# Measurement of $\Lambda^0$ EDM/MDM using LHCb data

Tianze Rong

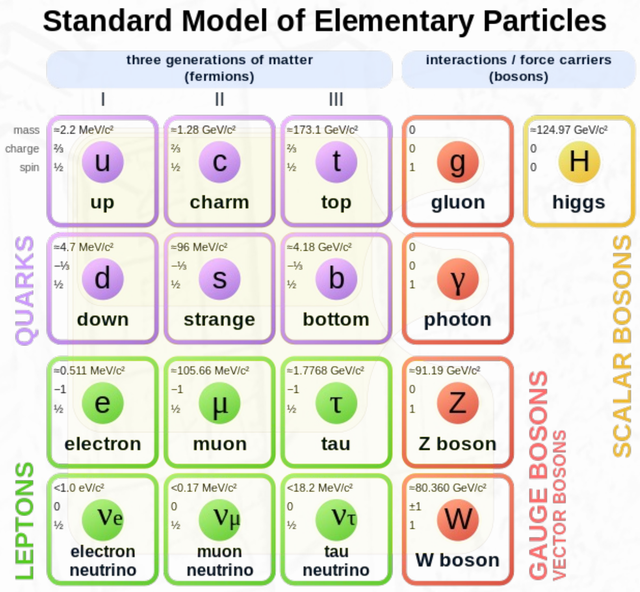
Supervisors: Nicola Neri, Mengzhen Wang

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

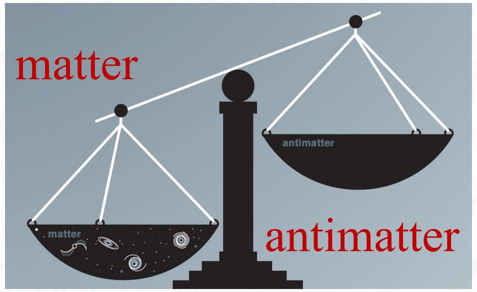
⇩

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

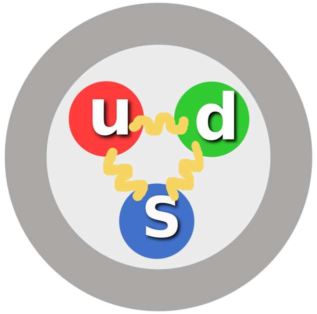
- Search for new sources of CP violation !



# $\Lambda^0$ EDM/MDM

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

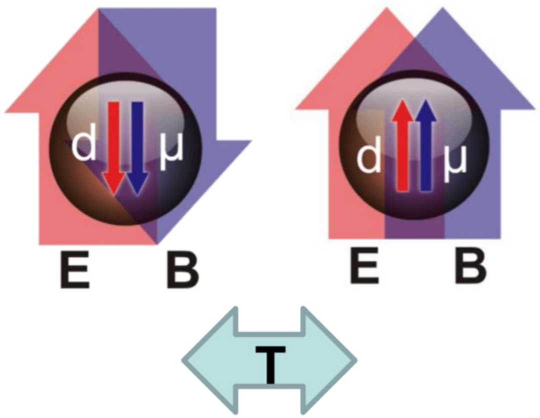
The $\Lambda^0$ baryon




- EDM ($\delta$): electric dipole moment
  - Violates CP
  - SM predict minuscule EDM $< 4.4\times10^{-26}$ e cm

  → sensitive to new sources of CPV and BSM physics

EDM breaks T symmetry




- MDM ($\mu$): magnetic dipole moment
  - Measurement of asymmetry in the MDM of $\Lambda^0$ and $\overline{\Lambda}^0$

  → test of CPT symmetry

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

It is time to revisit them !

World average result for $\Lambda^0$ EDM/MDM

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

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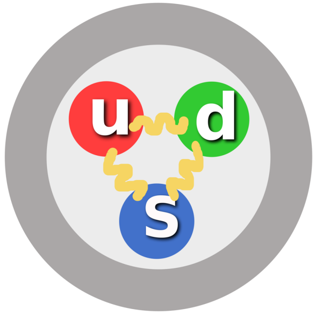
Try to push the boundary of experimental precision

Reduce the gap between theory & experiment

The $\Lambda^0$ baryon

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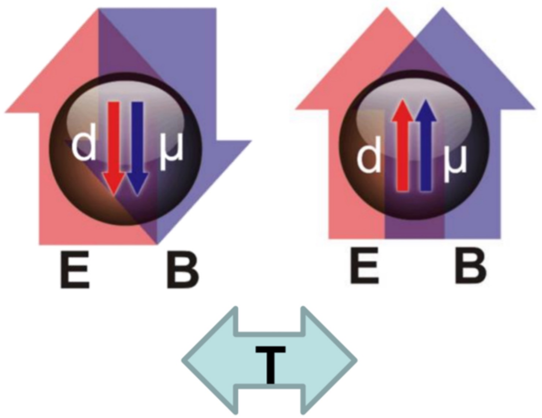


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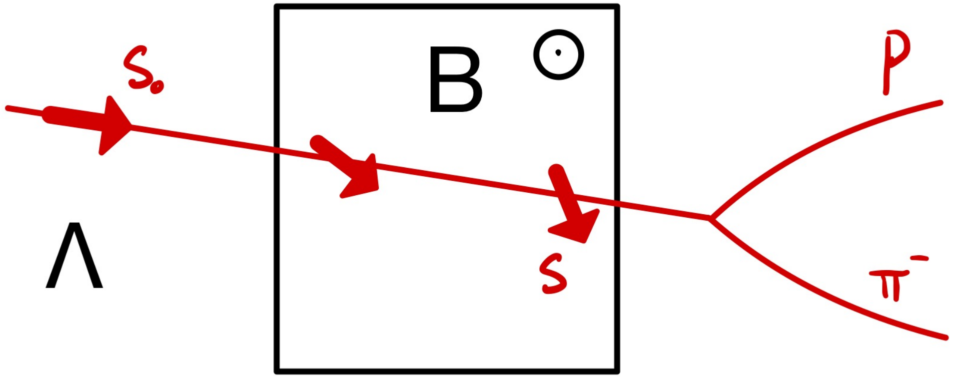
# How to measure ?

