Relative Branching Fraction Measurements of $B \rightarrow 3h$ Decays

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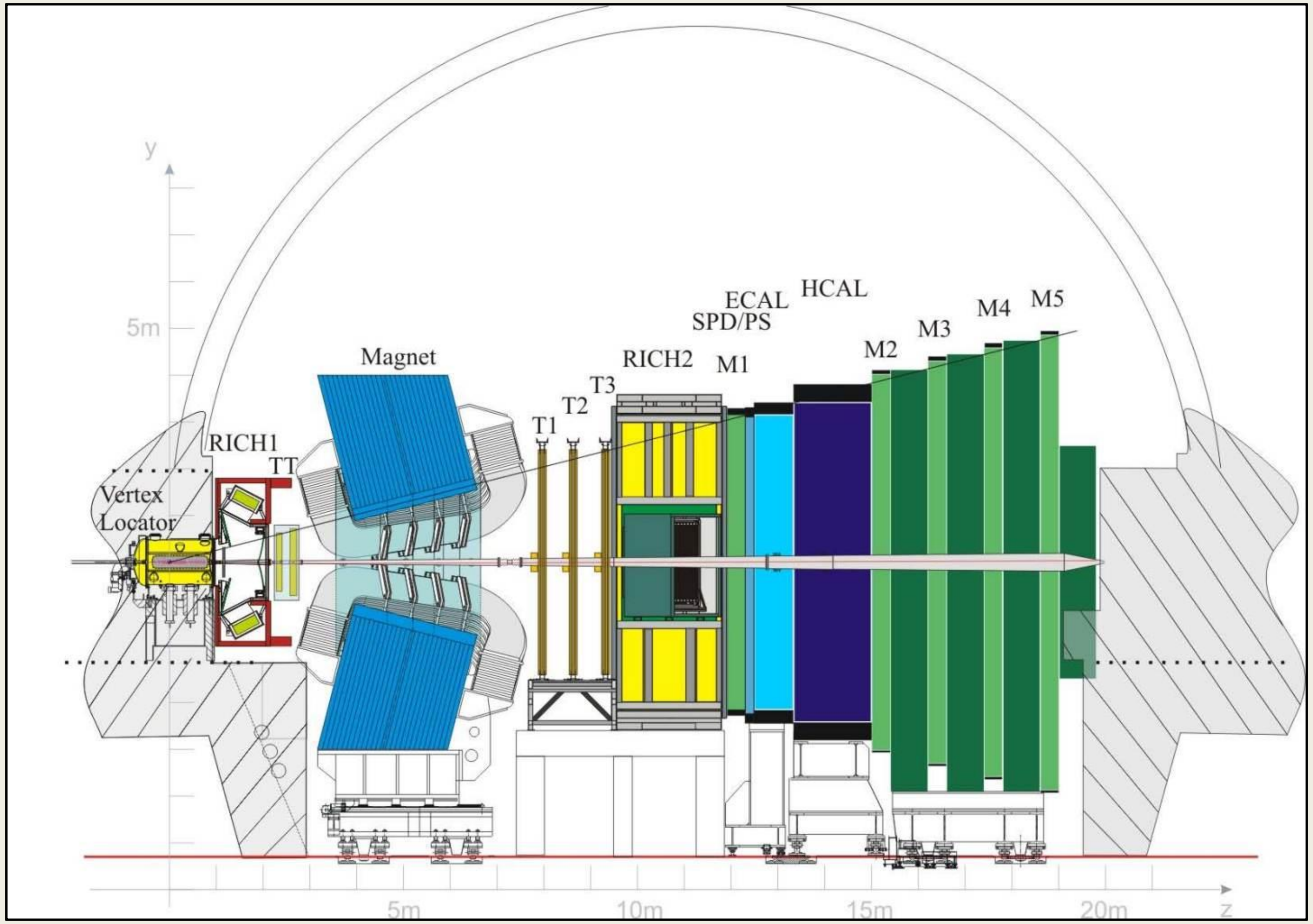
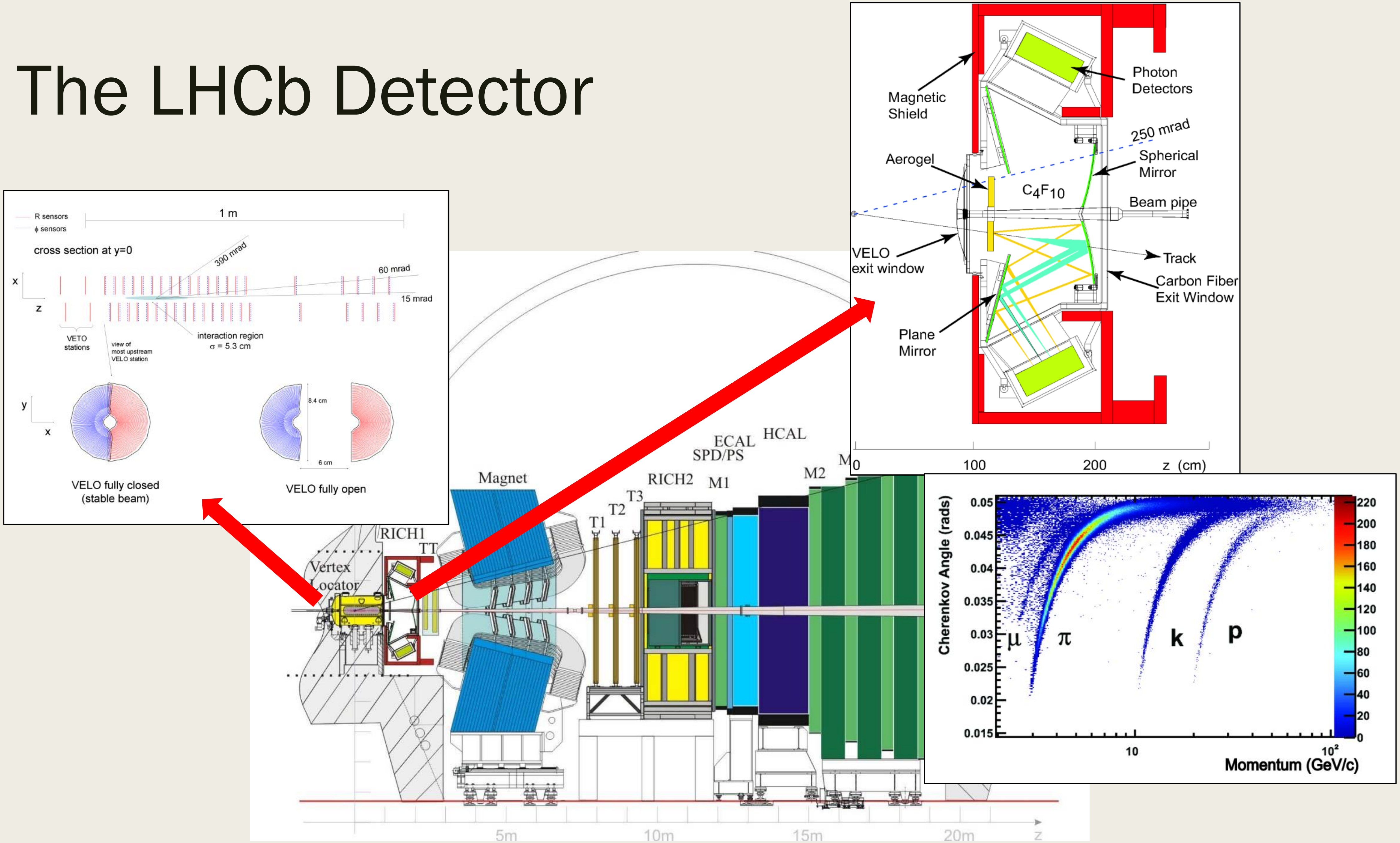
Outline

- The LHCb detector
- Charmless $B \rightarrow 3h$ decays
- Relative BF measurement:
  - Analysis strategy
  - Event selection
  - Preliminary Run 1 results
  - Plan for completion

