Measurement of Λ^0 EDM/MDM using LHCb data

Tianze Rong

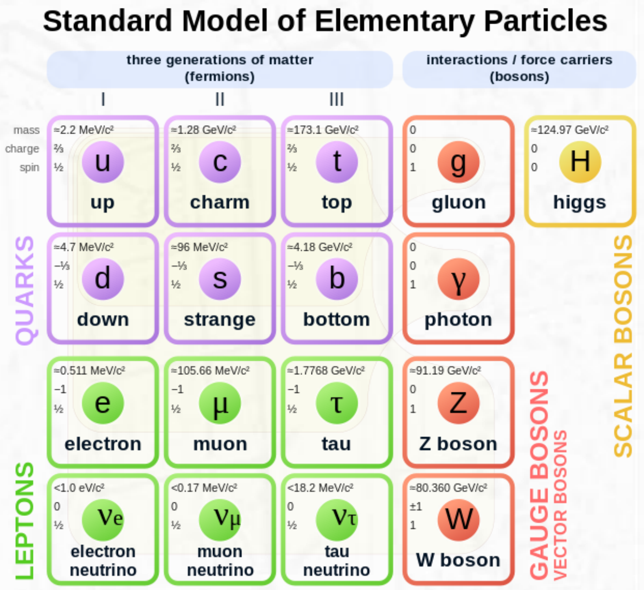
Supervisors: Nicola Neri, Mengzhen Wang

UNIVERSITÀ
DEGLI STUDI
DI MILANO

北京大學
PEKING UNIVERSITY

Introduction

- The Standard Model (SM) of particle physics is the theory of elementary particles and fundamental interactions



- Still some phenomena cannot be explained by the SM
  - ➢ e.g. matter–antimatter asymmetry

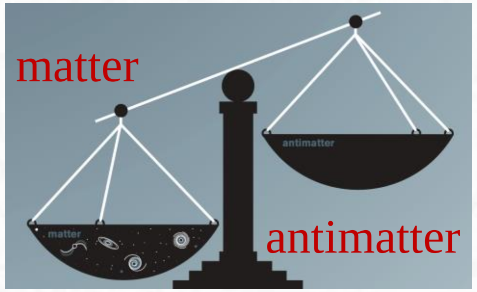
⇩

Calls for CP violation (CPV)

C: charge conjugation, P: parity

- CPV in SM is insufficient to account for the observed asymmetry
- Beyond-Standard Model sources are needed

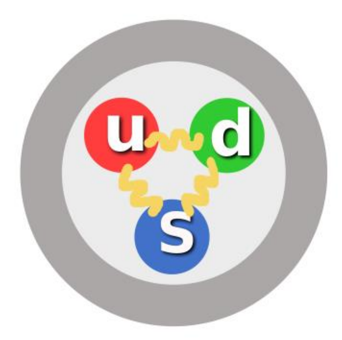
- Search for new sources of CP violation !



Λ^0 EDM/MDM

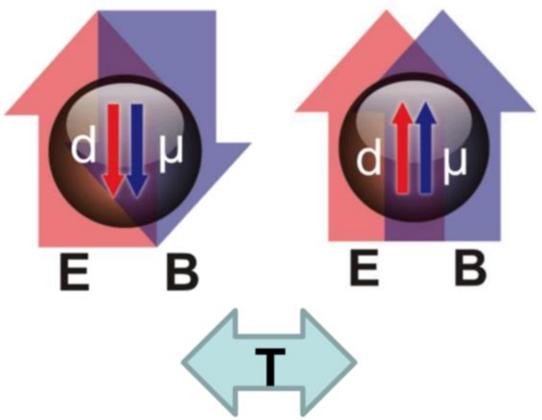
- Λ^0 is a long-lived baryon made of [u d s] quarks

The Λ^0 baryon



- EDM (δ): electric dipole moment
  - ➢Violates CP
  - ➢SM predict minuscule EDM $< 4.4 \times 10^{-26}$ e cm
    → sensitive to new sources of CPV and BSM physics

EDM breaks T symmetry



- MDM (μ): magnetic dipole moment
  - ➢Measurement of asymmetry in the MDM of Λ^0 and $\overline{\Lambda}^0$
    → test of CPT symmetry

- The latest measurements of Λ^0 EDM/MDM date back more than 40 years

It is time to revisit them !

World average result for Λ^0 EDM/MDM

Λ MAGNETIC MOMENT	$-0.613 \pm 0.004\ \mu_N$
Λ ELECTRIC DIPOLE MOMENT	$< 1.5 \times 10^{-16}$ e cm CL=95.0%

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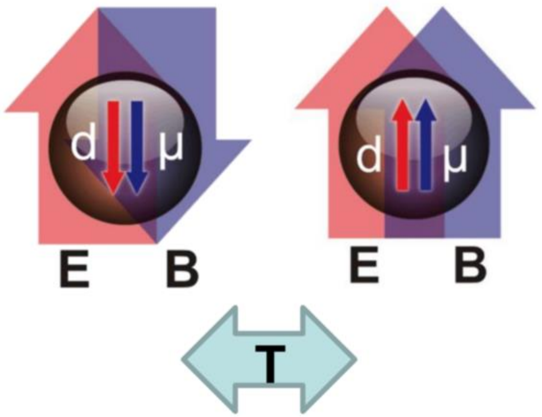
Try to push the boundary of experimental precision

Reduce the gap between theory & experiment

The Λ^0 baryon

EDM breaks T symmetry



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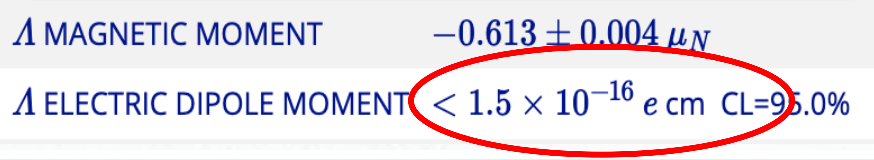

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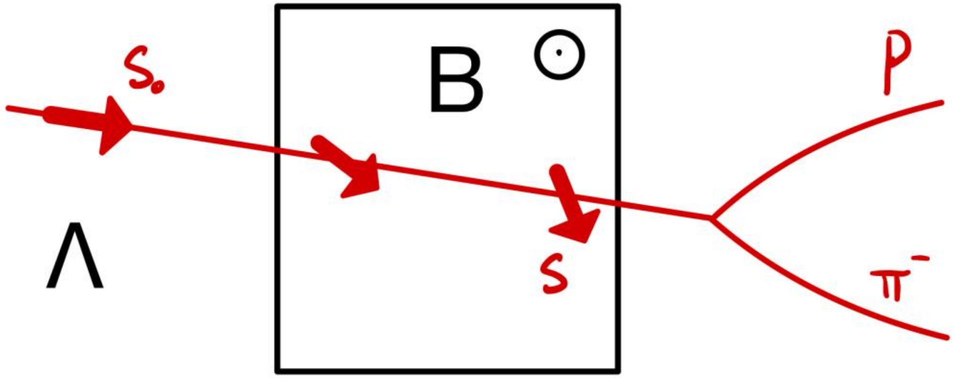
How to measure ?

