Experiment E676@GANIL: Lifetime measurements of excited states in neutron-rich C and O isotopes as a test of the three-body forces

M. CIEMAŁA, IFJ PAN KRAKOW

SPOKESPERSONS: S. LEONI, B. FORNAL, M. CIEMALA

MILANO – IFJ PAN KRAKOW

GANIL LOCAL CONTACT: G. DEFRANCE, M. CIEMALA

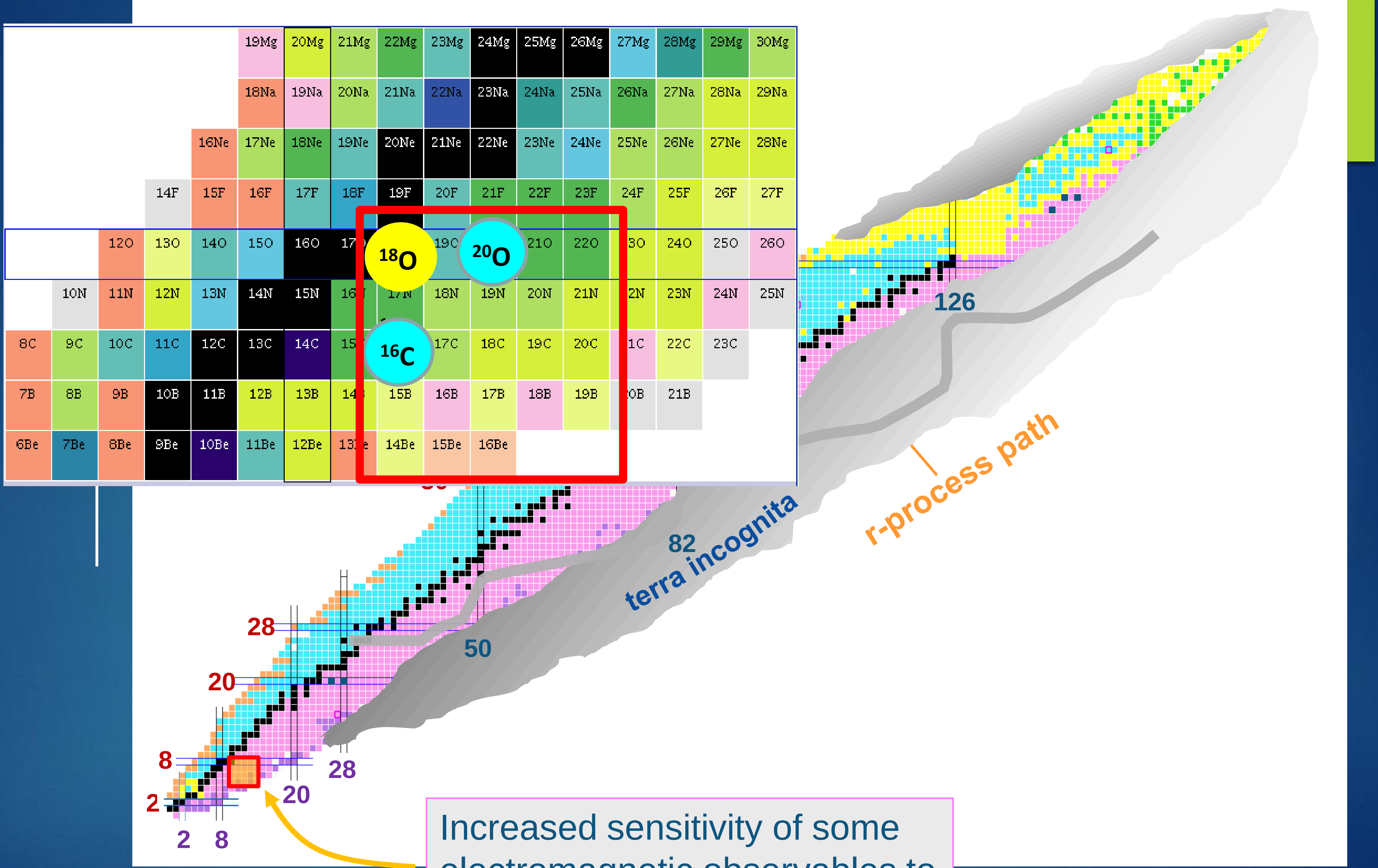
AGATA@GANIL COLLABORATION, COORDINATORS: **E. CLEMENT, S. LENZI**

VAMOS COLLABORATION, COORDINATOR: **A. LEMASSON,** GANIL, CAEN

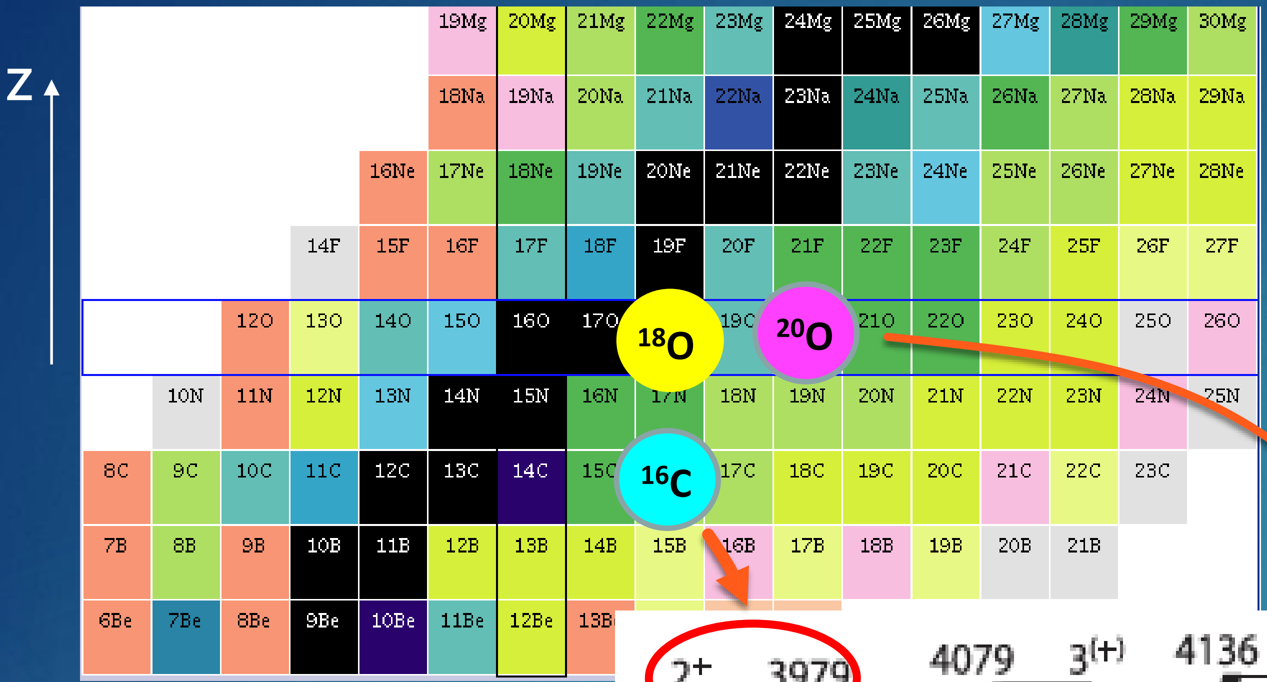
PARIS COLLABORATION, COORDINATOR **A. MAJ**, IFJ PAN, KRAKOW

Colloque GANIL

September 9 – 13, 2019



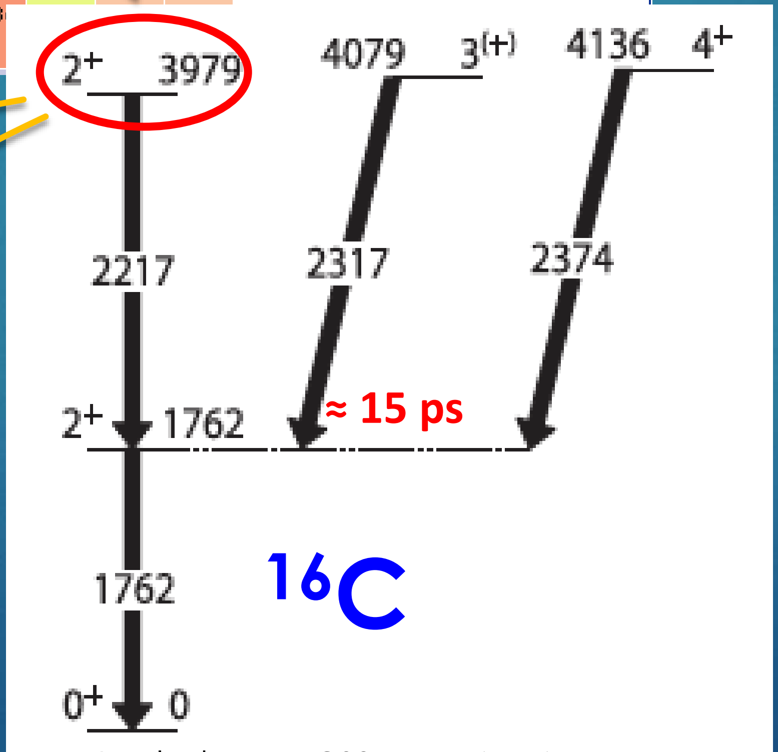
Increased sensitivity of some electromagnetic observables to the details of n-n force



