$\Lambda_b \to p\pi\mu\mu$ analysis with Run1+Run2 data with the LHCb detector

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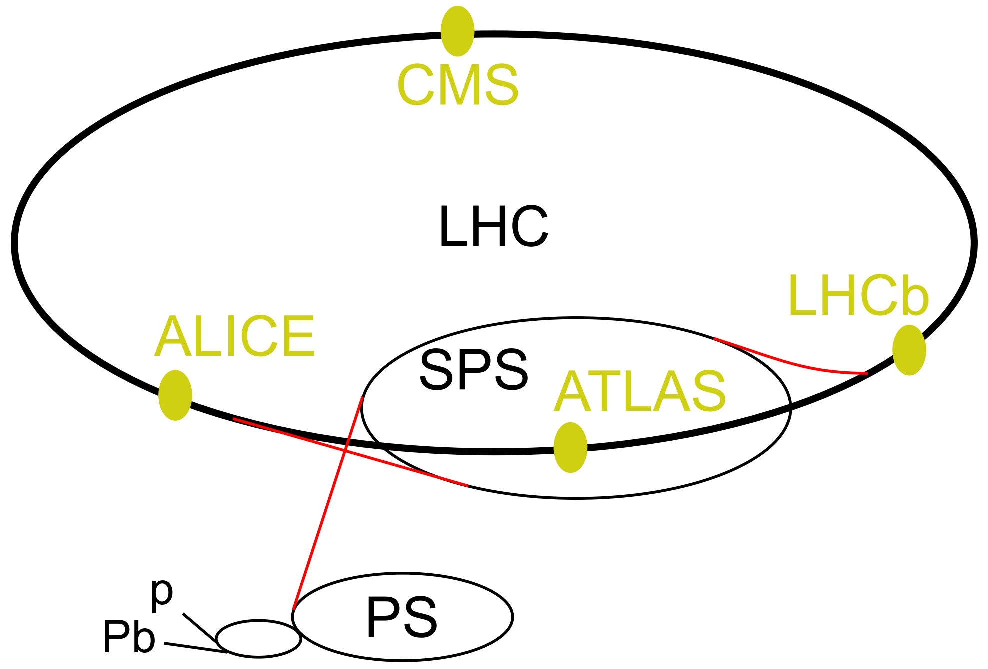
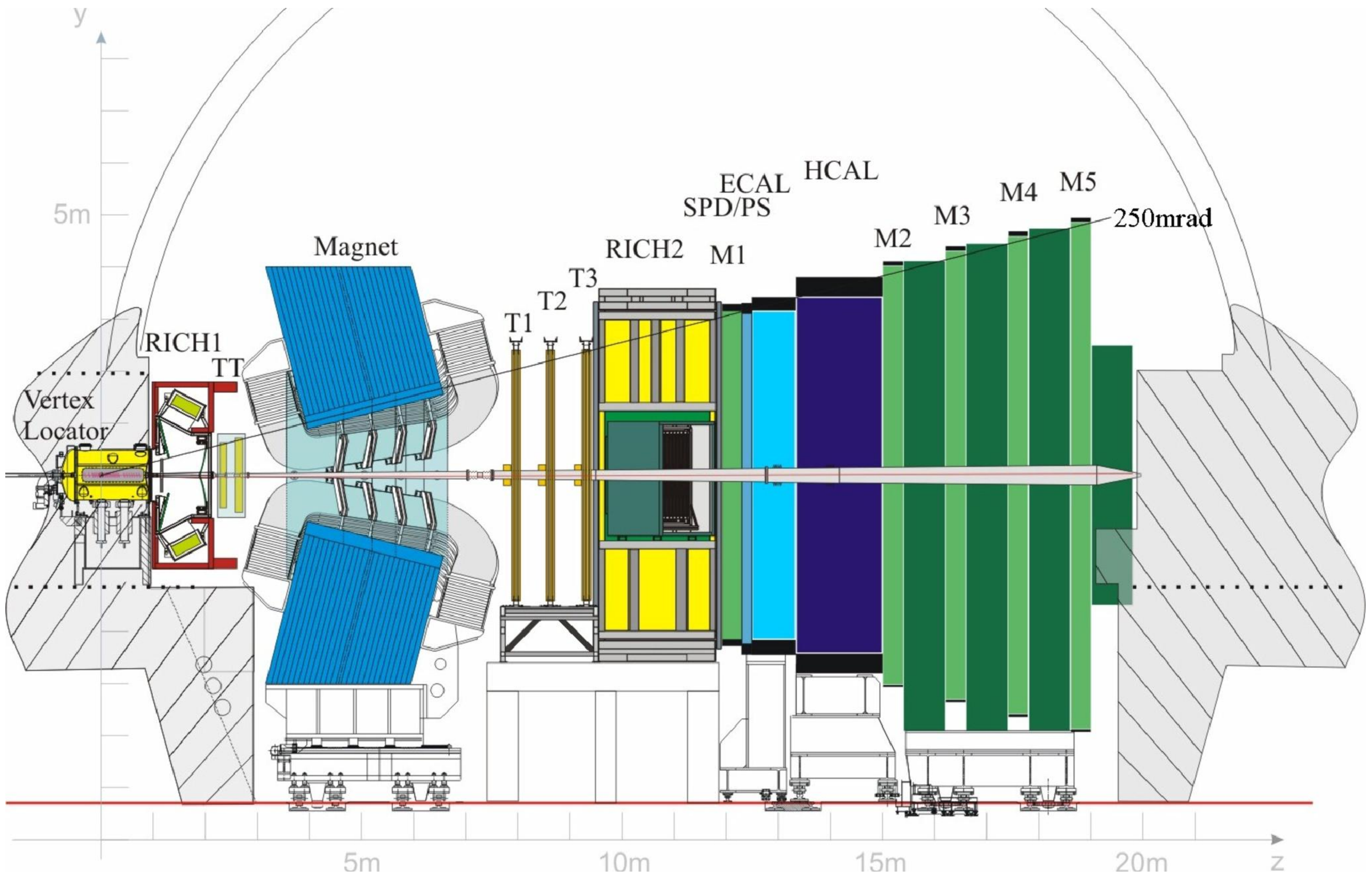
PHENIICS fest, 3.07.2025

LHCb detector

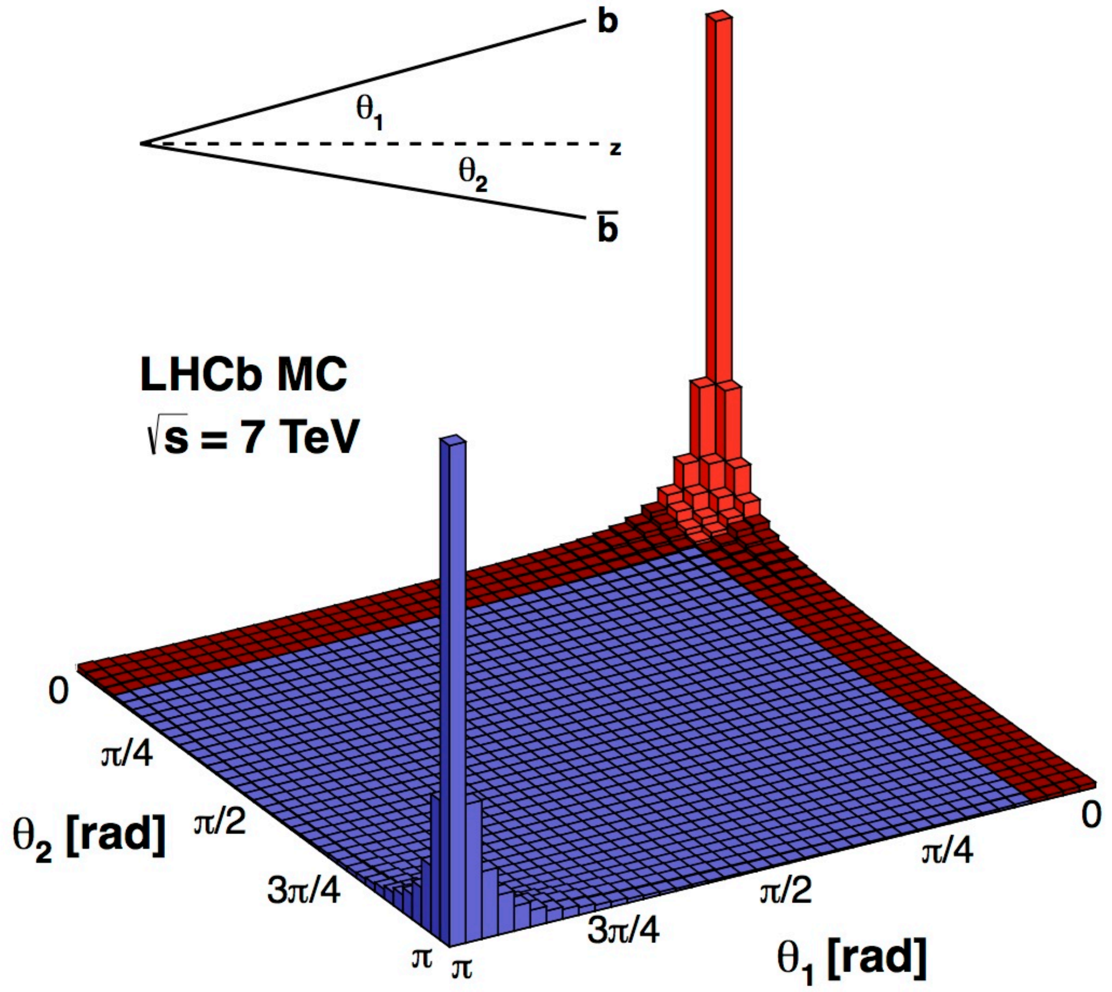


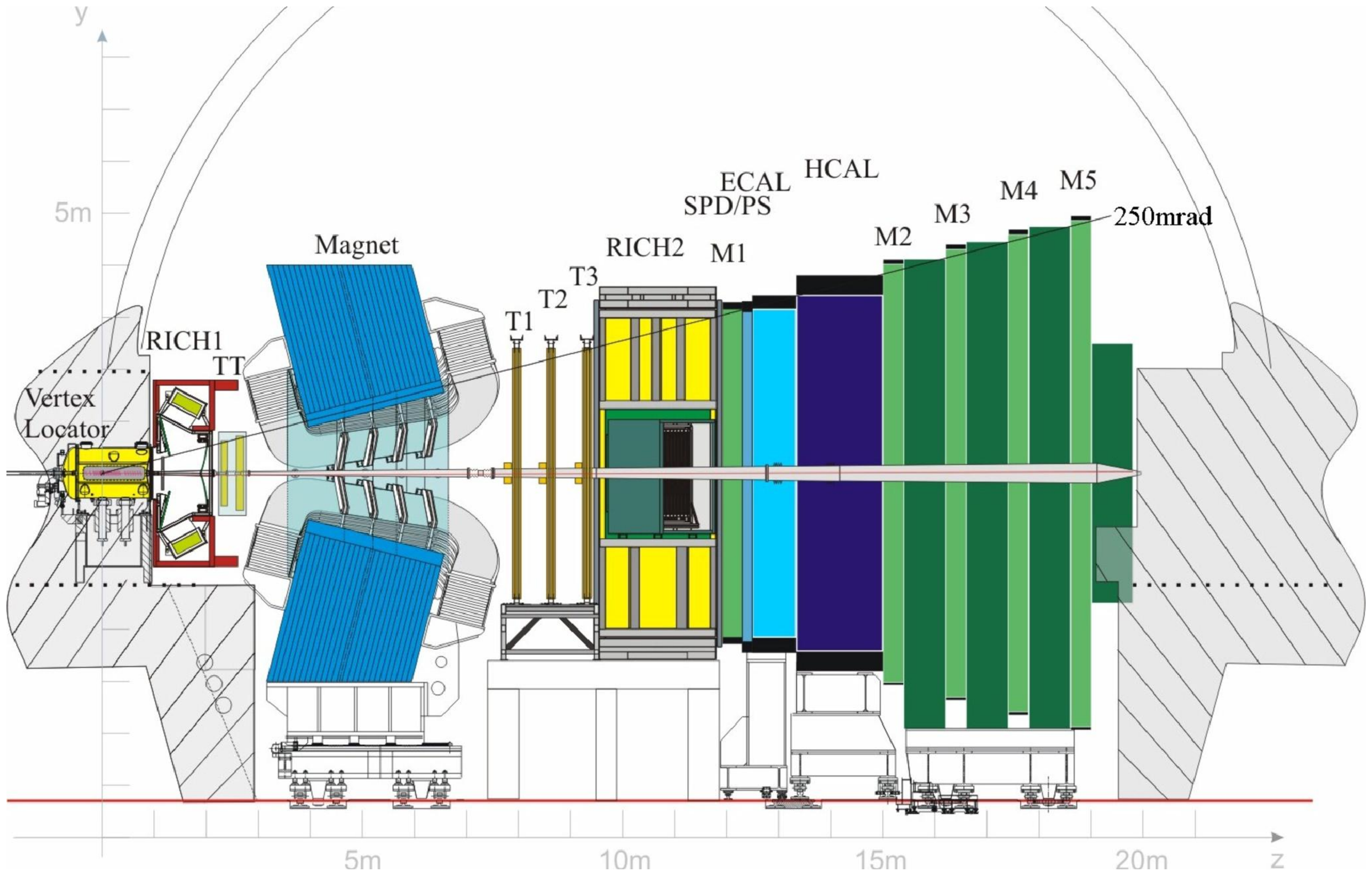
- The LHCb detector is one of the 4 experiments on the Large Hadron Collider (LHC) at CERN
- Different configuration to other detectors: forward arm spectrometer
- 25% of $b\bar{b}$ pairs are produced in LHCb acceptance

