Observation of a doubly charmed baryon at LHCb

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Outline

- ☐ Introduction
- ☐ LHCb
- ☐ Experimental status
- ☐ Dataset, reconstruction and selection
- ☐ Results
- ☐ Prospects and conclusion

Doubly Heavy Baryons

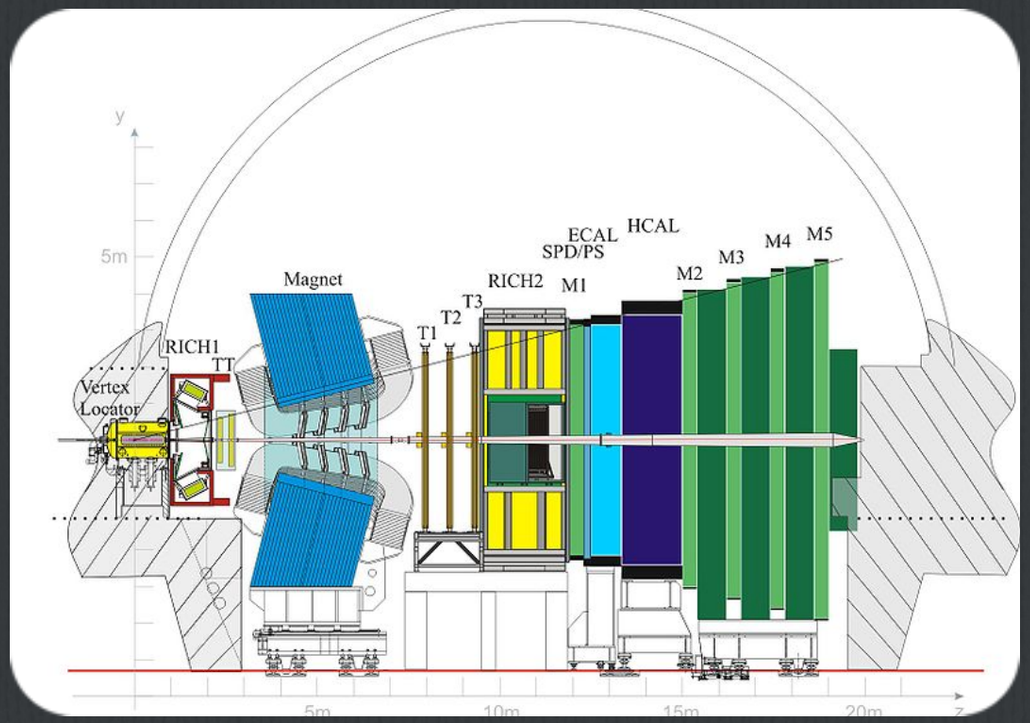
- Baryon spectroscopy is an important test for the Standard Model (SM)
- Charm doubly heavy baryons predicted include: Ξ_{cc}^{+}(dcc), Ξ_{cc}^{++}(ucc), and Ω_{cc}^{+}(scc)
- Theoretical predictions of Ξ_{cc}^{++} mass are 3.5-3.7 GeV/c^2 and expected to be close to Ξ_{cc}^{+}[1-6]
- Theoretical predictions of Ξ_{cc}^{++} lifetime are within the 150-1550 fs [7-12]
- Bottom doubly heavy baryons: Ξ_{bc}, Ω_{bc}, Ξ_{bb}, …

LHCb

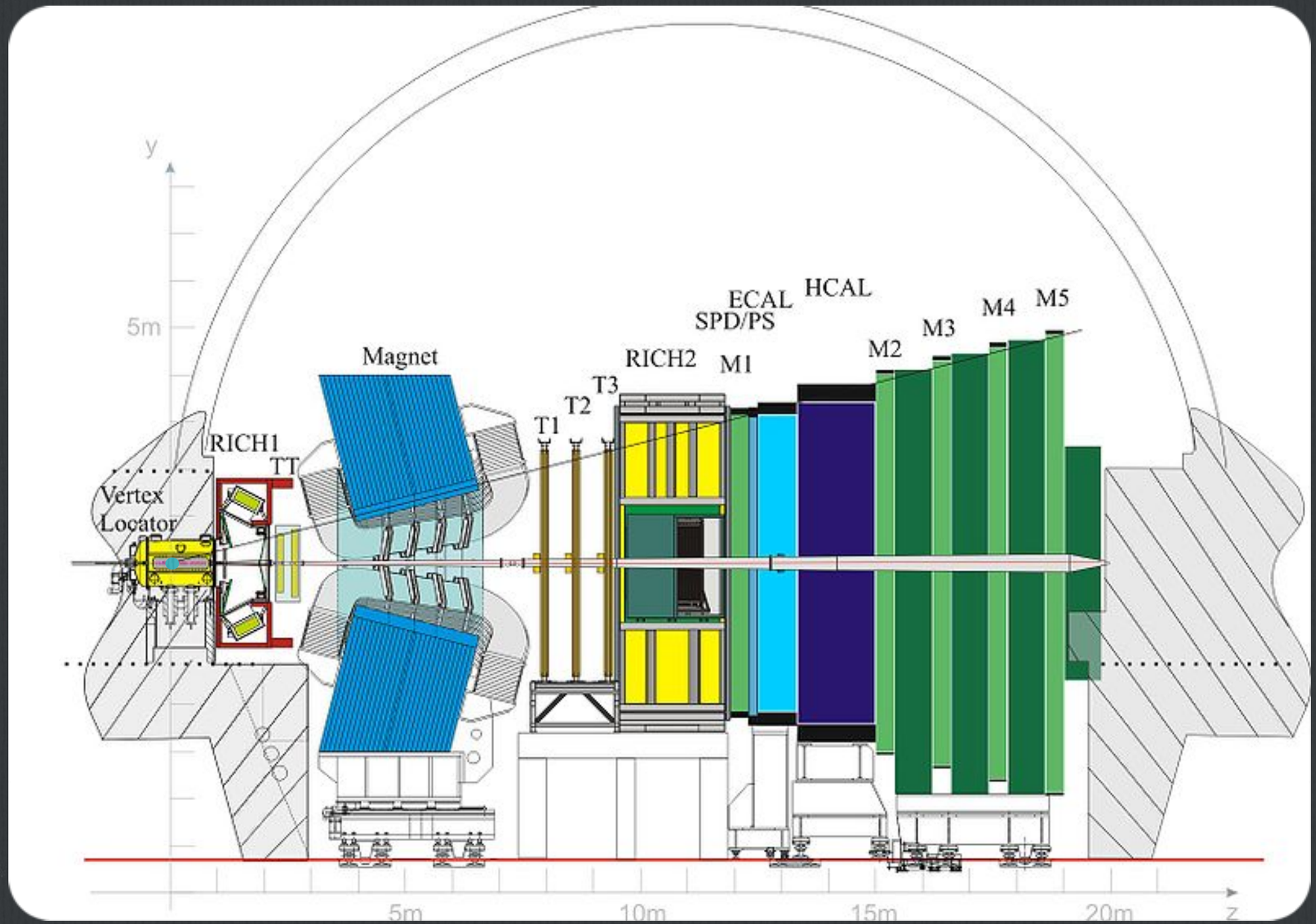
- CP violation, hadron spectroscopy and rare decays in b and c quark systems

- 2011 - 2012 -> Run I ($3.0\ fb^{-1}$)

- 2015 - 2017 -> Run II ($3.5\ fb^{-1}$)



