Magnetic moment and lifetime measurements in ^{140}Ba

(following HIE-ISOLDE Letter of Intent I-093)

Proposal to the INTC Committee

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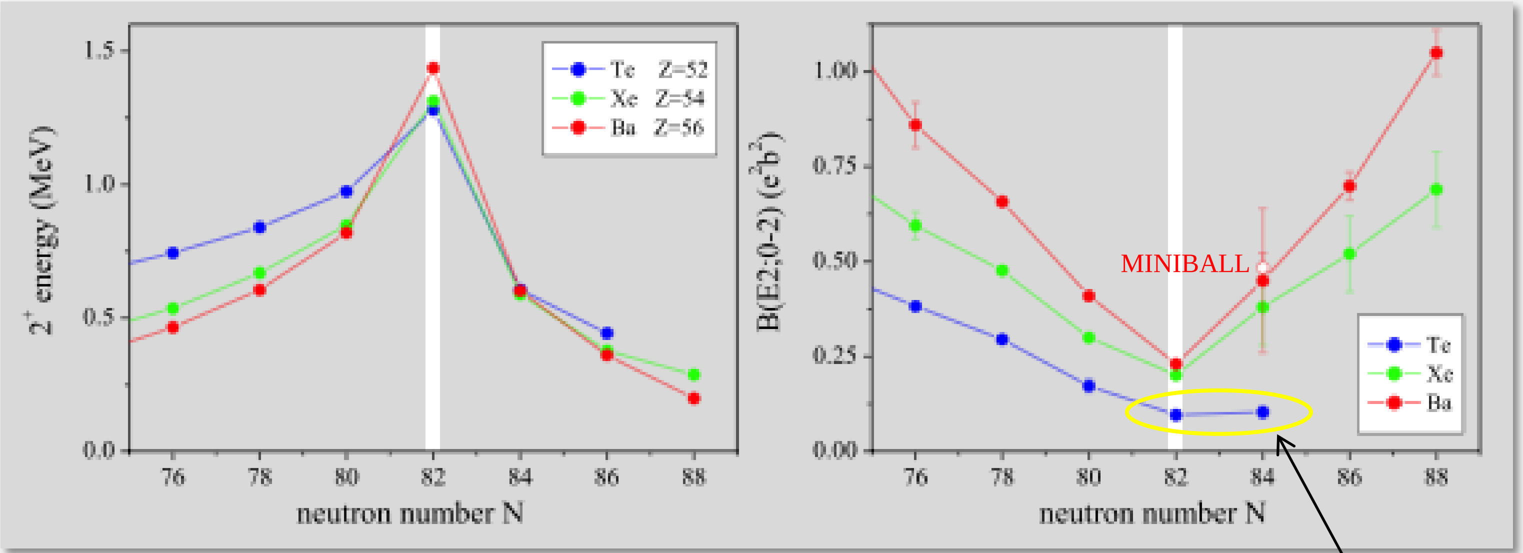
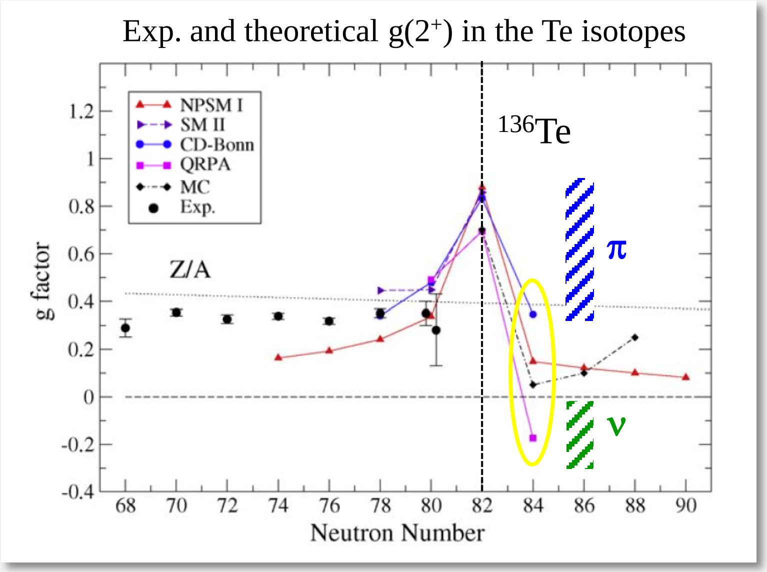
ISOLDE-CERN October 31, 2012

LoI I-093: Magnetic moment measurements in A~140 Te, Xe, Ba and Ce isotopes using the Transient Field technique





Low B(E2) value in ^{136}Te !

Neutron dominated 2^+ wavefunction ?

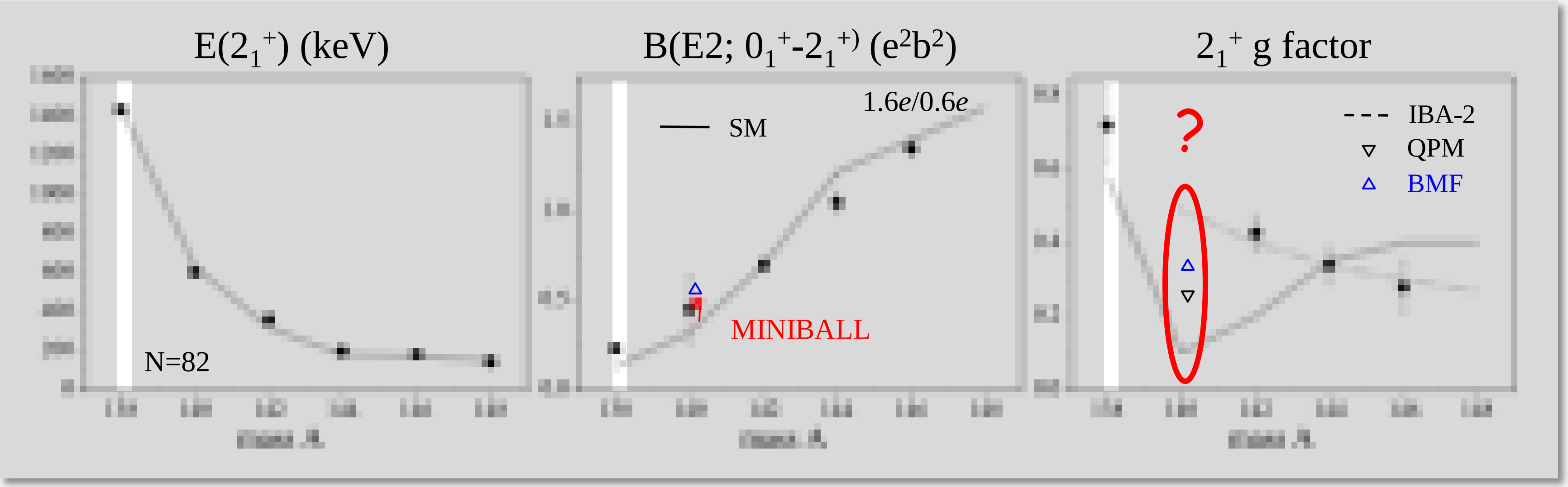
⇦ **g factor measurement will tell !**

g(2^+) in ^{136}Te main goal of LoI I-093, but has to wait until Te beams are available.

