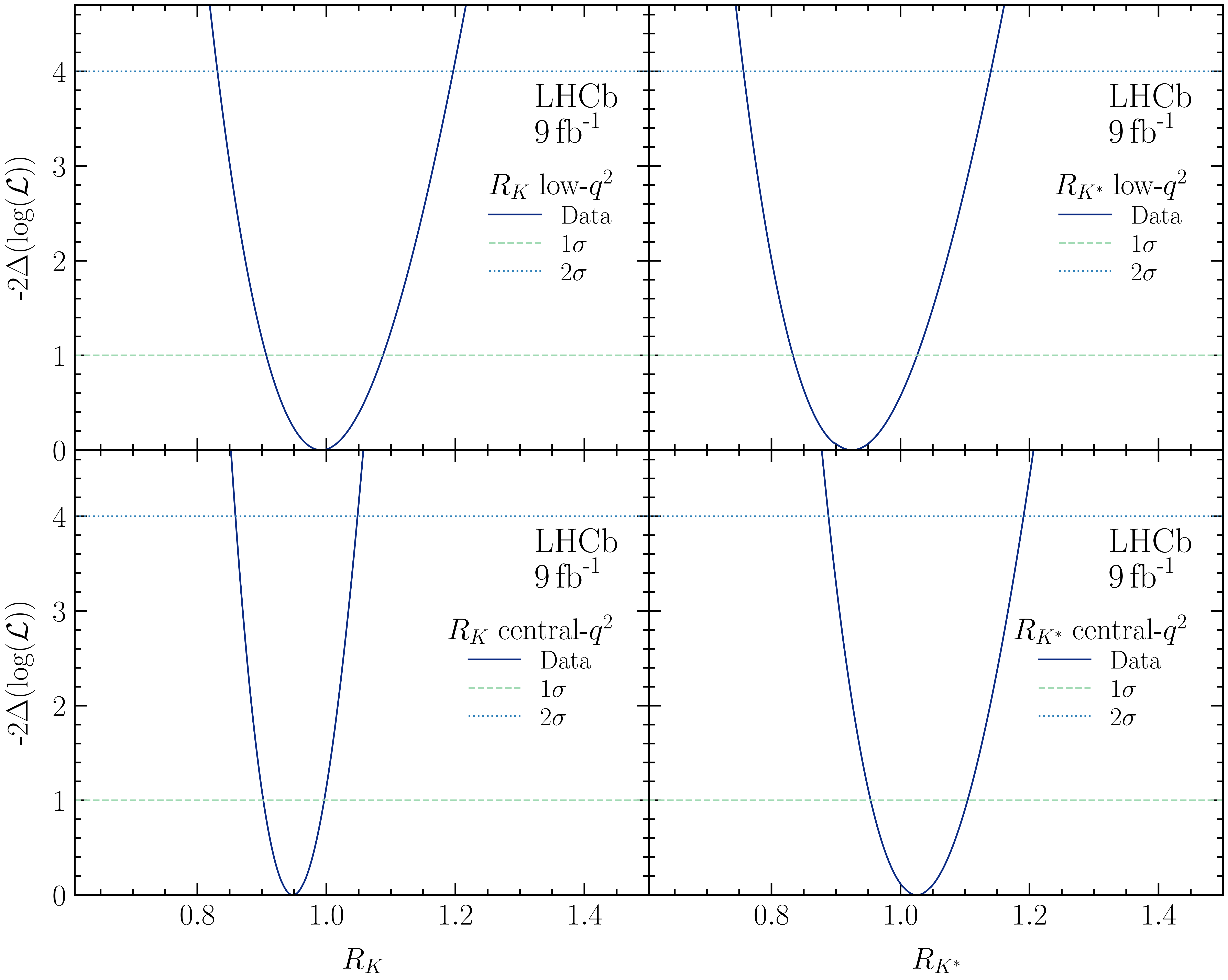
Results using misidentified background at different PID



- *Tight*
  - 80% misID suppression
  - 50-60% signal loss
- *Intermediate*
  - 50% misID suppression
  - 20-30% signal loss

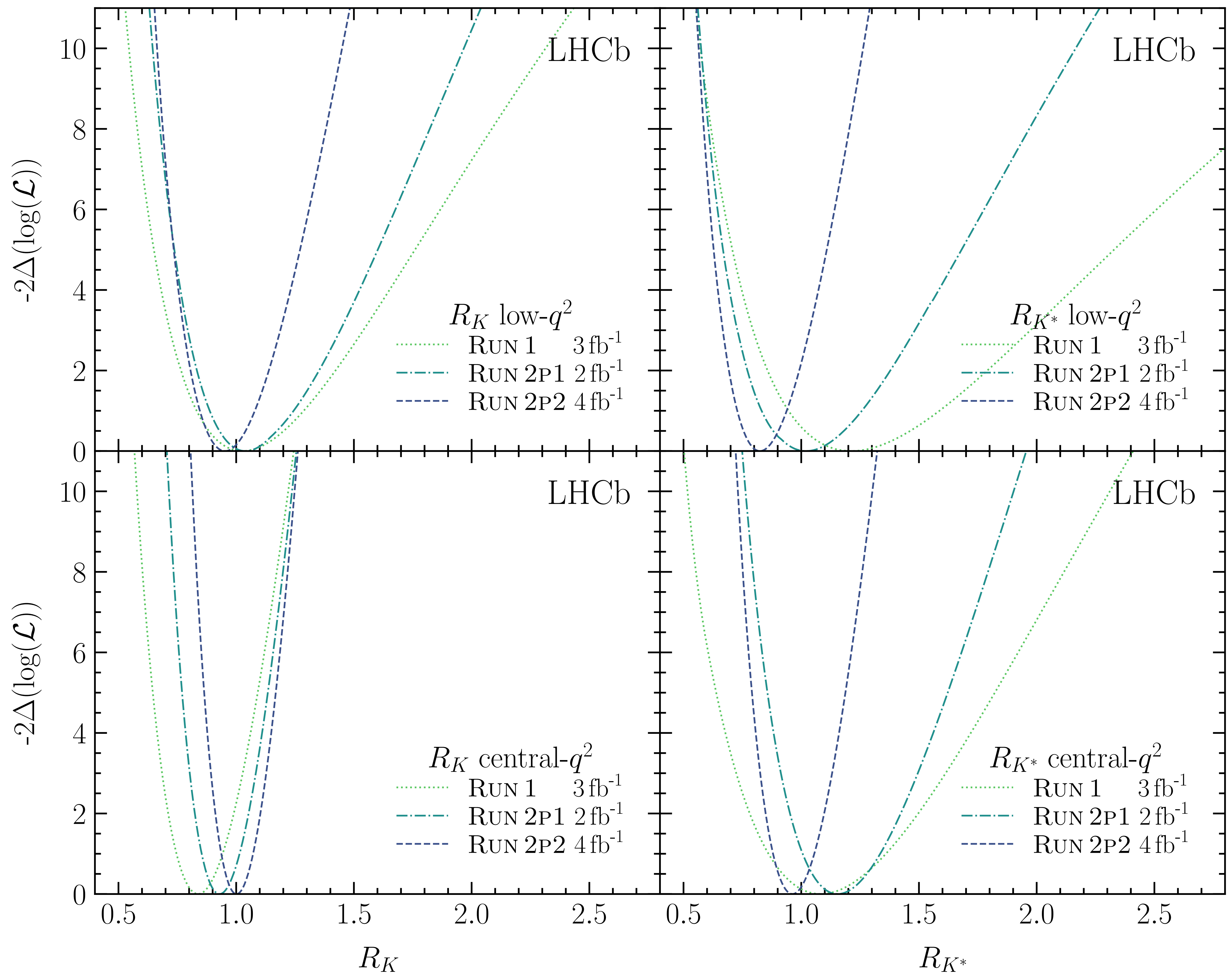
Misidentified background
included in fit model
at tighter working point
results are stable

