Lepton Flavour Universality tests at high-q^2

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INTENSITY frontier

GDR-InF

GDR-InF annual workshop
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The RK(*) ratios

LFU in $b \to s\ell\ell$ (FCNC) with $\ell = e,\, \mu$

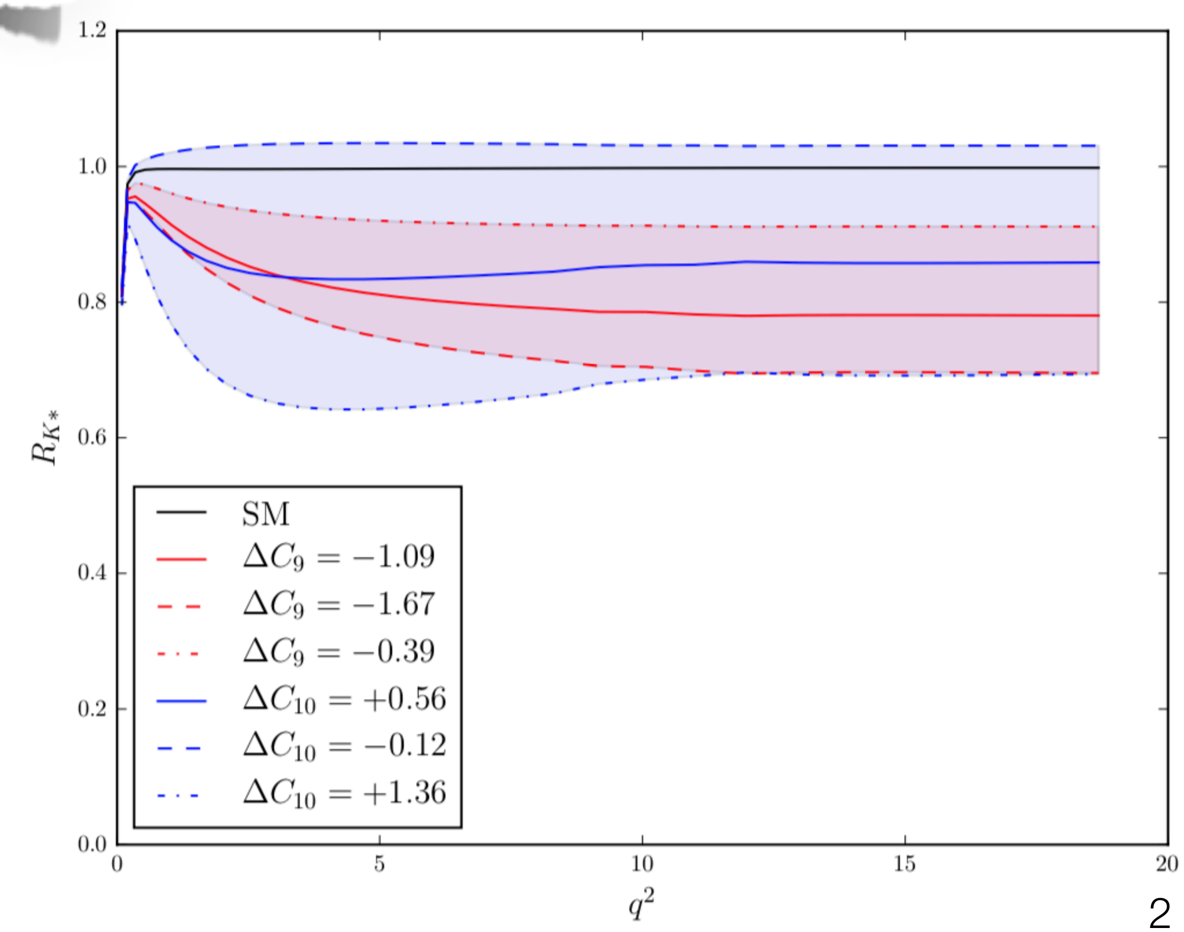
- Measurements of **RK** and **RK***:

$$R_K = \frac{\int_{q^2_{min}}^{q^2_{max}} \frac{d\Gamma(B^+ \to K^+\mu^+\mu-)}{dq^2} dq^2}{\int_{q^2_{min}}^{q^2_{max}} \frac{d\Gamma(B^+ \to K^+e^+e-)}{dq^2} dq^2}$$

$$R_{K*} = \frac{\int_{q^2_{min}}^{q^2_{max}} \frac{d\Gamma(B^0 \to K^{*0}\mu^+\mu-)}{dq^2} dq^2}{\int_{q^2_{min}}^{q^2_{max}} \frac{d\Gamma(B^0 \to K^{*0}e^+e-)}{dq^2} dq^2}$$

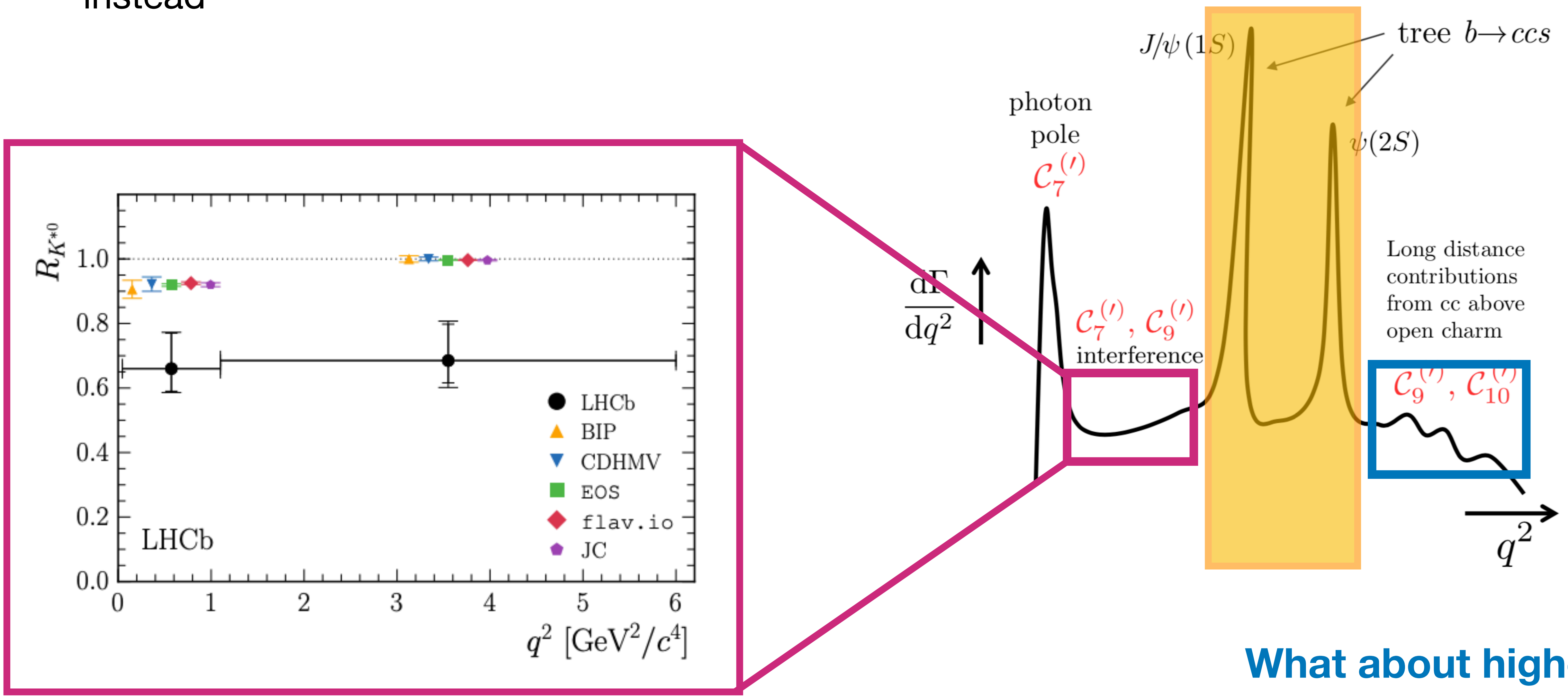
$$q^2 = m(\ell, \ell)^2$$

- Theoretically clean and independent of hadronic terms
- Experimentally accessible
- Expected to be ~ **1** in the SM
- NP could have a dependence in q^2



Completing the q^2 spectrum

- Advantages of performing analysis in **bins of q^2**:
  - NP could have a dependence in q^2 - having a differential analysis helps distinguish different BSM scenarios
  - Exclude $c\bar{c}$ **resonances** (SM contributions dominates) - can be used as **control modes** instead