Meanwhile …

N. Benczer-Koller et al., PLB 664(2008)241

Spherical-deformed transition in the $_{56}$Ba isotopes



spherical semi-magic → axially deformed symmetric rotor

$Q_{exp}(2_1^+) = -0.52(34)$
$Q_{SM}(2_1^+) = -0.51$
$Q_{BMF}(2_1^+) = -0.522$

π SP structure | π/ν SP structure | g~Z/A collective

$\pi(g_{7/2})$: $g_{eff} = +0.83$
$\nu(f_{7/2})$: $g_{eff} = -0.28$
$\nu(p_{3/2})$: $g_{eff} = -0.23$

Monte Carlo shell model calculations nicely describe $E(2_1^+)$ and B(E2) in the transitional region !

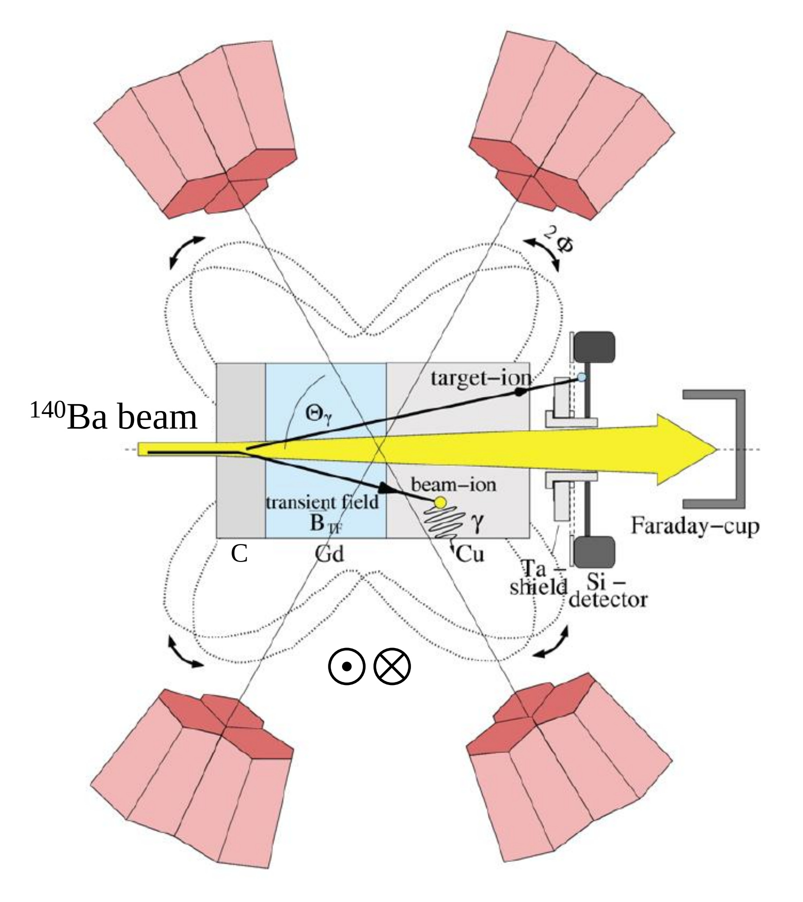
But what about $g(2_1^+)$ in ^{140}Ba ?

MINIBALL: *C. Bauer et al., PRC86 (2012) 034310*

SM: *N. Shimizu et al., PRL. 86 (2001) 1171*
T. Otsuka et al., PPNP. 47 (2001) 319

QPM: *T.K. Dinh et al., JPG18 (1992) 329*
BMF: *J.L. Egido, priv. comm.*

Projectile Coulomb excitation and transient fields



- Coulomb excitation on a **C layer**
- recoil through a thick polarized **Gd layer** in which the magnetic moment of the excited state interacts with the transient field (Larmor precession)
- beam ions stopped in a non-magnetic **Cu backing**
- C target reoils detected in Si detectors

Observe precession of γ-ray angular correlation !

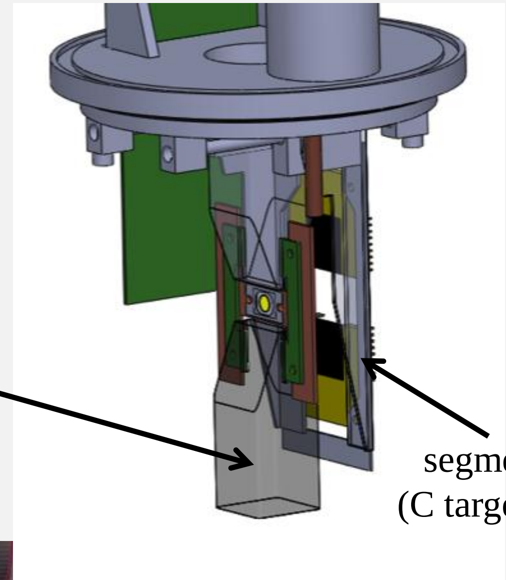
Result: $g(2_1^+)$ with sign !

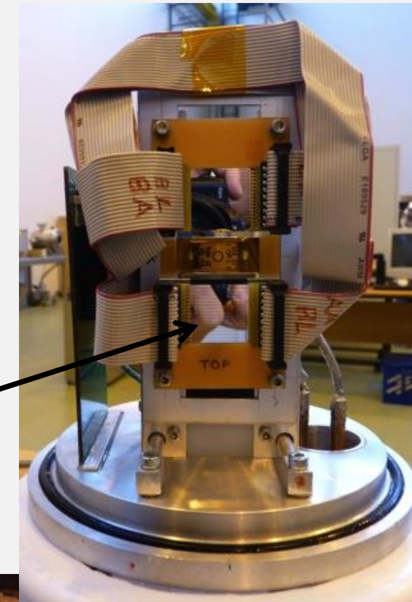
Problem: Target thickness $\gtrsim$ 10 mg/cm^2 ➡ beam straggling ➡ activation !

