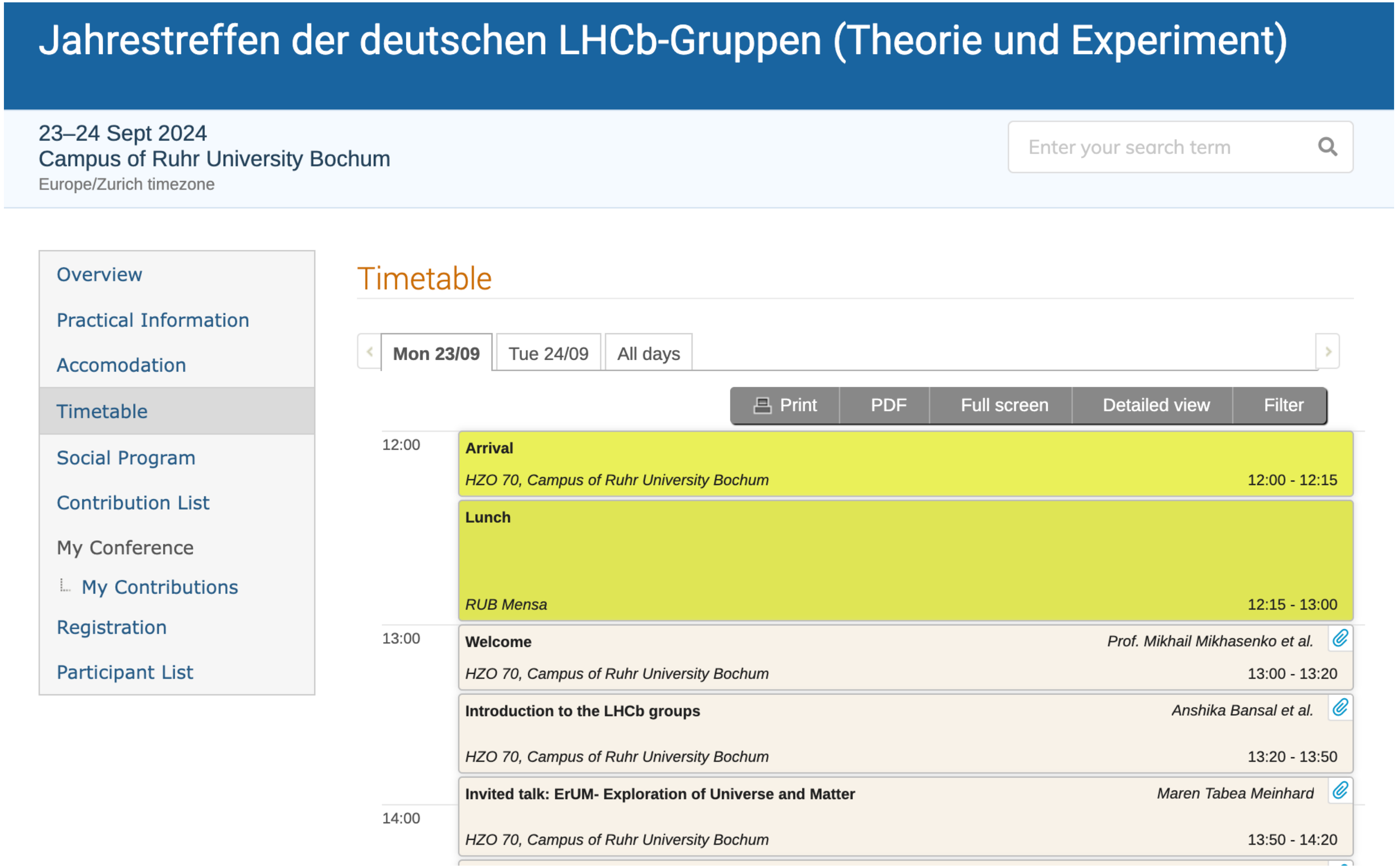
News from LHCb

Mikhail Mikhasenko

Ruhr University Bochum 23.09.2024

Greetings from FSP-LHCb meeting



Experiment

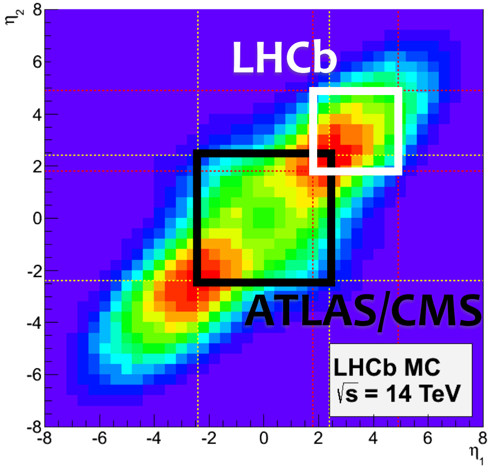
LHCb@CERN: heavy flavor quarks factory

One of four large experiments at LHC

LHCb has the largest production cross-sections of b- and c-hadrons ever

$\sigma(b\bar{b}) \approx 600\mu b$ @ 14TeV
$\sigma(c\bar{c}) \approx 20 \times \sigma(b\bar{b})$ in pp collisions

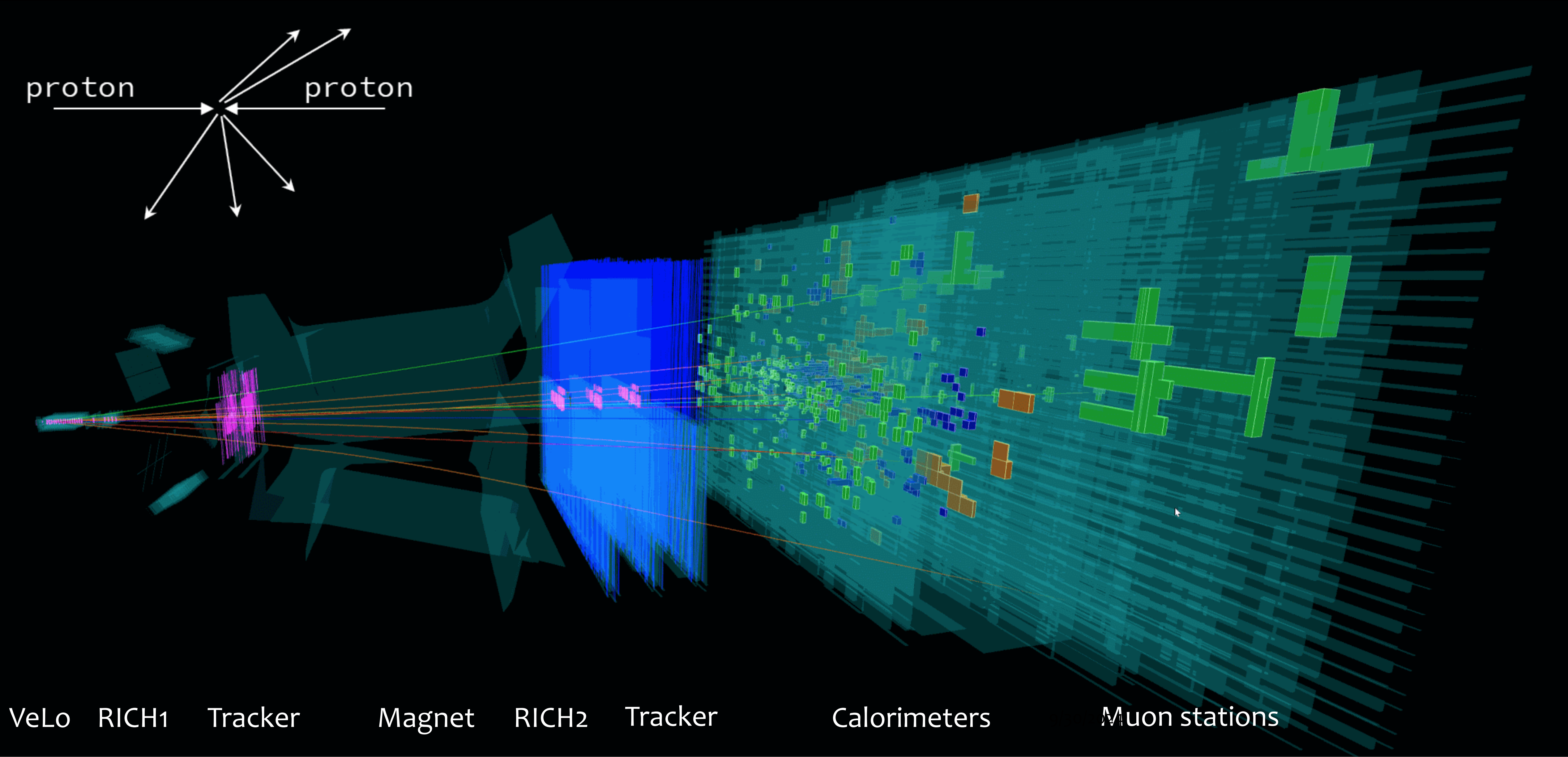
High track multiplicity



b-quark product cross-section

[detector, performance, event display]

The LHCb experiment



Upgraded detector

[LHCb, JINST **19** (2024) P05065]

Software only trigger

New RICH2 optics
new sensors and readout for RiCH

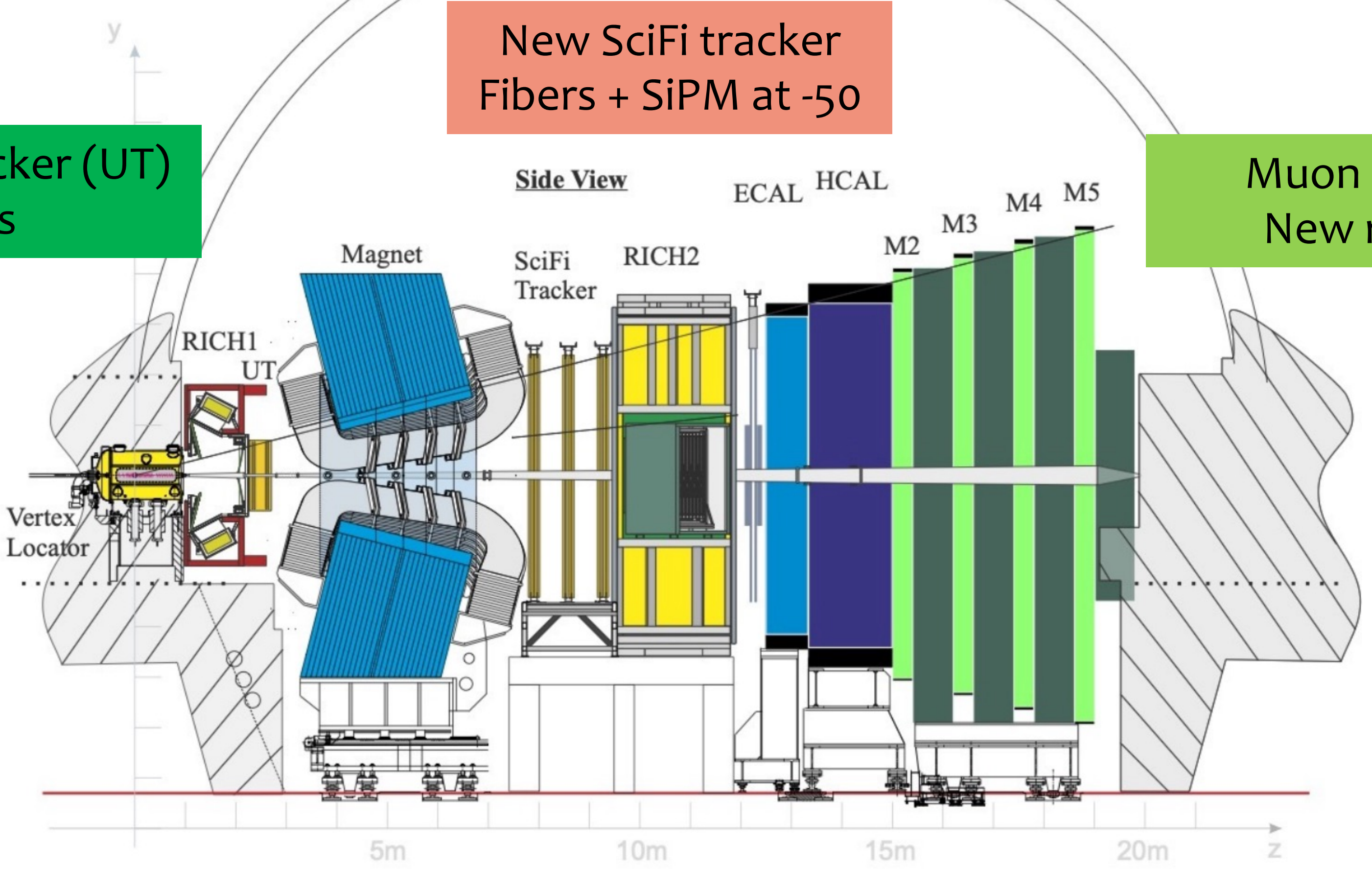
Calo: removed preshawer,
Scintillating Pad Detector, new readout

