Optimisation of Decay Selections $\Lambda_b^0 \to pK^-$ e $\Lambda_b^0 \to p\pi^-$ for $\mathcal{CP}$ Asymmetry Measument

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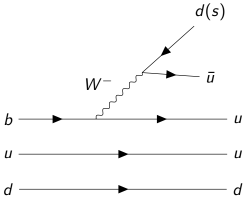
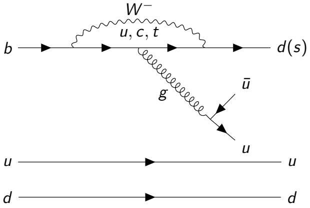
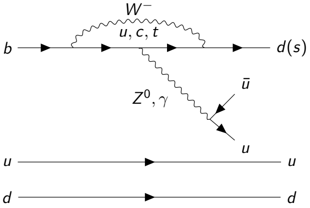
- Violation given by δ is not sufficient to explain observed matter-antimatter asymmetry of the Universe
- Research of new $\mathcal{CP}$ violation sources $\rightarrow$ Physics beyond Standard Model

$\Lambda_b^0 \to pK^-$, $\Lambda_b^0 \to p\pi^-$ decays

Principal diagrams for charmless 2-bodies decays of Λ_b^0







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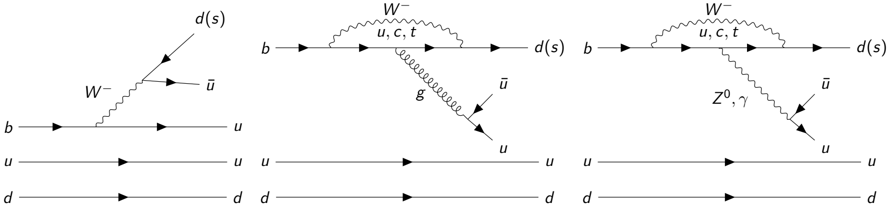

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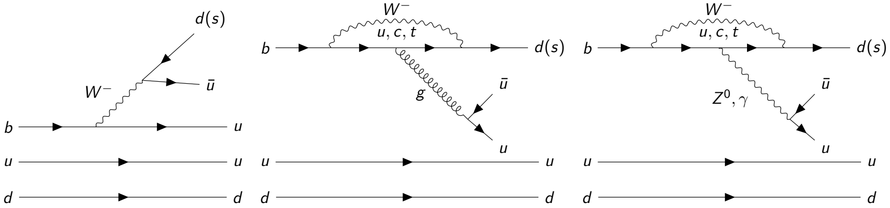

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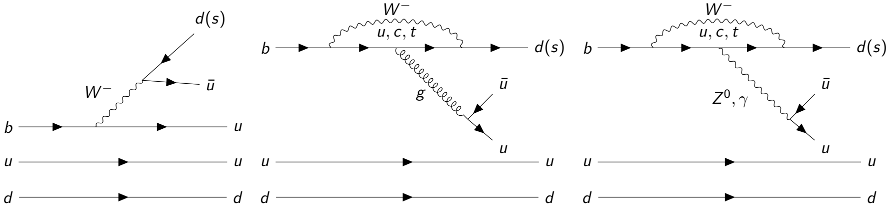

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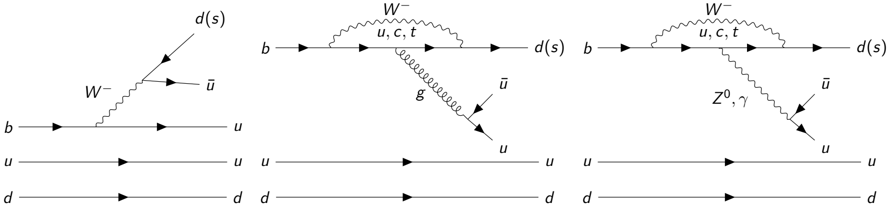

