



Direct CP Violation in the decay $B^+ \rightarrow K^+ \pi^0$ at LHCb

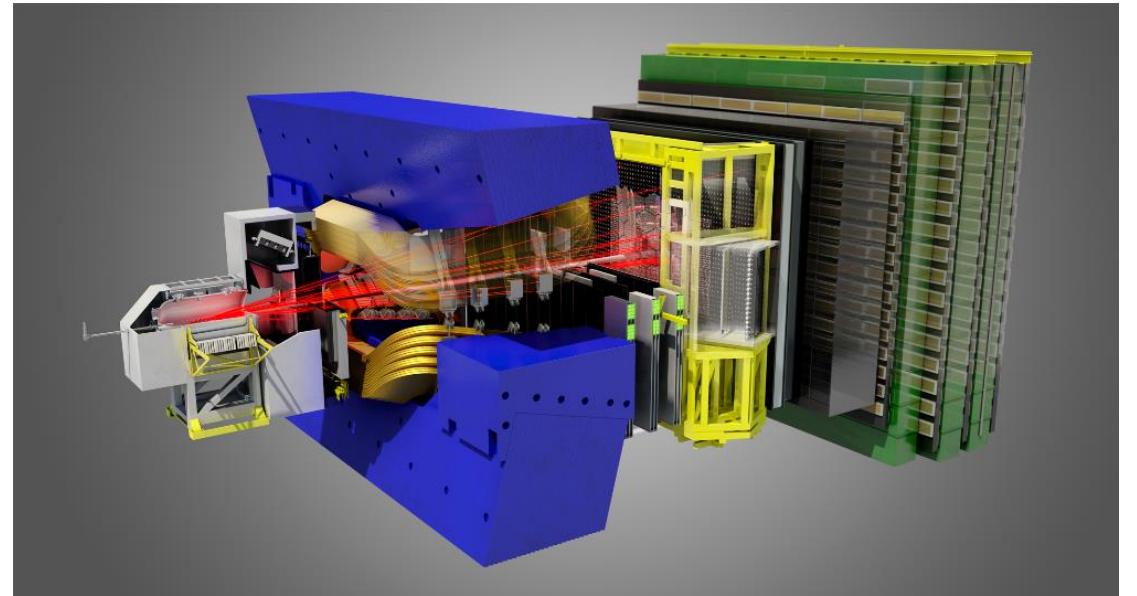
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On behalf of the LHCb Collaboration

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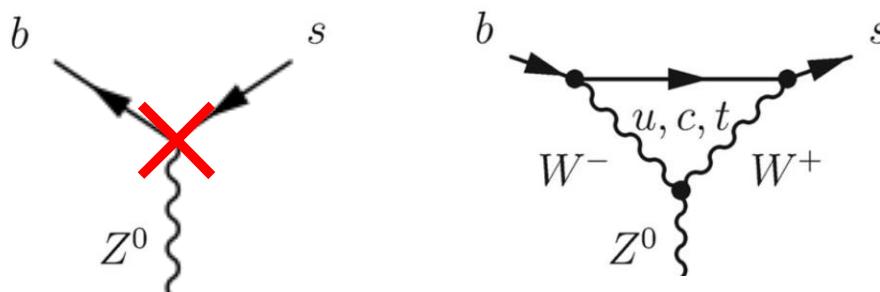
Overview

- Introduction to B physics and the $K\pi$ puzzle
- LHCb and neutral particles
- New measurement of $A_{CP}(B^+ \rightarrow K^+\pi^0)$



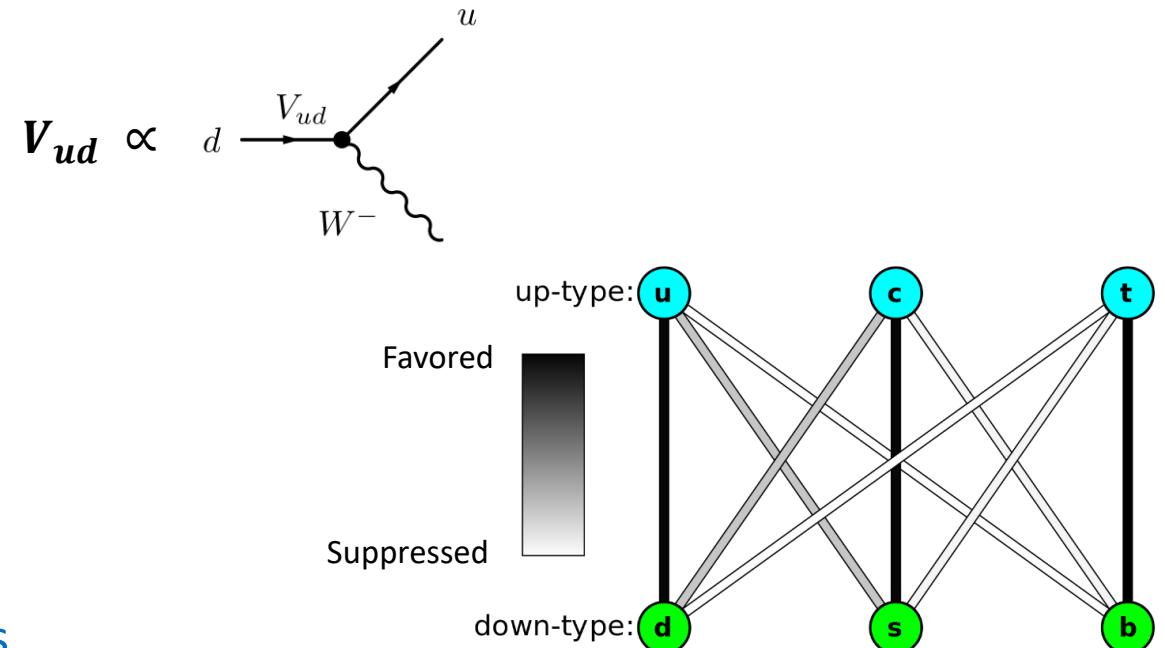
The CKM Matrix

- CKM matrix describes the interaction of quarks with the weak force
- Inter-generation transitions suppressed
 - Interesting b quark properties: long lifetime $\gamma c\tau_B \sim 7\text{mm}$, particular sensitivity to NP
- Flavor Changing Neutral Currents forbidden to first order



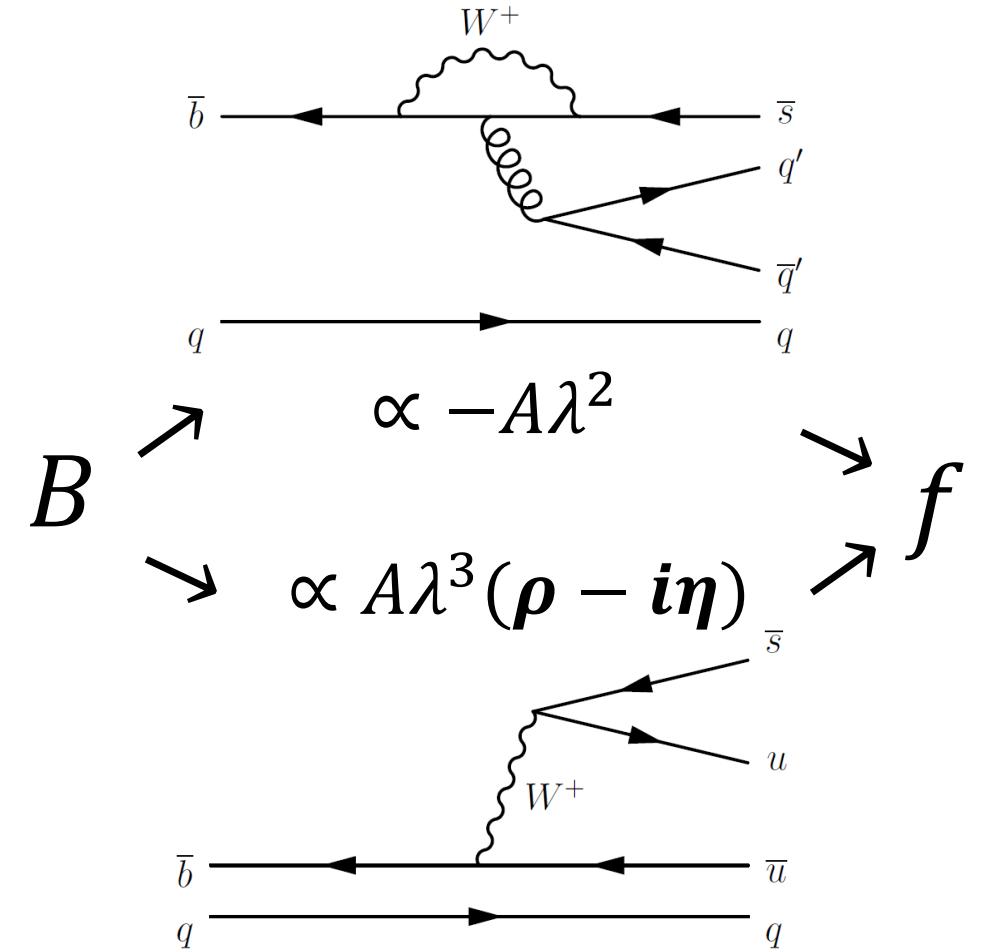
- Single complex phase source of CP asymmetry
 - CP violation requires at least three generations

$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \approx \begin{bmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{bmatrix}$$



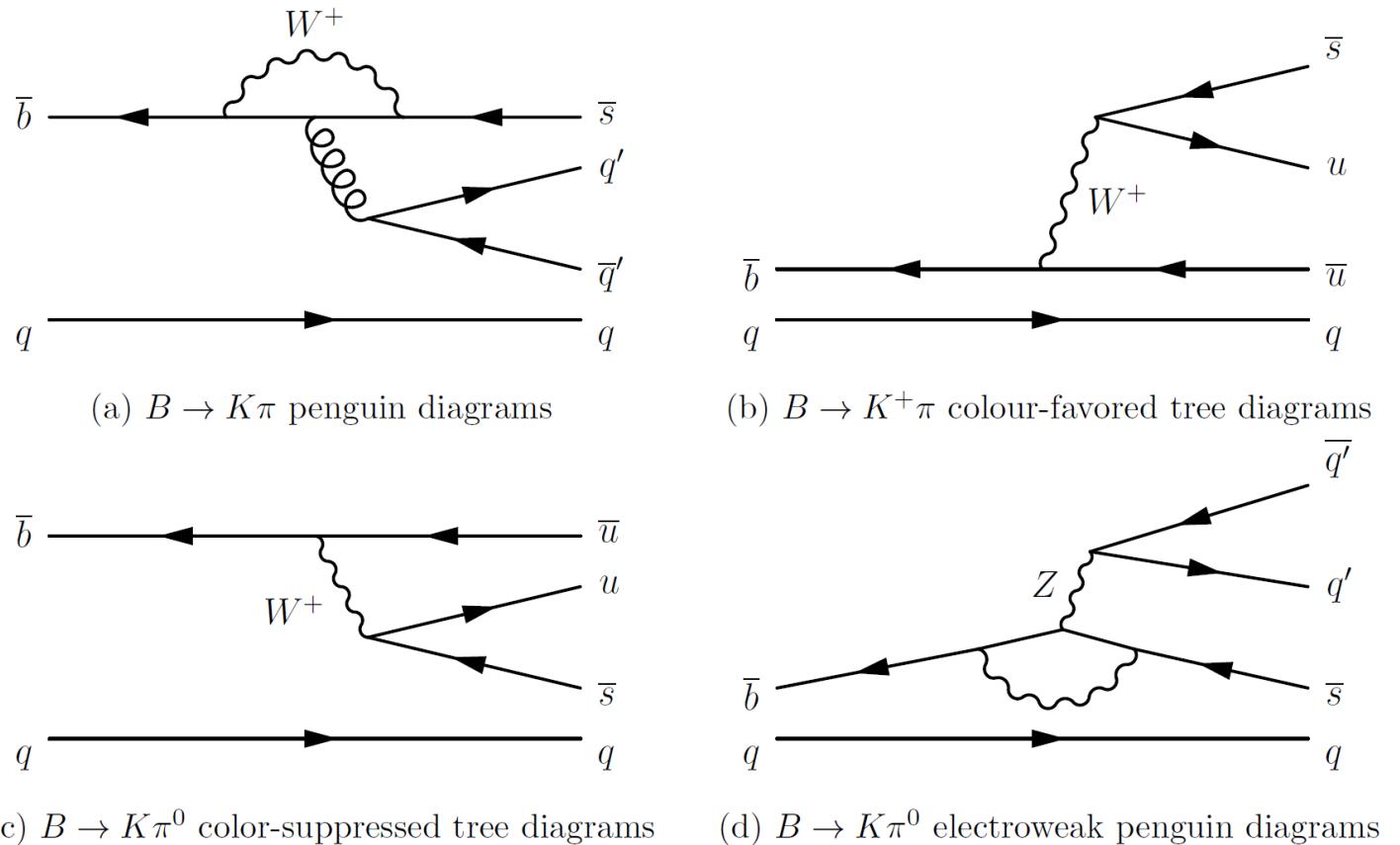
CP Violation

- Physical laws not invariant under charge conjugation + parity inversion (mirror flip)
- Consequence of interference when a physical process can proceed in different ways
- CP violation in mixing: $B^0 \rightarrow \bar{B}^0 \neq \bar{B}^0 \rightarrow B^0$
- Indirect CP violation: asymmetry due to interference between mixing and decay amplitudes
- Direct CP violation:** $B \rightarrow f \neq \bar{B} \rightarrow \bar{f}$ due to interference in decay amplitudes
 - Requires non-zero relative weak and strong phase between amplitudes



The $B \rightarrow K\pi$ System

- $B^0 \rightarrow K^+\pi^-$, $B^0 \rightarrow K^0\pi^0$,
 $B^+ \rightarrow K^+\pi^0$, $B^+ \rightarrow K^0\pi^+$
- Dominated by QCD penguin diagrams
 - Suppressed by loop
 - Tree suppressed by V_{ub}
- Different $K\pi$ decays have contributions from different diagrams
- Potentially sensitive to new physics through massive virtual particles in loops



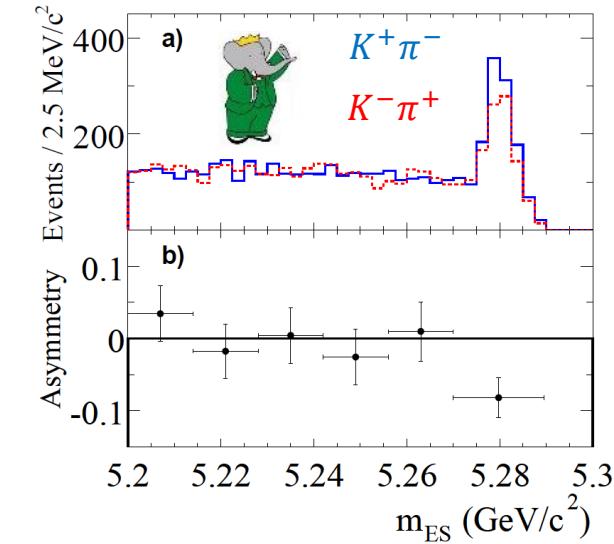
Observation of Direct CPV in B mesons

A_{CP} and branching fraction world averages for the $B \rightarrow K\pi$ decay modes.