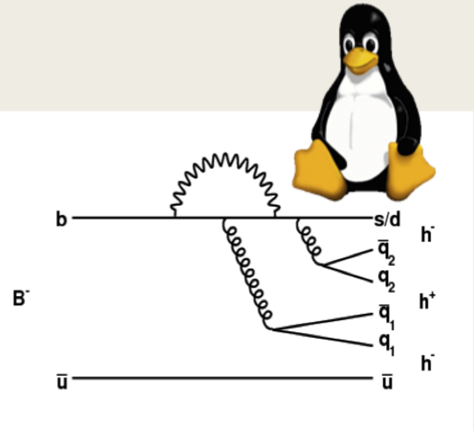


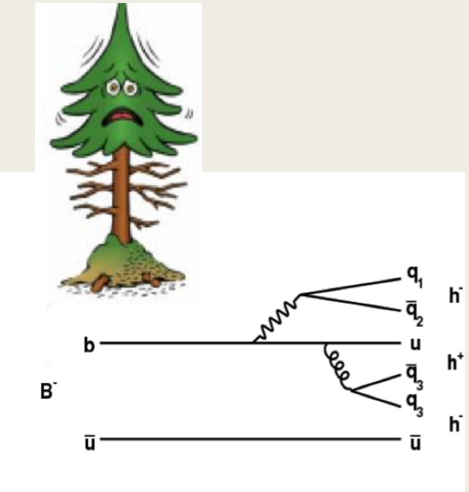
The LHCb Detector



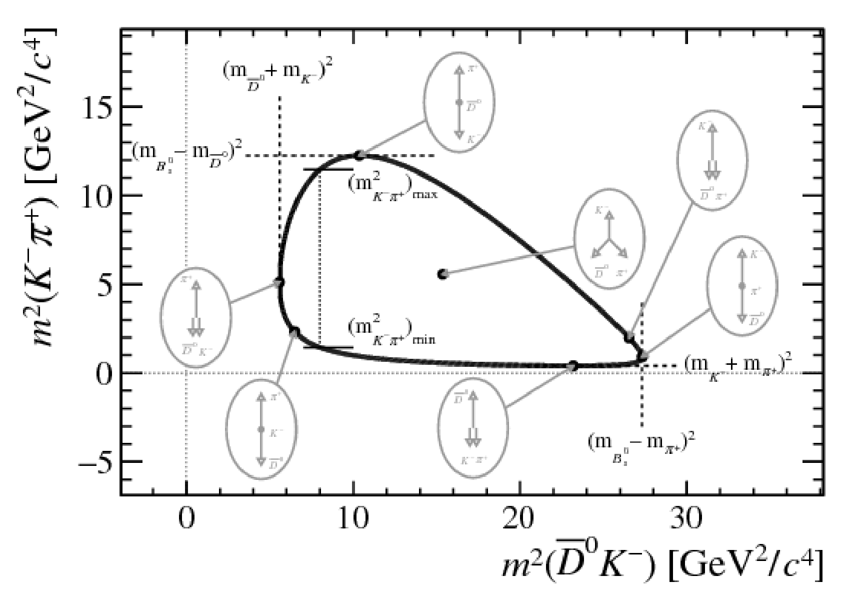
Charmless $B \to 3h$ decays

- Tree-level $b \to u$ amplitudes have comparable size to loop-level $b \to d, s$ contributions
  - Amplitudes can interfere leading to large CP violation effects
  - New Physics can contribute to loops – extra CPV sources





- Decays of a spin-0 particle to three spin-0 particles can be described by the **Dalitz plot** (DP)
  - Can be used to study resonant structures + CP violation effects in this type of decay
  - DP analyses can extract, in principle, all observable information about the decay:
    - Usually measure fit fractions (FF) and A_{CP}
    - $BF(B \to Rh) = BF(B \to h'h''h) \cdot FF_R$

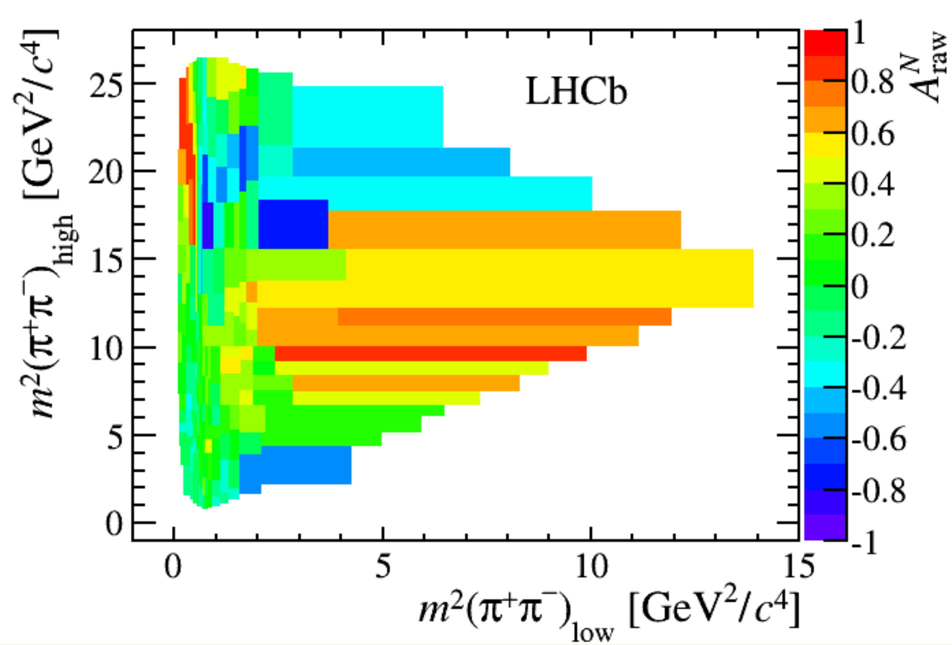


J. Back *et al.*, arXiv:1711.09854

Charmless $B \to 3h$ decays

- Previous LHCb analysis measured A_{CP}:
  - Model-independent – no info on contributing resonances
  - Non-zero inclusive A_{CP} ranging $[2.8 - 5.6]\sigma$
  - Areas of phase space where large A_{CP} observed
- Next steps:
  - Amplitude analyses (AA) of each individual mode
  - $B \to 3h$ relative BF measurements **(this talk)**
- This analysis:
  - Improved BF measurement + fit fractions from AAs
    - BFs for resonant contributions
  - Improve on previous event selection:
    - Include new information – isolation variables
    - Establish Run 2 optimisation

$A_{CP}(B^\pm \to K^+K^+K^-) = -0.036 \pm 0.004 \pm 0.002 \pm 0.007$
$A_{CP}(B^\pm \to \pi^\pm K^+K^-) = -0.123 \pm 0.017 \pm 0.012 \pm 0.007$
$A_{CP}(B^\pm \to K^\pm\pi^+\pi^-) = +0.025 \pm 0.004 \pm 0.004 \pm 0.007$
$A_{CP}(B^\pm \to \pi^\pm\pi^+\pi^-) = +0.058 \pm 0.008 \pm 0.009 \pm 0.007$



R. Aaij *et al.*, Phys. Rev. D **90**, 112004 (2014)

Analysis strategy

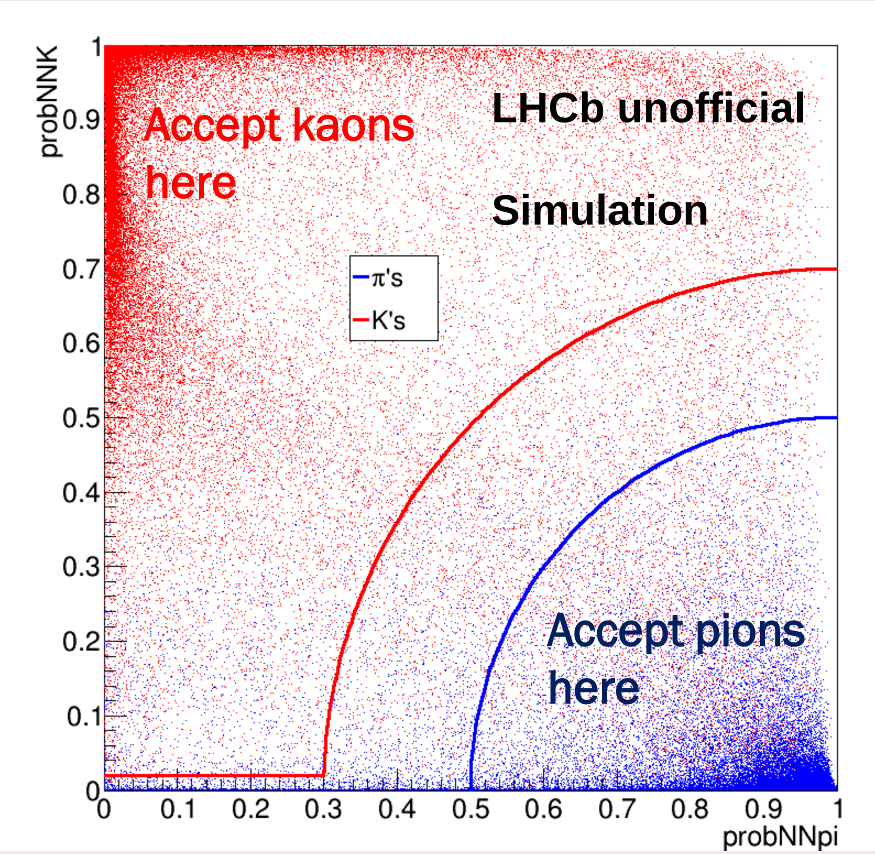
- Measure $B \to 3h$ BF, relative to $B \to KKK$
  - Plan to also report ratios relative to the other modes