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

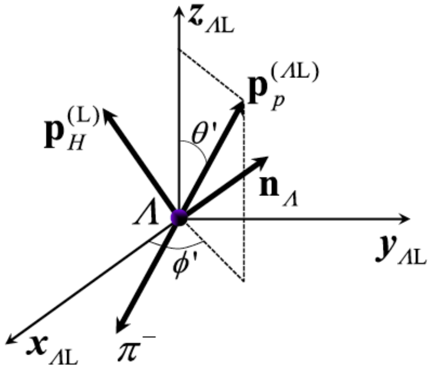



$B = (0, B_y, 0)$

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

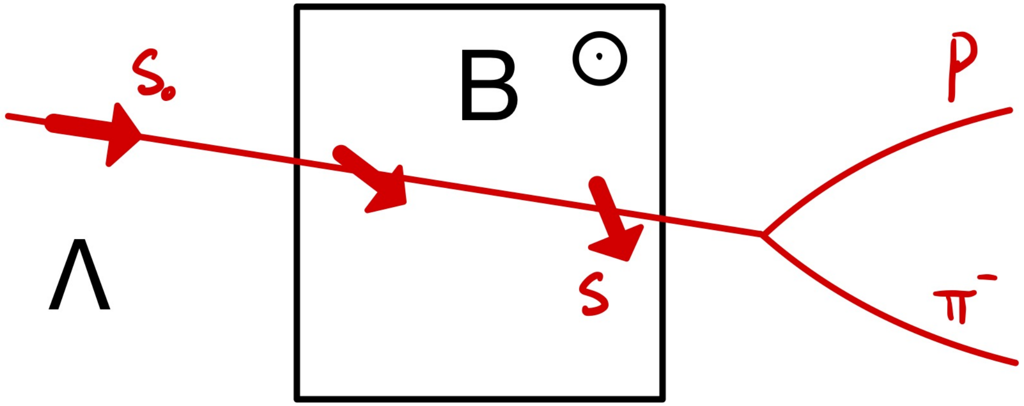
- Spin-polarization vector $\boldsymbol{s}$ can be analyzed through the angular distribution of the decay $\Lambda^0 \to p\,\pi^-$

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



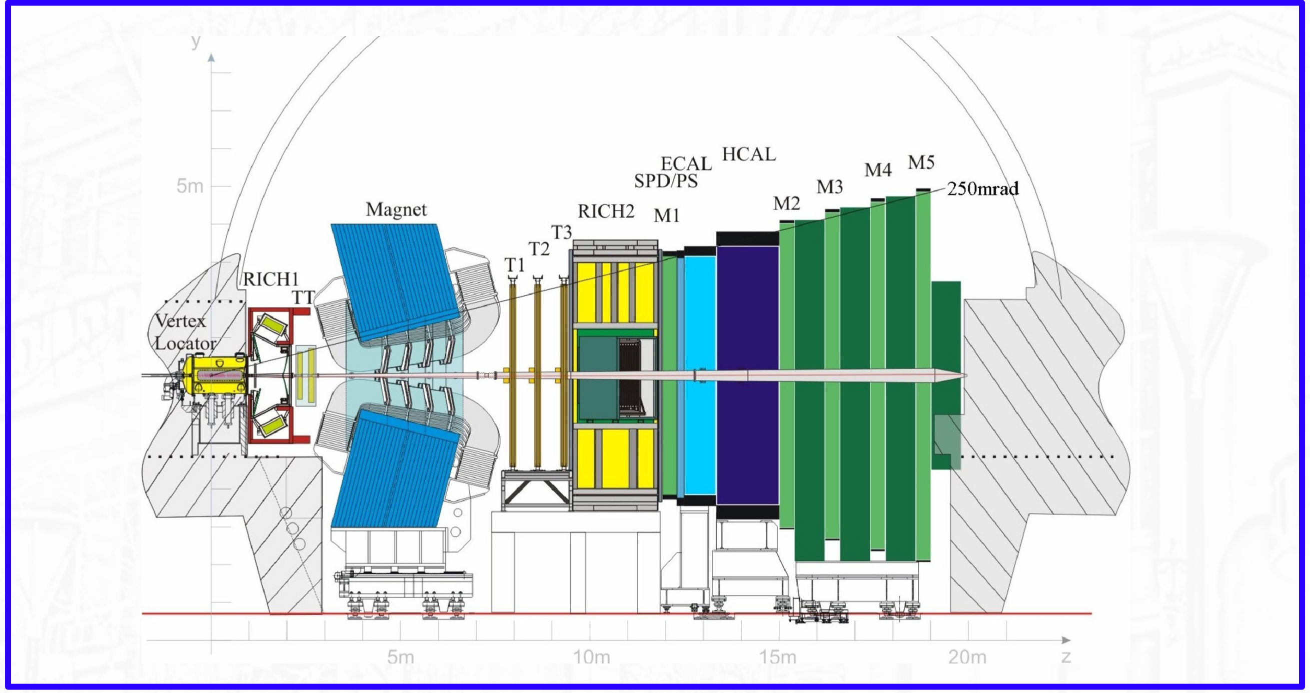
# How to measure ? (cont.)

