First measurement of $\Xi_b^0 \to J/\psi(\to \mu^+\mu^-)pK^-$ with Run 2 and 3 Data

Yibo Zhu, Dan Moise, Sebastian Schmitt, Stefan Schael

RWTH Aachen

FSP Aachen

02/10/2026

Bundesministerium für Forschung, Technologie und Raumfahrt

FSP LHCb Erforschung von Universum und Materie

I. Physikalisches Institut

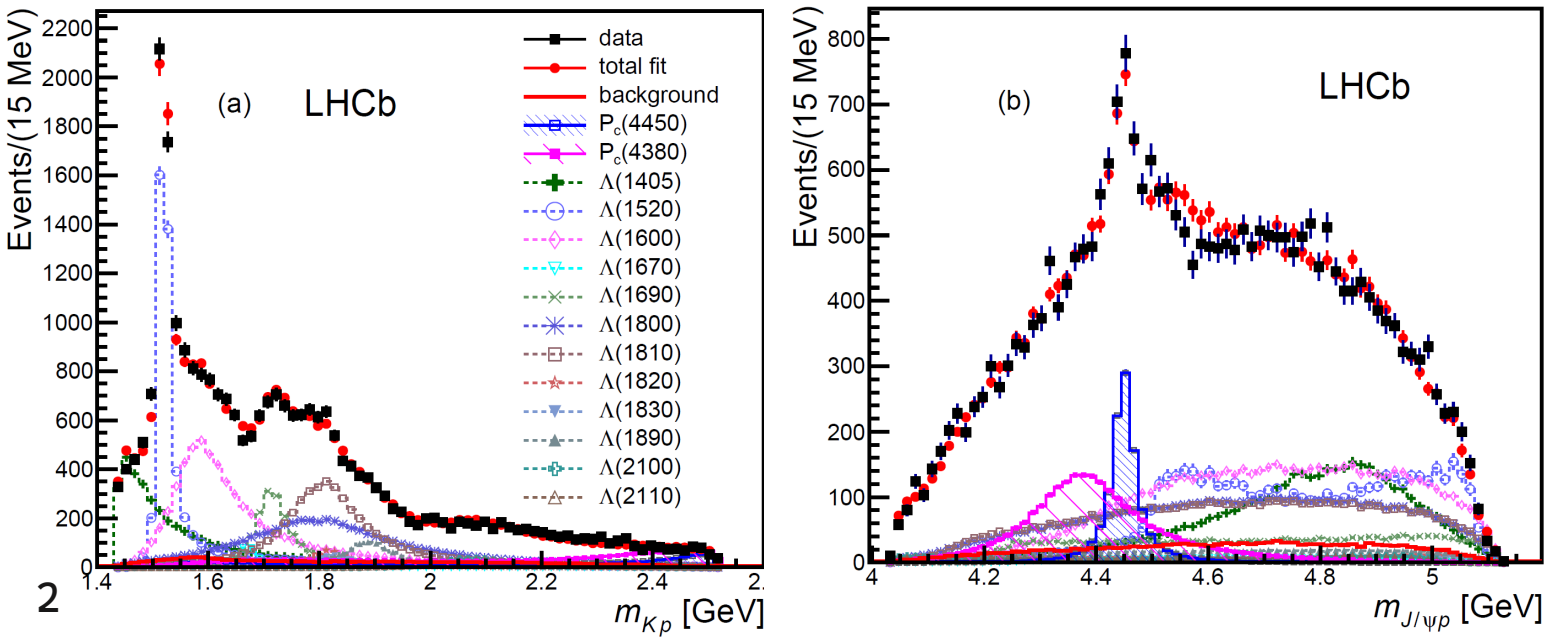
RWTH AACHEN UNIVERSITY

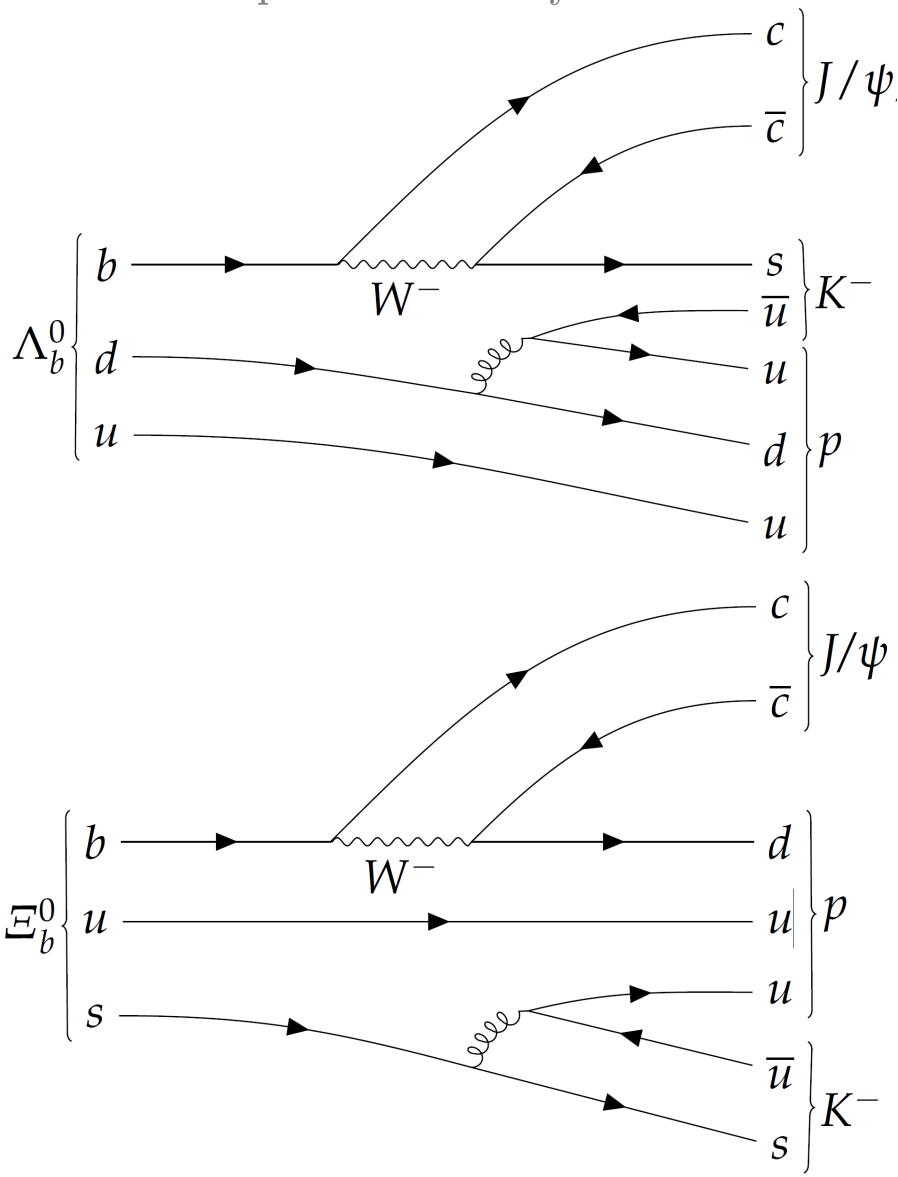
LHCb

Motivation

- Same final state particles for $\Xi_b^0 \to J/\psi p K^-$ and well-established $\Lambda_b^0 \to J/\psi p K^-$ decay
- Ξ_b^0 and Λ_b^0 signals from the same selection
- $\Xi_b^0 \to J/\psi p K^-$ open to exotic contribution, which has been observed in the Λ_b^0 decay

Observation of $J/\psi p$ resonances consistent with pentaquark states in Λ_b^0 decays





Feynman diagrams of the $\Lambda_b^0 \to J/\psi p K^-$ and $\Xi_b^0 \to J/\psi p K^-$ decays

