ALBERT PUIG *ON BEHALF OF THE LHCb COLLABORATION*

RARE $b \to s\ell\ell$ ANALYSES WITH ELECTRONS

FONDS NATIONAL SUISSE
SCHWEIZERISCHER NATIONALFONDS
FONDO NAZIONALE SVIZZERO
SWISS NATIONAL SCIENCE FOUNDATION

Universität Zürich[UZH]

BEAUTY 2018, 6–11 May 2018

DISCLAIMER

I will only cover $b \to s\ell\ell$ modes containing electrons, and therefore only part of the semileptonic anomalies

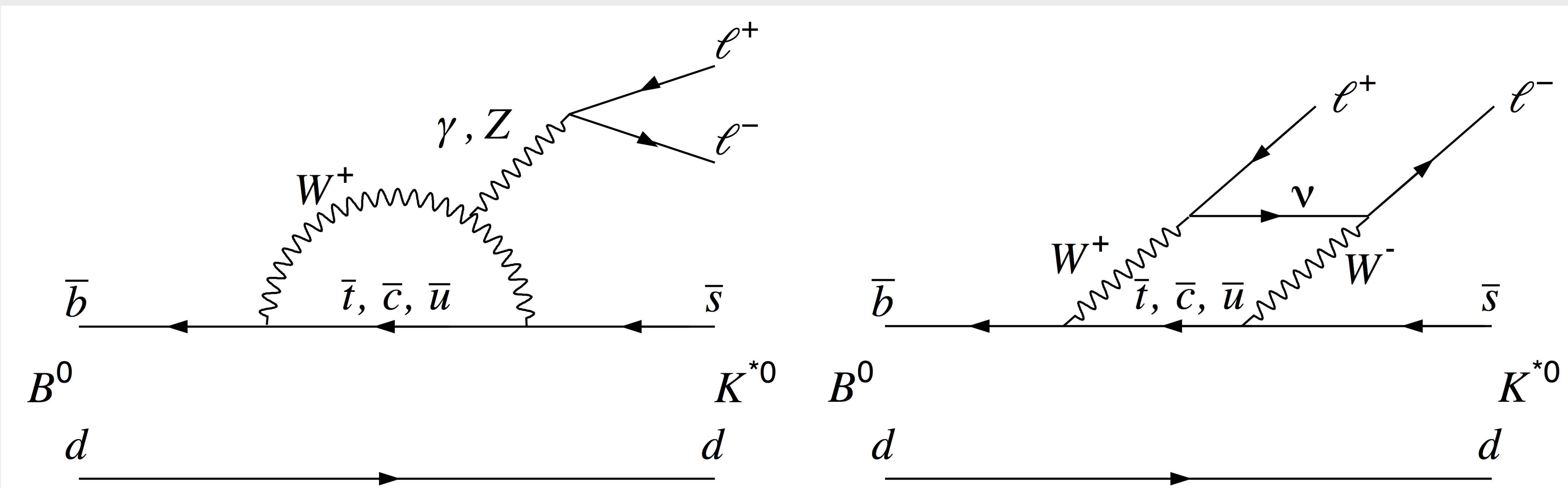
The rest has been covered by E. Smith just before

She will give more details on theory and phenomenology, so I can focus on specific experimental aspects of dealing with electrons

See Eluned's talk!

RARE SEMILEPTONIC B DECAYS

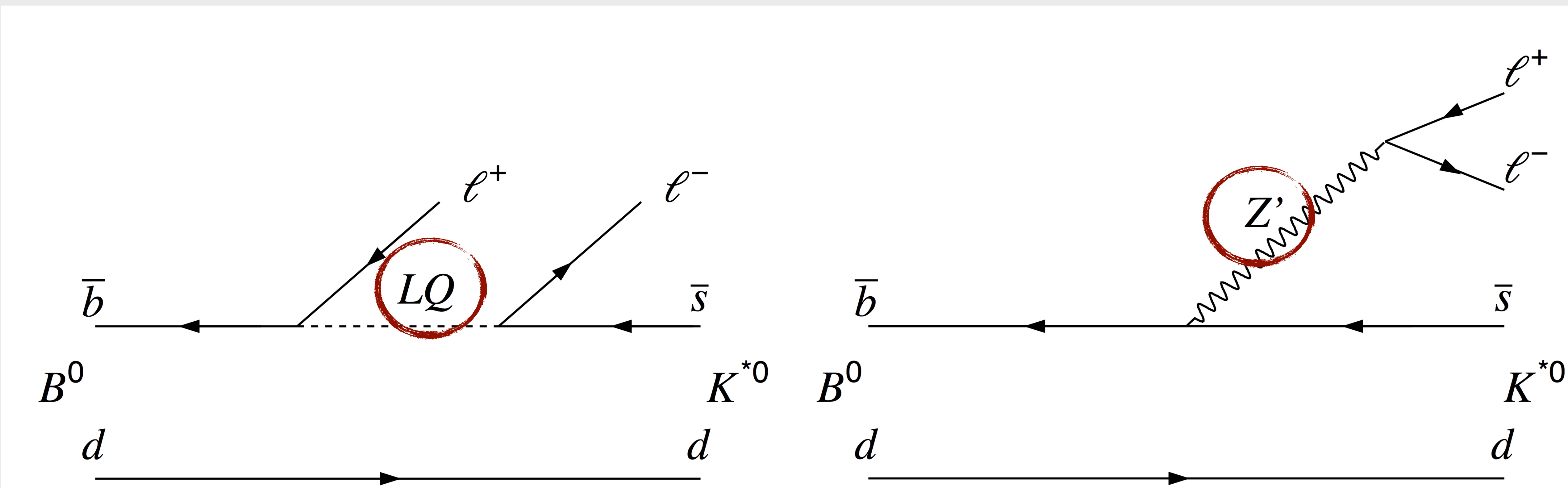
Rare FCNC only allowed at loop-level in the SM and thus very sensitive to NP effects from new heavy particles



See Eluned's talk!

RARE SEMILEPTONIC B DECAYS

Rare FCNC only allowed at loop-level in the SM and thus very sensitive to NP effects from new heavy particles



WHY ELECTRONS?

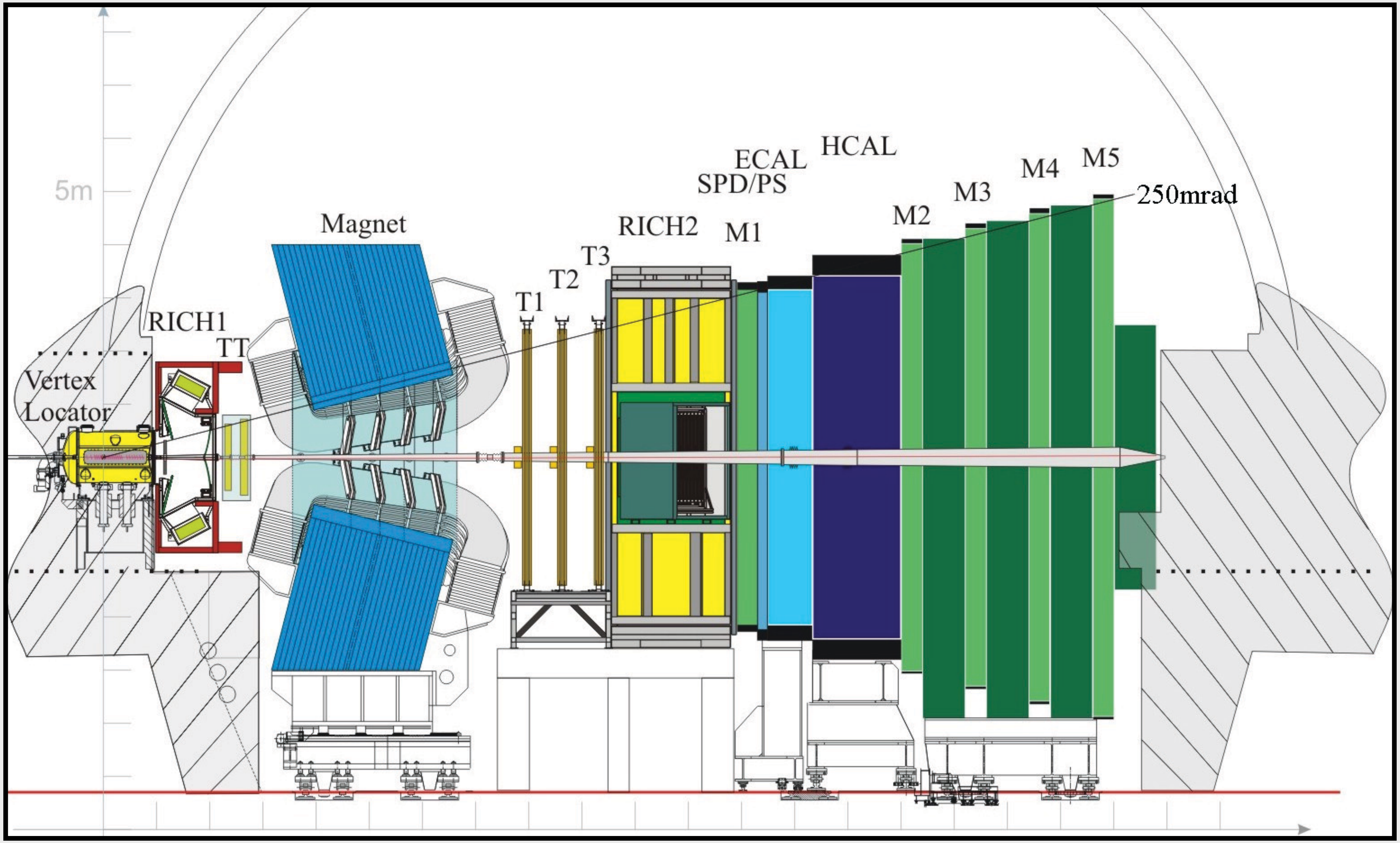
Access the photon polarisation at very low q^2

Test lepton flavour universality comparing muon and electron modes

Lepton flavour violation (see Matteo Rama's talk this morning): $B \to e\mu$, $B \to X_s e\mu$, …

[JINST 3 (2008) S08005]