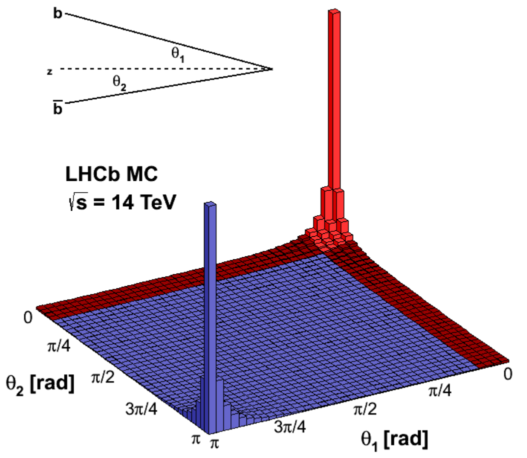
New SciFi tracker
Fibers + SiPM at -50

New Upstream Tracker (UT)
Silicon strips

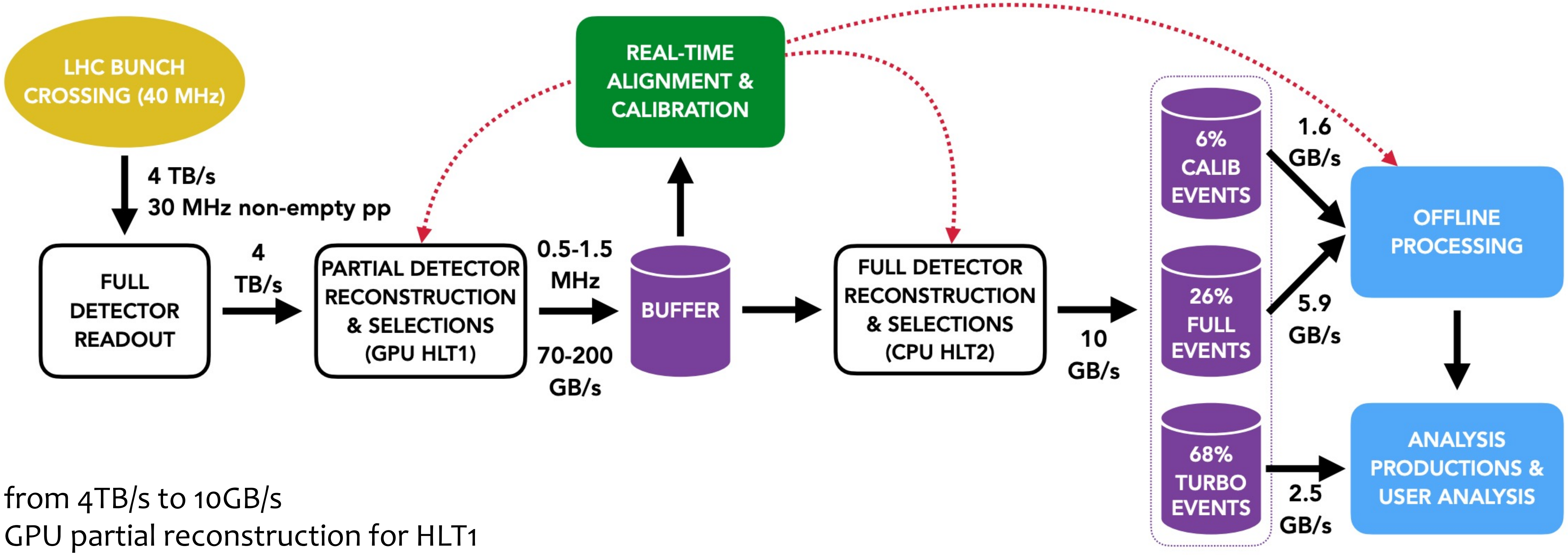
Muon stations:
New readout

New VeLo
Pixel detector





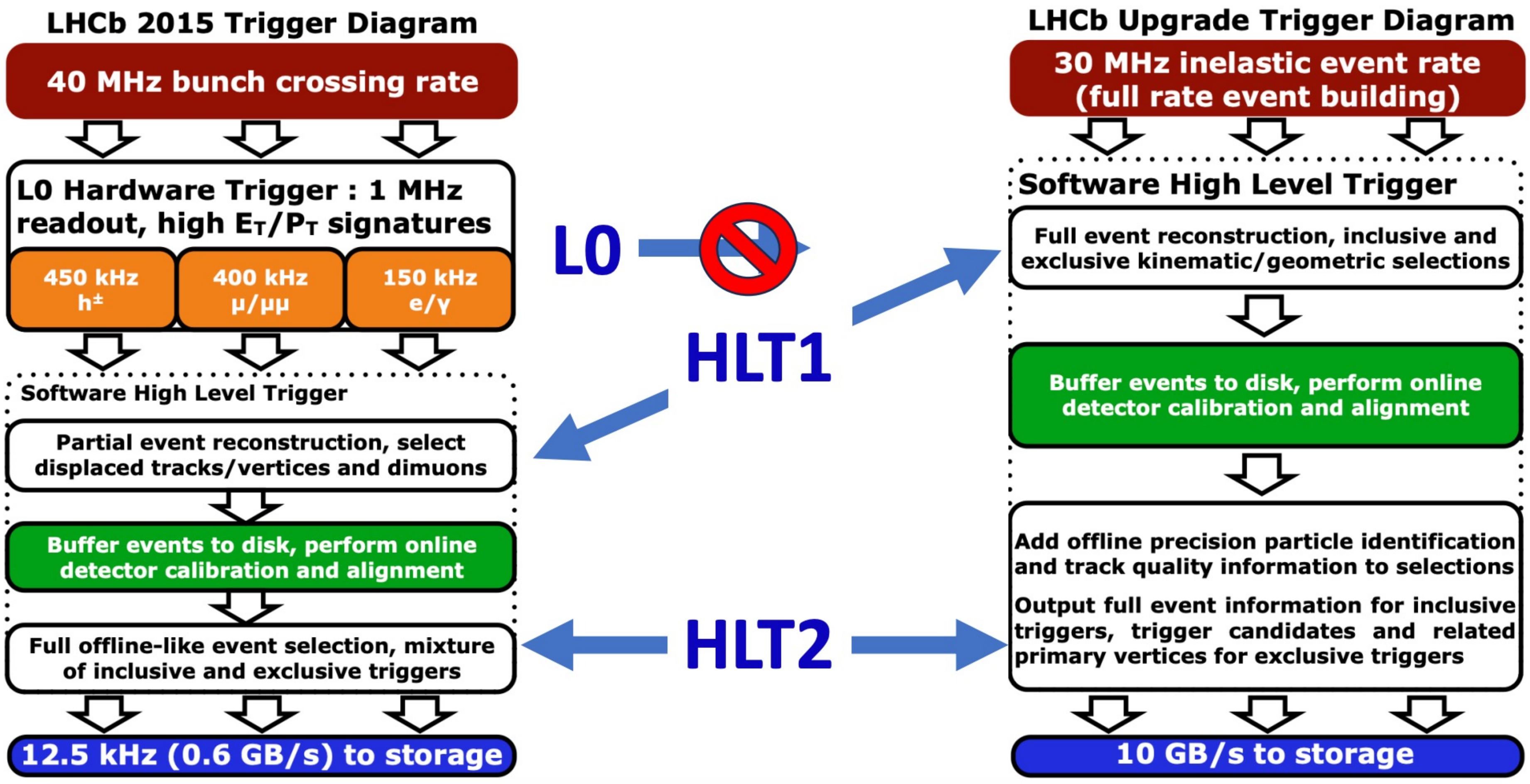
Trigger



from 4TB/s to 10GB/s
GPU partial reconstruction for HLT1
CPU full reconstruction for HLT2

No level zero hardware trigger anymore

Run2 (2014-2018) / Run3 (2022-2026)



Start of the Run-III

[LHCb Upgrade]

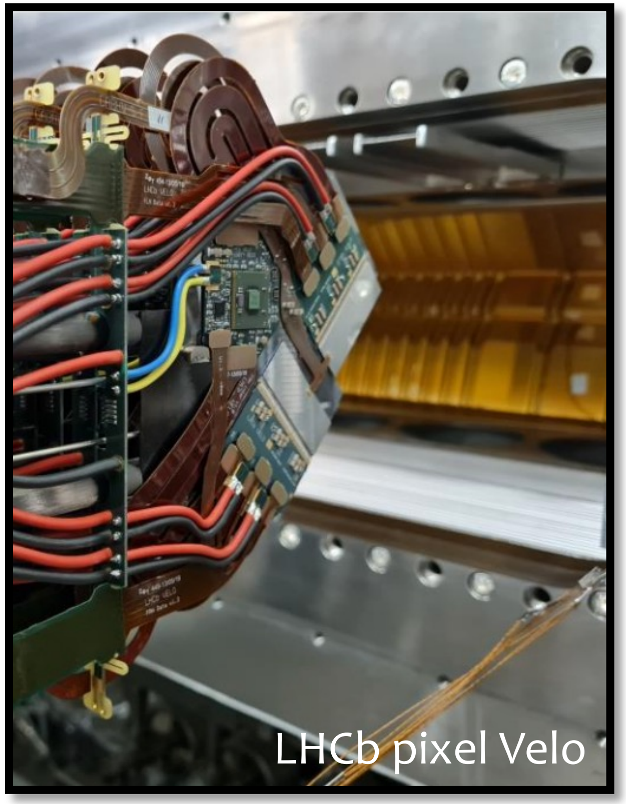
Vertex detector is successfully reinstalled

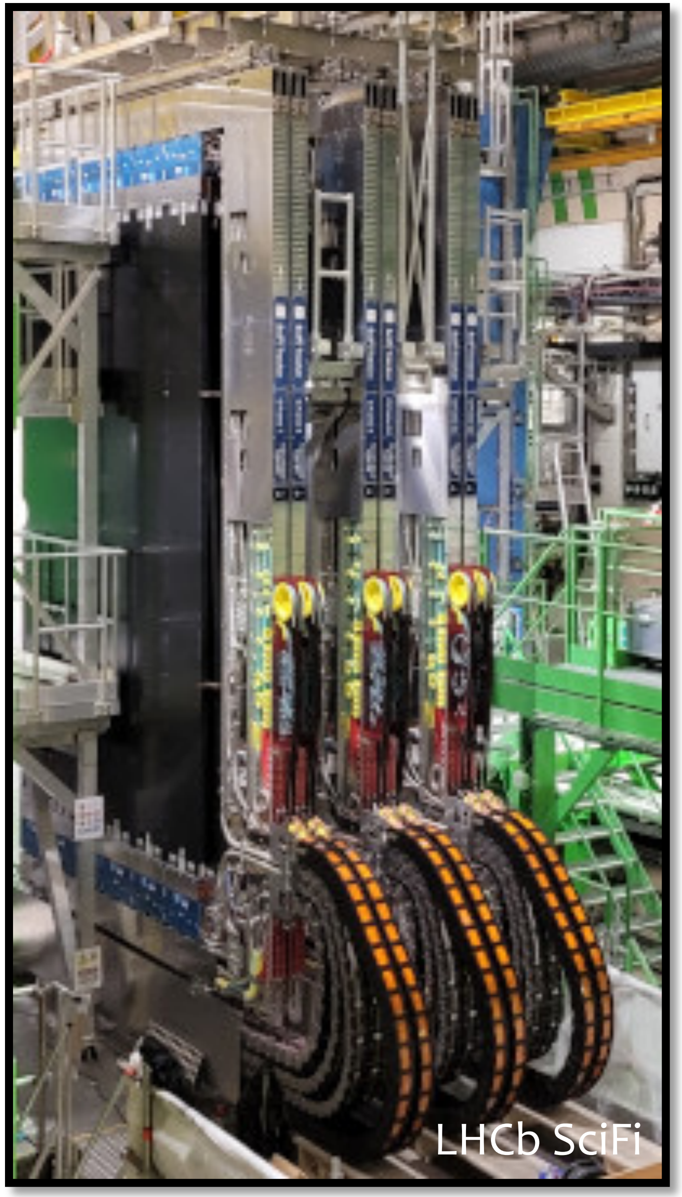
LHC recover

Schedule:

- 6 March: cavern closed
- 11 March: first circulating beam
- 3 April: first stable beams
- 12-25 April: intensity ramp up
- 25 April: start luminosity production

Goal: 120 days (2024) + 140 days (2025) + 140 days (2026)





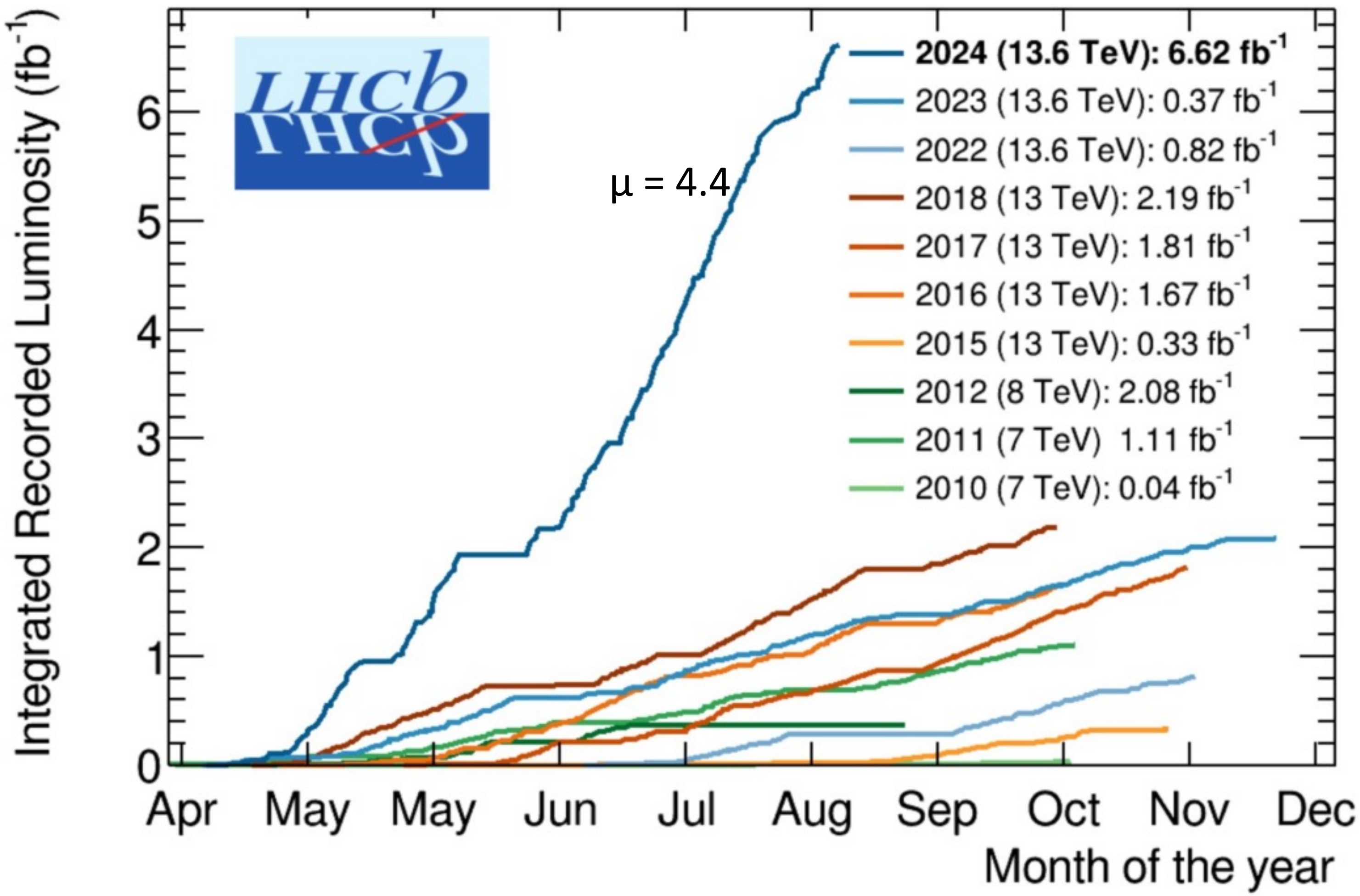
Data taking at LHCb

Run 1: (2011-2012):
$\mathcal{L}_{\text{int}} = 1\text{ fb}^{-1}$ @ 7 TeV
$\mathcal{L}_{\text{int}} = 2\text{ fb}^{-1}$ @ 8 TeV

