Coulomb excitation of $^{138,140,142,144}Xe$ - IS411 campaign

Corinna Henrich

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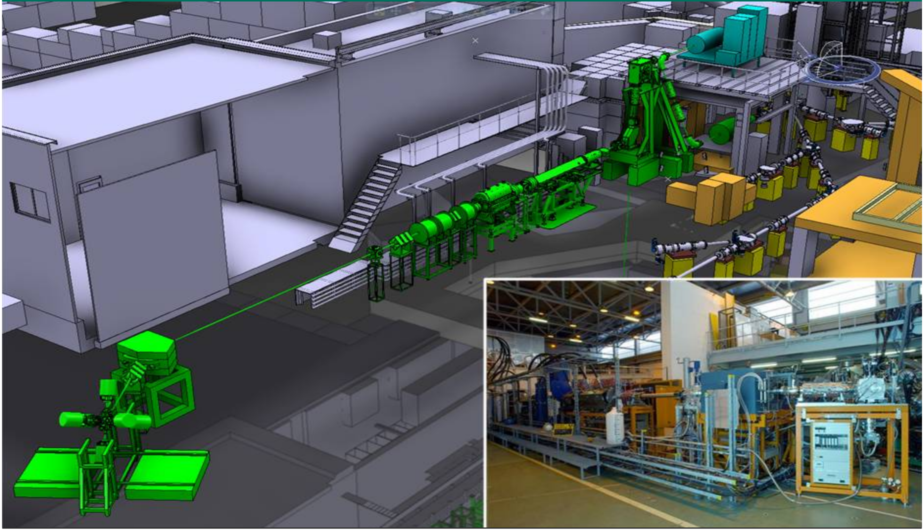

Introduction -
Area of interest

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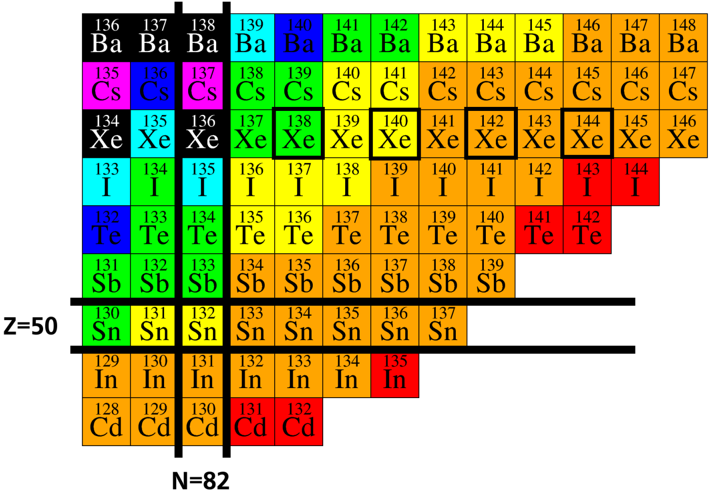

Motivation -
Evolution of the energy of the 2_1^+-state

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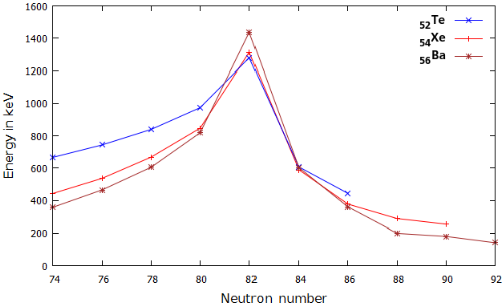

Figure : Energy of the first 2^+-state

Motivation - Evolution of the energy of the 2_1^+-state

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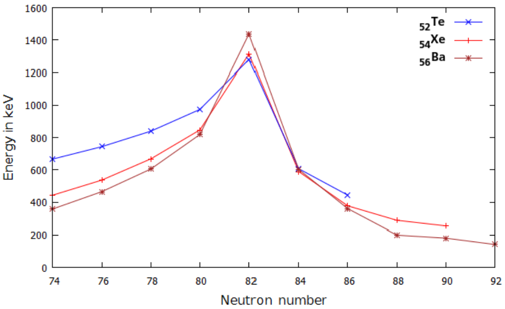

