GDR-InF workshop - LPNHE 8-9 July 2019
“QED corrections to (semi-)leptonic B decays”

Electron reconstruction at LHCb and Belle II

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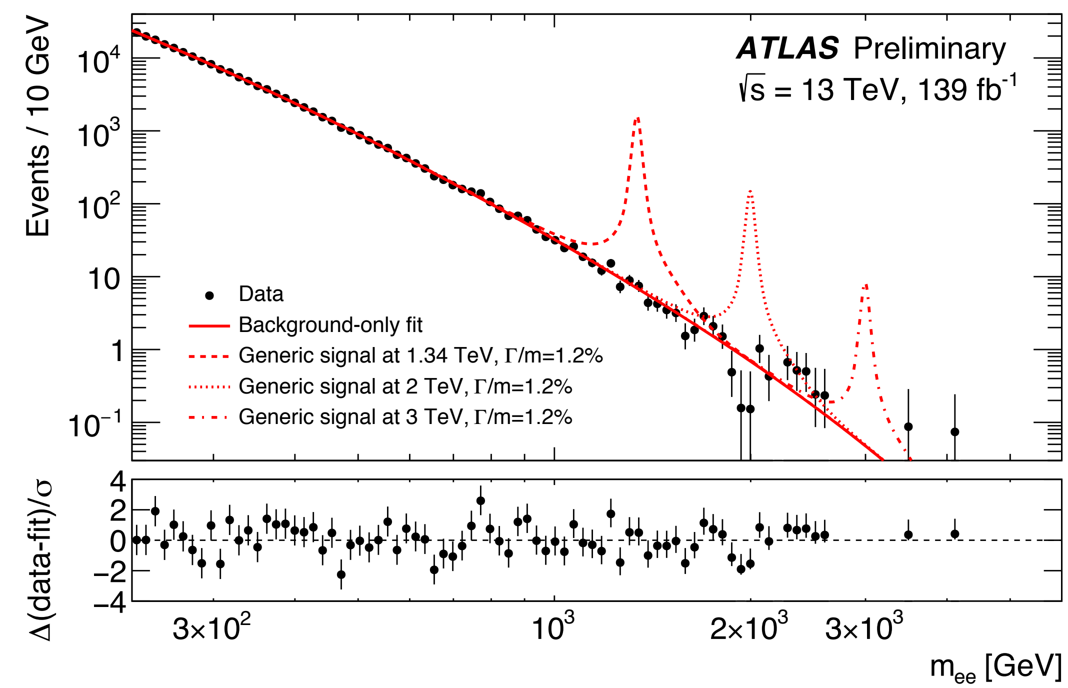
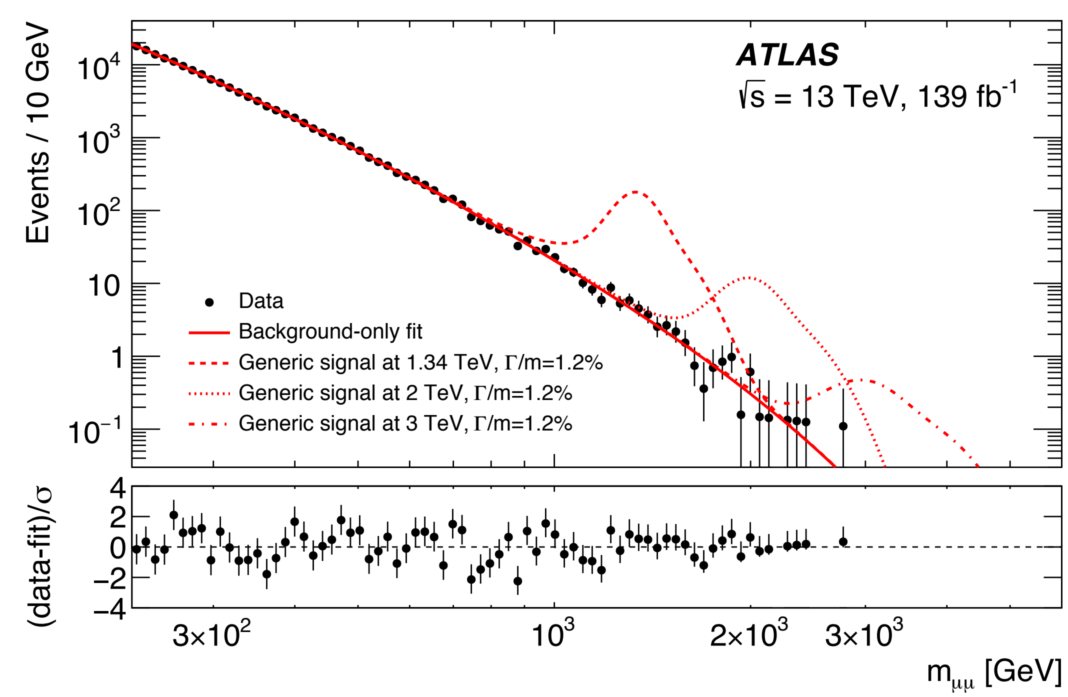
Electrons at GPDs

- ATLAS and CMS reconstruct $e^{\pm}$ as well as $\mu^{\pm}$ (if not better)
  → True, cause they are interested mainly in larger energies
  1. Good $E(e^{\pm})$ resolution from ECal
  2. Can trigger efficiently $e^{\pm}$ in ECal despite busy LHC environment



arXiv:1903.06248



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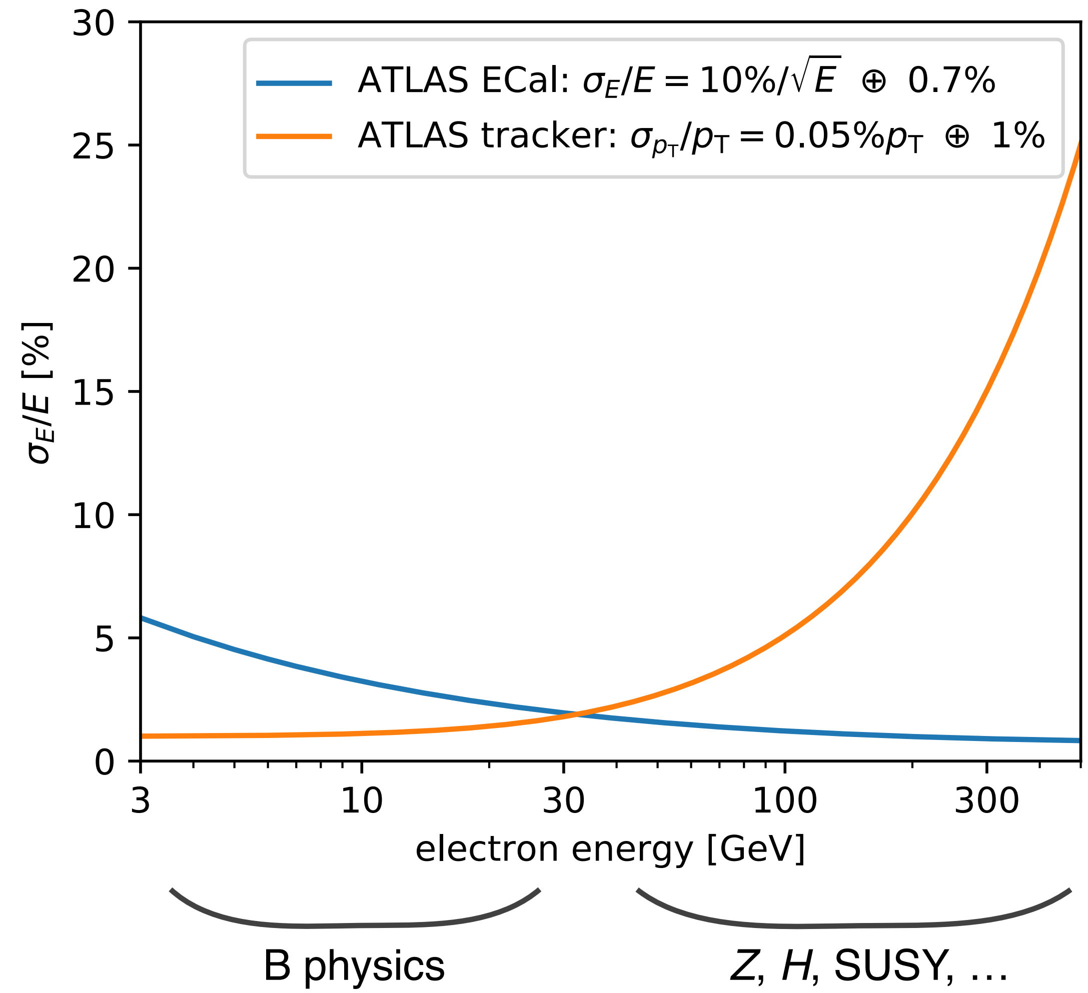
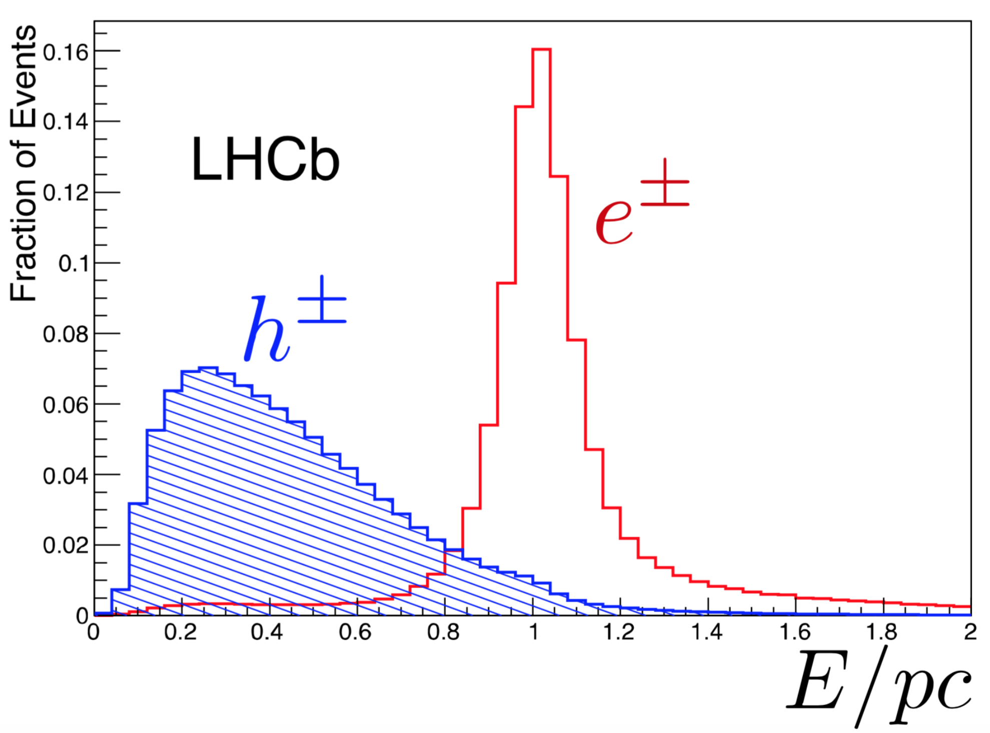
Electrons for *B* physics

