Test of IMME in fp shell via direct mass measurements of T_Z = -3/2 nuclides

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CSRe Mass Measurement Collaboration

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Outline

1. Introduction
2. Mass measurements in CSRe
3. Test the IMME in fp-shell nuclides
4. Summary

1. Introduction

Isospin

Isospin projection (good quantum number)

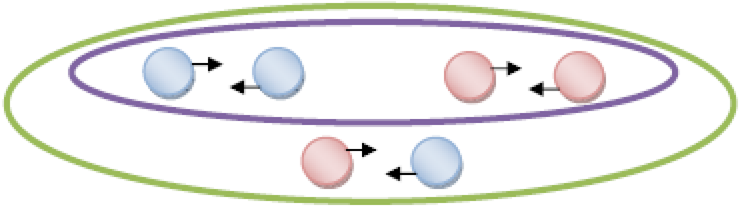
$$T_Z = \sum_{i=1}^{A} t_{z,i} = \frac{N-Z}{2}$$

Isospin

$$\left|\frac{N-Z}{2}\right| \leq T \leq \frac{N+Z}{2} \quad \text{and } T \geq T_Z$$

Charge Symmetry: $V_{pp} = V_{nn}$

Charge Independence: $V_{pp} = V_{nn} = V_{pn}$

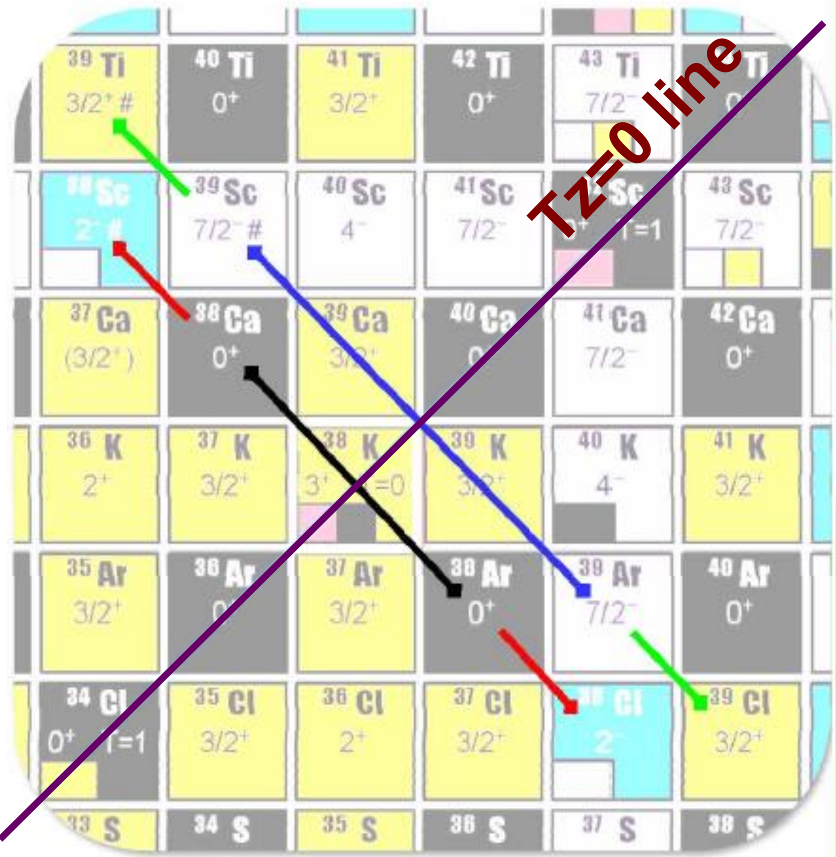


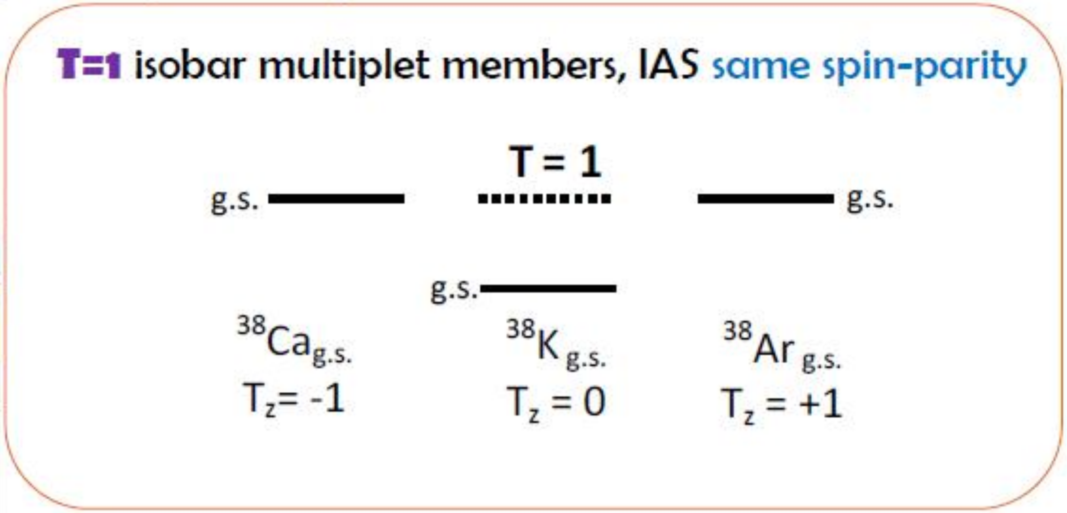
1932: Heisenberg applies the Pauli matrices to the problem of labelling the two charge states of the nucleon.

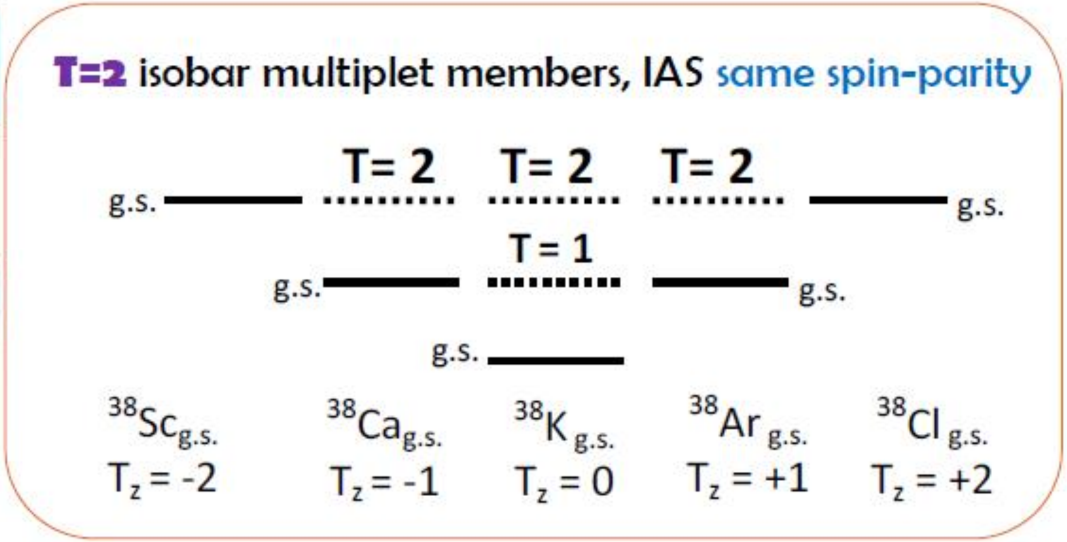
1937: Wigner points to isospin as a good quantum number to characterize isotopic multiplets (or isospin multiplets).