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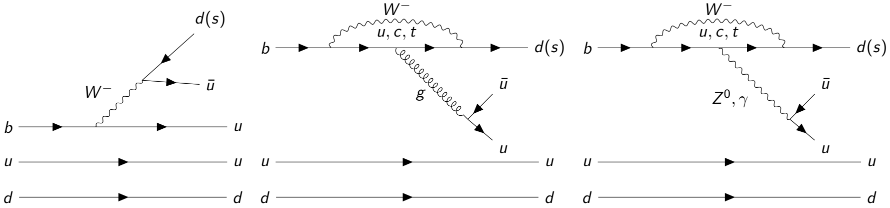

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New Physics $\to$ may be observable via $\mathcal{CP}$ violation

$\mathcal{CP}$ violation already observed in decays of B^0, B_s^0 mesons
Similar transitions $\to$ $\mathcal{CP}$ violation for Λ_b^0?

Experimental Status

CDF measurements[1] (3 fb^{-1} @ $\sqrt{s}$ =1.96 TeV):

- $\mathcal{A}_{\mathcal{CP}}^{pK} = (-10 \pm 8 \pm 4)\%$
- $\mathcal{A}_{\mathcal{CP}}^{p\pi} = (-6 \pm 7 \pm 3)\%$

$$\mathcal{A}_{\mathcal{CP}} = \frac{|A|^2 - |\bar{A}|^2}{|A|^2 + |\bar{A}|^2}$$

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Run 2 data (LHCb, 6 fb^{-1} @ $\sqrt{s}$ =13 TeV)*(+ Run 1 review)*
Bigger data sample + Selection optimisation
→ Reduction of statistical uncertainty

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[2] LHCb Collaboration, Physics Letters B, 787 (2018)

Analysis Strategy

Experimental observable $\mathcal{A}_{RAW}$

$$\mathcal{A}^f_{RAW} = \frac{N(\Lambda^0_b \to f) - N(\bar{\Lambda}^0_b \to \bar{f})}{N(\Lambda^0_b \to f) + N(\bar{\Lambda}^0_b \to \bar{f})}, \; f = pK^-, p\pi^-$$

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Some of various contributions:

- $\mathcal{A}_{\mathcal{CP}}$ (what we want to measure)
- $\mathcal{A}_P$ $\Lambda_b^0/\bar{\Lambda}_b^0$ production asymmetry
- $\mathcal{A}_D^{h^\pm}$ Final states $(p, \bar{p}; K^+, K^-; \pi^+, \pi^-)$ detection asymmetry
- $\mathcal{A}_{PID}$ Particle IDentification (PID) asymmetry
- $\mathcal{A}_{trigger}$ Trigger (hardware and software) asymmetry

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$$\mathcal{A}^{ph^-}_{RAW} = \mathcal{A}^{ph^-}_{\mathcal{CP}} + \mathcal{A}^{p}_{D} + \mathcal{A}^{h^-}_{D} + \mathcal{A}^{ph^-}_{PID} + \mathcal{A}^{\Lambda^0_b}_{P} + \mathcal{A}^{ph^-}_{trigger}, \; h^- = K^-, \pi^-$$

BDT and PID

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- BDT (Boosted Decision Tree) classifier
  - Separate signal and combinatorial background via the use of kinematic and geometric variables
- PID (Particle IDentification) variables
  - Identify possible final states $(p, \bar{p}; K^+, K^-; \pi^+, \pi^-)$
  - Reduce contribution of cross-feed decays

Optimisation of BDT and PID variables
Investigation of cuts in a 5-dimensional space
(1 BDT + 4 PID) $\rightarrow$ Best precision on $\mathcal{A}_{RAW}$

