

# A New Setup for Transfer Reactions at REX-ISOLDE

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IKS, K.U.Leuven

**DREB  
2007** **Direct Reaction  
with Exotic Beams**

Riken, 30 May – 2 June, 2007

# Collaboration

- Instituut voor Kern-en Stralingsfysica, K.U.Leuven, Belgium

BriX



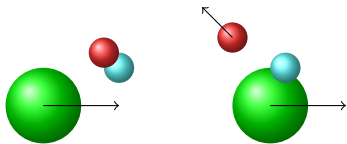
Belgian Research Initiative on eXotic nuclei

- Physik-Department E12, T.U. München, Germany
- The Miniball Collaboration
- Manchester, York, Edinburgh
- **V. Bildstein** (T.U. München), **N. Patronis** (IKS, K.U.Leuven)

# Outline

- 1 **Transfer reactions with RIBs**
- 2 **REX-ISOLDE at CERN**
  - Ion Sources
  - The REX post-accelerator
  - Miniball  $\gamma$ -array
- 3 **New setup for charged particles: T-REX**
  - Detector
  - Electronics
- 4 **First physics cases**
  - $d(^{30}\text{Mg}, ^{31}\text{Mg})p$
  - $d(^{66}\text{Ni}, ^{67}\text{Ni})p$
- 5 **Summary**

# Transfer as spectroscopic tool



- Q-values  $\Rightarrow$  position of levels
- Angular distribution  
 $\Rightarrow$  spin and parities
- Cross sections  
 $\Rightarrow$  (relative) spectroscopic factors, ANCs

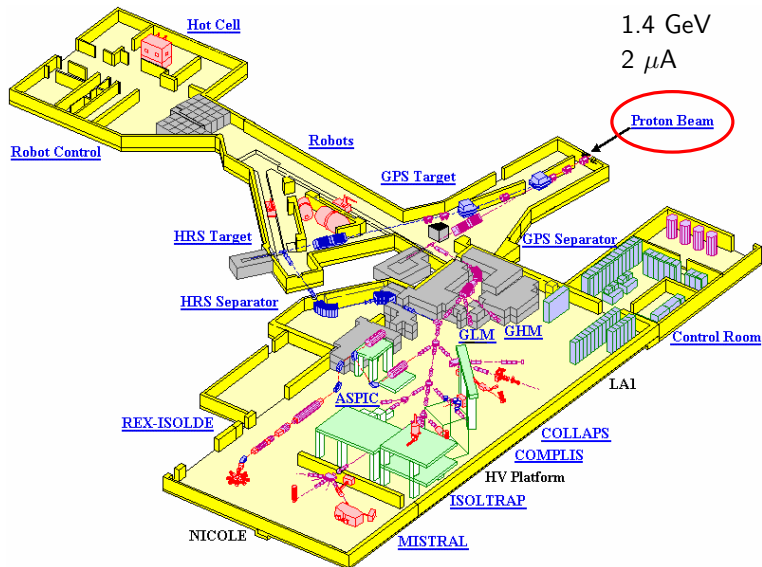
## Measuring with RIBs

- Inverse kinematics
- Low intensity beams ("thick" targets)
- Detection of  
beam-like ejectile  $\Rightarrow$  spectrometer  
target-like ejectile  $\Rightarrow$  Si array  
 $\gamma$ -rays  $\Rightarrow$  Ge array

