Super-allowed beta decay – a tool for weak-interaction studies

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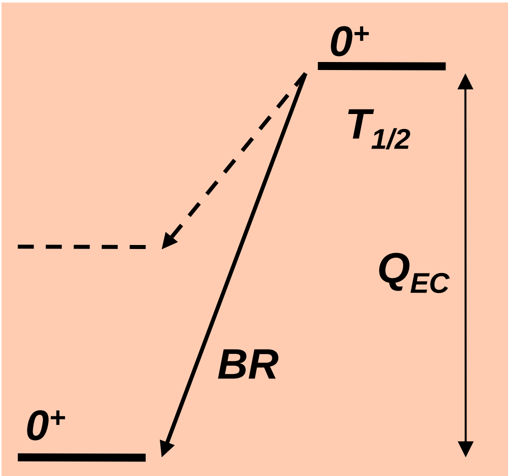
- Germanium detector calibration
- experimental studies: 0^+ - 0^+ β decay
  mirror β decay
- future work

Beta-Decay Weak Interaction Studies in the Era of the LHC
International Solvay Institutes, Brussels, September 3-5, 2014

Nuclear beta decay



$0^+ \rightarrow 0^+$:

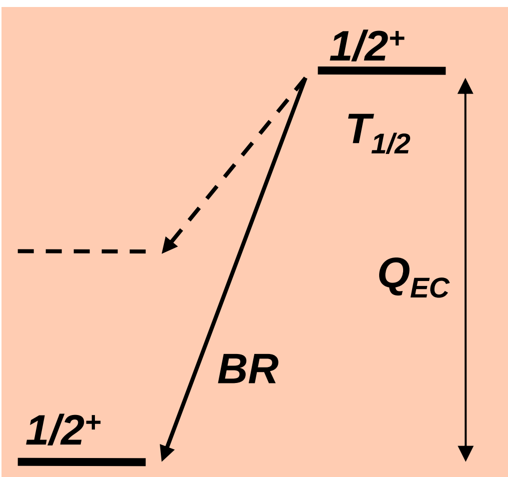
$$Ft = ft\,(1 + \delta_R')\,(1 - \delta_c + \delta_{NS}) = \frac{K}{g_V^2\,(1 + \Delta_R)\,\langle M_F \rangle^2} = cnst$$

f(Z, Q_{EC}) ~ 1.5%

f(nucl. structure) ~ 0.3-1.5%

f(weak interaction) ~ 2.4%

additional measurement needed



mirror decays:

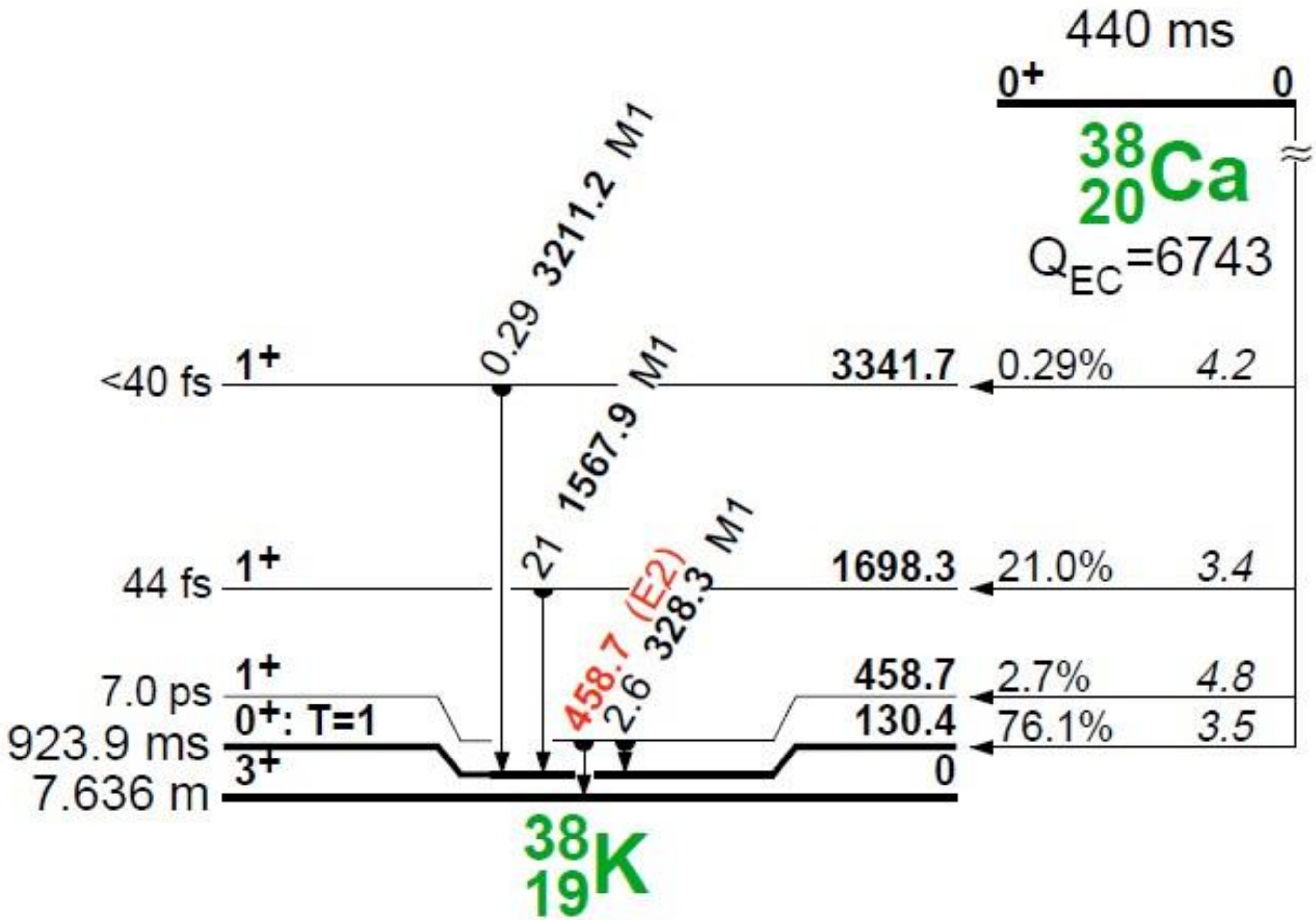
$$Ft = ft\,(1 + \delta_R')\,(1 - \delta_c + \delta_{NS}) = \frac{K}{g_V^2\,(1 + \Delta_R)\,\langle M_F \rangle^2} \times \frac{1}{(1 + f_a/f_v)\,\rho^2} = cnst$$

Precision measurements required: 10^{-3}

- ✓ Q_{EC} → *mass measurements: $f \sim Q_{EC}^5$*
- ✓ $T_{1/2}$, BR → *β-decay studies: $t = T_{1/2} / BR$*
- ✓ ρ^2 → *β-decay angular correlation studies*

Germanium detector calibration

Super-allowed Fermi transitions for T_z = -1



- many decay channels open
- strong non-analog transitions
- high precision of γ efficiency needed ➔ 0.1%

Calibration Procedure

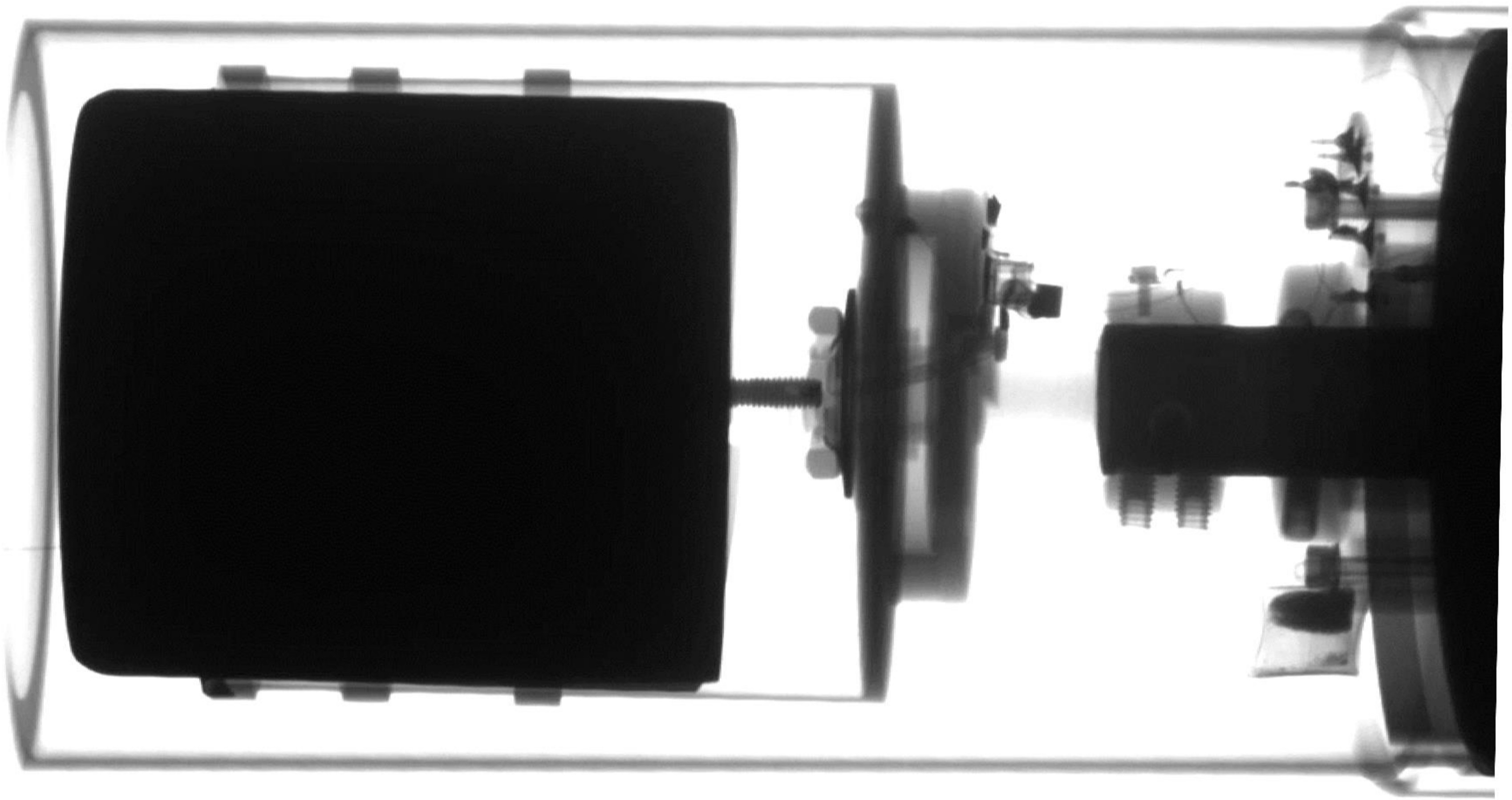
- X-ray radiography
- γ-ray detector scans
- source measurements
- MC simulations
  (GEANT4 or CYLTRAN)

➔➔ **develop a model of the detector**

to calculate efficiencies at any energy

at a fixed distance of 15 cm

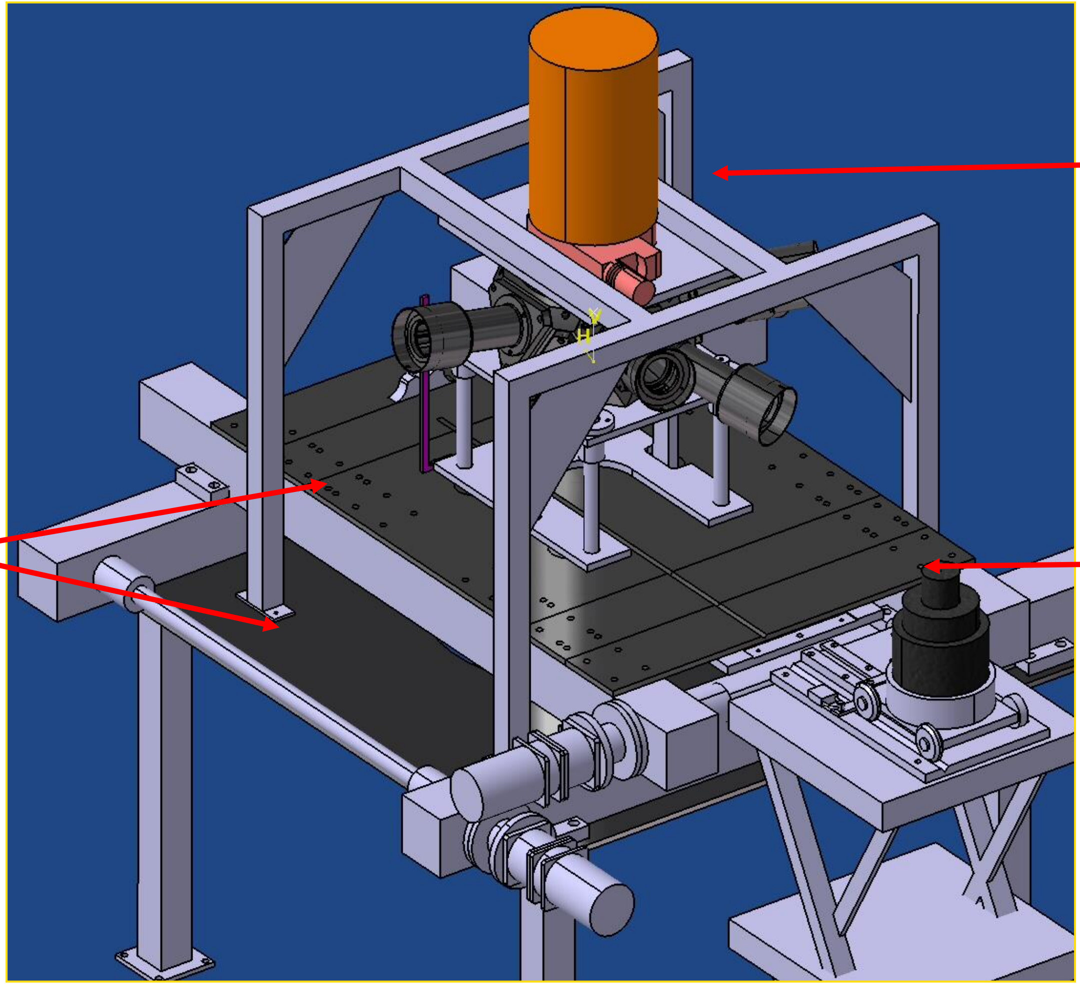
X-ray photography of detector



- ➔ rough size of crystal
- ➔ tilt of crystal with respect to detector housing of 1°
- ➔ according to GEANT4 simulations no influence on results