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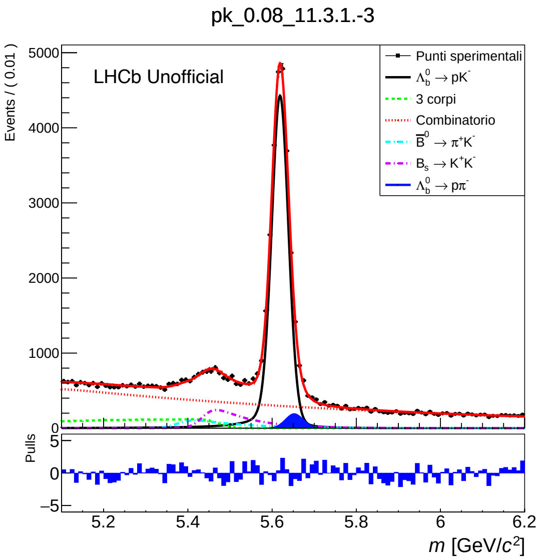
- Simultaneous fit to the 8 possible two-body final states with the optimal cuts, leading to the final $\mathcal{A}_{RAW}$ measurement

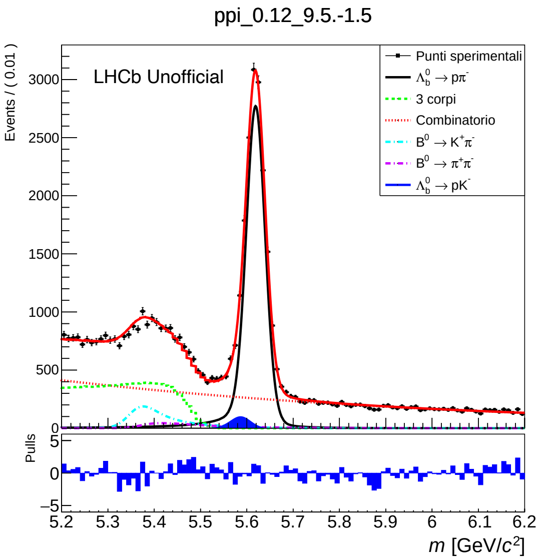
pK Normalisation Fit



Fit components:

- Signal ($\Lambda_b^0 \to pK$)
- 3 bodies
- Combinatorial bkg
- Cross-feed (misID)

$p\pi$ Normalisation Fit



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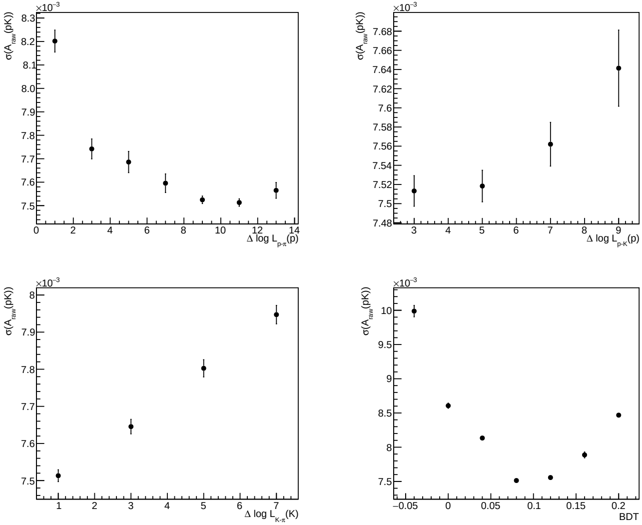
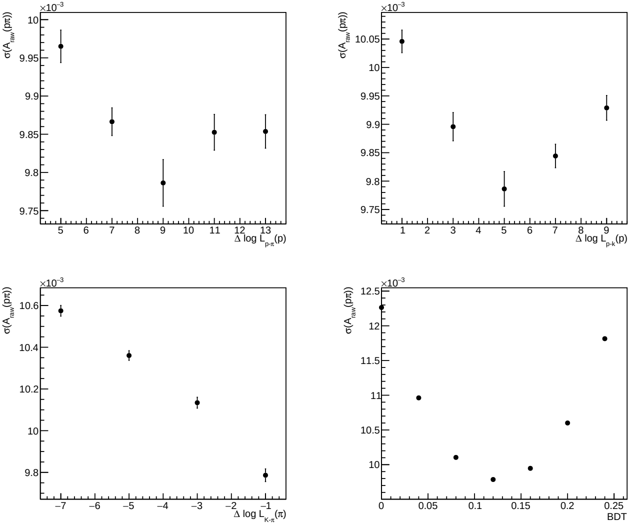
$\sigma(\mathcal{A}_{RAW}(pK))$ Trends