THE LHCB EXPERIMENT

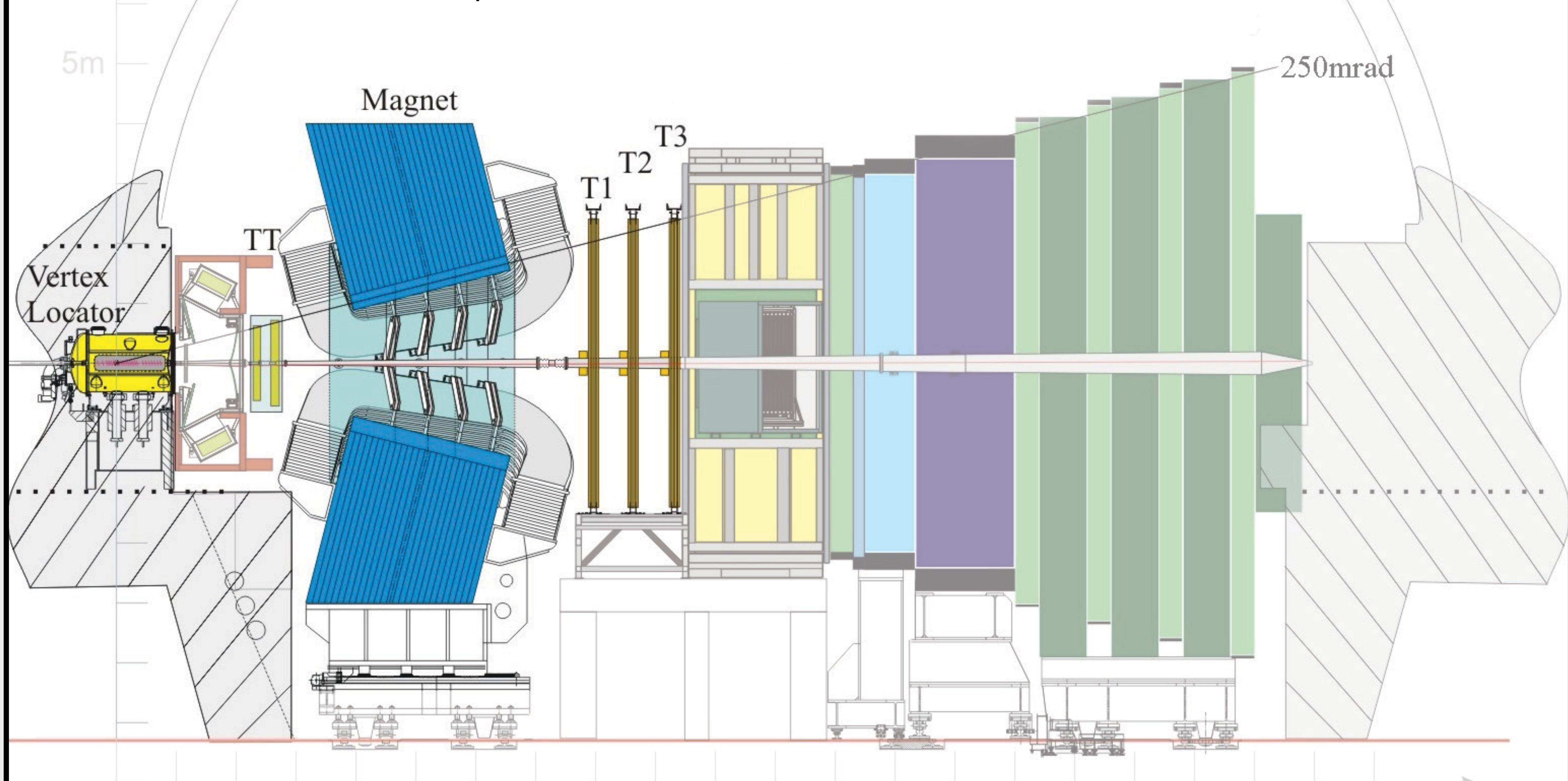


THE LHCB EXPERIMENT: TRACKING

Precise tracking

Good momentum ($\Delta p/p$~0.4% at 5GeV) resolution

Good IP (20μm for high-p_T tracks) and decay time (~45fs) resolution



THE LHCB EXPERIMENT: PID

Excellent particle identification

π/K separation over 2-100 GeV (ε_K~90% for ~5% π→K mis-id)

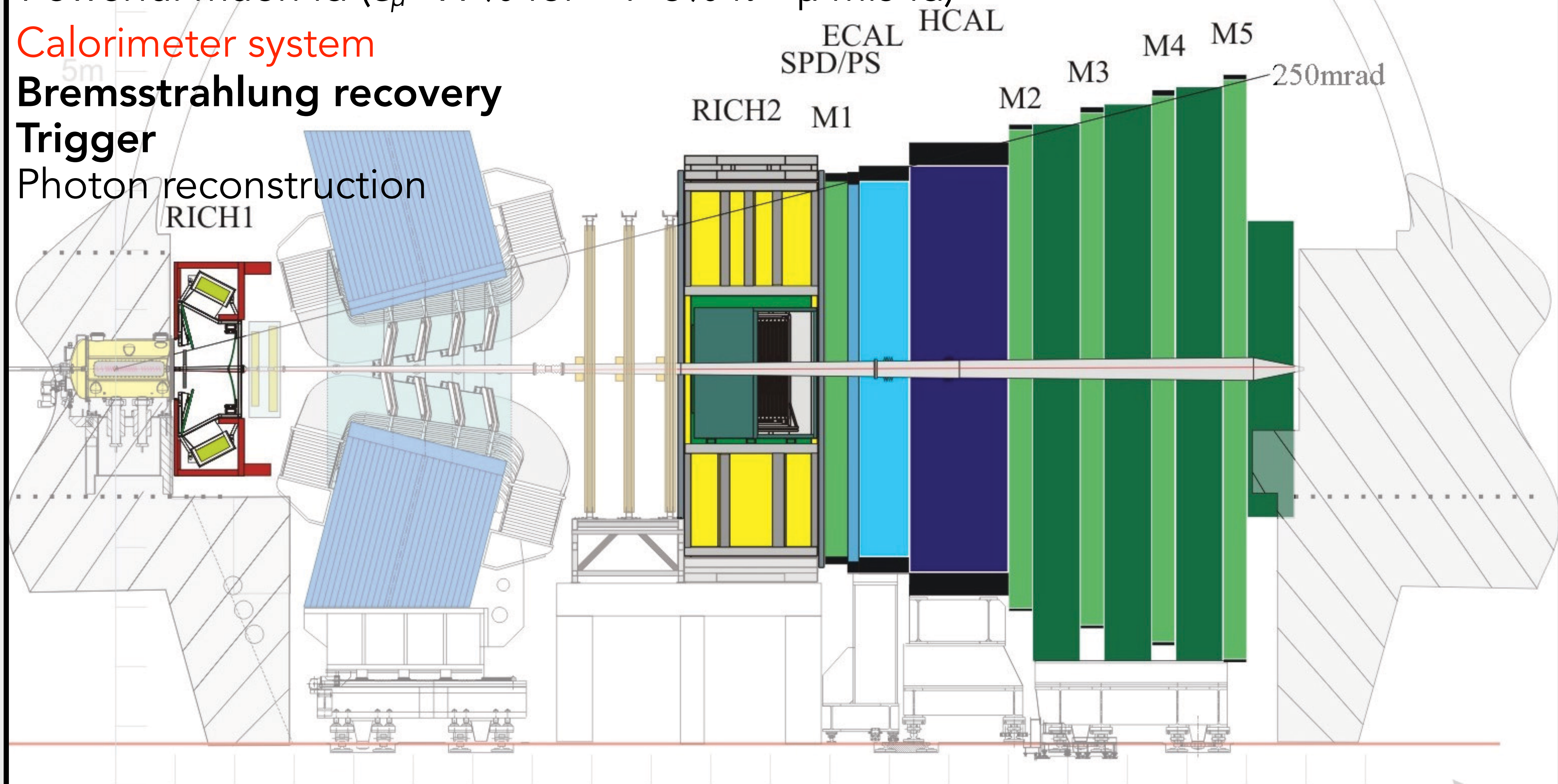
Powerful muon id (ε_μ~97% for ~1–3% π→μ mis-id)