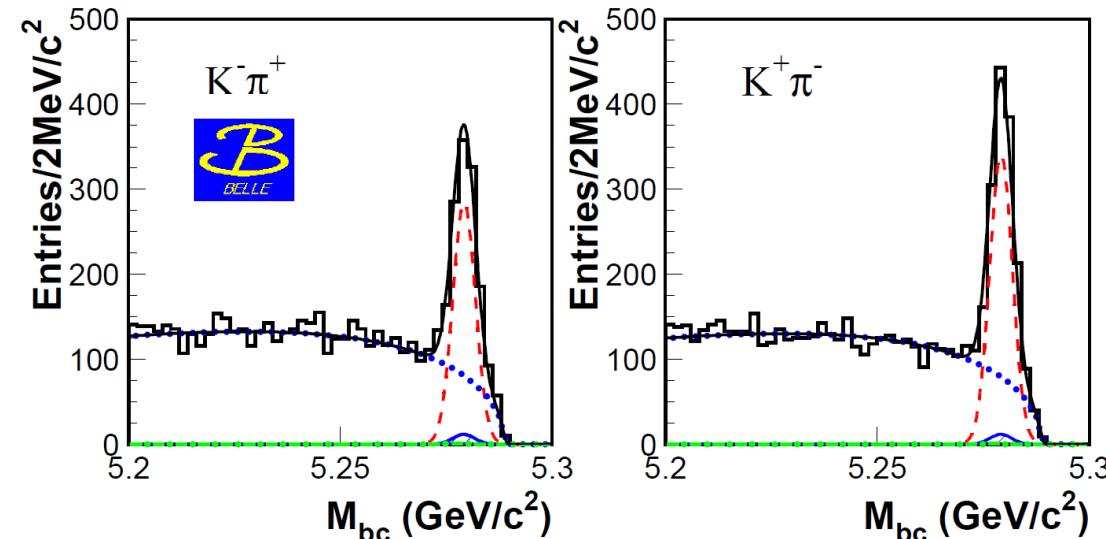
	$BF \times 10^{-6}$	Direct A_{CP}	$\sin(2\beta^{eff})$
$B^0 \rightarrow K^0\pi^0$	9.9 ± 0.5	0.01 ± 0.10	0.57 ± 0.17
$B^+ \rightarrow K^0\pi^+$	23.8 ± 0.8	-0.017 ± 0.016	
$B^0 \rightarrow K^+\pi^-$	19.6 ± 0.5	-0.084 ± 0.004	
$B^+ \rightarrow K^+\pi^0$	12.9 ± 0.5	0.040 ± 0.021	

[HFLAV 2018](#)

- BaBar and Belle: experiments at e^+e^- colliders devoted to studying B mesons
- First observed direct CP violation in B mesons in $B^0 \rightarrow K^+\pi^-$ decays
- Measured branching fractions and CP asymmetries for all $K\pi$ modes



[Phys. Rev. Lett. 93 \(2004\) 131801](#)

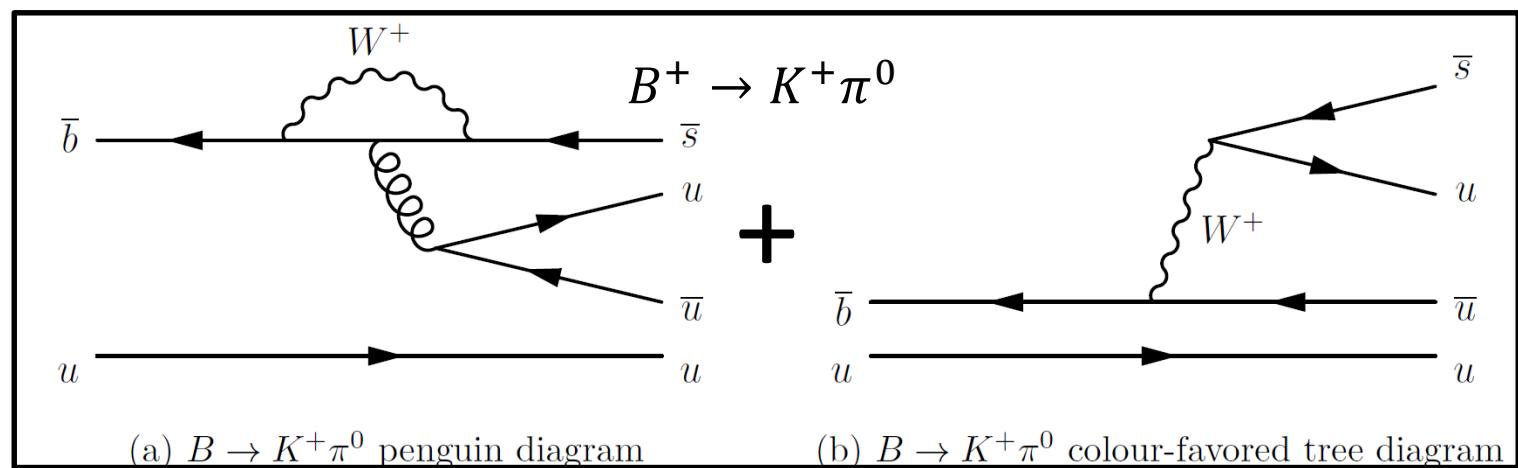
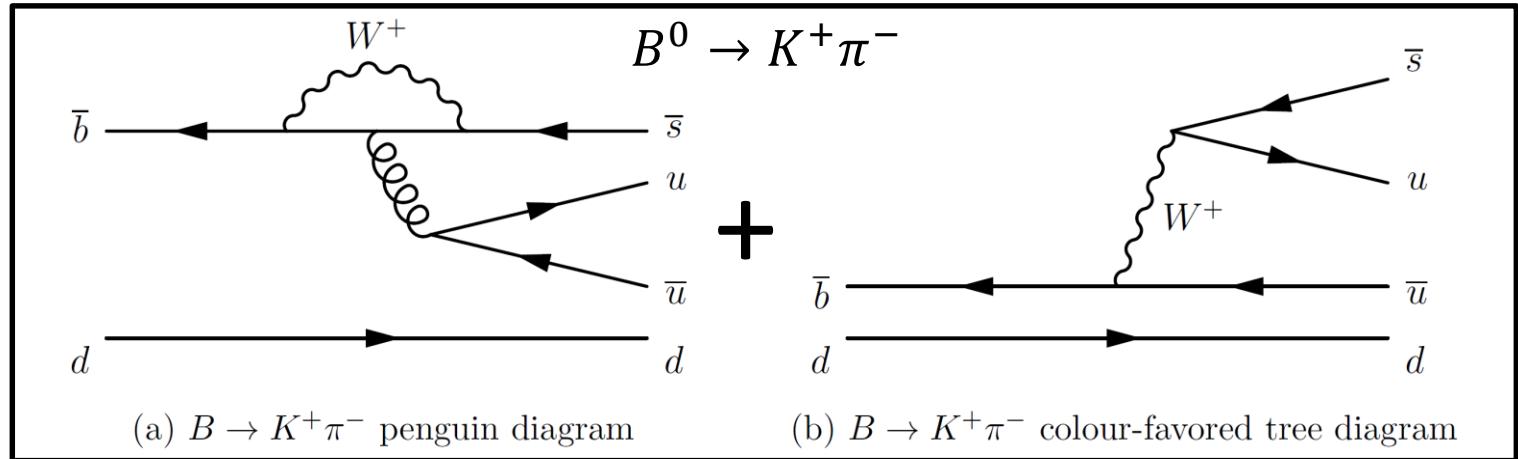


[Phys. Rev. Lett. 93 \(2004\) 191802](#)

The $K\pi$ Puzzle

- CP asymmetry in $B^0 \rightarrow K^+\pi^-$ and $B^+ \rightarrow K^+\pi^0$ from interference between tree and penguin diagrams
- Expected to be equal from isospin arguments
- Differs by more than 5σ according to current measurements

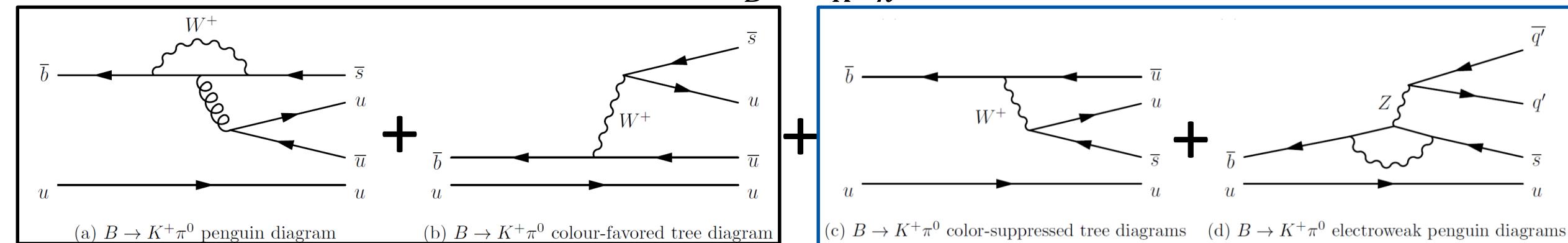
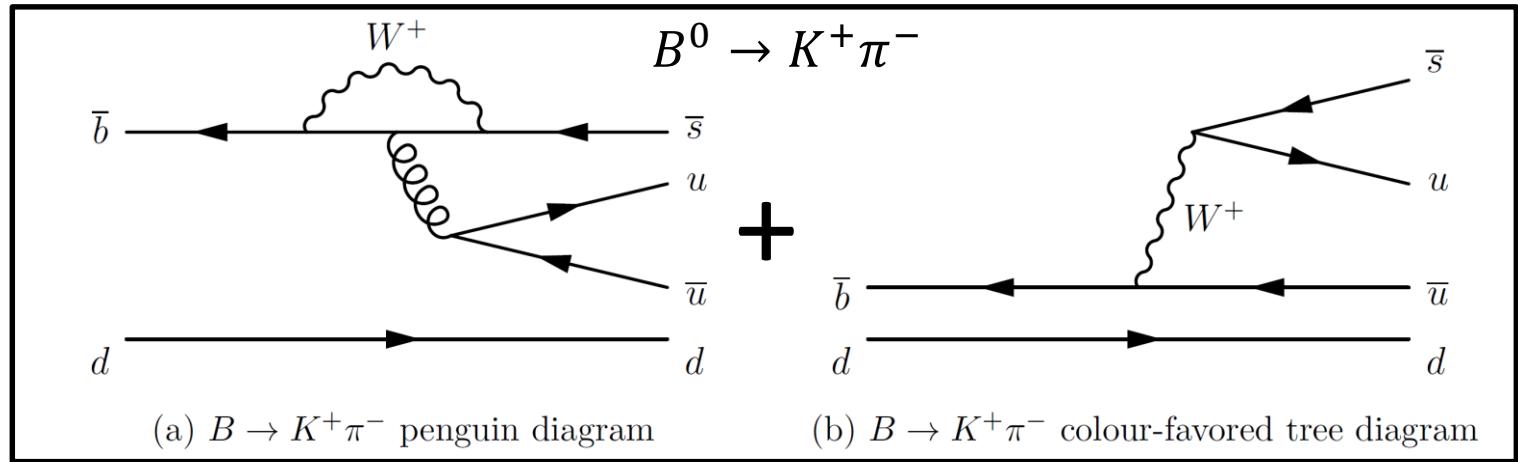
$$A_{CP}(B^+ \rightarrow K^+\pi^0) - A_{CP}(B^0 \rightarrow K^+\pi^-) = 0.124 \pm 0.021$$



The $K\pi$ Puzzle

$$A_{CP}(B^+ \rightarrow K^+\pi^0) - A_{CP}(B^0 \rightarrow K^+\pi^-) \\ = 0.124 \pm 0.021$$

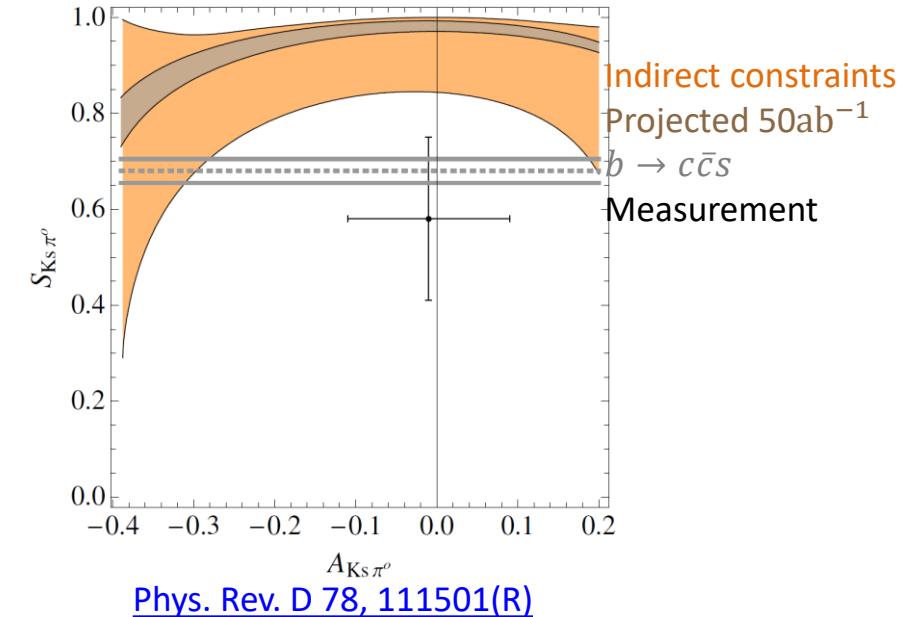
- Color-suppressed tree and electroweak penguin diagrams contribute to $K^+\pi^0$ but not $K^+\pi^-$



The $K\pi$ Puzzle Continued

$$A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+) \frac{B(K^0\pi^+) \tau_0}{B(K^+\pi^-) \tau_+} = A_{CP}(K^+\pi^0) \frac{2B(K^+\pi^0) \tau_0}{B(K^+\pi^-) \tau_+} + A_{CP}(K^0\pi^0) \frac{2B(K^0\pi^0)}{B(K^+\pi^-)}$$

- All $K\pi$ CP asymmetries and branching fractions can be incorporated in more precise equivalence
- Current measurements ([HFLAV 2018](#)) predict $A_{CP}(K^0\pi^0) = -0.150 \pm 0.032$, value measured by B factories: 0.01 ± 0.10
- Fits to $K\pi$ observables show some tension
- Can be resolved by enhancement of color-suppressed trees or NP in penguins
- $B^0 \rightarrow K_S^0\pi^0$ is a key component of Belle II physics program



[Buras et al., Eur. Phys. J. C 32 \(2003\) 45](#), [Phys. Rev. Lett. 92 \(2004\) 101804](#), [Nucl. Phys. B 697 \(2004\) 133](#);

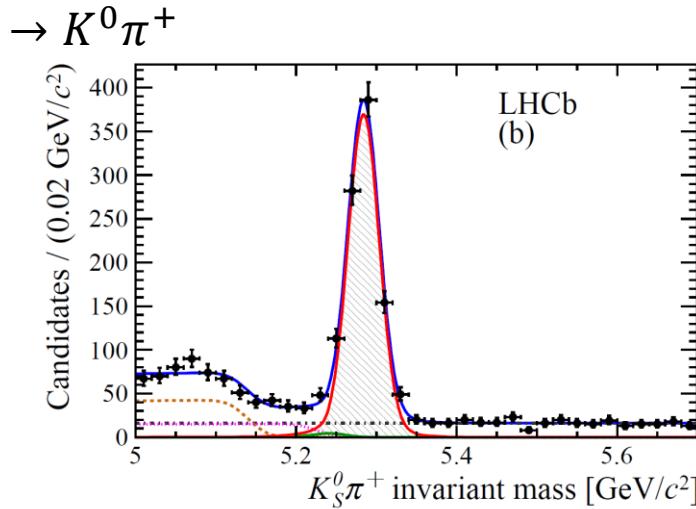
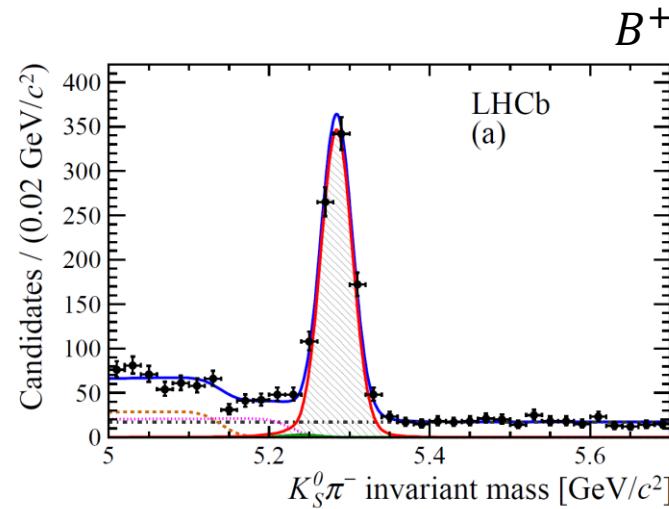
[S. Baek et al., Phys. Rev. D 71 \(2005\) 057502](#), [Phys. Lett. B 653 \(2007\) 249](#), [Phys. Lett. B 675 \(2009\) 59](#);

[M. Gronau, Phys. Lett.B 627 \(2005\) 82](#); [N. B. Beaudry et al., JHEP01\(2018\) 074](#); [R. Fleischer et al., Phys. Lett. B 785 \(2018\) 525](#)

