Probing Multiple Shape Coexistence in ^{110,112}Cd with Coulomb excitation

Report on the AGATA experiments number E22.41 & E24.26

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on behalf of the E22.41 & E24.26 collaborations

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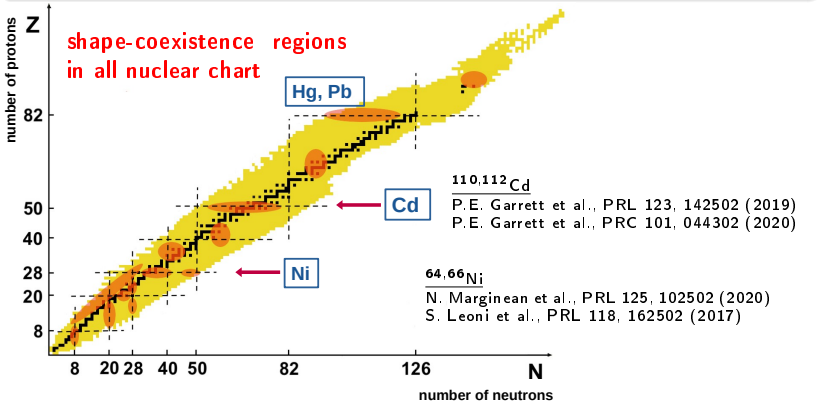
[5]INFN, Sezione di Firenze, Italy

Shape coexistence

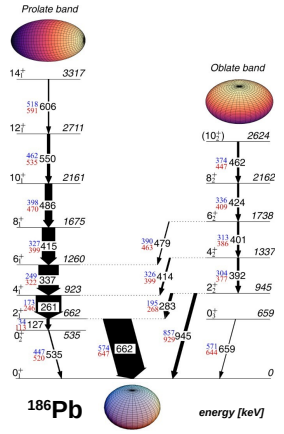
Nucleus may possess distinct shapes at similar excitation energies

P.E. Garrett, M. Zielińska, E. Clément, Prog. in Part. and Nucl. Phys. 124 (2022) 103931
K. Heyde and J. L. Wood, Rev. Mod. Phys 83 (2011)
S. Leoni, B.Fornal, A.Bracco, Y.Tsunoda, T.Otsuka, Prog. in Part. and Nucl. Phys. 139 (2024) 104119



^{110,112}Cd
P.E. Garrett et al., PRL 123, 142502 (2019)
P.E. Garrett et al., PRC 101, 044302 (2020)

^{64,66}Ni
N. Marginean et al., PRL 125, 102502 (2020)
S. Leoni et al., PRL 118, 162502 (2017)

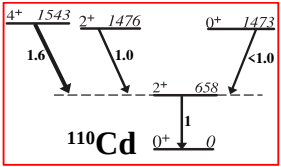


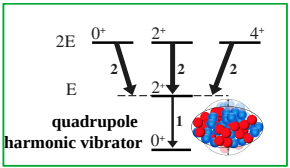
J. Ojala et al., Nature Communications Physics 5 (2022) 213

Fig.:M. Zielińska HDR thesis, University Paris-Saclay, Paris, 2023

^{110,112}Cd – from vibrational structure to ... ?

($\rightarrow$) *relative B(E2)*





P.E. Garrett *et al.*, PRC 86 (2012) 044304
K.Wrzosek-Lipska *et al.*, PLB 875 (2026) 140315

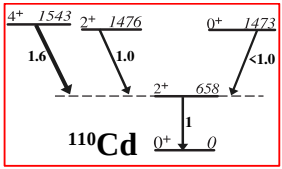
✓ energy of $(0_2^+,\ 2_2^+,\ 4_1^+)$

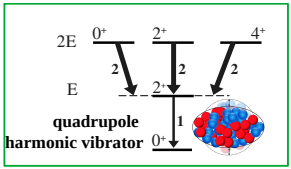
$\rightarrow$ **textbook examples of multiphonon spherical vibrators**

R.F.Casten, Nuclear Structure from a Simple Perspective (Oxford Univ. Press 1990)

^{110,112}Cd – from vibrational structure to ... ?