New IEM target chamber for Transient Field experiments with MINIBALL at REX-ISOLDE

large diameter beam-out

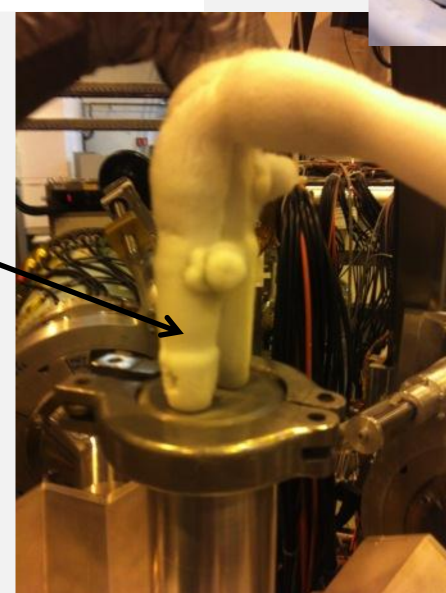
external magnetic field



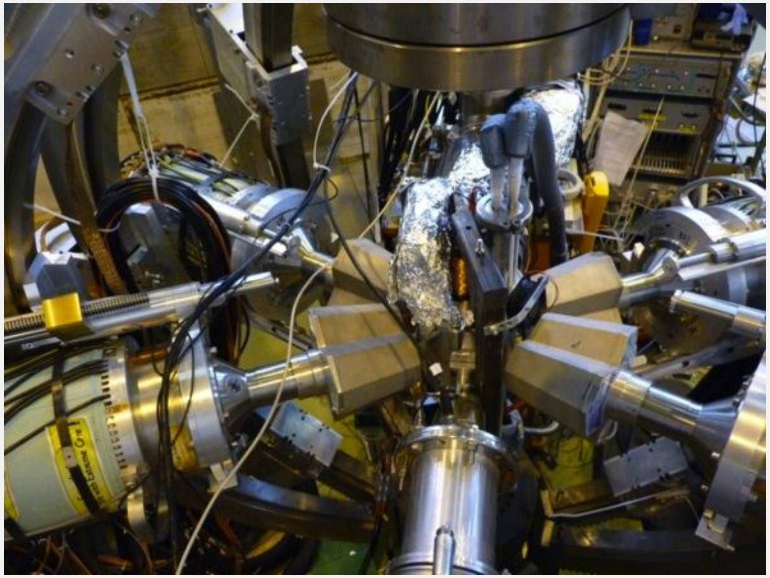


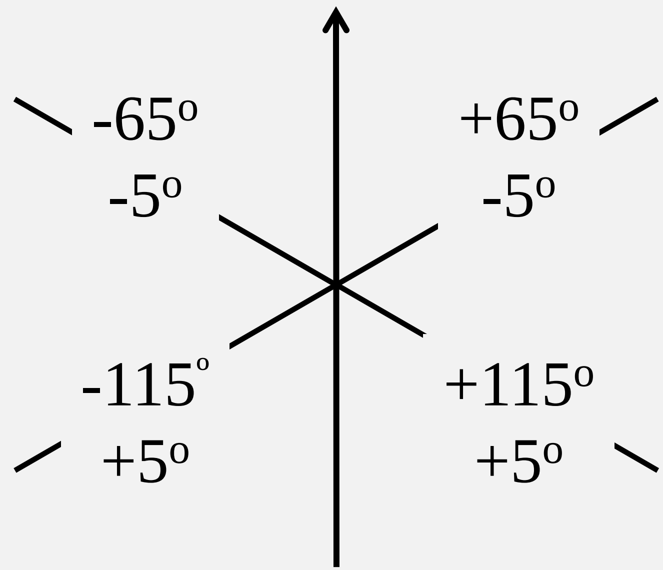
segmented Si (C target recoils)

cooling of the target (Gd layer)

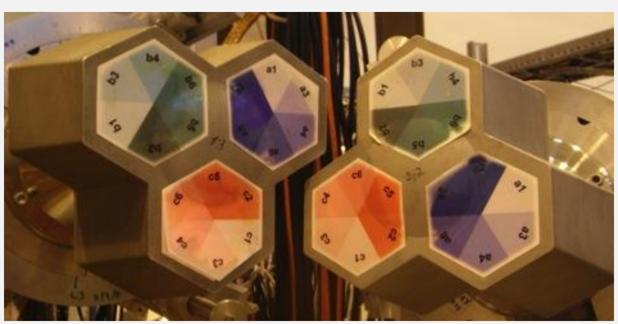


IS483: 4 MINIBALL clusters in a horizontal plane





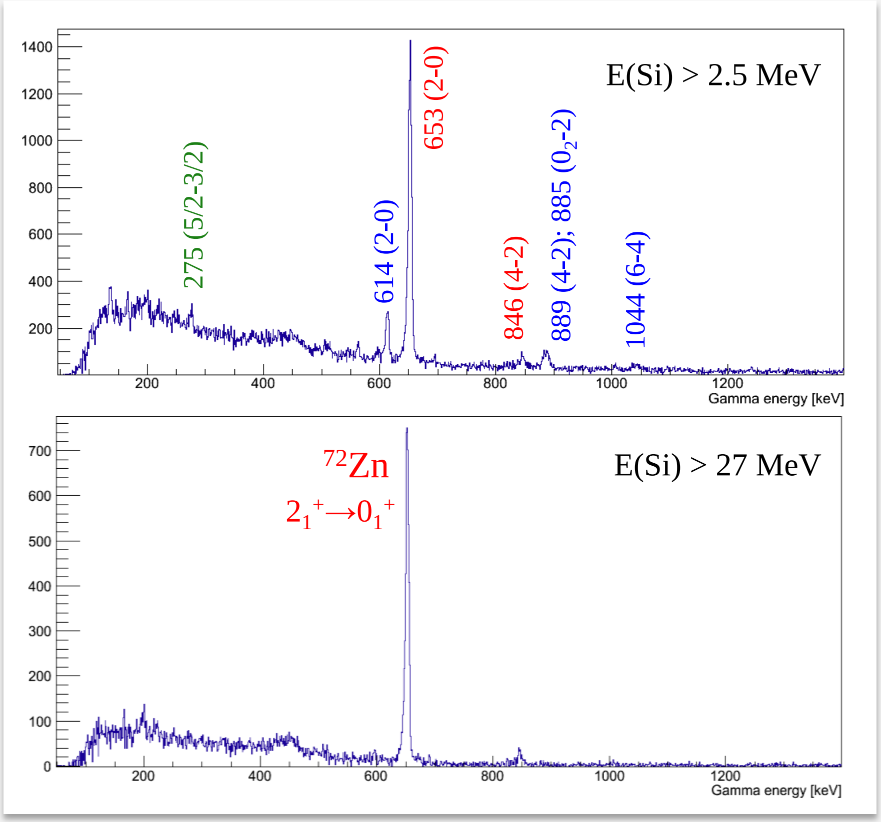
Clusters as seen from the target position:



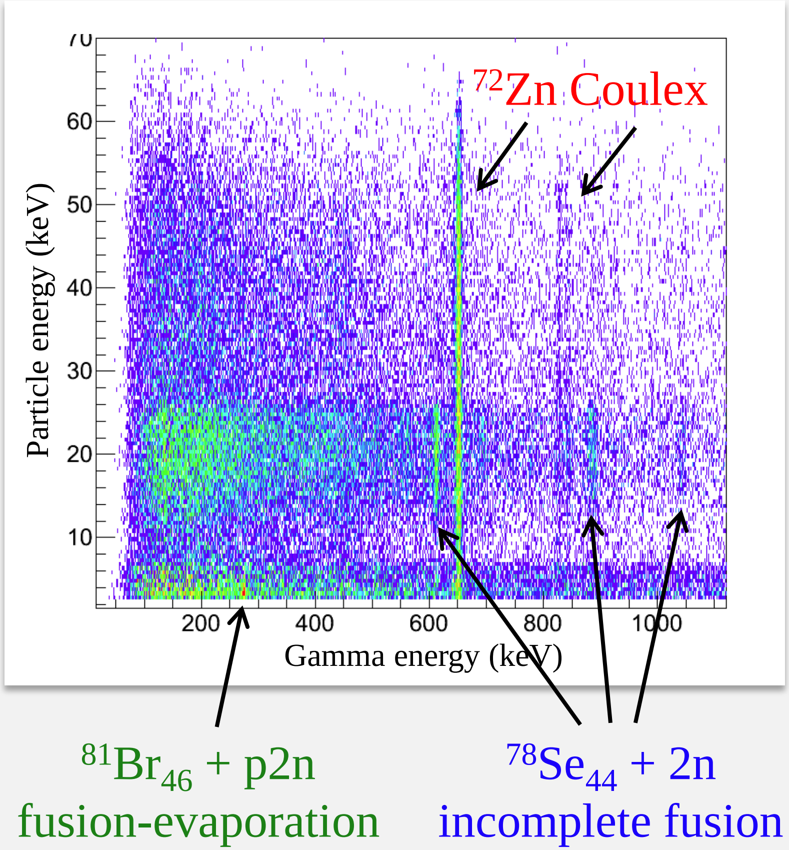
Compact geometry !

November 2011

IS483: $g(2_1^+)$ in ^{72}Zn using projectile Coulex and TF



Preliminary: $g(2_1^+) = +0.4(1)$ $T_{1/2}$=46.5 h



Only third successful TF g factor measurement with radioactive beams !

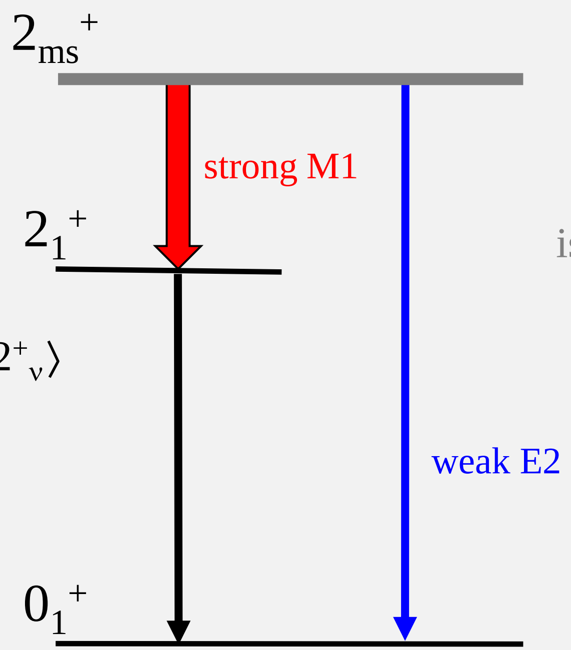
Previous runs at Oak Ridge: $g(2_1^+) = +0.28(15)$ in ^{132}Te $T_{1/2}$=76.3 h   *N. Benczer-Koller et al., PLB664 (2008) 241*

$g(2_1^+) = -0.25(21)$ in ^{126}Sn $T_{1/2}=10^5$ a   *G.J. Kumbartzki et al., PRC86 (2012) 034319*

Identification of 2^+ mixed-symmetry state in ^{140}Ba

Due to the two-fluid nature of nuclear matter:

2^+ states in <u>even vibrational nuclei</u> appear as <u>symmetric</u> or <u>antisymmetric</u> combination of the involved proton and neutron configurations.



symmetric
one-phonon state

$|2_1^+\rangle \approx a\,|2^+_\pi\rangle + b\,|2^+_\nu\rangle$

one-phonon state with mixed
proton-neutron symmetry

$|2_{ms}^+\rangle \approx b\,|2^+_\pi\rangle - a\,|2^+_\nu\rangle$

isovector analogue of the 2_1^+ state

Absolute B(M1) strength is sensitive to the p-n balance of the wave functions !

J.D. Holt et al., Phys. Rev. C 76 (2007) 034325

Main signature for a 2_{ms}^+ state:

Strong $2_{ms}^+ \rightarrow 2_1^+$ M1 decay   (large absolute B(M1) value)

Systematics of 2_{ms}^{+} states in N=80,84 isotones

^{132}Te

<u>First</u> identification of a 2_{ms}^{+} state in an unstable nucleus !

