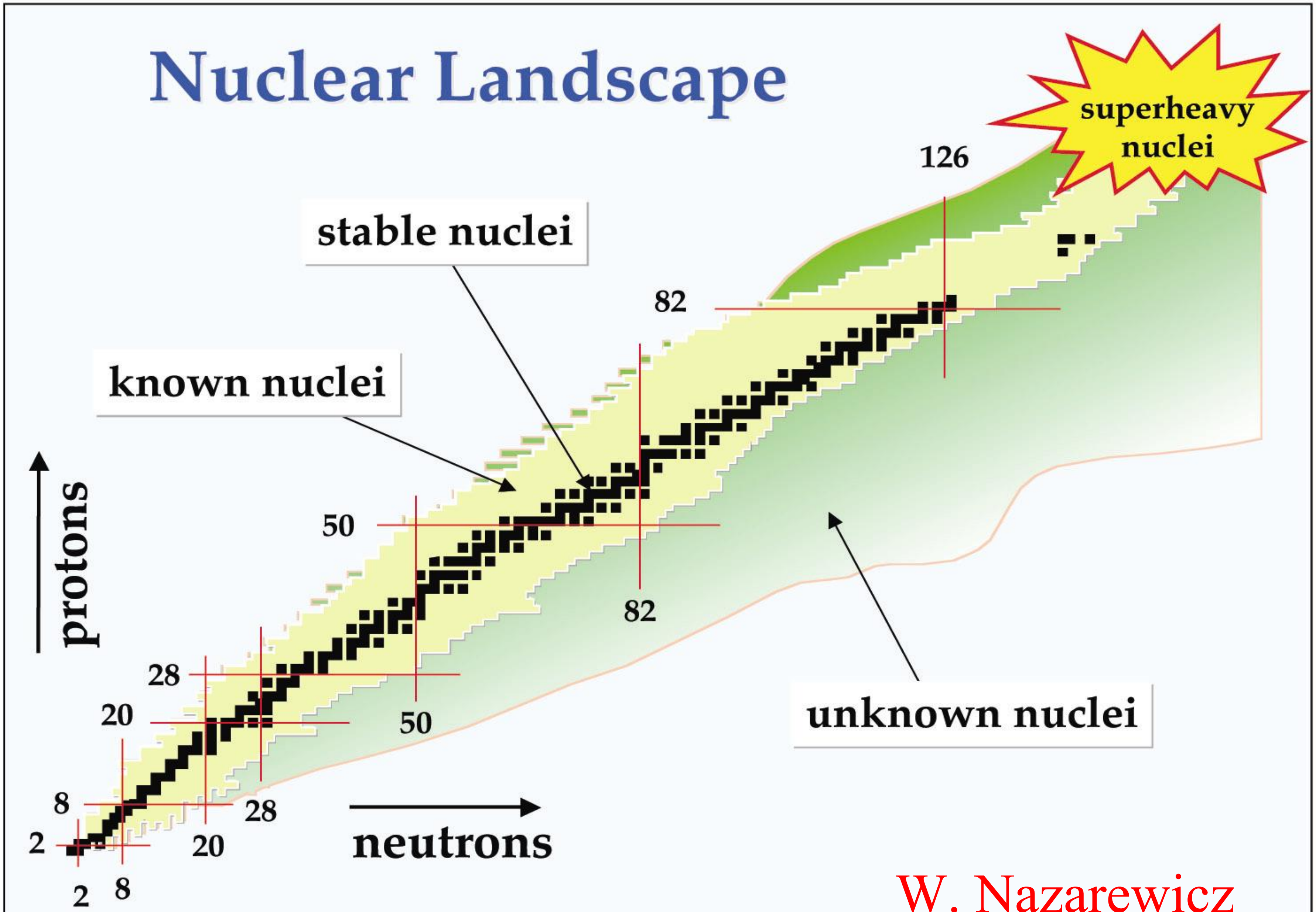
Експерименти с радиоактивни снопове проведени на HRIBF в националната лаборатория в Оук Ридж

Мирослав Данчев

Nuclear Landscape



W. Nazarewicz

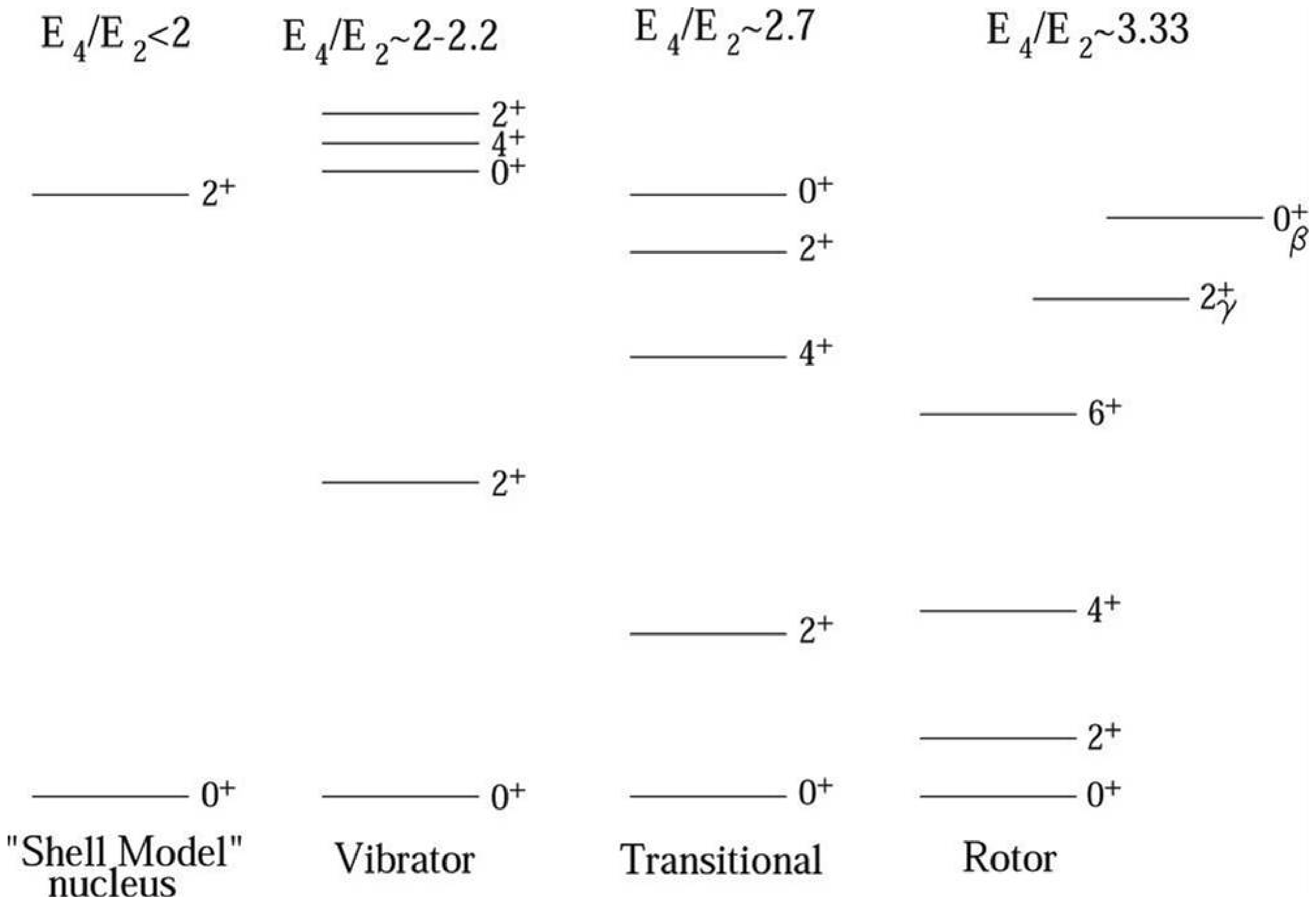
Goals of today nuclear physics

Central goal: to explain the properties of nuclei and of nuclear mater

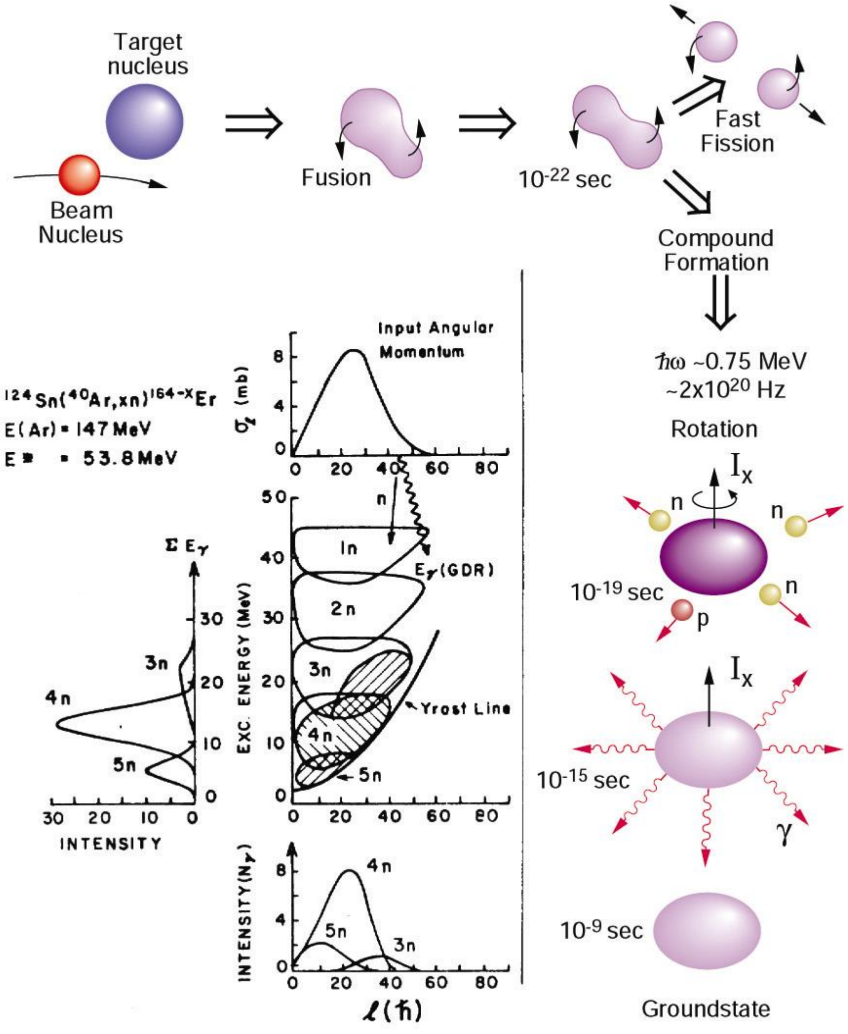
- What are the limits of nuclear existence ?
- What is the mechanism of nuclear binding ? (QCD)
- How do weak binding and extreme proton-to neutron asymmetries affect nuclear properties ?
- How the properties of nuclei evolve with changes in proton and neutron number excitation energy and angular momentum ?
- What is the origin of simple patterns in complex nuclei ?

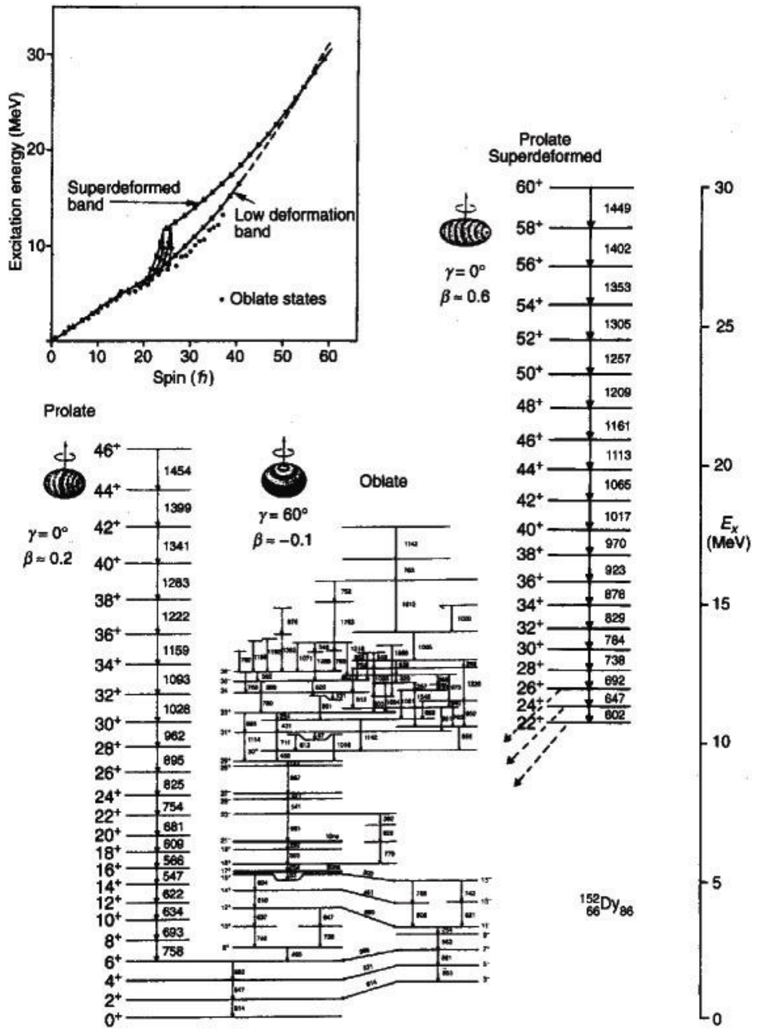
- What is the quantitative origin of the chemical elements in the Big Bang and continuing to the supernovae we observe today ?
- What is the mechanism of energy generation in stars ?

