A Search for Doubly Charmed Baryons at LHCb

Ao Xu
Tsinghua University
Supervised by: Yuanning Gao, Patrick Spradlin
11 August, 2016

About me

- Third-year undergraduate at Tsinghua University, Beijing, China

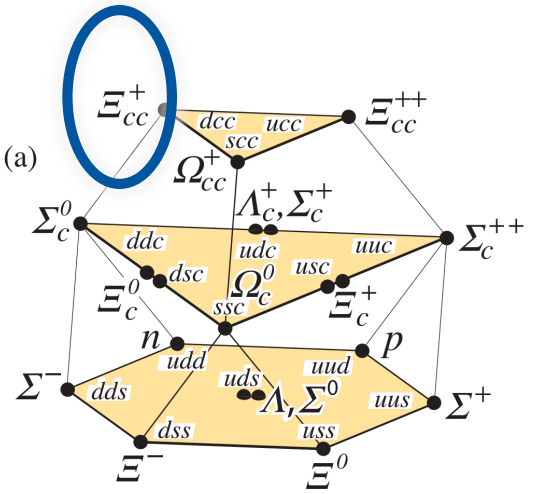
Tsinghua University

Outline

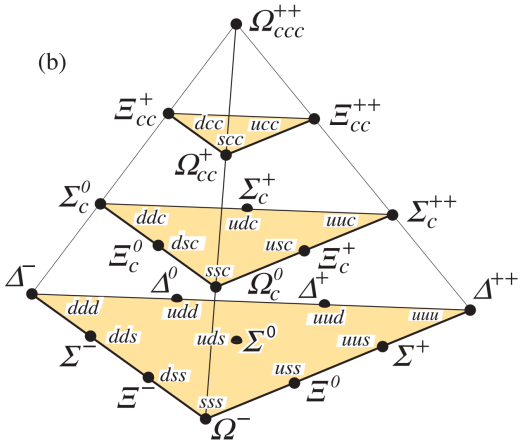
- Introduction
- Experimental status
- Analysis strategy
- Generator level cuts
- Study of offline selection
- Plan

Introduction

- Theoretical motivation
  - The quark model proposed by Gell-Mann and Zweig in 1964 revolutionized our understanding of the structure of matter with strong interactions.
  - It predicts several doubly heavy flavor baryons, but none of them is solidly observed.
  - Doubly charmed baryons are interesting places for the study of non-perturbative QCD.
- Production
  - Formation
    - Production of two c quarks
    - Binding into di-quark structure
    - Hadronization
  - $\sigma(pp \to \Xi_{cc}^{\pm} X) \approx 110$ nb
- Theoretical predictions of Ξ_{cc}^{+} mass and lifetime
  - $m_{\Xi_{cc}^{+}}$: ranges from 3500 to 3700 MeV$/c^2$
  - $\tau_{\Xi_{cc}^{+}}$: ranges from 110 to 250 fs



20-plet with SU(3) octet



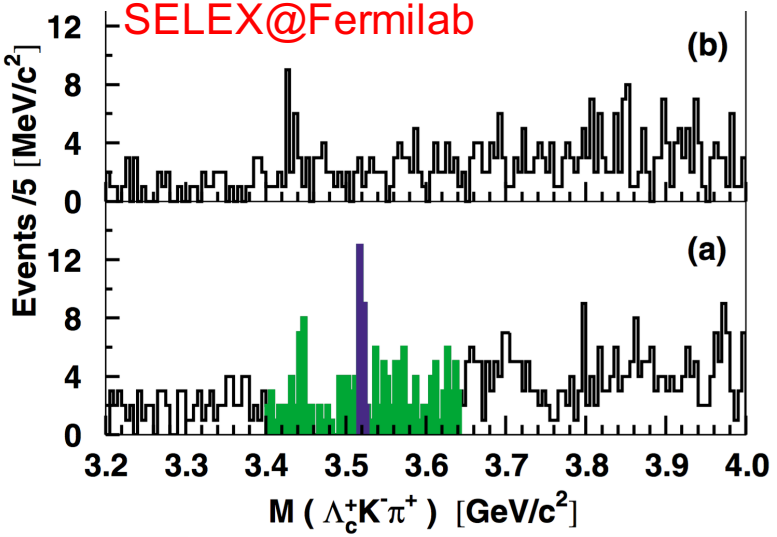
20-plet with SU(3) decuplet

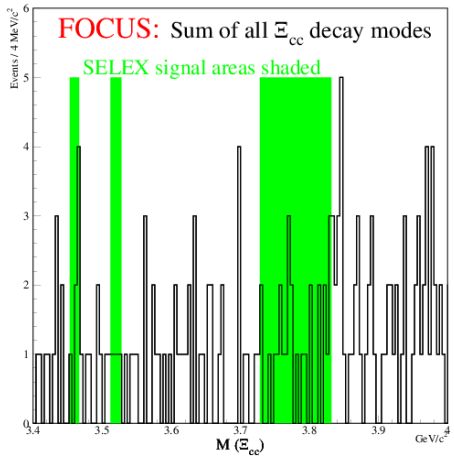
- LHCb is a good place to search for Ξ_{cc}^{+} and other doubly heavy flavor baryons.