- Connection to B(E2; $0_{gs}^+ \rightarrow 2_1^+$): Empirical Grodzins' rule (1962):

$$E_{2_1^+}[\mathrm{keV}] \cdot B(E2; 0_{gs}^+ \rightarrow 2_1^+)[\mathrm{e}^2\mathrm{b}^2] = 16.3 \cdot Z^2 \cdot A^{-1}$$

Motivation - Empirical Grodzins' rule and B(E2)-values

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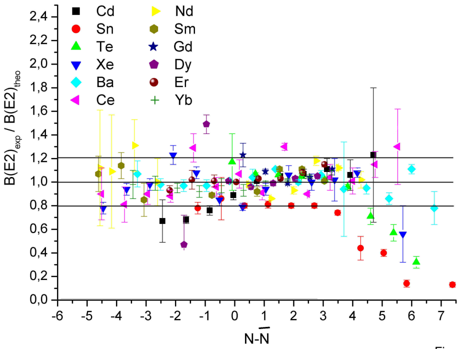
- By S. Raman et al. (2001) and D. Habs et al. (2002) modified Grodzins' rule:

$$E_{2_1^+}[\text{keV}] \cdot B(E2; 0^+_{gs} \rightarrow 2^+_1)[\text{e}^2\text{b}^2] = 3.242 \cdot Z^2 \cdot A^{-\frac{2}{3}}(1.000 - 0.0608(N - \overline{N}))$$



- $\overline{N} = \frac{A}{2} \cdot \frac{1.0070+0.0128 \cdot A^{\frac{2}{3}}}{1+0.0064 \cdot A^{\frac{2}{3}}}$

Data from: S. Raman, At. Data Nucl. Data Tables 78, 1 (2001)
Figure taken from: D. Habs et al.: CERN-INTC-2002-015; INTC-P-156 (2002)

Motivation - Former experimental results

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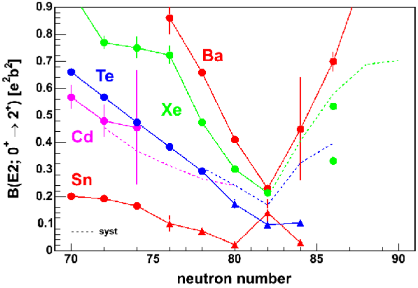

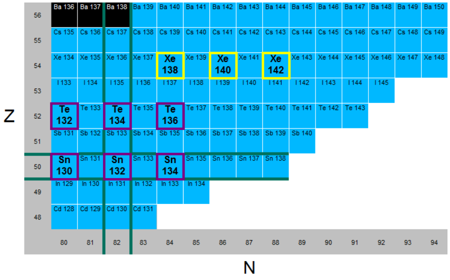

Data measured at HRIBF (Oak Ridge): D. C. Radford et al., Phys. Rev. Lett. 88, 222501 (2002)
R. L. Varner et al., Eur. Phys. J. A 25, s01, 391 (2005)
D.C. Radford et al., Eur. Phys. J. A 25, 383 (2005)

Experiment - Coulex setup

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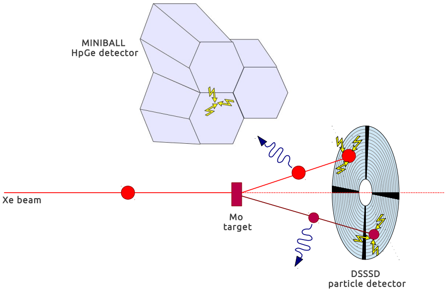
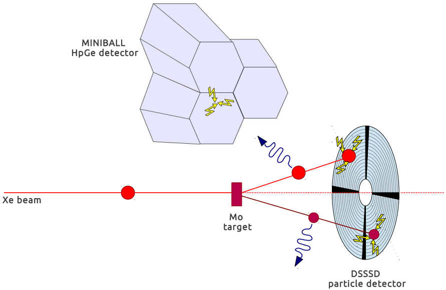


- Projectile:
  - Xenon beam with 2.8 MeV/u (85 % of max energy for Safe Coulex)
  - Provided by REX-ISOLDE facility at CERN in 2005 and 2006
  - Nuclides $^{138,140,142,144}Xe$