Evolution of nuclear structure

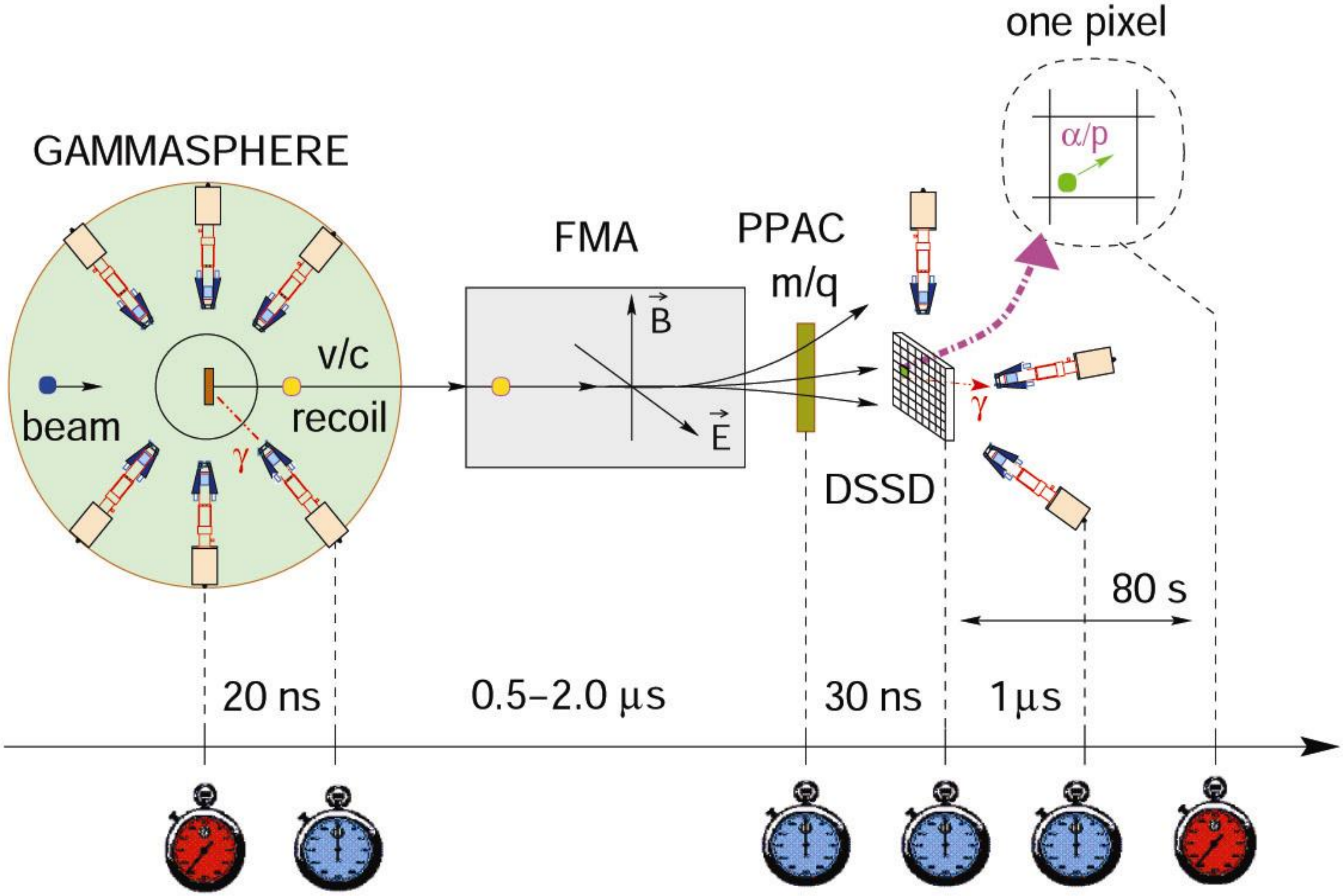


Fusion evaporation reactions

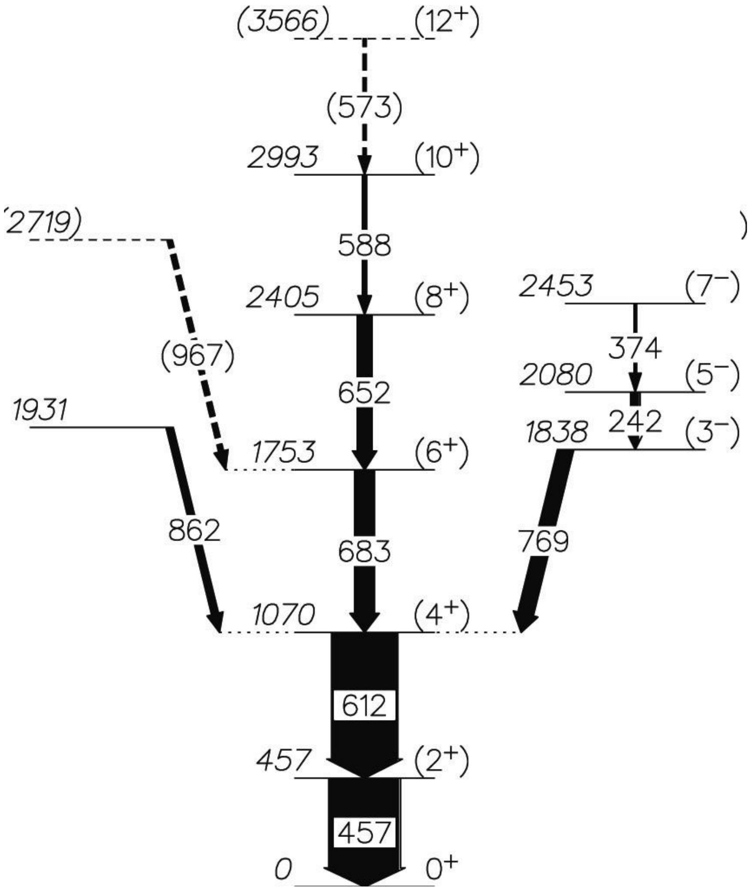


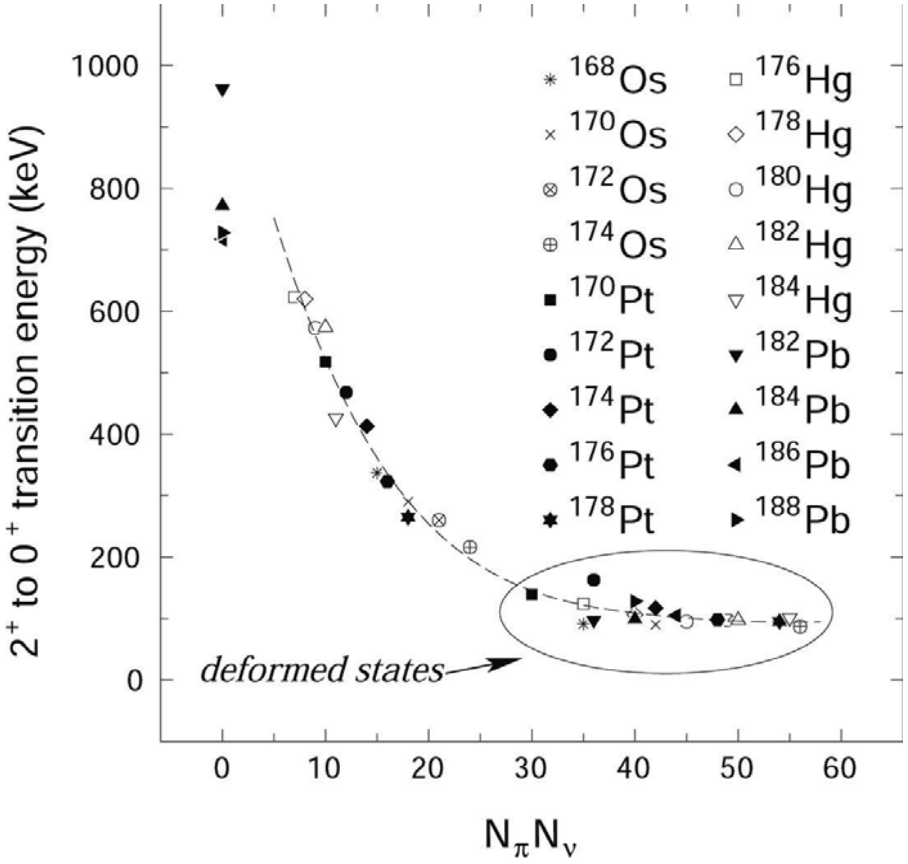


Recoil–Decay Tagging Technique

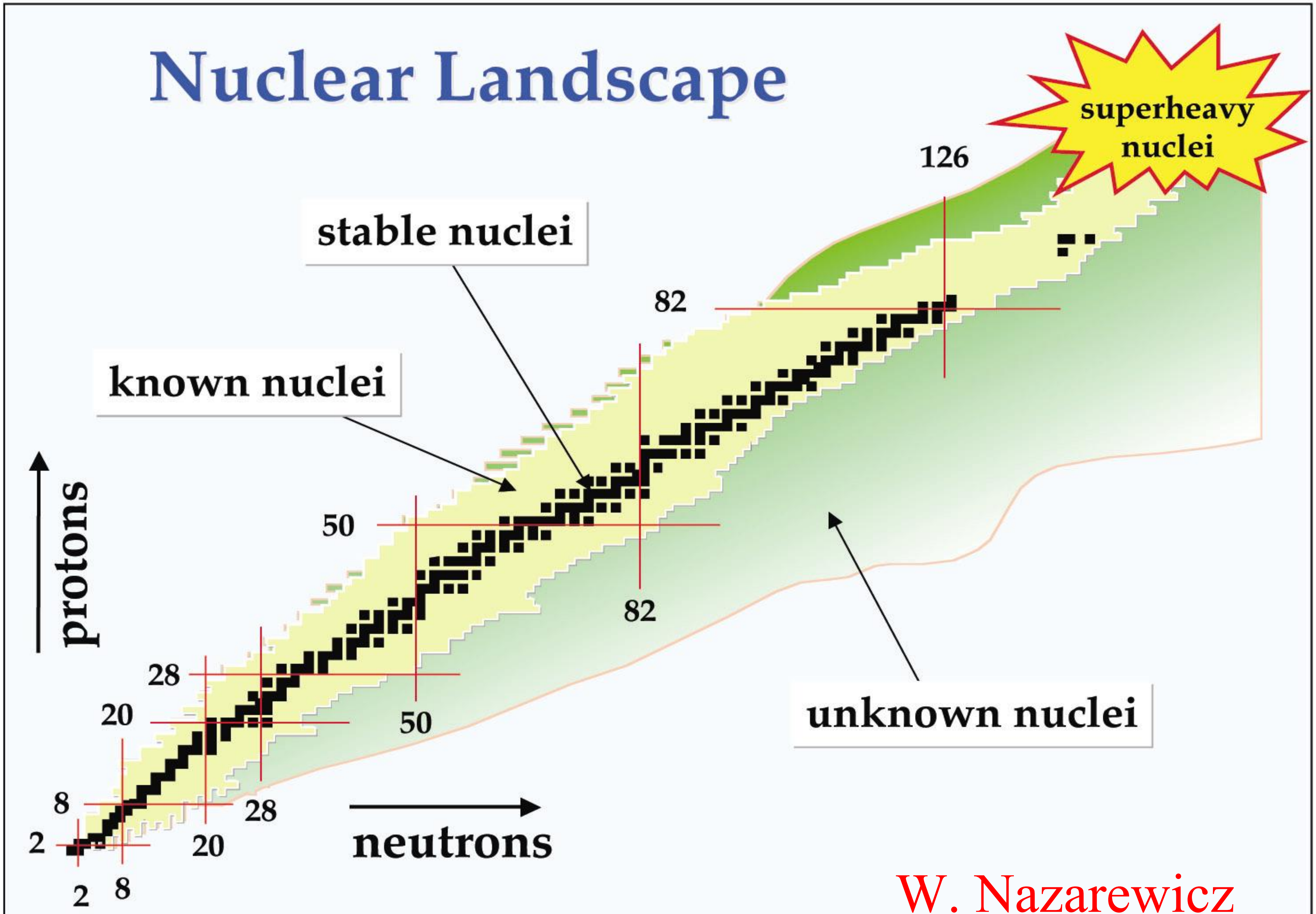


Results for ^{172}Pt





Nuclear Landscape



superheavy nuclei

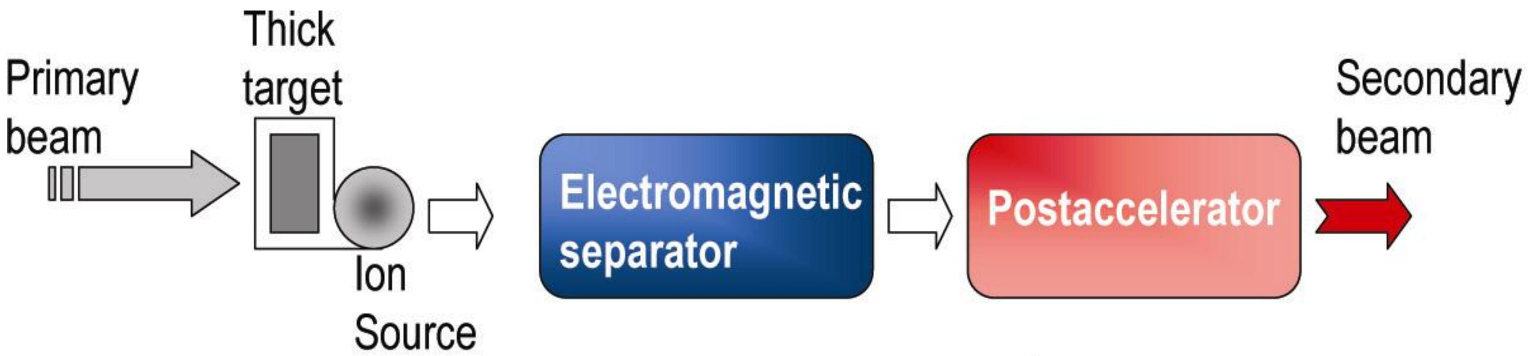
stable nuclei

known nuclei

unknown nuclei

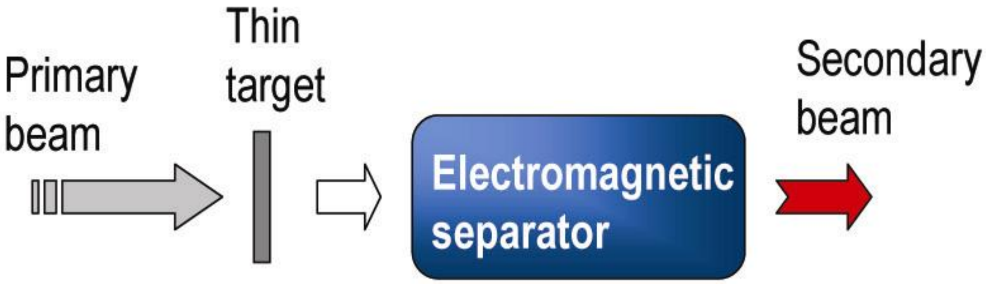
W. Nazarewicz

Radioactive Ion Beams production



ISOL (Isotope Separation On-Line)

