Exotic hadron naming scheme

Round table:

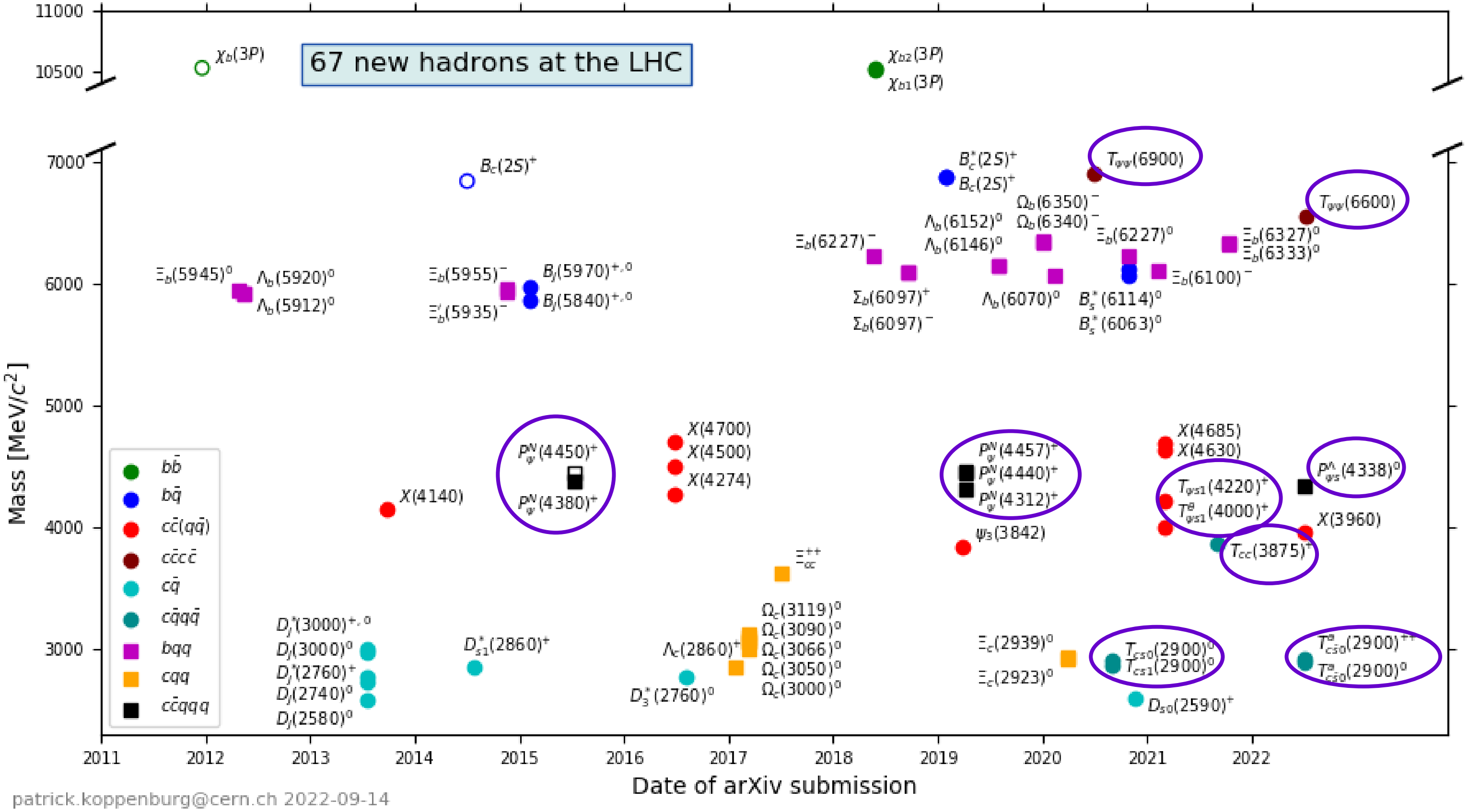
Tim Gershon, Christoph Hanhart, Ryan Mitchell, Umberto Tamponi, Liming Zhang

