CMS Experiment at the LHC, CERN
Data recorded: 2017-Jul-31 02:43:27.876032 GMT
Run / Event / LS: 300156 / 28539391 / 26

Heavy flavour spectroscopy and properties at CMS

Kirill Ivanov [1] on behalf of the CMS Collaboration

kirill.ivanov@cern.ch

[1] Moscow Institute of Physics and Technology (MIPT)

22nd Conference on Flavor Physics and CP Violation (FPCP 2024)
Chulalongkorn University, Bangkok (Thailand)

30th May 2024

The work is supported by RSF (grant № 23-12-00083)

Overview

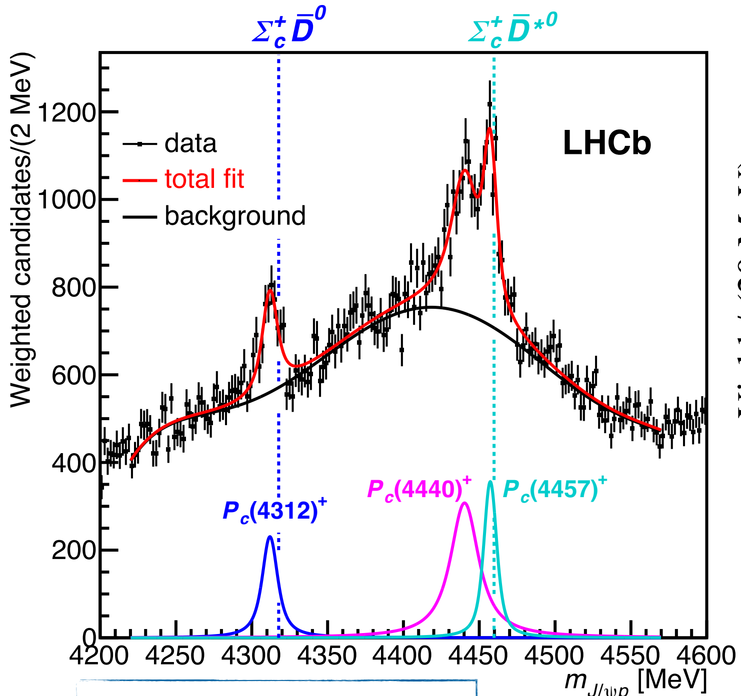
- Observation of the $\Lambda_b^0 \rightarrow J/\psi \Xi^- K^+$ decay
- Observation of $\Xi_b^- \rightarrow \psi(2S)\Xi^-$ decay and studies of Ξ_b^{*0} baryon at $\sqrt{s} = 13$ TeV
- Conclusion and summary

Observation of the $\Lambda_b^0 \to J/\psi \Xi^- K^+$ decay

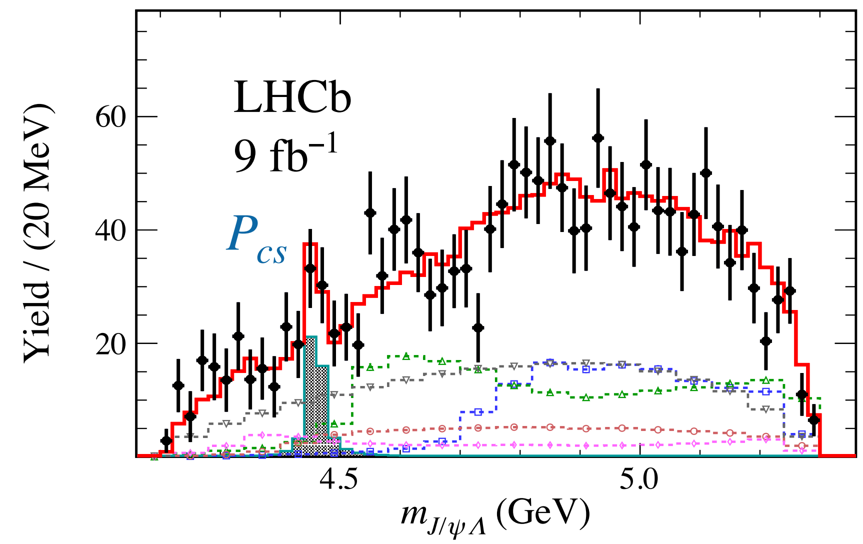
CMS-BPH-22-002, arXiv:2401.16303

Submitted to EPJC

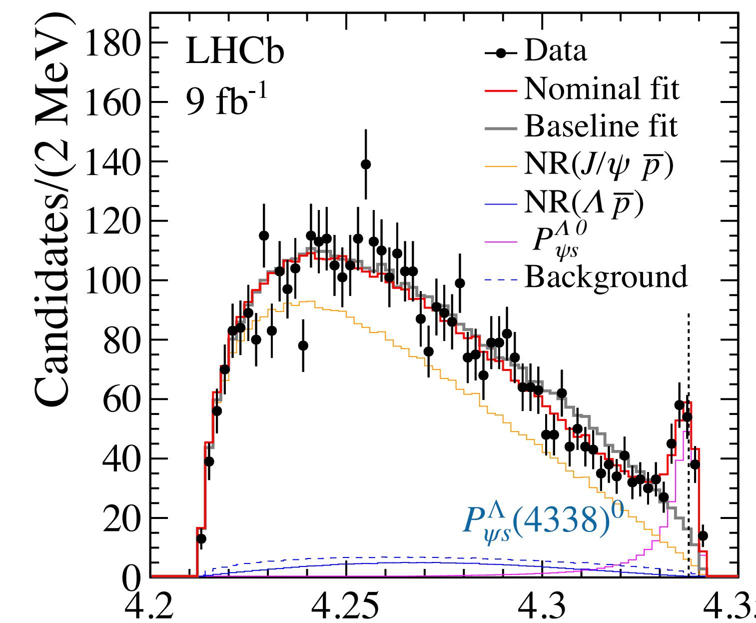
Introduction and motivation



[PRL 122, 222001 (2019)]



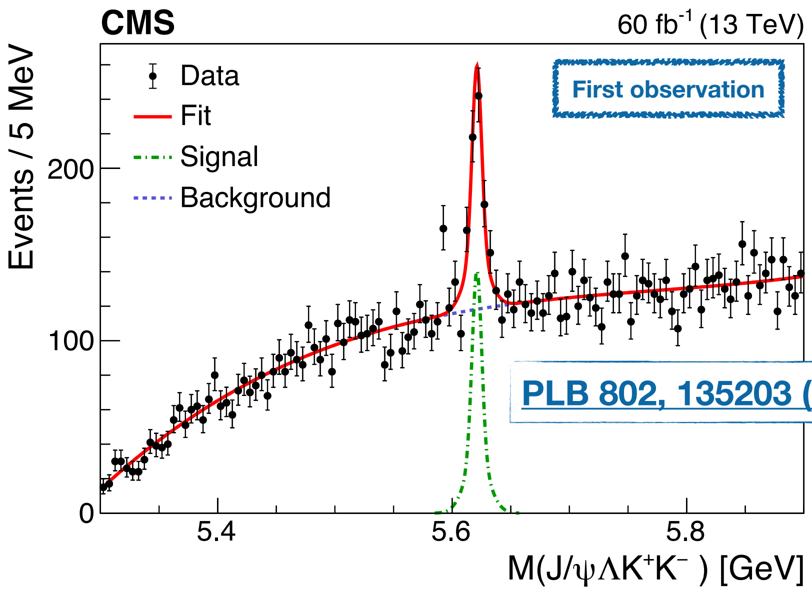
[Sci.Bull. 66 1278-1287 (2020)]



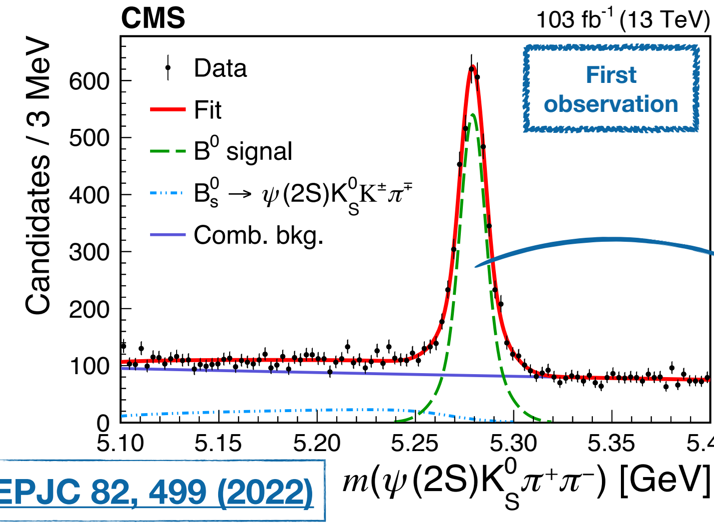
[PRL 131, 031901 (2022)]

- 3-body decays of b-hadrons to charmonia are good laboratory to search for the intermediate “exotic” (multi-quark) resonances
- Important for our understanding of QCD mechanisms behind hadron formation
- Over the last years, LHCb Collaboration has reported several new pentaquark-like particles in J/ψ + light hadron final state (with hidden-charm and hidden-charm strange)
- While many of the observed states are narrow, a 6D amplitude analysis is often required to disentangle between various overlaps and interference

Previous CMS efforts

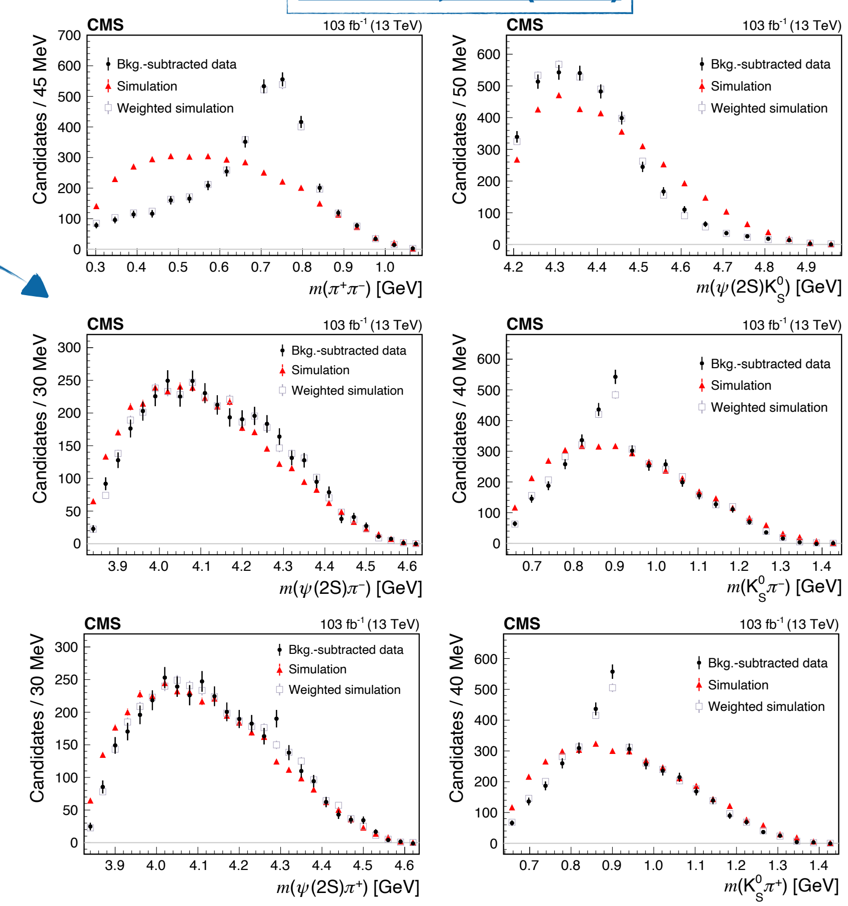


PLB 802, 135203 (2019)



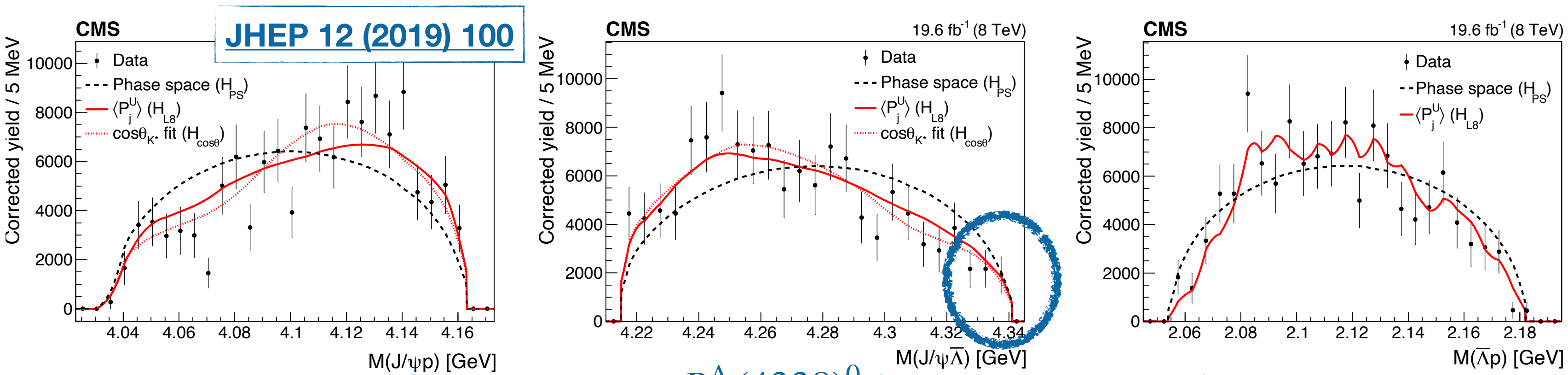
EPJC 82, 499 (2022)

EPJC 82, 499 (2022)



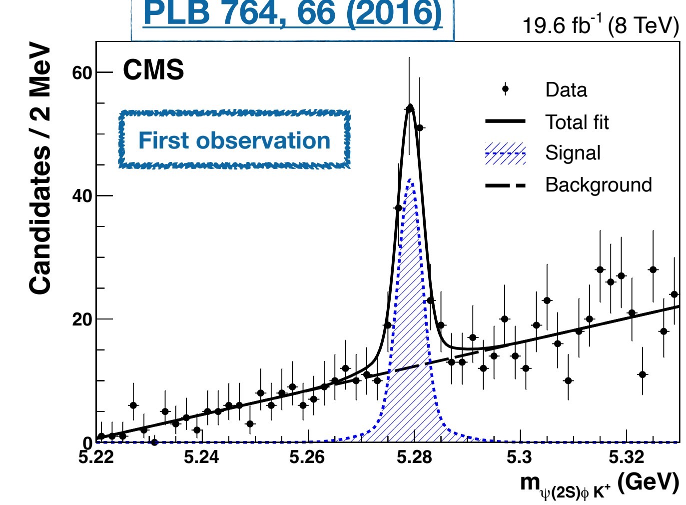
No exotic contribution observed so far!

