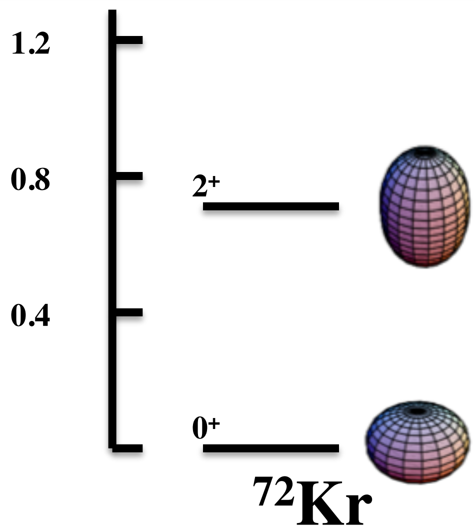
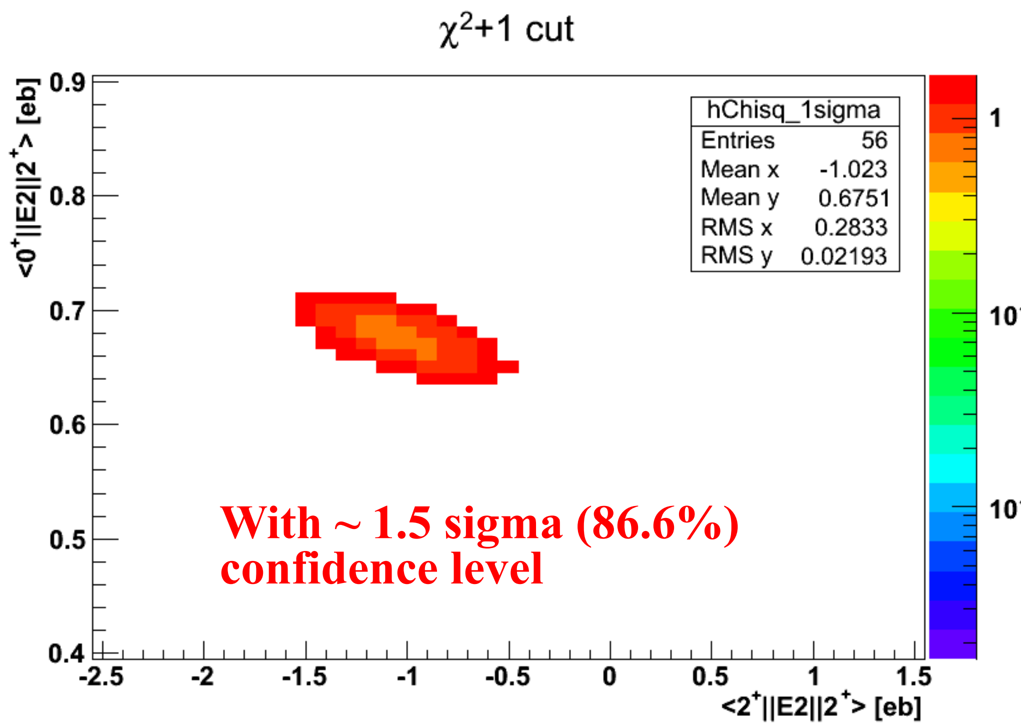
Status report for IS478

Shape determination in Coulomb excitation of ^{72}Kr



B.S. Nara Singh
University of the West of Scotland
and the IS478 collaboration



Preliminary results indicate prolate configurations for the 2_1^+ state

|Background and results from 2012| |Remaining 13 shifts|

IS478: The original beam time request

Condition	Desirable	Manageable
Energy (MeV/u)	3.1	2.9
Yield/uc	5000	2000
Transmission	8%	5%
Yield@target/2uc	~800	~200
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Assumptions

CD coverage: 16.2° to 53.3°

ε_γ = 7% at 1.3 MeV

^{76}kr at 3-3.1 MeV/u, ~10^6 pps at target position for 1+1 days

Status report for IS478

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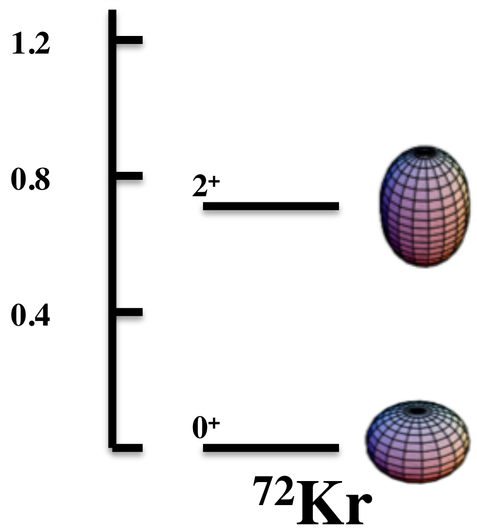

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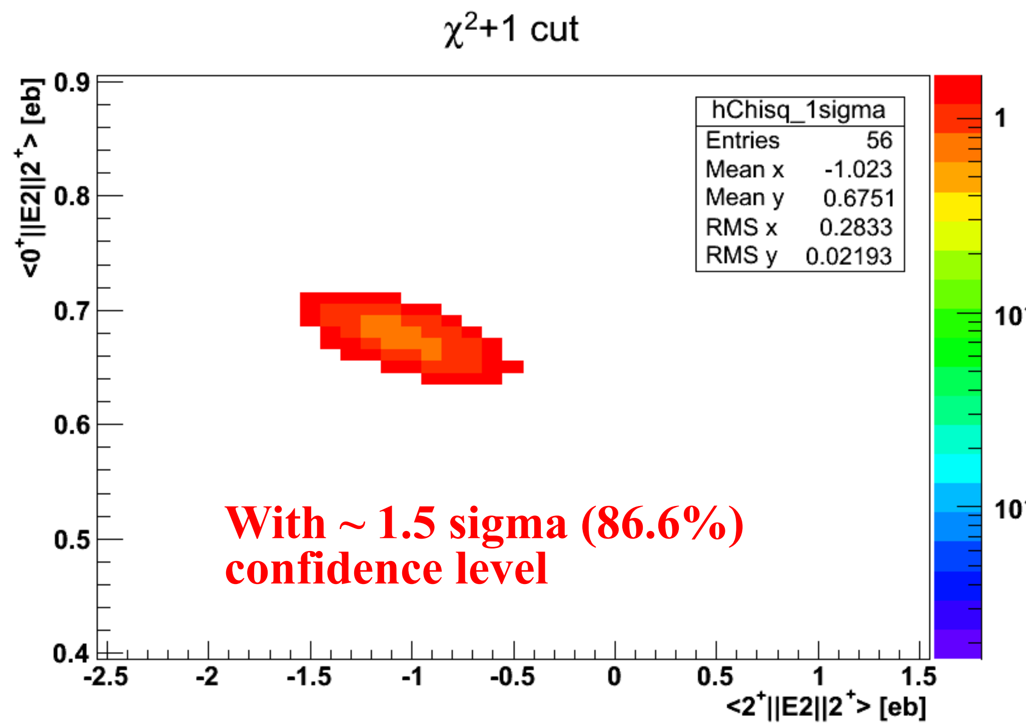
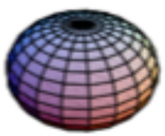
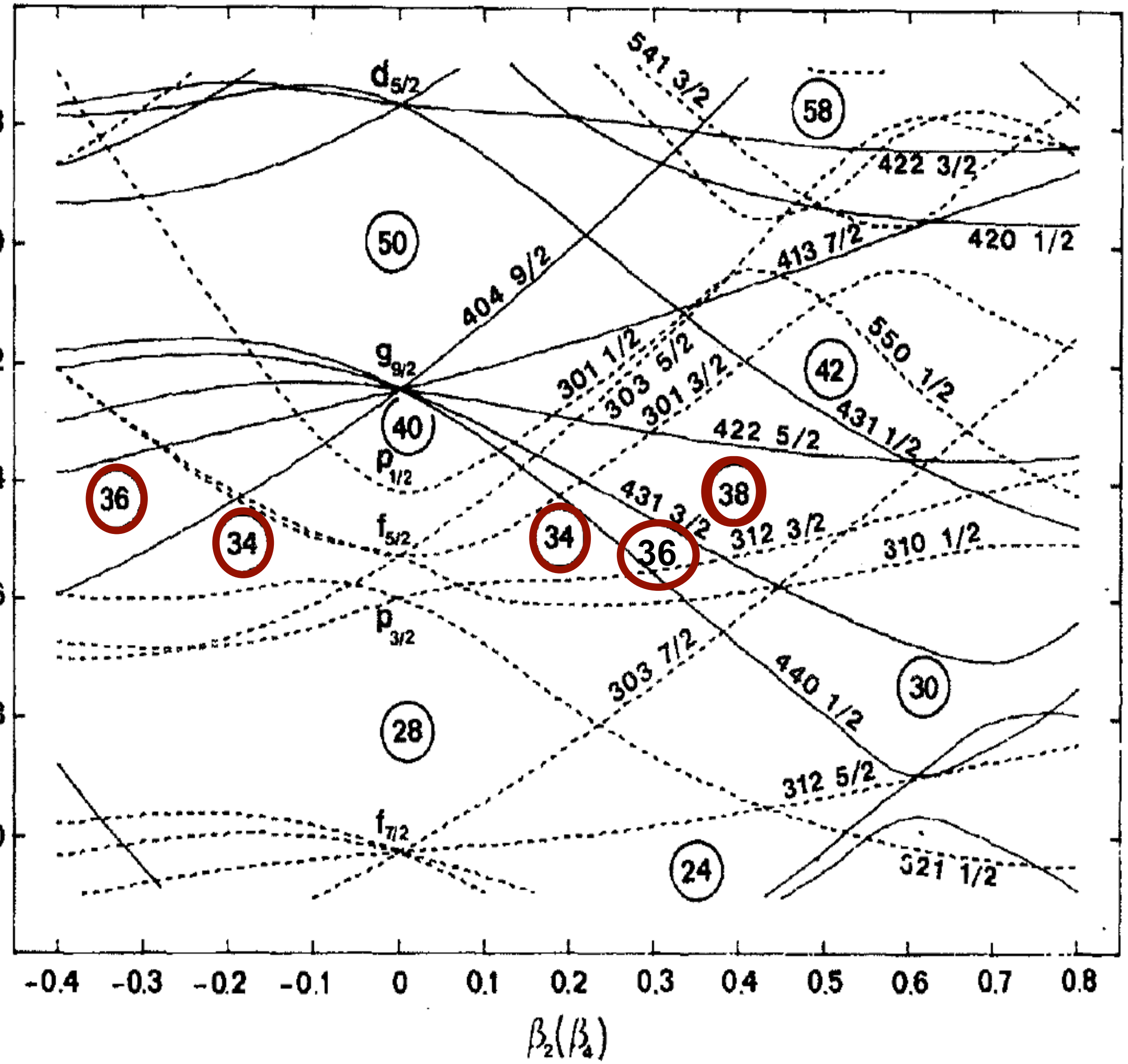


