Search for $\Lambda_b^0 \to \Lambda(1520)\mu^{\pm}e^{\mp}$

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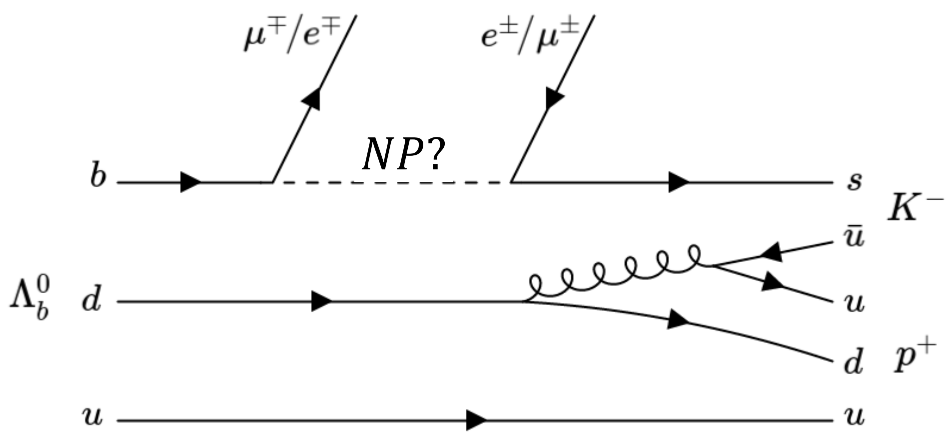
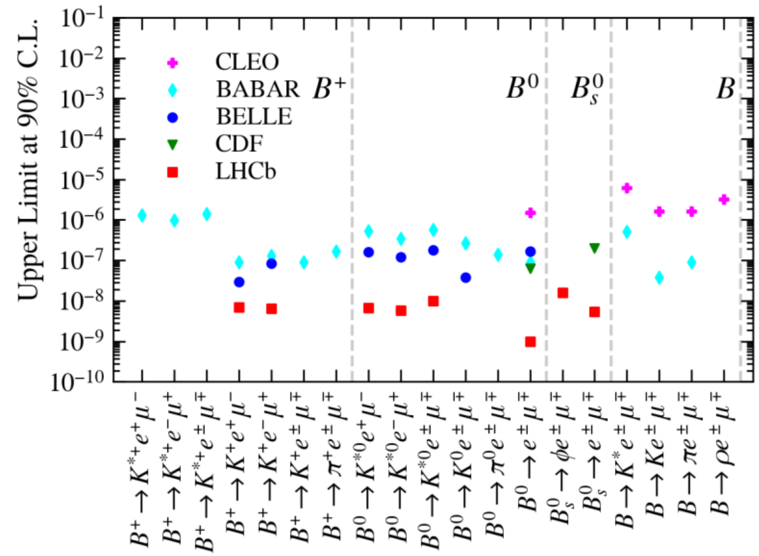
10/04/24



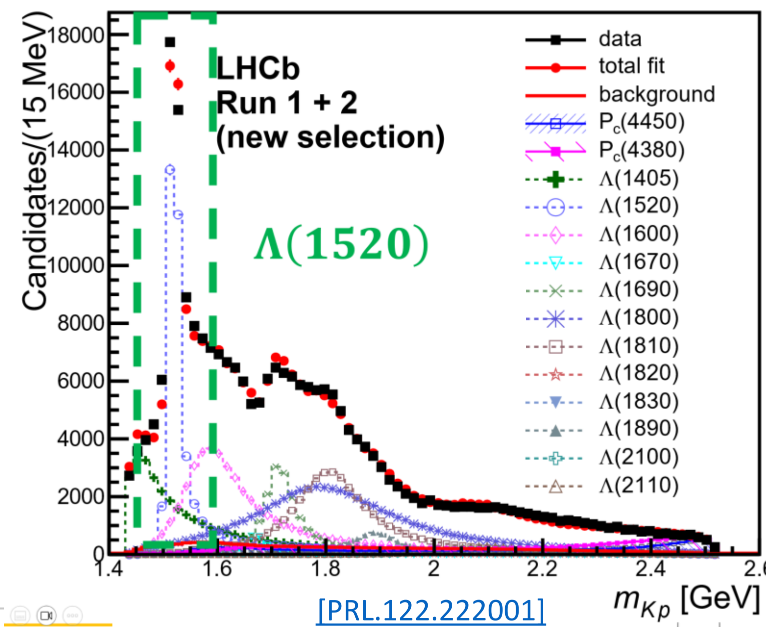
Motivation - $b \to s\ell^+\ell'^-$

- FCNC $b \to s\ell^+\ell^-$ loops suppressed in SM
  - $\mathcal{B}(\Lambda_b^0 \to pK\ell^+\ell^-) \approx 3 \times 10^{-7}$ [JHEP2020,40]
- Lepton Flavour Violation (LFV) only possible in SM via ν oscillation ($\mathcal{B} \sim \mathcal{O}(10^{-50})$)
- **Detection of LFV clear signature of NP**
- New Physics models in $b \to s\ell^+\ell^-$ naturally introduce LFV @ $\sim 10^{-9}$ [PRL.114.091801]



Baryonic LFV with $\Lambda(1520)$

- Builds on recent interest in $\Lambda(1520)\ell\ell$ with $\Lambda(1520)\mu\mu$ **BF** and **Angular** analyses [PRL.131.151801] [F.VOLLE-THESIS]
- LFV studied in decays of b-mesons, **no published searches in b-baryons.** [JHEP06(2023)073] [PRL.123.241802]
- Search for $\boldsymbol{\Lambda_b^0 \to \Lambda(1520)\mu e}$ with **b-baryon** complementary to b-meson searches.



[PRL.122.222001]

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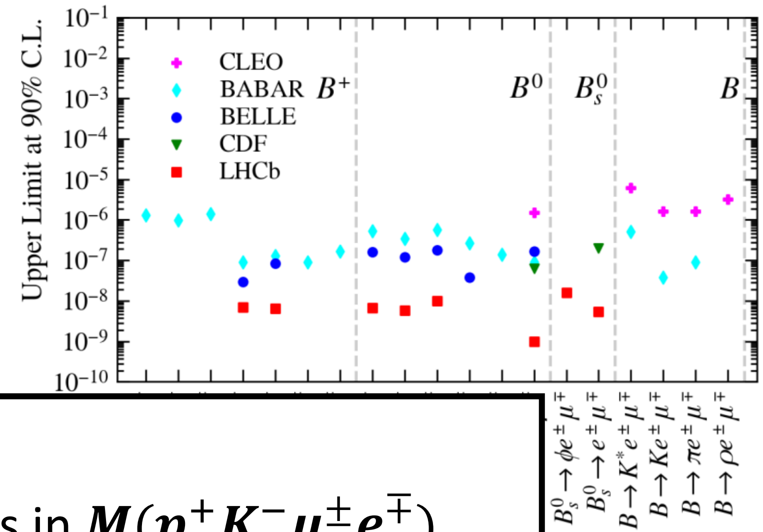

Baryoni

- Builds o
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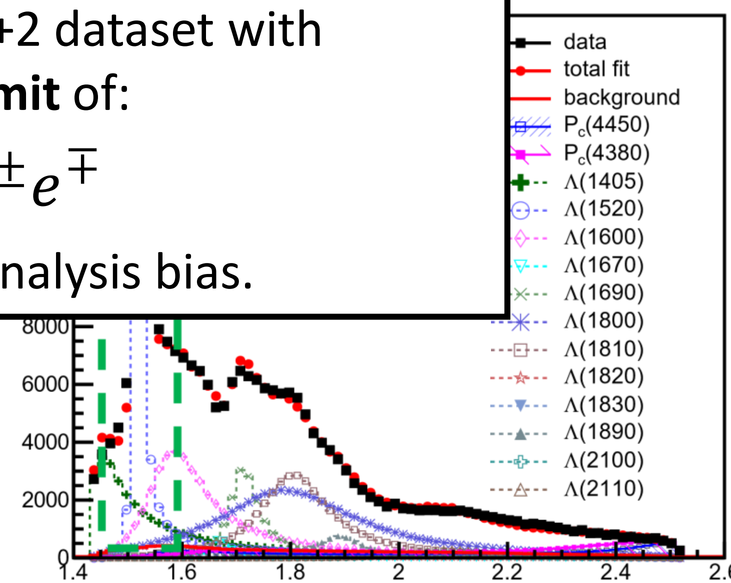
<u>Analysis Overview</u>

Reconstruct and select $\boldsymbol{\Lambda_b^0}$ candidates in $\boldsymbol{M(p^+K^-\mu^\pm e^\mp)}$ final state using complete LHCb Run 1+2 dataset with objective to **discover** or **set the first limit** of:

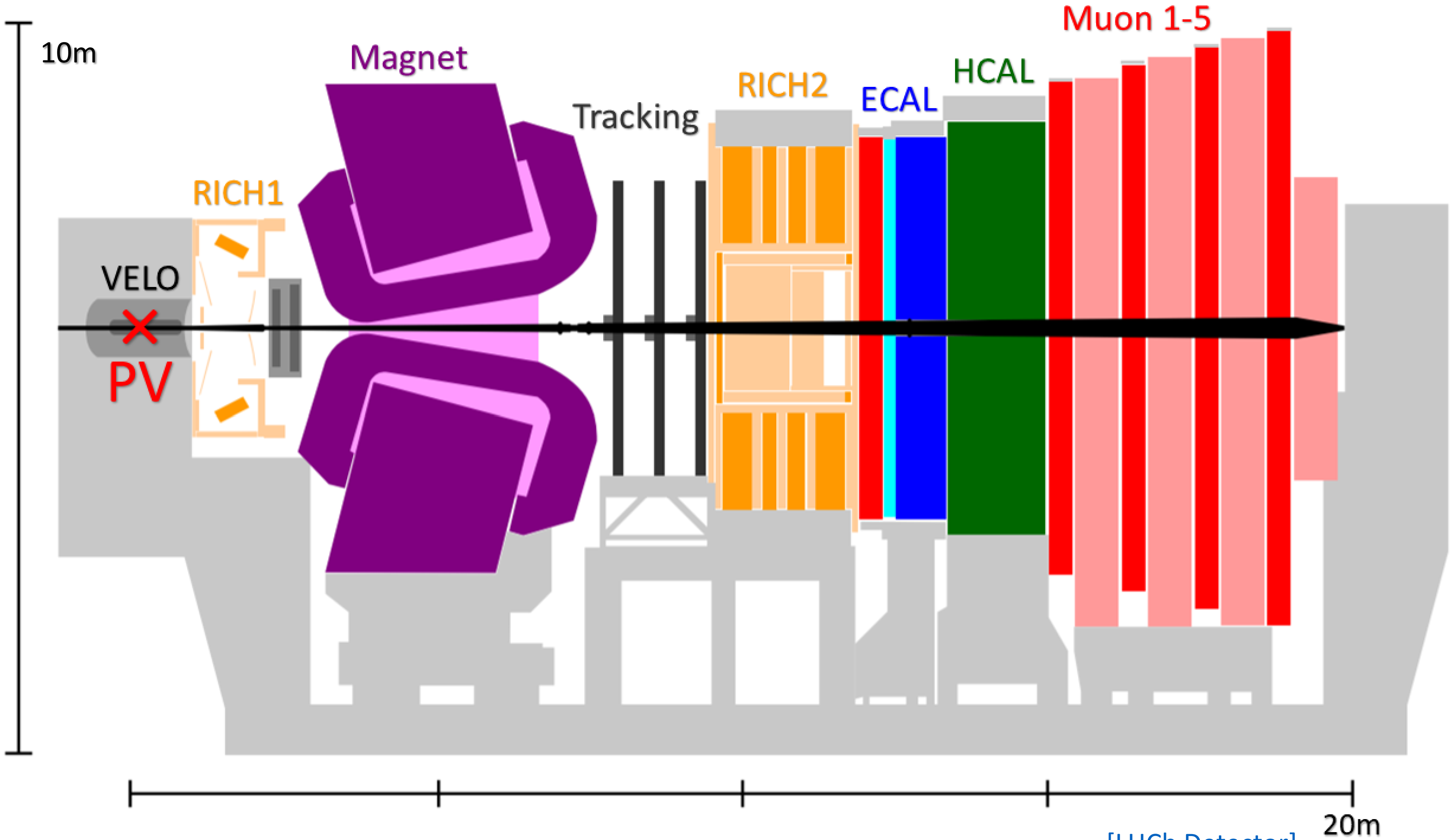
$$\Lambda_b^0 \to \Lambda(1520)\mu^\pm e^\mp$$

with **signal region blinded** to reduce analysis bias.



[PRL.122.222001]

Signature in the LHCb Run 1+2 Detector



[LHCb Detector]

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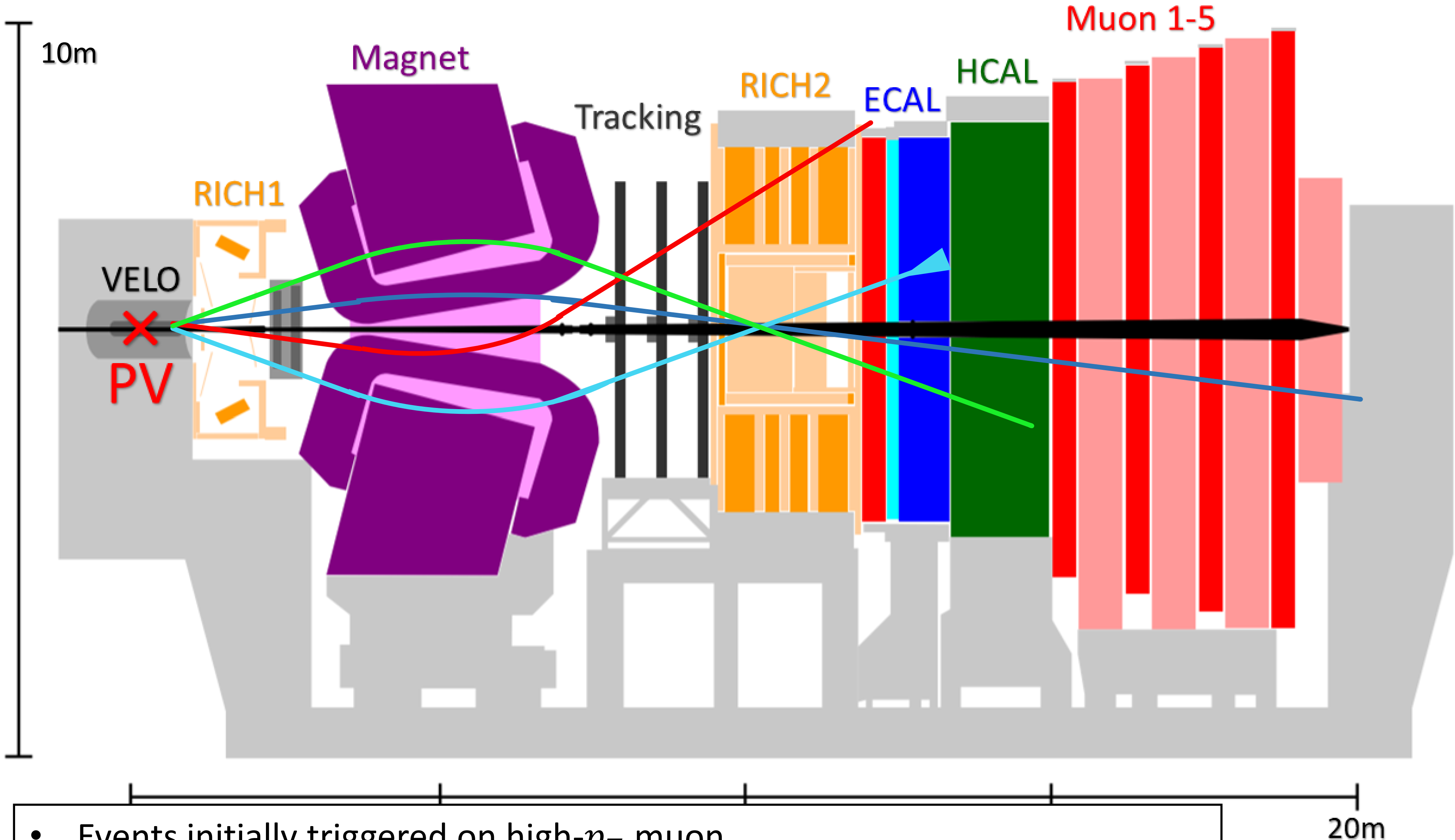

- Events initially triggered on high-p_T muon
- Select four high quality **long tracks**, originating from common **displaced vertex** w/r to the Primary Vertex (PV)
- Each particle passes Particle-Identification (PID) requirements

