

**Investigation of beam purity after in-trap decay and Coulomb
excitation of ^{62}Mn - ^{62}Fe**

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TUM, Garching, Germany

and the MINIBALL collaboration

OUTLINE

1/ In-Trap decay and beam contamination : is there a problem ?

2/ Why investigating it ?

3/ Test beam and application : Coulomb excitation of $^{62}\text{Mn}/^{62}\text{Fe}$

Z=28

26

24

Ni 61 1.1399 α 2.5 m, α 0.00003	Ni 62 3.6345 α 15	Ni 63 100 a β^- 0.07 no γ α 20	Ni 64 0.9256 α 1.6	Ni 65 2.52 h β^- 2.1... γ 1482; 1115; 366... α 22	Ni 66 54.6 h β^- 0.2 no γ	Ni 67 21 s β^- 3.8... γ (1937; 1115; 622...)	Ni 68 29 s β^- γ 758; 84 α	Ni 69 11.4 s β^- γ 1871; 680; 1213; 1483...	Ni 70 6.0 s β^- 3.3... γ 1036; 78... m_2	Ni 71 2.56 s β^- γ 534; 2016	Ni 72 1.57 s β^- γ 376; 94
Co 60 10.5 m 5.272 a β^- 59 γ 59 α 58 α 2.0	Co 61 1.65 h β^- 0.3 α 15 β^- 1.2... γ 1332; 1173... α 20	Co 62 14.0 m 1.5 m β^- 2.8... γ 1173; 1163; 2032; 2033; α 1129	Co 63 27.5 s β^- 3.6... γ 87; 982...	Co 64 0.3 s β^- 7.0... γ 1346; 931	Co 65 1.14 s β^- 6.0... γ 1142; 311; 964...	Co 66 0.18 s β^- 7.2; 8.5... γ 1428; 1246; 1805	Co 67 425 ms β^- 8.0... γ 694...	Co 68 1.6 s 0.23 s β^- 2033; γ 175; 1745; 2033; 2745; 815	Co 69 227 ms β^- γ 594...	Co 70 0.50 s 119 ms β^- 1260; γ 608; 1968; 970	Co 71 79 ms β^- 566; 774; 253; 281 βn
Fe 59 44.503 d β^- 0.5; 1.6... γ 1059; 1292... α 13	Fe 60 1.5 · 10 ⁶ a β^- 0.1 m	Fe 61 6.0 m β^- 2.8; 2.8... γ 1205; 1027; 298...	Fe 62 68 s β^- 2.5 γ 506	Fe 63 6.1 s β^- 6.7... γ 995; 1427; 1299	Fe 64 2.0 s β^- γ 311	Fe 65 0.45 s β^-	Fe 66 0.44 s β^-	Fe 67 0.47 s β^-	Fe 68 0.1 s β^-	Fe 69 0.17 s β^-	Fe 70 94 ms β^-
Mn 58 66.3 s 3.0 s β^- 3.9... γ 811; 1323... γ 72; 47	Mn 59 4.6 s β^- 6.1... γ 1447; 2433...	Mn 60 1.77 s 0.28 s β^- 5.7... γ 535; 1969; γ 272	Mn 61 0.71 s β^- 8.2... γ 823; 1152; γ 629; 207...	Mn 62 0.625 ms β^- 8.77... γ 862; 962	Mn 63 0.25 s β^- > 3.7 γ 356	Mn 64 88.8 ms βn γ 746...	Mn 65 92 ms β^- γ 366 βn	Mn 66 64.4 ms β^- γ 573... βn	Mn 67 45 ms β^- βn	Mn 68 28 ms β^- βn	Mn 69 14 ms β^-
Cr 57 21.1 s β^- 5.1... γ 83; 850; 1752; 1535...	Cr 58 7.0 s β^- γ 583; 126; 290; 520... m	Cr 59 1.05 s β^- γ 1238; 1900; 112; 663...	Cr 60 0.49 s β^- 6.7... γ 349; 410; 758 g	Cr 61 0.27 s β^-	Cr 62 209 ms β^- γ 285; 355; 640...	Cr 63 129 ms β^- γ 250 - 3454	Cr 64 43 ms β^- γ 188	Cr 65 27 ms β^- γ 272; 1368 βn ?	Cr 66 10 ms β^-	Cr 67 >300 ns β^- ?	2.60E-7 3.51E-6

35

40

43

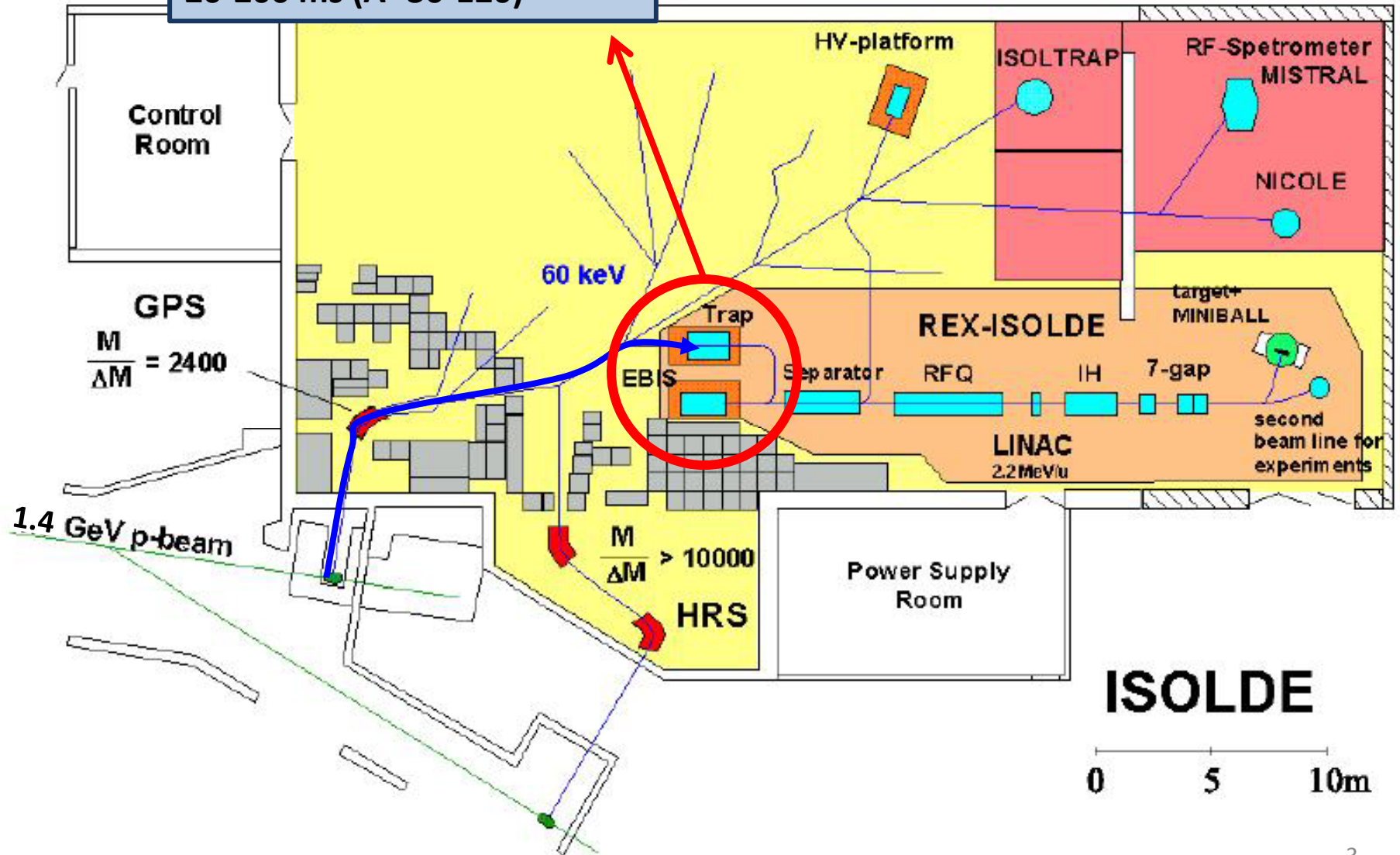
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1/ TRAPPING in REXTRAP
2/ CHARGE BREEDING in EBIS