Previous observation

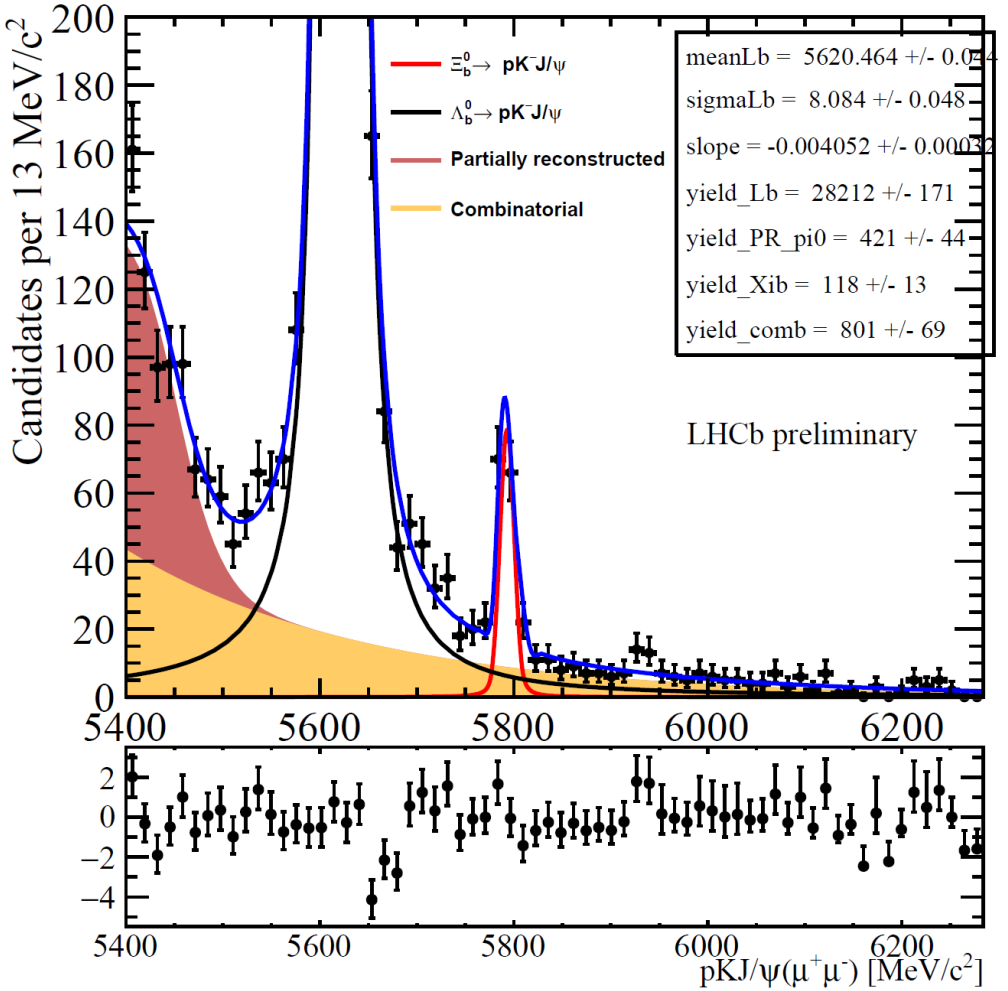
- $\Xi_b^0 \to J/\psi p K^-$ has been previously observed in Vitalii Lisovskyi's thesis (Université Paris Saclay) with Run 1 and 2016 data.
- Previous preliminary result with 2016 data on $\mathcal{R}$:

$$\mathcal{R} = \frac{\mathcal{B}(\Xi_b^0 \to J/\psi p K^-)}{\mathcal{B}(\Lambda_b^0 \to J/\psi p K^-)} \cdot \frac{f_{\Xi_b^0}}{f_{\Lambda_b^0}} = \frac{N_{\Xi_b^0}}{N_{\Lambda_b^0}} \Big/ \frac{\epsilon_{\Xi_b^0}}{\epsilon_{\Lambda_b^0}}$$

$$\mathcal{R} = (3.05 \pm 0.51(\text{stat.})) \times 10^{-3}$$

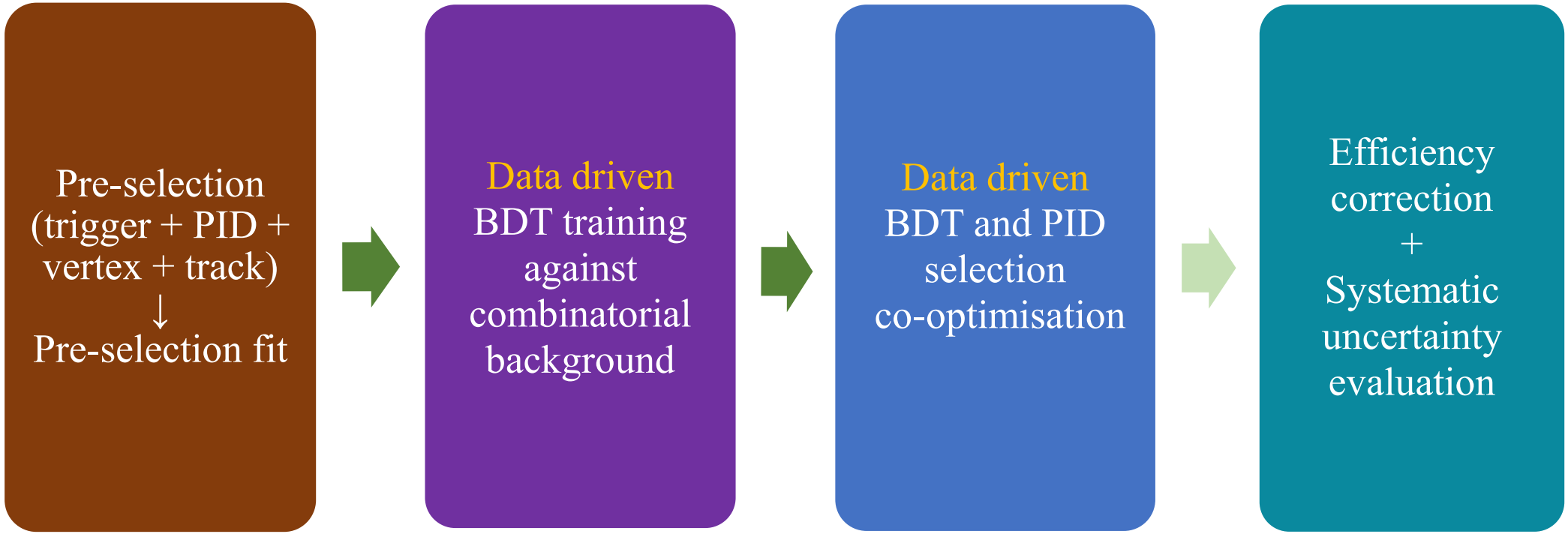
- Previous analysis heavily limited by the stats of Ξ_b^0 (only 54 signals in 2016 data), expect factors of 3 and close to 20 increase from the Run 2 data and Run 3 data, respectively

Vitalii Lisovskyi. Study of rare b-baryon decays and test of lepton universality at LHCb.



Fit on $m(\mu^+\mu^- pK^-)$ with Run 1 and 2016 data combined in previous analysis

Optimise same analysis strategy on different datasets



- Develop selection with similar efficiencies between Λ_b^0 and Ξ_b^0
- Expect the efficiencies between the two channels mostly cancel

➢ Reduce systematic uncertainty from the efficiencies correction

Status of the analysis

	Run 2:	Run 3:
Preselection & fit to preselected data	✓	✓
BDT training	✓	✓
BDT-PID selection co-optimisation	✓	✓
MC correction	✓	Waiting for approval
Efficiencies ratio estimation	✓	of Run 2 MC
Systematics evaluation	WIP	correction

To be covered in this talk:

- Updated fit to Run 2 data with the finalised selection and preliminary MC corrections
- Fit to combined Run 3 (2024-26) data
- Preliminary results on Run 2 MC correction, efficiencies ratio and systematics
  - For more information on selections, also see my talk at LHCb week Vilnius

Current Run 2 working point

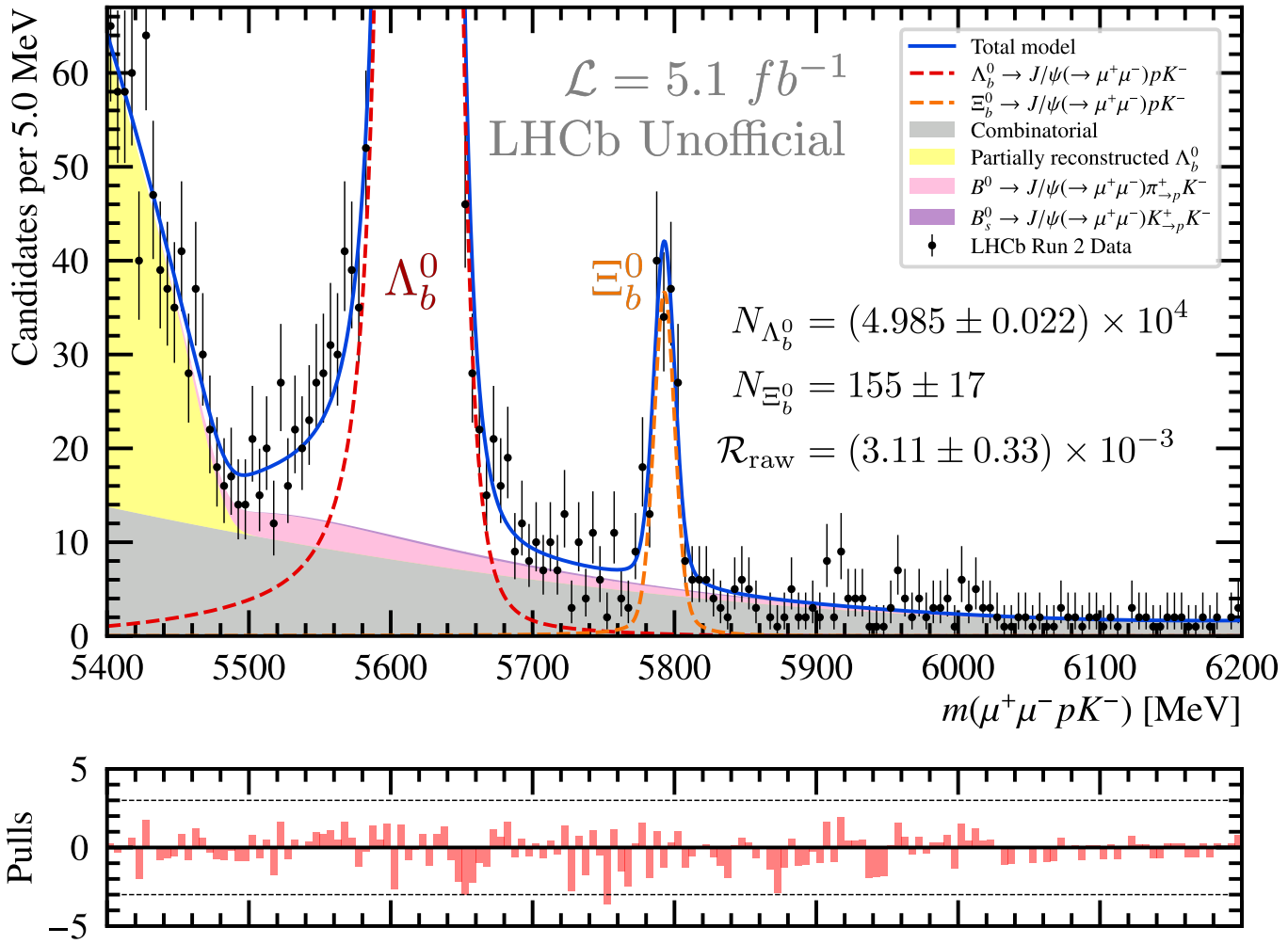
Fixed	Optimised
$\text{ProbNN}_\pi < 0.2$	$\text{BDT} > 0.9$
$\text{ProbNN}_K < 0.5$	$\text{ProbNN}_p > 0.94$

