

Physics beyond the Standard Model and the beta decay of ^{10}C

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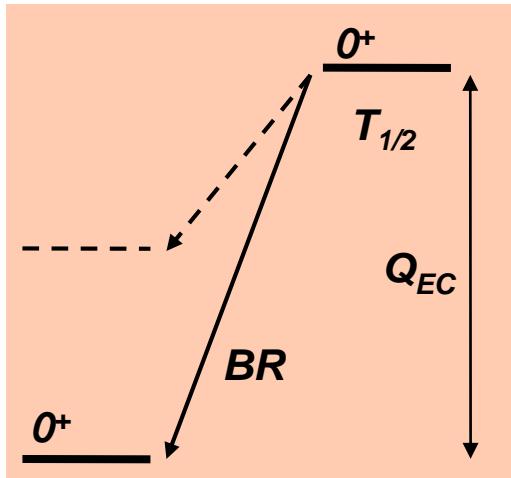
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● ● ● Nuclear beta decay



$0^+ \rightarrow 0^+$:

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

$f(Z, Q_{EC}) \sim 1.5\%$

$f(\text{nucl. structure}) \sim 0.3-1.5\%$

$f(\text{weak interaction}) \sim 2.4\%$

Obtain precise value of G_V^2

Determine V_{ud}^2

$V_{ud}^2 = G_V^2 / G_\mu^2$

Test CKM unitarity

$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1$

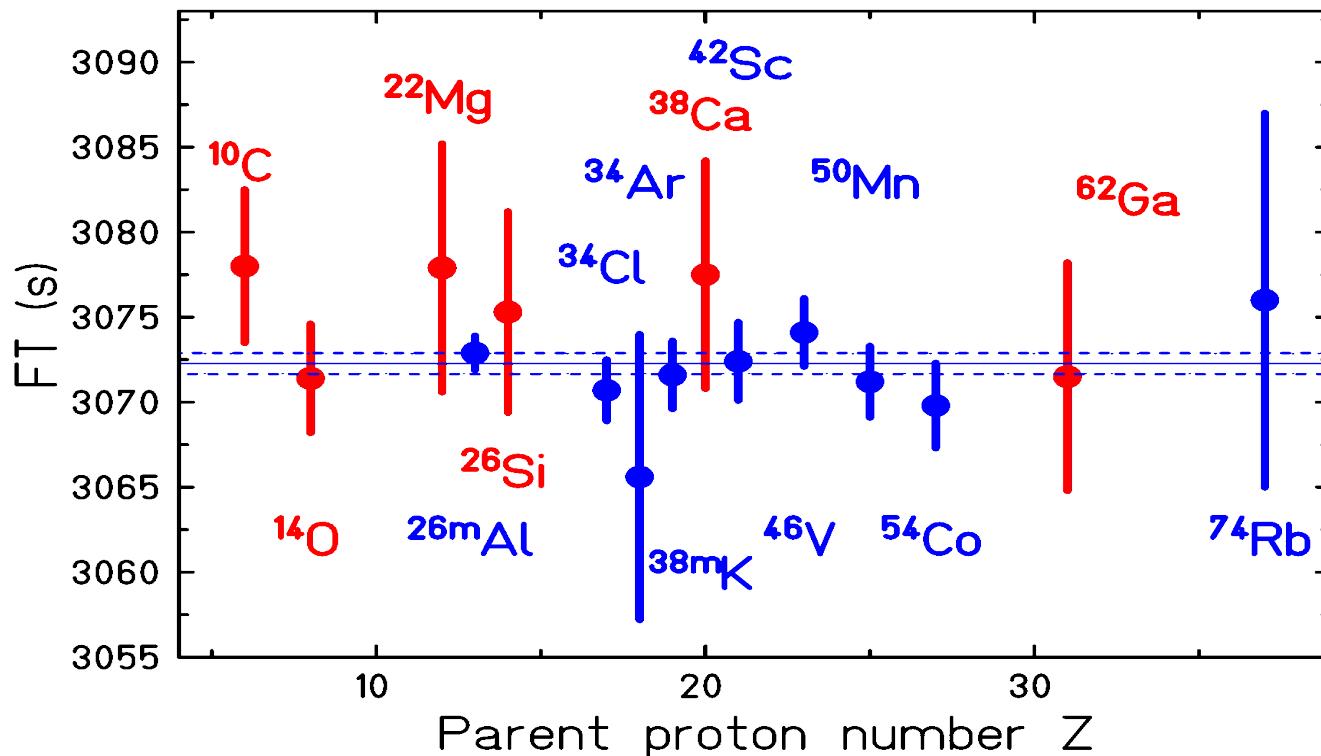
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

weak eigenstates Cabibbo Kobayashi Maskawa (CKM) matrix mass eigenstates

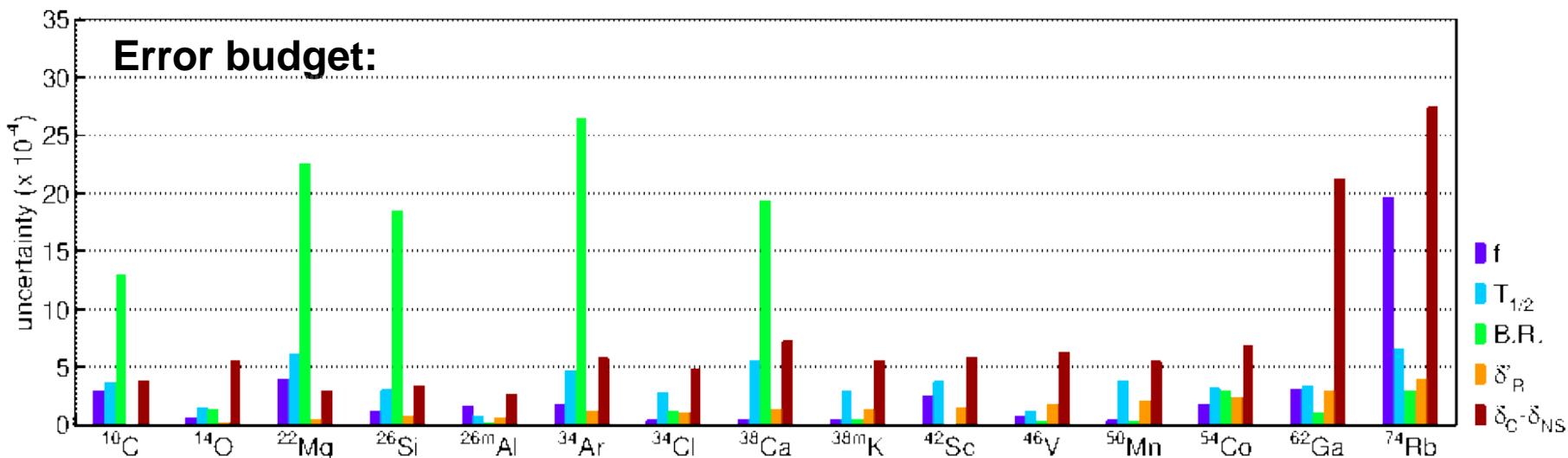
Precision measurements required: 10^{-3}

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

● ● ● **$0^+ \rightarrow 0^+$ decays: present status**



- 15 nuclei
- other nuclei under study:
 - ^{18}Ne
 - ^{30}S
 - ^{42}Ti
 - ^{58}Zn
- + heavier to come



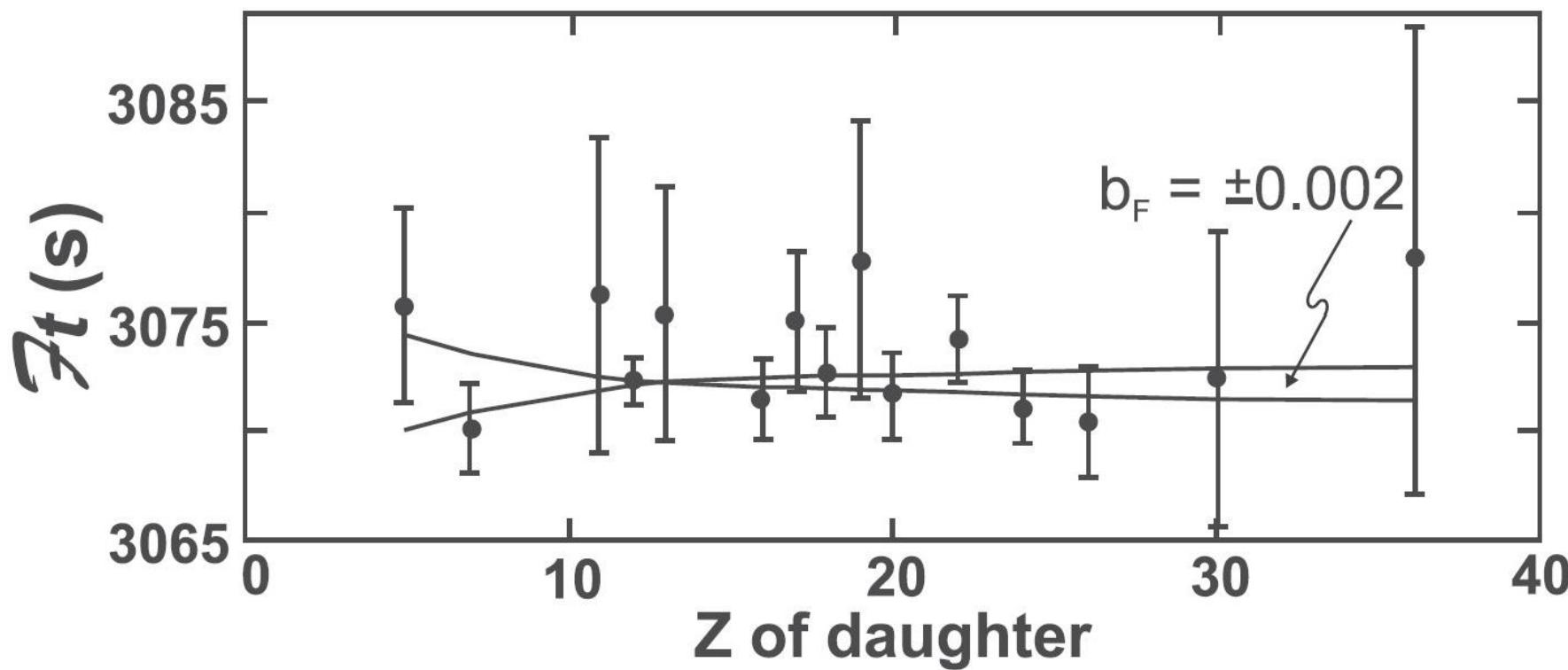
● ● ● **$0^+ \rightarrow 0^+$ decays: limits on exotic currents**