Likelihood scans (include all systematics)

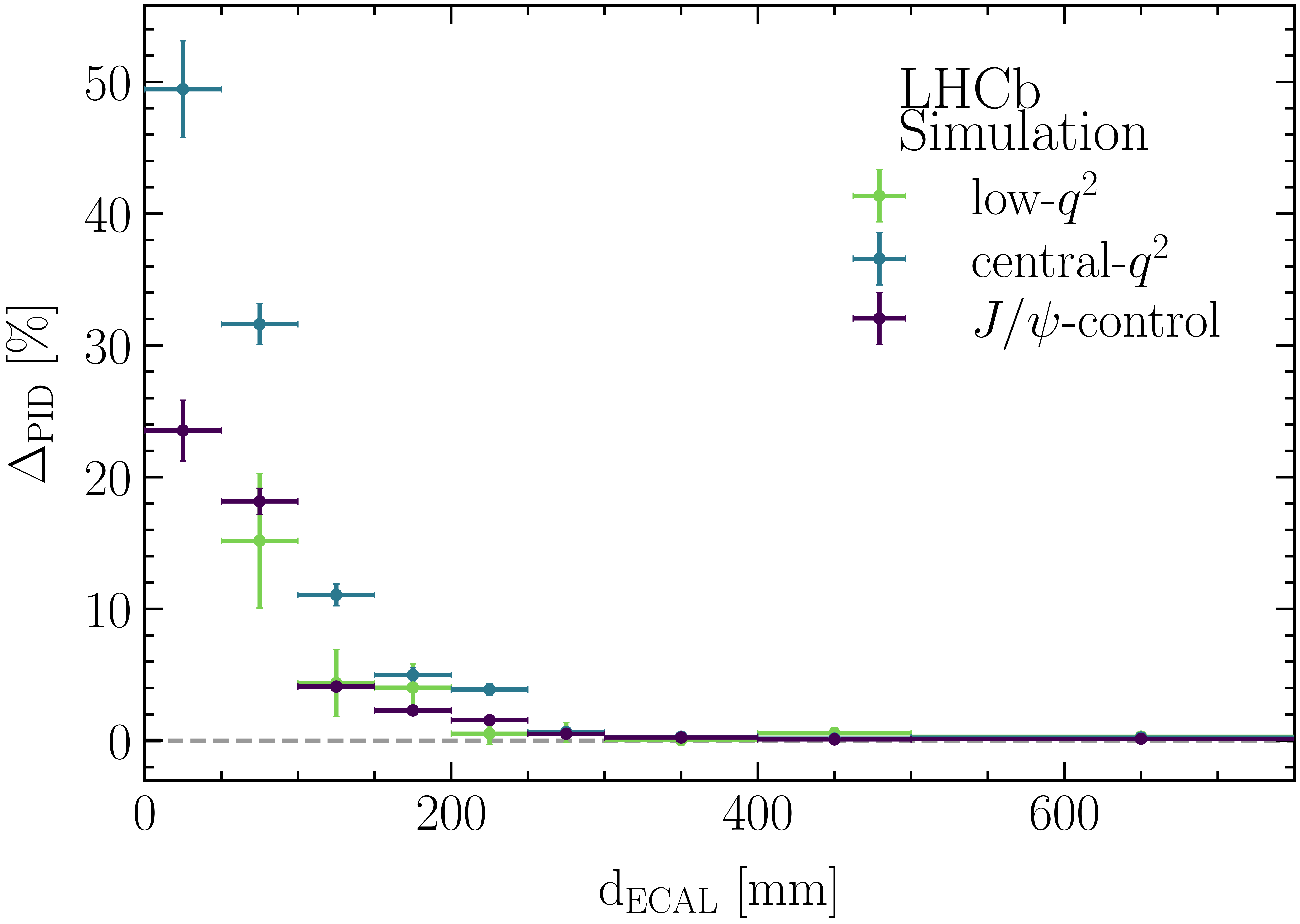


Likelihood scans (include all systematics) Run-Period split

LU observable	Run 1	Run 2p1	Run 2p2
R_K low-q^2	$1.027\ ^{+0.243\ +0.092}_{-0.180\ -0.073}$	$1.039\ ^{+0.203\ +0.027}_{-0.149\ -0.027}$	$0.953\ ^{+0.123\ +0.029}_{-0.104\ -0.026}$
R_{K^*} low-q^2	$1.212\ ^{+0.344\ +0.149}_{-0.240\ -0.114}$	$1.021\ ^{+0.234\ +0.036}_{-0.187\ -0.027}$	$0.825\ ^{+0.108\ +0.036}_{-0.091\ -0.031}$
R_K central-q^2	$0.839\ ^{+0.083\ +0.062}_{-0.073\ -0.056}$	$0.929\ ^{+0.082\ +0.023}_{-0.073\ -0.020}$	$1.001\ ^{+0.066\ +0.024}_{-0.061\ -0.022}$
R_{K^*} central-q^2	$1.082\ ^{+0.214\ +0.176}_{-0.165\ -0.148}$	$1.154\ ^{+0.179\ +0.027}_{-0.147\ -0.023}$	$0.962\ ^{+0.091\ +0.020}_{-0.080\ -0.018}$
	$2011+2012$ $3\ \text{fb}^{-1}$	$2015+2016$ $2\ \text{fb}^{-1}$	$2017+2018$ $4\ \text{fb}^{-1}$