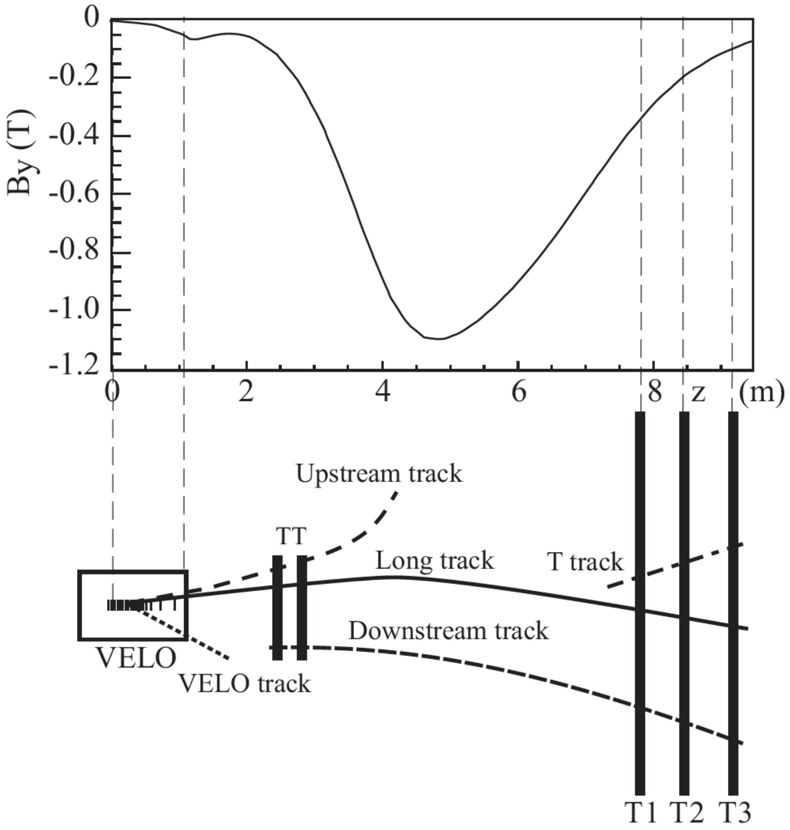
- The experimental setup to measure this effect relies on three main elements:
  - 1. a source of polarized $\Lambda^0$ whose direction and polarization degree are known
  - 2. an intense electromagnetic field able to induce a sizable spin precession angle during the lifetime of the particle
  - 3. the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



# Why LHCb ?

- Detector optimized for beauty & charm physics
  - ➢$\Lambda^0$ 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 $\Lambda^0$
- Tracking & particle identification available in the downstream area
  - ➢Possible to measure polarization of long-lived $\Lambda^0$

[See Lyv's talk for details]

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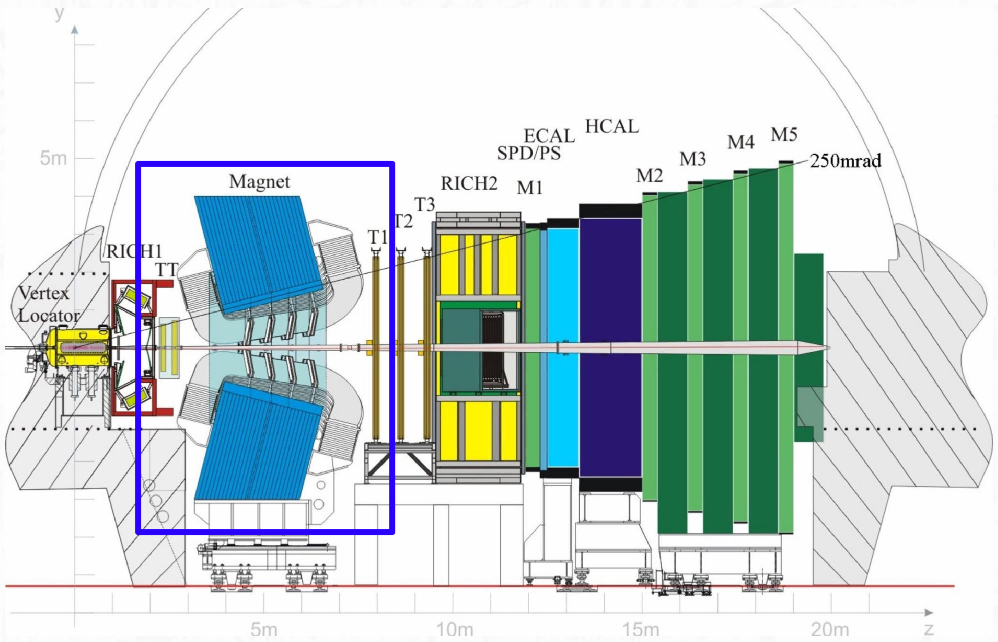