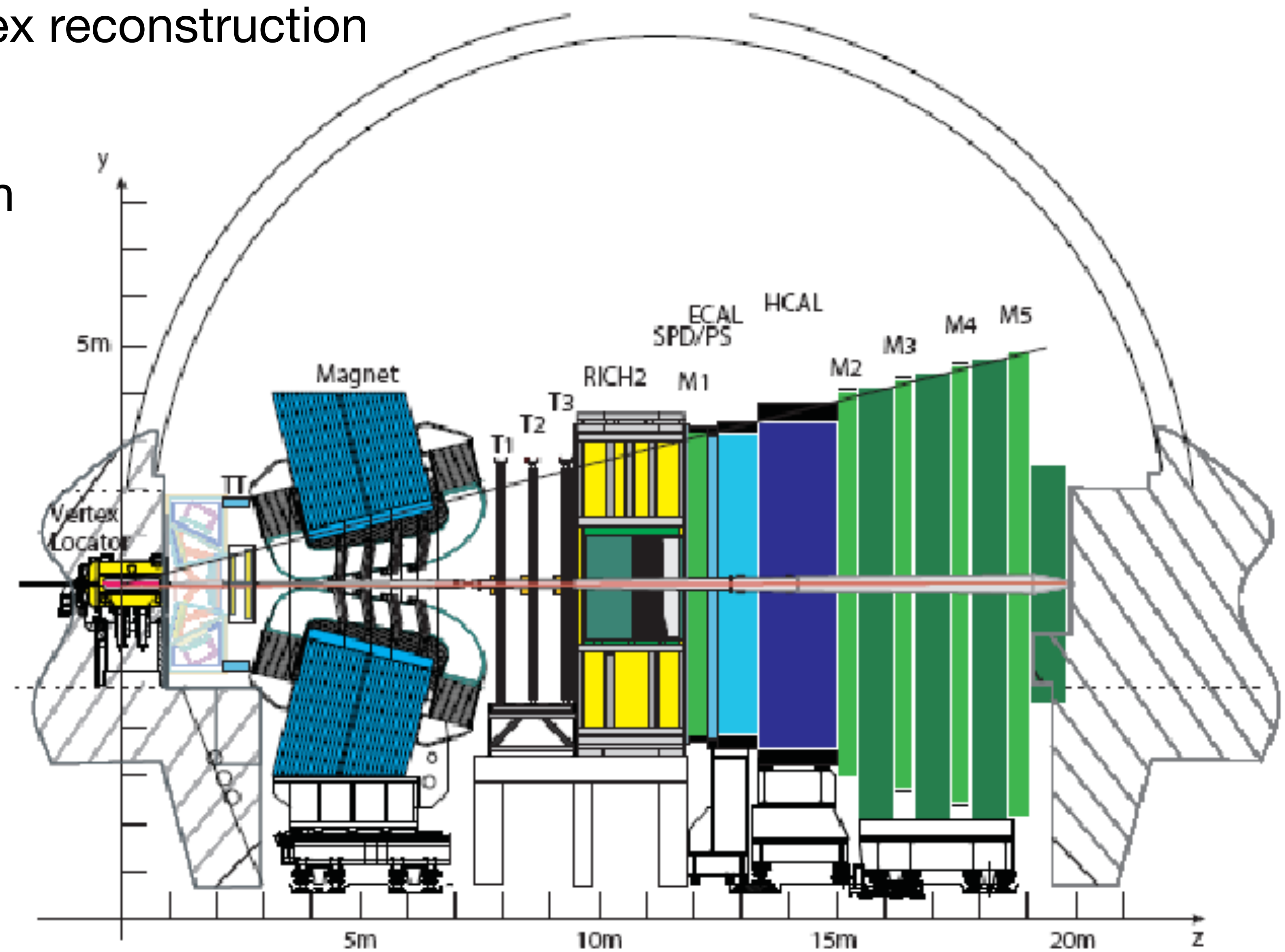
No LHCb measurement above $q^2 = 6\ GeV^2/c^4$

What about higher q^2?

LFU with the LHCb detector

The LHCb experiment at CERN:

- Single-arm spectrometer designed for high-precision flavour physics measurements
- Pseudorapidity range $\eta \in [2, 5]$
- Excellent primary and secondary vertex reconstruction
- Highly efficient particle identification
- Excellent momentum and IP resolution



Electrons and muons at LHCb

- Electrons and muons interact in significantly different ways with the LHCb detector
- Understanding these differences is essential for correctly interpreting LFU ratio measurements

Muon reconstruction:

- Hits from muon stations matched to extrapolated tracks
- Momentum measured from the bending of the track

Electron reconstruction:

- Tracks matched to ECAL clusters
- Momentum measured from the bending of the track

Two main differences:

ECAL has higher occupancy than MS → higher hardware trigger thresholds

Electrons emit Bremsstrahlung radiation

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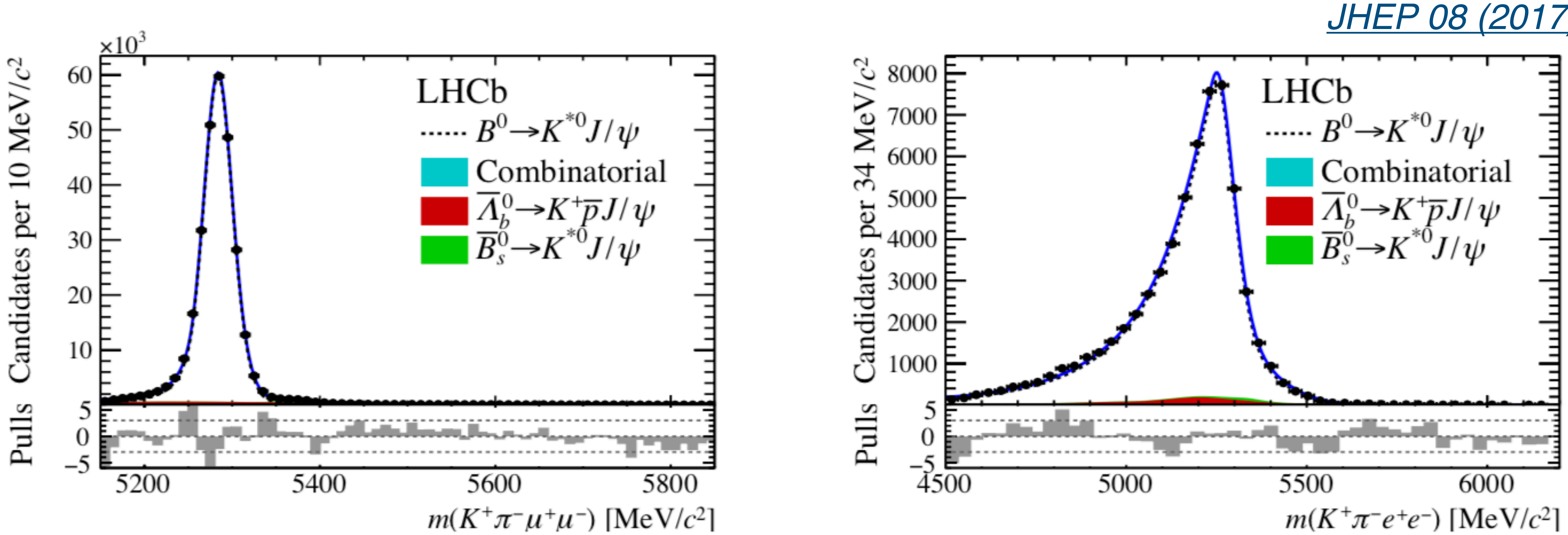
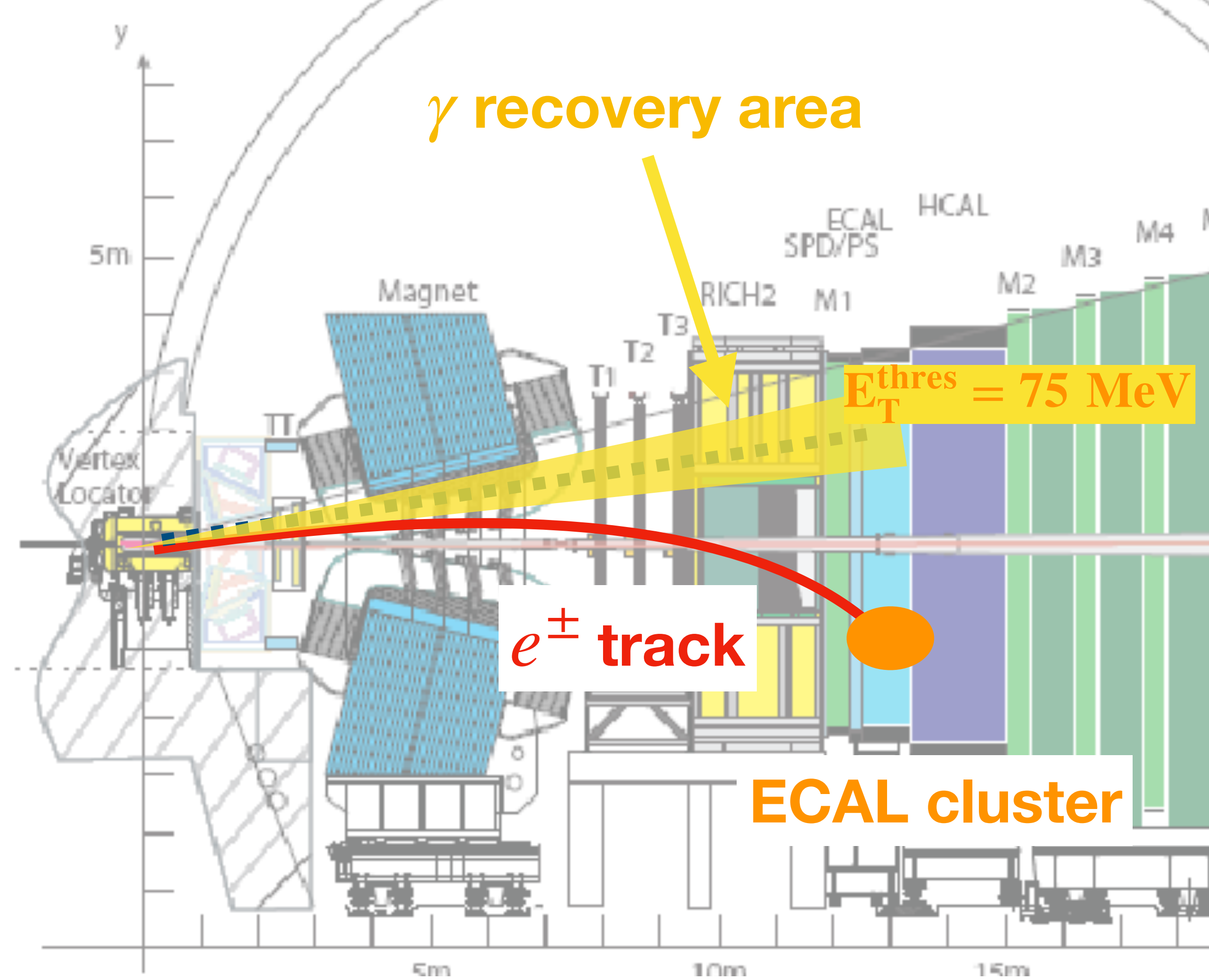
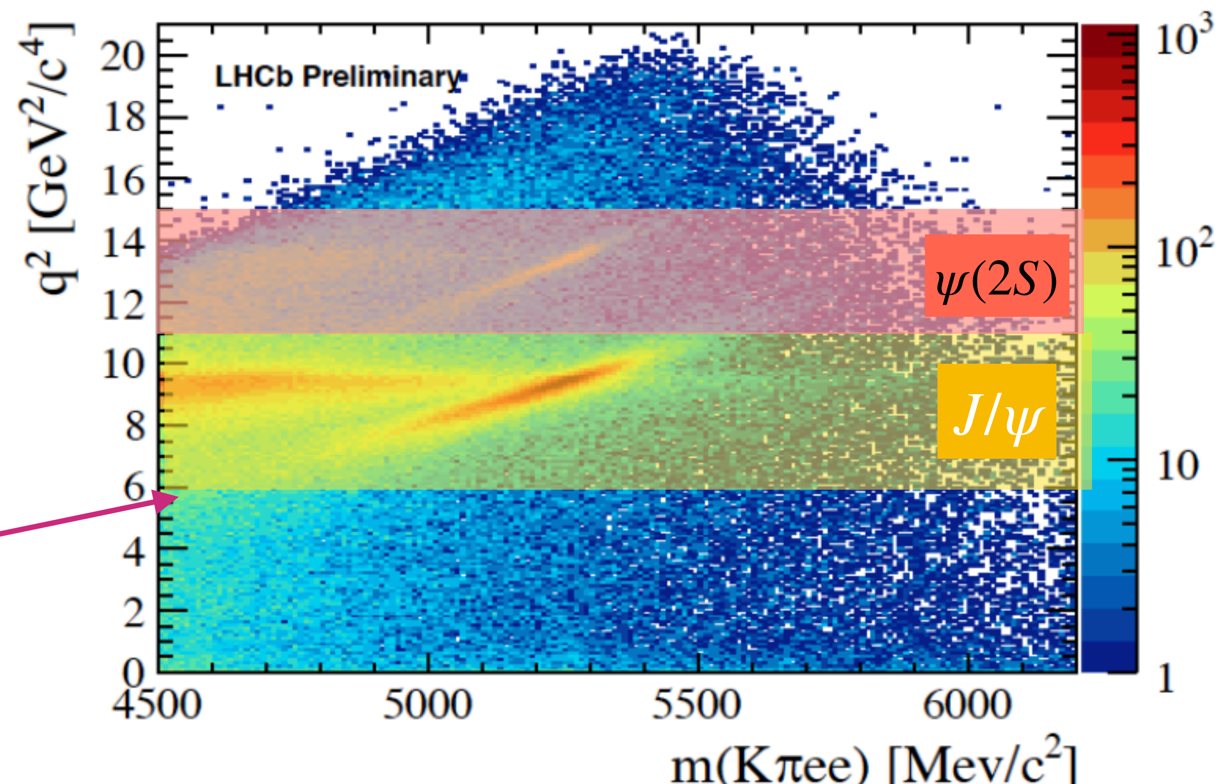


