
# Half-lives and β-delayed Neutron emission measurements beyond N=126

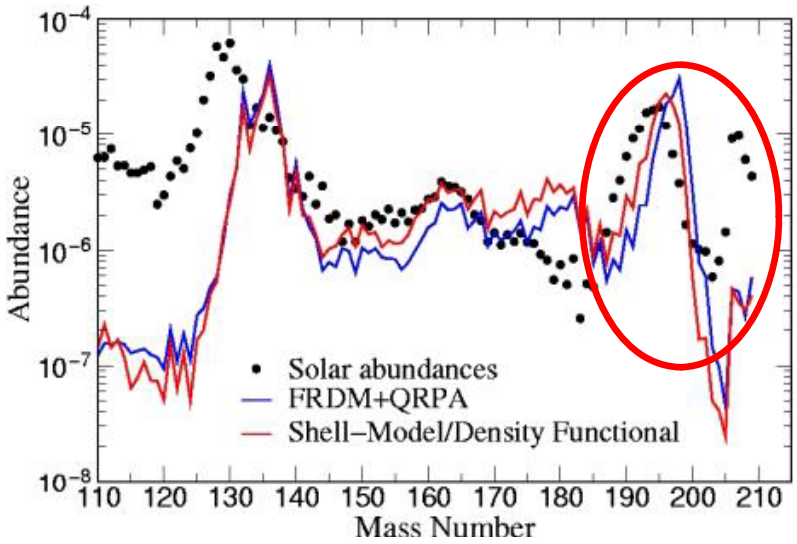
**ROGER CABALLERO-FOLCH**
**& S410 experiment collaboration**
*Universitat Politècnica de Catalunya*
7 de març de 2013

Contents

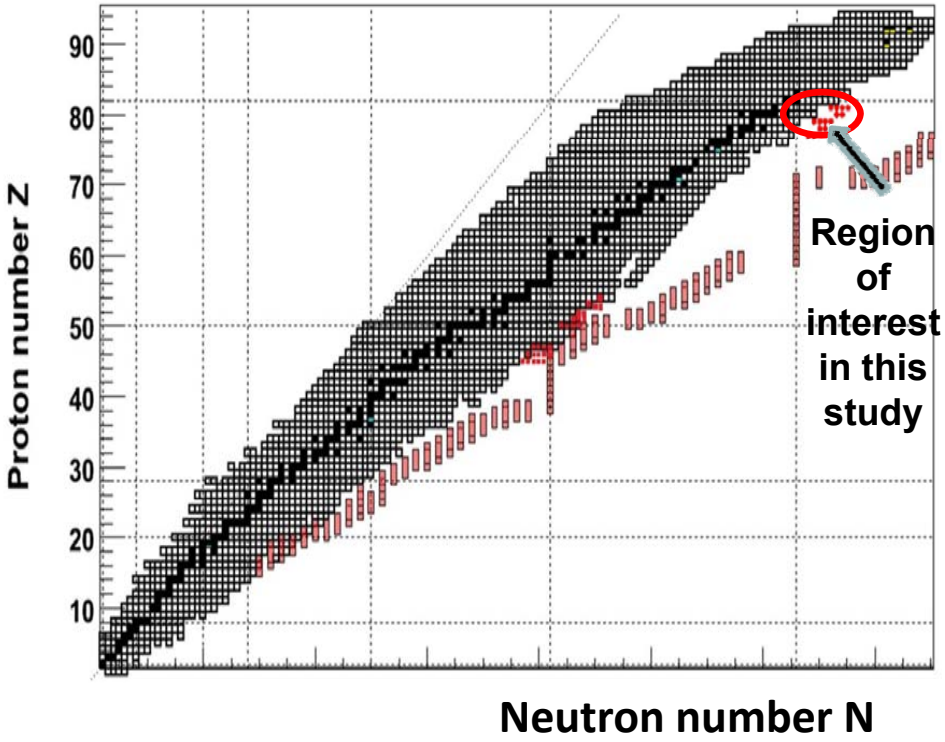
- Motivation
- Introduction: Experimental setup at GSI-FRS facility
- Identified nuclei
- Detection System: SIMBA & BELEN detector
- Ongoing analysis and preliminary results
- Analysis method to determine half lives
- Isotope statistics
- Summary and outlook

## Motivation

Goal: Experimental determination of half lives and neutron branchings of several exotic nuclei in the neutron rich region beyond N=126




The Astr. Jour., 579 (2002), H. Schatz et al.
Proc. CGS-13 (2009), G. Martinez-Pinedo



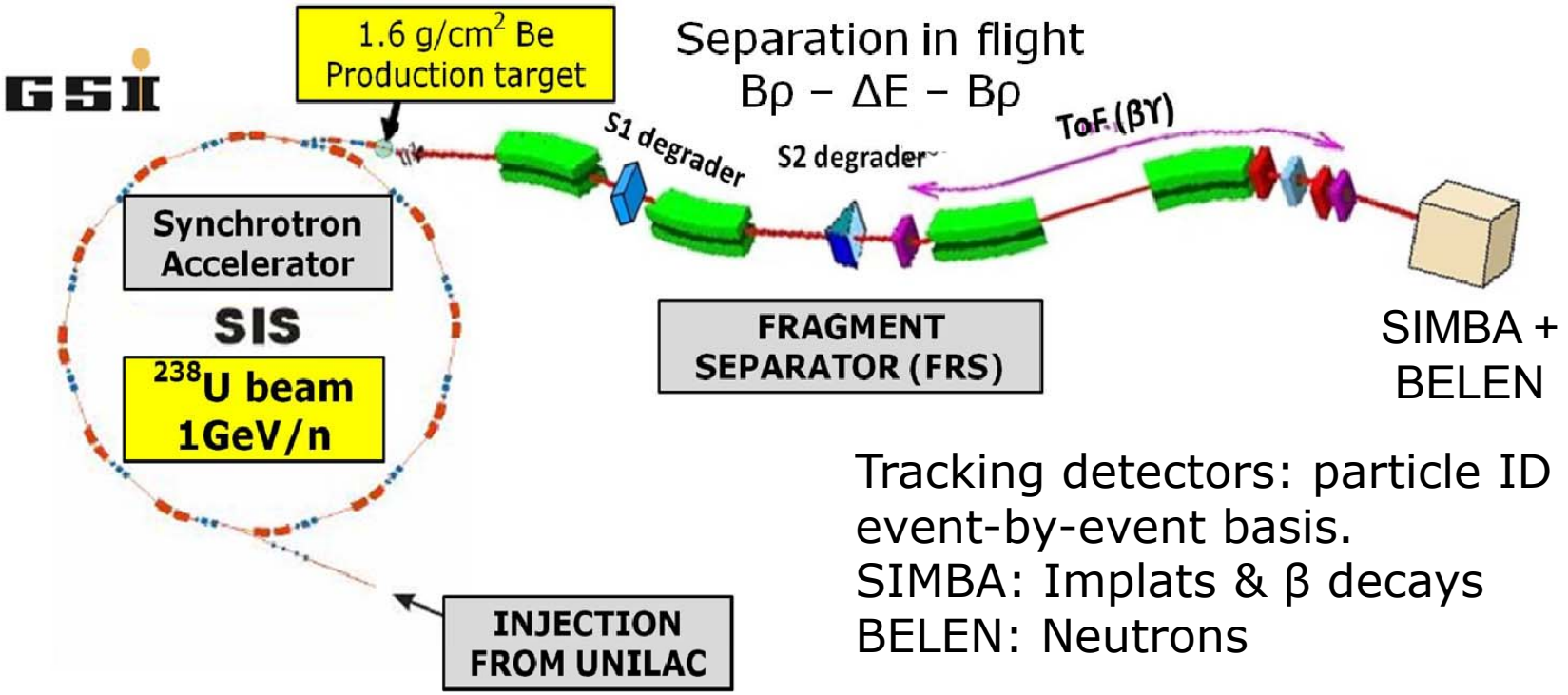

Understanding of A=195 peak in the r-process abundance pattern.

R-process calculations rely on theoretical predictions (QRPA & FRDM), with remarkable discrepancies and large uncertainties.

# Experiment at GSI – FRS facility. $^{238}$U fragmentation beam.

## Introduction

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

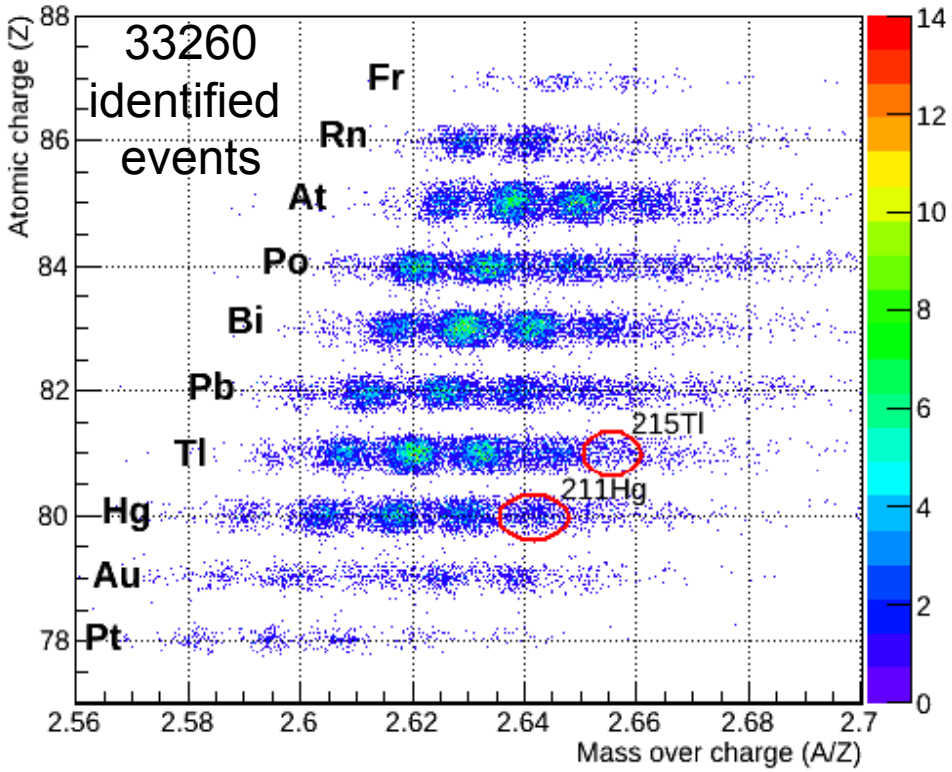



Tracking detectors: particle ID on an event-by-event basis.
SIMBA: Implats & β decays
BELEN: Neutrons

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.