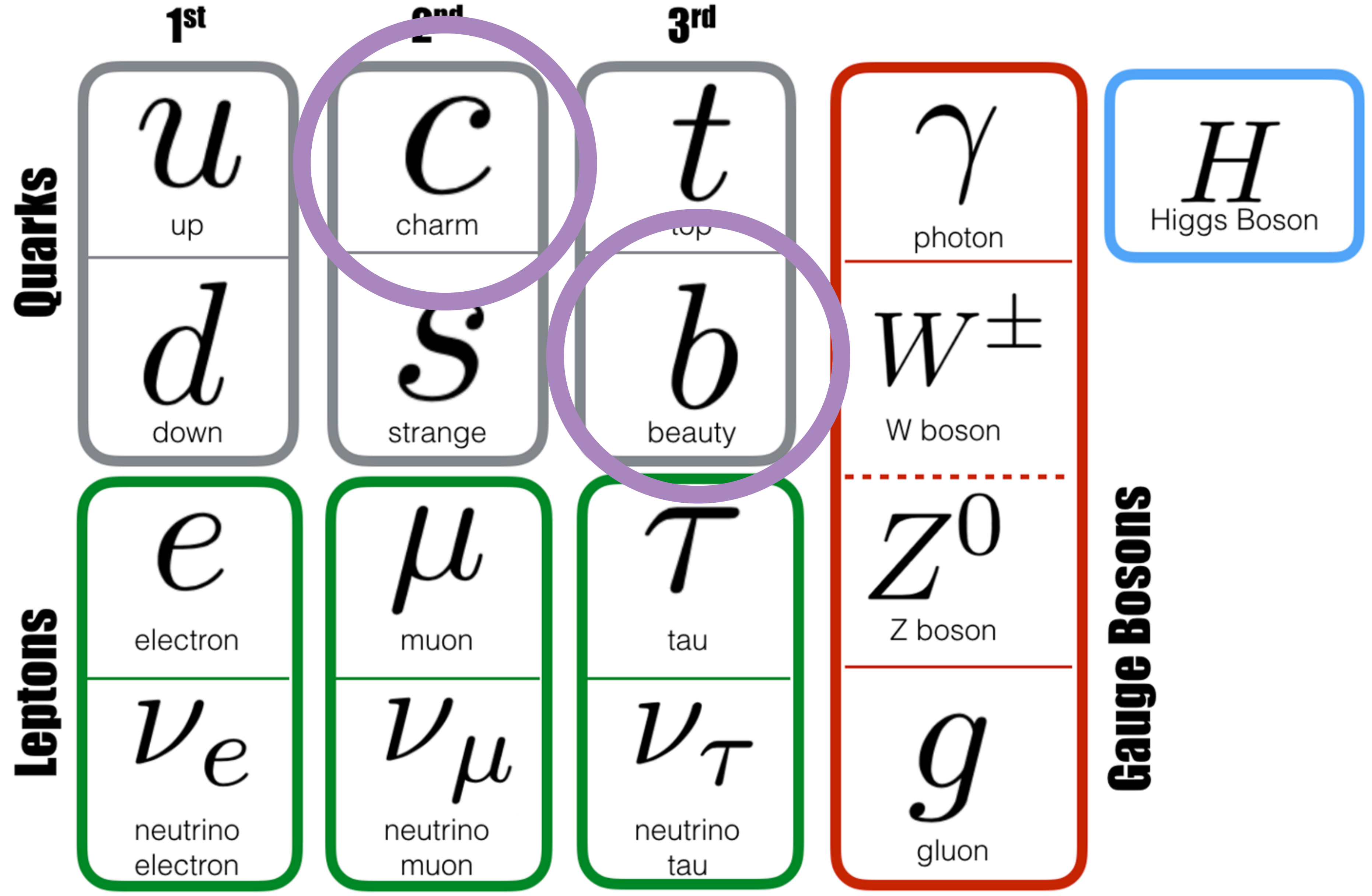


The LHCb detector

- The LHCb detector is specialised in **heavy flavour physics**



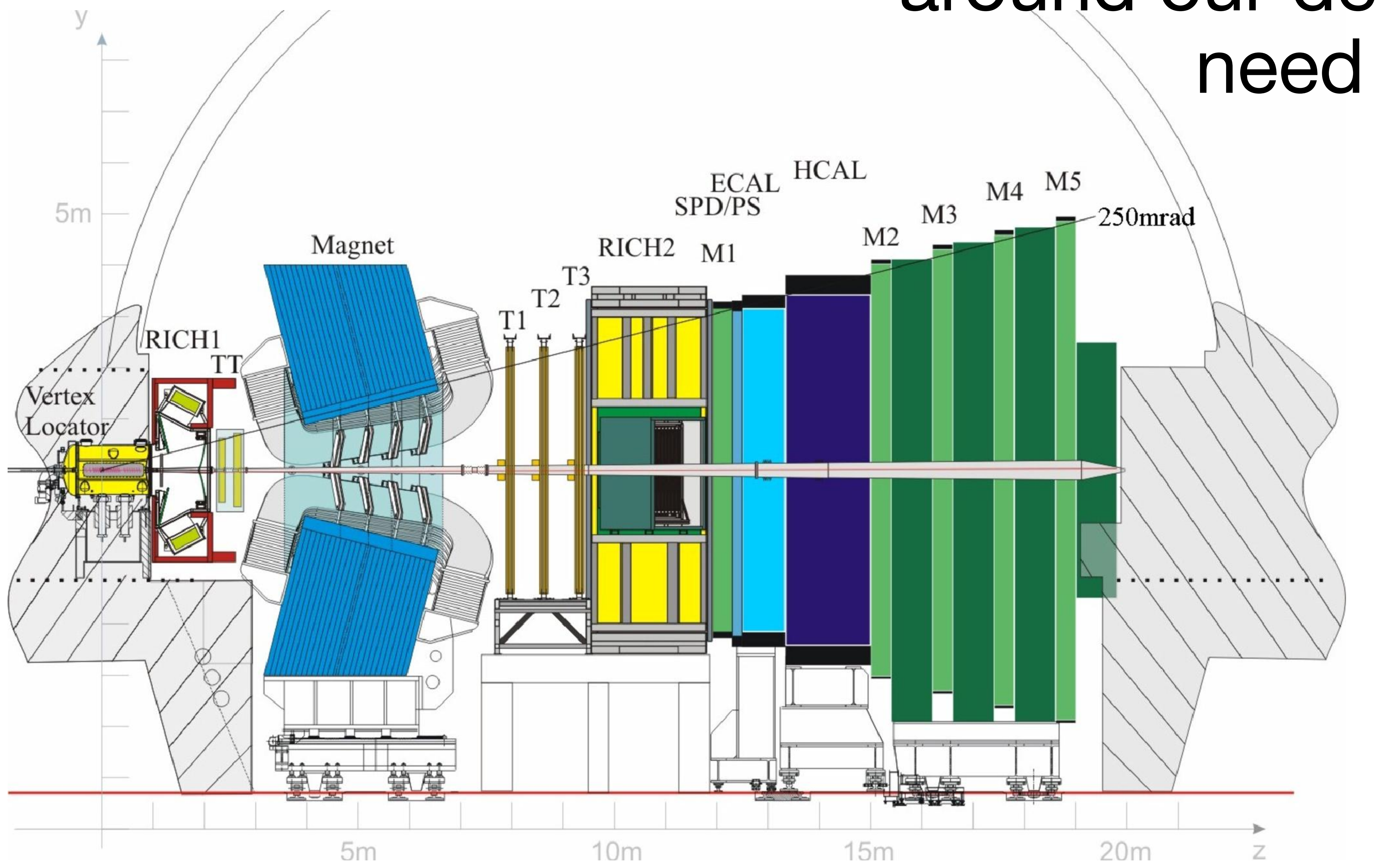




The LHCb detector

- The LHCb detector is specialised in **heavy flavour physics**
  - Lower pileup and luminosity → cleaner event reconstruction

less background events floating around our detector that we would need to get rid of



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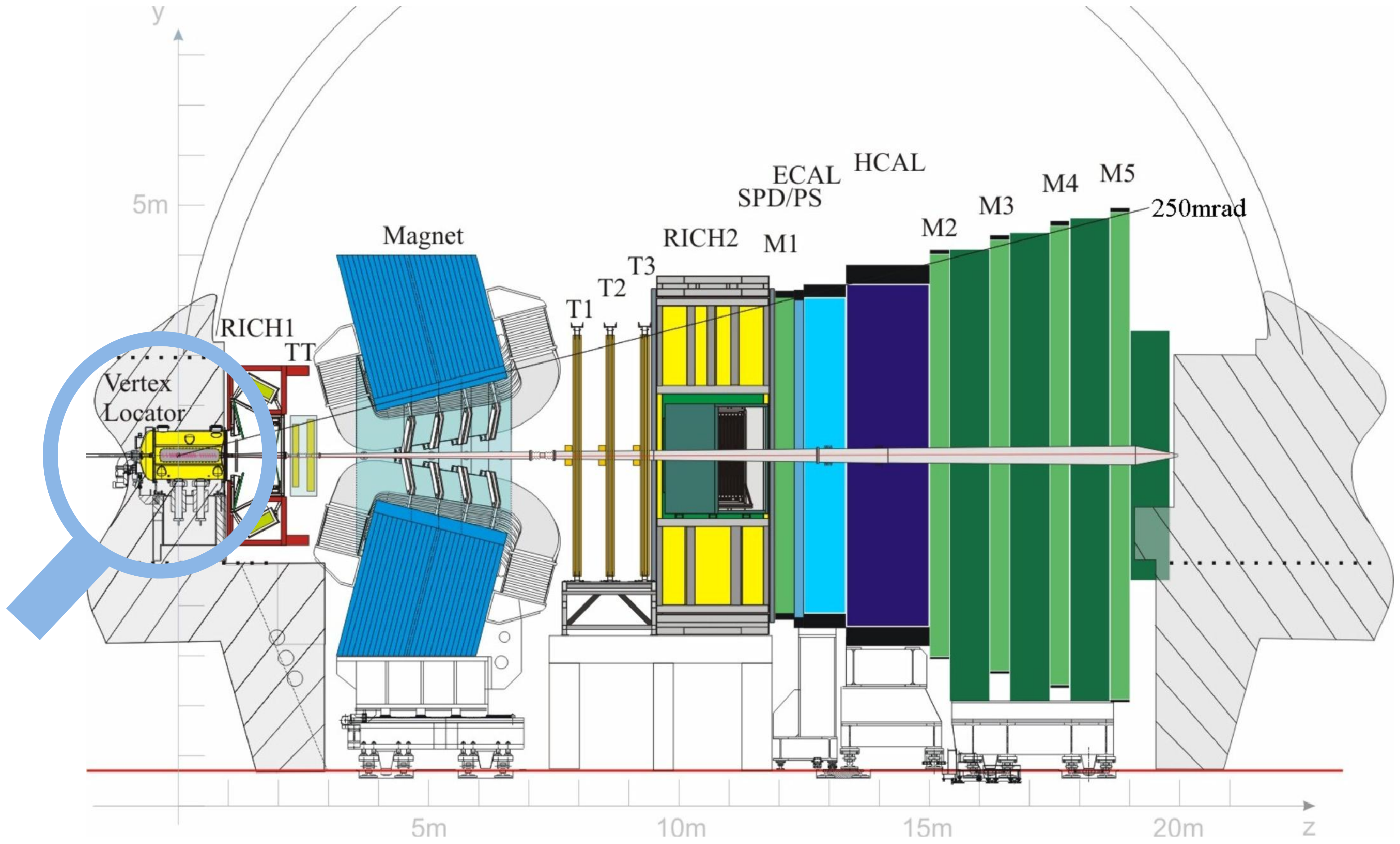

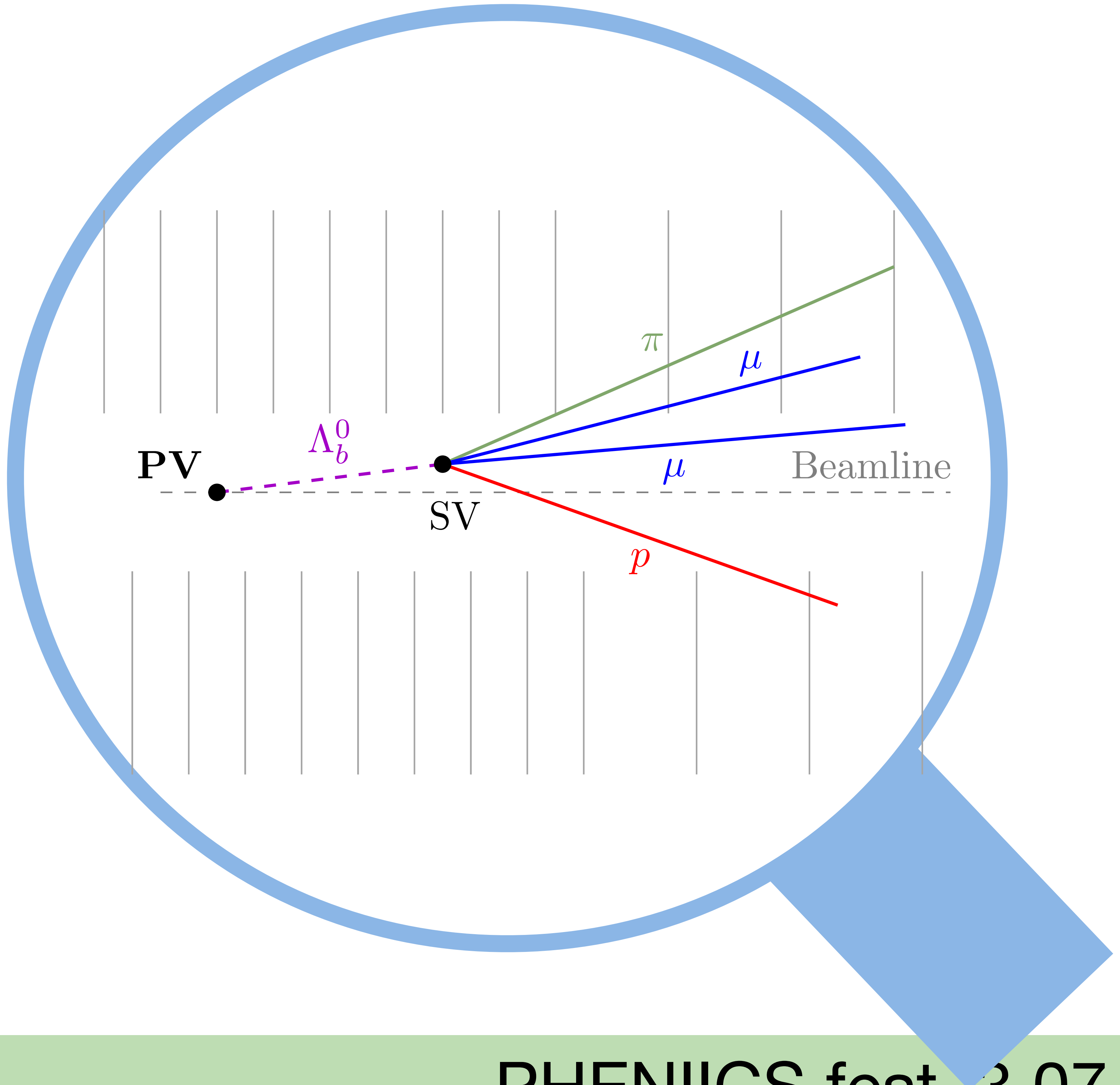

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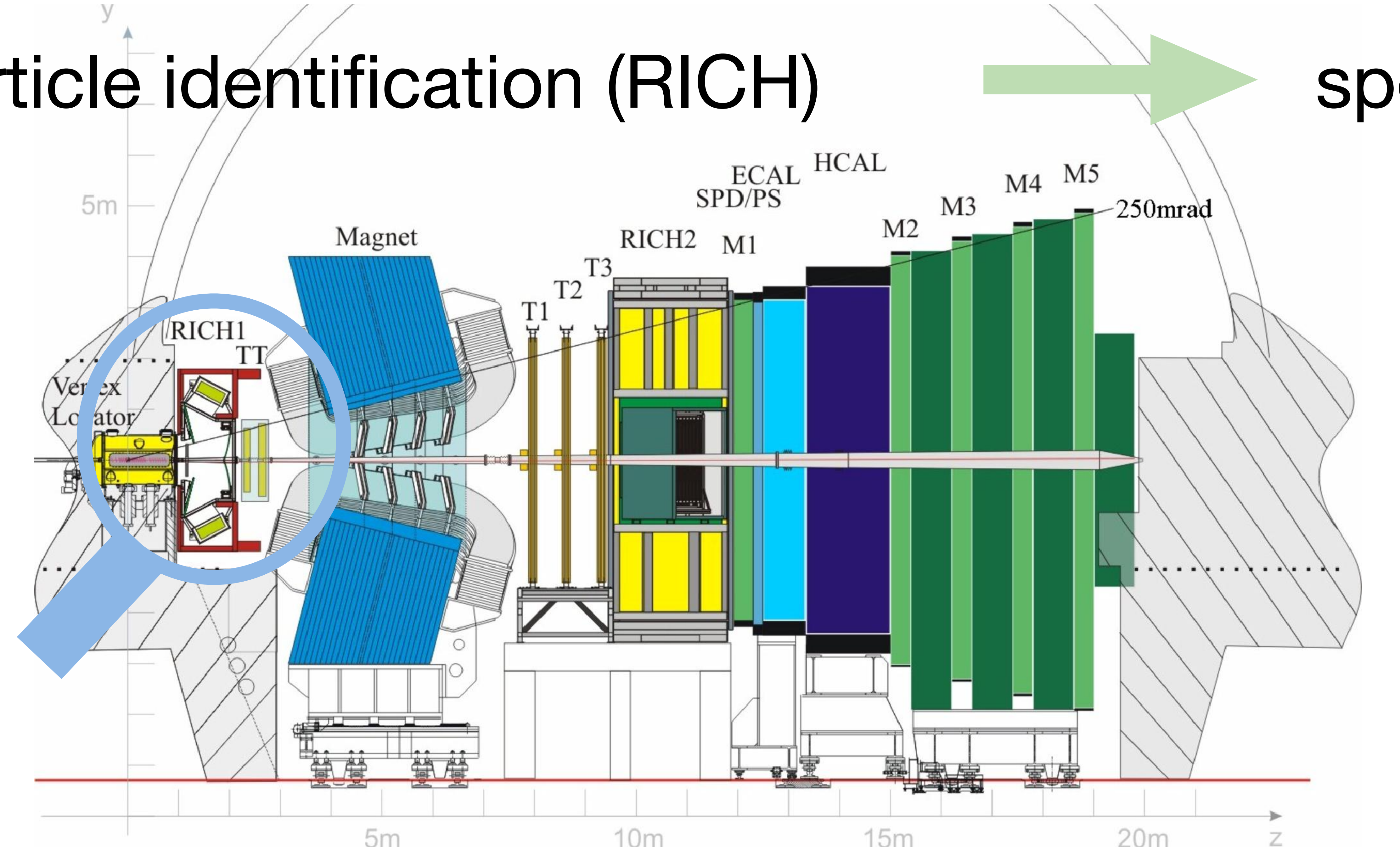
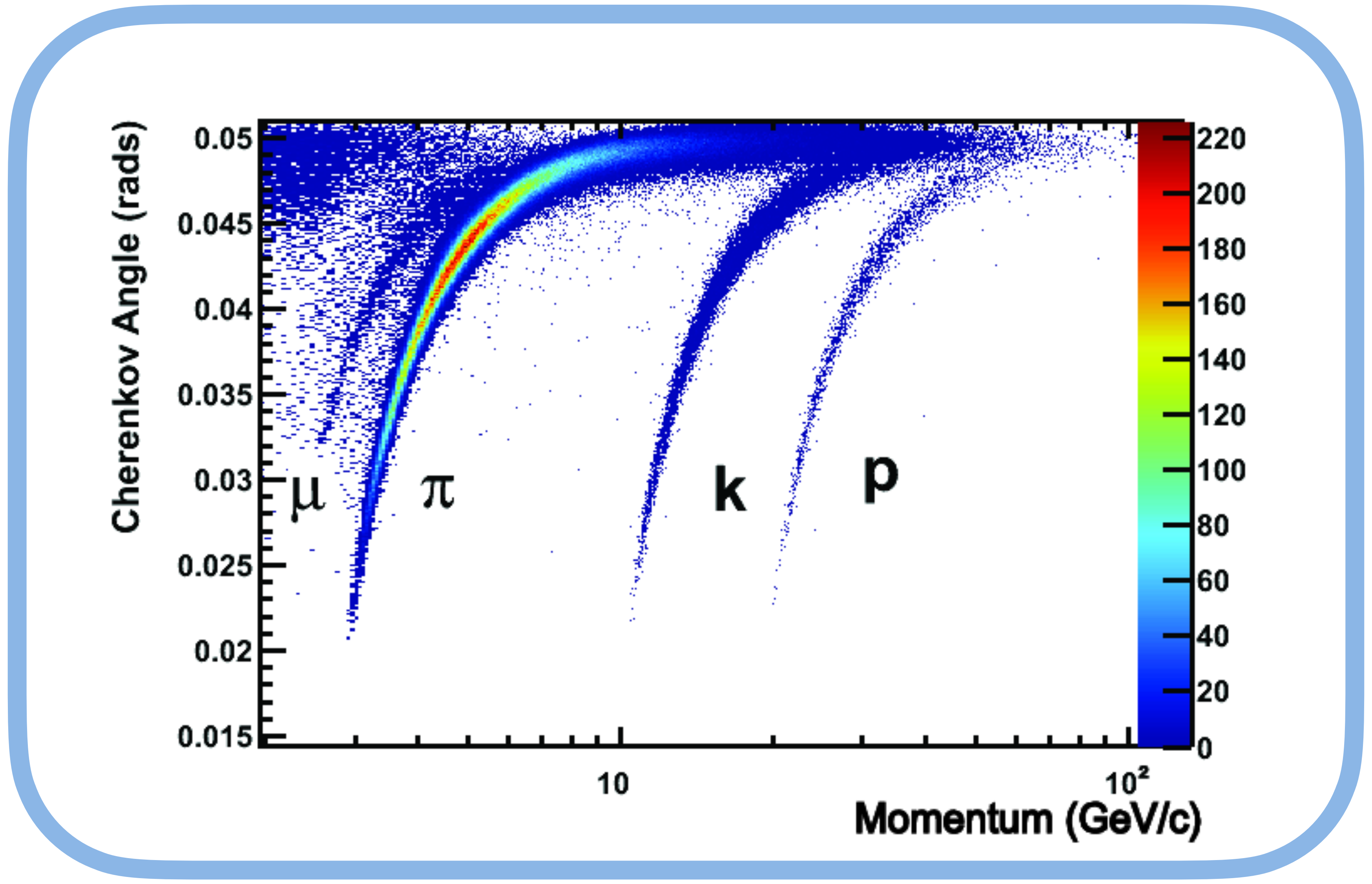
  - Particle identification (RICH) → specialised in distinguishing p, K and π