20-200 ms ($A \approx 30-120$)



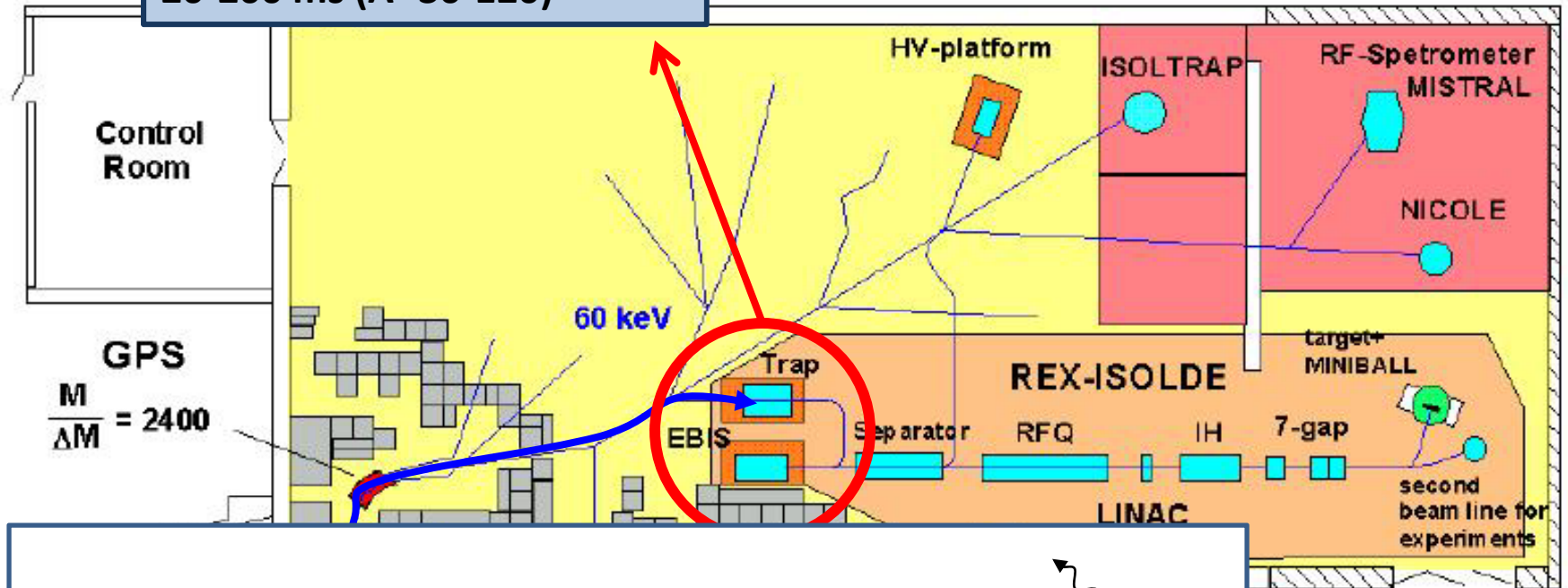
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1.4



→ Isotope of interest

→ Decay product

SOLDE

5 10m

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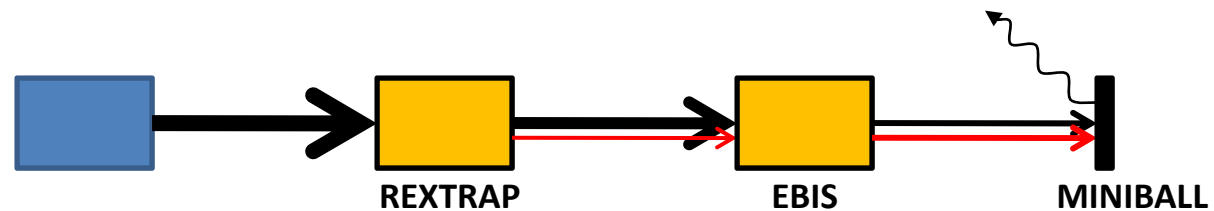
Post accelerated beams < 2008 :

^{31}Mg : 232(15) ms

^{32}Mg : 95(16) ms

^{80}Zn : 545(20) ms

ACCEPTED ^{128}Cd : 280(40) ms



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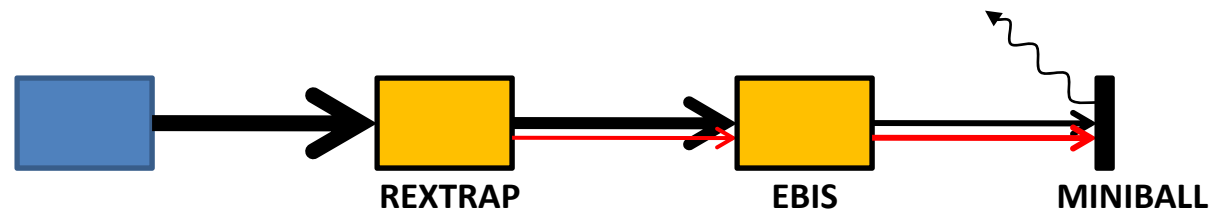
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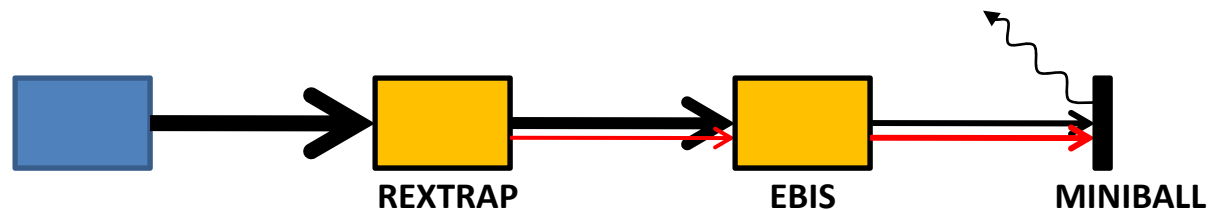
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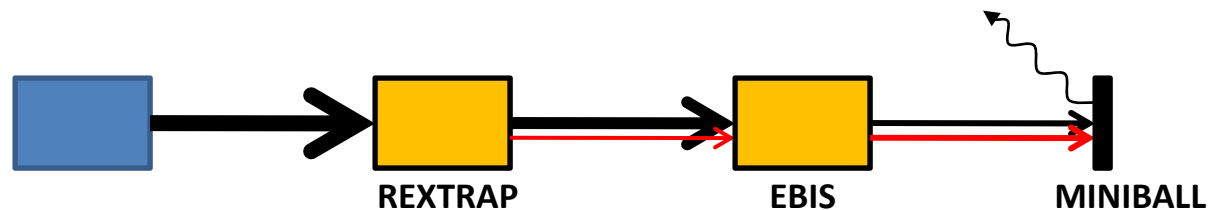
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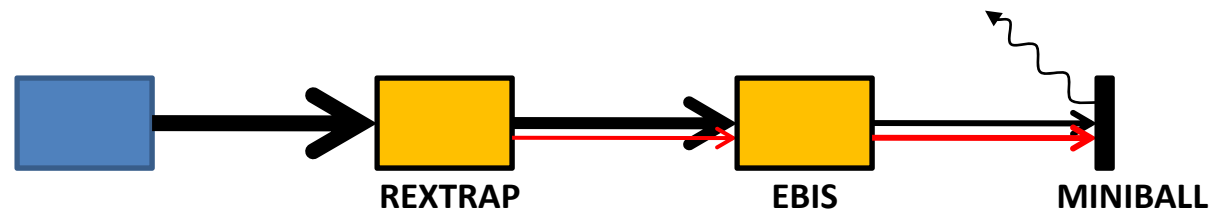
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Ex. Fe mass measurements at ISOLTRAP with in-trap decay of mother ions (Mn)