- In energy range relevant for B physics at the LHC, electron energy is measured with the tracker, not with the ECal
- ECal used for electron identification and bremsstrahlung recovery



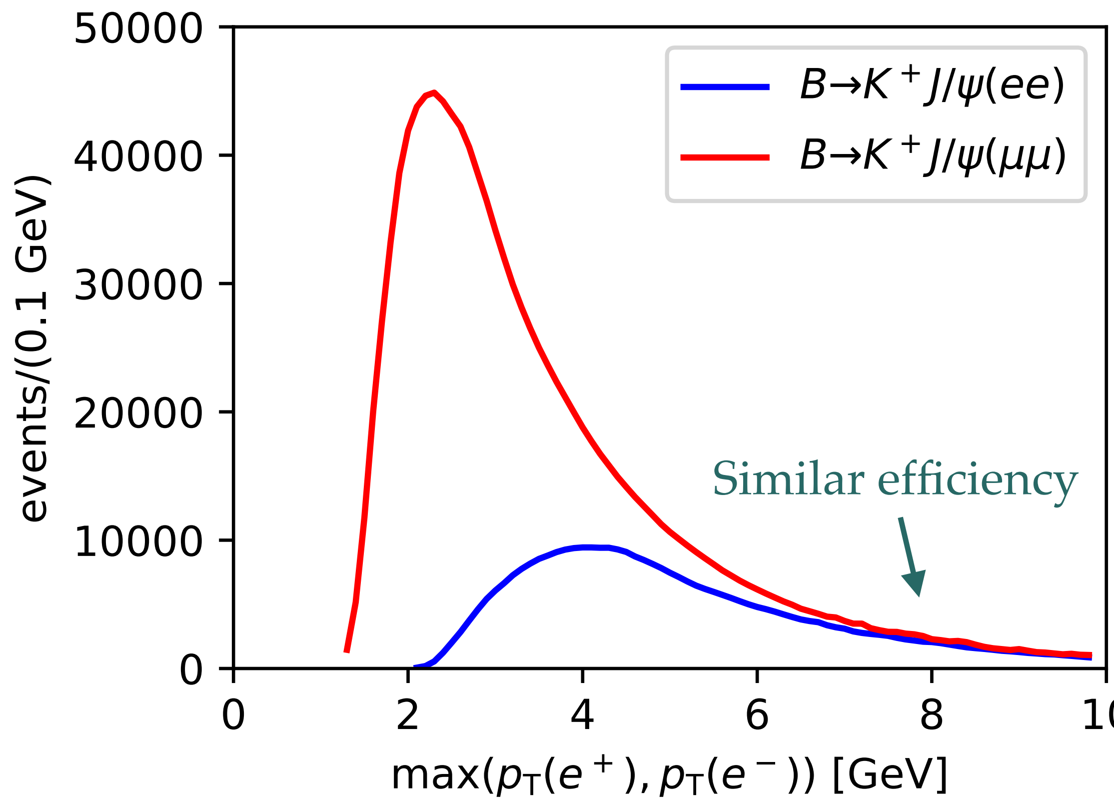
Electron ID at LHCb



- Both true also for Belle II despite lower energy range

LHCb electron efficiency

- LHCb discards low-p_T electrons
  - Cannot do hardware trigger with ECal
    - ECal threshold at $E_T > 3.5$ GeV
  - Can get swept out of acceptance due to brem loss (80% efficiency at $p_T = 1$ GeV)
  - Come with larger combinatorial (MVA cut)
  - However, $e^{\pm}$ vs $\pi^{\pm}$ separation is excellent at low momentum below RICH threshold (RICH1: 2.6 GeV, RICH2: 4.4 GeV)



Phys. Rev. Lett. 122, 191801 (2019)

- Comparing first and second R_K:
  - Large efficiency improvement
- Could do better in LHCb upgrade (no hardware trigger bottleneck)

Analysis	$B^+ \to K^+ J/\psi(\mu\mu)$	$B^+ \to K^+ J/\psi(ee)$	B^+ in LHCb	$\varepsilon(ee)/\varepsilon(\mu\mu)$
1st R_K	667k	88k	130b	**13%**
2nd R_K	1162k	344k	270b	**30%**
2nd / 1st	1.7	**3.9**	**2.1**	

Belle(II) electron efficiency

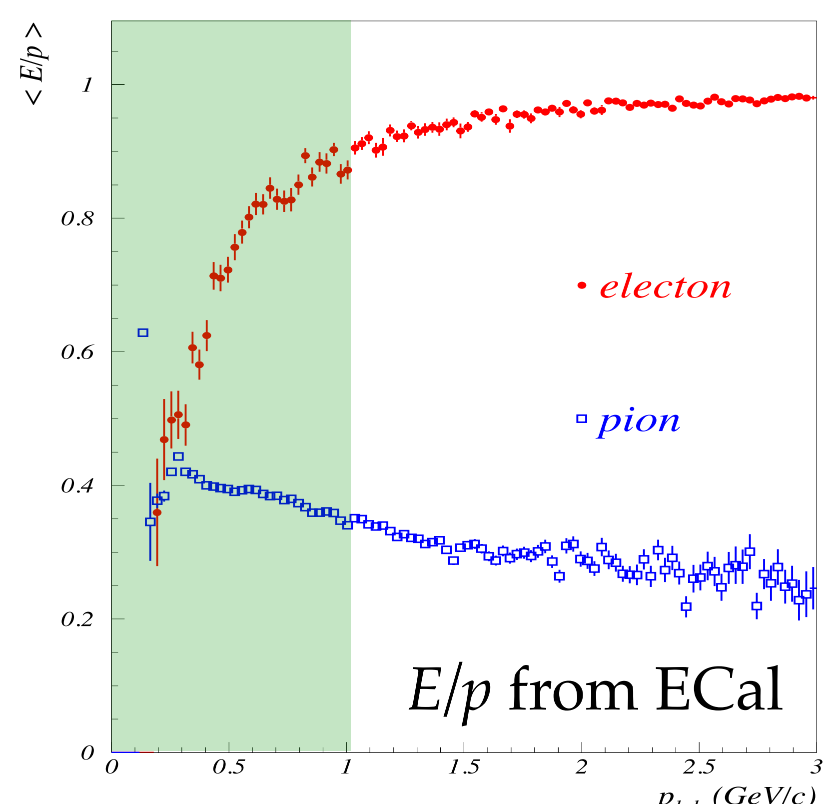
- Much smaller differences between $\mu^\pm$ and $e^\pm$ in Belle(II)
- Tracking efficiency similar to $\mu^\pm$
- Efficiency difference mainly due to tighter $e^\pm$ PID requirements (based on ECal rather than KLM)

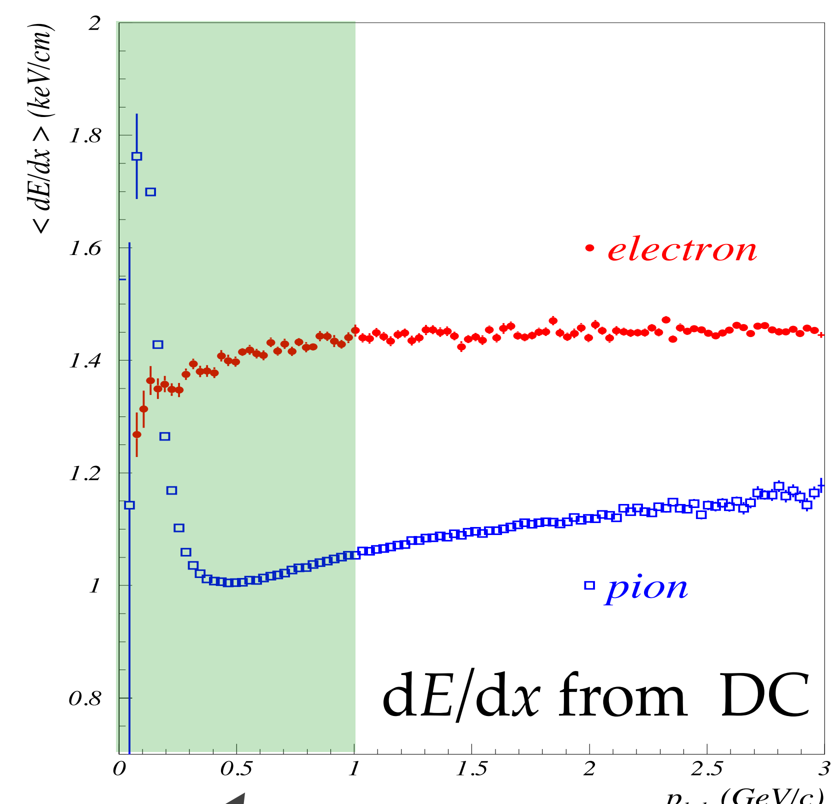
Simon Where PhD thesis and Phys. Rev. Lett. 118, 111801