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- Studies performed at LHCb
  - CP violation*
  - Rare decays
  - Lepton Flavour Universality tests (e, μ and τ!)

*hence our very cool logo!!

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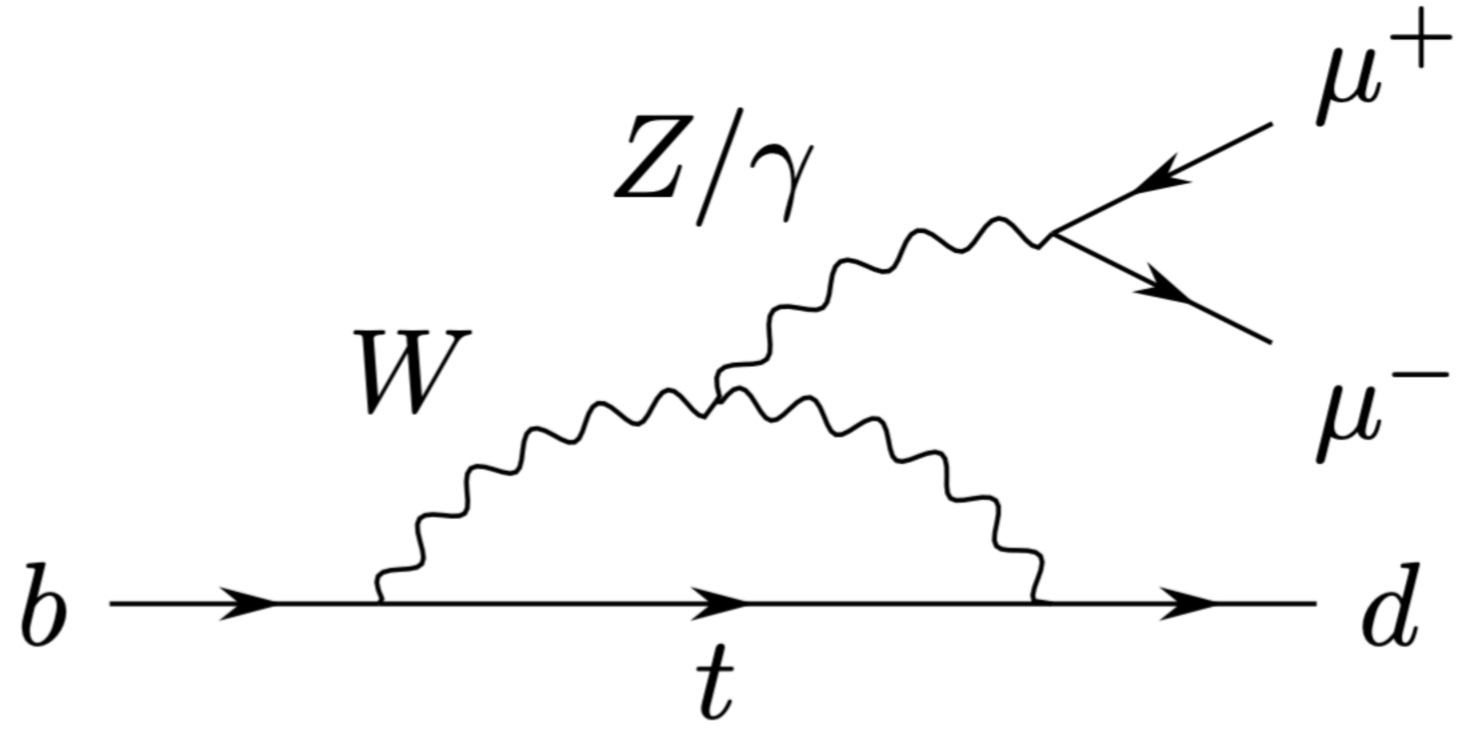
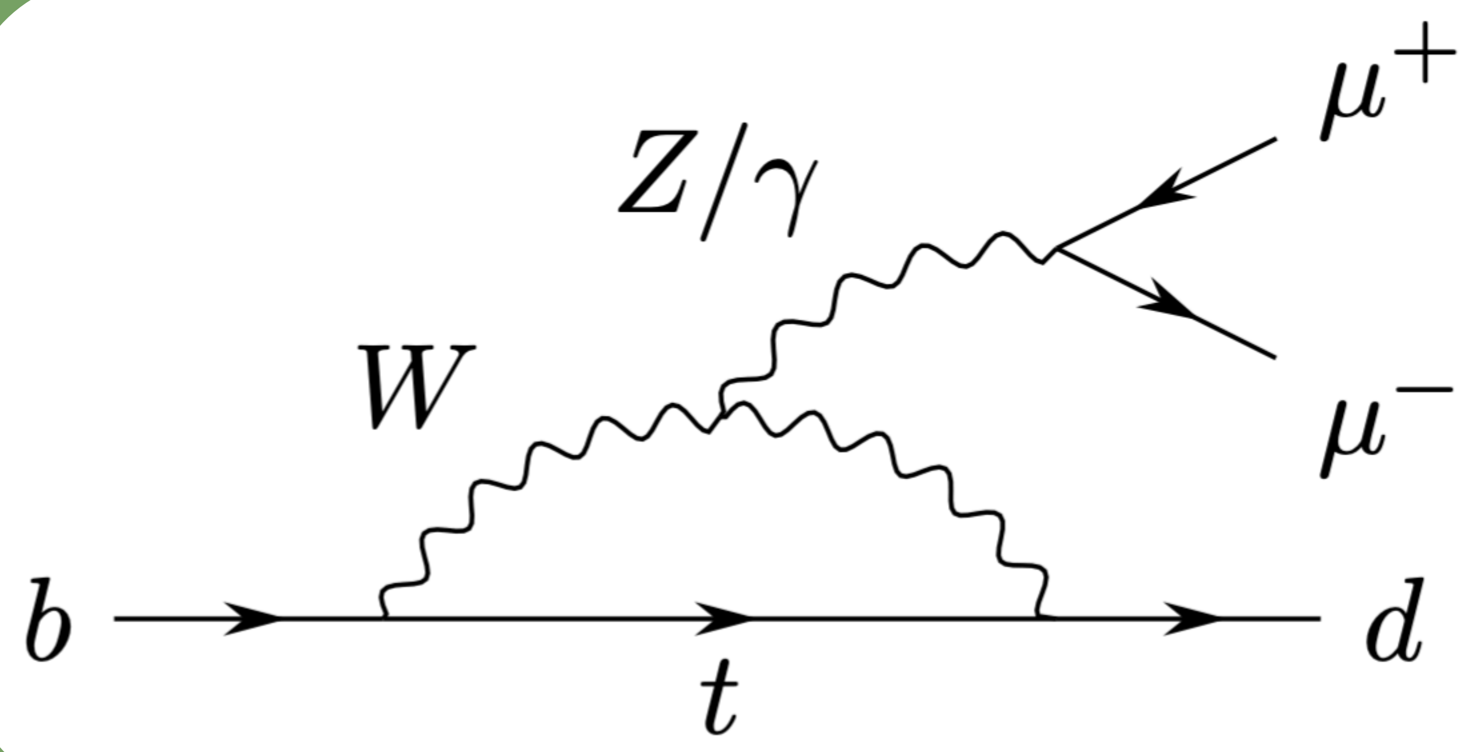
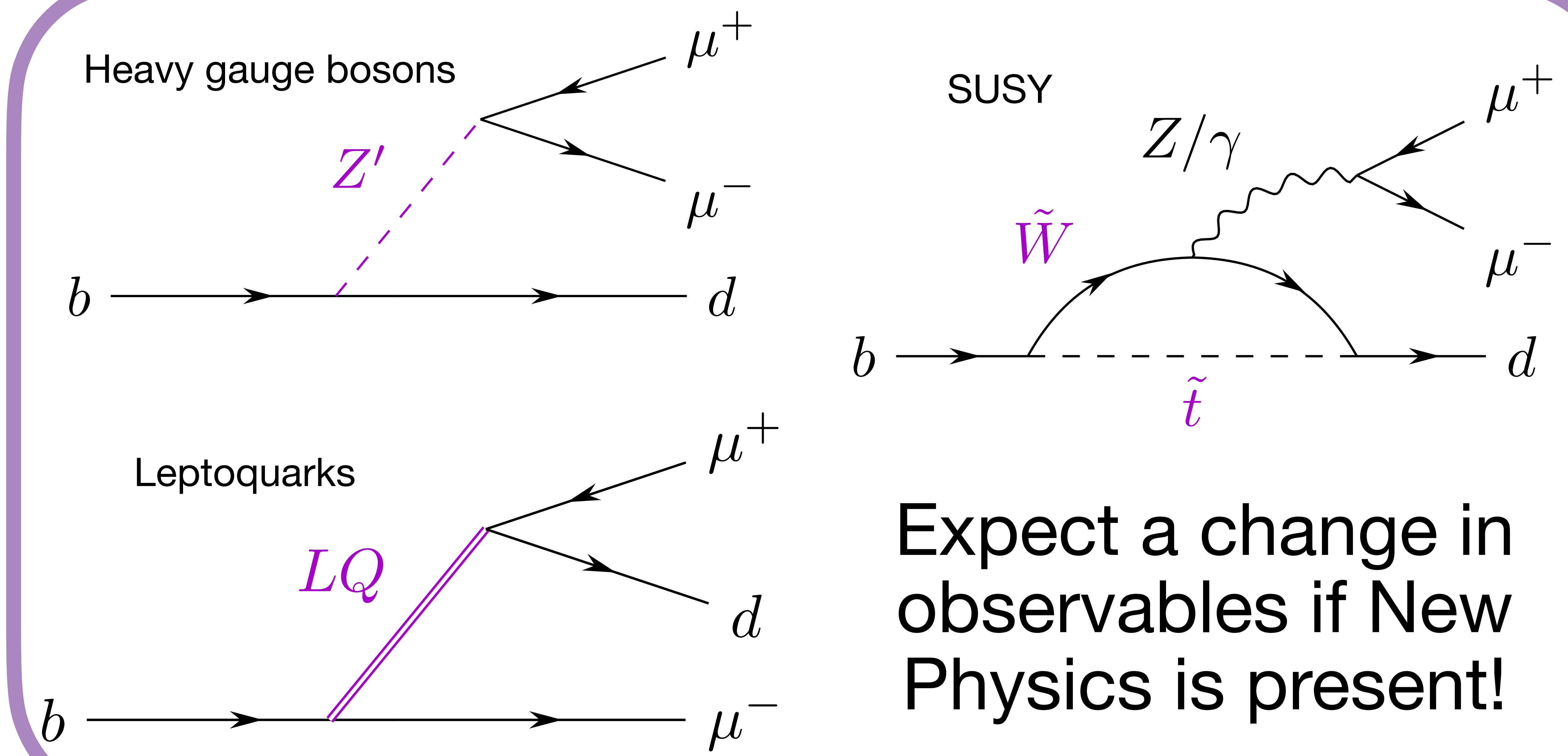


Rare decays

- Rare decays diagrams have small branching fractions $\mathscr{B}$ in the **Standard Model**
- Very sensitive probes for **New Physics**
- $b \to sl^+l^-$ have been extensively studied and $b \to dl^+l^-$, suppressed by a $|V_{td}/V_{ts}|^2 \sim 4\,\%$ factor are starting to be investigated further now



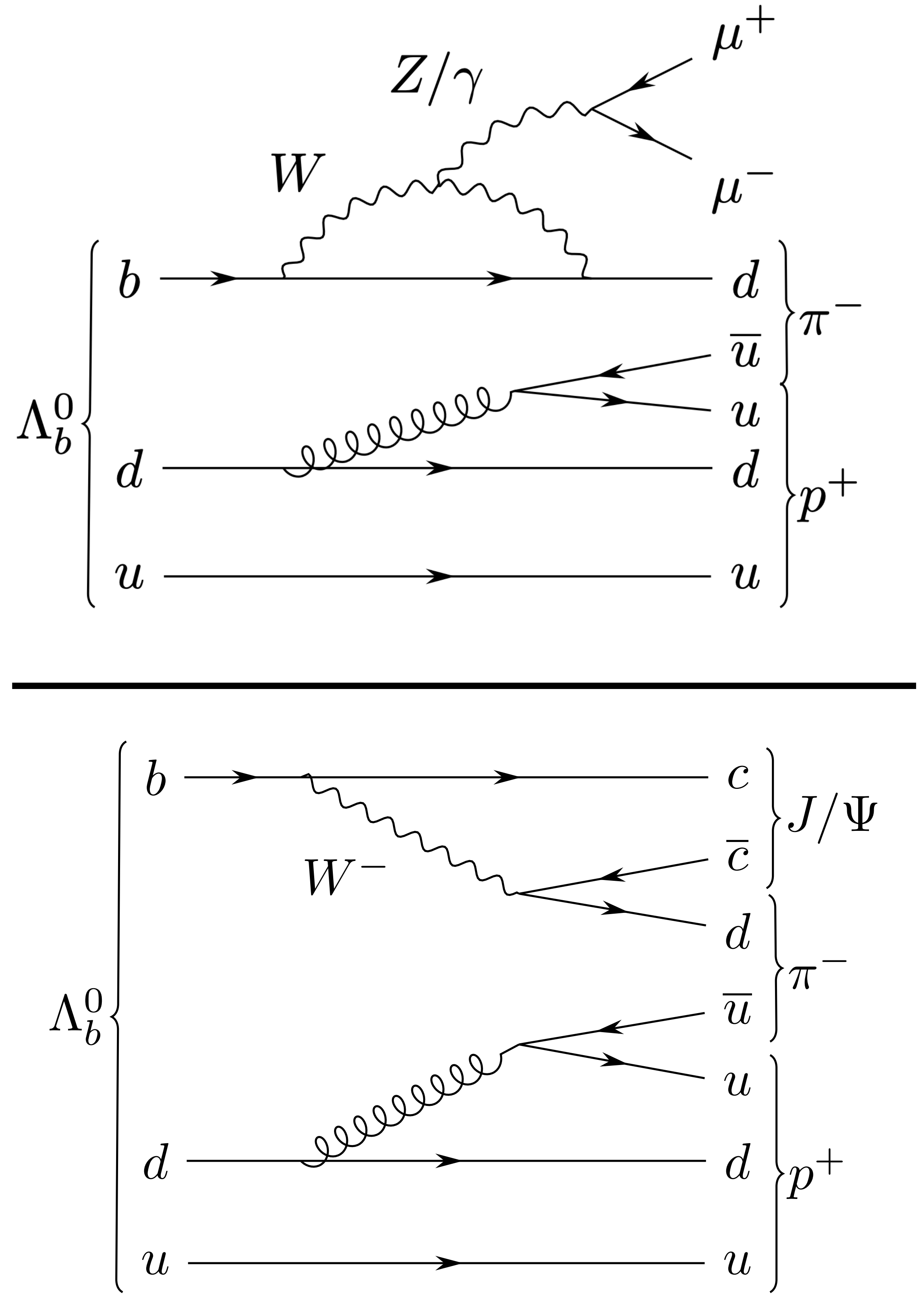


Expect a change in observables if New Physics is present!

