Lifetime measurements of excited states in neutron-rich C and O isotopes

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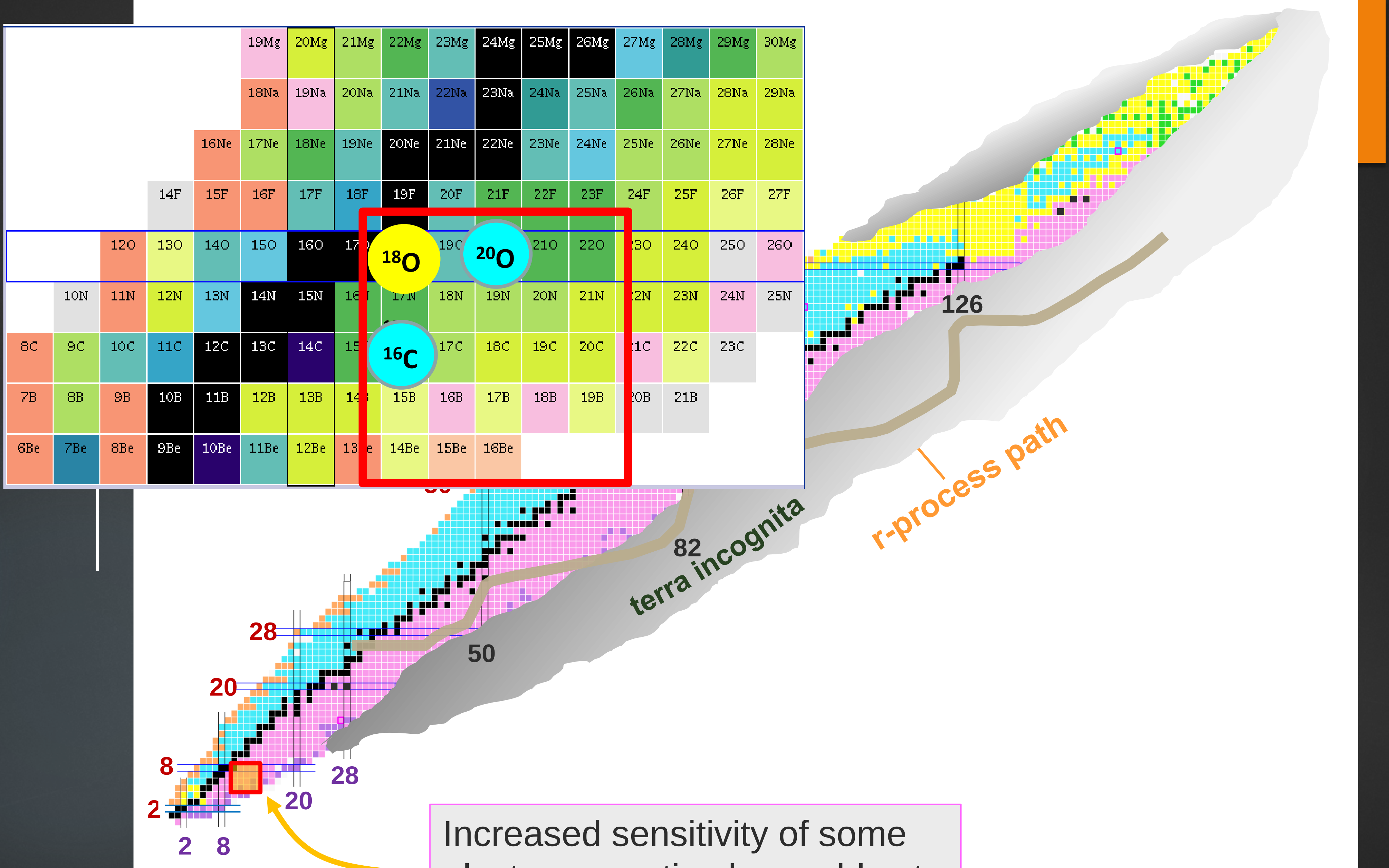
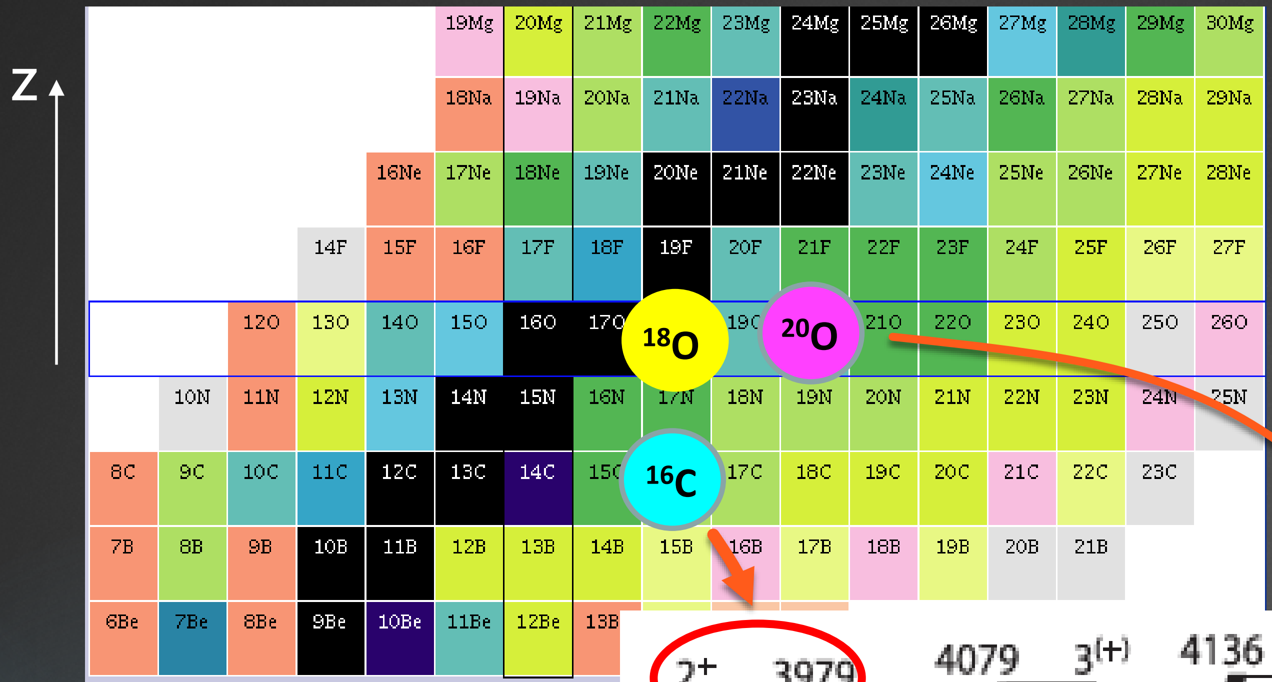
PARIS COLLABORATION, COORDINATOR **A. MAJ**, IFJ PAN, KRAKOW

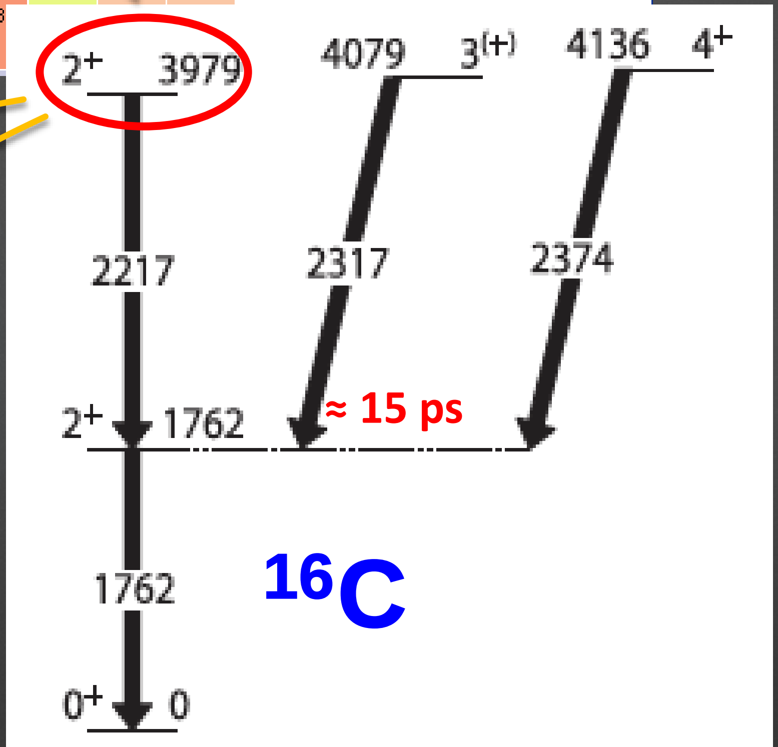


Increased sensitivity of some electromagnetic observables to the details of n-n force

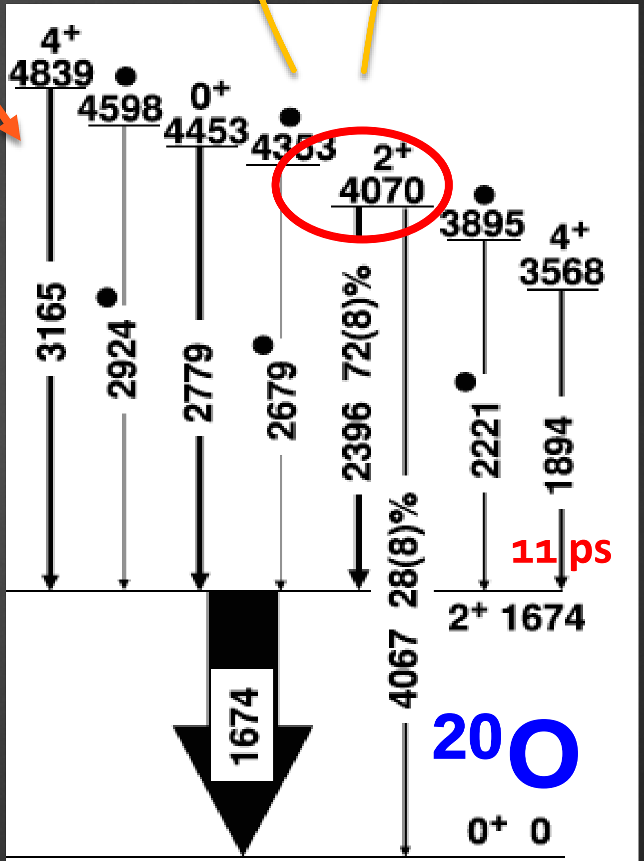


ab initio
Many-Body-Pert. Theory calculations of the 2^+_2 lifetimes

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

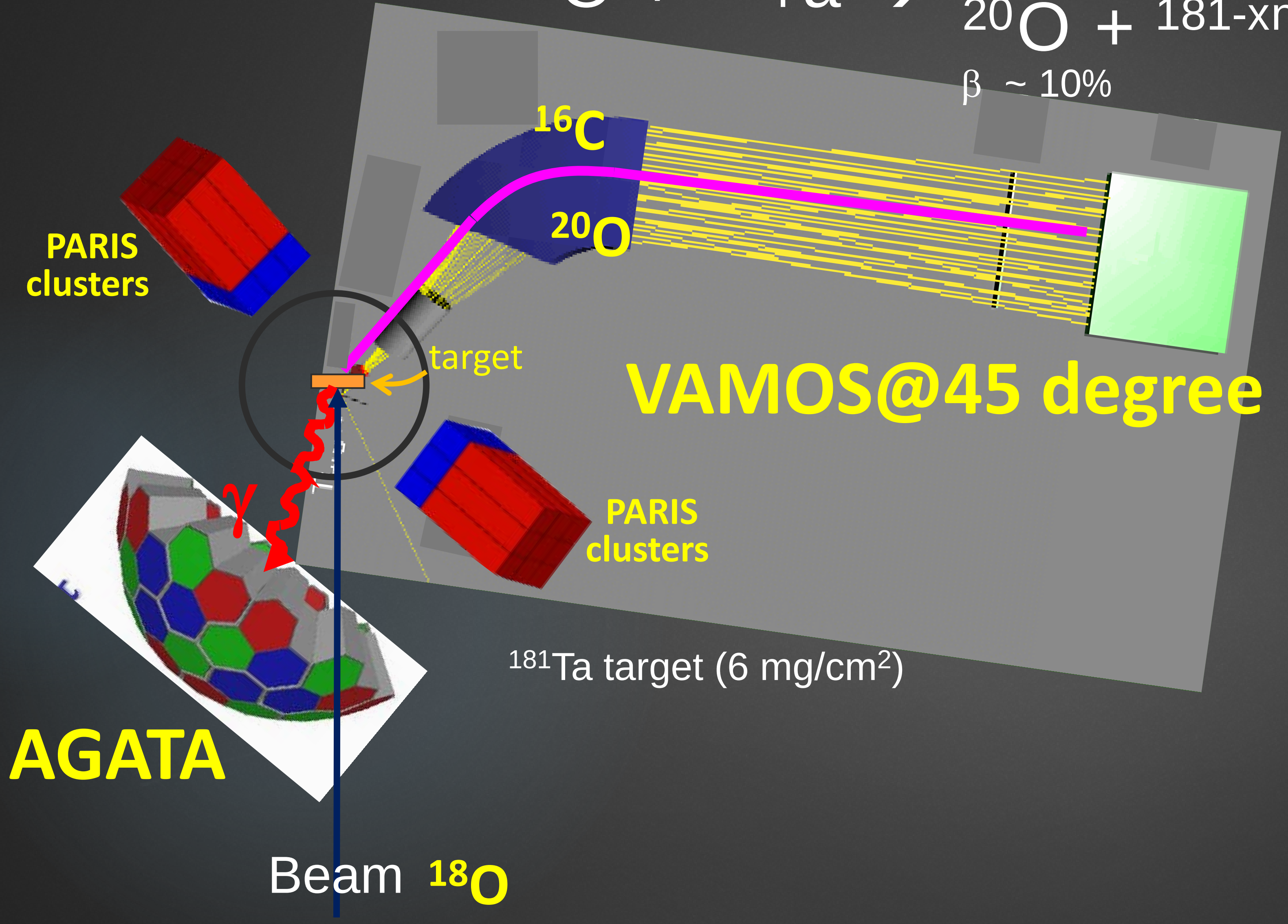
ab initio
No-Core-SHELL Model calculations

Experimental setup - E676@GANIL

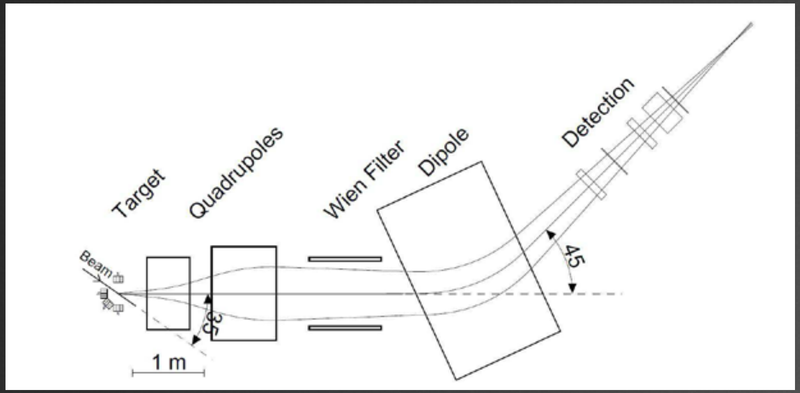
$^{18}O + ^{181}Ta \rightarrow$ $^{16}C + ^{183\text{-}xn}Re$

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

$\beta \sim 10\%$

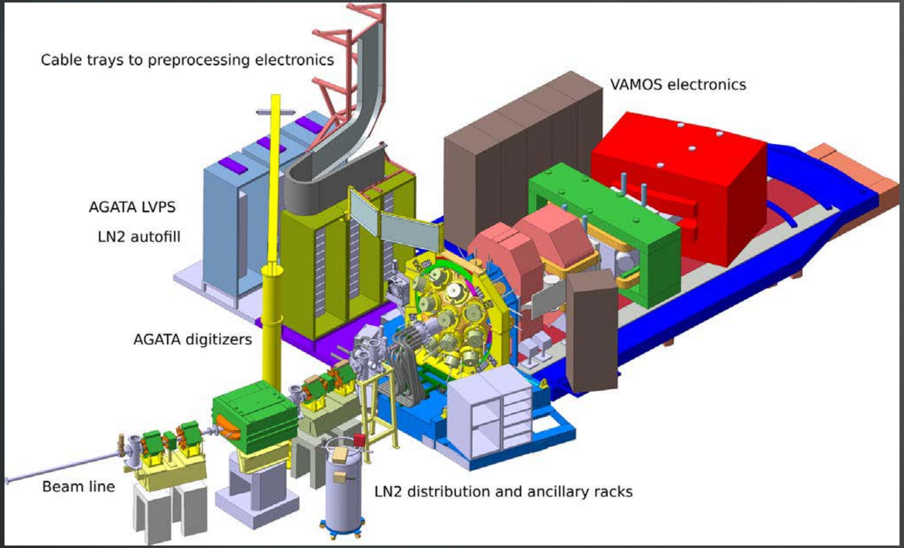


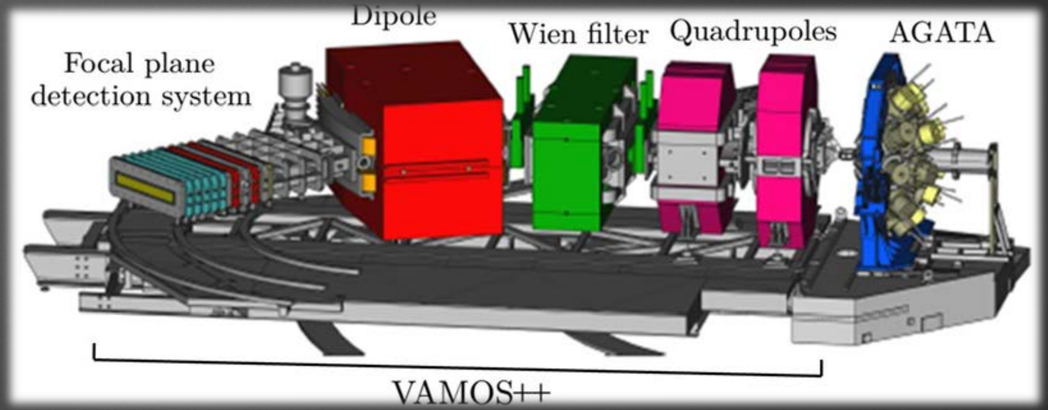
Experimental setup –VAMOS++ spectrometer



Scheme of VAMOS++

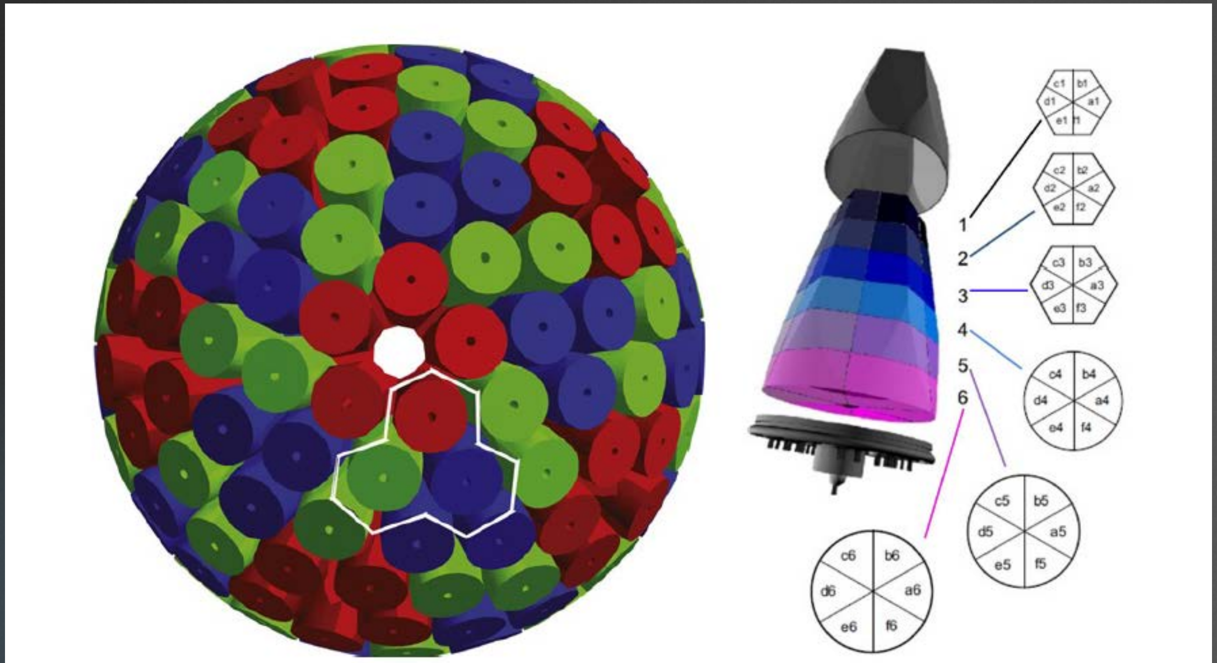
VAMOS++ at 45 degree
VAMOS entrance detector:
2 DC (for ions angle)
VAMOS focal plane:
DC (for Brho reconstruction),
6 rows of IC (for ΔE)
Plastic (for trigger and ToF)
Angular acceptance:
+/- 6 degree in theta, +/- 15 degree in phi