Analysis	$\varepsilon(B\to K^{*0}\mu\mu)$	$\varepsilon(B\to K^{*0}ee)$	$\varepsilon(ee)/\varepsilon(\mu\mu)$
Angular $K^*\ell\ell$ q^2= [1,6] GeV^2	15.3%	12.7%	83%

- Excellent PID from
  - E/p from ECal
  - Shower shape in ECal
  - dE/dx from drift chamber
  - Cherenkov light in aerogel (TOP)

Nucl.Instrum.Meth.A485:490-503,2002





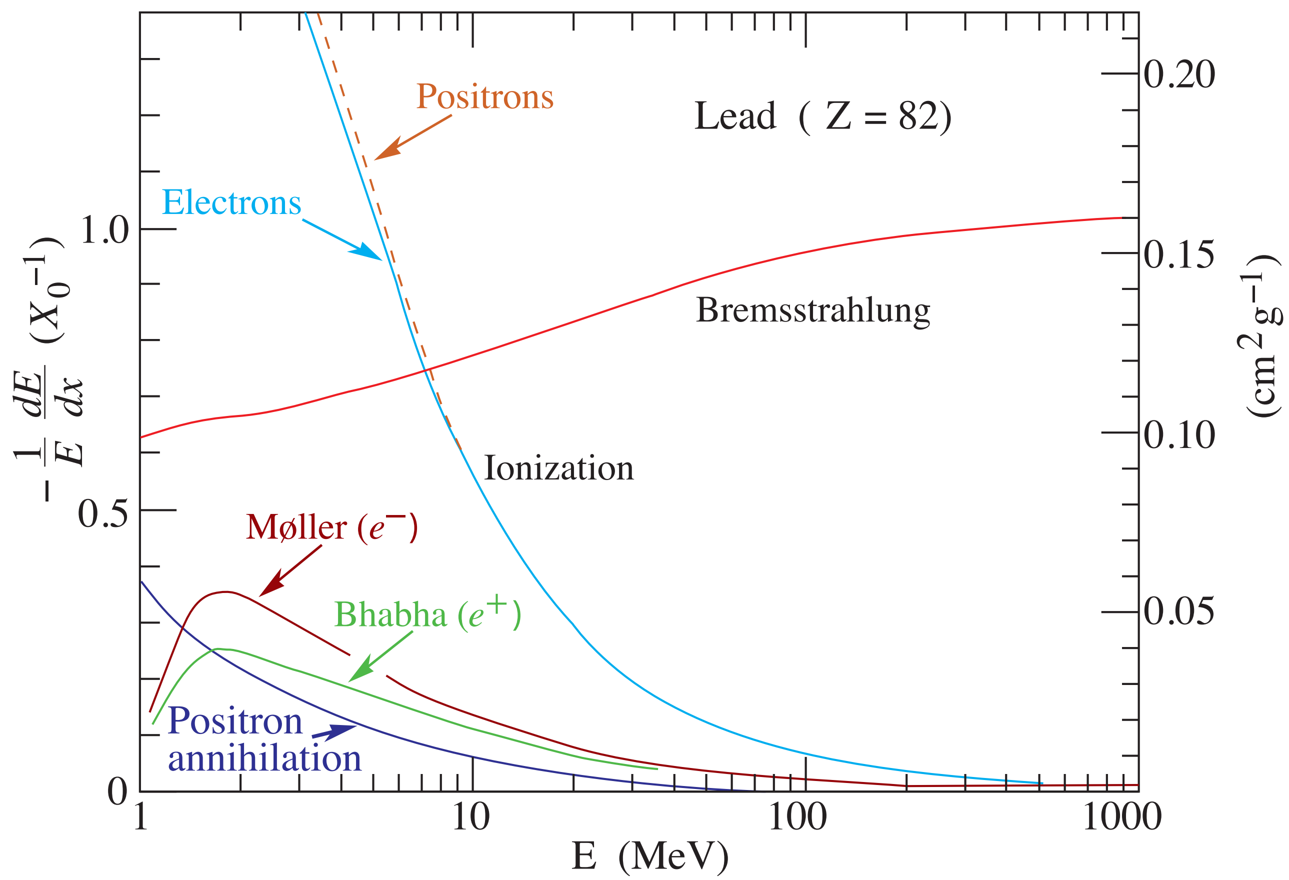
$\pi^\pm$ don't produce Cherenkov light

Bremsstrahlung at LHCb and Belle (II)

Bremsstrahlung

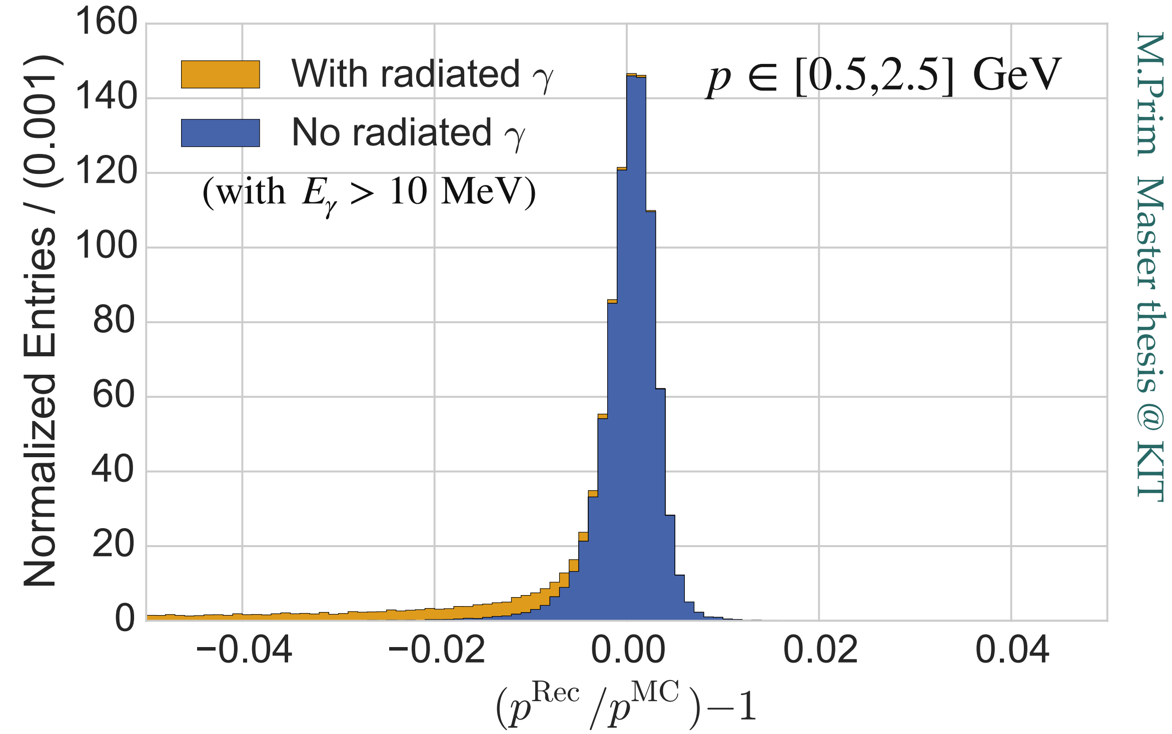
- Common misconception:
  - Relevant bremsstrahlung effects at LHCb/Belle are not due to the magnetic field used for tracking
  - It's the interaction with the detector material (Coulomb field of atoms)
  - Probability goes with $E/m^2 \to$ mainly affecting electrons
- Energy loss due to bremsstrahlung rises linearly with $e^{\pm}$ energy
  → fractional loss roughly independent of $e^{\pm}$ energy
  (easier to model)