- Λ^0 EDM/MDM measurement through spin polarization vector precession in the magnetic field

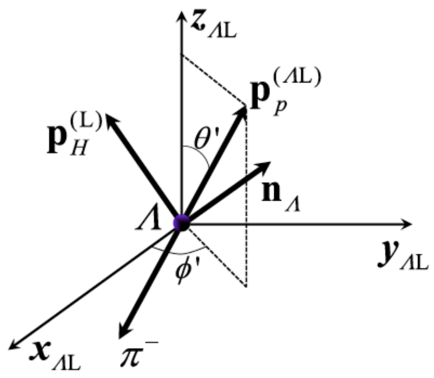


$$B = (0, B_y, 0)$$

$$\boldsymbol{s_0} = (0,0,S_0) \longrightarrow \boldsymbol{s_f} = \left(-S_0 \sin\Phi, -S_0 \frac{d\beta}{g} \sin\Phi, S_0 \cos\Phi\right), \Phi \approx \frac{g D_y \mu_B}{\beta \hbar c}$$

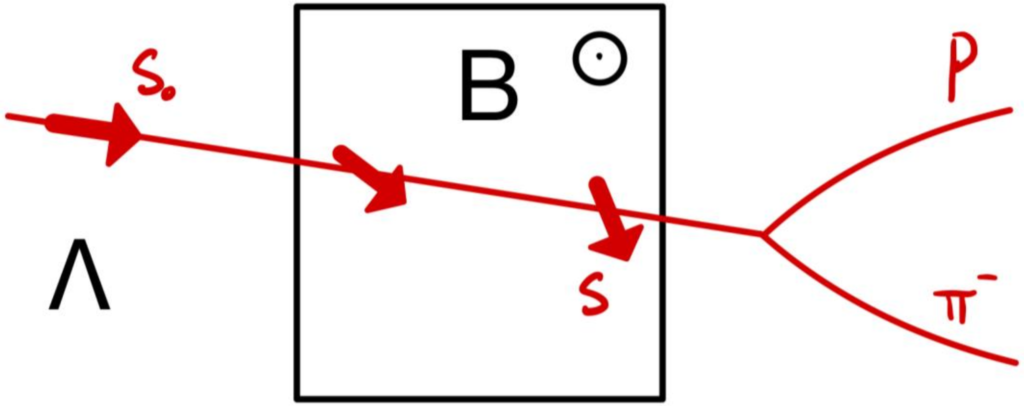
- Spin-polarization vector $\boldsymbol{s}$ can be analyzed through the angular distribution of the decay $\Lambda^0 \to p\,\pi^-$

$$\frac{\mathrm{d}N}{\mathrm{d}\Omega} = 1 + \alpha\, \boldsymbol{s} \cdot \boldsymbol{k}$$



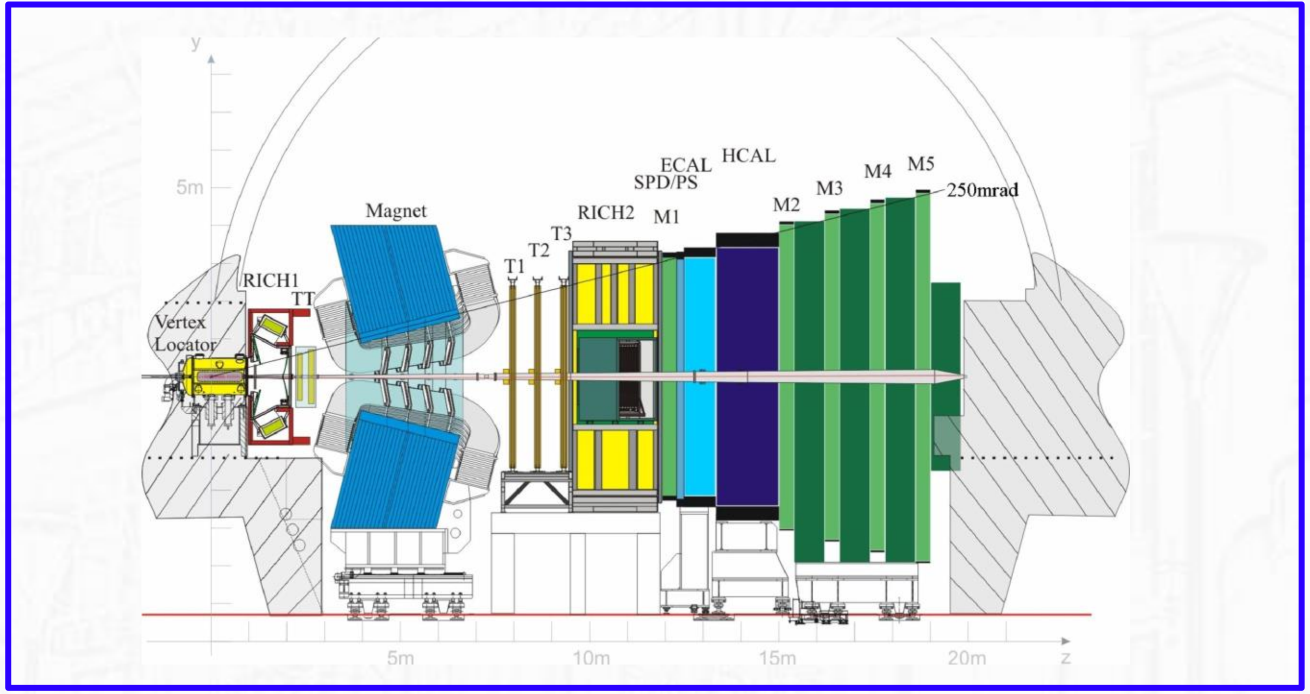
How to measure ? (cont.)

