UNIWERSYTET WARSZAWSKI

ŚLCJ

Coulomb excitations of superheavy nuclei – dreams or research project?

Paweł J. Napiorkowski
for the COULEX collaboration

Why COULEX?

SHE structure:

- nuclear deformation
  (from spherical to prolate and oblate shapes)
- possible triaxiality
  Ćwiok S, Heenen P-H and Nazarewicz W
  Nature 433 (2005) 705
- superdeformation
  Polikanov S M *et al*, **I Sov. Phys. JETP 15** (1962)1016
- collective octupole excitations
  Kondev F G, Dracoulis G D and Kibédi T, **Data Nucl. Data Tables 103–104** (2015) 50
- high-K states
  Löbner K E G, **Phys. Lett. B 26 (**1968) 369

Coulomb excitation:

- low energy of interaction
  (good separation of nuclear surfaces, big distance of closest approach to neglect nuclear interaction)
- high cross-section for the excitation process
  (depends on nuclear deformation)
- applicable for a low beam intensities
- precision measurements of electric moments in a model independent way
- efficient population of high-spin states to study their spectroscopic properties
  (including non-yrast states)

COULEX of $^{248}_{96}$Cm classic approach

Experiments:

- GSI Darmstadt,
  Target: ^{248}Cm (250 μg/cm^2)
  Beam ^{208}Pb (5.3 MeV*A)
  Piercey R B *et al.*, Phys. Rev. Lett. 46 (1981) 415

- LBNL
  Target: ^{248}Cm (1.18 mg/cm^2)
  Beams: ^{58}Ni (4.5 MeV*A),
  ^{136}Xe (4.7 MeV*A)
  Czosnyka T *et al.*, Nucl. Phys. A458 (1986) 123

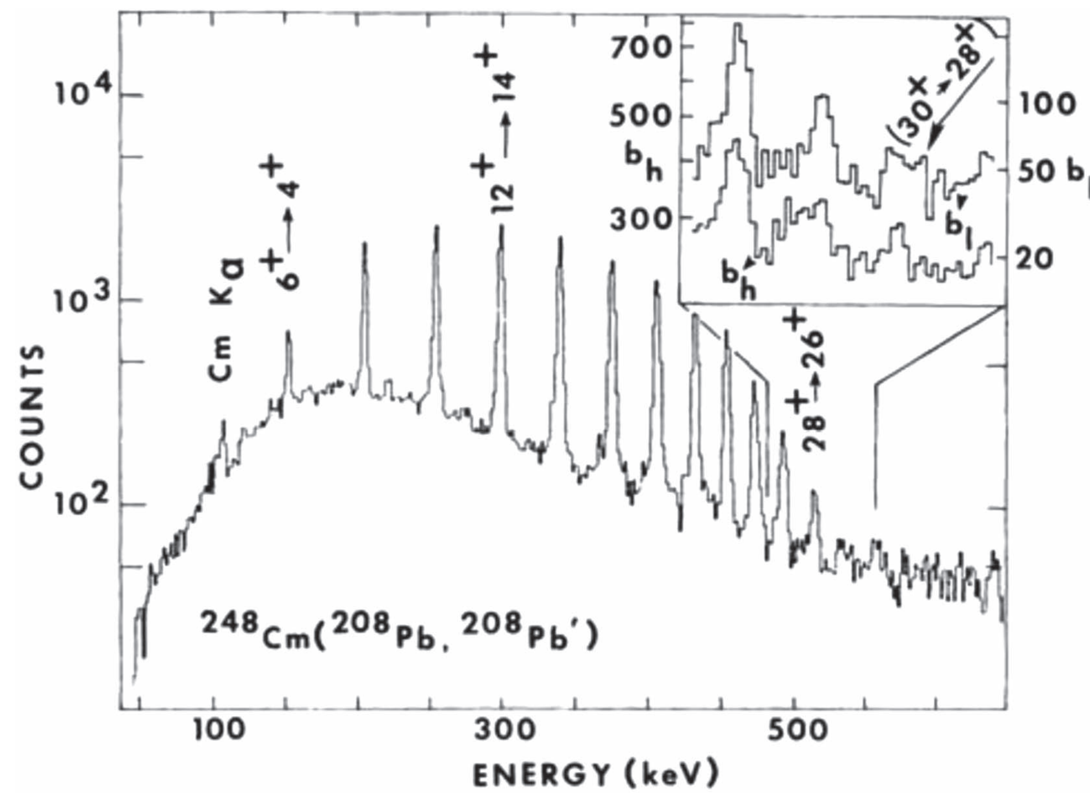


Figure 46. Ground-state rotational band of ^{248}Cm populated in Coulomb excitation using a ^{208}Pb beam at 5.3 MeV/u. Reprinted figure with permission from [329], Copyright (1981) by the American Physical Society.