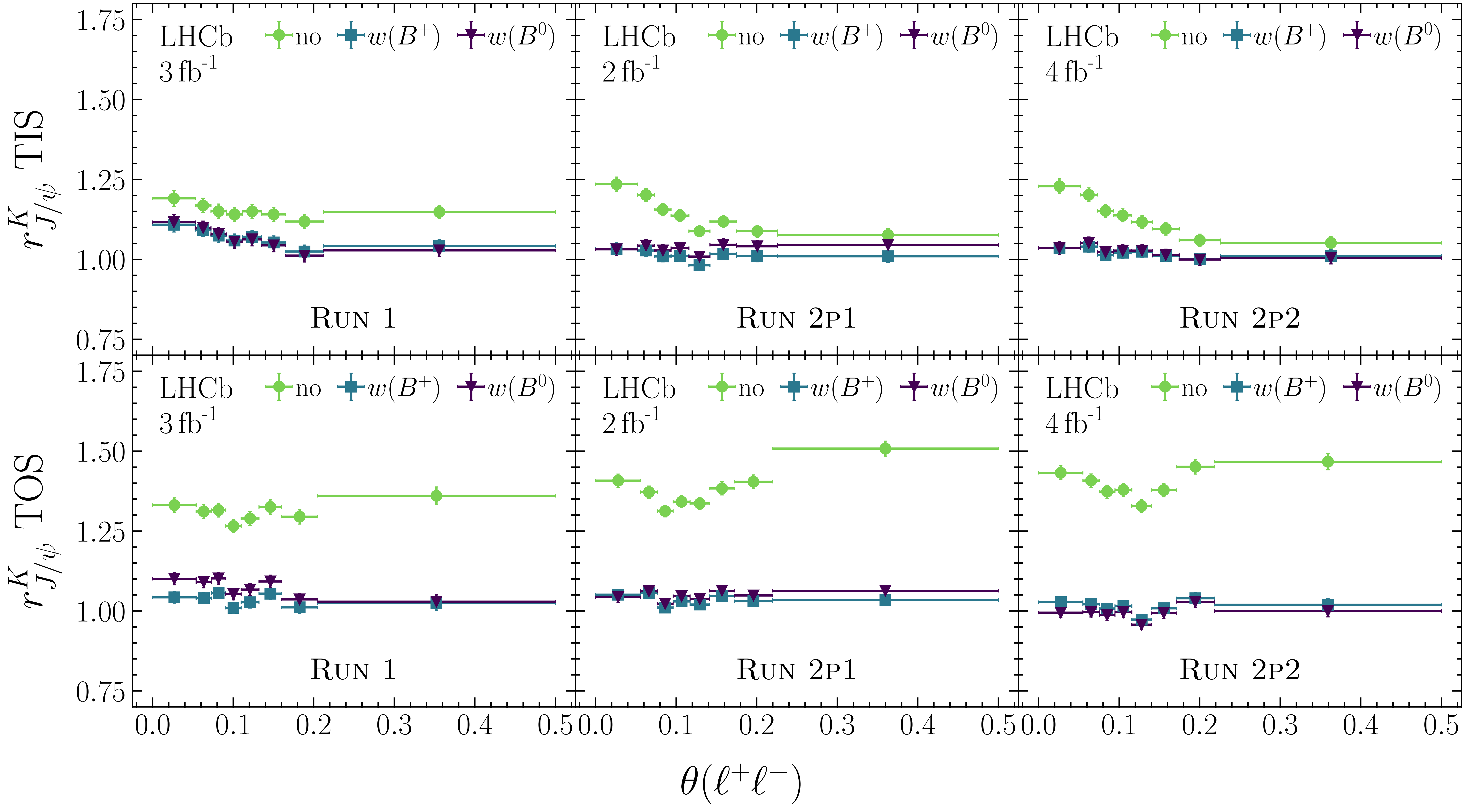


Electron PID factorisation

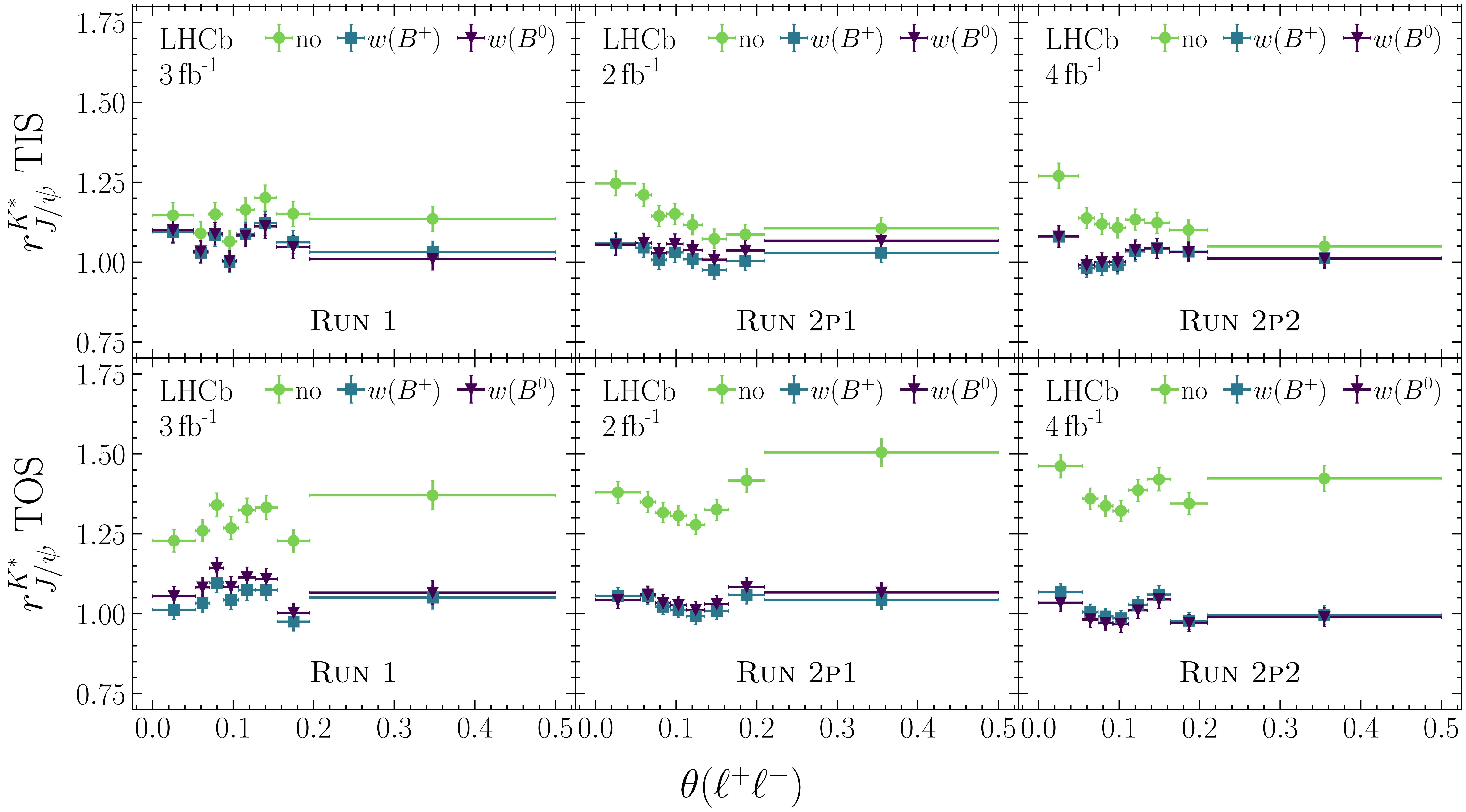


If electrons are close in ECAL,
Efficiencies of PID selection
do not factorise, additional selection
to prevent bias,
removing a tiny (few %)
amount of signal