# Isotopes of Pt, Au, Hg, Tl, Pb, Bi, Po, At, Rn and Fr identified

## Identified nuclei



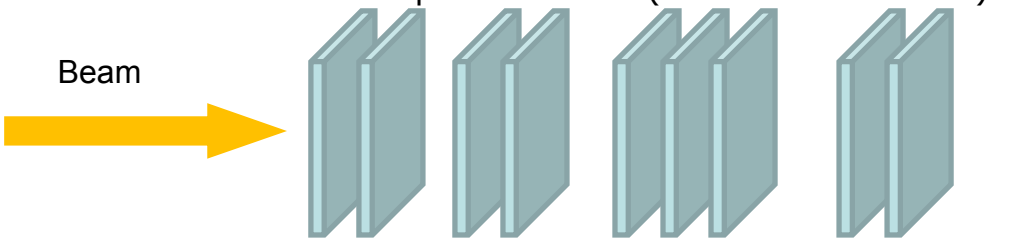

This identification information should allow us to estimate **fragmentation cross-sections** for $^{238}$U at 1 GeV/u.

The results will be compared versus the CSs reported in *PRC82 (2010), H.Alvarez-Pol, et al.*, which represent the only experimental information available so far.

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.

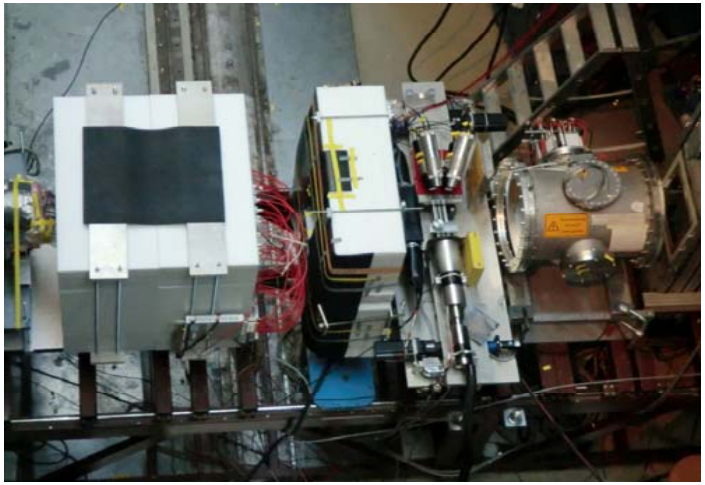
## Detection system: SIMBA & BELEN detector

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

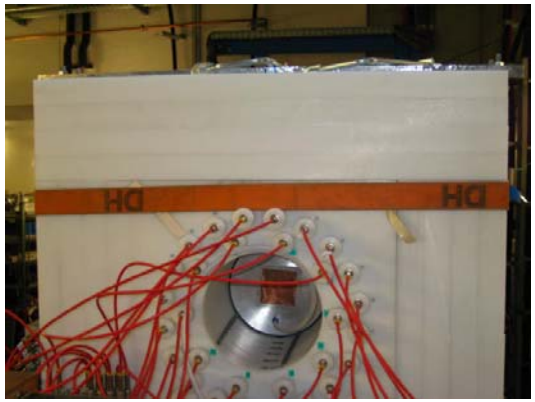



Tracking: (X,Y) Implants | β- absorber | **Implantation area** | β- absorber

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



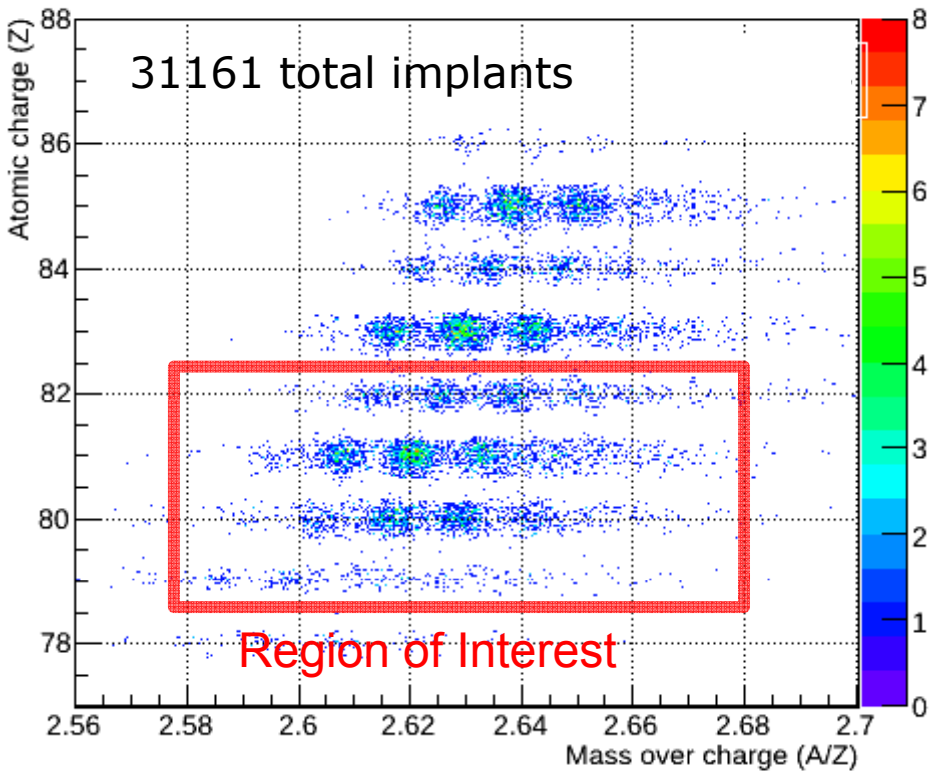
BELEN efficiency was about 40% (checked experimentally)

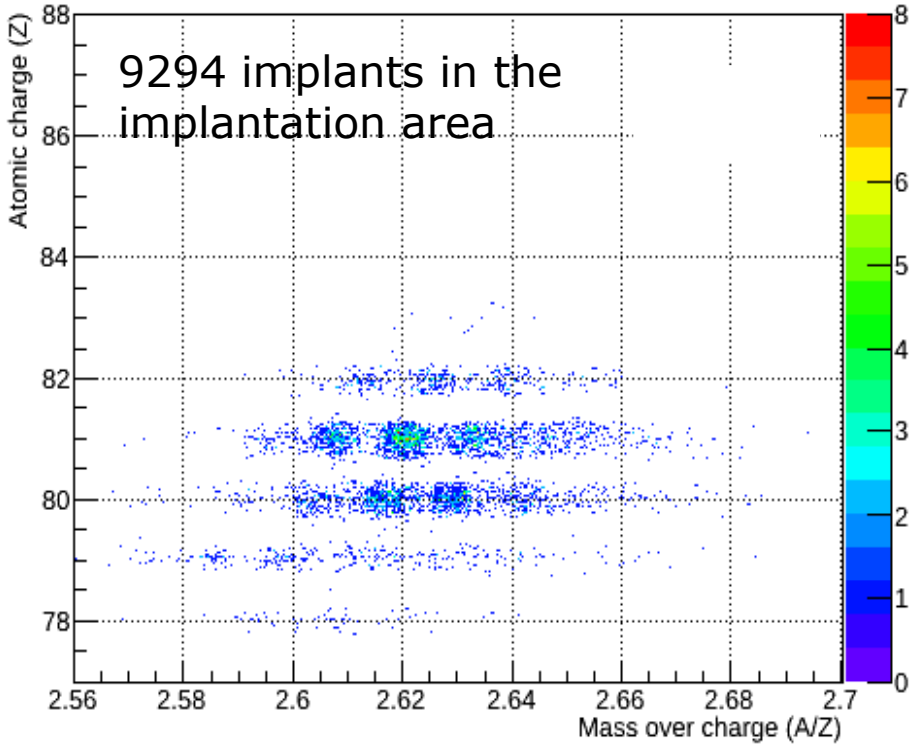


The Beta dELayEd Neutron (BELEN) detector, based in $^{3}He$ counters embedded in a polyethylene matrix, located around Silicon IMplantation Beta Absorber (SIMBA).