Trends obtained varying one cut at a time around the optimal values

Prediction:
$\sigma(\mathcal{A}_{RAW}^{pK}) \approx 0.75\%$

$\sigma(\mathcal{A}_{RAW}(p\pi))$ Trends



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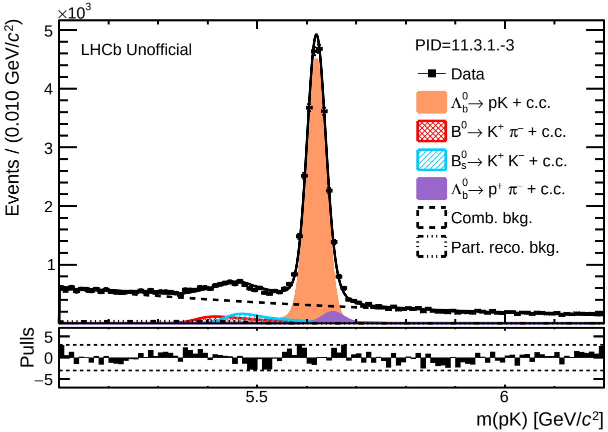
Prediction:
$\sigma(\mathcal{A}^{p\pi}_{RAW}) \approx 0.98\%$

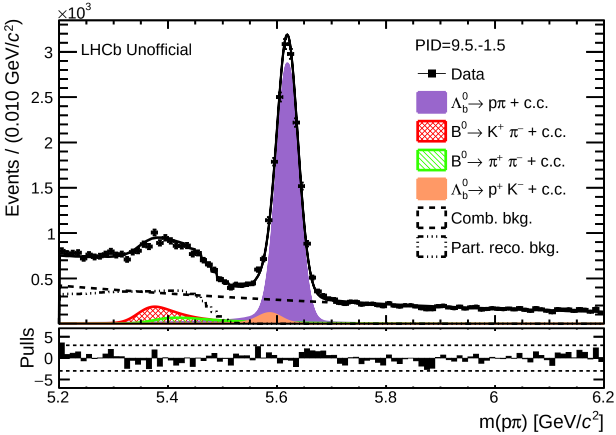
pK Spectrum Fit



$\sigma(\mathcal{A}_{RAW}^{pK}) = 0.76\%$

$\approx$ 22000 signal events (Run 1 $\rightarrow \approx$ 9000)

$p\pi$ Spectrum Fit



$\sigma(\mathcal{A}_{RAW}^{p\pi}) = 0.95\%$

$\approx$ 15000 signal events (Run 1 $\rightarrow \approx$ 6000)

Conclusions

Optimisation of events selection $\Lambda_b^0 \to pK, p\pi$ decays for Run 2 $\mathcal{CP}$ asymmetry measurements at LHCb
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$$\sigma(\mathcal{A}_{\mathcal{CP}}^{pK})^{stat}_{Run1} = 1.3\%$$

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- Improvement by a factor ≈ 2, in line with prediction
- Complete analysis for $\mathcal{A}_{\mathcal{CP}}$ in the two decay channels still in progress (LHCb group)
  - Determine all missing contributions to $\mathcal{A}_{\mathcal{CP}}$
  - Measurements of systematic effects and related uncertainties
  - (Review of Run 1 measurement)

Thank you for your attention.