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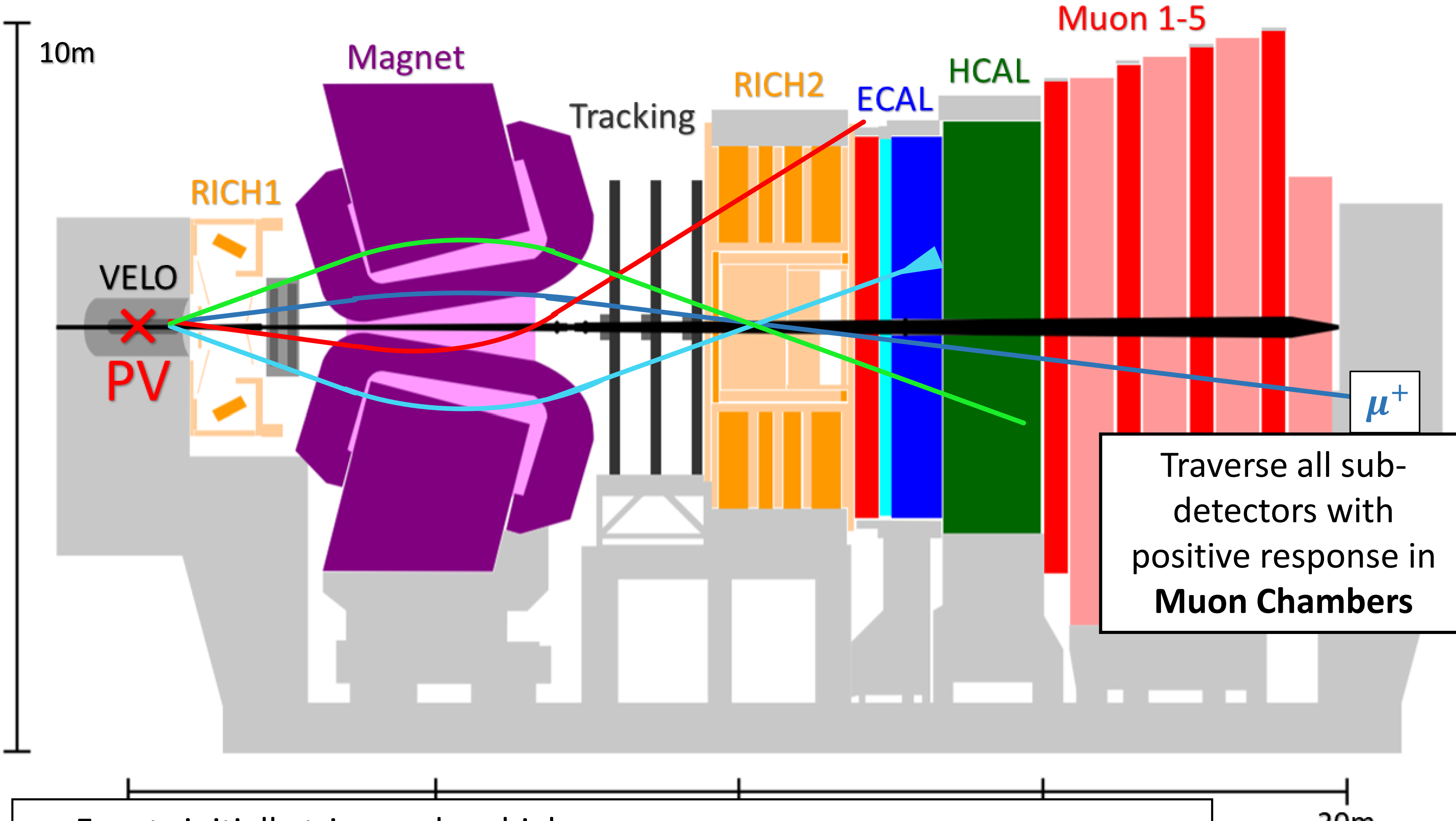

Traverse all sub-detectors with positive response in **Muon Chambers**

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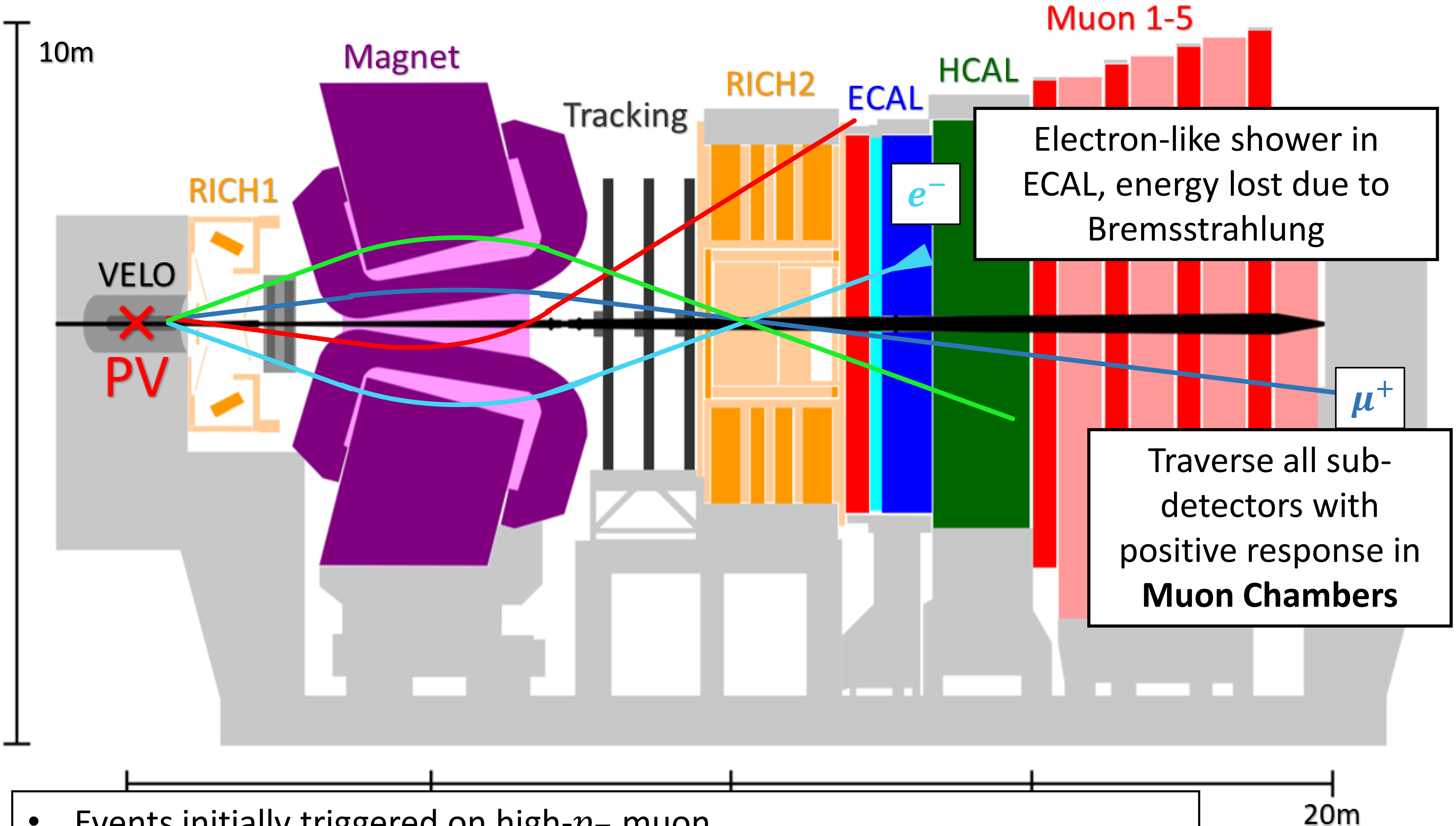