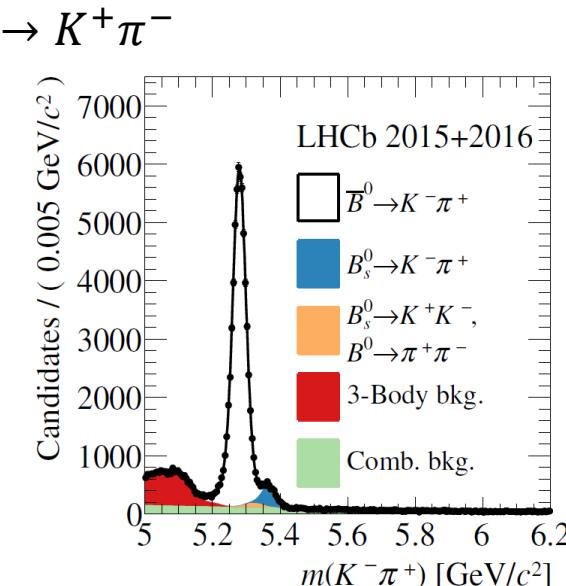
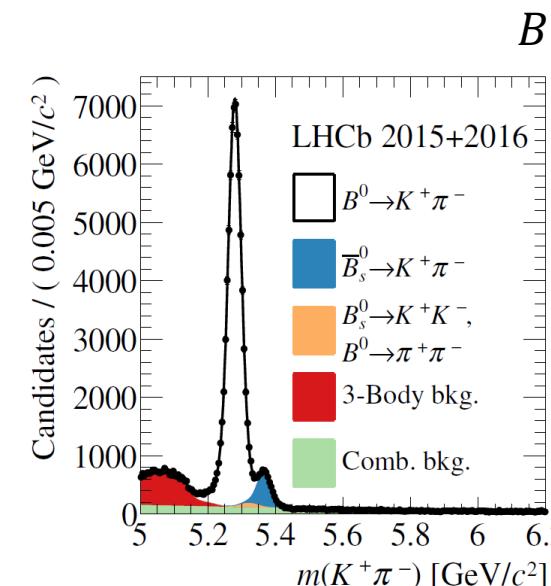
$K\pi$ at LHCb

- $A_{CP}(B^+ \rightarrow K_s^0 \pi^+)$,
 $A_{CP}(B^+ \rightarrow K_s^0 K^+)$, ratio of
branching fractions measured
with Run I data
- Most precise measurement
of $A_{CP}(B^0 \rightarrow K^+ \pi^-)$ with
 1.9fb^{-1} Run II data
 - Also measured A_{CP} in
 $B_s^0 \rightarrow K^+ \pi^-$, $K^+ K^-$
- Provide additional
information about diagrams
related to $K\pi$ system by U-
spin symmetry
 - First observation of time-
dependent CP violation in
 B_s^0 decays

03/24/2021



[Phys.Lett.
B 726
\(2013\) 646](#)



[JHEP 03\(2021\)075](#)

Experimental Status

\mathcal{A}^{CP} measurements for the $B \rightarrow K\pi$ decay modes

	BaBar	Belle	LHCb
$B^0 \rightarrow K^0\pi^0$	$+0.13 \pm 0.13 \pm 0.03$ [1]	$-0.14 \pm 0.13 \pm 0.06$ [2]	
$B^+ \rightarrow K^0\pi^+$	$-0.029 \pm 0.039 \pm 0.010$ [3]	$-0.011 \pm 0.021 \pm 0.006$ [4]	$-0.022 \pm 0.025 \pm 0.010$ [5]
$B^0 \rightarrow K^+\pi^-$	$-0.107 \pm 0.016^{+0.006}_{-0.004}$ [6]	$-0.069 \pm 0.014 \pm 0.007$ [4]	$-0.0824 \pm 0.0033 \pm 0.0033$ [7]
$B^+ \rightarrow K^+\pi^0$	$+0.030 \pm 0.039 \pm 0.010$ [8]	$+0.043 \pm 0.024 \pm 0.002$ [4]	

- LHCb has measured charged pion modes, modes with π^0 only measured at B factories
- **$B^+ \rightarrow K^+\pi^0$ is first analysis of a one-track B decay at a hadron collider**
- Experimentally challenging
 - No secondary vertex to identify B decay
 - Relatively low π^0 efficiency
 - High combinatorial background
- Proof of concept for other modes of similar topology such as $B^0 \rightarrow K^0\pi^0$

[1]:[Phys.Rev.D 79, 052003](#)

[2]:[Phys.Rev.D 81, 011101\(R\)](#)

[3]:[Phys.Rev.Lett. 97, 171805](#)

[4]:[Phys.Rev.D 87, 031103\(R\)](#)

[5]:[Phys.Lett.B 726 \(2013\) 646](#) [6]:[Phys.Rev.D 87, 052009](#)

[7]:[JHEP 03\(2021\)075](#)

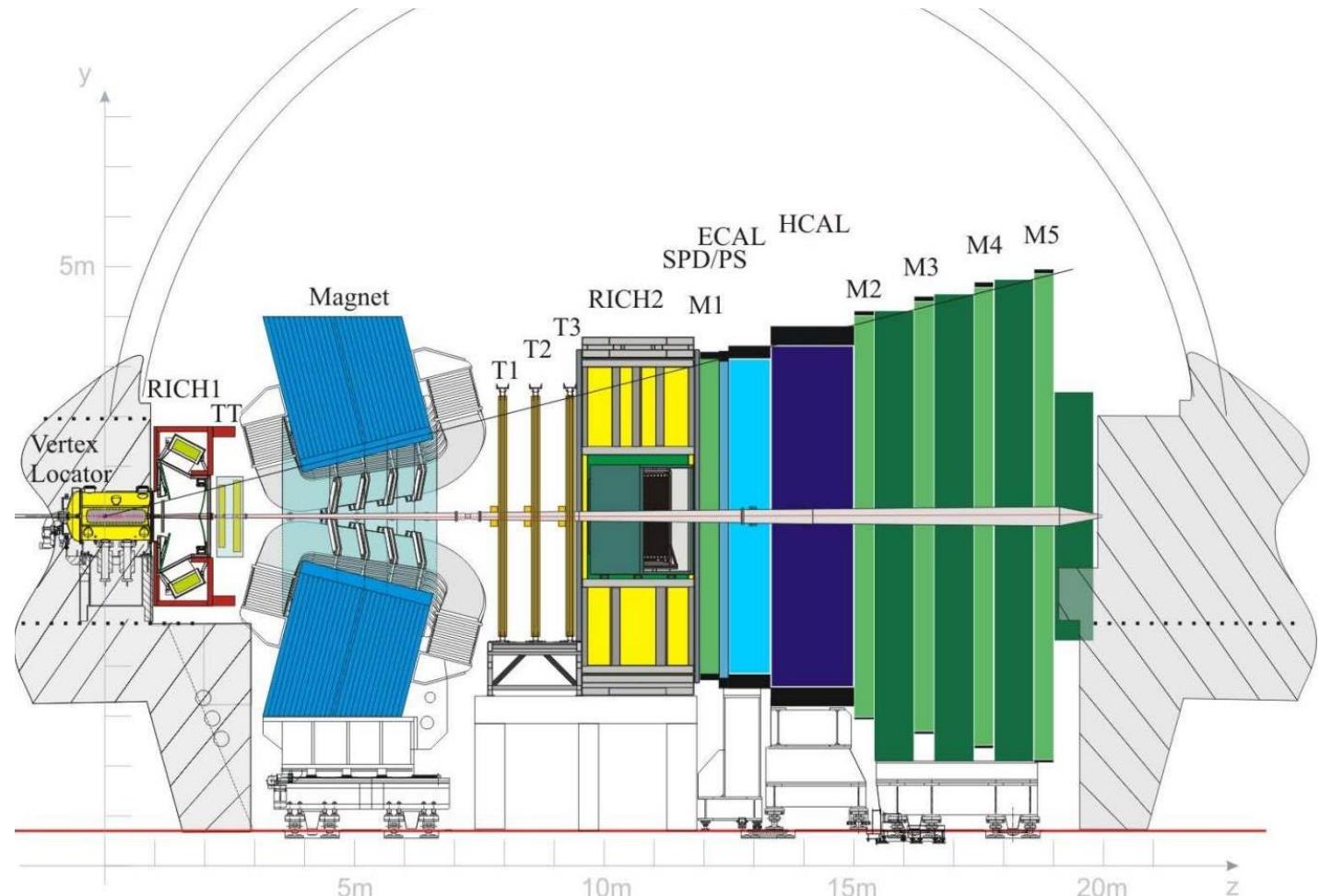
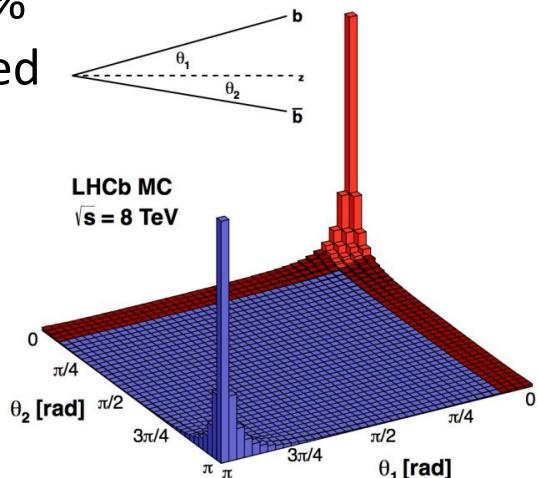
[8]:[Phys.Rev.D 76, 091102\(R\)](#)



The LHCb Detector

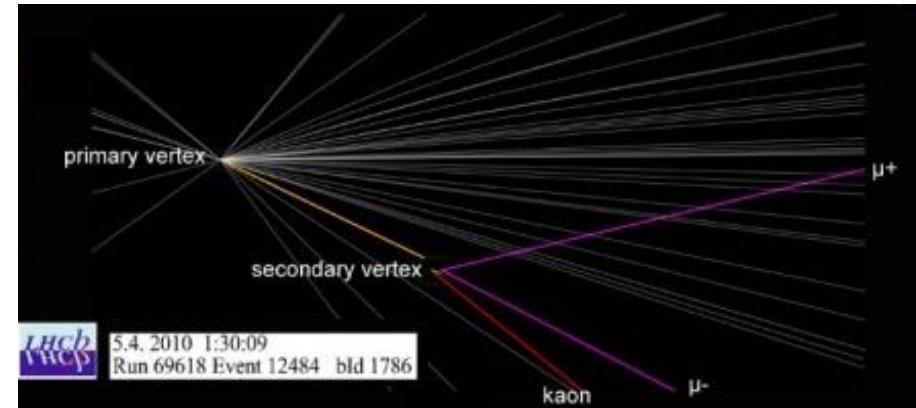
The LHCb Detector

- High cross sections for b and c production at the LHC
 - $\sigma_{b\bar{b}} \sim 500 \mu b$ at 14 TeV
 - Produced predominantly at high η
- Central detector instrumenting $|\eta| < 2.5$ would instrument 98% solid angle and capture 45% of $b\bar{b}$ pairs
- Instrumenting $2 < \eta < 5$ ($\sim 4\%$ solid angle) captures 25% of $b\bar{b}$ pairs produced



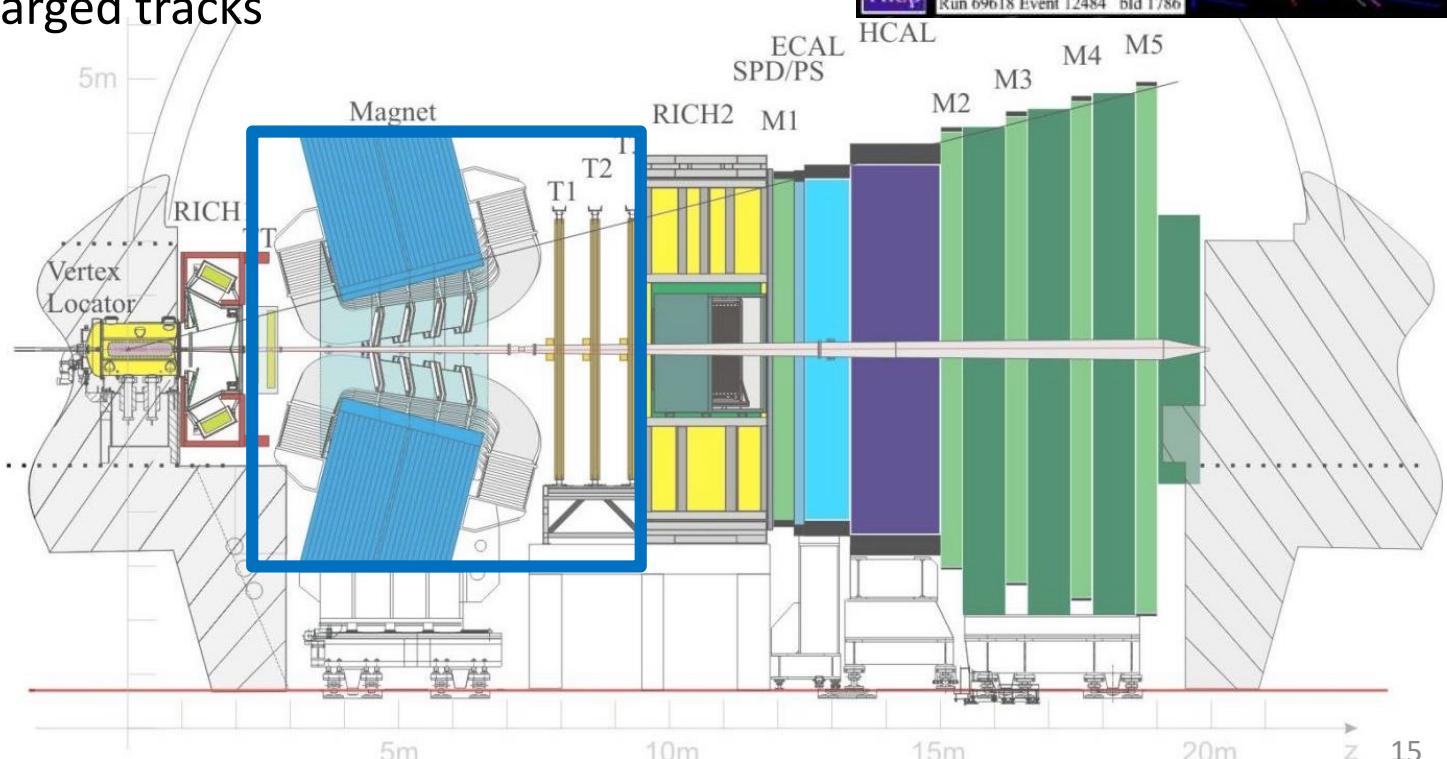
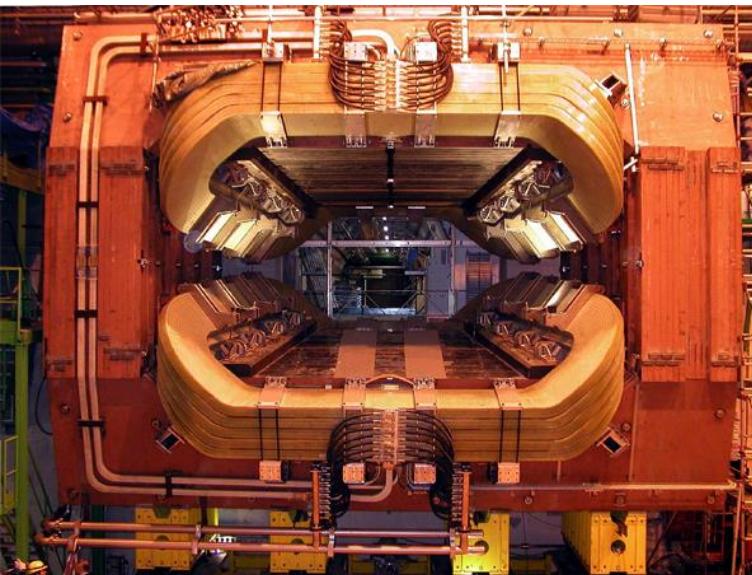
Vertex Locator

- Silicon strip detector located inside the beam pipe, 8mm from beam
- Provides precision information on charged track position
- $\sigma_{IP} = \left(15 + \frac{29}{p_T[\text{GeV}]} \right) \mu\text{m}$



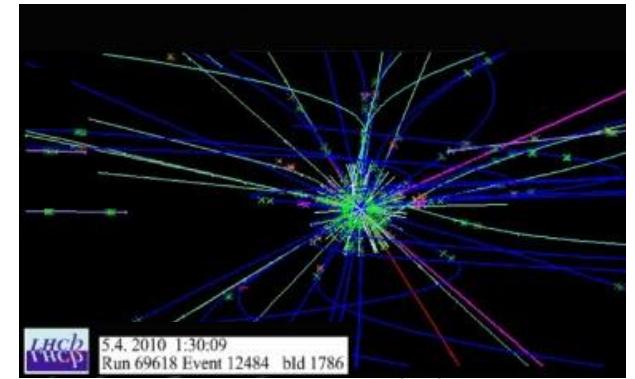
Tracking System

- 4 Tm dipole magnet
- Silicon strip sensors before magnet and in high-occupancy region around beampipe
- Straw tubes for coverage of lower occupancy region
- Provides momentum information for charged tracks
- $\frac{\sigma_p}{p} = 1\%$ at 200 [GeV/c]