Gamma-ray scan of detector

- **AGATA scan table at CSNSM: strongly collaminated ^{137}Cs source**



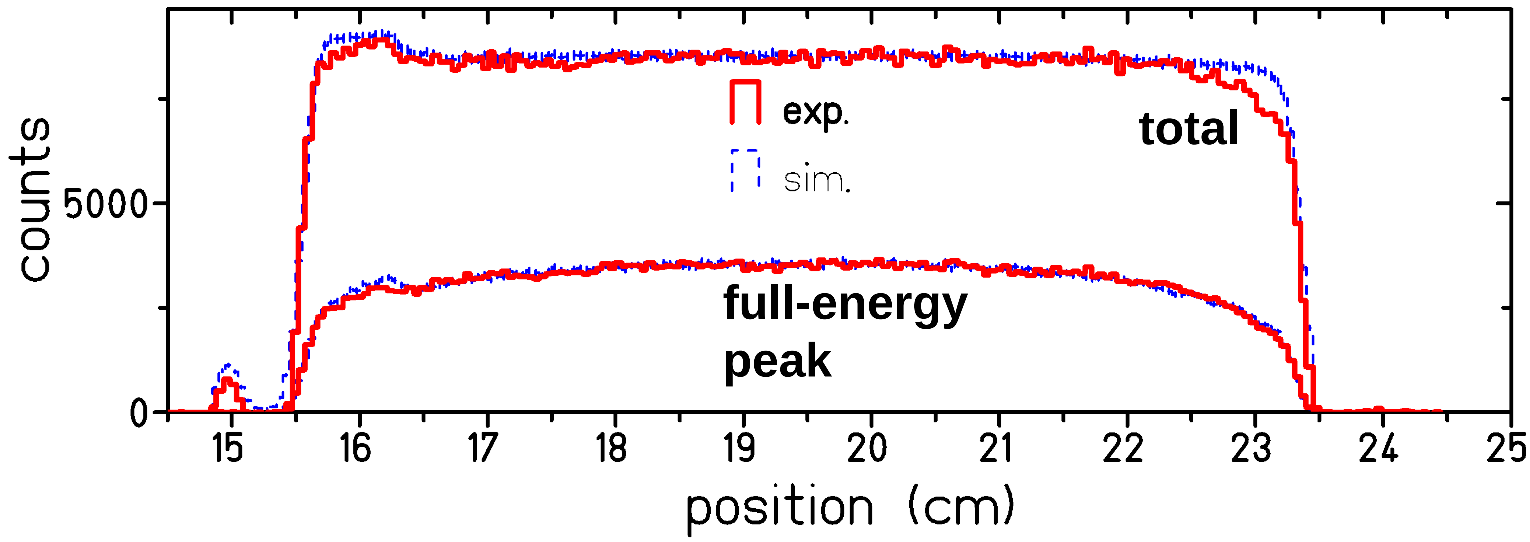
HPGe

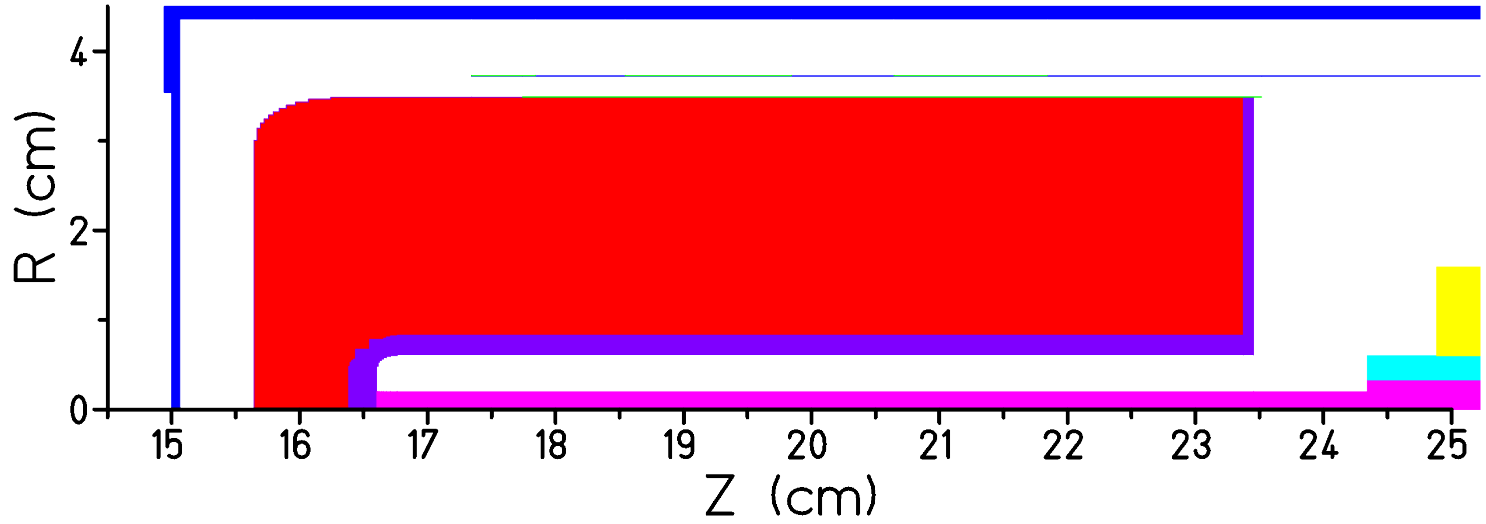
X-Y table

^{137}Cs (477MBq)

A. Korichi et al.

Longitudinal scan: 662 keV





- **excellent full-energy peak spectrum**
- **good total-energy spectrum**

Calibration sources

- **peak-to-total sources:**

  ➔ **close to « one single γ ray with 100% branching ratio »**

  - **standard sources:**

    ^{57}Co, ^{51}Cr, ^{85}Sr, ^{137}Cs, ^{54}Mn, ^{60}Co, ^{22}Na

  - **short-lived online source at ISOLDE:**

    ^{58}Co, ^{65}Zn, ^{41}Ar

- **relative efficiency sources:**

  ➔ **a few well-known branches (BR error <1%) at largely different energies**

  - **standard sources:**

    ^{60}Co, ^{88}Y, ^{133}Ba, ^{134}Cs, ^{137}Cs, ^{152}Eu, ^{207}Bi

  - **short-lived online source at ISOLDE and IPNO:**

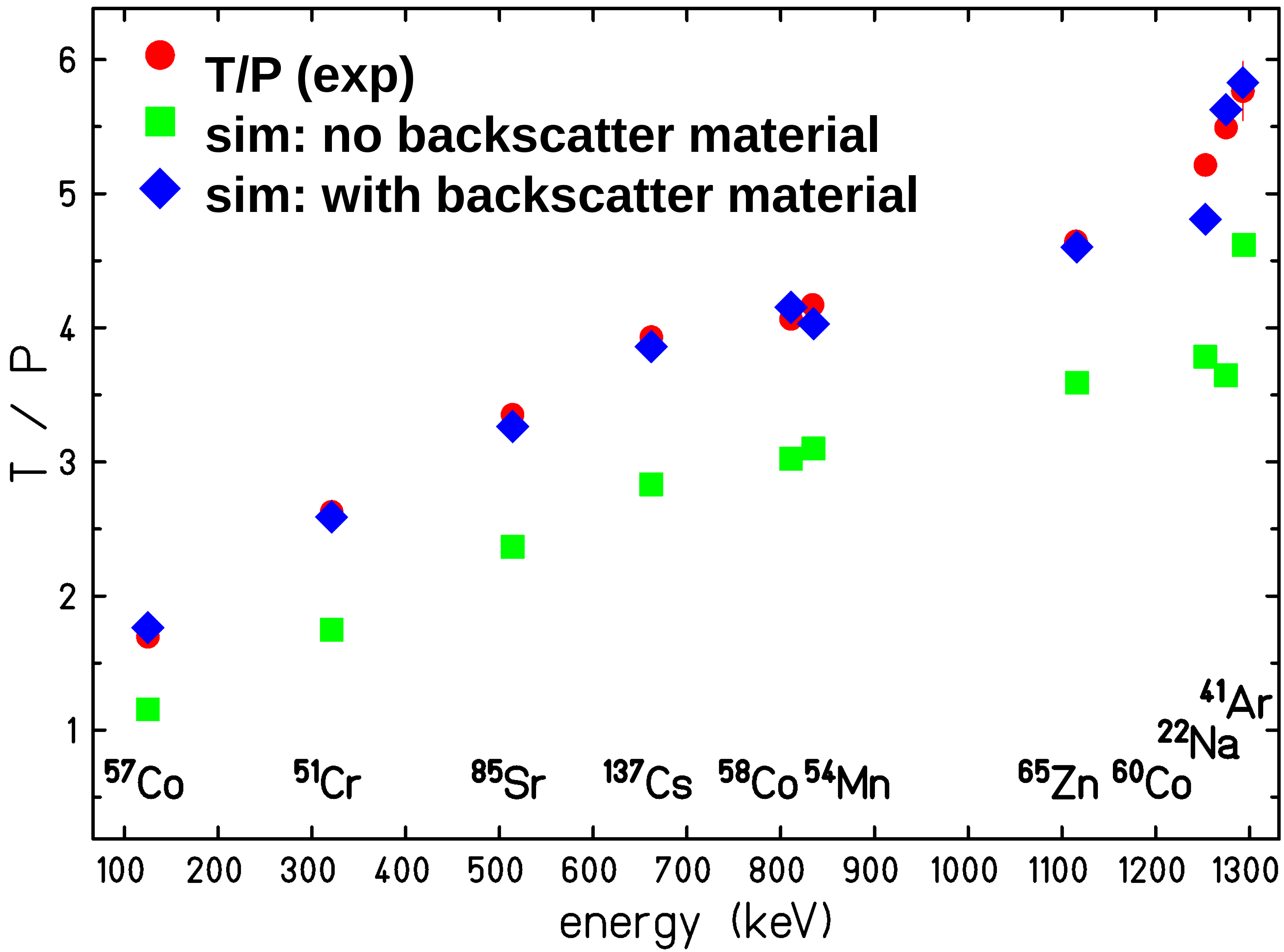
    ^{24}Na, ^{27}Mg, ^{48}Cr, ^{56}Co, ^{66}Ga, ^{75}Se, ^{180m}Hf

- **absolute efficiency:**

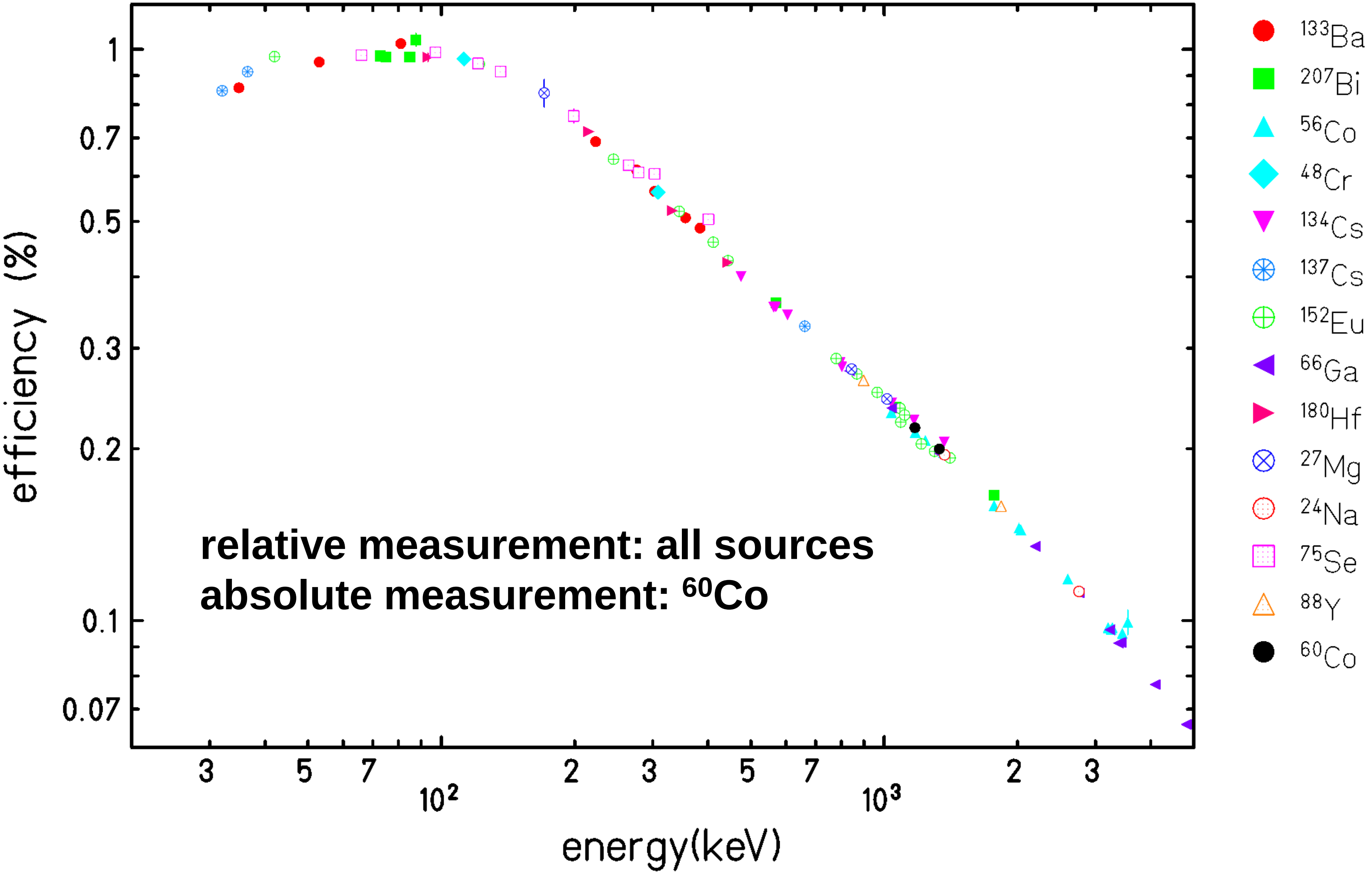
  - **^{60}Co with activity precision of 0.7‰**