1. Introduction

Isospin Multiplet



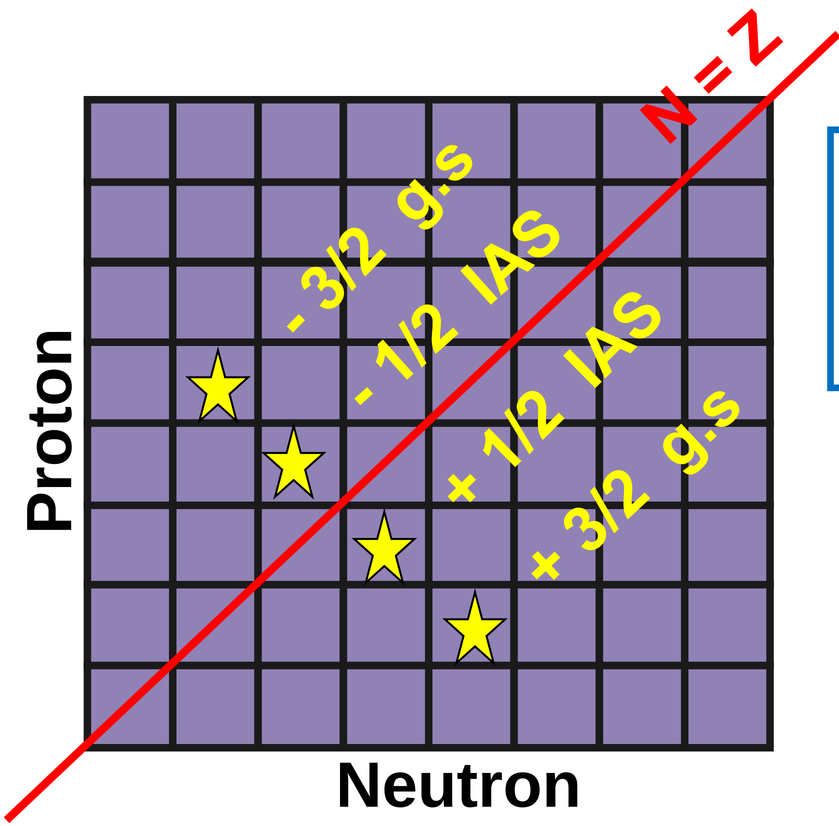


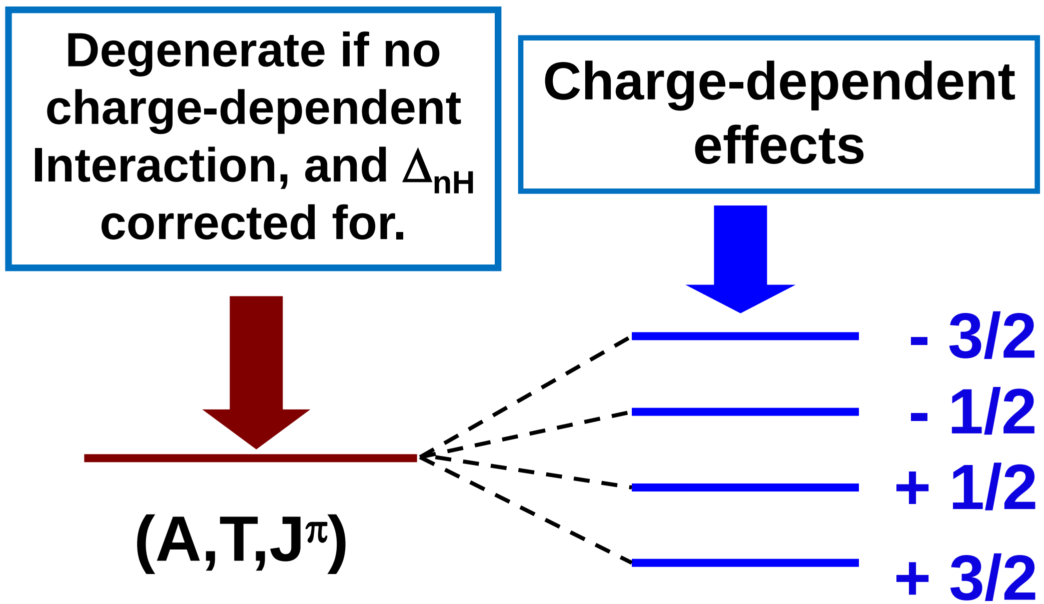


1. Introduction

T=3/2 quartet

Isospin Multiplet Mass Equation



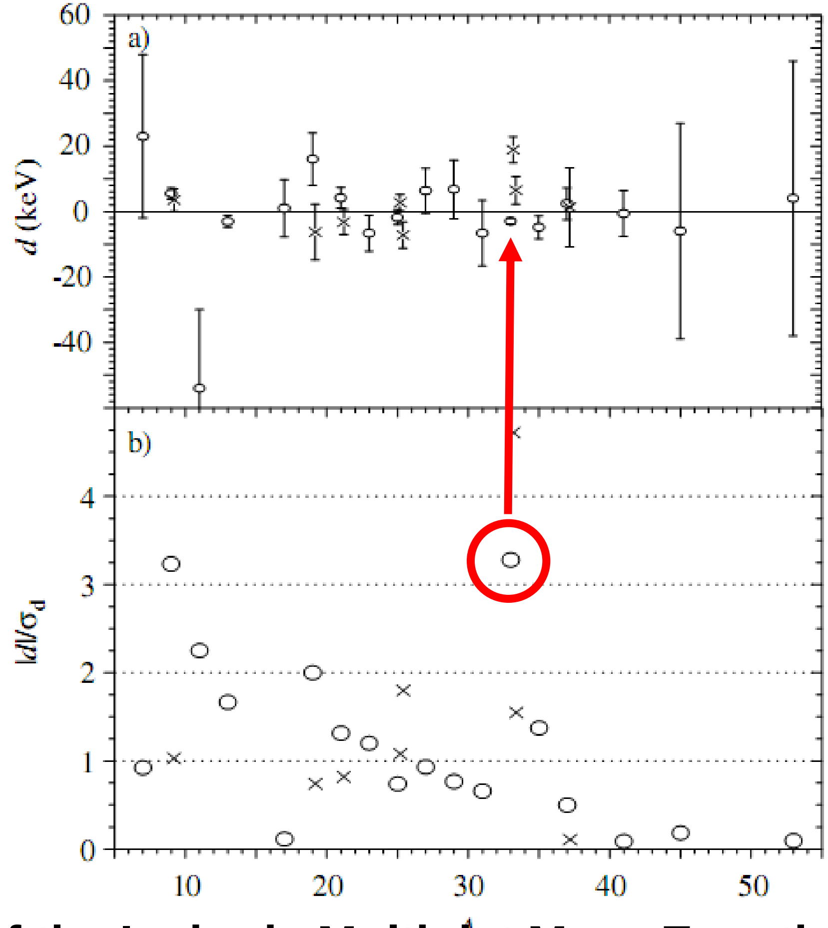


$$M(A,T,T_z)=a(A,T)+b(A,T)T_z+c(A,T)T_z^2$$

Any charge-dependent effects are two body interactions and be regarded as a perturbation.

Test the IMME: the case of A=33,T=3/2

$$M(T,A,T_3) = a(T,A,) + b(T,A)T_3 + c(T,A)T_3^2 + d(T,A)T_3^3$$



Breakdown of the Isobaric Multiplet Mass Equation at *A*= 33, *T*=*3*/2

F. Herfurth, PhysRevLett.87.142501(2001)

Related publications

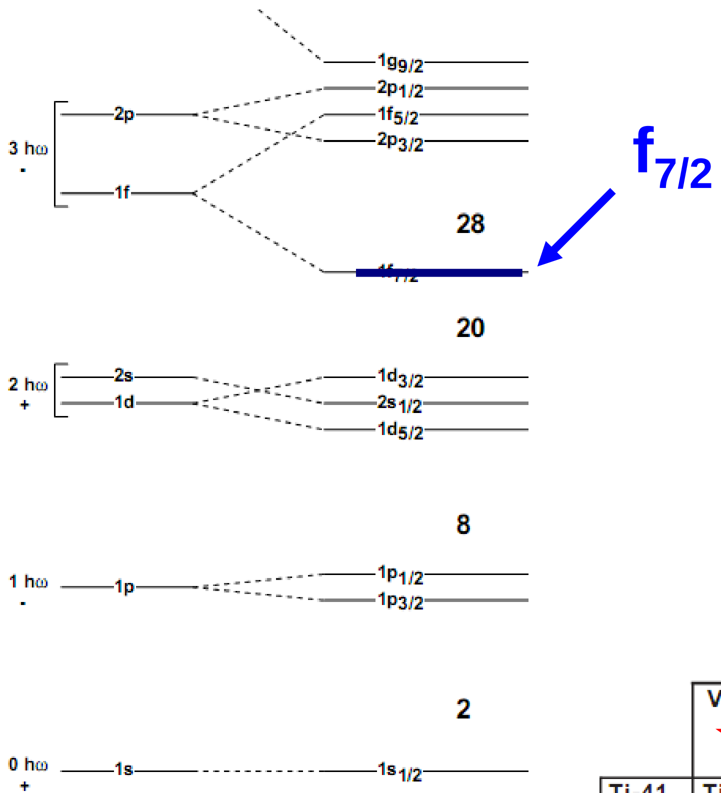
Breakdown of the Isobaric Multiplet Mass Equation at *A*= 33, *T*=*3*/2
F. Herfurth,1,3,* J. Dilling,1 A. Kellerbauer,2,5 G. Audi,4 D. Beck,6,1 G. Bollen,3,8 H.-J. Kluge,1 D. Lunney,4
DOI: 10.1103/PhysRevLett.87.142501(2001)

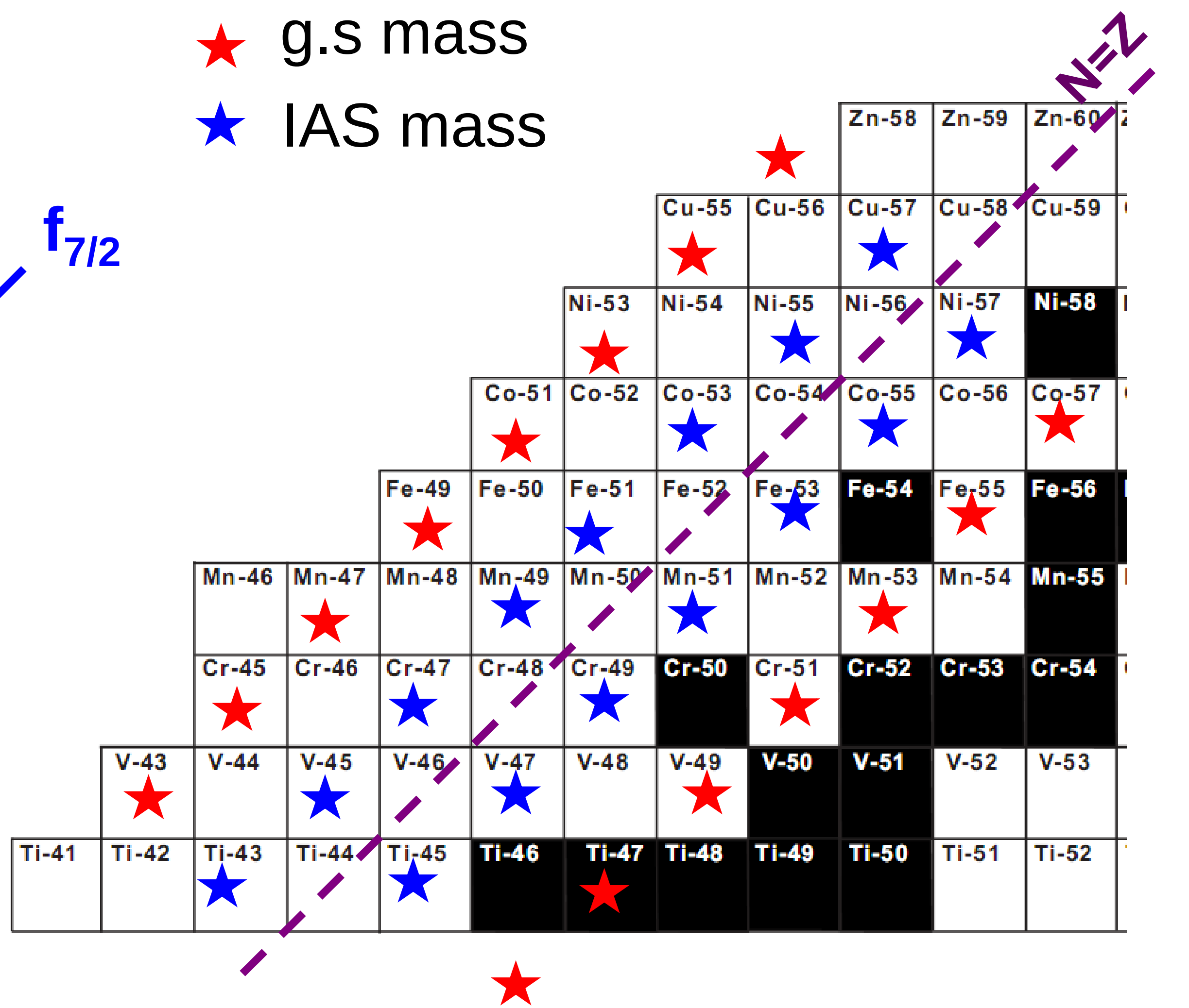
Revalidation of the Isobaric Multiplet Mass Equation
M. C. Pyle,1 A. García,1 E. Tatar,1 J. Cox,1 B. K. Nayak,1 S. Triambak,1 B. Laughman,1 A. Komives,1 L. O. Lamm,1
DOI: 10.1103/PhysRevLett.88.122501 (2002)

Masses of 32Ar and 33Ar for Fundamental Tests
K. Blaum,1,2,* G. Audi,3 D. Beck,2 G. Bollen,4 F. Herfurth,1 A. Kellerbauer,1 H.-J.
PhysRevLett.91.260801 (2003)

