STUDY OF THE $\Lambda_b^0 \to D^0 p K^-$ DECAY FOR A MEASUREMENT OF CKM ANGLE γ

Chiara Mancuso, Nicola Neri, Patrick Robbe

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chiara.mancuso@cern.ch

INTRODUCTION AND MOTIVATIONS

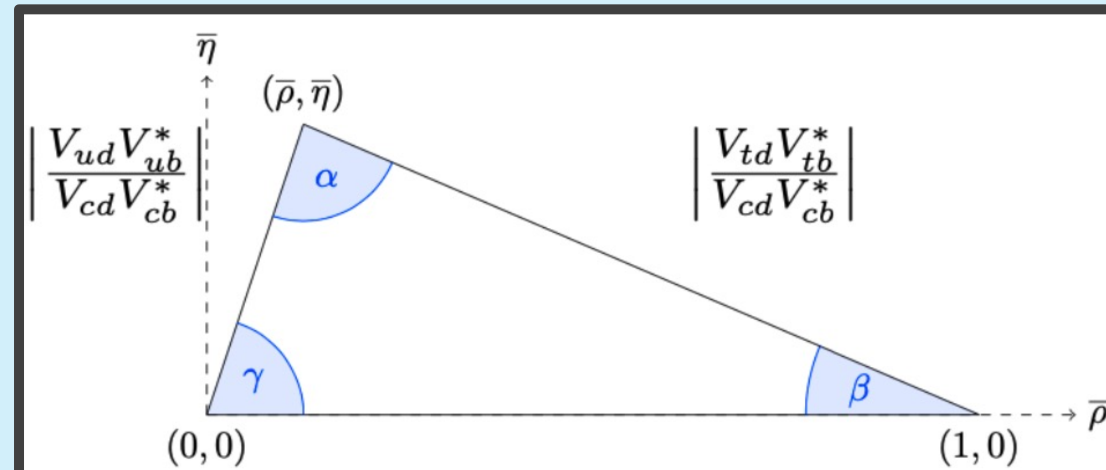
- Aims of the study:
  - Measuring CP violation in baryons – a dream!
  - Performing a measurement of the CKM angle γ

- CP violation is accommodated within the SM through the CKM matrix
  - Wolfenstein parametrization

- From the unitarity, we can extract the unitarity triangle

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} =$$

$$= \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$



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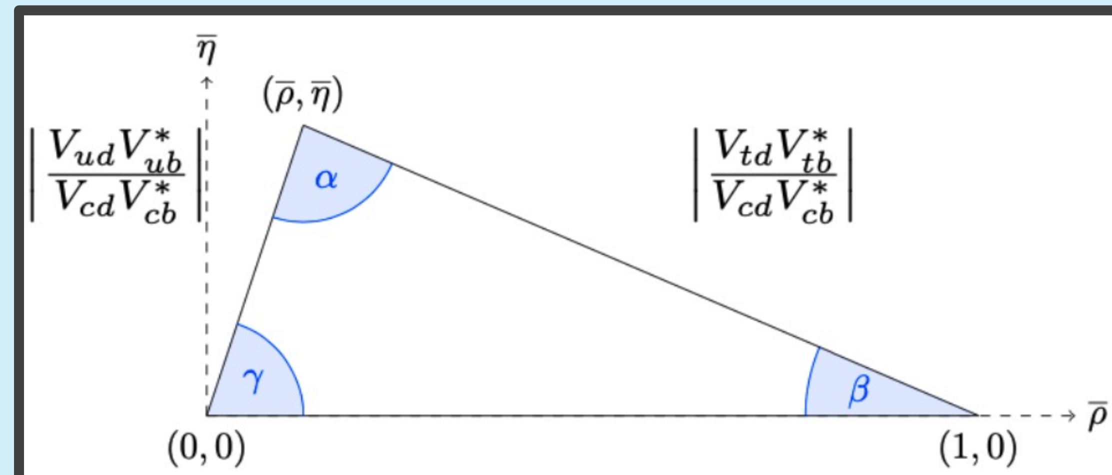
$$\gamma \equiv \arg[-V_{ud}V_{ub}^*/V_{cd}V_{cb}^*]$$

$$\gamma = (65.6^{+1.1}_{-2.7})^\circ$$

[http://ckmfitter.in2p3.fr]