(→) relative B(E2)





P.E. Garrett *et al.*, PRC 86 (2012) 044304
K.Wrzosek-Lipska *et al.*, PLB 875 (2026) 140315

✓ energy of $(0_2^+,\ 2_2^+,\ 4_1^+)$

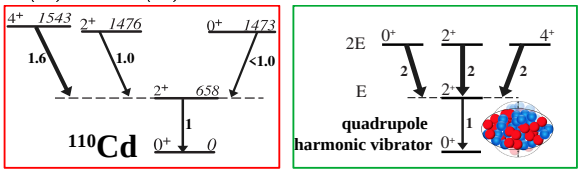
× $\dfrac{B(E2;\ (0_2^+,2_2^+,4_1^+)\rightarrow 2_1^+)}{B(E2;\ 2_1^+\rightarrow 0_1^+)} \not\approx 2$

These B(E2) values can however be reconciled with a vibrational picture within new IBM calculations invoking partial dynamical symmetry.

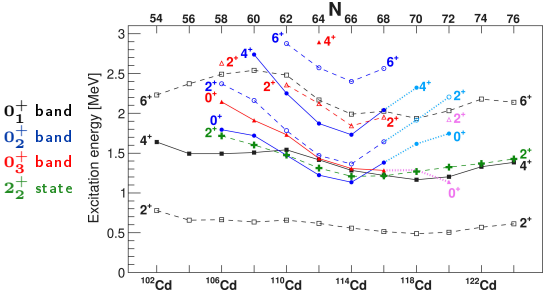
A. Leviatan et al., PRC 98, 031302(R) (2018) N. Gavrielov et al., PRC108, L031305 (2023)

^{110,112}Cd – from vibrational structure to ... ?

(→) relative B(E2)

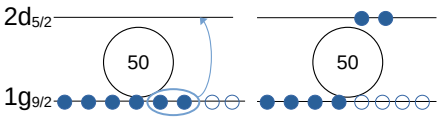


P.E. Garrett *et al.*, PRC 86 (2012) 044304
K.Wrzosek-Lipska *et al.*, PLB 875 (2026) 140315

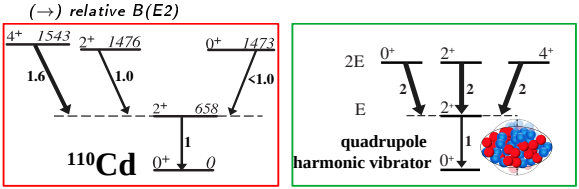


P.E. Garrett, M. Zielinska, and E. Clément, Prog. Part. Nucl. Phys. 122 (2021) 103931

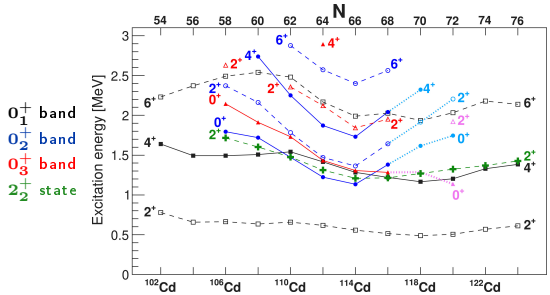
0_2^+ band → exhibits **intruder**-like behaviour, showing a minimum at the neutron mid-shell



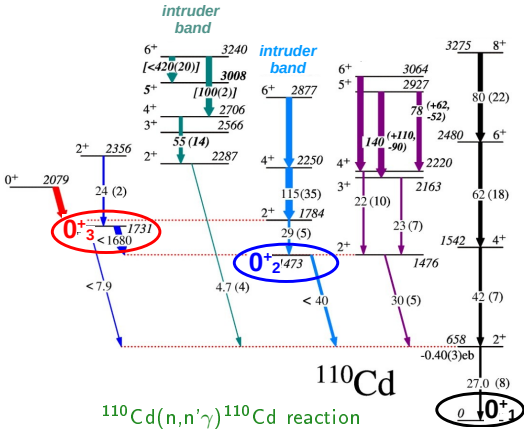
^{110,112}Cd – from vibrational structure to ... ?



