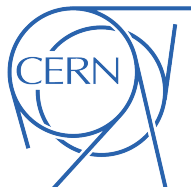


New Observations of Beauty Baryon Decays at LHCb

Team-Based Summer Student Project by
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Summer Student Session
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- 1 Project: Analysis of new Λ_b decays in a team
- 2 Succeeding in a Team-Based Project with “Scrum”

Motivation for new observations of Λ_b^0 decays

Motivation

- CP violation in baryons not observed yet
- gain better understanding of QCD
- beauty baryons not well-known yet
- baryons important for background understanding of many processes

The decays we analyze:

$$\Lambda_b^0 \rightarrow \Lambda_c^+ K^- K^+ \pi^-$$

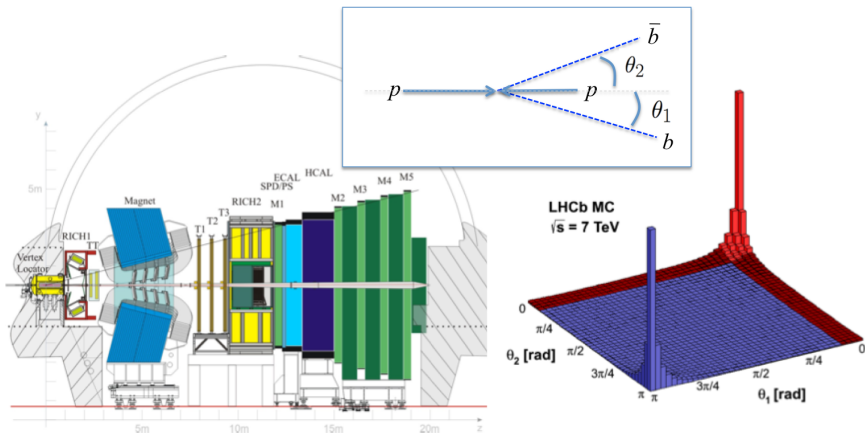
$$\Lambda_b^0 \rightarrow \Lambda_c^+ \bar{D}_0 K^-$$

$$\Lambda_b^0 \rightarrow \Lambda_c^+ \bar{p} p \pi^-$$



LHCb Detector: Designed for beauty physics

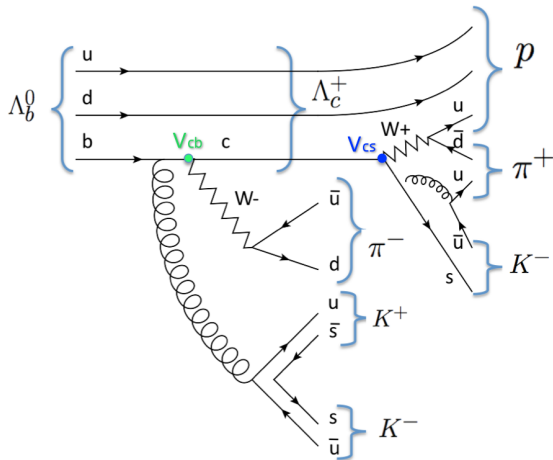
- $b\bar{b}$ -pairs most likely produced in forward or backward direction
- Detector parts: high precision vertex locator (“VELO”), Cherenkov detectors for particle identification, Silicon-detectors for tracking, electromagnetic and hadronic calorimeters, muon system
- Dipole Magnet (integrated field 4 Tm) can run with both polarities



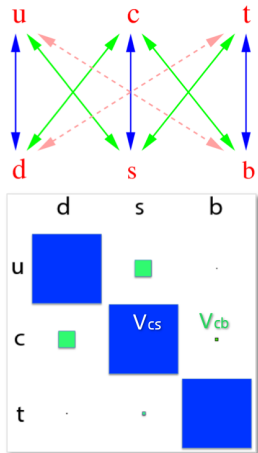
Example of yet unobserved Λ_b^0 decay

Example decay:

$$\Lambda_b^0 \rightarrow \Lambda_c^+ K^- K^+ \pi^- \quad , \quad \Lambda_c^+ \text{ recognized by } \Lambda_c^+ \xrightarrow{5\%} p K^- \pi^+$$

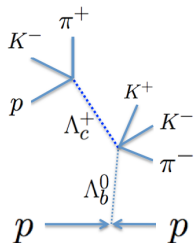


CKM quark mixing



First steps of analysis: how to find a new decay

Example decay: $\Lambda_b^0 \rightarrow \Lambda_c^+ K^- K^+ \pi^-$, $\Lambda_c^+ \rightarrow p K^- \pi^+$



“Pre-filtering” the raw LHCb data:

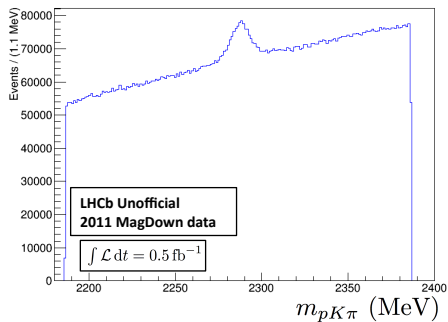
- charged particles reconstructed in the detector
- decay topology (vertices)
- loose kinematic and particle identification selection

Need to prove that particles come from the proposed decay
⇒ Identify decay pattern by selecting characteristic features (“cuts” on variables)

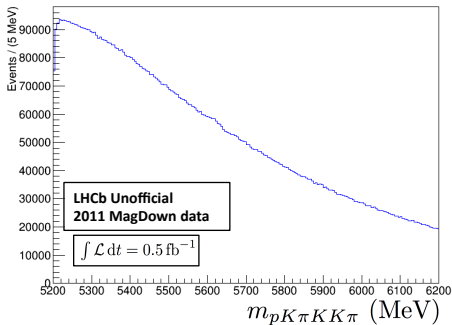
First steps of analysis: how to find a new decay

Raw mass spectrum after pre-selection (without any cuts):

Invariant mass of $pK\pi$
(without any cuts)



Invariant mass of $\overbrace{pK\pi}^{\Lambda_c} KK\pi$
(without any cuts)

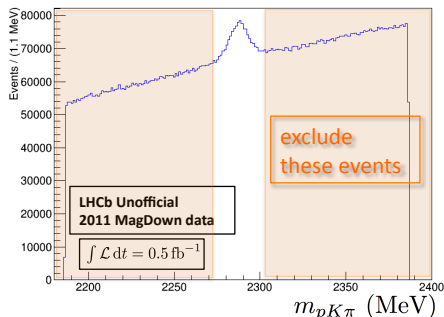


First steps of analysis: how to find a new decay

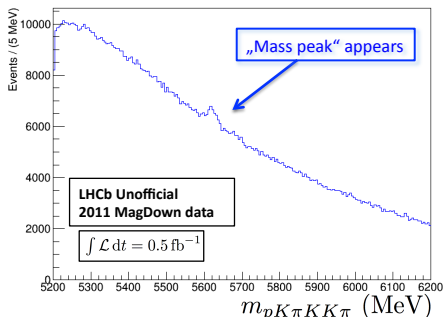
We know: $\Lambda_c^+ \rightarrow p K^- \pi^+$, $m_{\Lambda_c} = 2286.46 \pm 0.14$ MeV

\Rightarrow apply cut on invariant mass of Λ_c daughters $pK\pi$:

Invariant mass of $pK\pi$
(without any cuts)



Invariant mass of $\overbrace{pK\pi}^{\Lambda_c} KK\pi$
(with cut on $m_{pK\pi}$)

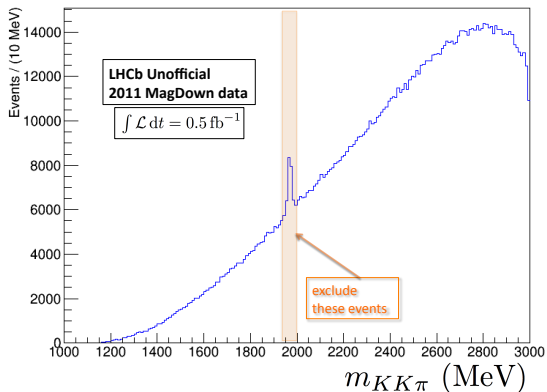


First steps of analysis: how to find a new decay

Plot the invariant mass of $KK\pi$ -system \Rightarrow Why should the peak in the $\Lambda_c KK\pi$ -system mass correspond to our proposed decay $\Lambda_b^0 \rightarrow \Lambda_c^+ K^+ K^- \pi^-$ and not to $\Lambda_b^0 \rightarrow \Lambda_c^+ D_s^-$ where $D_s^- \rightarrow K^+ K^- \pi^-$?

\Rightarrow Exclude the region with D_s mass peak ($m_{D_s} = 1968.49 \pm 0.32$ MeV)

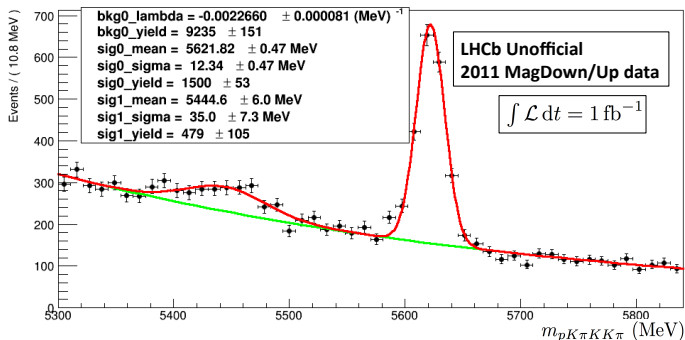
Invariant mass of $KK\pi$ system (with cut on $m_{pK\pi}$)



First steps of analysis: how to find a new decay

After applying more cuts (e.g. particle identification variables, impact parameters) and excluding the D_s a clear Λ_b peak is measurable. The peak on the left represents the decay $\Lambda_b \rightarrow \Sigma_c K K \pi$, where $\Sigma_c \rightarrow \Lambda_c \pi$ and one π is missed.