Calorimeter system

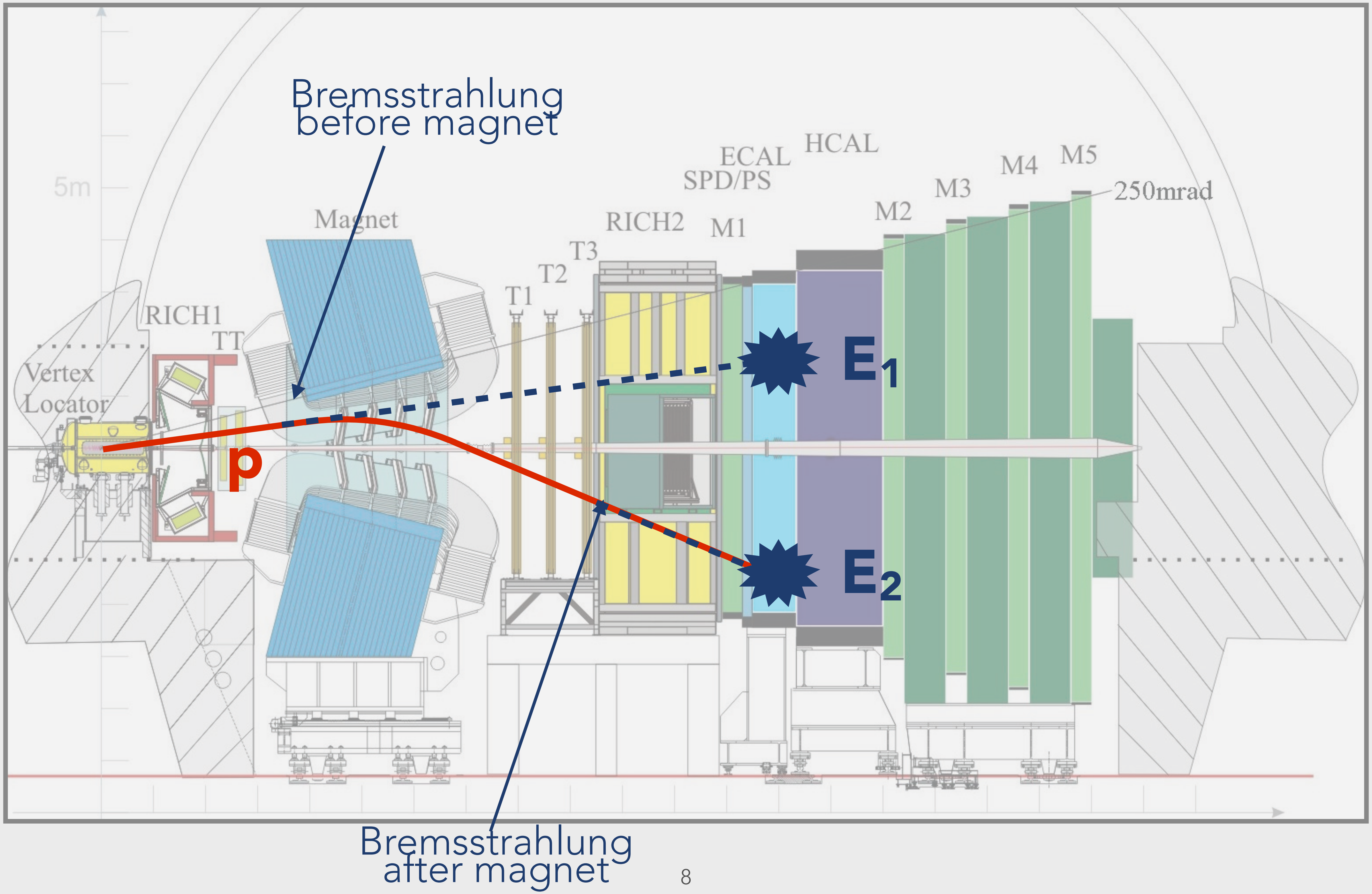
Bremsstrahlung recovery

Trigger

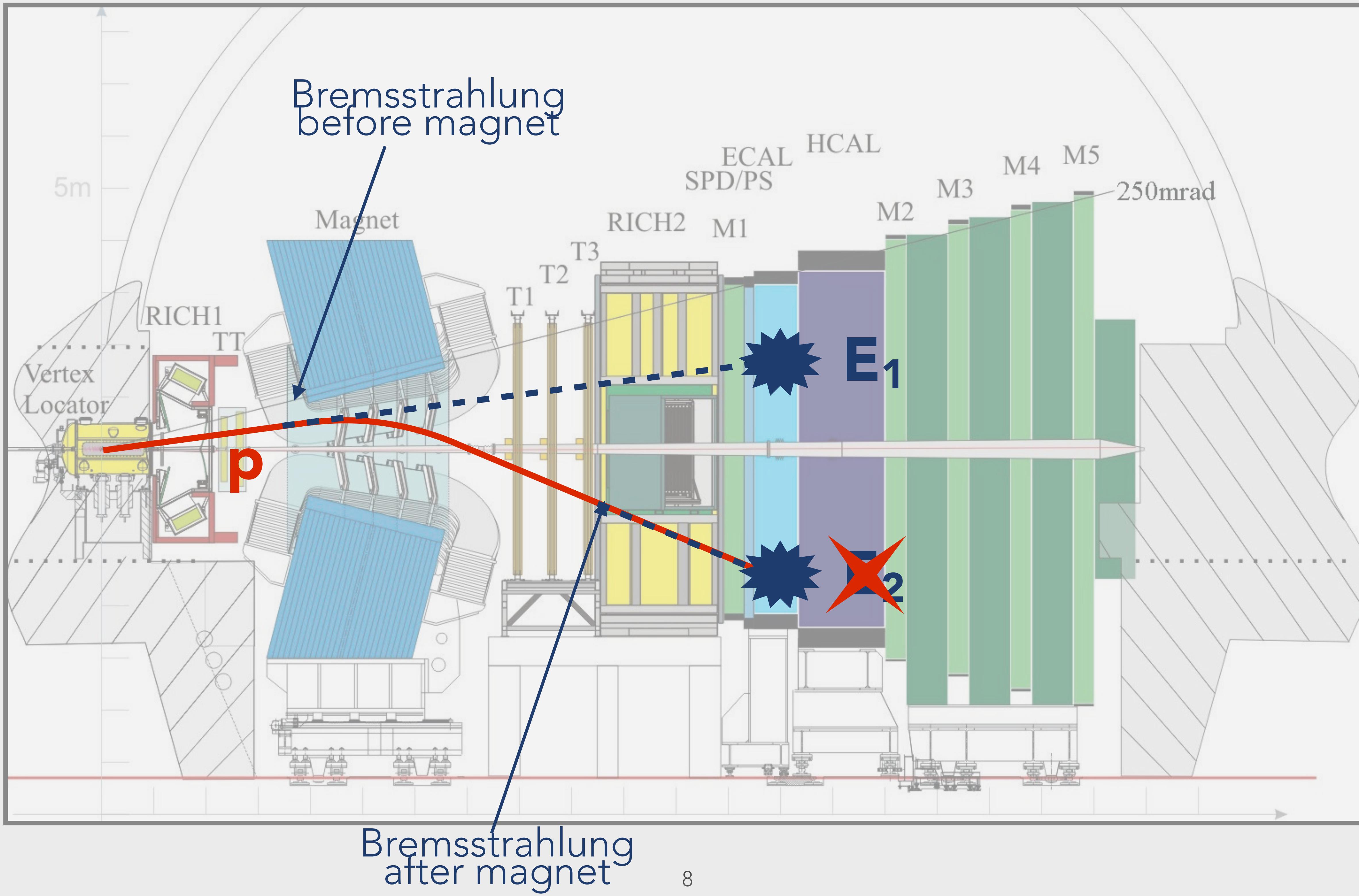
Photon reconstruction



RECONSTRUCTING ELECTRONS



RECONSTRUCTING ELECTRONS

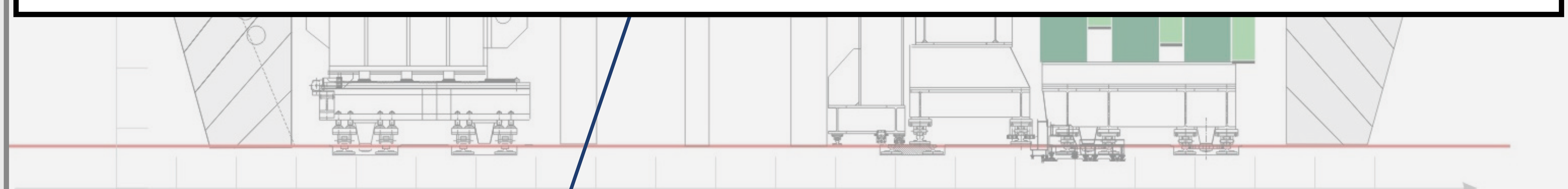


RECONSTRUCTING ELECTRONS

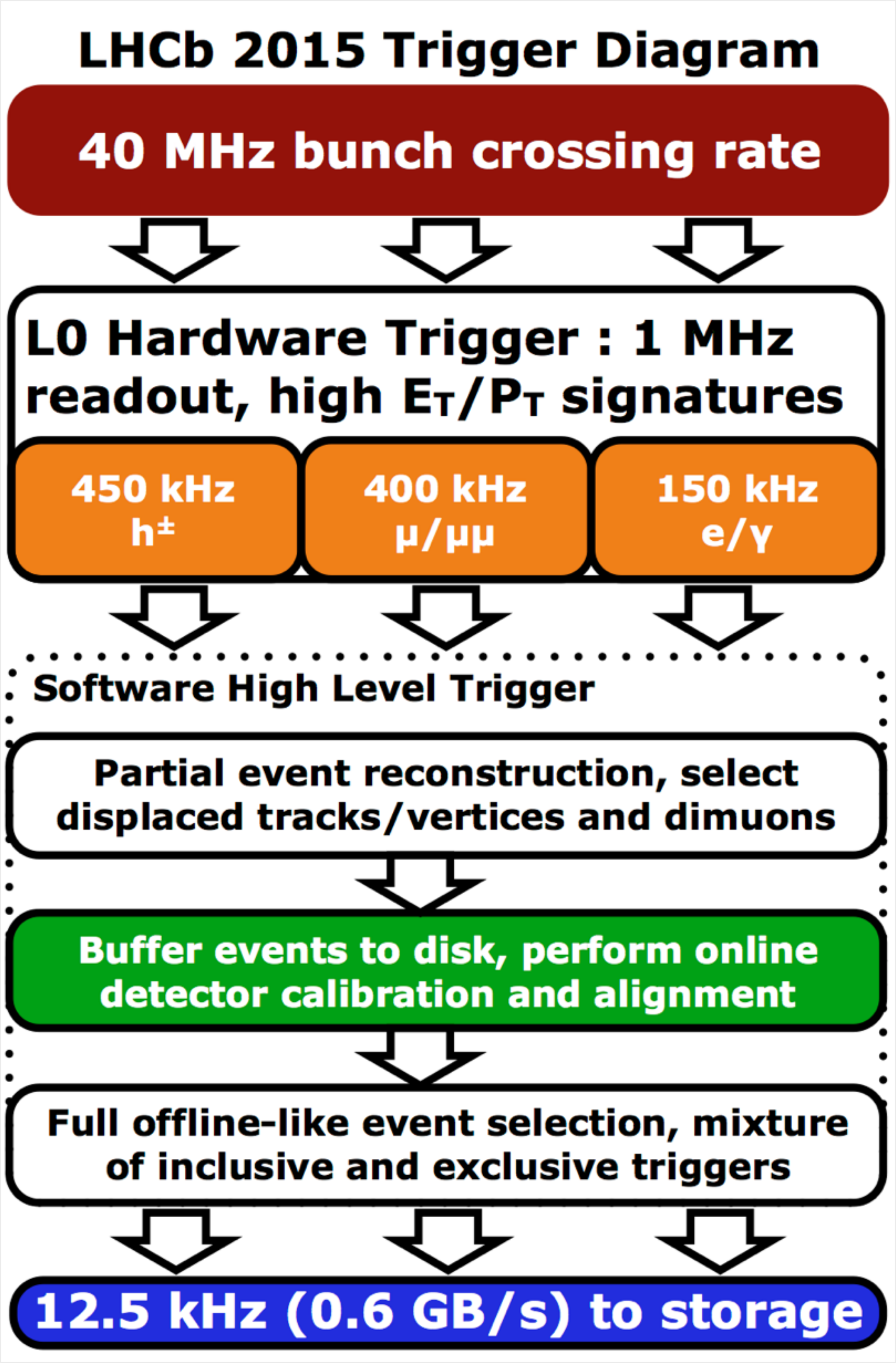
Di-electron systems are split in three categories:

- 0 brem clusters recovered
- 1 brem cluster recovered (1 electron)
- ≥2 brem clusters recovered (2 electrons)

Each of the cases has different mass shape (tail, resolution) and therefore need to be treated separately



TRIGGERING $b \to s\ell\ell$



L0 hardware trigger:

- Muon: $p_T(\mu) > 1.8$ GeV
- Electron:
  - E_T(ECAL) > 2.5–3 GeV
  - E_T(HCAL) > 3.5–4 GeV
  - other *B*

Software trigger:

- Inclusive selections: high-p_T displaced tracks, topological selection of 2-,3- and 4-body B decays.