- Use 2011+2012 (Run 1) and 2015+2016 (Run 2) data
- Treat the two runs separately:
  - Independent selection optimisation
  - Determine ratios separately
  - Combine results once ratios+uncertainties calculated

PID selection

- Mis-identified $B \to 3h$ are important backgrounds
- Optimise PID on these cross-feed backgrounds only
- Use circular cuts in PID parameter space
  - Kaons: $\sqrt{p_{\text{kaon}}^2 + (p_{\text{pion}} - 1)^2} > r_K^2$
  - Pions: $\sqrt{p_{\text{kaon}}^2 + (p_{\text{pion}} - 1)^2} < r_\pi^2$
  - For kaons, also require $p_{\text{kaon}} > 0.02$
  - Impose the constraint $r_K^2 \geq r_\pi^2$
- Optimise cut with the Figure of Merit (FoM):
  - $\text{FoM} = \frac{\epsilon_{\text{sig}}}{\sqrt{\epsilon_{\text{sig}} + \sum f \cdot \epsilon_{\text{misID}}}}$
    - $f = \text{BF}_{\text{misID}}/\text{BF}_{\text{sig}}$

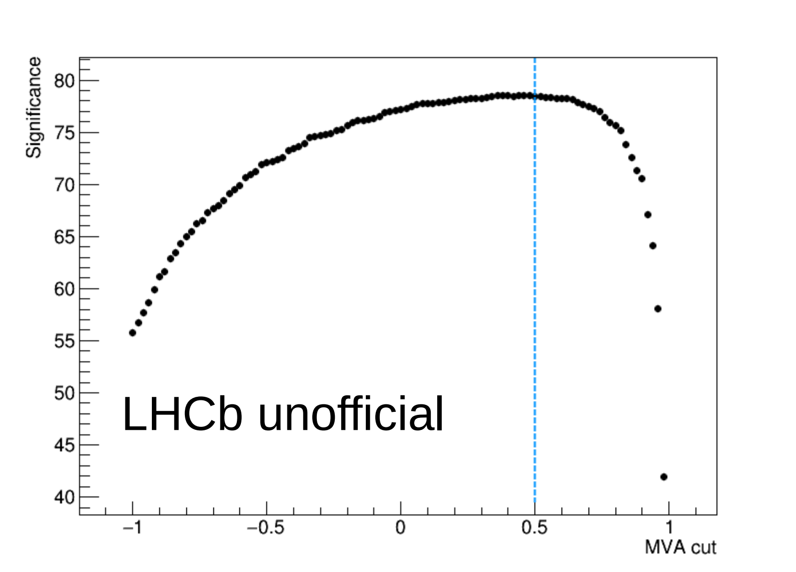
Channel	misID considered
KKK	$\pi KK, K\pi\pi$
πKK	$KKK, K\pi\pi$
$K\pi\pi$	$\pi KK, \pi\pi\pi$
$\pi\pi\pi$	$K\pi\pi$

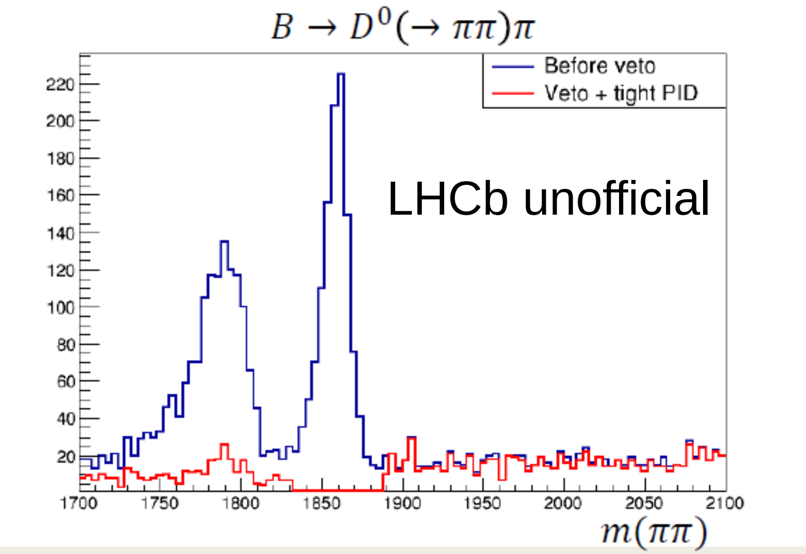


MVA selection + vetoes

- Use multivariate analysis (MVA) to reduce combinatorial background
  - Neural network using the NeuroBayes algorithm
  - Train using Monte Carlo (MC) sample for signal, high-mass sideband data for background
  - Combination of 7 kinematical+topological input variables
  - Use πKK MC+data to maximise sensitivity to this mode

- Exclude charmed contributions through a veto
  - Veto region $[1830{,}1890]\ \mathrm{MeV}/c^2$, centred on D^0 mass
  - Also see misID charm contributions
  - Apply tighter PID cuts rather than vetoes in this case



