10th AGATA Week
Lyon 22-26 November 2010

Lifetime measurement of the 6.792 MeV state in ^{15}O

C. Michelagnoli[1,2], R. Depalo[1,3], R. Menegazzo[1], C.A. Ur[1], D. Bazzacco[1], D. Bemmerer[4], C. Broggini[1], A. Caciolli[1] , M. Erhard[1], E. Farnea[1], F. Recchia[1], A. Gottardo[5], Zs. Fülöp[6], M. Marta[4], D. Mengoni[1,7], T. Mijatović[8] , T. Szücs[6], J.J. Valiente–Dobon[5]

and the AGATA collaboration

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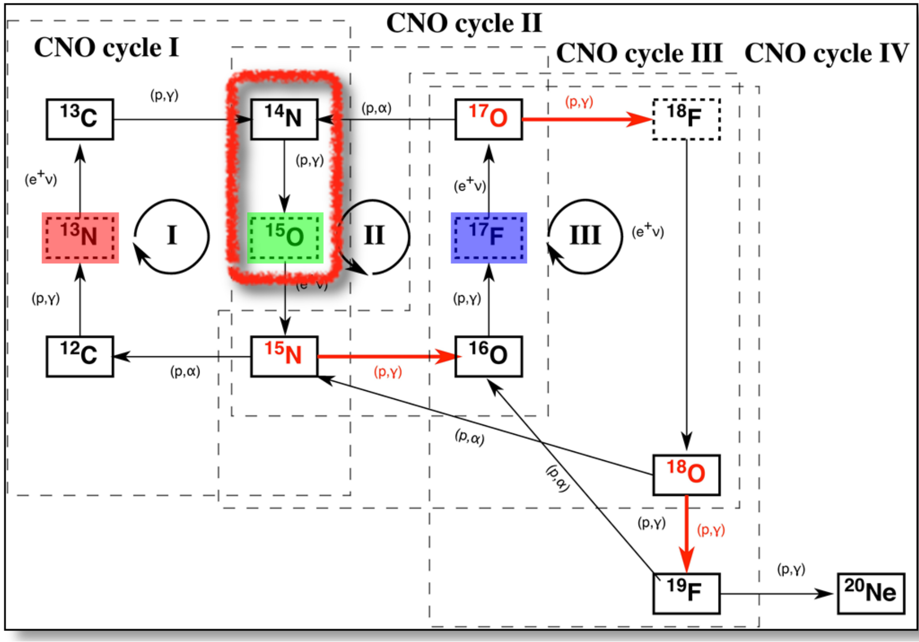
[3]*Dipartimento di Astronomia, Università degli studi di Padova, Italy*
[4]*Forschungszentrum Dresden–Rossendorf, Dresden, Germany* [5]*INFN Laboratori Nazionali di Legnaro, Italy*
[6]*ATOMKI, Debrecen, Hungary*
[7]*University of the West of Scotland, Paisley, United Kingdom*
[8]*Ruđer Bošković Institute, Zagreb, Croatia*

- **Status of the data analysis**
- **(experiment performed in *week* 29-2010 (24.07-02.08.2010))**

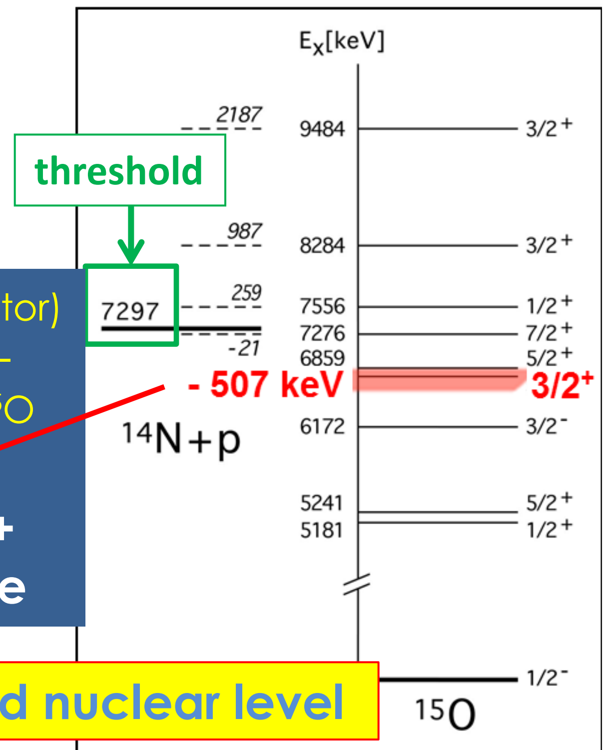
CNO cycle contribution to the solar energy production ≈ 0.8 %



From the neutrino fluxes the C and N abundances in the center of the Sun can be derived (once the cross section is known)

The $^{14}N(p,\gamma)^{15}O$ reaction is the slowest one, thus determining the overall rate

(C. Broggini et al., Annu. Rev. Nucl. Part. Sci. 2010. 60:53–73)



When extrapolating the cross section (astrophysical S-factor) to the Gamow peak energy region the occurrence of sub-threshold resonances corresponding to bound states in ^{15}O has to be taken into account

The one corresponding to the first excited 3/2+ state in ^{15}O is predicted to play a dominant role

width of the resonance ⟺ lifetime of the excited nuclear level

Some bibliography ...

★*direct methods*

Group	Method	$\tau_\gamma^{6.792}$ [fs]
Oxford 1968	DSAM d(^{14}N, ^{15}0)n ★	< 28
TUNL 2001	DSAM ^{14}N(p,γ)^{15}O ★	1.6±0.7
RIKEN 2004	CE ^{208}Pb(^{15}O, ^{15}O*)	0.69±0.43
LUNA 2004	Cross section + R-matrix fit	1.1±0.5
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To improve the accuracy in the determination of the width of the resonance:
measurement of the lifetime of the 3/2+ state in ^{15}O with the Doppler Shift Attenuation technique using the AGATA Demonstrator

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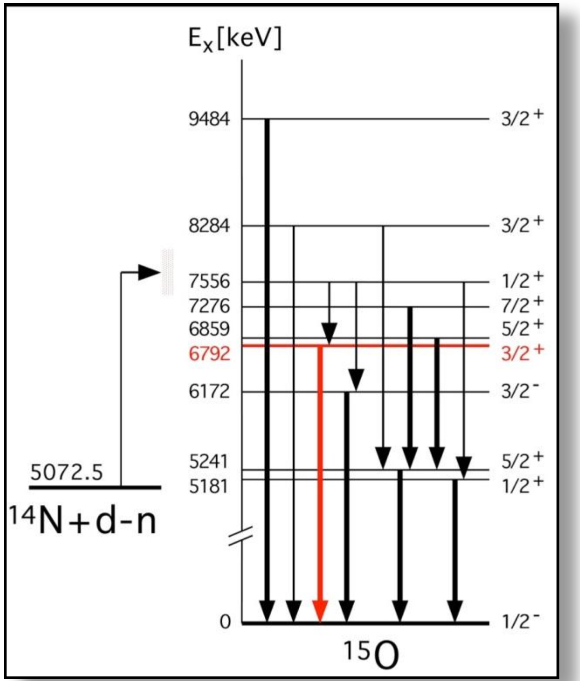

