



#### Ground State Properties (Masses) From Post-transition Metals To Actinides And

(perhaps) Applications In Beyond Standard Model Searches

Moritz Pascal Reiter



The mass of an atomic nucleus reflects its binding energy and hence its stability and structure



Z Protons (Proton number) N Neutrons (Neutron number) A = N + Z (Mass number) B = Bindung energy

Nuclear mass  $M(N, Z) = Z \cdot m_p + N \cdot m_n - B(N, Z)/c^2$ Atomic mass  $M_{at}(N, Z) = Z \cdot m_p + N \cdot m_p + Z \cdot m_{el} - B(N, Z)/c^2 - B_{el}(Z)/c^2$ 



- Structure of nuclei from mass measurements
  - Binding energies
  - Separation energies
  - Shell structure, pairing
  - Location of the driplines
  - Deformations
  - Halo / skin nuclei





# Mass Uncertainties between Post-transition Metals To Actinides



The Colourfull Nuclear Chart





- Mass measurements near N=126
  - Short-lived isotopes of Po (Z=84) to Ra (Z=88) measured via MR-TOF-MS at the FRS Ion Catcher



# Nuclear Mass Models





# Nuclear Mass Models



- Masses of Th isotopes
  - Some agreement between models and experimental masses
  - Huge variation towards the unknown (beyond N>148)
    - Masses of more n-rich Th isotopes



# Nuclear Structure Theory



- Huge advances in nuclear theory
  - Quality and reach of *Ab-initio* calculations has expanded of the last decade
  - State of the art calculations can reproduce e.g. 2<sup>+</sup> Ex energies in Sn
  - Ongoing work towards Pb and beyond
    - Ab-initio calculation of <sup>208</sup>Pb
- Binding energies, masses etc <sup>208</sup>Pb -1560 $\Delta NNLO_{GO}$ -1580 $e_{max} = 16$ -0.2 0.0 -0.4Extrap. Energy + 1692 MeV -1600MeV MBPT3 -1620 Used in fit  $E_{gs}$ best fit Experiment -1640 -1660-1680Extrapolated: -1692.16 MeV 18 16 20 22 24 26 28 30 32 J. Holt (2021) private communication  $E_{3max}$



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S. Beck et al., PRL 127 (2021) 112501

- State of the art mean field calculations span the full nuclear chart
  - Predictions of ground state properties
    - Excited states
      - e.g. even N=81 isotopes
    - Etc.



# Nuclear Structure Theory





### Production via MNT reactions

• Promising cross sections for the production of n-rich isotopes





#### LINAC Ion Catcher: Conceptual Layout



Slide: T. Dickel



# In-flight + ISOL MR-TOF-MS techniques

• Rate capability meets

#### TITAN MR-TOF-MS Isobar separator (TRIUMF)



Resolving Power / Sensitivity

MR-TOF-MS at FRS Ion Catcher (GSI)





 Rate capability meets
 Mass selective re-trapping to suppress unwanted isobaric contamination by orders of magnitude

- Signal to background 1 to 10<sup>6</sup>



Resolving Power / Sensitivity Ultrahigh resolving power MR-TOF-MS to identify and to preform mass measurements with few ions overall

- Close to 1 million mass resolving power



# Mass Uncertainties between Post-transition Metals To Actinides



The Colourfull Nuclear Chart

# Radioactive molecules



- RaM get a lot of attention in recent years
  - High sensitivity to BSM physics,
    EDM , P- and T-violation
    - Strong internal electric fields
  - RaF as one of the promising candidates
    - Only perused by ISOL facilities
  - However other molecules e.g. ThO, AcOH...
    expected to have equal or even sensitivity
    - Most stringed limit for e EDM  $\rightarrow$  ThO
  - Key change is production of RaM
    - Stopping cells regularly produce molecules
    - UOH, AcOH, ThO, PuO regularly observed



# Radioactive molecules



RaM get a lot of attention in recent years

- High sensitivity to BSM physics, EDM , P- and T-violation
  - Strong internal electric fields
- **RaF** as one of the promising candidates

Standard Model Generic Models Pre-LHC SUSY LHC era SUSY

Standard

Model

Exact

Universality

10-38

10-33

ACME Collaboration. Nature 562, 355 (201%) (e cm)

10-25 10-26 10-27 10-28 10-29

10-30

10-31

10-32



Thank you!