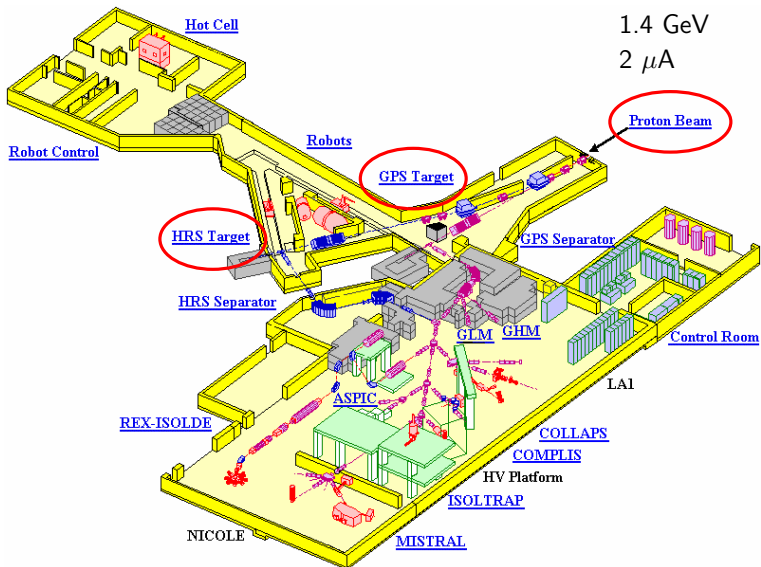
## Problems

- Energy (angular) resolution
- Efficiency
- Background

# REX-ISOLDE @ CERN



# REX-ISOLDE @ CERN



# ISOLDE Ion Sources

Ion source:																			
		+		Surface		-													
		hot		Plasma		cool													
				Laser															
1 H																	2 He		
3 Li	4 Be													5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg													13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr		
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe		
55 Cs	56 Ba	* 71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn		
87 Fr	** 88 Ra	** 103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg									
		* 57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb				
		** 89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No				

# ISOLDE Ion Sources

## RILIS: Resonant Ionization Laser Ion Source

1																	2
H																	He
3	4											5	6	7	8	9	10
Li	Be											B	C	N	O	F	Ne
11	12											13	14	15	16	17	18
Na	Mg											Al	Si	P	S	Cl	Ar
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
87	88	89	104	105	106	107	108	109	110	111	112						
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt									

58	59	60	61	62	63	64	65	66	67	68	69	70	71
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
90	91	92	93	94	95	96	97	98	99	100	101	102	103
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