Piercey R B *et al*, Phys. Rev. Lett. 46 (1981) 415

COULEX of exotic beams (like „the ^{254}No breakthrough")

- projectile excitation (also inverse kinematics)
- low beam current acceptable (high efficiency of detectors)
- normalisation to target excitations.

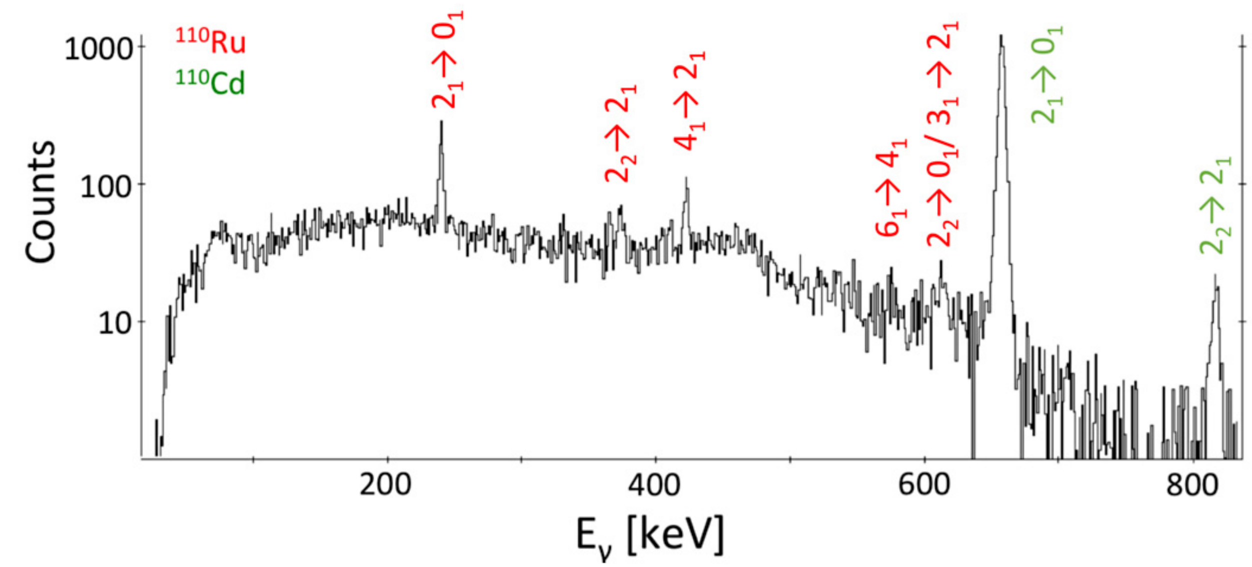
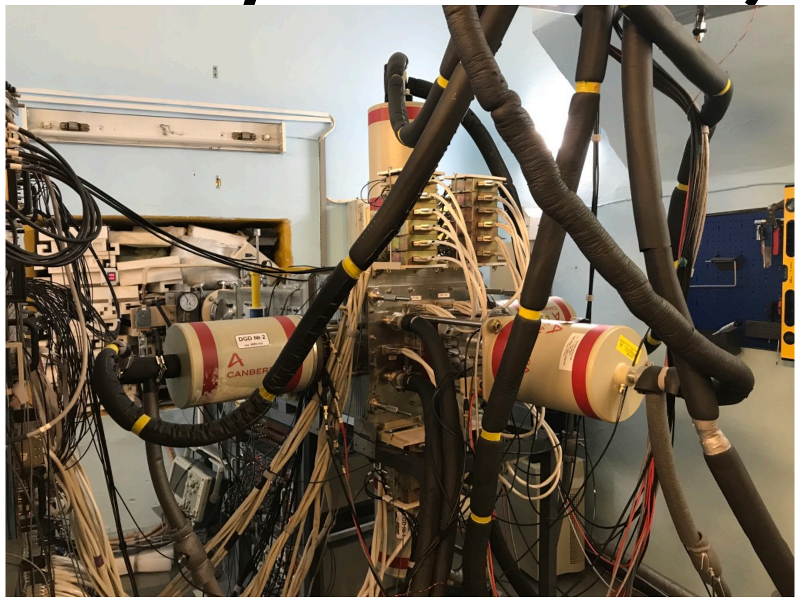