Experiment - Coulex setup



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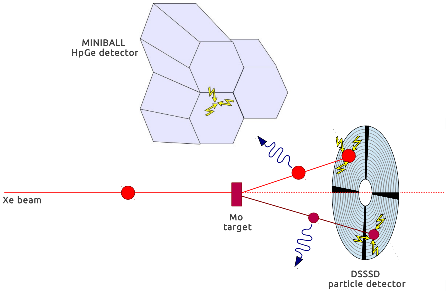
- Target:
  - ^{96}Mo target with thickness of 1.7 $\frac{mg}{cm^2}$
  - Reasons for choice: sufficient information on nucleus, preparable as target, scattering kinematics

Experiment - Coulex setup



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- Target:
  - ^{96}Mo target with thickness of 1.7 $\frac{mg}{cm^2}$
  - Reasons for choice: sufficient information on nucleus, preparable as target, scattering kinematics
- Inverse kinematics
- In-flight emission of γ-rays
  $\Rightarrow$ angles are of importance!

Data analysis - Approach

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- Determine projectile Coulex cross section σ^{p}_{Coul} relative to target σ^{t}_{Coul} using CLX & DCY

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$$\sigma^p_{Coul} = \frac{1}{P} \cdot \frac{N^p_\gamma}{\epsilon^p_\gamma} \cdot \frac{\epsilon^t_\gamma}{N^t_\gamma} \cdot \sigma^t_{Coul}$$

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- σ^{t}_{Coul}: CLX & DCY need matrix elements of target ^{96}Mo: (M_{02}, M_{22}) [1]
- Counts in efficiency corrected peak $\frac{N_{\gamma}}{\epsilon_{\gamma}}$
- Beam purity P
  - Cold plasma ion source used
  - Breeding time of REX-EBIS ⇒ beam purity

1: P. Paradis et al. Phys. Rev. C. 14:835-841

Data analysis - Approach

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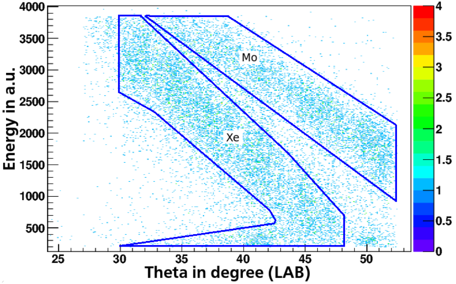
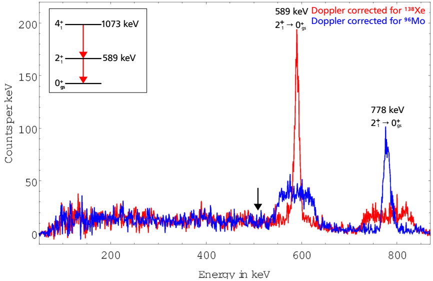
- Counts in efficiency corrected peak $\frac{N_\gamma}{\epsilon_\gamma}$
- Beam purity P
  - Cold plasma ion source used
  - Breeding time of REX-EBIS $\Rightarrow$ beam purity

- σ^p_{Coul} = CLX/DCY(M_{02}, M_{22}, ..) $\Rightarrow$ M_{02} $\Rightarrow$ B(E2;$0^+_{gs} \rightarrow 2^+_1$)

1: P. Paradis et al. Phys. Rev. C. 14:835-841

Analysis of ^{138}Xe - Kinematics and Doppler-corrected spectra





- High count rates (10^5 part./s)
  $\Rightarrow$ Inner four rings covered
  $\Rightarrow$ Only small angular range on DSSSD available!

Analysis of ^{138}Xe - Lifetime measurements

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- ⇒ Not enough information to determine B(E2)-value and quadrupole moment with reasonable confidence intervals
- ⇒ Additional information by direct lifetime measurements: $\tau(2_1^+) = (17.3 \pm 3.4)$ ps [1]

1: S. Ilieva, preliminary value; EXILL-FATIMA campaign at ILL in 2013

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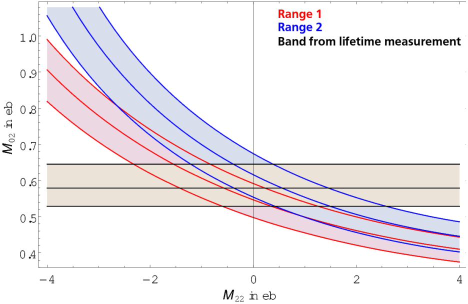