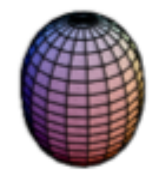
Preliminary results indicate prolate configurations for the 2_1^+ state

|Background and results from 2012| |Remaining 13 shifts|

Shape coexistence is expected for Kr, Se isotopes







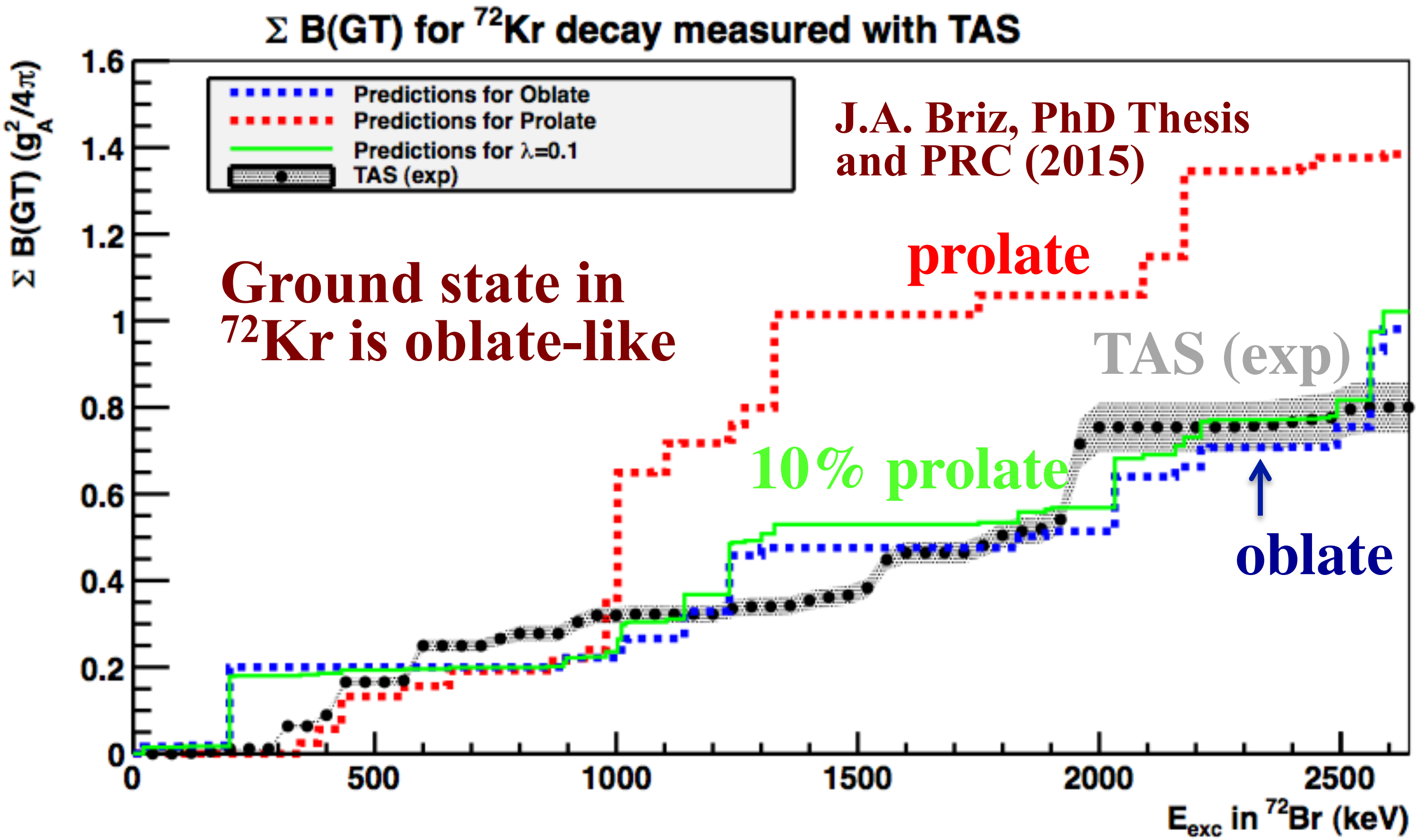
Moments of inertia, B(E2) ^{68}Se,^{72}Kr →oblate low-lying and prolate high-lying states

S. Fischer et al., PRC 67, 064318 (2003), PRL 84, 4064 (2000), A. Gade et al., PRL 95, 022502 (2005), W. Nazarewicz et al., NPA, 1985, E. Clement et al, PRC, 2007

