Precision branching-ratio measurement for the superallowed Fermi β emitter ^{18}Ne

Kushal Kapoor

University of Regina

Kushal.Kapoor@uregina.ca

February 10, 2021

Overview

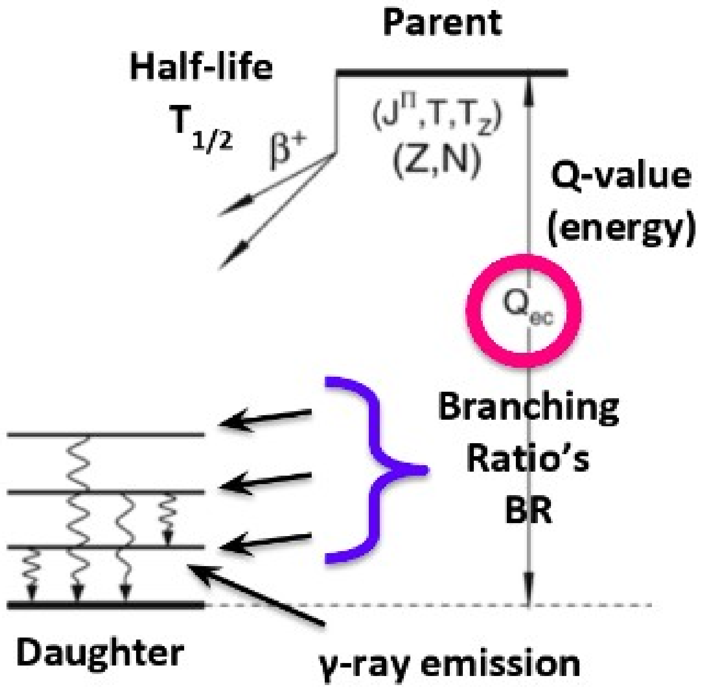
- Introduction
  - I. Nuclear β decay
  - II. Why ^{18}Ne?
- Experimental Setup
  - I. GANIL Lab
  - II. Detector system
- Results
- Future plan

Nuclear β decay

- Nuclear β decay occurs when an unstable nucleus of an atom, with atomic number *(Z)* and neutron number *(N)*, transforms into a more stable nucleus, with *Z±1* and *N±1*

$$\beta^+ \text{ decay} \quad : \quad {}^{A}_{Z}X_N \rightarrow {}_{Z-1}^{\quad A}Y_{N+1} + e^+ + \nu_e,$$

$$\beta^- \text{ decay} \quad : \quad {}^{A}_{Z}X_N \rightarrow {}_{Z+1}^{\quad A}W_{N-1} + e^- + \overline{\nu_e},$$



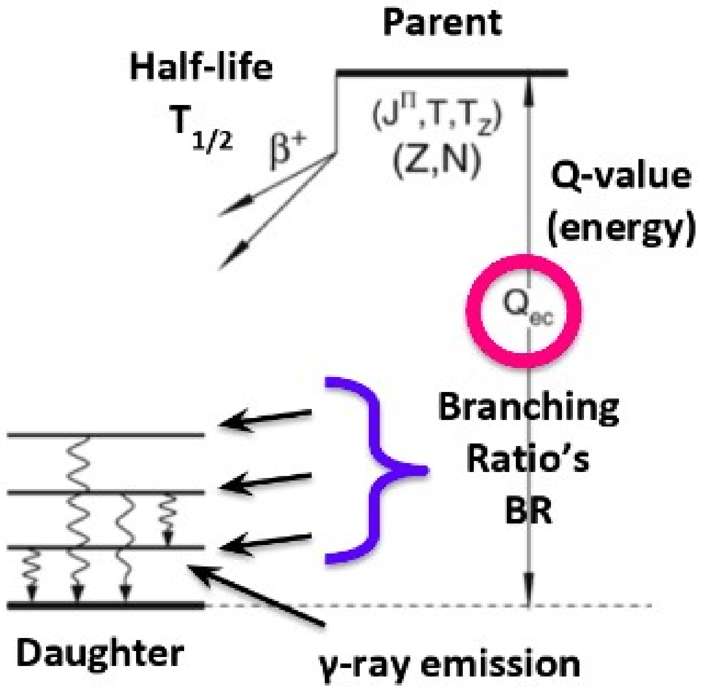
Nuclear β decay

- Nuclear β decay occurs when an unstable nucleus of an atom, with atomic number *(Z)* and neutron number *(N)*, transforms into a more stable nucleus, with *Z±1* and *N±1*

$$\beta^{+} \text{ decay} \quad : \quad {}^{A}_{Z}X_{N} \rightarrow {}_{Z-1}^{\;\;A}Y_{N+1} + e^{+} + \nu_{e},$$

$$\beta^{-} \text{ decay} \quad : \quad {}^{A}_{Z}X_{N} \rightarrow {}_{Z+1}^{\;\;A}W_{N-1} + e^{-} + \overline{\nu_{e}},$$

- β decays can be characterized by:
  - ***Q* value** (energy released)
  - **Half life $T_{1/2}$** (parent nucleus)
  - **Branching ratio (BR)** (to a particular state of interest in the daughter)



Nuclear β decay

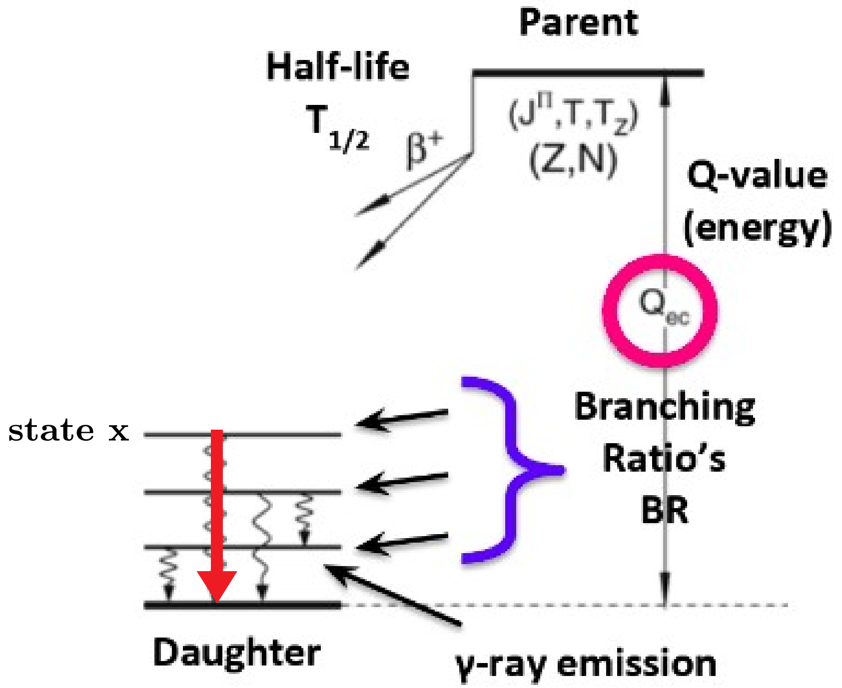
- Nuclear β decay occurs when an unstable nucleus of an atom, with atomic number *(Z)* and neutron number *(N)*, transforms into a more stable nucleus, with *Z±1* and *N±1*

$$\beta^+ \text{ decay} \quad : \quad {}^A_Z X_N \rightarrow {}_{Z-1}^{\ A}Y_{N+1} + e^+ + \nu_e,$$

$$\beta^- \text{ decay} \quad : \quad {}^A_Z X_N \rightarrow {}_{Z+1}^{\ A}W_{N-1} + e^- + \overline{\nu_e},$$

- β decays can be characterized by:
  - ***Q* value** (energy released)
  - **Half life $T_{1/2}$** (parent nucleus)
  - **Branching ratio (BR)** (to a particular state of interest in the daughter)

$$BR \cong \frac{N_{\gamma(x)}}{N_{\beta_{Tot}}}$$



Nuclear β decay – selection rules

Angular momentum (L):

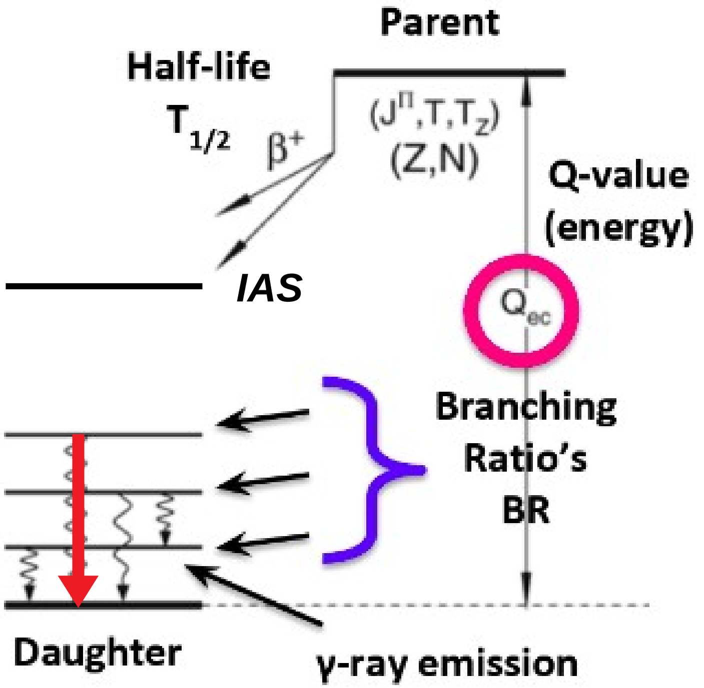
Allowed decays (L=0),

Forbidden decays (L=1,2,3,...)

