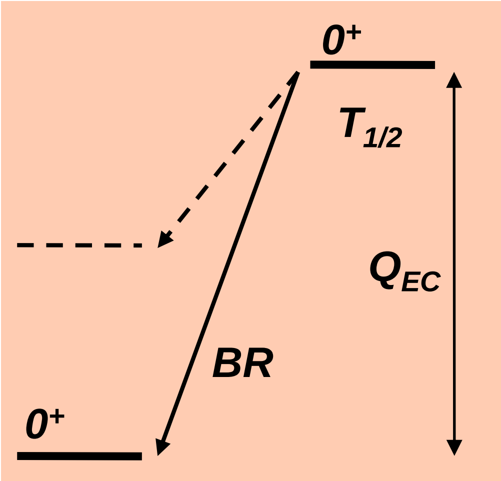
Experimental challenges in extracting the V_{ud} matrix element

Bertram Blank
CEN Bordeaux-Gradignan

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

Solvay Workshop: Beyond the Standard Model with Neutrinos and Nuclear Physics
November 29 – December 1, 2017

Nuclear beta decay



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

- for **0⁺ → 0⁺ transitions**: only vector current due to selection rules

$$\mathrm{ft} = \frac{k}{G_v^2 < M_F >^2}$$

- experimental quantities: precise measurements of masses of parent and daughter, half-life, branching ratio ➔ 0.1 %

- correct for other interactions:

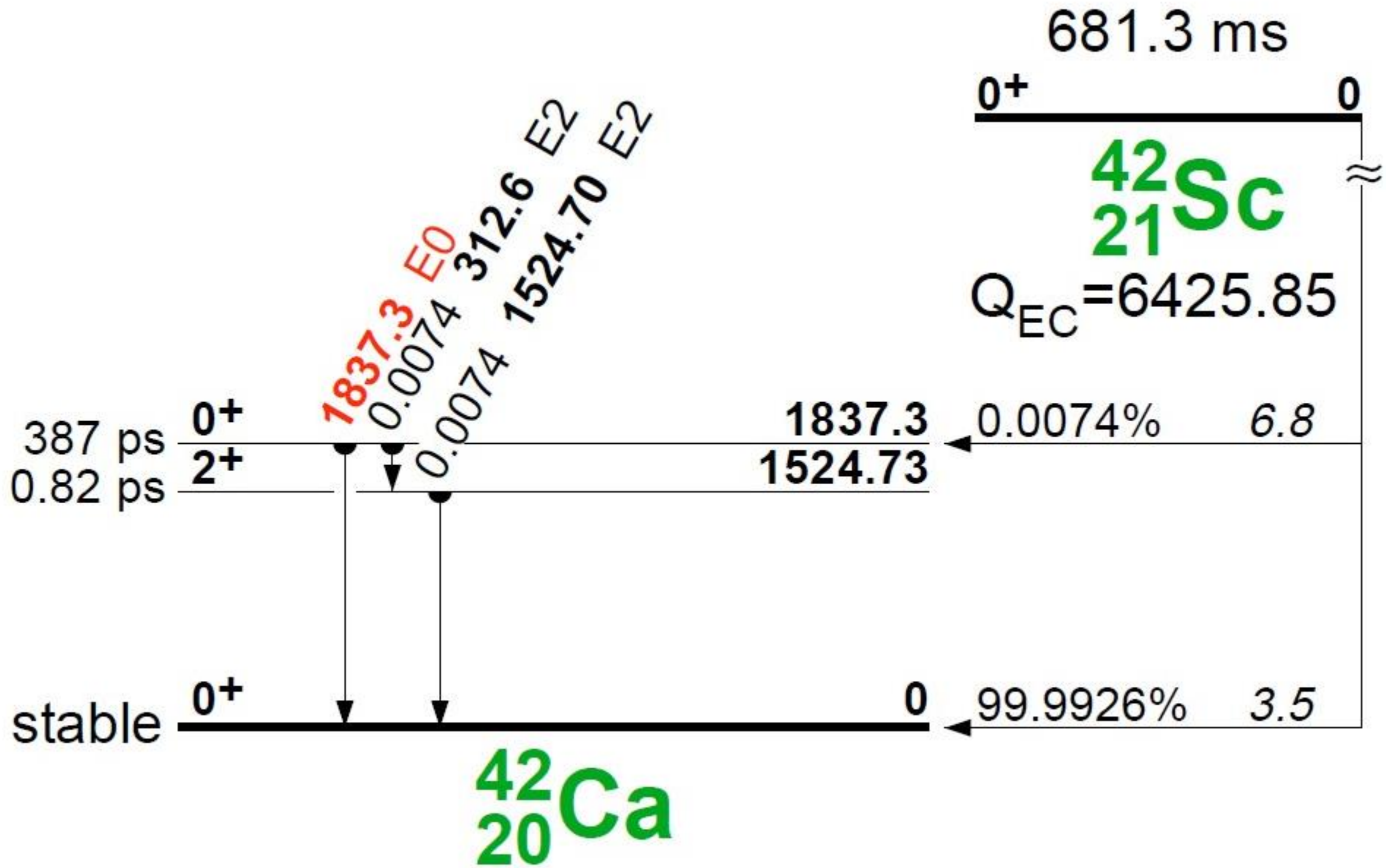
$$\mathcal{F}t = \mathrm{ft}(1+\delta'_R)(1+\delta_{NS}-\delta_C) = \frac{k}{G_v^2 < M_F >^2 (1+\Delta_R^v)}$$

$$\mathcal{F}t = \mathrm{ft}(1+\delta'_R)(1+\delta_{NS}-\delta_C) = \frac{k}{2G_v^2(1+\Delta_R^v)}$$ for T=1

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

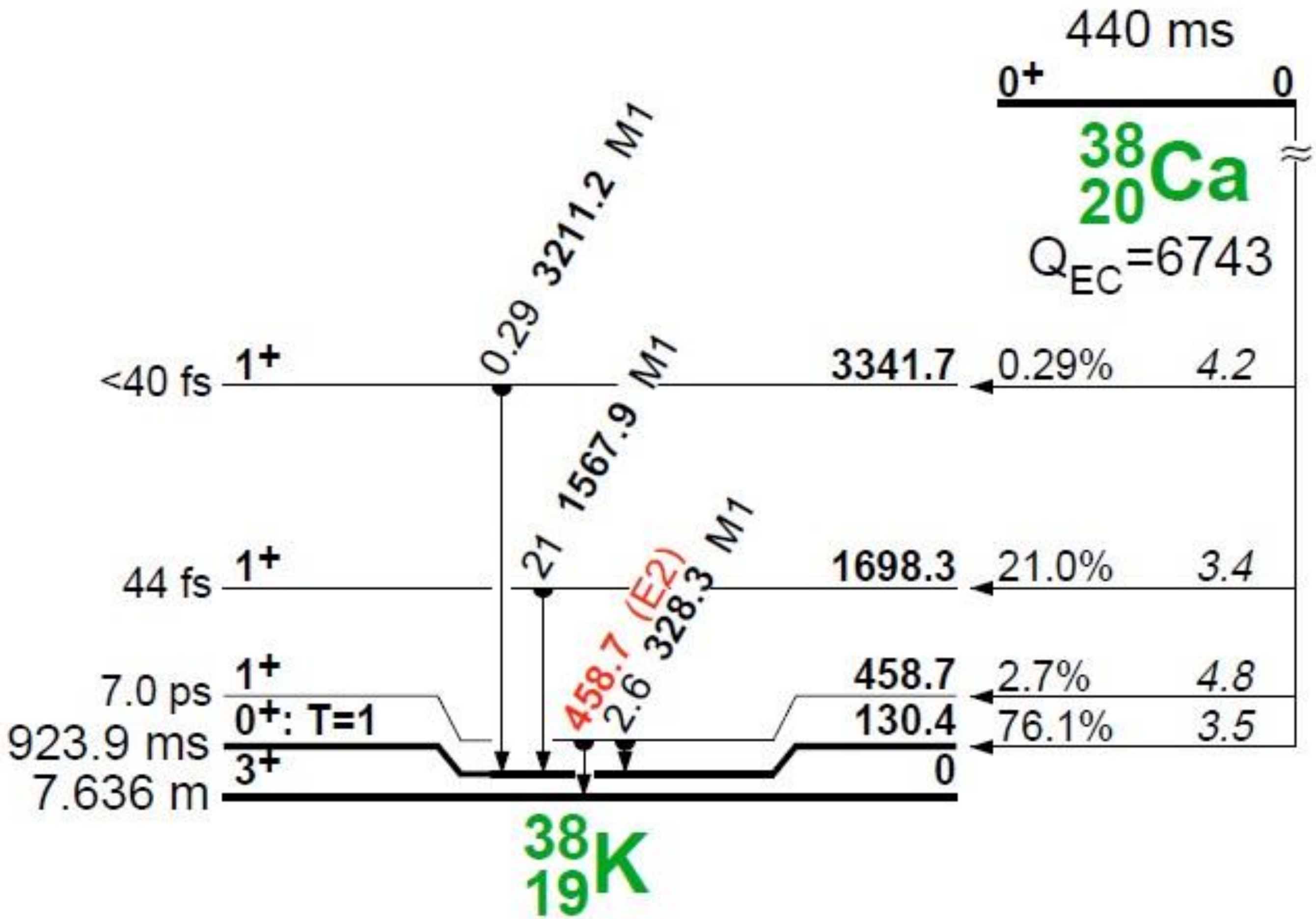
Germanium detector calibration

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

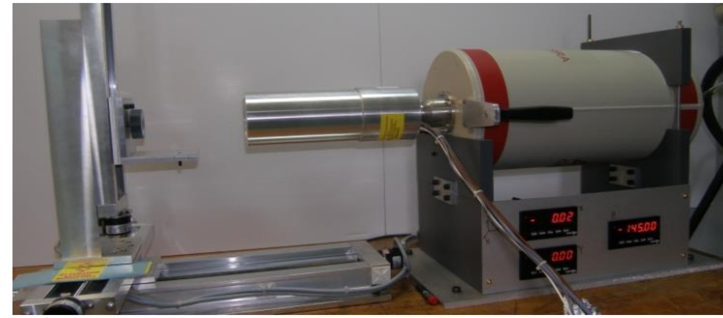


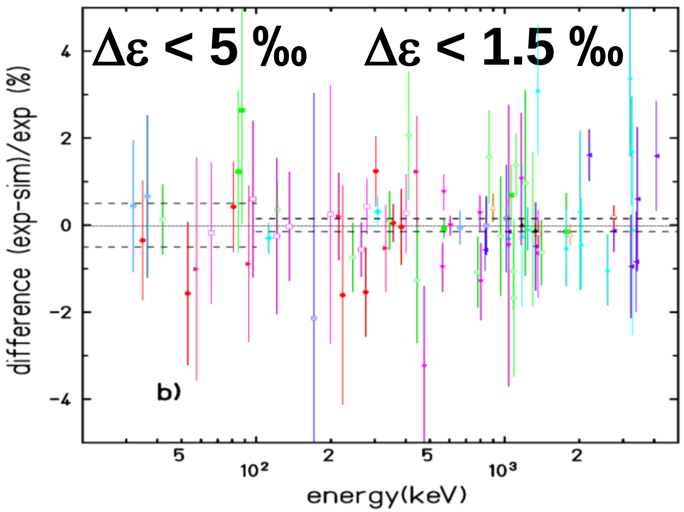
- many decay channels open
- strong non-analog transitions
- high precision of γ efficiency needed ➔ 0.1%

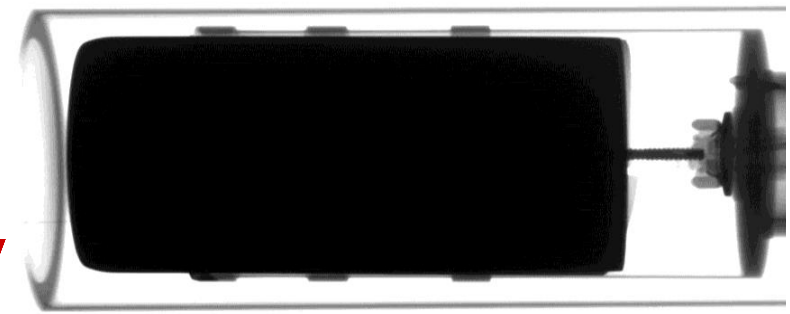
B. Blank et al., NIMA776 (2015) 34

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

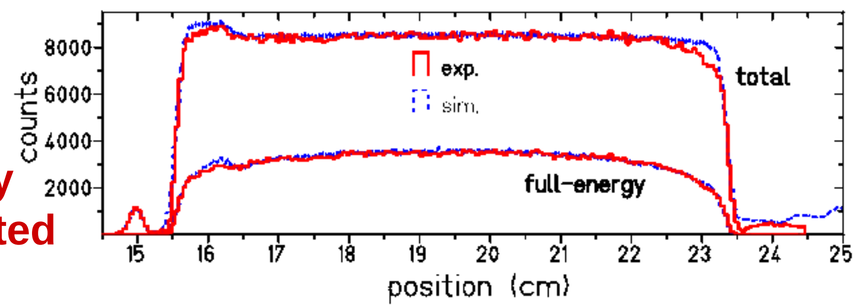


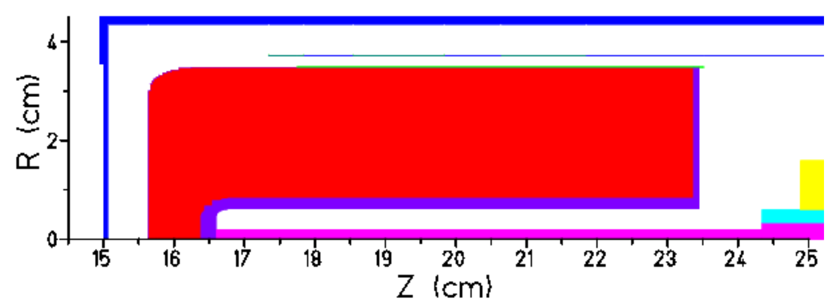




X-ray photography

Scan at CSNSM ^{137}Cs strongly collimated



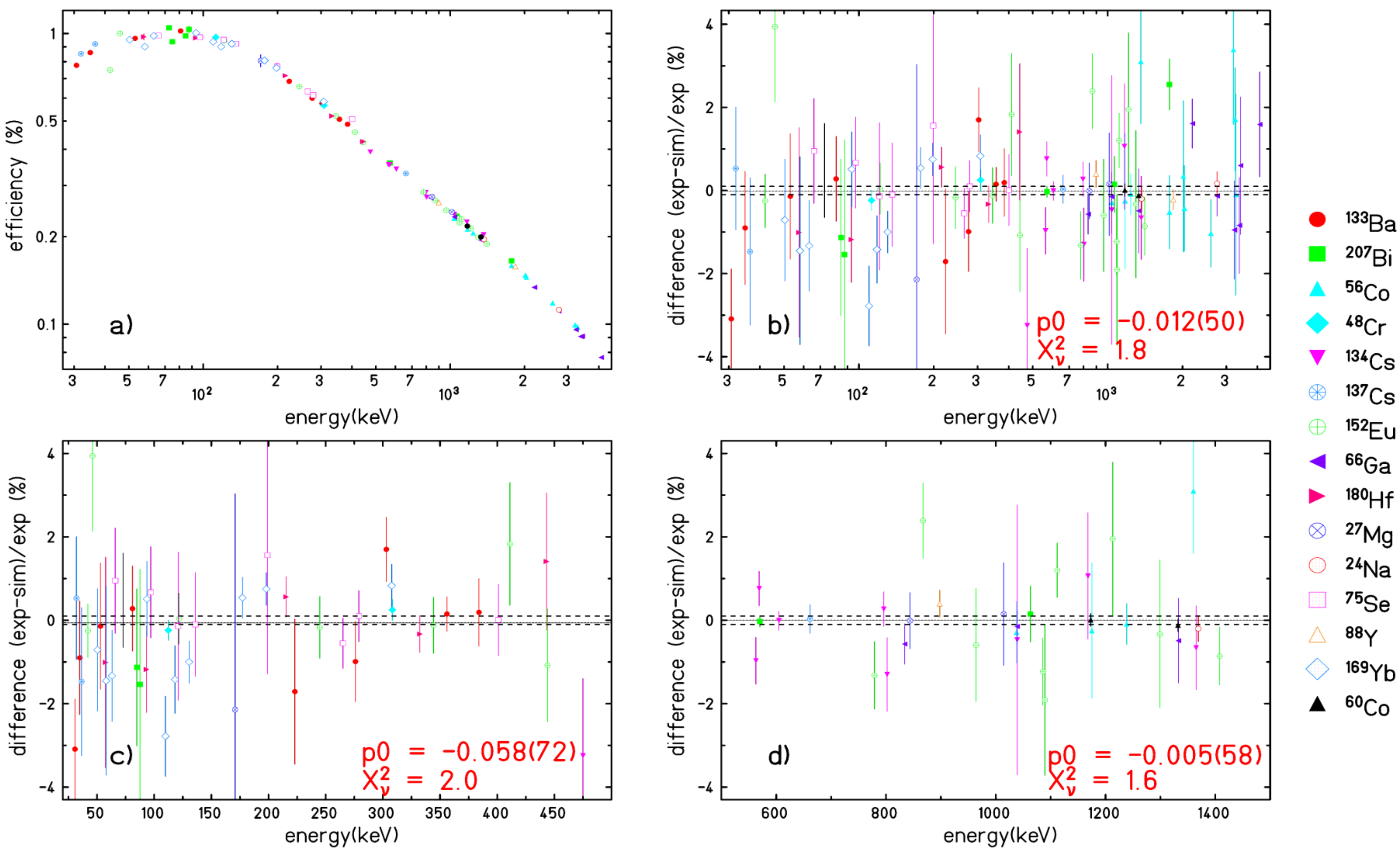


Relative detection efficiency:
^{24}Na, ^{27}Mg, ^{48}Cr, ^{56}Co, ^{60}Co, ^{66}Ga, ^{75}Se, ^{88}Y, ^{133}Ba, ^{134}Cs, ^{137}Ce, ^{152}Eu, ^{180}Hf, ^{207}Bi