Experimental status

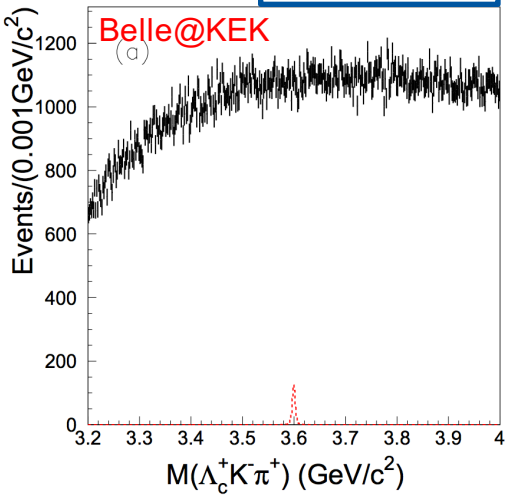
- SELEX reported observation of Ξ_{cc}^{+} with more than 5σ significane in 2002. But observed Ξ_{cc}^{+} has much smaller lifetime and much larger cross-section than theoretical predictions.
- FOCUS, Belle and BaBar failed to repeat this observation.

arXiv:hep-ex/0208014

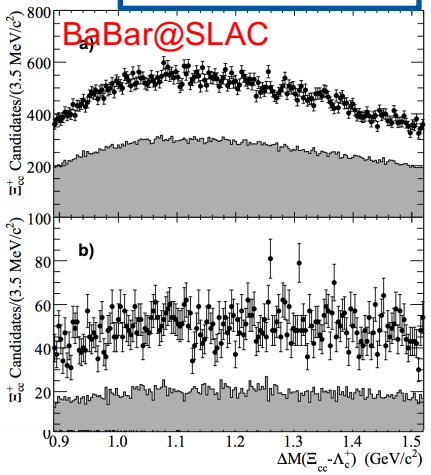




arXiv:1312.1026

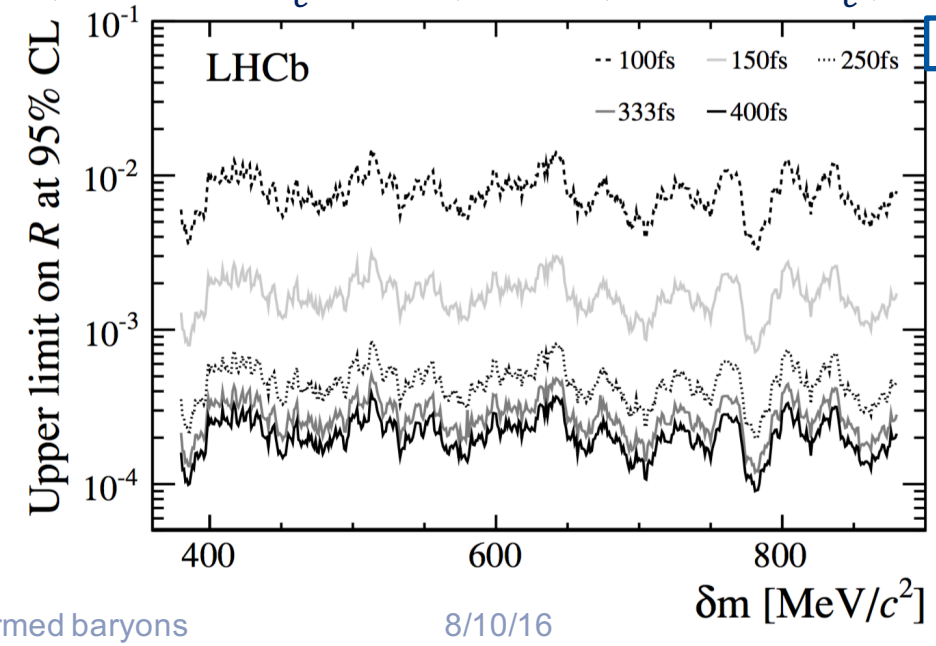


arXiv:hep-ex/0605075



Experimental status

- Search @LHCb in 2013
  - In $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ decay mode using 2011 data of $0.65\ \mathrm{fb}^{-1}$
  - No significant signal is found.
  - Upper limits on R (@95% CL) are given as a function of δm for different lifetime hypotheses, where $R \equiv \frac{\sigma(\Xi_{cc}^{+})\mathcal{B}(\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+})}{\sigma(\Lambda_c^{+})}$,
    $\delta m \equiv m\left([pK^{-}\pi^{+}]_{\Lambda_c^{+}} K^{-} \pi^{+}\right) - m\left([pK^{-}\pi^{+}]_{\Lambda_c^{+}}\right) - m(K^{-}) - m(\pi^{+})$.