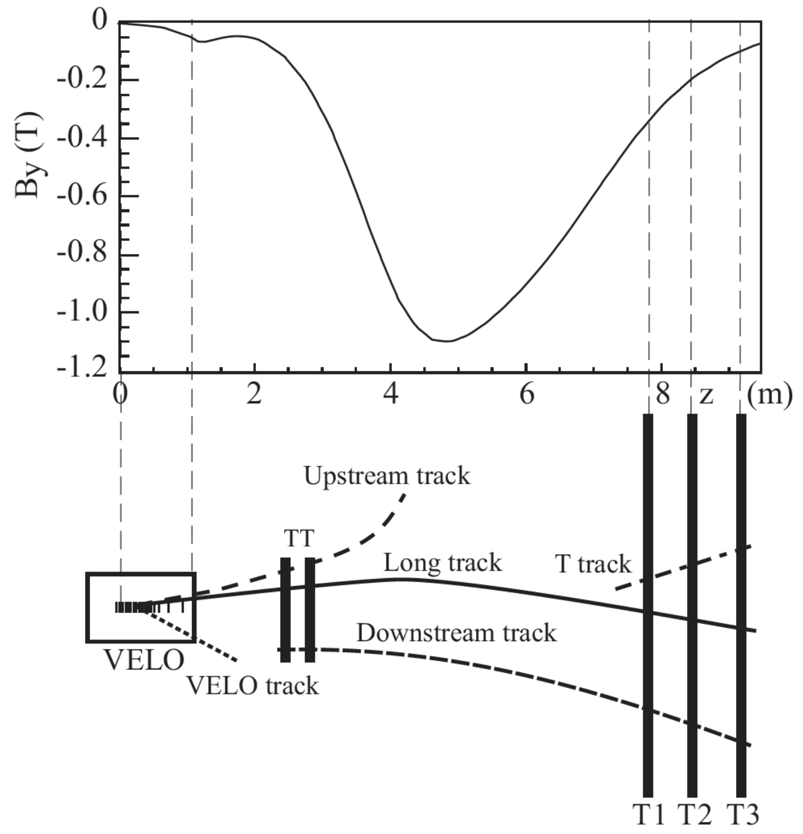
- The experimental setup to measure this effect relies on three main elements:
  - 1. a source of polarized Λ^0 whose direction and polarization degree are known
  - 2. an intense electromagnetic field able to induce a sizable spin precession angle during the lifetime of the particle
  - 3. the detector to measure the final polarization vector by analysing the angular distribution of the particle decays



Why LHCb ?

- Detector optimized for beauty & charm physics
  - ➢Λ^0 from beauty or charm decays: a clean & exclusive source





- A dipole magnet with a bending power of ~ 4 Tm
  - ➢Offers a sizable spin procession for Λ^0
- Tracking & particle identification available in the downstream area
  - ➢Possible to measure polarization of long-lived Λ^0

[See Lyv's talk for details]

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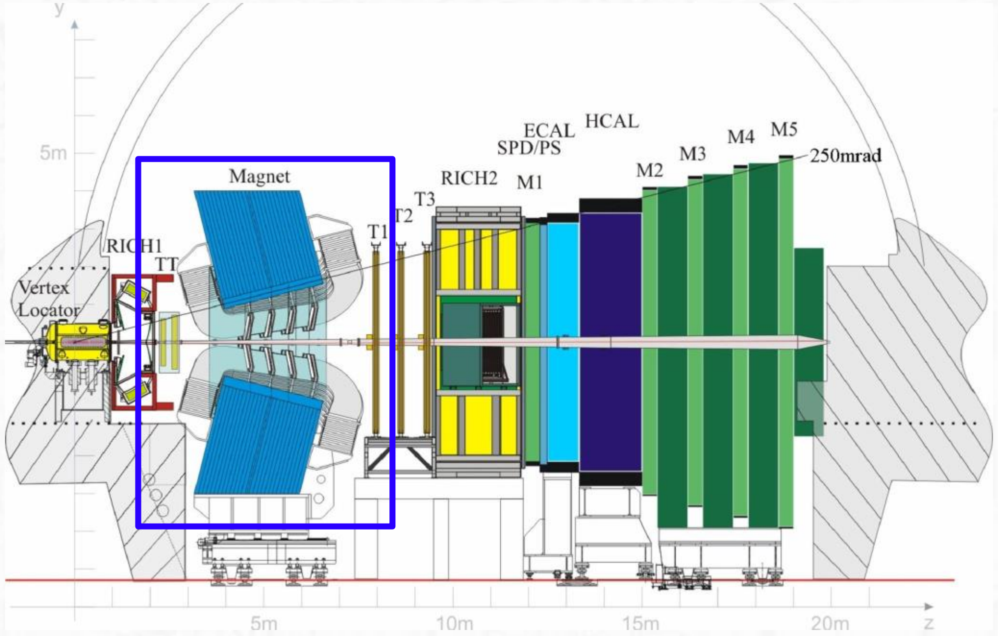