Experimental studies – ^{72}Kr

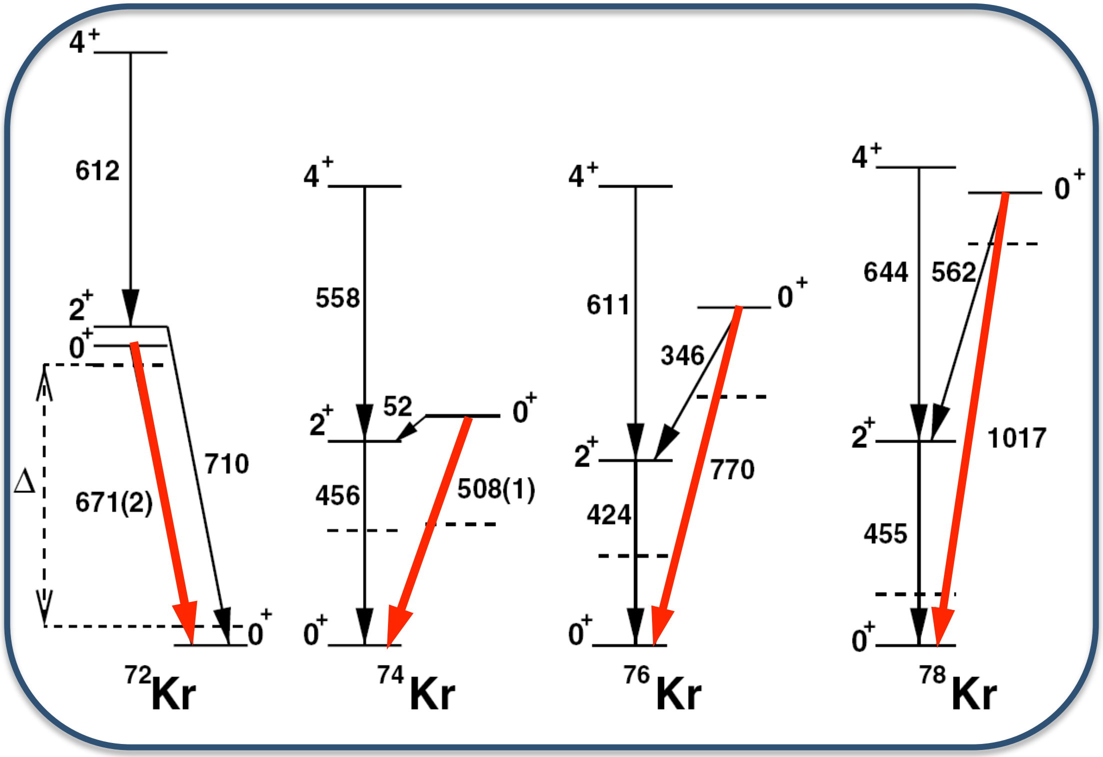
β-decay

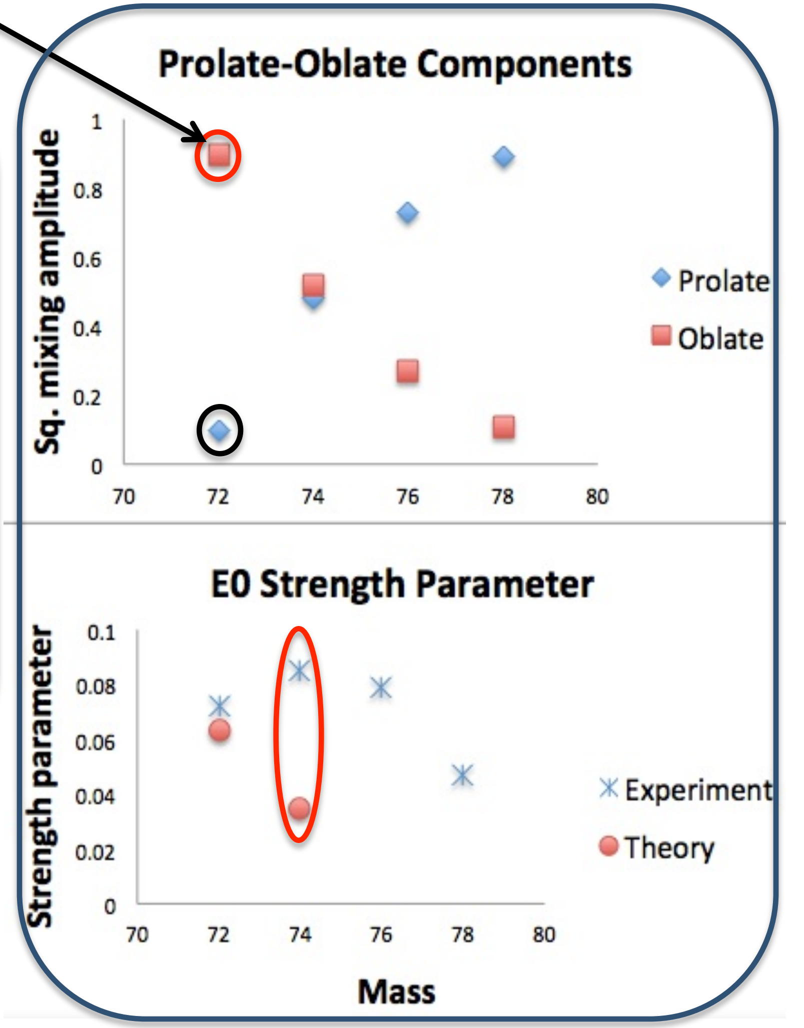
A comparison between the calculated and the experimental B(GT) indicate oblate dominated ground state -prolate mixtures > 10% cannot be excluded.



Experimental studies – ^{72}Kr
Level structures, EM, E0 strengths

^{72}Kr (g. s.): 90% oblate and 10% prolate components from an analysis of unperturbed and experimental 0^+ states

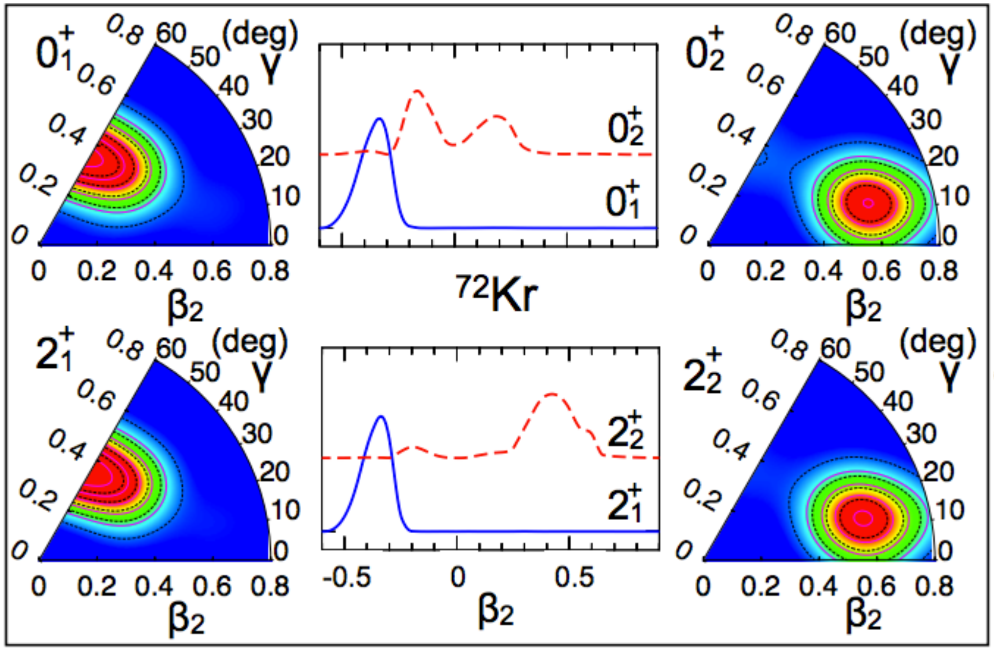


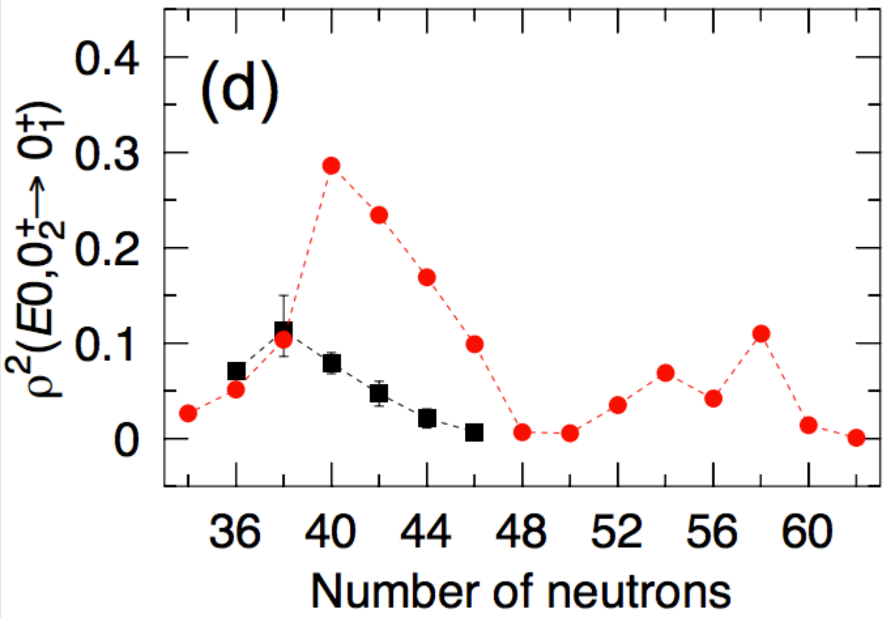


S. Fischer et al., PRC 67, 064318 (2003), PRL 84, 4064 (2000)
E. Bouchez et al., PRL (2003)
G. de Angelis et al., PLB (1997)
E. Clément et al, PRC (2007)

Calculations do not reproduce data of ^{72}Kr

Symmetry Conserving Configuration Mixing (SCCM) Method + Quantum number restoration + shape mixing of axial and triaxial states + GCM + Gogny D1S