Spin angular momentum (S) = $S_\beta + S_{\nu}$:

Fermi decays (S=0),

Gamow-Teller decays (S=1)



Isobaric Analogue State (IAS)

Nuclear β decay – selection rules

Angular momentum (L):

Allowed decays (L=0),

Forbidden decays (L=1,2,3,...)

Spin angular momentum (S) = $S_\beta + S_{\nu}$:

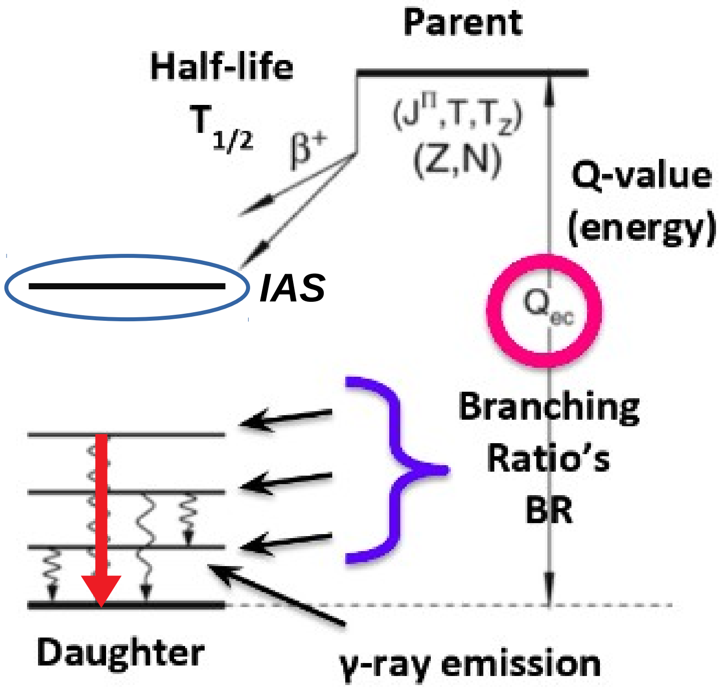
Fermi decays (S=0),

Gamow-Teller decays (S=1)

Total Isospin (T), projection (*tz= +1/2 (Neutron), -1/2(Proton)*)

Super (δT=0, *transition to IAS*)

Super (δT=0, IAS) Allowed (L=0) Fermi (S=0) decays,



Isobaric Analogue State (IAS)

Nuclear β decay – ft values

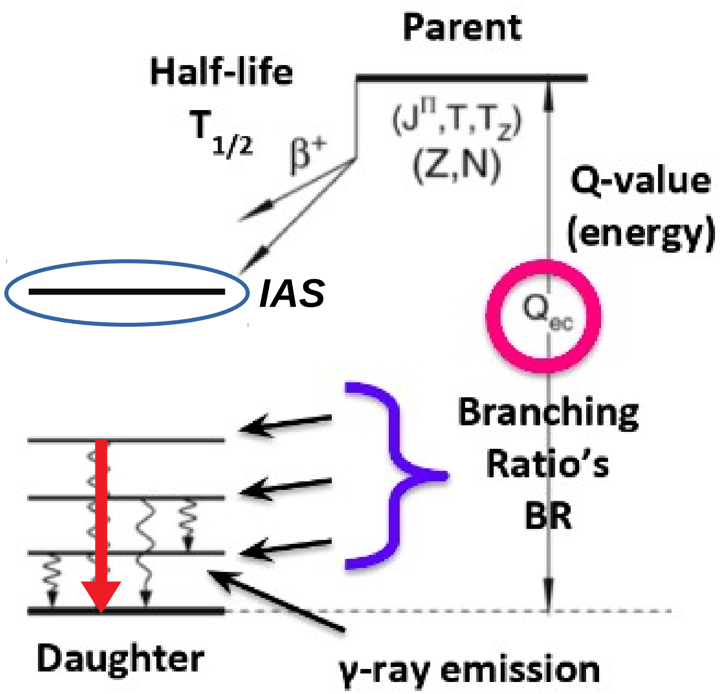
Super ($\delta T=0$, IAS) Allowed ($L=0$) Fermi($S=0$) decays,

- All nuclear β decays to any daughter state can be characterized in terms of a single quantity known as the *ft* value

$$ft = \frac{f_x T_{1/2}}{BR_x} = \frac{K}{g^2 |M_{fi}|^2} \longrightarrow = \frac{K}{2G_v} = \text{Constant}$$

Q-value, *Half-life*, *Branching Ratio*, *Constants*, *Strength*, *Matrix element*

For the special case of superallowed Fermi beta decay between isospin T=1 states



Isobaric Analogue State (IAS)

Nuclear β decay – ft values

Super ($\delta T=0$, IAS) Allowed ($L=0$) Fermi($S=0$) decays,

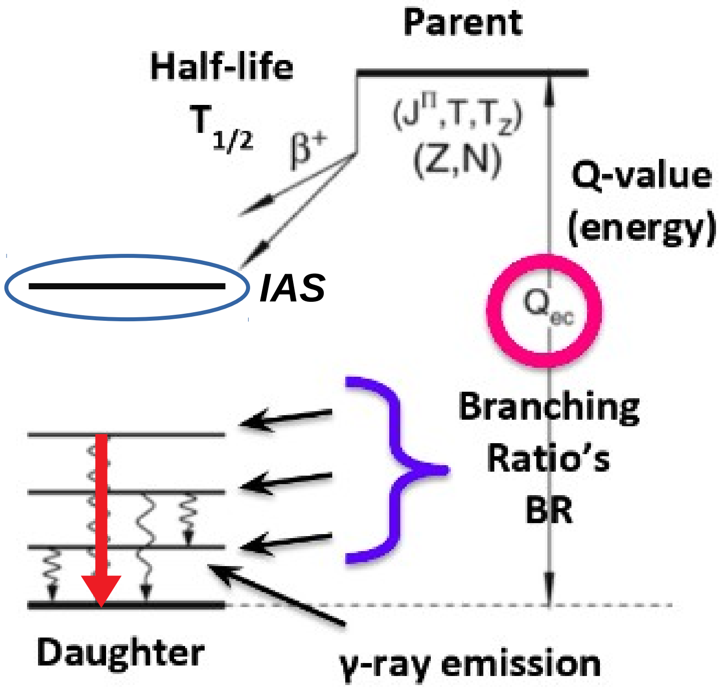
- All nuclear β decays to any daughter state can be characterized in terms of a single quantity known as the ft value

Q-value, *Half-life*, *Constants*, *Branching Ratio*, *Strength*, *Matrix element*

$$ft = \frac{f_x T_{1/2}}{BR_x} = \frac{K}{g^2|M_{fi}|^2} \longrightarrow = \frac{K}{2G_v} = \text{Constant}$$

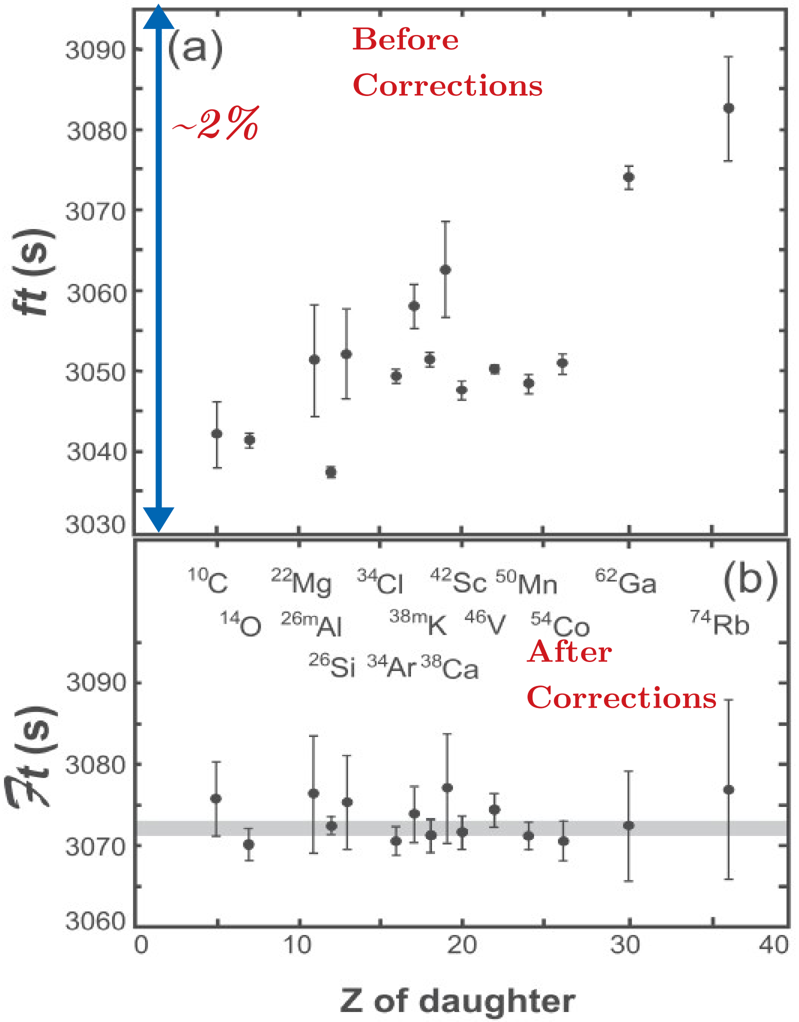
For the special case of superallowed Fermi beta decay between isospin T=1 states

This can be test experimentally!