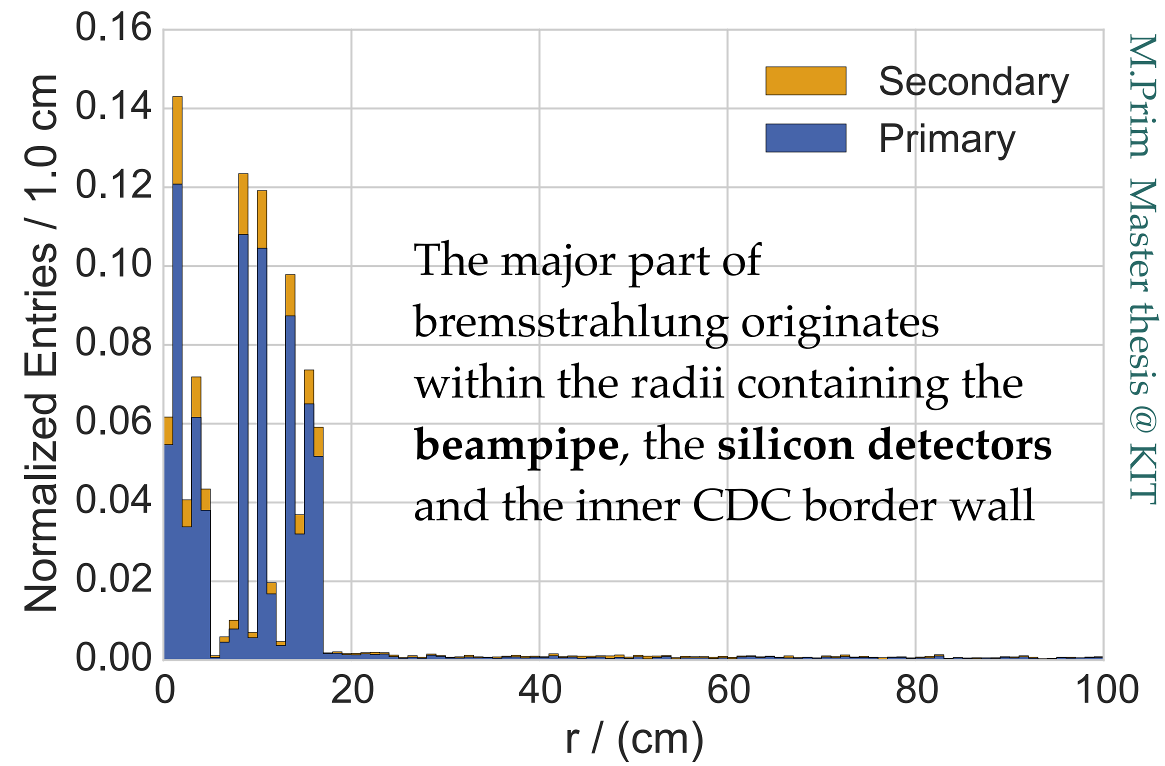
PDG



Brem reco at Belle

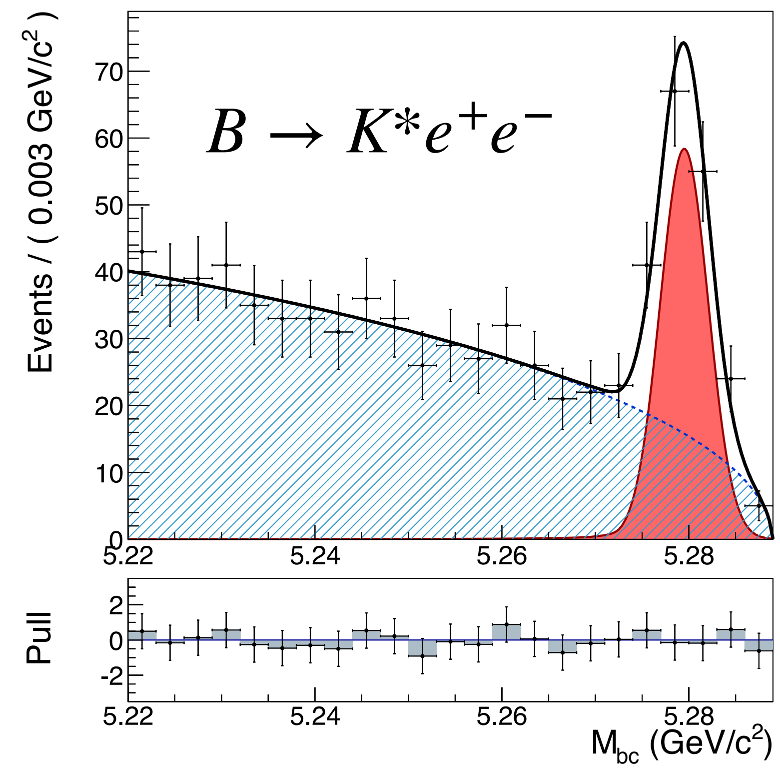
- Belle ECal threshold to reconstruct neutral deposit is 10 MeV
- Probability to emit at least a brem ($E_\gamma > 10$ MeV) is about 25%
- Brem emission results in kinked track
  - Effects considered via noise matrix in track fit
  - Work ongoing to improve this using information on the material distribution
- In Belle energy loss from bremsstrahlung is recovered by adding back the energy of photons in a cone of 0.05 rad around the $e^\pm$
  - Sensitive to beam-induced background
  - Work ongoing to optimise procedure for Belle II



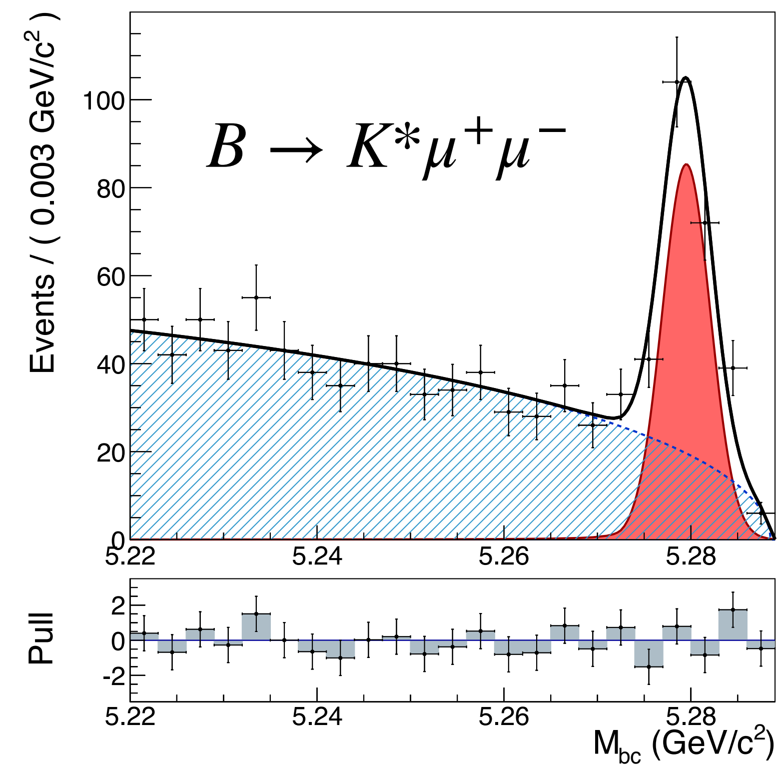


Belle brem correction

- Use beam-energy constrained mass $M_{\text{bc}} = \sqrt{E_{\text{beam}}^{\star 2} - \boldsymbol{p}_B^{\star 2}}$
  - Less dependence on measured momenta: $\sigma^2_{M_{\text{bc}}} \approx \sigma^2_{E^\star_{\text{beam}}} + \left(\frac{p^\star_B}{m_B}\right)^2 \sigma^2_{p^2_B}$ and $p^*_B/m_B \simeq 0.06$
- **Muon and electron modes look identical in beam-energy constrained *B* mass**
- Bremsstrahlung effect enter only in the q^2 bins definition
  - $-0.25\ \text{GeV} < m(ee) - m_{J/\psi} < 0.08\ \text{GeV}$
  - $-0.15\ \text{GeV} < m(\mu\mu) - m_{J/\psi} < 0.08\ \text{GeV}$