Bremsstrahlung recovery process

- Material interactions cause electrons to emit Bremsstrahlung photons
- Emission happens often before the magnet → electron momentum measurement is affected!
- **Very frequent at LHCb - most electrons emit one energetic brem before the magnet!**
- Try to find brem photon and add back its energy to the electron
- Recovery efficiency ~ 50%



- Two problematic scenarios:
  - If Brem is missed → down-ward shift of B-mass
  - If random ECAL cluster is assigned → up - ward shift of B-mass
  - **Migration in and out of q^2 bins!**

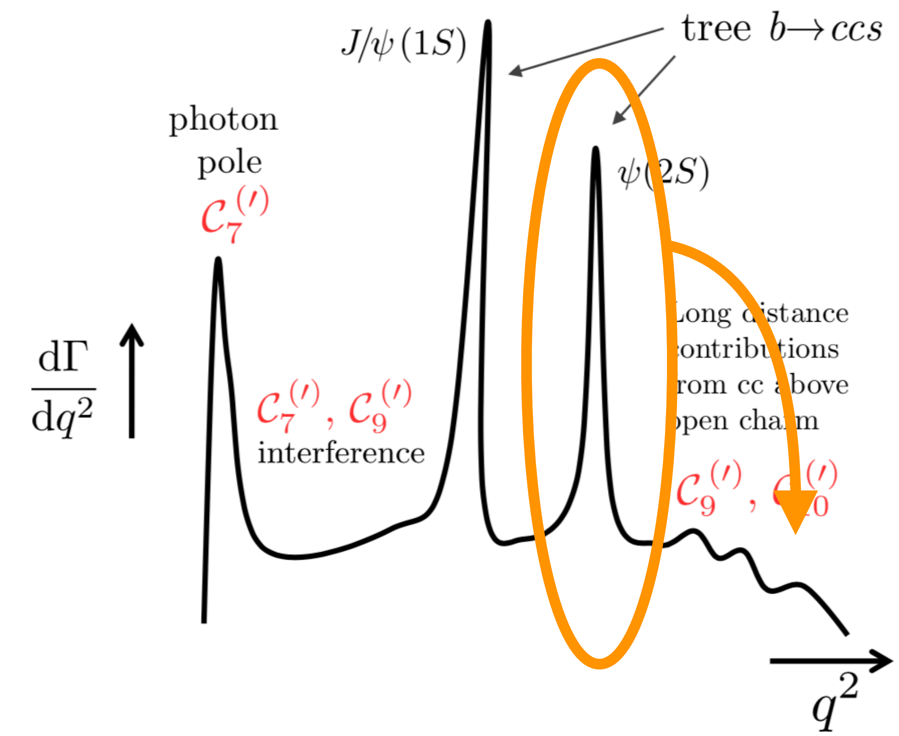


The challenge of the high-q² bin

Muons are well under control… but what about the electrons?

Challenging background estimation for the electron mode:

- $B^0 \to K^{*0}\psi(2S)(\to ee)$ **leakage** into the rare mode q2 region due to the Bremsstrahlung photon recovery process that sometimes overcorrects the electrons - peaks on the right-hand side of the signal



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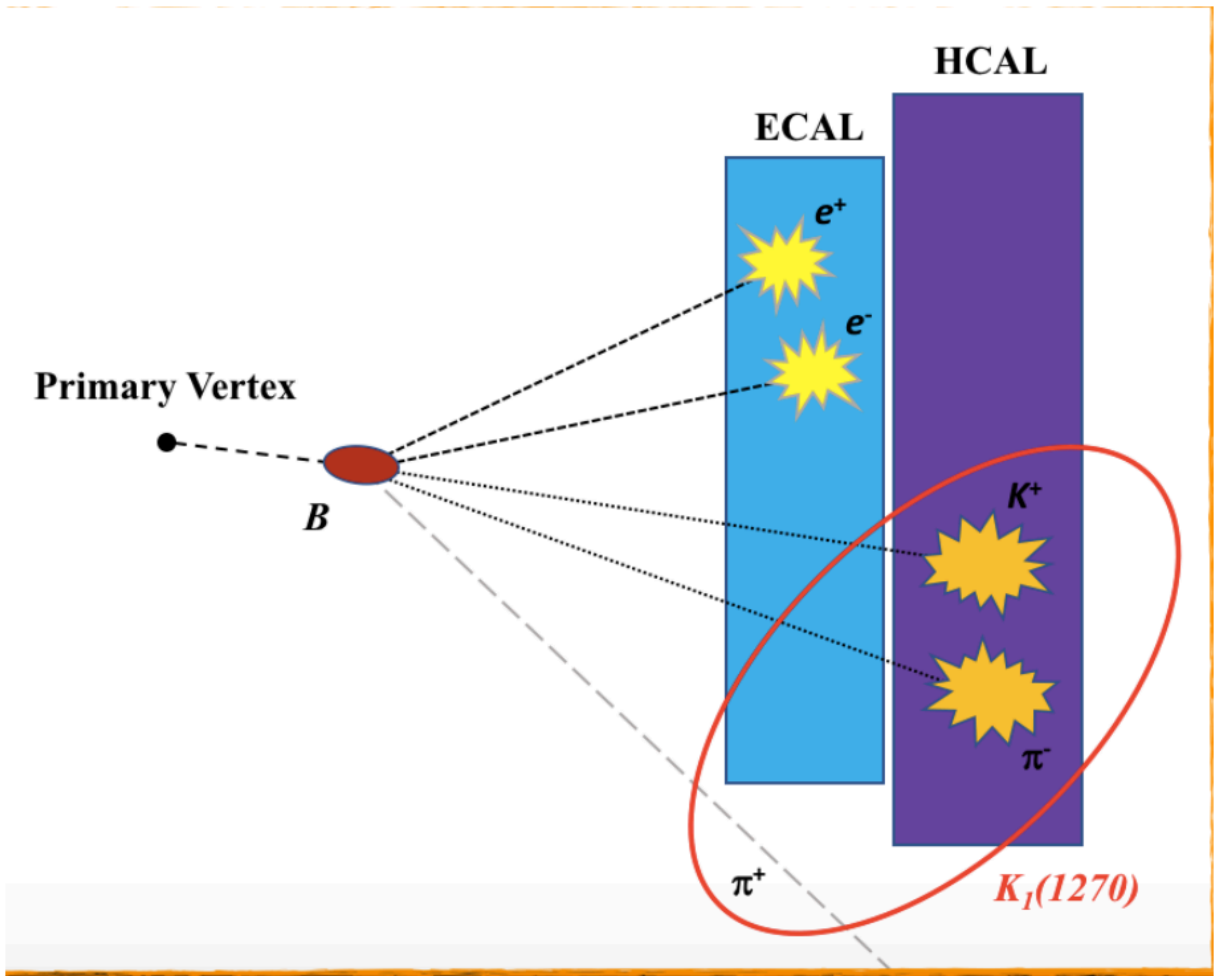