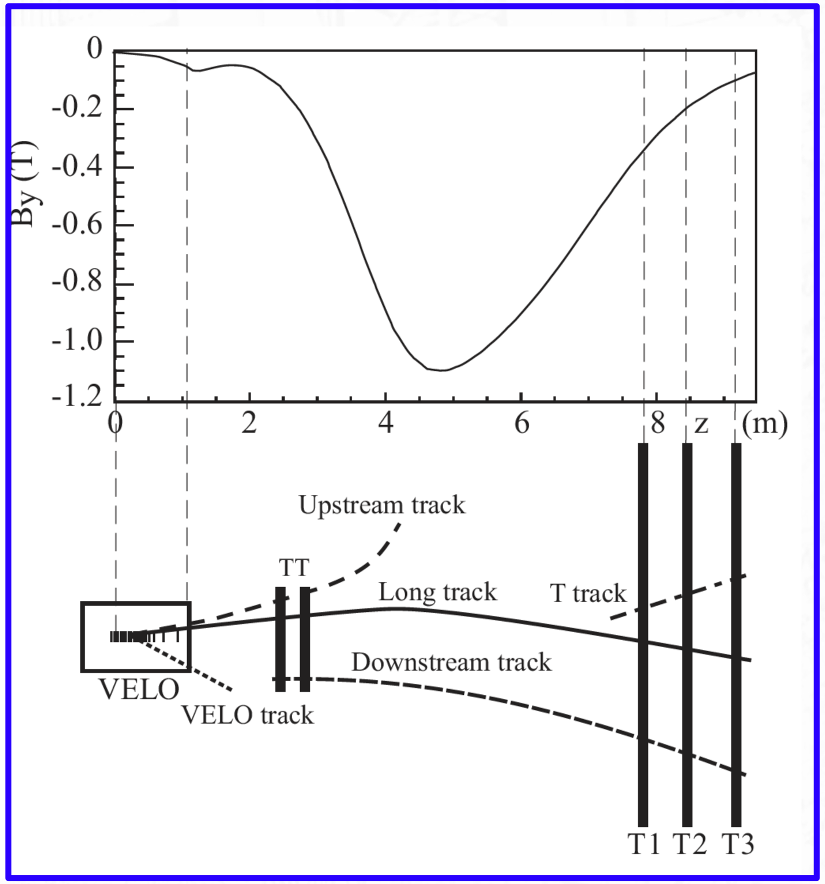


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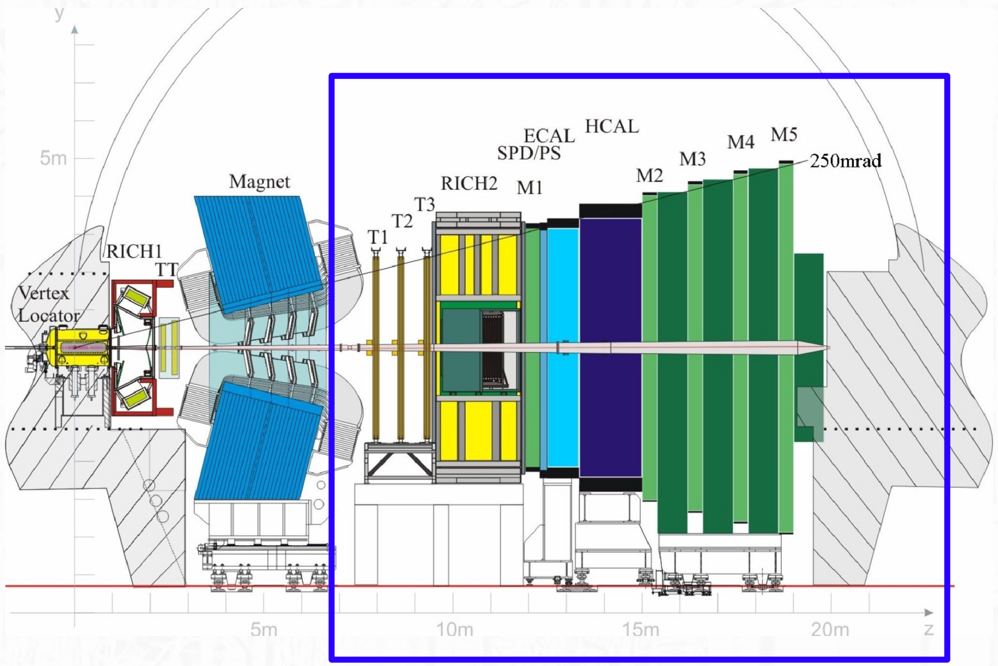


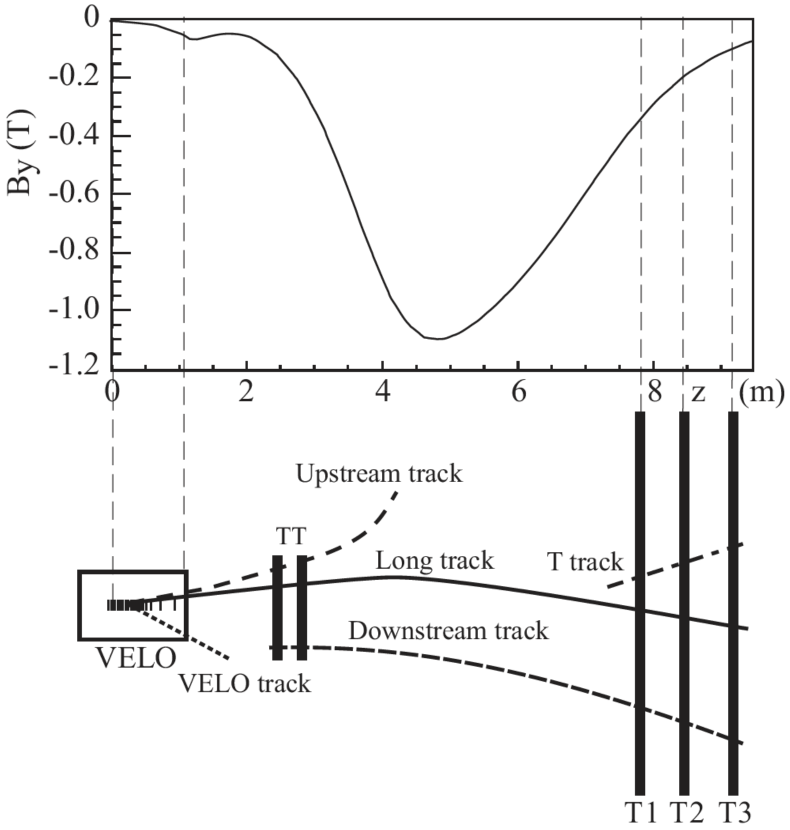


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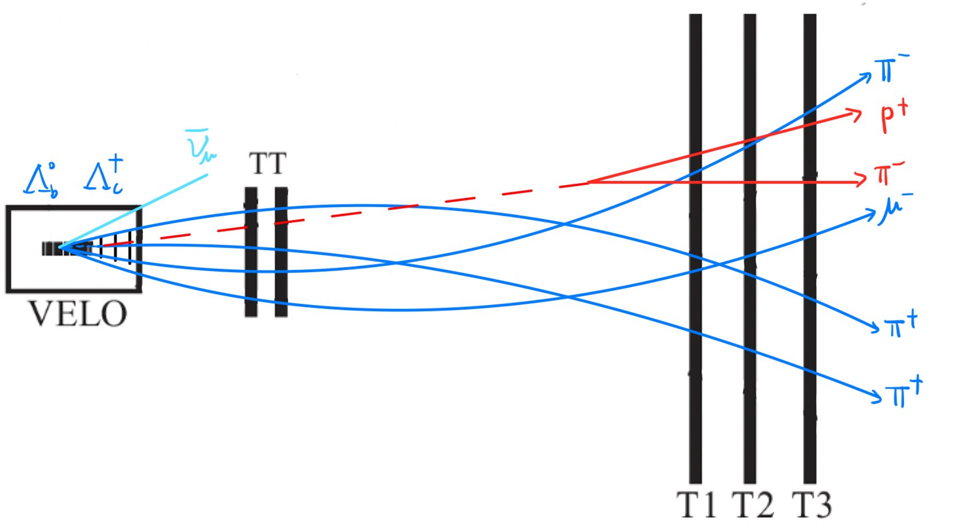
# Decay Channel

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

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

  - ➢ large branching fraction
  
    → expected to have larger yield than the golden channel
    
    $\Lambda_b^0 \to J/\Psi\ \Lambda^0$

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




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

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

  - ➢ Decay asymmetry parameter of $\Lambda_c^+$ is $-0.84 \pm 0.09$
  
    → $\Lambda^0$ produced with large longitudinal polarization

- $\Lambda^0 \to p^+\ \pi^-$
  - ➢ Reconstruct $\Lambda^0$ decaying after the LHCb magnet using T tracks

