Workshop on Thermonuclear Reaction Rates for Astrophysics Applications
Athens 24-25 November 2011

Lifetime measurement of the 6.79 MeV state in ^{15}O with the AGATA Demonstrator array

Caterina Michelagnoli

INFN and University of Padova, Italy

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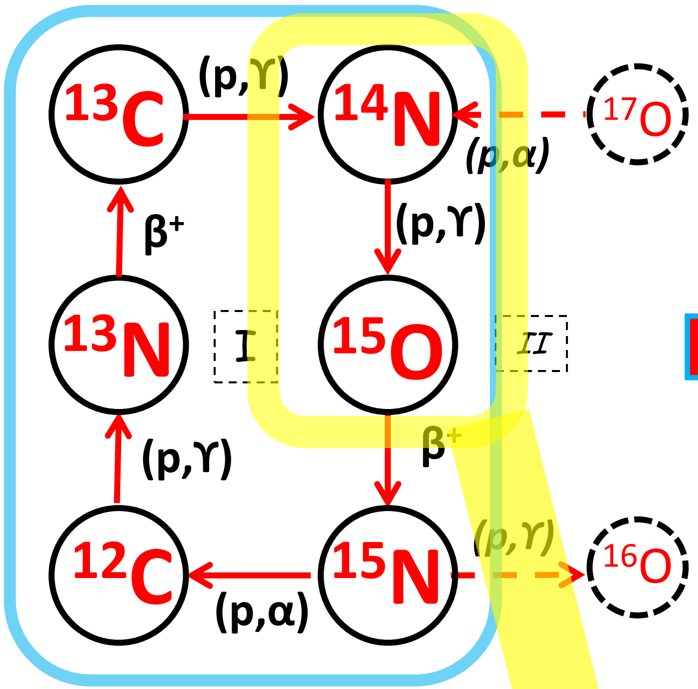
the Carbon-Nitrogen-Oxygen (CNO) cycle and the $^{14}N(p,\gamma)^{15}O$ reaction



nuclear *x*-sections are precisely known

C,N abundances in the solar core can be obtained by measuring the neutrino fluxes

[W.C.Haxton et al., As.J.687(2008)678]

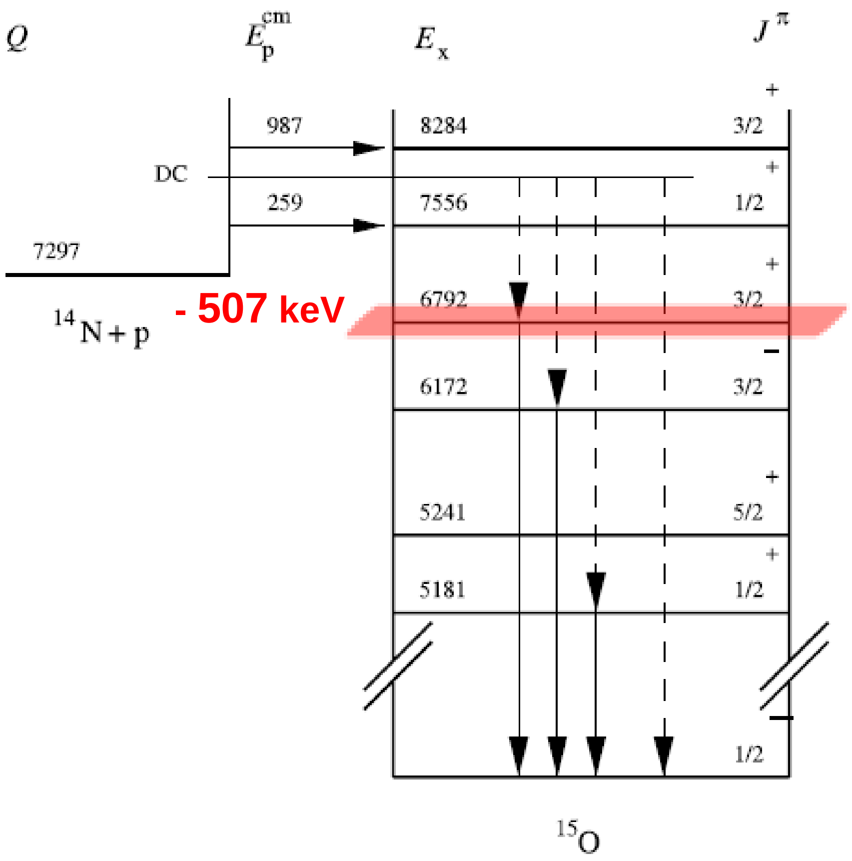
possible solution for the "solar composition problem"

[A.M.Serenelli et al., As.J.Lett. 705, L123-L127 (2009)]

$^{14}N(p,\gamma)^{15}O$ is the "bottle neck"

$^{14}N(p,\gamma)^{15}O$ *x*-section: the capture to the ground state in ^{15}O

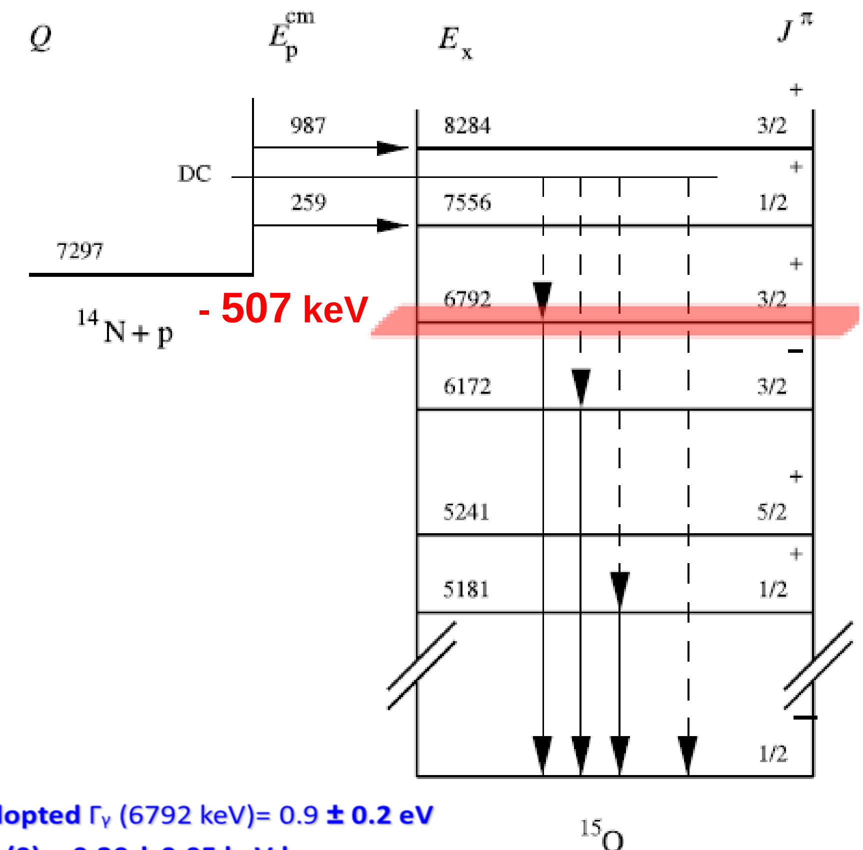
M. Marta / Progress in Particle and Nuclear Physics 66 (2011) 303–308