LHCb



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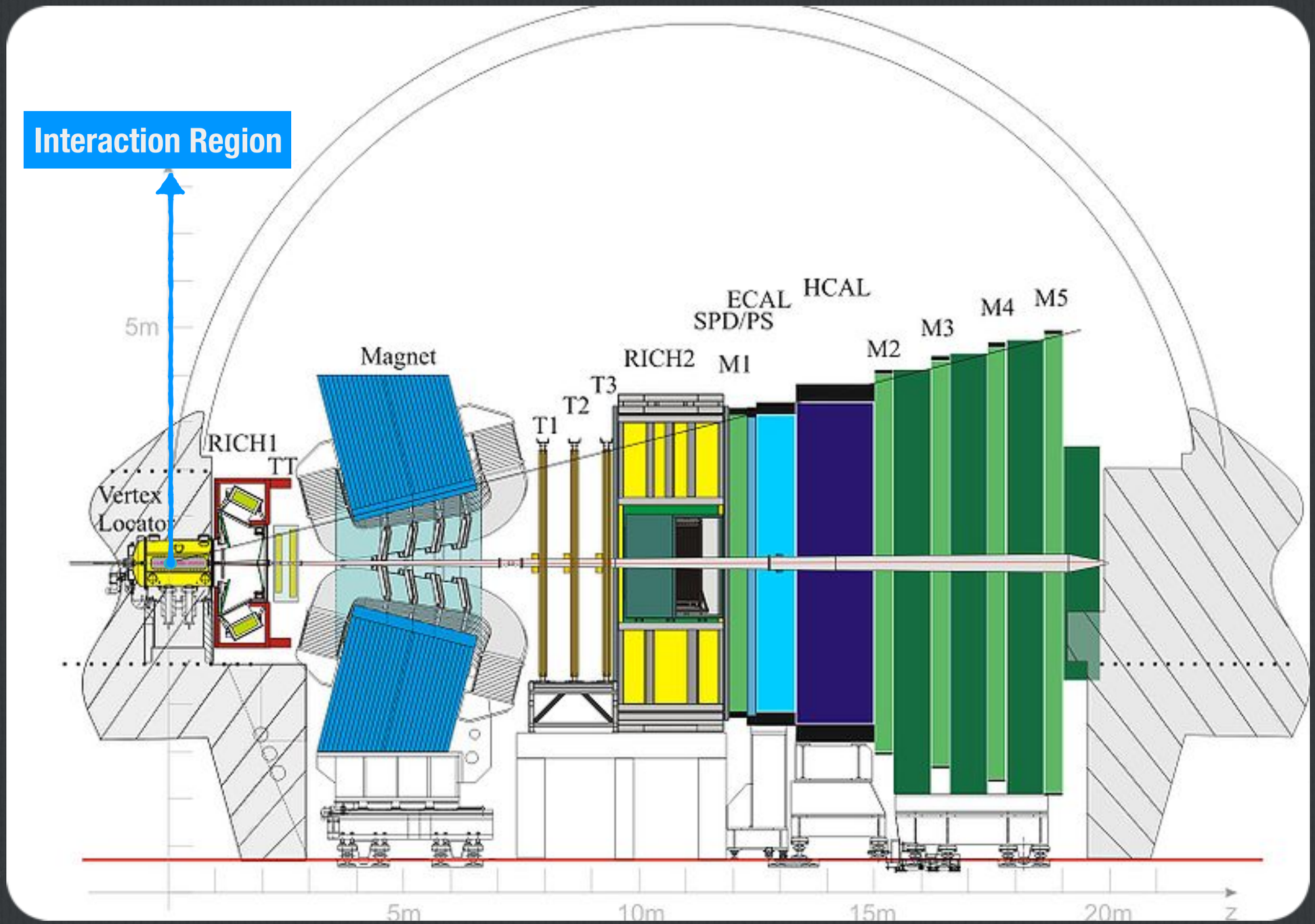
LHCb



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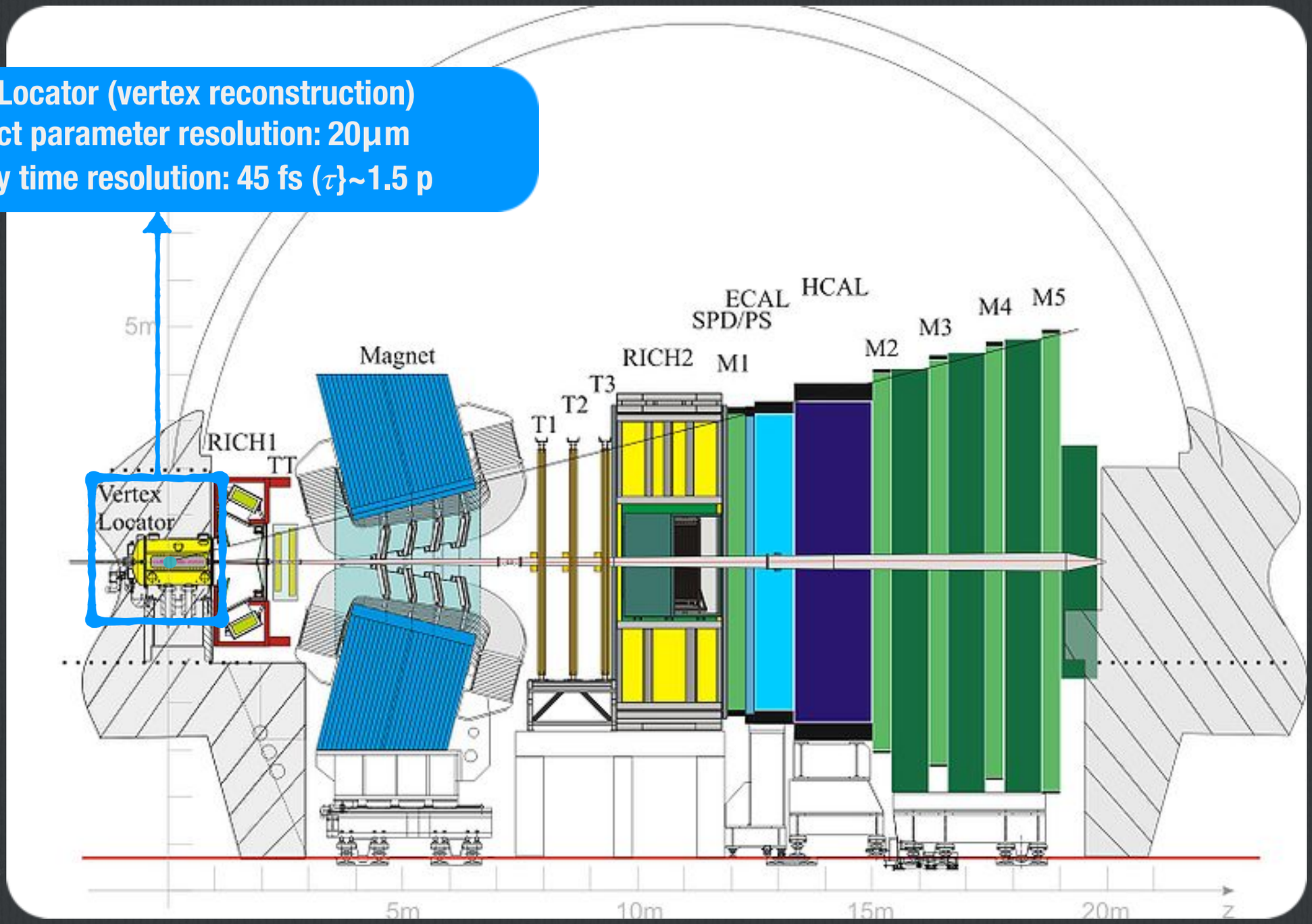
LHCb