standard model assumption: only vector current

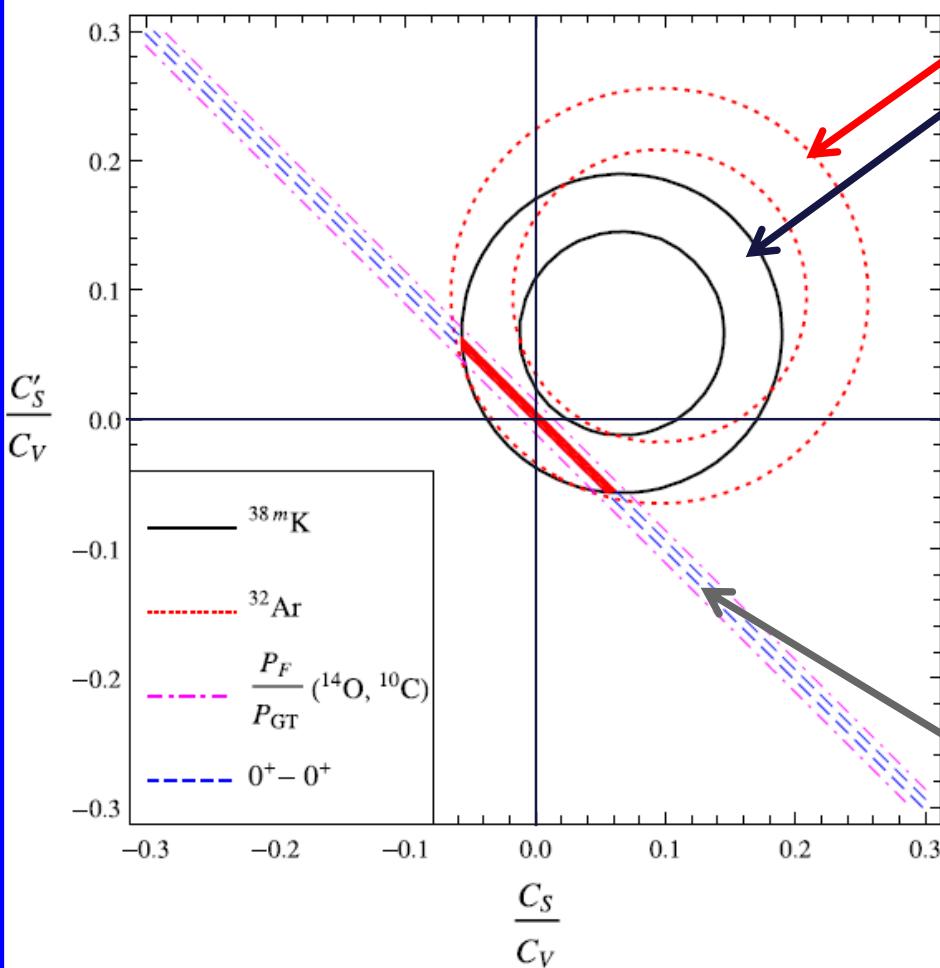
- limit on scalar current from term in f function: $(1 + b_F * \gamma_1 / \langle E \rangle)$
from β decay: $b_F = 0.0000 \pm 0.0020$

→→ improve on low-Z nuclei

Hardy & Towner, 2020



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



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

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

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

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

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

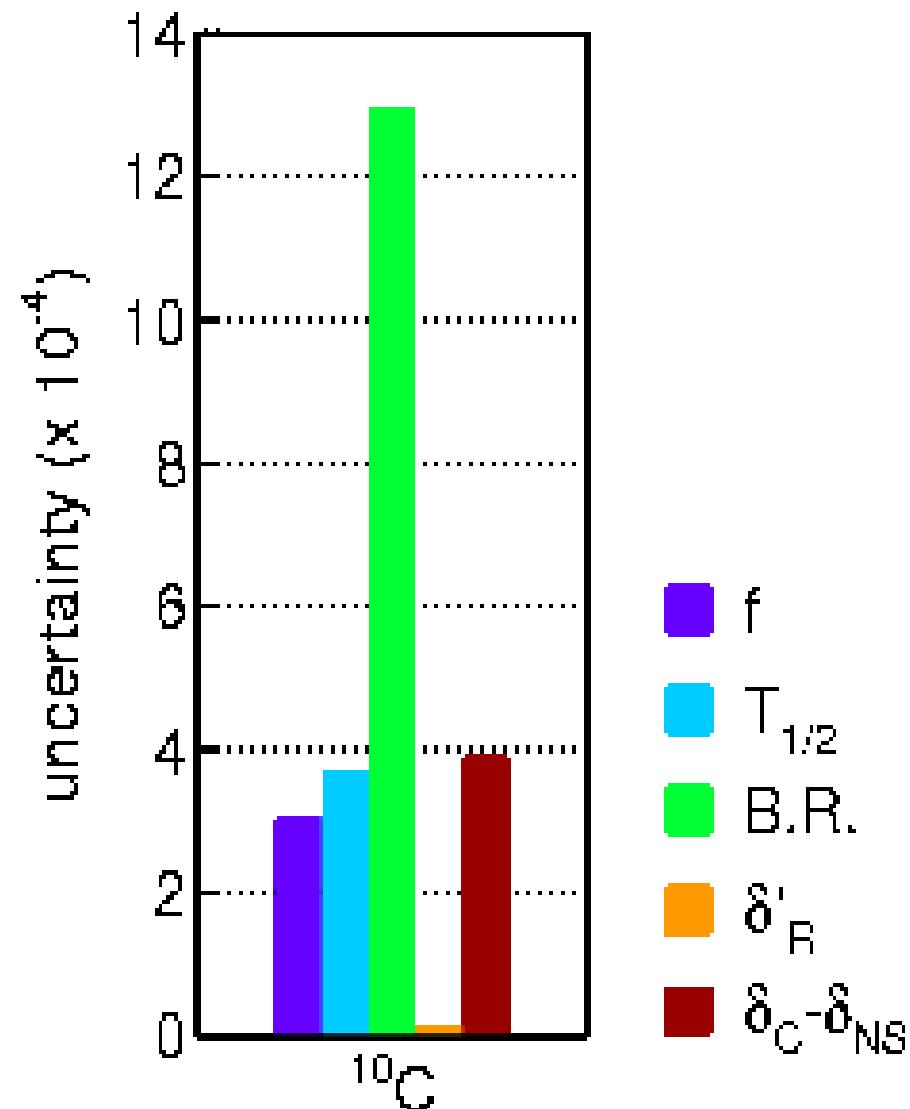
$$\mathcal{F}t^{0^+ \rightarrow 0^+} = \frac{K}{2G_F^2 V_{ud}^2 C_V^2 (1 + \Delta_R^V)} \frac{1}{(1 + b'_F)}$$

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

• • • $0^+ \rightarrow 0^+$ 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:
remasuring the BR of ^{10}C
with out precisely calibrated
Germanium detector