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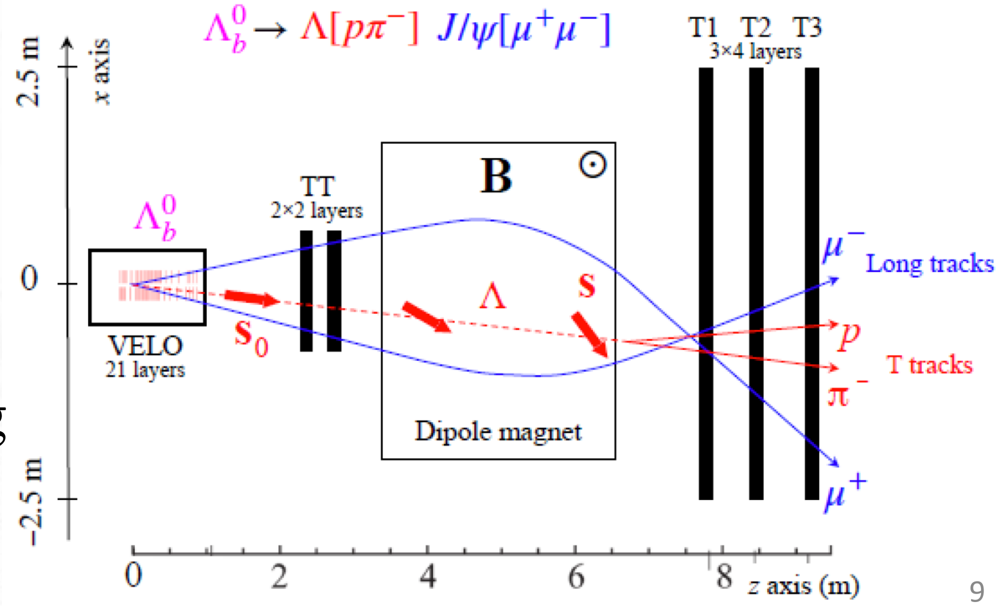


# Reconstruction

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

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

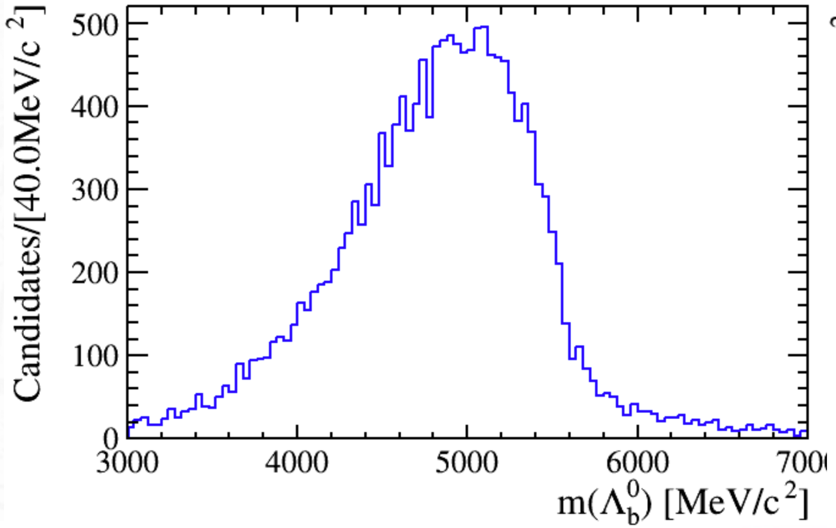
$$\times \frac{\varepsilon_{acc.\&rec.}(\Lambda_b^0 \to \Lambda_c^+ \pi^+ \pi^- \mu^- \bar{\nu}_\mu)}{\varepsilon_{acc.\&rec.}(\Lambda_b^0 \to J/\Psi\, \Lambda^0)}$$

$\approx 5.5$

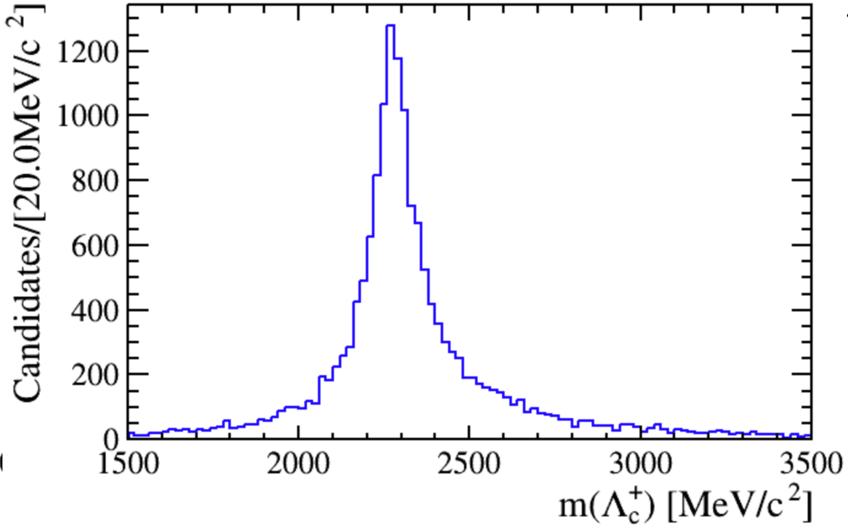
From PDG ($B(\Lambda_c^+ \to \Lambda^0 \pi^+)$)

From simulation: 2.2 ‰ (numerator efficiency), 9.1 ‰ (denominator efficiency)