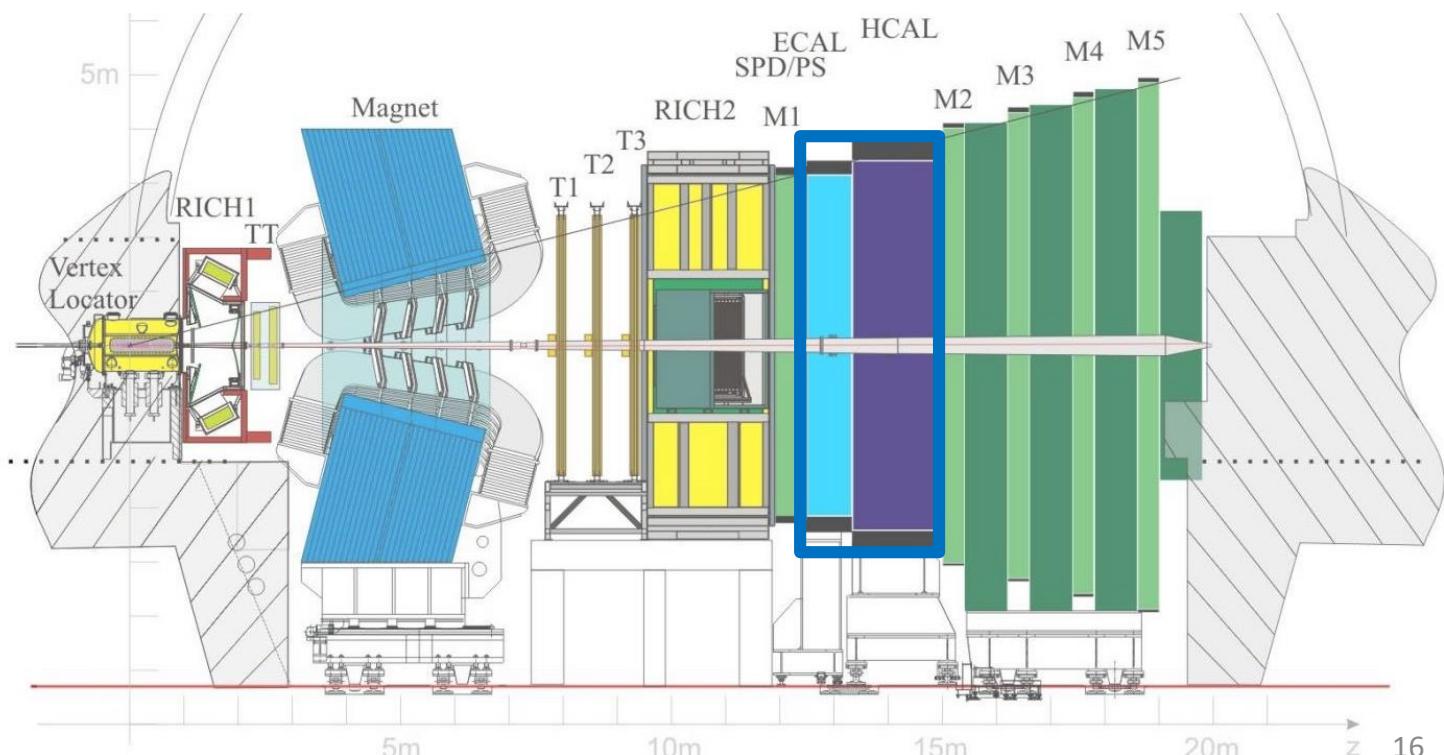
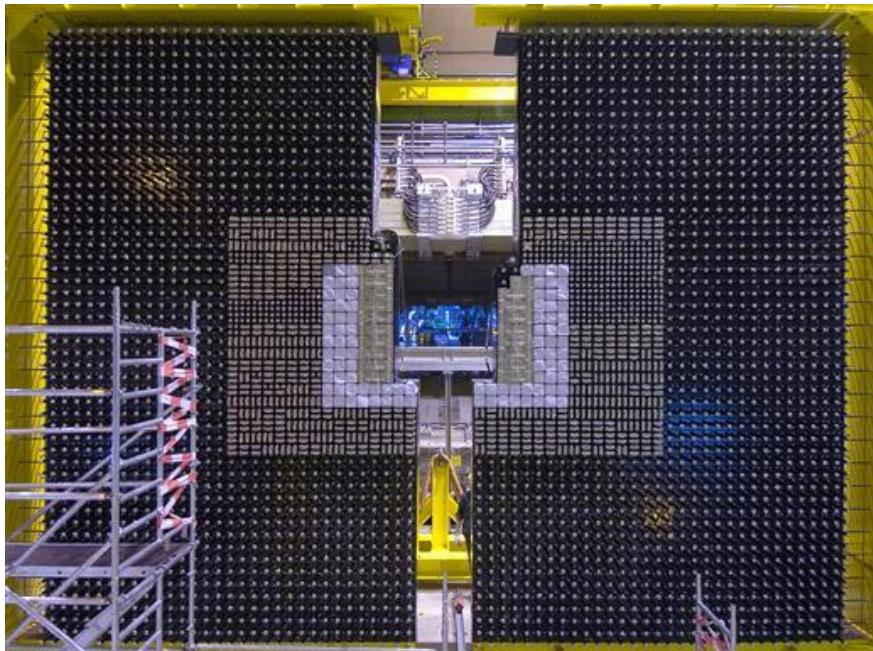
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[JINST 3 \(2008\) S08005, Int.J.Mod.Phys. A30 \(2015\) 153022](https://doi.org/10.1088/1742-6588/30/15/153022)



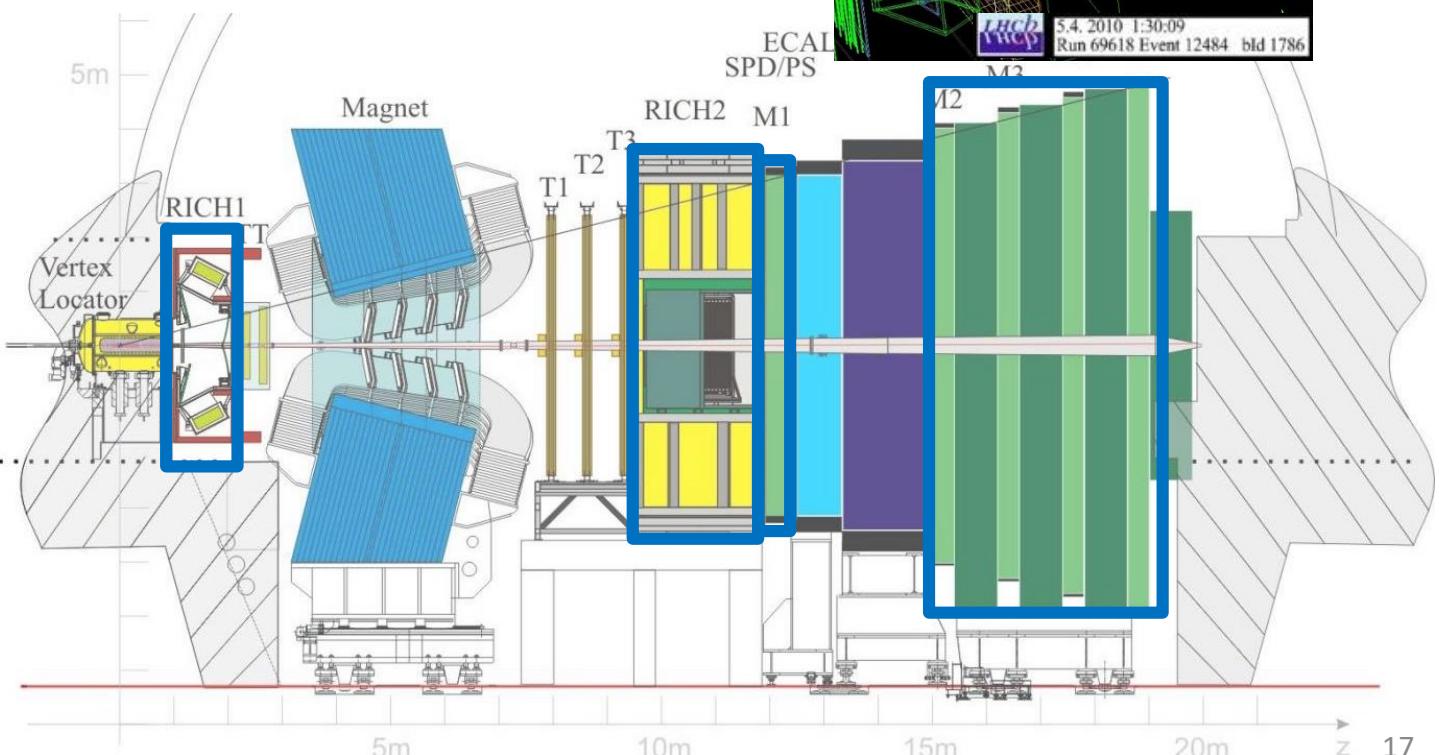
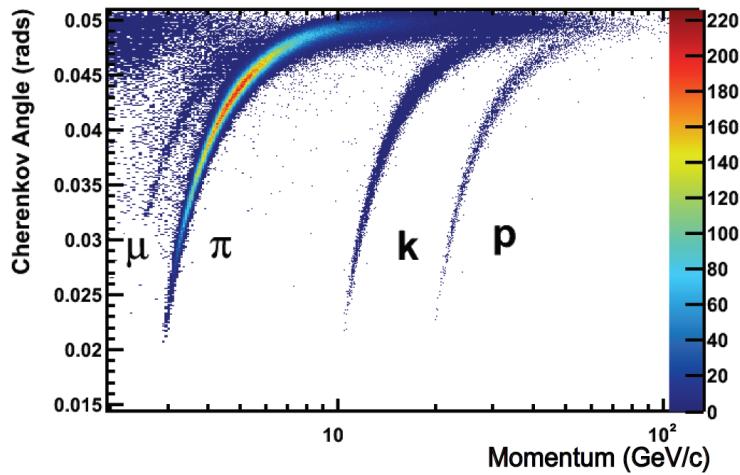
Calorimeter

- Sampling calorimeter with SPD/PS for $e/h/\gamma$ identification
- Measures and triggers on energy deposited by charged and neutral particles
- **Only information about neutral particles**
- $\frac{\sigma_E}{E} = 1\% + 10\%/\sqrt{E[\text{GeV}]}$



Particle Identification

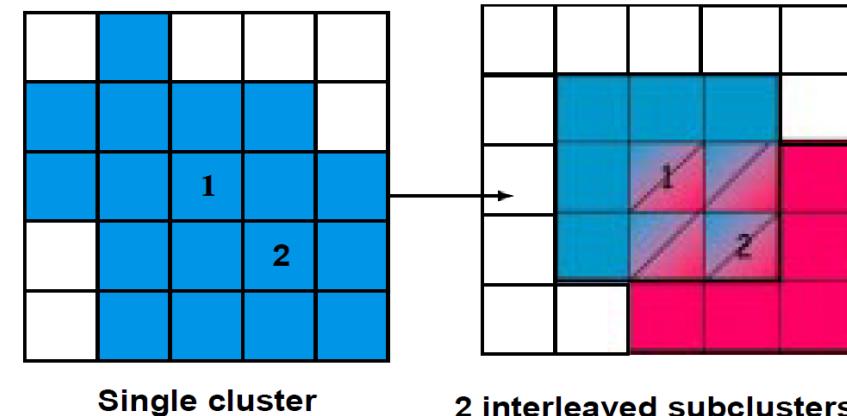
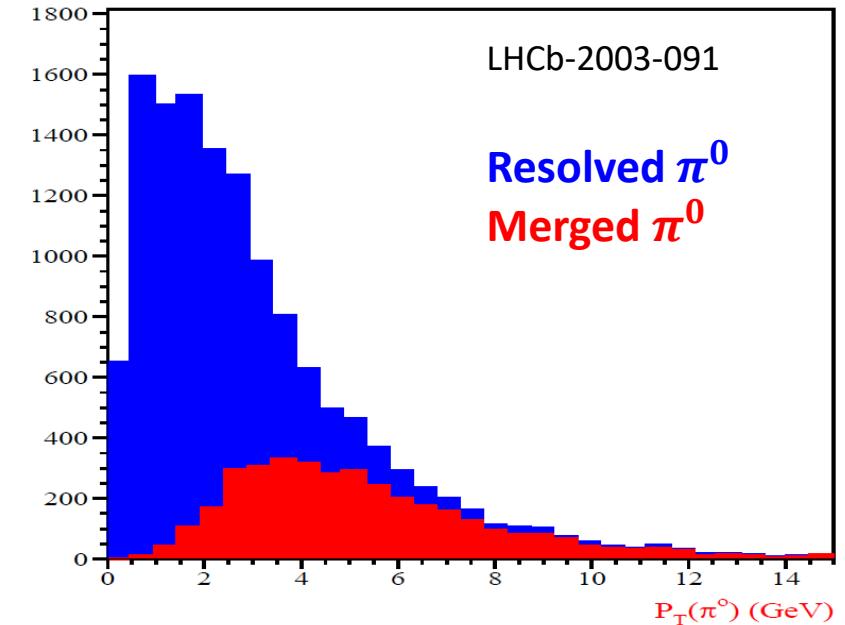
- Ring Imaging Cherenkov Detector measures particle velocity for identification
- Muon MWPC identifies and triggers on muons
- $e \sim 90\%$ at $\sim 5\% e \rightarrow h$ mis-id
- $K \sim 95\%$ at $\sim 5\% \pi \rightarrow K$ mis-id
- $\mu \sim 97\%$ at $\sim 1\text{-}3\% \pi \rightarrow \mu$ mis-id



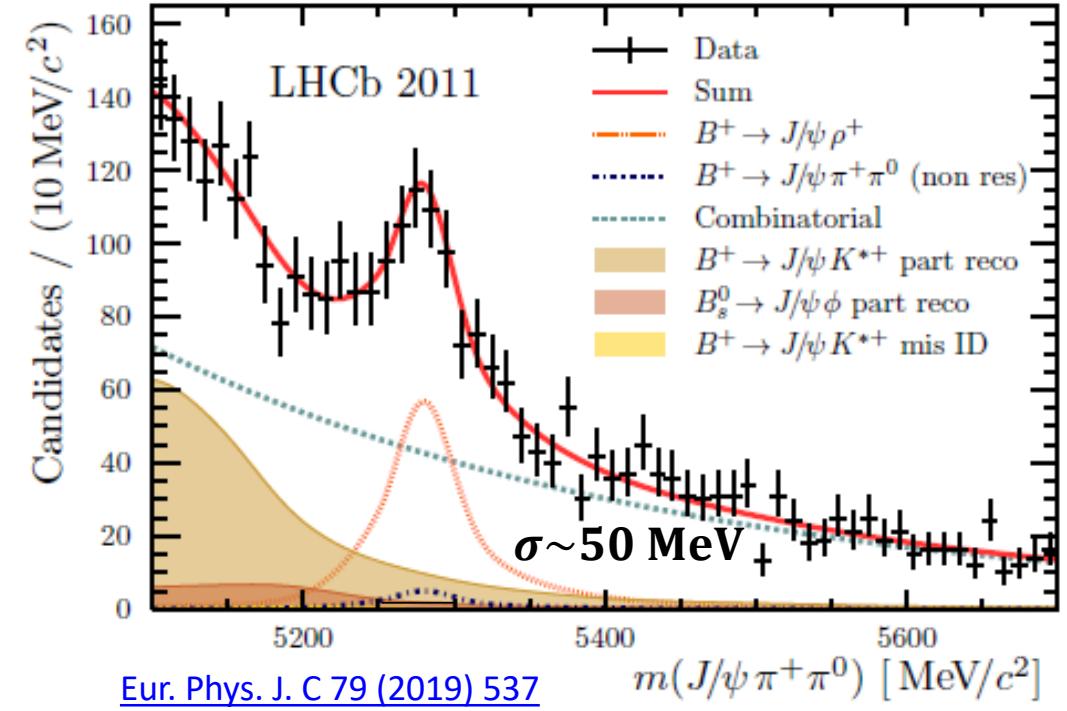
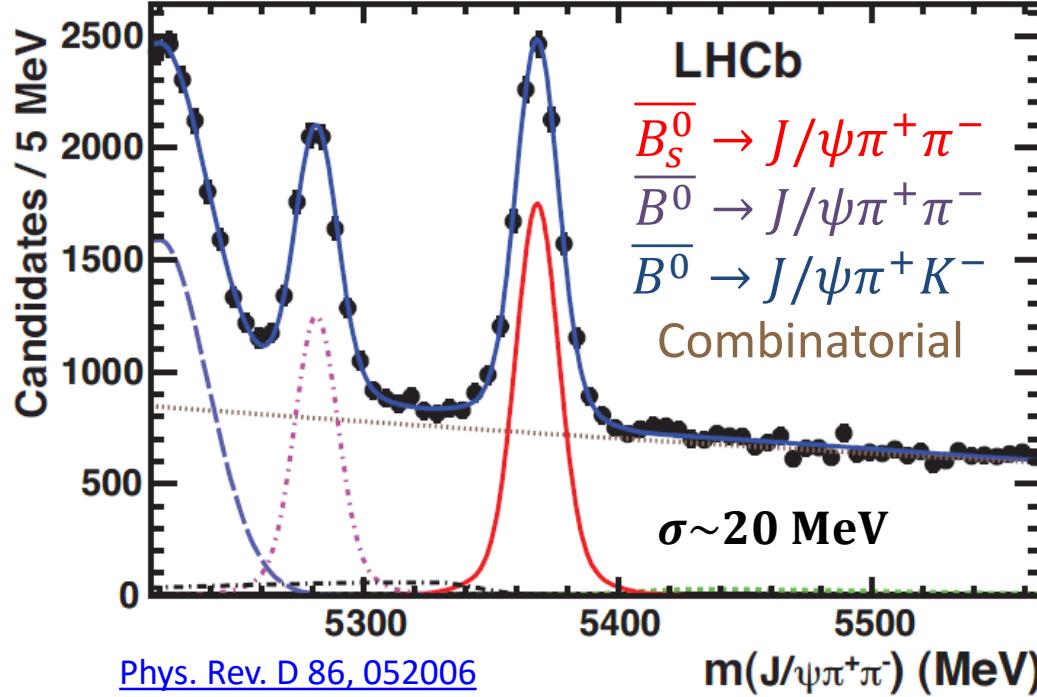
π^0 Reconstruction