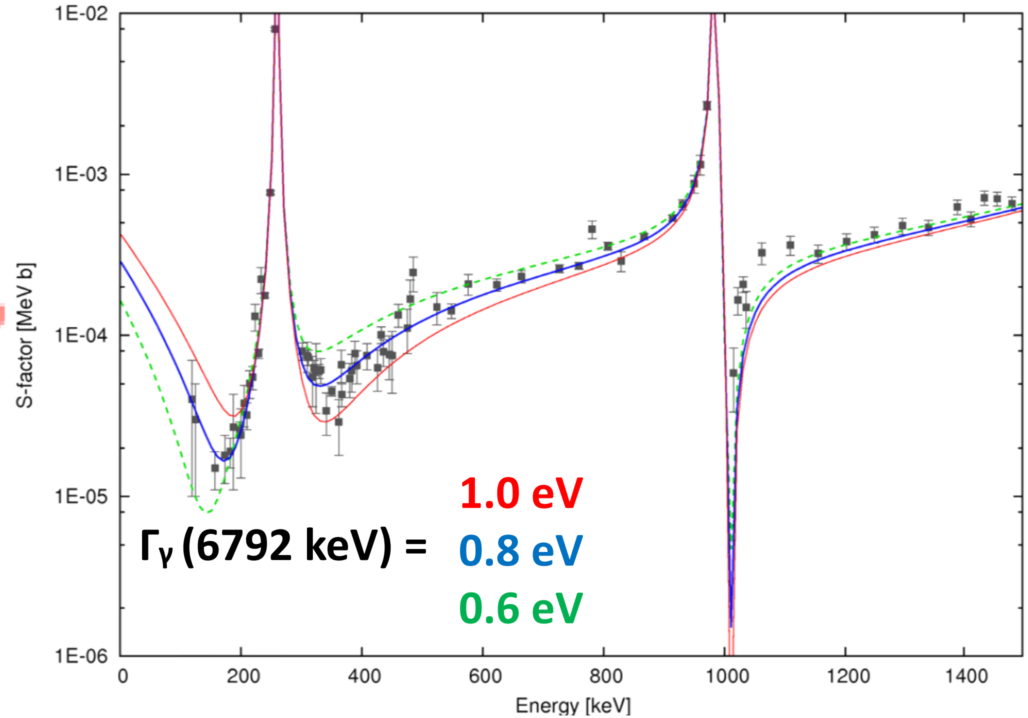
Captures to different excited states in ^{15}O contribute to the x-section.
The one to the gs in ^{15}O is dominated by the tail of the sub-threshold resonance at -507 keV (**6.79 MeV state in ^{15}O**)
[C.Angulo et al., NP A690 (2001) 755, M.Marta et al., PR C78 (2008) 022802(R), ….]

$^{14}N(p,\gamma)^{15}O$ *x*-section: the width of the *-507 keV* sub-threshold resonance

M. Marta / Progress in Particle and Nuclear Physics 66 (2011) 303–308



H.P. Trautvetter et al., JPG 35 (2008) 014019
and courtesy of M. Marta



Adopted Γ_γ (6792 keV)= 0.9 ± 0.2 eV

$S_{GS}(0)$ = 0.20 ± 0.05 keV·b

M. Marta et al., Phys. Rev. C 78, 022802(R) (2008)

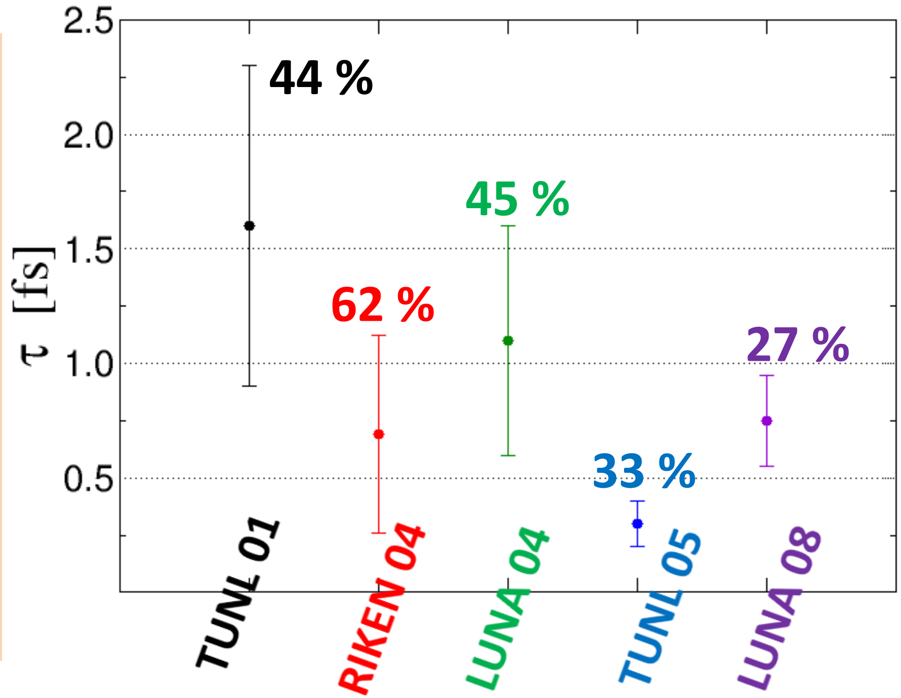
change of ≈20% in $\Gamma=\hbar/\tau$ →
change of ≈30% in $S_{gs}(0)$

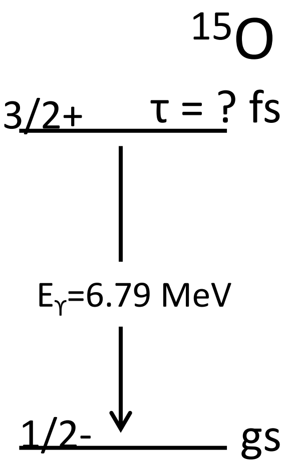
Lifetime of the 6.79 MeV state in ^{15}O:

already measured…**but the uncertainty is still too large!!!**

GROUP	METHOD	T [fs]	*Ref.*
Oxford 1968	DSAM d(14N,15O)n	< 28	W. Gill et al., NP A121, 209 (1968)
TUNL 2001	DSAM 14N(p,γ)15O	1.6±0.7	P.F. Bertone et al., PRL 87, 152501 (2001)
RIKEN 2004	CE 208Pb(15O,15O*)	0.69±0.43	K. Yamada et al., PL B579, 265 (2004)
LUNA 2004	X-section+R matr. fit	1.1±0.5	A. Formicola et al., PL B591, 61 (2004)
TUNL 2005	X-section+R matr. fit	0.3±0.1	R. Runkle et al., PRL 94, 082503 (2005)
Bochum 2008	DSAM 14N(p,γ)15O	< 0.77	D. Schuermann et al., PR C77, 055803 (2008)
LUNA 2008	X-section+R matr. fit	0.75±0.20	M. Marta et al., PR C78, 022802(R) (2008)