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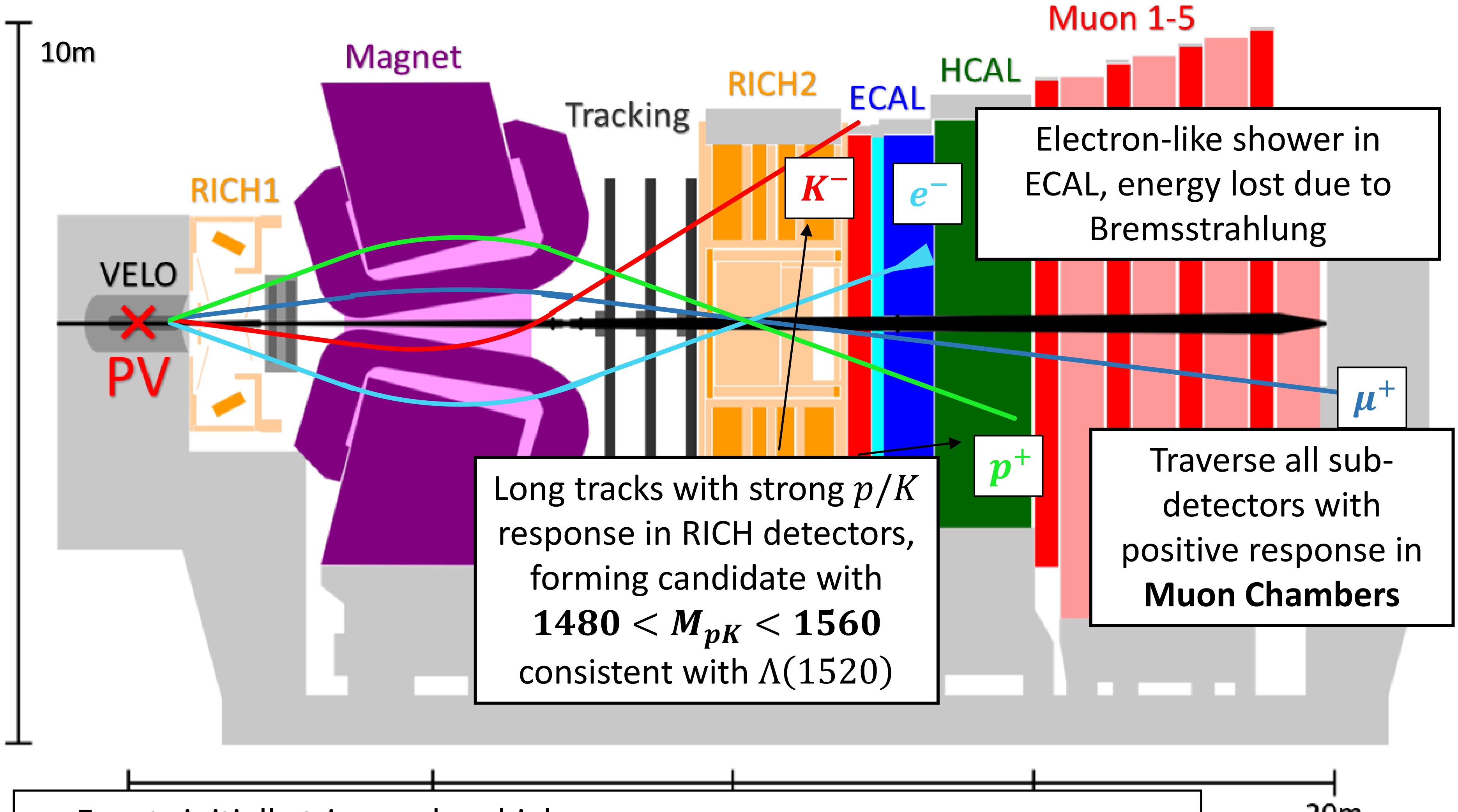

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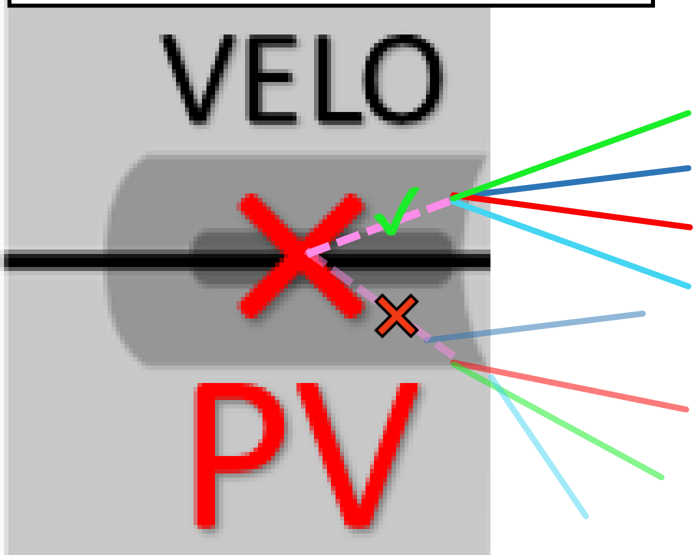
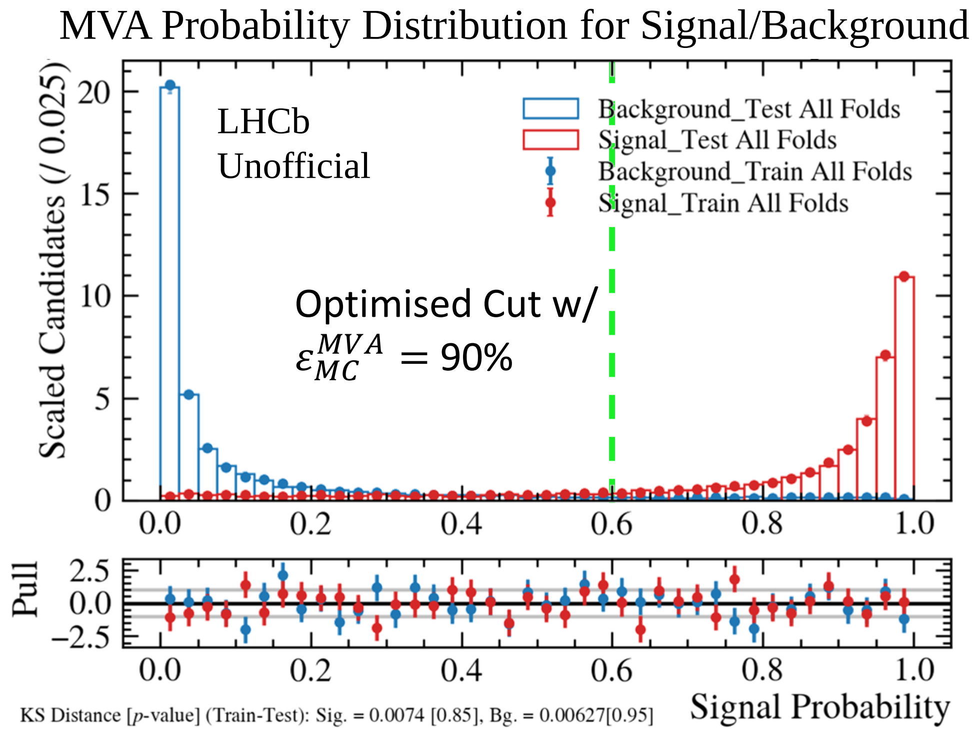
Λ_b^0 Candidates refined by Cut-Based + MVA Selection

Selecting displaced high-p_T Λ_b^0 with high-quality 4-body secondary vertex

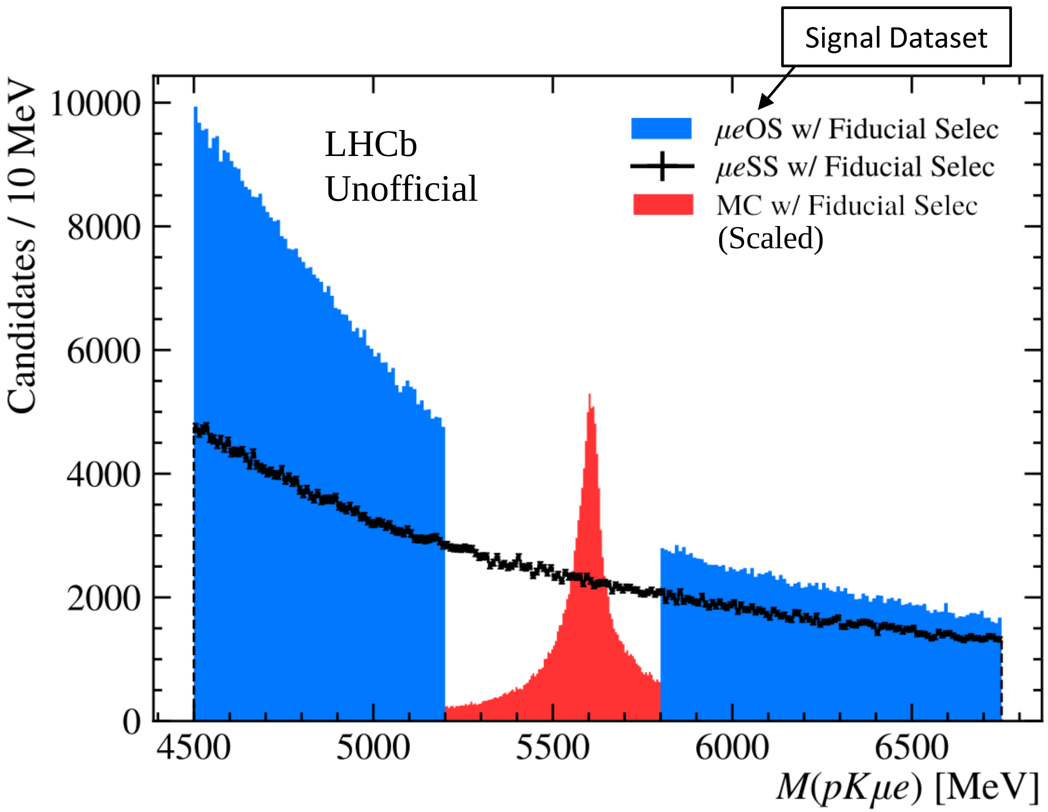




- Topological selection + cut based vetoes of Background resonances ($\phi, D^0, J/\psi$) and Semileptonic $X \to X'\ell\nu_\ell$ decays ($\Lambda_c^{(*)+}, D_s^{\pm}$) reduce background level significantly
- **Remaining combinatorial component removed by MVA approach** to draw on higher order correlations
    - Trained on $\boldsymbol{pK\mu^{\pm}e^{\mp}}$ corrected simulation + **upper** sideband data with kinematic and topological Λ_b^0, Λ^* and $\ell\ell$ variables
    - **Further reduces background by 95% while retaining 90% of signal**