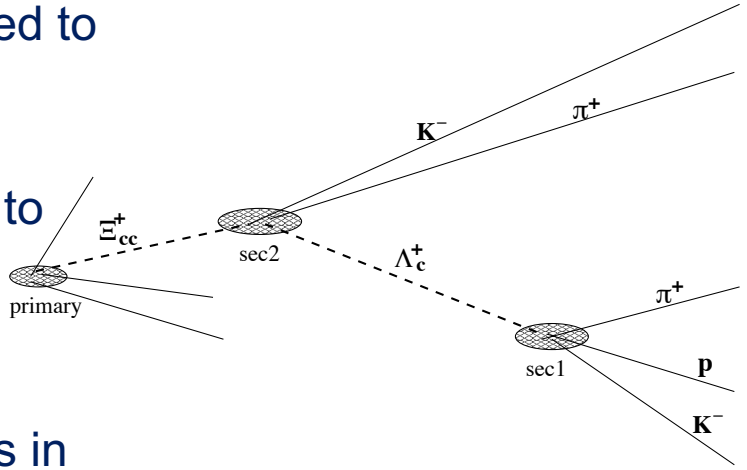
arXiv:1310.2538v2

Analysis strategy

- Larger data sample
  - Run1: $1\ \mathrm{fb}^{-1}$ in 2011 and $2\ \mathrm{fb}^{-1}$ in 2012
- Combined decay modes to improve sensitivity, considering branching ratio and detection efficiency
  - $\Xi_{cc}^{+} \to \Lambda_c^{+}(\to pK^{-}\pi^{+})K^{-}\pi^{+}$
  - $\Xi_{cc}^{+} \to D^{0}(\to K^{-}\pi^{+})pK^{-}\pi^{+}$
  - $\Xi_{cc}^{+} \to D^{+}(\to K^{-}\pi^{+}\pi^{+})pK^{-}$
  - $\Xi_{cc}^{+} \to \Xi_c^{+}(\to \Xi^{-}\pi^{+}\pi^{+})\pi^{+}\pi^{-}$
  - $\Xi_{cc}^{+} \to \Xi_c^{0}(\to \Xi^{-}\pi^{+})\pi^{+}$
- Improved stripping cuts

Generator level cuts of $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$

- Motivation
  - Generator level cuts are criteria designed to filter candidates with desired properties during Monte Carlo event generation.
  - Useful generator level cuts are needed to improve MC selection efficiency and optimize computing resources usage.
  - MC selection efficiency: efficiency for candidates to pass certain requirements in reconstruction.
  - MC selection efficiency of current sample is about 0.2%.
- MC sample used
  - Sample size: 510,338 events
  - Each event contains one Ξ_{cc}^{+} candidate within LHCb detector acceptance.

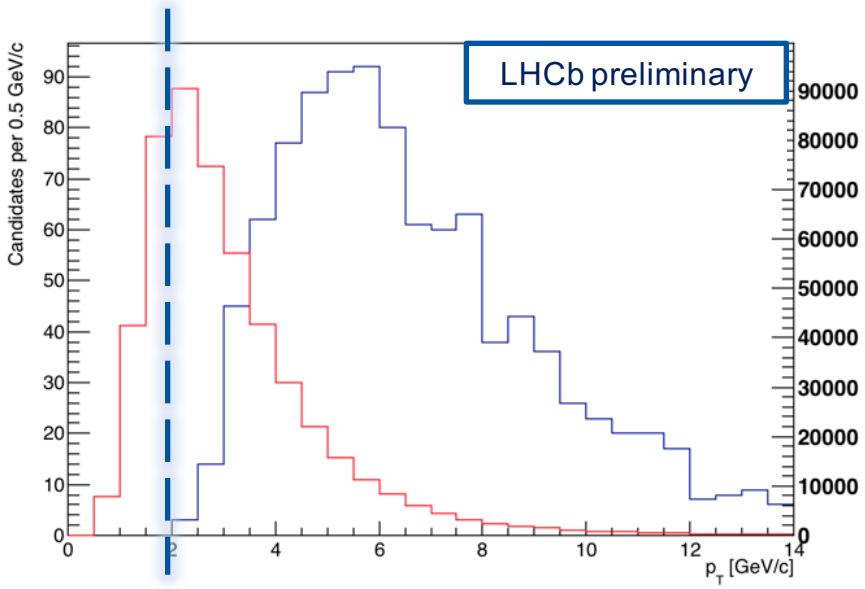


$$\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$$
$$\hookrightarrow p K^{-} \pi^{+}$$