- **Currently available**
- **Tested**
- **Feasible**

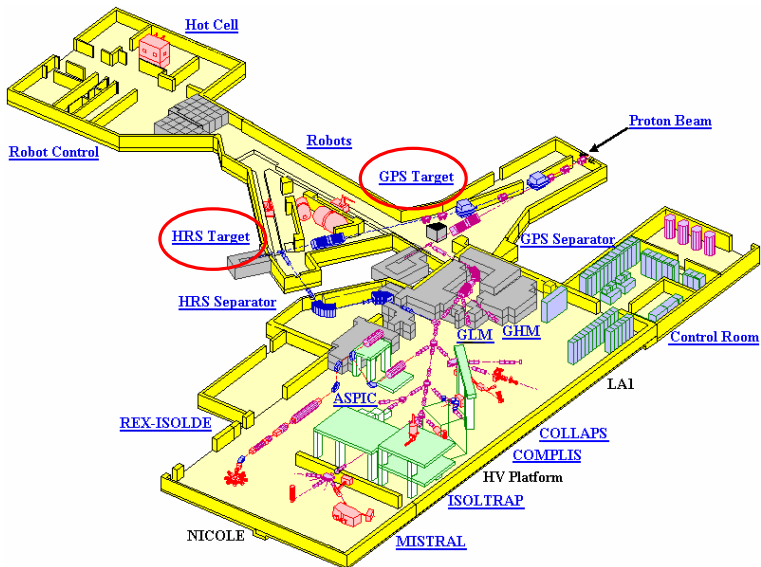
### Isomeric Beams

I. Stefanescu, PRL 98 (2007) 122701  
 COULEX with  $^{68m,70g}\text{Cu}$

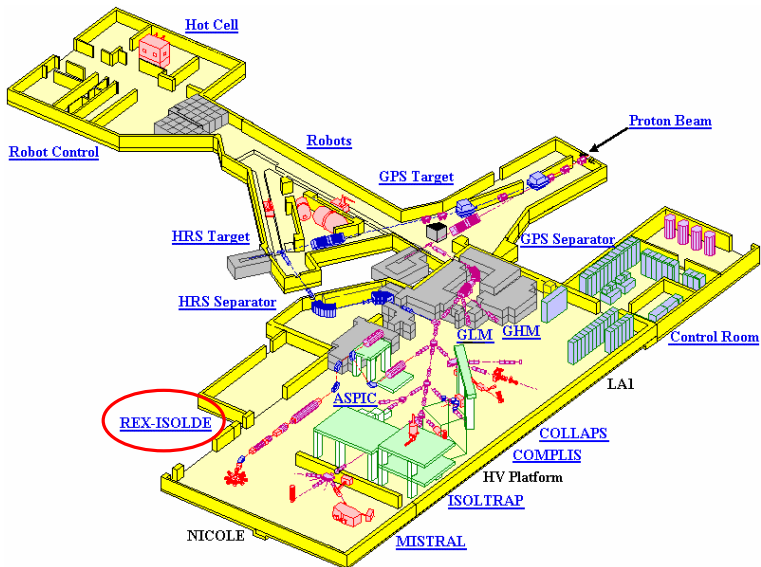




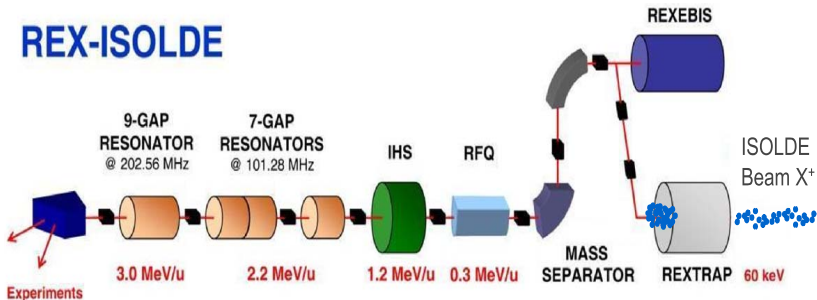
# REX-ISOLDE @ CERN



# REX-ISOLDE @ CERN

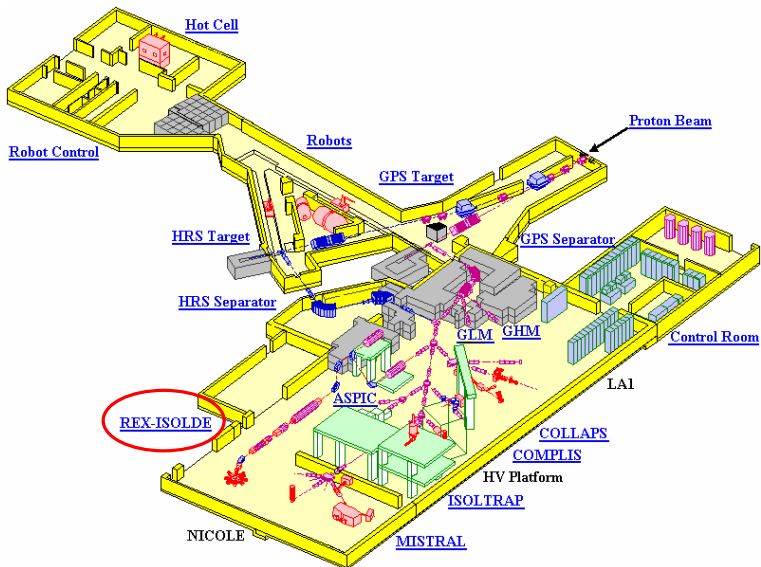


# REX: Radioactive Beam EXperiment

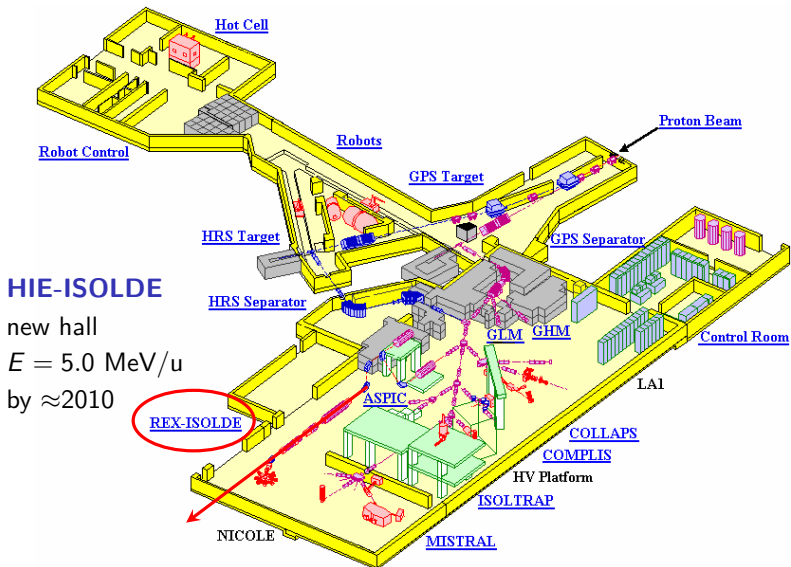


- REXTRAP: Penning trap at 60 kV
- REXEBS: Efficiency  $\lesssim 30\%$   
 $\tau = 10\text{-}100$  ms  
 $A/q < 4.5$ , pulse width  $< 100\mu\text{s}$
- Separator:  $q/A$  resolution  $\approx 150$
- LINAC:  $L = 10$  m  
 $0.8 < E < 3.0$  MeV/u
- **Total efficiency: 1-5%**