Calculating $\mathcal{B}(\Lambda_b^0 \to \Lambda(1520)\mu^{\pm}e^{\mp})$

Before Selection Chain Applied



- Post-selection, background level minimised
- $M(p^+K^-\mu^{\pm}e^{\pm})$ charge-violating dataset used as combinatorial "μeSS" proxy showing **remaining background is ≈ combinatorial only**
- Measure $\mathcal{B}(\Lambda_b^0 \to \Lambda(1520)\mu^{\pm}e^{\mp})$ by fitting to extract N_{signal} with respect to a **well-defined control mode**
  - Before unblinding **all other components must be fixed**

$$\mathcal{B}(\Lambda_b^0 \to \Lambda(1520)\mu^{\pm}e^{\mp}) = \frac{N_{Signal}}{\epsilon_{Signal}} \times \frac{\epsilon_{Control}}{N_{Control}} \times \frac{\mathcal{B}(\Lambda_b^0 \to J/\psi(\to \mu^{\pm}\mu^{\mp})pK)}{\mathcal{B}(\Lambda(1520) \to pK)}$$

High-statistics control mode $\Lambda_b^0 \to J/\psi(\to \mu^{\pm}\mu^{\mp})pK$ topologically similar to signal mode

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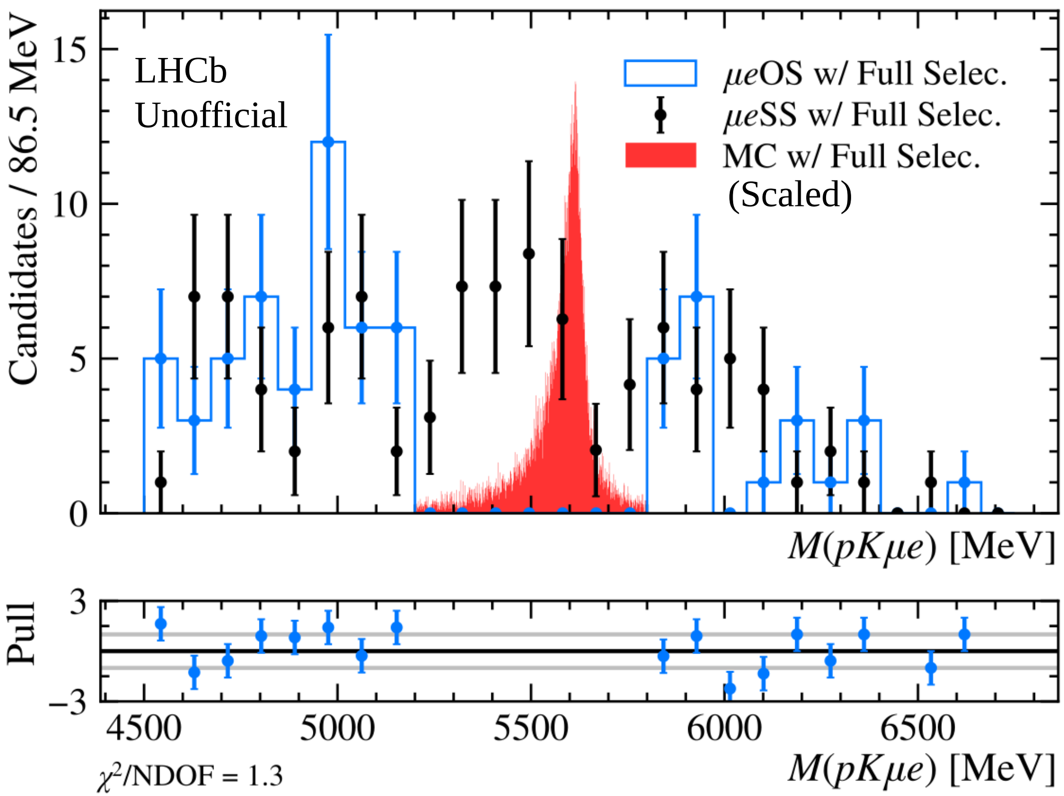
After Selection Chain Applied



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Data-Driven ε Corrections to Simulation

Simulation mis-modelling/reconstruction affects **efficiency measurements**
∴ correct MC with weights using **sWeighted data as "target"** for reweighting

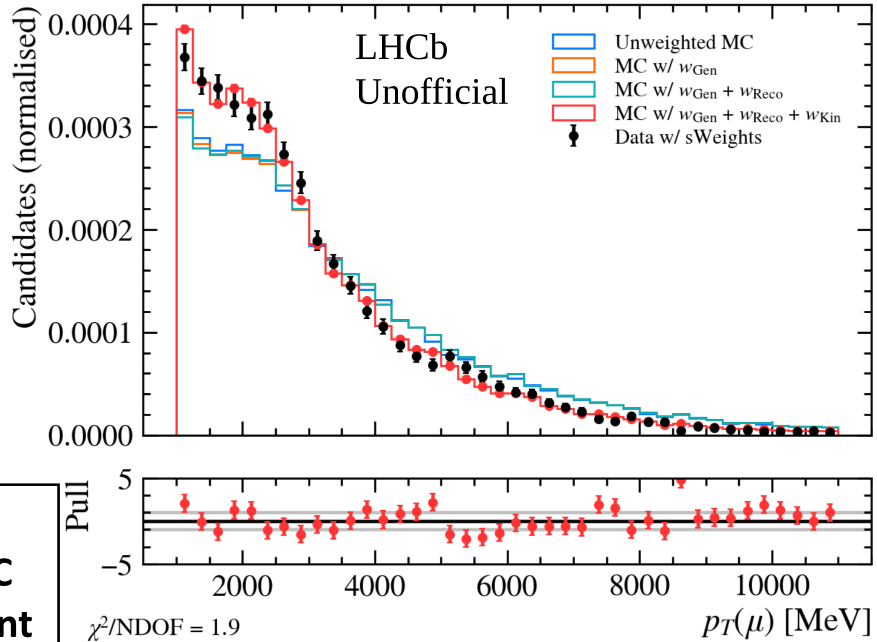
Modelling Corrections

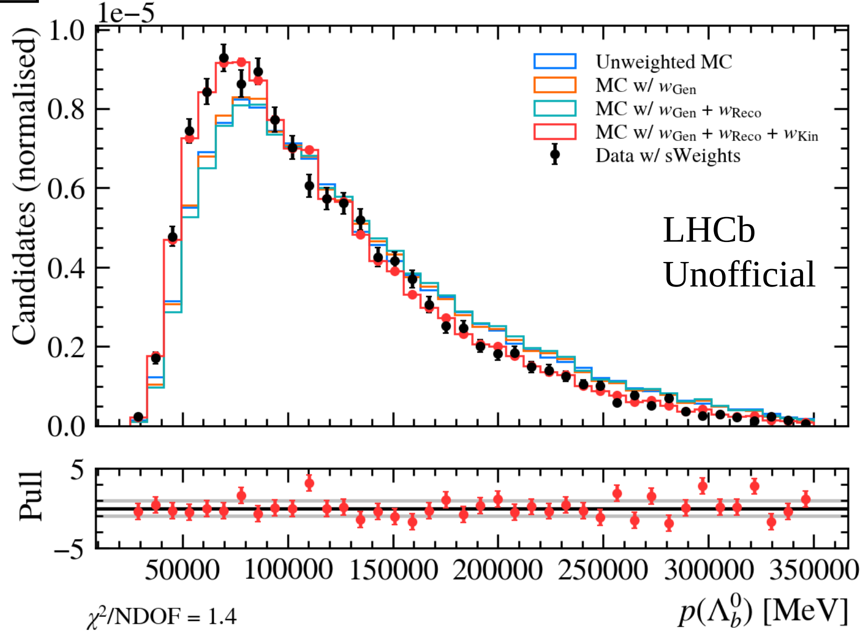
- Λ_b^0 Lifetime analytical correction
- $\boldsymbol{M_{pK}}$ **"Pentaquark" Reweighting** for control mode to correct $\boldsymbol{M_{pK}}$ **distribution**
- Correct Λ_b^0 production kinematics using **Gradient Boosted Reweighter**

Reconstruction Corrections

- MC PID selection replaced by weights from **PIDCalib2**
- Track efficiency corrected using weights from **TrackCalib2**
- **TISTOS** method to correct trigger efficiency using $\boldsymbol{B^+ \to J/\psi K^+}$