Corrections and stability of $r^K_{J/\psi}$



Corrections and stability of $r^{K^*}_{J/\psi}$

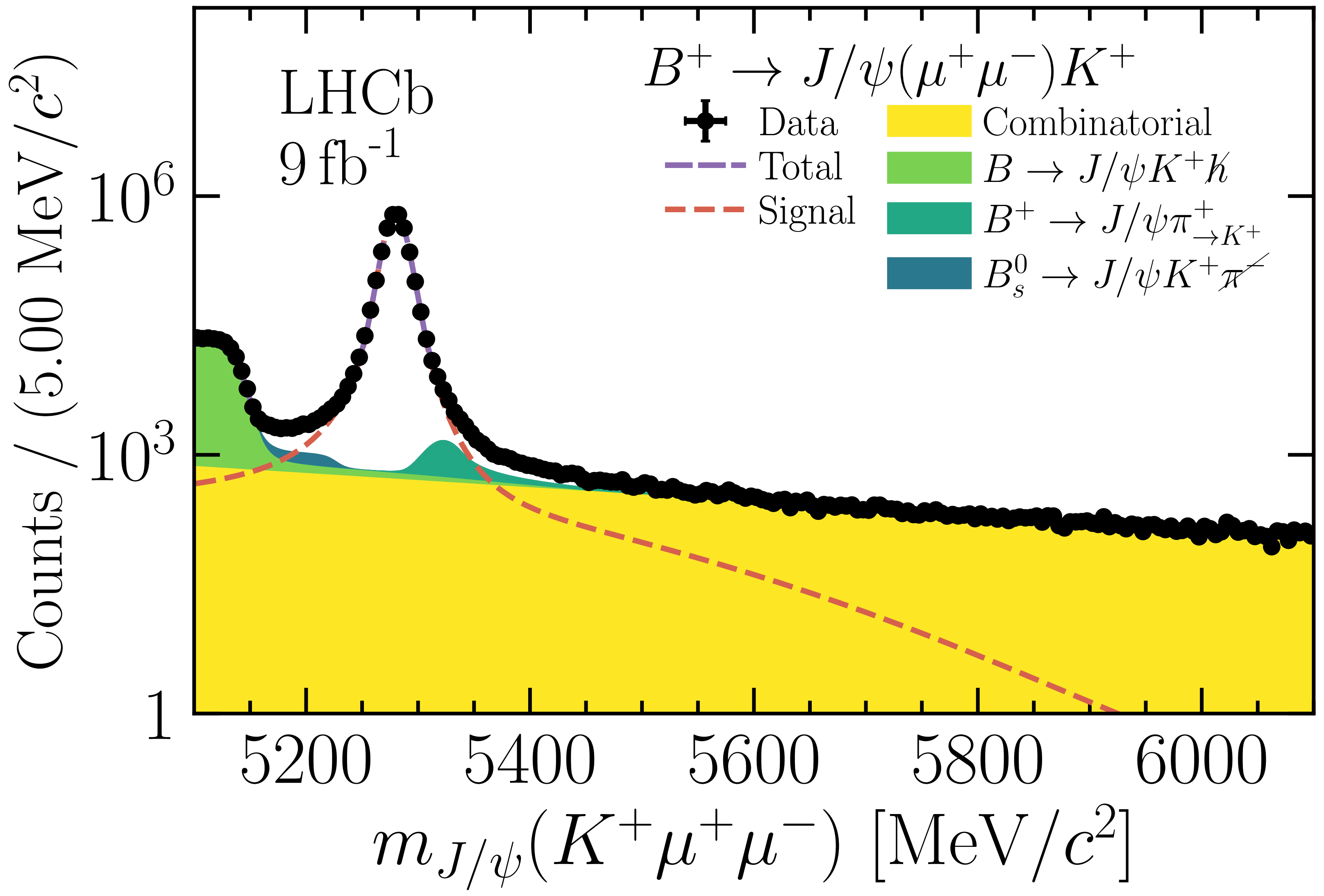


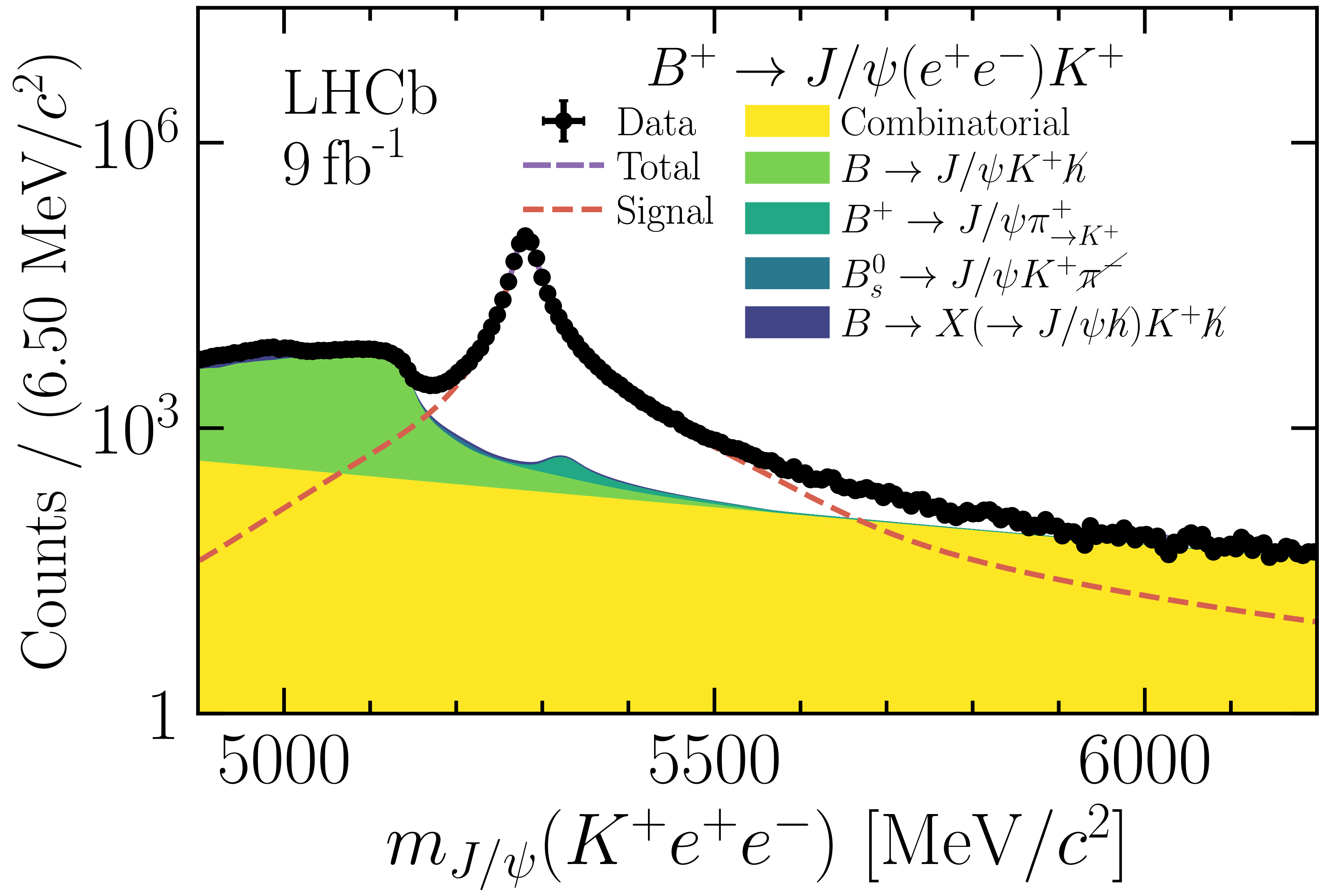
Cross-check resonant modes: mass fits

Partially reconstructed

$B_s \to J/\psi K^+ pi\!\!\!/$