DSAM (Doppler Shift Attenuation Method) **(DIRECT!)**
lifetime measurement
in inverse kinematics
exploiting the detection efficiency and energy resolution of the
AGATA HPGe array



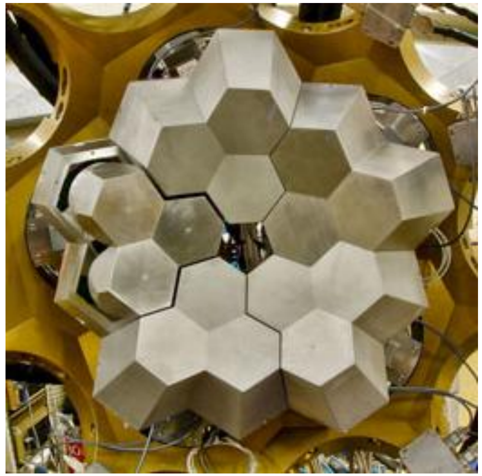


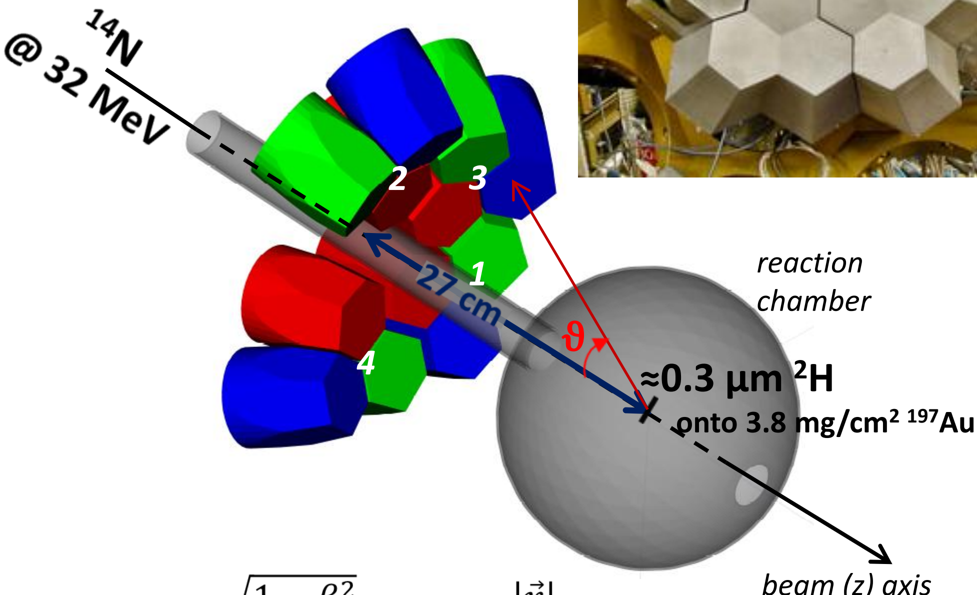
the experiment: reaction and setup

$^{14}N + ^{2}H$ @ 32 MeV (Tandem XTU, LNL) → main reaction prod.: **^{15}O** (Q_{gs}=5.1 MeV)

^{15}N (Q_{gs}=8.6 MeV)

ϑ ≈ 160 deg →
cos ϑ ≈ -0.94





$$E_\gamma = E_{0\gamma}\,\frac{\sqrt{1-\beta^2}}{1-\beta cos\theta_\gamma} \qquad \beta = \frac{|\vec{v}|}{c}$$

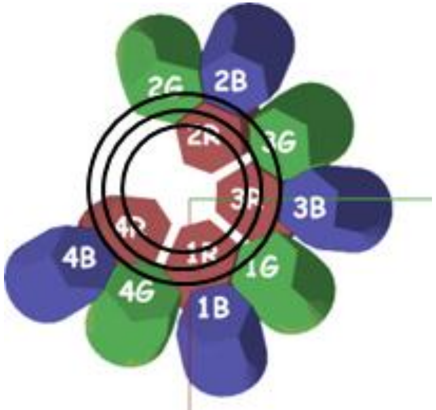
Advanced**GA**mma**T**racking**A**rray
Demonstrator

4 (**nowadays 5**) asymmetric triple-clusters:
12(15) 36-fold **segmented** HPGe

Efficiency and Energy resolution
@ 1.3MeV : ≈2% (≈2.7%), 2.5 keV
@ 7 MeV : ≈0.5% (≈0.7%), 4.8 keV