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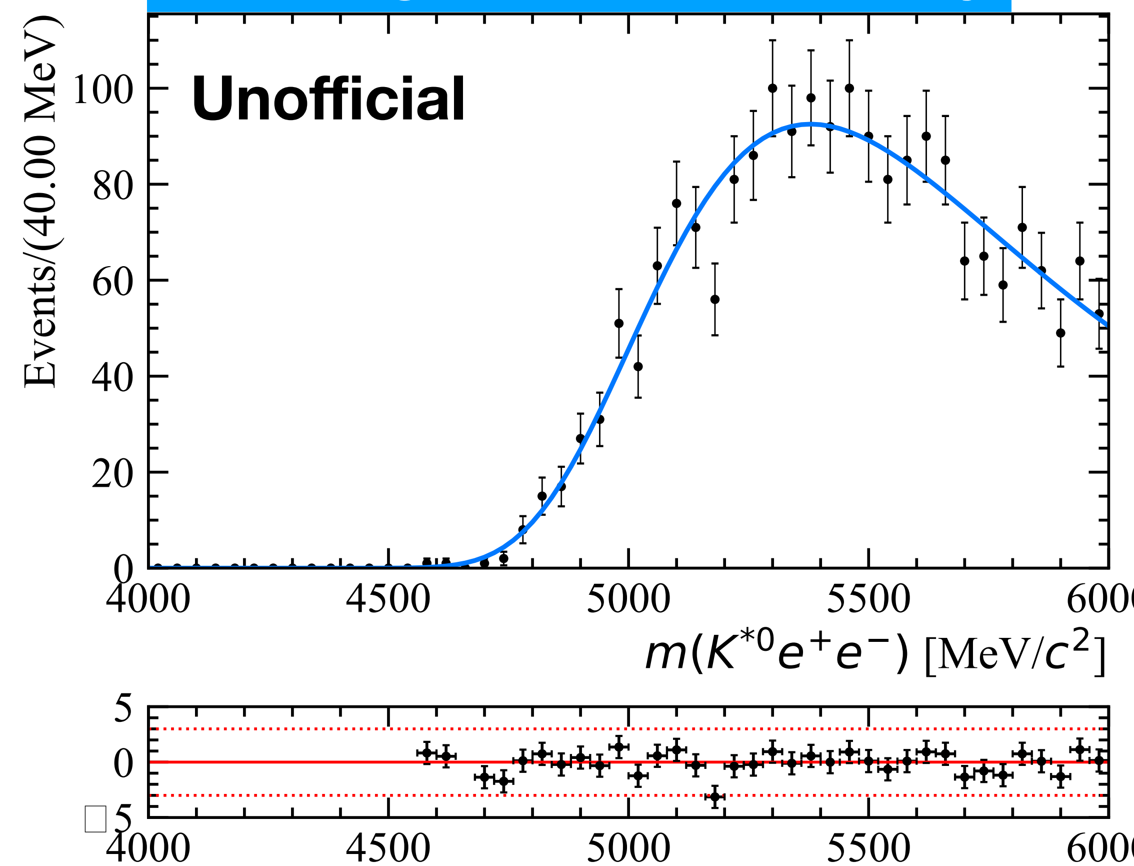
- **Combinatorial** background (from combinations of random tracks) does not follow usual exponential shape but is sculpted - we're at the kinematic limit

Same-sign data used as proxy



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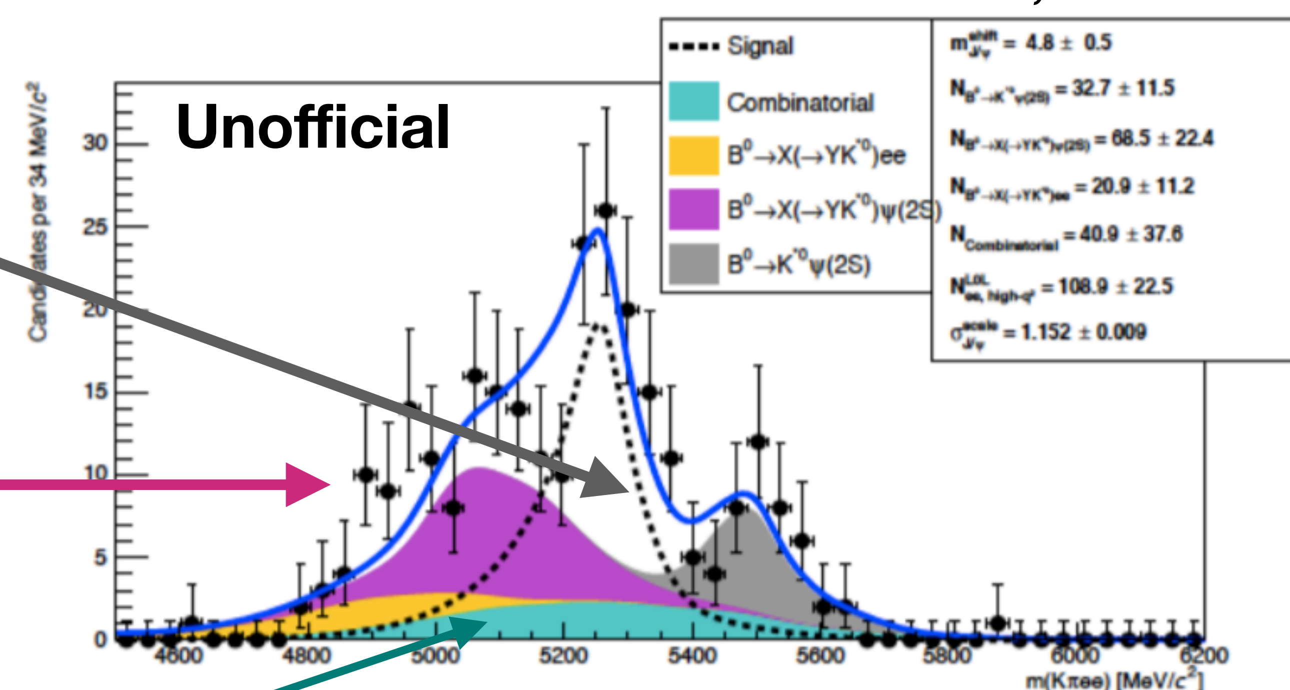
Studies from M-H Schune, F. Polci



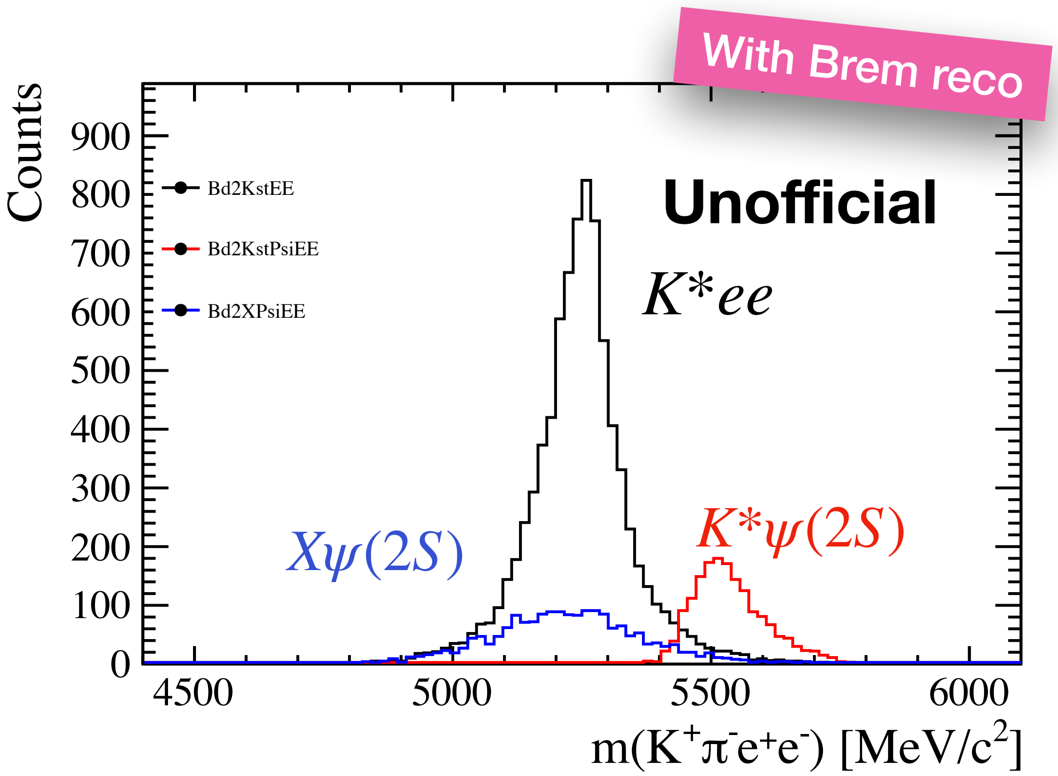
Having a stable mass fit doesn't seem that easy

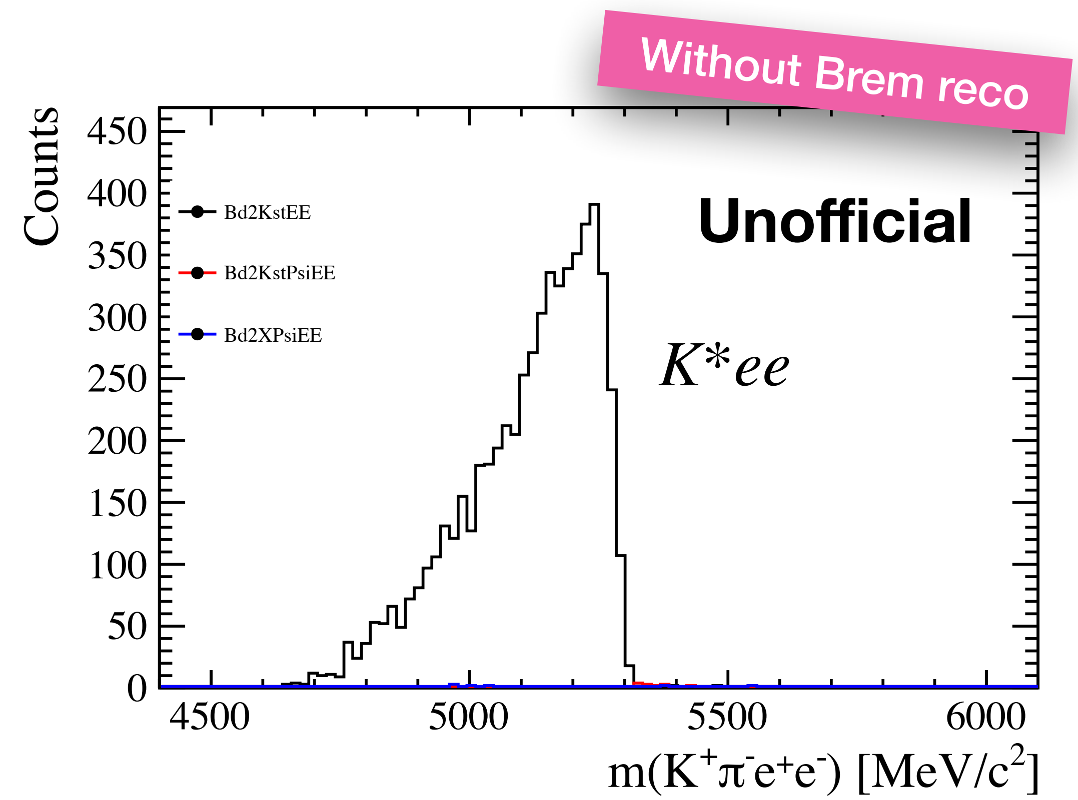
And what if…

We removed the Bremsstrahlung recovery process?