  - **γ–γ coincidences**

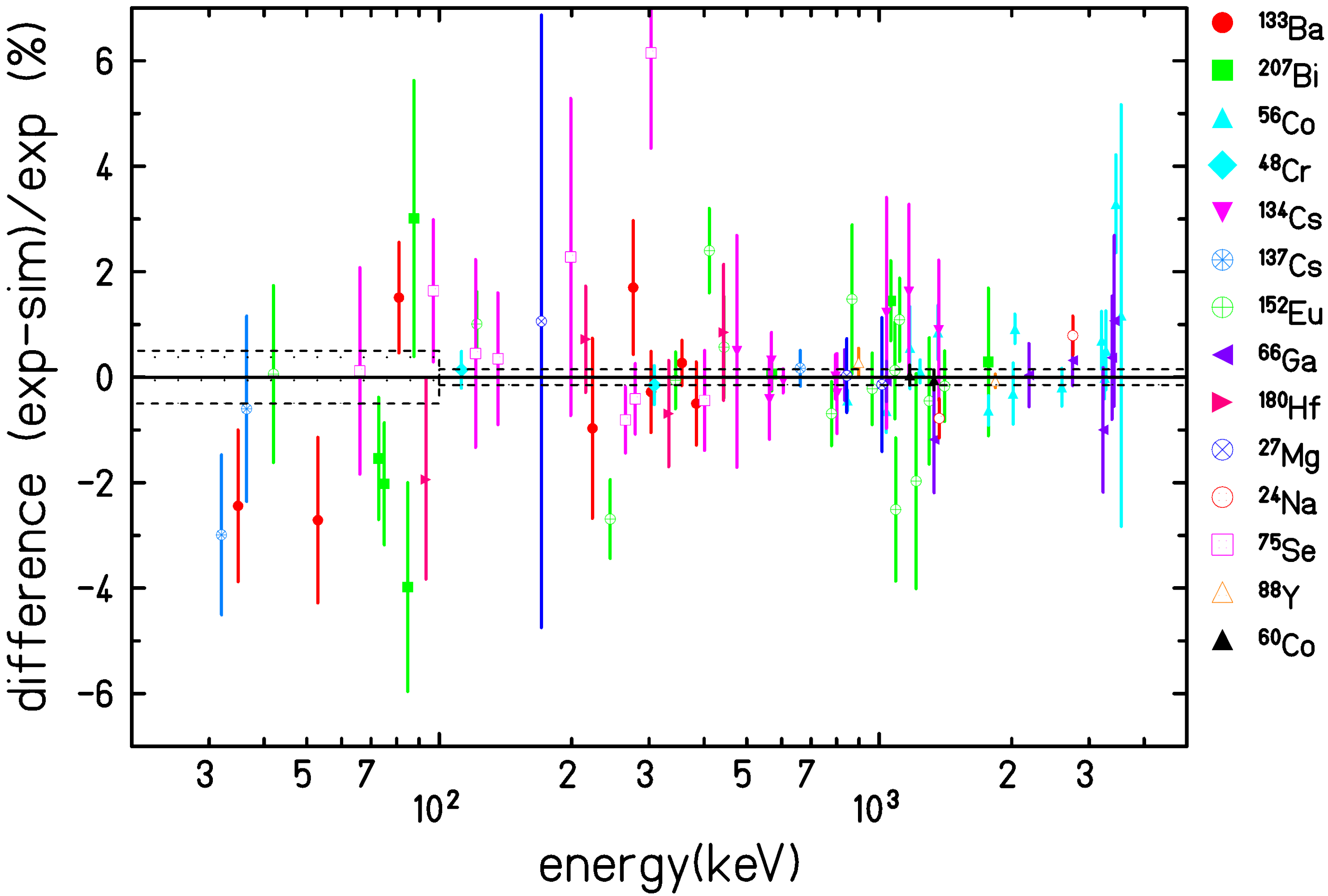
Calibration of germanium detector: peak-to-total



Calibration of germanium detector: absolute efficiency



Calibration of germanium detector: absolute efficiency



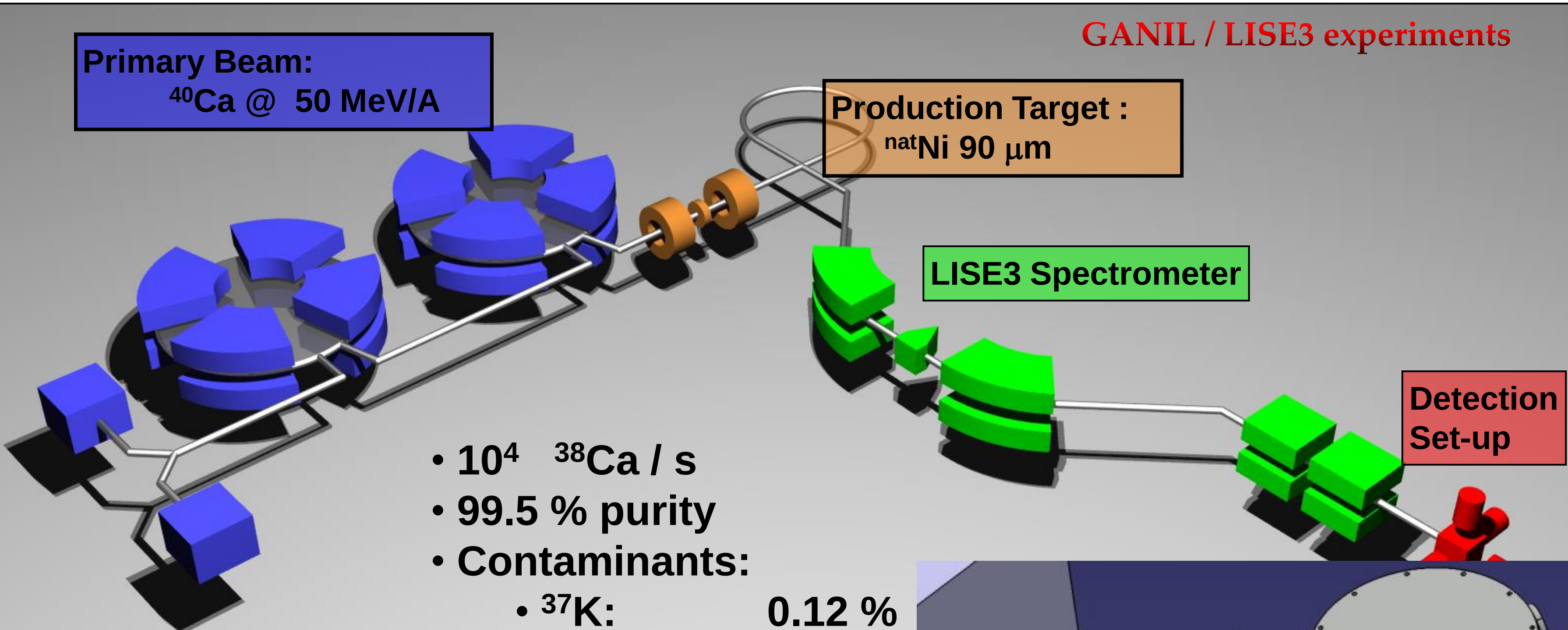
Fit 1: P_0 = 0.0022 ± 0.0659; χ^2 = 1.5 ← < 0.8 ‰ precision

Fit 2: P_0 = -0.51 ± 0.49

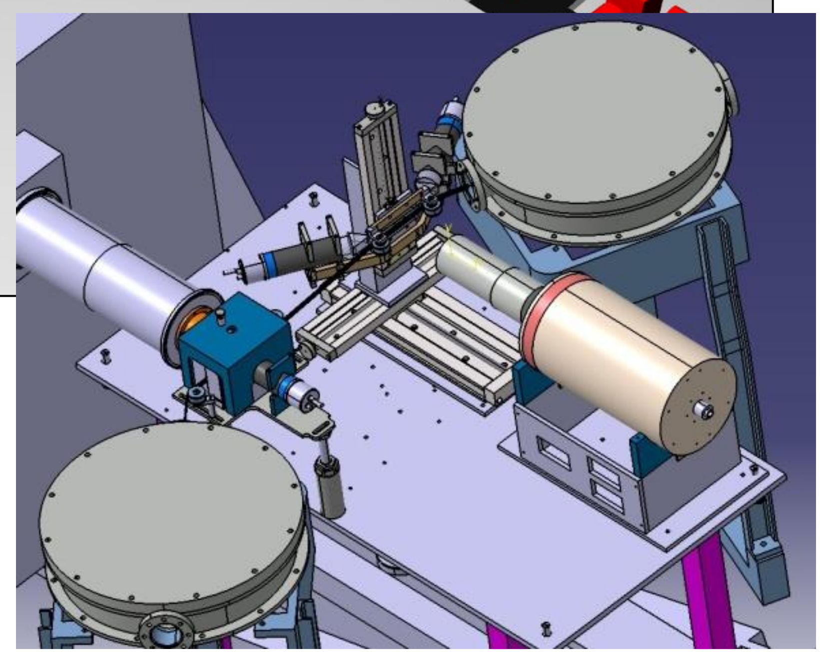
from Eγ < 50 keV → P_1 = 0.17 ± 0.17; χ^2 = 1.6

0^+ - 0^+ β decay: ^{38}Ca

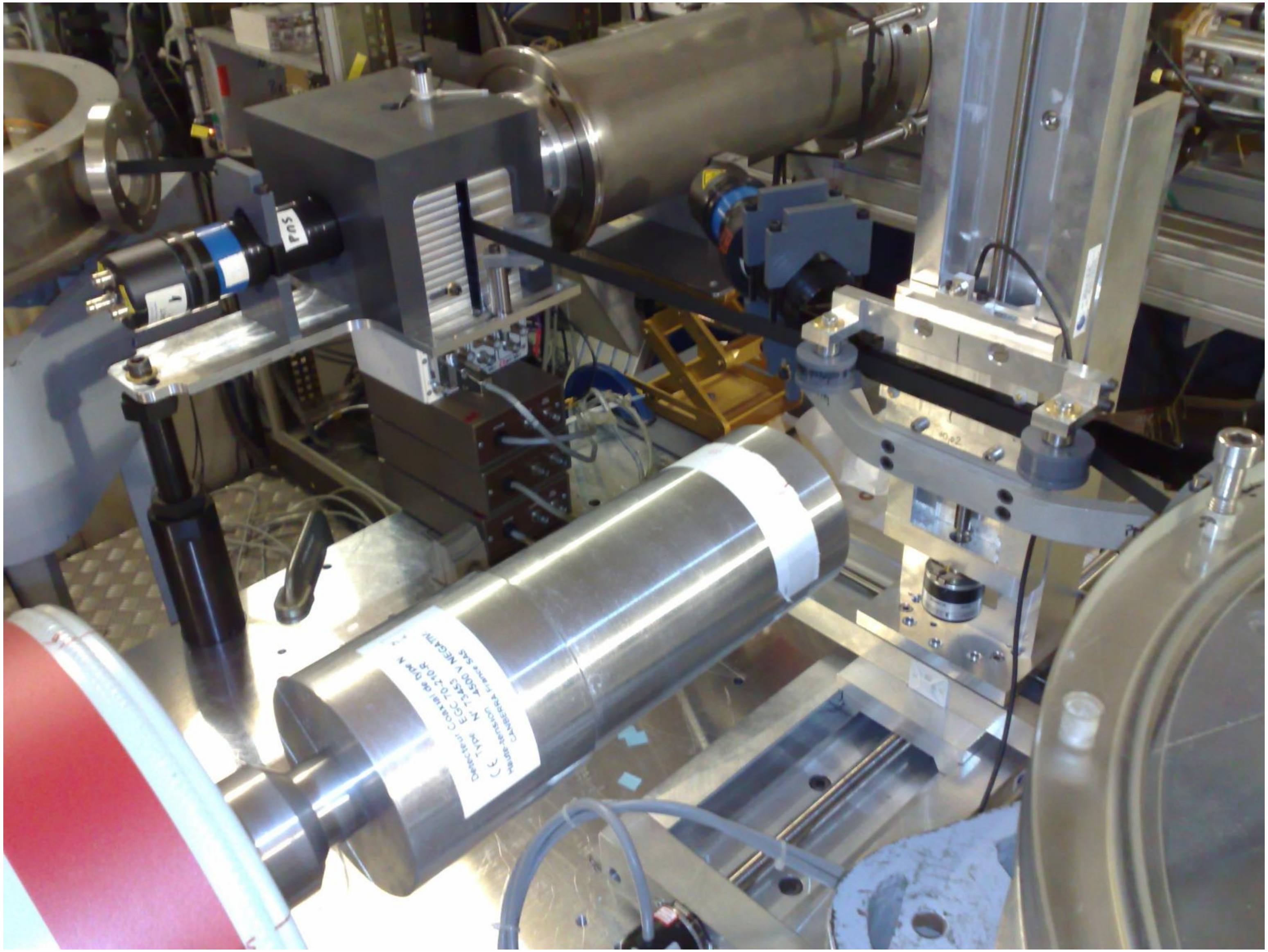
^{38}Ca production at GANIL/LISE3



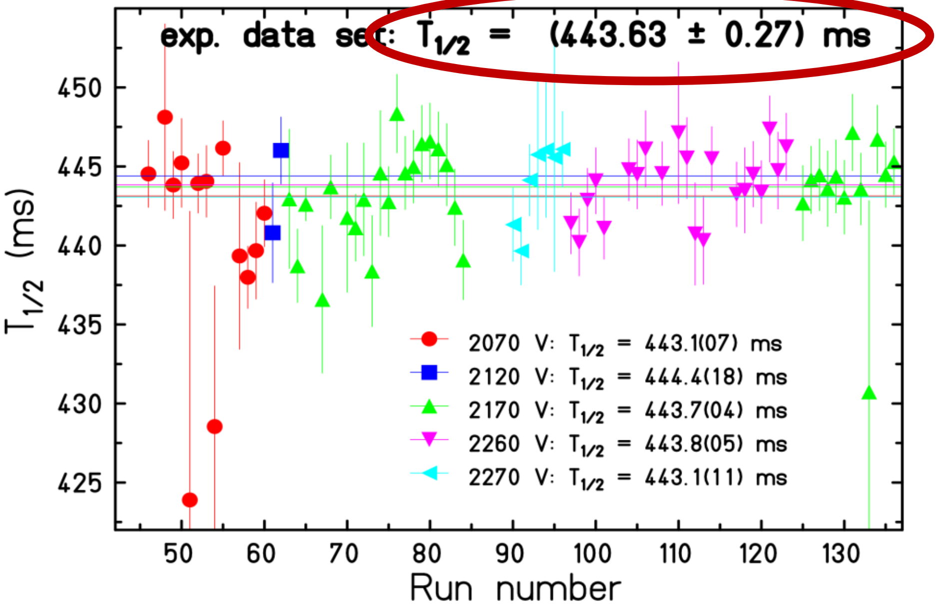
- 10^4 ^{38}Ca / s
- 99.5 % purity
- Contaminants:
  - ^{37}K: 0.12 %
  - ^{36}Ar: 0.11 %
  - ^{35}Cl: 0.09 %
  - ^{34}S: 0.14 %

