Coulomb excitation of the exotic, neutron-rich nuclei ^{94}Kr and ^{96}Kr

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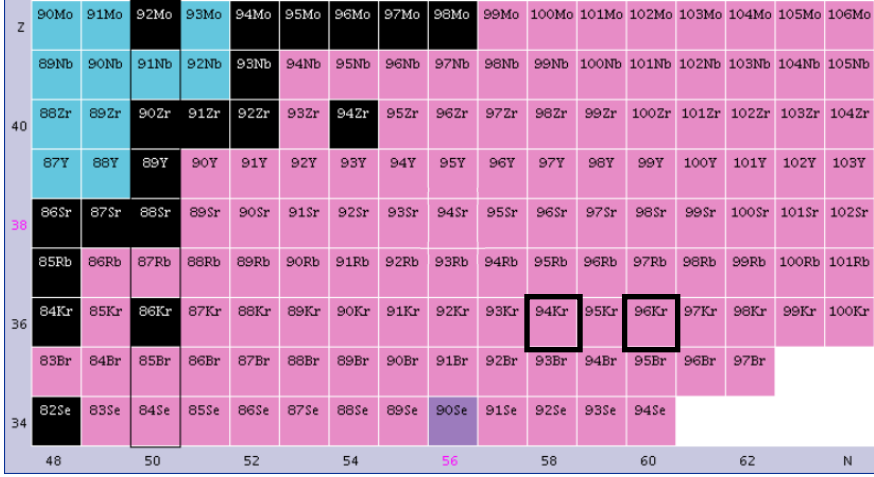
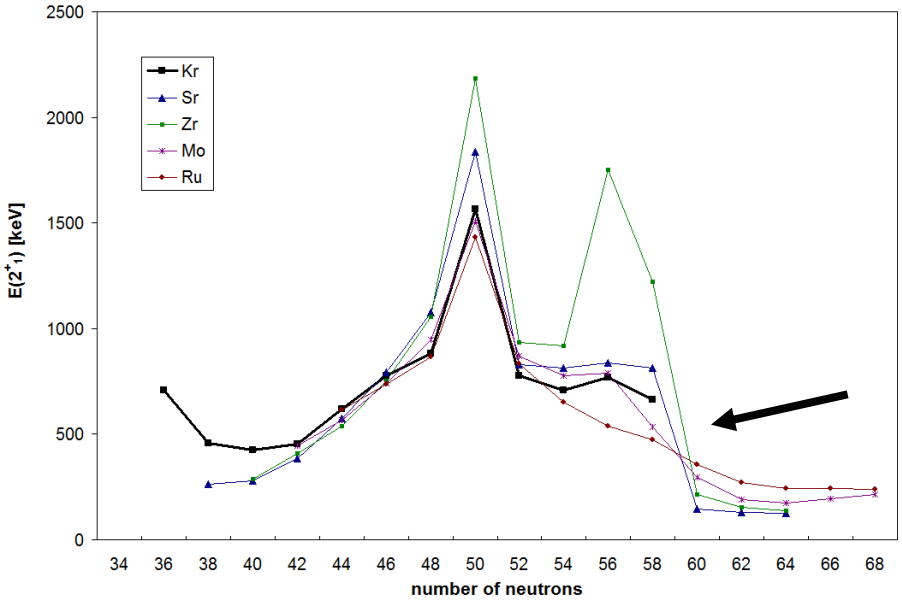
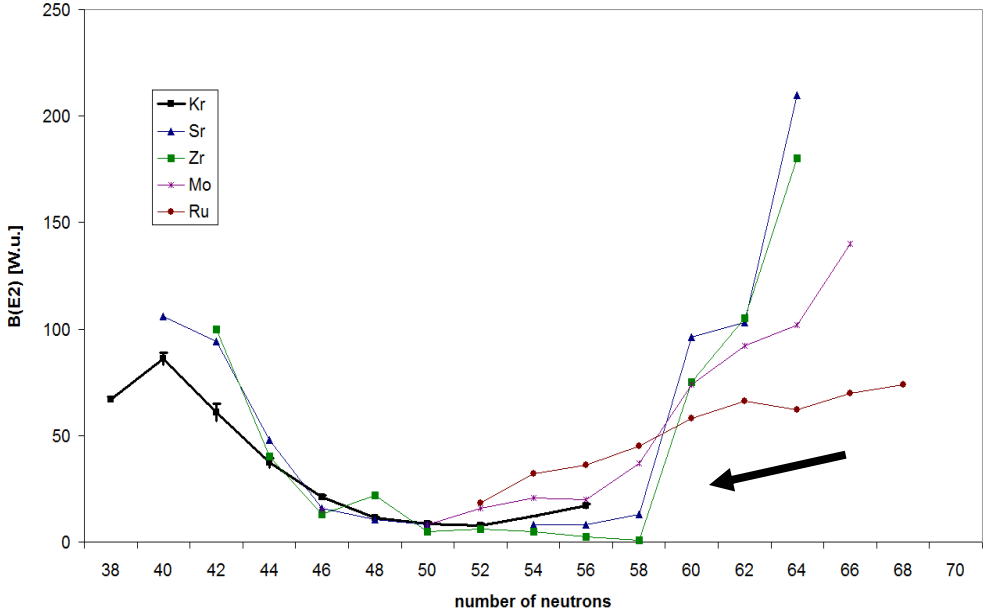
Introduction

The mass region around Z~40, N~60 is well suited to investigate the development of collective effects







Interpretation: correlated occupation of Nilsson states:

$$\pi g_{9/2} \leftrightarrow \nu h_{11/2} \quad (1,2)$$

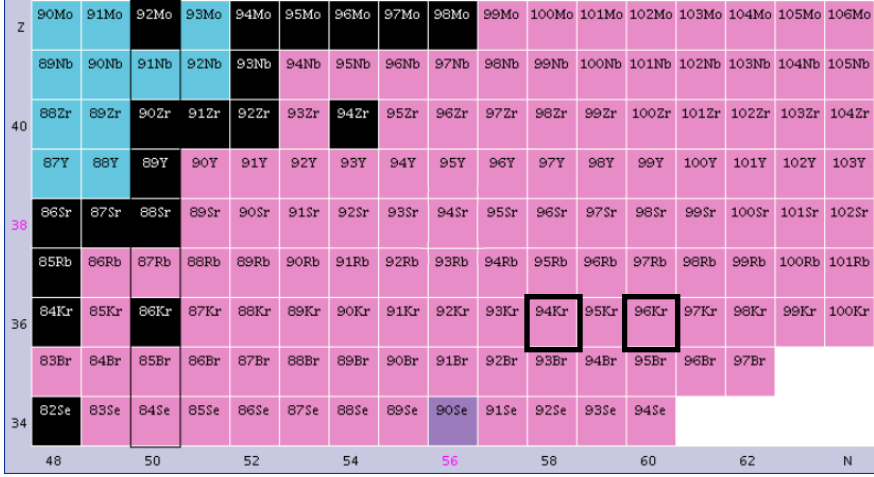
Krypton isotops: Z=36 → reduced pn-interaction?

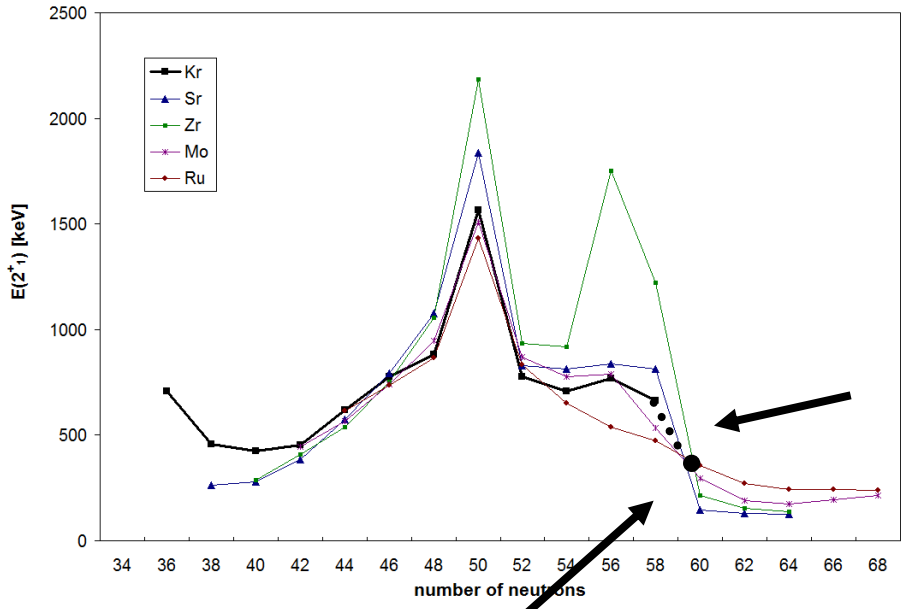
1: A. Kumar, M.R. Guyne, *Phys. Rev. C32(1985)2116;*

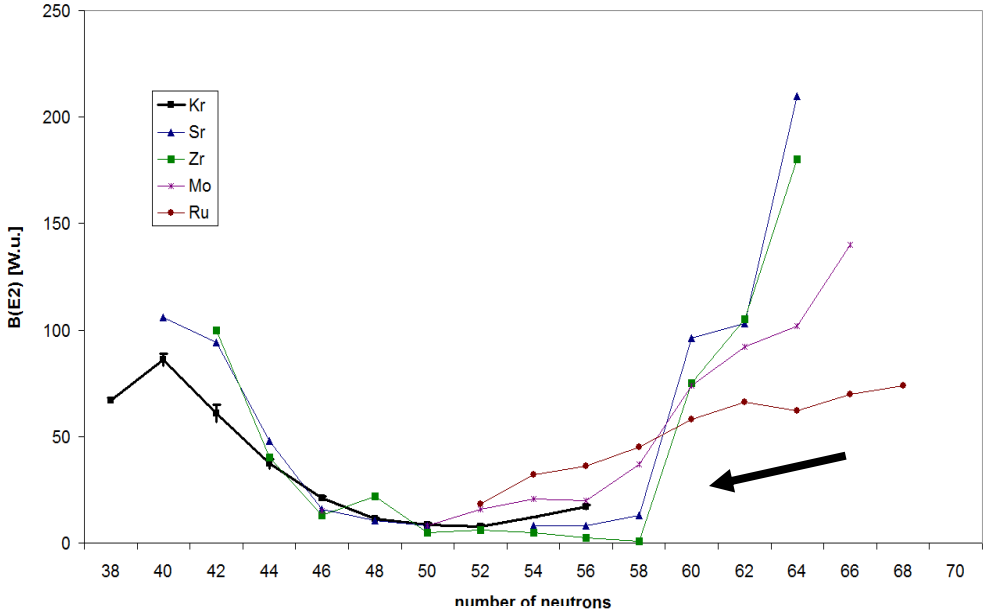
2: W. Urban et al., *Nucl. Phys.* A *689 (2001) 605*

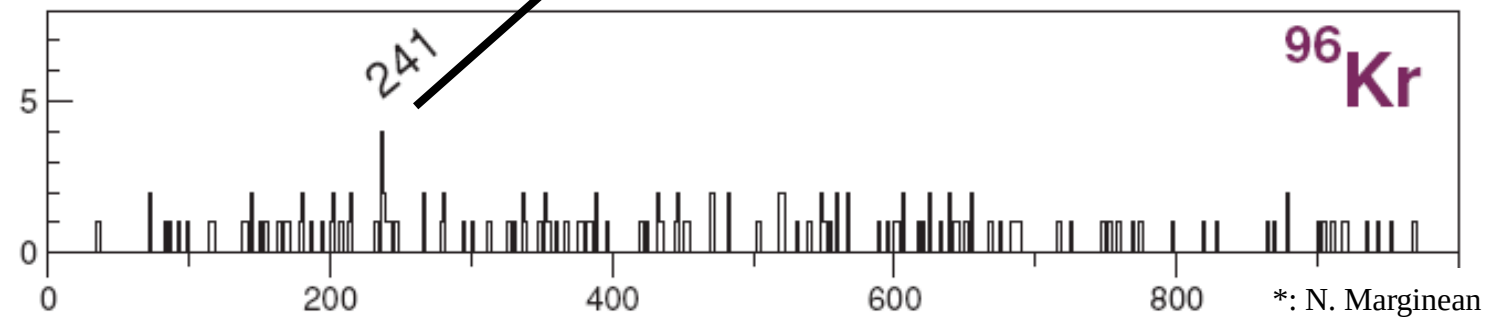
Introduction

The mass region around Z~40, N~60 is well suited to investigate the development of collective effects