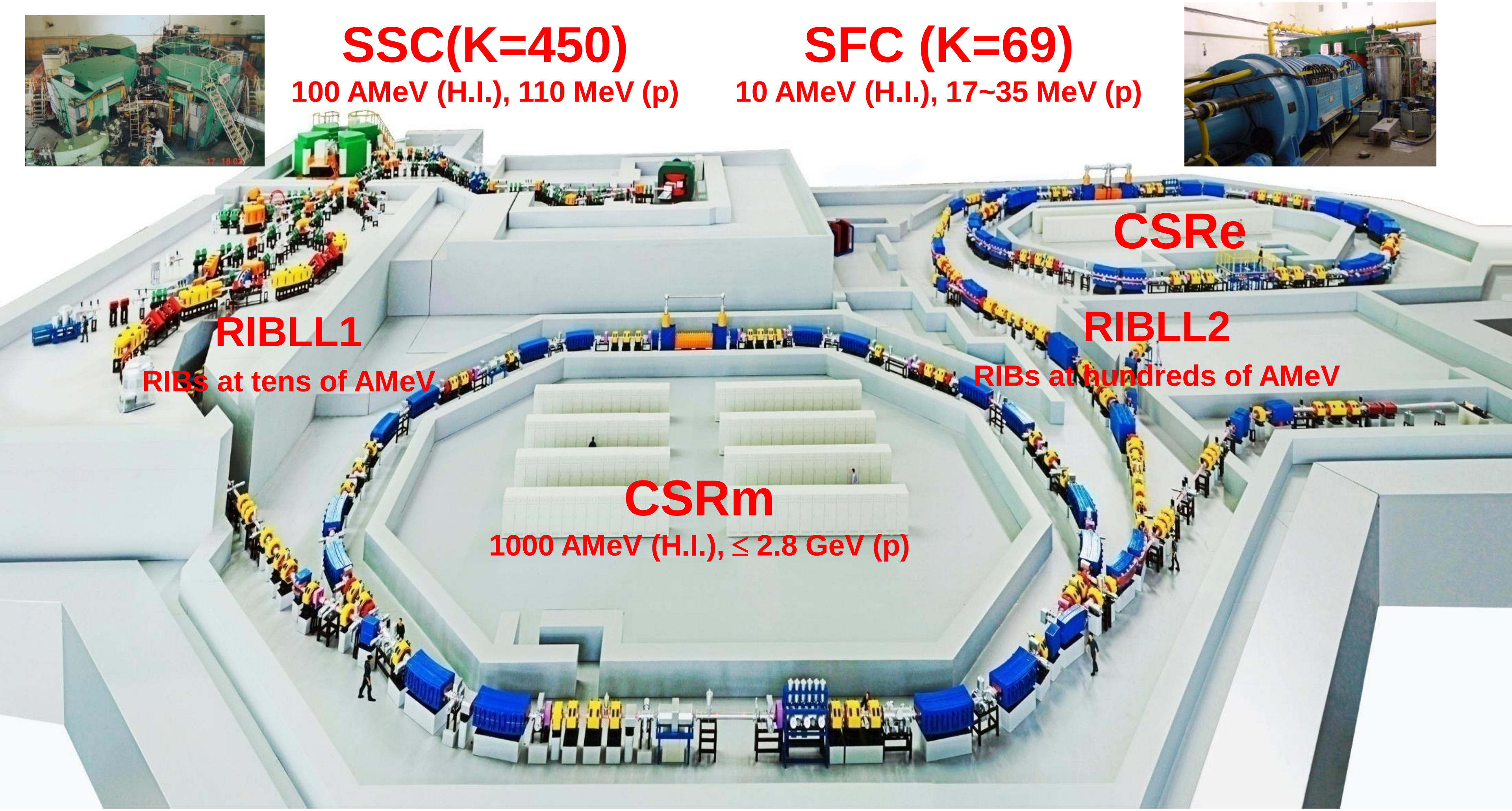
PHYSICAL REVIEW C **73**, 054313 (2006)
Mass of the lowest *T* = 2 state in 32S: A test of the isobaric multiplet mass equation
S.Triambak, A.Garcia, E.G.Adelberger, G.J.P.Hodges, D.Melconian, H.E.Swanson, S.A.Hoedl, S.K.L.Sjue, A.L.Sallaska, H.Iwamoto S.Triambak, A.Garcia, E.G.Adelberger, G.J.P.Hodges, D.Melconian, H.E.Swanson, S.A.Hoedl, S.K.L.Sjue, A.L.Sallaska, H.Iwamoto

Test the IMME in pf Shell

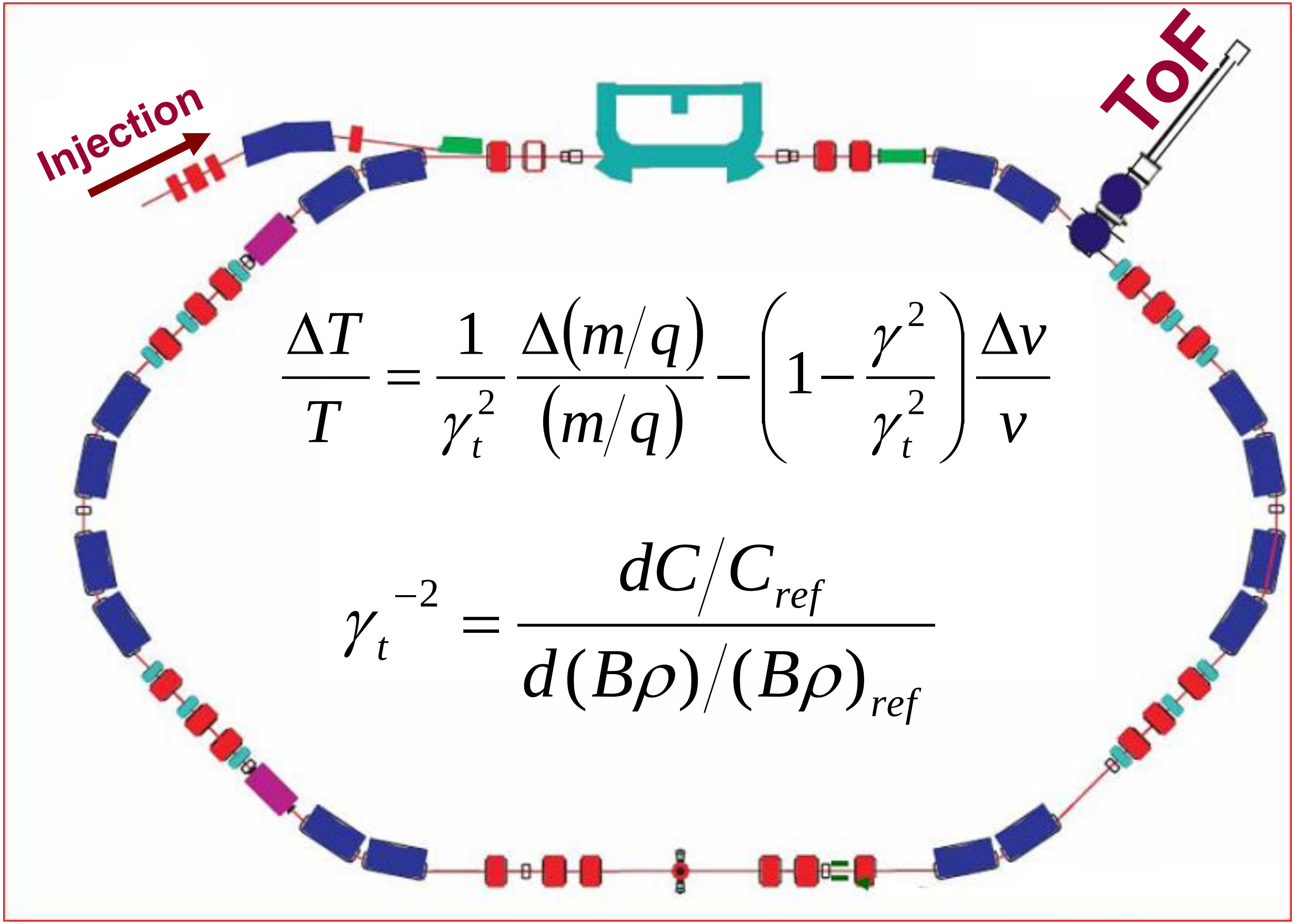




2. Mass measurements in CSRe



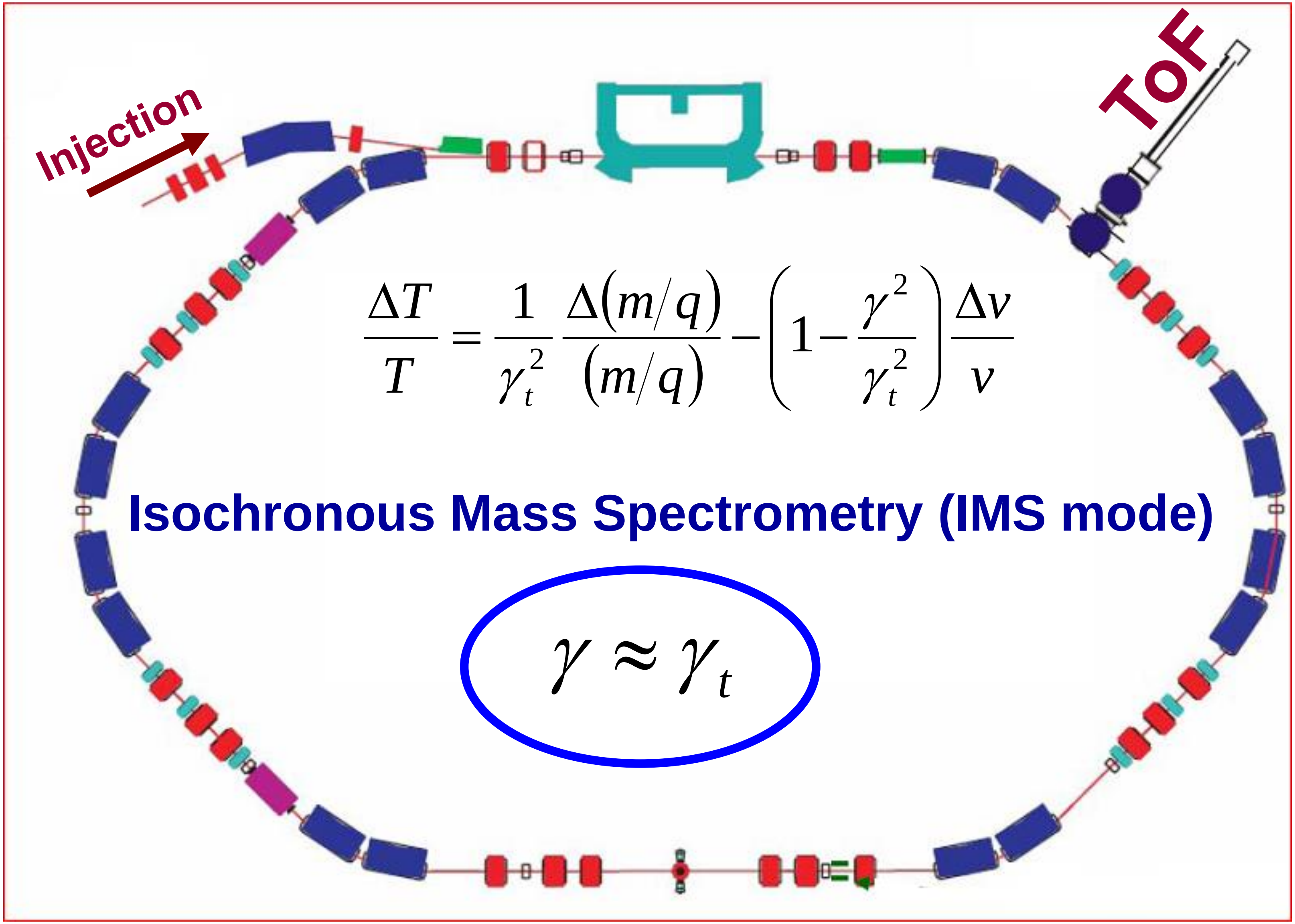
Principle of mass measurement in CSRe



$$\frac{\Delta T}{T} = \frac{1}{\gamma_t^2}\frac{\Delta(m/q)}{(m/q)} - \left(1 - \frac{\gamma^2}{\gamma_t^2}\right)\frac{\Delta v}{v}$$