TRIGGERING $b \to s\ell\ell$

Large thresholds in electron modes cause loss of efficiency, which is partially recovered by using 3 categories, but this requires to treat and calibrate them separately, adding complexity

L0 hardware trigger:

- Muon: $p_T(\mu) > 1.8$ GeV
- Electron:
  - E_T(ECAL) > 2.5–3 GeV
  - E_T(HCAL) > 3.5–4 GeV
  - other *B*

Software trigger:

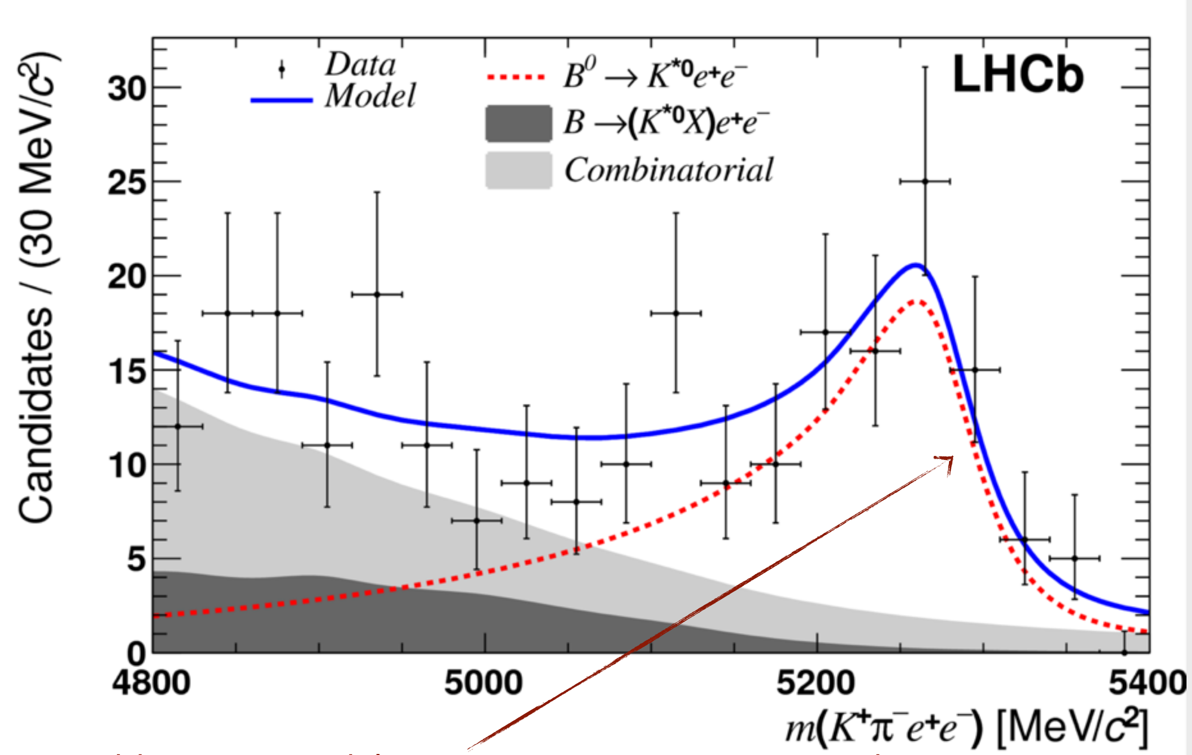
- Inclusive selections: high-p_T displaced tracks, topological selection of 2-,3- and 4-body B decays.

$B^0 \to K^{*0} ee$ ANGULAR ANALYSIS

Study the very low q^2 region, [0.002, 1.120] GeV^2, sensititive to the photon pole at $q^2 \to 0$

- Access the photon polarisation with sensitivity comparable to radiative b→sγ transitions

Angular analysis with a simplified model due to low statistics (Run I only)



Trigger and bremsstrahlung categories merged

$$F_L = 0.16 \pm 0.06 \pm 0.03$$
$$A_T^{(2)} = -0.23 \pm 0.23 \pm 0.05$$
$$A_T^{\mathrm{Im}} = 0.14 \pm 0.22 \pm 0.05$$
$$A_T^{\mathrm{Re}} = 0.10 \pm 0.18 \pm 0.05$$

sensitive to photon polarisation

LFU: R MEASUREMENTS

LFU is tested measuring ratios of $b \to s\ell\ell$ branching fractions between muons and electrons

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

These are predicted to be 1 up to O(1%) [EPJC 76 (2016) no.8] for $q^2 \in [1.1, 6]\ \mathrm{GeV}^2$, so they are excellent null tests of the SM

In 2014, LHCb observed a tension in R_K with its Run I dataset, which sparked the interest of the community in these measurements

$$R_K = 0.745^{+0.090}_{-0.074}\,(\mathrm{stat}) \pm 0.036\,(\mathrm{syst})$$ [PRL 113 (2014) 151601]

[JHEP 08 (2017) 055]

R_X STRATEGY

Measure R_X as a double ratio with the resonant modes

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

(this allows to reduce systematic uncertainties from differences between electrons and muons)

Use **corrected** simulation for extracting most efficiencies

Electron modes are studied in categories of bremsstrahlung and trigger

[JHEP 08 (2017) 055]

DATA/SIMULATION DIFFERENCES

Simulation is not perfect, need to correct to obtain correct efficiencies

- Kinematic effects
- Hardware trigger response
- Reconstruction effects
- Particle identification

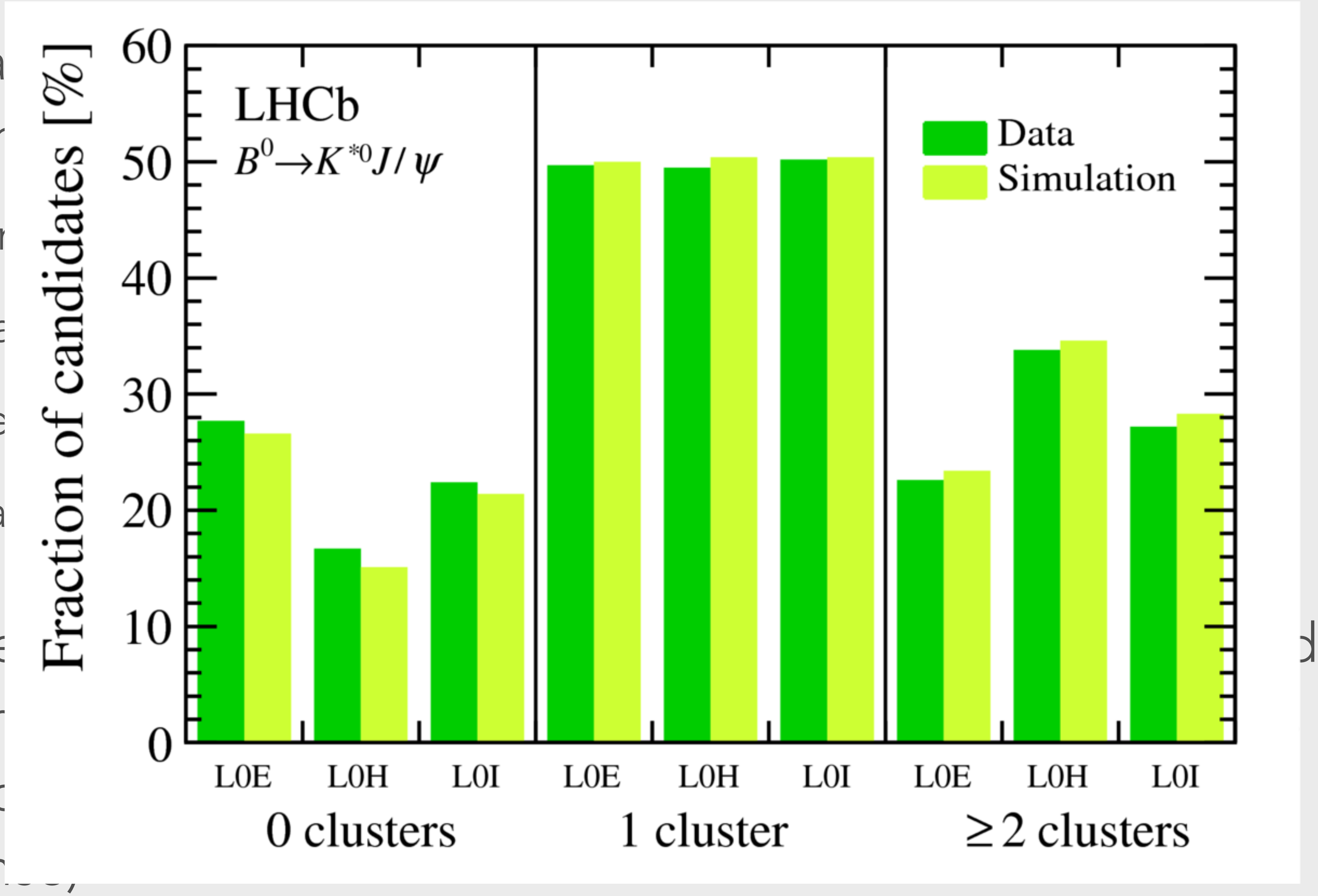
A large fraction of these effects are cancelled thanks to the double ratio method, but differences between electrons and muons need to be carefully corrected to avoid biases (especially trigger response)

- Use data-driven methods and control modes

DATA/SIMULATION DIFFERENCES

Simula
efficier

- Kir
- Ha
- Re
- Pa



A large … double ratio m… need to be c… respon…

- Use data-driven methods and control modes

CROSSCHECKS

The control of the absolute scale of efficiencies as a function of kinematics is tested with the resonant modes

$$r_{J/\psi} = \frac{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to \mu^+\mu^-))}{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to e^+e^-))} \underbrace{=1}_{\text{SM}}$$