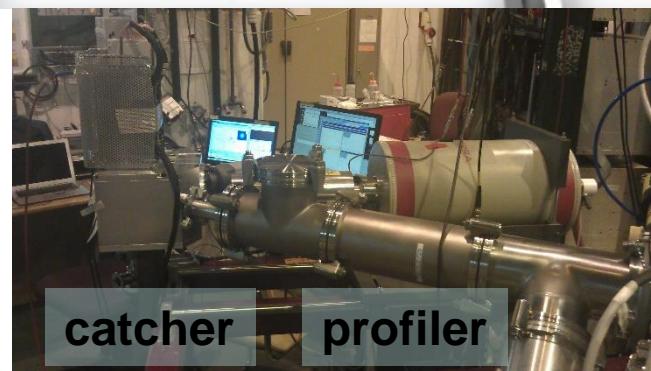
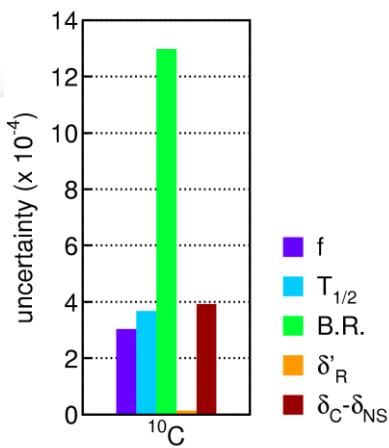
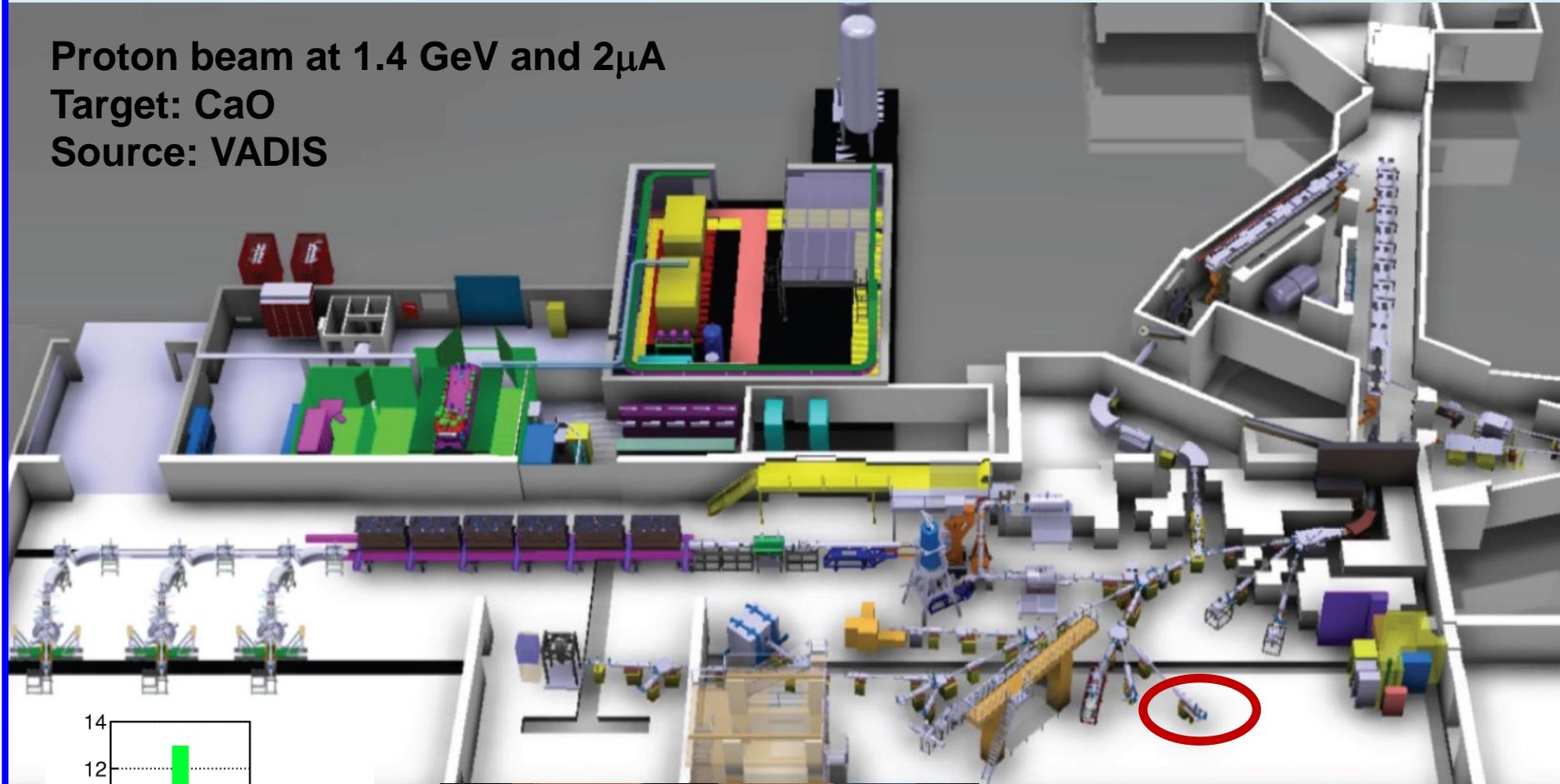


● ● ● ^{10}C measurement at ISOLDE

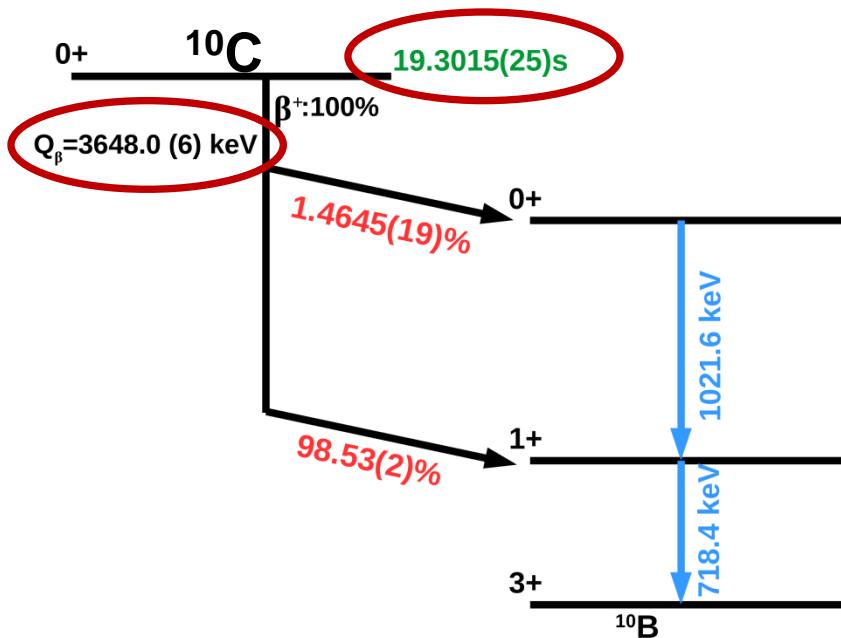
Proton beam at 1.4 GeV and $2\mu\text{A}$

