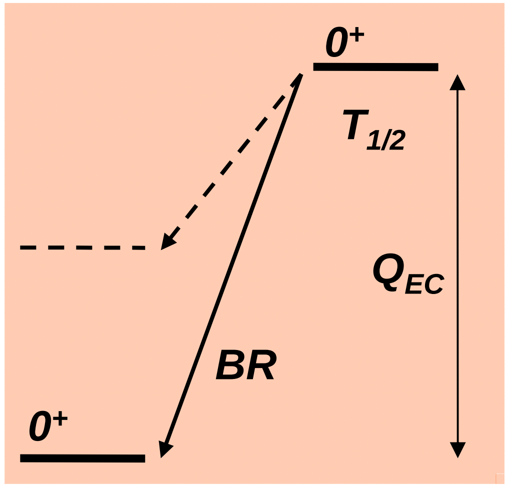
High-precision beta-decay studies to test the weak-interaction standard model

Bertram Blank
CEN Bordeaux-Gradignan

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

20th Colloque de GANIL, Amboise, October 15th – 20th , 2017

Nuclear beta decay



- in general: $$ft = \frac{k}{G_V^2 < M_F >^2 + G_A^2 < M_{GT} >^2}$$
- for $0^+ \rightarrow 0^+$ transitions: only vector current due to selection rules $$ft = \frac{k}{G_V^2 < M_F >^2}$$
- experimental quantities: precise measurements of masses of parent and daughter, half-life, branching ratio
- correct for other interactions:

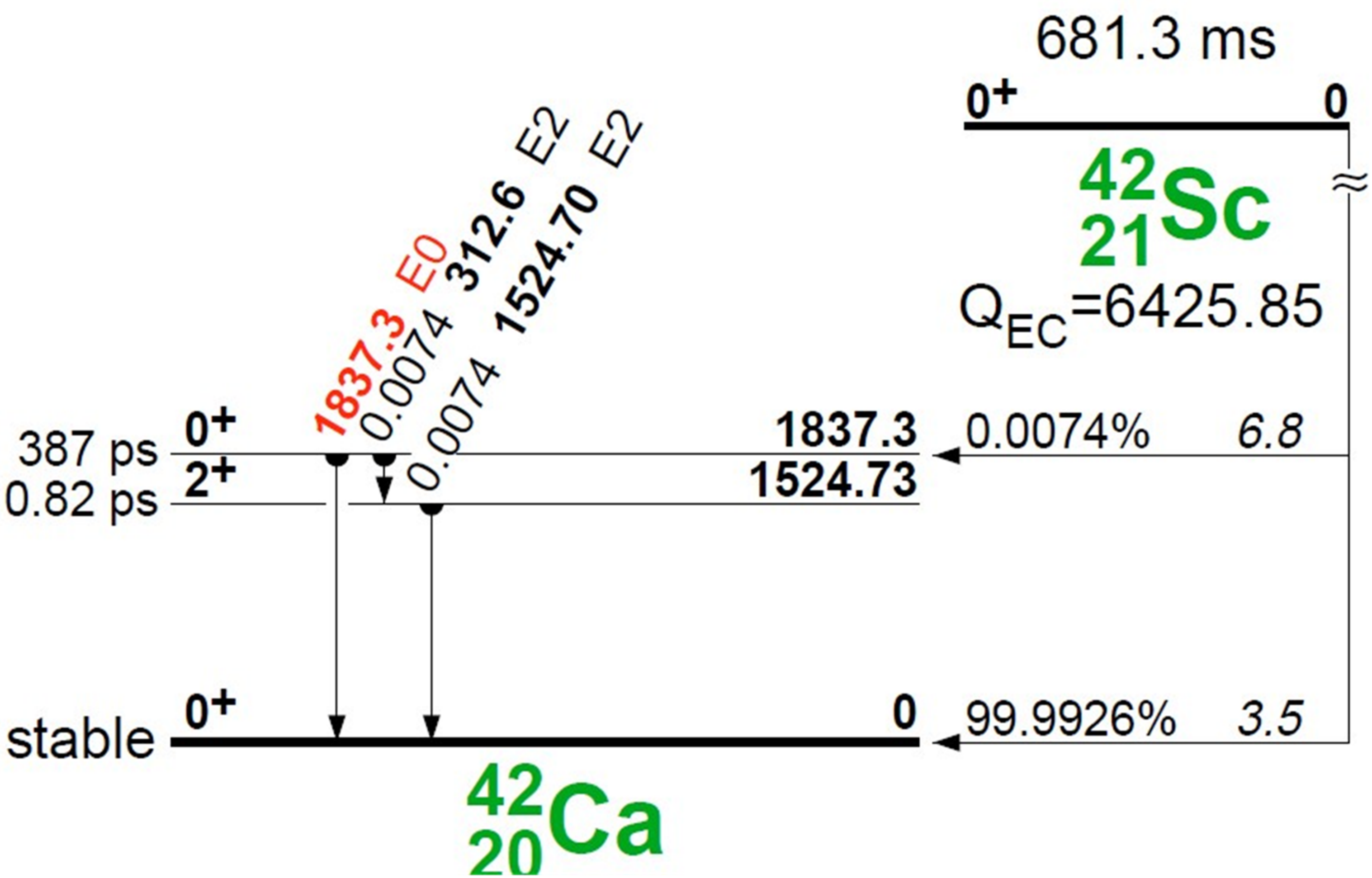
$$\mathcal{F}t = ft(1+\delta_R')(1+\delta_{NS}-\delta_C) = \frac{k}{G_V^2 < M_F >^2 (1+\Delta_R^V)}$$

$$\mathcal{F}t = ft(1+\delta_R')(1+\delta_{NS}-\delta_C) = \frac{k}{2G_V^2(1+\Delta_R^V)}$$ for T=1

- many transitions: validate corrections, test CVC, determine V_{ud} matrix element, test CKM matrix unitarity, test scalar contributions…

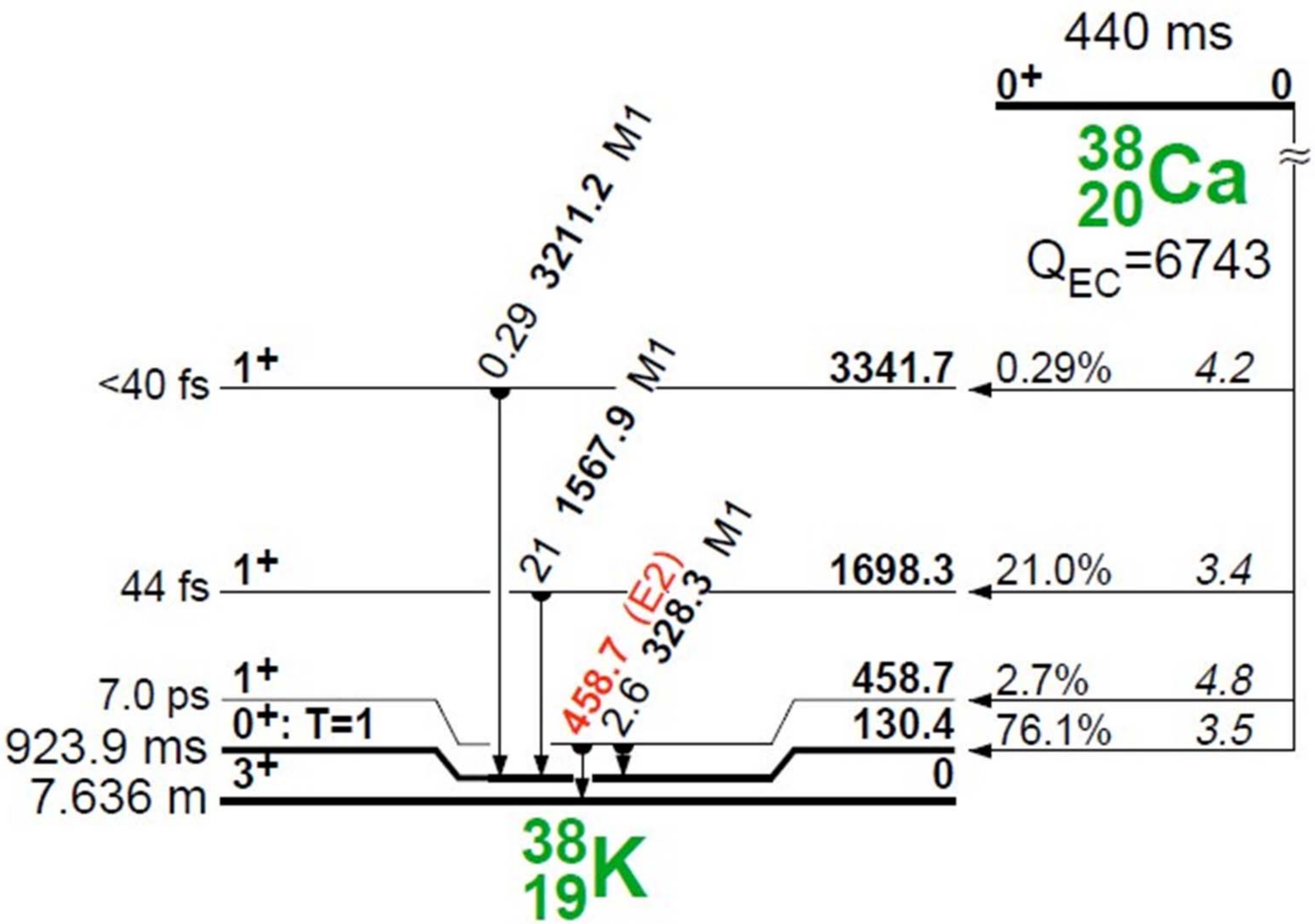
Germanium detector calibration

Super-allowed Fermi transitions for $T_z = 0$



- close to 100% g.s. to g.s. transition
- low precision needed for non-analog transitions

Super-allowed Fermi transitions for T_z = -1

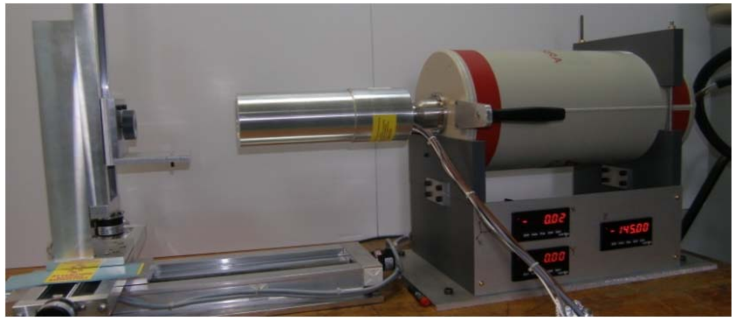


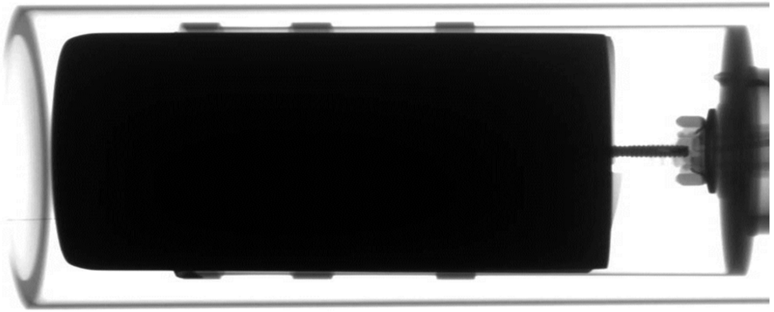
- many decay channels open
- strong non-analog transitions
- high precision of γ efficiency needed ➔ 0.1%