$$\gamma = (63.8\,^{+3.5}_{-3.7})^\circ$$

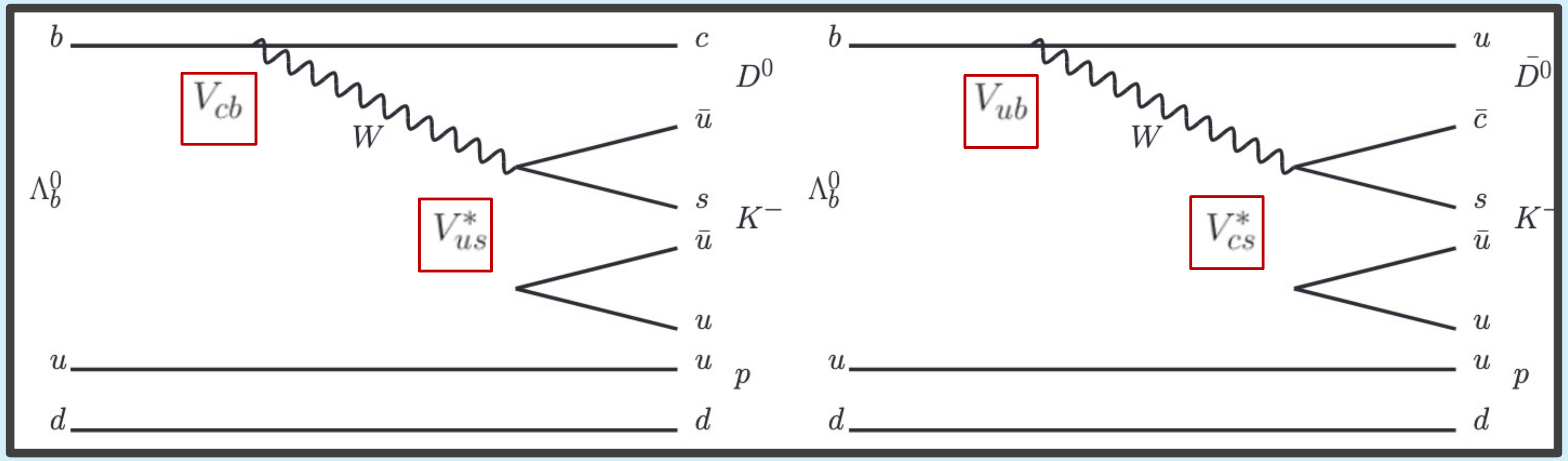
[LHCb-CONF-2022-002]

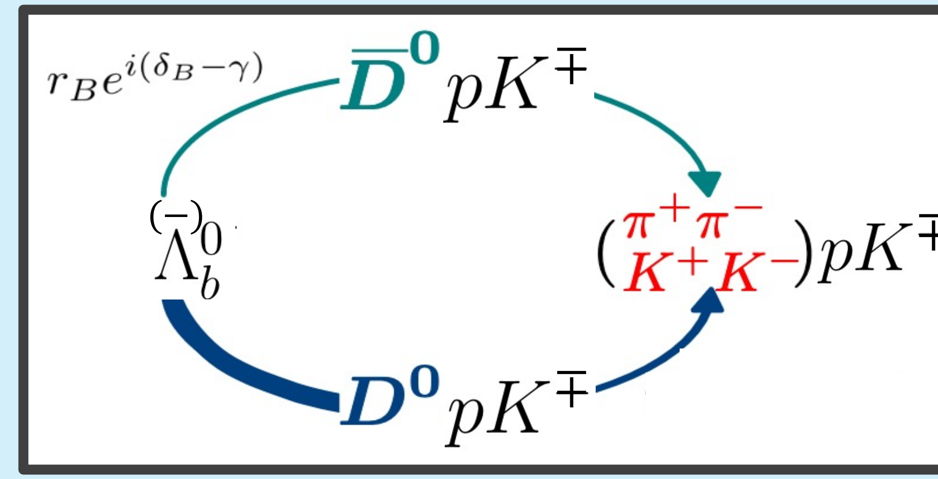


INTRODUCTION AND MOTIVATIONS

Gronau, London, Wyler (GLW) method → D^0 decays into CP eigenstates [Phys. Lett. B265 (1991), pp. 172–176]

- CP-even eigenstates: $K^-K^+, \pi^-\pi^+$
- CP-odd eigenstates: $K_S\pi^0, K_S\rho^0, \ldots$



