Notes on the New Exotic Hadron Naming Convention Proposed by LHCb

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* The new scheme applies to states with **manifestly exotic flavor quantum numbers** (also including $c\bar{c}$, $b\bar{b}$ and possibly $s\bar{s}$ as pseudo "flavor quantum numbers").

* The current naming scheme for mesons and baryons with non-exotic flavor quantum numbers is left unchanged.

* For exotic mesons: the scheme for $I \neq 0$ states containing $c\bar{c}$ or $b\bar{b}$ is replaced and expanded.

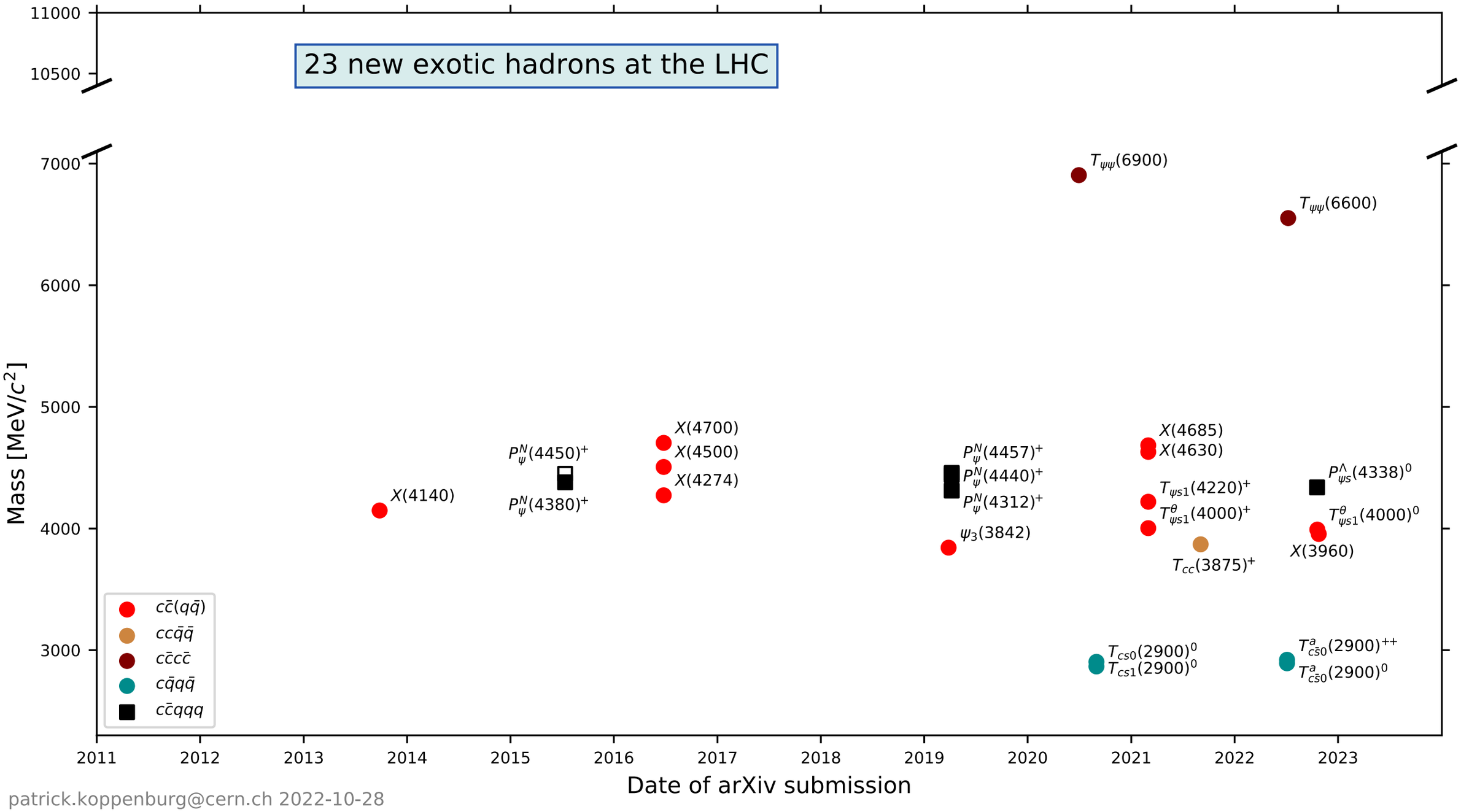
* For exotic baryons: there currently is no naming scheme; a new scheme is introduced.