E. Clement et al. NIMA 885, 1-12 (2017)

Experimental setup -AGATA

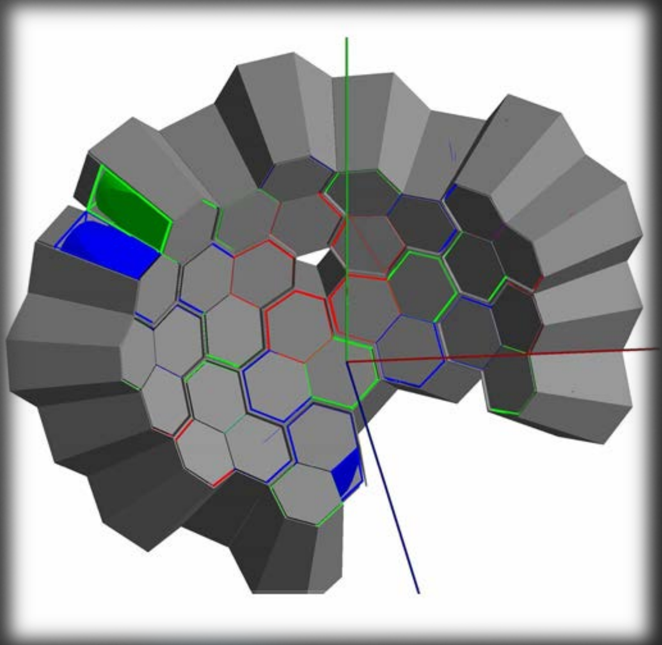


AGATA - *Advanced Gamma Tracking Array.*
36 segments per crystal (6 longitudinal rings and 6 transversal sectors)

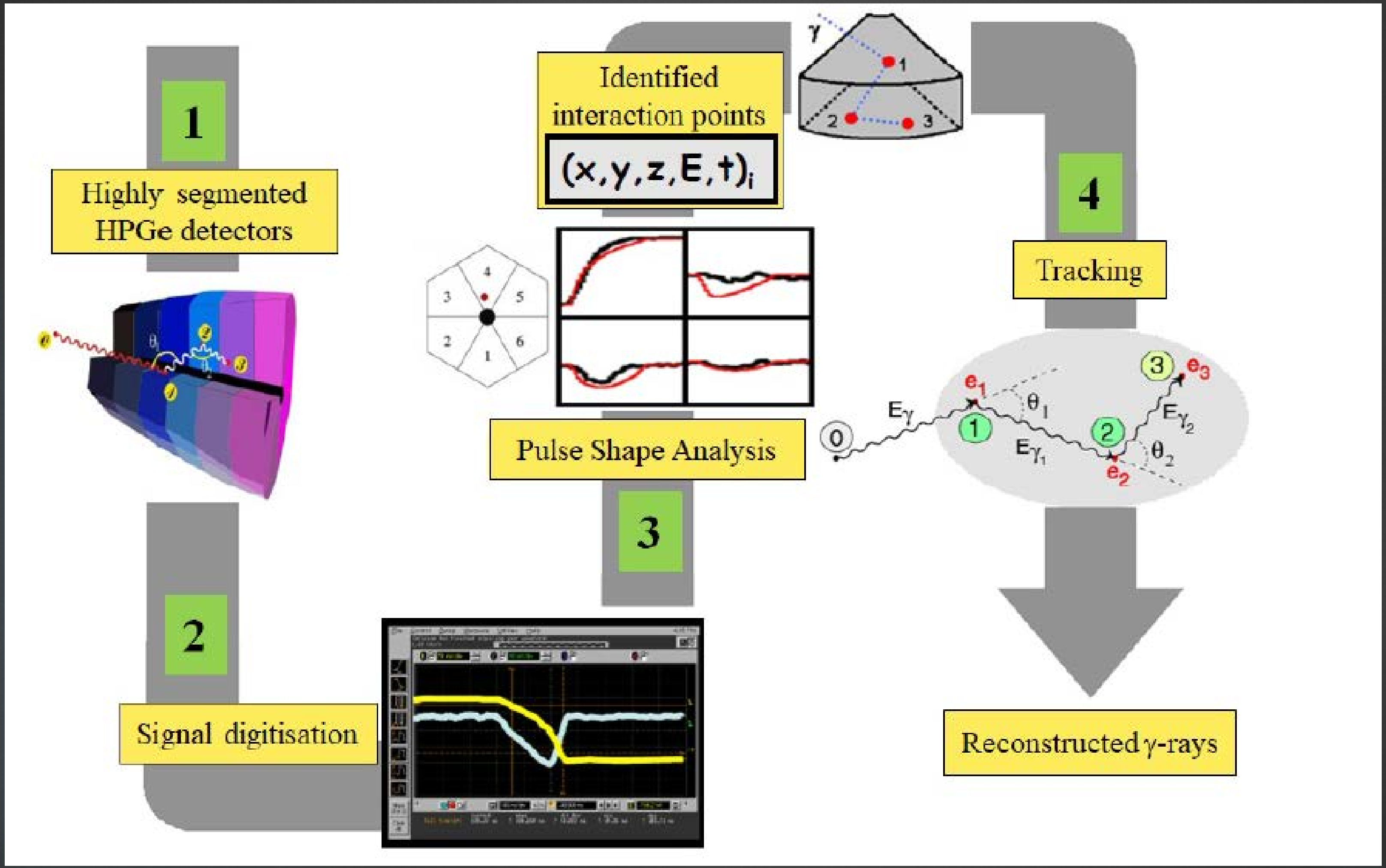
Tracking algorithms allows to reconstruct the path of the interacting γ-ray in the detection material, its energy and incoming direction.

AGATA
ADVANCED GAMMA TRACKING ARRAY

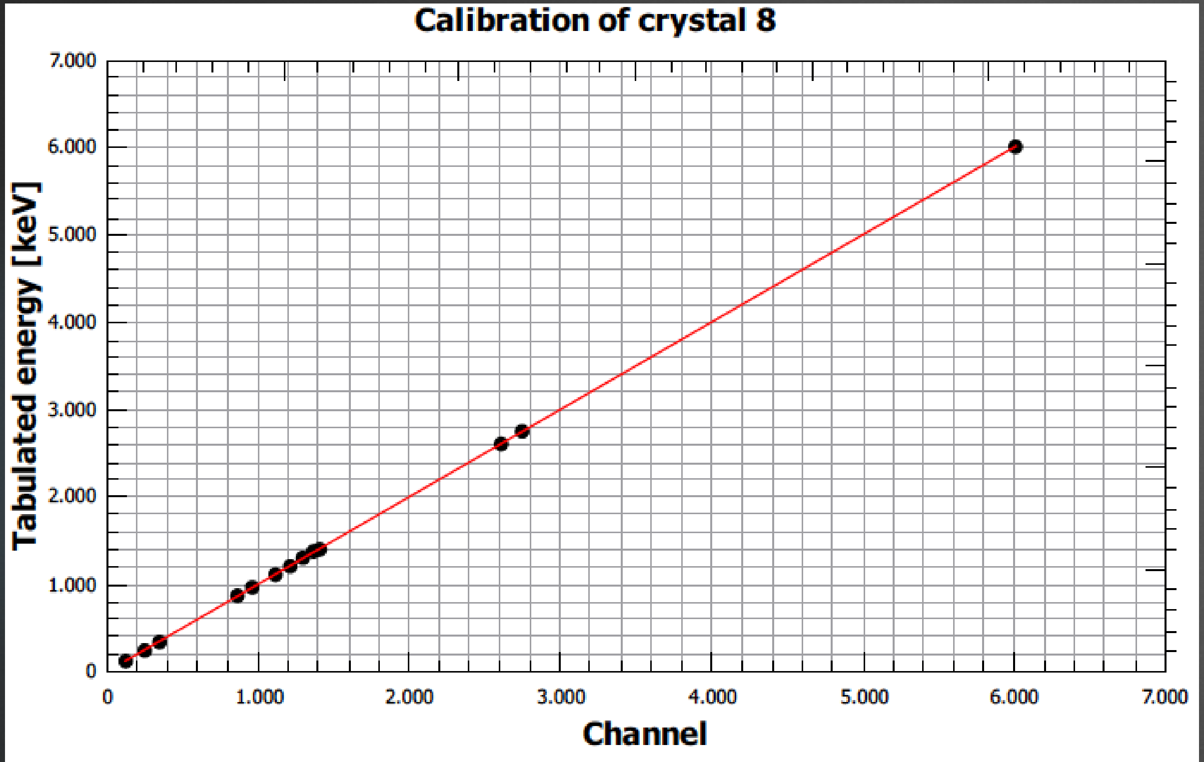
- **AGATA**
  31 crystals (backward angles)
  Working d**uring our experiment at GANIL**



Experimental setup –AGATA

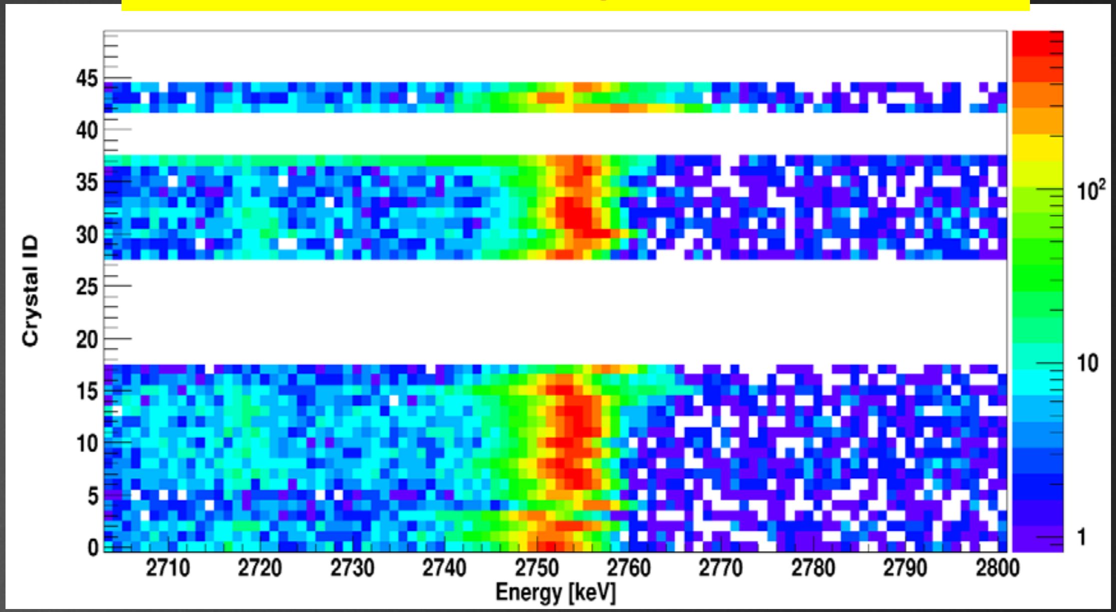


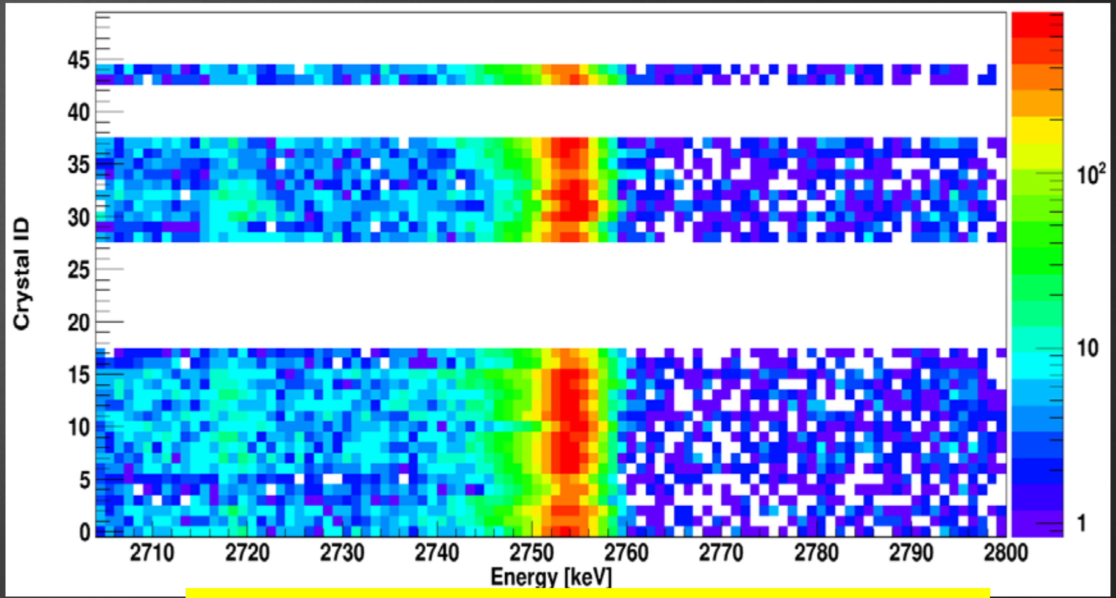
AGATA
Example of typical linear calibration curve