											Fission	β+	Fission	α	a	۵	۵	β+	۵	a	Fission	۵	Fission	a	Fission	a	a
								<sup>244</sup> Md م	<sup>245</sup> Md م	<sup>246</sup> Μd α	<sup>247</sup> Md م	<sup>248</sup> Md <sub>β+</sub>	<sup>249</sup> Md م	<sup>250</sup> Μd <sub>β+</sub>	$^{251}_{\beta+}$ Md	$^{252}_{\beta+}$ Md	$^{253}_{\beta^+}Md$	$^{254}_{\beta*}$ Md	<sup>255</sup> Md <sub>β+</sub>	<sup>256</sup> Md <sub>β+</sub>	<sup>257</sup> Md e- capture	<sup>258</sup> Μd α	<sup>259</sup> Md Fission	<sup>260</sup> Md Fission	<sup>261</sup> Md	<sup>262</sup> Md Fission	
						<sup>241</sup> <b>Fm</b> Fission	<sup>242</sup> Fm Fission	<sup>243</sup> Fm ª	<sup>244</sup> Fm Fission	<sup>245</sup> Fm ۵	<sup>246</sup> Fm	<sup>247</sup> Fm	<sup>248</sup> Fm	<sup>249</sup> Fm <sub>β+</sub>	250 <b>Fm</b>	<sup>251</sup> Fm <sub>β+</sub>	<sup>252</sup> Fm ۹	<sup>253</sup> Fm e- capture	<sup>254</sup> Fm ۵	<sup>255</sup> Fm ۹	<sup>256</sup> Fm Fission	<sup>257</sup> Fm	<sup>258</sup> Fm Fission	<sup>259</sup> Fm Fission	<sup>260</sup> Fm Fission		
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				<sup>237</sup> Cf α	<sup>238</sup> Cf Fission	<sup>239</sup> Cf °	<sup>240</sup> Cf α	<sup>241</sup> Cf <sub>β+</sub>	<sup>242</sup> Cf α	<sup>243</sup> Cf β+	<sup>244</sup> Cf ۵	<sup>245</sup> Cf β+	<sup>246</sup> Cf ۵	<sup>247</sup> Cf e- capture	<sup>248</sup> Cf ۵	<sup>249</sup> Cf α	<sup>250</sup> Cf م	<sup>251</sup> Cf م	<sup>252</sup> Cf α	<sup>253</sup> Cf β-	<sup>254</sup> Cf Fission	<sup>255</sup> Cf β-	<sup>256</sup> Cf Fission				
	<sup>233</sup> Bk a	<sup>234</sup> Bk a	<sup>235</sup> Βk <sub>β+</sub>	<sup>236</sup> Βk <sub>β+</sub>	<sup>237</sup> Βk <sub>β+</sub>	<sup>238</sup> Βk <sub>β+</sub>	<sup>239</sup> Βk <sub>β+</sub>	<sup>240</sup> Βk <sub>β+</sub>	<sup>241</sup> <b>Bk</b> <sub>β+</sub>	<sup>242</sup> Βk <sub>β+</sub>	<sup>243</sup> Βk <sub>β*</sub>	<sup>244</sup> Βk <sub>β+</sub>	<sup>245</sup> Bk e-capture	<sup>246</sup> Βk <sub>β+</sub>	a <sup>247</sup> Bk	a <sup>248</sup> Bk	<sup>249</sup> Βk β-	<sup>250</sup> Βk β-	<sup>251</sup> Βk β-	<sup>252</sup> Βk	<sup>253</sup> Βk β-	<sup>254</sup> Βk					
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