M. Danchev et al., Phys. Rev. C84 (2011) 061306(R)

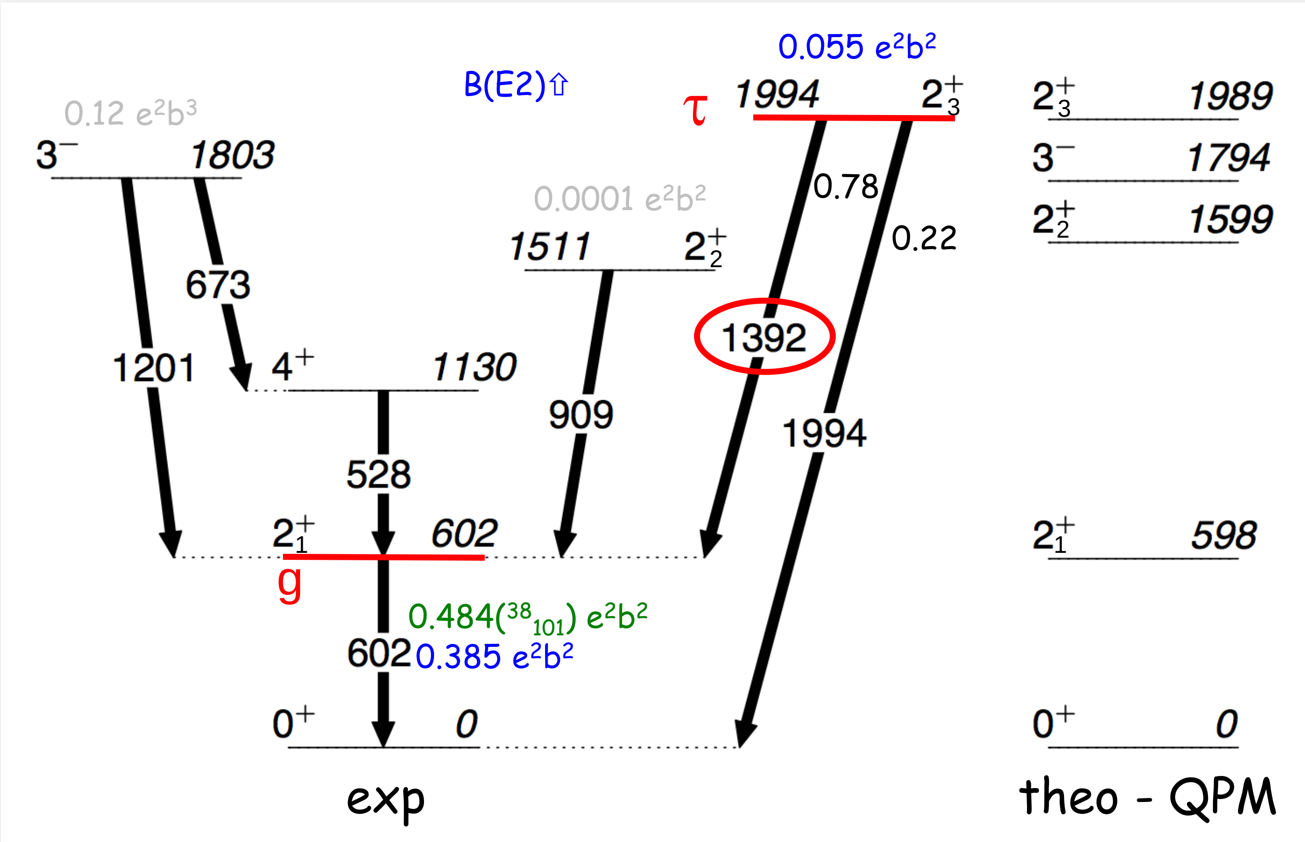
2_3^+ at 1994 keV in ^{140}Ba proposed as ms candidate on the basis of the small mixing ratio of the $2_3^+ \rightarrow 2_1^+$ transition

W.D. Hamilton et al., Phys. Rev. Lett. 53 (1984) 2469

Relation between single-particle structure and ms state properties !

$\tau(2_3^+)$ needed to fix ms character !

Experimental excitation scheme of ^{140}Ba



For ms states, typically $B(M1; 2_{ms}^+ \rightarrow 2_1^+) > 0.1\ \mu_N^2$

$\tau(2_3^+) < 160$ fs

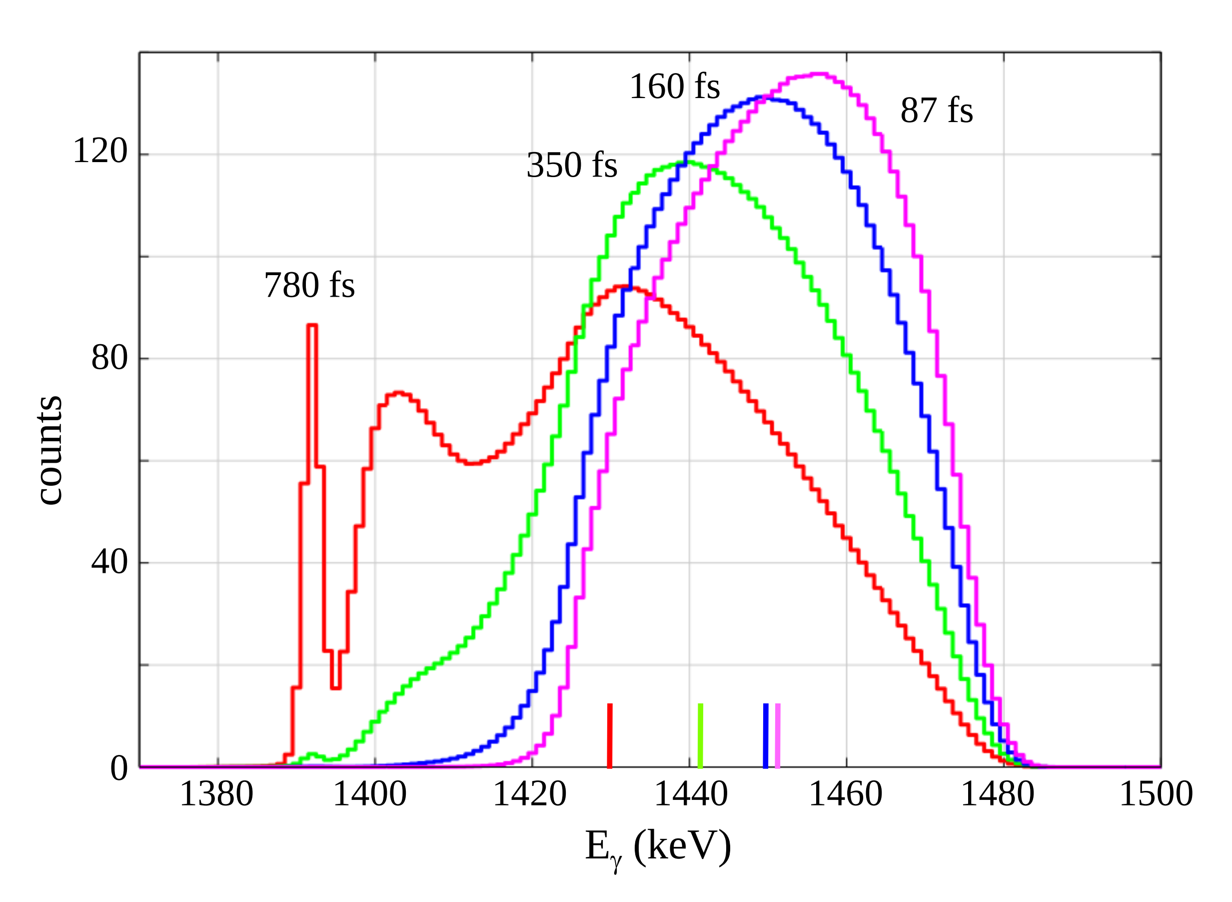
Measure centroid position of 1392 keV γ-ray !