P.E. Garrett *et al.*, PRC 86 (2012) 044304
K.Wrzosek-Lipska *et al.*, PLB 875 (2026) 140315



P.E. Garrett, M. Zielinska, and E. Clément, Prog. Part. Nucl. Phys. 122 (2021) 103931



^{110}Cd(n,n'γ)^{110}Cd reaction
& DSAM lifetime
& β^+/EC decay of ^{110}In
University of Kentucky (USA)
& TRIUMF (Canada)

P.E.Garrett *et al.*, PRL123 (2019) 142502

Theoretical models

Probability density distributions in the (β,γ) plane for the 0^+ states in ^{110}Cd

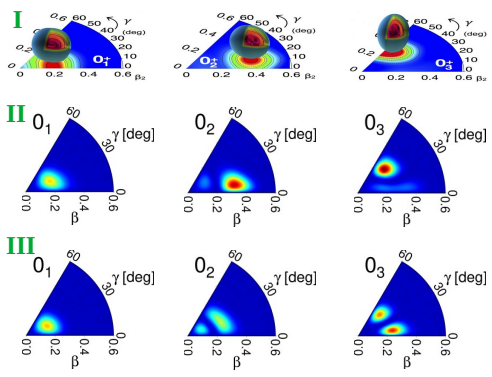
shape coexistence

I **Symmetry-Conserving Configuration Mixing**
P.E.Garrett, T.R.Rodríguez *et al.*, PRL 123 (2019) 142502
P.E.Garrett, T.R.Rodríguez *et al.*, PRC 101 (2020) 044302

II **General Bohr Hamiltonian**
using Skyrme energy density functional **SLy4**
K.Wrzosek-Lipska, L.Próchniak *et al.*, APPB51 (2020) 789
K.Wrzosek-Lipska *et al.*, PLB 875 (2026) 140315

vibrational structure

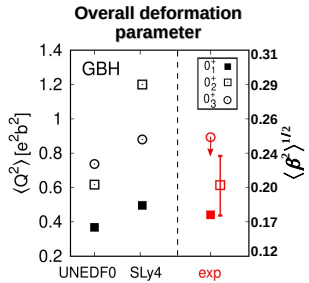
III **General Bohr Hamiltonian**
using energy density functional **UNEDF0**
K.Wrzosek-Lipska, L.Próchniak *et al.*, APPB51 (2020) 789
K.Wrzosek-Lipska *et al.*, PLB 875 (2026) 140315



IV **Interacting Boson Model** – the theoretical approach employing the **U(5) Hamiltonian** provides a satisfactory reproduction of the existing experimental data for the ^{110,112,114,116}Cd nuclei. This model incorporates rotational bands while maintaining the overall vibrational character of the Cd nuclei.

A. Leviatan et al., PRC 98, 031302(R) (2018) N. Gavrielov et al., PRC108, L031305 (2023)

Deformation of in ^{110}Cd – β and γ parameter



K.Wrzosek-Lipska, I.Z.Piętka, L.Próchniak *et al.*, Phys.Lett.B 875 (2026) 140315

- $\mathbf{0_1^+, 0_2^+, 0_3^+}$: comparable overall deformation $\langle\beta\rangle$
- An overall agreement between theoretical and experimental quadrupole deformation parameters, especially for the GBH (UNDF0) model.

$$\sqrt{\langle\beta^2\rangle} = \sqrt{\frac{\langle Q^2\rangle}{q_0^2}}, \quad q_0^2 = \frac{2}{4\pi} Z R_0^2$$

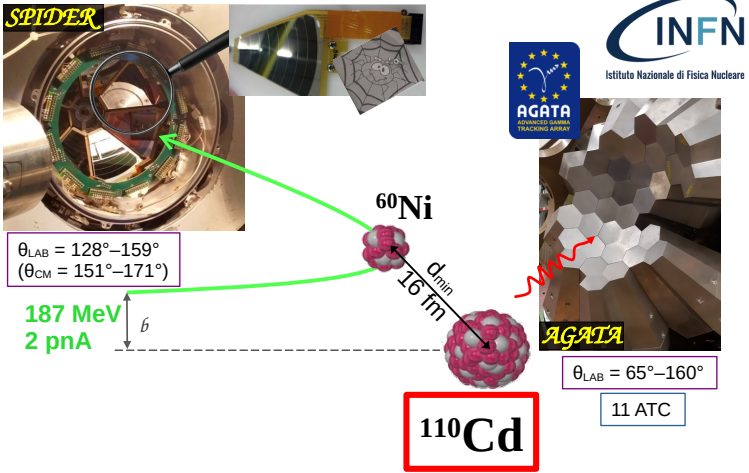
- Experimental evidence for the non-axial character of the ground state obtained for the first time.
- The non-axiality of the ground state very well reproduced by the GBH model, independently of the interaction used.
- GBH (SLy4) predicts **multiple shape coexistence** in ^{110}Cd manifested in a **different degree of triaxiality** of the $0^+_{1,2,3}$ states.