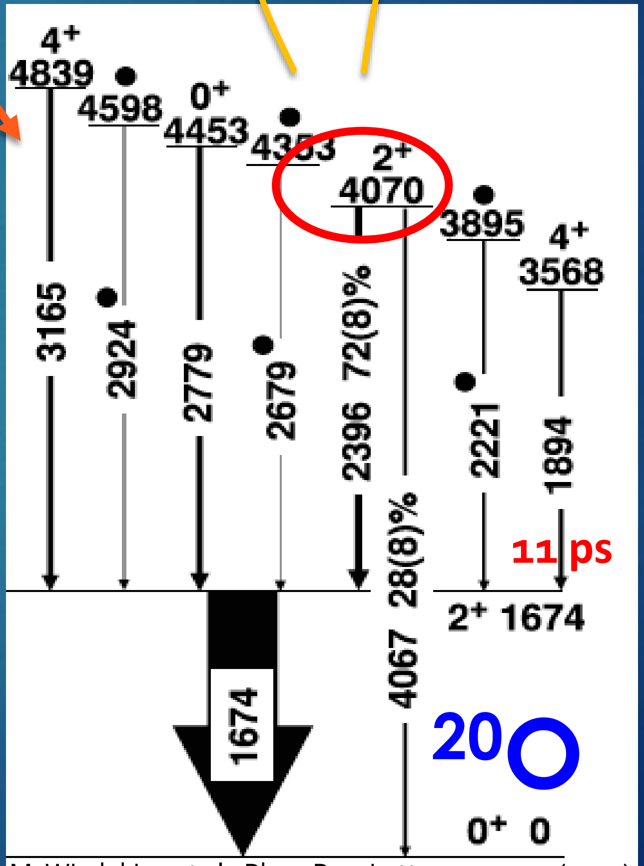
ab initio

Many-Body-Pert. Theory calculations of the 2^+_2 lifetimes

NN	NNN
0.32 ps	0.2 ps



M. Petri et al., Phys. Rev. C 86, 044329 (2012).



M. Wiedeking et al., Phys. Rev. Lett. 94, 132501 (2005).

NN	NNN
0.3 ps	0.08 ps

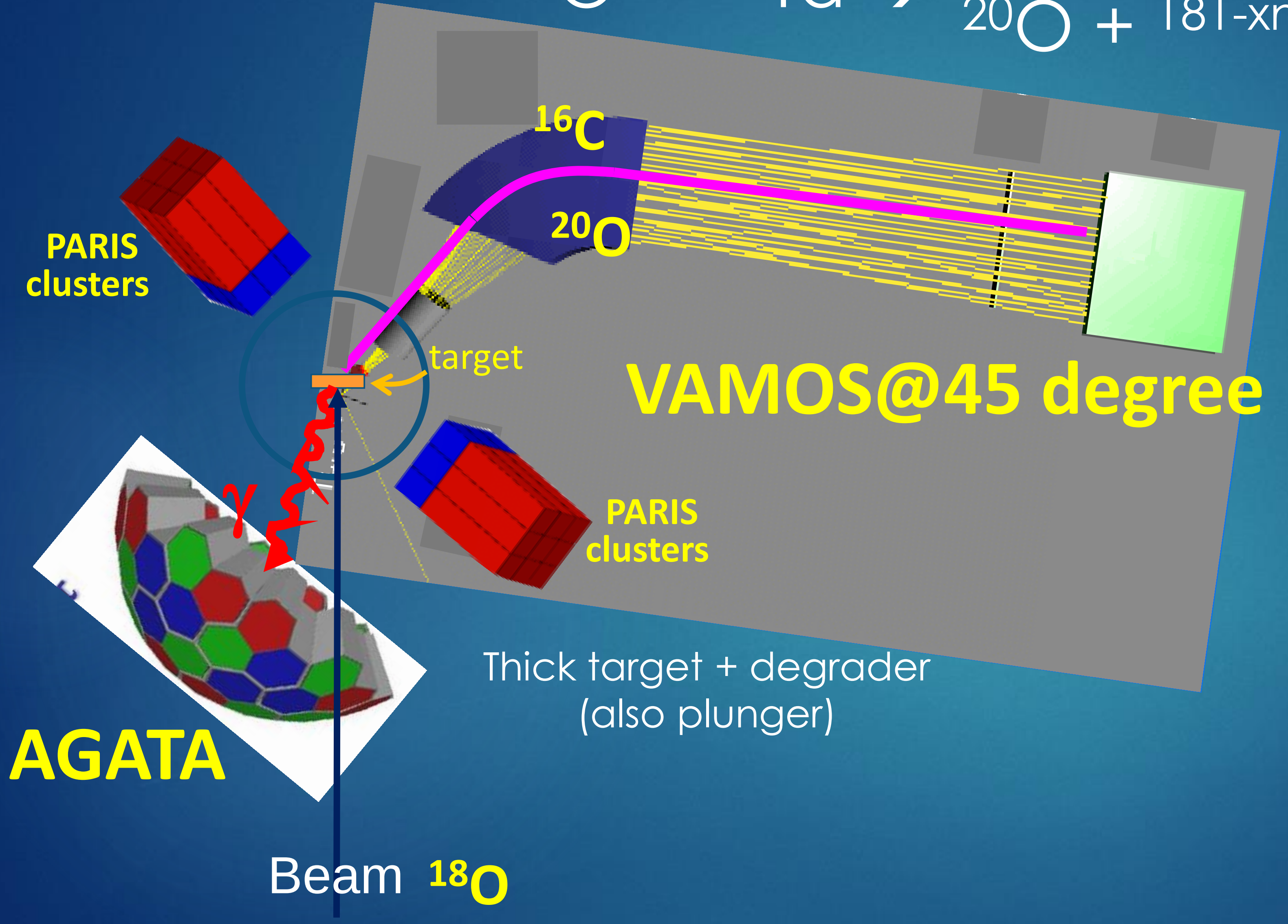
ab initio

No-Core-SHELL Model calculations

Experimental setup - E676@GANIL

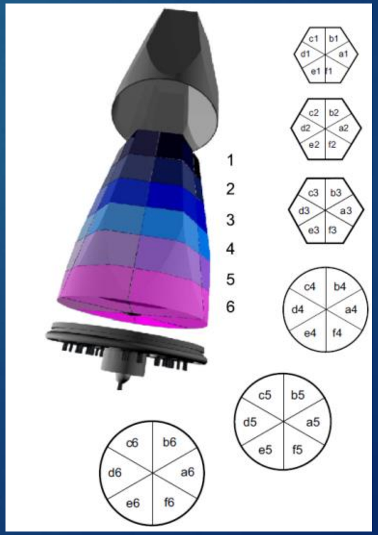
$^{18}O + ^{181}Ta \rightarrow$ $^{16}C + ^{183-xn}Re$

$^{20}O + ^{181-xn}Ta$

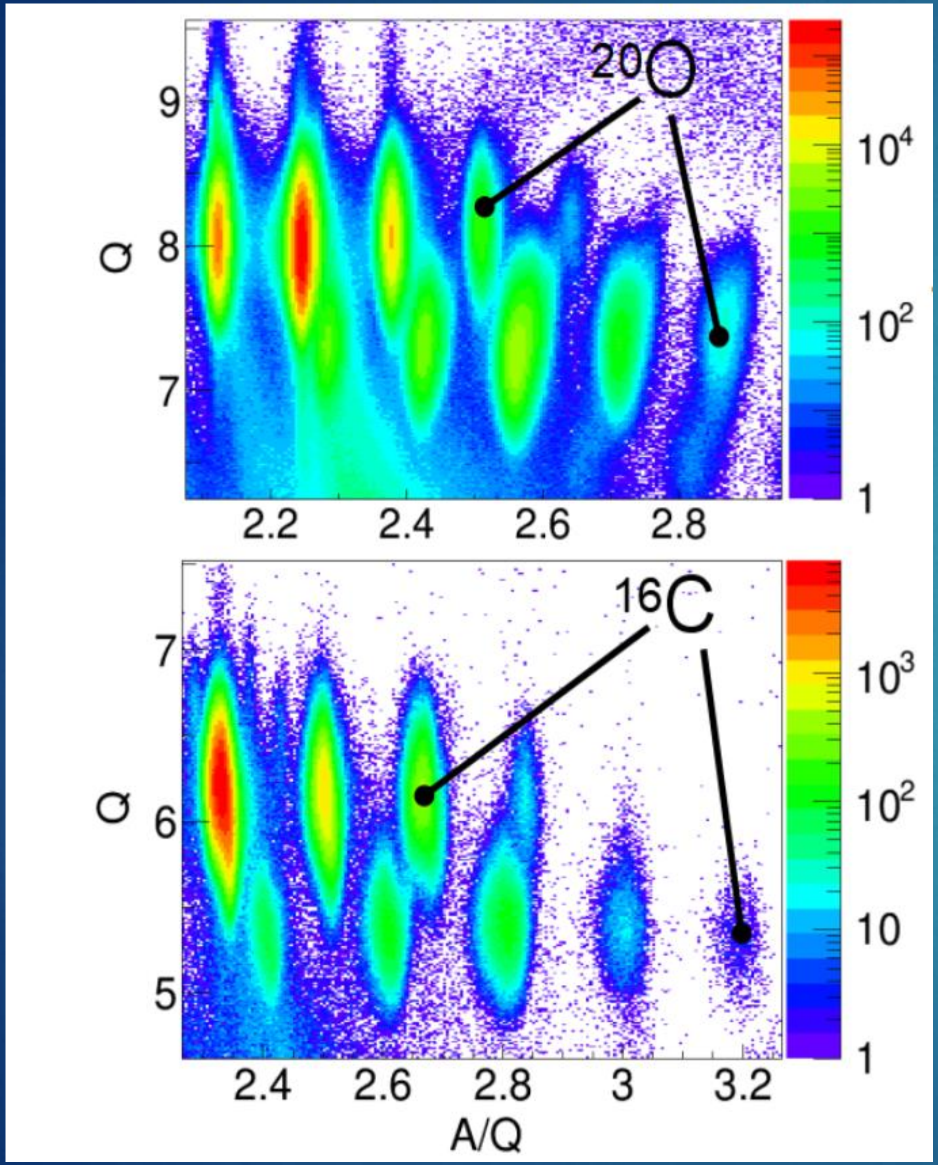


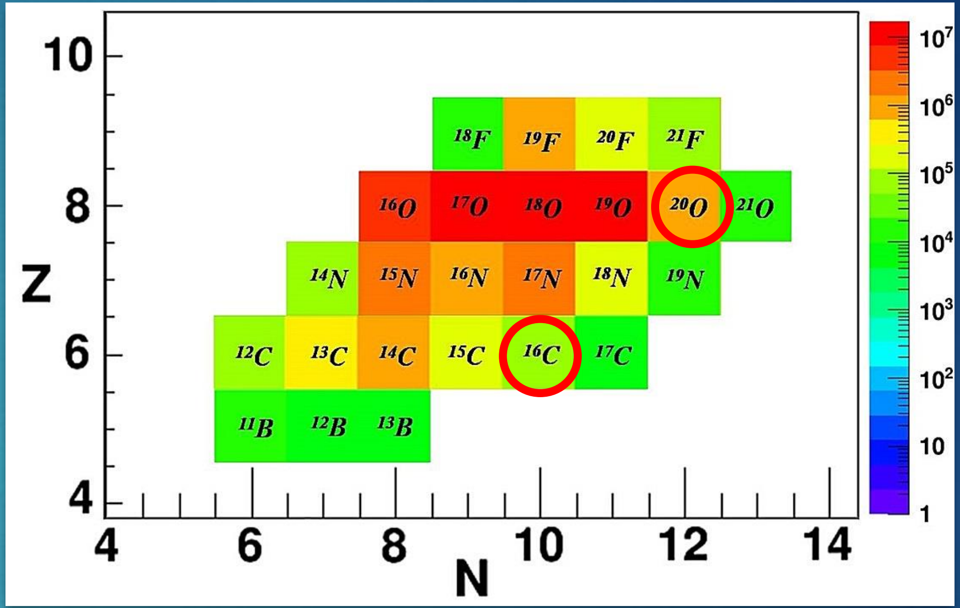
VAMOS entrance detectors:
2 DC (for ions entrance angles)
VAMOS focal plane detectors:
DC (for Brho reconstruction),
6 rows of IC (for ΔE)
Plastic (for trigger and ToF)

The Advanced GAmma Tracking Array (AGATA):
31 crystals



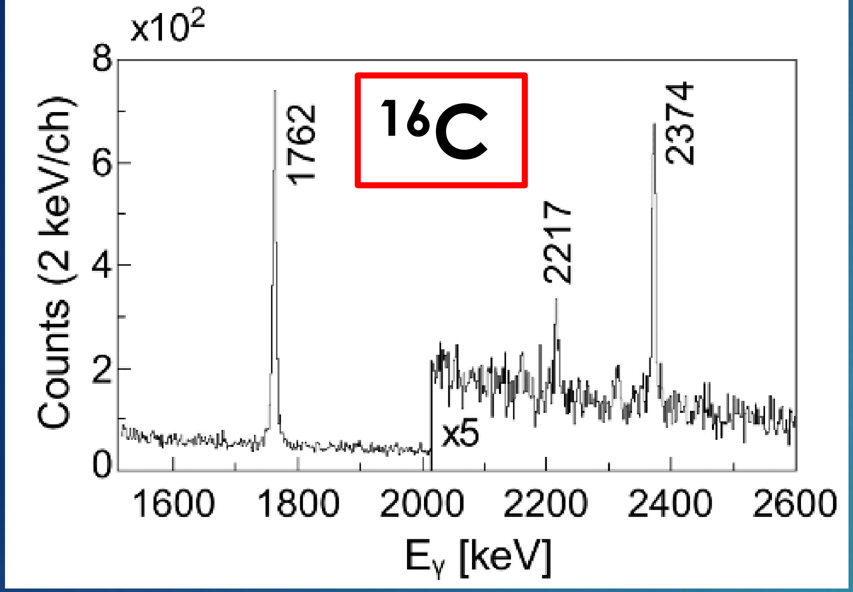
VAMOS spectrometer, ion selection

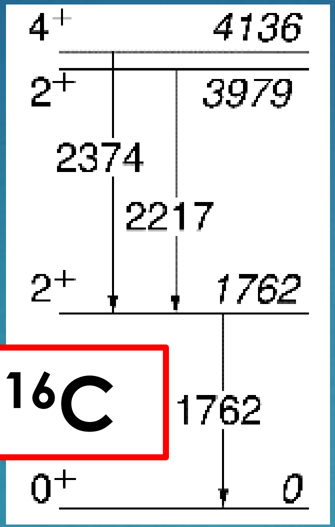


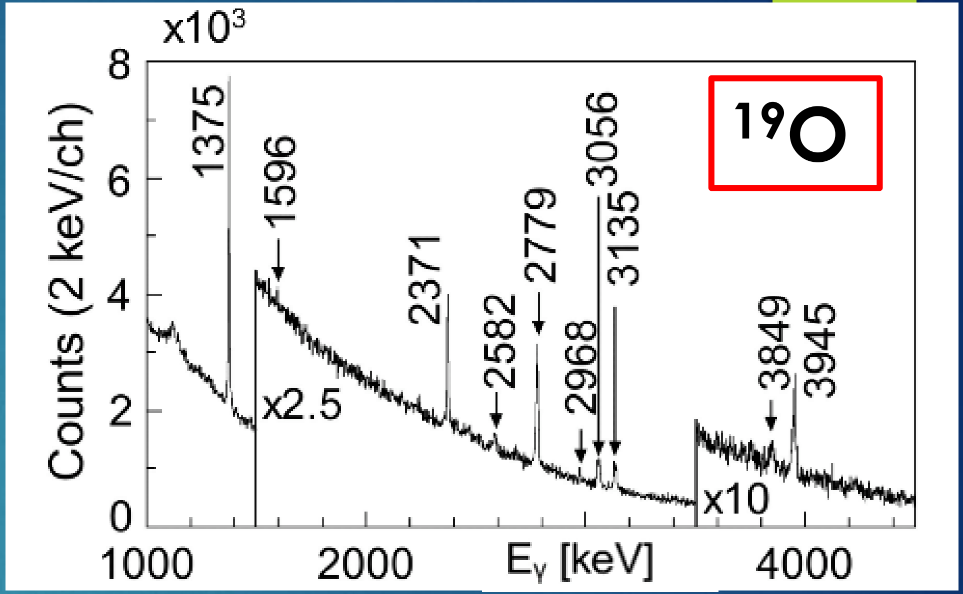


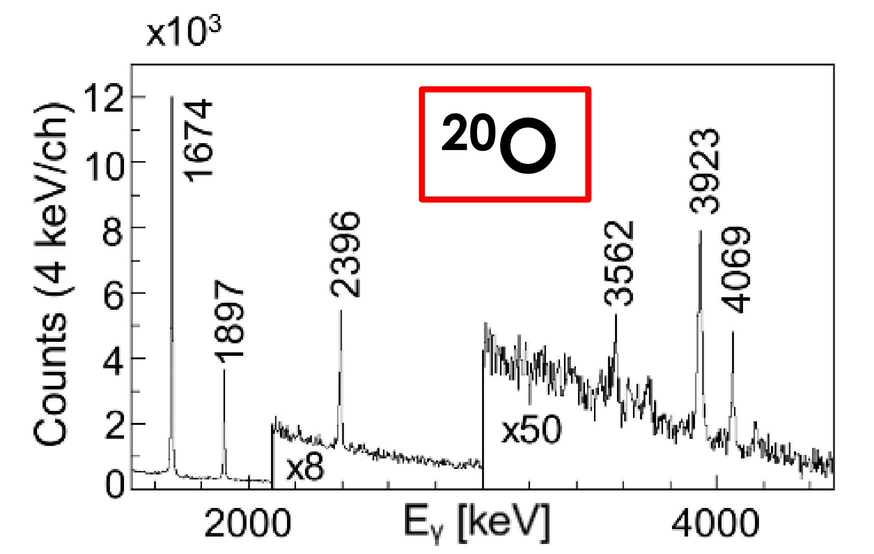
Identified isotopes from B to F.