MINIBALL: *C. Bauer et al., PRC86 (2012) 034310*

T.K. Dinh et al., J. Phys. G18 (1992) 329

Use experimental $B(E2; 0_1^+ \rightarrow 2_1^+)$ and theoretical $B(E2; 0_1^+ \rightarrow 2_3^+)$ for beam time estimate.

Expected lineshape of the $2_3^+ \rightarrow 2_1^+$ 1392 keV transition



- MINIBALL crystal at Θ=50º with respect to the beam
- C – Gd – Cu multilayer target

Beam time estimate

Assumptions

Multilayer target: 1.0 mg/cm^2 C + 9.0 mg/cm^2 Gd + 1.0 mg/cm^2 Ta + 6.5 mg/cm^2 Cu

Beam: ^{140}Ba @ 3.36 MeV/u with average intensity of 5x10^6 pps on reaction target (measured in IS411)

γ-ray detection efficiency: 0.5% at 0.6 MeV and 0.3% at 1.4 MeV for each crystal (d=10 cm)

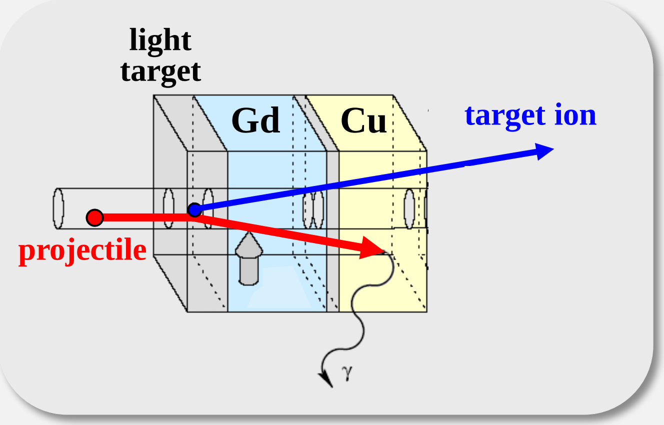
Charged particle detection: Four 20x20 mm^2 segmented Si (only two for g factor analysis)

Within **15 shifts** with beam on target:

- $g(2_1^+)$ uncertainty of 10% for $g(2_1^+) = 0.3$ and 20% for $g(2_1^+) = 0.1$
- 100 counts per crystal for the $2_3^+ \rightarrow 2_1^+$ transition (1392 keV)
  (at least 2 crystals are positioned at similar polar angle Θ)

⇒ sufficient to get at least an upper limit on $\tau(2_3^+)$
- corresponding to a lower limit on $B(M1; 2_3^+ \rightarrow 2_1^+)$

Two different targets used in IS483



Activation !

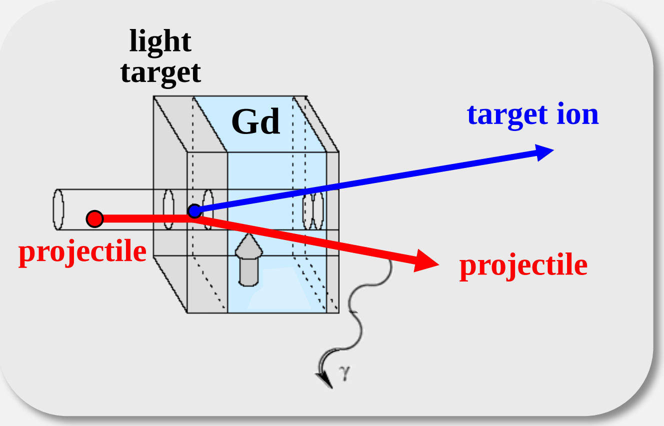
"**thick** target": 0.48 mg/cm^2 **C** + **11.8** mg/cm^2 Gd + 1.0 mg/cm^2 Ta

- (+) excited projectiles stopped → full anisotropy observed
- (+) thick Gd → maximum precession angle
- (-) huge straggling → a lot of radioactivity close to the Ge

^{72}**Zn** beam @ 2.94 MeV/u

10-50 pA, 20$^+$ 3x10^6 – 1.5x10^7 pps

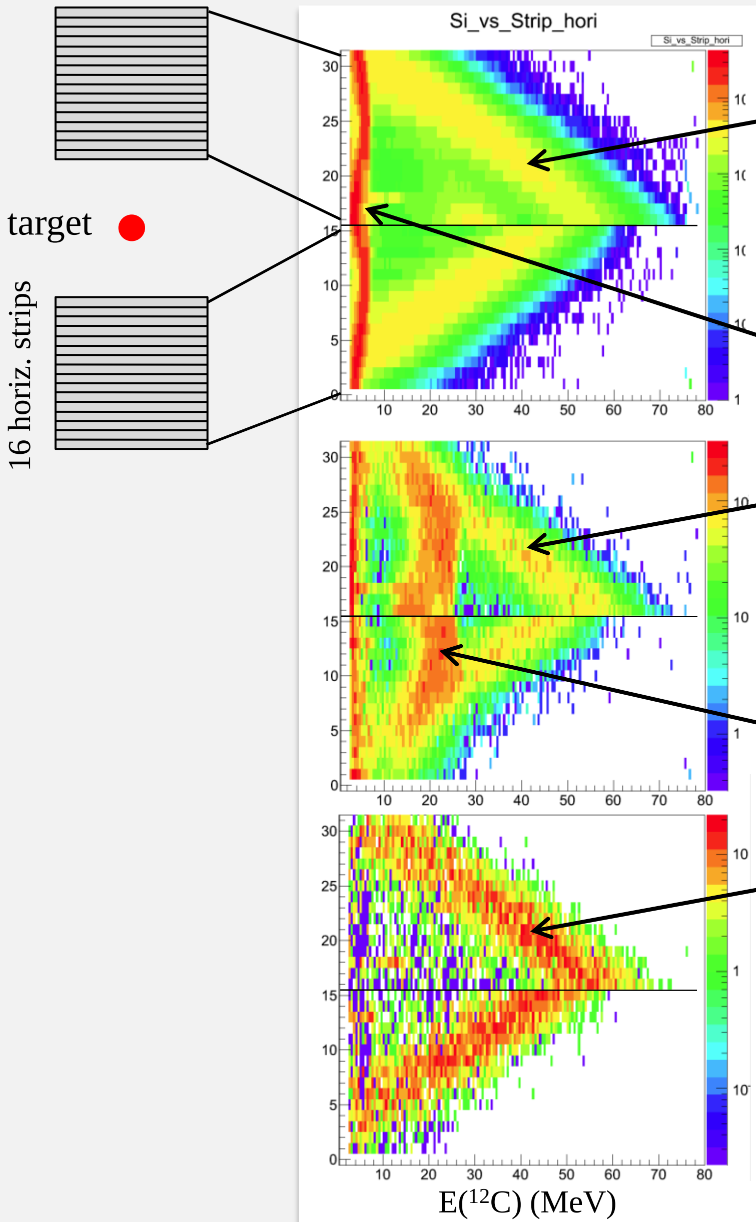
Smaller effects !



