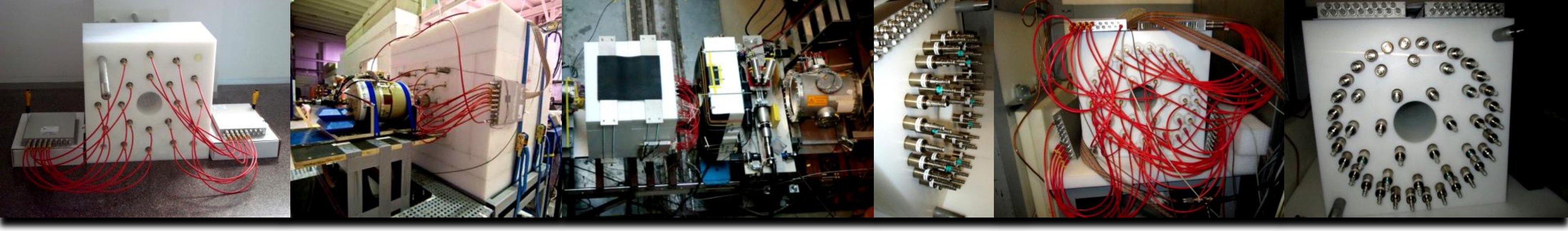


Experiments performed with the Beta dELayEd Neutron detector (BELEN) at JYFL & GSI/FAIR

ROGER CABALLERO-FOLCH (DFEN –UPC)
RIKEN - Japan, 30 de juliol de 2013

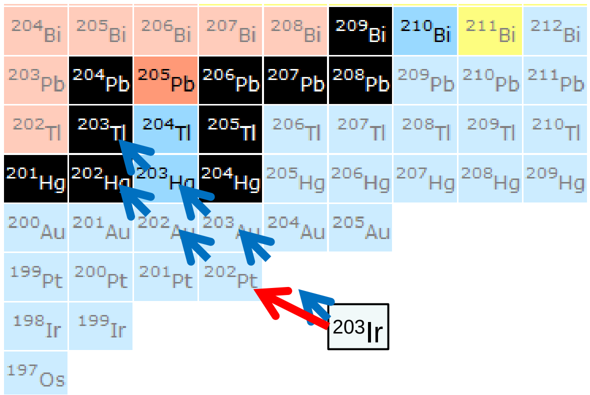
IFIC INSTITUT DE FÍSICA CORPUSCULAR
GSI
NSCL
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
THE UNIVERSITY OF EDINBURGH
Science & Technology Facilities Council
TRIUMF
FIAT LUX
RIKEN NISHINA CENTER
UPC
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN
MICHIGAN STATE UNIVERSITY
OAK RIDGE National Laboratory
…

Contents

- Beta delayed neutron emission measurements motivation
- BELEN – ^{3}He detection method and electronic chain
- JYFL experiments with BELEN 20 (2009-2010)
- GSI/FAIR experiments BELEN 30
- Summary, outlook and other tests:
    - ✓ LSC – Canfranc
    - ✓ PTB with BELEN-48 (2013)

Nuclear structure: Study different aspects of nuclei. Provide information about their decay mechanism and structure.

Astrophysics. R-process nucleosynthesis: The delayed neutron emission modulates the final element abundances in the decay chain after the **r-process nucleosynthesis**

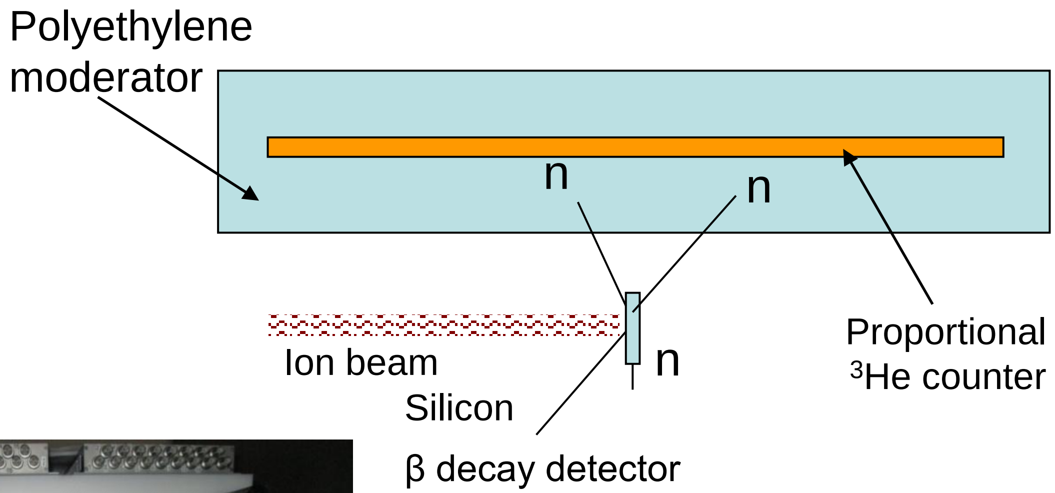


1. It enhances the neutron density of the environment after freeze-out (re-activation).
2. It shifts the abundances towards lower masses (Pn: A → A-1, P2n: A → A-2, etc).

Nuclear reactor safety: Delayed neutron emission **(decay heat)** after fission is key to the safety and sustainability of the fission chain in the nuclear power reactor. New data is needed in the context of the nuclear fuel that will be used in the next generation of reactors.

- ✓ The detection of the neutron is based on an indirect method: the detection of the products of the reaction of the neutron with ^{3}He counters:

$^{3}He + n \rightarrow {}^{3}H + {}^{1}H + 765$ keV

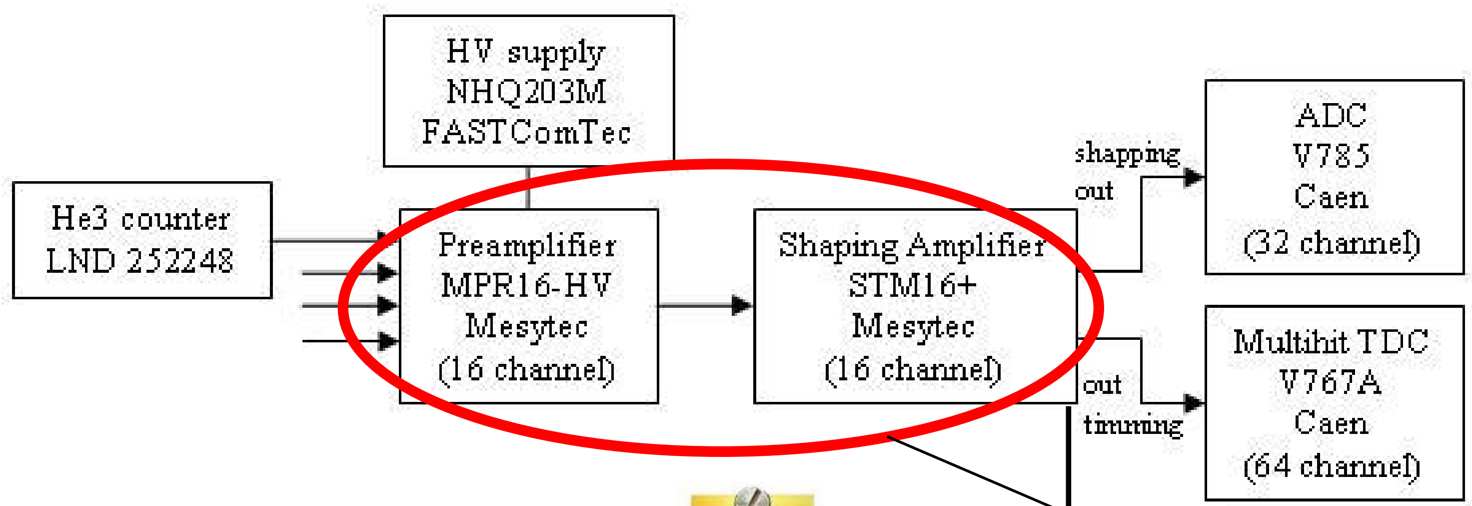


Counters embeeded in a polyethylene matrix (version with 48 counters)

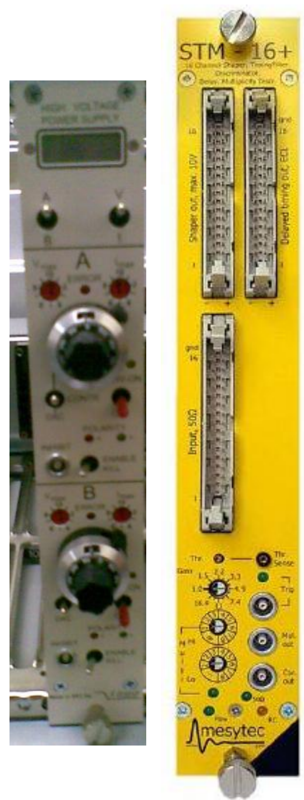
Other reactions:

$^{10}B + n \rightarrow {}^{7}Li^{*} + {}^{4}He + 2310$ keV (NERO)

$^{7}Li^{*} \rightarrow {}^{7}Li + 480$ keV



The electronic chain of the acquisition system operates independently of the other systems of the experiment and detectors along the beamline. It only needs to sinchronize the timestamp.