$$\gamma_t^{-2} = \frac{dC/C_{ref}}{d(B\rho)/(B\rho)_{ref}}$$

Principle of mass measurement in CSRe



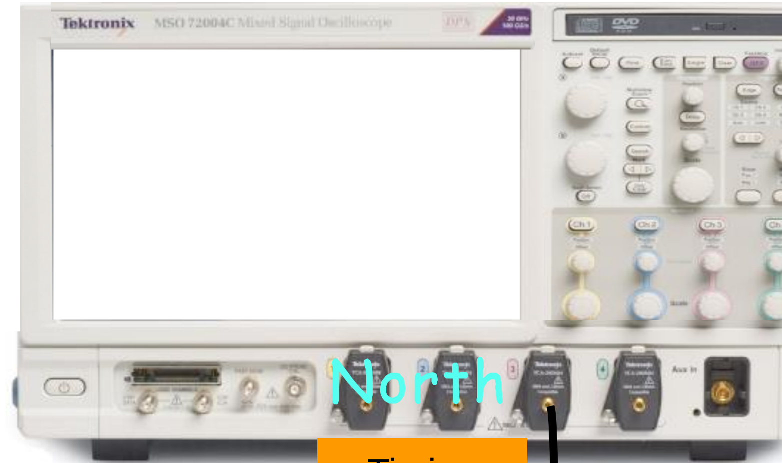
$$\frac{\Delta T}{T} = \frac{1}{\gamma_t^2}\frac{\Delta(m/q)}{(m/q)} - \left(1 - \frac{\gamma^2}{\gamma_t^2}\right)\frac{\Delta v}{v}$$

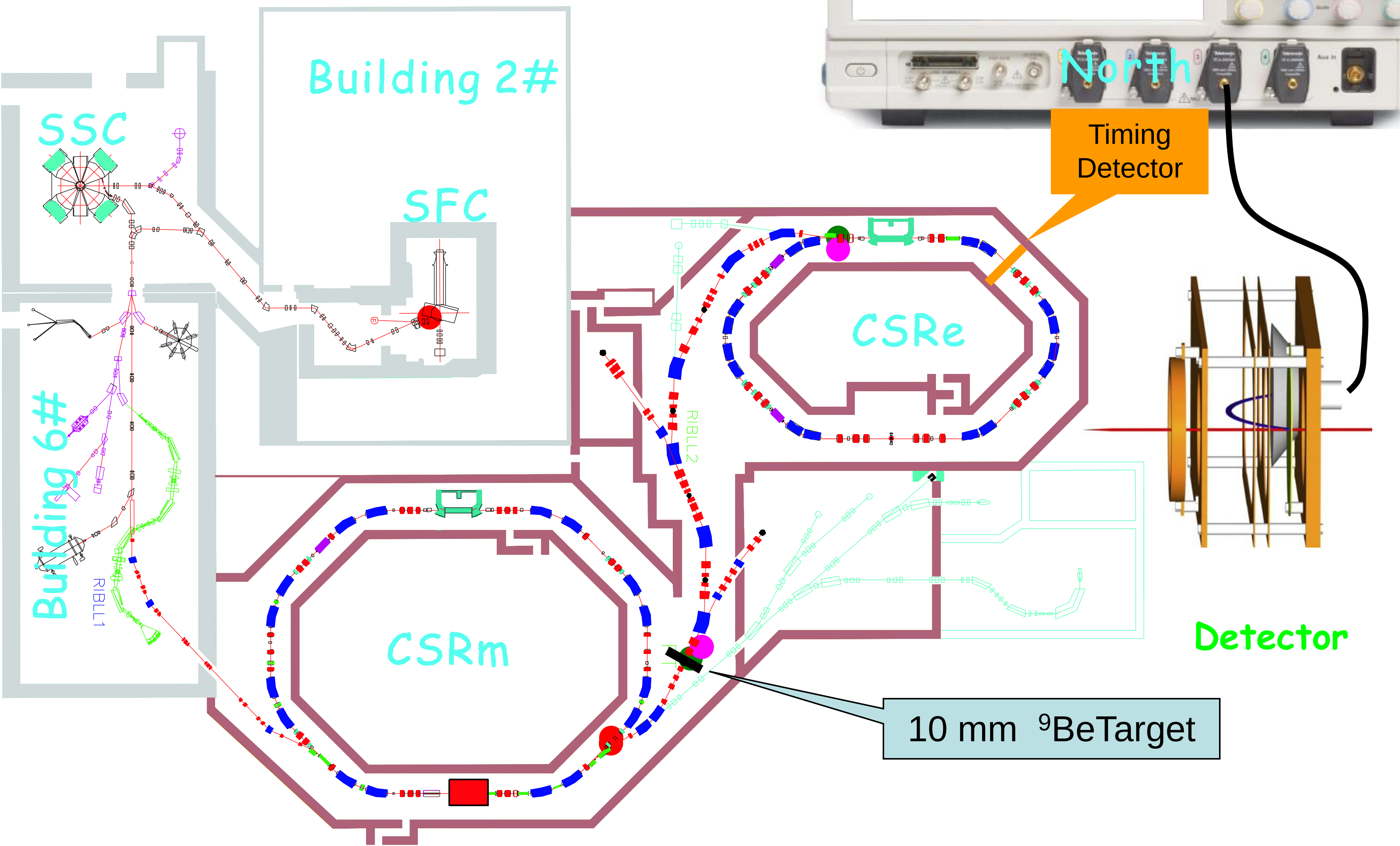
Isochronous Mass Spectrometry (IMS mode)