- Vertex Locator (vertex reconstruction)
  - Impact parameter resolution: 20μm
  - Decay time resolution: 45 fs (τ}~1.5 p



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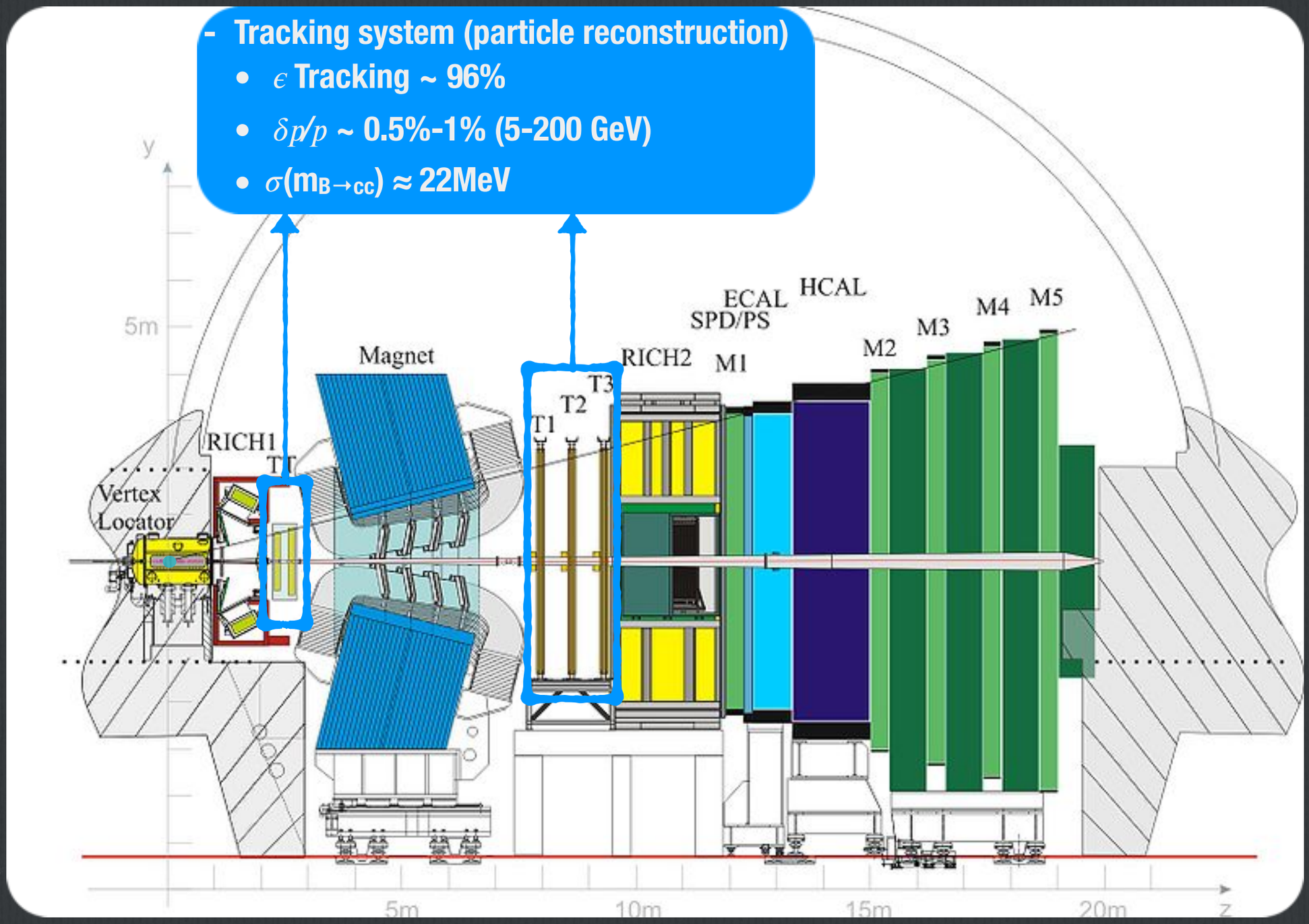
LHCb

- Tracking system (particle reconstruction)
  - ϵ Tracking ~ 96%
  - $\delta p/p$ ~ 0.5%-1% (5-200 GeV)
  - $\sigma(m_{B\to cc}) \approx 22$MeV



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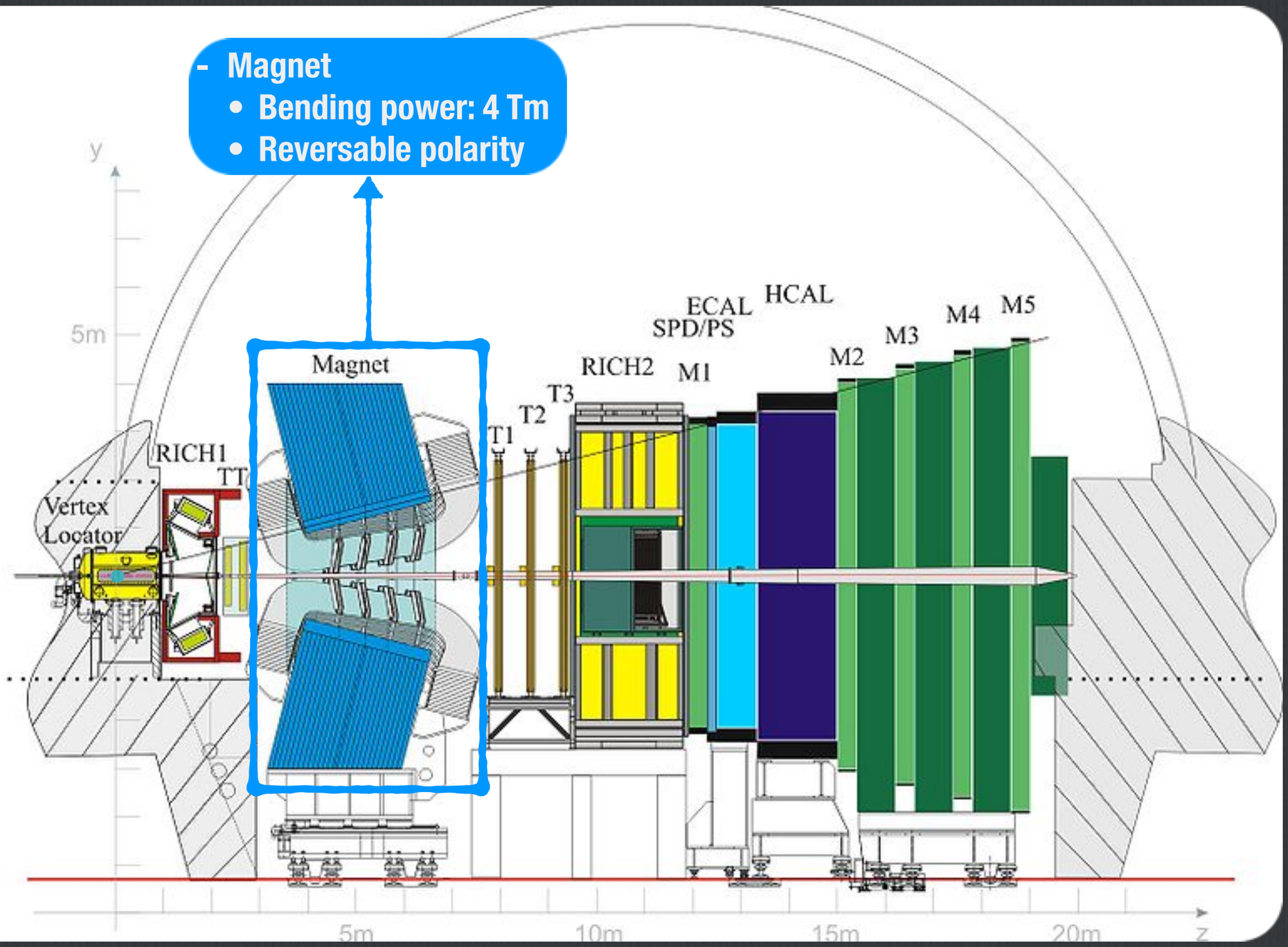
LHCb