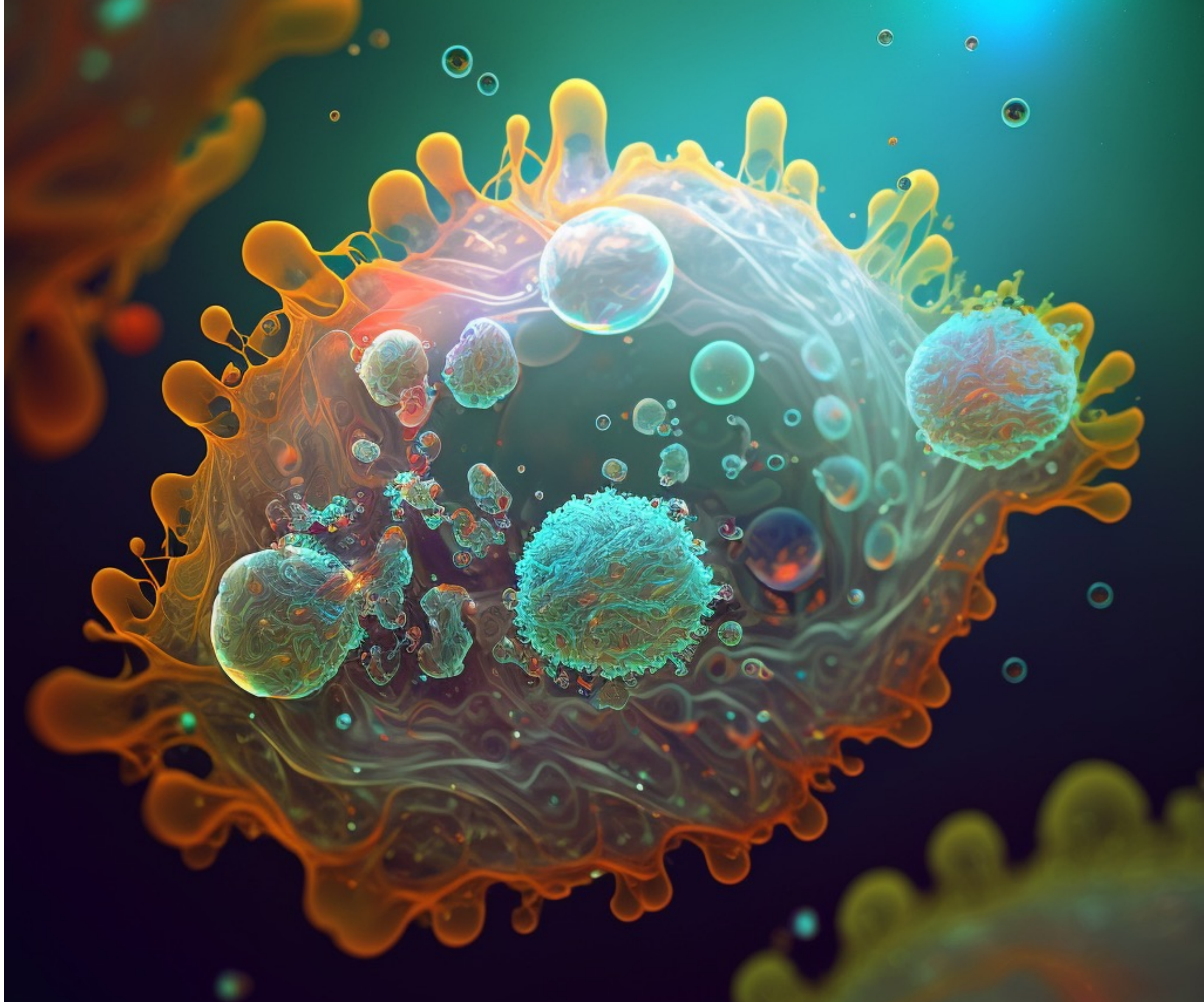
Run 2: (2015-2018):
$\mathcal{L}_{\text{int}} = 6\text{ fb}^{-1}$ @ 13 TeV

Run 3: (2022-2026):
rapidly growing @ 13.6 TeV
nominal μ = 5.5

Target of 7 fb^{-1} is archived in September



Physics

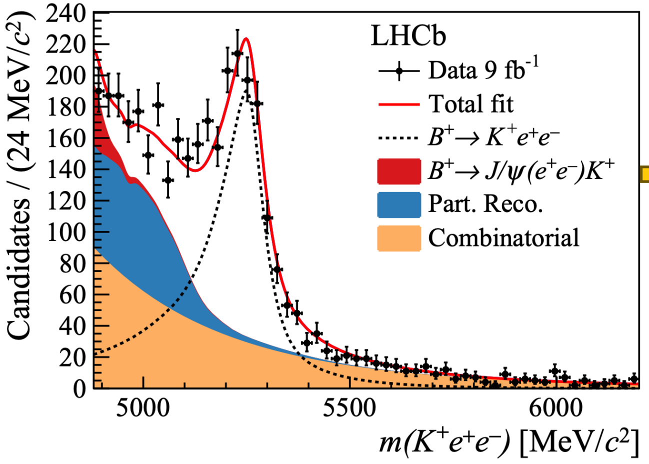


CP violation | Rare decays | Electroweak | Heavy ions & fixed target | Dark sector | Hadron physics

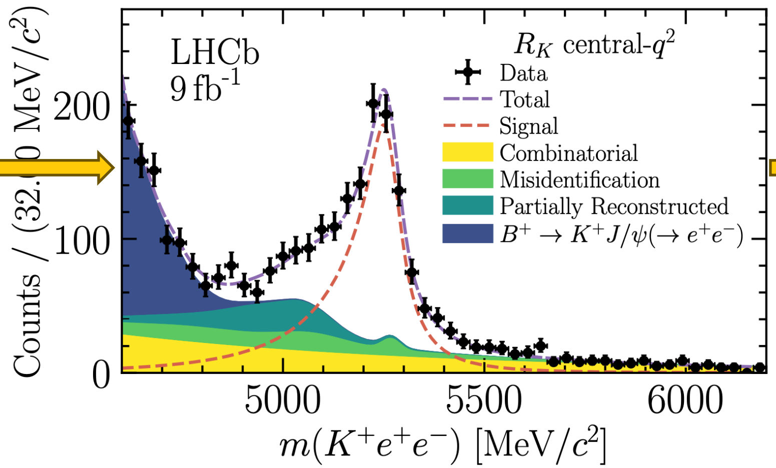
Lepton Flavor Universality

$R_{K^{(*)}}$
Evaporates
18 Dec 2022

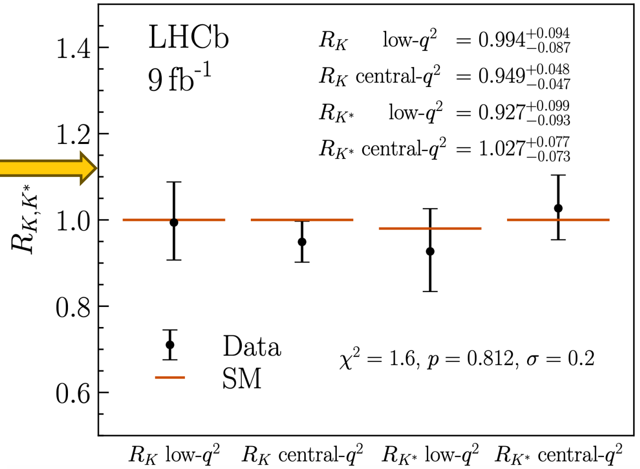
[NP 18 (2022) 3, 277-282]



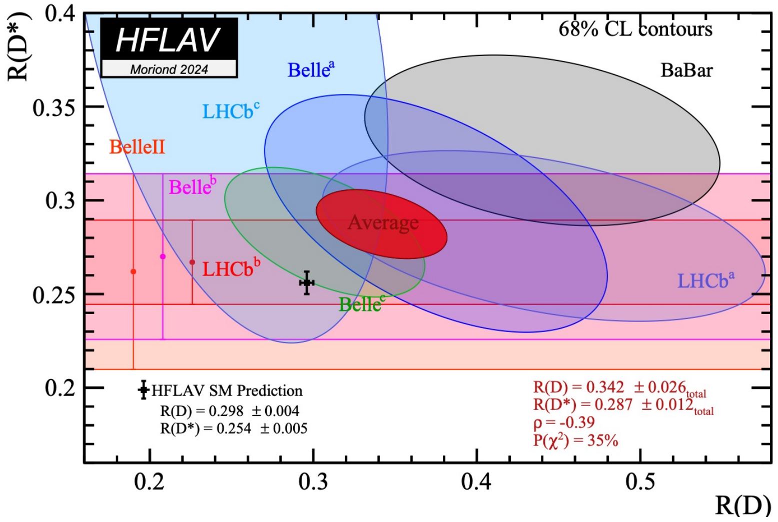
[PRL 131 (2023) 5, 051803]



[PRL 131 (2023) 5, 051803]



$R_{D^{(*)}}$
holds

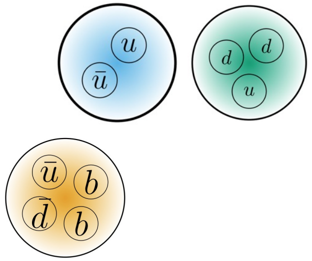


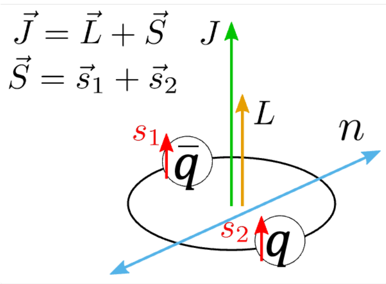
[several papers by Belle]
[LHCb, PRL (2023) 111802]
[LHCb, hep-ex: 2406.03387]

Possible configurations of hadrons

Conventional Quark Model: $(q\bar{q}, qqq)$

Bigger Quark Model $(q\bar{q}q\bar{q}, qqqq\bar{q}, \ldots)$



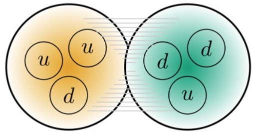


+ excitations

Conventional Hadronic Molecules = Nuclei: $(qqq)(qqq)$

Heavy-Flavor Hadronic Molecules: $(Qqq)(Qqq), (Q\bar{q})(Qqq), \ldots$

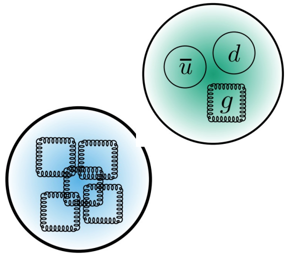
Admixed Molecules: $q\bar{q} \to (q\bar{q})(q\bar{q})$



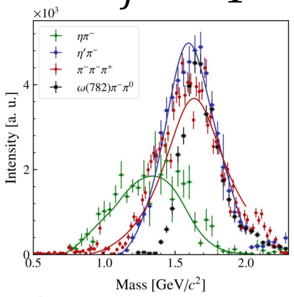
+ nuclei chart

Hybrids: $q{\sim}g{\sim}\bar{q}$

Glueballs: $g{\sim}g$



$J^{PC} = 1^{-+}$



[P.Haas, HADRON2023]

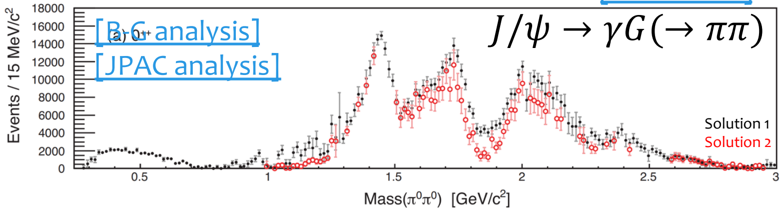
[D. Spülbeck, B3 / 194]

[BESIII data]

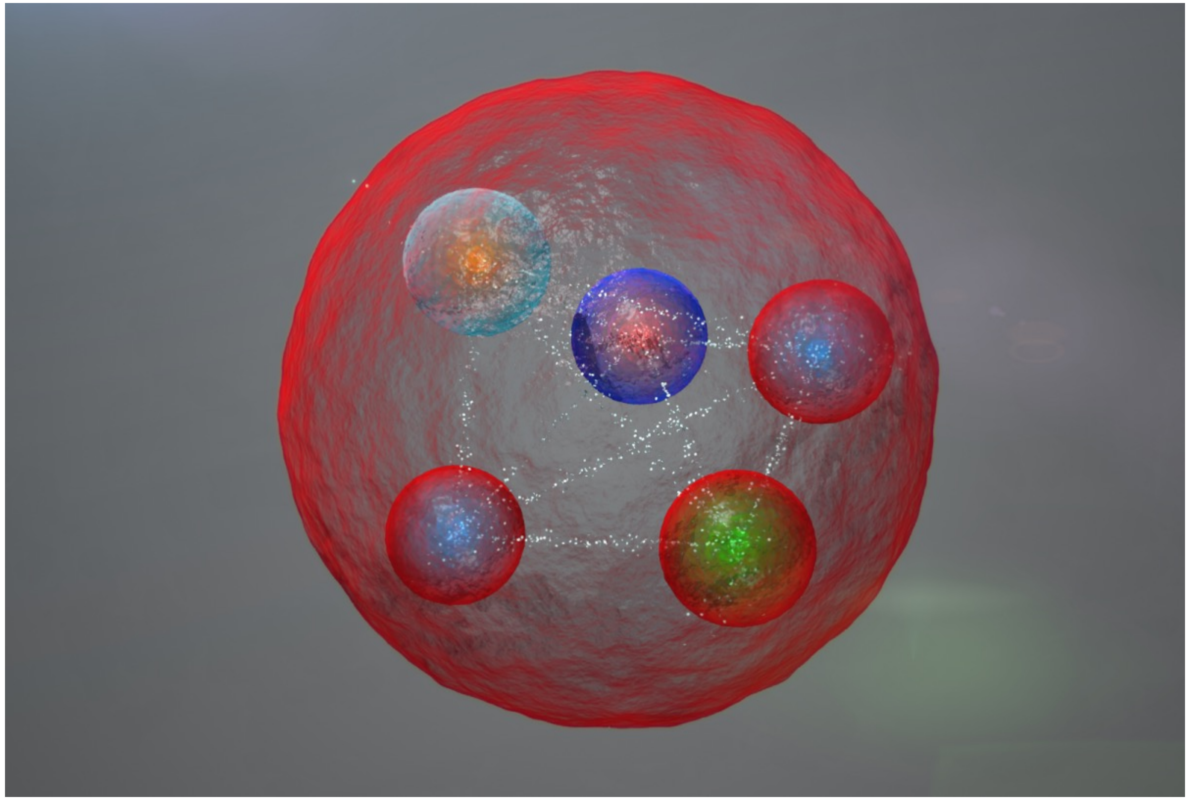
[B.G analysis]

