Investigation of neutron rich Cd isotopes and test of the valence proton symmetry

AGATA Physics Workshop 2010, Istanbul, Turkey

C. Fransen, A. Dewald, A. Blazhev, N. Braun, B. Bruyneel, M. Gorska, M. Hackstein, H. Iwasaki, J. Jolie, A. Jungclaus, T. Kröll, R. Krücken, R. Orlandi, P. Petkov, T. Pissulla, P. Reiter, W. Rother

- Measurement of B(E2,0_1^+ -> 2_1^+) values in ^{124,126}Cd with AGATA@GSI.

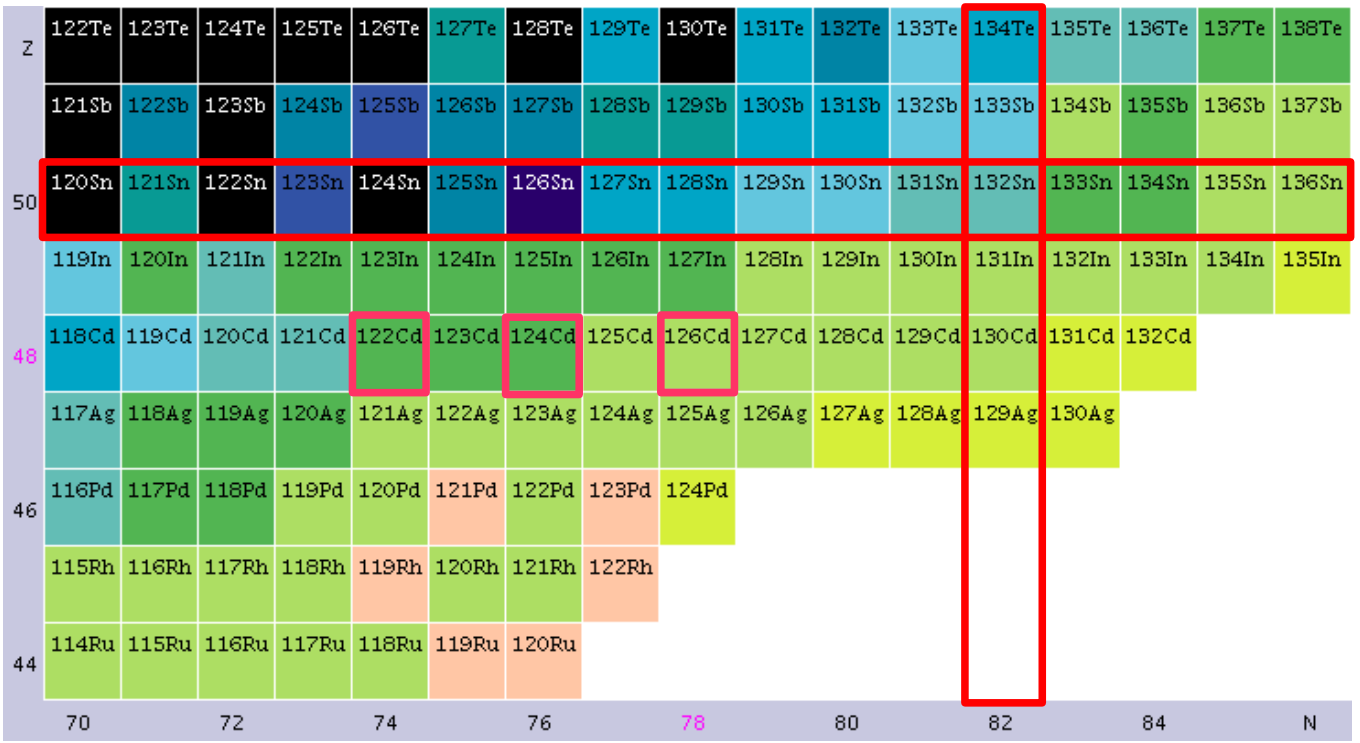
- Determination from lifetimes measured with RDDS with new Cologne differential plunger.

- ^{124}Cd: B(E2,2_1^+ -> 0_1^+) known from Coulomb excitation, but check with model independent technique and higher precision.

- ^{126}Cd: preliminary value B(E2,2_1^+ -> 0_1^+) from Coulex test experiment. Feasibility to measure 2_1^+ lifetime precisely with RDDS.

Institut für Kernphysik, Universität zu Köln

Motivation (1)

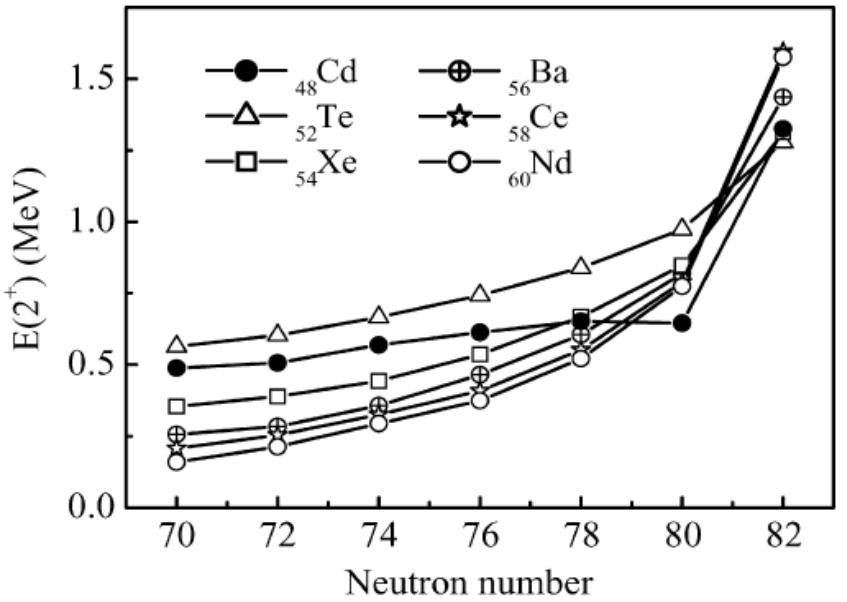


- Investigate collectivity when approaching N=82
- B(E2,2_1^+ -> 0_1^+) related to nuclear quadrupole deformation
- Milestone in understanding properties of these nuclei