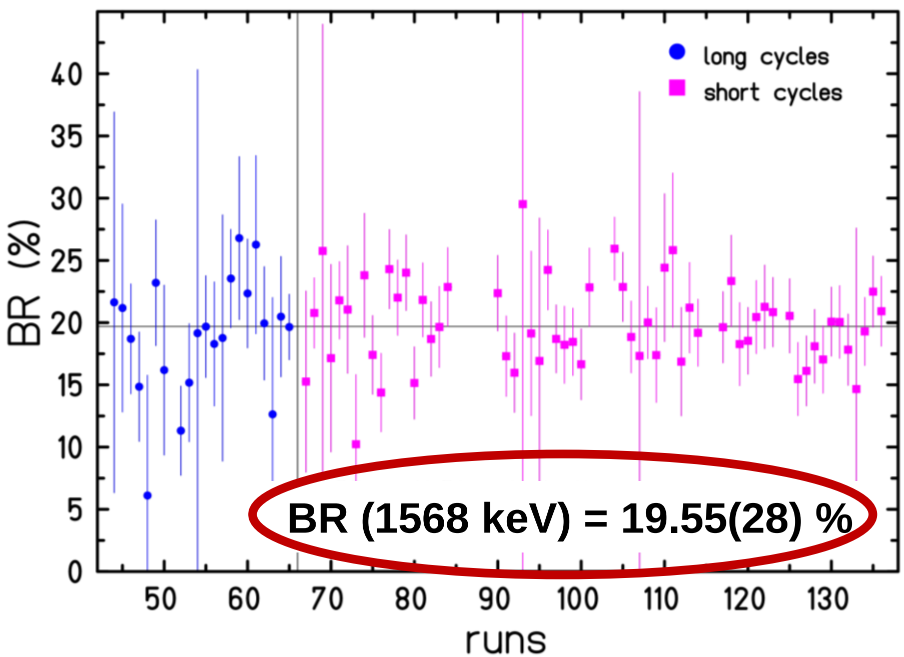


^{38}Ca detection

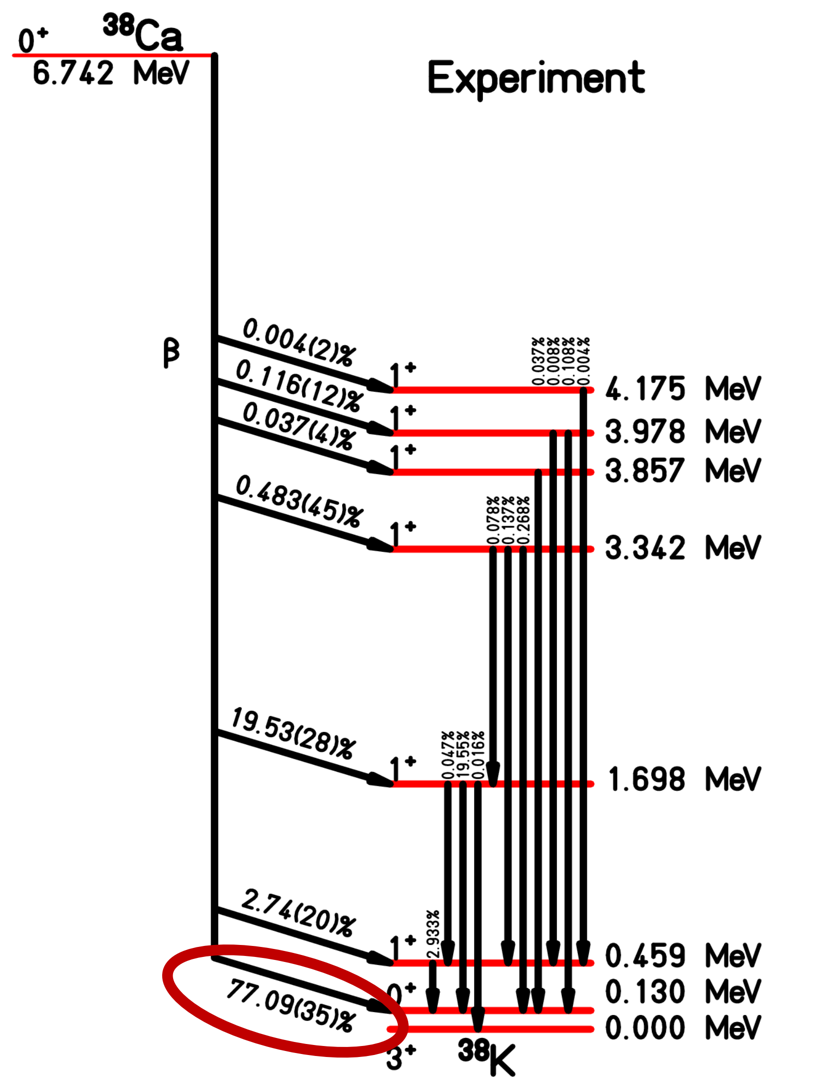


^{38}Ca branching ratios and half-life





Present work and Anderson et al.



B. Blank et al., submitted to EPJA

^{38}Ca: result

- **half-life:**

Kavanagh et al. [25]	Gallmann et al. [26]	Zioni et al. [27]	Wilson et al. [28]	Blank et al. [19]	Park et al. [5]	present	average
470(20)	439(12)	450(70)	430(12)	443.8(19)	443.77(36)	443.63(28)	443.71(22)

➔➔ **443.71(22) ms**

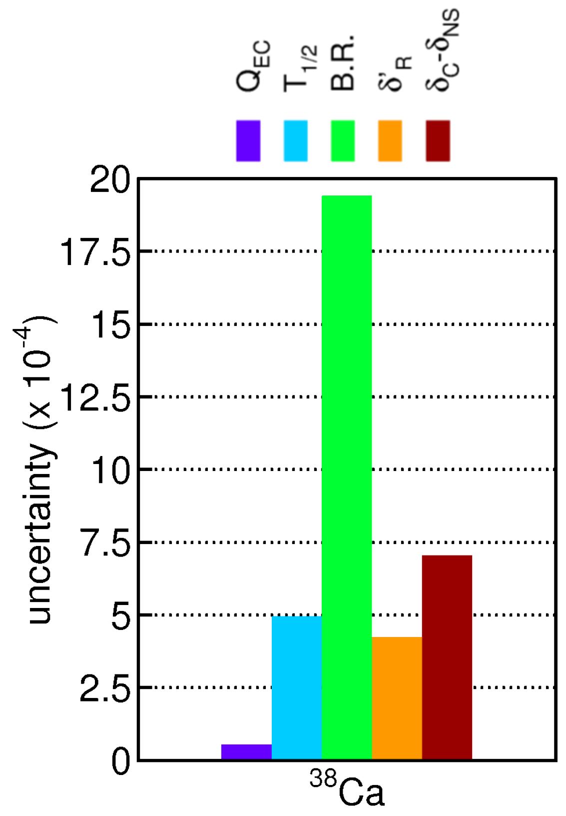
- **BR (0^+ — 0^+):** **present:** **77.09(35) %**
  Park et al.: **77.28(16) %**

➔➔ **77.25(15) %**

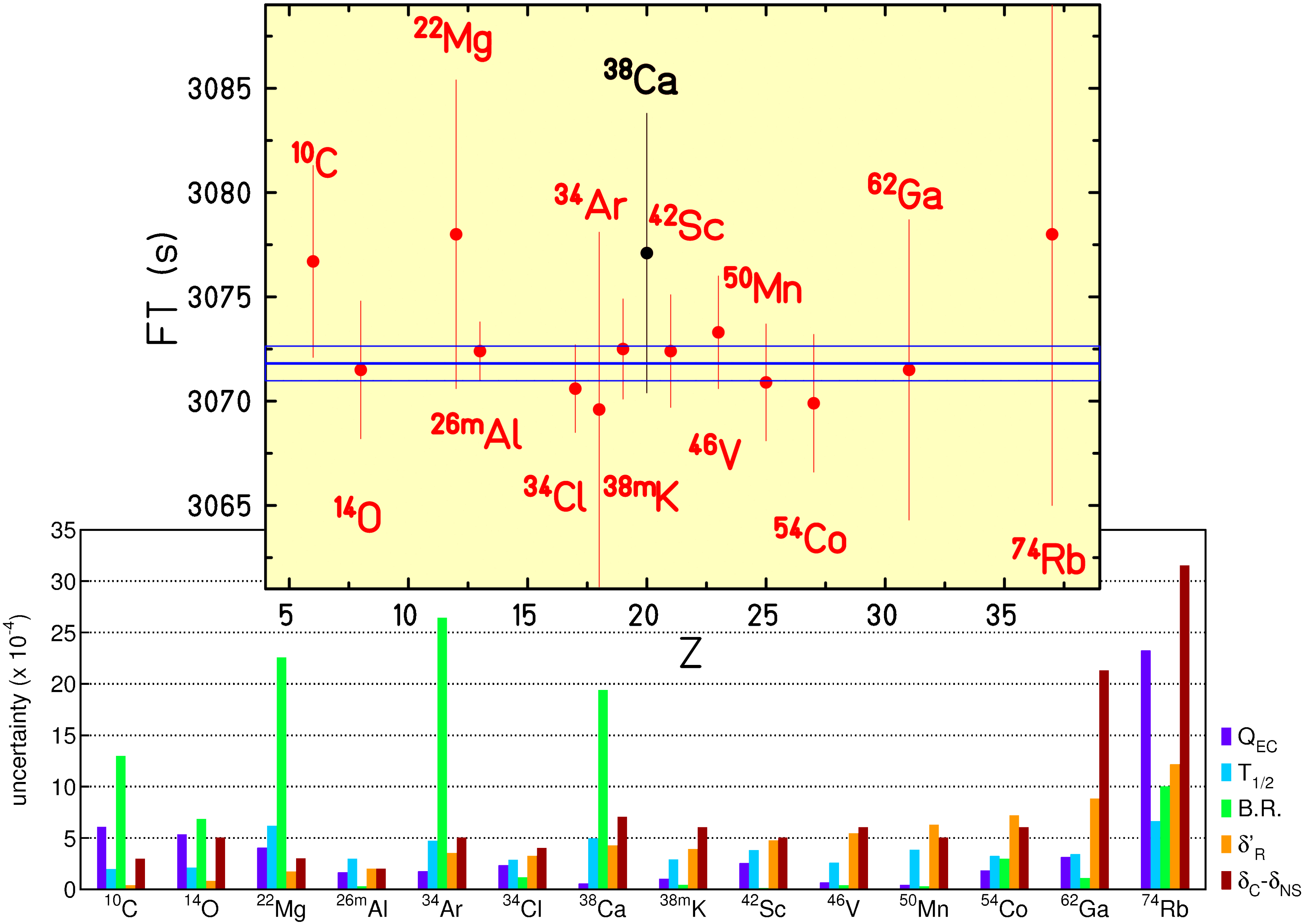
- **Q value:** **Eronen et al.:** **6612.11(7) keV**

➔ **ft = 3063.4(61) s**

➔ **Ft = 3077.5(67) s**



^{38}Ca: result



FT (s)
Z
uncertainty (x 10^-4)
10C
14O
22Mg
26mAl
34Ar
34Cl
38Ca
38mK
42Sc
46V
50Mn
54Co
62Ga
74Rb
Q_EC
T_1/2
B.R.
δ'_R
δ_C-δ_NS

Mirror β decay: ^{23}Mg and ^{27}Si

Measurement at JYFL

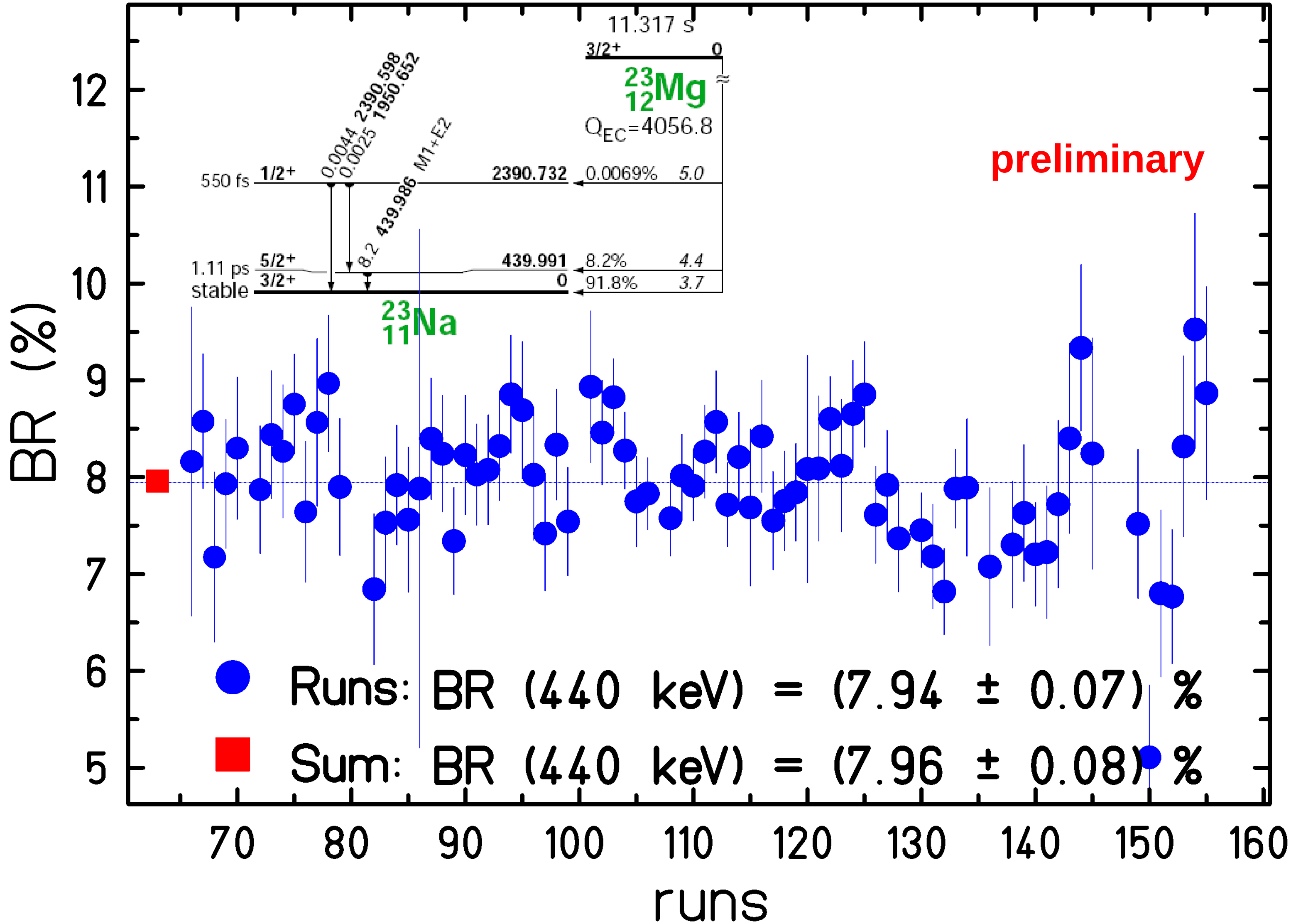
Production: IGISOL
Purification: $M/\Delta M = 500$