✓ Leakage from $\psi(2S)$ processes is removed

⊗ BUT, we also loose a lot of signal!





Is there a way to have the best of both worlds?

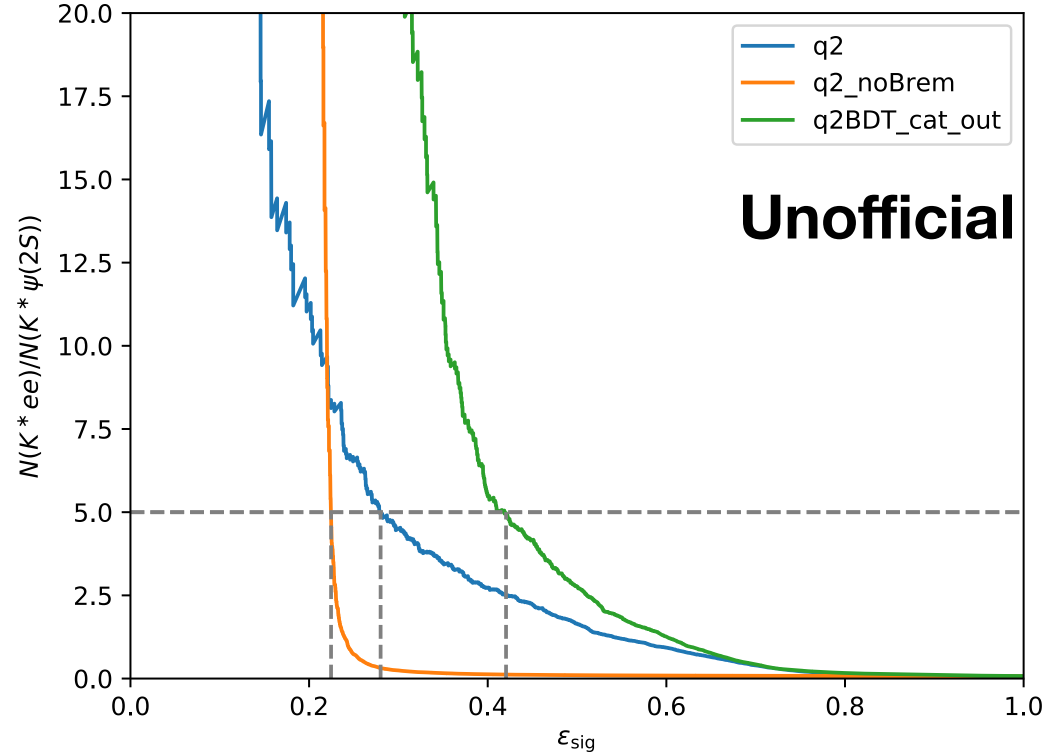
Yes!

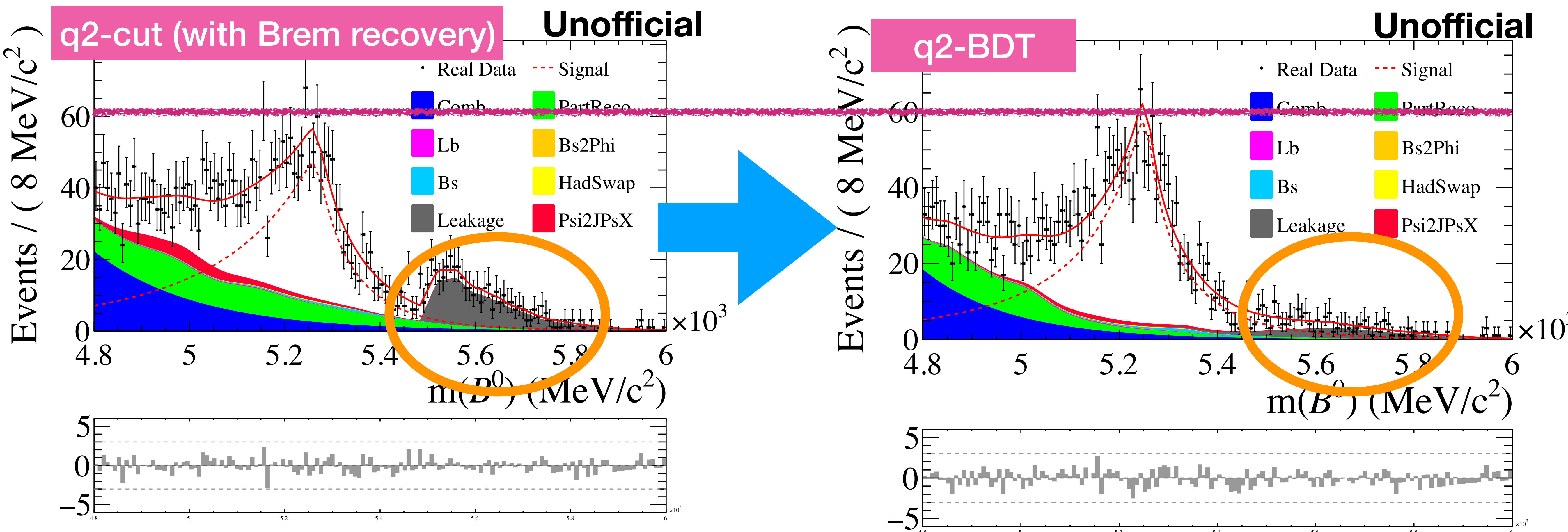
- Replace the normal q² definition by a **"q²"-BDT,** optimised to reduce leakage backgrounds while maintaining as much signal as possible

- For an S/B ~ 5, signal efficiency is around
  - q² (without Brem): 20%
  - q² (with Brem): 25%
  - **q² BDT: 42%**

- Idea is being tested in the $\psi(2S)$ **control mode** with encouraging results so far

Idea and first tests from M. Borsato





Analysis strategy

- Use **double ratios** to reduce systematic effects

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

- **Selection** as similar as possible between electrons and muons
  - Pre-selection cuts on trigger and candidate quality
  - Veto peaking backgrounds
  - PID cuts
  - Multi-variate classifiers to reject residual combinatorial and partially reconstructed backgrounds
- **Efficiencies:**
  - Measurement using mix of simulation and data-driven methods
  - Corrections to simulation in order to achieve good Data/MC agreement
- **Mass fit:**
  - Used to extract the rare and control mode yields
  - Simultaneous fit of control and rare modes →can aid in estimation of leakage

Summary

Lepton Flavour Universality tests at high-q2

- q^2-binned analysis missing a high-q^2 measurement - important for disentangling BSM scenarios
- Main challenge of the high-q^2 bin is the background estimation
- Novel approach to redefine the q^2 bin by a BDT variable is being investigated and shows promising results
- RK and RK* analyses progressing in parallel

Status of the RK* high-q^2 analysis

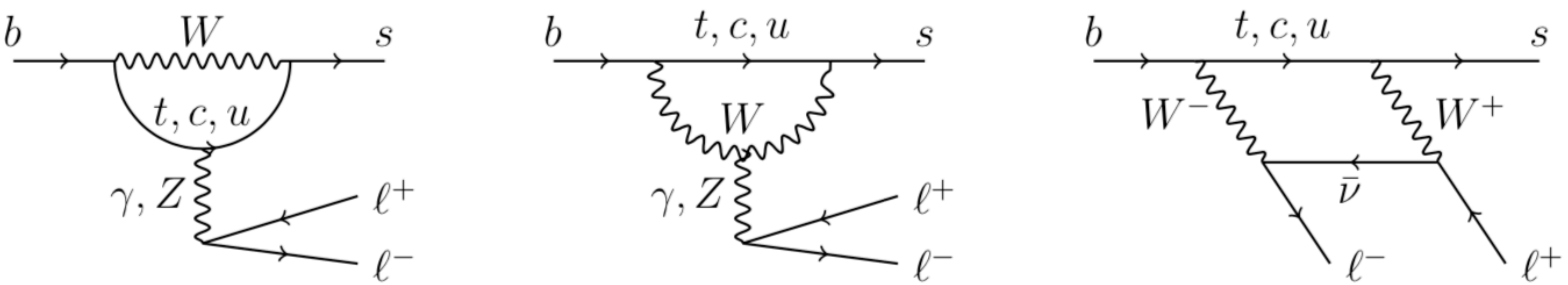
- Selection is being optimised
- Corrections to simulation almost finalised
- Fit is being implemented
- **More results soon!**


wallpapersbuzz
Thank you for your attention!

