Outline: Transient magnetic field

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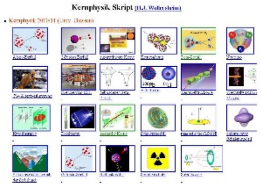
web-page: https://web-docs.gsi.de/~wolle/ and click on



Kernphysik Skript

1. how to measure magnetic moments?
2. optimal beam energy
3. precision of γ–angular correlation
4. g-factor measurements using α-transfer reaction

Success of the extreme single-particle shell model

- ***Magnetic moments:***

The g-factor g_j is given by:

$$\overrightarrow{\mu_j} = g_\ell \cdot \vec{\ell} + g_s \cdot \vec{s} = g_j \cdot \vec{j}$$

$$\Rightarrow \quad \overrightarrow{\mu_j} = \left[\left(g_\ell \cdot \vec{\ell} + g_s \cdot \vec{s} \right) \cdot \frac{\vec{j}}{|j|} \right] \cdot \frac{\vec{j}}{|j|}$$

with $\vec{\ell}^2 = (\vec{j} - \vec{s})^2 = \vec{j}^2 - 2 \cdot \vec{j} \cdot \vec{s} + \vec{s}^2$ $\quad \vec{s}^2 = \left(\vec{j} - \vec{\ell}\right)^2 = \vec{j}^2 - 2 \cdot \vec{j} \cdot \vec{\ell} + \vec{\ell}^2$

$$\vec{\mu}_j = \frac{g_\ell \cdot \{j(j+1) + \ell(\ell+1) - 3/4\} + g_s \cdot \{j(j+1) - \ell(\ell+1) + 3/4\}}{2 \cdot j(j+1)} \cdot \vec{j}$$

$$g_j = \frac{1}{2} \cdot (g_\ell + g_s) + \frac{1}{2} \cdot \frac{\ell(\ell+1) - s(s+1)}{2j(j+1)} \cdot (g_\ell - g_s)$$

Simple relation for the g-factor
of single-particle states

$$\frac{\mu}{\mu_N} = g_{nucleus} = g_\ell \pm \frac{(g_s - g_\ell)}{2\ell + 1} \quad for \quad j = \ell \pm 1$$

			μ/μ_N	
nucleus	state	J^π	model	experiment
^{15}N	p-$1p_{1/2}^{-1}$	$1/2^-$	$-0,264$	$-0,283$
^{15}O	n-$1p_{1/2}^{-1}$	$1/2^-$	$+0,638$	$+0,719$
^{17}O	n-$1d_{5/2}$	$5/2^+$	$-1,913$	$-1,894$
^{17}F	p-$1d_{5/2}$	$5/2^+$	$+4,722$	$+4,793$

Success of the extreme single-particle shell model

- ***magnetic moments:***

$$\langle\mu_z\rangle = \begin{Bmatrix} \left[g_\ell \cdot \left(j - \frac{1}{2}\right) + \frac{1}{2} \cdot g_s\right] \cdot \mu_N \quad for \quad j = \ell + 1/2 \\ \frac{j}{j+1} \cdot \left[g_\ell \cdot \left(j + \frac{3}{2}\right) - \frac{1}{2} \cdot g_s\right] \cdot \mu_N \quad for \quad j = \ell - 1/2 \end{Bmatrix}$$

- ***g-factor of nukleons:***

proton: $g_\ell = 1$; $g_s = +5.585$
neutron: $g_\ell = 0$; $g_s = -3.82$

proton:

$$\langle\mu_z\rangle = \begin{Bmatrix} (j + 2.293) \cdot \mu_N \quad for \quad j = \ell + 1/2 \\ (j - 2.293) \cdot \frac{j}{j+1} \cdot \mu_N \quad for \quad j = \ell - 1/2 \end{Bmatrix}$$

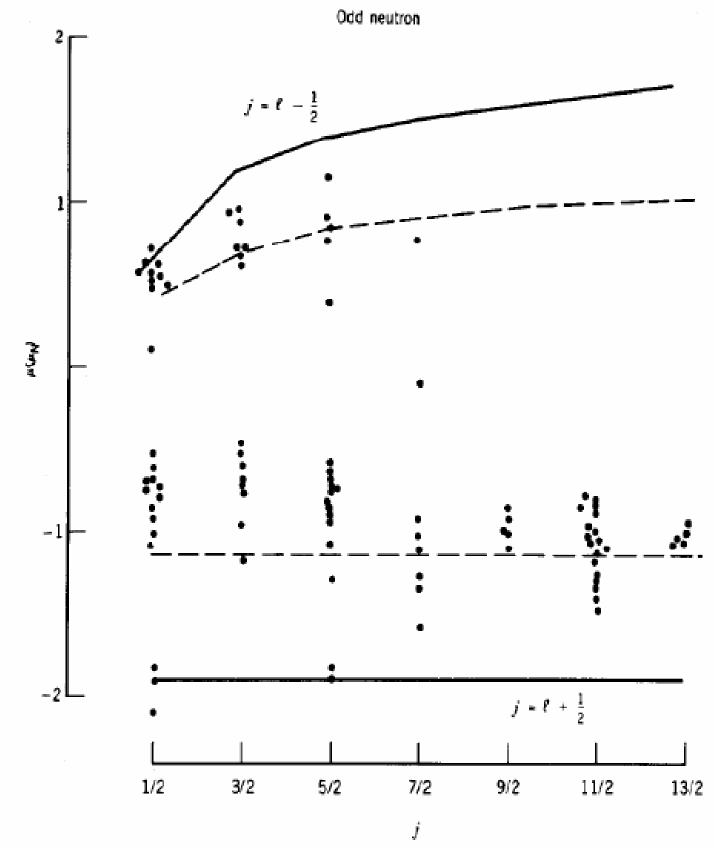
neutron:

$$\langle\mu_z\rangle = \begin{Bmatrix} -1.91 \cdot \mu_N \quad for \quad j = \ell + 1/2 \\ +1.91 \cdot \frac{j}{j+1} \cdot \mu_N \quad for \quad j = \ell - 1/2 \end{Bmatrix}$$