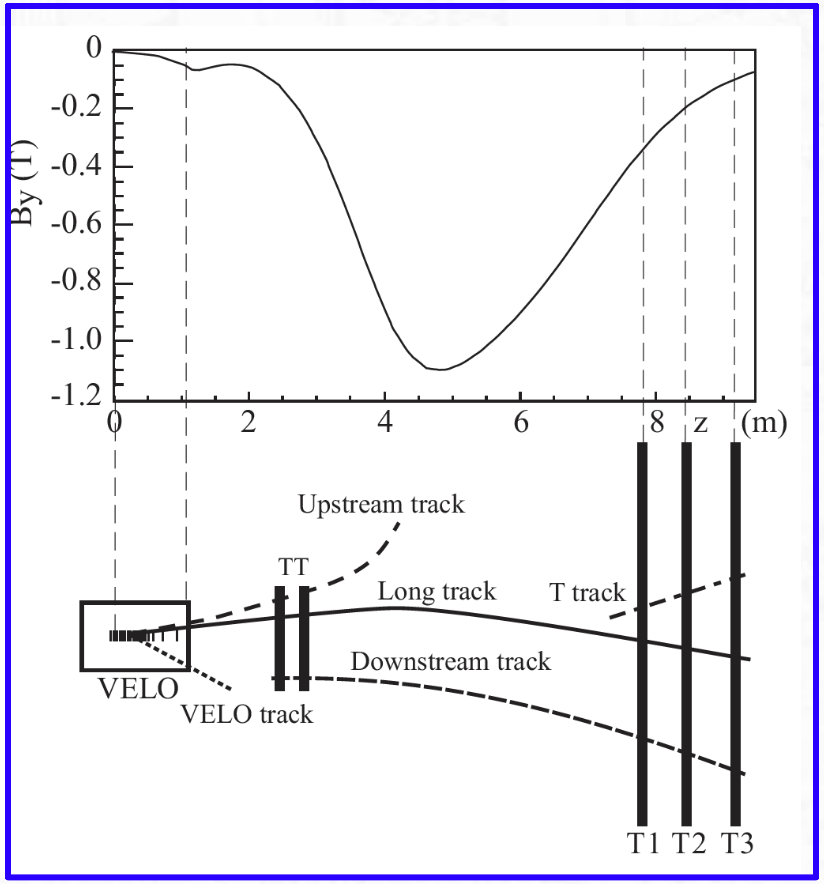

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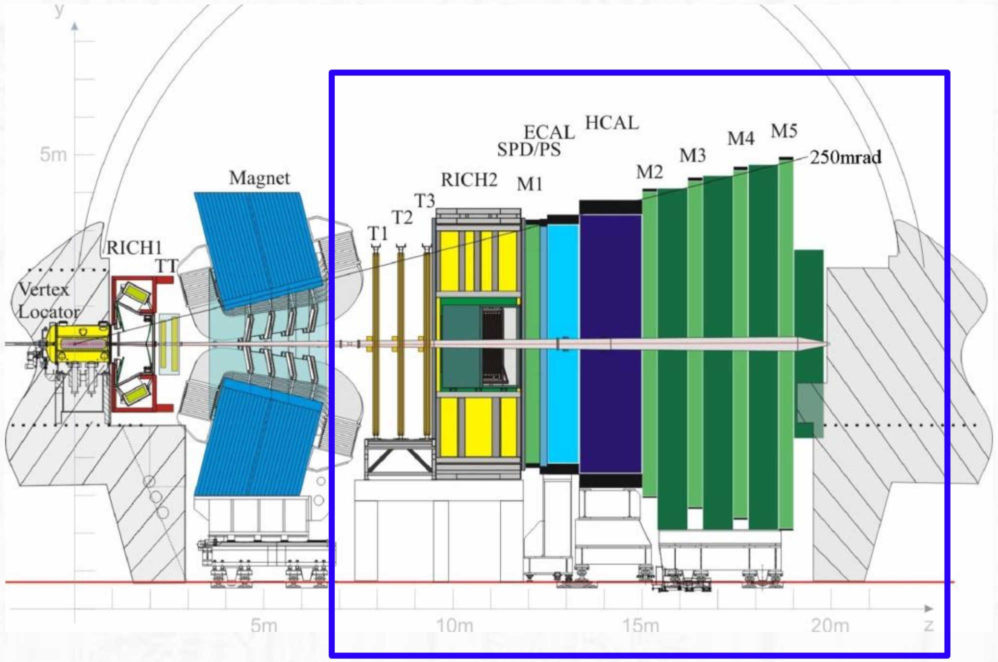

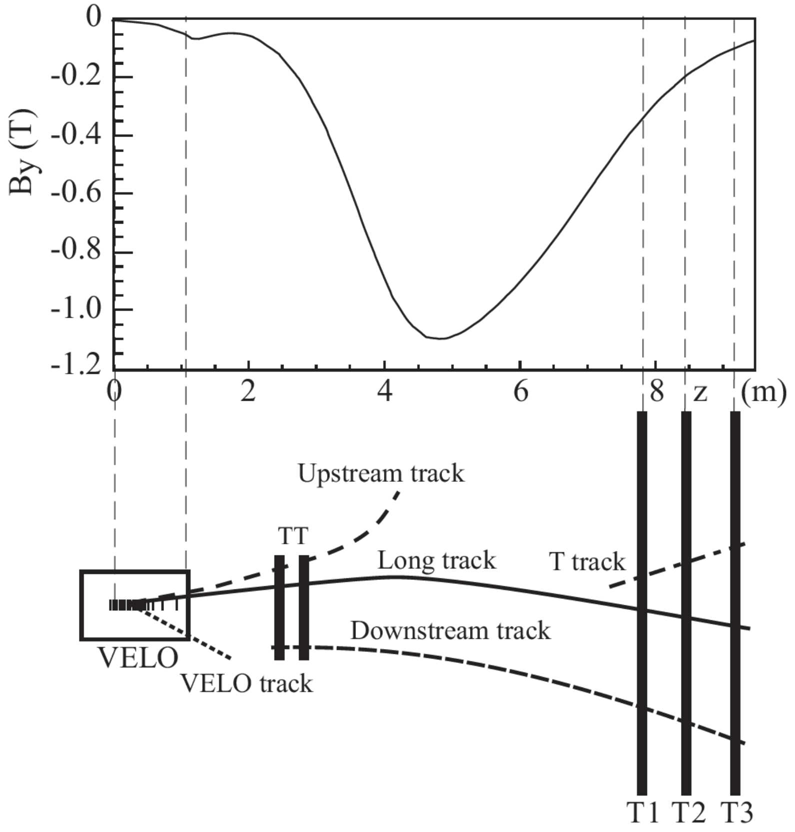

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Decay Channel

- $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^+ \pi^- \mu^- \bar{\nu}_\mu$

$\Lambda_b^0\ [u\ d\ b]$

  - ➢large branching fraction

    → expected to have larger yield than the golden channel

$$\Lambda_b^0 \rightarrow J/\Psi\ \Lambda^0$$

$$\frac{B(\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^+ \pi^- \mu^- \bar{\nu}_\mu)}{B(\Lambda_b^0 \rightarrow J/\Psi\ \Lambda^0)} \approx 10^2$$