Absolute detection efficiency: ^{60}Co

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

Additional calibration of germanium detector: preliminary



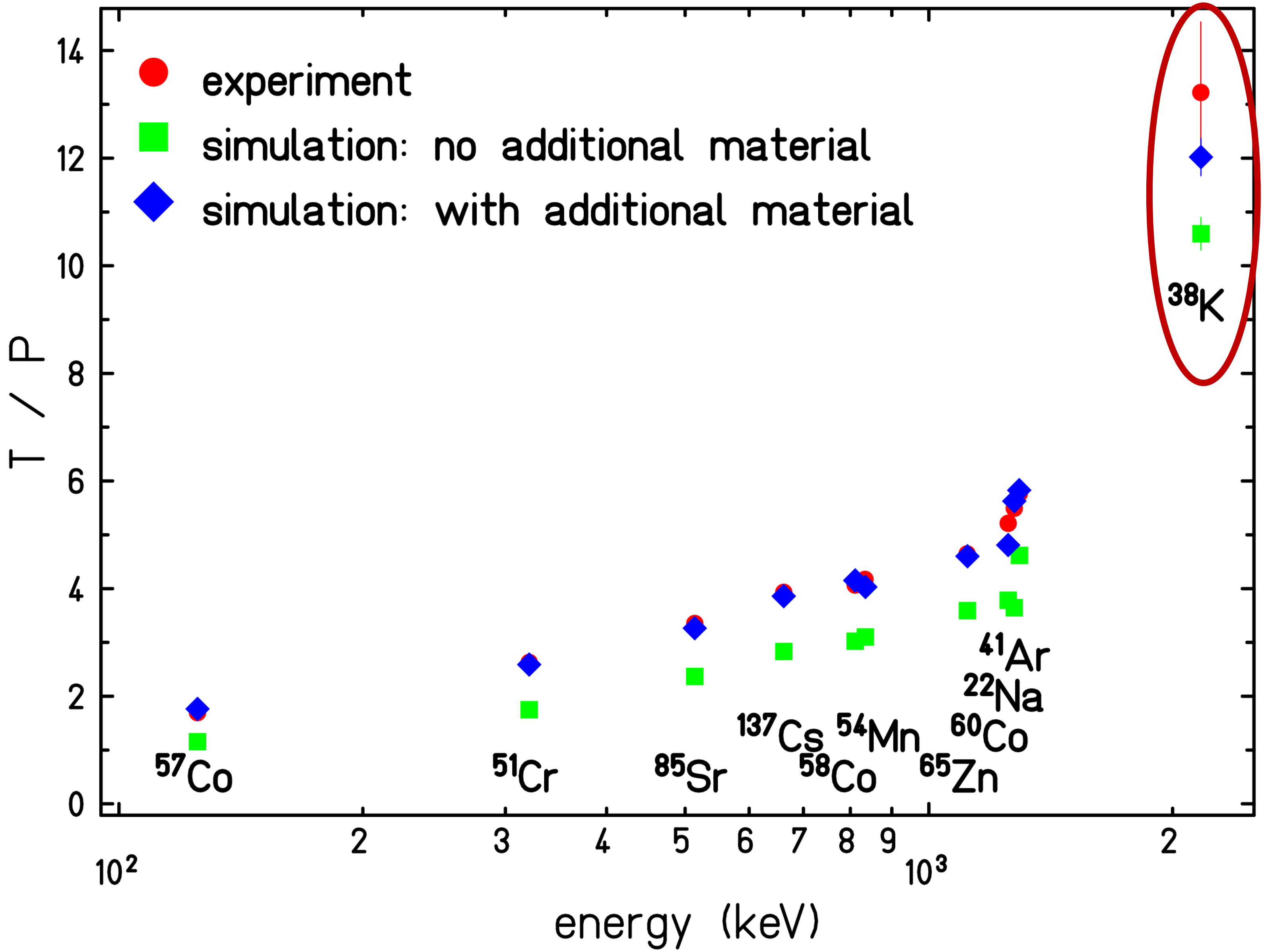
Newly added: ^{169}Yb, ^{48}Cr (add. measurements), ^{207}Bi (new analysis), ~~^{49}Cr~~

Still to come: ^{109}Cd

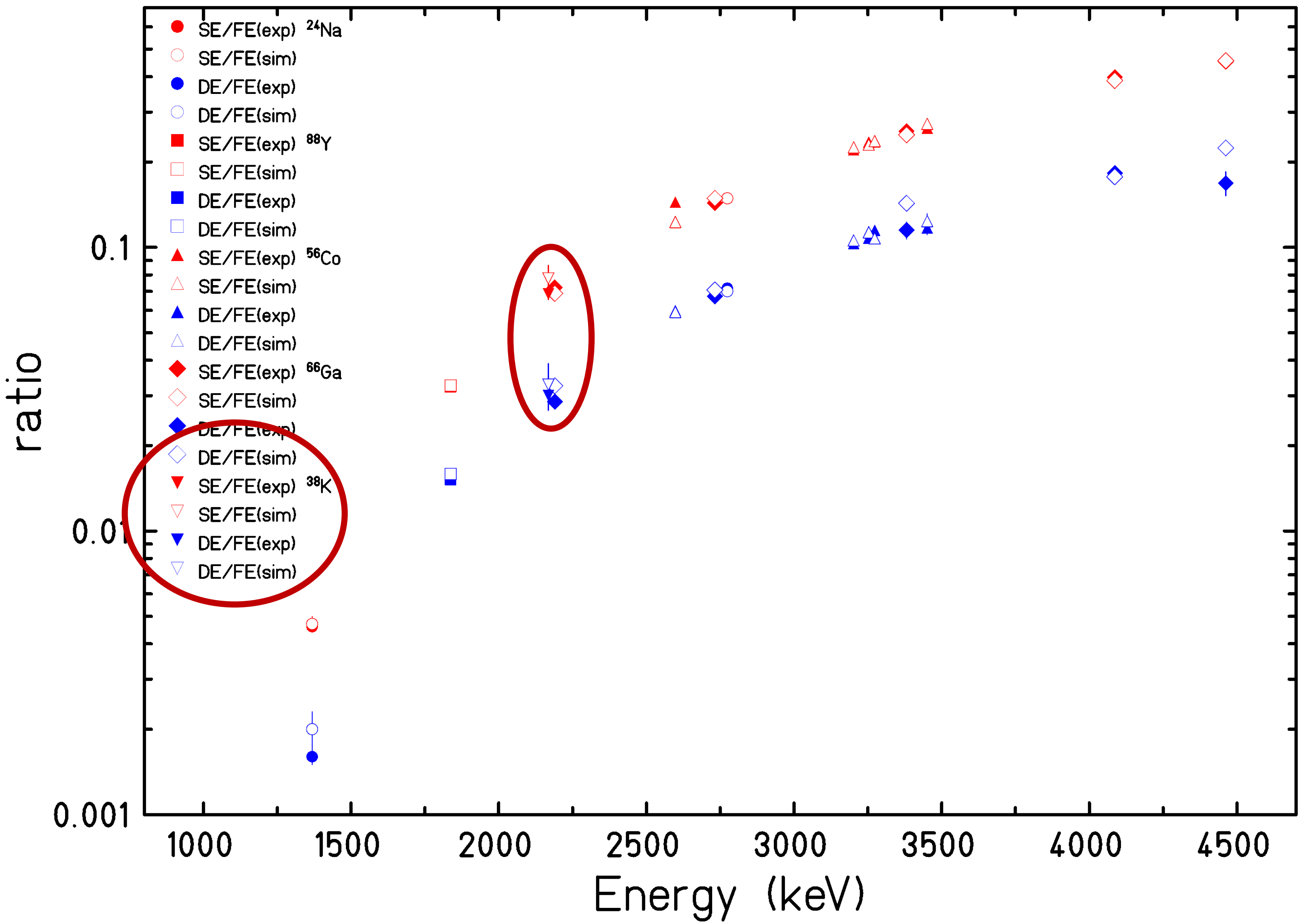
Higher-statistics calculations: ^{75}Se, ^{180}Hf