- Fit with MC correction applied, updated HLT1 selection and combinatorics shape
- Observation of 155 ± 17 $\Xi_b^0 \to J/\psi p K^-$ candidates
- In agreement with previous result:
  - Run 2 (assuming the efficiencies cancel):

$$\mathcal{R}_{\text{raw}} = (3.11 \pm 0.33(\text{stat.})) \times 10^{-3}$$

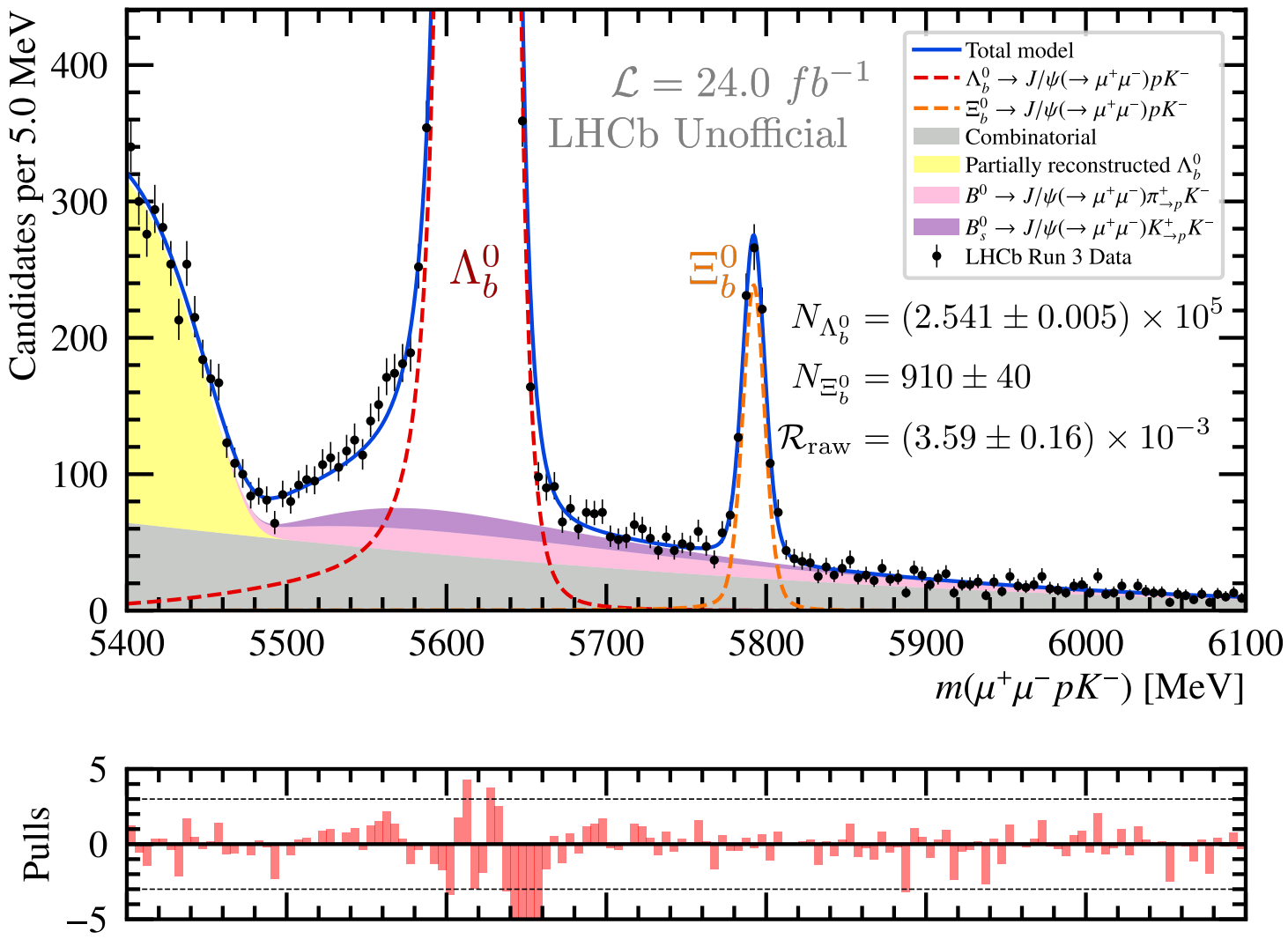
  - Previous (corrected with efficiencies):

$$\mathcal{R} = (3.05 \pm 0.51(\text{stat.})) \times 10^{-3}$$



Fit to Run 2 data with current selection working point, zoomed in

Current working point with combined Run 3 data (2024-26)



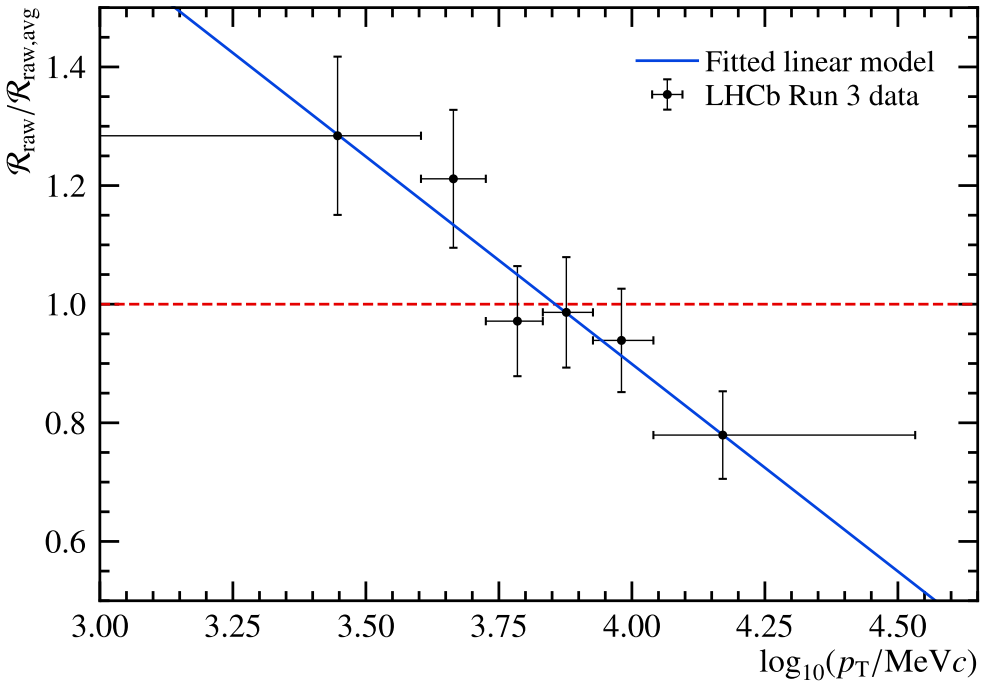
Fit to combined 2024-26 data with current selection working point, zoomed in