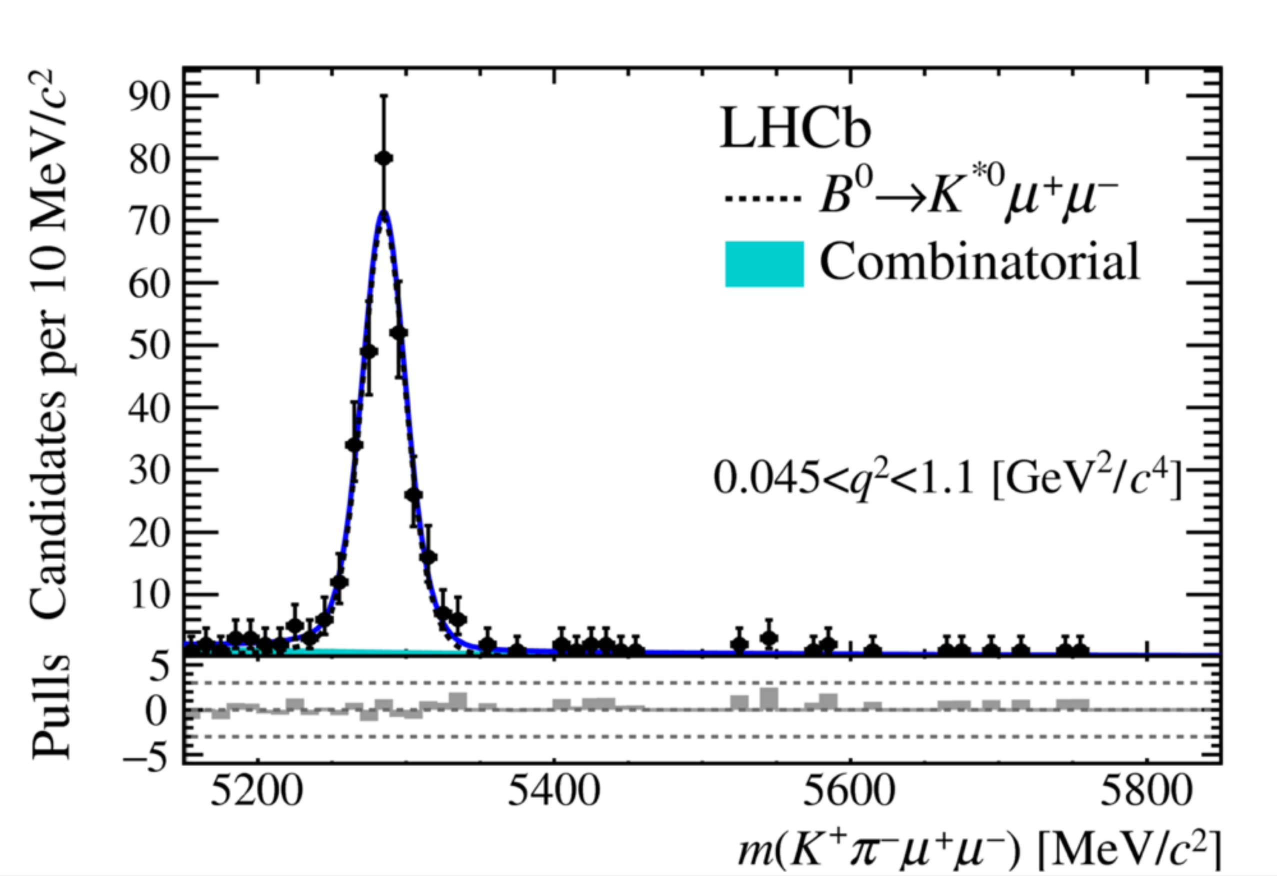
Extremely stringent test, as no cancellations occur

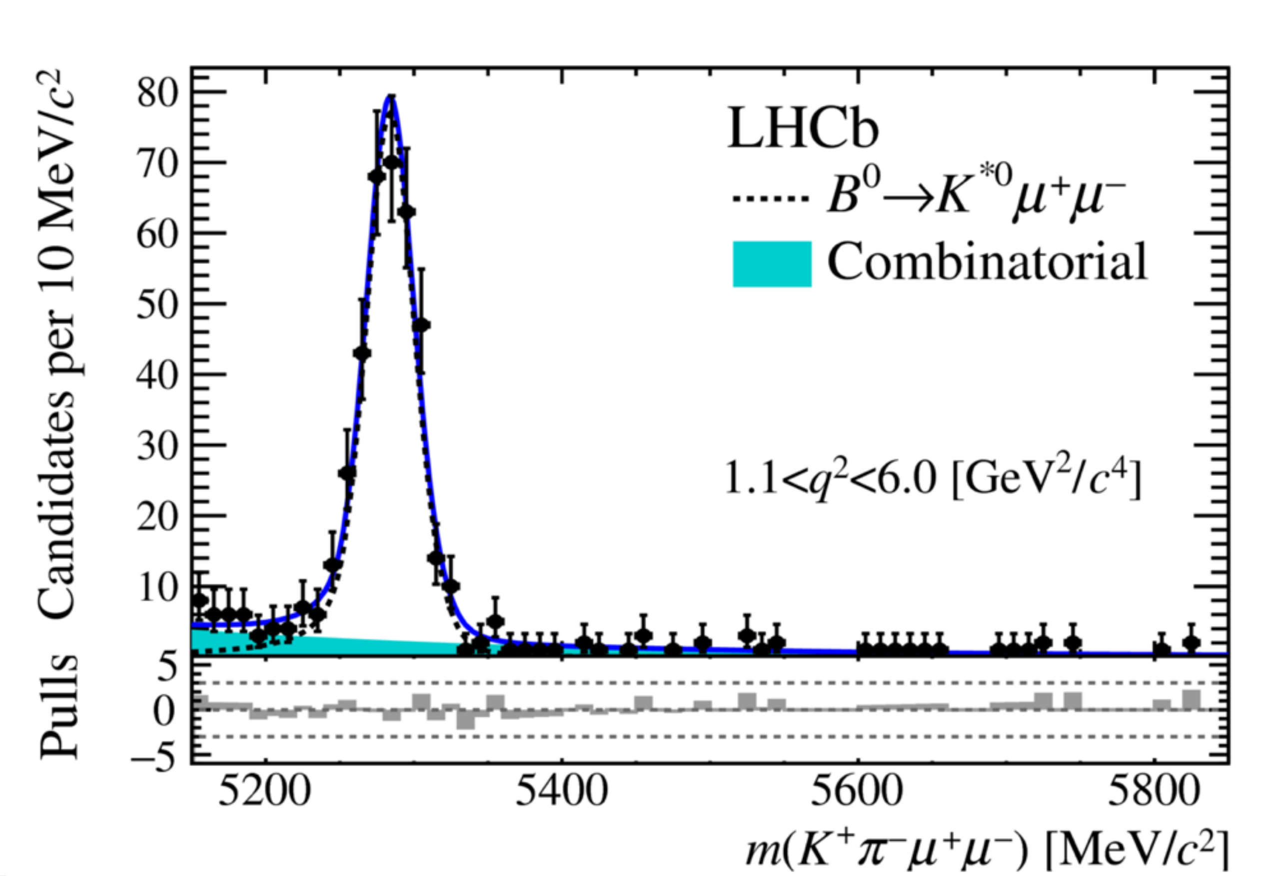
Further verification of the cancellations from the double ratio is performed measuring $R_{\psi(2S)}$

Measure the BF of $B^0 \to K^*\mu\mu$ and $B^0 \to K^*\gamma(\to ee)$

[JHEP 08 (2017) 055]

