Beta-decay studies to explore physics beyond the weak-interaction standard model

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CENBG

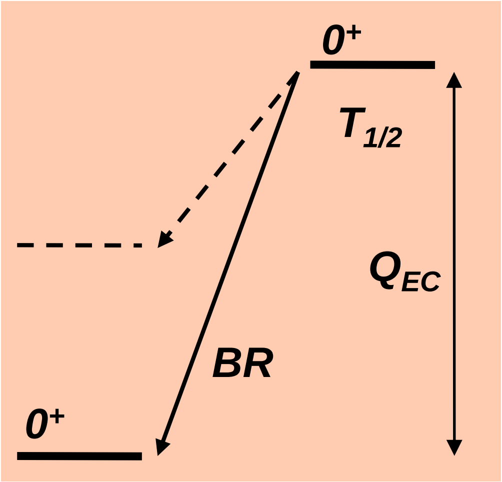
CNRS IN2P3 Les deux infinis

université de BORDEAUX

- THE Germanium detector
- Experimental studies: 0^+ - 0^+ β decay
- future work

ISOLDE Workshop and Users Meeting
14-16 December 2021

Nuclear 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 $0^+ \rightarrow 0^+$ transitions: only vector current due to selection rules
$$\mathrm{ft} = \frac{\mathrm{k}}{\mathrm{G_V^2} < \mathrm{M_F} >^2}$$

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

- correct for other interactions:

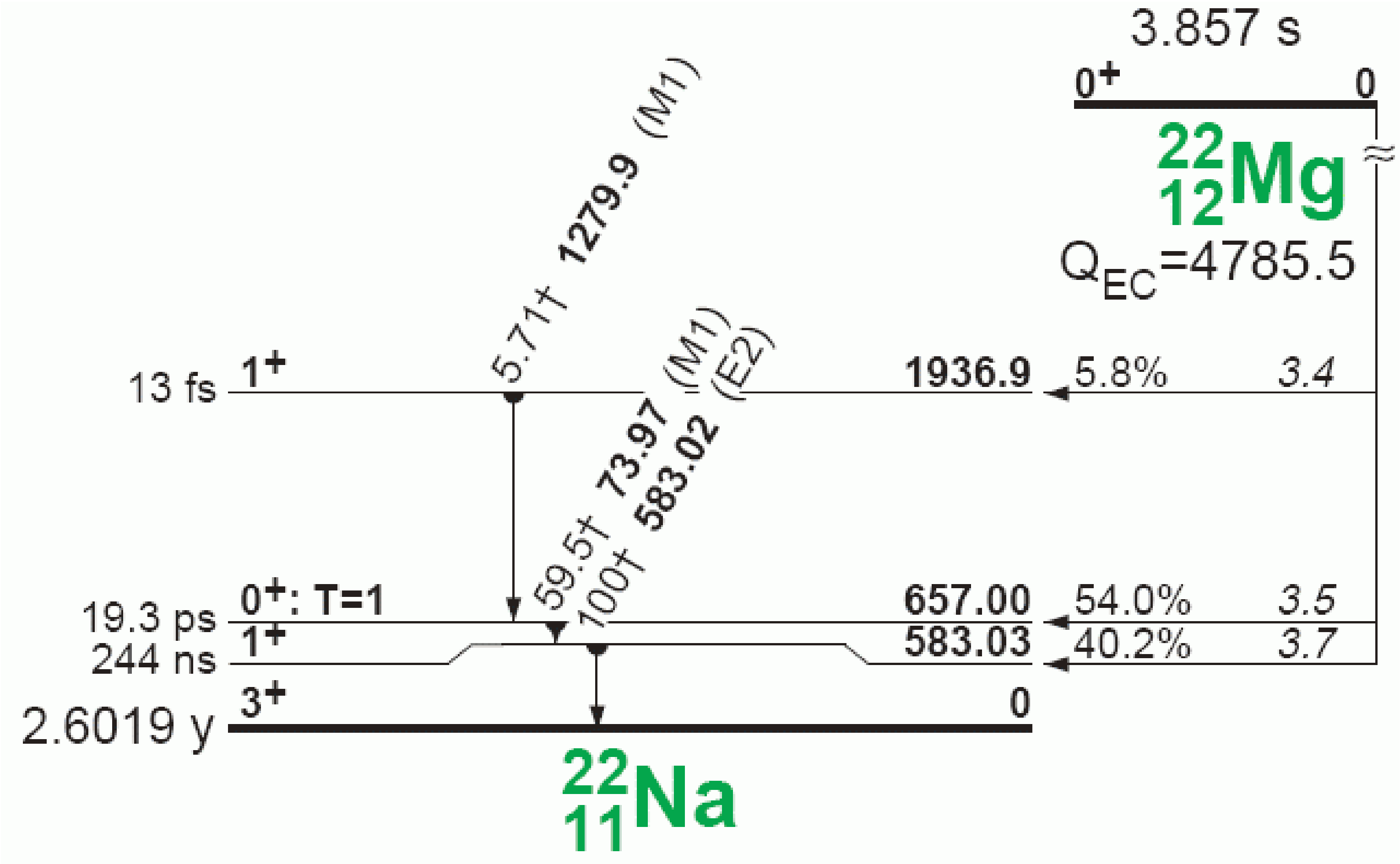
$$\mathcal{F}\mathrm{t} = \mathrm{ft}(1+\delta'_R)(1+\delta_{NS}-\delta_C) = \frac{\mathrm{k}}{\mathrm{G_V^2} < \mathrm{M_F} >^2 (1+\Delta_R^V)}$$

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

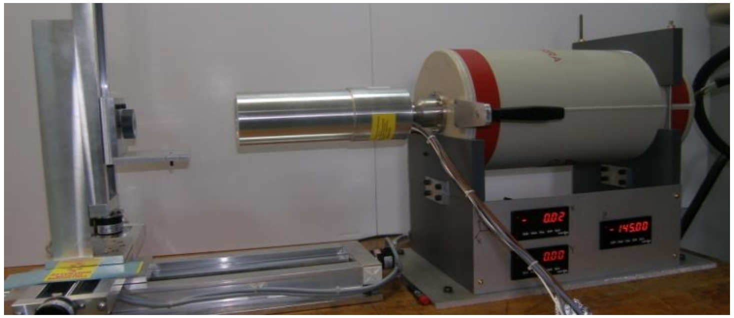


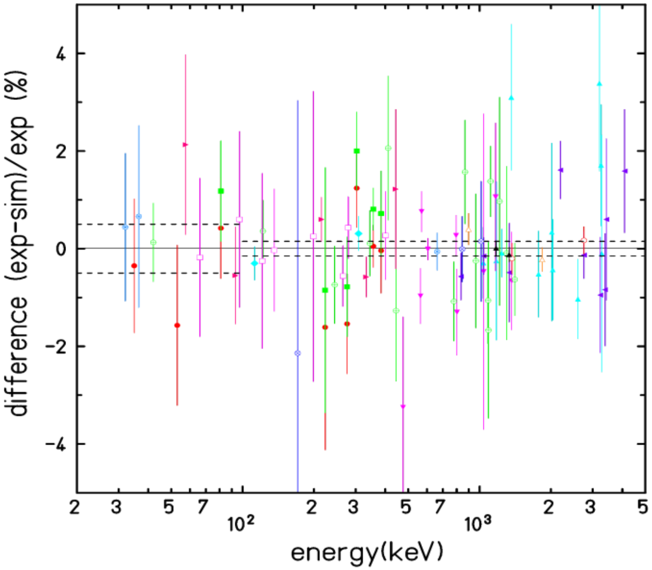
- many decay channels open
- strong non-analog transitions
- low decay energies
- high precision of γ efficiency needed ➔ 0.1%

Calibration of germanium detector

- calibration programme of a HP Ge detector:

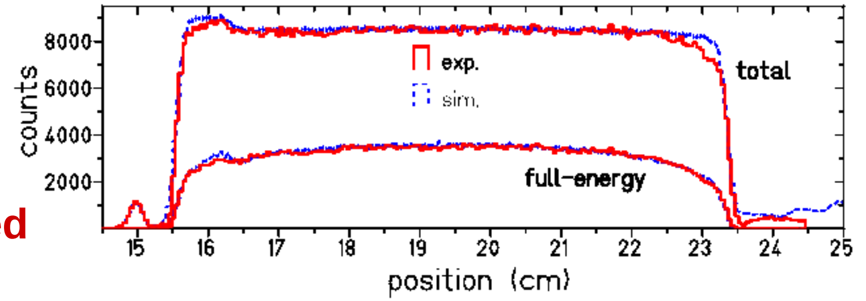
- x-ray photography of detector
- scan of the crystal at CSNSM
- source measurements
- MC simulations: CYLTRAN, GEANT4

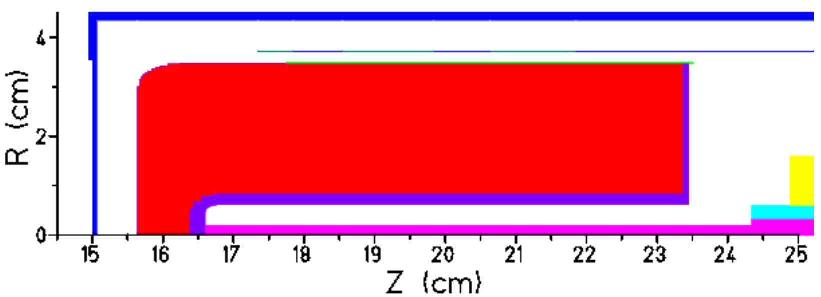




X-ray photography

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

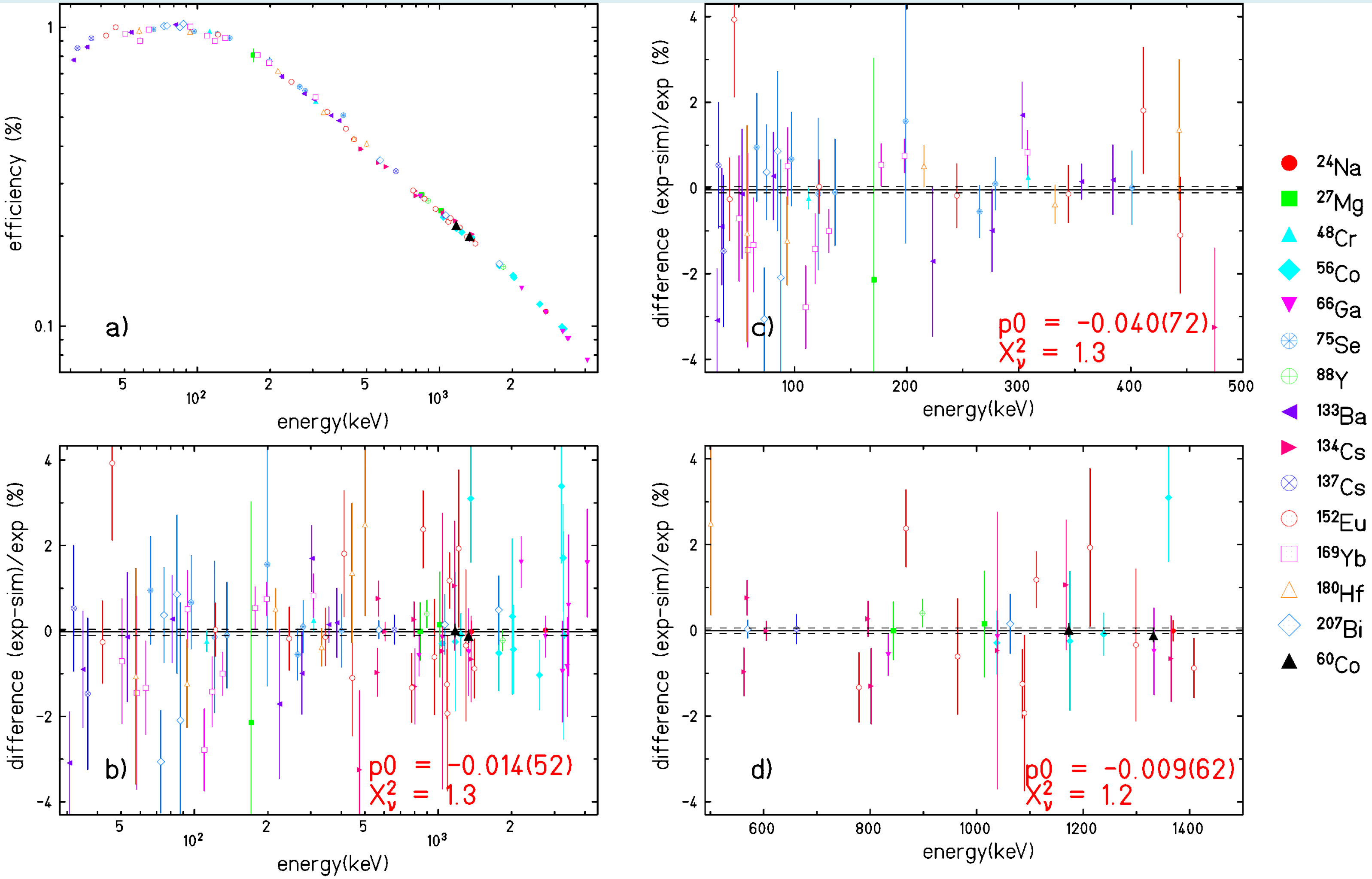
Peak/total: ^{22}Na, ^{41}Ar, ^{51}Cr, ^{54}Mn, ^{57}Co, ^{58}Co, ^{60}Co, ^{65}Zn, ^{85}Sr, ^{137}Cs …ISOLDE, IPNO sources

