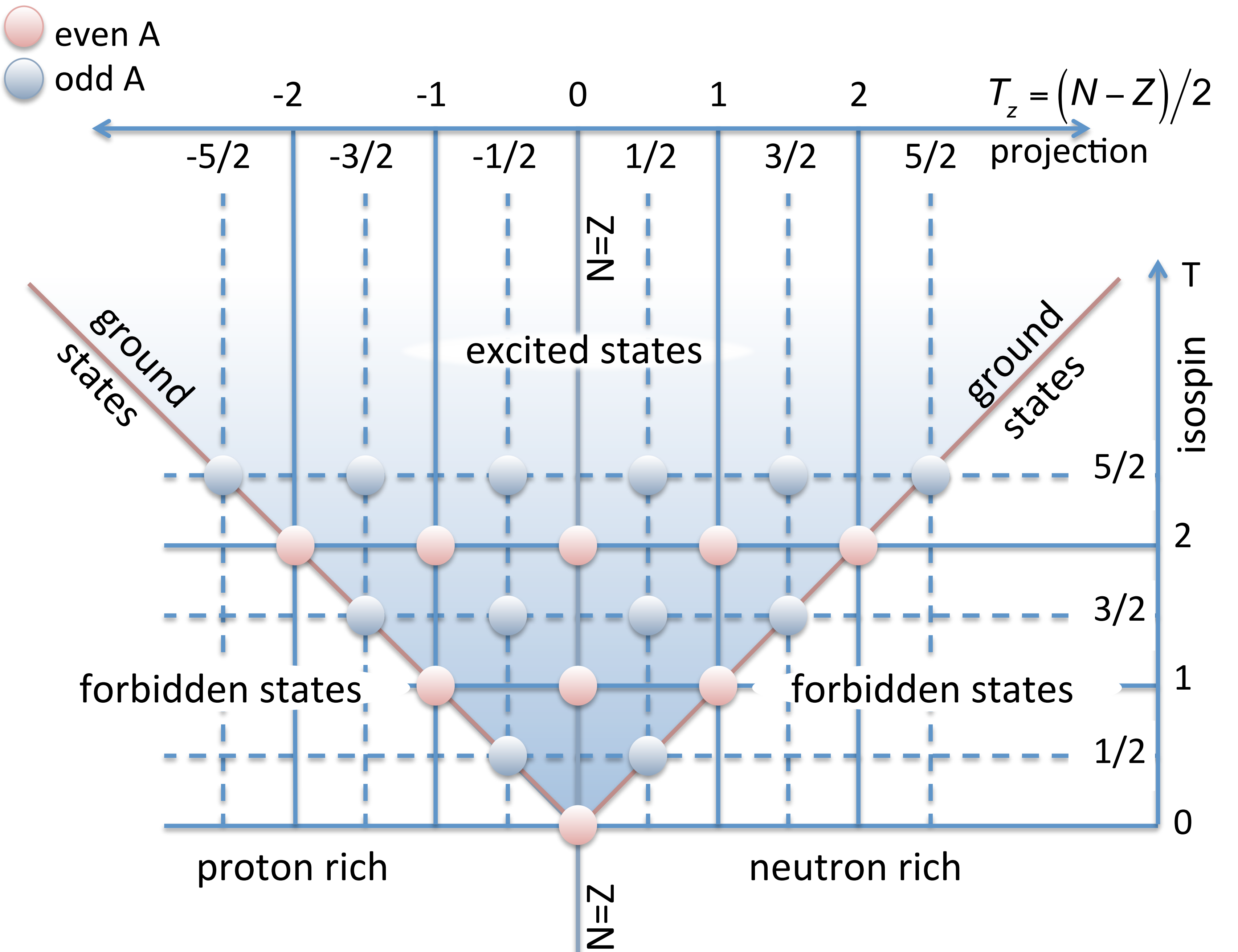
Isospin Symmetry of the A=46 T=1 triplet studied with AGATA

A Boso, S.A.Milne, M.A.Bentley, F. Recchia, S.M.Lenzi, M.Labiche *et al*.

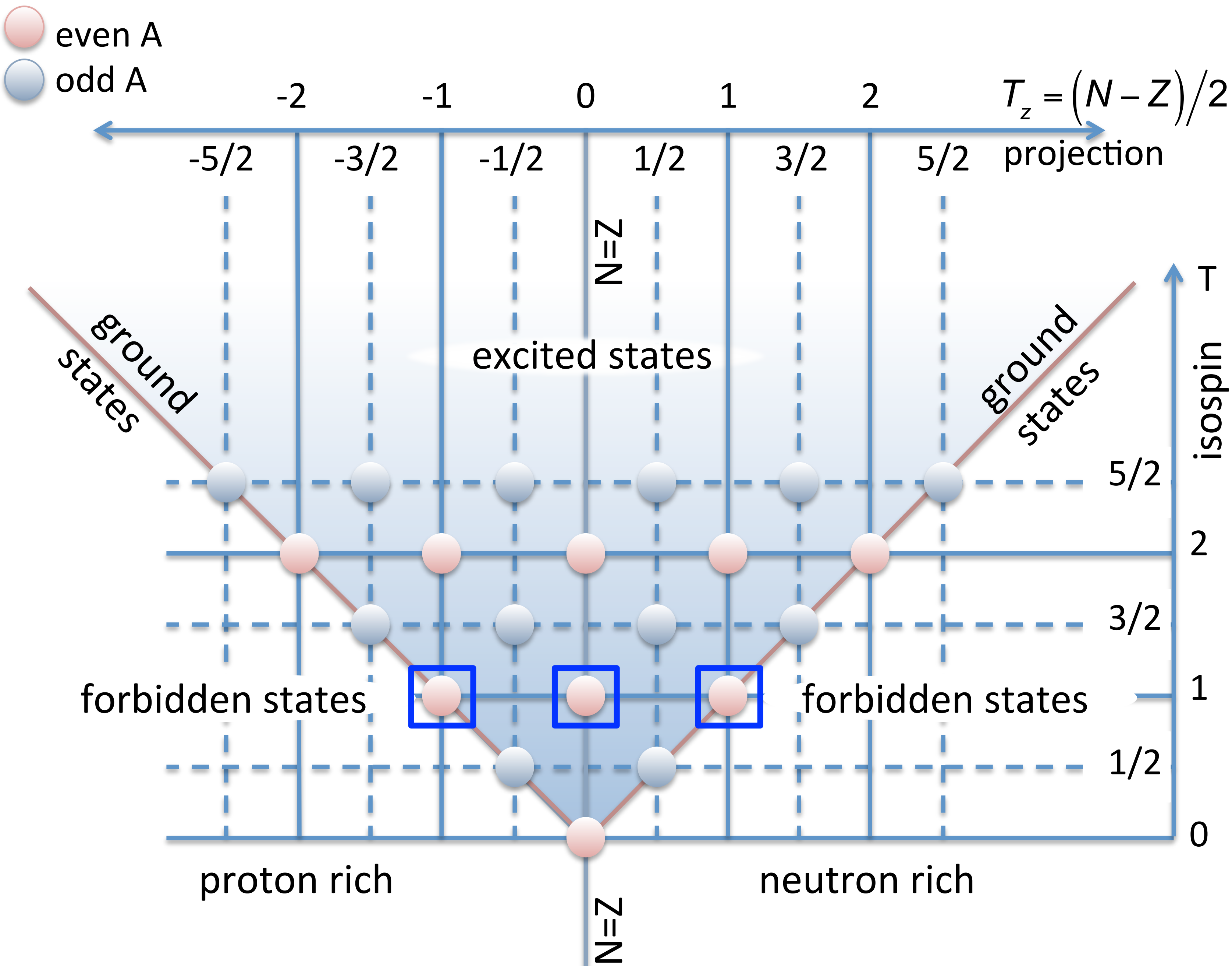
(on behalf of AGATA, PRESPEC and LYCCA Collaborations)

- Introduction
- T=1 triplets and Isospin symmetry
- AGATA S434 experiment
- Coulex of ^{46}Cr and ^{46}Ti 2^+_1 states
- Lifetimes of ^{46}V and ^{46}Ti 2^+_1 states - stretched target method
- Test of one of the fundamental rules of isospin