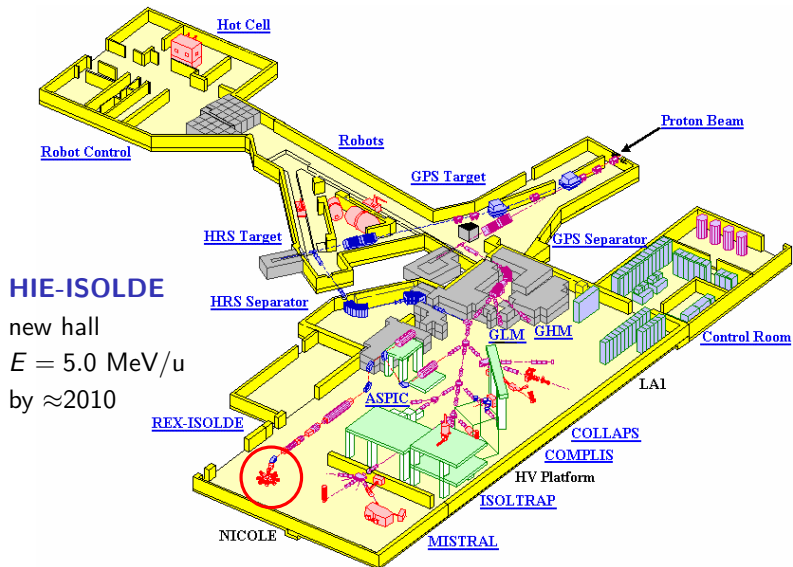
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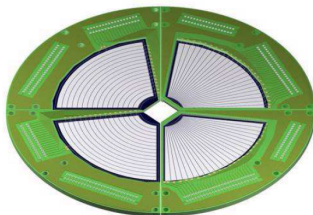


# Miniball Ge-array



- Emphasis on efficiency:  
20% @ 1.3 MeV photopeak
- High granularity:  
8 clusters  $\times$  3 detectors  $\times$   
6 segments  
+ pulse-shape analysis
- Rate 10 kHz per detector
- Resolution 2-3 keV

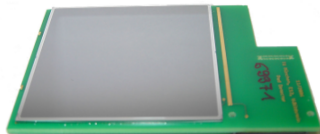
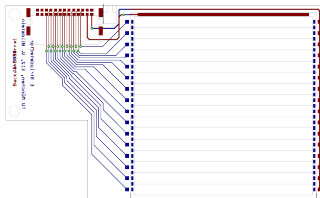
# The charged-particle detector array (T-REX)



Detector	Angles (deg)	Thickness ( $\mu\text{m}$ )	Segmentation
CD Front $\Delta E$	8-27	300-500	$4 \times 16 \times 24$
CD Front $E$	8-27	1500	4

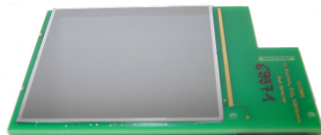
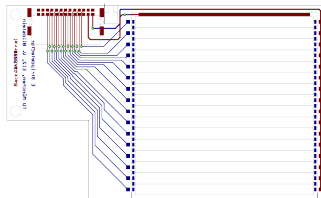


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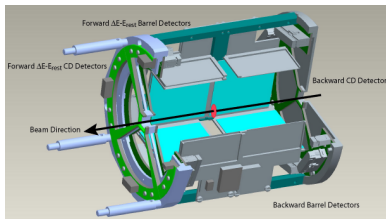
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Barrel forward $\Delta E$	31-78	60-140	$4 \times 16$ PSD
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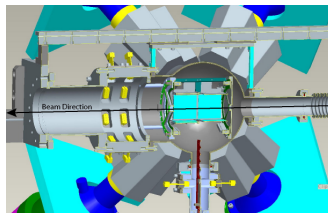
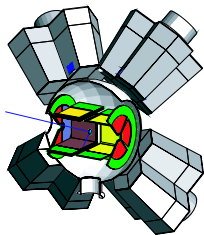
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Barrel forward $E$	31-78	1000	4
Barrel backward $E$	99-148	1000	$4 \times 16$ PSD
CD Back $E$	153-172	300-500	$4 \times 16 \times 24$