A. Herlert et al. NJP 7 44 (2005)

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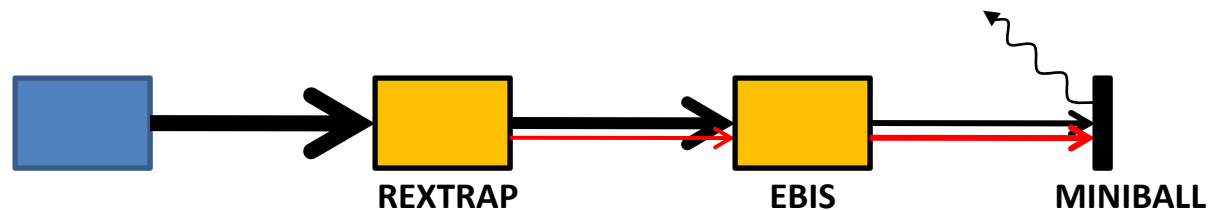
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⇒ **Decay losses** during trapping and charge breeding become significant.

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to produce a post-accelerated beam of decay products.



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WHY ?

1/ Nuclear physics interest in decay products ;

Hard to produce beam ...

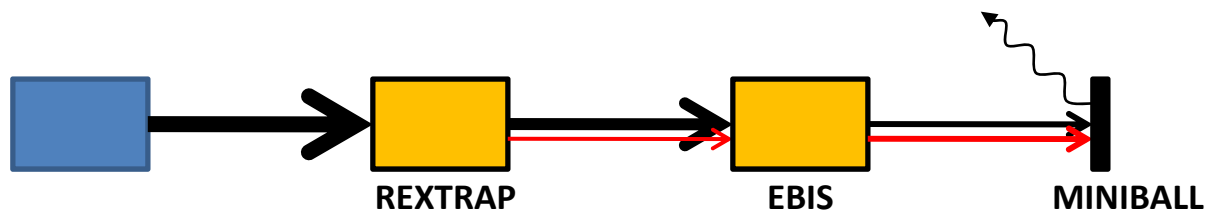


produce "easy beam" ...



and let it decay to "interesting beam"

if the "easy beam" is short half life ... !!!



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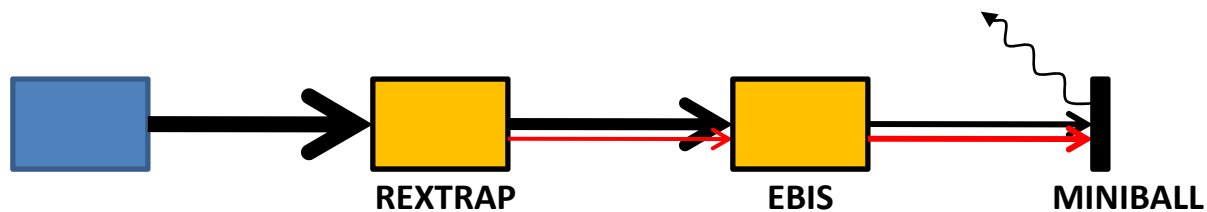
and let it decay to "interesting beam"

For example :

Ca

K

sufficiently short lived ?



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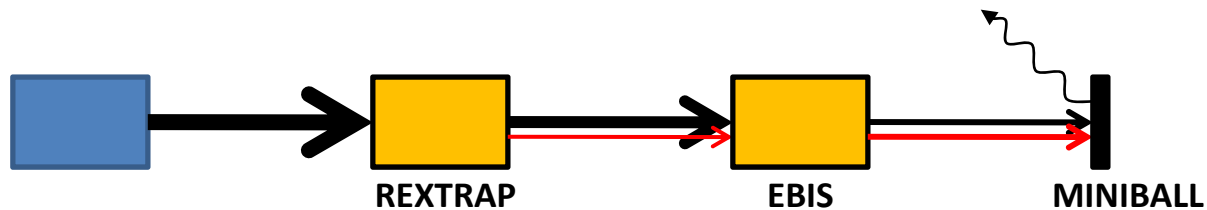
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sufficiently short lived ?



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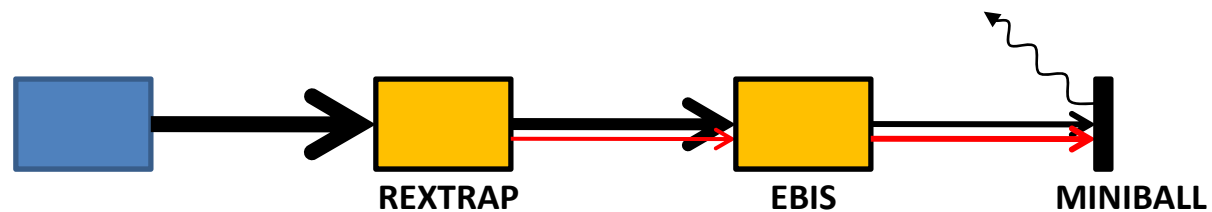
2/ Why investigating it ?

3/ The application : Coulomb excitation of $^{62}\text{Mn}/^{62}\text{Fe}$

WHY ?

1/ Nuclear physics interest in decay products ;

2/ Gain deeper insight in the (possible) loss of decay products in the REXTRAP/EBIS
(crucial for normalization of Coulomb excitation experiments)



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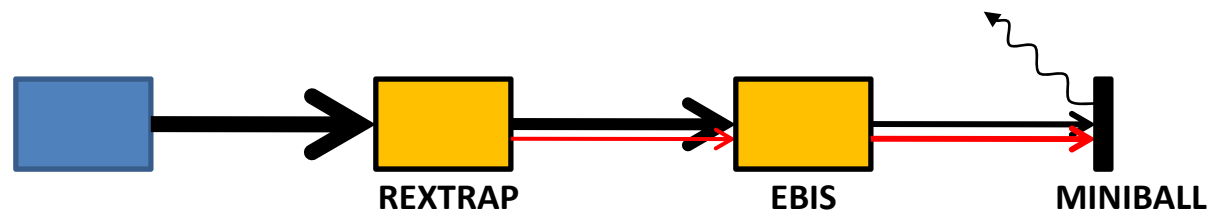
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a) Are decay products lost in the REXTRAP/EBIS ?

b) How long can these ions be trapped before there are significant losses ?

c) Can we monitor the change in beam composition with the available beam diagnostics ?



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a) Are decay products lost in the REXTRAP/EBIS ?

Ion recoil energy after β -decay \Rightarrow order of few 100 eV (depends on Q-value)

Typical trap barrier height is of the same order of magnitude

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a) Are decay products lost in the REXTRAP/EBIS ?

Ion recoil energy after β -decay \Rightarrow order of few 100 eV (depends on Q-value)
Typical trap barrier height is of the same order of magnitude



1/ Poorly cooled daughter ions \Rightarrow worse emittance

\Rightarrow **worse transmission to EBIS**

2/ Recoil energy sufficient to **escape longitudinal potential well** (~ 100 eV)

3/ Radius of transverse motion increases and **collides with the walls**

4/ **Sideband cooling** works for specific A/q (different for daughter product)

\Rightarrow **Losses** of daughter isotopes

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b) How long can these ions be trapped before there are significant losses ?