- $\Lambda_c^+ \rightarrow \Lambda^0 \pi^+$

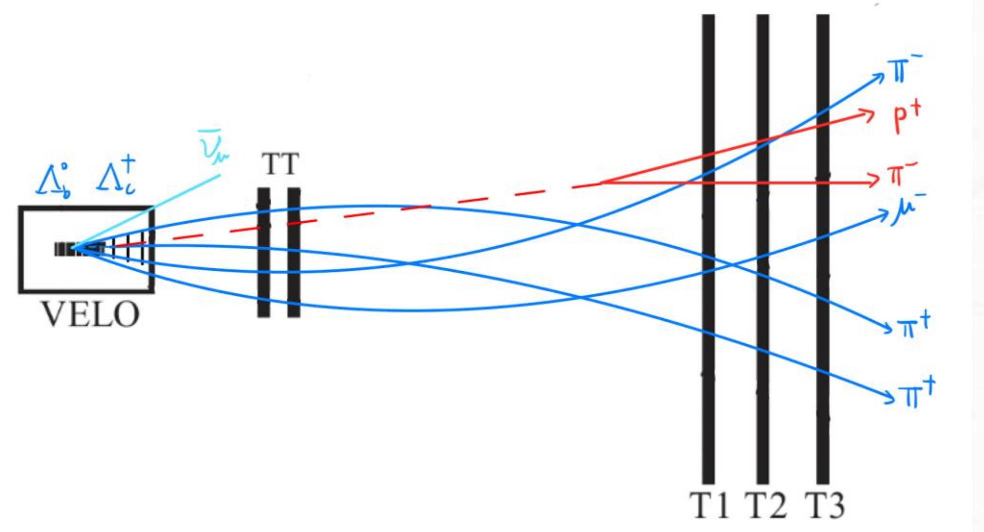
$\Lambda_c^+\ [u\ d\ c]$

  - ➢Decay asymmetry parameter of Λ_c^+ is -0.84 ± 0.09

    → Λ^0 produced with large longitudinal polarization

- $\Lambda^0 \rightarrow p^+ \pi^-$

  - ➢Reconstruct Λ^0 decaying after the LHCb magnet using T tracks



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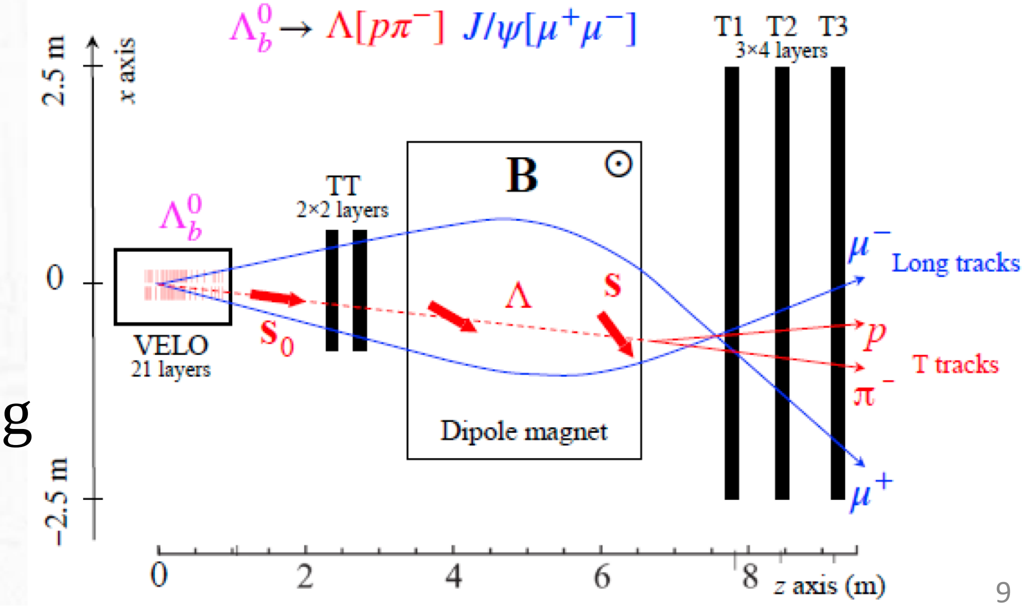


Reconstruction

- Full simulation MC samples are used to reconstruct the decay
- Reconstructed yields ratio estimation

From PDG

$$\frac{N(\Lambda_b^0 \to \Lambda_c^+ \, \pi^+ \, \pi^- \, \mu^- \, \bar{\nu}_\mu)}{N(\Lambda_b^0 \to J/\Psi \, \Lambda^0)} = \frac{B\left(\Lambda_b^0 \to \Lambda_c^+ \, \pi^+ \, \pi^- \, \mu^- \, \bar{\nu}_\mu\right) \times B(\Lambda_c^+ \to \Lambda^0 \, \pi^+)}{B(\Lambda_b^0 \to J/\Psi \, \Lambda^0) \times B(J/\Psi \to \mu^+\mu^-)}$$

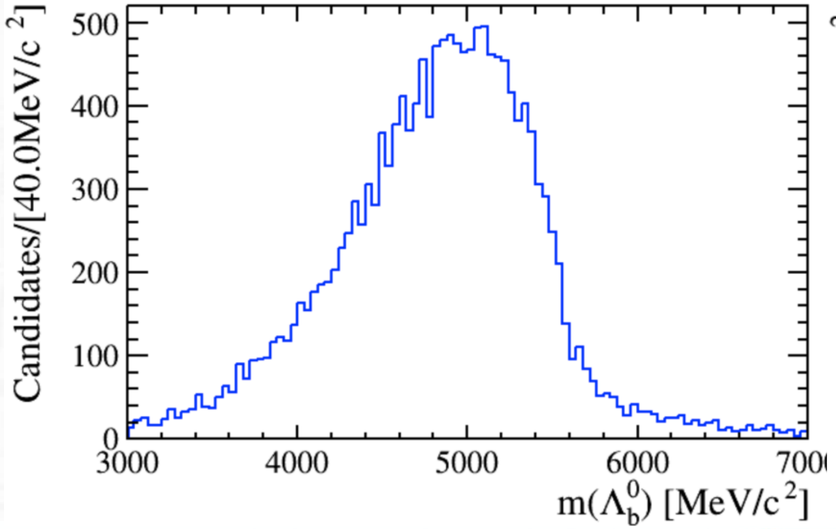
$$\times \frac{\varepsilon_{acc.\&rec.}(\Lambda_b^0 \to \Lambda_c^+ \, \pi^+ \, \pi^- \, \mu^- \, \bar{\nu}_\mu)}{\varepsilon_{acc.\&rec.}(\Lambda_b^0 \to J/\Psi \, \Lambda^0)}$$