# Implants detected in SIMBA detector

## Ongoing analysis and preliminary results

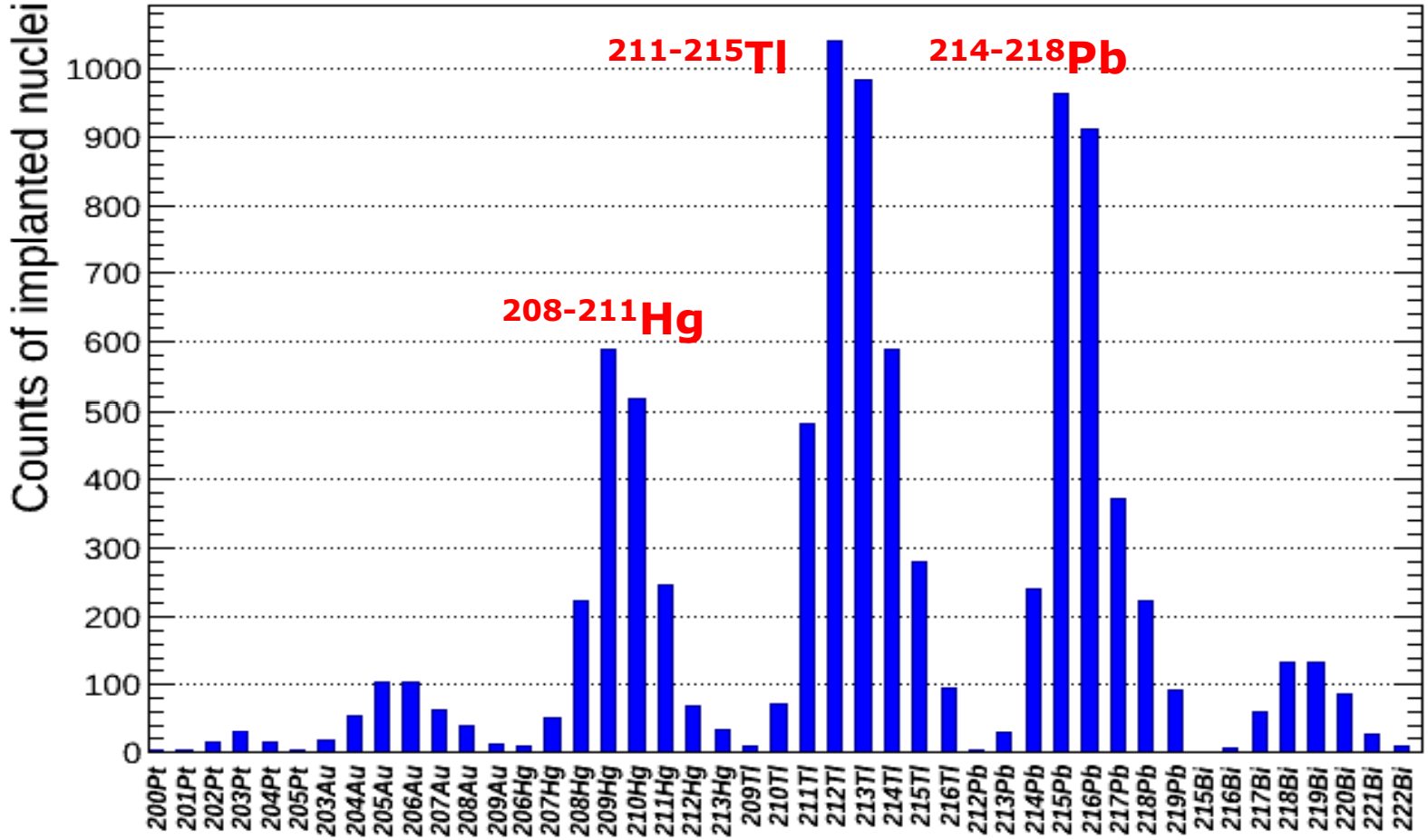



Implants on the high segmented layers of SIMBA detector DSSD area.

# Good statistics implantation for $^{208-211}$Hg, $^{211-215}$Tl and $^{214-218}$Pb

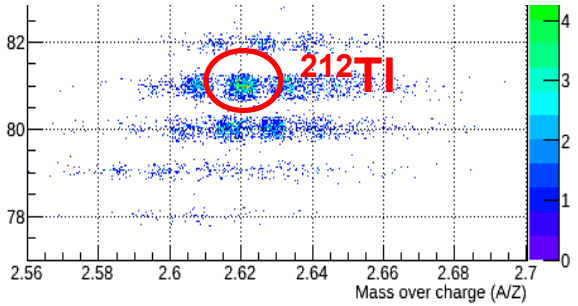
## Ongoing analysis and preliminary results




Implants on the high segmented layers of SIMBA detector

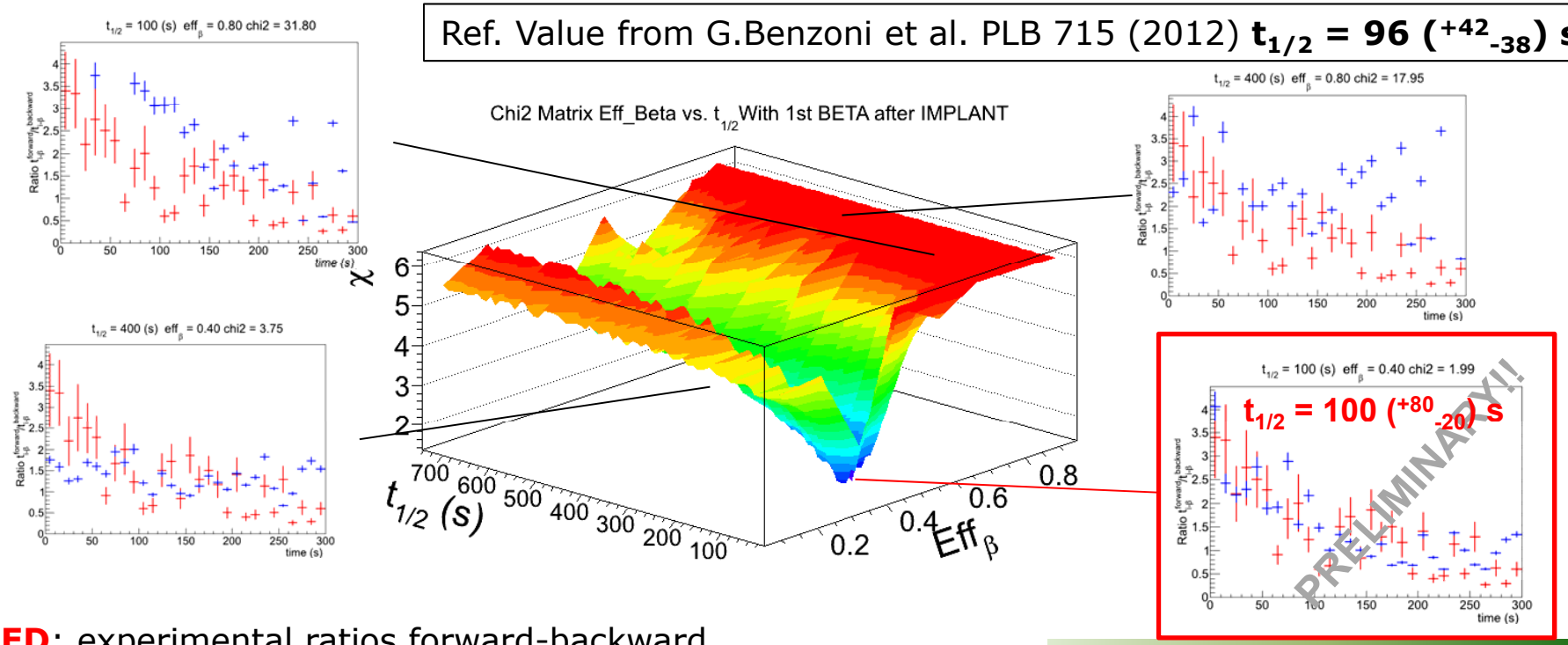
# Preliminary Analysis of beta-decay Half-lives $^{212}$Tl

## Analysis method to determine half lives: $^{212}$Tl



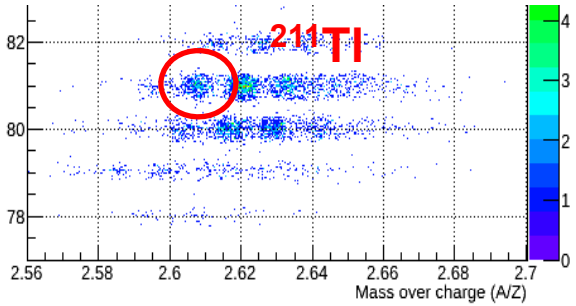

As first approach, we apply the method developed at USC for long half-lives in complex background environments (*NIM-A-589 (2008),T.Kurtukian*).
Basically, the method consists of comparing implant-beta time-correlation spectra (actually the ratios forward/backward) for several values of the unknown quantities: beta efficiencies and half-lives, for certain (known) rates of implantation and beta-decay events.