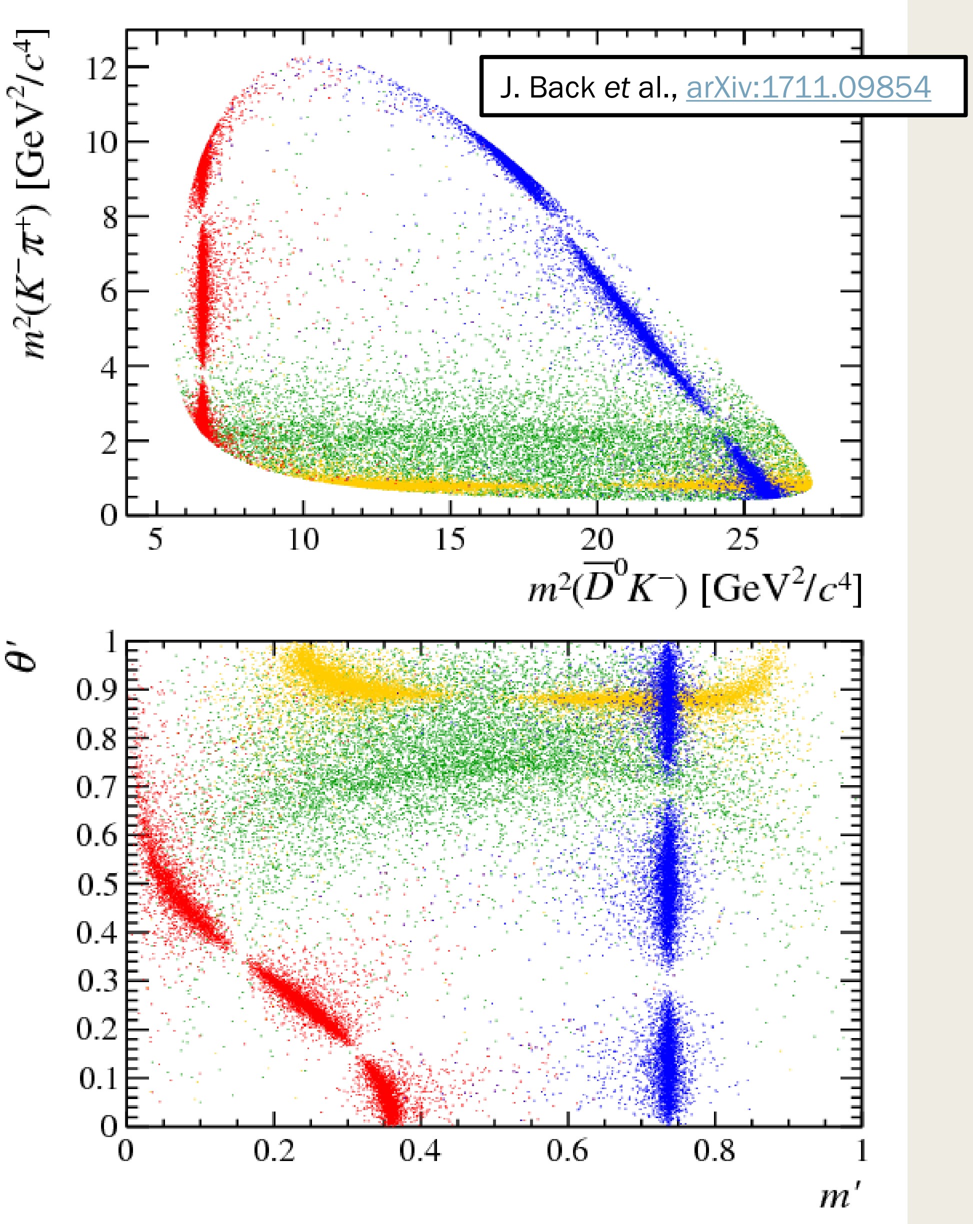


Square Dalitz plot

- Most signal is concentrated along the edges of DP
- Rapid efficiency variation in these regions
- Square DP transformation spreads out these areas

$$m' = \frac{1}{\pi}\arccos\left(2\frac{m_{ij}-(m_i+m_j)}{m_B-(m_i+m_j+m_k)}-1\right),$$

$$\theta' = \frac{1}{\pi}\left(\frac{m_{ij}^2(m_{jk}^2-m_{ij}^2)-(m_j^2-m_i^2)(m_B^2-m_k^2)}{\sqrt{(m_{ij}^2+m_i^2-m_j^2)^2-4m_{ij}^2m_i^2}\sqrt{(m_B^2-m_k^2-m_i^2)^2-4m_{ij}^2m_k^2}}\right).$$

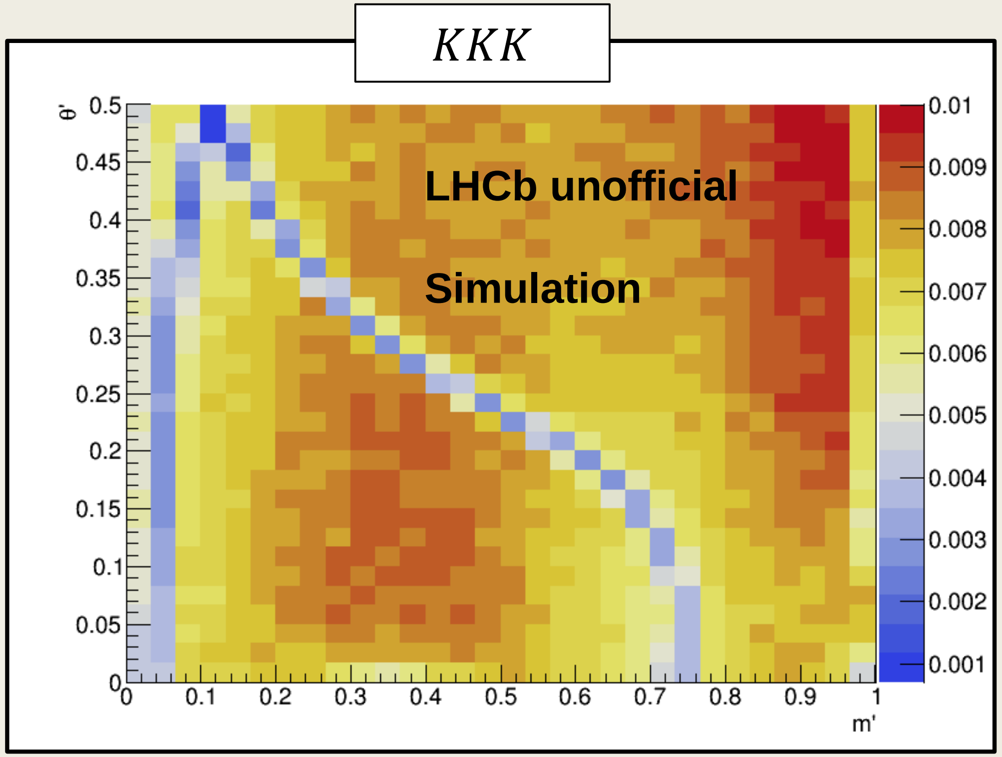


Efficiencies

- Event selection can favour certain areas of the phase space over others
  - Must correct this by calculating selection efficiency as function of DP
- PID efficiencies are obtained through data-driven method
- Geometric + selection efficiencies calculated from MC

Channel	$\epsilon^{\text{sel+geom}}$ (%)	ϵ^{PID} (%)	ϵ^{tot} (%)
KKK	0.9205 ± 0.0007	76.86 ± 0.17	0.7075 ± 0.0016
$K\pi K$	0.8841 ± 0.0007	58.58 ± 0.16	0.5179 ± 0.0015
$K\pi\pi$	0.8637 ± 0.0007	67.65 ± 0.16	0.5843 ± 0.0015
$\pi\pi\pi$	0.8137 ± 0.0007	72.49 ± 0.17	0.5898 ± 0.0014