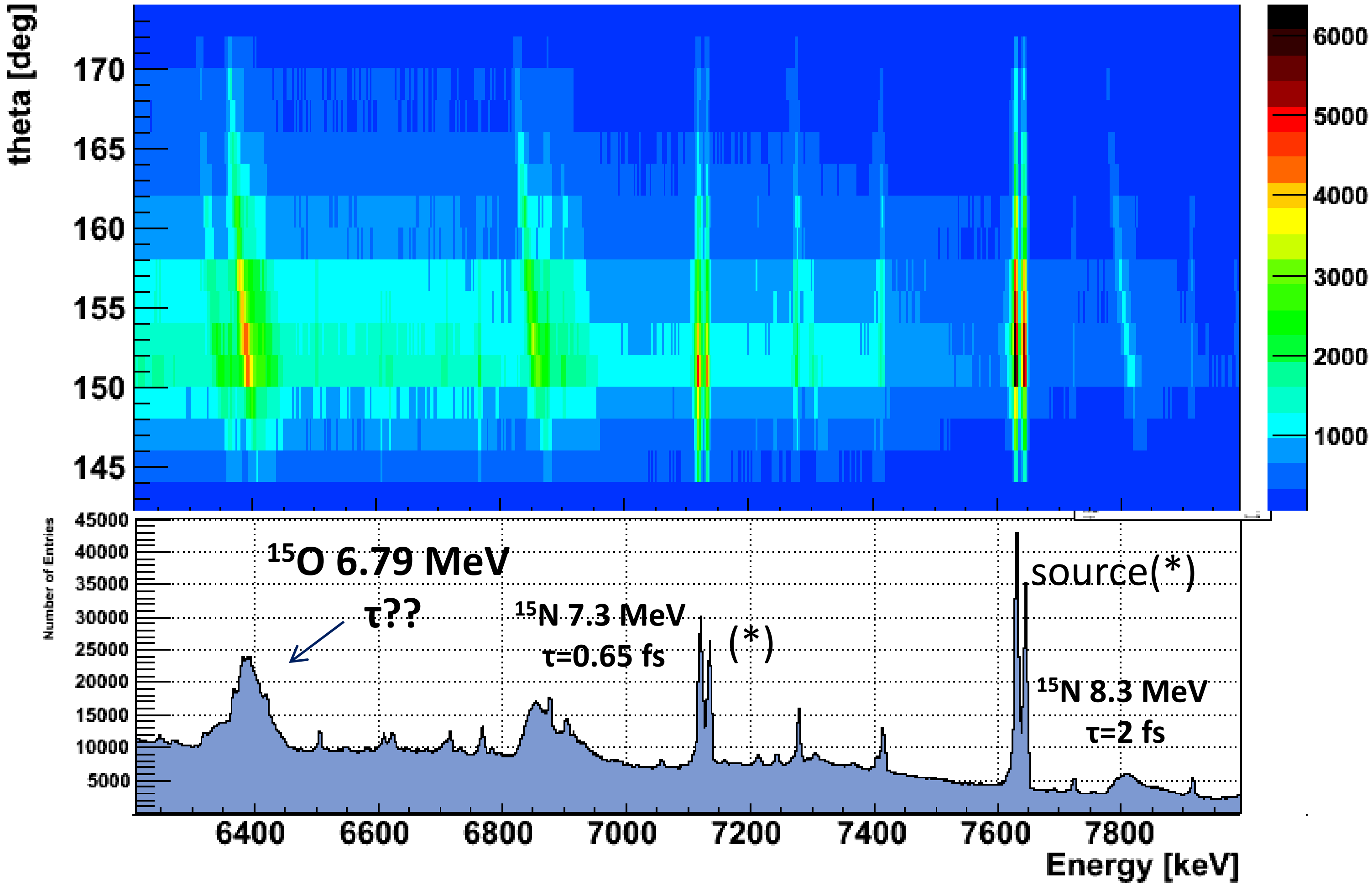
digital electronics →
decomposition of signal shapes
→ pulse Shape Analysis →
gamma-ray tracking

data analysis:
θ first interaction point *vs* gamma energy



first interaction point of each gamma-ray reconstructed event-by-event with a 4mm indetermination

detected gamma-rays can be sorted in few degrees θ "slices"



data analysis:
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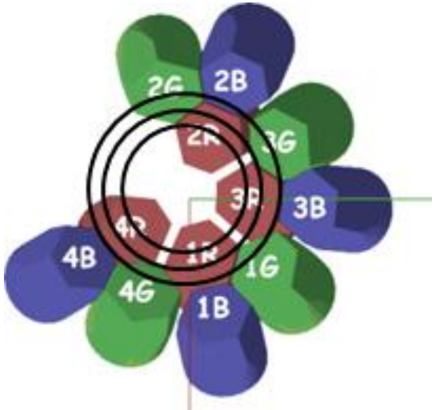
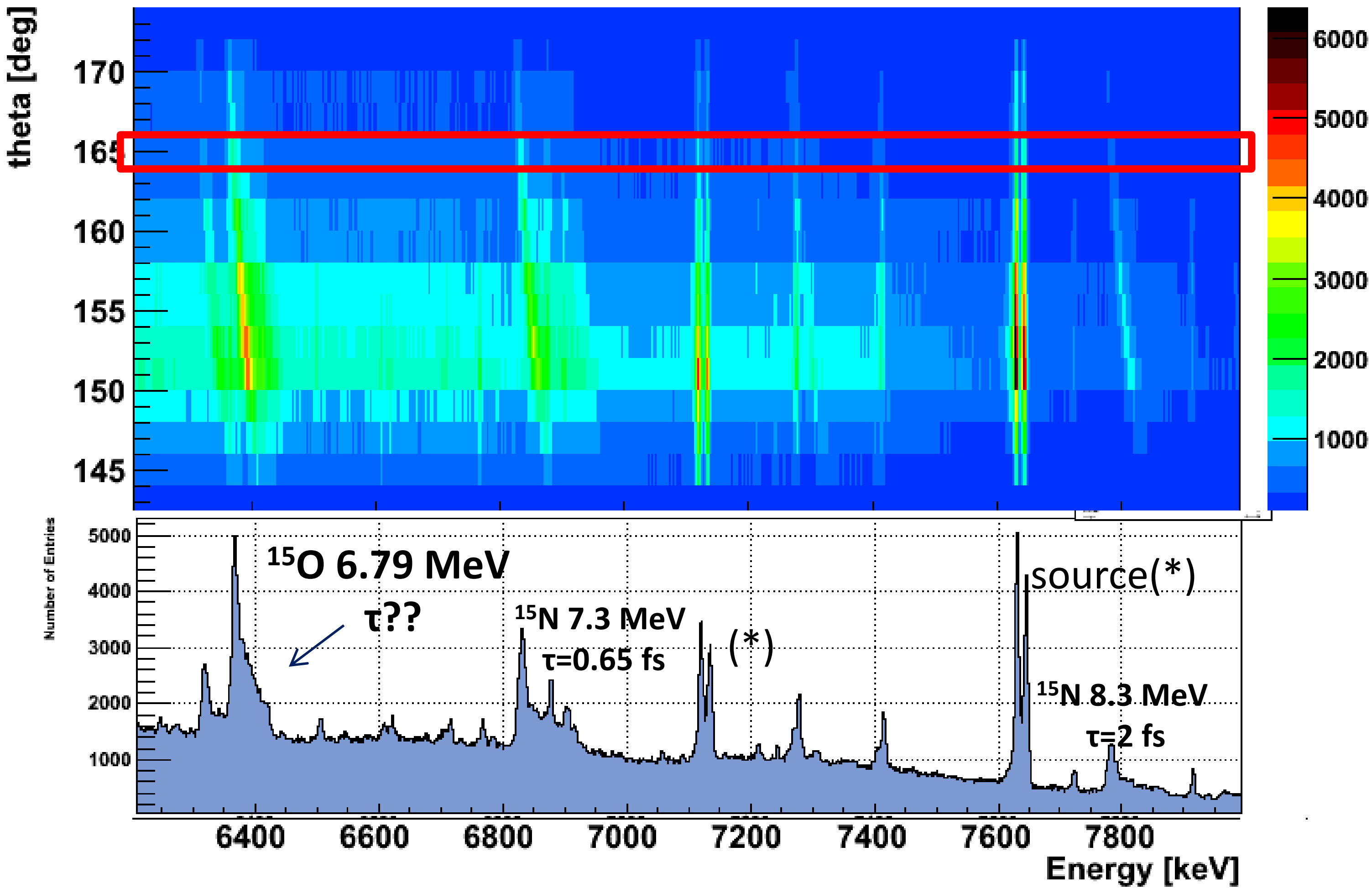
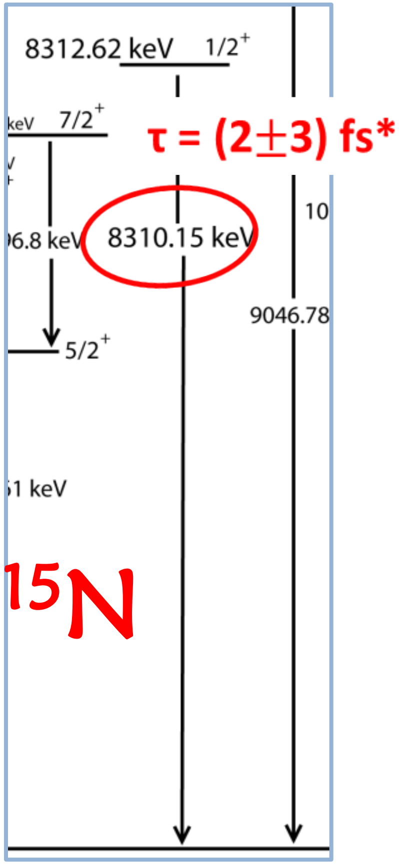