Isobaric Analogue State (IAS)

Why ^{18}Ne?



Hardy and I. S. Towner, Phys. Rev. C 102, 045501 (2020)

Matrix Elements → $|M_{fi}|^2 = 2(1-\delta_c)$

$$\mathcal{F}t \equiv ft(1+\delta'_{\mathrm{R}})(1+\delta_{\mathrm{NS}}-\delta_{\mathrm{C}}) = \frac{K}{2G_{\mathrm{V}}^2(1+\Delta_{\mathrm{R}}^{\mathrm{V}})},$$

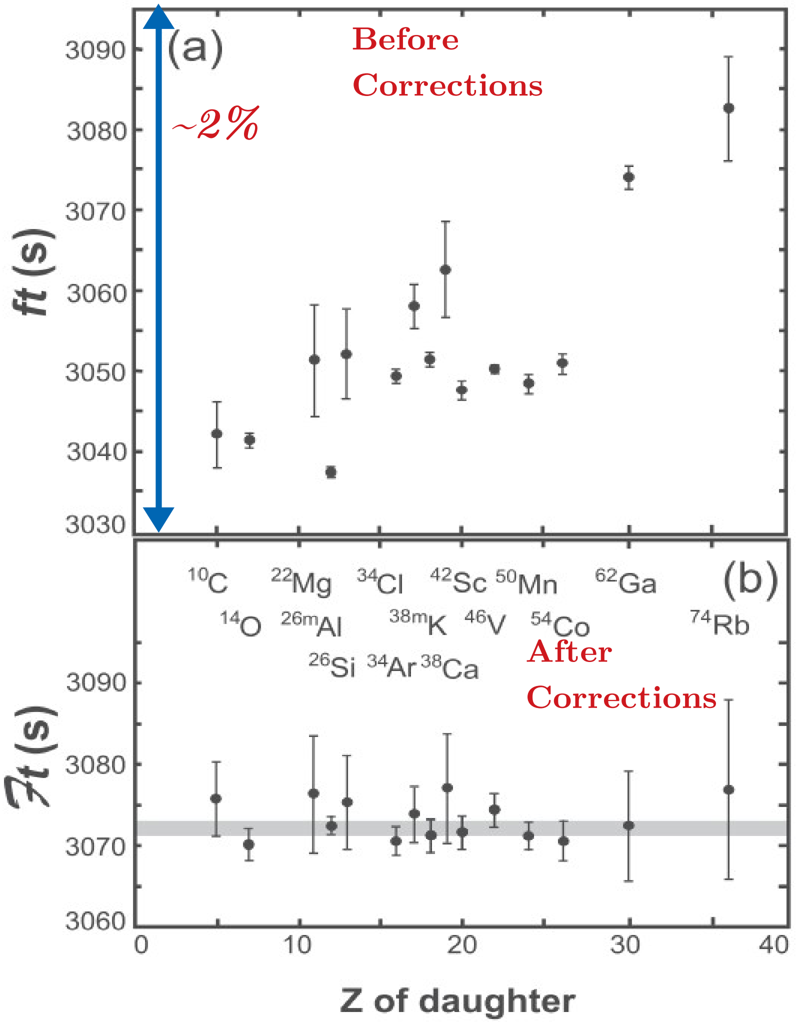
- *Δ^V_R- nucleus independent- radiative correction, δ'_R – radiative correction -transition-dependent (Z-dependent), δ_C – isospin symmetry breaking correction and δ_{NS} -nuclear-structure-dependent part of radiative correction*

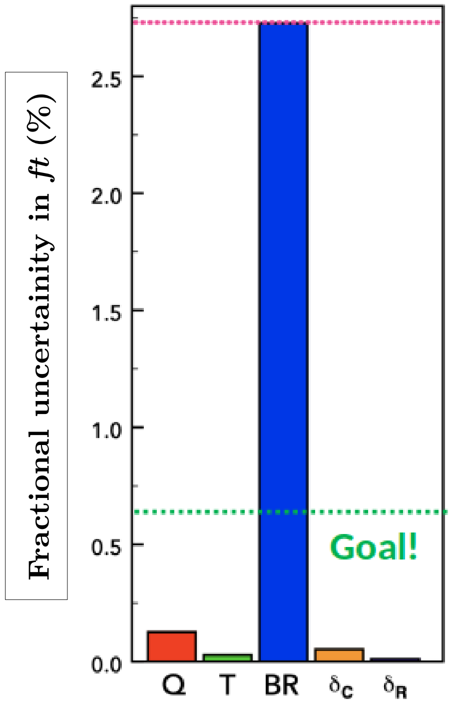
- In the recent years, our group has been investigating low Z superallowed emitters (*^{10}C, ^{14}O, ^{18}Ne*)
- *ft value for ^{18}Ne is* ***2912 ± 79 (s)***
- *^{18}Ne* is not on the plot because of the large uncertainty in the BR for this decay.
- *^{18}Ne* ft-value is also one of the most interesting cases to better constrain isospin symmetry breaking

**Hardy et. al., Nucl. Phys. A 246, 61 (1975).*

Why ^{18}Ne?