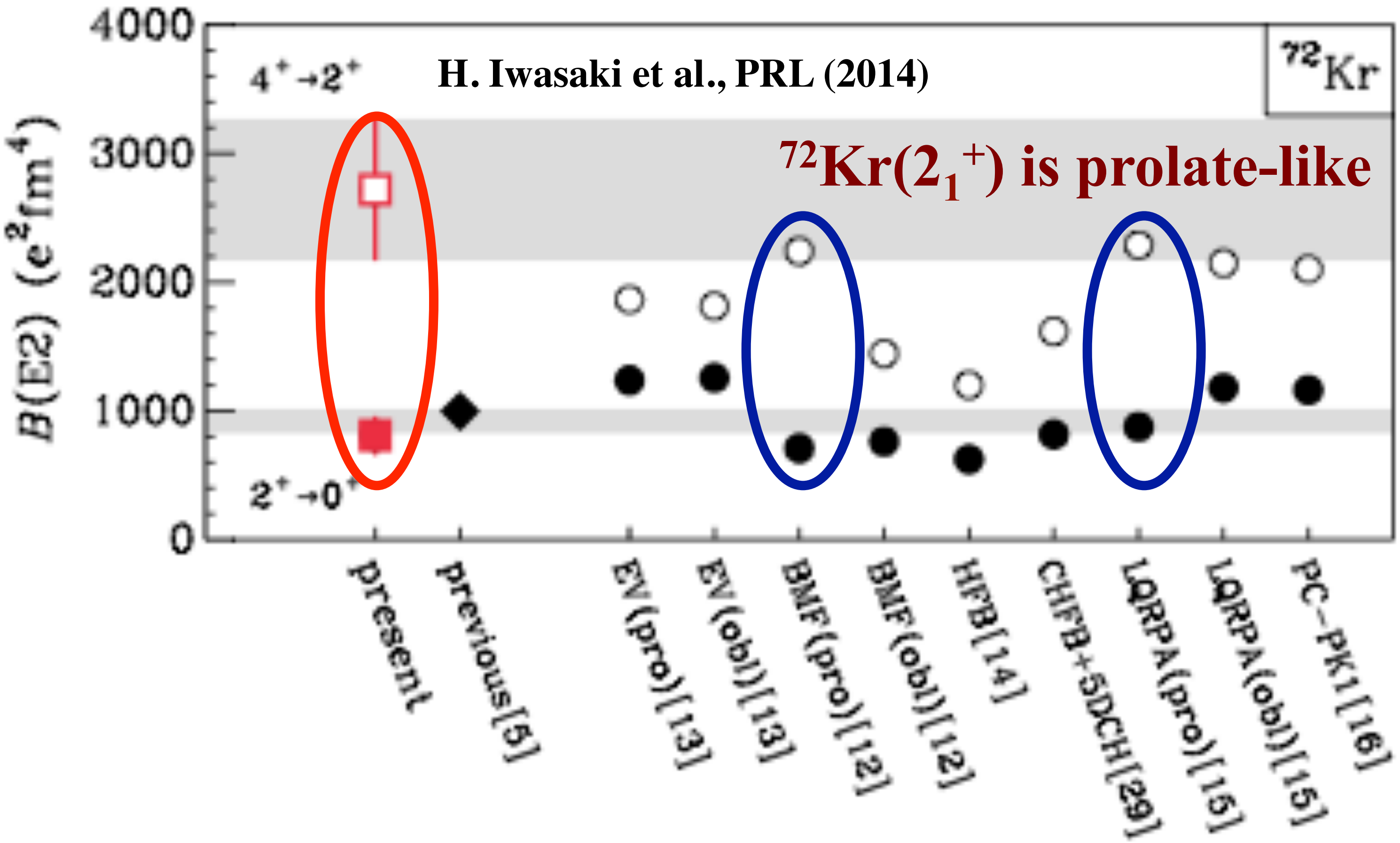


T. R. Rodr´ıguez, http://arxiv.org/pdf/1408.5170v2.pdf, 25 Aug 2014 and PRC (2014)

A.P. Zuker et al., PRC (2015), K. Kaneko et al., Phys. Scr. (2017)

Experimental studies – ^{72}Kr

Lifetime measurements



$B(E2:4_1^+ \rightarrow 2_1^+)/B(E2:2_1^+ \rightarrow 0_1^+)$=3.36, away both from rotor (1.43) and vibrational (2) limits, also indicate weak coupling between 2_1^+ and 0_1^+ compared to that for 4_1^+ and 2_1^+

This is based on the prolate nature for the 4$^+$ state, but no direct information ….

A. Gade et al., PRL 95, 022502 (2005). H. Iwasaki et al., Phys. Rev. Lett. 112, 142502 (2014)

Present Interest – ^{72}Kr

- ^{72}Kr: Shape coexistence expected with oblate low-lying states
- Discrepancies between data and calculations for E0 strengths. $R_{4/2}$ and our results indicate that the 2^+ state is prolate etc…
- A medium mass access point for models

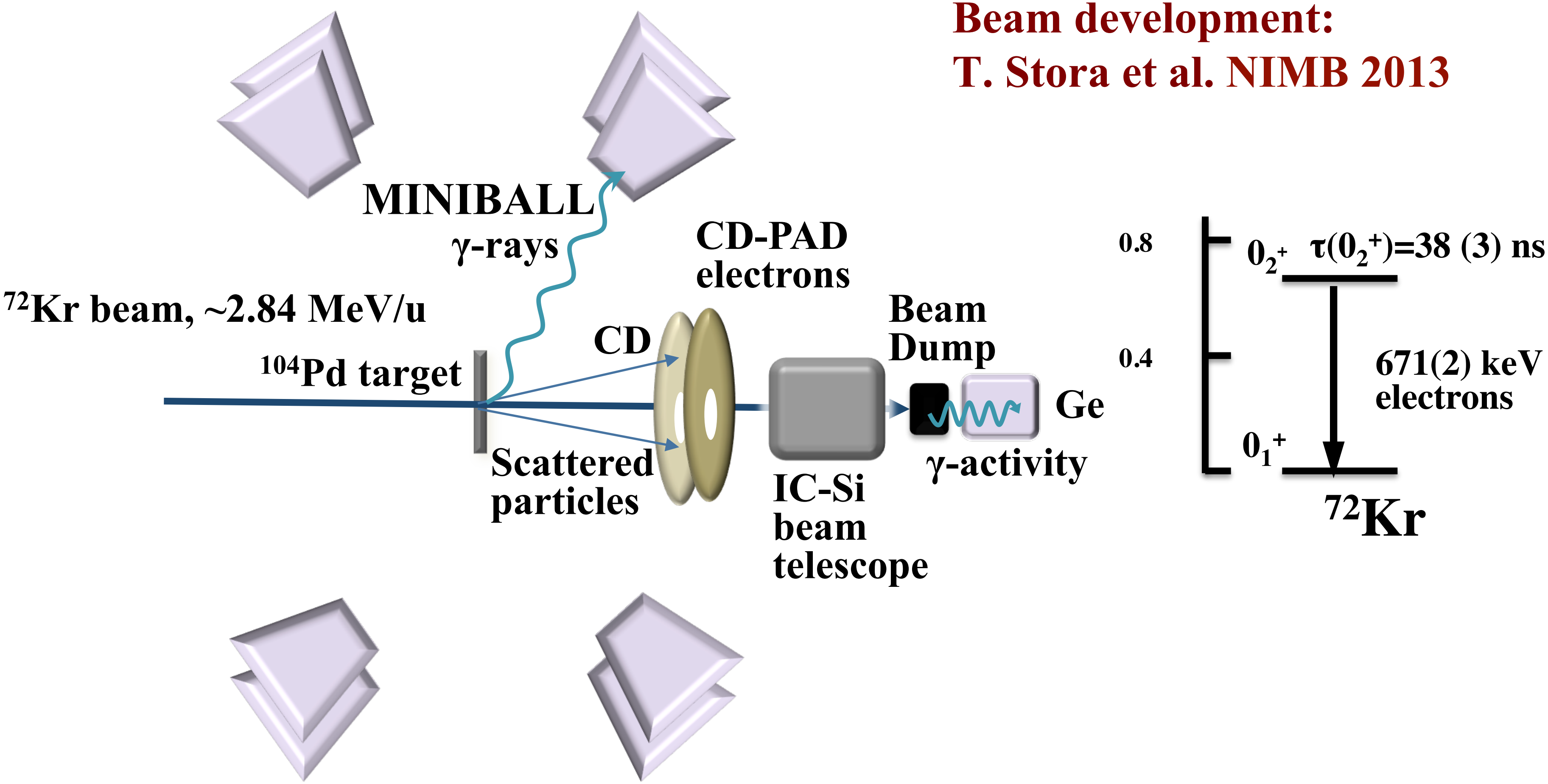
- ^{70}Kr: The second 2^+ and 4^+ states observed in ^{70}Kr two neutrons away from ^{72}Kr suggest shape coexistence and isospin symmetry – K. Wimmer et al. PLB 785, 441 (2018)
- A waiting point nucleus in the rp process