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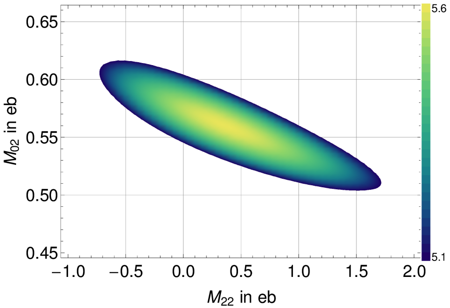
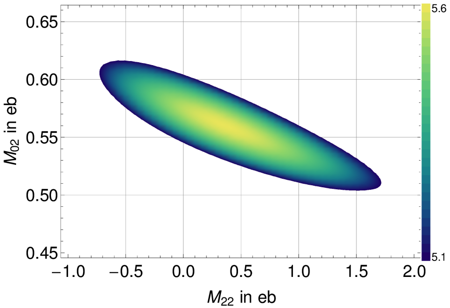
Preliminary results for ^{138}Xe - 1σ-contour plot



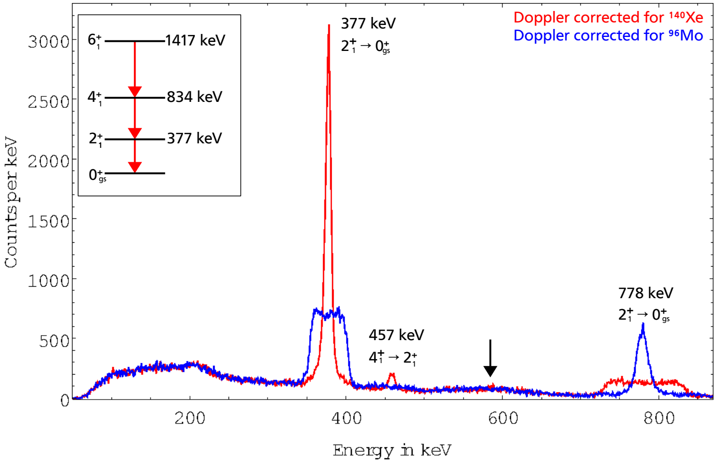
Preliminary results for ^{138}Xe - 1σ-contour plot



⇒ B(E2)-value and quadrupole moment

- $B(E2; 0^+_{gs} \rightarrow 2^+_1) = (0.31 \pm 0.07)\,e^2b^2$
- $eQ_s(2^+_1) = (0.27\ ^{+1.02}_{-0.83})\,eb$

Analysis of ^{140}Xe - Doppler-corrected spectra using full statistics



Analysis of ^{140}Xe - Approach

- Relevant matrix elements: M_{02}, M_{22}, M_{24}, and M_{44}
- Mean lifetime $\tau(2_1^+) = (101.7 \pm 3.2)$ ps[1] and $\tau(4_1^+) = (22.8 \pm 4.9)$ ps[1]

1: A. Lindroth et al. Phys. Rev. Lett. 82:4783-4786

Analysis of ^{140}Xe - Approach

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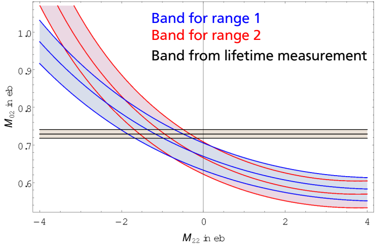
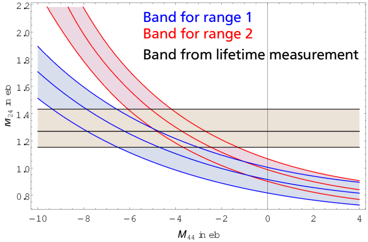
- Relevant matrix elements: M_{02}, M_{22}, M_{24}, and M_{44}
- Mean lifetime $\tau(2_1^+) = (101.7 \pm 3.2)\,\mathrm{ps}$[1] and $\tau(4_1^+) = (22.8 \pm 4.9)\,\mathrm{ps}$[1]

M_{24}, M_{44} = 0



new M_{24}, M_{44}

new M_{02}, M_{22}



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Analysis of ^{140}Xe - Approach