$\Delta\varepsilon_{rel} = 0.1\%$, $\Delta\varepsilon_{abs} = 0.15\%$

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

Additional calibration of germanium detector: preliminary

B. Blank et al., NIMA984 (2020) 164631

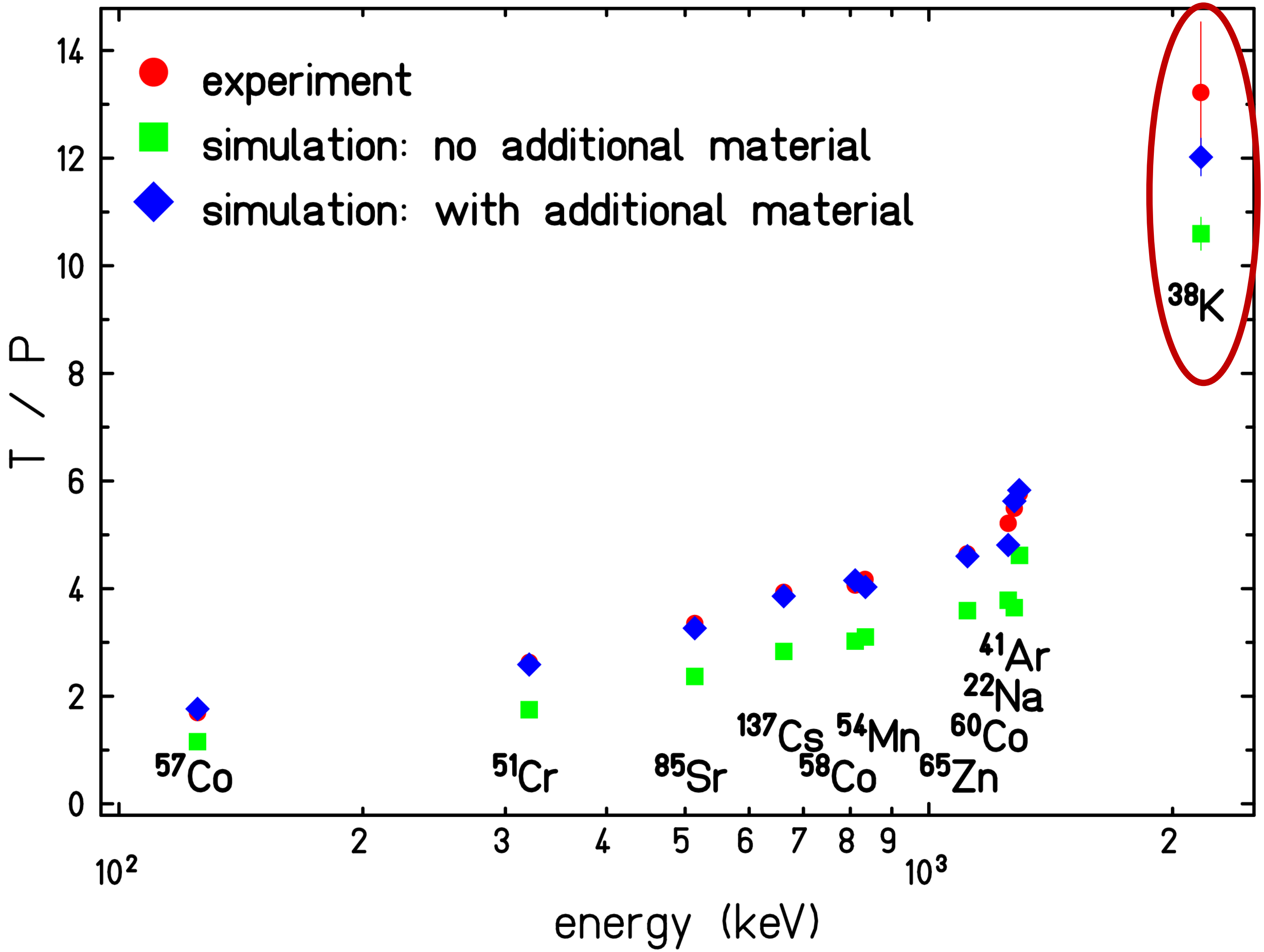


Newly added: ^{38}K, ^{169}Yb

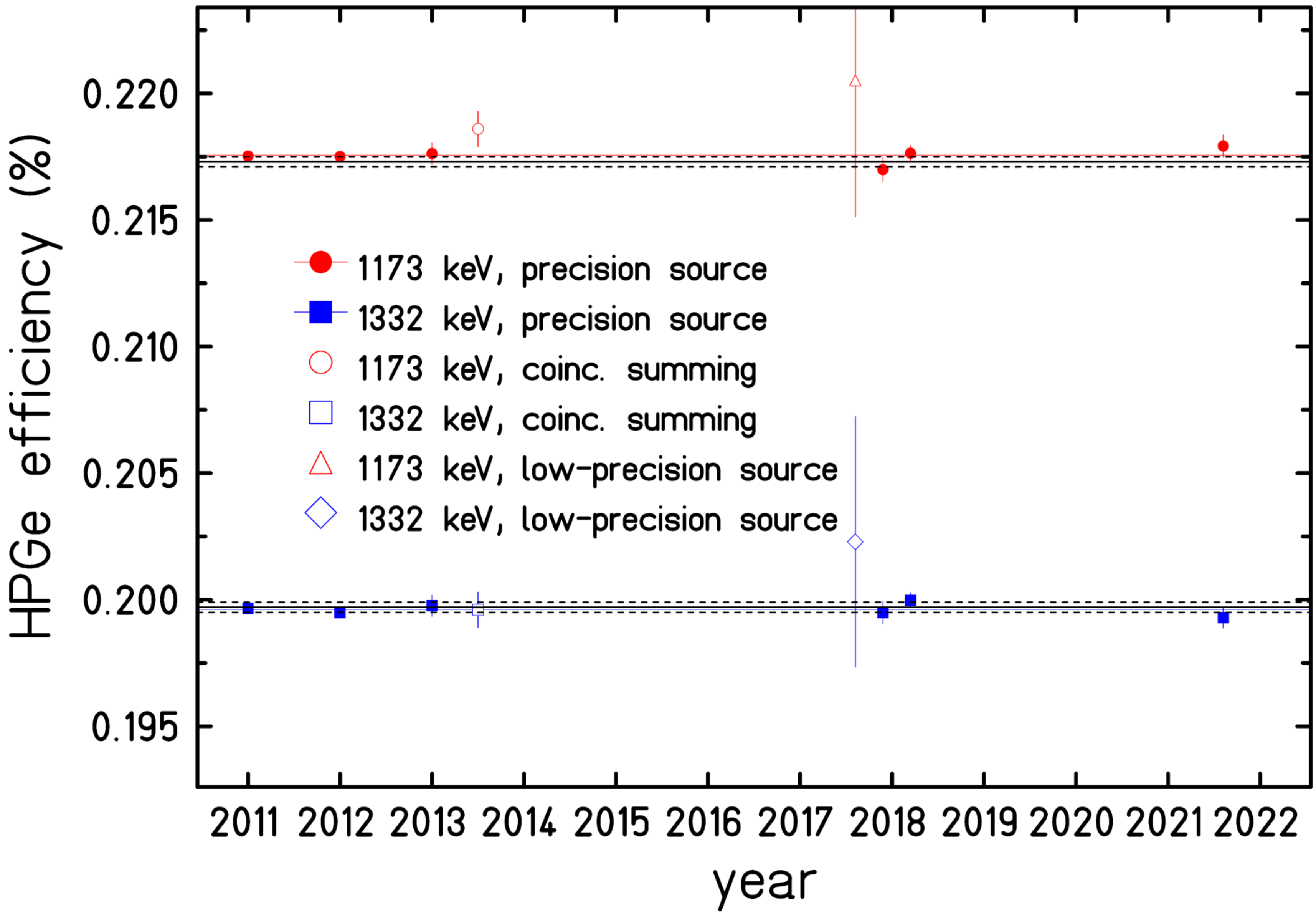
Improved: ^{48}Cr, ^{24}Na, ^{48}Cr (add. meas.), ^{207}Bi (new analysis)
^{75}Se, ^{133}Ba, ^{137}Cs, ^{152}Eu, ^{180}Hf (higher statistics simulations)

➔ ➔ 0.15 % precision for E < 100keV

Peak-to-total

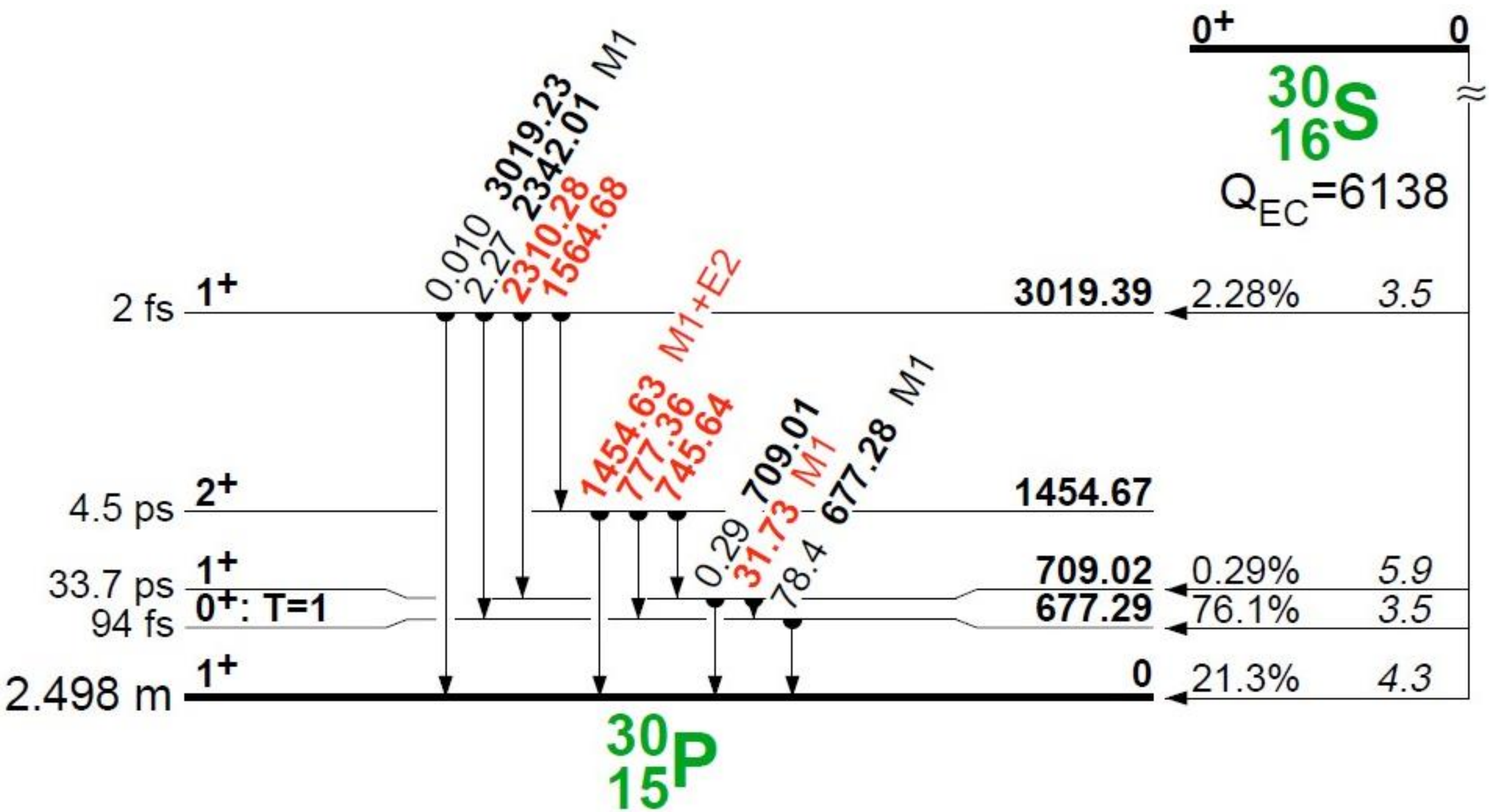


Long-term stability of germanium detector: ^{60}Co

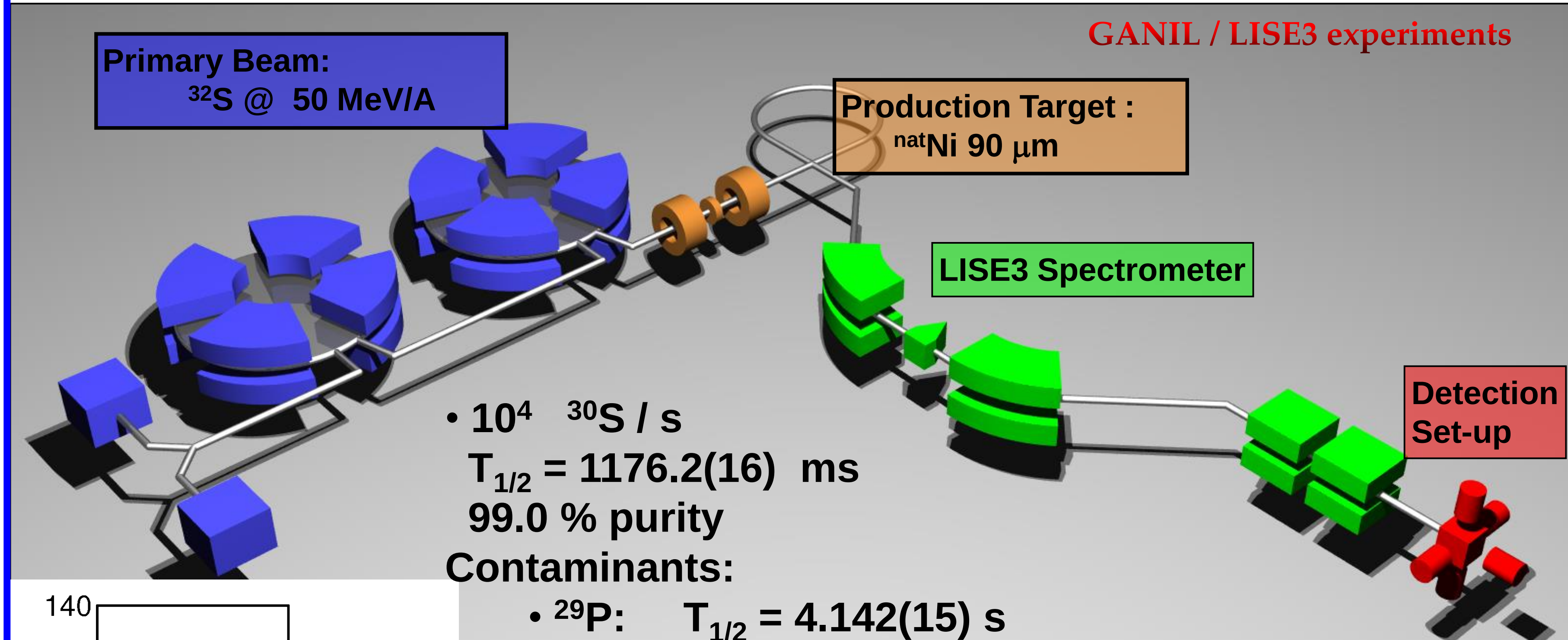


0^+ - 0^+ β decay: ^{30}S

Super-allowed Fermi transitions for $T_z = -1$



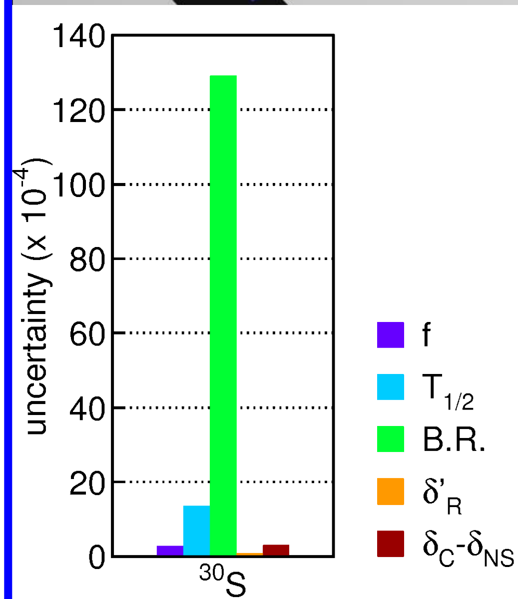
^{30}S production at GANIL/LISE3

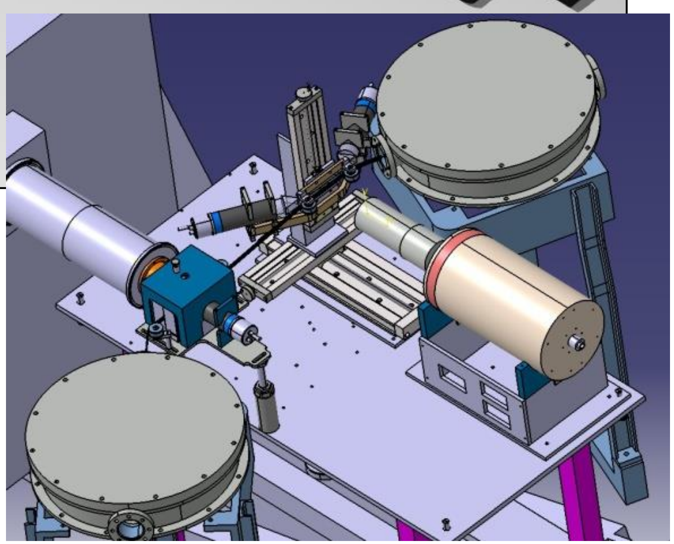


- 10^4 ^{30}S / s
  $T_{1/2}$ = 1176.2(16) ms
  99.0 % purity

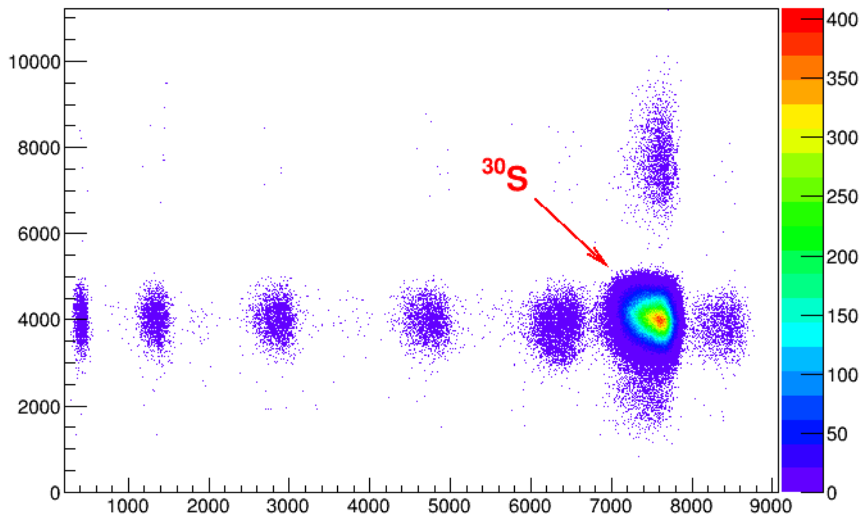
Contaminants:

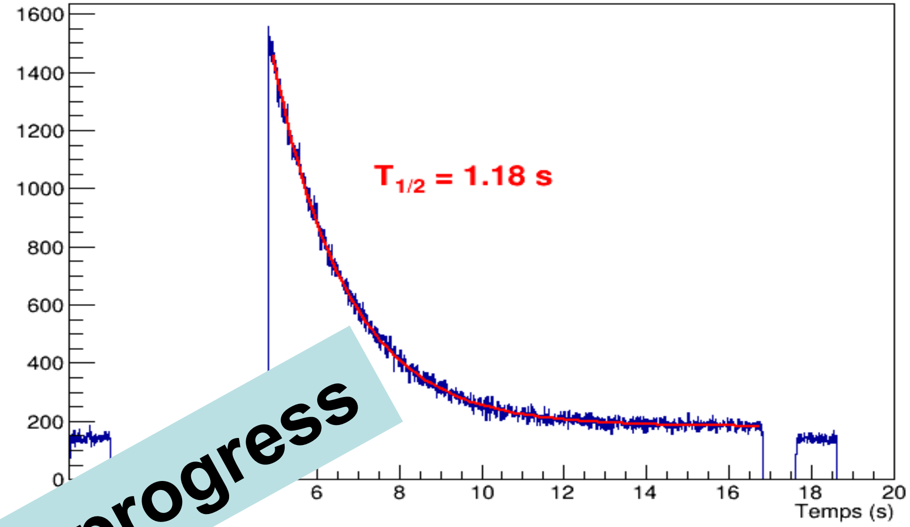
- ^{29}P: $T_{1/2}$ = 4.142(15) s
- ^{28}Si: stable
- ^{27}Al: stable
- ^{26}Mg: stable

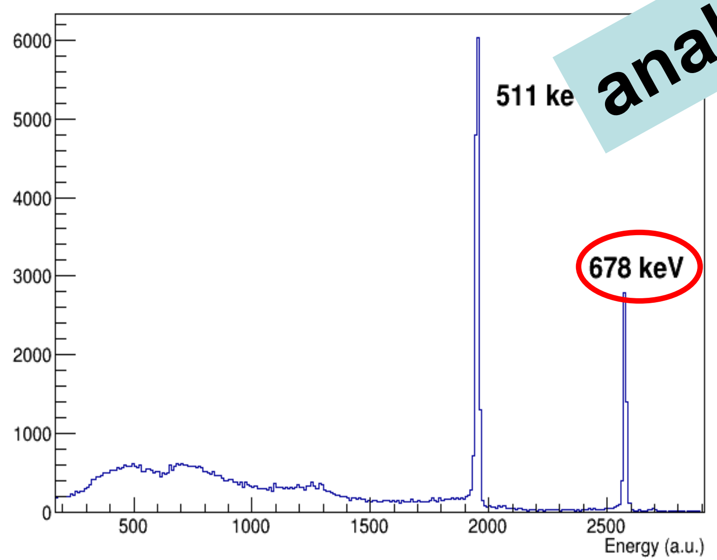


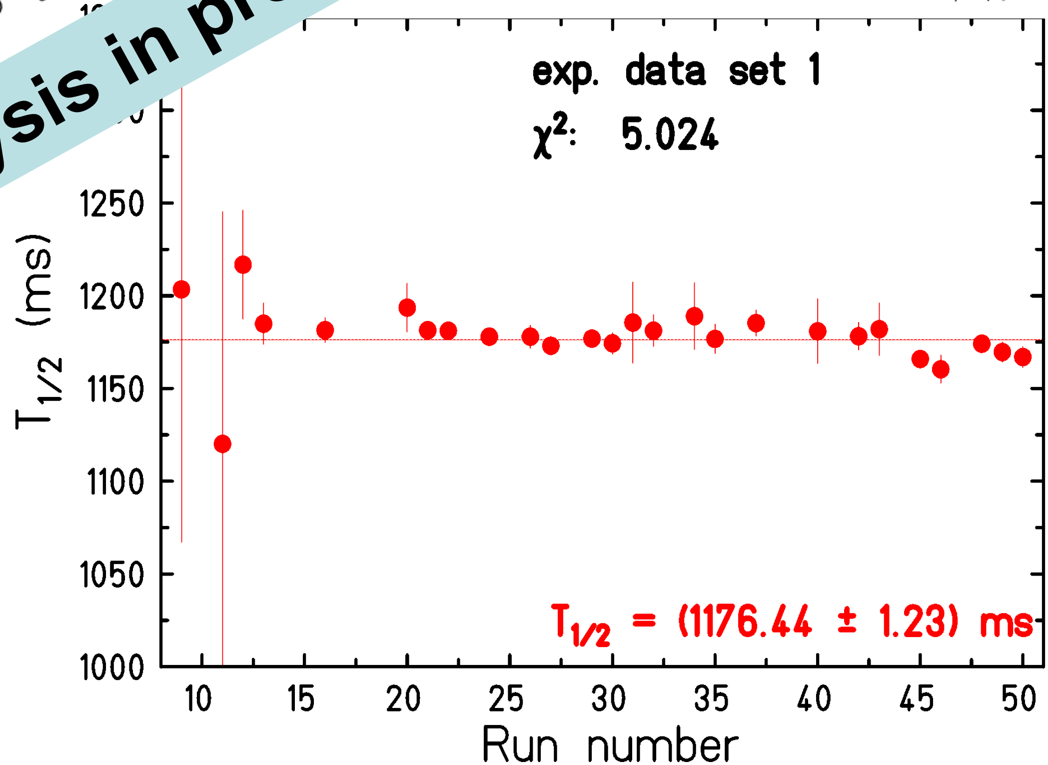


^{30}S: very preliminary result





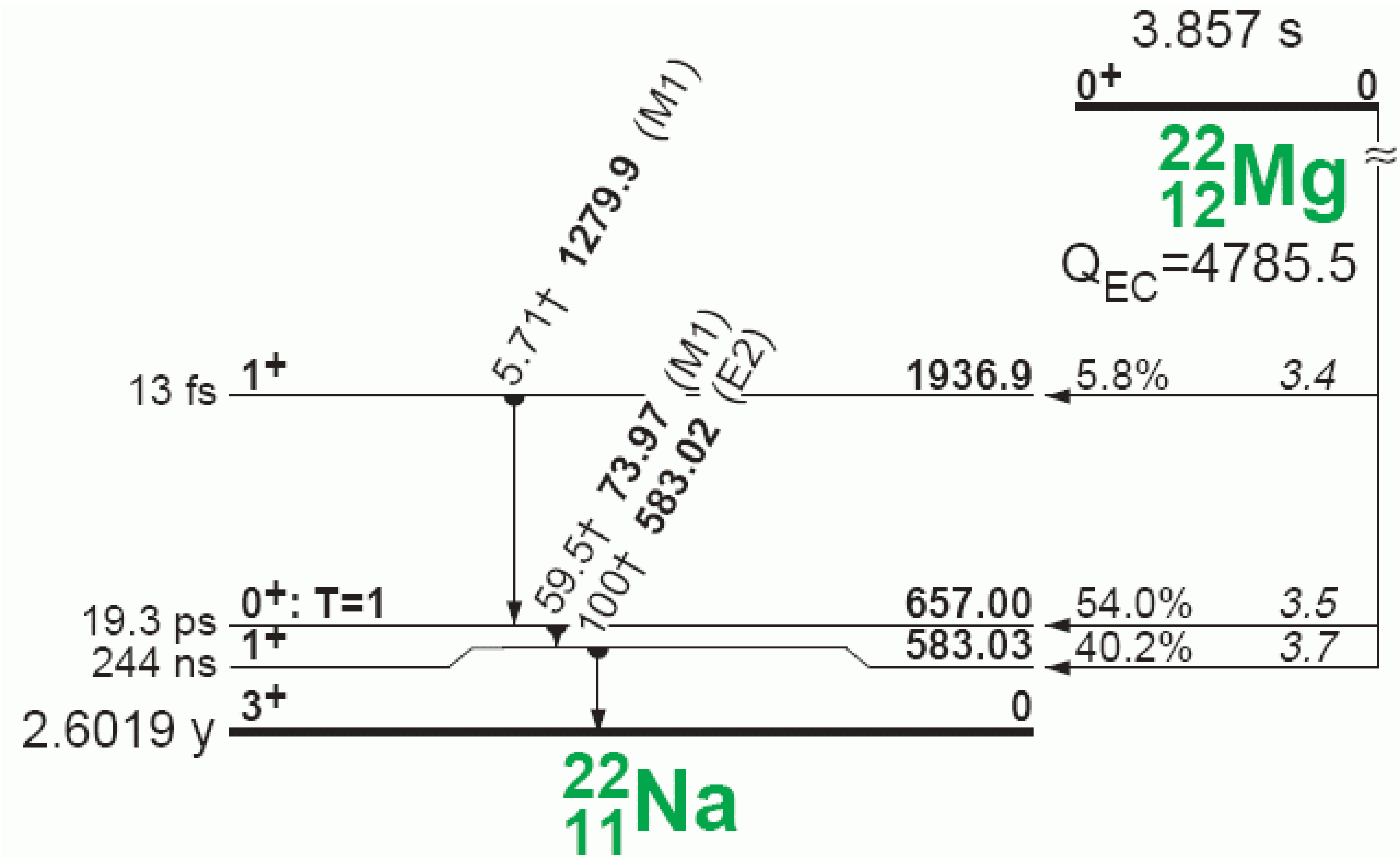




analysis in progress

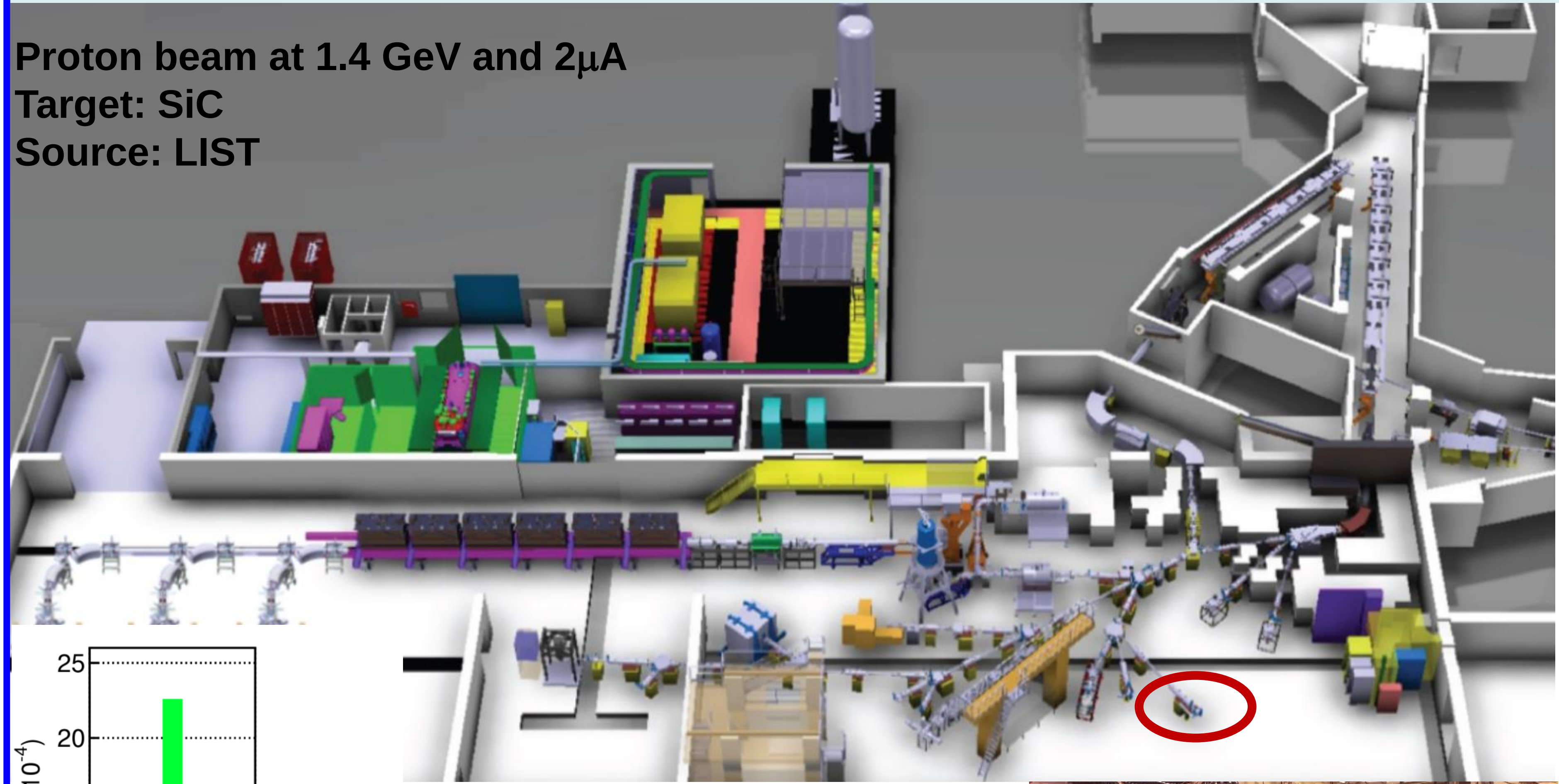
0^+ - 0^+ β decay: ^{22}Mg

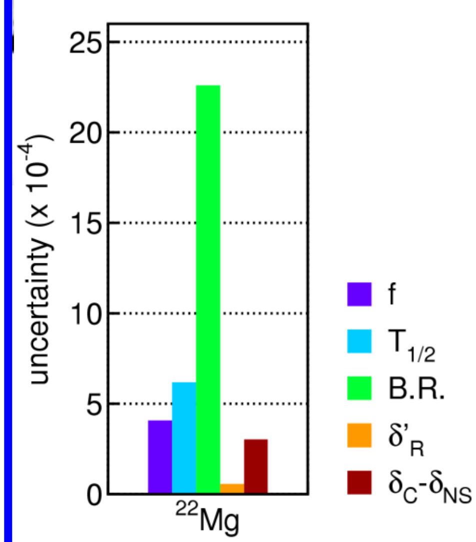
Super-allowed Fermi transitions for $T_z = -1$