AGATA (re)calibration – performed by Milano group – S. Ziliani

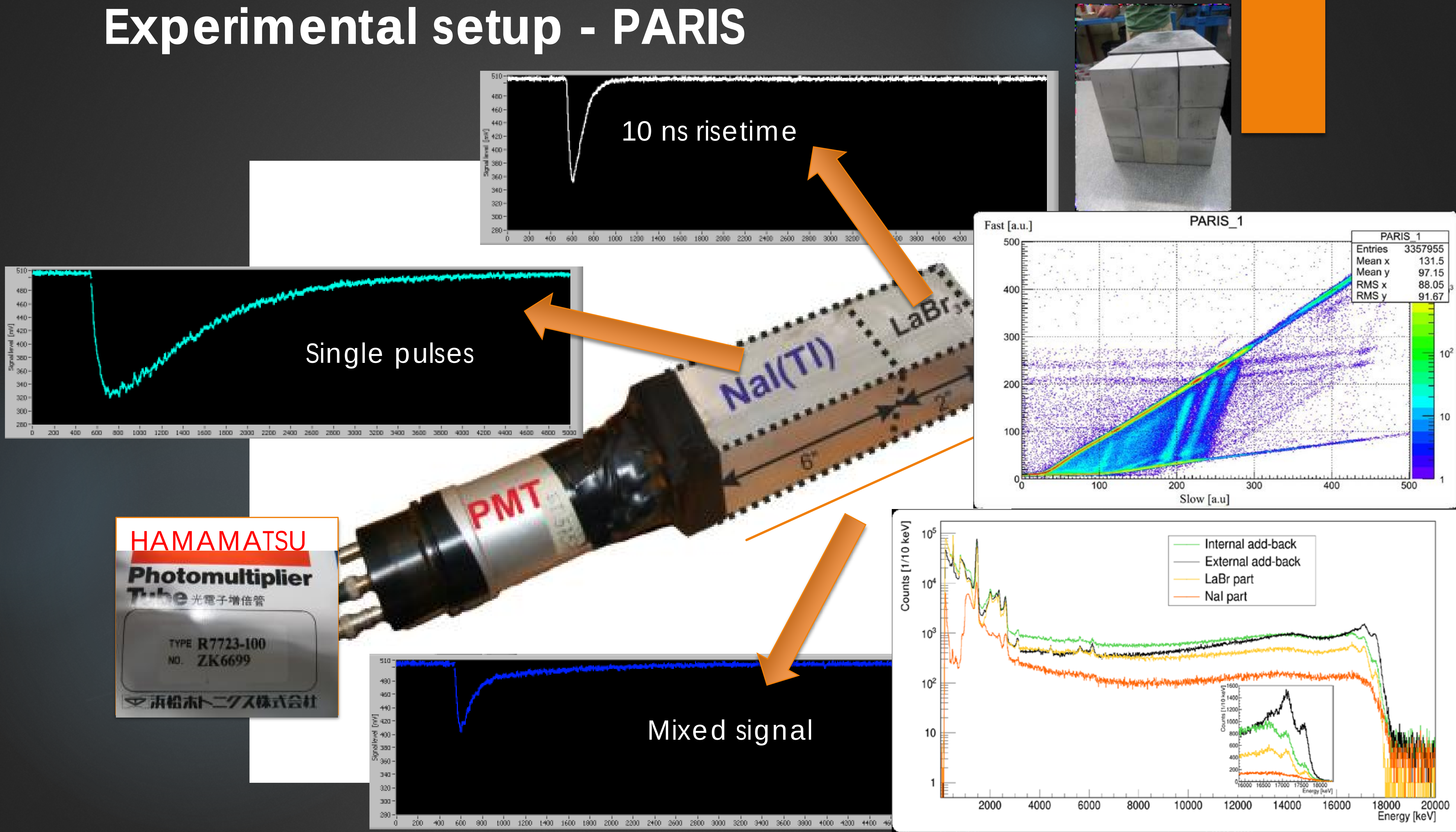
Nearline sorting coefficients



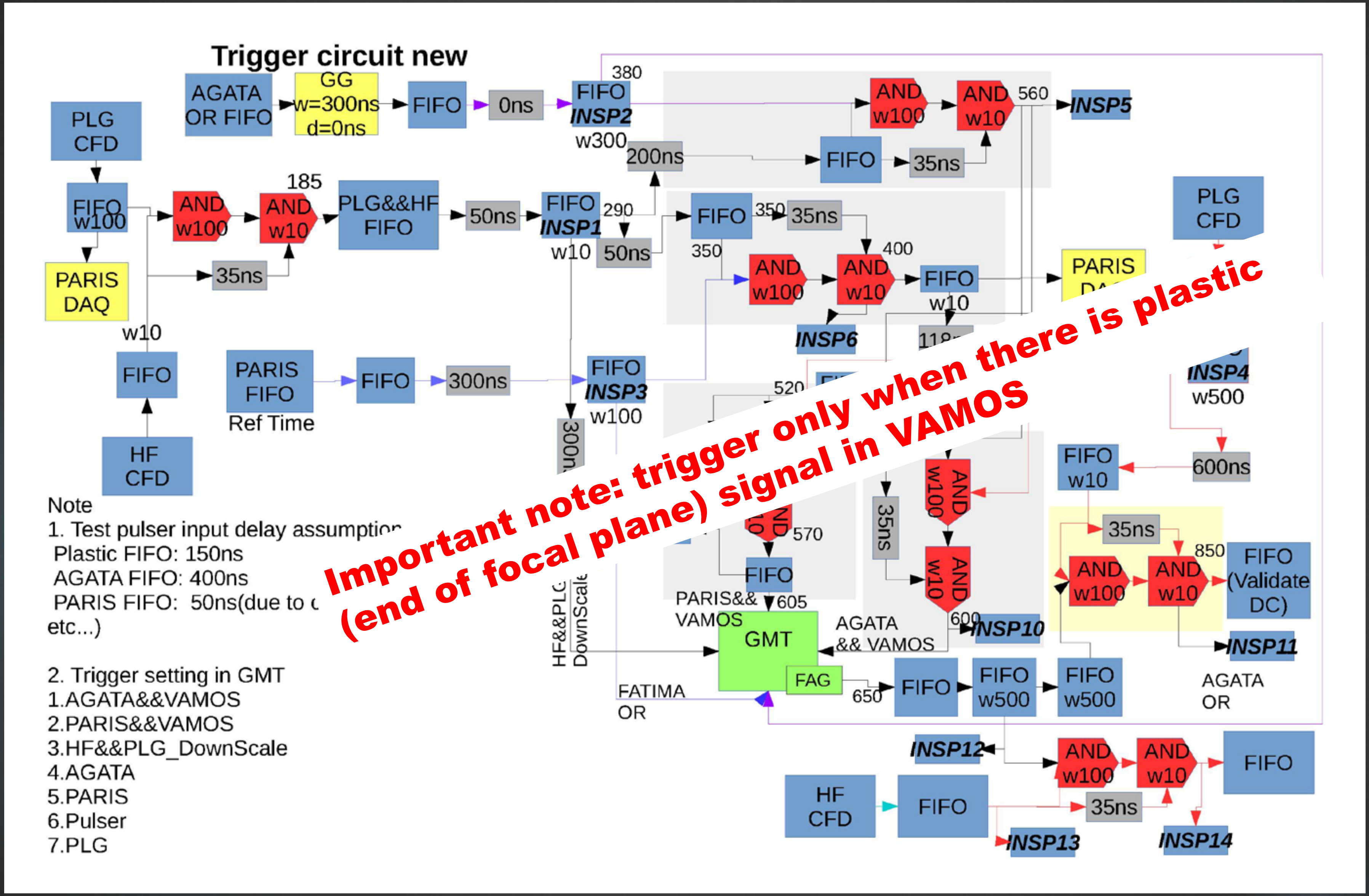


NEW sorting coefficients

Experimental setup - PARIS



Experimental setup – trigger conditions



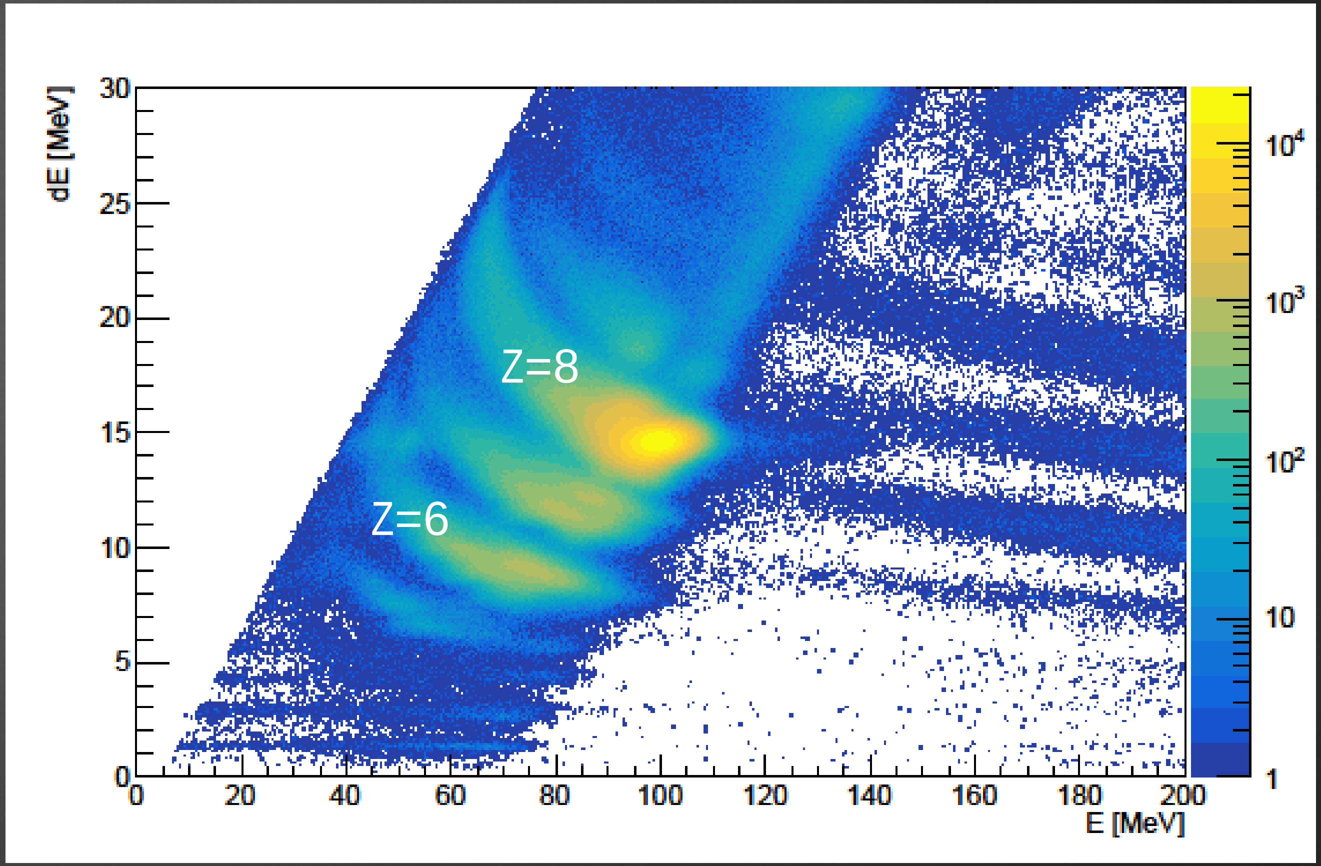
VAMOS spectrometer, ion identification and velocity measurement

V = D/TOF
TOF time of flight calculated as a difference between the RF and the plastic detector time signals

D is ion path length

Z determination:

dE (ionization chambers) versus E (IC + plastic E deposit)



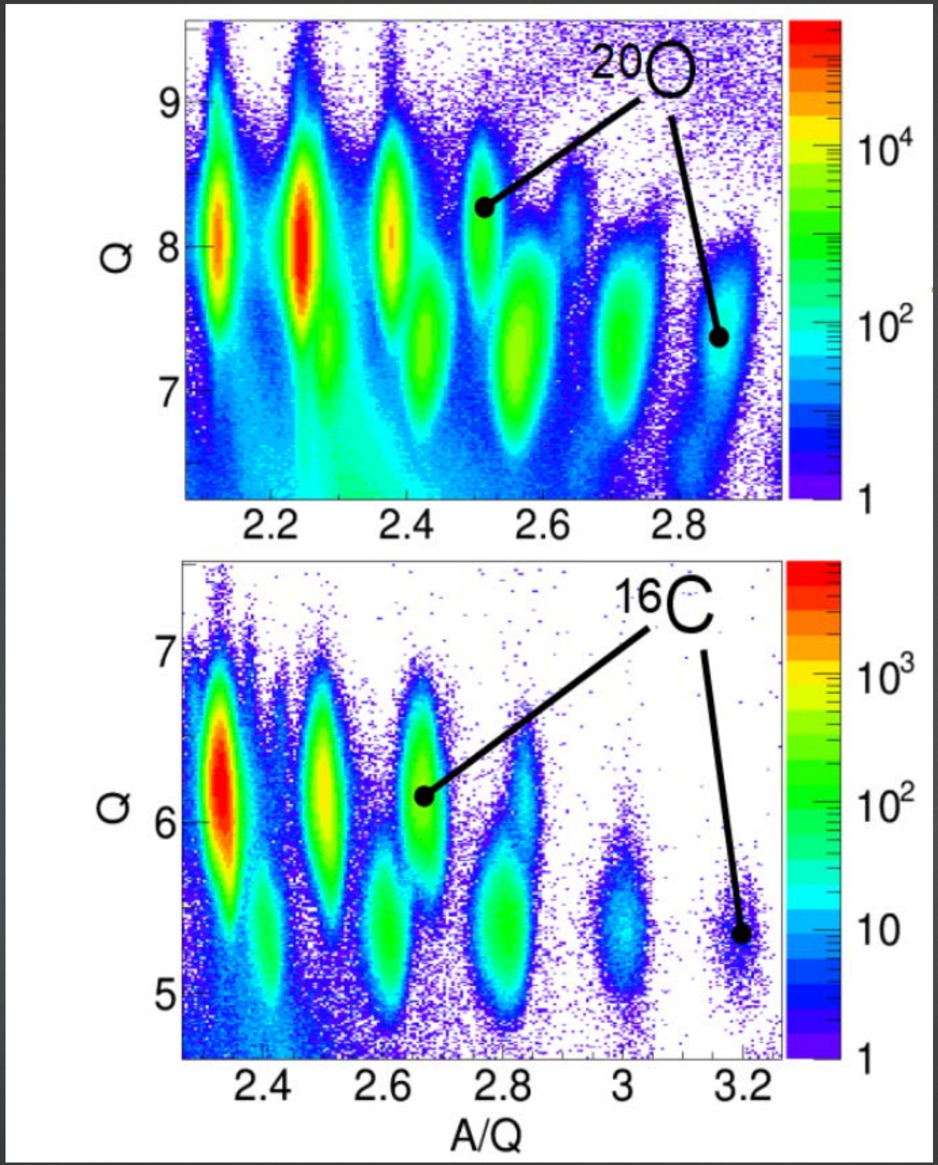
VAMOS spectrometer, ion selection

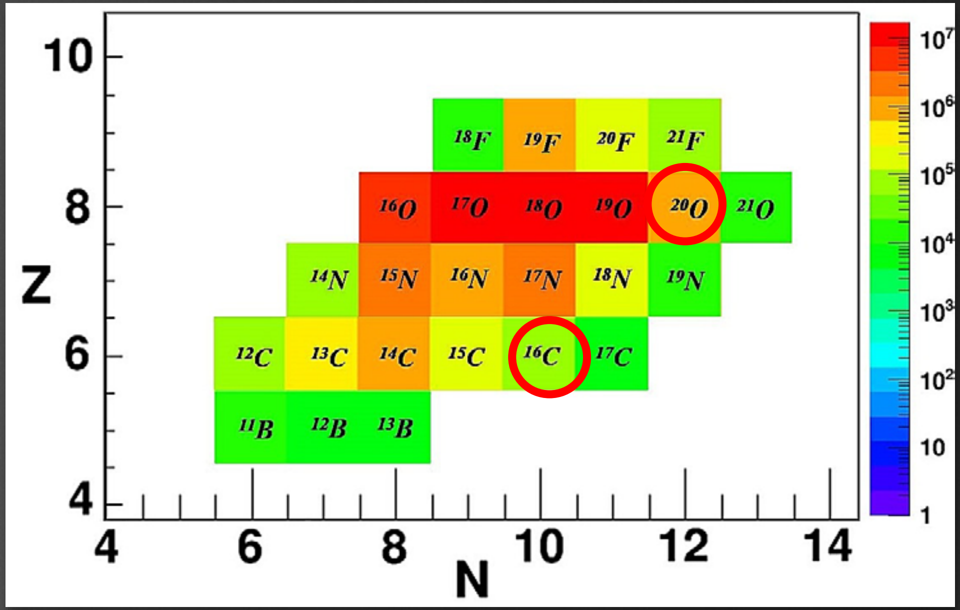
$M/Q = B\rho/(3.105\gamma\beta)$

$M_0 = E/(931.5(\gamma - 1))$

$Q = M_0/(M/Q)$

$M_r = (M/Q)Q_{int}$

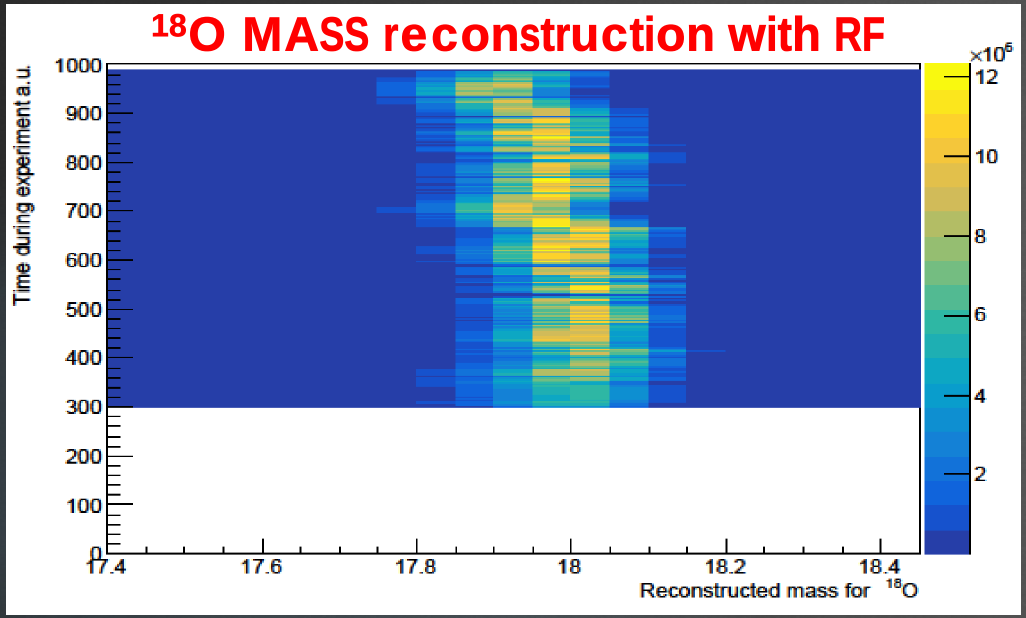




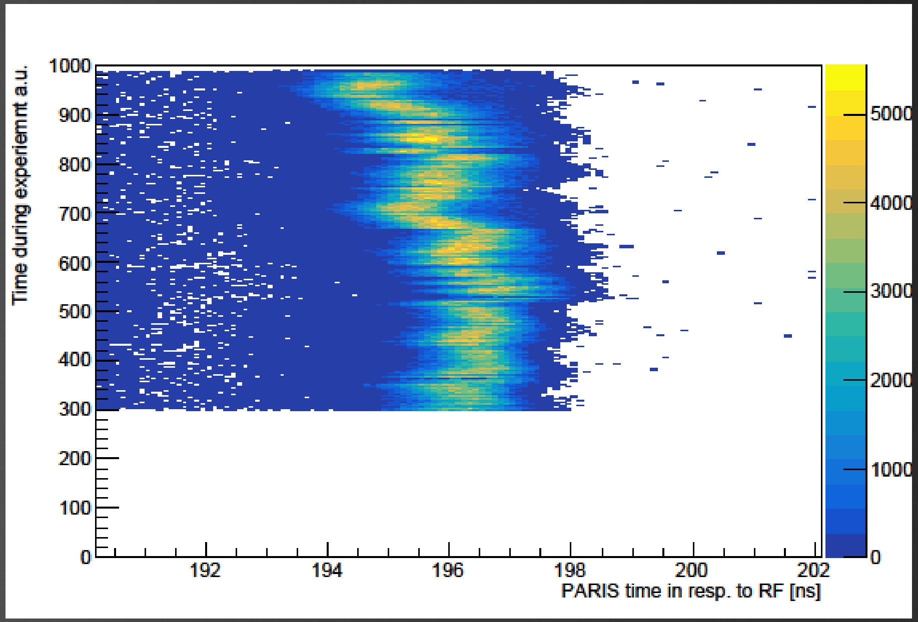
Identified isotopes from B to F.

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

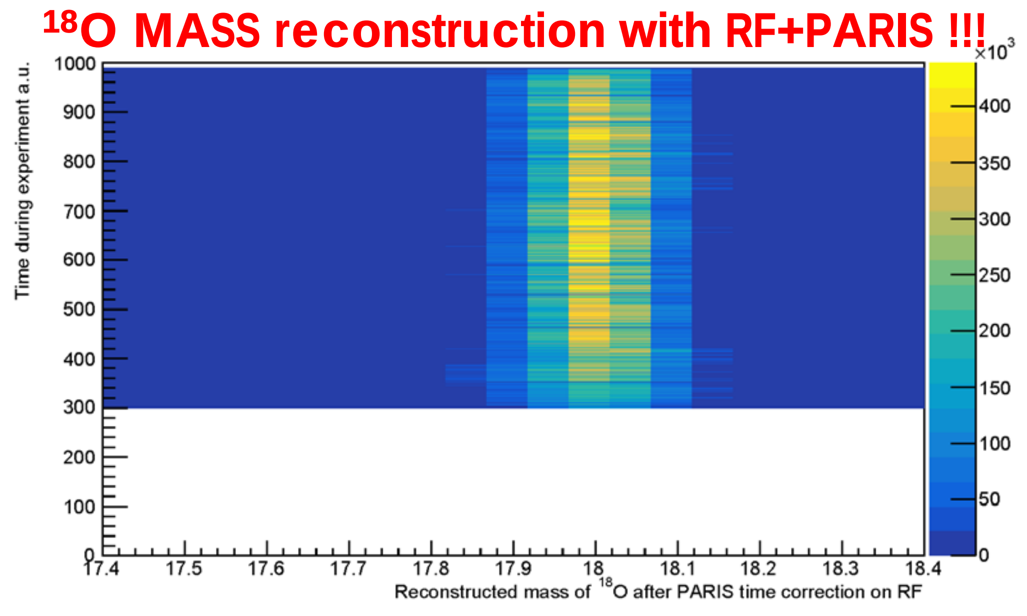


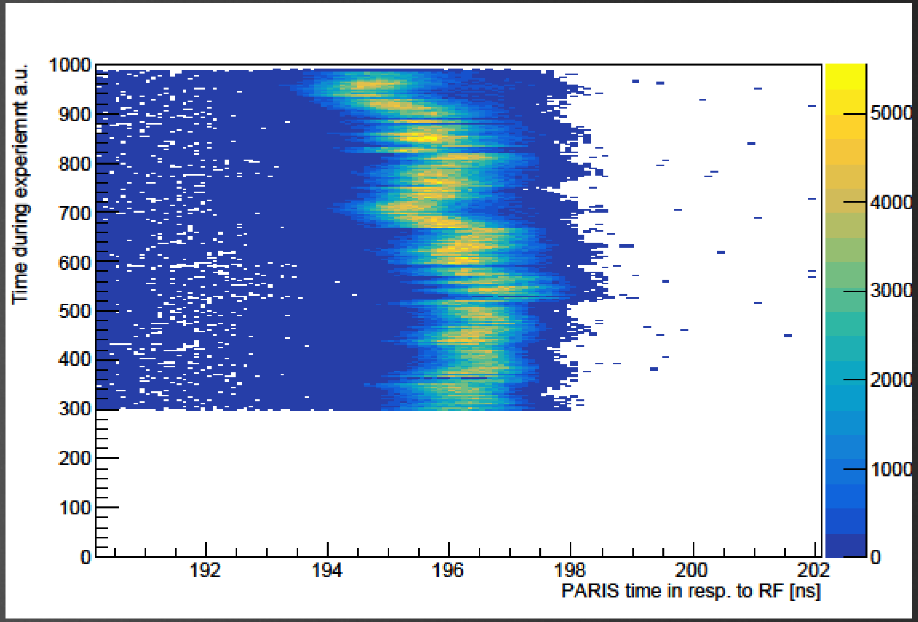
But **RF** signal is **NOT stable** in time in respect to beam on target – best observable is Mass (calculated from Brho and V)

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.