- Magnet
  - Bending power: 4 Tm
  - Reversable polarity



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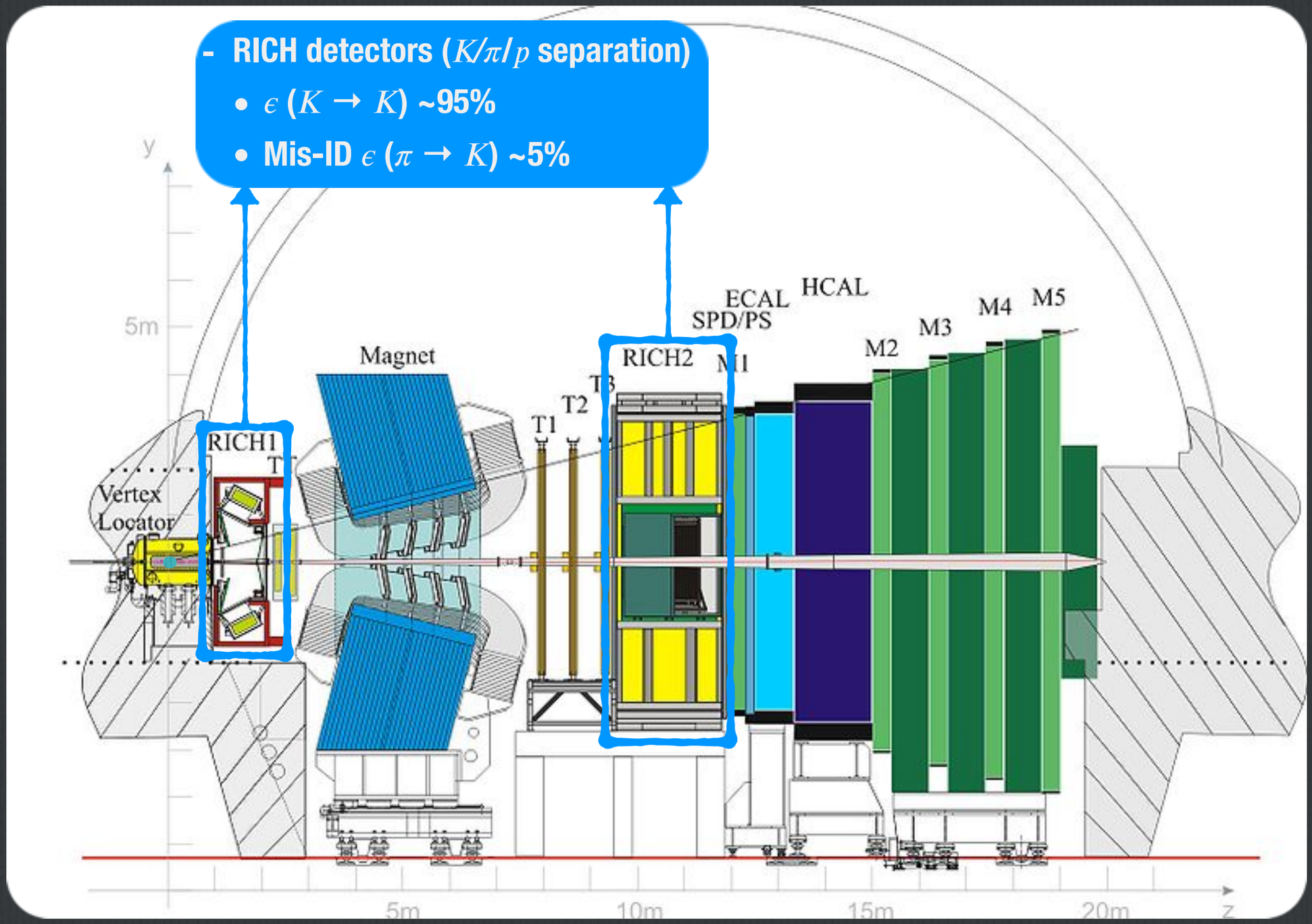
LHCb

- **RICH detectors ($K/\pi/p$ separation)**
  - ϵ ($K \rightarrow K$) ~95%
  - **Mis-ID** ϵ ($\pi \rightarrow K$) ~5%



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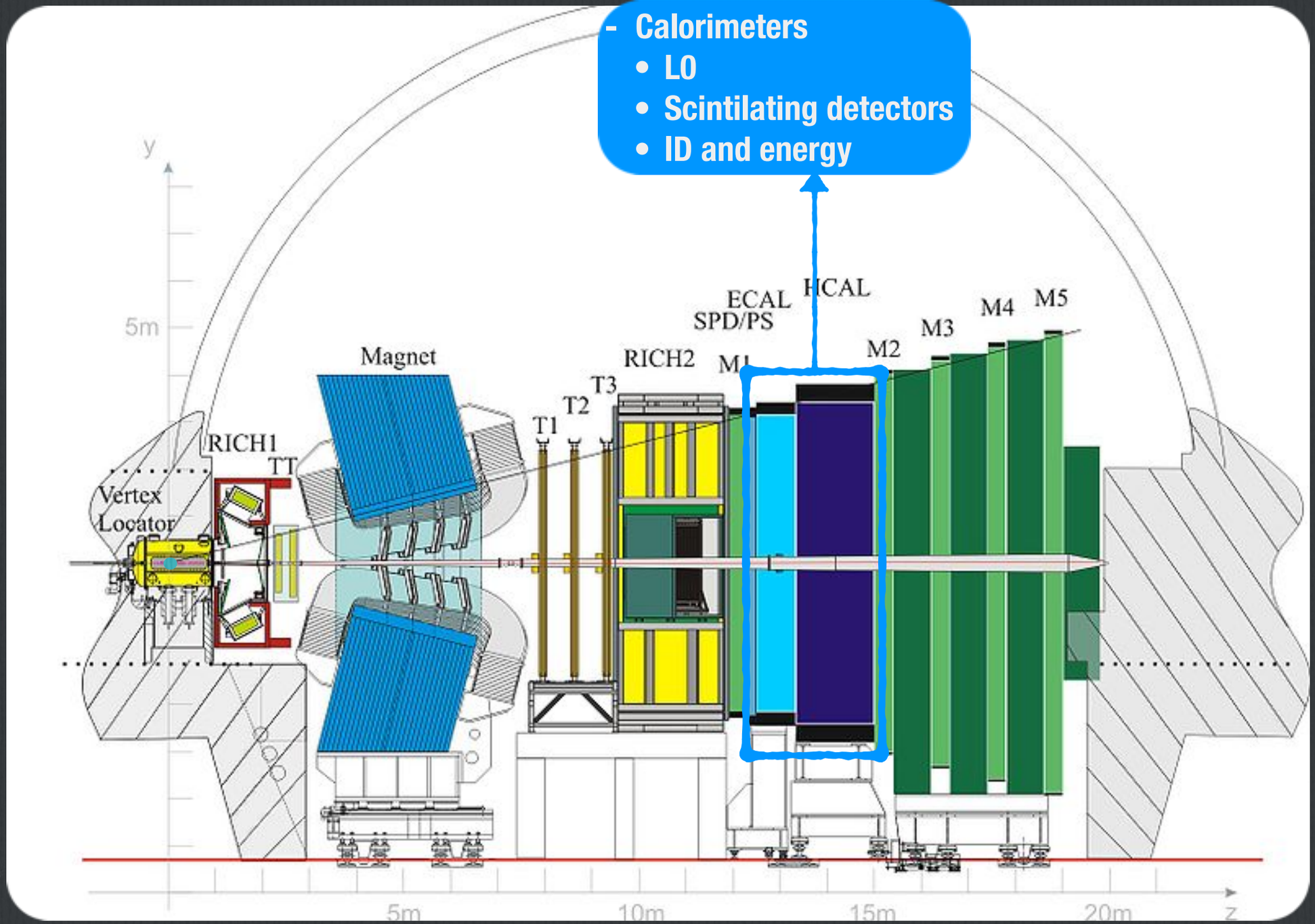
LHCb