B. Blank et al., NIMA776 (2015) 34

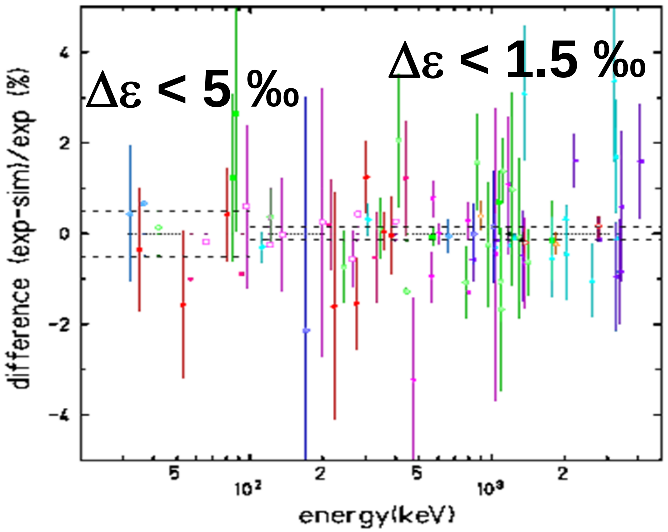
Calibration of germanium detector

- $\Delta\varepsilon_{rel}$ = 0.1%, $\Delta\varepsilon_{abs}$ = 0.15%
- calibration programme of a HP Ge detector:
  - x-ray photography of detector
  - scan of the crystal at CSNSM
  - source measurements
  - MC simulations: CYLTRAN, GEANT4

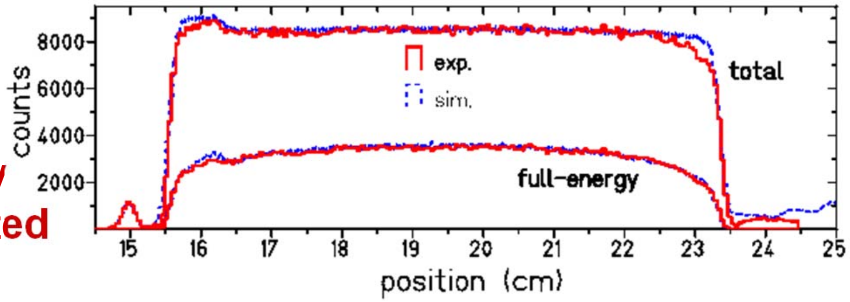


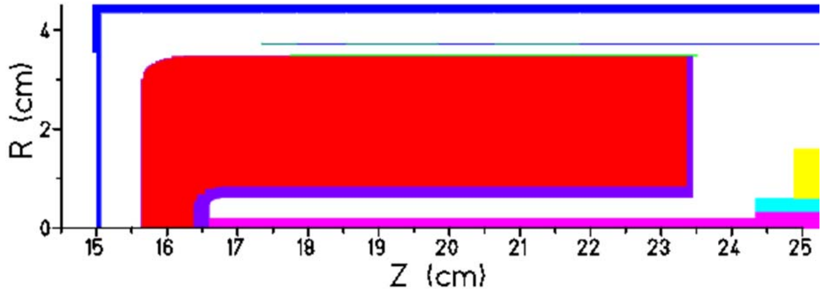


X-ray photography



Scan at CSNSM ^{137}Cs strongly collimated





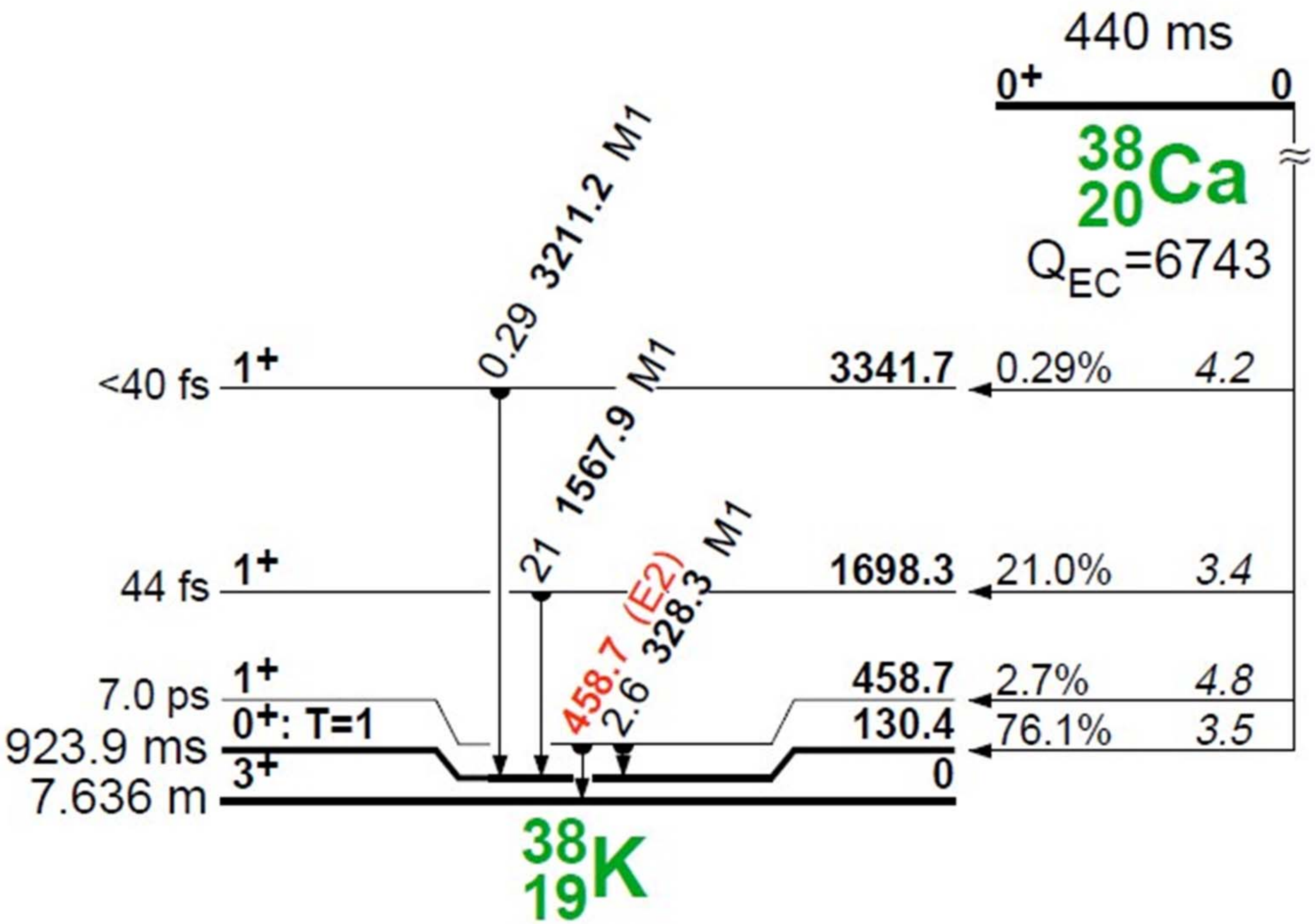
Relative detection efficiency:
^{24}Na, ^{27}Mg, ^{48}Cr, ^{56}Co, ^{60}Co, ^{66}Ga, ^{75}Se, ^{88}Y, ^{133}Ba, ^{134}Cs, ^{137}Ce, ^{152}Eu, ^{180}Hf, ^{207}Bi

Peak/total: ^{22}Na, ^{41}Ar, ^{51}Cr, ^{54}Mn, ^{57}Co, ^{58}Co, ^{65}Zn, ^{85}Sr