2.2 ‰

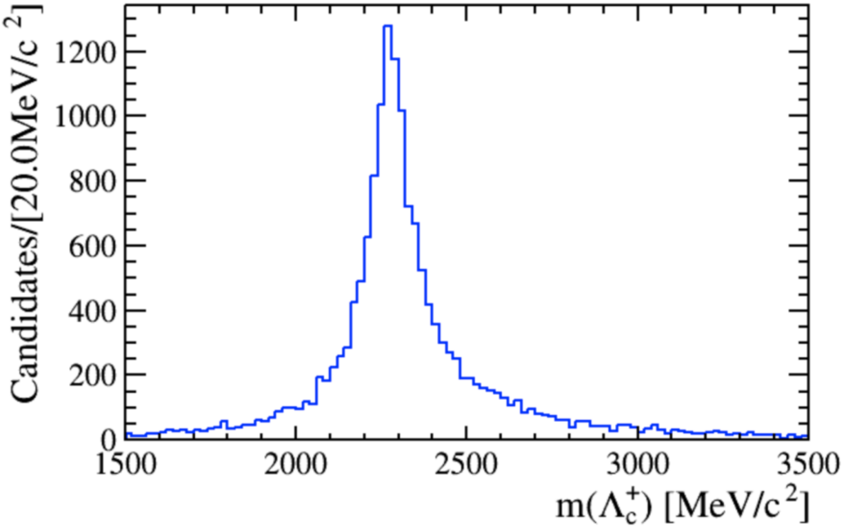
9.1 ‰

From simulation

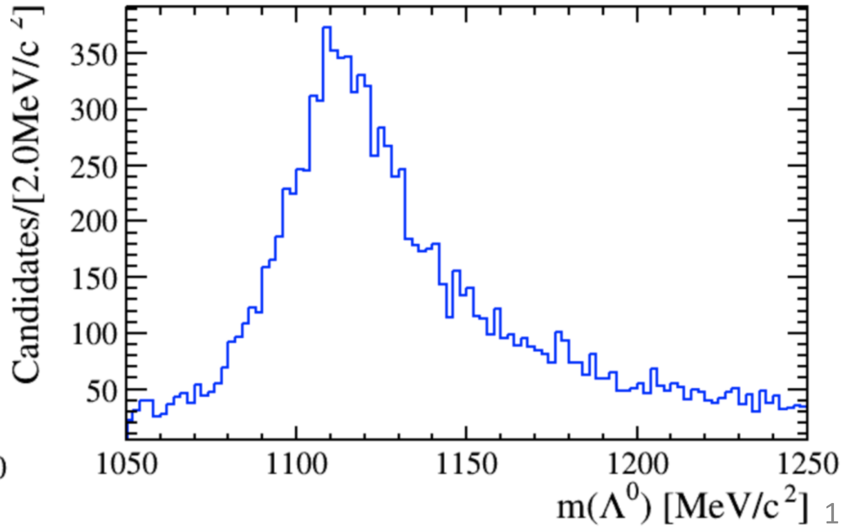
≈ 5.5



Λ_b^0 mass ($\bar{\nu}$ missing)



Λ_c^+ mass



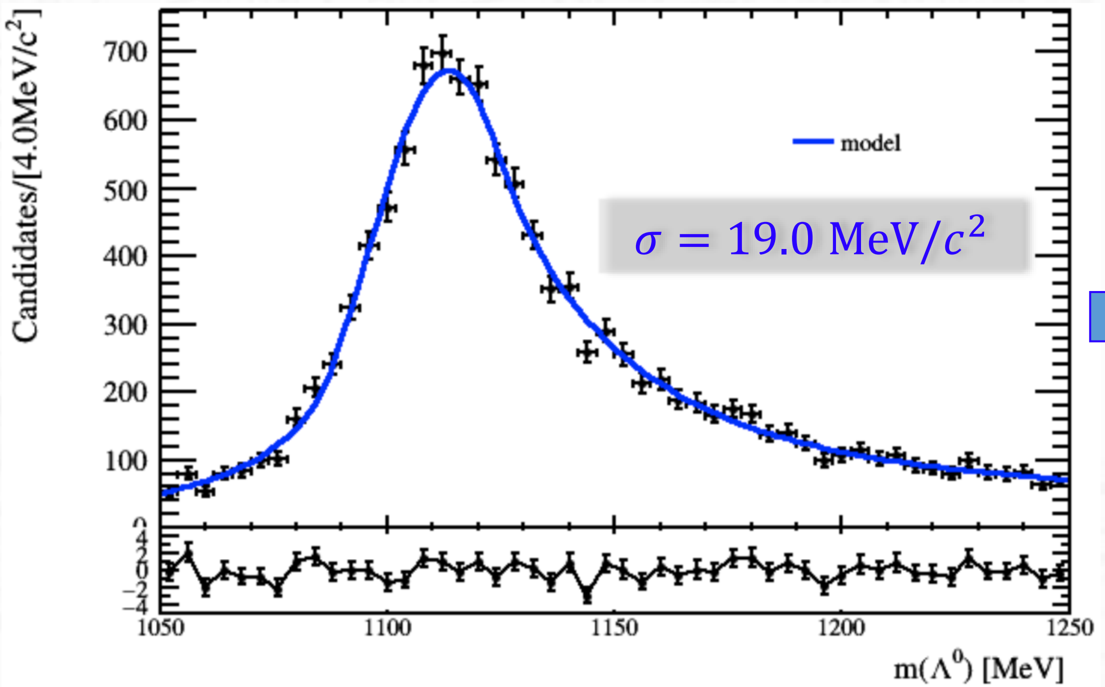
Λ^0 mass

Resolution Study

- With Decay Tree Fitter, a tool fitting a complete decay chain simultaneously, and applying constraint on Λ_c^+ mass, the resolution of Λ^0 mass improves a lot
- Λ^0 Mass resolution are comparable with that of the golden channel