- Calorimeters
  - L0
  - Scintilating detectors
  - ID and energy



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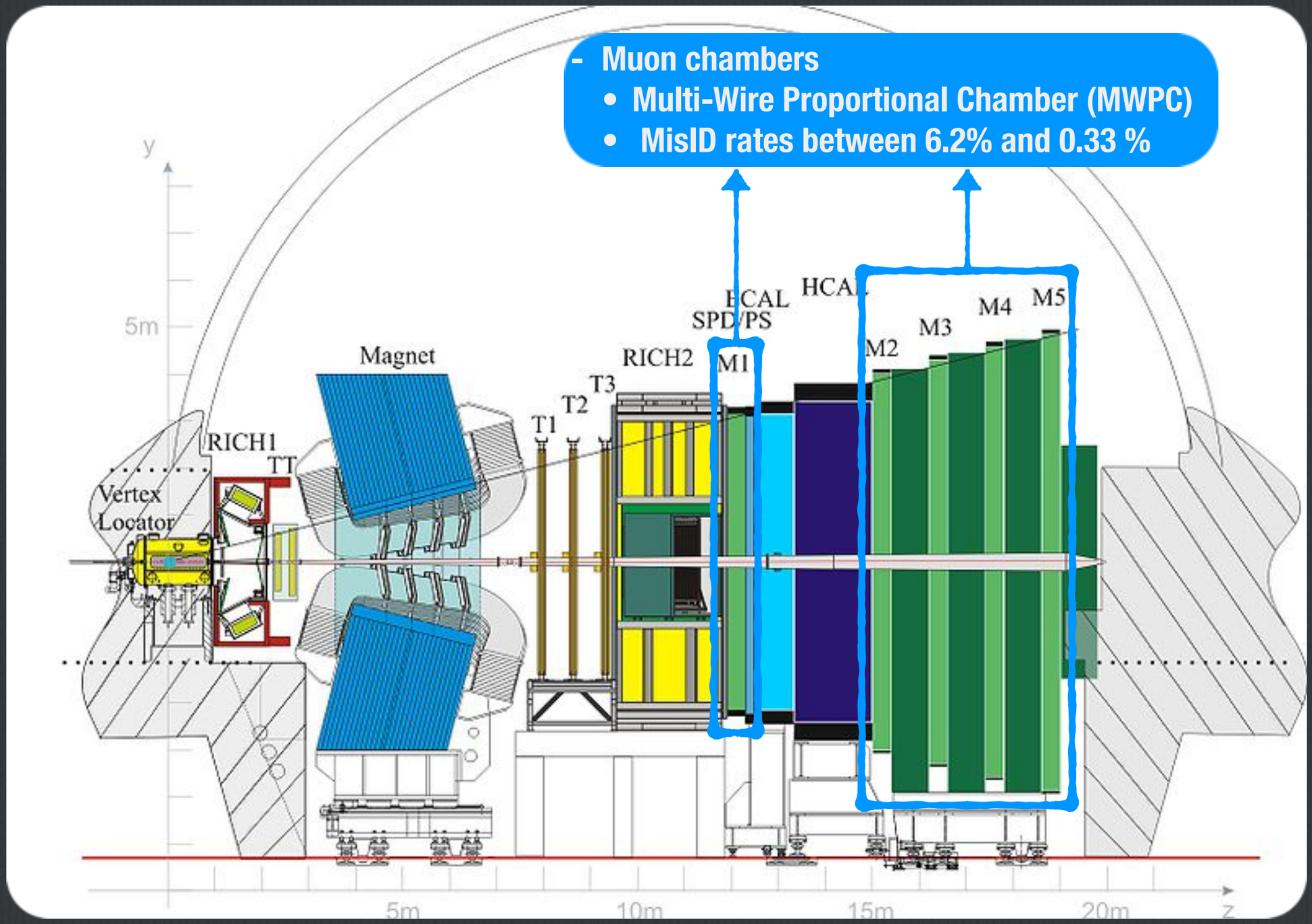
LHCb



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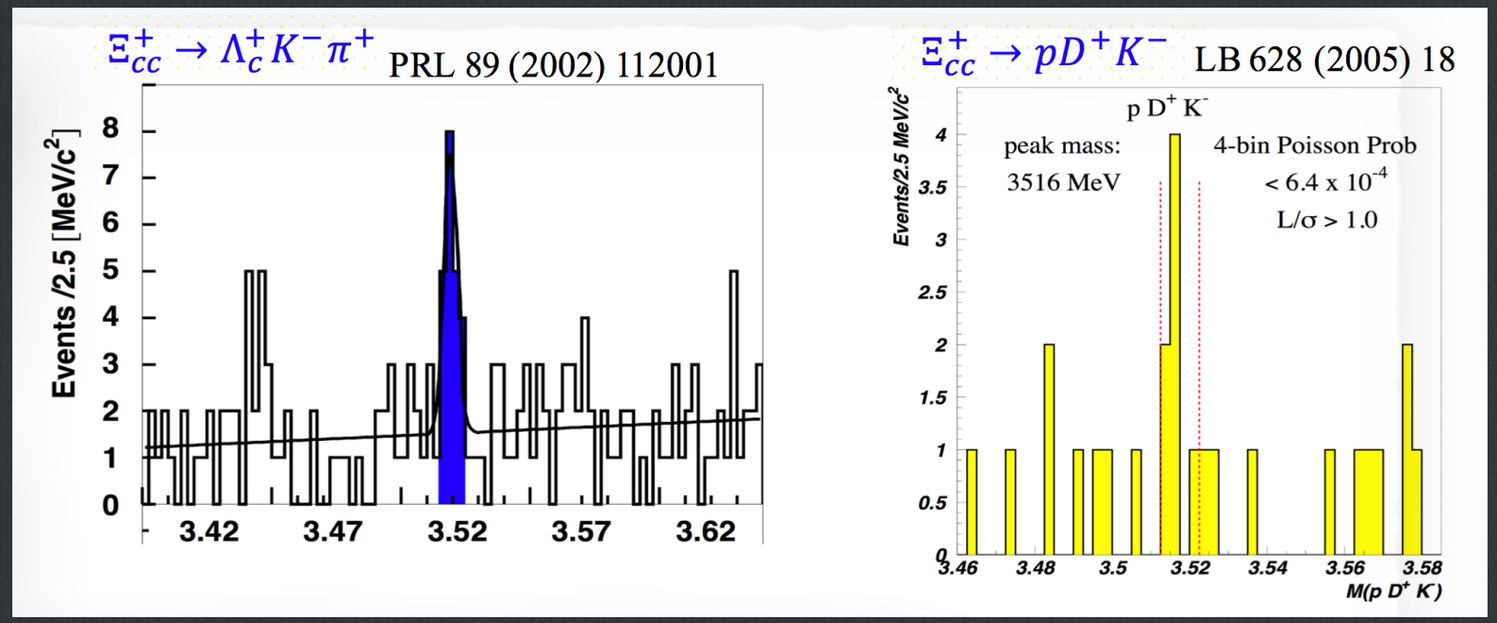
SELEX experiment Ξ_{cc}^{+} measurement