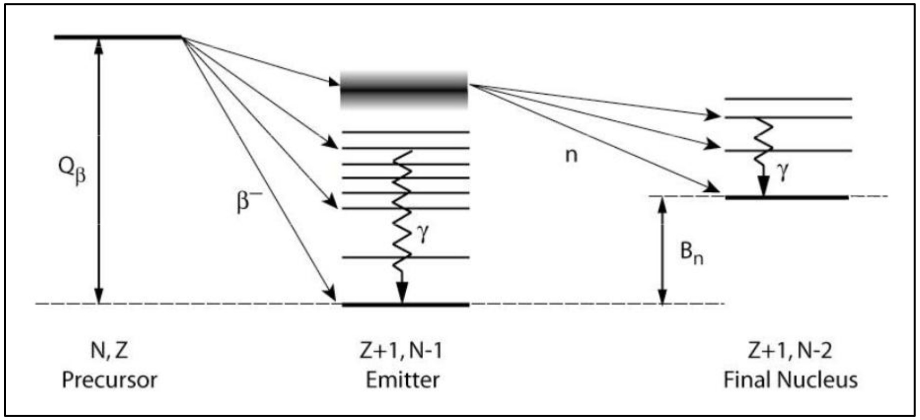


Revision

GASIFIC TL Digital system triggerless

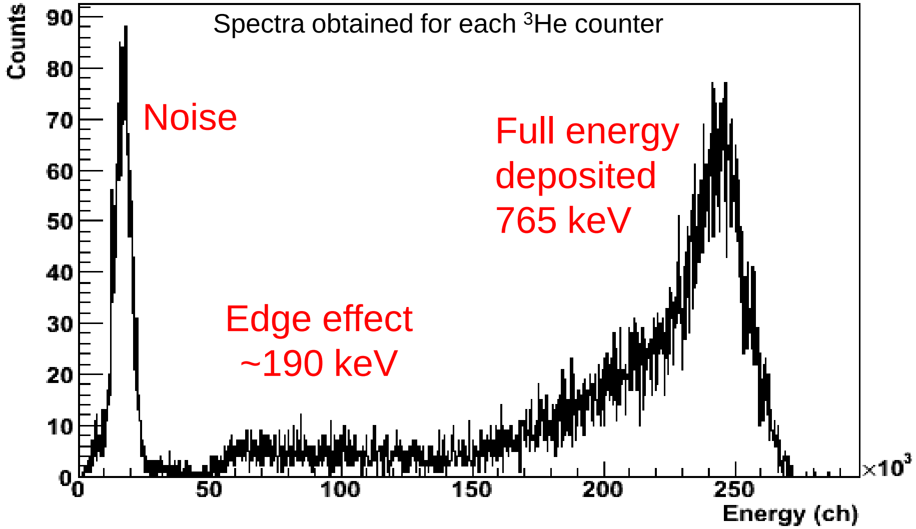
Digital Data Acquisition System

Talk of this part by J. Agramunt



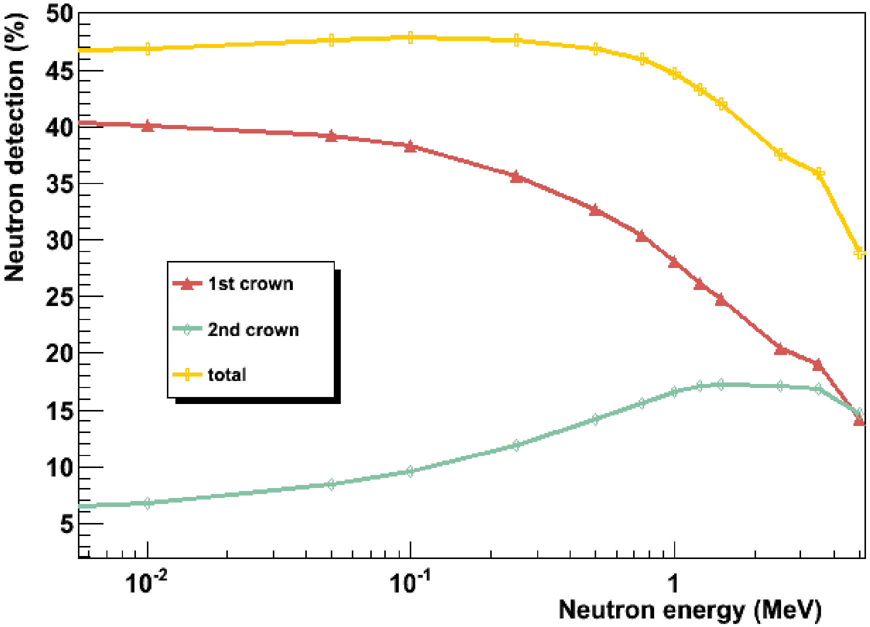
It has been designed to maximize the detection efficiency and reduce its energy dependence in the energy range of interest (flat efficiency from a few keV to a few MeV).

$^3He + n \rightarrow {}^3H + {}^1H + 765\ keV$



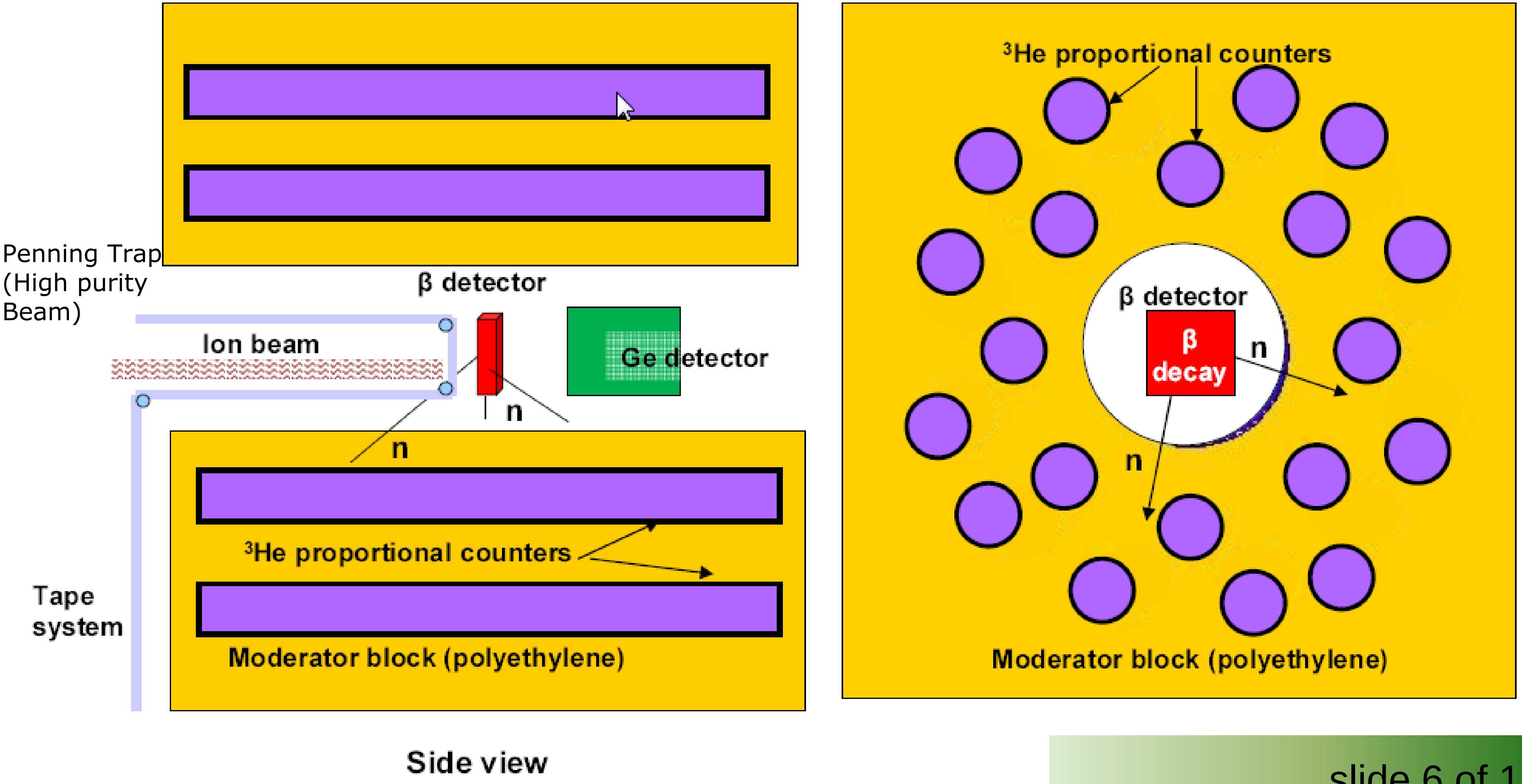
Energy deposited in the REACTION!

Not neutron energy



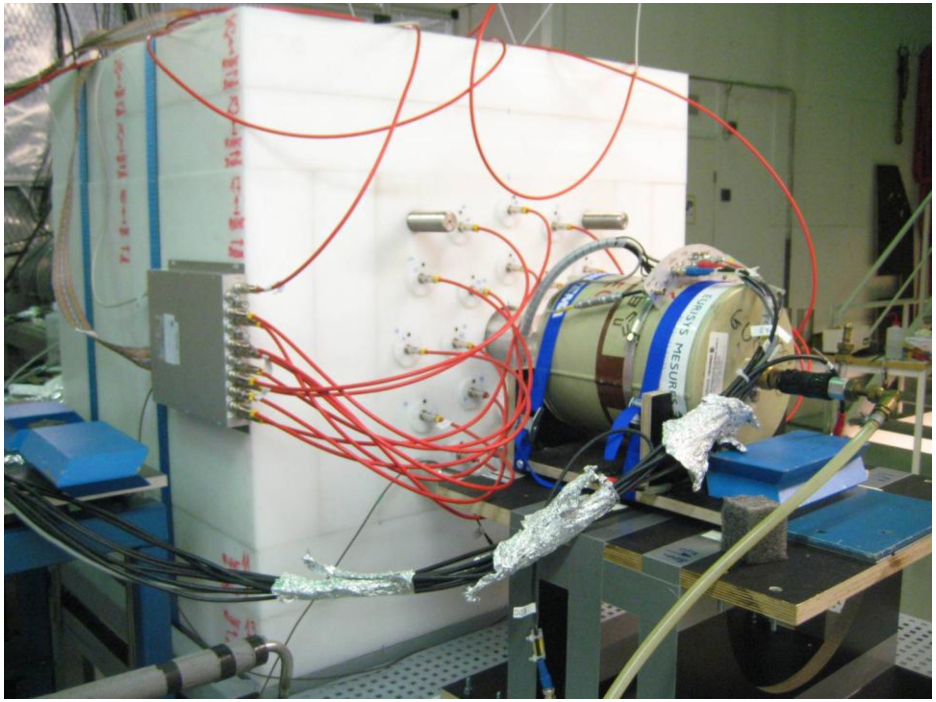
Experiments at IGISOL facility 2009 – 2010. Jyväskylä, Finland