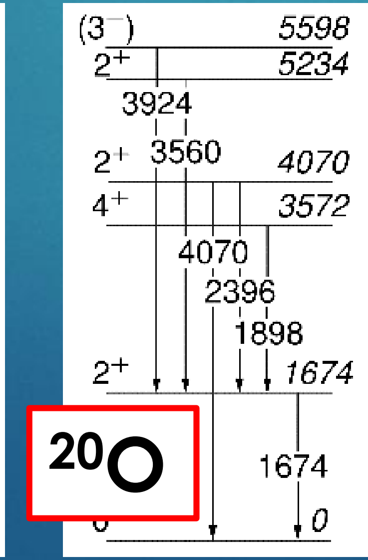
AGATA Spectra –Tracked and Doppler Corrected



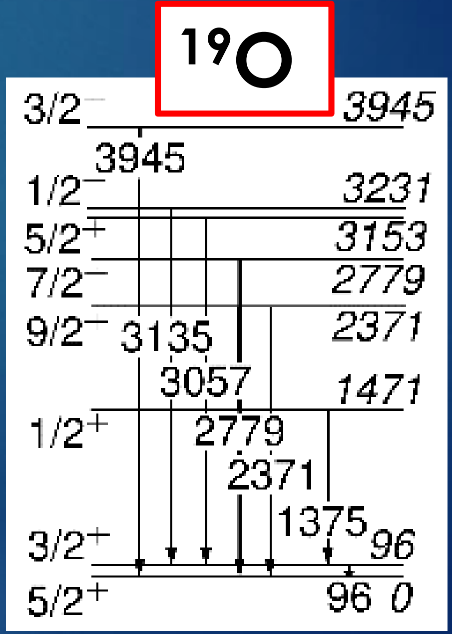






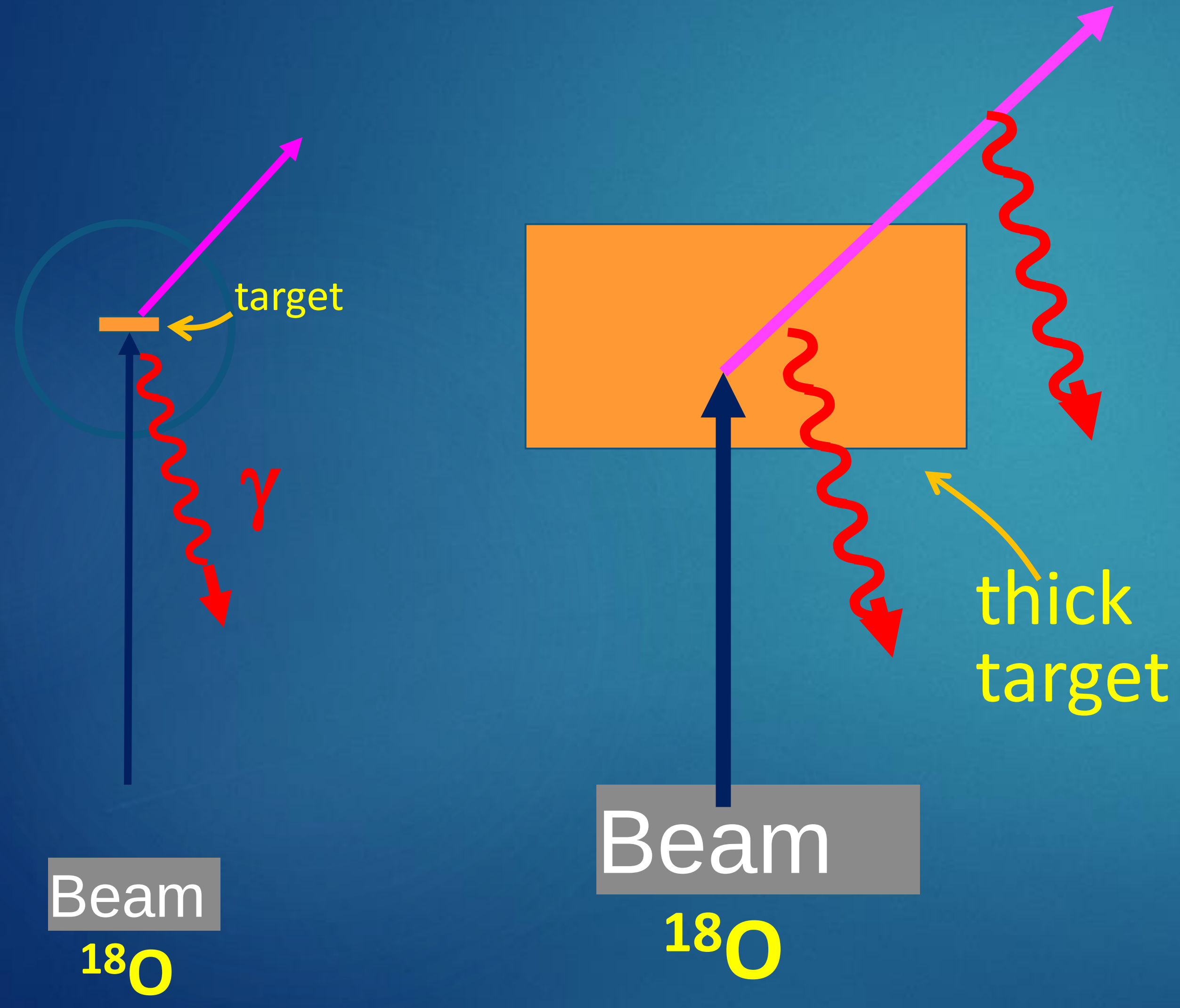


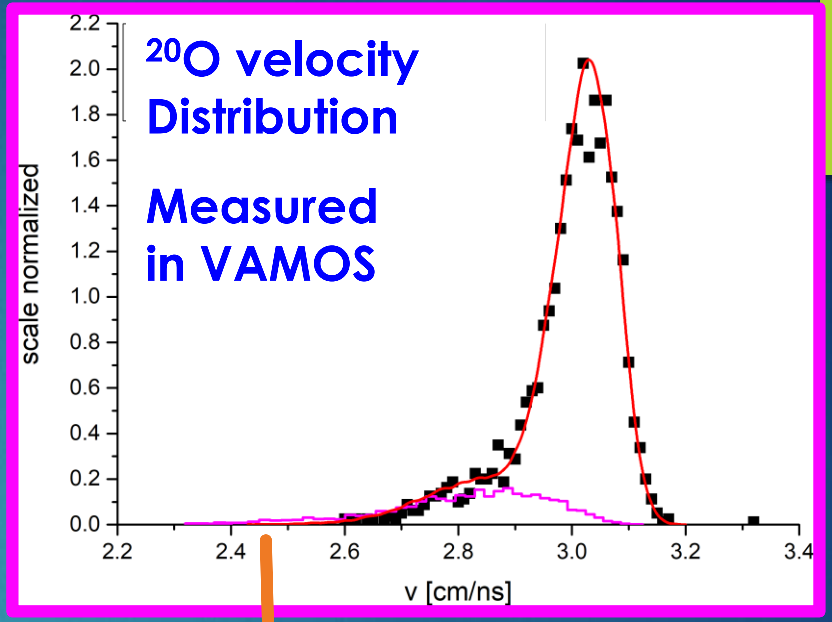
gated by VAMOS spectrometer

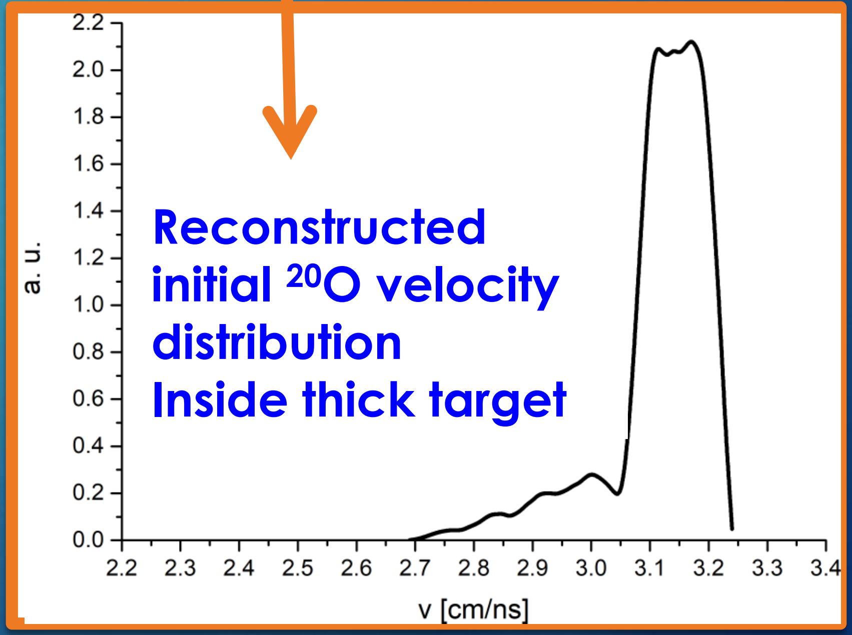


METHOD: Doppler shift dependence on the point of gamma emission

^{18}O (7 MeV/A) + ^{181}Ta target (6 mg/cm^2)







Simulations are needed to extract lifetimes from γ lineshape

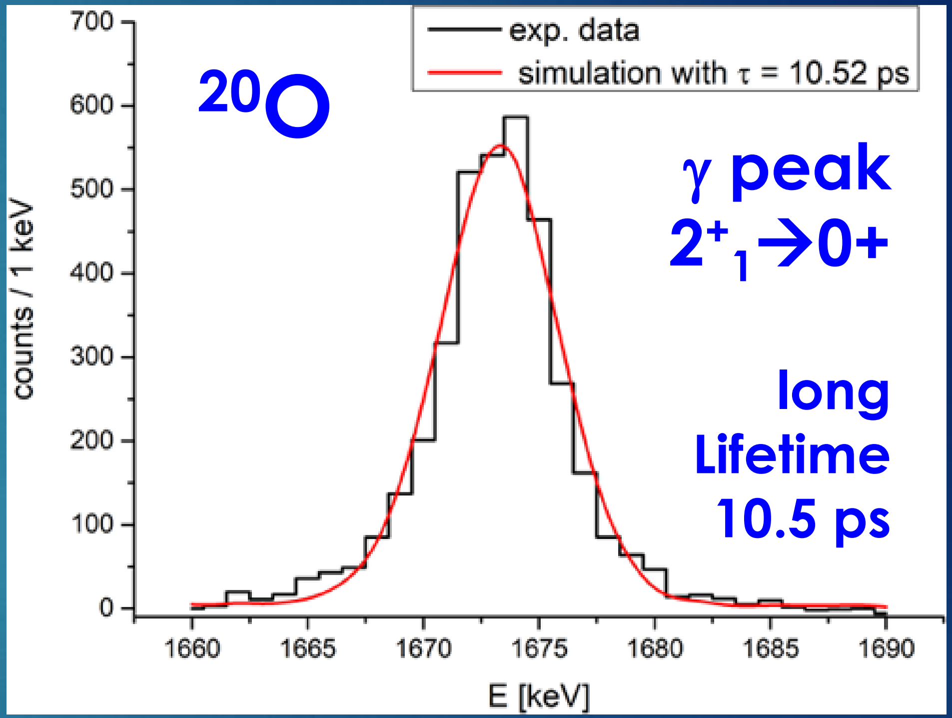
1. The beam is passing through the target decreasing its energy.
   Multi nucleon transfer reactions occur inside the target.
   An excited level is let to decay with fixed lifetime.