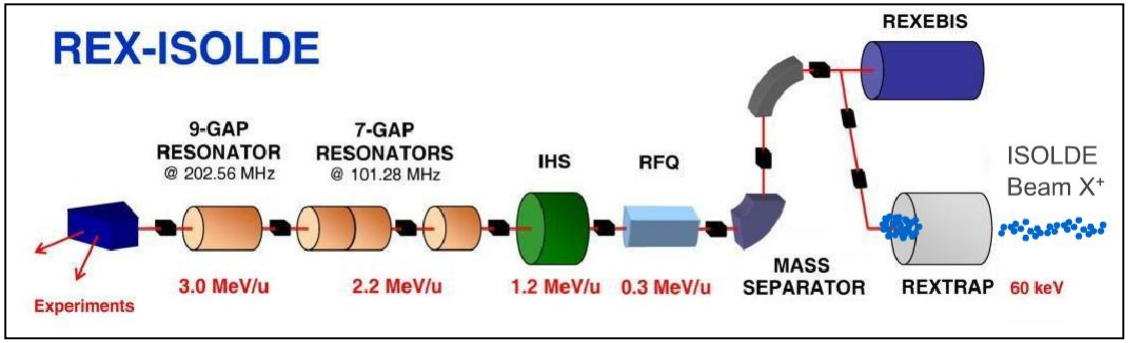


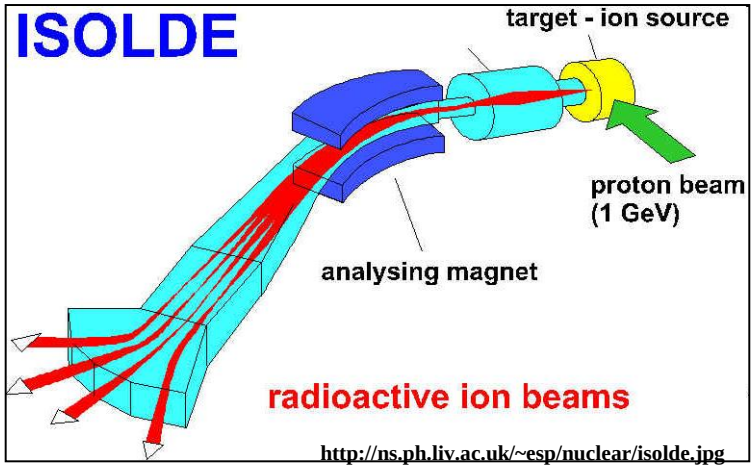




*: N. Marginean et al., PRC80, (2009), 021301

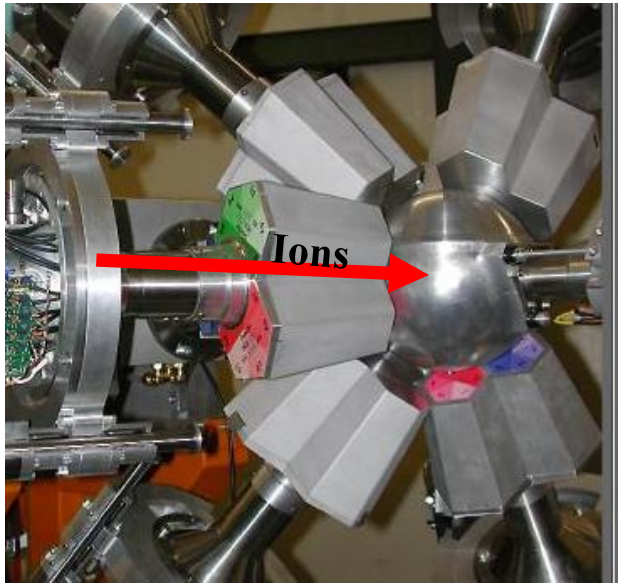
Experimental setup at the REX-ISOLDE post-accelerator at CERN



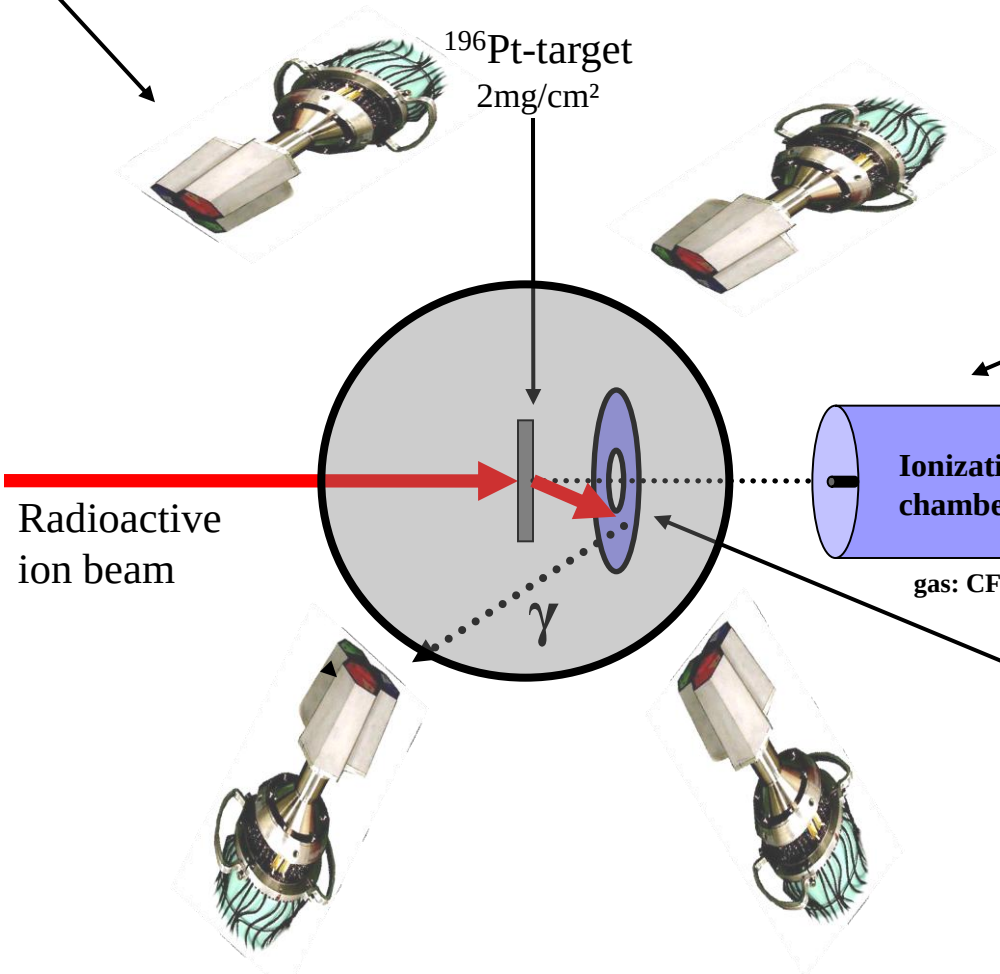


	^{94}Kr	^{96}Kr
Lifetime	212 (5) ms	80 (6) ms
Beam energy:	268 MeV	273.6 MeV
$t_{collect} + t_{breed}$	~ 80ms	~100ms
Charge state	22+	23+
A/q	4.27	4.17
# Ions at the target	$3 \cdot 10^5$ ionen/sec	$1.2 \cdot 10^4$ ionen/sec
Secondary target	^{196}Pt	^{196}Pt
Measuring duration	17h	9h

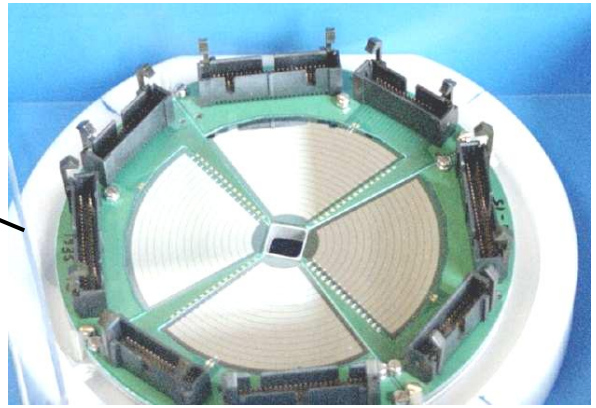
MINIBALL-γ-spectrometer
DSSSD-particle detector
ΔE-E telescope



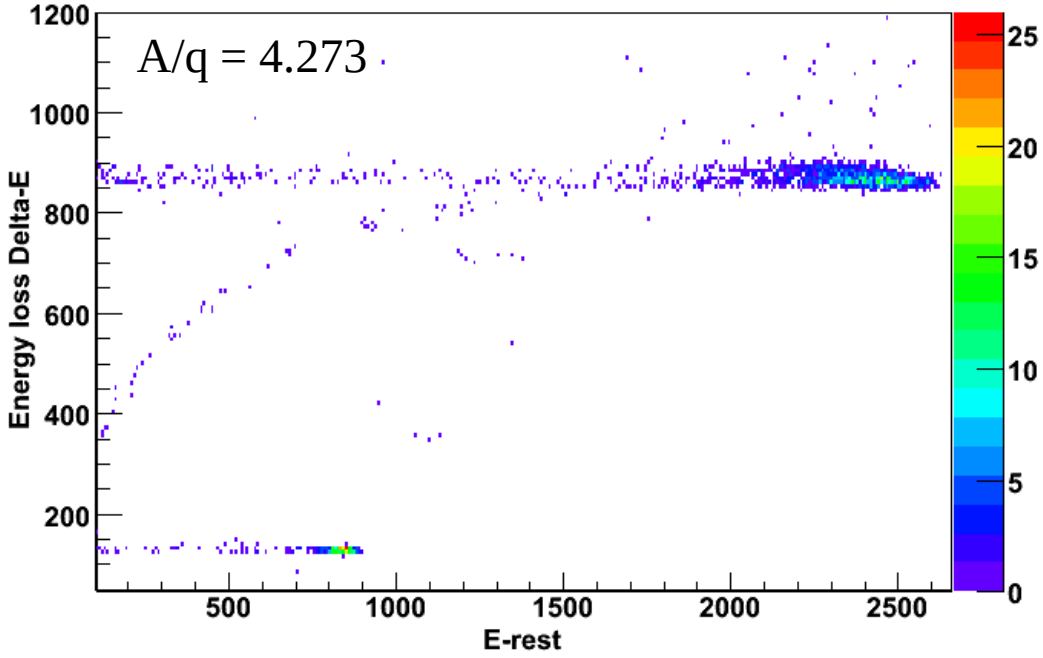
MINIBALL Cluster detectors

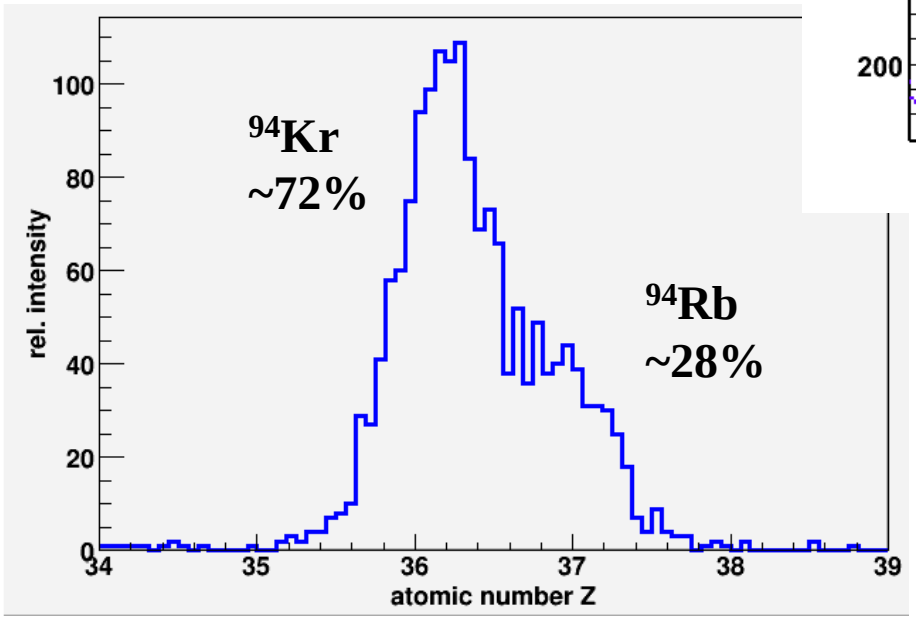


Double Sided Silicon Strip Detektor (DSSSD)



Identification of ^{94}Kr – beam composition





$T_{1/2}$ (^{94}Kr)=212 ms

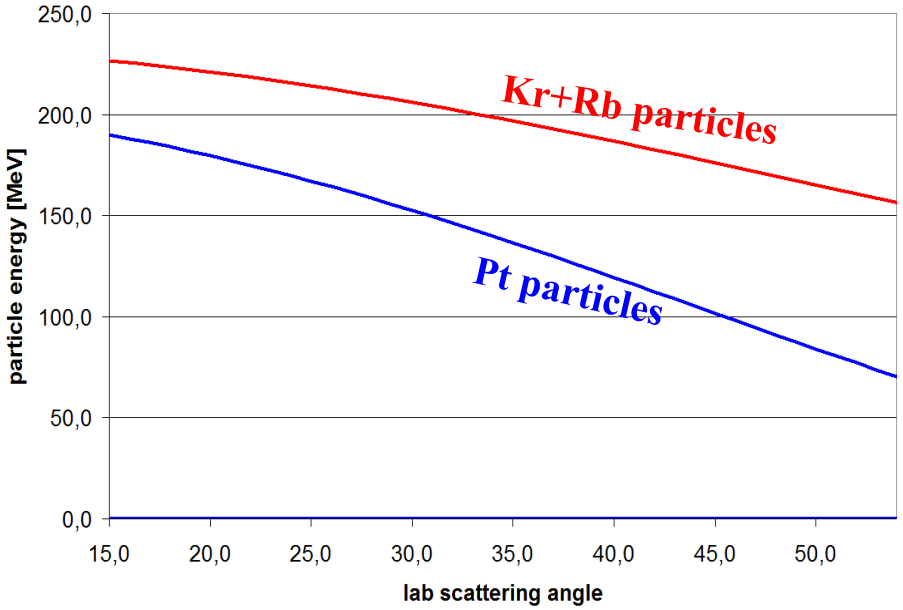
$t_{collect} + t_{breed} \approx 80$ms

Radioactive decay law:

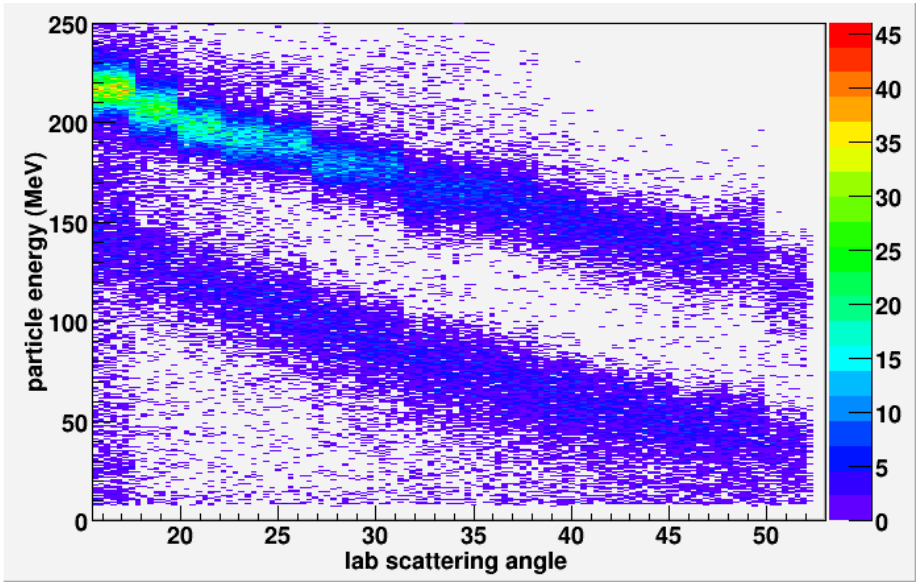
→ ~24% des ^{94}Kr decays to ^{94}Rb

Reaction kinematic

theoretical reaction kinematic*



Experimentally determined reaction kinematic



γ peaks caused by Coulex reaction appear Doppler shifted in the γ spectrum,
because the Coulomb excited ions emit their γ probably in flight.
By setting a particle gate, the Doppler shifted γ peaks
can be corrected.