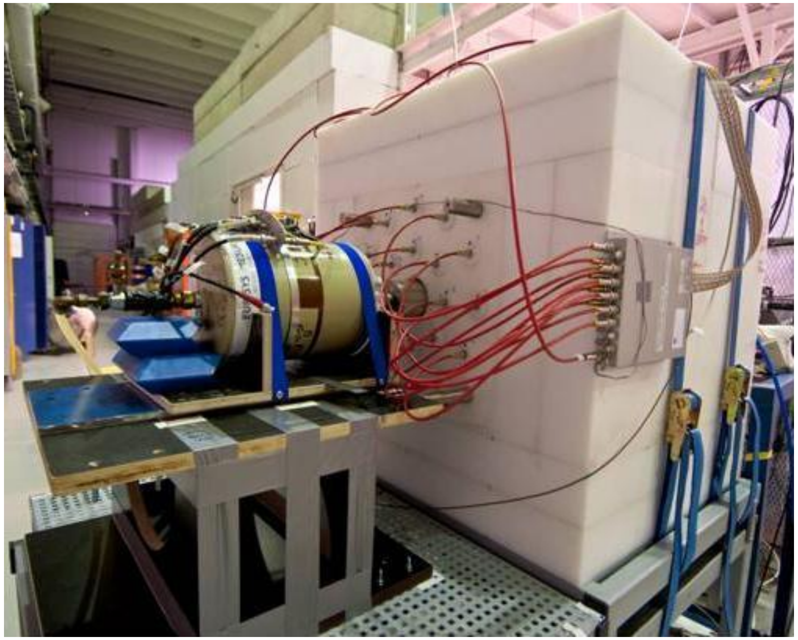
Prototype designed with 20 ^{3}He counters at 20 atm embedded in a polyethylene matrix around the beam hole in two concentric crowns. One with 8 counters at 9.5 cm and the outer with 12 counters at 14.5 cm



A Ge detector was also used to check the gamma rays in coincidence and to identify the implanted ions.

Silicon detector was located in front of the tape

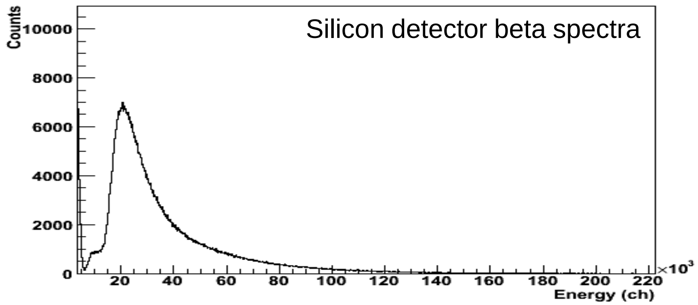




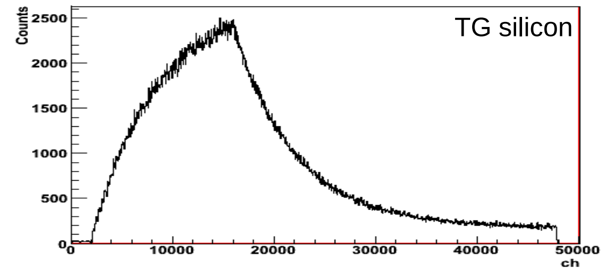
Different views of the experimental hall during measurements in JYFL - IGISIOL facility

BELEN 20 design for JYFL experiments (2009 & 2010)

Silicon and ^{3}He spectra obtained

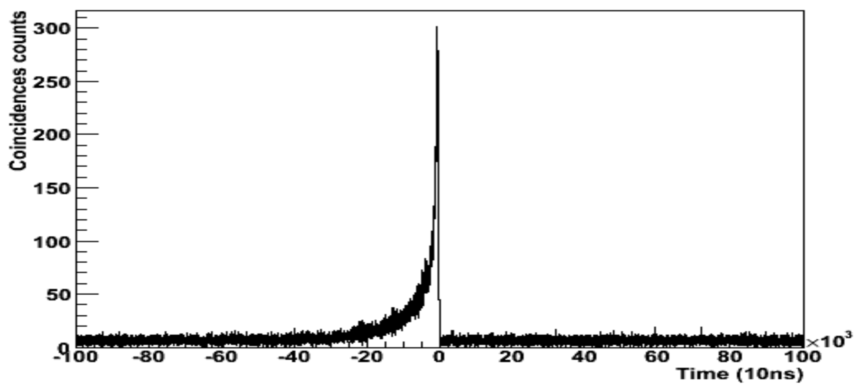


Growth (implant) and decay curves constructed



Implant for 3 $T_{1/2}$ and left decay for 7 $T_{1/2}$ before moving the tape

Preliminary beta – neutron correlations within a 1ms window.



The neutron emission probability is calculated from:

Measured nuclei: **^{94,95}Rb, ^{88}Br ^{137}I (calibration) ^{85}Ge, ^{85}As, ^{86}As, ^{91}Br**

$$P_n = \frac{1}{\varepsilon_n} \frac{N_{n\beta}}{N_\beta}$$

Some Pn values obtained and presented at ND2013 by J.L.Tain and at Bienal de Física by J. Agramunt & A.R.García

Experiments at GSI -FRS facility 2011. Darmstadt, Germany

BELEN-30: 20 ^{3}He (20 atm) & 10 ^{3}He (10 atm)

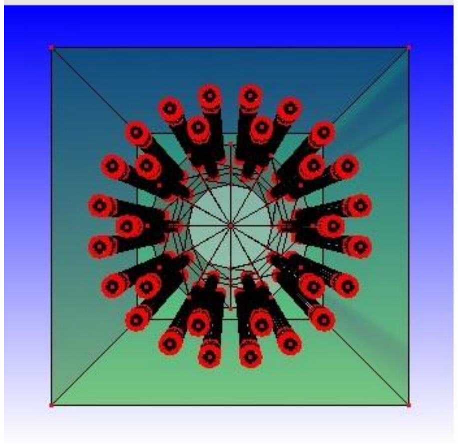
Inner ring (10 counters): 29 cm

Outer ring (20 counters): 37 cm

Efficiency (1keV-1MeV) ~40%,

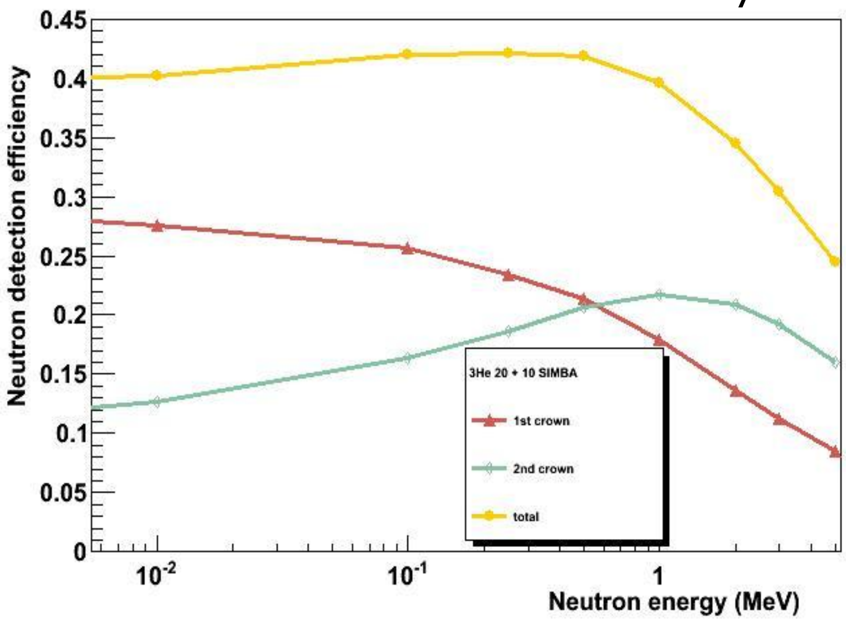
Efficiency at ~2MeV ~35% (Checked exp.)