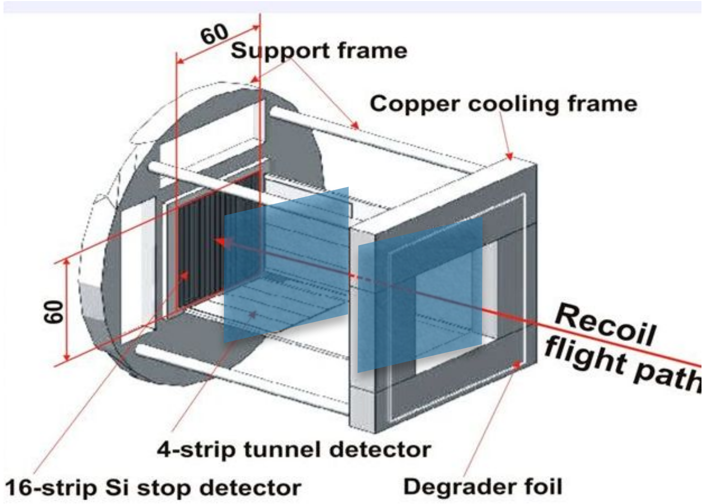
Fig. 2. (Color online.) Doppler corrected γ-ray energy spectrum gated on the A=110 group in the CHICO2 spectrum. A number of ^{110}Cd peaks (labeled in green) are visible in additions to the ^{110}Ru γ rays (red).

COULEX @ 2000 ^{110}Ru per sec (3.9 MeV*A)
ANL Caribu, GRETA & CHICO
D.T. Doherty *et al.*,**Physics Letters B 766** (2017) 334

Current spectroscopy setup for SHE (e.g. GABRIELA@JINR, Dubna)



- High efficient set of HPGe
- DSSSD front detector (HI and alpha)
- DSSSD side detector (alpha and EC)
- MCP for TOF
- ***Separator…***



A. Yeremin *et al.*, **EPJ Web of Conferences 86** (2015) 00065

Inspiration: Slow down beams Coulex setup at GSI

- 2 MSP detectors for tracking of projectiles
- target between MCP and DSSSD (e.g.
- scattering angle from tracking
- similar approach for SHE COULEX setup?
- Limit: SHE beam intensity!

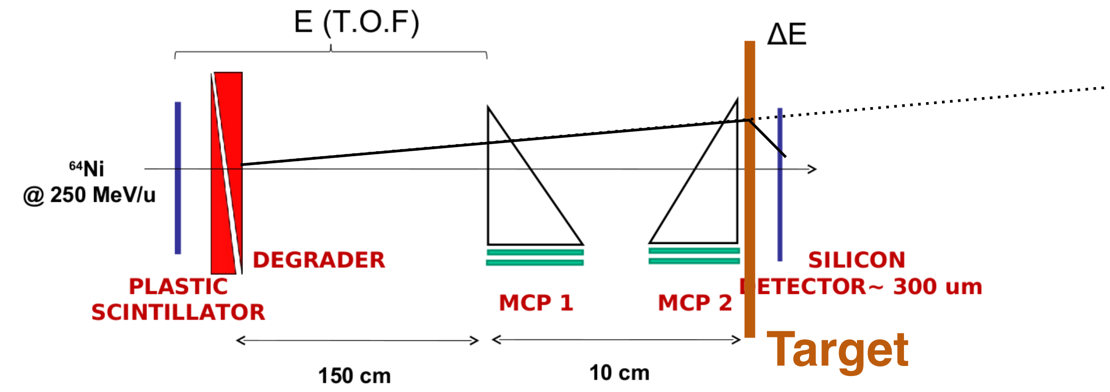
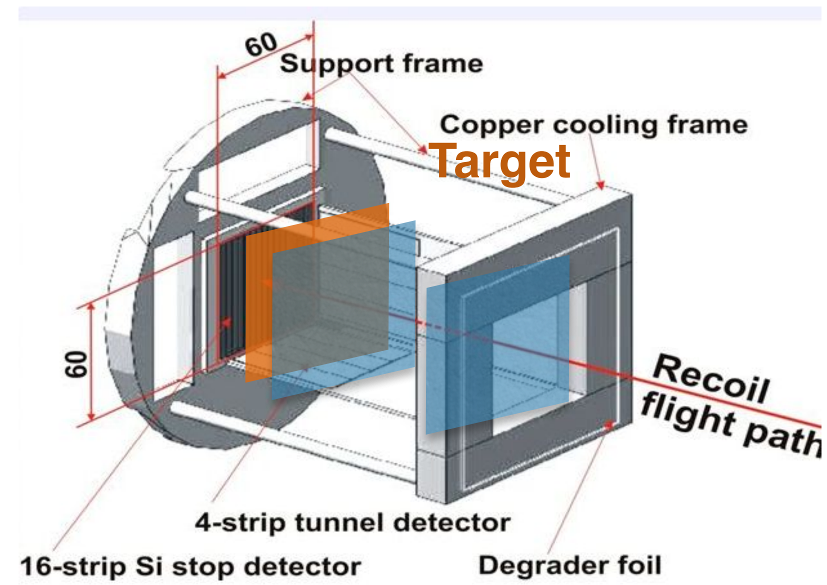