2. Simulation (with GEANT4 package) of AGATA response.

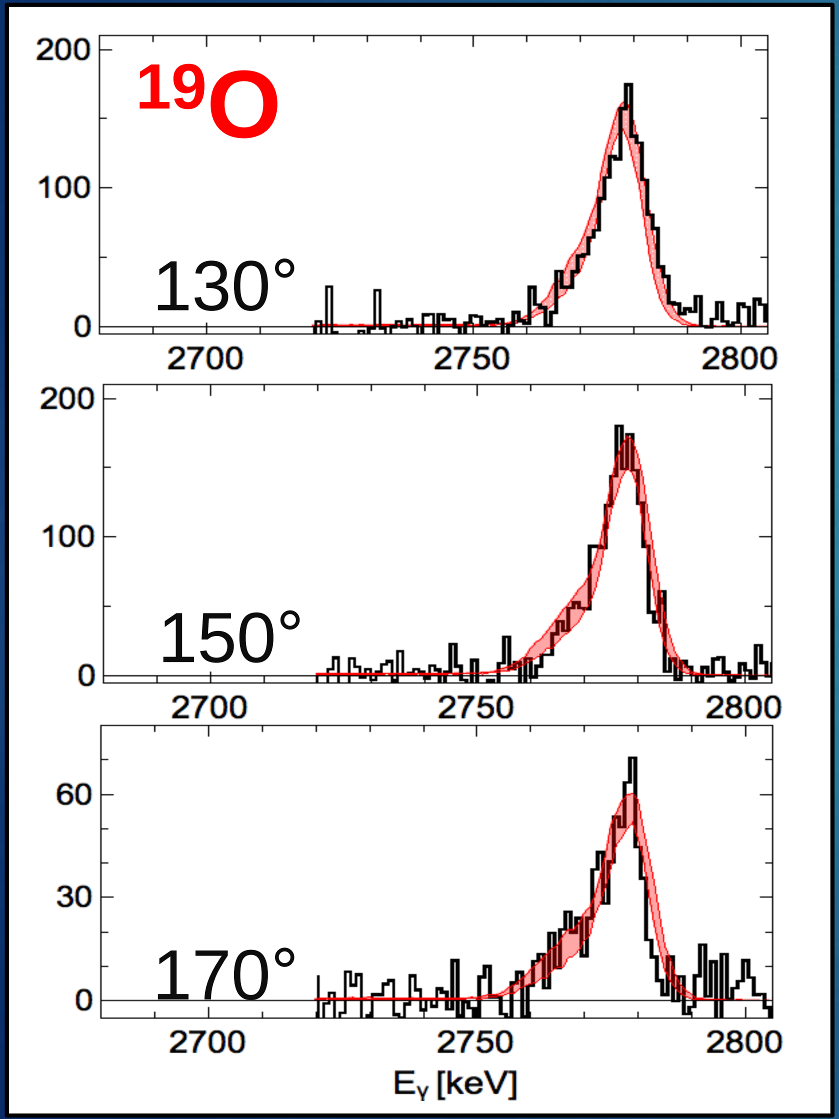
3. AGATA simulated data are tracked (similarly to experimental data) and Doppler corrected.

3. Experimental energy resolution of AGATA crystals and differences in counting rates are included in the simulation.

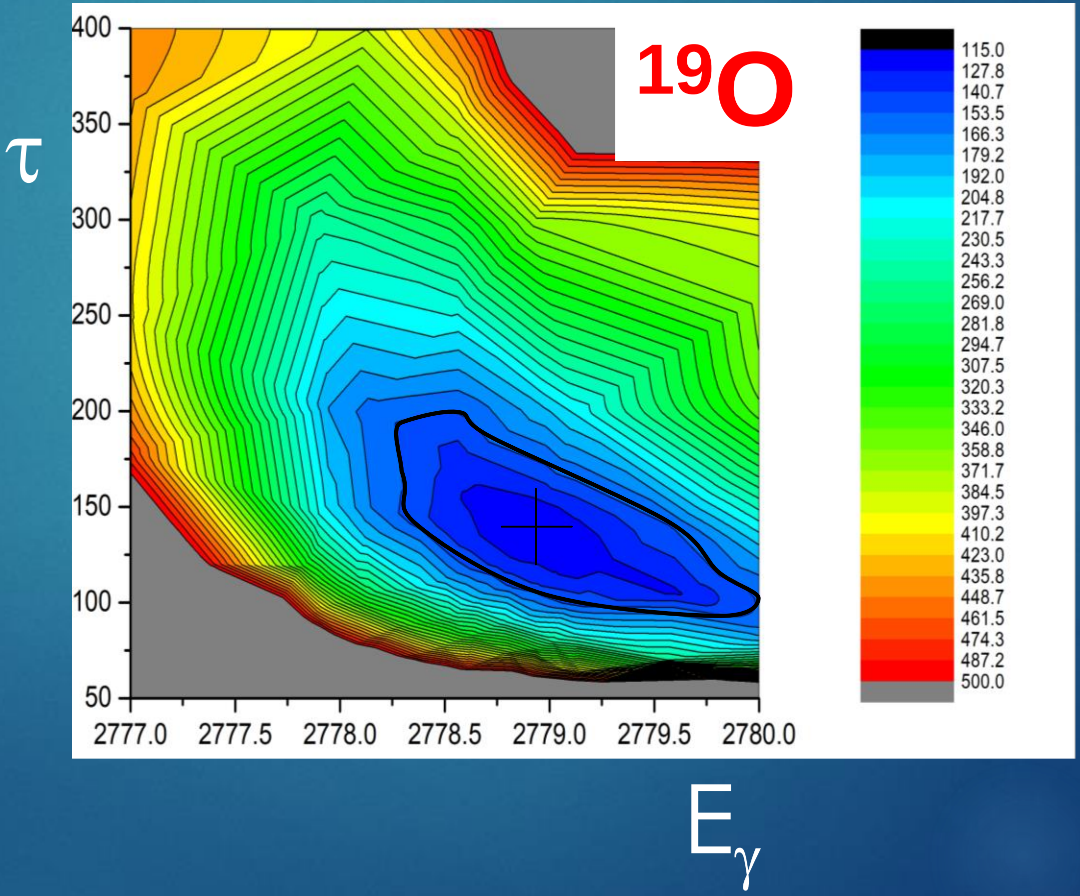
3. 2D chi^2 maps are used to determine optimum lifetime.

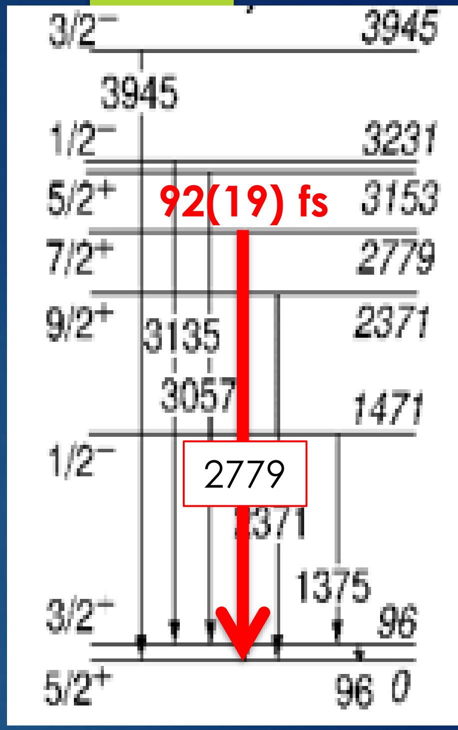


TEST of KNOWN lifetimes in the 100s femtoseconds region



^{18}O (7 MeV/A) + ^{181}Ta target (6 mg/cm^2)





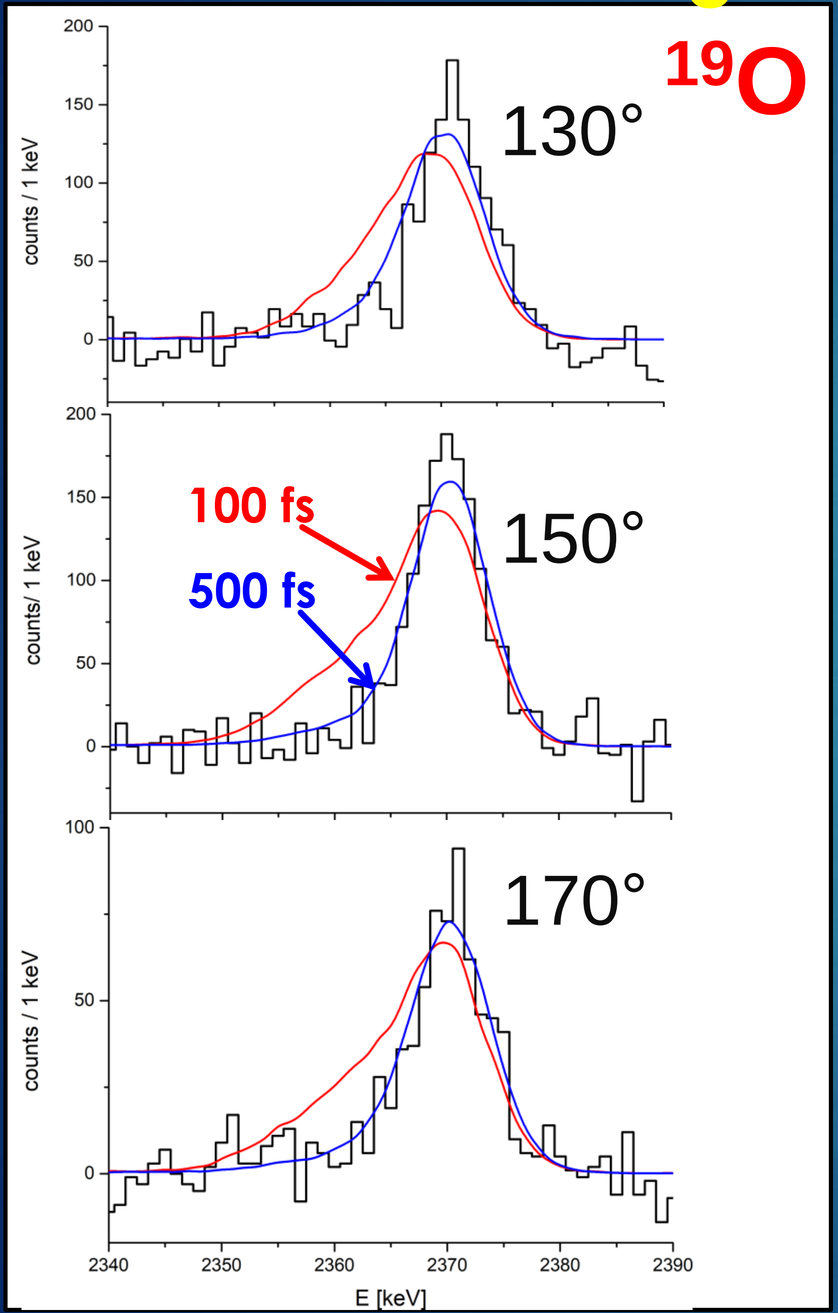
$\tau = 140^{+50}_{-40}$ fs

Very old litterature values (1971)