Isospin Symmetry and T=1 Triplets

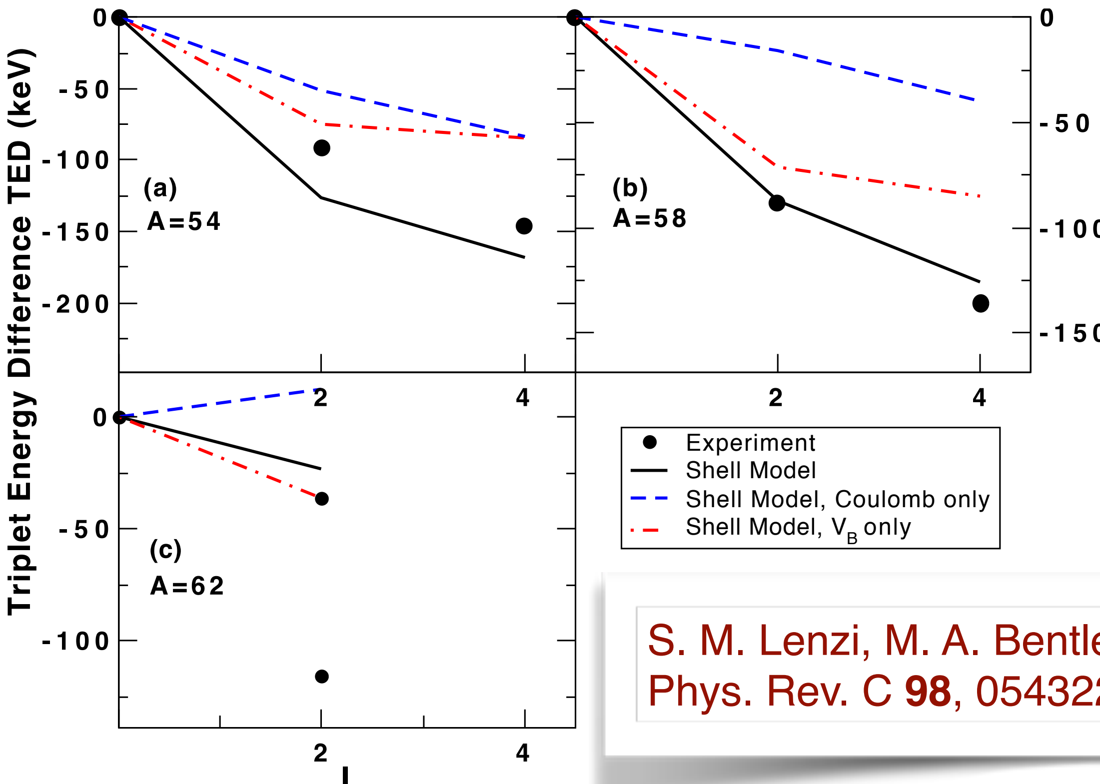


Isospin Symmetry and T=1 Triplets

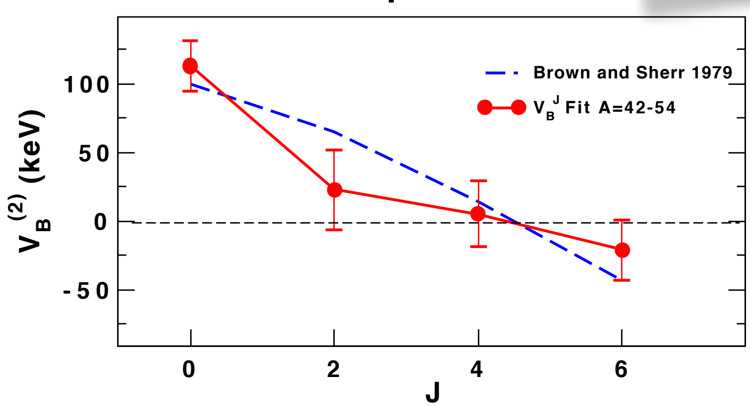


T=1 Triplet Energy Differences

$$TED(\alpha) = E^*_{J,T,T_z=-1} + E^*_{J,T,T_z=+1} - 2E^*_{J,T,T_z=0}$$



S. M. Lenzi, M. A. Bentley, R. Lau, and C. Aa. Diget
Phys. Rev. C **98**, 054322 (2018)



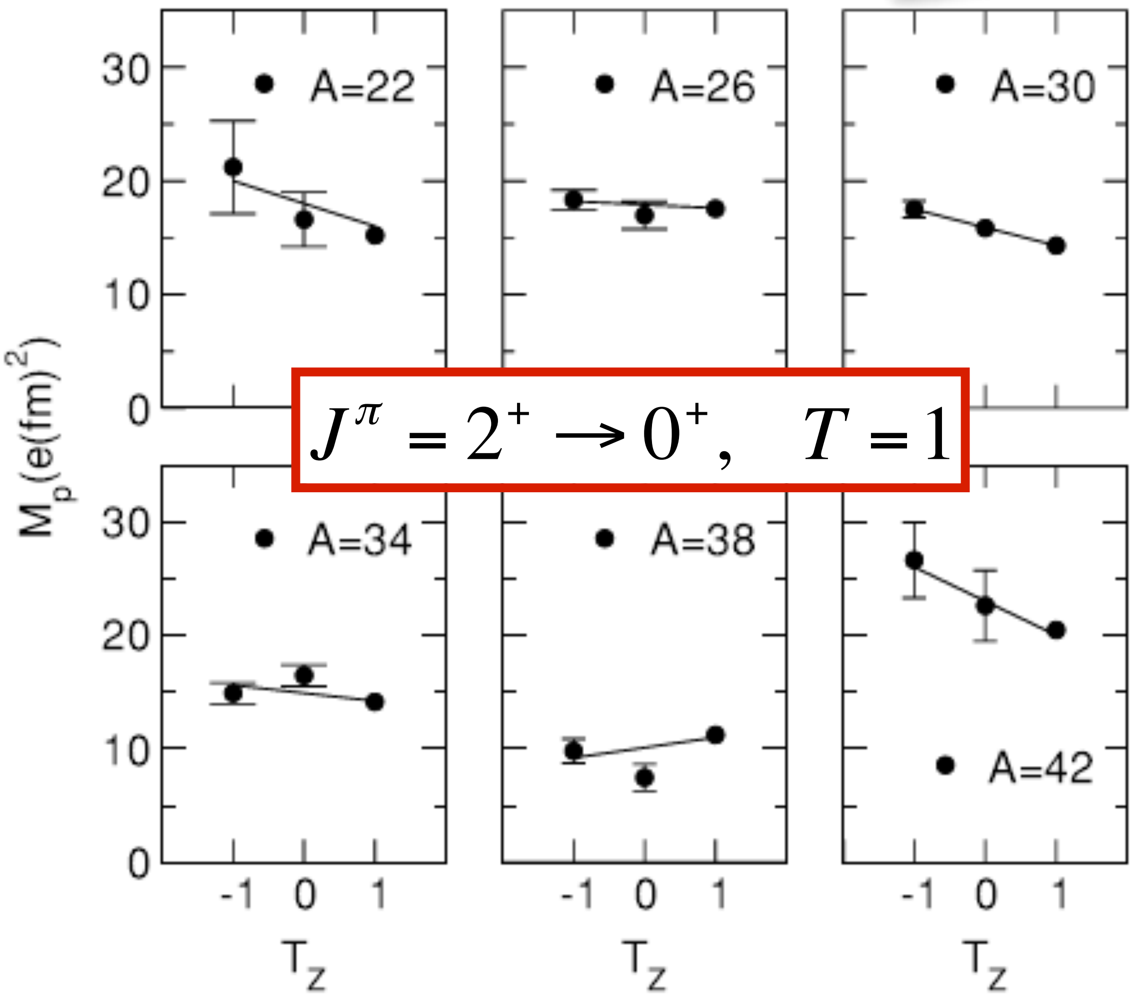
- **Isospin Symmetry-breaking corrections**
- Strong *J*-dependent terms
- Consistent with NN scattering data
- np interaction ~ 2-3% stronger than nn or pp.

Systematics of B(E2)s in Isobaric Triplets

Proton matrix element for isospin triplets:

$$M_p(T_z) = \frac{1}{2}[M_0 - T_z M_1^{T_z=1}]$$

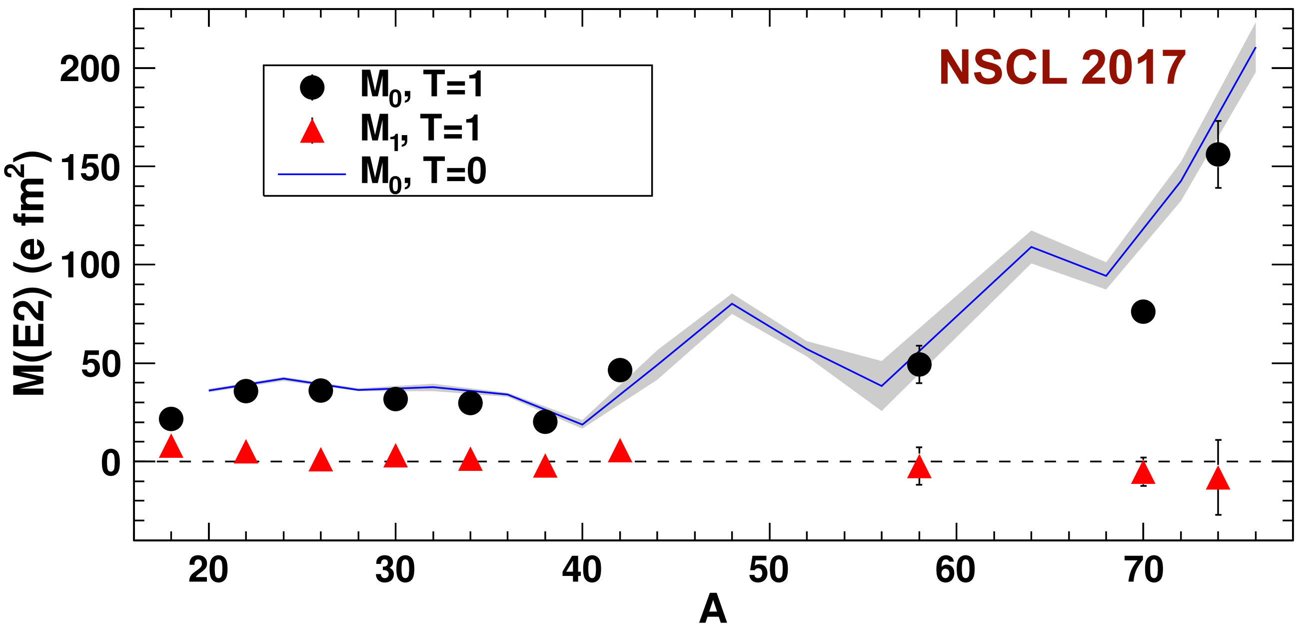
Isoscalar + isovector



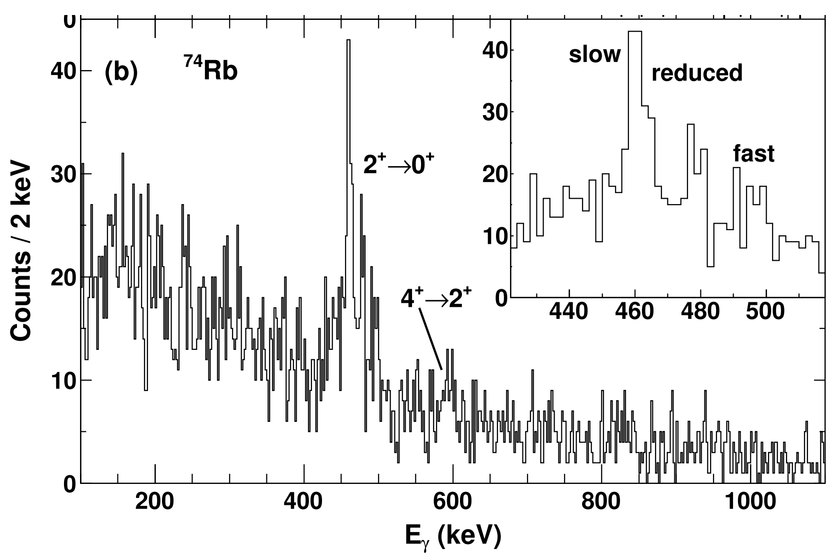
Prados Estavez et al., PRC75, 014309

2007 Compilation

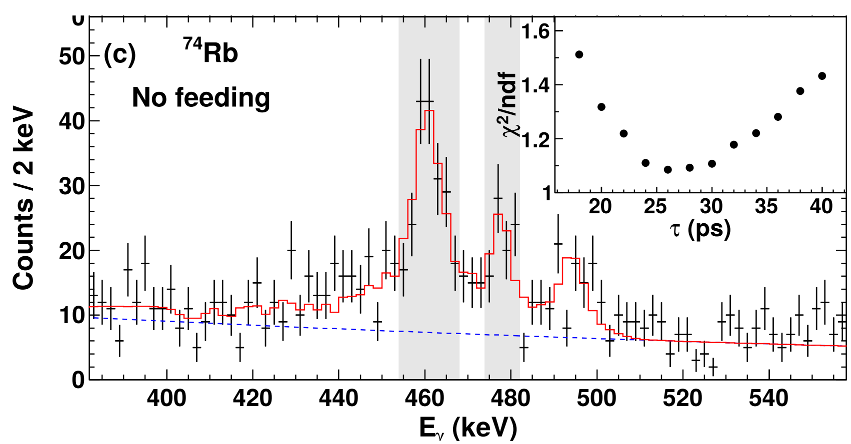
B(E2)s in odd-odd members of isobaric triplets



C Morse et al., PLB787,198 (2017)

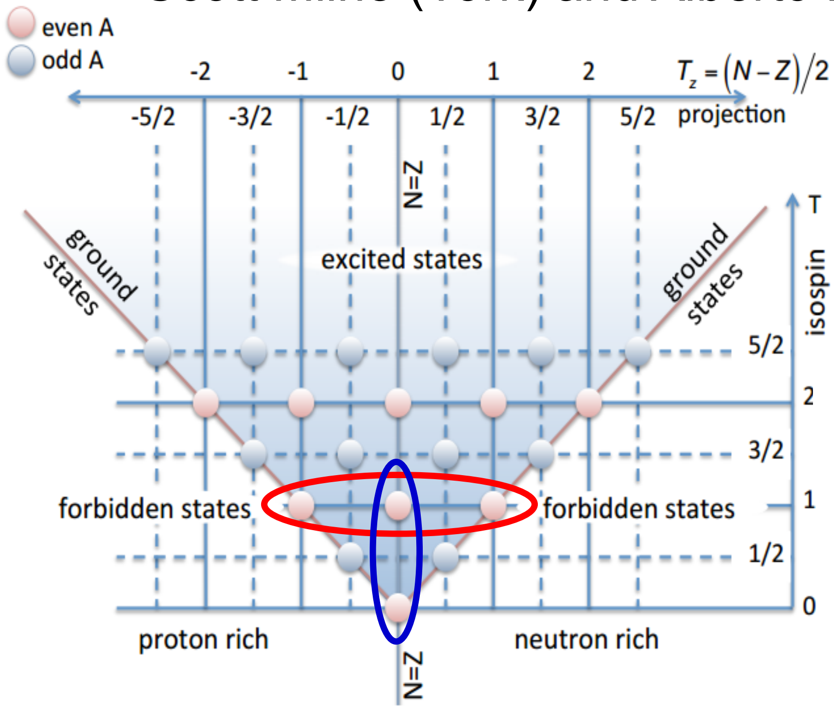


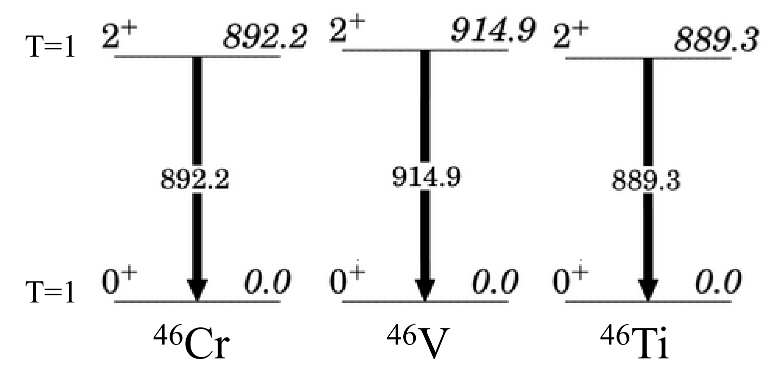
Triplex plunger NSCL (Be-Ta-Ta)



Isospin symmetry in the A=46 Isobaric Triplet

AGATA-PRESPEC Experiment, April 2014 - analysis by:
Scott Milne (York) and Alberto Boso (Padova)





B(E2) (e^2fm^4): 186(40) 188(24) 193(2)