Full text available at https://amslaurea.unibo.it/26551/

Extra

Investigated Cuts

Selection A ($\Lambda_b^0 \to pK$), 2940 combinations		
Variable		Explored values
$\Delta \log \mathcal{L}_{p-\pi}(p)$	$>$	$1, 3, 5, 7, 9, 11, 13$
$\Delta \log \mathcal{L}_{p-K}(p)$	$>$	$1, 3, 5, 7, 9$
$\Delta \log \mathcal{L}_{K-\pi}(K)$	$>$	$1, 3, 5, 7$
$\Delta \log \mathcal{L}_{K-p}(K)$	$>$	$-\Delta \log \mathcal{L}_{p-K}(p) \to -1$ (step-size: 2)
BDT	$>$	$-0.04 \to 0.2$ (step-size: 0.04)

Selection B ($\Lambda_b^0 \to p\pi$), 3920 combinations		
Variable		Explored cuts
$\Delta \log \mathcal{L}_{p-\pi}(p)$	$>$	$1, 3, 5, 7, 9, 11, 13$
$\Delta \log \mathcal{L}_{p-K}(p)$	$>$	$1, 3, 5, 7, 9$
$\Delta \log \mathcal{L}_{K-\pi}(\pi)$	$<$	$-1, -3, -5, -7$
$\Delta \log \mathcal{L}_{p-\pi}(\pi)$	$<$	$1 \to \Delta \log \mathcal{L}_{p-\pi}(p)$ (step-size: 2)
BDT	$>$	$0 \to 0.24$ (step-size: 0.04)

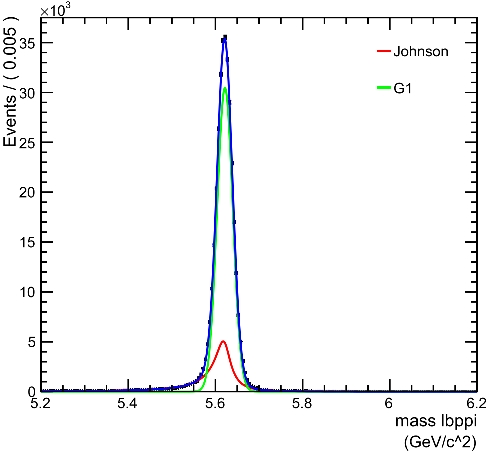
Fit Models

Considered contributions:

- Signal
- Cross-feed backgrounds
- Partially reconstructed background (3 bodies)
- Combinatorial background

Signal

$$g(m) = c_1 G(m; \mu = m_{\Lambda_b^0}, \lambda) + c_2 \mathcal{J}(m; \mu = m_{\Lambda_b^0}, \lambda, \gamma, \delta)$$



Cross-feed Background

One of the particles of the final state is wrongly identified

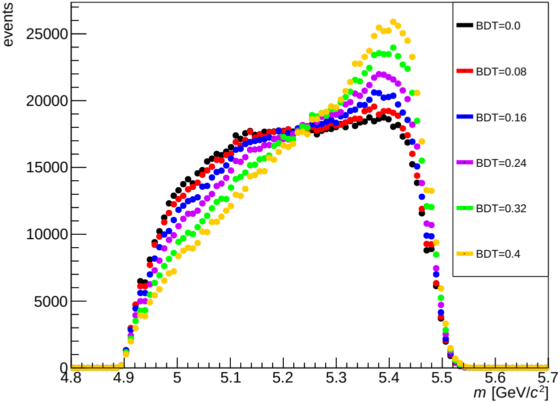
- $\Lambda_b^0 \to pK^-$ ($\bar{\Lambda}_b^0 \to \bar{p}K^+$) channel:
  - $\Lambda_b^0 \to p\pi^-$ ($\bar{\Lambda}_b^0 \to \bar{p}\pi^+$),
  - $\bar{B}^0 \to K^-\pi^+$ ($B^0 \to K^+\pi^-$) reconstructed as K^-p ($K^+\bar{p}$),
  - $B_s^0 \to K^+K^-$ reconstructed as pK^- or $\bar{p}K^+$.
- $\Lambda_b^0 \to p\pi^-$ ($\bar{\Lambda}_b^0 \to \bar{p}\pi^+$) channel:
  - $\Lambda_b^0 \to pK^-$ ($\bar{\Lambda}_b^0 \to \bar{p}K^+$),
  - $B^0 \to K^+\pi^-$ ($\bar{B}^0 \to K^-\pi^+$) reconstructed as $p\pi^-$ ($\bar{p}\pi^+$),
  - $B^0 \to \pi^+\pi^-$ reconstructed as $p\pi^-$ or $\bar{p}\pi^+$.