"**thin** target": 1.0 mg/cm^2 **C** + **6.7** mg/cm^2 Gd + 1.0 mg/cm^2 Ta

- (-) excited projectiles leave target → deorientation → reduced anisotropy observed
- (-) thinner Gd → smaller precession angle
- (+) less straggling → reduced radioactivity close to the Ge

IS483: g(2_1^+) in ^{72}Zn using projectile Coulex and TF



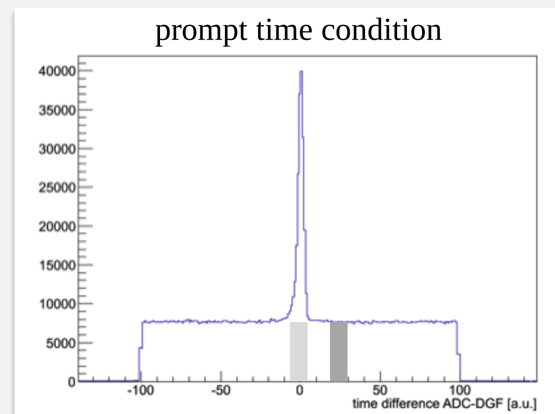
^{12}C from elast. scatt.

p's from fusion reaction

^{12}C from Coulex

α's from incomplete fusion reaction

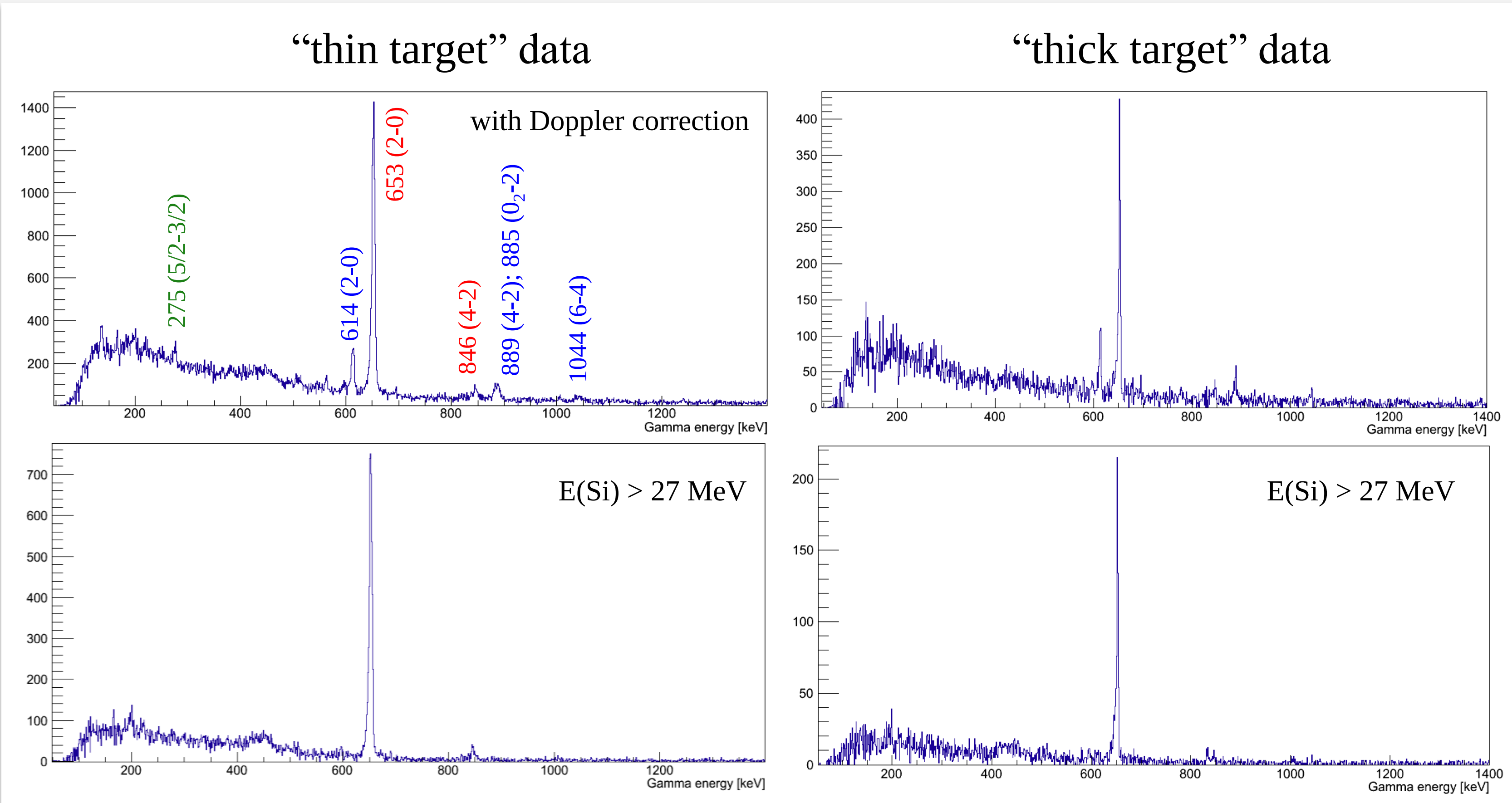
^{12}C from Coulex



<u>Additional gate</u> on energy of 2-0 transition in ^{72}Zn:

Only the ^{12}C ions which excited the 2^+ state are left !