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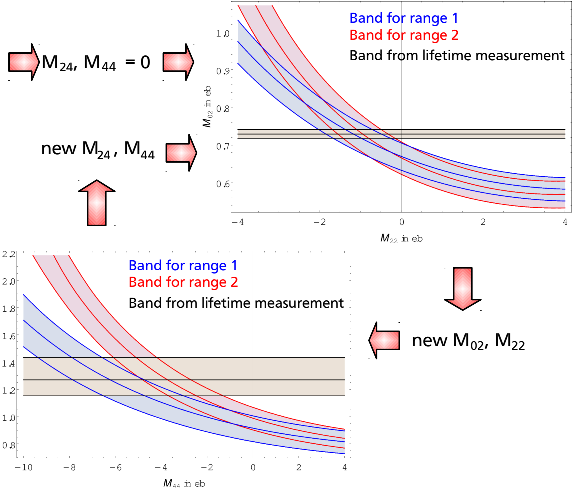
- Relevant matrix elements: M_{02}, M_{22}, M_{24}, and M_{44}
- Mean lifetime $\tau(2_1^+)$= (101.7 ± 3.2) ps[1] and $\tau(4_1^+)$ = (22.8 ± 4.9) ps[1]
- $\Rightarrow$ Consistent set of matrix elements (M_{02}, M_{22}, M_{24}, M_{44})



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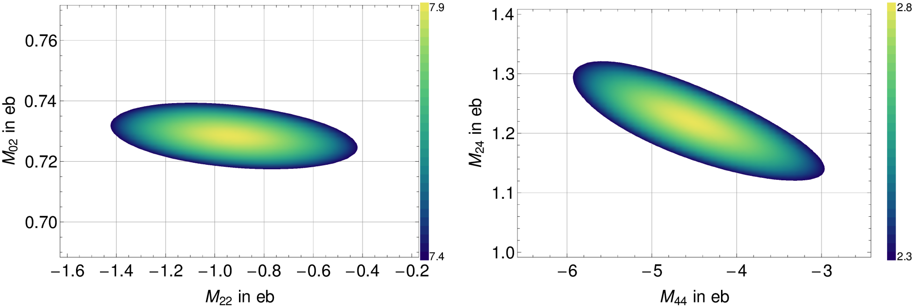

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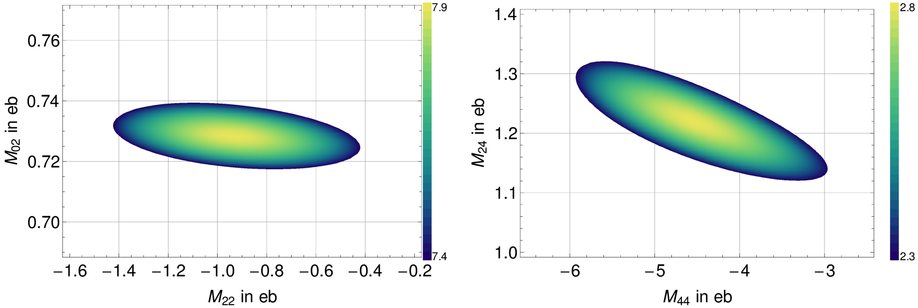

⇒ B(E2)-values and quadrupole moments

- B(E2; $0^+_{gs} \rightarrow 2^+_1$) = (0.53 ± 0.01) e^2b^2
- $eQ_s(2^+_1)$ = (-0.71 $^{+0.39}_{-0.36}$) eb
- B(E2; $2^+_1 \rightarrow 4^+_1$) = (0.30 ±0.05) e^2b^2
- $eQ_s(4^+_1)$ = (-2.56 $^{+0.88}_{-0.79}$) eb

Analysis of ^{144}Xe - Doppler-corrected spectra using full statistics

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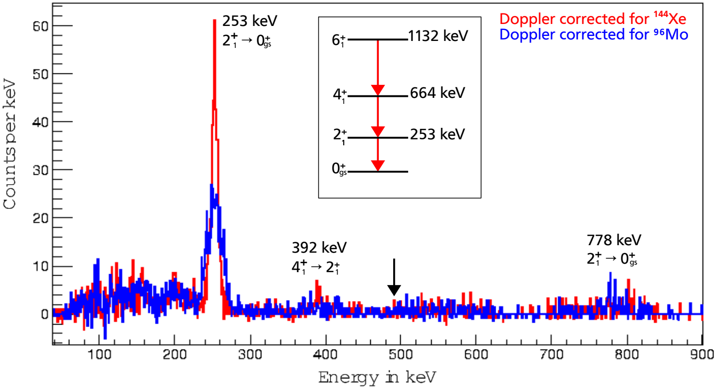