Literature values

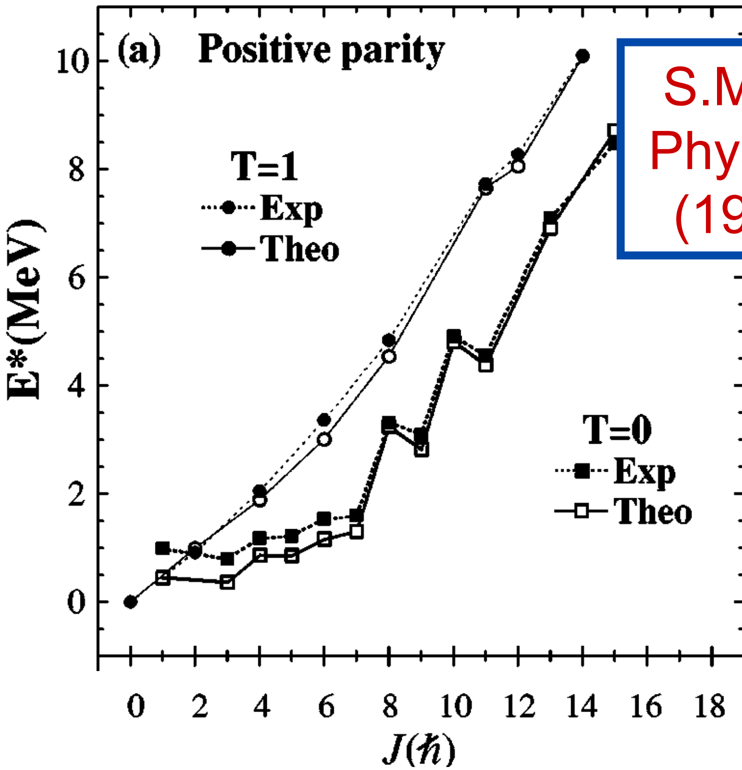
Test linearity of E2 matrix element with T_z - isospin selection rule

$$M_p(T_z) = \frac{1}{2}[M_0 - T_z M_1^{T_z=1}]$$

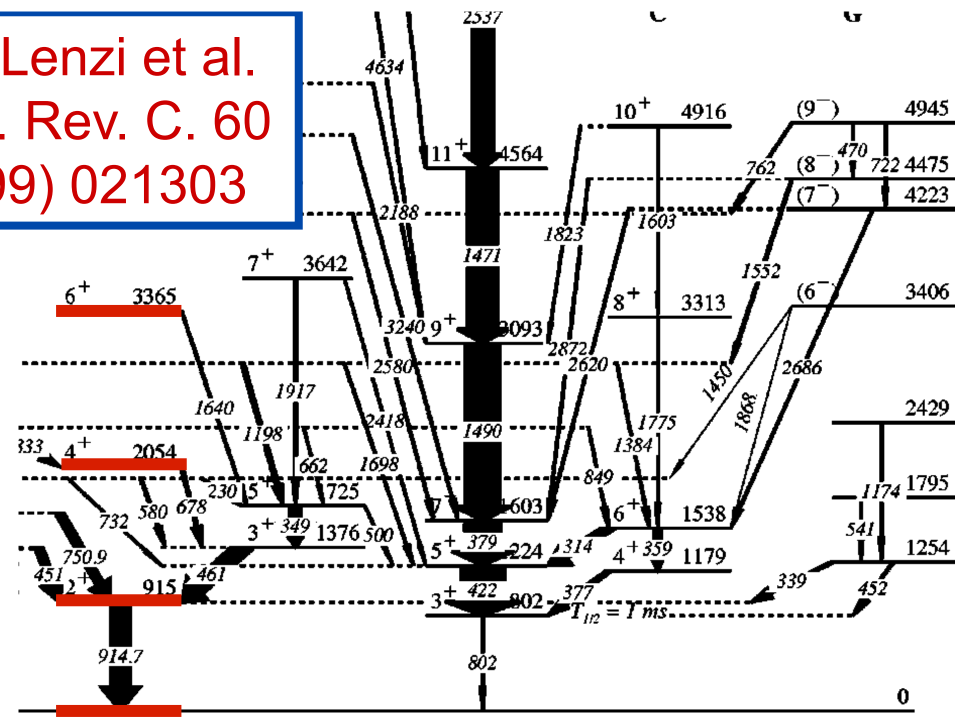
Isospin mixing in the A=46 Isobaric Triplet?

^{46}V - good case for close T=1 and T=0 2^+ state

- **VERY** close proximity of T=0 and T=1 in odd-odd ^{46}V

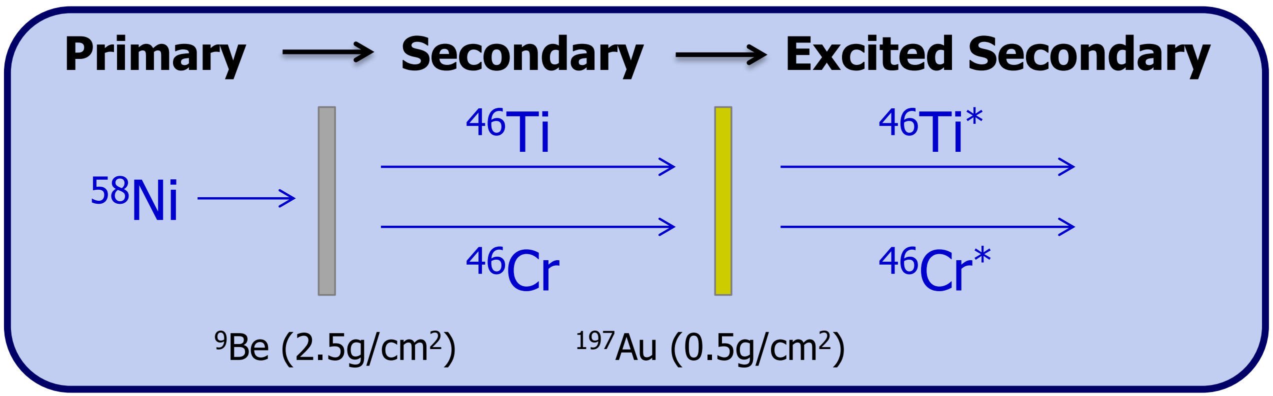


S.M.Lenzi et al.
Phys. Rev. C. 60
(1999) 021303

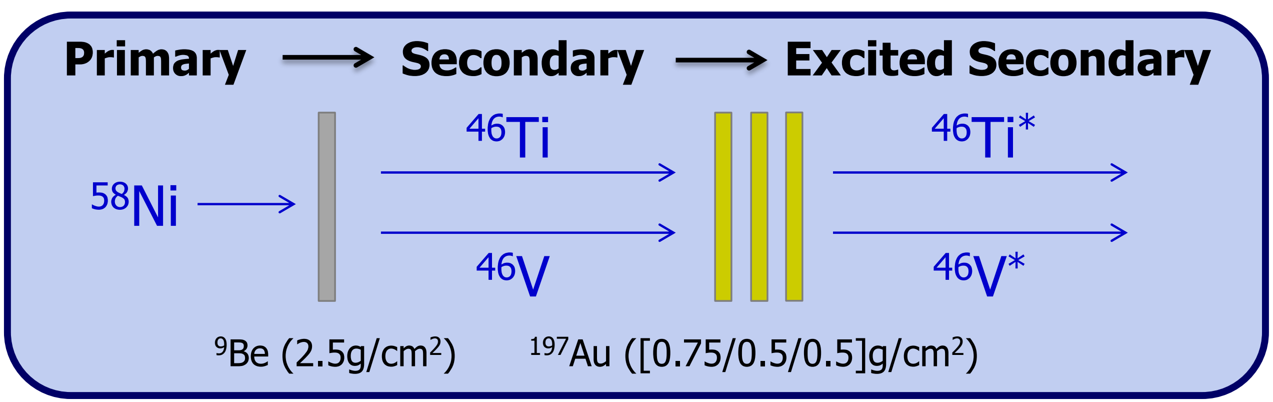


"Stretched Target" method

- **GSI Fragment Separator** + **AGATA** tracking array + **LYCCA** (Particle tracking)
- AGATA/PRESPEC Campaign in 2014



Relativistic **Coulomb excitation** - measure relative to ^{46}Ti



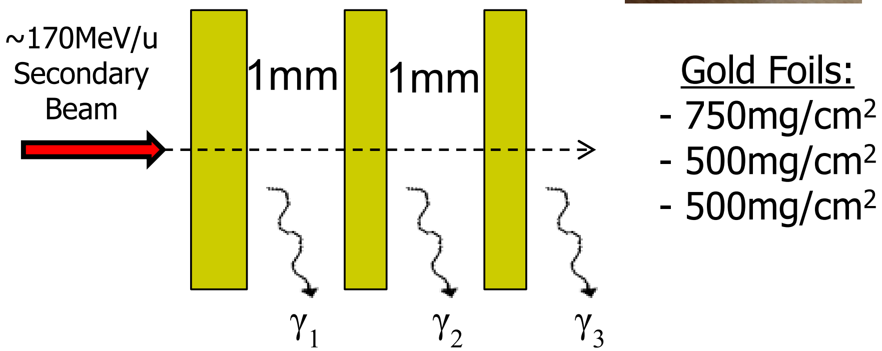
Lifetimes by "**stretched target**" - measure relative to ^{46}Ti

"Stretched Target" method

Using high **velocity** & **target-thickness** available in fragmentation reactions - **FRIB/FAIR/RIBF technique!**

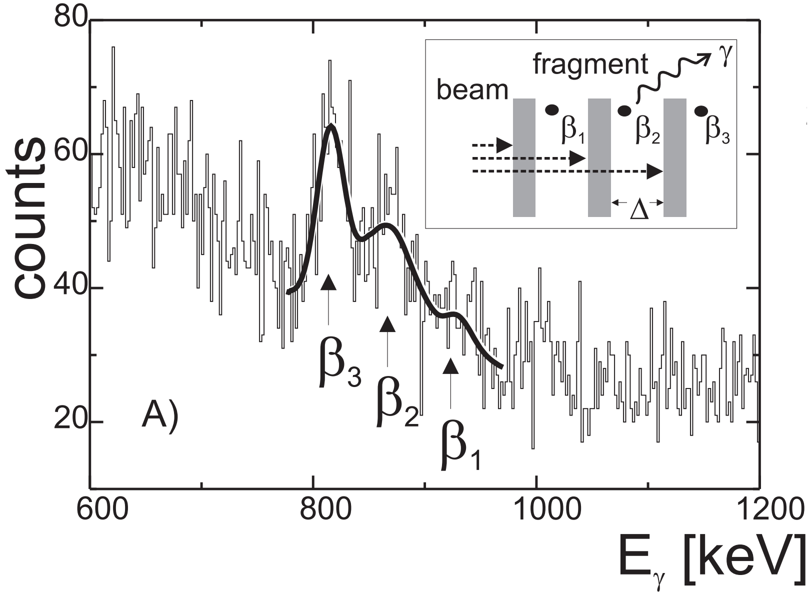
Lifetime measurement: Idea from **P.Bednarczyck**

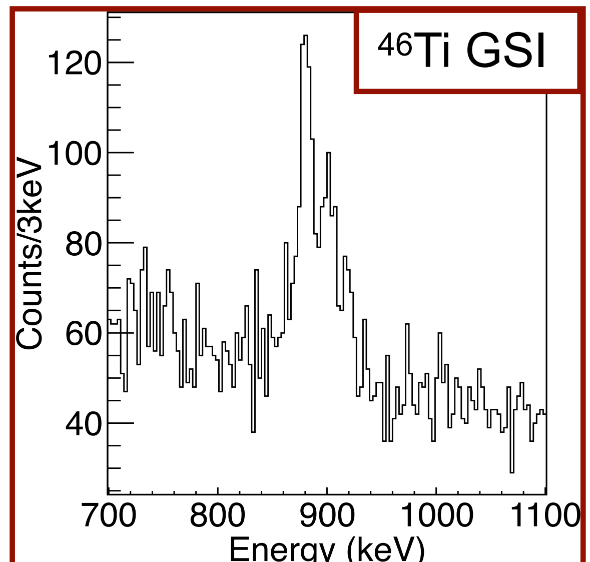
3 Fe foils (both target and degrader)



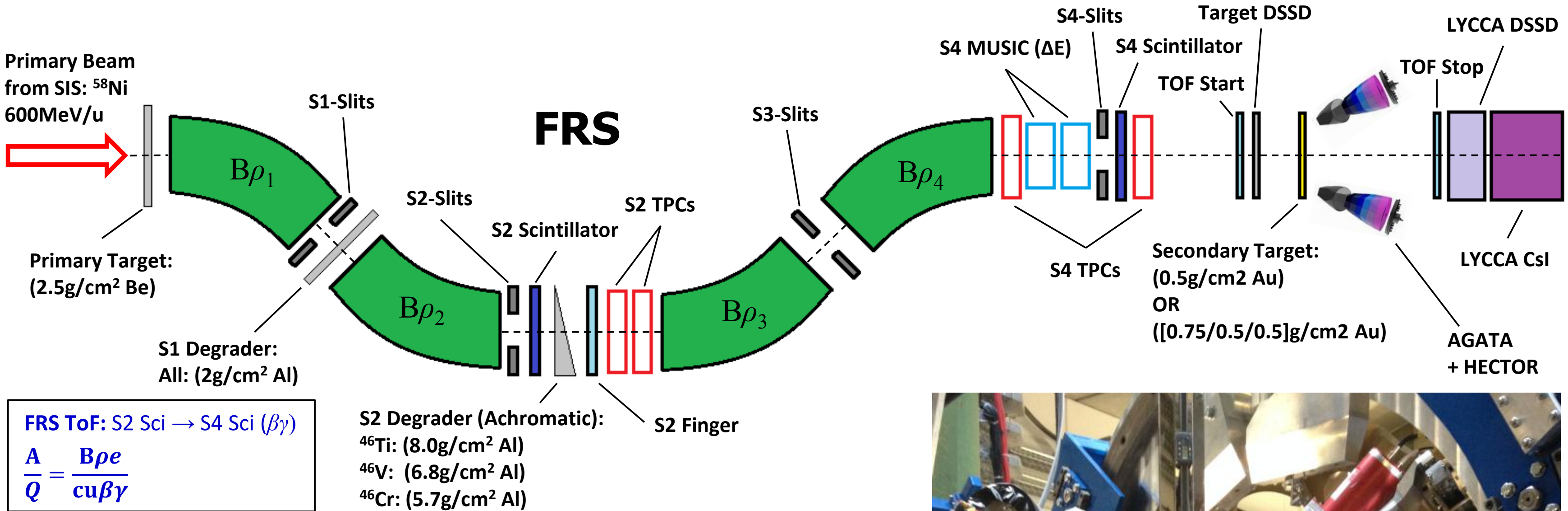
^{37}Ca -1p to ^{36}K

Acta Phys. Pol. B41 (2010) 505



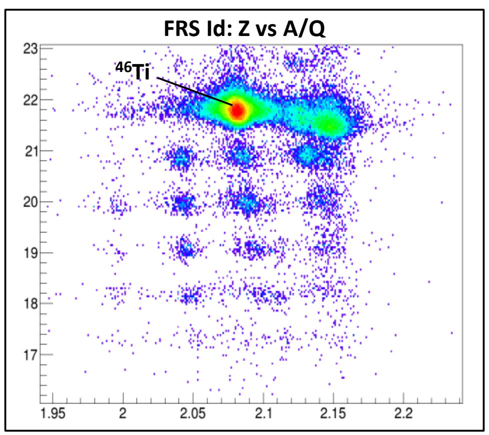


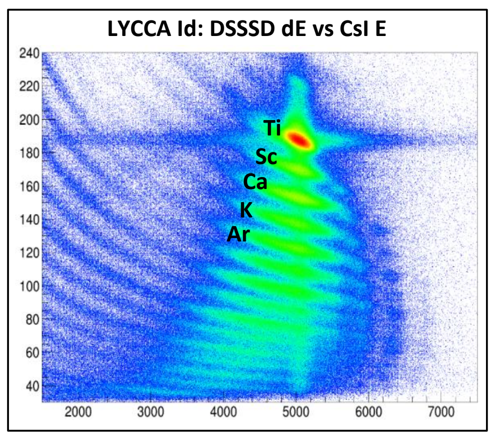
Isospin mixing in the A=46 Isobaric Triplet