…ISOLDE, IPNO sources

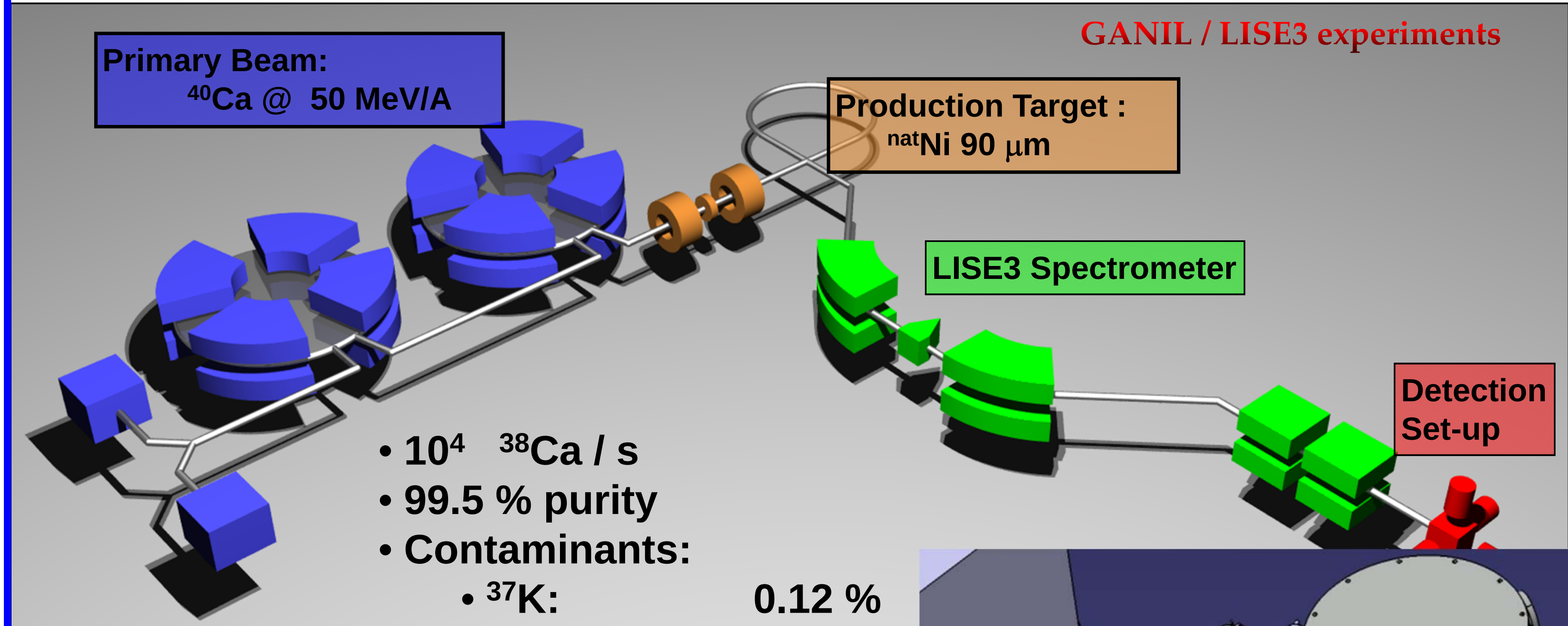
0^+ - 0^+ β decay: ^{38}Ca

Super-allowed Fermi transitions for T_z = -1

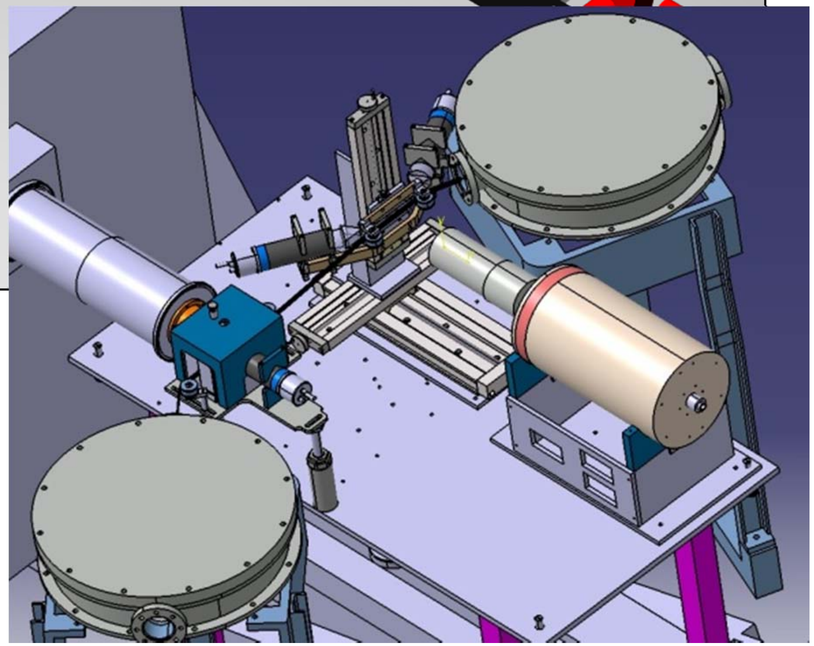


- many decay channels open
- strong non-analog transitions
- high precision of γ efficiency needed ➔ 0.1%

^{38}Ca production at GANIL/LISE3

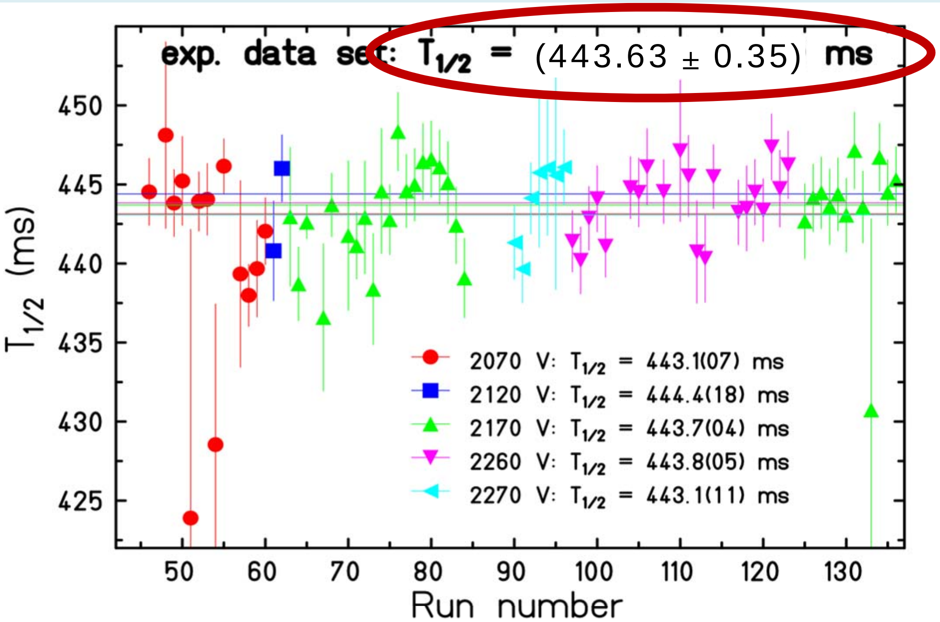


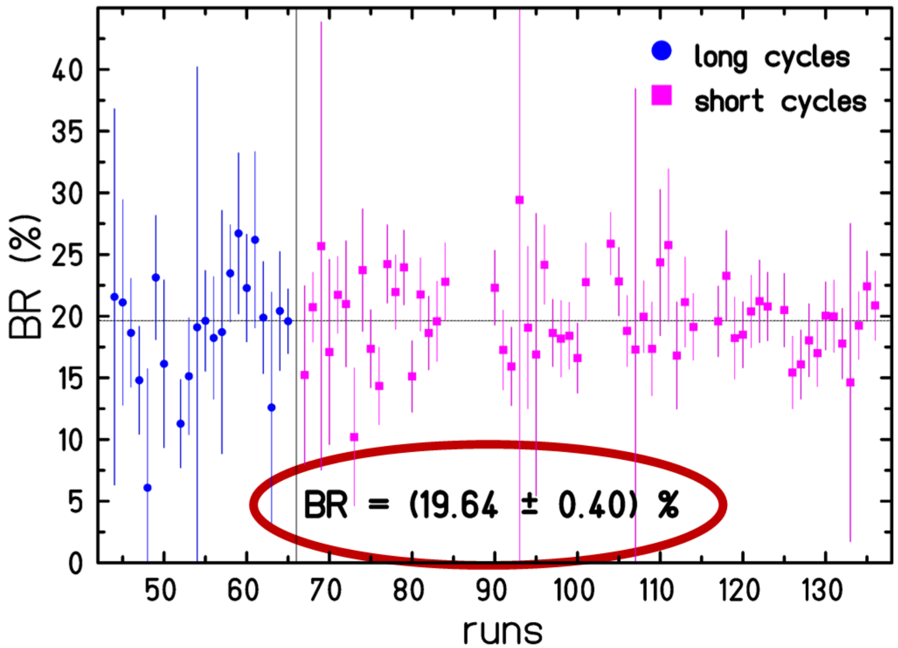
- 10^4 ^{38}Ca / s
- 99.5 % purity
- Contaminants:
  - ^{37}K: 0.12 %
  - ^{36}Ar (stable): 0.11 %
  - ^{35}Cl (stable): 0.09 %
  - ^{34}S (stable): 0.14 %



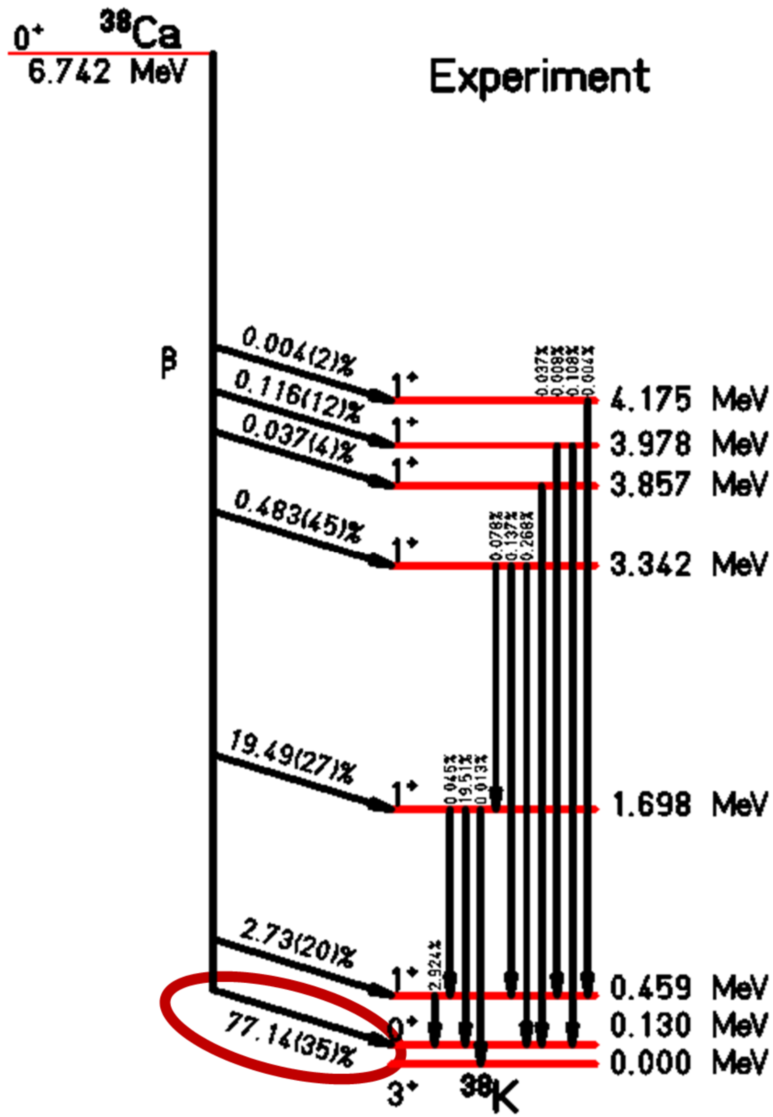
^{38}Ca branching ratios and half-life

B. Blank et al., EPJA 51 (2015) 8





Present work and Anderson et al.



^{38}Ca: result

B. Blank et al., EPJA 51 (2015) 8

- **half-life:**

Kavanagh *et al.* [26]	Gallmann *et al.* [27]	Zioni *et al.* [28]	Wilson *et al.* [29]	Blank *et al.* [20]	Park *et al.* [5]	Present	Average
470(20)	439(12)	450(70)	430(12)	443.8(19)	443.77(36)	443.63(35)	443.70(25)

➔➔ **443.70(25) ms**

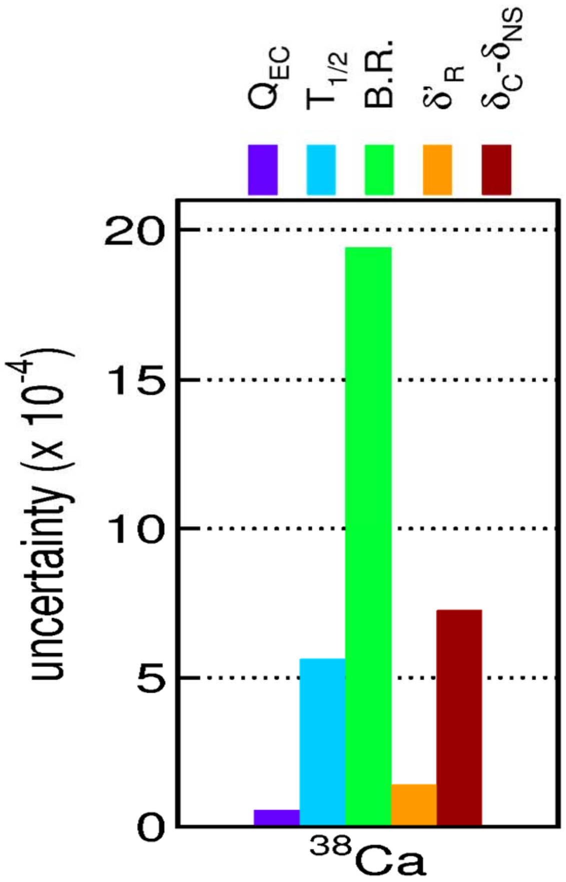
- **BR (0^+ — 0^+):** **present:** **77.09(35) %**
  Park et al.: **77.28(16) %**