8. Naming Scheme for Hadrons

Revised August 2021 by V.D. Burkert (Jefferson Lab), C. Hanhart (Jülich), R.E. Mitchell (Indiana U.), C. Patrignani (Bologna U.), U. Thoma (Bonn U.), L. Tiator (KPH, JGU Mainz) and R.L. Workman (George Washington U.).

$J^{PC} = \{$	0^{-+}	1^{+-}	1^{--}	0^{++}
	2^{-+}	3^{+-}	2^{--}	1^{++}
	$\vdots$	$\vdots$	$\vdots$	$\vdots$
Minimal quark content				
$u\bar{d}, u\bar{u} - d\bar{d}, d\bar{u}$ $(I = 1)$	π	b	ρ	a
$d\bar{d} + u\bar{u}$ and/or $s\bar{s}$ $(I = 0)$	η,η'	h,h'	ω,ϕ	f,f'
$c\bar{c}$	η_c	h_c	ψ^*	χ_c
$b\bar{b}$	η_b	h_b	Υ	χ_b
$I = 1$ with $c\bar{c}$	(Π_c)	Z_c	R_c	(W_c)
$I = 1/2$ with $sc\bar{c}$	(Π_{cs})	Z_{cs}	(R_{cs})	(W_{cs})
$I = 1$ with $b\bar{b}$	(Π_b)	Z_b	(R_b)	(W_b)
$I = 1/2$ with $sb\bar{b}$	(Π_{bs})	(Z_{bs})	(R_{bs})	(W_{bs})

The Need for an Expanded Naming Scheme



The LHCb Naming Convention *(the essentials)*

(1) Use **T** for states with a minimum of 4 quarks ($qq\bar{q}\bar{q}$);
use **P** for states with a minimum of 5 quarks ($qqqq\bar{q}$).

(2) Use **subscripts** to indicate the s, c, and b quark content,
abbreviating $s\bar{s}$ with ϕ, $c\bar{c}$ with ψ, and $b\bar{b}$ with Υ.

(3) Use **superscripts** for:

case i: isospin, parity, and G-parity
case ii: isospin, parity
case iii: isospin

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

(4) For cases i and ii, the spin J is a **subscript**;
for case iii, the J^P appears **last**.

(5) The mass is in **parentheses** and the electric charge
is a **superscript** after the mass.

Examples:

case i: T states with zero S, C, and B

$Z_c(3900)^+ \to \pi^+ J/\psi$
becomes

$$T^b_{\psi 1}(3900)^+$$

case ii: T states with nonzero S, C, or B

$Z_{cs}(4000)^+ \to K^+ J/\psi$
becomes

$$T^\theta_{\psi s 1}(4000)^+$$

case iii: P states

$P_c(4312)^+ \to pJ/\psi$
becomes

$$P^N_\psi(4312)^+ J^P$$

Modified Scheme for $IJ^{P(C)}$?

LHCb Scheme

case i: T states with zero S, C, and B

(a) superscript for I, P, and G
(b) subscript for J

$Z_c(3900)^+ \to \pi^+ J/\psi$
becomes
$T^{b}_{\psi 1}(3900)^+$

T states
zero net S, C, B

(P,G)	$I=0$	$I=1$
$(-,-)$	ω	π
$(-,+)$	η	ρ
$(+,+)$	f	b
$(+,-)$	h	a

case ii: T states with nonzero S, C, or B

(a) superscript for I and P
(b) subscript for J

$Z_{cs}(4000)^+ \to K^+ J/\psi$
becomes
$T^{\theta}_{\psi s 1}(4000)^+$

T states
non-zero net S, C, B

(P)	$I=0$	$I=\frac{1}{2}$	$I=1$
$(-)$	η	τ	π
$(+)$	f	θ	a

case iii: P states

(a) superscript for I
(b) J^P appended last

$P_c(4312)^+ \to pJ/\psi$
becomes
$P^{N}_{\psi}(4312)^+ J^P$

P states

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

Modified Scheme

all cases:

(a) superscript for $2I+1$
(b) $J^{P(C)}$ appended last

$Z_c(3900)^+ \to \pi^+ J/\psi$
becomes
$T^{3}_{\psi}(3900)^+ 1^{+-}$

$Z_{cs}(4000)^+ \to K^+ J/\psi$
becomes
$T^{2}_{\psi s}(4000)^+ 1^{+}$

$P_c(4312)^+ \to pJ/\psi$
becomes
$P^{2}_{\psi}(4312)^+ J^P$

$$T/P\ {}^{2I+1}_{\text{quarks}}\ (\text{mass})^q\ J^{P(C)}$$

Other Possibilities?