29th September 2022

Many states that do not fit into PDG naming scheme

(image shows only discoveries at the LHC)

14 manifestly exotic states (so far)

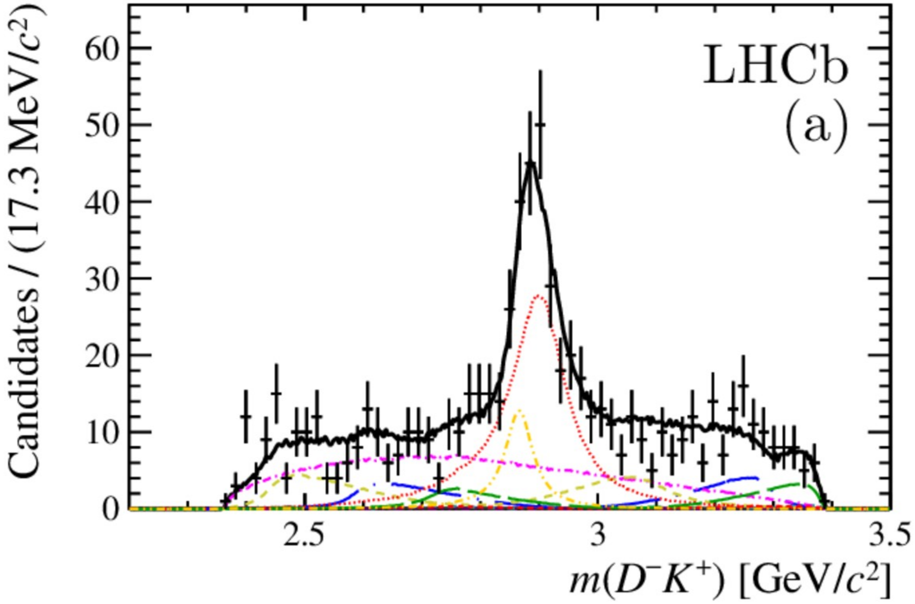


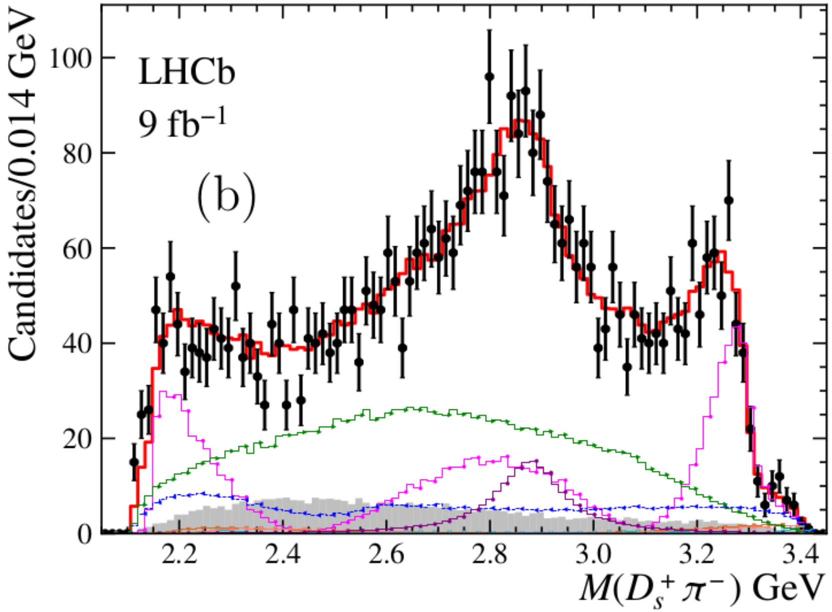
https://www.nikhef.nl/~pkoppenb/particles.html

Example of the problem

PR D102 (2020) 112003

LHCb-PAPER-2022-027





States with mass ~2900 MeV observed with minimal quark content

(left) $cs\overline{ud}$ and (right) $c\overline{su}d$

PDG scheme does not provide a name for either, and can’t call both X(2900)!