Comparison between “thin” and “thick” target data



42 h – 1 mg/cm^2 C

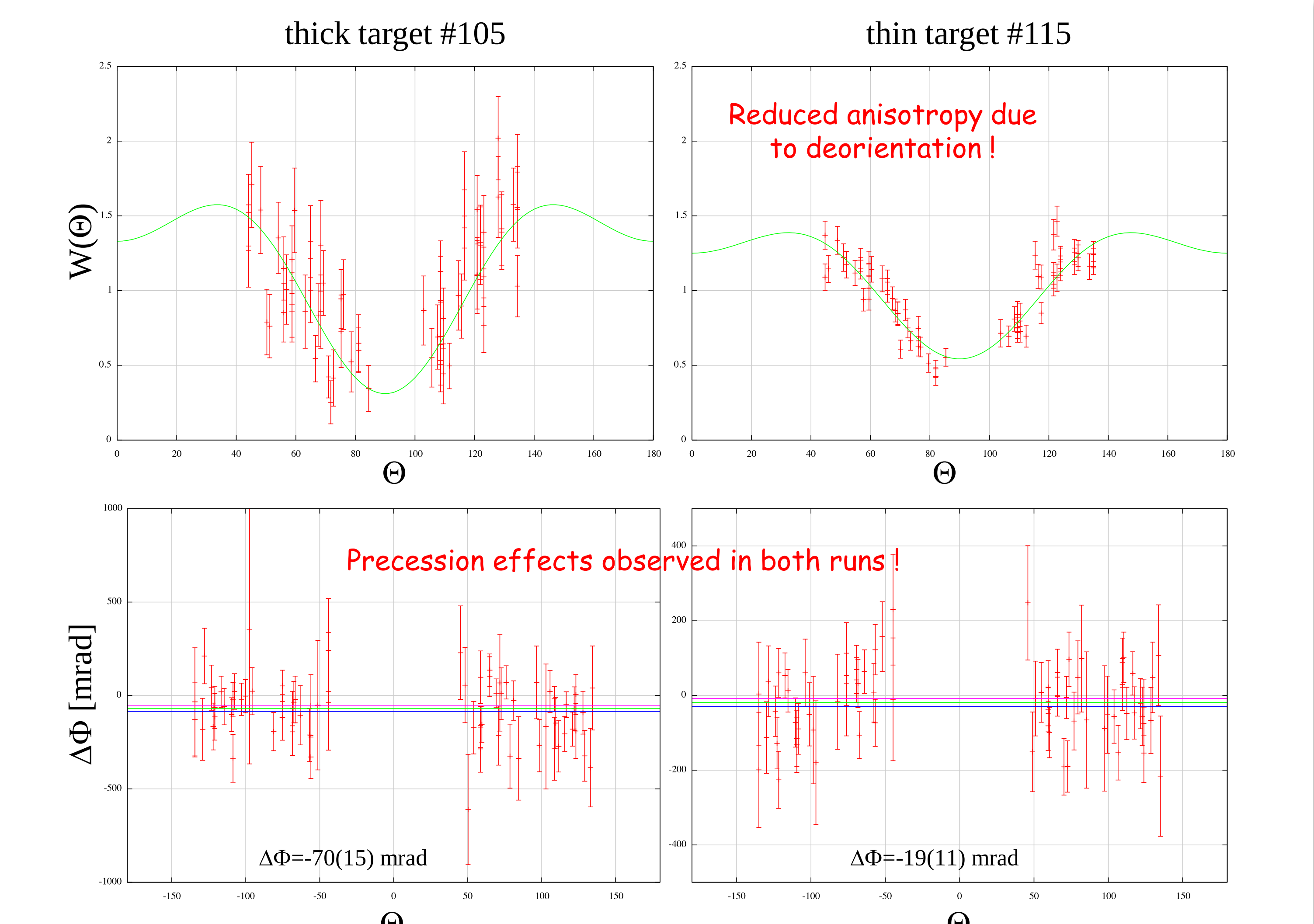
28 h – 0.48 mg/cm^2 C

11.450 counts total in 653 keV 2→0 peak
up: 5.072, down: 4.802

1.941 counts total in 653 keV 2→0 peak
up: 917, down: 1.016

Angular correlations W(Θ) and precession angles ΔΦ(Θ)

Analysis at the level of individual MINIBALL segments !



Preliminary result: g_{ave} = +0.4(1)

How can we measure the g factor of ps excited states

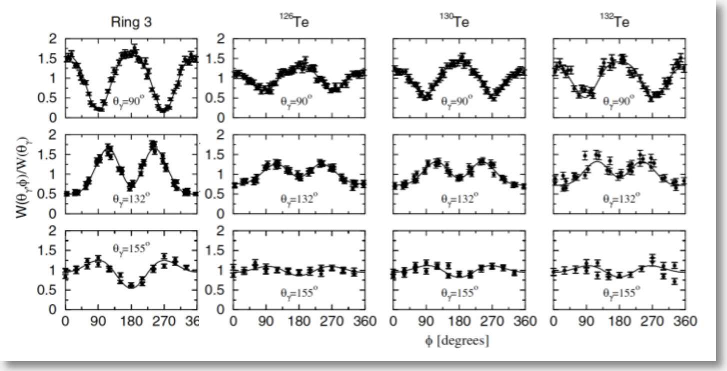
Recoil-in-vacuum method

hyperfine interaction between
aligned nuclear and randomly
oriented electron spin

precession of nuclear spin
about random axes

observe attenuation of γ-ray angular correlation

$$W(\theta,t)=1+a_2G_2(t)P_2(\cos\theta)+a_4G_4(t)P_4(\cos\theta)$$



N.J. Stone et al., Phys. Rev. Lett. 94 (2005) 192501

Result: $|g(2_1^+)|$

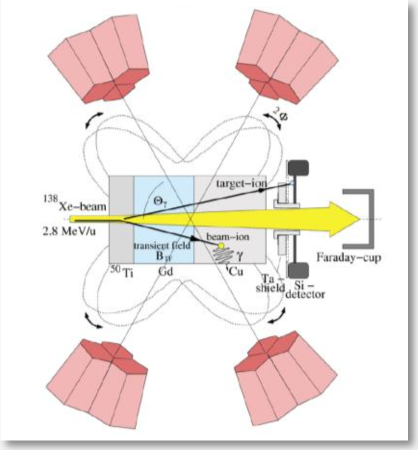
Transient Field technique

hyperfine interaction between
aligned nuclear and oriented
electron spin

precession of nuclear spin about
fixed axis (external field)

observe precession of γ-ray angular correlation

$$W(\theta,t)=1+a_2P_2[\cos(\theta-\omega_L t)]+a_4P_4[(\cos(\theta-\omega_L t)]$$



Result: $g(2_1^+)$ with sign

Possible origin of the low B(E2) value in ^{136}Te

balanced proton-neutron composition

$^{132}Te_{80}$ 974 keV p^2n^{-2}	$^{134}Te_{82}$ 1279 keV p^2	$^{136}Te_{84}$ 606 keV p^2n^2
$^{130}Sn_{80}$ 1221 keV n^{-2}	$^{132}Sn_{82}$ doubly-magic	$^{134}Sn_{82}$ 762 keV n^2

neutron dominated wavefunction

decrease of proton-neutron coherence in E2 transition; small effective charge for neutrons

reduced strength of 2→0 transition, e.g. small B(E2)

How can one possibly prove this simple picture ?

- measure g(2^+) in ^{136}Te
- search for a mixed-symmetry state in ^{136}Te