Anomalous behavior of 2^+ excitations in n-rich Cd

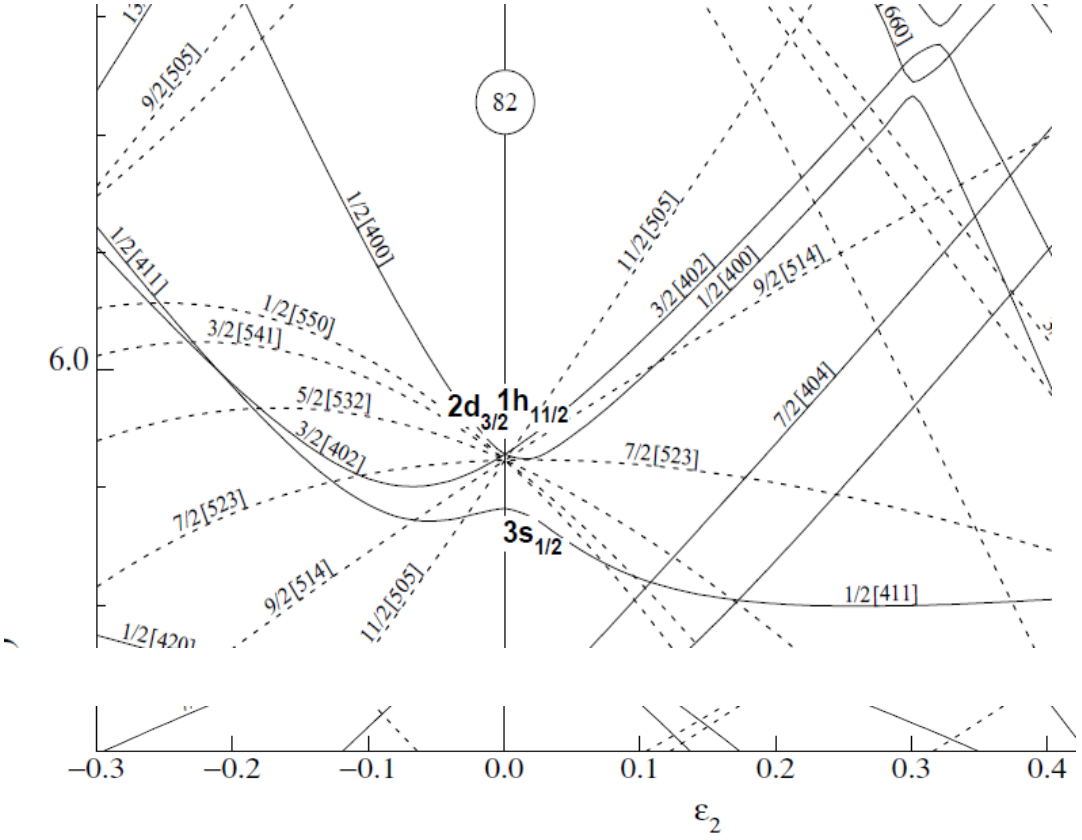
Low 2^+ excitation energy in ^{128}Cd consequence of doubly magic character for oblate deformation favoring prolate configurations

Rodriguez, Luis Egido, Jungclaus, PLB 668, 410 (08): beyond mean field techniques, gogny force

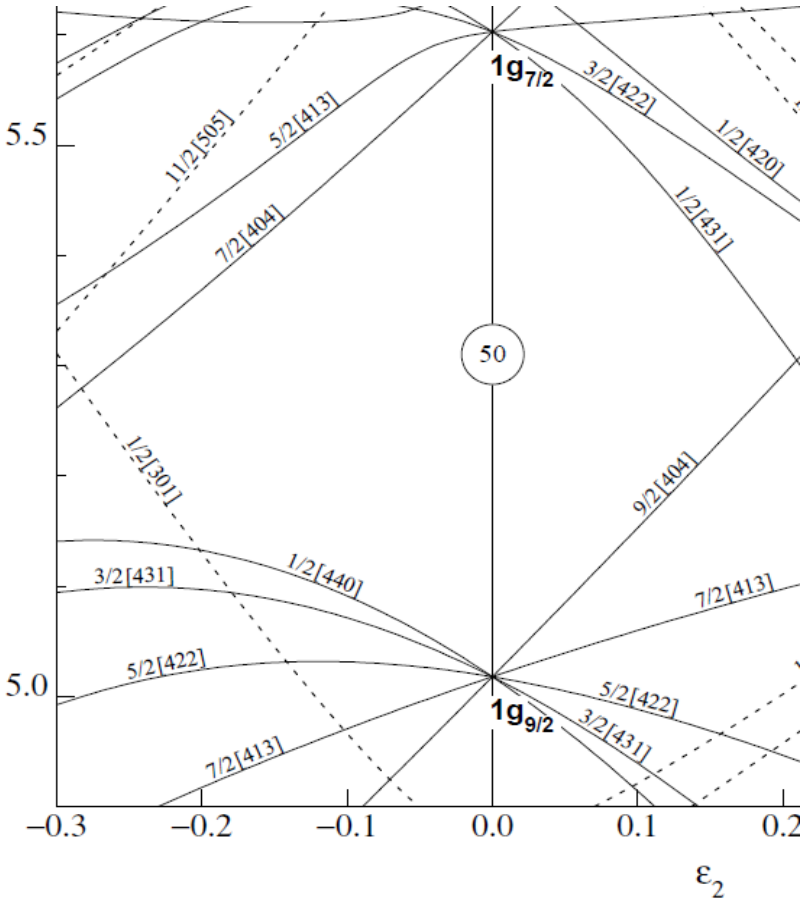


Motivation (1)

neutrons



protons



$B(E2,0_1^+ \rightarrow 2_1^+)=(2.8^+_-0.5)\ E^{-1}\ Z^2\ A^{-2/3}$
(for A > 60)