With the remaining shifts confirm or dispute the previously seen evidence for prolate nature for the 2^+ state and obtain properties of the second 2^+ state to provide further understanding of shape coexistence in krypton isotopes

2012: IS478 with Miniball + CD + PAD Setup

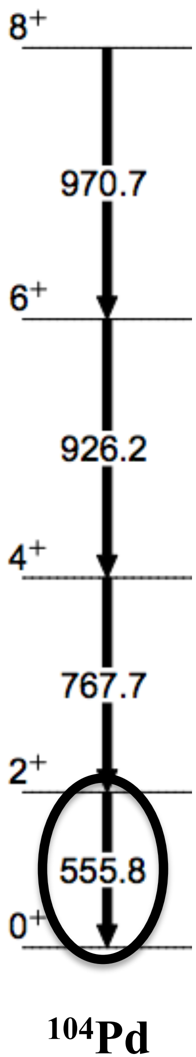
Y_2O_3 nano-material target

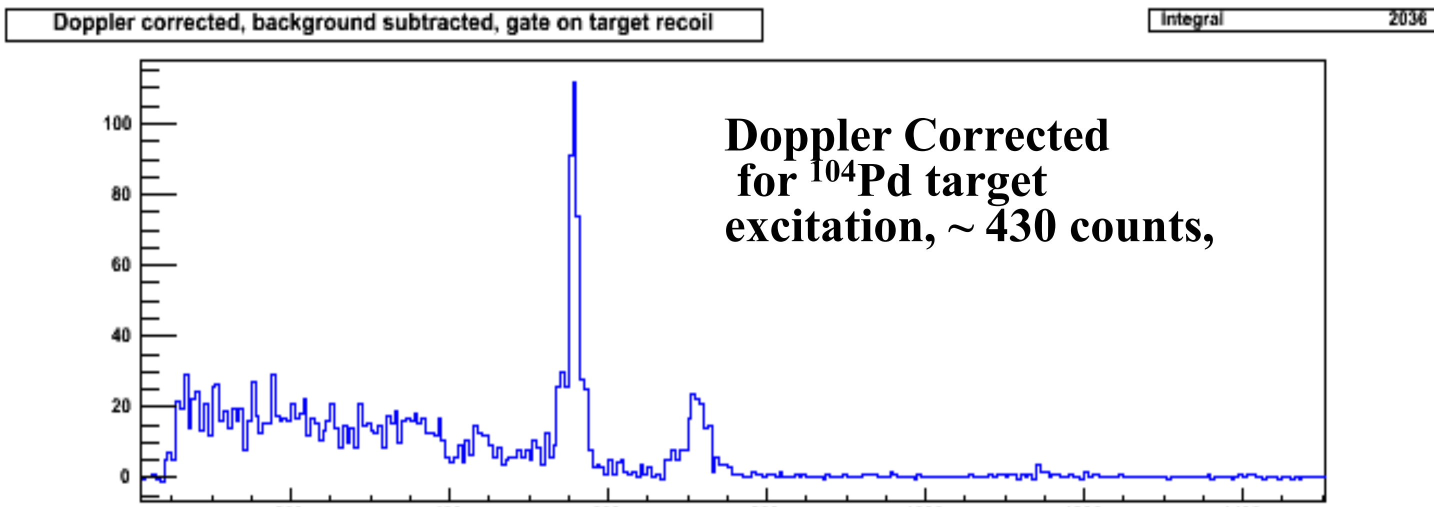
Beam development:
T. Stora et al. NIMB 2013



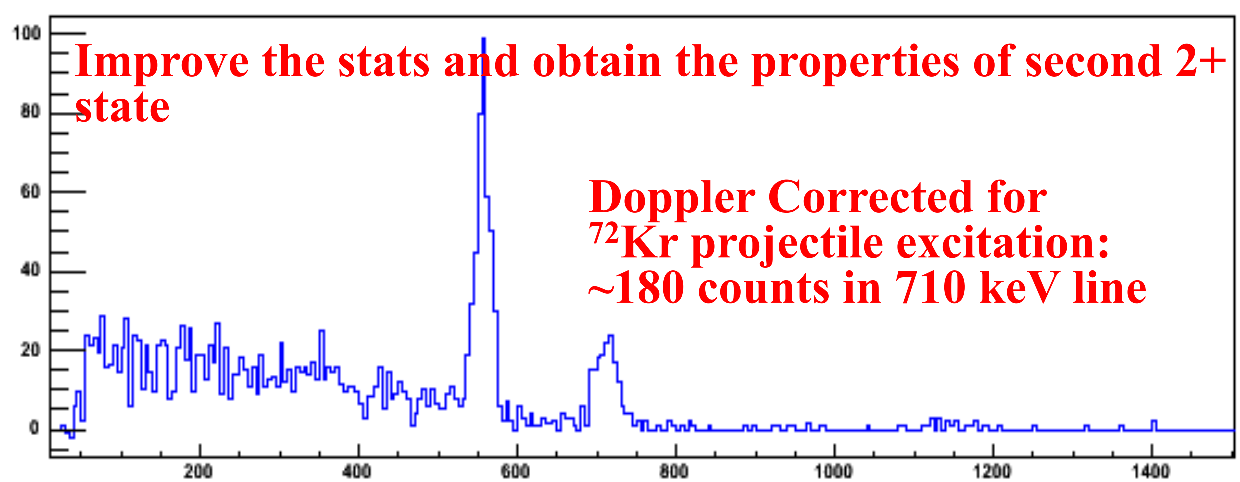
Electron detection from the decay of second 0_2^+ state in ^{72}Kr using a CD-PAD detector

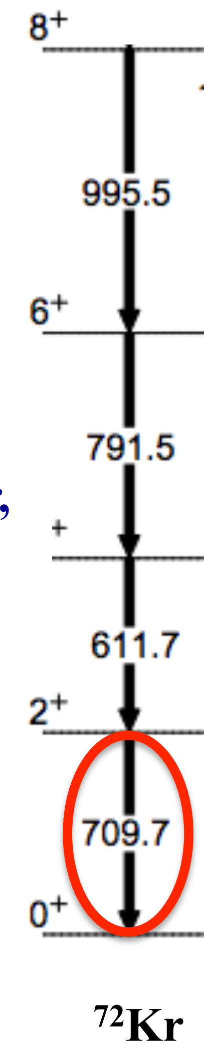
CD gated gamma spectra





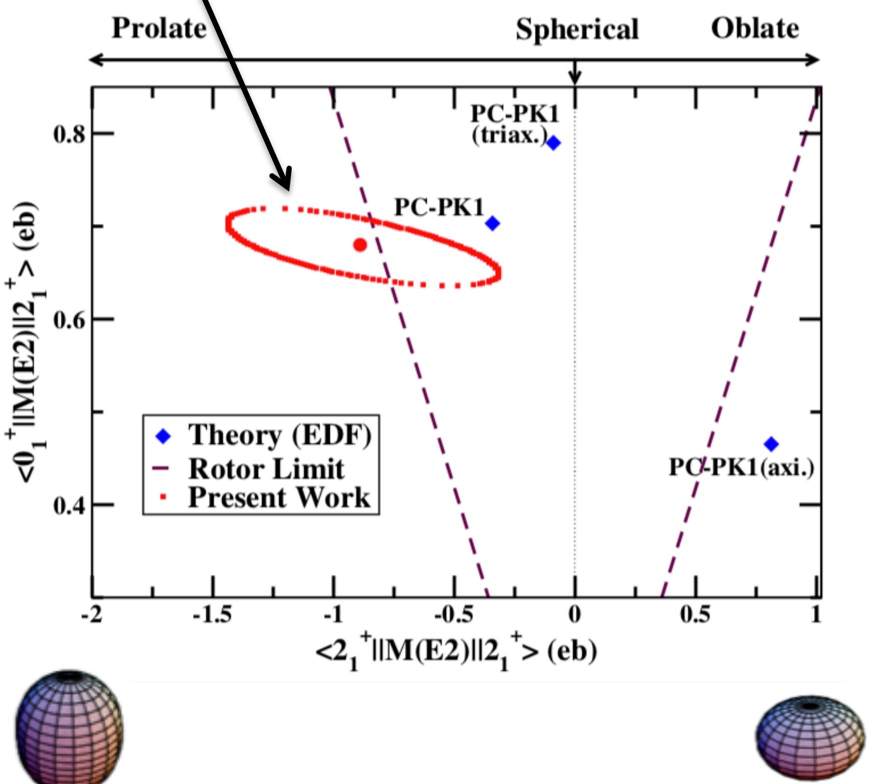
Corrected for excitations due to Contaminations using Ion Chamber, beta decay and Y555/Y709 evolution during the run