JHEP 12 (2019) 100



Later LHCb observed here $P^{\Lambda}_{\psi s}(4338)^0$ (we were not sensible)

PLB 764, 66 (2016)



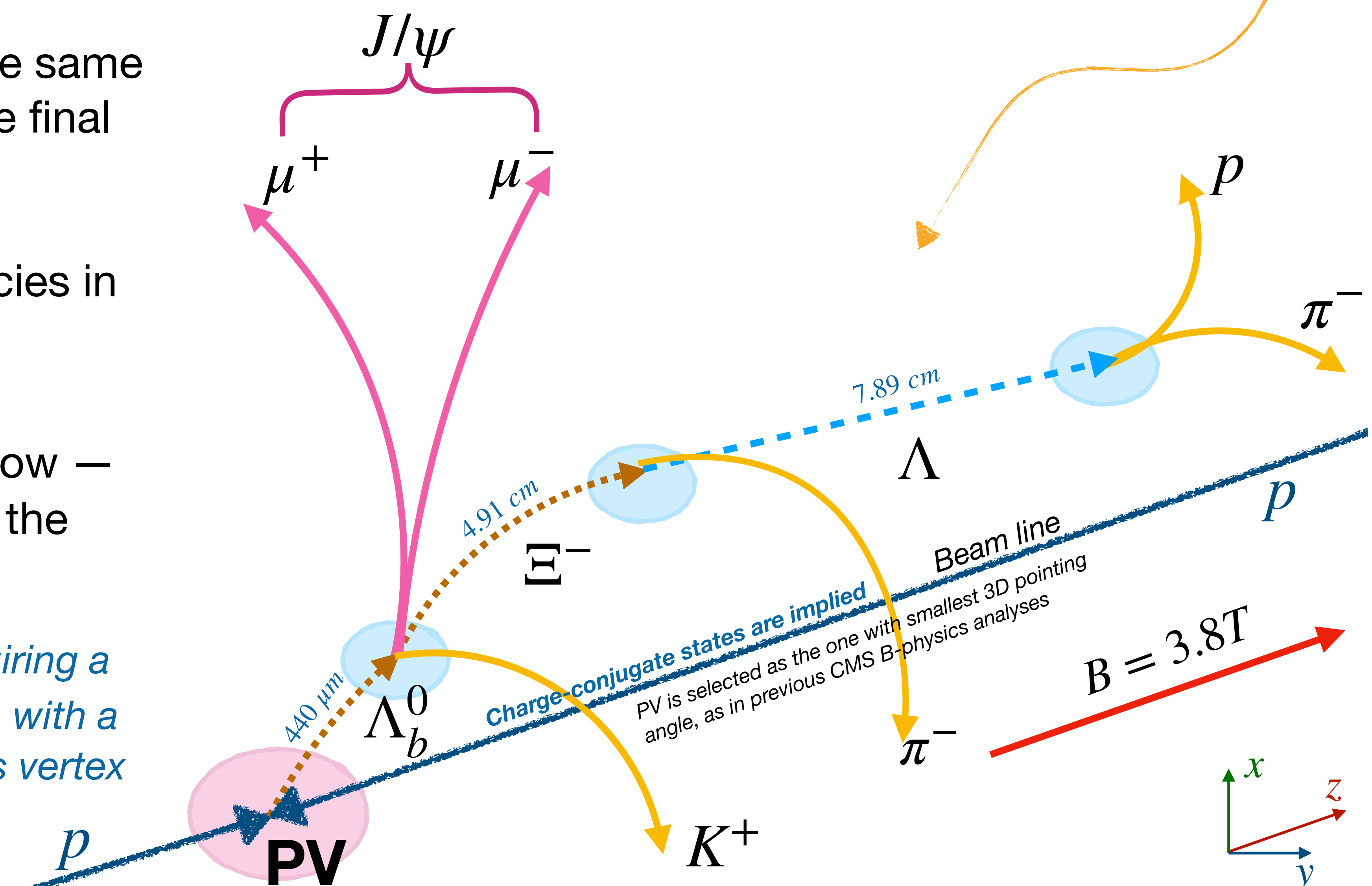
- Due to excellent muon system, CMS Experiment is contributing to hunt for exotic states \w $\psi \to \mu^+\mu^-$ in the final state (see also talk by Kai Yi about $X \to J/\psi J/\psi$)
- We have previously studied $B^+ \to J/\psi\overline{\Lambda}p$ decay with Run-1 (later LHCb observed there $P^{\Lambda}_{\psi s}(4338)^0$ with Run-2 data) and have reported the observations of $B^+ \to \psi(2S)\phi K^+$, $\Lambda^0_b \to J/\psi\Lambda\phi$ and $B^0 \to \psi(2S)K^0_S\pi^+\pi^-$ decays, where exotic contributions could be searched with larger statistics
- The double-strange pentaquark candidates $P^{\Xi}_{\psi ss}$ could be searched in the 3-body decay involving $J/\psi\Xi^-$

All above gives us the motivation to search for the $\Lambda^0_b \to J/\psi\Xi^-K^+$ decay at CMS, which is reported in this talk

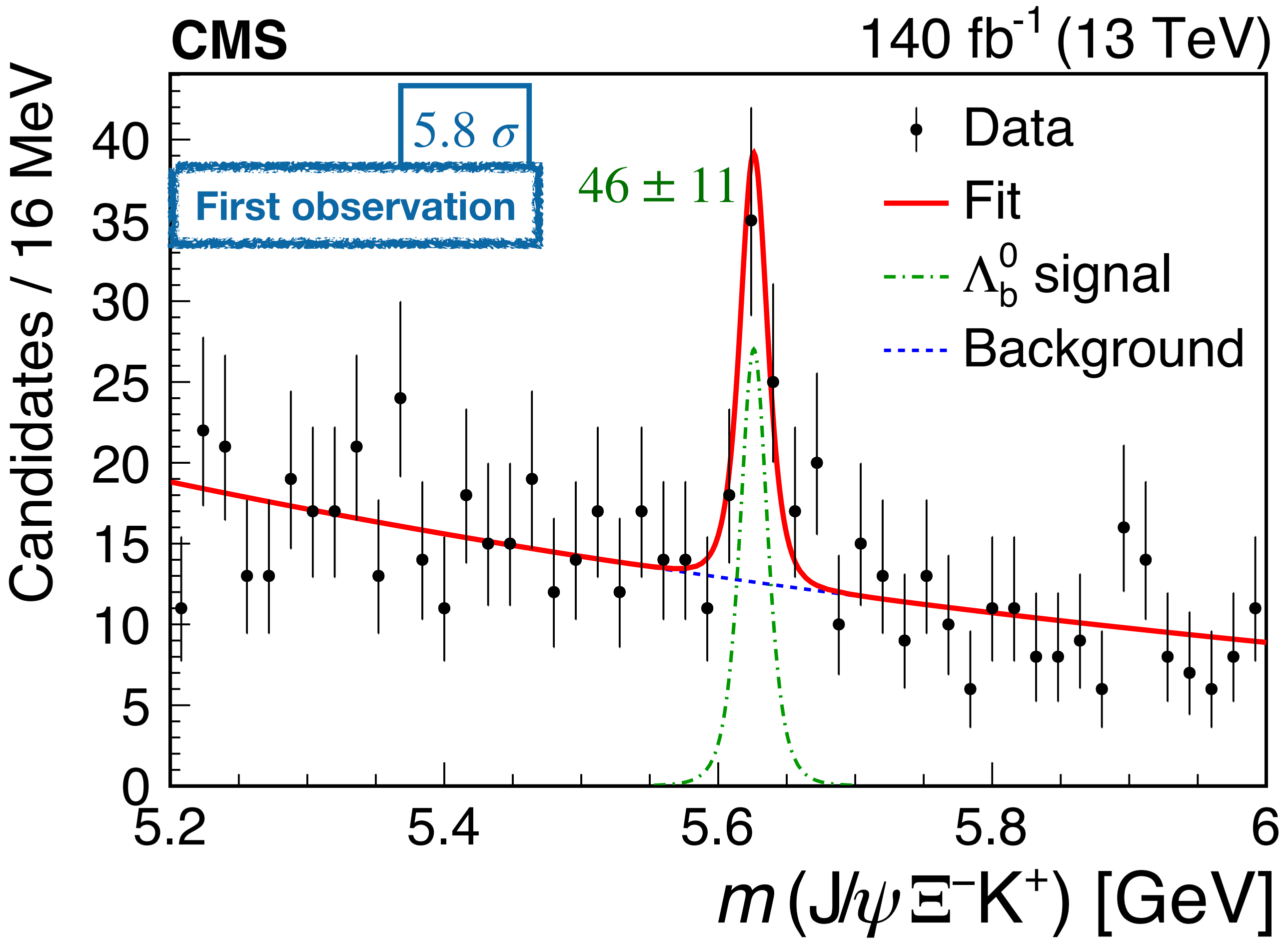
CMS Analysis Overview

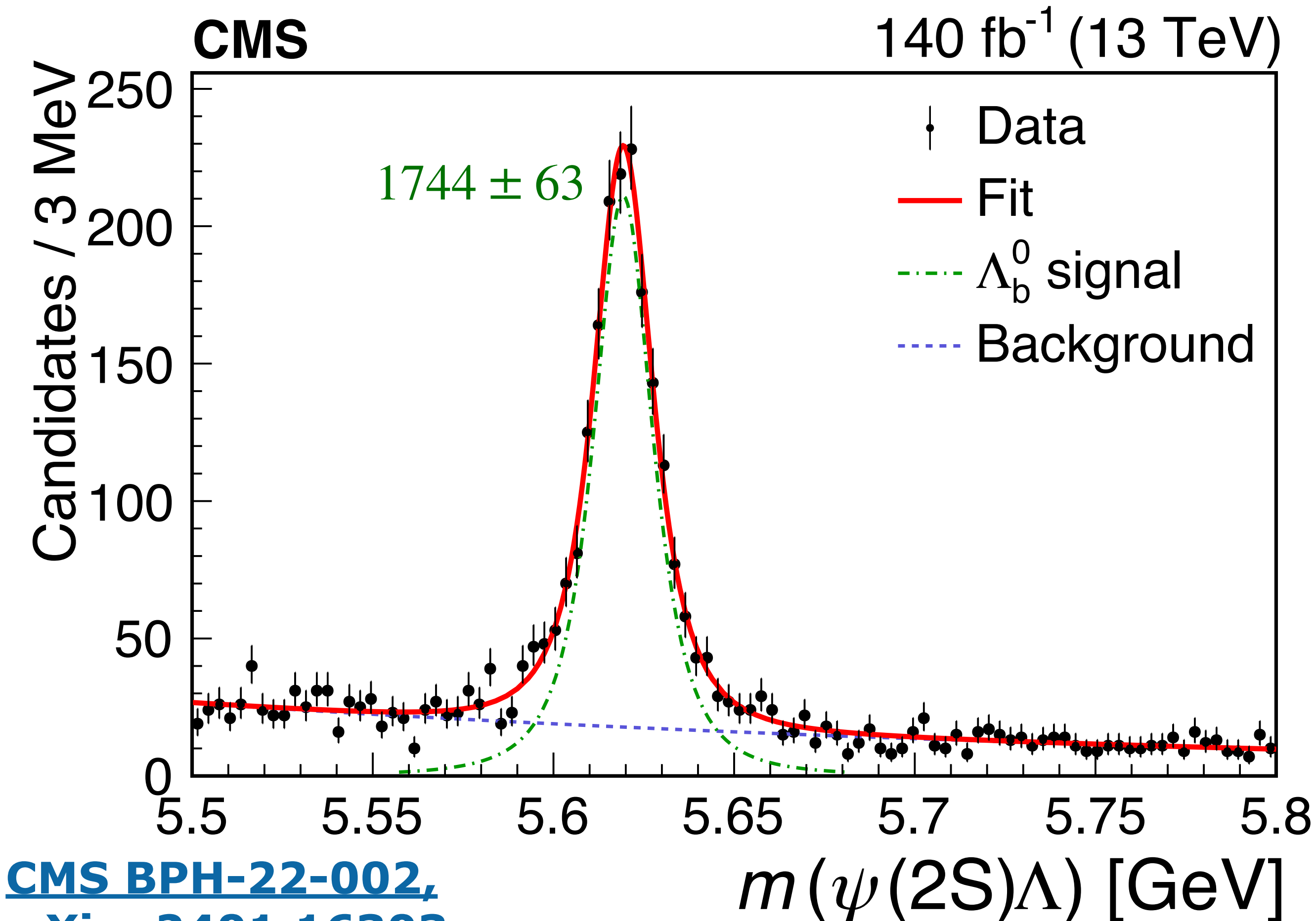
- We use full Run-2 CMS data ($140\ fb^{-1}$, $\sqrt{s} = 13$ TeV) to reconstruct two decays of Λ_b^0 baryon:
  - The signal one **(not observed before!)** — $\Lambda_b^0 \to J/\psi \Xi^- K^+$ with $J/\psi \to \mu^+\mu^-$, 2 tracks + V0 = $\Lambda \to p\pi^-$
    - The normalization one: $\Lambda_b^0 \to \psi(2S)\Lambda$, with $\psi(2S) \to J/\psi\pi^+\pi^-$, 2 tracks and V0 = $\Lambda \to p\pi^-$
- We measure the ratio of the branching fractions $\mathscr{R} = \mathscr{B}\left(\Lambda_b^0 \to \mathrm{J}/\psi\Xi^-\mathrm{K}^+\right) / \mathscr{B}\left(\Lambda_b^0 \to \psi(2\mathrm{S})\Lambda\right)$
- The topologies are similar, have the same number of muons and tracks in the final states — it allows to reduce the systematics related with the reconstruction and trigger efficiencies in $\mathscr{R}$
- The signal is expected to be very low — **Punzi Figure or Merit is used** for the optimization of selection criteria

Events are selected using trigger, requiring a dimuon J/ψ vertex, displaced from PV, with a track compatible to be produced in this vertex



Observation of the $\Lambda_b^0 \to J/\psi \Xi^- K^+$ decay





CMS BPH-22-002, arXiv: 2401.16303

- **Signal shape:** Student's t-distribution, its shape free (right) or partially fixed from MC (left)
  Background: Exponential function

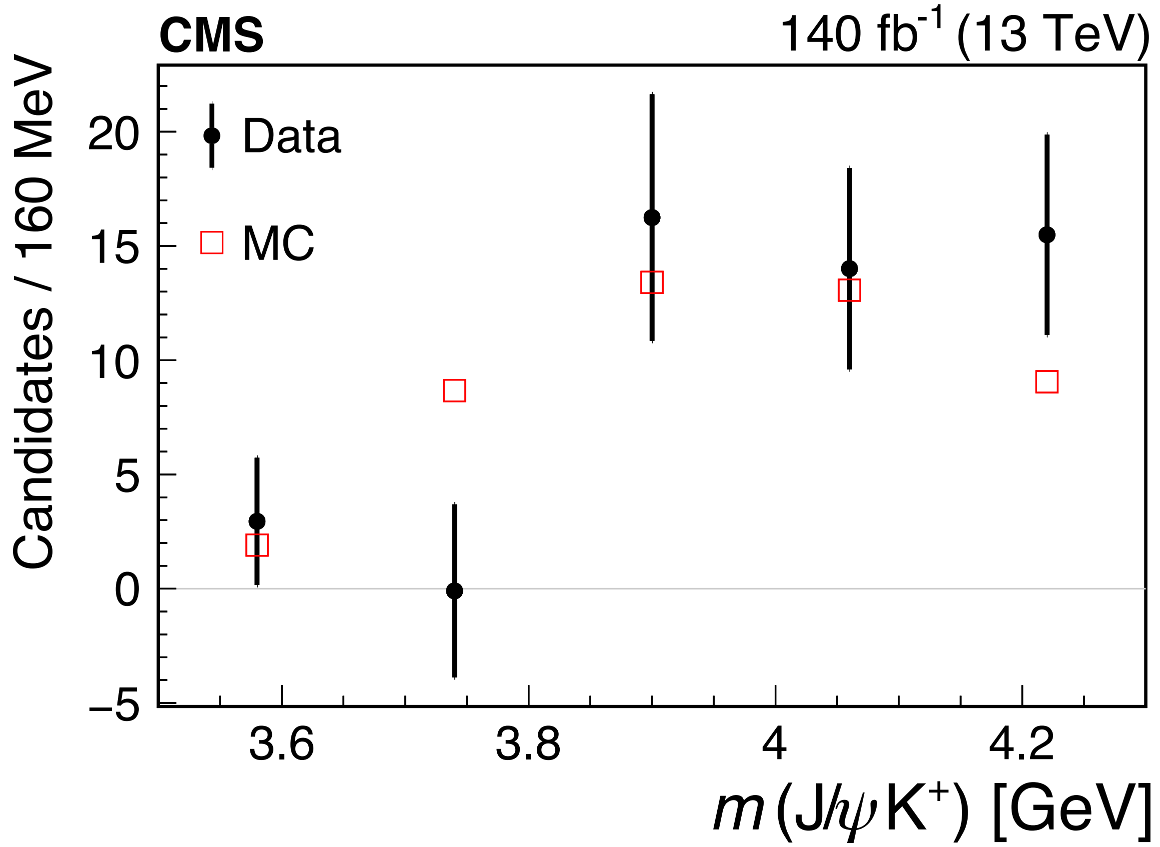
- **Local statistical significance** from likelihood ratio technique (Sig. + Bkg. versus Bkg. only hypothesis) is **5.8 sigma** for the baseline fit and varies from 5.3 to 5.9 considering systematics

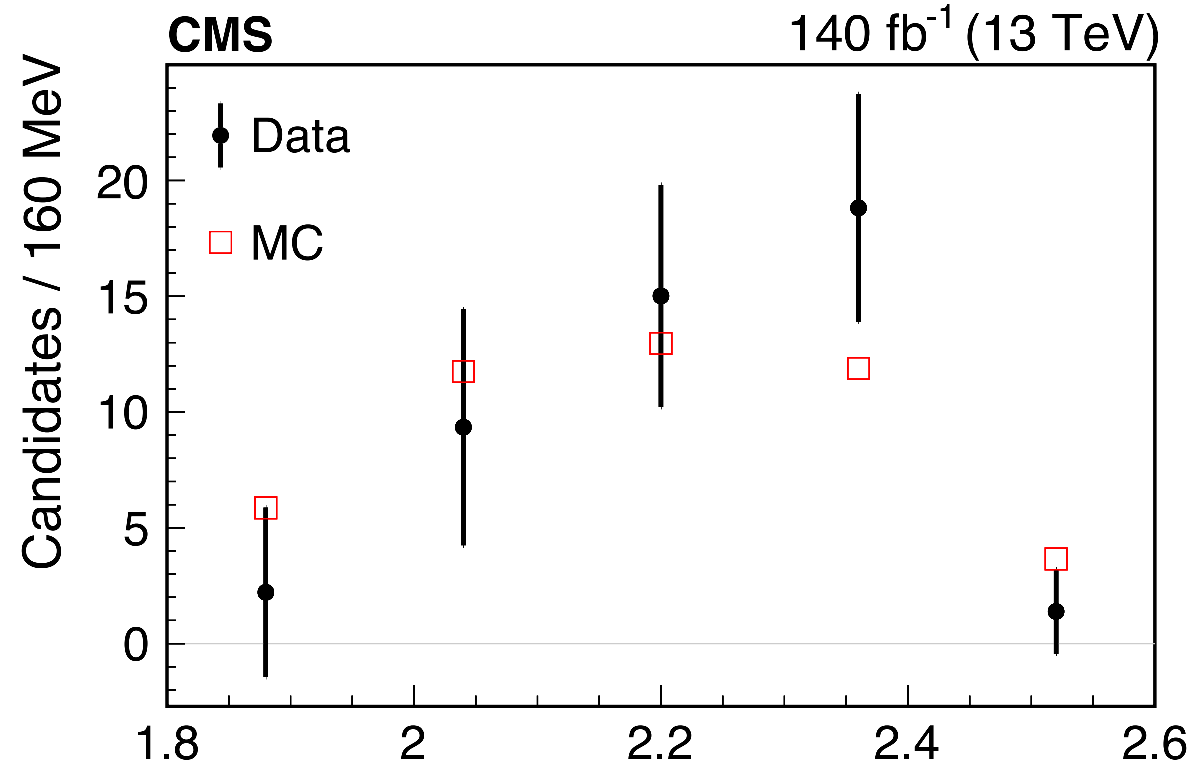
- Branching fraction of the new decay is estimated to be:

$$\mathcal{R} \equiv \frac{\mathcal{B}\left(\Lambda_b^0 \to J/\psi \Xi^- K^+\right)}{\mathcal{B}\left(\Lambda_b^0 \to \psi(2S)\Lambda\right)} = \frac{N\left(\Lambda_b^0 \to J/\psi \Xi^- K^+\right)}{N\left(\Lambda_b^0 \to \psi(2S)\Lambda\right)} \frac{\epsilon_{\psi(2S)\Lambda}}{\epsilon_{J/\psi \Xi^- K^+}} \frac{\mathcal{B}\left(\psi(2S) \to J/\psi \pi^+\pi^-\right)}{\mathcal{B}\left(\Xi^- \to \Lambda\pi^-\right)} = [3.38 \pm 1.02 \pm 0.61 \pm 0.03]\,\%$$