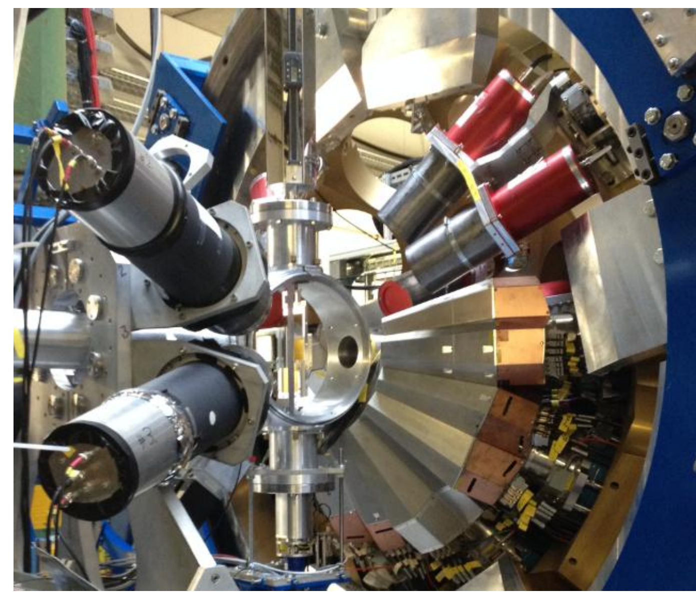


FRS ToF: S2 Sci → S4 Sci ($\beta\gamma$)

$$\frac{A}{Q} = \frac{B\rho e}{cu\beta\gamma}$$





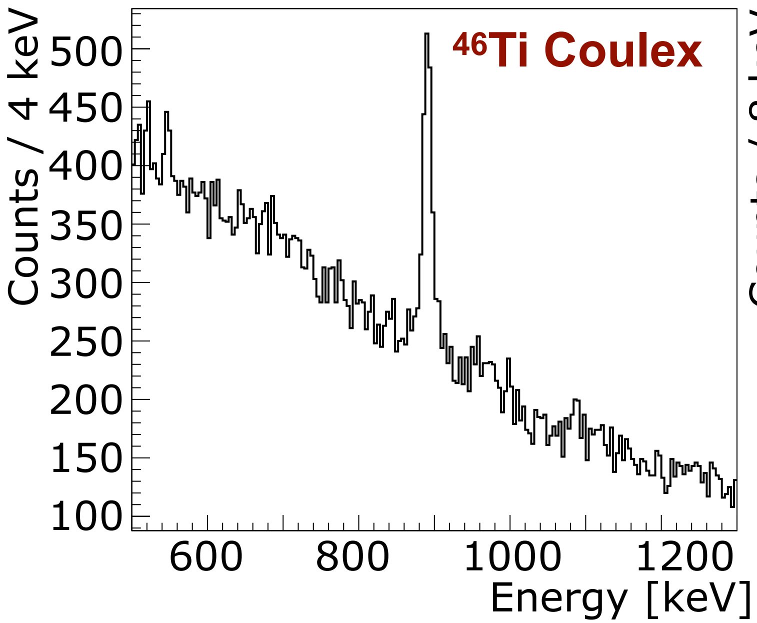


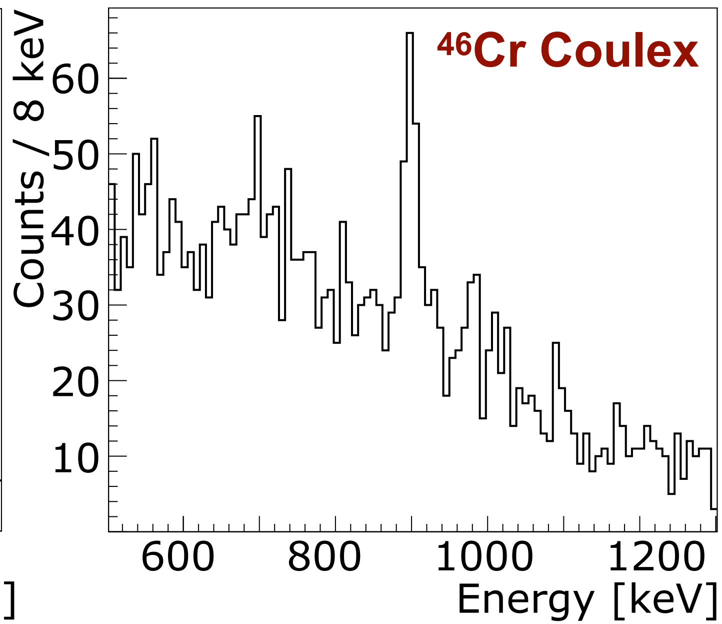
Isospin symmetry in the A=46 Isobaric Triplet

Analysis from Alberto Boso, Padova

Efficiency Corrections for:

- Dead time
- angular distributions

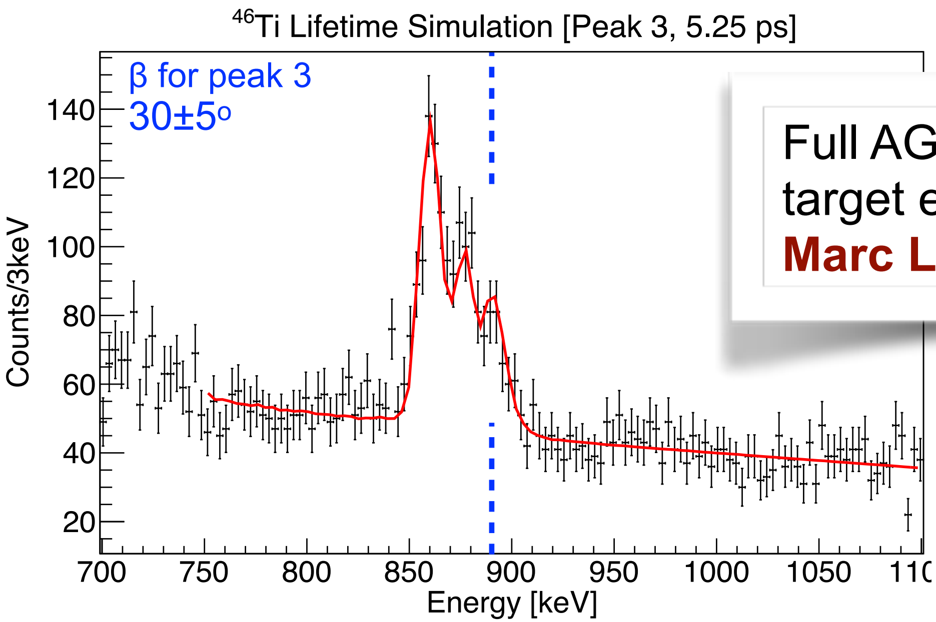




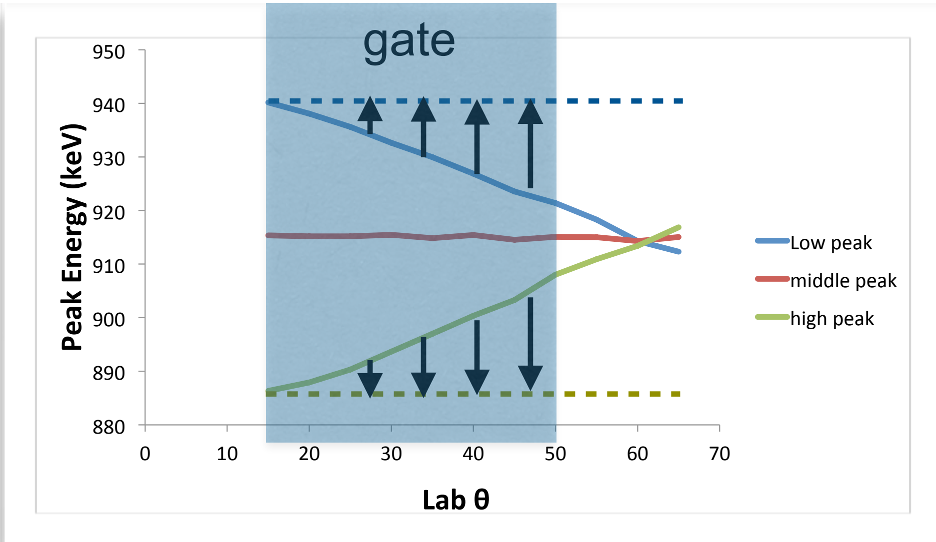
1087(88) counts
B(E2)↑ =
918(74) e^2fm^4

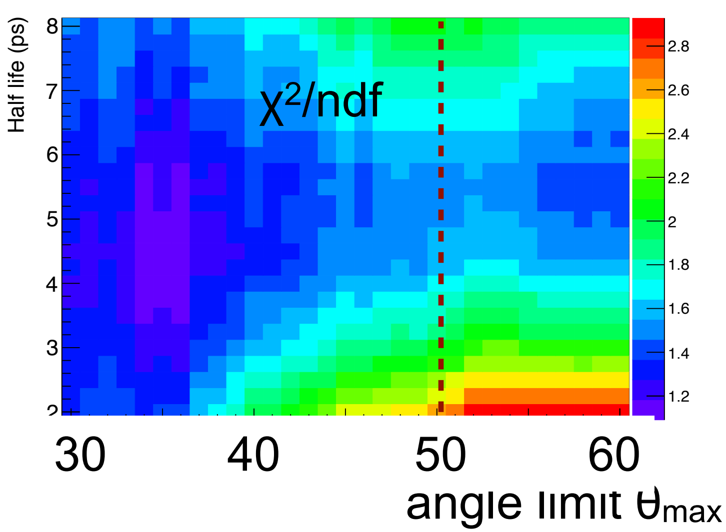
117(21) counts
B(E2)↑ =
886(158) e^2fm^4

Stretched Target Lifetime Measurement



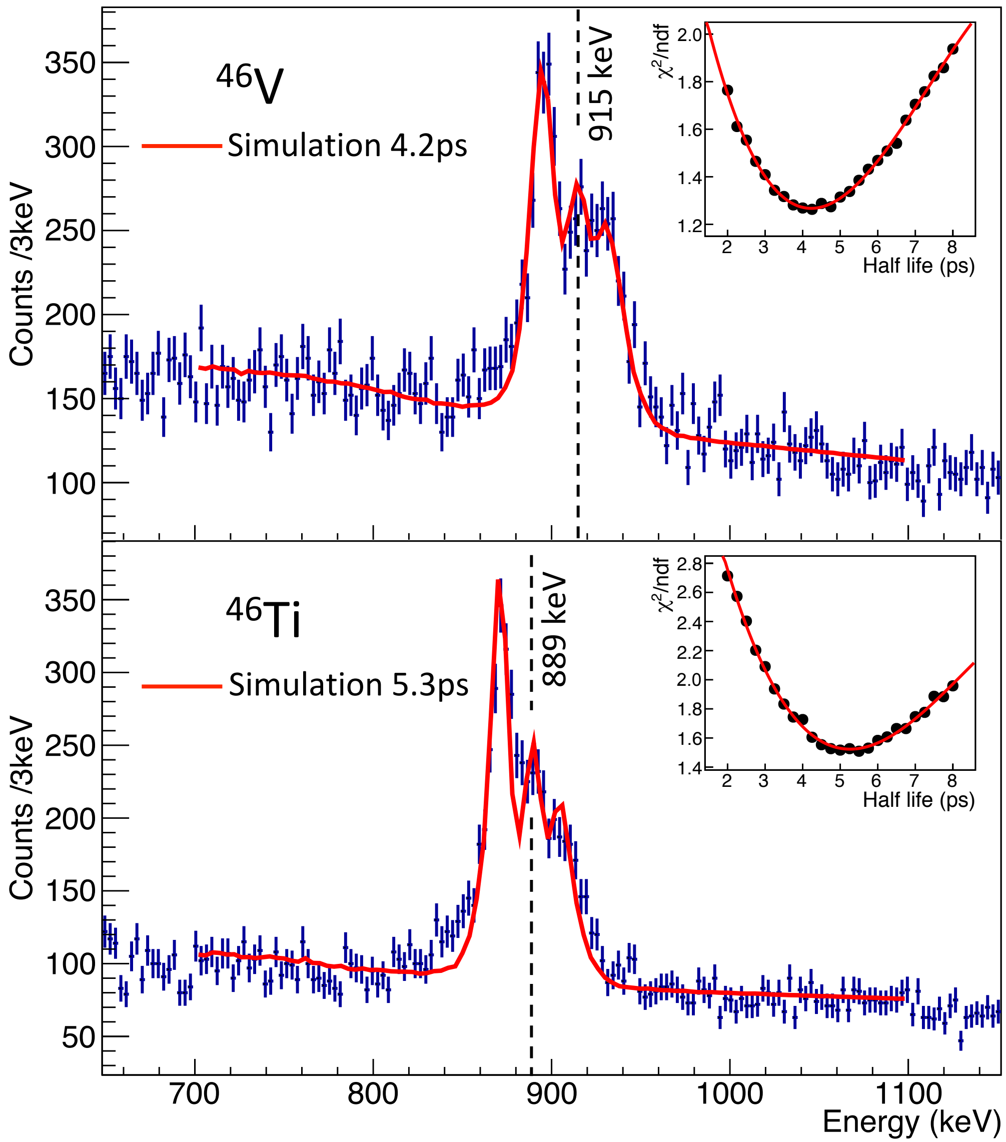
Full AGATA Simulation + stretched-target event generator
Marc Labiche + Scott Milne