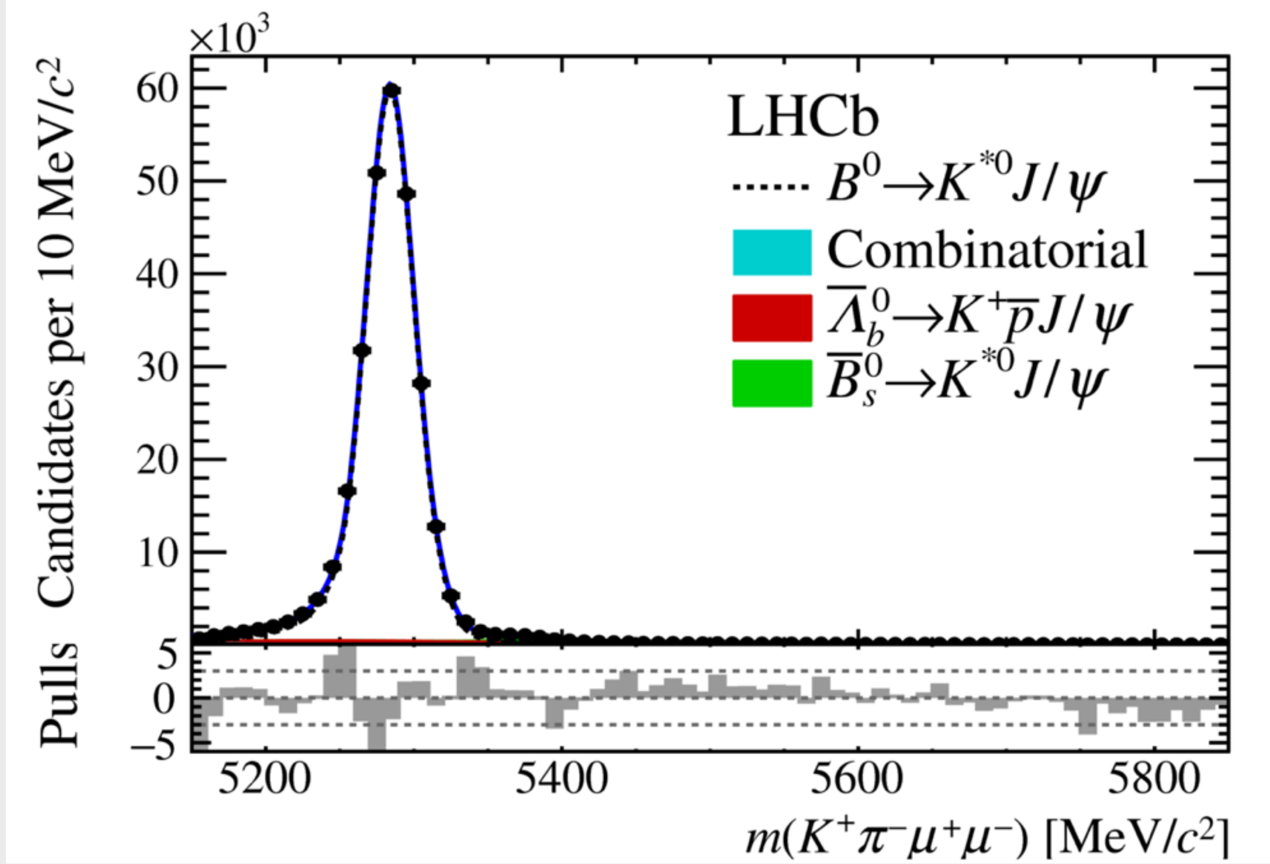
MASS FITS: MUONS





Very clean distributions

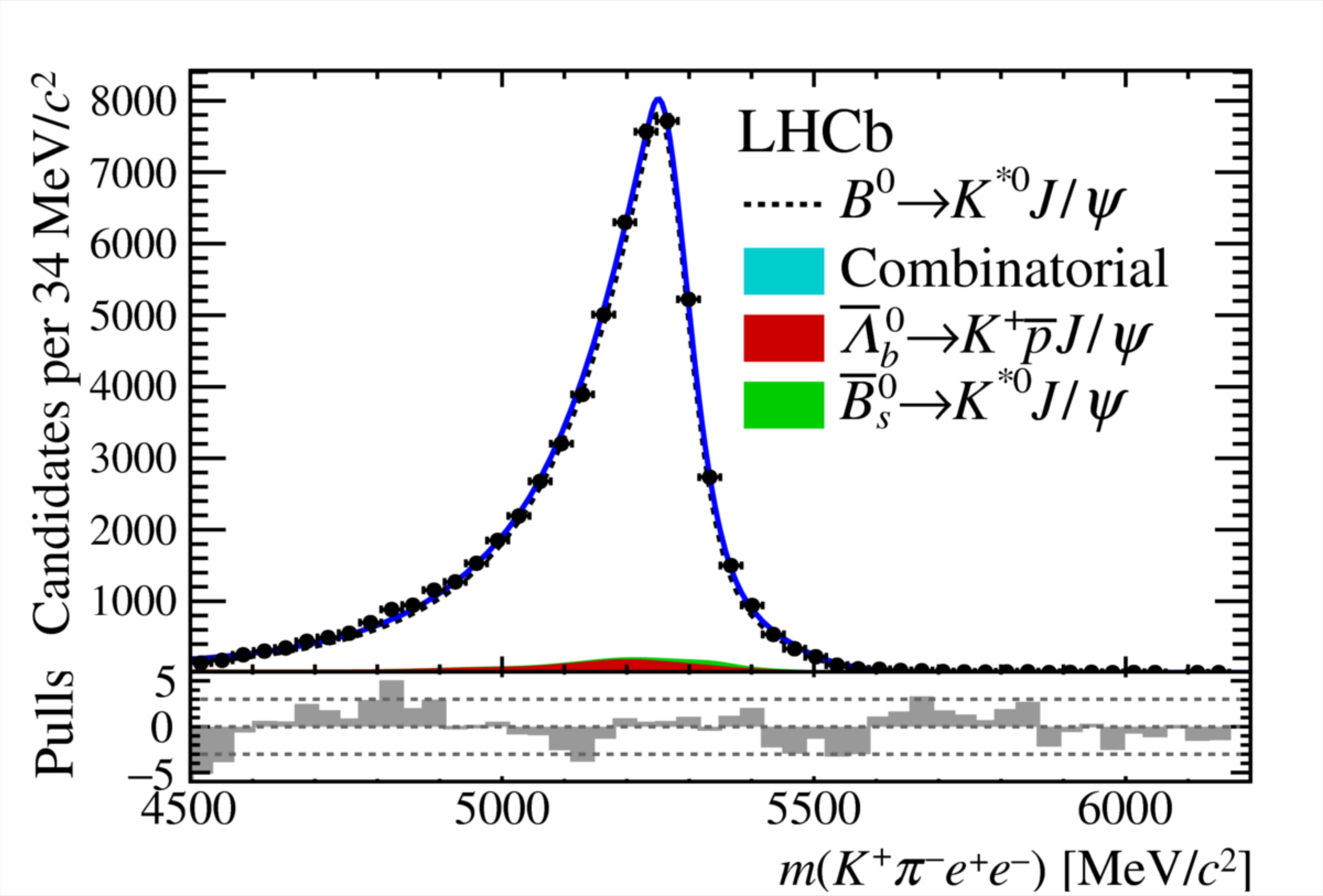
Small background contributions thanks to the very narrow mass peak



[JHEP 08 (2017) 055]

MASS FITS: ELECTRONS

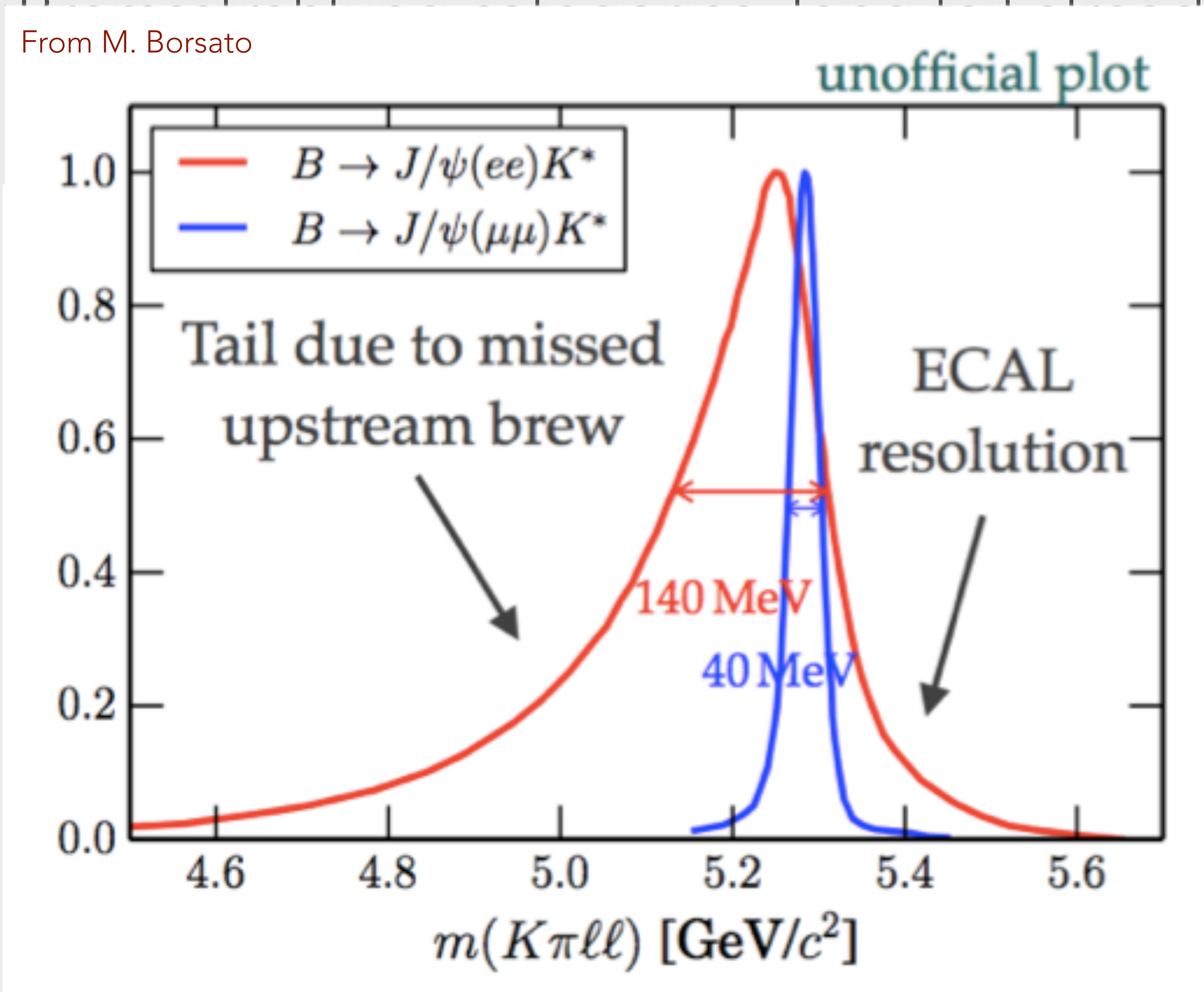
Merge Bremsstrahlung categories, long tail already in resonant mode



MASS FITS: ELECTRONS

Merge … y in

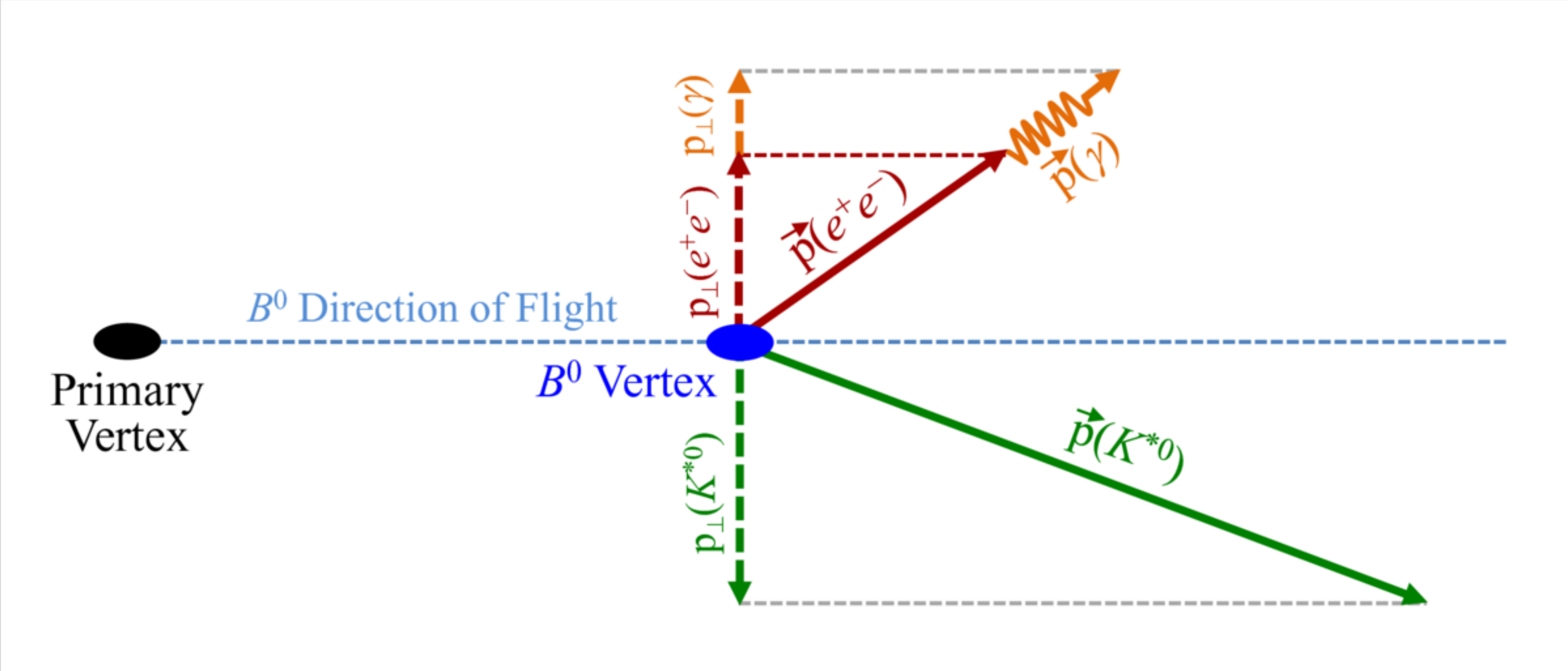
resona…



[JHEP 08 (2017) 055]