Mis-ID $B^+ \to J/\psi \pi^+_{\to K^+}$





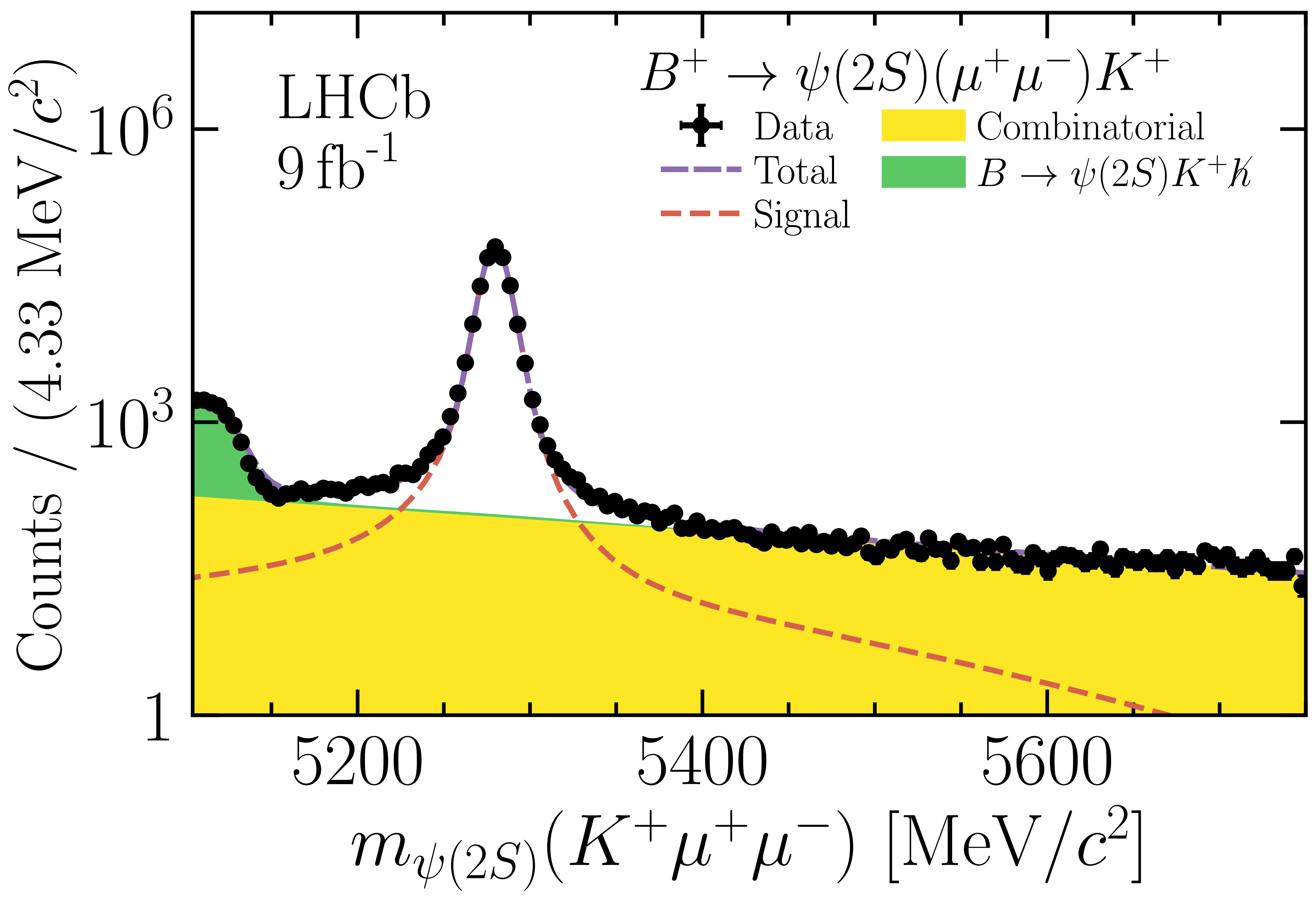
Partially reconstructed

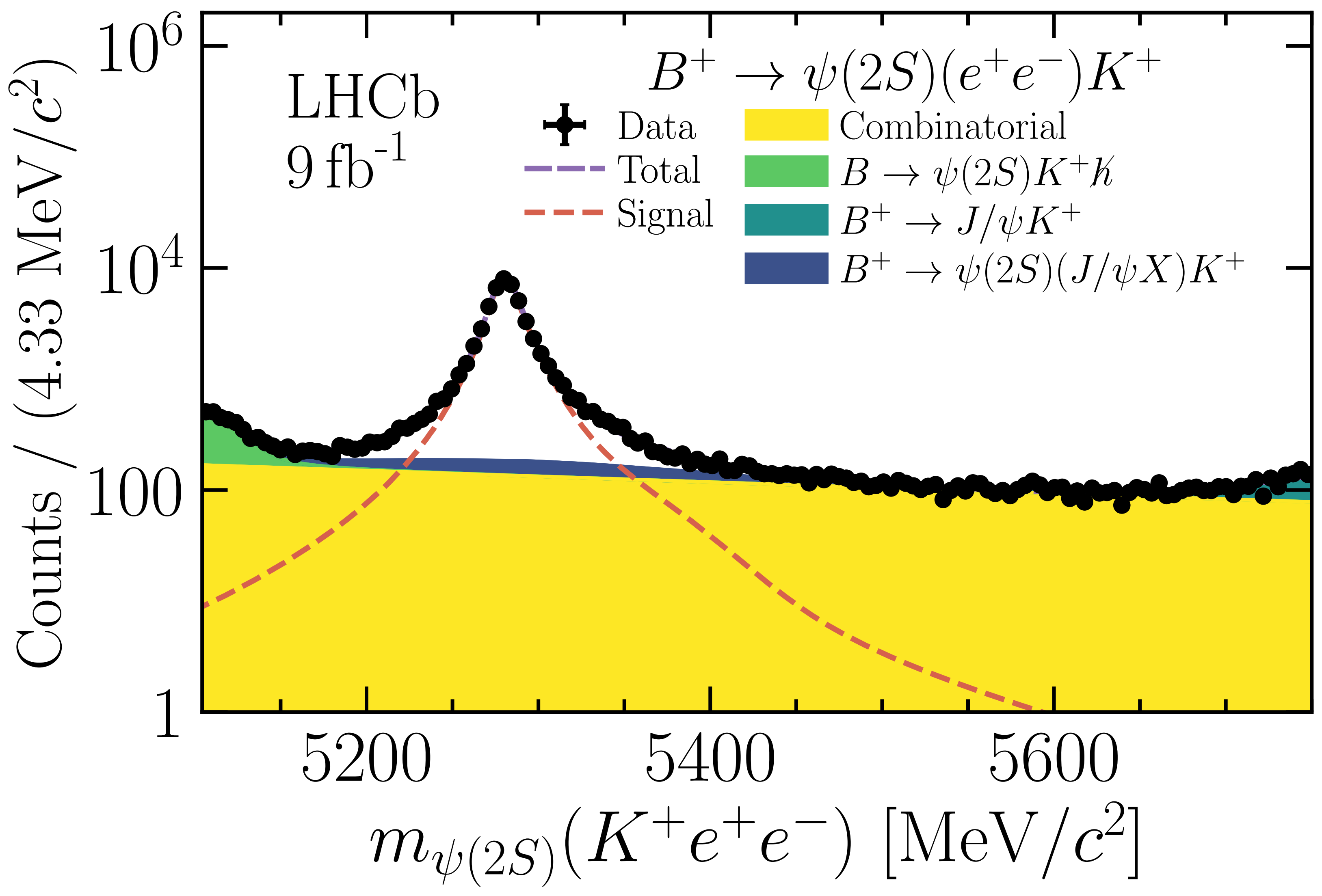
$B_s \to J/\psi K^+ pi\!\!\!/$

Mis-ID $B^+ \to J/\psi \pi^+_{\to K^+}$

Partially reconstructed (charmonia cascade)