Fig. 3. Schematic setup for the slowed down beam experiment.

F. Naqvi, P. Boutachkov et al., **ACTA PHYS. POL. B 42** (2011) 725



SHEs' Menu

SPIRAL2 & S3:

- ^{256}Rf ~ 10^{-1} pps @ 15 pμA
- ^{254}No ~ 10 pps @ 15 pμA

Nuclide	Reaction	Feature	Cross-section (pbarn) (ER)	Rate (h^{-1})	# of events per 7 days
^{254}No	^{48}Ca+^{208}Pb	*K*-isomer	2×10^6	6×10^4	6×10^7
^{256}Rf	^{50}Ti+^{208}Pb	*K*-isomer	17×10^3	550	540.000
^{266}Hs	^{64}Ni+^{207}Pb	ER	15 (^{270}Ds)	0.34	285
^{266m}Hs	^{64}Ni+^{207}Pb	*K*-isomer	15 (^{270}Ds)	0.01	12.5
^{270}Ds	^{64}Ni+^{207}Pb	ER	15	0.45	380
^{270m}Ds	^{64}Ni+^{207}Pb	*K*-isomer	15 (^{270}Ds)	0.22	190
^{262}Sg	^{64}Ni+^{207}Pb	α-decay	15 (^{270}Ds)	0.02	25
^{276}Cn	^{70}Zn+^{207}Pb	*K*-Isomer	0.5 (^{277}Cn)	0.01	12.5
^{288}115	^{48}Ca+^{243}Am	ER	10	0.3	300
^{288}115	^{48}Ca+^{243}Am	*L* x-rays	10	1,8	1800

D Ackermann and Ch Theisen ***Phys. Scr.* 92** (2017) 083002

Zielińska M private communication 2016

But in inverse kinematics to have 3 MeV*A:

^{254}No ~ 2 pps @ 2 pμA (Pb beam)

Coulomb excitation (Coulex) provides the most direct measurement of the electric quadrupole moment. Using the inverse kinematics reaction ^{48}Ca(^{208}Pb,2n)^{254}No, an energy of $\approx$3.1 MeV/A results for the residues. At this energy, the Coulomb excitation cross section on a Pb target is of $\approx$27, 11, 5 b for the 4^+, 6^+, 8^+ states, respectively [424]. However, a rather pure ^{254}No beam with a decent intensity of at least 10 ions s^{-1} should be delivered on the secondary target, which can only be achieved using a ^{208}Pb primary beam with an intensity at the pμA level, in conjunction with a high transmission separator with inverse kinematics capabilities. As far as we are aware, both requirements are not fulfilled by any existing or foreseen facility (the SC LINAC accelerator of SPIRAL2, Caen should provide in the future a pμA ^{208}Pb beam but the S^3 electric dipole is not suited for the high electric rigidities associated to inverse kinematics).