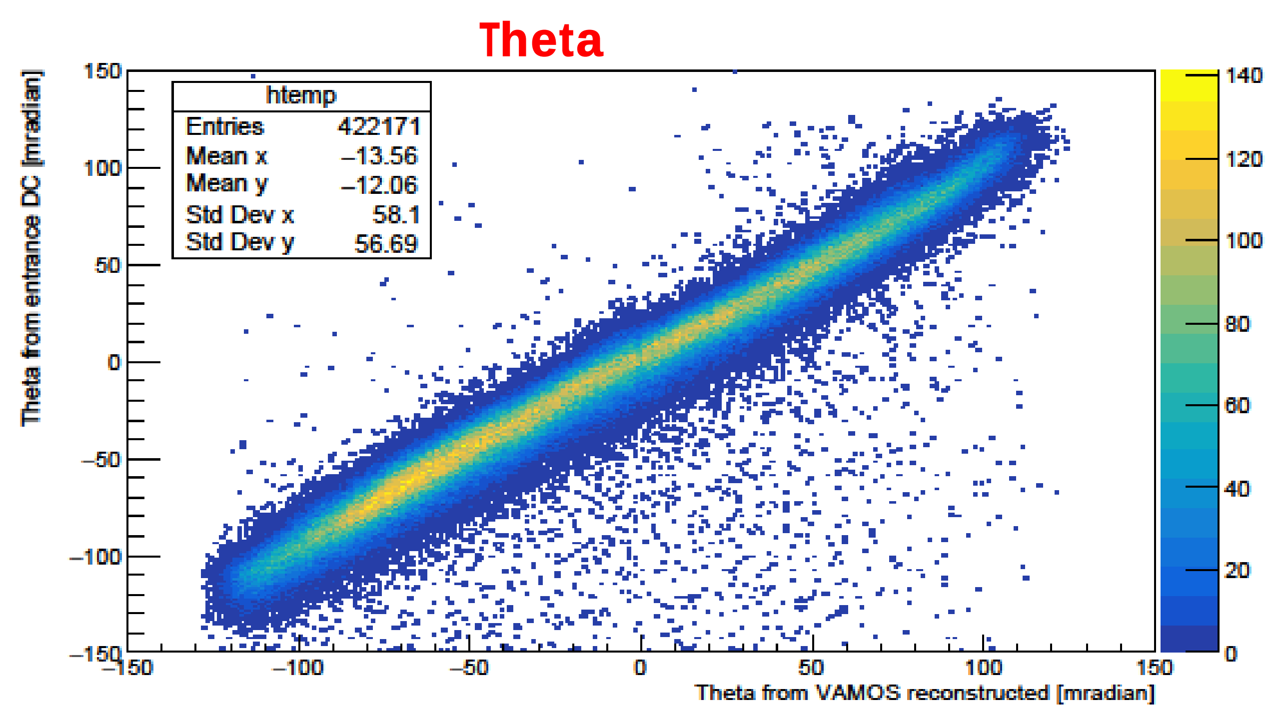


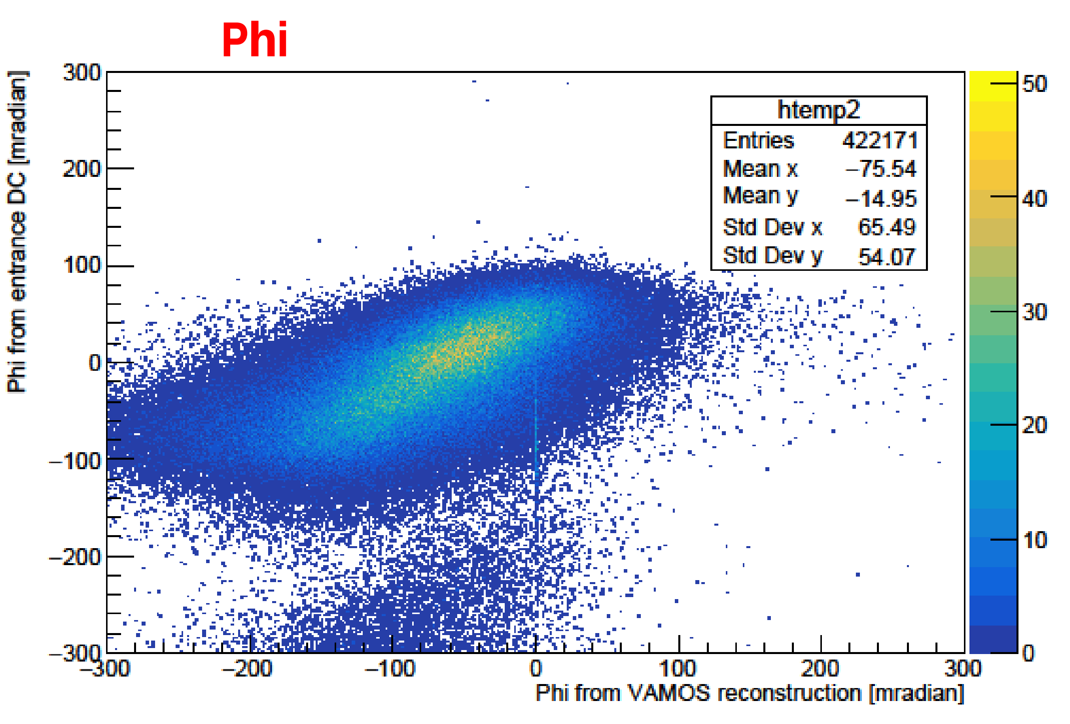


Thanks to **PARIS timing** we recovered **good A** reconstruction/stability (it means **also good V**)!

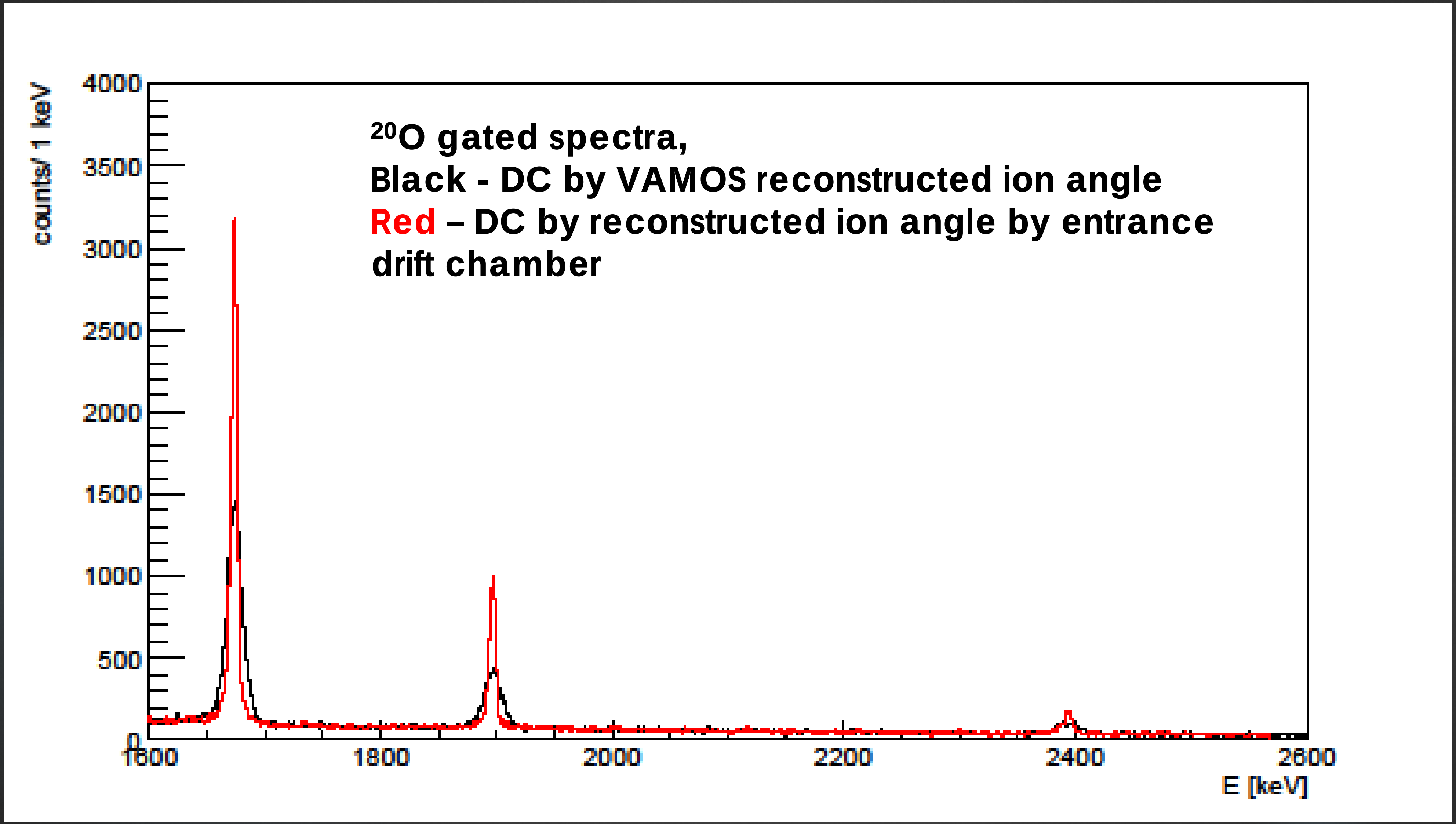
We are using (mean) PARIS vs. RF timing to correct RF fluctiations (up to 2 ns, epsecially at the end of exp.)

Doppler Correction (DC): ion angle determination

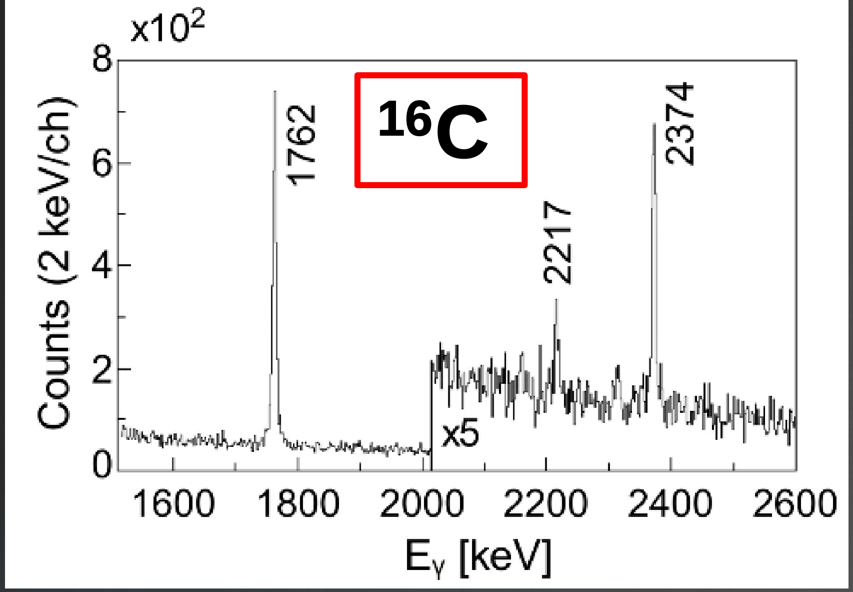


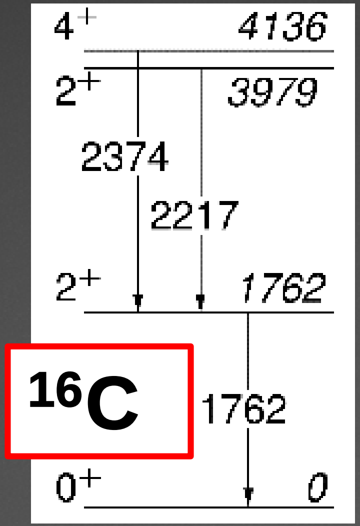


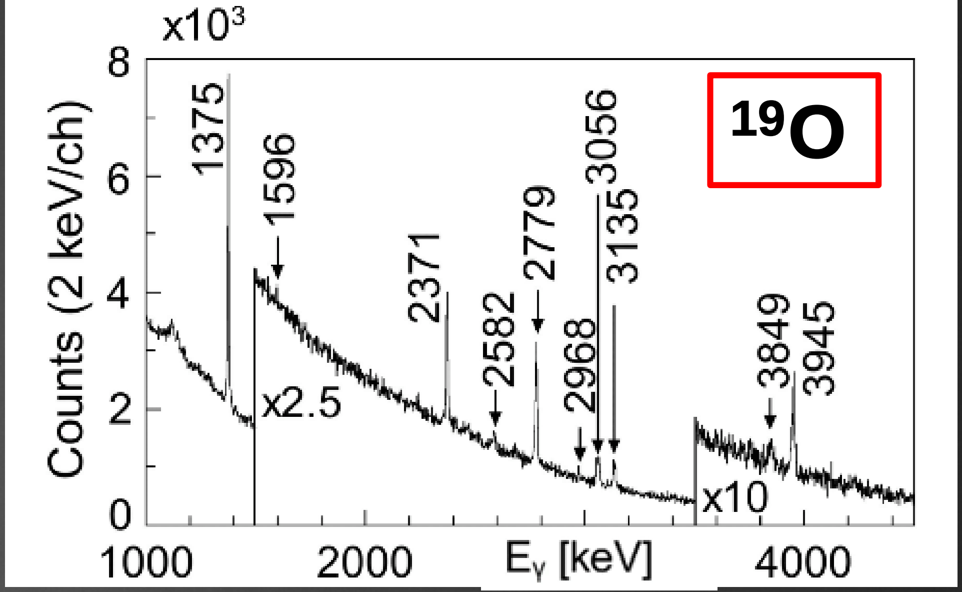
Doppler Correction (DC) – importance of entrance drift chambers

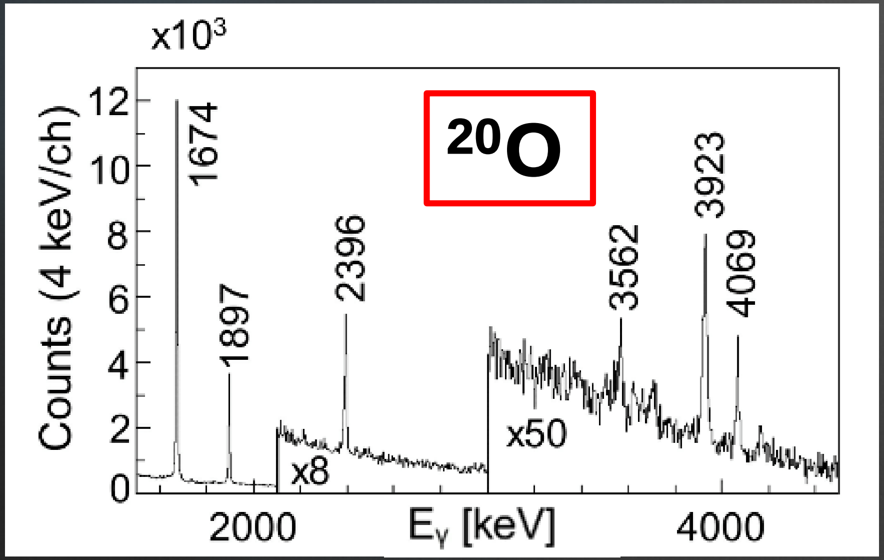


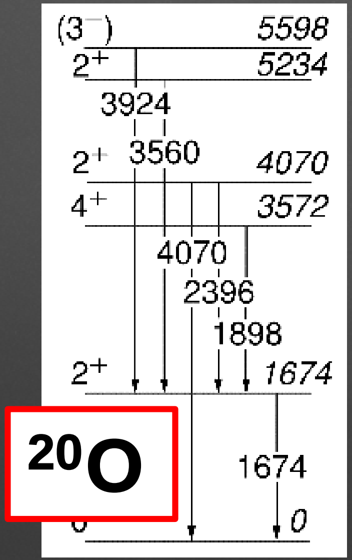
AGATA Spectra –Tracked and Doppler Corrected