Partially reconstructed





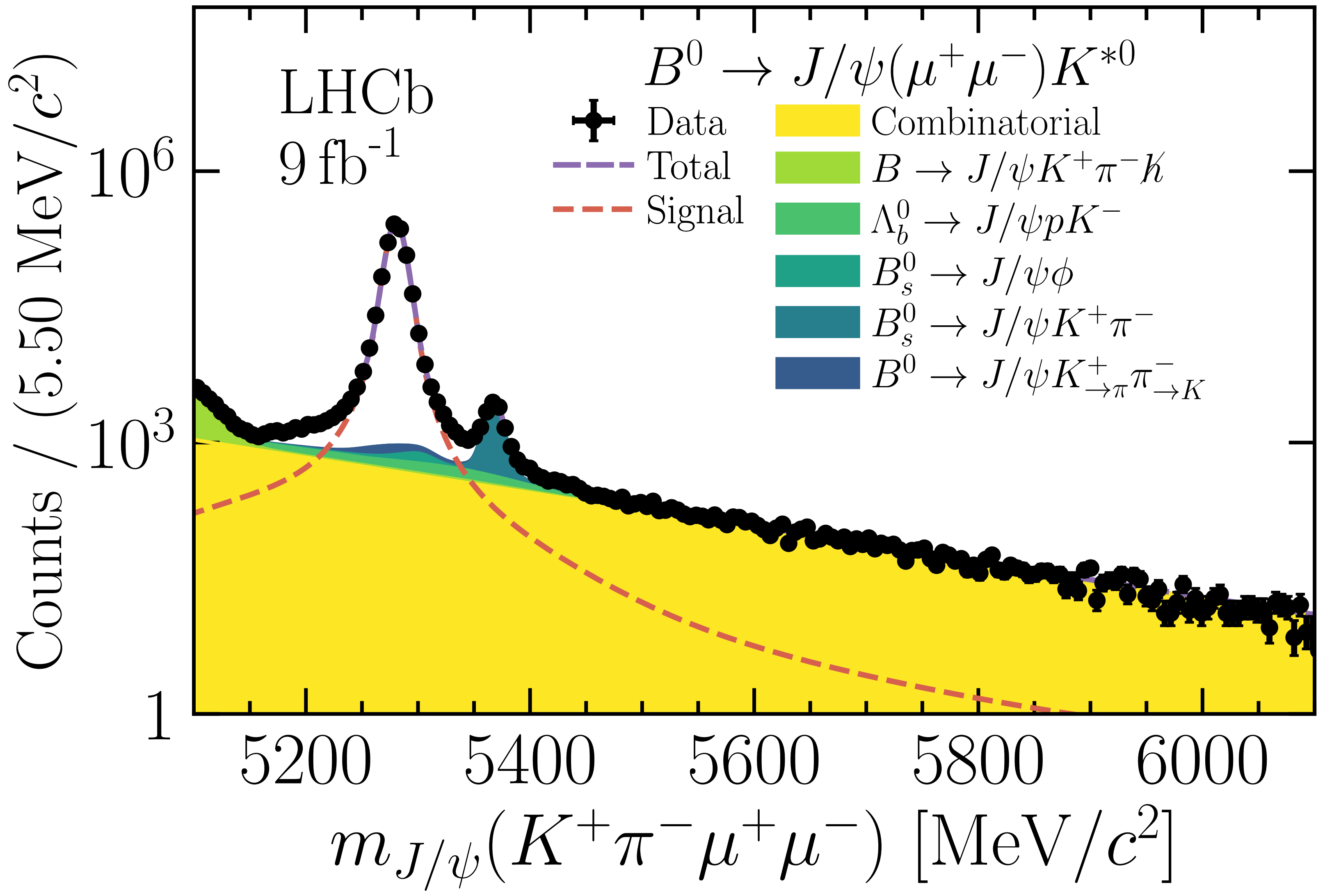
Partially reconstructed

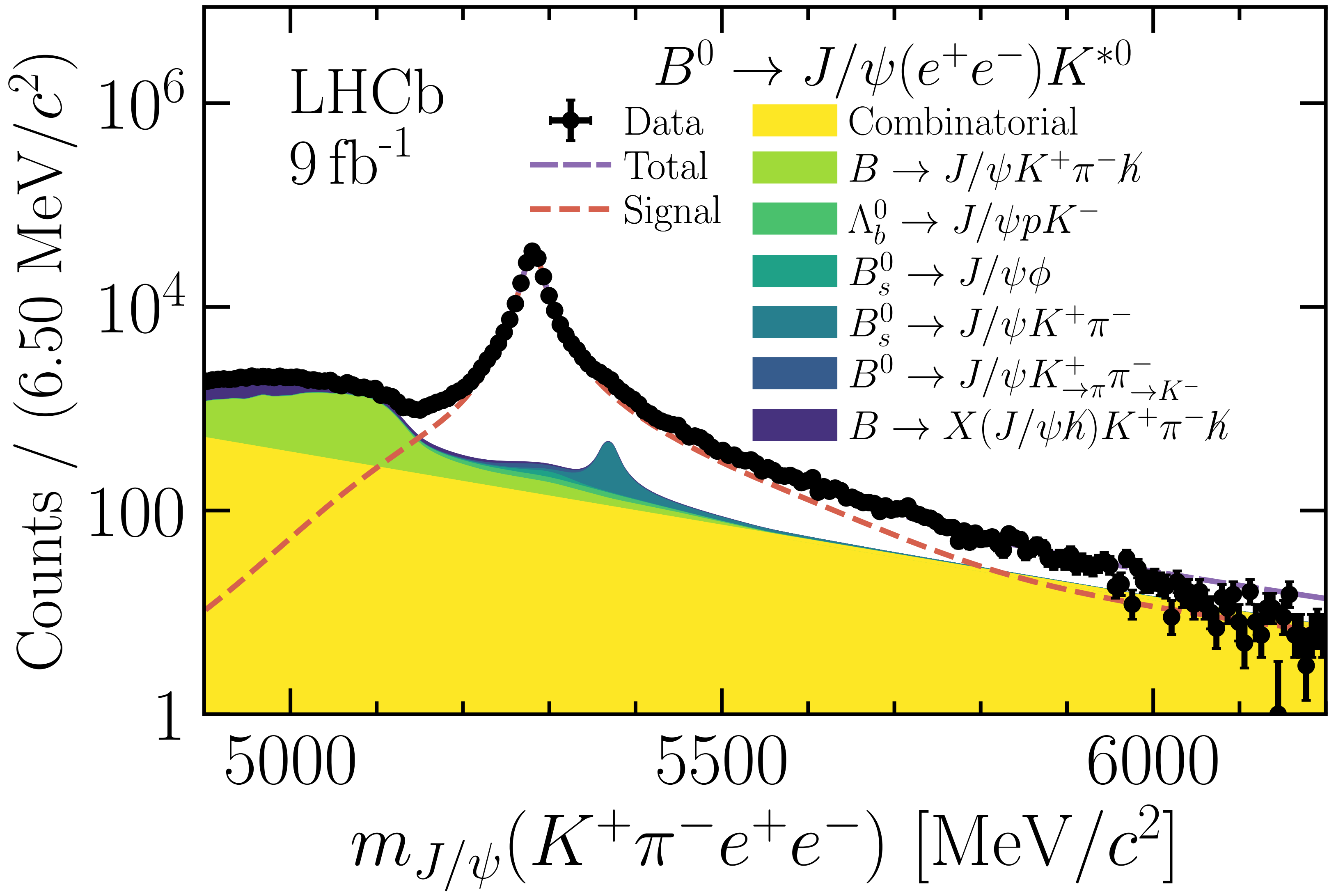
Leaking $B^+ \to J/\psi K^+$

$B^+ \to (\psi(2S) \to J/\psi X)K^+$