- Neutral pions identified by decay to two photons
- Below $p_T = 3$ GeV photons can be **resolved** in two separate clusters, at higher energies clusters **merge**
- Cluster separated into two subclusters centered on highest energy deposits according to expected transverse profile
- Photon separation and invariant mass required to be consistent with π^0
- Merged π^0 :
 - + Higher p_T
 - + Reduced combinatorial
 - Wider mass resolution
- For $B^+ \rightarrow K^+\pi^0$, keep only **merged π^0** to preserve trigger bandwidth

π^0 from $B^0 \rightarrow \pi^+\pi^-\pi^0$



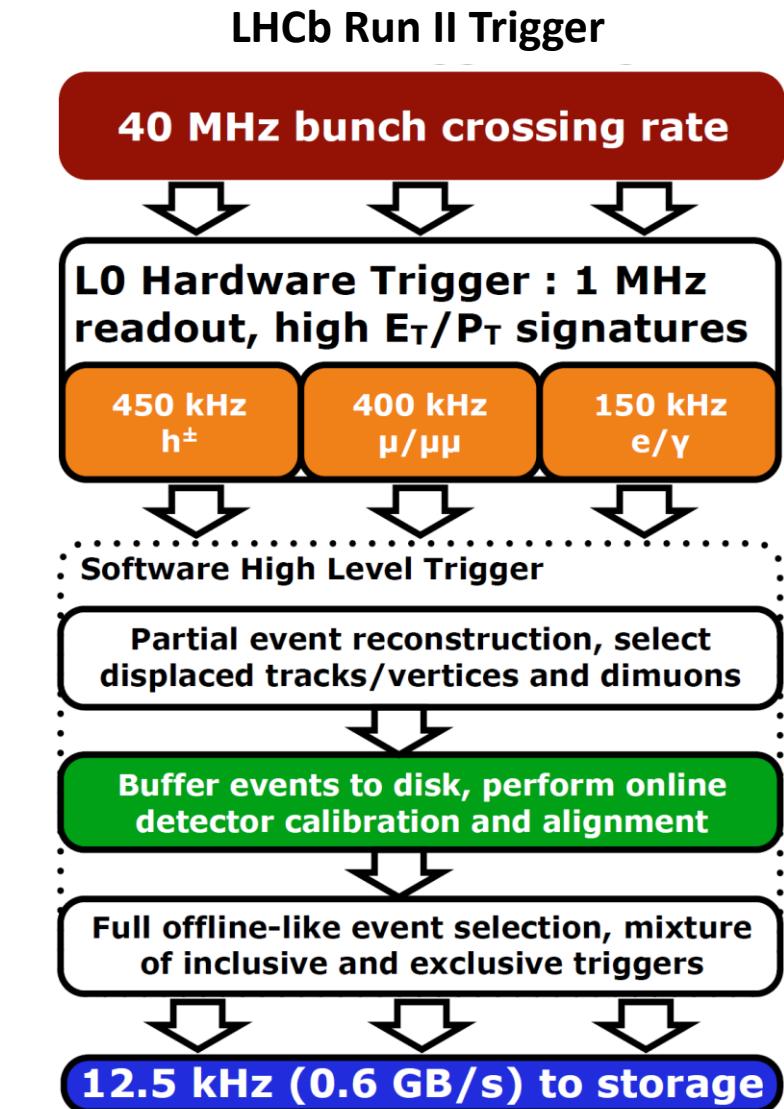
π^0 at LHCb



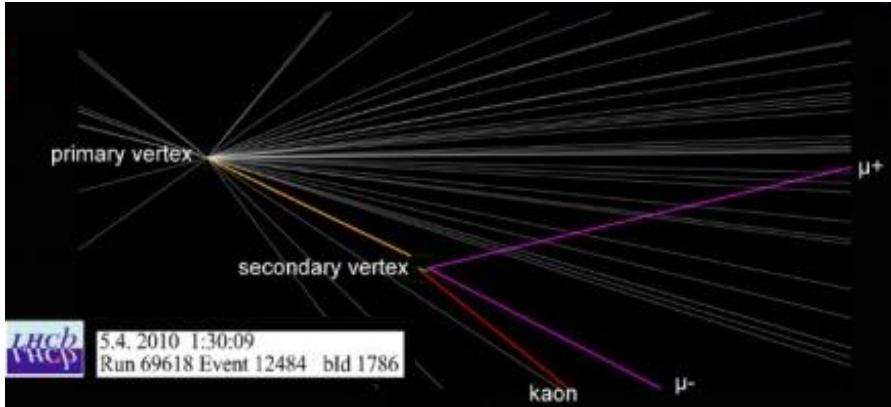
- LHCb analyses of 3- and 4-body decays include modes with π^0
- Wider mass resolution, lower efficiency compared to charged-only modes

Trigger Strategy

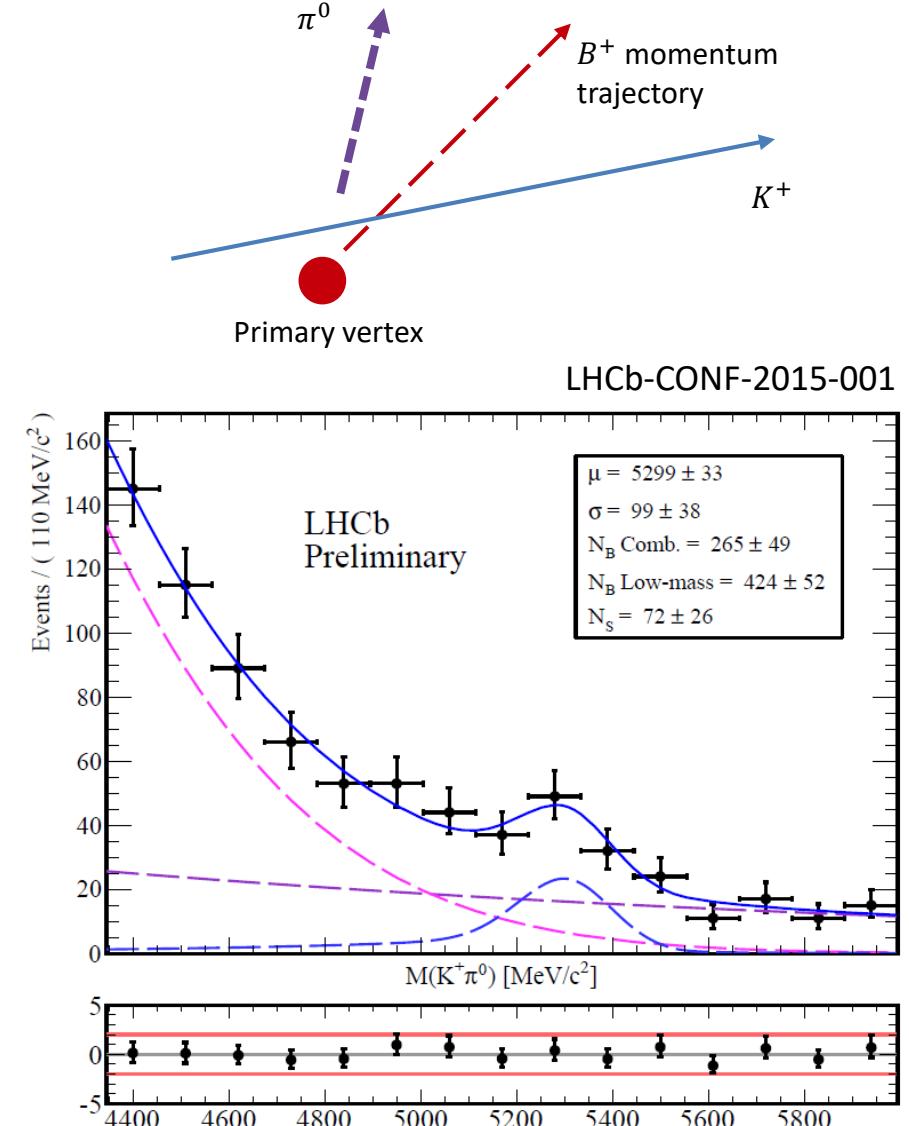
- Flavor physics results are largely limited by data recorded, rather than beam energy
- Trigger has to cope with high forward occupancy while preserving relatively low-energy b and c physics
- Low-level hardware trigger relies on high E_T/p_T signature from calorimeter or muon detector
- Two step high-level trigger buffers events to disk to perform full reconstruction



$B^+ \rightarrow K^+ \pi^0$ in Run I



- Long lifetime $c\tau_B \sim 400\mu m$ characteristic b signature
- All run I software triggers rely on secondary vertex
- Cannot be reconstructed for $B^+ \rightarrow K^+ \pi^0$ with only one charged track
- Trigger on the presence of an unrelated secondary vertex in the event (**8-11% efficiency**)
- Extremely high combinatorial background: $S/B \sim 10^{-7}$
- 72 ± 26 signal events observed in Run I
- Motivated the development of a dedicated trigger for Run II

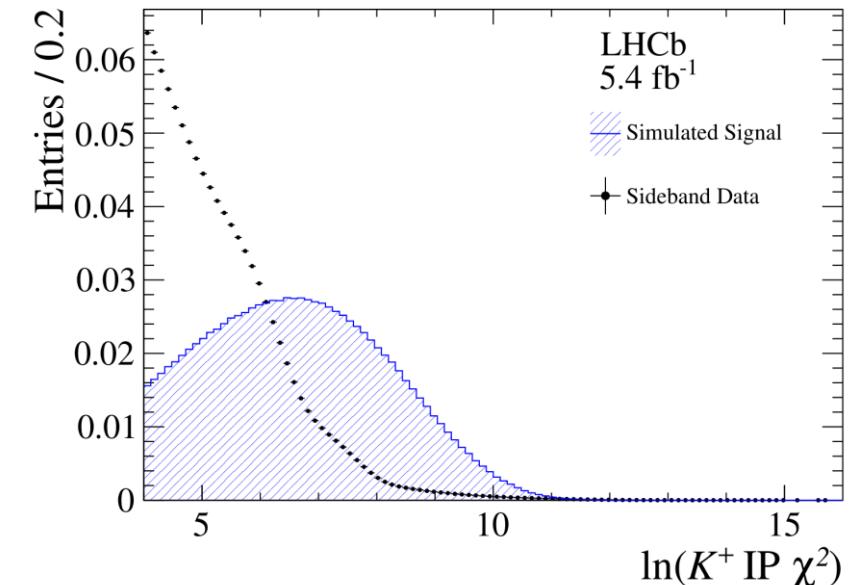
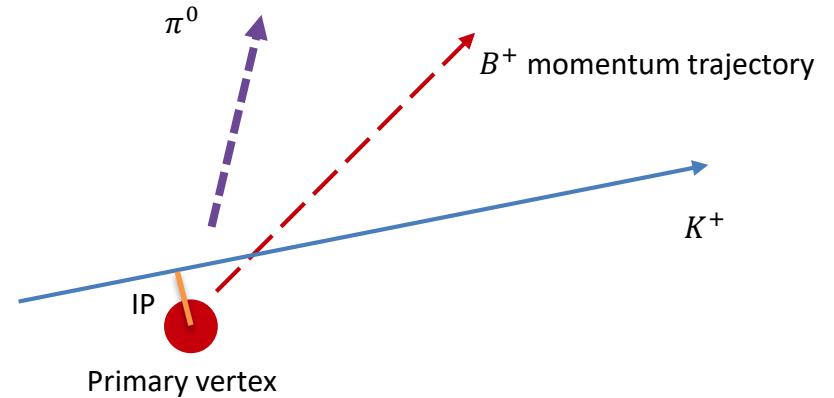


Run II Measurement

- Dedicated trigger and event selection
- Fit to determine CP asymmetry
- Corrections and systematics
- Results

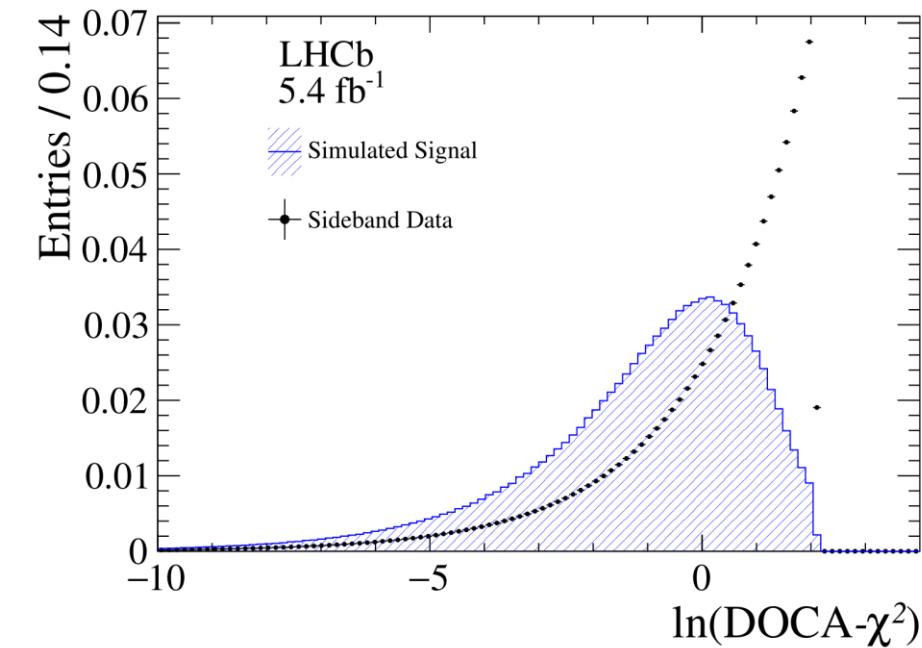
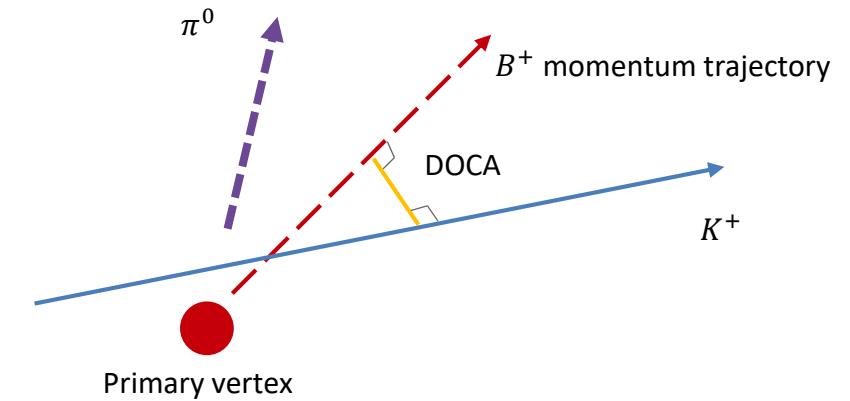
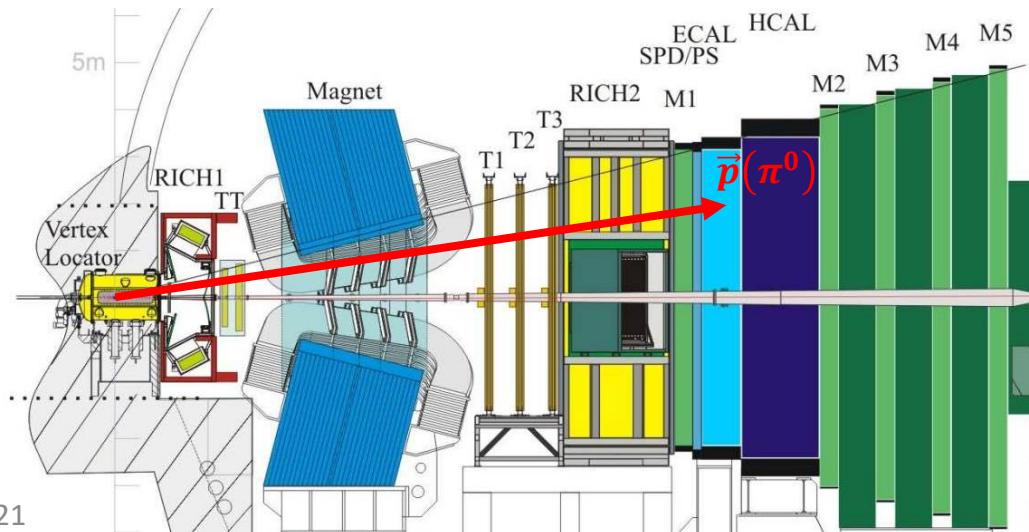
Dedicated Trigger: K^+ IP