Summary

- COULEX of SHE:
  Fm, No (Z=100,102)

- Detection setup - realistic update of existing facilities

- Ions rate:
  a few pps @ 3 MeV*A
  - on the limit.

- Challenge:
  SEPARATOR for inverse kinematics

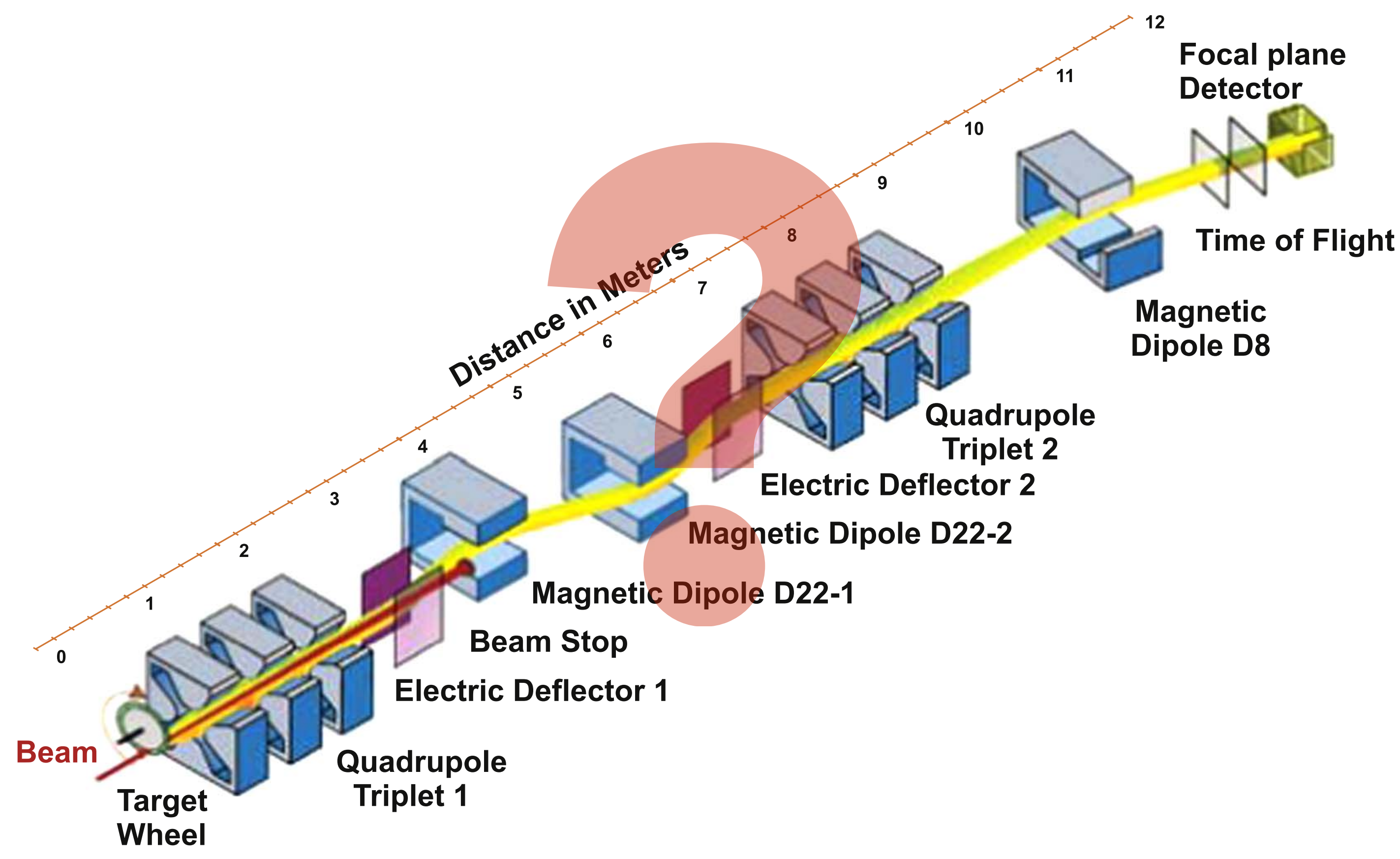


Figure 25. The SHELS separator at Dubna. Reprinted from [217], Copyright 2015, with permission from Elsevier.