Cross-check resonant modes: mass fits

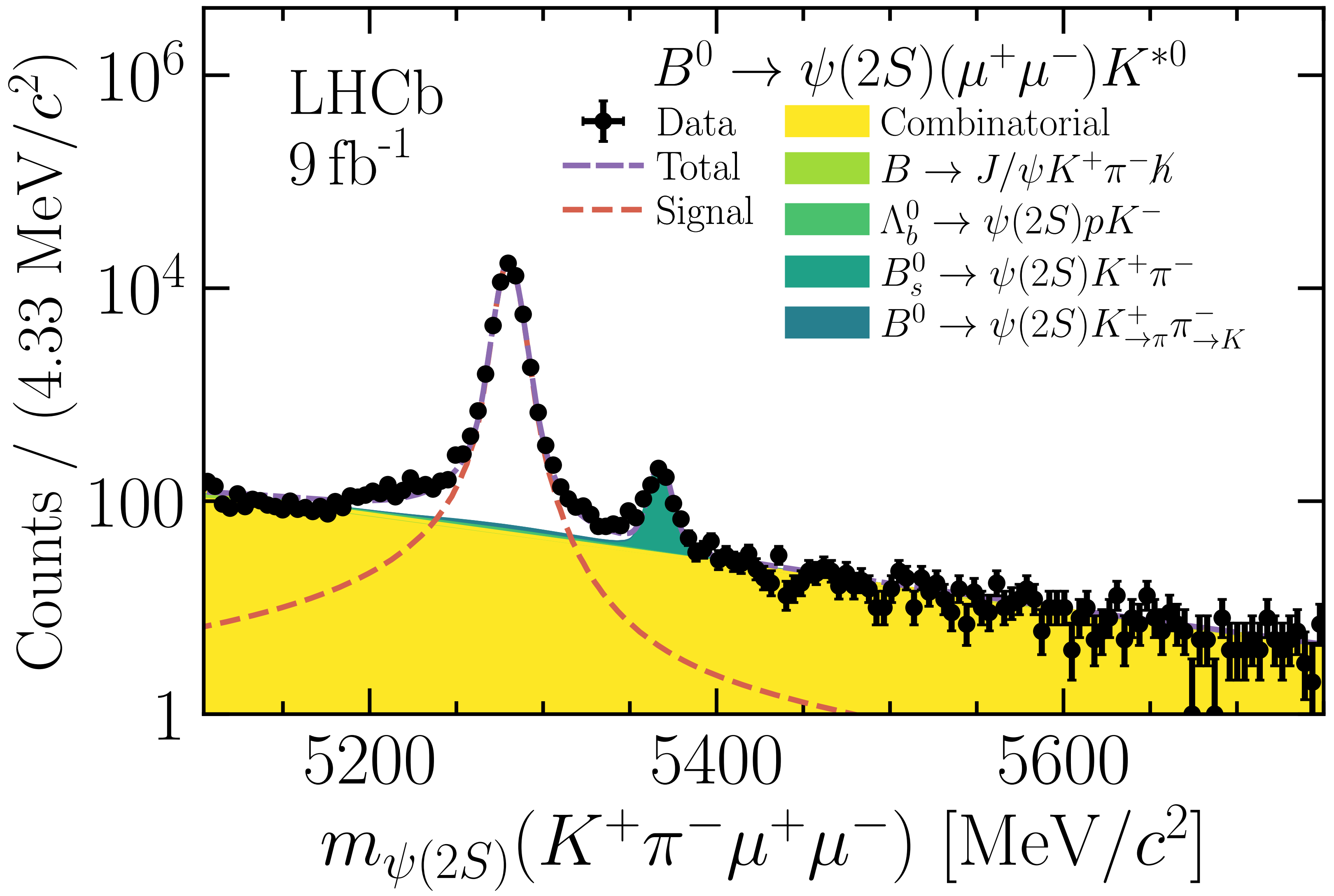
- Partially reconstructed
- $B_s \to J/\psi K^{*0}$
- Hadronic misID (Λ_b^0)
- Hadronic misID (B_s^0)
- Double misID $K \leftrightarrow \pi$