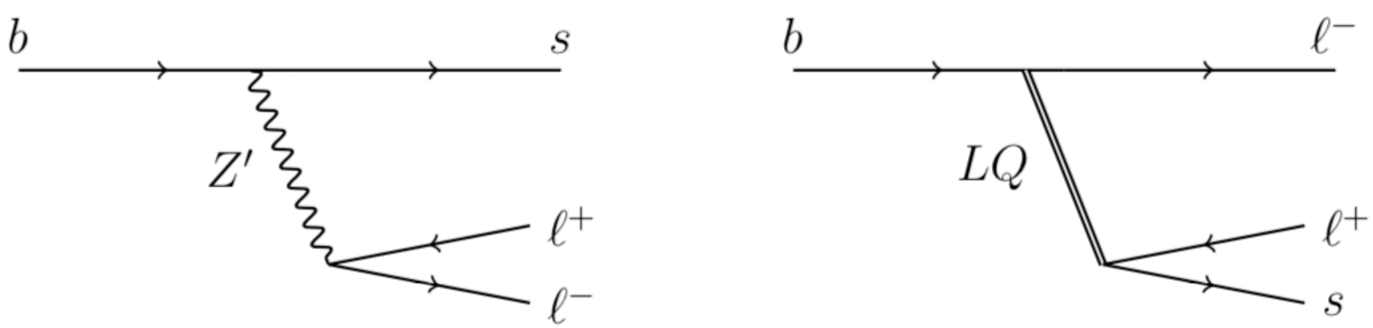
Backup

Feynman diagrams for $b \to s\ell\ell$

SM contributions to $b \to s\ell\ell$

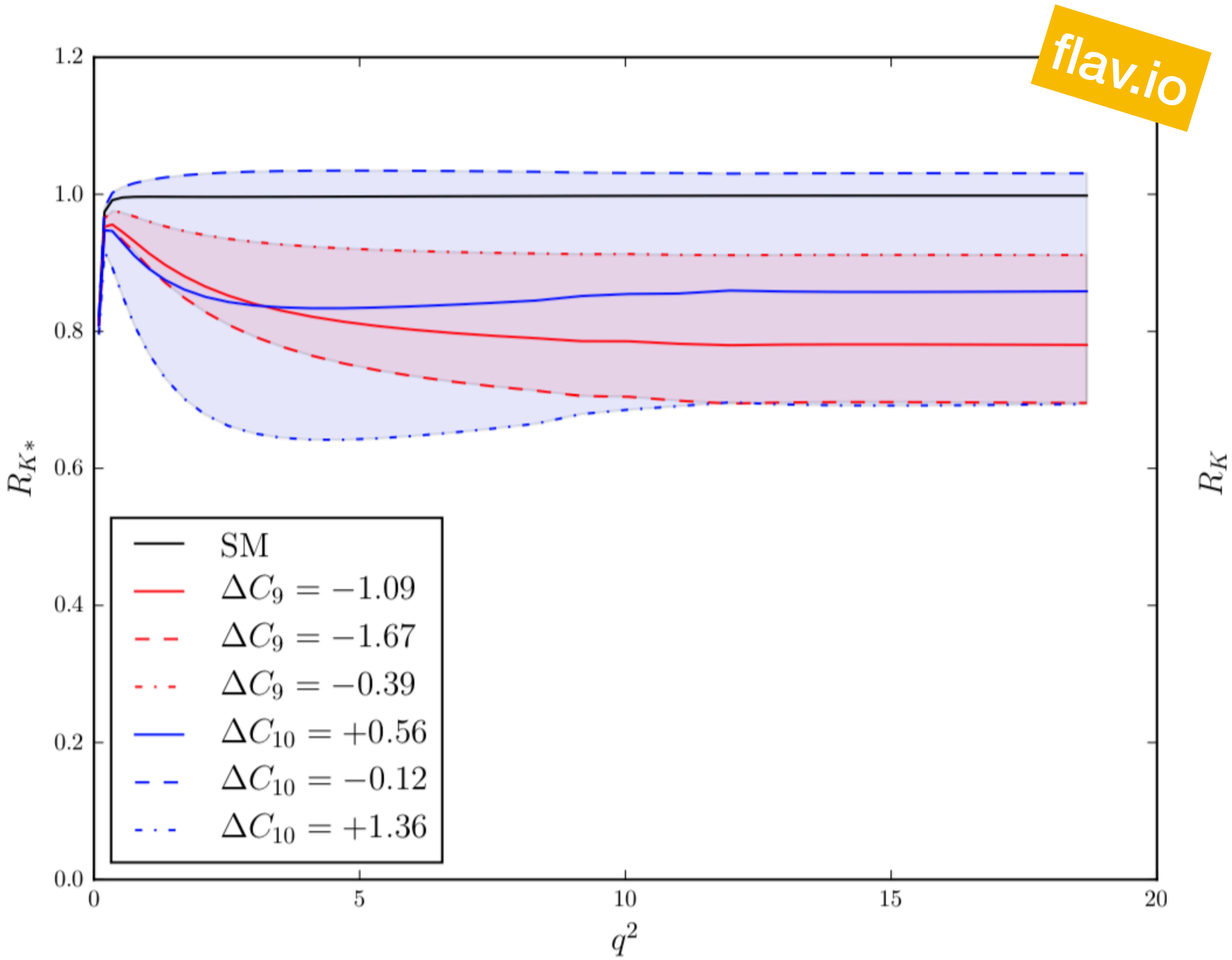


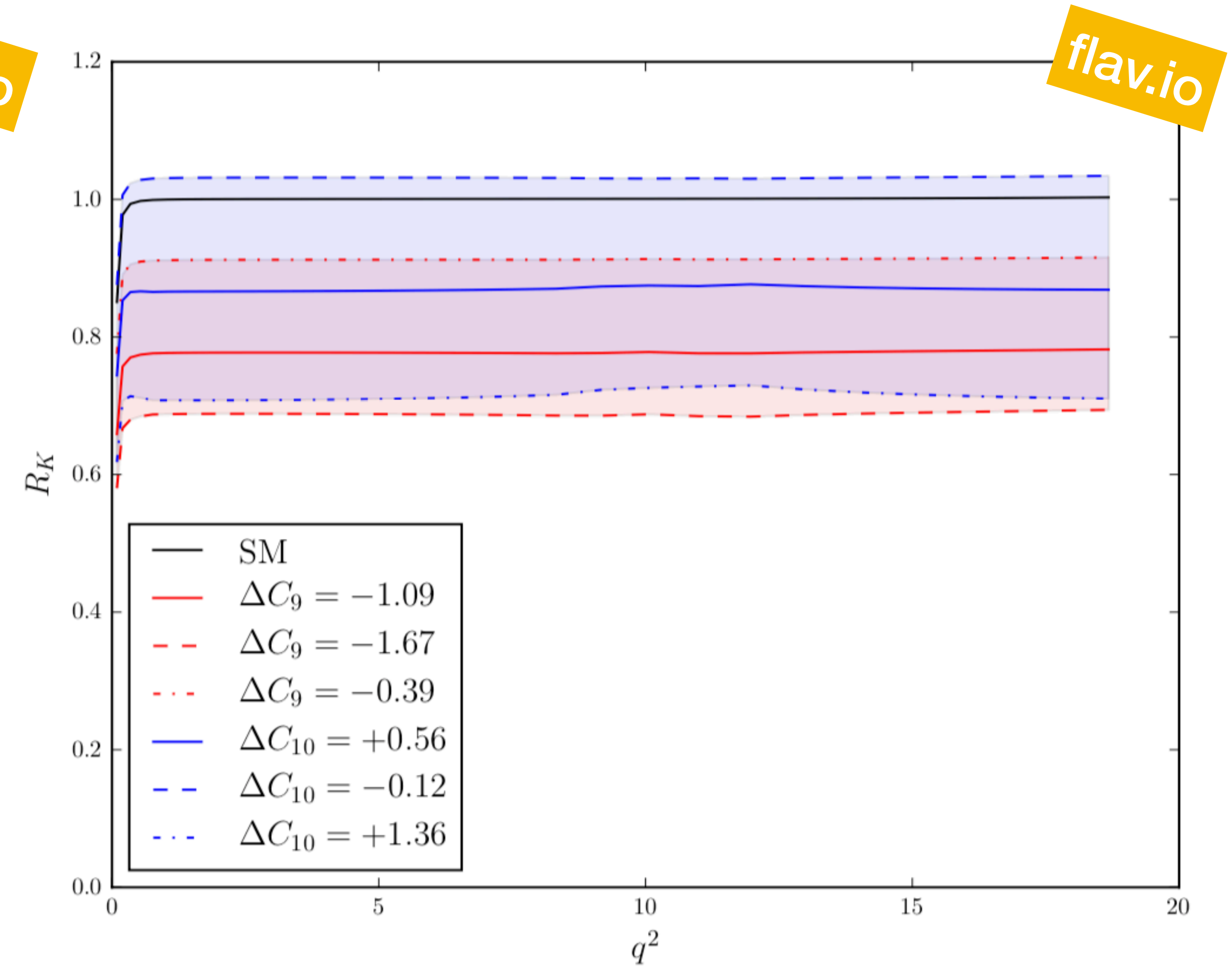
Potential NP contributions to $b \to s\ell\ell$



Sensitivity of R_{K^*}-high q^2 to BSM models

- Several BSM scenarios show dependence of R_{K^*} ratio on q^2
- Different C_9, C_{10} dependence of R_{K^*} between mid- and high-q^2
- No dependence expected in R_K