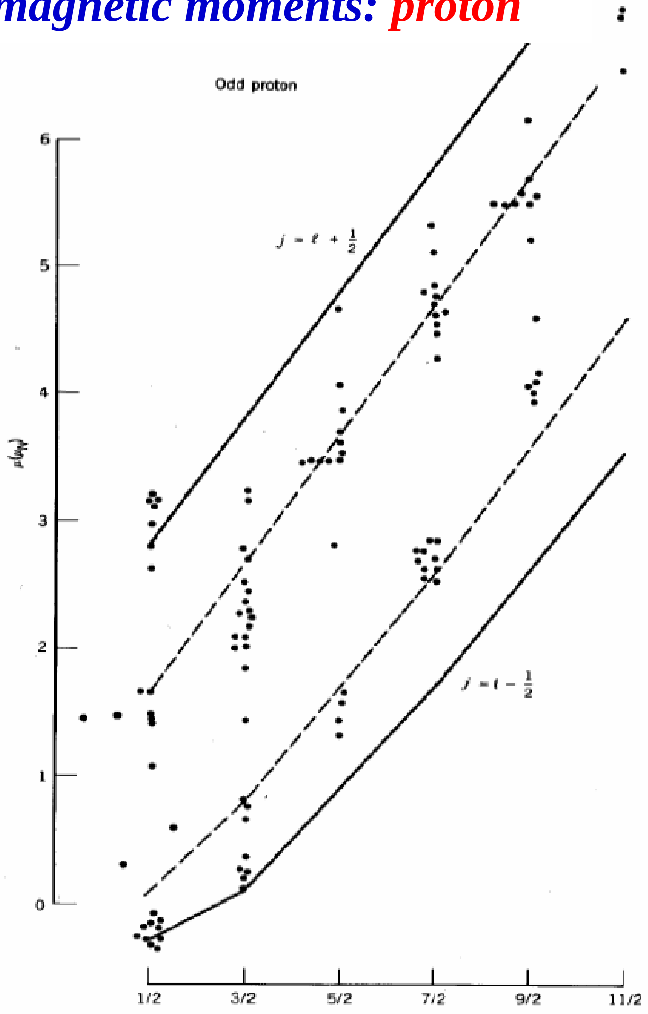
Magnetic moments: Schmidt lines

REMINDER

magnetic moments: neutron



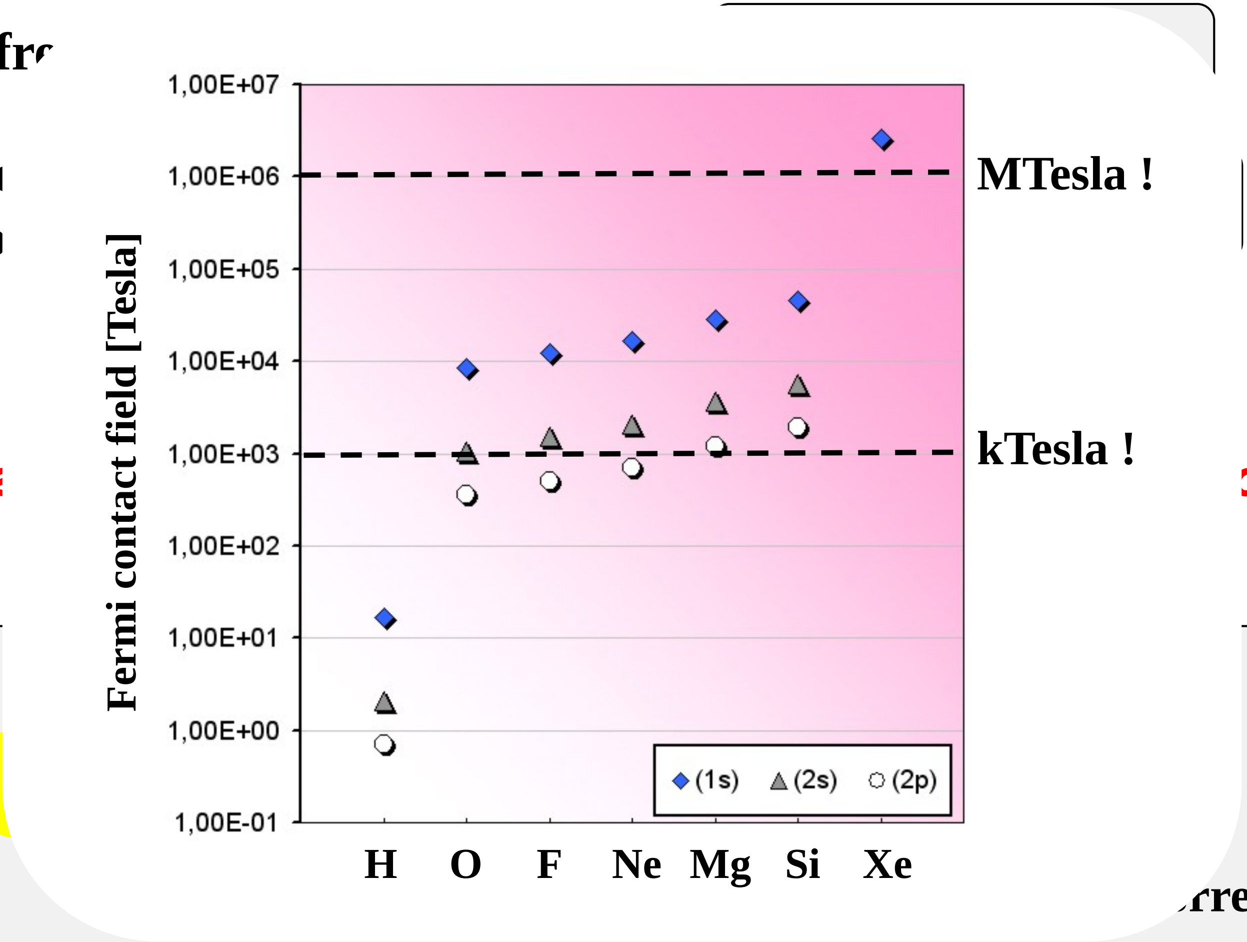
magnetic moments: proton



How to measure magnetic moments?

Larmor fr

Time int
precessio



t_{eff} (<τ) !

Magne

at the

Fermi co

rrection factor

randomly oriented electron spins:
<u>attenuation</u> of γ-ray angular distribution
"nuclear deorientation"

oriented electron spins (polarization):
<u>precession</u> of γ-ray angular distribution
"transient fields"

Three different techniques to measure g-factors of short-lived states using radioactive beams

high-velocity transient field

^{38,40}S @ MSU **40 MeV/u**
A.D. Davies et al., PRL 96 (2006) 112503
A.E. Stuchbery et al., PRC 74 (2006) 054307

^{72}Zn @ GANIL **60 MeV/u**
April 2008 SP: G. Georgiev, A. Jungclaus

^{42,44,46}Ar @ MSU & N=40 Fe @ MSU
October 2008 SP: A.E. Stuchbery

low-velocity transient field

^{132}Te @ Oak Ridge **3.0 MeV/u**
N. Benczer-Koller et al., PLB 664(2008)241

^{138}Xe @ REX-ISOLDE **2.8 MeV/u**
2006/2009 SP: A. Jungclaus

nuclear deorientation

^{132}Te @ Oak Ridge **3.0 MeV/u**
N.J. Stone, A.E. Stuchbery et al.,
Phys. Rev. Lett. 94 (2005) 192501

Nothing yet at relativistic energies !

Only very few experiments so far → advantages and disadvantages of the different techniques still need to be explored !

Transient fields: From the low- to the high-velocity regime

$$B_{tf}\,(v, Z) = \xi_{1s}(v, Z) \cdot F^{1}_{1s}(v, Z) \cdot B_{1s}(Z)$$

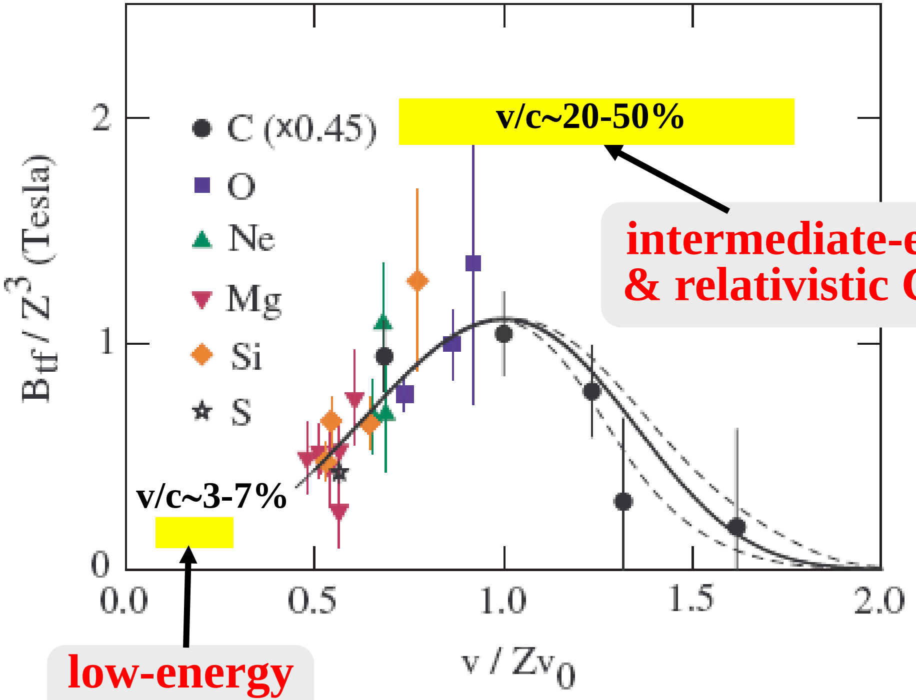
ξ_{1s}: degree of polarization of 1s electrons

F^{1}_{1s}: ion fraction with unpaired 1s electrons

B_{1s}: Fermi contact field of 1s electrons

$Z{\cdot}v_0$: 1s electron velocity (v_0=c/137 Bohr velocity)

Transient field strength in Fe host



v/c~20-50%

v/c~3-7%

intermediate-energy & relativistic Coulex

low-energy Coulex

A.E. Stuchbery et al.,
Phys. Rev. C74 (2006) 054307
Phys. Lett. B611 (2005) 81

- **maximum around $v = Z{\cdot}v_0$**
- **strength scales with Z^3 (Z^2 in Gd)**

Problem:
Transient field strength parametrized only up to Z ~ 16. What happens for higher Z ?

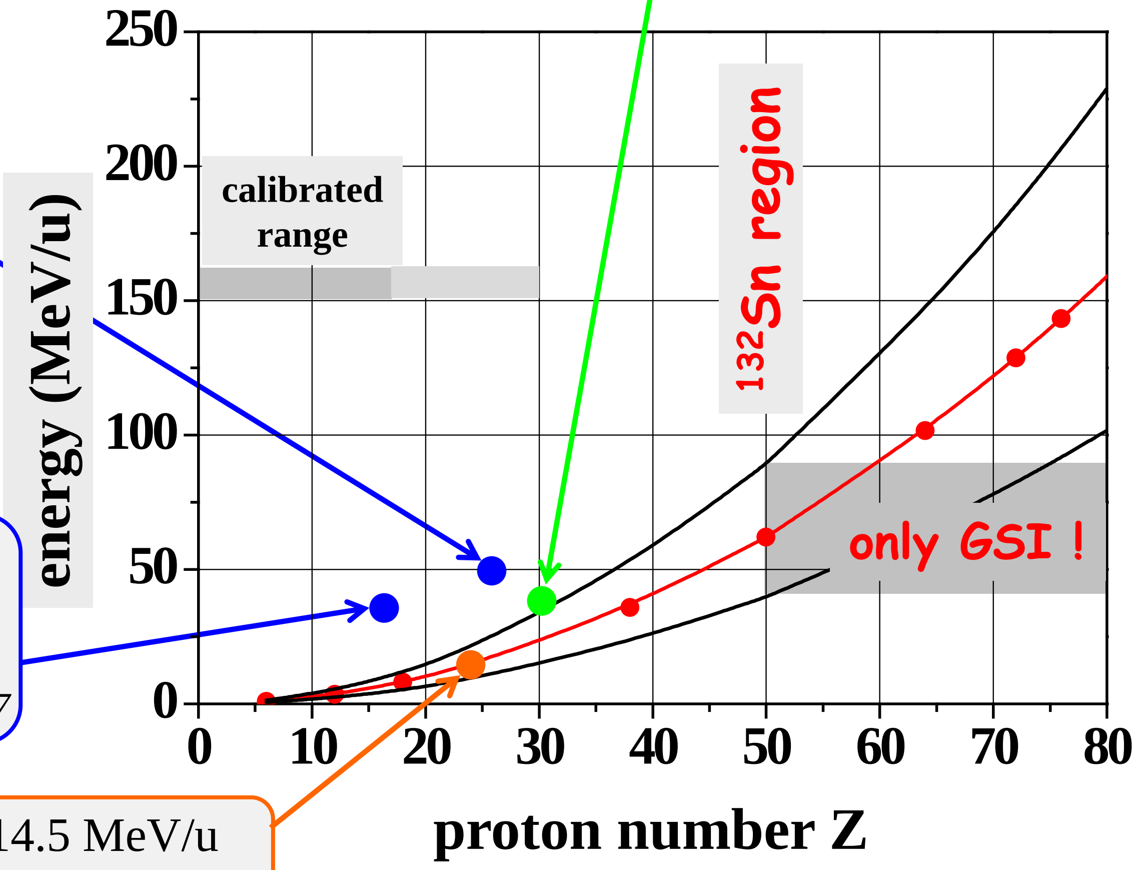
Ion kinetic energy (beam energy) at the 1s electron velocity Zv_0

No information for Z>30 !

^{72}**Zn@GANIL**: 40 MeV/u
prim. 60 MeV/u ^{76}Ge - 2008

Fe@MSU: 50 MeV/u
prim. 130 MeV/u ^{76}Ge
2008

^{38,40}**S@MSU**: 40 MeV/u
prim. 140 MeV/u ^{40}Ar,^{48}Ca
Davies et al., PRL 96 (2006) 112503
Stuchbery et al., PRC 74 (2006) 054307

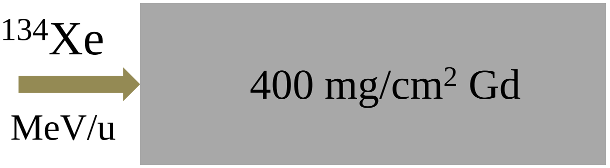


^{52}**Cr@UNILAC**: 14.5 MeV/u
Grabowy, Speidel et al., ZPA359 (1997) 377

How to measure the precession of a γ-ray angular correlation with PreSPEC?