Stretched Target Lifetime Measurement

angle limit $\theta_{max} = 50^o$



^{46}V: **4.23(35) ps**

Lit: 4.7(6) ps

Möller et al, PRC **67**, 011301R (2003)

^{46}Ti: **5.26(34) ps**

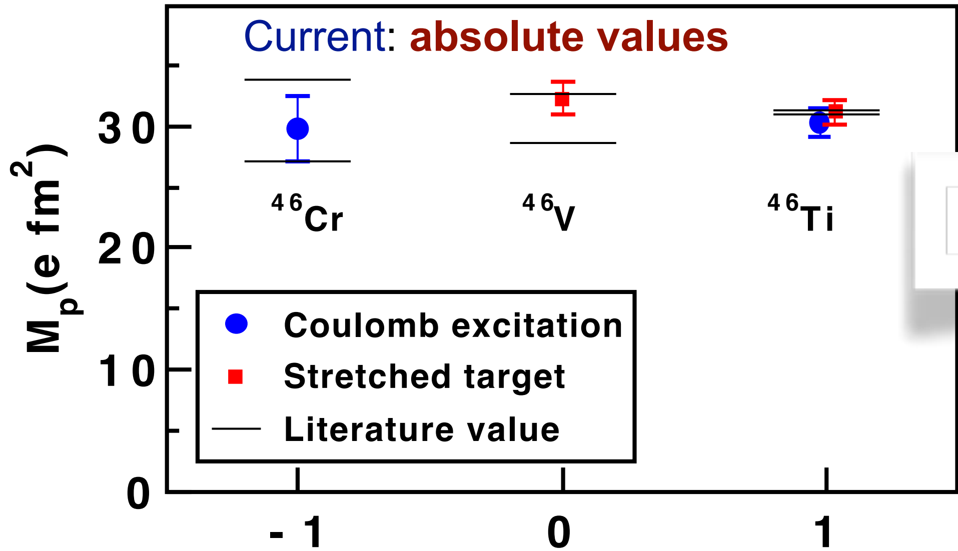
Lit: 5.28(5) ps

Statistical error ~0.3 ps

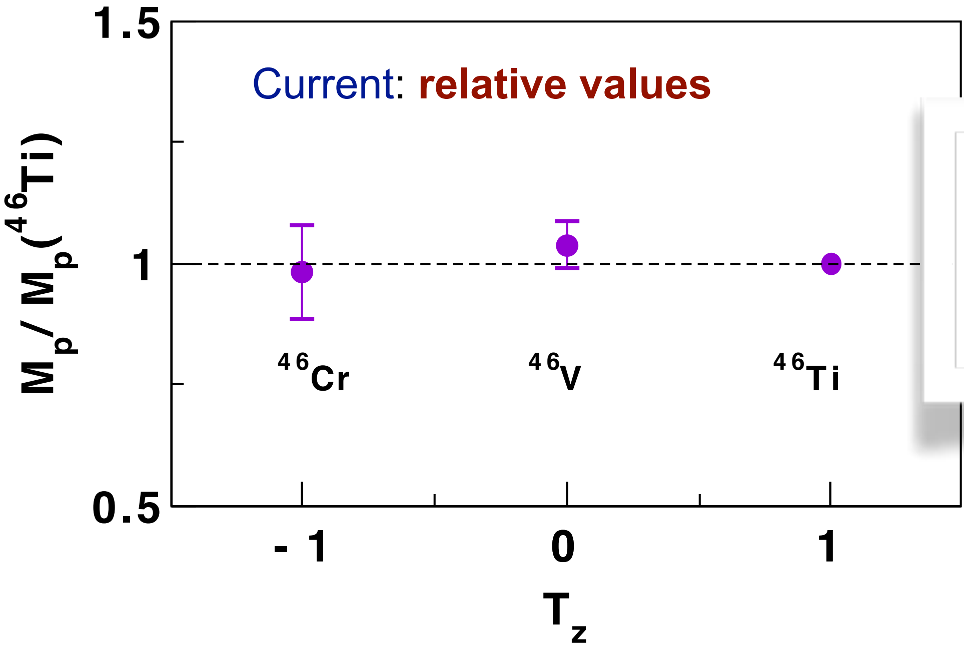
Systematic error estimate ~0.2ps

Isospin symmetry in the A=46 Isobaric Triplet

E2 matrix element as a function of T_z



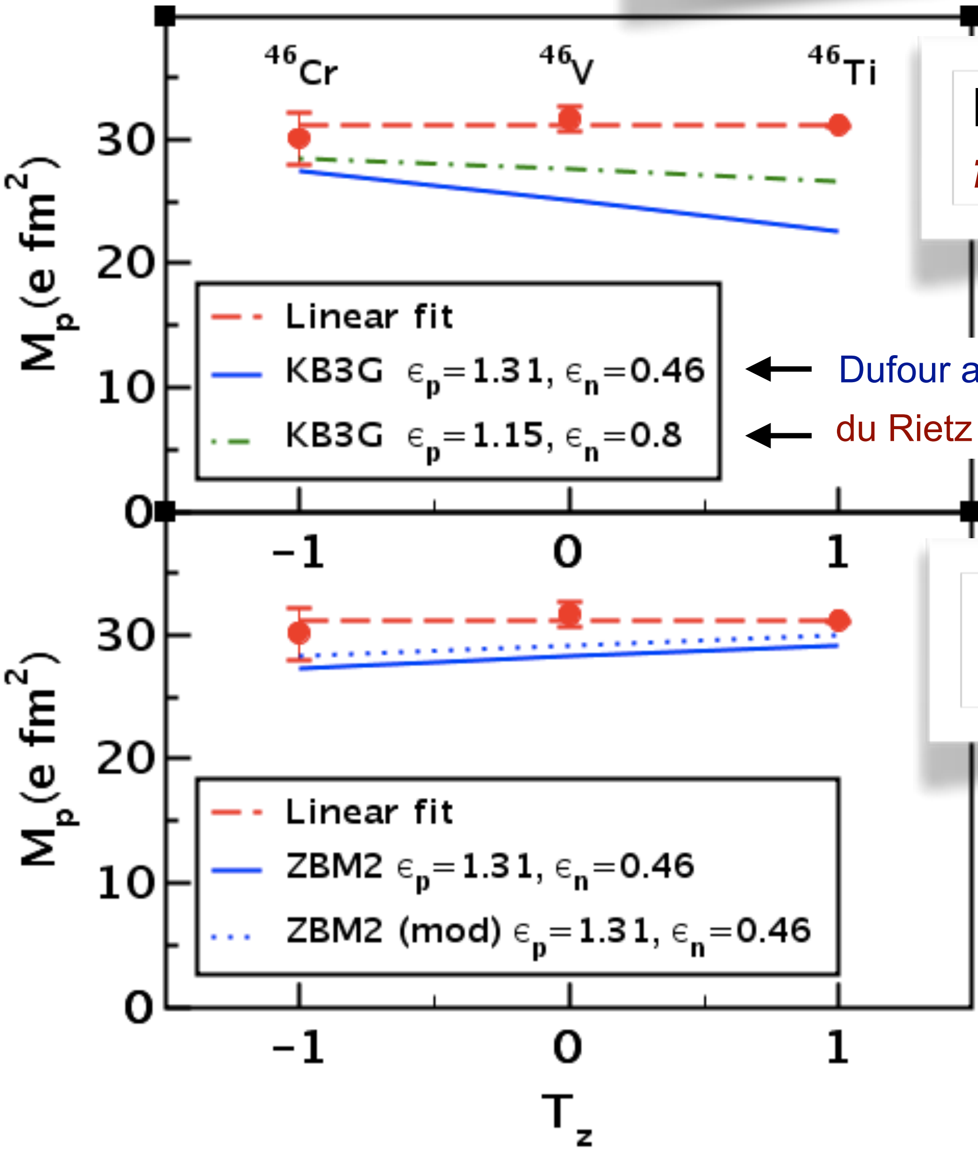
Absolute values



Relative values:
$^{46}Cr/^{46}Ti$ Coulex
$^{46}V/^{46}Ti$ Stretched target
statistical errors only

Isospin symmetry in the A=46 Isobaric Triplet

Weighted average (all available data)



KB3G interaction in $f_{7/2}p_{3/2}f_{5/2}p_{1/2}$ space

← Dufour and Zuker, PRC **54**, 1641 (1996)

← du Rietz *et al.*, PRL **93**,222501(2004) (from A=51 mirrors

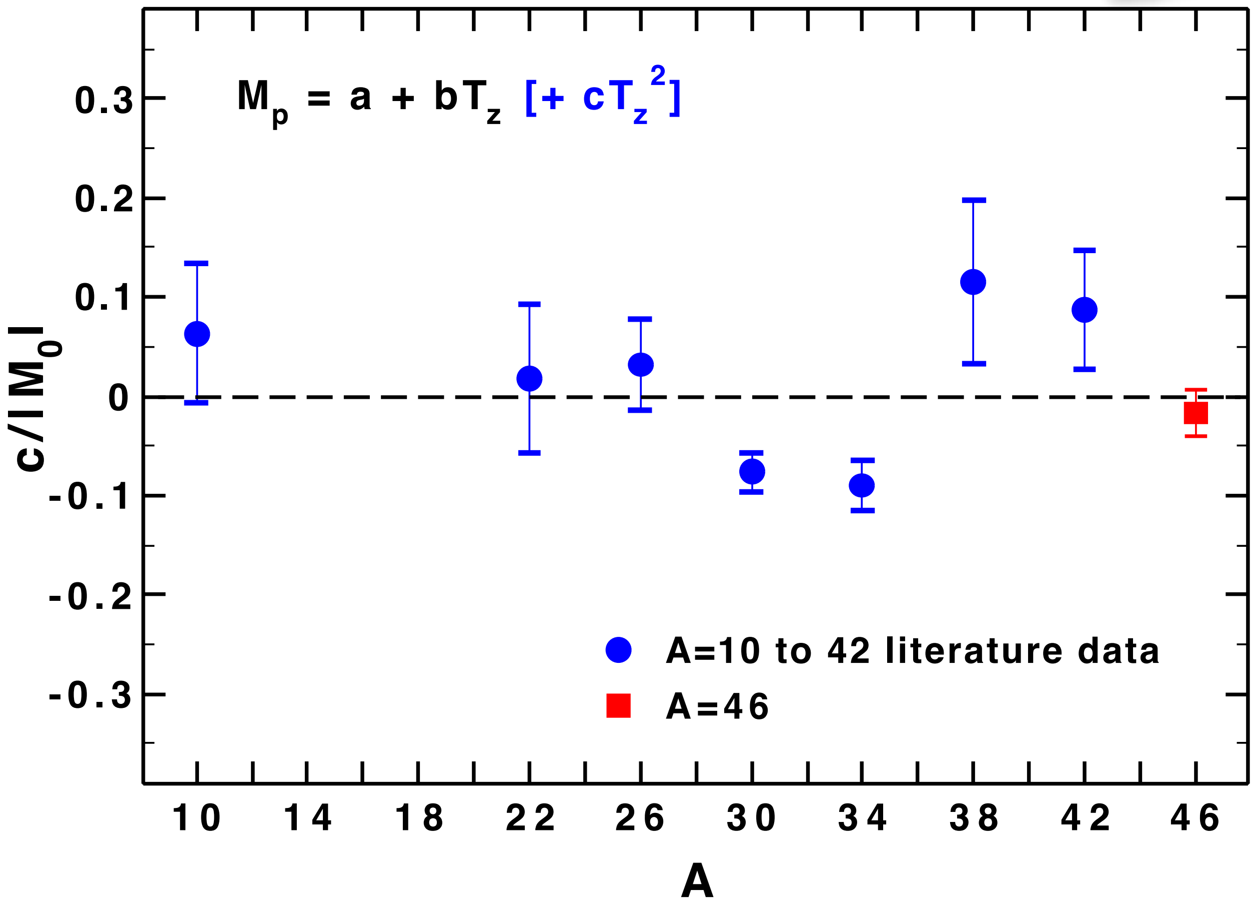
ZBM2 interaction in $s_{1/2}d_{3/2}f_{7/2}p_{3/2}$ space

A.Boso, S.A.Milne, M.A.Bentley, F.Recchia *et al. submitted PLB 2019*

Linearity of proton M.E with T_z

$$M_p(T_z) = \frac{1}{2}[M_0 - T_z M_1^{T_z=1}]$$

A.Boso, S.A.Milne, M.A.Bentley, F.Recchia
et al. ***submitted PLB 2019***



e-e Data from *Pritychencko et al., At.Nuc.Dat.Tab. 107,1139 (2016)* **+ recent results**
o-o Data from *Nuclear Data Sheets* **+ recent results**