Central hole radius: 11.5 cm - SIMBA Implantation detector



Experimental checking of the efficiency with a ^{252}Cf source (M.Marta)

MCNPX simulation efficiency



- MCNPX simulation (2MeV):

  (34.5±0.2)%

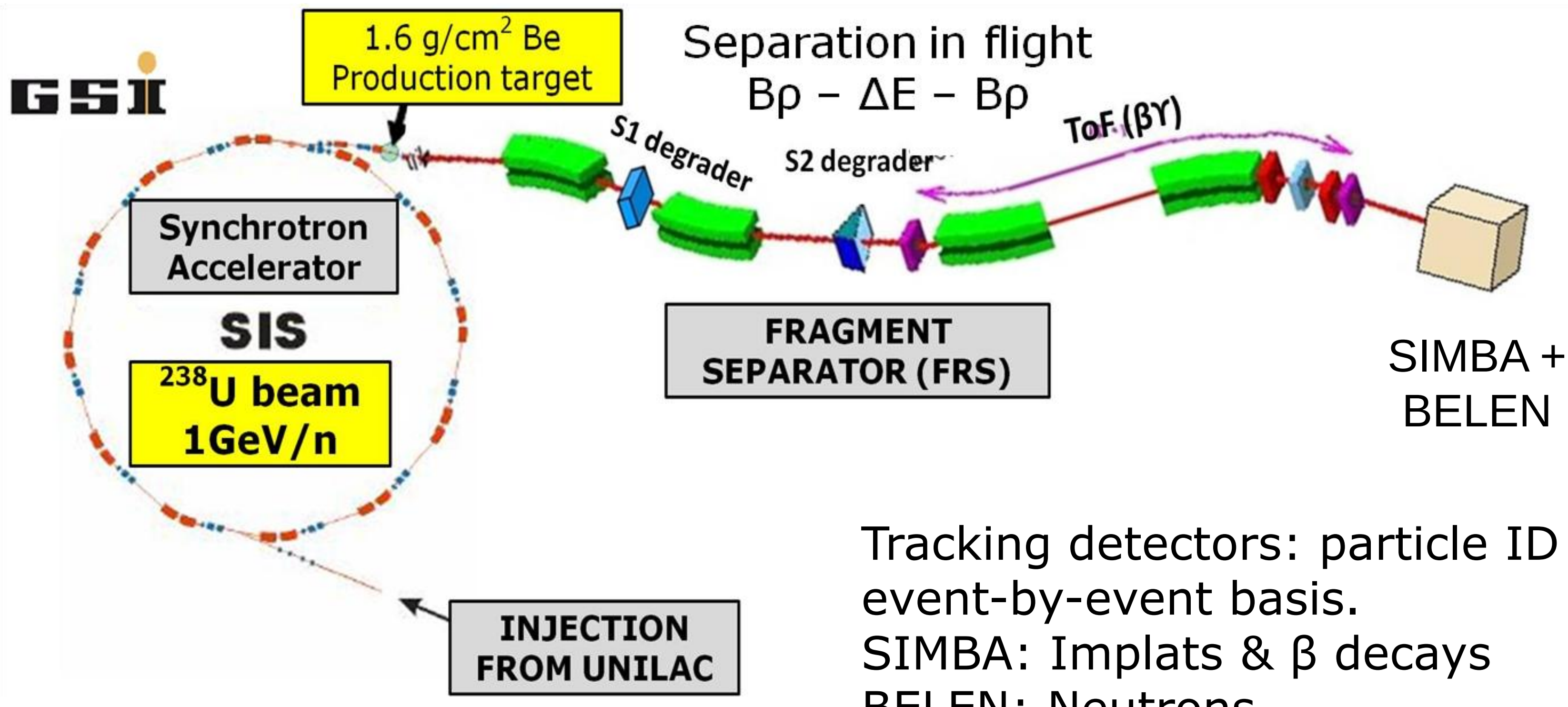
- Triggerless DACQ (IFIC) in MBS :

  (35.4±0.8)% (Talk by J.Agramunt)

- Analog branch:

  (25.5±0.9)% (electronics)

Large intensity ($2x10^9$ ions/pulse) & high-energy (1 GeV/u) for ^{238}U beams

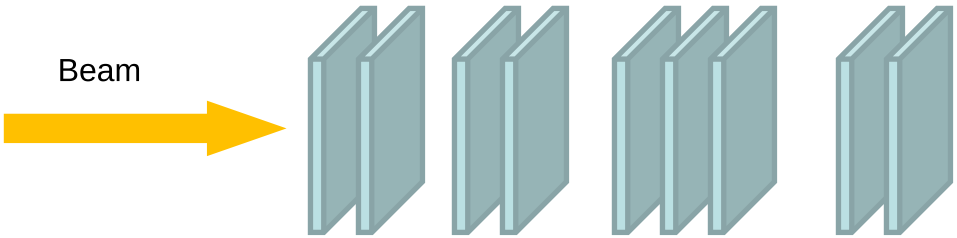


Tracking detectors: particle ID on an event-by-event basis.
SIMBA: Implats & β decays
BELEN: Neutrons

The detection system is based on a stack of SSSD- and DSSD-detectors for measuring ion-implants and beta-decays (SIMBA). Implants-region was surrounded by the 4π neutron detector BELEN.

BELEN 30: Implantation, β decay & neutron detection: SIMBA + BELEN

Silicon striped detectors (SSSD's and DSSD's)

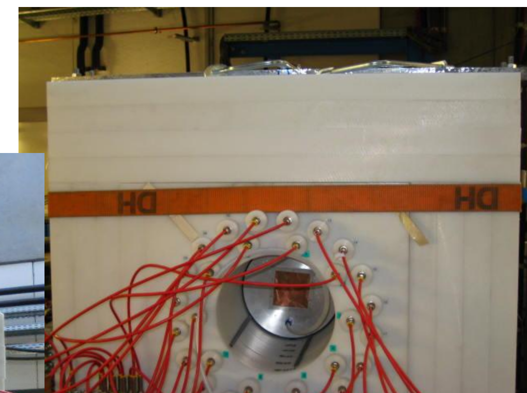


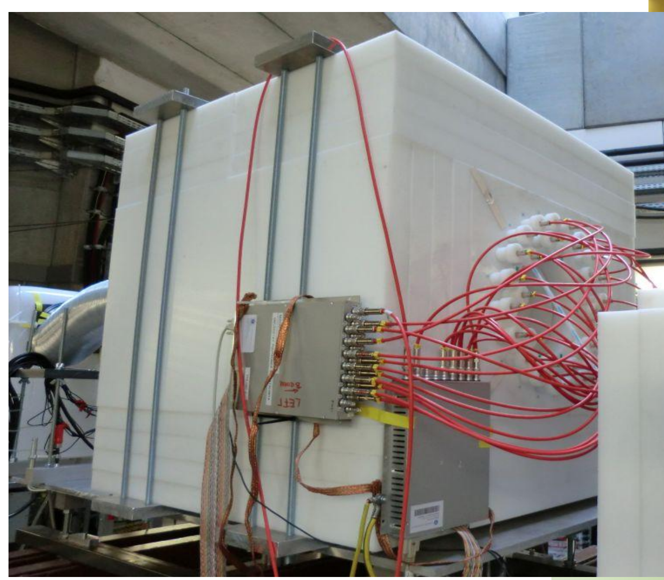
Tracking: (X,Y) Implants | β- absorber | **Implantation area** | β- absorber

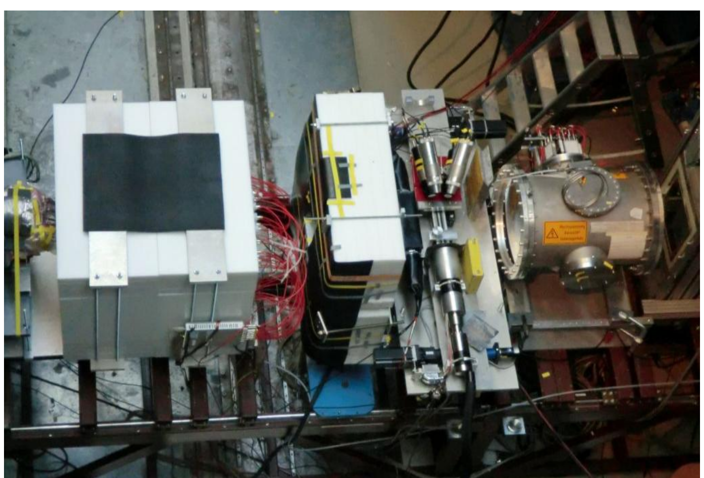
PhD thesis C. Hinke, TUM (2010)
Diploma thesis K. Steiger, TUM (2009)

Silicon Implantation Beta Absorber (SIMBA)