➔➔ **77.25(15) %**

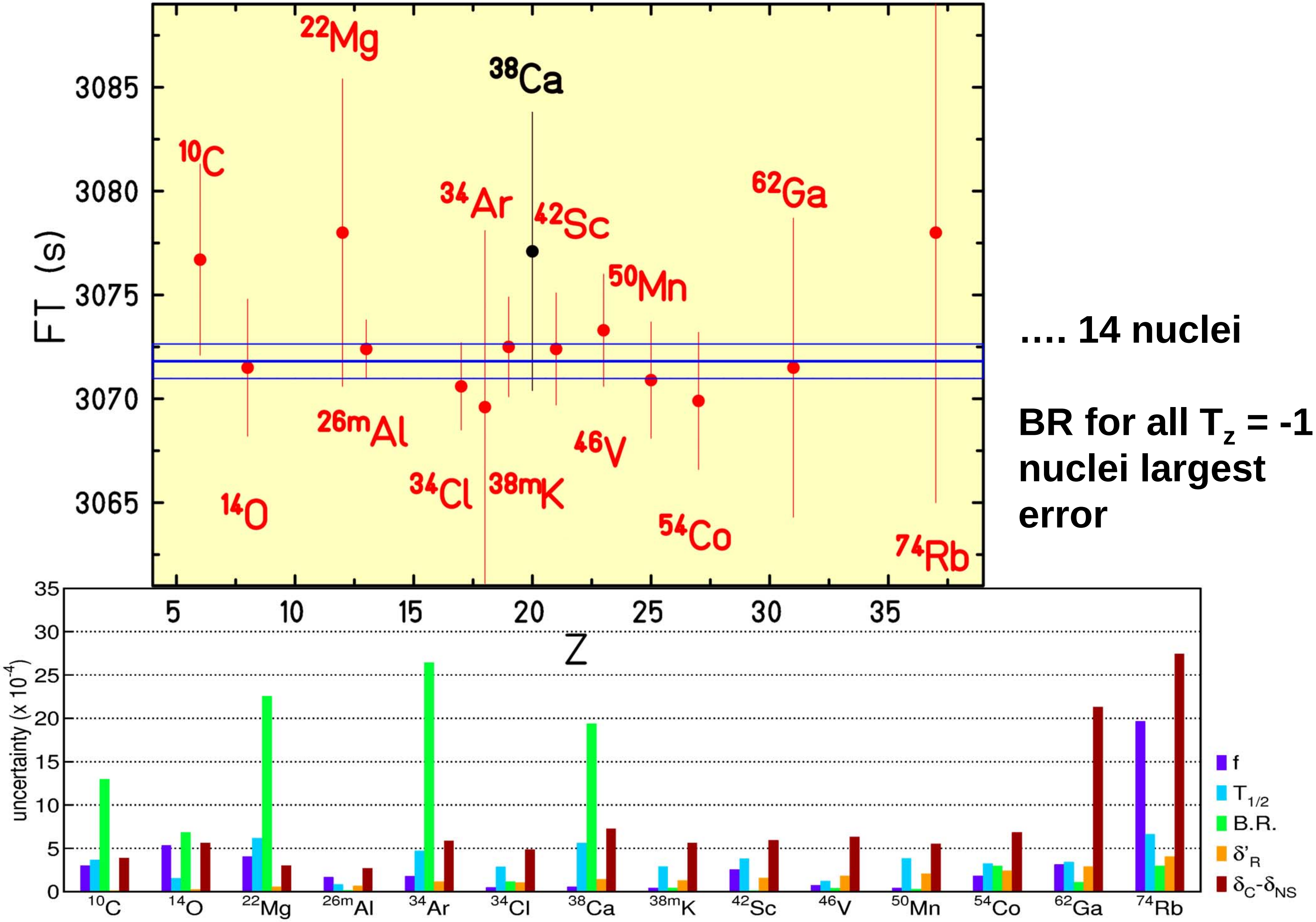
- **Q value:** **Eronen et al.:** **6612.11(7) keV**

➔ **ft = 3063.3(62) s**

➔ **$\mathcal{F}$t = 3077.5(67) s**



^{38}Ca: result

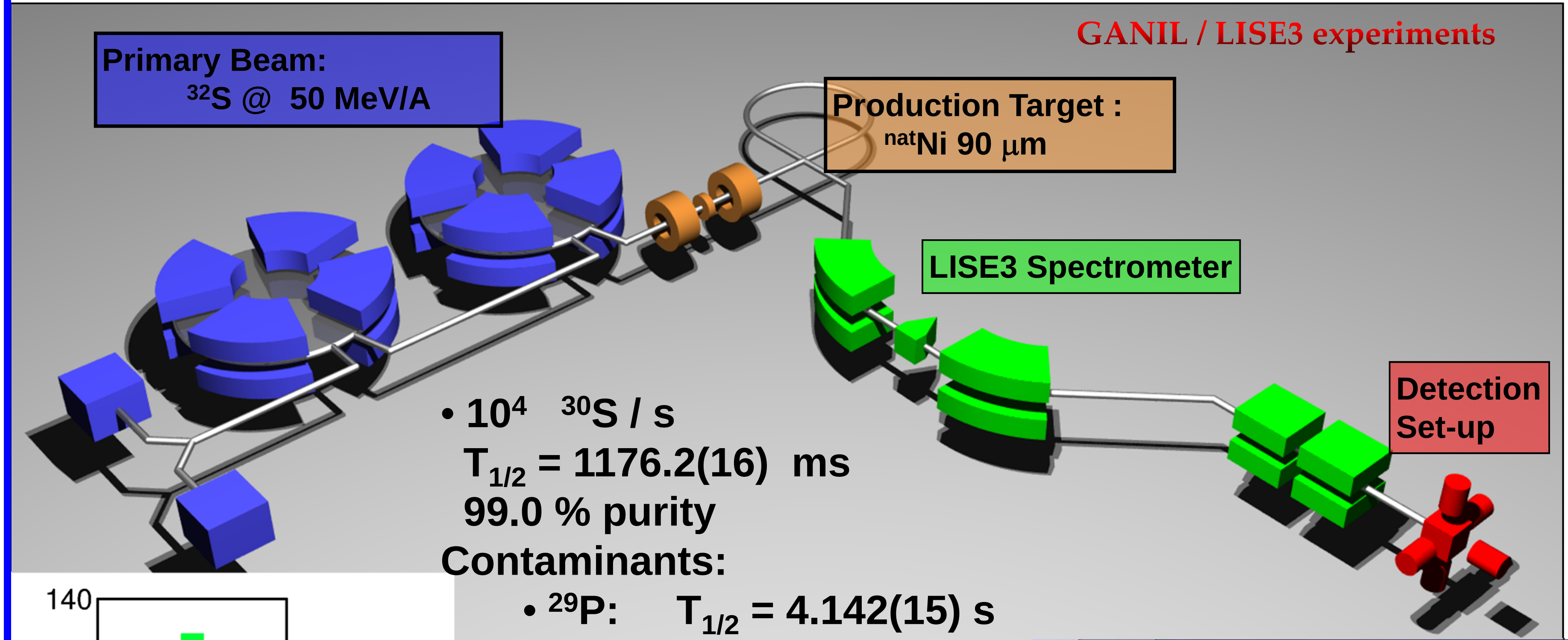


…. 14 nuclei

BR for all T_z = -1 nuclei largest error

$0^+ - 0^+$ β decay: ^{30}S

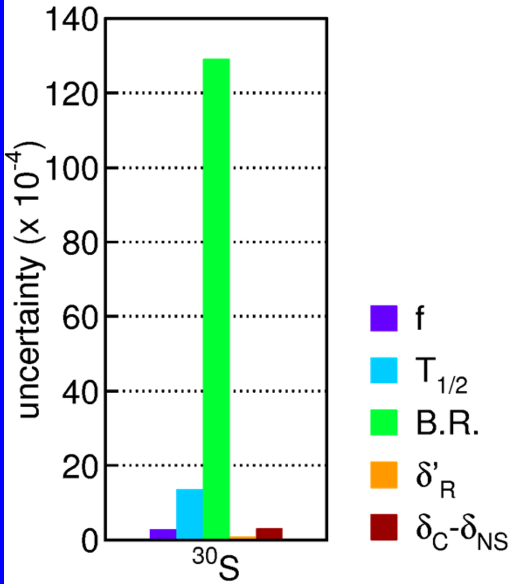
^{30}S production at GANIL / LISE3

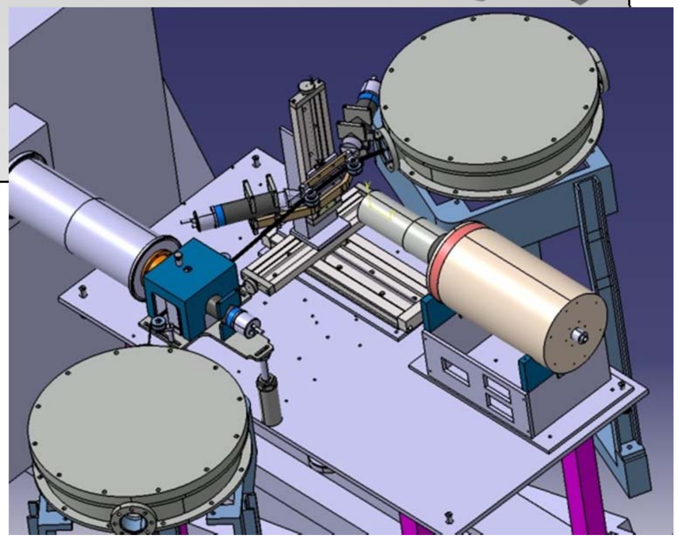


- 10^4 ^{30}S / s
  $T_{1/2}$ = 1176.2(16) ms
  99.0 % purity

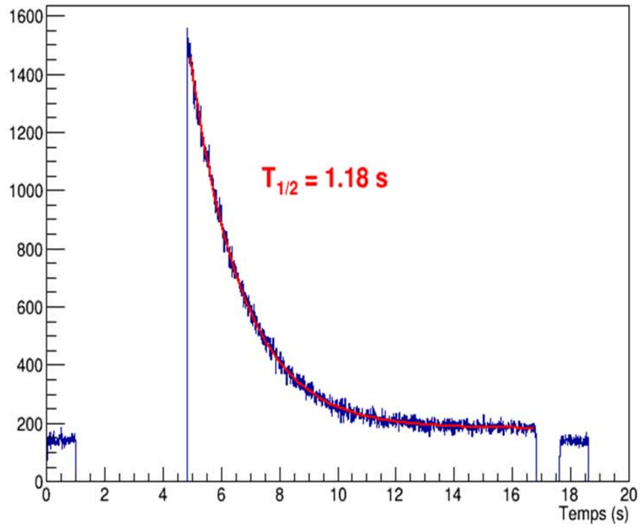
Contaminants:

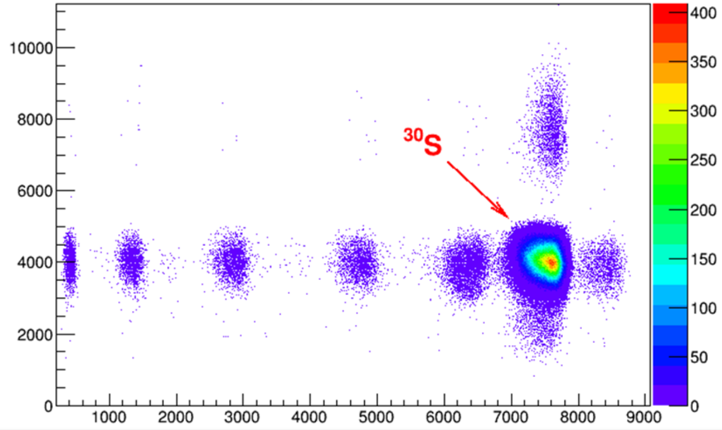
- ^{29}P: $T_{1/2}$ = 4.142(15) s
- ^{28}Si: stable
- ^{27}Al: stable
- ^{26}Mg: stable



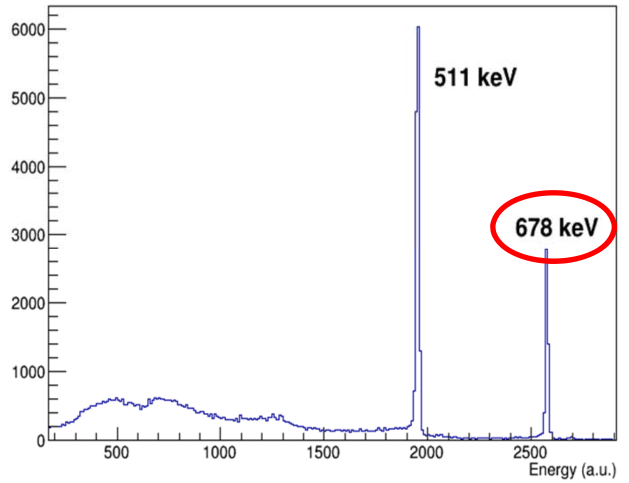


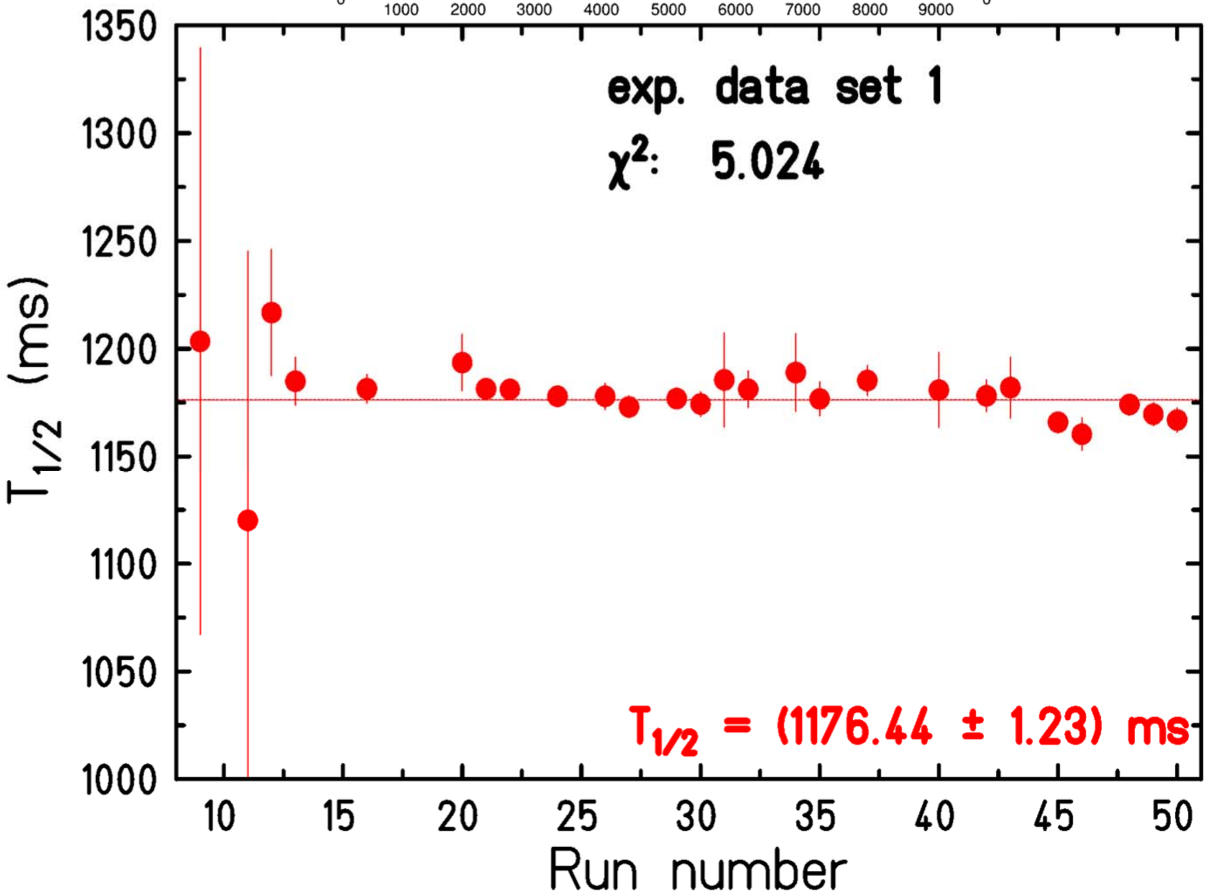
^{30}S: very preliminary result





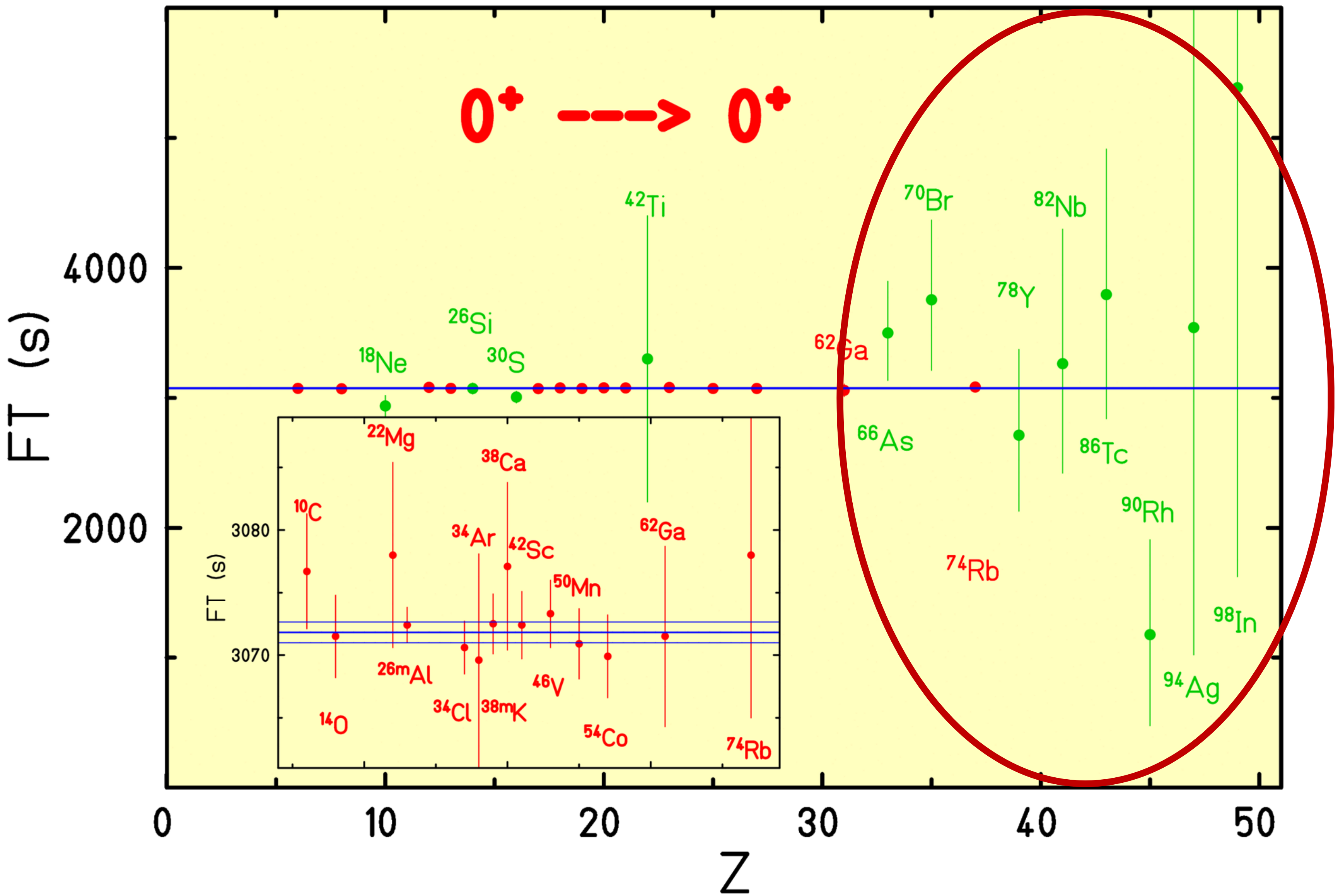
E691 - Ge spectrum





Future measurements at GANIL

Heavy T_z = 0 nuclei



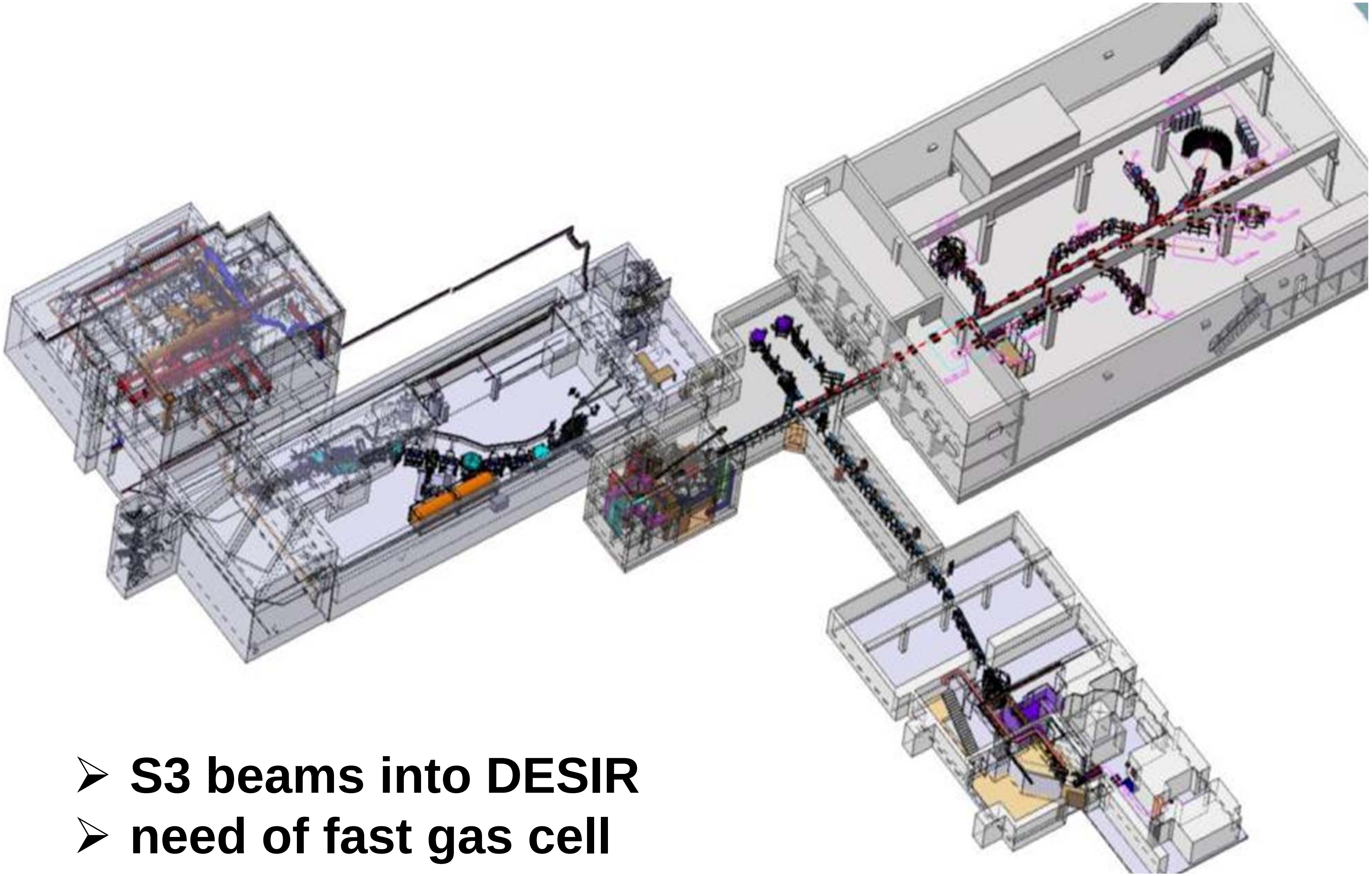
➢ **test CVC on a much larger basis**

• • • Heavy T_z = 0 nuclei: production at S3-LEB

	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**

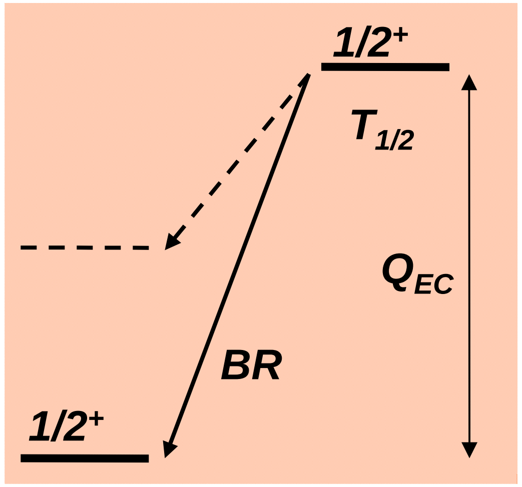
S3-LEB + DESIR



- ➢ **S3 beams into DESIR**
- ➢ **need of fast gas cell**
- ➢ **purification with HRS + MR-TOF-MS or PIPERADE**
- ➢ **best place world-wide to do this**

Mirror β decays

• • • Nuclear mirror beta decay