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# Electronics for T-REX

- Miniball: triggerless acquisition (DGF modules, 3200 \$/channel)
- T-REX:  $\approx$  450 channels

⇒ Limit the number of channels



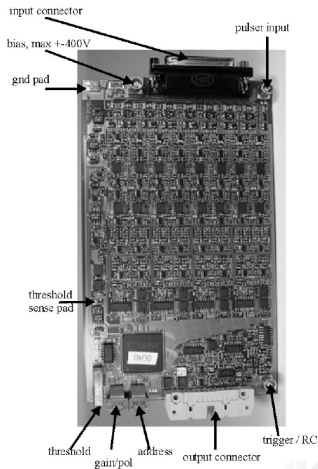
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## Mesytec MUX-16

- 16-into-2 channels (4 outputs)
- Low noise, high rate (500 MHz)
- One NIM trigger / LE timing
- Multiplicity (veto) output
- Replaceable preamp stage  
⇒ different ranges possible
- Eight modules on the same bus  
⇒ 128 channels into 4

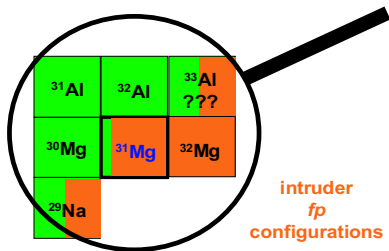
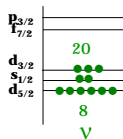


▶ Electronics scheme

# First case: $d(^{30}\text{Mg}, ^{31}\text{Mg})p$

## Single-particle states in $^{31}\text{Mg}$

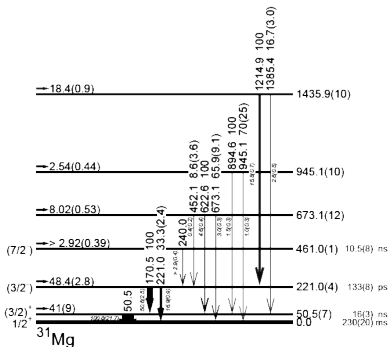
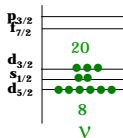
- Border of the “island of inversion”  
Niedermeier PRL 94 (2005) 172501



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- Border of the “island of inversion”  
Niedermeier PRL 94 (2005) 172501
- Studied with  $\beta$ -NMR, laser,  $\beta$ -decay  
Neyens PRL 94 (2005) 022501  
Maréchal PRC 72 (2005) 044314

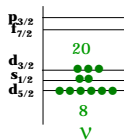




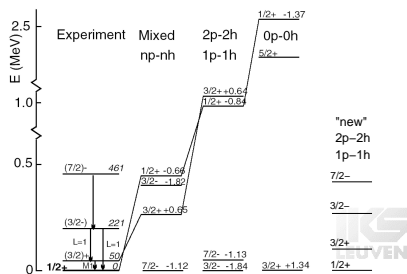
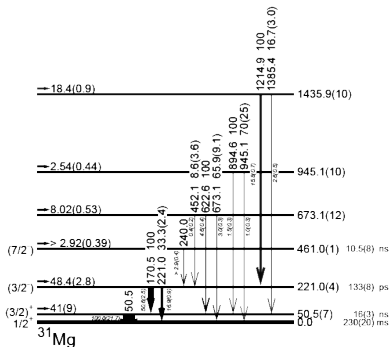
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Neyens PRL 94 (2005) 022501  
Maréchal PRC 72 (2005) 044314