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Reaction: ^{2}H(^{14}N,n)^{15}O @ 21.5 MeV
fusion-evaporation

Q = 5.0725 MeV
I(^{14}N^{3+}) ~12 enA

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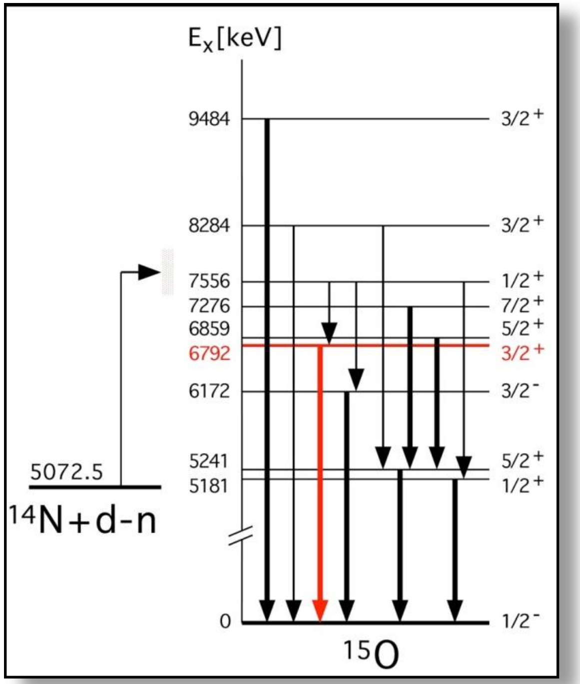

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Reaction: $^{2}H(^{14}N,n)^{15}O$ @ ~~21.5 MeV~~ 32 MeV
~~fusion-evaporation~~ fusion-evaporation and nucleon transfer
Q = 5.0725 MeV
I($^{14}N^{3+}$) ~12 enA

"distinguishing" features:

- high energy gammas (6.792 MeV) → low gain of the electronics (20 MeV dyn. range)

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- test (?!) of the capability of AGATA to exploit the Doppler shift effects in a continuous angular distribution
- application of this technique to ~fs lifetimes
- two different reaction mechanisms populating the level of interest

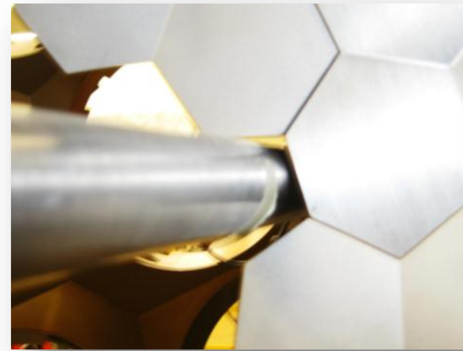
Reaction: $^{2}H(^{14}N,n)^{15}O$ @ 32 MeV

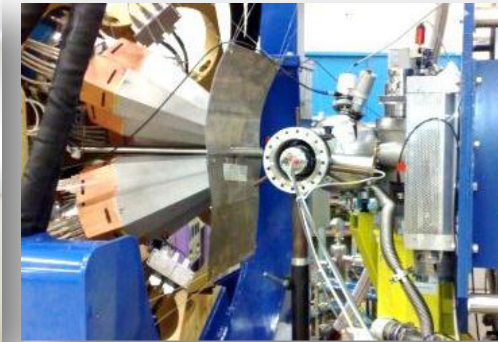
^{2}H implanted onto surface of ~4mg/cm^{2} Au

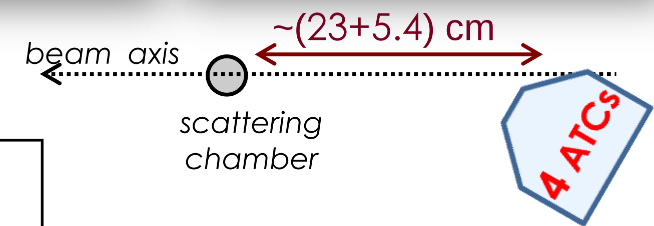
Q = 5.0725 MeV

Tandem XTU terminal voltage=8.95 MV

I($^{14}N^{3+}$) ~4-5 pnA







Crystal #	theta [deg]	cos (theta)	phi [deg]
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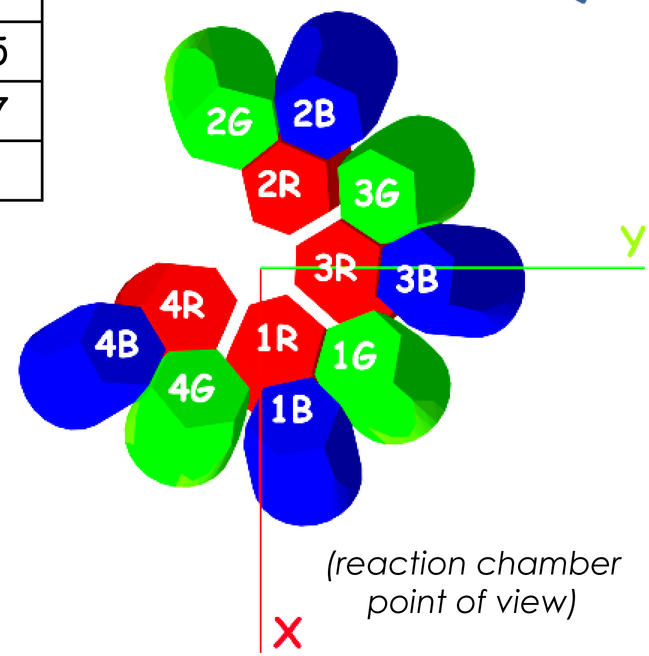

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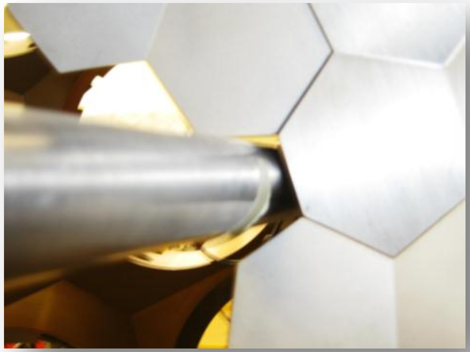