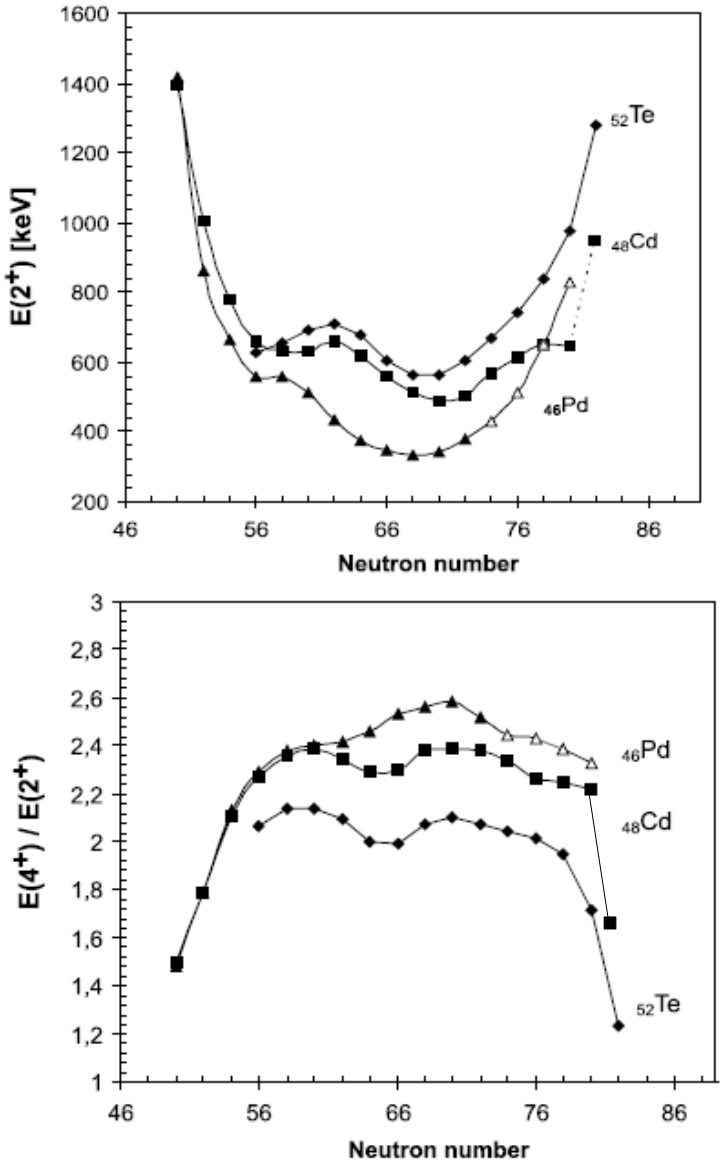
S. Raman et al., Phys. Rev. C 43, 556 (1991)

$$\beta_2 = \frac{4\pi}{3ZR_0^2} \cdot \left(B(E2)\uparrow/e^2\right)^{1/2} \qquad (1)$$

^{124}Cd: β_2 = 0.16 (Raman)
= 0.14 (Coulex, Kröll)
^{126}Cd: β_2 = 0.15 (Raman)
= 0.12 (Coulex, Kröll)
^{128}Cd: β_2 = 0.15 (Raman)

T. Kröll et al., FINUSTAR 2, AIP CP 1012, 84 (08)

Motivation (2)



Kautsch et al., Eur. J. Phys. A9, 201 (00)

Systematics of heavy Cd isotopes:
Kautsch et al., Eur. J. Phys. A9, 201 (00):
weakening of shell gap at N=82 for Z=50+-2
already one proton pair below ^{132}Sn

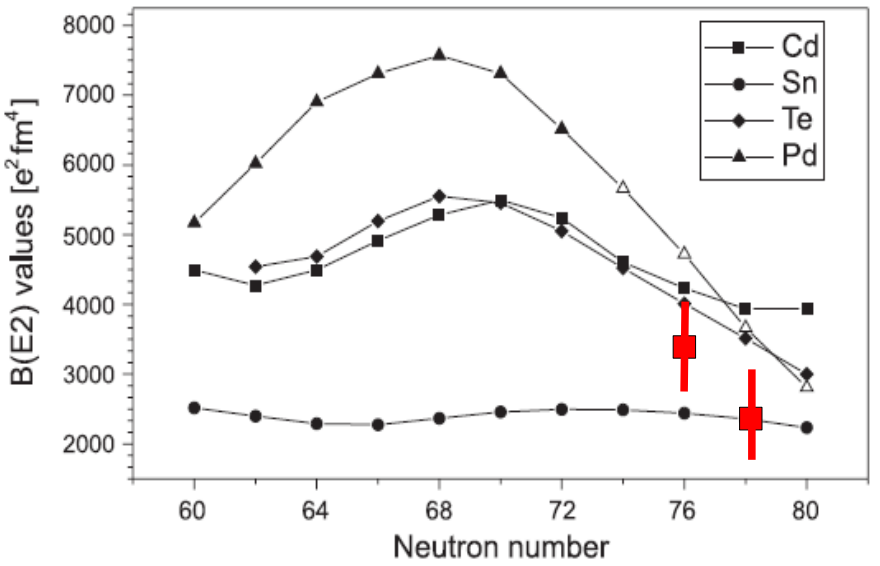


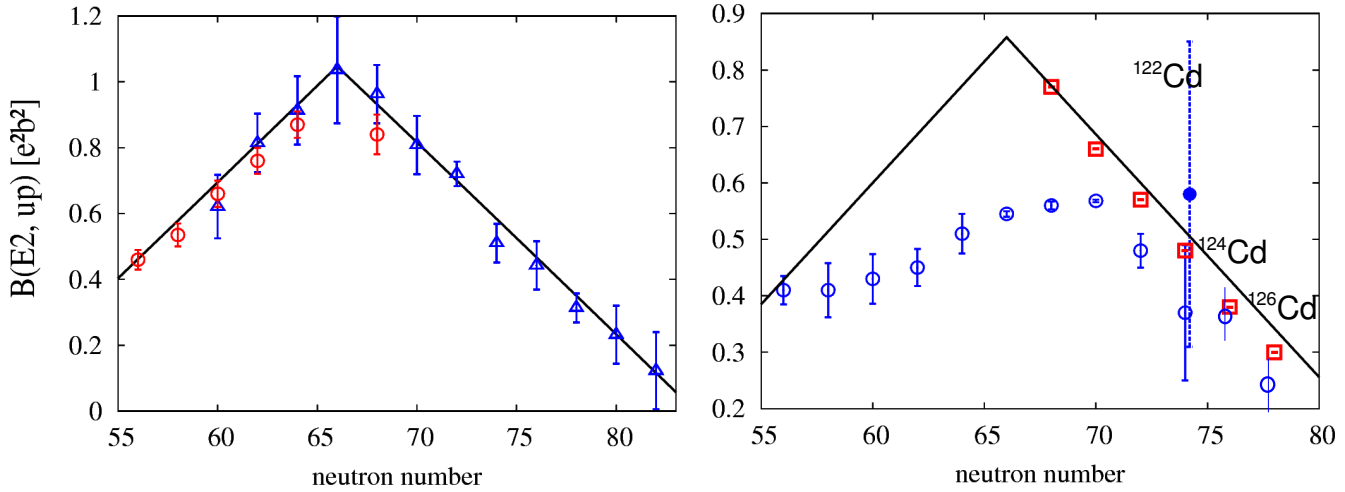
Fig. 3. $B(E2)$ values of neutron-rich $_{48}$Cd, $_{50}$Sn and $_{52}$Te isotopes, deduced from the $E(2^+)$ with the relation given by Raman *et al.* [32].