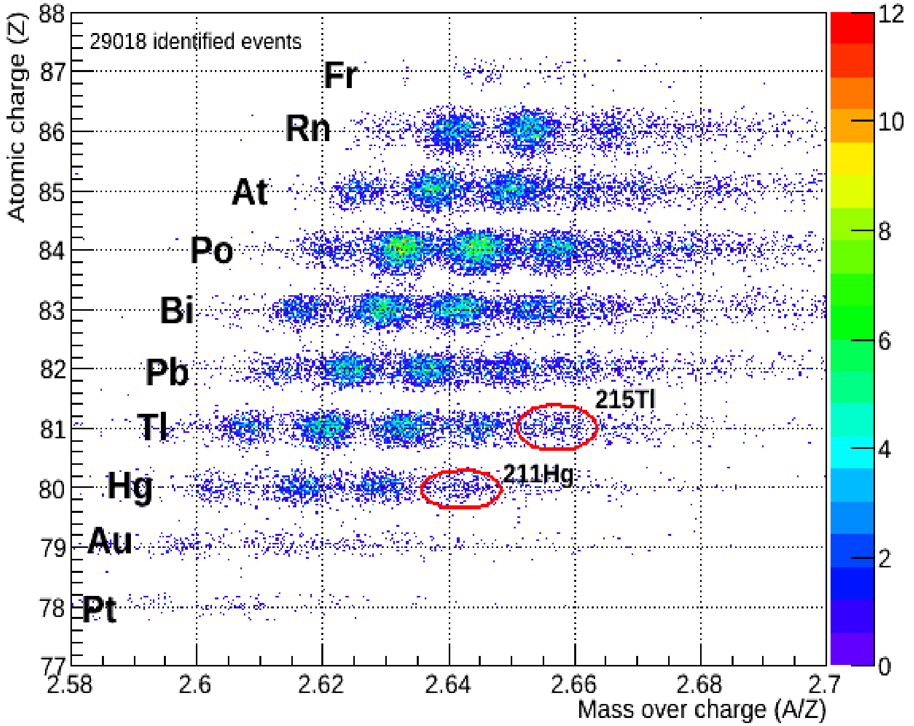
Technische Universität München

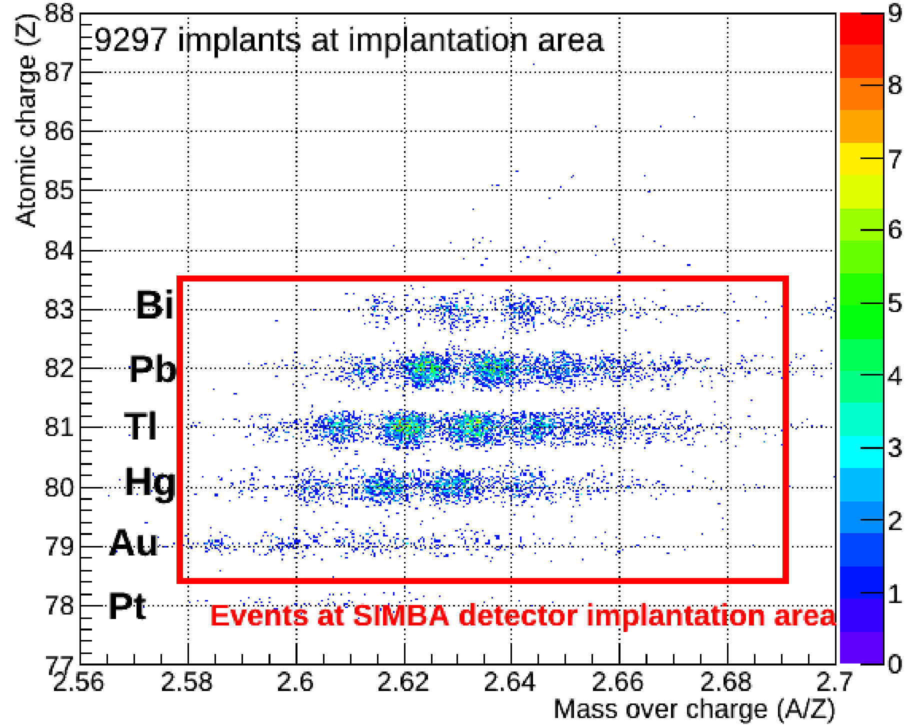




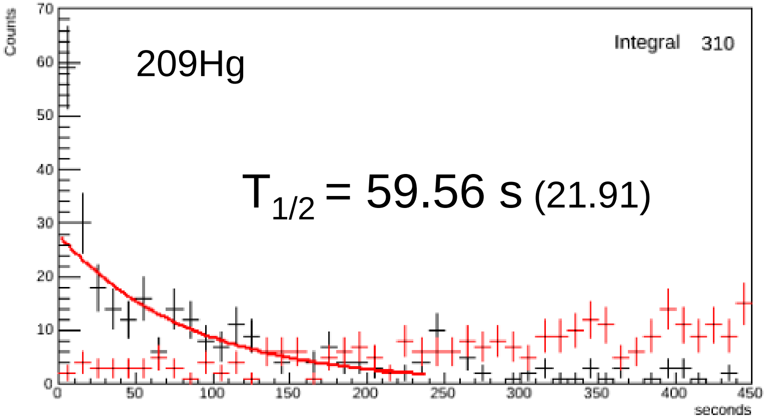


S410 ID plot & implants

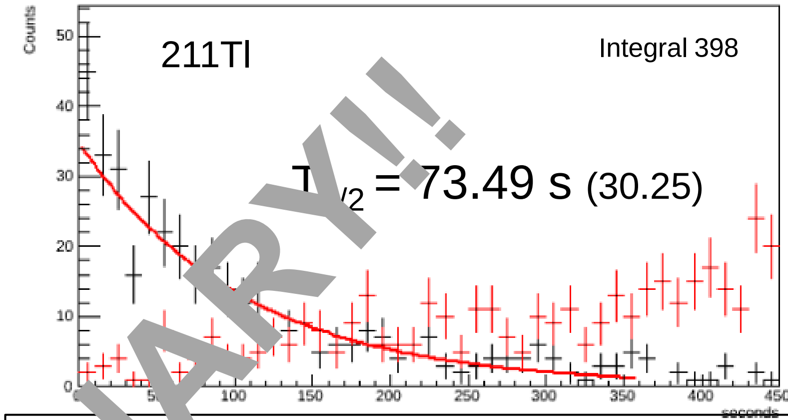




Isomer tagging was used for Z identification and two centred settings on ^{211}Hg and ^{215}Tl were measured during 4.5 days. The implantation area was optimized for Hg and Tl region where good resolution has been obtained. S323 was centered in ^{127}Pd and Ag nuclei.

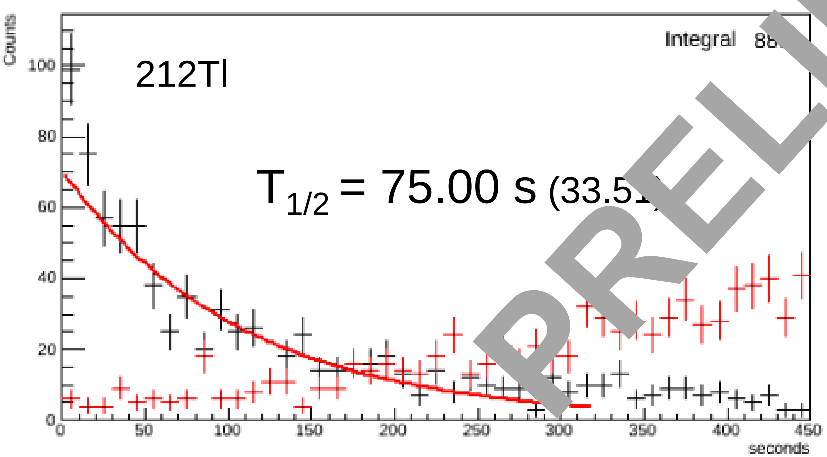


$t_{1/2}$ = 36.5(+/-7.5**) s**



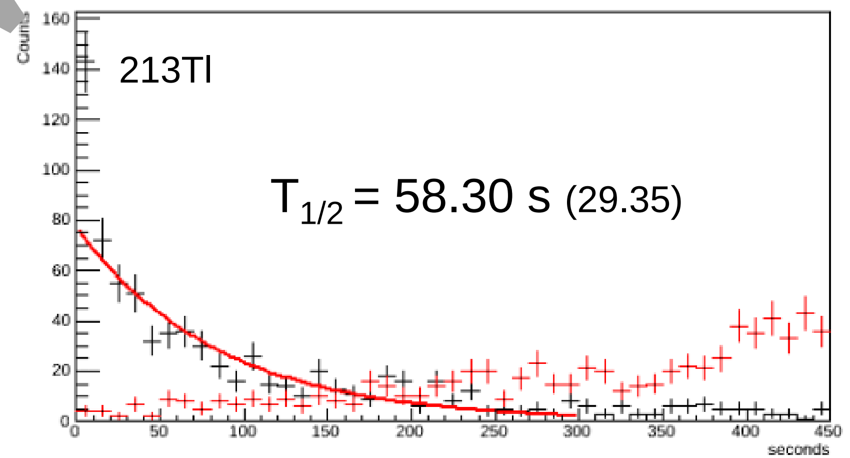
G.Benzoni et al. PLB 715 (2012)

$t_{1/2}$ = 88 ($^{+46}_{-29}$) s

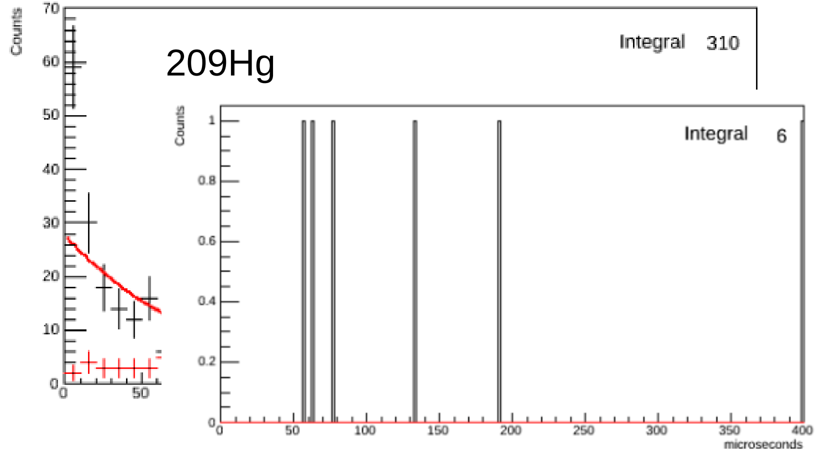


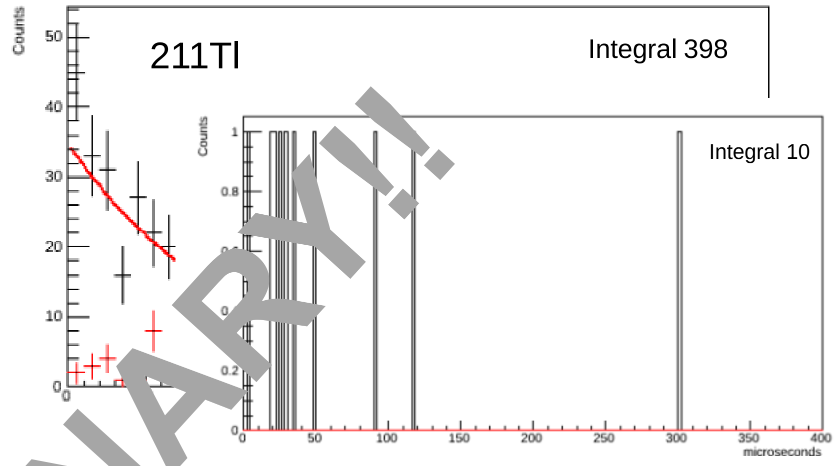
G.Benzoni et al. PLB 715 (2012)