*: catkin2.02, W.N. Catford (1998,2005)

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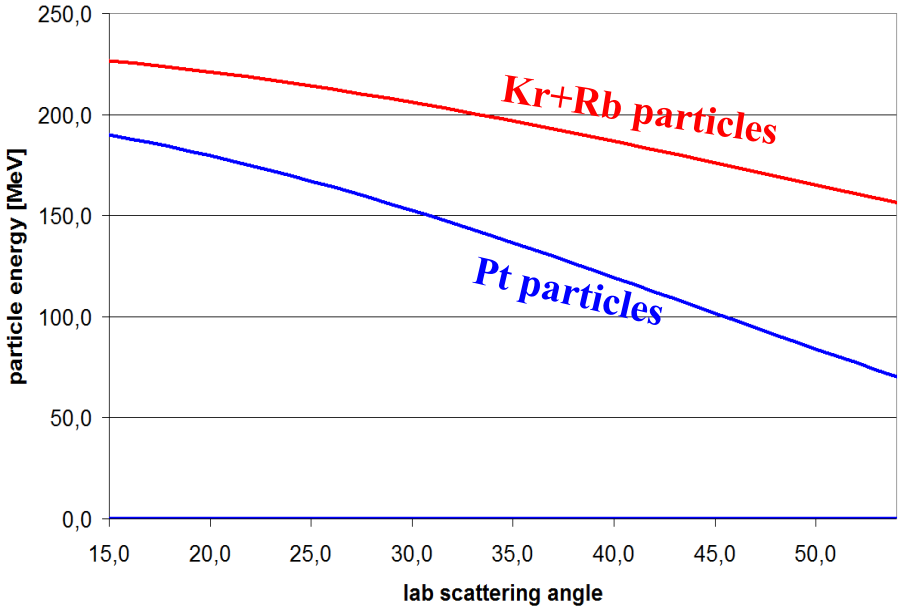

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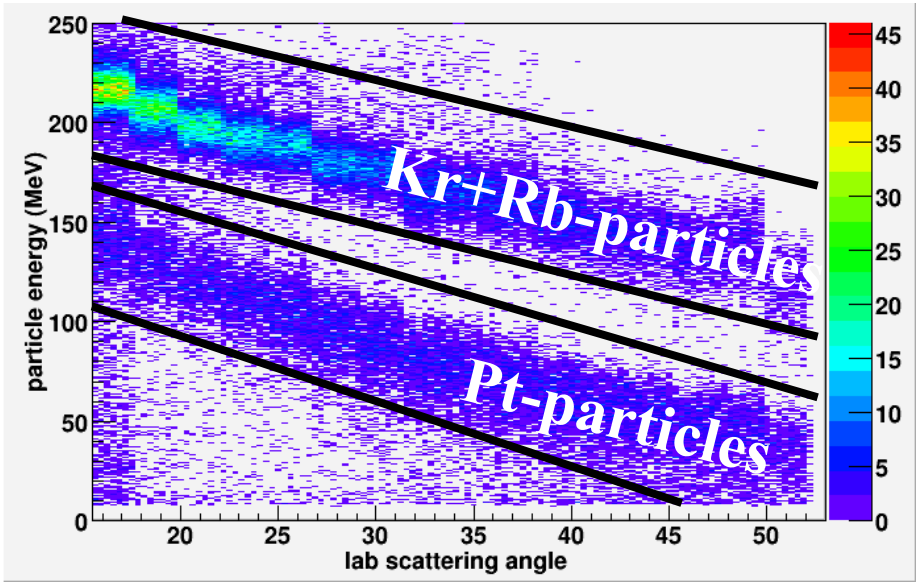

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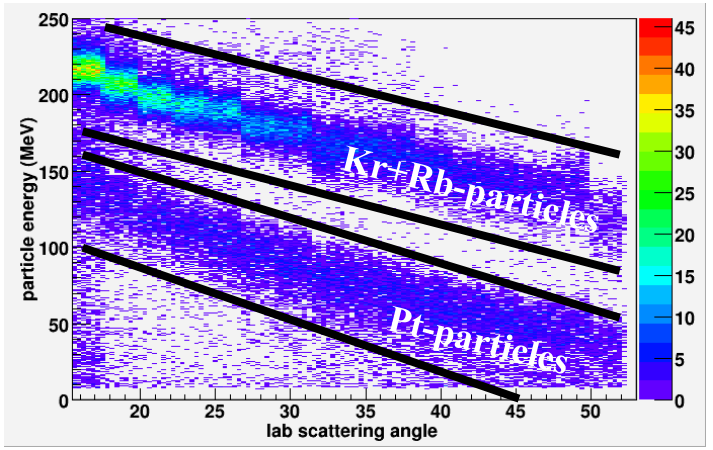
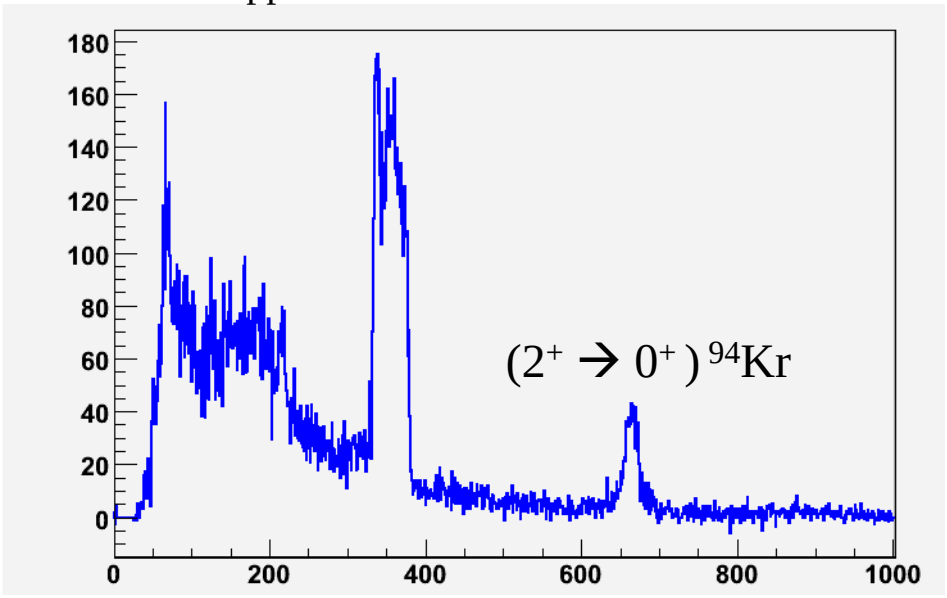
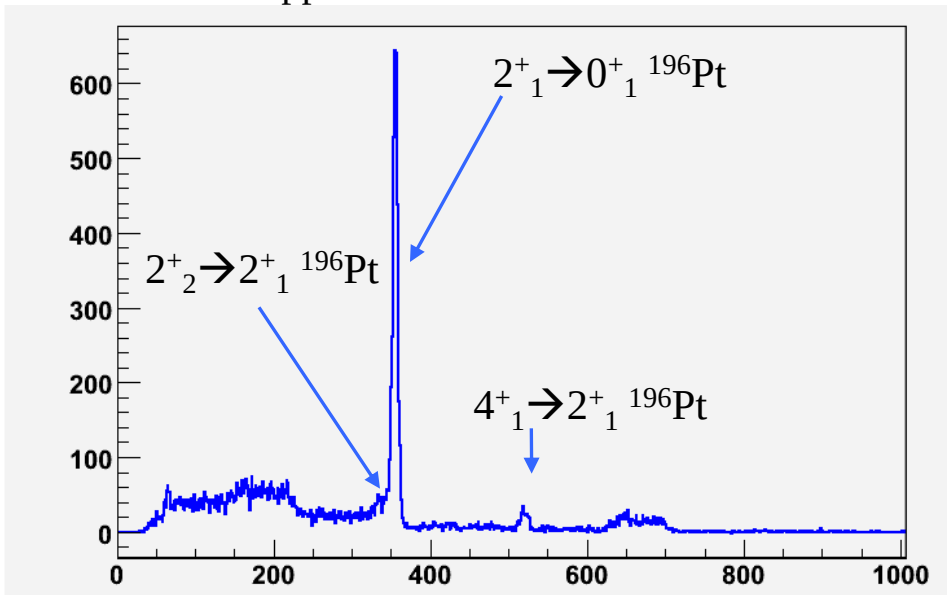
γ-spectra with particle-gates on ^{94}Kr- and ^{196}Pt-regions



particle-gate on Kr+Rb-region
Doppler-correction for A=94



particle-gate on Pt-region
Doppler-correction for A=196



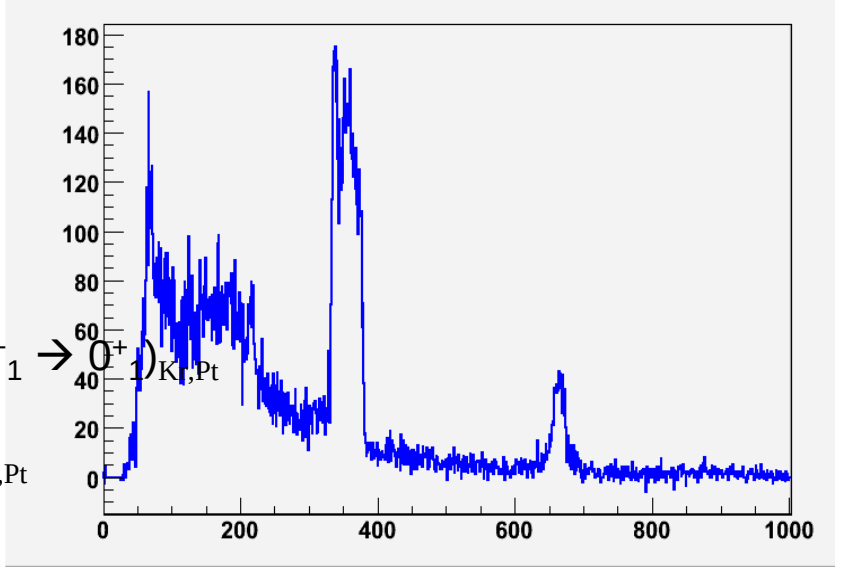
Determination of the absolute transition strength

- Utilizing the computer code CLX*, based upon the Coulex theorie of Winther and de Boer**, excitation cross-sections kann be determined.

$$\sigma_{Kr} \propto \frac{\varepsilon_{Pt}}{\varepsilon_{Kr}} \cdot \frac{N_{Kr}}{N_{Pt}} \cdot \sigma_{Pt}$$

For CLX used ^{196}Pt matrix elements		Final states		
		2+1	2+2	4+1
Initial states	0+1	1.172	----	----
	2+1	0.818	1.407	1.911
	2+2		-0.515	
	4+1			1.359

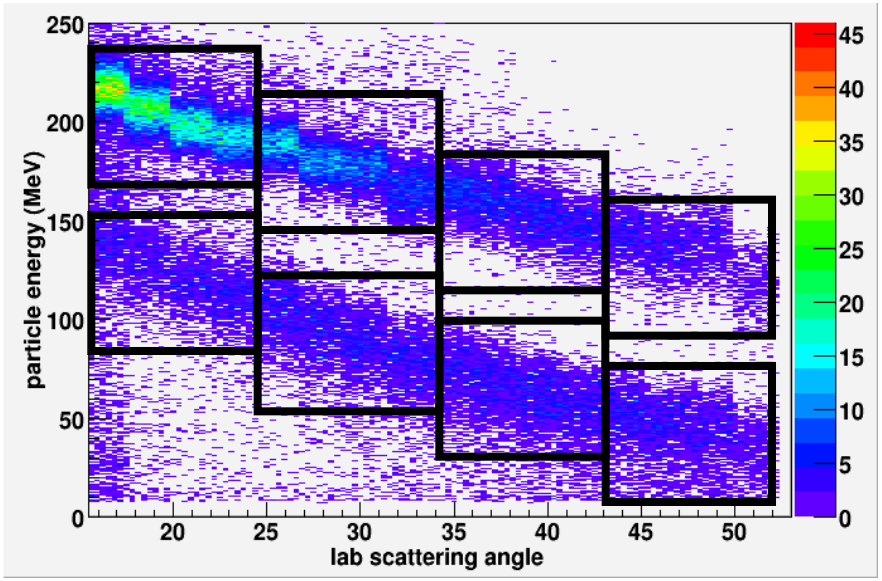
- $\sigma_{Kr,Pt} \sim < 0^+_1 \,||\, ME \,||> 2^+_1 >_{Kr,Pt} \sim B(E2 ; 2^+_1 \rightarrow 0^+_1)_{Kr,Pt}$
- But also: $\sigma_{Kr,Pt} \sim < 2^+_1 \,||\, ME \,||> 2^+_1 >_{Kr,Pt} \sim Q(2^+_1)_{Kr,Pt}$