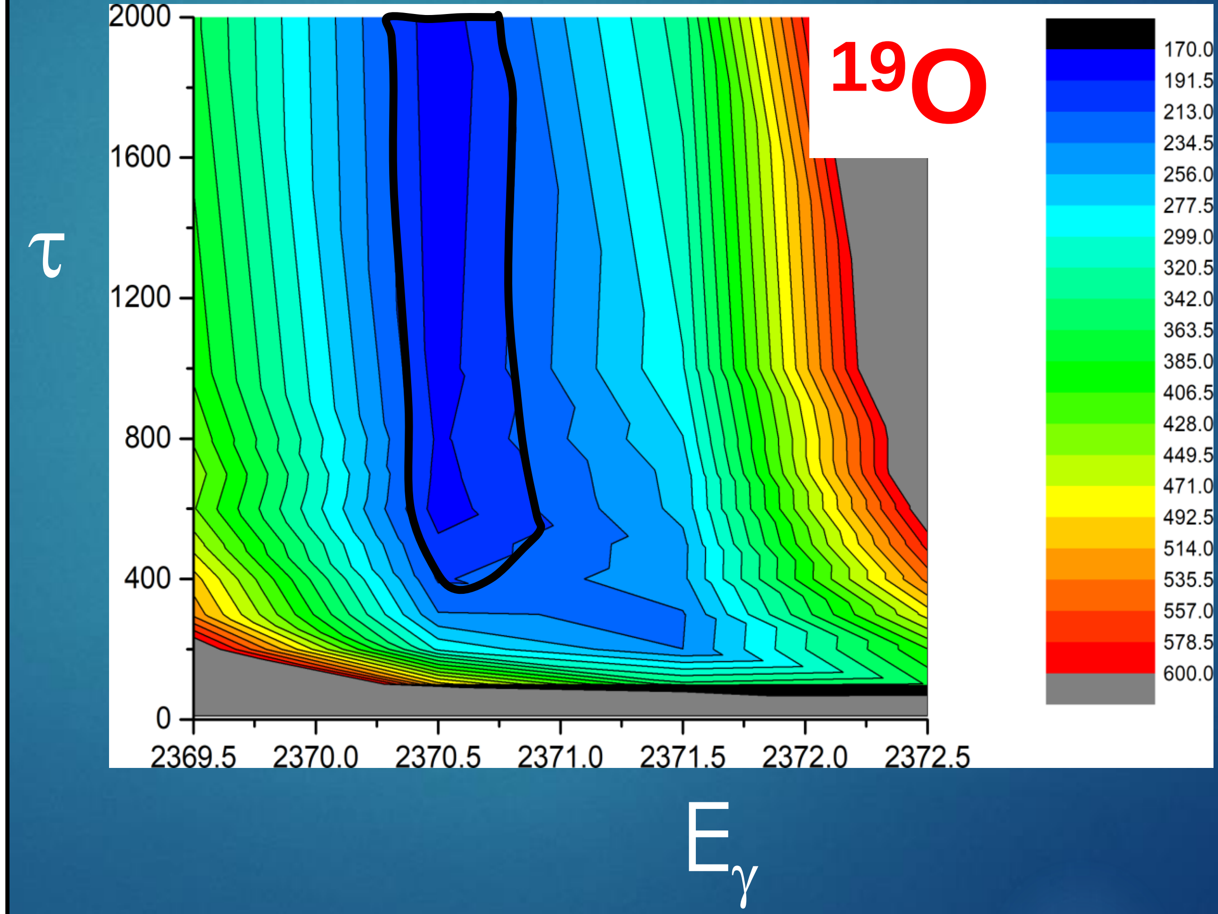
τ = 70(26) fs

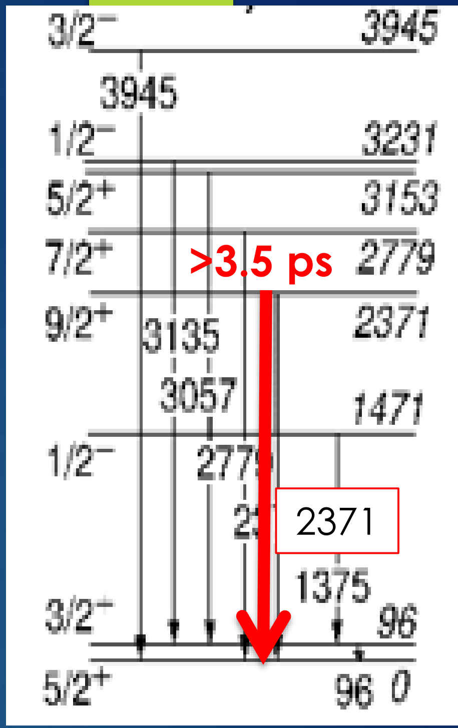
τ = 117(26) fs

TEST of KNOWN long lifetime in the region



^{18}O (7 MeV/A) + ^{181}Ta target (6 mg/cm^2)

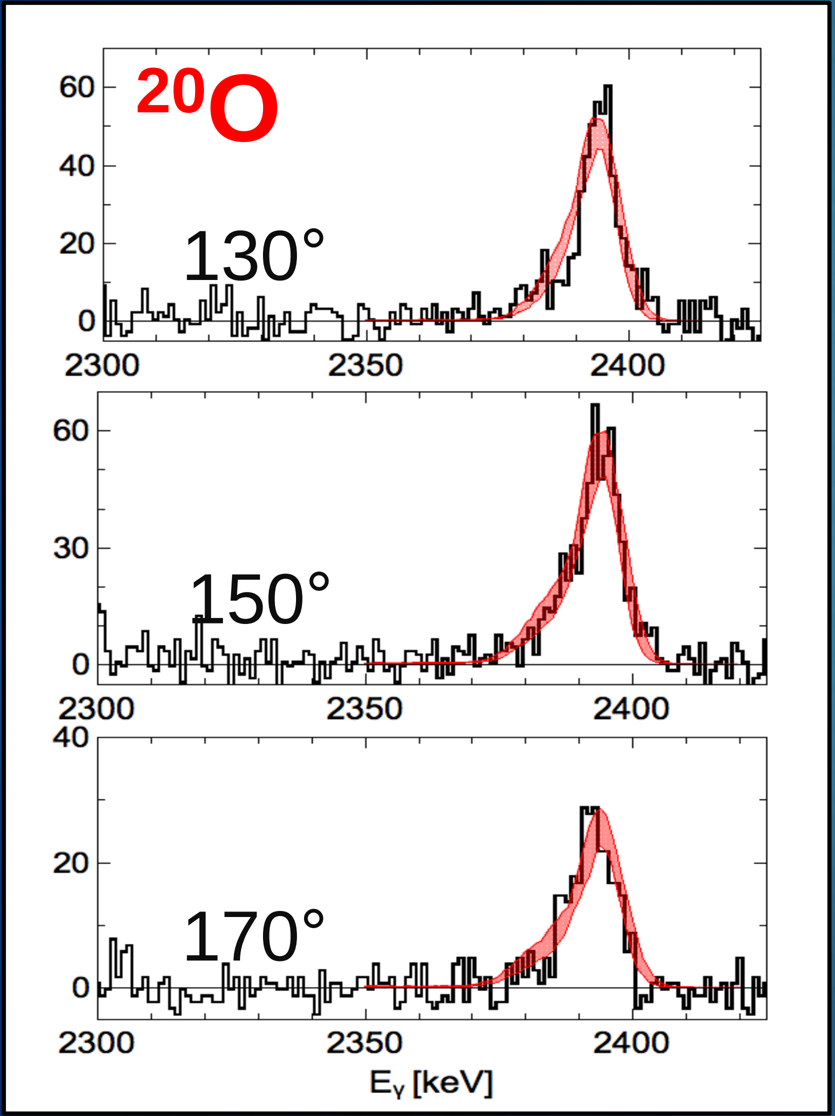


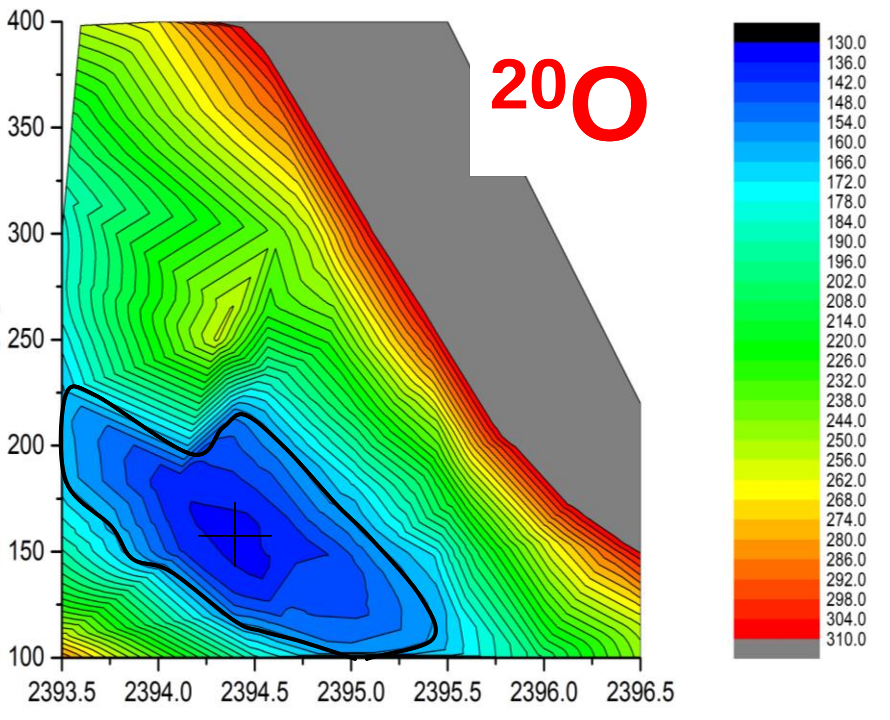


$\tau > 400$ fs

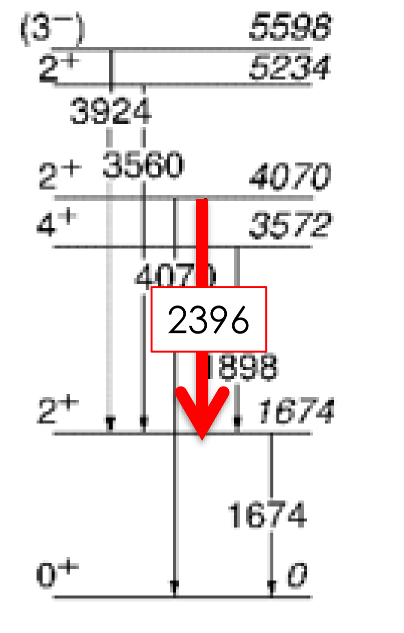
OUR Case of interest – ^{20}O

^{18}O (7 MeV/A) + ^{181}Ta target (6 mg/cm^2)





E_γ

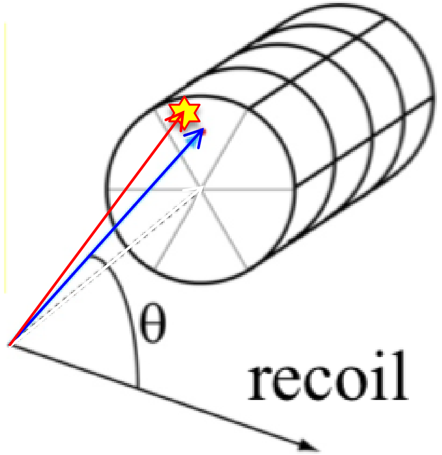


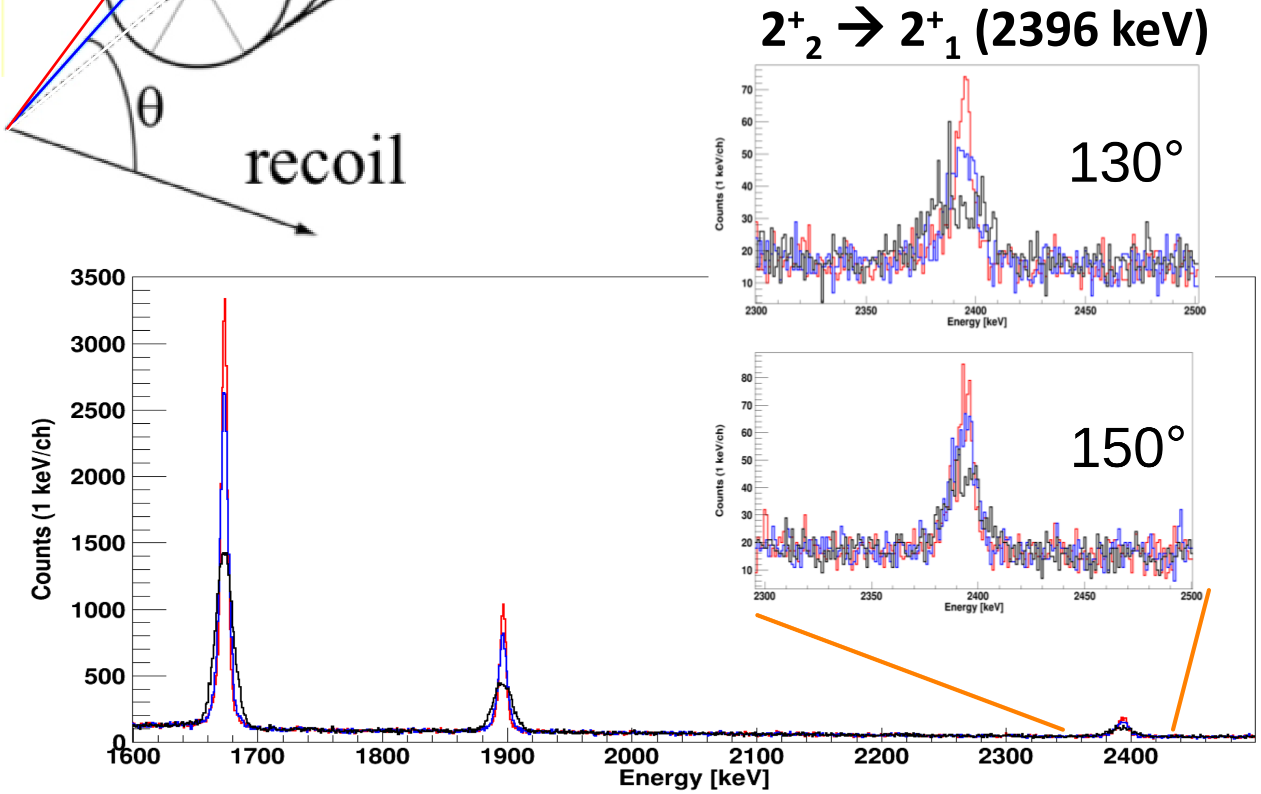
$\tau = 150^{+80}_{-30}$ fs

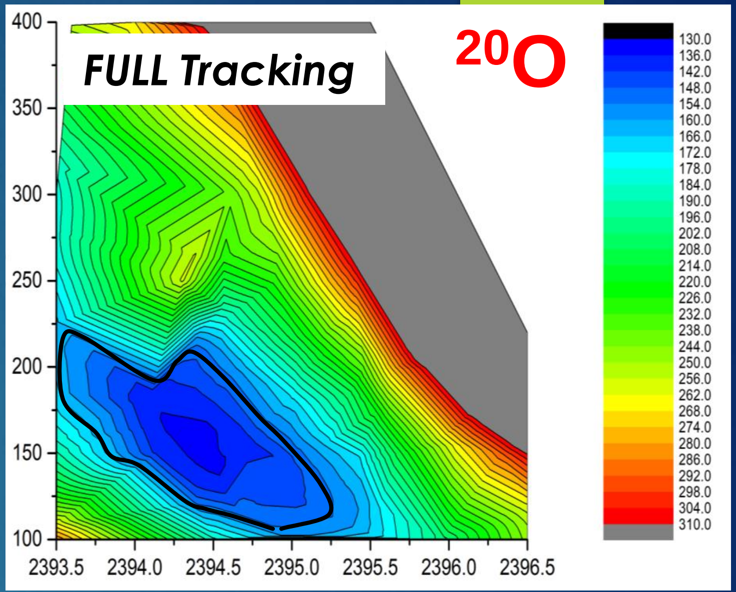
For 2_2-> 2_1 decay (79(5)% branching ratio), partial $\tau = 190^{+102}_{-39}$ fs