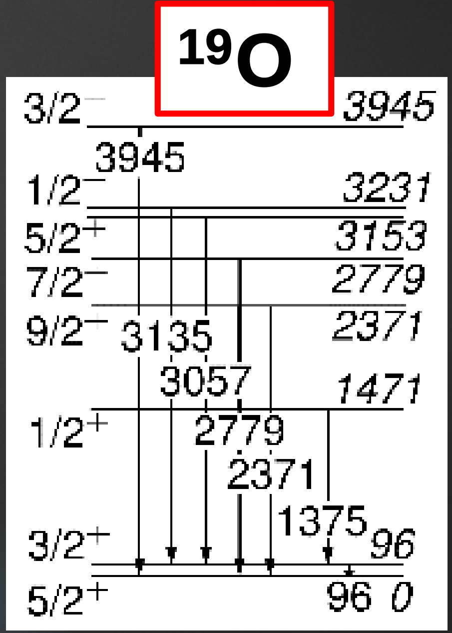








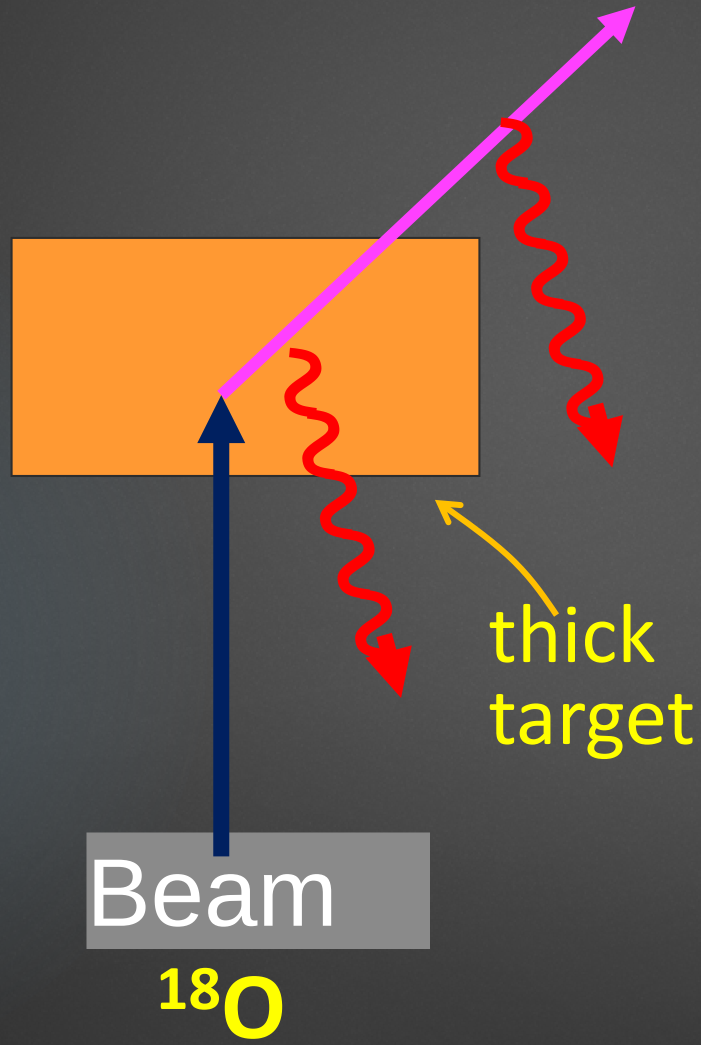
gated by VAMOS spectrometer

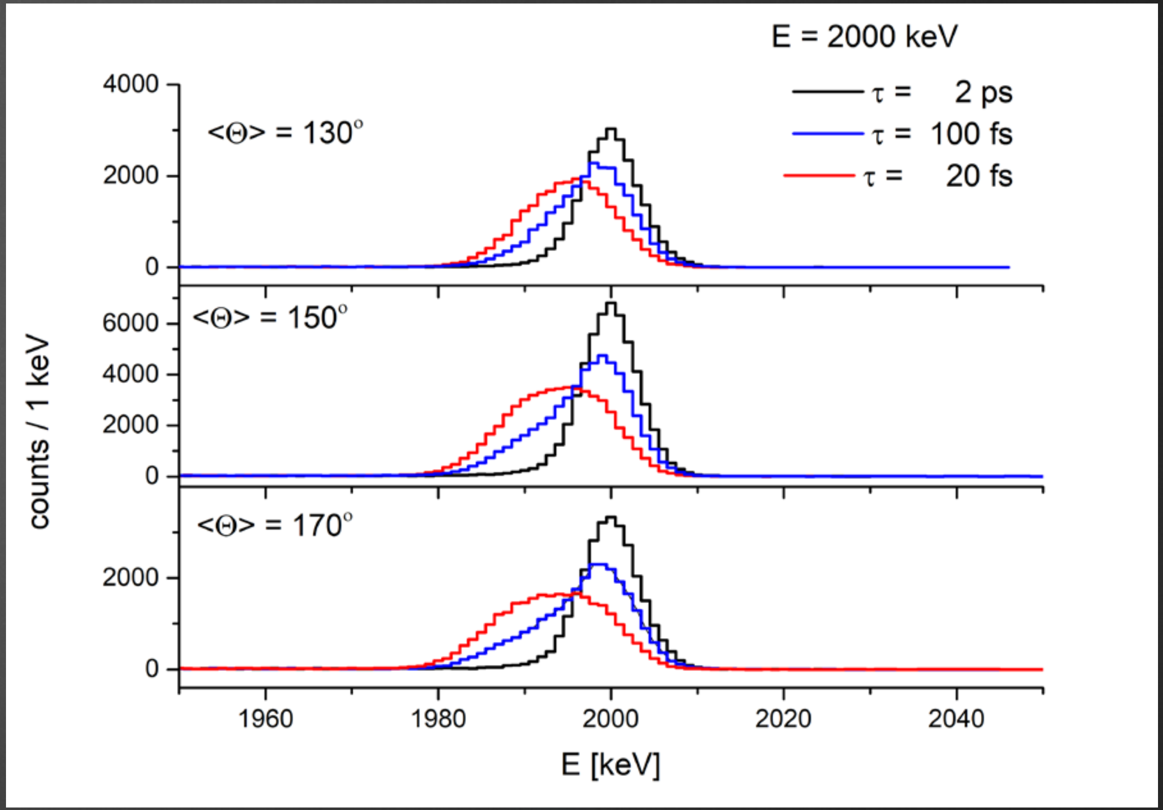


METHOD: Doppler shift dependence on the point of gamma emission

$$E = \frac{E_0}{\gamma(1-\beta\cos\Theta)}$$

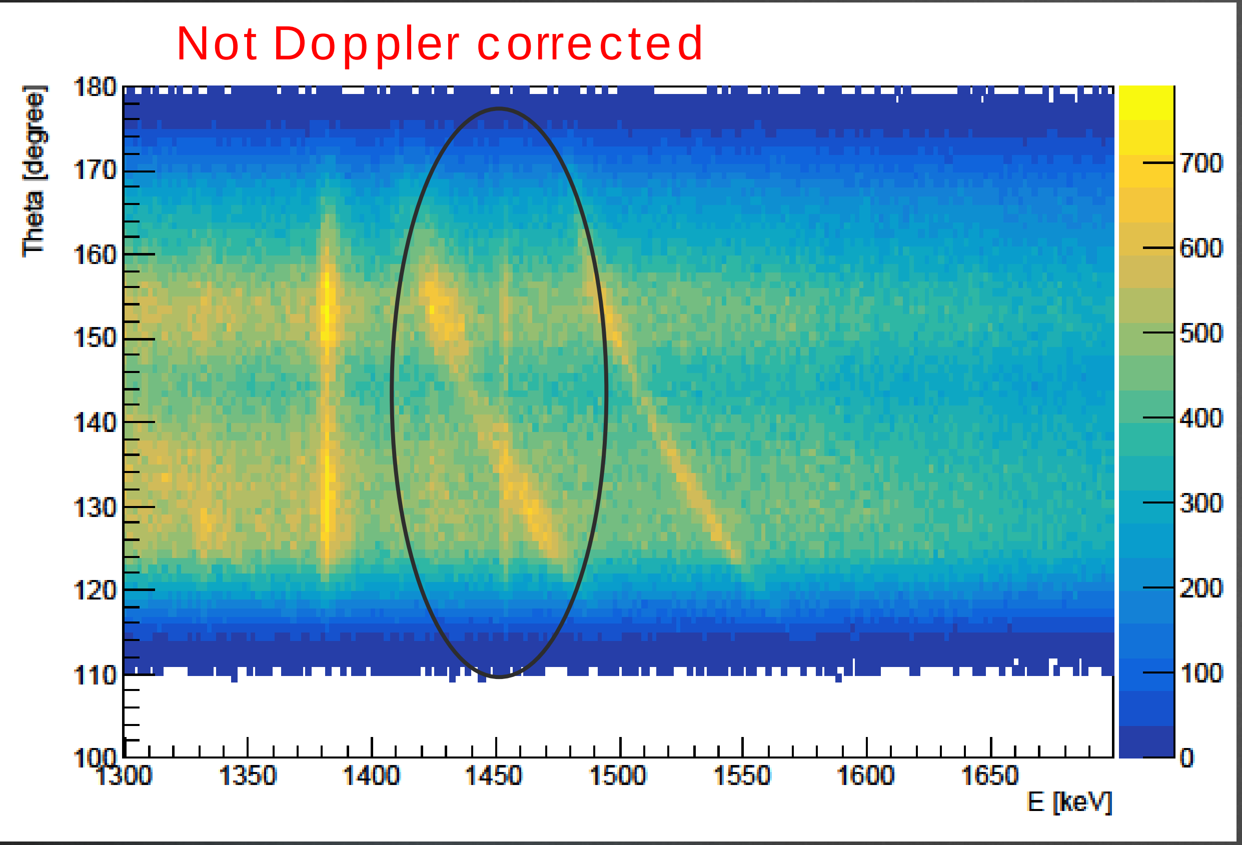
^{18}O (7 MeV/A) + ^{181}Ta target (6 mg/cm^2)

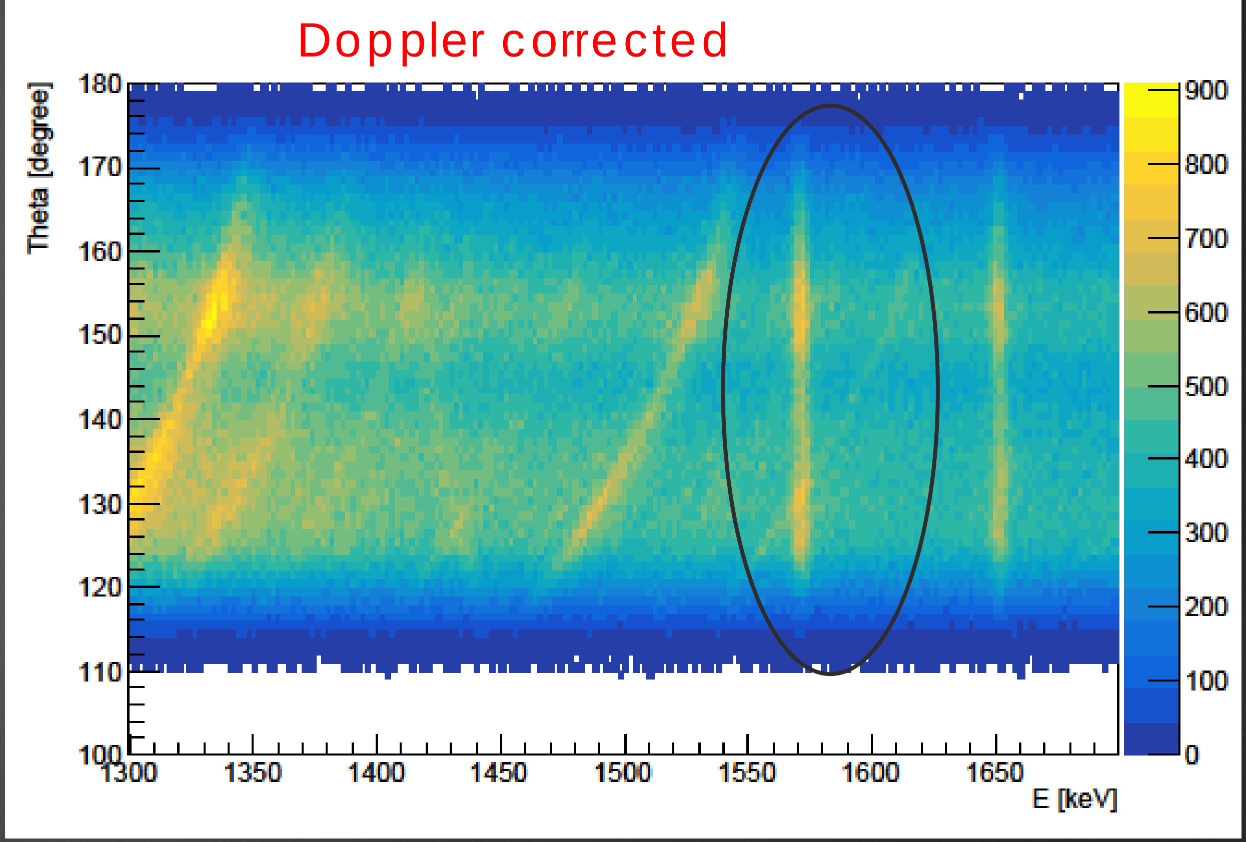




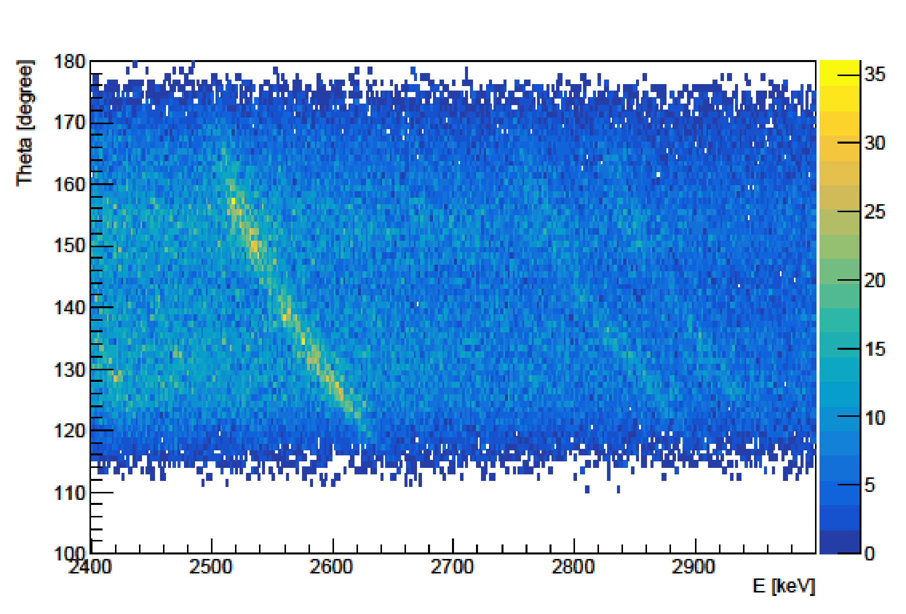
Possible problems - lines from partners

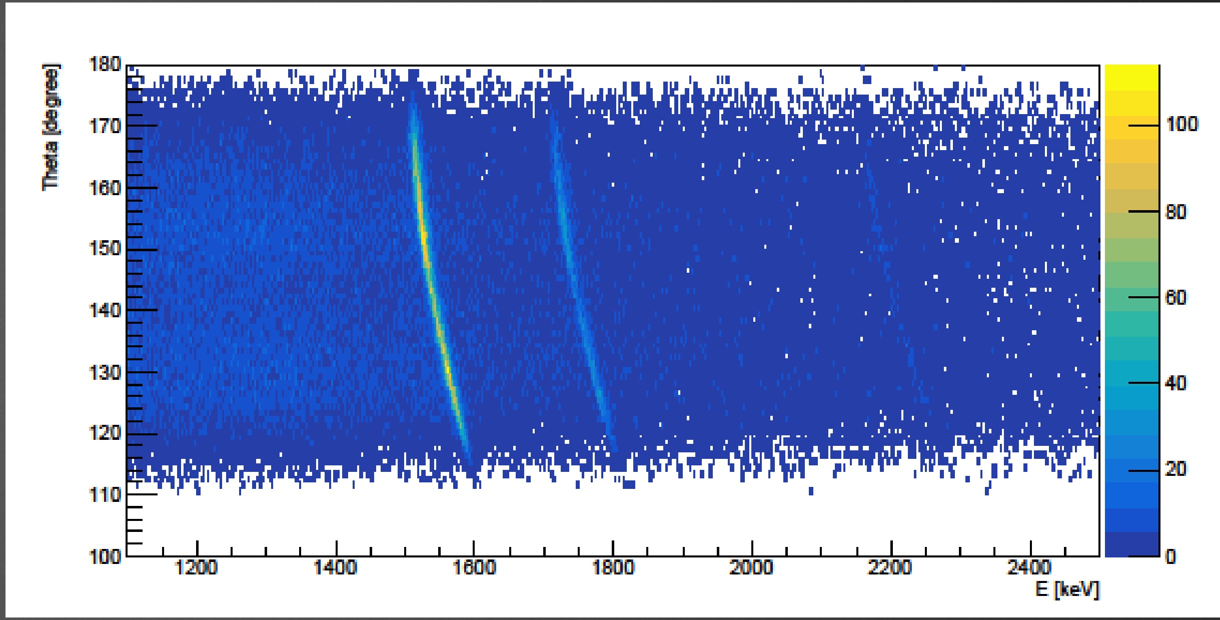
Example, ^{18}O





No contamination in all presented cases





Not corrected gamma-ray spectra for ^{19}O and ^{20}O

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.

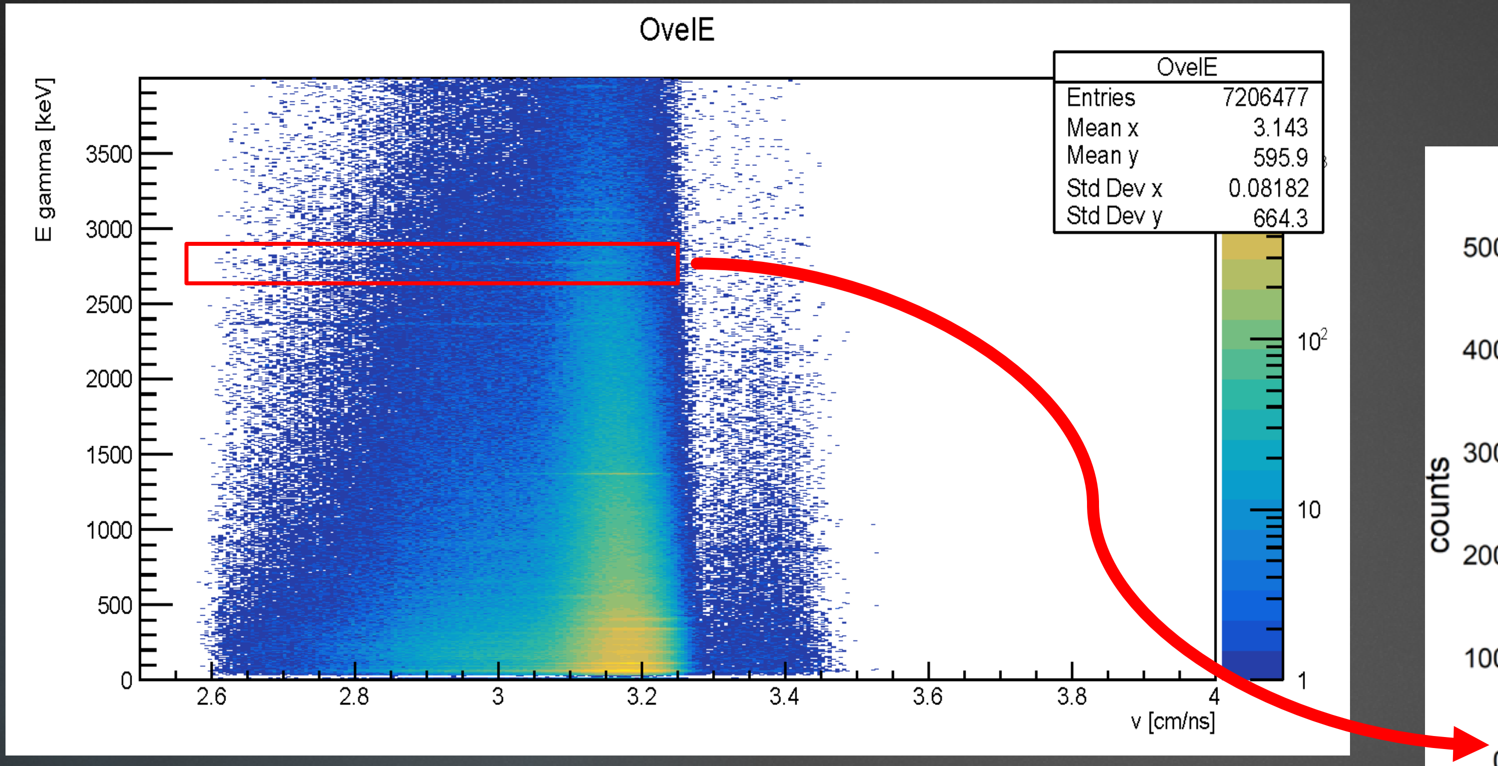
2. Simulation (with GEANT4 package) of AGATA response.

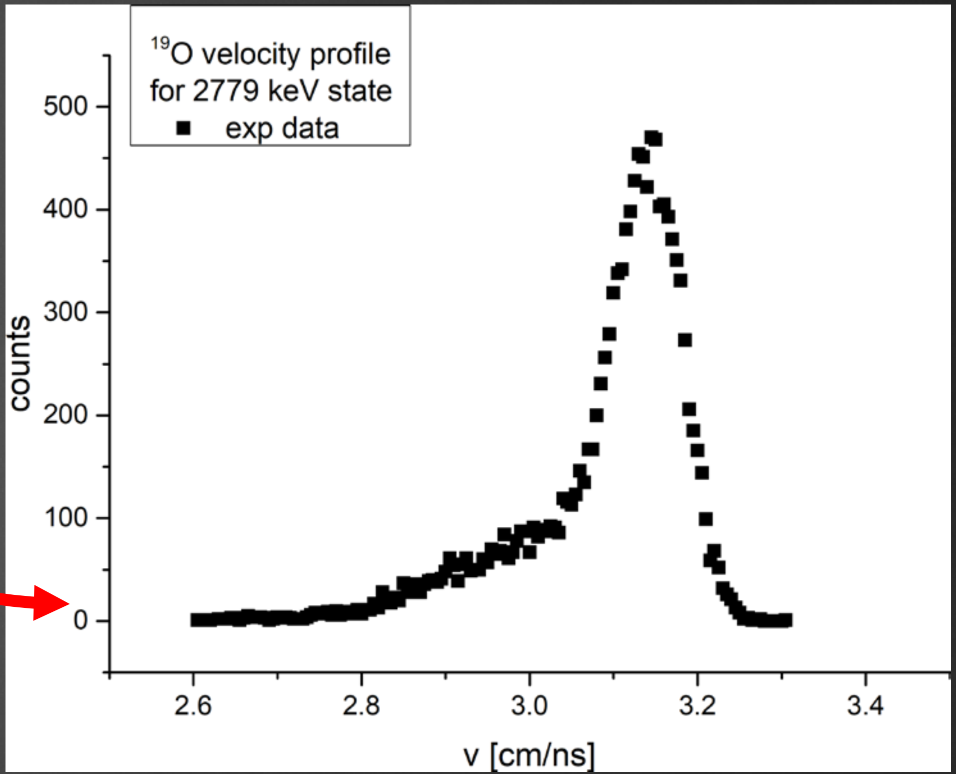
3. AGATA simulated data are tracked (similarly to experimental data) and Doppler corrected.

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.