➔ ➔ 0.15 % precision for E < 100keV

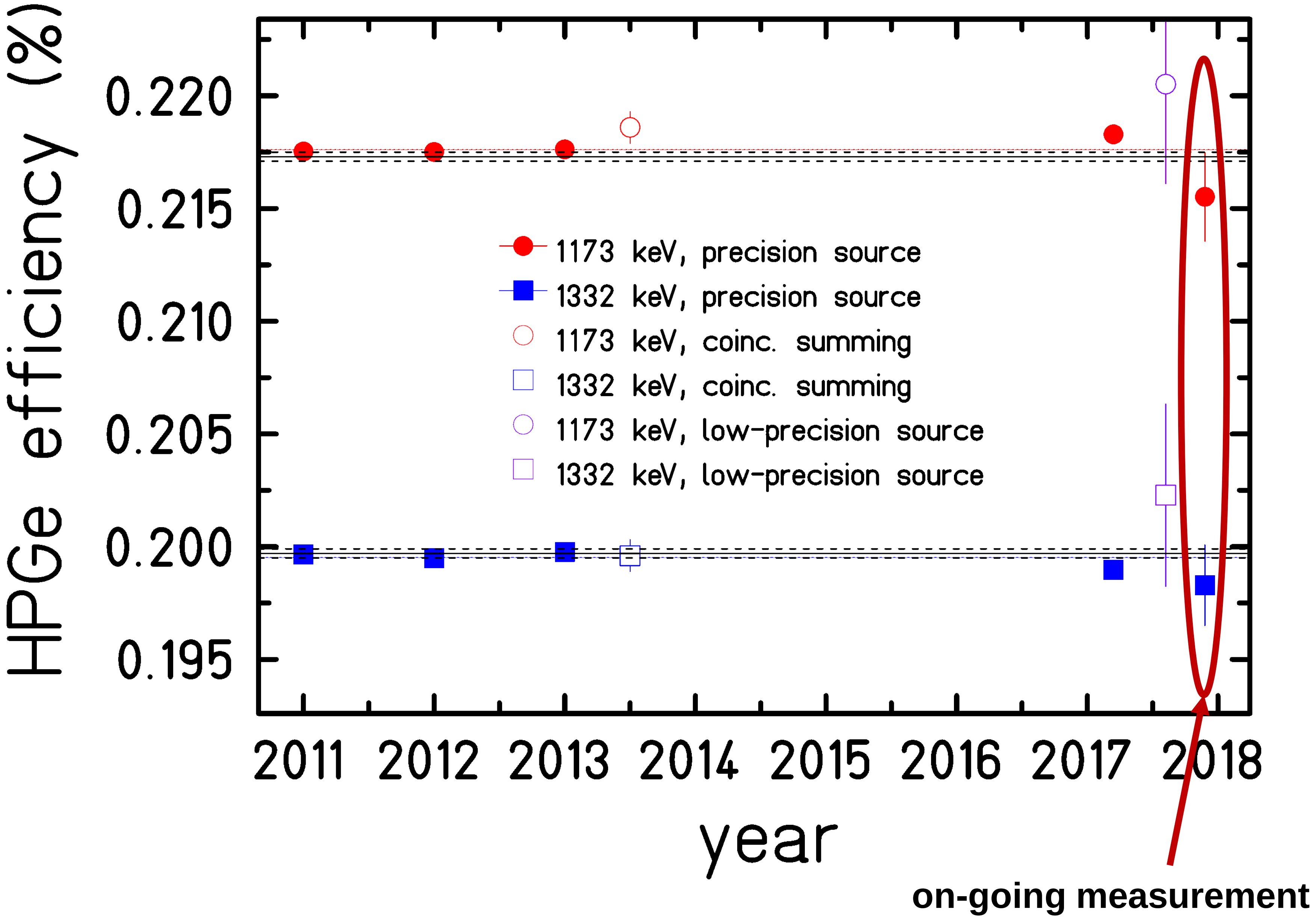
Peak-to-total



Escape peaks and simulation

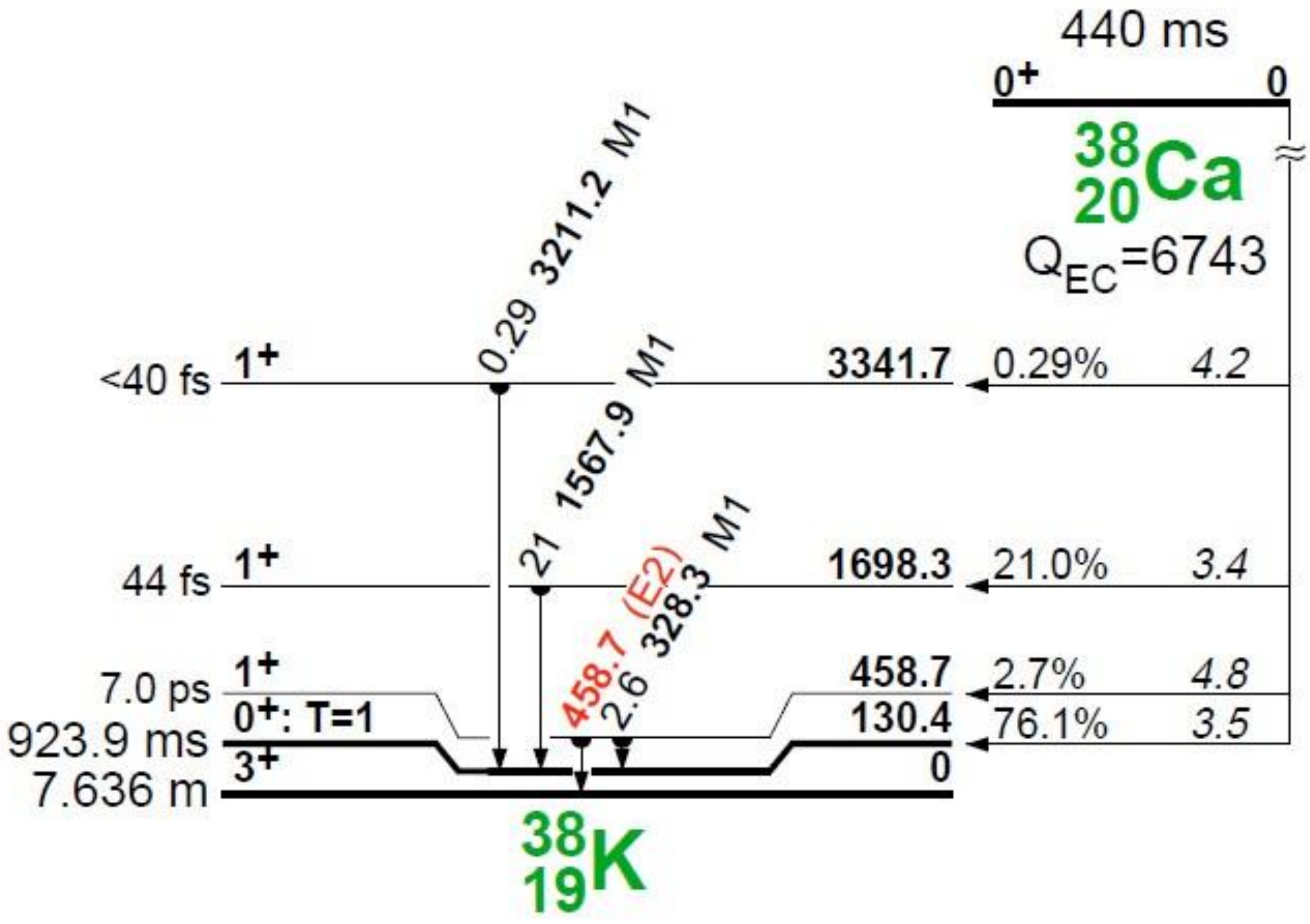


Stability of efficiency



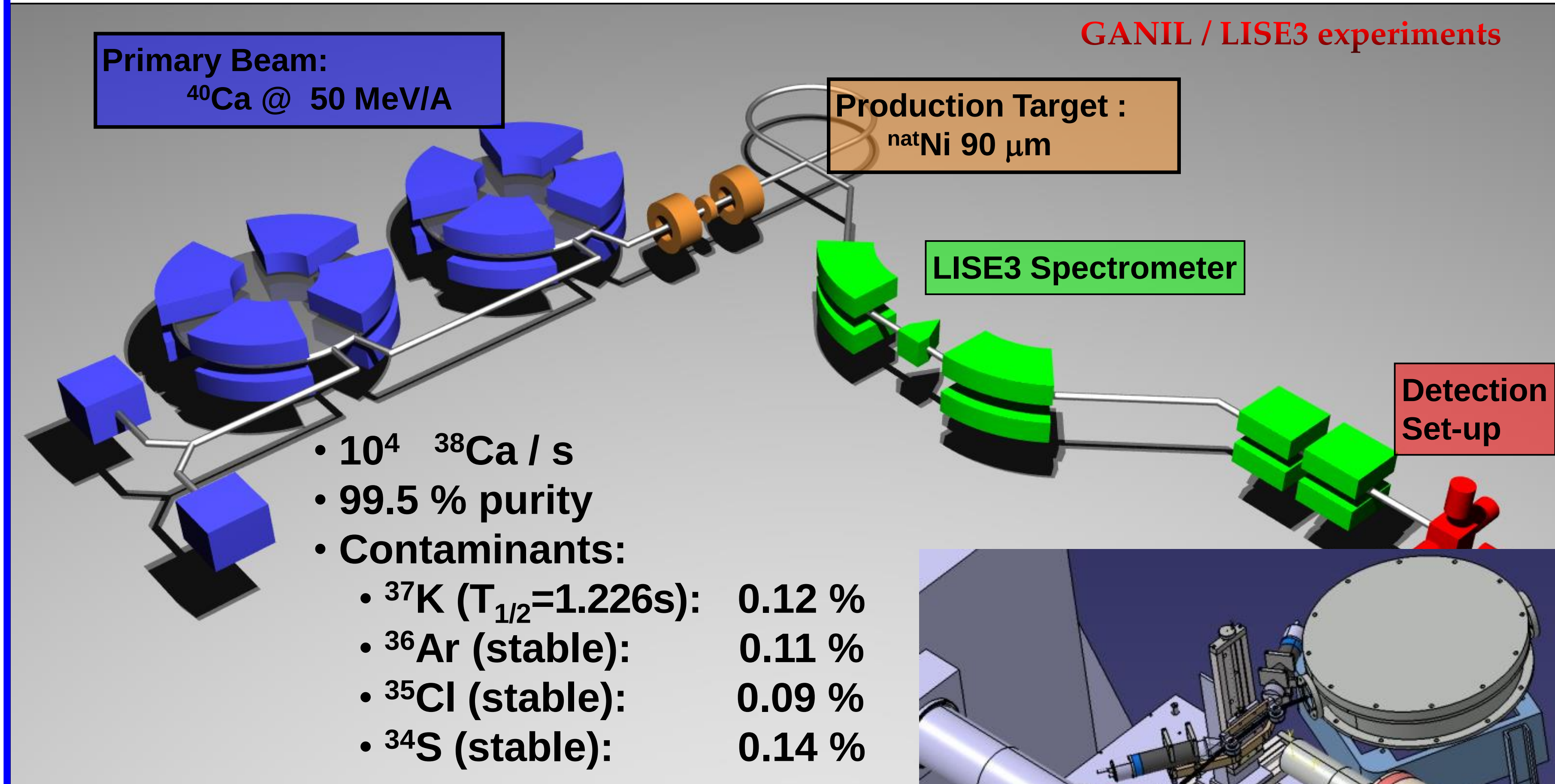
0^+ - 0^+ β decay: ^{38}Ca

Super-allowed Fermi transitions for T_z = -1

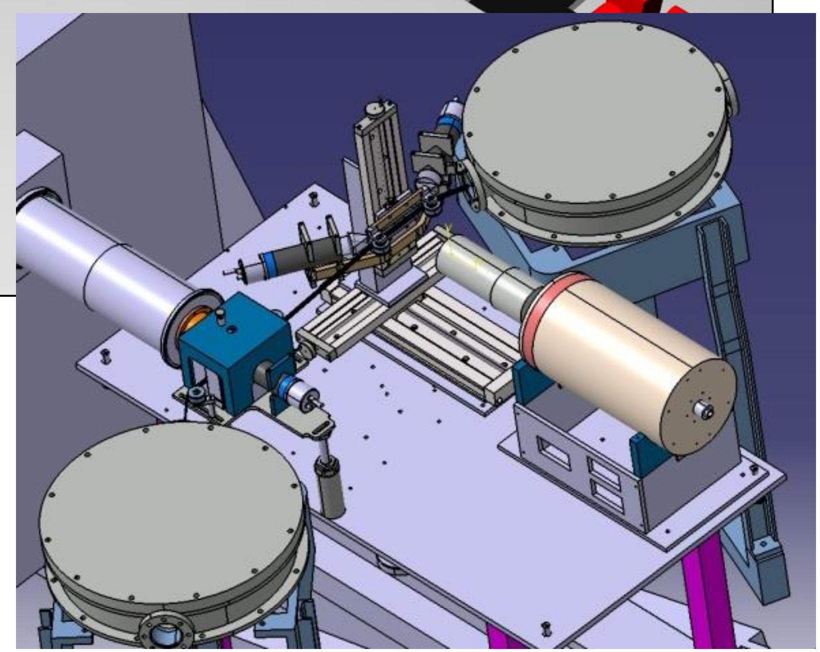


- many decay channels open
- strong non-analog transitions
- high precision of γ efficiency needed ➔ 0.1%

^{38}Ca production at GANIL/LISE3

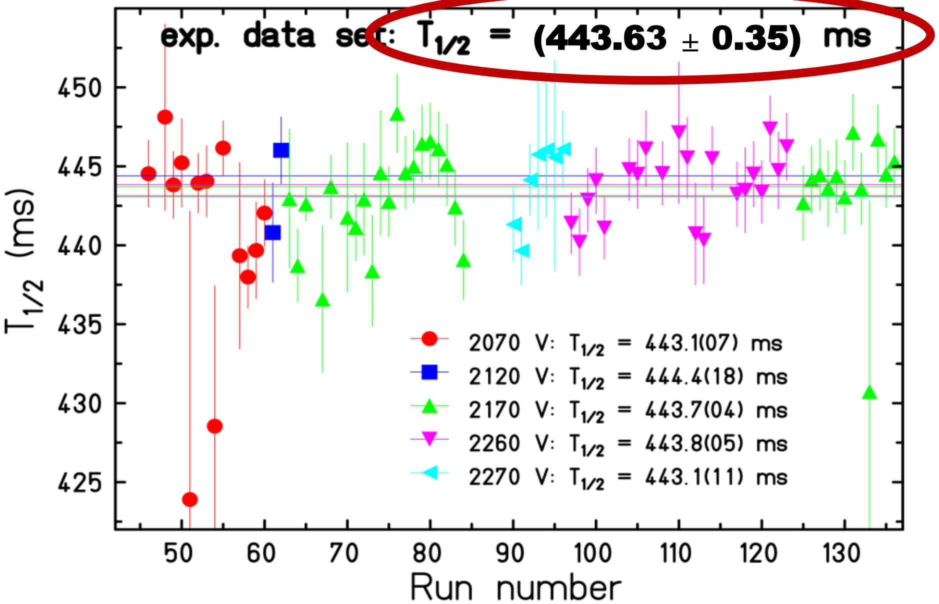


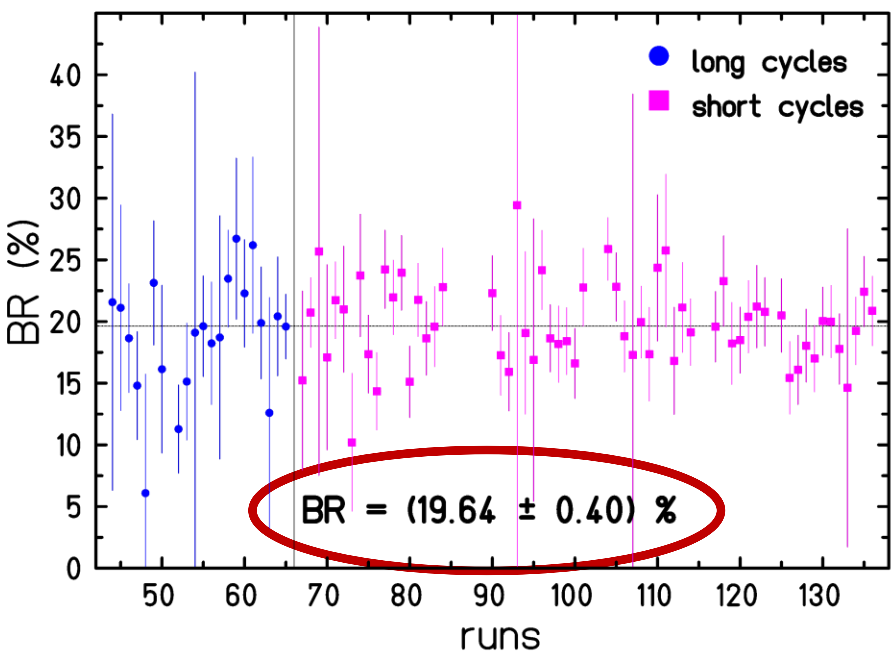
- 10^4 ^{38}Ca / s
- 99.5 % purity
- Contaminants:
  - ^{37}K ($T_{1/2}$=1.226s): 0.12 %
  - ^{36}Ar (stable): 0.11 %
  - ^{35}Cl (stable): 0.09 %
  - ^{34}S (stable): 0.14 %



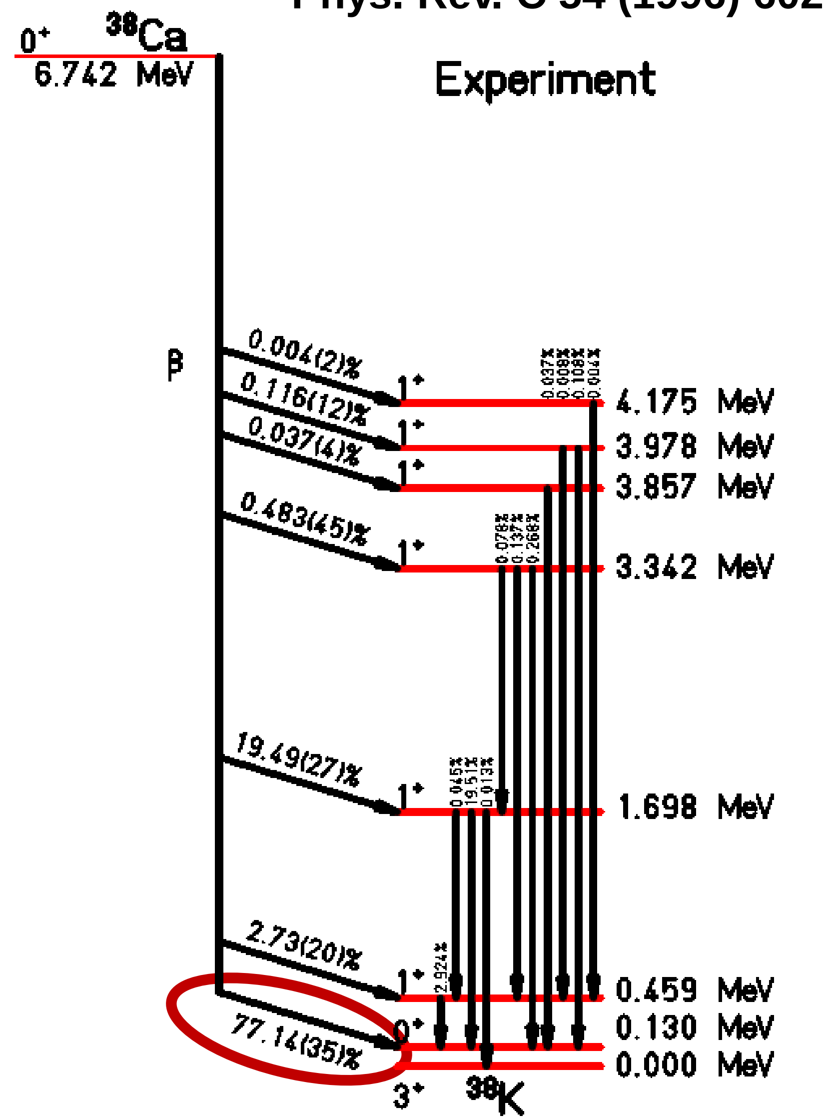
B. Blank et al., EPJA 51 (2015) 8

^{38}Ca branching ratios and half-life





Present work and Anderson et al.
Phys. Rev. C 54 (1996) 602



^{38}Ca: result

- **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**

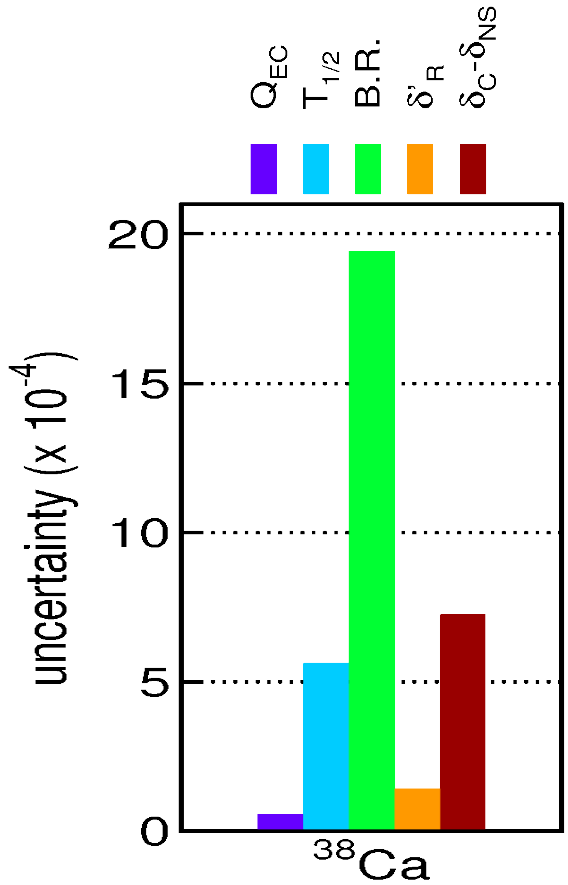
- **BR (0^+ — 0^+):** **present:** **77.09(35) %**
  Park et al.: **77.28(16) %**