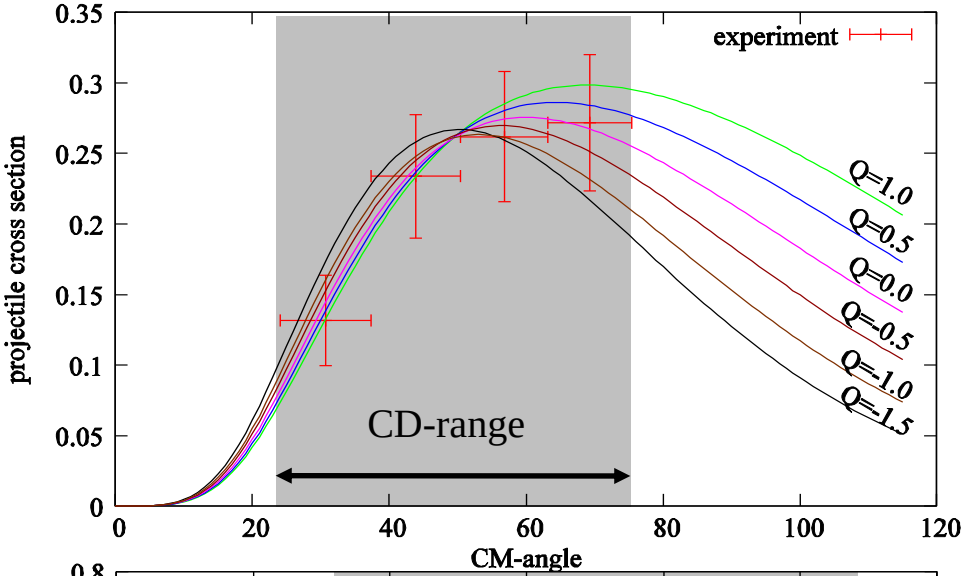
*: H. Ower, computer code CLX

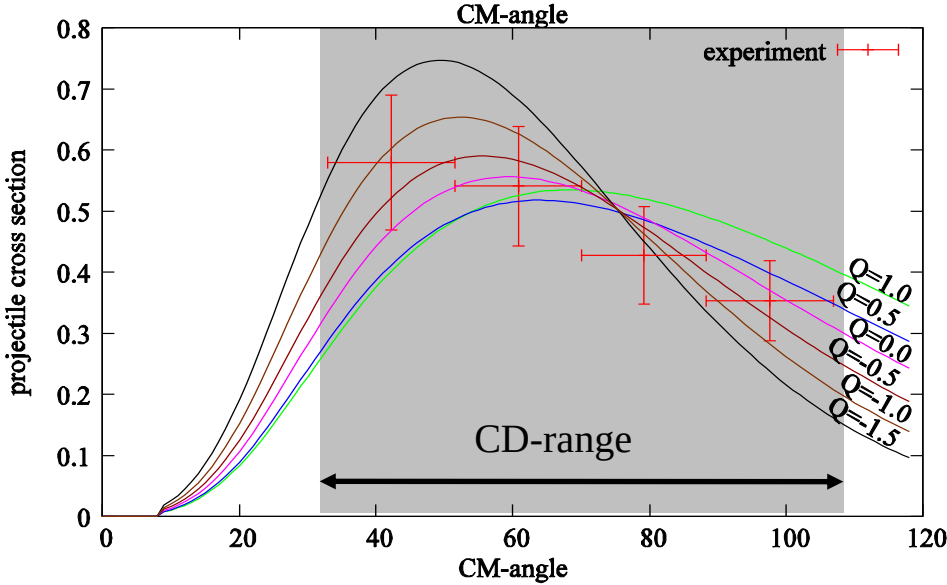
**: A. Winther and J. de Boer, *Coulomb Excitation*, (Academic, New York, 1965)

Determination of the absolute transition strength and the quadrupole moment



Lab angle	CM angles	
	Scattered Kr	Scattered Pt
16.4 – 25.63	24.1 – 37.4	33.0 – 51.5
25.63 – 34.85	37.4 – 50.5	51.5 – 70.1
34.85 – 44.08	50.5 – 63.2	70.1 – 88.5
44.08 – 53.3	63.2 – 75.5	88.5 – 107.6





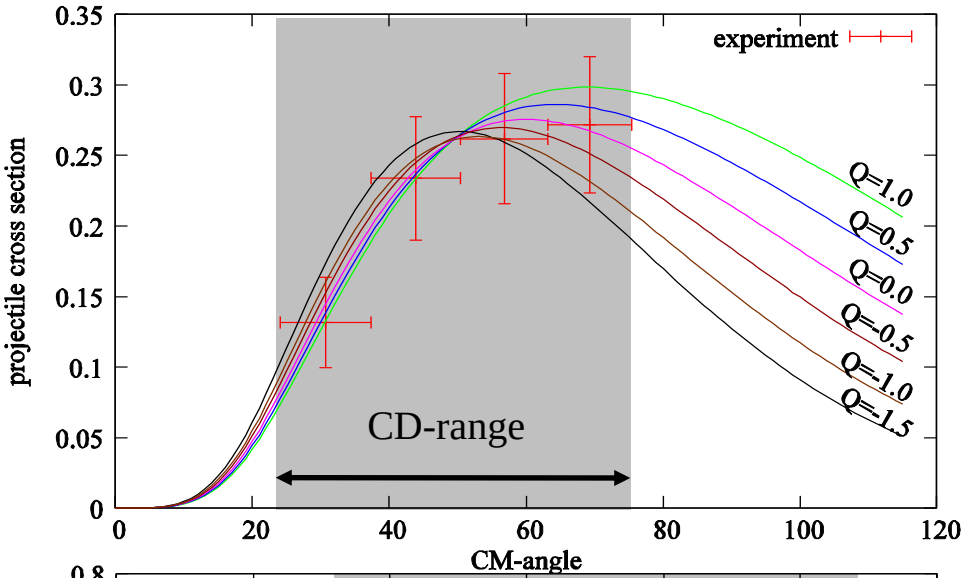
Determination of the absolute transition strength and the quadrupole moment

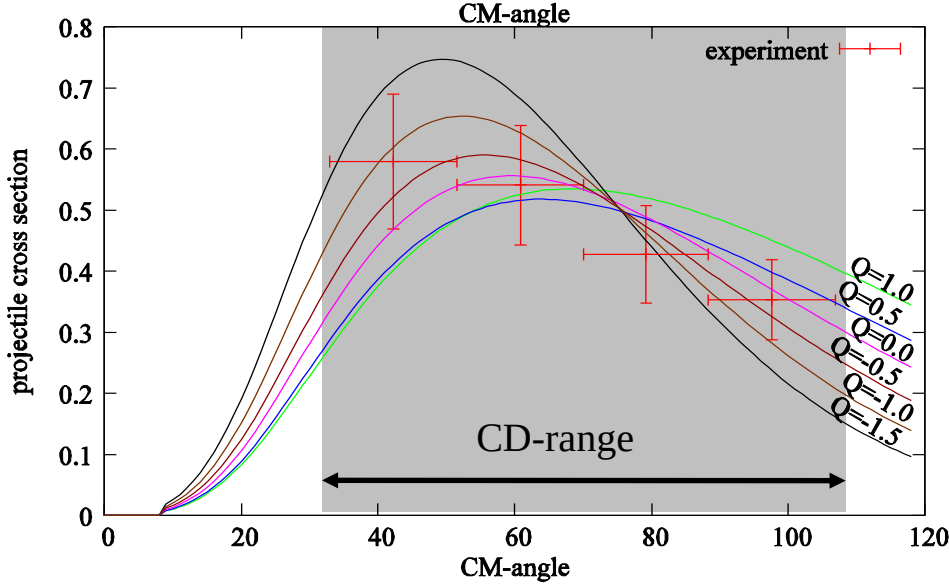
Gate on Kr-region

$< 2^+_1 \| ME \| 2^+_1 >$	$< 0^+_1 \| ME \| 2^+_1 >$	χ^2
1.0	0.453 (45)	0.032
0.5	0.477 (22)	0.012
0.0	0.503 (12)	0.006
-0.5	0.534 (6)	0.015
-1.0	0.565 (14)	0.033
-1.5	0.608 (20)	0.064

Gate on Pt-region

$< 2^+_1 \| ME \| 2^+_1 >$	$< 0^+_1 \| ME \| 2^+_1 >$	χ^2
1.0	0.489 (70)	0.29
0.5	0.528 (60)	0.21
0.0	0.576 (46)	0.13
-0.5	0.638 (35)	0.08
-1.0	0.722 (64)	0.11
-1.5	0.752 (83)	0.16



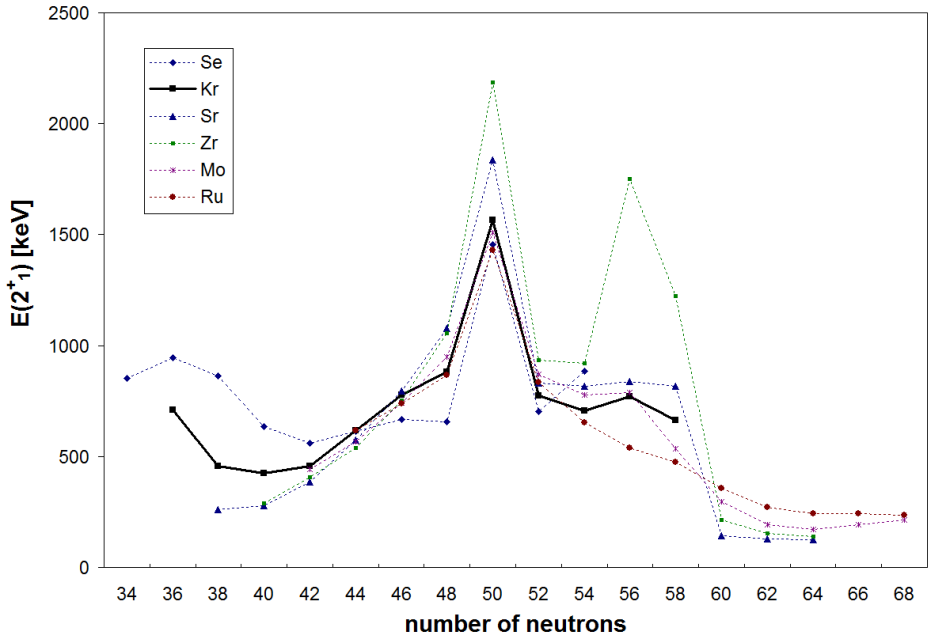


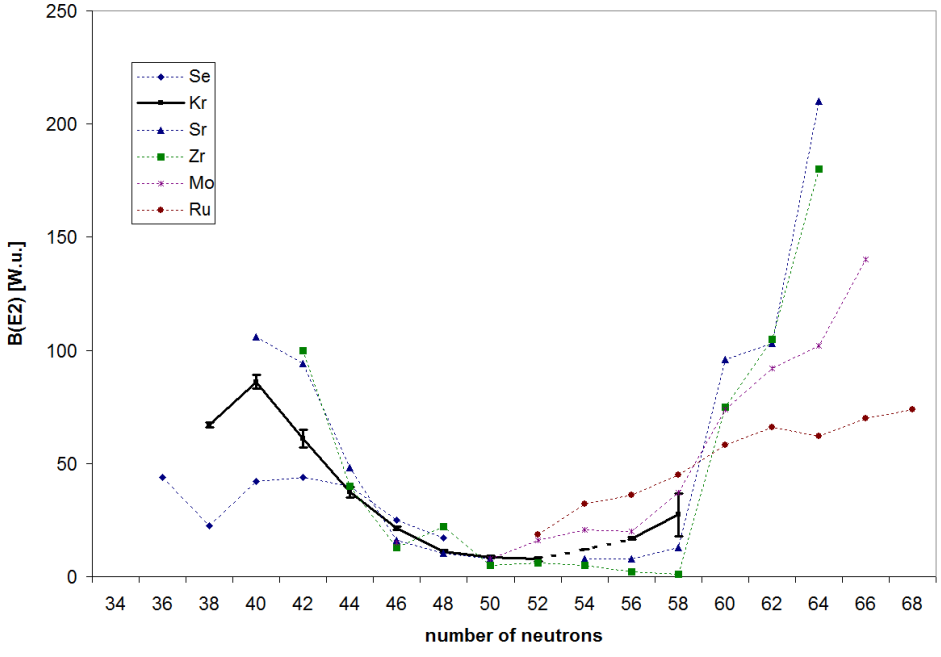
Preliminary Results

From matrix elements for small scattering angles (Kr-Gate) and large scattering angles (Pt-Gate) we obtain a weighted average for the B(E2; $2^+_1 \rightarrow 0^+_1$) and the Q-values:

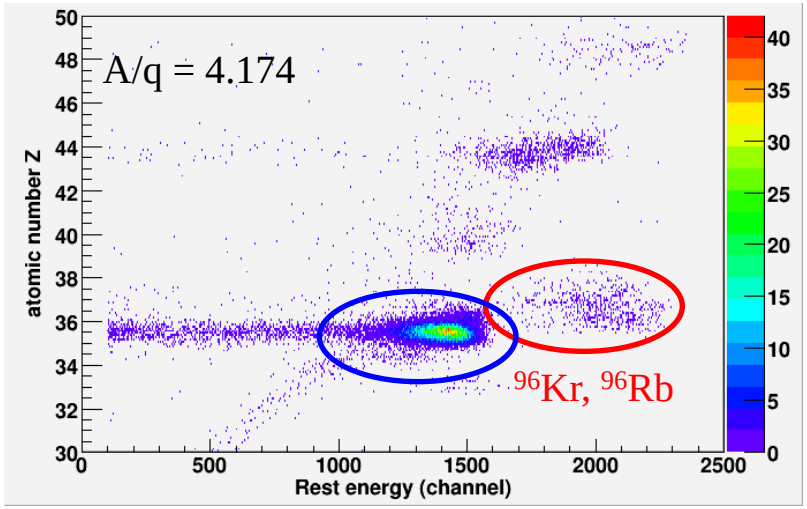
$$Q \approx -0.4^{+1.1}_{-0.7}$$

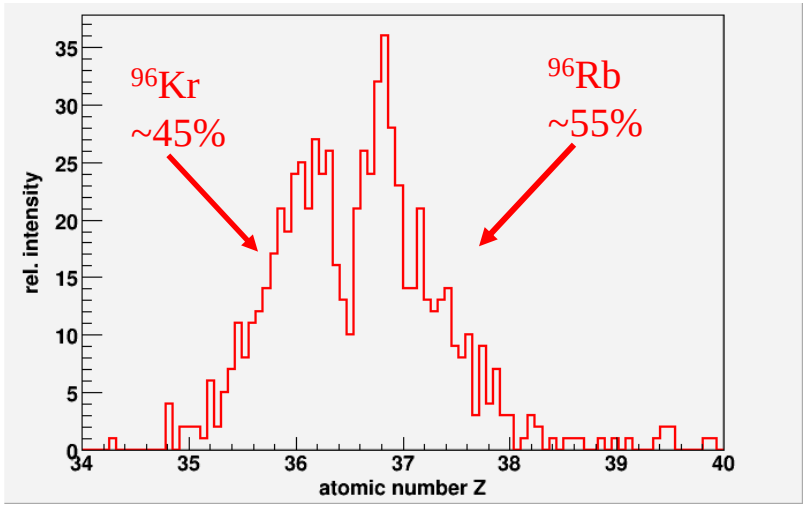
$$B(E2, 2_1 \rightarrow 0_1) = 27.3(9.5)$$



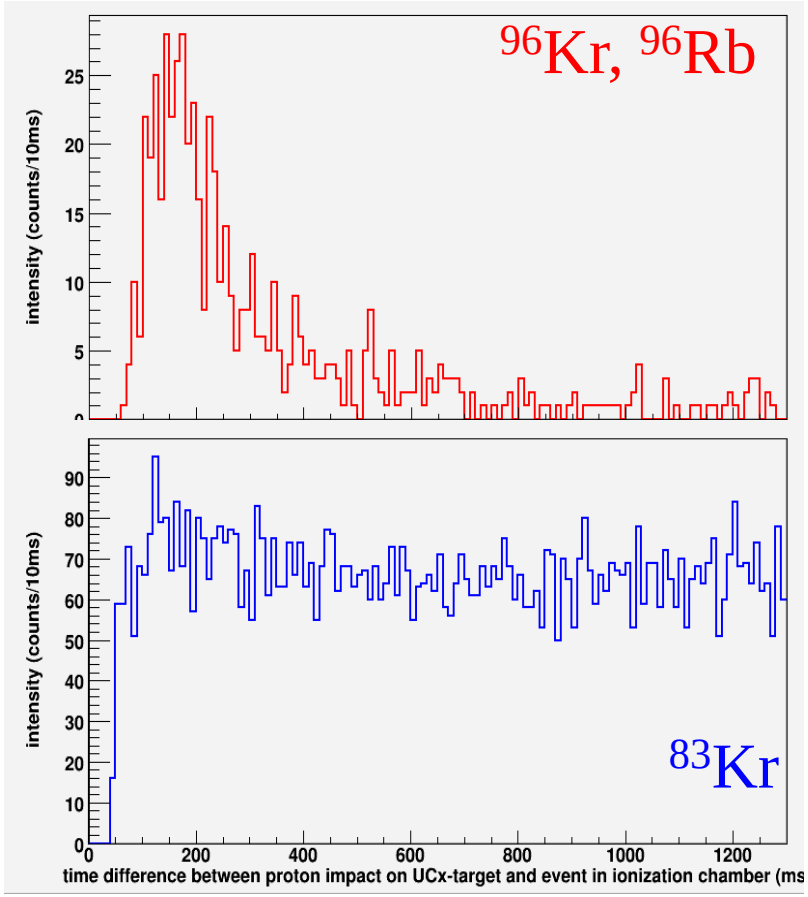


Identification of $^{96}Kr^{23+}$ - beam composition

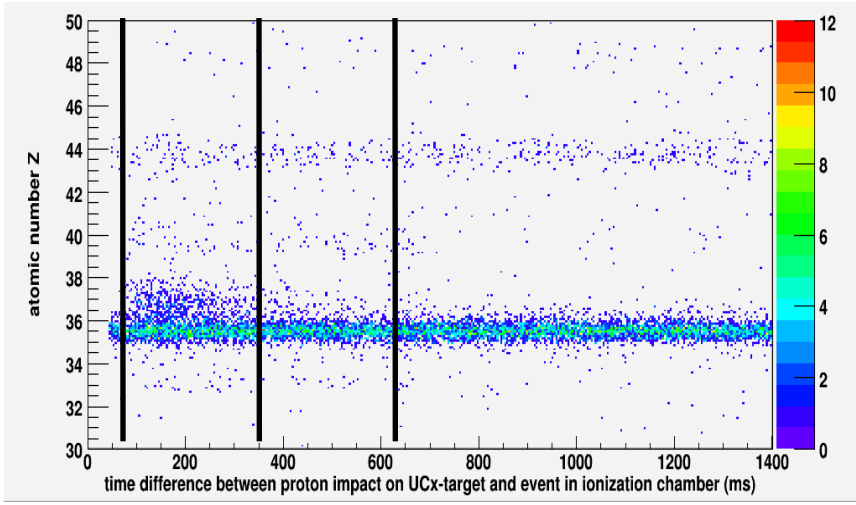




Time difference between proton impact on UCx target and event in ionization chamber

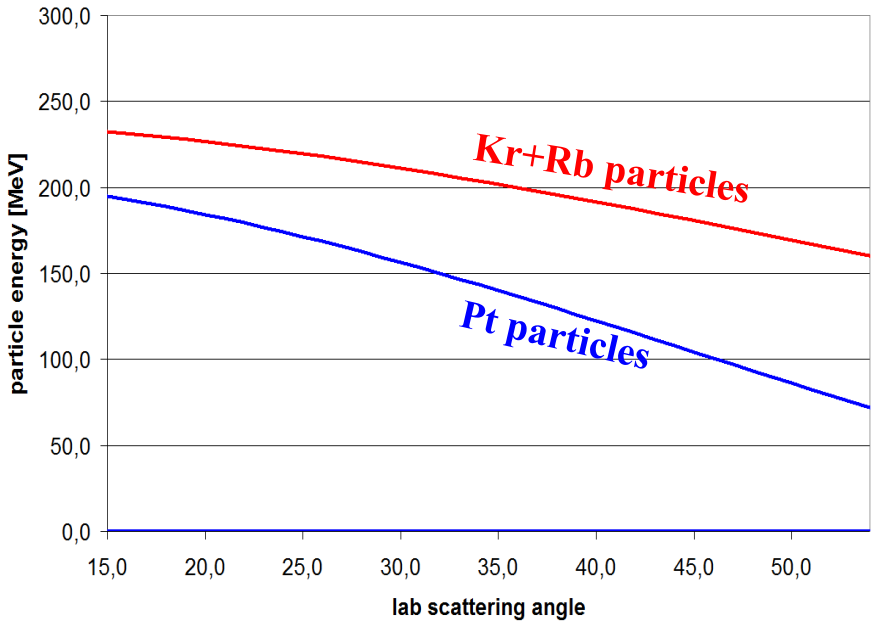


Reaction kinematic

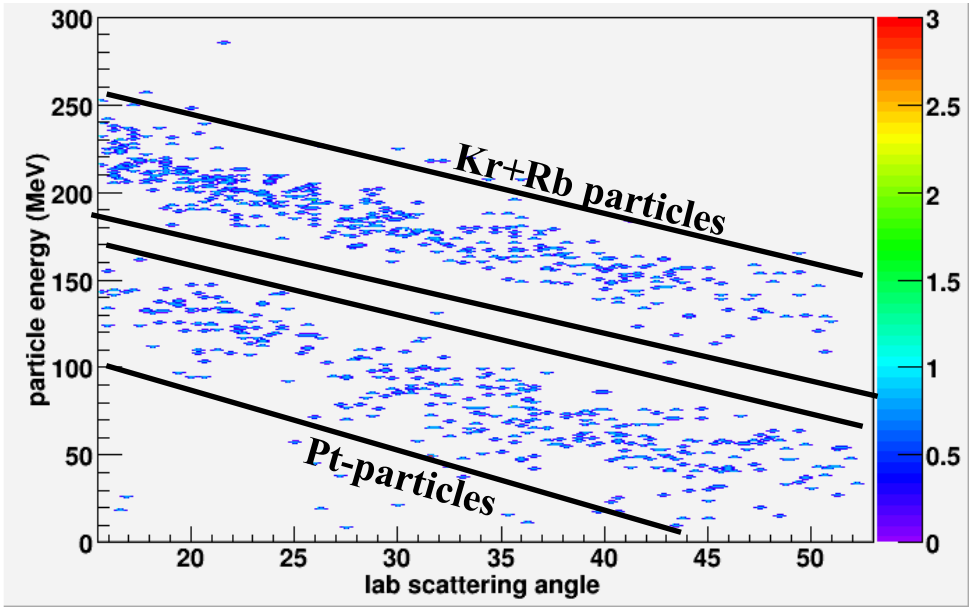


Additional time gate: 50 – 350 ms
Background gate: 350 – 650 ms

Theoretical reaction kinematic*

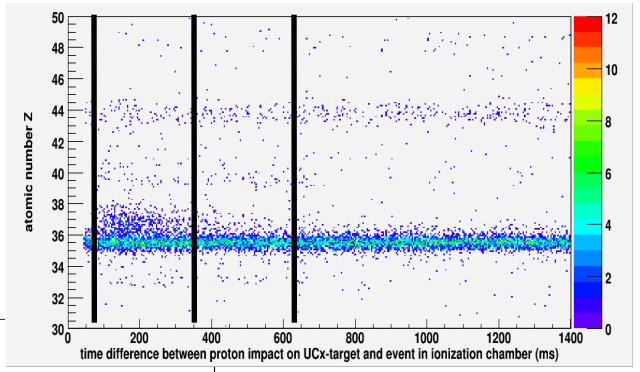


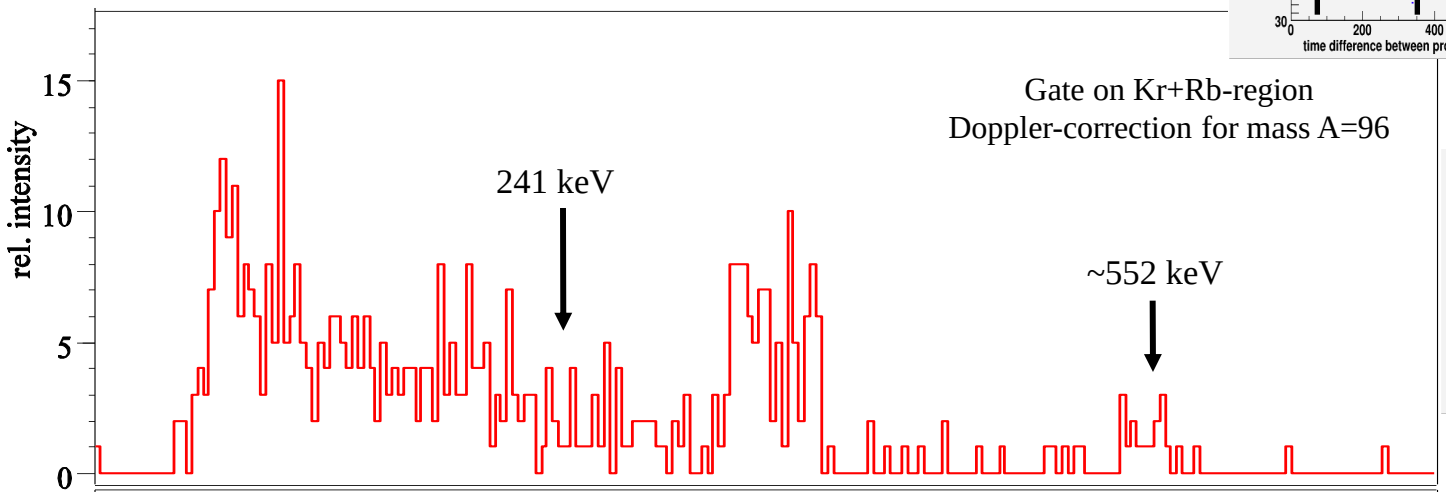
Experimentally determined reaction kinematic