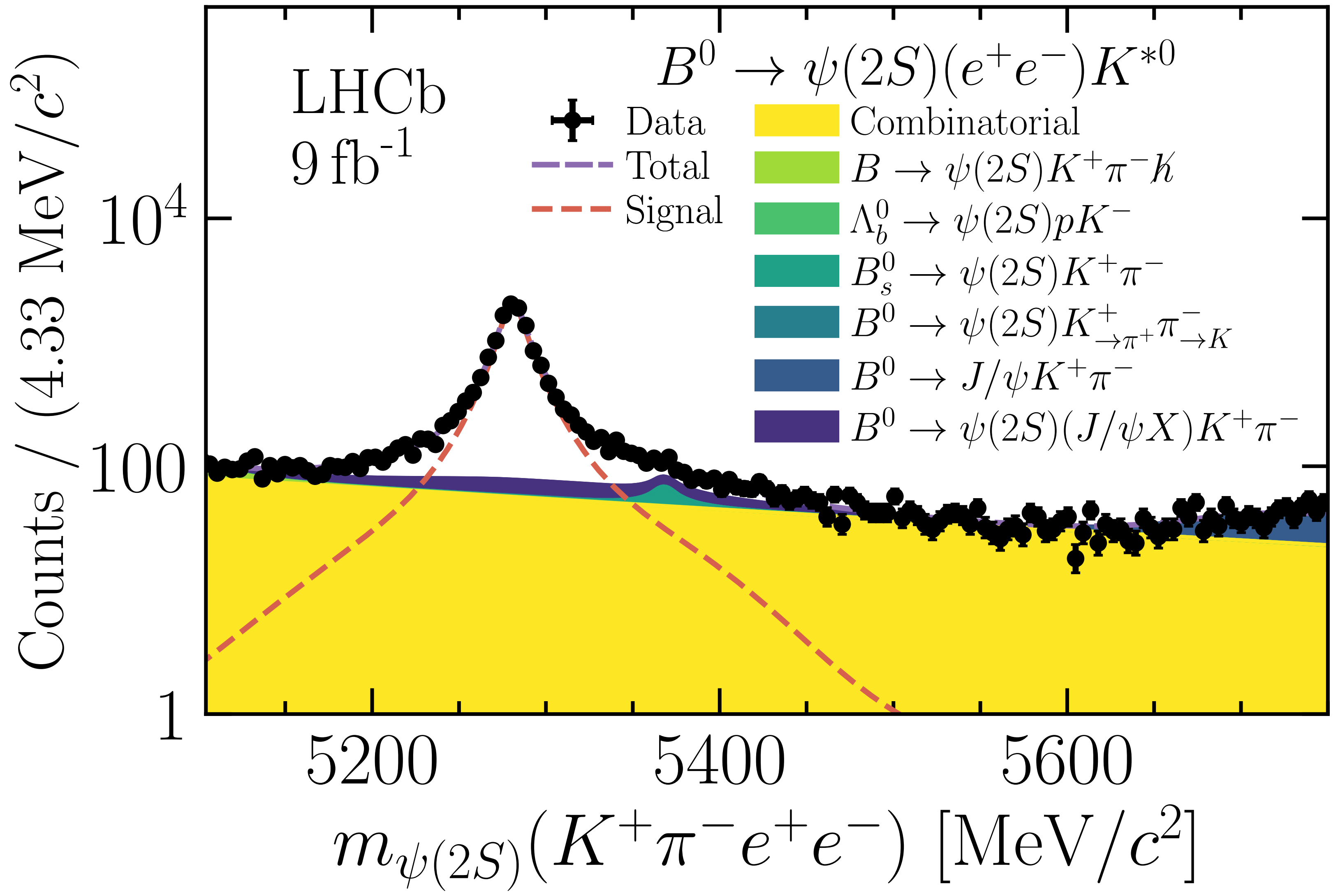




- Partially reconstructed
- $B_s \to J/\psi K^{*0}$
- Hadronic misID (Λ_b^0)
- Hadronic misID (B_s^0)
- Double misID $K \leftrightarrow \pi$
- Partially reconstructed (charmonia cascade)

- Partially reconstructed
- Hadronic misID (Λ_b^0)
- $B_s \to \psi(2S)K^{*0}$
- Double misID $K \leftrightarrow \pi$





- Partially reconstructed
- $B_s \to \psi(2S)K^{*0}$
- Hadronic misID (Λ_b^0)
- Double misID $K \leftrightarrow \pi$
- Leaking $B^+ \to J/\psi K^+$
- $B^+ \to (\psi(2S) \to J/\psi X)K^+$

Partially reconstructed background constraint

- Control missing pion background from $K^{*0}e^+e^-$ signal in $K^+e^+e^-$
  - $K^+\not{\pi}^- e^+e^-$ in $K^+e^+e^-$ fit range using relative ε ratios and scaling factors
    - (s+p-wave): $m_{K^+\pi^-} \in [792{,}992]$ directly from $K^{*0}e^+e^-$ signal yields and relative ε
    - (p-wave): $m_{K^+\pi^-} \notin [792{,}992]$ from breit-wigner tails and $\varepsilon(m(K^+\pi^-))$
    - (s-wave): $m_{K^+\pi^-} \notin [792{,}992] + m_{K^+\pi^-} \leq$ 1200MeV/c^2: use $F_s|_{644}^{1200}$ and $F_s|_{792}^{992}$ from JHEP 11 (2016) 047 JHEP 04 (2017) 142 and corrections for $\varepsilon(m(K^+\pi^-))$
    - (all): $m_{K^+\pi^-} \notin [792{,}992] + m_{K^+\pi^-} >$ 1200MeV/c^2: linear extrapolation from known BF or use full amplitude model from $K^+\pi^-J/\psi$ in Phys. Rev. Lett. 112, 222002 (2014) and corrections for $\varepsilon(m(K^+\pi^-))$
    - Iso-spin partner $K^+\not{\pi}^0$ obtained from all above corrected by ε and isospin extrapolation factor for τ_{B^+}/τ_{B^0} and K^* isospin factors and corrections for and corrections for $\varepsilon(m(K^+\pi^0))$ from simulation
  - m_{Corr} selection prevent and suppress ≥ 2 missing particles from $X_s e^+e^-$entering the mass fit window
- Partially reconstructed background in $K^{*0}e^+e^-$ free to float