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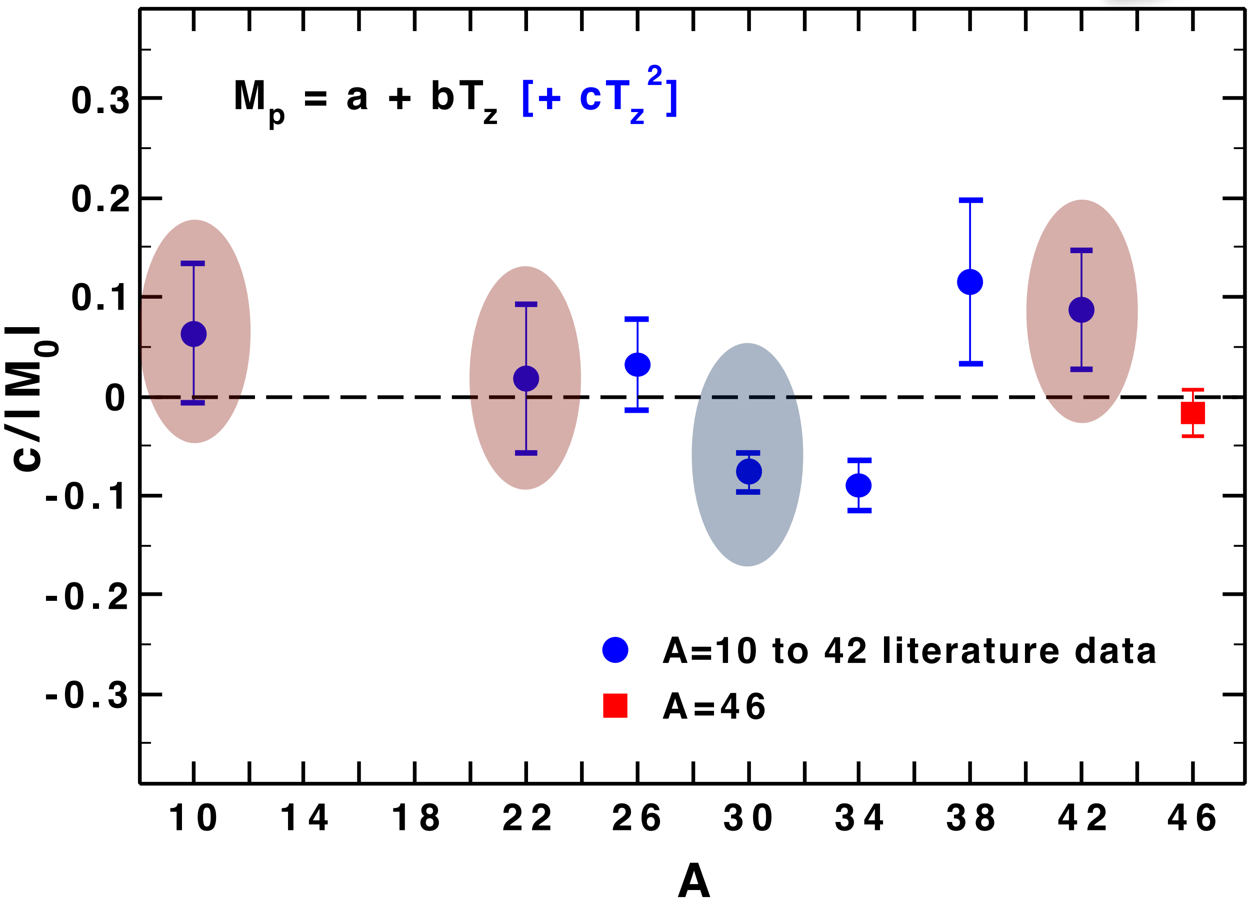

10B *Kuvin et al., PRC96, 041301(R) (2017)*

A=22, *Henderson et al., PLB782, 468 (2018)*

30S, *Petkov et. al., PRC96, 034326 (2017)*

42Ca, *K. Hadynska-Klek et al., PRL96, 117, 062502 (2016)*

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Linearity of proton M.E with T_z

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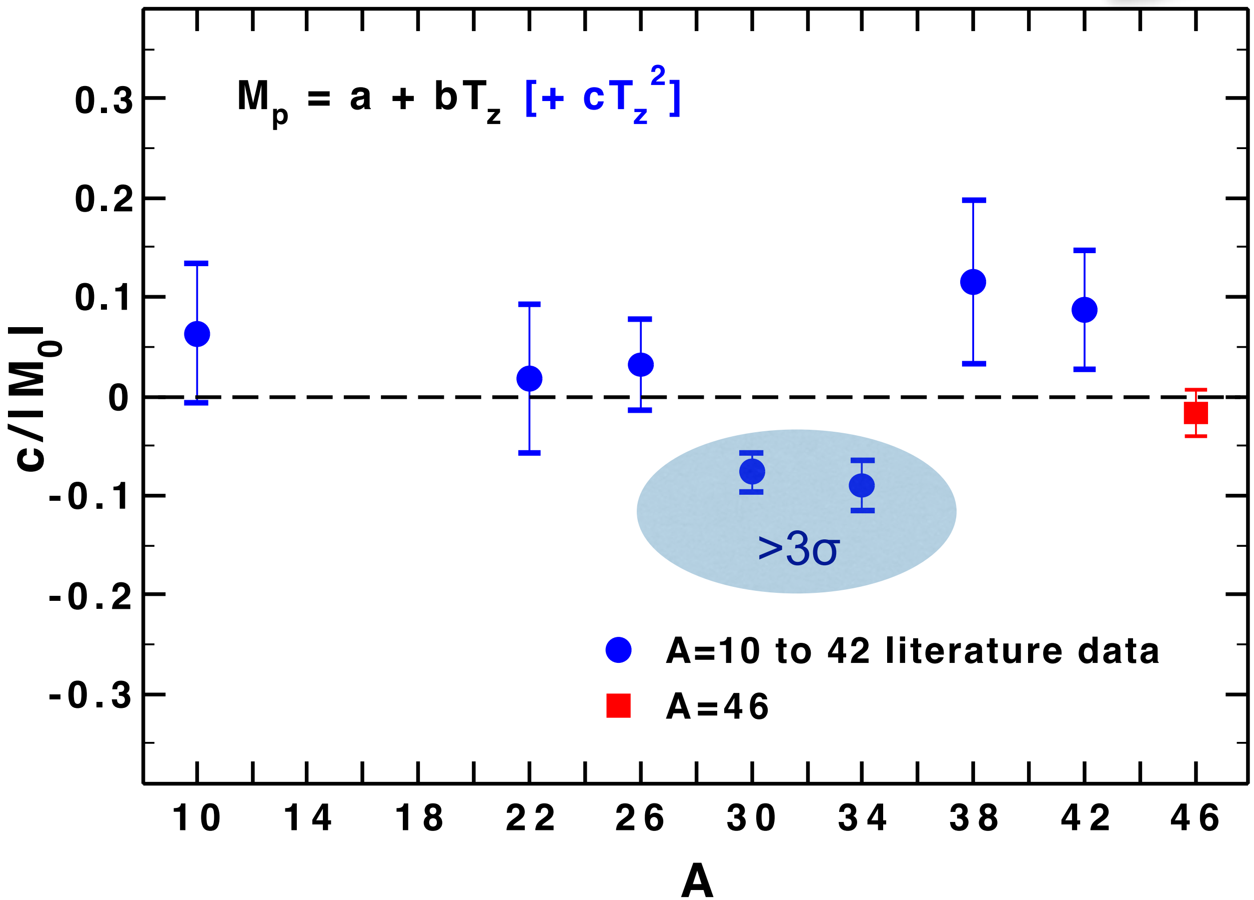

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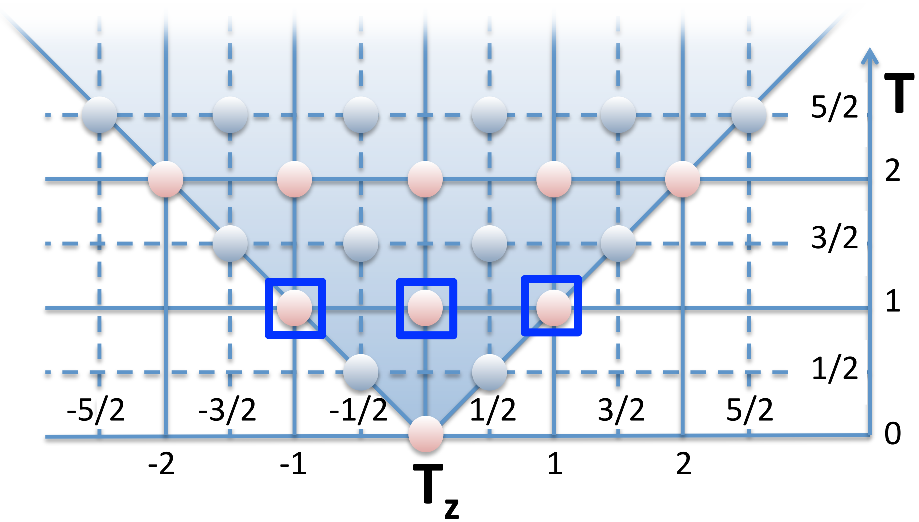
Conclusions

- High precision measurement of B(E2)s in T=1 triplet
- Heaviest triplet for which this has been done (so far!)
- No evidence for non-linear behaviour with T_z
- A=30 and 34 may deviate from the selection rule…
- Stretched target technique - **excellent technique for FAIR & FRIB**

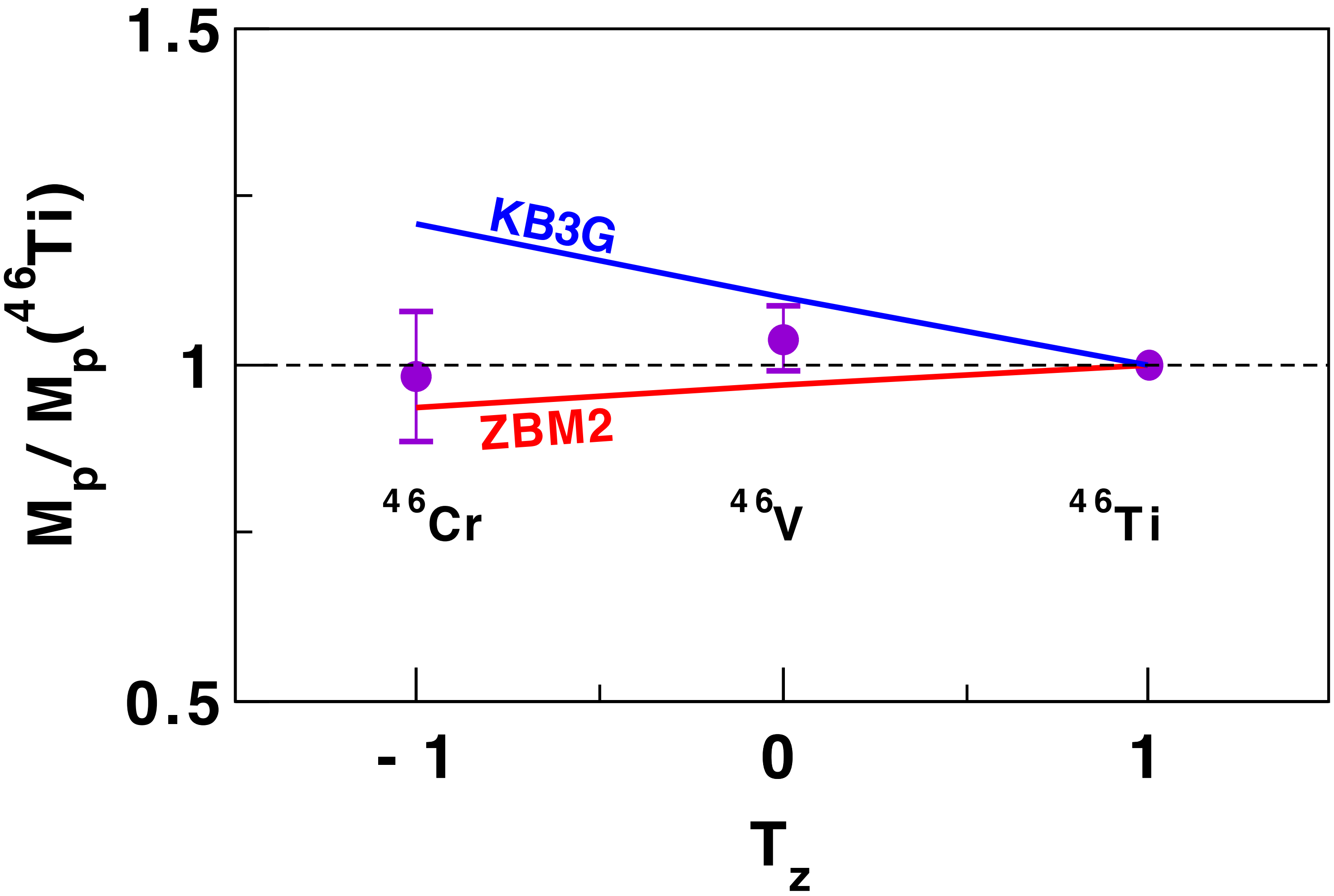


With thanks

Scott Milne (York)
Alberto Boso (Padova)
Marc Labiche (Daresbury)
Francesco Recchia and **Silvia Lenzi** (Padova)

X.Pereira-Lopez, D.Rudolph, S.Afara, F.Ameil, T.Arici, S.Aydin, M.Axiotis, D.Barrientos, G.Benzoni, B.Birkenbach, A.J.Boston, H.C.Boston, P.Boutachkov, A.Bracco, **A.M.Bruce**, B.Bruyneel, B.Cederwall, E.Clement, D.M.Cullen, M.L.Cortes, P.Desesquelles, Zs.Dombradi, C.Domingo-Pardo, J.Eberth, C.Fahlander, J.Gerl, M.Gelain, V.Gonzalez, P.Golubev, M.Gorska, A.Gottardo, T.Grahn, L.Grassi, T.Habermann, L.J.Harkness-Brennan, T.W.Henry, H.Hess, I.Kojouharov, P.John, W.Korten, N.Lalovic, M.Lettmann, C.Lizarazo, C.Louchart-Henning, R.Menegazzo, D.Mengoni, E.Merchan, C.Michelagnoli, B.Million, V.Modamio, T.Moeller, D.R.Napoli, J.Nyberg, H. Pai, N.Pietralla, S.Pietri, Zs.Podolyak, R.M.Perez Vidal, **D.Ralet**, G.Rainowski, **M.Reese**, P.Reiter, M.D.Salsac, L.Sarmiento, H.Schaffner, L.M.Scruton, B.S. Nara Singh, P.P.Singh, C.Stahl, S.Uthayakumaar, J.J.Valiente Dobon and O.Wieland.