Phys. Rev. Lett. 118, 111801



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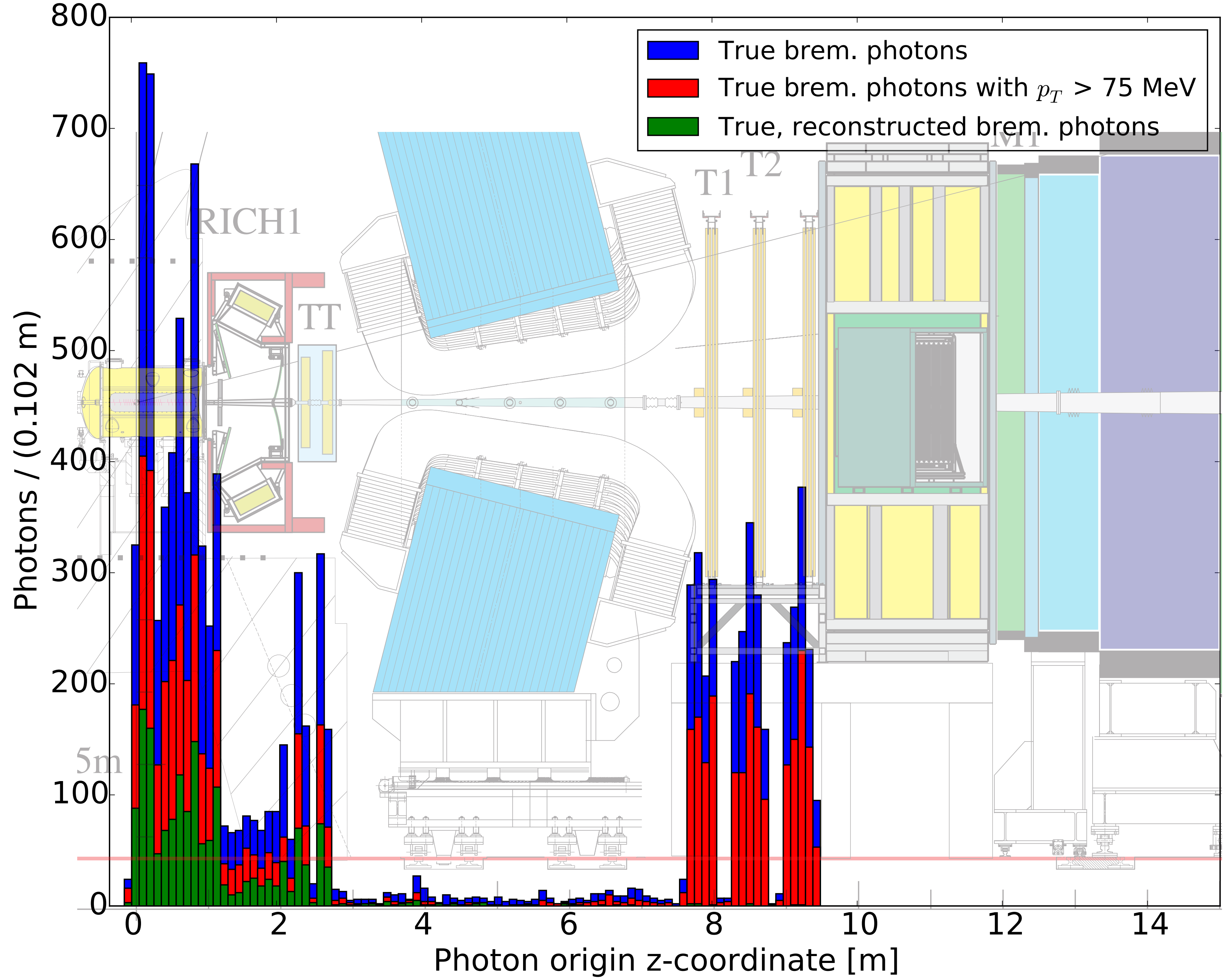
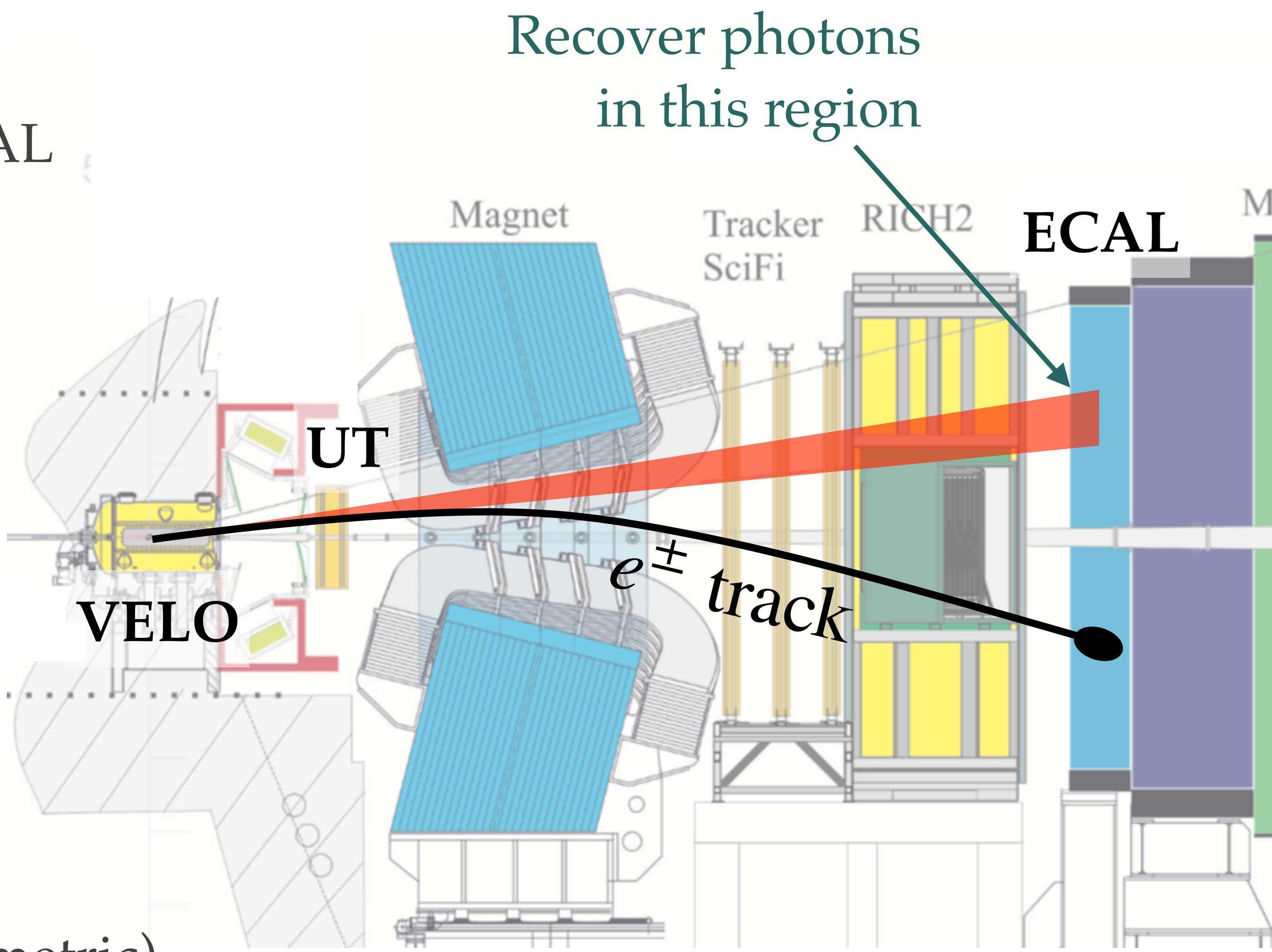
Brems emitted at LHCb

- Most brem emission due to material interaction
- If emitted before the magnet can affect momentum measurement
- Try to find brem photon and add its energy back



Brem recovery at LHCb

- LHCb brem recovery algorithm:
  - Extrapolate upstream $e^{\pm}$ track to the ECAL
  - Take all reconstructed neutral clusters with $E_{\mathrm{T}} > 75$ MeV
  - Add them back to electron momentum
- Main shortcomings
  - ECAL energy resolution worse than tracking resolution
  - Brem can be out of ECAL or too soft
- Electrons with brem recovered:
  - Better momentum resolution (more symmetric)
  - Better particle identification ($\pi^{\pm}$ don't emit brem)
- What if no brem is found?
  → most of the time it was missed

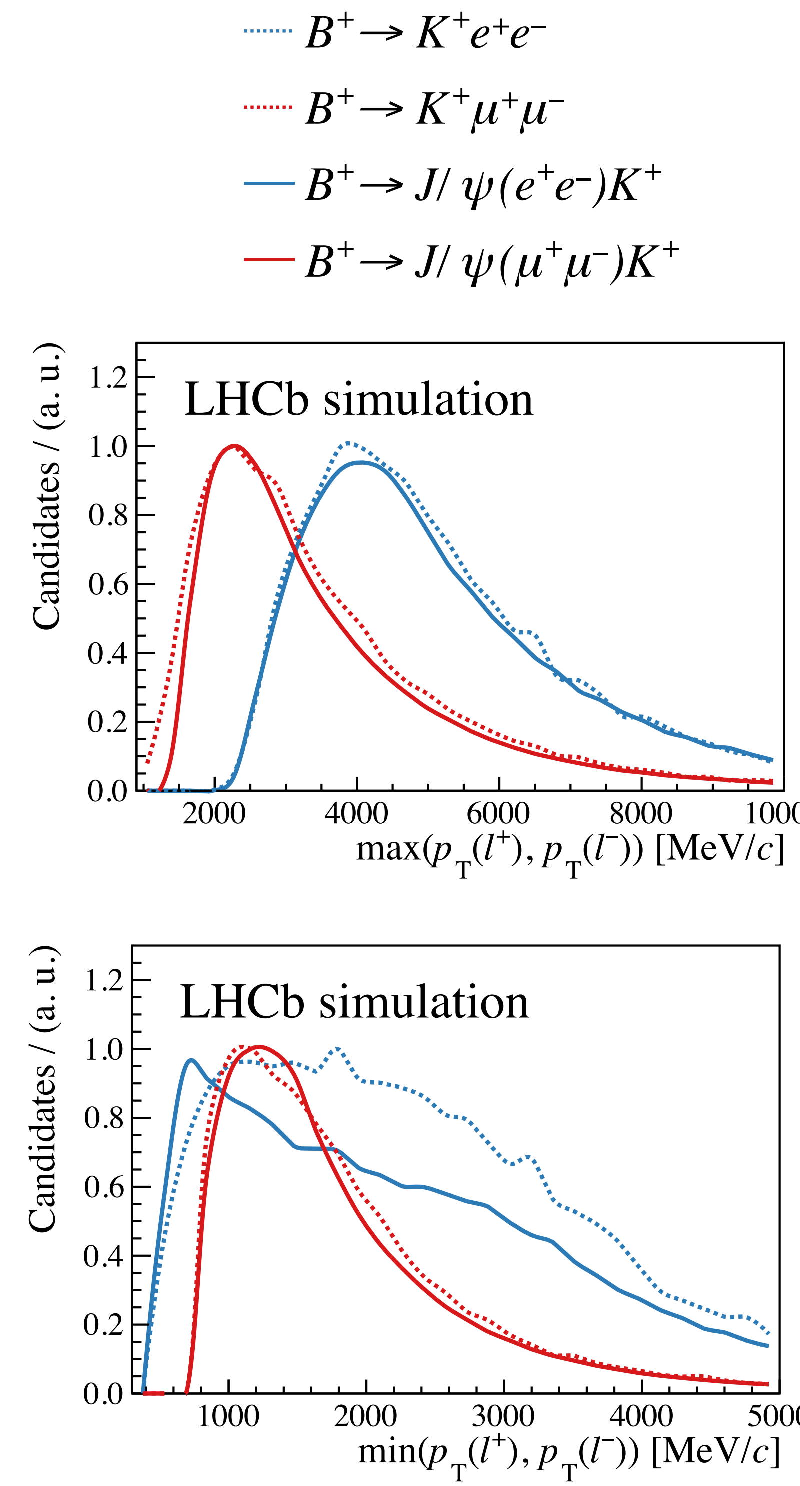


Brems emitted at LHCb

- How many brem/electron are typically emitted?
  - $E(e^{\pm}) > 10$ GeV complete screening approximation
  - Material budget before magnet: $d \simeq 38\,\%\,X_0$
  - $p_{\mathrm{T}}(e^{\pm}) \sim 3$ GeV $\;\Rightarrow \min(E_{\mathrm{T}}(\gamma)) = 75$ MeV $= 2.5\,\%$
  - Average number of brem emitted with at least 2.5% of the $e^{\pm}$ energy

$$< N_\gamma > = \frac{d}{X_0}\left[\frac{4}{3}\ln\left(\frac{k_{\max}}{k_{\min}}\right) - \frac{4\,(k_{\max}-k_{\min})}{3E} + \frac{k_{\max}^2 - k_{\min}^2}{2E^2}\right] \simeq 1$$