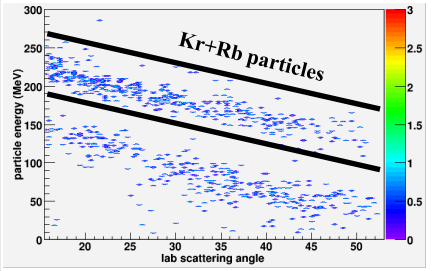


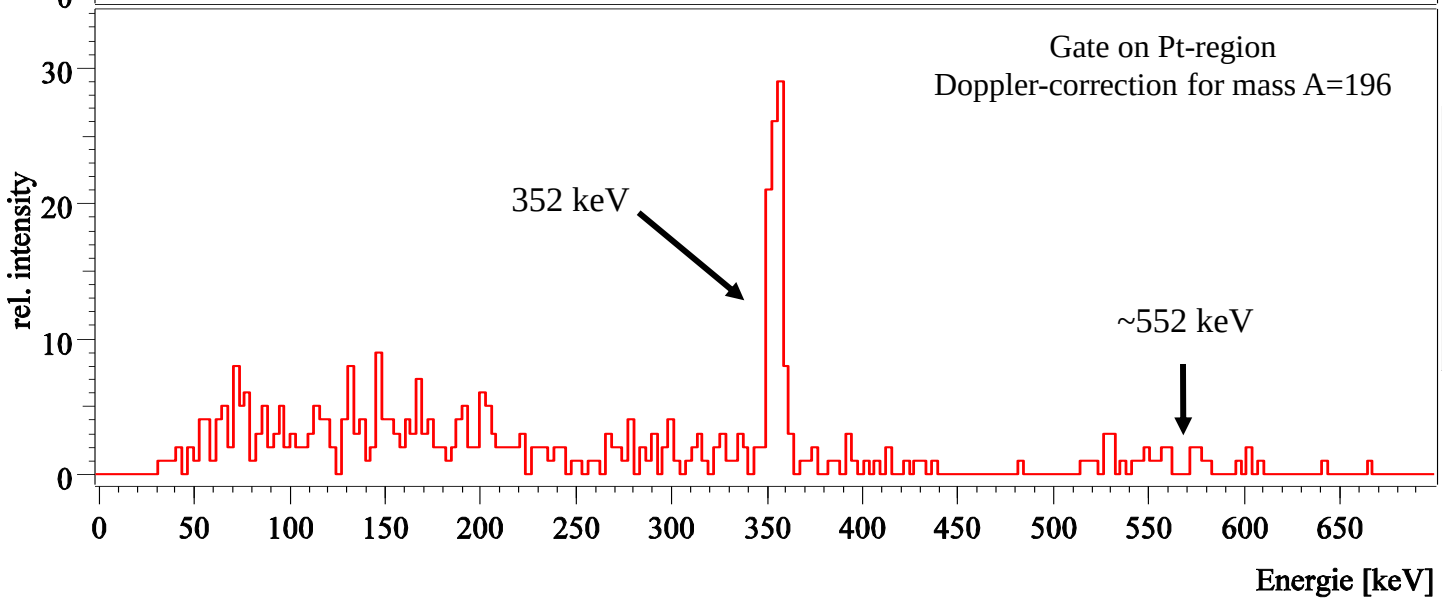
*: catkin2.02, W.N. Catford (1998,2005)

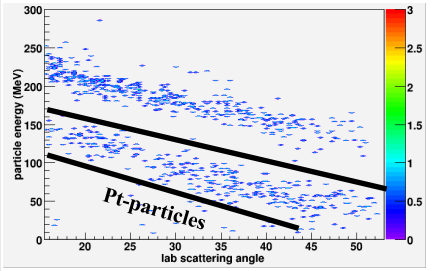
Preliminary results











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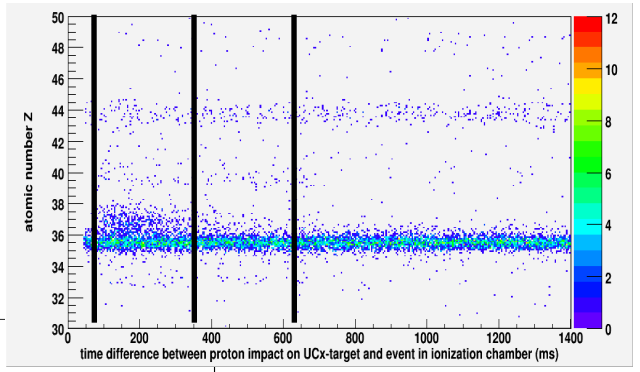
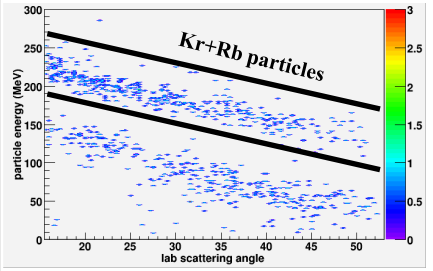


Gate on Kr+Rb-region
Doppler-correction for mass A=96

241 keV

~552 keV

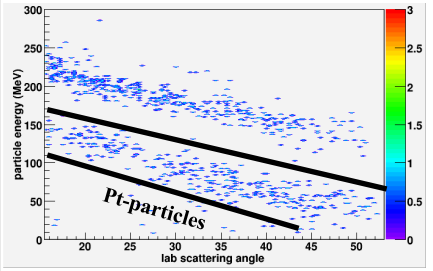
rel. intensity



Gate on Pt-region
er-correction for mass A=196

~552 keV

rel. intensity

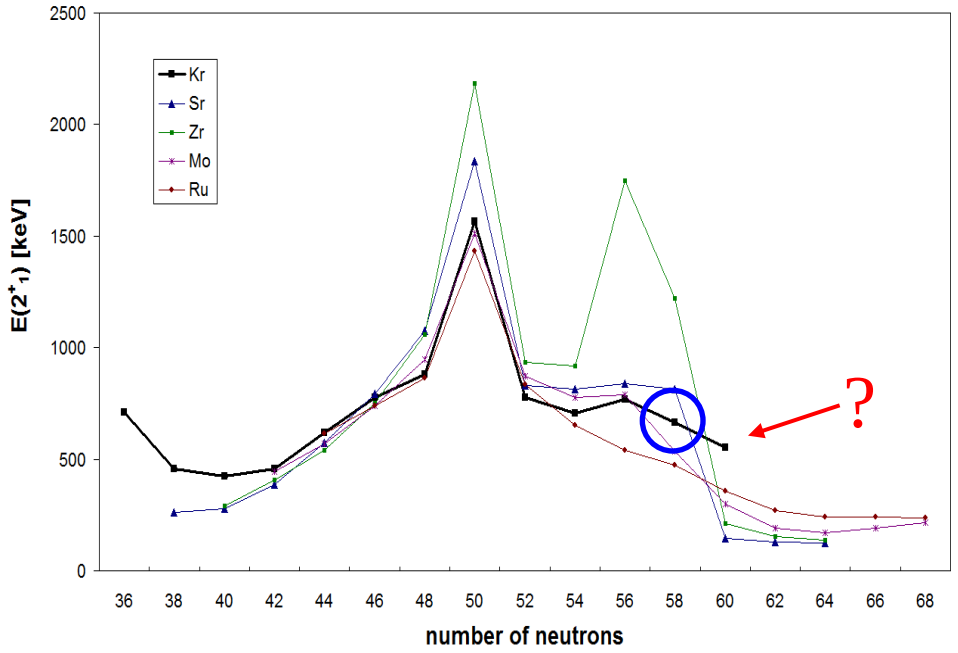


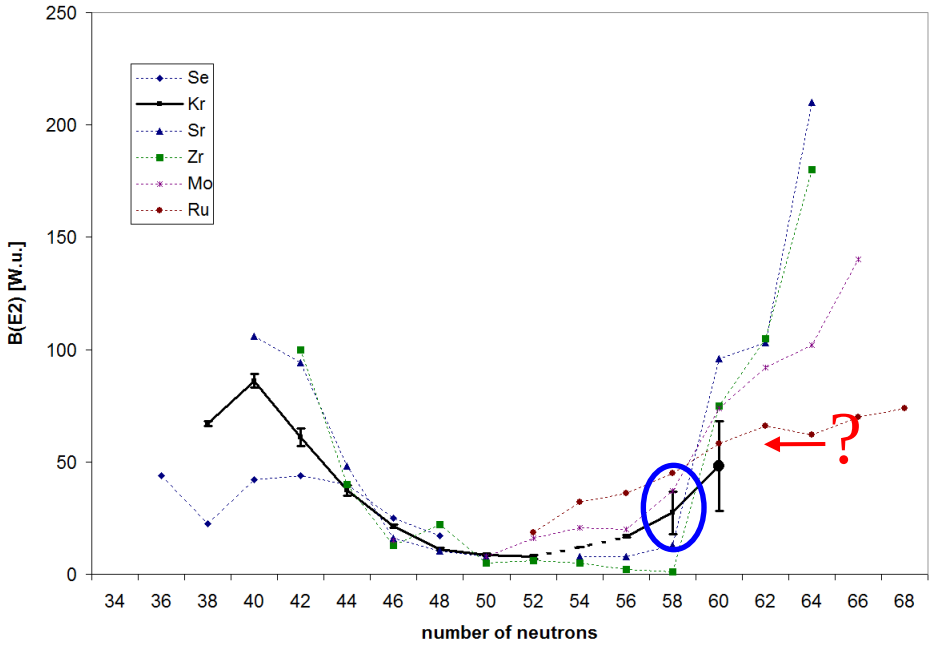
- No γ-peak at 241 keV!
- But: Unexpected γ-peak at ~ 552 keV

→ **B(E2; $2^+_1 \rightarrow 0^+_1$) ≈ 45(20) W.u.**

Energie [keV]

Summary and outlook





- ^{94}Kr: $E(2^+_1)$ confirmed and Q and $B(E2; 2^+_1 \rightarrow 0^+_1)$ determined for the first time
- ^{96}Kr: $E(2^+_1)$ not confirmed, but another candidate found and preliminary $B(E2; 2^+_1 \rightarrow 0^+_1)$ determined

Outlook:

- Continuation of the ^{96}Kr-Experiments (another charge state, another target, longer measurement) at the end of July 2010

Collaborators

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N. Warr (Spokeperson)	**IKP Köln (GER)**
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D. Mücher	**TU München (GER)**
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P. van Duppen, B. Bastin, H. de Witte, J. Diriken	**KU Leuven (BEL)**
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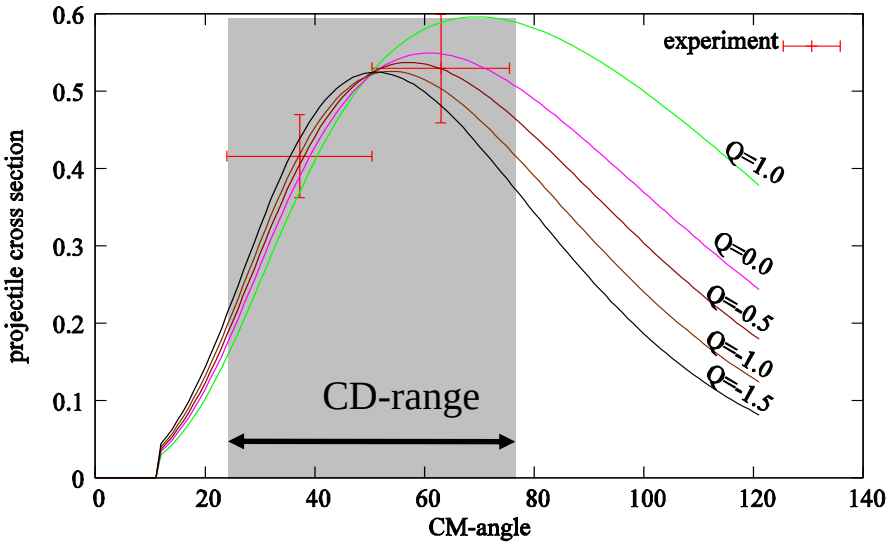
S. Das Gupta	**INFN-Sezione di Perugia (I)**
M. Scheck, L. Gaffney, S. Rigby	**University of Liverpool (UK)**
G. Simpson	**LPSC Grenoble (FR)**
J. van de Walle	**CERN, Genf, (SUI)**

the REX-ISOLDE Collaboration
the MINIBALL Collaboration

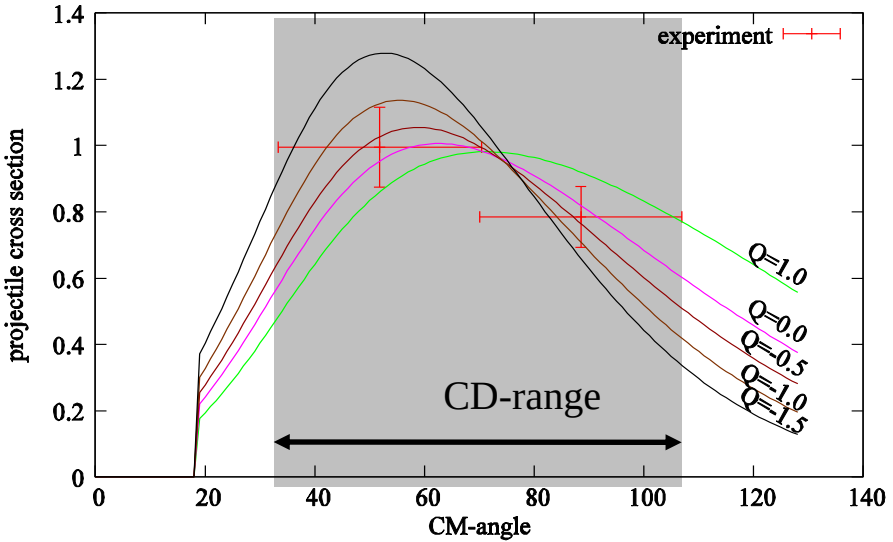
Granted by BMBF under Grant 06KY205I

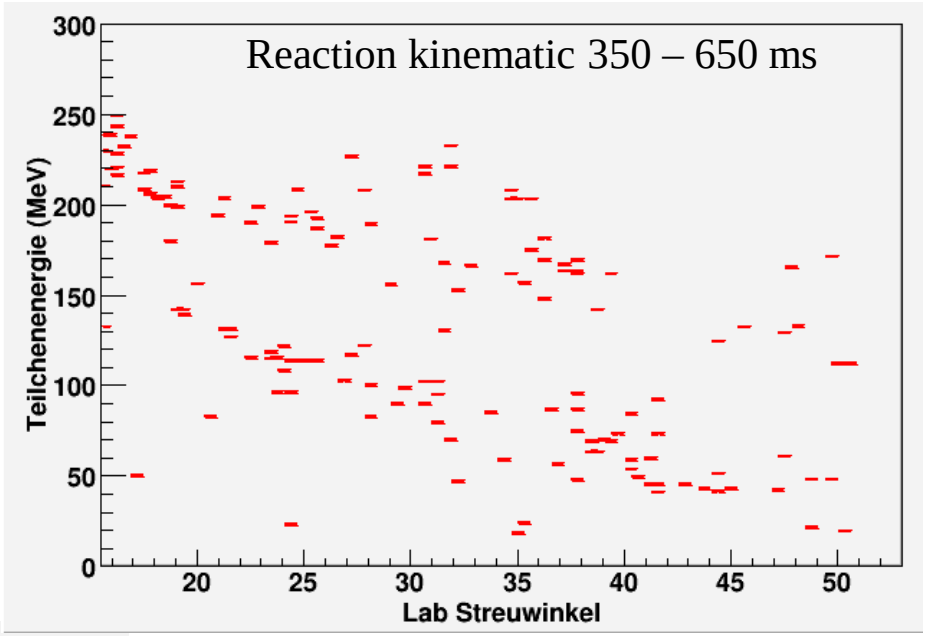
Determination of the absolute transition strength and the quadrupole moment

