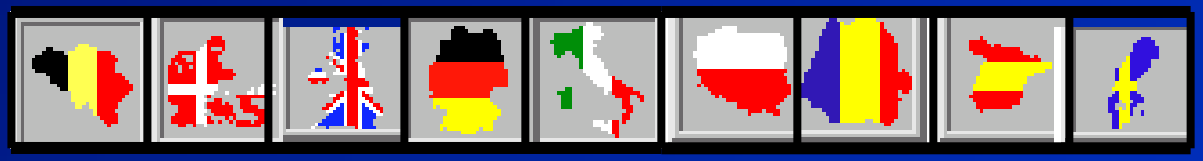
RISING

Rare ISotope INvestigation at GSI

F. Camera
University of Milano and INFN sez. Milano



Nuclear structure and dynamic of exotic nuclei

The Accelerators:

- **UNILAC** (injector) E<11.5 MeV/n
- **SIS 18Tm** U 1 GeV/n

Beam Currents: 10^8 - 10^9 pps

FRS ⇒ secondary radioactive ion beams:

- Fragmentation/fission of primary beams
- High secondary beam energies:
  - 100 – 700 MeV/u
- Fully stripped ions
- Reactions on a secondary target
- Implantation inside a stopper

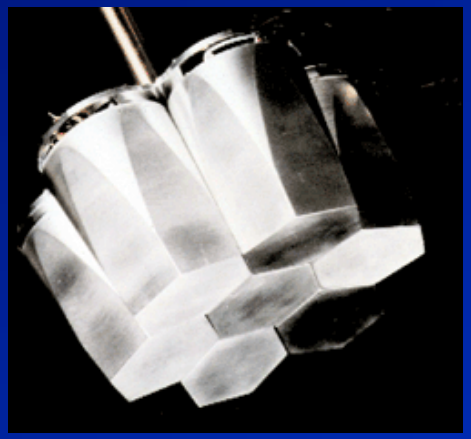
Why at FRS@GSI ?

RISING

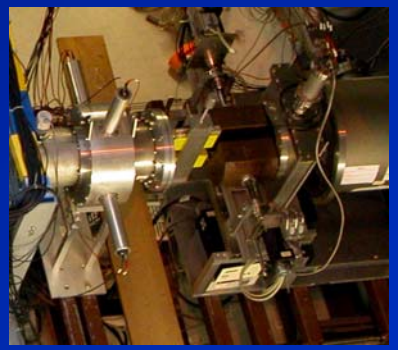
Unique European facility for relativistic ($\beta \geq 0.4$) exotic beams

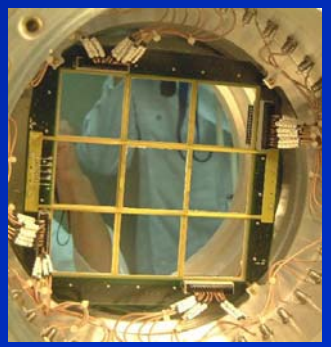
- High beam intensities
- lifetime range ≥ 100 ns
- fully stripped beams
- Spin Aligned beams
- Unique for exotic heavy nuclei

EUROBALL Cluster Detectors

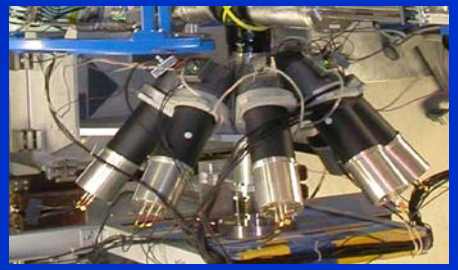


Beam Tracking system





Miniball – Hector Active Target



RISING

Beam Time

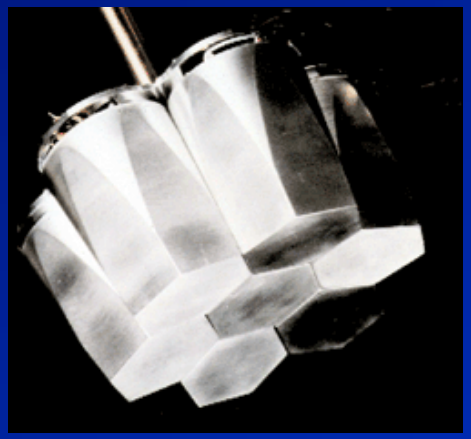
- Fast Beam Campaign ≈ 100 days
- g-factor Campaign ≈ 35 days
- Stopped Beam Campaign ≈ 100 days

Results

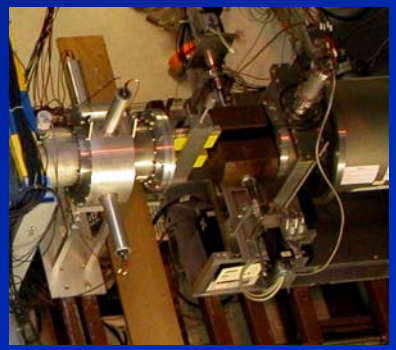
More than 40 papers

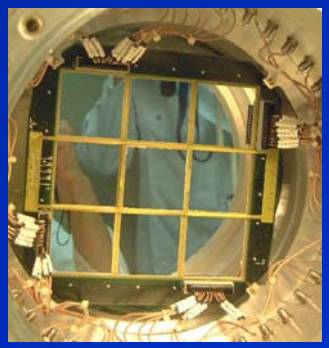
More than 50 talks at international conferences/workshops

EUROBALL Cluster Detectors

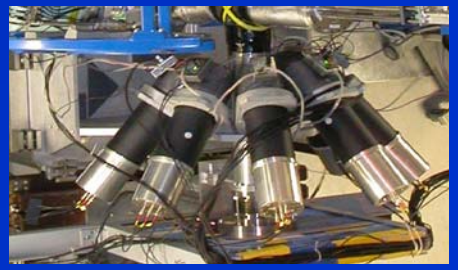


Beam Tracking system





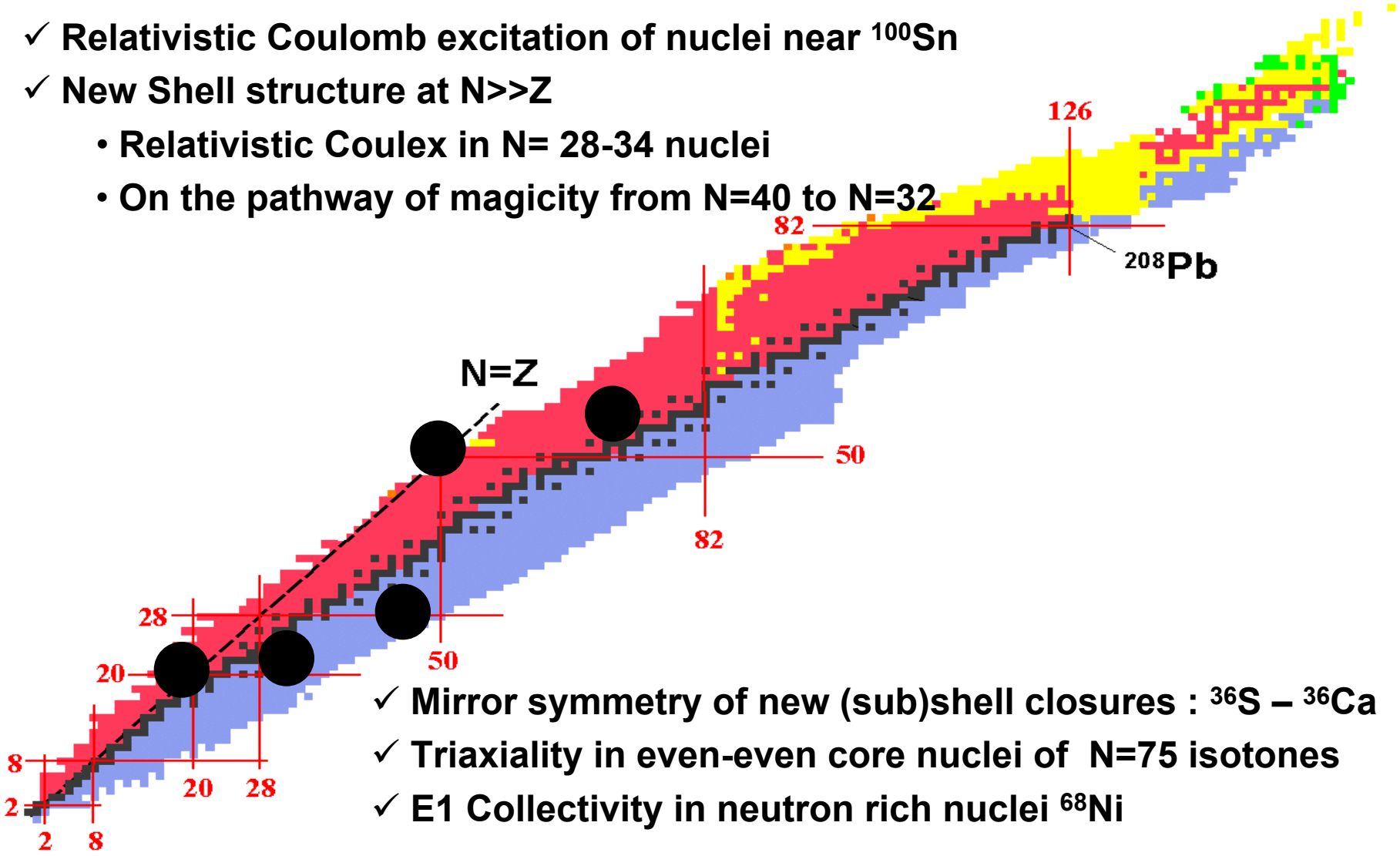
Miniball – Hector Active Target



Rising physics: FAST BEAM CAMPAIGN

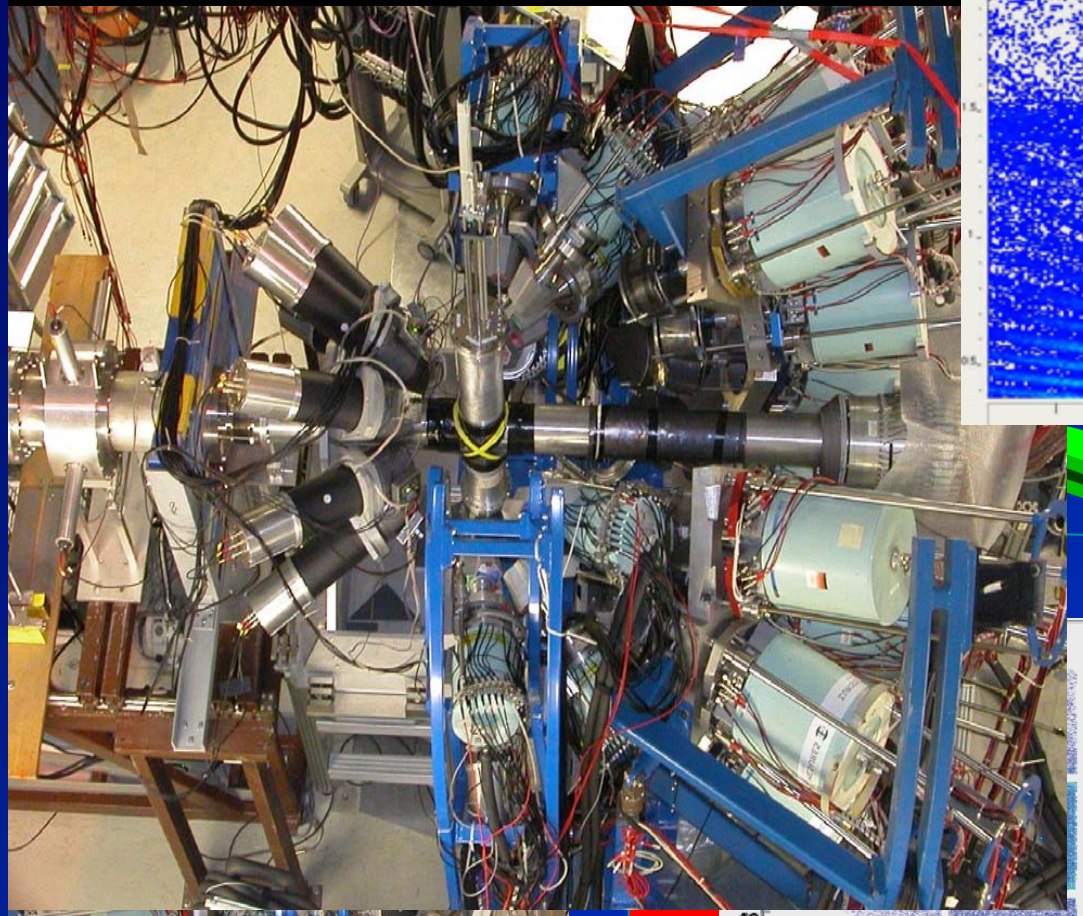
Coulomb Excitation and Fragmentation at Relativistic Energy

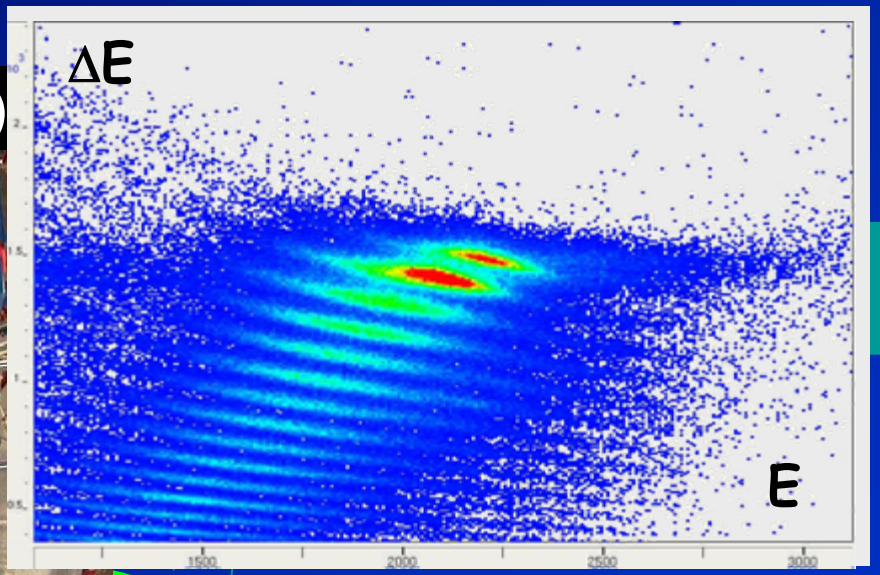
- ✓ Relativistic Coulomb excitation of nuclei near ^{100}Sn
- ✓ New Shell structure at N>>Z
  - Relativistic Coulex in N= 28-34 nuclei
  - On the pathway of magicity from N=40 to N=32