^{134}Te

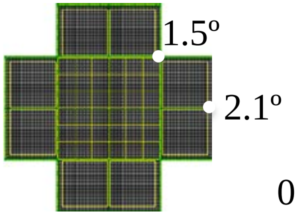
^{136}Xe primary beam @ 500 MeV/u
2.5 g/cm^2 Be target



τ = 3.0(2) ps

^{134}Xe

LYCCA-0



0.1°-1.7°

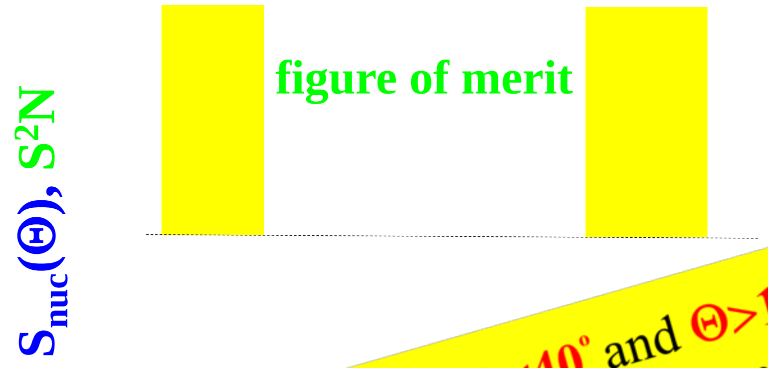
Including decay:

t_{eff} = 1.4 ps, v/Zv_0 = 1.07-0.93

Δϕ/g = 129 mrad, B_{ave} = 1.9 kTesla

N=7500 photopeak counts per field per day in Clusters A, D and E

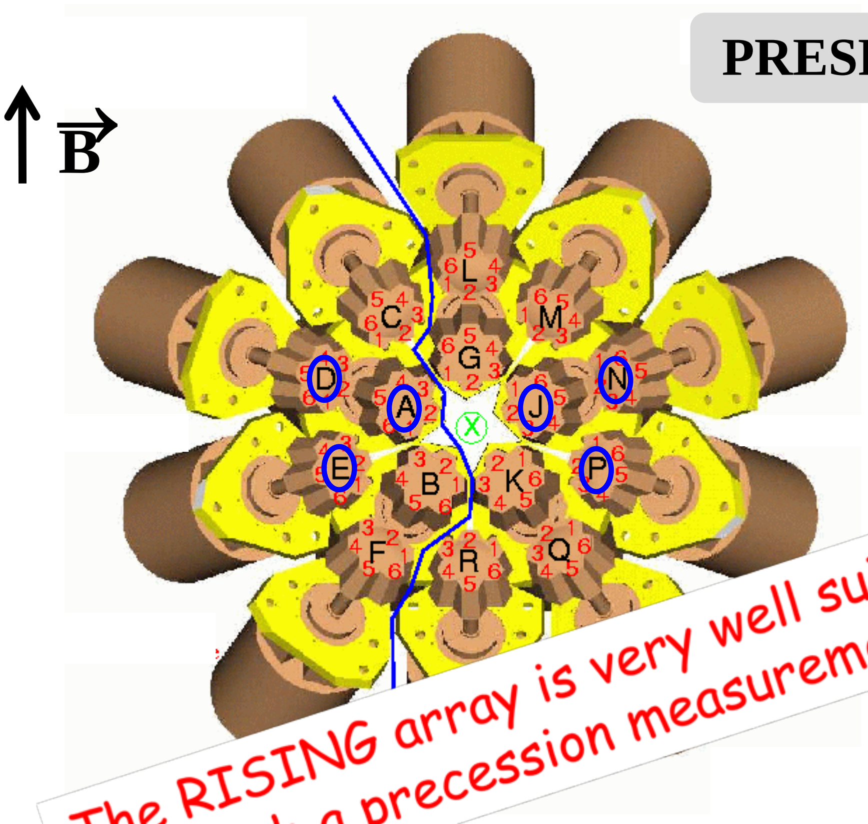
Full simulation performed using the code GKINT by A. Stuchbery



Only angular range Θ<40° and Θ>120° useful for precession measurement !

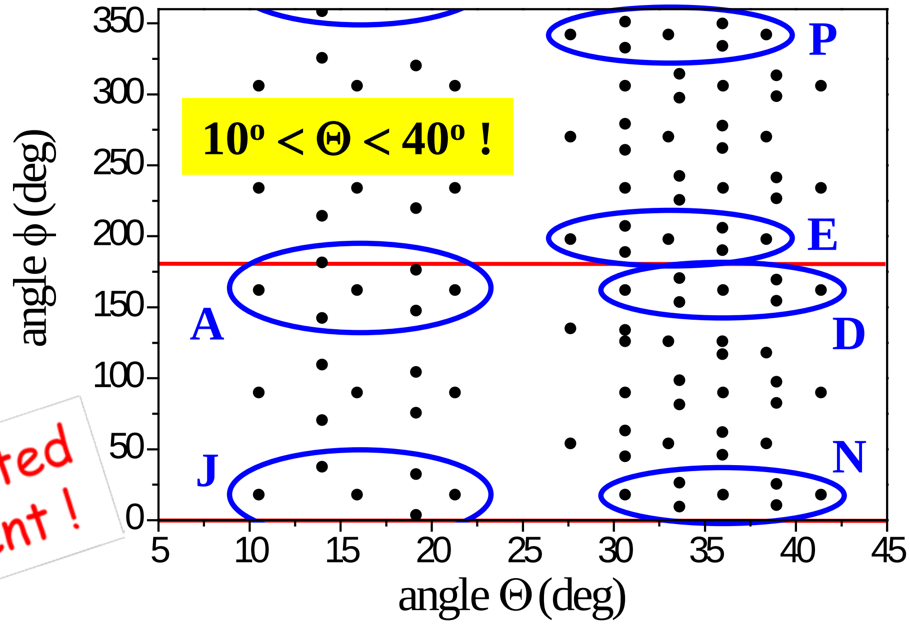
angle Θ (deg)

Geometry of the PreSPEC Ge-array



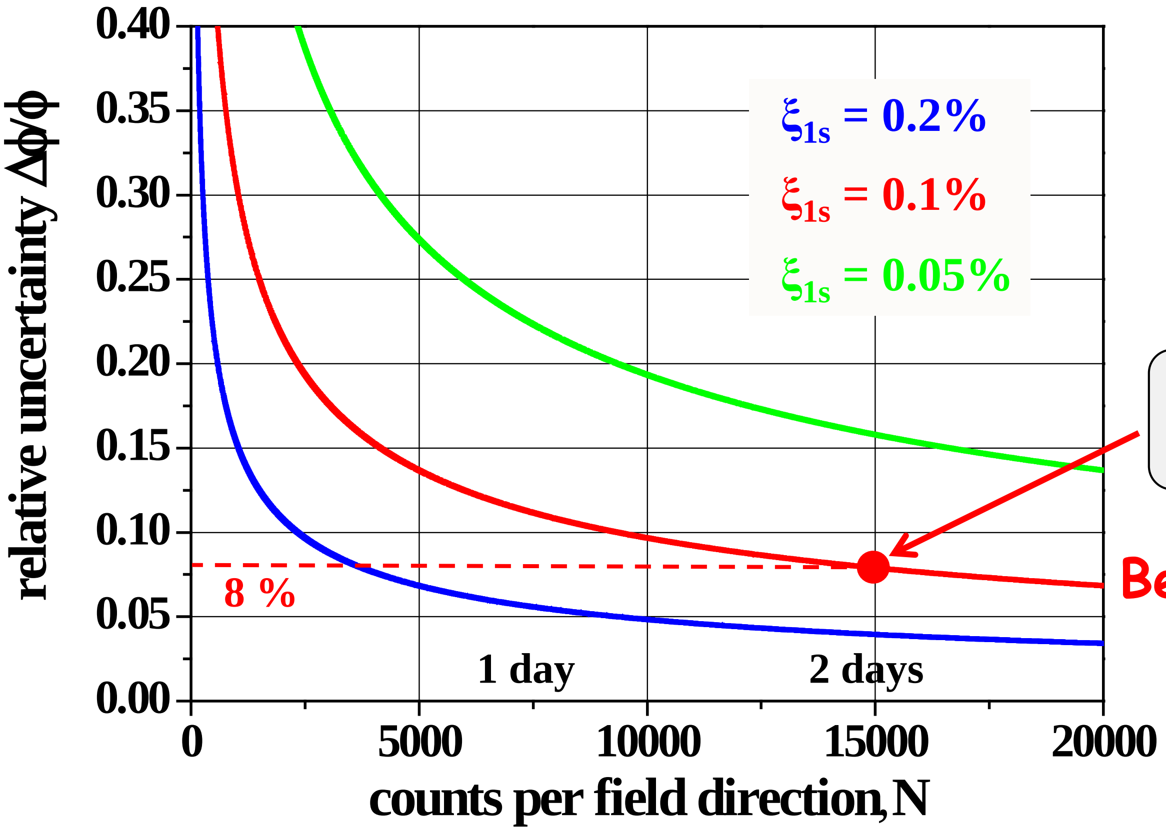
The RISING array is very well suited for such a precession measurement !

PRESPEC



All Ge crystals in the range **$\Theta<40^{\circ}$** and **three pairs** of Cluster detectors close to the horizontal plane !

Relative uncertainty of the TF strength as a function of statistics/time



Large uncertainties in this estimate due to:
- unknown field strength
- unclear rate limitations

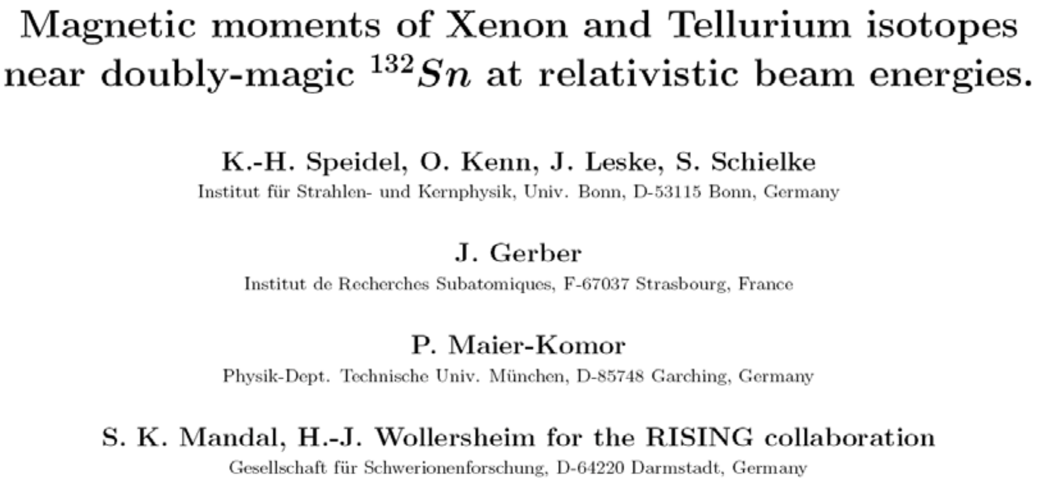
2 days or 60 shifts of parasitic beam

Best guess !