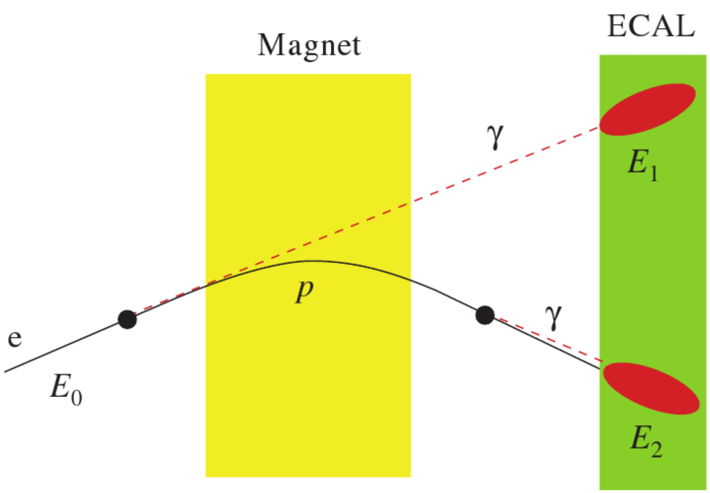
Good Data-MC Agreement





Split Analysis into Distinct Categories to calculate ε_{Signal} & $\varepsilon_{Control}$

- Detector, trigger and reco. differences at LHCb between run 1 and 2.
- Bremsstrahlung of electrons results in **partial-reconstruction** of candidates
- Bespoke recovery algorithms reconstruct lost energy, **but can over-reconstruct**



- Significant difference in efficiency for Λ_b^0 selection with 0γ and 1γ

  ∴ **Split analysis into four categories:**
  - **Run 1 and 2**
  - **0γ and 1γ**

Category	Efficiency ($\times 10^{-5}$)	
	Run 1	Run 2
$pK\mu^{\pm}e^{\mp}\ 0\gamma$	60.6 ± 0.5	51.0 ± 0.3
$pK\mu^{\pm}e^{\mp}\ 1\gamma$	69.7 ± 0.5	60.4 ± 0.3
$pK\mu^{+}\mu^{-}$	124.0 ± 0.8	99.8 ± 0.4

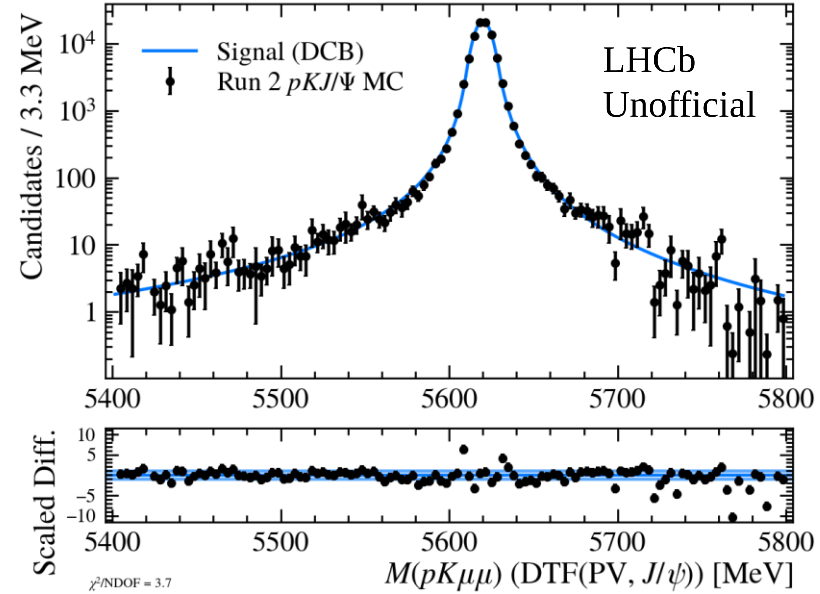
$$\varepsilon_{\text{tot}} = \varepsilon_{\text{gen}} \cdot \frac{\sum_{\text{rec+sel}} w_{\tau} \cdot (w_{\text{penta}}) \cdot w_{\text{kin}} \cdot w_{\text{PID}} \cdot w_{\text{trk}} \cdot w_{\text{trig}}}{\sum_{\text{gen}} w_{\tau} \cdot (w_{\text{penta}}) \cdot w_{\text{kin}}}$$
$$= \varepsilon_{\text{gen}} \cdot \varepsilon_{\text{rec+sel}}$$

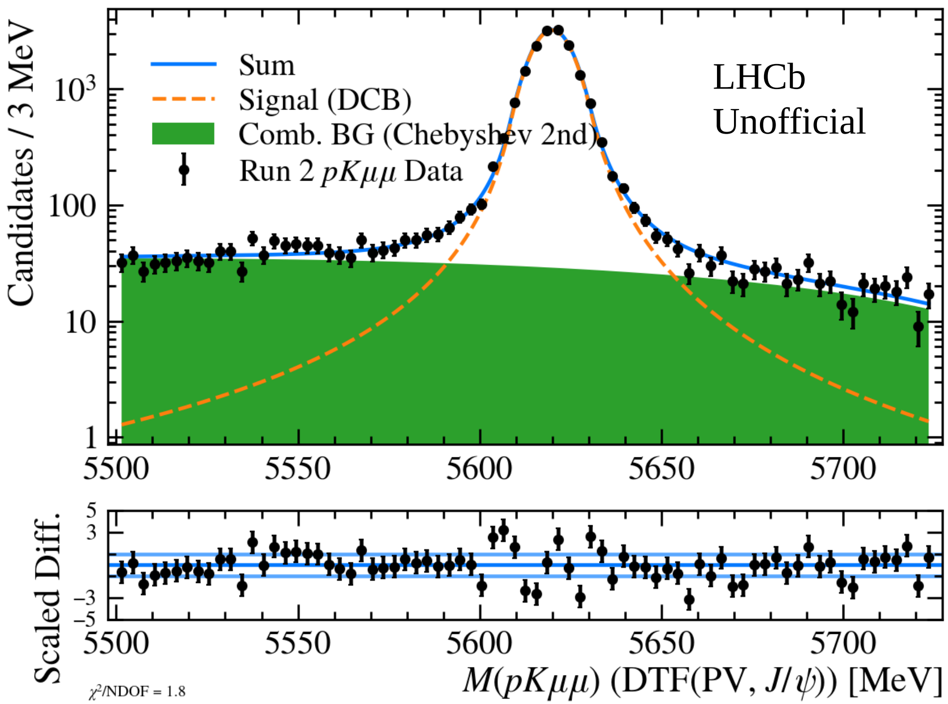
$N_{Control}$: Fits to $\Lambda_b^0 \to J/\psi(\to \mu^\pm\mu^\mp)pK$

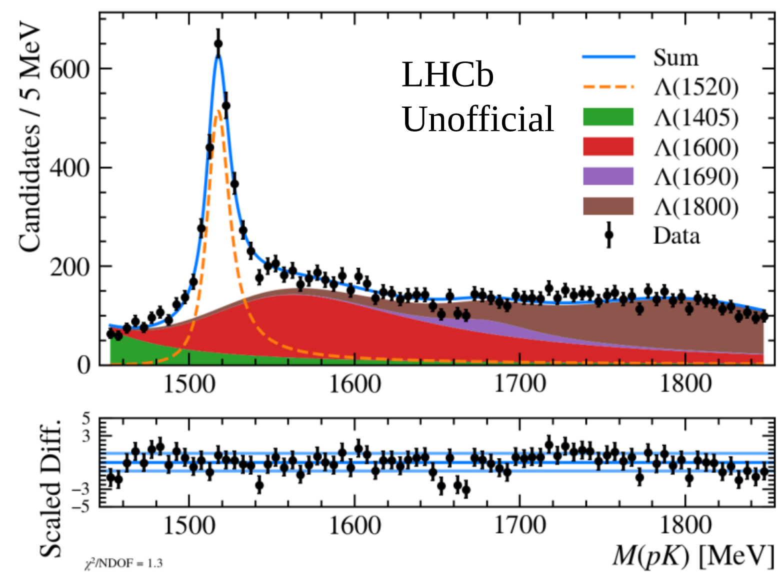
Selection aligned for Control mode

- Fit in Run 1/Run 2 with signal shape parameters from corr. MC fit
- Simple 2nd order Chebyshev + signal describes remaining data distribution effectively