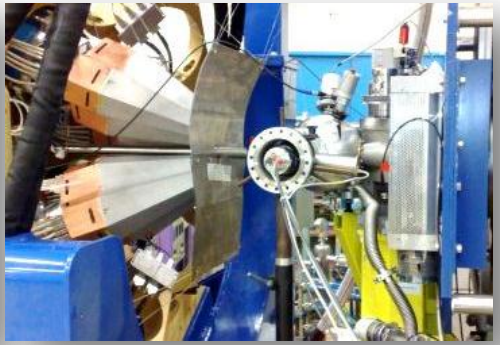

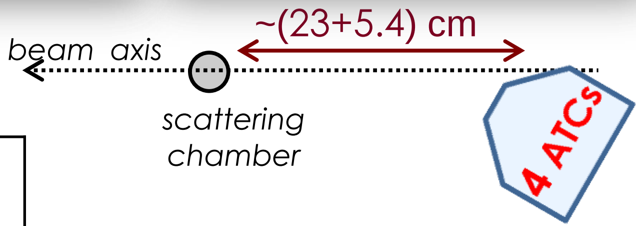

$\beta_{FE}(^{15}O)$ ~ 6.3 %

E_0= 6791.4 keV

$$E(\theta) = E_0 \frac{\sqrt{1-\beta^2}}{1-\beta\cos\theta}$$

R → ~6384 keV

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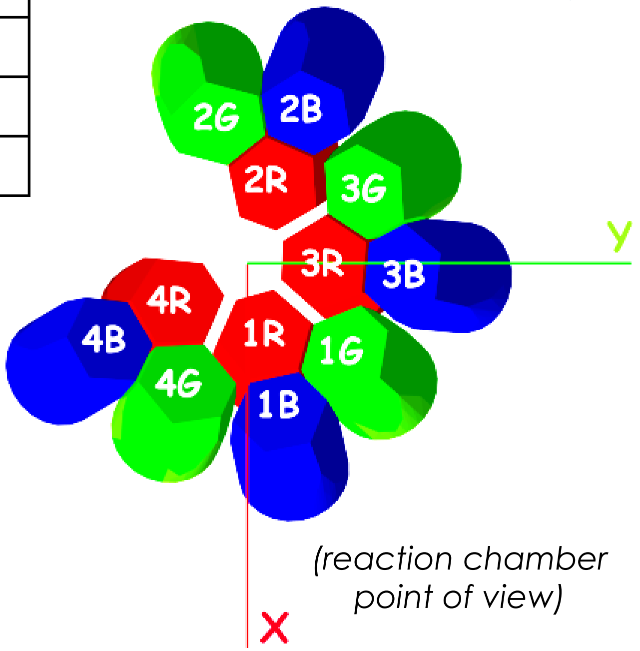

(reaction chamber point of view)

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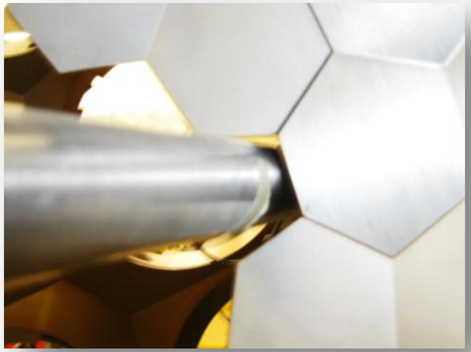

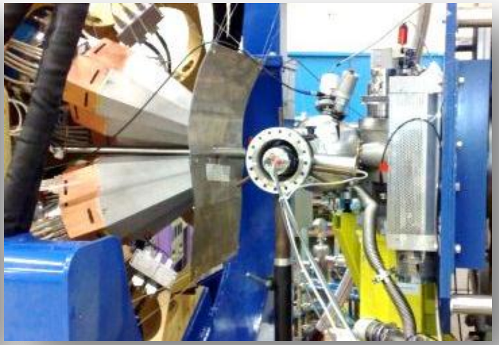

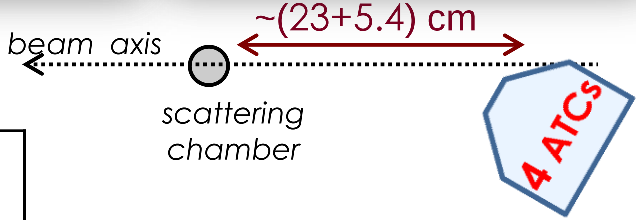

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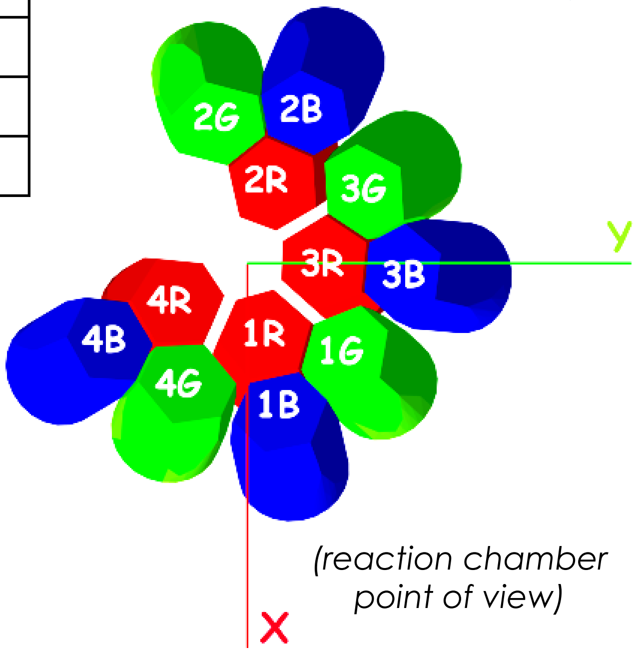


(reaction chamber point of view)

low gain of the electronics (20 MeV dynam. range)

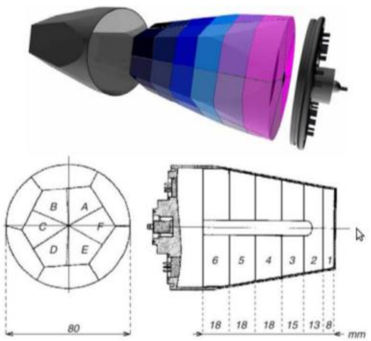
tau ~fs →"small" difference from full Doppler shift:

AmBe(Fe) during experiment

Data analysis
data replay

"Reminder": 4ATCs → 4*3*(36+2) = 456 channels to be handled in the analysis!!!