Produce intense beam of daughter isotopes



LONGEST POSSIBLE trapping/breeding time

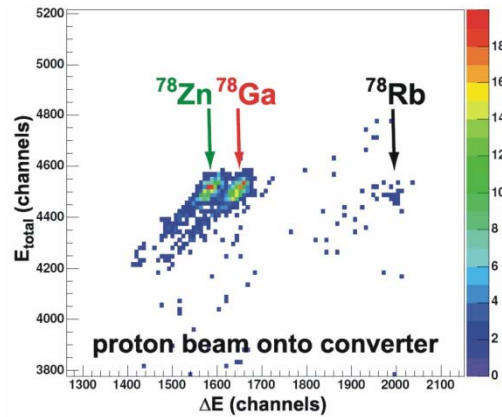
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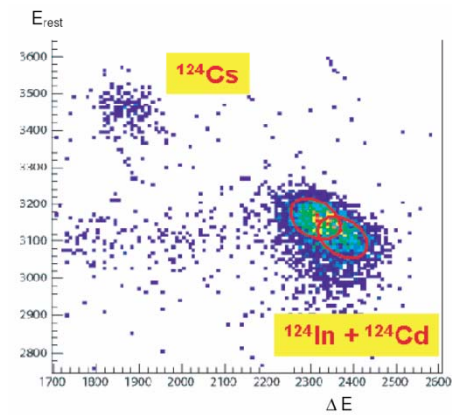
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c) Can we monitor the change in beam composition with the available beam diagnostics ?

1/ gas-Si dE-E telescope (zero degree beamline)



$Z \sim 30 : \Delta Z=1$ resolved



$Z \sim 50 : \Delta Z=1$ not resolved

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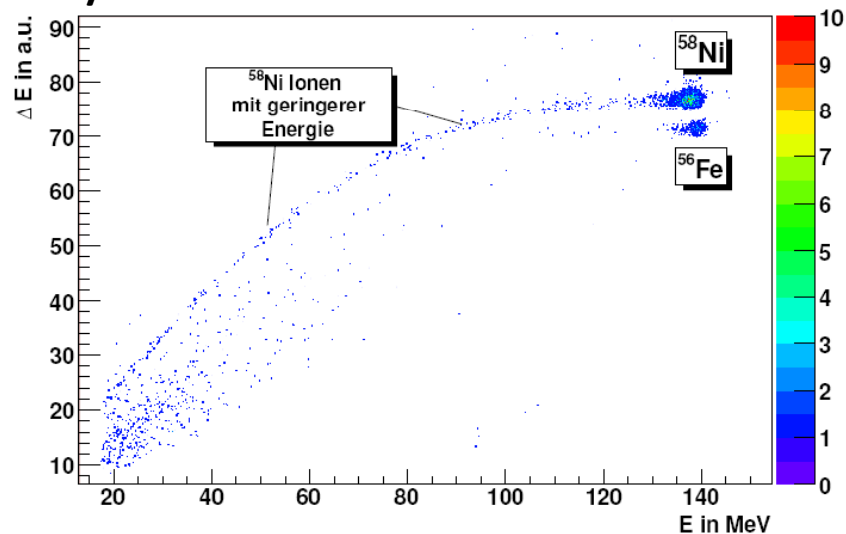
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2/ Bragg chamber (in MINIBALL beamdump)

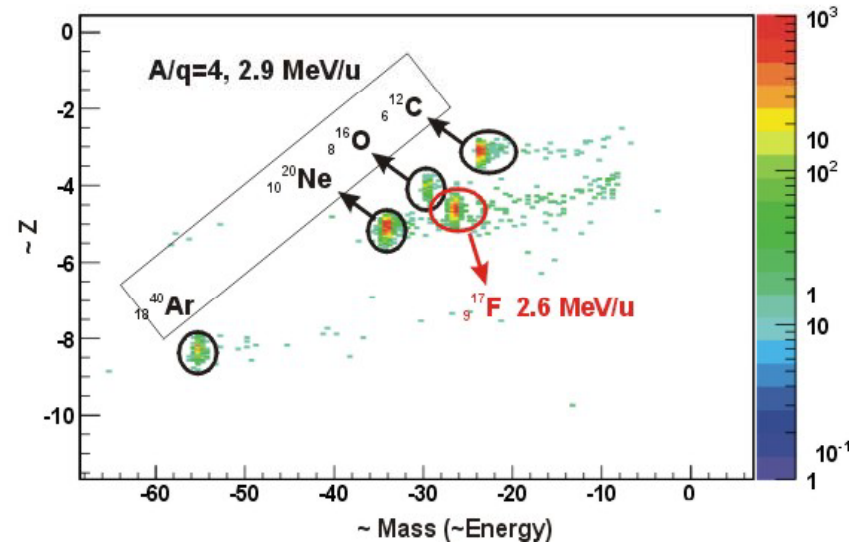
a/ Test at Tandem in Munich



**P10 gas,
500 mbar,
 ^{58}Ni beam on ^{56}Fe target**

W. Weinzierl, Diplomarbeit, TUM, Munich, 2006

b/ ONLINE REX 2007



**CF4 gas,
400 mbar,
cocktail beam C,O,Ne,Ar**

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c) Can we monitor the change in beam composition with the available beam diagnostics ?

1/ gas-Si dE-E telescope (zero degree beamline)

2/ Bragg chamber (in MINIBALL beamdump)

3/ Beamdump Germanium detector :

Monitor the change in γ -ray intensities with different trapping/breeding times

1/ In-Trap decay and beam contamination : is there a problem ?

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**CAN WE PRODUCE A “HARD-TO-GET”
POST-ACCELERATED BEAM OF DECAY PRODUCTS
AFTER IN-TRAP DECAY ???**

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CAN WE PRODUCE A “HARD-TO-GET”
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PROOF OF PRINCIPLE WITH **Mn-Fe**

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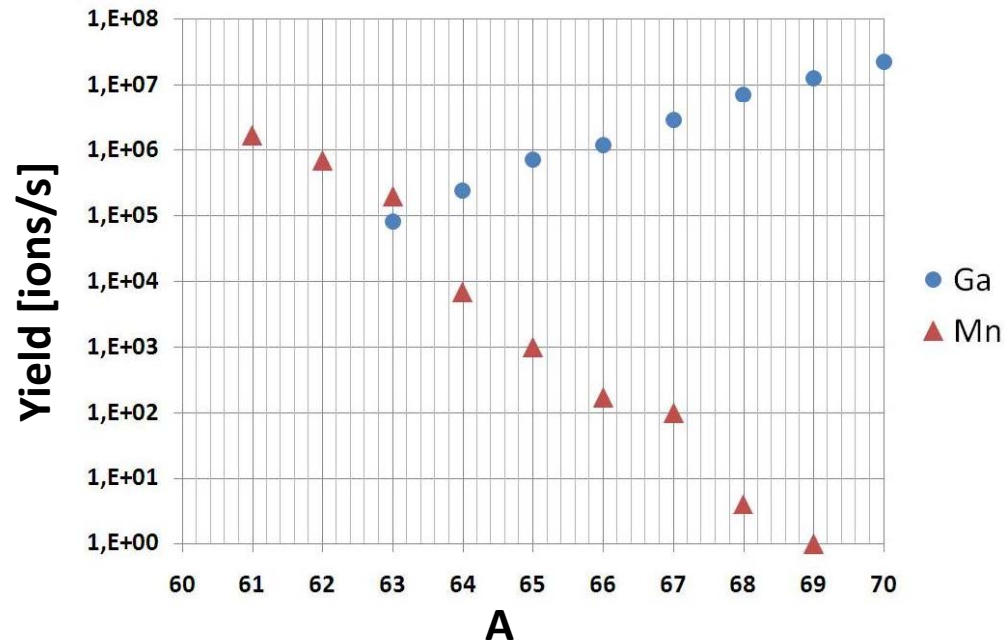
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Test beamtime : $^{61}\text{Mn} - ^{61}\text{Fe}$: 4 shifts