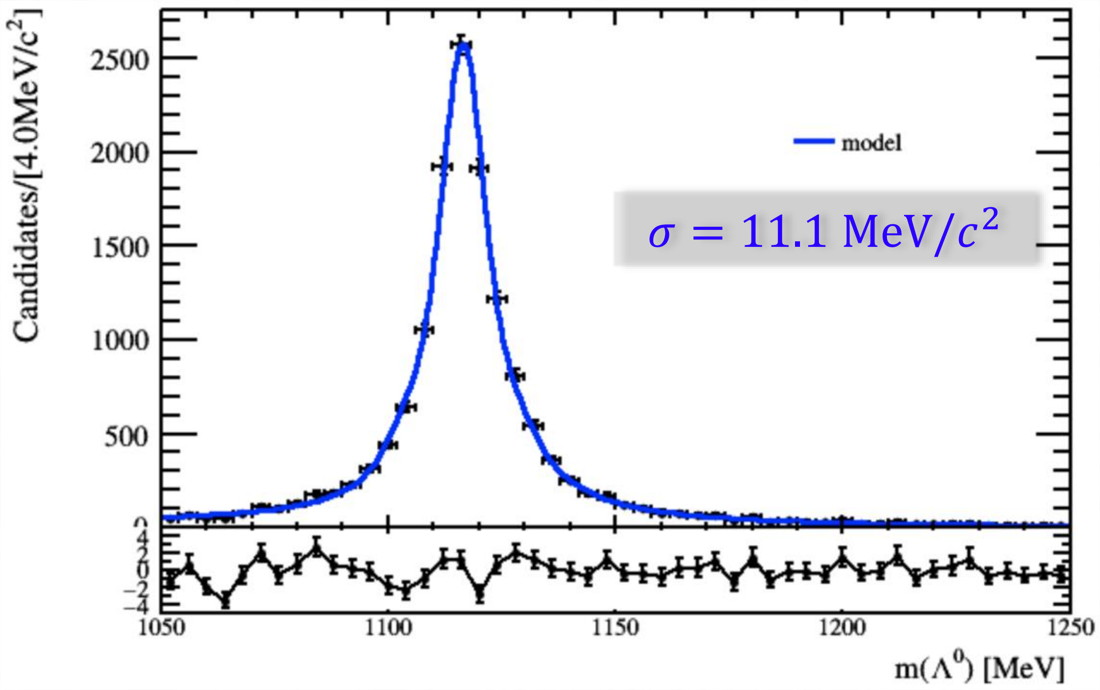
Fit model: DSCB + Gauss

Λ^0 mass without any constraint



$\sigma = 19.0\ \mathrm{MeV}/c^2$

Λ^0 mass with kinematic constraint



$\sigma = 11.1\ \mathrm{MeV}/c^2$

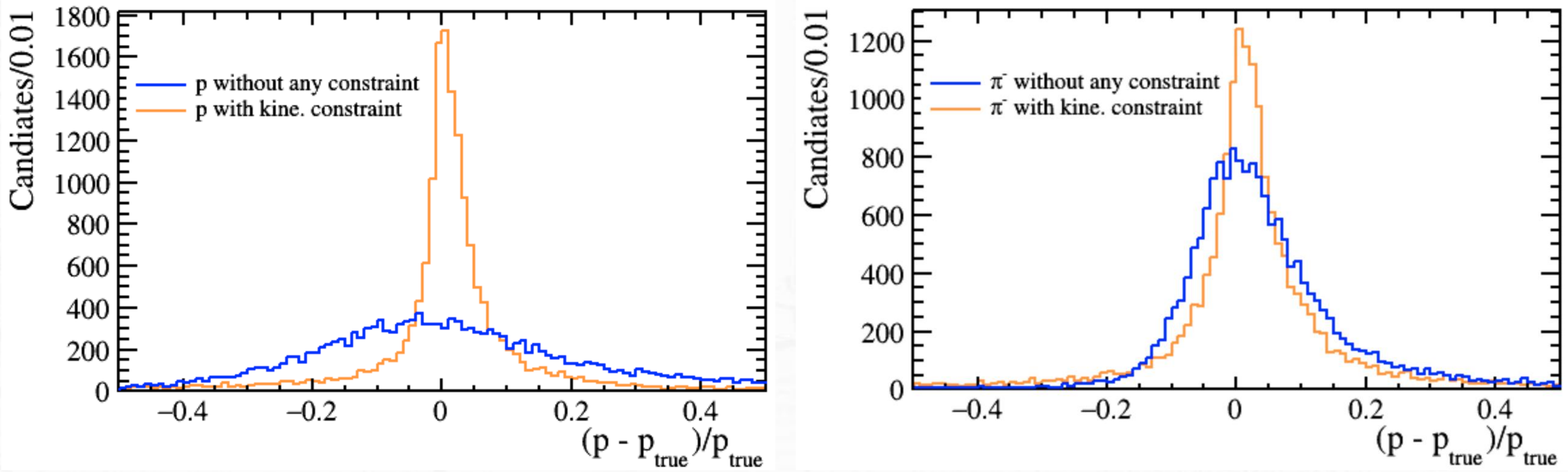
Resolution Study (cont.)

- With Decay Tree Fitter and Λ_c^+, Λ^0 mass constraints, the relative momentum resolutions of p^+ and π^- from Λ^0 decay improves to about 10%

$$\sigma(p) = \frac{p - p_{true}}{p_{true}}$$

p^+ momentum resolution

π^- momentum resolution



Summary

- Measurement of Λ^0 EDM/MDM plays a crucial role in precise test of SM

- For the decay channel $\Lambda_b^0 \to \Lambda_c^+ \pi^+ \pi^- \mu^- \bar{\nu}_\mu, \Lambda_c^+ \to \Lambda^0 \pi^+, \Lambda^0 \to p^+ \pi^-$, with Λ^0 reconstructed by t-tracks, we show that
  - A promising reconstruction efficiency at LHCb
  - Possible larger yield (× 5) than that of the current golden channel
  - Kinematic constraint improves mass and momentum resolution

Many Thanks!

- Further Studies
  - Resolution study of other variables: vertexing, angles …
  - Event selection strategy and efficiency estimation
  - Toy study of EDM/MDM sensitivity
  - …

Reference

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Backup

Golden Channel

- Golden channel
- $\Lambda_b^0 \to J/\Psi\ \Lambda^0,\quad J/\Psi \to \mu^+\mu^-$
  - ➢High reconstruction and selection efficiency due to dimuon
  - ➢Λ^0 produced with large longitudinal polarization ($\approx -100\%$)