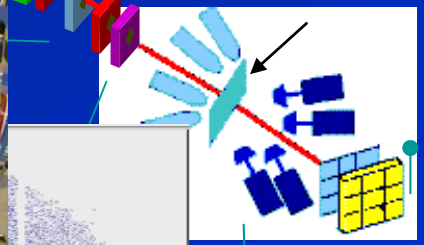
- ✓ Mirror symmetry of new (sub)shell closures : ^{36}S – ^{36}Ca
- ✓ Triaxiality in even-even core nuclei of N=75 isotones
- ✓ E1 Collectivity in neutron rich nuclei ^{68}Ni

Fast Beam Campaign (2003-2005)

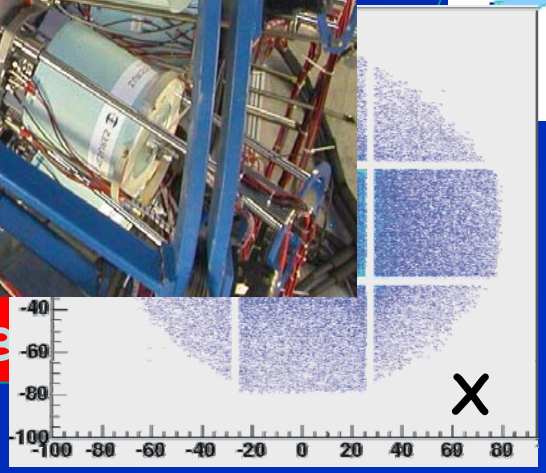




reaction target

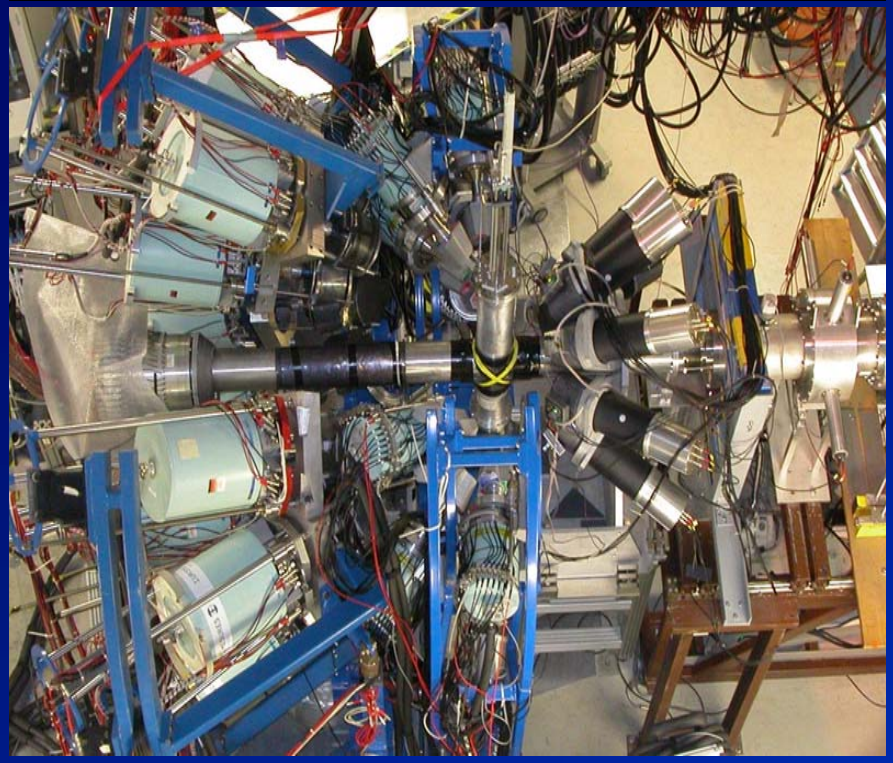


CATE
Si-CsI arrays;
(X,Y), Z,A



Ge-Cluster and
MINIBALL detectors

Fast Beam Campaign (2003-2005)

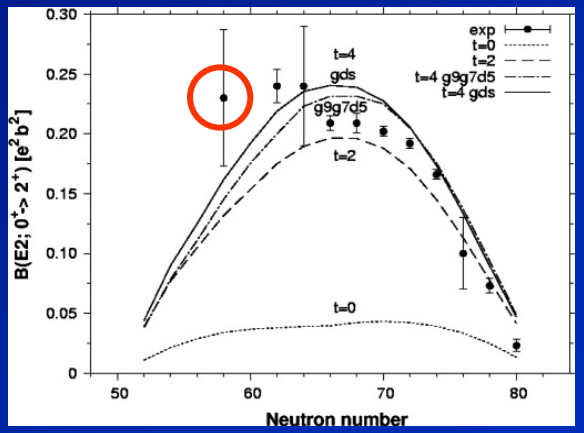


Evidence of low energy E1 collective Dipole strength PDR

Talk by O. Wieland

Some RESULTS

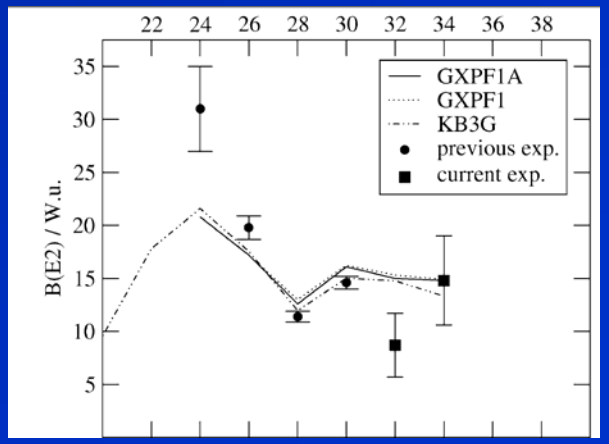
The B(E2) of the first 2^+ state in ^{108}Sn was measured



Data confirmed in a 2007 PRL from MSU

A,Banu et al PRC72(2005)061305R

The B(E2) of the first 2^+ state in ^{54,56,58}Cr was measured

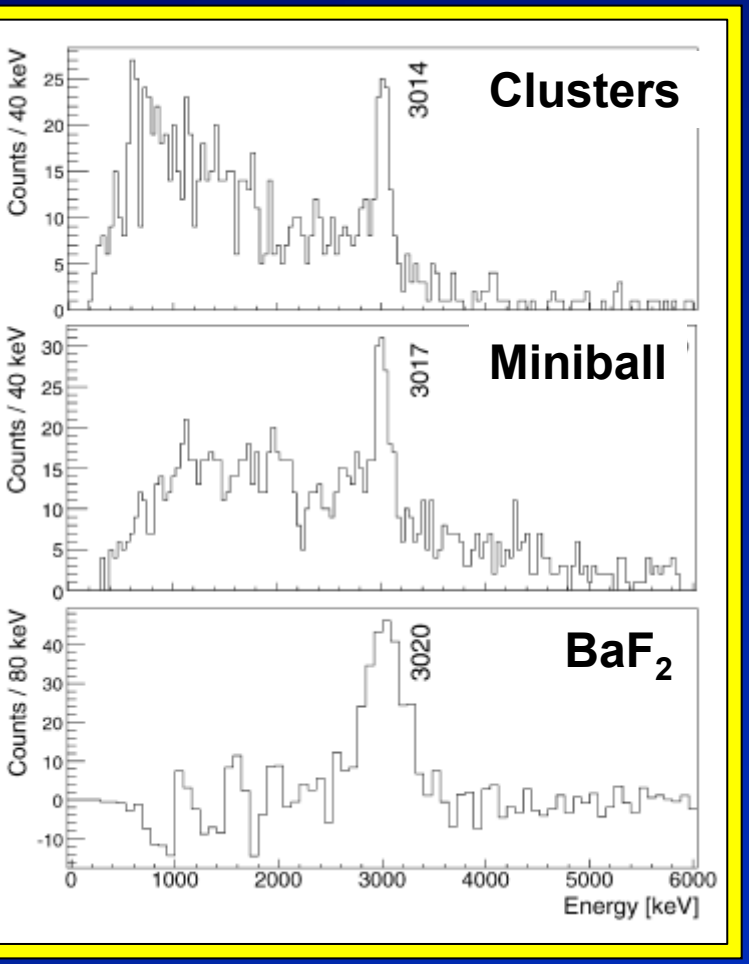


The results are consistent with a subshell closure at *N* = 32.
Shell model calculations fail to account for the *B*(E2) values at *N* = 32.

A. Burger Phys. Lett. B 622 (2005) 29–34

The T = 2 mirrors ^{36}Ca and ^{36}S: isospin symmetry of shell gaps at the dripline

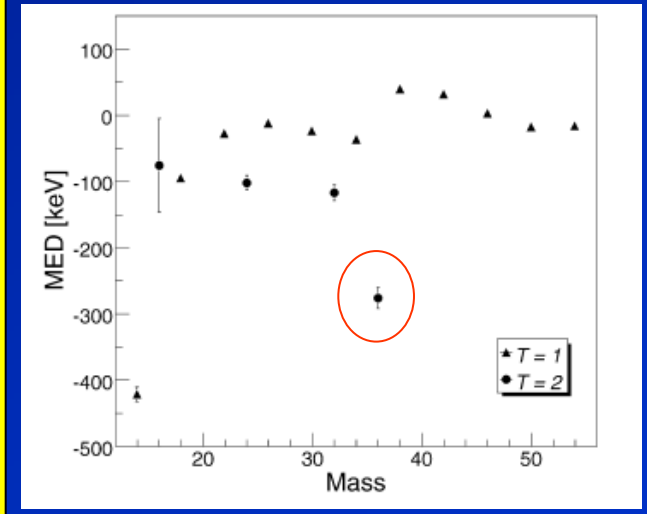
P.Doornebal et al Phys. Lett. B647(2007)237



First 2+ state observed for the first time

Different detectors have seen the same Things – consistency check

Mirror Energy Difference (MED) = 276 keV



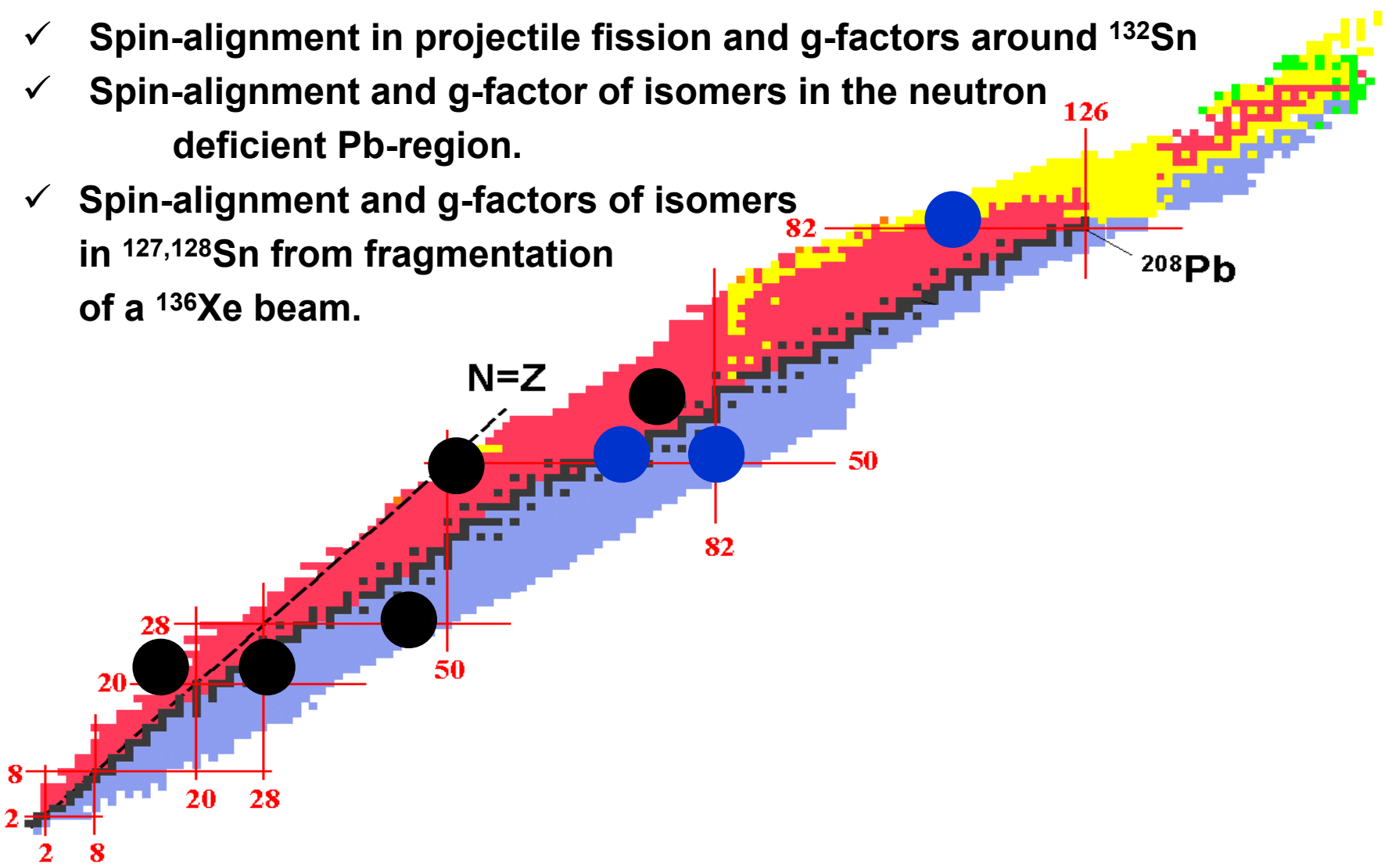
The large MED points to shell structure and/or coupling to the continuum.

The MED is understood with an isospin symmetric USD based interaction

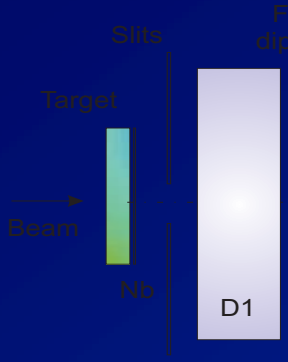
Ca isotopes below *N* = 16 develop another “island of inversion”.