Ref. Value from G.Benzoni et al. PLB 715 (2012) $\mathbf{t_{1/2} = 96\ (^{+42}_{-38})\ s}$

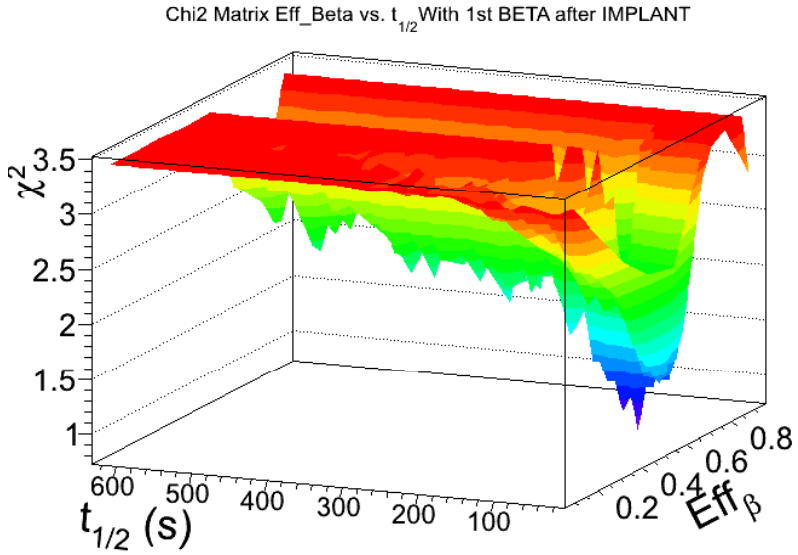


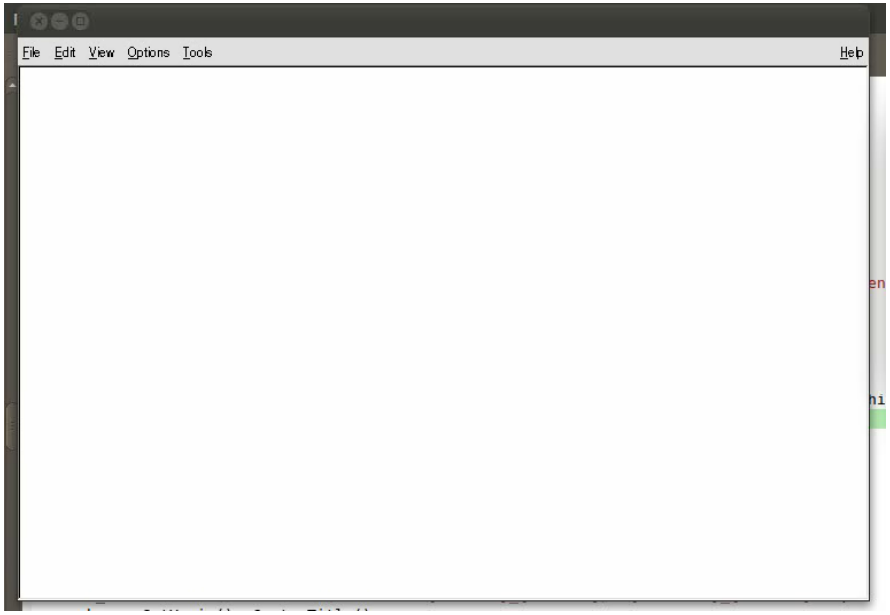

**RED**: experimental ratios forward-backward
**BLUE**: simulated ratios for different half lives and silicon efficiencies