$$\gamma \approx \gamma_t$$

Measurement

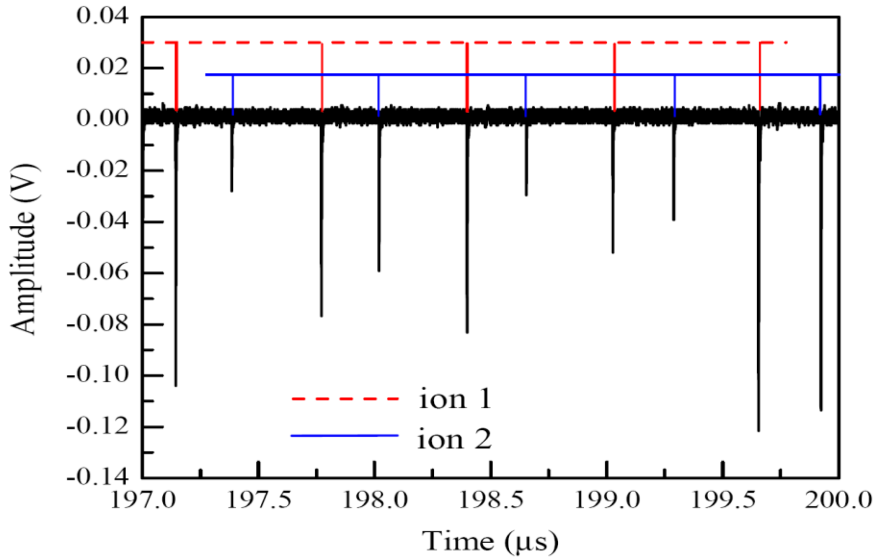
γ_t=1.395 — 460 MeV/u

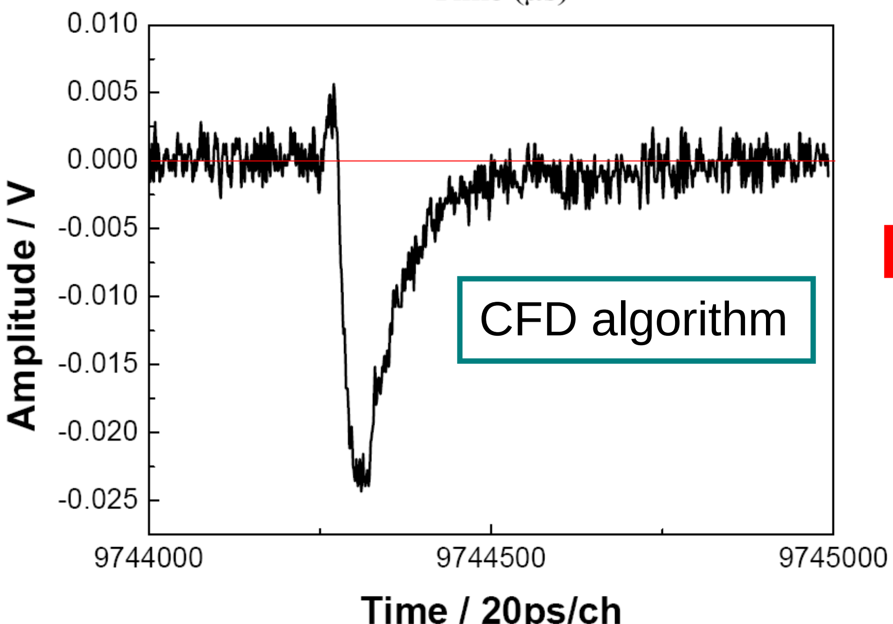




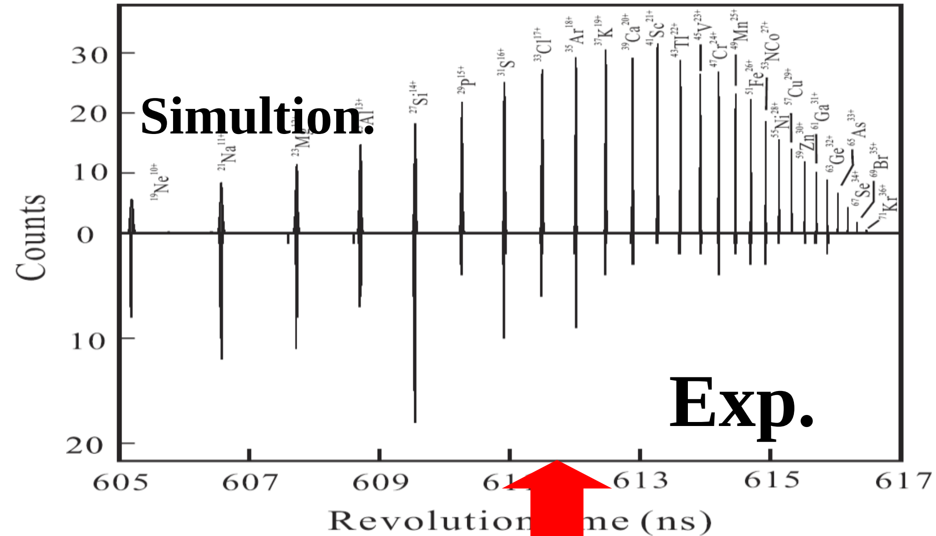
Procedure of Data analysis

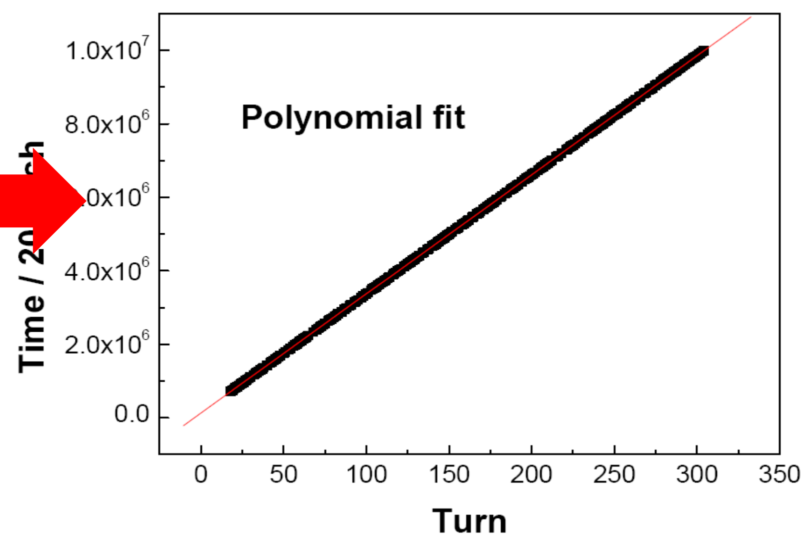
Signals in Oscilloscope



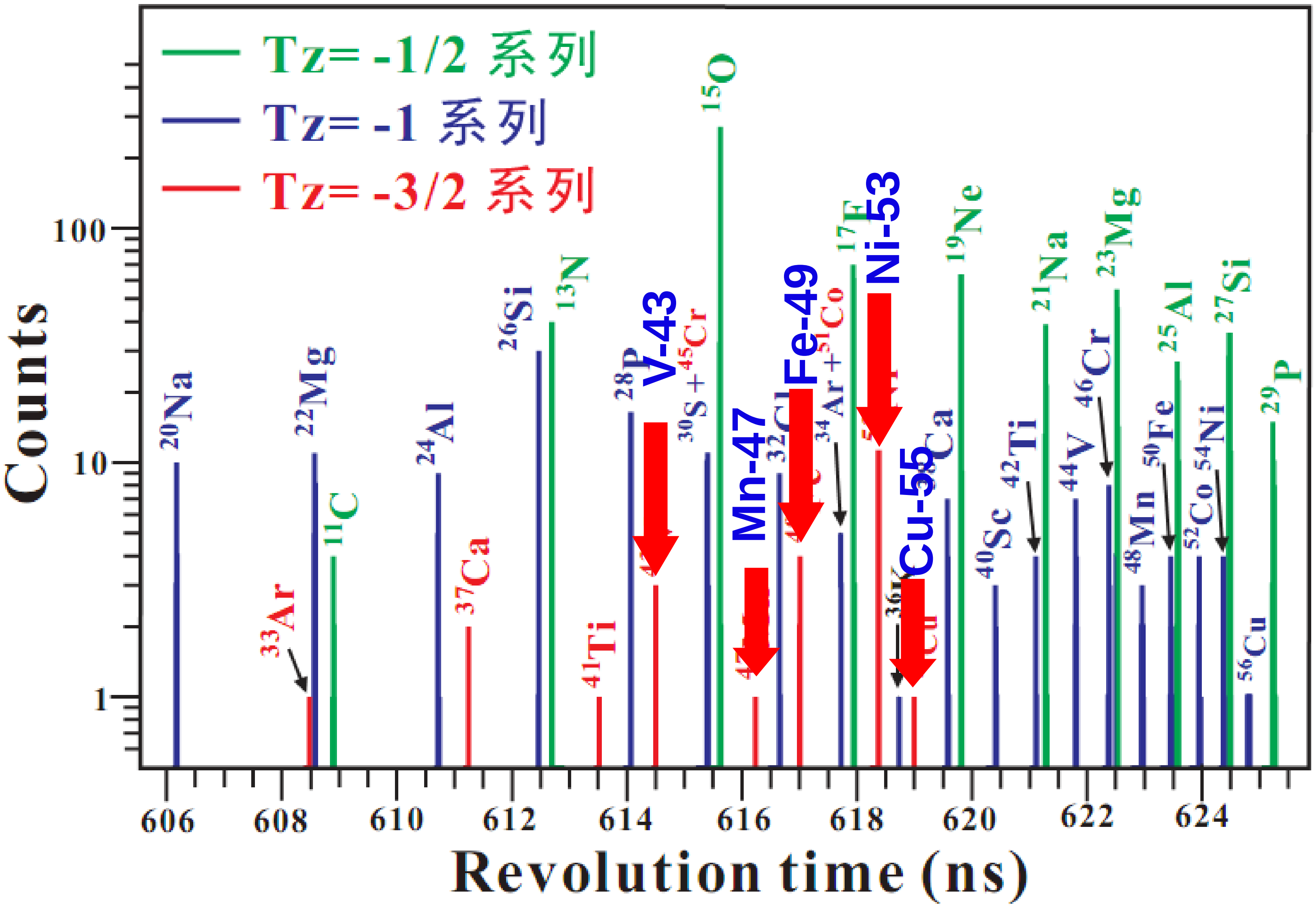


Ions Identification



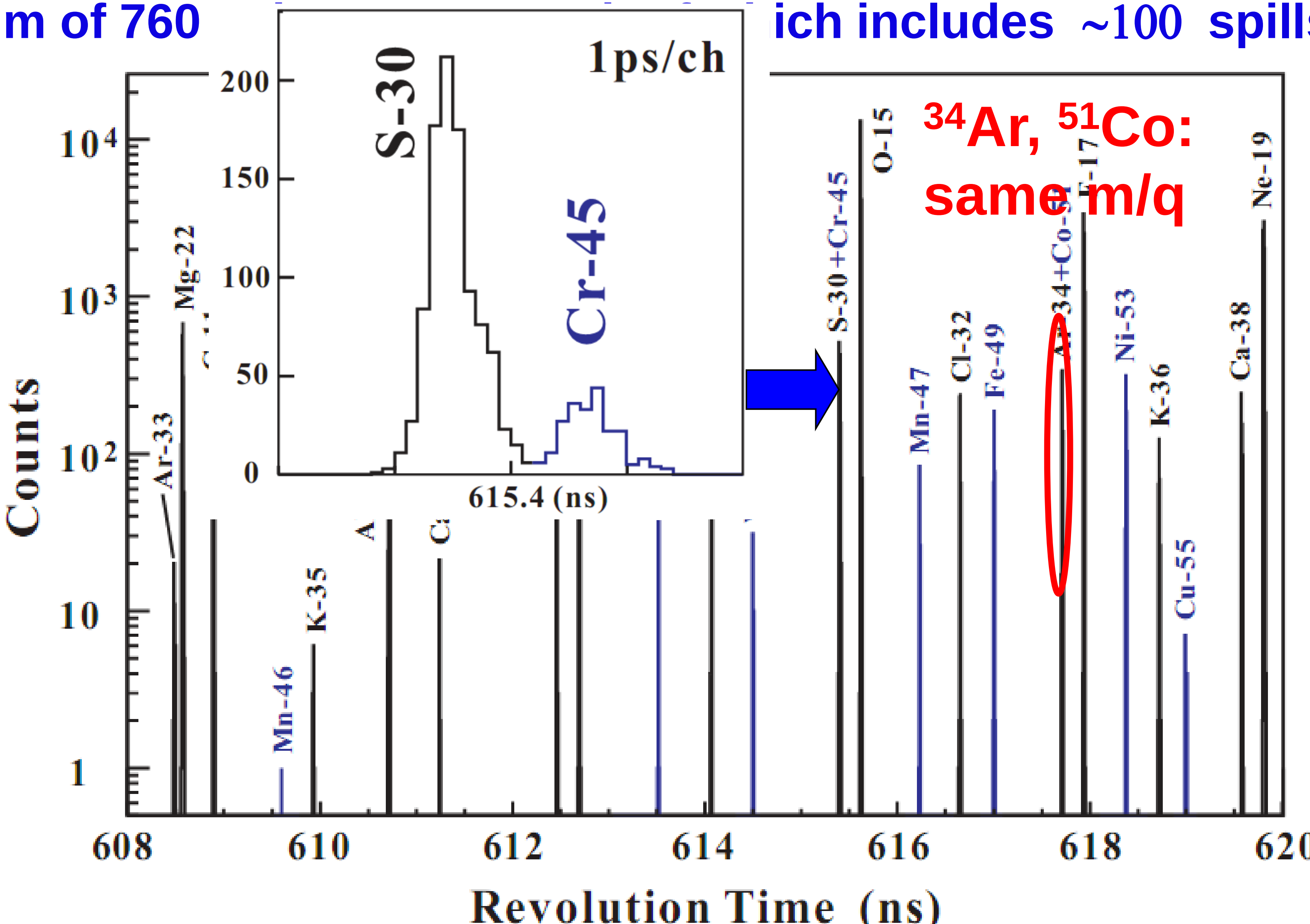


^{58}Ni beam: Revolution Time Spectrum

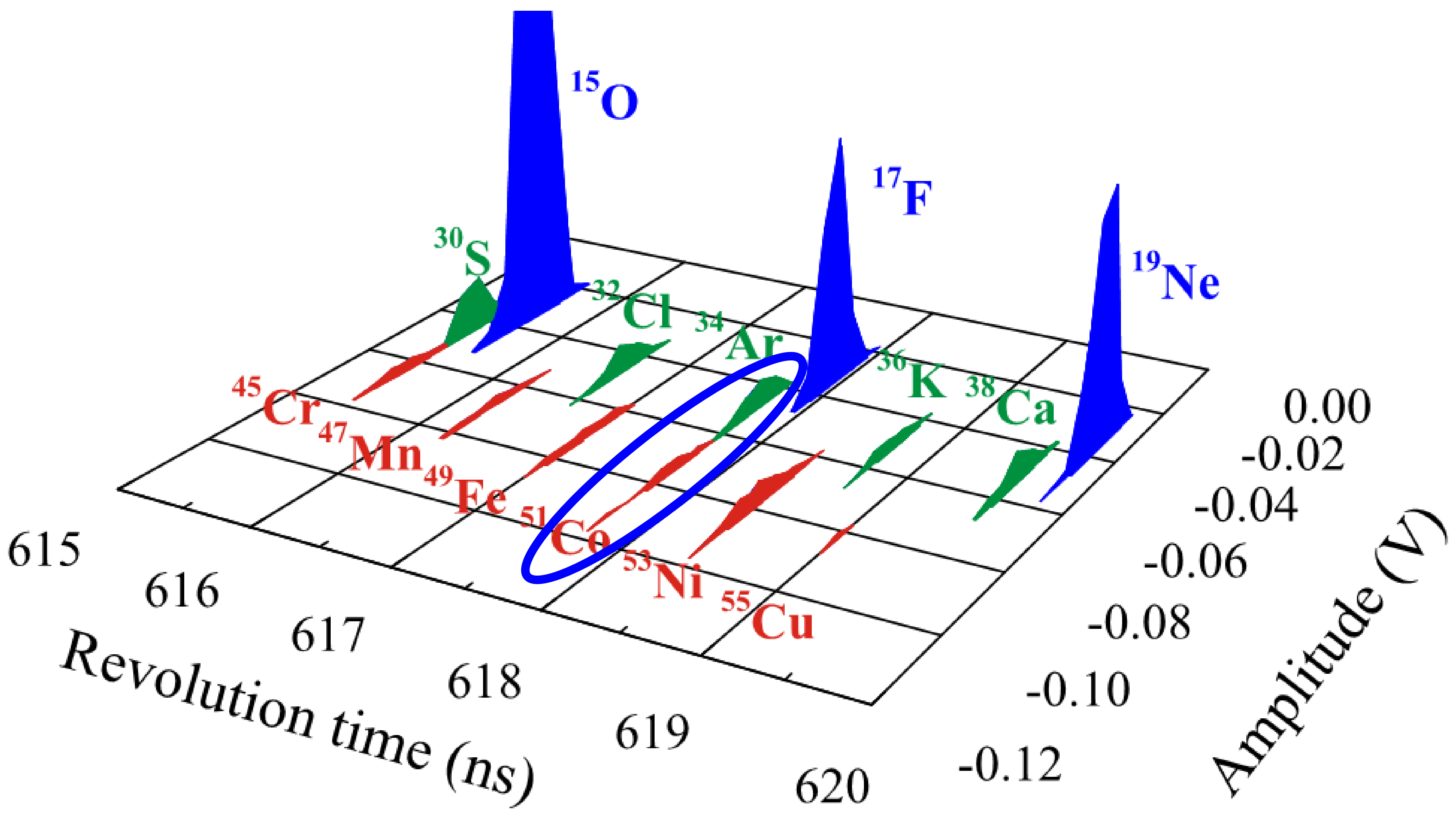


^{58}Ni beam: Revolution Time Spectrum

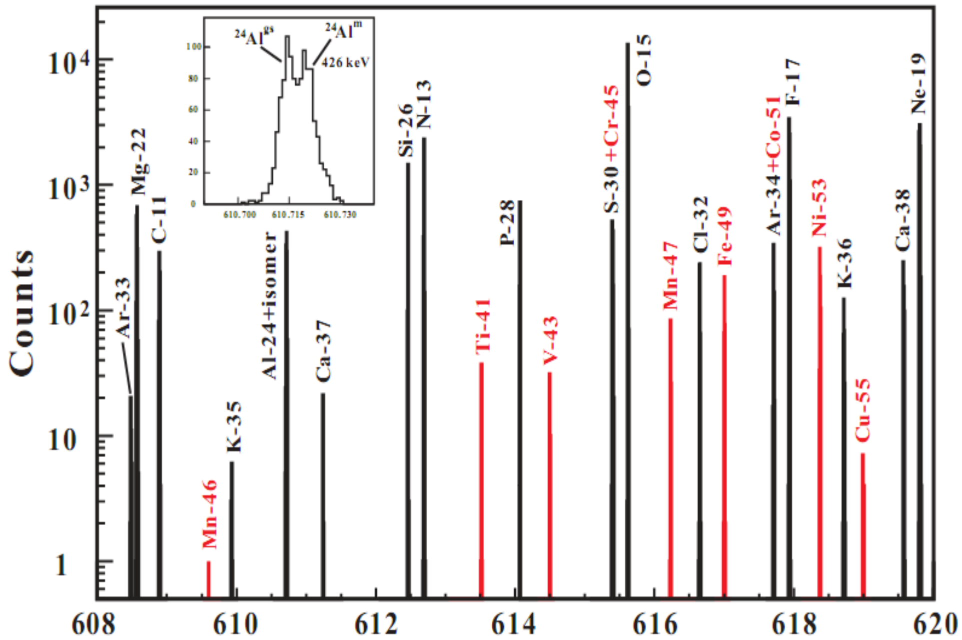