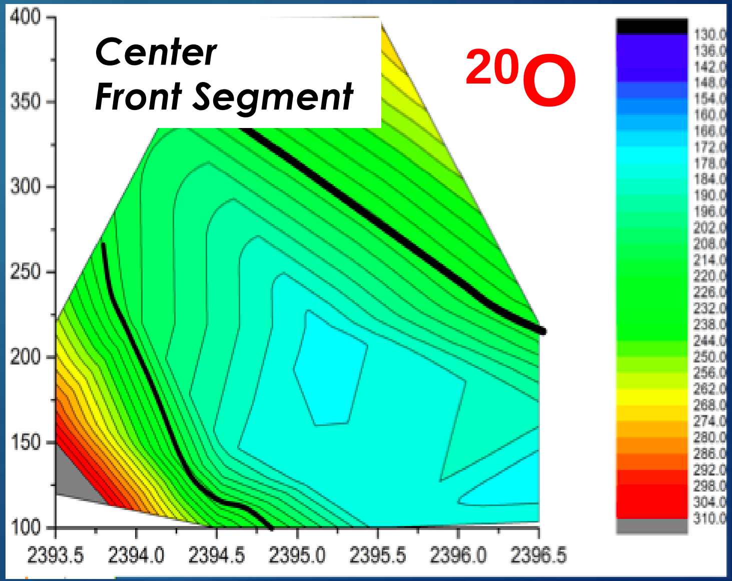
Large improvement with AGATA

$$\Delta E_\gamma = 2E_{\gamma 0}\frac{v}{c}\sin\theta_\gamma \sin\Delta\theta$$



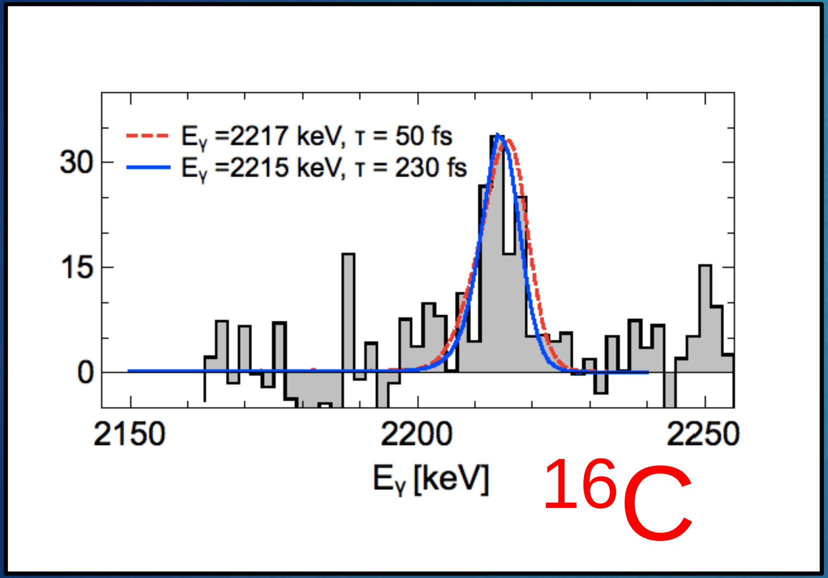




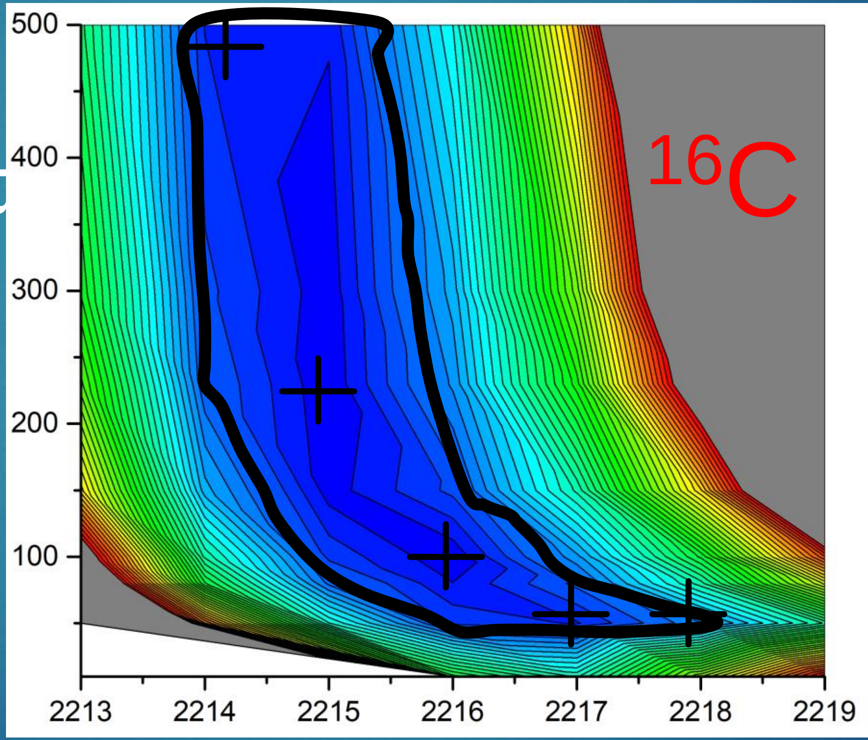


OUR Case of interest – ^{16}C

^{18}O (7 MeV/A) + ^{181}Ta target (6 mg/cm^2)



τ



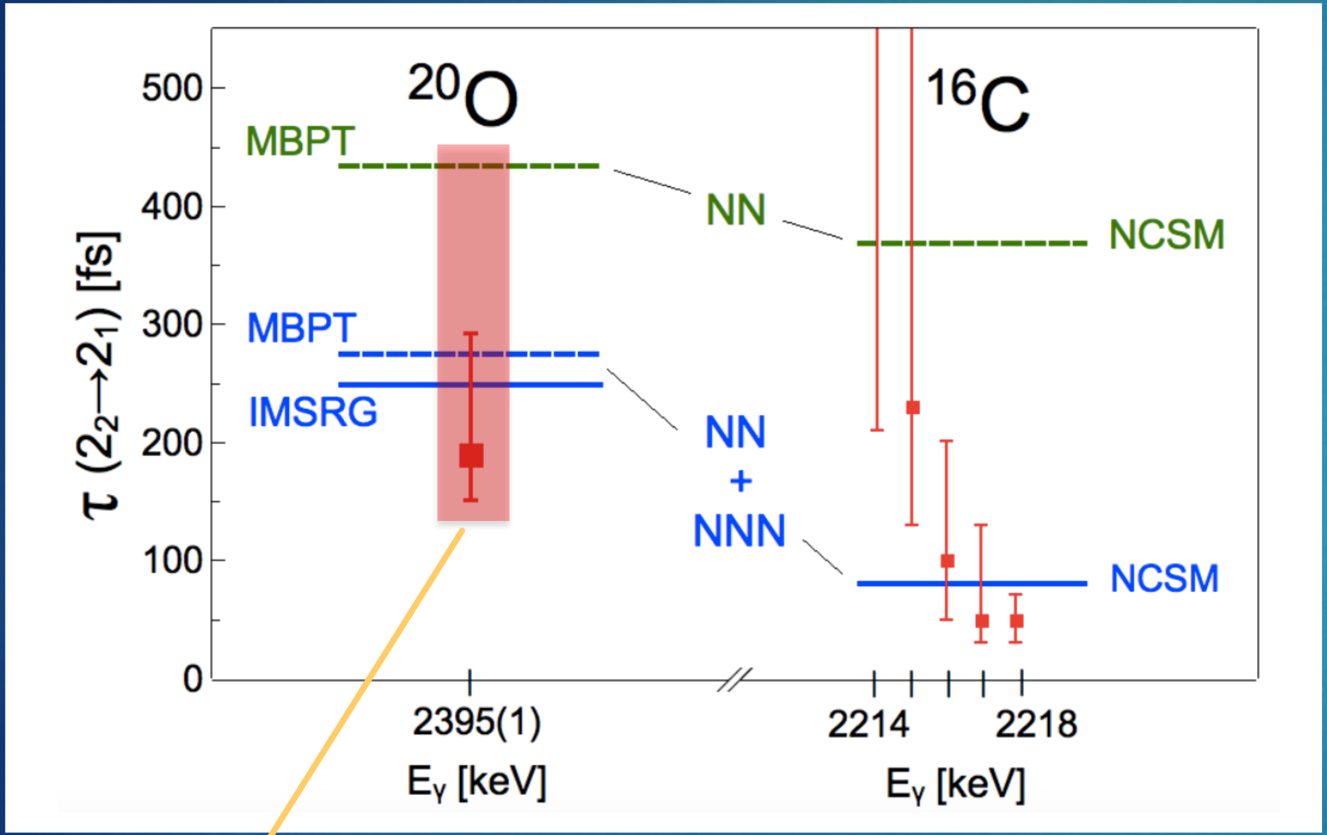
E_γ

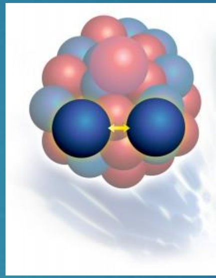
ab initio predictions

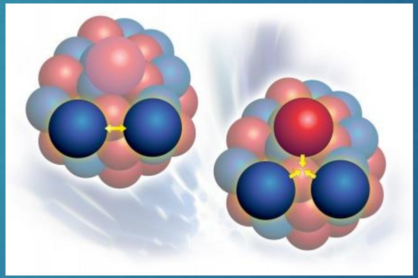
3 body force τ = 80 fs

2 body force τ = 360 fs

Summary:
Theory vs. exp. results comparison







NO sensitivity would be obtained with conventional HPGe detectors

For ^{16}C most precise measurement gives ***E = 2217(2) keV****, which do not allow to determine exact lifetime value (for now).*

Conclusions

- Italian-Polish-French collaboration allows to perform successful experiment at GANIL with combined **AGATA+VAMOS+PARIS** setup.
- (Re)-measurement of ^{19}O lifetimes – confirmation that DSAM method for AGATA and simulations works well.
- We measured lifetime of second 2^+ in ^{20}**O**: 150 fs (2_2-> 2_1 decay partial τ = 190 fs), which is consistent with ***ab initio*** calculations, including three body interactions.