✓ Yield $^{61}\text{Mn} = 1.7\text{E}6/\mu\text{C}$ (UC_x target + RILIS)

✓ ^{61}Ga ($T_{1/2}=168$ ms) contamination minimal

✓ Half life $^{61}\text{Mn} = 0.67(4)$ s



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→ Change trapping + breeding time : 50 - 200 - 400 ms

→ Change only trapping/breeding time and fix breeding/trapping time

→ Test the usage of the RFQ as injector to EBIS

Monitor the change in beam composition

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T [*]	Fe content	
	Analytical	Simulation [**]
50 ms	7%	6%
200 ms	26%	12%
400 ms	46%	29%

[*] T = Trapping time = Charge breeding time

[**] From F. Ohlsson MSc thesis, Chalmers University 2007

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- ✓ Half life $^{62}\text{Mn} = 0.671(5)$ s [1] + possible isomeric state of 92(13) ms



(1⁺) [3] ————— 92(13) ms [2] $P_n = 2.9(5)\%$ [1]

(3⁺) [3] ————— 671(5) ms [1] $P_n = 6.4(2)\%$ [1]

**Both produced,
7.0E5/ μC probably g.s.**

[1] M. Hannawald, PhD Thesis, U. Mainz 1999

[2] O. Sorlin et al., NPA 669, 351-367 (2000)

[3] G. Audi et al., NPA 729 ,3-128 (2003)

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→ Fix trapping + breeding time to longest possible ($\geq T_{1/2}$)

→ Check beam composition (no problem with normalization)

→ Perform Coulomb excitation on 4.0 mg/cm² ^{109}Ag target

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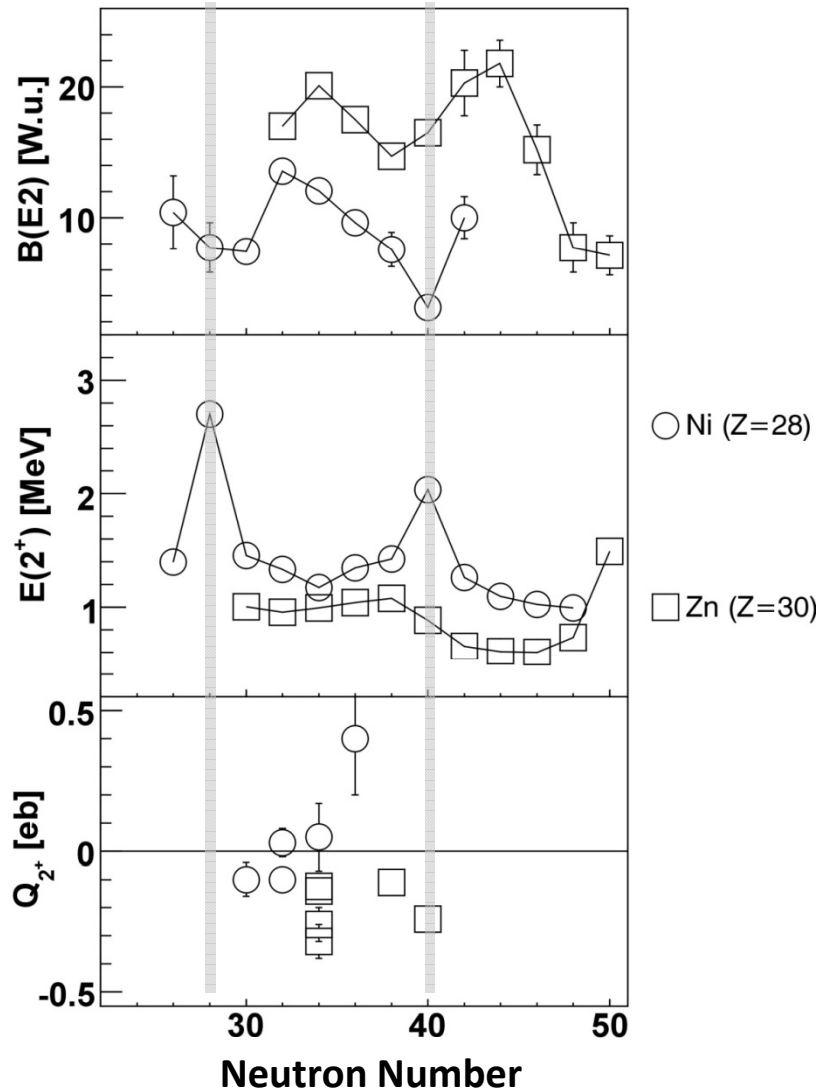
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Nuclear Structure Interest

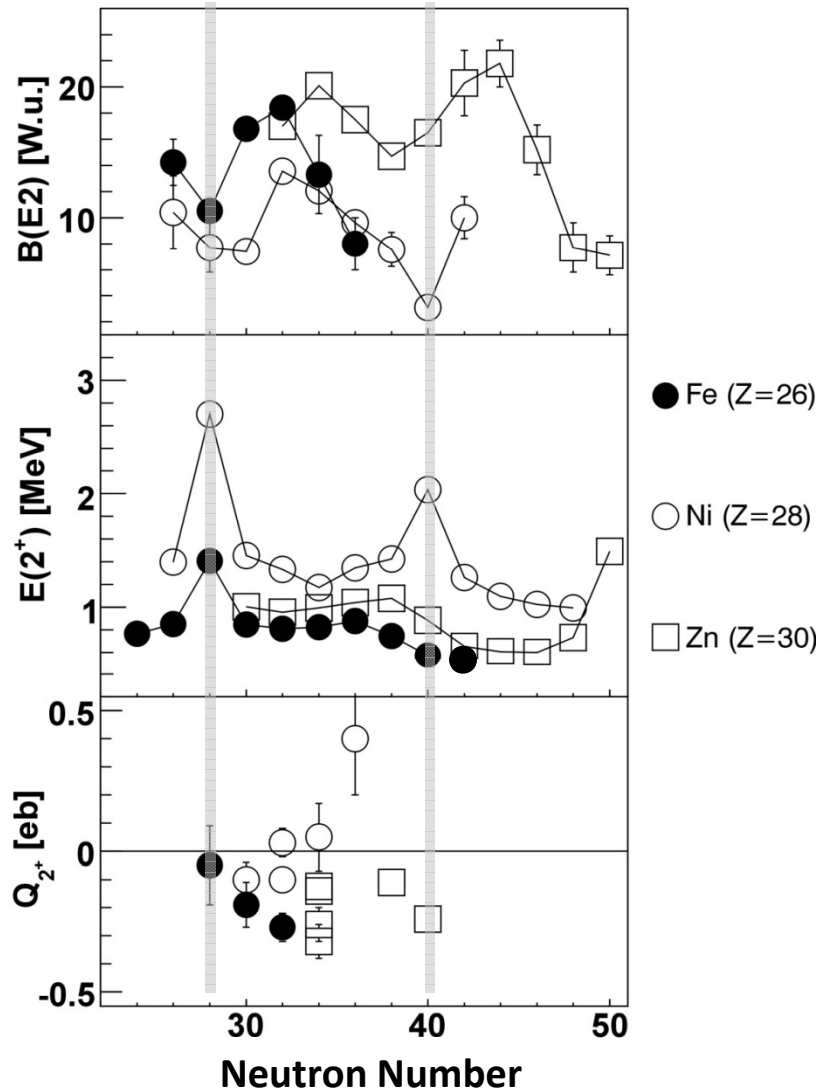
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Increased collectivity for $Z > 28$
and $38 < N < 44$