TOT ≈ 6.9 TB



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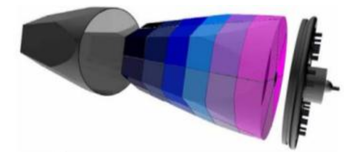
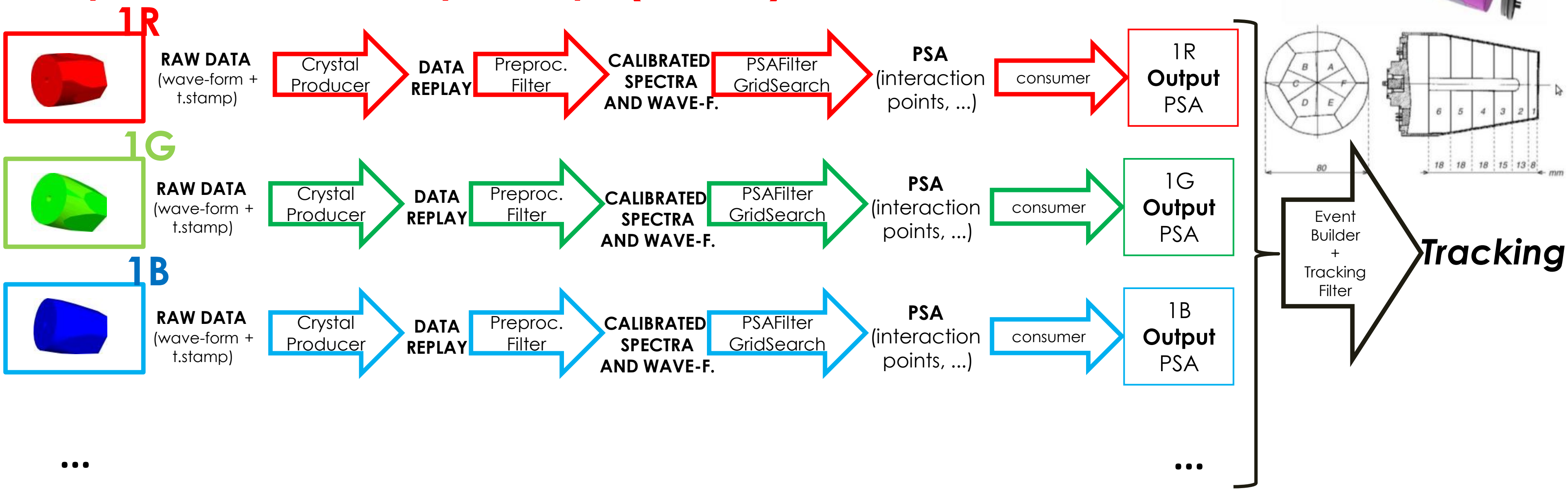


Sequence of the analysis steps (*Narval*):



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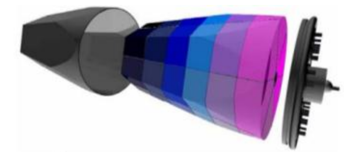

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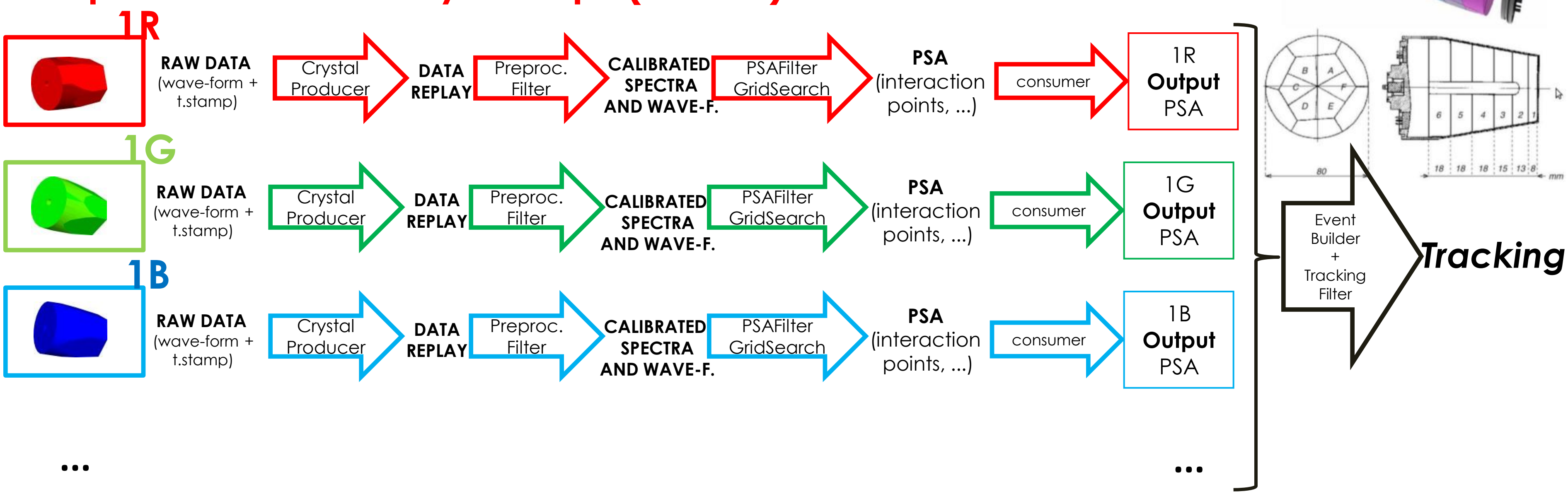