  AGATA tracking is crucial to obtain the needed sensitivity
- Extracted estimates of lifetime of second 2^+ in ^{16}**C**: it depends on non-shifted gamma-ray energy.
- Ongoing work on $^{18,19}N$ isotopes

The work **significantly broadens** the possibilities for nuclear structure high-precision measurements in hard-to-reach exotic systems

More comprehensive tests of ab initio theory approaches will be possible exploiting EM decays

Acknowledgements

S. Leoni, S. Ziliani, F.C.L. Crespi, G. Benzoni, A. Bracco, C. Boiano, S. Bottoni, S. Brambilla, F. Camera, S. Coelli, B. Million, O. Wieland *University and INFN Milano, Italy*

B. Fornal, M. C., A. Maj, P. Bednarczyk, Ł.W. Iskra, N. Cieplicka-Oryńczak, J. Grebosz, M. Kmiecik, K. Mazurek, B. Wasilewska *Institute of Nuclear Physics, PAN, Poland*

M. Bast, M. Beckers, T. Braunroth, C. Fransen, A. Goldkuhle, C. Muller-Gatermann - *IKP Cologne, Germany*

E. Clément, G. De France, B. Jacquot, Y. Kim, A. Lemasson, M. Lewitowicz, H. Li, M. Rejmund - *GANIL, CEA/DSAM and CNRS/IN2P3, France*

O. Dorvaux, Ch. Schmitt - *CNRS/IN2P3, IPHC UMR 7178, France*

S. Erturk - *Nigde University, Turkey*

M.N. Harakeh - *KVI - Center for Advanced Radiation Technology, Groningen, Netherlands*

A. Karpov - *JINR, Dubna, Russia*

M. Kicińska-Habior - *Faculty of Physics, Warsaw University, Poland*

S.M. Lenzi - Padova University and INFN, Italy

I. Matea, I. Stefan - *IPN Orsay Laboratory, Orsay, France*

C. Michelagnoli - *Institut Laue-Langevin (ILL), Grenoble, France*

M. Matejska-Minda, P. Napiorkowski - *Heavy Ion Laboratory, University of Warsaw, Poland*

V. Nanal, R. Palit - *Tata Institute of Fundamental Research, Mumbai, India*

D.R. Napoli - *INFN Laboratori Nazionali di Legnaro, Italy*

M. Stanoiu - *IFIN-HH, Bucharest, Romania*

E. Vardaci - *Università degli Studi di Napoli and INFN sez. Napoli, Italy*

M. Zielińska - *IRFU, CEA/DRF, Centre CEA de Saclay, F-91191 Gif-sur-Yvette Cedex, France*

J. Holt - *TRIUMF, Vancouver , Canada*

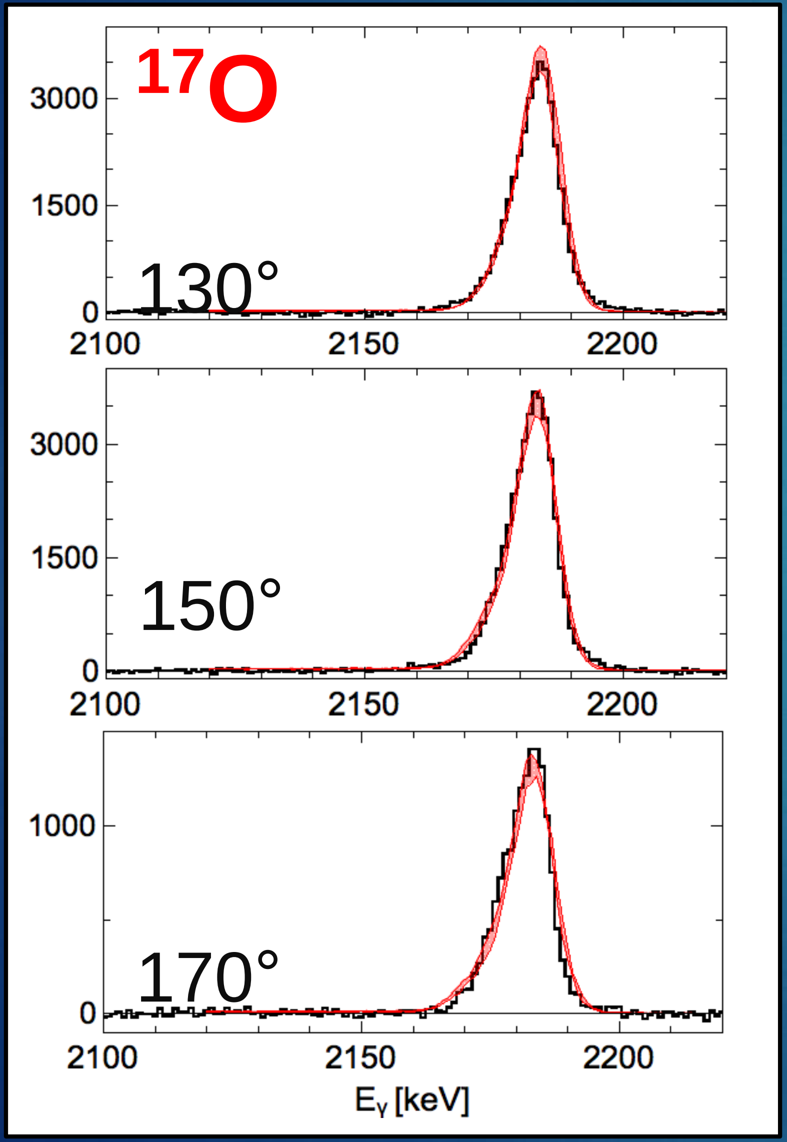
J. Menendez - *Center for Nuclear Study, University of Tokyo, Japan*

A. Schwenk - *TU Darmstadt, ExtreMe Matter Institute EMMI, GSI, Darmstadt and Max-Planck-Institut für Kernphysik, Heidelberg, Germany*

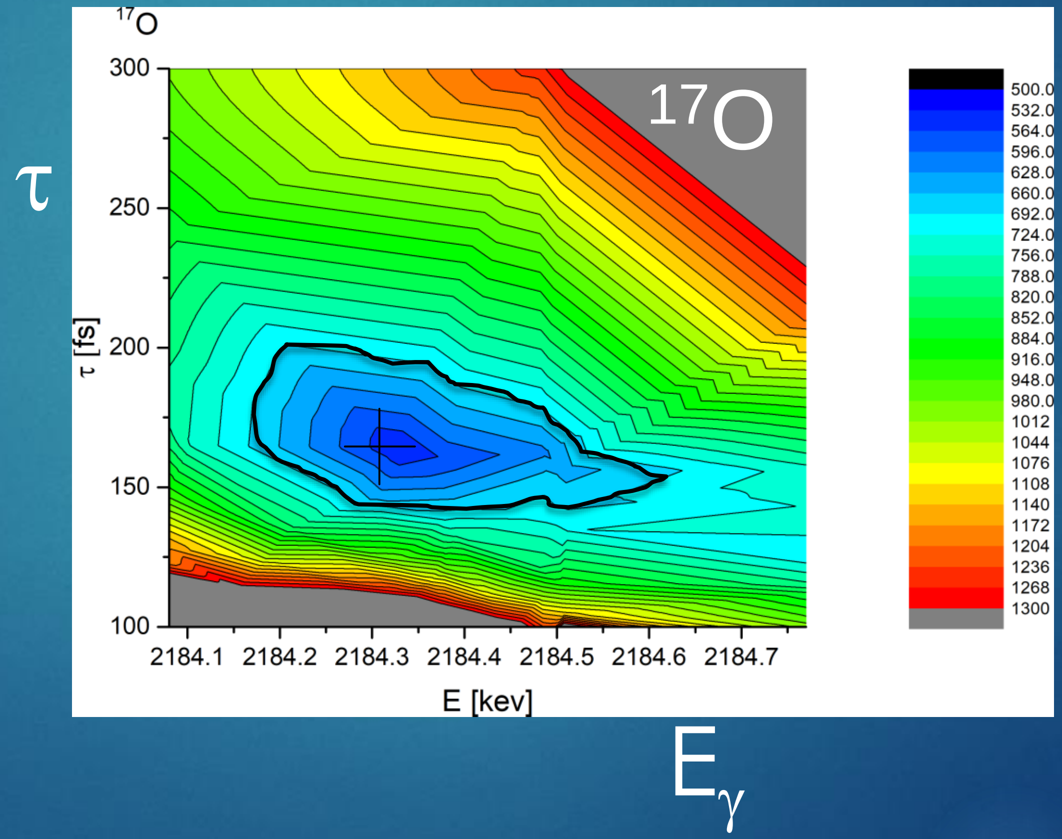
J. Simonis - *Institut fur Kernphysik and PRISMA Cluster of Excellence, Mainz University, Germany*

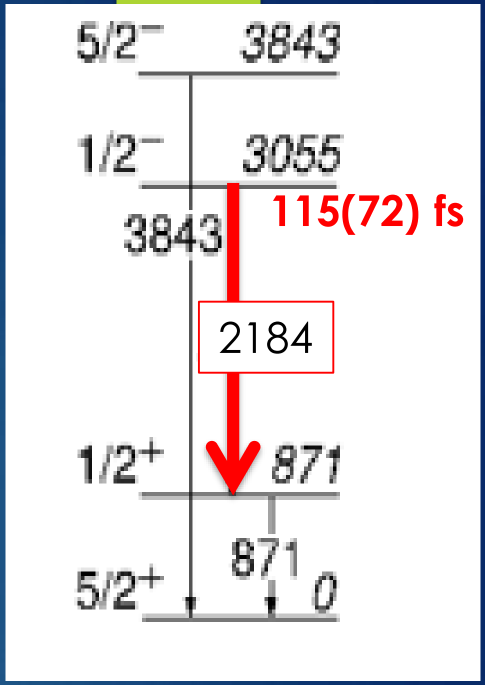
AGATA
PARIS
VAMOS
Collaborations

TEST of KNOWN Lifetimes in the 100s femtoseconds region



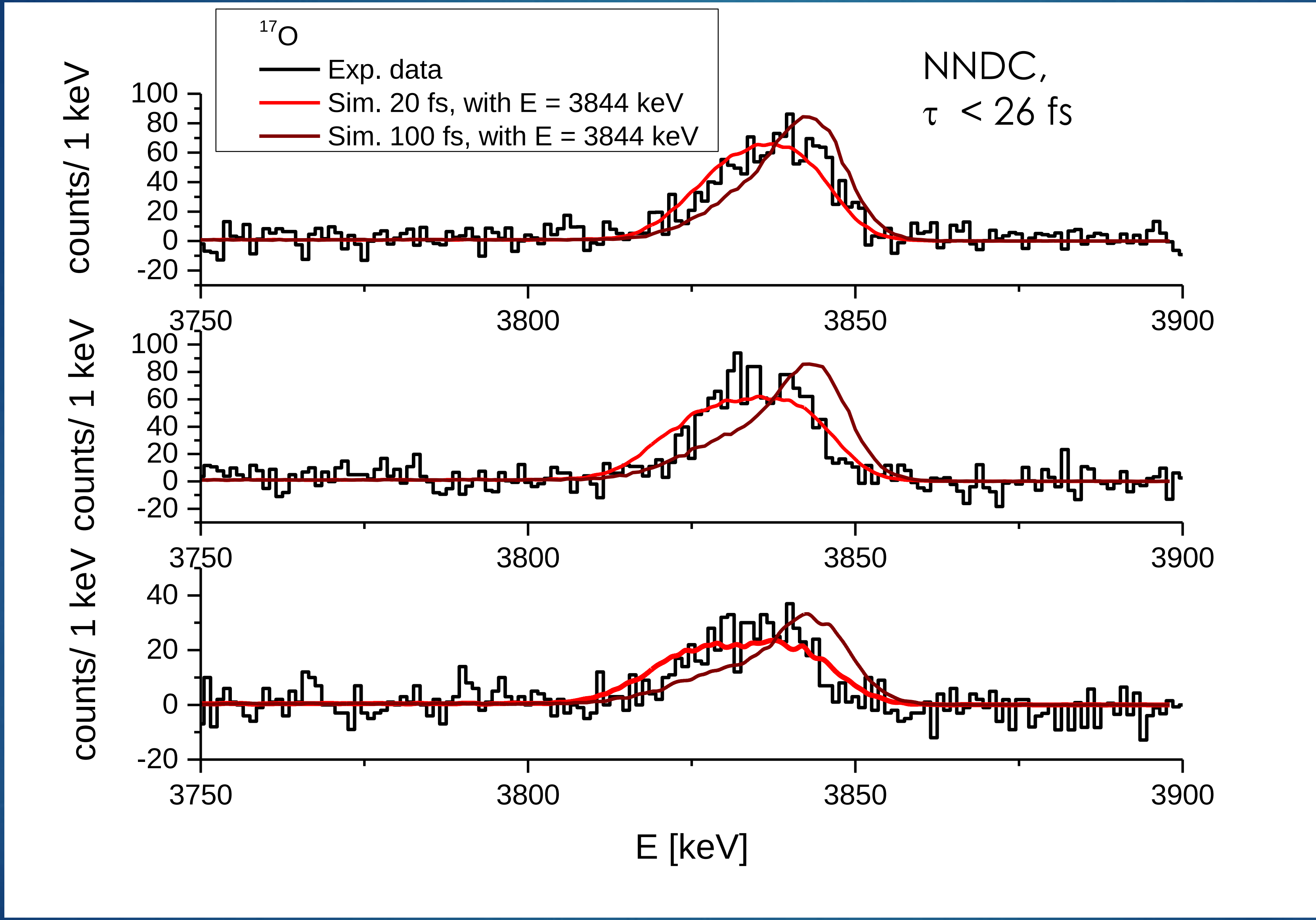
^{18}O (7 MeV/A) + ^{181}Ta target (6 mg/cm^2)





$\tau = 159^{+40}_{-20}$ fs

Very old litterature values (1964)
τ = 120(+80,-60) fs



^{17}O
Exp. data
Sim. 20 fs, with E = 3844 keV
Sim. 100 fs, with E = 3844 keV
NNDC,
τ < 26 fs
counts/ 1 keV
E [keV]
3750
3800
3850
3900