+**AGATA Team**
+**GSI/PRESPEC team**

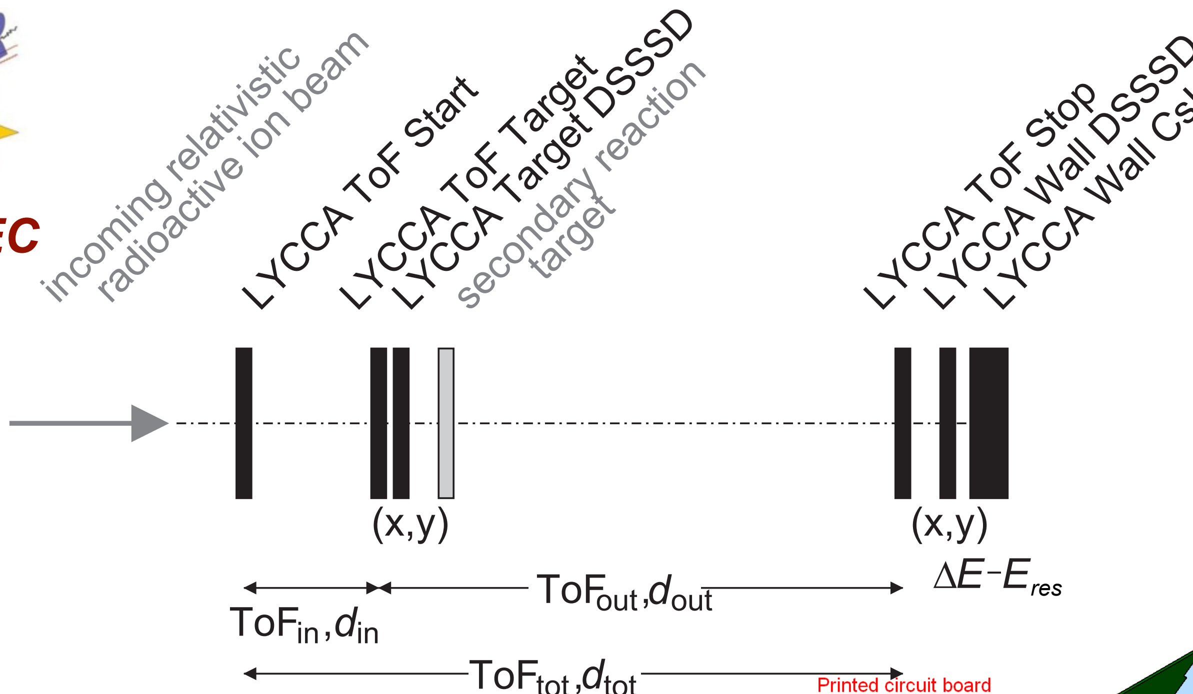


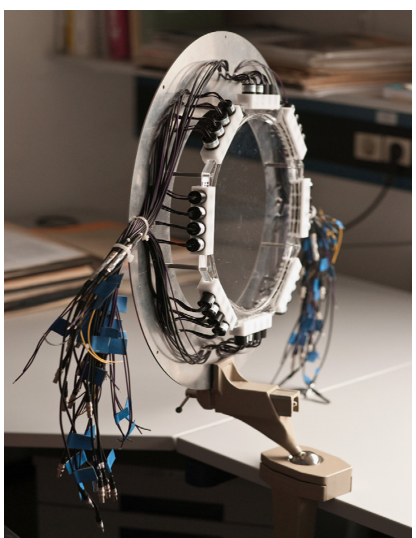
1.5
1
0.5
$M_p / M_p(^{46}Ti)$
KB3G
ZBM2
^{46}Cr
^{46}V
^{46}Ti
- 1
0
1
T_z

LYCCA - an operational HISPEC device

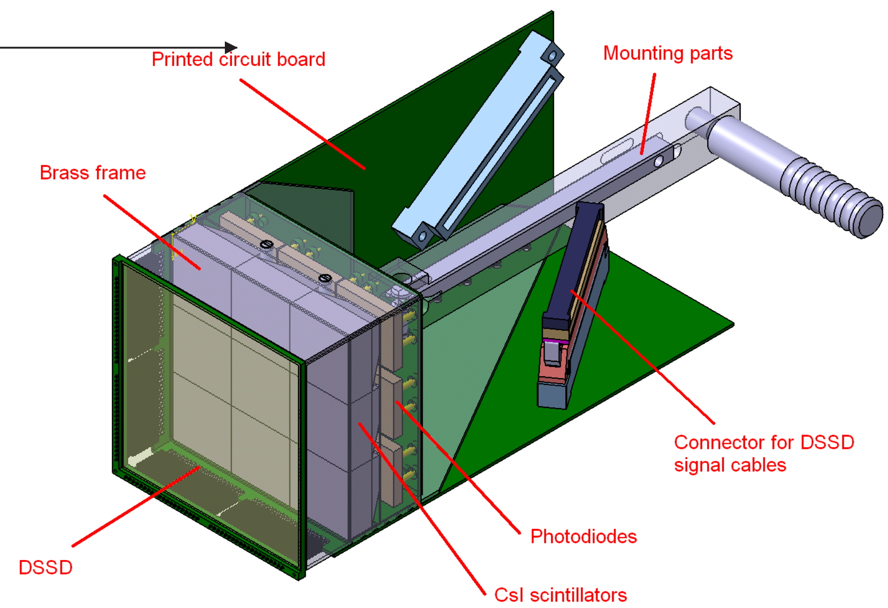
Lund York Cologne CAlorimeter

UK-HISPEC



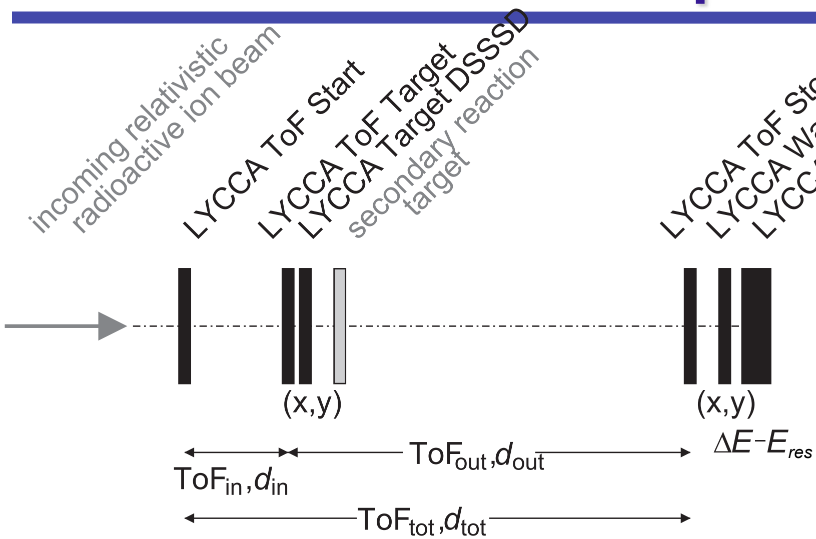


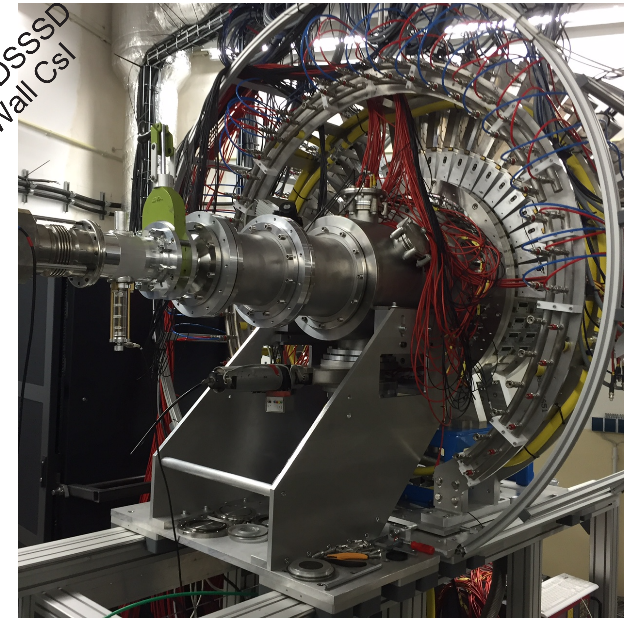
P. Golubev et al. NIMA. 723, 55-66 (2013)



LYCCA - an operational HISPEC device

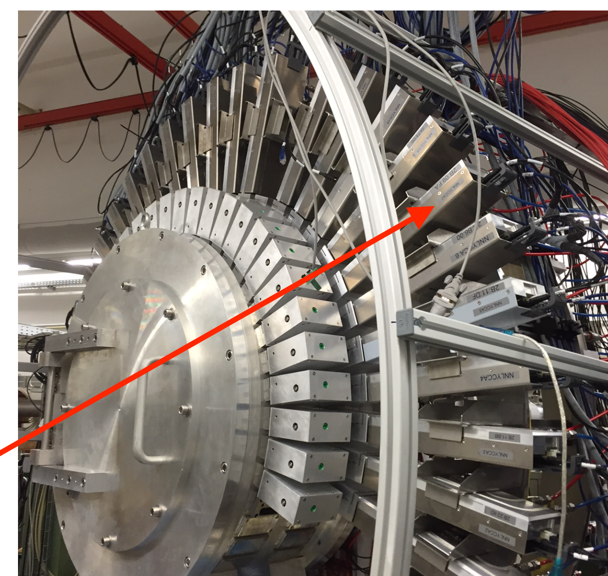
UK-HISPEC





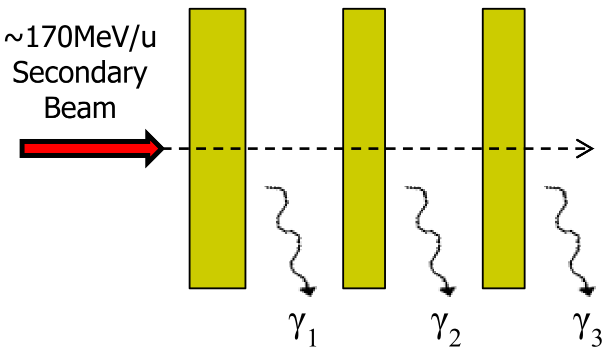
UK contribution of LYCCA:

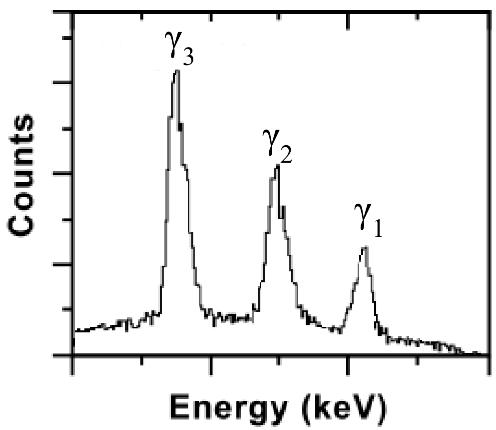
Large-area time-of-flight detectors



ASIC-based signal-processing and DAQ

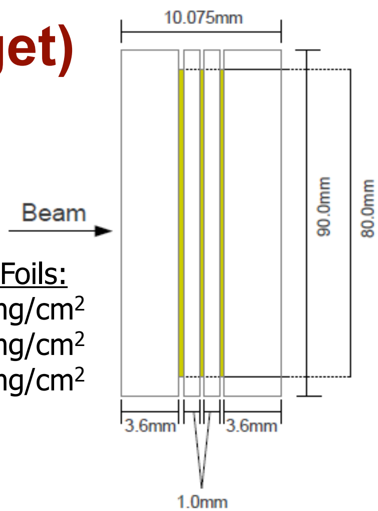
Triple Gold Foil (stretched target)