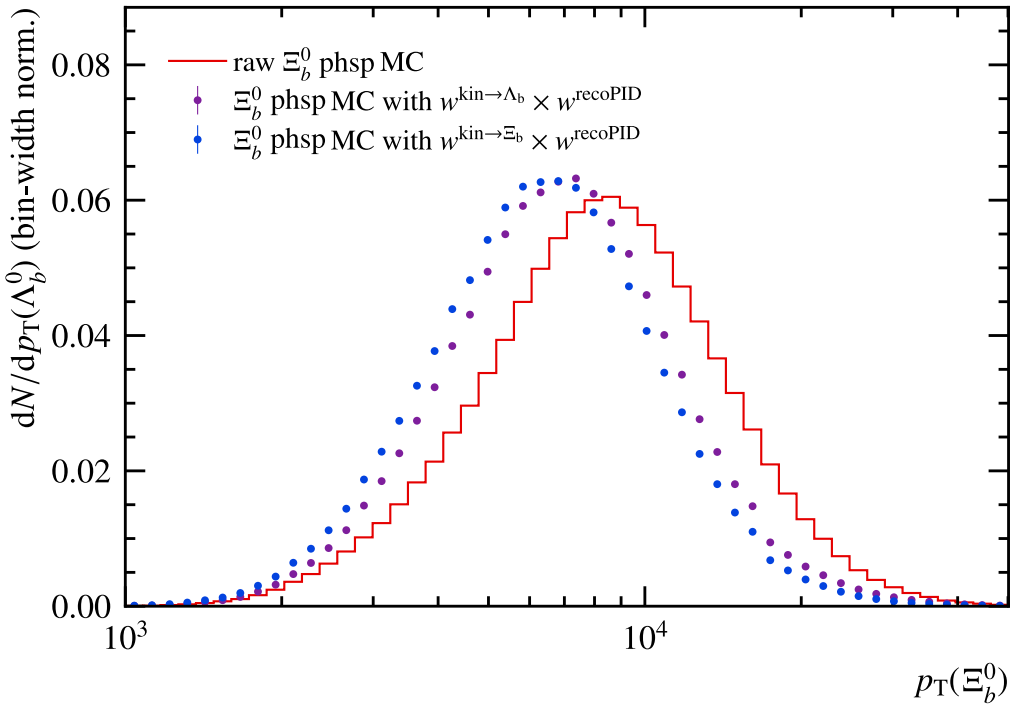
$$\text{BDT} > 0.84$$
$$\text{DLL}_{p\pi} > 37$$
$$\text{DLL}_{pK} > 20$$

- Cuts optimised for 2024 data but still in good shape
- <5% statistical uncertainty on the ratio of yields
- R_{raw} and yields per lumi. consistent between years
- Ξ_b^0 signal-to-bkg ratio slightly better in 24 data than in 25-26 data

MC correction - Kinematic

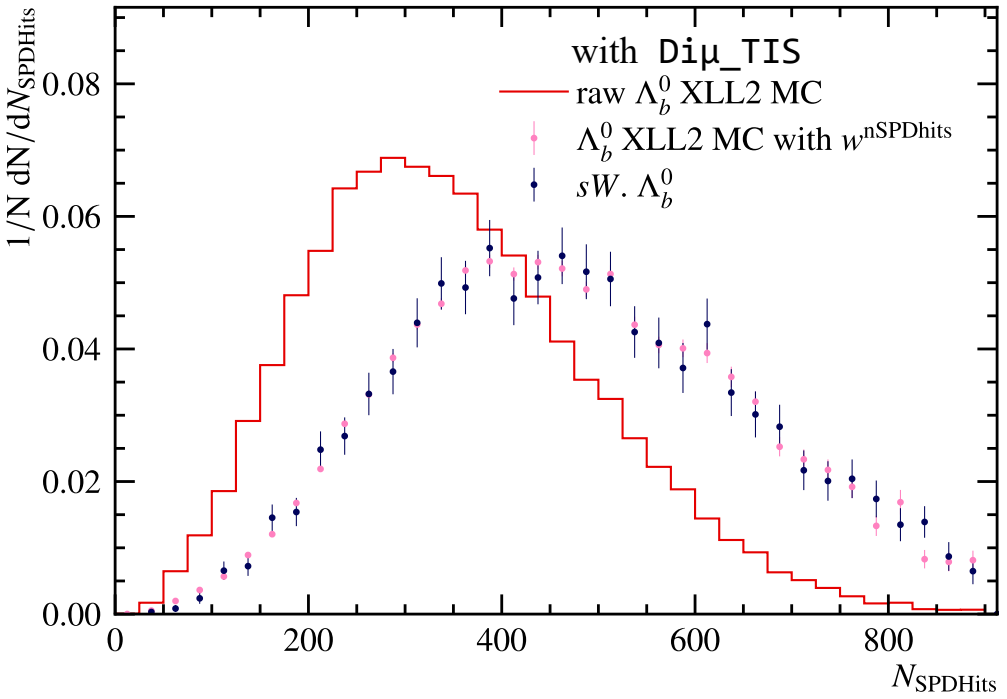
- For Λ_b^0:
  - Ratio between *sWeighted* Λ_b^0 signals and MC in 2-D isopopulated bins of $(p_{\mathrm{T}},\ \eta)$
  - *sWeights* extracted from fit to preselected Run 2 data
- For Ξ_b^0:
  - Also ratio that matches Ξ_b^0 MC to the *sWeighted* Λ_b^0 signals
  - Additional correction factor obtained from fit to $\mathcal{R}_{\mathrm{raw}}/\mathcal{R}_{\mathrm{raw,avg}}$ in Run 3 data after final selection (6 iso-populated lgp_{T} bins)

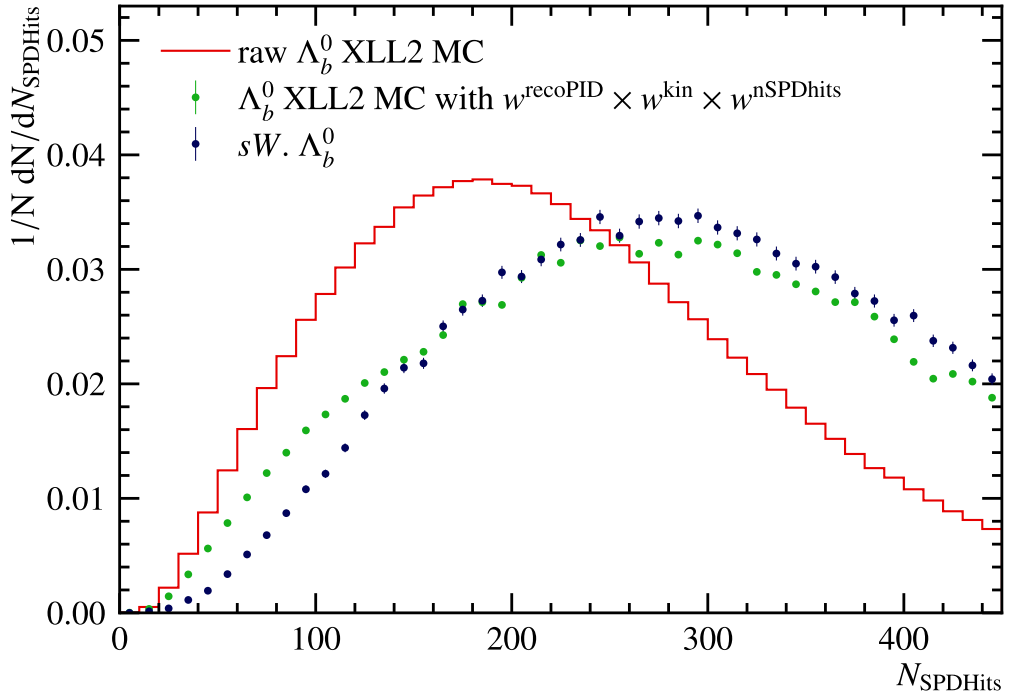




MC correction – Multiplicity

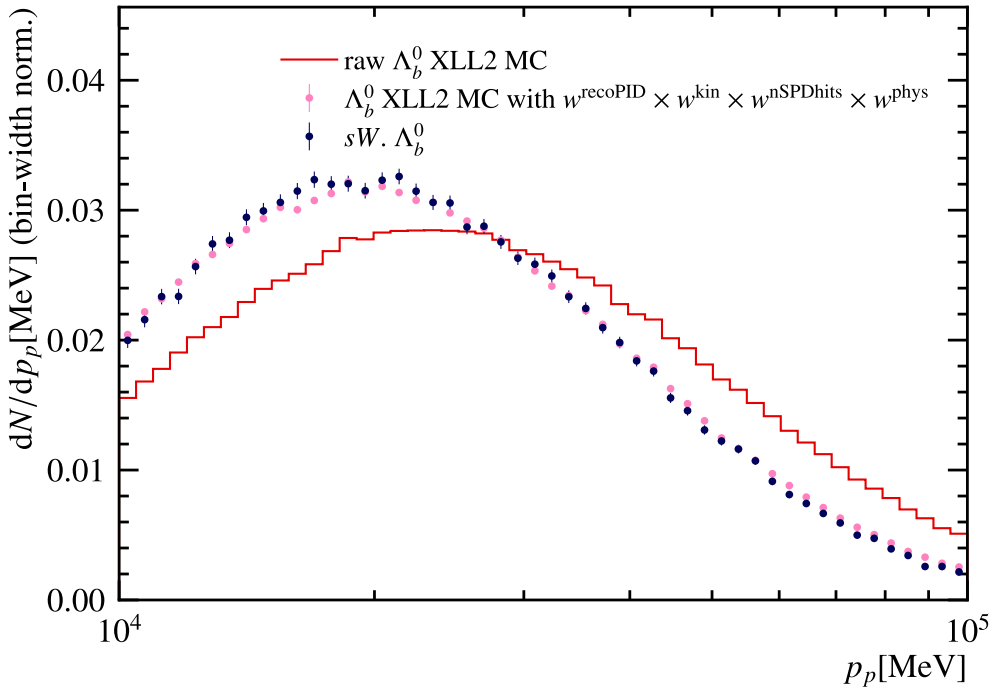
- `L0MuonDecision_TOS` has $N_{\mathrm{SPDHit}} < 450$ cut
- N_{SPDHit} too low in MC $\rightarrow$ ϵ_{L0} simulated too optimistic
- Utilising `L0DiMuonDecision_TIS` with $N_{\mathrm{SPDHit}} < 900$, calculate 1D reweighter that matches MC to *sWeighted* data, both with `L0DiMuonDecision_TIS` instead of `L0MuonDecision_TOS`

