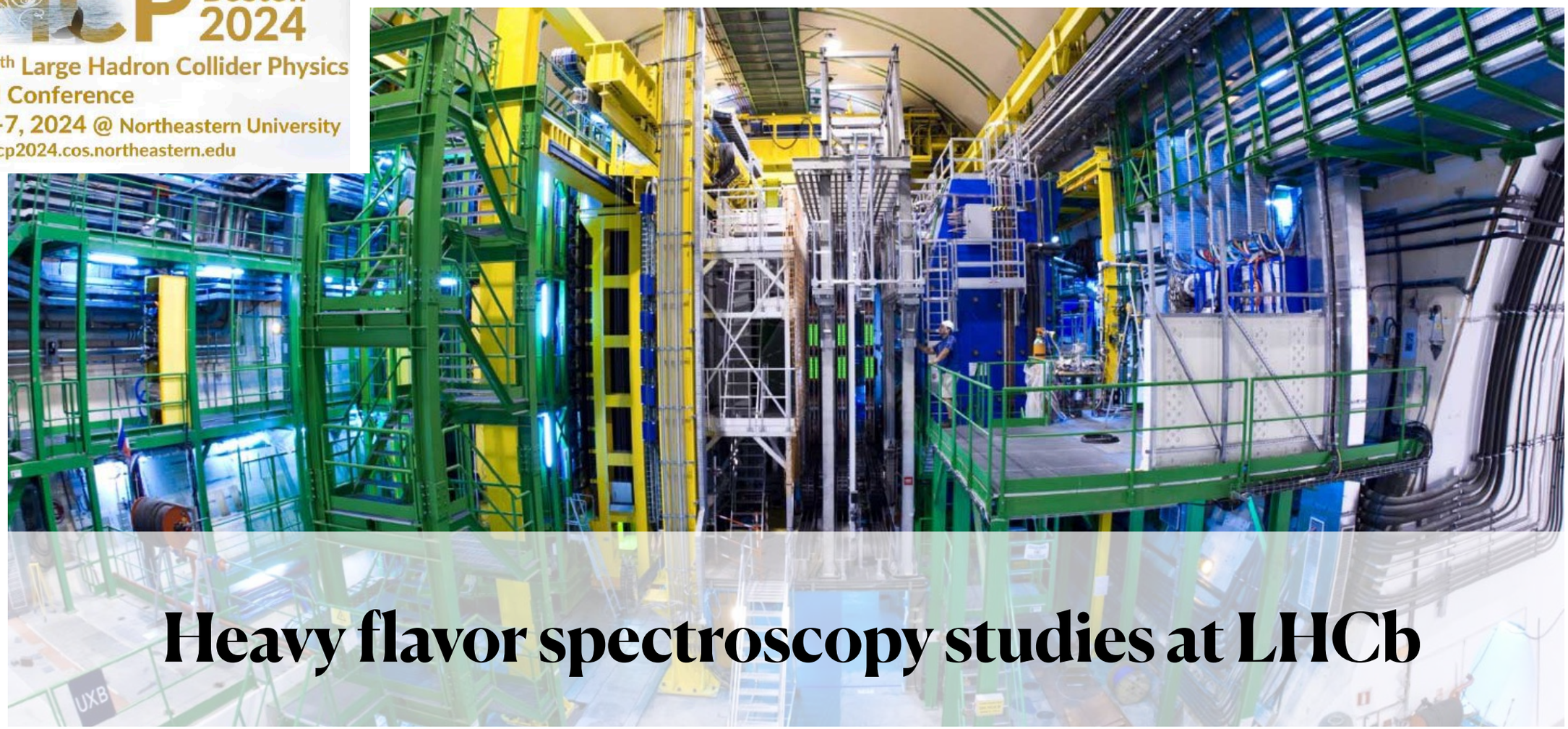
LHCP Boston 2024

The 12th Large Hadron Collider Physics Annual Conference

June 3-7, 2024 @ Northeastern University

http://lhcp2024.cos.northeastern.edu



Heavy flavor spectroscopy studies at LHCb

Paolo Gandini

INFN - Sezione di Milano

On behalf of the LHCb collaboration

INFN MILANO Istituto Nazionale di Fisica Nucleare Sezione di Milano

LHCb

Outline

- Shopping list of most recent results, no time to cover all results appeared so far after winter conferences
- Overlap with plenary talk about hadron interaction, here maybe cover more details

- Analyses use different approaches for spectroscopy investigations

- **Observation of $\Lambda_b^0 \to D^+ D^- \Lambda$**
  arXiv: 2403.03586 submitted to JHEP
  NEW

- **Observation of new charmonium(-like) states in $B^+ \to D^{*\pm} D^{\mp} K^+$ decays**
  PRELIMINARY: PAPER-2023-047 about to be submitted to arXiv
  NEW

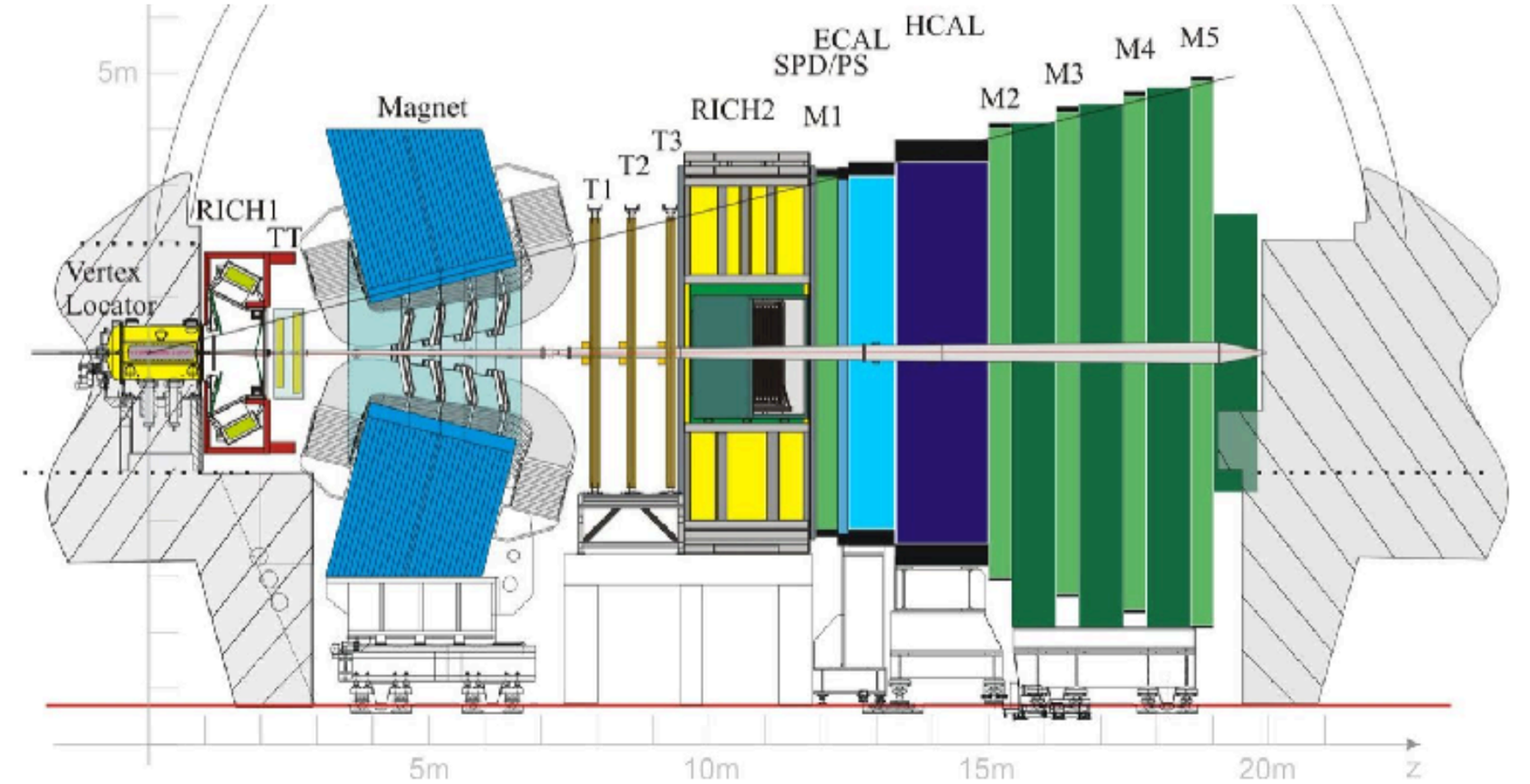
- **Observation of exotic $J/\psi\phi$ resonances in CEP collisions**
  PRELIMINARY: PAPER-2023-043 in preparation

- **Modification of $\chi_{c1}(3872)$ and $\psi(2S)$ production in pPb collisions**
  arXiv:2402.14975 submitted to PRL

The LHCb detector

Ingredients for good spectroscopy measurements

- **Excellent tracking** → mass and lifetime resolutions
- **Particle Identification** → important when dealing with charged hadrons in final states
- **Trigger efficiency** → use of muons & topological trigger give excellent efficiency



LHCb Detector Performance

Int. J. Mod. Phys. A 30 (2015) 1530022

Spectroscopy in brief...