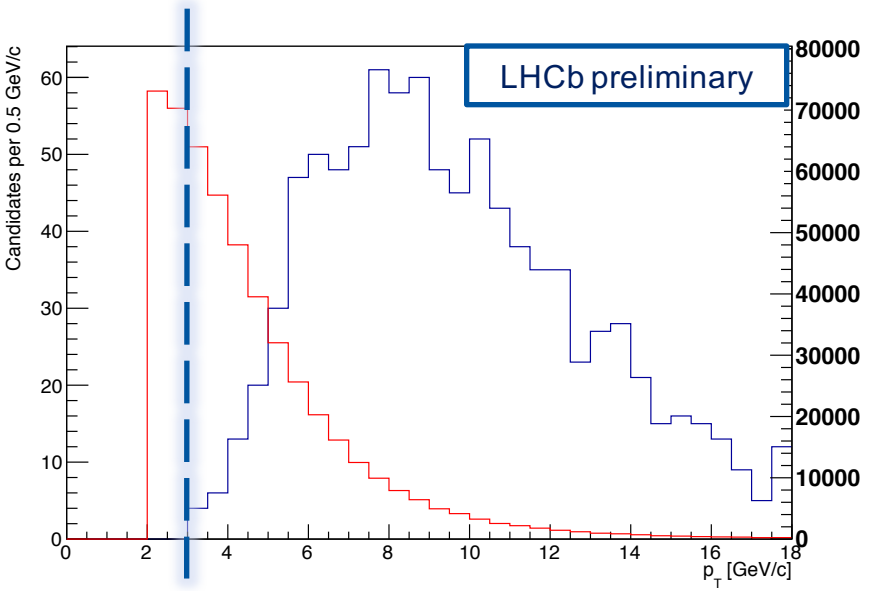
Generator level cuts of $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$

- Generator level cuts are determined by comparing the distributions of generator level candidates with that of reconstructed candidates.
  - Red: truth value of generator level candidates
  - Blue: truth value of reconstructed candidates

Λ_c^{+} p_{T} Distribution



Ξ_{cc}^{+} p_{T} Distribution



Generator level cuts of $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$

- Cuts with discrimination power can be determined in a similar way.

Generator level cuts to be applied in the new MC sample generation

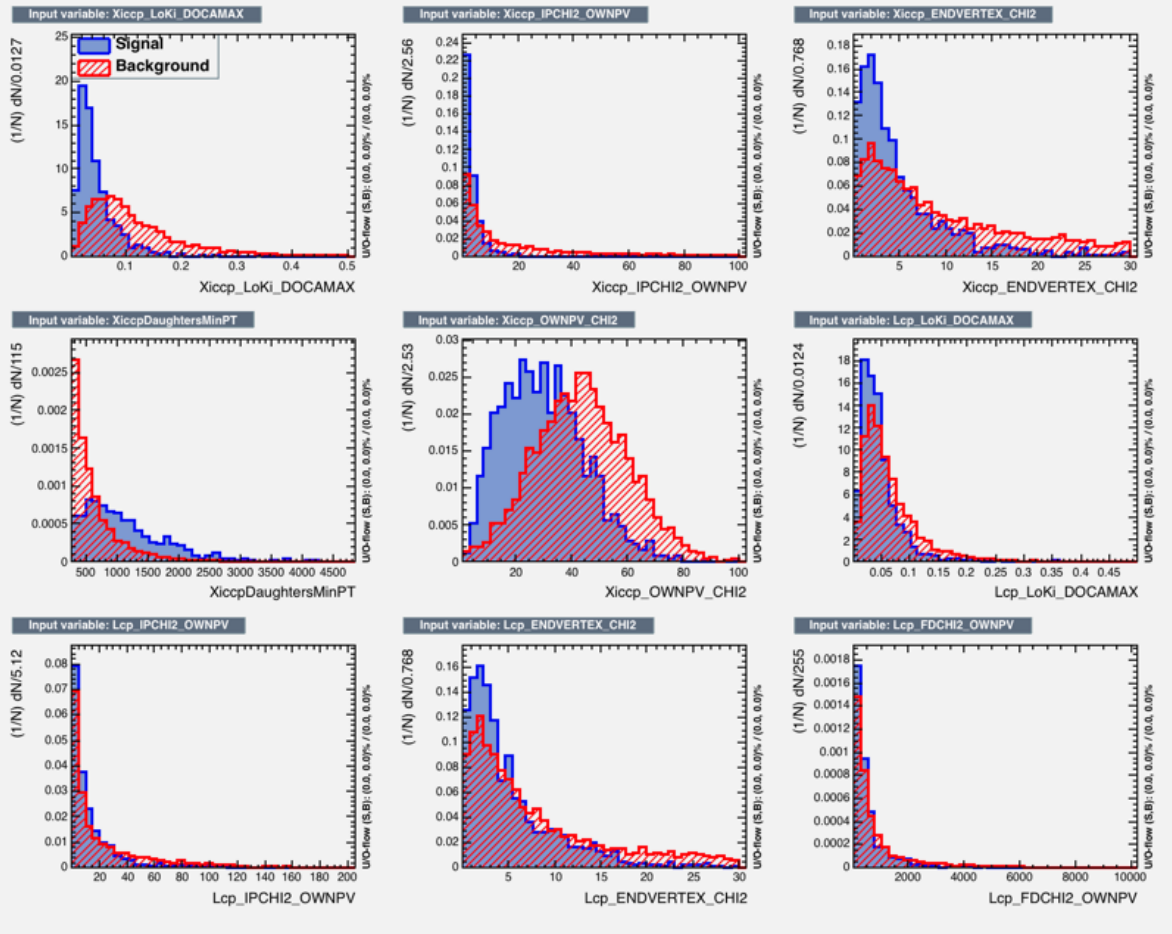
Λ_c^+	p_{T}	$\geq$ 2 GeV/c
	p	$\geq$ 20 GeV/c
	Flight distance	$\geq$ 1 mm
Ξ_{cc}^+	p_{T}	$\geq$ 3 GeV/c
	p	$\geq$ 30 GeV/c
K^- (from Ξ_{cc}^+)	p_{T}	≥ 0.2 GeV/c
π^+ (from Ξ_{cc}^+)	p_{T}	≥ 0.2 GeV/c
K^- (from Λ_c^+)	p_{T}	≥ 0.2 GeV/c
π^+ (from Λ_c^+)	p_{T}	≥ 0.2 GeV/c
Proton	p_{T}	≥ 0.2 GeV/c
Expected Efficiency		0.55%