My decay

$$\frac{\mathscr{B}(\Lambda_b \to p\pi\mu\mu)}{\mathscr{B}(\Lambda_b \to p\pi J/\psi(\to \mu\mu))}$$

- $b \to d\mu\mu$ transition using Λ_b^0 baryon
- **Main goal**: perform a branching fraction measurement with Run1 (2011-2012) and Run2 (2015-2016-2017-2018) data with respect to $\Lambda_b^0 \to p\pi J/\psi(\to \mu^+\mu^-)$
- Extra goals:
    - Branching fraction measurements in bins of di-muon mass squared q^2
    - Direct CP asymmetry between $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ and $\bar{\Lambda}_b^0 \to \bar{p}\pi^+\mu^-\mu^+$
    - Study the hadronic $p\pi$ spectrum



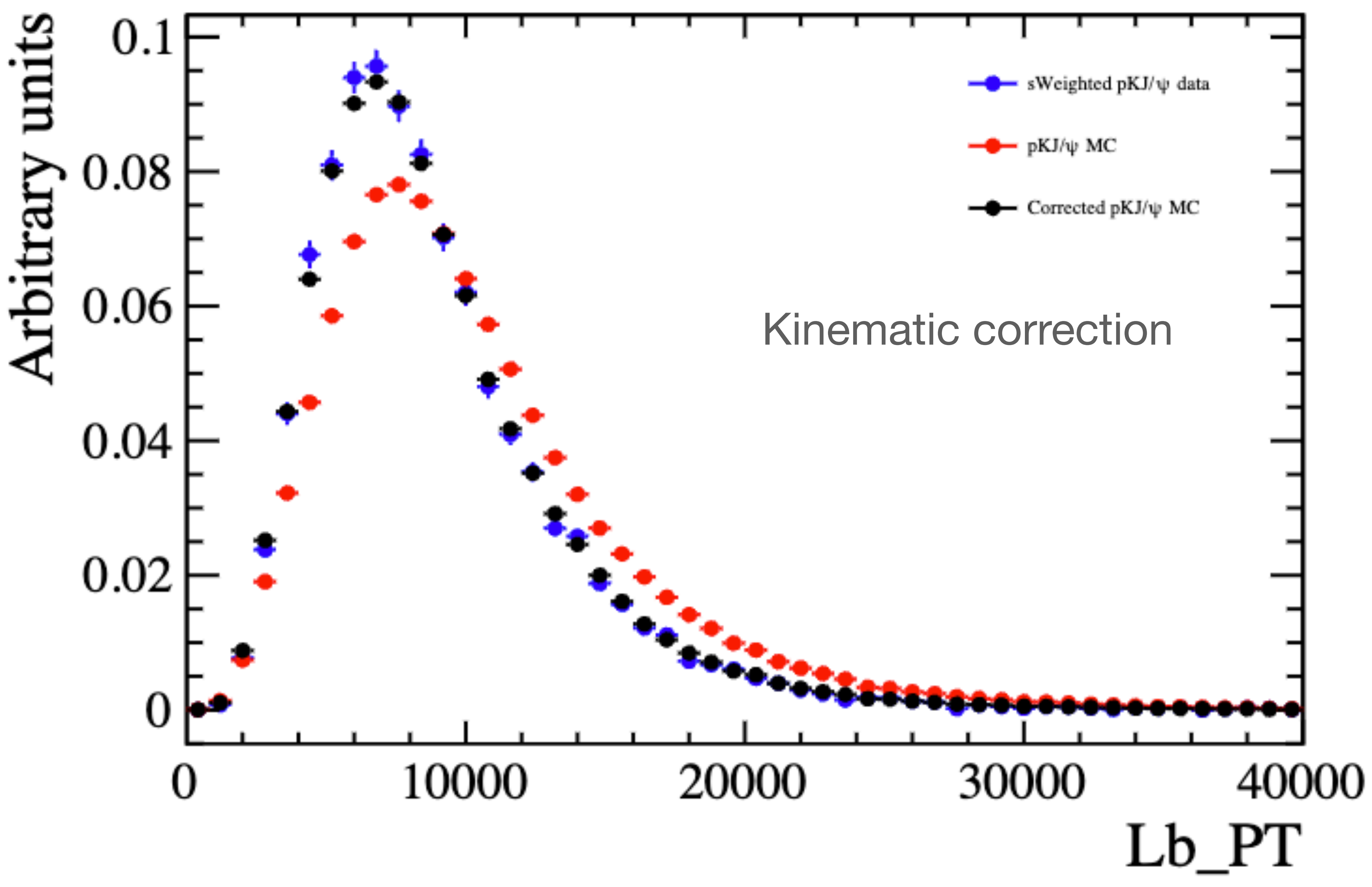
An analysis in LHCb

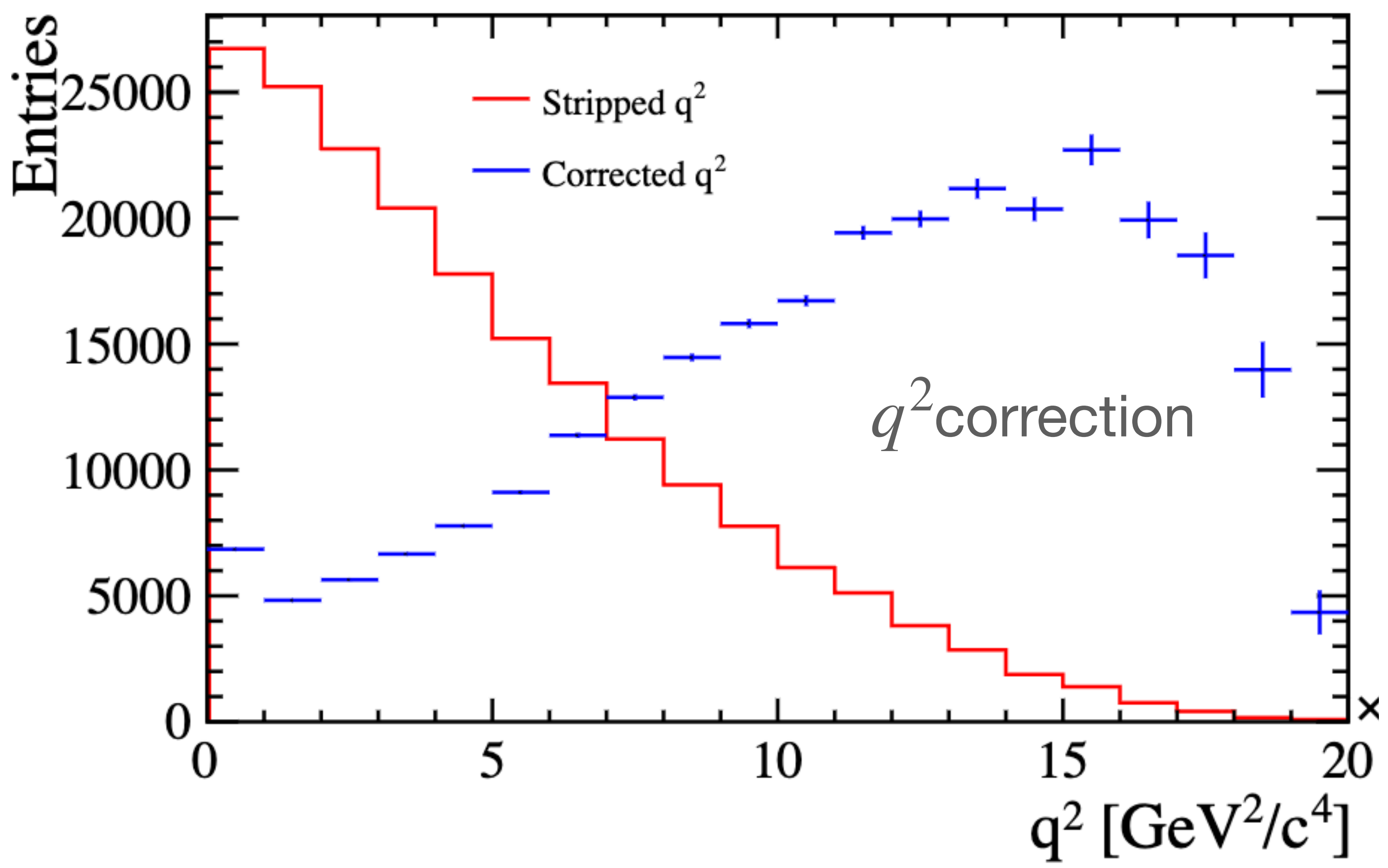
- Previous analysis published by LHCb using only Run1 data
- Data used in this analysis was taken with the LHCb detector in Run1 (2011-2012) and Run2 (2015-2016-2017-2018)
- Monte Carlo for the most prominent background sources and signal was used to model the shapes and compute efficiencies

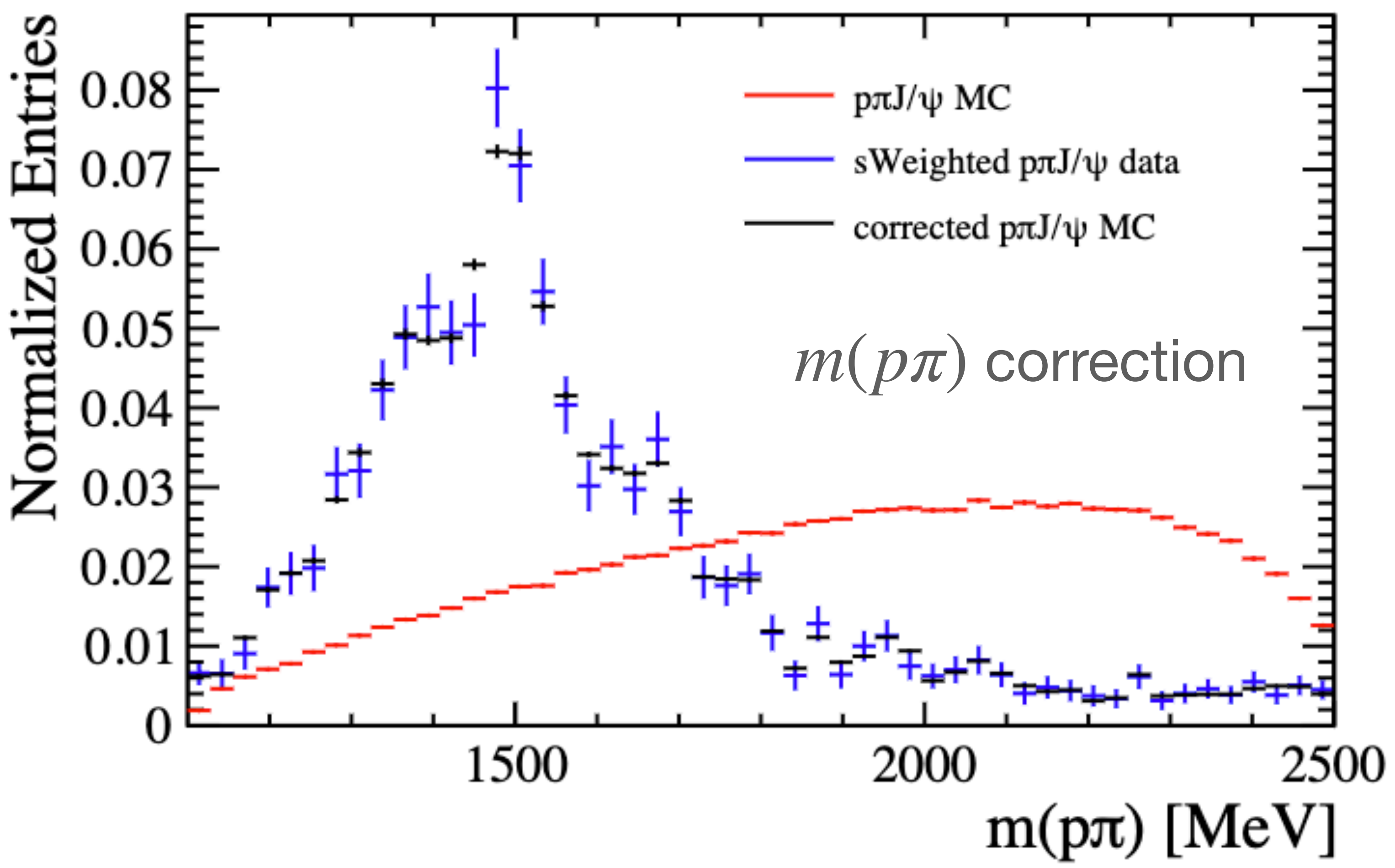
Task	Run 1	Run 2
Data production	✅	✅
Simulation corrections	✅	✅
Background studies	✅	✅
Multi variate analysis	✅	✅
Efficiencies	✅	✅
Fits & yields	🔄	🔄
Toys	🔄	🔄
Systematics		

Simulation correction

- Monte Carlo (MC) simulations are used for
  - Shape definition for signal and background
  - Efficiencies estimation
  - BDT training
- MC generation relies heavily on known theory about a decay
  - Baryons like Λ_b^0 are not well modelled yet in theory
  - MC does not agree with real data
- What we corrected:
  - Kinematic (i.e. p^{Λ_b}, $p_T^{\Lambda_b}$, τ^{Λ_b}, nTracks)
  - Di-muon squared invariant mass q^2
  - Hadronic mass spectrum $m(p\pi)$

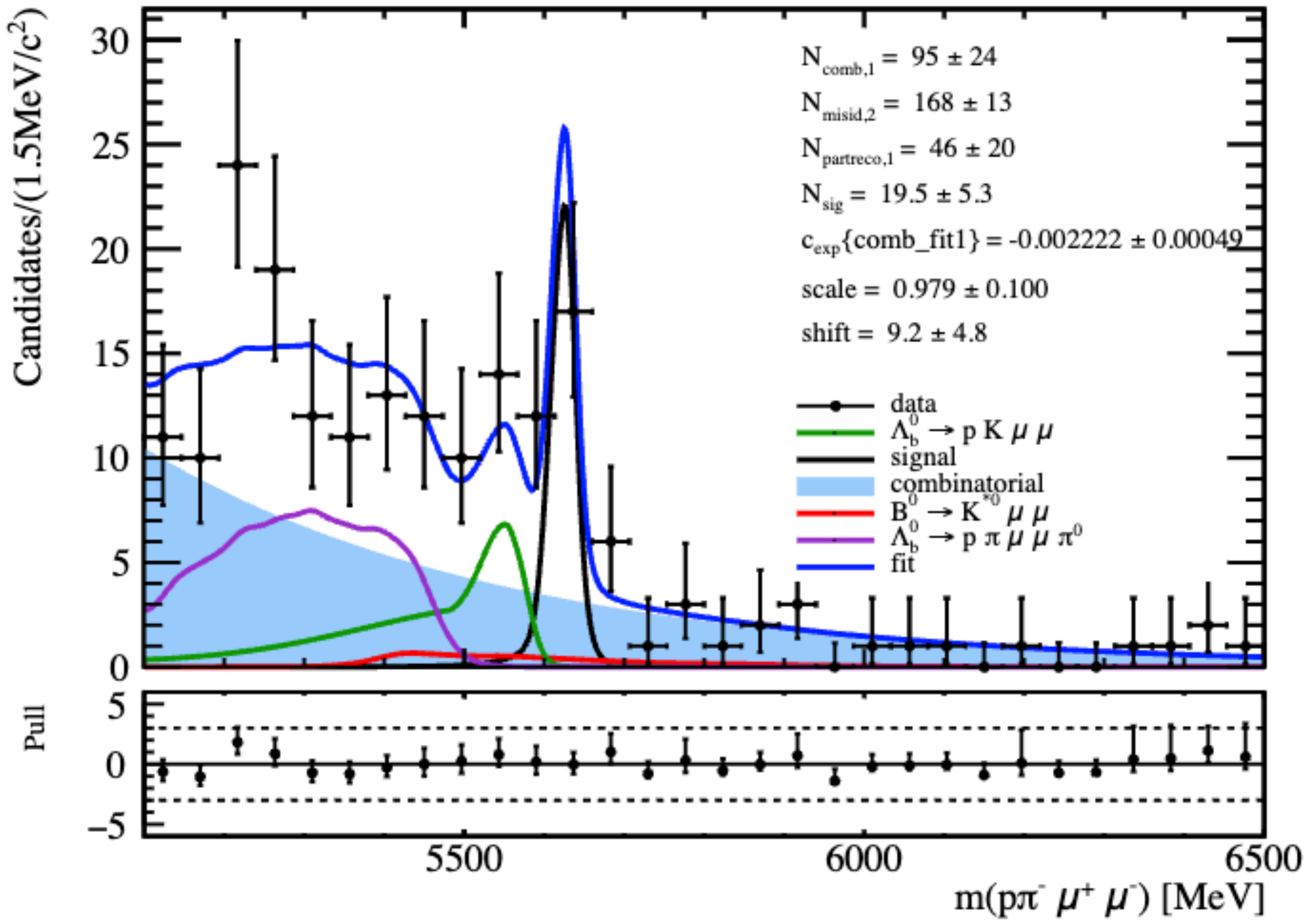






Background studies

- Even if LHCb presents a clean environment we still have remaining backgrounds that we need to get rid of / model in our fit