Searches for many states with different nature → conventional hadrons & exotics

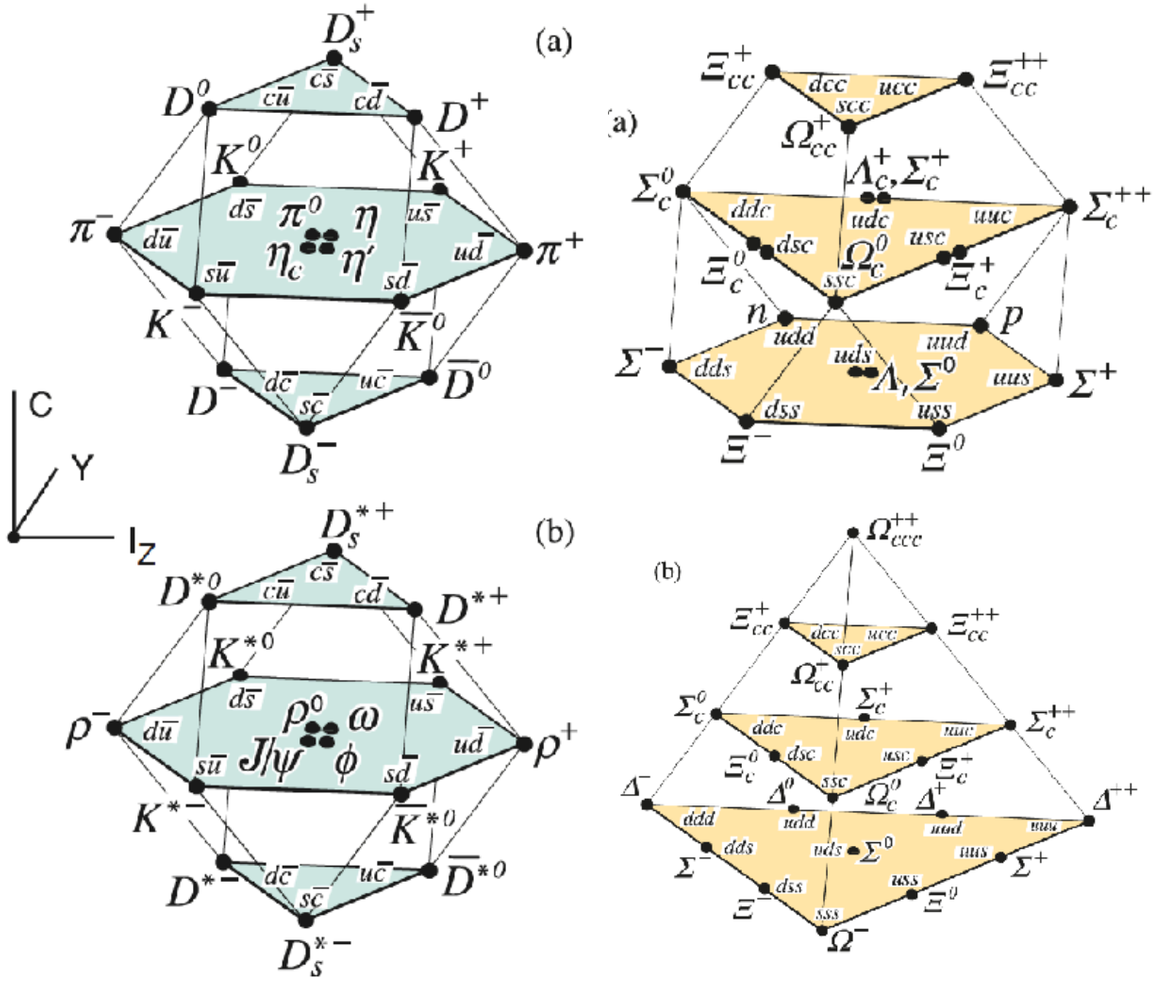
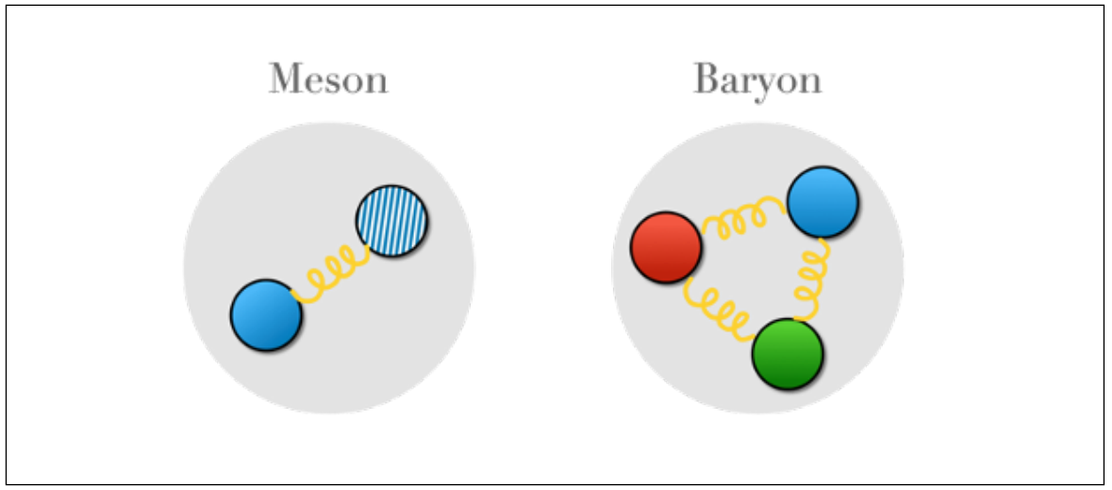
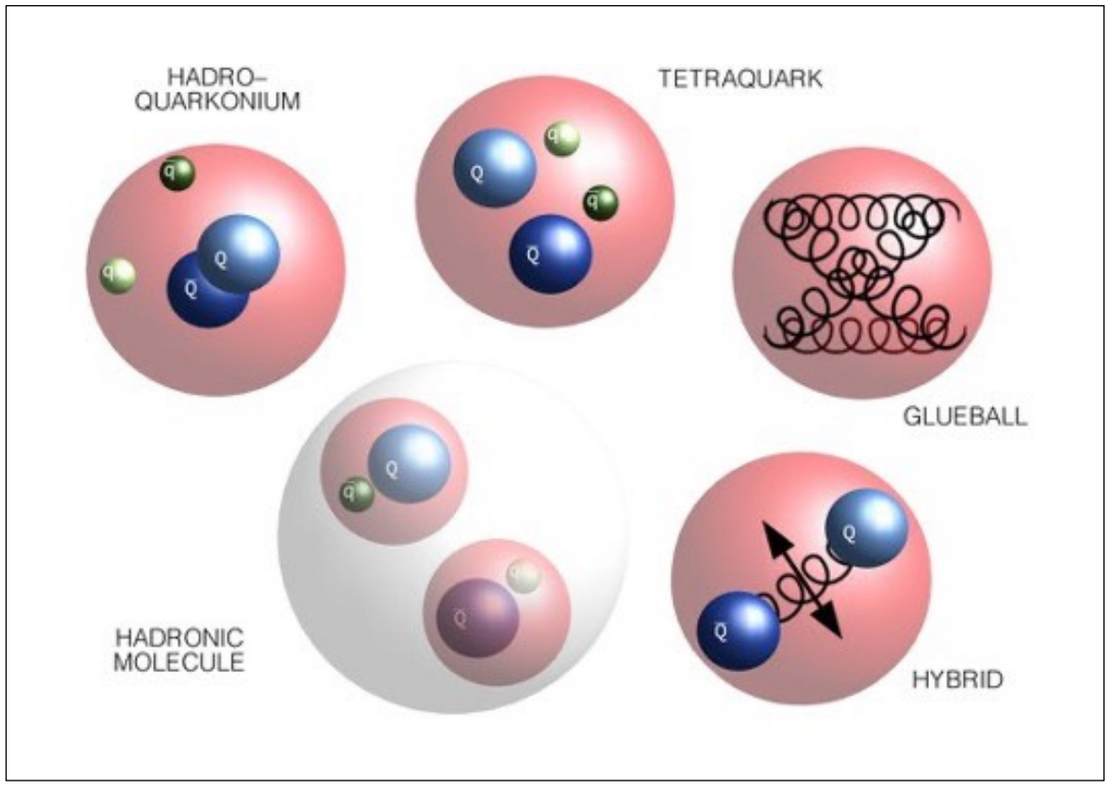