^{23}Mg: $^{23}Na(p,n)^{23}Mg$
^{27}Si: $^{27}Al(p,n)^{27}Si$

detection setup
- β: plastic scintillator
- γ 1 germanium detector

tape transport system

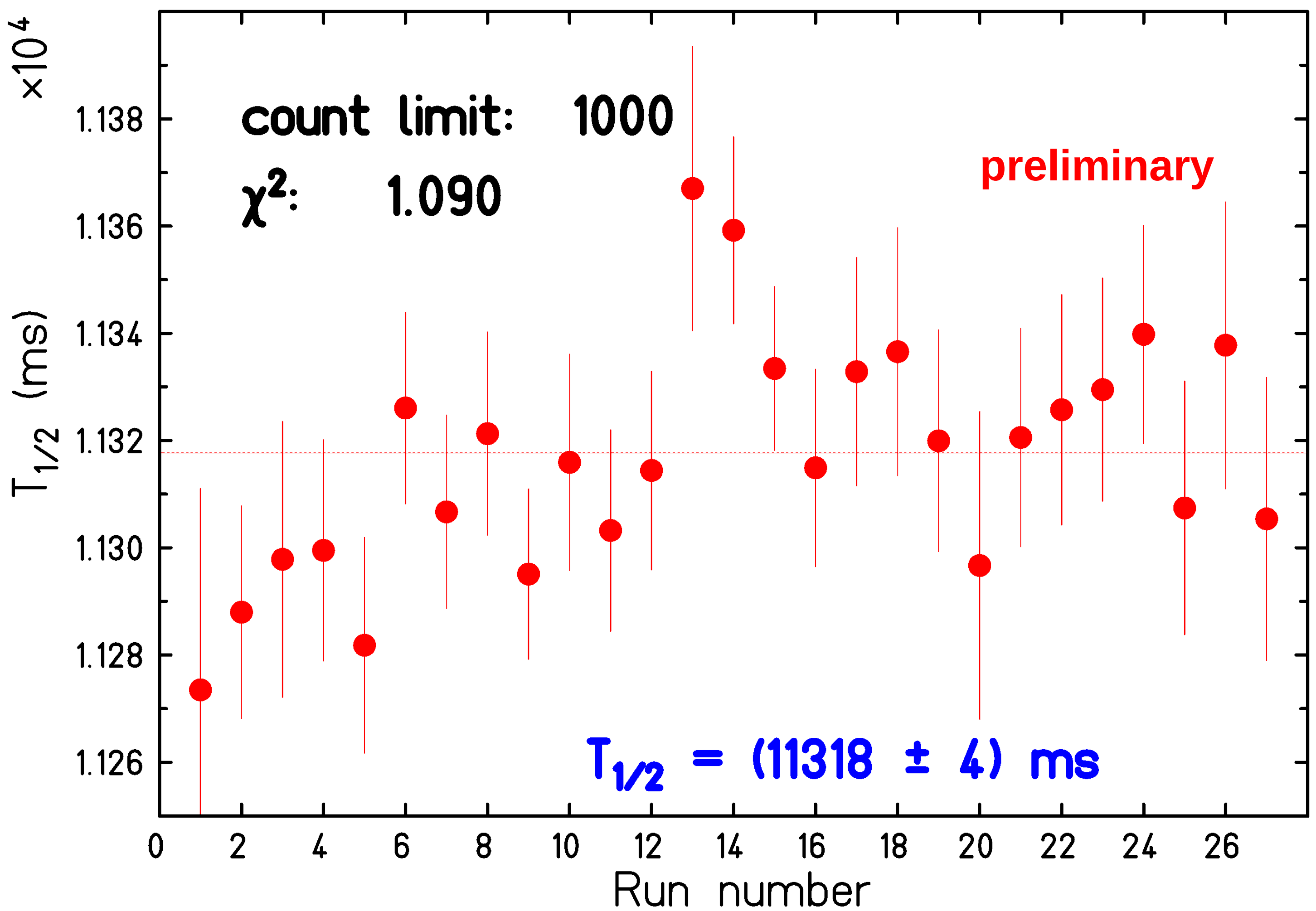
BR of ^{23}Mg



C. Magron et al.

Literature value: (91.78±0.26)%

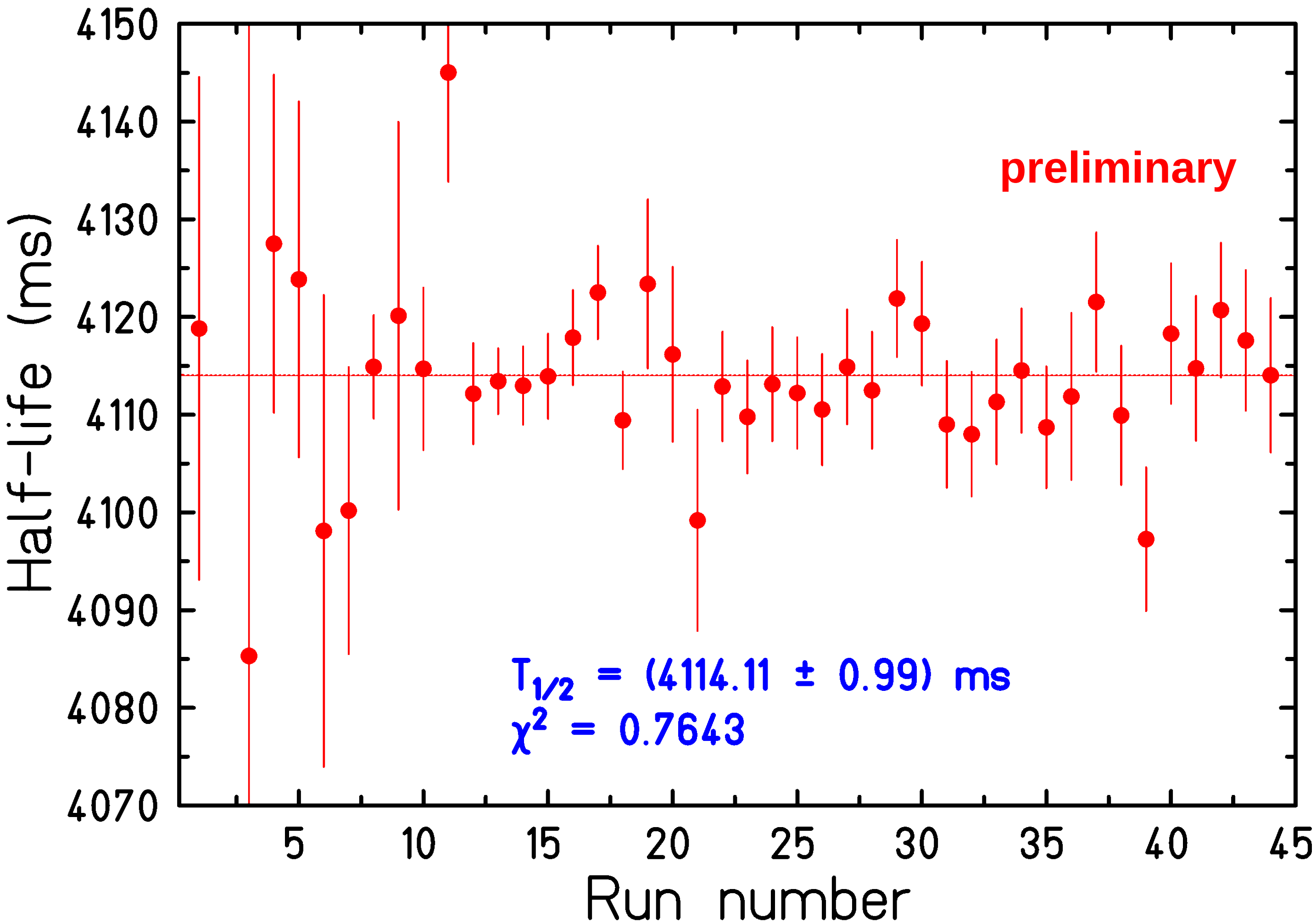
Half-lives of ^{23}Mg



C. Magron et al.

Literature value: (11324.3±9.8) ms

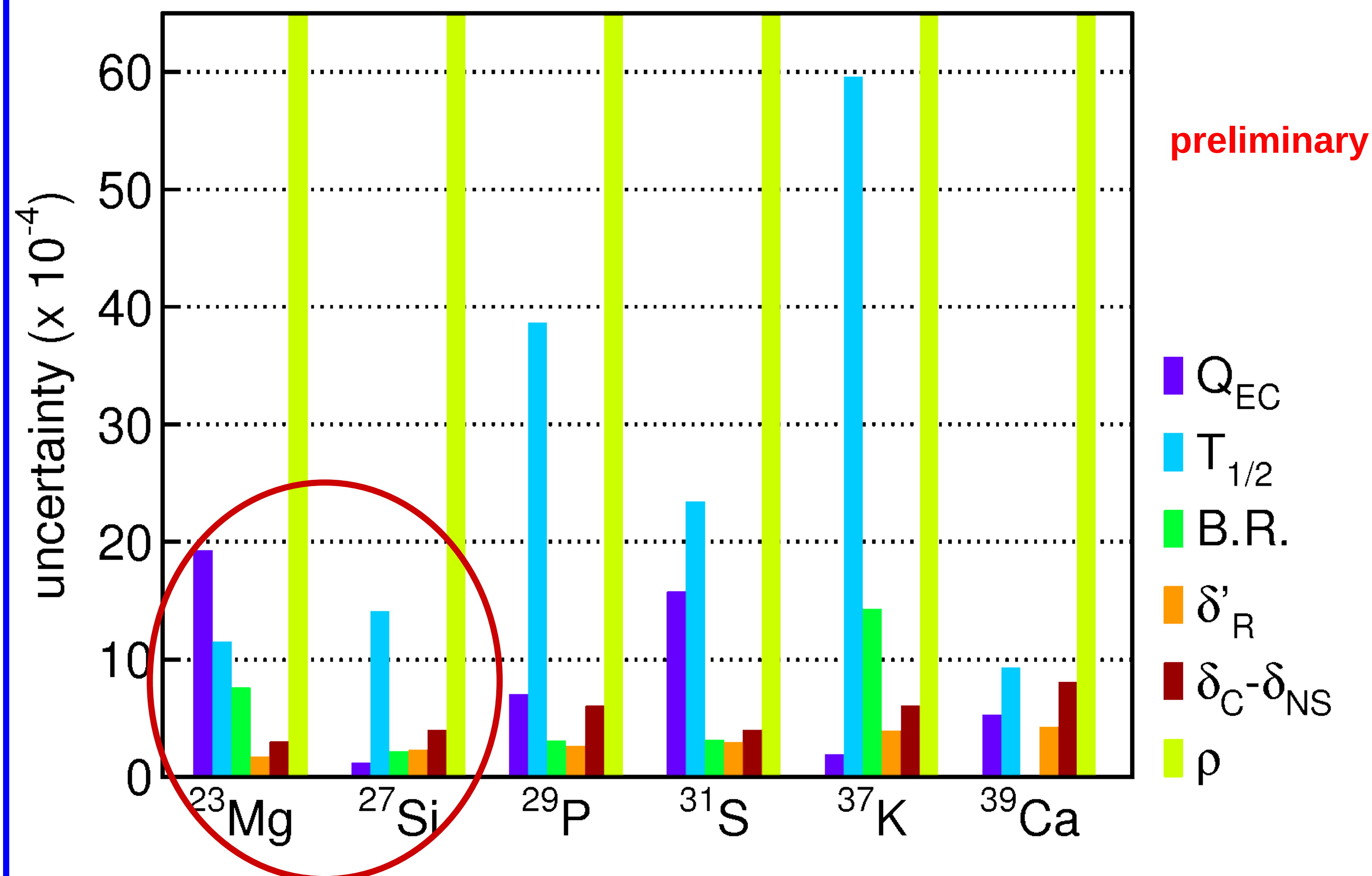
Half-lives of ^{27}Si



C. Magron et al.

Literature value: (4135±19) s

Uncertainties for ^{23}Mg and ^{27}Si

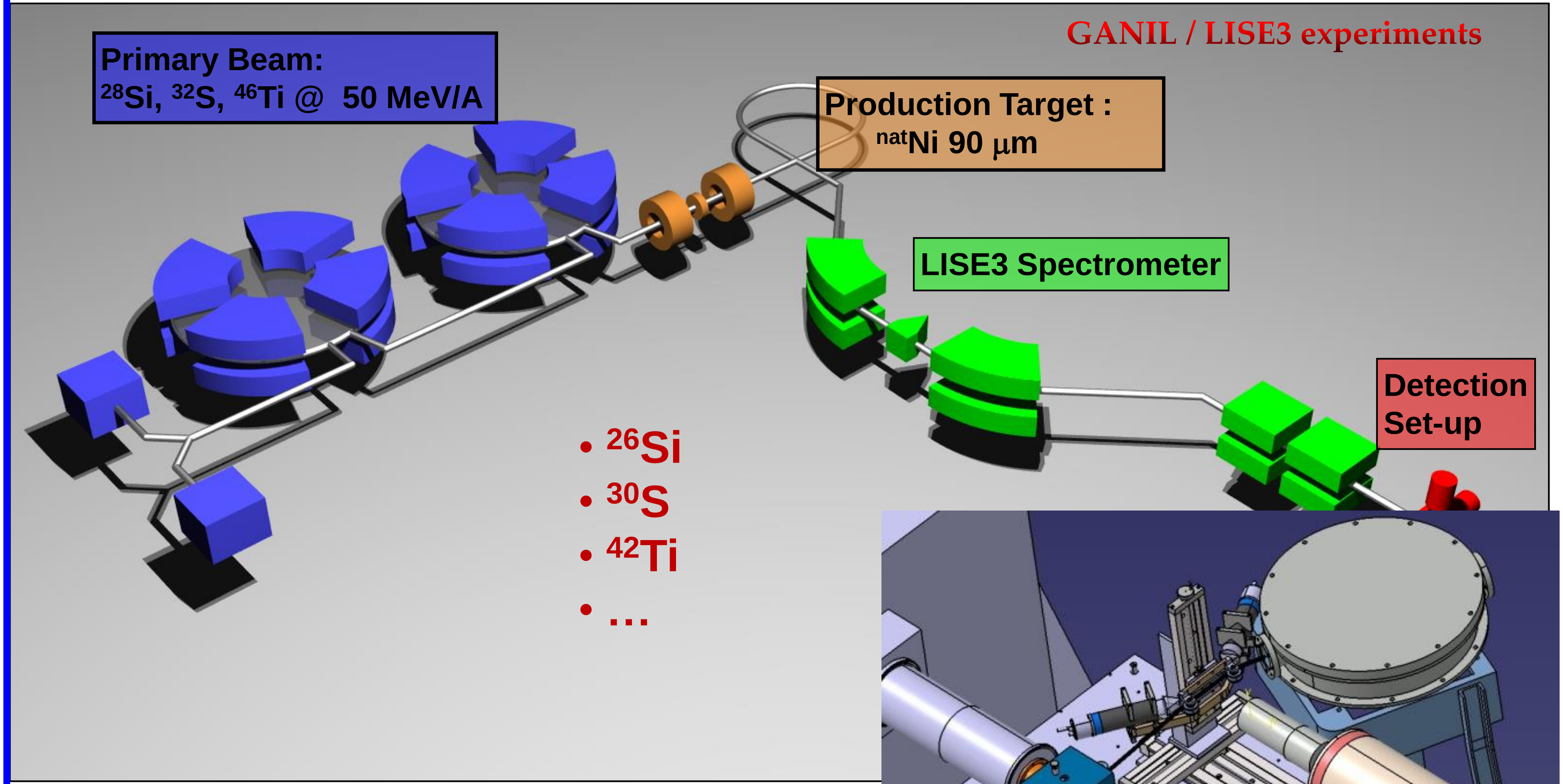


C. Magron et al.

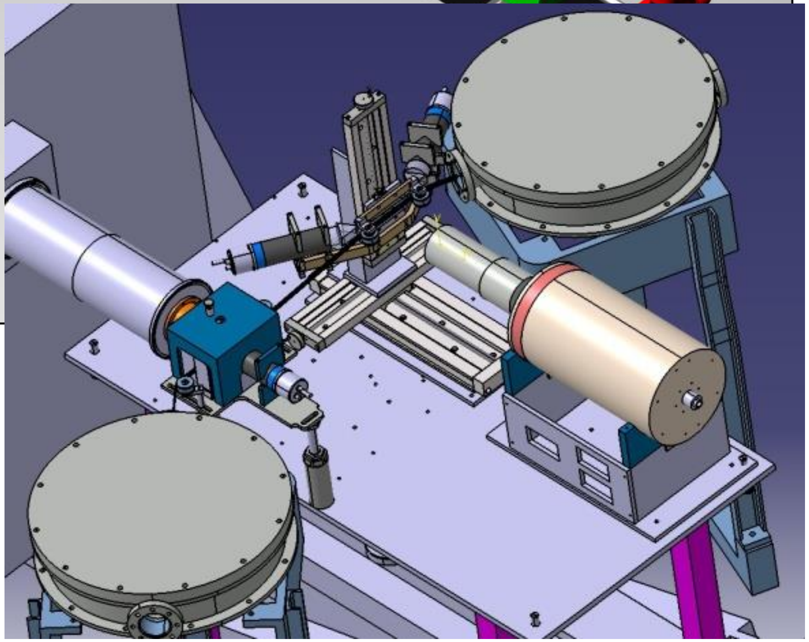