[JPAC analysis]

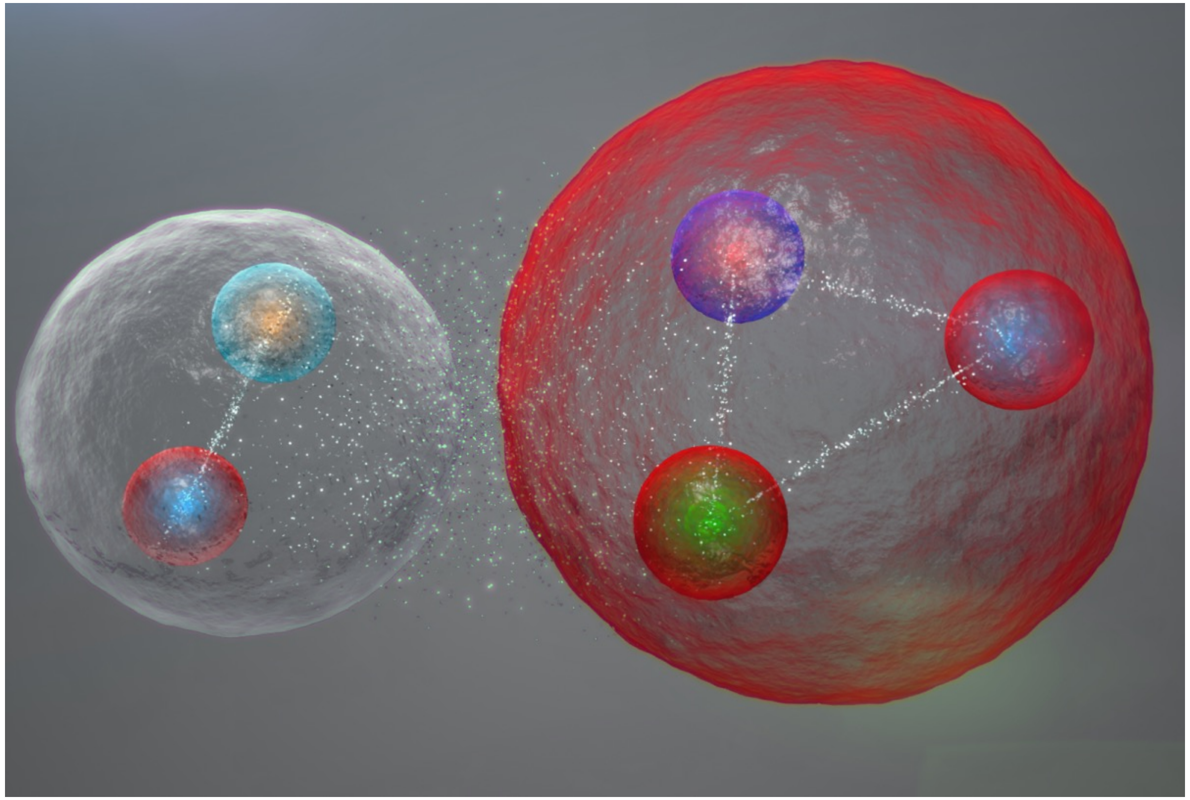
$J/\psi \to \gamma G(\to \pi\pi)$



“Compact pentaquark”



“Hadronic molecule”



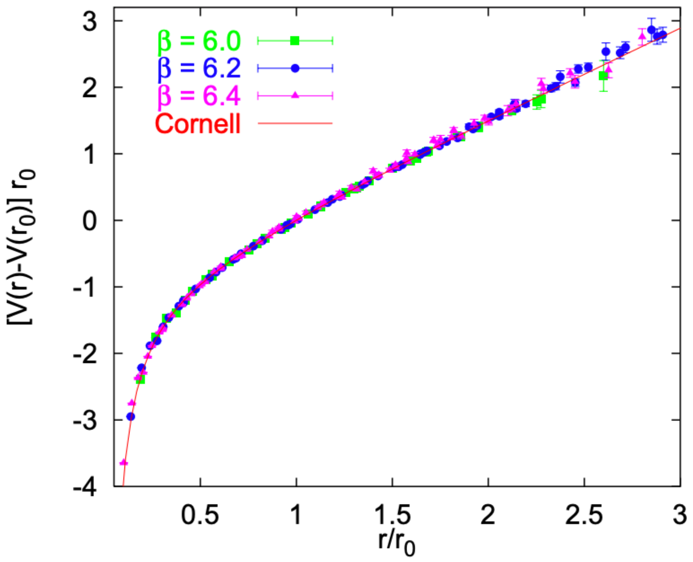
In fact, **quark-model states** are coupled to **continuum** (hadron-hadron), and have ~100% of wave function as a molecule if near threshold.

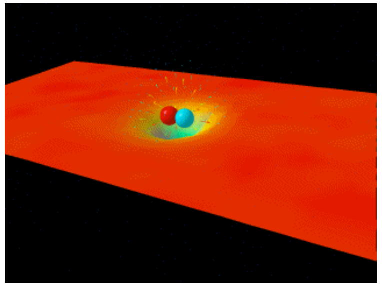
Q: does meson-exchange interaction provide sufficient binding? (molecules in absence of contract QM seed)

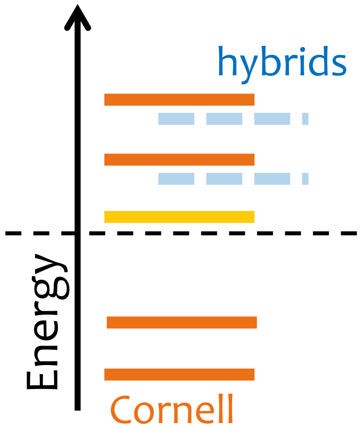
[G.S.Bali, PR 343 (2001) 1-136]
[D. Leinweber, CSSM, Adelaide]
[J. Bulava et al., PLB 793 (2019) 493-498]

Effect of string breaking

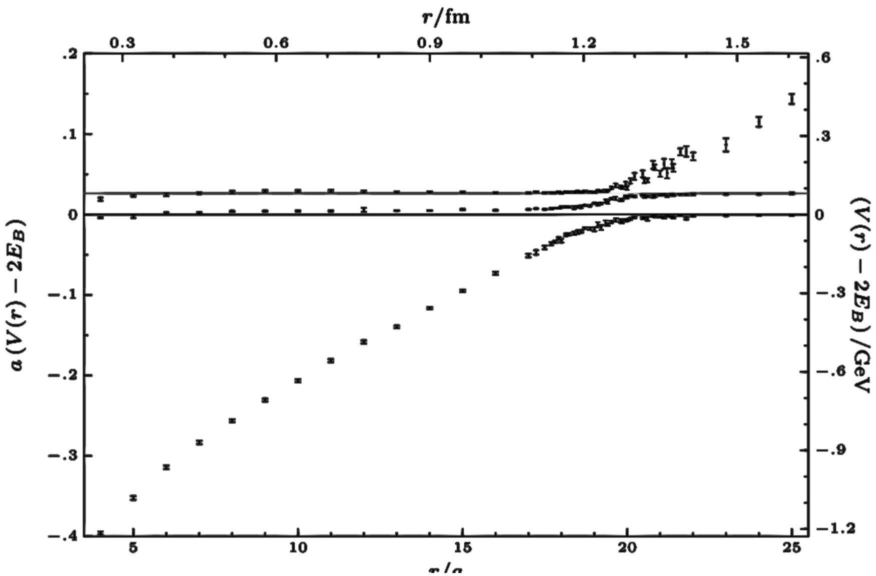
The quenched potential (no breaking)







The unquenched potential (breaking)



shifts “quenched” QCD states

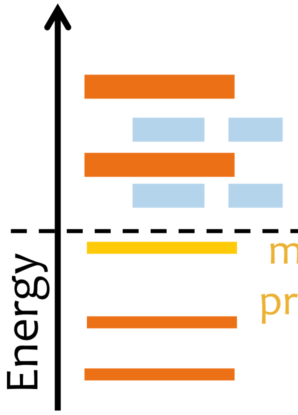


Exhibit molecular properties

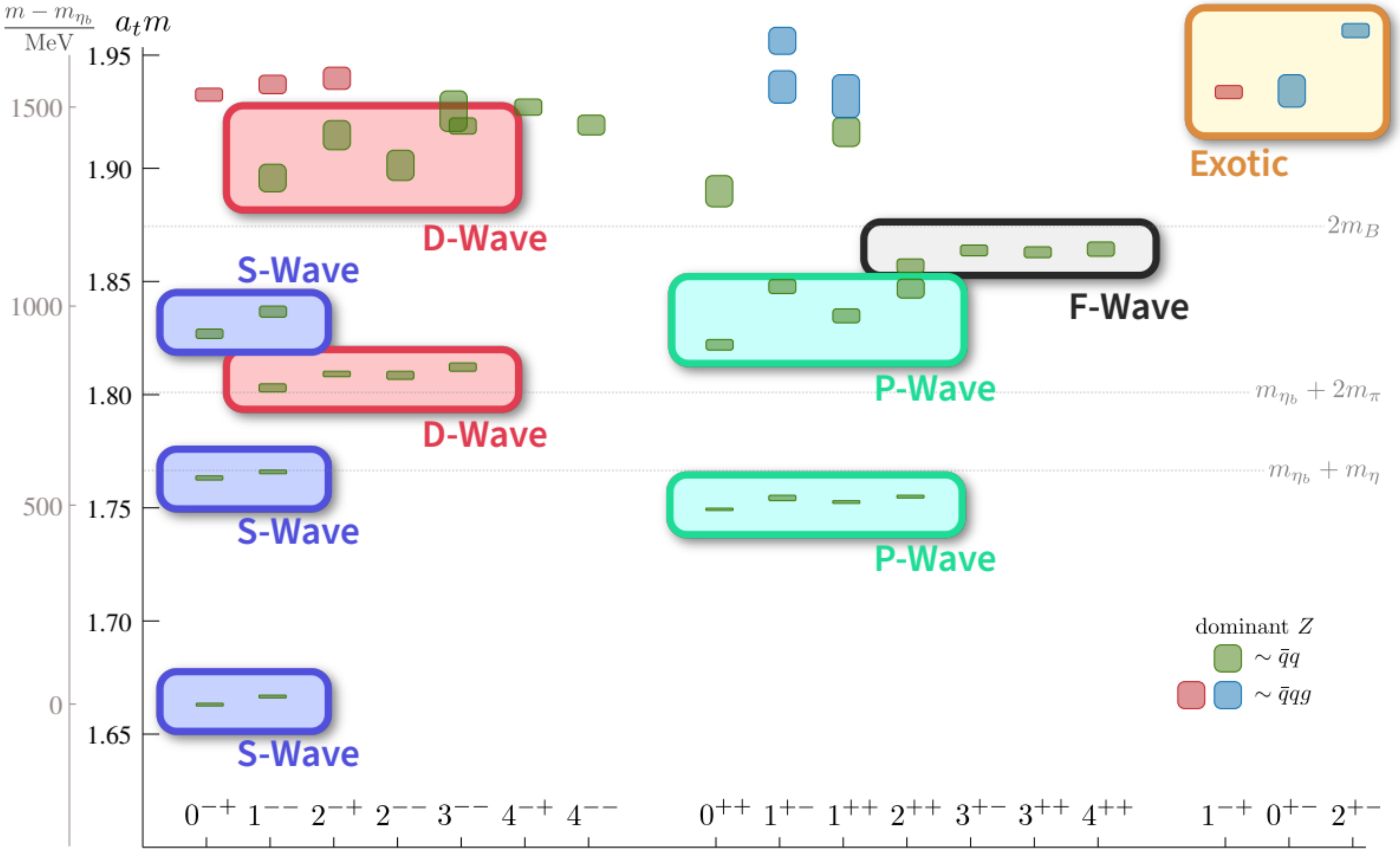
[HadSpec, JHEP 02 (2021) 214]

Pattern of meson excitation

Same patter for all mesons:

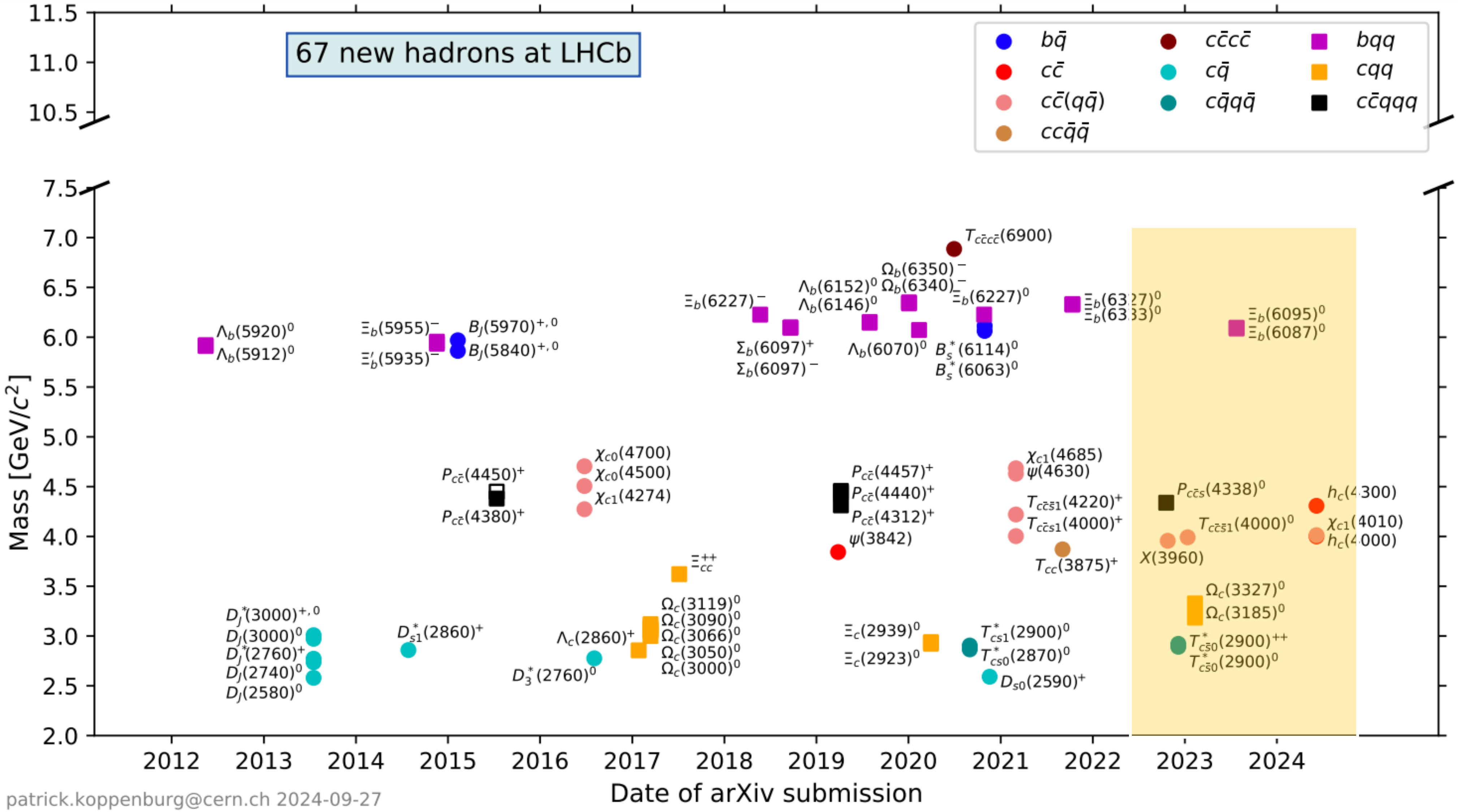
- Radial excitation
- Orbital excitation
- Hyper-fine splitting within every multiplet
  - 2 line for S-wave,
  - 4lines for L>0

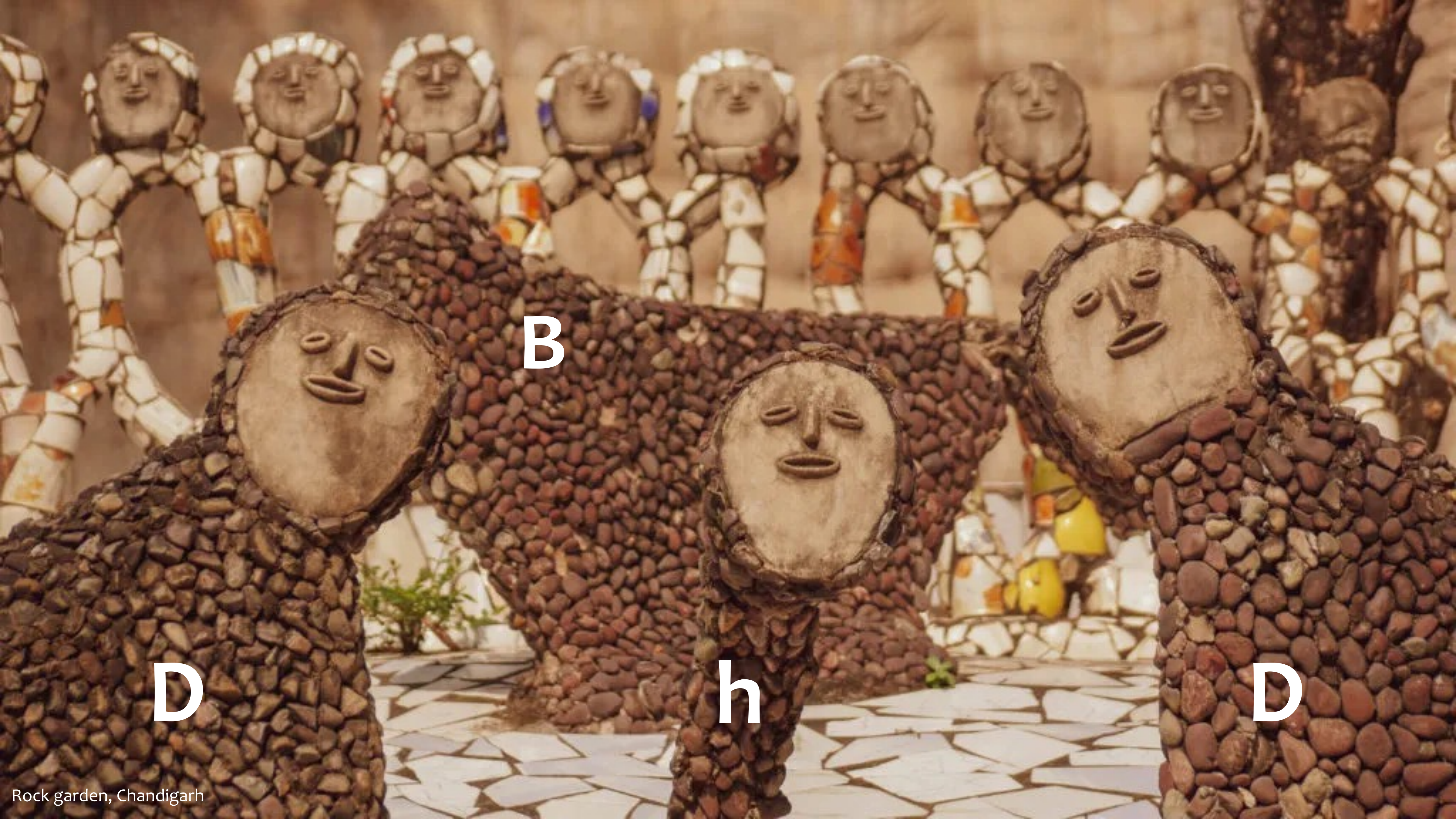
Bottomonium from lattice



https://www.nikhef.nl/~pkoppenb/particles.html

New particles





Rock garden, Chandigarh

B ⟶ D D h studies

is a $K^{\pm}$ or $\pi^{\pm}$

← Isospin → ← SU(3) →

s=0

$D^{*+}D^{-}K$

$D^{+}D^{-}K$

$D^{*0}\bar{D}^{0}K$

$D^{0}\bar{D}^{0}K$

*Belle (2008)

$D_s^{(*)+}D_s^{(*)-}K$

$D_s^{+}D_s^{-}K$

s=-1

$D_s^{+}D^{(*)-}h$

$D_s^{+}D^{-}\pi$

$D_s^{+}\bar{D}^{(*)0}\pi$

$D_s^{+}\bar{D}^{0}\pi$

$T_{c\bar{s}}$: $T^{0}_{c\bar{s}}(c\bar{s}d\bar{u}), T^{+}_{c\bar{s}}(c\bar{s}d\bar{d}), T^{++}_{c\bar{s}}(c\bar{s}u\bar{d})$

T_{cs} : $T^{-}_{cs}(cs\bar{u}\bar{u}), T^{0}_{cs}(cs\bar{u}\bar{d}), T^{+}_{cs}(cs\bar{d}\bar{d})$ (unknow isospin)

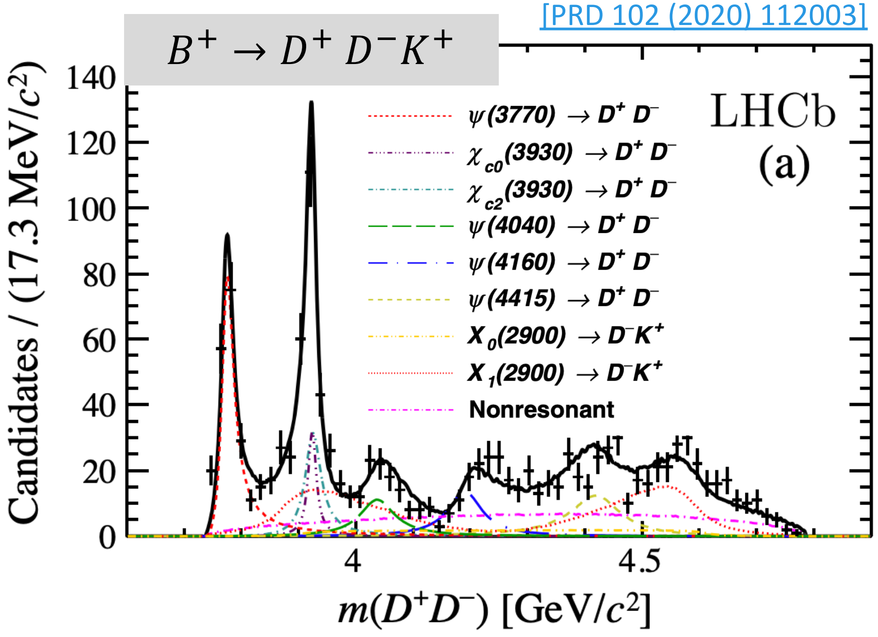
1 Studies of charmonium:
$D^{+}D^{-} : D^{0}\bar{D}^{0} : D_s^{+}D_s^{-}$

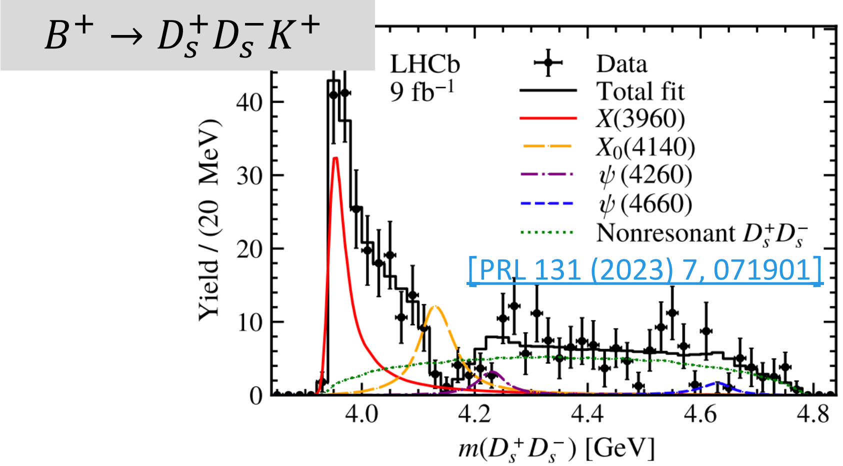
2. excited D states:
$D^{+}\pi^{-} : D_s^{+}K^{-}$

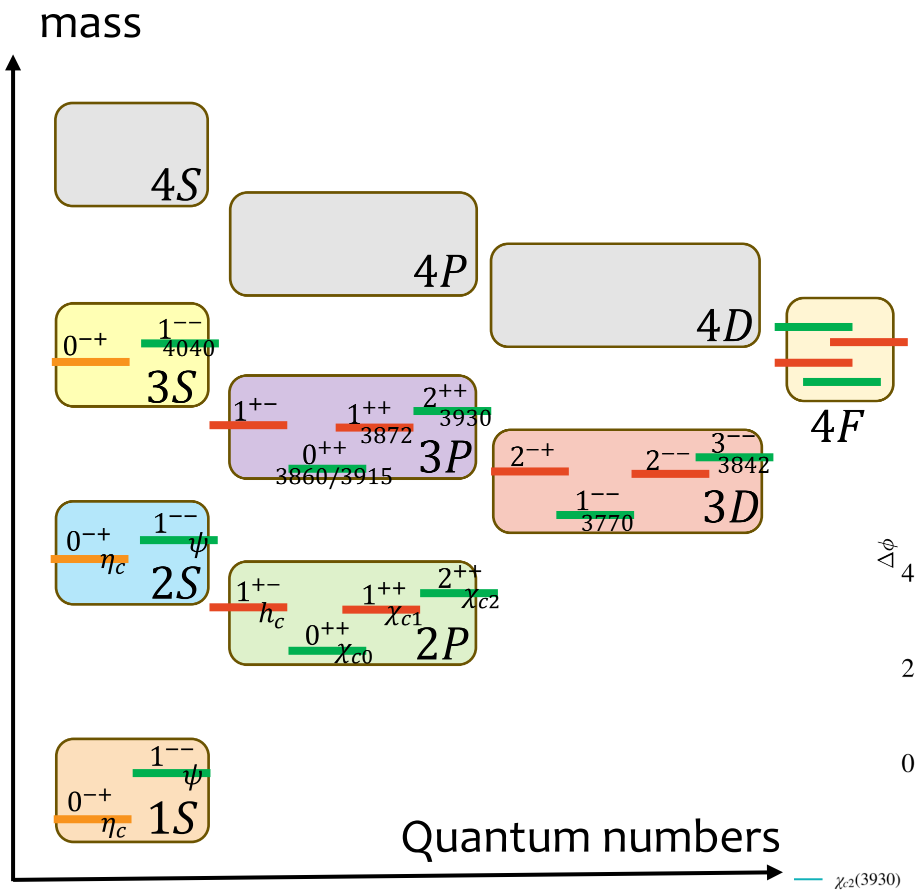
3. exotic $T_{c\bar{s}}$ states:
(like D_s^{+} but double charged / neutral)
$D^{+}K^{+} : D_s^{+}\pi^{+}$