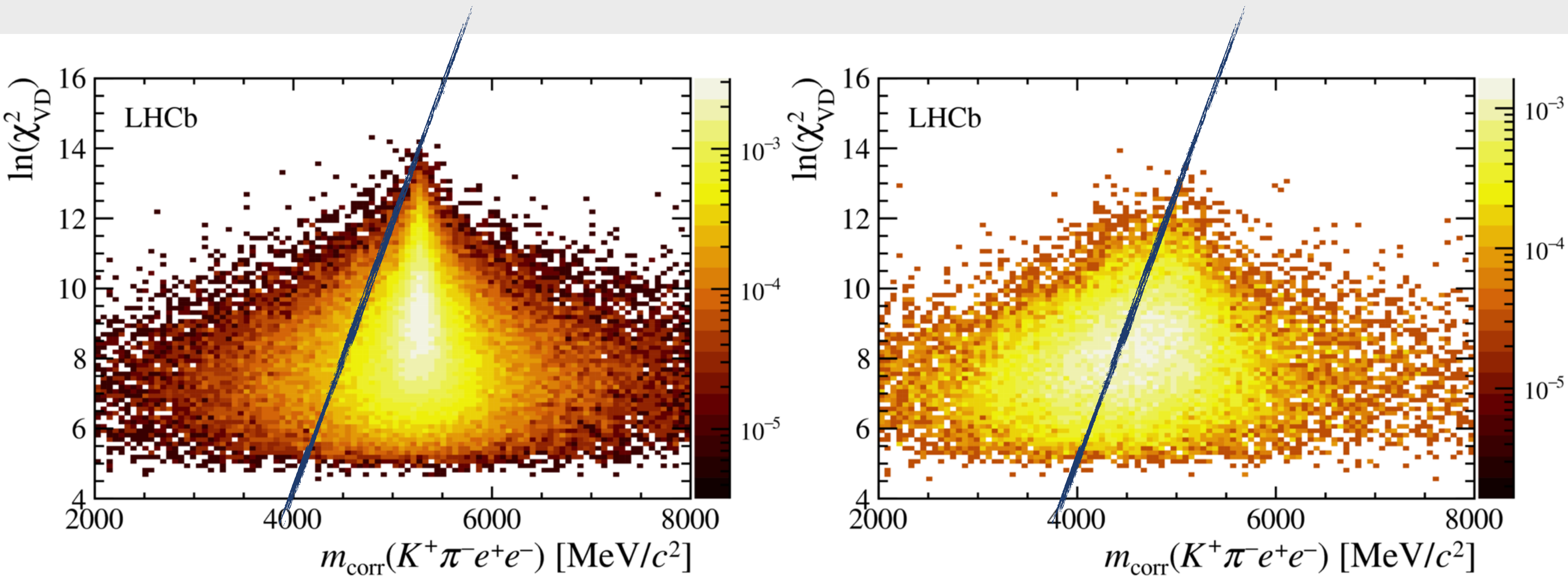
DEALING WITH LONG MASS TAIL

Use the event topology and assume the bremsstrahlung photons don't modify the dielectron direction to calculate a corrected mass (m_{corr}), which can be used to reduce the contamination from $B \to XK^{*}ee$ decays



DEALING WITH LONG MASS TAIL

Use the event topology and assume the bremsstrahlung photons don't modify the dielectron direction to calculate a corrected mass (m_{corr}), which can be used to reduce the contamination from $B \rightarrow XK^{*}ee$ decays

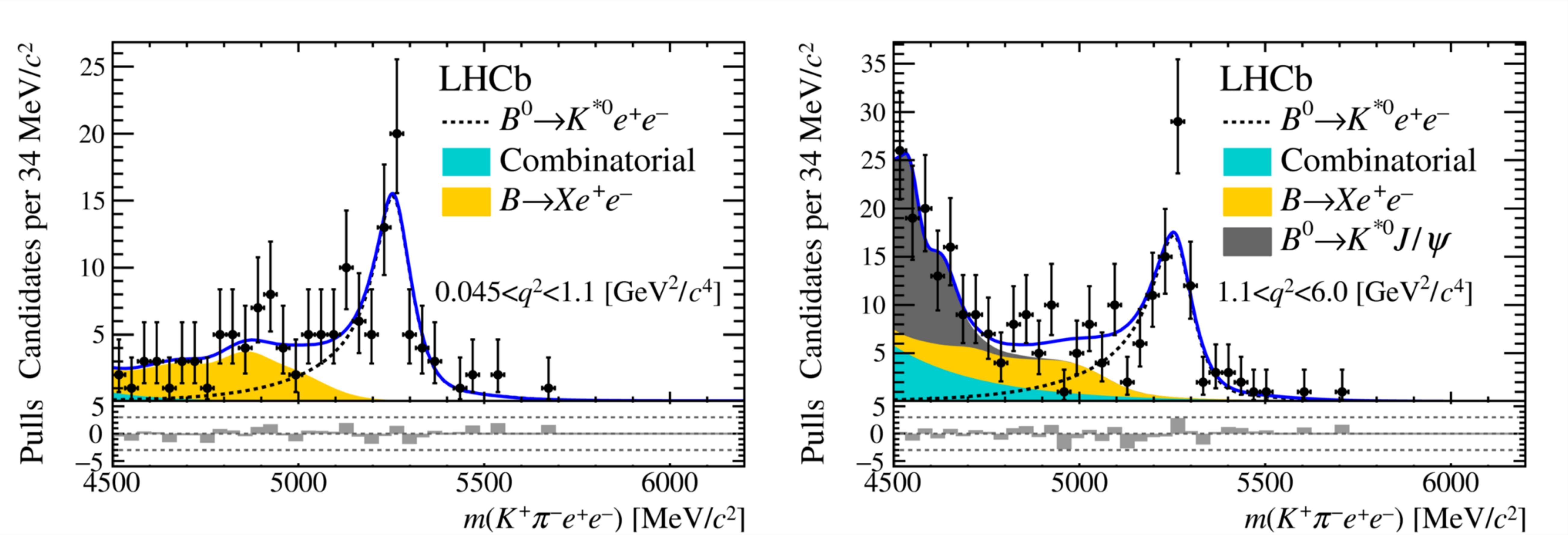


Not the true cut, just for illustration purposes

MASS FITS: ELECTRONS

Main backgrounds, modelled with histograms

- Partially reconstructed B decays
- Leak from J/ψ resonant mode for central-q^2

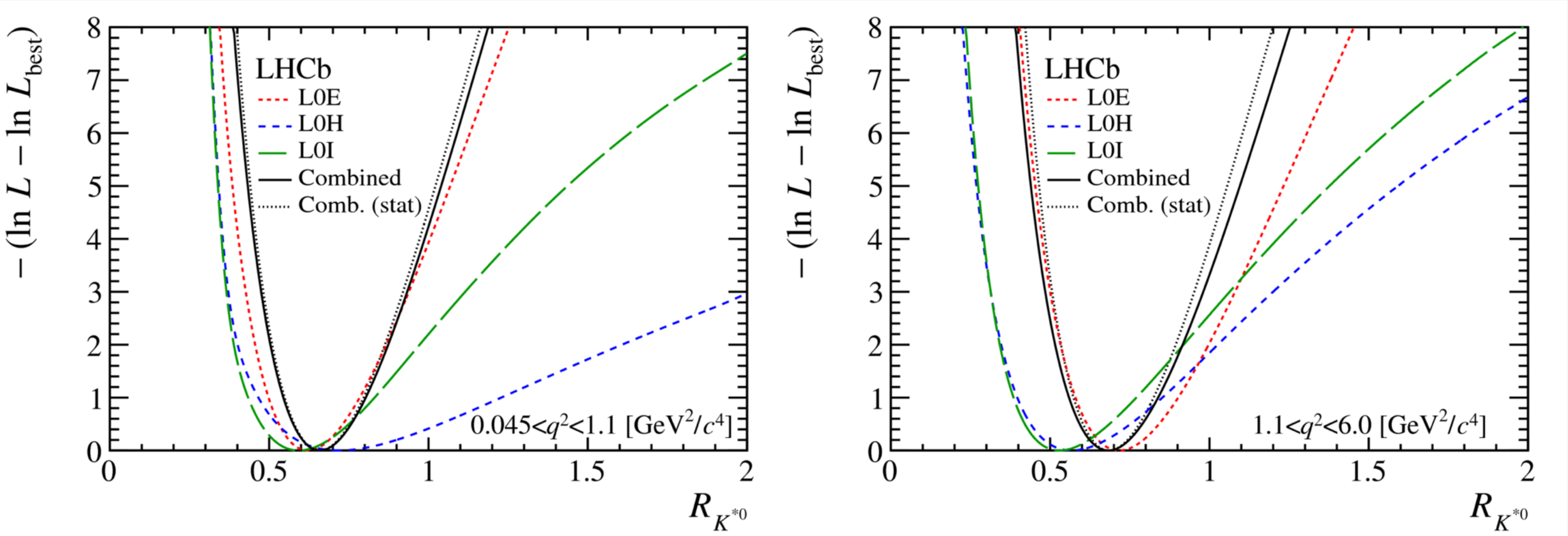


Trigger and bremsstrahlung categories merged

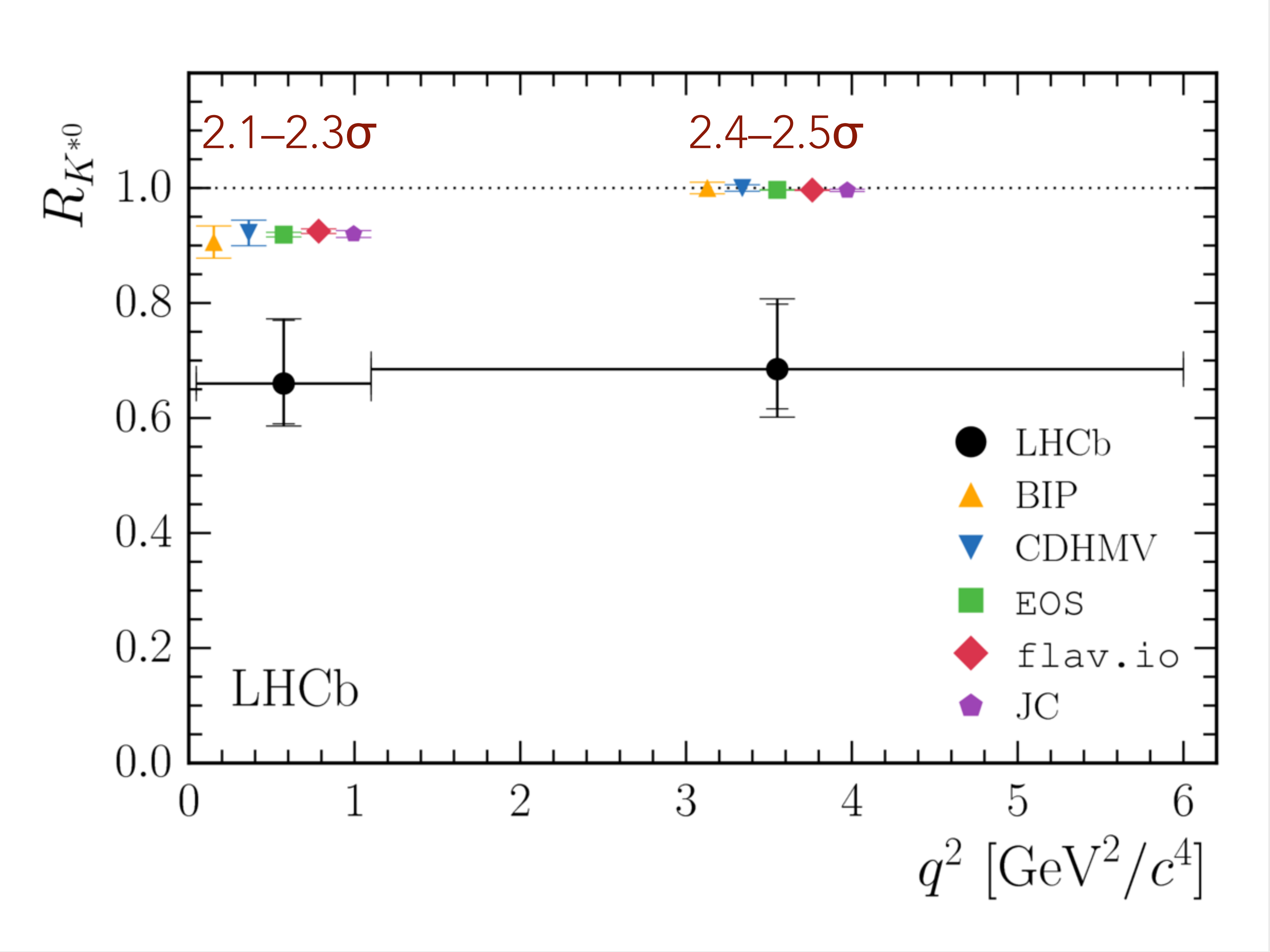
[JHEP 08 (2017) 055]