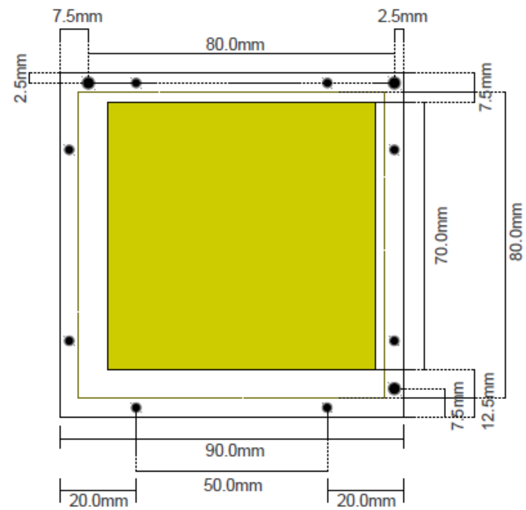


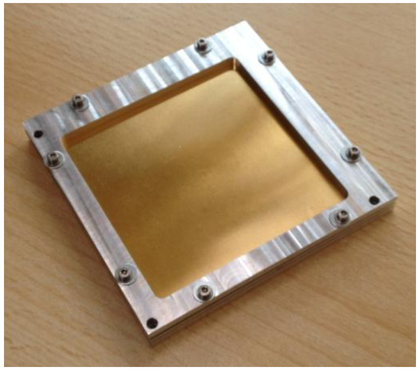


Doppler Shift: $E_{exp} = E_{cor} \frac{\sqrt{(1-\beta^2)}}{[1-\beta Cos(\theta_{dop})]}$

Gold Foils:
- 750mg/cm^2
- 500mg/cm^2
- 500mg/cm^2



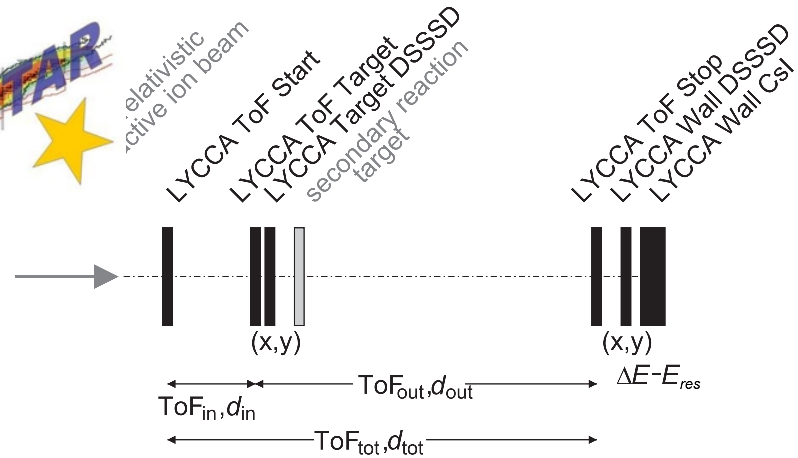


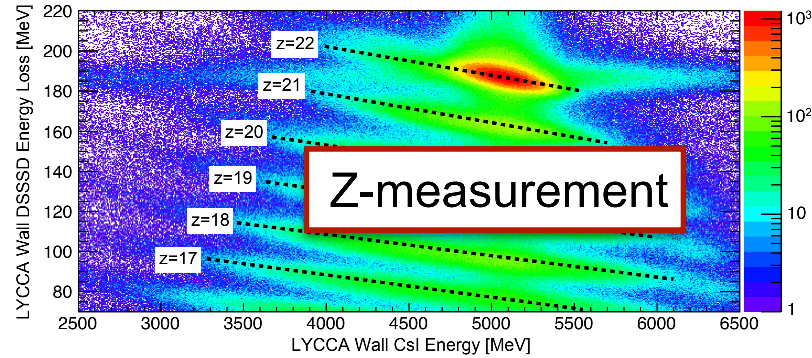


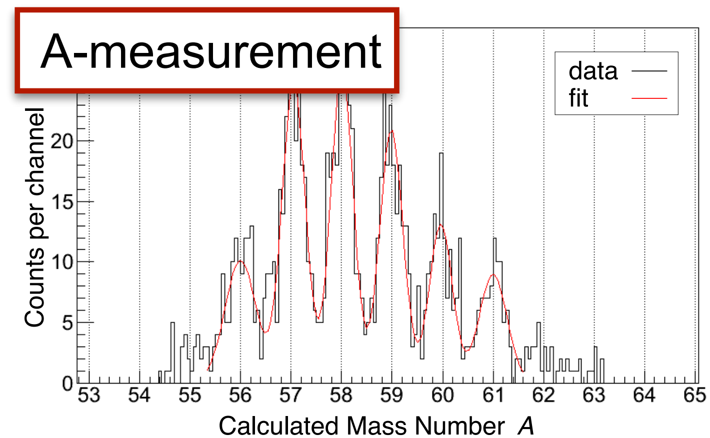
UK-HISPEC

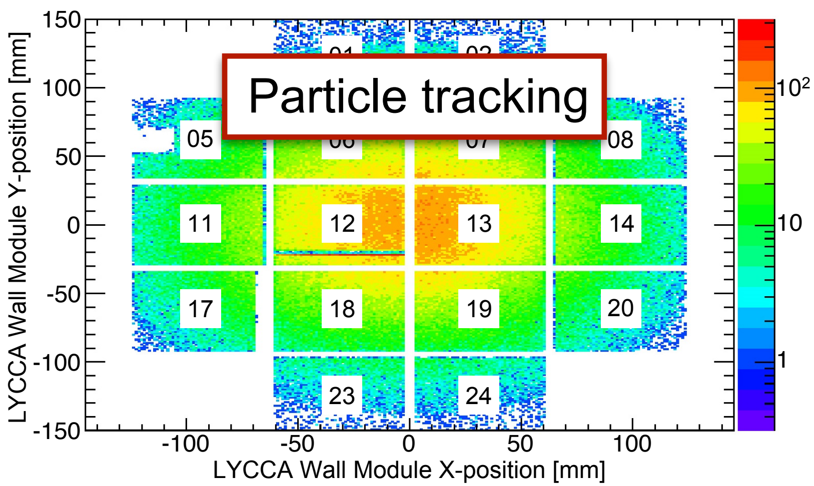
LYCCA - an operational HISPEC device

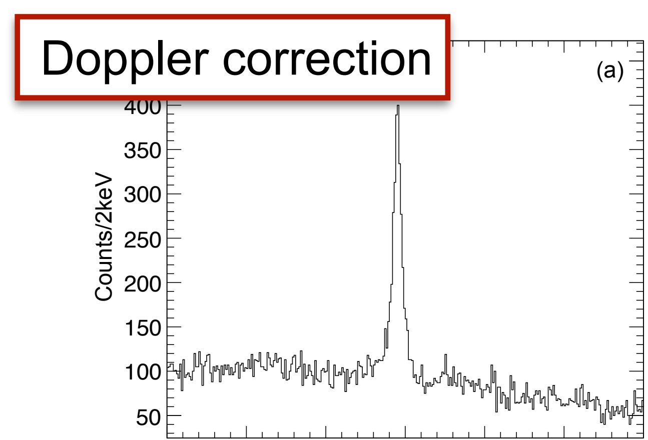
P. Golubev et al. NIMA. 723, 55-66 (2013)



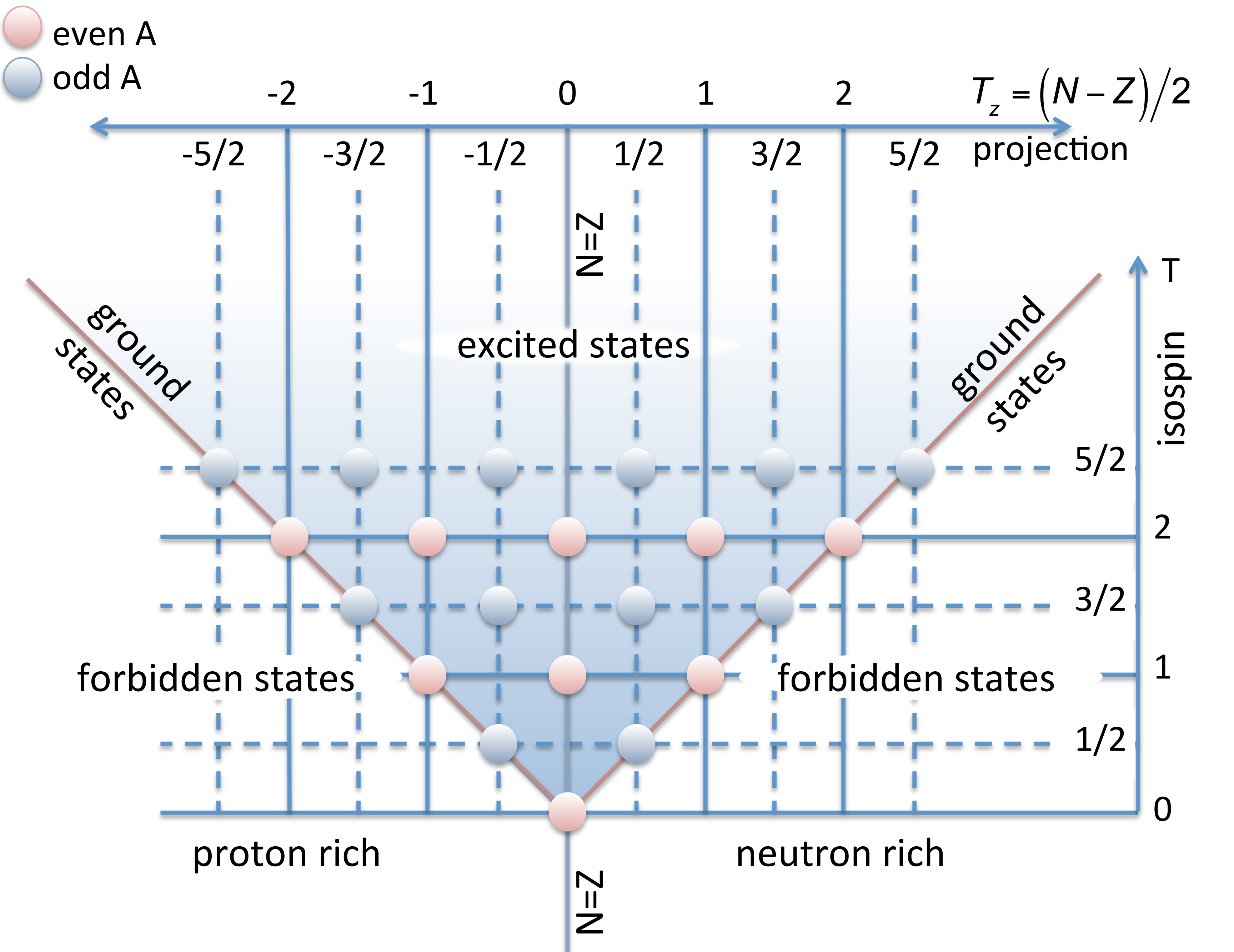






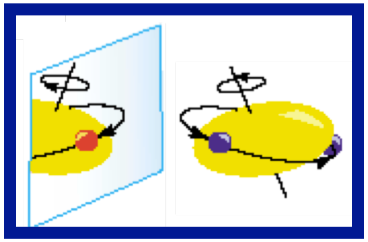


Isobaric Spin (Isospin)



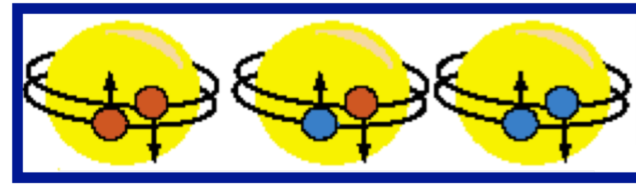
Isospin Symmetry and Isospin Breaking

Charge symmetry



$$V^J_{pp} = V^J_{nn}$$

Charge independence



$$\left(\frac{V^J_{pp} + V^J_{nn}}{2}\right) = V^J_{np}$$

Isospin invariance

Isospin non-conserving interactions (INC)

$$V^{(1),J} = V^J_{pp} - V^J_{nn}$$

Isovector interaction

Probed in mirror nuclei (MED)

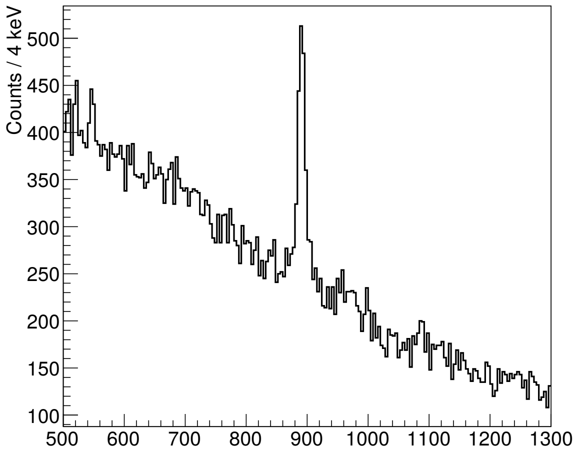
$$V^{(2),J} = V^J_{pp} + V^J_{nn} - 2V^J_{np}$$

Isotensor interaction

Probed in T=1 triplets (TED)

Isospin symmetry in the A=46 Isobaric Triplet

Analysis from Alberto Boso, Padova



"safe" impact parameter

$$b_{min} = r_0 \left(A_P^{1/3} + A_T^{1/3} \right) + 5\text{fm}$$

Efficiency Corrections for:

- Dead time
- angular distributions
- working detectors

^{46}Ti Coulex