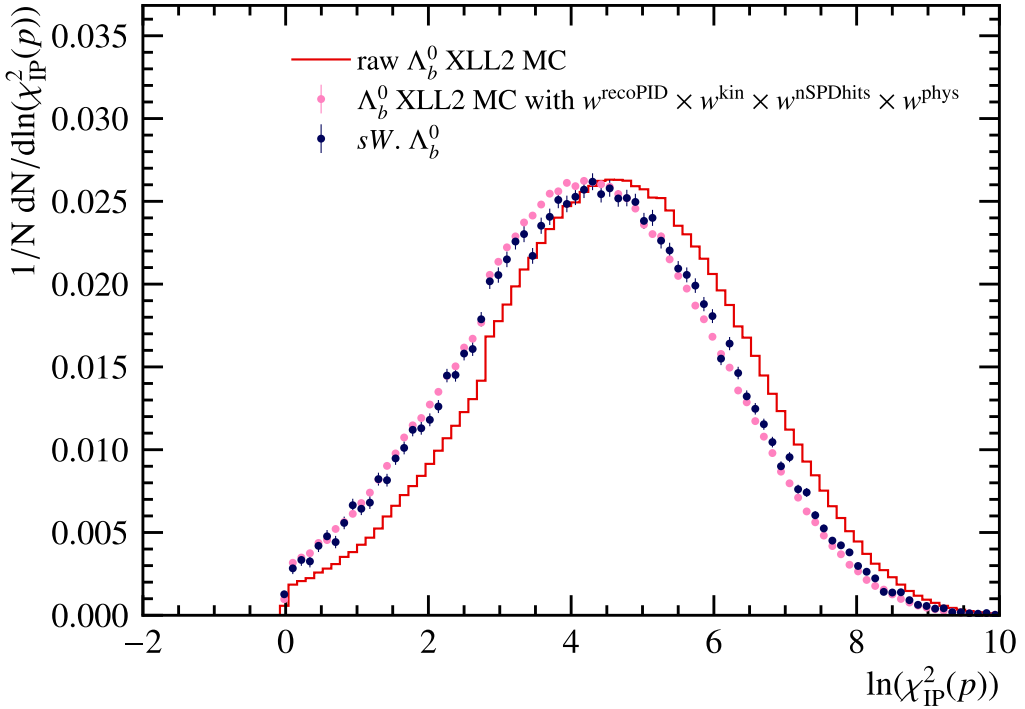




MC correction – Phys.

- Need to correct for the for effect of all the intermediate resonances
- 1D $m(pK^-)$ reweighter found to be insufficient
- Train 3-D $[m(pK^-), \theta'_{\text{open}}(J/\psi, p), \theta'_{\text{open}}(J/\psi, K^-)]$ `GBReweighter`, where $\theta'_{\text{open}}(A, B) =$ the opening angle between A and B in the Λ_b^0`s rest frame
- Λ_b^0: matches MC to *sWeighted* Λ_b^0 signals after preselection (same as the ones for kinematic correction)
  - Ξ_b^0: matches MC to combined Run 2+3 *sWeighted* Ξ_b^0 signals after final selection
  - All three variables` distributions found to be marginally warped by the selections, expect small systematics from training on *sWeighted* signals with tight selection