  - **At LHCb most electrons emit one energetic brem before the magnet**



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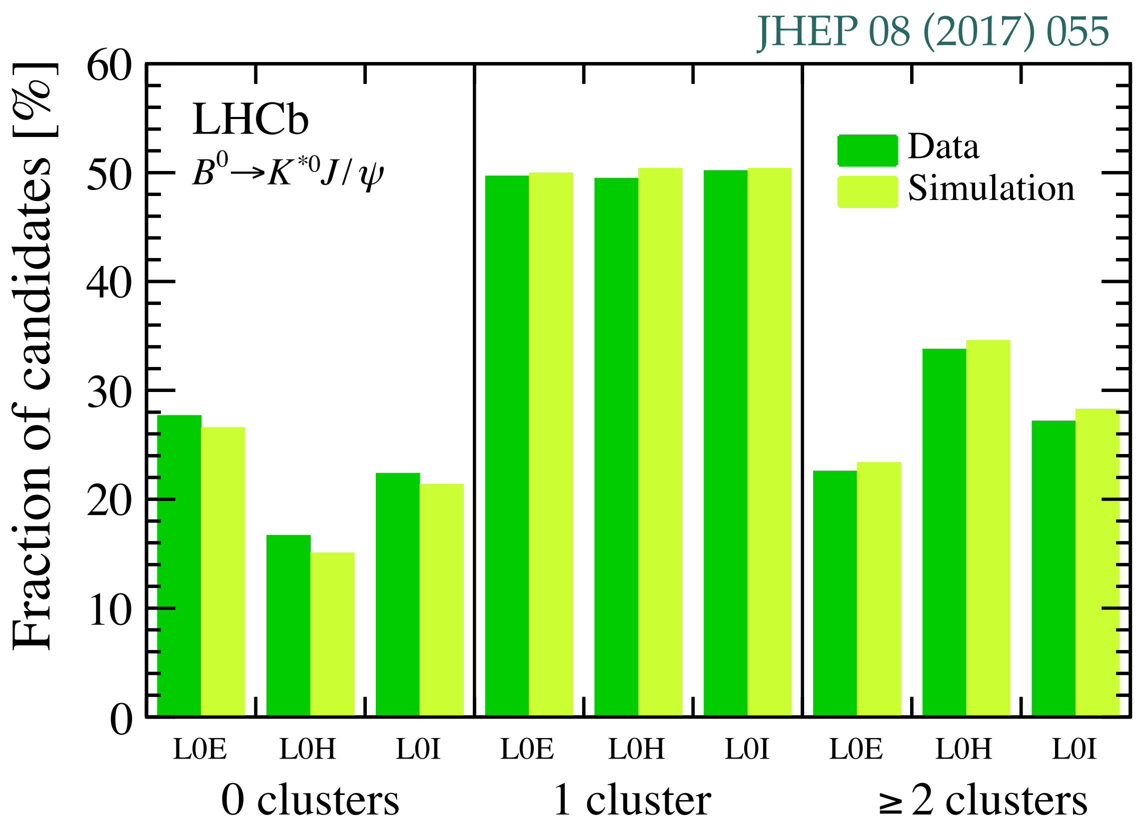
Brem recovery at LHCb

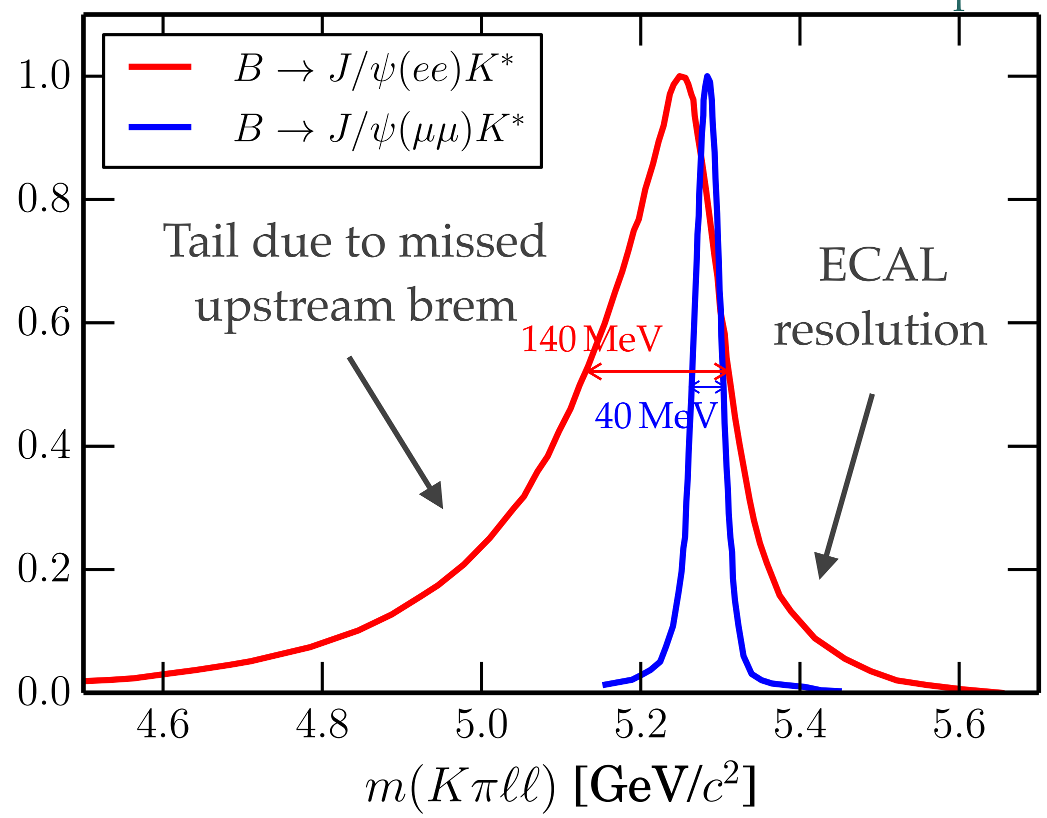


- Assuming every $e^{\pm}$ emits one brem and probability of brem recovery (P) is uncorrelated among e^{+} and e^{-}:

$$
\begin{aligned}
1 &= f^{ee}_{2\mathrm{cl}} + f^{ee}_{1\mathrm{cl}} + f^{ee}_{0\mathrm{cl}} \\
&= P^2 + 2P(1-P) + (1-P)^2 \\
&\Rightarrow P \simeq 50\,\%
\end{aligned}
$$

B mass resolution at LHCb

unofficial plot



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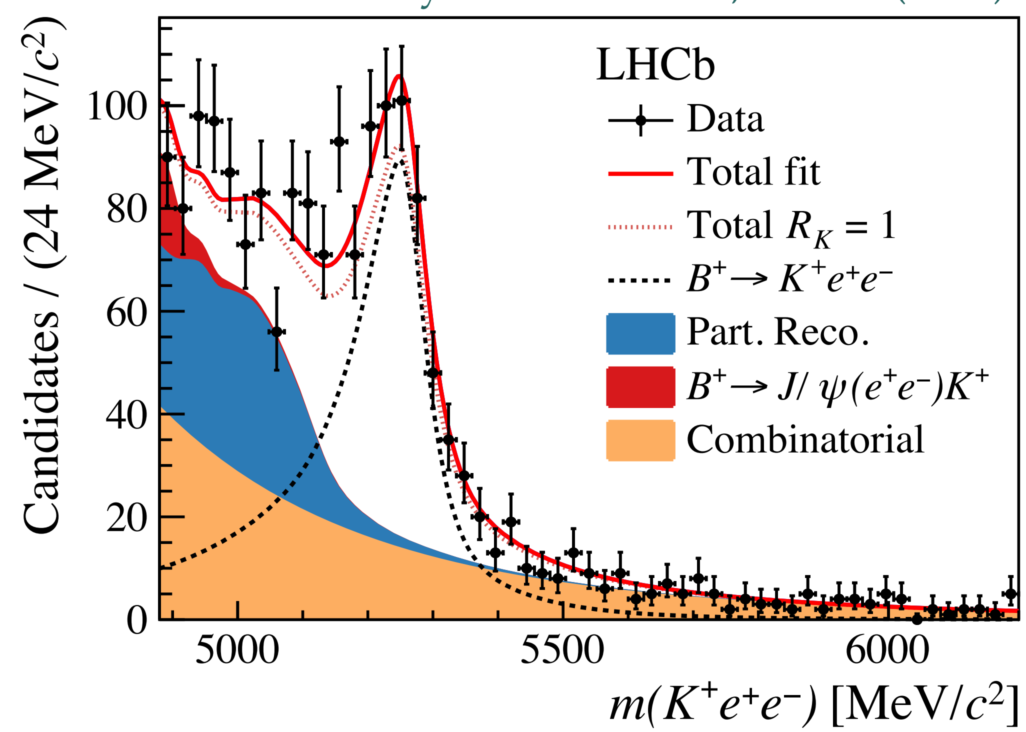