Rising physics: g-Factor CAMPAIGN

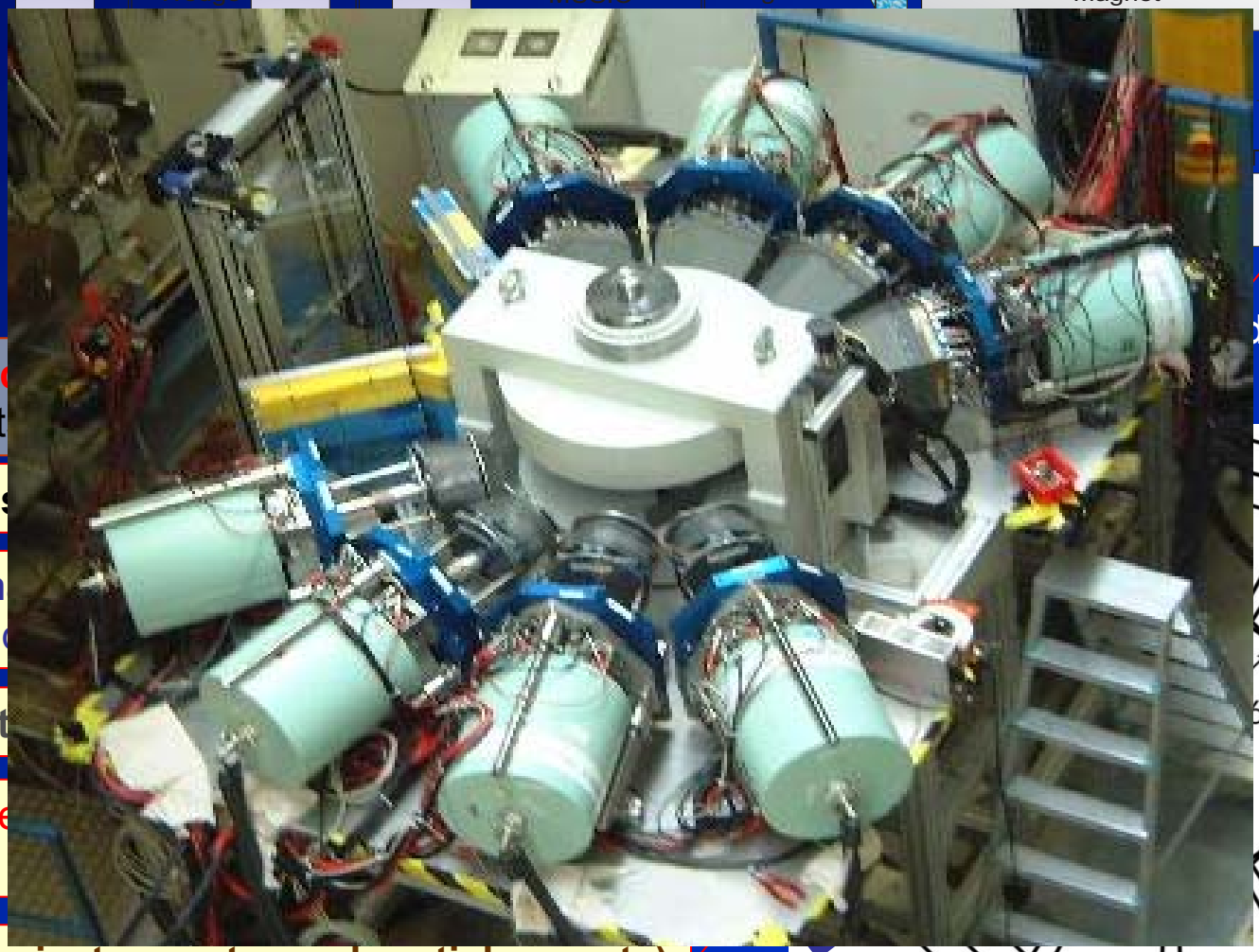
- ✓ Spin-alignment in projectile fission and g-factors around ^{132}Sn
- ✓ Spin-alignment and g-factor of isomers in the neutron deficient Pb-region.
- ✓ Spin-alignment and g-factors of isomers in ^{127,128}Sn from fragmentation of a ^{136}Xe beam.

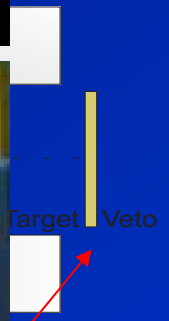


EXPERIMENTAL SET-UP



g-factor campaign (2005)





detectors

Spin-aligned se
(S2 slit

SC41 gives t=0 s

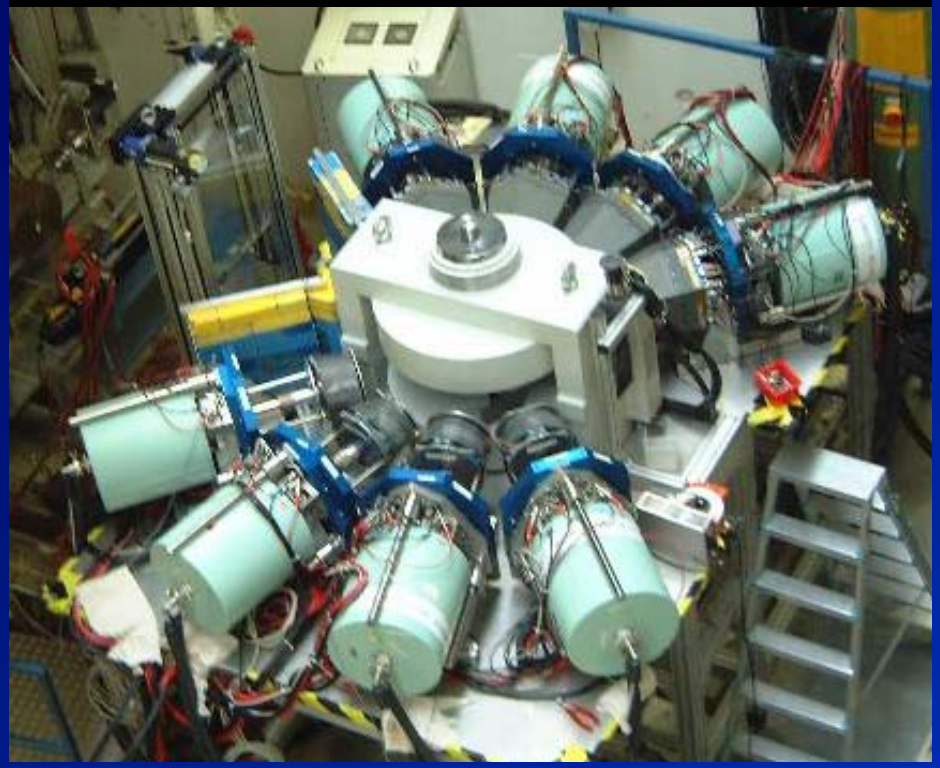
Pb-wall + collim
to avoi

SC42 validates t

Implantation: ple

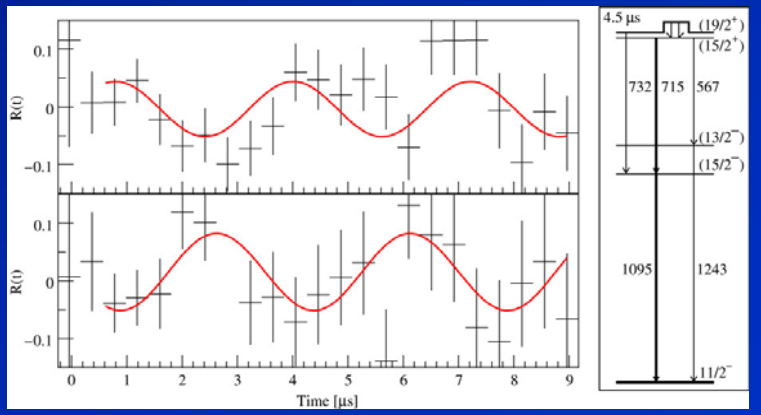
SC43 is a veto (reject non-stopped particle events)

g-factor campaign (2005)



Some RESULTS

g-factor measurement of the $19/2^+$ isomer in ^{127}Sn



L.Atanasova et al. Prog. in Part. and Nucl.Phys.59(2007)355

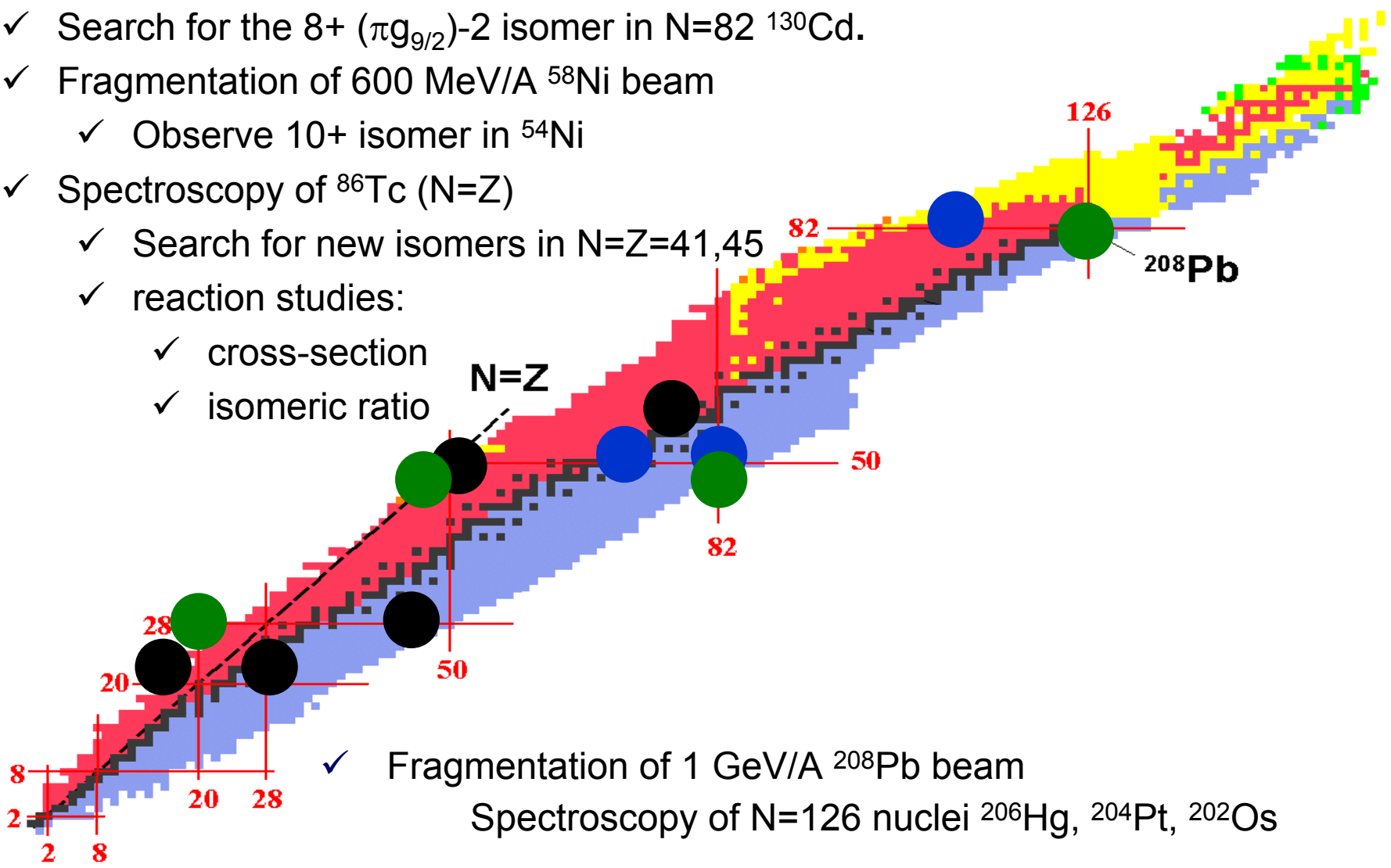
" The deduced g-factor |g| 0.16 is in agreement with theoretical estimates based on the empirical g-factors. "

g-factor and Spin Alignment In ^{192}Pb 12^+ isomer

Talk by M. Kmiecik

Rising physics: PASSIVE STOPPER BEAM CAMPAIGN

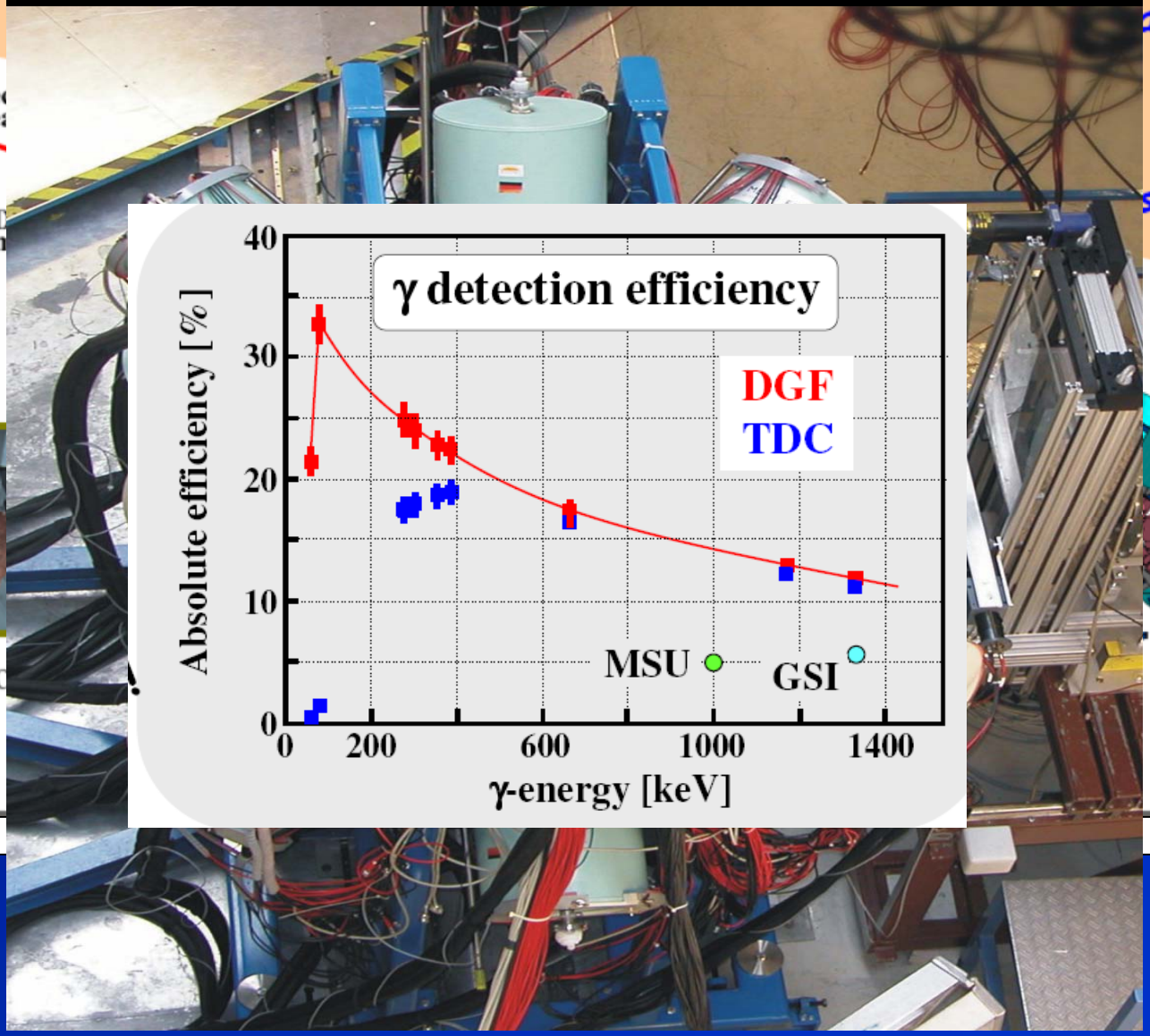
- ✓ Search for the 8+ ($\pi g_{9/2}$)-2 isomer in N=82 ^{130}Cd.
- ✓ Fragmentation of 600 MeV/A ^{58}Ni beam
  - ✓ Observe 10+ isomer in ^{54}Ni
- ✓ Spectroscopy of ^{86}Tc (N=Z)
  - ✓ Search for new isomers in N=Z=41,45
  - ✓ reaction studies:
    - ✓ cross-section
    - ✓ isomeric ratio