Sum of 760 ... ich includes ~100 spills



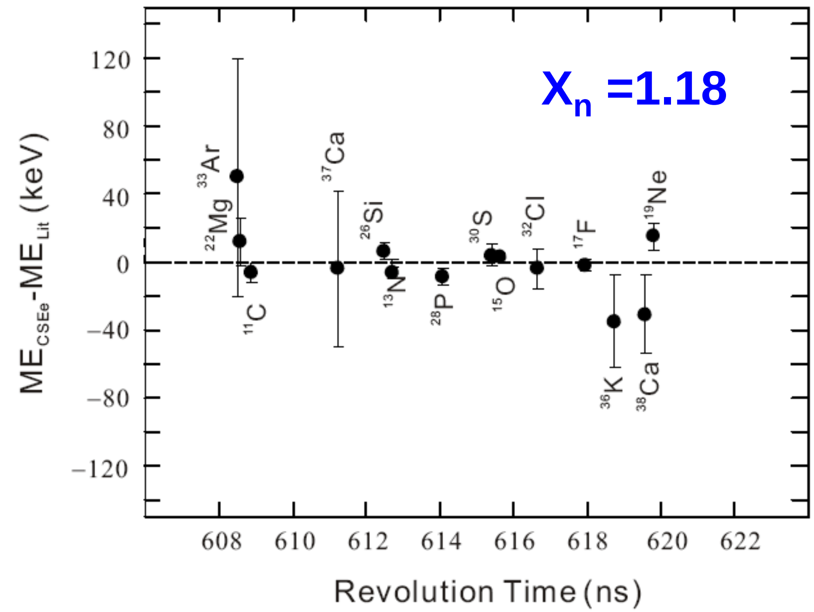
Ion-amplitude identification: ^{51}Co

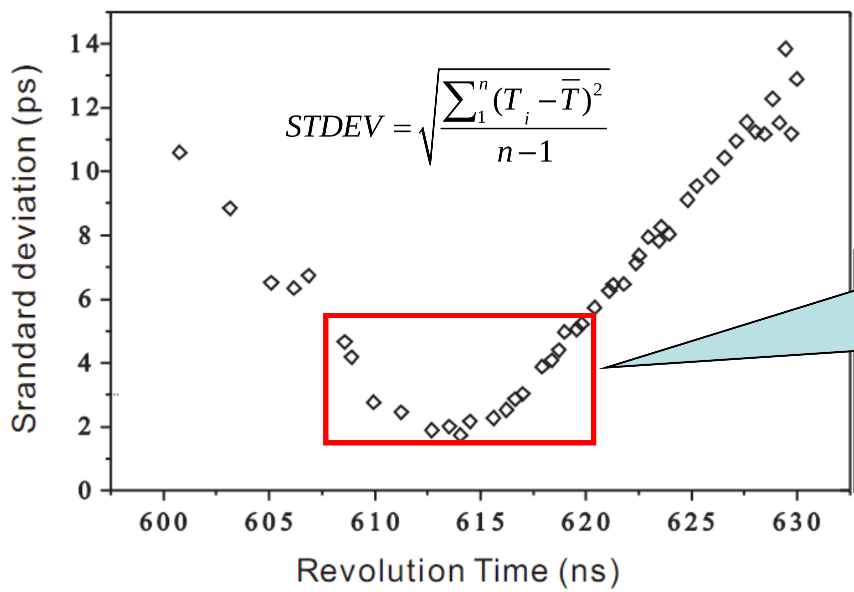


Mass excesses for the nuclides of interest (^{58}Ni beam)



M/q = a + b T + c T ^{2} + d T ^{3}





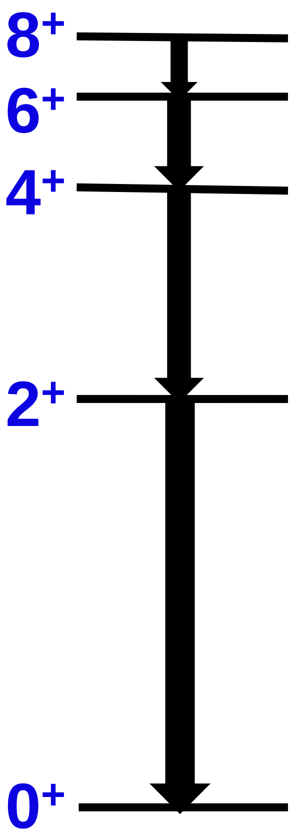
Nuclides for Calibration:

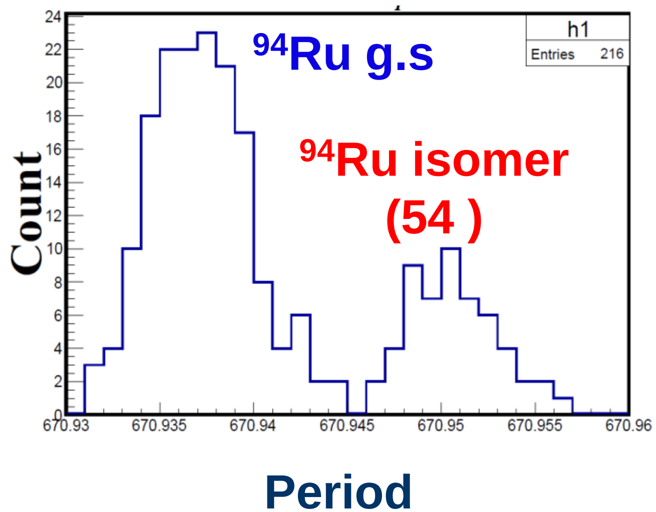
Nuclides used for M/q calibration are within a time window which is not far from the isochronous condition.

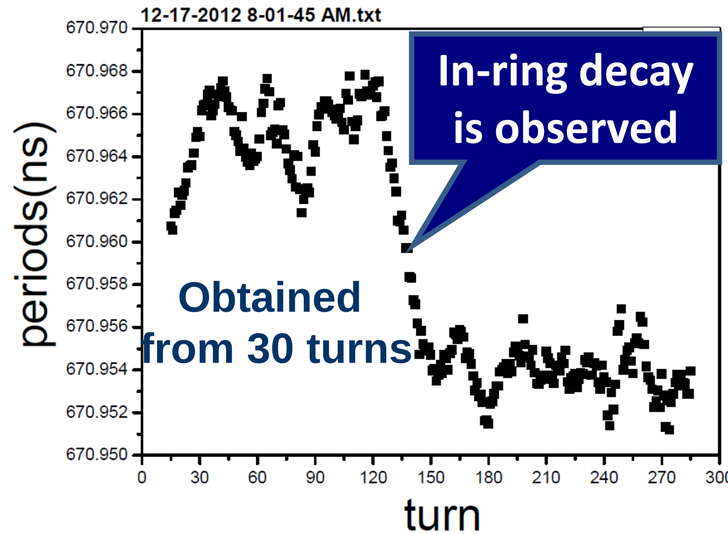
Mass and $T_{1/2}$ of short-lived Isomers in ^{94}Ru