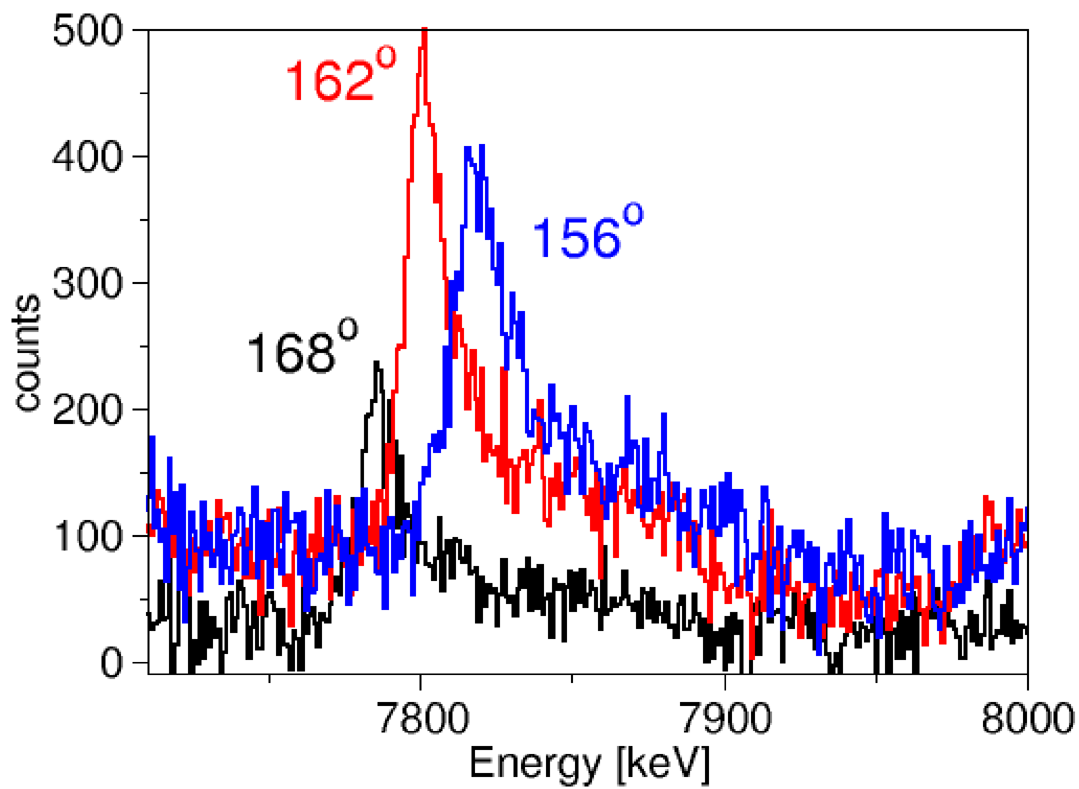
lineshape analysis on the 12 2-degrees "slices"



data analysis:
the "test" 8.31 MeV level in ^{15}N



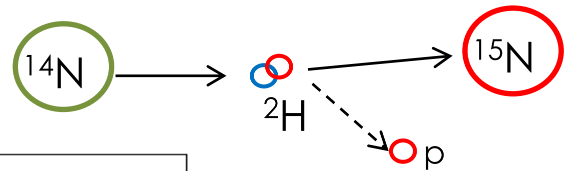
(*from Γ=(0.3±0.2) eV
[R. Moreh et al., PRC 23 (1981) 988])



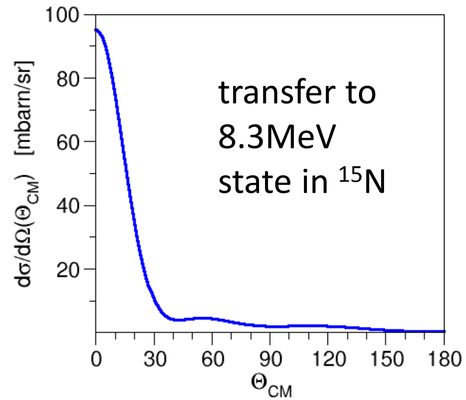
"short" lifetimes → the shape of the peaks in the gamma spectra "mimics" the kinematics of the nuclei produced in the reaction process→ "complex" kinematics

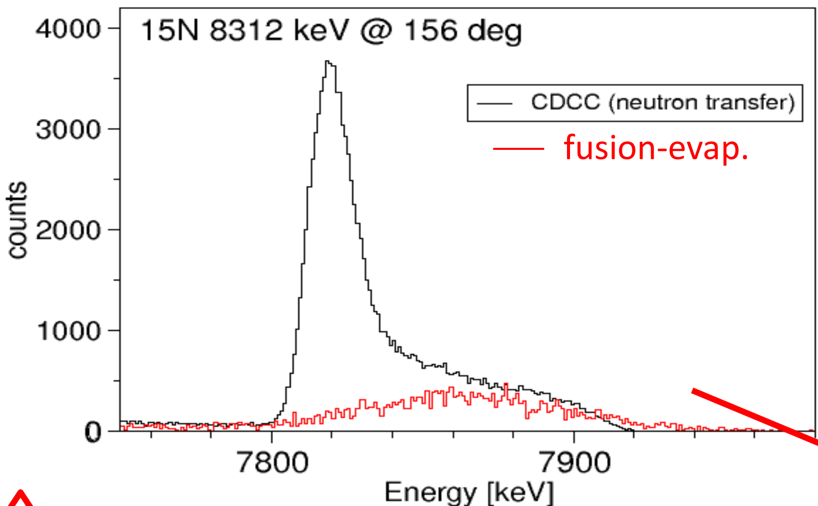
data analysis:
reaction kinematics

both ^{15}O and ^{15}N excited levels are mainly populated *via* nucleon (proton and neutron, respectively) transfer reactions



center of mass x-section angular distribution:

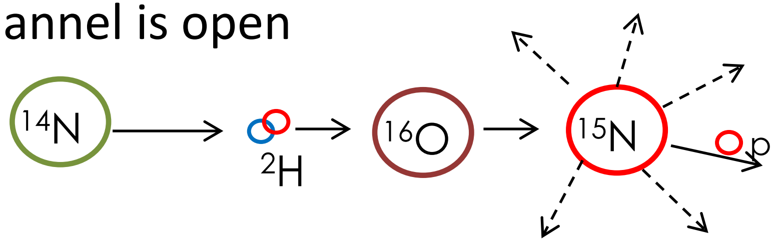




CDCC calculations of the nucleon transfer process by N. Keeley**

***Continuum-Discretized Coupled Channels*

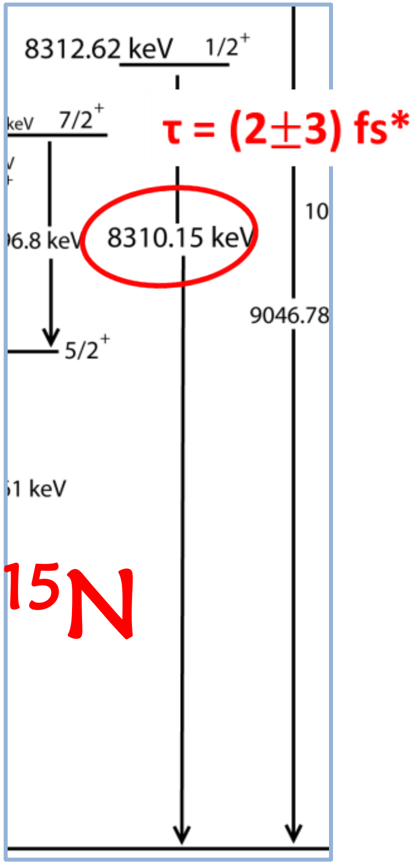
but also the fusion-evaporation channel is open



ratio between the two different mechanism and (energy) spectrum of the evaporated particle

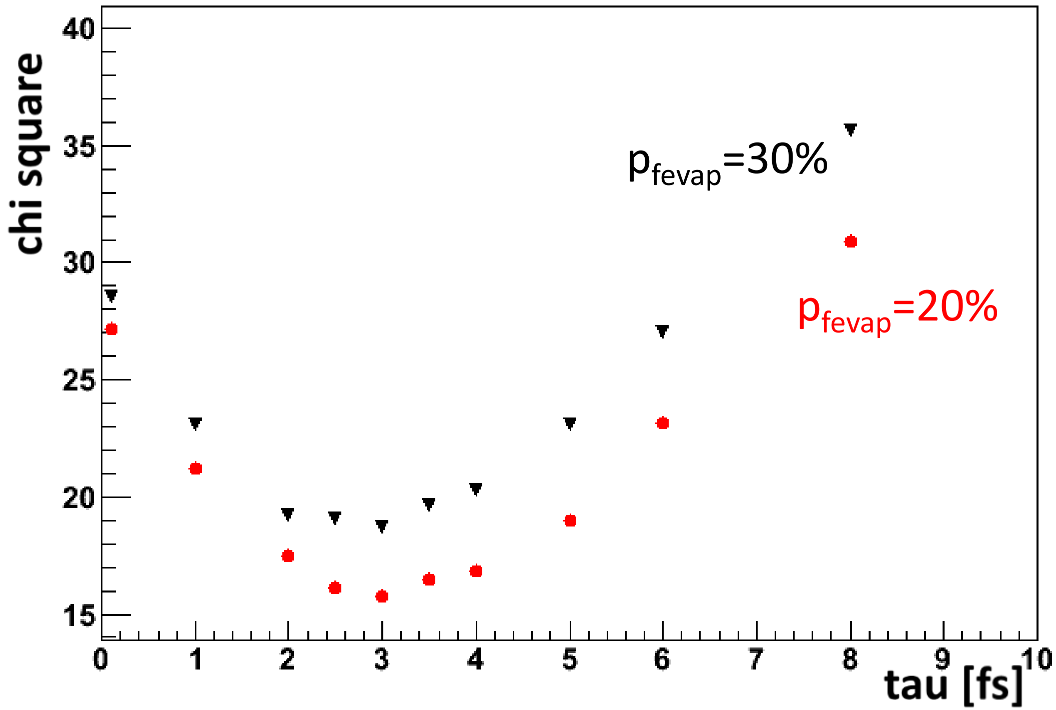
not much help in the literature....

data analysis:
the "test" 8.31 MeV level in ^{15}N



(*from Γ=(0.3±0.2) eV
[R. Moreh et al., PRC 23 (1981) 988])

"just a guess" : proton CM energy distribution = Maxwell-Boltzmann with kT=4MeV



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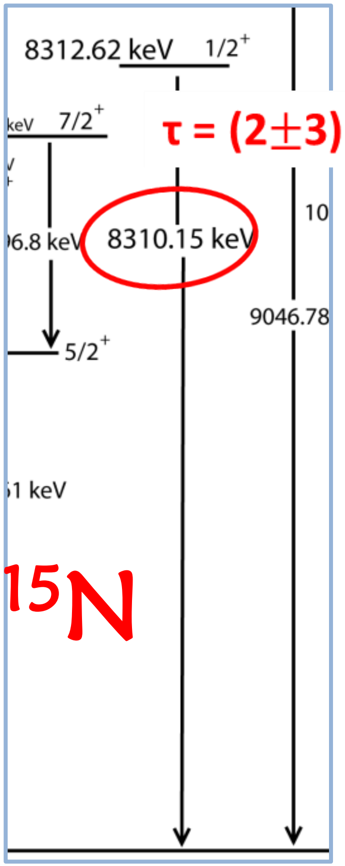
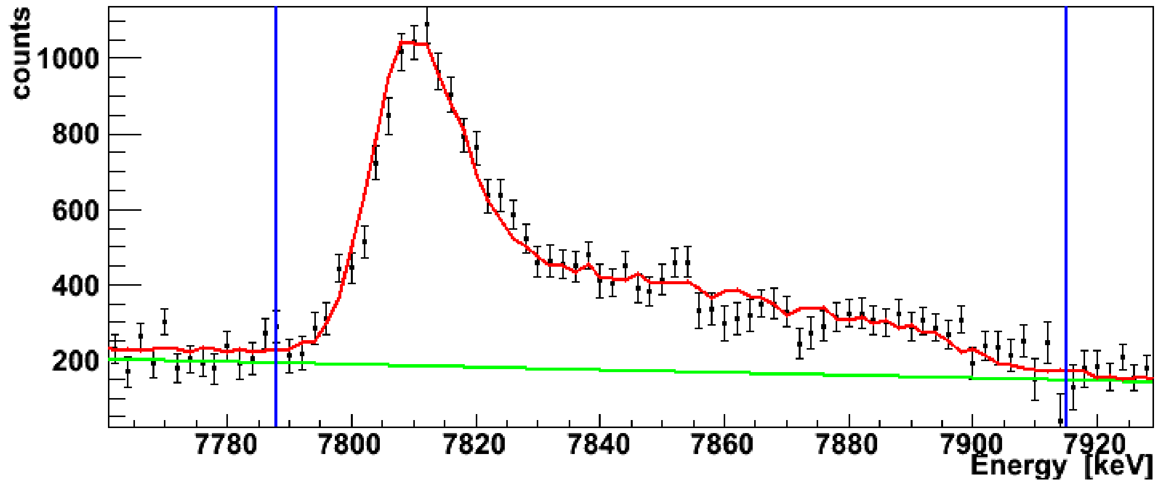
the "test" 8.31 MeV level in ^{15}N