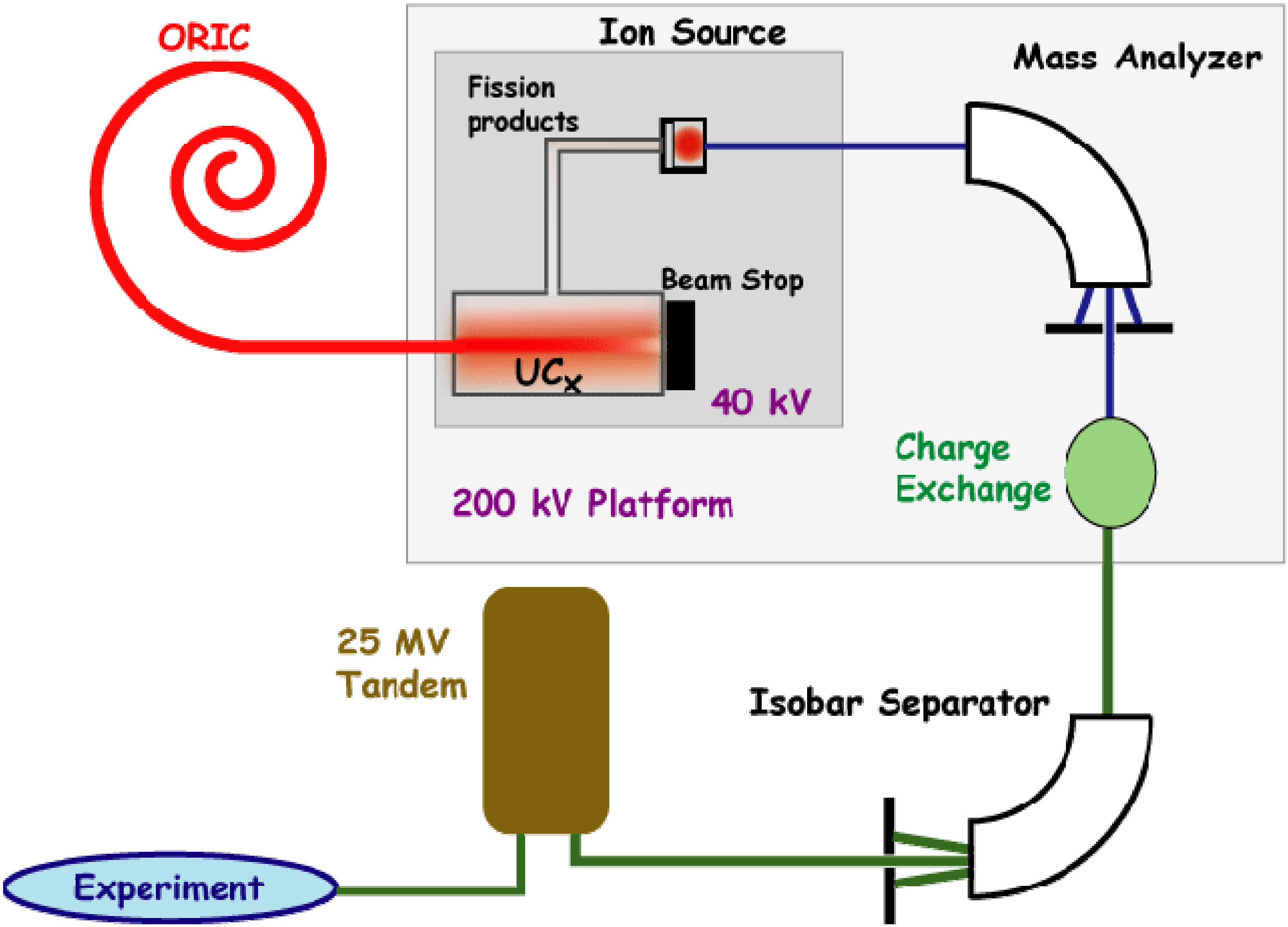
high beam intensity & quality
slow (diffusion and effusion)



IF (In-flight fragment separator)

lower beam intensity
worse beam quality
fast

Isotope Separator On-Line (ISOL) Technique at HRIBF



ORIC

Ion Source

Fission
products

Beam Stop

UC_x

40 kV

Mass Analyzer

Charge
Exchange

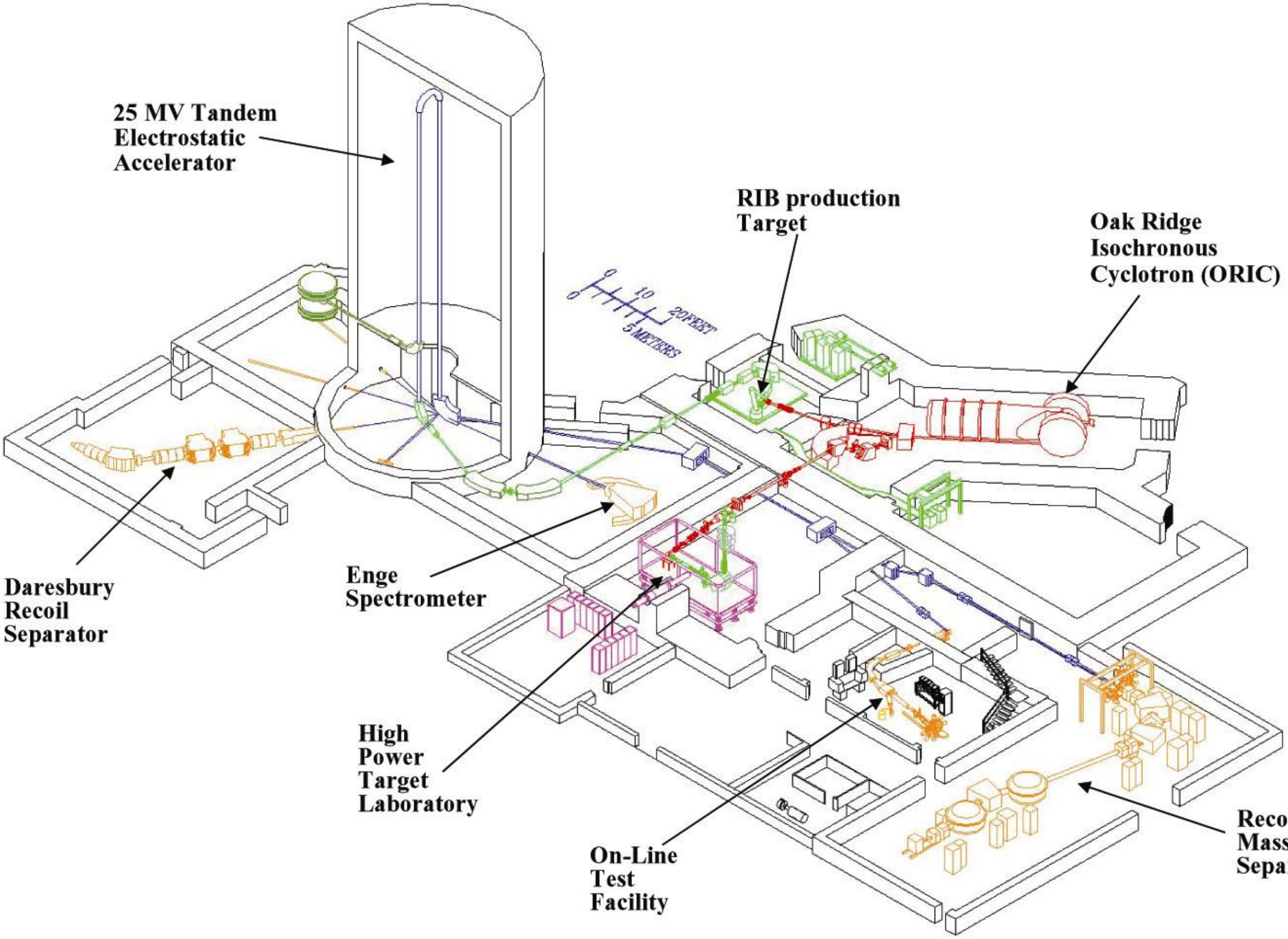
200 kV Platform

25 MV
Tandem

Isobar Separator

Experiment

Holifield Radioactive Ion Beam Facility



25 MV Tandem Electrostatic Accelerator

RIB production Target

Oak Ridge Isochronous Cyclotron (ORIC)