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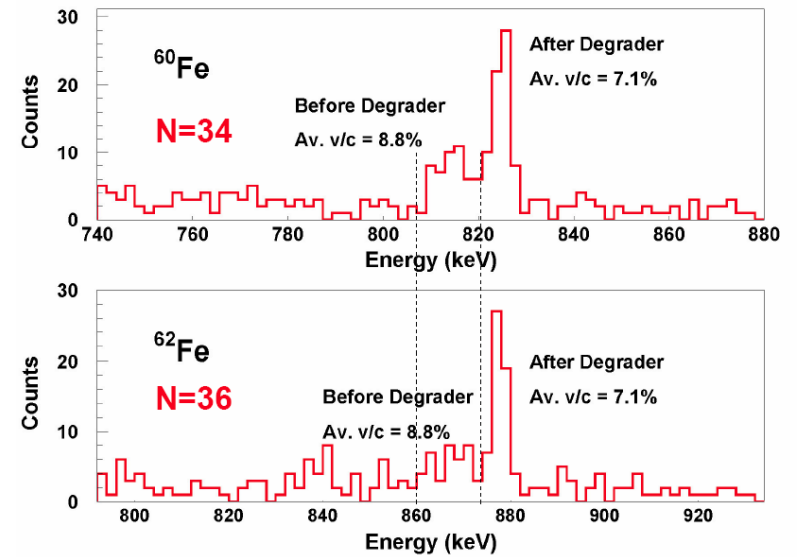
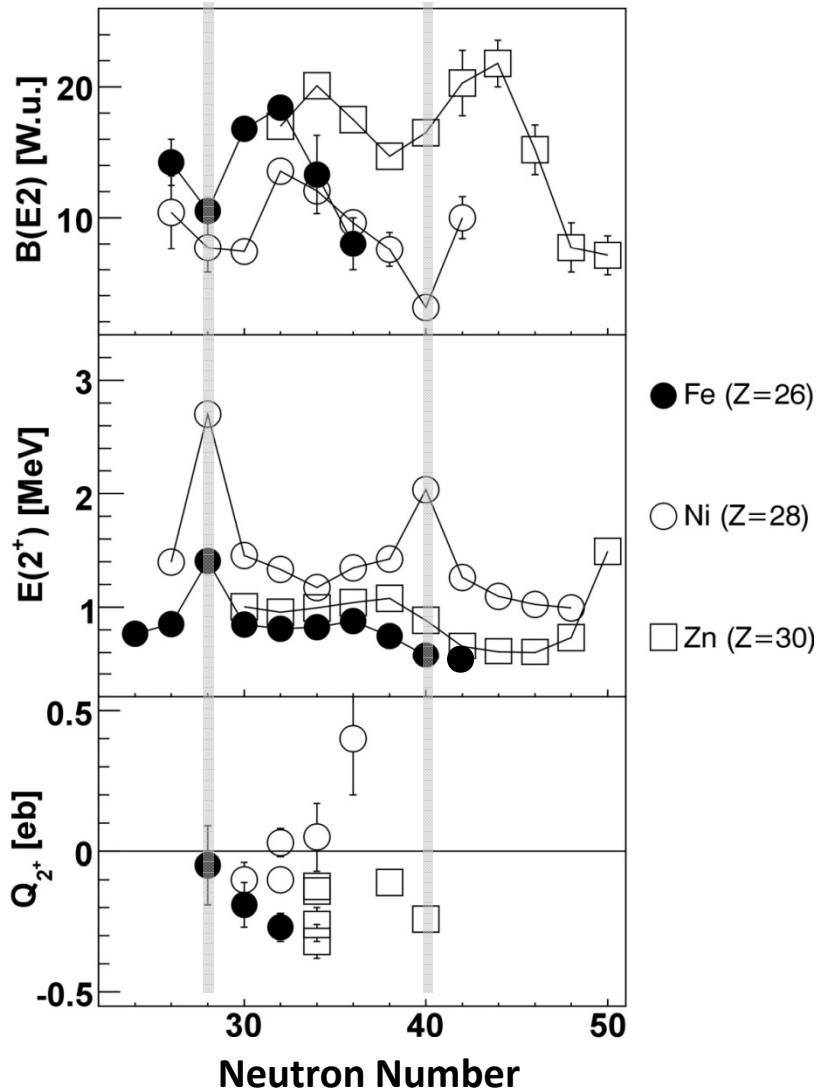


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ALSO for $Z < 28$, ex. $Z=26$ (Iron)
And $36 < N < ??$

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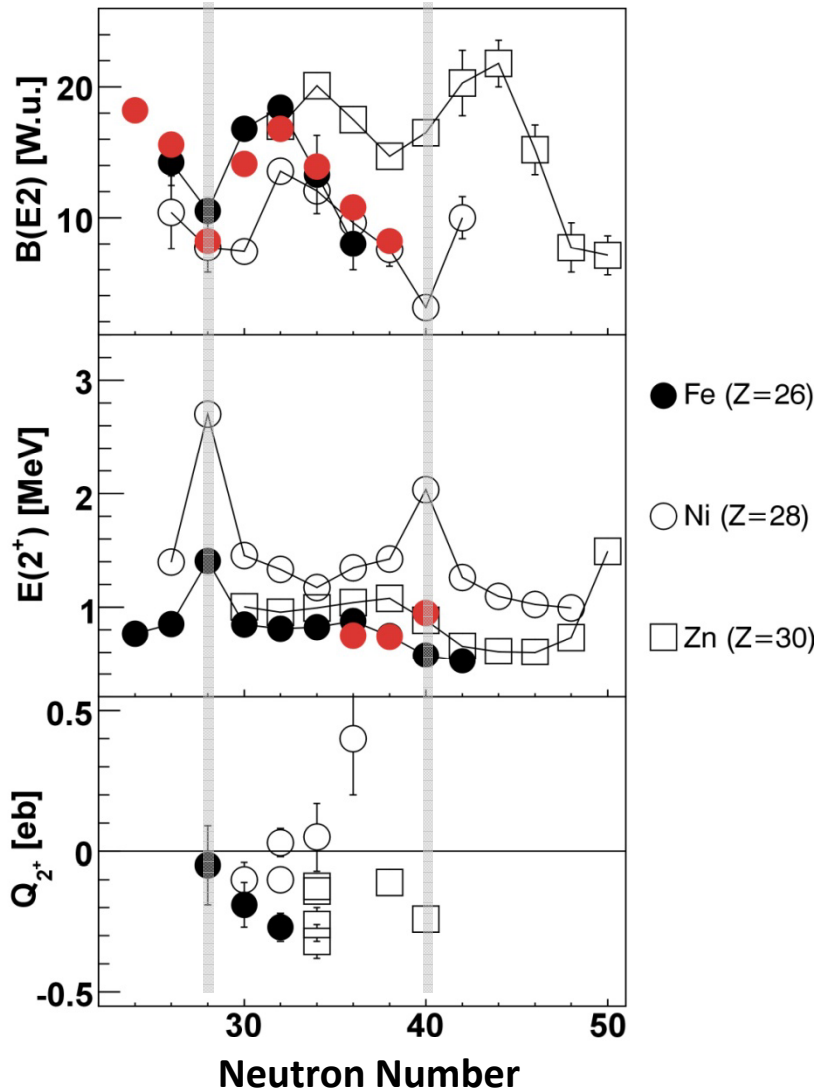
$$2^+ T_{1/2} = 9.5(20)\text{ps}$$

$$B(E2) = 8(2)\text{ W.u.}$$

Lifetime measurements at Legnaro,
Picture from presentation by
A. Gadea, Conference on Trends in Nuclear Structure,
Zakopane 4-10 sept. 2006