It is most important to see <u>an effect</u> at all for the first time !

Then we can do proper estimates for real $g(2^+)$ measurements …

RISING fast-beam proposal in 2002



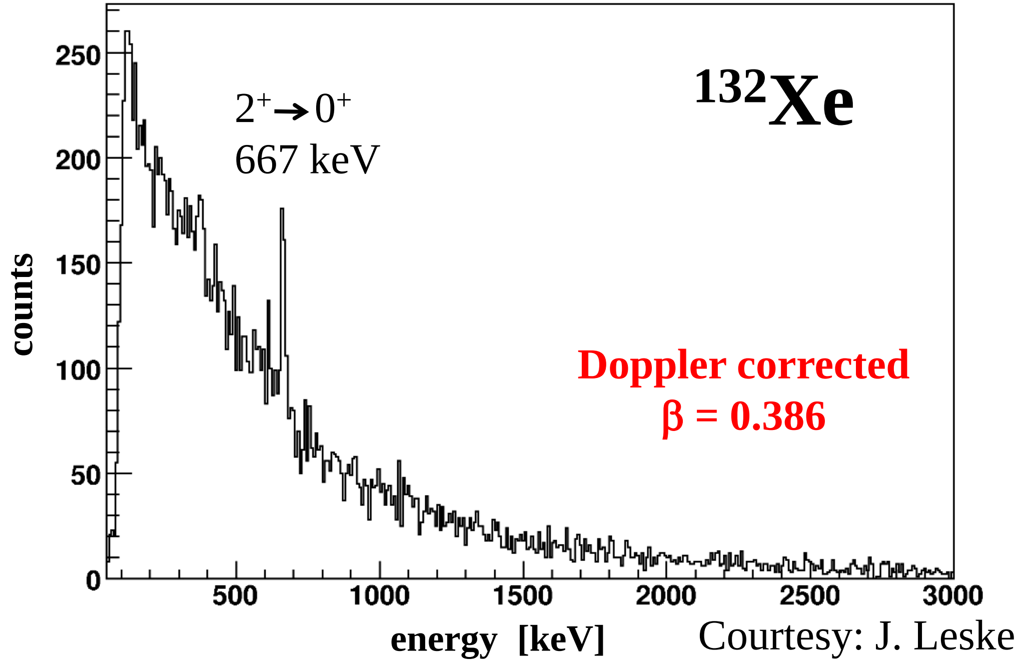
Magnetic moments of Xenon and Tellurium isotopes near doubly-magic ^{132}Sn at relativistic beam energies.

K.-H. Speidel, O. Kenn, J. Leske, S. Schielke
Institut für Strahlen- und Kernphysik, Univ. Bonn, D-53115 Bonn, Germany

J. Gerber
Institut de Recherches Subatomiques, F-67037 Strasbourg, France

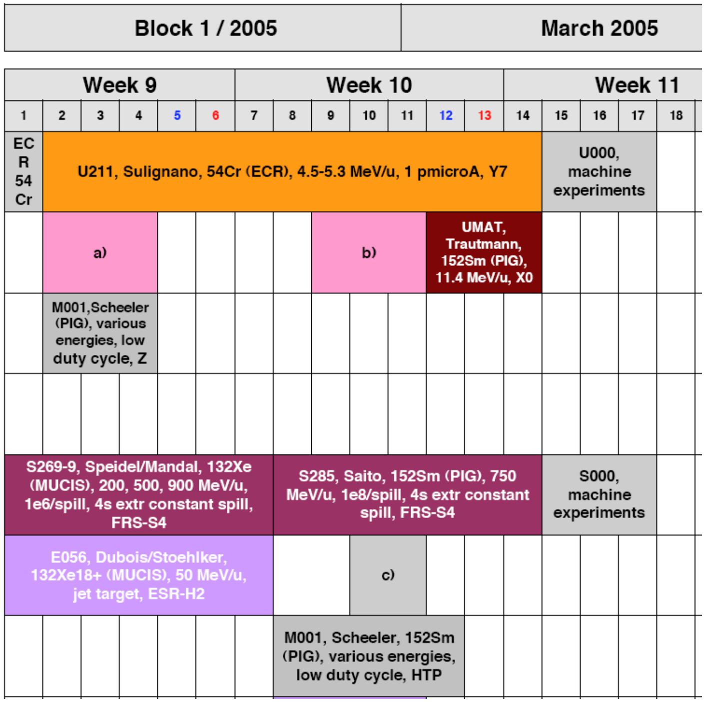
P. Maier-Komor
Physik-Dept. Technische Univ. München, D-85748 Garching, Germany

S. K. Mandal, H.-J. Wollersheim for the RISING collaboration
Gesellschaft für Schwerionenforschung, D-64220 Darmstadt, Germany



Courtesy: J. Leske

proposed and approved in 2002
comissioning run scheduled
in 2005



Block 1 / 2005										March 2005							
Week 9						Week 10							Week 11				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
EC R 54 Cr	U211, Sulignano, 54Cr (ECR), 4.5-5.3 MeV/u, 1 pmicroA, Y7													U000, machine experiments			
	a)							b)			UMAT, Trautmann, 152Sm (PIG), 11.4 MeV/u, X0						
	M001,Scheeler (PIG), various energies, low duty cycle, Z																
S269-9, Speidel/Mandal, 132Xe (MUCIS), 200, 500, 900 MeV/u, 1e6/spill, 4s extr constant spill, FRS-S4							S285, Saito, 152Sm (PIG), 750 MeV/u, 1e8/spill, 4s extr constant spill, FRS-S4							S000, machine experiments			
E056, Dubois/Stoehlker, 132Xe18+ (MUCIS), 50 MeV/u, jet target, ESR-H2									c)								
							M001, Scheeler, 152Sm (PIG), various energies, low duty cycle, HTP										

Stopped in 2005 after
only a few hours !

Summary & Conclusions

Magnetic moment information is important (sometime $E(2^+)$ and $B(E2)$ is not sufficient) !

Transient fields (TF) largest around 1s electron velocity

⬇

Relativistic heavy ions “in principle” well suited for $g(2^+)$ measurements !

TF strength only known up to Z=16 (30)

⬇

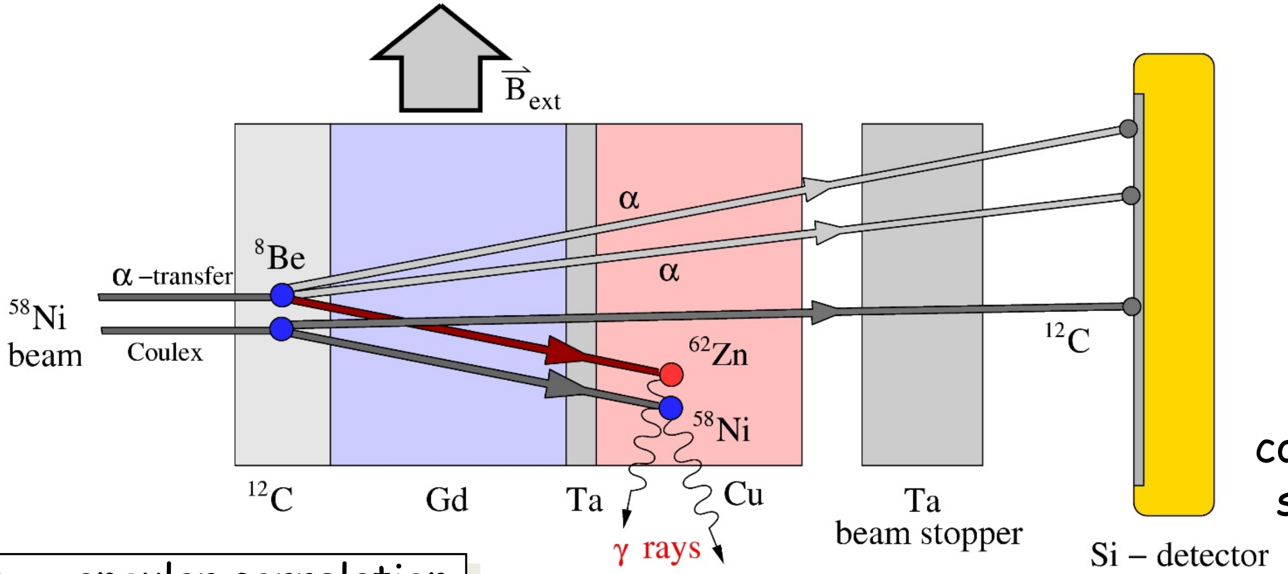
We need at least one calibration point to tackle the **^{132}Sn region** !

GSI only !