4. exotic T_{cs} states:
$D^{+}K^{-}$

Charmonium



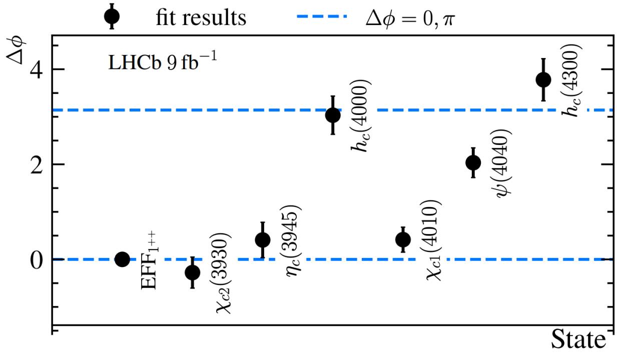


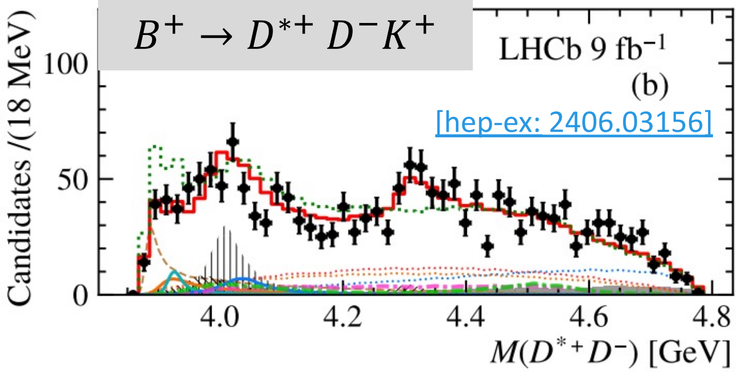


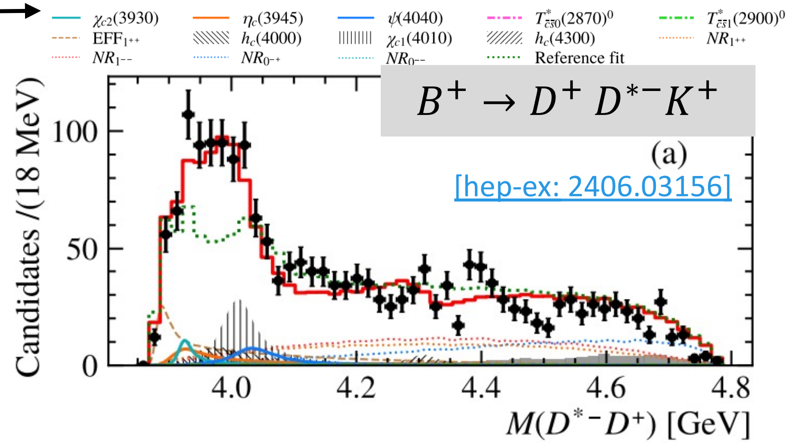
D^+D^-: $0^{++}, 1^{--}, 2^{++}, 3^{--}$

$D^{*+}D^-$: $1^{+x}, 0^{-x}, 1^{-x}, 2^{-x}, 2^{+x}$

$$|D^*\bar{D}> = \frac{D^{*+}D^- + e^{i\Delta\phi}D^{*-}D^+}{2}$$



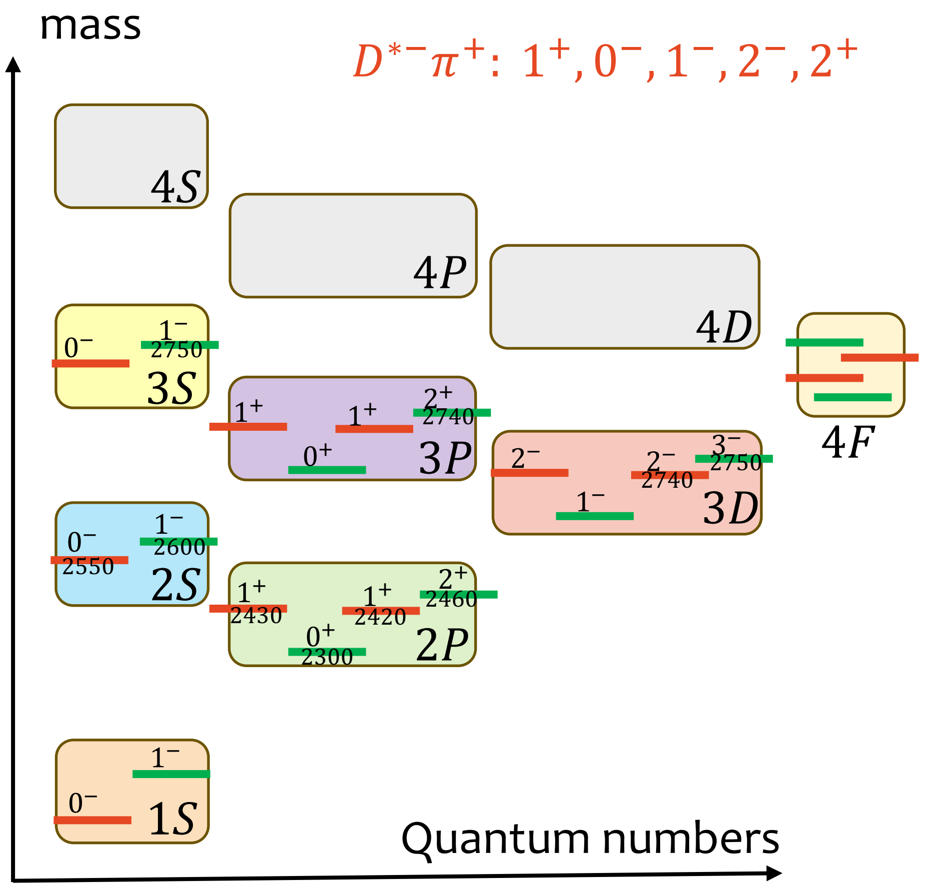




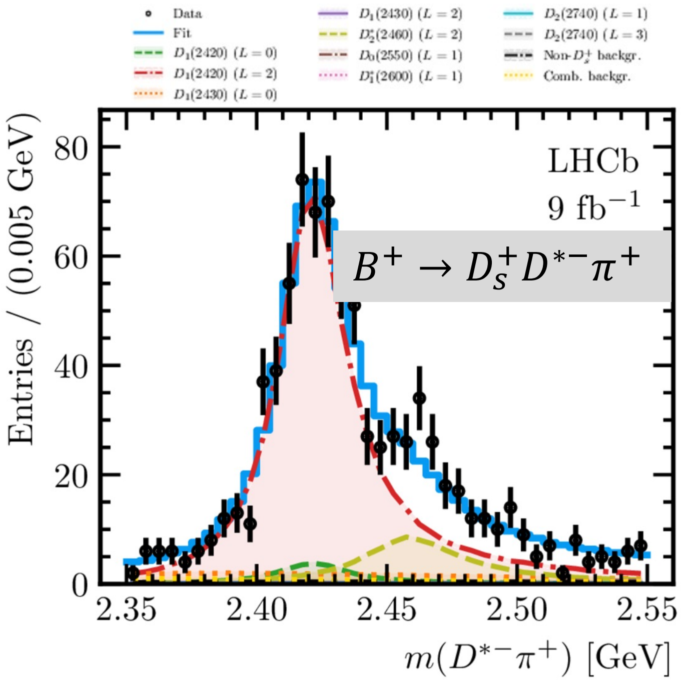
D-meson spectroscopy

$D^-\pi^+$: $0^+, 1^-, 2^+, 3^-$

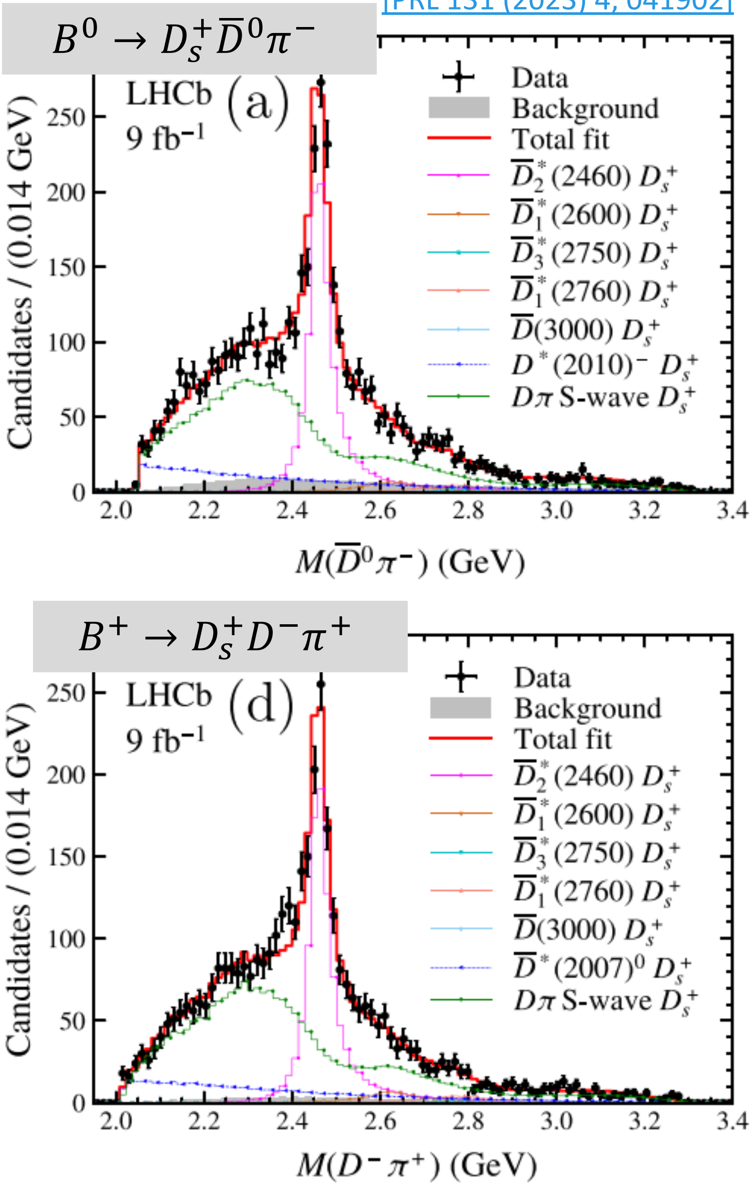
$D^{*-}\pi^+$: $1^+, 0^-, 1^-, 2^-, 2^+$



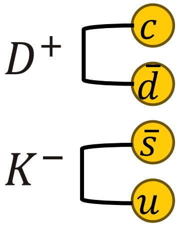
[JHEP 08 (2024) 165]



[PRL 131 (2023) 4, 041902]

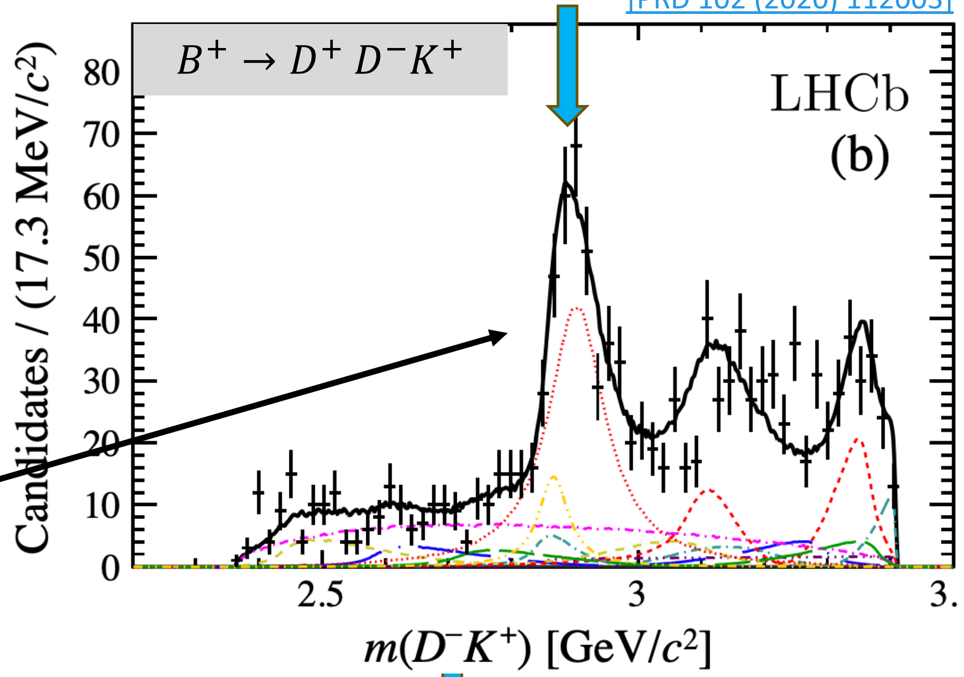


Exotic T_{cs} states

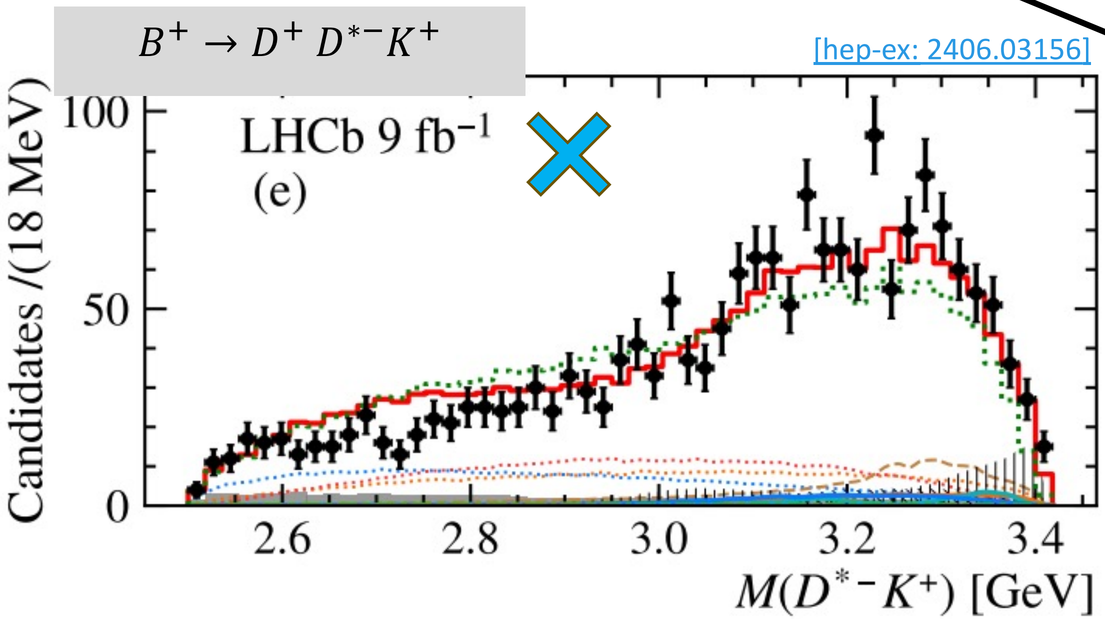


Property	This work	Previous work
$T^*_{\bar{c}\bar{s}0}(2870)^0$ mass [MeV]	$2914 \pm 11 \pm 15$	2866 ± 7
$T^*_{\bar{c}\bar{s}0}(2870)^0$ width [MeV]	$128 \pm 22 \pm 23$	57 ± 13
$T^*_{\bar{c}\bar{s}1}(2900)^0$ mass [MeV]	$2887 \pm 8 \pm 6$	2904 ± 5
$T^*_{\bar{c}\bar{s}1}(2900)^0$ width [MeV]	$92 \pm 16 \pm 16$	110 ± 12