^{22}Mg measurement at ISOLDE

Proton beam at 1.4 GeV and 2μA
Target: SiC
Source: LIST



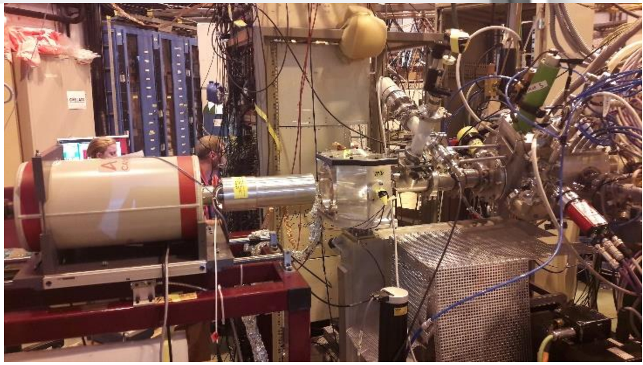


- **ISOL: lots of ^{22}Na**

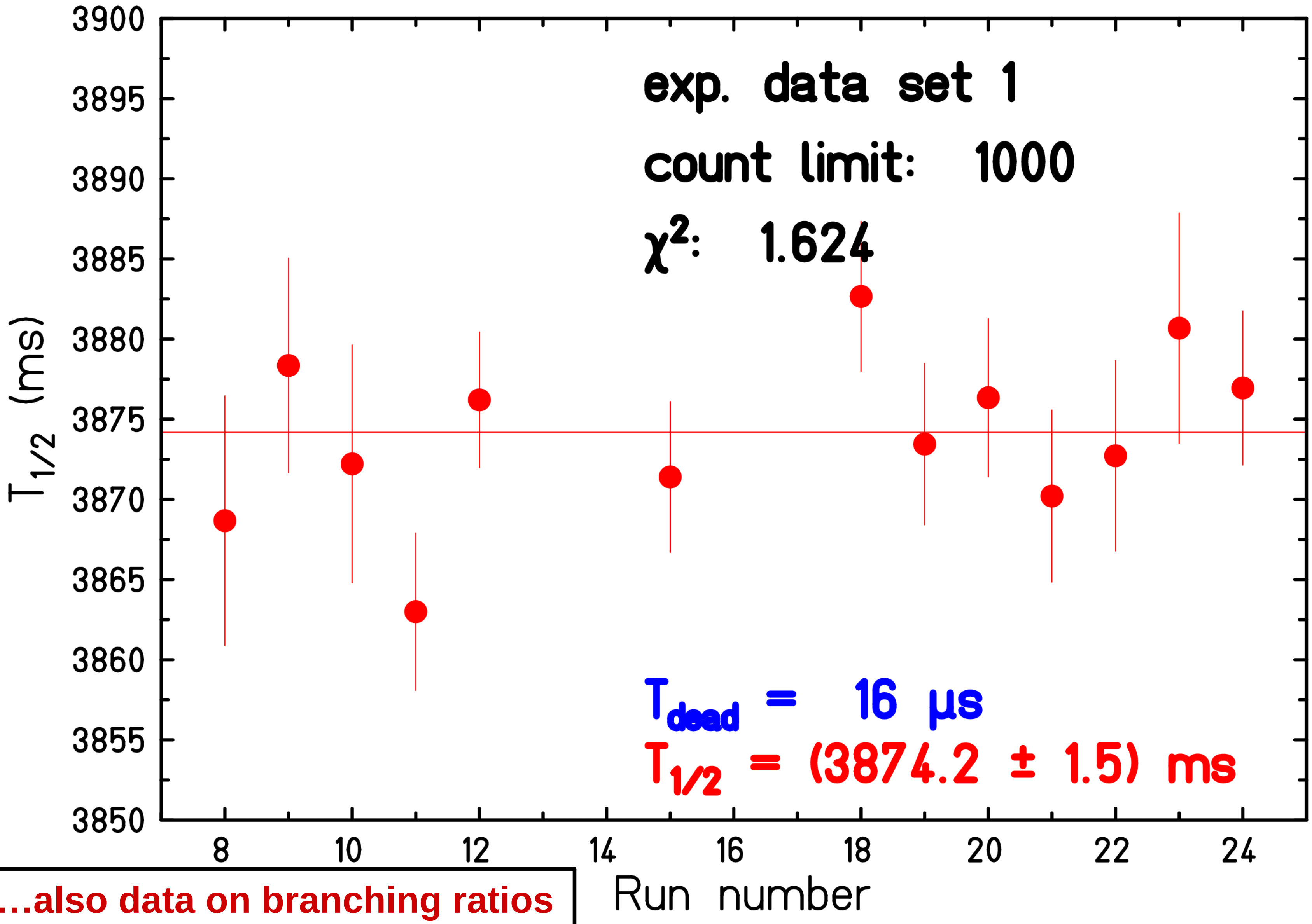
➔➔ LIST technique

➔➔ no measurable ^{22}Na

- **trigger - less DAQ**



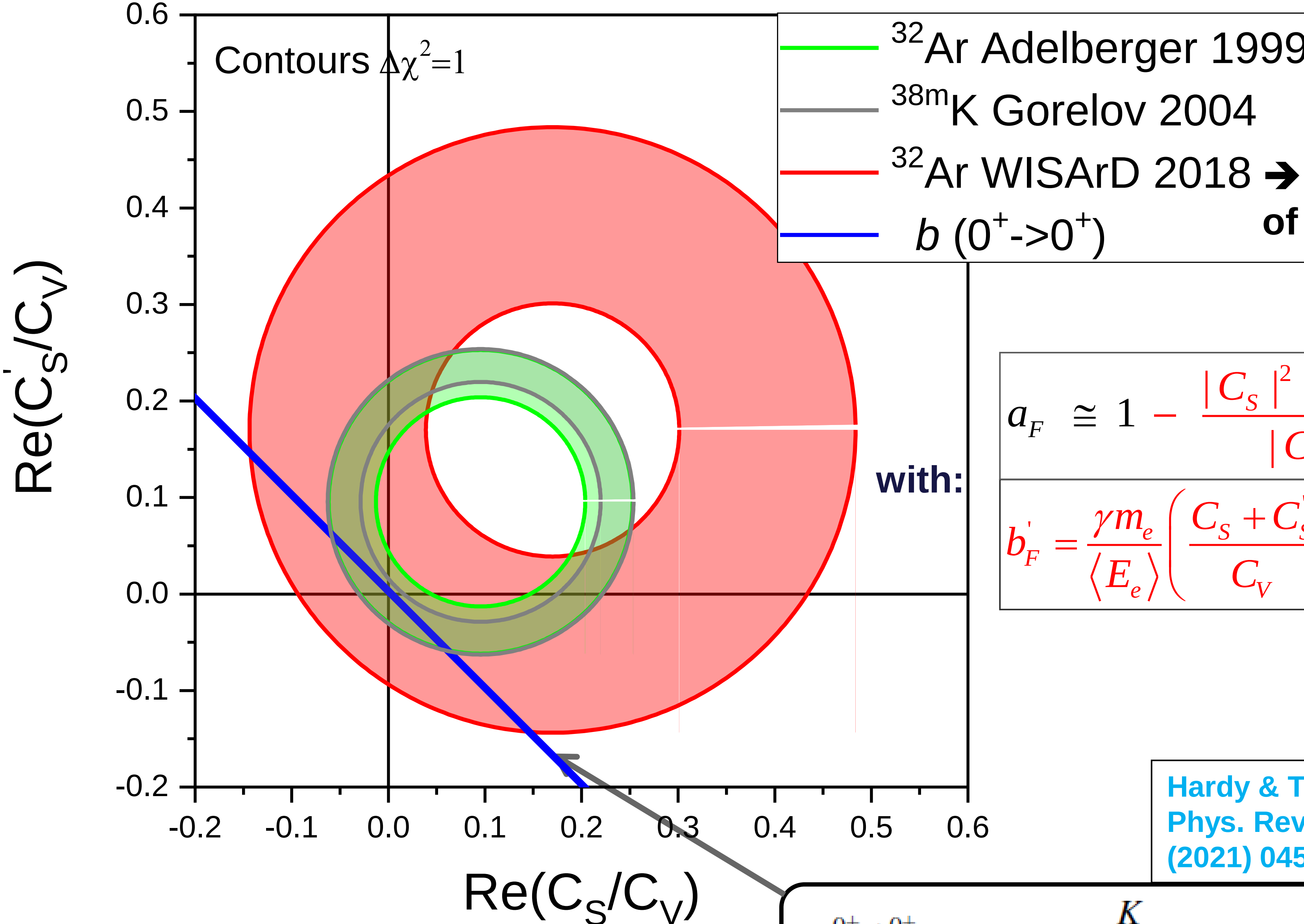
^{22}Mg: very preliminary result



…also data on branching ratios
…to be analysed

0^+ - 0^+ β decay: ^{10}C at ISOLDE

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



→ **Talk of F. Cresto**

with:

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

$$b_F' = \frac{\gamma m_e}{\langle E_e \rangle}\left(\frac{C_S + C_S'}{C_V}\right)$$

Hardy & Towner, Phys. Rev. C 102 (2021) 045501

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

0⁺ → 0⁺ decays: limits on exotic currents

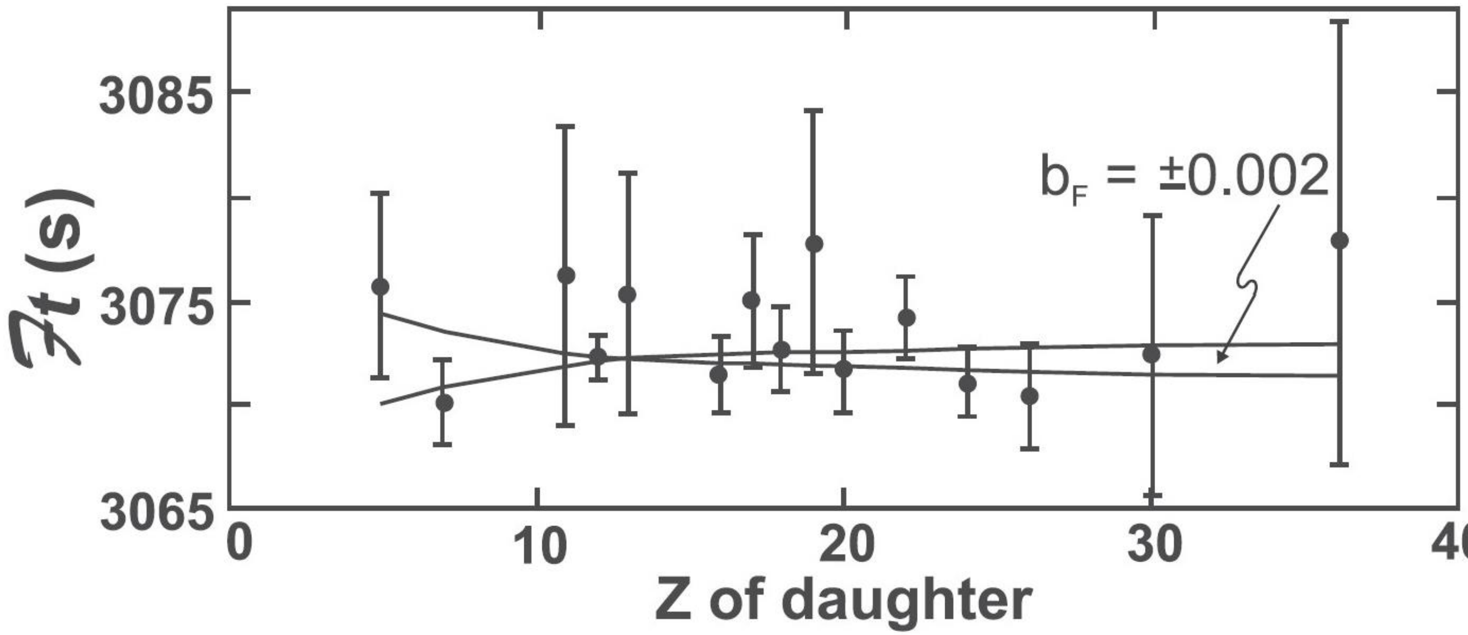
standard model assumption: only vector current

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

from β decay: $b_F = -0.000 \pm 0.002$

➔➔ improve on low-Z nuclei

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



Hardy & Towner, 2020

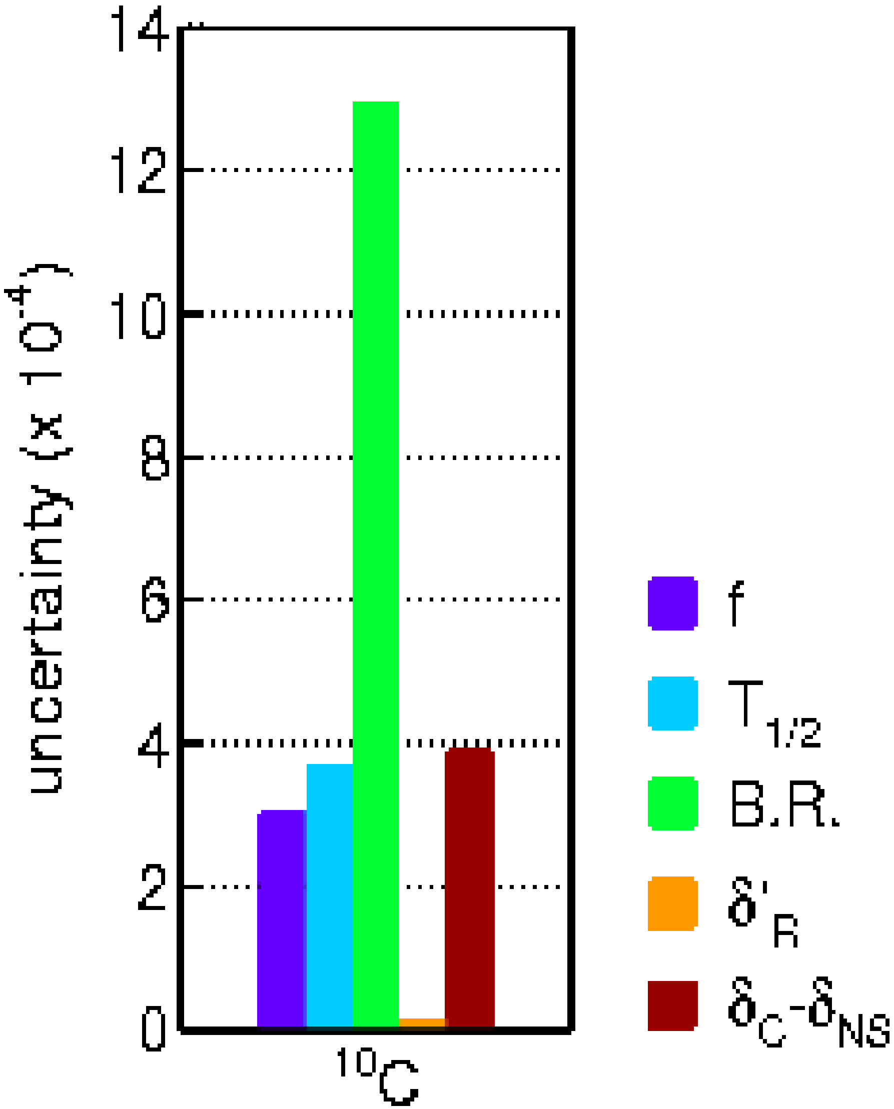
0⁺ → 0⁺ decays: ^{10}C error budget

- 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)