Hardy and I. S. Towner, *Phys. Rev. C 102, 045501 (2020)*



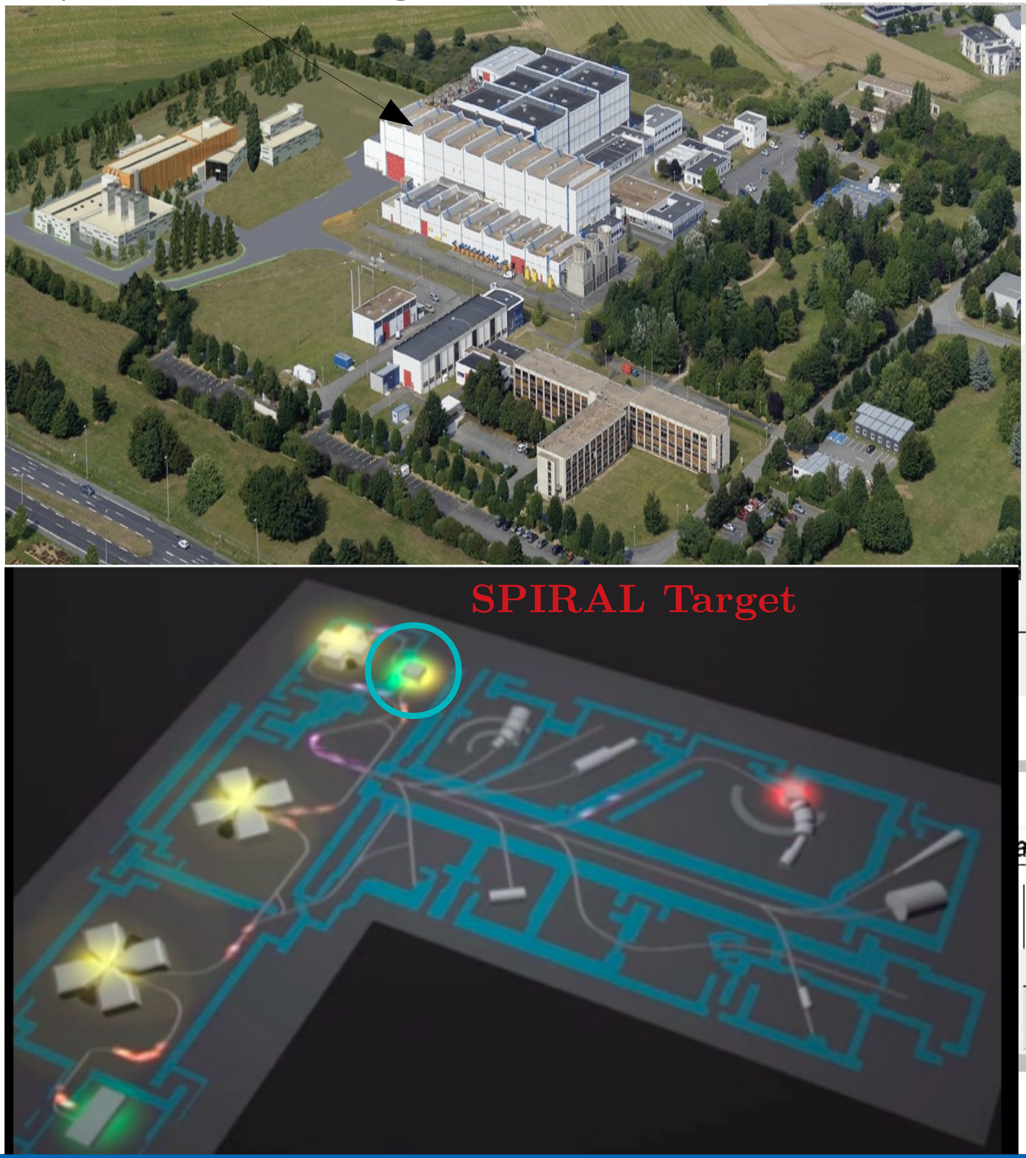


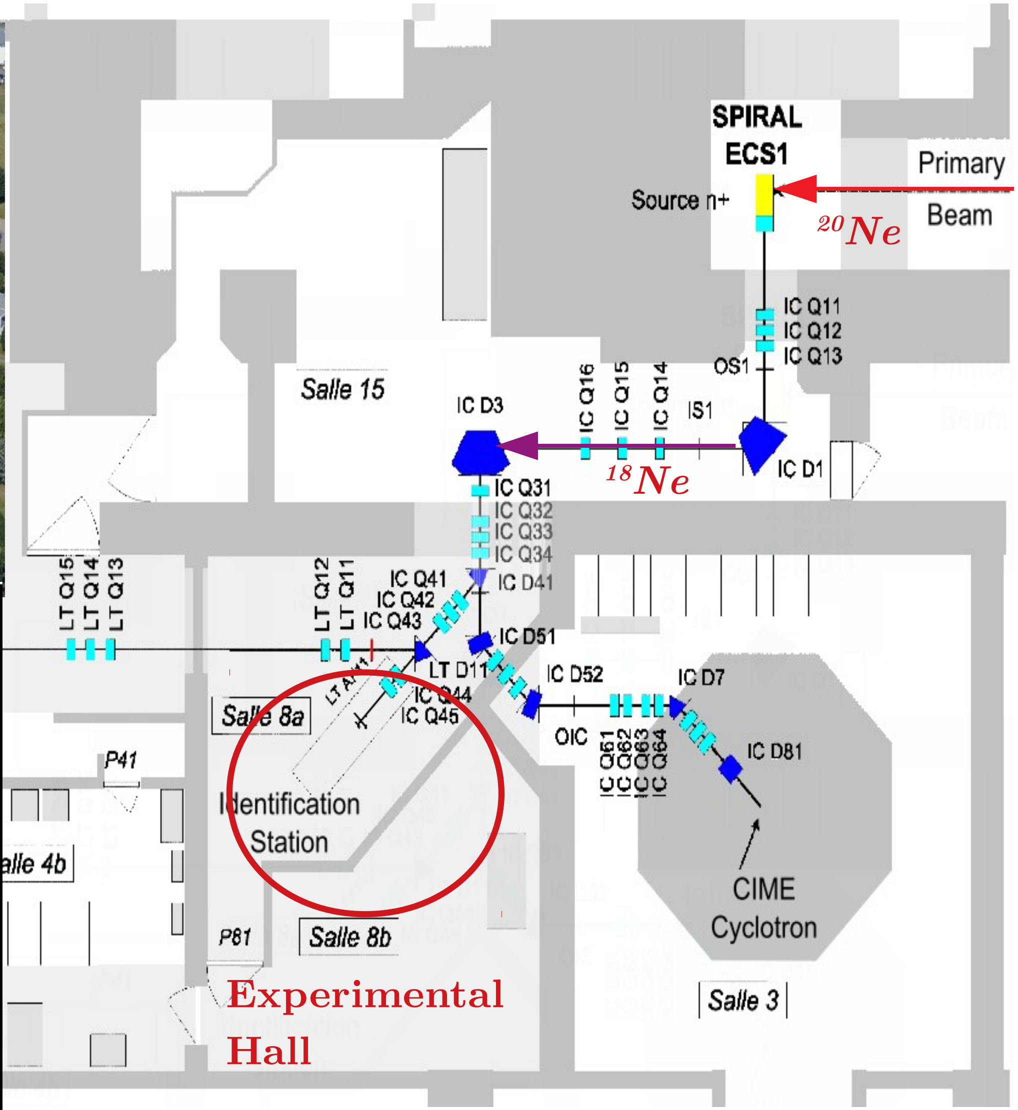
- *Uncertainties dominated by BR*
- Hardy *et. al.*, ^{18}Ne Branching Ratio = *7.66 (0.27)%**.
- *Only one previous measurement, so our goal is to reduce the uncertainties in the BR of* ^{18}Ne.

*Hardy *et. al., Nucl. Phys. A 246, 61 (1975).*

Experimental Setup - GANIL facility in Caen, France

Cyclotron building

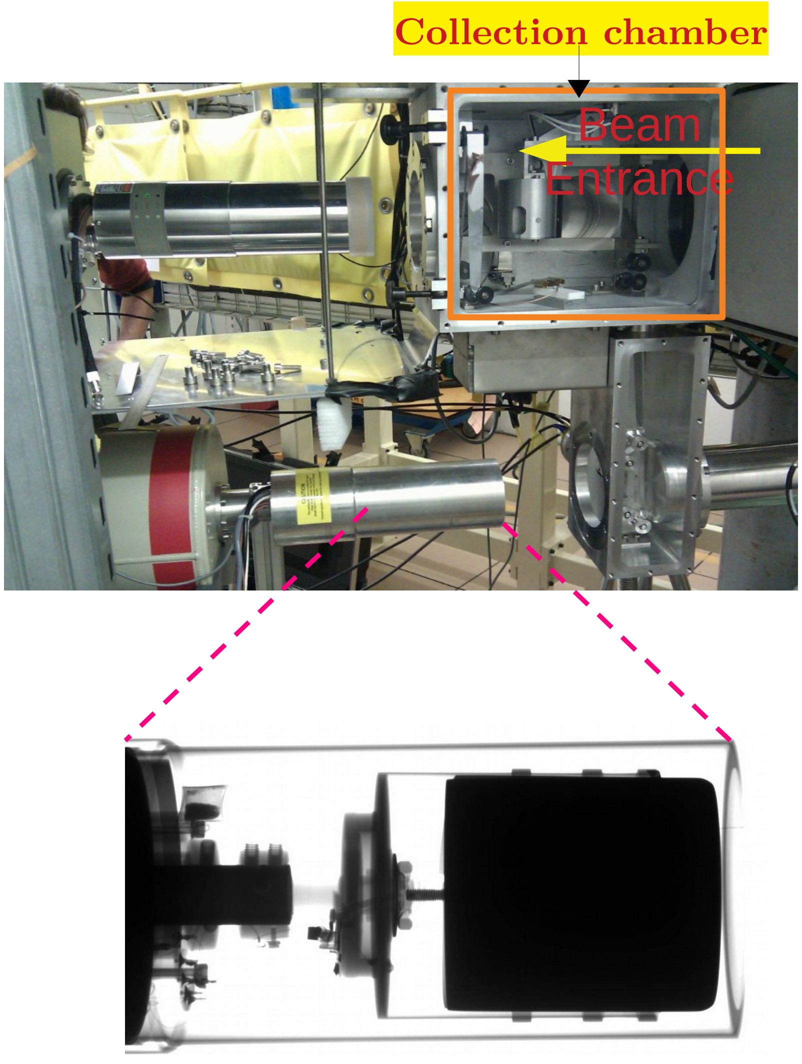




Gringer et. al., Nucl.Instrum.Meth.A 741 (2014) 18-25

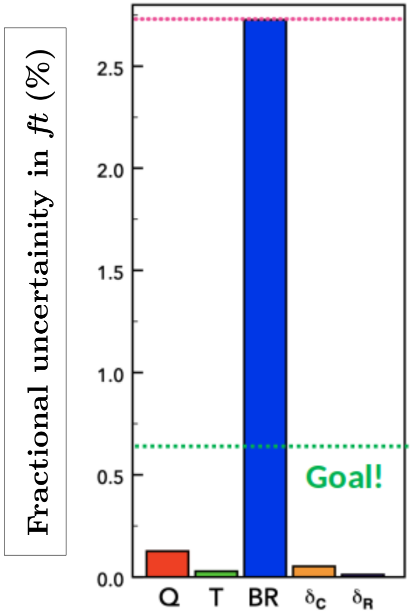
Experimental Setup

- Beams of radioactive isotopes enter the collection chamber from the right and are implanted into an aluminized-mylar tape
- The beam is then interrupted and the samples are moved to the decay counting chamber (bottom)



Grinyer et. al., Nucl.Instrum.Meth.A 741 (2014) 18-25

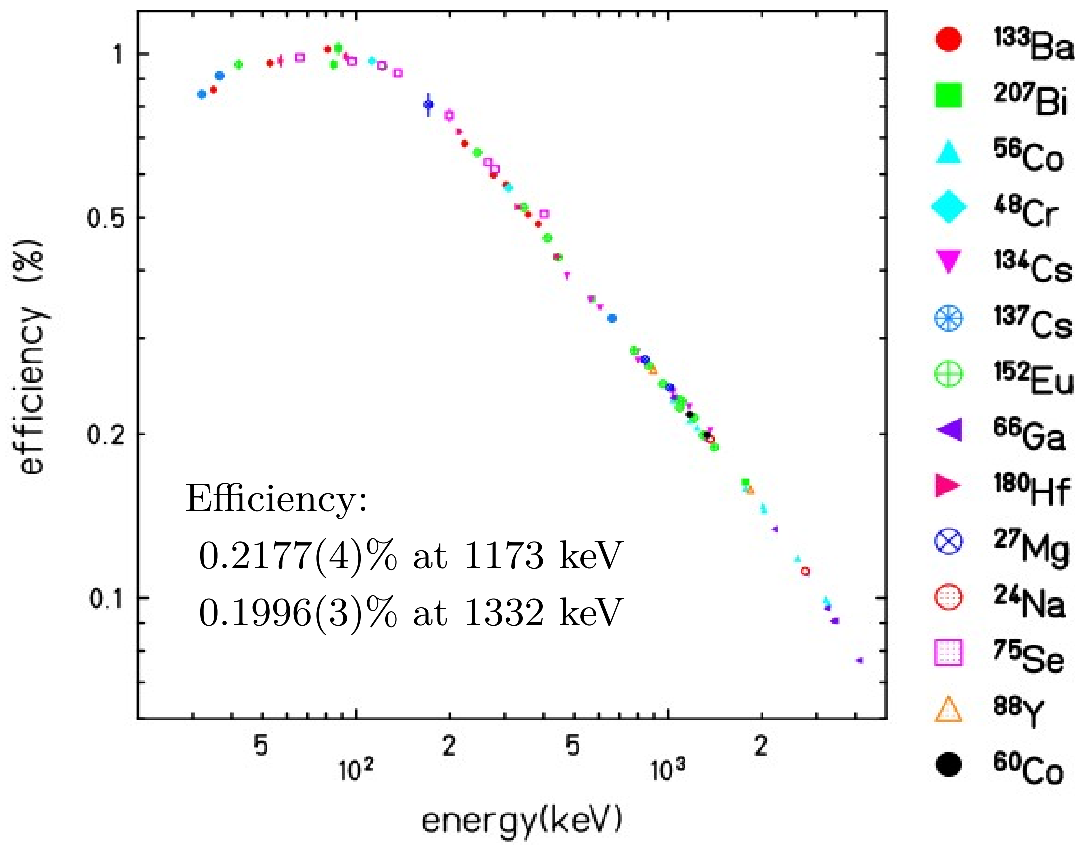
- **Absolute HPGe efficiency calibration**
  - Detailed source work
  - X-ray imaging
  - Source scanning table
  - Detailed simulations
  - 10 yrs of calibration!