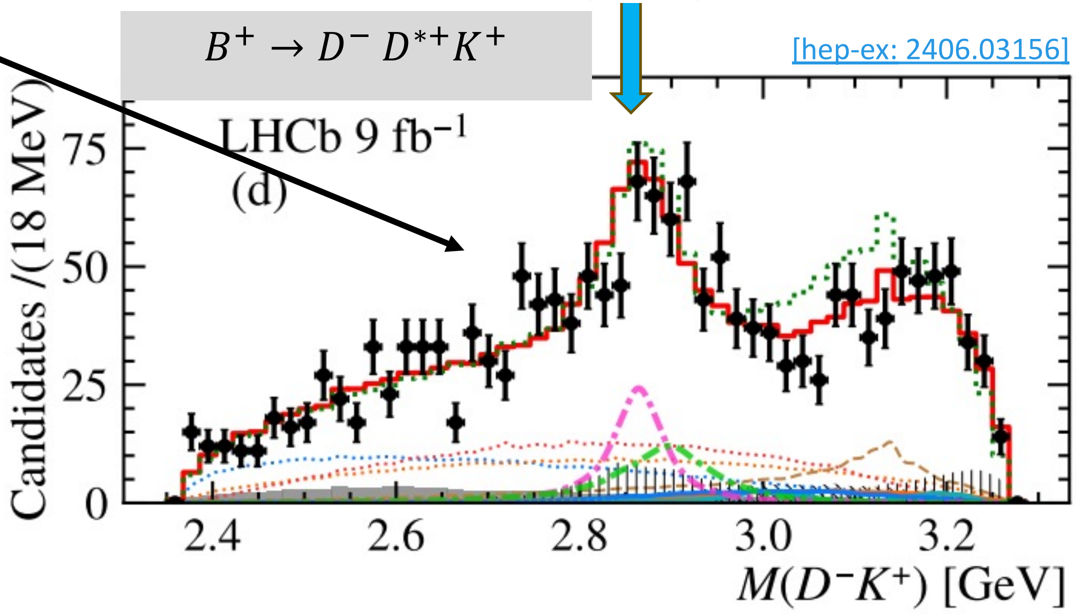
[PRD 102 (2020) 112003]



[hep-ex: 2406.03156]



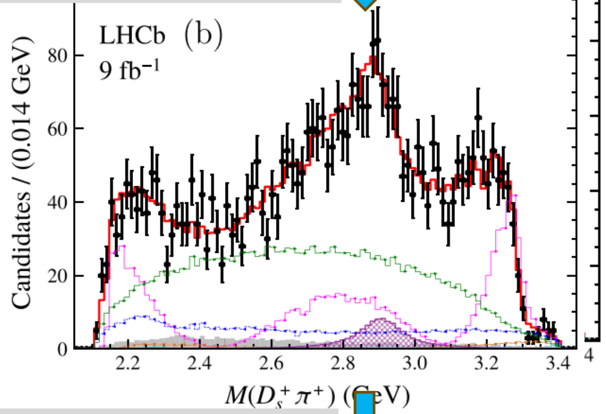
[hep-ex: 2406.03156]



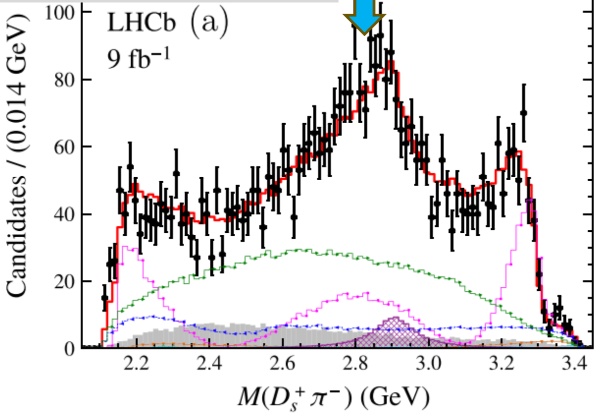
Exotic $T_{c\bar{s}}$ states

[PRL 131 (2023) 4, 041902]

$B^+ \to D_s^+ D^- \pi^+$

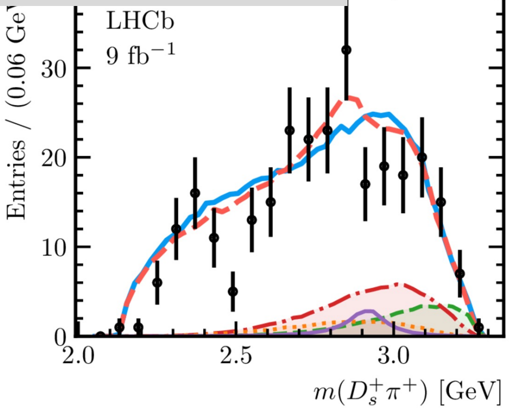


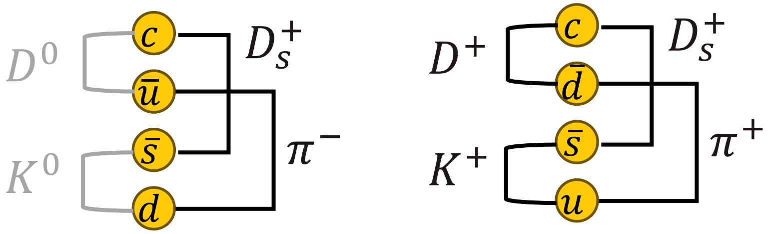
$B^0 \to D_s^+ \bar{D}^0 \pi^-$



[JHEP 08 (2024) 165]

$B^+ \to D_s^+ D^{*-} \pi^+$

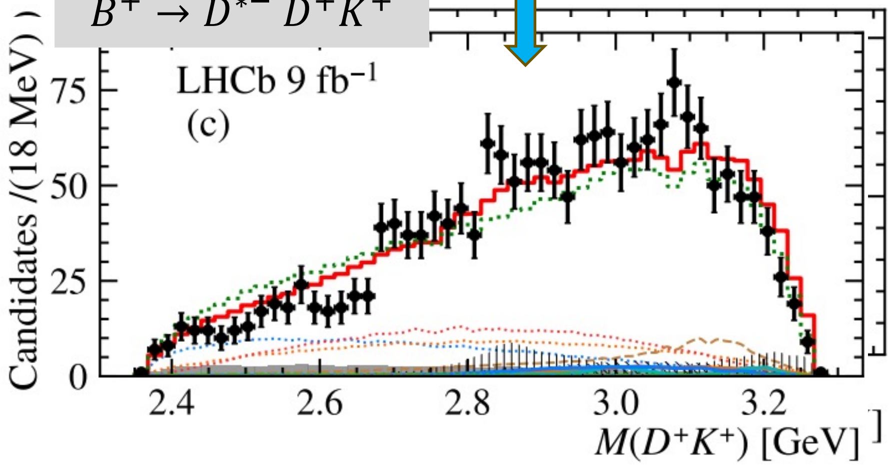




$T_{c\bar{s}}$: $T_{c\bar{s}}^0(c\bar{s}d\bar{u}), T_{c\bar{s}}^+(c\bar{s}d\bar{d}), T_{c\bar{s}}^{++}(c\bar{s}u\bar{d})$

[hep-ex: 2406.03156]

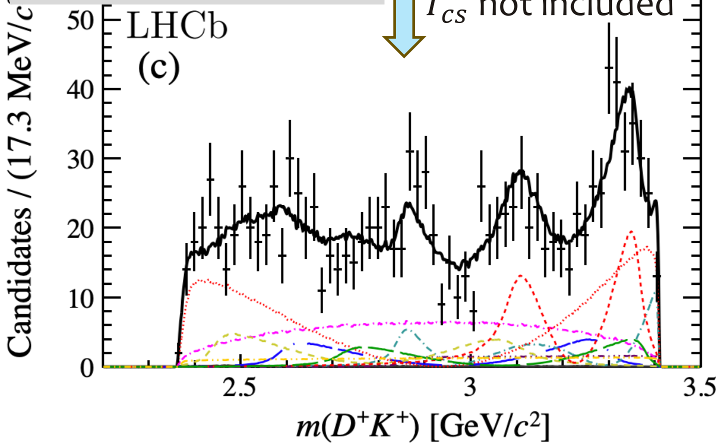
$B^+ \to D^{*-} D^+ K^+$



[PRD 102 (2020) 112003]

$B^+ \to D^+ D^- K^+$

T_{cs} not included



$J/\psi\ \varphi$ states

Reminder: $J/\psi\ \varphi$ states

Rich spectrum of previous-unseen states

$\chi_{c1}(4140)$
$\chi_{c1}(4274)$
$\chi_{c0}(4500)$
$\chi_{c0}(4700)$

(2017)
four
babies
0^+ & 1^+

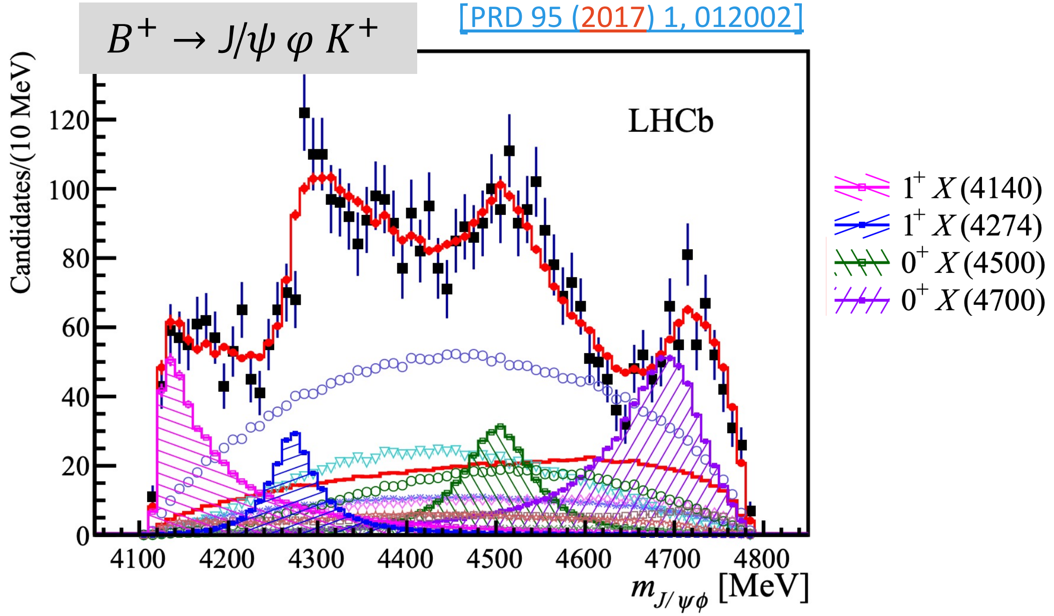
"I wonder if they'll be a doctor or an artist."
- some are probably charmonia, but some are exotic

$\chi_{c1}(4685)$
$\psi\ (4630)$
$X(4150)$

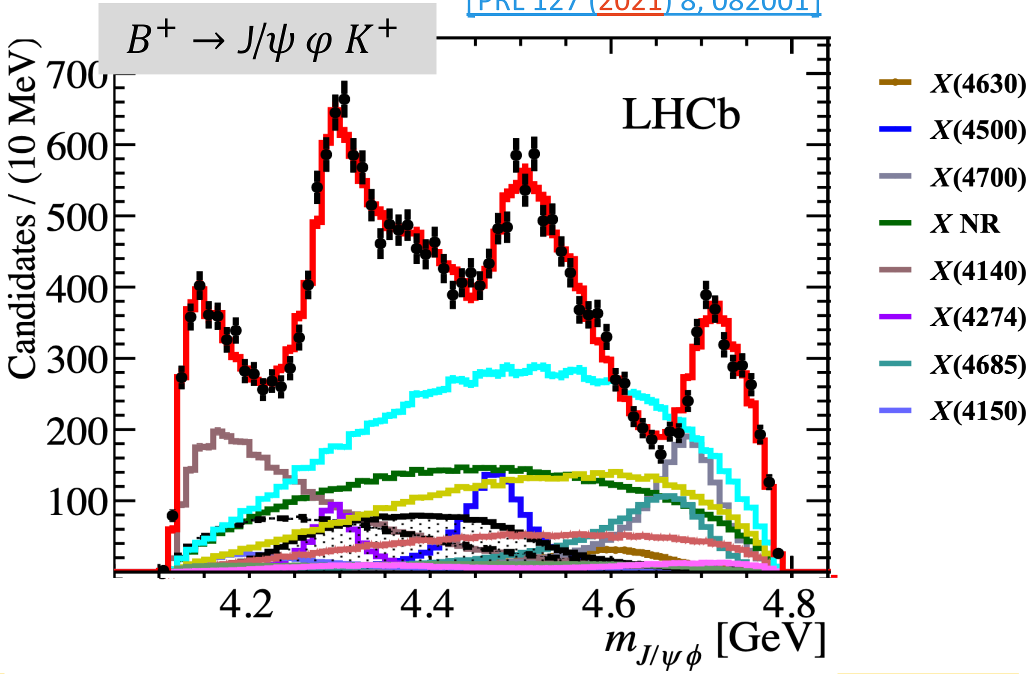
(2021)
three more
1^+ & 1^- & 2^-

Overall, 9 exotic states (7 X + 2 Z_{cs})

[PRD 95 (2017) 1, 012002]



[PRL 127 (2021) 8, 082001]