<u>60 shifts of parasitic Xe beam</u> sounds a lot, but:

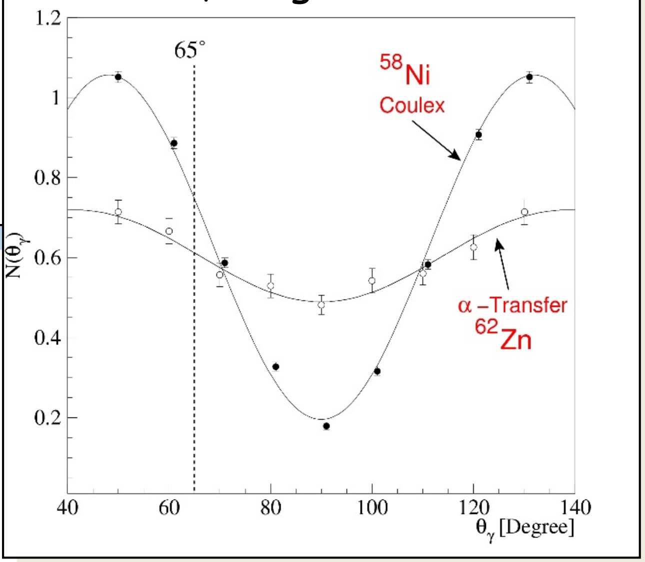
- can run in parallel to long proton beamtimes (HADES or FOPI)
- Xe beams often requested by material science community (^{132}Xe would be fine for us, too)
- allows for additional LYCCA tests in the mass 130 region

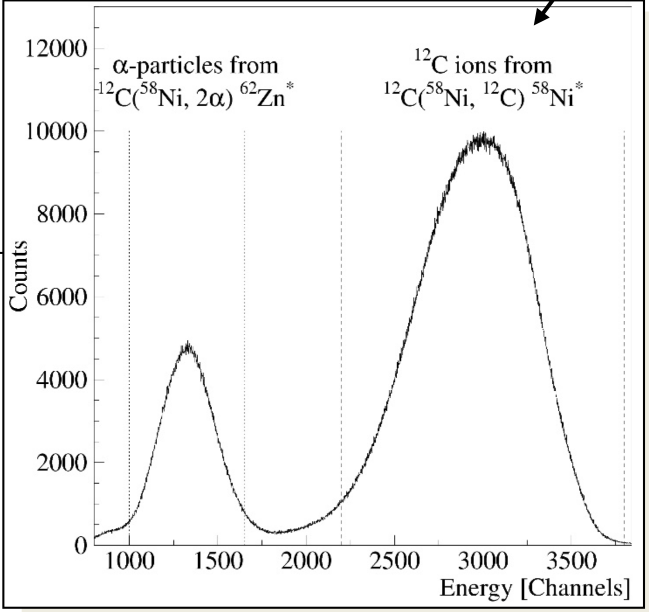
g-factor measurements using α transfer at UNILAC



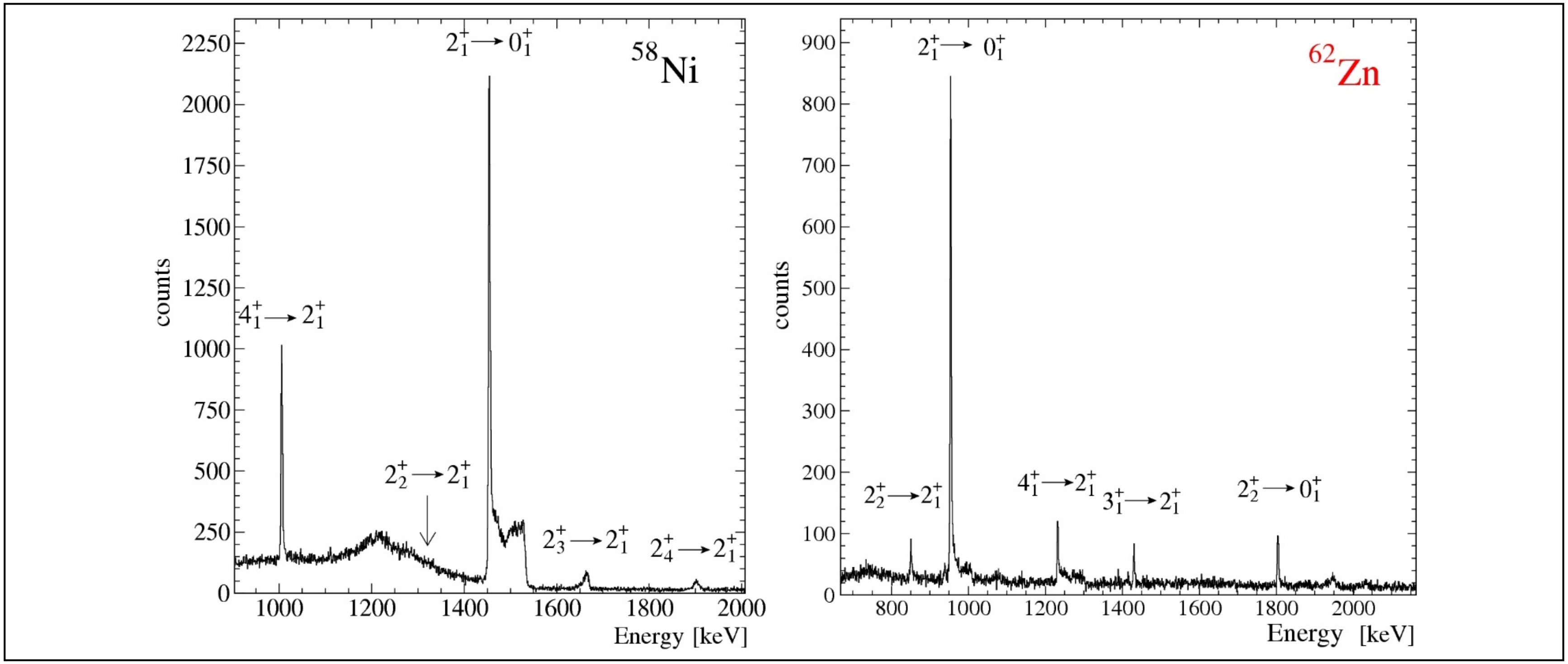
Particle coincidence spectrum

Particle-γ- angular correlation



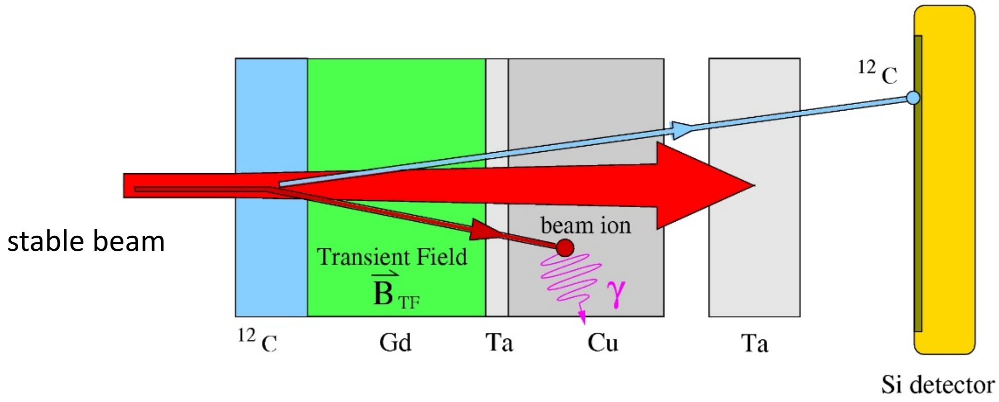


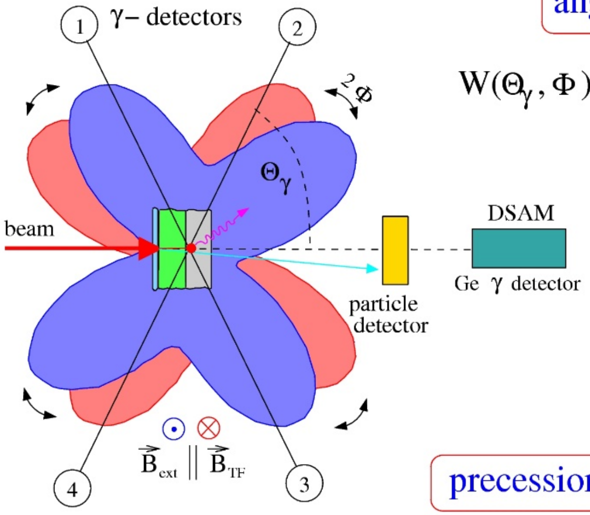
Particle gated γ–coincidence spectra



- two different nuclei studied simultaneously
- rates comparable those of Coulex experiments
- α transfer selective to low spin states

Transient magnetic fields





angular correlation

$$W(\Theta_\gamma, \Phi) = \sum_{k=0,2,4,..}^{k_{max}} Q_k \cdot A_k \cdot P_k\,(\cos(\Theta_\gamma \pm \Phi))$$

double ratio:

$$DR(1/4) = \frac{N1\uparrow}{N1\downarrow} \div \frac{N4\uparrow}{N4\downarrow}$$

precession angle

$$\Phi = \frac{\sqrt{DR} - 1}{\sqrt{DR} + 1} \Big/ \frac{1}{W} \cdot \frac{dW}{d\Theta}\bigg|_{\Theta_\gamma} = g\,\frac{\mu_N}{\hbar} \int_{t_{in}}^{t_{out}} B_{TF}(v_{ion})\, e^{-t/\tau}\, dt$$

$$\mathbf{B_{TF}} = \sum_n \mathbf{q_{ns}}(v_{Ion}, Z, host) \cdot \mathbf{p_{ns}}(v_{Ion}, Z, host) \cdot \mathbf{B_{ns}}(Z)$$

q_{ns} : fraction of ions with unpaired ns electrons
p_{ns} : polarization of ns electrons
B_{ns} : Fermi contact fields
$host$: ferromagnetic layer

- 🟥 excited ion with aligned nuclear spin travels through polarized ferromagnetic environment
- 🟥 polarized electrons and aligned nuclear spin

empirical parametrization required !

$$B_{TF}^{lin} = a(host) \cdot Z \cdot \frac{v_{Ion}}{v_0}$$

- 🟦 linear parametrisation with ion beam induced attenuation

$$\Phi^{exp} = G_{beam} \left(\frac{\Phi^{lin}}{g} \right)$$

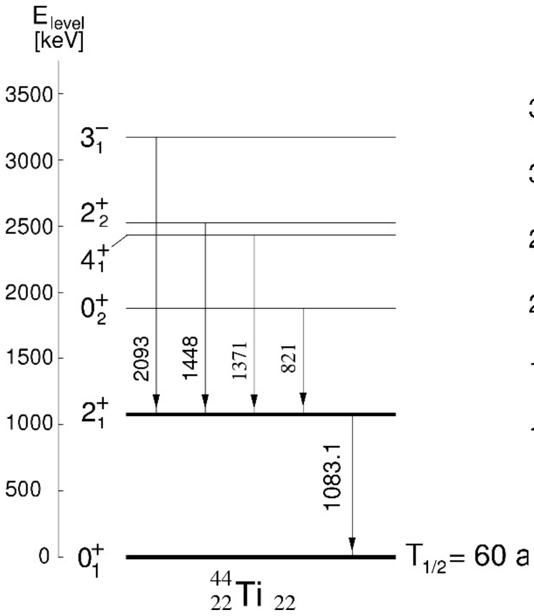
g-factors and B(E2)‘s from α–transfer experiment