Exp. data
T. Kröll et al.,
FINUSTAR 2
AIP CP 1012,
84 (08)

$B(E2,0_1^+ \rightarrow 2_1^+) = (2.8^+\_0.5)\ E^{-1}\ Z^2\ A^{-2/3}$
(for A > 60)

S. Raman et al., Phys. Rev. C 43, 556 (1991)

Motivation (3)
Valence proton symmetry



Pd Xe Cd Te

Valence proton symmetry:
nuclei X,Y with same N and
same valence proton number/holes
have equal collective properties
$|Z_m-Z_x| = |Z_m-Z_y| = N_\pi$
identical spectra and
transistion probabilities

B(E2) values described by $B(E2; 0_1^+ \rightarrow 2_1^+) = 0.0215 N_\pi \cdot N_\nu e^2b^2 + 0.17 e^2b^2$

Scaling factor $S(N, Z_m) = \left(\frac{Z_m - N_\pi}{Z_m + N_\pi}\right)^2 \cdot \frac{N + Z_m - N_\pi}{N + Z_m + N_\pi}$

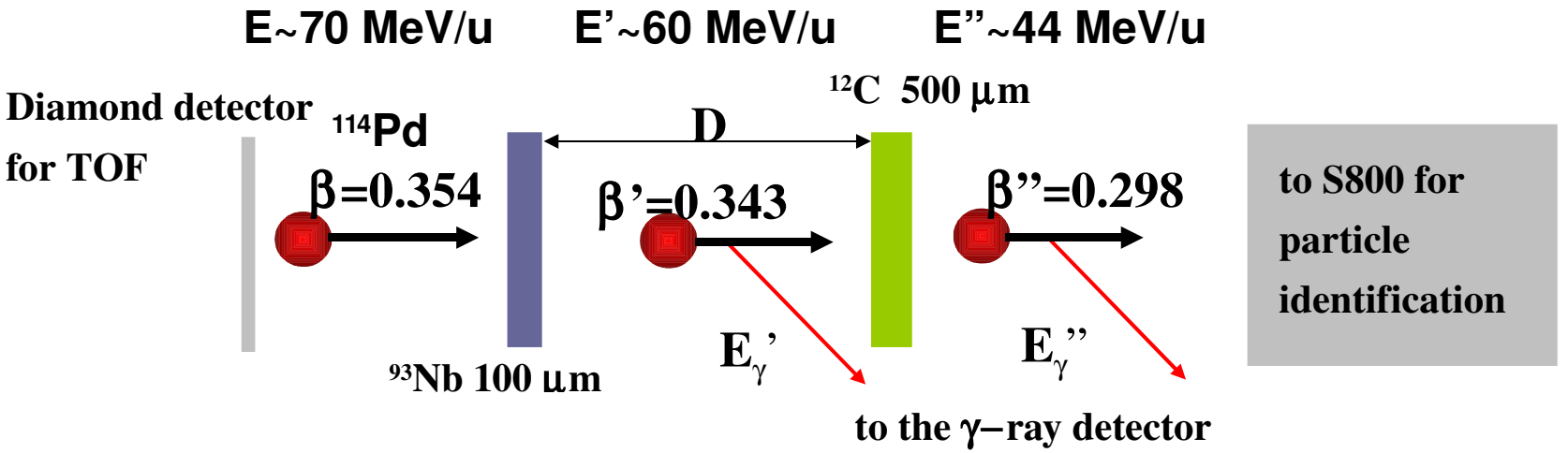
But: deviation from VPS for lighter Cd isotopes:
possibly caused by configuration mixing of quadrupole anharmonic vibration and intruder
K. Heyde, Phys. Rev. C 25, 3160 (82)
Data for n-rich Cd isotopes from Coulex
T. Kröll et al., FINUSTAR 2, AIP CP 1012, 84 (2008)
-> but: cannot exclude possible systematic errors

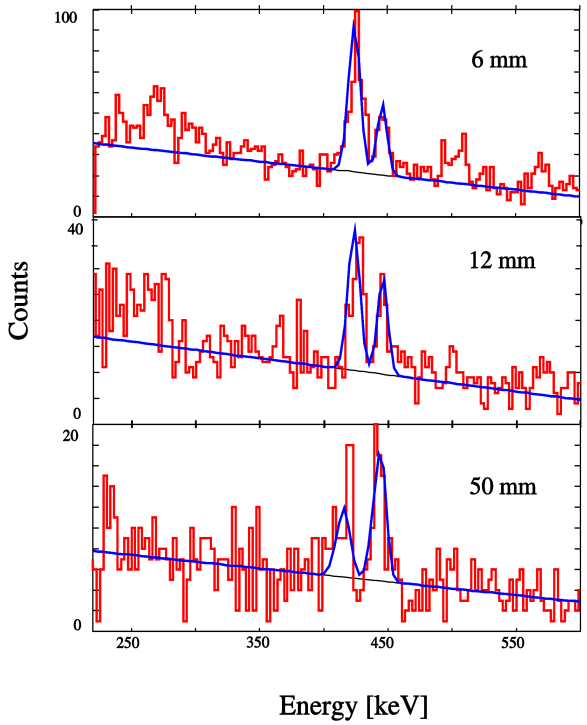
Motivation (4)

- Aim: determine B(E2;0_1^+ -> 2_1^+) in ^{124,126}Cd with RDDS with precision better than 10%
- Measurements performed on ^{124,126}Cd @ REX-ISOLDE with safe Coulex (2.85 MeV/u)
- Proposed experiment: Coulex with E_{beam} ~ 200 MeV/u, thus large Doppler-shifts
  → need good resolution which is provided by AGATA
- Expect larger cross sections of 300 - 400 mbarn
- Establish this new technique (Plunger+Coulex) at GSI
- Success of this method already proven in experiments at NSCL/MSU: n-rich Fe, Pd,...