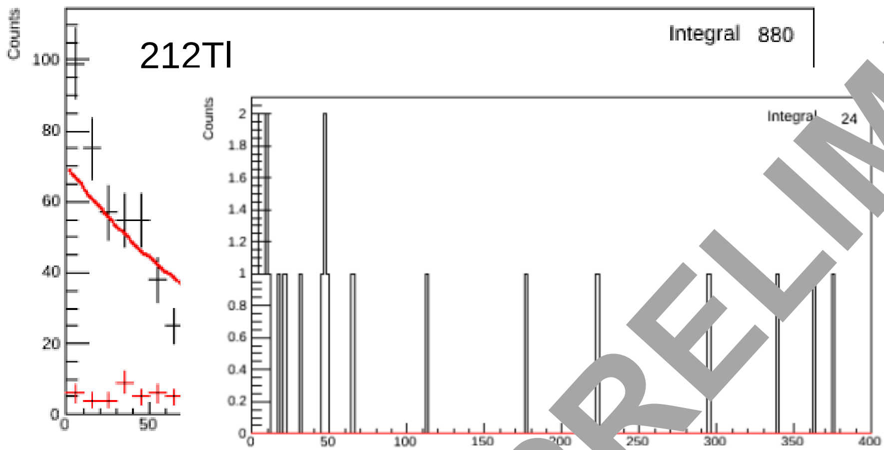
$t_{1/2}$ = 96 ($^{+42}_{-38}$) s

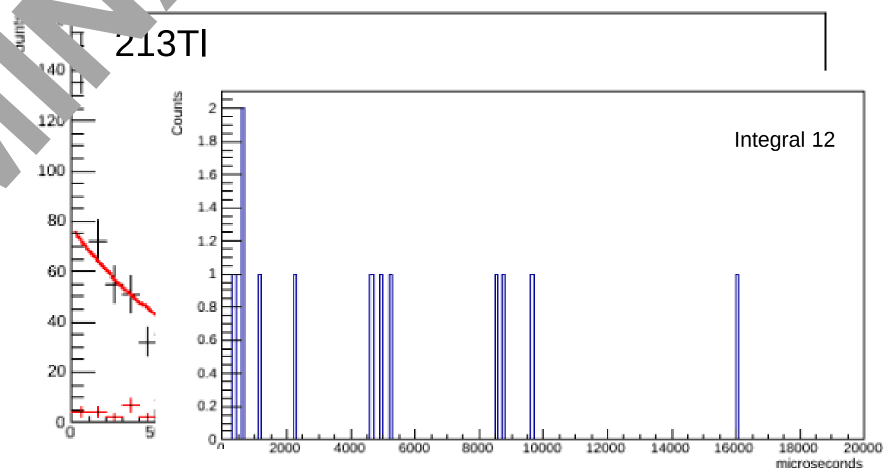


BELEN 30 S410 experiment preliminary beta – neutron correlations

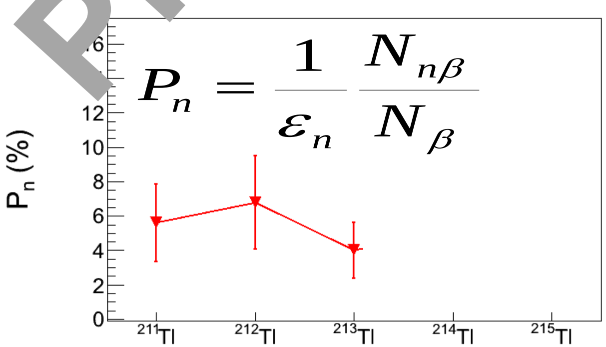








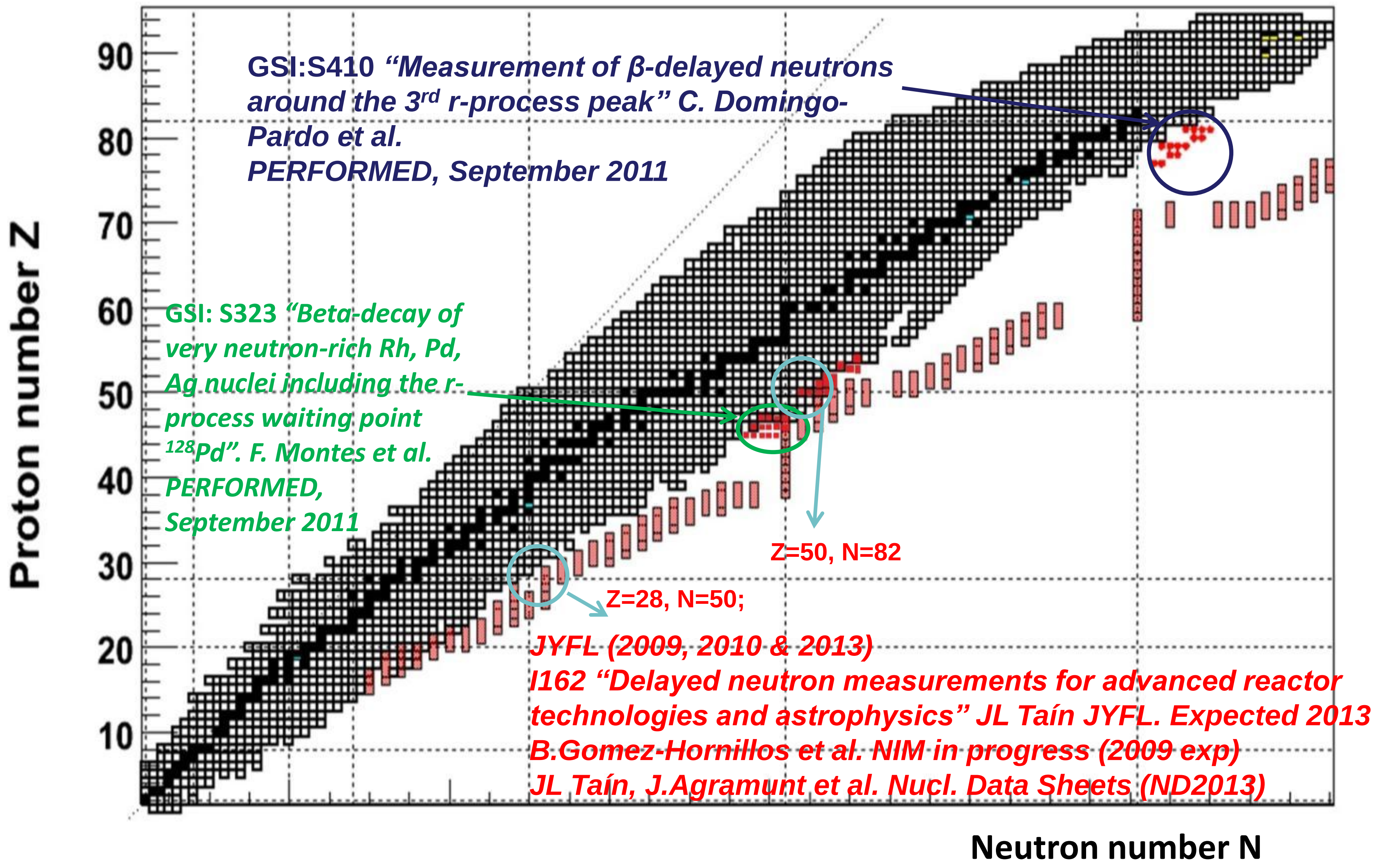
PRELIMINARY!!