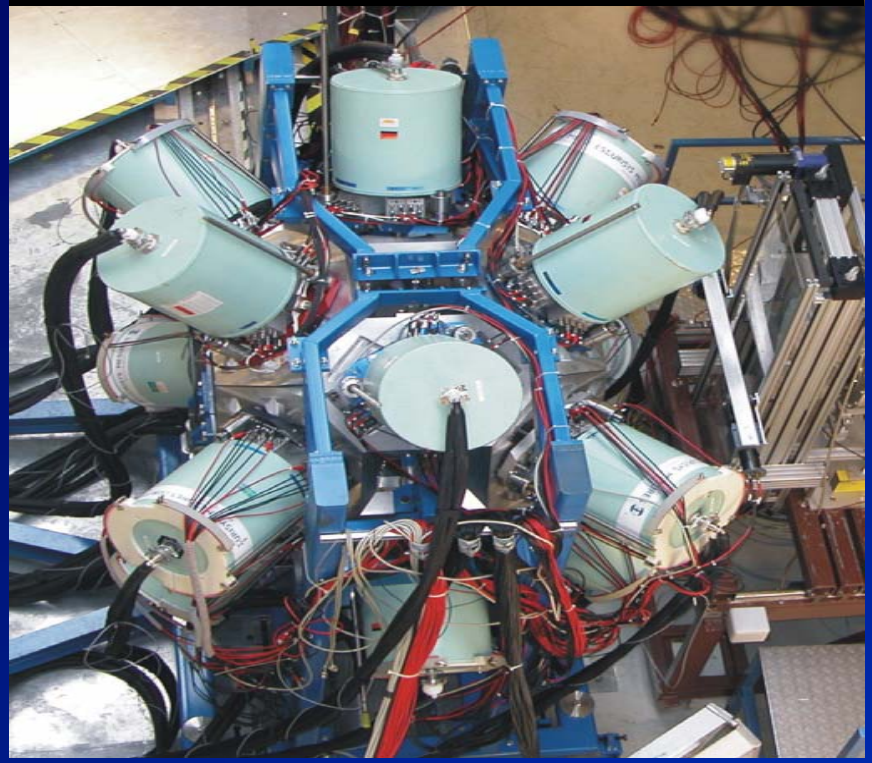
✓ Fragmentation of 1 GeV/A ^{208}Pb beam

Spectroscopy of N=126 nuclei ^{206}Hg, ^{204}Pt, ^{202}Os

Stopped beam campaign



Stopped beam campaign (running)



Passive stopper for isomer and β decay studies

Talks
A. Jungclaus – D. Rudolph

Some RESULTS

- Highest spin isomers ever seen in projectile fragmentation:
  - ^{148}Tb (27ħ)
  - ^{147}Gd (49/2)
- Isomeric ratios for ^{206}Hg
- New Isomers in:

^{205}Au, ^{204}Pt, ^{203}Ir, $^{189\text{-}190}$Ta

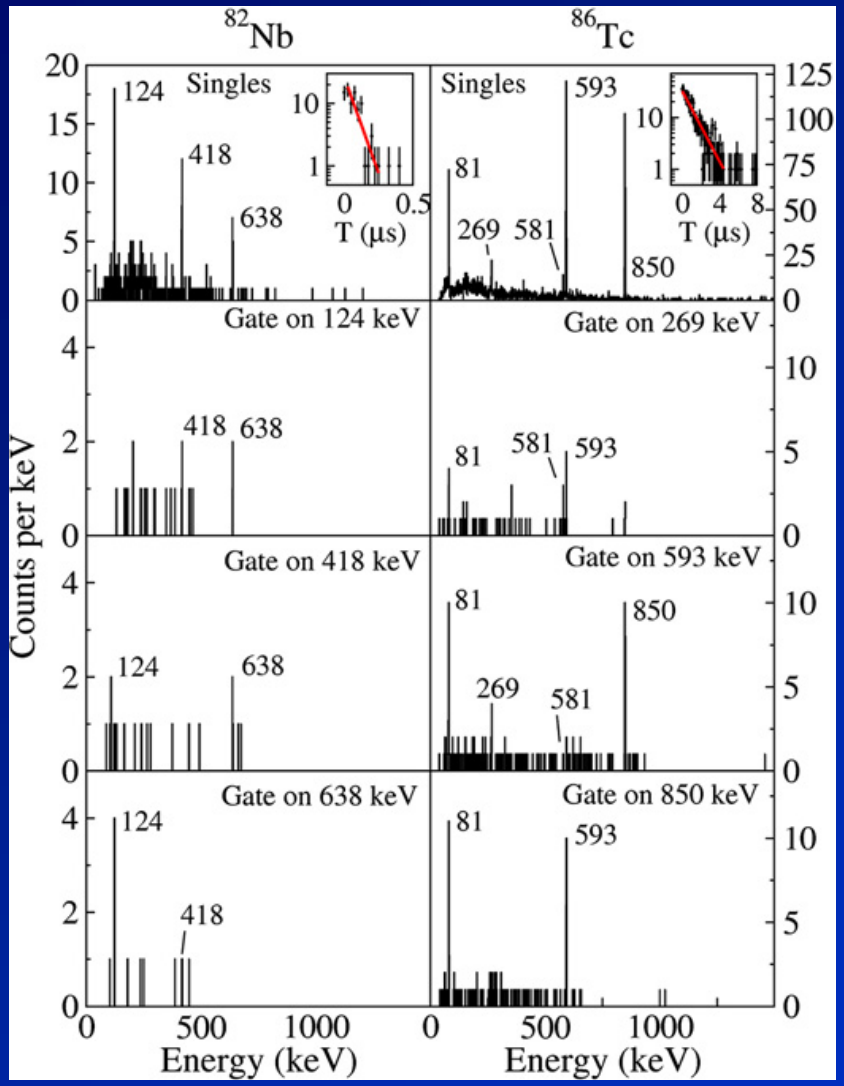
submitted to PRL

and in many other nuclei

Thanks to Z. Podolyak,

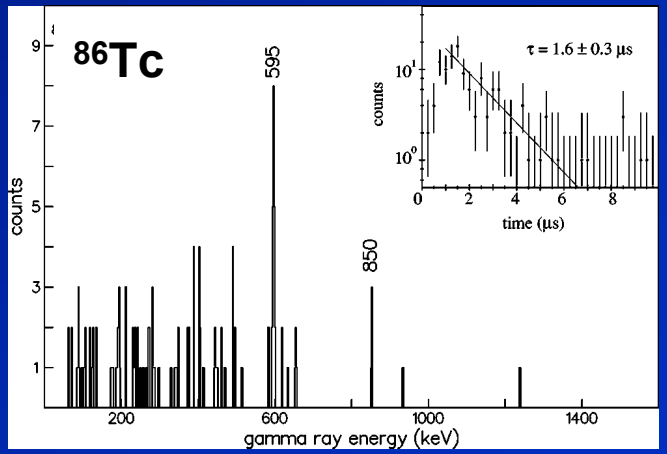
Neutron–proton pairing competition in $N = Z$ nuclei: Metastable state decays in the proton dripline nuclei ^{82}Nb and ^{86}Tc

A. Garnsworthy et al. Phys. Lett. B660(2008)326



Impressive improvement in statistics and spectral quality

Coincidence spectra have been obtained



C. Chandler, et al., Phys. Rev. C 61 (2000) 044309.

N=Z odd-odd nuclei are an ideal case for the study of np pairing

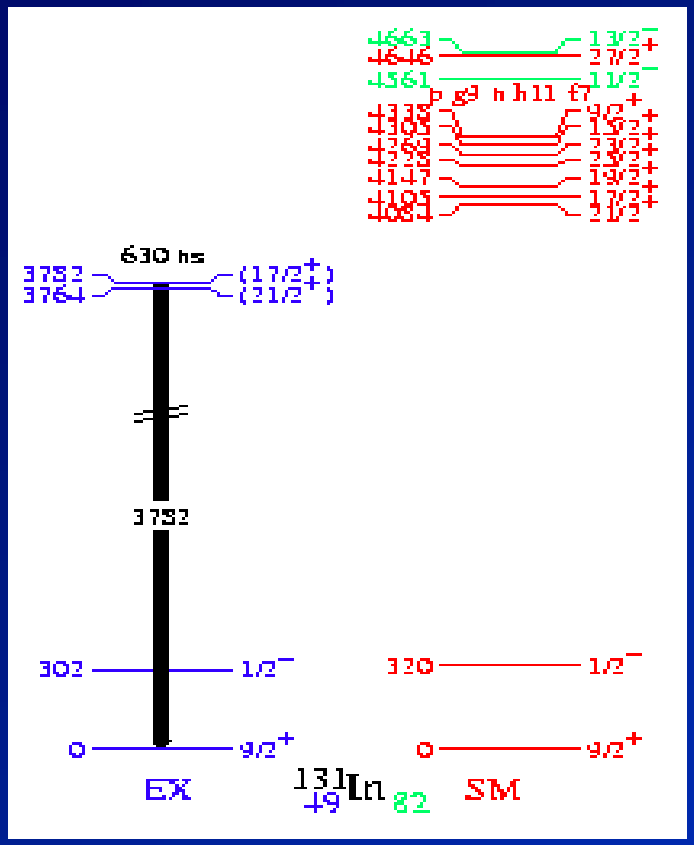
^{82}Nb and ^{86}Tc are the heaviest odd-odd nuclei in which γ-rays transitions have been observed

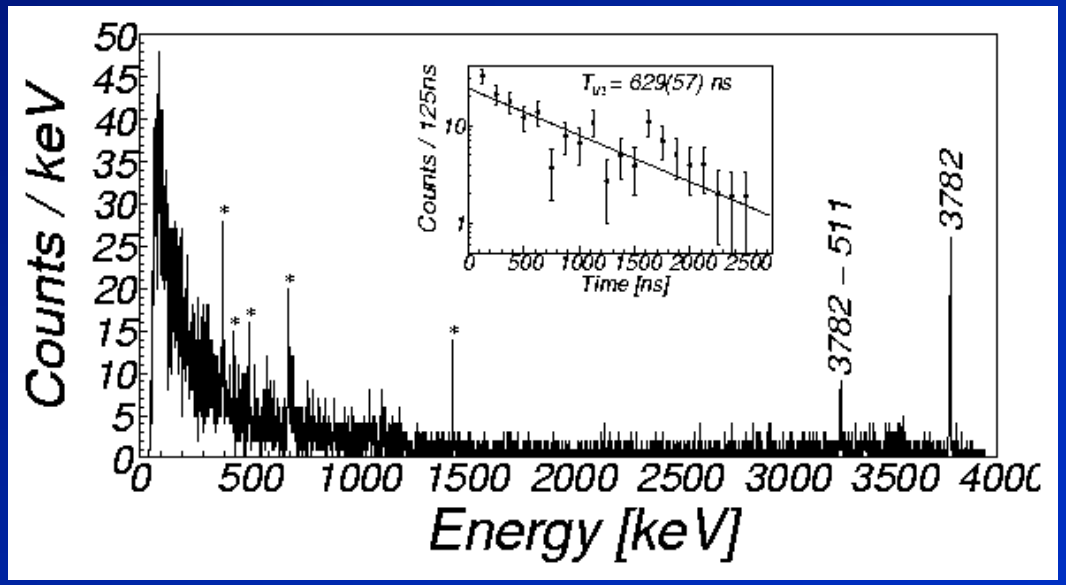
Proton decay branch ?

Axial symmetry and γ softness can be inferred $E(4^+)/E(2^+)$ ratio

Data suggest a dominance of T=1 pairing interaction over its T=0 counterpart

One π whole in ^{132}Sn spectrum -^{131}In





It is a measurement of a core excited ^{131}In γ-ray

Accurate estimate of the shell gap below ^{132}Sn

It can be extracted within the particle-hole residual interaction

This is the first time that interaction with the right monopole shift is available for this model space.

SM including v core excitation by H. Grawe

The same order of states expected!