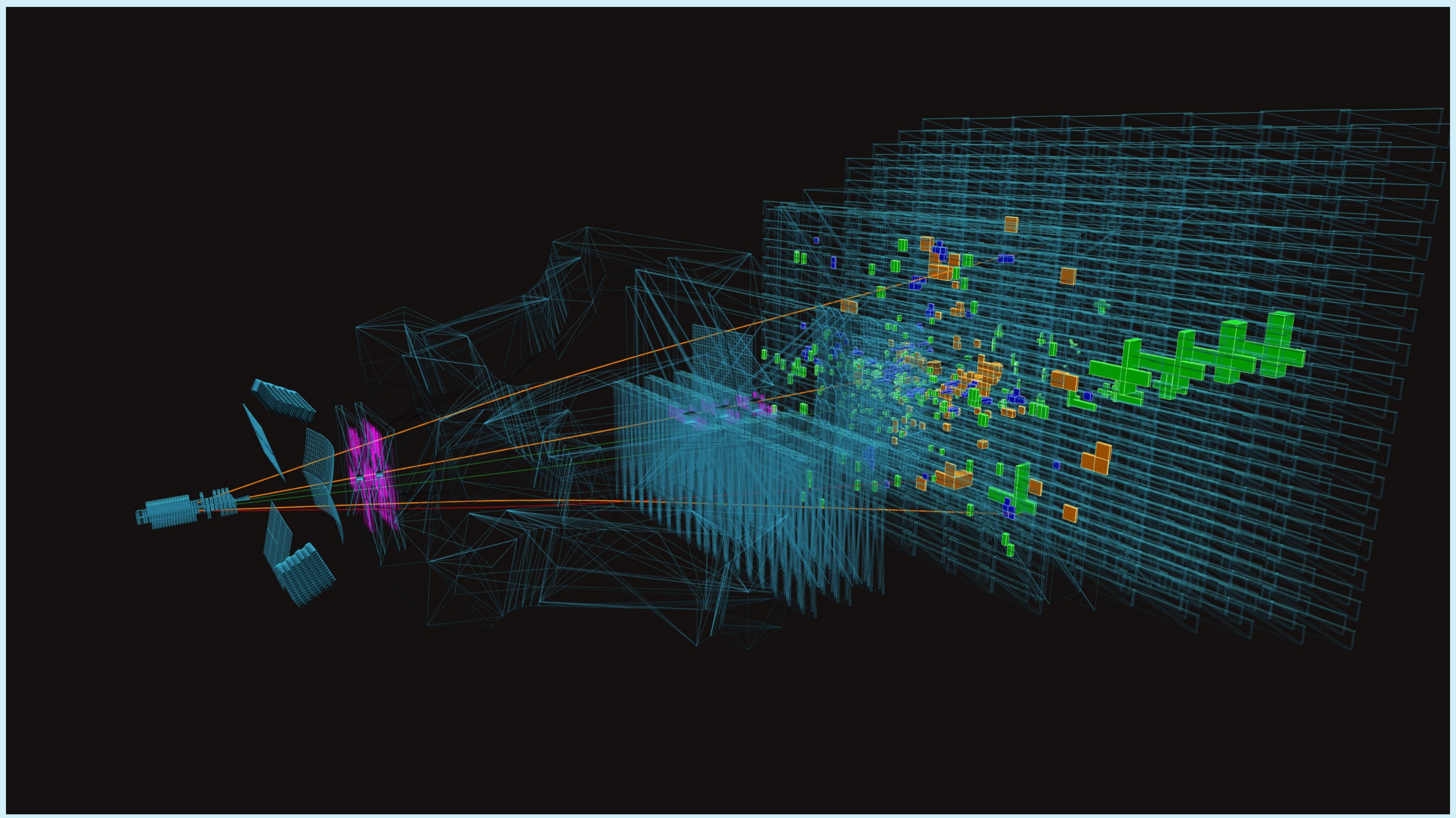


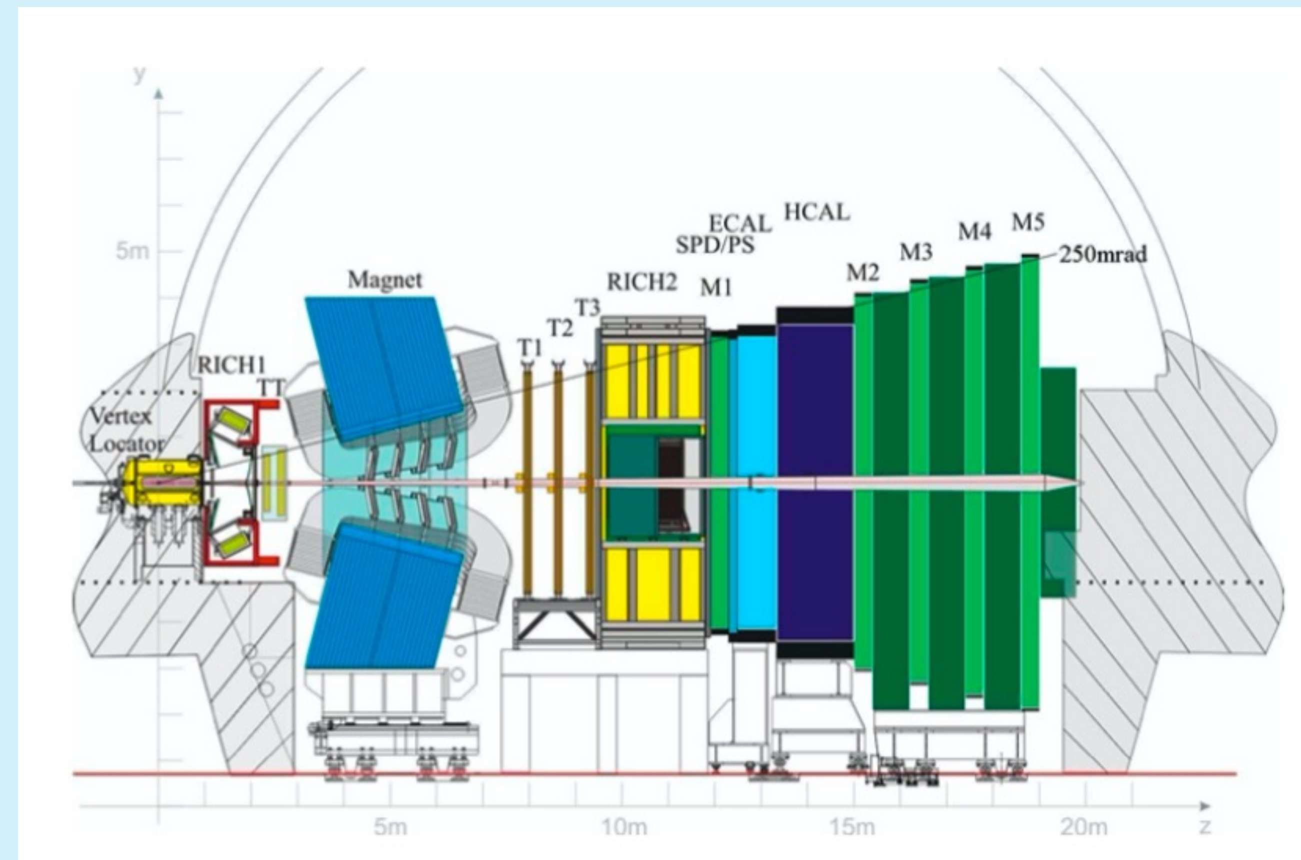
Observables:

$$A_{CP} = \frac{\Gamma(\Lambda_b^0 \to D_{CP} p K^-) - \Gamma(\bar{\Lambda}_b^0 \to D_{CP} \bar{p} K^+)}{\Gamma(\Lambda_b^0 \to D_{CP} p K^-) + \Gamma(\bar{\Lambda}_b^0 \to D_{CP} \bar{p} K^+)} = \frac{2 r_B \sin\delta_B \sin\gamma}{1 + r_B^2 + 2 r_B \cos\delta_B \cos\gamma}$$

$$R_{CP} = \frac{\Gamma(\Lambda_b^0 \to D_{CP} p K^-) - \Gamma(\bar{\Lambda}_b^0 \to D_{CP} \bar{p} K^+)}{\Gamma(\Lambda_b^0 \to D^0 p K^-) + \Gamma(\bar{\Lambda}_b^0 \to \bar{D}^0 \bar{p} K^+)} = 1 + r_B^2 + 2 r_B \cos\delta_B \cos\gamma$$

THE LHCB EXPERIMENT





- Asymmetric single-arm detector
- Primary goal is to look for indirect evidence of new physics and rare decays in CP violation

ANALYSIS STRATEGY

- Analysis performed on RunI and RunII data (2011 – 2018)
- Wide use of the control channel, i.e. $\Lambda_b^0 \to D^0 p \pi^-$

$\mathcal{B}(\Lambda_b^0 \to D^0 p\pi)$	$(6.3 \pm 0.7) \times 10^{-4}$
$\mathcal{B}(\Lambda_b^0 \to D^0 pK)$	$(4.6 \pm 0.8) \times 10^{-5}$

- First preselection of PID: proton, $h_D^{\pm}$
  - Optimized on the control channel and applied also to the signal