Need for a new scheme

- Well-established scheme for conventional hadrons
- Evolution responding to new discoveries somewhat ad-hoc
    - respecting names assigned following experimental discoveries
  - Inconsistent use of footnotes to indicate quark content
    - c (Z_c, P_c) indicates $c\bar{c}$ content, cc (T_{cc}) indicates cc, s (Z_{cs}, P_{cs}) indicates s (or $\bar{s}$)
  - No obvious way to extend to allow open charm, or beauty
- Clear need for a new scheme
  - Should be as simple as possible, but still unique
  - Unambiguously labelling quantum numbers

The LHCb convention

arXiv:2206.15233

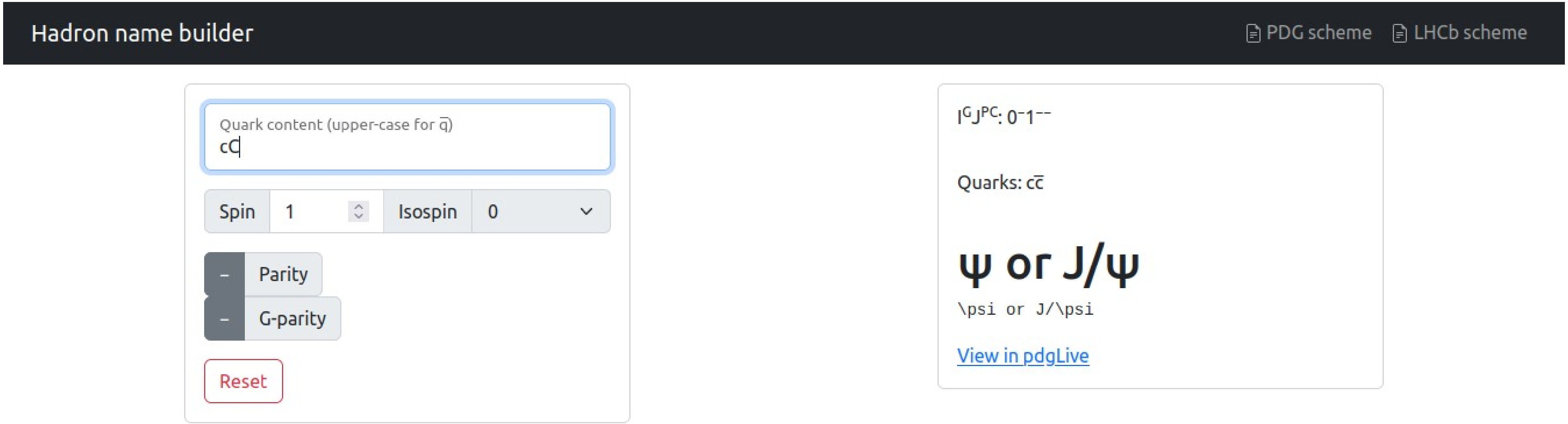
- LHCb has put forward a solution to the problem
  - following lengthy consultation both internally and externally
    - including with other experiments (BESIII, Belle 2, PANDA), discussions with PDG naming scheme authors, and at workshops with theorists
- Philosophy:
  - backwards compatibility, simplicity, extendability
  - based on measured properties, not interpretation
    - (as for current scheme)

T for tetra, P for penta

arXiv:2206.15233

- Superscript, based on existing symbols, to indicate isospin, parity and G-parity
  - n.b. superscript to avoid multiple subscripts
- Subscript Y, ψ, φ to denote hidden beauty, charm, strangeness
  - in order of mass, and repeated if necessary
- Subscript b, c, s to denote open flavour content
  - in order of mass, where more than 1 needed, e.g. T_{cs}
  - repeated if necessary, e.g. T_{bb} for a $bb\overline{ud}$ state

FYI: Work in progress



Developing code, with web front-end, to translate

quark content + quantum numbers ↔ name

Hope for public release before end of year

What’s next?