- No secondary vertex, but still take advantage of LHCb's precision tracking
- K^+ should be inconsistent with originating from any primary vertex
- Cut on $\text{IP} \chi^2(\text{PV})$, $\Delta \chi^2$ when K^+ is included in the primary vertex fit
- Suppresses background from promptly produced K^+ (unlikely to be B^+ decay product)



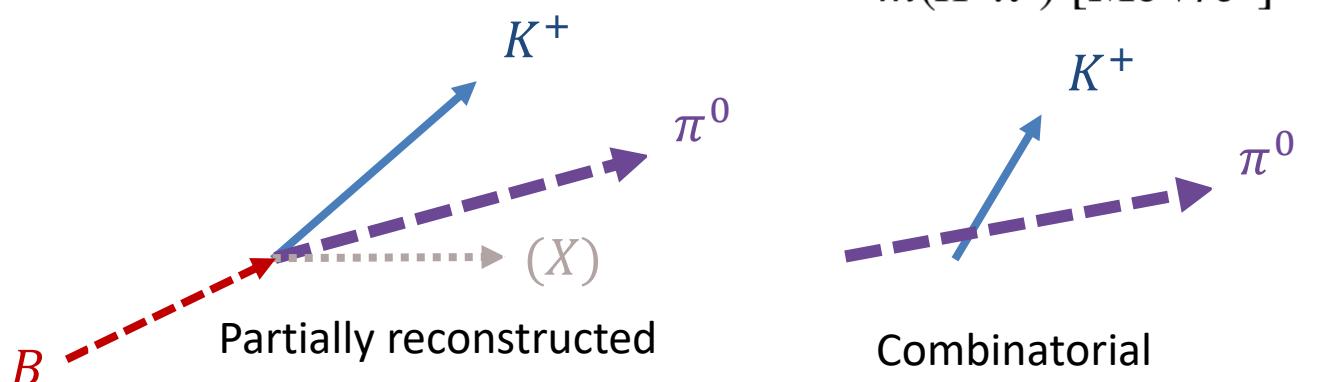
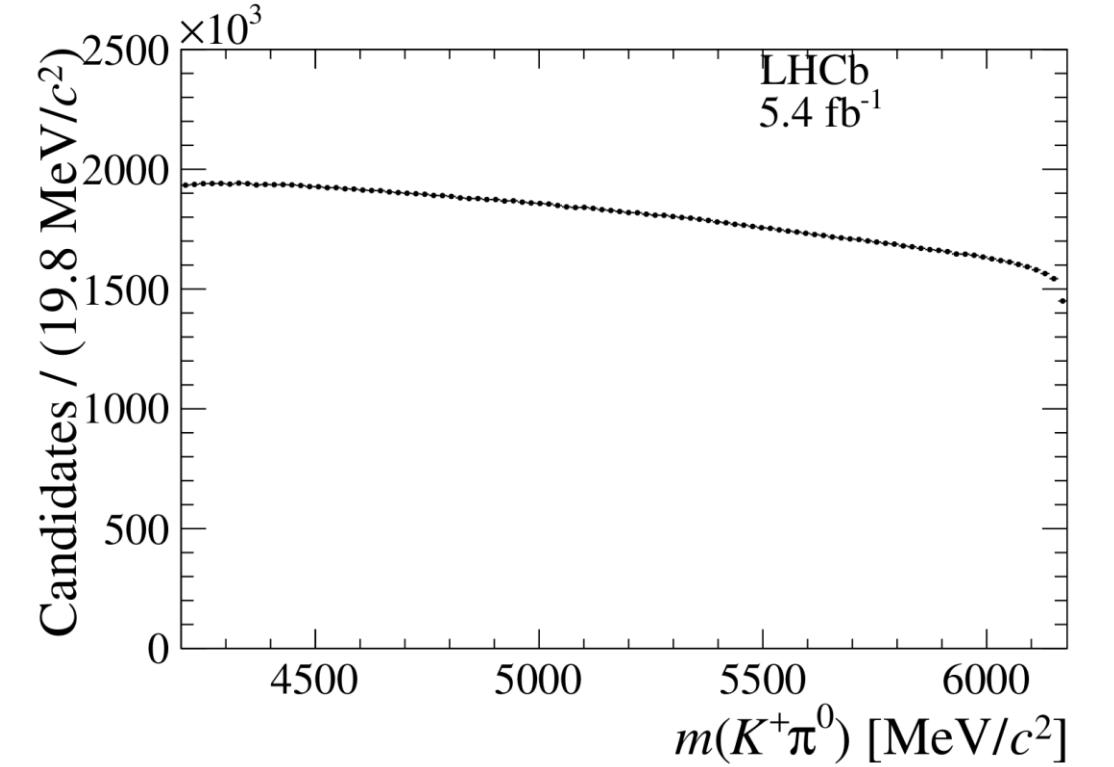
K^+ DOCA: The Key Variable

- K^+ should be consistent with originating from the trajectory of the B^+
- Add K^+ and π^0 momenta to form B^+ trajectory
 - Define π^0 momentum as pointing from interaction point to calorimeter energy deposit
- Cut on significance of distance of closest approach (DOCA) of K^+ and B^+
- Suppresses background from combinatorial K^+ and π^0



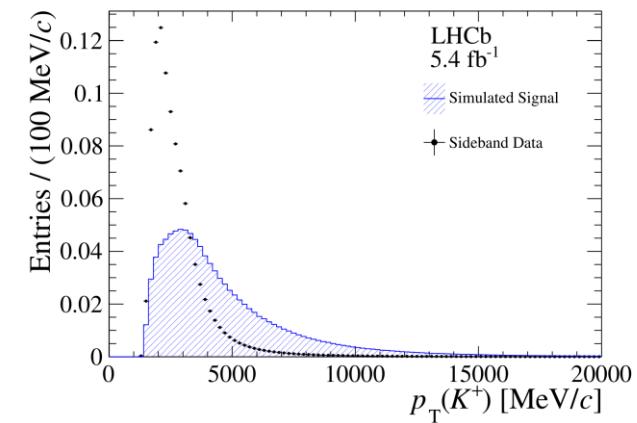
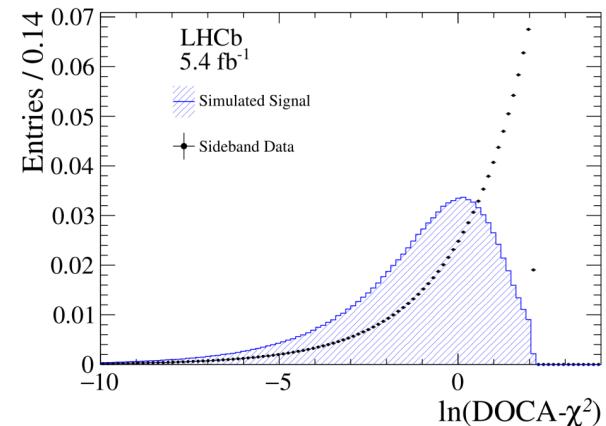
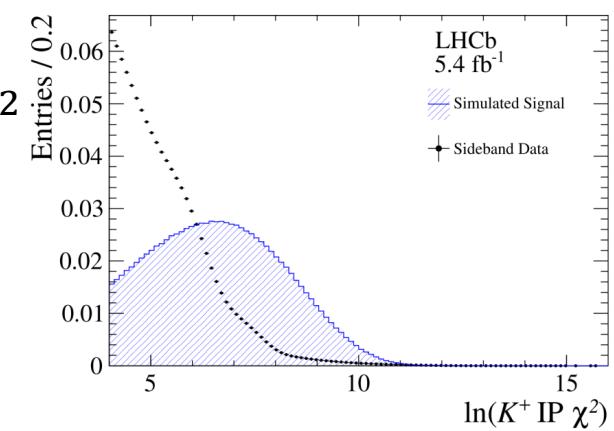
Trigger Output

- Dedicated software trigger takes advantage of $IP\chi^2(PV)$ and DOCA- χ^2 variables, B^+ invariant mass window and kinematic cuts of final selection
- S/B after trigger still $\sim 3.3 \times 10^{-4}$
- Dominant background comes from random combinations of K^+ and π^0
- Below the B mass $B \rightarrow K^+\pi^0X$ is also a significant background
 - Similar event topology to signal



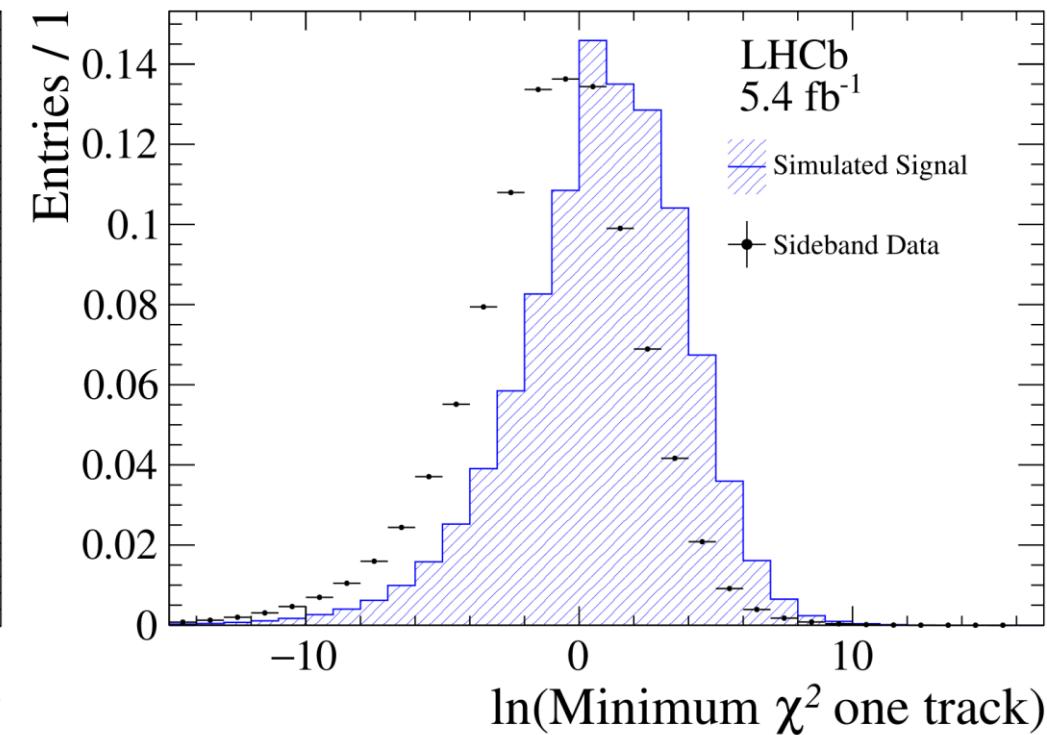
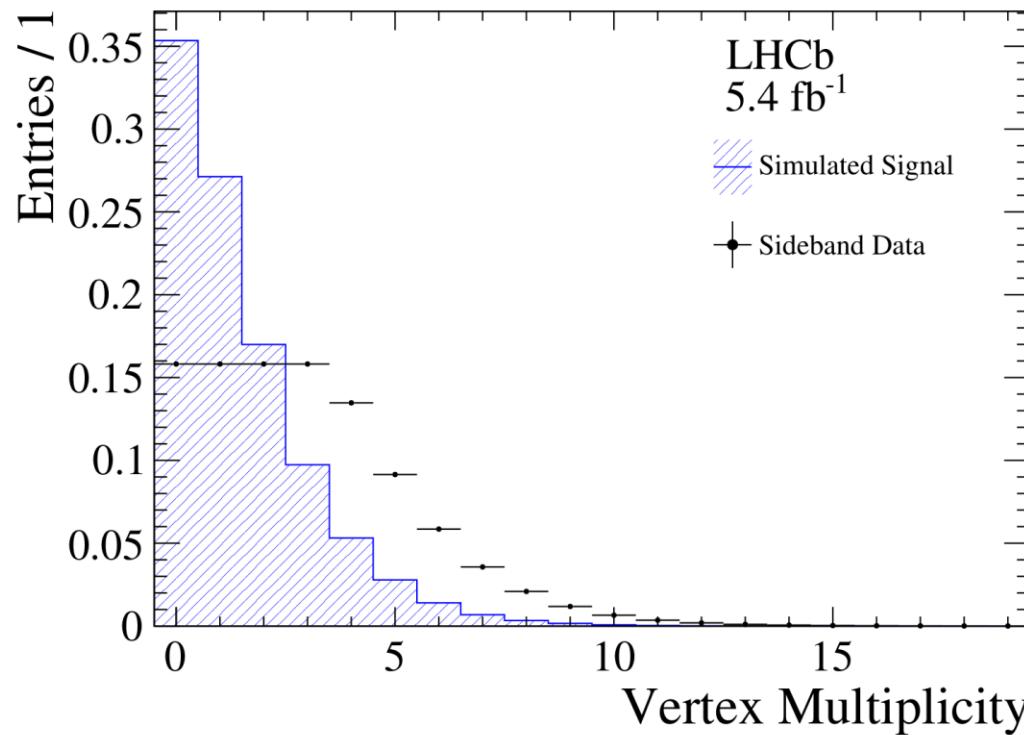
Multivariate Analysis

- Train Boosted Decision Trees to reject background efficiently
- Two BDTs trained against different backgrounds:
 - Upper mass sideband $M(K^+\pi^0) > 5700 \text{ MeV}/c^2$ (combinatorial)
 - Lower mass sideband $M(K^+\pi^0) < 4860 \text{ MeV}/c^2$ (partially reconstructed)
 - Both trained on simulated signal
- Split and cross-validated for best statistics without overtraining
- Same set of inputs for both BDTs:
 - $\text{IP}\chi^2(\text{PV})$ and $\text{DOCA-}\chi^2$
 - Kinematics (restricted to prevent reconstructing B^+ mass)
 - Isolation variables (next slides)



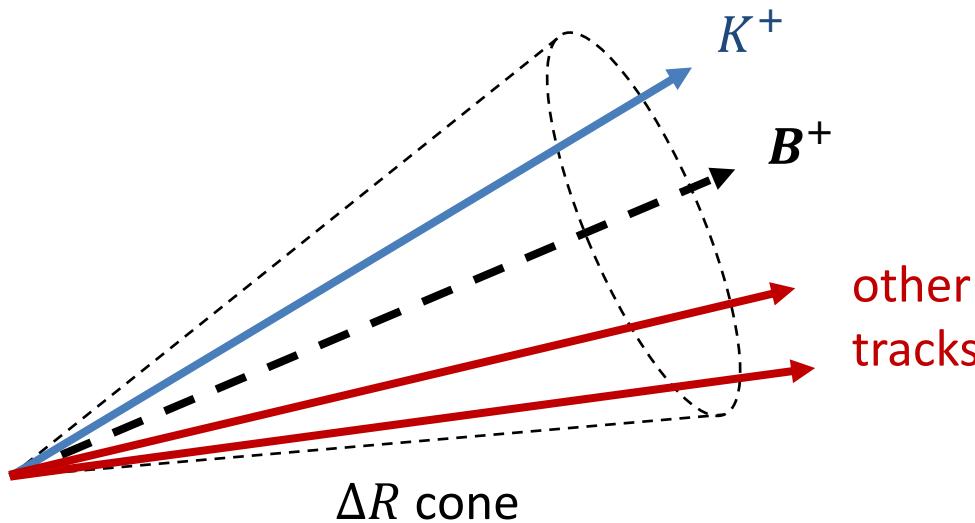
Isolation Variables: Vertex

- Events with other tracks pointing back to B candidate are unlikely to be $B^+ \rightarrow K^+\pi^0$ decays
- Combine each track in the event individually with K^+ to form vertices