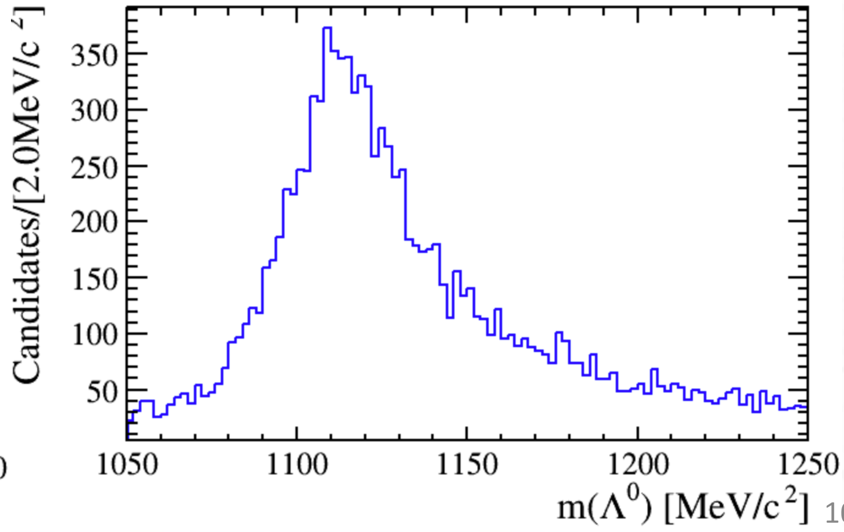
$\Lambda_b^0$ mass ( $\bar{\nu}$ missing )




$\Lambda_c^+$ mass




$\Lambda^0$ mass

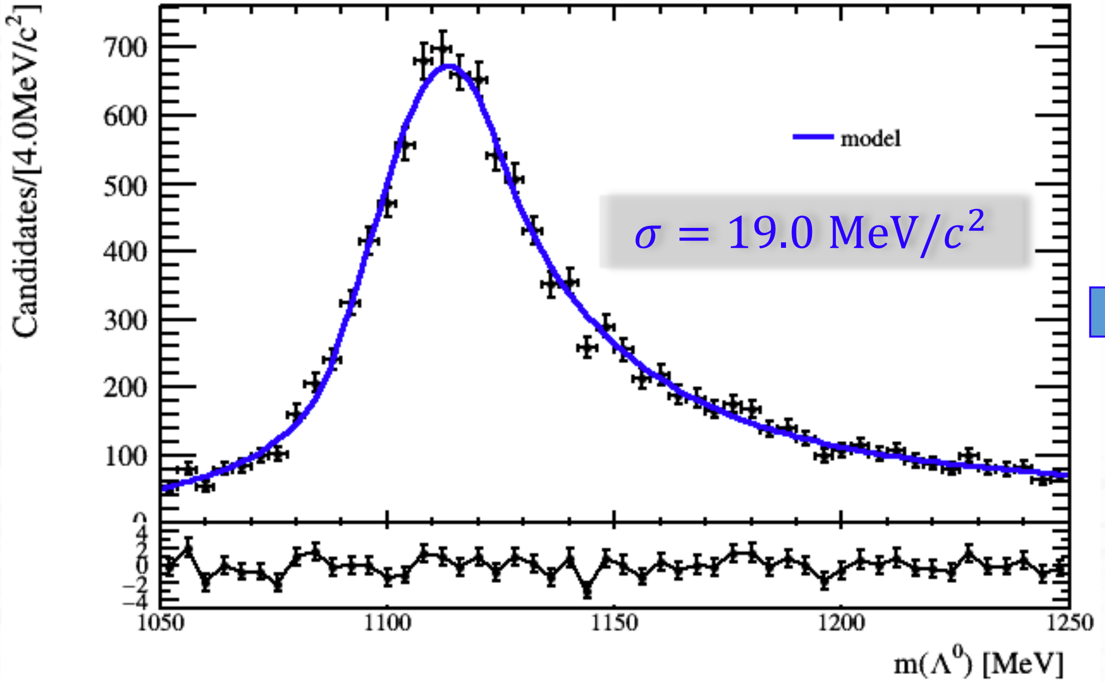


# Resolution Study

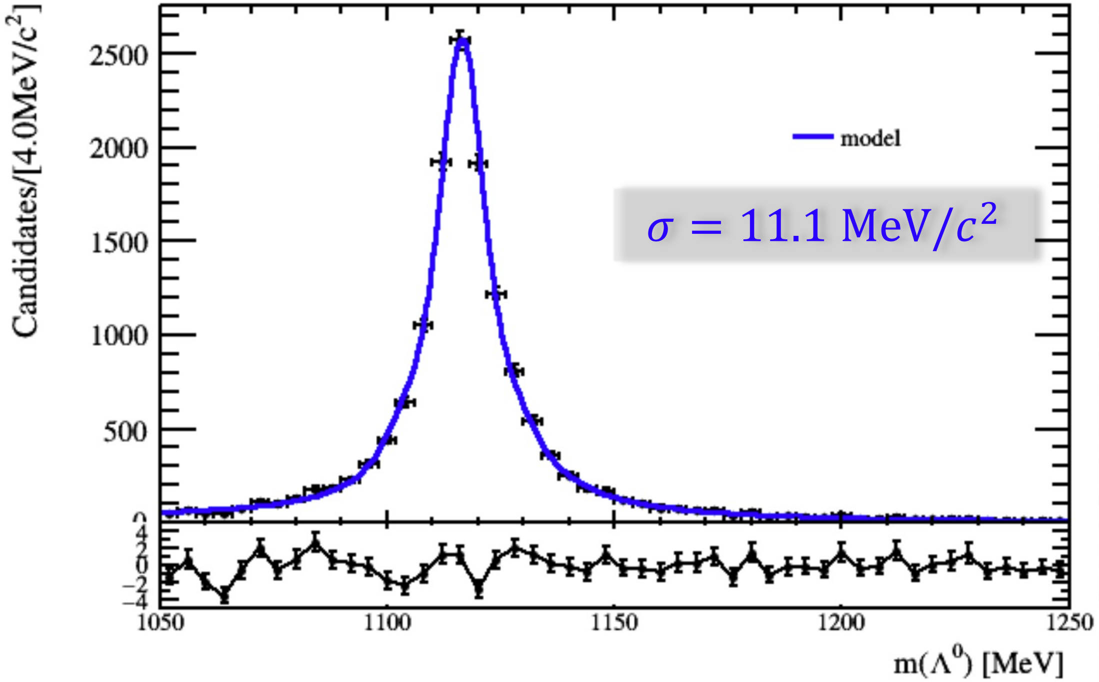
- With Decay Tree Fitter, a tool fitting a complete decay chain simultaneously, and applying constraint on $\Lambda_c^+$ mass, the resolution of $\Lambda^0$ mass improves a lot
- $\Lambda^0$ Mass resolution are comparable with that of the golden channel