COMPLEXITY FROM ELECTRONS

Calculation of R_{K*} requires combination of likelihoods for each trigger category



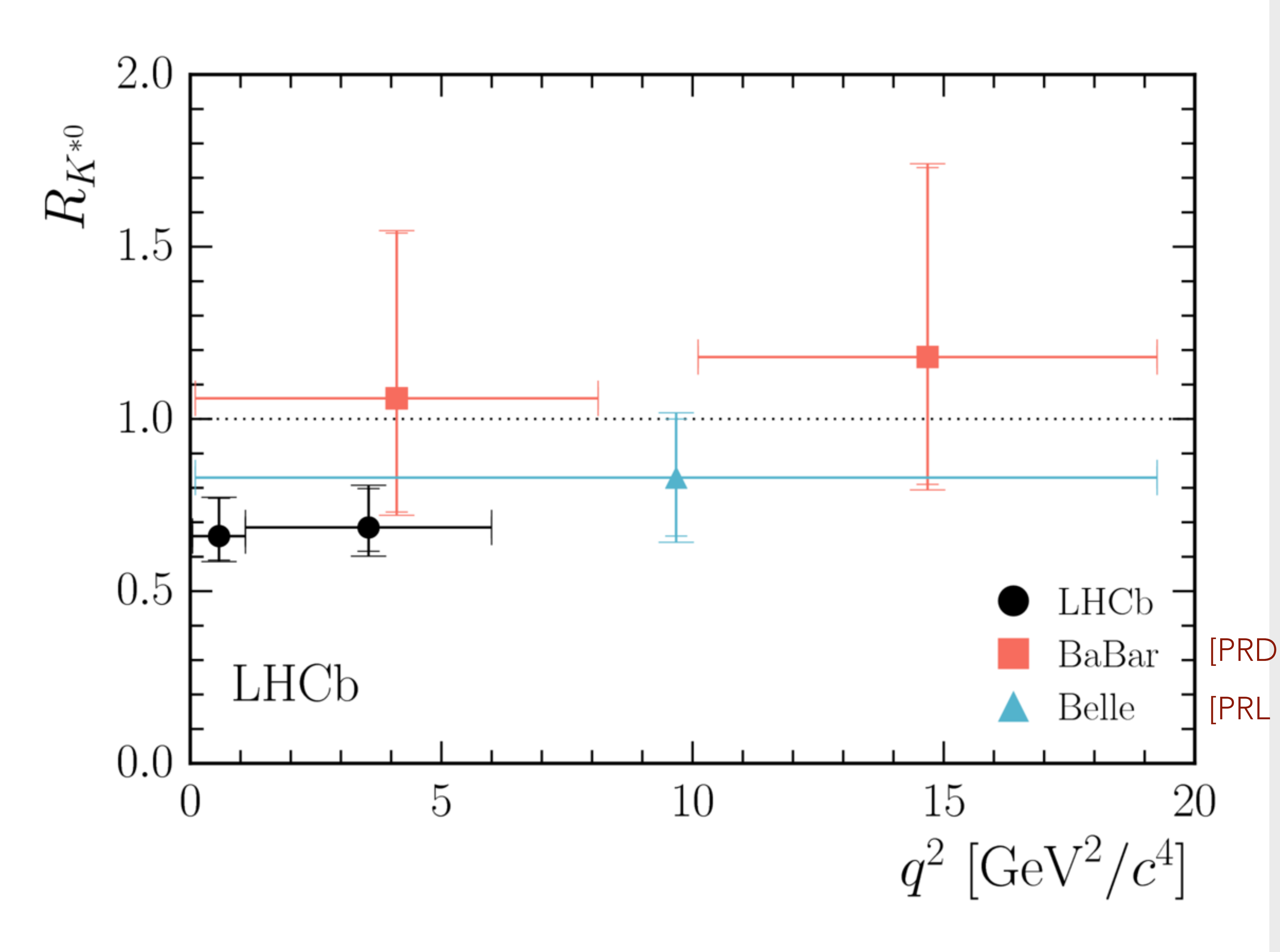
R_{K^*} RESULT



2.1–2.3σ
2.4–2.5σ
$R_{K^{*0}}$
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
q^2 [GeV^2/c^4]
LHCb
BIP
CDHMV
EOS
flav.io
JC
LHCb

[JHEP 08 (2017) 055]

R_{K^*} RESULT



[PRD 86 (2012) 032012]
[PRL 103 (2009) 171801]

THE FUTURE OF LFU

Full battery of R_X measurements ongoing, with similar strategies to R_{K^*}

- Updated R_K, $R_{K\pi\pi}$, R_{φ}, R_{pK}, R_{Λ}, R_{KS}…
- Potential for NP observation at the end of Run II

Measurement of LFU in angular distributions, especially in $B^0 \to K^* \ell \ell$

- $P_5'(\mu)$ - $P_5'(e)$ has reduced sensitivity to systematic effects of electron reconstruction, connected to anomalies in muonic P_5' measurement
- First measurement done by Belle [arXiv:1612.05014]

THE FUTURE OF LFU

Full

strat

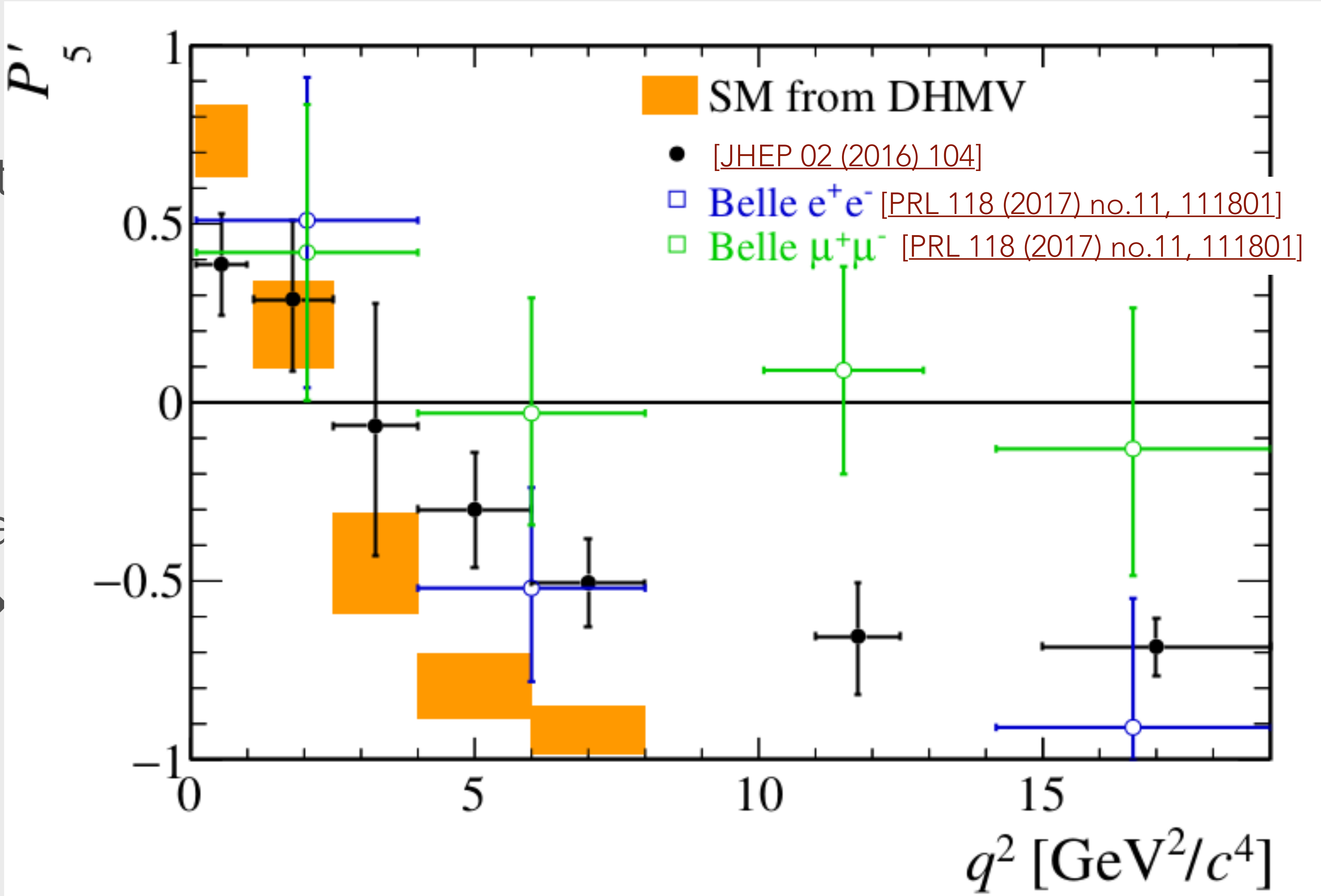
▪

▪

Mea in

$B^0\to$

▪ ,



▪ First measurement done by Belle [arXiv:1612.05014]

CONCLUSIONS

Performing analyses with electrons at LHCb is a challenging and nuanced task

Results using Run I data have had a large impact

Angular analysis of $B^0 \rightarrow K^*ee$ currently provides some of the best constraints on photon polarisation

LFU tests have resulted in tensions that add to those observed in $b \rightarrow s\mu\mu$, showing enormous potential to NP

- See E. Smith's talk for more details!

STAY TUNED FOR EXCITING RESULTS!

– THANK YOU