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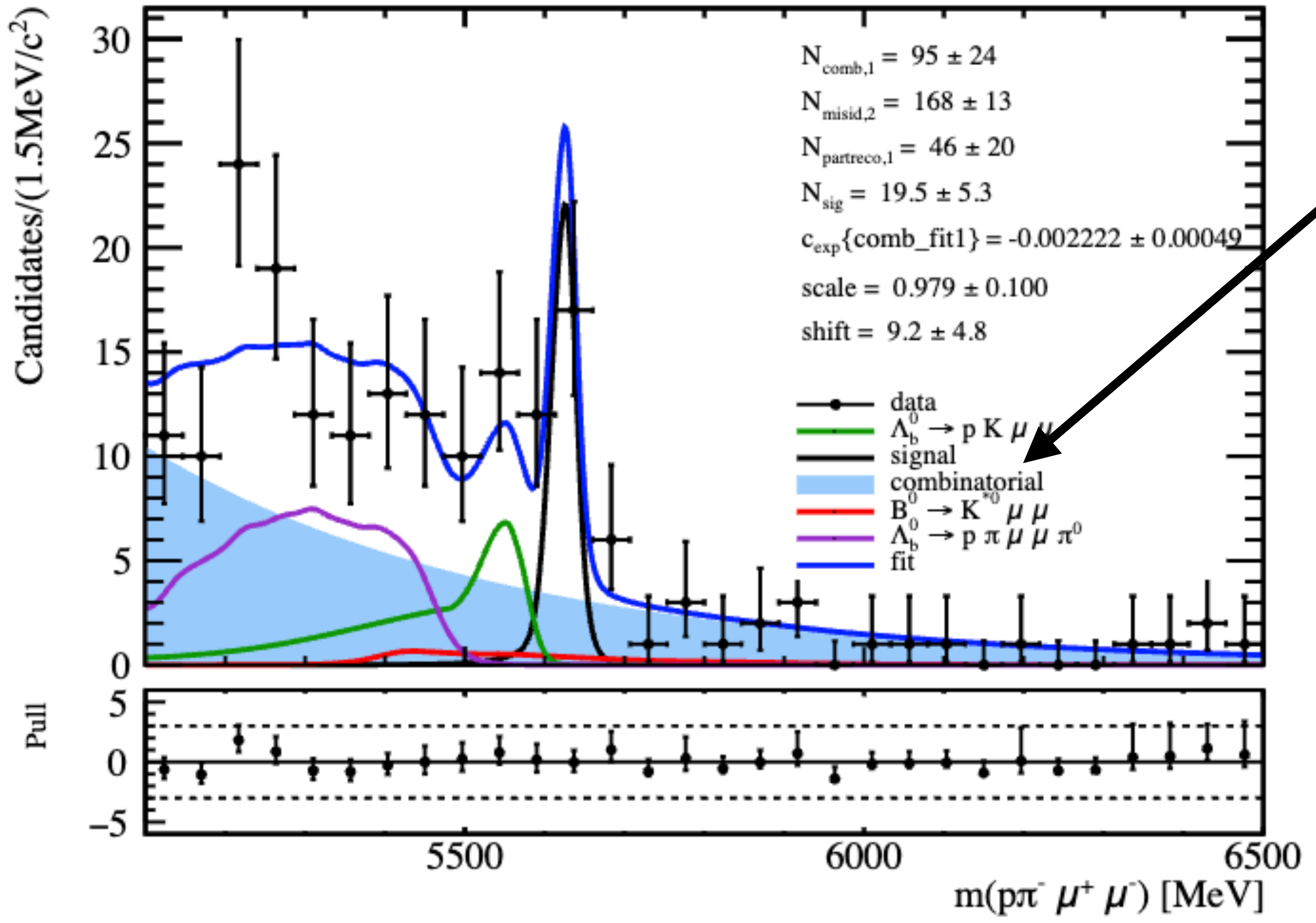

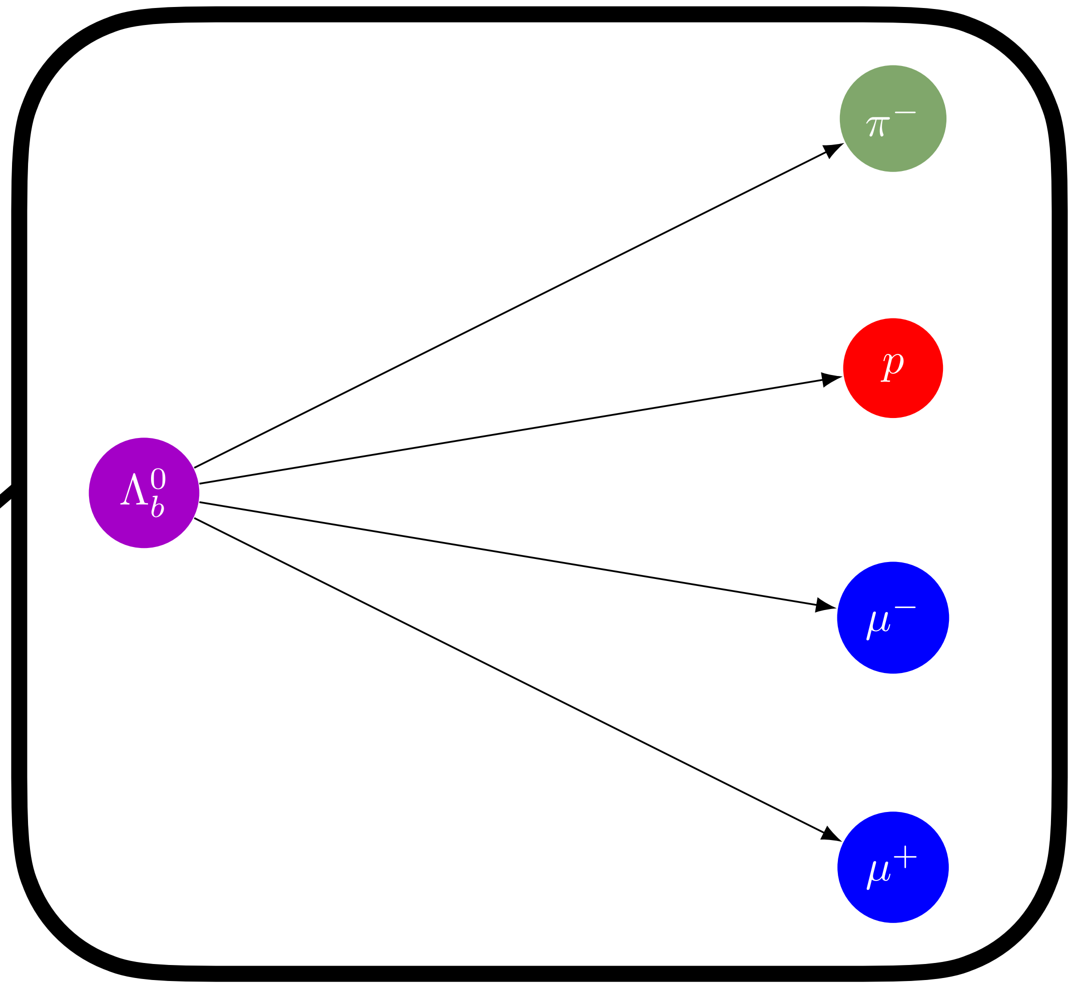

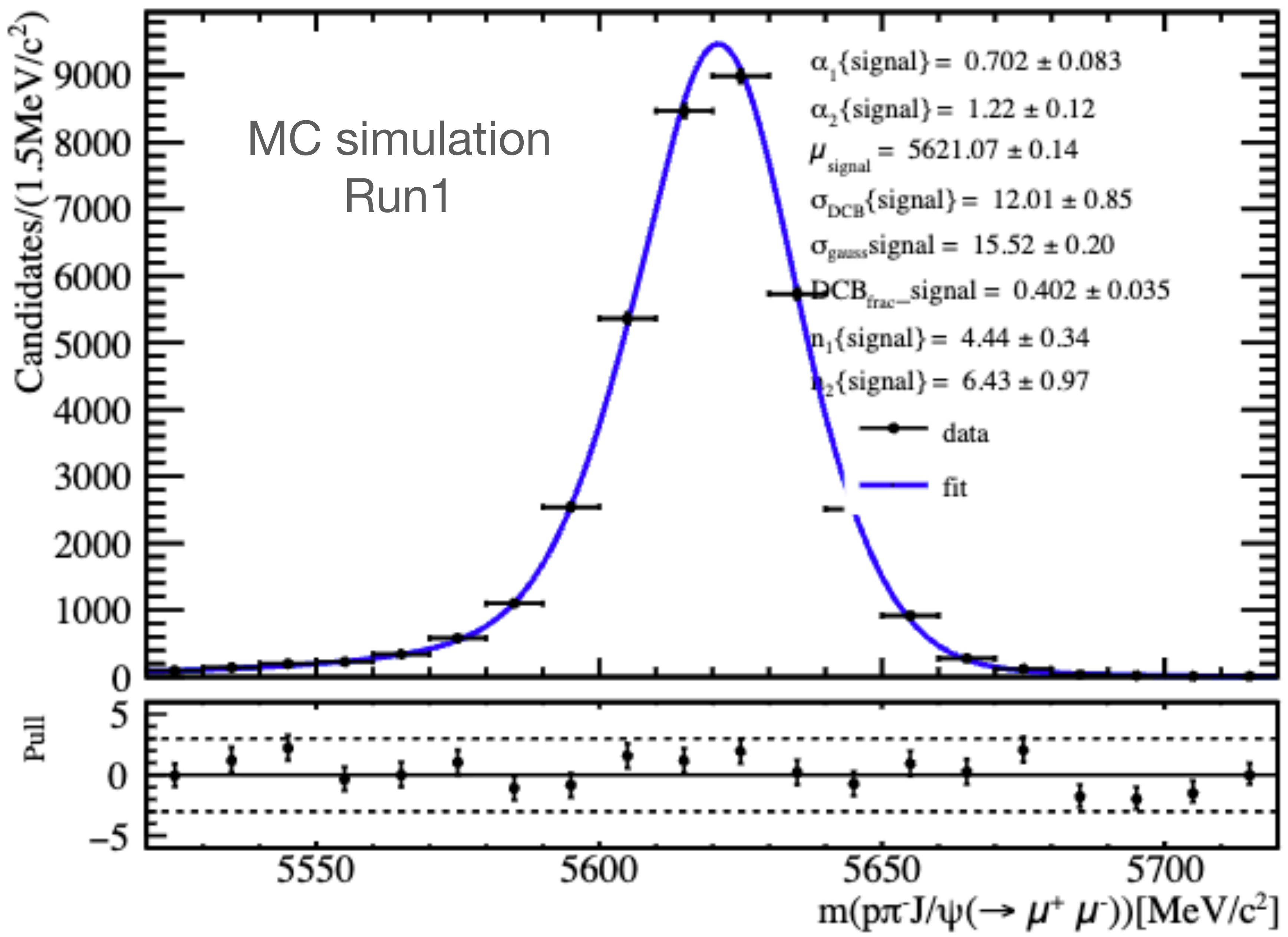

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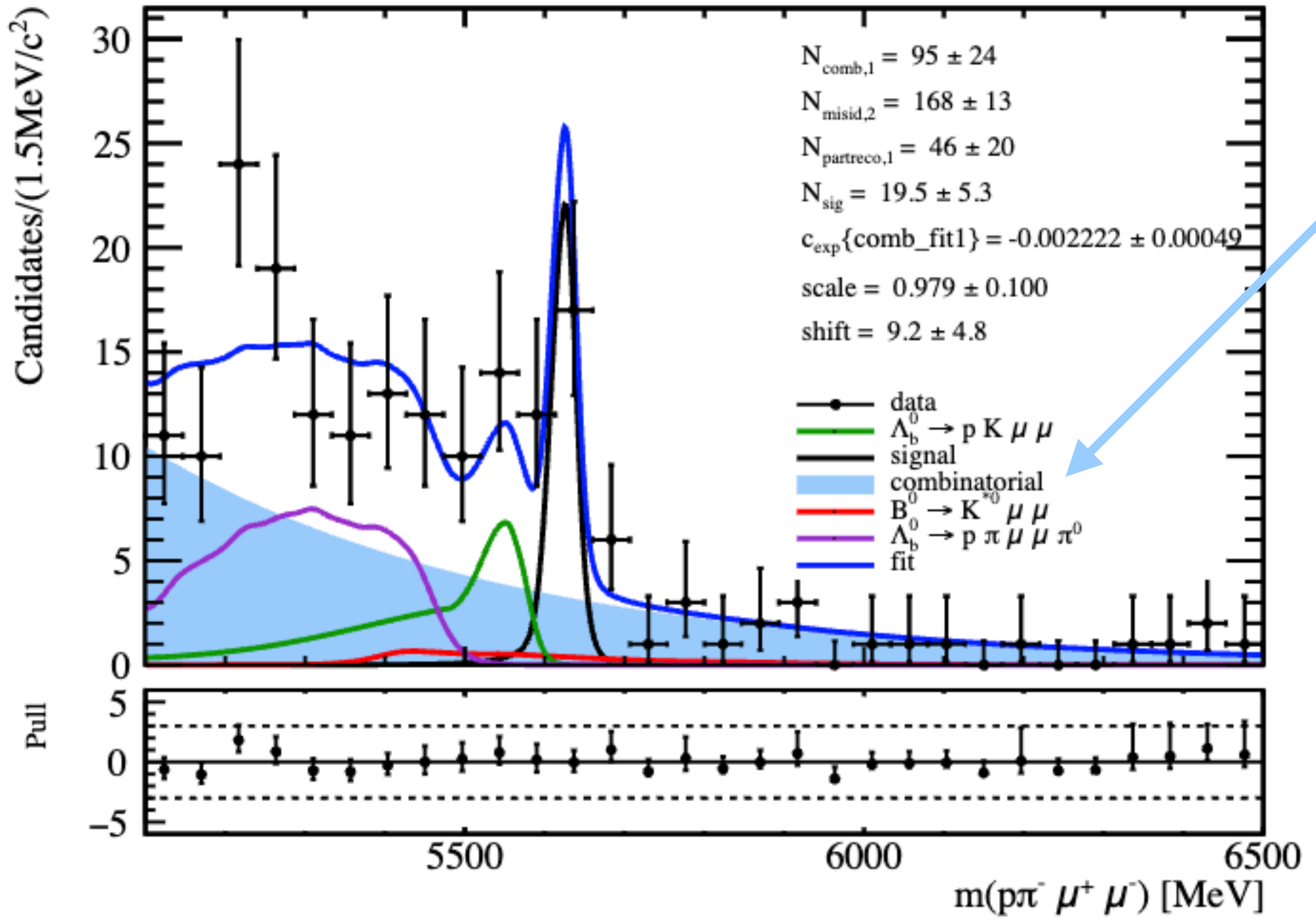
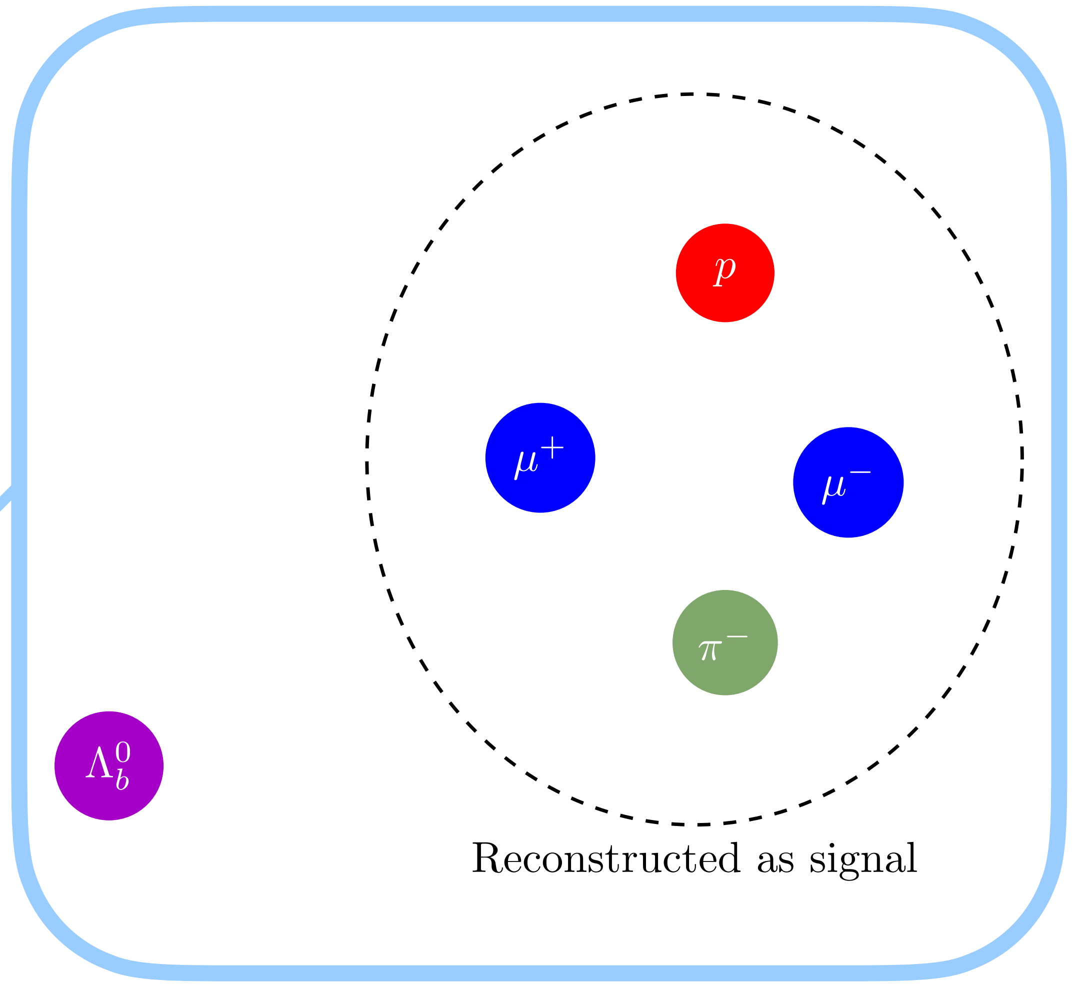
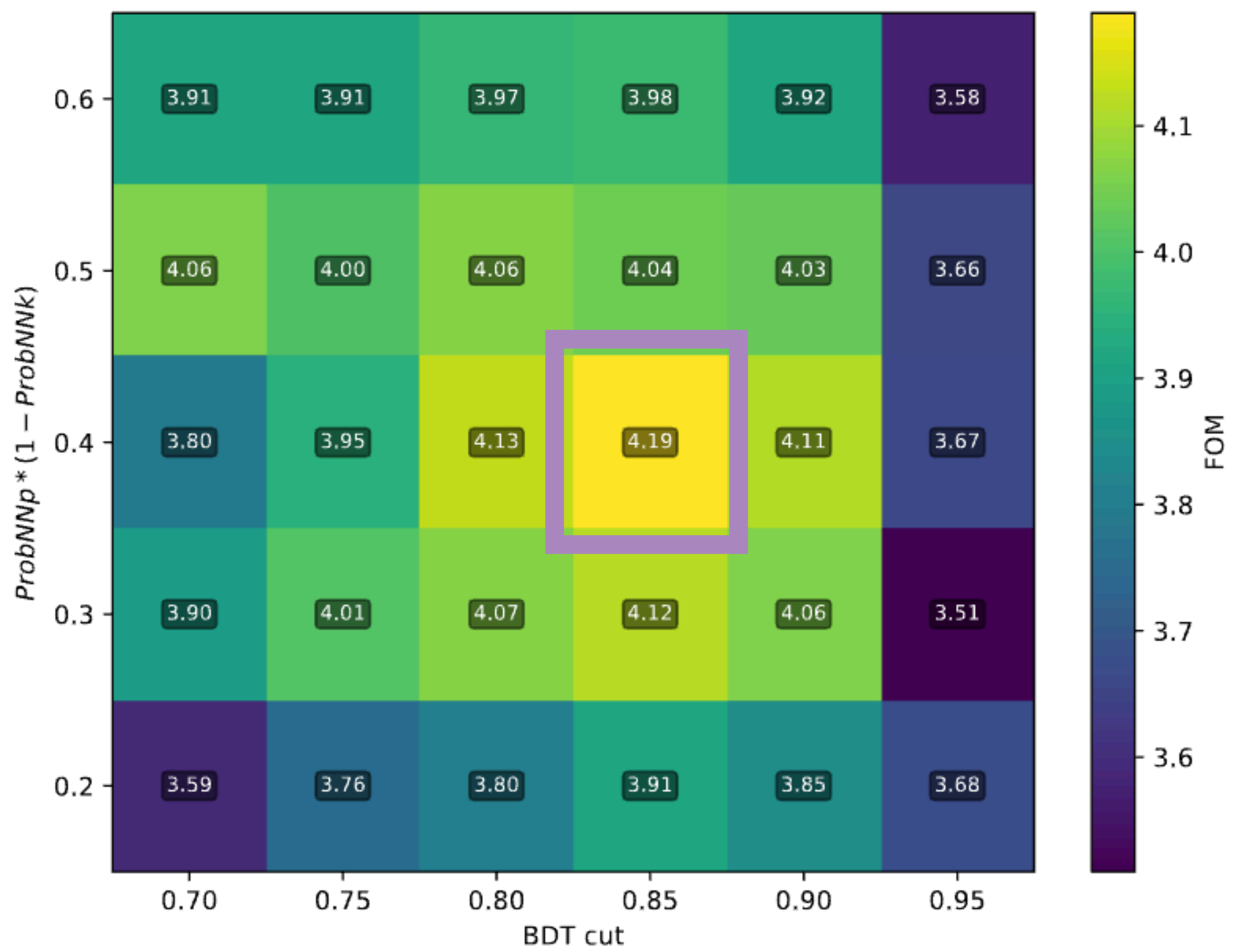