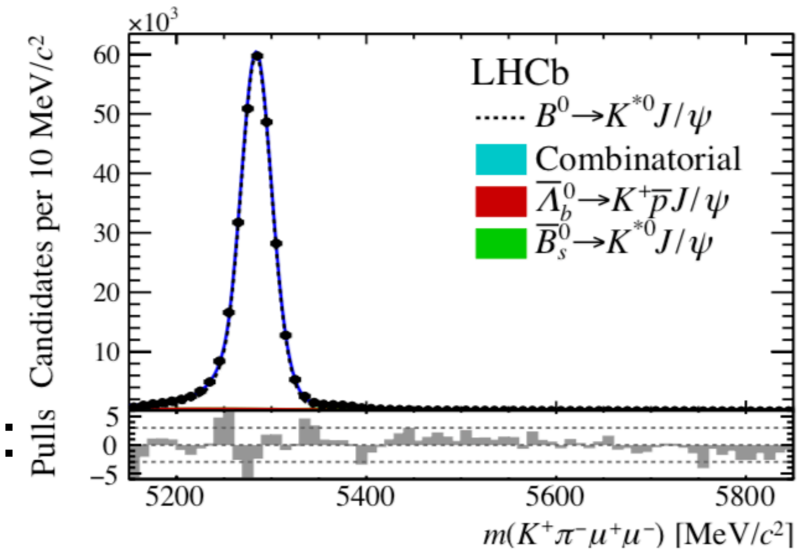


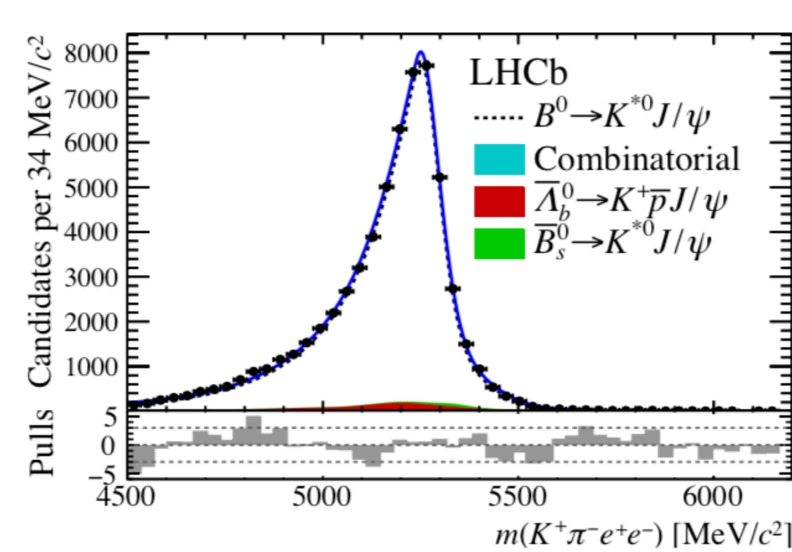


Performance comparison B-factories/LHCb

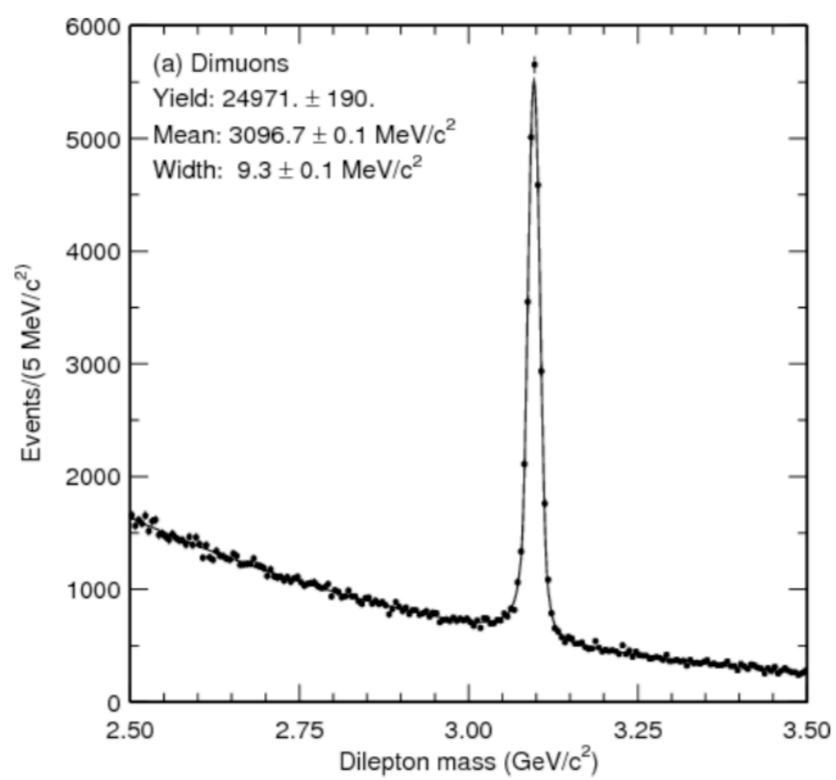
- Larger yields for LHCb
- PID performance similar
- Very different electron response:
  - Belle/BaBar have similar efficiencies for electron/muons
  - LHCb electron efficiency lower because of more Bremsstrahlung and higher trigger thresholds
- B-decays to τ leptons:
  - Belle/BaBar exploit full reco of 2nd B
  - LHCb reco of decay vertices