Plunger technique at intermediate-energy with coulex: NSCL, MSU

Example: ^{110,114}Pd





$2_1^+ \rightarrow 0_1^+$

Example:
^{114}Pd spectra after projectile Coulex at 3 different target – degrader separations
(SeGA array, MSU),
β=0.35

Lineshape analysis:

^{114}Pd:

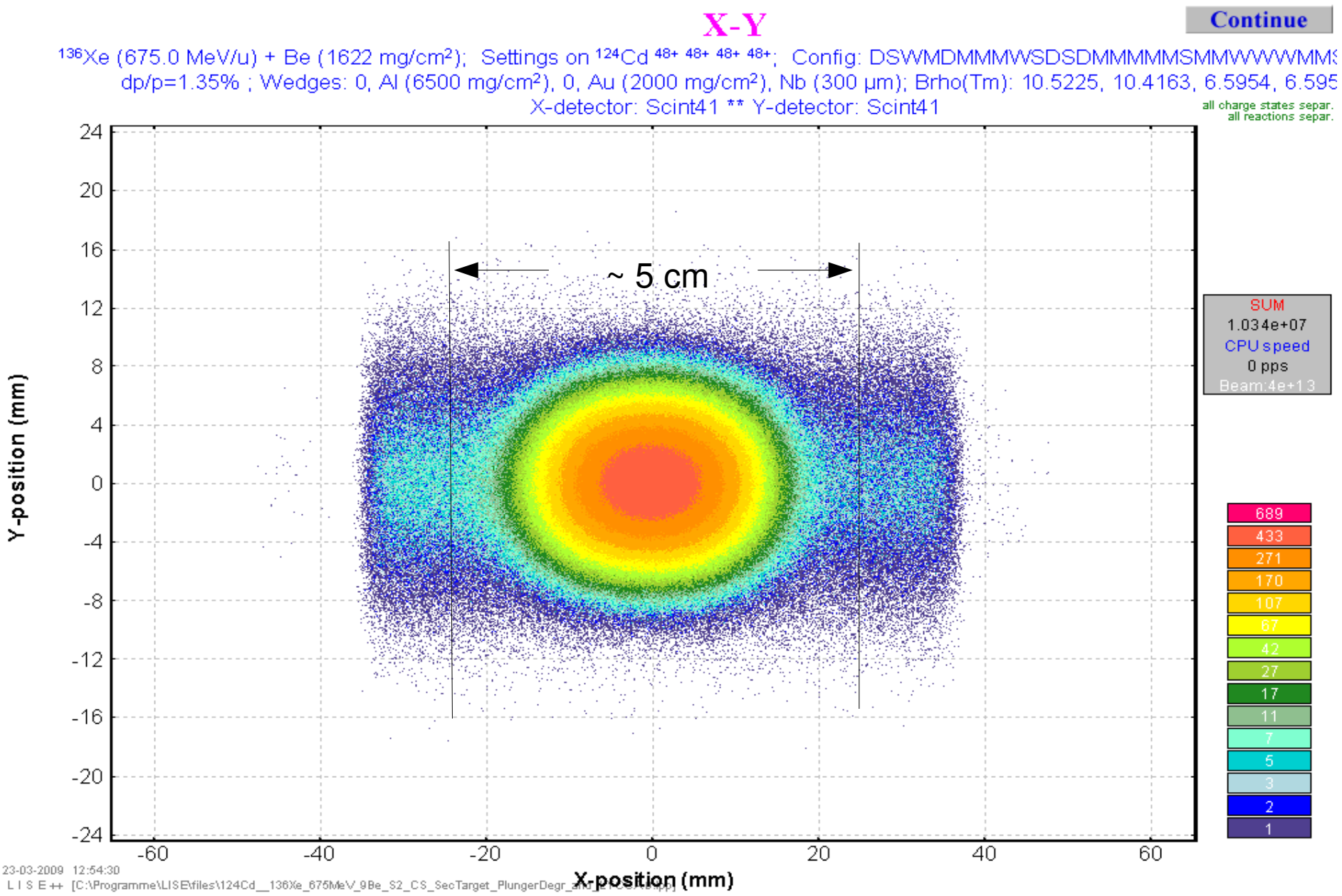
τ =118 (20) ps

^{110}Pd:

τ=67 (8) ps

A. Dewald et al, Phys. Rev C 78, 051302(R), 2008

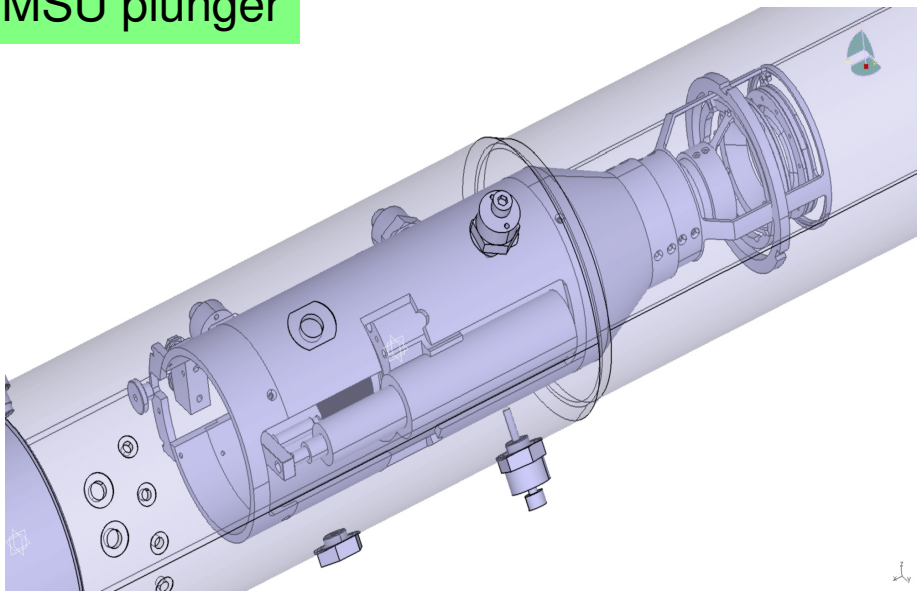
LISE++ simulation: beam @ PRESPEC



→ Large beam diameter > 40 mm + halo

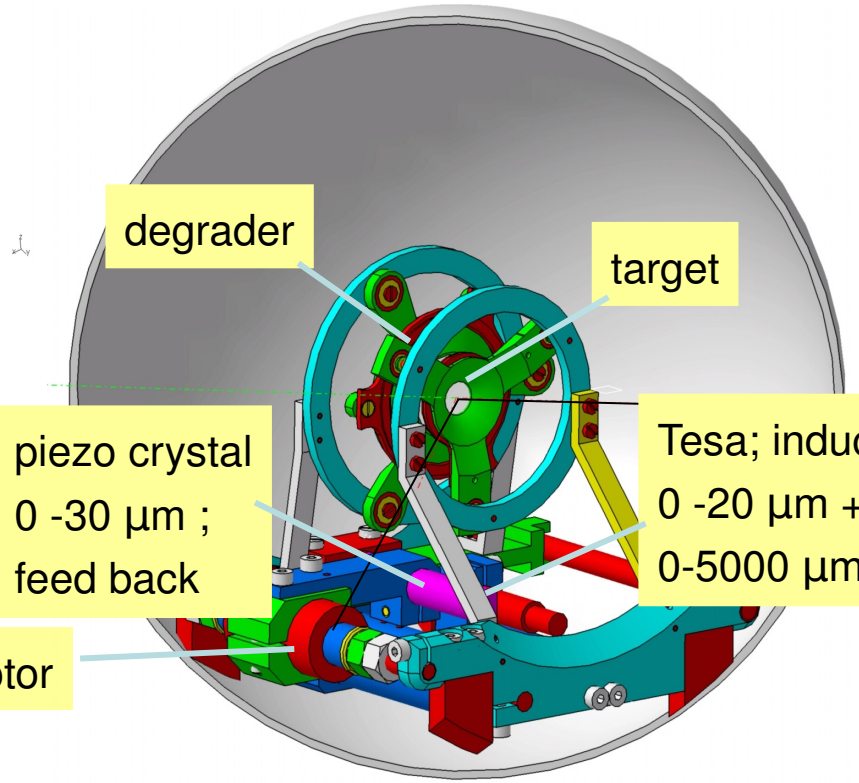
Existing plunger devices for radioactive beams

MSU plunger



target/ degrader diameter: 4 cm
target/ degrader separations: 0 - 2.5 cm
precision : ~ 1 µm
target/ degrader thickness: ~1µm -1mm

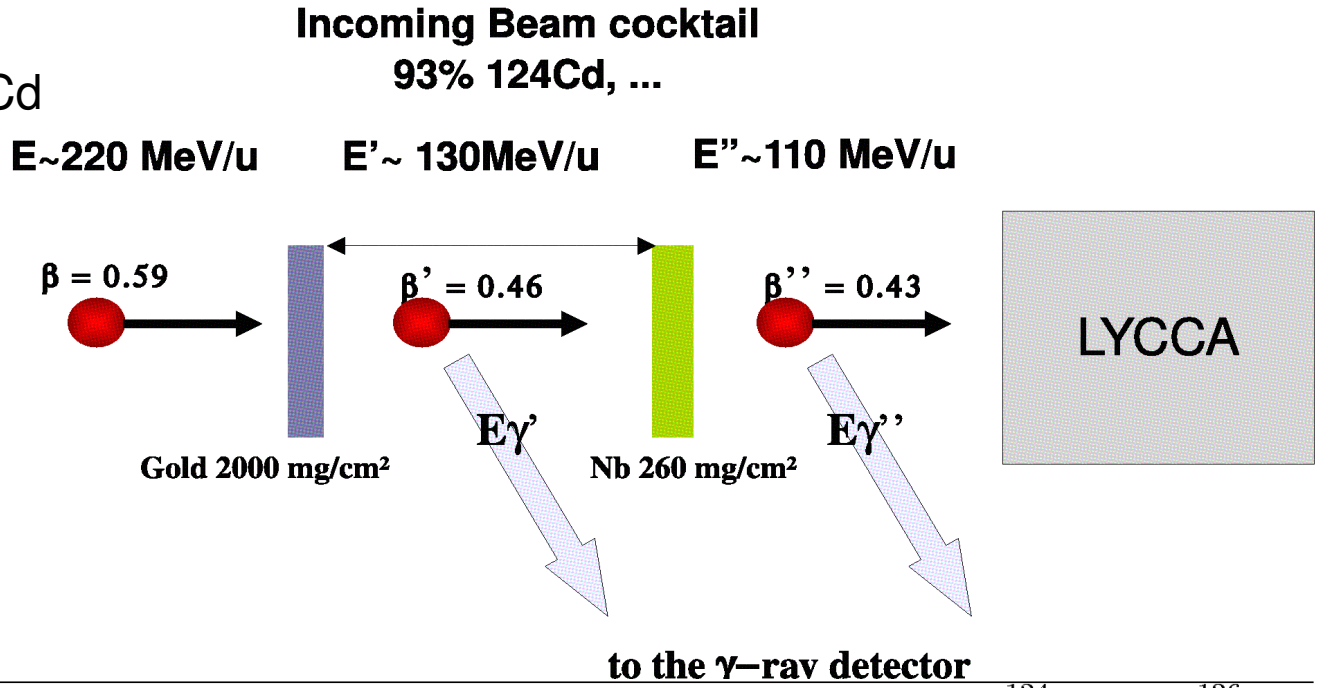
LNL/GANIL plunger



Construction for new GSI plunger based on this concept

Differential plunger technique: proposed experiment @ PRESPEC

Kinematics for ^{124}Cd



	^{124}Cd	^{126}Cd
S2 intensity	$4.50 \cdot 10^4$	$1.30 \cdot 10^3$
Transmission through FRS for nucleus of interest	22.09%	23.98%
Incoming beam energy on plunger-target [MeV/u]	220	280
Incoming velocity on plunger-target [c]	0.59	0.64
Total/^{12X}Cd incoming beam intensity on plunger target [pps]	230/209	34/31
Number of particles registered by LYCCA [pps]	200/186	30/27
$2_1^+ \rightarrow 0_1^+$ γ-ray energy [keV]	612	652
Assumed lifetime τ [ps]	16.4	16.4
Change in Doppler-shifted energy at 15° [keV]	37.4	40.1
PRESPEC γ-ray energy resolution [%]	4	4
Averaged cross section for Coulex in target [mb]	300	400
Number of Coulomb excitations on target [1/s]	0.24	0.14
Number of detected good PRESPEC-LYCCA coincidences/h	35	20
Estimated number of shifts	9	18

Differential plunger technique: proposed experiment @ PRESPEC

	^{124}Cd	^{126}Cd
S2 intensity	$4.50 \cdot 10^4$	$1.30 \cdot 10^3$
Transmission through FRS for nucleus of interest	22.09%	23.98%
Incoming beam energy on plunger-target [MeV/u]	220	280
Incoming velocity on plunger-target [c]	0.59	0.64
Total/^{12X}Cd incoming beam intensity on plunger target [pps]	230/209	34/31
Number of particles registered by LYCCA [pps]	200/186	30/27
$2_1^+ \rightarrow 0_1^+$ γ-ray energy [keV]	612	652
Assumed lifetime τ [ps]	16.4	16.4
Change in Doppler-shifted energy at 15° [keV]	37.4	40.1
PRESPEC γ-ray energy resolution [%]	4	4
Averaged cross section for Coulex in target [mb]	300	400
Number of Coulomb excitations on target [1/s]	0.24	0.14
Number of detected good PRESPEC-LYCCA coincidences/h	35	20
Estimated number of shifts	9	18