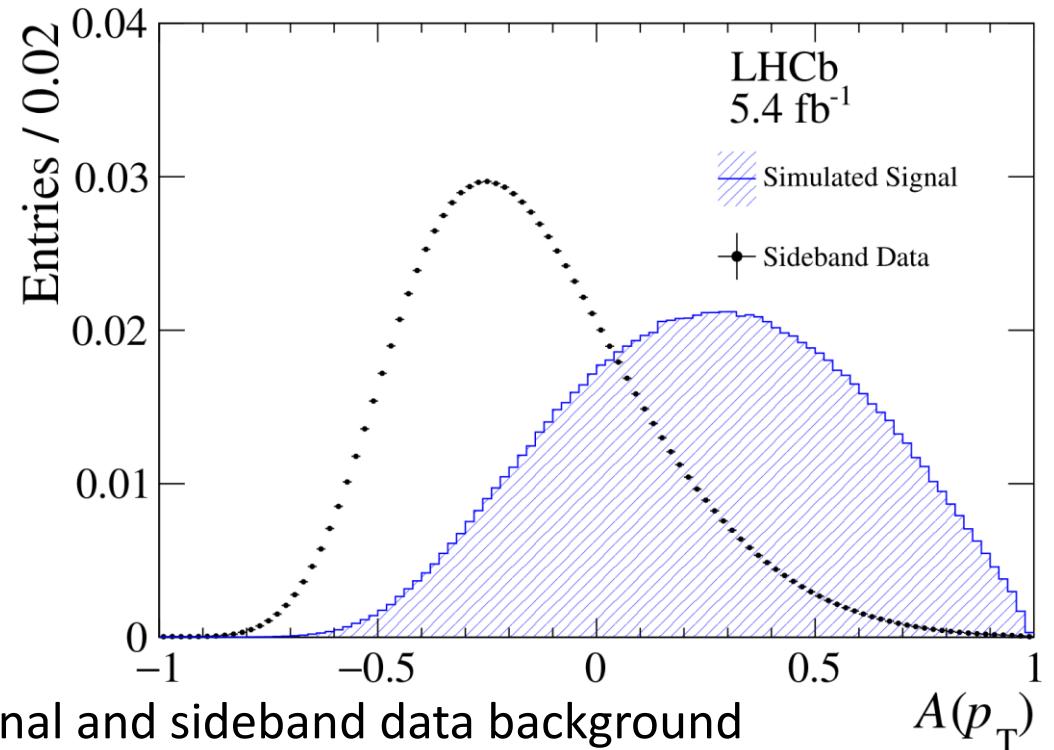


Isolation Variables: Cone

- Consider tracks in cone of $\Delta R = 1.7$ around B^+
- Define cone p_T asymmetry $A(p_T) \equiv \frac{p_T(B) - p_T(\text{cone})}{p_T(B) + p_T(\text{cone})}$

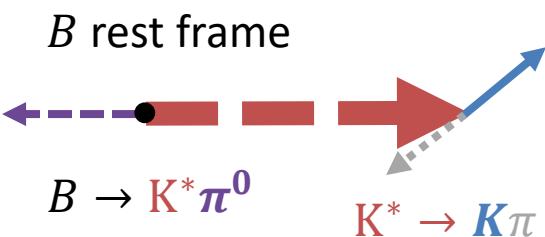


- BDTs trained on simulated signal and sideband data background
- Isolation variables depend on track multiplicity
- Corrected by comparing $B^0 \rightarrow K^+ \pi^-$ data and simulation
 - Good signal efficiency and purity

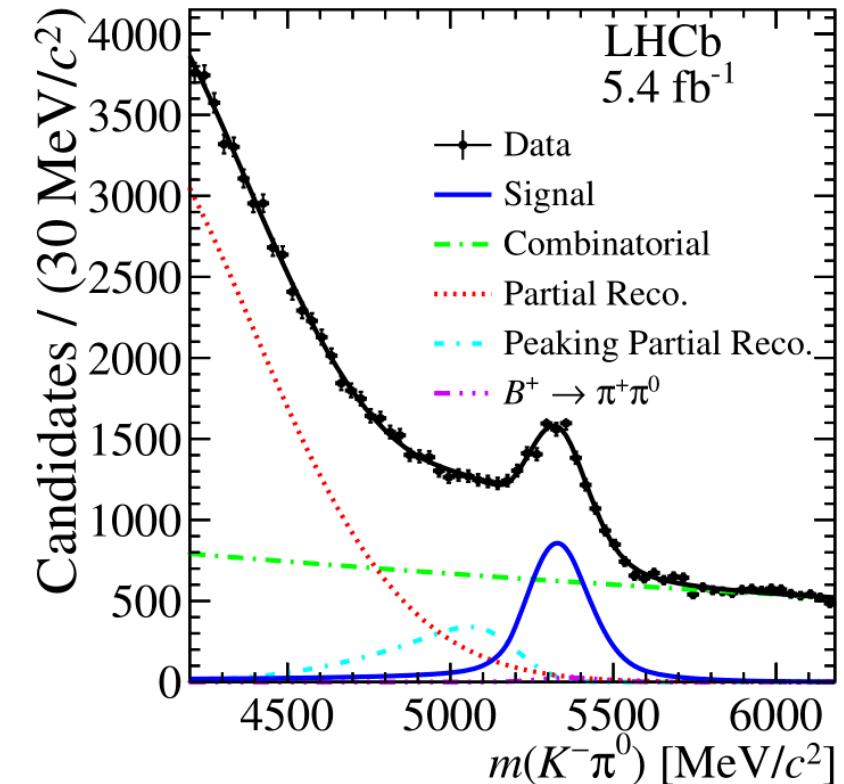
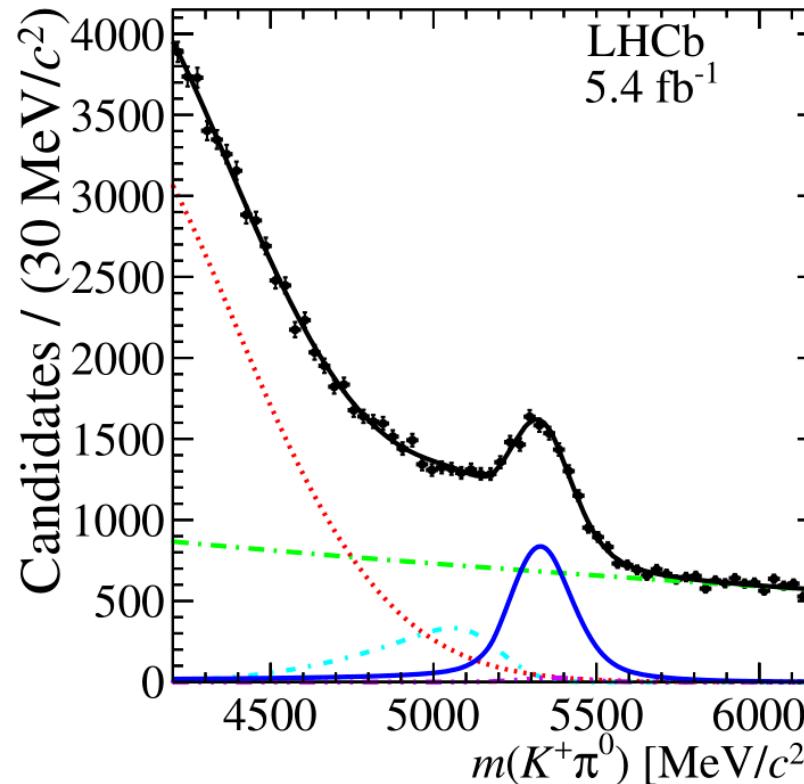


Final Event Selection

- Find 2D cut on BDT outputs that maximizes $\epsilon_{MC}/\sqrt{S + B}$
- S/B improved by factor of ~ 300
- Two more background categories:
- $B^+ \rightarrow \pi^+\pi^0$ where π^+ is misidentified as K^+
- Peaking partial reco. e.g. $B^{+/0} \rightarrow (K^{*+/0} \rightarrow K^+\pi^{0/-})\pi^0$, $B \rightarrow K^+(\rho^- \rightarrow \pi^-\pi^0)$
 - K^*/ρ polarization in B rest frame results in double-peaked mass structure

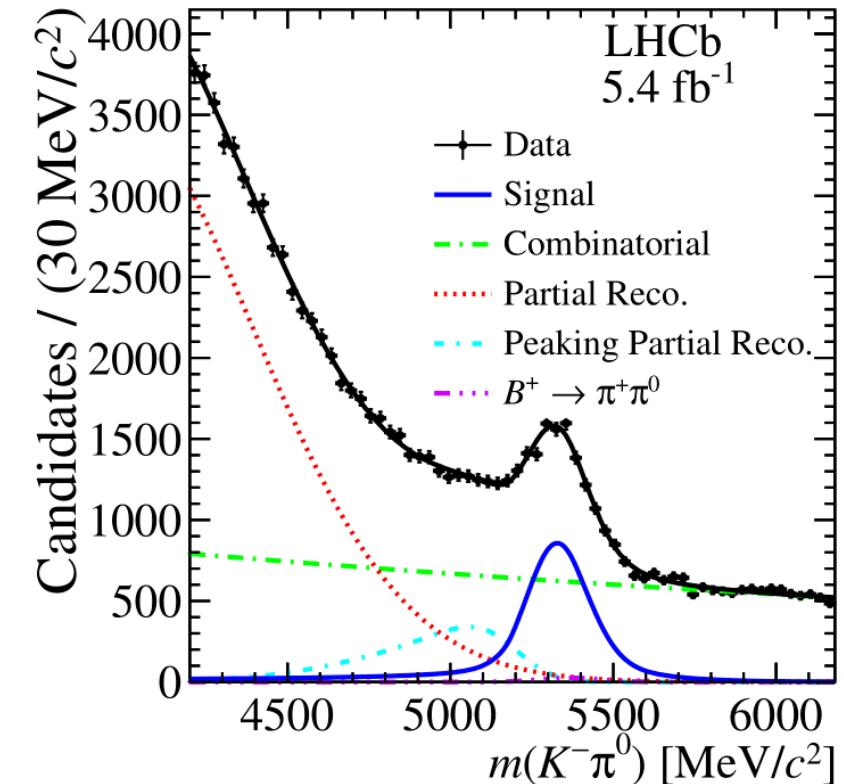
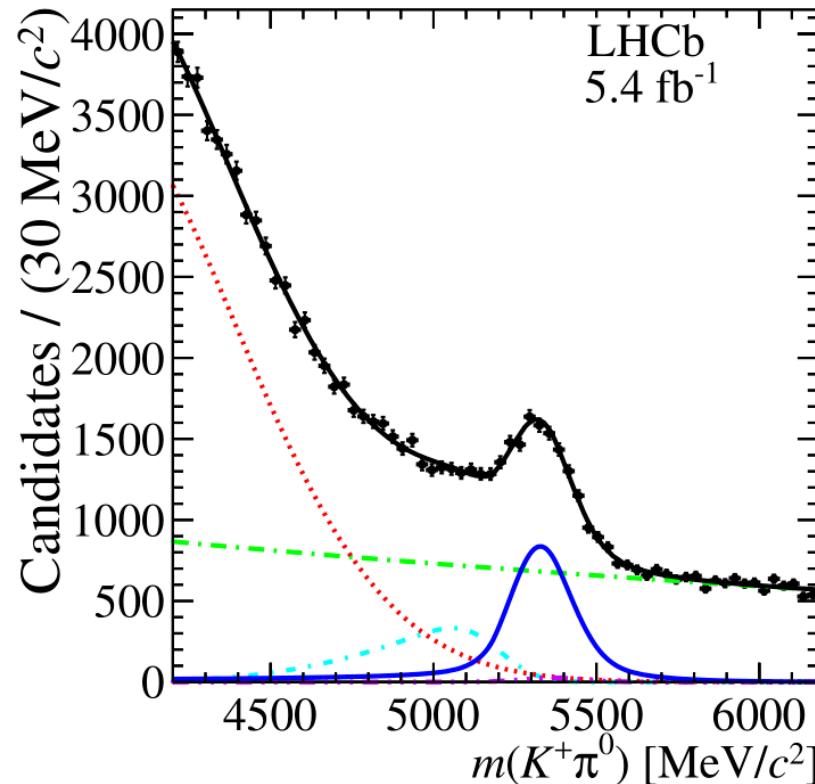


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Invariant Mass Fit

- Fit to mass distribution separated by B^\pm
- Further separate by magnet polarity (not shown) to correct for detector effects
- Shape parameters fixed between sub-samples, signal and background yields float independently
- $A_{raw} = \frac{N(B^- \rightarrow K^- \pi^0) - N(B^+ \rightarrow K^+ \pi^0)}{N(B^- \rightarrow K^- \pi^0) + N(B^+ \rightarrow K^+ \pi^0)}$



- $A_{raw} = 0.005 \pm 0.022$ (Magnet Up),
 0.019 ± 0.021 (Magnet Down)
- $\sim 16,500$ signal events (200x Run I)

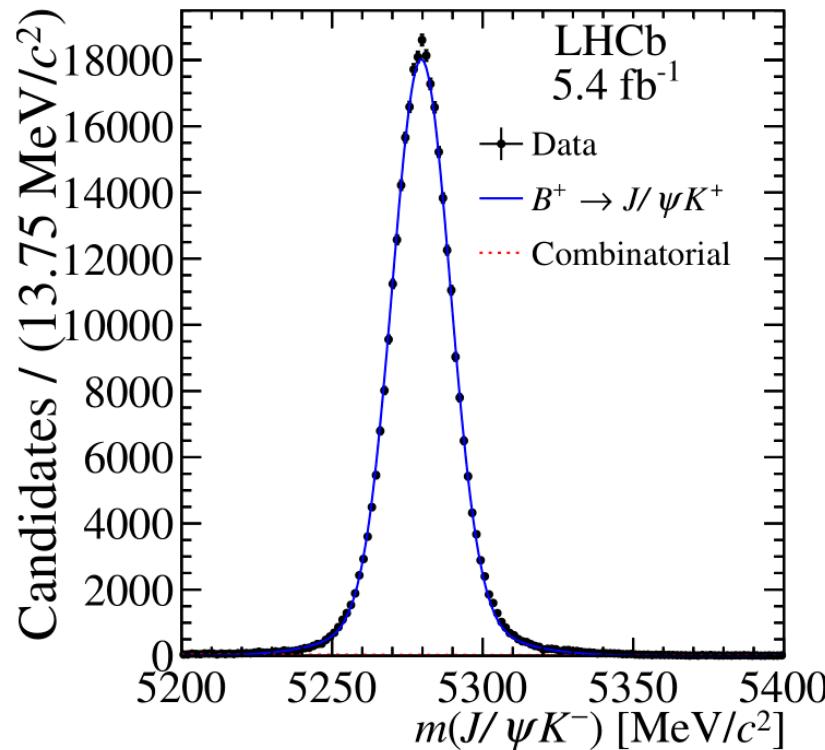
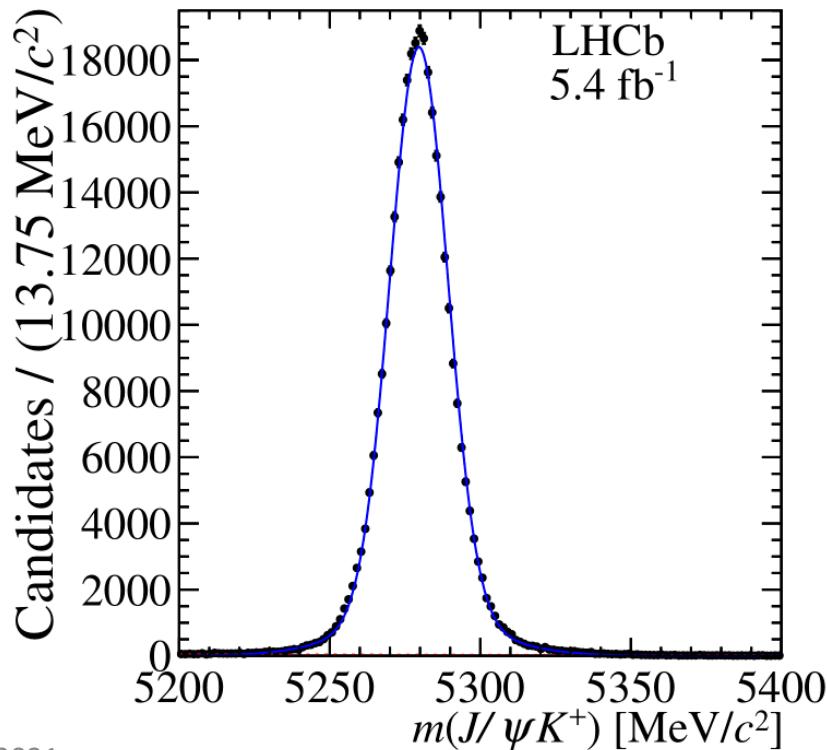
Production and Detection Asymmetry

$$A_{CP}(B^+ \rightarrow K^+\pi^0) = A_{raw}(B^+ \rightarrow K^+\pi^0) - A_{prod.}^B - A_{det.}^K.$$

- LHC is a proton-proton collider $\rightarrow B^\pm$ production asymmetry
- LHCb is made of matter $\rightarrow K^\pm$ detection asymmetry
- Same order of magnitude as physical CP asymmetry
- Can measure the same combination of effects in decay $B^+ \rightarrow (J/\psi \rightarrow \mu^+\mu^-)K^+$
 - π^0 and J/ψ own antiparticles – no asymmetry
 - Match K^+ selection to signal – trigger, kinematics, particle identification
 - Weight $p/p_T(B^+/K^+)$ distributions to signal kinematics

Prod./Det. Asymmetry Correction

- Charged tracks and reconstructible J/ψ mass make selection clean (99%)
- Follow same procedure as signal to extract raw asymmetry
- CP asymmetry in $B^+ \rightarrow J/\psi K^+$ known precisely (0.002 ± 0.003 , [PDG](#))
- Remainder attributed to same combination of B production and K detection as in $B^+ \rightarrow K^+ \pi^0$ measurement



$$A_{\text{raw}}(B^+ \rightarrow J/\psi K^+) = -0.009 \pm 0.002 \text{ (MU)}, \\ -0.012 \pm 0.002 \text{ (MD)}$$

Systematic Uncertainties

- Assess systematics on fit variations
 - Signal and background shapes
 - Parameters fixed to simulation/physical values
- Dominant uncertainty: modeling of signal tails in the fit
- Small statistical uncertainty in determining production/detection asymmetry
- Effect of weighting used to estimate any residual kinematic differences in $B^+ \rightarrow K^+\pi^0$ and $B^+ \rightarrow J/\psi K^+$ asymmetries

Table 1: Systematic uncertainties on $A_{CP}(B^+ \rightarrow K^+\pi^0)$.