## Analysis method to determine half lives: $^{211}$Tl



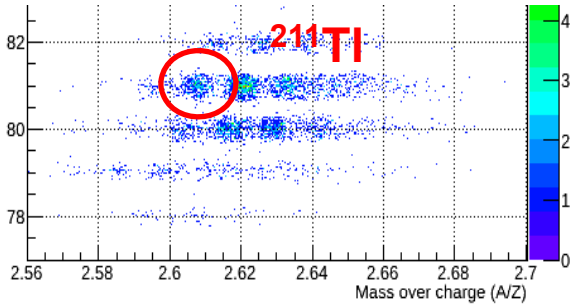

Ref. Value from G.Benzoni et al. PLB 715 (2012) $t_{1/2} = 88\ (^{+46}_{-29})$ s



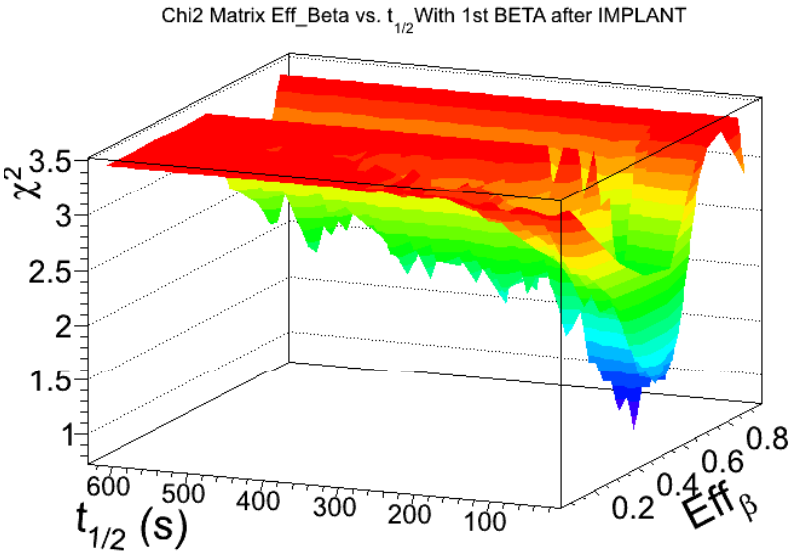



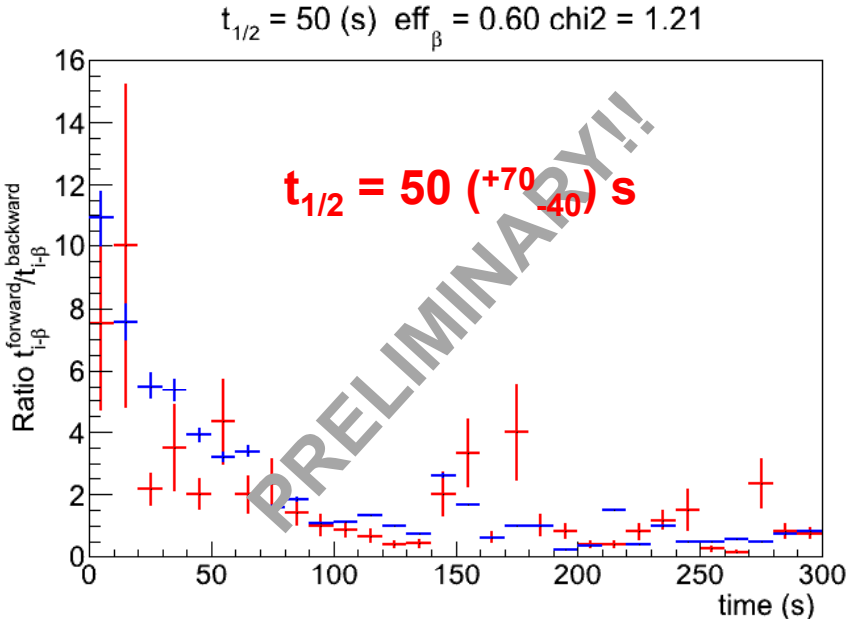

**RED**: experimental ratios
**BLUE**: simulated ratios

## Analysis method to determine half lives: $^{211}$Tl




Ref. Value from G.Benzoni et al. PLB 715 (2012) $t_{1/2} = 88\ (^{+46}_{-29})$ s

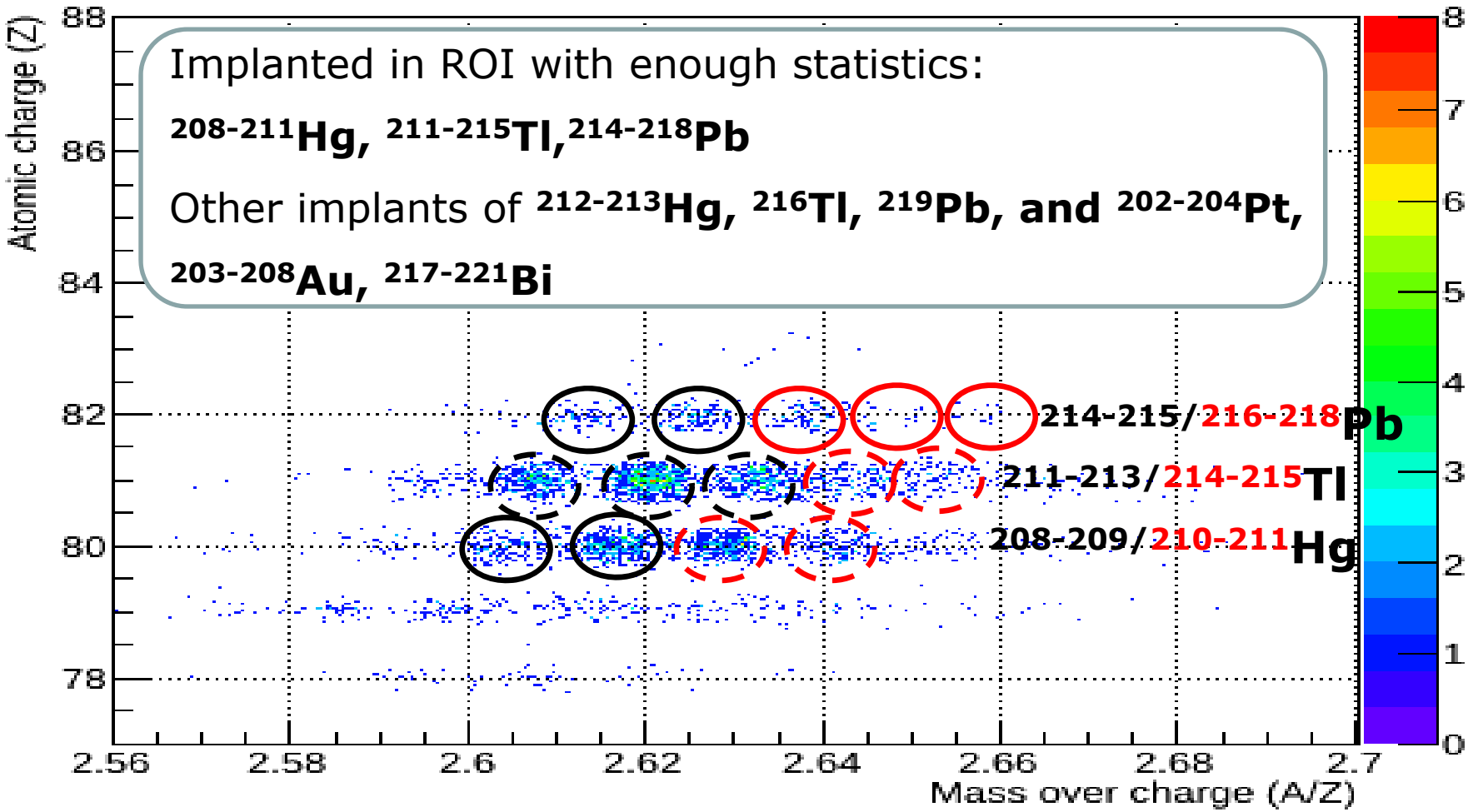



**RED**: experimental ratios
**BLUE**: simulated ratios

# Data available and data expected to obtain

## Isotope statistics




Possible evaluation of more nuclei implanted implanted in other layers.

**http://www.nndc.bnl.gov**

- - - **G.Benzoni-A.I.Morales et al, Ph.Lett.B 715 (2012)**

## Summary and outlook

- Several species of neutron rich heavy nuclei have been produced and identified in the Hg/Tl/Pb region, beyond the shell closure N=126.

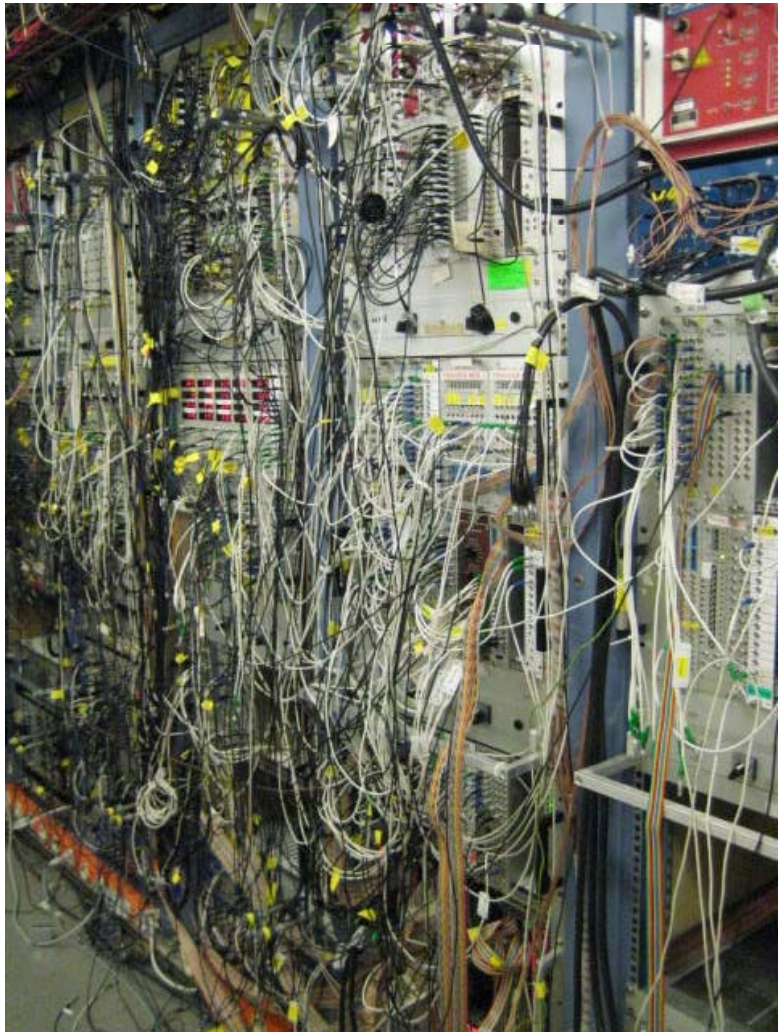
-Preliminary **half-lives** have been obtained by applying the numerical method of Ref.[*NIM-A, T.Kurtukian et al. 589 (2008)*], which has been specifically developed for high-background environments and large half-live values.

- In order to obtain final results, we need to improve several aspects in our data-analysis (simulation, statistical comparator, spatial correlations, time-correlations, etc).

- The analysis of **β-delayed neutron emission** probabilities is ongoing.

- Possibility to obtain with other methods in the Storage Ring (ESR) at GSI without neutron detectors. A.Evdokimov et al. PoS [NICXII].

# S410 experiment collaboration



**Universitat Politècnica de Catalunya (UPC)**

**Institut de Física Corpuscular de València (IFIC)**

**Helmholtzzentrum für Schwerionenforschung GmbH (GSI)**

**NSCL, Michigan State University (MSU-USA)**

**CIEMAT (Madrid)**

**Universidade de Santigo de Compostela (USC)**

**Department of Physics, University of Surrey (UK)**

**CFNUL Universidade de Lisboa (Portugal)**

**School of Physics & Astronomy, U. Edinburgh (UK)**

**Department of Physics, University of Liverpool (UK)**

**STFC, Daresbury Laboratory (UK)**

**Laboratori Nazionali di Legnaro, INFN (Italy)**

**Flerov Laboratory, JINR, Dubna (Russia)**

**CENBG, Université Bordeaux (France)**

**et al.**

**Contact: roger.caballero@upc.edu**

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

## **S410/S323** experiments at **GSI** (2011). Design & efficiency.

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

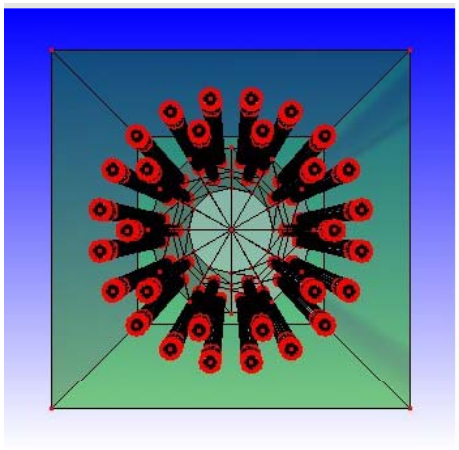
Inner ring (10 counters): 29 cm

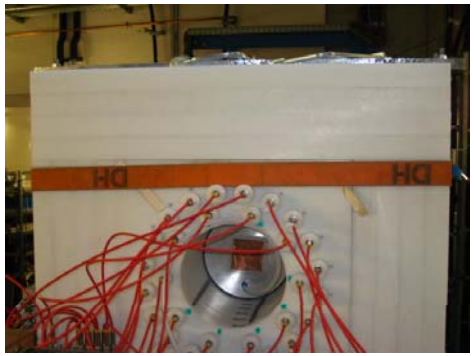
Outer ring (20 counters): 37 cm

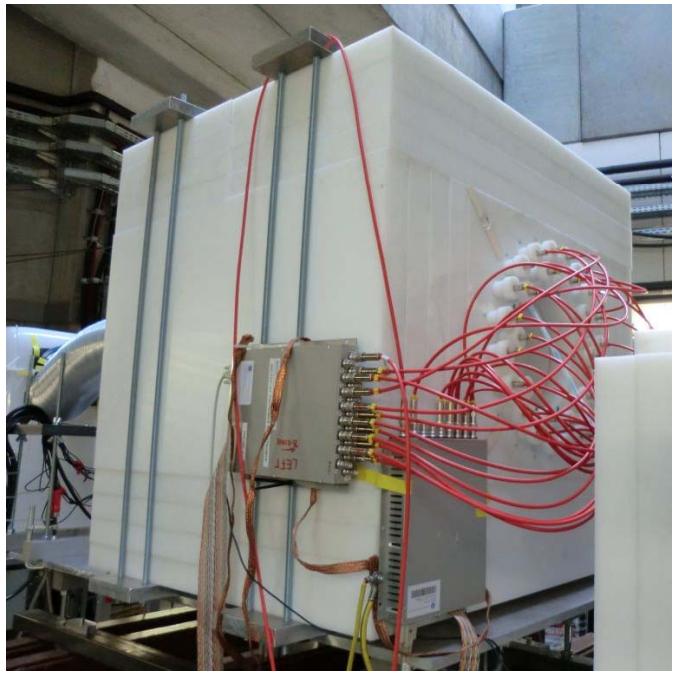
Efficiency (1keV-1MeV) ~40%

Average up to 5MeV ~ 35%

Central hole radius: 11.5 cm (SIMBA)







Silicon Implantation Beta Absorber (SIMBA)