1. Don't include the $J^{P(C)}$ as part of the name?

   $\Longrightarrow$ The $J^{P(C)}$ is specified in the header in the particle listings.

   $\Longrightarrow$ The mass label is (usually) enough to distinguish states.

2. Replace the subscripts ψ and Υ in the quarks label with $c\bar{c}$ and $b\bar{b}$?

   $\Longrightarrow$ Avoids confusion with ψ and Υ quantum numbers.

   $\Longrightarrow$ Makes the connection between $T_\psi = T_{\bar{c}c}$ and T_{cc} more explicit.

3. Move the superscript to the left of the base symbol?

   $\Longrightarrow$ ${}^3T_{c\bar{c}}(3900)$ has a more natural pronunciation than $T^3_{c\bar{c}}(3900)$.

   $\Longrightarrow$ It can also be more easily written in text.

Summary of the Satellite Meeting

- **Points of Consensus:**

  * We should use the LHCb naming scheme as (at least) a starting point for the PDG naming scheme.

  * If we make modifications, they should be aimed at:
    - *simplification*
    - *understandability*
    - *readability*
    - *encodability* …

- **Next steps:**

  * Typeset different options within the listings to see how they look.

  * Further discussions — if possible, reach a PDG consensus by March.

Backup Slides

A Table of Test Cases

Minimal quark content	Current name	$I^{(G)}$, $J^{P(C)}$	LHCb Proposed name	Modified name?
$c\bar{c}$	$\chi_{c1}(3872)$	$I^G = 0^+,\ J^{PC} = 1^{++}$	$\chi_{c1}(3872)$	$\chi_{c1}(3872)$
$c\bar{c}u\bar{d}$	$Z_c(3900)^+$	$I^G = 1^+,\ J^P = 1^+$	$T^b_{\psi 1}(3900)^+$	$T^3_\psi(3900)^+1^{+-}$
$c\bar{c}u\bar{d}$	$Z_c(4100)^+$	$I^G = 1^-$	$T_\psi(4100)^+$	$T^3_\psi(4100)^+$
$c\bar{c}u\bar{d}$	$Z_c(4430)^+$	$I^G = 1^+,\ J^P = 1^+$	$T^b_{\psi 1}(4430)^+$	$T^3_\psi(4430)^+1^{+-}$
$c\bar{c}u\bar{s}$	$Z_{cs}(4000)^+$	$I = \frac{1}{2},\ J^P = 1^+$	$T^\theta_{\psi s1}(4000)^+$	$T^2_{\psi s}(4000)^+1^+$
$c\bar{c}u\bar{s}$	$Z_{cs}(4220)^+$	$I = \frac{1}{2},\ J^P = 1^?$	$T_{\psi s1}(4220)^+$	$T^2_{\psi s}(4220)^+$
$c\bar{c}c\bar{c}$	$X(6900)$	$I^G = 0^+,\ J^{PC} = ?^{?+}$	$T_{\psi\psi}(6900)$	$T^1_{\psi\psi}(6900)$
$cs\bar{u}\bar{d}$	$X_0(2900)$	$J^P = 0^+$	$T_{cs0}(2900)^0$	$T_{cs}(2900)^0 0^+$
$cs\bar{u}\bar{d}$	$X_1(2900)$	$J^P = 1^-$	$T_{cs1}(2900)^0$	$T_{cs}(2900)^0 1^-$
$cc\bar{u}\bar{d}$	$T_{cc}(3875)^+$		$T_{cc}(3875)^+$	$T_{cc}(3875)^+$
$b\bar{b}u\bar{d}$	$Z_b(10610)^+$	$I^G = 1^+,\ J^P = 1^+$	$T^b_{\Upsilon 1}(10610)^+$	$T^3_\Upsilon(10610)^+1^{+-}$
$c\bar{c}uud$	$P_c(4312)^+$	$I = \frac{1}{2}$	$P^N_\psi(4312)^+$	$P^2_\psi(4312)^+$
$c\bar{c}uds$	$P_{cs}(4459)^0$	$I = 0$	$P^\Lambda_{\psi s}(4459)^0$	$P^1_{\psi s}(4459)^0$

(Adapted from Table 5 of the LHCb proposal.)