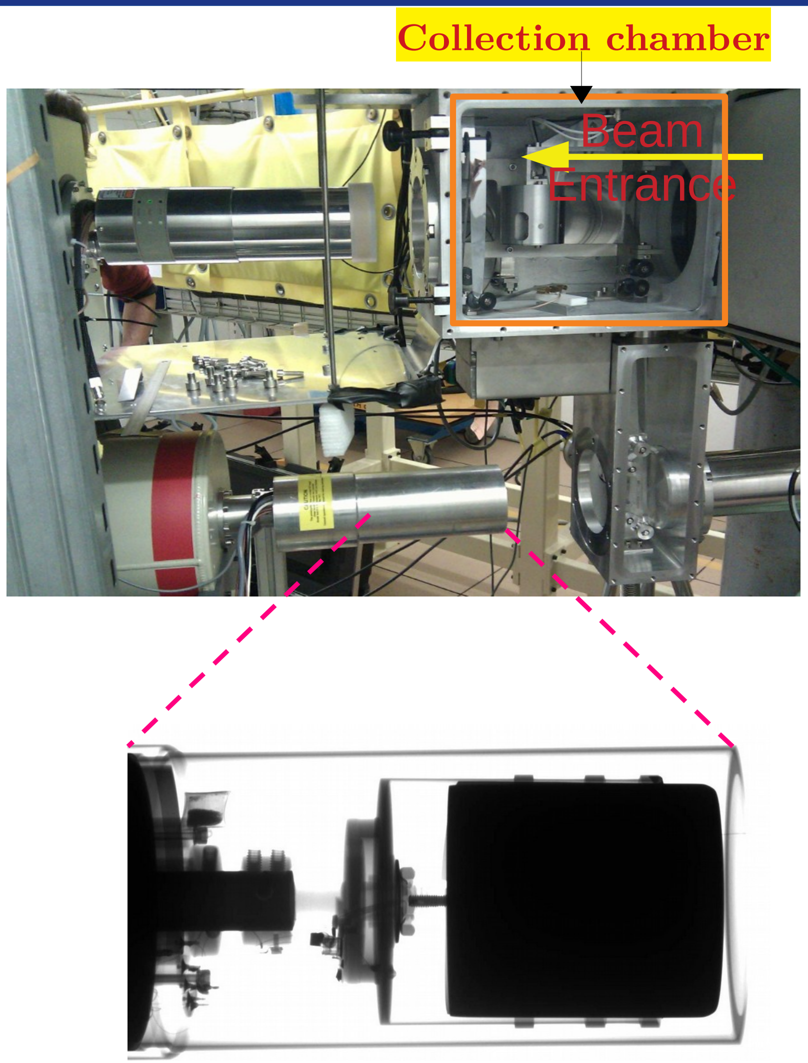
CENBG **Bordeaux Group**

Experimental Setup

- A total of 23 different radioactive sources were used.
- Some of them are only available as a radioactive beam.
- Efficiency = 0.231 (4)% at 1042 keV.



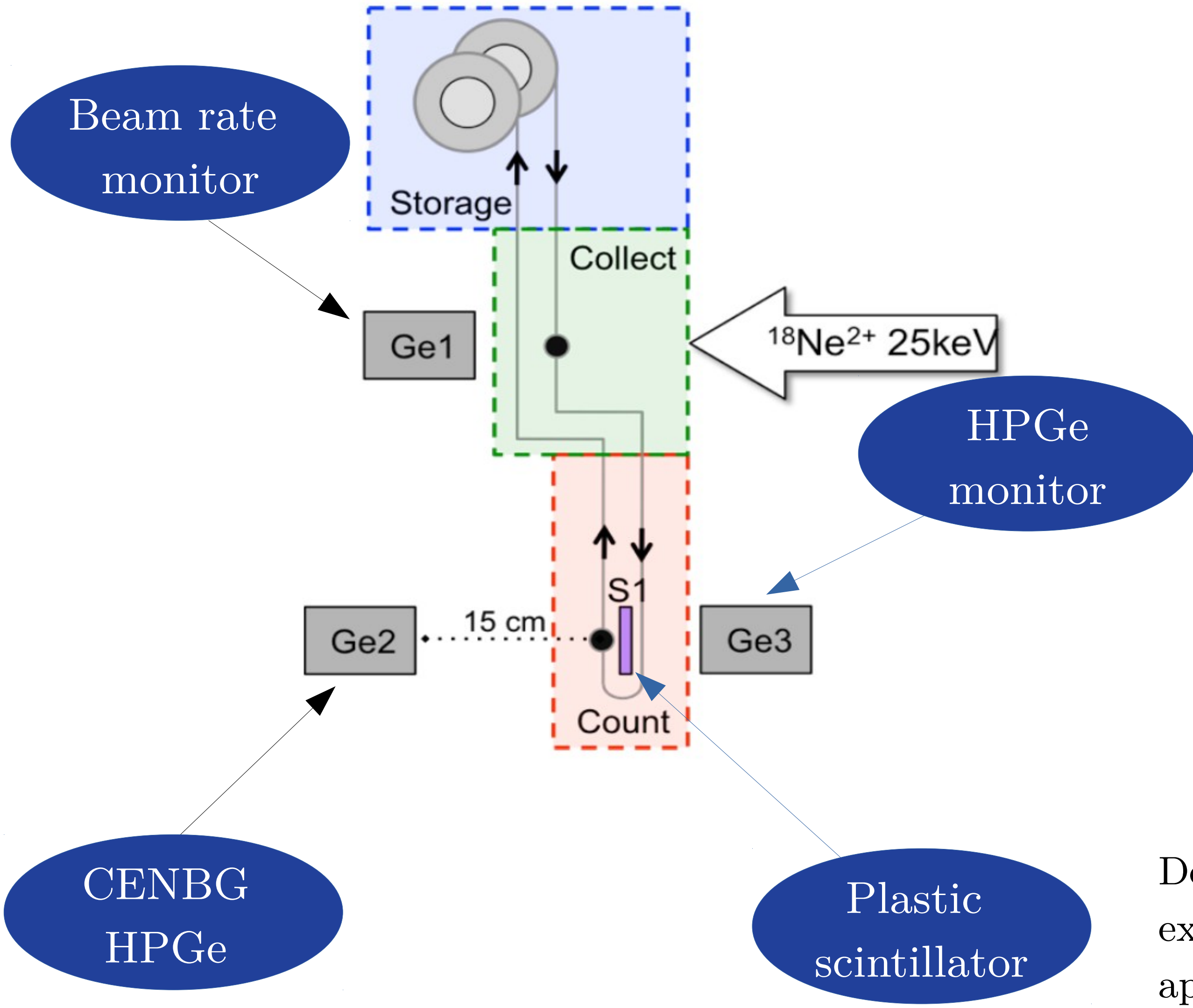
Blank et. al., Nucl. Instr and Meth in Phys Res A 776 (2015) 34-38