- 2D optimisation between the output of a **BDT** trained on kinematic variables and **proton particle identification** variables

$$FOM = \frac{S}{\sqrt{S+B}}$$



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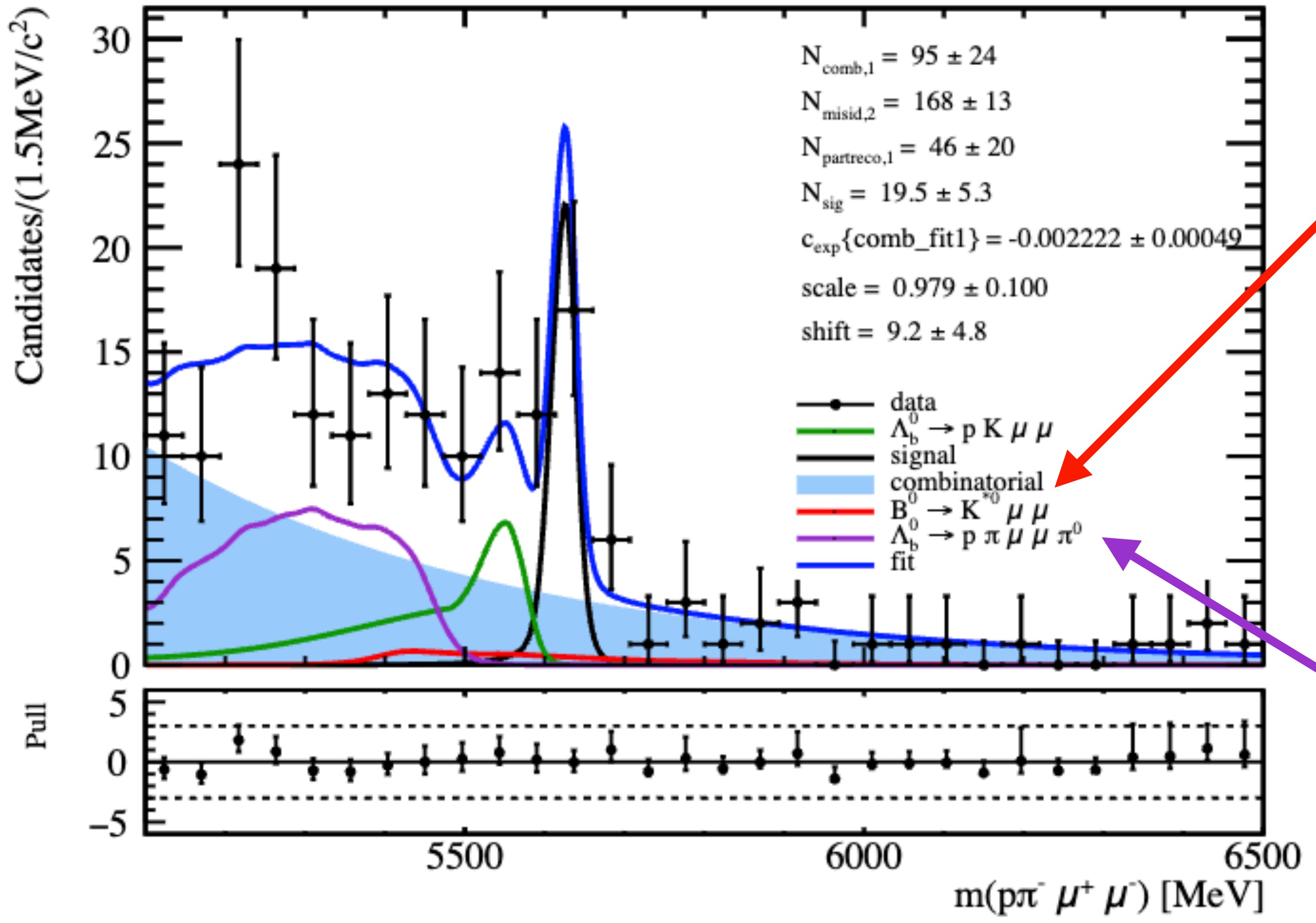
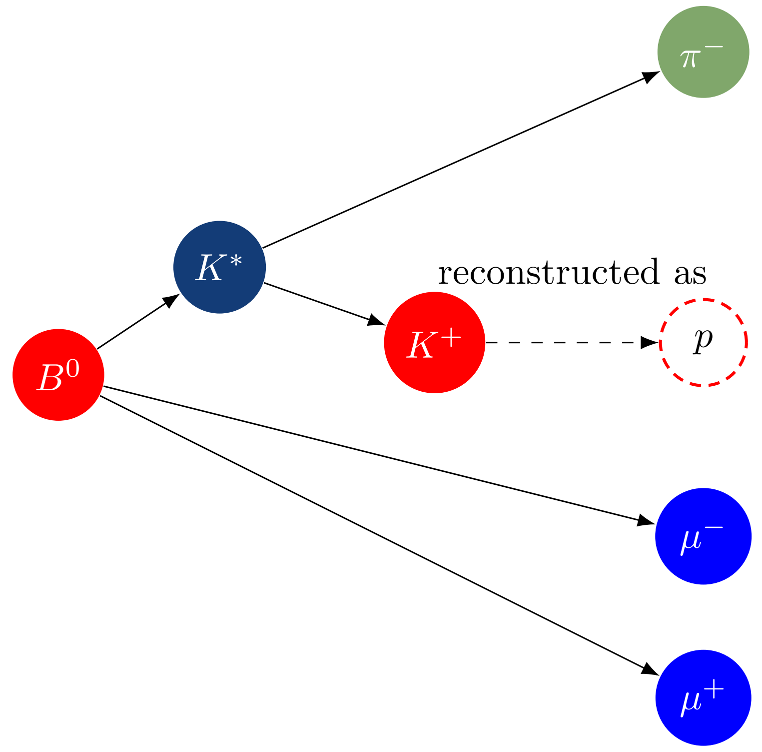
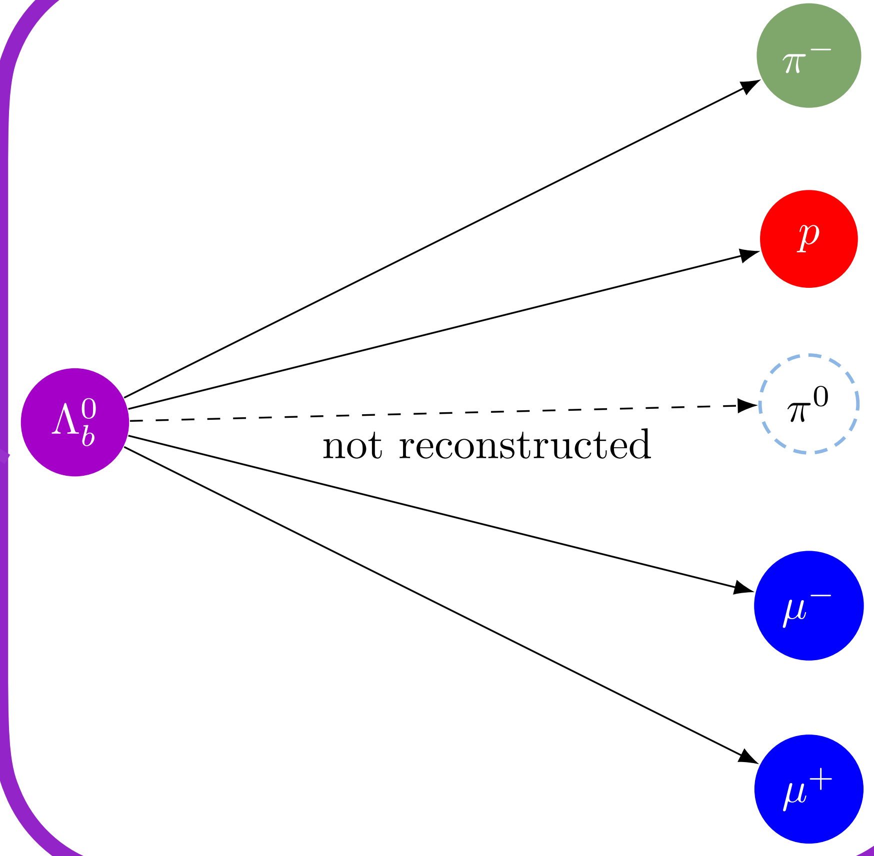
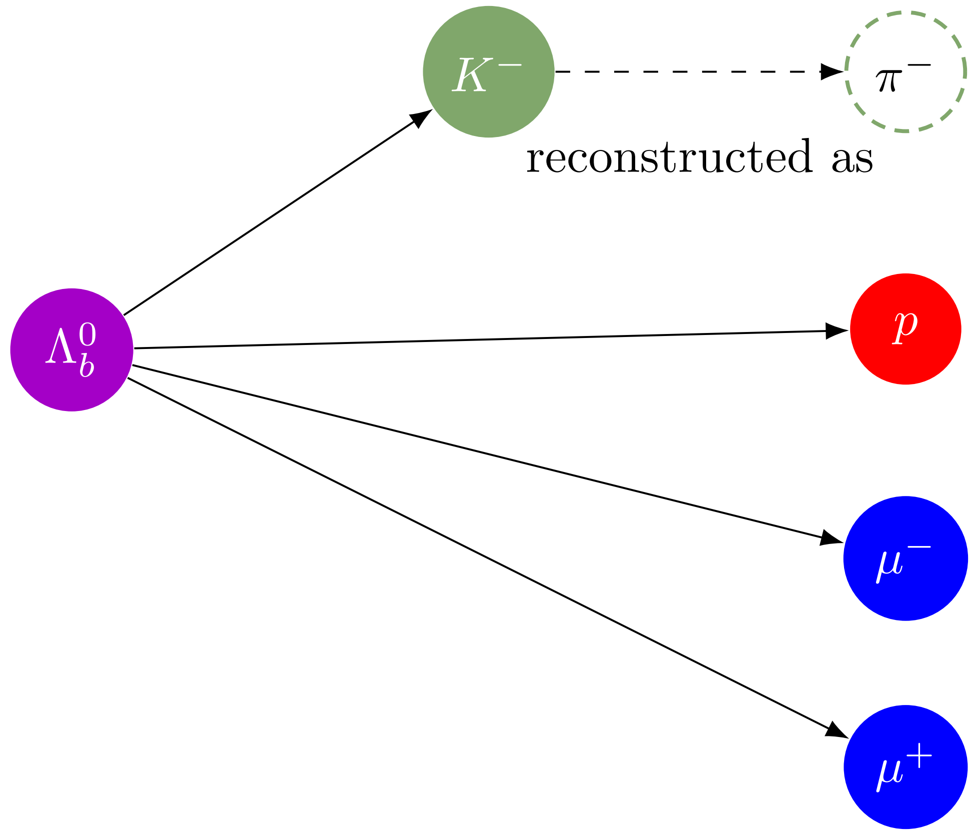








MisID modelled in signal data ($p\pi\mu\mu$). In addition the signal data $p\pi\mu\mu$ is simultaneously fit with $pK\mu\mu$ data to constrain scale, shift and amount of misID.