➔➔ **77.25(15) %**

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

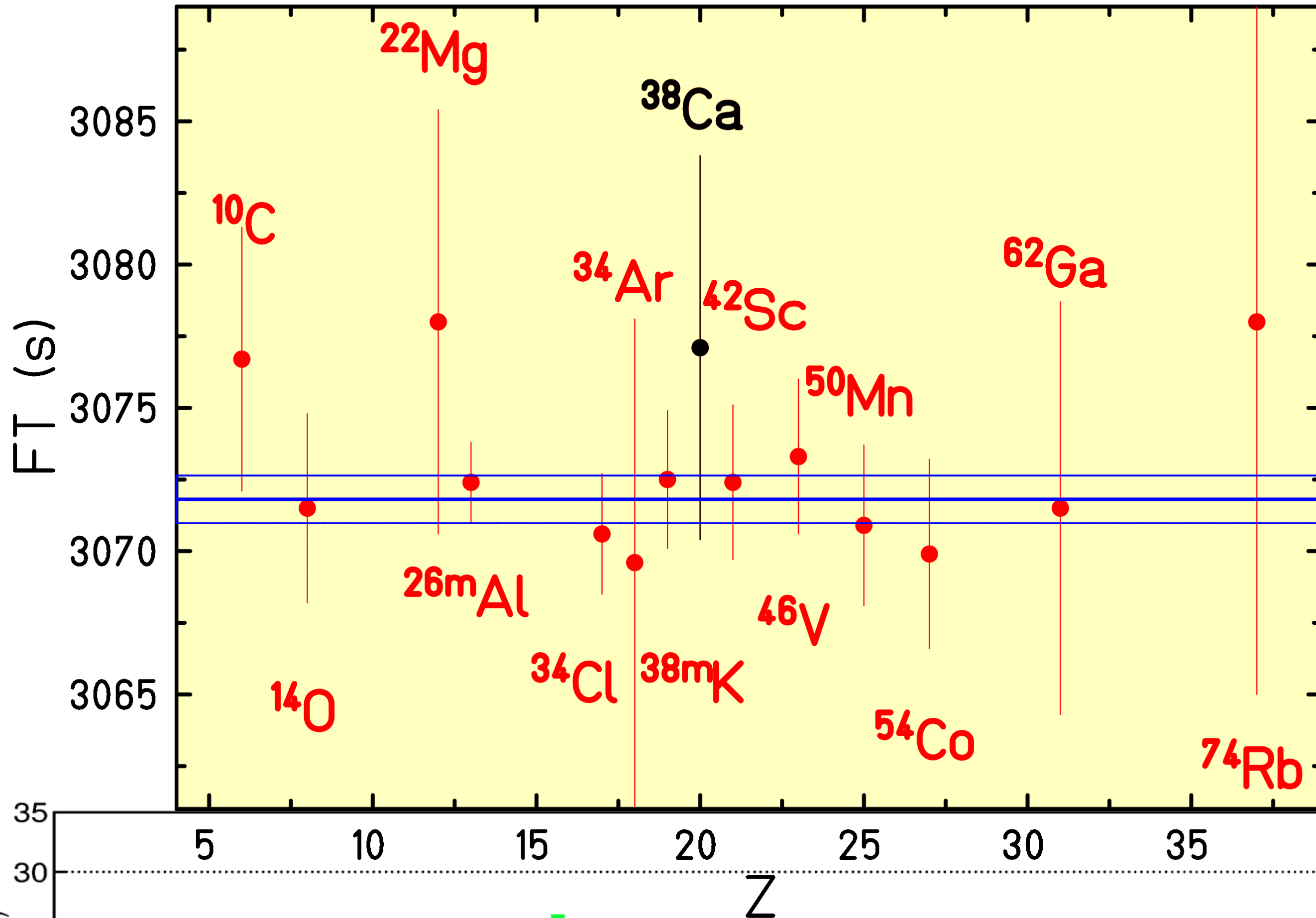
➔ **ft = 3063.3(62) s**

➔ **Ft = 3077.5(67) s**



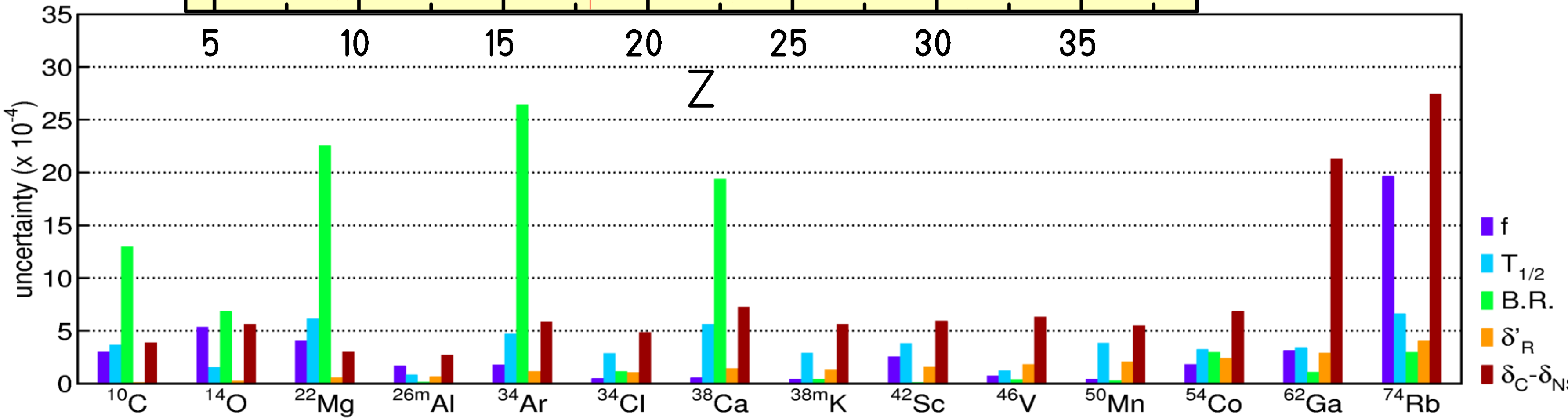
B. Blank et al., EPJA 51 (2015) 8

^{38}Ca: result



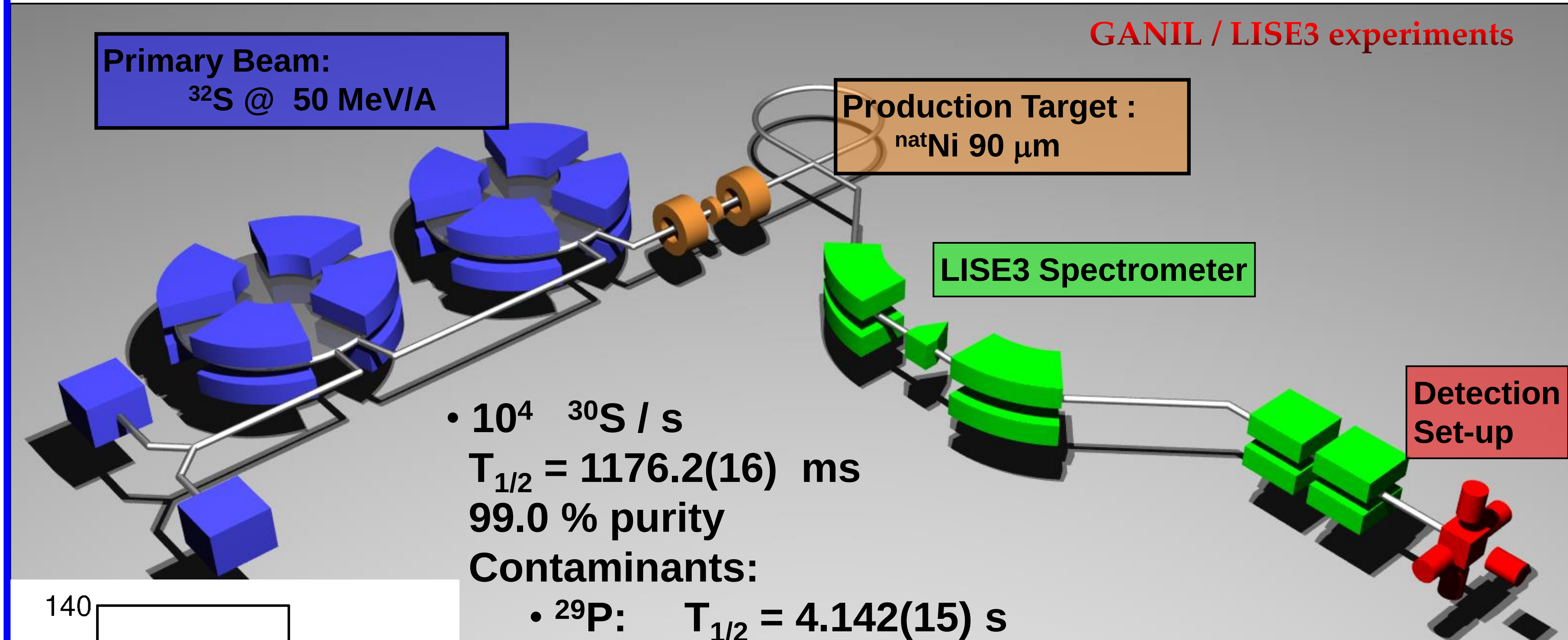
…. 14 nuclei

BR for all T_z = -1 nuclei largest error

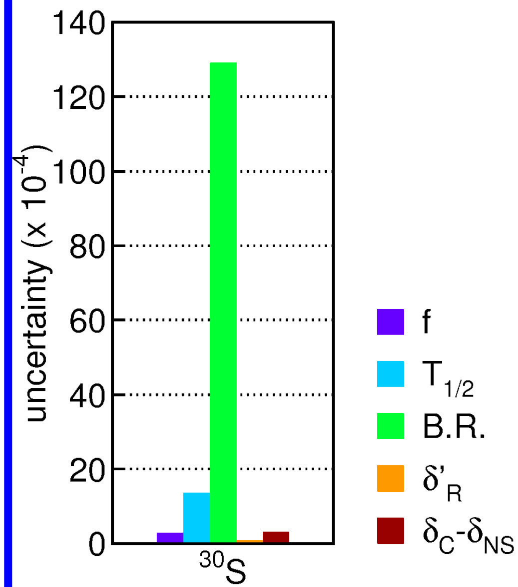


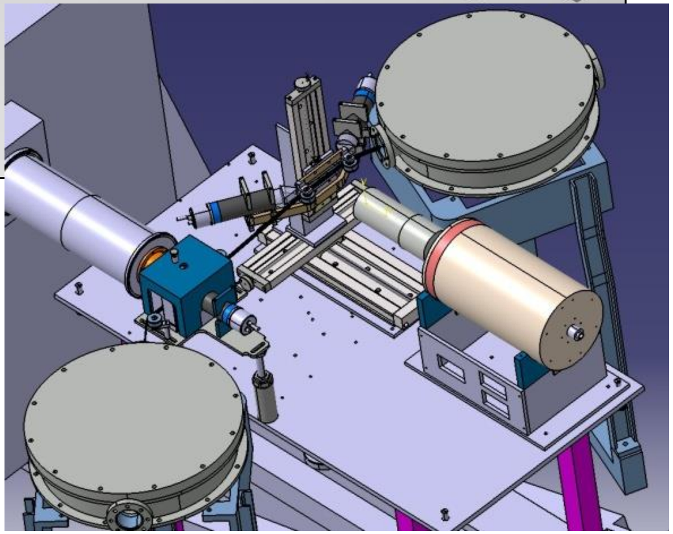
0^+ - 0^+ β decay: ^{30}S

^{30}S production at GANIL/LISE3

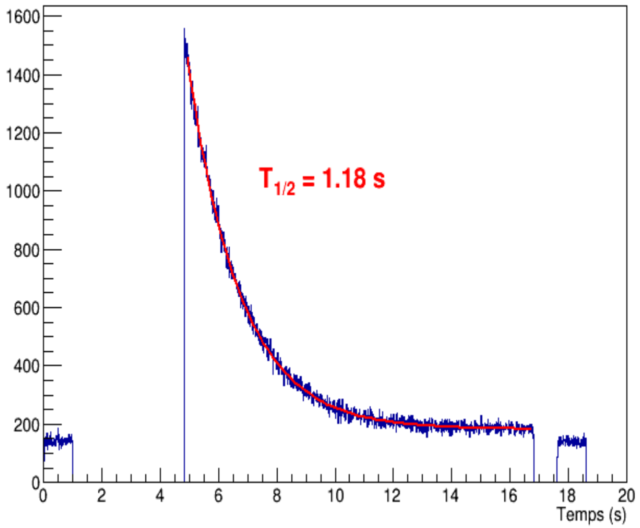


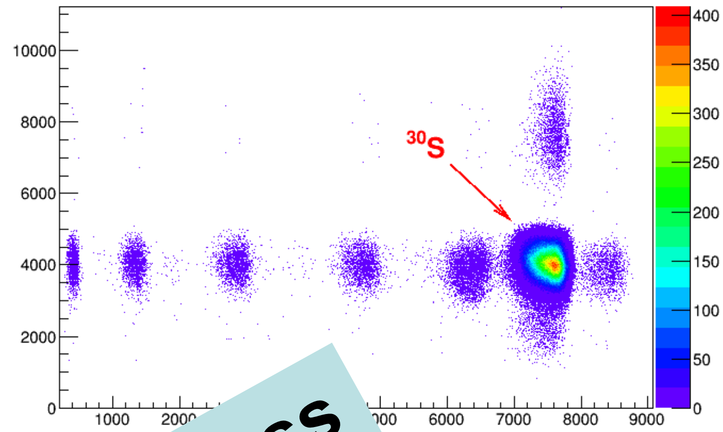
- 10^4 ^{30}S / s
  $T_{1/2}$ = 1176.2(16) ms
  99.0 % purity
  Contaminants:
  - ^{29}P: $T_{1/2}$ = 4.142(15) s
  - ^{28}Si: stable
  - ^{27}Al: stable
  - ^{26}Mg: stable

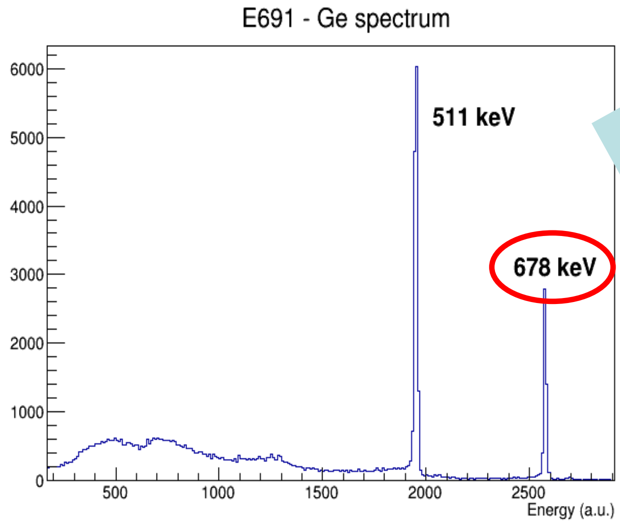


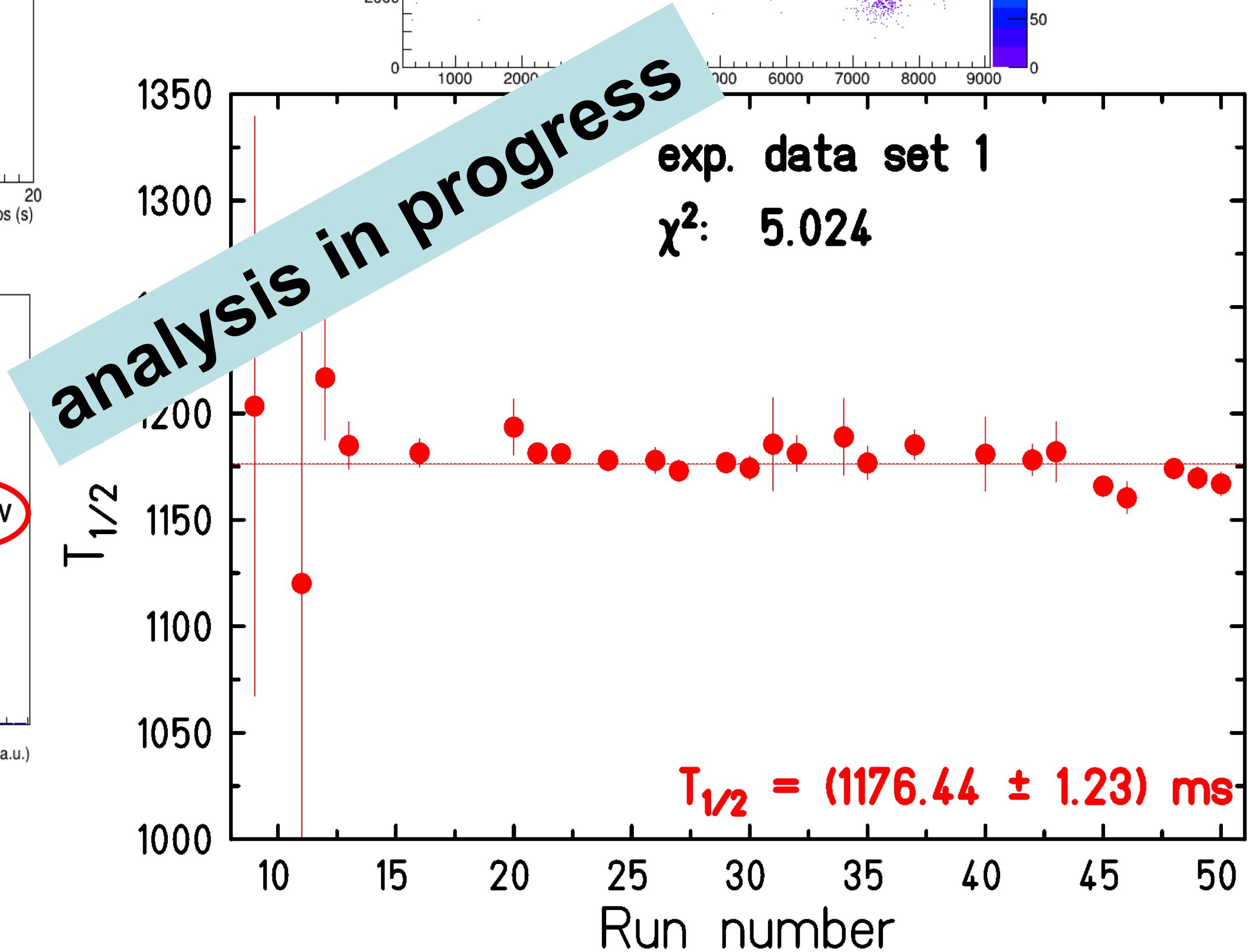


^{30}S: very preliminary result









Physics beyond the standard model:
^{10}C at ISOLDE

$0^+ \rightarrow 0^+$ decays: limits on exotic currents

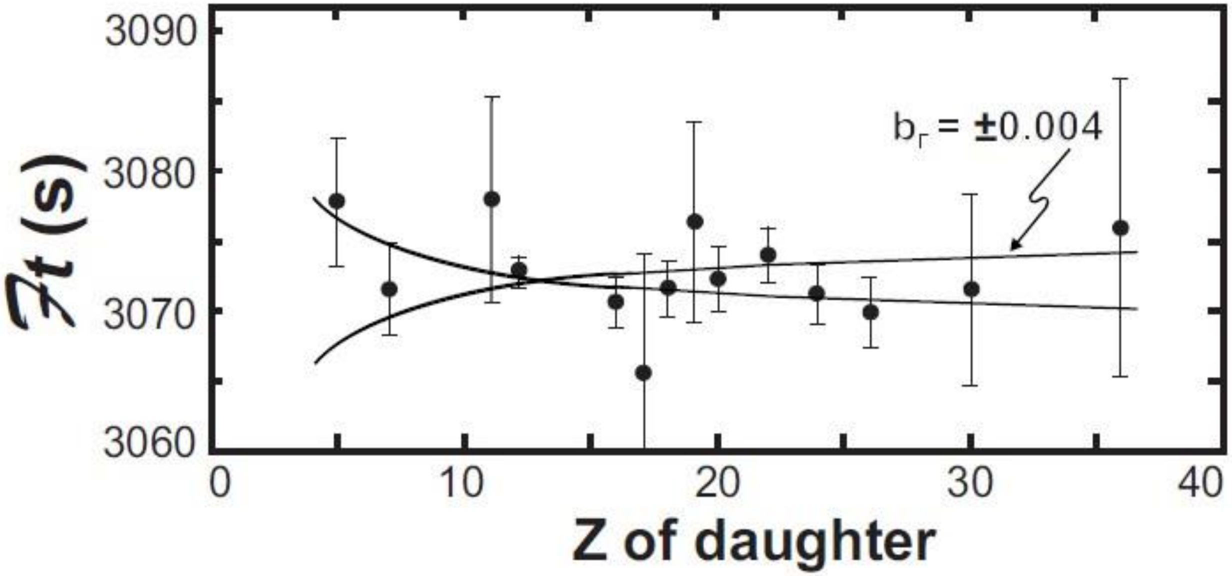
standard model assumption: only vector current