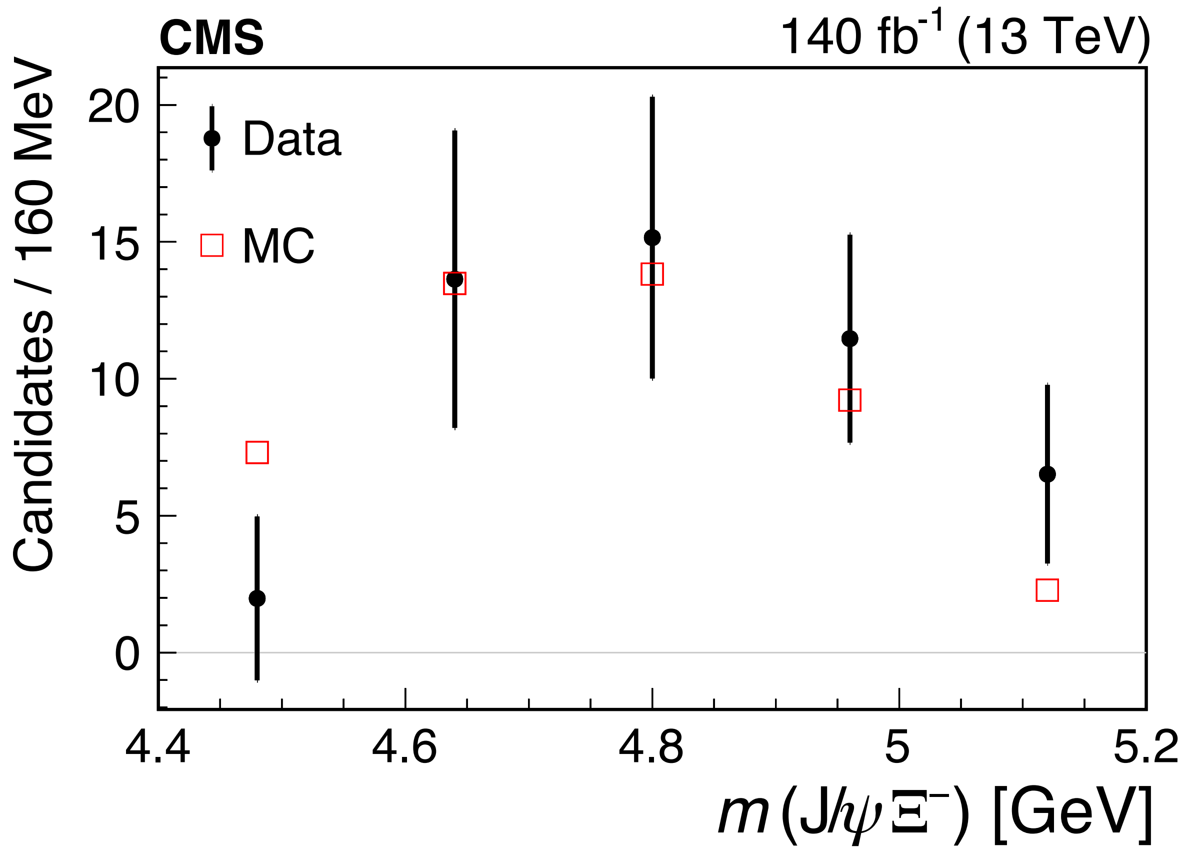
from data fits — from MC simulation

$J/\psi\Xi^- K^+$ intermediate mass distributions





[CMS BPH-22-002, arXiv: 2401.16303](https://arxiv.org/abs/2401.16303)



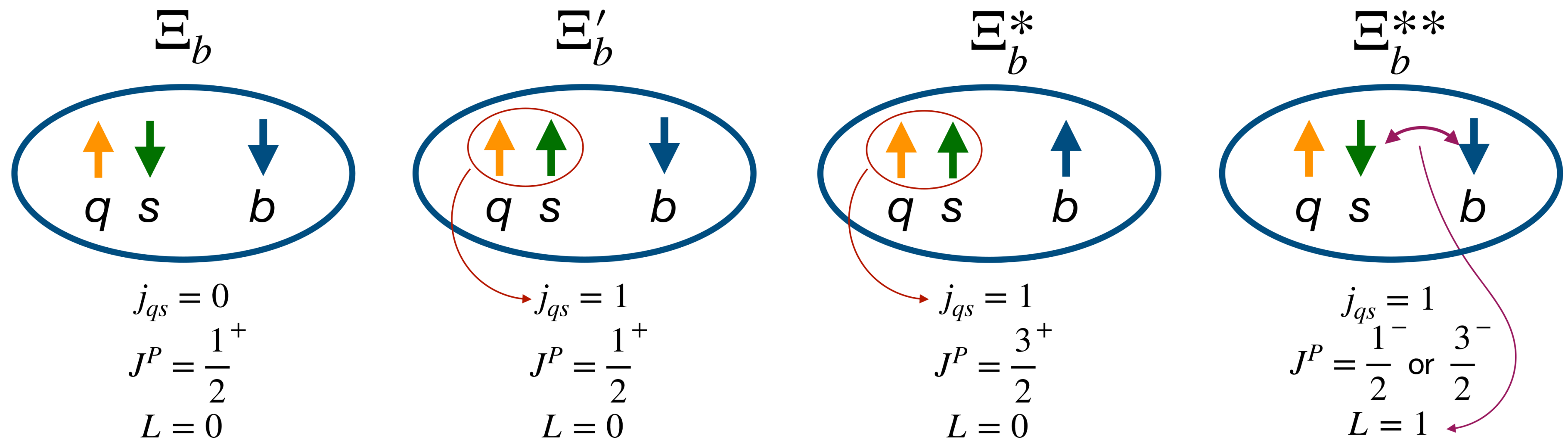
- We've taken a look to the 2-body intermediate mass distributions
- Background-subtraction $_{s}Plot$ technique is used
- With the current (*very low, 46 signal events!)* statistics data is in agreement with phase-space MC expectations
- **More data is needed** to fully explore the internal dynamics of this 3-body system — a task for Run-3 and beyond?

Observation of $\Xi_b^- \to \psi(2S)\Xi^-$ decay and studies of Ξ_b^{*0} baryon at $\sqrt{s} = 13$ TeV

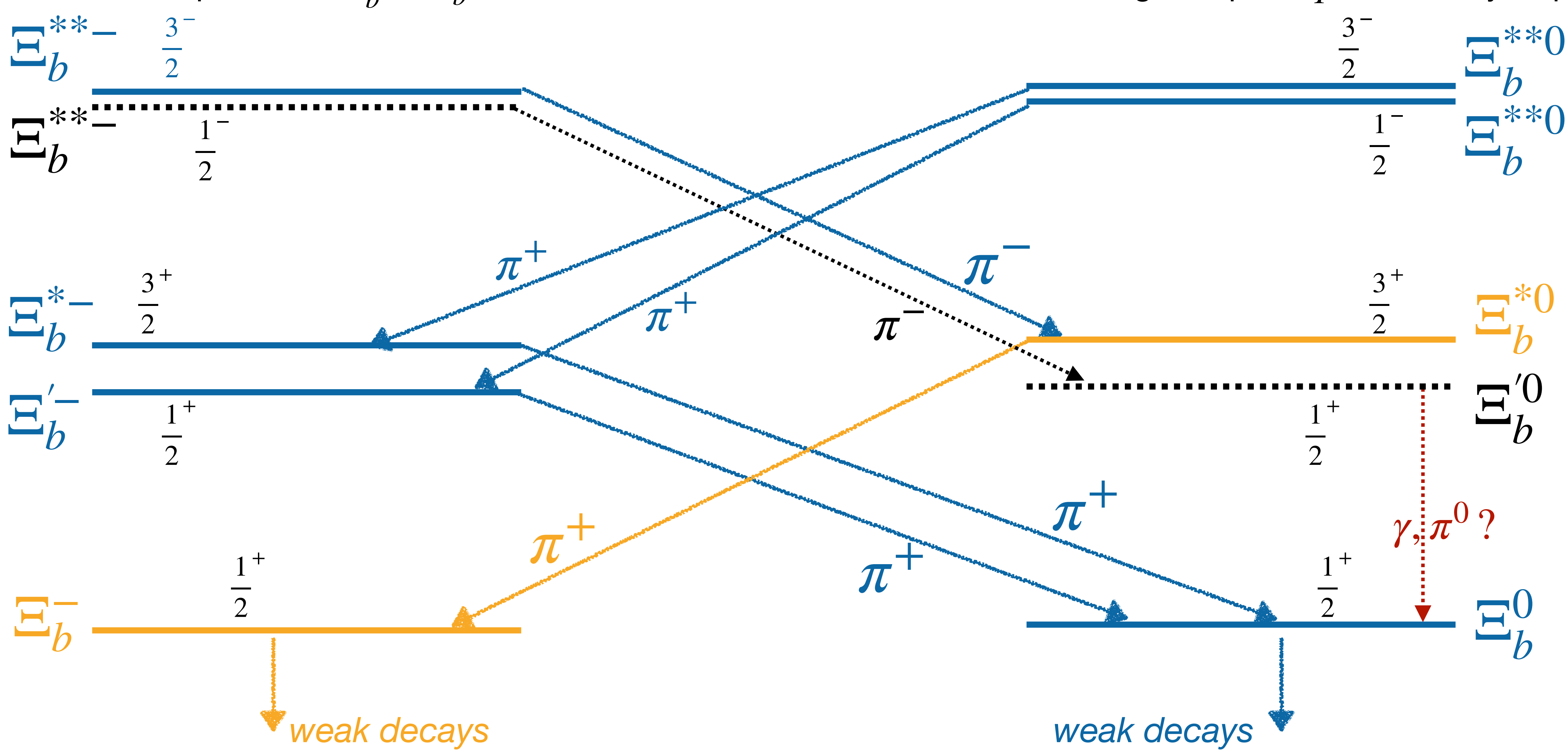
CMS-BPH-23-002, arXiv:2402.17738,

accepted by Phys. Rev. D

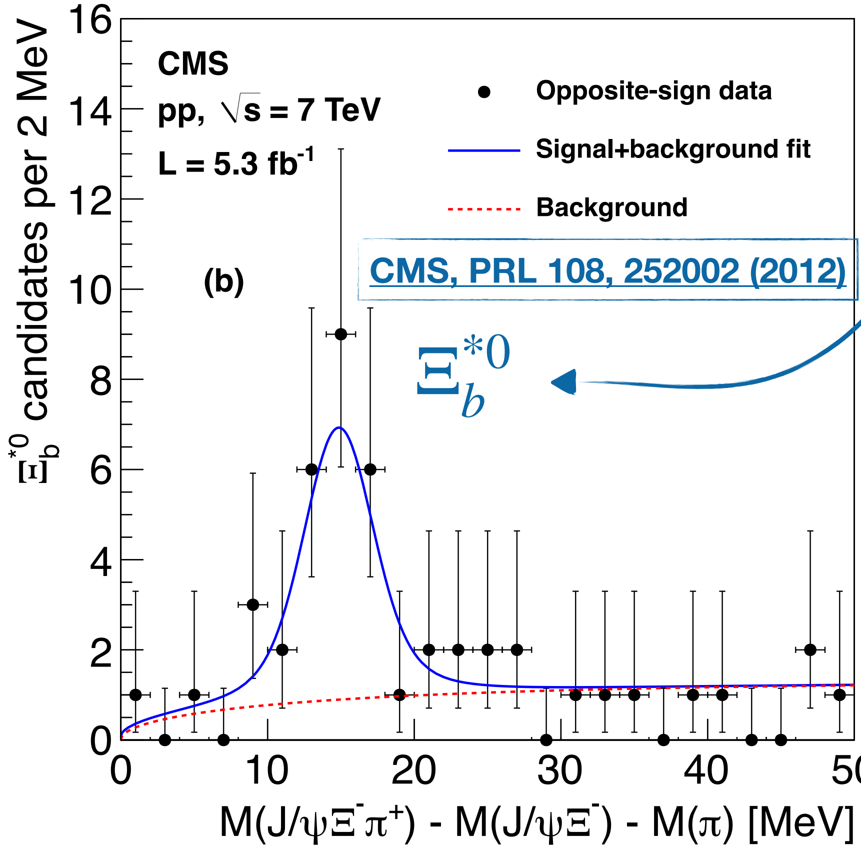
Ξ_b baryons spectroscopy



q denotes u or d quarks for Ξ_b^0 or Ξ_b^-. $L = 1$ is the orbital excitation between the light diquark qs and heavy b quark.

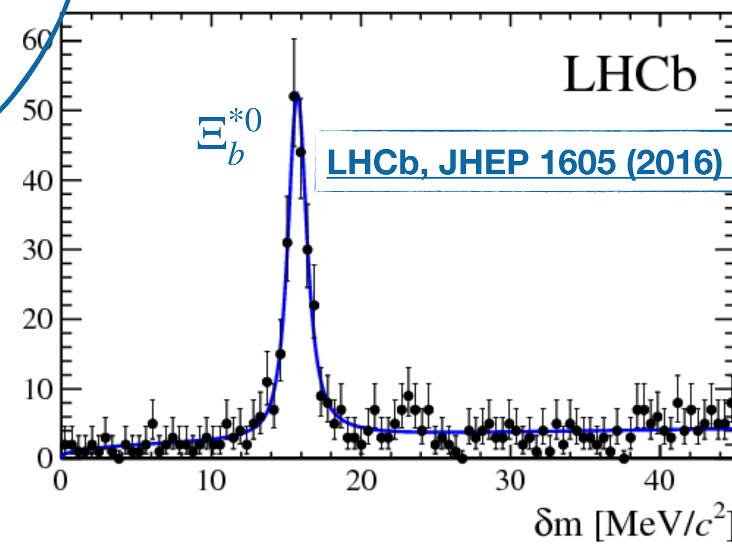


Previous results of Ξ_b resonances

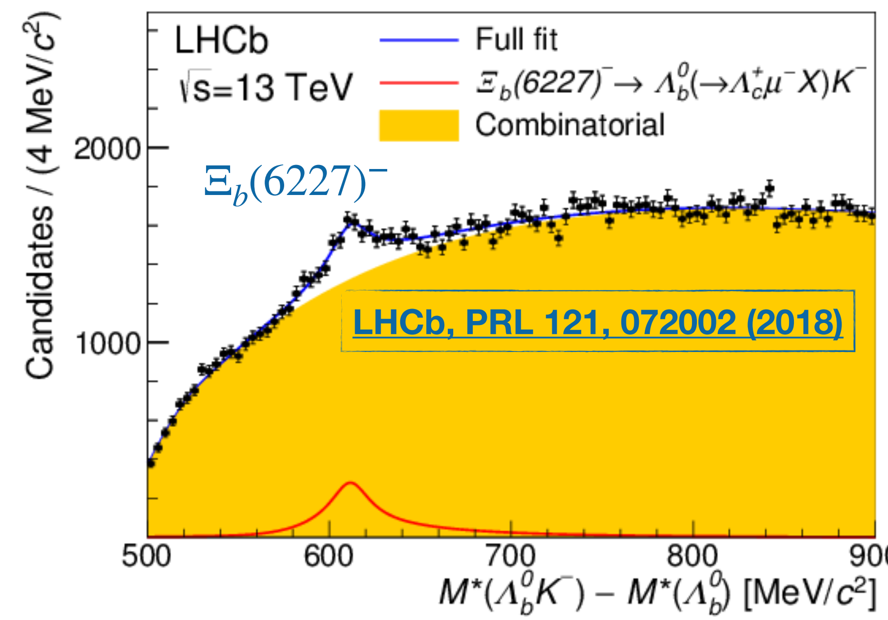


CMS, PRL 108, 252002 (2012)

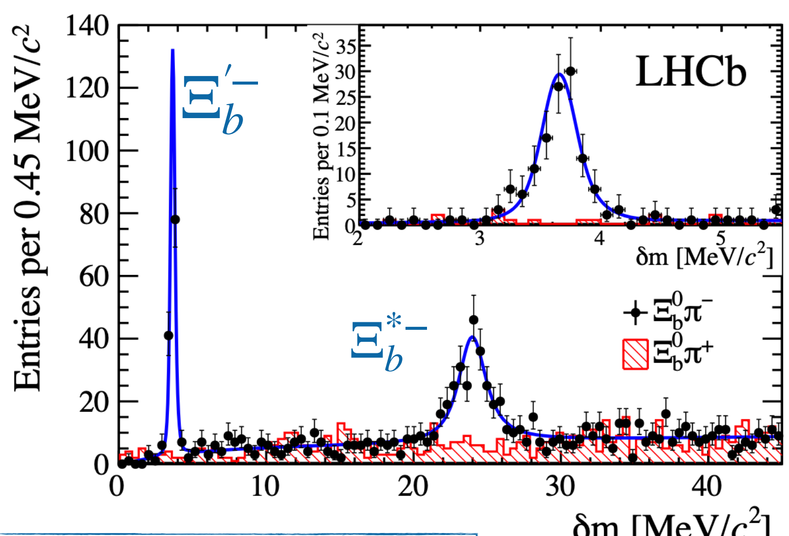
First new particle ever at CMS and 2^{nd} new at the LHC!