Image taken from PDG

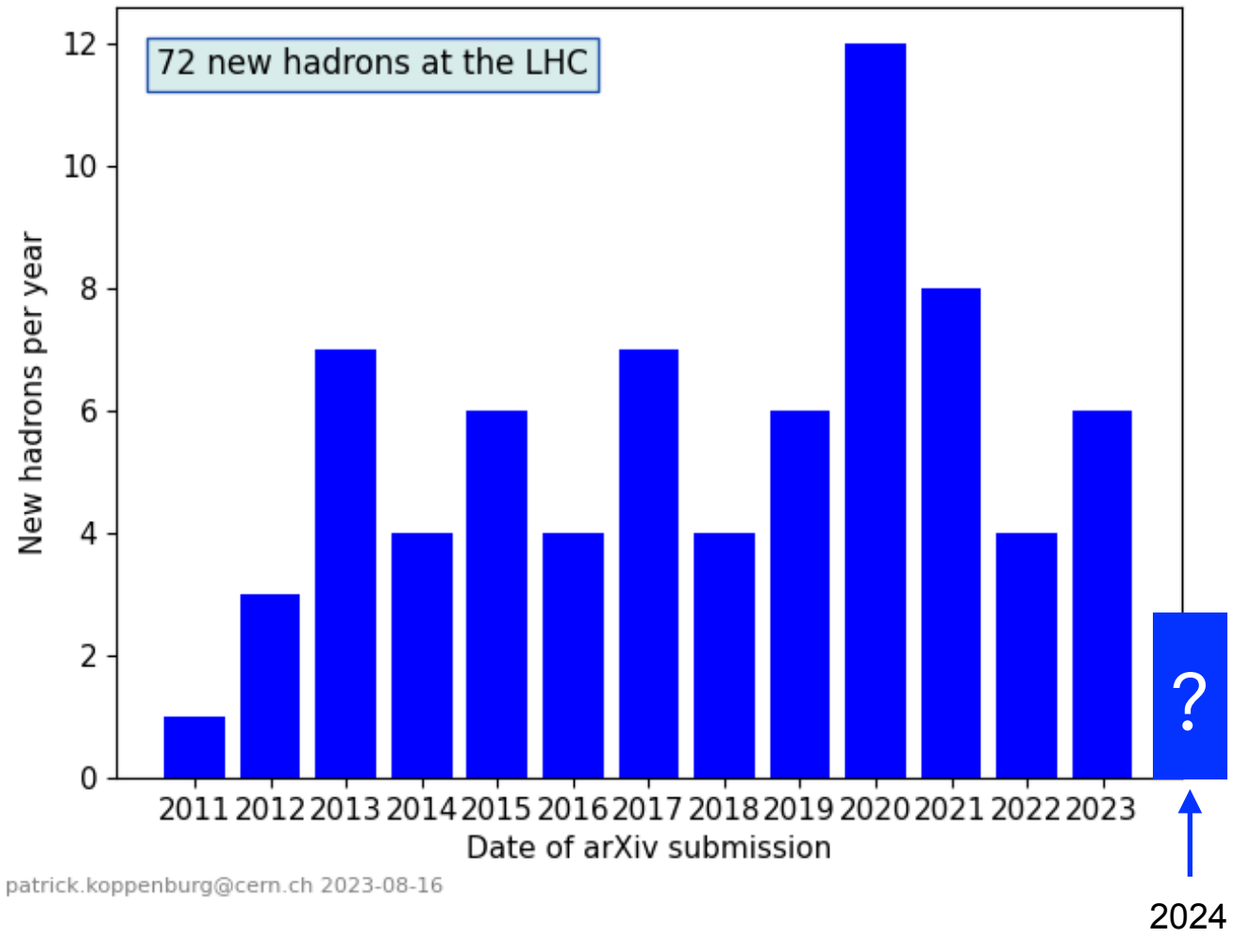
Review of Particle Physics

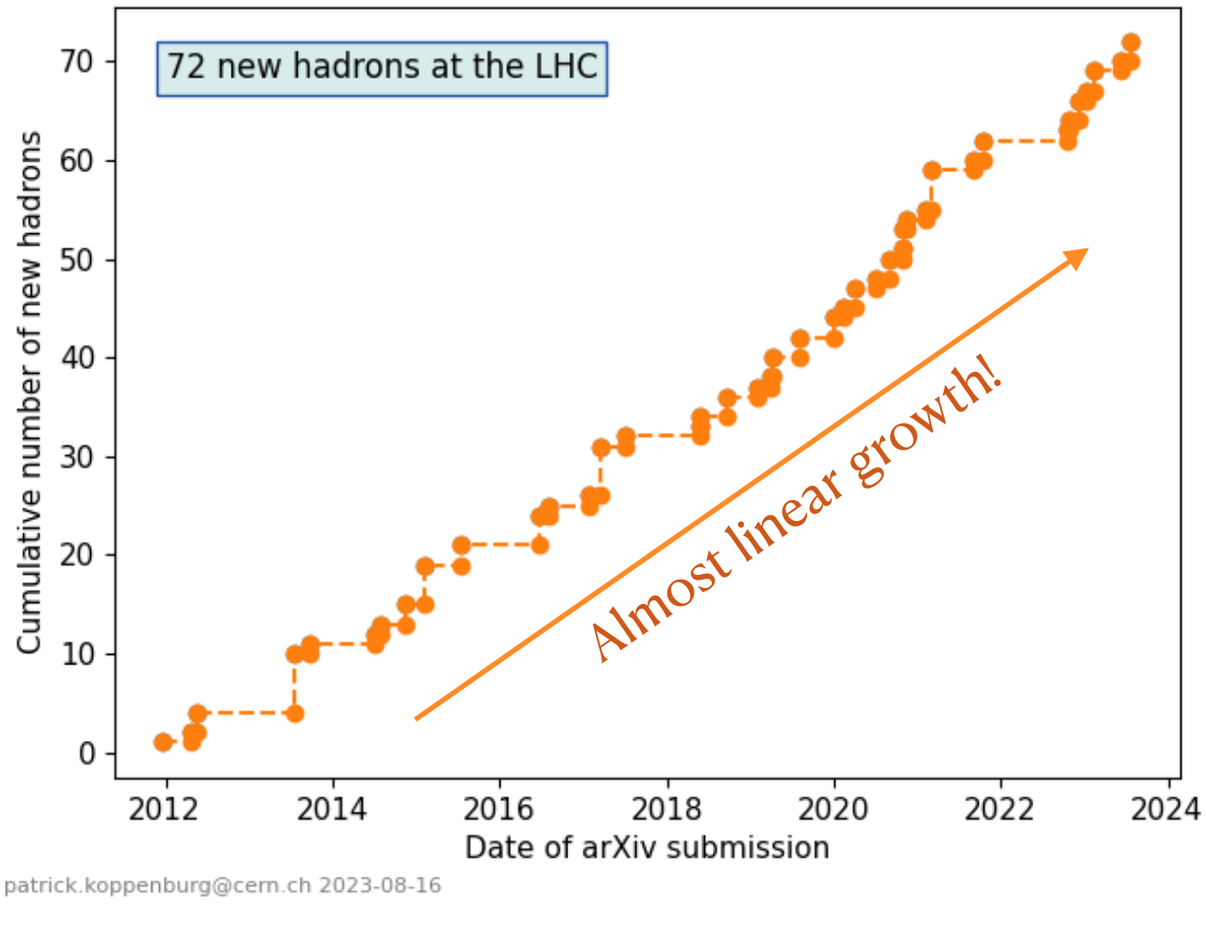




New hadrons at LHC

- It's usual practice in this type of talks to show a summary of LHC new states found
- In 2024, no new hadrons yet!
- But summer conferences have just started...
- And Run3 data taking is in full steam...

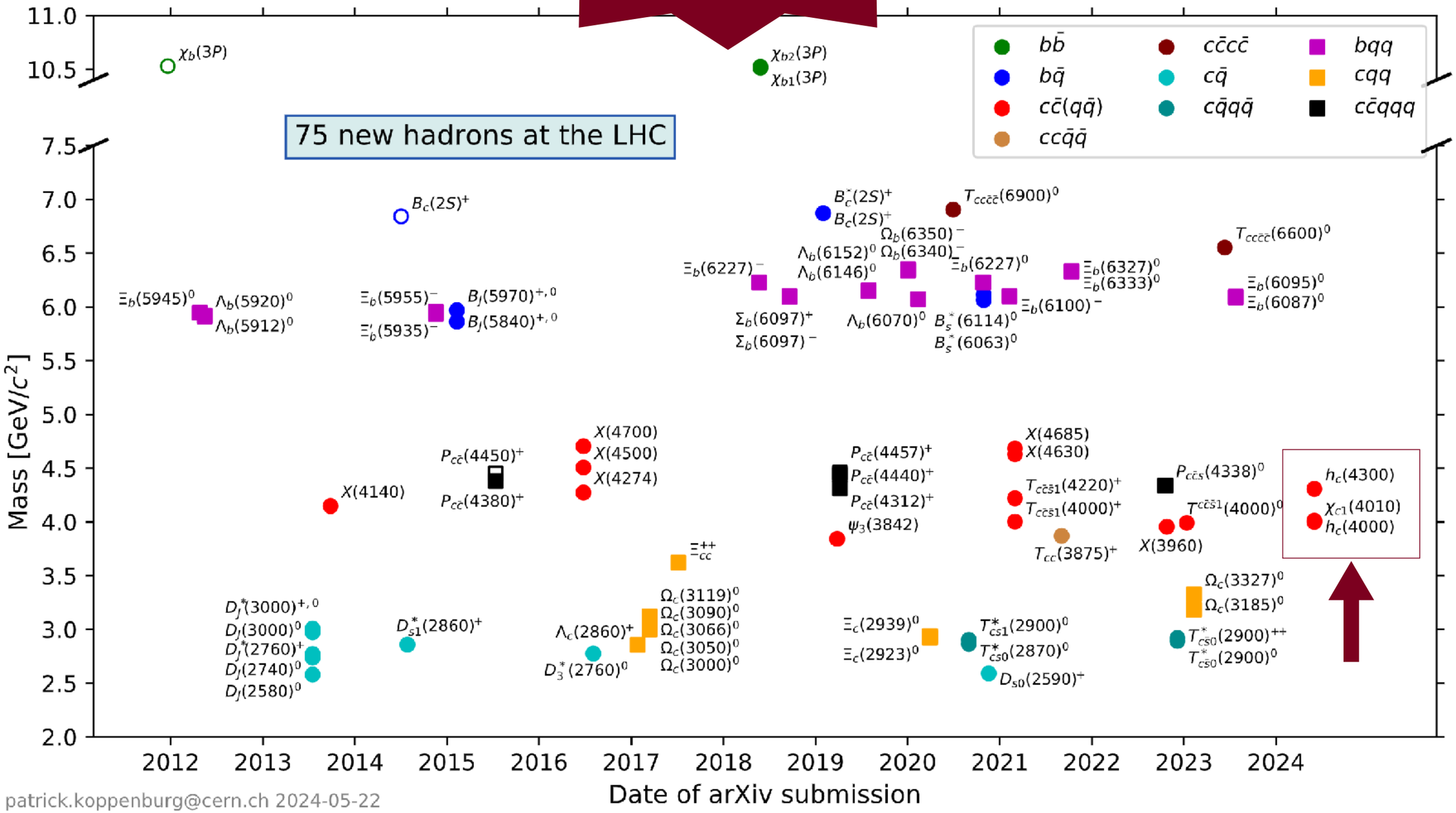




LHCb collaboration, P. Koppenburg, List of hadrons observed at the LHC, LHCb-FIGURE-2021-001, 2021, and 2023 updates.

New hadrons at LHC

SPOILER ALERT
3 new states



LHCb collaboration, P. Koppenburg, List of hadrons observed at the LHC, LHCb-FIGURE-2021-001, 2021, and 2023 updates.