Safe Coulomb excitation of ^{110}Cd with ^{60}Ni beam at LNL

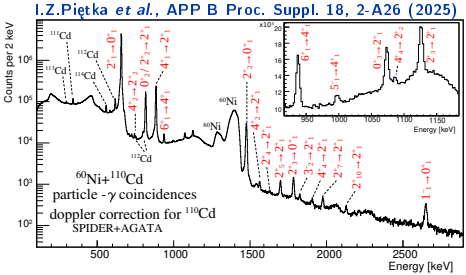
Experiment number: **E22.41**

3-5 June 2022: 1 day 10 hours
17-21 October 2022: 3 days 12 hours

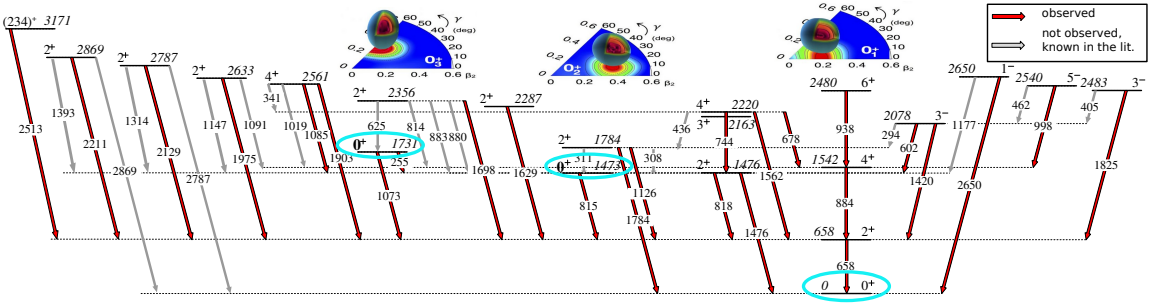
Spokepersons:
K. Wrzosek-Lipska (HIL UW),
P.E. Garrett (Univ. of Guelph),
M. Zielińska (IRFU/CAE),
A. Nannini (INFN Florence),
M. Rocchini (INFN Florence)



Coulomb excitation of ^{110}Cd with ^{60}Ni beam at LNL



- 19 excited states
- energy up to 3.1 MeV
- 0_2^+ state
- 0_3^+ state

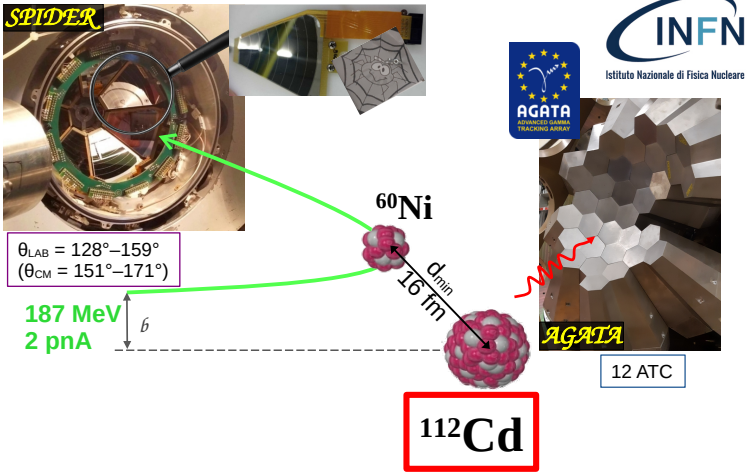


Safe Coulomb excitation of ^{112}Cd with ^{60}Ni beam at LNL

Experiment number: **E24.26**

11-15 March 2025: 5 days

Spokepersons:
K. Wrzosek-Lipska (HIL UW),
P.E. Garrett (Univ. of Guelph),
M. Zielińska (IRFU/CAE),
A. Nannini (INFN Florence)



M.Sc. thesis of T. La Marca, Uni. of Florence, 2025
B.Sc. thesis of K. Jakowinicz, Uni. of Warsaw, ongoing

The Post Pulse Shape Analysis (PostPSA)