Target: CaO

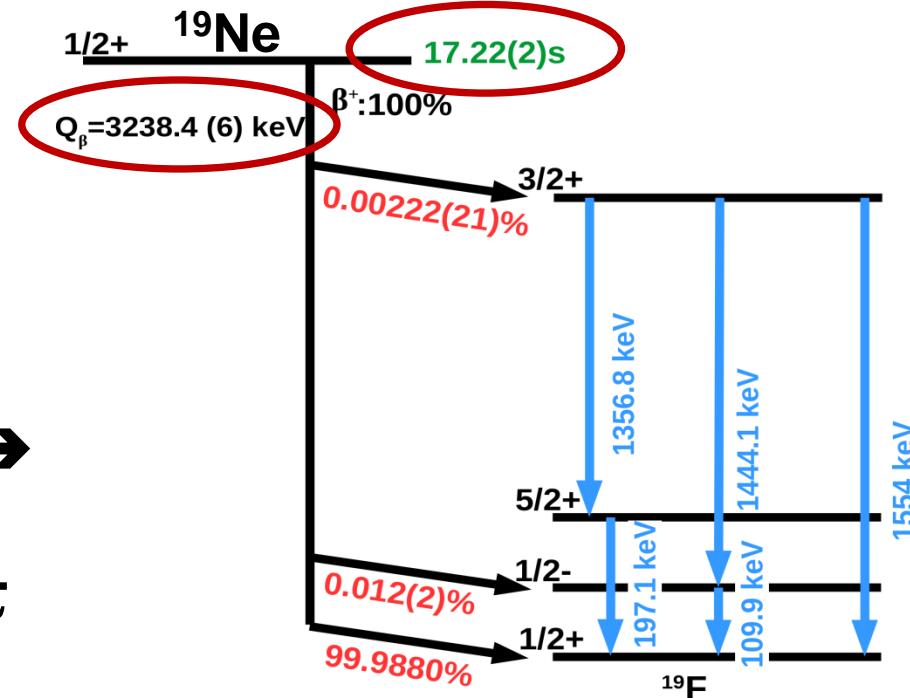
Source: VADIS



● ● ● **$^{10}\text{C}/^{19}\text{Ne}$ decay scheme**



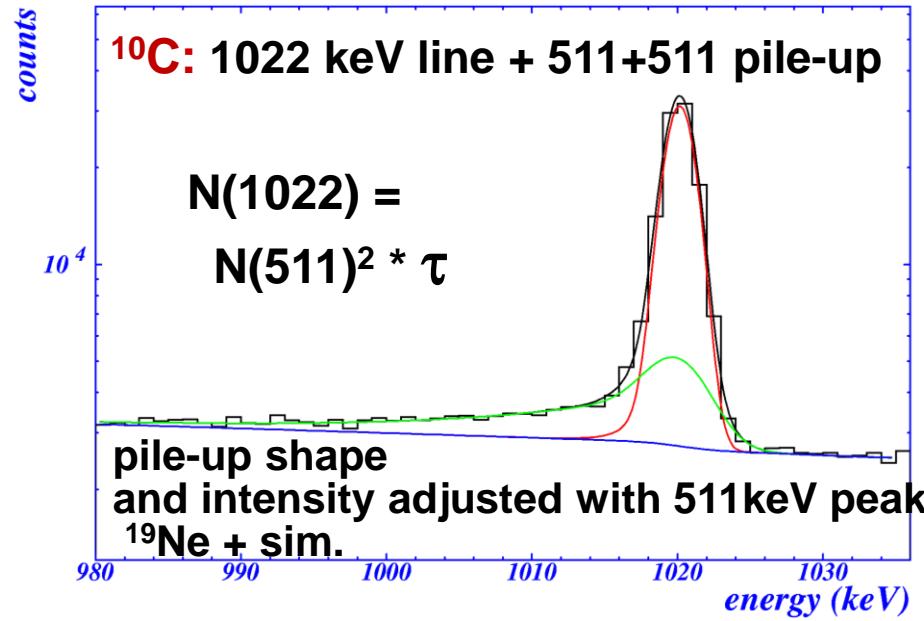
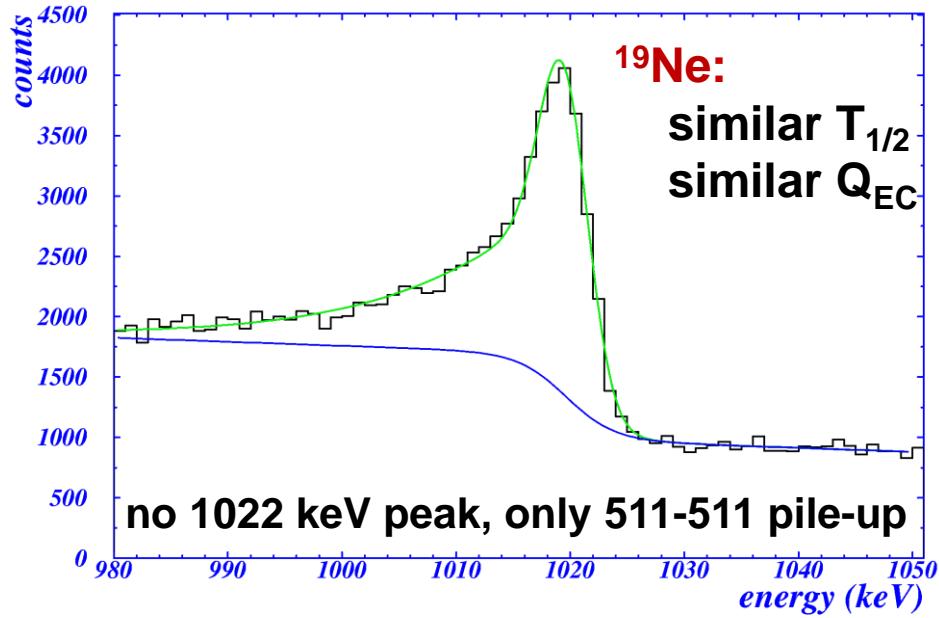
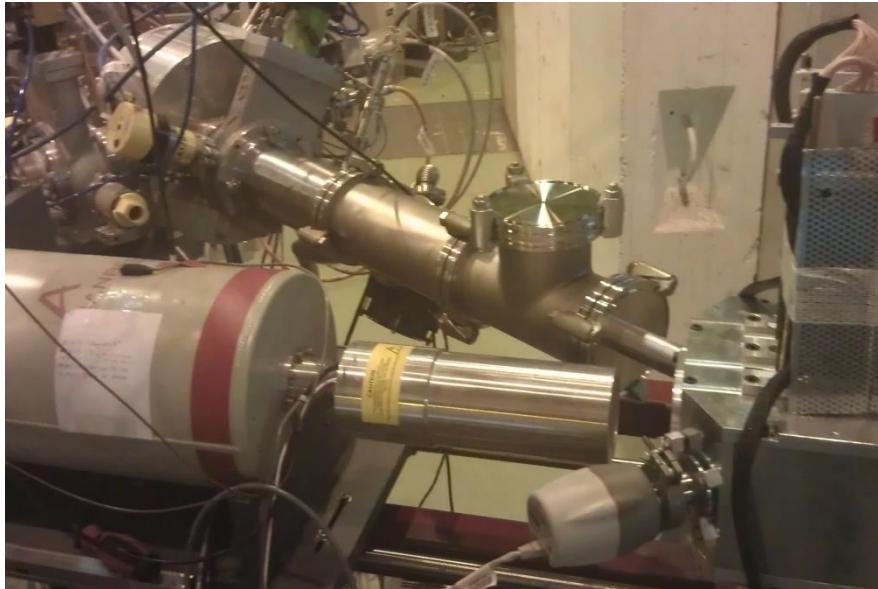
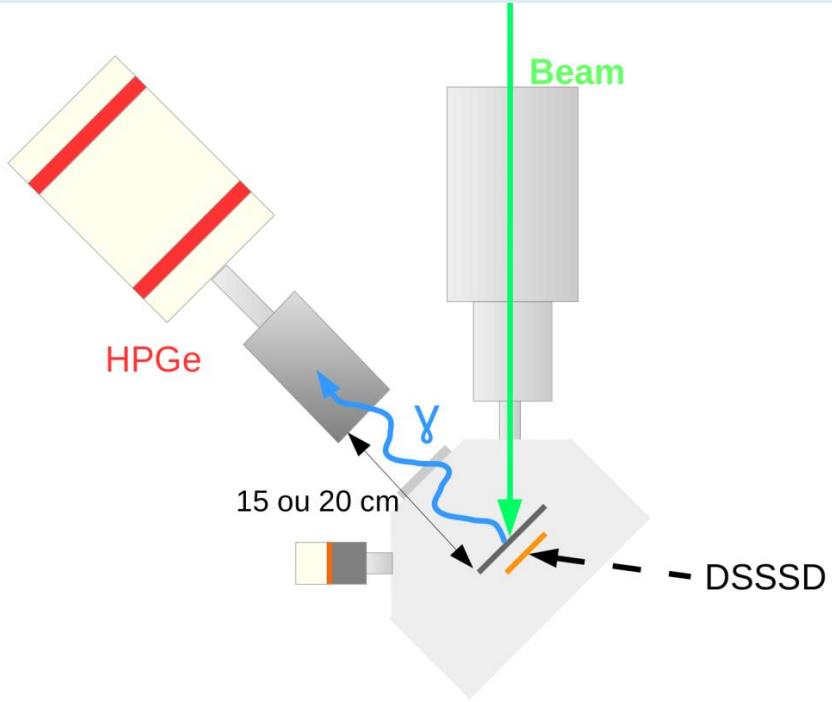
← to determine the BR



to evaluate pile-up →

$$N_{1022} = N_{511}^2 * \tau$$

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

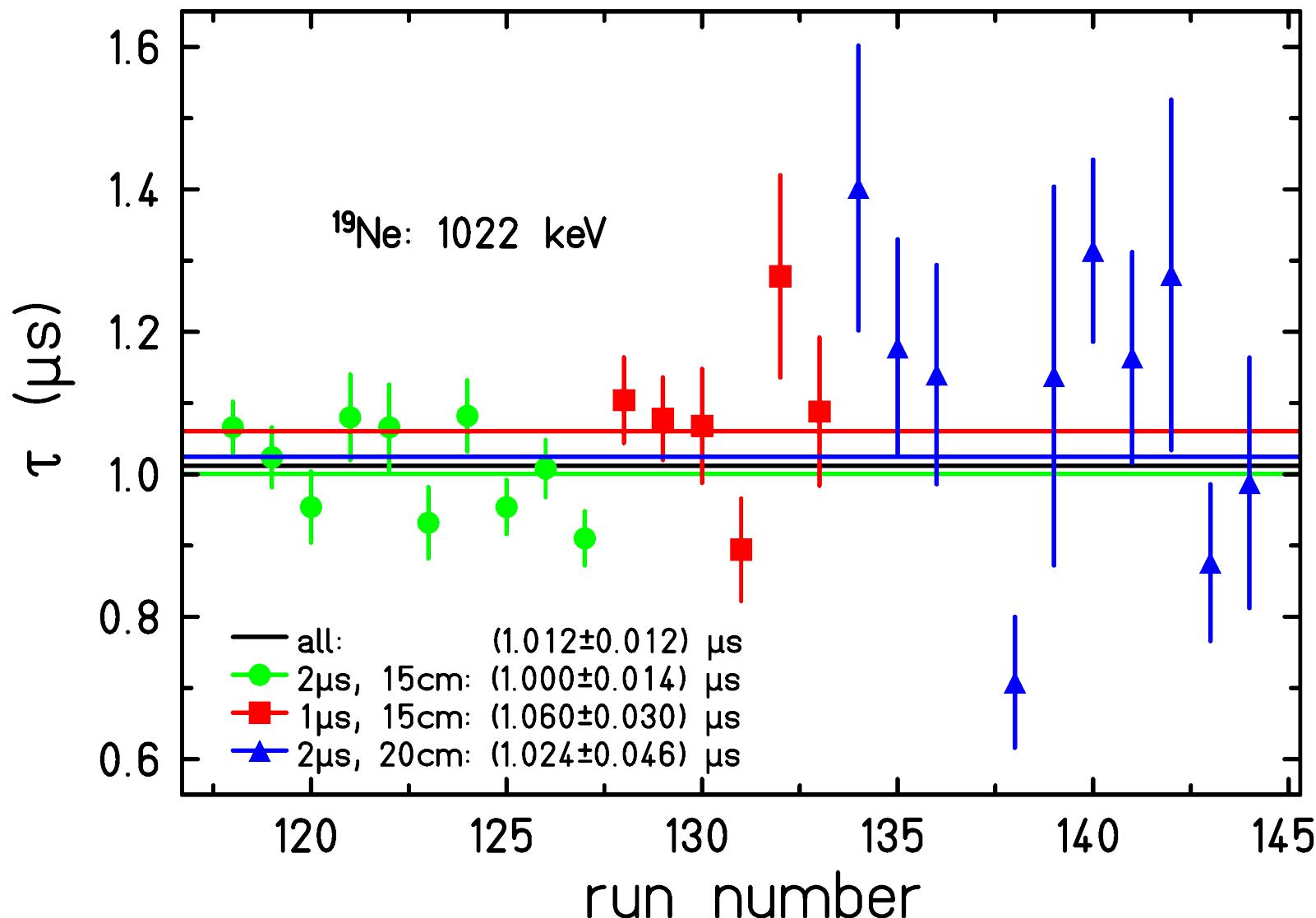


• • • **¹⁰C analysis procedure**

- selection of runs: constant intensity over full run
- determination of pile-up with ¹⁹Ne: $N(1022) = N(511)^2 * \tau$
 - all parameters of pile-up peak (including intensity) fixed