Simulation ingredients - velocity

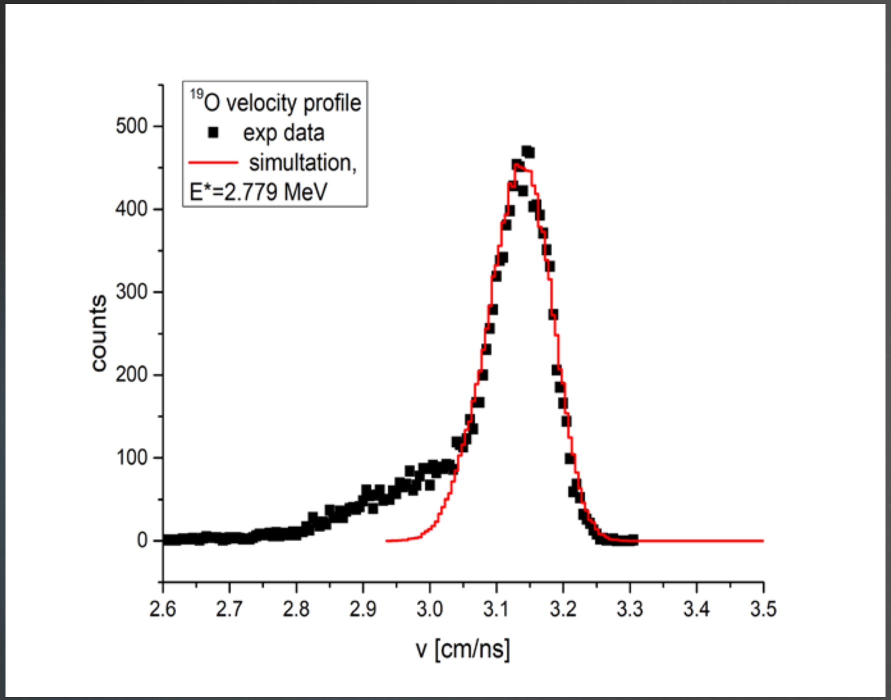


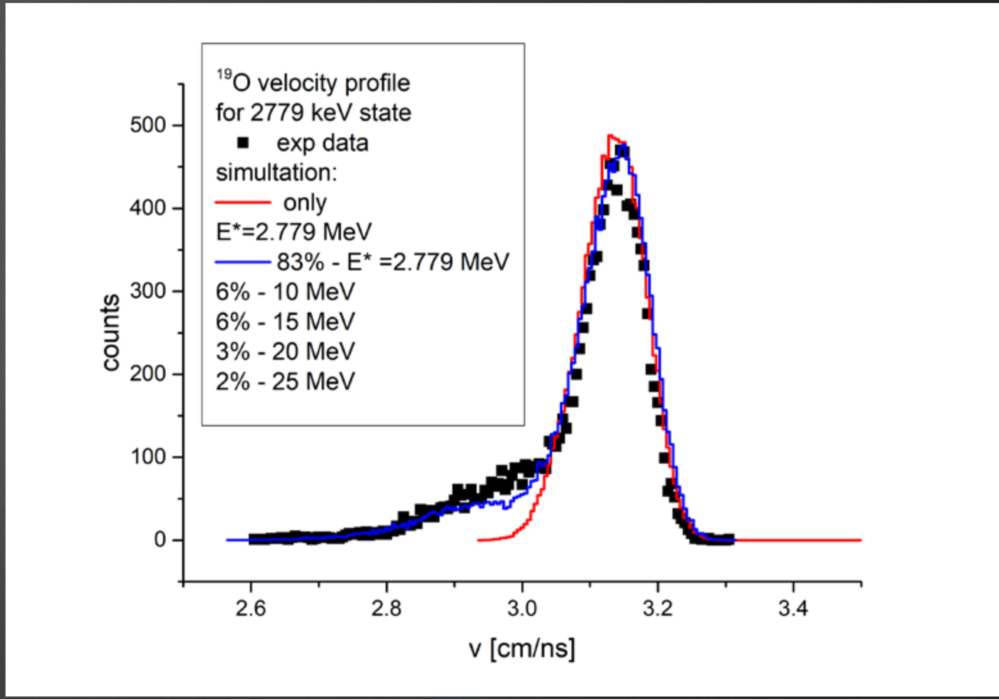


Example:
^{19}O ion velocity and gamma-ray matrix

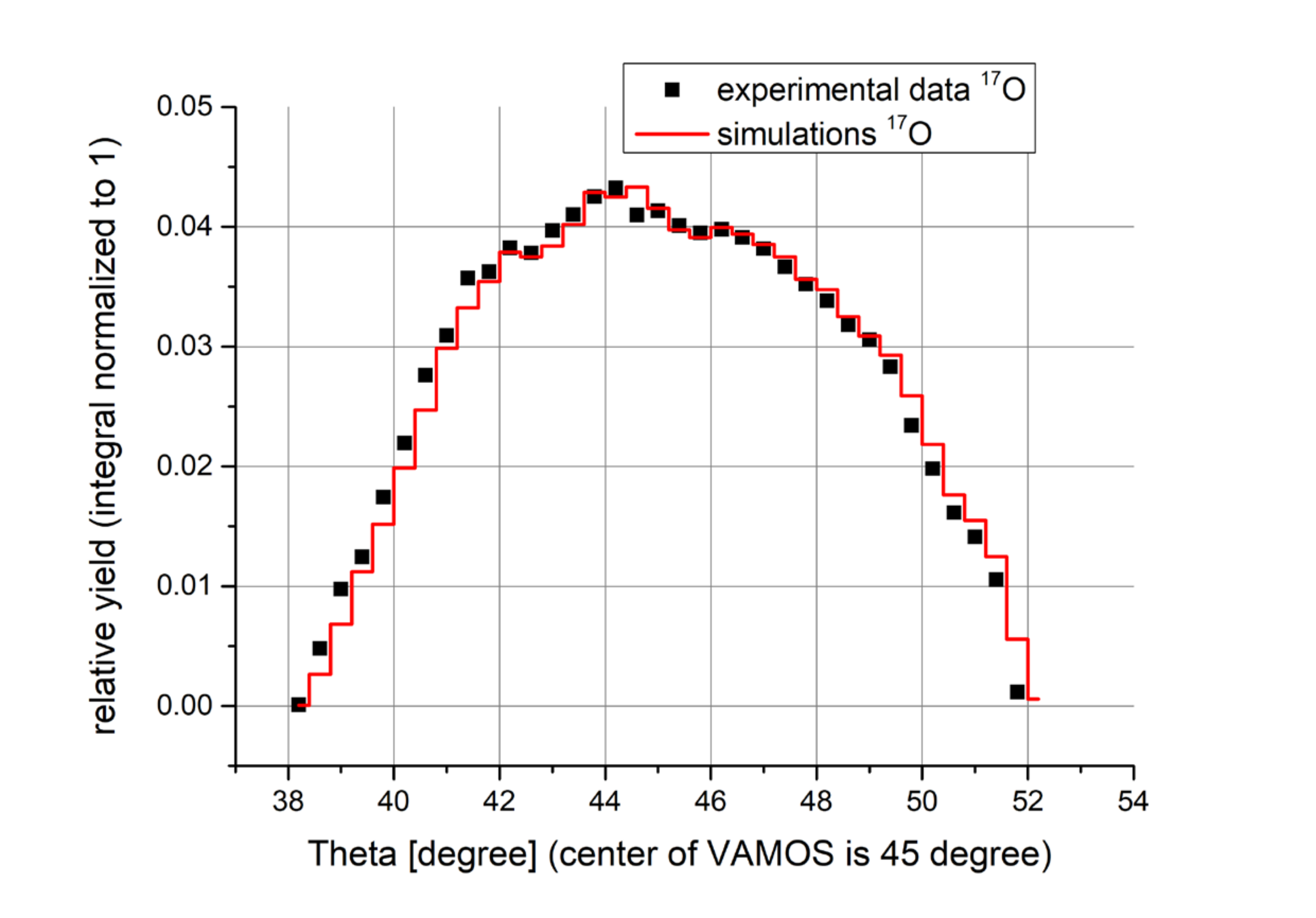
Simulation ingredients - velocity

Example:
Iterative method to reconstruct initial ion velocity from measured velocity



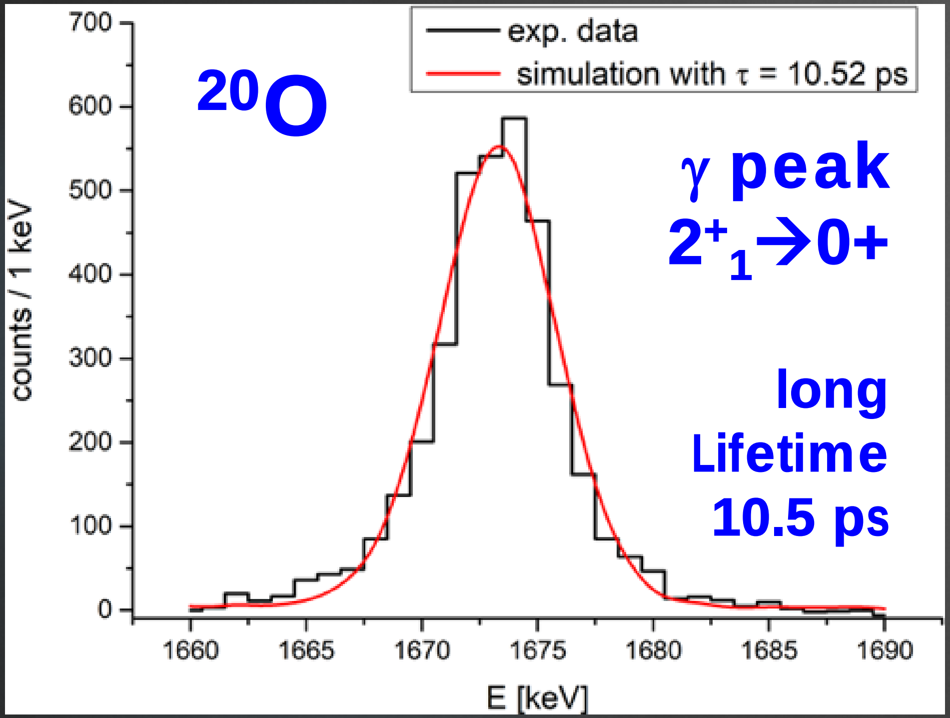


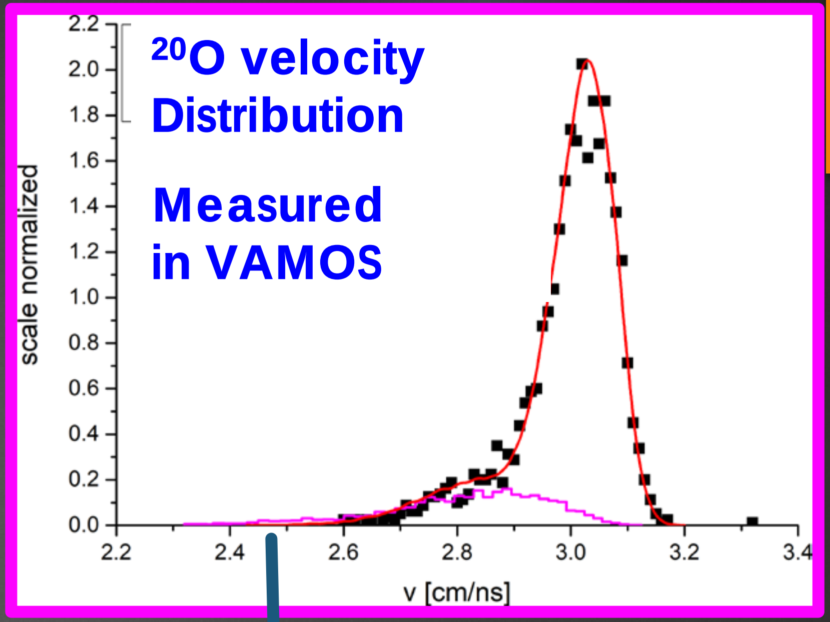
Simulation ingredients - theta

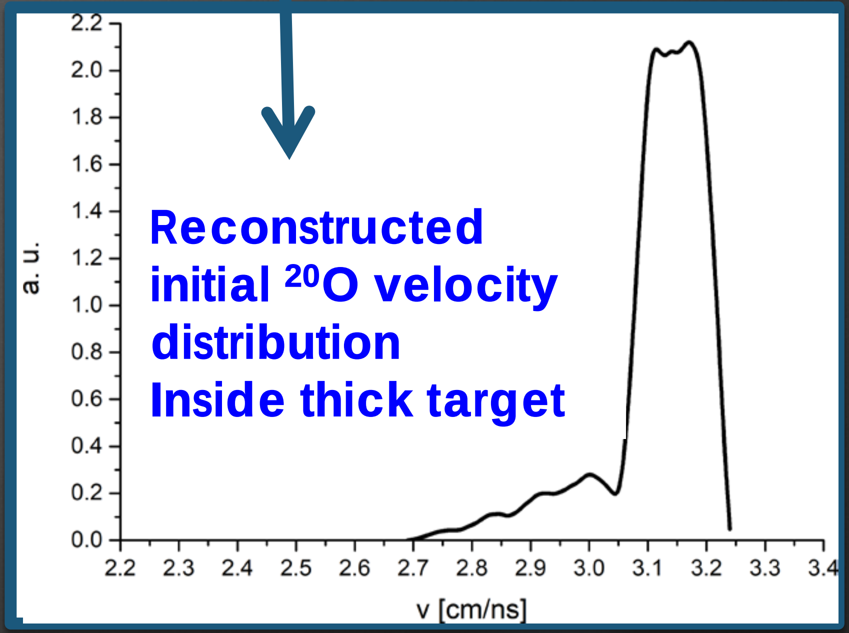


Simulation ingredients - v

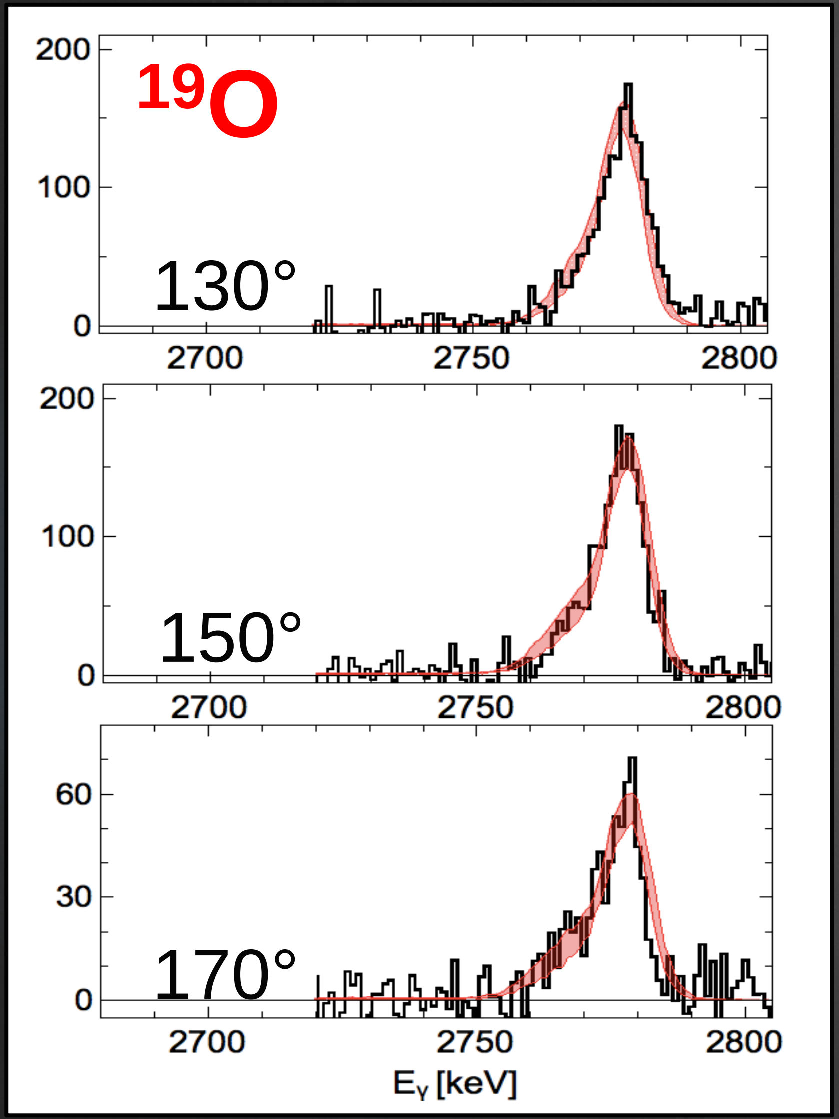
^{20}O – excited state of interest



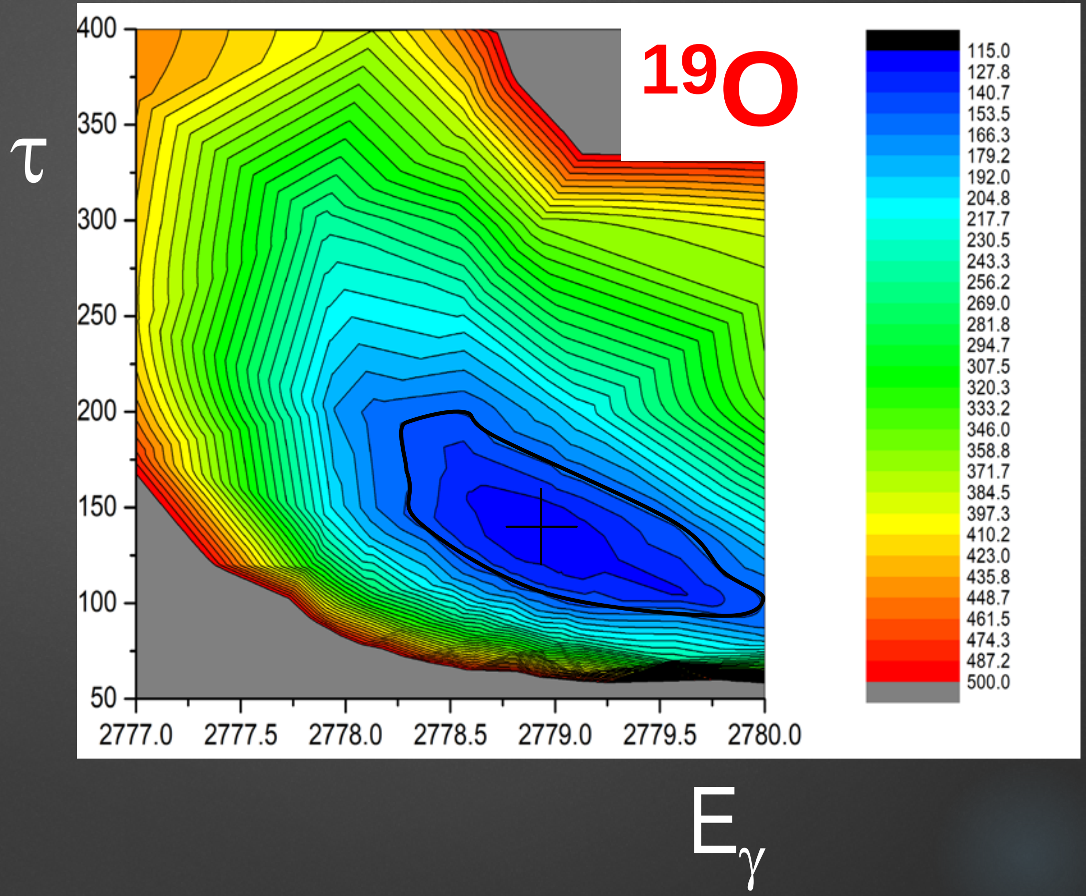


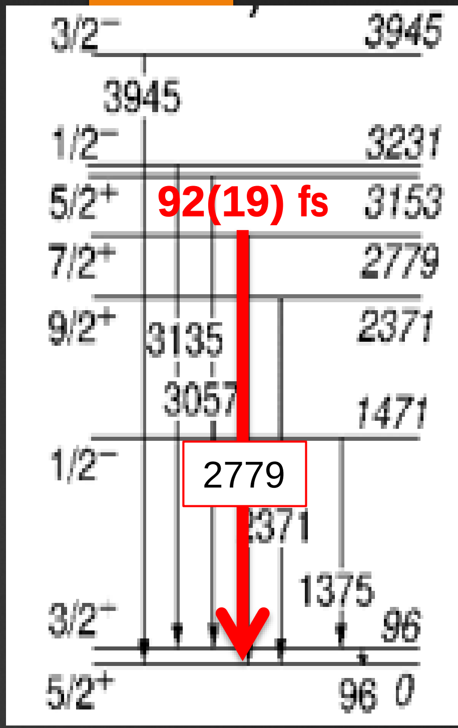


TEST of KNOWN lifetimes in the 100s femtoseconds region



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





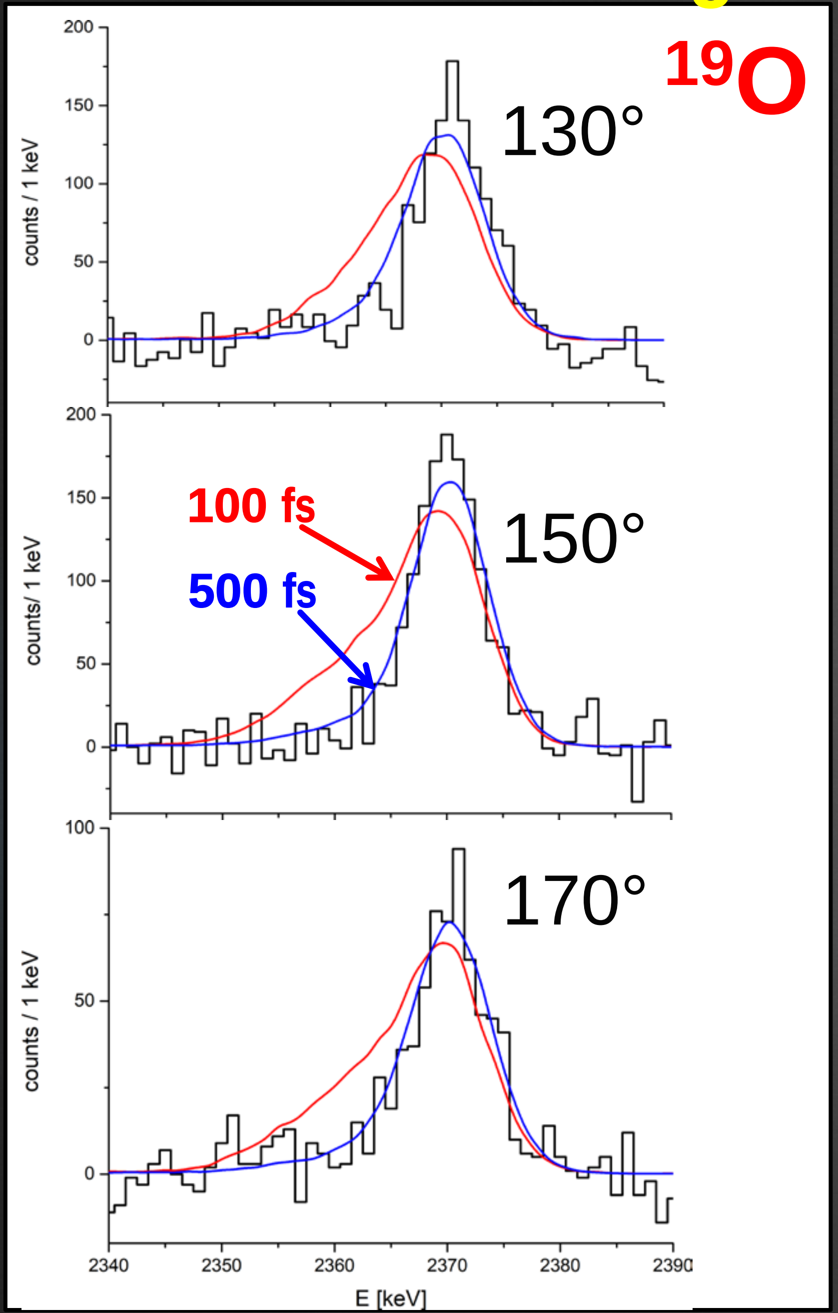
$\tau = 140^{+50}_{-40}$ fs

Very old litterature values (1971)