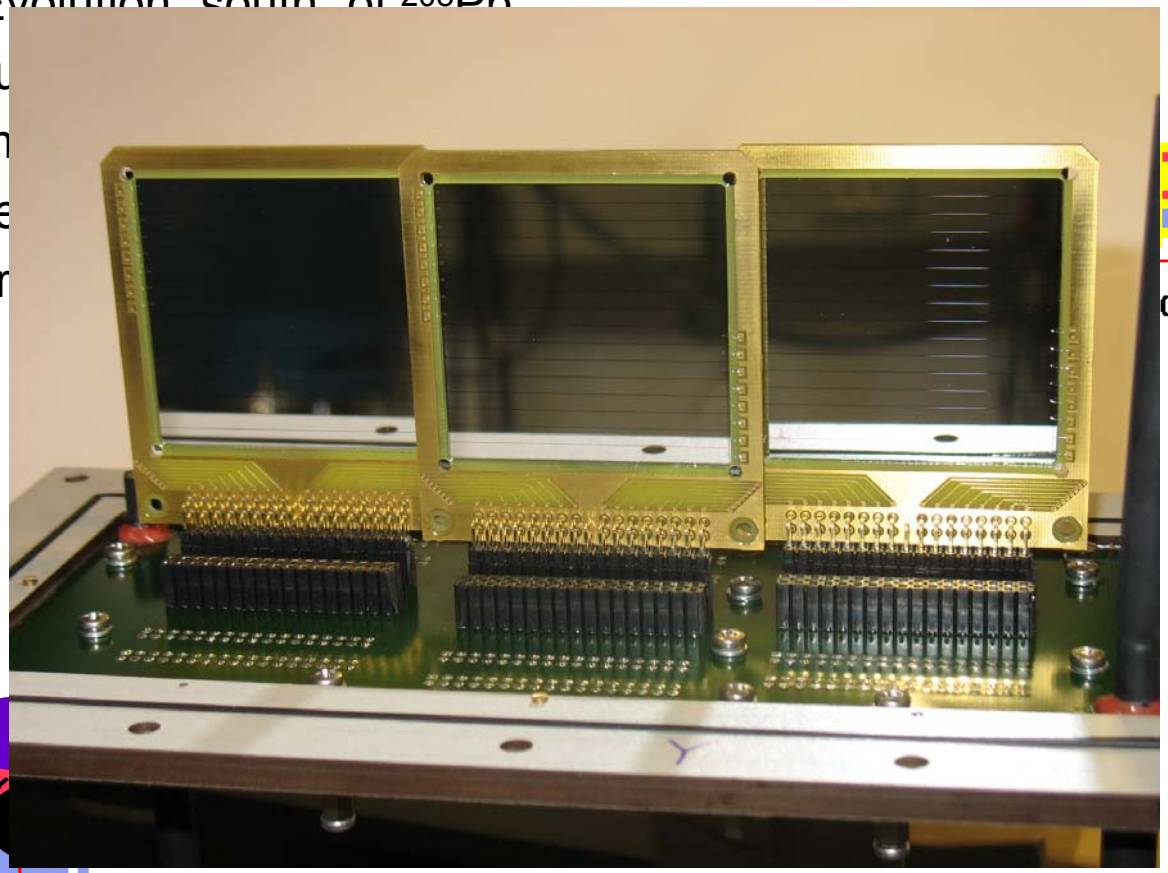
Preliminary: Shell gap reduction of <200keV

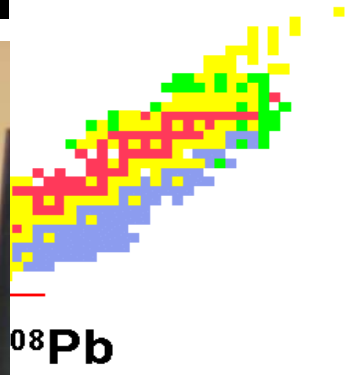
M.Gorska, L. Caceres, paper in preparation.

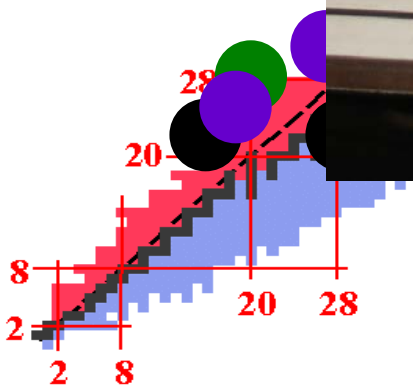
Rising physics: ACTIVE STOPPER BEAM CAMPAIGN

Active Stopper beam campaign (running)

- ✓ Collective E[illegible] "south" of ^{208}Pb
- ✓ Shape evolu[illegible]
- ✓ Isospin Sym[illegible]
- ✓ p-n pairing e[illegible]
- ✓ ^{100}Sn GT str[illegible]





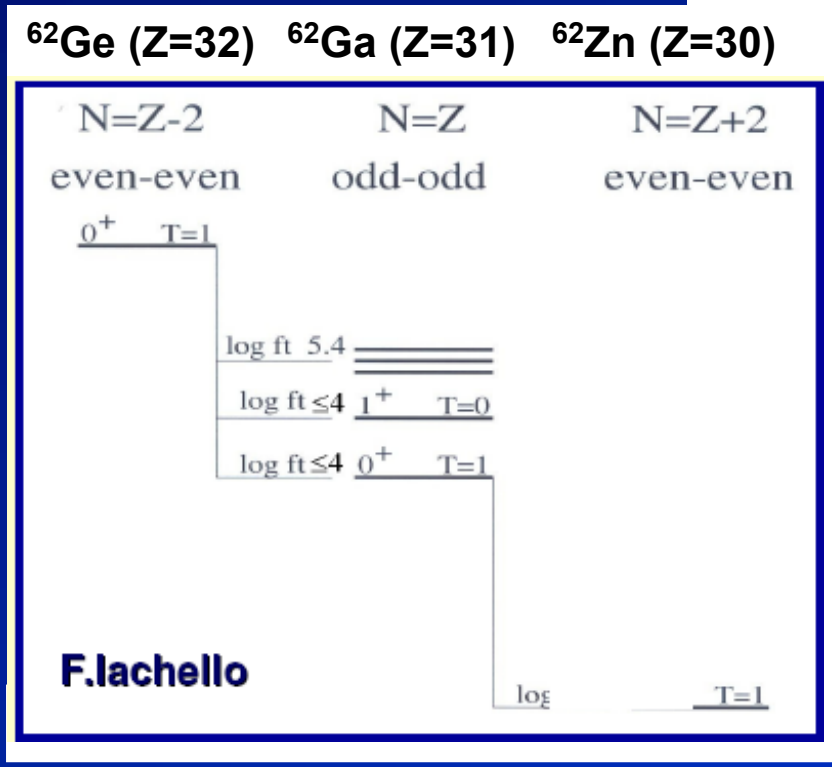


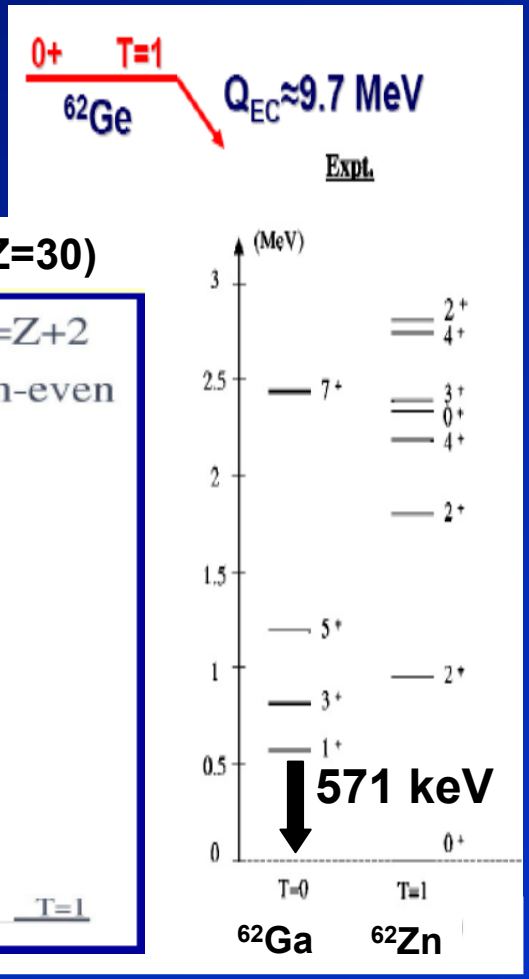
NIM A in preparation

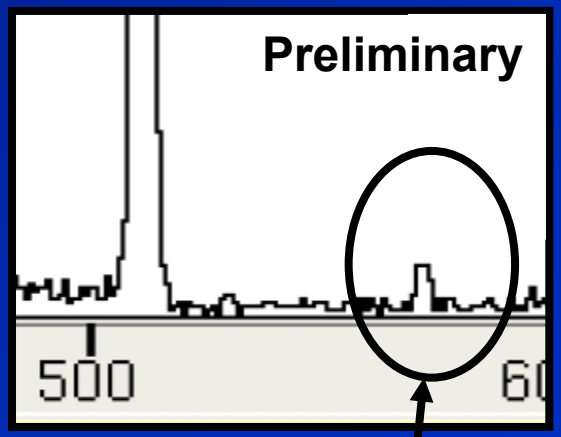
p-n pairing effects in ^{62}Ge beta decay

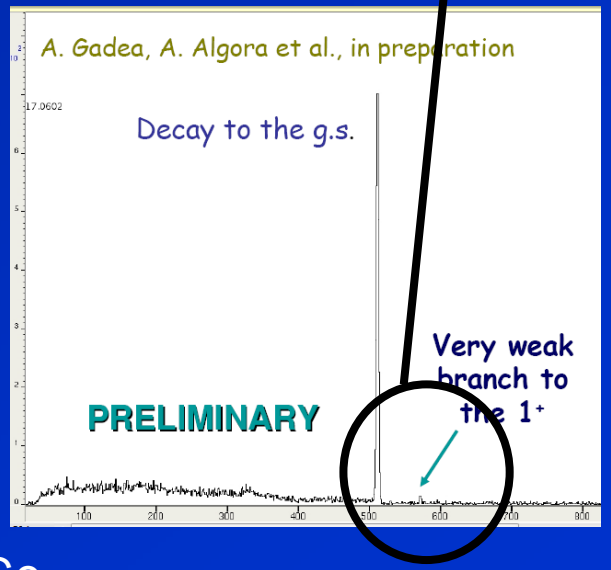
Does a deuteron-like condensate isoscalar (*T*=0) np pairs exists ?

Existence of an enhanced β-decay rates between the ground state of an even-even *N+2=Z* nucleus and the lowest *I*=1 state of its odd-odd N=Z neighbour









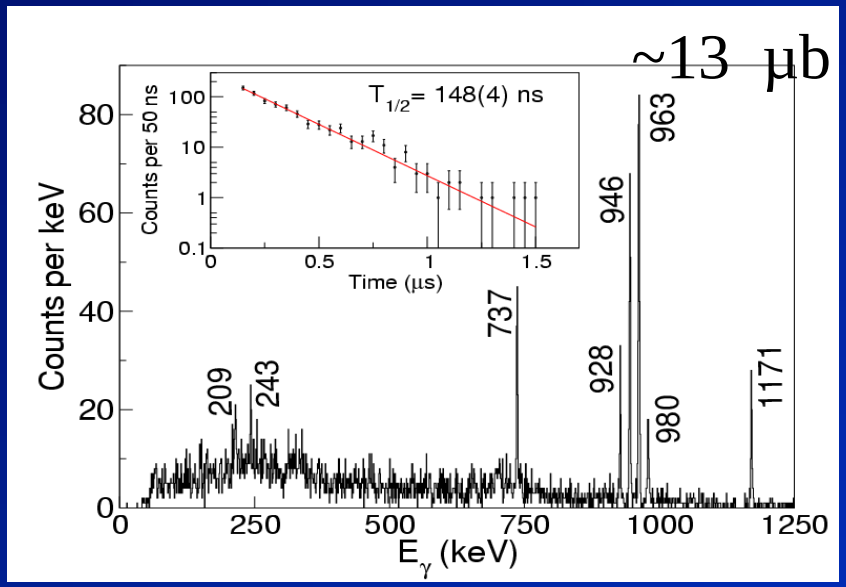
No p-n T=0 pairing effects observed in the β-decay of ^{62}Ge

Thanks to A.Gadea and A.Algora

Nuclear Structure "south" of ^{208}Pb

Stopped Beam – Passive Stopper

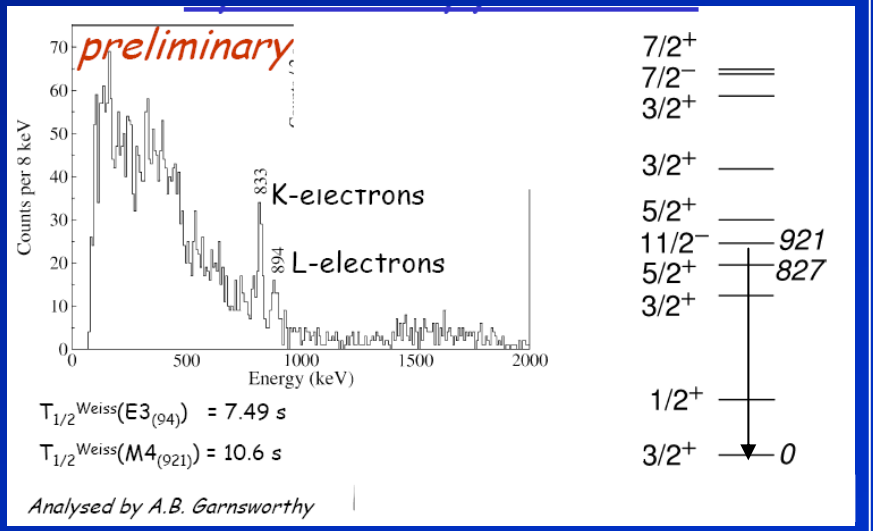
^{205}Au



γ-ray spectra are limited to Isomer cascades with $T_{1/2}$ for ~ 10 ns to 1 ms.