Invariant mass of $\Lambda_c K K \pi$ (with all preselection cuts)



Next step after this preselection

Apply a BDT (Boosted Decision Tree) to exploit correlations between variables for highest signal to background ratio for final measurement.

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Success in a Team-Based Project

Why teams are successful:

- communication
- feedback
- recognition and motivation
- flexibility to adapt for new tasks
- organization and self-organization

Success in a Team-Based Project

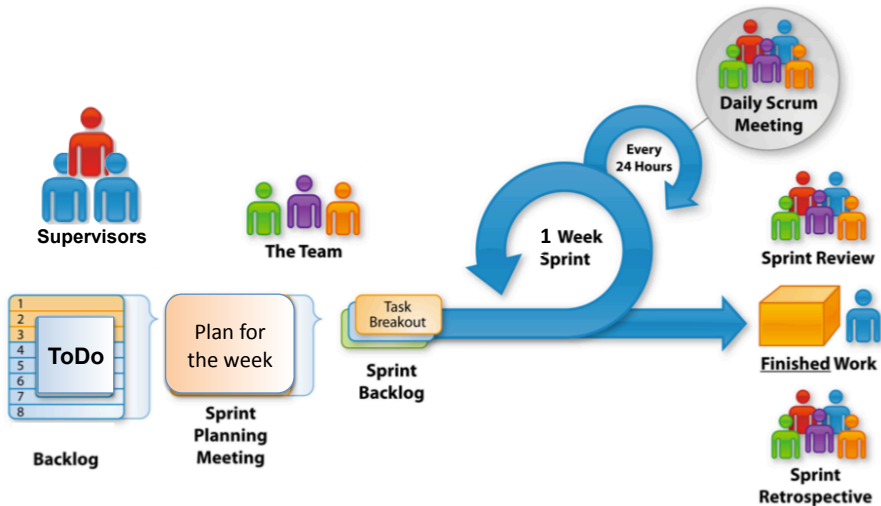
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- communication
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- flexibility to adapt for new tasks
- organization and self-organization

How to achieve this:

- daily **planned** face-to-face communication
- regular **planned** feedback rounds
- inspect and track progress, make problems visible
- enable repeatability and reproducibility for analysis strategy
- split the work into clear defined small projects or pieces

“Scrum”: a framework for managing team work



Trello: a useful tool for organizing work

- provides a nice overview of the to-do list, helps to organize your own work
- each (small) task is assigned to a “card”
- “lists” for sorting tasks into categories
- one can add certain members, make comments on cards, attach files

The screenshot shows a Trello board titled "SummieProject: First Observations at LHCb". The board is organized into several lists:

- Backlog:** Contains three cards. The first card is "Get kinematic efficiency from MC: geometric, trigger, selection". The second card is "New observations of L_b decay: cut out peak and fit single gaussian" with a progress indicator of 0/4. The third card is "Look at Lb CP asymmetry." with a progress indicator of 0/6. Below the cards is a plot showing σ_{eff}^2 and $\sigma_{\text{eff}}^2 \text{ mb}$ versus \sqrt{s} GeV.
- Sprint Backlog:** Contains four cards: "bs Define FOM for bdt optimisation" (DB), "Save bdt response to ntuple", "Produce TMVA control plots", and "Optimize the cut on the bdt response using $s/\sqrt{s+b}$ ". There is also a card "Write the tool to save bdt response to ntuple".
- In progress:** Contains two cards: "Reproducing 2012 ntuples Lb2LcKpi on correct stripping" (SN) and "Looking at variables for BDT" (KH, VA). Below these is a card "Bs: Fit Bs and f2 Mass peaks after applying different cuts on BDT response" (DB) and another "Bs: Reproduce previous Analysis (apply their cuts)" (3/4).
- For Sprint review:** Contains three cards: "Produce sWeights for 2011 Up/Down and 2012 Up data." (KH), "Combine 2012MagUp ntuples" (KH), and "Refactor the training script" (3/3) (DB, KH). Below these is a plot titled "Invariant meson-meson $\pi_0 \rightarrow \pi^0 \pi^0$ ".
- Done:** Contains three cards: "Bs: apply BD1" (7/4), "Plot invariant subsystems" (6/6), and "provide ntuple".

Acknowledgement

Thank you all for your attention and a great time!



I thank very much my team members Daniel and Kevin for the very supportive and nice working atmosphere! I am very grateful to Sebastian, Moritz and Christian, for their outstanding support and thank a lot Sebastian for introducing scrum, providing material for the talk and very fruitful feedback!