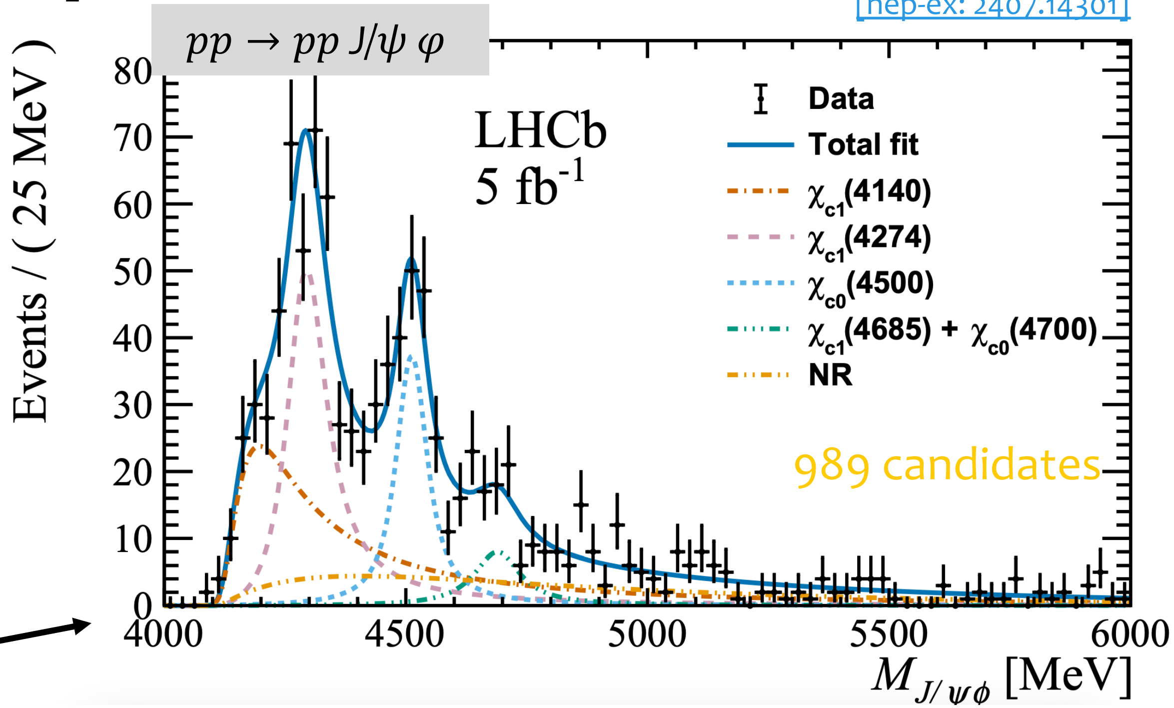


New results on diffractive $J/\psi\ \varphi$ production

[hep-ex: 2407.14301]

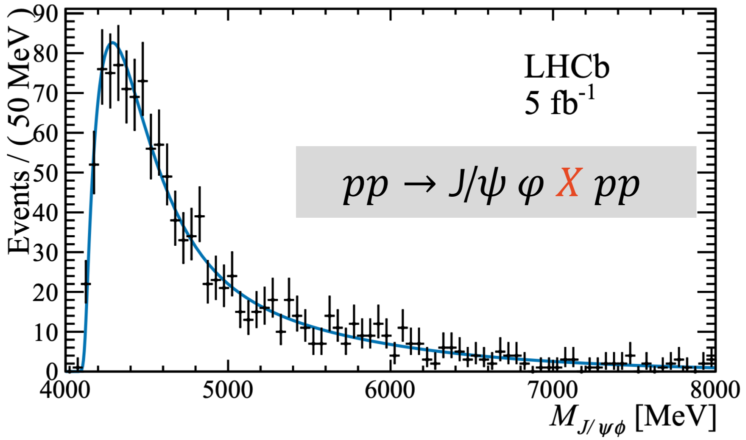
For diffractive studies,
the acceptance is extended with HeRSChel,
5 < |η| < 10
=> cross section measurement

$$\sigma_{J/\psi\phi} \times \mathcal{B}(J/\psi \to \mu^+\mu^-) \times \mathcal{B}(\phi \to K^+K^-) = (2.52 \pm 0.08 \pm 0.12 \pm 0.05)\,\text{pb},$$



For selection, #track in VeLo is used

- only four tracks
- with additional tracks



Hm, strong couplings to gluons?

Future of LHCb

Upgrade II

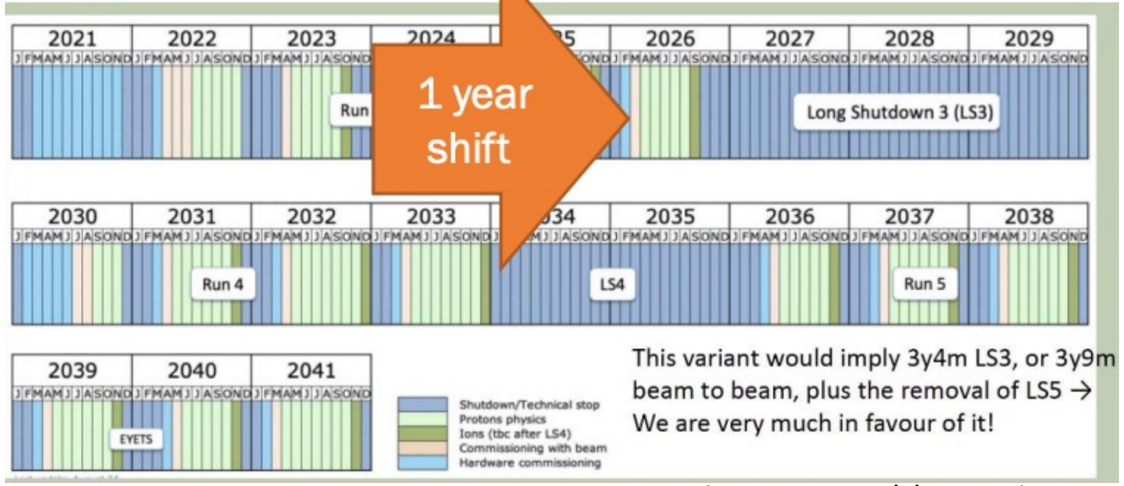
The current Run is prolongated by 1y (2022-2026)

LS3: no major changes at LHCb

Run4: 2030-2033

LS4: Upgrade II, 2036-2041 start of data taking

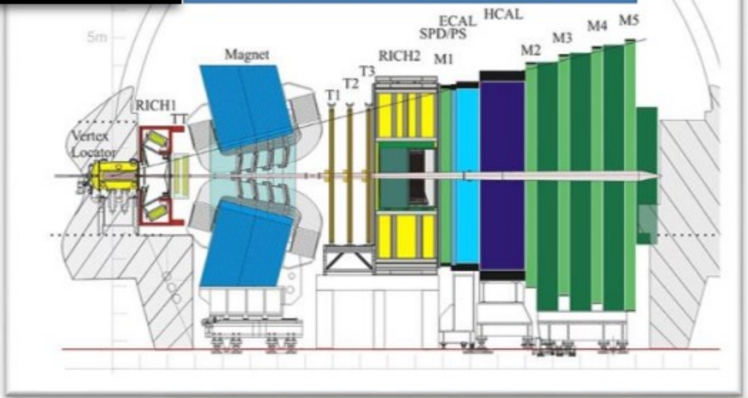
Shown in the LHCb Tuesday meeting
Sept 17, 2024 (not official)



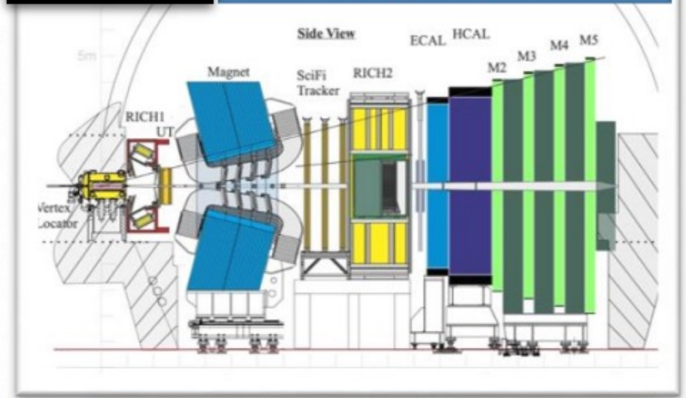
Comparison courtesy Blake Leverington

HERA-B →

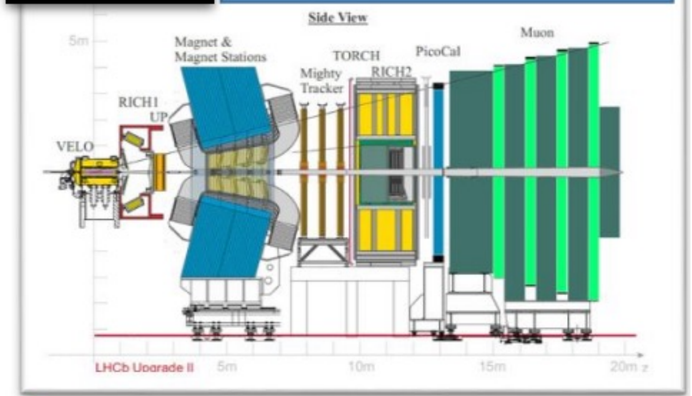
LHCb	L0 Hardware Trigger



LHCb-U1	30 MHz Software trigger



LHCb-U2	30 MHz Software trigger



Design:

LHCb	LHCb-U1	LHCb-U2
$L = 0.4\ 10^{33}$ Goal: $10\ fb^{-1}$	$L = 2\ 10^{33}$ Goal: $+45\ fb^{-1}$	$L_{peak} = 10\text{-}15\ 10^{33}$; $+200\text{-}300\ fb^{-1}$
1 to 2 fb^{-1} per year ; mu = 1.1	~7-9 fb^{-1} per year; mu = 5.3	~40-50 fb-1 per year; mu = 42

Mighty Tracker: the main German project for U-II

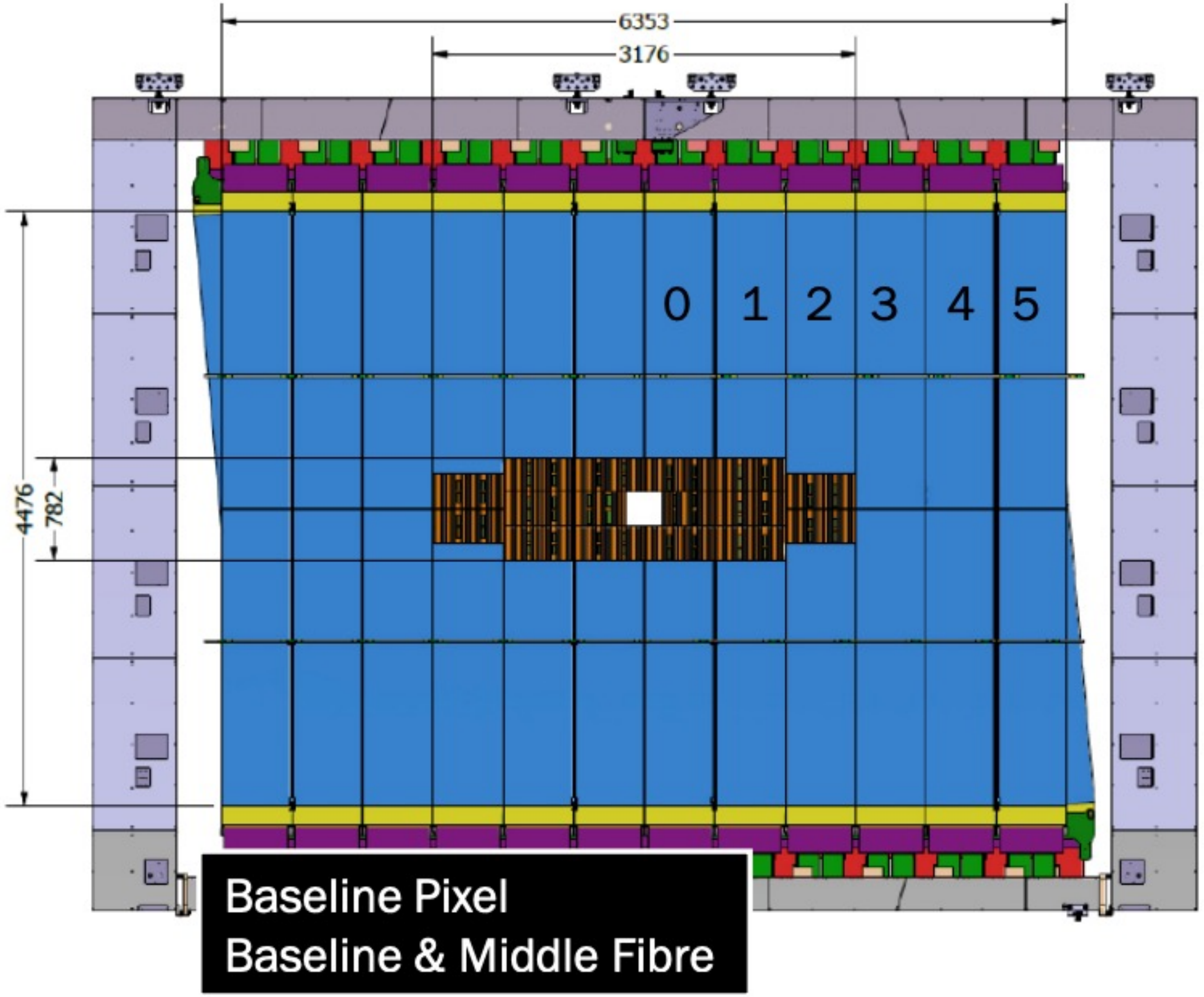
Fiber part:

- noise-free SiPM sensors at -100 deg.
- new readout boards

Pixel part:

- DMAPS technology (MightyPix), (Depleted Fully Monolithic Active CMOS Pixel Sensors)
- New technology for LHCb, take experience of ALICE, ATLAS, Mu3e
- Large area: 12.6 m^2

Germany is ~6% of the LHCb collaboration (“fair-share” limits resources)



Summary

A lot of physics with Run-1,2 data (2012-2018)

- Charm spectroscopy
- D-spectroscopy
- New exotic state (“neutral Ds”)

The Run-3 has seriously started:

- already more B mesons than in Run-2 already.
- running for the next 2 years

Upgrade 2: 2036-2041