- Analysis ongoing. Challenging due to low statistics :(

Preliminary results - Comparison to theory

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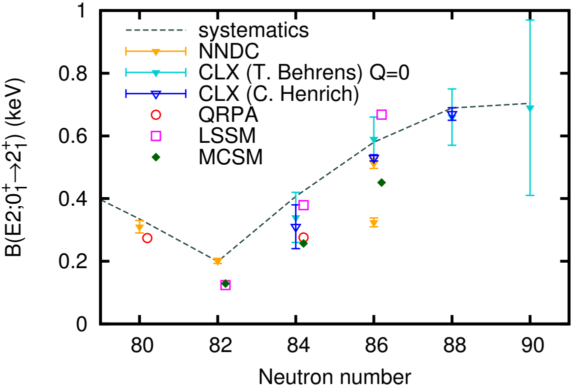

systematics: modified Grodzins' systematics
NNDC: National Nuclear Data Center
T. Behrens, PhD thesis
QRPA: J. Terasaki et al., Phys. Rev. C 66 (2002) 054313
LSSM: D. Bianco et al., Phys. Rev. C 88 (2013) 024303
MCSM: N. Shimizu et al., J. Phys.: Conf. Ser. 49 (2006) 178

Summary and outlook - Preliminary results

	Transition $I_i \rightarrow I_f$	$B(E2)_\uparrow$ in e^2b^2	$eQ_s(I_f)$ in eb
^{138}Xe	$0^+_{gs} \rightarrow 2^+_1$	0.31 ± 0.07	$0.27\ ^{+1.02}_{-0.83}$
^{140}Xe	$0^+_{gs} \rightarrow 2^+_1$	0.53 ± 0.01	$-0.71\ ^{+0.39}_{-0.36}$
	$2^+_1 \rightarrow 4^+_1$	0.30 ± 0.05	$-2.56\ ^{+0.88}_{-0.79}$
^{142}Xe	$0^+_{gs} \rightarrow 2^+_1$	0.67 ± 0.02	$-1.02\ ^{+0.64}_{-0.60}$
	$2^+_1 \rightarrow 4^+_1$	$0.41\ ^{+0.22}_{-0.18}$	$-2.45\ ^{+\infty}_{-1.88}$

Summary and outlook - Preliminary results

	Transition $I_i \rightarrow I_f$	B(E2)↑ in e^2b^2	$eQ_s(I_f)$ in eb
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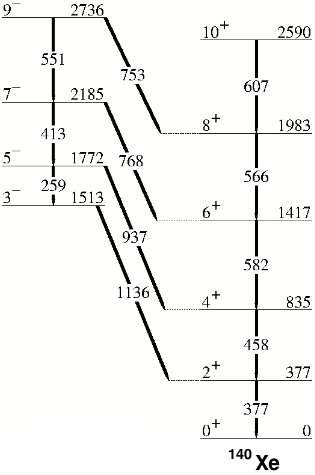
- HIE-ISOLDE: Influence of multiple Coulex increases (additional matrix elements)
- → Combined analysis of Coulex and lifetime measurements necessary



Level scheme taken from: W. Urban et al., Eur. Phys. J. A 16, 303307 (2003)

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Thank you for your attention!

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HIC for FAIR Helmholtz International Center

EURONS

(506065)