Fit model: DSCB + Gauss

$\Lambda^0$ mass without any constraint




$\Lambda^0$ mass with kinematic constraint

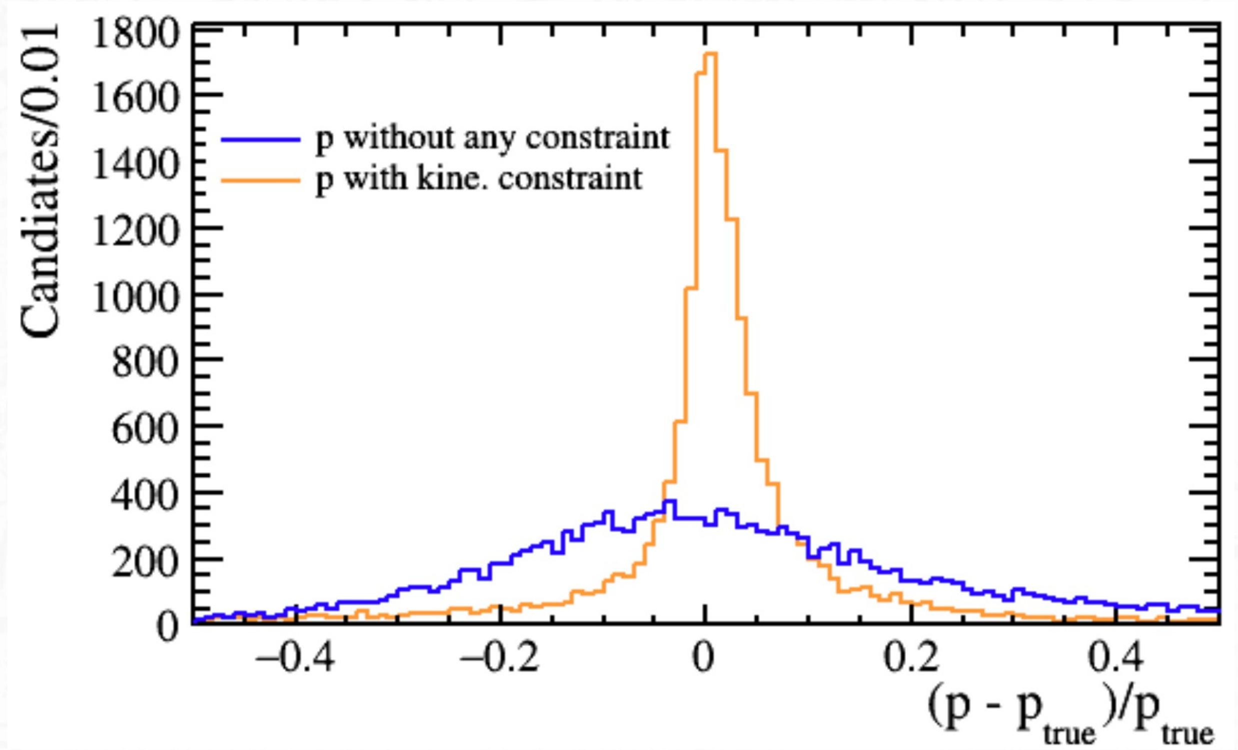


# Resolution Study (cont.)

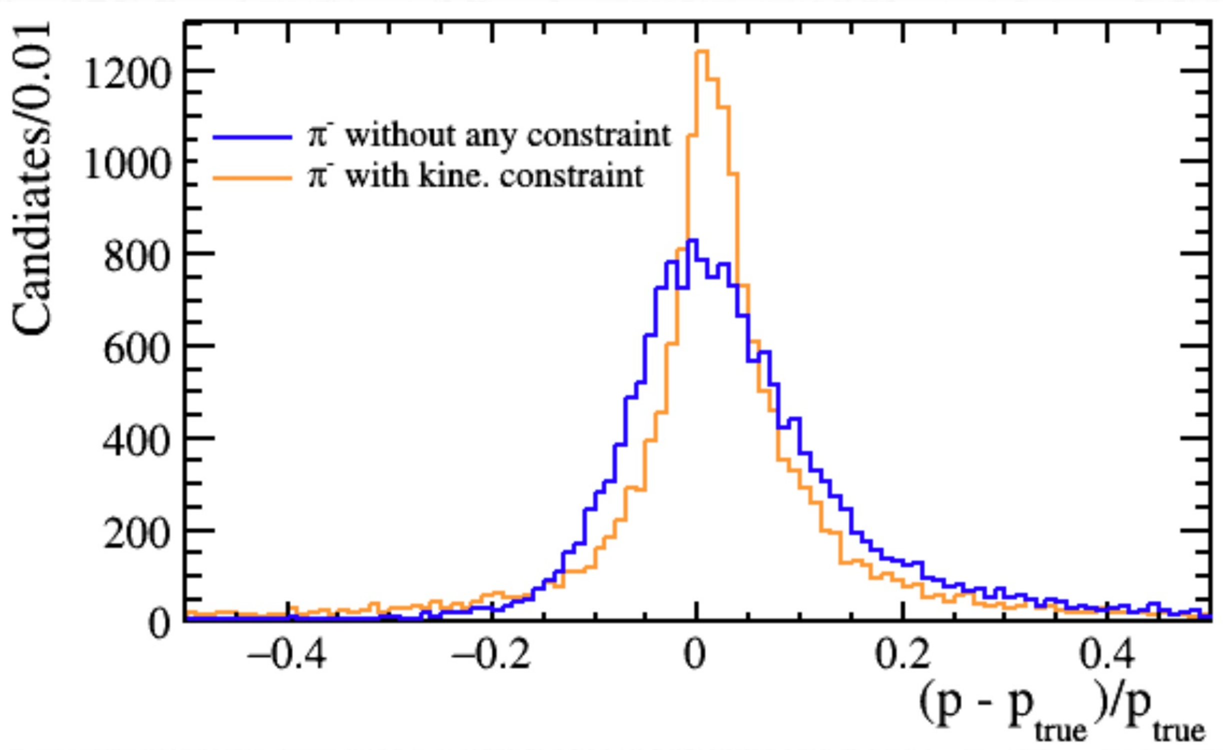
- With Decay Tree Fitter and $\Lambda_c^+, \Lambda^0$ mass constraints, the relative momentum resolutions of $p^+$ and $\pi^-$ from $\Lambda^0$ decay improves to about 10%

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

$p^+$ momentum resolution




$\pi^-$ momentum resolution



# Summary

- Measurement of $\Lambda^0$ 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 $\Lambda^0$ 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

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

Many Thanks!