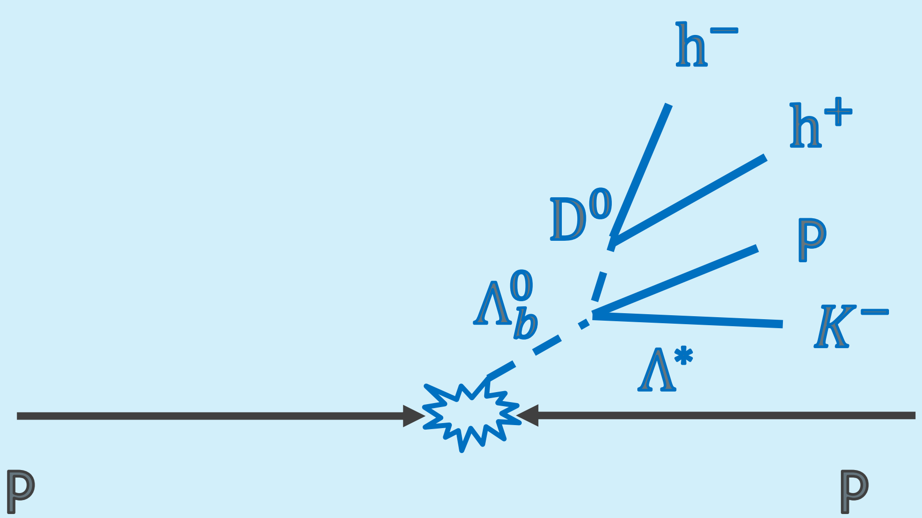
$$S_{FoM} = \frac{S}{\sqrt{S+B}} = \frac{\epsilon_S S_0}{\sqrt{\epsilon_S S_0 + \epsilon_B B_0}}$$

ANALYSIS STRATEGY – THE CHALLENGE

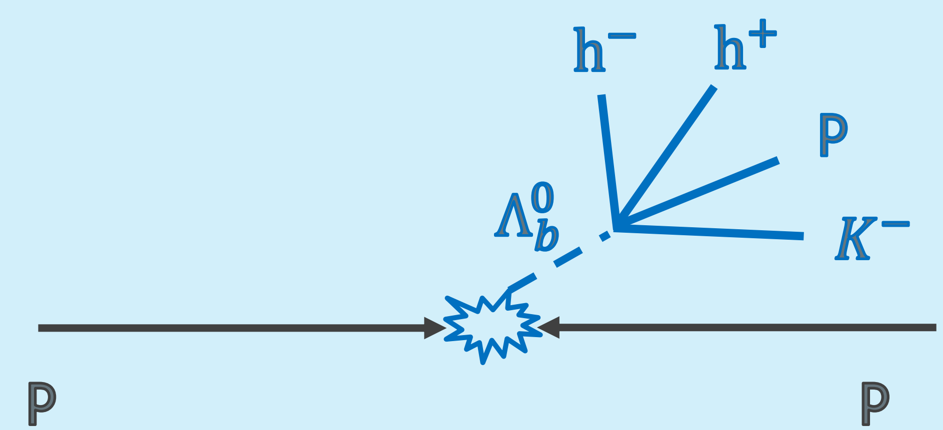
Preliminary studies shown:

- The charmless background (i.e. $\Lambda_b^0 \to p h^- h^+ h^-$) is an highly contaminating background

Why are we so concerned by this specific background?



No D^0 → diluted sensitivity to γ



- Could it be removed in a more efficient way than with a rectangular cut? [Phys. Rev. D 104, 112008 (2021)], [CERN-THESIS-2020-314]

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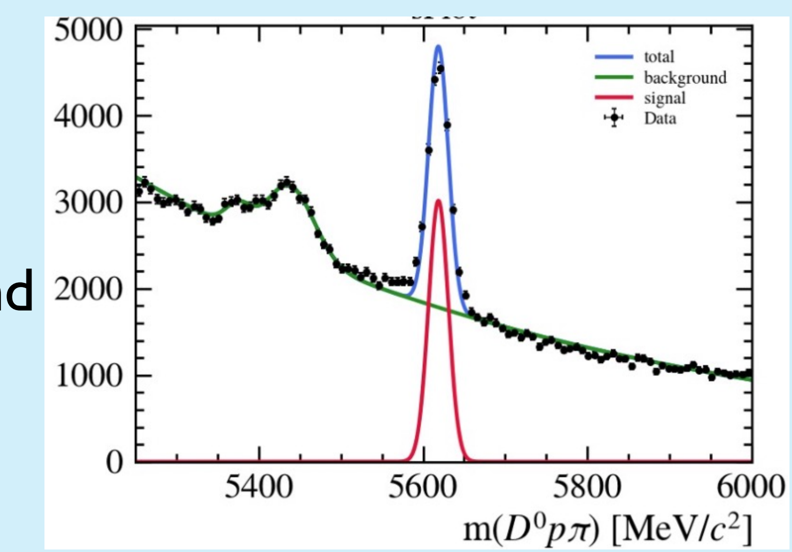
Proposals:

1. Train 2 BDTs
2. Train 1 BDT able to discriminate 3 categories:
   signal, combinatorial background, charmless background

1.