Comparison with calculations – Preliminary

First Direct Evidence for the prolate 2_1^+ state



Stae-of-the-art 5DCH calculations based on several popularly used non-relativistic and relativistic EDF. Role of triaxiality can be seen

***Conclusion*: Theoretical calculations are non conclusive, possibly far from having predictability and the experiments such as this and those to measure the properties of the second 2^+ state will play crucial roles.**

Theory (EDF): by J.M. Yao

B.S. Nara Singh et al. to be resubmitted

For remaining 13 shifts

- Thicker target and higher energy (3.1 MeV/u)– improves statistics by a factor of 3.
- Definitive conclusions on shape, confirmation of excited 2^+ state (by confirming the presence of 0.44 and 1.150 MeV gamma rays), better understanding of the ground and excited 0^+ states.
- Additional ME involving this 2_2^+state that will provide insights into the shape coexistence in ^{72}Kr and in general shape dynamics in the A~70 region of open shell nuclei.

IS478: The original beam time request

Assumptions
CD coverage: 16.2° to 53.3°
ε_γ = 7% at 1.3 MeV

Condition	Desirable	Manageable
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^{76}kr at 3-3.1 MeV/u, ~10^6 pps at target position for 1+1 days

Status report on IS478:Shape determination in Coulomb excitation of ^{72}Kr

Rare shape dynamics at low excitation energy in the nucleus ^{72}Kr

Submitted to Nature Communications – to be resubmitted

B.S. Nara Singh[1,2], R. Wadsworth[1], A.N. Andreyev[1,3], C.J. Barton[1], B. Bastin[4], C. Bauer[5], A. Blazhev[6], S. Bönig[5], M.J.G. Borge[7,8], J.A. Briz[8], T.S. Brock[1], P.A. Butler[9], J. Butterworth[1], E. Clément[7], D.M. Cullen[2], A. Damyanova[10], T. Davinson[11], H. De Witte[4], L.M. Fraile[7], L.P. Gaffney[9], J. Henderson[1,12], M. Huyse[4], D.G. Jenkins[1], P. Joshi[1], N. Kesteloot[4], J. Konki[7], Z.P. Li[13], R. Lutter[14], D.R. Napoli[15], A.J. Nichols[1], J. Pakarinen[7,16,17], A. Poves[18], E. Rapisarda[7], P. Reiter[6], P. Ruotsalainen[12,16,17], M. Scheck[9,19], M. Seidlitz[6], B. Siebeck[6], L.F. Sinclair[1], T. Stora[7], M.J. Taylor[1], J. Van de Walle[7], P. Van Duppen[4], M.J. Vermeulen[1], N. Warr[6], F. Wenander[7], K. Wrzosek-Lipska[4], J.M. Yao[13,20], N. Yavuzkanat[1], M. Zielińska[21] and the REX-ISOLDE and the MINIBALL Collaboration

Thanks

Some points on why we need new measurements

- **Having the direct and indirect evidence on the prolate nature for the 2^+ state, can we take help from existing mean-field/shell model based theories to look into the true nature of the ground state ?**

- **If B(GT), B(E2), T(E0) and level structure data indeed helps concluding shape configurations of the 0^+ and 2^+ states in ^{72}Kr – Can we expect predictive power of theories for a) nearby nuclei and b) beyond ?**

- **What role the proton-neutron interaction plays in this region? – can we clearly attribute the shape co-existence phenomena to this interaction?.**

- **Does triaxiality play a role beyond the 2^+_1 state?**

- **Can we pin-down the change in the mean-filed that occurs as we go from ^{70}Br to ^{72}Kr**

A~70 region

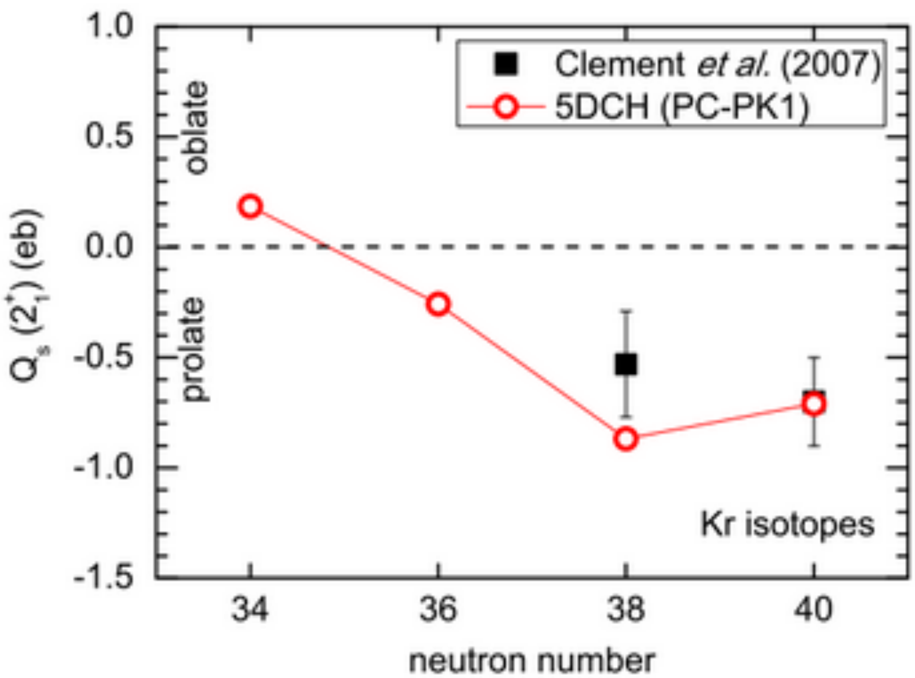
Moments of inertia, B(E2) values on ^{68}Se,^{72}Kr
→oblate low-lying and prolate high-lying states
S. Fischer et al., PRC 67, 064318 (2003), PRL 84, 4064 (2000)
A. Gade et al., PRL 95, 022502 (2005)

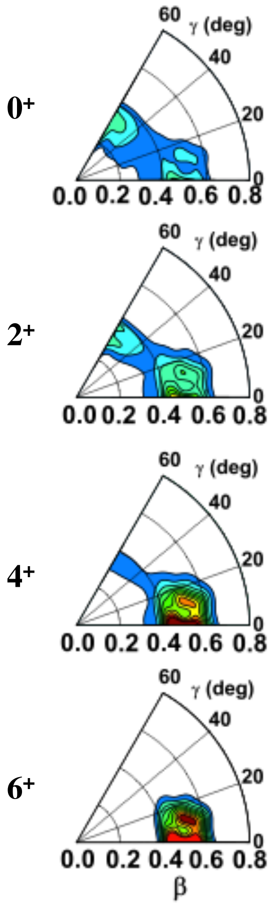
Coulomb energy differences, ^{70}Se,^{70}Br
→ prolate (β_2=0.18) to prolate (0.33) shape change
B.S. Nara Singh et al., Submitted to PRC Rapid com.