- **limit on scalar current from term in f function:** $(1+b_f * \gamma_1 / \langle E \rangle)$

  from β decay: $b_F = -0.0028 \pm 0.0026$

➔➔ **improve on low-Z nuclei**

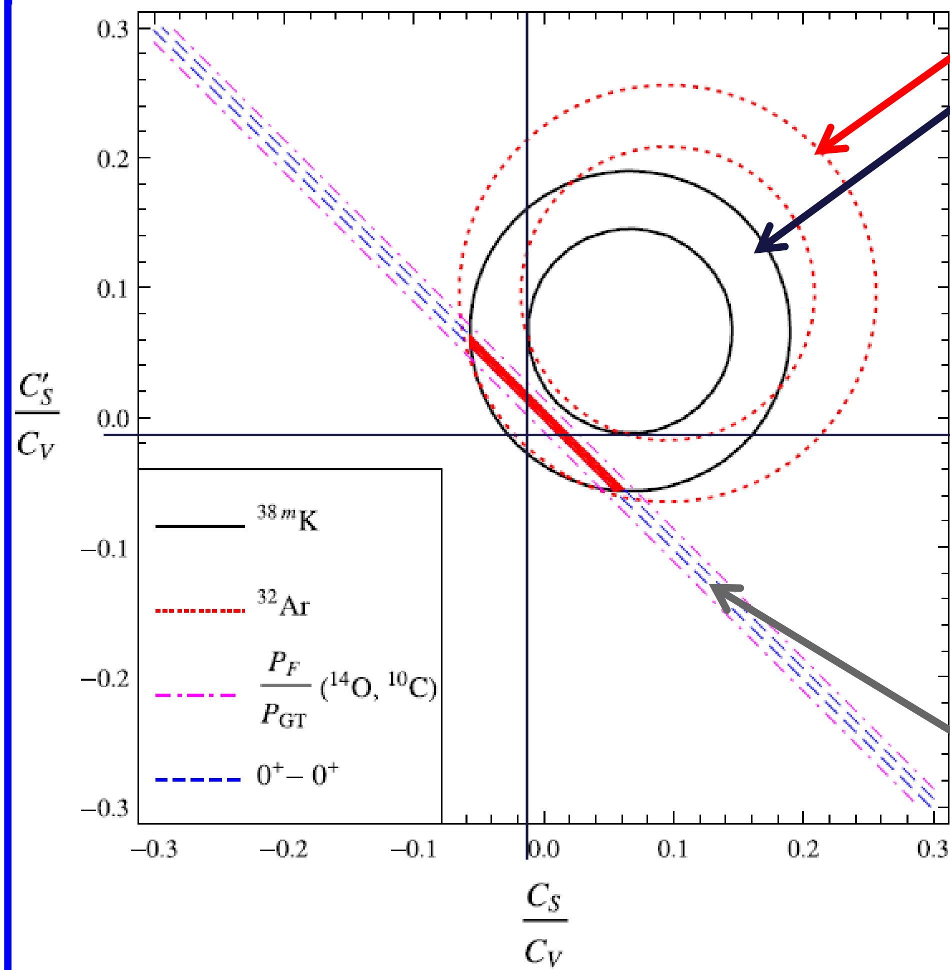
Hardy & Towner, 2015



- **limit on scalar currents:**

  $b_F = Re((C_S + C'_S) / C_V) = 0.0026(42)$ (90% CL) **Severijns et al.**

$0^+ \rightarrow 0^+$ decays: limits on exotic currents



^{32}Ar: Adelberger et al., PRL 83 (1999) 1299

^{38m}K: Gorelov, Behr et al., PRL 94 (2005) 142501

$$\tilde{a} = \frac{a}{1 + b\,\frac{\gamma m_e}{E_e}}$$

with:

$$a_F \cong 1 - \frac{|C_S|^2 + |C'_S|^2}{|C_V|^2}$$

$$b'_F = \frac{\gamma m_e}{\langle E_e \rangle}\left(\frac{C_S + C'_S}{C_V}\right)$$

$$\mathcal{F}t^{0^+\rightarrow 0^+} = \frac{K}{2G_F^2 V_{ud}^2 C_V^2 \left(1 + \Delta_R^V\right)} \, \frac{1}{(1 + b'_F)}$$

Hardy & Towner , Phys. Rev. C 91 (2015) 025501

B. R. Holstein, J. Phys. G 41 (2014) 114001

0⁺ → 0⁺ decays: limits on exotic currents

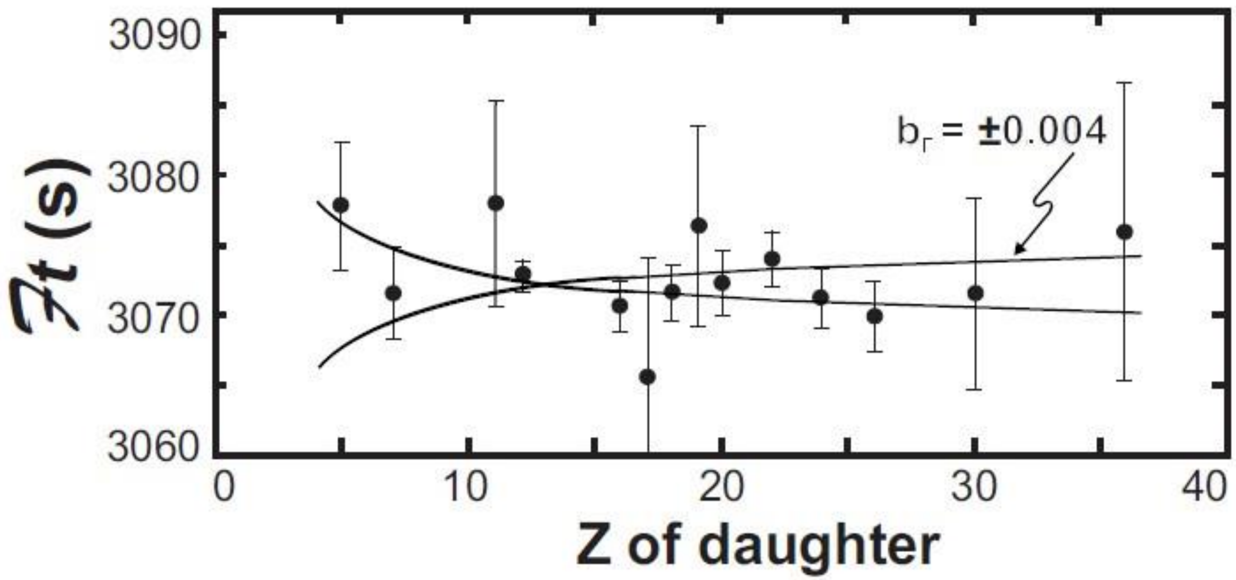
standard model assumption: only vector current

- **limit on scalar current from term in f function:** $(1+b_f * \gamma_1 / \langle E \rangle)$

  from β decay: $b_F = -0.0028 \pm 0.0026$

➔➔ improve on low-Z nuclei

Hardy & Towner, 2015



- **limit on scalar currents:**

  $b_F = Re((C_s + C'_s) / C_v) = 0.0026(42)$ (90% CL) Severijns et al.

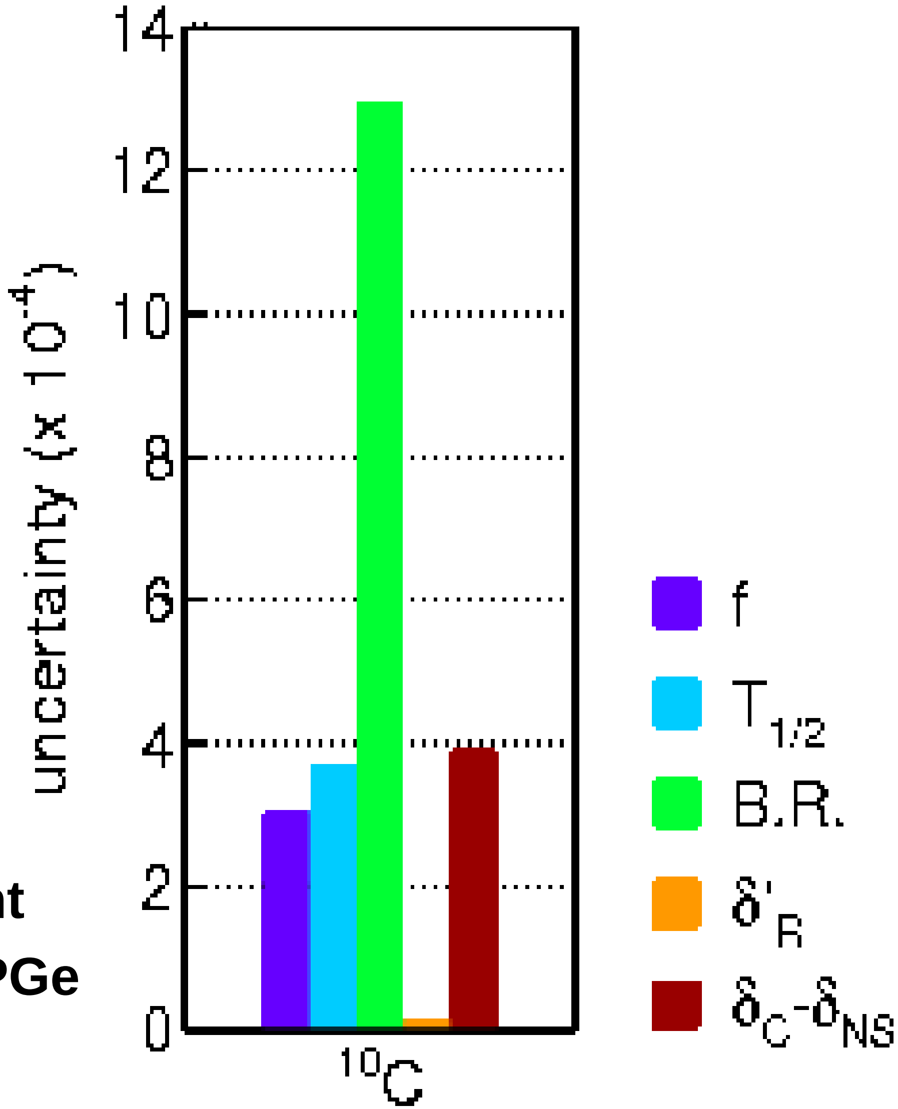
0+ → 0+ decays: ^{10}C error budget

- **BR by far largest error**
- **two precise measurements:**
  - **Savard et al.: 1.4625(25)%**
    (PRL 74 (1995) 1521)
  - **Fujikawa et al.: 1.4665(38)%**
    (PLB 449 (1999) 6)

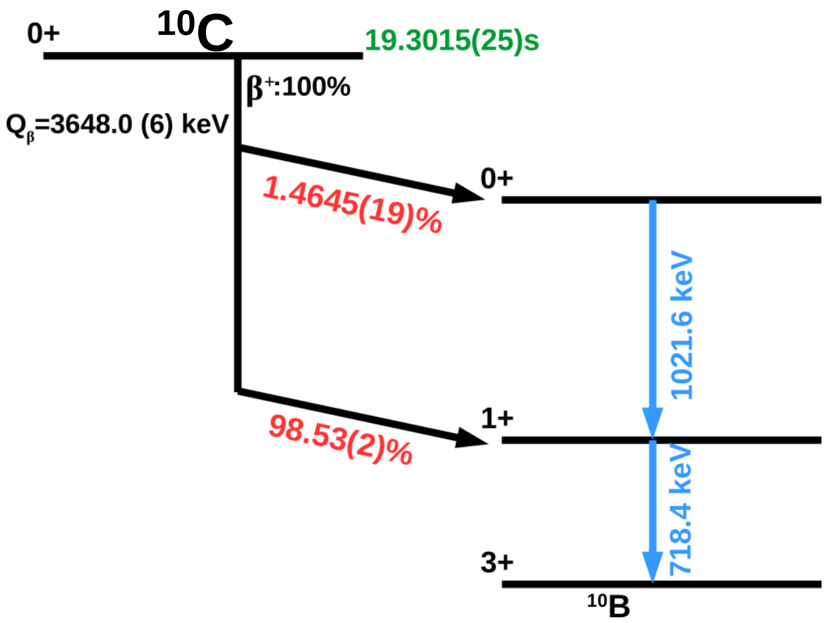
  ➔ measurements with Ge multi-detector array

our approach:

branching ratio measurement with our highly calibrated HPGe

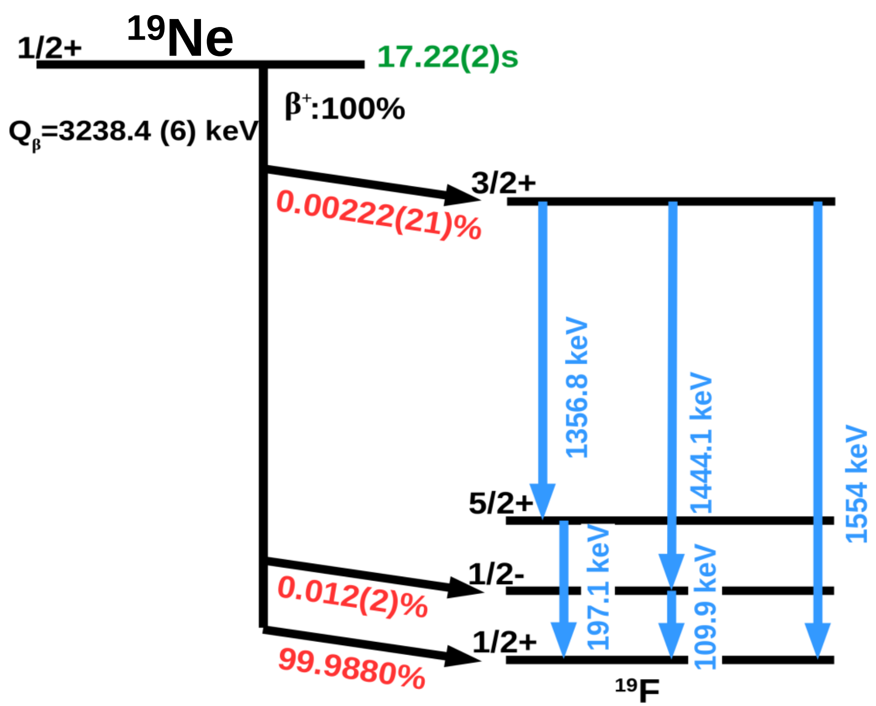


$^{10}C/^{19}Ne$ decay scheme

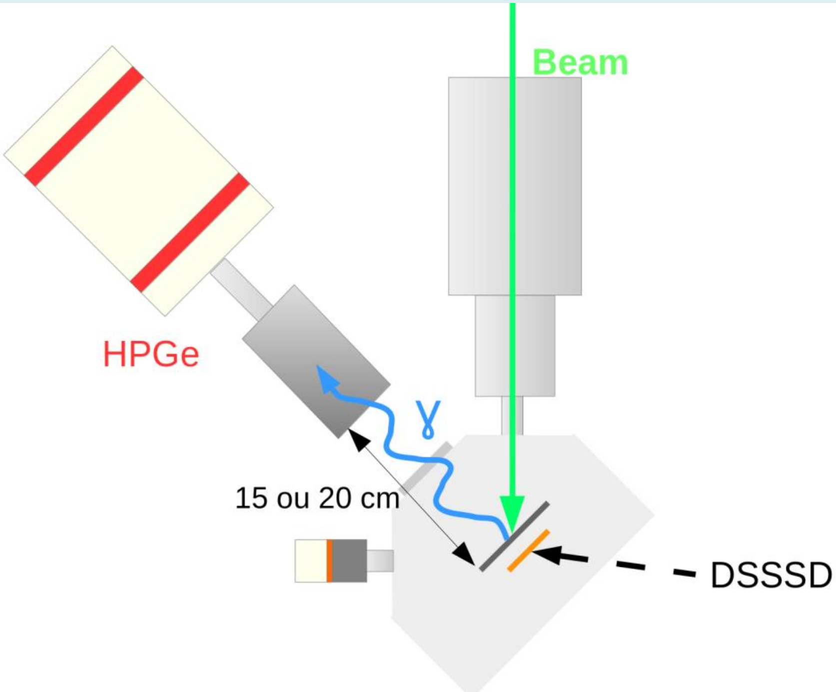


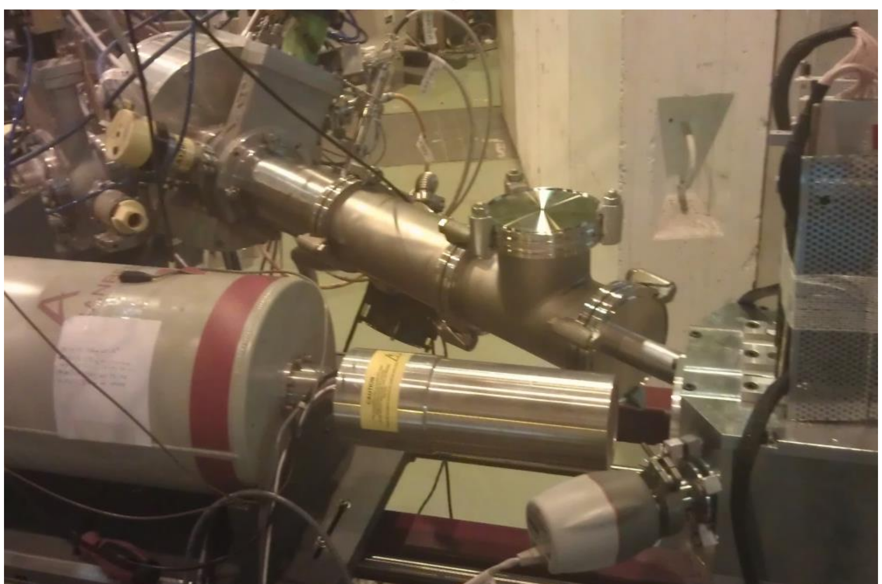
← to determine the BR

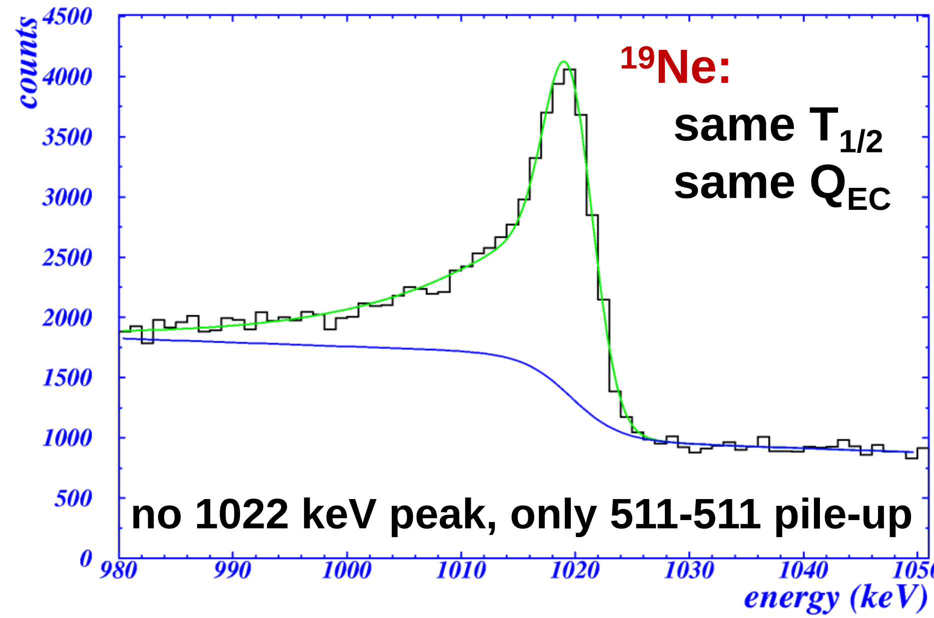
to evaluate pile-up →

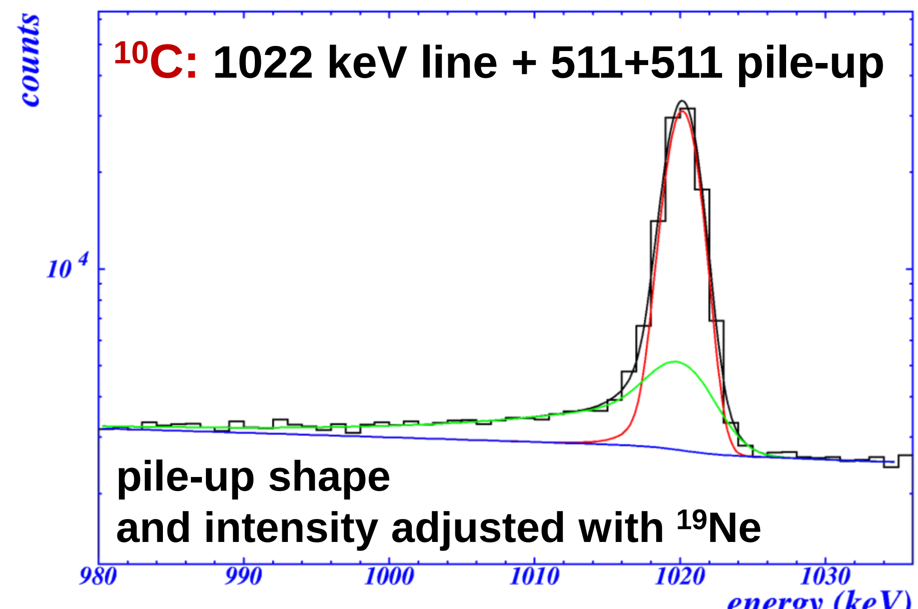


^{10}C experimental set-up and very preliminary results

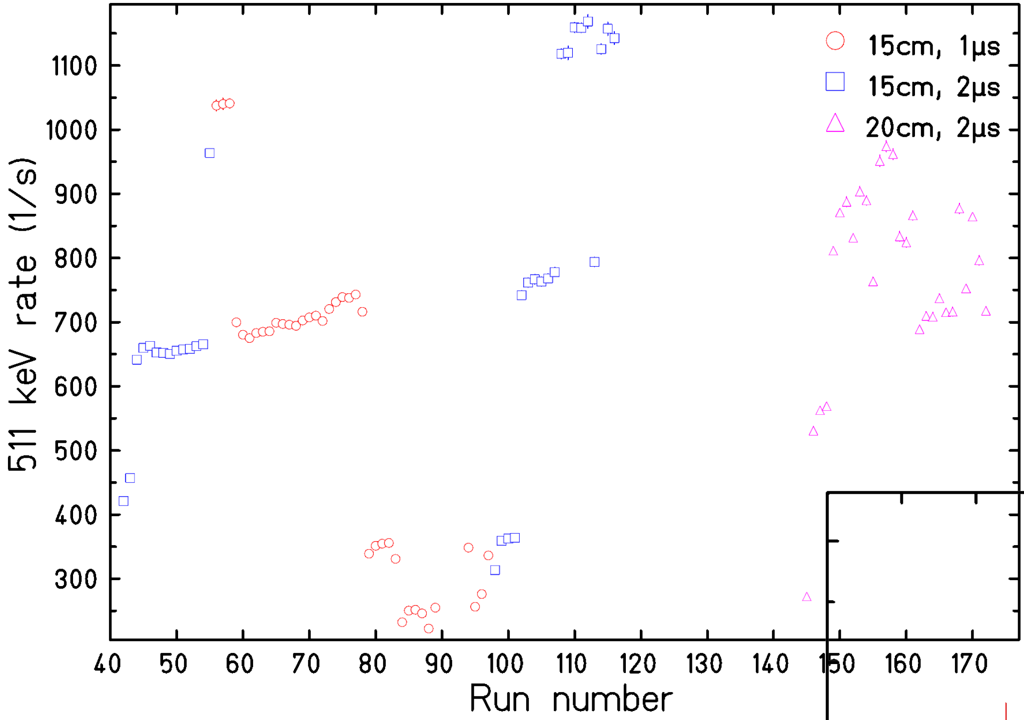




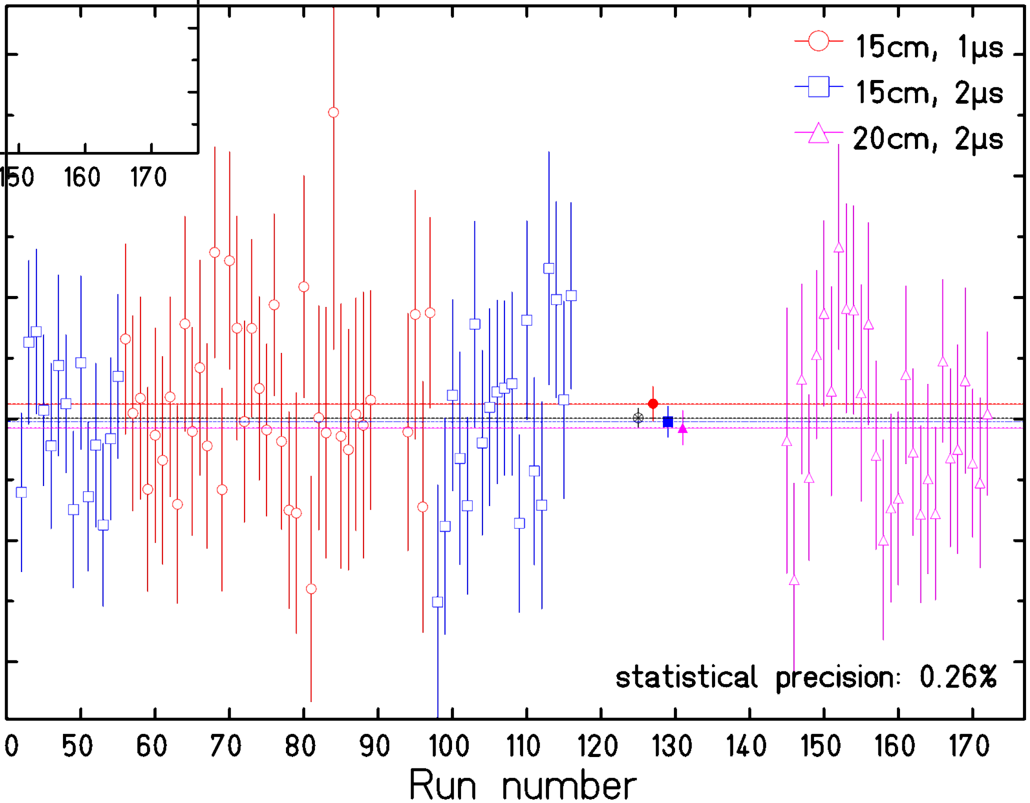




First steps of analysis



analysis in progress….



measurements:

- **widely varying beam intensity (x 6)**
- **different shaping times (1 & 2 µs)**
- **different distances (15 & 20 cm)**

Physics beyond the standard model:
^{10}C at ALTO

Future experiment: ^{10}C with nu-ball @ ALTO

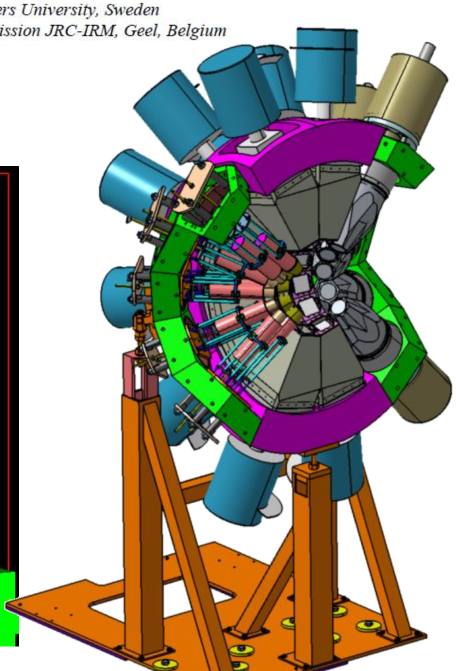
nu – ball

A hybrid LaBr$_3$-Ge array for fast timing spectroscopic studies at the IPN Orsay

J.N. Wilson[1], P.H.Regan[2,3] ,G. Georgiev[4], I. Matea[1], D. Verney[1], M. Lebois[1], P. Halipre[1], L. Qi[1], A. Gottardo[1], J. Ljungvall[4], Zs.Podolyak[2], S.M.Judge[2,3], R. Shearman[2,3], R. Carroll[2], M. Rudigier[2], A.Pearce[3], G.Lorusso[2,3], A.M. Bruce[5], N. Marginean[6], T. Kroell[7], S. Ilieva[7], A. Ignatov[7], G. Fernandez[7], V. Werner[7], L.M. Fraile[8], V. Vedia[8], J. Jolie[9], J.M. Regis[9], W. Korten[10], J.F. Smith[11], P.M. McKee[11], E. Parr[11], M. Smolen[11], S.Lalkovski[2,12], S. Kisyov[12], A. Görgen[13], S.Siem[13], K. Hadynska-Klek [13], E. Sahin[13]A. Oberstedt[1,14], S. Oberstedt[15]

[1]*Institut de Physique Nucléaire Orsay, F- 91406 Orsay, France*
[2]*Department of Physics, University of Surrey, UK*
[3]*AIR Division, National Physical Laboratory,Teddington, UK*
[4]*CSNSM Orsay, France*
[5]*University of Brighton, UK*
[6]*IFIN-HH. Maguerele, Bucharest, Romania*
[7]*TU Darmstadt, Germany*
[8]*U. Complutense, Madrid, Spain*
[9]*IFK- Köln, Germany*
[10]*CEA Saclay, France*
[11]*Universiyt of West of Scotland, Paisley, UK*
[12] *University of Sofia, Bulgaria*
[13] *University of Oslo, Norway*
[14] *Chalmers University, Sweden*
[15]*European Commission JRC-IRM, Geel, Belgium*