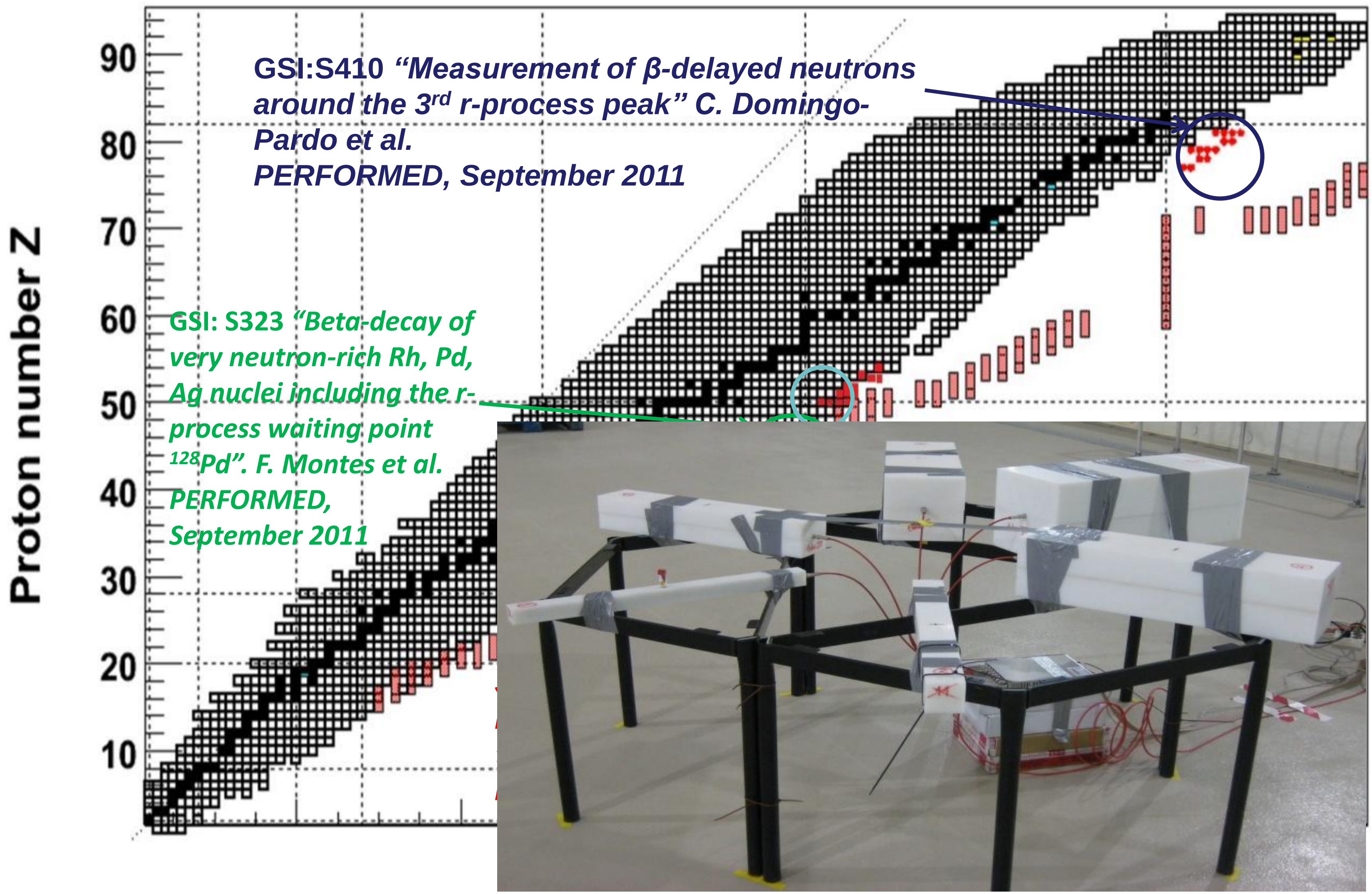


$$P_n = \frac{1}{\varepsilon_n}\frac{N_{n\beta}}{N_\beta}$$

(Efficiency ~40%)

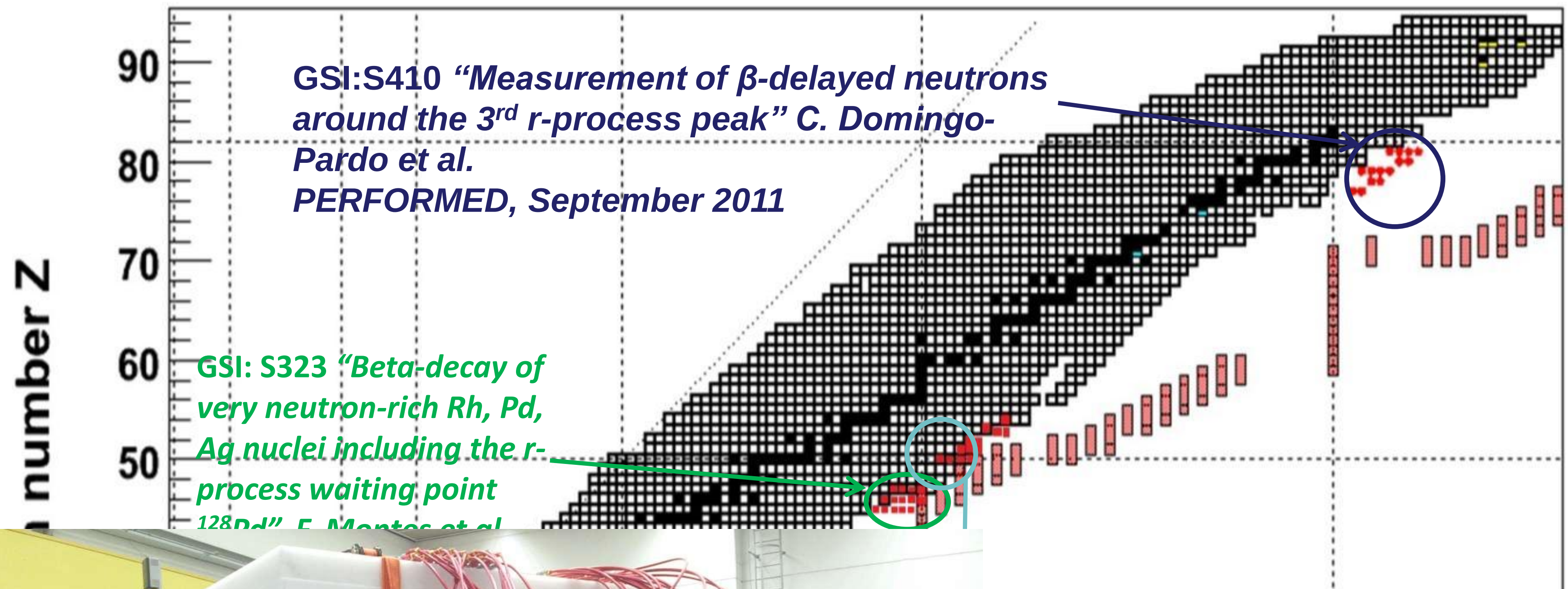
SUMMARY: Tests and experiments with BELEN detector

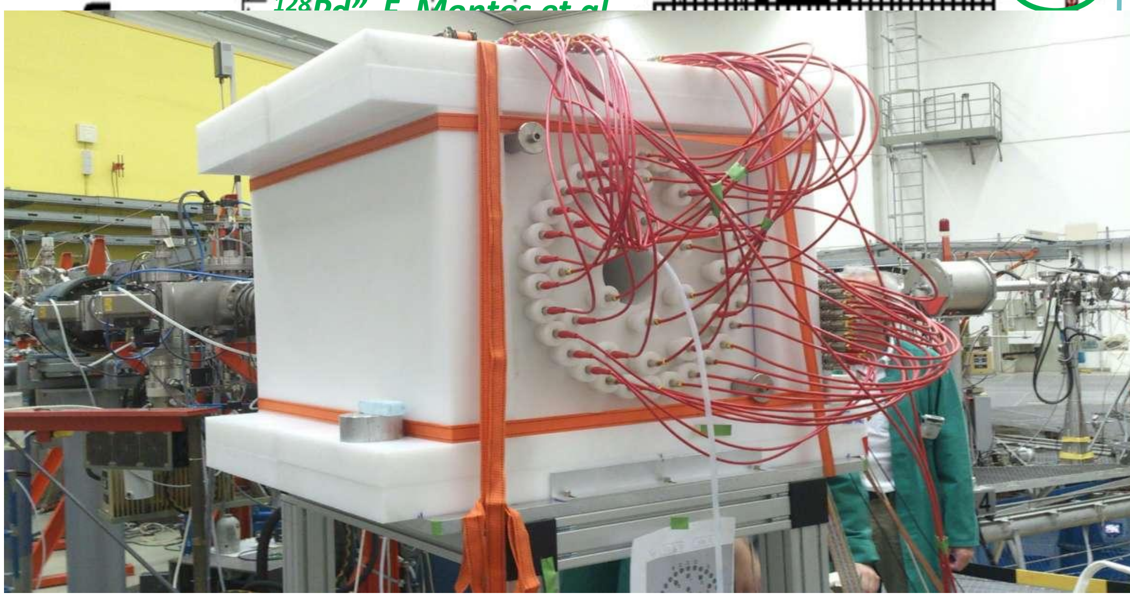


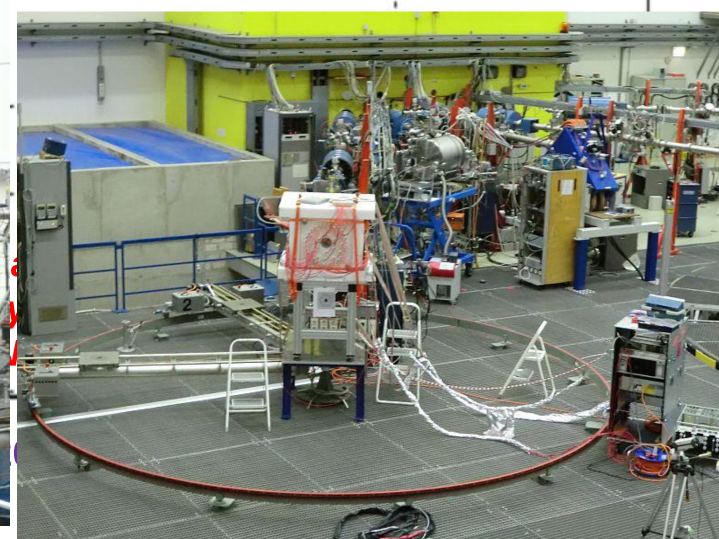


Background measurements at GSI (2010) and LSC Canfranc (2011)
D.Jordan et al. Astr.Phys Vol.42, Feb 2013, p.1–6

SUMMARY: Tests and experiments with BELEN detector







PTB : Efficiency calibration of the BELEN neutron detector. (June 2013)

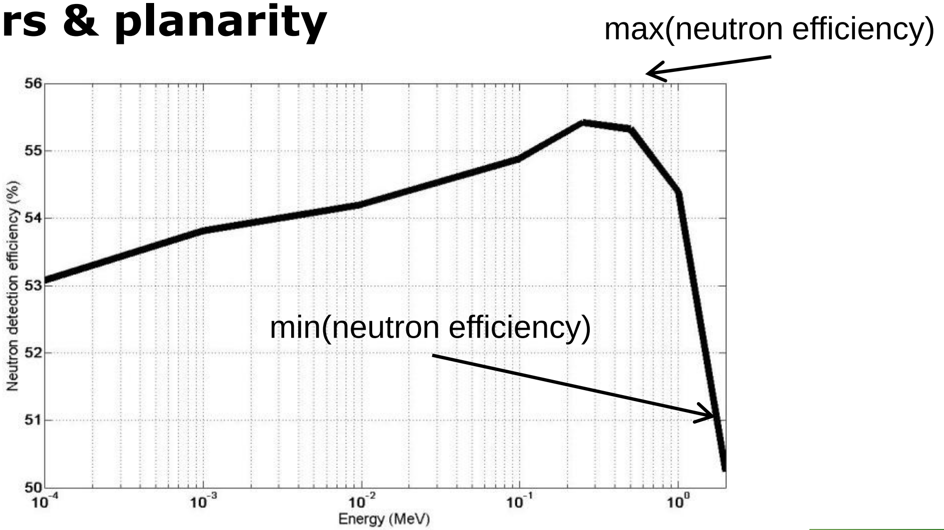
SUMMARY: BELEN versions and main design parameters