$^{44}_{22}\text{Ti}_{22}$ $T_{1/2}$ = 60 y

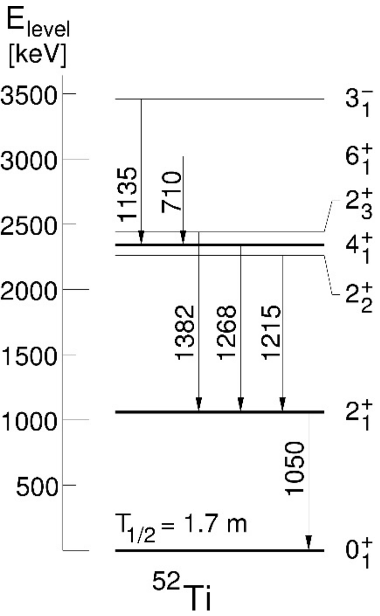
$^{52}_{22}\text{Ti}_{30}$ $T_{1/2}$ = 1.7 m

$^{62}_{30}\text{Zn}_{32}$ $T_{1/2}$ = 9.2 h

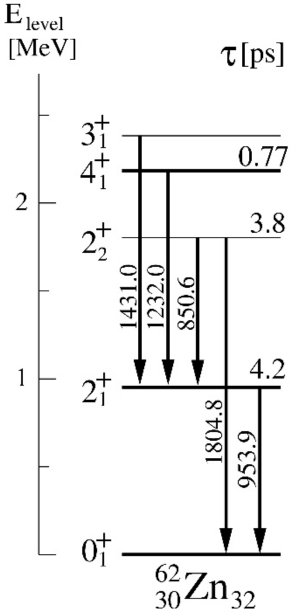
$^{68}_{32}\text{Ge}_{36}$ $T_{1/2}$ = 271 d



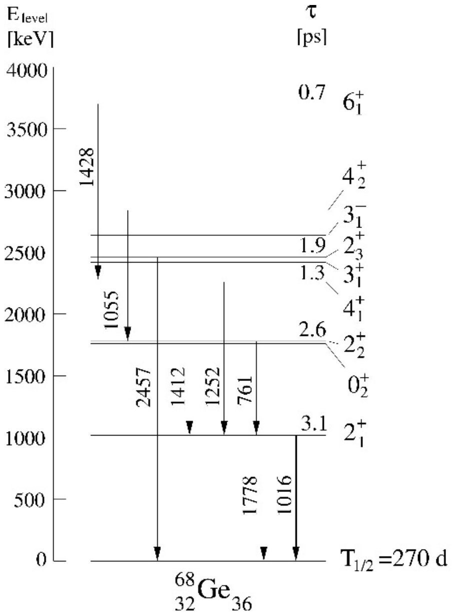
S. Schielke et al., Phys. Lett. B 567 (2003) 153



K.-H. Speidel et al., Phys. Lett. B 633 (2006) 219



O. Kenn et al., Phys. Rev. C65 (2002) 034308



J. Leske et al., Phys. Rev. C71 (2005) 044316

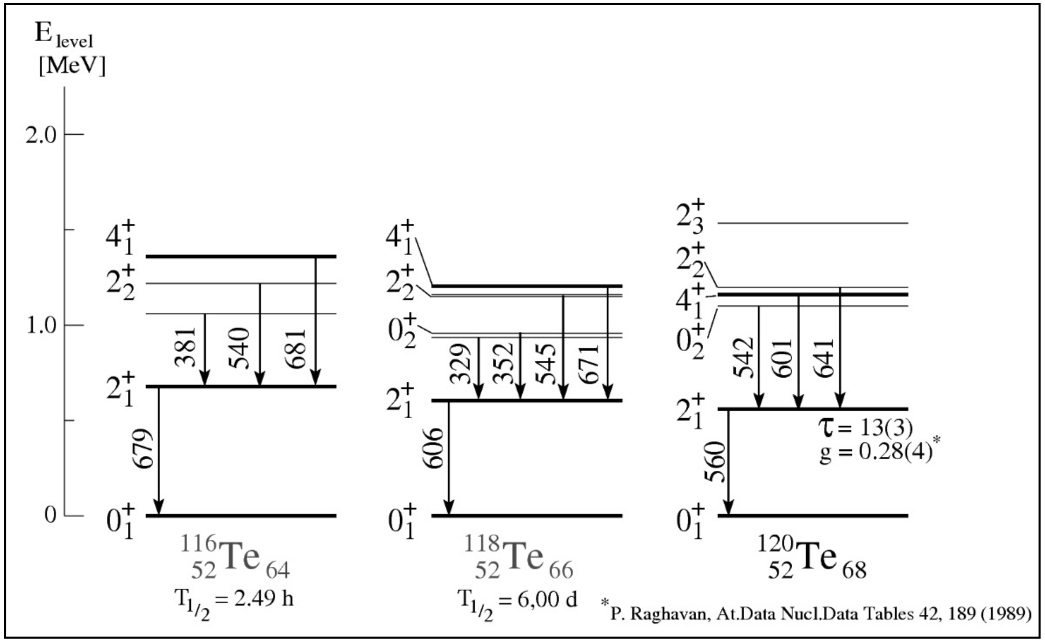
- Is α transfer also applicable for isotopes heavier than A = 68 ?

UNILAC experiment U234 (see also HK 48.7 from J. Walker)

“Measurement of the g-factors of 2^+ states in stable A=112,114,116 Sn isotopes using the transient field technique”

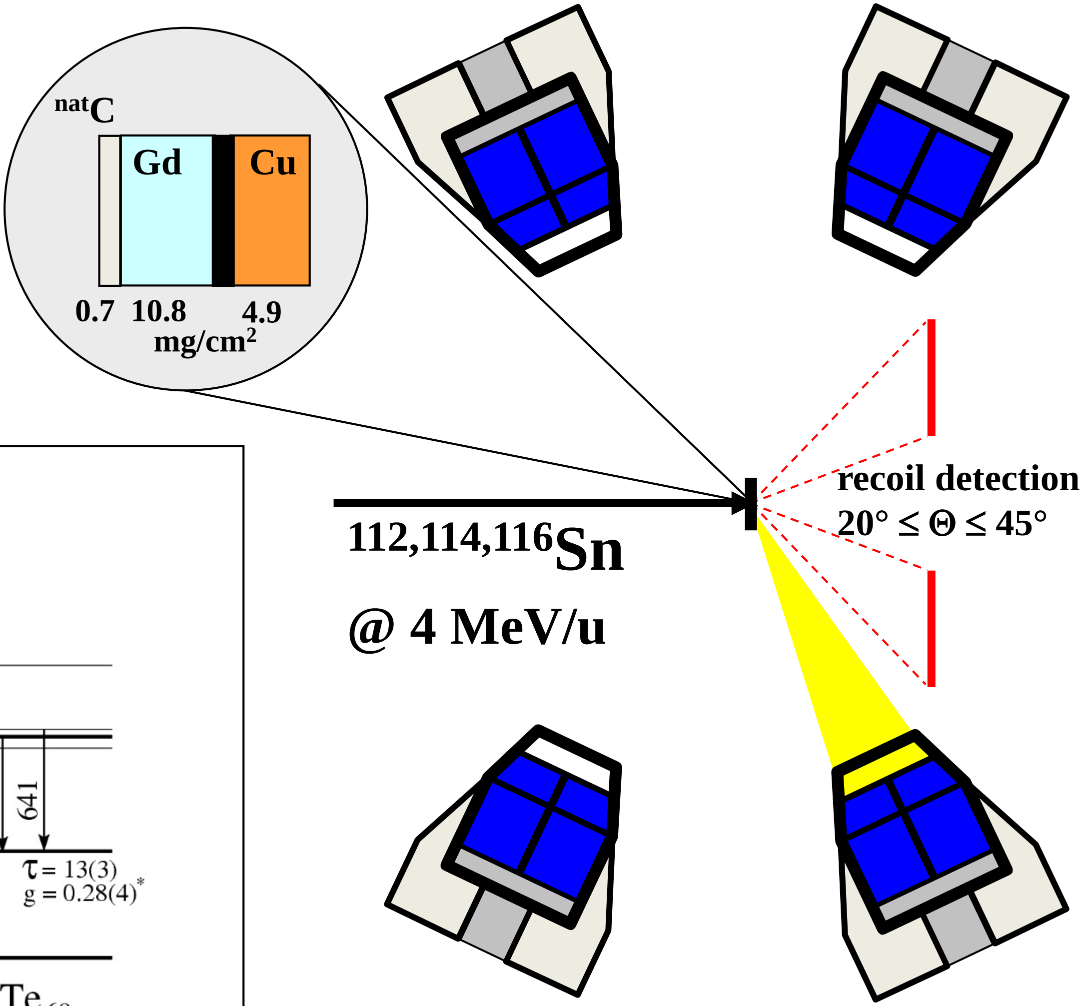
- excitation layer natural carbon

$$^{112,114,116}\mathrm{Sn} + {}^{12}\mathrm{C} \;\begin{cases} \to \; ^{112,114,116}\mathrm{Sn}^* \\ \to \; ^{116,118,120}\mathrm{Te}^* \end{cases}$$



*P. Raghavan, At.Data Nucl.Data Tables 42, 189 (1989)