Study of offline selection of $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$

- Preselection: relatively loose rectangular cuts to reduce background
- Multivariate analysis (MVA) is developed to further suppress background.
  - Signal sample: MC sample of size 1449 events, half for training and the other half for testing
  - Background sample: 2012 data reconstructed with wrong charge decay chain $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{-}$ of size 13559 events, which is a good description of combinatorial background distribution. Half sample are used for training and the other half for testing.

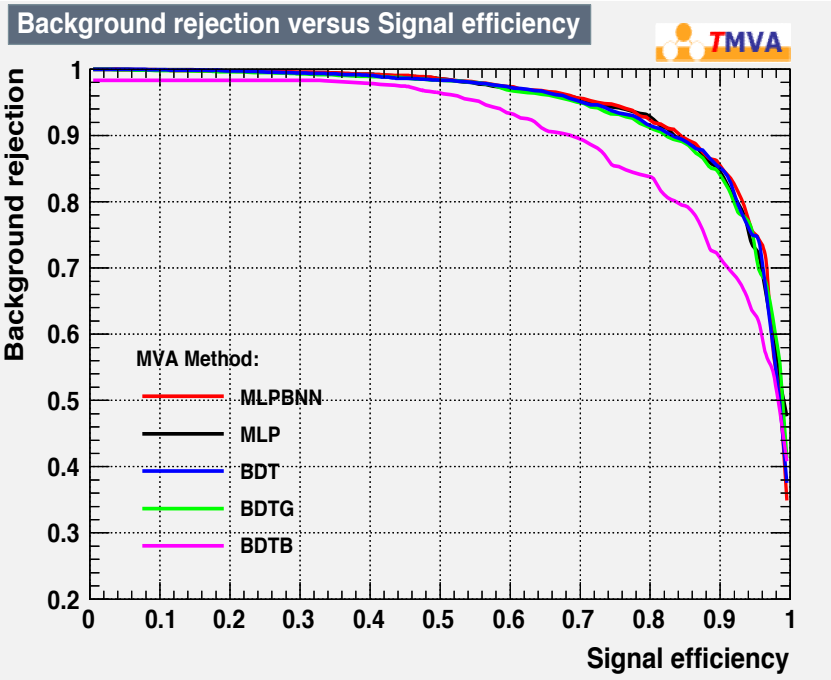
Input variables of MVA for $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$

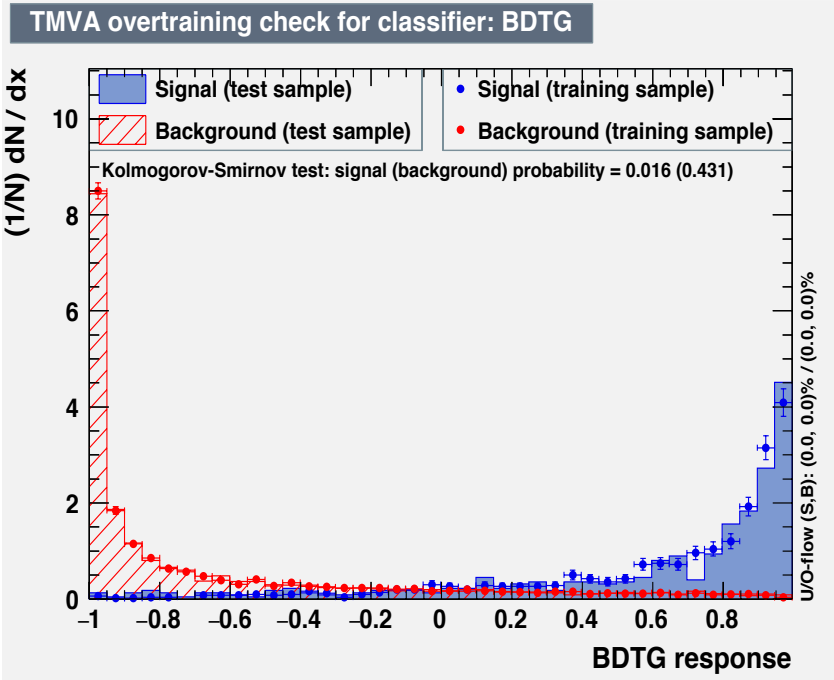
- Nine input variables are used, including kinematics variables of Ξ_{cc}^{+} and its daughters and the topological variables of the decay chain.