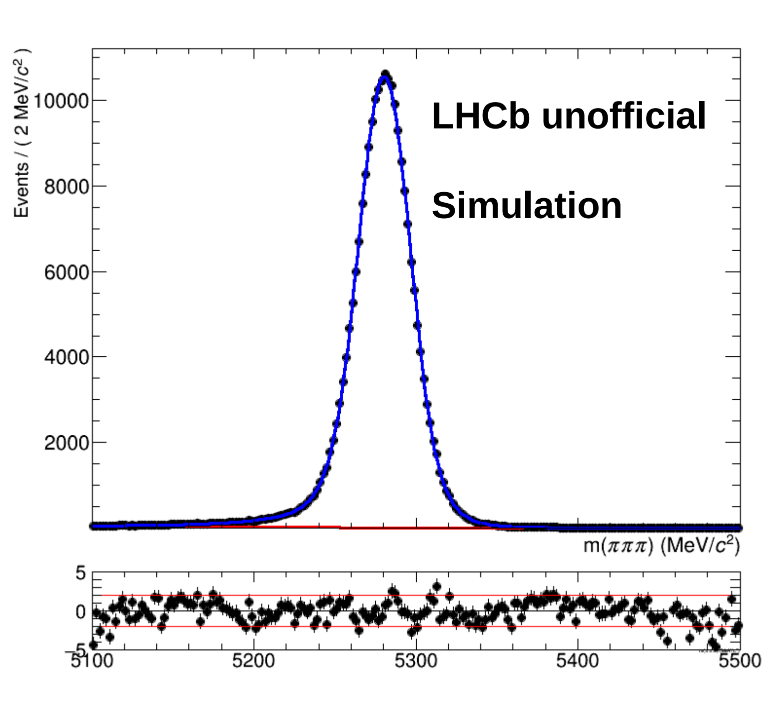
*statistical uncertainties only



Fit model

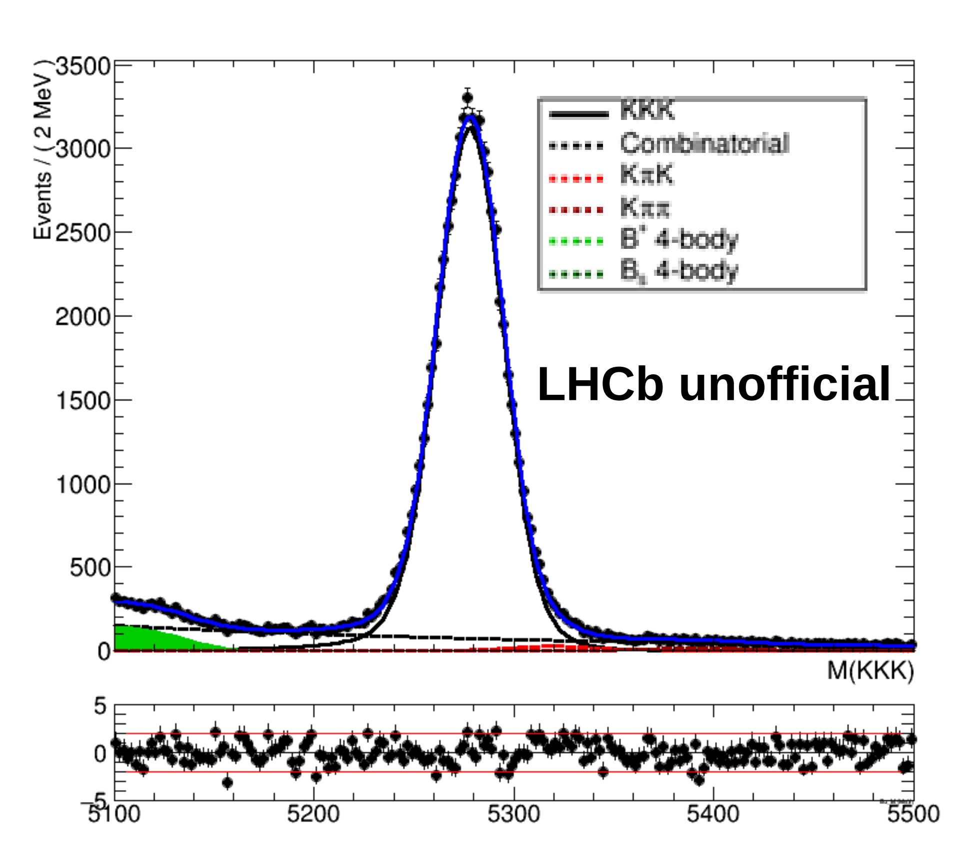
- Signal modes – Double Crystal Ball (DCB):
  - Tail parameters fixed to MC fit
  - Width in data fit = width from MC (fixed) × scale parameter (floating)
  - Peak position floats in data fit – shared between the four modes
- Cross-feed modes – DCB:
  - Reweighted according to physical DP distribution
  - Peak position and tail parameters fixed to MC fit

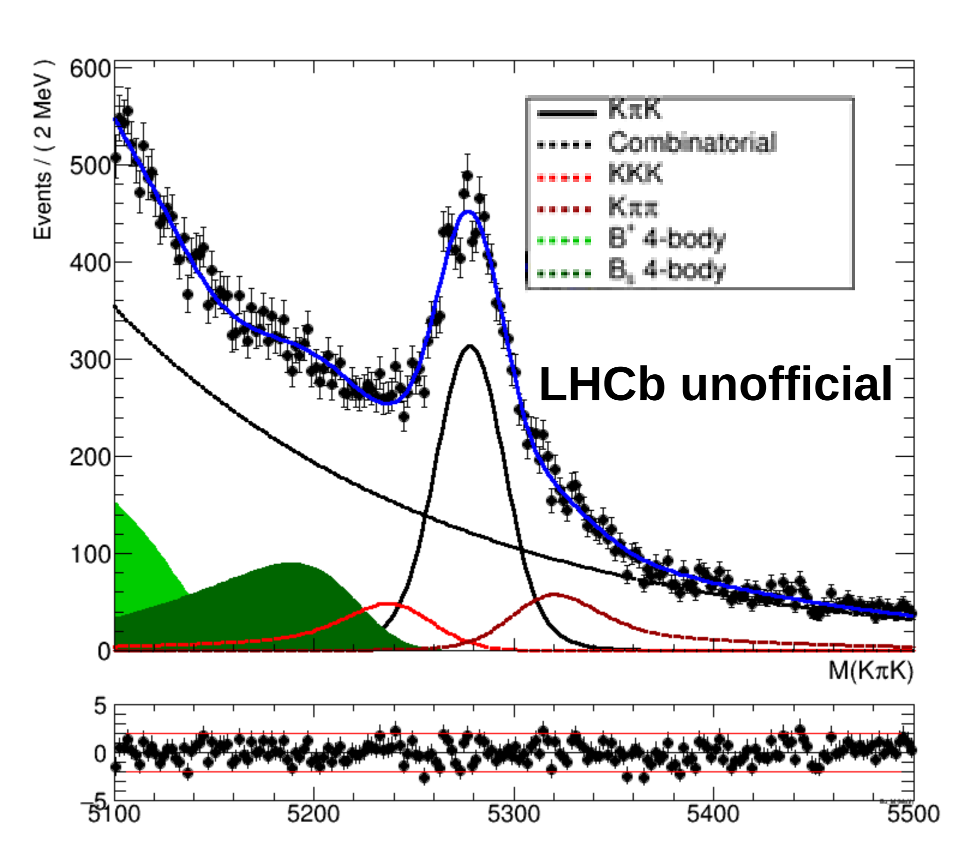
- Combinatorial – exponential
- Partially reconstructed – ARGUS ⊗ Gaussian:
  - Include one PDF for $B^+, B^0 \to 4\text{body}$ and one for $B_s \to 4\text{body}$
  - Extra $B \to \eta' K$ component in the $B \to K\pi\pi$ model



Simultaneous fit

- Perform simultaneous fit of all four signal modes on Run 1 data
- Cross-feed yields are constrained by misID efficiencies