Comparison with *ab initio* predictions

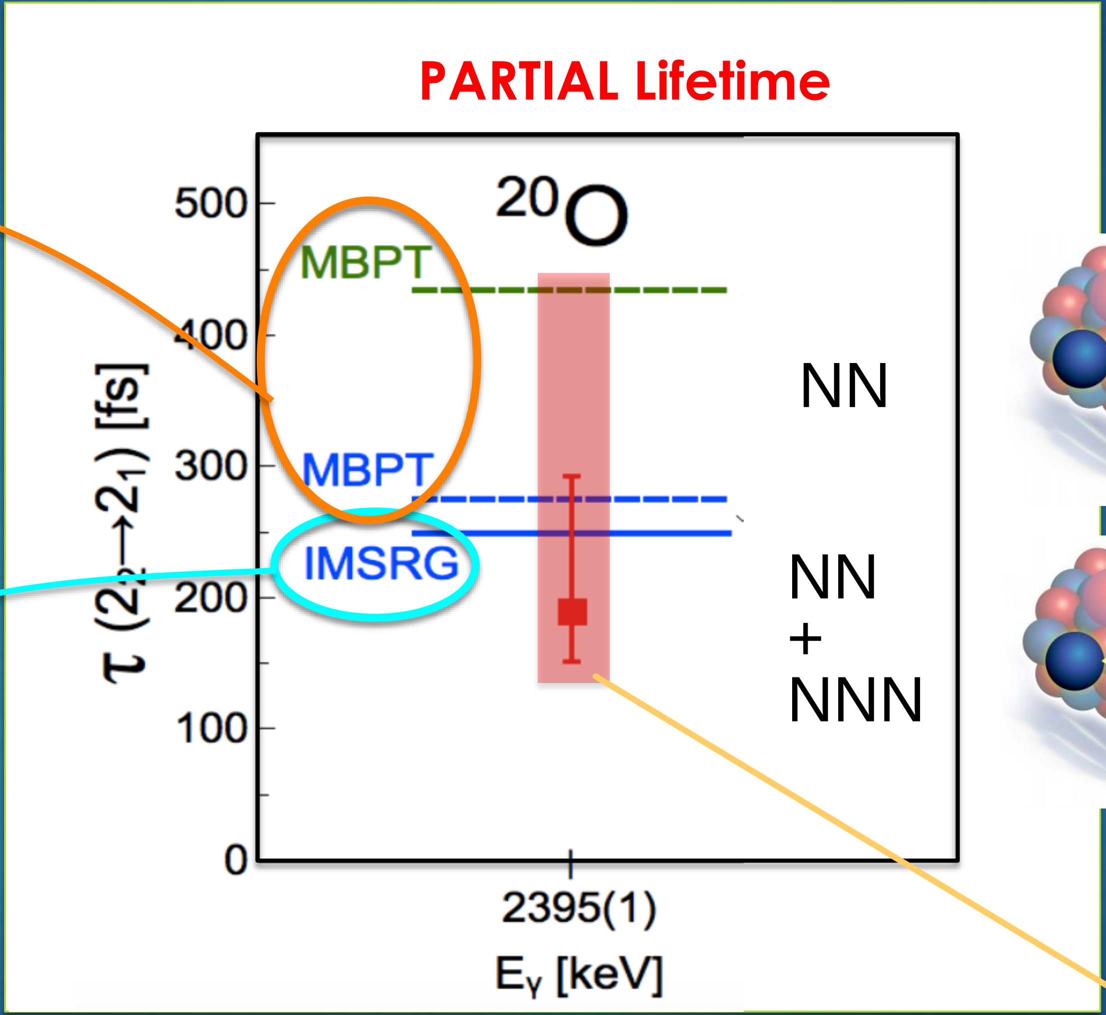
^{20}O

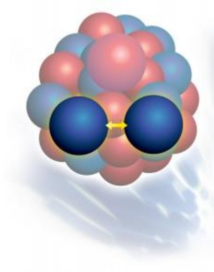
MANY BODY Pert. THEORY

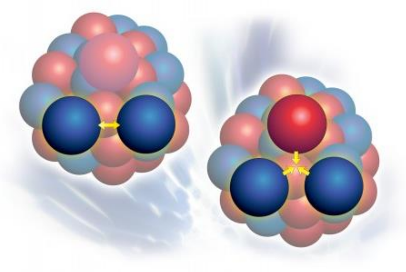
Clear need for Three body term

In-Medium Similarity Renormalization Group (IMSRG)

One of most advanced approaches (including three-body terms)



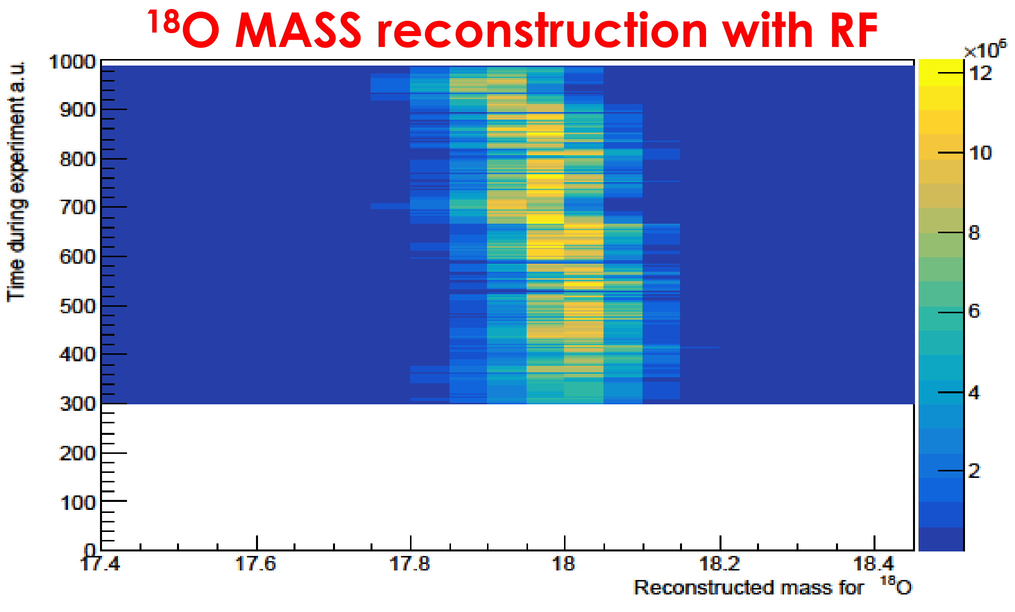


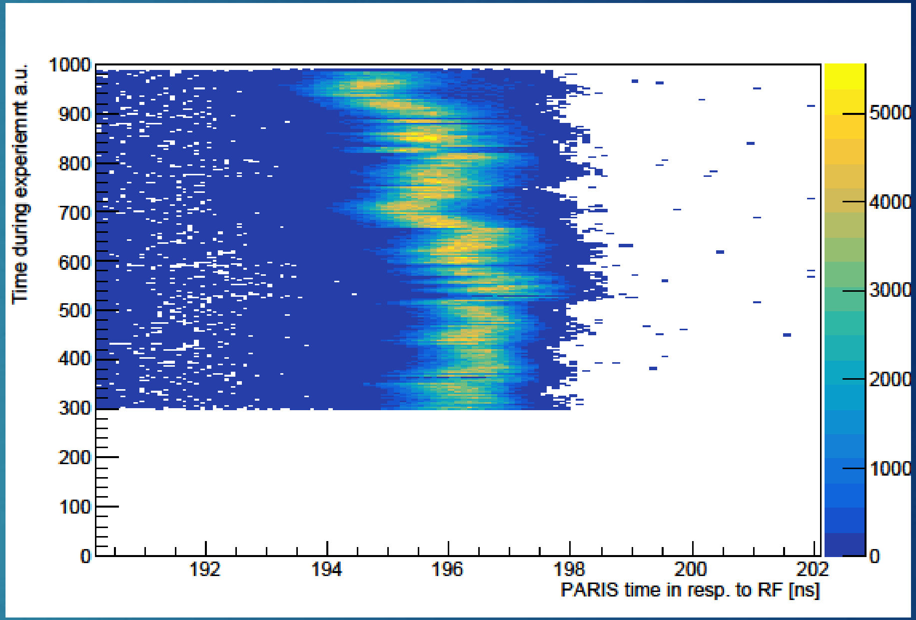


NO sensitivity would be obtained with conventional HPGe detectors

PARIS timing – correction to velocity

We measure V by path in spectrometer and time between RF and Plastic at the end of focal plane.





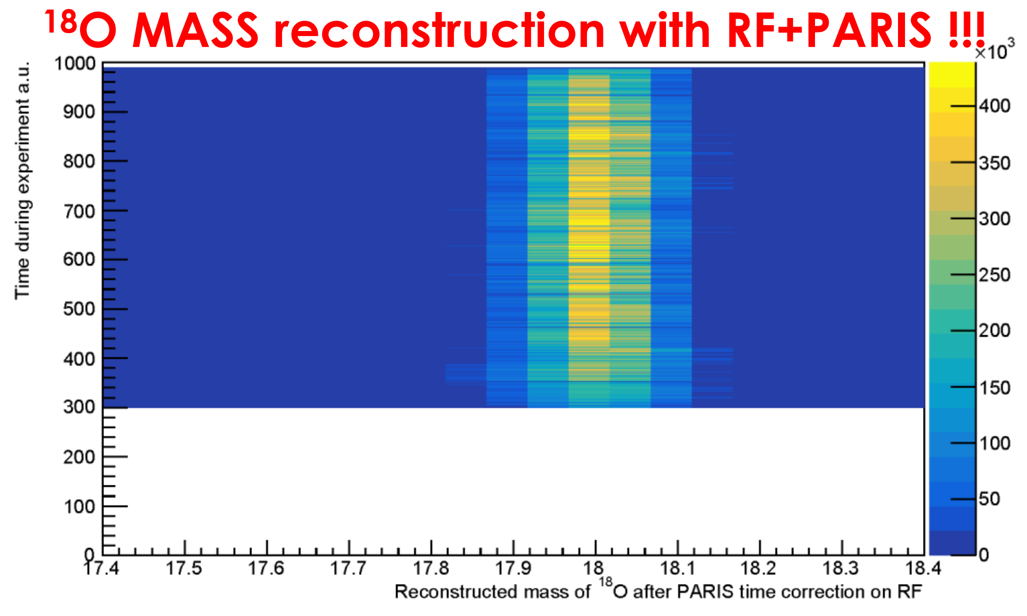
Time of experiment

But **RF** signal is **NOT stable** in time in respect to beam on target – best observable is Mass (calculated from Brho and V)

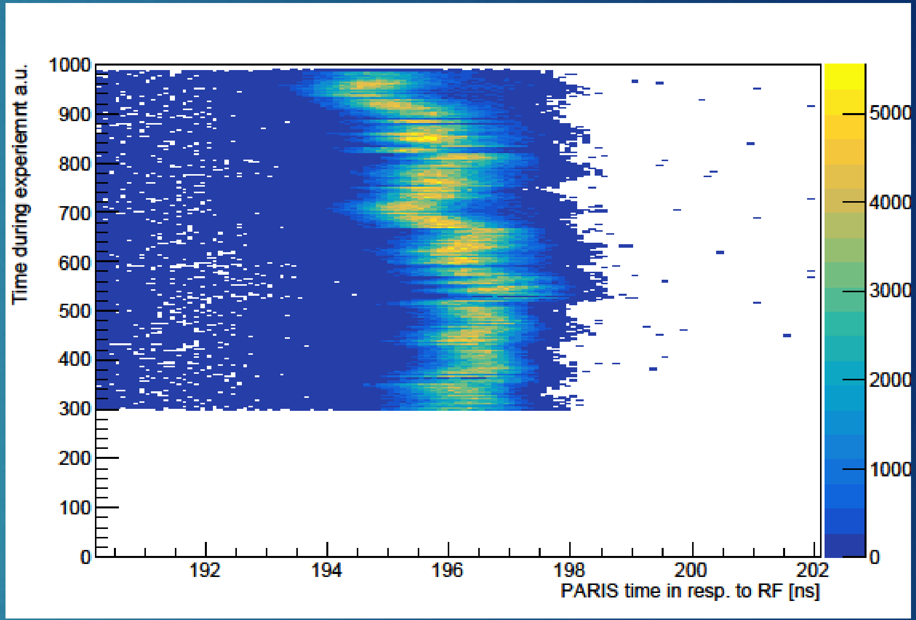
We are using PARIS (LaBr part) vs. RF timing to correct RF fluctiations (up to 2 ns, epsecially at the end of exp.)

PARIS timing – correction to velocity

We measure V by: measure path in spectrometer and time between RF and Plastic at the end of focal plane.



Time of experiment



Thanks to **PARIS timing** we recovered **good A** reconstruction/stability (it means **also good V**)!

We are using (mean) PARIS vs. RF timing to correct RF fluctiations (up to 2 ns, epsecially at the end of exp.)