4 Euroball Cluster at ±65°



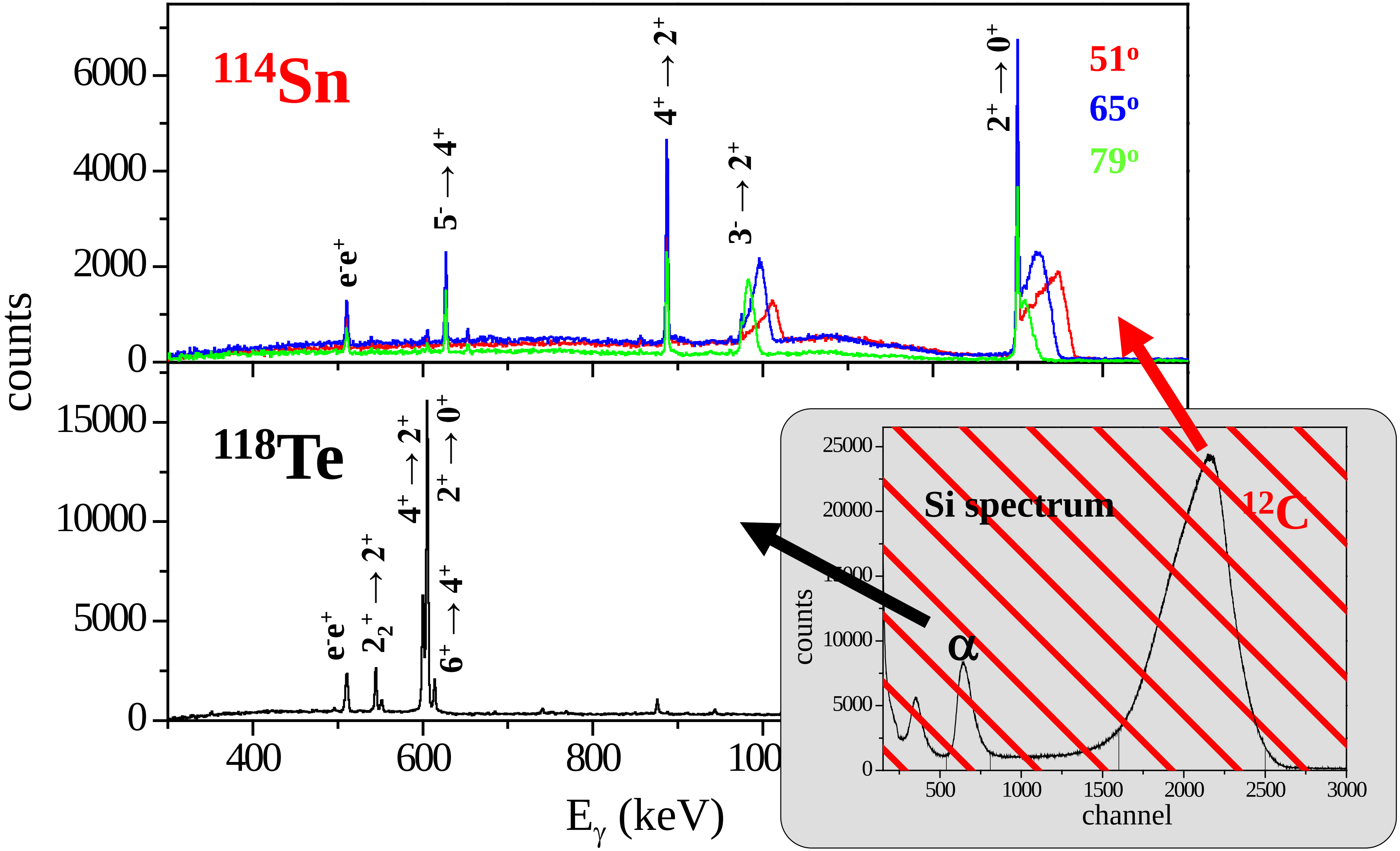
recoil detection
20° ≤ Θ ≤ 45°

^{112,114,116}Sn

@ 4 MeV/u

UNILAC experiment U234

Prompt particle gated γ-ray spectra

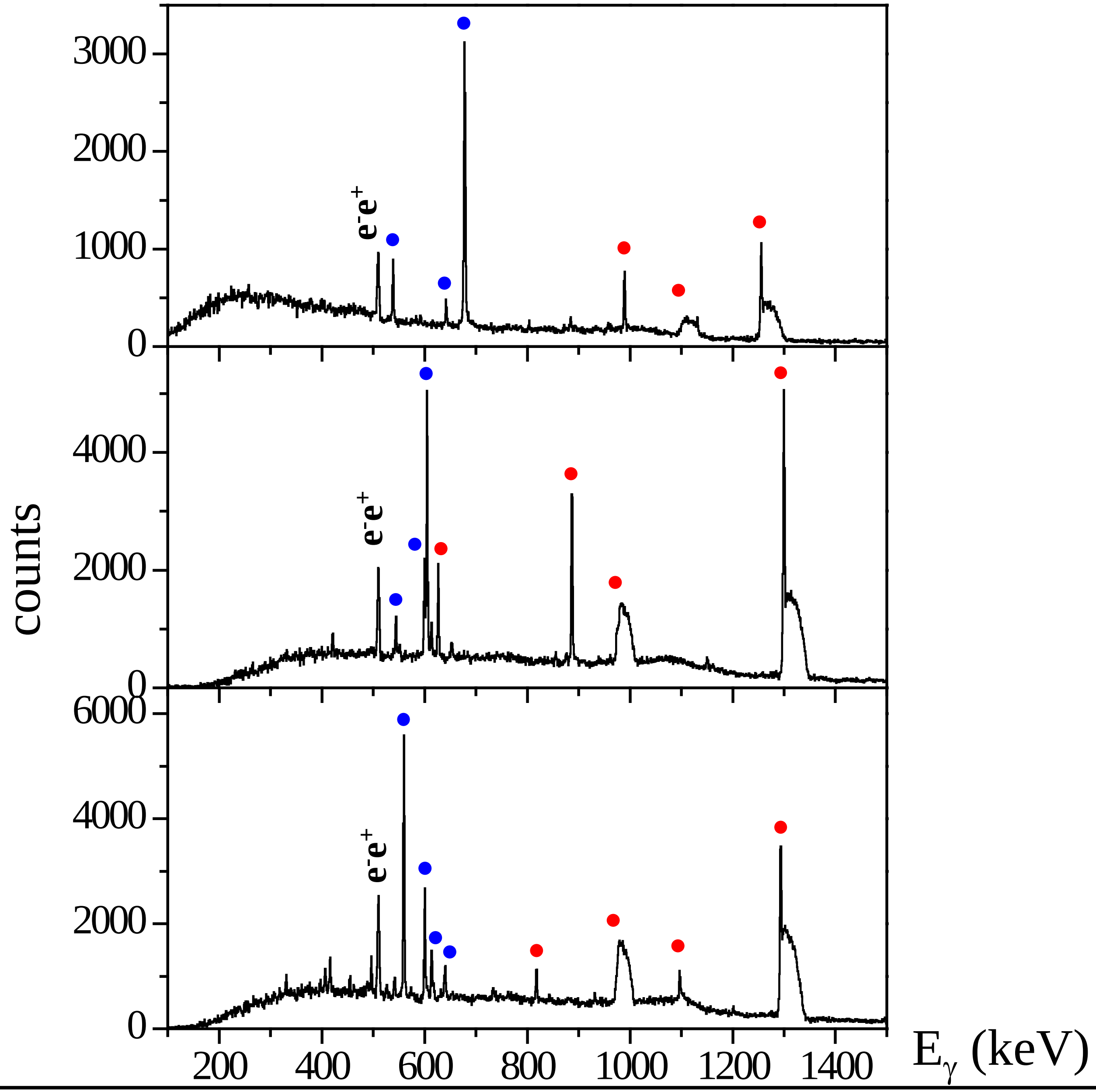


γ-ray spectra

^{112}Sn/^{116}Te

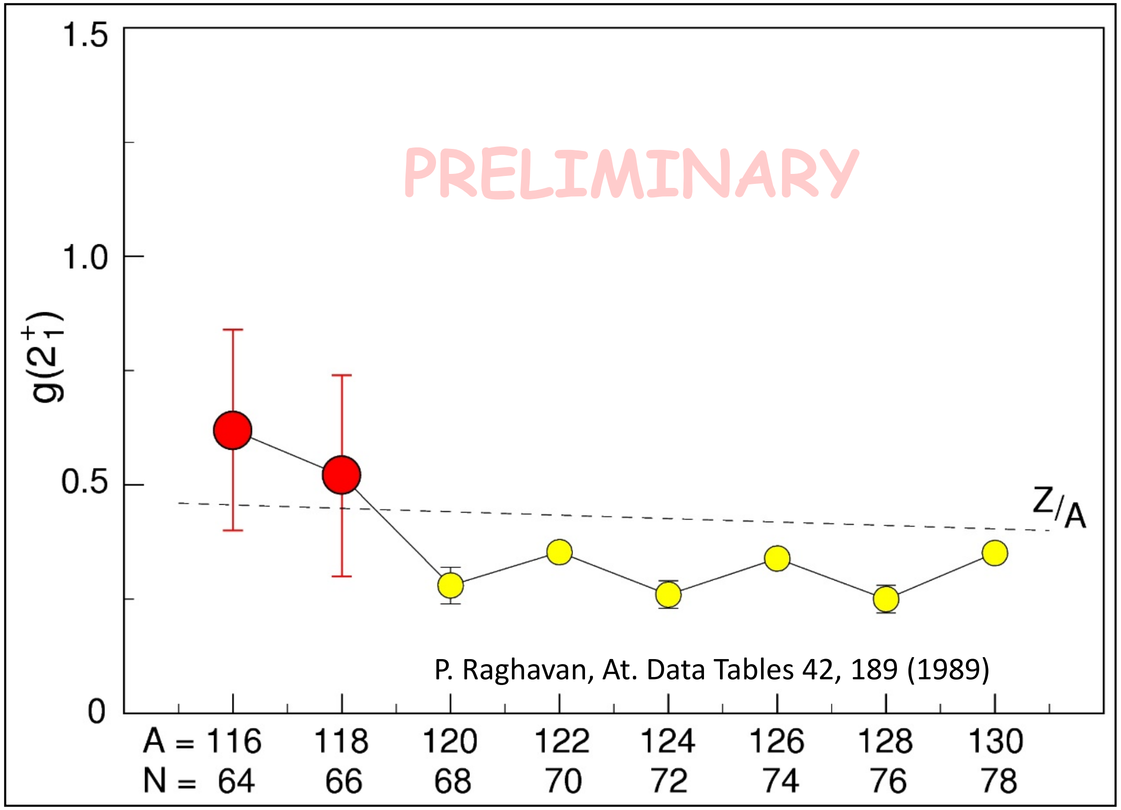
^{114}Sn/^{118}Te

^{116}Sn/^{120}Te



Experimental results

- $g(2^+_1)$ factors in ^{116,118,120}Te
- lifetimes from DSAM analysis in ^{116,118,120}Te