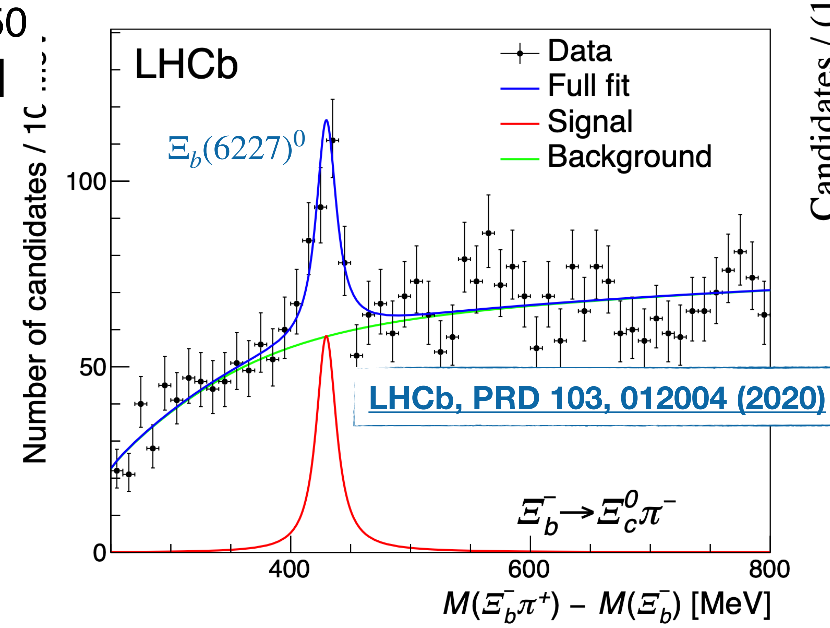
LHCb, JHEP 1605 (2016) 161



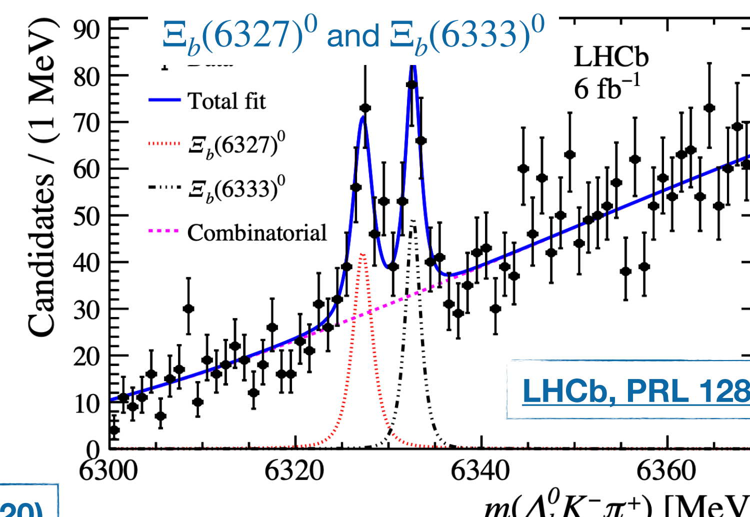
LHCb, PRL 121, 072002 (2018)



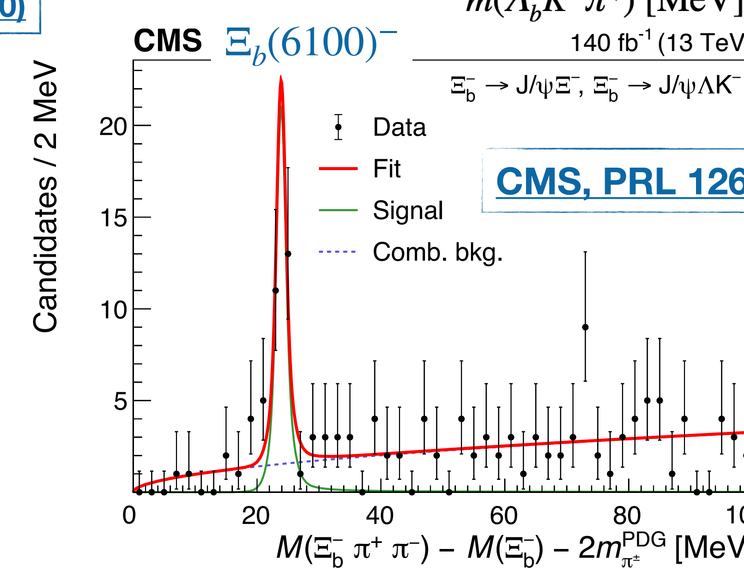
LHCb, PRL 114, 062004 (2014)



LHCb, PRD 103, 012004 (2020)



LHCb, PRL 128 16, 162001 (2021)



CMS, PRL 126, 252003 (2021)

Cannot reconstruct Ξ_b^0 at CMS (no hadron ID, hard to work with non-charged particles)

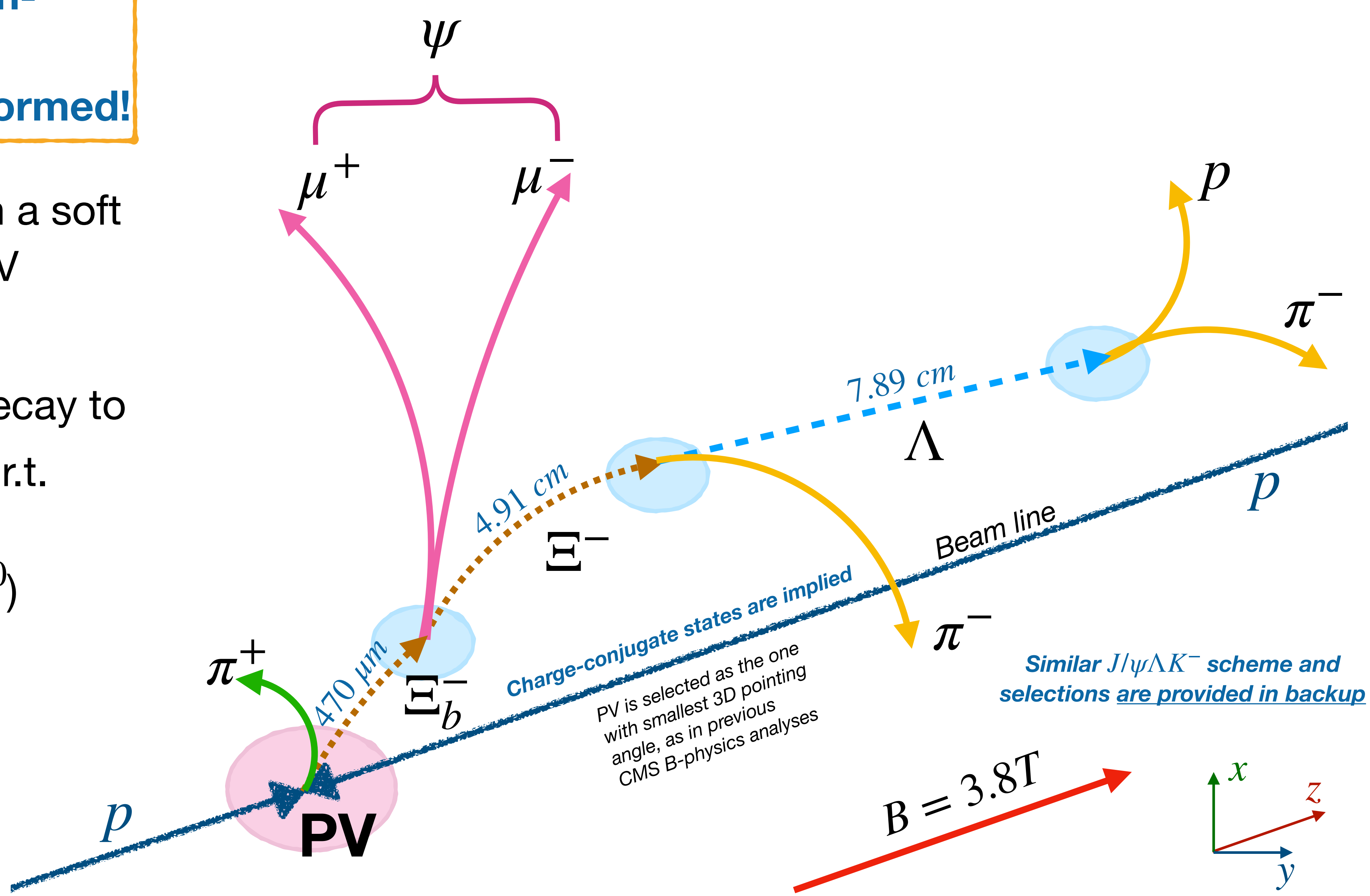
CMS Analysis Overview

- We use full Run-2 CMS data ($140\ fb^{-1}$, $\sqrt{s} = 13$ TeV) to reconstruct Ξ_b^- ground state via $\psi\Xi^-$ (= $J/\psi\Xi^-$ and $\psi(2S)\Xi^-$ with $\psi \to \mu^+\mu^-$ or $\psi(2S) \to J/\psi\pi^+\pi^-$) and $J/\psi\Lambda K^-$ channels, where latter one also presents the partially reconstructed $J/\psi\Sigma^0 K^-$ component

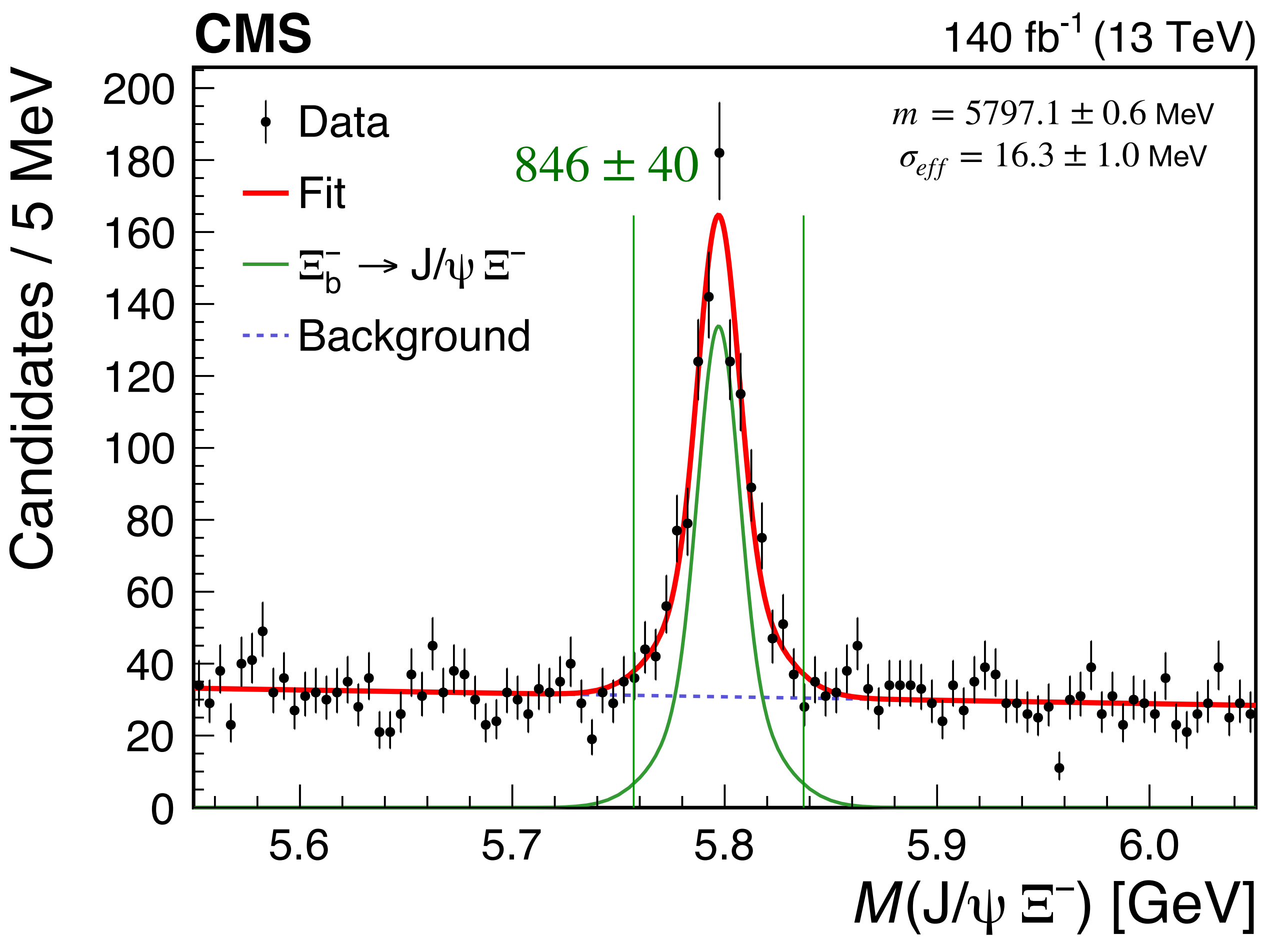
- **Search for the new (non-observed) decay $\Xi_b^- \to \psi(2S)\Xi^-$ is performed!**

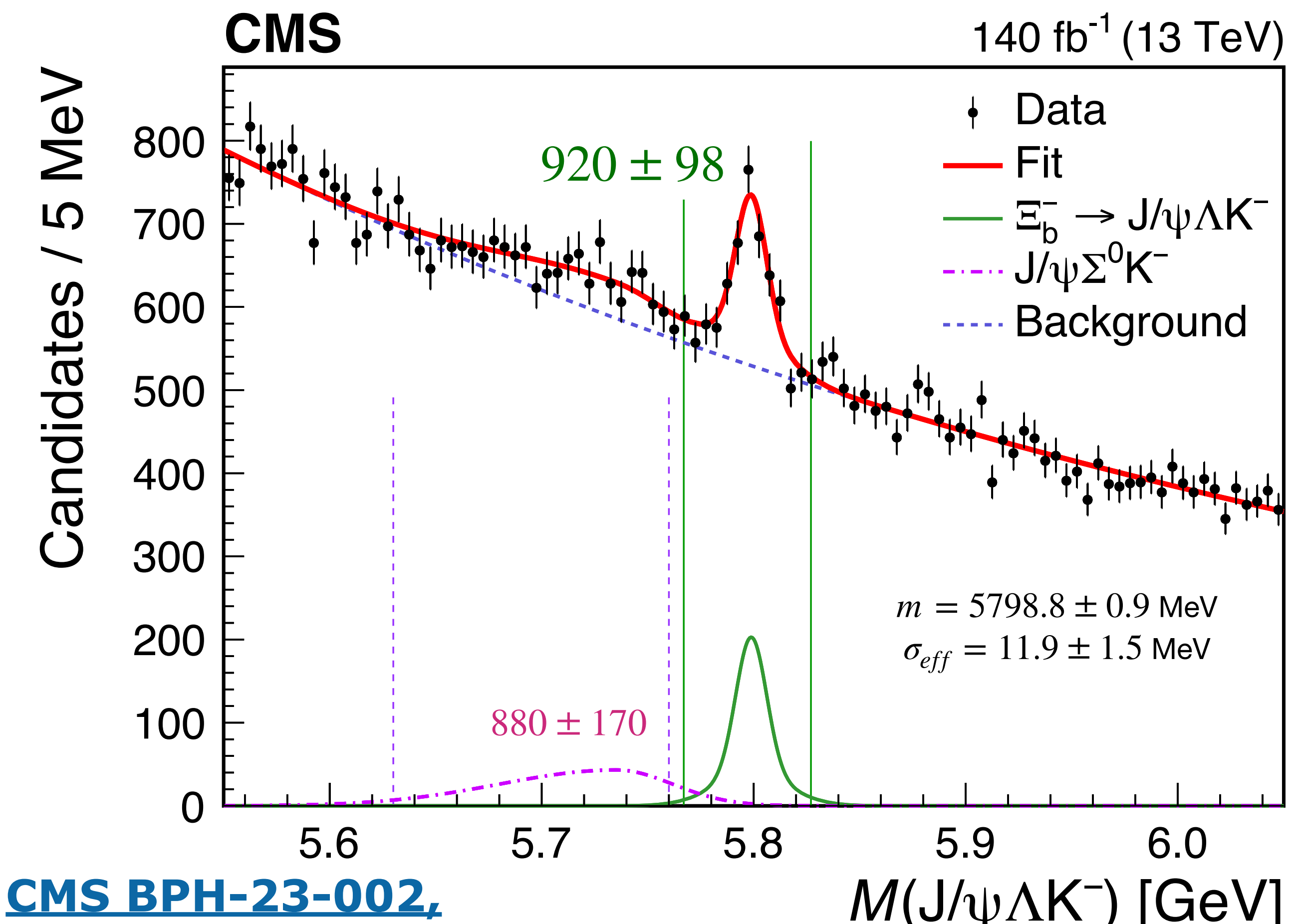
- Then Ξ_b^- is combined with a soft positive pion track from PV