Observation of $\Lambda_b^0 \to D^+ D^- \Lambda$

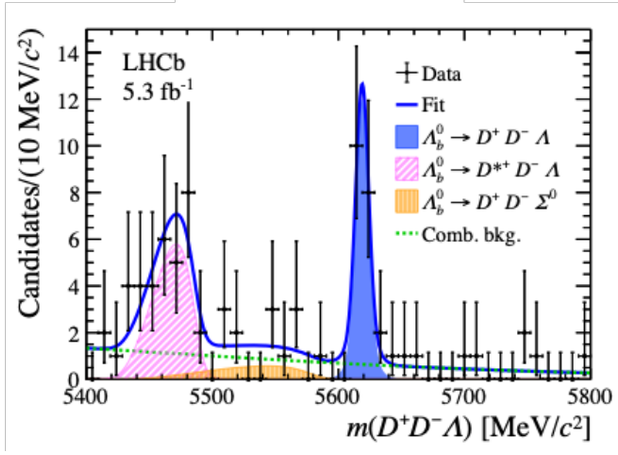
NEW

- Let's start with Dalitz analysis of a baryon
- First observation: significance of 16σ. Use $B^0 \to D^+ D^- K_S$ as a reference channel
- $D^+\Lambda$ and D^+D^- invariant-mass distributions → rich presence of intermediate resonances

arXiv: 2403.03586
submitted to JHEP

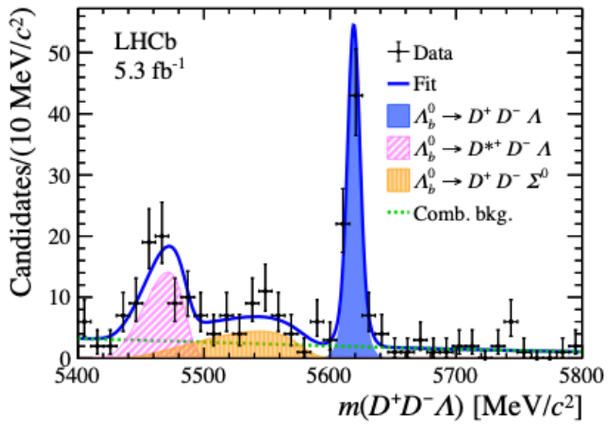
Λ decay inside VELO

$N = 19 \pm 5$



Λ decay outside VELO

$N = 73 \pm 9$



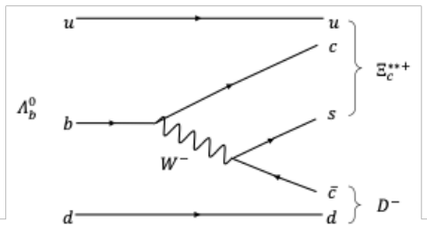
$$\mathcal{R} = \frac{\sigma_{\Lambda_b^0}}{\sigma_{B^0}} \times \frac{\mathcal{B}(\Lambda_b^0 \to D^+ D^- \Lambda)}{\mathcal{B}(B^0 \to D^+ D^- K_S^0)} = 0.179 \pm 0.022 \pm 0.014,$$

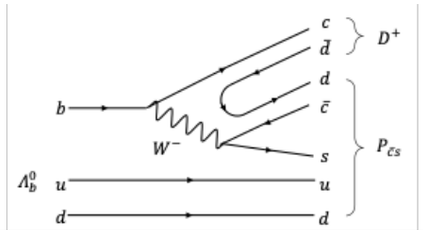
$$\mathcal{B}(\Lambda_b^0 \to D^+ D^- \Lambda) = (1.24 \pm 0.15 \pm 0.10 \pm 0.28 \pm 0.11) \times 10^{-4},$$

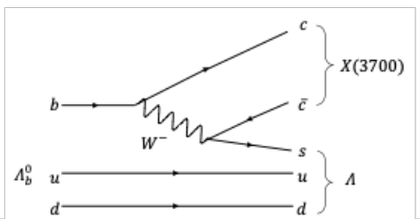
PRD 103 (2021) 114013

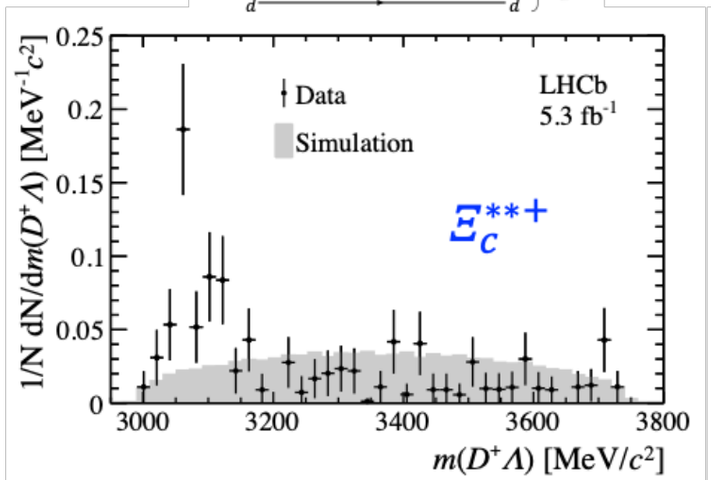
Search for a $D\bar{D}$ bound state in the $\Lambda_b \to \Lambda D\bar{D}$ process

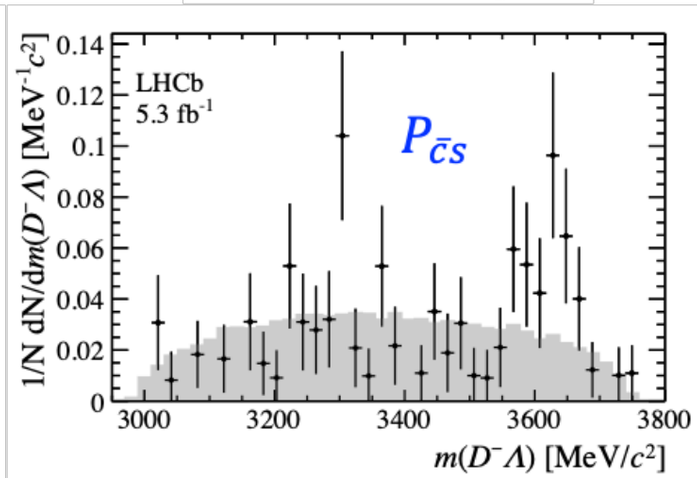
Le-Le Wei, Hong-Shen Li, En Wang, Ju-Jun Xie, De-Min Li, and Yu-Xiao Li
Phys. Rev. D **103**, 114013 – Published 9 June 2021

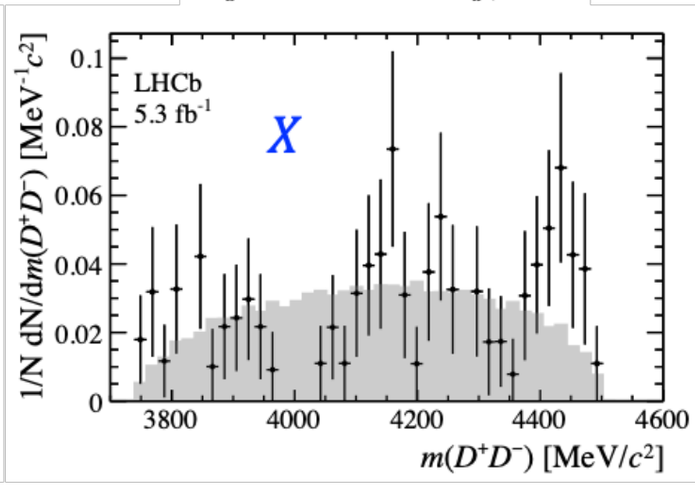












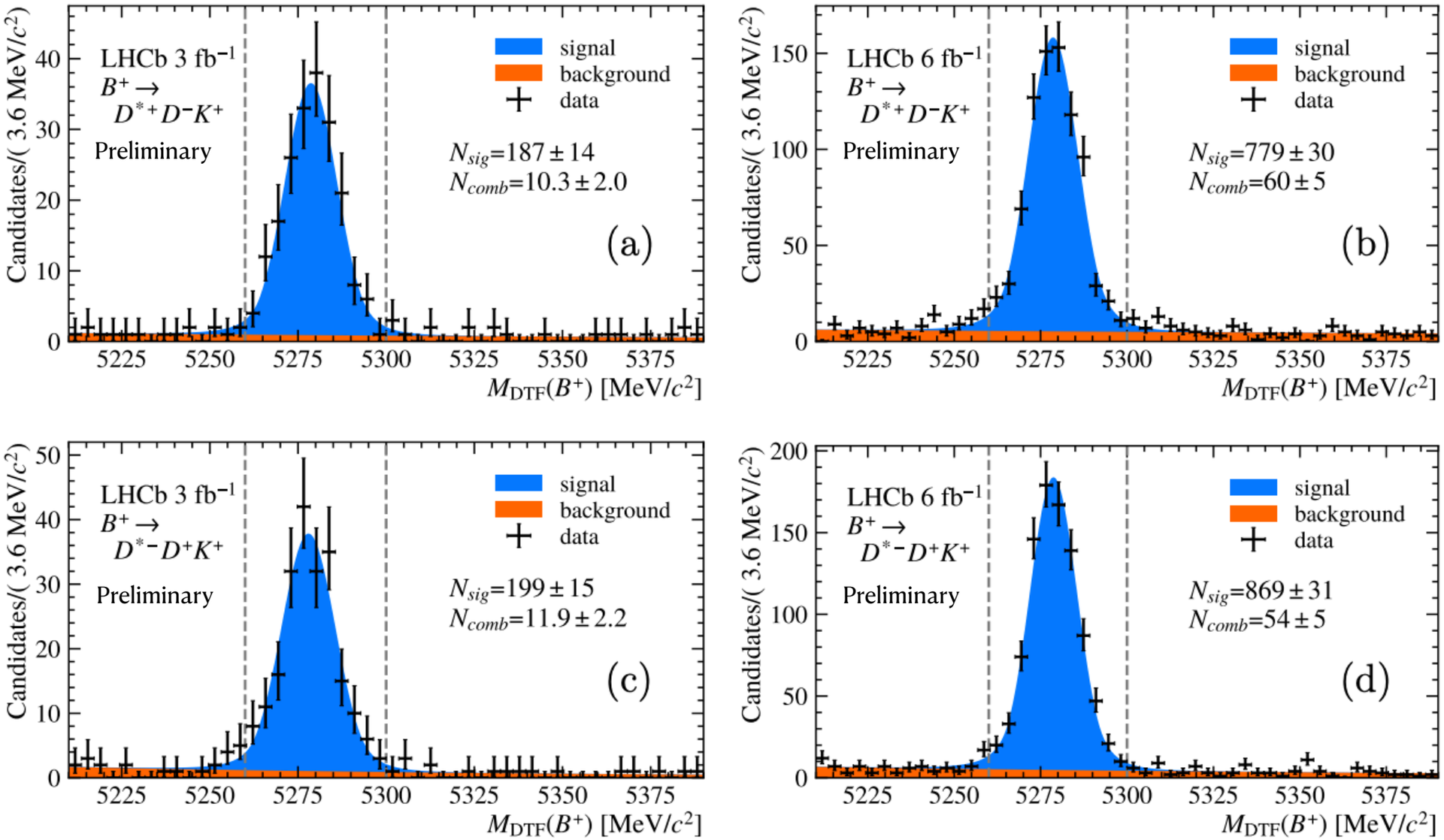
Observation of new charmonium(-like) states in $B^+ \to D^{*\pm} D^{\mp} K^+$