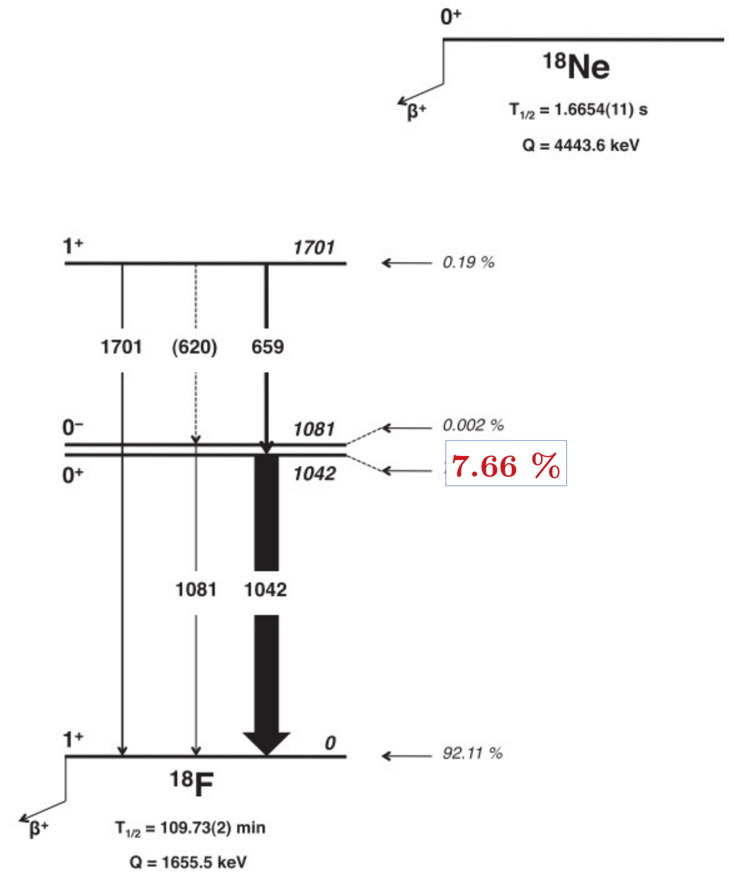


Grinyer et. al., Nucl.Instrum.Meth.A 741 (2014) 18-25

CENBG Bordeaux Group

Experimental Setup

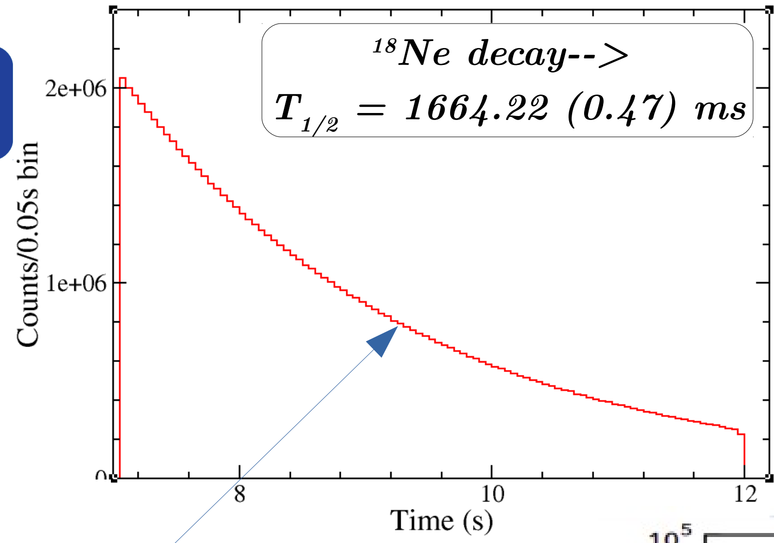


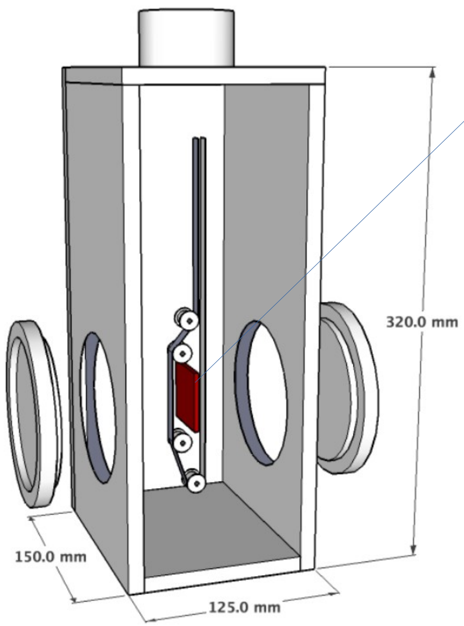


Decay scheme for ^{18}Ne, the *IAS* is the 0^+ excited state at 1042 keV, with a BR of approximately 7.66%