Results of a LISE++ calculation (1)

	^{122}Cd	^{124}Cd	^{126}Cd
Primary beam	^{136}Xe	^{136}Xe	^{136}Xe
Energy [MeV/u]	700	675	675
Intensity [pps]	$1 \cdot 10^9$	$1 \cdot 10^9$	$1 \cdot 10^9$
^{9}Be target [mg/cm^2]	1622	1622	1622
S1 wedge Al [mg/cm^2]	2000	–	–
S2 wedge Al [mg/cm^2]	5000	6400	5500
Secondary beam	^{122}Cd	^{124}Cd	^{126}Cd
Purity [%]	93	93	90
S2 intensity	$9.80 \cdot 10^4$	$4.50 \cdot 10^4$	$1.30 \cdot 10^3$
Transmission through FRS for nucleus of interest	15.86%	22.09%	23.98%
Beamspot size at plunger-target X-plane [mm]	$\pm$20	$\pm$20	$\pm$15
Incoming beam energy on plunger-target [MeV/u]	220	220	280
Incoming velocity on plunger-target [c]	0.59	0.59	0.64
Total/^{12X}Cd incoming beam intensity on plunger target [pps]	770/727	230/209	34/31
Number of particles registered by LYCCA [pps]	700/651	200/186	30/27
Thickness Au plunger target [g/cm^2]	2.0	2.0	3.5
Outgoing beam energy plunger target [MeV/u]	120	120	130
Outgoing velocity plunger target [c]	0.464	0.464	0.480
Thickness plunger-degrader (Nb) [μm]	300	300	300
Outgoing beam energy plunger-degrader [MeV/u]	100	100	110
Outgoing beam velocity plunger-degrader [c]	0.430	0.430	0.447
Change in beam velocity target-degrader [c]	0.034	0.034	0.033

Results of a LISE++ calculation (2)

	^{122}Cd	^{124}Cd	^{126}Cd
State of interest	2_1^+	2_1^+	2_1^+
Transition of interest	$2_1^+ \rightarrow 0_1^+$	$2_1^+ \rightarrow 0_1^+$	$2_1^+ \rightarrow 0_1^+$
γ-ray energy of interest [keV]	562	612	652
Assumed lifetime τ [ps]	14.4	16.4	16.4
Flight-path corresponding to τ [mm]	2.1	2.4	2.4
Doppler-shiftet γ-ray energy of interest after plunger-target at 30° [keV]	843.4	907.5	979.0
Doppler-shiftet γ-ray energy of interest after plunger-target at 15° [keV]	914.2	983.7	1066.5
Doppler-shiftet γ-ray energy of interest after plunger-degrader at 30° [keV]	819.2	881.5	951.6
Doppler-shiftet γ-ray energy of interest after plunger-degrader at 15° [keV]	879.4	946.4	1026.4
Change in Doppler-shifted energy at 30° [keV]	24.2	26.0	26.6
Change in Doppler-shifted energy at 15° [keV]	34.8	37.4	40.1
PRESPEC γ-ray energy resolution [%]	4	4	4
Averaged cross section for Coulex in target [mb]	300	300	400
Number of Coulomb excitations on target [1/s]	1.19	0.24	0.14
Cross section for Coulex on degrader [mb]	140	140	140
Number of excitations on degrader [1/s]	0.15	0.05	0.008
Photopeak efficiency for three rings of PRESPEC at forward angles [%]	4	4	4
Number of detected good PRESPEC-LYCCA coincidences [1/s]	0.0477	0.0096	0.0056
Number of detected good PRESPEC-LYCCA coincidences per hour	172	35	20
Number of shifts per single target-degrader data point	1	3	6
Estimated number of shifts to complete the measurement	3	9	18

Collaboration

C. Fransen, A. Dewald, A. Blazhev, N. Braun, T. Braunroth, B. Bruyneel,
M. Hackstein, J. Jolie, T. Pissulla, P. Reiter, W. Rother
Institut für Kernphysik, Universität zu Köln, Cologne, Germany