- We study $\Xi_b^{*0} \to \Xi_b^-\pi^+$ decay to update Ξ_b^{*0} parameters w.r.t. previously reported (also known as $\Xi_b(5945)^0$)



Ξ_b^- "known" signals



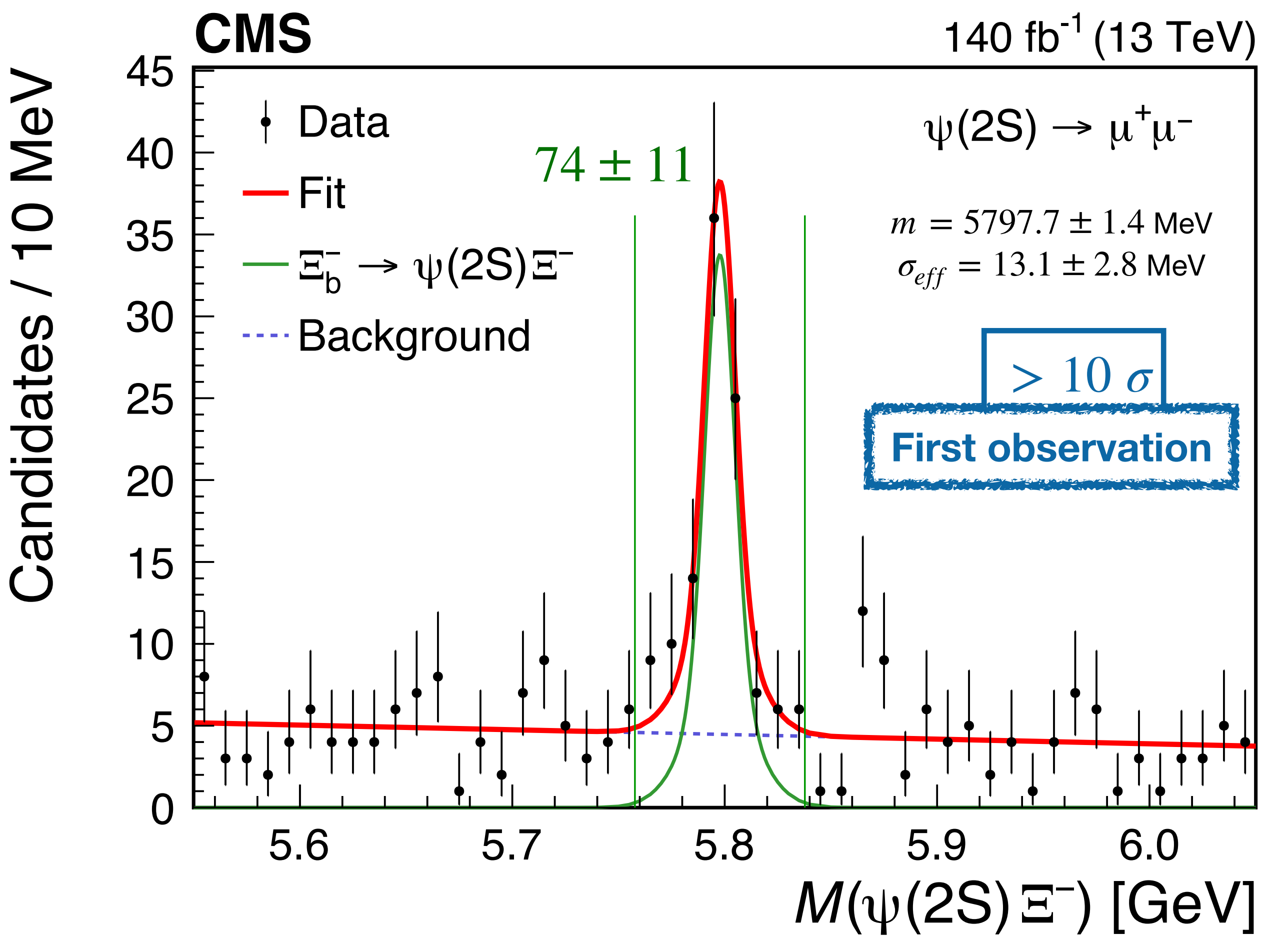


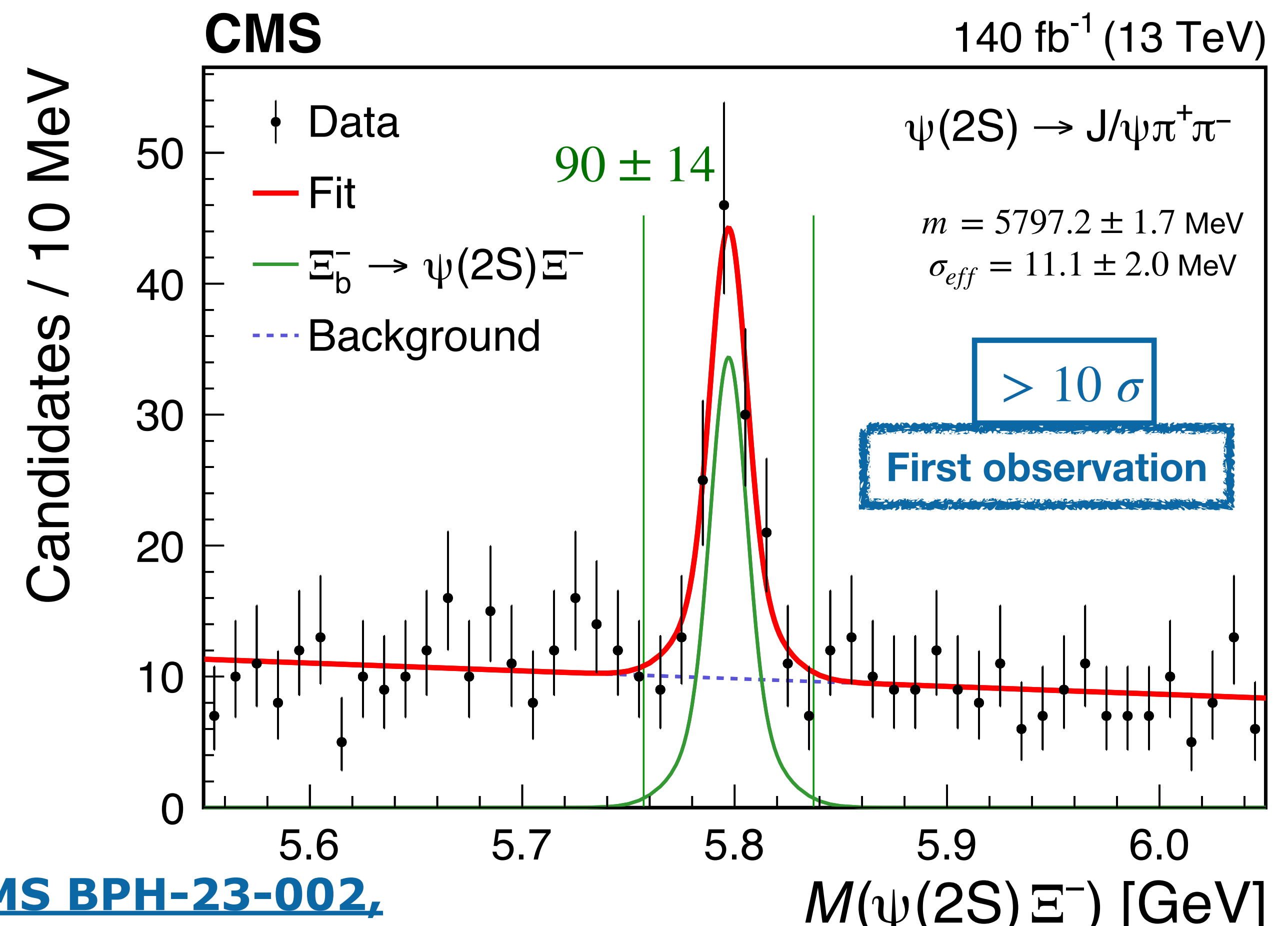
CMS BPH-23-002,
arXiv: 2402.17738

- **Signal:** double-Gaussian (MC-shape scaled to data); **Background:** linear/exponential function
  Partially reconstructed $\Xi_b^- \to J/\psi\Sigma^0 K^-$ decay: asymmetrical Gaussian (from MC)
  photon from $\Sigma^0 \to \Lambda\gamma$ is too soft to be reconstructed

- For $\Xi_b^-\pi^+$ studies, fully reconstructed Ξ_b^- = green lines, $\pm 40 (\pm 30)$ MeV for $J/\psi\Xi^- (J/\psi\Lambda K^-)$ channels,
  partially reconstructed Ξ_b^- = purple lines, [5.63, 5.76] GeV window

Observation of $\Xi_b^- \to \psi(2S)\Xi^-$ decay





CMS BPH-23-002, arXiv: 2402.17738

- **Signal shape:** Double Gaussian, shape is fixed from MC but allowed to be scaled from data
  Background: 1st order polynomial

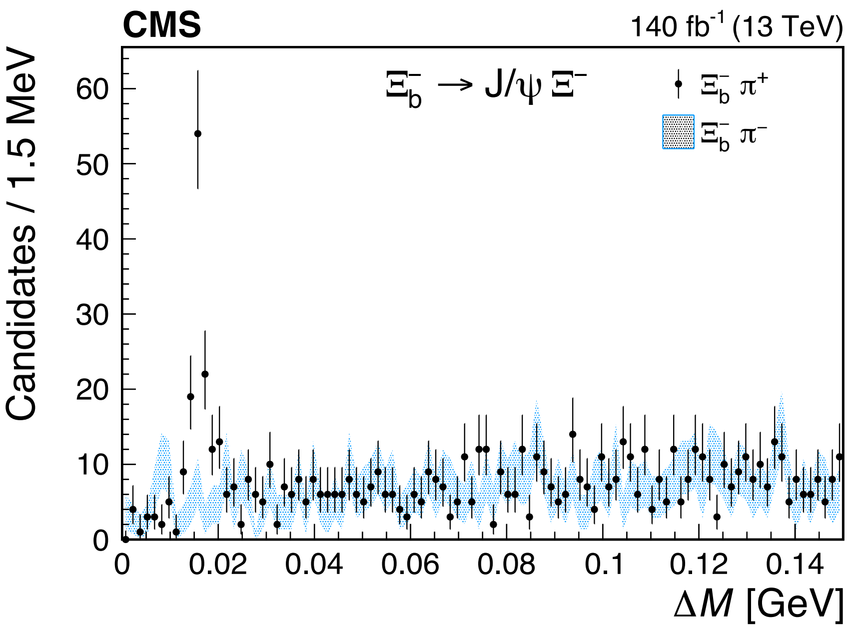
- **Local statistical significance** from likelihood ratio technique (Sig. + Bkg. versus Bkg. only hypothesis)
  Well above 5 sigma for both $\psi(2S) \to \mu^+\mu^-$ and modes $\psi(2S) \to J/\psi\pi^+\pi^-$

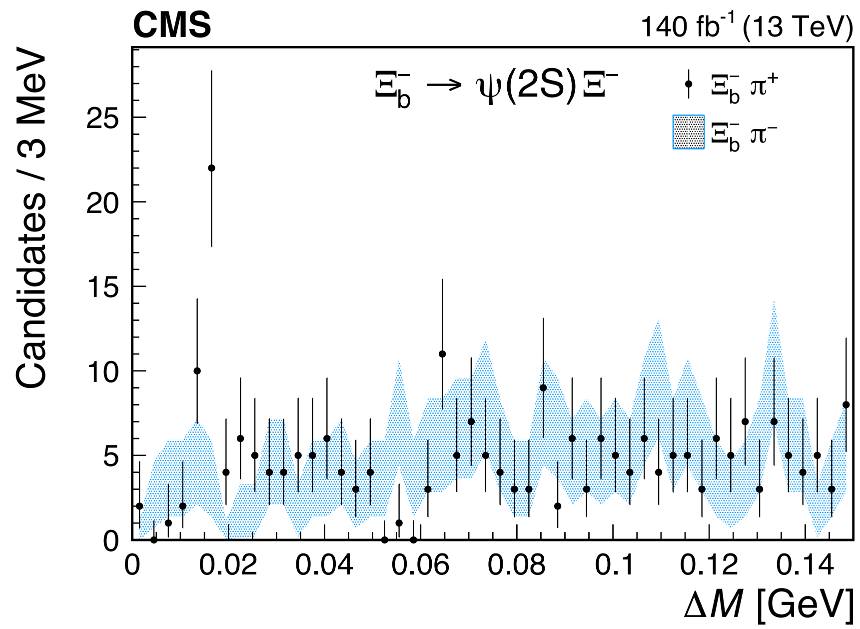
- Branching fraction of the new decay is estimated to be:

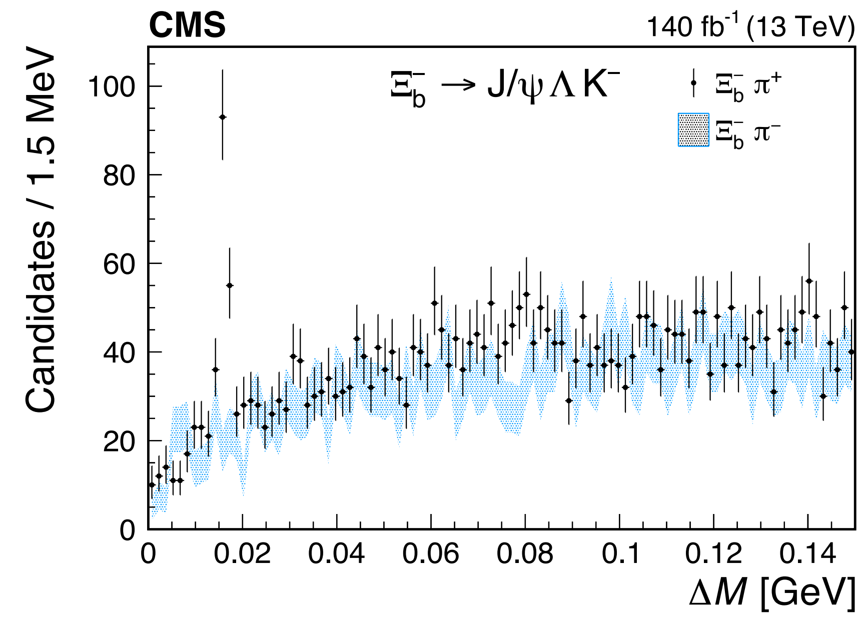
$$R = \frac{\mathscr{B}\left(\Xi_b^- \to \psi(2S)\Xi^-\right)}{\mathscr{B}\left(\Xi_b^- \to J/\psi\Xi^-\right)} = \frac{N_{\Xi_b^- \to \psi(2S)\Xi^-}}{N_{\Xi_b^- \to J/\psi\Xi^-}} \cdot \frac{\epsilon_{\Xi_b^- \to J/\psi\Xi^-}}{\epsilon_{\Xi_b^- \to \psi(2S)\Xi^-}} \cdot \frac{\mathscr{B}\left(J/\psi \to \mu^+\mu^-\right)}{\mathscr{B}\left(\psi(2S) \to \mu^+\mu^-\right)} = 0.84^{+0.21}_{-0.19} \pm 0.10 \pm 0.02$$