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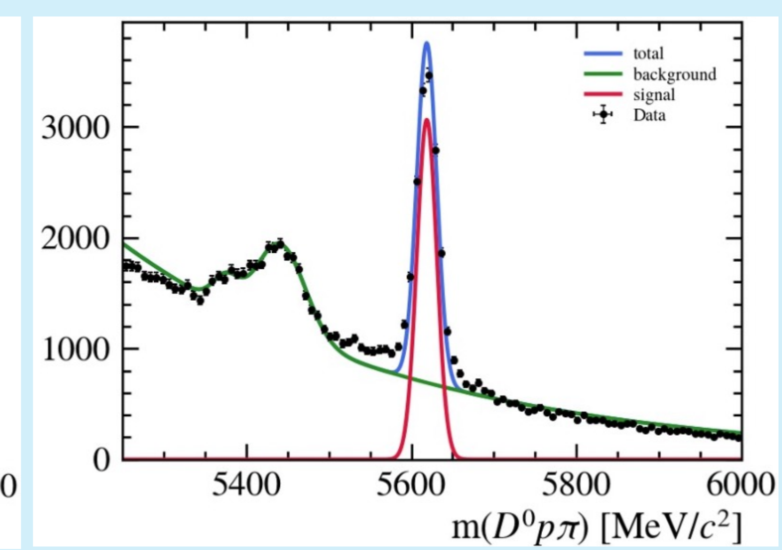

$\Lambda_b^0 \to [K^- \pi^+]_D p\, \pi^-$ RunI

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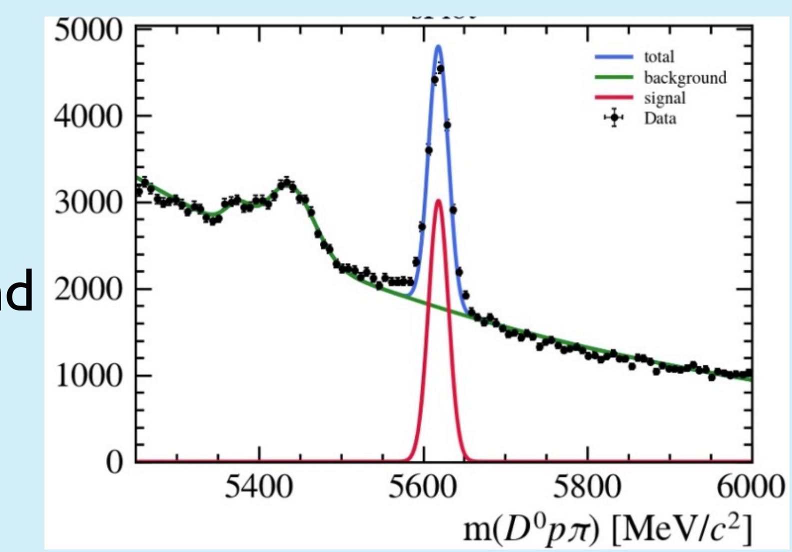

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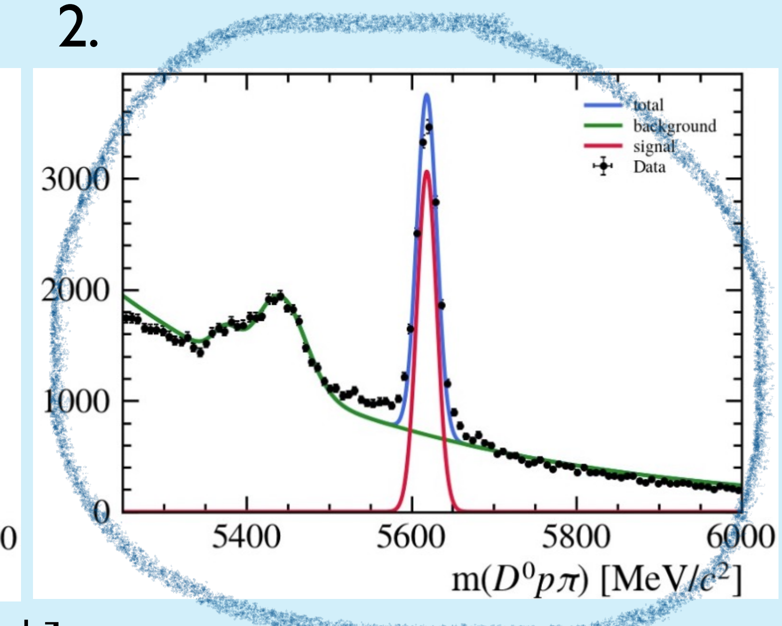


$\Lambda_b^0 \to [K^-\pi^+]_D p\,\pi^-$ RunI

ANALYSIS STRATEGY – THE SELECTION

- Choosing the tool was only part of the work, also a strategy has been optimized