- Ground state, first excited state:  
> 95% 2p-2h intruder

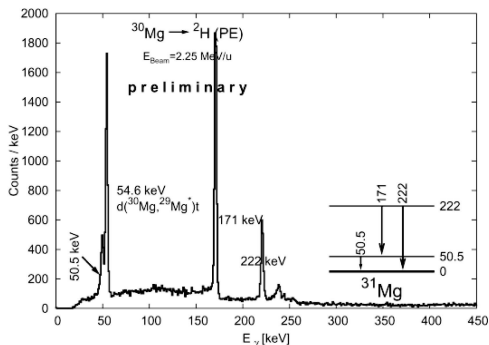


# $d(^{30}\text{Mg}, ^{31}\text{Mg})p$ with T-REX + Miniball

- $^{30}\text{Mg}$  at 3.0 MeV/u,  $5 \times 10^4$  pps

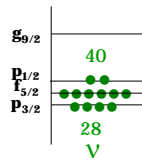
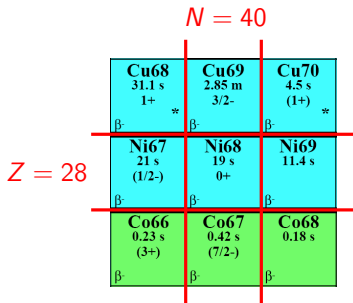
# $d(^{30}\text{Mg}, ^{31}\text{Mg})p$ with T-REX + Miniball

- $^{30}\text{Mg}$  at 3.0 MeV/u,  $5 \times 10^4$  pps
- Coincidence with  $\gamma$ 's to identify the states
- p, d, bgr identified in telescopes



# d( $^{66}\text{Ni}, ^{67}\text{Ni}$ )p

## The $N = 40$ subshell closure

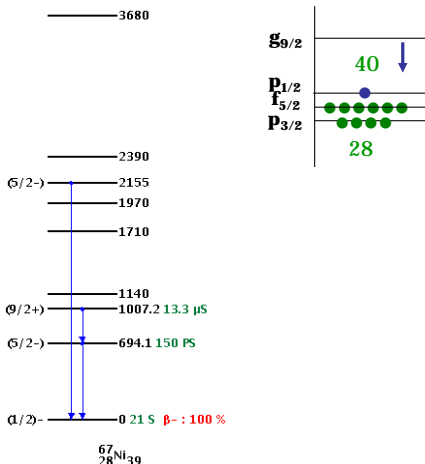


- Neighbours of  $^{68}\text{Ni}$  probed by  $\beta$ -decay (and Coulex on  $^{69}\text{Cu}$ )
- $N = 40$  strongly weakened by adding/removing a nucleon

⇒ Measure *structure of states*

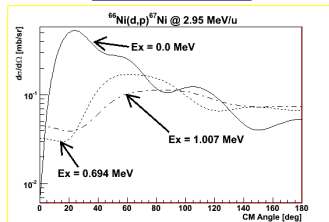
► Details

# $d(^{66}\text{Ni}, ^{67}\text{Ni})p$ with T-REX + Miniball



- $^{66}\text{Ni}$  at 3 MeV/u,  $10^6$  pps
- Prompt and delayed  $\gamma$ -coincidence

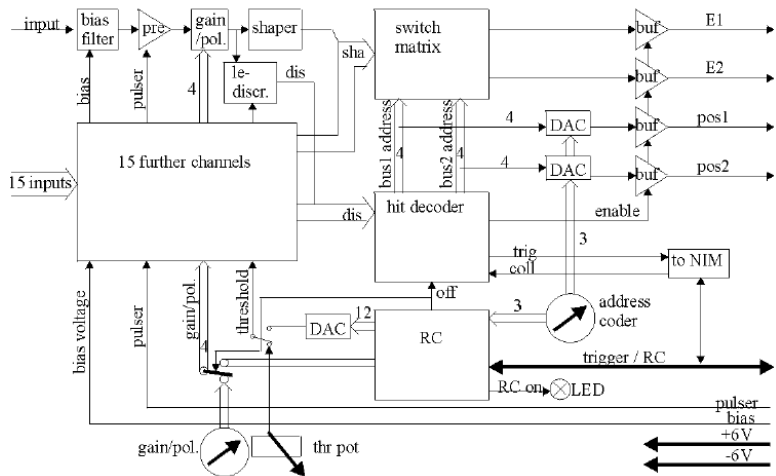
$$\begin{aligned}
 v(g_{9/2}) &\Rightarrow 9/2^+ ; l=4 \\
 v(p_{1/2}) &\Rightarrow 1/2^- ; l=1 \\
 v(f_{5/2}) &\Rightarrow 5/2^- ; l=3 \\
 v(p_{3/2}) &\Rightarrow 3/2^- ; l=1
 \end{aligned}$$