• in general: $$\mathrm{ft} = \frac{\mathrm{k}}{\mathrm{G_V^2} < \mathrm{M_F} >^2 + \mathrm{G_A^2} < \mathrm{M_{GT}} >^2}$$

• for **mirror transitions**: vector and axial-vector currents

• experimental quantities: precise measurements of masses of parent and daughter, half-life, branching ratio, **mixing ratio**

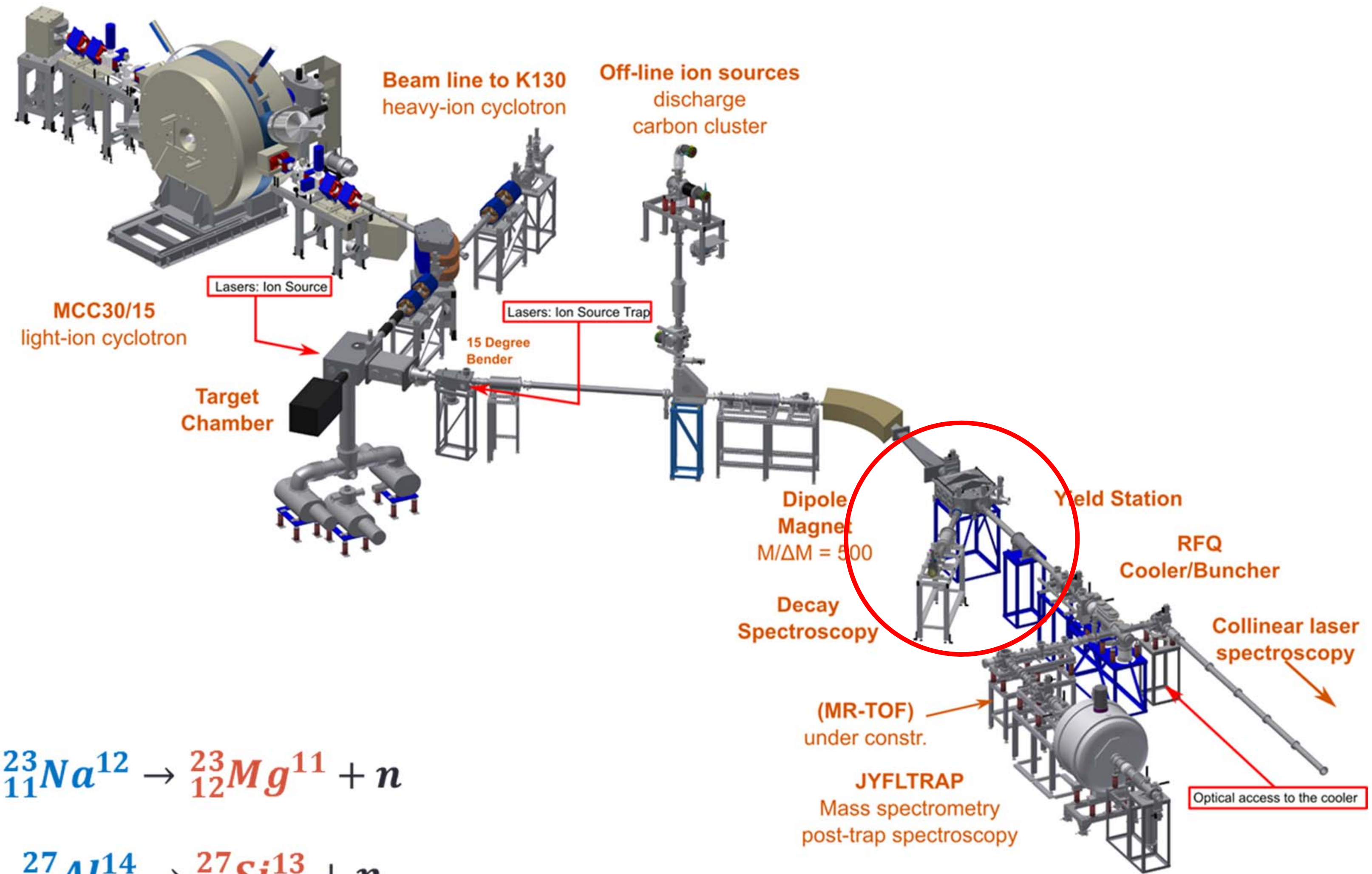
• correct for other interactions:

$$\mathcal{F}\mathrm{t_0} = \mathrm{ft}(1+\delta_R')(1+\delta_{NS}-\delta_C)(1+\frac{f_A}{f_V}\rho^2) = \frac{\mathrm{k}}{\mathrm{G_V^2} < \mathrm{M_F} >^2 (1+\Delta_R^V)}$$

• many transitions: validate corrections, test **CVC**, determine **V_{ud}** matrix element, test **CKM** matrix unitarity…

Mirror β decays: ^{23}Mg, ^{27}Si, ^{37}K

Experiment JYFL2013: ^{23}Mg & ^{27}Si

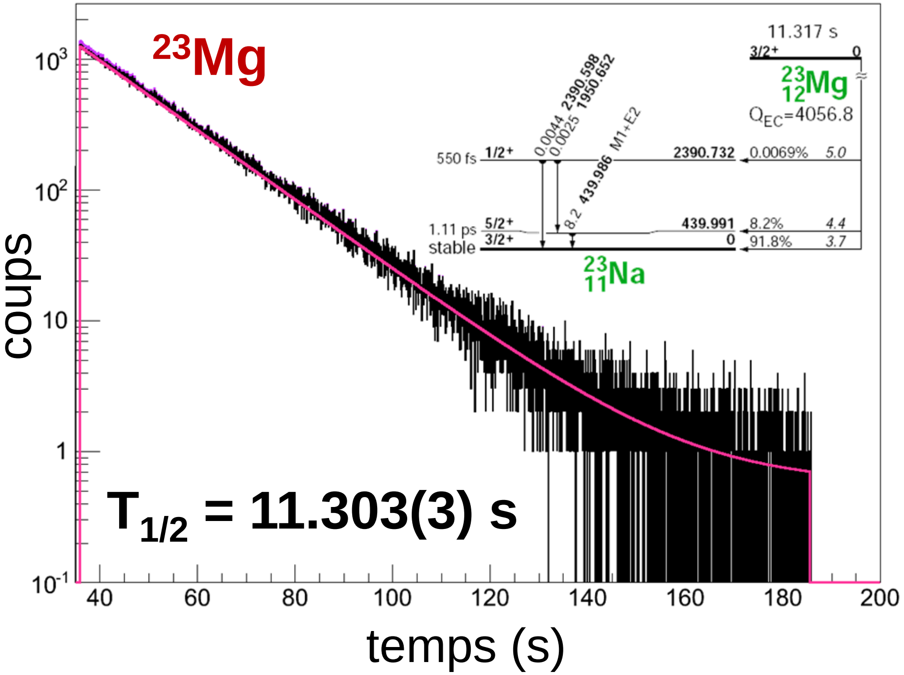


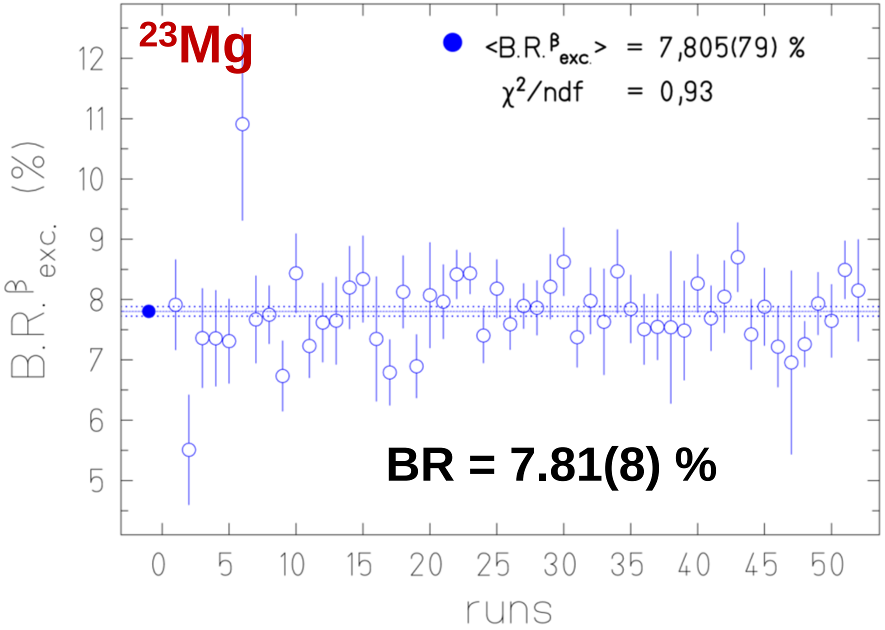
$$p + {}^{23}_{11}Na^{12} \rightarrow {}^{23}_{12}Mg^{11} + n$$