Simultaneous fit

- For fit stability the final fit on data is performed simultaneously between the $p\pi\mu\mu$ dataset and the $pK\mu\mu$ dataset

$p\pi\mu\mu$ parameters

$N_{p\pi\mu\mu\pi^0}$

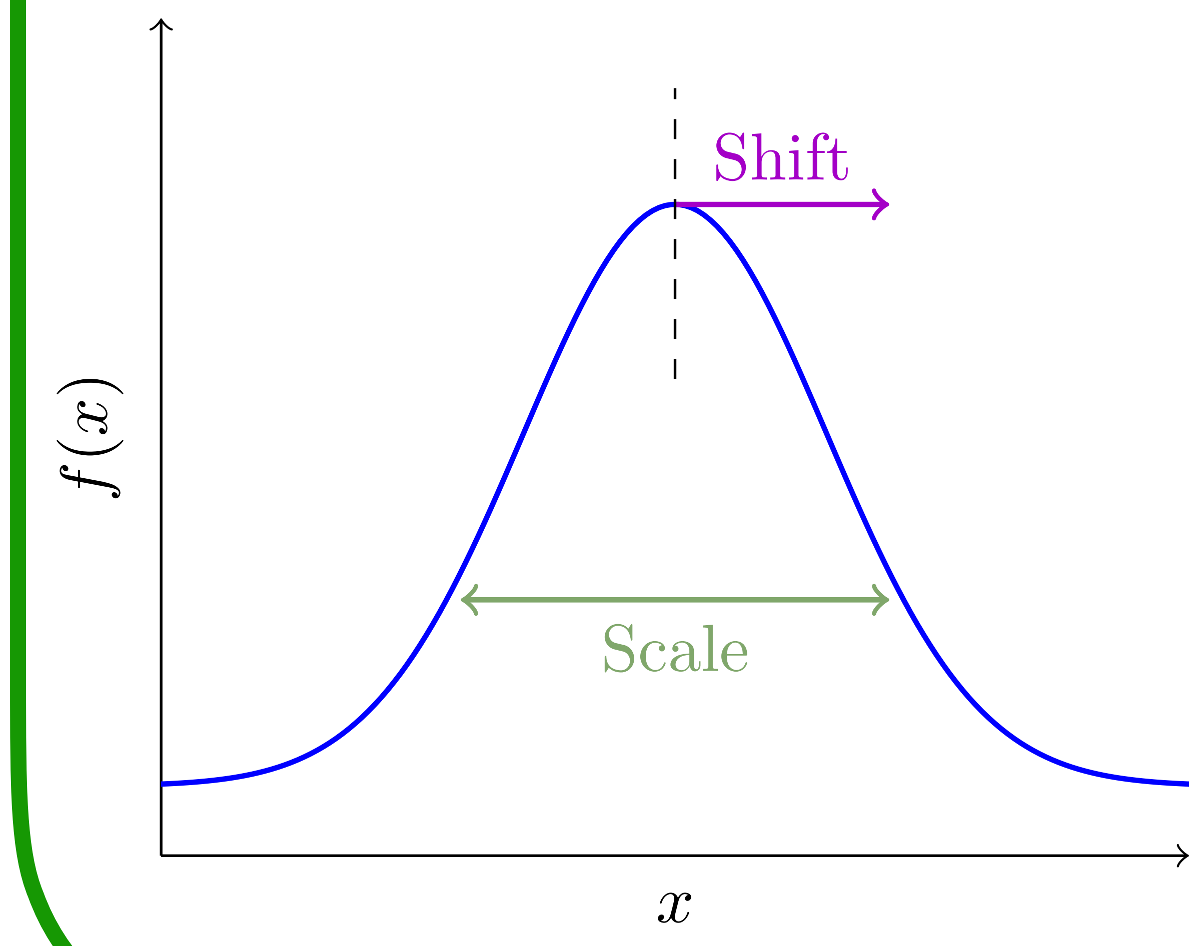
$N_{p\pi\mu\mu}$

$N_{comb;p\pi}$

c_{exp} decay constant

shared parameters

scale shift



$pK\mu\mu$ parameters

$N_{pK\mu\mu\pi^0}$

$N_{pK\mu\mu}$

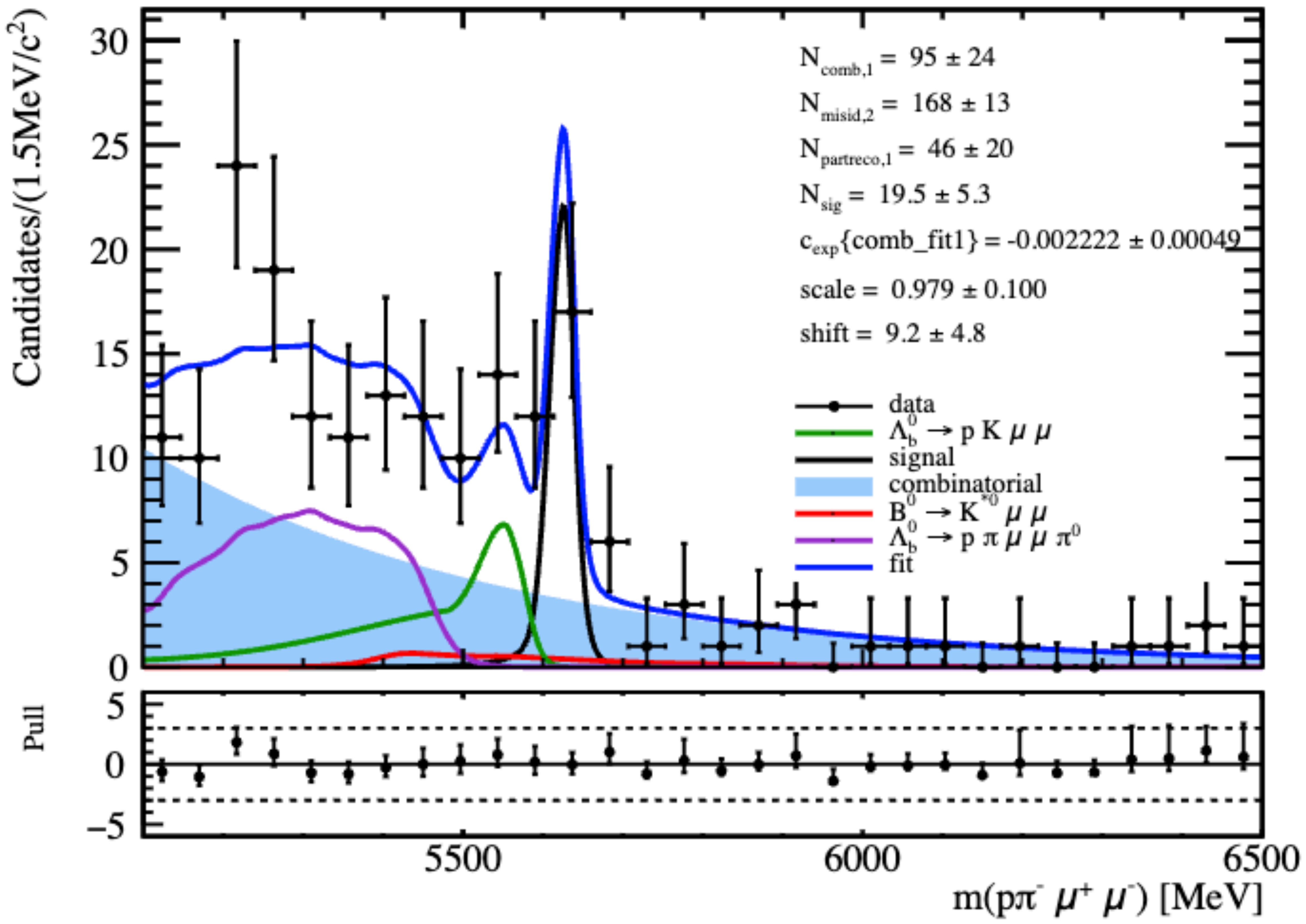
$N_{\Xi_b^0}$

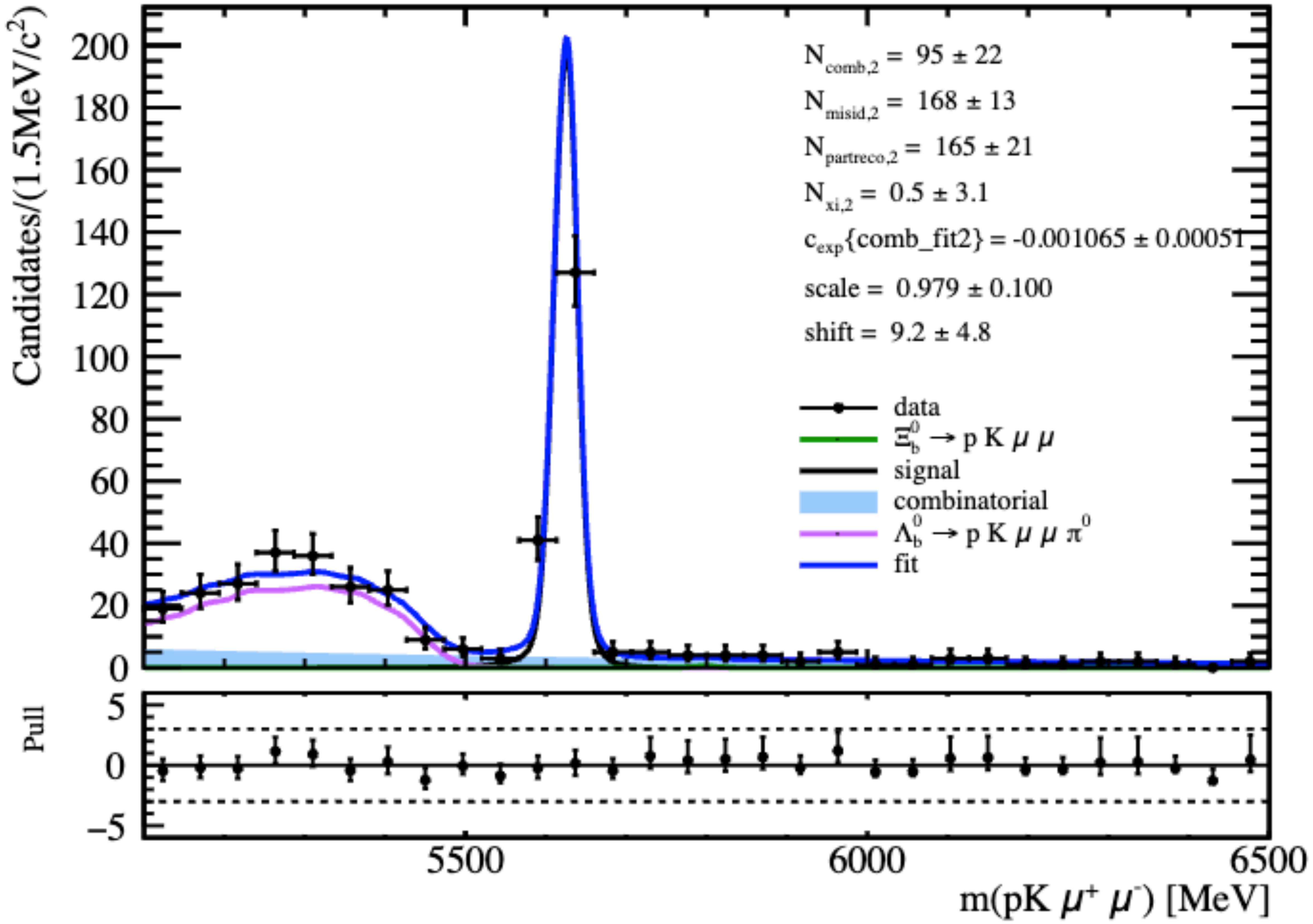
$N_{comb;pK}$

c_{exp} decay constant

Simultaneous fit

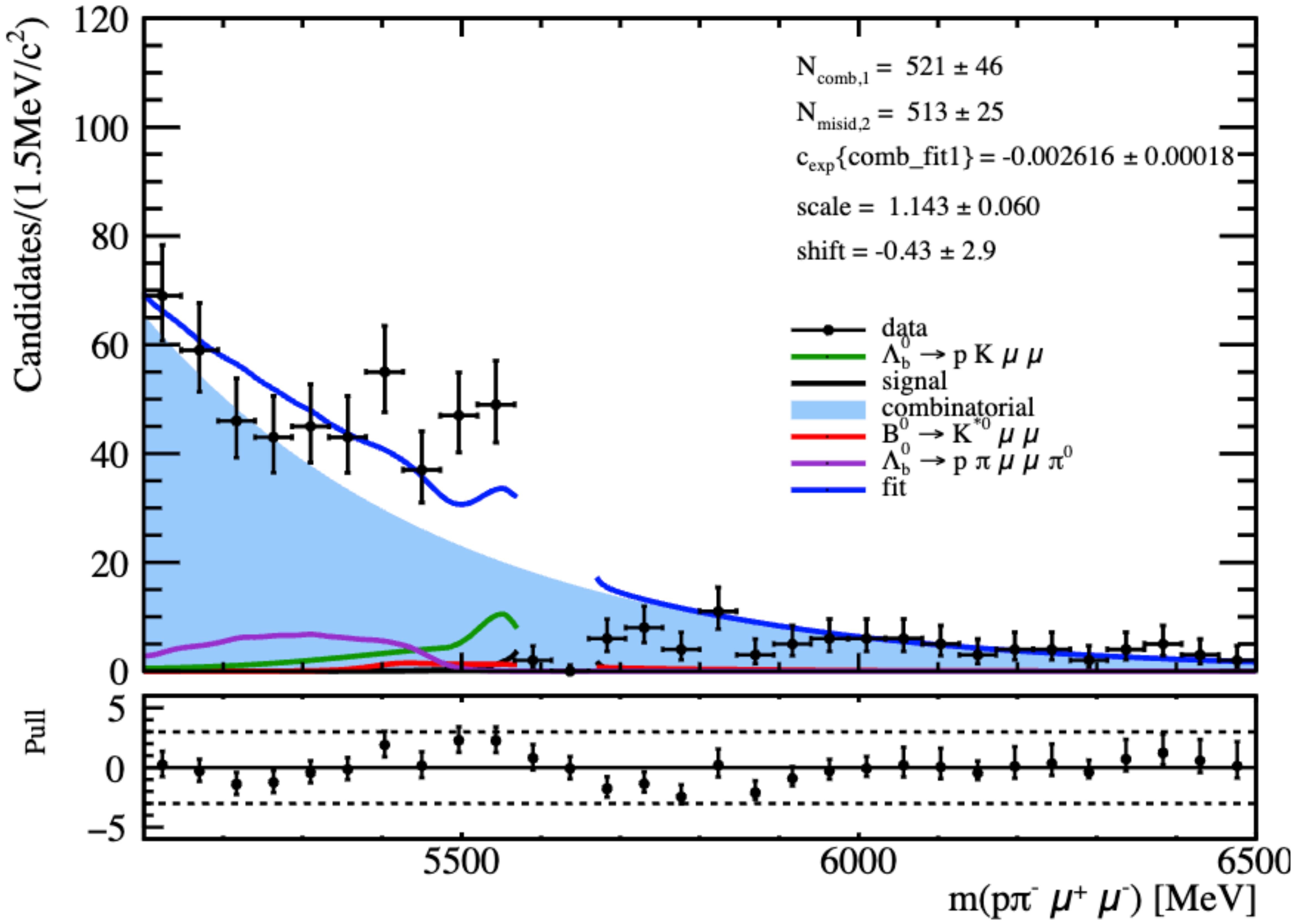
- Simultaneously fit $p\pi\mu\mu$ and $pK\mu\mu$ for fit stability