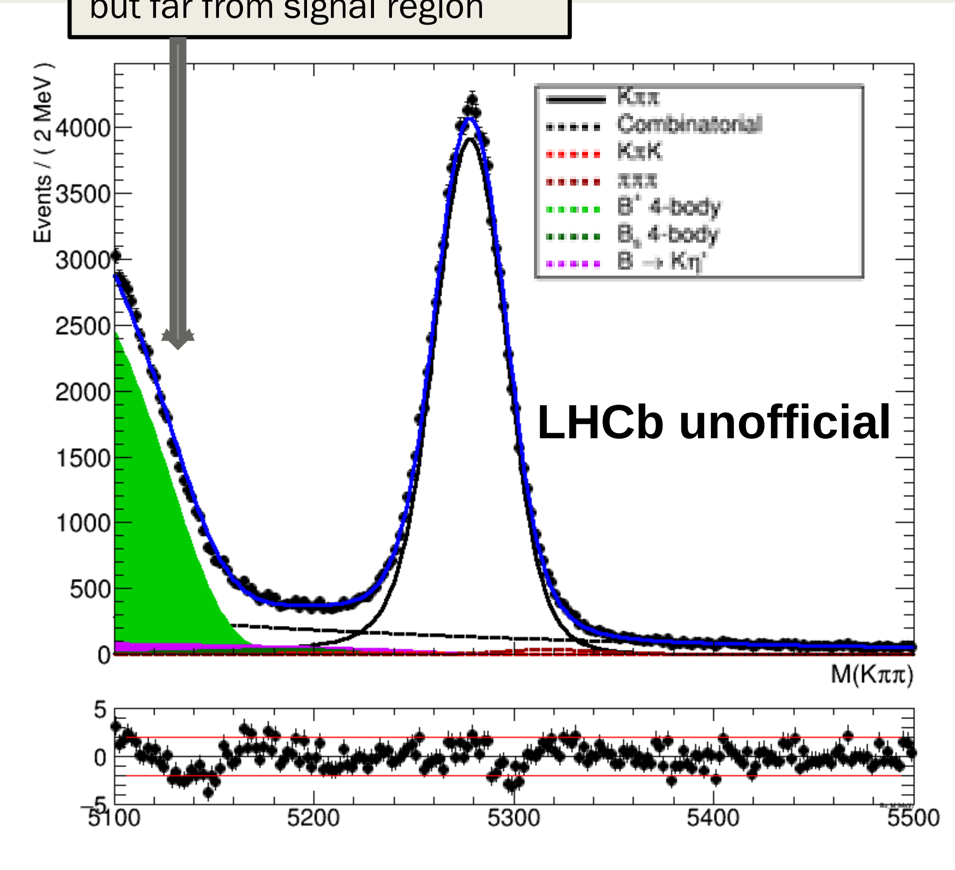


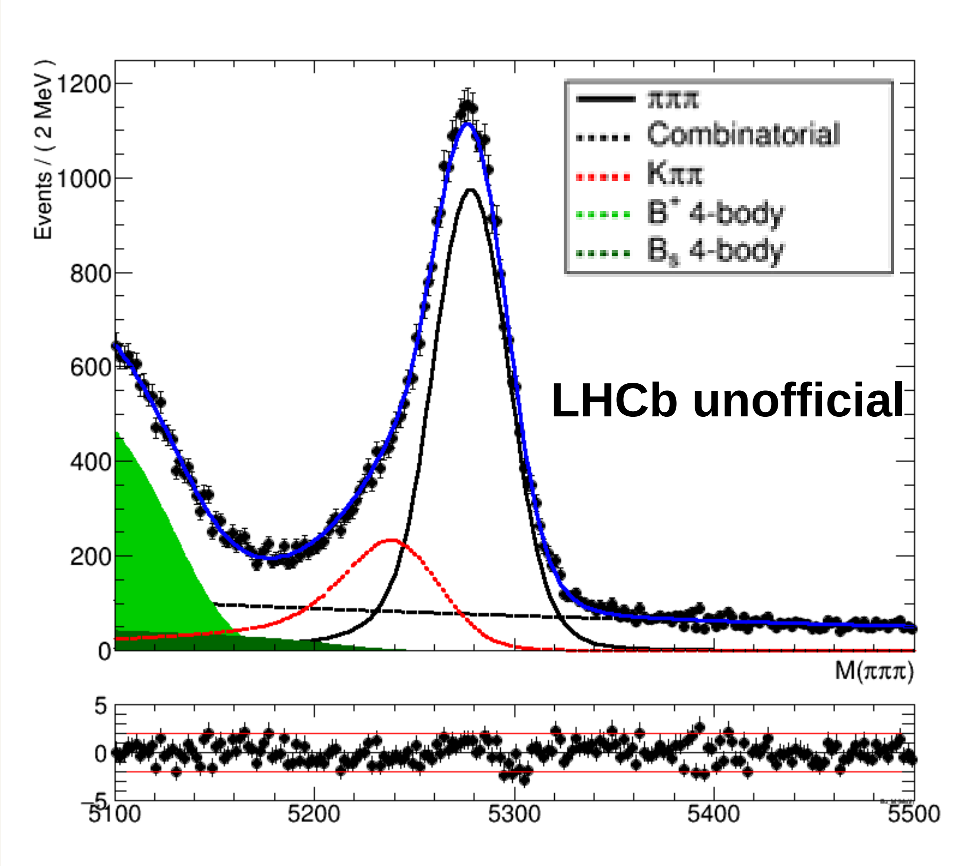


Simultaneous fit

Channel	Fit yield
KKK	68387 ± 310
πKK	7213 ± 160
$K\pi\pi$	$93929 + 409$
$\pi\pi\pi$	24960 ± 223

Trend seen at low $K\pi\pi$ mass but far from signal region





Branching fraction ratios

- BF ratios given by (per event) efficiency-corrected yields: $\frac{BF(hhh)}{BF(KKK)} = \frac{N^{\text{corr}}(hhh)}{N^{\text{corr}}(KKK)}$
  - Background subtraction done using the *sPlot* technique
  - $N^{\text{corr}} = \sum_i \frac{w_i}{\epsilon_i}$ + correction due to constrained cross-feed yields ($w_i = \text{event } s\text{Weight}$)

- Ratios are consistent with ratios using PDG values:
  - Statistical uncertainties considerably improved compared to PDG
  - Results are likely to be systematically limited

LHCb unofficial

	PDG ratio	Measured ratio
$BF(\pi KK)/BF(KKK)$	0.147 ± 0.021	0.1406 ± 0.0034 (stat)
$BF(K\pi\pi)/BF(KKK)$	1.50 ± 0.11	1.738 ± 0.013 (stat)
$BF(\pi\pi\pi)/BF(KKK)$	0.447 ± 0.045	0.5052 ± 0.0054 (stat)

Sources of systematics

- Fit model:
  - Choice of model – try alternative PDFs
  - Fixed parameters – vary within uncertainties
  - Fit bias – check with toys
- Finite MC statistics
- Event selection:
  - Data/MC discrepancies
  - Veto windows
- Efficiencies:
  - Trigger, tracking corrections

Summary

- Selection strategy finalised for both runs
- Simultaneous fit to Run 1 is in good shape
  - Run 2 fit being worked on
- Preliminary results consistent with PDG
  - Potential significant improvement in precision
- Towards completion:
  - Calculate systematic uncertainties
  - Measure Run 2 ratios

Backup

Branching fraction ratios

PDG ratios

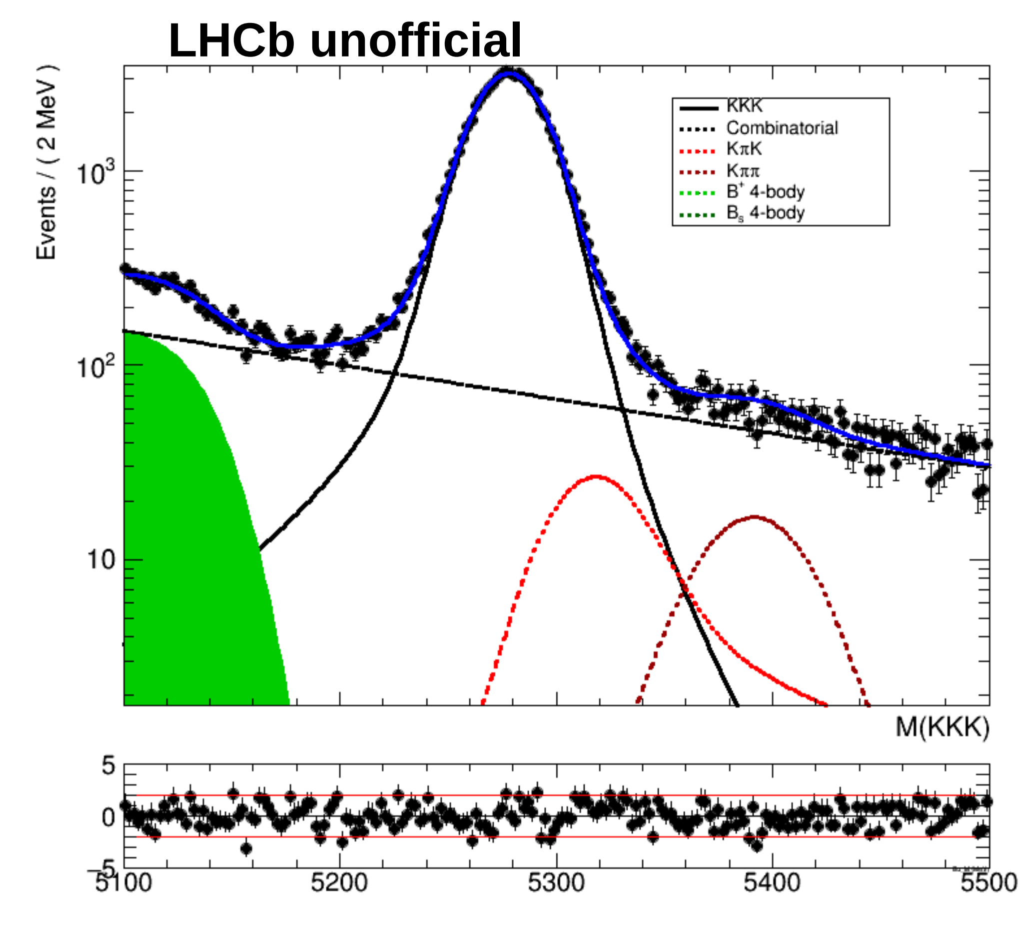
row/col	KKK	$K\pi K$	$K\pi\pi$	$\pi\pi\pi$
KKK	1	6.80 ± 0.99	0.667 ± 0.047	2.24 ± 0.23
$K\pi K$	0.147 ± 0.021	1	0.098 ± 0.015	0.329 ± 0.055
$K\pi\pi$	1.50 ± 0.11	10.2 ± 1.5	1	3.36 ± 0.36
$\pi\pi\pi$	0.447 ± 0.045	3.04 ± 0.51	0.298 ± 0.032	1