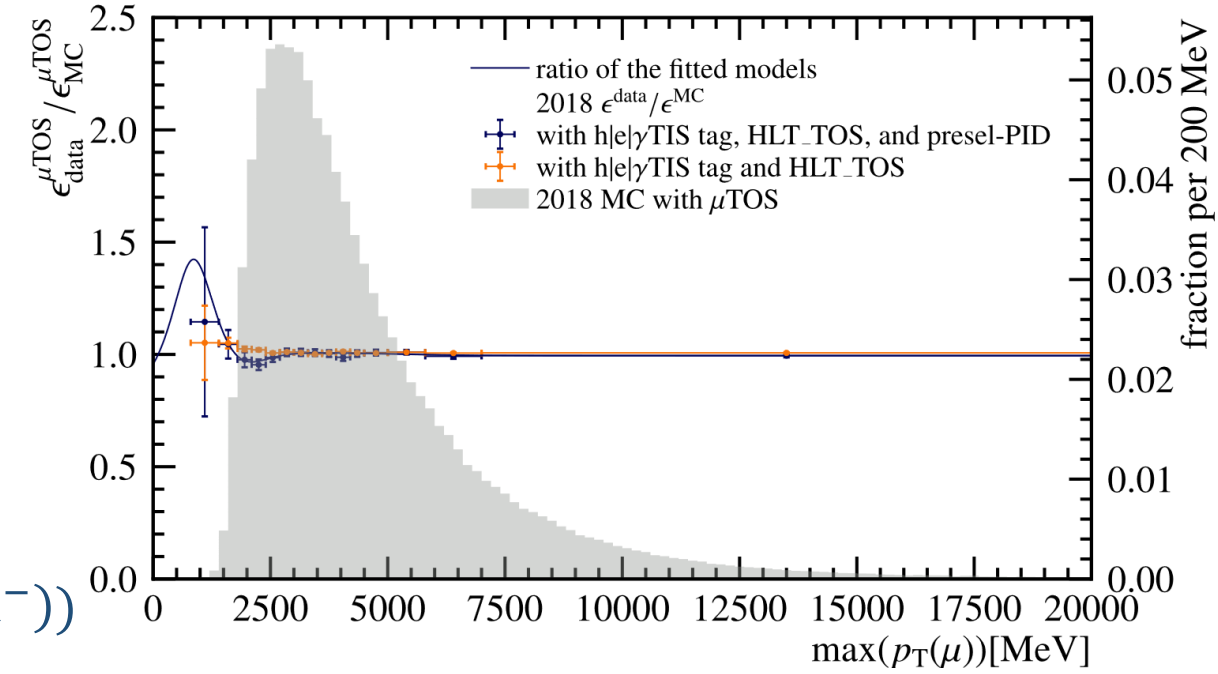


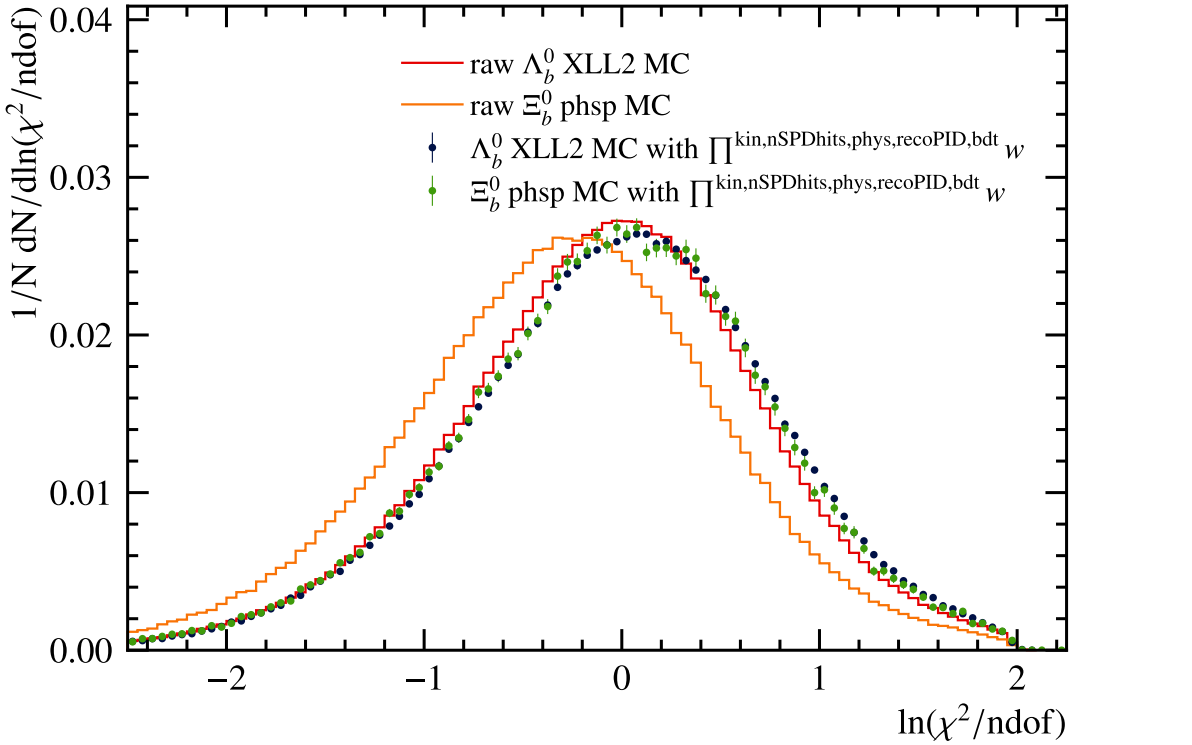
MC correction – L0 & BDTvar

- L0:
  - Additional correction for imperfect simulation of L0 efficiencies (from wrong threshold config., detector resolution, etc.)
  - $w_{\mathrm{L0}} = \epsilon^{\mathrm{Data}}(p_{\mathrm{T}})/\epsilon^{\mathrm{MC}}(p_{\mathrm{T}})$, where $p_{\mathrm{T}} = \max(p_{\mathrm{T}}(\mu^+\mu^-))$ and $\epsilon(p_{\mathrm{T}})$ obtained from fits
- BDTvar:
  - Correct the remaining differences in the BDT variables

$$[(\chi^2_{\mathrm{vtx}}, \chi^2_{\mathrm{DTF}}, \cos^{-1}\mathrm{DIRA}, \chi^2_{\mathrm{IP}}(\Lambda_b^0)]$$

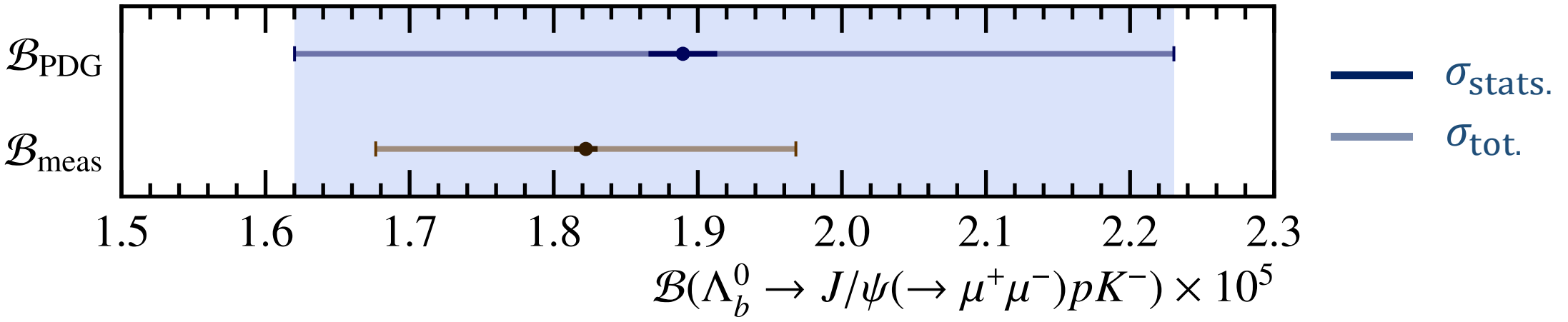
  - Two separate 4-D `GBReweighter` (for Λ_b^0 and Ξ_b^0 respectively) to match MCs to the *sWeighted* Λ_b^0 signals after preselection





Preliminary results on efficiencies (stats. error only)

$\epsilon_{\Lambda_b^0}[\%]$	$\epsilon_{\Xi_b^0}[\%]$	$\epsilon_{\Xi_b^0}/\epsilon_{\Lambda_b^0}[\%]$
$\mathbf{1.4811 \pm 0.0012}$	$\mathbf{1.660 \pm 0.004}$	$\mathbf{112.09 \pm 0.28}$



- Systematic uncertainty of the B_{meas} from what one would expect if $\Lambda_b^0 \to J/\psi pK^-$ is measured w.r.t. $B^0 \to J/\psi K^{*0}$, and if the uncertainties on the current PDG values of $B(B^0 \to J/\psi K^{*0})$ and $f_{\Lambda_b^0}/f_d$ are included.
- Systematic uncertainty on $\epsilon_{\Xi_b^0}/\epsilon_{\Lambda_b^0}$ expected to be ~5% (see slide 17)

Summary

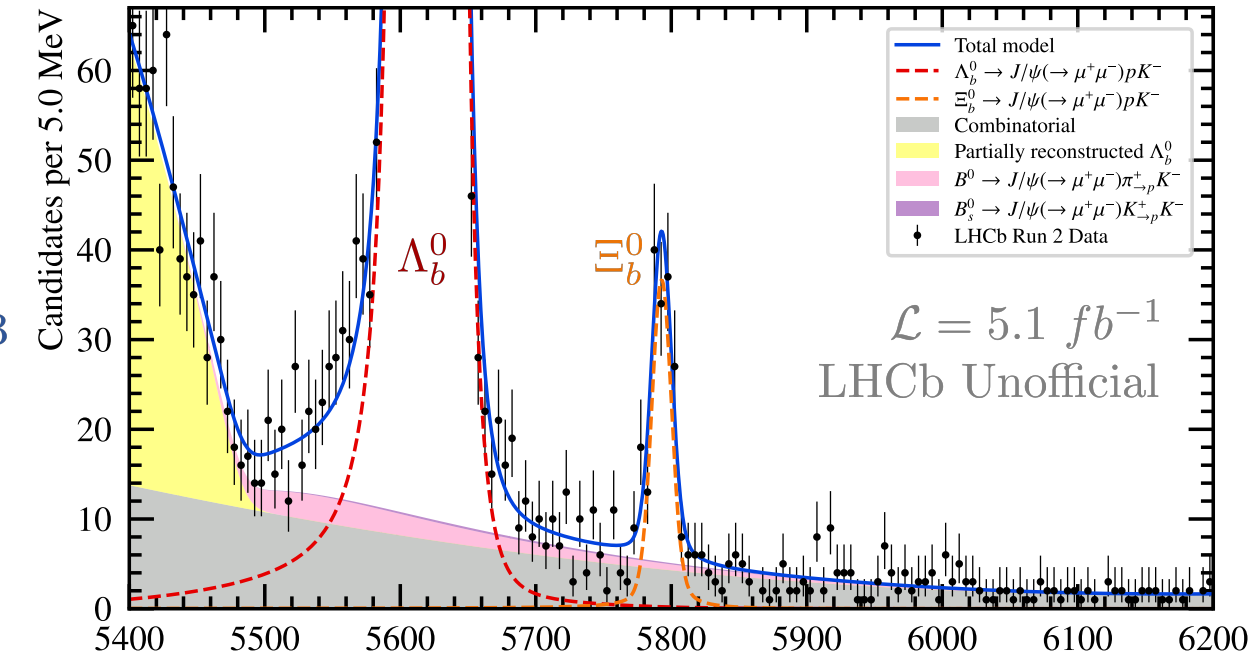
- Run 2:

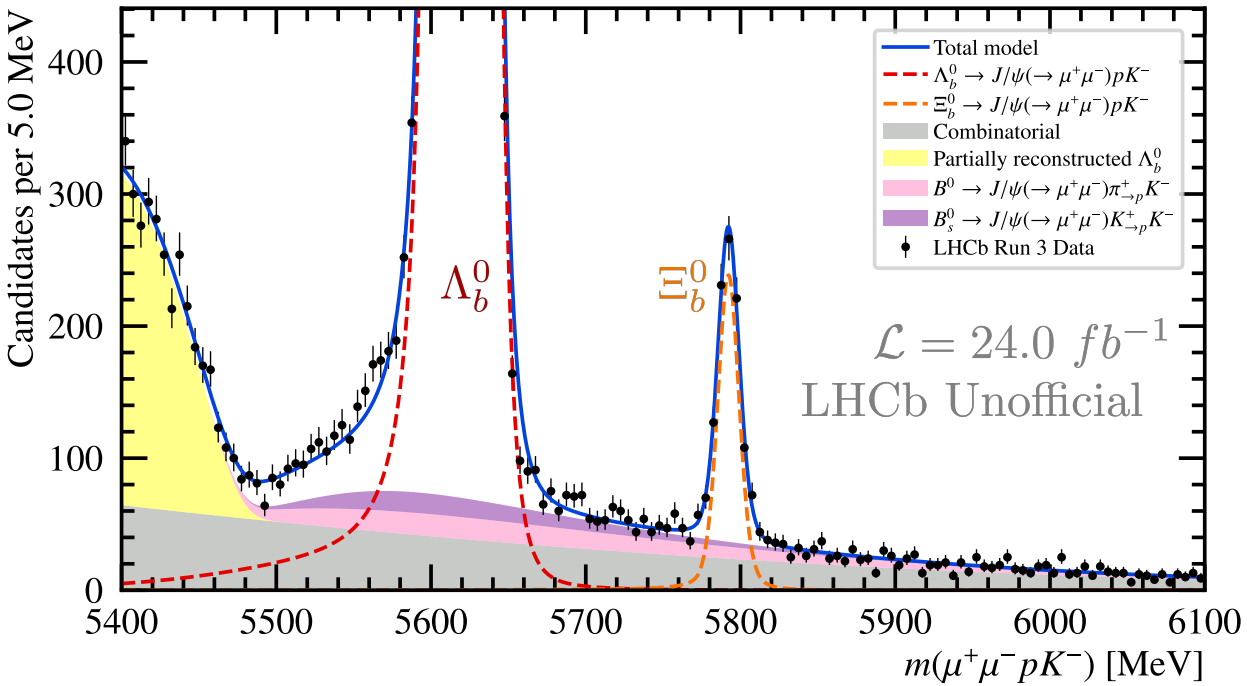
$\mathcal{R} = (2.80 \pm 0.30(\text{stat.}) \pm 0.14(\text{sys.})) \times 10^{-3}$