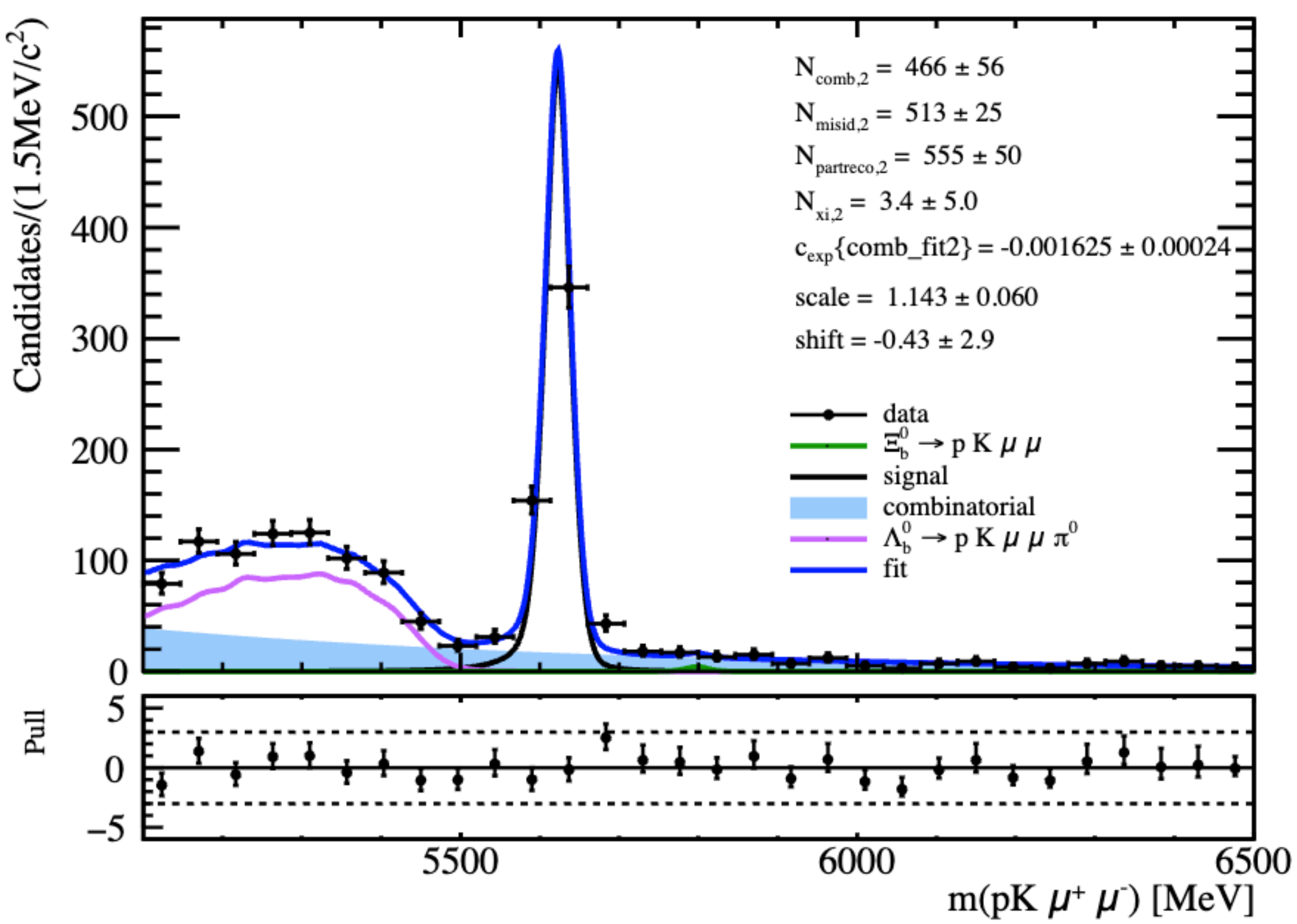




Simultaneous fit Run2

- The same is done for Run2, which is still kept **blinded** for now

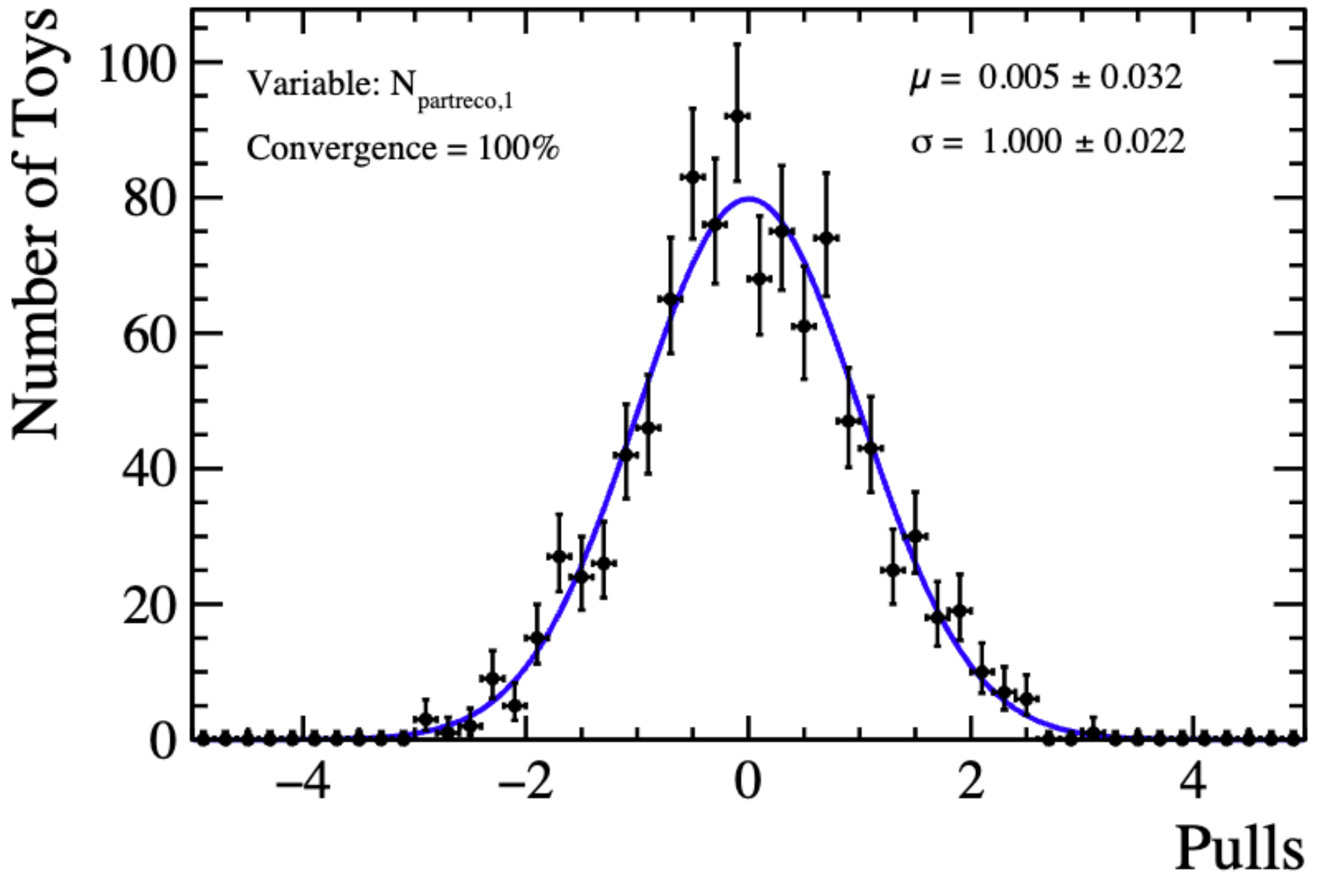


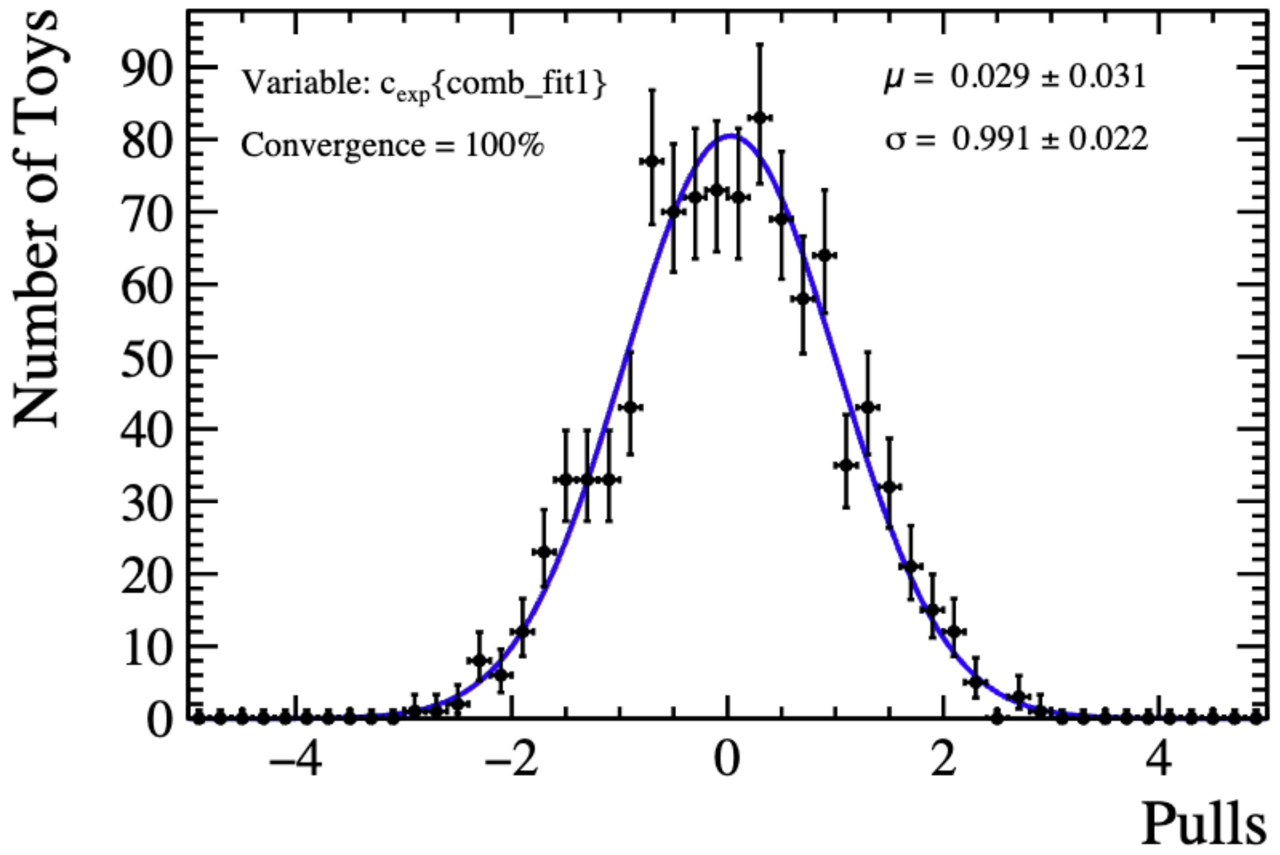


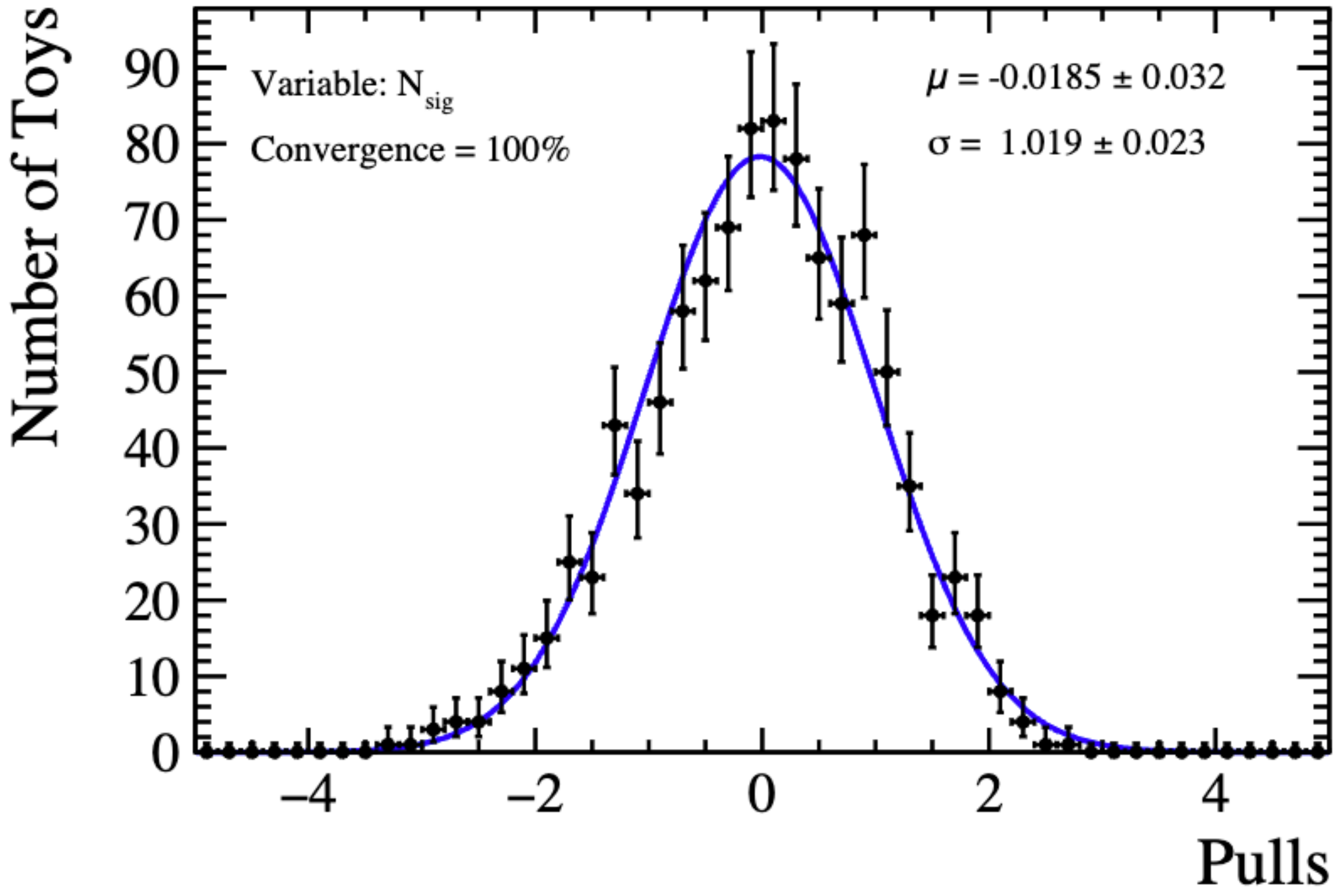
Toys

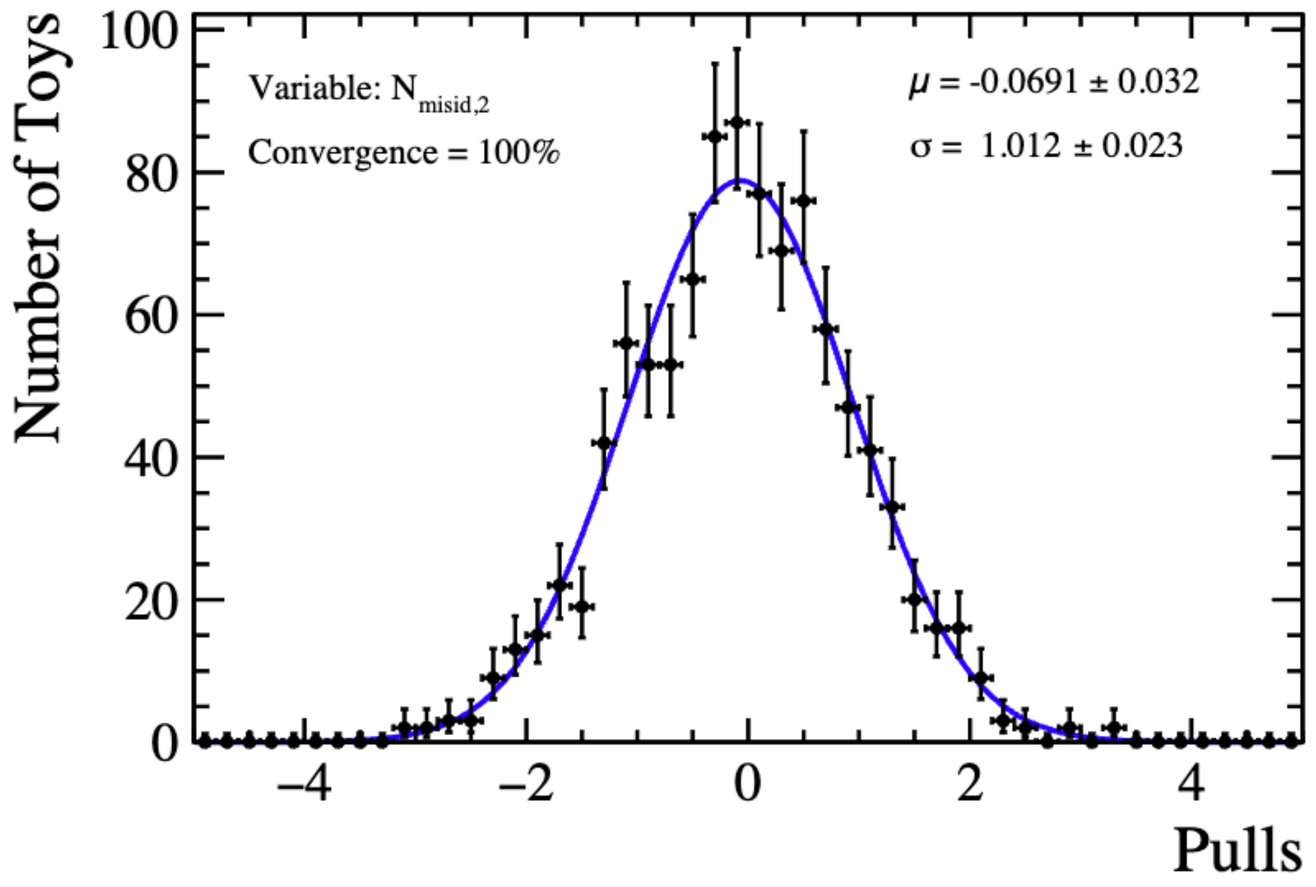
- Run toy simulation to validate the fitting strategy:
  1. Generate 1000 simulation of toys from nominal fit of simultaneous pdf
  2. Fit each toy
  3. Retrieve new fit parameters from each toy
  4. Plot pull of fitted parameters for each toy

$$p = \frac{N_{true} - N^i_{toy}}{\sigma^i_{toy}}$$









Conclusion

$$\frac{\mathcal{B}(\Lambda_b \to p\pi\mu\mu)}{\mathcal{B}(\Lambda_b \to p\pi J/\psi(\to \mu\mu))}$$

Run1 analysis	0.044 ± 0.012 ± 0.007
Run1	0.041 ± 0.012 ± XXX
Run2*	XXX ± 0.005 ± XXX

- Run2 still blind
- Need to start thinking about systematic uncertainties
- Can start circulating the analysis

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Thank you for your attention

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