Daresbury Recoil Separator

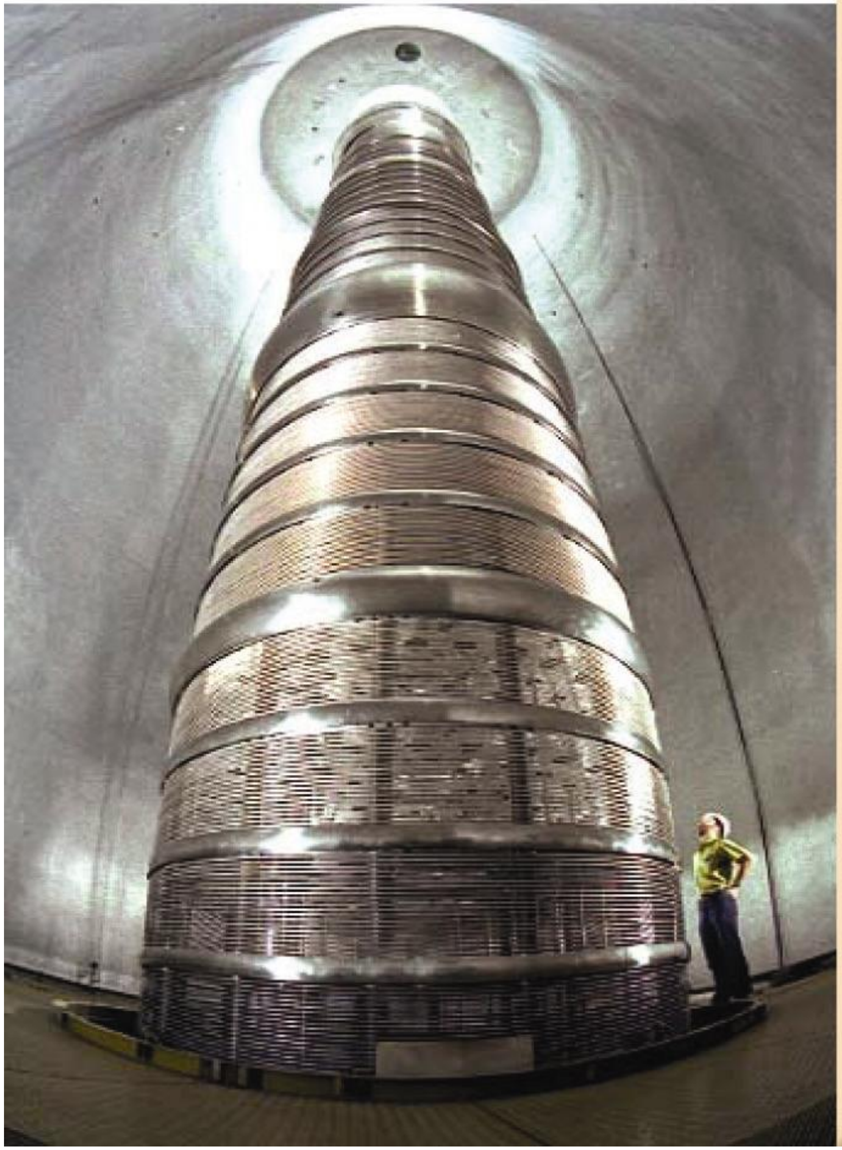
Enge Spectrometer

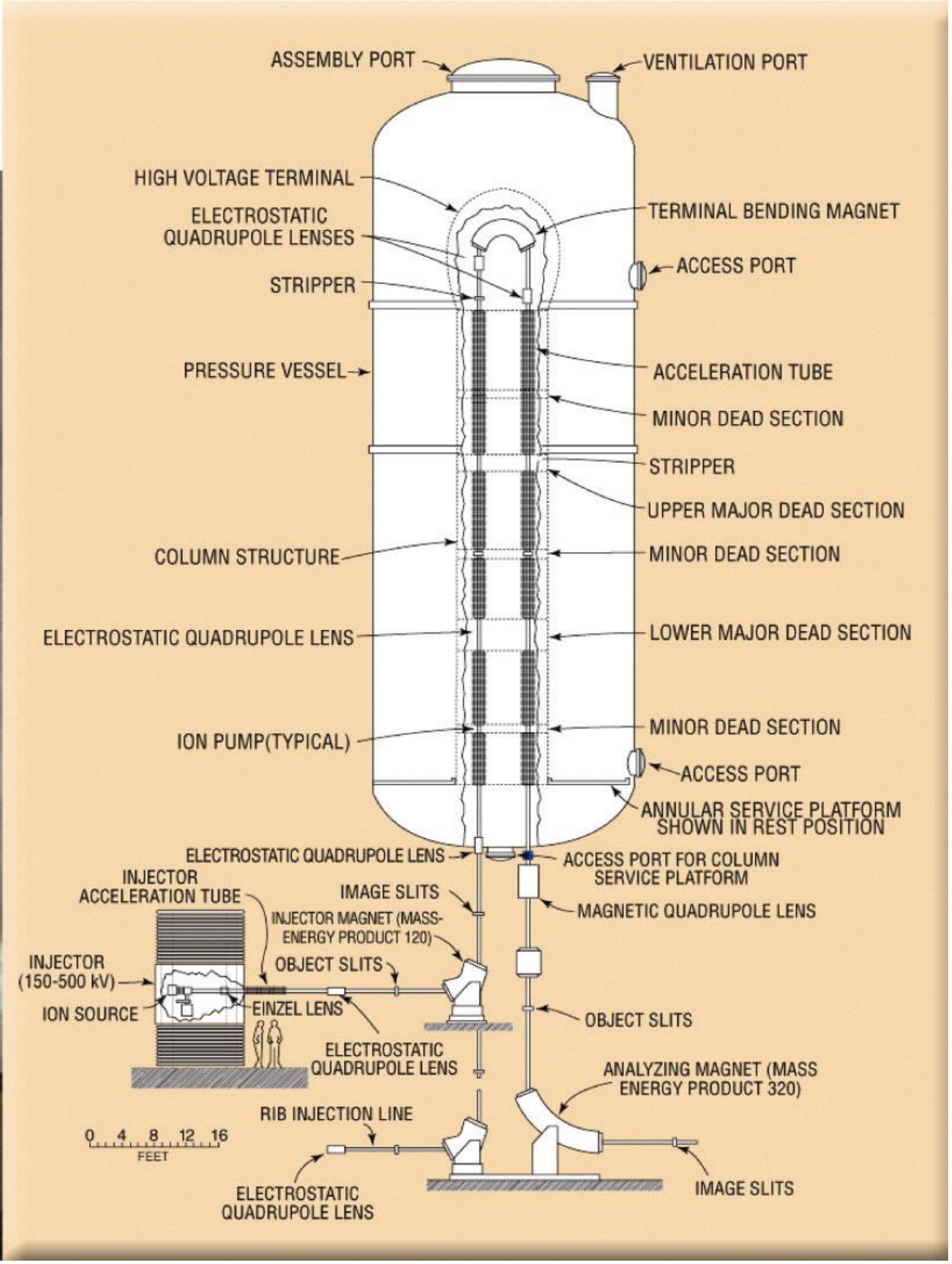
High Power Target Laboratory

On-Line Test Facility

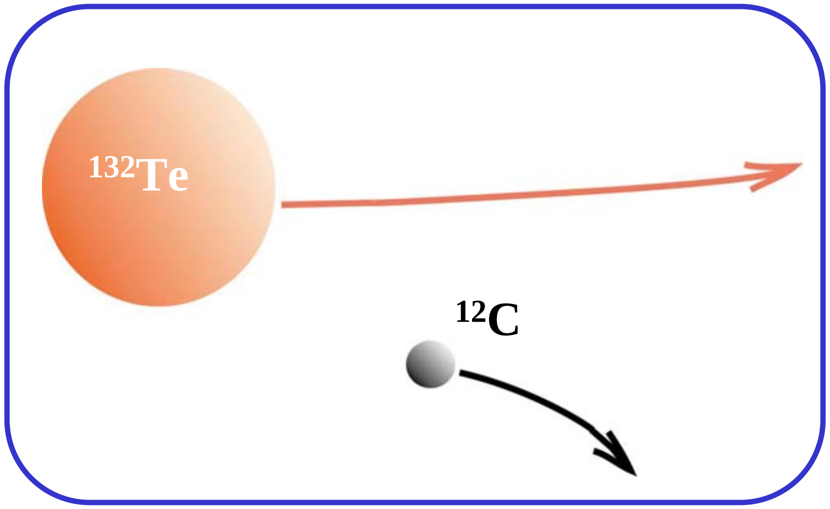
Recoil Mass Separator

25 MV Tandem




ASSEMBLY PORT
VENTILATION PORT
HIGH VOLTAGE TERMINAL
TERMINAL BENDING MAGNET
ELECTROSTATIC QUADRUPOLE LENSES
ACCESS PORT
STRIPPER
PRESSURE VESSEL
ACCELERATION TUBE
MINOR DEAD SECTION
STRIPPER
UPPER MAJOR DEAD SECTION
COLUMN STRUCTURE
MINOR DEAD SECTION
ELECTROSTATIC QUADRUPOLE LENS
LOWER MAJOR DEAD SECTION
ION PUMP(TYPICAL)
MINOR DEAD SECTION
ACCESS PORT
ANNULAR SERVICE PLATFORM SHOWN IN REST POSITION
ELECTROSTATIC QUADRUPOLE LENS
ACCESS PORT FOR COLUMN SERVICE PLATFORM
INJECTOR ACCELERATION TUBE
IMAGE SLITS
MAGNETIC QUADRUPOLE LENS
INJECTOR MAGNET (MASS-ENERGY PRODUCT 120)
INJECTOR (150-500 kV)
OBJECT SLITS
ION SOURCE
EINZEL LENS
OBJECT SLITS
ELECTROSTATIC QUADRUPOLE LENS
ANALYZING MAGNET (MASS ENERGY PRODUCT 320)
RIB INJECTION LINE
0 4 8 12 16
FEET
ELECTROSTATIC QUADRUPOLE LENS
IMAGE SLITS

Coulomb excitation of RIBs



- useful to excite low lying states
- exact theory (Alder and Winther) - can calculate Rutherford and Coulomb cross section
- can measure transition rates and g-factors

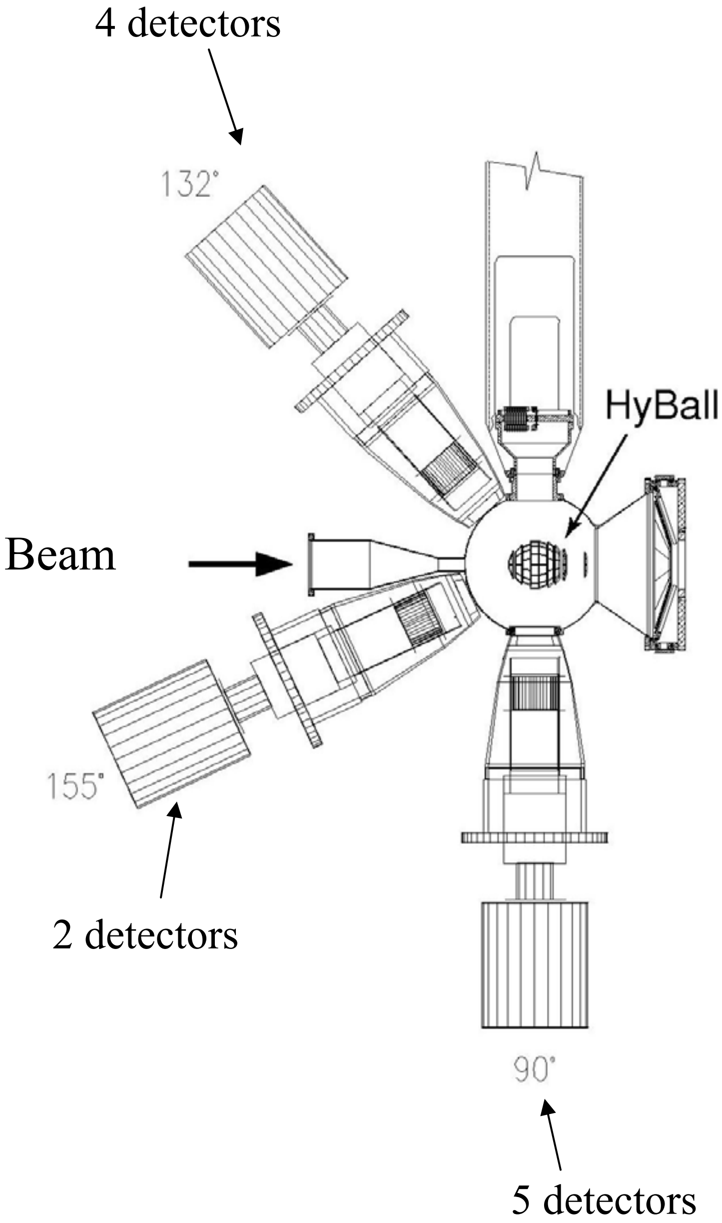
Problems:

- high v/c~5-6%
- high background from rad. decay
- isobaric contamination of the beam
- low intensity

Solutions:

- use of segmented Ge detectors
- use of auxiliary detectors (HyBall)
- monitoring of the beam composition with Bragg detector