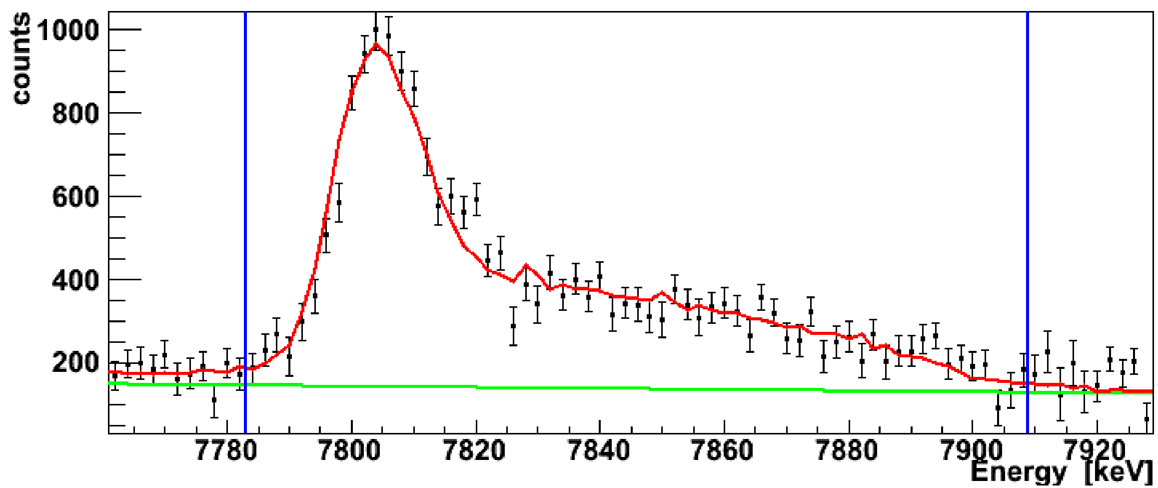
$\tau = (2 \pm 3)$ fs*

(*from $\Gamma = (0.3 \pm 0.2)$ eV
[R. Moreh et al., PRC 23 (1981) 988])

angle=158 deg, red_chi=0.031 (128 points)

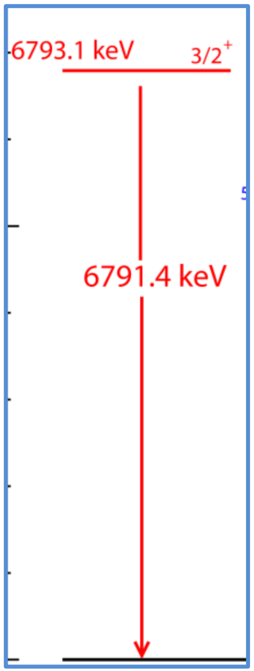


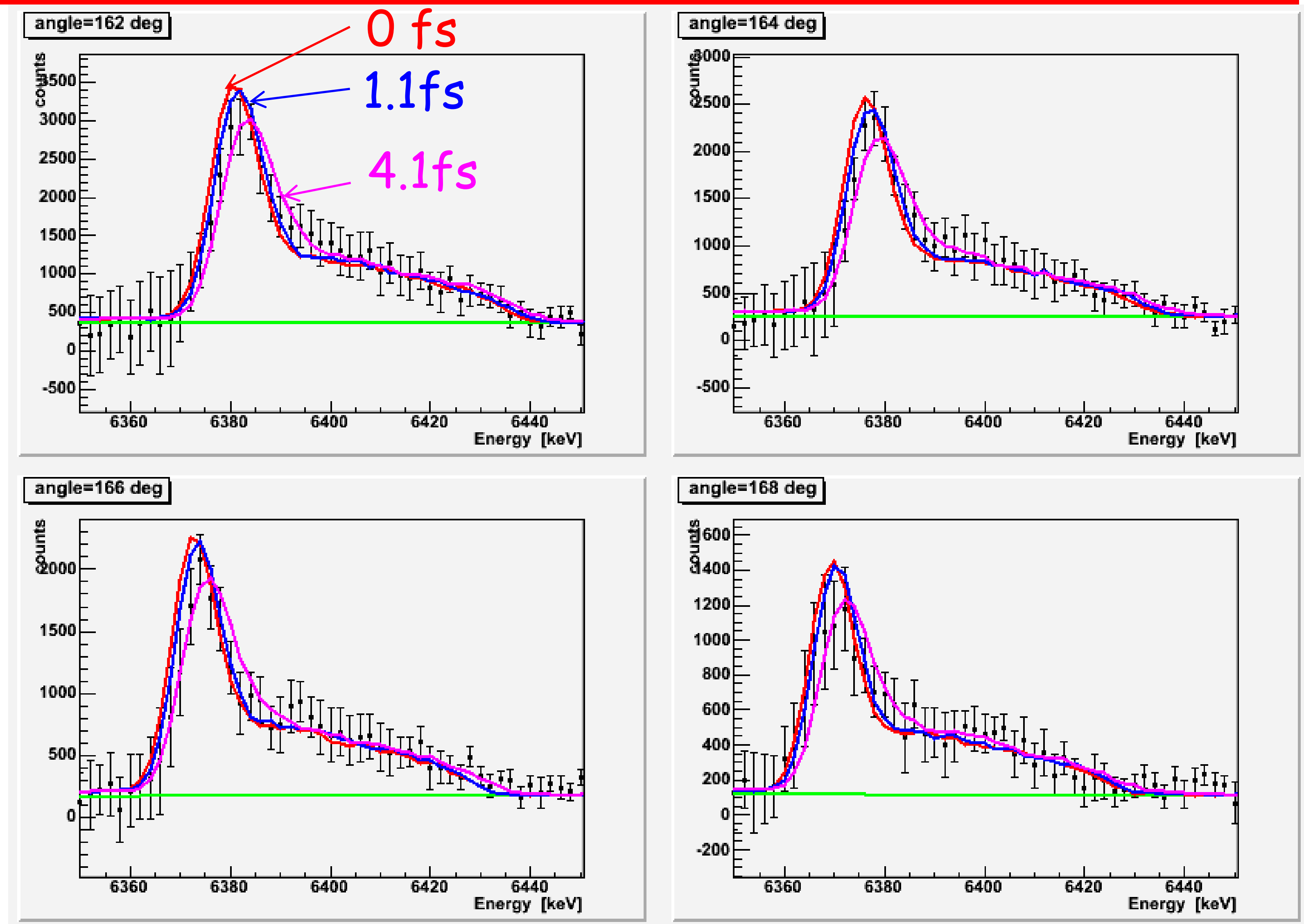
angle=160 deg, red_chi=0.068 (127 points)