from data fits — from MC simulation

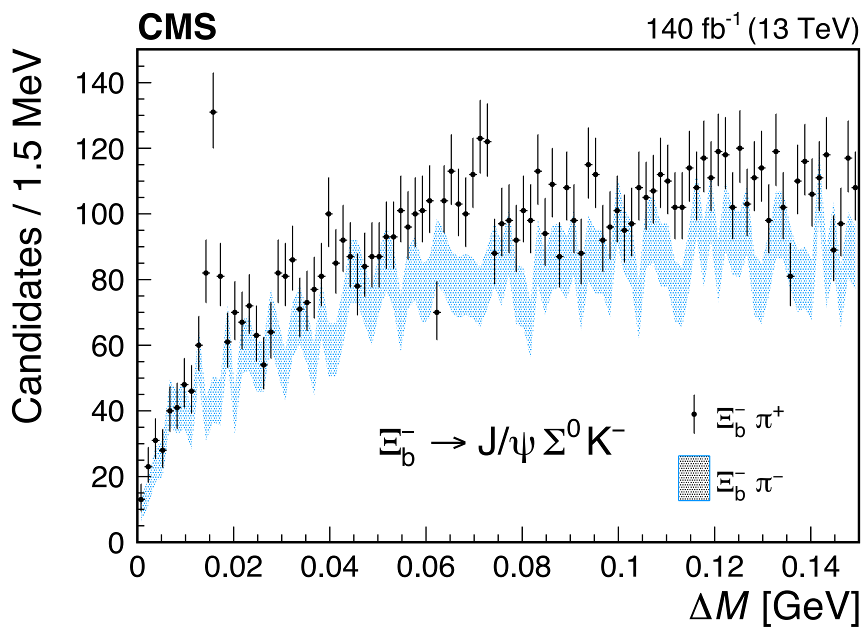
Exploration of $\Xi_b^- \pi^+$ system







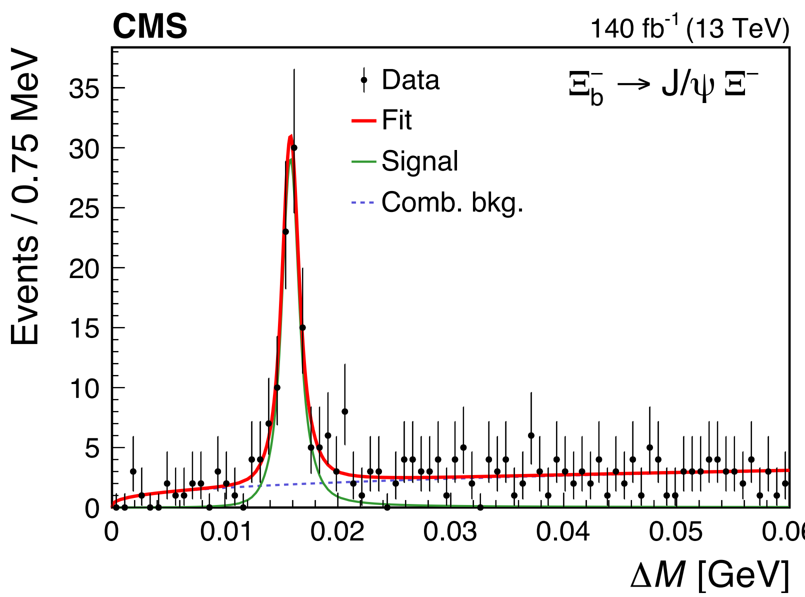
CMS BPH-23-002, arXiv: 2402.17738

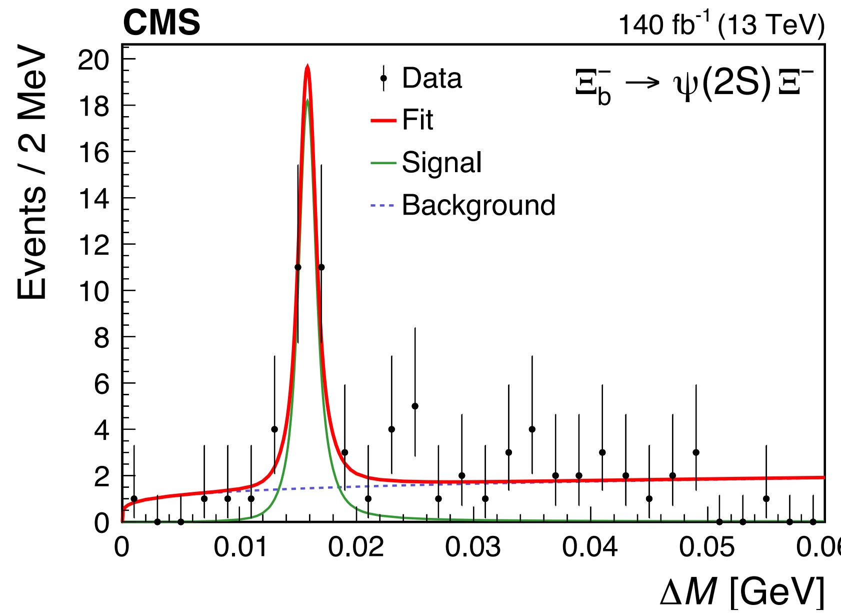


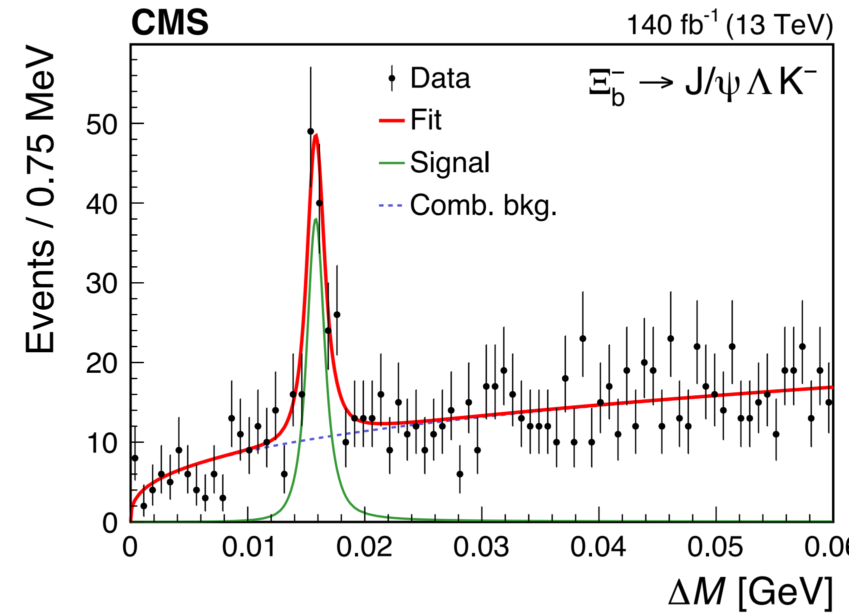
- Clear, significant peak of Ξ_b^{*0} near the kinematic threshold in $M(\Xi_b^- \pi^+)$ for all 4 channels of Ξ_b^- reconstruction
- No other structures observed in the near-threshold area *(as expected)*
- Combinatorial background is in agreement with wrong-sign *(showing us that the bkg **is** combinatorial indeed)*

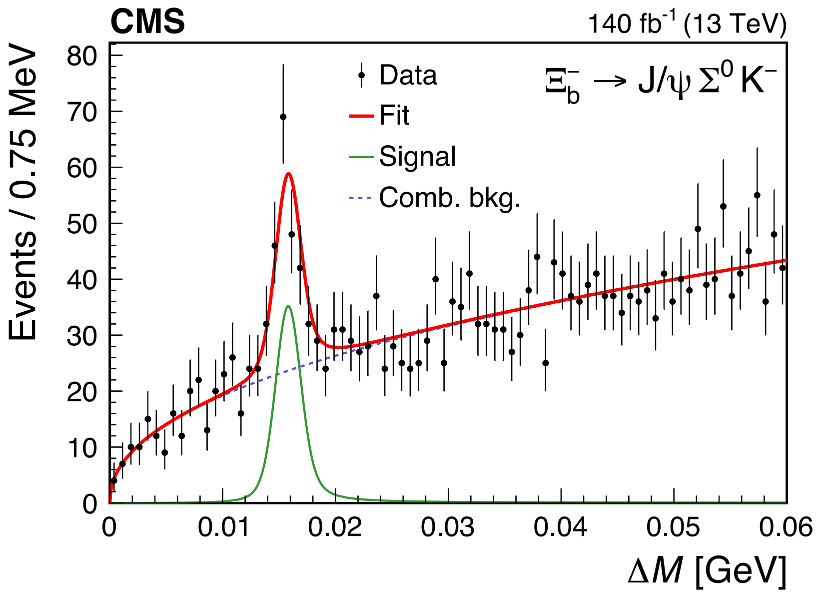
Mass difference variable $\Delta M = M(\Xi_b^- \pi^+) - M(\Xi_b^-) - m_{\pi^+}^{\text{PDG}}$ and PV refit technique (see backup) are used to improve detector resolution

Fit of the $\Xi_b^{*0} \to \Xi_b^- \pi^+$ signal









CMS BPH-23-002, arXiv: 2402.17738

Decay channel	$N(\Xi_b^{*0})$
$\Xi_b^- \to J/\psi \Xi^-$	$97\,^{+13}_{-12}$
$\Xi_b^- \to \psi(2S) \Xi^-$	$24\,^{+6}_{-5}$
$\Xi_b^- \to J/\psi \Lambda K^-$	$124\,^{+17}_{-16}$
$\Xi_b^- \to J/\psi \Sigma^0 K^-$	$155\,^{+22}_{-20}$

$$\Delta M = 15.810 \pm 0.077\,(\text{stat}) \pm 0.032\,(\text{syst})\,\text{MeV}$$
$$\Gamma(\Xi_b^{*0}) = 0.87^{+0.22}_{-0.20}\,(\text{stat}) \pm 0.16\,(\text{syst})\,\text{MeV}$$

Excellent agreement with previous CMS & LHCb results!

- We perform simultaneous fit of 4 Ξ_b^- channels,
  using Relativistic Breit-Wigner $\otimes$ MC resolutions for signals;
  mass and Γ are shared parameters of the fit
  Background is described \w $(\Delta M)^\alpha$ threshold function

- We also measure relative Ξ_b^{*0}/Ξ_b^- production ratio:

from MC simulation

$$R_{\Xi_b^{*0}} = \frac{\sigma\left(pp \to \Xi_b^{*0} X\right) \cdot \mathscr{B}\left(\Xi_b^{*0} \to \Xi_b^- \pi^+\right)}{\sigma\left(pp \to \Xi_b^- X\right)} = \frac{N\left(\Xi_b^{*0}\right)}{N\left(\Xi_b^-\right)} \cdot \frac{\epsilon_{\Xi_b^-}}{\epsilon_{\Xi_b^{*0}}} = 0.23 \pm 0.04 \pm 0.02$$

from data fits

***BLUE** method is used to combine results from different channels*

Conclusion and summary

- CMS Experiment is actively contributing to the heavy flavour physics, providing the observations of the new beauty decays

- We report first observation of $\Lambda_b^0 \to J/\psi \Xi^- K^+$ decay and measurement of ratio
  - 2-body intermediate invariant mass distributions are also explored

$$\frac{\mathcal{B}(\Lambda_b^0 \to J/\psi \Xi^- K^+)}{\mathcal{B}(\Lambda_b^0 \to \psi(2S)\Lambda)} = [3.38 \pm 1.02\,(\text{stat}) \pm 0.61\,(\text{syst}) \pm 0.03\,(\mathcal{B})]\%$$

- We report the first observation of $\Xi_b^- \to \psi(2S)\Xi^-$ decay and measurement of ratio

$$\frac{\mathcal{B}(\Xi_b^- \to \psi(2S)\Xi^-)}{\mathcal{B}(\Xi_b^- \to J/\psi \Xi^-)} = 0.84^{+0.21}_{-0.19}\,(\text{stat}) \pm 0.10\,(\text{syst}) \pm 0.02\,(\mathcal{B})$$

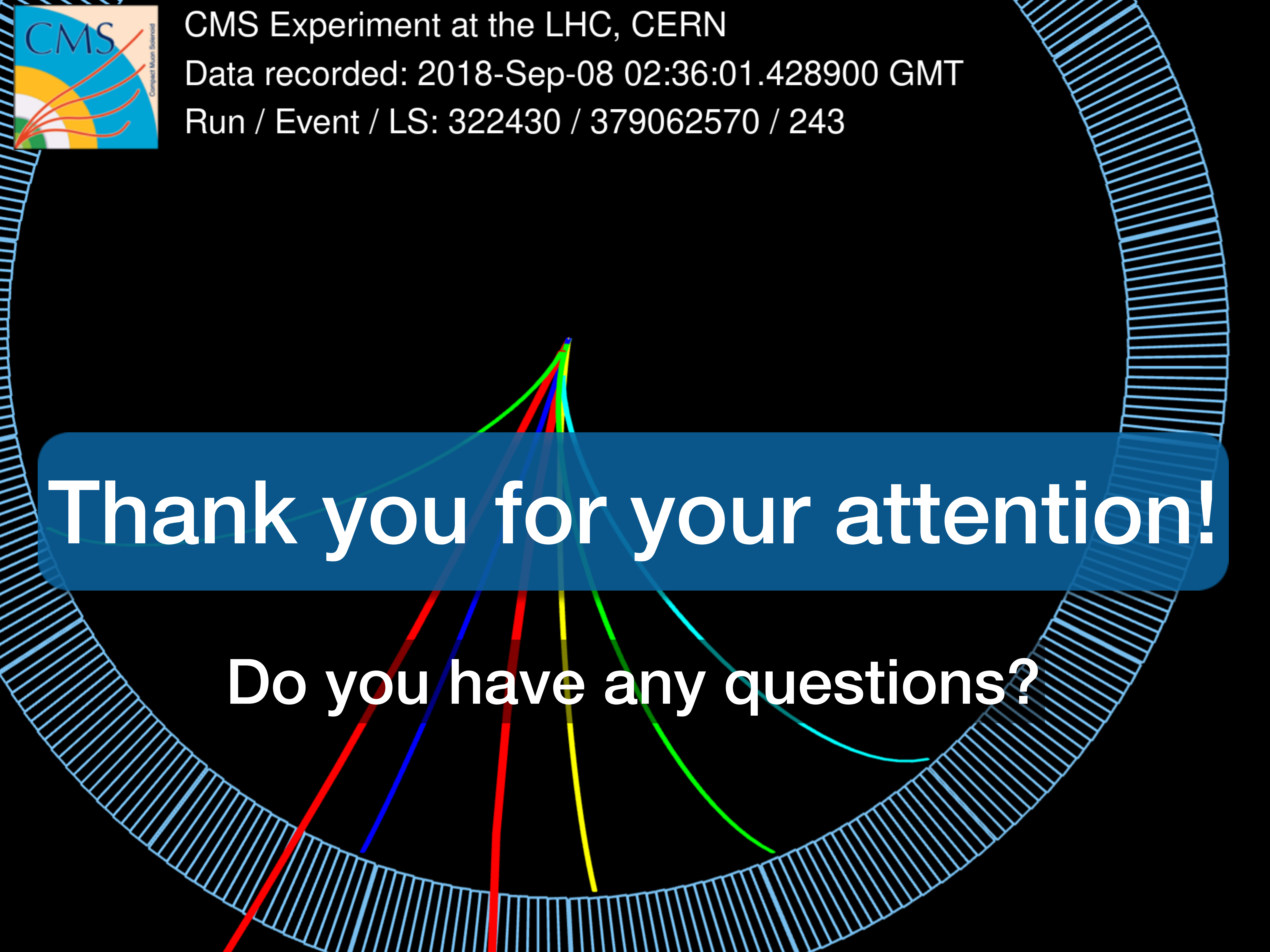
- Measurement of $\Xi_b^{*0} = \Xi_b(5945)^0$ resonance mass and natural width using $\Xi_b^{*0} \to \Xi_b^- \pi^+$ with Ξ_b^- coming from $J/\psi\Xi^-$, $\psi(2S)\Xi^-$, $J/\psi\Lambda K^-$ and $J/\psi\Sigma^0 K^-$ is performed; consistent with LHCb and good precision is observed — great contribution to the world-average

$$M(\Xi_b^{*0}) = 5952.4 \pm 0.1 \pm 0.6\,(m_{\Xi_b^-})\,\text{MeV} \quad \Gamma(\Xi_b^{*0}) = 0.87^{+0.22}_{-0.20}\,(\text{stat}) \pm 0.16\,(\text{syst})\,\text{MeV}$$

Ξ_b^{*0}/Ξ_b^- production ratio is also reported (second measurement after LHCb)

$$R_{\Xi_b^{*0}} = \frac{\sigma(pp \to \Xi_b^{*0}X) \cdot \mathcal{B}(\Xi_b^{*0} \to \Xi_b^- \pi^+)}{\sigma(pp \to \Xi_b^- X)} = 0.23 \pm 0.04(\text{stat.}) \pm 0.02(\text{syst.})$$

- Stay tuned for the new flavour results from the CMS Collaboration!