Output of MVA training and testing

- BDTG algorithm is adopted.
- Evident overtraining is observed possibly due to:
  - the small sample size
  - real overtraining which can be avoided by further algorithm configuration

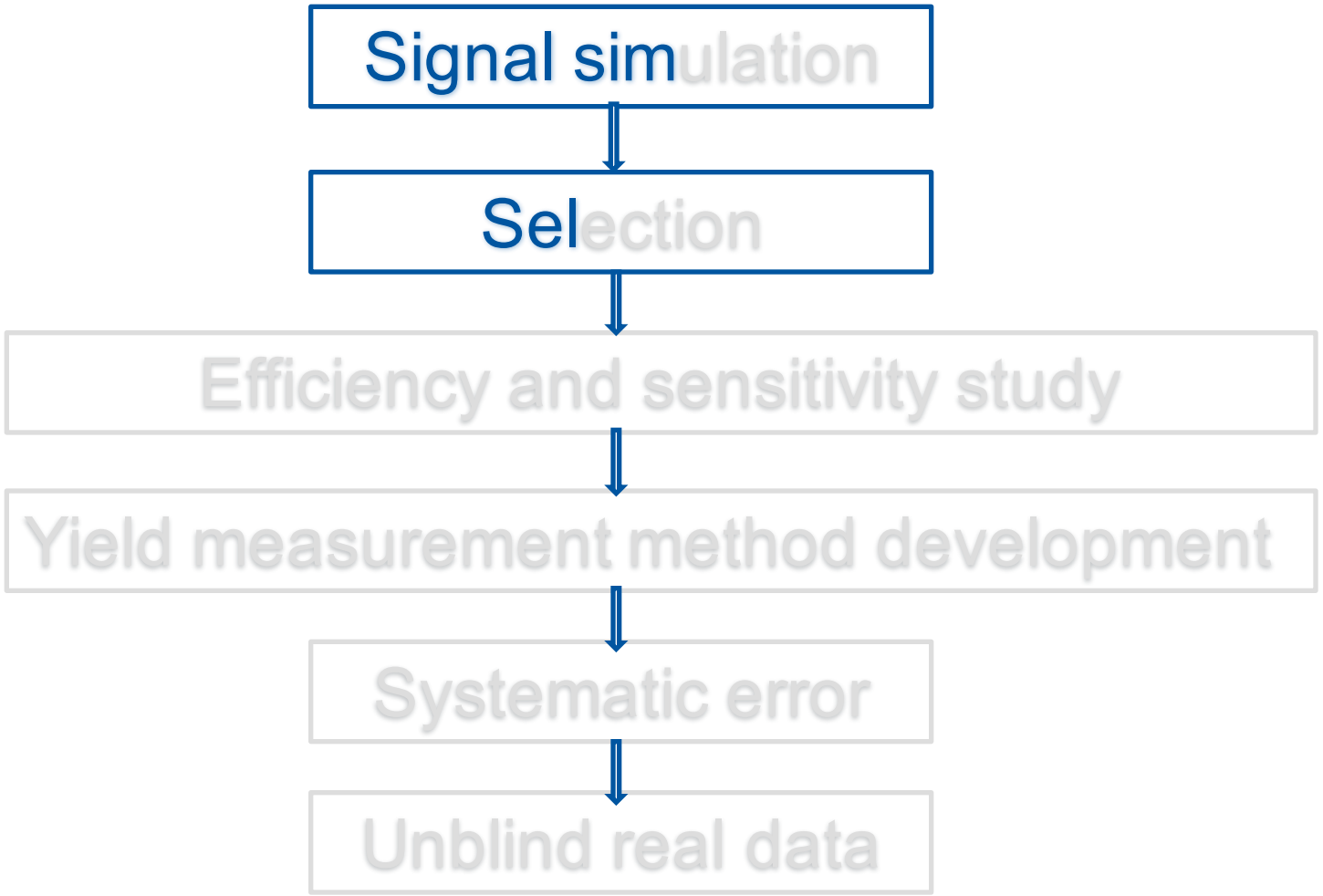




Plan

- Apply generator level cuts to new MC sample generation with GenXicc generator
- Conduct offline selections using new MC sample
- Determine optimal MVA cut by maximizing the sensitivity