Re-orientation effect in low energy Coulex on ^{70}Se
→ prolate 2^+state for ^{70}Se
A.M. Hurst et al., PRL 98, 072501 (2007)

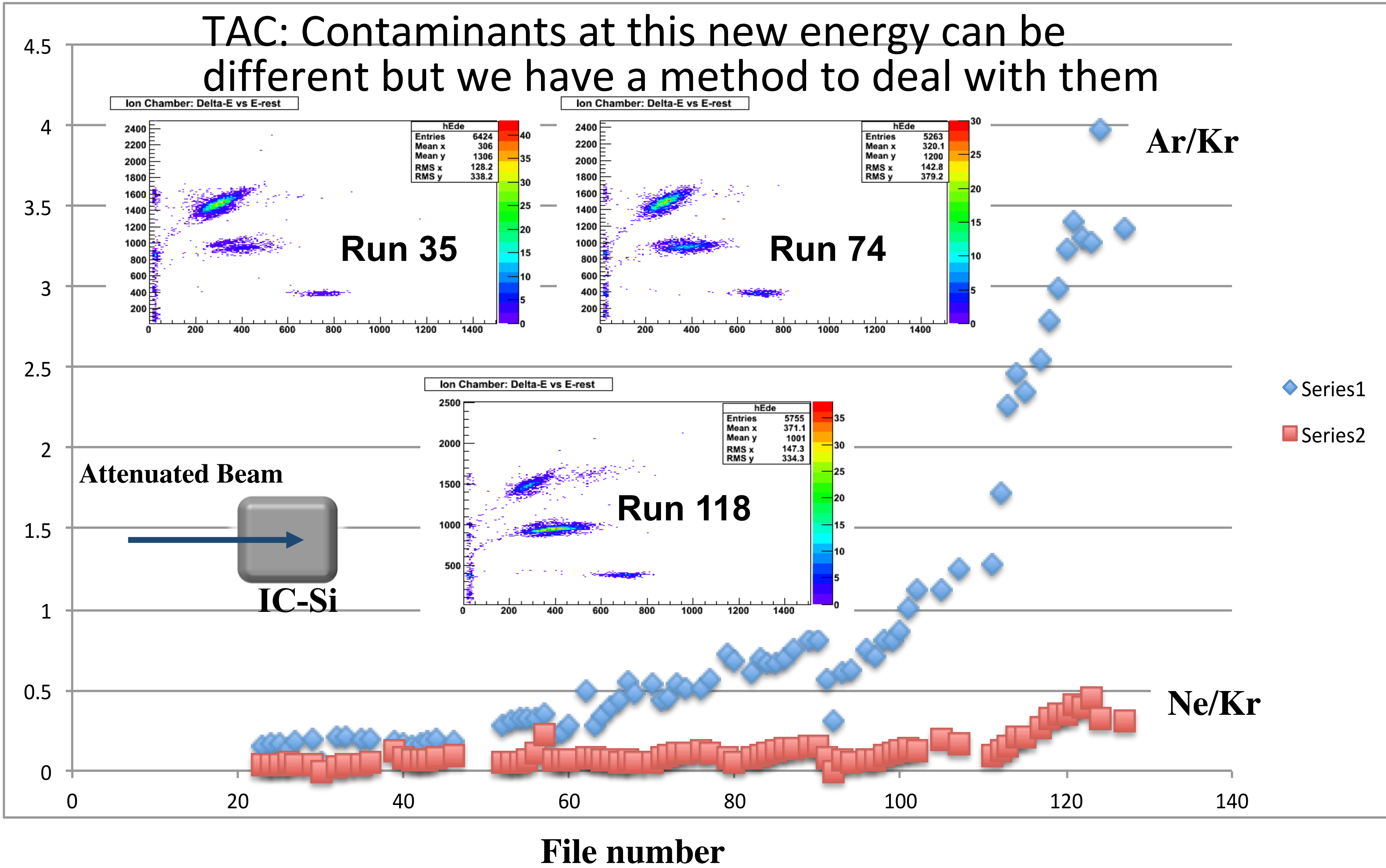
- **No excited 0^+ state found in $^{68, 70}$Se**
- **No direct evidence for oblate ground/low-lying states**