Constraint on the cross-feed yield to reference yield

$$N_i = N_j \cdot \frac{\Gamma(i)}{\Gamma(j)} \frac{f_i}{f_j} \frac{\varepsilon_i}{\varepsilon_j}$$

Partially Reconstructed Background (3 Bodies)

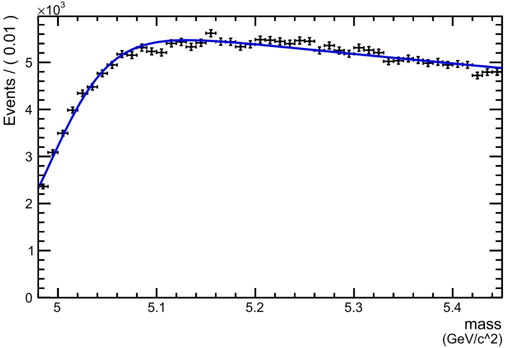
Obtained with RapidSim (`https://github.com/gcowan/RapidSim`)



- Negligible PID dependence
- BDT cut variation leads to relevant shape variations

Combinatorial Background

$$f(m) = C(1 + \tanh(b \cdot (m - s)))e^{-k \cdot m}$$



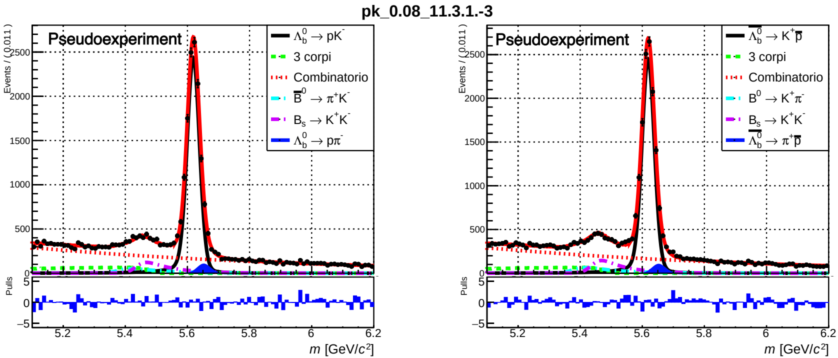
- Using $b = 0$ for $\Lambda_b^0 \to p\pi$ (pure exponential background)

Optimal Selections

Selection A ($\Lambda_b^0 \to pK$)		
Variable		Optimal value
$\Delta \log \mathcal{L}_{p-\pi}(p)$	$>$	11
$\Delta \log \mathcal{L}_{p-K}(p)$	$>$	3
$\Delta \log \mathcal{L}_{K-\pi}(K)$	$>$	1
$\Delta \log \mathcal{L}_{K-p}(K)$	$>$	-3
BDT	$>$	0.08

Selection B ($\Lambda_b^0 \to p\pi$)		
Variable		Optimal value
$\Delta \log \mathcal{L}_{p-\pi}(p)$	$>$	9
$\Delta \log \mathcal{L}_{p-K}(p)$	$>$	5
$\Delta \log \mathcal{L}_{K-\pi}(\pi)$	$<$	-1
$\Delta \log \mathcal{L}_{p-\pi}(\pi)$	$<$	5
BDT	$>$	0.12

Pseudoexperiment *pK*



Pseudoexperiment $p\pi$