Technische Universität München

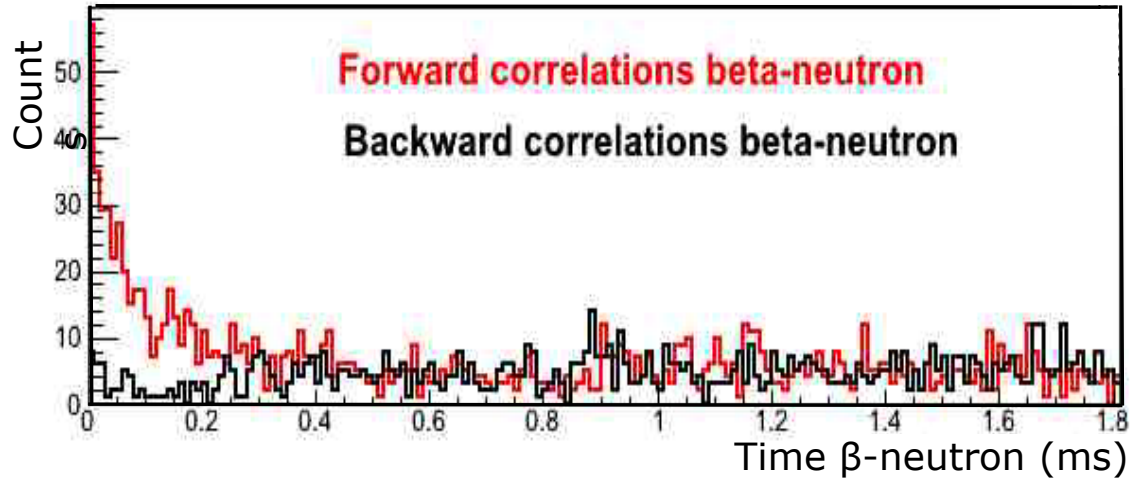
$^{252}$Cf neutron source detection efficiency (M.Marta):

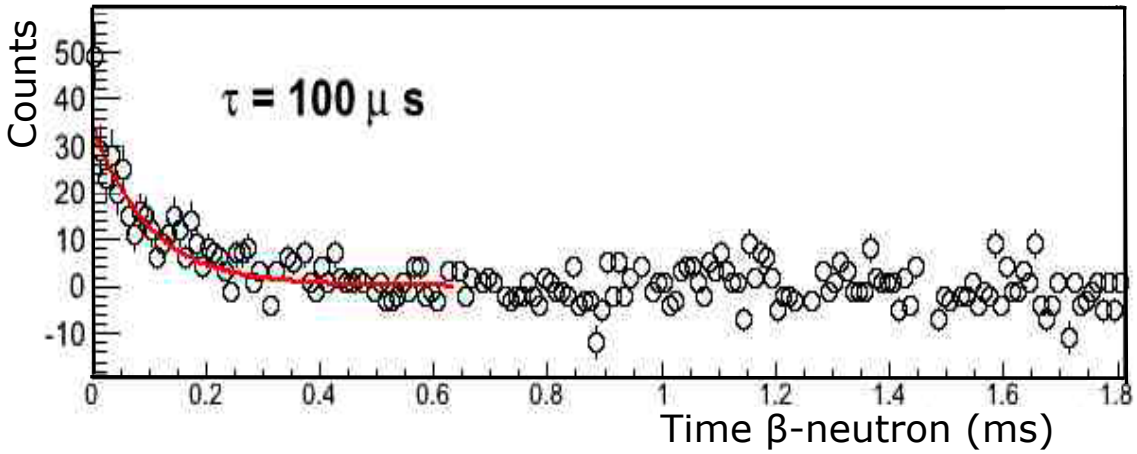
- MCNPX simulation: (34.5±0.2)%
- Triggerless DACQ (IFIC) in MBS : (35.4±0.8)%
- Analog branch: (25.5±0.9)% (electronics)

slide +1

Results and ongoing analysis:

**Performance test** time correlation between neutron and β-decay for $^{213}$Tl

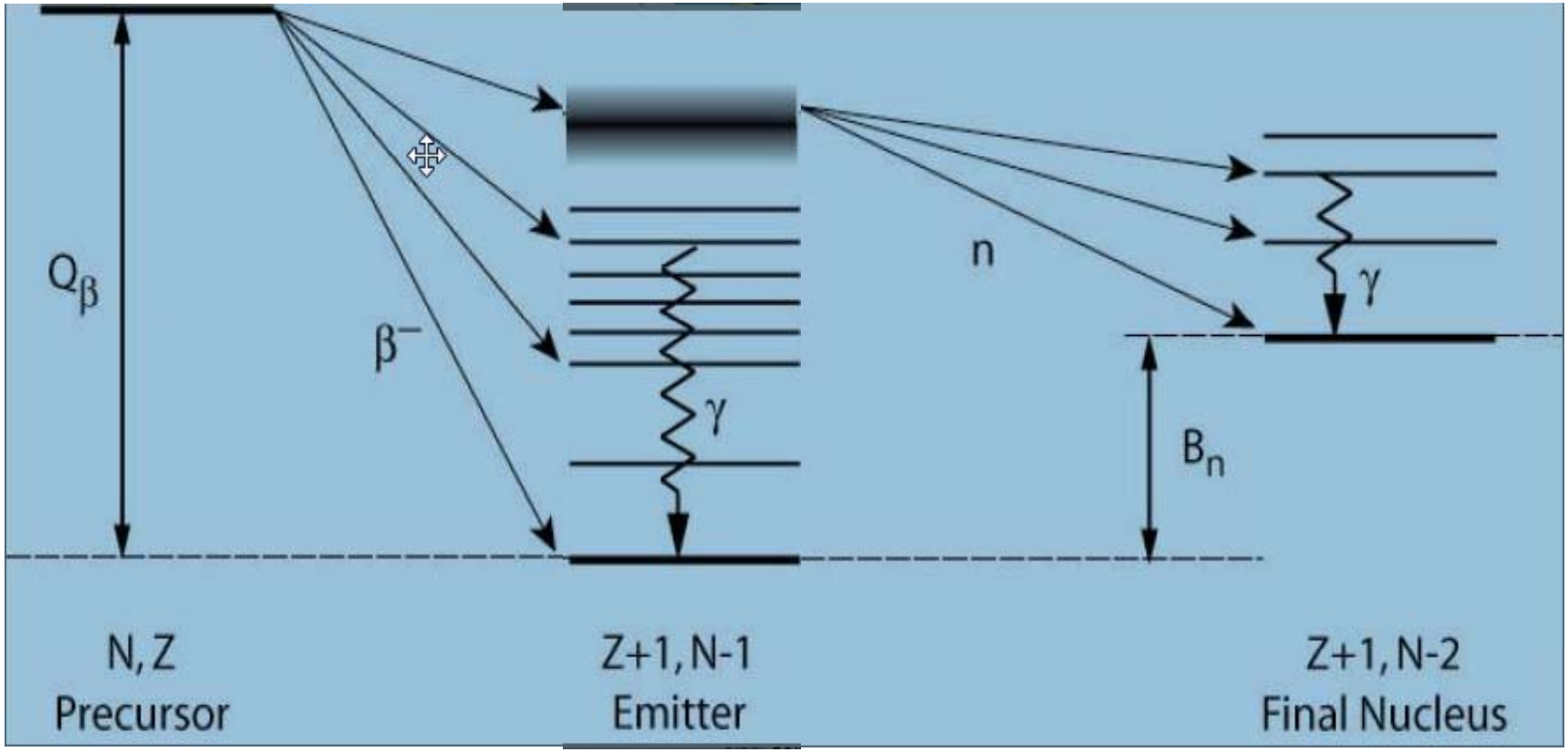



$$P_n = \frac{1}{\varepsilon_n} \frac{N_{n\beta}}{N_\beta}$$

R.Caballero-Folch, C.Domingo-Pardo et al.

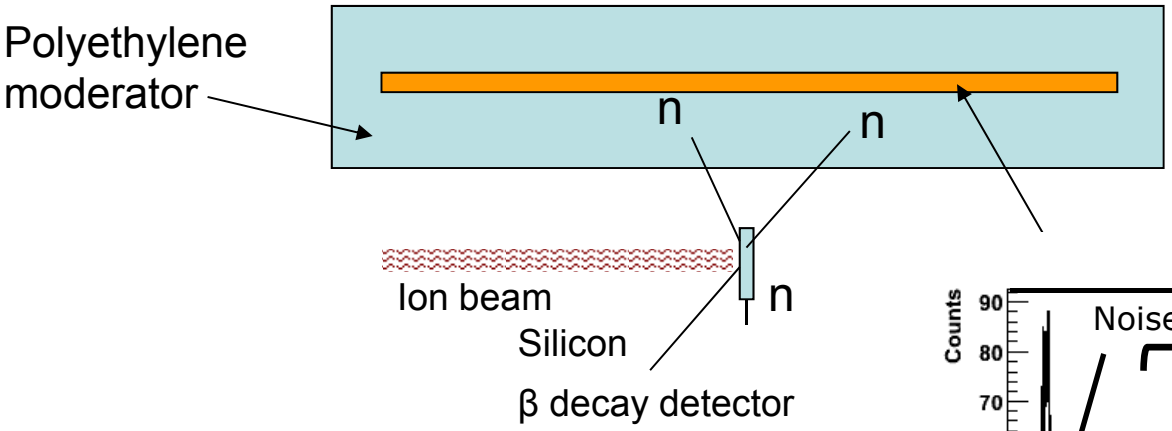
# β delayed neutron emission



## $^3$He counters as detector

- ✓ 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:

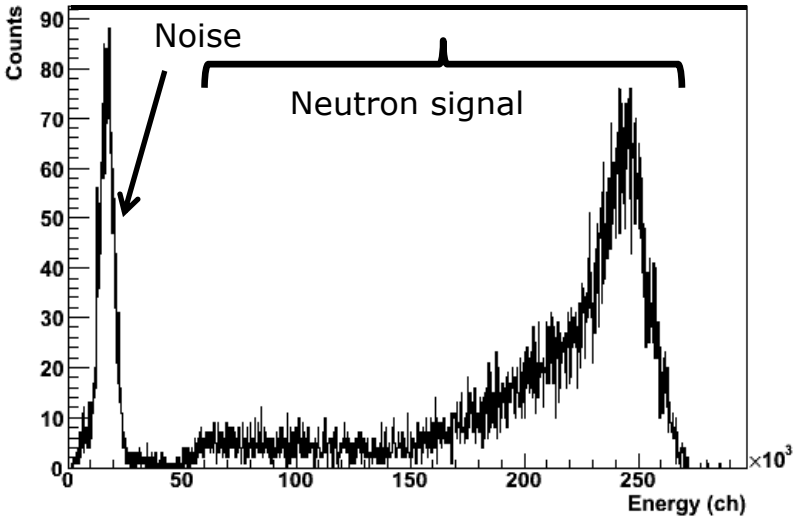
**$^3$He + n → $^3$H + $^1$H + 765 keV**




Other reactions:

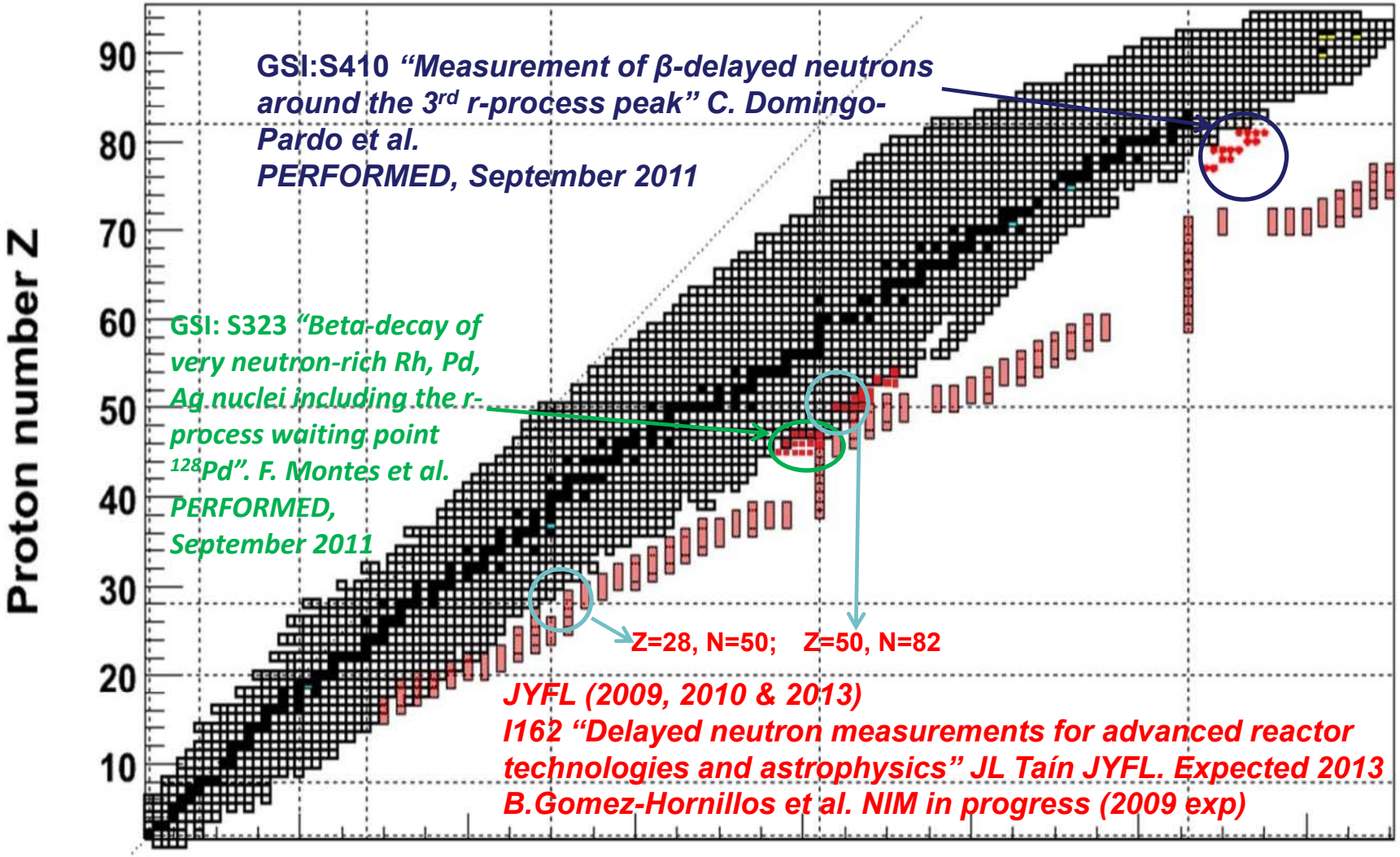
$^{10}$B + n → $^7$Li* + $^4$He + 2310 keV

$^7$Li* → $^7$Li + 480 keV




| Counter | Gas | Maximum length (mm) | Effective length (mm) | Ma dia ( |
|---|---|---|---|---|
| 2527 LND inc | $^3$He | 686.84 | 604.8 | |

## 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

## BELEN versions designed

| 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]** | **27%** | **5.5** |
| **BELEN-20** | **20** | **20** | **JYFL-2010** | **1.17** | **[1.60]** | **35%** | **5.5** |
| **BELEN-30** | **20+10** | **20 & 10** | **GSI-2011** | **1.17** | **[1.70]** | **35 %** | **11.5 (SIMBA)** |
| **BELEN-48** | **40+8** | **8 & 10** | **JYFL-2013** | **1.02** | **1.16** | **54%-39%** | **5.5** |
| **BELEN-48** | **40+8** | **8 & 10** | **DESPEC** | **1.04** | **1.15** | **45%-34%** | **8 (AIDA)** |

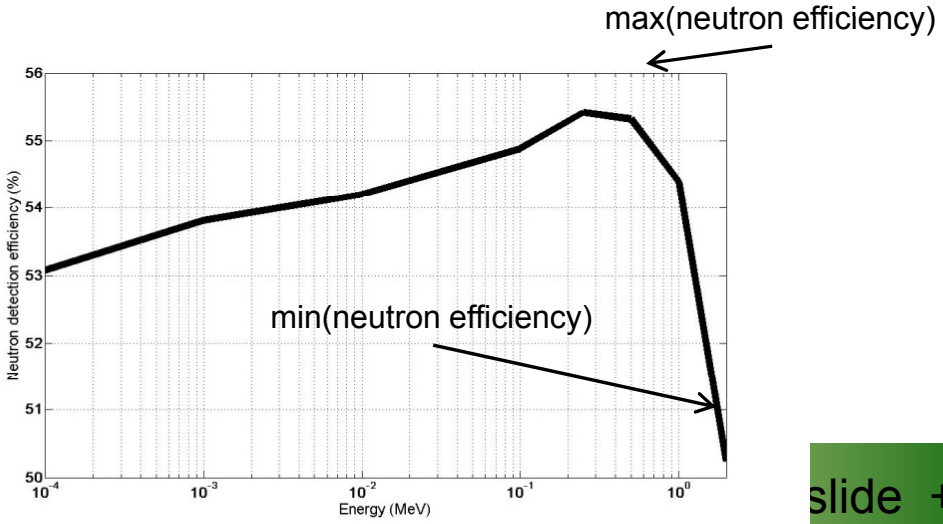
5MeV

2-5MeV

**Observe: Central hole, num. counters & planarity**

To define the efficiency flatness for a range of neutron energies

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




slide +6

## Digital Data Acquisition System (DDAS)

Triggerless digital data acquisition system:

✓ Struck digitizer modules (SIS3302): provide time-stamps very versatile for time correlations

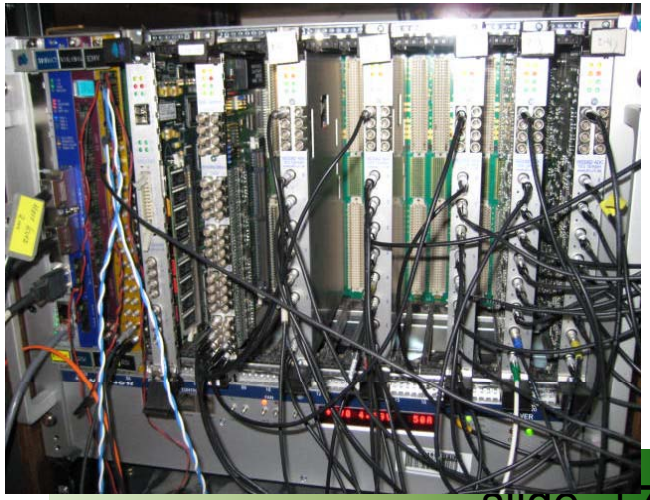
✓ Negligible dead-time when compared to analog systems

✓ Increase the efficiency.