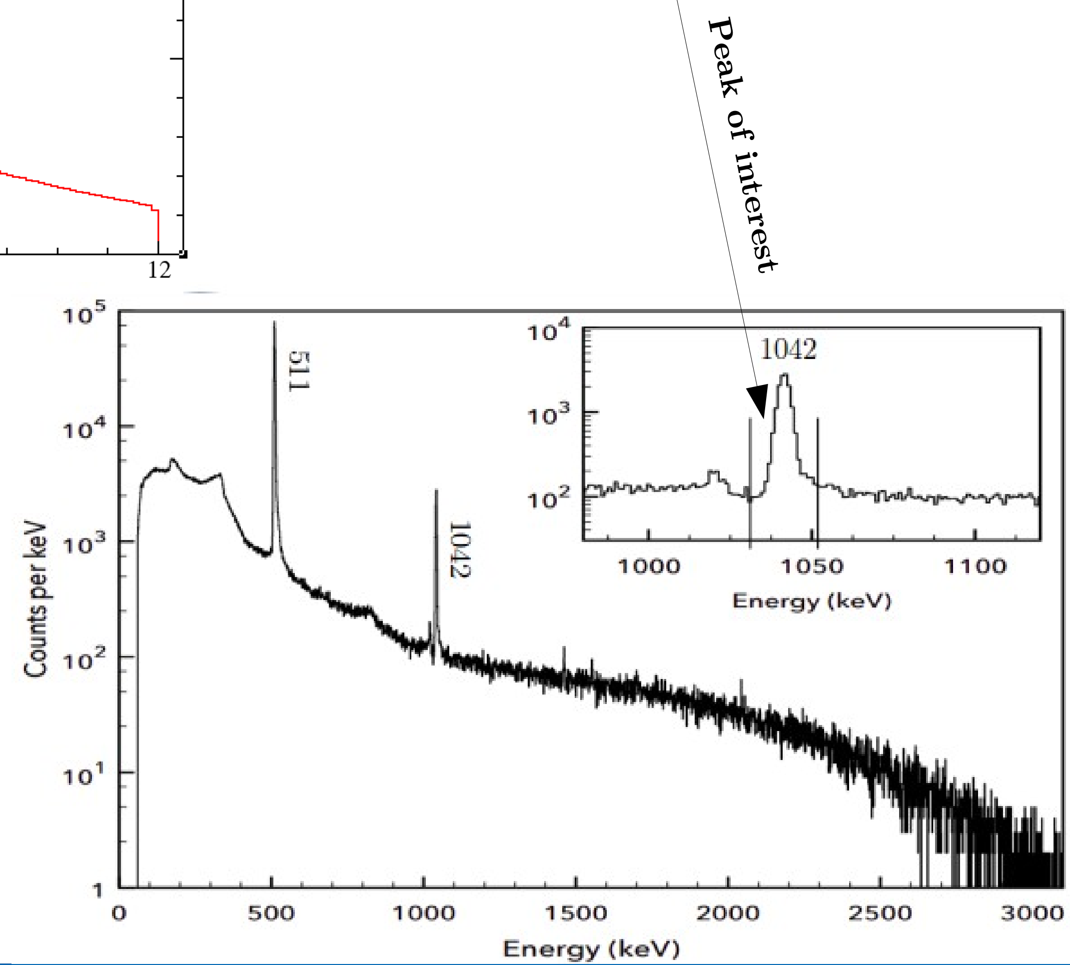
Results

Beta Decay-- plastic scintillator

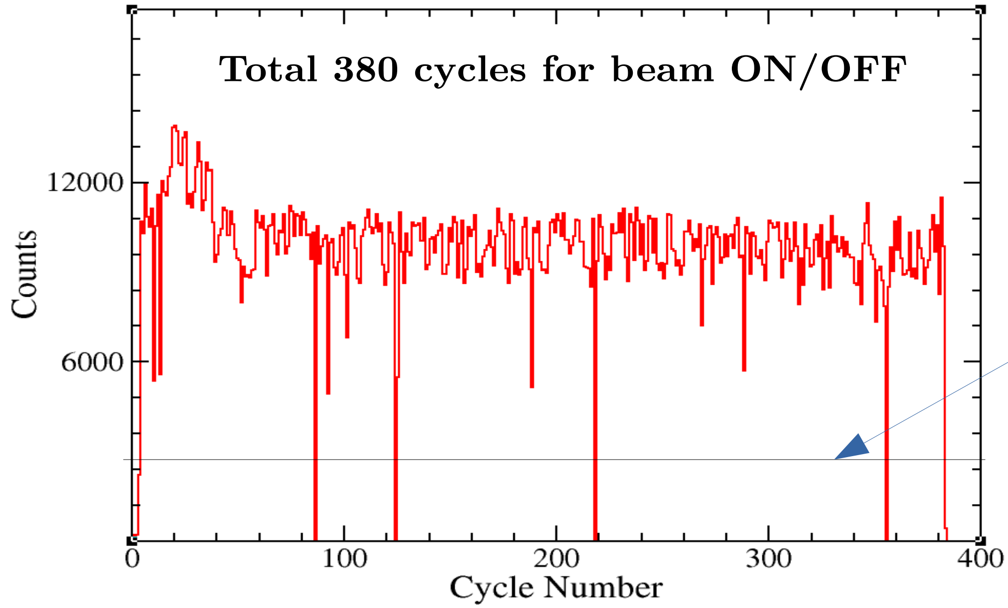




Gamma rays-- HPGe detector



Results



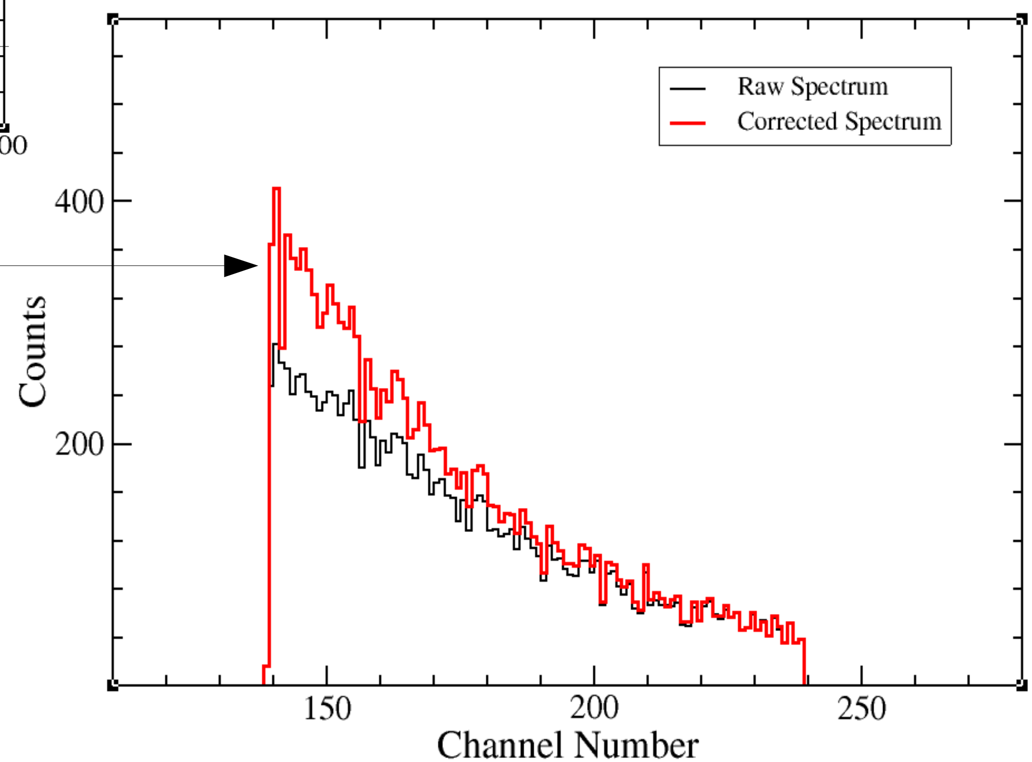
Single run:-->

$$BR \cong \frac{N_{\gamma(1042)}}{N_{\beta_{Tot}}} = \mathbf{7.57\ (0.13)\ \%}$$

Cycle threshold

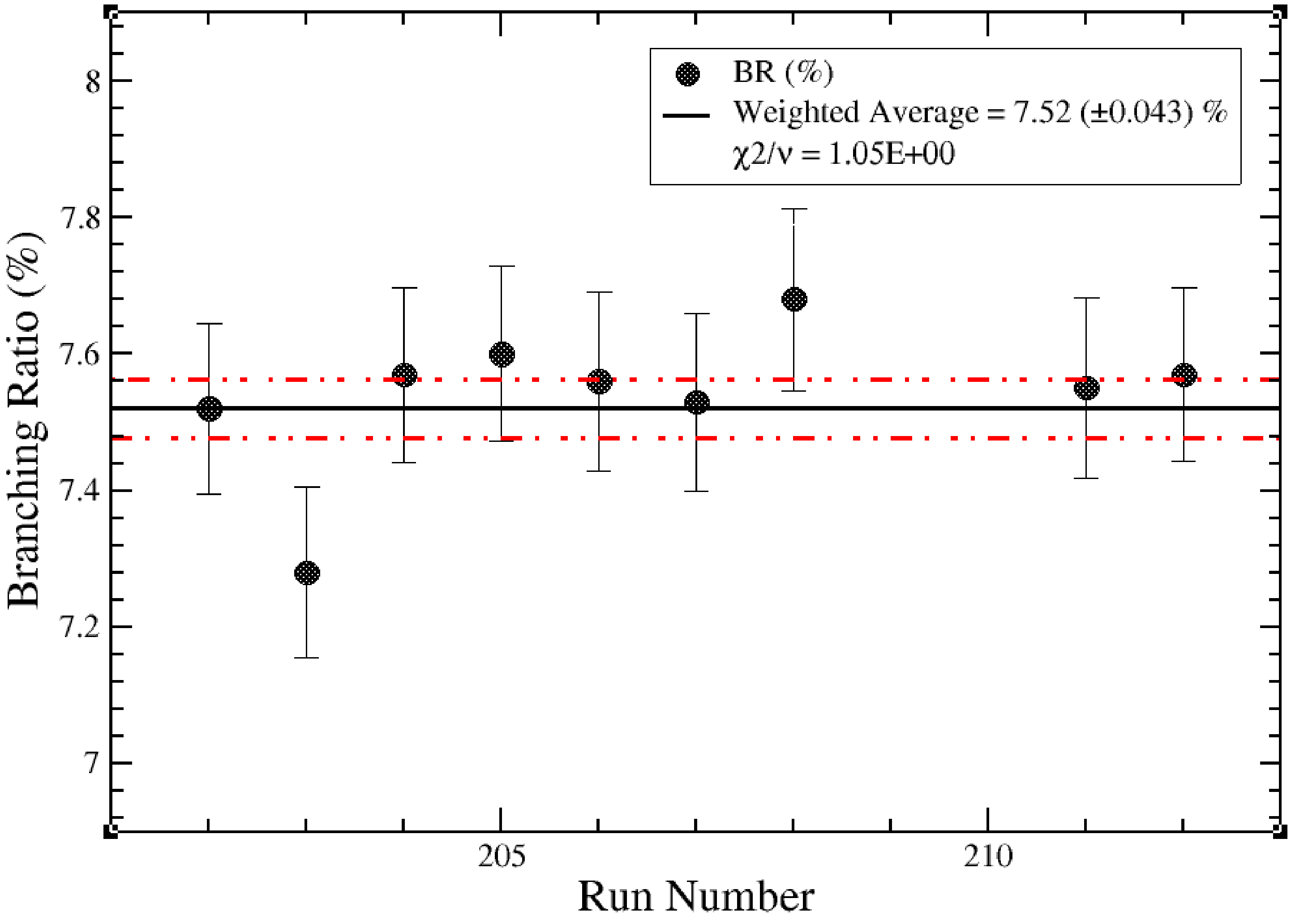
Rate dependent Corrections
~33 % (max) - correction (γ-counts)
Well known effects:

I. Pile-up and dead-time corrections
II. Background subtraction



Grinyer et al., Nucl. Instr. and Meth. in Phys Res A 579 (2007) 1005–1033

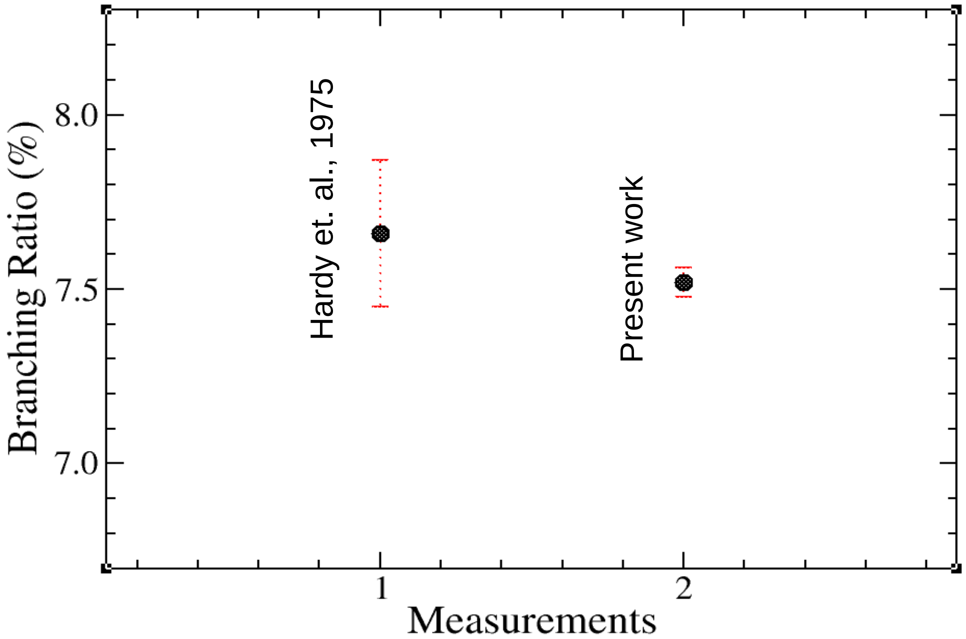
Results



Preliminary results for Branching Ratio = ***7.52 (±0.043)%***

This is in excellent agreement and ~5 times more precise than the previous reported value: *7.66 (±0.21)%*

Summary & Future Plan



Preliminary results for Branching Ratio = ***7.52 (±0.043)%***

This is in excellent agreement and ~5 times more precise than the previous reported value: *7.66 (±0.21)%*

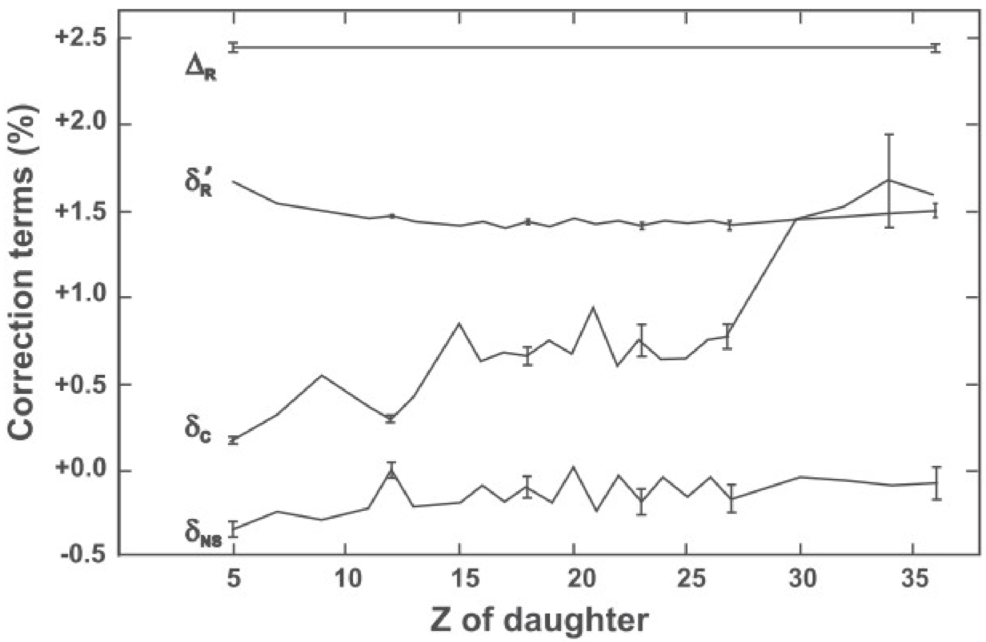
- We deduced the branching ratio of ^{18}Ne from an experiment perfomed at GANIL.
- Obtained the value *7.52 (±0.043)%*, which is *5x* more precise than the only previous measurments.
- Results are preliminary, a detailed evaluation of systematic uncertainties is required.
- In future, we plan on revisiting the simulations of the detector efficiency. Since the branching ratio measurment is dominated by the uncertainitites in the efficiency, any improvement we can make will directly decrease the uncertainty in the final result.