Experimental setup



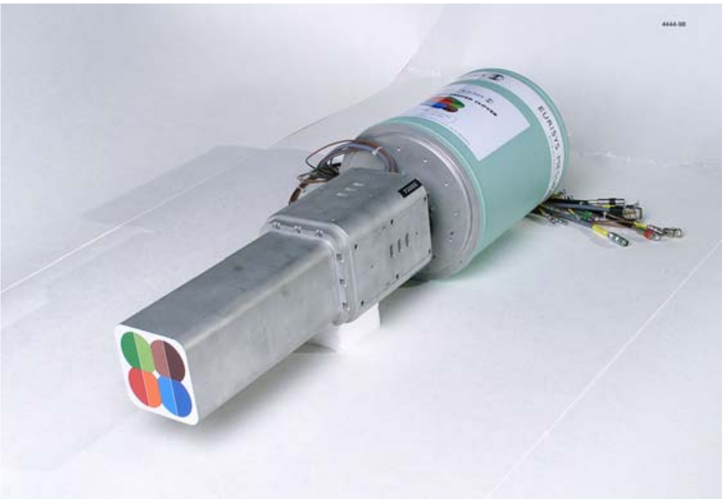
4 detectors

HyBall

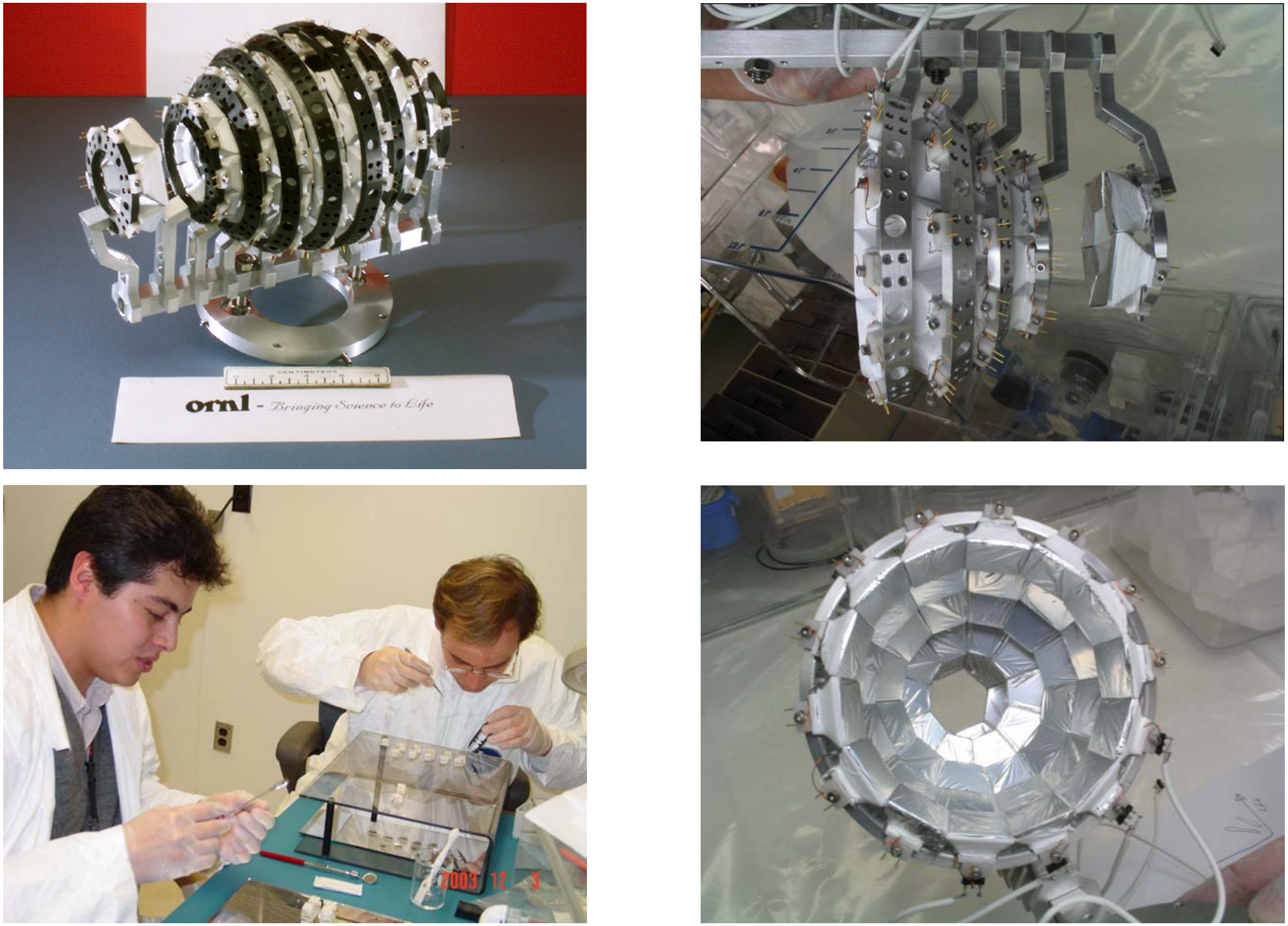
Beam

2 detectors

5 detectors



HyBall – CsI charged particle detector



g-factors

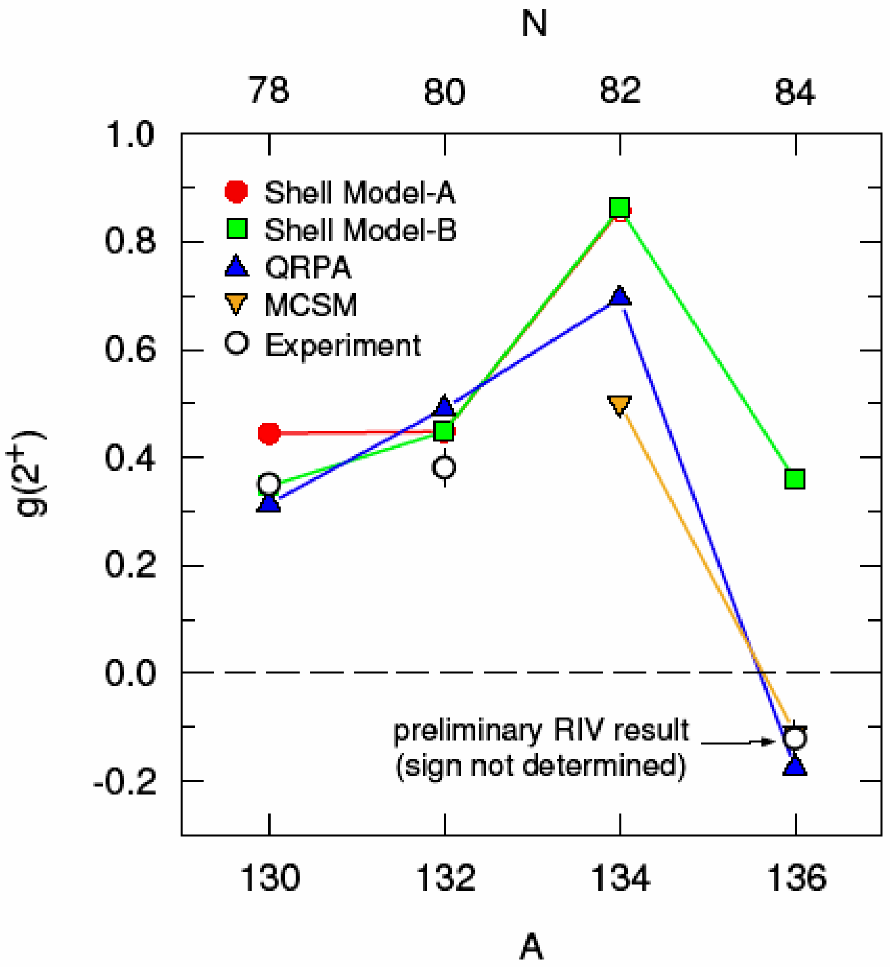
- orbital magnetic moment of nucleons $\mu = g_l l \mu_N$ $\mu_N = \frac{e\hbar}{2m_p}$
  - proton $g_l = 1$
  - neutron $g_l = 0$
- intrinsic magnetic moment of nucleons $\mu = g_s s \mu_N$
  - proton – $g_s = 5.6$
  - neutron – $g_s = -3.8$

For well deformed nuclei (good rotors) magnetic moment is:

$$\mu(I) = I \frac{Z}{A} \mu_N$$

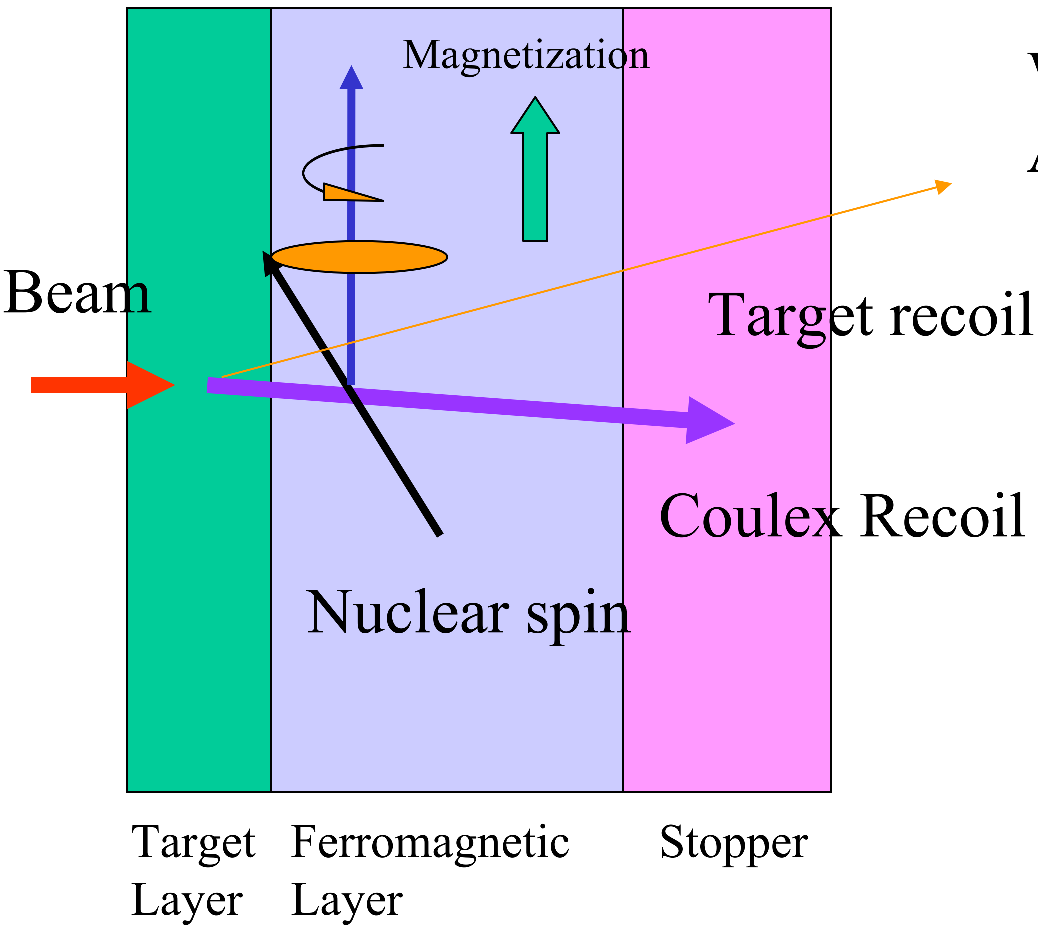
The only interesting magnetic moments are for nuclei near the closed shells !

Motivation for g-factor measurement of the 2^+ state of ^{132}Te



Transient Field Method

External magnetic field $\vec{B}$



Magnetization

Beam

Target recoil

Coulex Recoil

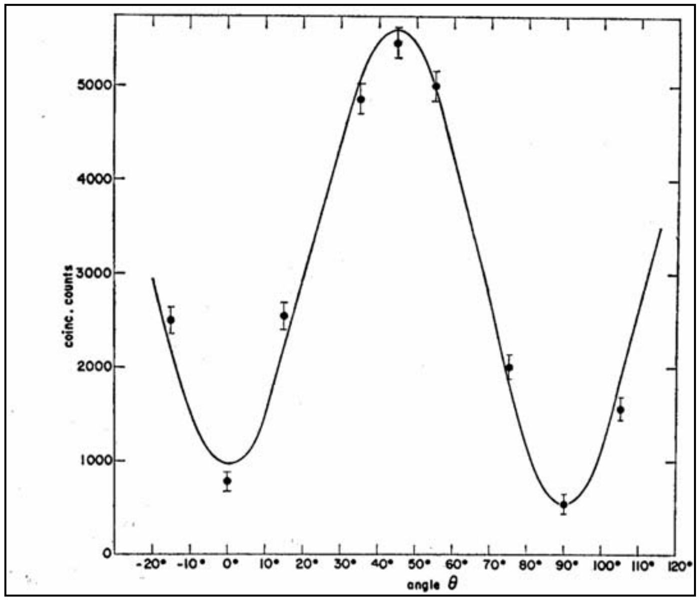
Nuclear spin

Target Layer

Ferromagnetic Layer

Stopper

$$W(\theta_{\gamma})=1+A_2P_2(\cos(\theta\gamma))+A_4P_4(\cos(\theta\gamma))$$



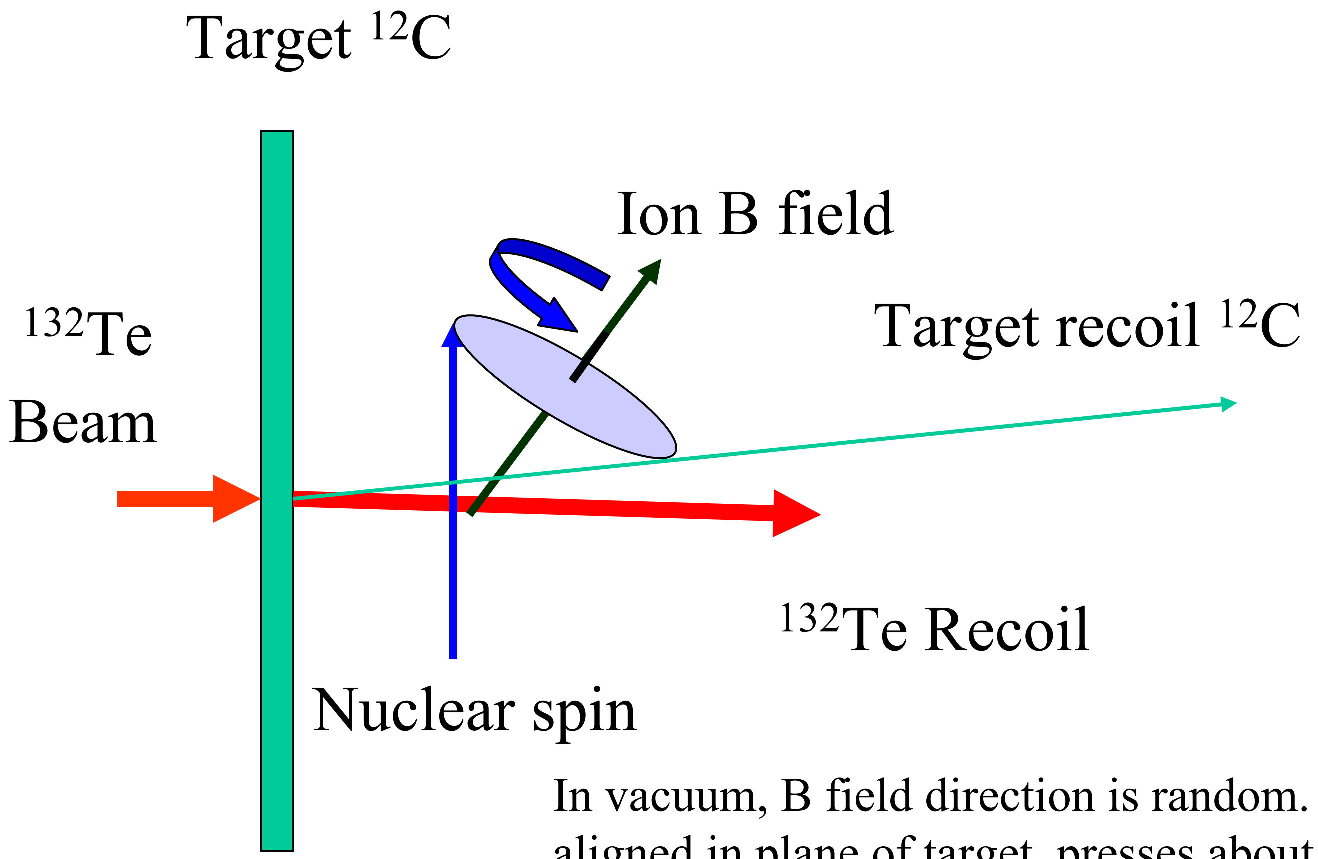
Difficulties for direct transfer to RIBs experiments

1. $\Delta\theta$ always small - few degrees, requiring high statistics for accurate measurement.