ISOLDE

and the IS411-MINIBALL Collaboration

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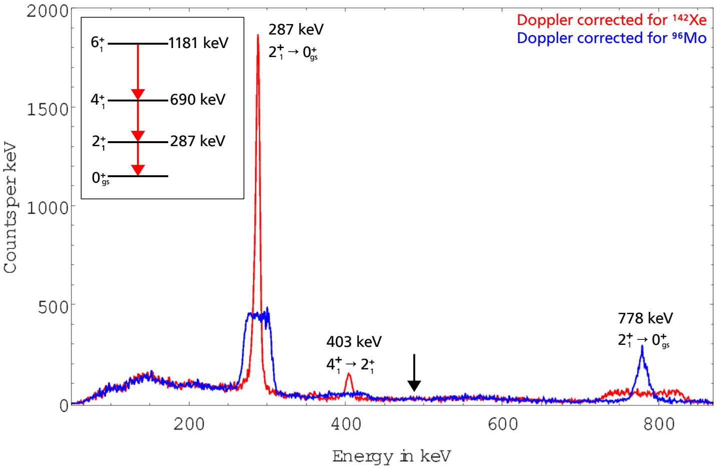
Backup - Analysis of ^{142}Xe - Doppler-corrected spectra using full statistics



Backup -
Preliminary results for ^{142}Xe -
1σ-contour plot

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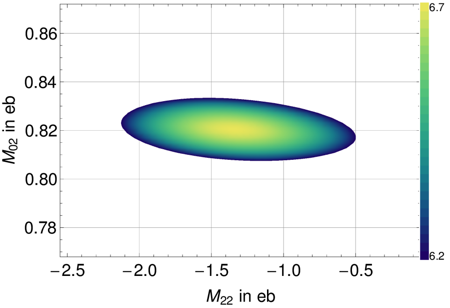

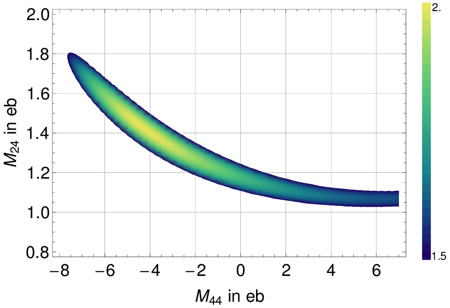

$\Rightarrow$ B(E2)-values and quadrupole moments

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- $eQ_s(2^+_1) = (-1.02\ ^{+0.64}_{-0.60})\, eb$
- $B(E2; 2^+_1 \rightarrow 4^+_1) = (0.41\ ^{+0.22}_{-0.18})\, e^2b^2$
- $eQ_s(4^+_1) = (-2.45\ ^{+\infty}_{-1.88})\, eb$

Used mean lifetime $\tau(2^+_1) = (270 \pm 10)$ ps: S. Ilieva, preliminary value; EXILL-FATIMA campaign at ILL in 2013

Backup - Matrix elements

- B(E2)-values are dependent on off-diagonal matrix elements

$$B(E2; I_i \to I_f) = \frac{1}{2I_i + 1} |M_{if}|^2$$

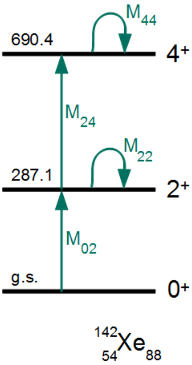
- Connection of the mean lifetime τ to B(E2)-values

$$\frac{1}{\tau(I_f)} \propto E_\gamma^5 \cdot B(E2; I_i \to I_f)$$

- Quadrupole moments are dependent on diagonal matrix elements

$$M_{22} = \sqrt{\frac{7}{2\pi}\frac{5}{4}} eQ_s$$

$$M_{44} = \frac{1}{2}\sqrt{\frac{275}{7\pi}} eQ_s$$



Backup - Analysis of ^{138}Xe - Approach

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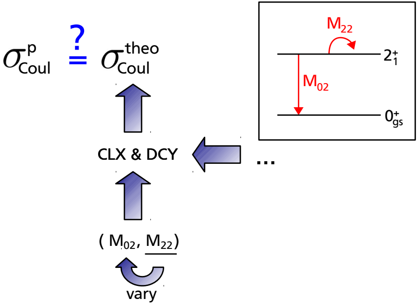
$$\sigma^{p}_{Coul} = P \cdot \frac{N^{p}_{\gamma}}{\epsilon^{p}_{\gamma}} \cdot \frac{\epsilon^{t}_{\gamma}}{N^{t}_{\gamma}} \cdot \sigma^{t}_{Coul}$$



- Determine all observables on right side ⇒ experimental projectile cross section σ^{p}_{Coul}
- ⇒ (M_{02}, M_{22})-pairs determined from experimental projectile cross section

Backup - Grodzins' rule