Name	^{3}He counters	Pressure (atm)	Experiment	Ratio @ 2 MeV	Ratio @ 5 MeV	Average efficiency	Central hole radius (cm)
BELEN-20	**20**	**20**	**JYFL-2009**	**1.17**	**[1.60]**	**35% 2MeV**	**5.5**
BELEN-20	**20**	**20**	**JYFL-2010**	**1.17**	**[1.60]**	**45% -35% 1-5MeV**	**5.5**
BELEN-30	**20+10**	**20 & 10**	**GSI-2011**	**1.17**	**[1.70]**	**40 % 1MeV 35% 1-5MeV**	**11.5 (SIMBA)**
BELEN-48	**40+8**	**8 & 10**	**PTB JYFL-2013**	**1.02**	**1.16**	**54%-39%** 2-5MeV	**5.5**
BELEN-48	**40+8**	**8 & 10**	**DESPEC**	**1.04**	**1.15**	**45%-34%**	**8 (AIDA)**

Observe: Central hole, num. counters & planarity

To define the efficiency flatness for a range of neutron energies

$$Ratio = \frac{\max(\text{neutron efficiency})}{\min(\text{neutron efficiency})}$$



BELEN characteristics

- ✓ Based on ^{3}He counters embedded in a 4π polyethylene matrix .
- ✓ Optimized to maximize the efficiency and reduce its energy dependence in the energy range of interest.
- ✓ Laboratory tests and several successful experiments performed.
- ✓ The efficiency of the previous configurations has been validated experimentally with ^{252}Cf sources and some reference isotopes
- ✓ Implantation detector characteristics determine the central hole
- ✓ Number of counters and planarity is crucial for efficiency in the energy range
- ✓ Dimensions of presented versions: 90 x 90 x 80 cm^3 (including shielding)
- ✓ Approximate 700 kg weight

BELEN ongoing work, improvements and management

- ✓ Improvements on BELEN efficiency simulations (Talk Guillem Cortès - UPC)
- ✓ Specific triggerless DACQ provides a very low dead time. Digital data acquisition system developed at IFIC (Talk by J.Agramunt)
- ✓ Integration of the acquisition system s

  (RIKEN tracking detectors + AIDA + BELEN)

➢ **Logistics for measurements with BELEN at RIKEN→ TO DISCUSS**

- ✓ Transportation of the detectors (Counters & electronics)

  Price of UPC + GSI (52) counters: < 1000€ (Dang. G.Decl. Incl / Return?)
- ✓ Which part can be built at RIKEN (Japan)?

  Polyethylene Matrix (due to the shipping cost)
- ✓ Design of the support structure. Adapted to the experimental hall.
- ✓ Availability of neutron sources to test/calibrate the detector.
- ✓ Human resources.

BELEN detector team 2007-2013

UPC (Barcelona)
R.Caballero-Folch, F.Calviño, G.Cortès, A.Poch, C.Pretel, A.Riego, A.Torner
Old members: M.B.Gómez-Hornillos, V.Gorlychev

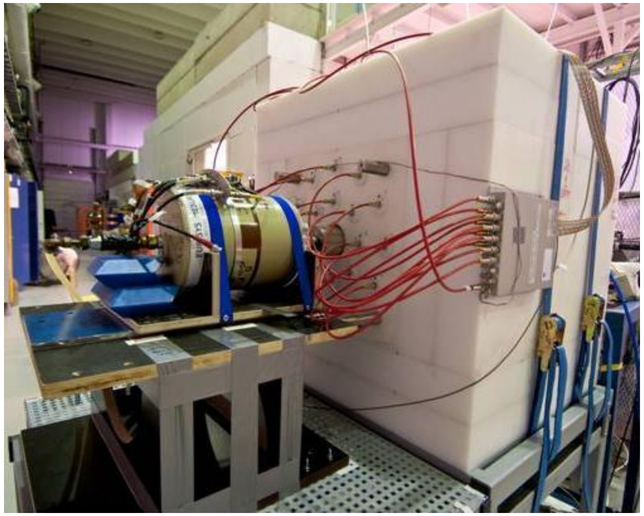
IFIC (València)
J.Agramunt, A.Algora, C.Domingo-Pardo, D.Jordan, J.L.Taín

GSI (Darmstadt – Germany)
I.Dillmann, A.Evdokimov, M.Marta

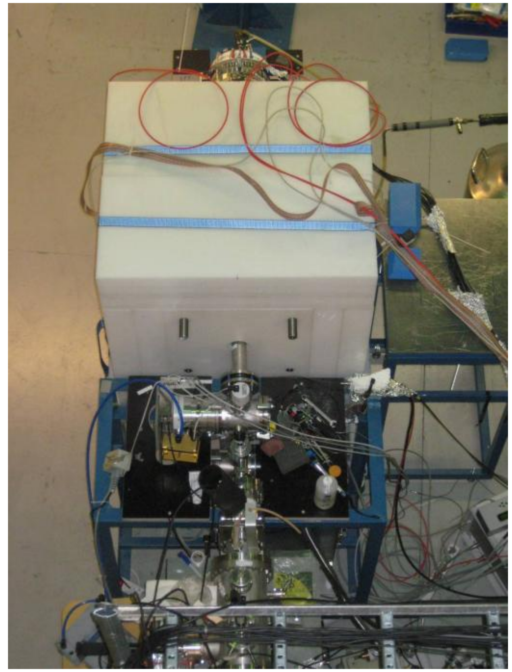
CIEMAT (Madrid)
D.Cano-Ott, T.Martínez, E.Mendoza, A.García

Contact: roger.caballero@upc.edu

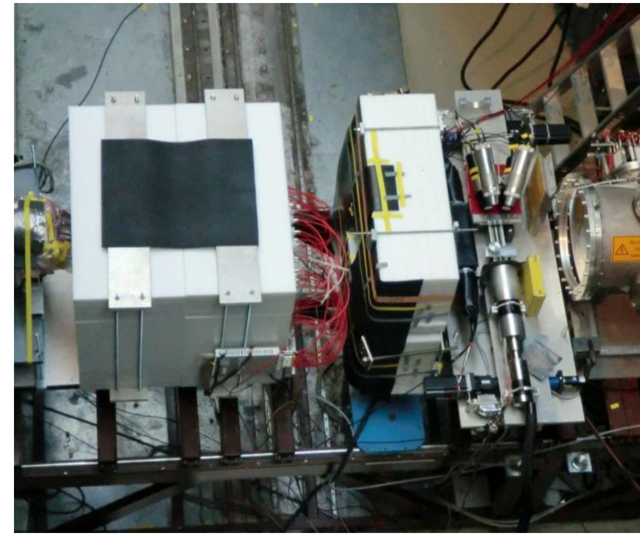
Work supported by the Spanish Ministry of Economy and Competitivity under contract ***FPA 2011-28770-C03-03***



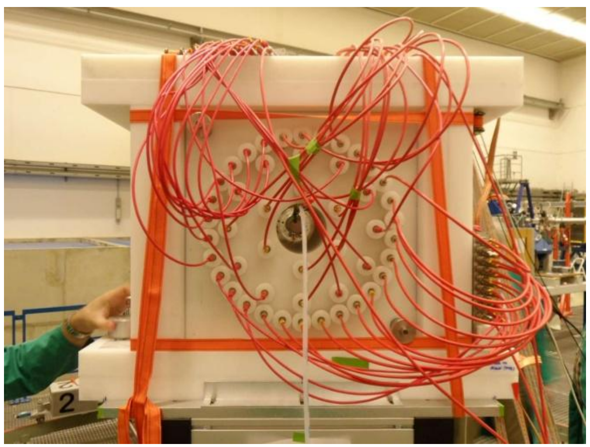
JYFL 2009



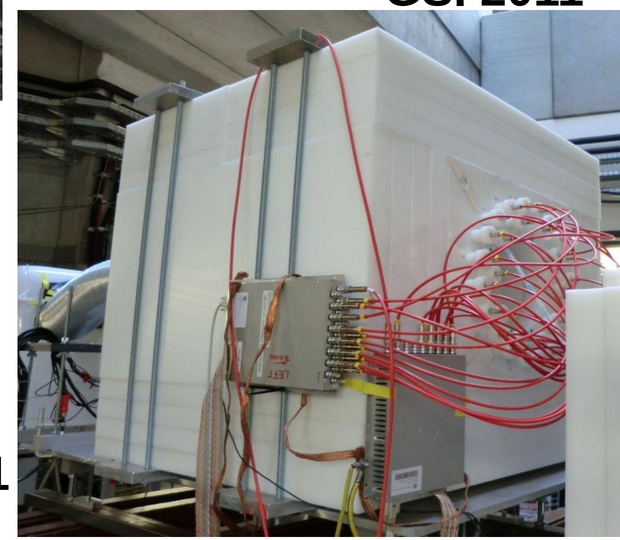
JYFL 2009



GSI 2011



PTB 2013



GSI 2011

Contact: roger.caballero@upc.edu

IFIC Institut de Física Corpuscular · GSI · NSCL · Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas · The University of Edinburgh · Science & Technology Facilities Council · TRIUMF · RIKEN Nishina Center · UPC · Justus-Liebig-Universität Giessen · Michigan State University · Oak Ridge National Laboratory · ...