2. Elastic scattered beam nuclei behave like Coulomb excited nuclei and are stopped in the same region. With an RIB these will give a strong background activity [~ 100 x Coulex]

3. The RIB may contain contaminant activity including decay through the Coulomb exited state - more unwanted coincidences.

Recoil in Vacuum



Target ^{12}C

Ion B field

^{132}Te

Beam

Target recoil ^{12}C

^{132}Te Recoil

Nuclear spin

In vacuum, B field direction is random. Nuclear spins, initially aligned in plane of target, presses about B fields so attenuating angular distribution of decay gamma emission

Experimental details

^{132}Te RIB

Beam energy: 3 MeV/u

Target: 0.83mg/cm^2 thick ^{12}C
Run time 64 h with beam intensity of 3x10^7

^{122,126,130}Te SIBs

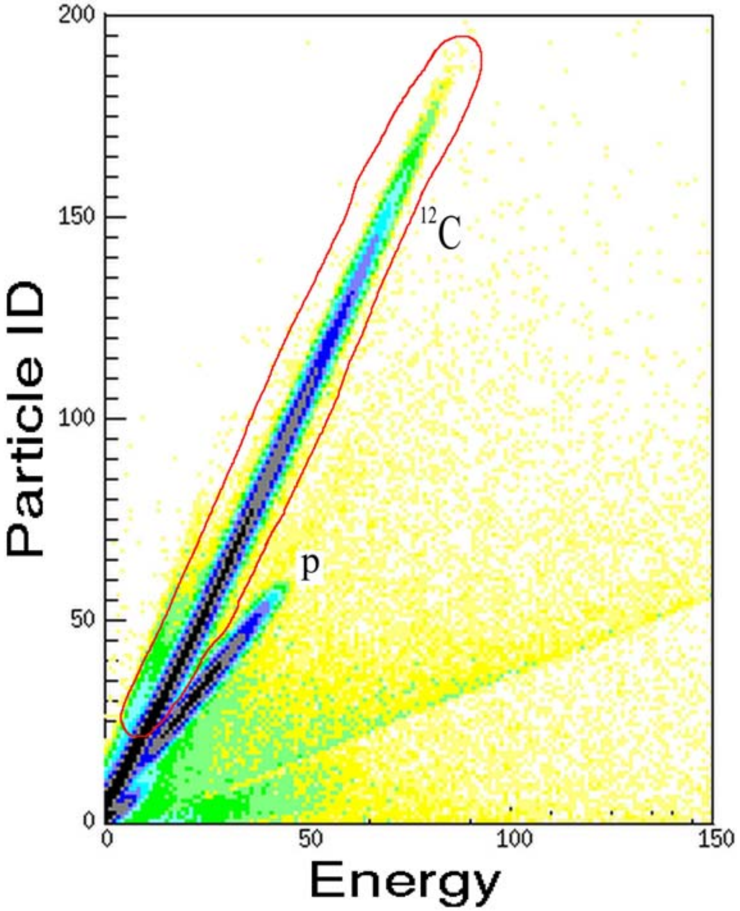
Beam energy: 3 MeV/u

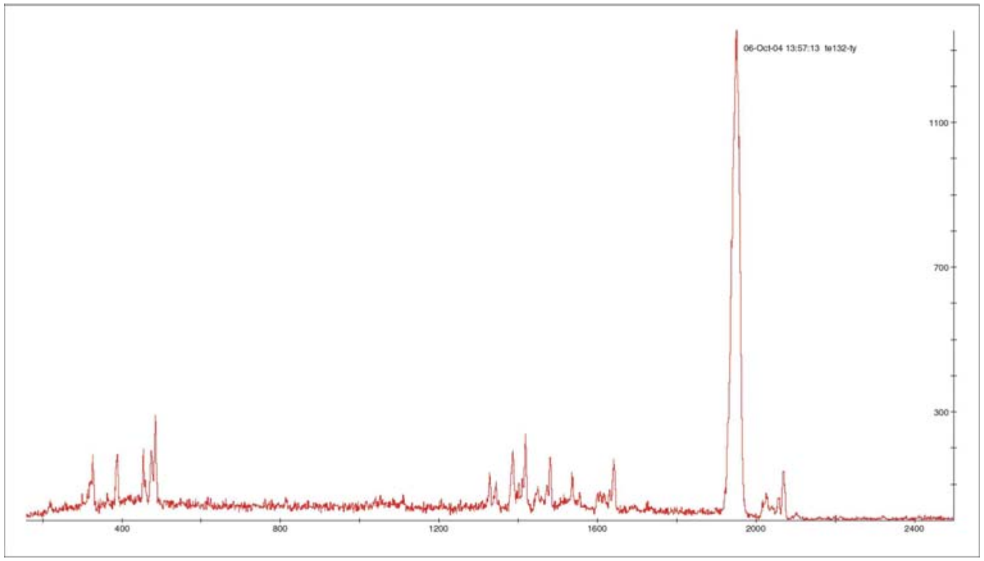
Target 1: 0.956 mg/cm^2 ^{12}C

Target 2: 0.63mg/cm^2 ^{12}C + 14.3mg/cm^2 Cu

Te isotopes	**122**	**126**	**130**	**132**
2^+ state lifetimes t_n (ps)	**10.8(1)**	**6.5(2)**	**3.3(1)**	**2.60(26)**
g-factors (TF averages)	**0.340(10)**	**0.275(30)**	**0.295(35)**	

Offline reduction of experimental data



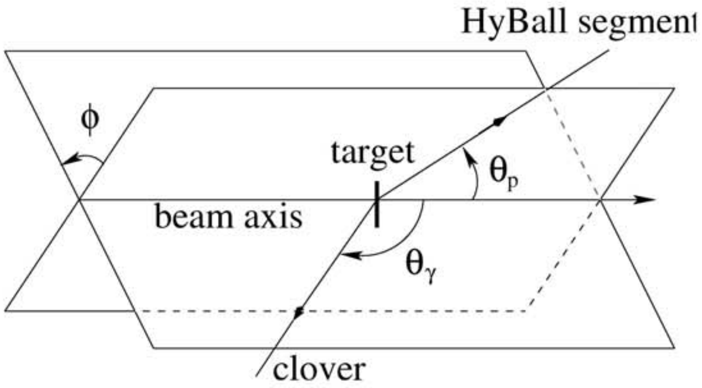


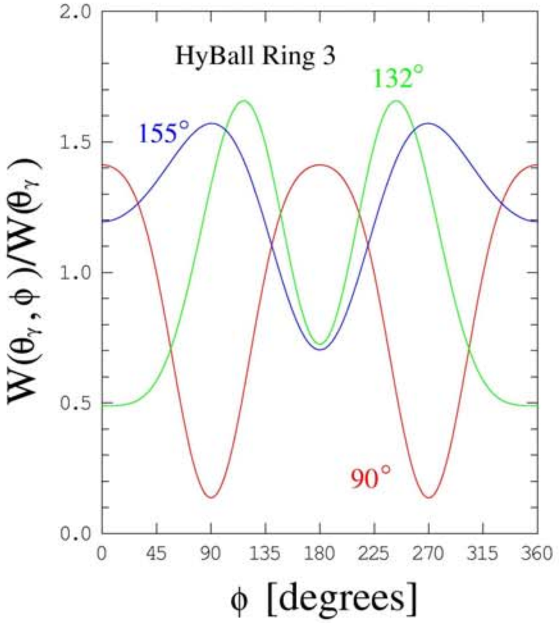
Ring 1 – 6 detectors 7° - 14°
Ring 2 – 10 detectors 14° - 28°
Ring 3 - 12 detectors 28° - 44°

Analysis of the data

The general expression of angular correlation function is given by:

$$W(\theta_\gamma, \theta_p, \phi) = \sum_{kq} \langle \rho_{kq}(\theta_p) \rangle \sqrt{2k+1} F_k(2220) Q_k G_k D^{k*}_{q0}(\phi, \theta_\gamma, 0)$$