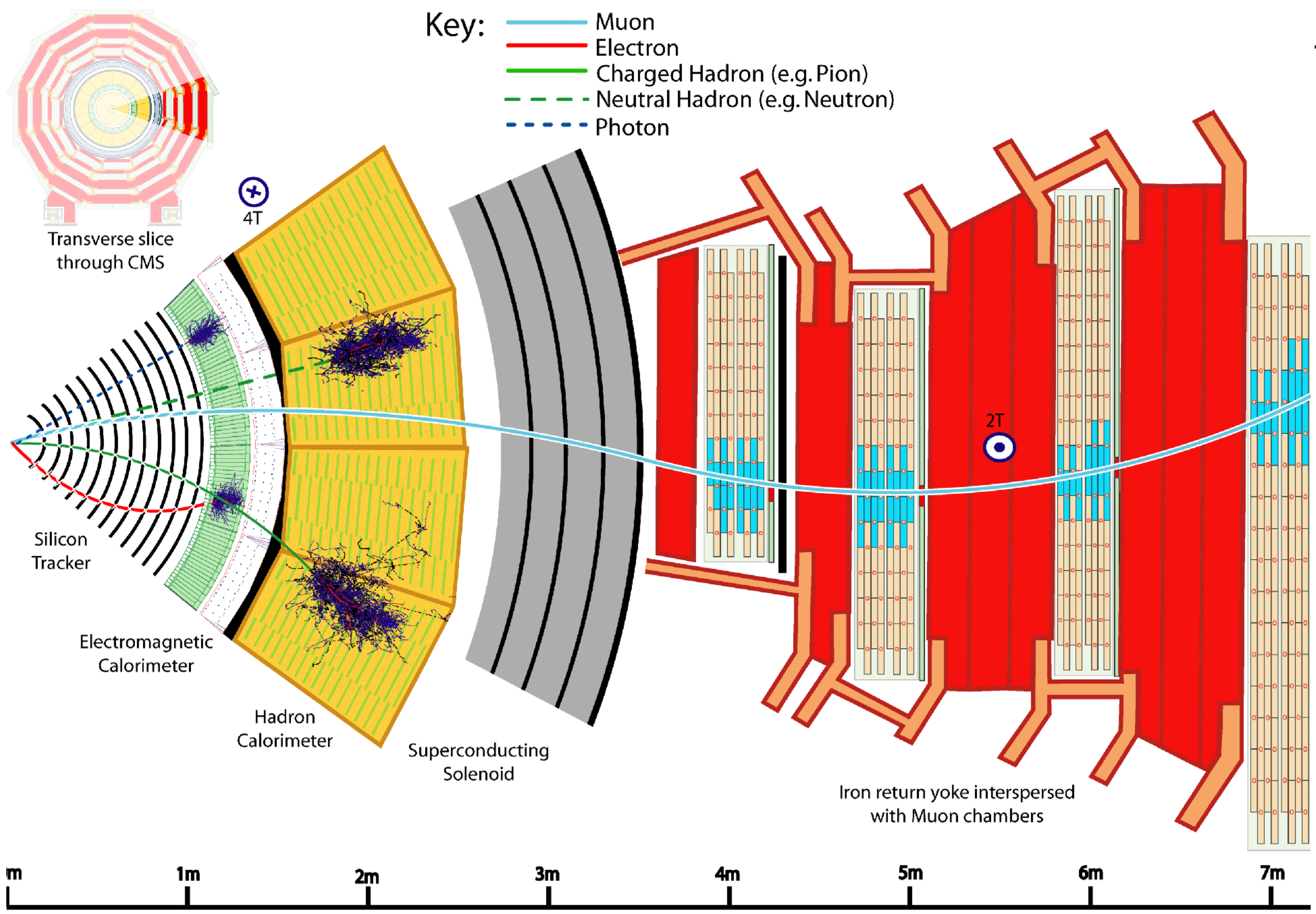


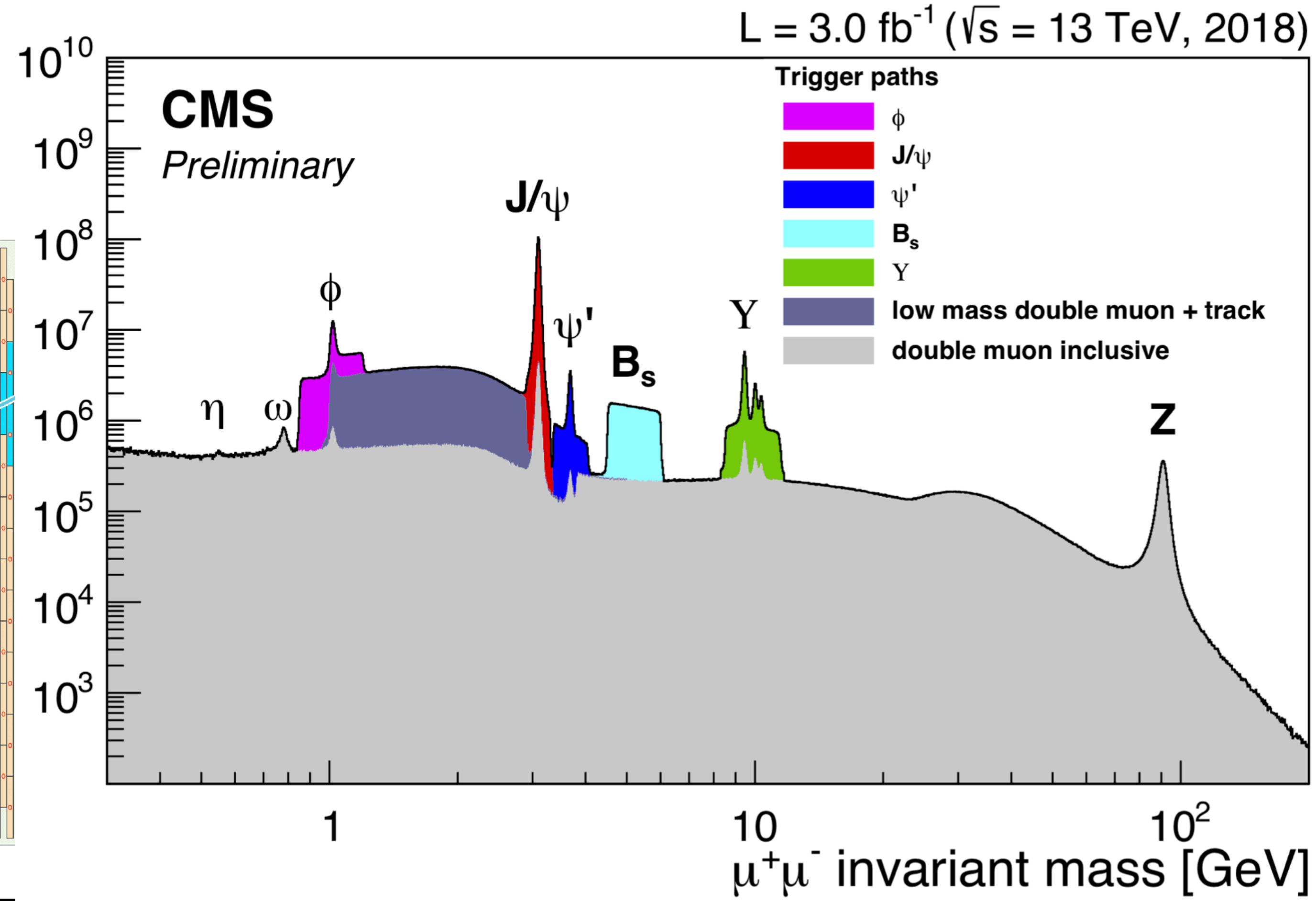
Thank you for your attention!

Do you have any questions?

Backup slides

The CMS Experiment





- The CMS Experiment at the LHC was designed mainly for high-p_T physics (Higgs, top-quark, SM precision measurement, New Physics searches etc)

- However, robust muon system, good p_T resolution and perfect vertex reconstruction provide promising opportunities for heavy flavour and quarkonia-related analyses

Punzi optimisation details

Punzi formula is used for optimization,
with SC recommendation
as it does not rely on **S** normalization

$$f = \mathbf{S}/\left(\frac{463}{13} + 4\sqrt{\mathbf{B}} + 5\sqrt{25 + 8\sqrt{\mathbf{B}} + 4\mathbf{B}}\right)$$

S is number of signal events from MC
(double-Gaussian function with common mean)

B is expected number of background events in the signal region

Extracted from data with $m_{PDG}(\Lambda_b^0) \pm 2\sigma_{eff}$ region excluded from the (bkg-only, exponential) fit.

Wrong-sign events are added to the sample to improve statistics.
CS and WS distributions are found to be consistent.

The bkg integral in the signal region is taken as **B**

Variables

Mass windows:

$m(\Lambda)$, $m(\Xi^-)$

Distance significance between vertices

$L_{xy}/\sigma_{L_{xy}}(\Xi^-, \Lambda_b^0)$, $L_{xy}/\sigma_{L_{xy}}(\Lambda, \Xi^-)$, $L_{xy}/\sigma_{L_{xy}}(\Lambda_b^0, PV)$

Angle between particle momentum and the line passing joining its birth vertex and decay vertex

$\cos(\overrightarrow{L_{xy}}, \overrightarrow{p_T})\ (\Xi^-, \Lambda_b)$, $\cos(\overrightarrow{L_{xy}}, \overrightarrow{p_T})\ (\Lambda, \Xi^-)$,
$\cos(\overrightarrow{L_{xy}}, \overrightarrow{p_T})\ (\Lambda_b, PV)$

Transverse momentum

$p_T(\Lambda_b^0)$, $p_T(J/\psi)$, $p_T(\Xi^-)$, $p_T(\Lambda)$, $p_T(K^+)$, $p_T(\pi^-)$

Vertex fit probabilities

$P_{vtx}(\Lambda_b^0)$ $P_{vtx}(\Xi^-)$ $P_{vtx}(\Lambda)$

Track impact parameter w.r.t. PV

$IPS(\pi)$, $IPS(K^+)$

$\Lambda_b^0 \to J/\psi \Xi^- K^+$ systematics

Source	Uncertainty (%)
Tracking efficiency	2.3
$p_T(\Lambda_b^0)$ spectrum	4.7
Signal model	3.9
Background model	6.7
Non-$\psi(2S)$ contribution	2.5
Limited size of MC samples	5.6
Selection efficiency	14.3
Total	18.2

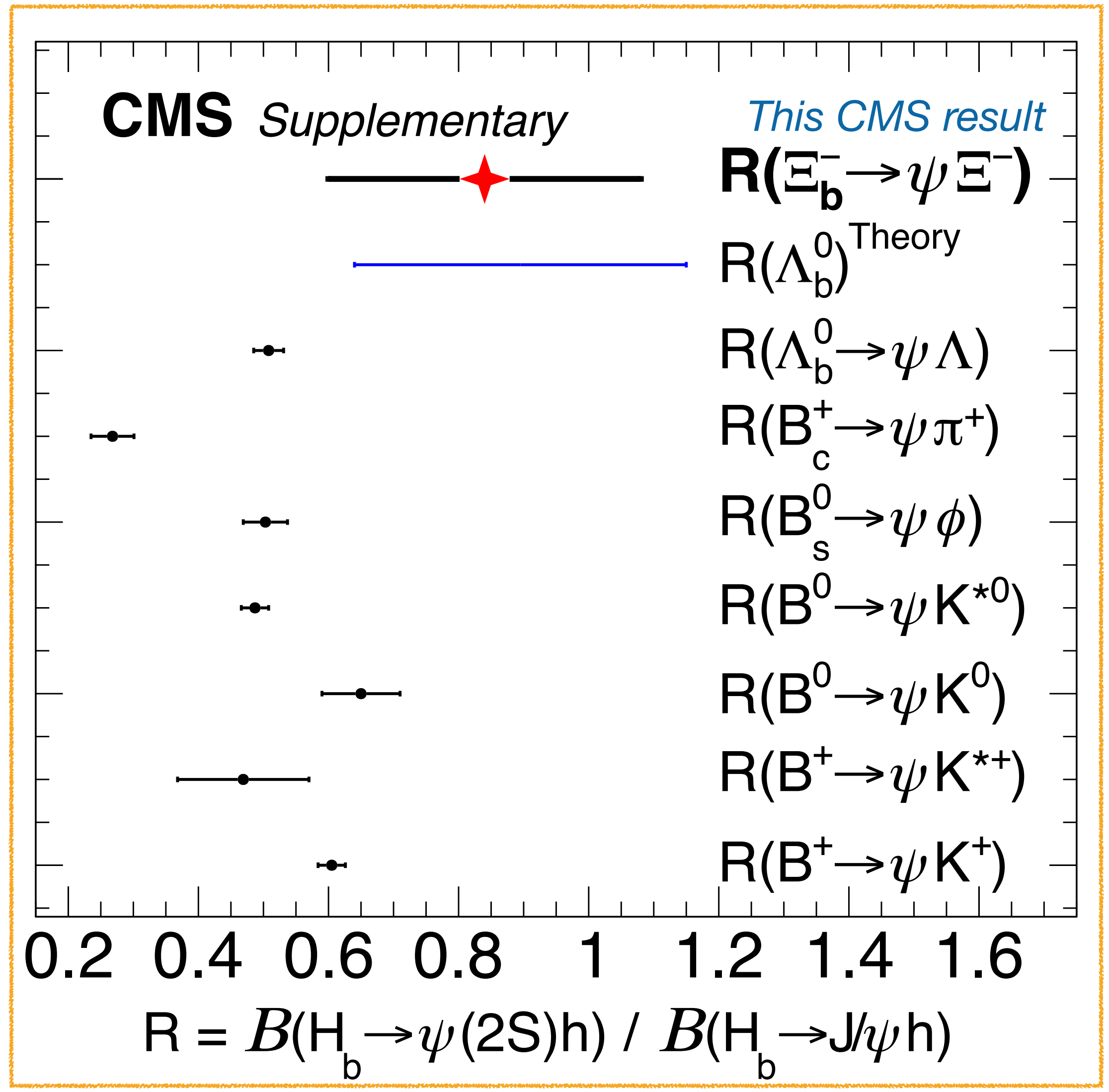
Total uncertainty is calculated as
sum in quadrature of individual sources

Branching fraction ratio discussion

- We compare our result for the measured $\mathscr{B}$ ratio with other "similar" decays: a b-hadron H_b decays to J/ψ or $\psi(2S)$ *(both referred as ψ)* plus a light hadron h

- Our $R(\Xi_b^- \to \psi\Xi^-)$ seems to be an agreement with others, but uncertainty is large

- The previously measured $R(\Lambda_b^0 \to \psi\Lambda)$ ratio is in disagreement with the theory prediction — will $R(\Xi_b^- \to \psi\Xi^-)$ repeat this "baryon deviation"?



- In general we do not see any clear, "straightforward" trend for these ratios, likewise there is no great theoretical model to describe this plot

- Both new, precise measurements of such ratios and theoretical predictions are required, especially for the beauty baryon sector (Λ_b, Ξ_b, Ω_b decays…)

Ξ_b^{*0} results discussion

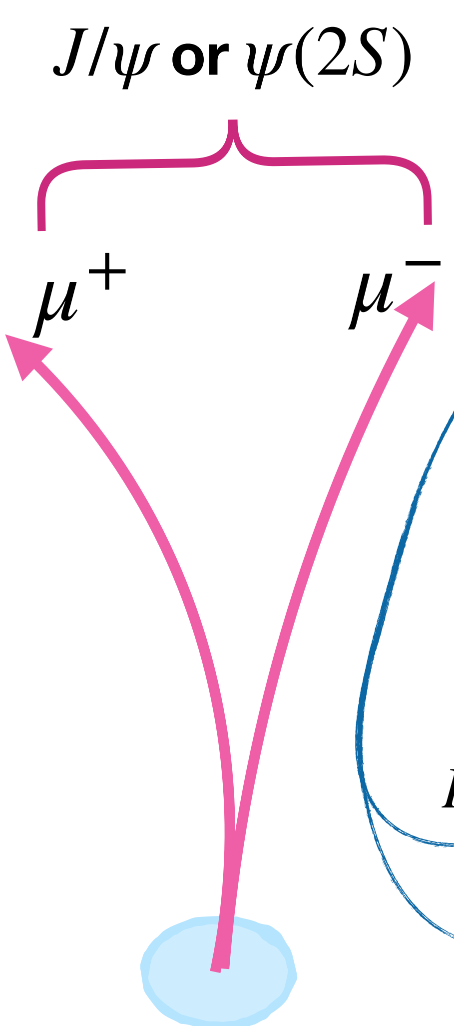
	N_{signal}	ΔM	$\Gamma(\Xi_b^{*0})$	$R_{\Xi_b^{*0}}$
CMS Run-1 5 fb^{-1}	22.4 ± 5.4	$14.84 \pm 0.74 \pm 0.28$	2.1 ± 1.7	—
LHCb Run-1 3 fb^{-1}	232 ± 19	$15.727 \pm 0.068 \pm 0.023$	$0.90 \pm 0.16 \pm 0.08$	0.28 ± 0.03
CMS Run-2 140 fb^{-1}	400 ± 30	$15.810 \pm 0.077 \pm 0.032$	$0.87 \pm 0.21 \pm 0.16$	0.23 ± 0.05
LHCb Run-1+2 9 fb^{-1}	2019 ± 58	$15.80 \pm 0.02 \pm 0.01$	$0.87 \pm 0.06 \pm 0.05$	—

This analysis results

- Our results are in perfect agreement with previous CMS and LHCb Run-1 measurements;
  also with new LHCb Run1+2 results presented at Moriond 2023
- Our accuracy is similar, but less than LHCb
  However the precision is compatible
- New results would be important independent contribution w.r.t. LHCb to the world-average:
  no other Ξ_b^{*0} results are expected from anyone else in reasonable future rather than this CMS publication

Trigger strategy

- While the analysis in general uses combination of all charmonia-compatible dimuon CMS HLT paths, we need to select a single dedicated HLT for $\mathscr{B}$ and production measurements
  - *to ensure robust signal yields and efficiency and cancel trigger-related systematics*
- We select the HLT suitable for the decay topology; then re-do our fits it data to estimate signal yield N we use for the ratio measurements
- Generated MC events are required to pass the selected HLT using the same reconstruction algorithm we have for data $\longrightarrow$ extract efficiency ϵ for the for the ratio measurements