  - Preliminary results with MC correction, validated by the agreement of $\Lambda_b^0 \to J/\psi p K^-$ branching fraction with PDG value

- Run 3:

  - Observation of ~900 $\Xi_b^0 \to J/\psi p K^-$ candidates with combined Run 3 data, a factor of 5 increase compared to Run 2
  - Achieve <5% statistical precision in the ratio of yields with Run 3 data





Supplementary material

MC correction and efficiencies

- Total selection efficiency evaluated with

$$\epsilon_{\text{sel}} = \epsilon_{\text{strip,reco,P}} \times \epsilon_{\text{recoPID}} \times \epsilon_{\text{presel}} \times \epsilon_{\text{trigger}} \times \epsilon_{\text{BDT}} \times \epsilon_{\text{finalPID}} \times \epsilon_{\phi,B^+\text{ veto}}$$

- Efficiency in each stage calculated as

$$\epsilon_{\text{X}} = \frac{\sum_{\text{selected}} w_{\text{tot}}}{\sum_{\text{before}} w_{\text{tot}}}$$

- $w_{\text{tot}} = w_{\text{kin}} \times w_{\text{phys}} \times w_{\text{nSPDhit}} (\times w_{\text{recoPID}} \times w_{\text{L0}} \times w_{\text{BDT}} \times w_{\text{finalPID}})$
- w_{kin}, w_{phys}, w_{nSPDhit} always included
- w_{L0} only included after ϵ_{presel} evaluation
- w_{BDT} included after $\epsilon_{\text{trigger}}$
- ϵ_{PID} evaluated with w_{PID} from `PIDCalib2`

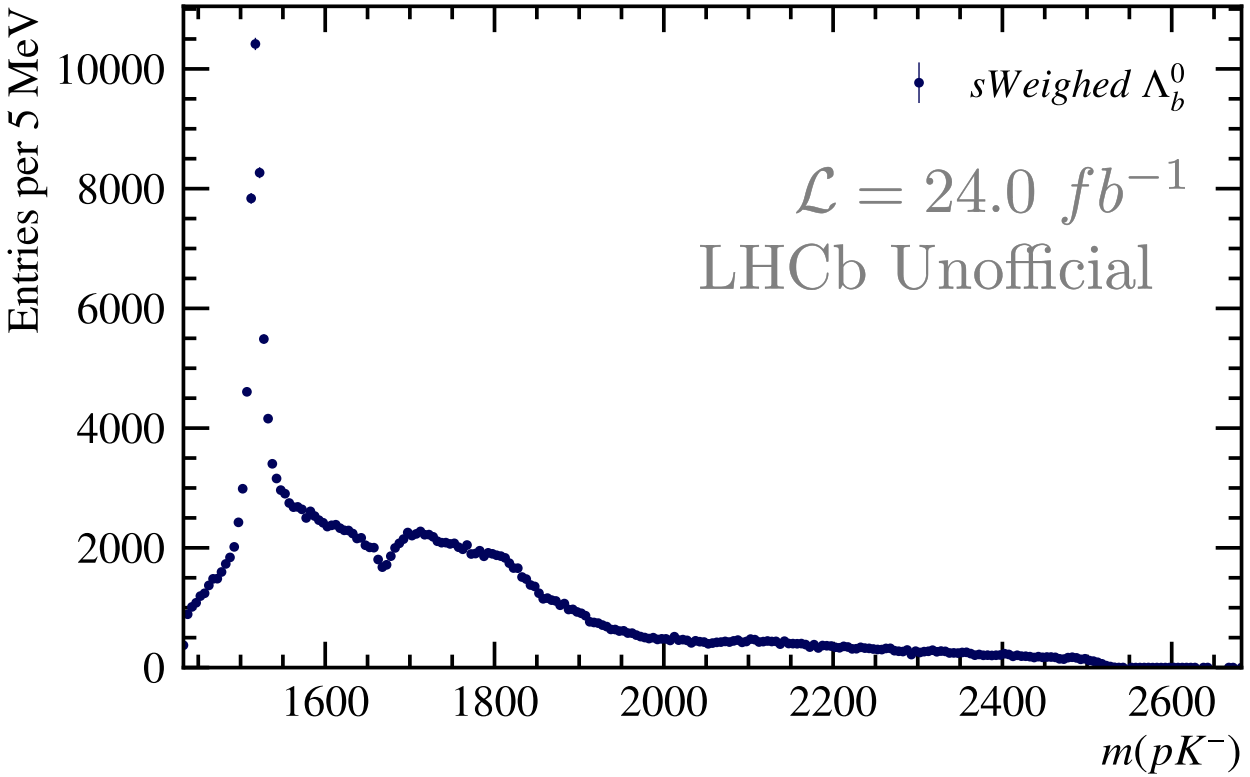
Efficiencies table with nominal MC correction

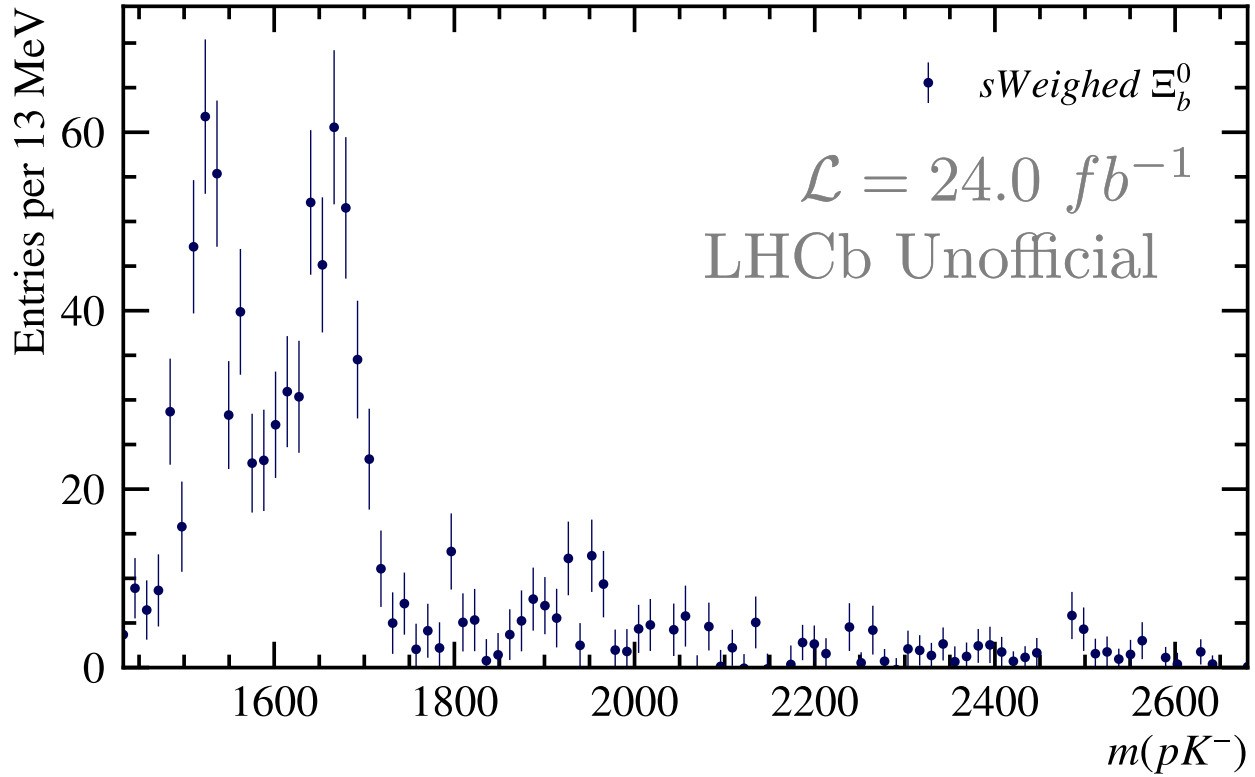
	Stage	$\epsilon_{\Lambda_b^0}[\%]$	$\epsilon_{\Xi_b^0}[\%]$	$\epsilon_{\Xi_b^0}/\epsilon_{\Lambda_b^0}[\%]$
	Striprecomom	13.881 ± 0.011	14.200 ± 0.032	102.30 ± 0.25
	recoPID	80.0384 ± 0.0016	79.968 ± 0.005	99.912 ± 0.007
ϵ_{presel}	notMuon	94.1967 ± 0.0022	94.722 ± 0.006	100.558 ± 0.007
ϵ_{presel}	notClone	99.97289 ± 0.00011	99.97857 ± 0.00026	100.00569 ± 0.00028
ϵ_{presel}	presel(nonPID)	75.592 ± 0.004	76.813 ± 0.011	101.616 ± 0.016
$\epsilon_{\text{trigger}}$	L0	66.883 ± 0.006	63.462 ± 0.017	94.886 ± 0.026
$\epsilon_{\text{trigger}}$	HLT1	84.115 ± 0.004	85.102 ± 0.012	101.174 ± 0.015
$\epsilon_{\text{trigger}}$	HLT2	86.613 ± 0.004	85.261 ± 0.014	98.439 ± 0.016
	BDT	77.653 ± 0.005	82.289 ± 0.014	105.971 ± 0.019
	PID	52.5235 ± 0.0035	55.668 ± 0.011	105.987 ± 0.023
	ϕ, B^+ veto	94.2749 ± 0.0030	95.337 ± 0.011	101.126 ± 0.012
	Total	$\mathbf{1.4811 \pm 0.0012}$	$\mathbf{1.660 \pm 0.004}$	$\mathbf{112.09 \pm 0.28}$