# Summary

- New charged particle detection setup at REX-ISOLDE to measure transfer reactions
- Coupling with Miniball
- First measurement:  $d(^{30}\text{Mg}, ^{31}\text{Mg})p$  in 2007
- First test of the setup at Munich with  $d(^{64}\text{Ni}, ^{65}\text{Ni})p$

# MUX-16 electronic scheme



← back



# Around $^{68}\text{Ni}$

$^{68}\text{Ni} \otimes (\nu^{-1} \pi^{+1})$			
$\pi p_{1/2}$	$\nu p_{1/2}^{-1}$	<u>1+</u>	<u>842</u>
		<u>2+</u>	<u>84</u>
$\pi p_{3/2}$	$\nu p_{1/2}^{-1}$	<u>1+</u>	<u>0</u>

J. Van Roosbroeck, Phys.Rev.C 69 2004

$^{68}\text{Ni} \otimes (\pi^{+1})$			
$\pi g_{9/2}$		<u>9/2+</u>	<u>2553</u>
$\pi f_{5/2}$		<u>5/2-</u>	<u>1214</u>
$\pi p_{1/2}$		<u>1/2-</u>	<u>1110</u>
$\pi p_{3/2}$		<u>3/2-</u>	<u>0</u>

S. Franchoo Ph.D. Thesis, Leuven 1999

$^{68}\text{Ni} \otimes (\nu^{+1} \pi^{+1})$			
$\pi g_{9/2}$	$\nu g_{9/2}$	<u>1+</u>	<u>1980</u>
$\pi f_{5/2}$	$\nu g_{9/2}$	<u>2-</u>	<u>369</u>
$\pi p_{3/2}$	$\nu p_{1/2}^{-1}$	<u>1+</u>	<u>242</u>
	$(\nu g_{9/2})^{+2}$		
$\pi p_{3/2}$	$\nu g_{9/2}$	<u>6-</u>	<u>0</u>

J.Van Roosbroeck, Phys.Rev.C 69 2004

$^{68}\text{Ni} \otimes \nu^{-1}$			
$\nu g_{9/2}$	$(\nu p_{1/2})^{-2}$	<u>9/2+</u>	<u>1007</u>
$\nu f_{5/2}^{-1}$		<u>5/2-</u>	<u>694</u>
$\nu p_{1/2}^{-1}$		<u>1/2-</u>	<u>0</u>

L. Weissman, Phys.Rev.C 59 1999

$N = 40$

	$N = 40$			
	$\beta$	$\beta$	$\beta$	
$\beta$	Cu68 31.1 s 1+	Cu69 2.85 m 3/2-	Cu70 4.5 s (1+)	$\beta$
$\beta$	Ni67 21 s (1/2-)	Ni68 19 s 0+	Ni69 11.4 s	$\beta$
$\beta$	Co66 0.23 s (3+)	Co67 0.42 s (7/2-)	Co68 0.18 s	$\beta$
	$\beta$	$\beta$	$\beta$	

$Z = 28$

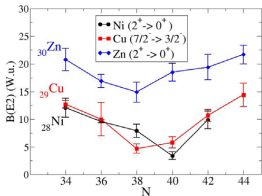
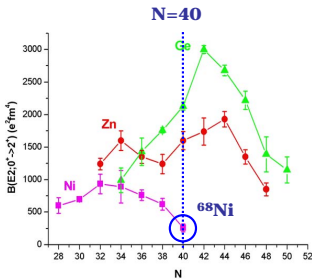
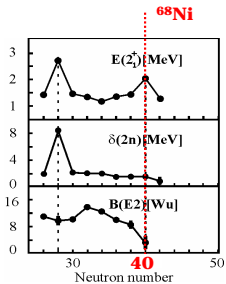
$^{68}\text{Ni} \otimes \nu^{+1}$			
$\nu p_{3/2}^{-1}$	$(\nu g_{9/2})^{+2}$	<u>3/2-</u>	<u>1400</u>
$\nu f_{5/2}^{-1}$	$(\nu g_{9/2})^{+2}$	<u>5/2-</u>	<u>915</u>
$\nu p_{1/2}^{-1}$	$(\nu g_{9/2})^{+2}$	<u>1/2-</u>	<u>321</u>
$\nu g_{9/2}$		<u>9/2+</u>	<u>0</u>

W.F. Mueller, Phys.Rev.Lett. 83, 1999





# Around $^{68}\text{Ni}$



Courtesy of I. Stefanescu

◀ back