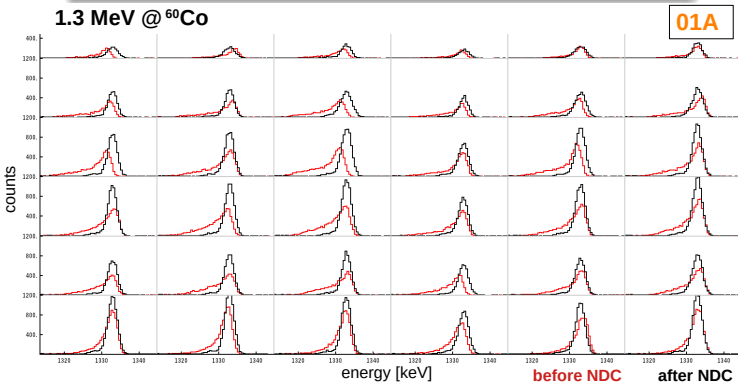
AGATA crystals

00A	00B	00C
01A	01B	01C
02A	02B	02C
04A	04B	04C
	05B	05C
06A	06B	06C
07A	07B	
08A	08B	
09A	09B	09C
10A	10B	10C
11A		11C
14A	14B	14C

32 crys. – working during experiment

12 crys. – analysed by K. Jakowinicz (B.Sc. thesis, Uni. of Warsaw, ongoing)

6 crys. – neutron damage corrections applied



The Post Pulse Shape Analysis (PostPSA)

- ✓ Neutron damage corrections
- ✓ Final energy re-calibrations
- ✓ Force Segments to Core
- ✓ Global time alignments

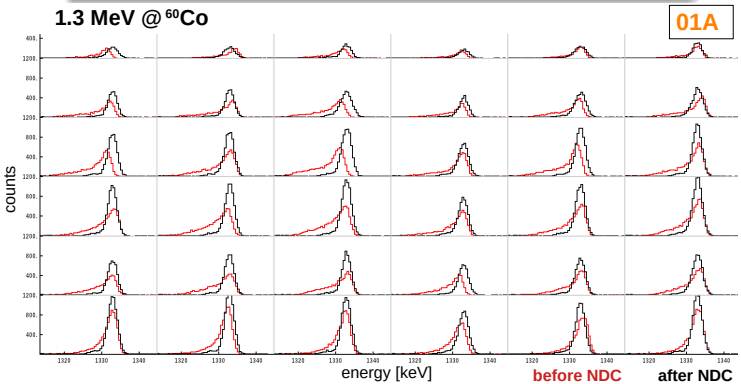
32 crys. – working during experiment

12 crys. – analysed by K. Jakowinicz (B.Sc. thesis, Uni. of Warsaw, ongoing)

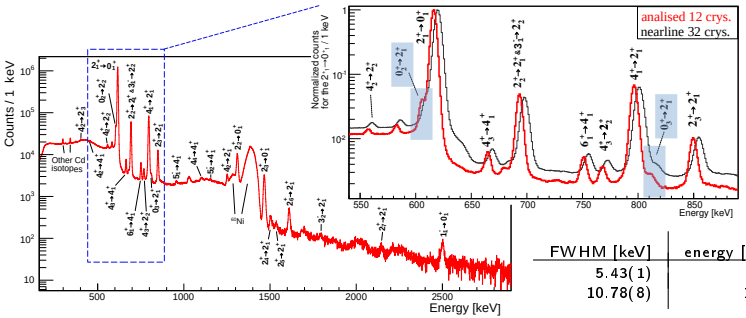
6 crys. – neutron damage corrections applied

FWHM – after tracking

FWHM [keV]	energy [keV]	12 crys.
2.50(1)	356	@ ^{133}Ba
2.75(1)	661	@ ^{137}Cs
3.28(1)	1332	@ ^{60}Co