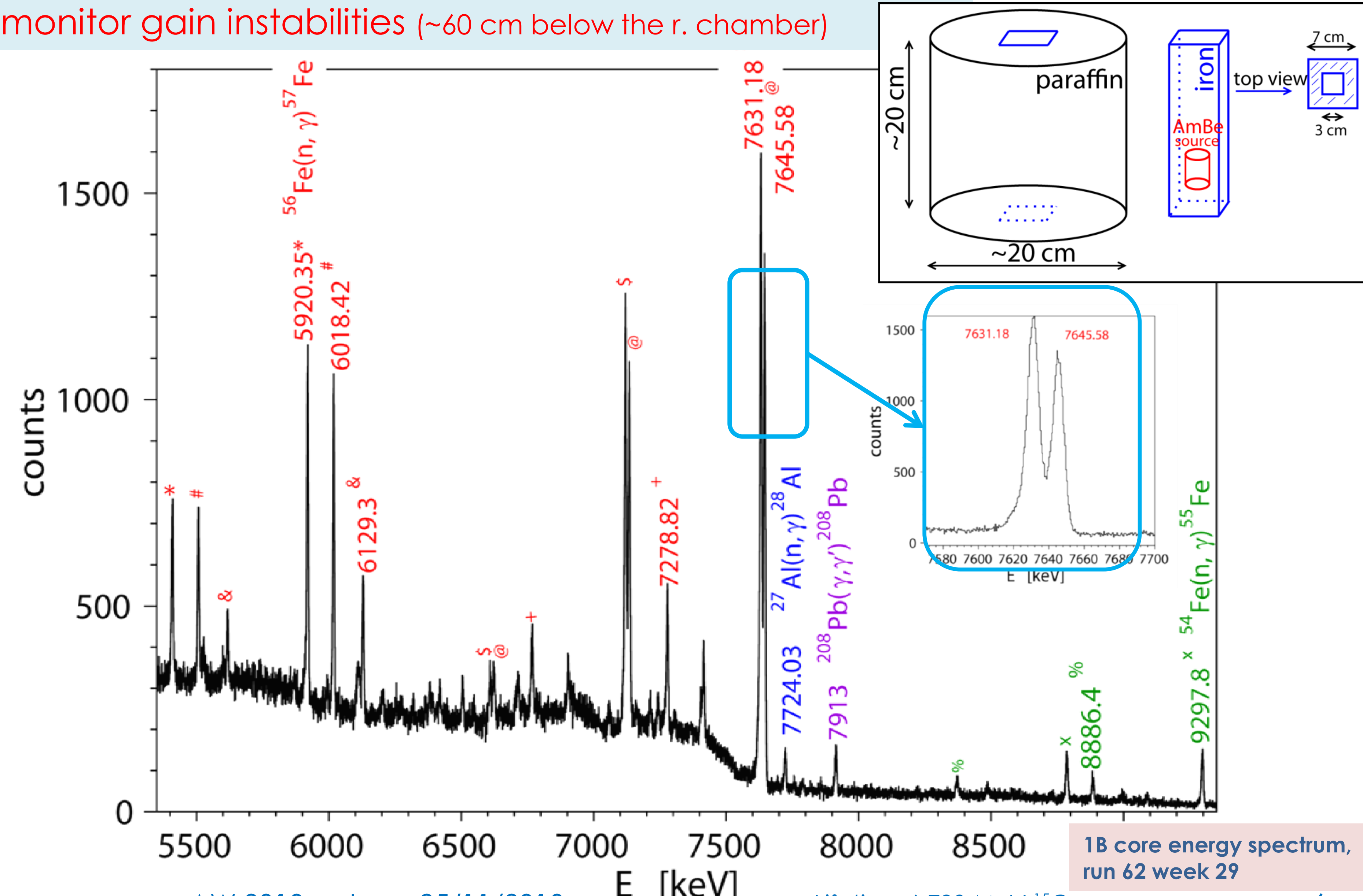
Each crystal is followed independently until the PSA output.

Outline:

1. Energy calibrations (low gain electronics, i.e. large dynam. range)
2. PSA
3. Tracking
4. Discussion of the thus obtained spectra ... !!!

Data analysis
energy calibrations

^{241}AmBe + Fe source kept while beam-on-target to monitor gain instabilities (~60 cm below the r. chamber)



1B core energy spectrum, run 62 week 29

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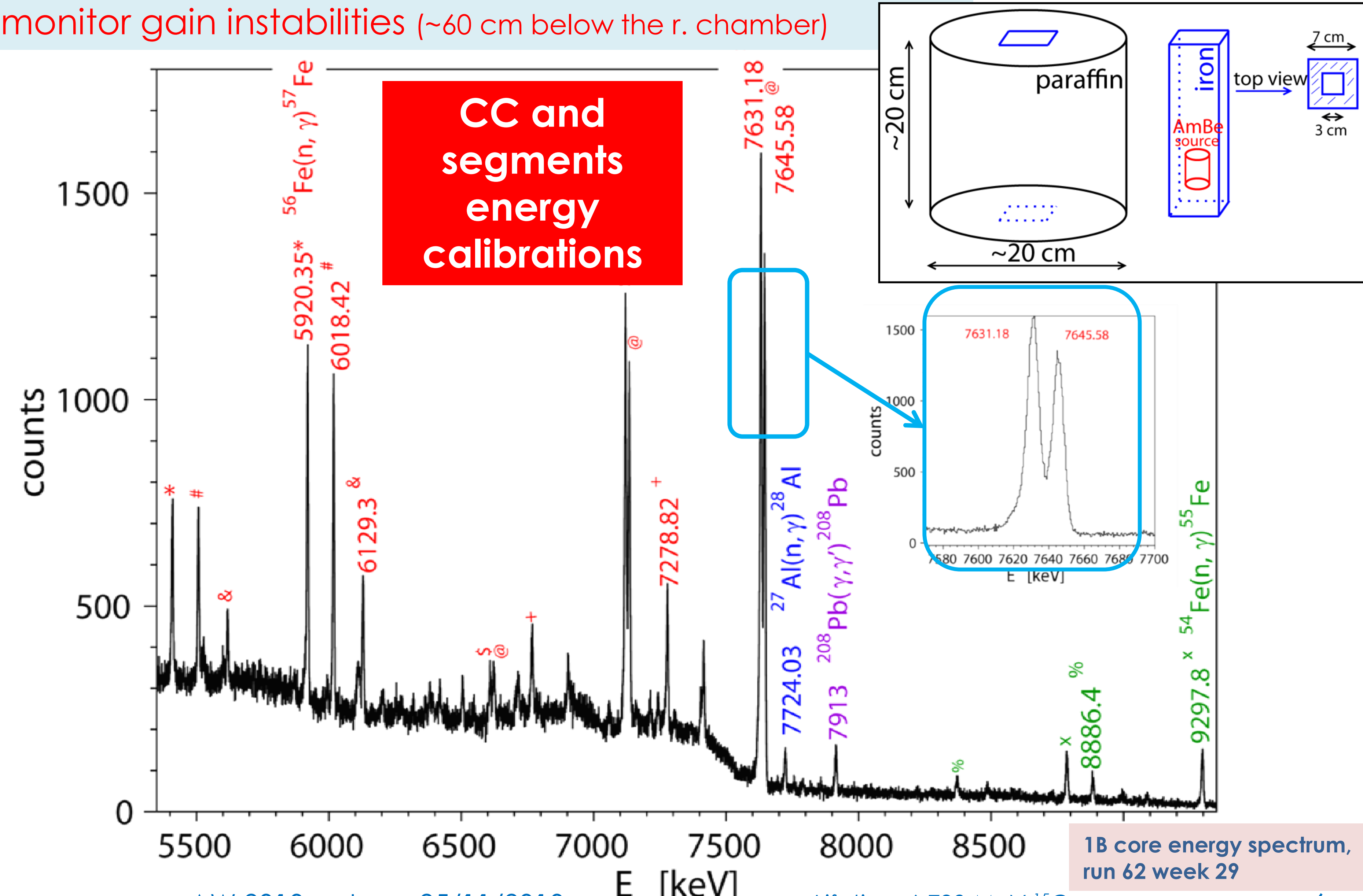
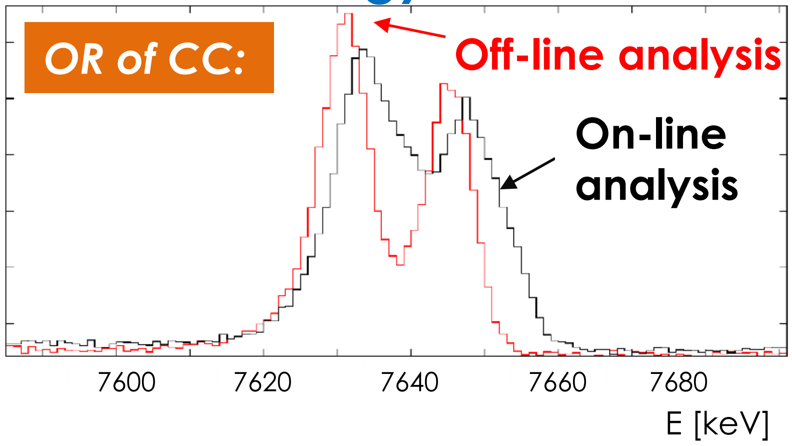
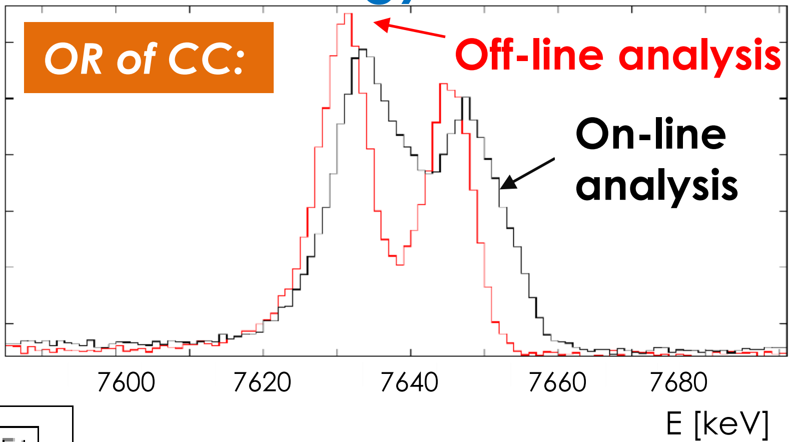