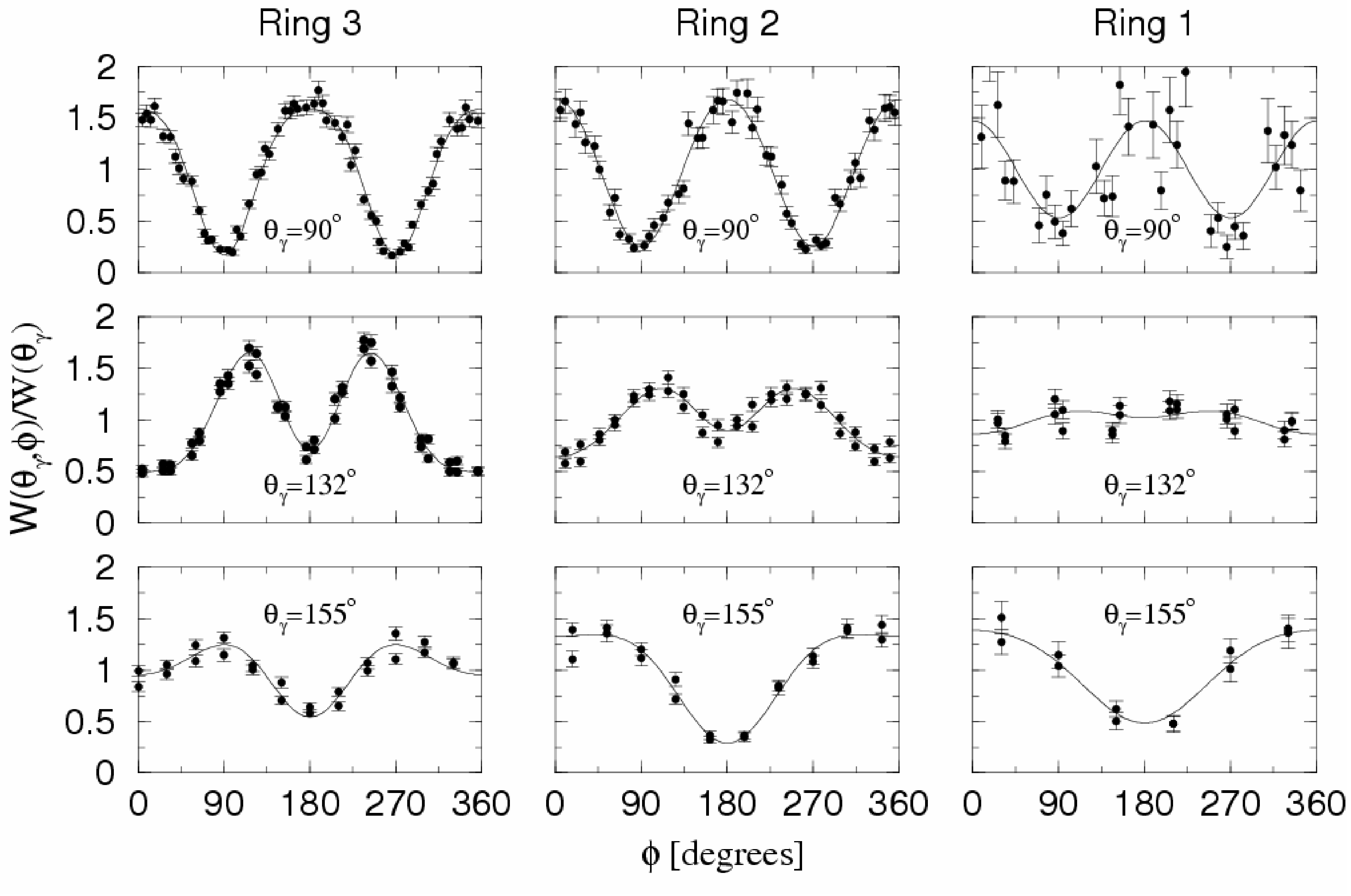




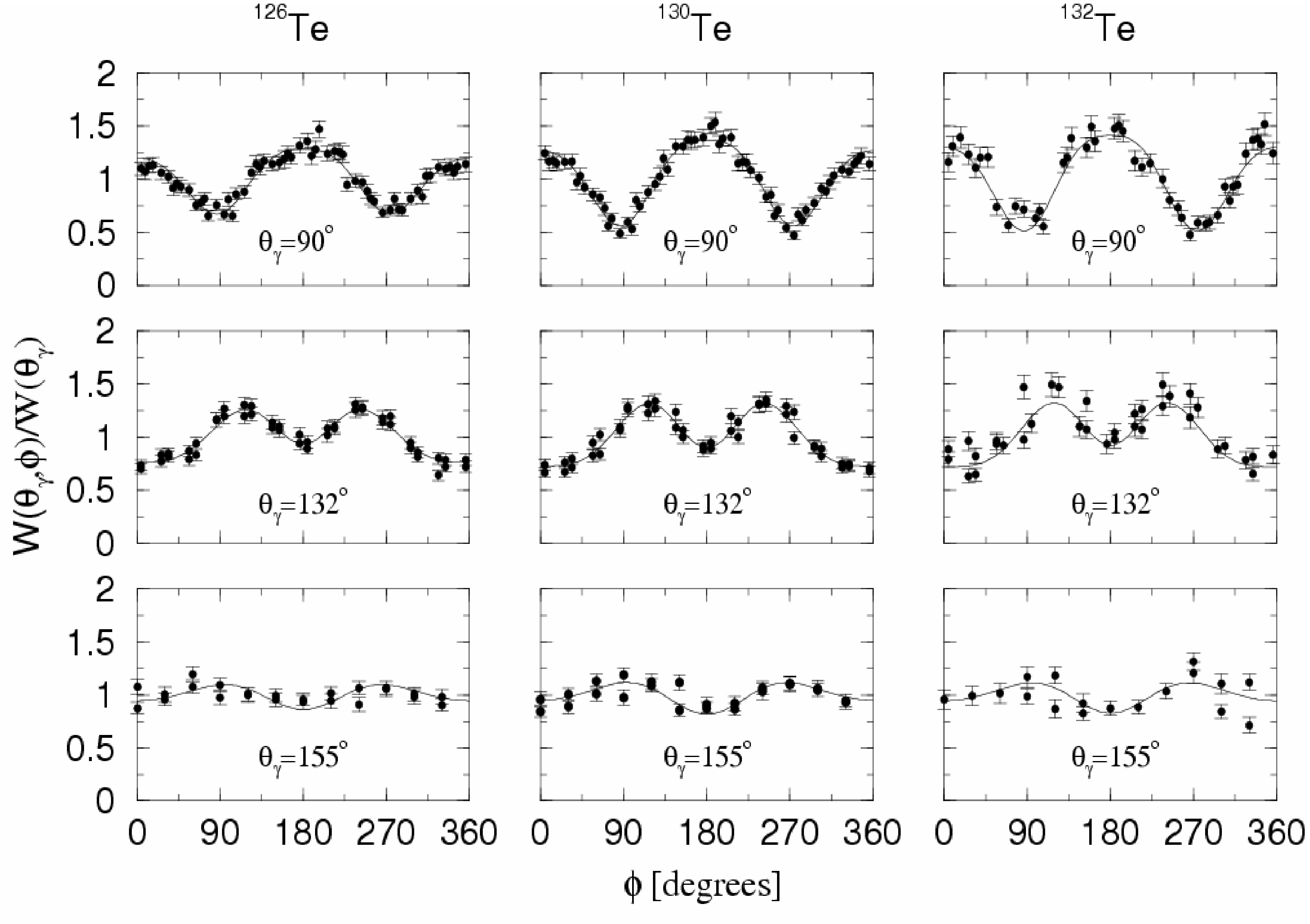
All coincident data were divided into 9 groups (3 HyBall rings × 3 CLARION rings) and were investigated as function of angle ϕ.

- Understanding unattenuated distribution.
- Understanding attenuated distribution. Fitting the experimental data with respect to G_2 and G_4 attenuation factors. Deriving g-factor from G_2 and G_4.

Unattenuated distributions for ^{130}Te



Fitted attenuated distributions for ring 3 of HyBall



Fast relaxation model (Abragam and Pound theory)

- When electronic states lifetime is short compared to lifetime of the nuclear state and the precession time.

$\tau_{\text{electronic}} \ll \tau_{\text{nuclear}}$

$\tau_{\text{electronic}} \ll \omega_m^{-1}$ where $\omega_m = g\mu_N \langle H^2 \rangle^{1/2}/\hbar$

The hyperfine interaction varies both in magnitude and direction with short fluctuation time.

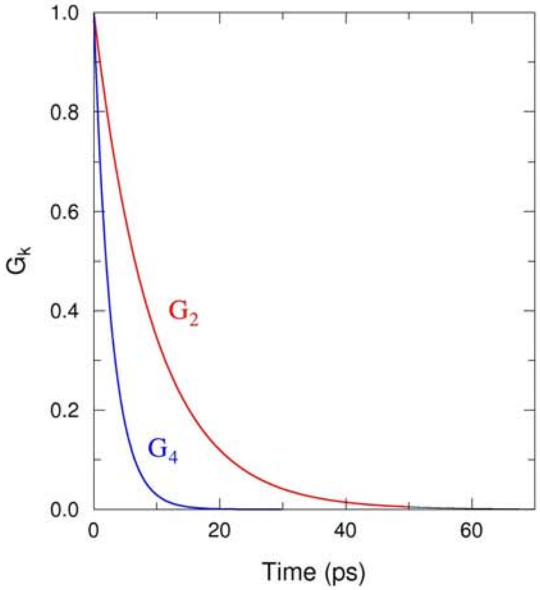
Abragam-Pound theory gives:

$$G_k(t) = \exp(-t/\tau_k) \Longleftarrow \tau_2 \sim 1/g^2 \text{ and } \tau_4 = 0.3\tau_2$$

Only one free parameter left: τ_2

Attenuation factors integrated over the nuclear lifetime:

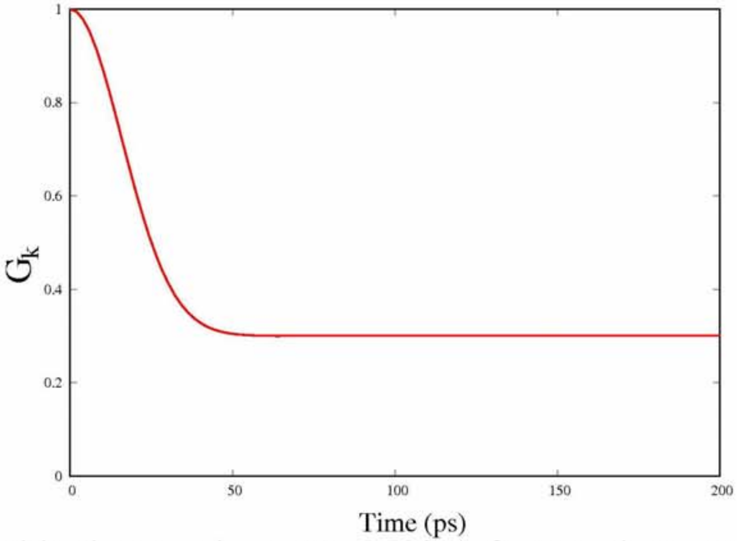
$$G_k = \frac{\tau_k}{\tau_k + \tau_{\text{nuclear}}},$$



- Easy to calibrate theory. We need only one isotope with known g-factor

Slow relaxation (Static model)

$\tau_{\text{electronic}} \gg \tau_{\text{nuclear}} \Rightarrow$ hyperfine interaction is constant both in magnitude and direction over the nuclear lifetime.



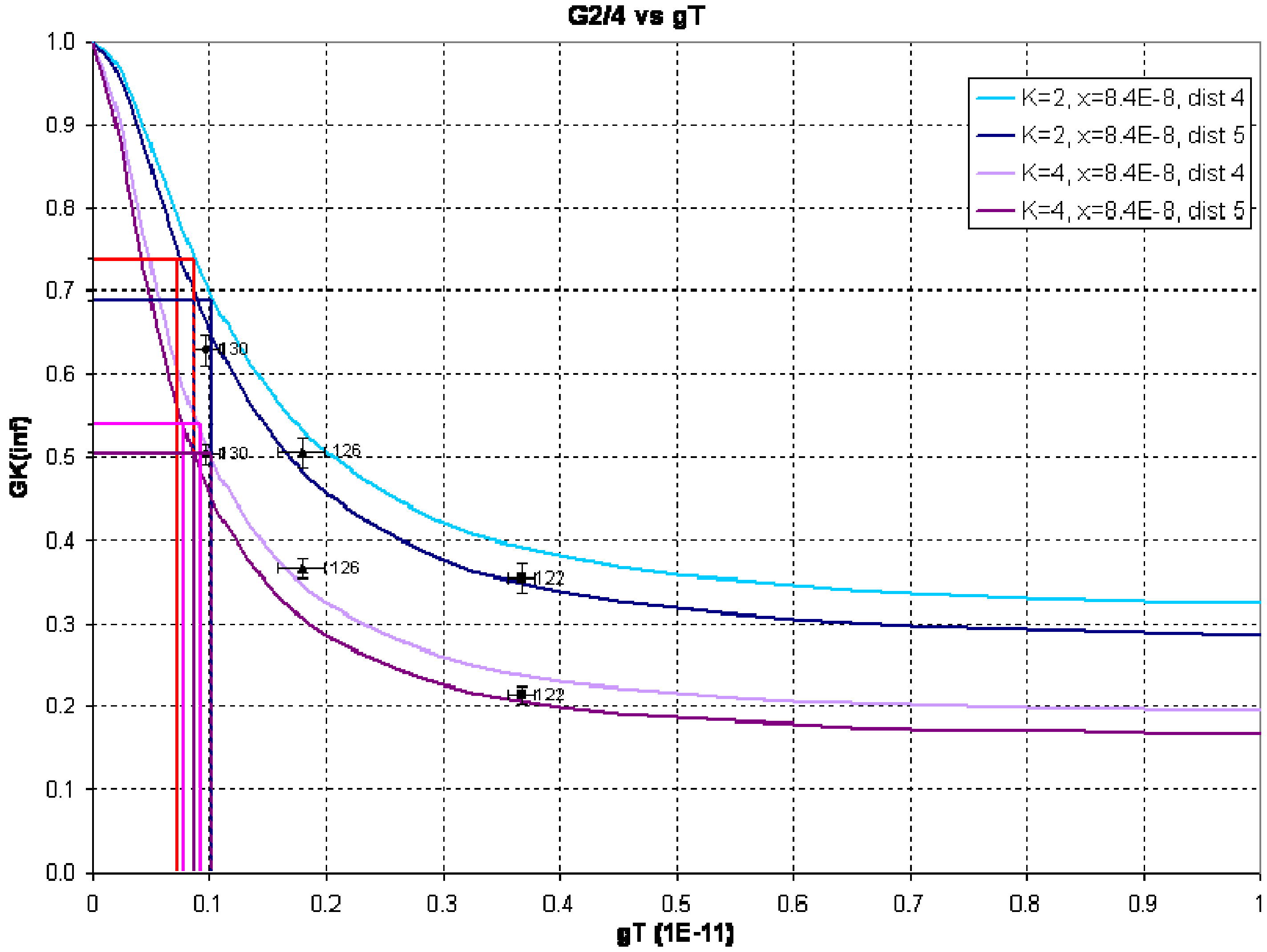
- Difficult to teoreticaly approach model. Requires knowledge of electronic states
- G_2 and G_4 are independent $\Rightarrow$ experimental data are fitted with two free parameters.

This theory gives attenuation factors, integrated over the nuclear lifetime:

$$G_k = \sum_q \left(A_q + \frac{B_q}{D_q g^2 \tau_{\text{nuclear}}^2 + 1} \right)$$

q denote different ionic states with quantum numbers $\mathbf{I} + \mathbf{J} = \mathbf{F}$

Experimental G_2,G_4 for ^{132}Te and values of extracted gτ on static model



modeled by Timlin, Oxford 2004

Final result

Comparison of experimental G_2, G_4 distinguishes between the chaotic and static models.

When they are allowed to range freely, the ratio G_2/G_4 does NOT agree with chaotic model.