Future plans: GANIL – SPIRAL2 – S3 – DESIR

- T_z = -1, 0+ - 0+ decays
- heavy 0+ - 0+ decays
- β–ν correlations

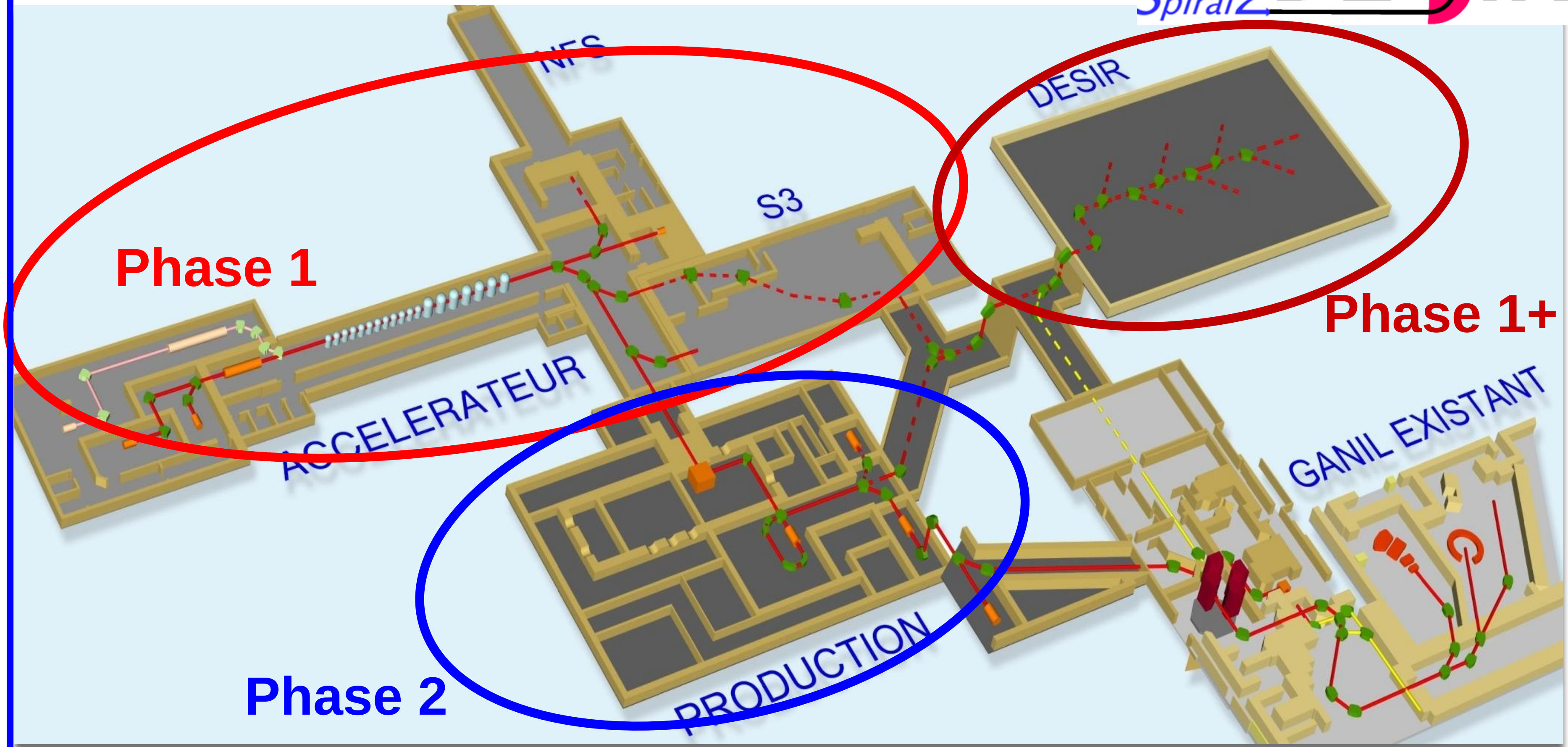
Super-allowed emitter production at GANIL/LISE3



- ^{26}Si
- ^{30}S
- ^{42}Ti
- ...

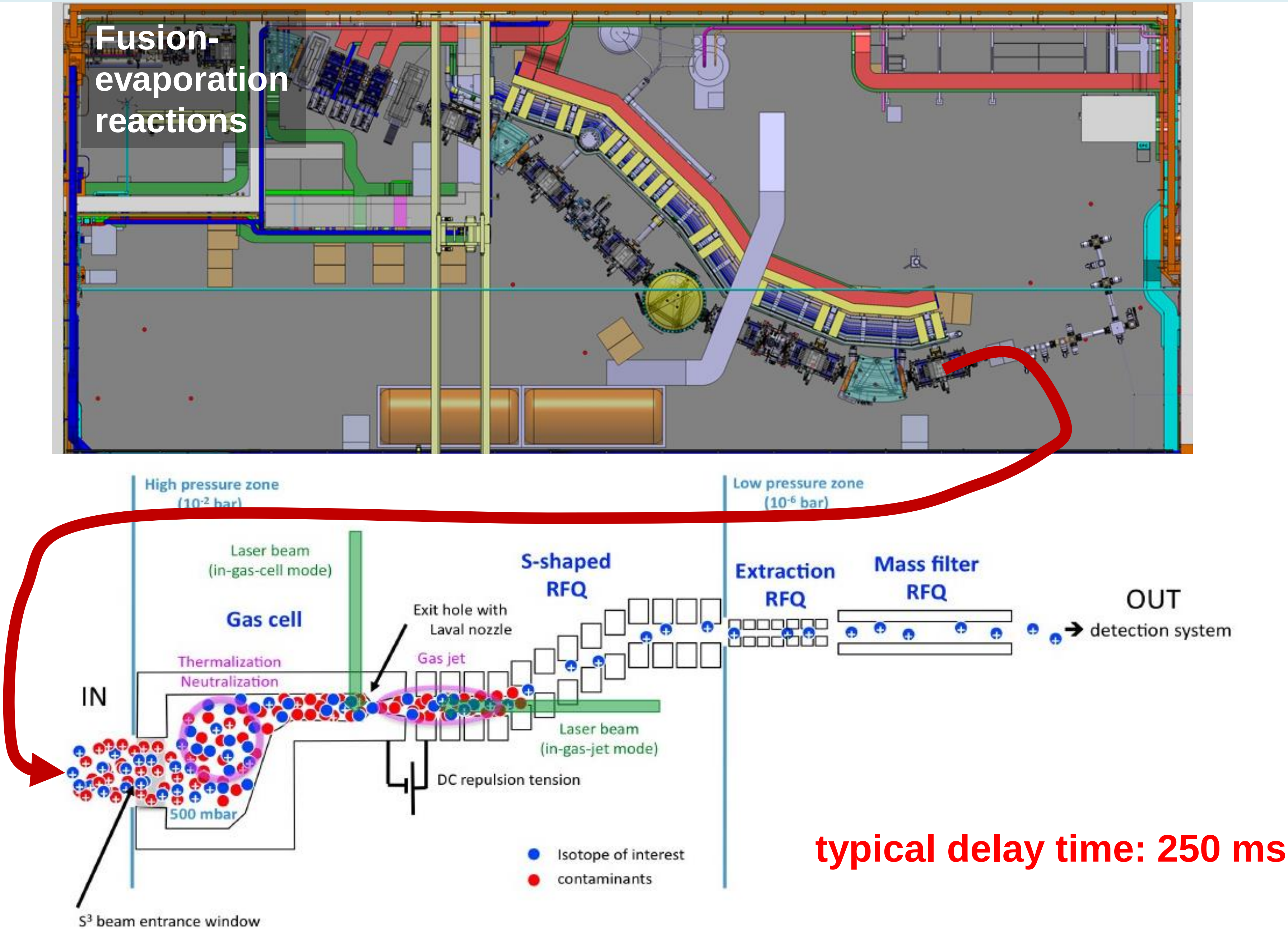


SPIRAL2 facility



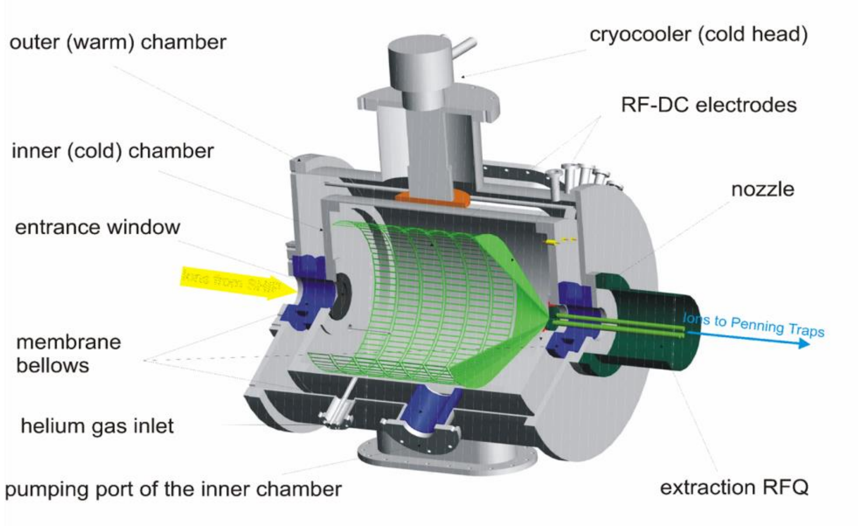
- NFS and S3 experiments
- for DESIR:
  - SPIRAL1 (light nuclei from beam/target fragmentation)
  - ~~SPIRAL2 (n-rich fission fragments, transfer and fusion-evaporation products)~~ at earliest 2020
  - S3 (fusion-evaporation, refractory elements)

S3 and its low-energy branch (laser gas cell)