● ● ● **^{19}Ne : pile-up of two 511 keV γ rays**

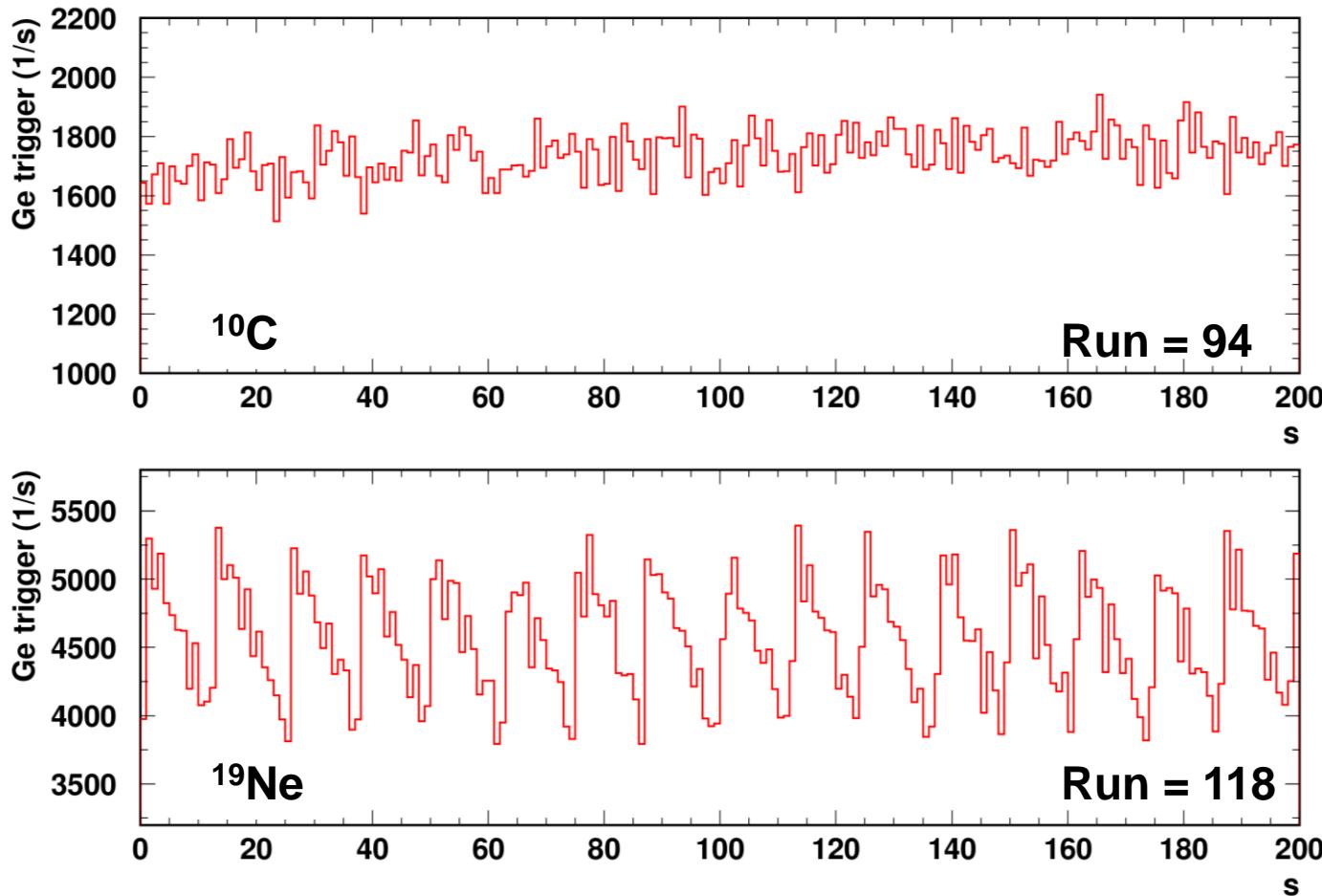
Pile-up analysis: 511 keV \rightarrow 1022 keV



• • • **¹⁰C analysis procedure**

- selection of runs: constant intensity over full run
- determination of pile-up with ¹⁹Ne: $N(1022) = N(511)^2 * \tau$
 - all parameters of pile-up peak (including intensity) fixed
- beam time structure influences pile-up

● ● ● **^{10}C and ^{19}Ne release**



Release time
much longer
for $^{10}\text{C}^{160}$

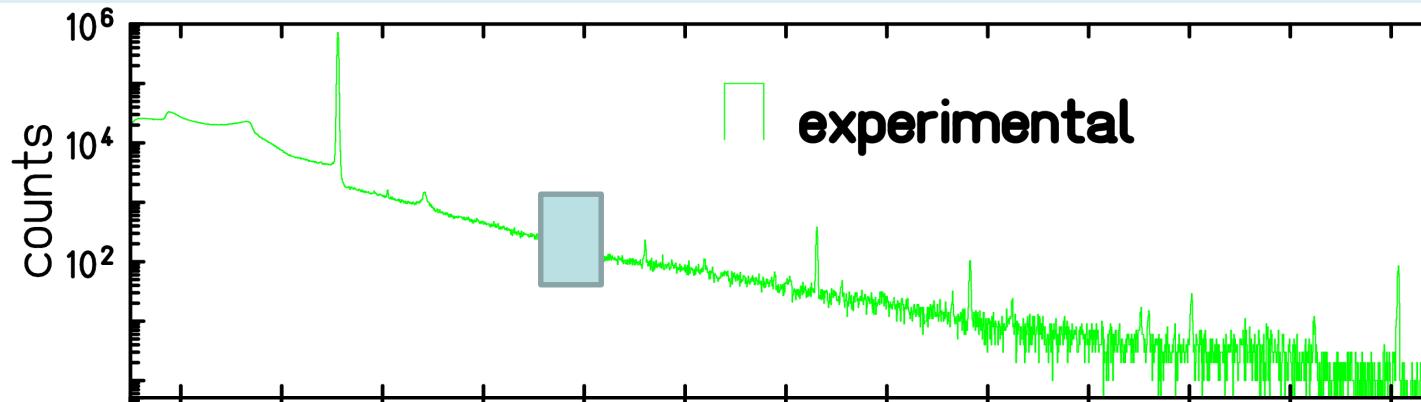
Contaminants:
 $^{13}\text{N}_2$ ($T_{1/2} = 10$ min)
 $^{14}\text{O}^{12}\text{C}$ ($T_{1/2} = 70$ s)
→ increase of rate

- use ^{19}Ne to study pile-up conditions
- use MC simulations for ^{19}Ne and ^{10}C to determine pile-up contribution

• • • **¹⁰C analysis procedure**

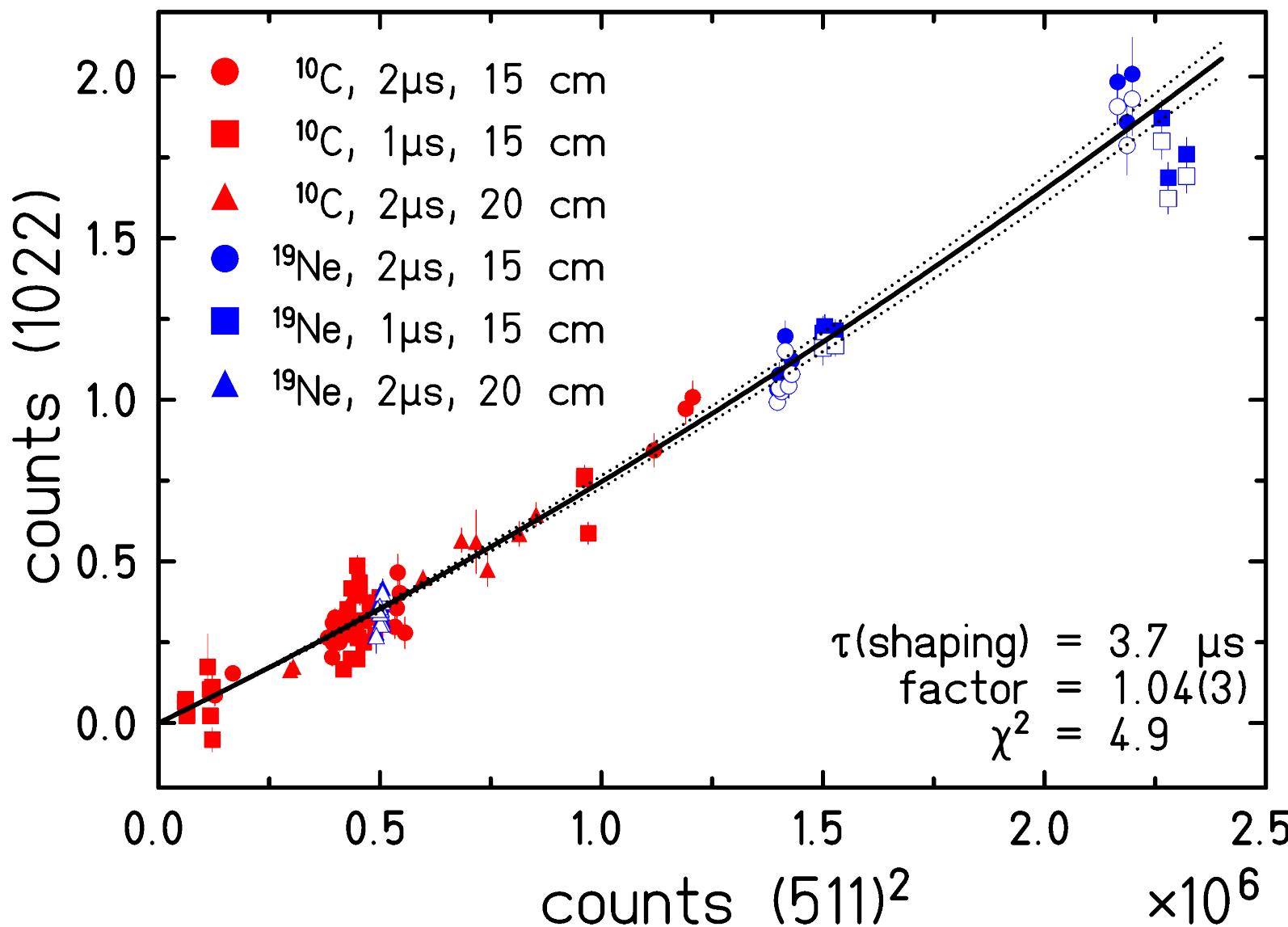
- selection of runs: constant intensity over full run
- determination of pile-up with ¹⁹Ne: $N(1022) = N(511)^2 * \tau$
 - all parameters of pile-up peak (including intensity) fixed
- beam time structure influences pile-up
- MC procedure to evaluate pile-up