G.F. Grinyer
A.T.Laffoley
J.C.Thomas
B.Blank
H.Bouzomita
R.A.E.Austin
G.C.Ball
F.Bucaille
P.Delahaye
P.Finlay
G.Fremont
J.Gibelin
J.Giovinazzo
T.Kurtukian-Nieto
K.G.Leach
A.Lefevre
F.Legruel
G.Lescalie
D.Perez-Loureiro

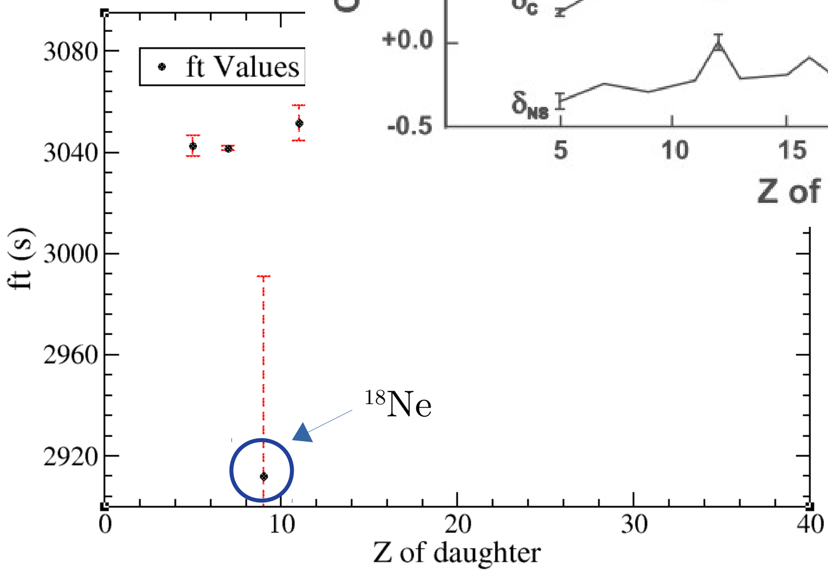
THANK YOU

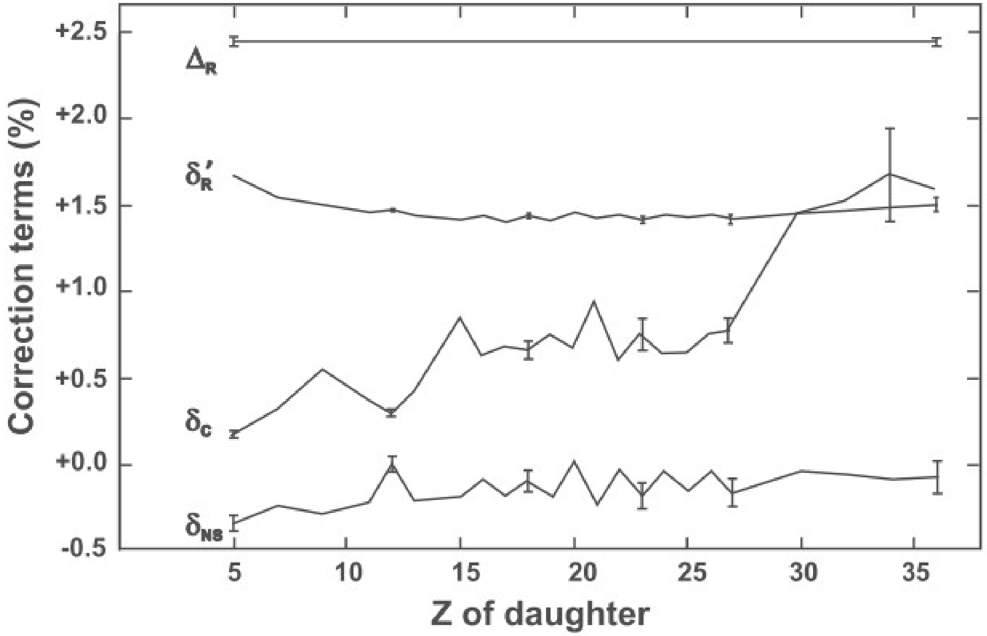
Q-value

Branching Ratio



$$= \frac{K}{2G_v}$$

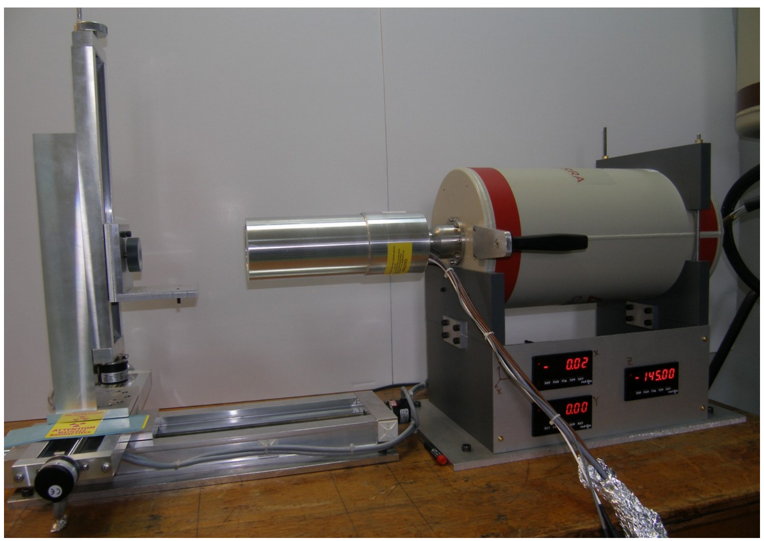


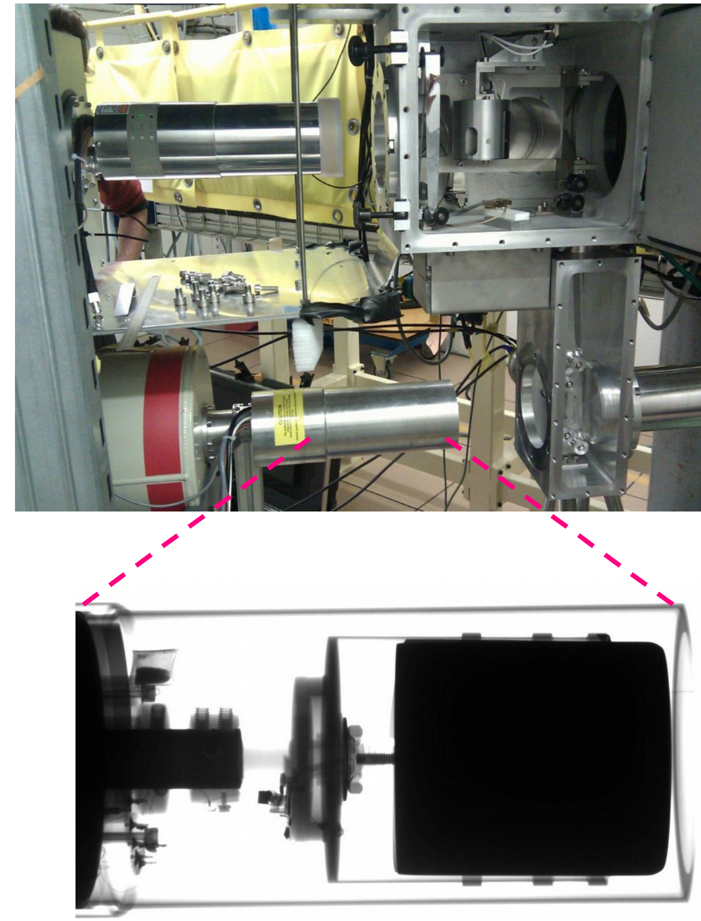


+2.5
+2.0
+1.5
+1.0
+0.5
+0.0
-0.5
Correction terms (%)
Δ_R
δ_R'
δ_C
δ_{NS}
5
10
15
20
25
30
35
Z of daughter

Experimental Setup

- **Detector calibration table**
  - **Precise positioning of the source**
  - **Laser calibrated x,y positioning**





Blank et. al., Nucl.Instrum.Meth.A 984, 164631 (2020)

Bordeaux Group