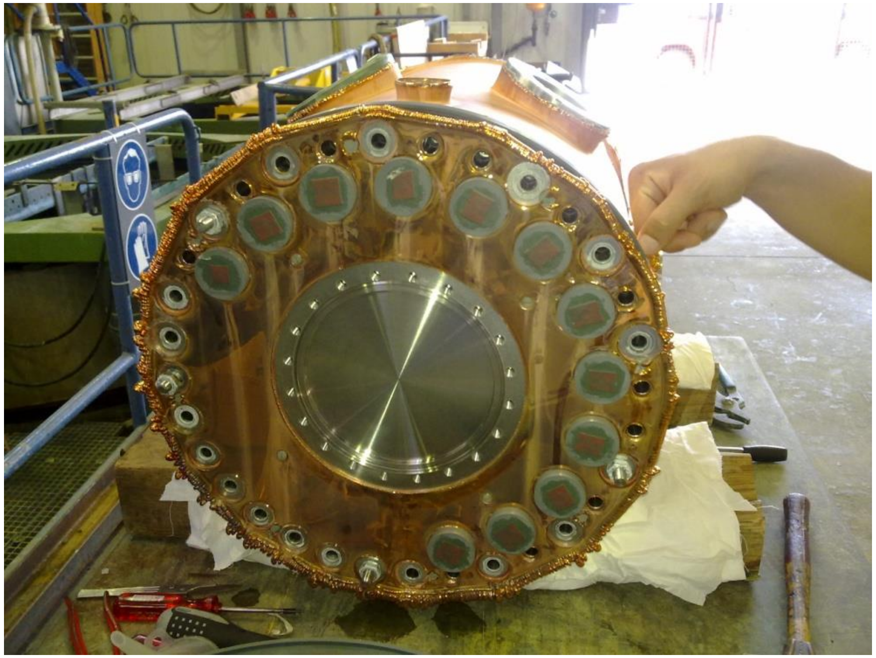
typical delay time: 250 ms

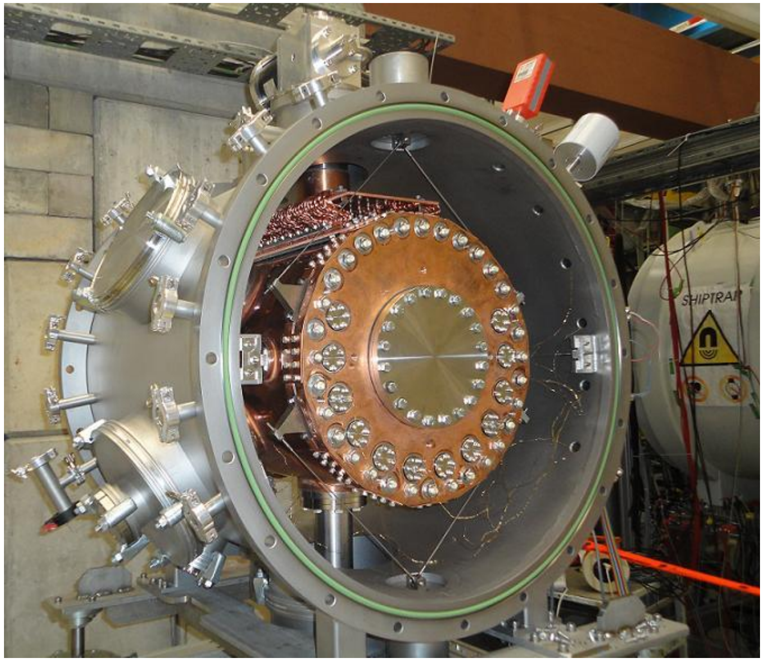
... cryo gas cell



SHIPTRAP cryo gas cell
E. Minaya Ramirez et al.

- **universal**
- **relatively high efficiency**
- **20 ms delay time**



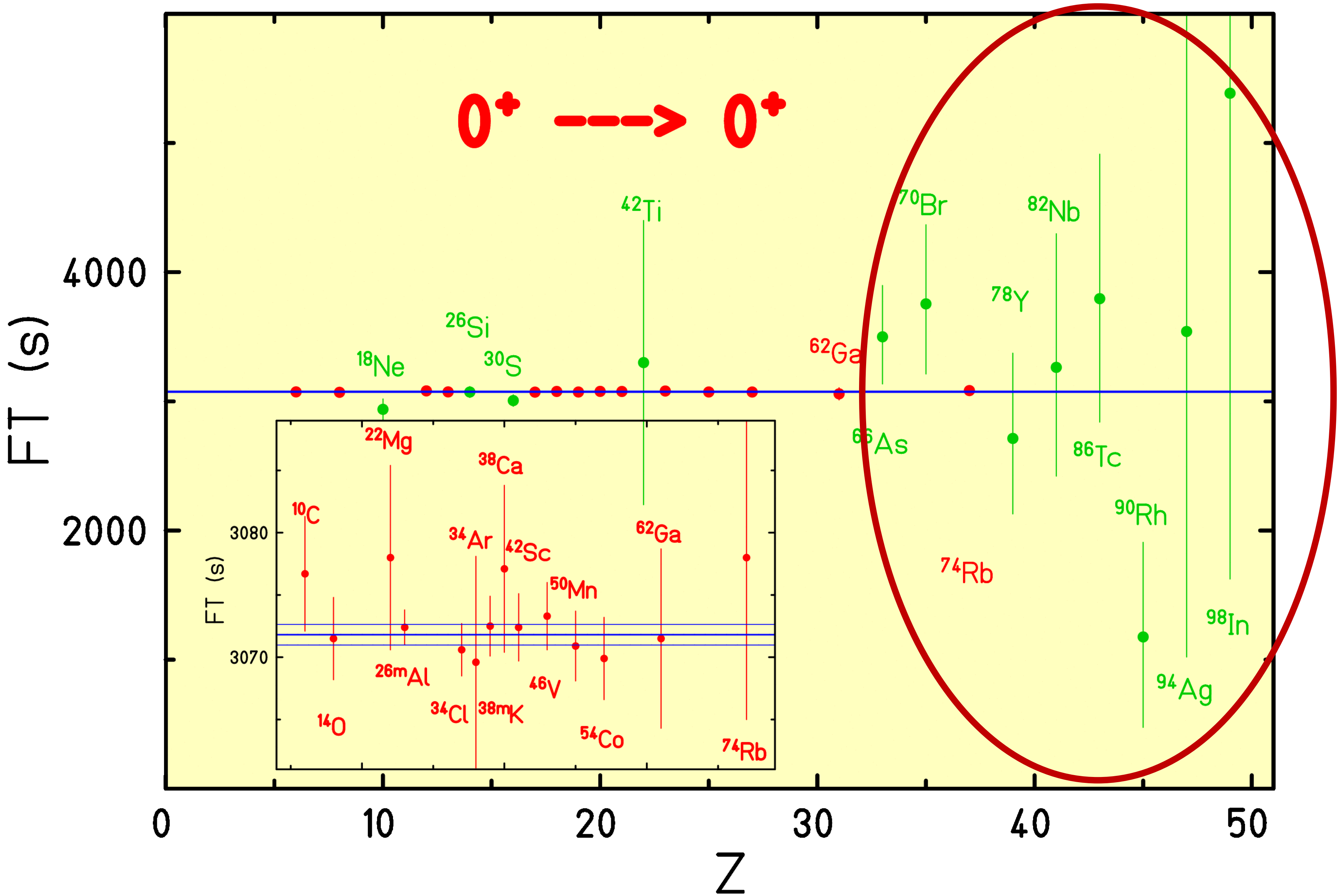


Heavy $T_z = 0$ nuclei

	isotope	half-life (ms)	production rate (pps)
$T_z = 0$	^{66}As	95.77(23)	50000
	^{70}Br	79 .1(8)	35000
	^{74}Rb	64.776(30)	30000
	^{78}Y	54(5)	1500
	^{82}Nb	50(5)	300
	^{86}Tc	55(6)	250
	^{90}Rh	15(7)	200
	^{94}Ag	37(18)	400
	^{98}In	37(5)	0.3

➔ test CVC over a larger range of Z

Heavy T_z = 0 nuclei



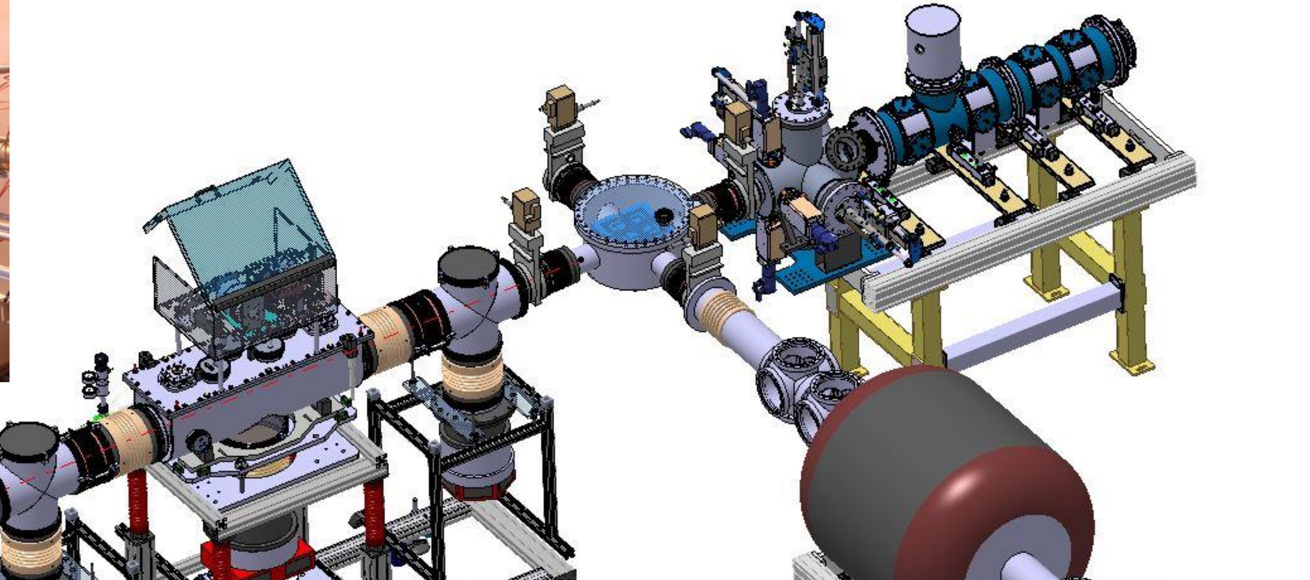
PIPERADE at DESIR

Double Penning trap for high-resolution separation at DESIR facility of SPIRAL2

Requirements

- Purify large samples (>10^4 ions)
- Mass resolution > 10^5
- Fast separation methods

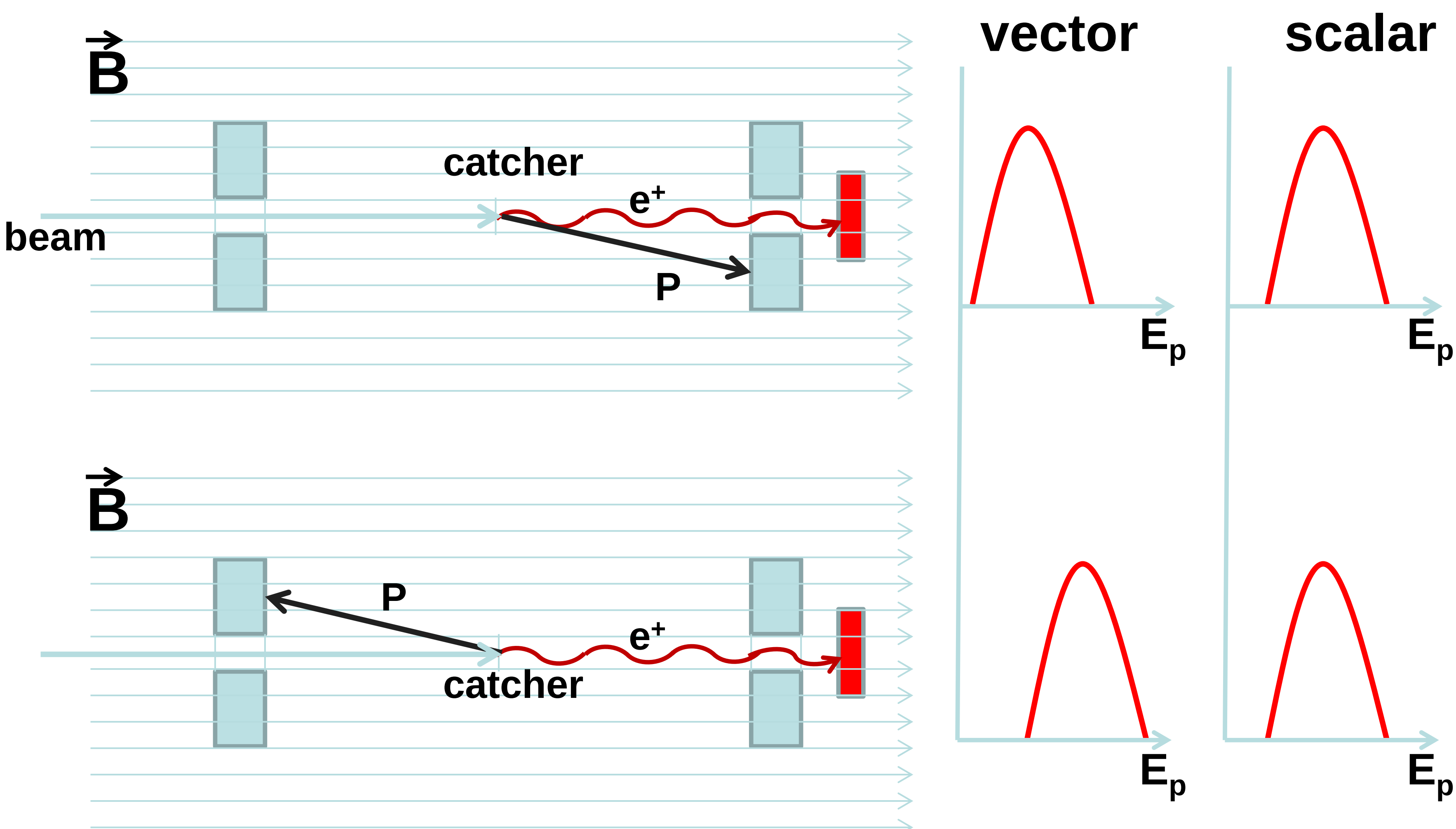
Test set-up at CENBG Bordeaux



Collaboration:
- CEN Bordeaux-Gradignan
- MPIK Heidelberg
- CSNSM Orsay
- GANIL Caen
- LPC Caen