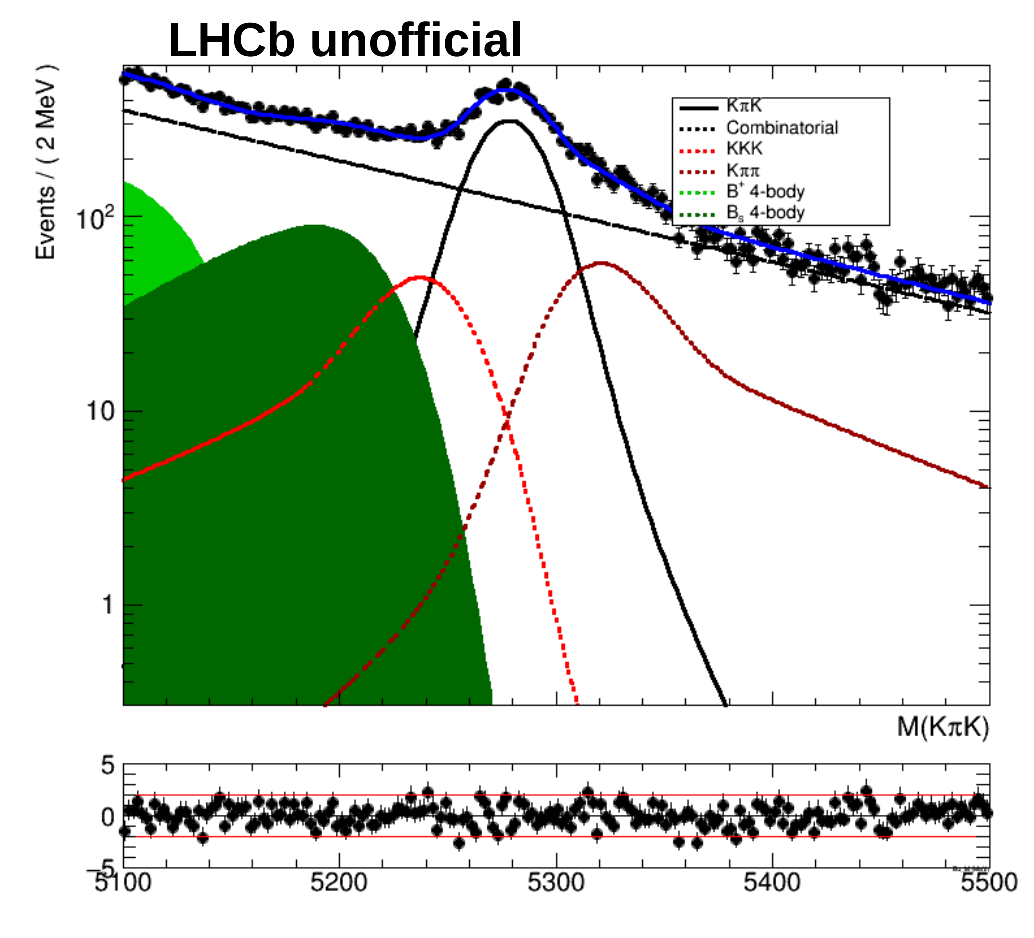
Measured ratios (stat uncertainties only)

LHCb unofficial

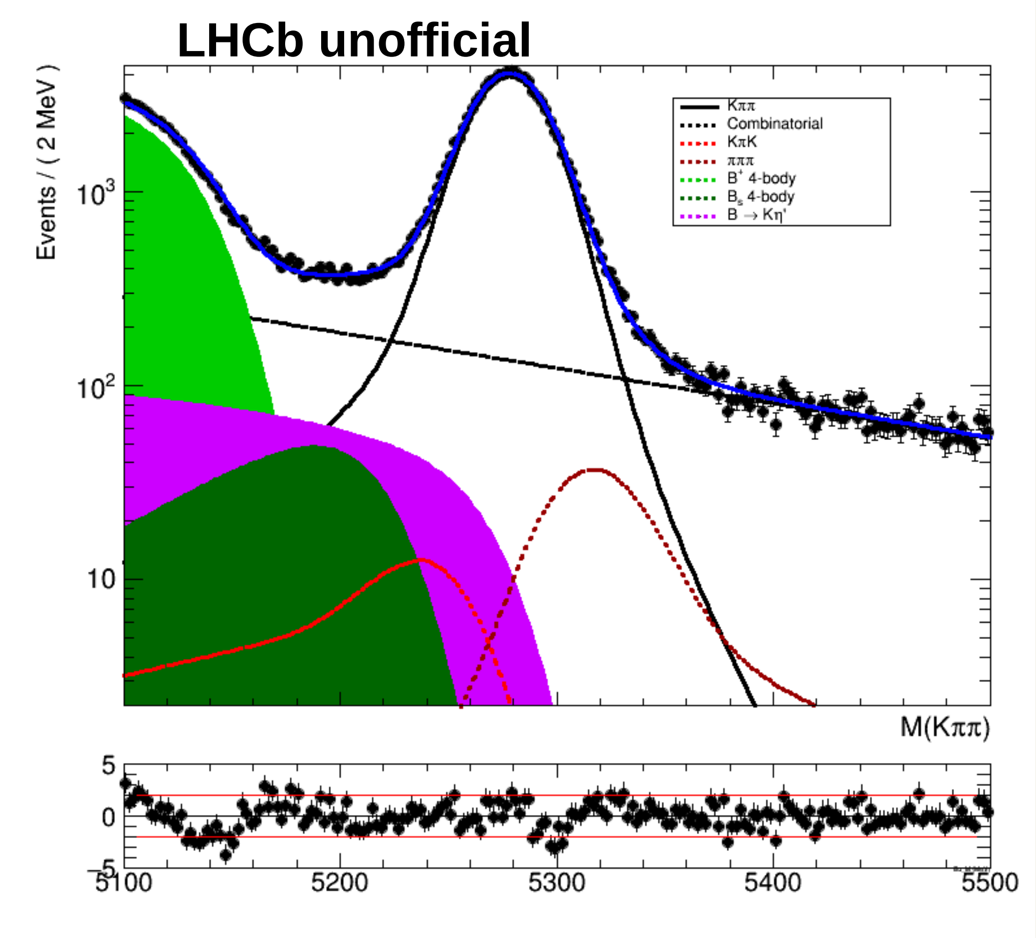
row/col	KKK	$K\pi K$	$K\pi\pi$	$\pi\pi\pi$
KKK	1	7.11 ± 0.17	0.5755 ± 0.0044	1.980 ± 0.021
$K\pi K$	0.1406 ± 0.0034	1	0.0809 ± 0.0020	0.2783 ± 0.0071
$K\pi\pi$	1.738 ± 0.013	12.36 ± 0.30	1	3.440 ± 0.039
$\pi\pi\pi$	0.5052 ± 0.0054	3.594 ± 0.092	0.2907 ± 0.0033	1