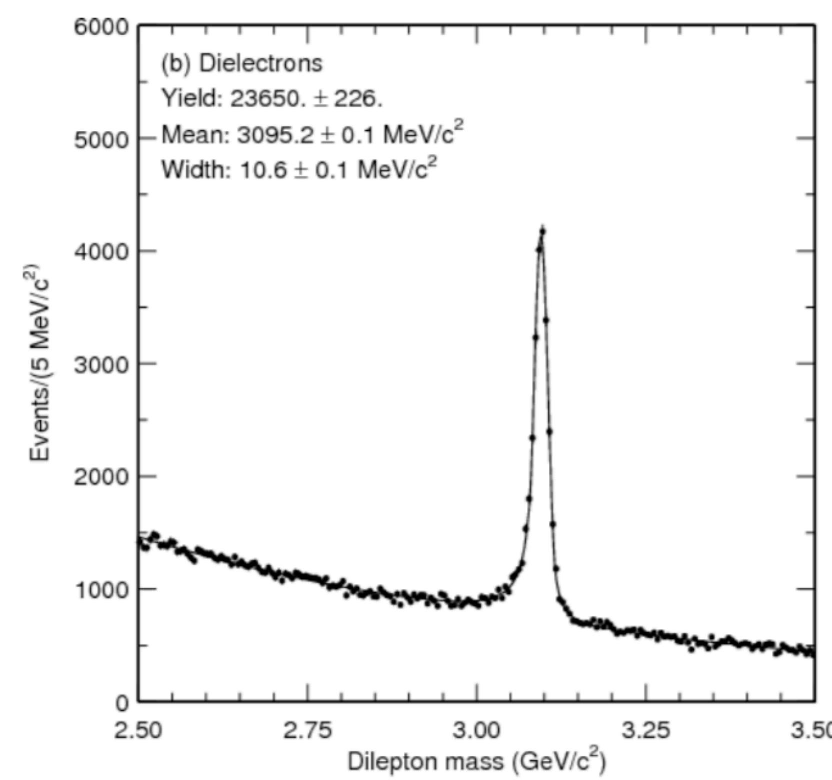
LHCb





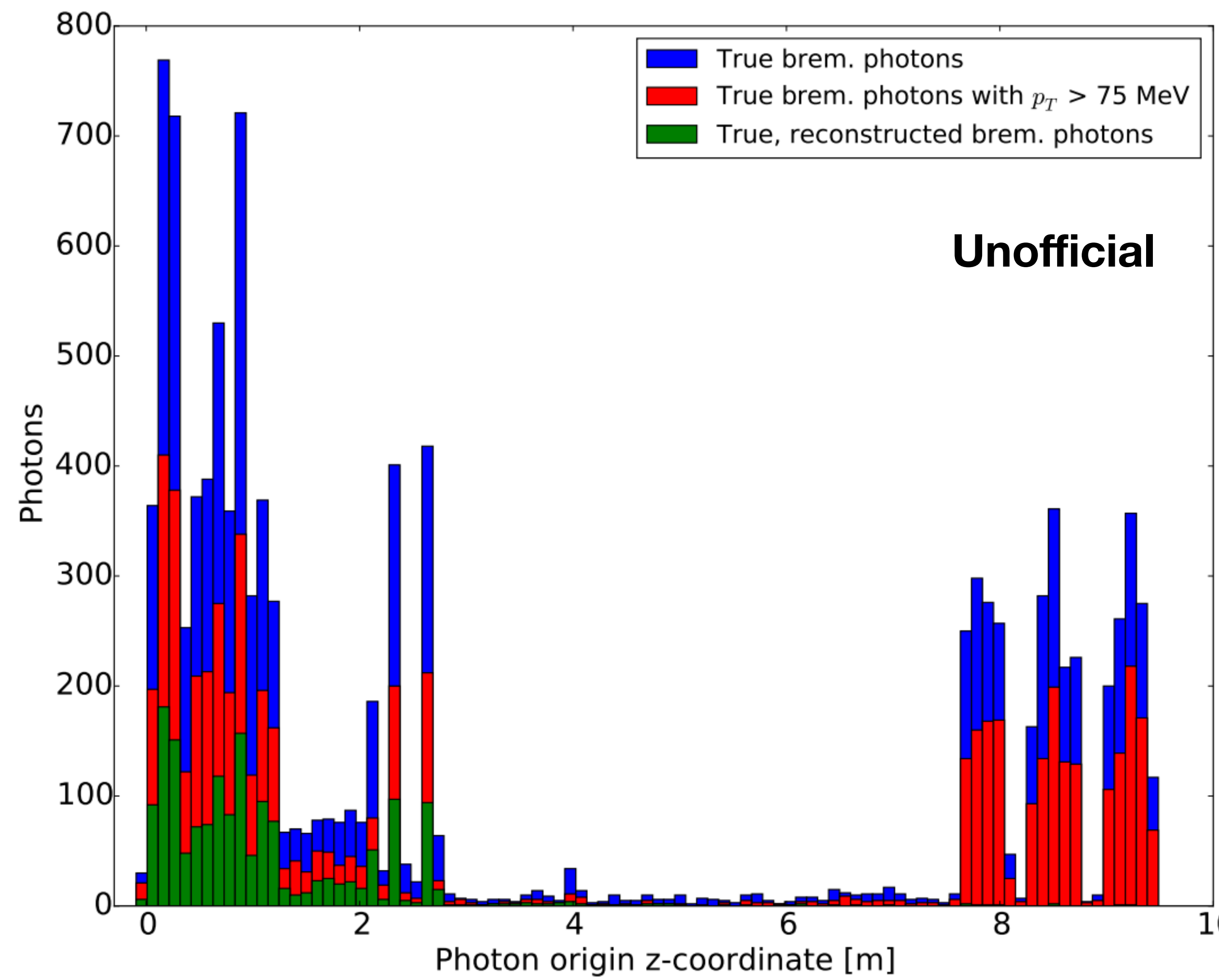
Belle





Bremsstrahlung recovery efficiency

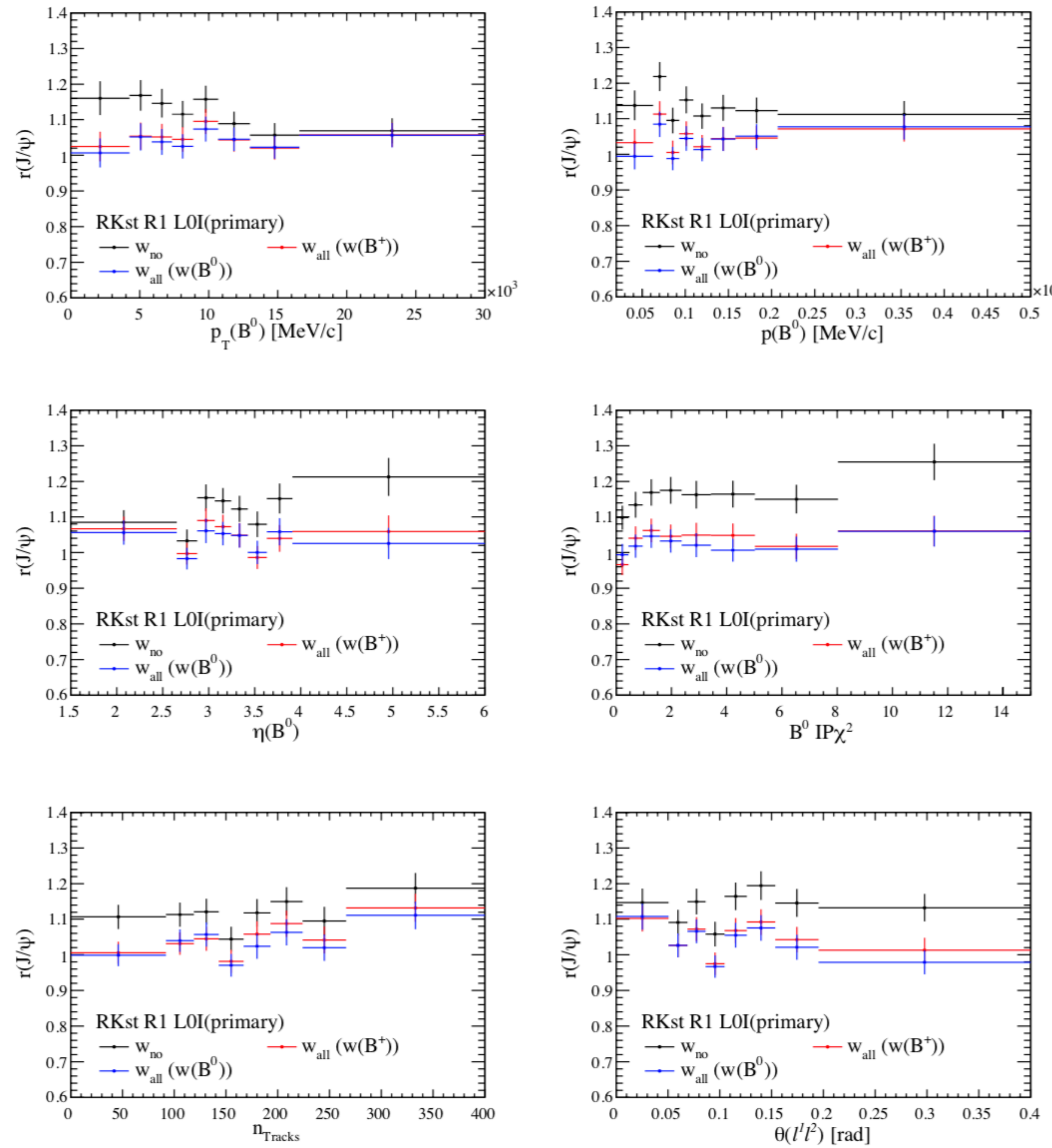
- Most brem photons emitted due to material interactions before the magnet
- If emitted after the magnet, they usually end up in the same cluster as the electron, so they don't get reconstructed separately, but they don't affect (much) the electron trajectory - momentum measurement
- Recovery process:
  - Extrapolate upstream electron to ECAL
  - Add all reconstructed neutral clusters with E_T>75 MeV to electron momentum
- Potential failings:
  - Brem out of acceptance
  - Brem too soft
  - ECAL resolution worse than tracking resolution



J/ψ Flatness

- Using the Rx 1-D flatness framework
- Run both B^{+}/B^{0} correction chain
- Almost all correction steps
- Missing q^2 smearing for bin migration (this needs special treatment for the high-q^2 bin with a q^2-BDT cut)
- J/ψ flatness looks good in all checked variables!
- Next steps:
  - Complete correction chain with all Rx recent updates
  - Flatness in ψ(2S)

Unofficial



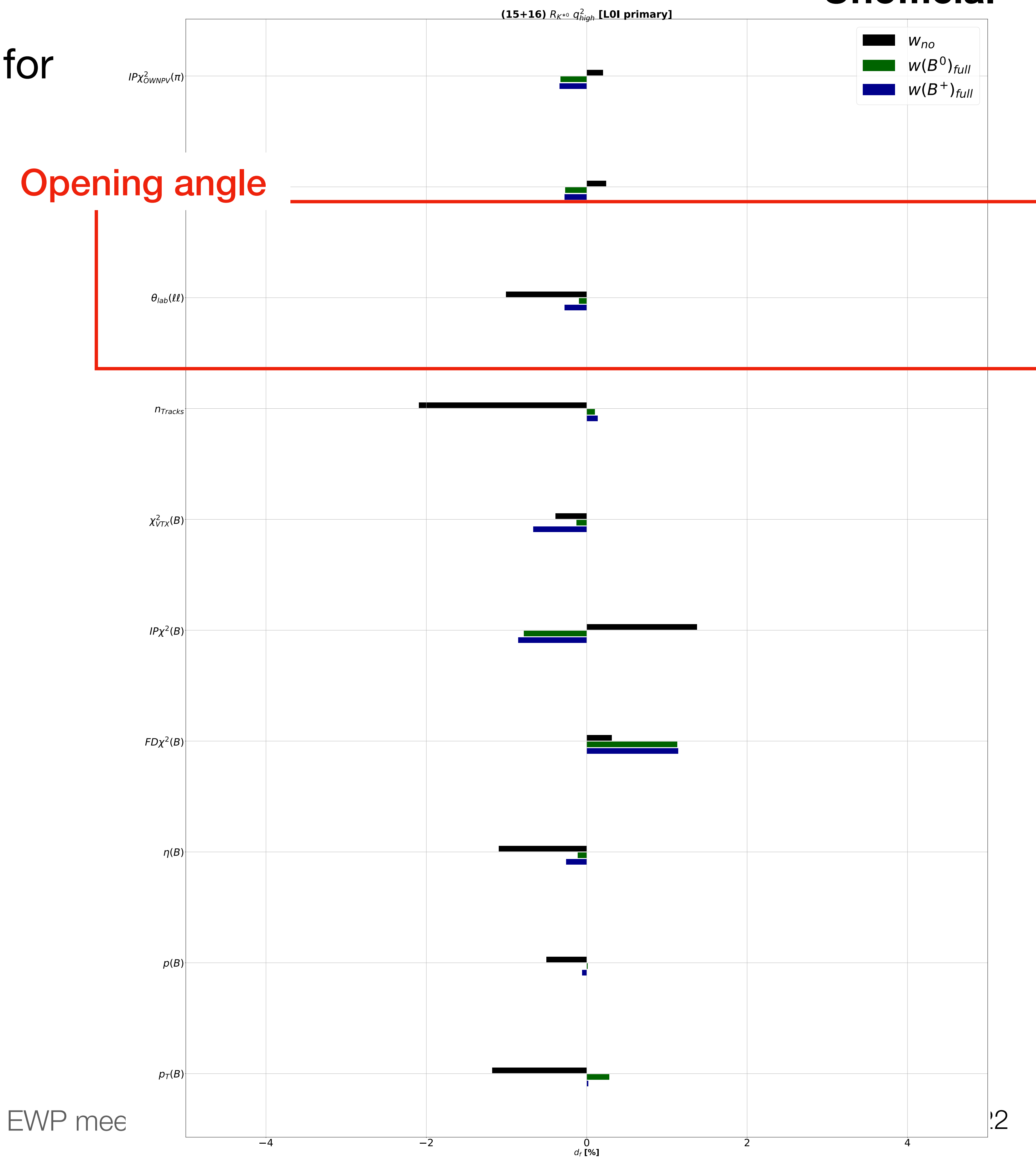
Flatness Systematics

Unofficial

- Flatness systematics extracted for all Run periods / triggers

- After correction all checked uncertainties are below 2%

- OA(l,l) shows good behaviour



Additional backgrounds

π-> e mis-ID was seen to be more significant in high-q^2 by RK

- For us, the relevant background is double π-> e mis-ID
- Unfortunately, there's no B2K*ππ dec file without mass cuts - we've created one and submitted an MC request with BnoC
- B2Ksthh stripping line:
  - Loose pion-ID and no mass cuts
  - Can be used along with MC for background estimation
  - B->K*ππ measurement paper also under development

Cascade backgrounds

- Currently investigating if cascade vetoes are as efficient as for low-central q^2 or if cascade BDT is needed similarly to RK

StrippingB2KsthhLine

Properties:

OutputLocation	Phys/B2KsthhLine/Particles
Author	Rafael Coutinho
Postscale	1.0000000
HLT1	HLT_PASS_RE('Hlt1(Two)?TrackMVADecision')
HLT2	HLT_PASS_RE('Hlt2Topo[234]BodyDecision')
Prescale	1.0000000
L0DU	None
ODIN	None

Filter sequence:

LoKi::VoidFilter/StrippingGoodEventConditionBhadron
LoKi::VoidFilter/StrippingB2KsthhLineVOIDFilter
CheckPV/checkPVmin1
LoKi::VoidFilter/SelFilterPhys_StdVeryLooseDetachedKst2Kpi_Particles
FilterDesktop/KstforB2Ksthh
LoKi::VoidFilter/SelFilterPhys_StdLoosePions_Particles
CombineParticles/B2KsthhLine
AddRelatedInfo/RelatedInfo1_B2KsthhLine
AddRelatedInfo/RelatedInfo2_B2KsthhLine
AddRelatedInfo/RelatedInfo3_B2KsthhLine
AddRelatedInfo/RelatedInfo4_B2KsthhLine