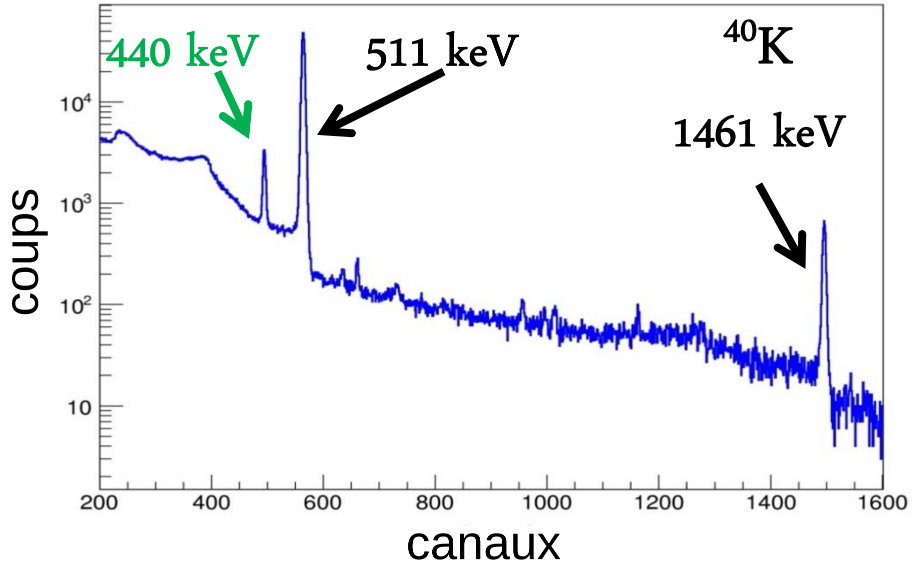
$$p + {}^{27}_{13}Al^{14} \rightarrow {}^{27}_{14}Si^{13} + n$$

Results of ^{23}Mg and ^{27}Si

C. Magron et al., EPJA 53 (2017 55







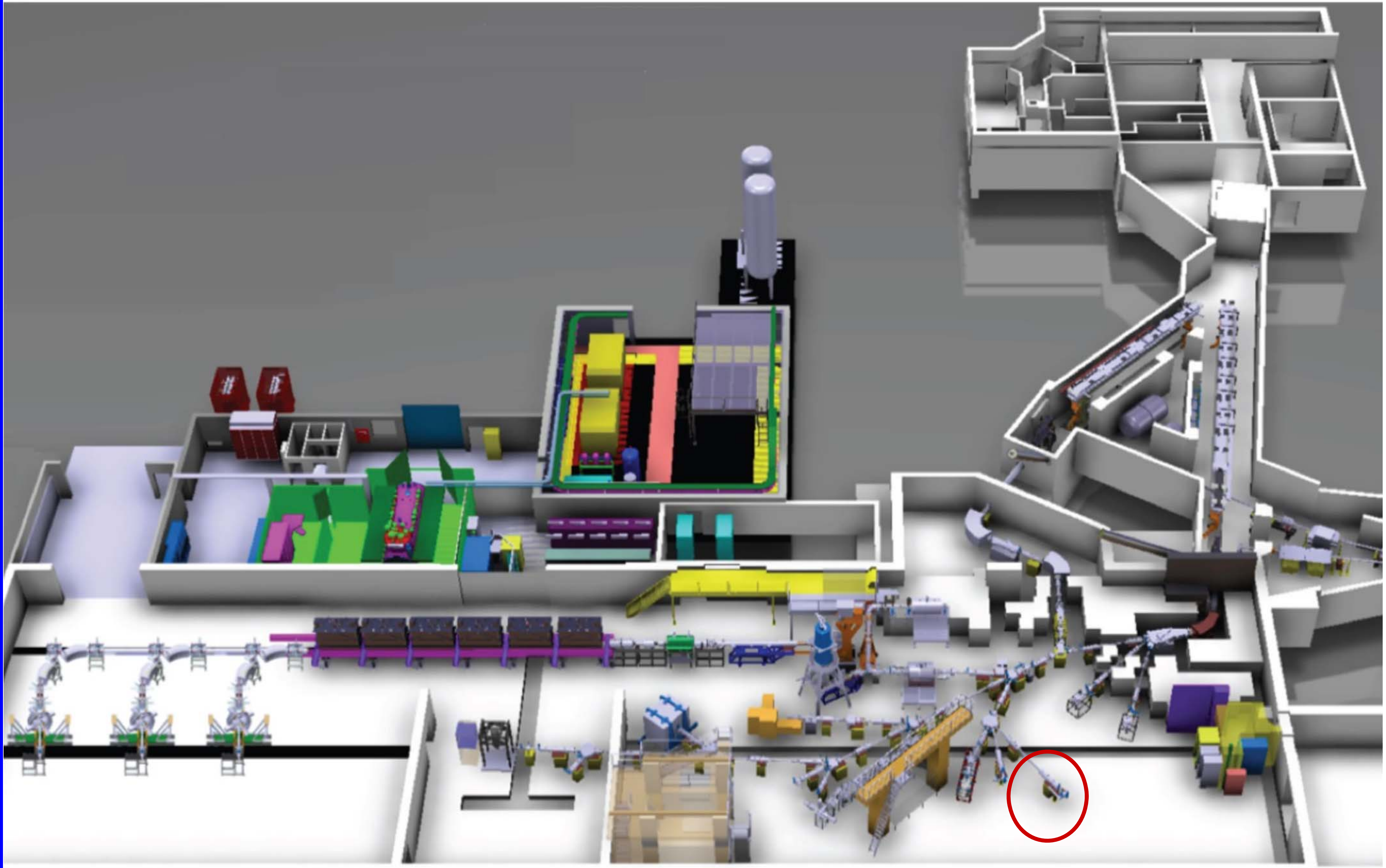
^{23}Mg:

- $T_{1/2}$ = 11.303(3)s Lit. = 11.330(8)s
- BR = 7.81(8) % Lit. = 8.13(12) %
  - ➔ BR_{sa} = 92.07(14) %

^{27}Si:

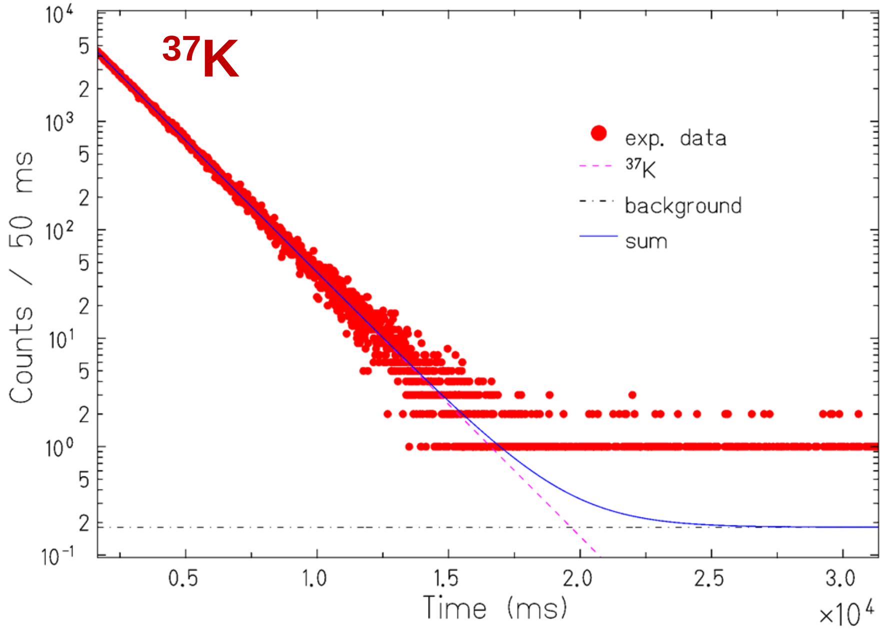
- $T_{1/2}$ = 4.112(2)s Lit. = 4.135(15)s
- BR = 0.164(28) % Lit. = 0.151(9) %
  - ➔ BR_{sa} = 99.74(2) %