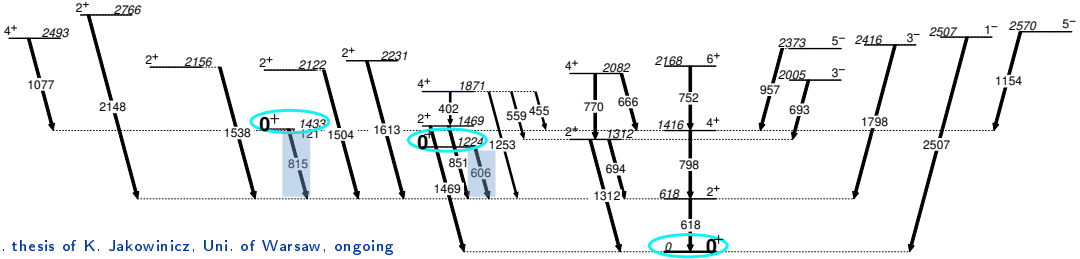


Coulomb excitation of ^{112}Cd with ^{60}Ni beam at LNL



FWHM [keV]	energy [keV]
5.43(1)	618
10.78(8)	1469

- 19 excited states
- energy up to 2.7 MeV
- 0_2^+ state
- 0_3^+ state



Summary

Probing Multiple Shape Coexistence in ^{110}Cd

→ similar overall deformation parameter $\langle\beta\rangle$ of $0^+_{1,2,3}$ in ^{110}Cd

→ shape coexistence can only be manifested in different non-axiality $\langle\gamma\rangle$ of $0^+_{1,2,3}$ (next step of on-going analysis)

Probing Multiple Shape Coexistence in ^{112}Cd

✓ the Post Pulse Shape Analysis of 12 crystals

✓ identification of the γ-ray transitions in the spectrum of ^{112}Cd

→ next step:

- the Post Pulse Shape Analysis of 20 crystals
- data division in terms of the scattering angle of ^{60}Ni projectile
- extraction of matrix elements in ^{112}Cd (GOSIA analysis)

PROBING LOW-ENERGY STATES IN ^{110}Cd USING COULOMB EXCITATION*

I.Z. Piętka[a], K. Wrzosek-Lipska[a], P.E. Garrett[b], M. Zielińska[c], L. Próchniak[a], A. Nannini[d], M. Rocchini[b,d], T. Abraham[a], P. Aguilera[e,f], Z.T. Ahmed[b], J.M. Allmond[g], F. Angelini[f,h], M. Balogh[h], F.L. Bello Garrote[i], J. Benito[e,f,j], H. Bidaman[b], V. Bildstein[b], D. Brugnara[h], S. Buck[b], C. Burbadge[b,†], S. Carollo[e], J. Cederkäll[k], M. Chiari[d,l], R. Coleman[b], G. Colombi[m,n,o,‡], G. Colucci[a], A. Diaz Varela[b], D.T. Doherty[c,p], S. Dutt[q,r], F. Ercolano[s,t], A. Ertoprak[h], R. Escudeiro[e], F. Galtarossa[e], A. Goasduff[h], B. Góngora-Servín[b,u], A. Gottardo[h], A. Gozzelino[h], B. Greaves[b], K. Hadyńska-Klęk[a], J. Heery[p], S.F. Hicks[v], Z. Huang[e], D. Hymers[b], A. Illana[w,§], J. Iwanicki[a], G. Jaworski[a], B. Jigmeddorj[b,¶], D. Kalaydjieva[c,¶], M. Kisieliński[a], R. Kjus[c], M. Komorowska[a], N. Kopeć[a], M. Kowalczyk[a], J. Kowalska[a], K.Z. Krutul-Bitowska[a], R. Kumar[q,§], A. Mai Quynh[x], N. Marchini[d], T. Marchlewski[a], K.R. Mashtakov[b], M. Matejska-Minda[a,y], D. Mengoni[e,f], C. Michelagnoli[m], P.J. Napiorkowski[a], D.R. Napoli[h], B. Olaizola[b,‖], M. Palacz[a], S. Pannu[b], E. Pasquali[z], J. Pellumaj[h,s], E.E. Peters[v], R.M. Pérez-Vidal[h,α], S. Pigliapoco[e,f], E. Pilotto[e,f], F. Recchia[e,f], K. Rezynkina[e,f], E. Sahin[i], J. Samorajczyk-Pyśk[a], M. Saxena[β,††], M. Sedlák[h,γ], J. Srebrny[a], A. Stolarz[a], K. Stoychev[δ,¶], C.E. Svensson[b], A. Tucholski[a], A. Trzcińska[a], S. Valbuena[b], J.J. Valiente-Dobón[h], J.L. Wood[c], S.W. Yates[v], L. Zago[f,h], I. Zanon[h,‡‡], G. Zhang[e], T. Zidar[b]

F. Demyani, C. Fahlander, A. Herzan, K. Jakowinicz, A. Krzysiek, T. La Marca, S. Lange, R. Nicolás del Álamo, P. Sekrecka, G. Szymanek

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