Comparison with calculations – Preliminary

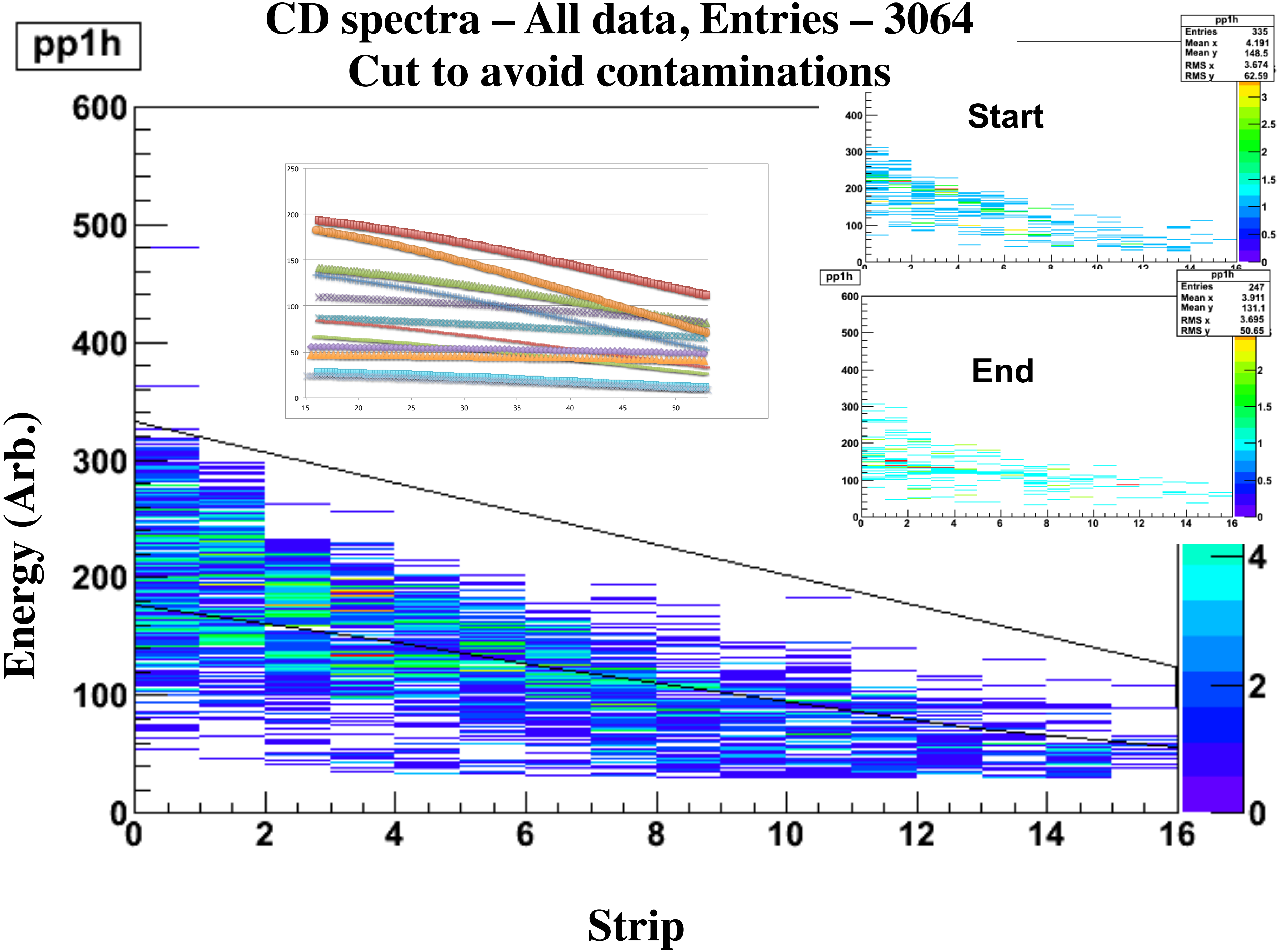




Contaminations

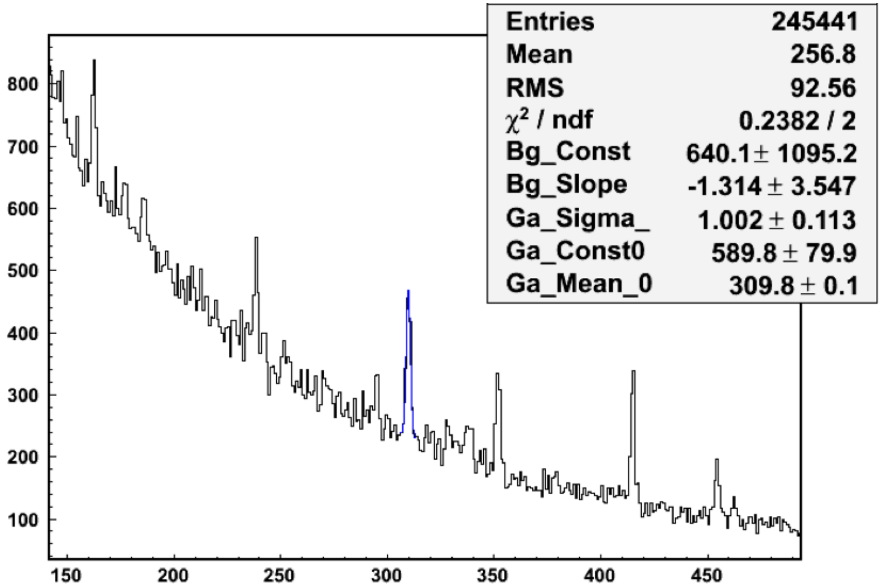


CD spectra – All data, Entries – 3064
Cut to avoid contaminations

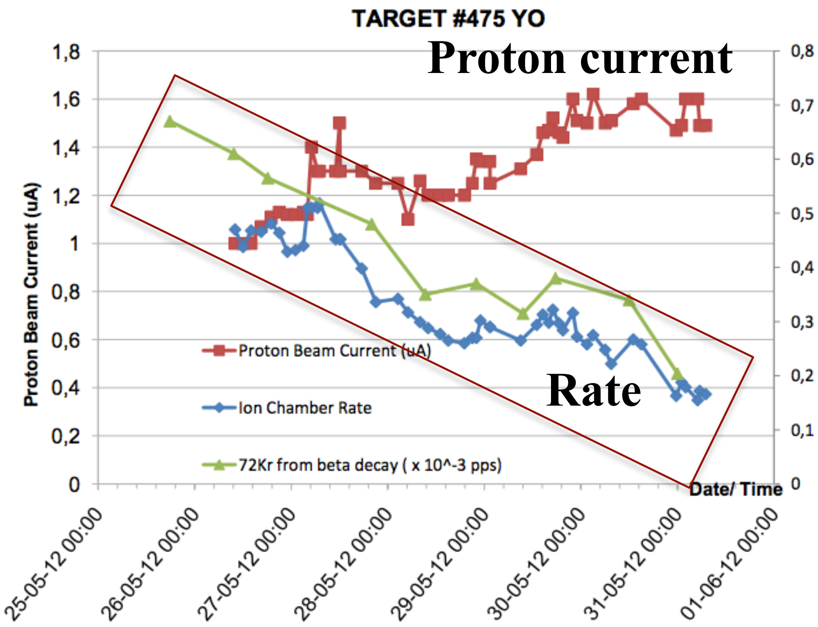


^{72}Kr beta decay at Miniball

TAC: Drop by a factor of 10 not understood



Target degradation during the experiment



^{72}Kr beam development
- e.g. see T. Stora et al. NIMB 2013

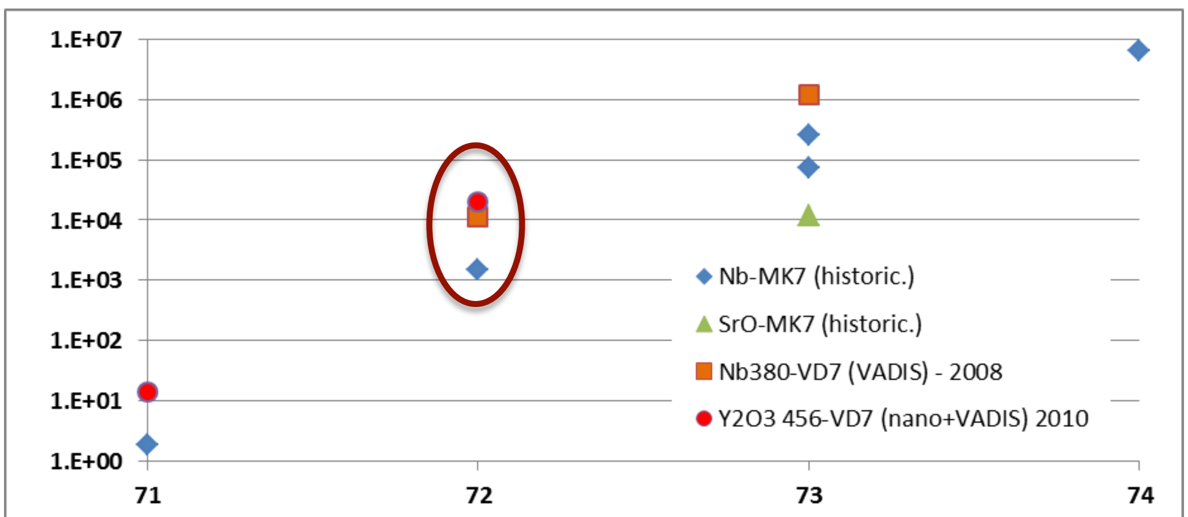
TAC: Molten target versus Y2O3 nano-material target

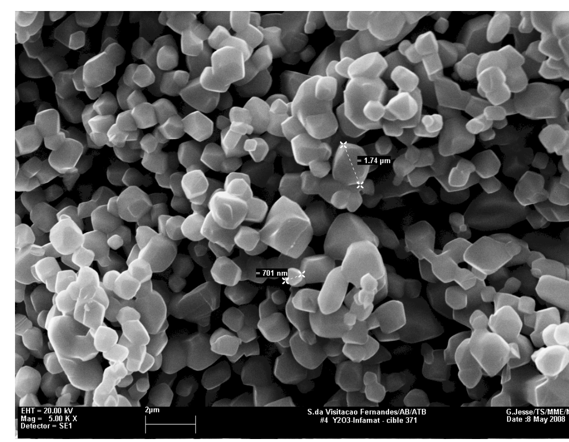
☞ **ZrO2-MK7 FEBIAD unit, not sufficient to reach 800 pps at Miniball**

☞ **ZrO2-MK7 FEBIAD new unit 2 times improvement, Nb380 -MK7 FEBIAD new unit 9 times improvement, (2008)**

☞ **Y2O3 456 – VD7 FEBIAD unit further improvement**

New targets based on nano-materials and new ion sources (VADIS) FEBIAD type





Isotope	M_{02} (eb)	M_{02} (eb)	M_{22} (eb)	ρ^2(E0)	T(E2)/T(E0)
^{78}Kr	0.80(4)			0.047 (13)	3360 (150)
^{76}Kr	0.849 (6)	-0.490 (11)	-0.9 (3)	0.079 (11)	490 (19)
^{74}Kr	0.782 (7)	0.68 (4)	-0.7 (3)	0.085 (19)	
^{72}Kr	0.71 (9)	??	??	0.072 (6)	0

Unlikely ?? $M_{22} \ll M_{02}$

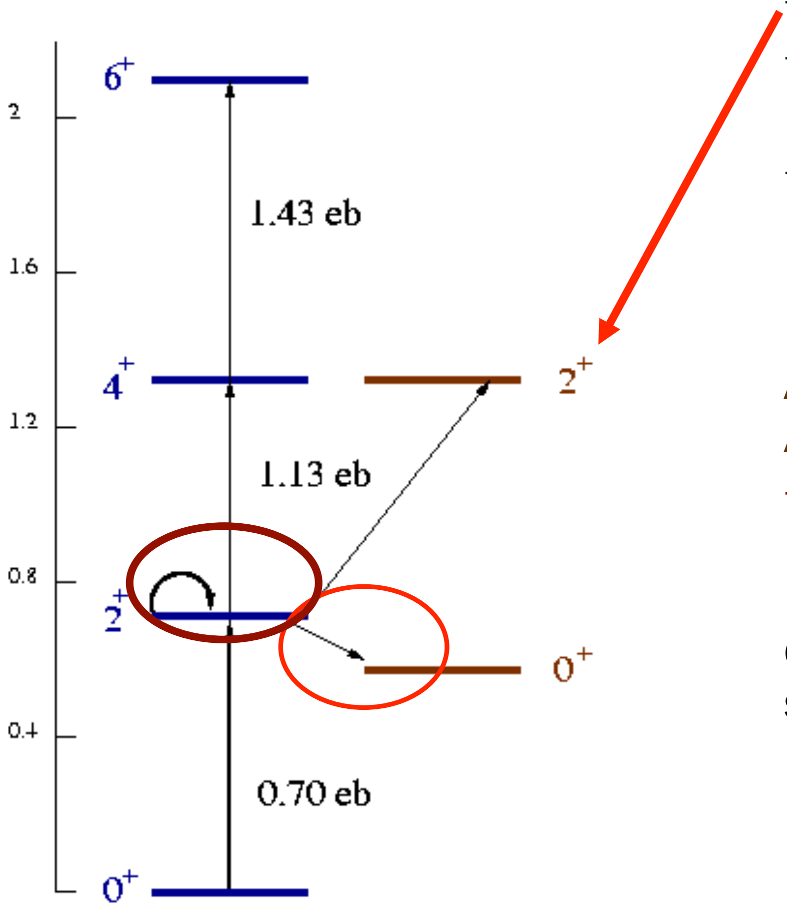
Likely !! $M_{22} > M_{02}$

M_{22} > 0.71 eb , M_{02} < 0.71 eb

Assumed

M_{02} ~ 0.70 eb

Rotational value for M_{22}



Unlikely

M_{22} << M_{02}

→ Second 2+ would be observed
→ Re-orientation effect and the depletions at similar levels.
→ More accurate B(E2) value

An independent B(E2) value + Angular distributions
→ determination of the shape

Interpretation may have to be done for two possible scenarios ??.