Stopped Beam – Active Stopper

^{205}Au

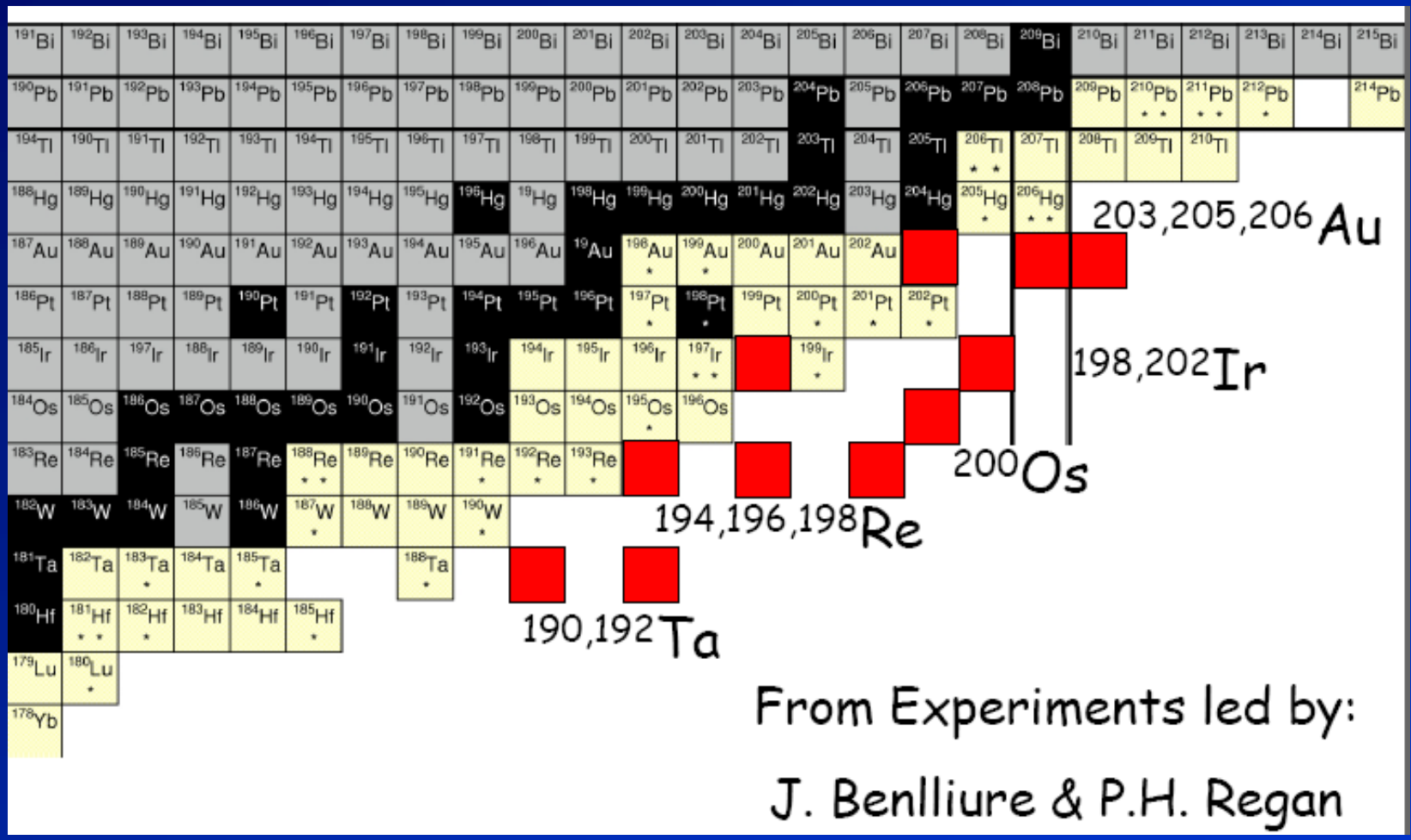


To be submitted

β−particles for $T_{1/2}$ up to ~ minutes and associated delayed γ-rays.

Thanks to Z. Podolyak, Farrelly, Regan, S.Steer

RESULTS WILL CONTINUE TO ARRIVE



Rising Technical Achievement

In addition to excellent physics results the RISING collaboration has worked also on the technical aspects concerning measurements with exotic beams

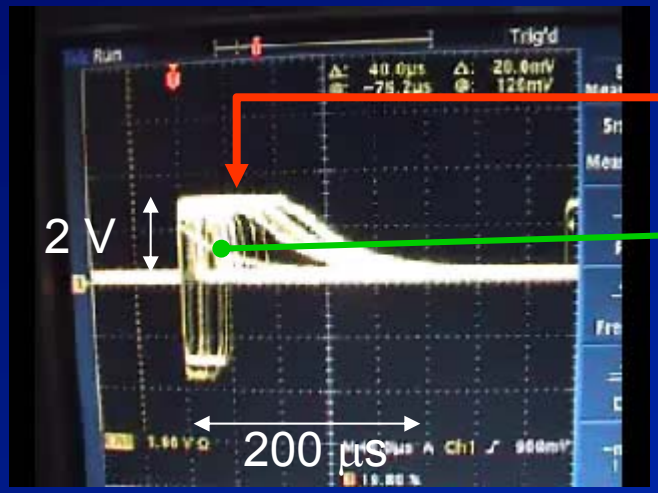
RISING experimental campaigns should pave the way for experimentalists to the future measurements using high efficiency tracking arrays (p.es. AGATA) in high intensity radioactive beams facilities

With the RISING array the community is able to identity and solve all the 'technical' problems in preparation to second generation gamma arrays.

- **Fast protons/LCP**
- **Background**
- **Secondary beam spin alignment**
- **Prompt gamma flash**
- **Angular Distributions**
- **Transition from Analog to Digital Electronics**
- **Software and for offline/online analysis and Diagnostic**

Pre-amplifier saturation and dead time induced by fast LCP

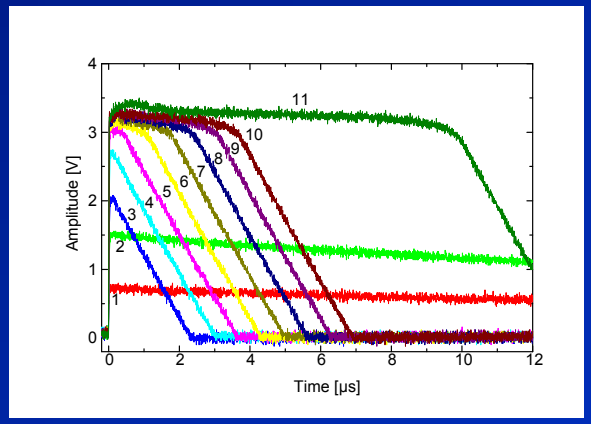
In-beam pre-amplified Ge signal



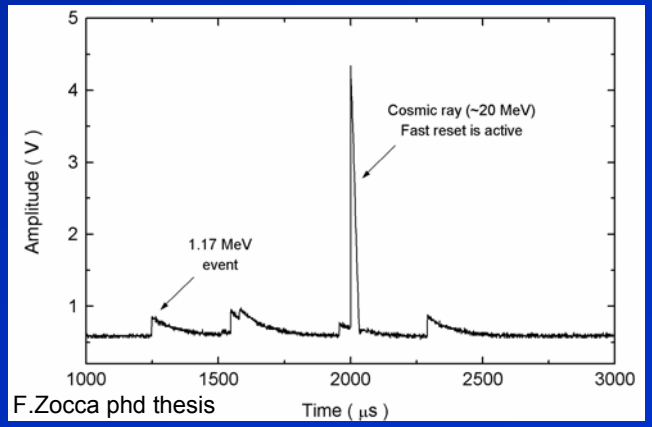
Huge amplitude (>> 20MeV), overshooting signals due to charged particles directly hitting the Ge crystal

"normal" low energy gamma rays

The AGATA preamplifier has been especially designed to correct this saturation effect firstly observed during RISING experiments



~7us to reset 50MeV event



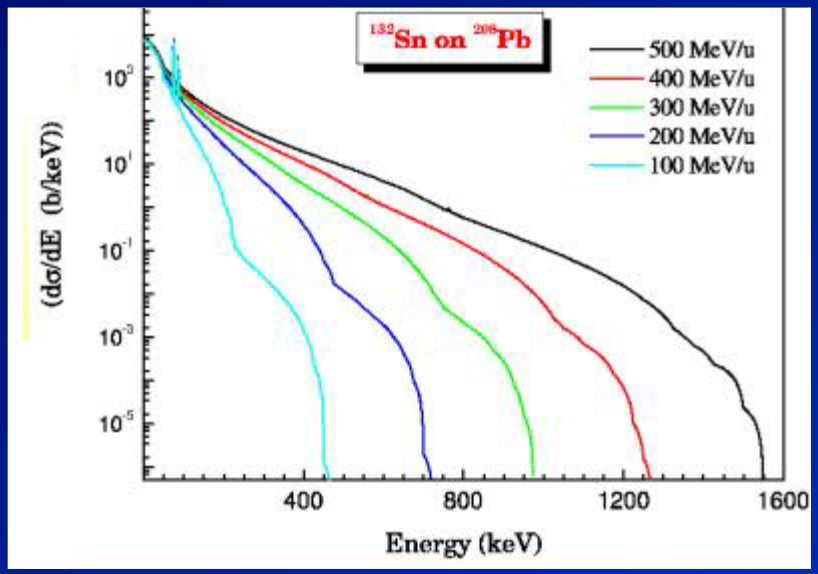
AGATA Preamplifier

Milano release

Thanks to P.Bednarczyk and A. Pullia

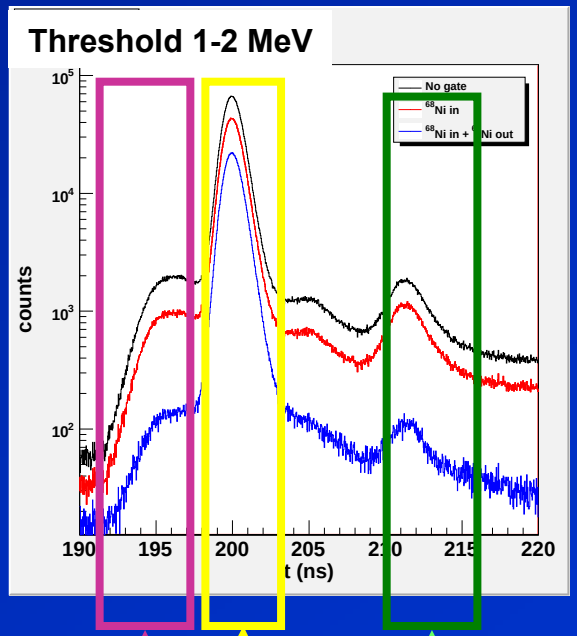
Background

Since the very beginning it was well known that most of the radiation detected in the array did not come from the target. What was not known was the nature, intensity, time and energy spectra of such background



NIM A357(2005)637

BaF_2 TOF spectrum (Thr. ≈ 1-2 MeV)
FWHM = 1 ns



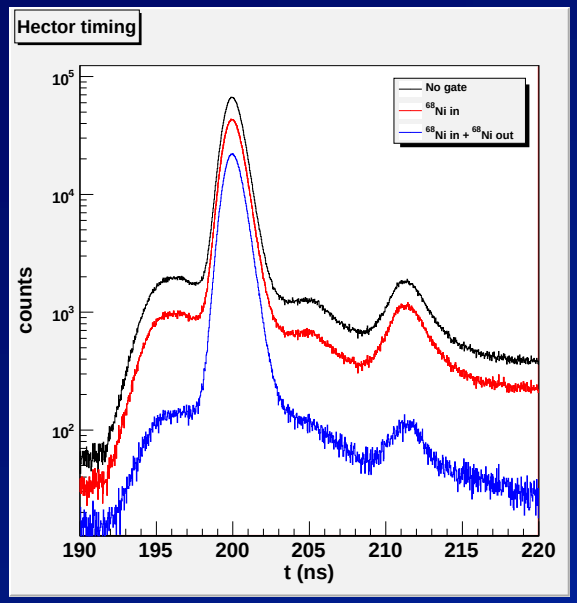
Ions which fragment after Z and AoQ identification

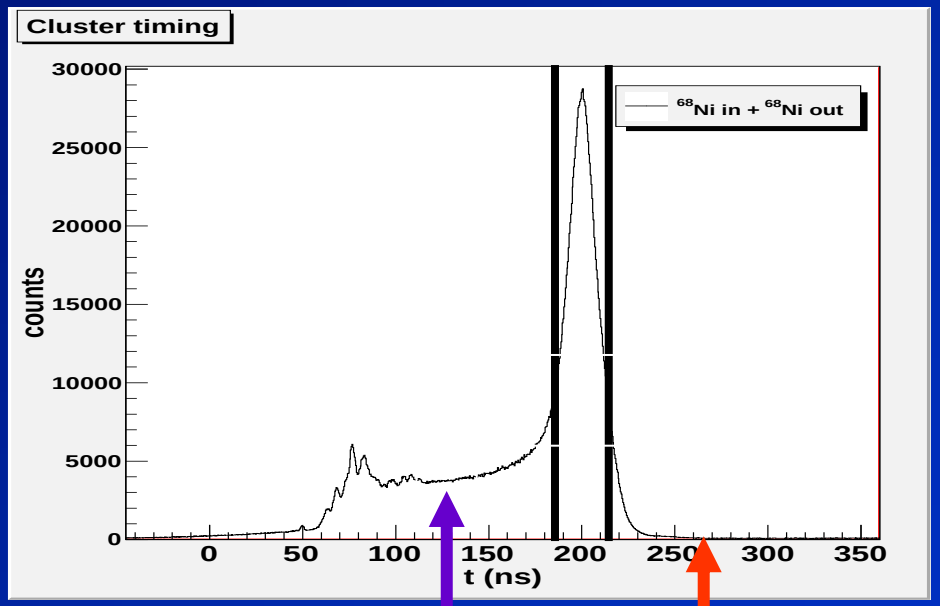
Target emissionn (ΔT = 1 ns)

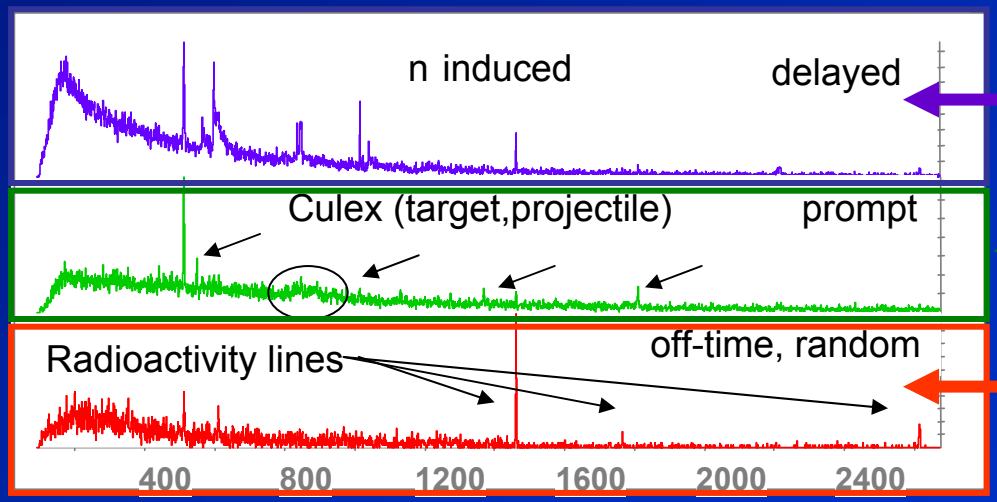
Active beam stopper (CATE) emission (12 ns later)