● ● ● **^{19}Ne : MC simulation results**



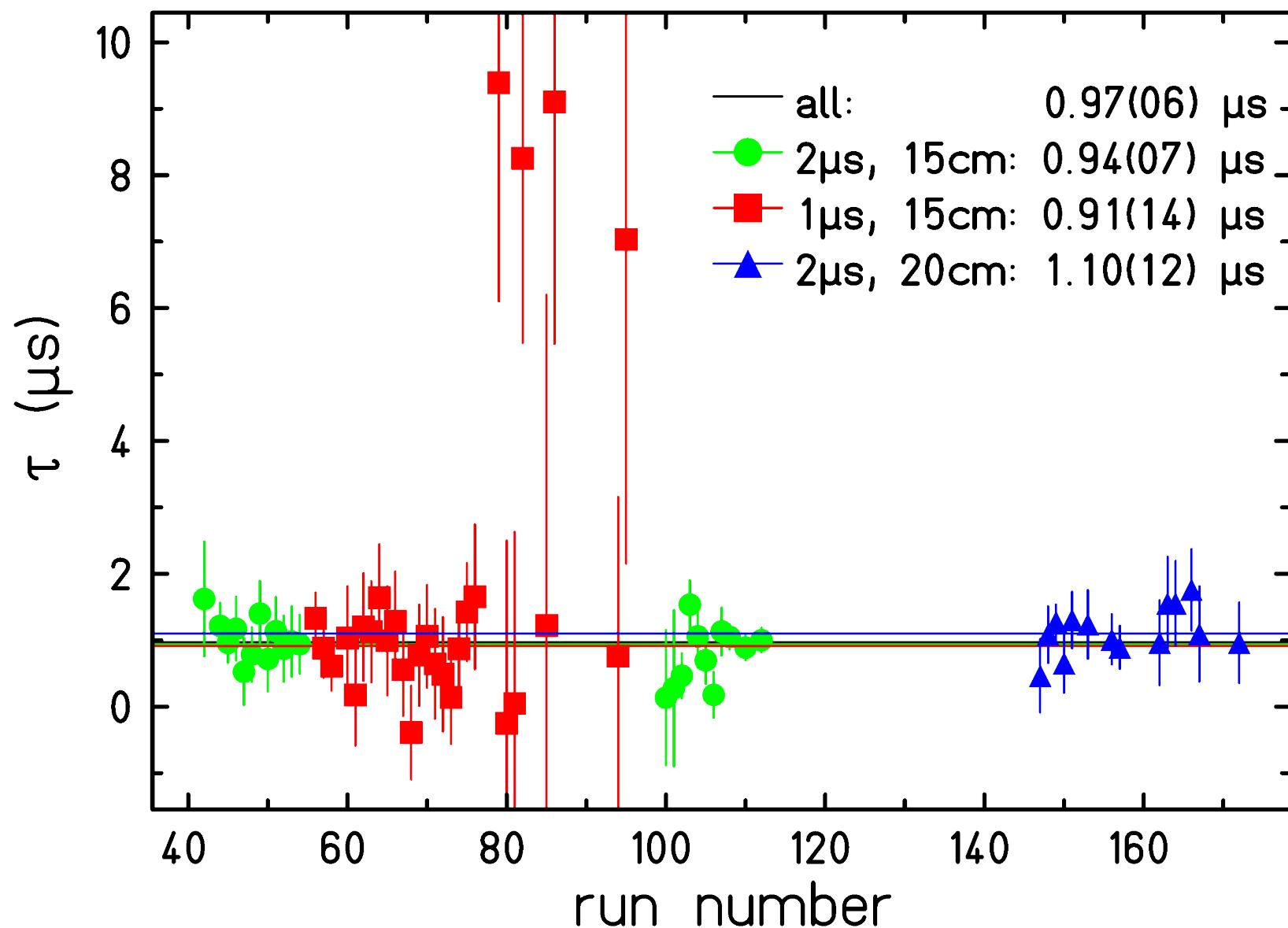
● ● ● **^{10}C / ^{19}Ne simulation results**

Pile-up simulations: 1022 keV counts versus 511 keV counts

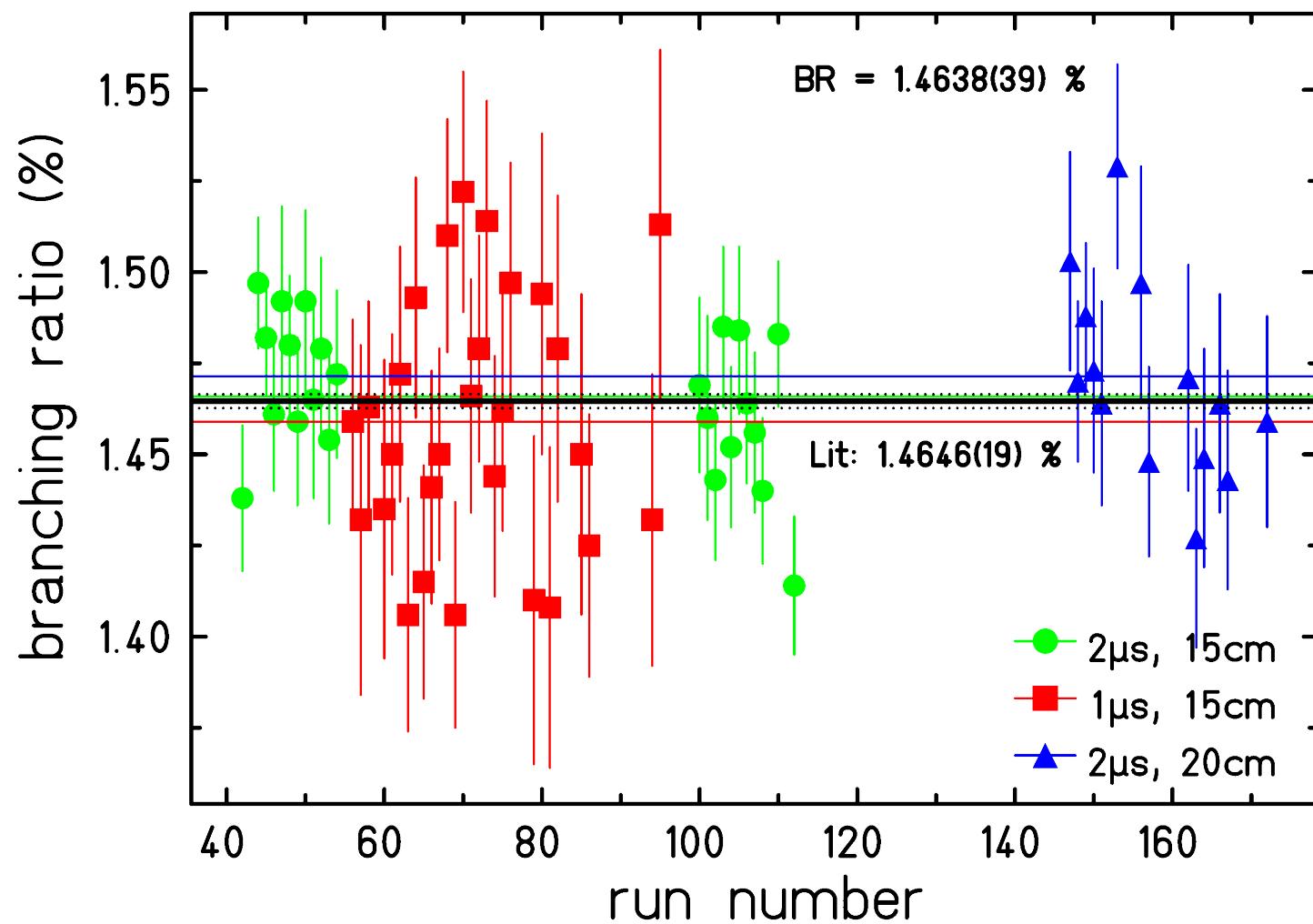


● ● ● ^{10}C : pile-up of two 718 keV γ rays

Pile-up analysis: 718 keV \rightarrow 1436 keV



● ● ● Super-allowed ranching ratio of ^{10}C



Final result: 1.4638(50) %

Literature: 1.4646(19) %

• • • How to improve?

Error budget:

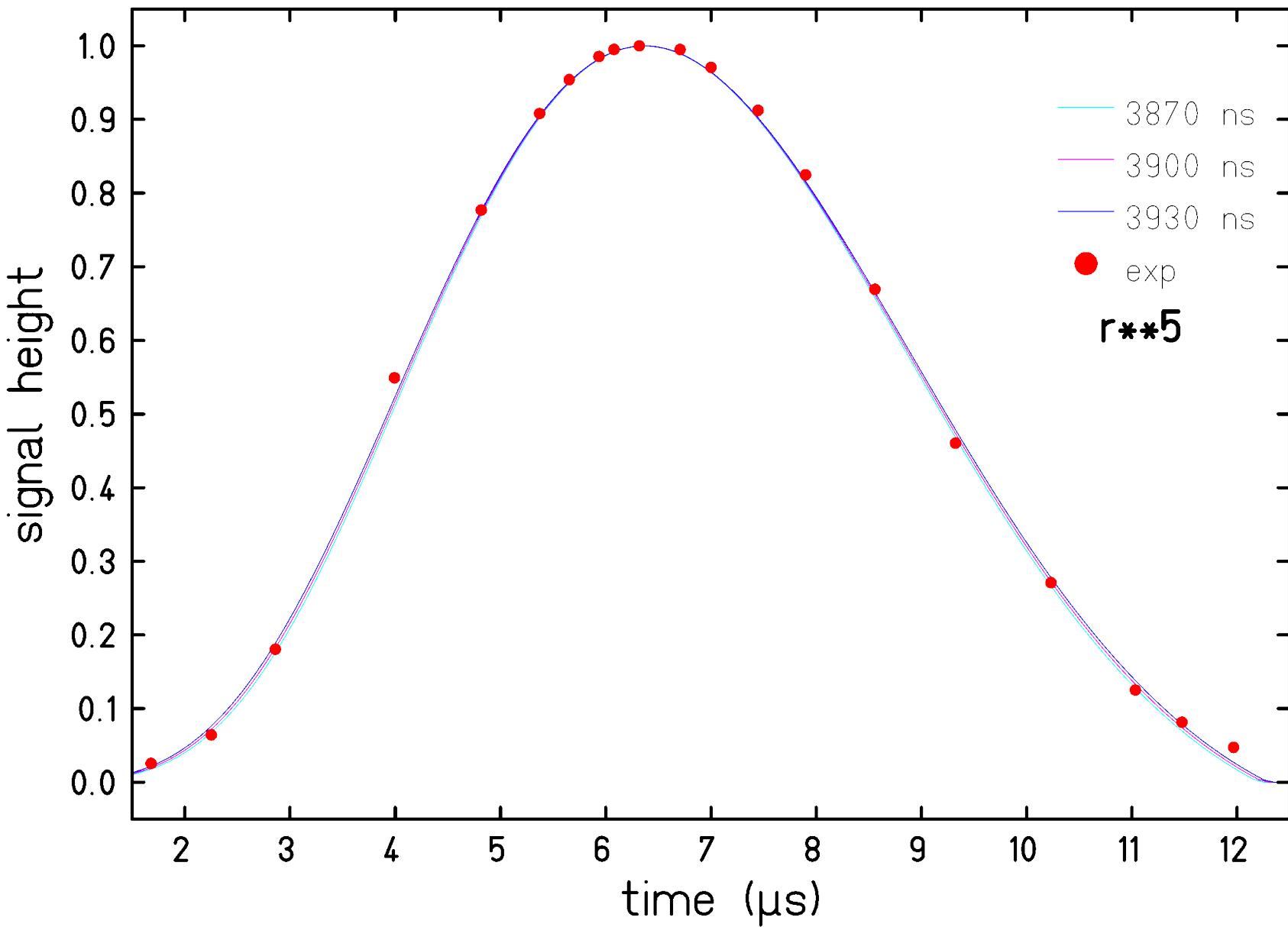
• Statistics	0.0039 %
• Efficiency simulations	0.0009 %
• Pile-up correction	0.0030 %
<hr/>	
Total:	0.0050 %