$\Lambda_b^0 \to J/\psi pK$ Run 1 & 2 Yield = 24500 ± 200



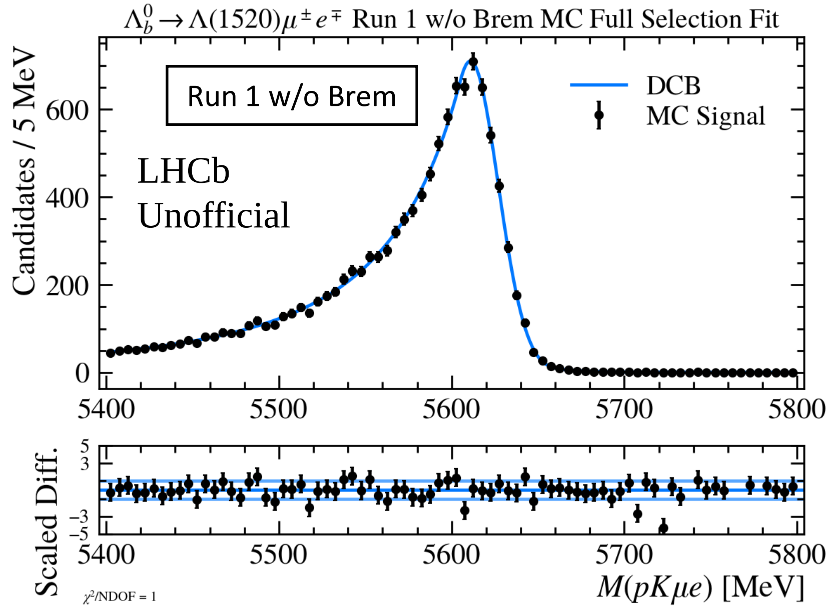




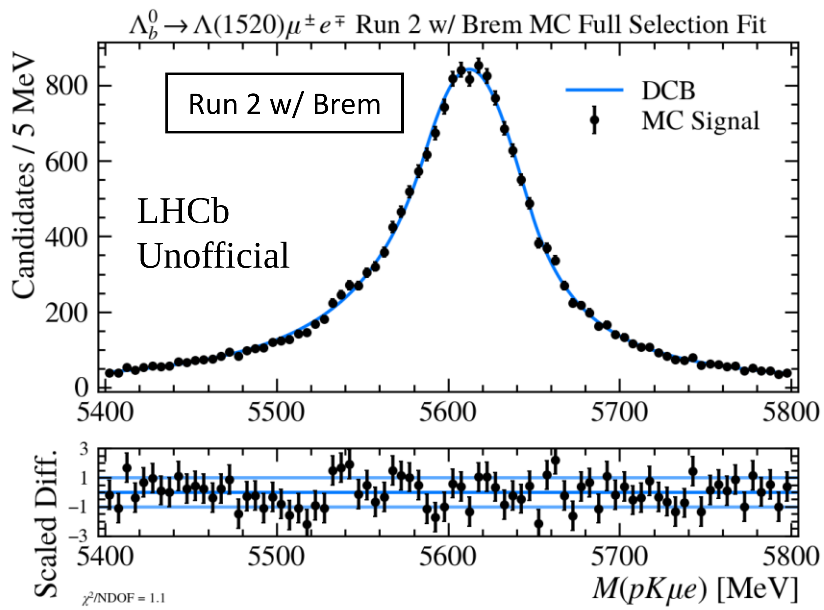
M_{pK} Fit implemented as cross check

$\Lambda_b^0 \to pK\mu^{\pm}e^{\mp}$ Full Selection MC Fits

- Double-sided Crystal ball fit to fully corrected $\Lambda_b^0 \to \Lambda(1520)(\to pK)\mu^{\pm}e^{\mp}$ simulation

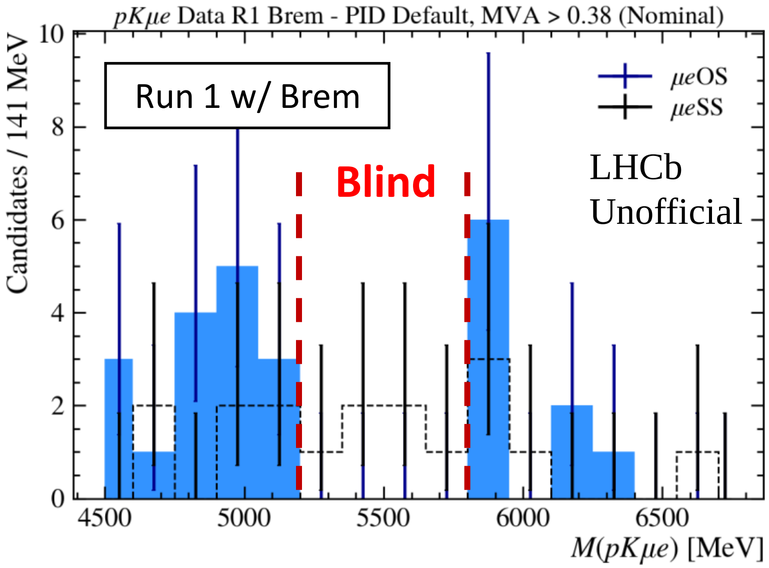


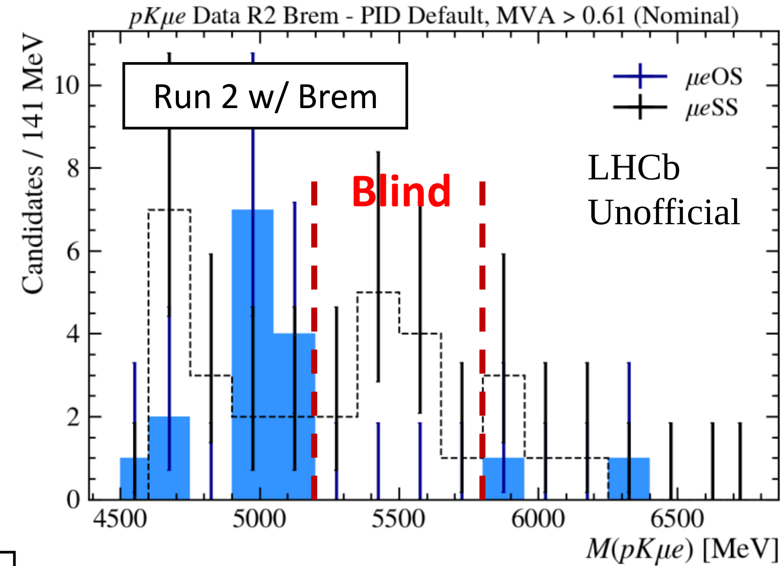
Bremsstrahlung causes major difference in signal shape -> **Further justifying fitting in different categories**



$$\frac{\mathcal{N}_{Signal}}{\epsilon_{Signal}} \times \frac{\epsilon_{Control}}{\mathcal{N}_{Control}}$$

$\Lambda_b^0 \to pK\mu e$ Data after Full Selection



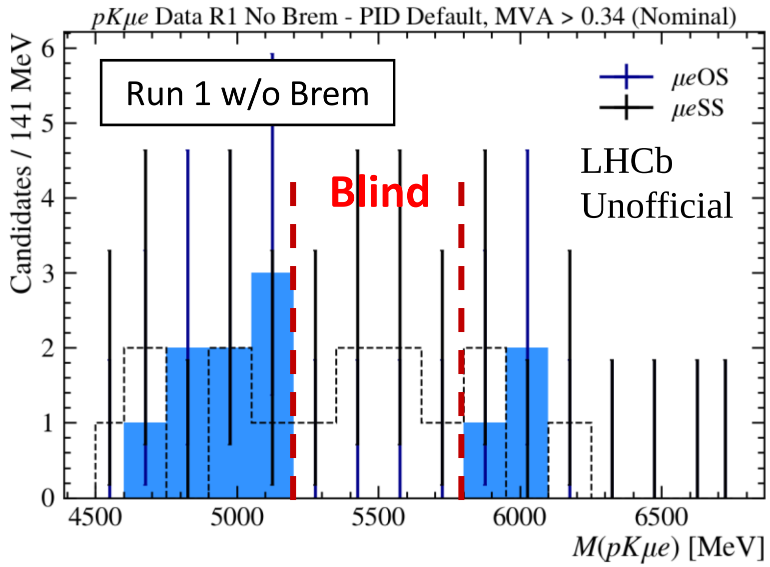


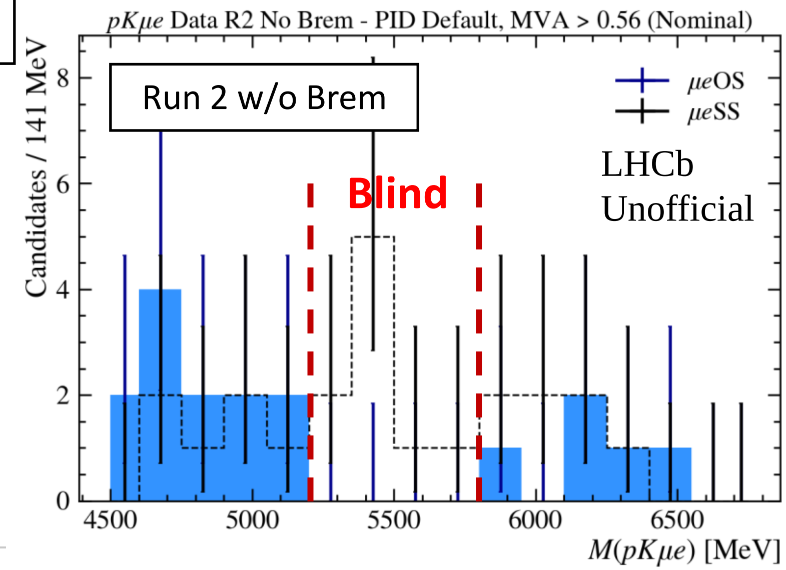
μeOS

*μe*SS (proxy)