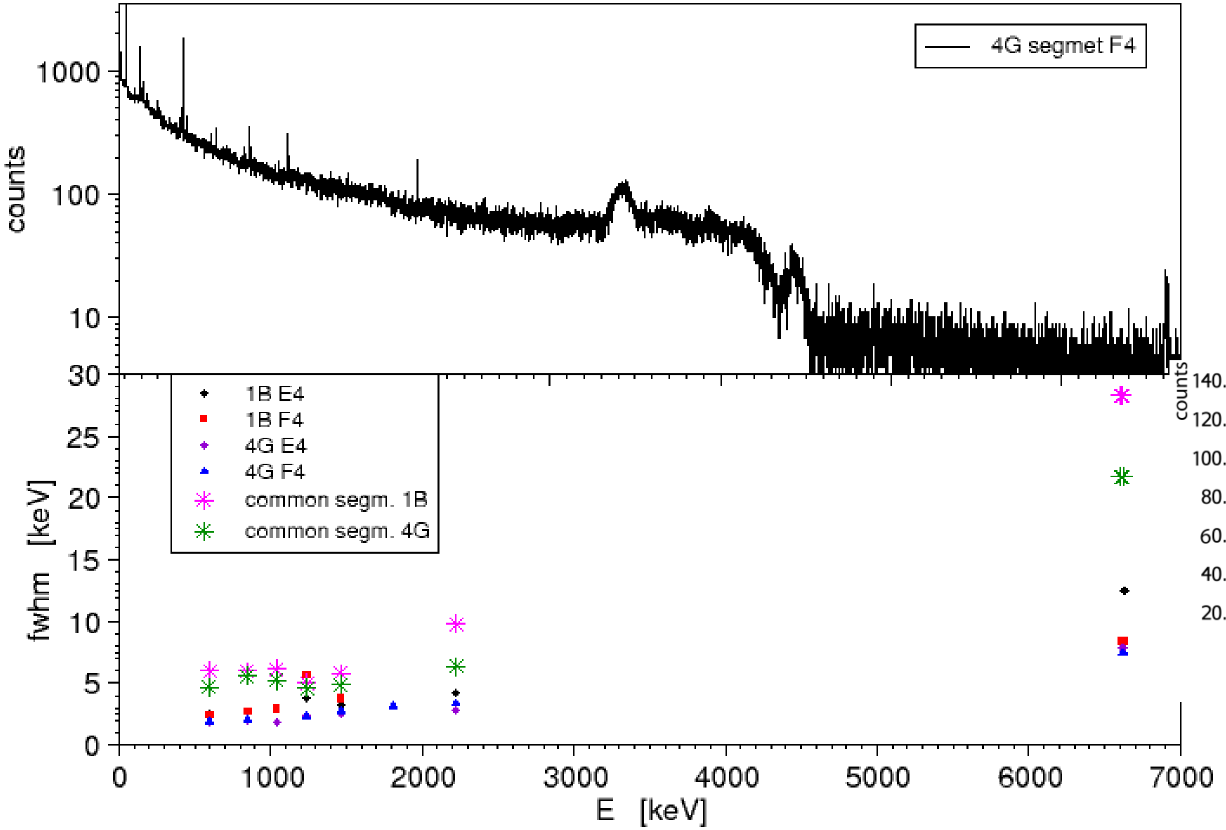
1B core energy spectrum, run 62 week 29

while the off-line alignment of the different core spectra was "successfull"

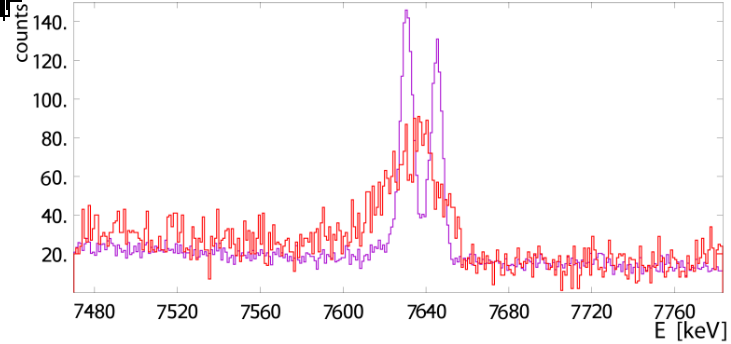


while the off-line alignment of the different core spectra was "successfull", segments are strongly non linear in the low gain configuration