M. Gorska and the PRESPEC collaboration
GSI, Darmstadt, Germany

T. Kröll, R. Krücken
TU München, Garching, Germany

A. Jungclaus, R. Orlandi
IEM-CSIC, Madrid, Spain

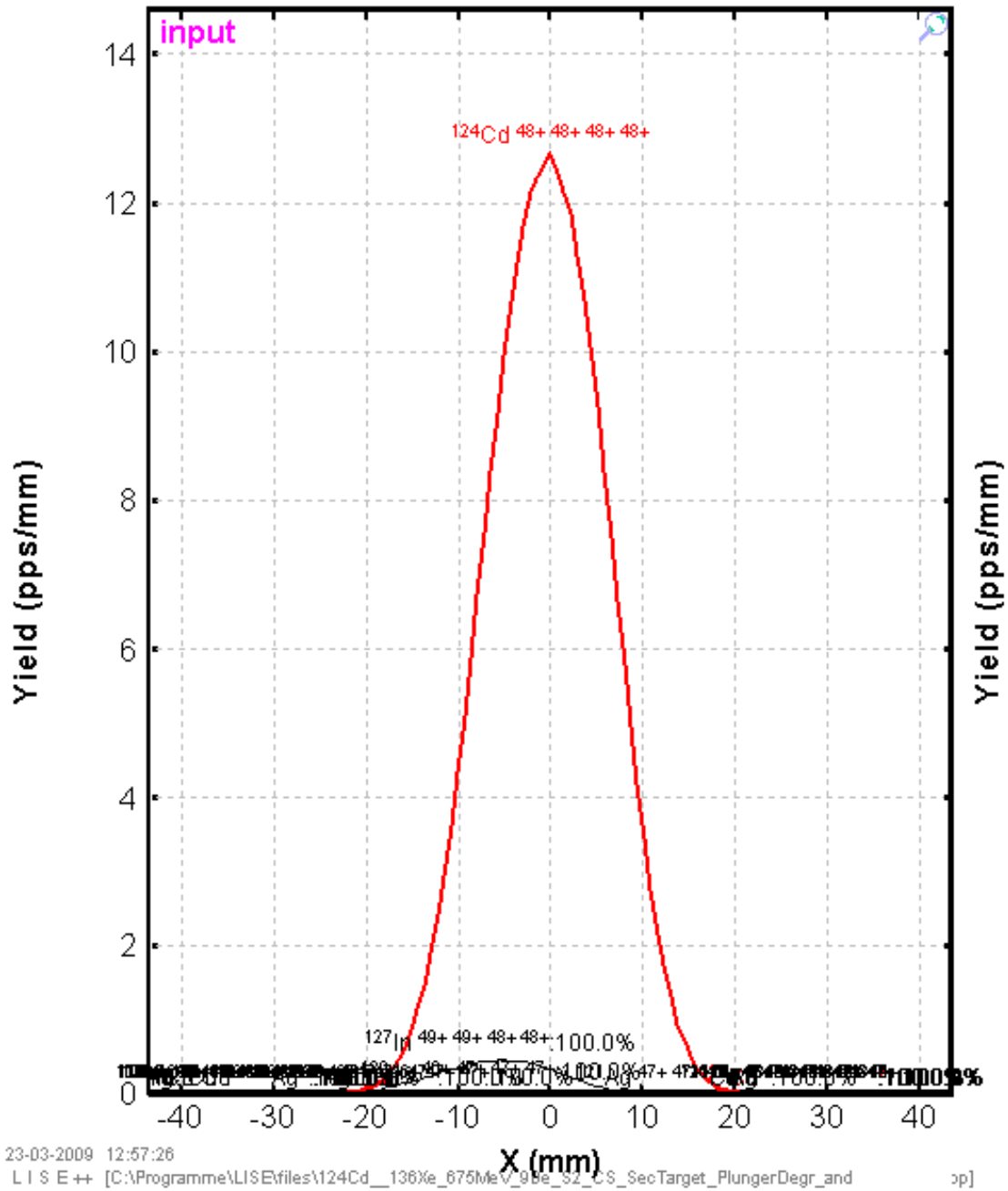
P. Petkov
INRNE, Sofia, Bulgaria

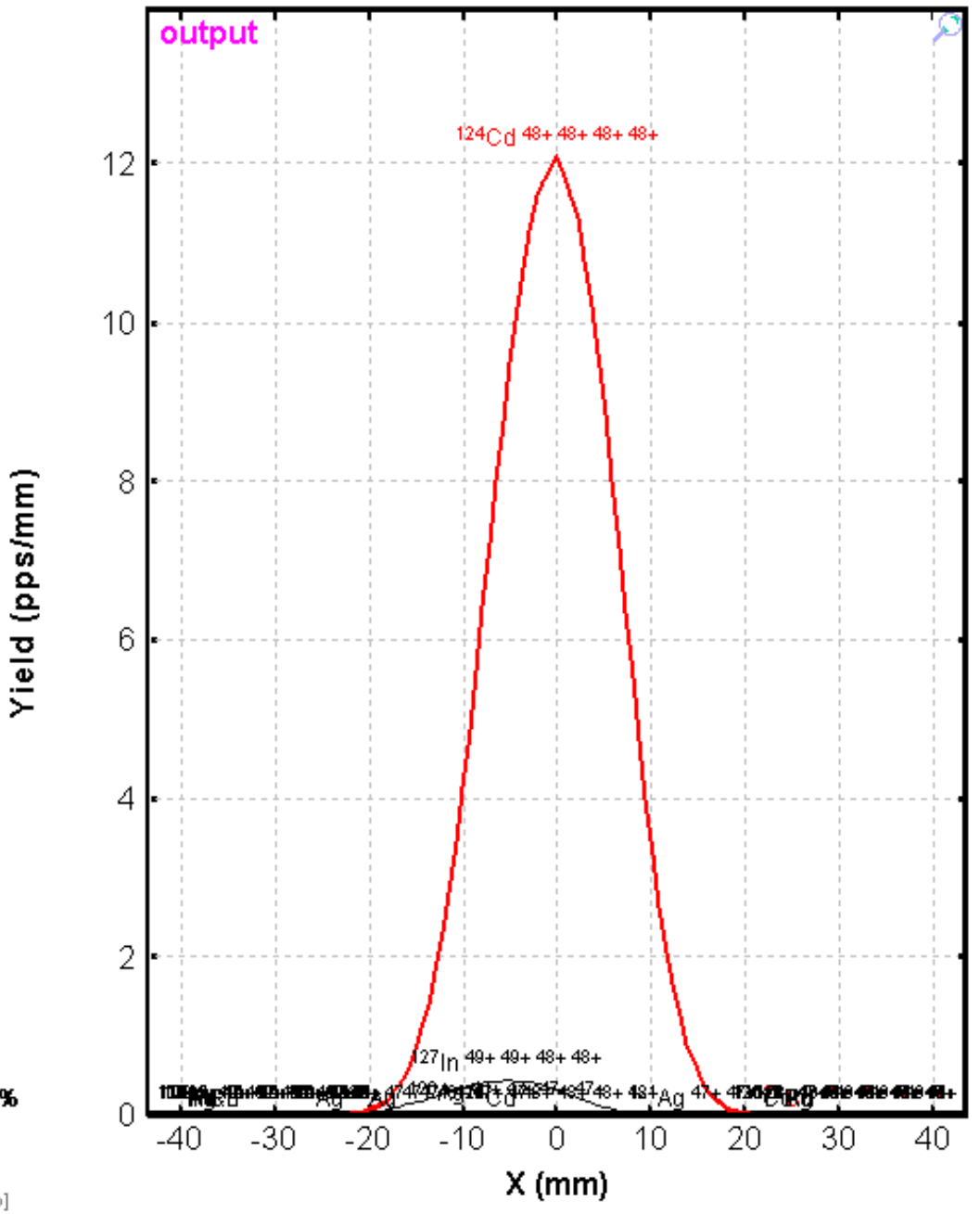
H. Iwasaki
NSCL, MSU, East Lansing MI, USA

Secondary Target-Xspace

^{136}Xe (675.0 MeV/u) + Be (1622 mg/cm^2); Settings on ^{124}Cd $^{48+}$ $^{48+}$ $^{48+}$ $^{48+}$; Config: DSVVMDMMMVVSDSDMMMMMSMMVVVVMMS
dp/p=1.35% ; Wedges: 0, Al (6500 mg/cm^2), 0, Au (2000 mg/cm^2), Nb (300 µm); Brho(Tm): 10.5225, 10.4163, 6.5954, 6.595

all charge states separ.
sum of reactions





23-03-2009 12:57:26
L I S E++ [C:\Programme\LISE\files\124Cd__136Xe_675MeV_9Be_S2_CS_SecTarget_PlungerDegr_and ...op]

Plunger at GSI: PRESPEC/LYCCA -> HISPEC