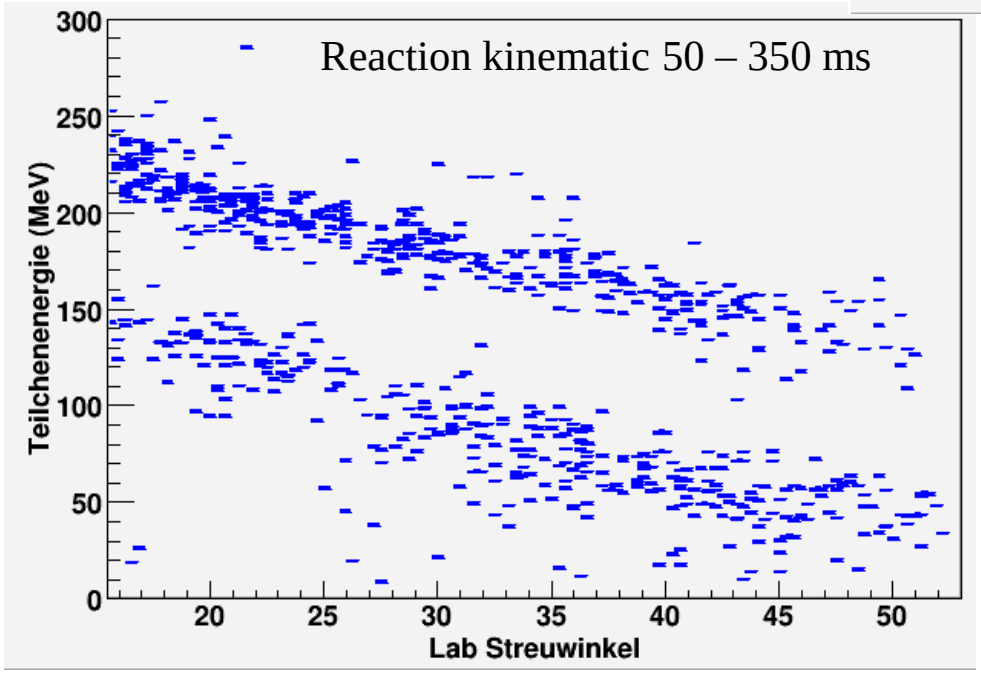
$< 2^+_1 \parallel ME \parallel > 2^+_1 >$	$< 2^+_1 \parallel ME \parallel > 0^+_1 >$	χ^2
1.0	0.455	0.158
0.0	0.506	0.059
-0.5	0.538	0.007
-1.0	0.571	0.059
-1.5	0.611	0.128



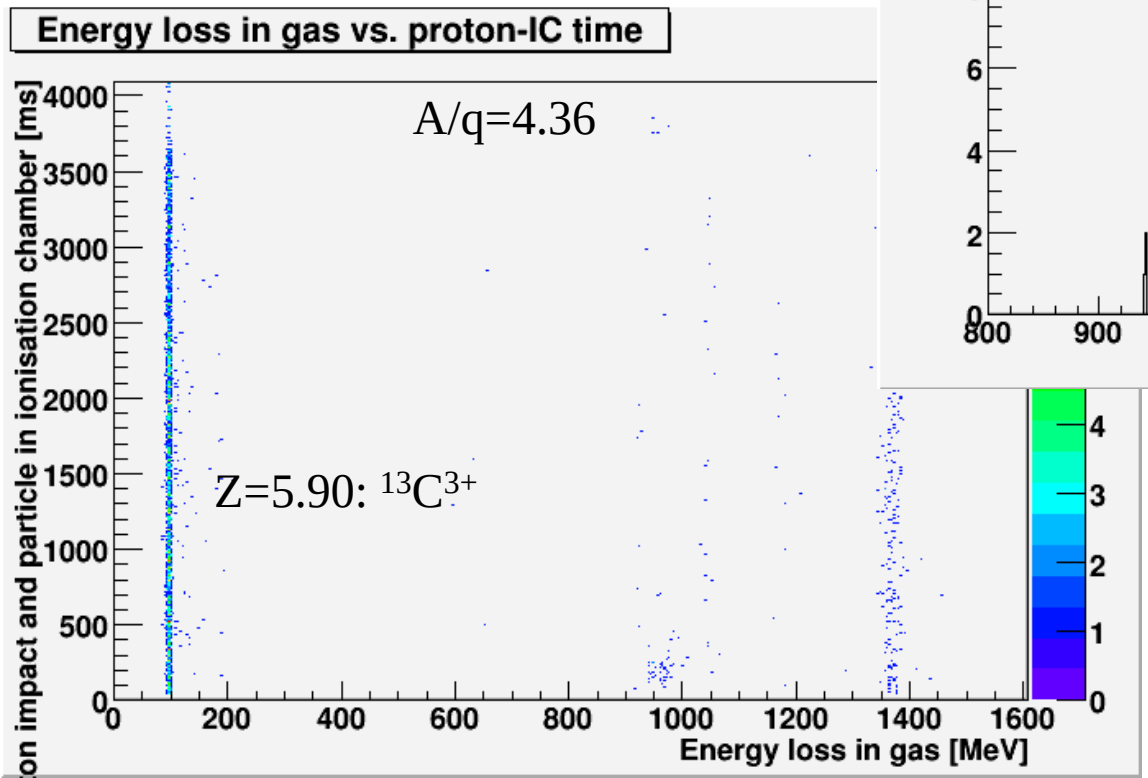
$< 2^+_1 \parallel ME \parallel > 2^+_1 >$	$< 2^+_1 \parallel ME \parallel > 0^+_1 >$	χ^2
1.0	0.482	0.37
0.0	0.570	0.11
-0.5	0.630	0.05
-1.0	0.706	0.25
-1.5	0.809	0.56

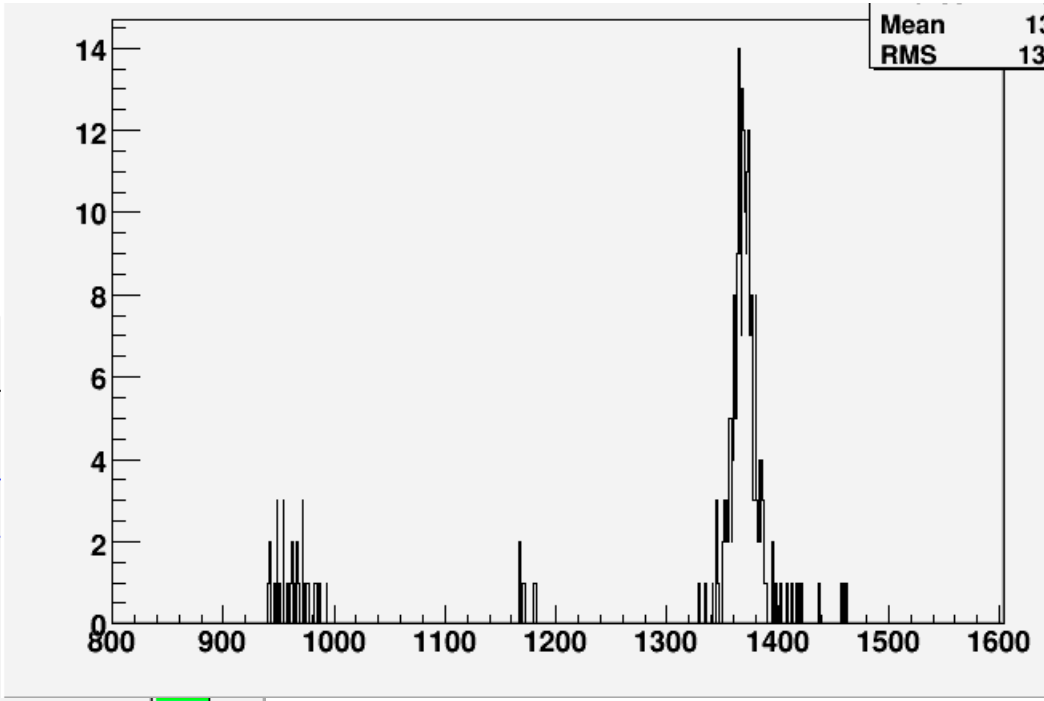



Reaction kinematic 350 – 650 ms
Teilchenenergie (MeV)
Lab Streuwinkel
0
50
100
150
200
250
300
20
25
30
35
40
45
50

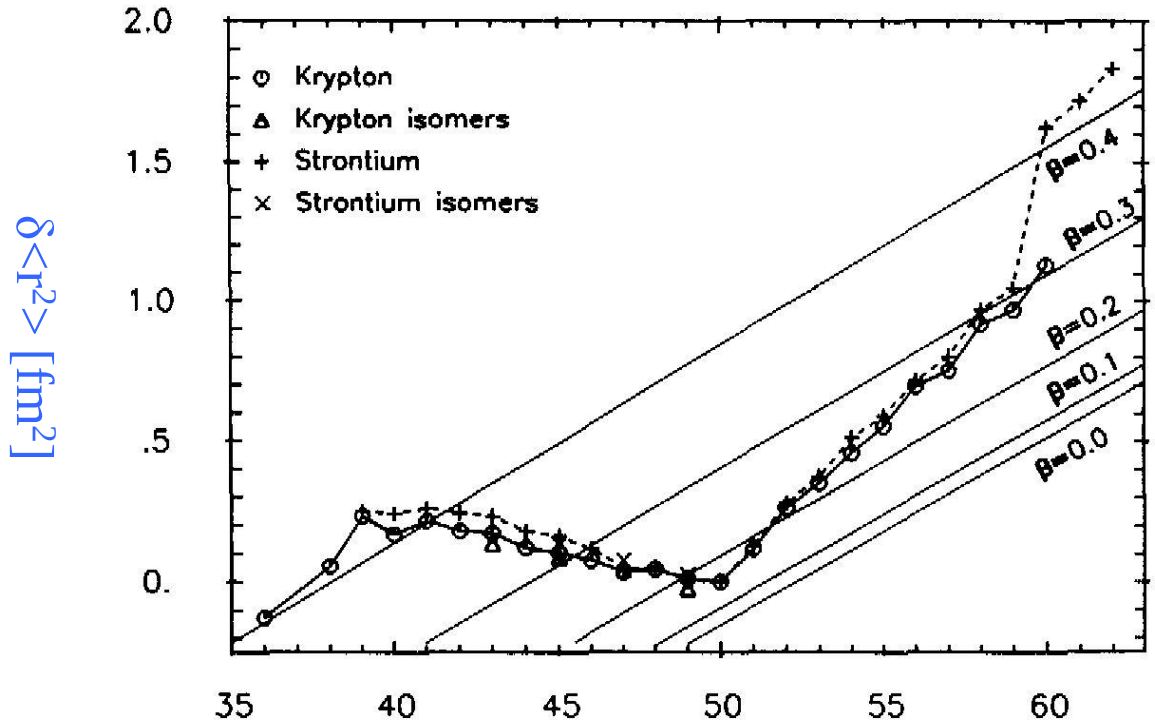

Reaction kinematic 50 – 350 ms
Teilchenenergie (MeV)
Lab Streuwinkel
0
50
100
150
200
250
300
20
25
30
35
40
45
50