$\Xi_b^- \to J/\psi \Xi^-$

$\Xi_b^- \to \psi(2S) \Xi^-$

- Inclusive dimuon triggers are used:
  - **HLT_Dimuon25_Jpsi**
  - **HLT_Dimuon18_PsiPrime**
- Require OS muons from one vertex with $J/\psi(\psi(2S))$ mass window and $p_T(\mu^+\mu^-) > 25\,(18)$ GeV

$$R = \frac{\mathscr{B}\left(\Xi_b^- \to \psi(2S)\Xi^-\right)}{\mathscr{B}\left(\Xi_b^- \to J/\psi\Xi^-\right)}$$

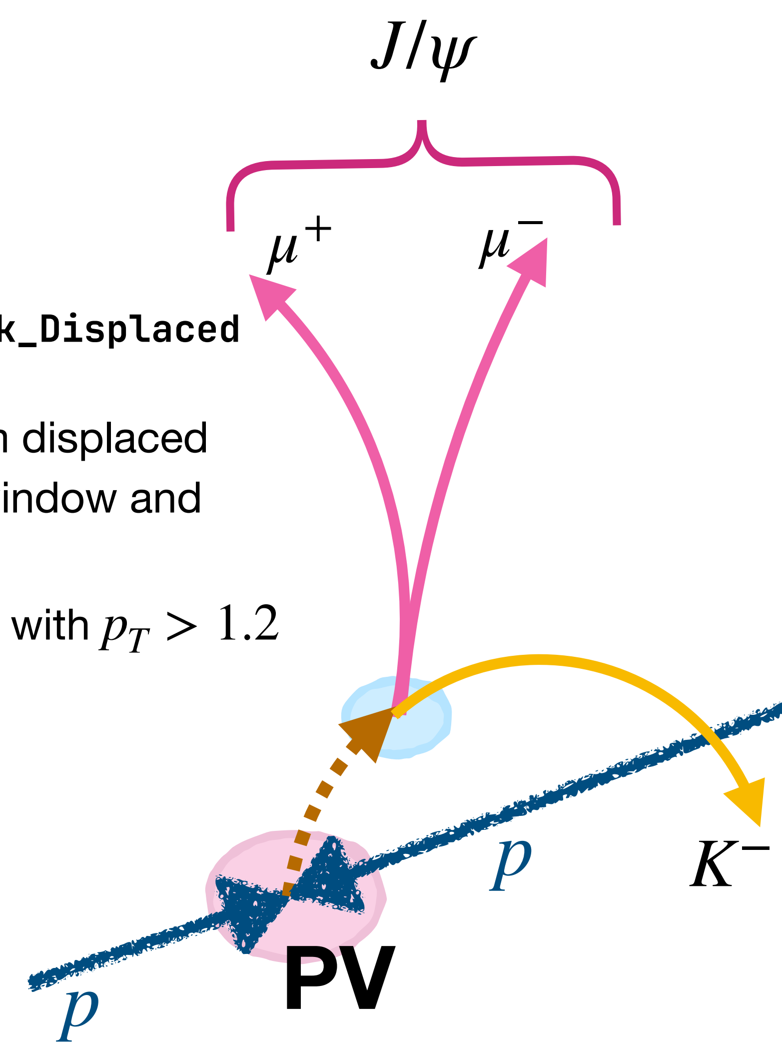
$R_{\Xi_b^{*0}}\left(J/\psi\Xi^-\right)$

HLT_Dimuon20_Jpsi and HLT_Dimuon13_PsiPrime are used for the 2016 conditions

$\Xi_b^- \to J/\psi \Lambda K^-$

- We use dedicated HLT: **HLT_DoubleMu4_JpsiTrk_Displaced**
- Require OS muons from displaced vertex with J/ψ mass window and $p_T(\mu^\pm) > 4$ GeV and Trk from this vertex with $p_T > 1.2$ GeV and $d_{xy}/\sigma_{d_{xy}} > 2$

$R_{\Xi_b^{*0}}\left(J/\psi \Lambda K^-\right)$



This selection is very tough — there was no good inclusive dimuon HLT @ Run-2!

New BPH Run-3 trigger Parking would significantly improve $\psi\Xi^-$ signal

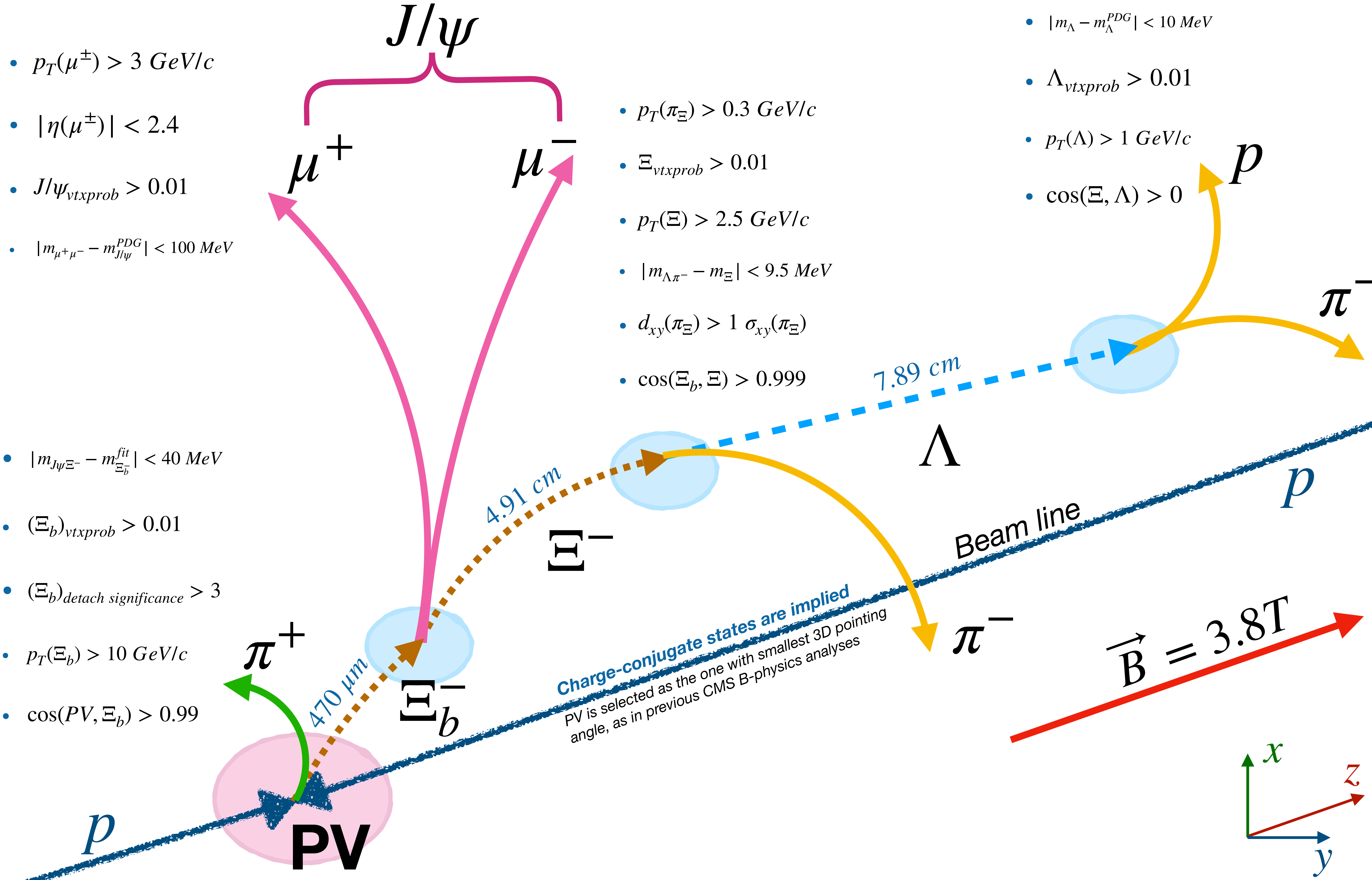
$J/\psi\Xi^-$ decay scheme

- $p_T(\mu^\pm) > 3\ GeV/c$
- $|\eta(\mu^\pm)| < 2.4$
- $J/\psi_{vtxprob} > 0.01$
- $|m_{\mu^+\mu^-} - m_{J/\psi}^{PDG}| < 100\ MeV$

- $p_T(\pi_\Xi) > 0.3\ GeV/c$
- $\Xi_{vtxprob} > 0.01$
- $p_T(\Xi) > 2.5\ GeV/c$
- $|m_{\Lambda\pi^-} - m_\Xi| < 9.5\ MeV$
- $d_{xy}(\pi_\Xi) > 1\ \sigma_{xy}(\pi_\Xi)$
- $\cos(\Xi_b, \Xi) > 0.999$

- $|m_\Lambda - m_\Lambda^{PDG}| < 10\ MeV$
- $\Lambda_{vtxprob} > 0.01$
- $p_T(\Lambda) > 1\ GeV/c$
- $\cos(\Xi, \Lambda) > 0$

- $|m_{J\psi\Xi^-} - m_{\Xi_b^-}^{fit}| < 40\ MeV$
- $(\Xi_b)_{vtxprob} > 0.01$
- $(\Xi_b)_{detach\ significance} > 3$
- $p_T(\Xi_b) > 10\ GeV/c$
- $\cos(PV, \Xi_b) > 0.99$



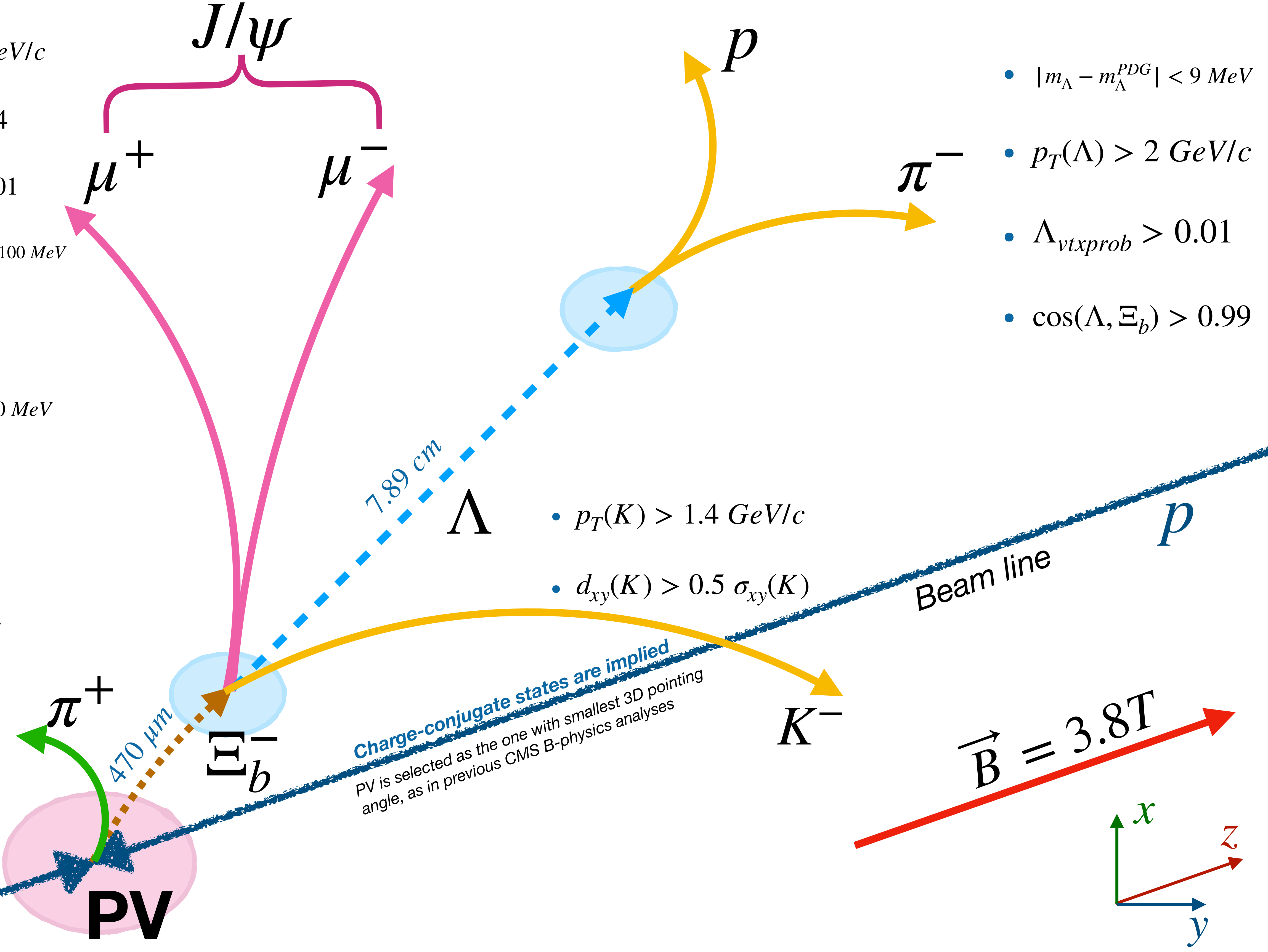
$J/\psi \Lambda K^-$ decay scheme

- $p_T(\mu^{\pm}) > 3\ GeV/c$
- $|\eta(\mu^{\pm})| < 2.4$
- $J/\psi_{vtxprob} > 0.01$
- $|m_{\mu^+\mu^-} - m^{PDG}_{J/\psi}| < 100\ MeV$

- $|m_{J\psi\Lambda K^-} - m^{fit}_{\Xi_b^-}| < 30\ MeV$
- $(\Xi_b)_{vtxprob} > 0.01$
- $(\Xi_b)_{detach\ significance} > 3$
- $p_T(\Xi_b) > 15\ GeV/c$
- $\cos(\Xi_b, PV) > 0.999$

- $|m_\Lambda - m^{PDG}_\Lambda| < 9\ MeV$
- $p_T(\Lambda) > 2\ GeV/c$
- $\Lambda_{vtxprob} > 0.01$
- $\cos(\Lambda, \Xi_b) > 0.99$

- $p_T(K) > 1.4\ GeV/c$
- $d_{xy}(K) > 0.5\ \sigma_{xy}(K)$

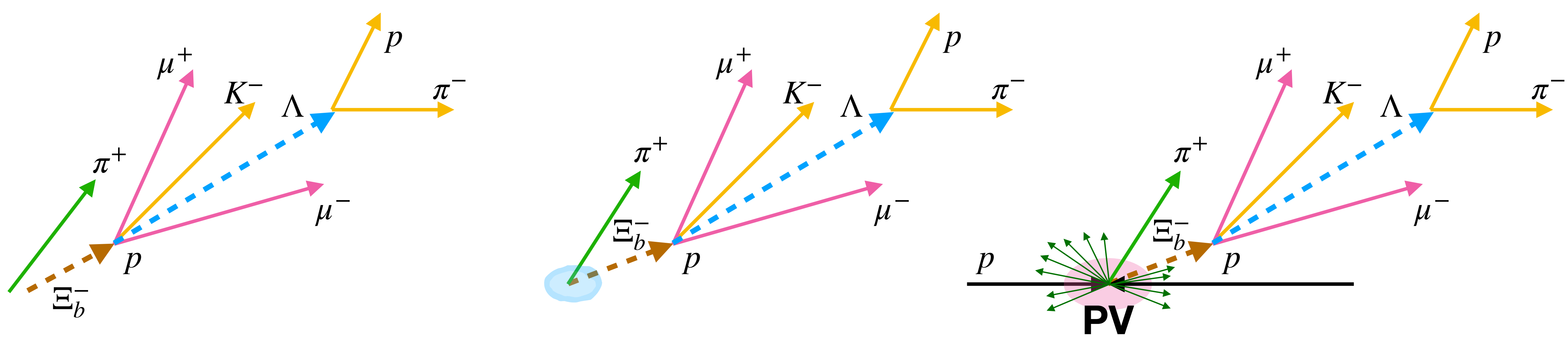


Different approaches for exited B-hadrons mass calculation

- We can extract "raw" 4-momenta from prompt PV's tracks or make exited B-hadron vertex fit and extract 4-momenta from fit for signal enhancement (used in CMS $B_c^+\pi^+\pi^-$ PRL 122 (2019) 132001 analysis)

- More complicated approach for exited B-hadrons study was applied for the current $\Xi_b^-\pi^+$ study (analogously to recent CMS $\Lambda_b^0\pi^+\pi^-$ PLB 803 (2020) 135345 analysis):

- We fit ALL the tracks forming the PV + B-candidate (about 20-100 tracks in each) and use 4-momenta from this vertex fit. The PV refitting procedure has improved the $\Xi_b^-\pi^+\pi^-$ mass resolution by up to 50%



Ξ_b analysis systematics

Source	Uncertainty (%)
Signal model	8.8
Background model	4.5
R_{B^+} uncertainty	5.0
MC finite size	4.6
Total	12.0

R systematics

Source	$J/\psi\Xi^-$ (%)	$J/\psi\Lambda K^-$ (%)
Ξ_b^- fit model	4.0	6.9
Ξ_b^{*0} fit model	7.7	6.7
Tracking efficiency	5.2	5.2
MC finite size	6.5	4.4
Total	12.0	11.8

$R_{\Xi_b^{*0}}$ systematics

Source	ΔM (MeV)	$\Gamma(\Xi_b^{*0})$ (MeV)
Signal model	0.003	< 0.01
Background model	0.002	0.04
Fit range	0.023	0.13
RBW shape	0.022	0.02
Mass resolution	0.004	0.08
Total	0.032	0.16

Total uncertainty is calculated as
sum in quadrature of individual sources