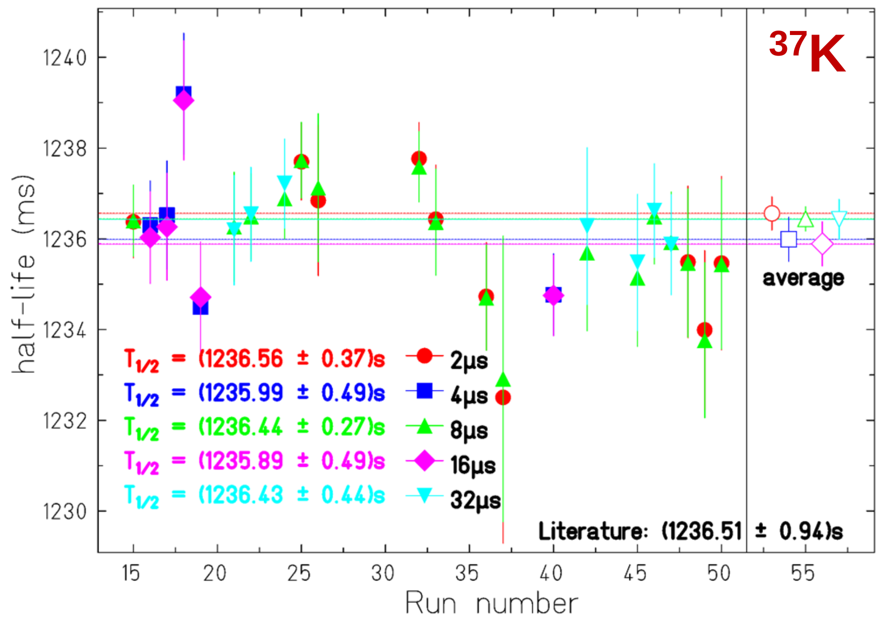
ISOLDE

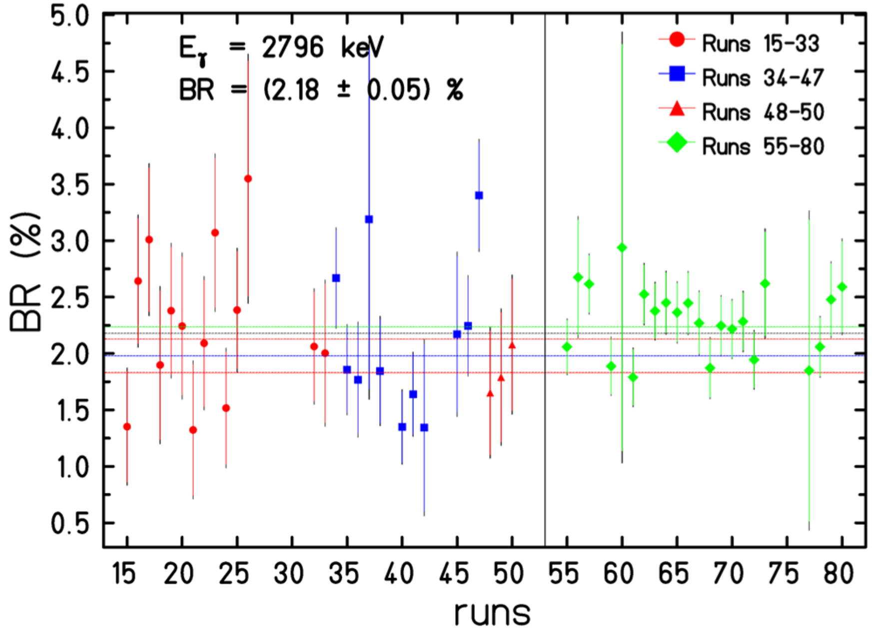


• • • Nuclear mirror beta decay: ^{37}K at ISOLDE

T. Kurtukian Nieto et al.



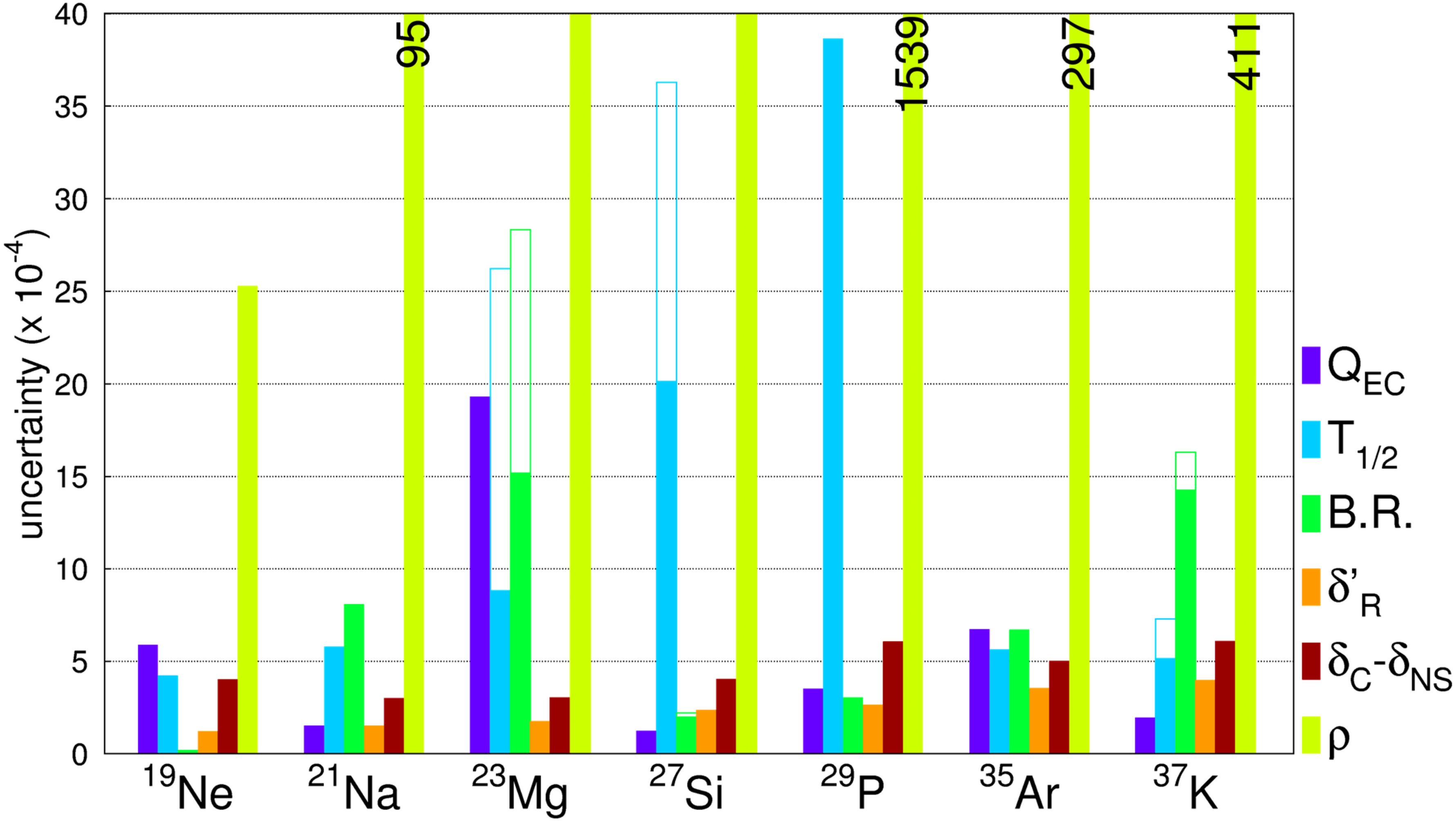




$T_{1/2}$ = 1.23635(88) s

BR = 97.96(14) %

Nuclear mirror beta decay: improvements



Recent measurements at GANIL:

- **$T_{1/2}$: ^{17}F, ^{19}Ne, ^{21}Na, ^{33}Cl**
- **ρ: ^{19}Ne, ^{35}Ar**

Conclusions

- High-precision Germanium detector is available

  ➔ Tz = -1 nuclei can be addressed: ^{18}Ne, ^{22}Mg, ^{26}Si, ^{42}Ti

- Big potential for nuclear mirror decays

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

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

  ➔CVC tests over much broader range

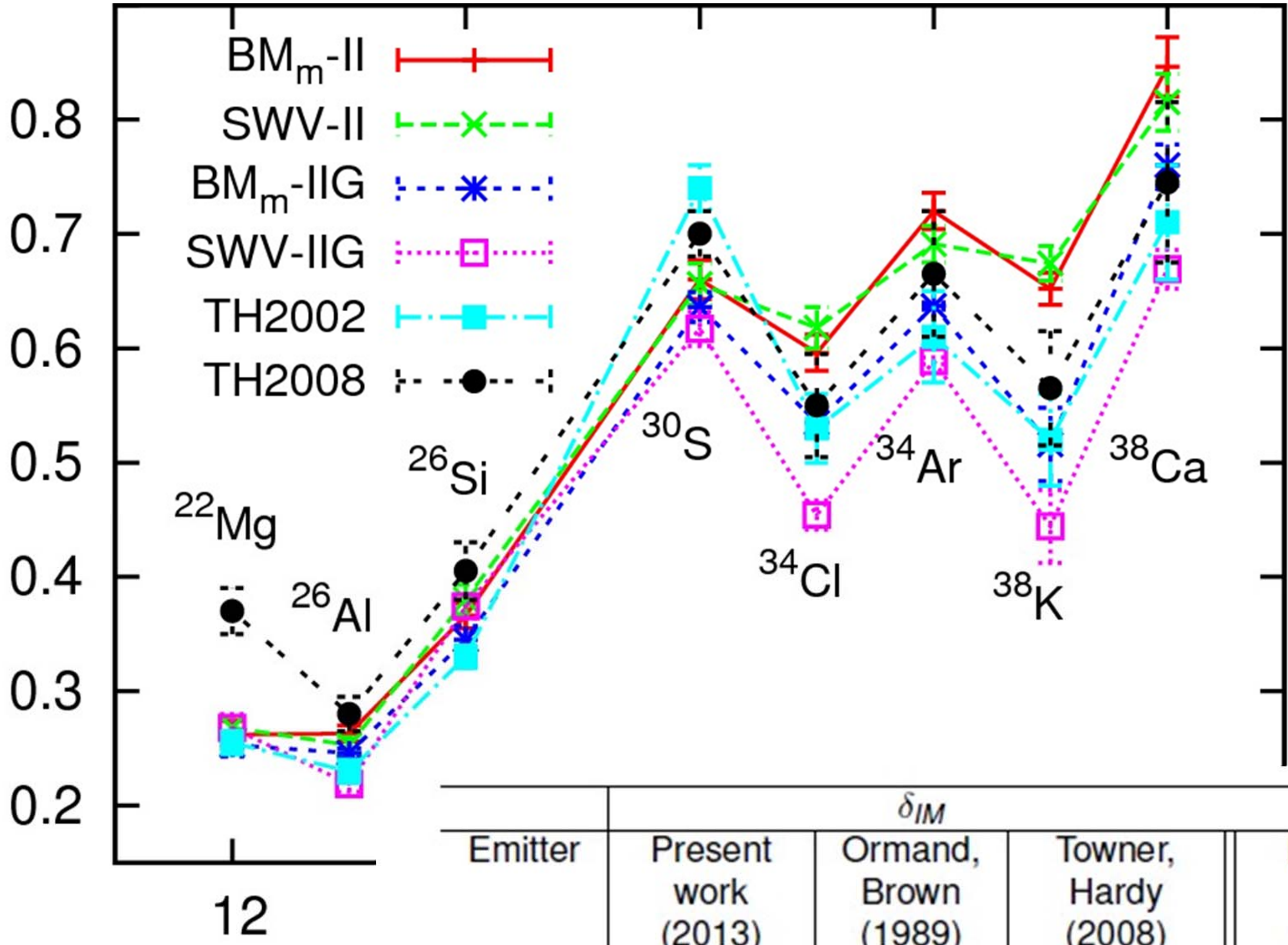
- Search for physics beyond standard model: ^{10}C

- Improve theoretical corrections…. work on-going at CENBG

  (N. Smirnova et al.)

Theoretical corrections (*sd* shell)

N. Smirnova, Y. Lam, L. Xayavong et al.



Emitter	δ_{IM} Present work (2013)	δ_{IM} Ormand, Brown (1989)	δ_{IM} Towner, Hardy (2008)	Ft Present work (2013)	Ft Towner, Hardy (2010)
^{22}Mg	0.0216(9)	0.017	0.010 (10)	3077.6(72)	3077.6(74)
^{26m}Al	0.0120(8)	0.01	0.025 (10)	3072.9(13)	3072.4(14)
^{26}Si	0.046(0)	0.028	0.022 (10)		
^{30}S	0.027(1)	0.056	0.137 (20)		
^{34}Cl	0.0363(5)	0.06	0.091 (10)	3072.6(21)	3070.6(21)
^{34}Ar	0.0060(4)	0.008	0.023 (10)	3070.7(84)	3069.6(85)

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Thanks for your attention

Collaborations: CENBG, GANIL, TRIUMF, Univ. of Guelph, JYFL