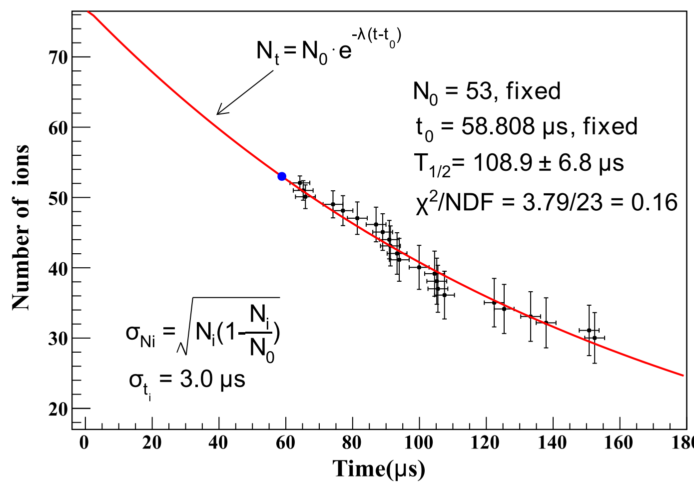
$T_{1/2}$ = 71 μs

Ex=2645 KeV









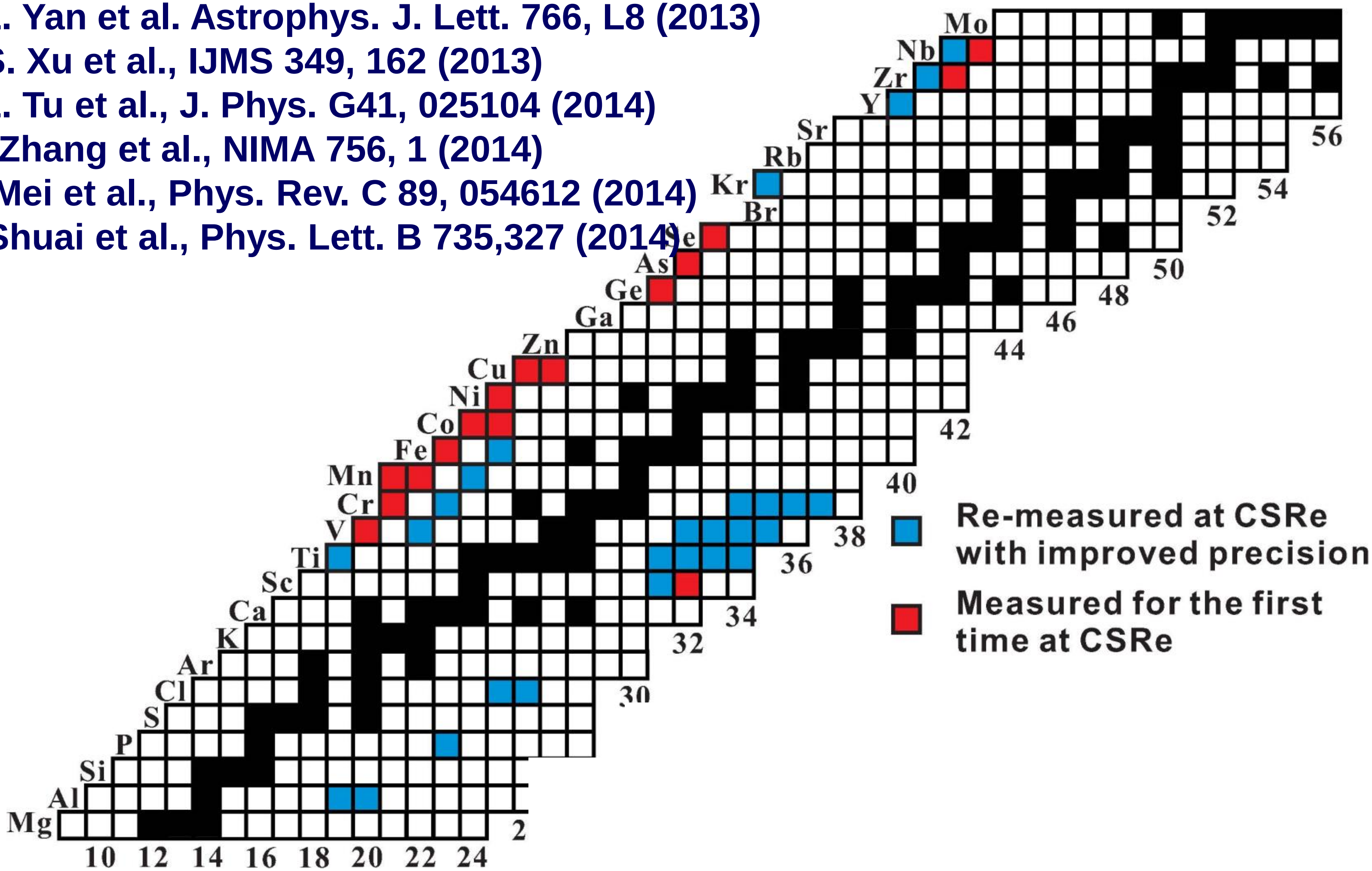
Using γ =1.3, we have partial $T_{1/2}$ = 84 (5) μs

theoretical ICC = 0.334, then we deduce $T_{1/2}$ (^{94m}Ru) = 63 (4) μs

Results from CSRe mass measurements

1. B. Mei et al., NIMA A 624, 109 (2010)
2. X.L. Tu etal., PRL 106, 112501 (2011)
3. X.L. Tu et al., NIMA A 654, 213 (2011)
4. Y.H. Zhang et al., PRL 109, 102501 (2012)
5. X.L. Yan et al. Astrophys. J. Lett. 766, L8 (2013)
6. H.S. Xu et al., IJMS 349, 162 (2013)
7. X.L. Tu et al., J. Phys. G41, 025104 (2014)
8. W. Zhang et al., NIMA 756, 1 (2014)
9. B. Mei et al., Phys. Rev. C 89, 054612 (2014)
10. P. Shuai et al., Phys. Lett. B 735,327 (2014)

Beams: ^{56}Ni, ^{78}Kr, ^{86}Kr, ^{112}Sn



3. Test the IMME in fp shell nuclides

$M(A,T,T_3)=a(A,T)+b(A,T)T_3+c(A,T)\,T_3^{\,2}$ $+\,d(A,T)T_3^{\,3}$

Atom	T_z	ME(g. s) (keV)	E_x (keV)	ME(IAS) (keV)
^{53}Ni	−3/2	−29631(25)**	0	−29631(25)
^{53}Co	−1/2	−42658.6(1.7) [26]	4393(19) [32]	−38266(19)
^{53}Fe	+1/2	−50946.7(1.7) [26]	4250(3) [31]	−46696.7(3.4)
^{53}Mn	+3/2	−54689.0(6) [26]	0	−54689.0(6)

Quadratic fit: $\chi^2/n = 13.6$

Cubic fit: $d = 39(11)$

Atom	T_z	ME(g. s) (keV)	E_x (keV)
^{49}Fe	−3/2	−24751(24)**	0
^{49}Mn	−1/2	−37615(24) [26]	4809(2
^{49}Cr	+1/2	−45333(2) [26]	4764(5
^{49}V	+3/2	−47961.0(9) [26]	0

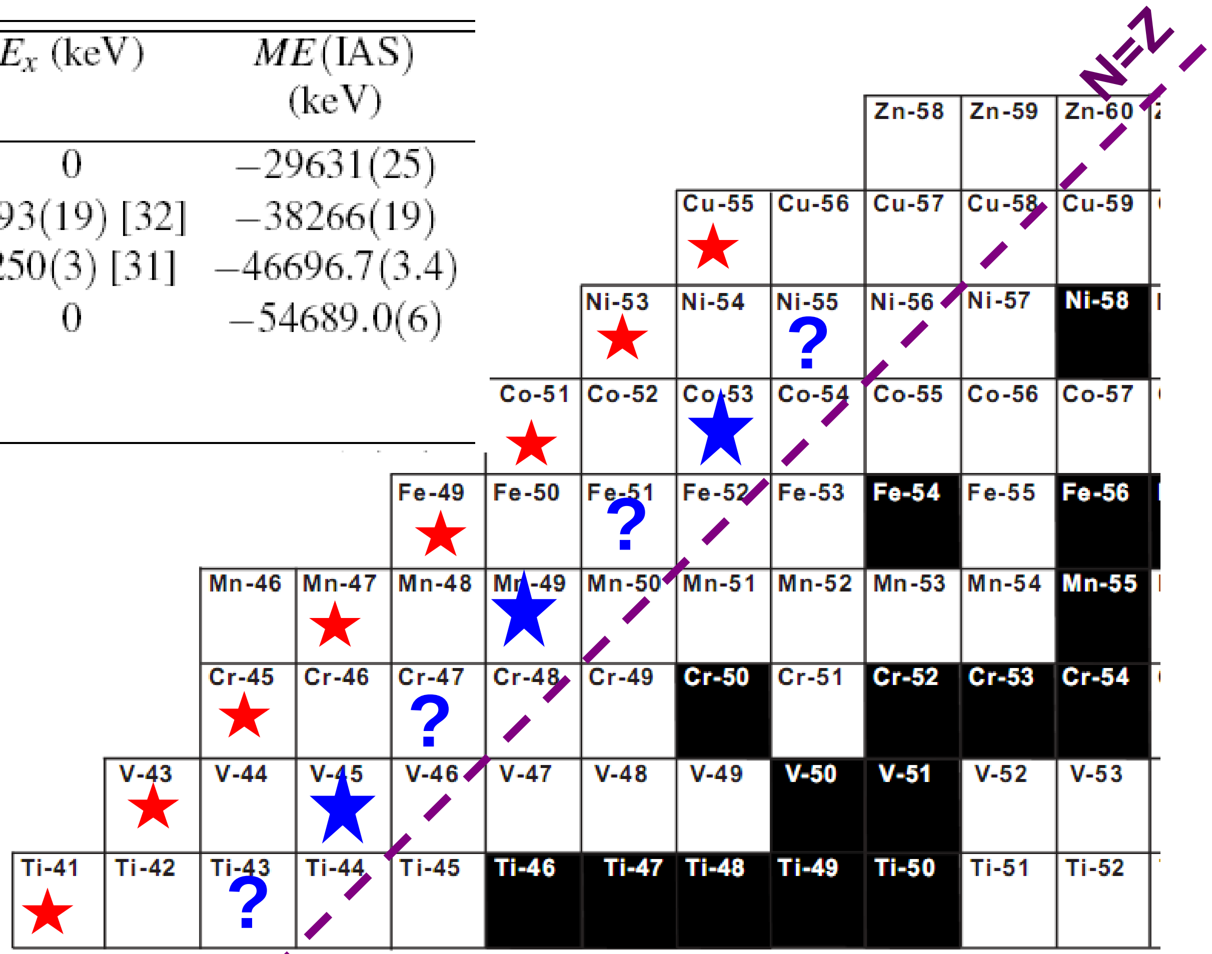
Quadratic fit: $\chi^2/n = 2.2$

Cubic fit: $d = 13.2(8.7)$

Atom	T_z	ME(g. s) (keV)	E_x (keV)
^{45}Cr	−3/2	−19515(35)**	0
^{45}V	−1/2	−31880(17) [26]	4791(1
^{45}Ti	+1/2	−39008.3(8) [26]	4723(7
^{45}Sc	+3/2	−41070.4(6) [26]	0