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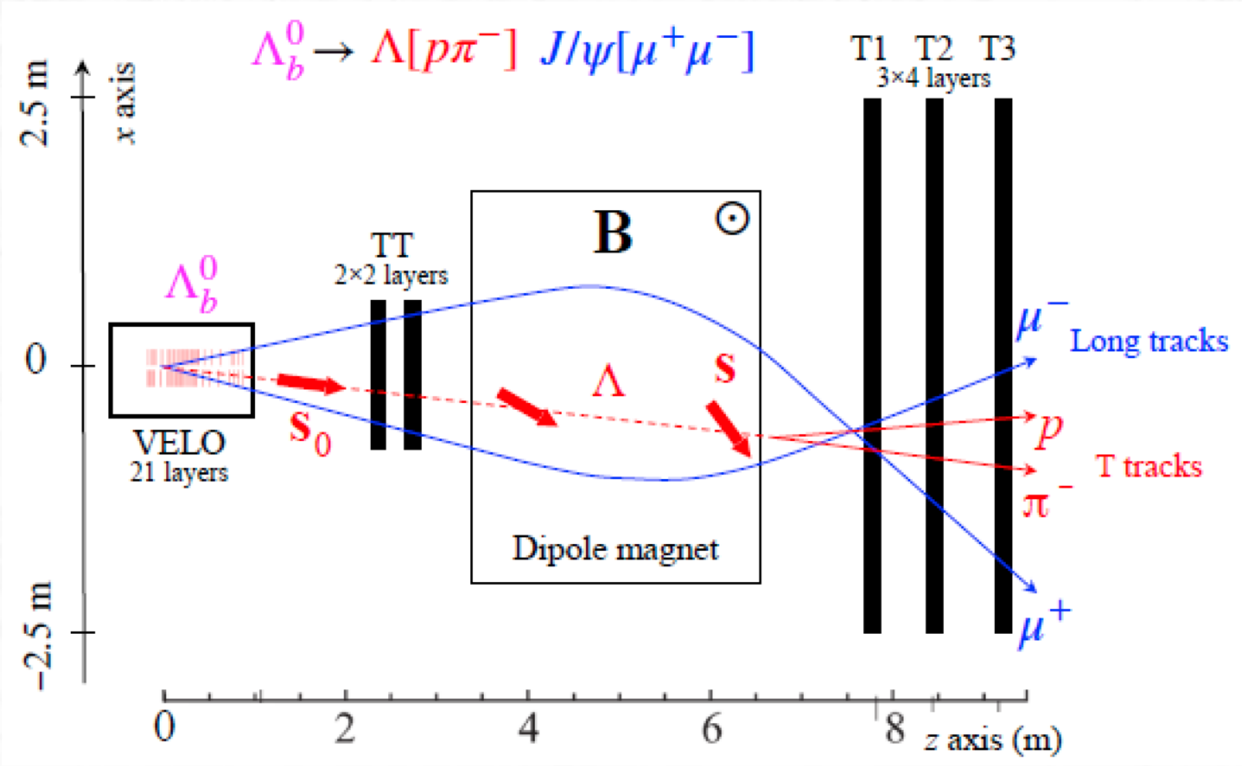

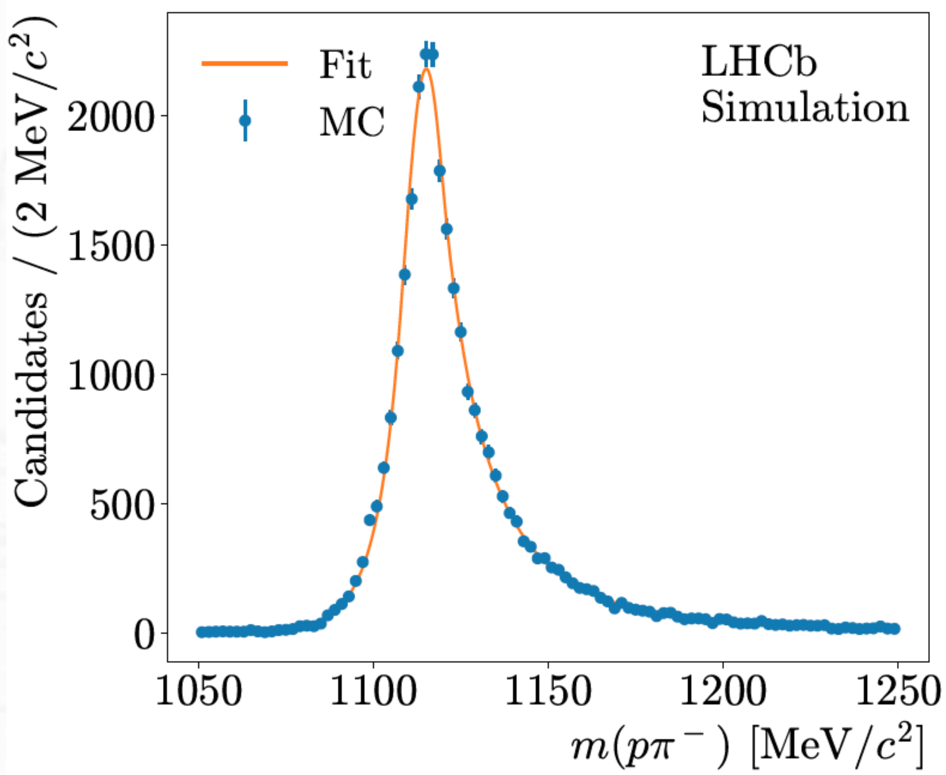

Branching fractions

- $\Lambda_b^0 \rightarrow \Lambda_c^+ \, \pi^+ \, \pi^- \, \mu^- \, \bar{\nu}_\mu, \Lambda_c^+ \rightarrow \Lambda^0 \, \pi^+$
- $B\left(\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^+ \pi^- l^- \, \bar{\nu}_l\right) = (5.6 \pm 3.1)\%$
- $B(\Lambda_c^+ \rightarrow \Lambda^0 \pi^+) = (1.29 \pm 0.05)\%$

- $\Lambda_b^0 \rightarrow J/\Psi \, \Lambda^0$
- $B\left(\Lambda_b^0 \rightarrow J/\Psi \, \Lambda^0\right) \times B(b \rightarrow \Lambda_b^0) = (5.8 \pm 0.8) \times 10^{-5}$
- $B(J/\Psi \rightarrow \mu^+ \mu^-) \; = (5.961 \pm 0.033)\%$

- $B\left(b \rightarrow \Lambda_b^0\right) \approx 0.259/(1 + 1 + 0.259 + 0.122)$

Reconstruction

- We try to reconstruct the decay

$$\Lambda_b^0 \rightarrow \Lambda_c^+ \, \pi^+ \, \pi^- \, \mu^- \, \bar{\nu}_\mu$$

- Full simulation MC samples are used

$$\Lambda_c^+ \rightarrow \Lambda^0 \, \pi^+$$

$$\Lambda^0 \rightarrow p^+ \, \pi^-$$

- ~180,000 events generated (requiring Λ^0 to decay after 2.7m)
- ~18,000 events reconstructed

Decay channel	$\Lambda_b^0 \rightarrow \Lambda_c^+ \, \pi^+ \, \pi^- \, \mu^- \, \bar{\nu}_\mu$, $\Lambda_c^+ \rightarrow \Lambda^0 \, \pi^+$	$\Lambda_b^0 \rightarrow J/\Psi \, \Lambda^0$
Generator level cut efficiency	3.0 %	19.8 %
Reconstruction efficiency	7.4 %	4.6 %