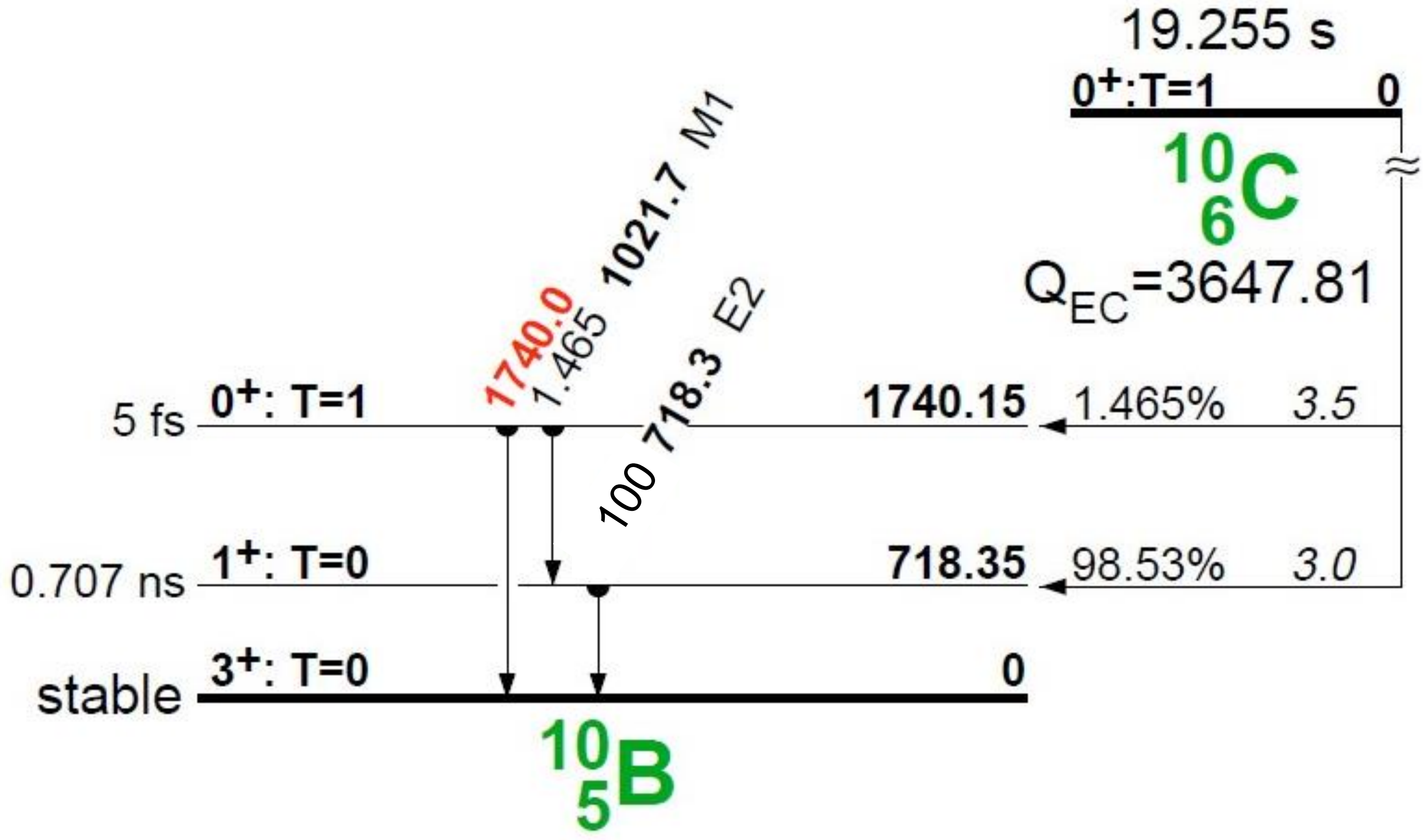
  → measurements with Ge multi-detector array

our approach:

experiment with our single-crystal Ge detector

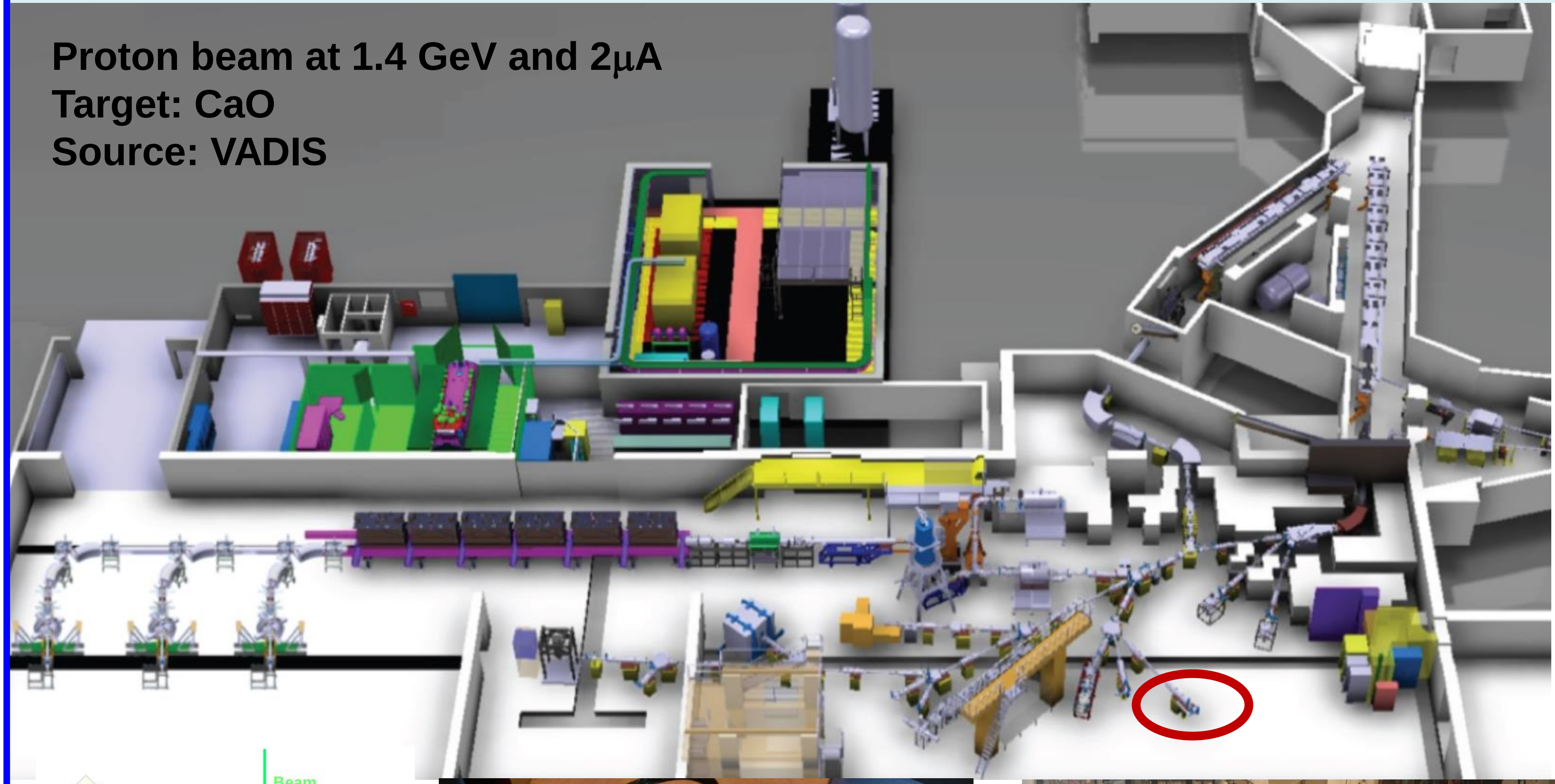


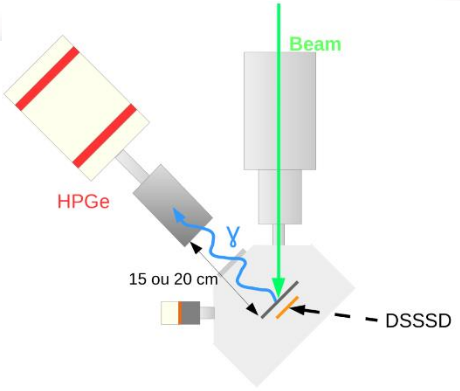
Super-allowed Fermi transitions for $T_z = -1$

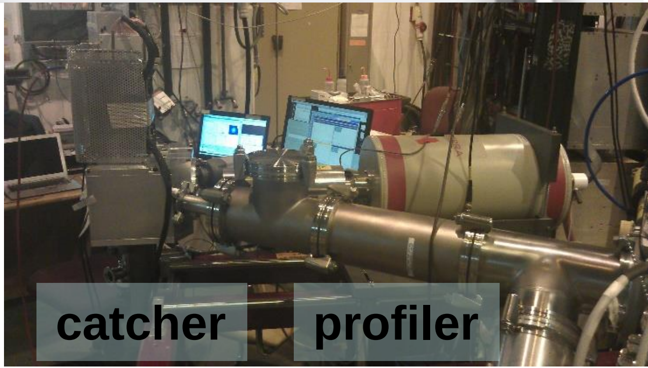


^{10}C measurement at ISOLDE

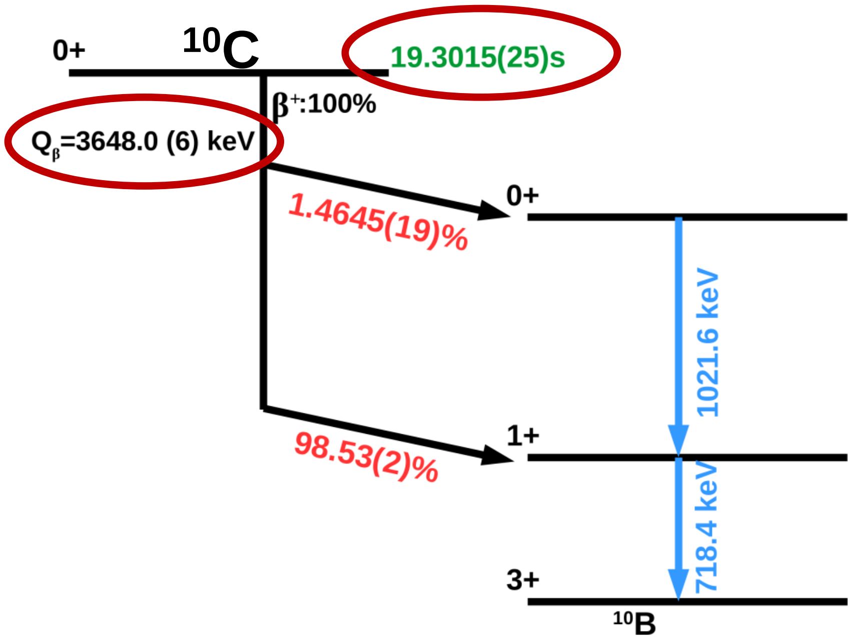
Proton beam at 1.4 GeV and 2μA
Target: CaO
Source: VADIS