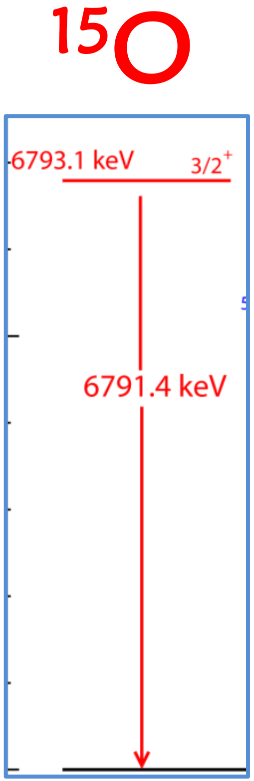
data analysis: the 6.79 MeV level in ^{15}O

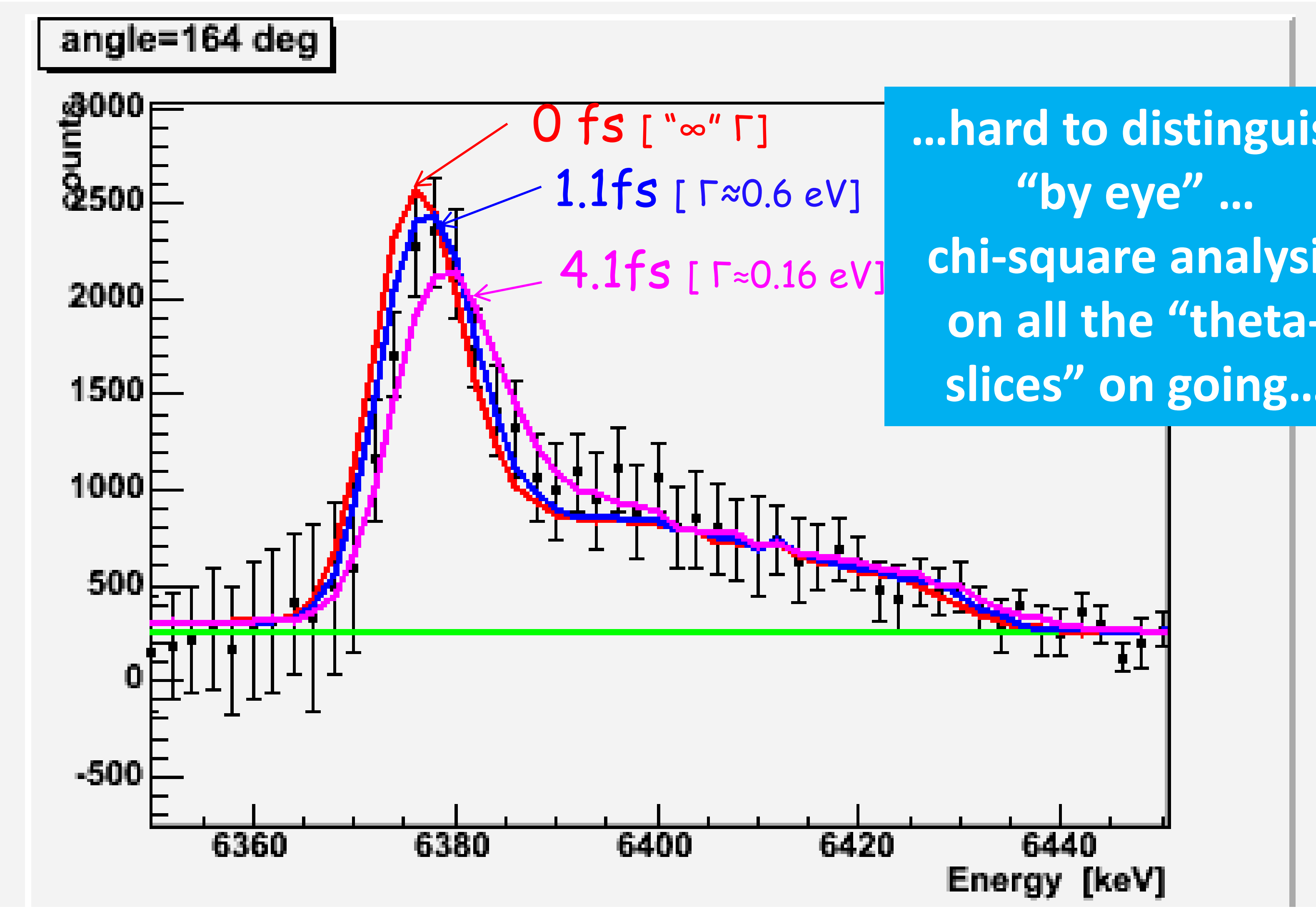
^{15}O





data analysis: the 6.79 MeV level in ^{15}O





…hard to distinguish "by eye" … chi-square analysis on all the "theta-slices" on going…

concluding remarks

- first application of advanced gamma-ray detection for the study of high-energy gamma rays of astrophysical interest
- first DSAM studies exploiting a continuum of angles
- “test” lifetime(s) in ^{15}N → method sounds ok!
- insights on the reaction mechanism are needed to fully trust and use the Montecarlo simulations for the lineshape analysis…
- qualitative (for the moment…) considerations on ^{15}O: “short” lifetime …once we have a value → new R-matrix fit

Collaborators

R.Depalo[1,2], C.A. Ur[3], R. Menegazzo[3], C. Broggini[3], D. Bazzacco[3], A. Caciolli[3], E. Farnea[3], S. Lunardi[3], D. Bemmerer[4], N. Keeley[5], M. Erhard[3] , Zs. Fülöp[6], A. Gottardo[1] , M. Marta[4], D. Mengoni[3], T. Mijatović[7] , F. Recchia[3], T. Szücs[6], J.J. Valiente–Dobon[1]

[1]INFN Laboratori Nazionali di Legnaro, Italy

[2]Dipartimento di Astronomia dell'Univ. di Padova,Italy

[3]INFN Padova, Italy

[4]Forschungszentrum Dresden Rossendorf, Dresden, Germany

[5]The Andrzej Soltan Institute for Nuclear Studies, Warsaw, Poland

[6] ATOMKI, Debrecen, Hungary

[7]Ruđer Bošković Institute, Zagreb, Croatia

and the AGATA collaboration