Plan

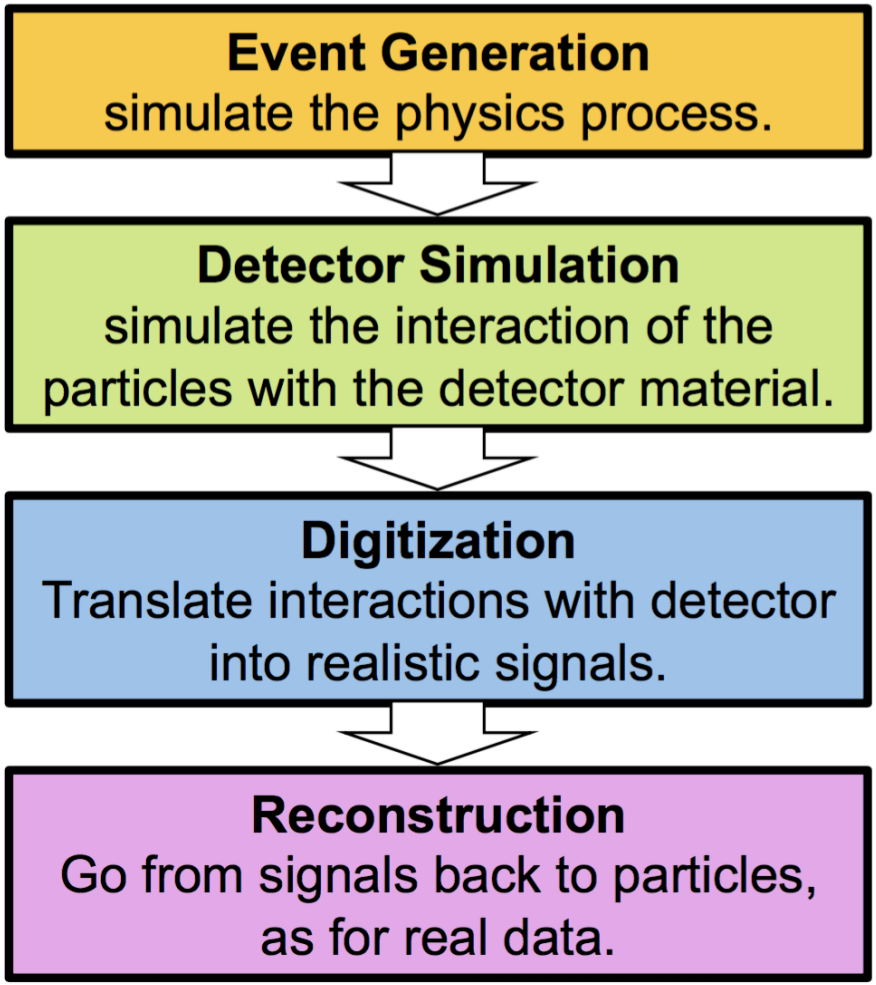

Signal simulation
Selection
Efficiency and sensitivity study
Yield measurement method development
Systematic error
Unblind real data

Acknowledgment

- My supervisors Yuanning Gao and Patrick Spradlin for patient instructions
- My colleagues Paul Soler, Murdo Traill and Zhenwei Yang for inspiring discussions
- The summer student program for an exciting summer