Preliminary results on systematics from MC correction

- Kinematic correction (relative to $\epsilon_{\Xi_b^0}$):
  - 0.65% from limited Ξ_b^0 stats. in the fit to get additional correction factor (estimated with bootstrapping)
  - 0.45% from choice of binning scheme in the fit
- Phys. correction (relative to $\epsilon_{\Xi_b^0}/\epsilon_{\Lambda_b^0}$):
  - 2.7% from the 3 variables used to the model the underlying physics (estimated with alternative sets of variables used in the `GBReweighter`)
  - 0.77% from limited Ξ_b^0 stats. used to train the reweighter (estimated with bootstrapping)
  - 1.9% from the warping of the reweighter variables` distributions by the tight selection and inclusion of Run 3 data (estimated using Λ_b^0)
- `PIDCalib2` (relative to $\epsilon_{\Xi_b^0}/\epsilon_{\Lambda_b^0}$):
  - 2.5% (conservative estimation by taking difference between different proton calibration sample, WIP)
- Other correction expected to have contribution of <1% each
- Overall expect ~5% systematics from the MC correction on the efficiencies ratio

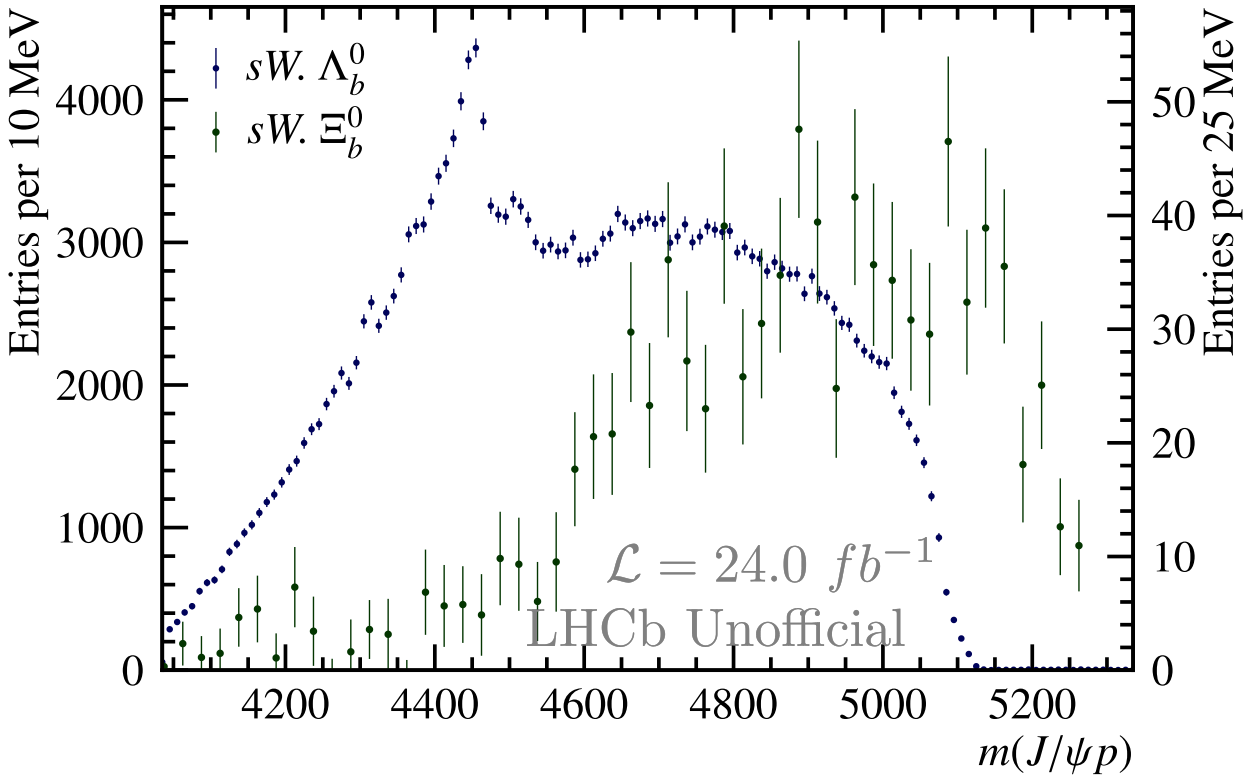
$m(pK^-)$ distributions of Λ_b^0 and Ξ_b^0 with full Run 3 data

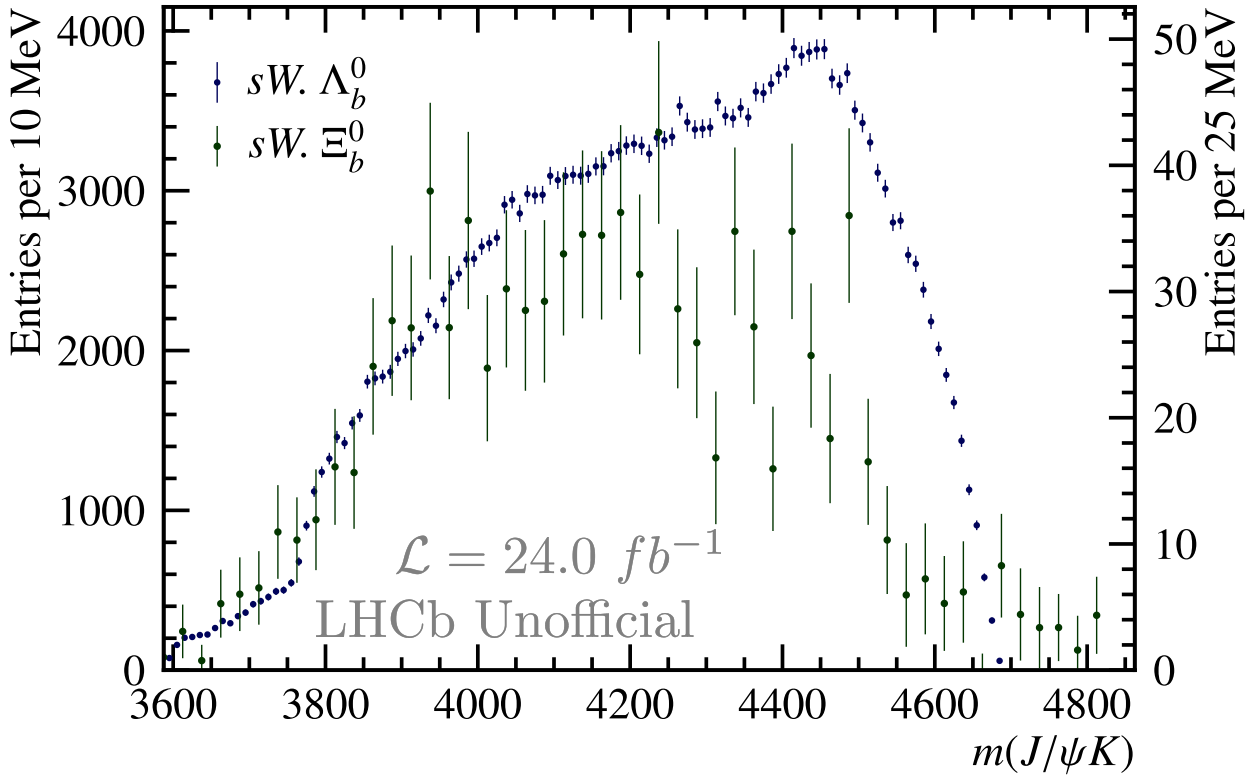




18

$m(pJ/\psi)$, $m(K^-J/\psi)$ distributions of Λ_b^0 and Ξ_b^0 with full Run 3 data





19