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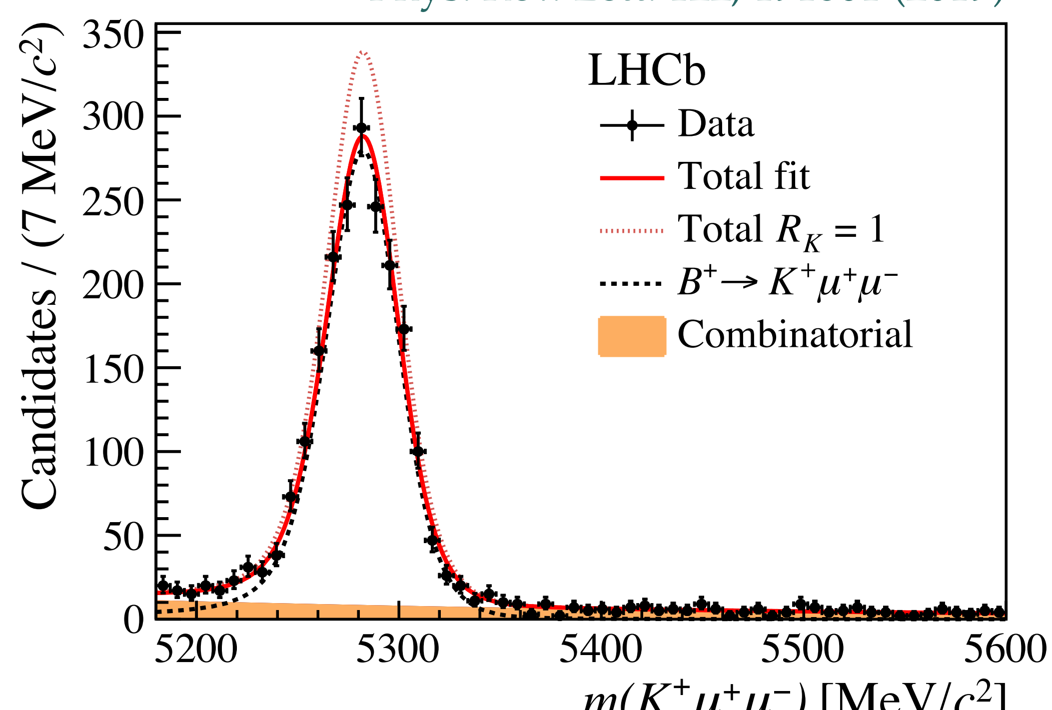
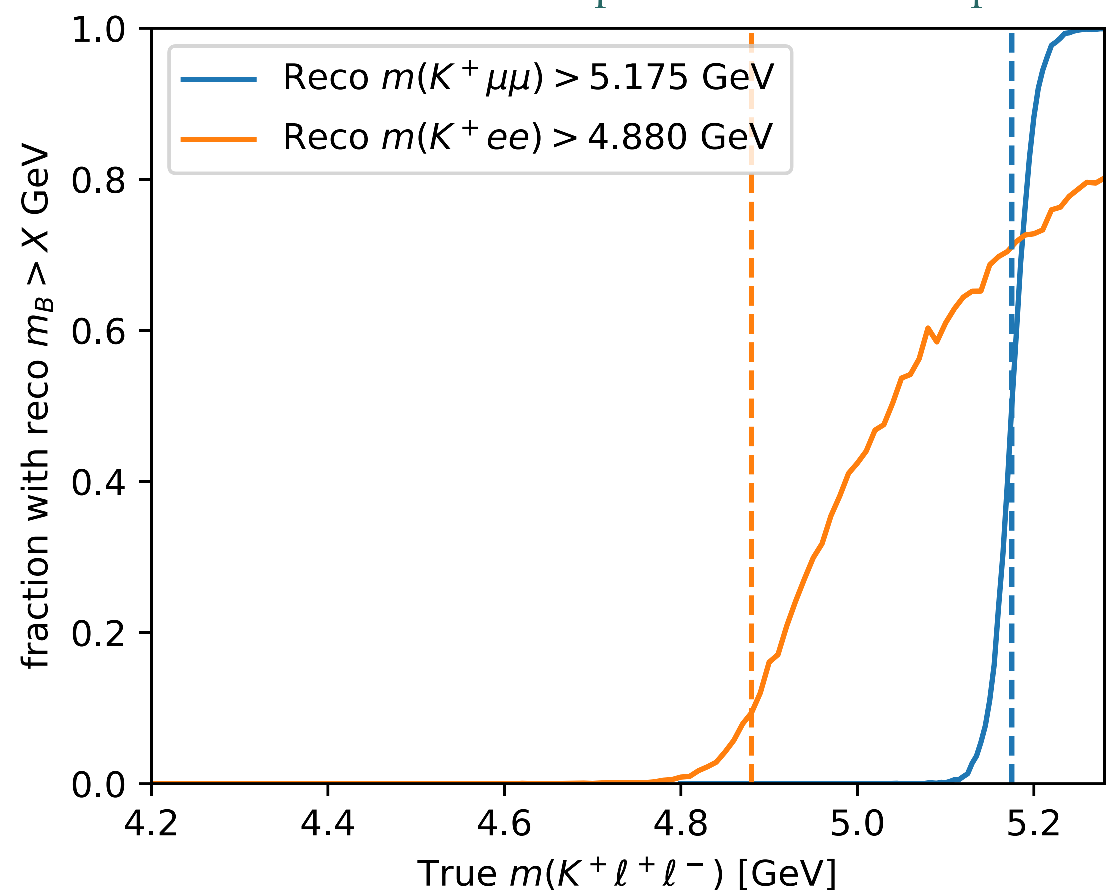


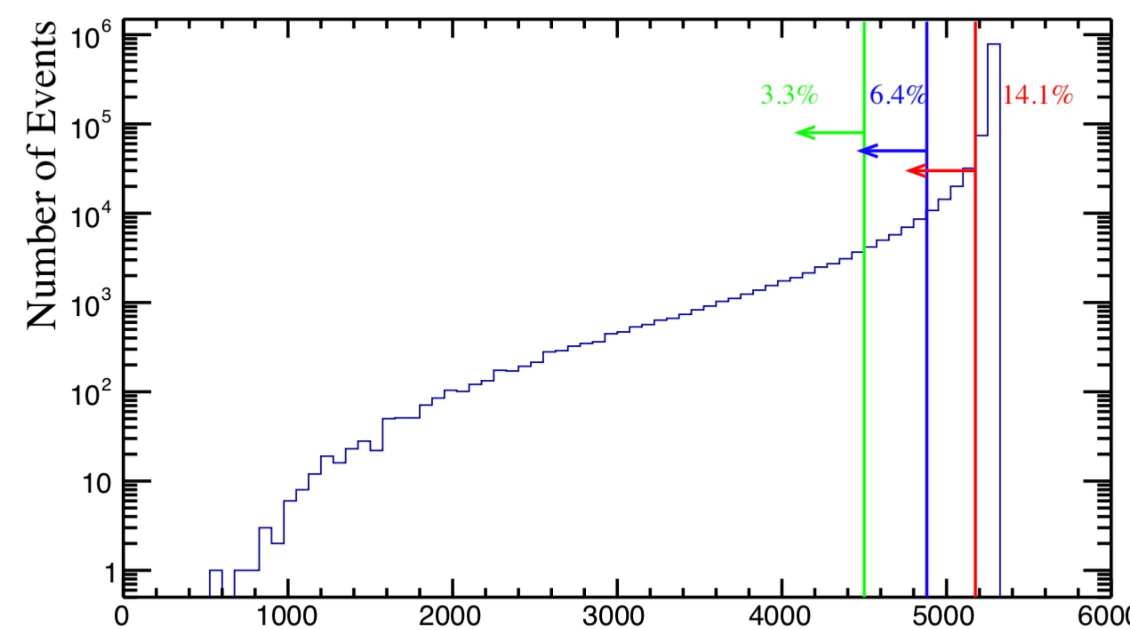
- B mass resolution essential to separate signal from partially reconstructed and combinatorial

Minimum reconstructed B mass

- Maybe one should take into account $m(K\ell\ell)$ resolution when testing PHOTOS approximation
- Due to brem losses, minimum true $m(Kee)$ is far from a step function
  - no problem for $m(K\mu\mu)$
- Tested quickly using RapidSim (latest version includes an approximation of brem losses at LHCb)
- Not taking into account FSR recovery through brem adder (included through PHOTOS in actual LHCb simulation)