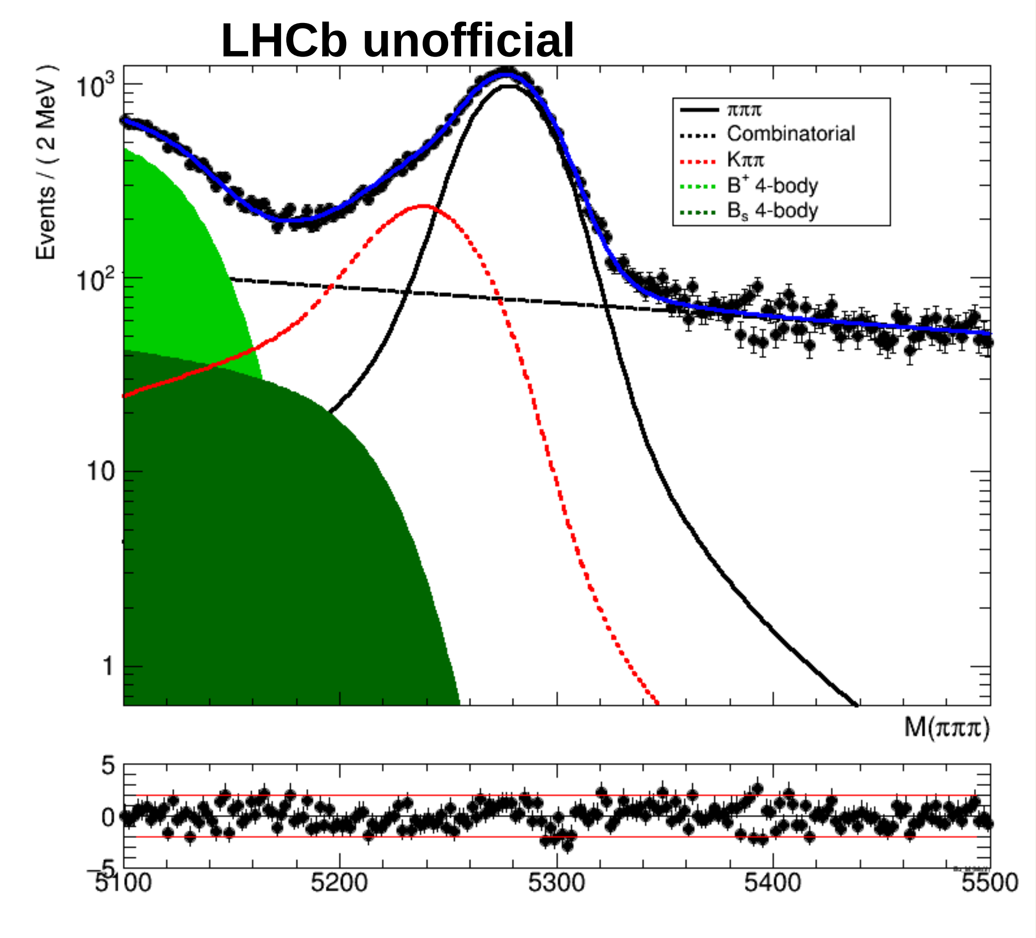
Simultaneous fit – log





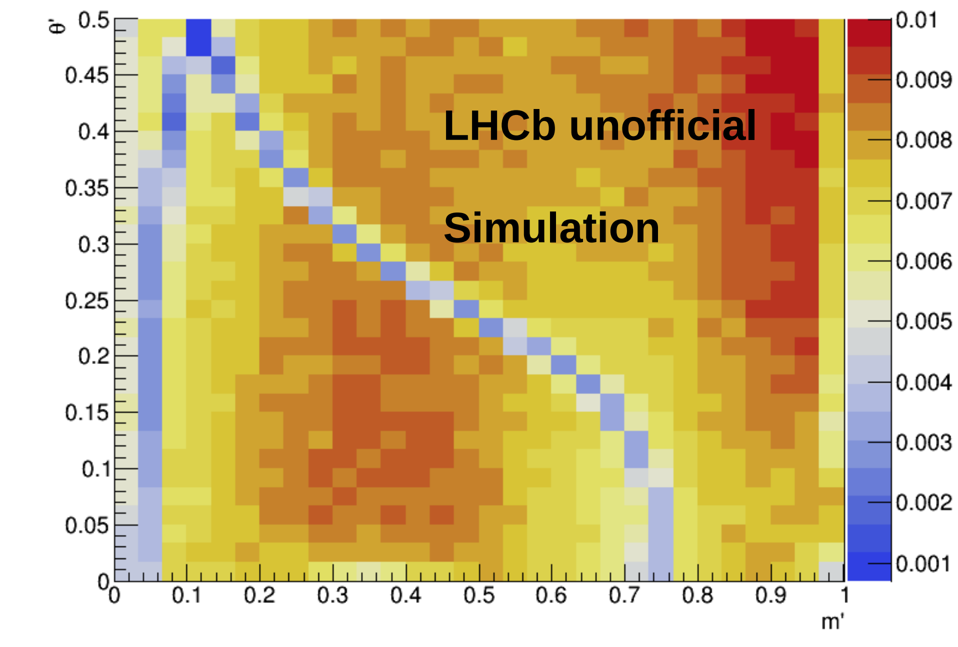
Simultaneous fit – log



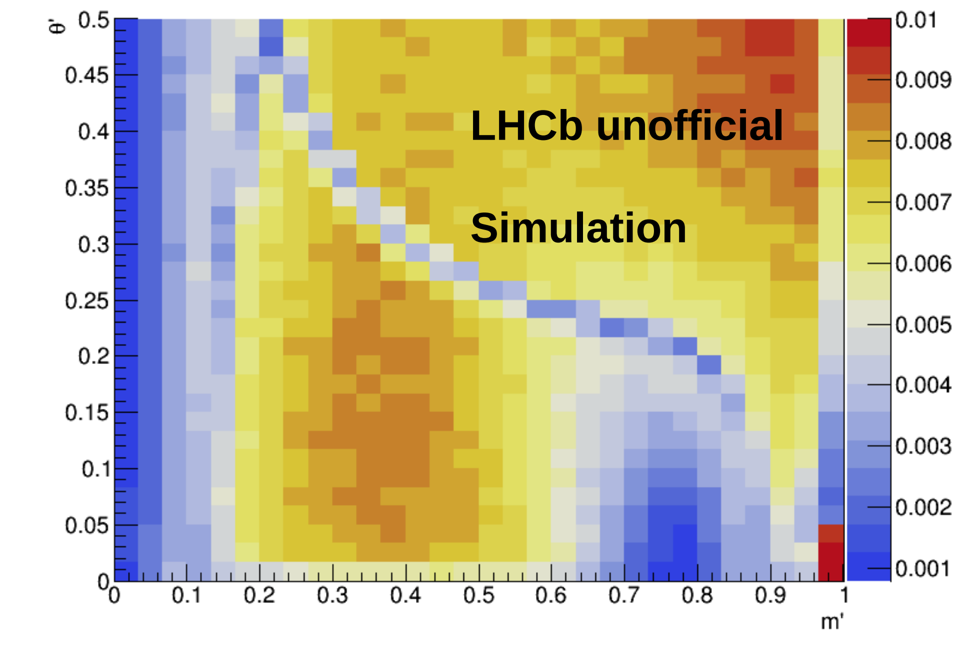


Efficiencies

KKK

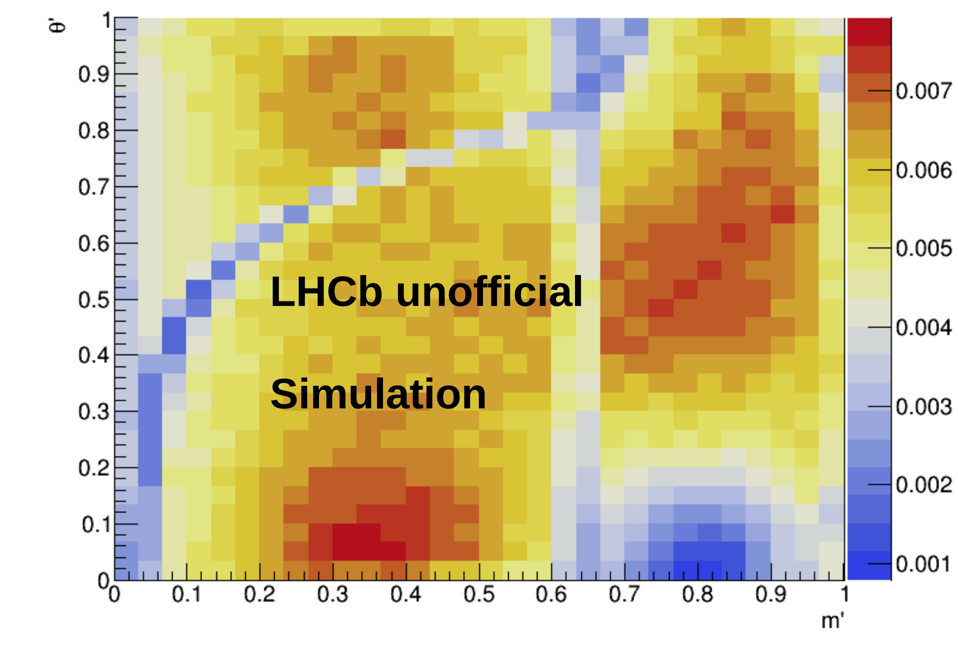


$\pi\pi\pi$



Efficiencies

$K\pi K$



$K\pi\pi$