- more beam (time):
 - we already had $2\mu\text{A}$
but only $2\text{-}5 * 10^4$ pps of ^{10}C
ISOLDE production rate:
 - $7 * 10^5$ pps with CaO target
but we were limited by total γ rate
- 2/3 of 511 keV quanta from contaminants
 - MR-ToF to separate ^{10}CO and $^{13}\text{N}^{13}\text{N}$

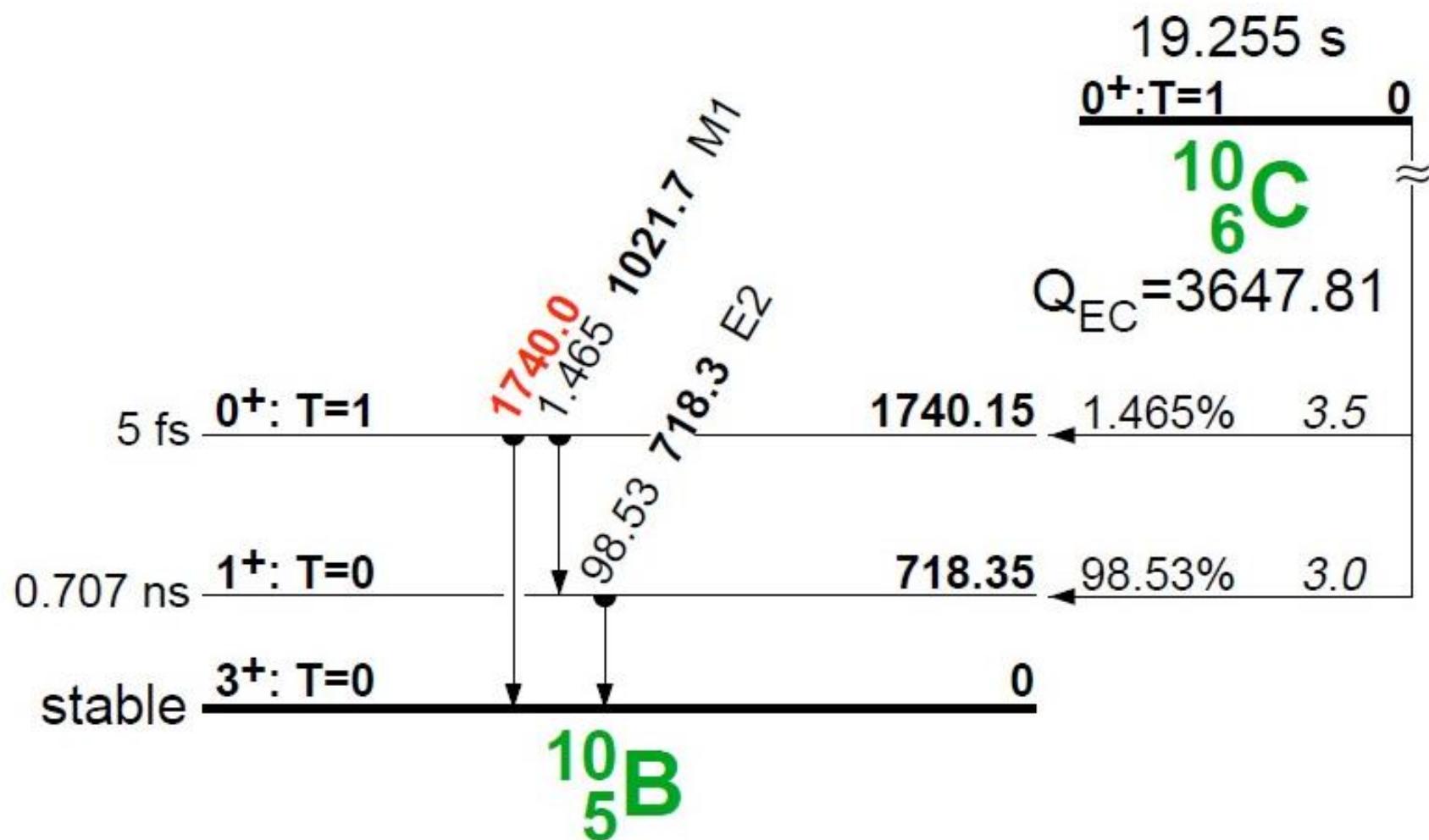


Thanks for
your attention

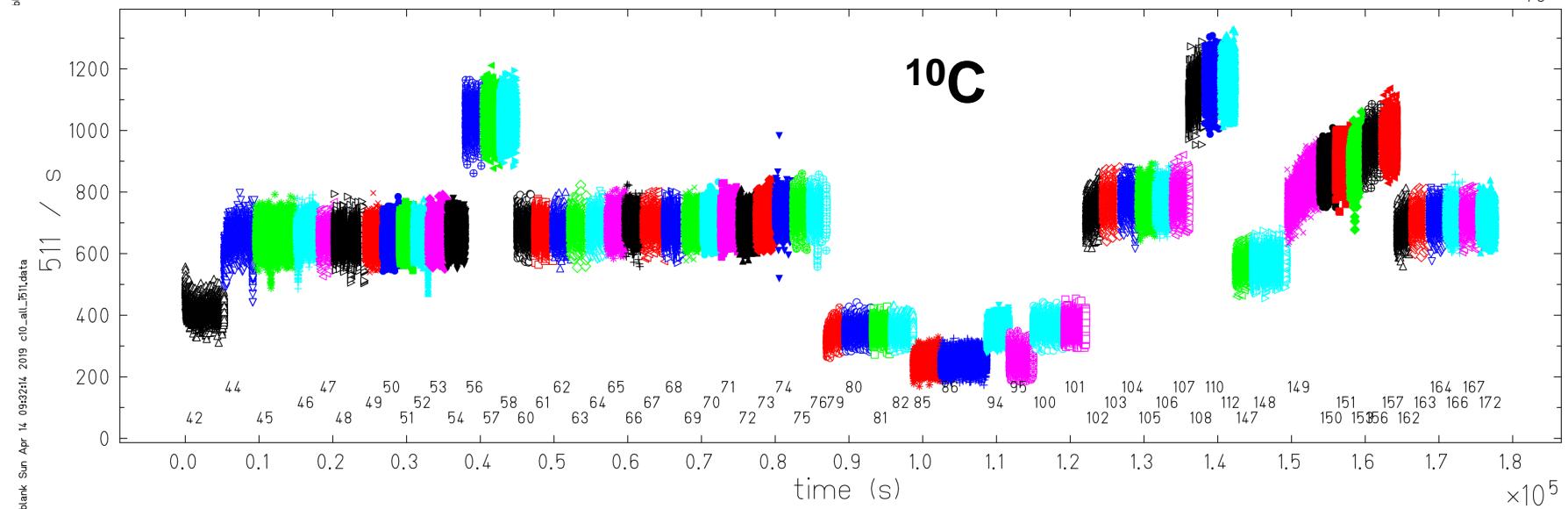
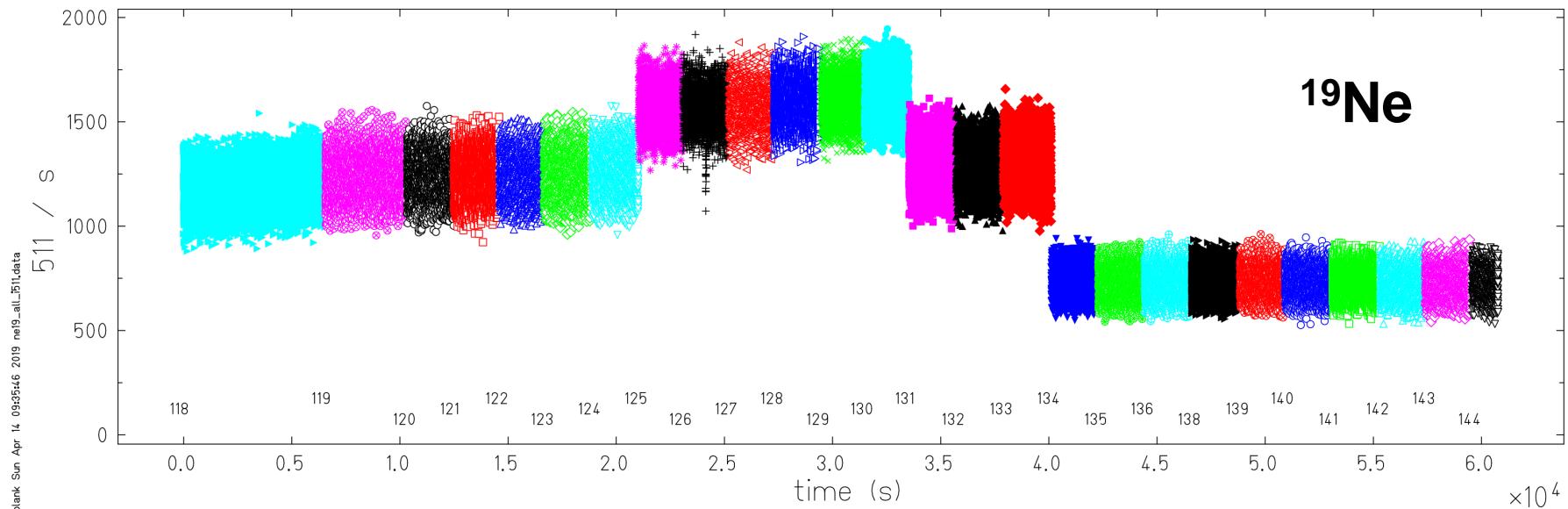
● ● ● Germanium signal for simulations