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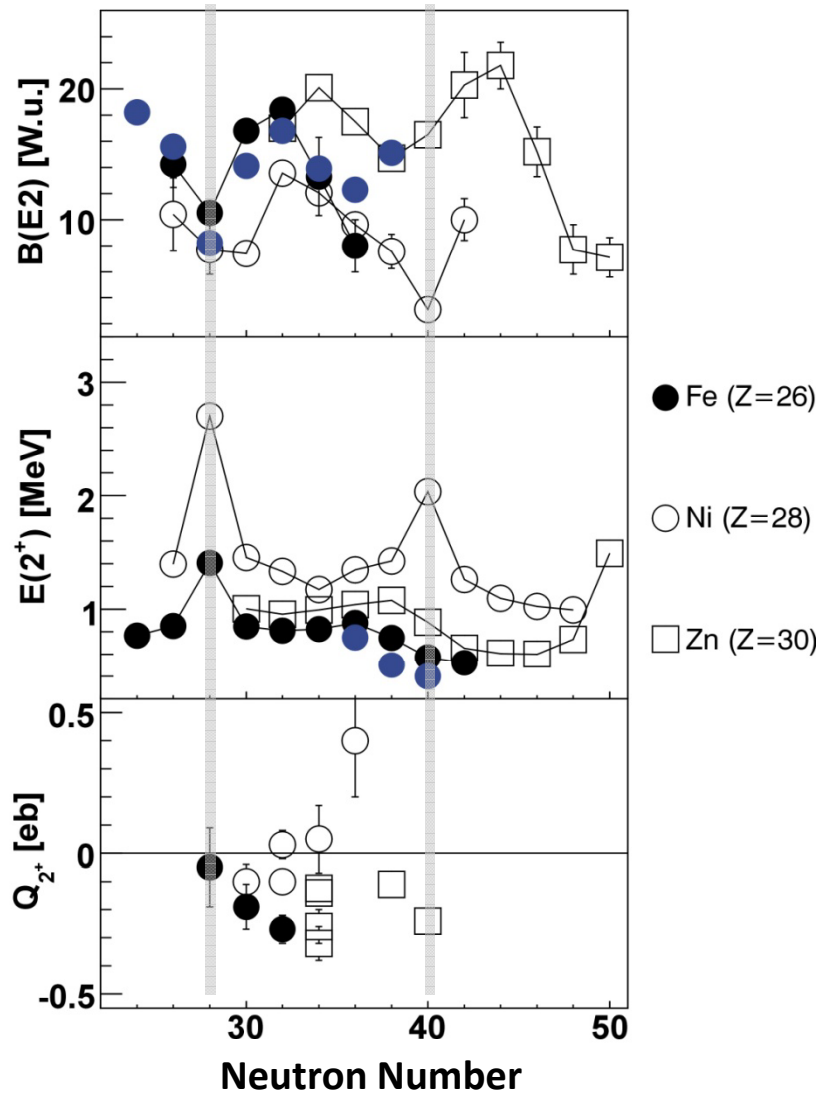


Calculations from Caurier et al.
EPJA, 15, 145-150 (2002)

● Fe (Z=26) ● pf-shell (KB3G interaction)
○ Ni (Z=28)
□ Zn (Z=30)

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- 2/ Why investigating it ?
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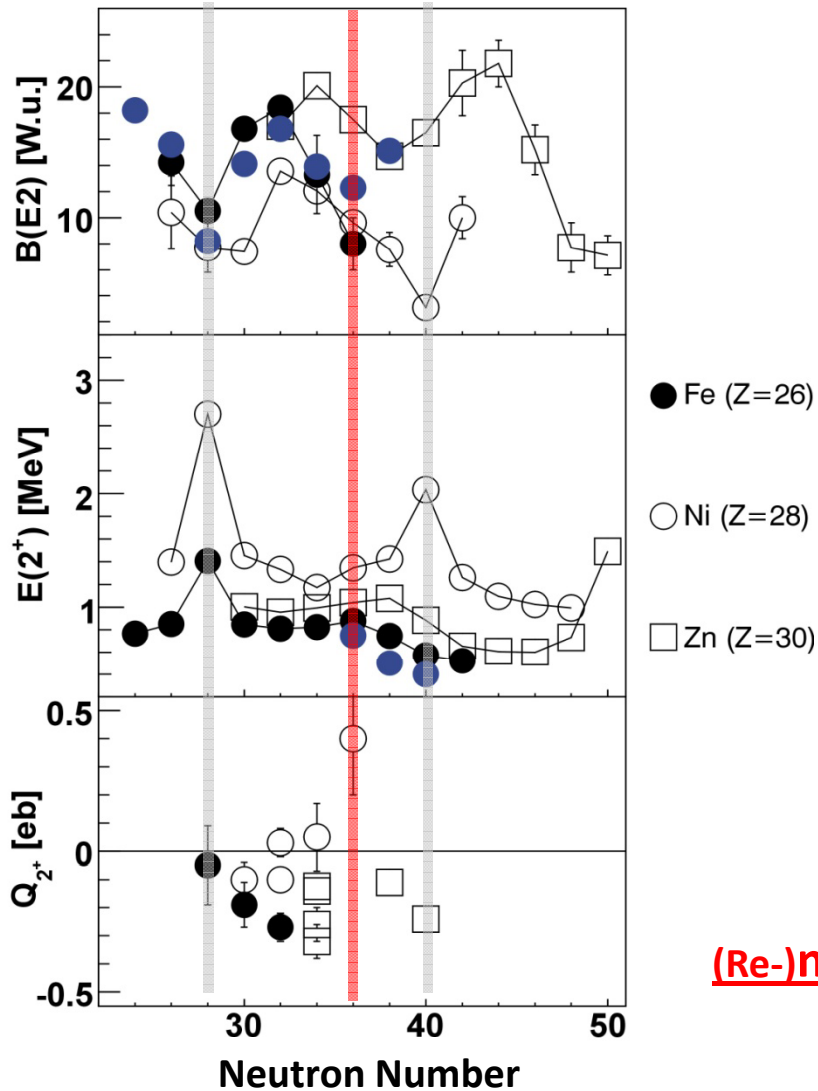
Calculations from Caurier et al.
EPJA, 15, 145-150 (2002)

● pf-shell (KB3G interaction)
● pfgd (^{52}Ca core)

How do the $1g_{9/2}$ and possibly $2d_{5/2}$ neutron orbitals influence the quadrupole collectivity below Z=28 ?