NEW

Preliminary
PAPER-2023-047to be submitted to arXiv

$$B^+ \to D^{*+} D^- K^+ \qquad B^+ \to D^{*-} D^+ K^+$$

- A simultaneous amplitude fit performed to two channels
- Include contributions from resonances decaying to $D^{*-}D^+$ and $D^{*+}D^-$ (states linked by C parity)
- Determine the C parity of any new states



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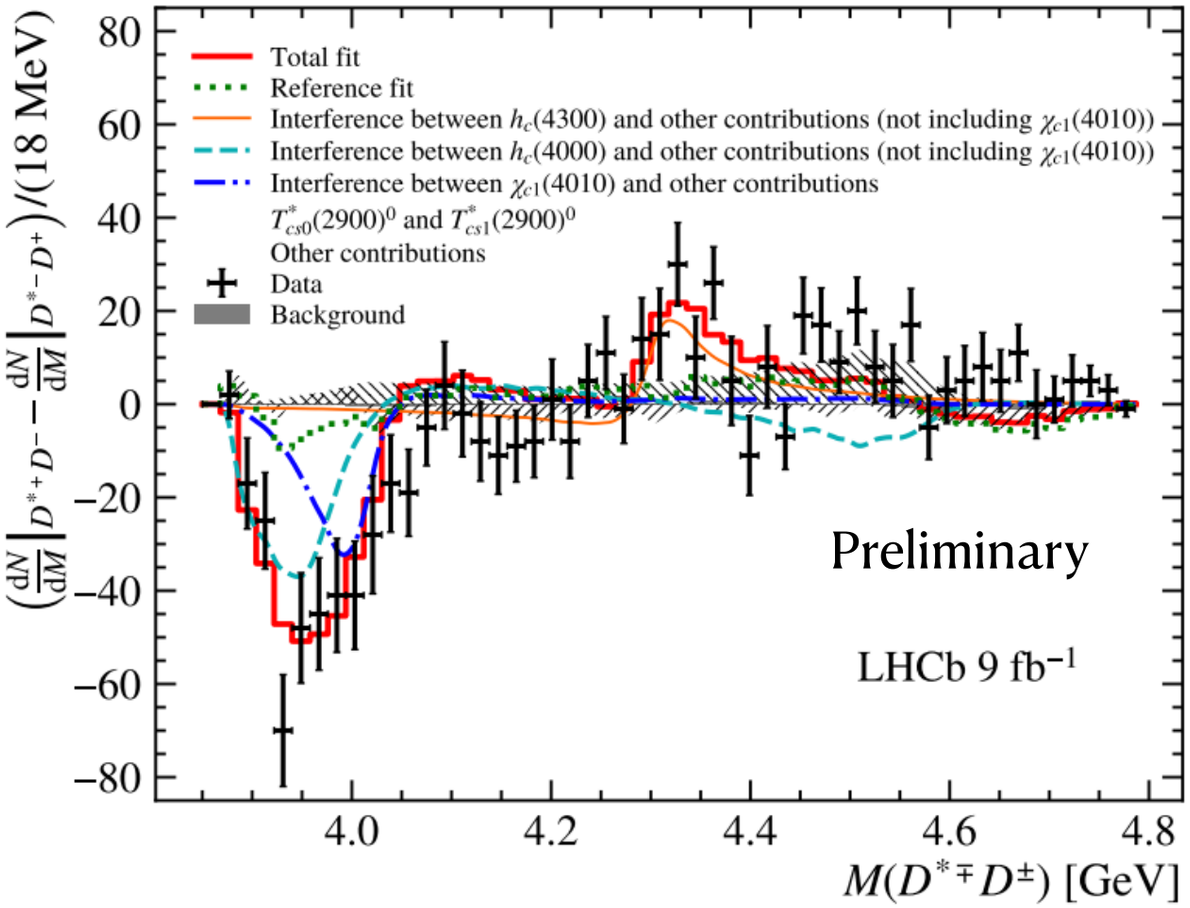


$\eta_c(3945)$, $h_c(4000)$, $\chi_{c1}(4010)$ and $h_c(4300)$
J^{PC} equal to 0^{-+}, 1^{+-}, 1^{++} and 1^{+-}

Figure 3: Difference between the $M(D^*D)$ distributions of the two channels ($B^+ \to D^{*+}D^-K^+$ and $B^+ \to D^{*-}D^+K^+$). Only interference between states with the same J^P but different C-parities, and reflections from $T^*_{\bar{c}s0,1}(2900)^0$ resonances, have significant contributions. The reference fit where $h_c(4000)$, $\chi_{c1}(4010)$ and $h_c(4300)$ are not included is shown as green dashed line.

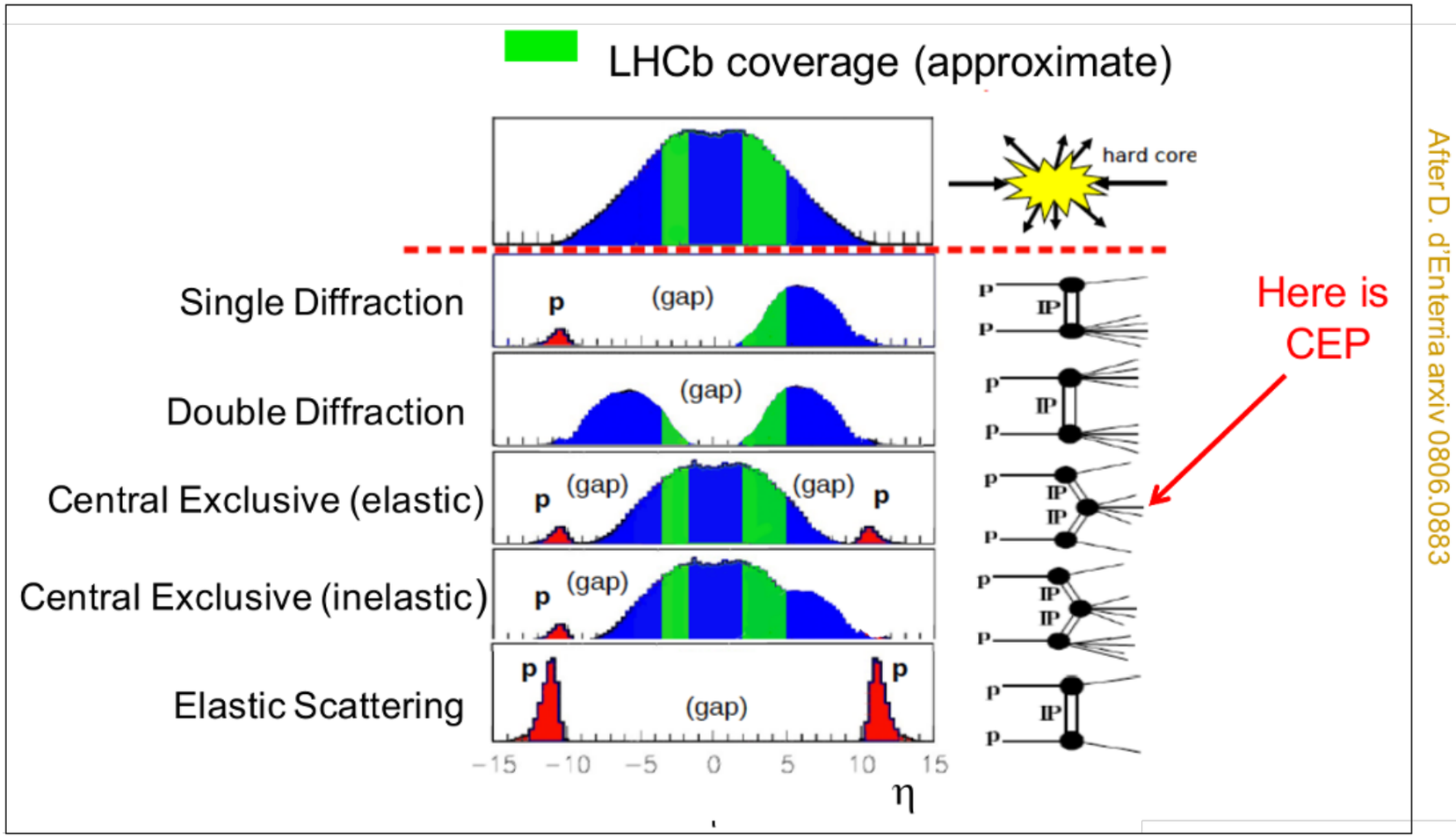
- Four charmonium(-like) states are observed: at least 3 are new
- Existence of 2 tetraquark resonances in D^-K^+ confirmed (different channel, already observed $B^+ \to D^+D^-K^+$)

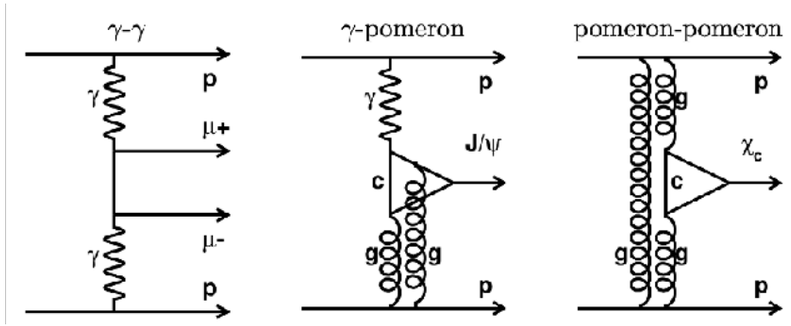
Observation of exotic J/ψΦ resonances in CEP