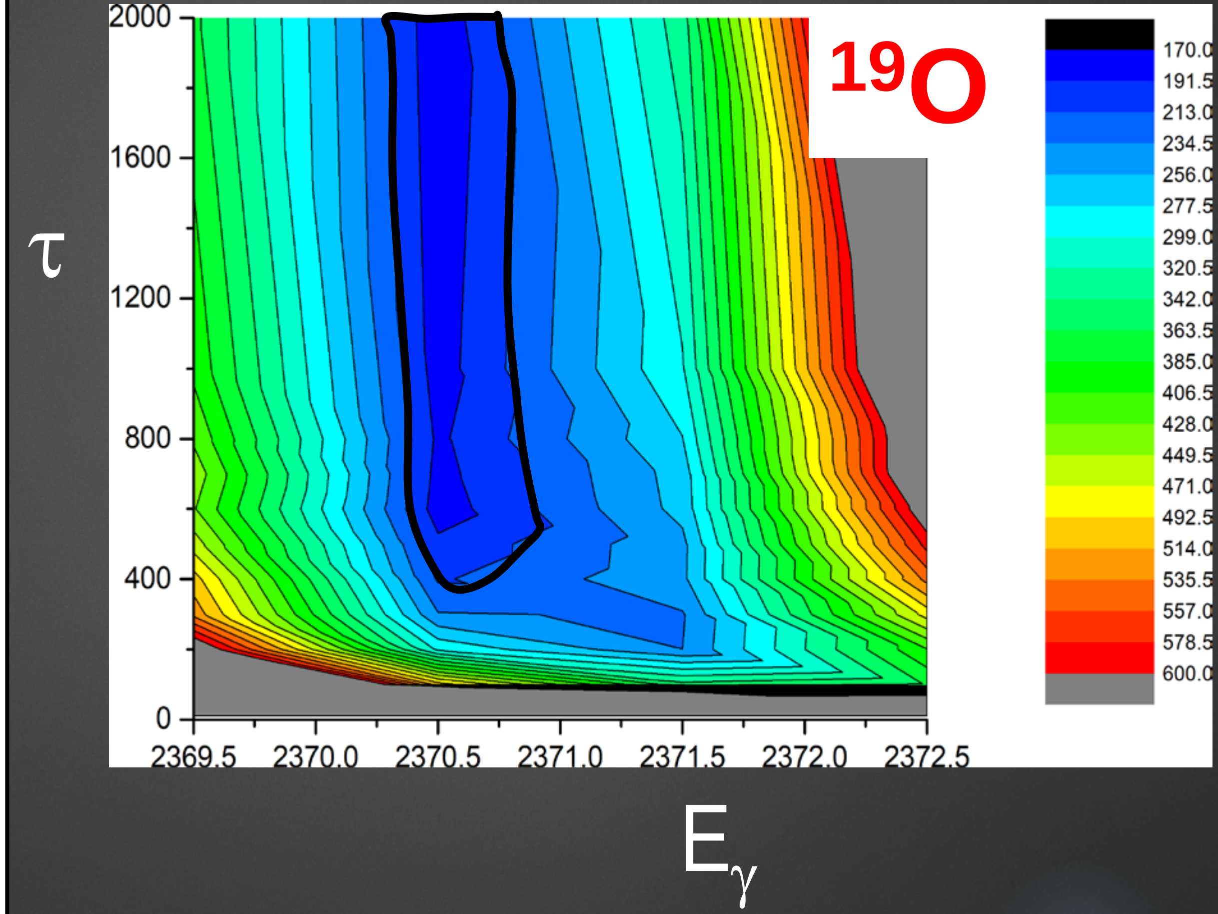
τ = 70(26) fs

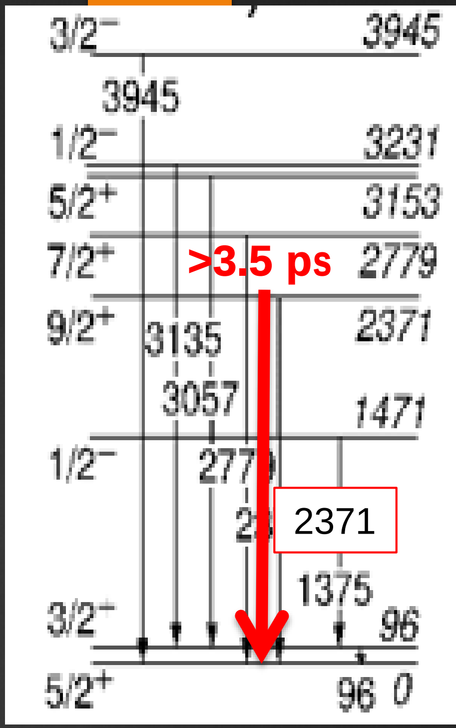
τ = 117(26) fs

TEST of KNOWN long lifetime in the region



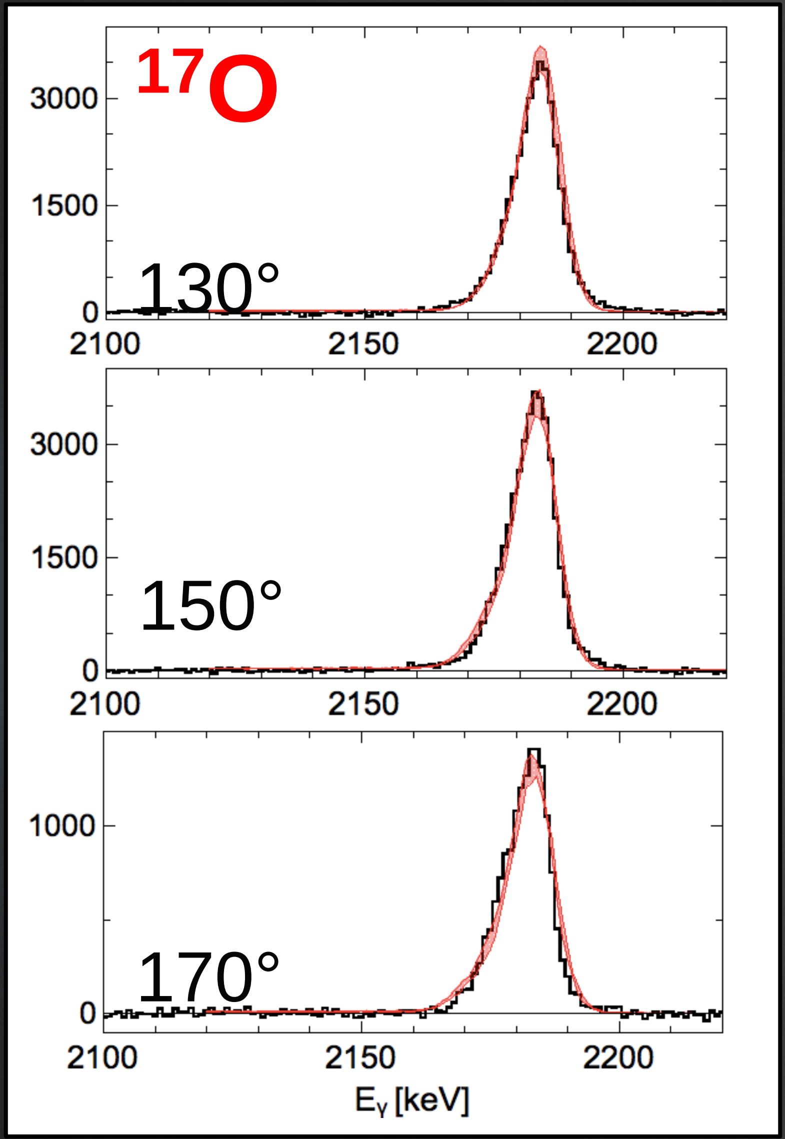
^{18}O (7 MeV/A) + ^{181}Ta target (6 mg/cm^2)





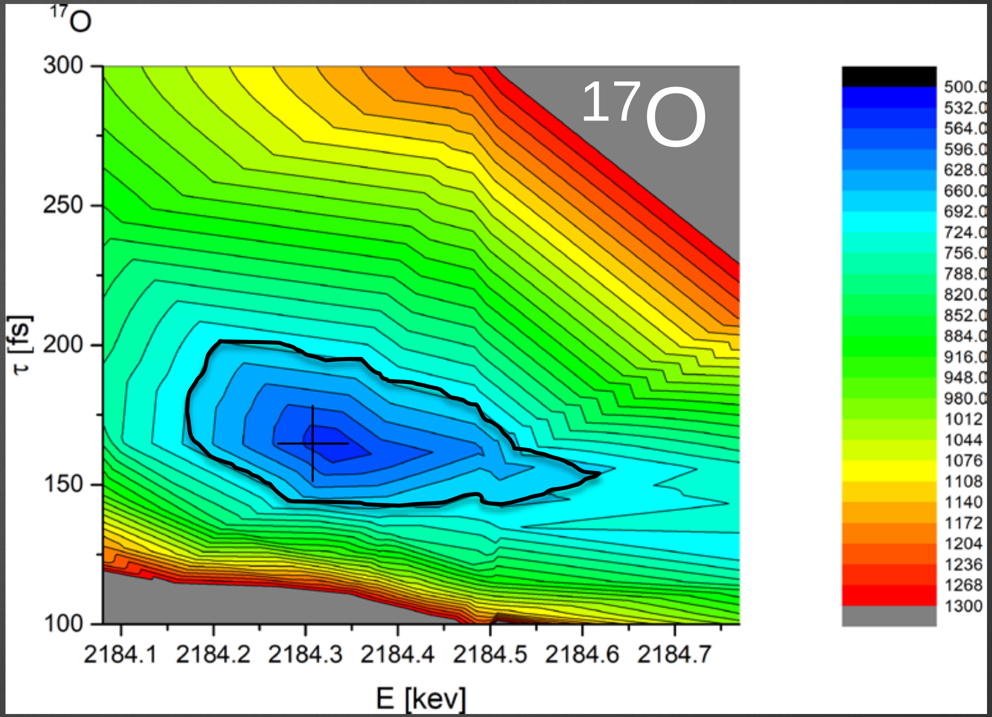
$\tau > 400$ fs

TEST of KNOWN Lifetimes in the 100s femtoseconds region

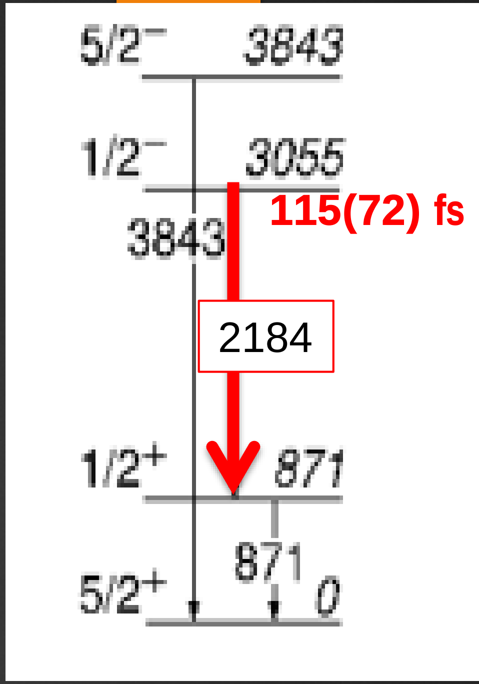


^{18}O (7 MeV/A) + ^{181}Ta target (6 mg/cm^2)

τ



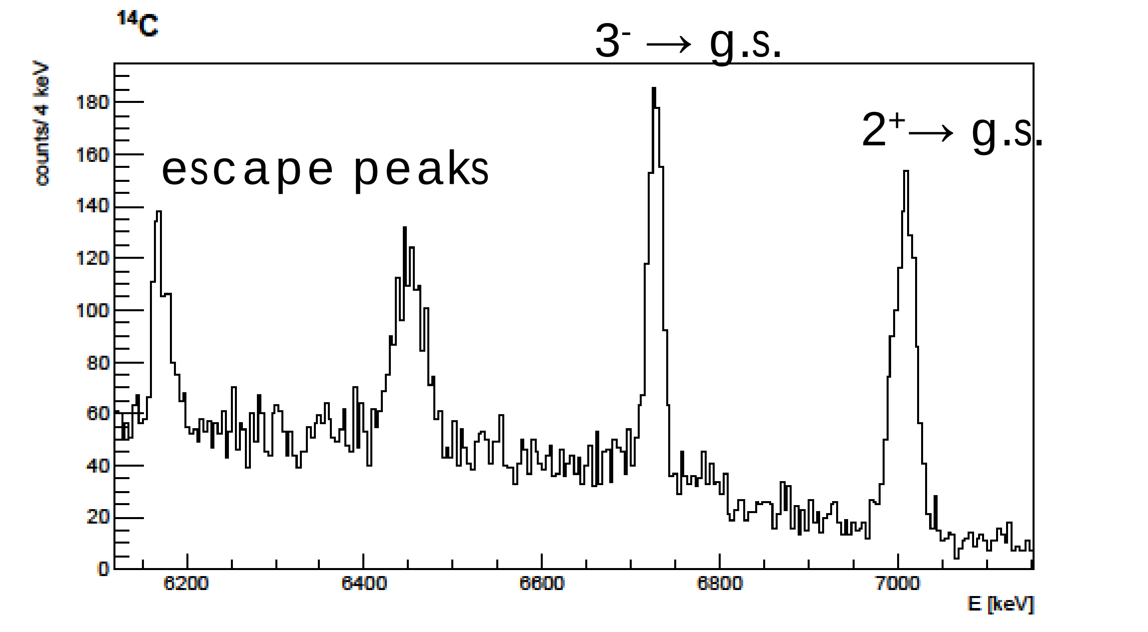
E_γ

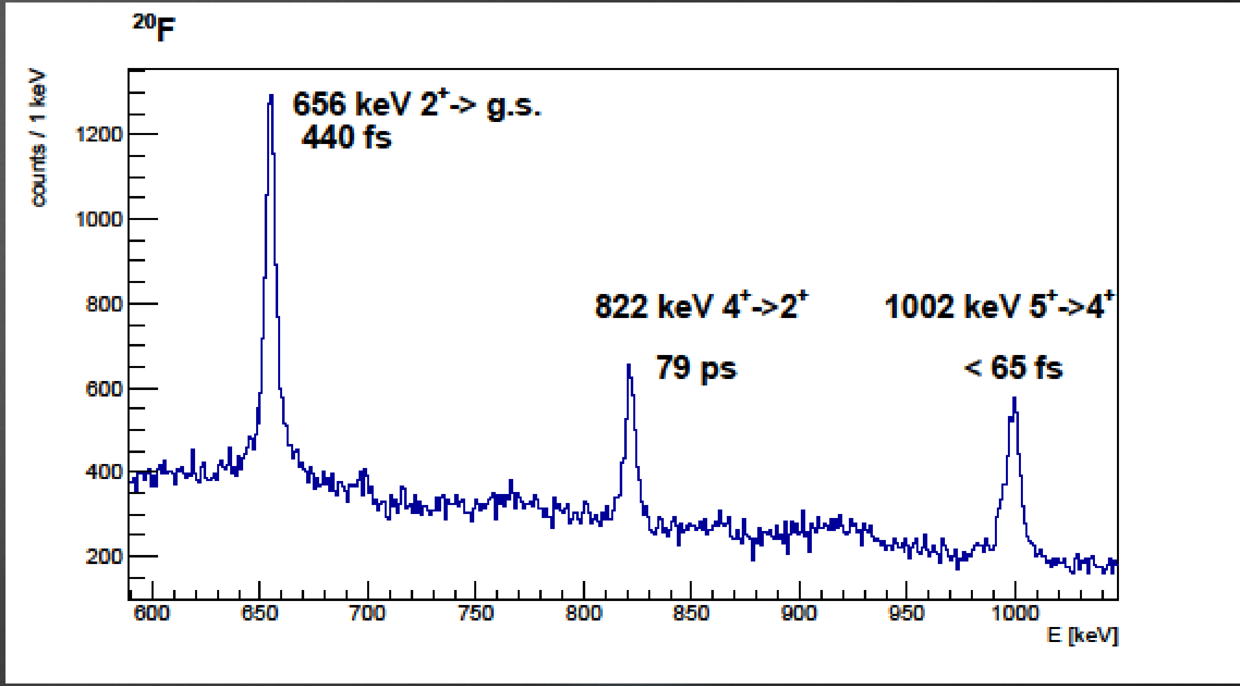


$\tau = 159^{+40}_{-20}$ fs

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

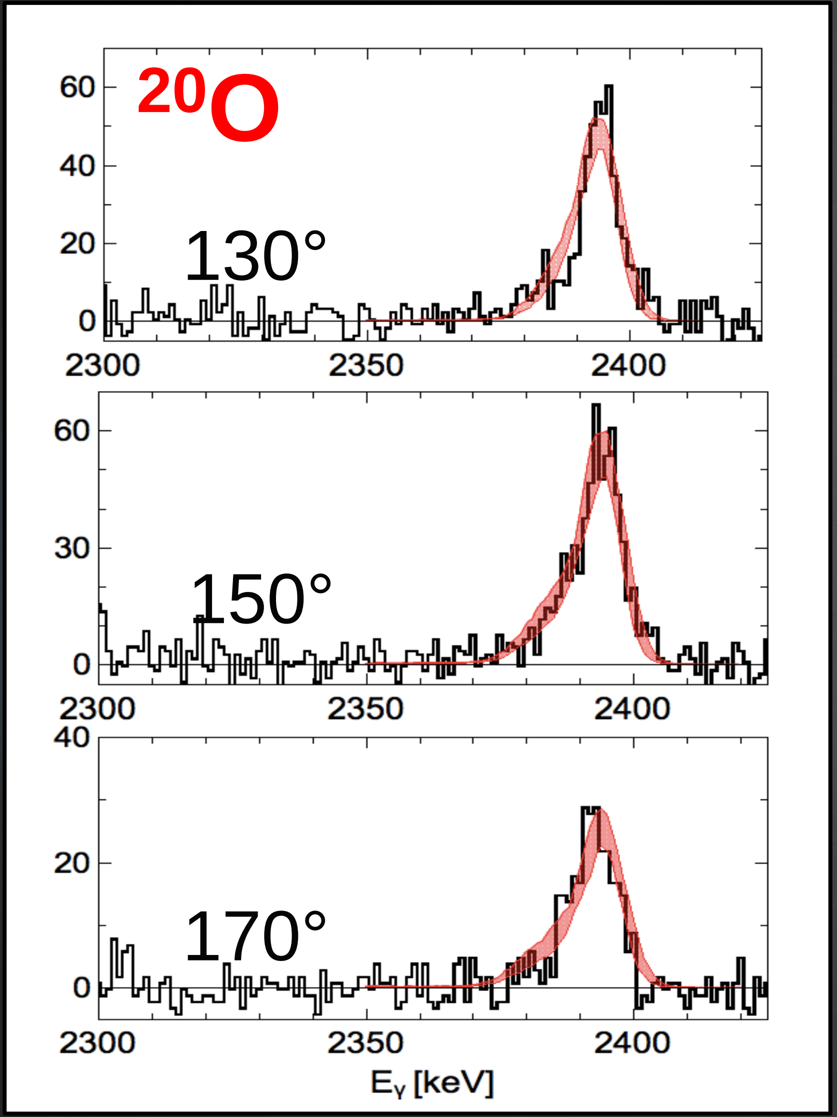
Observed other known lifetimes – i.e. in ^{14}C, ^{20}F …