RapidSim of LHCb response





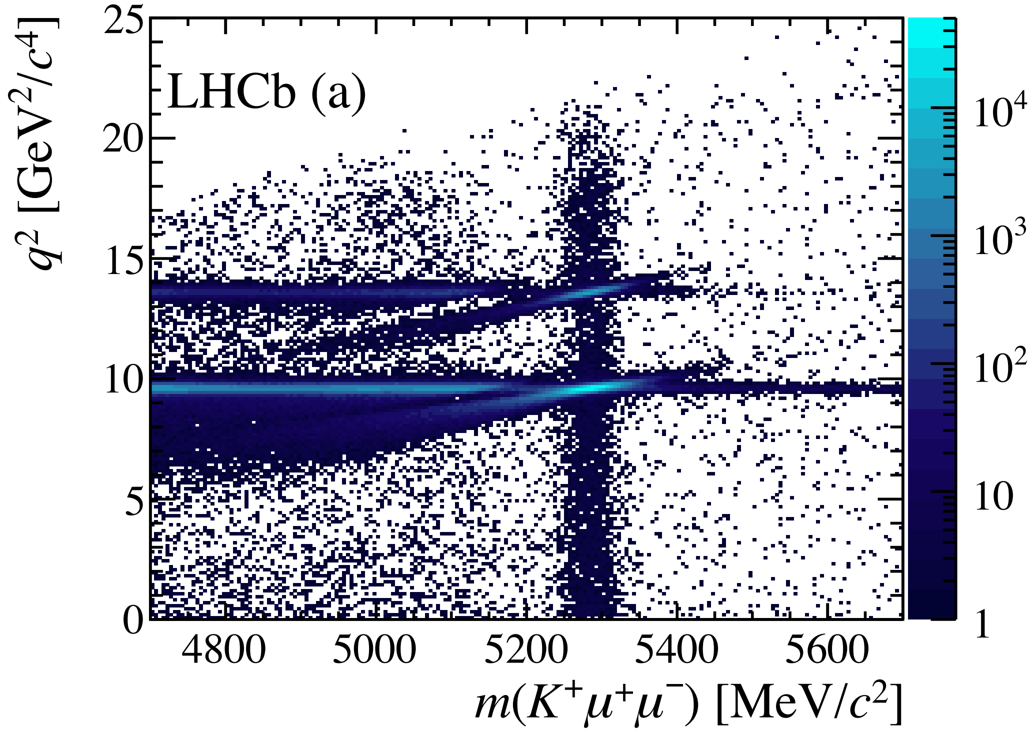
Plot from R.Coutiño

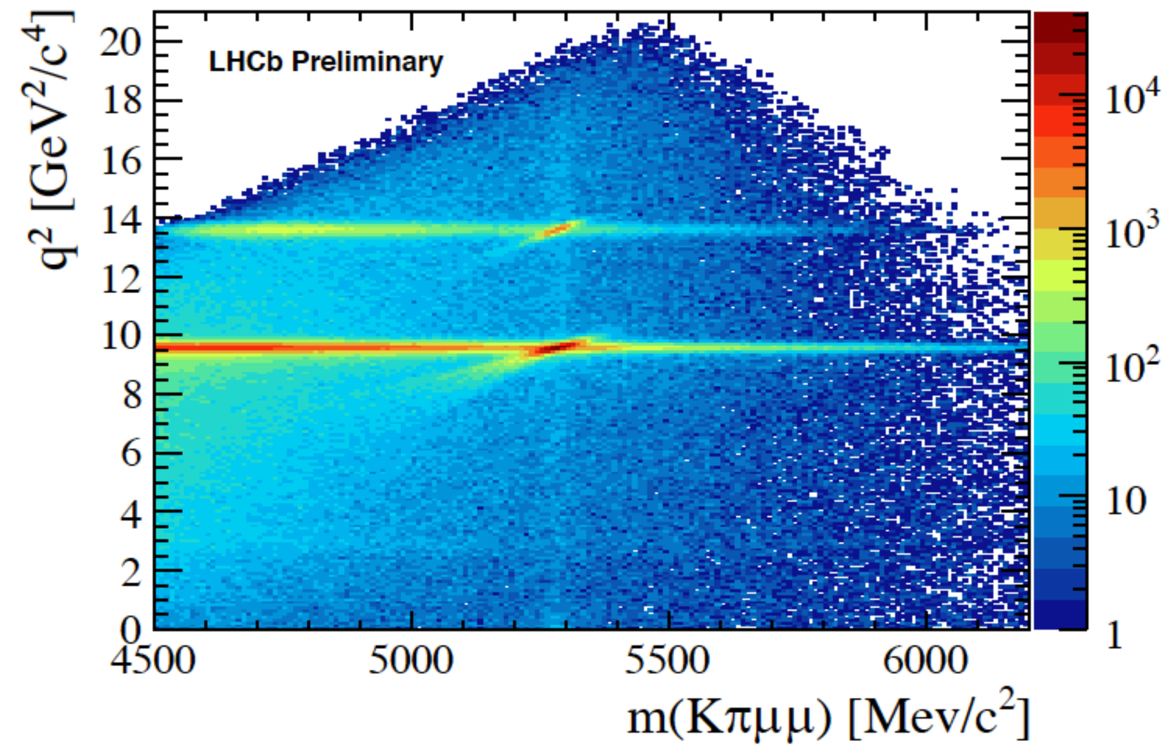
Summary

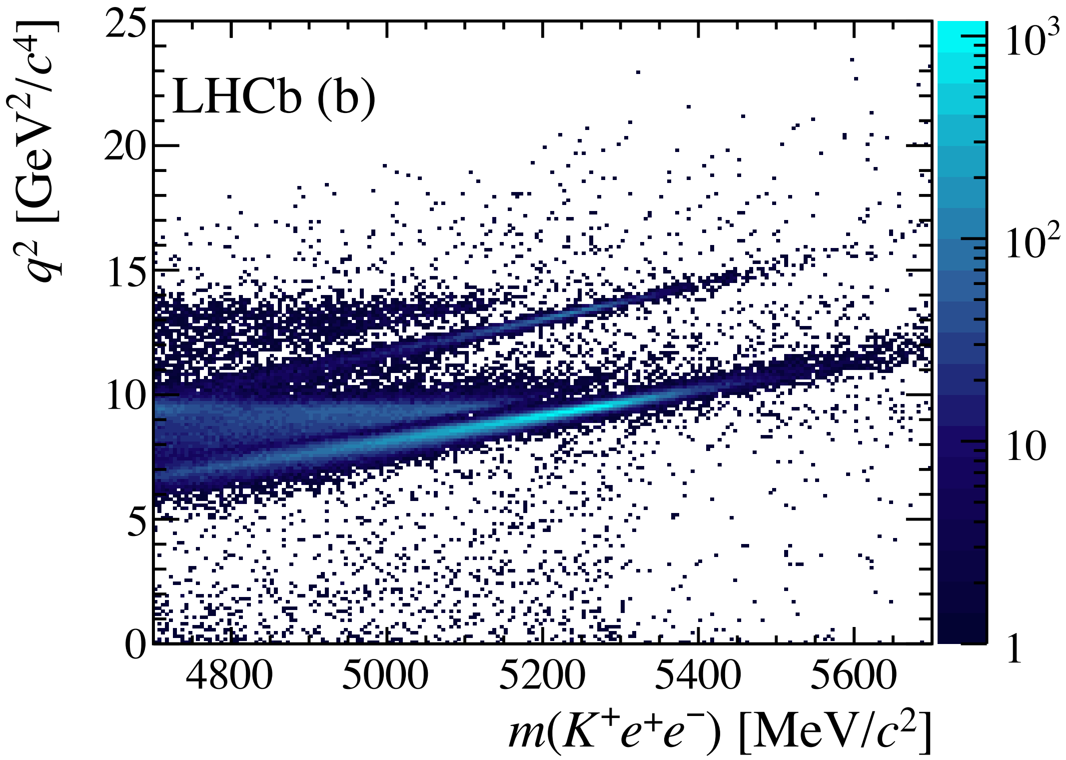
- Electron reconstruction efficiency
  - Belle(II): very similar between $\mu^{\pm}$ and $e^{\pm}$ at
  - LHCb: improved significantly in past years (more expected in upgrade)
- Bremsstrahlung recovery
  - Belle(II): few photons emitted, recovered if $E_{\gamma} > 10$ MeV and within 0.05 rad
  - LHCb: most electrons emit a hard brem before the magnet, recovered with efficiency about 50%
- QED corrections:
  - Need to test PHOTOS using more realistic mass thresholds for LHCb?

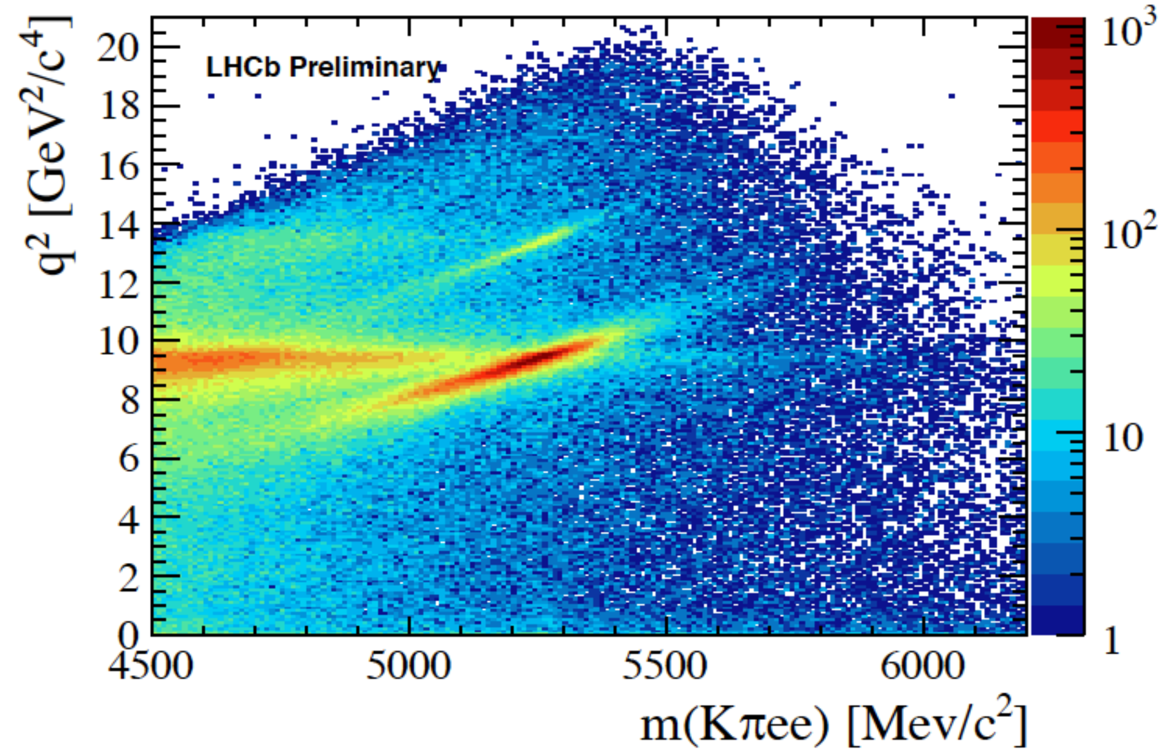
BACKUP

q^2 versus B mass









Double ratio