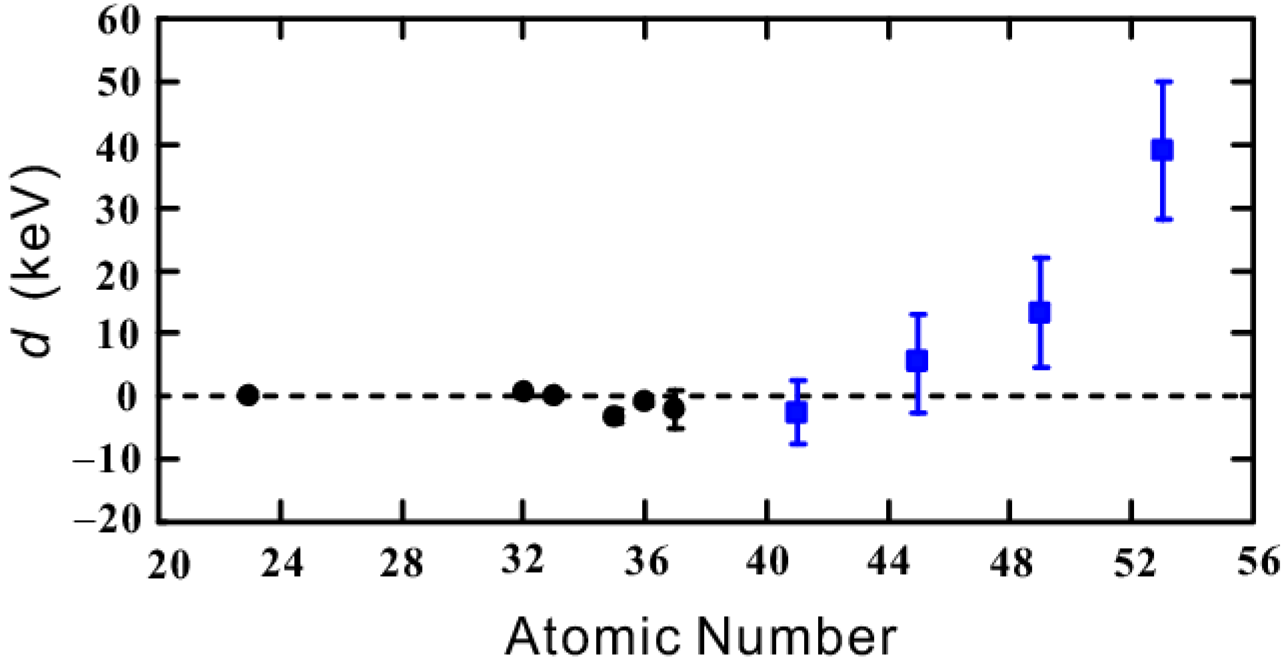
Quadratic fit: $\chi^2/n = 0.5$

Cubic fit: $d = 5.4(7.9)$



Test the IMME in fp shell nuclei

$$M(T,A,T_3) = a(T,A,) + b(T,A)T_3 + c(T,A)T_3^2 + d(T,A)T_3^3$$



d **coeficients increase gradually up to A=53 for which *d* is 3.5σ deviated from zero.**

Shell model calculations

TABLE III: $b_{3,1}$, $b_{3,3}$ and d coefficients for $A = 53$.

	b_{33} (keV)	b_{31} (keV)	d (keV)
Experiment	8353(8)	8431(19)	39(12)
Theory ($f_{7/2}$ model)	8366	8365	-0.5
Theory (full pf model)	8292	8290	-1.0

The second result is obtained for the full ($f_{7/2}$, $f_{5/2}$, $p_{3/2}$, $p_{1/2}$) (pf) model space. The Hamiltonian is composed of the GPFX1A isospin conserving Hamiltonian [34–36] plus the Ormand-Brown (OB) isospin non-conserving Hamiltonian [37]. Details of the GPFX1A part and its applications to many pf shell data are given in Refs. [34–36]. The OB part was

Mass Excesses

uncertainty:	0.6 keV	25 keV	3. 4 keV	19 keV
	^{53}Mn gs	^{53}Ni gs	^{53}Fe IAS	^{53}Co IAS

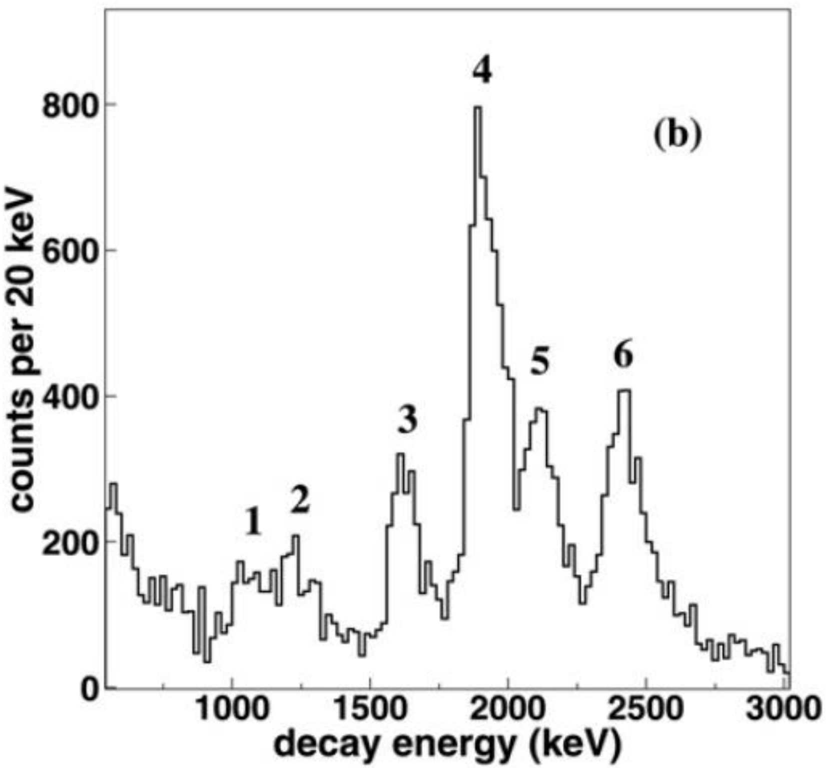
$$d = \frac{1}{6}\{[\mathrm{ME}_{(+\frac{3}{2})} - \mathrm{ME}_{(-\frac{3}{2})}] - 3[\mathrm{ME}_{(+\frac{1}{2})} - \mathrm{ME}_{(-\frac{1}{2})}]\}.$$

More attention should be paid to the excitation Energies of IAS's in ^{53}Co & ^{53}Fe since the errors are three times as important as those of the g.s masses of ^{53}N and ^{53}Mn for an evaluation of *d* & in checking the validity of the IMME.

Previous results

Result from: C. Dossat et al., Nucl. Phys. A792 (2007) 18-86

Beta-delayed proton



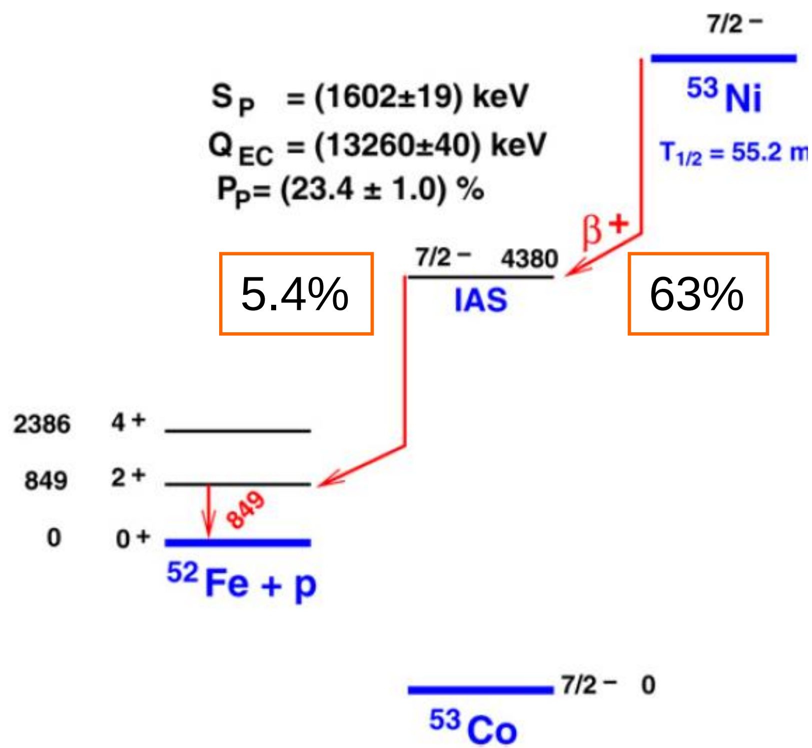
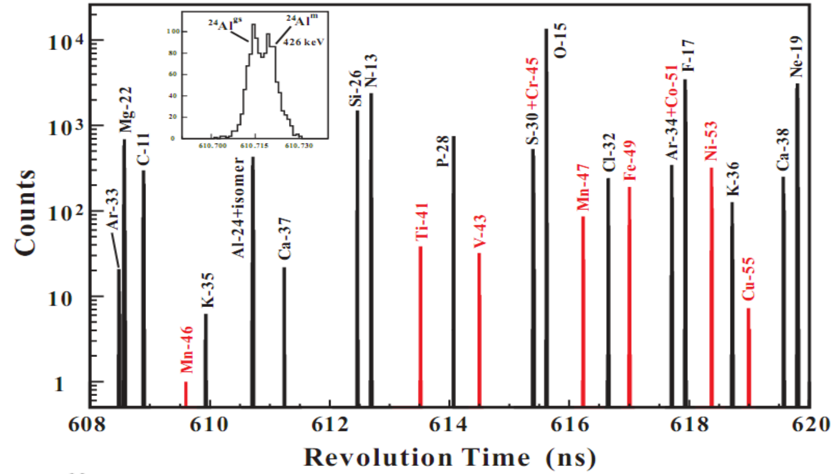


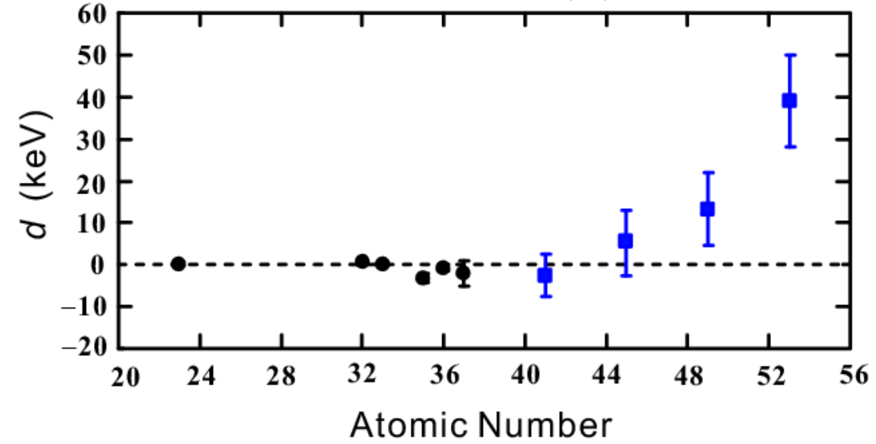
Fig. 41. Partial decay scheme for the β decay of ^{53}Ni.

4. Summary

1) CSRe IMS + interpolation Masses of T_3= -3/2 nuclei measured.



2) Breakdown of quadratic form of IMME found for A=53, T=3/2 quartet



3) More precise mass measurements of (^{53}Ni; gs) and (^{53}Co; IAS) are needed in order to check the validity of IMME in the pf-shell nuclides.

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