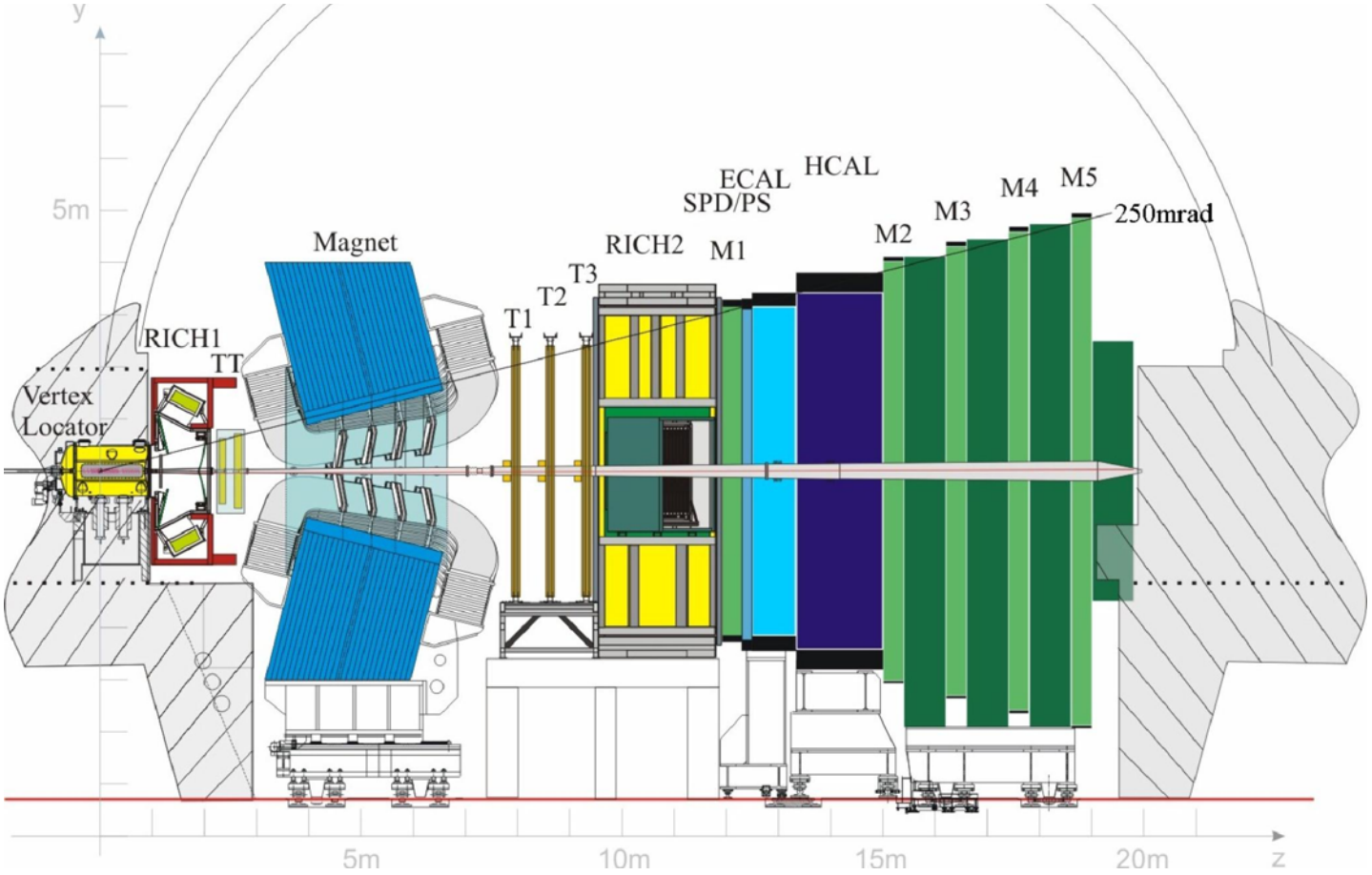
Back up

Monte Carlo production chain



LHCb detector

- A single-arm forward spectrometer



Generator level study of $\Xi_{cc}^{+} \to \Xi_{c}^{+}\pi^{+}\pi^{-}$

- Decay Chain
  - $\Xi_{cc}^{+} \to \Xi_{c}^{+}\pi^{+}\pi^{-}$
    $\hookrightarrow \Xi^{-}\pi^{+}\pi^{+}$
    $\hookrightarrow \Lambda^{0}\ \pi^{-}$
    $\hookrightarrow p\pi^{-}$

- MC sample: 571,447 events
- Five truth matched Ξ_{cc}^{+} and 30 truth matched Λ^{0}
- Inefficiency due to the long flight distance of Λ^{0}
- Not a promising decay mode

Information about MC and data sample

- MC sample for generator level study of $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$
  - Event Type: 26265012
  - 2012 MagDown sample with Sim08f and Reco14a
  - StrippingXiccPlusToLcKPi line of Stripping21
- MC sample for generator level study of $\Xi_{cc}^{+} \to \Xi_c^{+} \pi^{+} \pi^{-}$
  - Event Type: 26167110
  - 2012 MagDown sample with Sim08f and Reco14a
  - StrippingXiccXiccPlusToXicPlusPiPi line of Stripping21
- Data sample for MVA
  - Collision12, Beam4000GeV and Reco14
  - StrippingXiccXiccPlusToLcKPiWC line in Stripping21

MVA input variables definition

- Input variables
  - Ξ_{cc}^{+} MAXDOCA: Maximum distance of the closest approach between all possible pairs of daughters
  - Ξ_{cc}^{+} IP χ^2: Difference between the PV fit χ^2 with and without candidate included in the track set
  - Ξ_{cc}^{+} ENDVX χ^2: Decay vertex fit χ^2
  - Ξ_{cc}^{+} PV χ^2: Primary vertex fit χ^2
  - Ξ_{cc}^{+} minDaughtersPT: Minimum p_T of daughters
  - Λ_c^{+} MAXDOCA
  - Λ_c^{+} IP χ^2
  - Λ_c^{+} ENDVX χ^2
  - Λ_c^{+} FD χ^2: Difference between the PV fit χ^2 with and without candidate included in the track set