- **24 cover**
- **10 LaBr3**

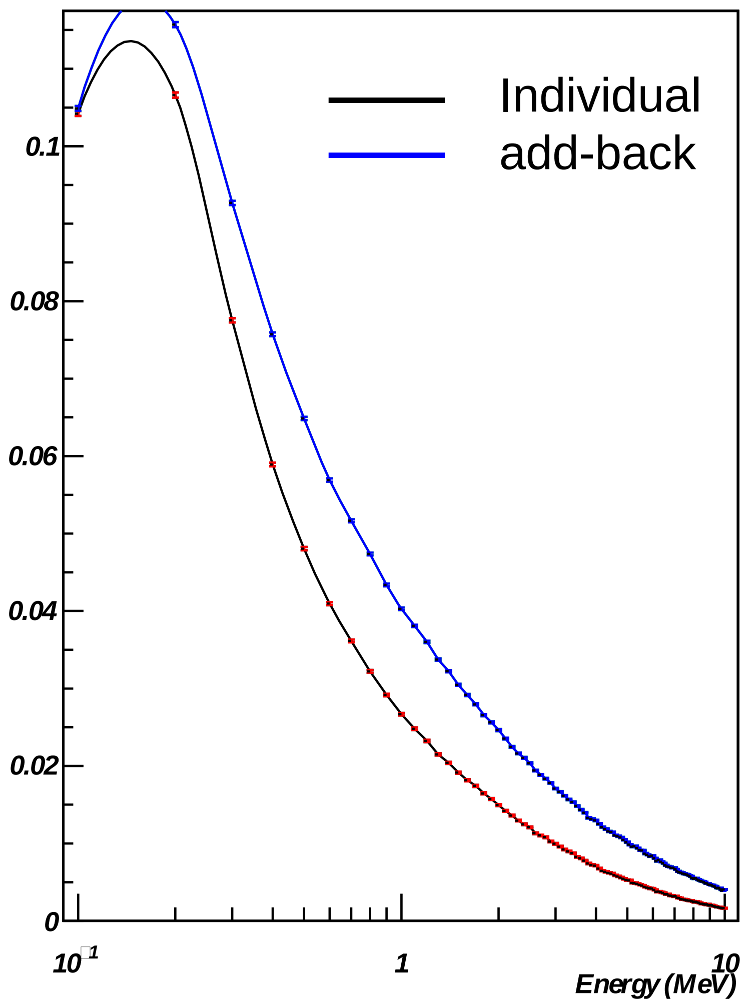


<u>Scientific Manager:</u> M. Lebois
<u>Technical Manager:</u> B. Genolini

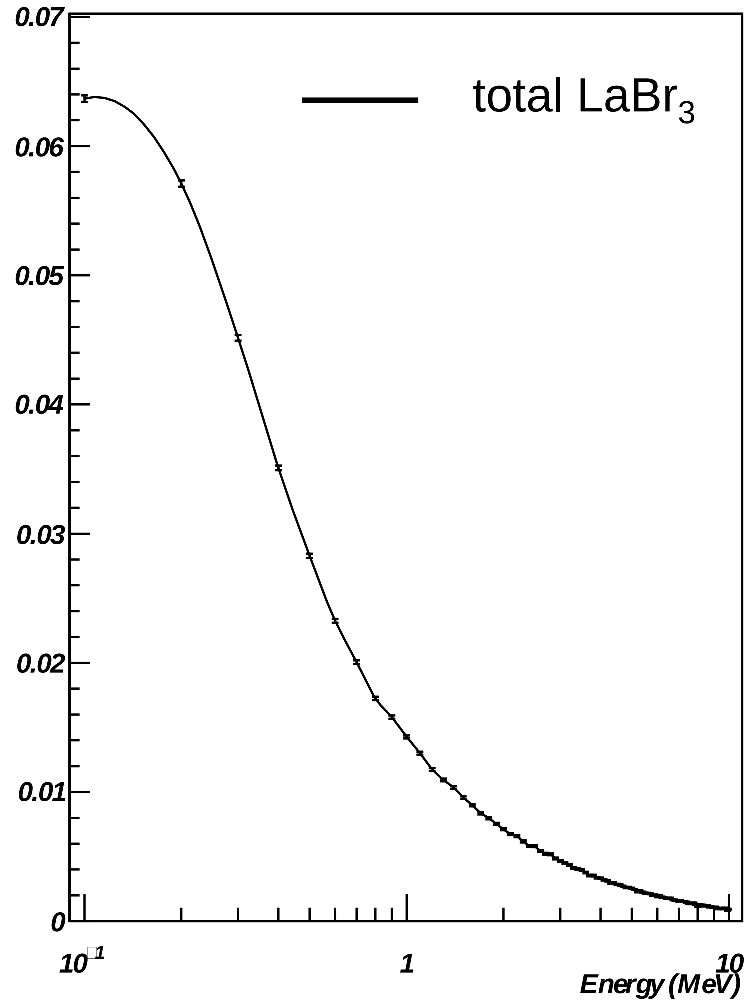
LICORNE

Future experiment: nu-ball @ ALTO

Efficiency for Ge clover array



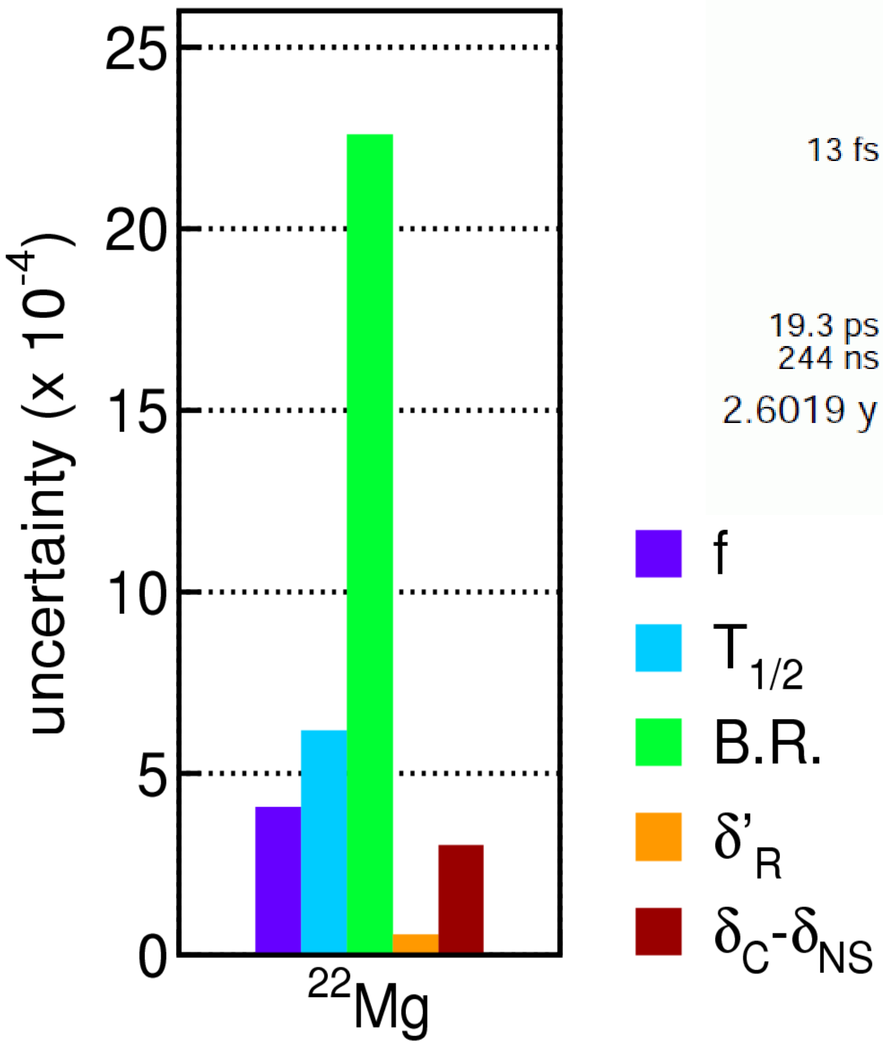
Efficiency for $LaBR_3$ array

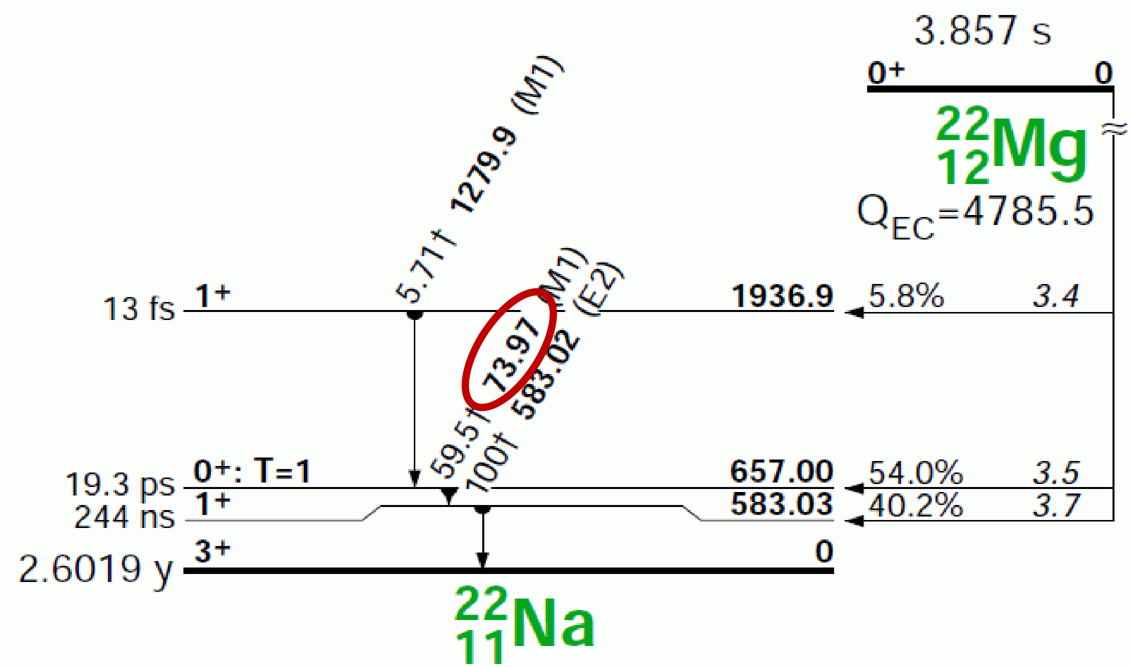


…scheduled for March 2017

Branching ratio and half-life at ISOLDE

Branching ratio of ^{22}Mg at ISOLDE





➔ Extent high-precision efficiency calibration below 100 keV

➔ ISOLDE rates: 8.0E+06 pps

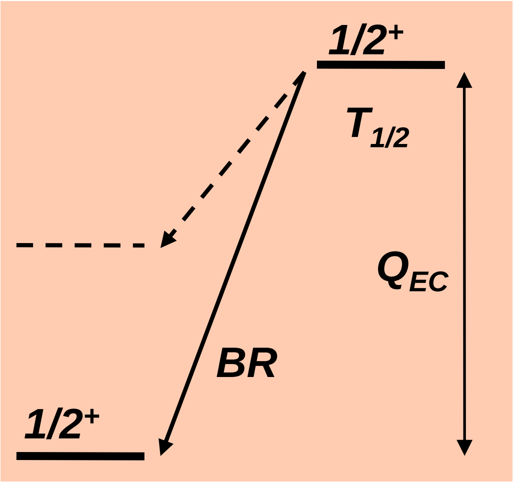
➔ Purification with LIST

➔ Purification with ISOLTRAP MR-TOF

… spring 2018

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

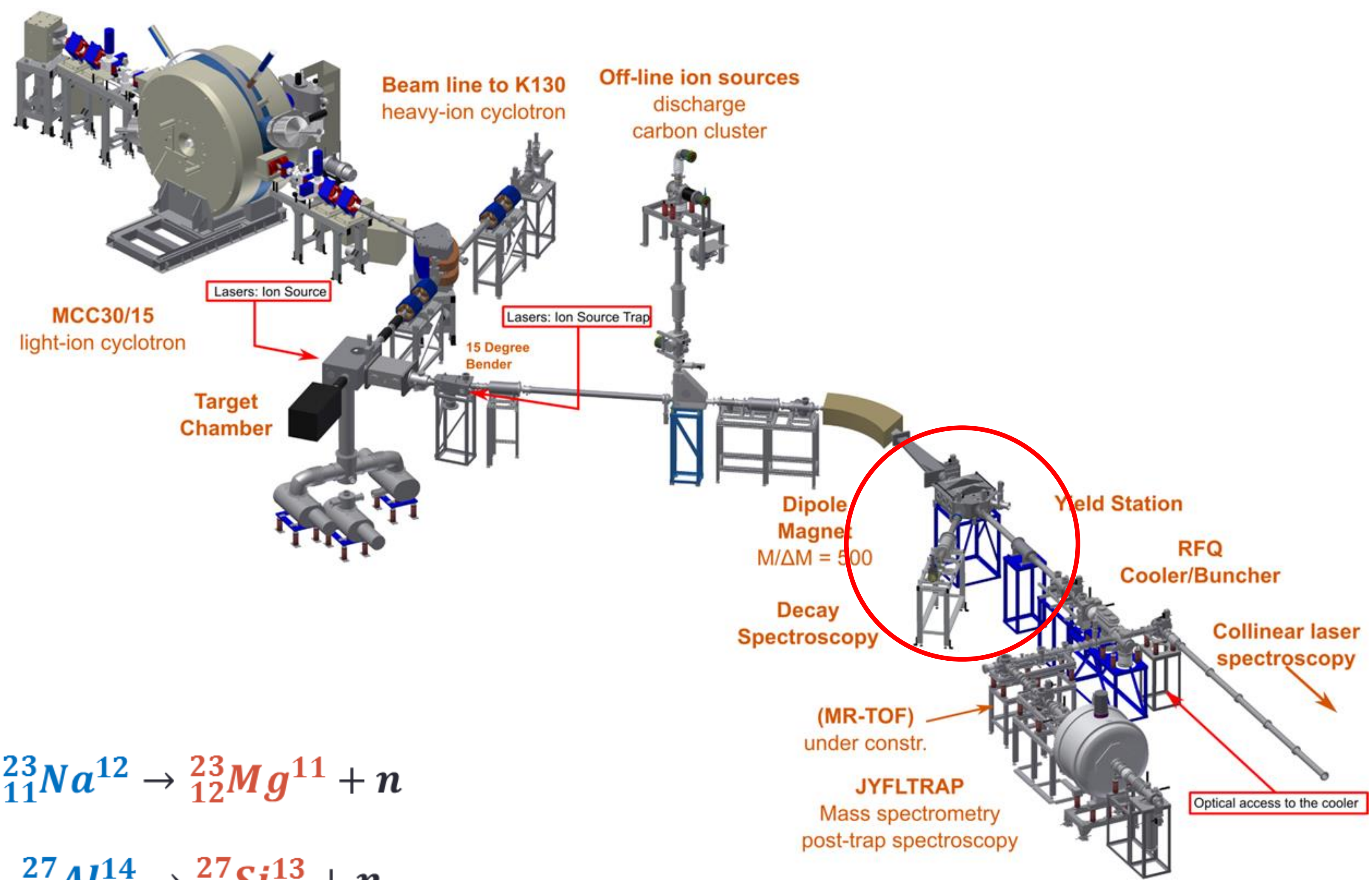
- correct for other interactions:

$$\mathcal{F}\mathrm{t}_0 = \mathrm{ft}(1+\delta'_R)(1+\delta_{NS}-\delta_C)\left(1+\frac{\mathrm{f_A}}{\mathrm{f_V}}\rho^2\right) = \frac{\mathrm{k}}{\mathrm{G_V^2} < \mathrm{M_F} >^2 (1+\Delta_R^V)}$$

- 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

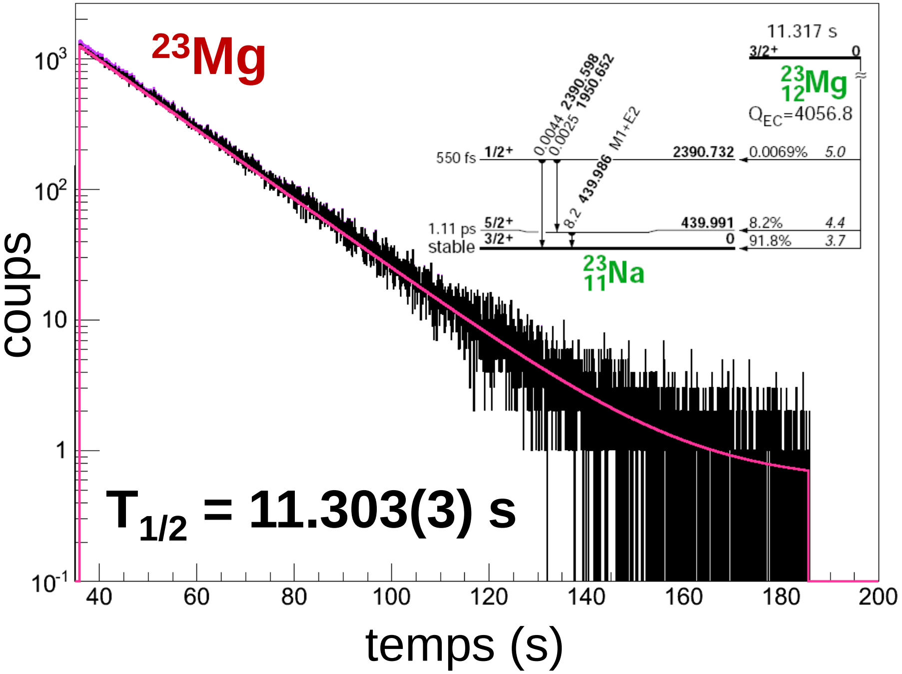


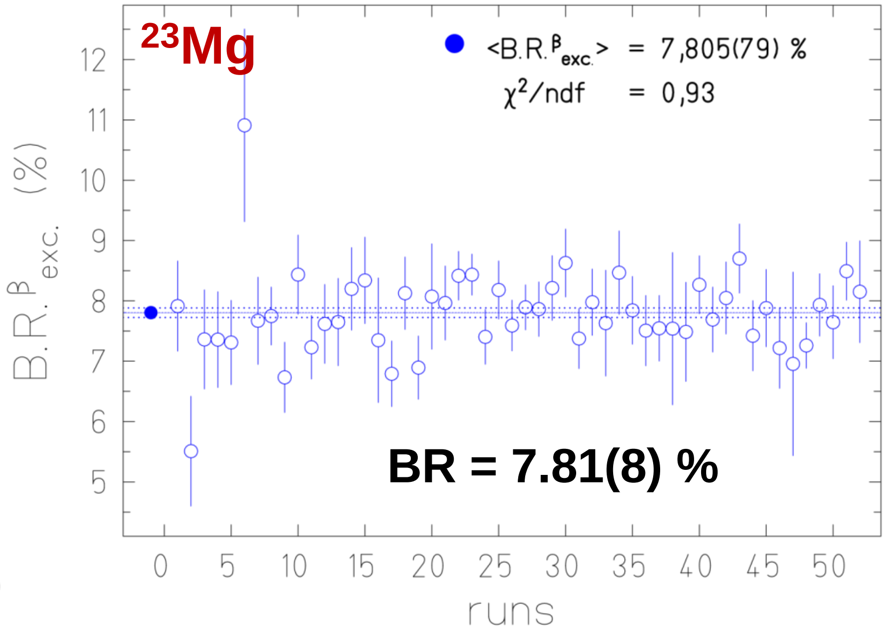
$$p + {}^{23}_{11}Na^{12} \rightarrow {}^{23}_{12}Mg^{11} + n$$

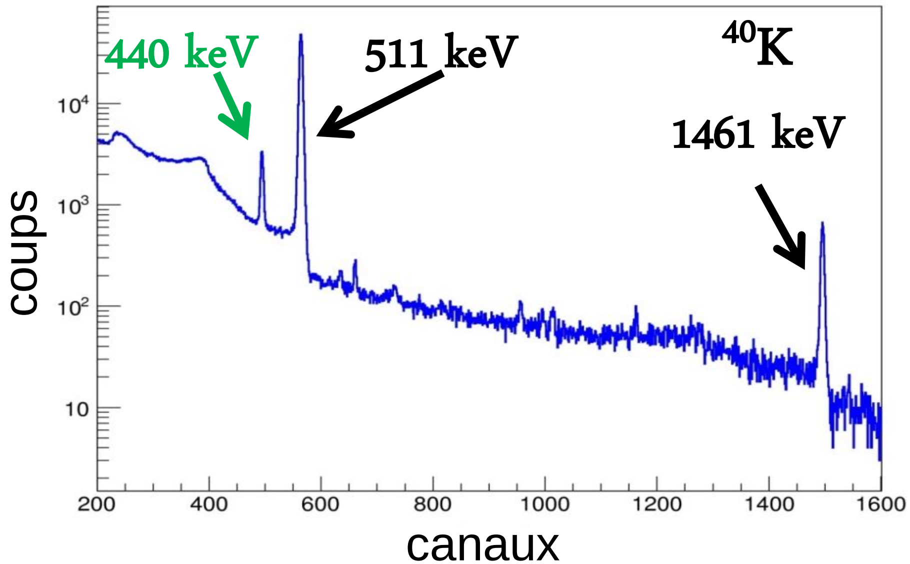
$$p + {}^{27}_{13}Al^{14} \rightarrow {}^{27}_{14}Si^{13} + n$$

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

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







^{23}Mg:

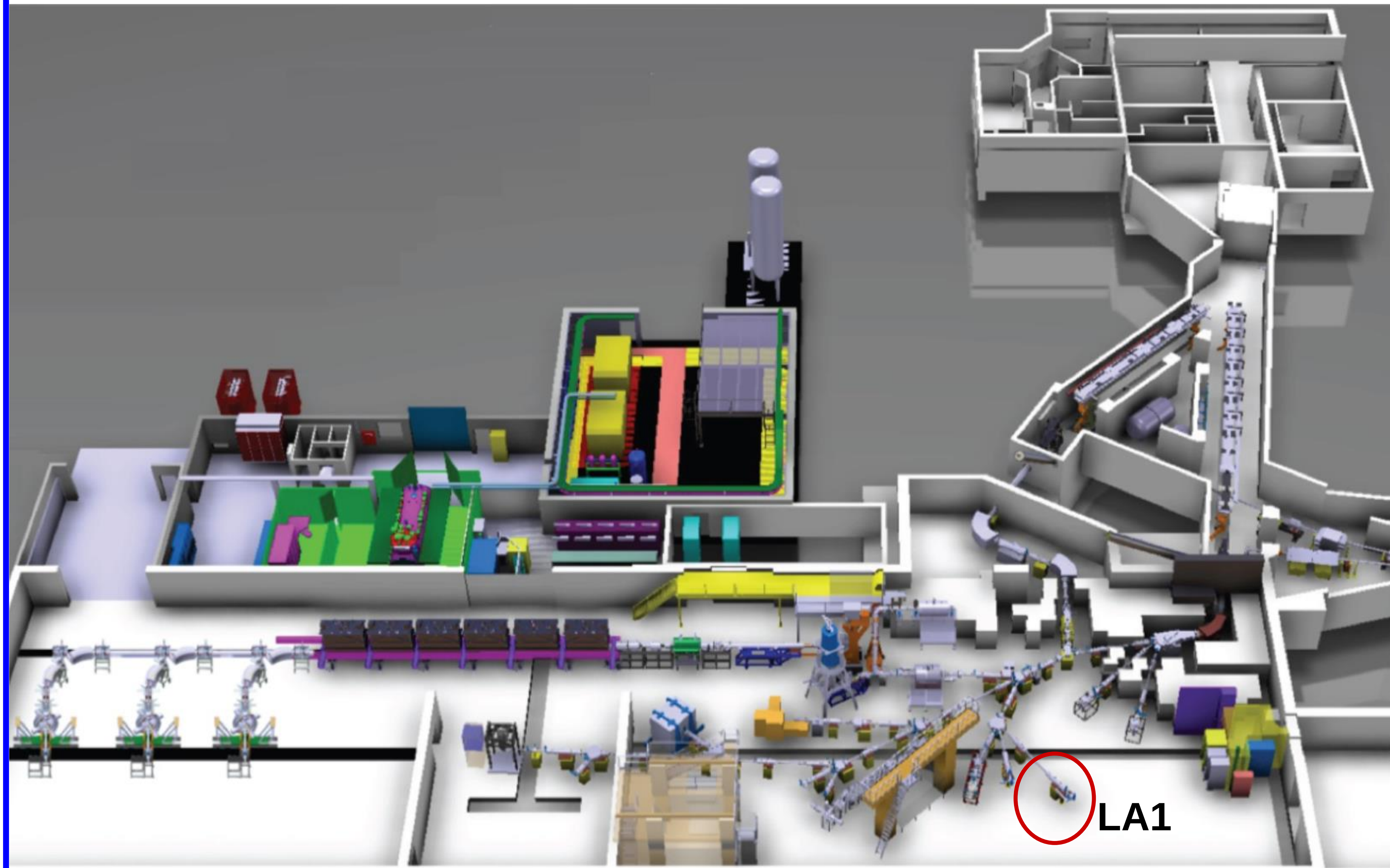
- $T_{1/2}$ = 11.303(3)s Lit. = 11.330(8)s
- BR = 7.81(8) % Lit. = 8.13(12) %
  - ➔ BR_{sa} = 92.07(14) %

^{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) %

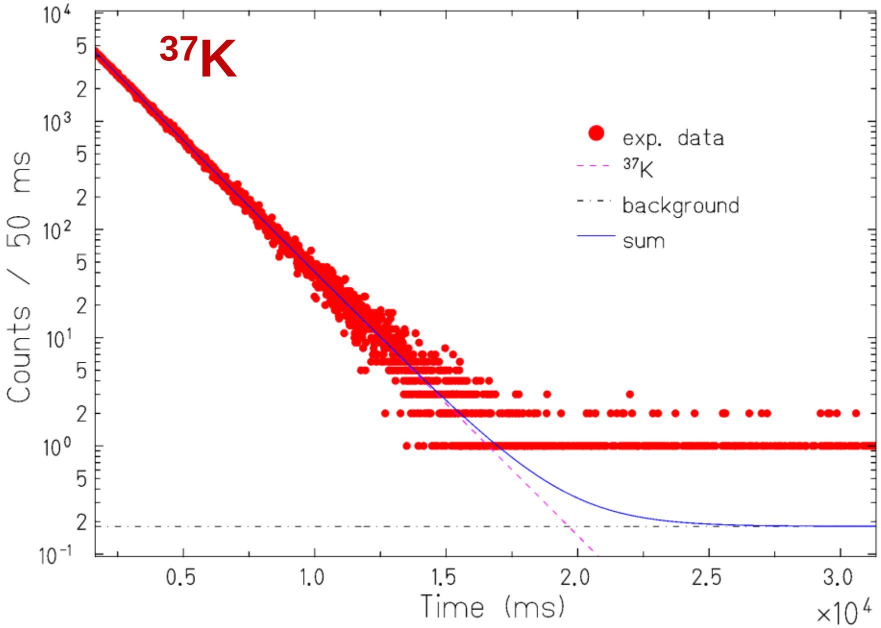
➔ **mixing ratio to be measured**

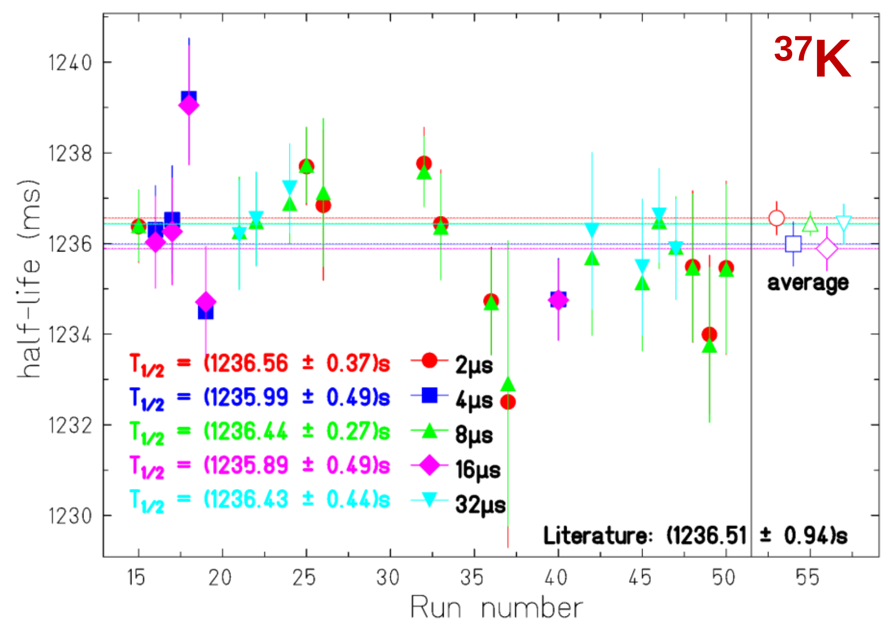
ISOLDE: ^{37}K

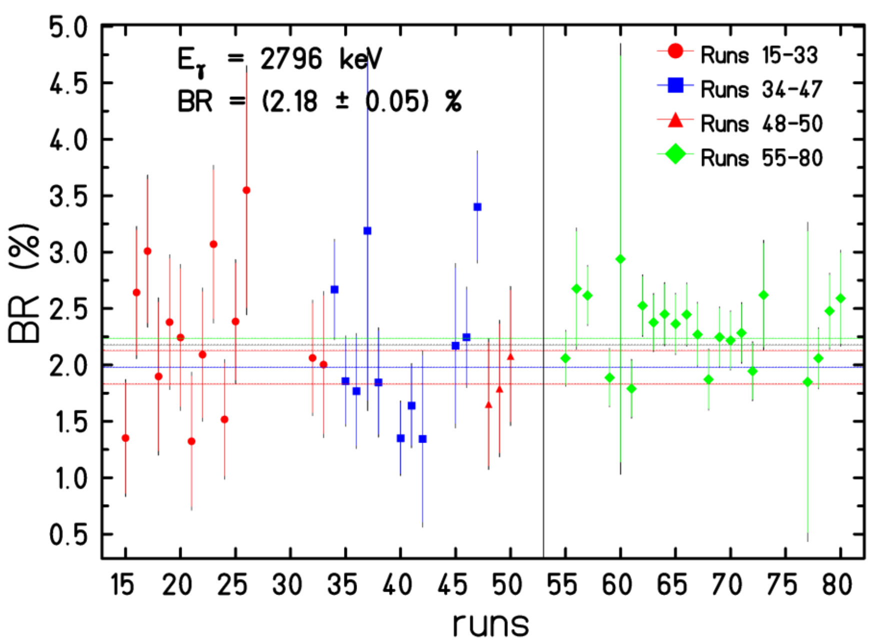


Nuclear mirror beta decay: ^{37}K at ISOLDE

T. Kurtukian Nieto et al.



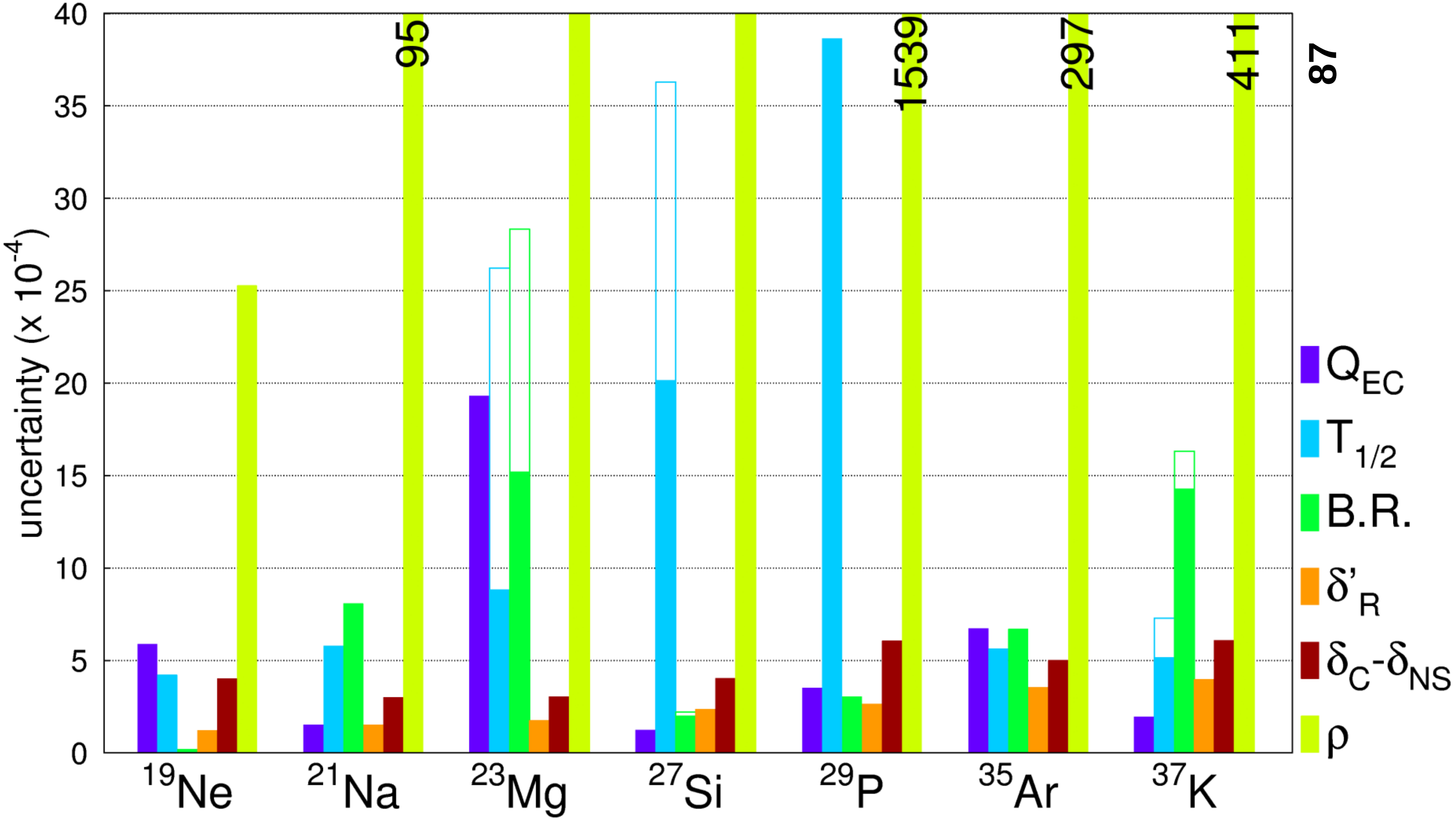




$T_{1/2} = 1.23635(88)$ s

BR = 97.96(14) %

Nuclear mirror beta decay: improvements



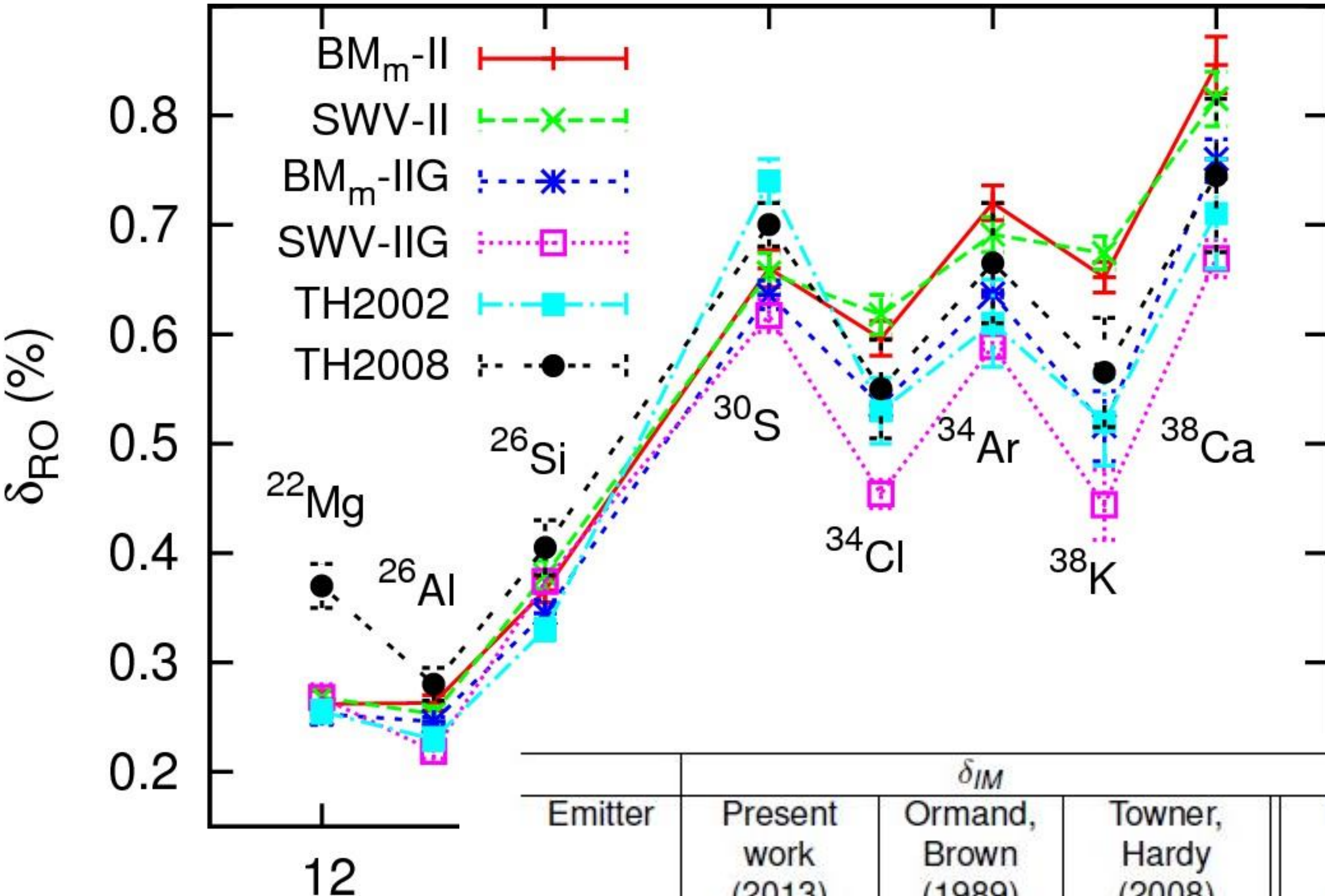
Recent measurements at GANIL:

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

Conclusions

- High-precision Germanium detector is available ($E\gamma$ <100 keV)
  - ➔ 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
- Search for physics beyond standard model: ^{10}C
- Improve theoretical corrections…. work on-going at CENBG (N. Smirnova et al.)

Theoretical corrections (*sd* shell)



	δ_{IM}			*Ft*	
Emitter	Present work (2013)	Ormand, Brown (1989)	Towner, Hardy (2008)	Present work (2013)	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)

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

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

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

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

  (N. Smirnova et al.)

Thanks for your attention

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