Fit Component	Systematic	Value
Combinatorial bkg.	Shape	0.0013
Partial Reco. bkg.	Shape	0.0013
Peaking Partial Reco. bkg.	Shape Offset Resolution	0.0012 0.0013 0.0014
$B^+ \rightarrow \pi^+\pi^0$	Yield	0.0013
CP Asymmetry		0.0015
Signal modeling	Shape	0.0043
Production/detection asymmetry	stat. weights	0.0021 0.0005
	Multiple candidates	0.0013
	Sum in quadrature	0.0061
Statistical uncertainty	0.015	

A_{CP} Determination

- Correcting and averaging Magnet Up and Magnet Down results and adding systematic uncertainties in quadrature we find

$$A_{CP}(B^+ \rightarrow K^+\pi^0) = 0.025 \pm 0.015(\text{stat.}) \pm 0.006(\text{syst.}) \pm 0.003(\text{ext.})$$

- Result is consistent between years, magnet polarity, and bins of kaon momentum
- **Most precise measurement of $A_{CP}(B^+ \rightarrow K^+\pi^0)$**
- Combining with world average $A_{CP}(B^+ \rightarrow K^+\pi^0) = 0.031 \pm 0.013$

Status of the $B \rightarrow K\pi$ System

Table 15: \mathcal{A}^{CP} measurements for the $B \rightarrow K\pi$ decay modes

	BaBar	Belle	LHCb
$B^0 \rightarrow K^0\pi^0$	$+0.13 \pm 0.13 \pm 0.03$ [1]	$-0.14 \pm 0.13 \pm 0.06$ [2]	JHEP 03(2021)075
$B^+ \rightarrow K^0\pi^+$	$-0.029 \pm 0.039 \pm 0.010$ [3]	$-0.011 \pm 0.021 \pm 0.006$ [4]	$-0.022 \pm 0.025 \pm 0.010$ [5]
$B^0 \rightarrow K^+\pi^-$	$-0.107 \pm 0.016^{+0.006}_{-0.004}$ [6]	$-0.069 \pm 0.014 \pm 0.007$ [4]	$-0.0824 \pm 0.0033 \pm 0.0033$ [7]
$B^+ \rightarrow K^+\pi^0$	$+0.030 \pm 0.039 \pm 0.010$ [8]	$+0.043 \pm 0.024 \pm 0.002$ [4]	Phys. Rev. Lett. 126, 091802

- $A_{CP}(B^+ \rightarrow K^+\pi^0) - A_{CP}(B^0 \rightarrow K^+\pi^-) = 0.115 \pm 0.014$, non-zero at 8.2σ (previously 0.124 ± 0.021 , 5.9σ)
 - LHCb results: $A_{CP}(B^+ \rightarrow K^+\pi^0) - A_{CP}(B^0 \rightarrow K^+\pi^-) = 0.106 \pm 0.017$
- Updated sum rule prediction for $A_{CP}(K^0\pi^0)$: -0.138 ± 0.025 , non-zero at 5.5σ (previously -0.150 ± 0.032 , 4.7σ)

$$A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+) \frac{B(K^0\pi^+) \tau_0}{B(K^+\pi^-) \tau_+} = A_{CP}(K^+\pi^0) \frac{2B(K^+\pi^0) \tau_0}{B(K^+\pi^-) \tau_+} + A_{CP}(K^0\pi^0) \frac{2B(K^0\pi^0)}{B(K^+\pi^-)}$$

[1]:[Phys.Rev.D 79, 052003](#)

[2]:[Phys.Rev.D 81, 011101\(R\)](#)

[3]:[Phys.Rev.Lett. 97, 171805](#)

[4]:[Phys.Rev.D 87, 031103\(R\)](#)

LHCb Upgrades



- $\mathcal{L} = 4 \times 10^{32} \text{ cm}^{-2} \text{s}^{-1}$
- 9 fb^{-1} integrated luminosity
- $\mathcal{L} = 2 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$
- 50 fb^{-1} integrated luminosity
- Introducing software-only trigger
- Replacing tracking detectors and detector electronics
- $\mathcal{L} = 2 \times 10^{34} \text{ cm}^{-2} \text{s}^{-1}$
- 300 fb^{-1} integrated luminosity
- Adding fast timing
- Replacing VELO, calorimeter
- Still in development, many possible upgrades

$B^+ \rightarrow K^+ \pi^0$ Upgrade Prospects

$$A_{CP}(B^+ \rightarrow K^+ \pi^0) = 0.025 \pm 0.015(\text{stat.}) \pm 0.006(\text{syst.}) \pm 0.003(\text{ext.})$$

- Assume simple scaling with luminosity
- Statistical uncertainty with 50fb^{-1} : ± 0.005
 - Upgrade I: Expect improved efficiency from trigger but more difficult selection due to higher occupancy
- With 300fb^{-1} : ± 0.002
 - Upgrade II: Timing and improved granularity in ECAL – entirely new measurement
- Dominant sources of systematic uncertainty
 - Modeling of signal tails, can improve with tighter event selection
 - Uncertainty on raw and CP asymmetry in $B \rightarrow J/\psi K^+$ currently statistically limited
- Current prediction for $A_{CP}(K^0 \pi^0)$: -0.138 ± 0.025
 - Belle II prospective uncertainty: ± 0.018 with 50ab^{-1} ([Phys. Rev. D 78, 111501\(R\)](#))

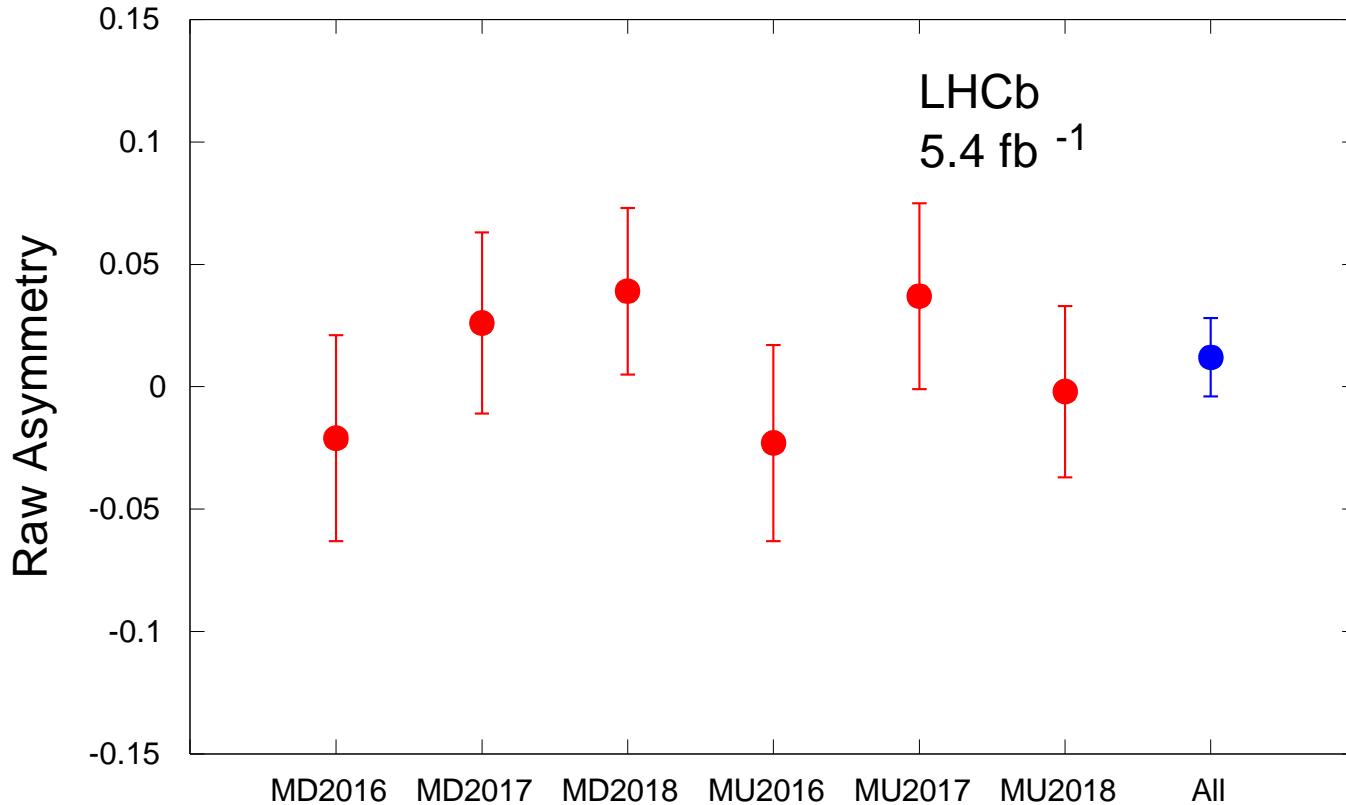
Conclusion

- A measurement of direct CP violation in $B^+ \rightarrow K^+\pi^0$ decays has been performed
 - Most precise to date
 - Confirms and strengthens the $K\pi$ puzzle
 - Recently published: Phys. Rev. Lett. **126**, 091802
- The $B \rightarrow K\pi$ system has the potential to indirectly reveal new physics
- First measurement of a single track B decay at the LHC
 - An example of LHCb's potential in modes with neutral particles
- Similar trigger in place for $B^0 \rightarrow K^0\pi^0$
- More to come in Run III and beyond



Backup

Consistency by Year



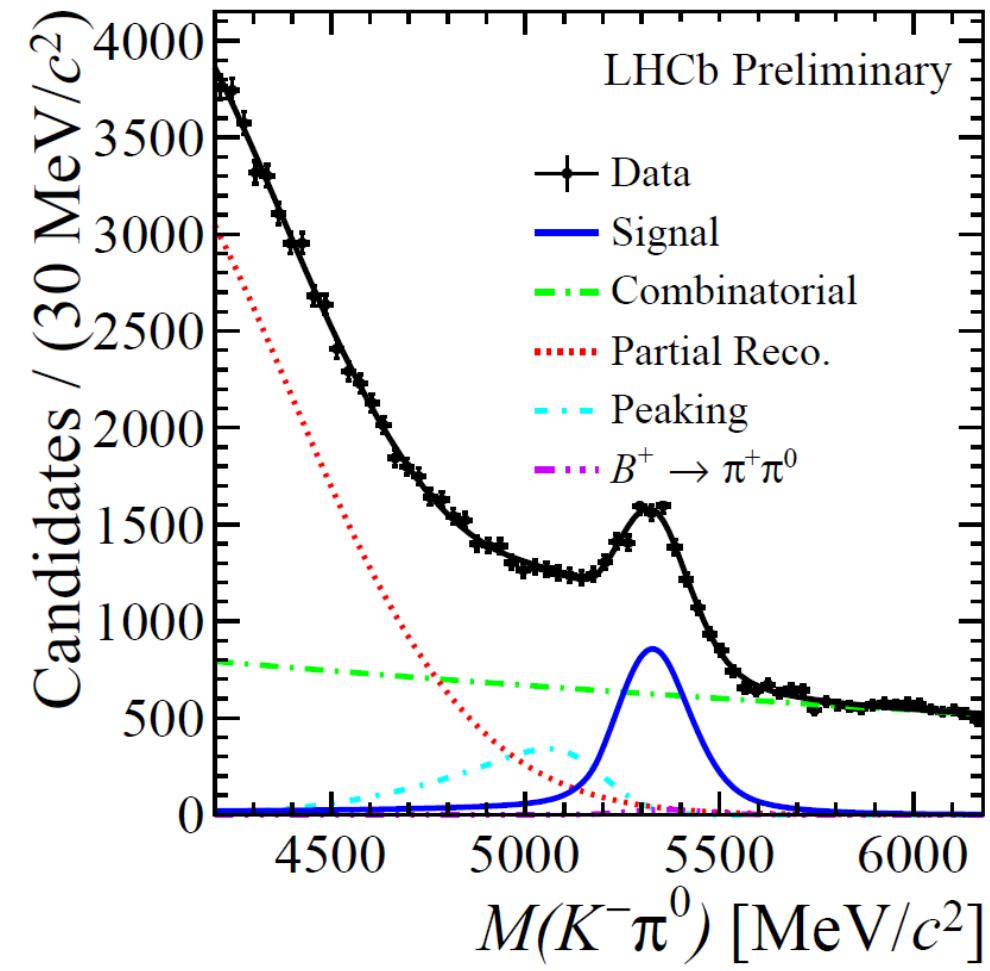
- Consistent between years and magnet polarities
- Additional checks: Binning by kaon p_T and magnet polarity, allowing shape parameters to vary between charges and magnet polarities
- Raw asymmetry consistent in all cases

$B^+ \rightarrow K^+ \pi^0$ Trigger

Variables	Requirements
$K^+ p_T$	$> 1200 \text{ MeV}/c$
$K^+ p$	$> 12000 \text{ MeV}/c$
K^+ IP χ^2 PV	> 50
K^+ PIDk	> -0.5
$\pi^0 p$	$> 5000 \text{ MeV}/c$
$\pi^0 p_T$	$> 3500 \text{ MeV}/c$
π^0 mass	$76.0 < m < 195.0 \text{ MeV}/c^2$
$K^+ + \pi^0 p_T$	$> 6500 \text{ MeV}/c$
$B^+ p_T$	$> 5000 \text{ MeV}/c$
B^+ mass	$4000 < m < 6200 \text{ MeV}/c^2$
B^+ MTDOCA χ^2	< 8

Invariant Mass Fit

- Signal
 - Crystal Ball function (low mass tail), and Gaussian with exponential tail (high mass tail)
 - Tail shape parameters fixed to values from simulation
- Combinatorial background
 - Exponential
- Partially reconstructed background
 - Gaussian tail
- Partially reconstructed peaking backgrounds
 - Parabolic \times Gaussian function ([JHEP 06 \(2020\) 058](#))
 - Endpoints fixed to $B^+ \rightarrow (K^{*+} \rightarrow K^+\pi^0)\pi^0$ kinematically allowed values
 - Mass shift fixed to (signal mean – $M(B^+)$)
 - Resolution fixed to signal resolution
 - Rel. height fixed to simulation values (insensitive)
- $B^+ \rightarrow \pi^+\pi^0$
 - Gaussian with exp. tail convoluted with π^0 res. Gaussian
 - Shape parameters and offset fixed to simulation values
 - Yield fixed to 2.4% of signal yield



Systematics – Fit Variations

- Signal
 - Crystal Ball + Gaussian w/tail → single Gaussian
- Combinatorial background
 - Exponential → linear
- Partially reconstructed background
 - Gaussian tail → Argus cut off at $M(B - 2\pi)$
- Partially reconstructed peaking backgrounds
 - Parabolic × Gaussian function → Argus cut off at $M(B - \pi)$
 - Mass shift fixed to (signal mean – $M(B^+)$) → floating
 - Resolution fixed to signal resolution → floating
- $B^+ \rightarrow \pi^+\pi^0$
 - Yield fixed to 2.4% of signal yield → removed from fit
 - CP asymmetry fixed to 0 → fixed to $\pm 1\sigma$ of measured value
- Events with multiple candidates removed from fit