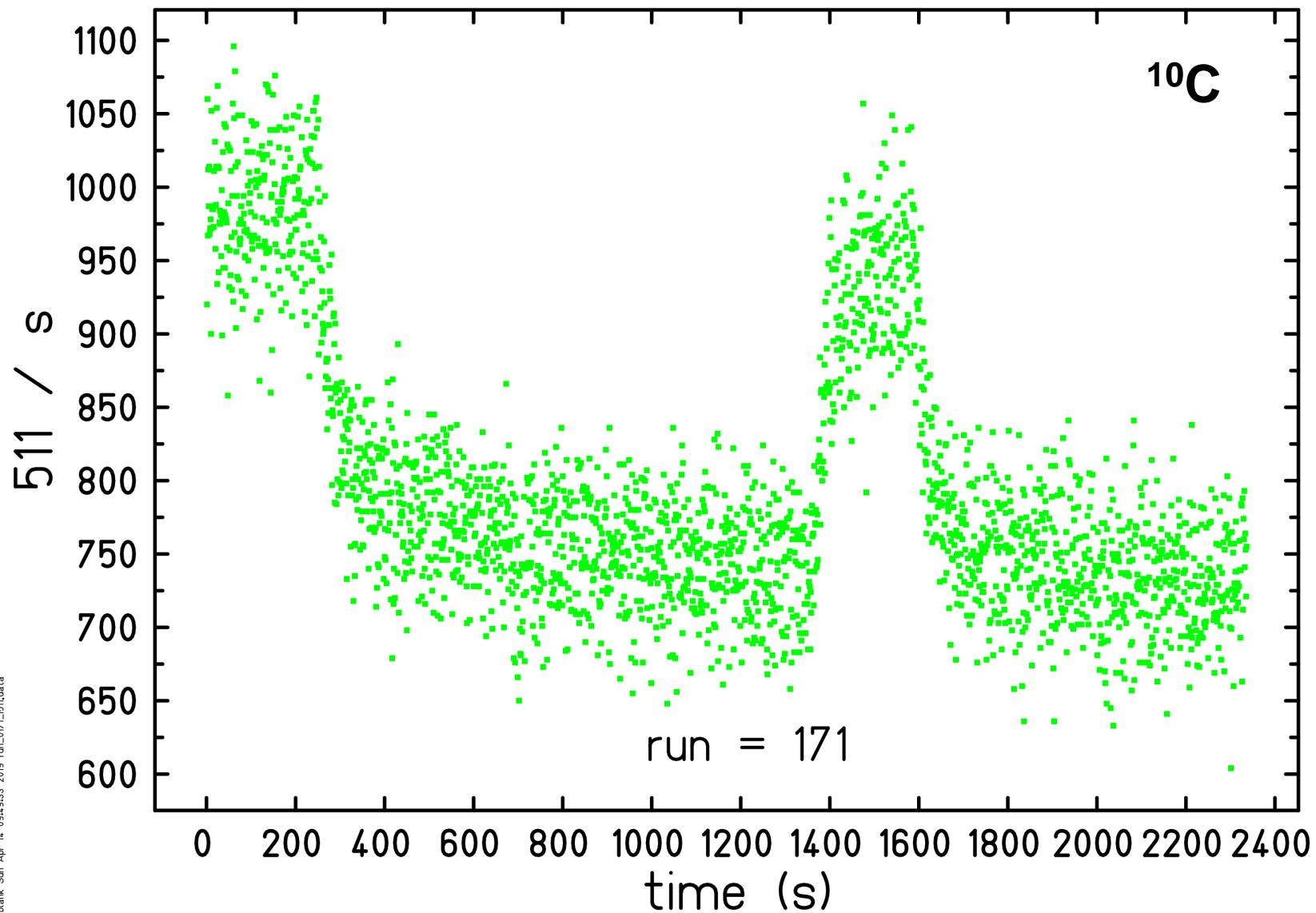
Super-allowed Fermi transitions for $T_z = -1$



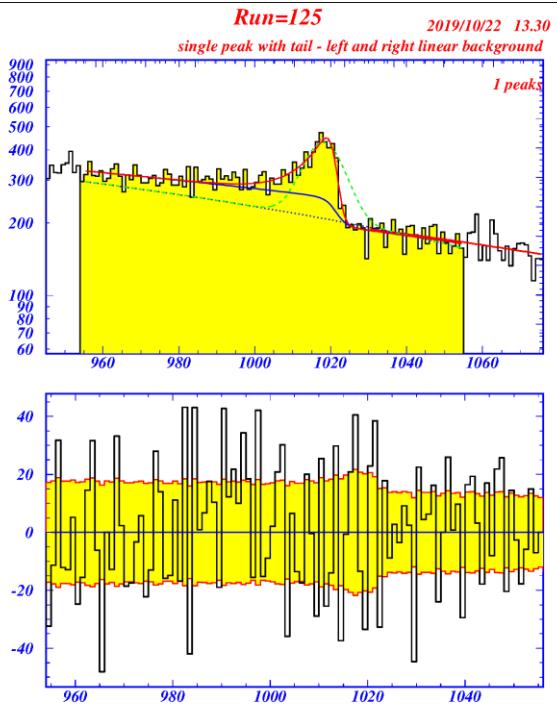
● ● ● **^{10}C analysis procedure**



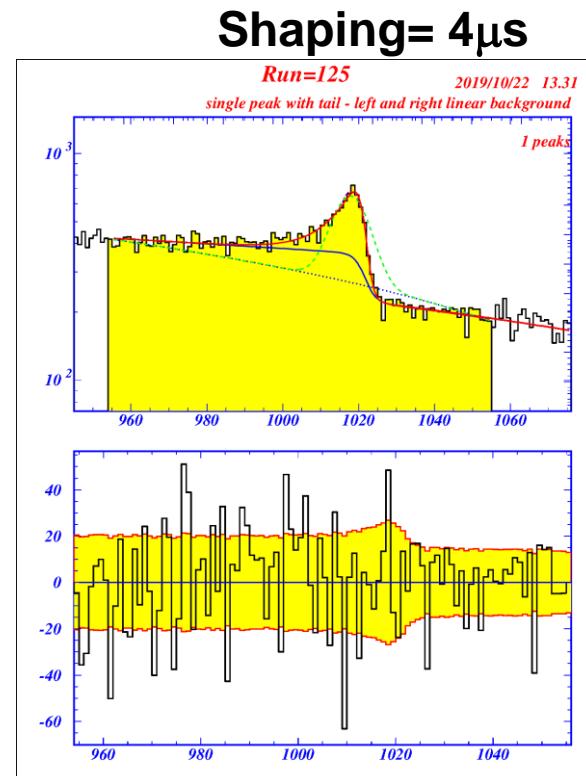
● ● ● **^{10}C analysis procedure**



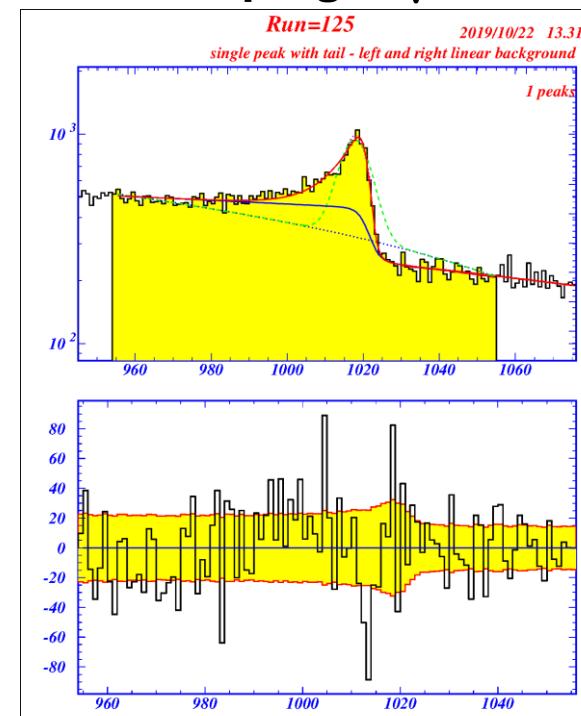
● ● ● ^{19}Ne simulation results



Shaping= $2\mu\text{s}$



Shaping= $6\mu\text{s}$



→ same peak shape, only peak height changes

• • • $^{10}\text{C} / ^{19}\text{Ne}$ simulation results

Pile-up simulations: pile-up event percentage