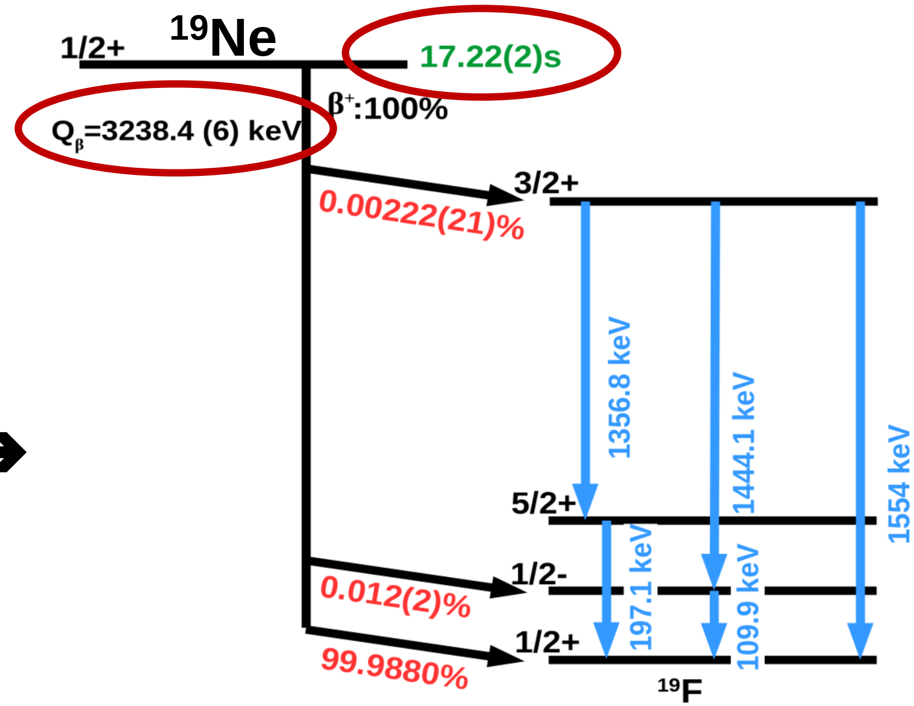




$^{10}C/^{19}Ne$ decay scheme

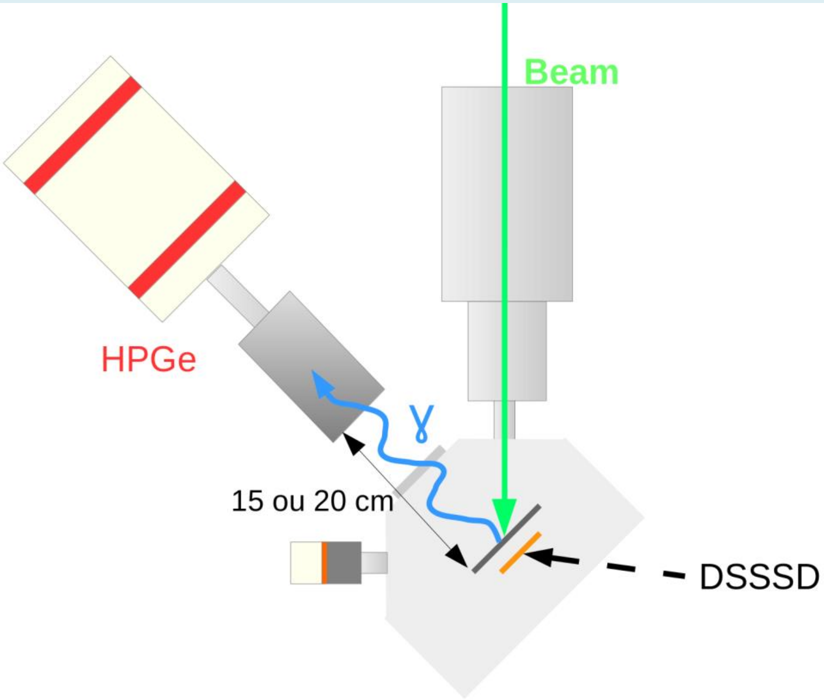


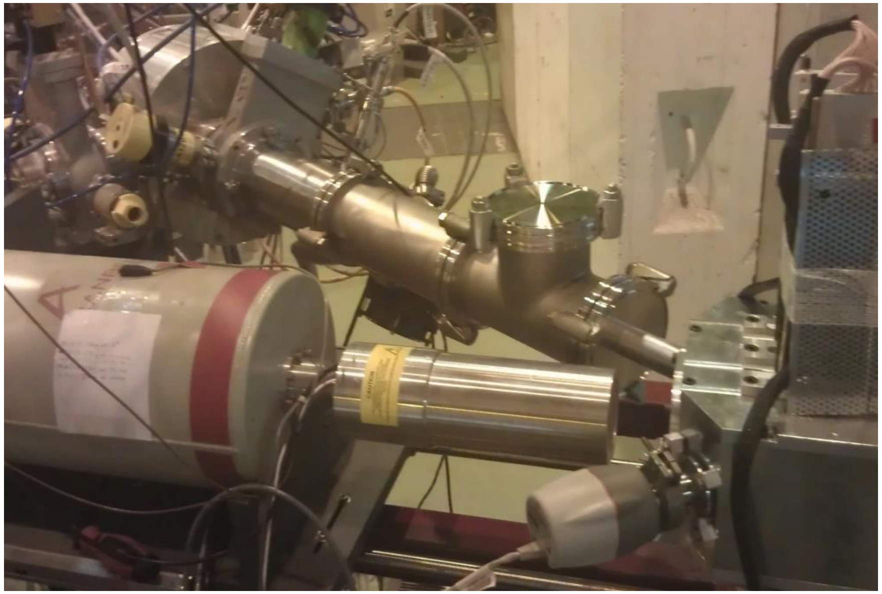
← to determine the BR

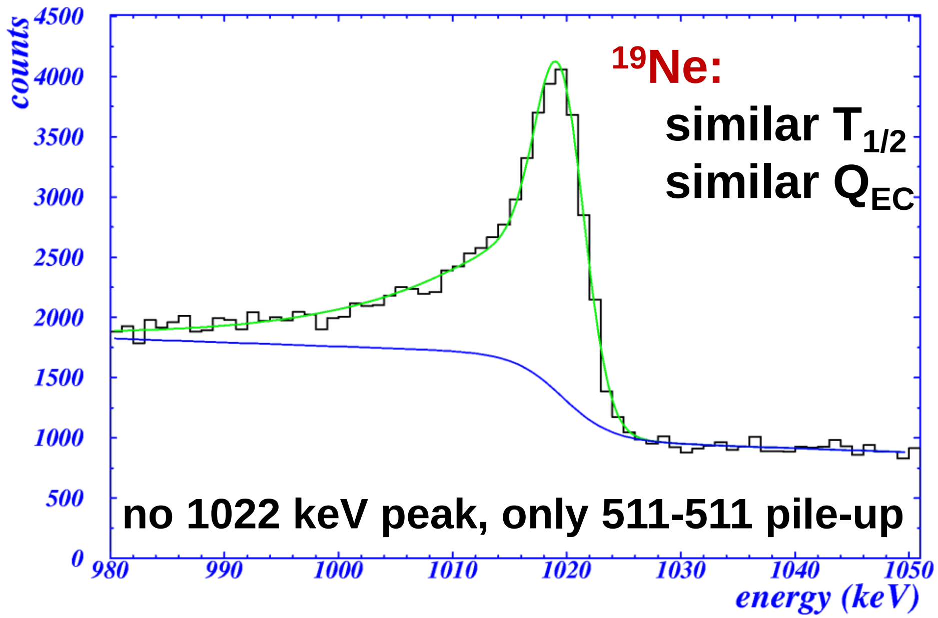


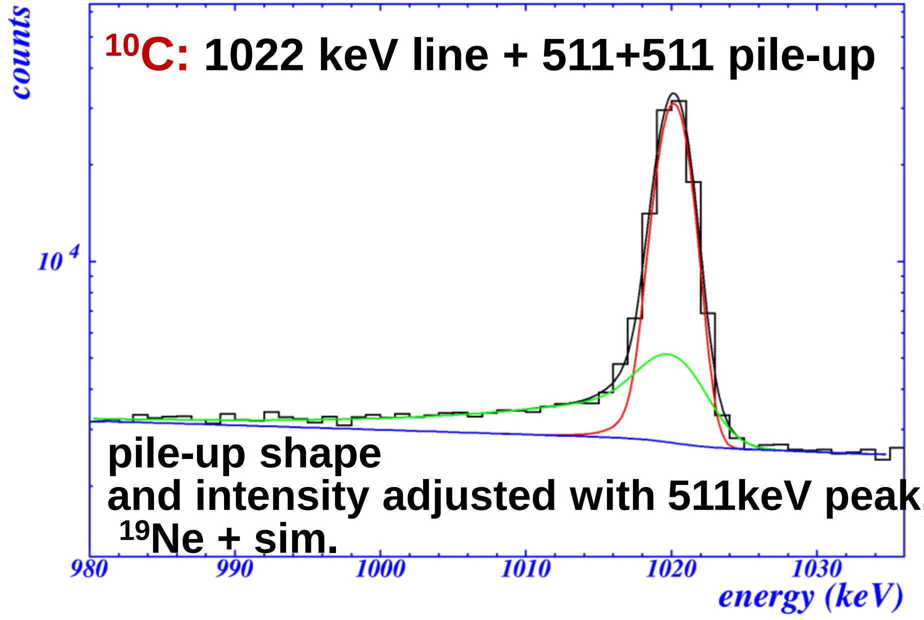
to evaluate pile-up →

^{10}C experimental set-up and analysis procedure

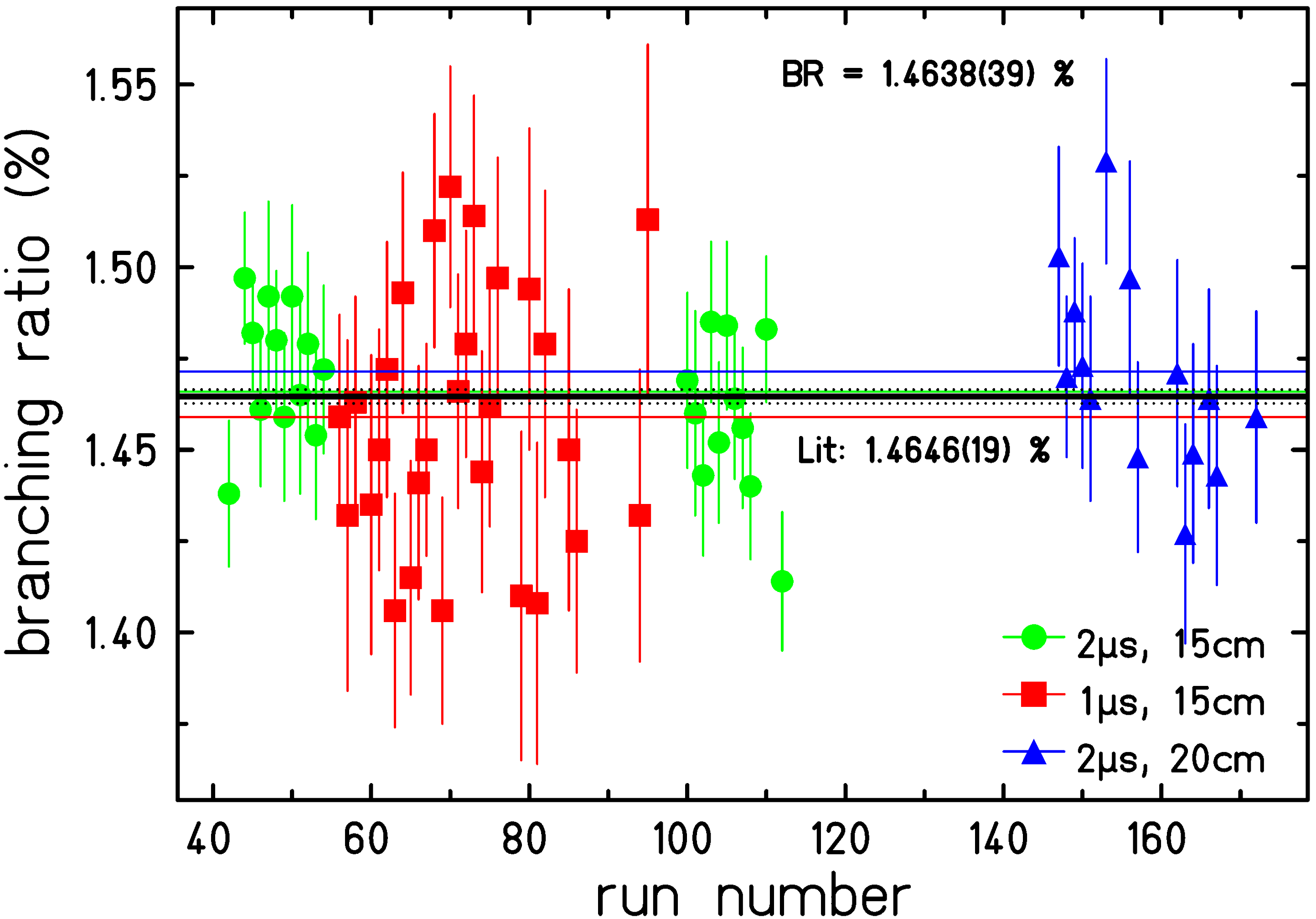








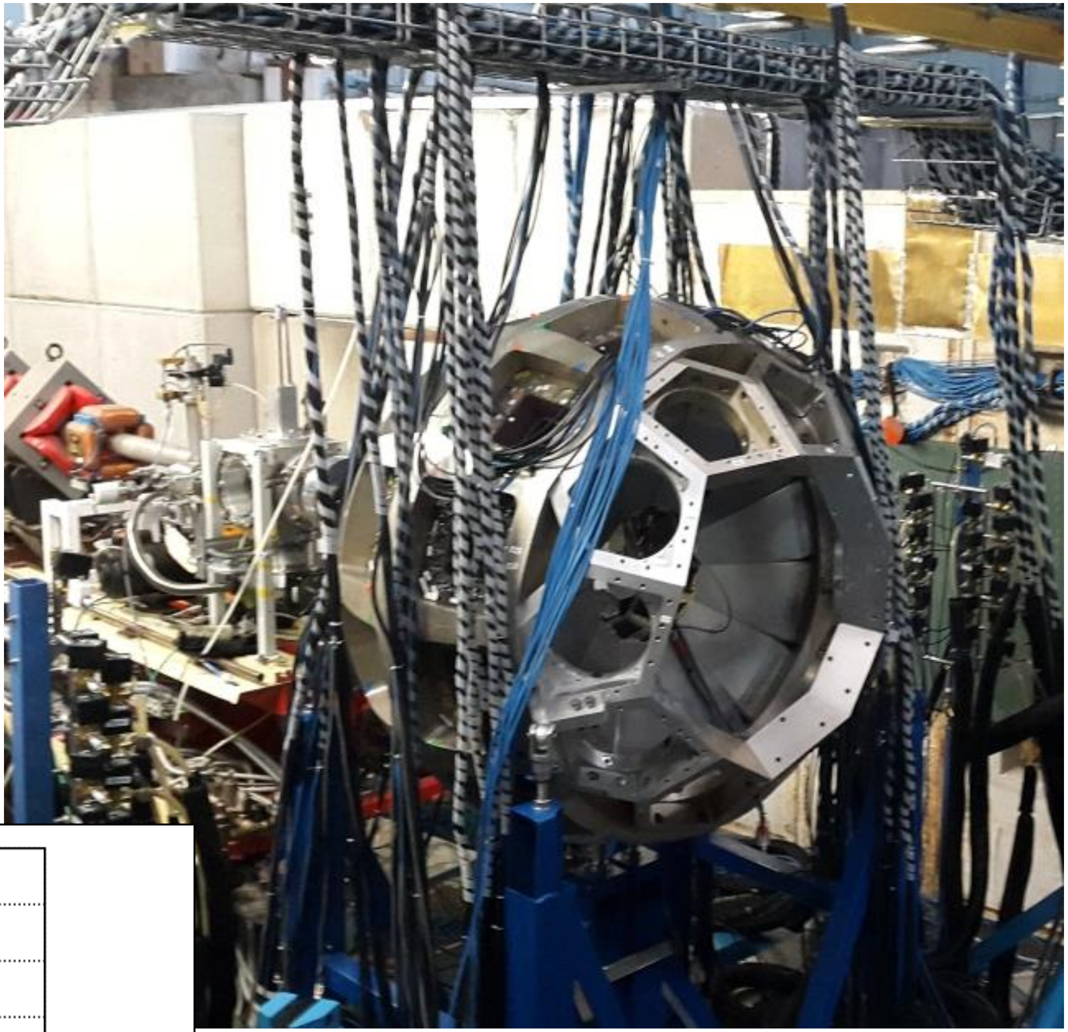
Super-allowed ranching ratio of ^{10}C

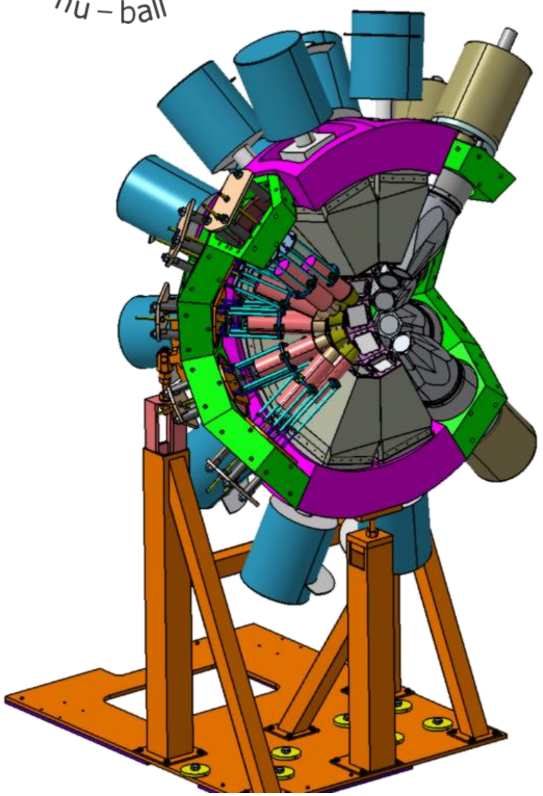


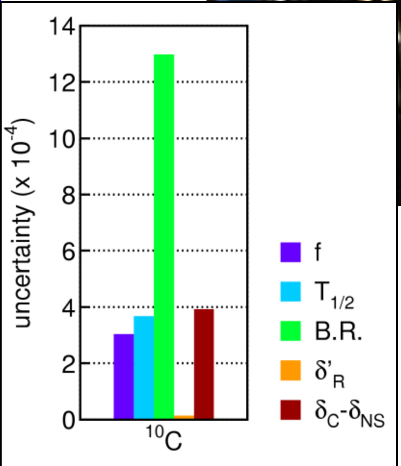
Final result: 1.4638(50) %; **Savard: 1.4625(25)%; Fujikawa: 1.4665(38)%**