# Reference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# Backup

# Golden Channel

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

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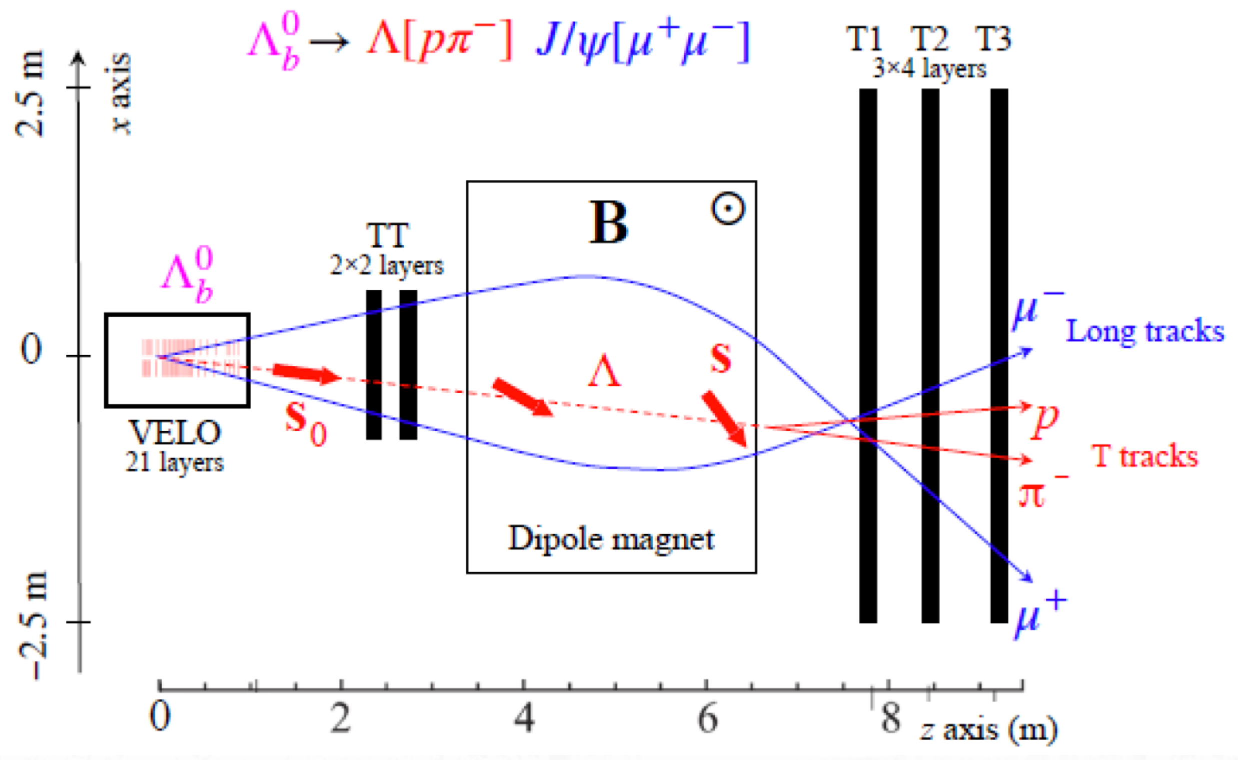


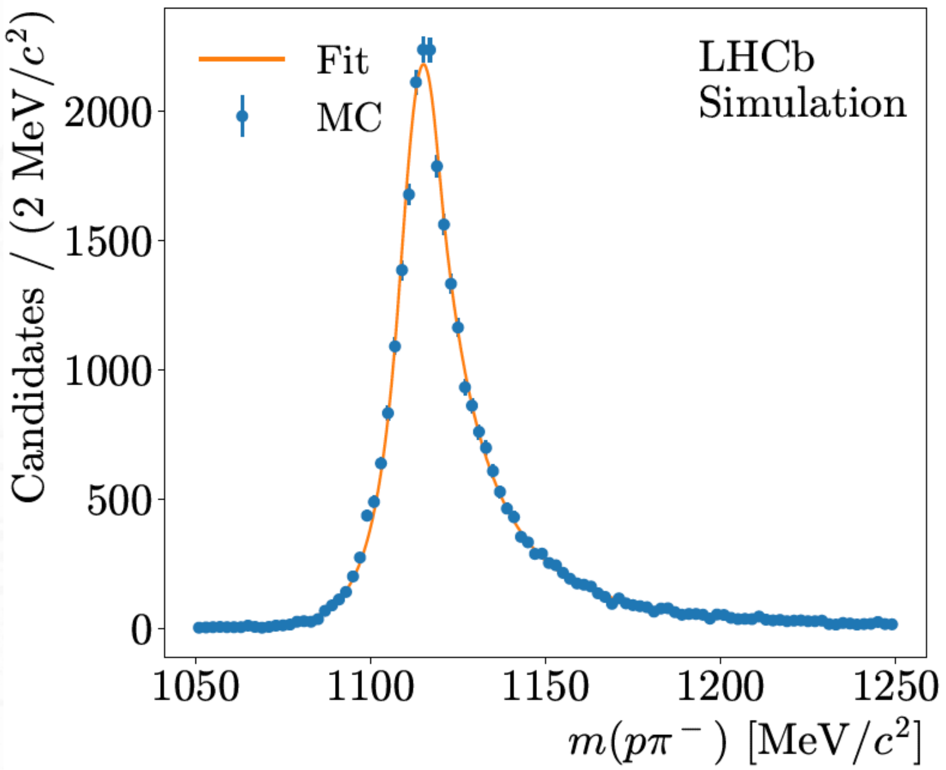

# Reconstruction

- We try to reconstruct the decay
- Full simulation MC samples are used

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

- ~180,000 events generated (requiring $\Lambda^0$ 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 % |