NEW

Preliminary
PAPER-2023-043
in preparation

- Central Exclusive Production can be done at LHCb → What do we look for?
- pp → p + X + p (rapidity gaps and protons intact)
- Colourless objects in QCD, Very low PT objects, Clean experimental environment
- Rich Physics: Photon-Pomeron, Double-Pomeron, Photoproduction, Glueballs, Exotica





✓Experimentally clean even @LHC

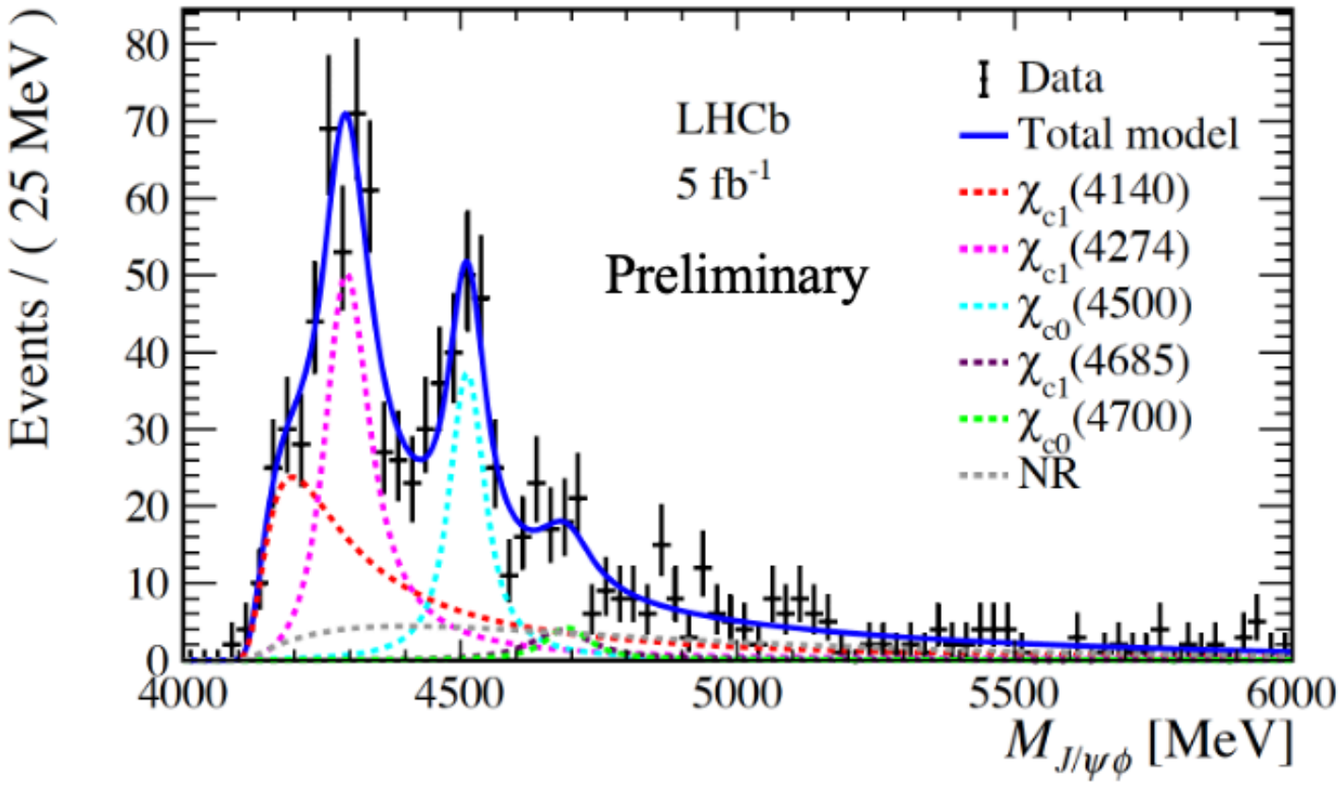
✓Spin-parity option narrowed down

✘Much smaller rate

Observation of exotic J/ψΦ resonances in CEP

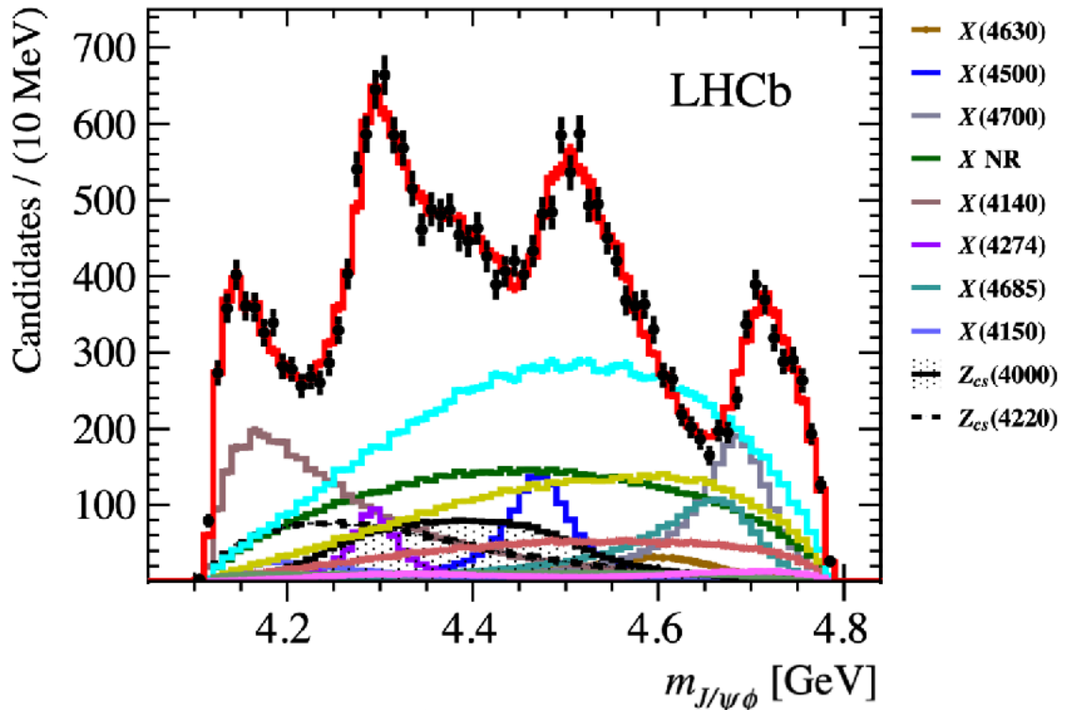
NEW

Preliminary
PAPER-2023-043
in preparation



[PRL 127 (2021) 082001]

Zoomed version of the spectrum
from tetraquark original paper



Mass & width measurement
slightly higher mass of X(4500)

Parameter (MeV)	This Letter	Ref. [12]
$M_{\chi_{c1}(4274)}$	$4298 \pm 6 \pm 9$	$4294 \pm 4^{+3}_{-6}$
$\Gamma_{\chi_{c1}(4274)}$	$92^{+22}_{-18} \pm 57$	$53 \pm 5 \pm 5$
$M_{\chi_{c0}(4500)}$	$4512.5^{+6.0}_{-6.2} \pm 3.0$	$4474 \pm 3 \pm 3$
$\Gamma_{\chi_{c0}(4500)}$	$65^{+20}_{-16} \pm 32$	$77 \pm 6^{+10}_{-8}$

Cross-section measurement

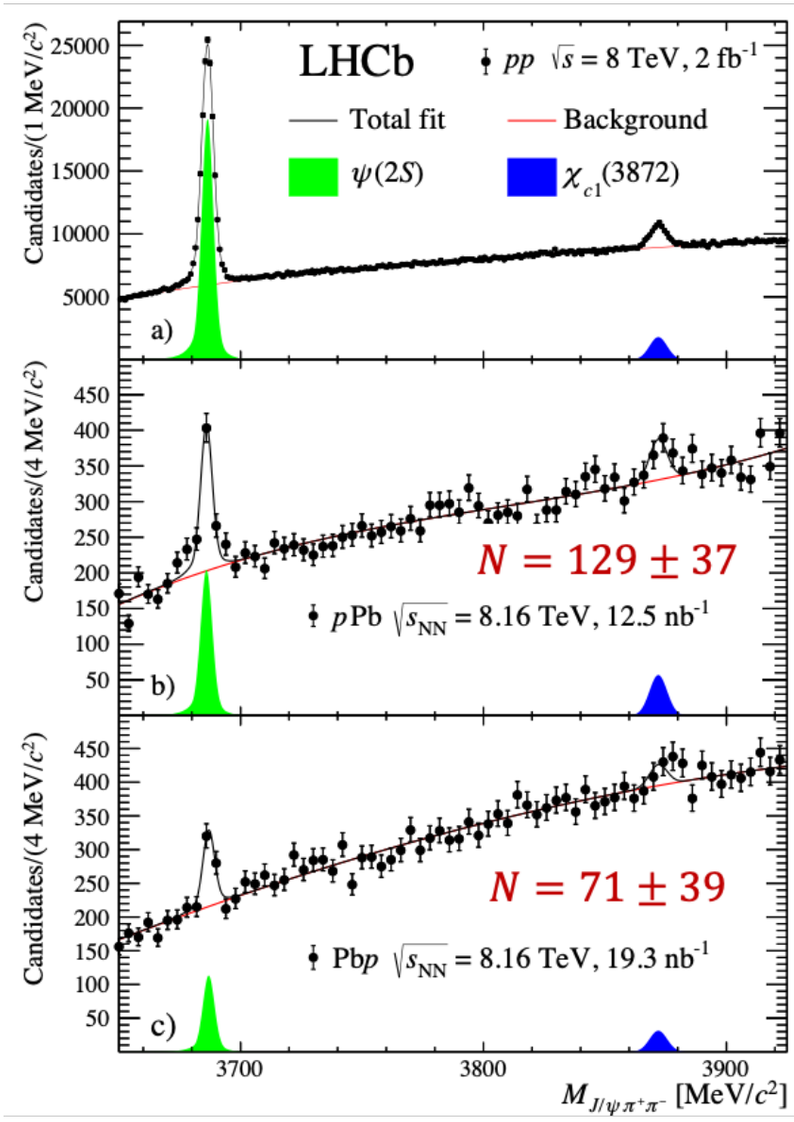
$$\sigma_{\chi_{c1}(4140)} \times \mathcal{B}_{\text{eff}}^{\chi_{c1}(4140)} = (0.85 \pm 0.16 \pm 0.30)\,\text{pb},$$
$$\sigma_{\chi_{c1}(4274)} \times \mathcal{B}_{\text{eff}}^{\chi_{c1}(4274)} = (0.77^{+0.14}_{-0.13} \pm 0.18)\,\text{pb},$$
$$\sigma_{\chi_{c0}(4500)} \times \mathcal{B}_{\text{eff}}^{\chi_{c0}(4500)} = (0.44^{+0.09}_{-0.08} \pm 0.07)\,\text{pb},$$
$$\sigma_{\chi_{c1}(4685)+\chi_{c0}(4700)} \times \mathcal{B}_{\text{eff}}^{\chi_{c1}(4685)+\chi_{c0}(4700)} = (0.14^{+0.07}_{-0.06} \pm 0.06)\,\text{pb},$$
$$\sigma_{NR} \times \mathcal{B}_{\text{eff}}^{NR} = (0.46^{+0.25\ +0.21}_{-0.19\ -0.22})\,\text{pb},$$