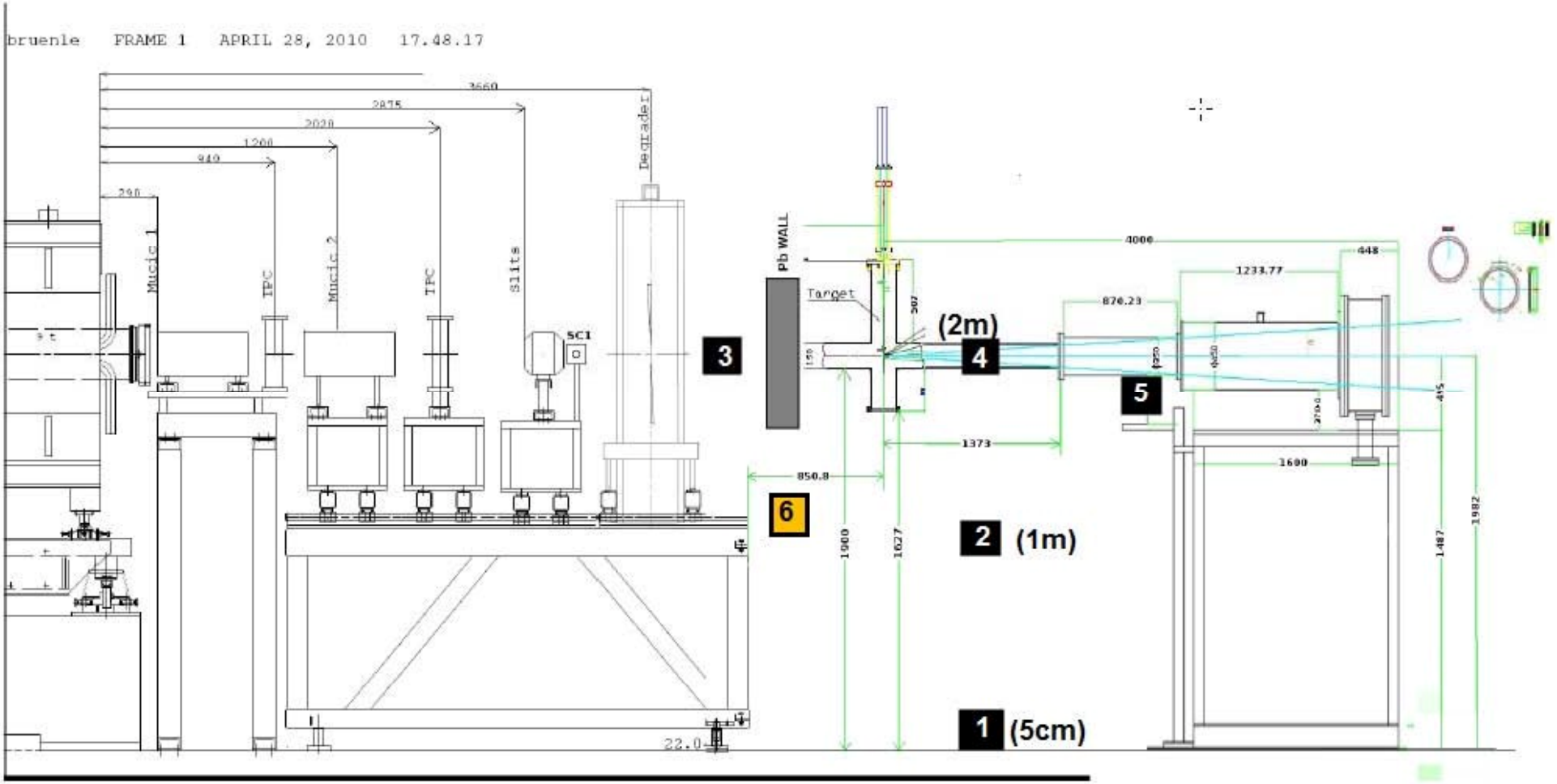
✓ Flexibility for large time correlation (fundamental to obtain correlations with all neutron and to change the gates offline)

✓ Allows to correct some experimental effects, e.g. To reduce neutron background from uncorrelated neutrons

✓ Being developed at IFIC (València-Spain)

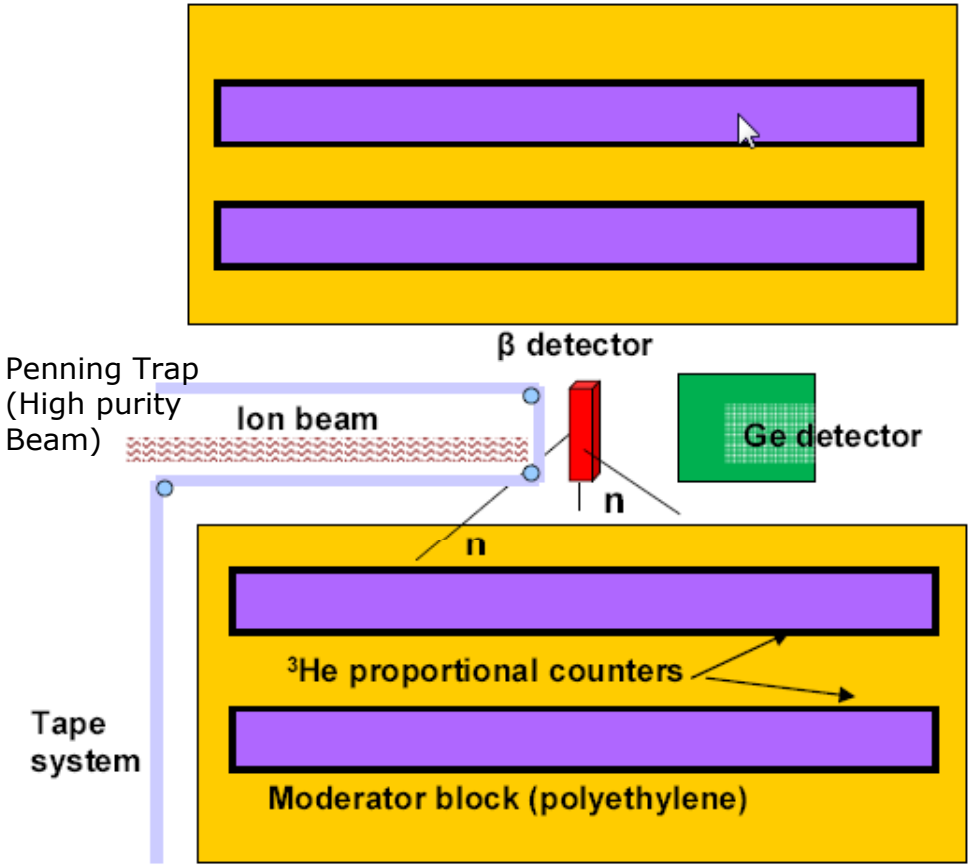


# Experimental hall for background measurements at GSI

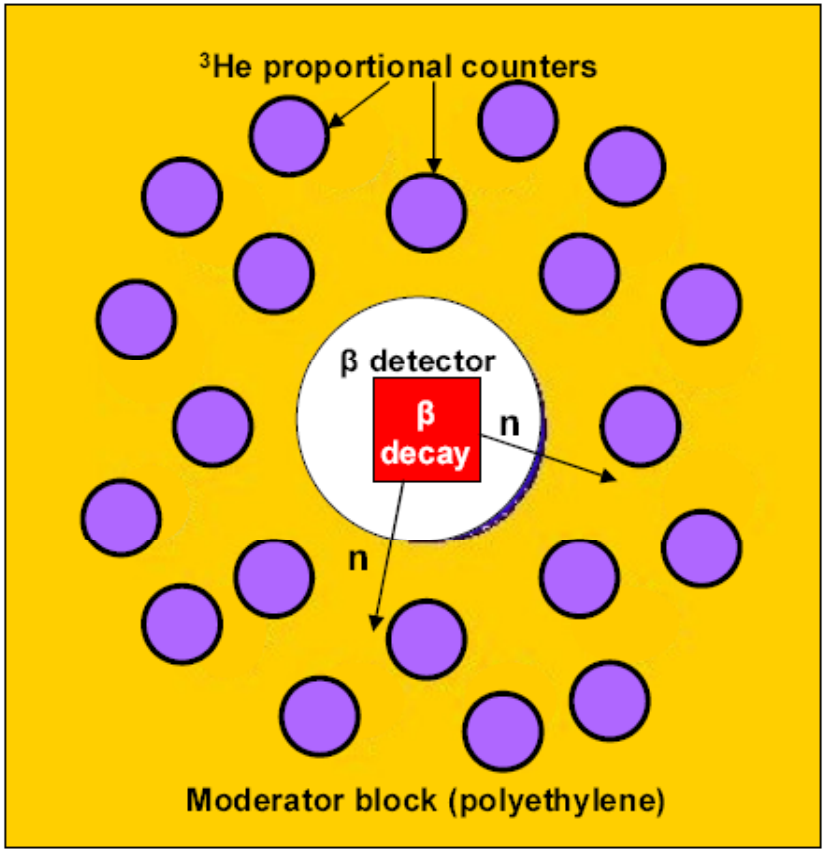


## BELEN design for **JYFL** experiments (2009 & 2010)

Prototype designed for JYFL 2009 with 20 counters




Side view




Front view

MCNPX simulation efficiency