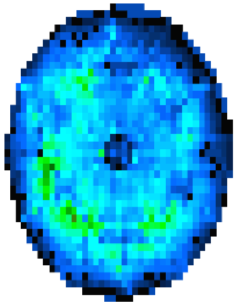




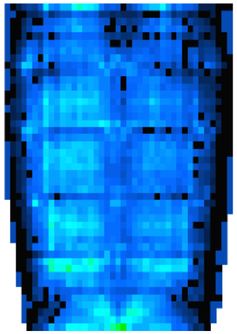
(1B) central contact
vs
(1B) sum segments



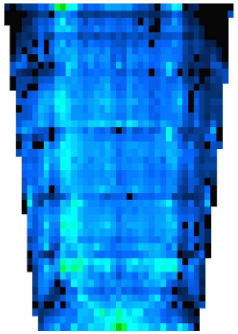
reconstructed interaction point distributions 4G crystal AmBe(Fe) source



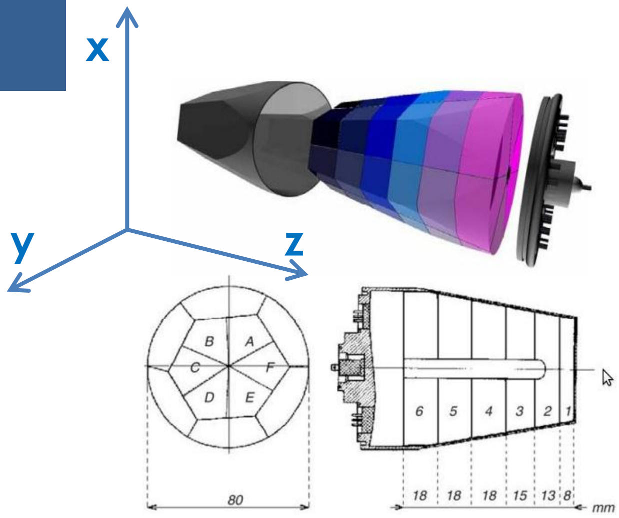
z projection



x projection



y projection



Data analysis
PSA and tracking

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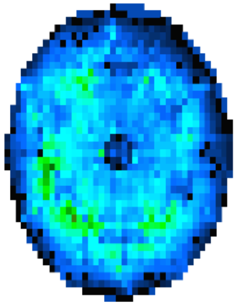

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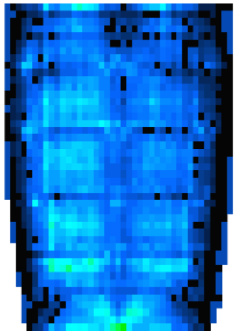

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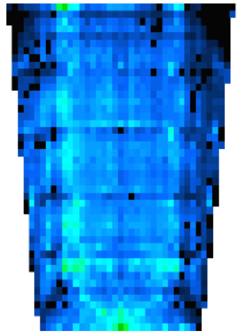

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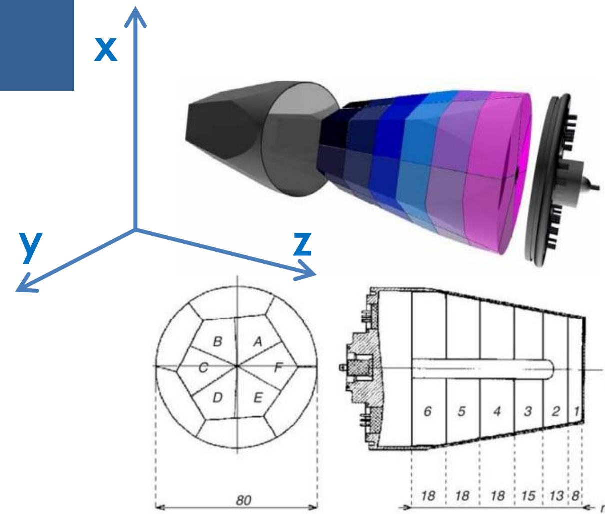
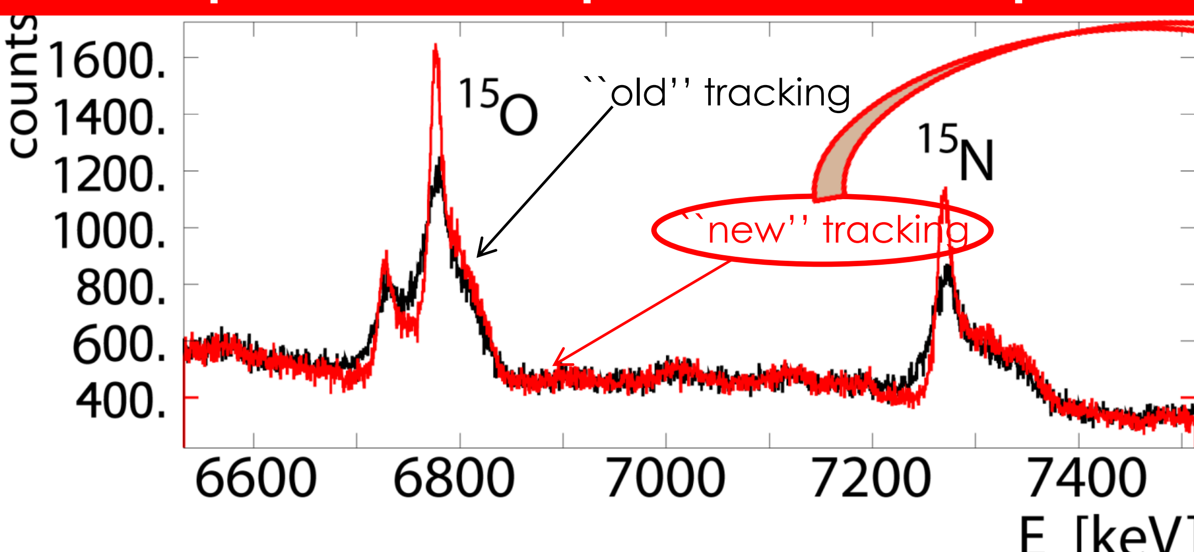
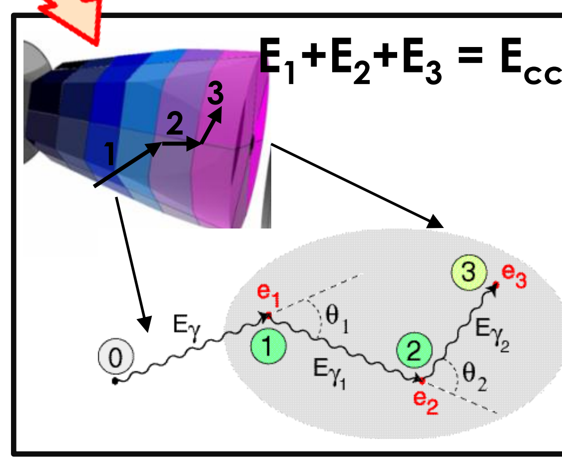
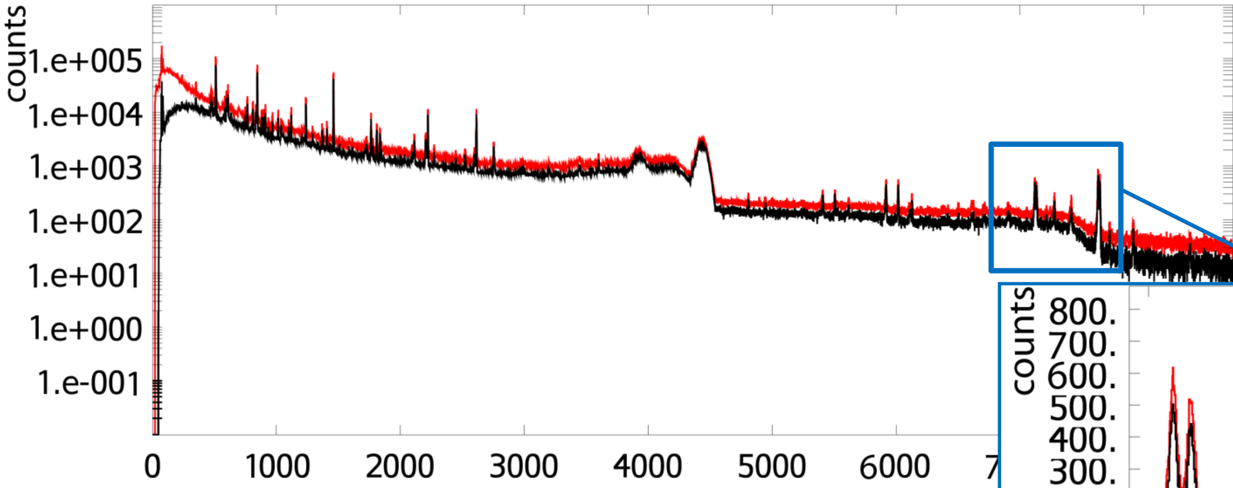