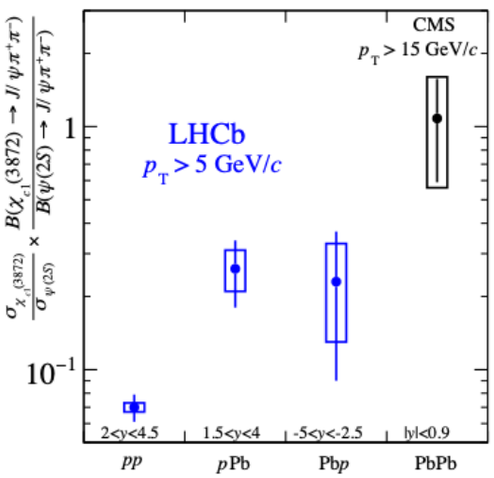
First exotic measurement in CEP

Modification of $\chi c1(3872)$ and $\psi(2S)$ production in pPb collisions at $\sqrt{s_{NN}}$=8.16 TeV

- First measurement of the production of the exotic hadron $\chi_{c1}(3872)$ in pPb collisions
- Comparison with the charmonium state $\psi(2S)$
- The exotic $\chi c1(3872)$ experiences different dynamics in the nuclear medium than conventional hadrons
- Comparison with data from pp collisions → rhe presence of the nucleus may modify $\chi c1(3872)$ production rates

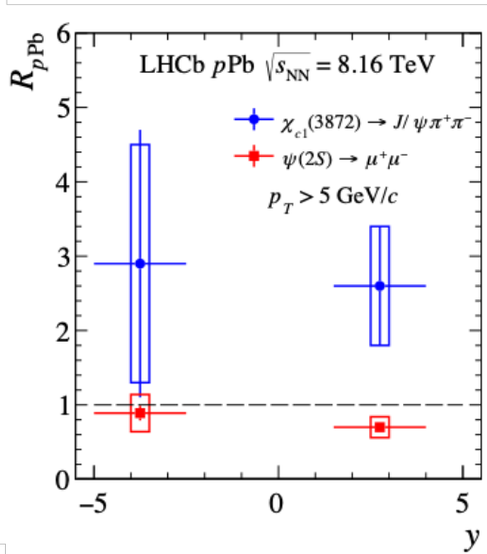
arXiv:2402.14975
submitted to PRL





$$\frac{\sigma^{\chi_{c1}(3872)}}{\sigma^{\psi(2S)}} \times \frac{\mathcal{B}[\chi_{c1}(3872) \to J/\psi\pi^+\pi^-]}{\mathcal{B}[\psi(2S) \to J/\psi\pi^+\pi^-]}$$

Increase with system size
→ $\chi_{c1}(3872)$ experience different dynamics in nuclear medium than $\psi(2S)$



$$R_{pA}^{\chi_{c1}(3872)} = \frac{\sigma_{pA}^{\chi_{c1}(3872)}}{208 \times \sigma_{pp}^{\chi_{c1}(3872)}}$$

Enhancement in pPb
→ enhancement due to coalescence dominates over suppression due to breakup

X(3872) have been determined by the LHCb experiment at CERN in March 2013.
The values for J^{PC} are 1^{++}

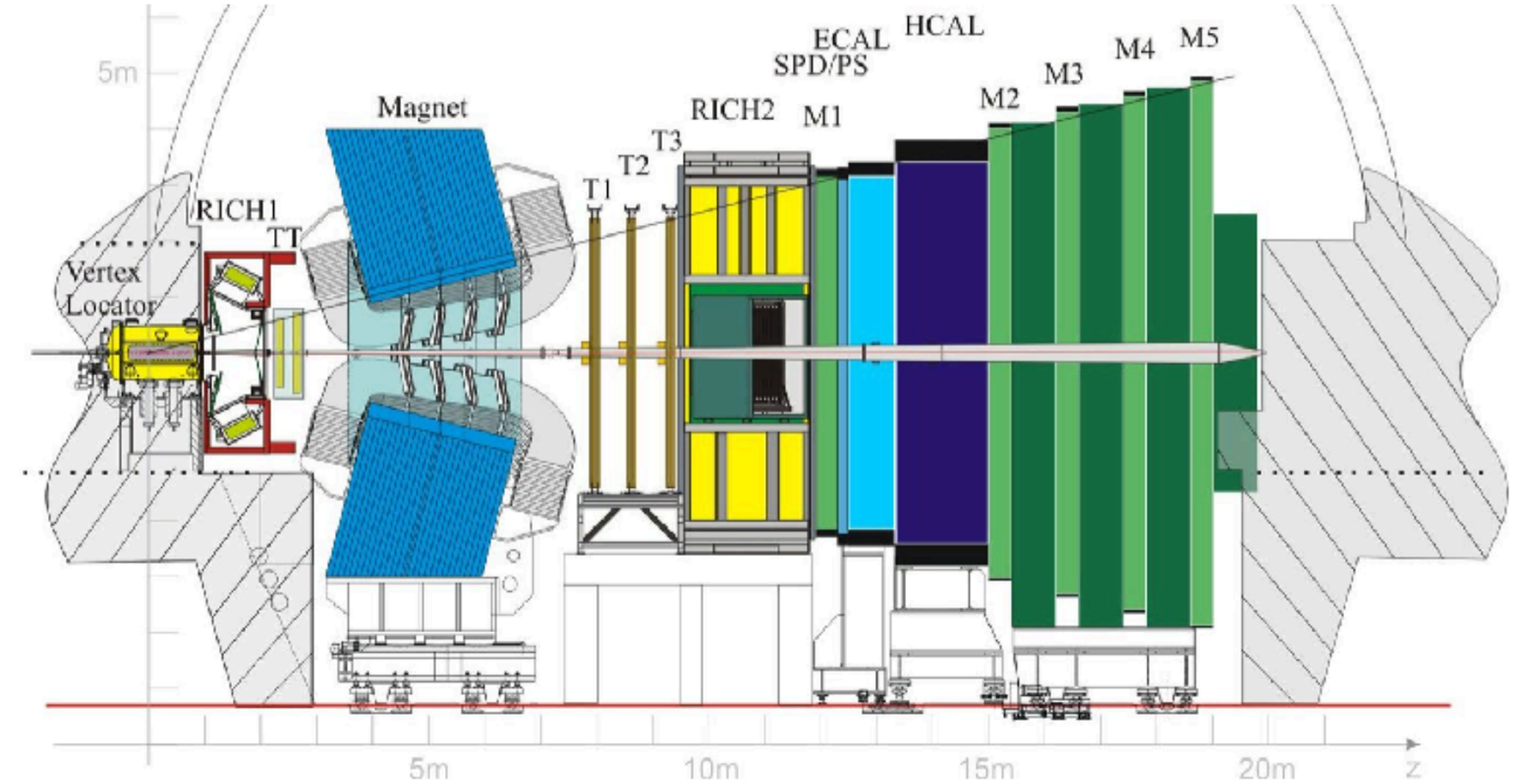
Conclusions

- This was a very short talk contains only the very latest LHCb results
- All results are using Run1-Run2 datasets but now collecting datasets for Run3
- Expect high statistics and unprecedented number of heavy hadron produced
- Full software trigger will increase efficiency (and discovery potential!)