Identification of $^{96}Kr^{22+}$ beam composition



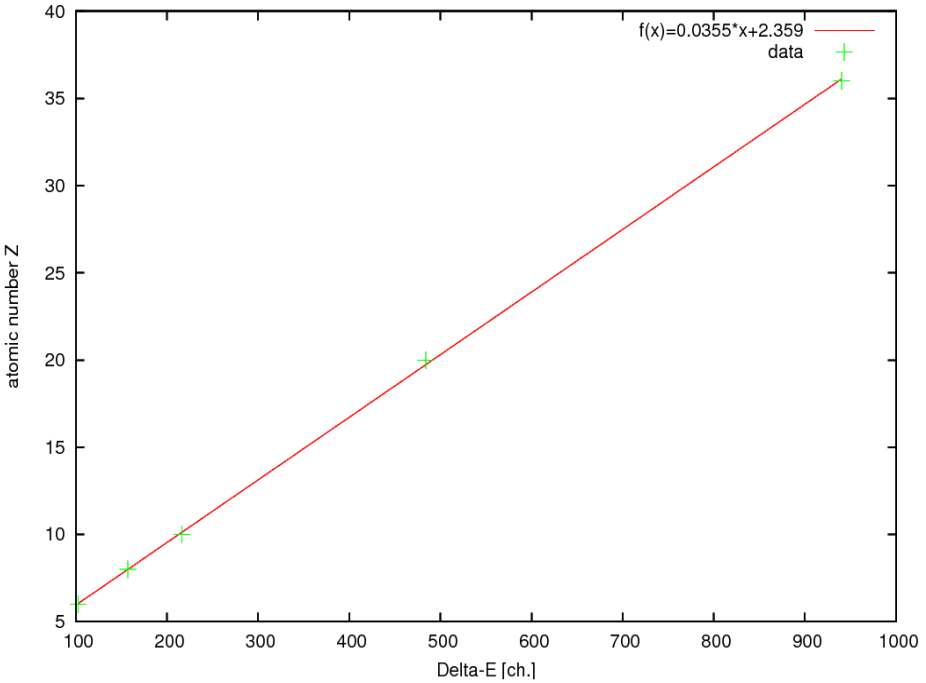


Mean-Square Charge Radii

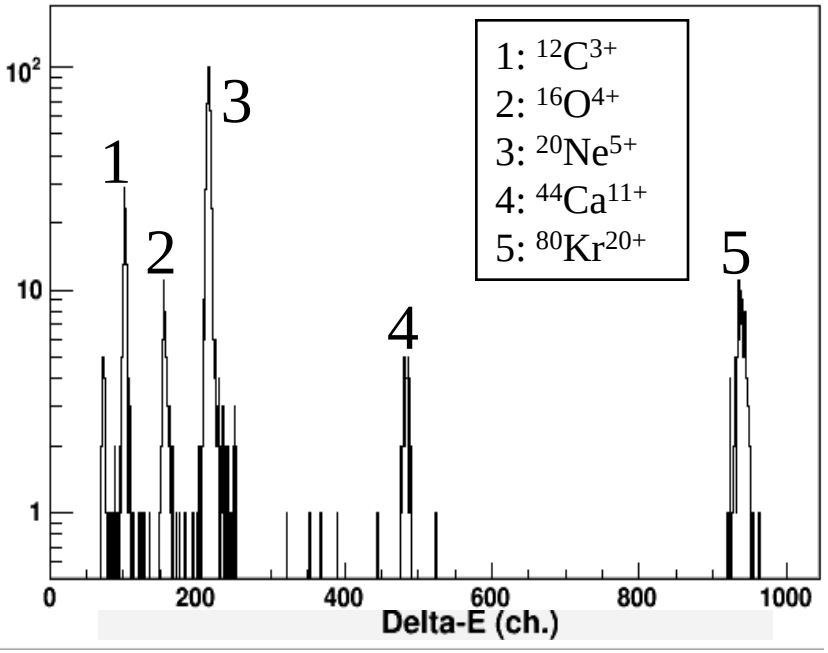


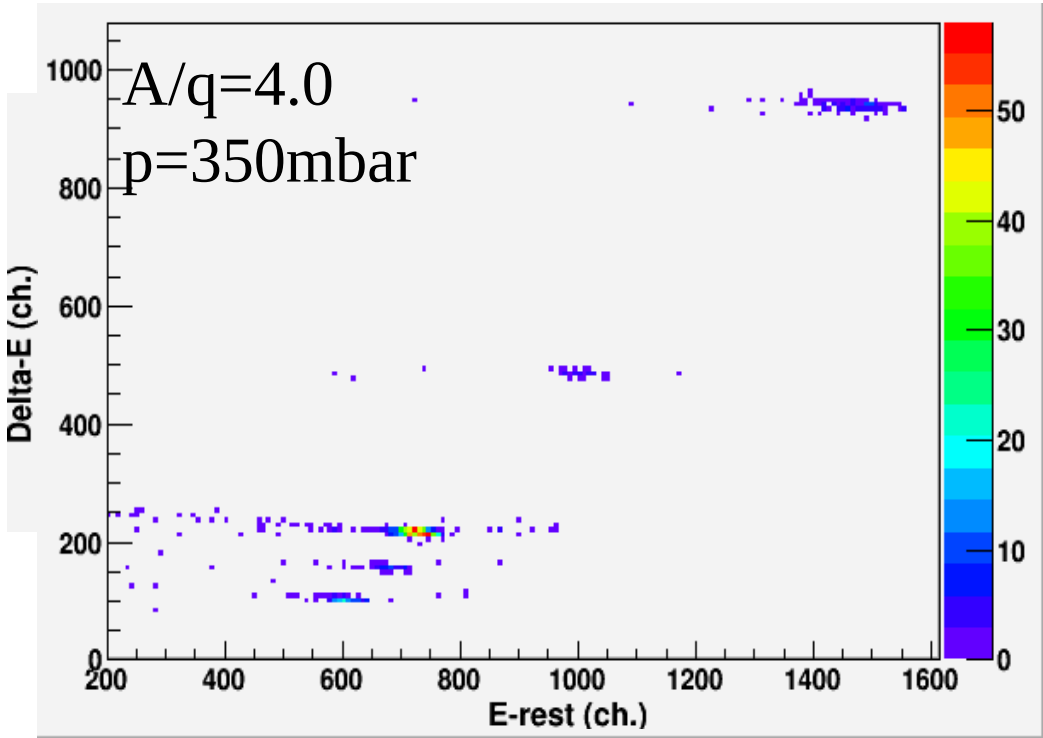
M. Keim et al., Nucl. Phys. A586 (1995) 219-239

Ionization chamber



350mbar gas pressure: f(x)=0.0355*x+2.359
300mbar gas pressure: f(x)=0.0355*x+5.439

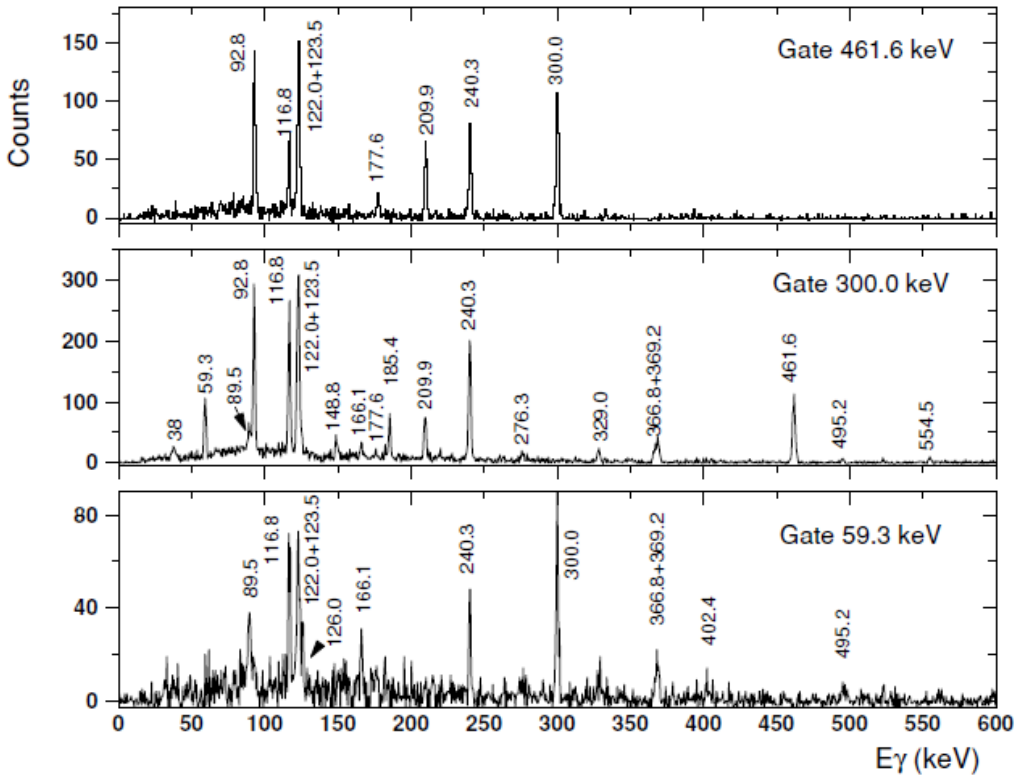


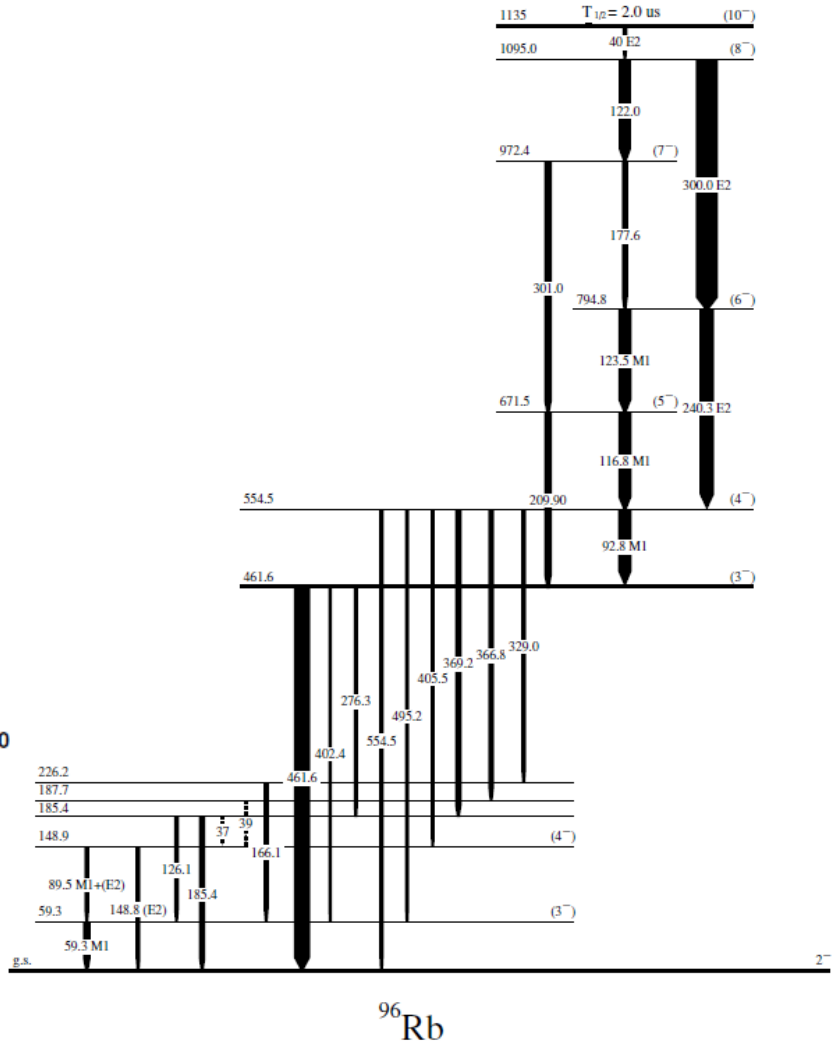


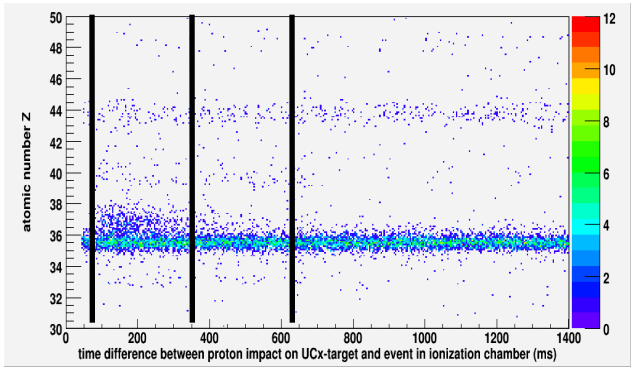
Shape coexistence in the very neutron-rich odd-odd ^{96}Rb

J. A. Pinston

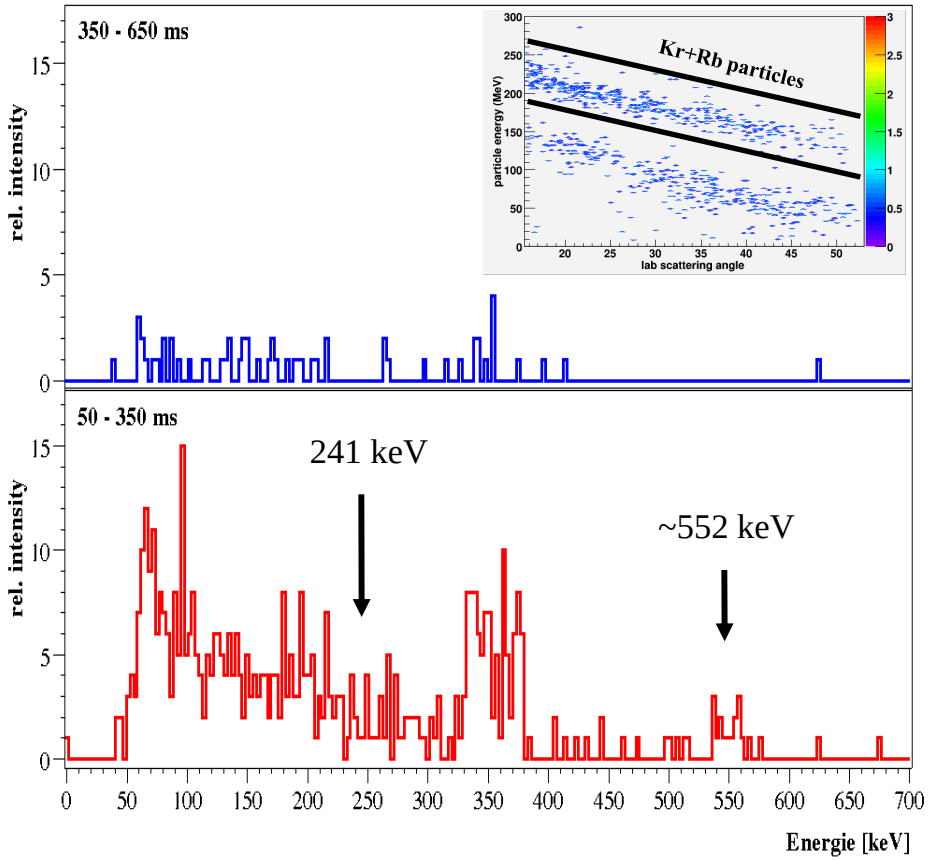
PHYSICAL REVIEW C **71**, 064327 (2005)







Gate on Kr+Rb-region
Doppler-correction for mass A=96



Gate on Pt-region
Doppler-correction for mass A=196