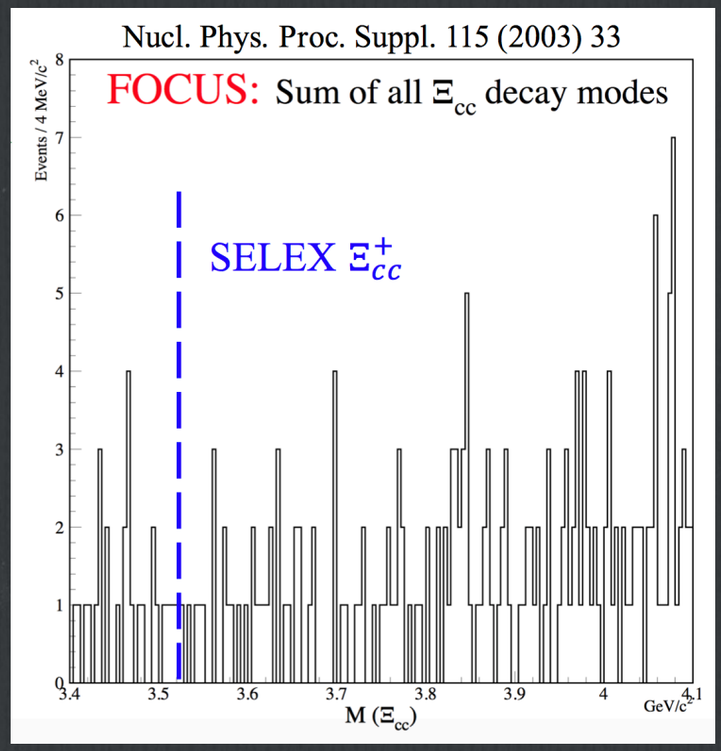
- SELEX (Fermilab E781) collides high energy hyperon beams (Σ^-,p) with nuclear fixed targets, dedicated to study charm baryons

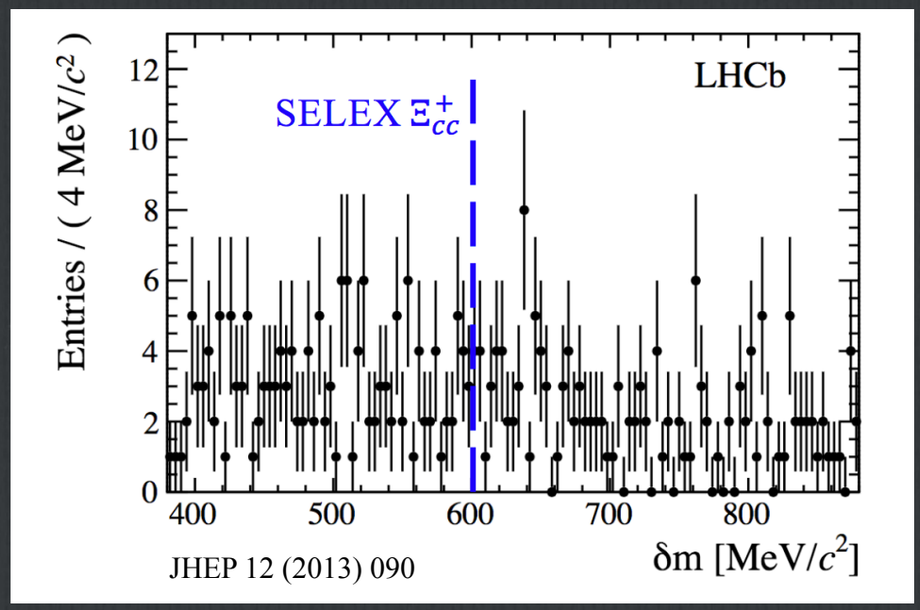


- Observed $\Xi_{cc}^{+} \to \Lambda_c^{+}\, K^-\, \pi^+$ and $\Xi_{cc}^{+} \to p\, D^+\, K^-$ decays
  - Signal yields: 15.9 and 5.62
  - Short lifetime: $\tau_{\Xi cc+} < 33$ fs @90% CL, but not zero
  - Large production: exceeding theoretical predictions by ~20%
  - Mass (combined): 3518.7 ± 1.7 MeV

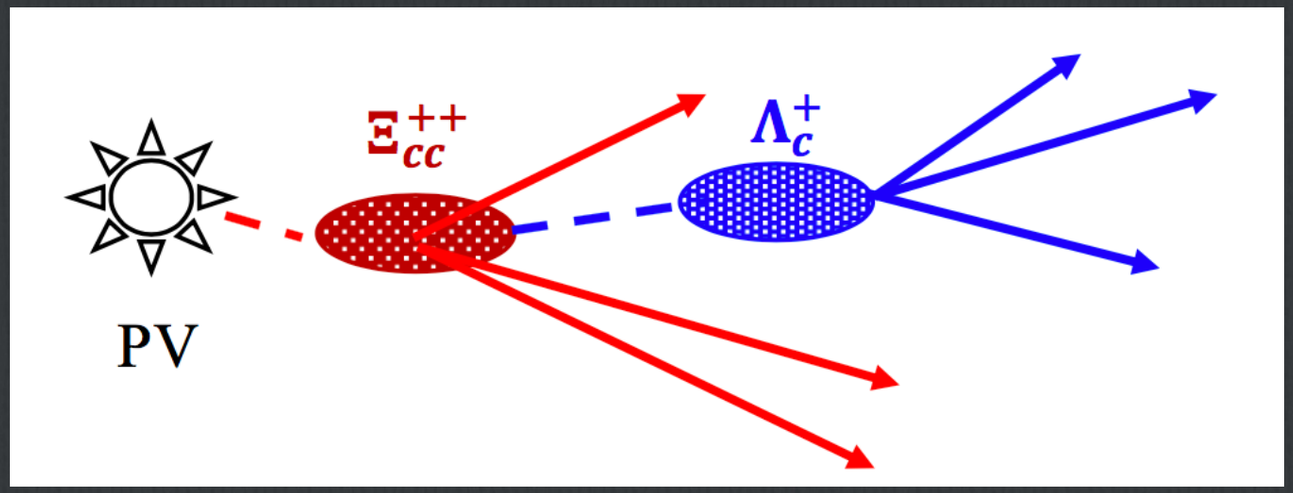
Other Ξ_{cc}^{+} searches

- Other experiments attempted to confirm SELEX's results, but no confirmation was obtained yet
- FOCUS, BaBar, Belle and LHCb
- LHCb new search ongoing, with selection criteria and methodology drastically improved
- Nevertheless, SELEX's result cannot be discarded