Thanks to Hector collaboration

HPGe detectors (Thr. ≈100 keV) FWHM ≈ 20 ns





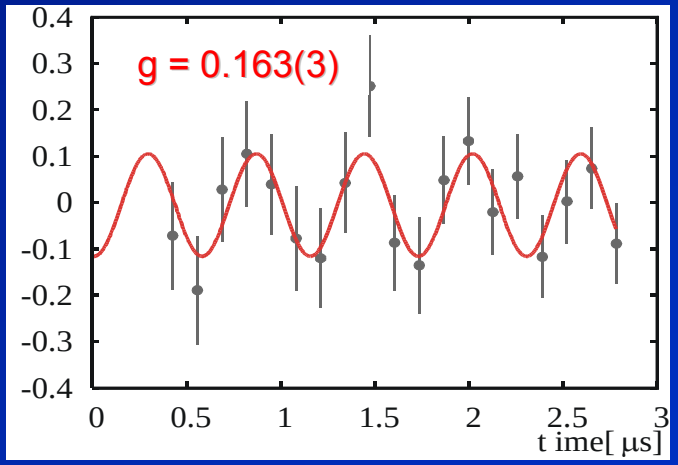


Thanks to P.Bednarczyk and Hector collaboration

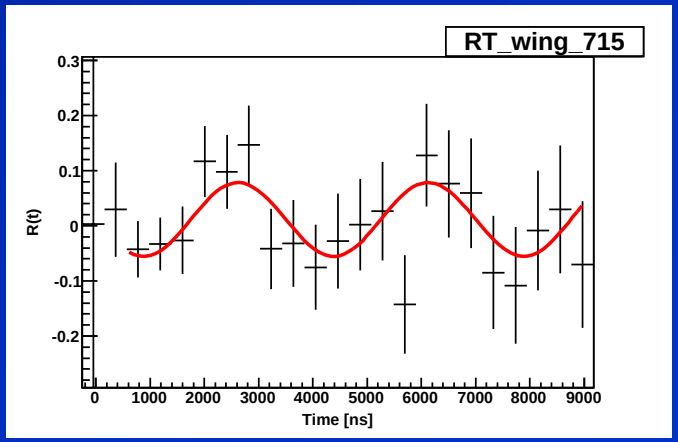
Secondary Beam spin alignment

It was proved the PRESENCE of spin-alignment

- ^{127}Sn produced using ^{238}U-fission at 750 MeV/u
  - g-factor (4.5 μs – 19/2 isomer) ≈ 0.164
  - A ≈ 3.5 %



- in ^{136}Xe-fagmentation at 700 MeV/u
  - g-factor (4.5 μs – 19/2 isomer) ≈ 0.168
  - A ≈ 3-6 %



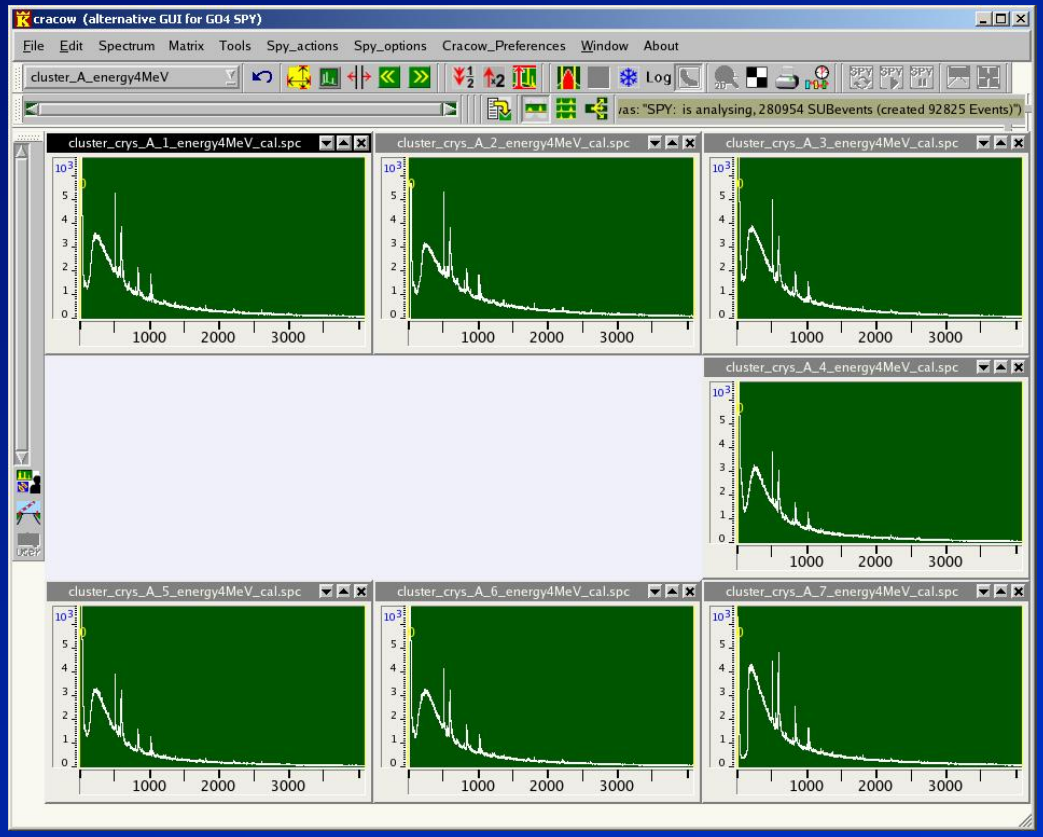
Neutron rich heavy nuclei become accessible for moments studies

Thanks to G. Neyens

Software and for offline/online analysis and Diagnostic

CRACOW: an interactive and sophisticated online analysis code

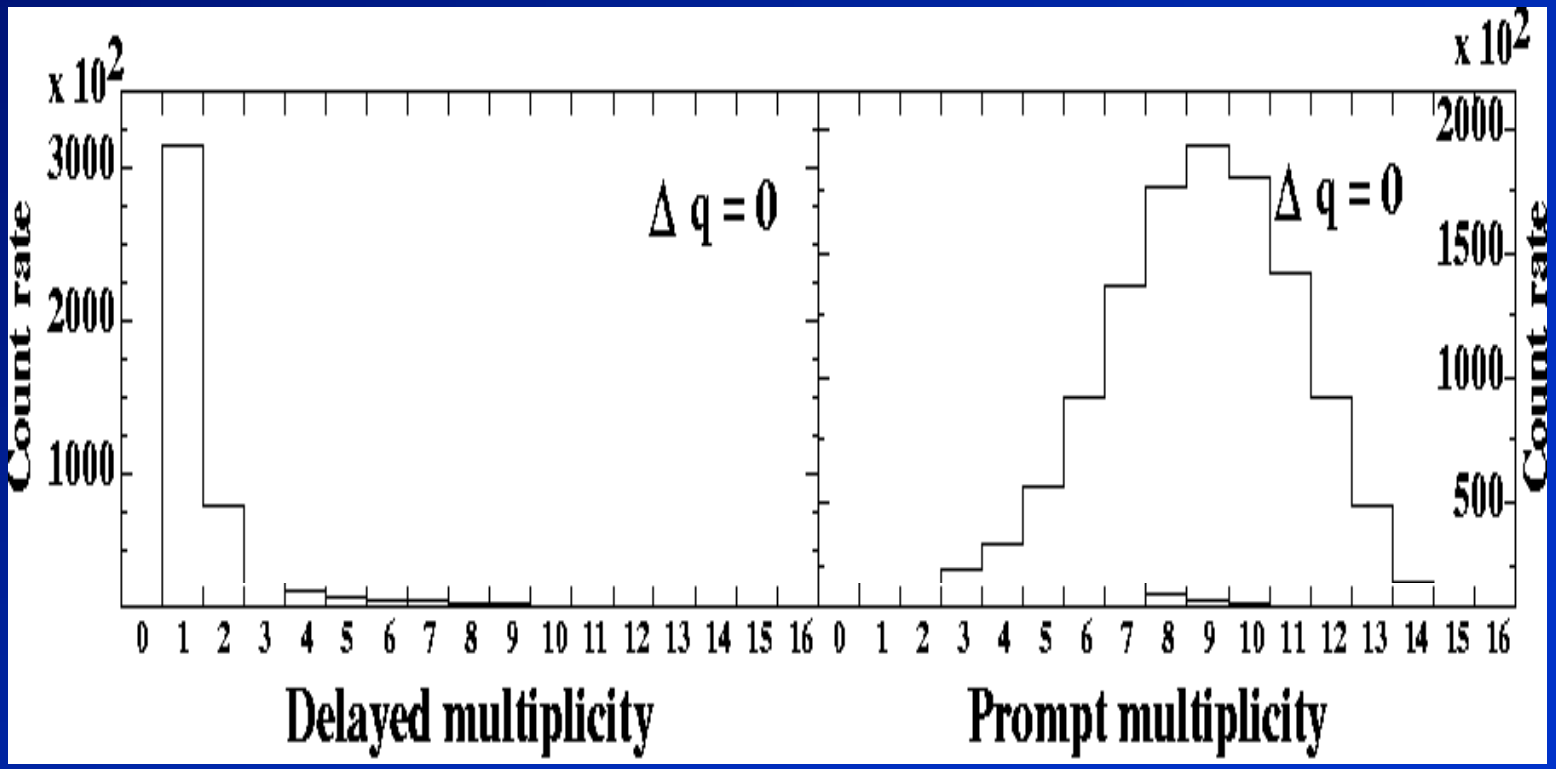
Jerzy Grebosz, Comp. Phys. Comm.



Thank to the extended debugging and the experience acquired during RISING campaign CRACOW like code will be used also for the AGATA demonstrator campaigns

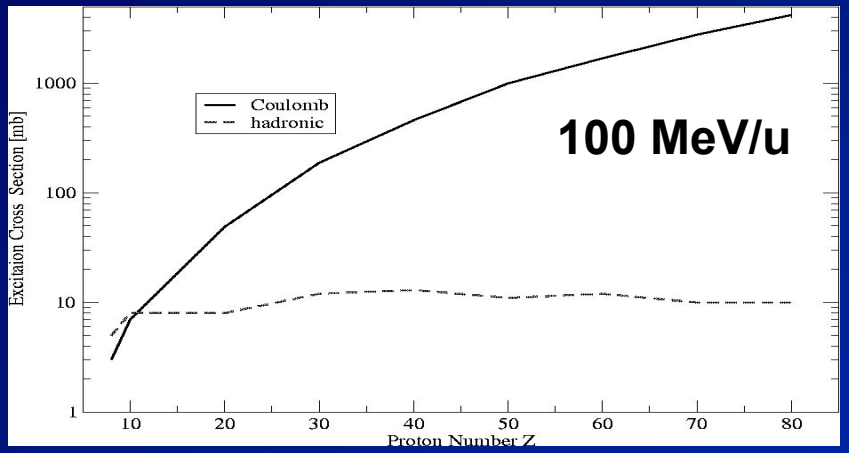
Prompt gamma flash

At the beginning of RISING Stopped beam campaign an open problem was the 'blinding' effect due to prompt radiation which could destroy the efficiency of the array for the detection of delayed gamma rays



Thanks to S.Pietri

γ Angular Distribution at intermediate energies

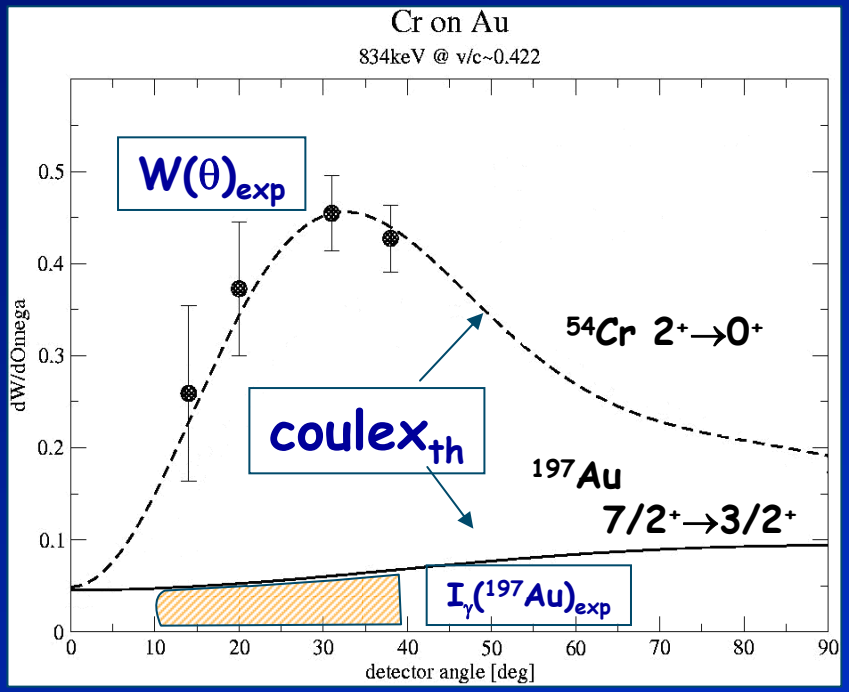


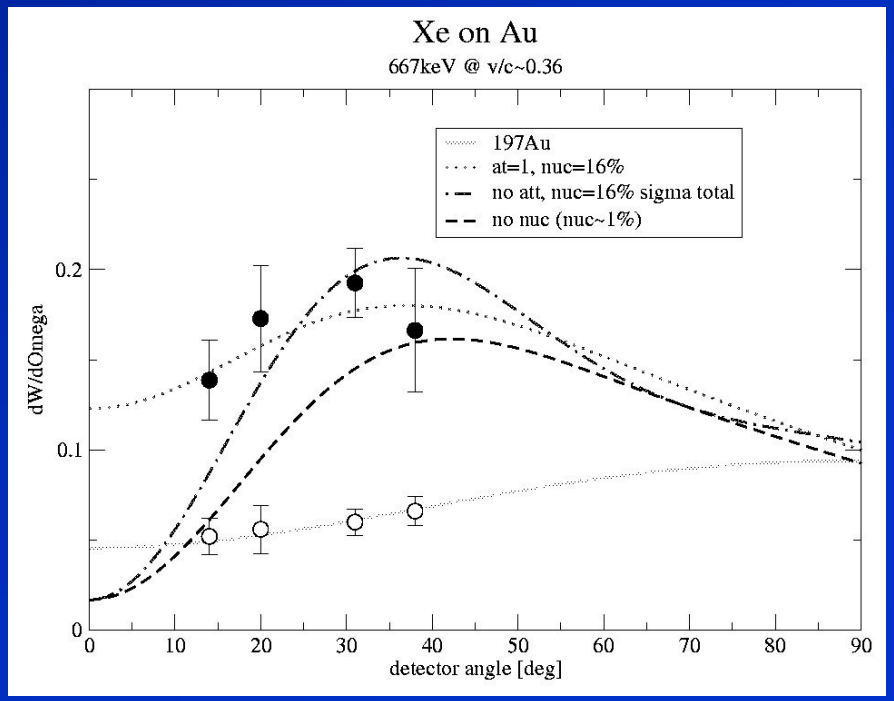
Coulomb Excitation should dominate

- as beam energy increases
- as Z increases

As expected for low Z projectiles

Some discrepancies for high Z nuclei





Thanks to P.Bednarczyk

FUTURE

- EOC has accepted Rising bid of clusters up to the end 2009
- RISING $\Rightarrow$ PRESPEC
  - New MOU to be signed
- Four Class A RISING experiment in the backlog (2009)
- New Fast Beam Campaign
  - Fast Ramping Magnets
  - New source
  - New Calorimeter Telescope – LYCCA-0
  - $LaBr_3$ detectors
  - ……

FAST RAMPING MAGNETS + NEW SOURCE

Past:

- it took up to 2.5 s to ramp up the energy in SIS from injection to 1 GeV/u

Now:

- It can be done in 0.7 s reducing the spill-off time accordingly increasing the mean beam current.