So, go for static limits with combined error

|g-factor| for ^{132}Te 2^+ = 0.350(50)

Second experiment for ^{136}Te

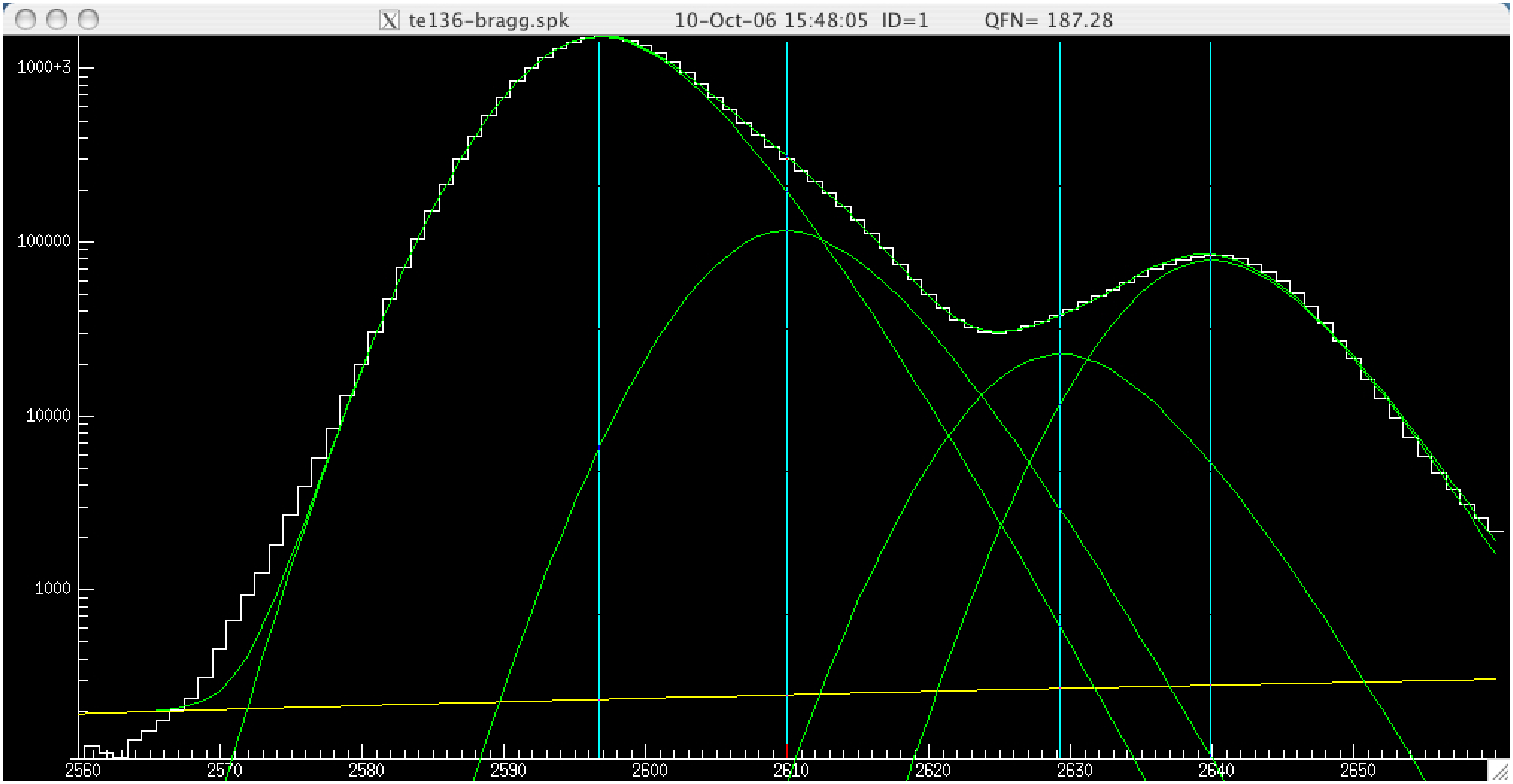
- Motivation: In view of the anomalously small B(E2), we decided to test SM and RPA theories through measuring B(E2) of other 2^+ states

- Setup: Rings 1 to 5 of BareBall & 10 Clovers
  - Bragg detector to monitor isobaric composition of the beam

- Beams and targets
  - 410 MeV ^{136}Te + "1.5 mg ^{50}Ti" target. But target has ~90% ^{50}Ti & ~8% ^{48}Ti
  - SIB Run: 390 MeV ^{126}Te + "1.5 mg ^{50}Ti"

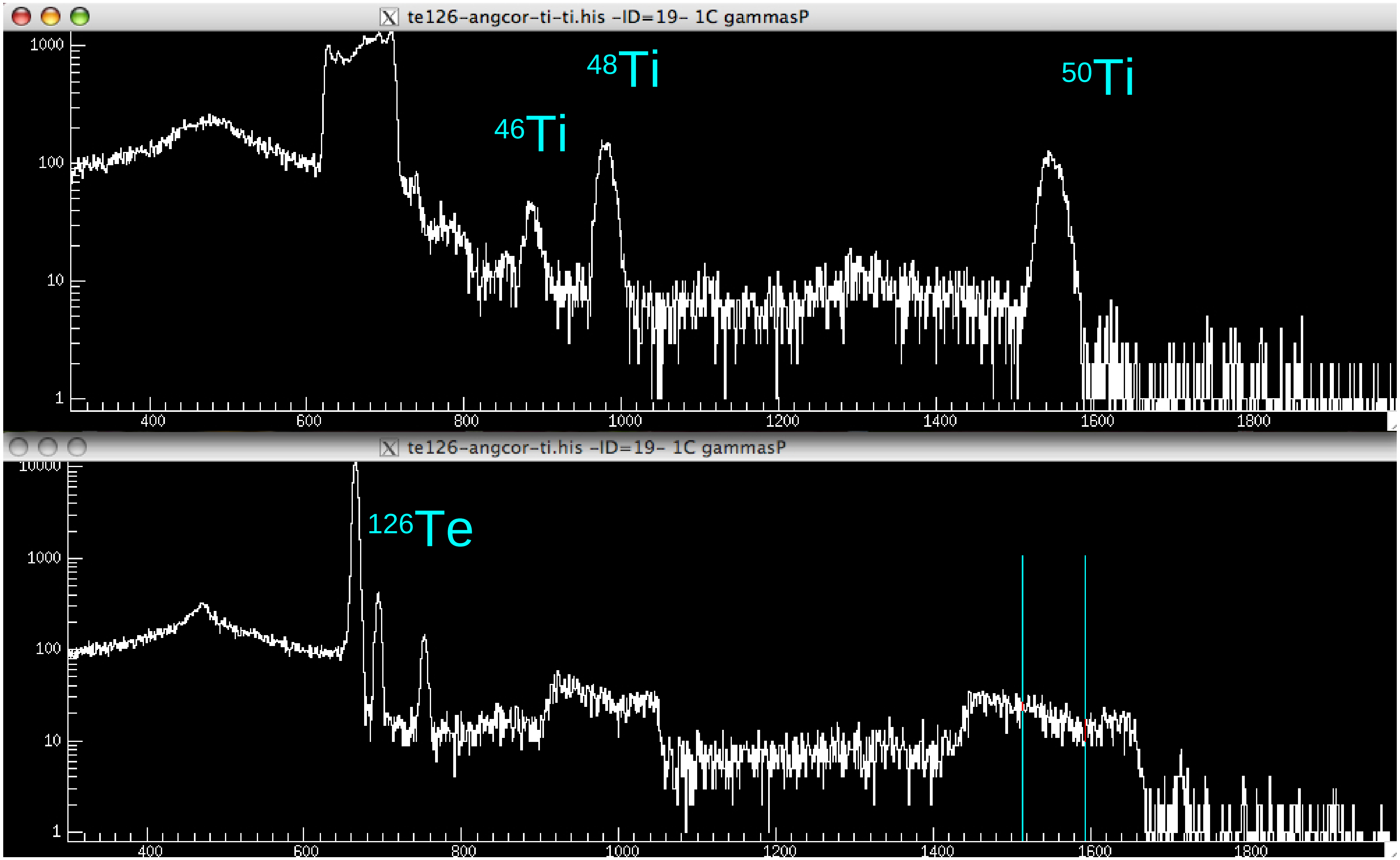
Isobaric composition (Bragg data)

- We fitted the ^{126}Te peak shape to get fit parameters for asymmetric shape. We used this to fit the A=136 spectrum that was taken simultaneously with Coulex.
- Composition: Te 86(1.5)%, I 8.2(1)%, Cs 1.3(.5)%, Ba 4.6(.6)%



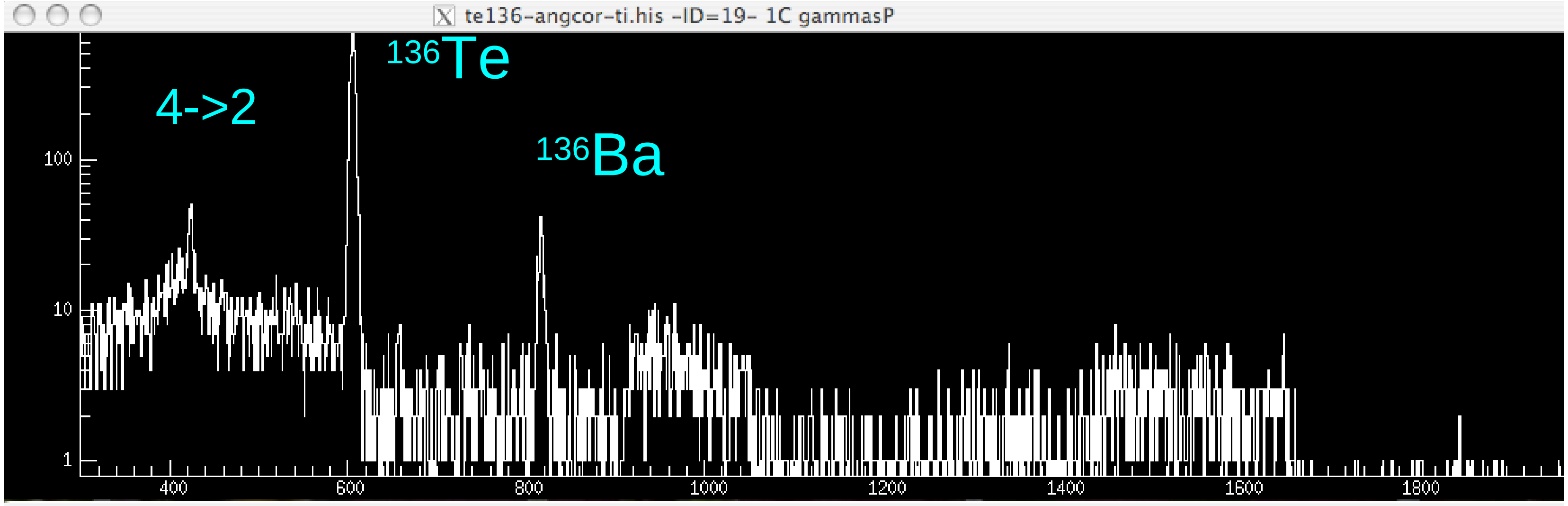
^{126}Te data

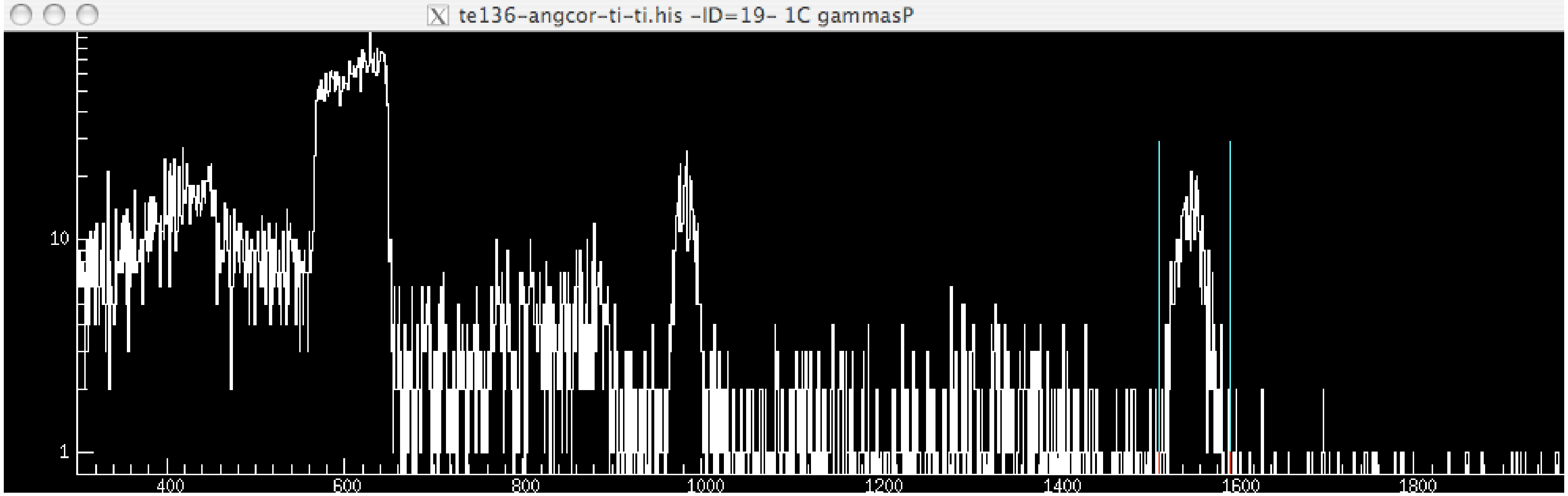
- Nearly 70k p-g counts in rings 3 & 4.
- Use these data to determine target composition (~90% ^{50}Ti) & to get $[^{126}\mathrm{Te}/^{50}\mathrm{Ti}]_{\mathrm{Exp}}$



^{136}Te data

- Nearly 4k p-g counts in rings 2 to 4. Improvements: ~x4 Ti, ~x2 intensity, ~x2 ring 4
- We extracted $[^{136}\text{Te/Ruth}]_{\text{Exp}}$, $[^{136}\text{Te}/^{50}\text{Ti}]_{\text{Exp}}$, $[^{136}\text{Te}/^{136}\text{Ba}]_{\text{Exp}}$





Analysis of ^{136}Te data

Several way to deduce B(E2) value

- ^{136}Te/Ruth
- ^{136}Te/^{50}Ti
- ^{136}Te/^{136}Ba
- [^{136}te/^{50}Ti]/[^{126}Te/^{50}Ti]

Preliminary result – B(E2)~0.15(5)

It is possible also to deduce g-factor. Analysis of calibration data is still in progress !

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