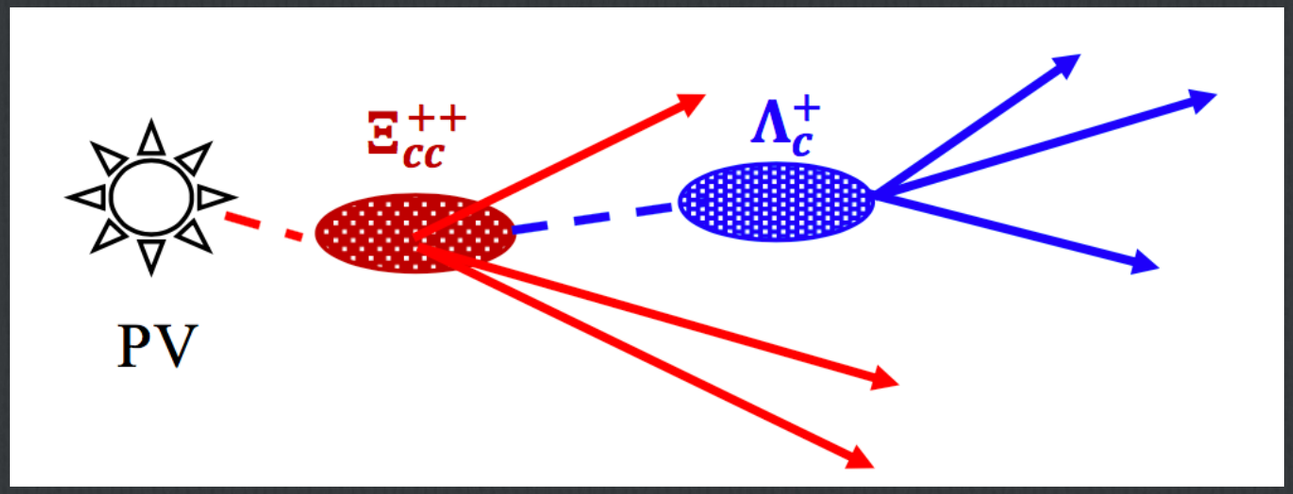


Dataset, reconstruction and selection

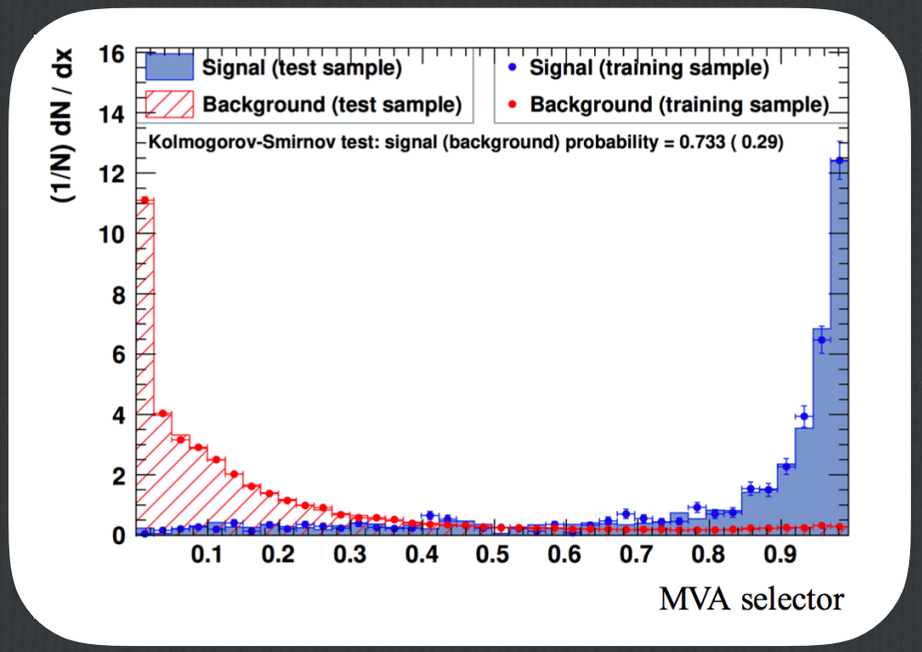


- 2016 data (1.7fb^{-1})
- $\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+\pi^+$ [13]
- Signal kinematical distributions taken from MC
- Background distributions taken from wrong-sign $\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+\pi^-$ samples
- First reconstruct $\Lambda_c^+ \rightarrow pK^-\pi^+$, then combine with $K^-\pi^+\pi^+$

Dataset, reconstruction and selection



- Selection is performed in three steps:
  - Trigger (dedicated trigger line): Kinematical constraints, PID, track and vertex quality
  - Preselection: Ghost probability, kinematical constraints, vertex and PV refit quality
  - MVA: Kinematical constraints and Vertex refit quality



Mass fit

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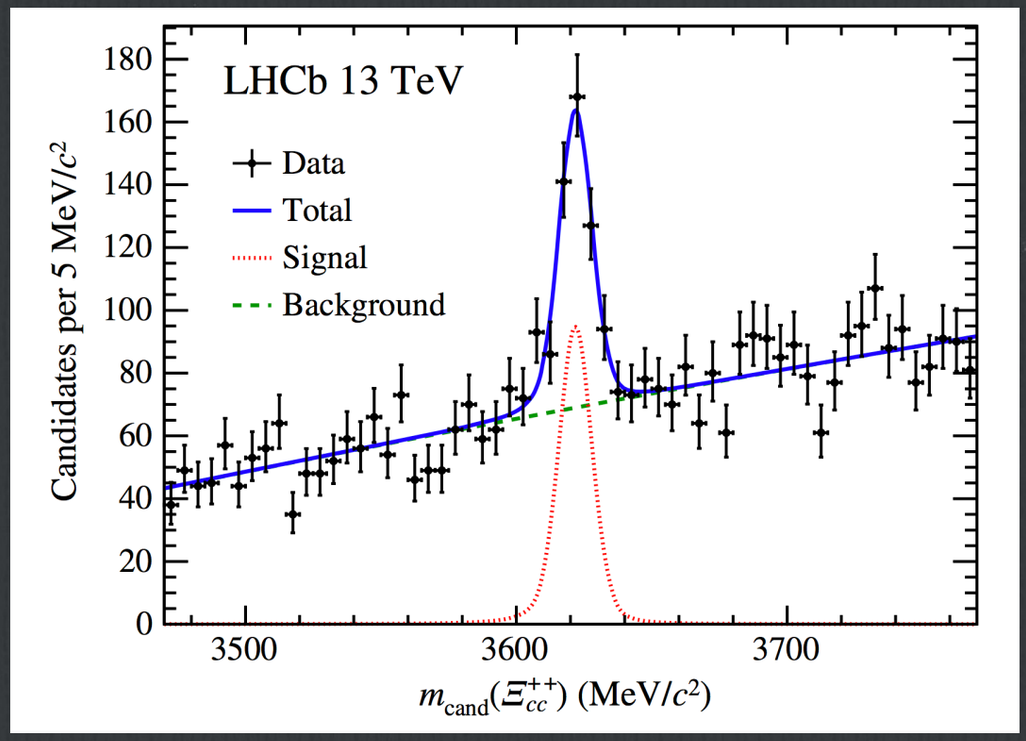
- **Observable:**
  $m(\Xi_{cc}^{++}) = m(\Lambda_c^+ K^- \pi^+) - m(\Lambda_c^+) + m_{PDG}(\Lambda_c^+)$
- **Gaussian + double sided crystal ball for signal**
- **Chebychev Polynomial for background**
- **Signal yield: 313 ± 33**
- **Resolution: 6.6 ± 0.8 MeV, consistent with detector resolution**
- **Local significance > 12σ**



$$m_{\Xi_{cc}^{++}} = 3621.40 \pm 0.72(stat) \pm 0.27(syst) \pm 0.14(\Lambda_c) MeV$$

Mass value consistent with theoretical range of predictions!