Ion	Old fast campaign	New Campaign
^{124}Xe	6 10^{7} ions/second	2 10^{9} ions/second
^{238}U		2 10^{9} ions/second
^{40}Ca	3 10^{8} ions/second	10^{9} ions/second
^{58}Ni		2 10^{9} ions/second

LYCCA-0 Calorimeter

Lund – York – Cologne CAlorimeter

- Physic
- Energy
- Time re

ΔE – detecto

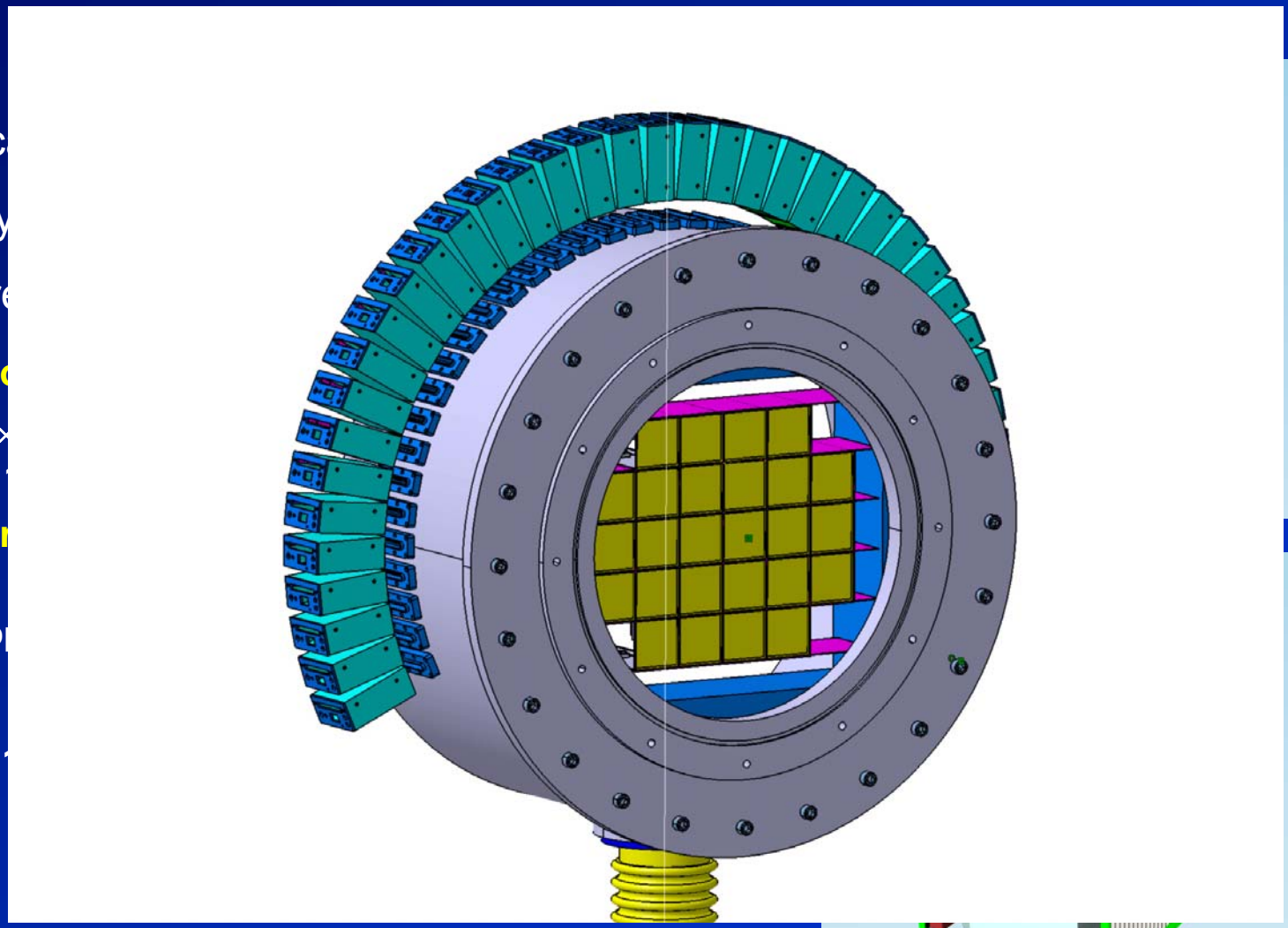
- **DSSSD, 58 ×**
- **PCB frame,**

E – detector

- **CsI, 19 × 19**
- **Teflon wrap**

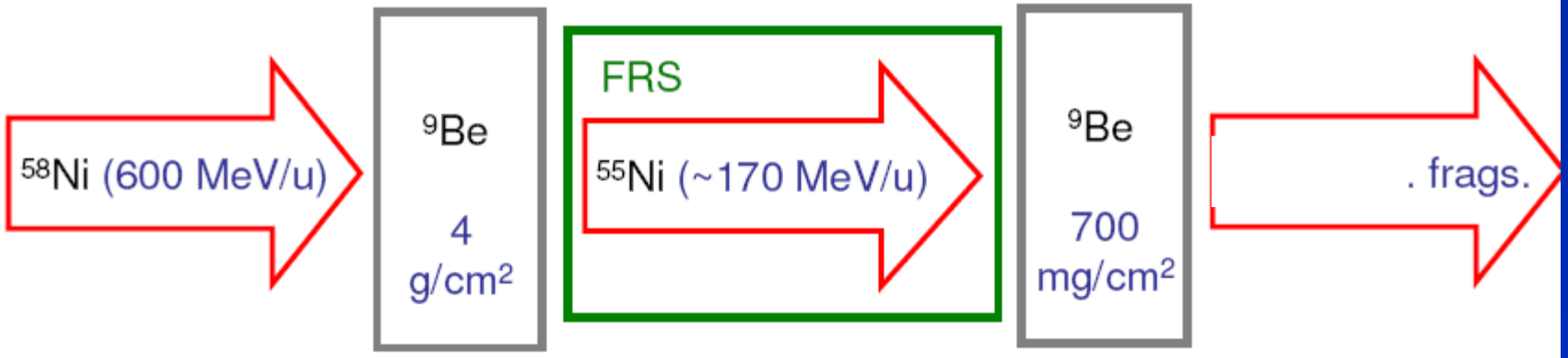
PD readout

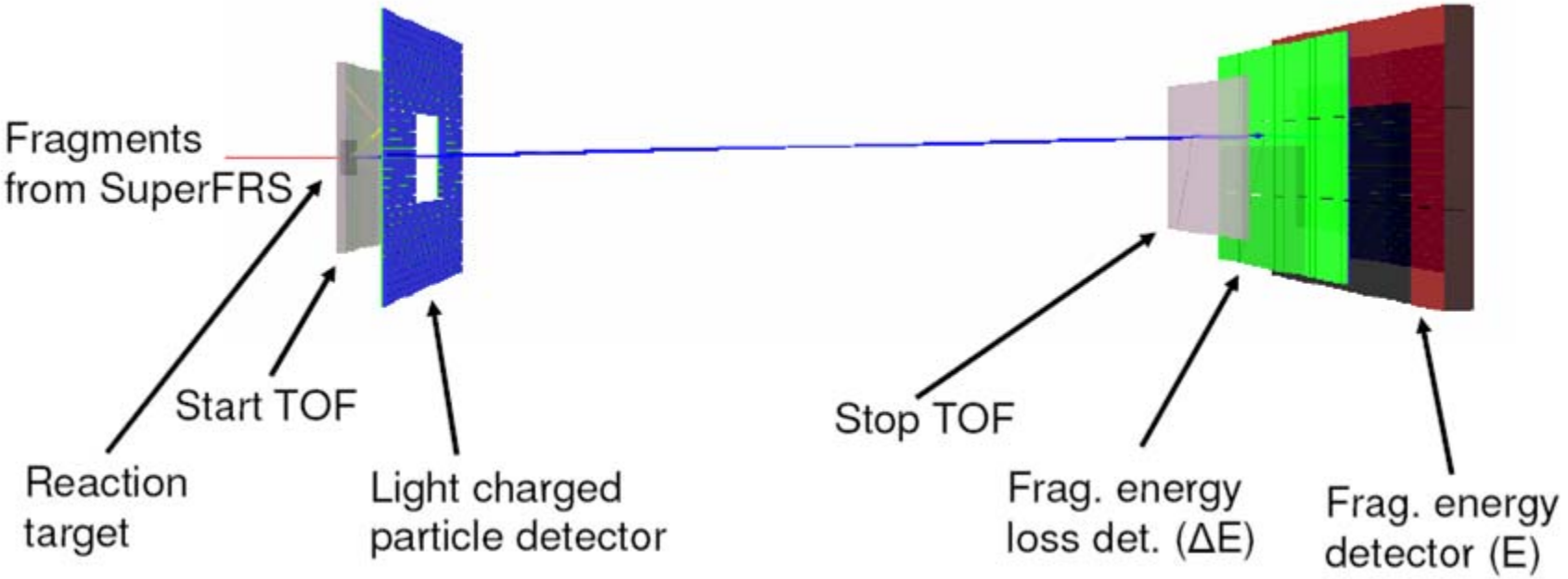
- **PD, 10.5 × 1**
- **PCB, signal**



Thanks to D.Rudolph and M.Taylor

Mocadi: Reaction + FRS





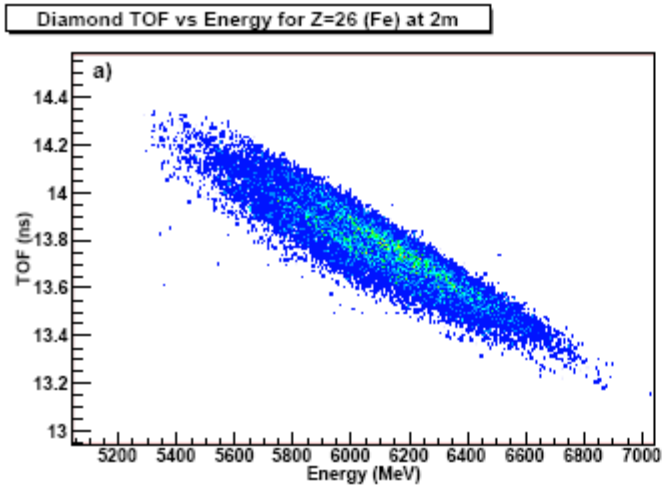
Thanks to D.Rudolph and M.Taylor

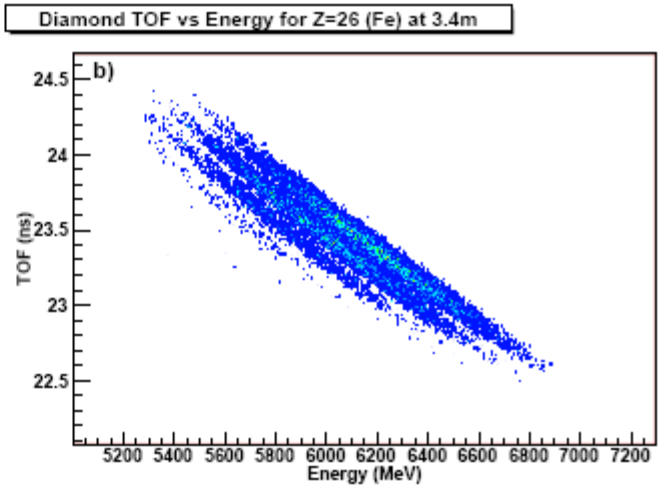
D = 2 m

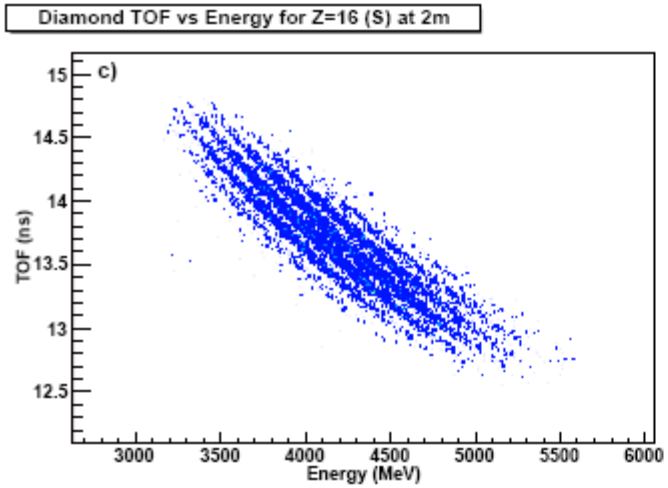
D = 3.4 m

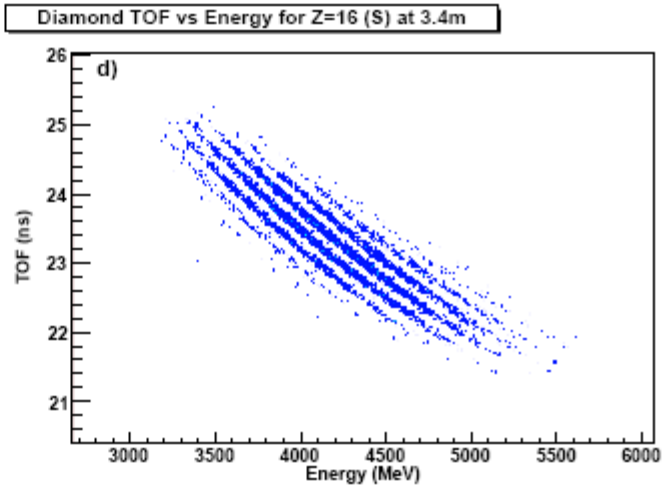
Z = 26

Z = 16









Thanks to D.Rudolph and M.Taylor

D.Rudolph LYCCA Technical Design Report, V1.1, May 2008

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and many others

GSI

Bonn, Darmstadt, Koln, Kracow, Louvain, Madrid, Milano, Liverpool, Lund, Surrey, ...

Thanks to everyone

Thank you for the attention