- LHCb convention being used in the community
  - not only LHCb-PAPERs-2022-018, 019, 026, 027, 031
  - also numerous hep-ph papers (but not all)
- Should the PDG adopt a new scheme?
  - if so, should it be the LHCb scheme as is … or with modifications?
  - possible to improve overall simplicity sacrificing some backwards compatibility?
- Objective of today’s discussion:
  - how to best aid scientific communication in the community?

Discuss

Exotic hadrons: impact on existing states

Minimal quark content	Current name	$I^{(G)}, J^{P(C)}$	Proposed name	Reference
$c\bar{c}$	$\chi_{c1}(3872)$	$I^G = 0^+,\ J^{PC} = 1^{++}$	$\chi_{c1}(3872)$	[24, 25]
$c\bar{c}u\bar{d}$	$Z_c(3900)^+$	$I^G = 1^+,\ J^P = 1^+$	$T^b_{\psi 1}(3900)^+$	[26–28]
$c\bar{c}u\bar{d}$	$Z_c(4100)^+$	$I^G = 1^-$	$T_\psi(4100)^+$	[29]
$c\bar{c}u\bar{d}$	$Z_c(4430)^+$	$I^G = 1^+,\ J^P = 1^+$	$T^b_{\psi 1}(4430)^+$	[30, 31]
$c\bar{c}(s\bar{s})$	$\chi_{c1}(4140)$	$I^G = 0^+, J^{PC} = 1^{++}$	$\chi_{c1}(4140)$	[32–35]
$c\bar{c}u\bar{s}$	$Z_{cs}(4000)^+$	$I = \frac{1}{2},\ J^P = 1^+$	$T^\theta_{\psi s1}(4000)^+$	[7]
$c\bar{c}u\bar{s}$	$Z_{cs}(4220)^+$	$I = \frac{1}{2},\ J^P = 1^?$	$T_{\psi s1}(4220)^+$	[7]
$c\bar{c}c\bar{c}$	$X(6900)$	$I^G = 0^+,\ J^{PC} = ?^{?+}$	$T_{\psi\psi}(6900)$	[4]
$cs\bar{u}\bar{d}$	$X_0(2900)$	$J^P = 0^+$	$T_{cs0}(2900)^0$	[5, 6]
$cs\bar{u}\bar{d}$	$X_1(2900)$	$J^P = 1^-$	$T_{cs1}(2900)^0$	[5, 6]
$cc\bar{u}\bar{d}$	$T_{cc}(3875)^+$		$T_{cc}(3875)^+$	[8, 9]
$b\bar{b}u\bar{d}$	$Z_b(10610)^+$	$I^G = 1^+,\ J^P = 1^+$	$T^b_{\Upsilon 1}(10610)^+$	[36]
$c\bar{c}uud$	$P_c(4312)^+$	$I = \frac{1}{2}$	$P^N_\psi(4312)^+$	[3]
$c\bar{c}uds$	$P_{cs}(4459)^0$	$I = 0$	$P^\Lambda_{\psi s}(4459)^0$	[20]

No change

No change unless 4-quark content clearly established

Exotic hadrons: examples of hypothetical states

assume weak decays here; all others strong (→ $bb\bar{u}\bar{d}$)