P. Raghavan, At. Data Tables 42, 189 (1989)

Summary

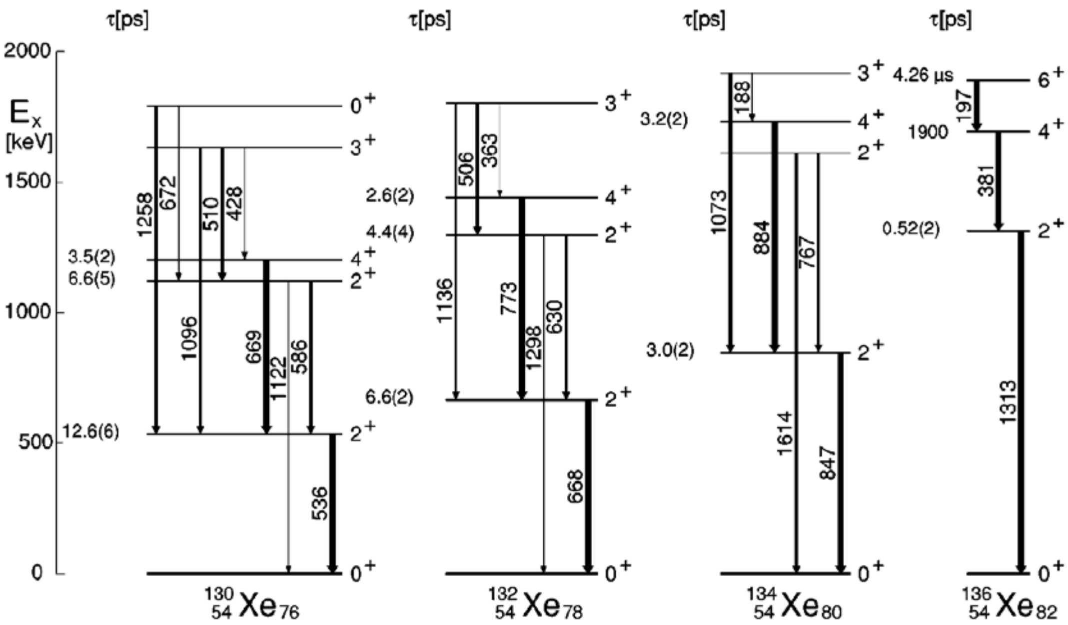
- α Transfer observed in nuclei beyond $A \sim 110$
- Proof of principle for g-factor and DSAM experiments using α transfer to stable nuclei in a mass region between $32 < A < 116$

<u>α Transfer to stable Ion Beams (examples)</u>

Beam :	^{78}Kr	^{86}Kr	^{84}Sr	^{96}Ru	^{124}Xe	^{136}Xe
Isotope :	$^{82}Sr_{44}$	$^{90}Sr_{52}$	$^{88}Zr_{48}$	$^{100}Pd_{54}$	$^{128}Ba_{72}$	$^{140}Ba_{84}$
$T_{1/2}$:	25.5 d	28.5 y	83.4 d	3.6 d	2.4 d	12.8 d

More exotic nuclei by
α Transfer to radioactive Ion Beams !

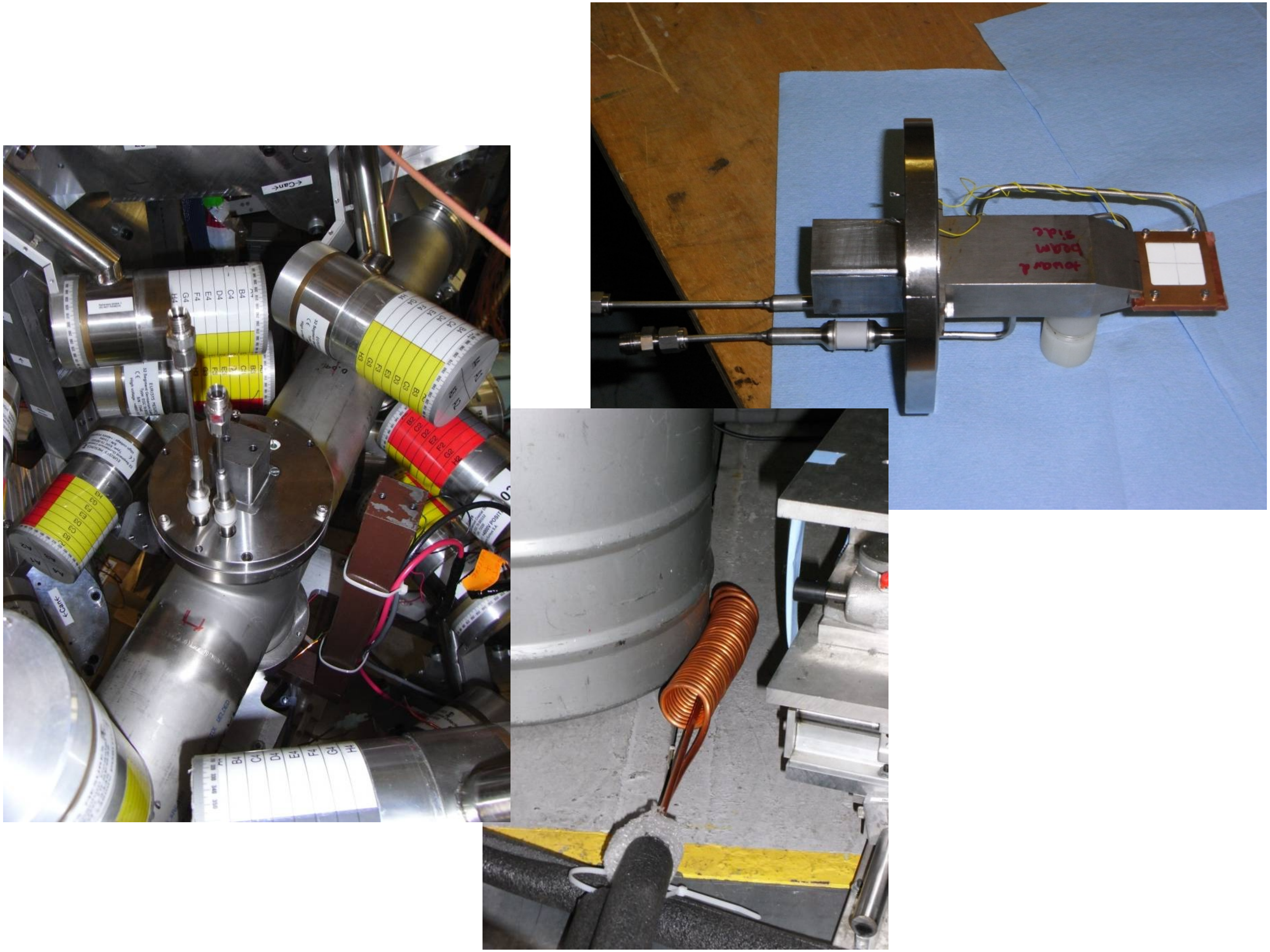
Appendix: The chain of Xe isotopes



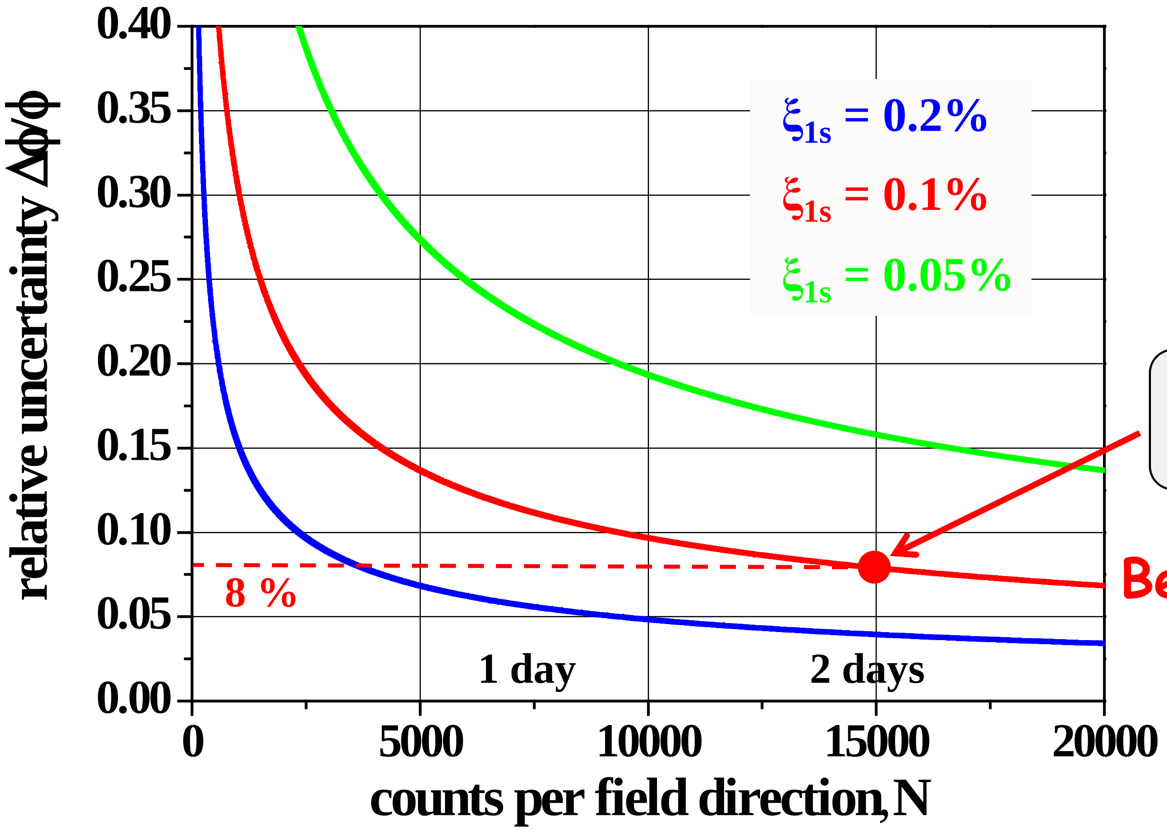
	^{130}Xe	**^{132}Xe**	**^{134}Xe**	**^{136}Xe**
E(2$^+$) (keV)	536	668	847	1313
τ(2$^+$) (ps)	12.6(6)	6.6(2)	3.0(2)	0.52(2)
g(2$^+$)	+0.334(11)	+0.314(12)	+0.354(7)	+0.766(45)

← alignment

Appendix: The target chamber used at MSU



Relative uncertainty of the TF strength as a function of statistics/time



Large uncertainties in this estimate due to:

- unknown field strength
- unclear rate limitations

2 days or 60 shifts of parasitic beam

Best guess !

It is most important to see **an effect** for the first time !

Then we can do proper estimates for real g(2^+) measurements …