0^+ - 0^+ β decay: ^{10}C at ALTO/Orsay

^{10}C measurement at ALTO/Orsay





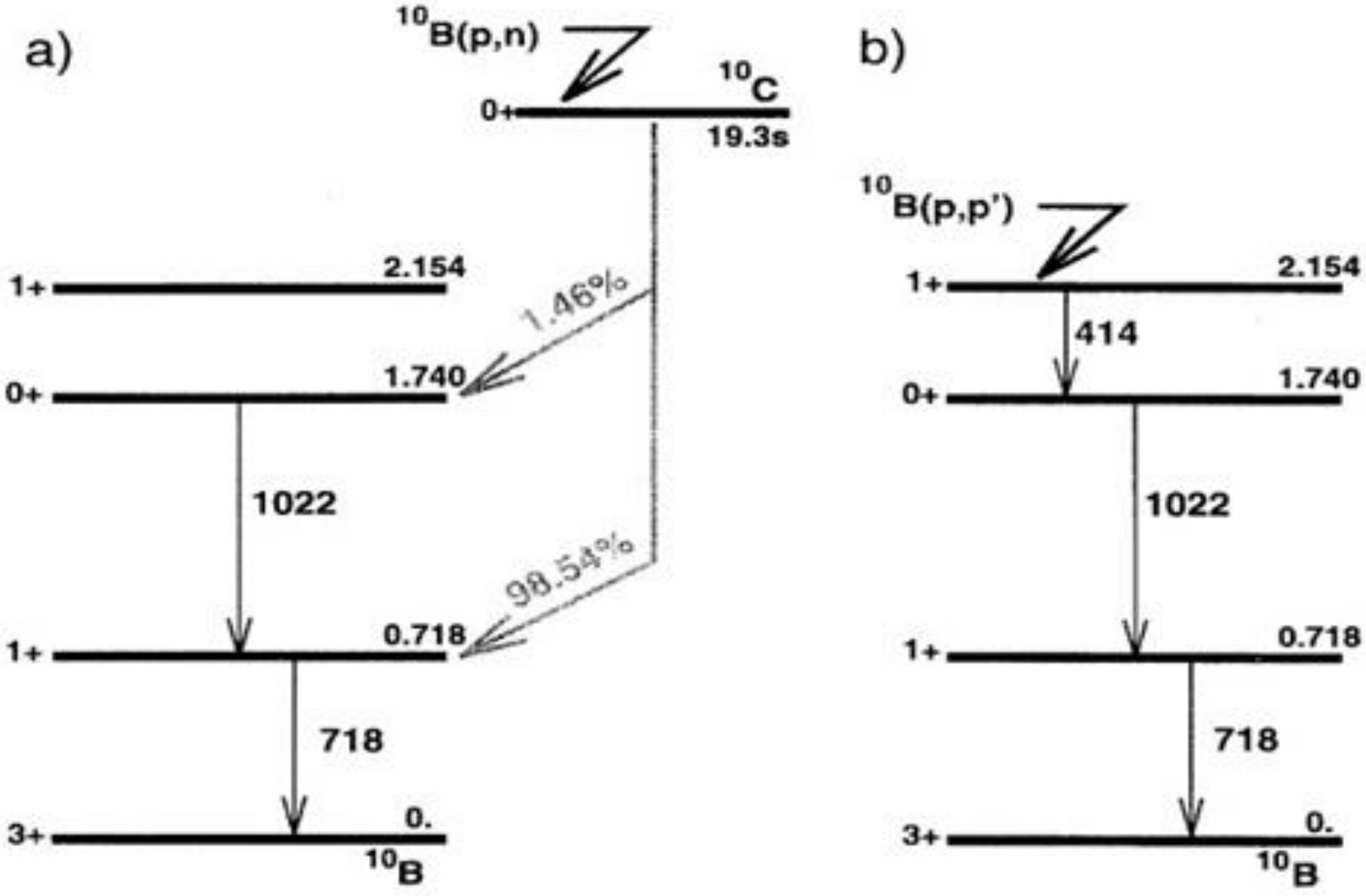


Scientific Manager: M. Lebois
Technical Manager: B. Genolini

100 Ge crystals: 5.5% @ 1 MeV
18 $LaBr_3$: 1.5% @ 1 MeV

^{10}C decay scheme

Decay of interest **Calibration reaction**



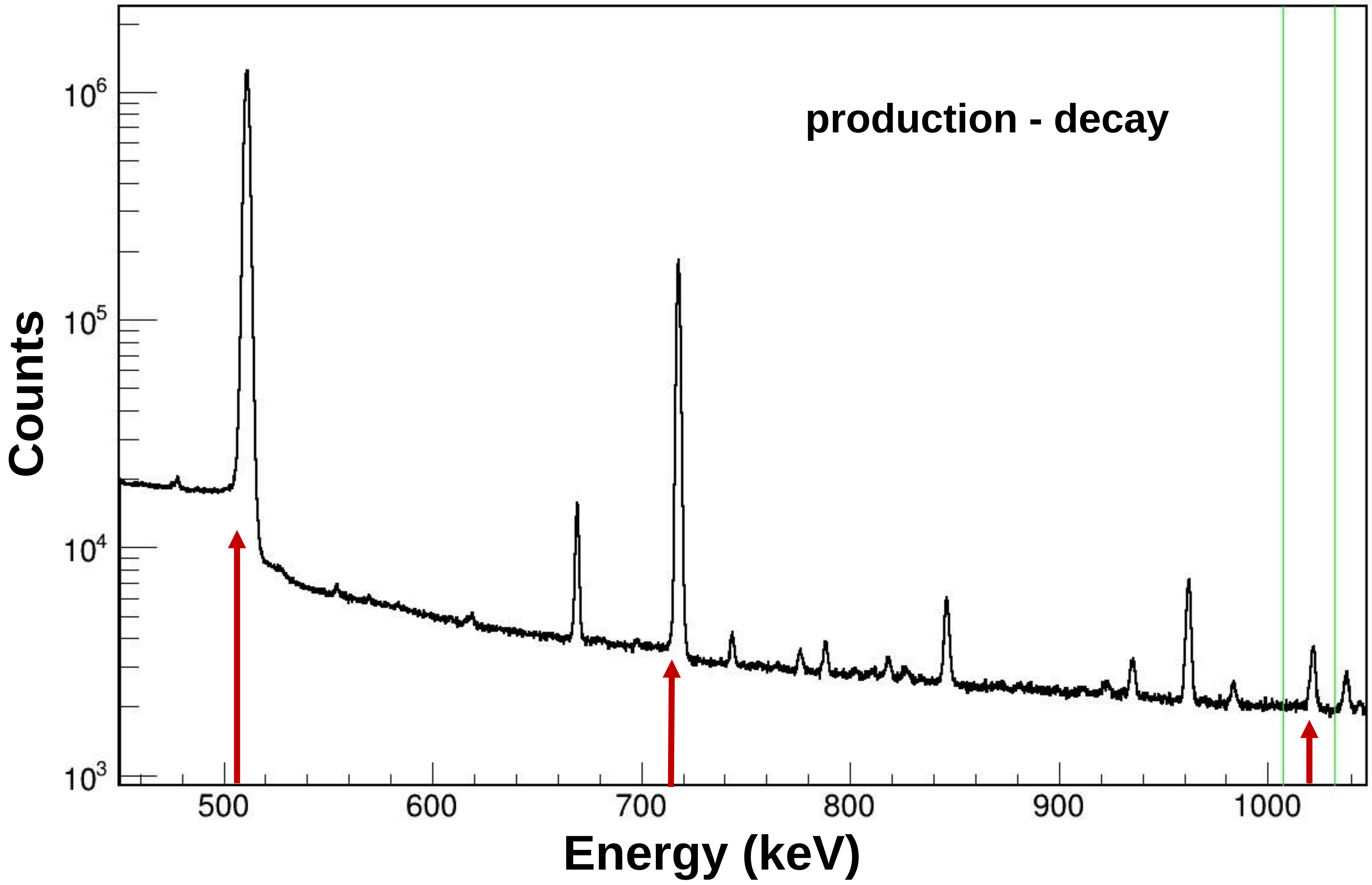
… additional measurement of ^{19}Ne decay

^{10}C decay data

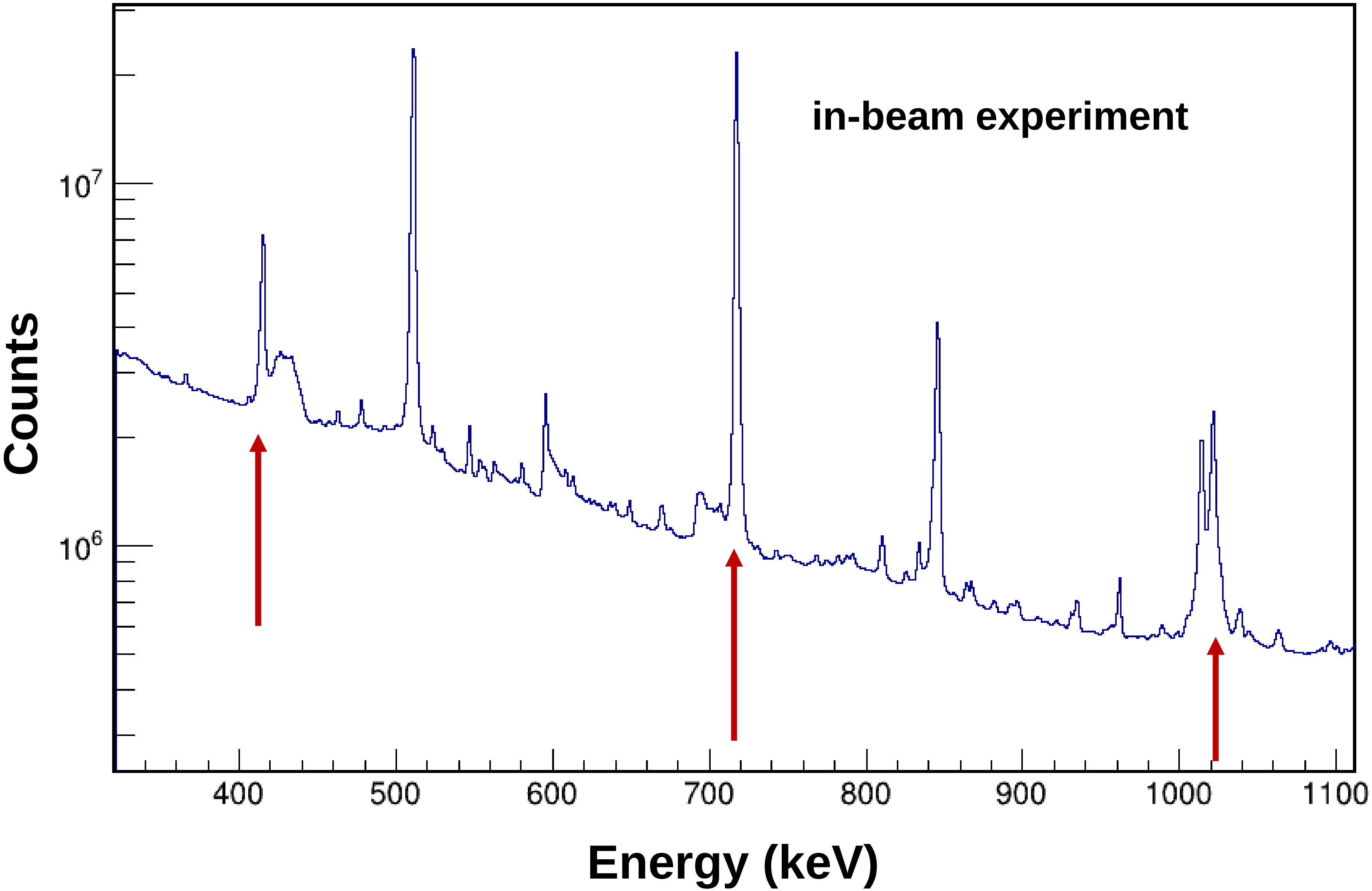
- **Measurements:**
  - **^{10}C (^{10}B [300-400 μg/cm2] on 4 mg Au backing):**
    - **511 keV: 1.4 e9**
    - **718 keV: 1.2 e8**
    - **1022 keV: 1.6 e6**
  - **^{10}B (^{10}B [300-400 μg/cm2] on 4 mg Au backing):**
    - **414 keV: 8.5 e7**
    - **718 keV: 4.5 e6**
    - **1022 keV: 3.5 e6**
  - **^{19}Ne (CaF [400-500 μg/cm2] & PbF on 4 mg Au backing)):**
    - **511 keV: 4.6 e8**

➔➔ expected overall statistical precision: < 0.1 %

Experimental results: ^{10}C spectrum, singles



Experimental results: ^{10}B spectrum, singles



Conclusions

- High-precision Germanium detector is available

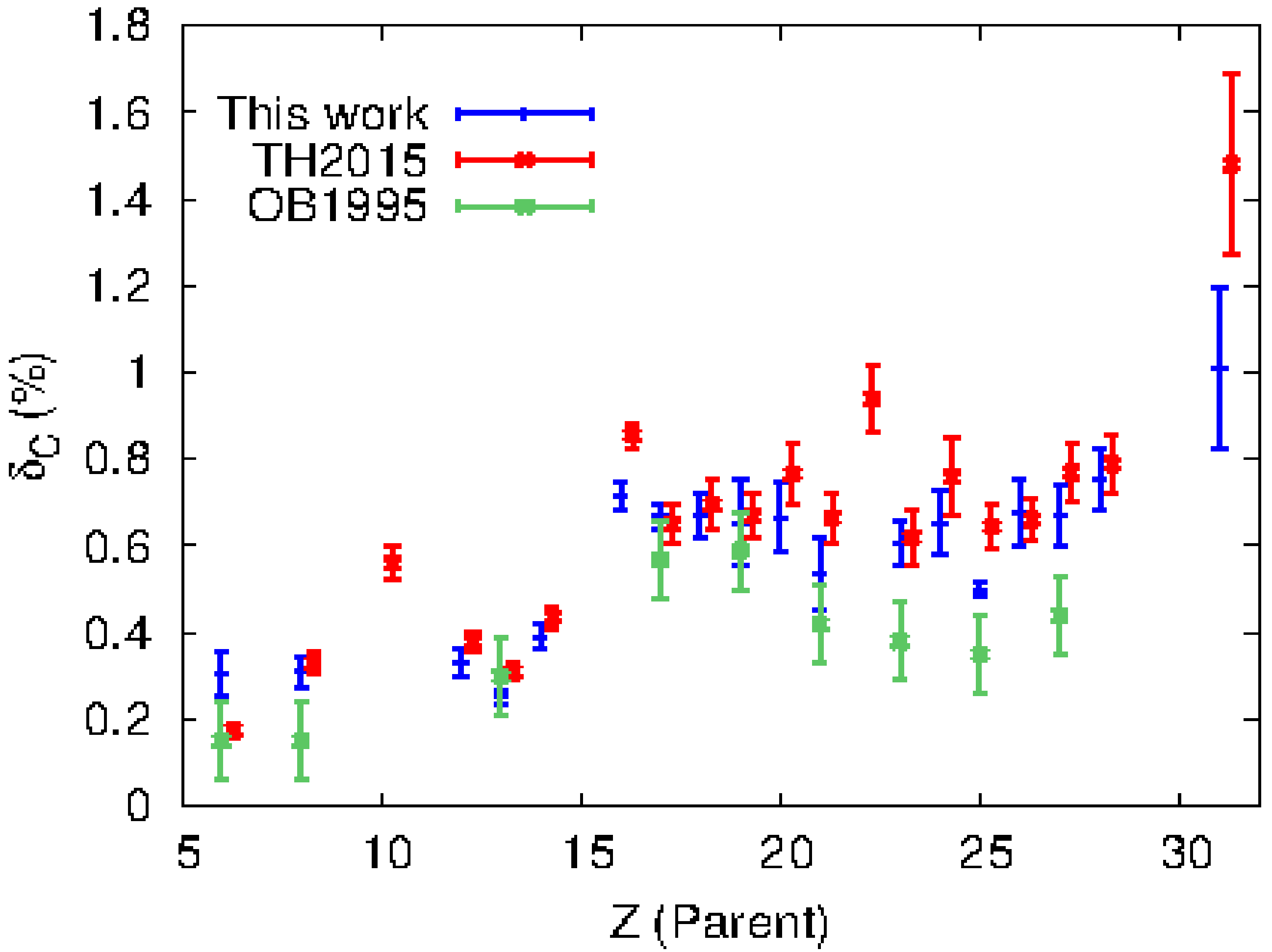
  ➔ T_z = -1 nuclei have be addressed: ^{10}C, ^{22}Mg, ^{30}S

- Multi-detector array: 120 Ge and LaBr3 detector

  ➔ Branching ratio measurement of ^{10}C

- Theoretical corrections (N. Smirnova et al.)