P. Ascher et al., EPJ Web of Conf. 66, 11002 (2014)

βp: Positron – proton pile-up: Penning-trap magnet



nuclei: ^{20}Mg, ^{24}Si, ^{28}S, ^{32}Ar, ^{36}Ca…

Conclusions

- High-precision Germanium detector is available

  ➔ Tz = -1 nuclei can be addressed: ^{18}Ne, ^{26}Si, ^{30}S, ^{42}Ti

- Big potential for nuclear mirror decays

  ➔ need for high-precision GT-F mixing ratio measurements

- What about Tz = -2 nuclei? ^{32}Ar, ^{36}Ca…

- SPIRAL2/S3/DESIR: heaviest N=Z odd-odd nuclei

  ➔CVC tests over much broader range

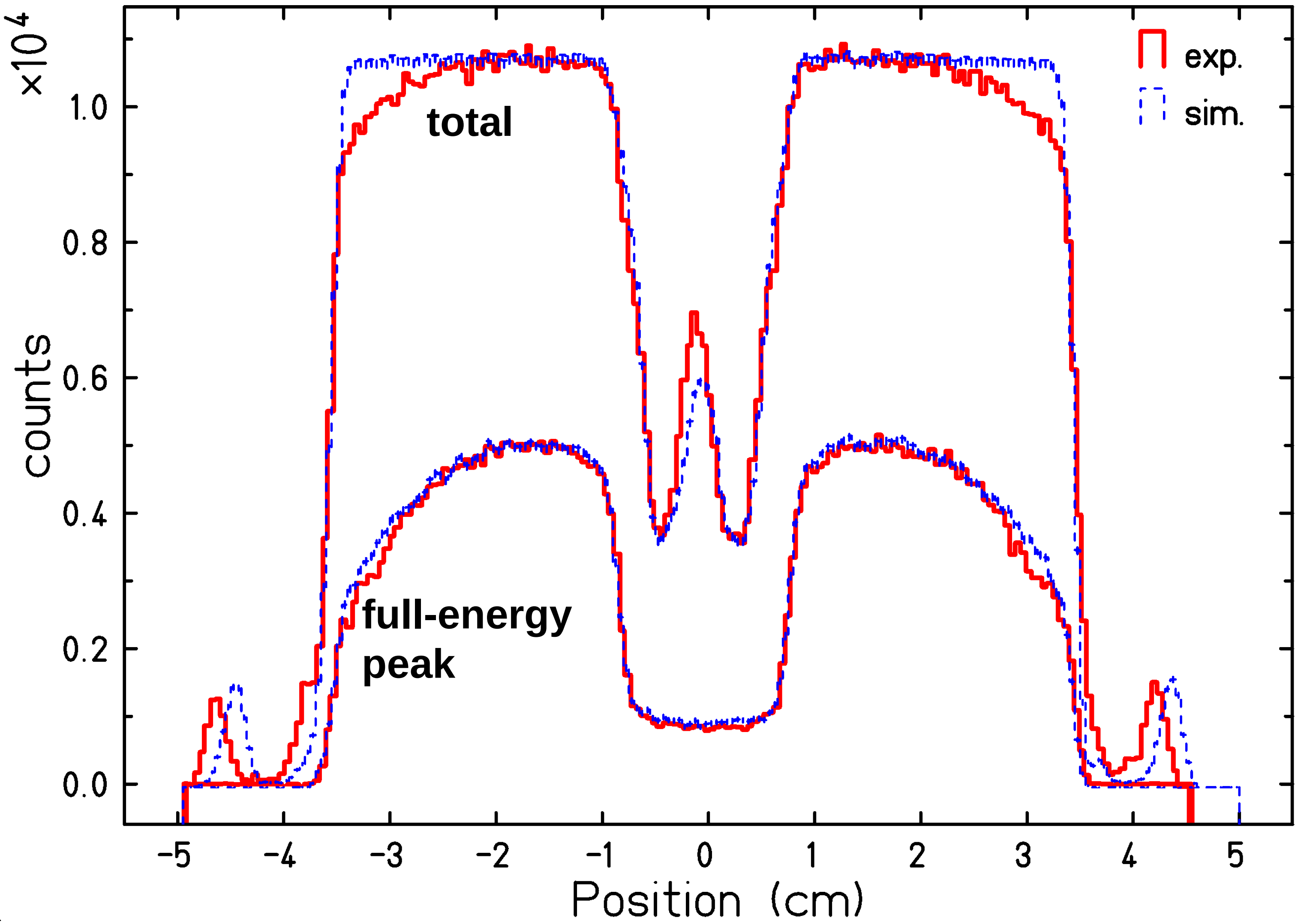
- β–ν correlation measurements in a supra-conducting magnet

- Improve theoretical corrections….

Thanks for your attention

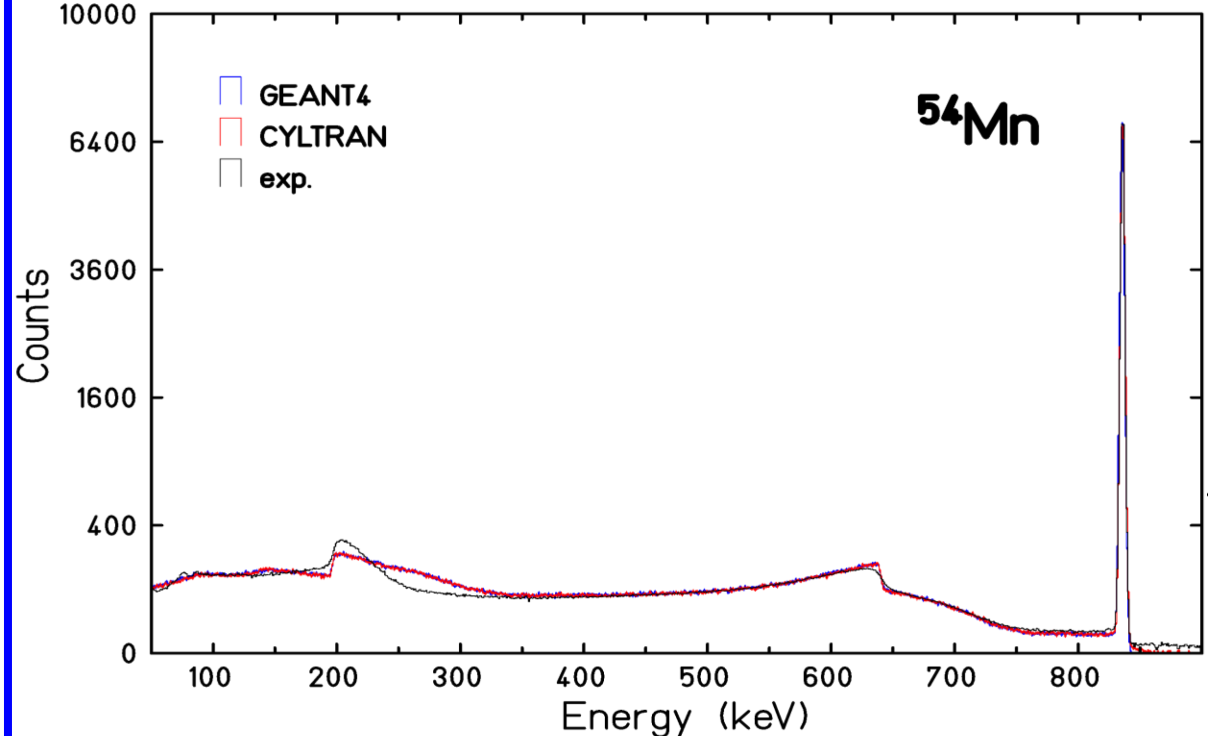
Collaborations: CENBG, IGISOL, GANIL, IPNO, IPHC

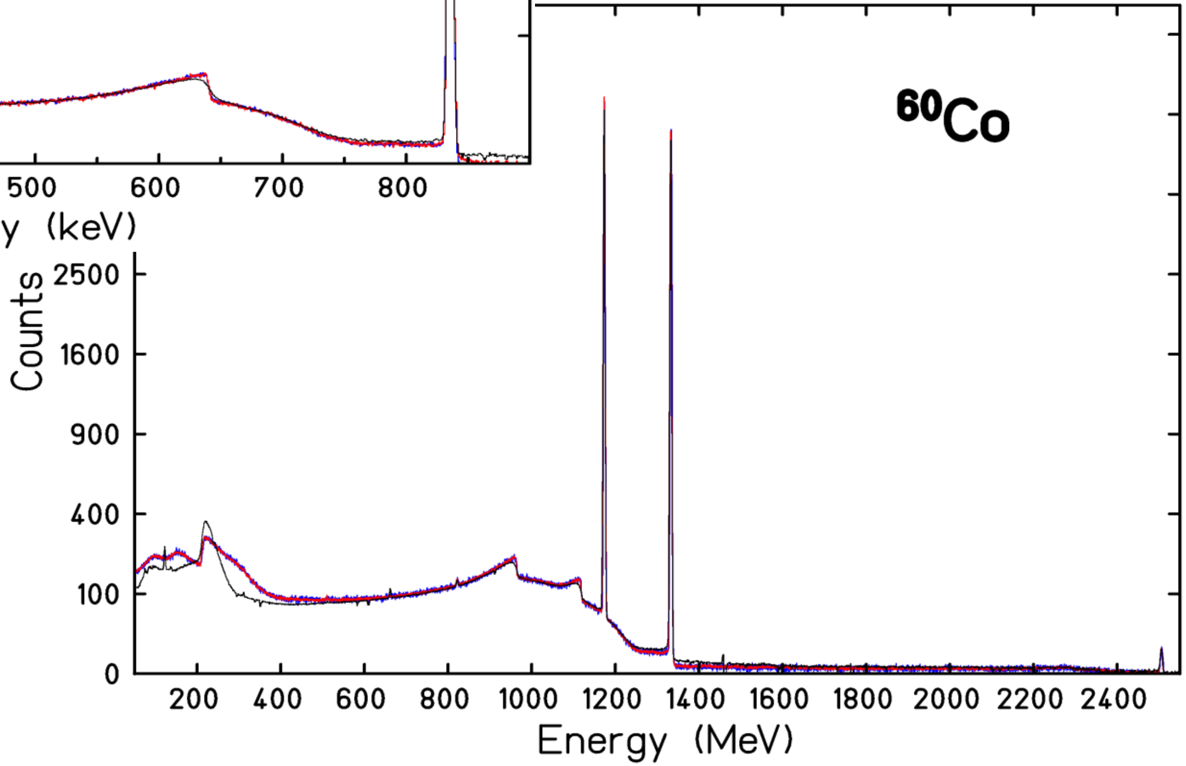
Front scan: 662 keV



- tilt….
- full-energy peak: excellent
- total spectrum: raisonable

Comparison experiment - simulations

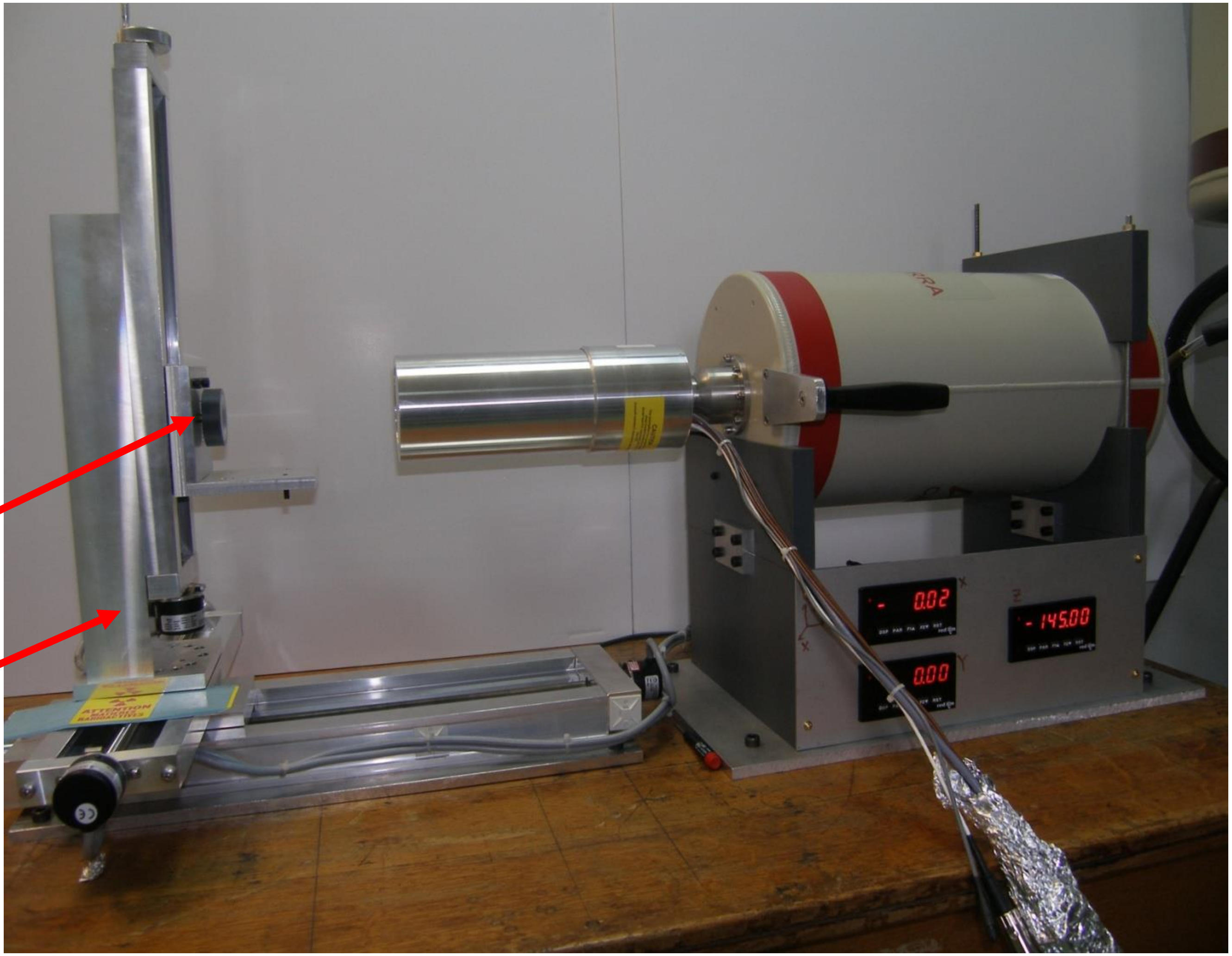




70% HP Germanium on precision test bench

Source position

high-precision X-Y-Z table



• all source measurements at exactly 15 cm from entrance window

➔ ➔ position precision of better than 10 μm