Nuclear Structure Interest

- 1/ In-Trap decay and beam contamination : is there a problem ?
- 2/ Why investigating it ?
- 3/ Test beam and application : Coulomb excitation of $^{62}\text{Mn}/^{62}\text{Fe}$

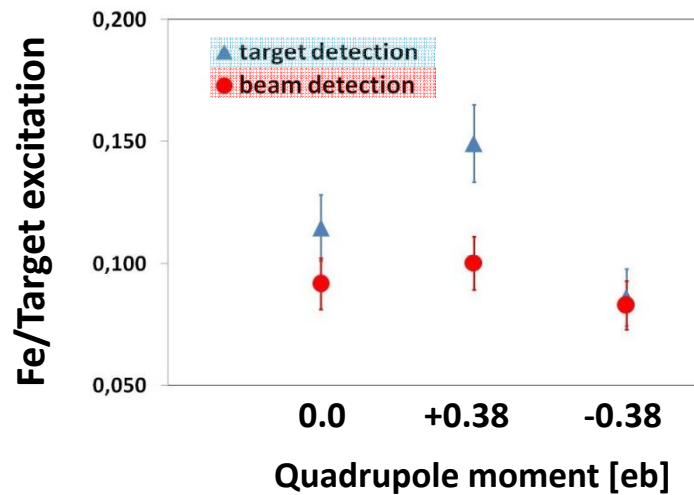
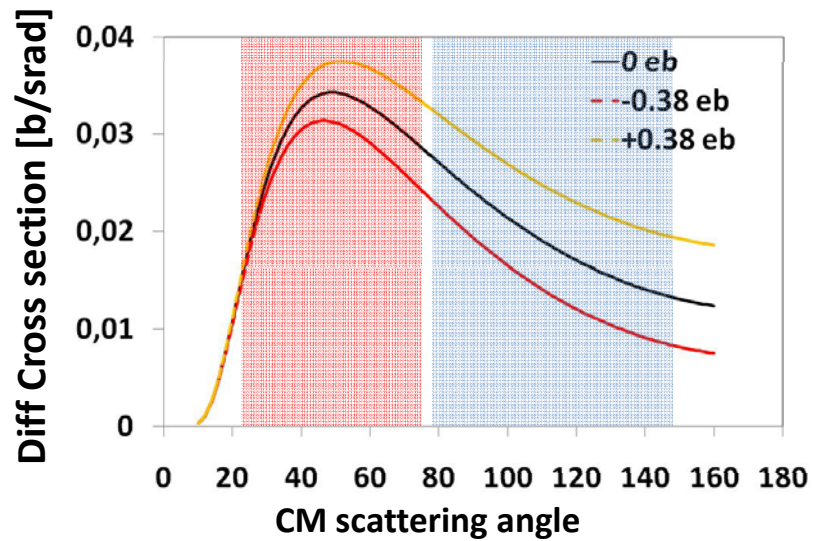


Calculations from Caurier et al.
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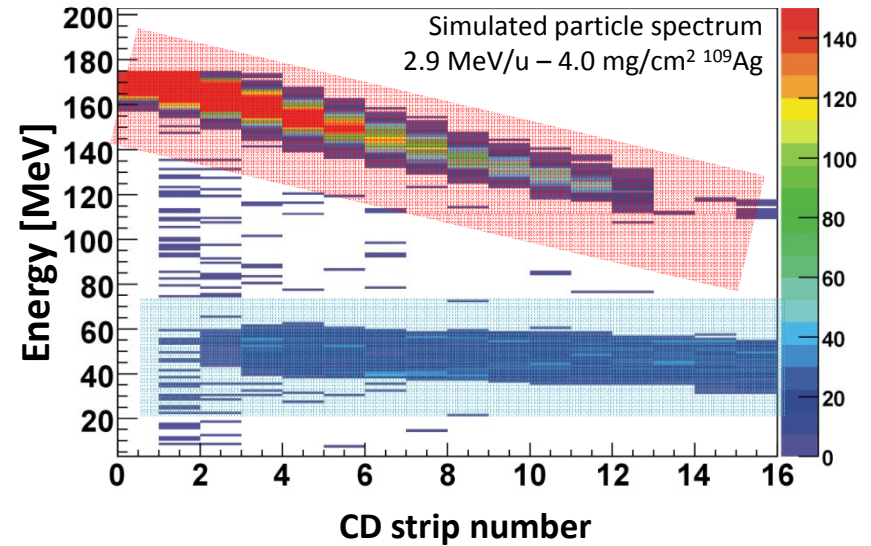
How do the $1g_{9/2}$ and possibly $2d_{5/2}$ neutron orbitals influence the quadrupole collectivity below Z=28 ?

(Re-)measure the (unpublished) B(E2) value in ^{62}Fe

Nuclear Structure Interest



- 1/ In-Trap decay and beam contamination : is there a problem ?
- 2/ Why investigating it ?
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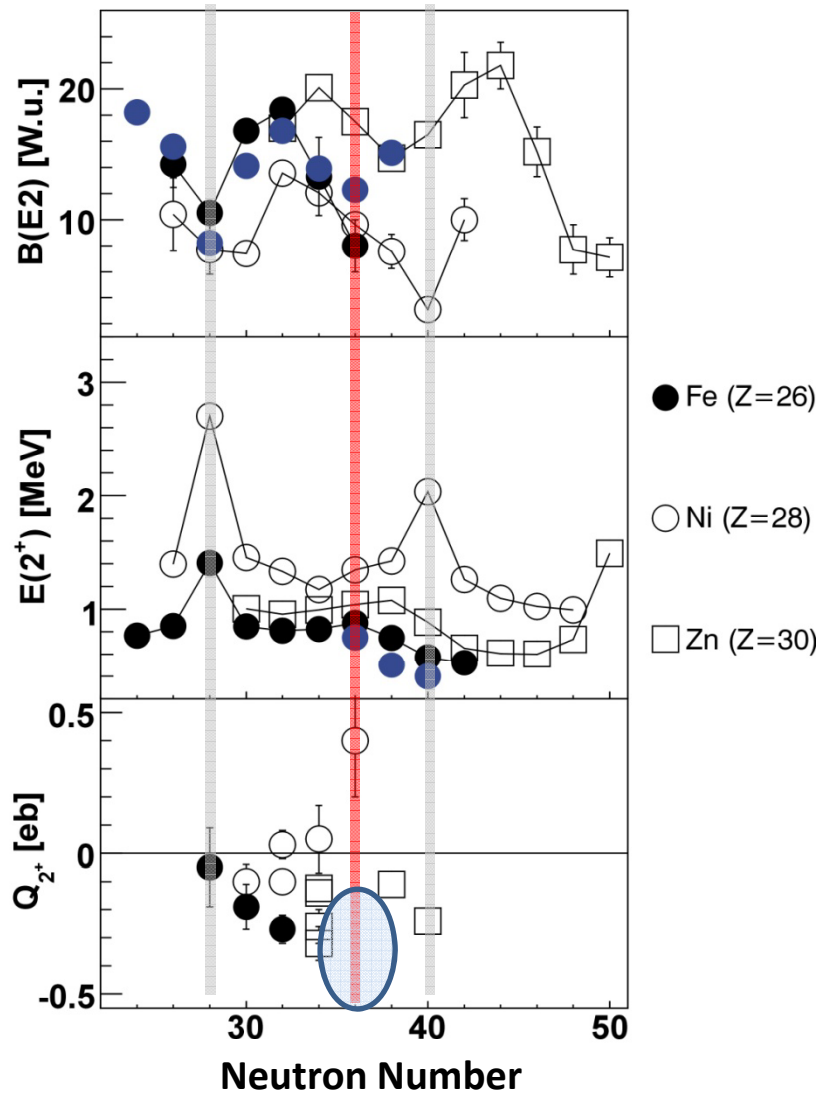


Statistics in 4 shifts assuming :
 200 ms trapping and breeding time
 2 μA proton beam
 4 mg/cm^2 ^{109}Ag target

Sensitivity to quadrupole moment :
 -Target and beam detection in CD detector
 -Combination with lifetime measurements

Nuclear Structure Interest

- 1/ In-Trap decay and beam contamination : is there a problem ?
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Sensitivity to quadrupole moment :

- Target and beam detection in CD detector
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- 1/ In-Trap decay and beam contamination : is there a problem ?
- 2/ Why investigating it ?
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CONCLUSION : RADIOACTIVE BEAM TIME REQUEST : **8 SHIFTS**

4 shifts :

- ^{61}Mn
- 1 shift optimization Bragg chamber + dE-E
- 3 shifts characterizing the change in beam composition with different trapping/charge breeding times

4 shifts :

- ^{62}Mn
- Coulomb excitation on Ag target to obtain a relevant physics result