Minimal quark content	Potential decay channel(s)	$I^{(G)}$, $J^{P(C)}$	Proposed name
$bc\bar{u}\bar{d}$	B^-D^{*+}	$I=0,\ J^P=1^+$	$T^f_{bc1}(\text{mass})^0$
$b\bar{c}\bar{u}d$	B^-D^{*-}	$I=1,\ J^P=1^+$	$T^a_{b\bar{c}1}(\text{mass})^{--}$
$bb\bar{u}\bar{d}$	$B^-\pi^-D^+,\ \overline{B}^0J/\psi K^-$	$I=0,\ J^P=1^+$	$T^f_{bb1}(\text{mass})^-$
$c\bar{c}b\bar{d}$	$J/\psi\overline{B}^0$	$I=\frac{1}{2},\ J^P=1^+$	$T^\theta_{\psi b1}(\text{mass})^0$
$c\bar{s}u\bar{d}/c\bar{s}\bar{u}d$	$D_s^+\pi^+/D_s^+\pi^-$	$I=1,\ J^P=0^+$	$T^a_{c\bar{s}0}(\text{mass})^{++}/T^a_{c\bar{s}0}(\text{mass})^0$
$b\bar{b}uud$	Υp	$I=\frac{1}{2}$	$P^N_\Upsilon(\text{mass})^+$
$b\bar{c}uud$	B_c^-p	$I=\frac{1}{2}$	$P^N_{b\bar{c}}(\text{mass})^0$
$b\bar{u}cds$	$B^-\Xi_c^0$	$I=1$	$P^\Sigma_{bcs}(\text{mass})^-$
$c\bar{d}cus$	$D^+\Xi_c^+$	$I=1$	$P^\Sigma_{ccs}(\text{mass})^{++}$
$c\bar{c}cud$	$J/\psi\Lambda_c^+$	$I=0$	$P^\Lambda_{\psi c}(\text{mass})^+$
$c\bar{c}cus$	$J/\psi\Xi_c^+$	$I=\frac{1}{2}$	$P^N_{\psi cs}(\text{mass})^+$

PDG naming scheme for conventional hadrons

Mesons, no net S,C,B

J^{PC} (1)	0^{-+}	1^{+-}	1^{--}	0^{++}
Minimal quark content				
$u\bar{d}$, $u\bar{u}-d\bar{d}$, $\bar{u}d$ $(I=1)$	π	b	ρ	a
$u\bar{u}+d\bar{d}$ and/or $s\bar{s}$ $(I=0)$	$\eta^{(\prime)}$	$h^{(\prime)}$	ω, ϕ	$f^{(\prime)}$
$c\bar{c}$	η_c	h_c	ψ (2)	χ_c
$b\bar{b}$	η_b	h_b	Υ	χ_b

Mesons, non-zero S,C or B

	$\bar{u}$	$\bar{d}$	$\bar{s}$	$\bar{c}$	$\bar{b}$
u	See Table 1		K^+	$\overline{D}^0$	B^+
d			K^0	D^-	B^0
s	K^-	$\overline{K}^0$		D_s^-	B_s^0
c	D^0	D^+	D_s^+		B_c^+
b	B^-	$\overline{B}^0$	$\overline{B}_s^0$	B_c^-	

Baryons

Three u/d quarks

$I=\frac{1}{2}$	$I=\frac{3}{2}$
N	Δ

Two u/d quarks

$I=0$	$I=1$
Λ	Σ
Λ_c	Σ_c
Λ_b	Σ_b

One or zero u/d quarks

$I=\frac{1}{2}$	$I=0$
Ξ	Ω
$\Xi_c^{(\prime)}$	Ω_c
$\Xi_b^{(\prime)}$	Ω_b
Ξ_{cc}	Ω_{cc}
...	...

Superscripts to indicate isospin, parity, G-parity

T states zero net S, C, B		
(P, G)	$I = 0$	$I = 1$
$(-,-)$	ω	π
$(-,+)$	η	ρ
$(+,+)$	f	b
$(+,-)$	h	a

T states non-zero net S, C, B			
(P)	$I = 0$	$I = \frac{1}{2}$	$I = 1$
$(-)$	η	τ	π
$(+)$	f	θ	a

P states			
$I = 0$	$I = \frac{1}{2}$	$I = 1$	$I = \frac{3}{2}$
Λ	N	Σ	Δ

Extension to allow I=2, 5/2 states may be needed later

n.b. hat-tip to historical naming of kaons