- The selection has been optimized to reduce other background sources:
  - Mis-identification of $\Lambda_b^0 \to D^0 p K^-$ with $\Lambda_b^0 \to D^0 p \pi^-$
  - $\Lambda_c^+ \to p h^- h^+$ veto
  - Selection on proton PID has been very effective with the multiple background sources

- The optimization followed the maximization of the Figure of Merit

$$S_{FoM} = \frac{S}{\sqrt{S+B}} = \frac{\epsilon_S S_0}{\sqrt{\epsilon_S S_0 + \epsilon_B B_0}}$$

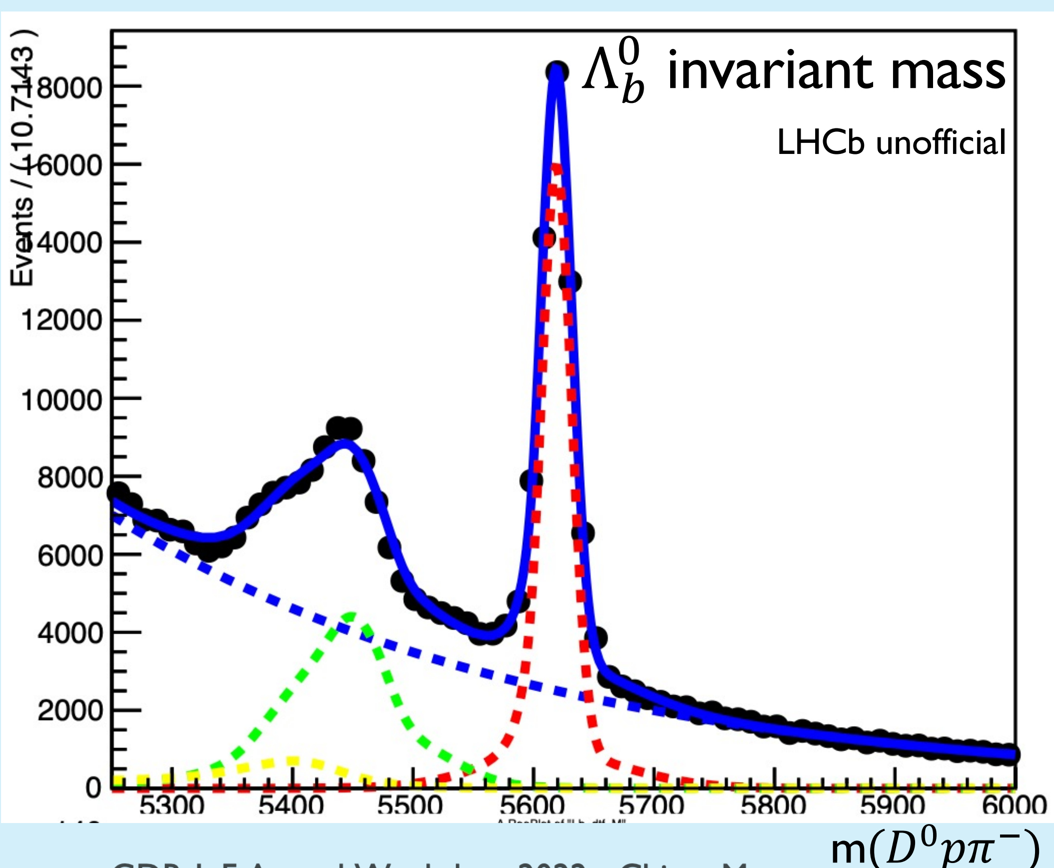
- For $\Lambda_b^0 \to D^0 p K^-$, the number of signal events was estimated from efficiencies and physical quantities, in order to proceed "blind"