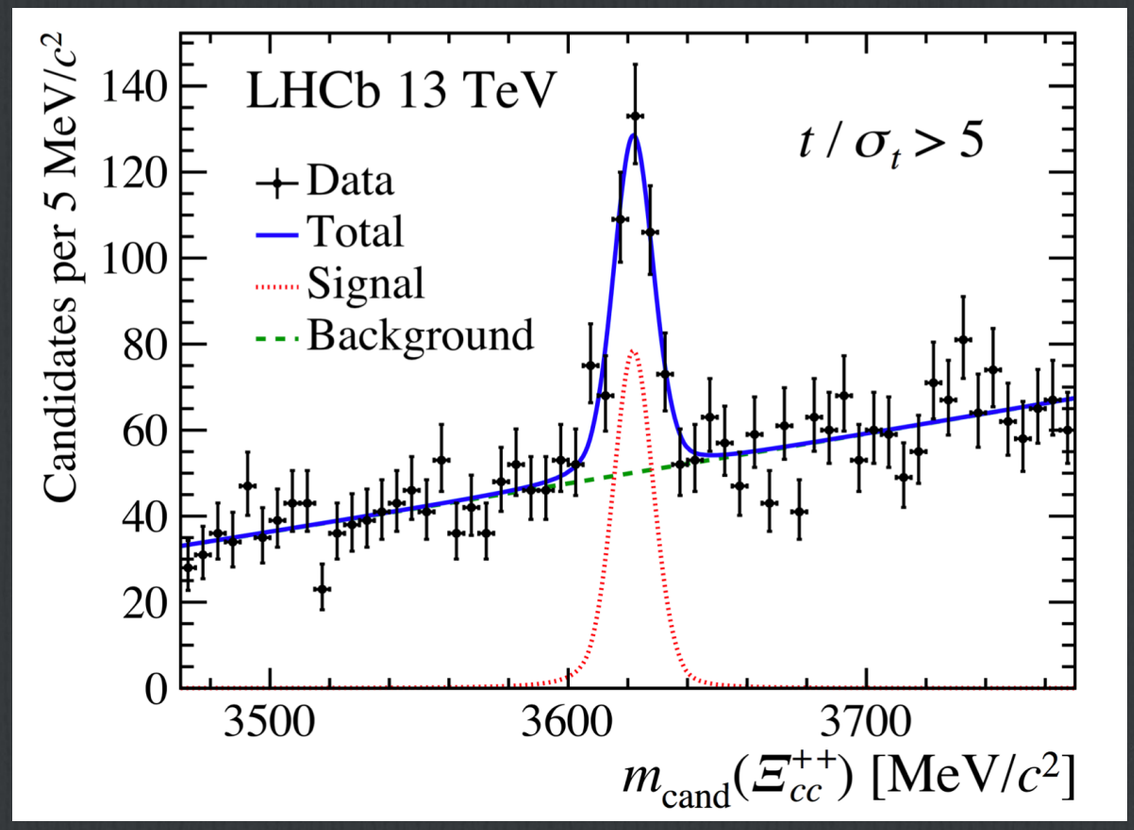
Not consistent with Ξ_{cc}^+ SELEX measurement [$M_{LHCb}(\Xi_{cc}^{++}) - M_{SELEX}(\Xi_{cc}^+) = 102.7$ MeV]

Additional tests

- ☐ Multiple candidates: not creating fake narrow structure
- ☐ Checking combinations of tracks from Λ_c^+ and Ξ_{cc}^{++} : not peaking
- ☐ MVA efficiency as a function of mass: very smooth
- ☐ Varying threshold value of MVA selector and using cut based selection: structure stays significant
- ☐ Varying particle ID selections: no peaking structure emerging in WS combinations, structure stays in RS sample
- ☐ Run I sample used as crosscheck: same structure seen

Additional tests

- Structure still significant with $\tau_{\Xi cc} > 5\sigma$
- Consistent with weak decay



Future prospects

- Mid-term
  - Searching for Ξ_{cc}^{++} with more channels: $\Xi_c^+\pi^+$, $\Lambda_c^+\pi^+$, $pD^+K^-\pi^+$
  - Measurement of the Ξ_{cc}^{++} lifetime
  - Measurement of the production cross-section
  - Searching for its isospin partner Ξ_{cc}^{+} in a larger sample than the previous measurement
  - Searching for Ω_{cc}^{+}
  - Doubly heavy baryons with bottom quark: Ξ_{bc}, Ω_{bc}, Ξ_{bb}
  - The excited states?
- Long-Term:
  - Confirming its spin-parity: $1/2^+$
  - CP violation studies

Conclusions

- A significant structure consistent with Ξ_{cc}^{++} was observed in LHCb 2016 data

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- Measured mass is consistent with theoretical range of predictions, but not with SELEX Ξ_{cc}^{+} measurement

- Many studies more to come!

References

[1]W. Roberts and M. Pervin, *Heavy baryons in a quark model*, Int. J. Mod. Phys. A23 (2008) 2817, arXiv:0711.2492.

[2]D.-H. He et al., *Evaluation of spectra of baryons containing two heavy quarks in bag model*, Phys. Rev. D70 (2004) 094004, arXiv:hep-ph/0403301.

[3]Z.-G. Wang, *Analysis of the 1 + doubly heavy baryon states with QCD sum rules*, Eur. 2 Phys. J. A45 (2010) 267, arXiv:1001.4693.

[4]C.-H. Chang, C.-F. Qiao, J.-X. Wang, and X.-G. Wu, *Estimate of the hadronic production of the doubly charmed baryon Ξcc under GM-VFN scheme*, Phys. Rev. D73 (2006) 094022, arXiv:hep-ph/0601032.

[5]A. Valcarce, H. Garcilazo, and J. Vijande, *Towards an understanding of heavy baryon spectroscopy,* Eur. Phys. J. A37 (2008) 217, arXiv:0807.2973.

[6]J.-R. Zhang and M.-Q. Huang, *Doubly heavy baryons in QCD sum rules*, Phys. Rev. D78 (2008) 094007, arXiv:0810.5396.

[7]M. Karliner and J. L. Rosner, *Baryons with two heavy quarks: Masses, production, decays, and detection,* Phys. Rev. D90 (2014), no. 9 094007, arXiv:1408.5877.

[8]C.-H. Chang, T. Li, X.-Q. Li, and Y.-M. Wang, *Lifetime of doubly charmed baryons,* Commun. Theor. Phys. 49 (2008) 993, arXiv:0704.0016.

[9]D. Ebert, R. N. Faustov, V. O. Galkin, and A. P. Martynenko, *Mass spectra of doubly heavy baryons in the relativistic quark model*, Phys. Rev. D66 (2002) 014008, arXiv:hep-ph/0201217.

[10]B. Guberina, B. Melic, and H. Stefancic, *Inclusive decays and lifetimes of doubly charmed baryons*, Eur. Phys. J. C9 (1999) 213, arXiv:hep-ph/9901323.

[11]V. V. Kiselev, A. K. Likhoded, and A. I. Onishchenko, *Lifetimes of dou- bly charmed baryons: Xi(cc)+ and Xi(cc)++*, Phys. Rev. D60 (1999) 014007, arXiv:hep-ph/9807354.

[12] V. V. Kiselev and A. K. Likhoded, *Baryons with two heavy quarks*, Phys. Usp. 45 (2002) 455, arXiv:hep-ph/0103169, [Usp. Fiz. Nauk172,497(2002)].

[13]F.-S. Yu, H.-Y. Jiang, R.-H. Li, C.-D. L, W. Wang, and Z.-X. Zhao, arXiv:1703.09086.

Backup

Systematic uncertainties

Source	Value (MeV/c^2)
Momentum-scale calibration	0.22
Selection bias correction	0.14
Unknown Ξ_{cc}^{++} lifetime	0.06
Mass fit model	0.07
Sum of above in quadrature	0.27
Λ_c^+ mass uncertainty	0.14