$\varepsilon_{MC}^{MVA} = 90\%$
Working
Point

Clearly cannot fit the comb. bg. at this WP





$\Lambda_b^0 \to pK\mu^\pm e^\mp$ Data Fits

Blinded Data Fit Procedure

- **Combinatorial** with O(3) Chebyshev using fixed parameters from μeSS proxy dataset fits **at looser WP**
- Exclusive BG component(s) with fitted with JohnsonSU (next slide)

Comb. BG. Fit Strategy

Floating fit @

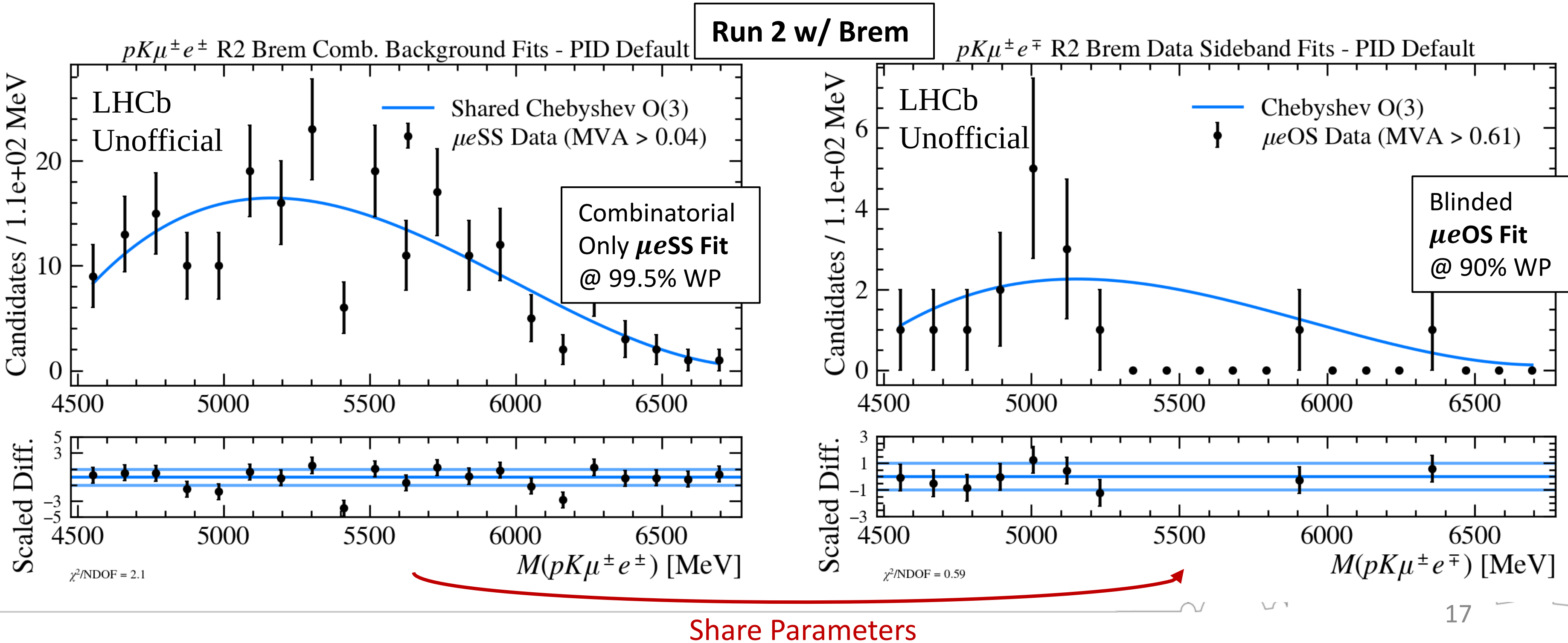
$\varepsilon_{MC}^{MVA} = 99.5\%$ WP

↓ Constrain ↓

$\varepsilon_{MC}^{MVA} = 97\%$ WP

↓ Fix ↓

$\varepsilon_{MC}^{MVA} = 90\%$ WP



Exclusive Background Components

Use Data Driven Technique to monitor exclusive backgrounds

$$N^{BG}_{normalised} = \varepsilon_{BG} \cdot \mathcal{B}_{BG} \cdot \frac{N_{Control}}{\mathcal{B}_{Control} \cdot \varepsilon_{Control}}$$

- Corrected ε_{BG} from selection chain
- $N_{Control}$ from $J/\psi pK$ fits

Full Coverage of diff. background types:

42 samples covering

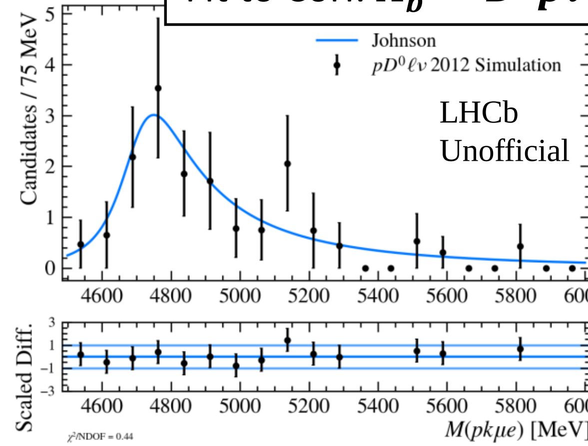
- $h - \ell$ Mis-ID
- $\ell - \ell'$ Mis-ID
- ℓ from X $\rightarrow$ X$'\ell\nu_\ell$

} $N_{/cat} \approx 0$

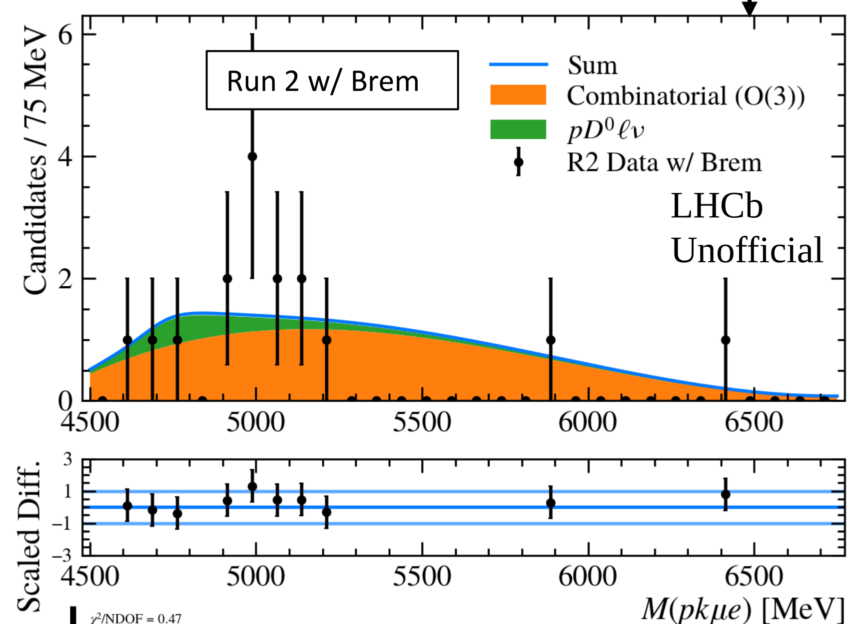
- **$\ell\ell'$ from Double Semileptonic**
  - **Only significant background w/ $N_{/cat} \approx 3$**

$$\boldsymbol{\Lambda_b^0 \rightarrow D^0(\rightarrow K\ell^+\nu_\ell)p\ell'^-\overline{\nu}_{\ell'}}$$

Fit to Corr. $\boldsymbol{\Lambda_b^0 \rightarrow D^0 p\ell'^- \overline{\nu}_{\ell'}}$ MC



Constrain yield from N_{BG} eq.



Pass fit to GammaCombo for CLs limit determination

WIP

Summary

Search for LFV in $\Lambda_b^0 \to \Lambda(1520)(\to pK)\mu^{\pm}e^{\mp}$

- Analysis is significantly advanced
- Comprehensive set of background samples prepared and studied
- Extensive simulation correction chain using data-driven techniques
- Initial **Single Event Sensitivity** Test:
  - $\mathcal{B}\left(\Lambda_b^0 \to \Lambda(1520)\mu^{\pm}e^{\mp}\right) \approx 6 \times 10^{-9}$
  - Final limit setting using **GammaCombo** planned
- Final result will be **world-first measurement/limit of this mode**