Backup Slides

The LHCb detector

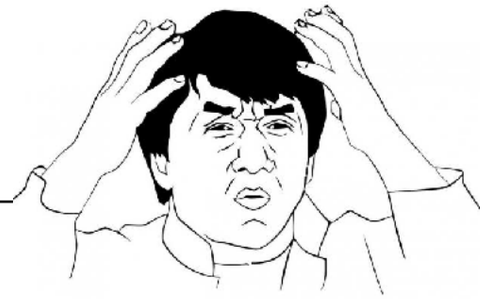
- LHCb designed as forward spectrometer covering the pseudo rapidity range $2<\eta<5$
- The LHCb experiment is an extraordinary spectroscopy gym both for “conventional” and “exotic” states
- At LHC *b* and *c* baryons are produced in unprecedented quantities (high cross sections & luminosity)
- Perfect conditions for both precision measurements & observations of new states
- Drawbacks: reconstructing neutrals is experimentally challenging (but doable)



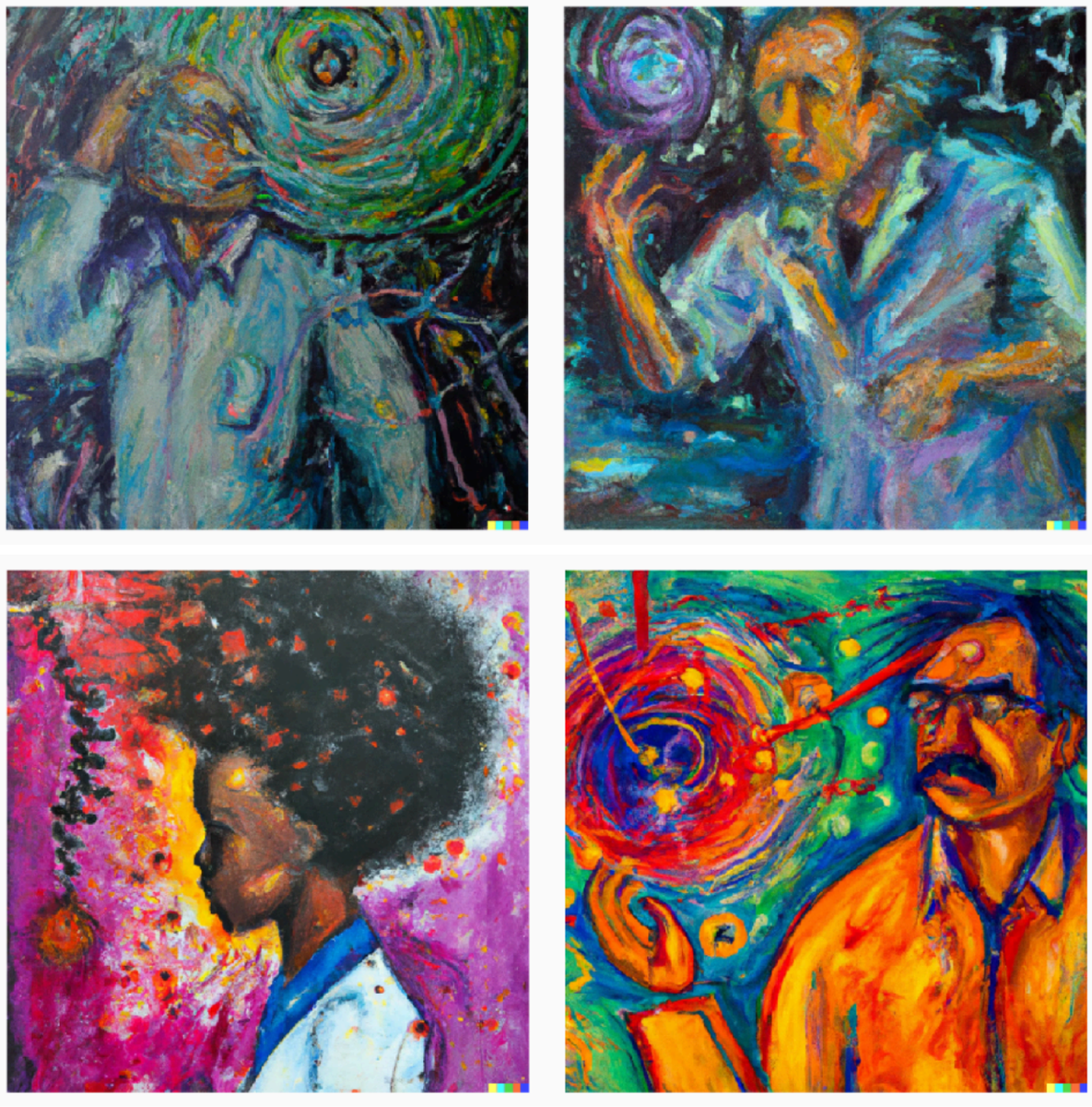
LHCb Detector Performance

Int. J. Mod. Phys. A 30 (2015) 1530022

AI fun

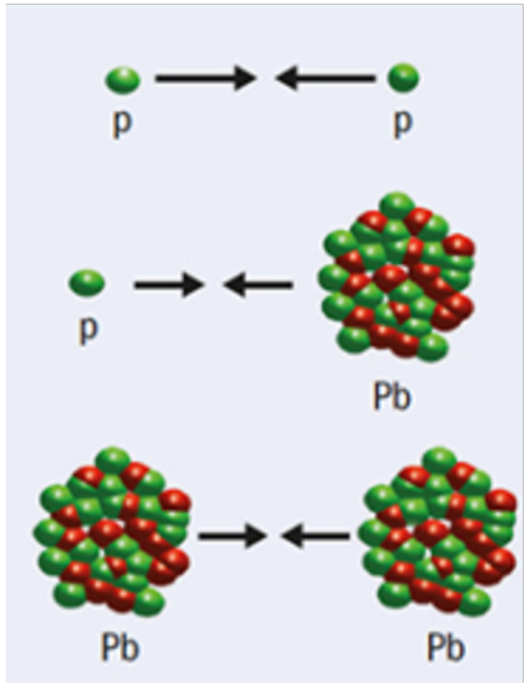


Images generated by DALL-E
artificial intelligence



And using Midjourney
More oneiric... less inclusive

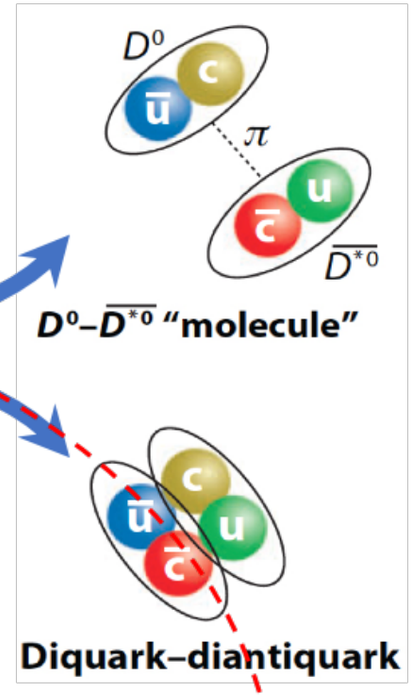
$\chi_{c1}(3872)$ in hadronic collisions



✓ Enhancement:
quark coalescence...

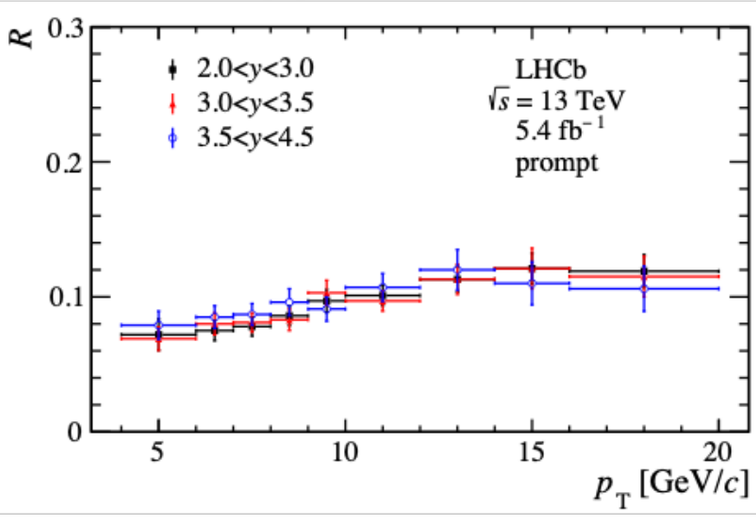
✘ Suppression:
breakup due to interactions
with comoving particles...

differ in



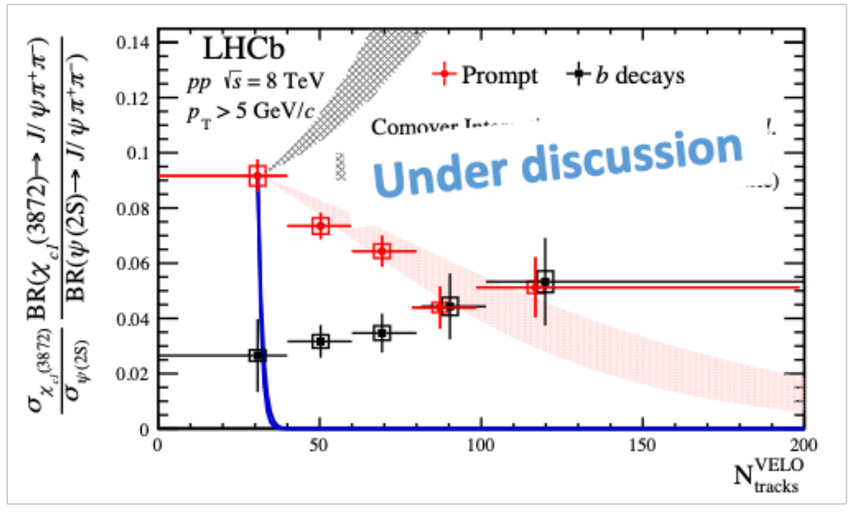
Measurements of $\chi_{c1}(3872)$ production wrt $\psi(2S)$

In pp collisions



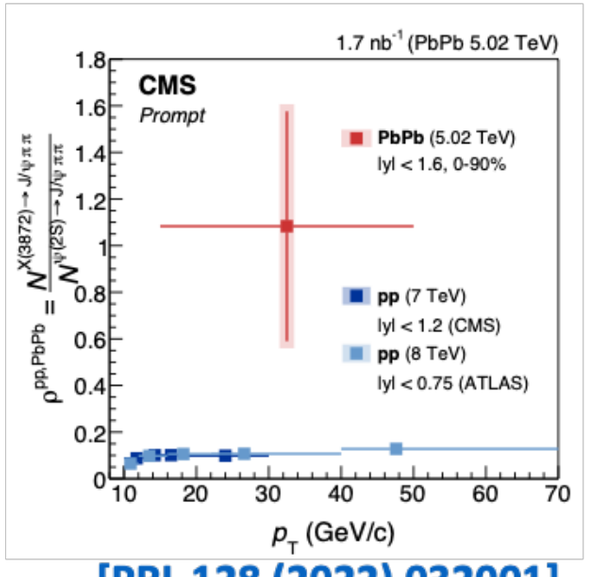
[JHEP 01 (2022) 131]

In pp collisions vs multiplicity



[PRL 126 (2021) 092001]

In PbPb collisions



[PRL 128 (2022) 032001]