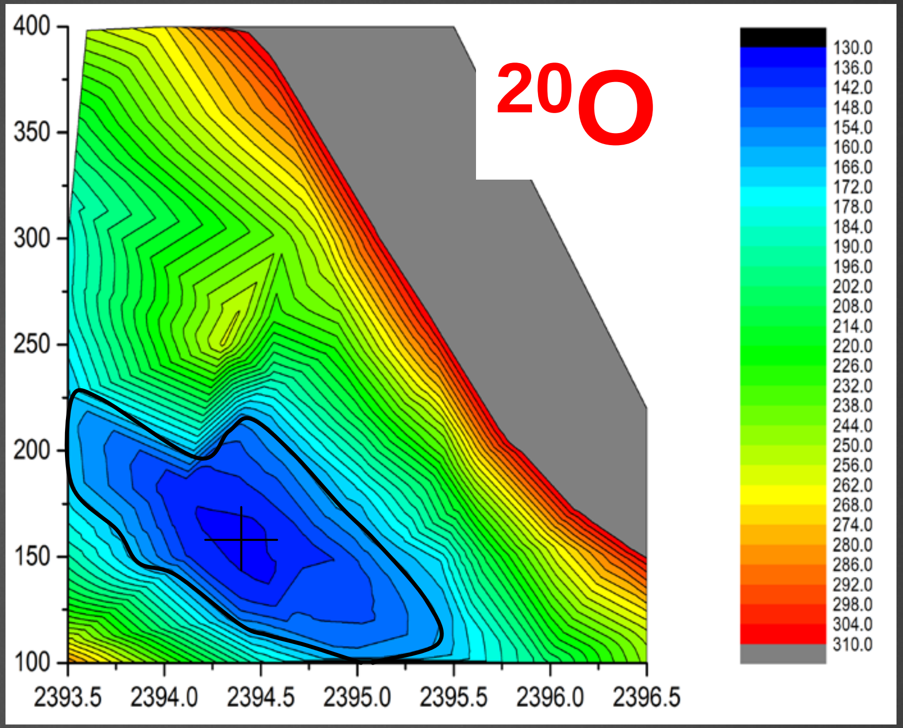


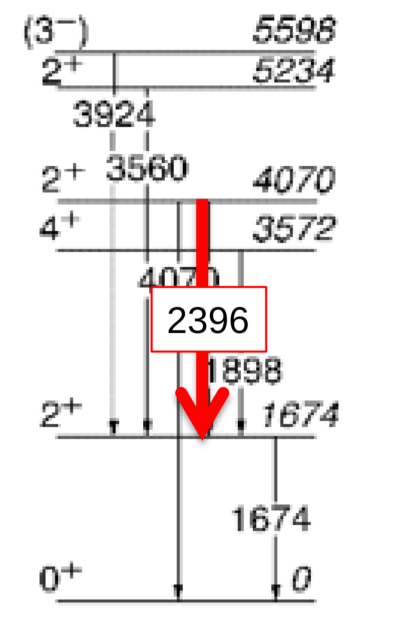


OUR Case of interest – ^{20}O

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





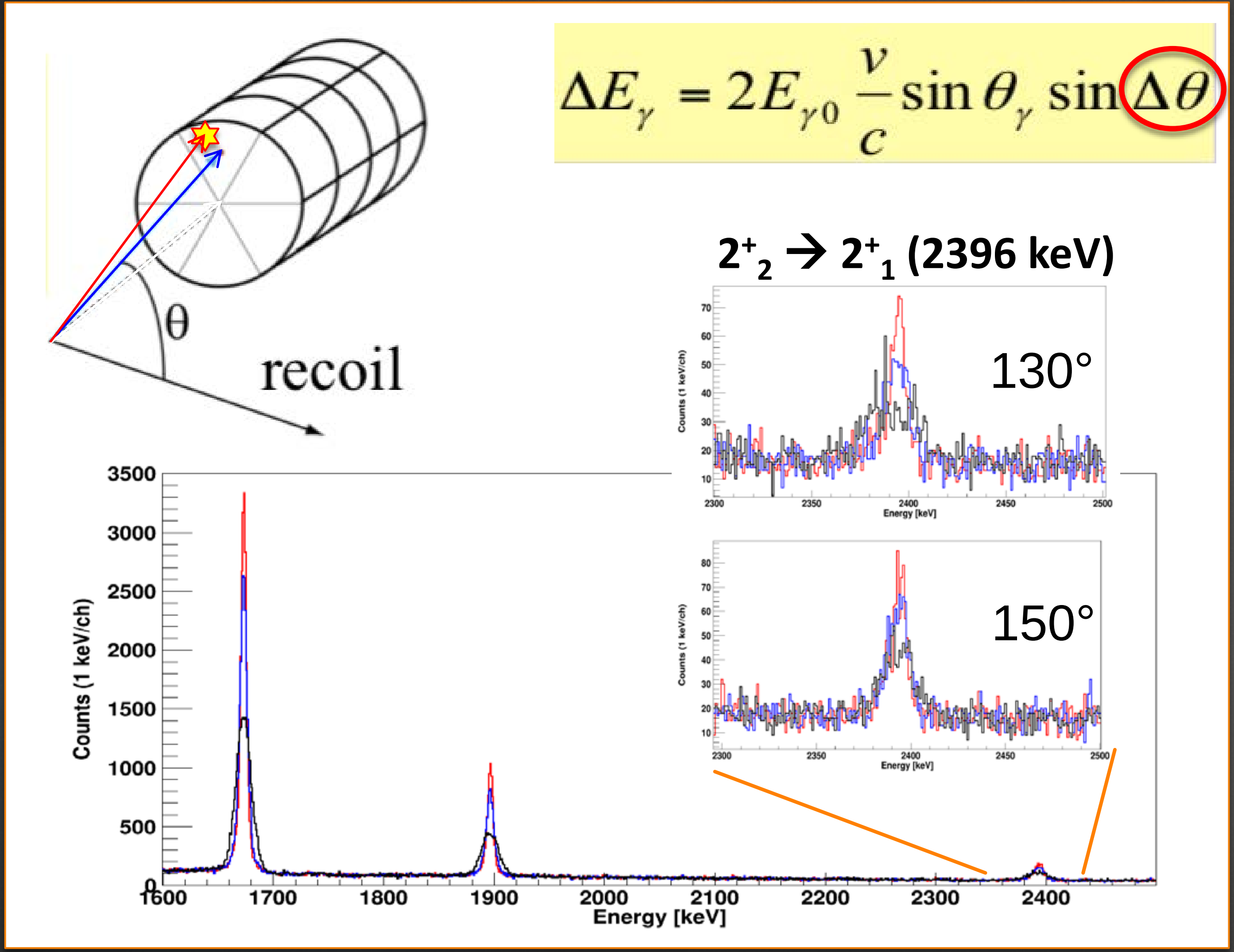


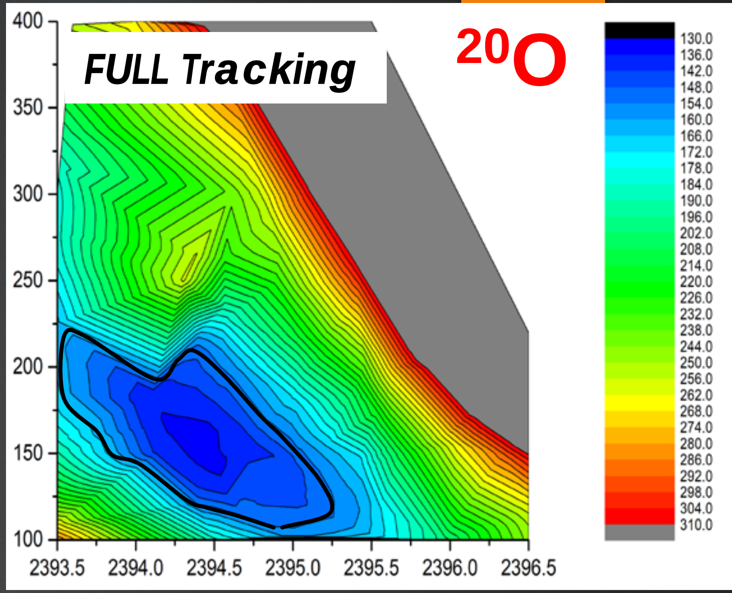
$\tau = 150^{+80}_{-30}$ fs

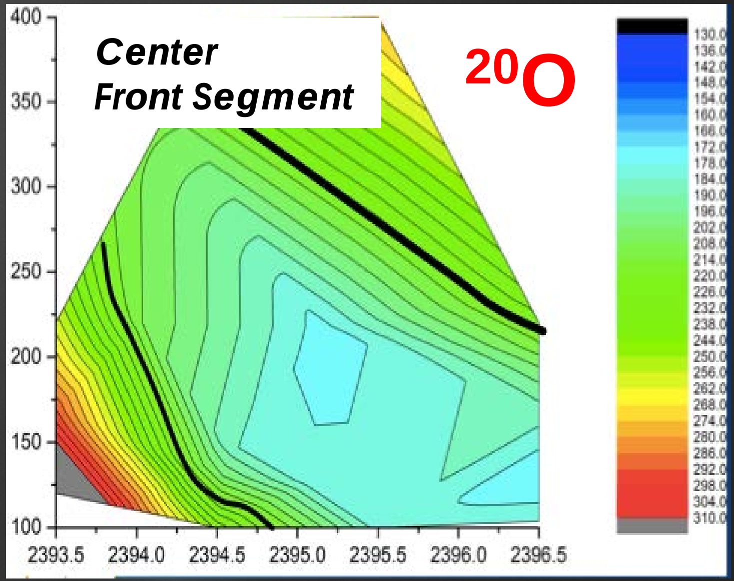
For 2_2-> 2_1 decay (79(5)% branching ratio), partial $\tau = 190^{+102}_{-39}$ fs

Large improvement with AGATA

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

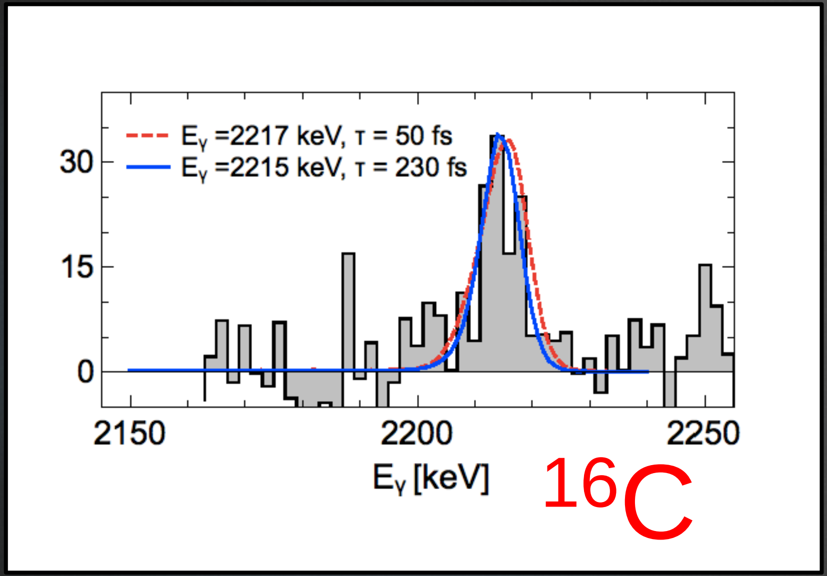


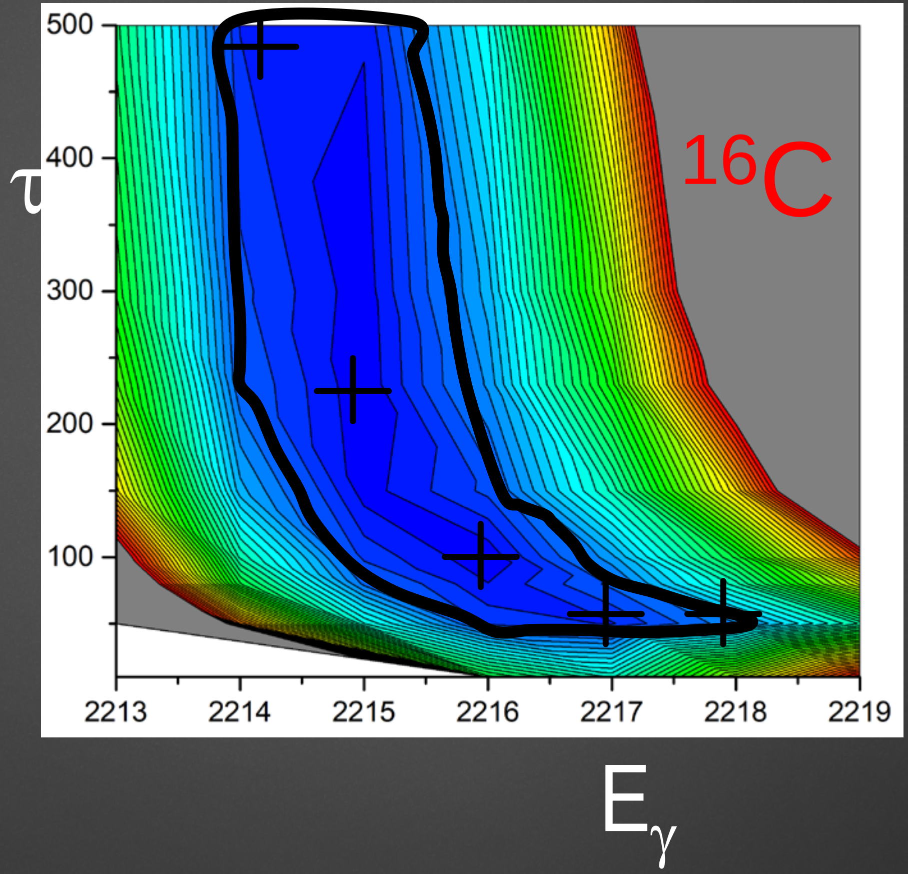




OUR Case of interest – ^{16}C

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



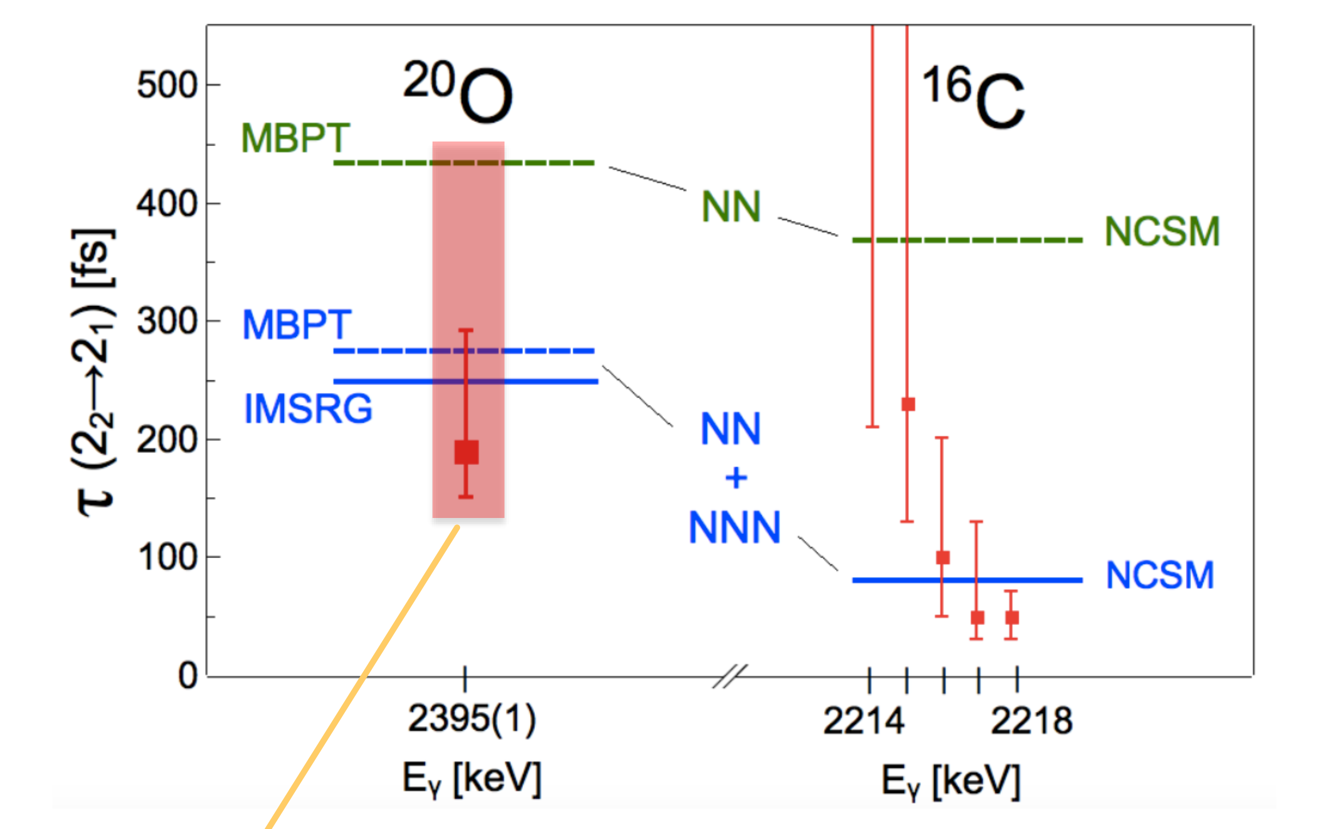


ab initio predictions

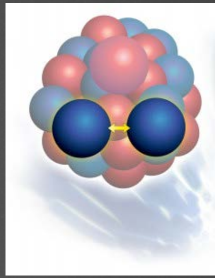
3 body force τ = 80 fs

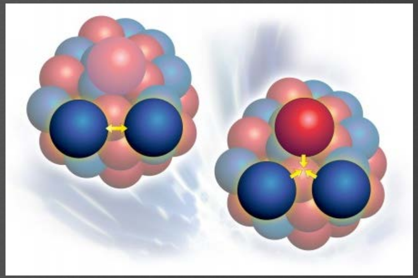
2 body force τ = 360 fs

Summary:
Theory vs. exp. results comparison



NO sensitivity would be obtained with conventional HPGe detectors





Give For ^{16}C most precise measurement es ***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

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AGATA
PARIS
VAMOS
Collaborations