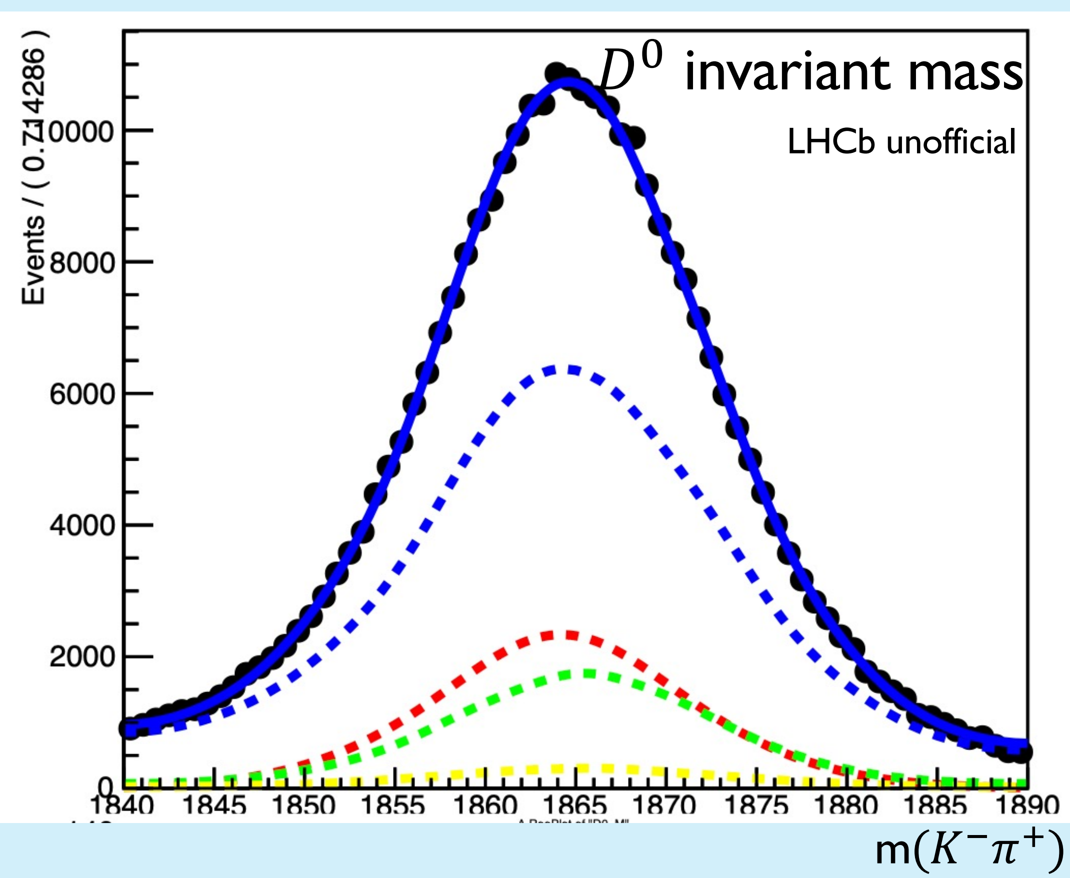
ANALYSIS STRATEGY – CONTROL CHANNEL RESULTS

In order to quantify the charmless contribution, if exists, a simultaneous fit to both the Λ_b^0 and D^0 invariant mass is performed

The fit strategy is first tested on the control channel:

- Signal modelled with the sum of two Crystal Balls
- Combinatorial background modelled by an exponential
- D^{*0} shape estimated with one-dimensional kernel estimator p.d.f





$\Lambda_b^0 \to [K^-\pi^+]_D p\pi^-$ RunII

- Comb bkg = 205 476
- Signal = 57 970
- $\Lambda_b^0 \to D^{*0} p\pi^-$ = 46 942
- $\Lambda_b^0 \to D^{*0} pK^-$ = 9 104

CONCLUSIONS AND FUTURE PLANS

- We are studying $\Lambda_b^0 \to D^0 p K^-$ and $\Lambda_b^0 \to D^0 p \pi^-$ to try to measure CP violation in baryons
- The selection has been optimised and a fitting strategy has been chosen
- Active collaboration with UCAS group for binning optimization in their CKM angle γ measurements using $\Lambda_b^0 \to D^0 p K^-$, with $D^0 \to K^- 3\pi$, $D^0 \to K_S^0 \pi^- \pi^+$

Thanks for your attention!

BACKUP – CHARMLESS BRANCHING FRACTION

Charmless Mode	DATA Sample	$\frac{\mathcal{B}(\Lambda_b^0 \to ph^-h^+h^-)}{\mathcal{B}(\Lambda_b^0 \to D^0 ph)\mathcal{B}(D^0)}$
$\Lambda_b^0 \to pK^-K^+K^-$	$[K^-K^+]_{D^0}pK^-$	$\sim 6.8 \times 10^1$
$\Lambda_b^0 \to pK^-K^+\pi^-$	$[K^+\pi^-]_{D^0}pK^-$	$\sim 5.9 \times 10^2$
	$[K^-K^+]_{D^0}p\pi^-$	$\sim 1.6 \times 10^0$
$\Lambda_b^0 \to pK^-\pi^+\pi^-$	$[\pi^-\pi^+]_{D^0}pK^-$	$\sim 7.6 \times 10^2$
	$[K^-\pi^+]_{D^0}p\pi^-$	$\sim 2.1 \times 10^0$
$\Lambda_b^0 \to p\pi^-\pi^+\pi^-$	$[\pi^-\pi^+]_{D^0}p\pi^-$	$\sim 5.6 \times 10^1$