Theoretical corrections (*sd* shell)



Present work: $\mathcal{F}t = 3073.8 \pm 0.7 sec$ | $\chi^2/\nu = 1.40$ ➔ smaller g_V

Hardy, Towner 2020: $\mathcal{F}t = 3072.2 \pm 0.6\ sec$ | $\chi^2/\nu = 0.47$ ➔ larger deviation from unitarity

Conclusions

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  → T_z = -1 nuclei have be addressed: ^{10}C, ^{22}Mg, ^{30}S

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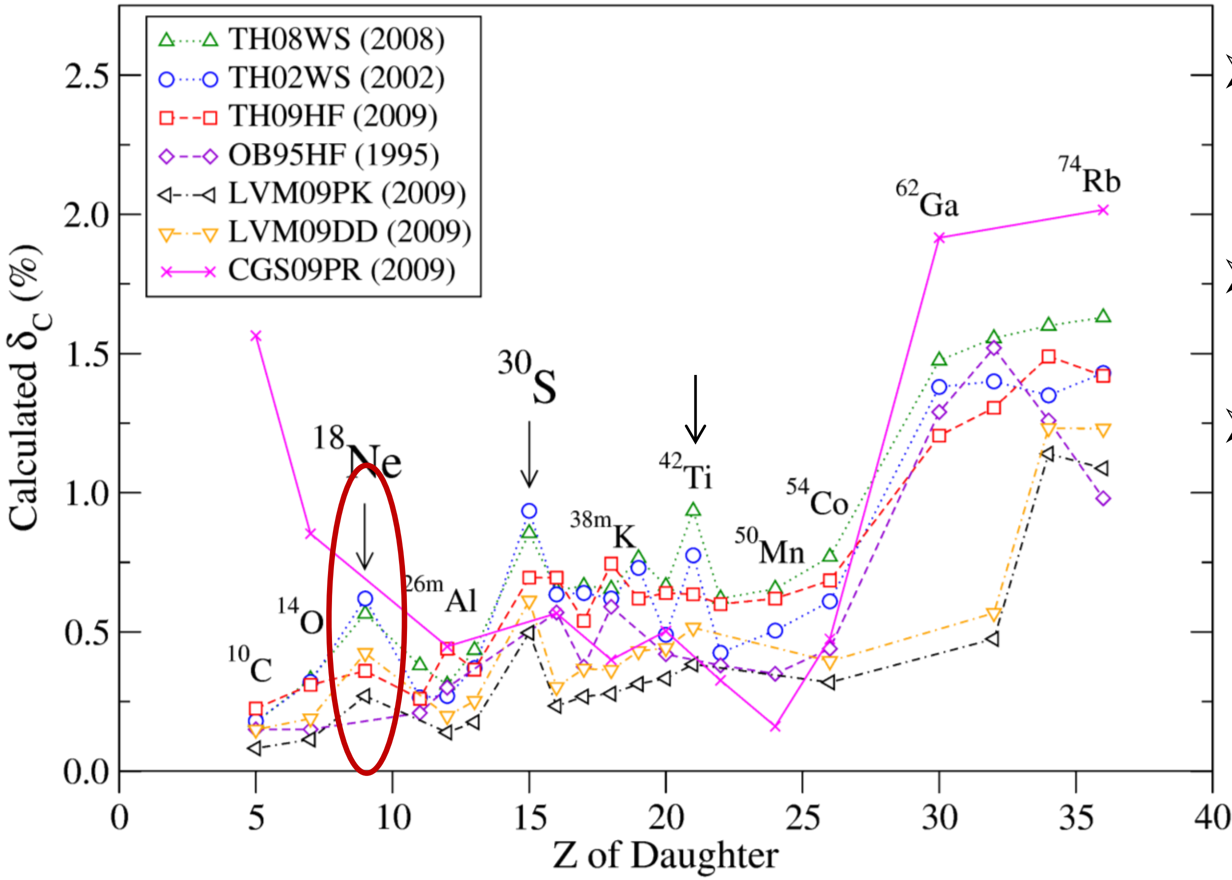
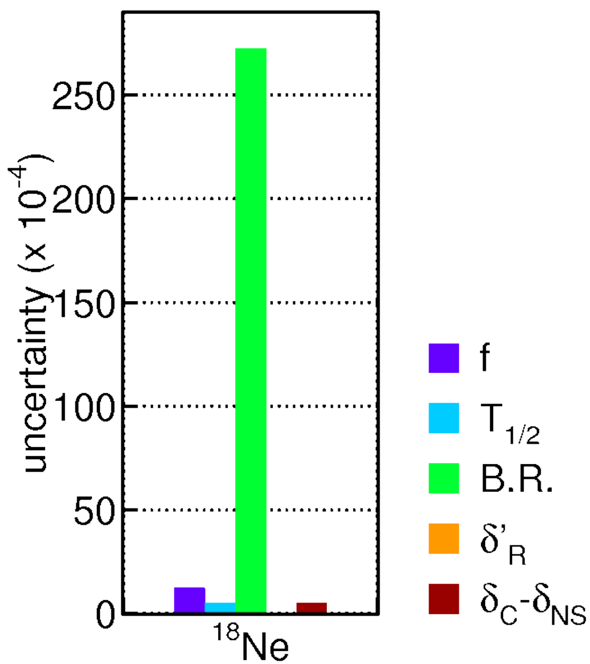
  → Branching ratio measurement of ^{10}C

- Theoretical corrections (N. Smirnova et al.)
- Future experiments

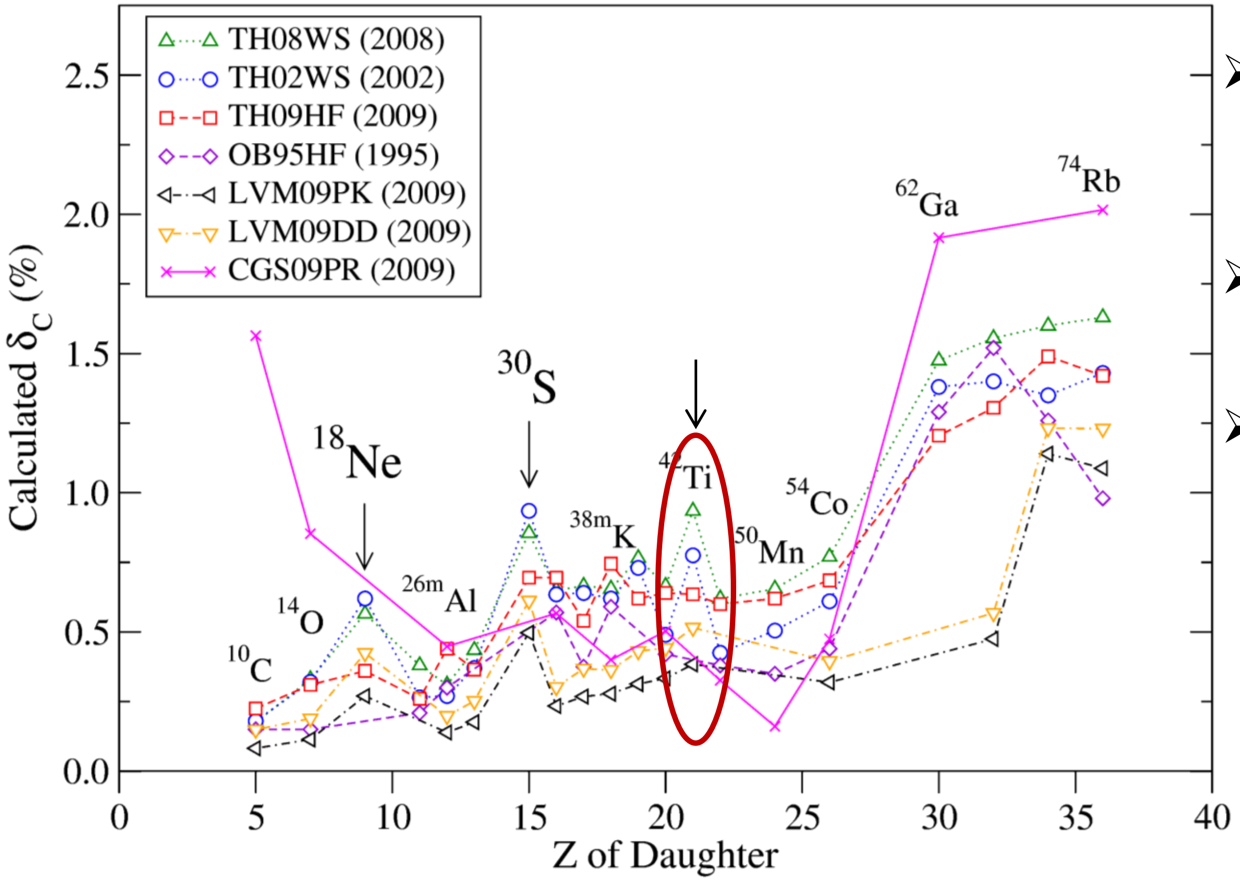
^{18}Ne



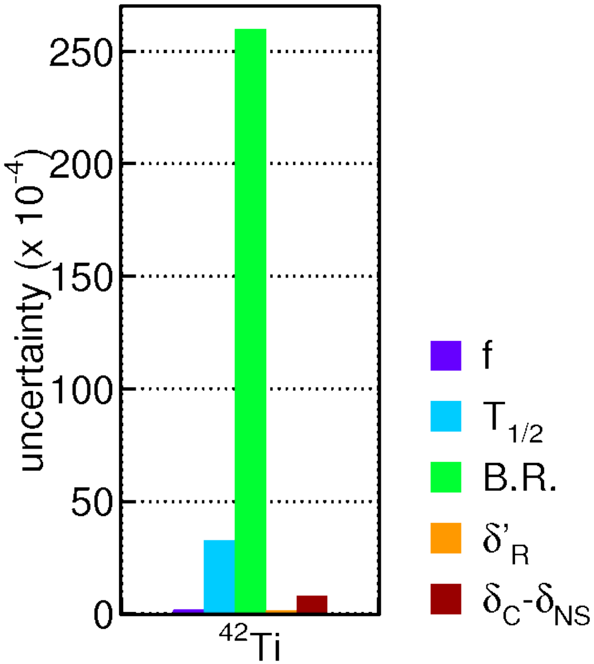
- **Light nucleus important for physics beyond the standard model**
- **up to factor of 3 difference in δ_C**
- **easily feasible at SPIRAL1 or ISOLDE**



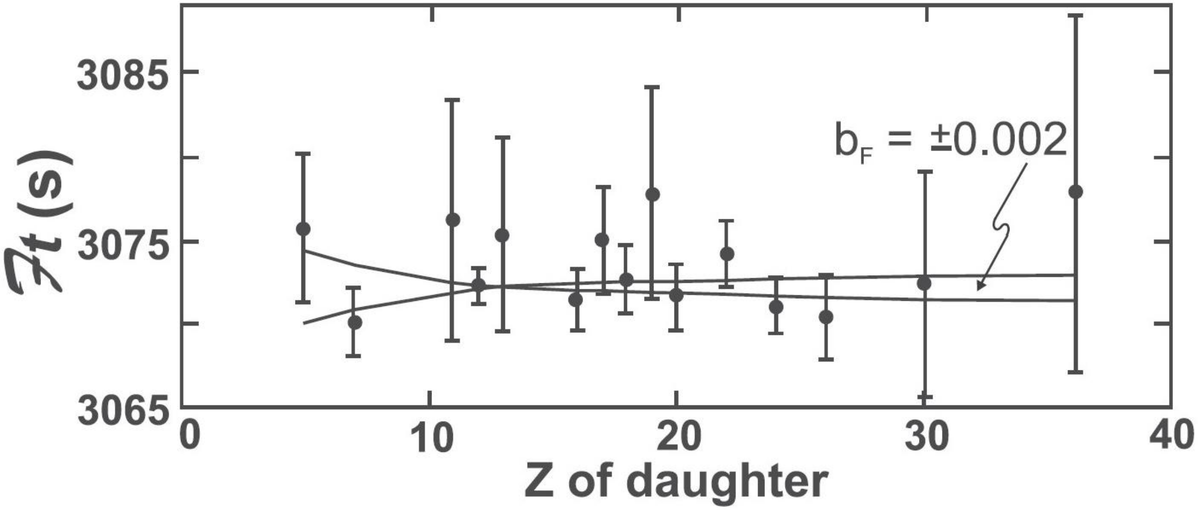
^{42}Ti

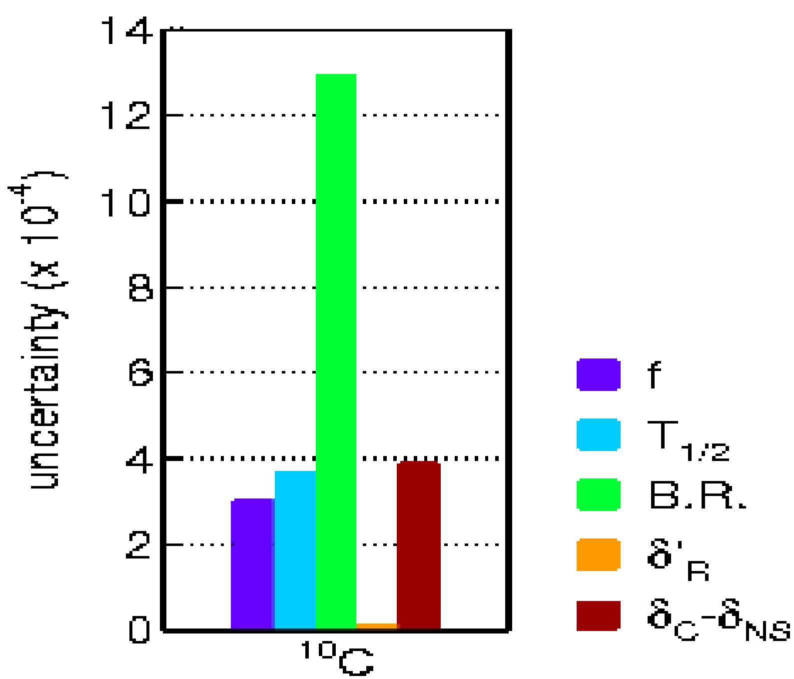


- heaviest T_z = -1 nucleus accessible with high statistics
- up to factor of 3 difference in δ_C
- only feasible at GANIL



^{10}C





- **feasile at ISOLDE**
- **lightest T_z = -1 nucleus accessible with high statistics**
- **highest impact on beyond SM physics**
- **only feasible with MR-ToF**
  - **removal of contaminants:**
    - **^{13}N-^{13}N**
    - **^{10}C-^{16}O**
    - **???**

Conclusions

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    ➔ T_z = -1 nuclei have be addressed: ^{10}C, ^{22}Mg, ^{30}S

- Multi-detector array: 140 Ge and LaBr3 detector

    ➔ Branching ratio measurement of ^{10}C

- Theoretical corrections (N. Smirnova et al.)

- Future experiments

Thanks for your attention

Collaborations: CENBG, GANIL, IPNO, LPC Caen,

TRIUMF, Univ. of Guelph, JYFL, ISOLDE