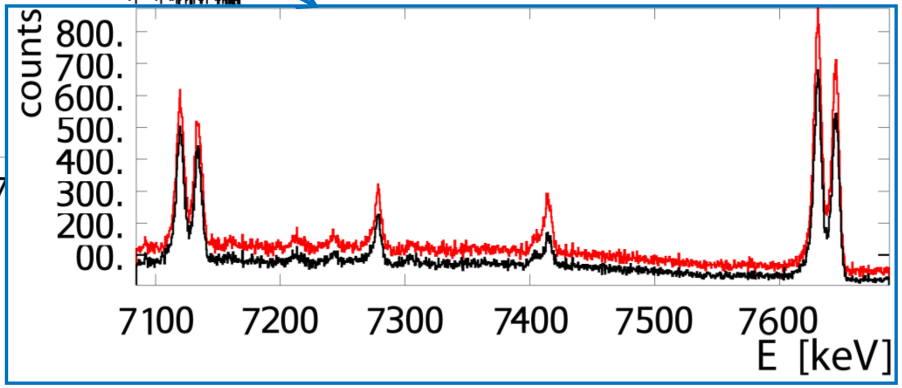
the <u>tracking</u> was performed forcing the sum of the energy releases of the tracked points to be equal to the corresponding energy seen in the CC



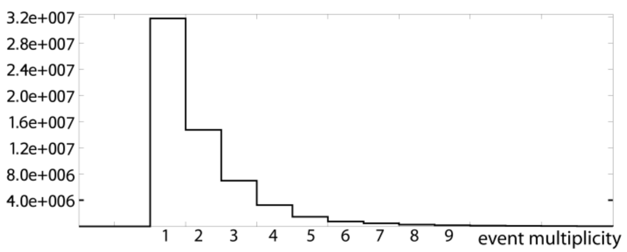




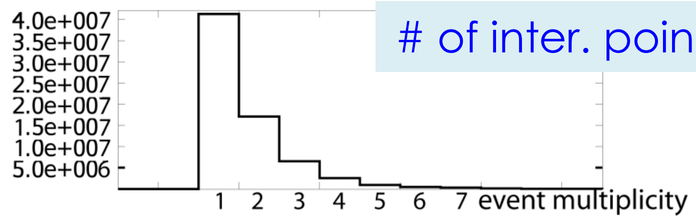
core sum vs **tracking**



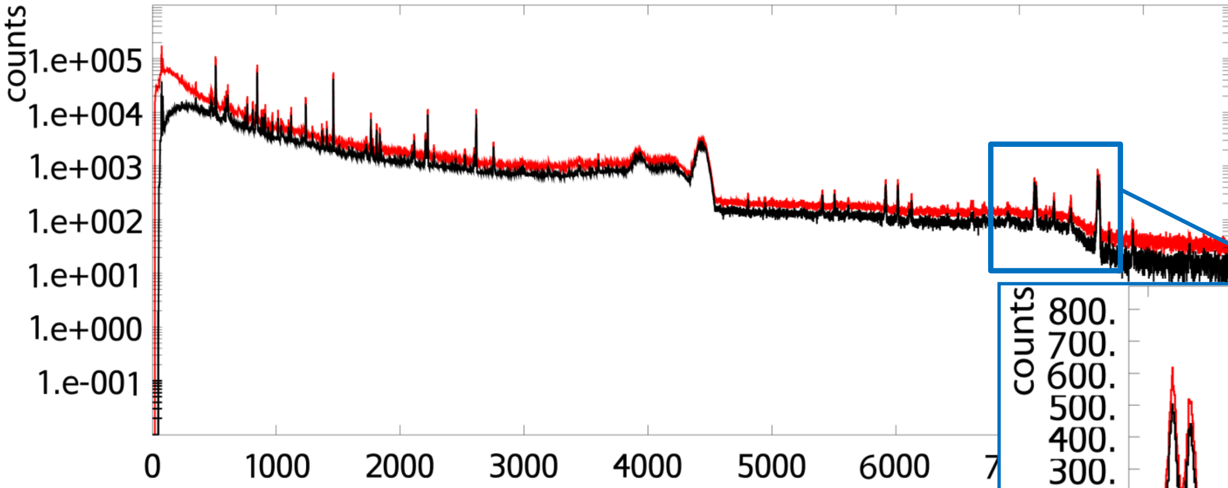
# of points (segments) /event



# of inter. points/detector

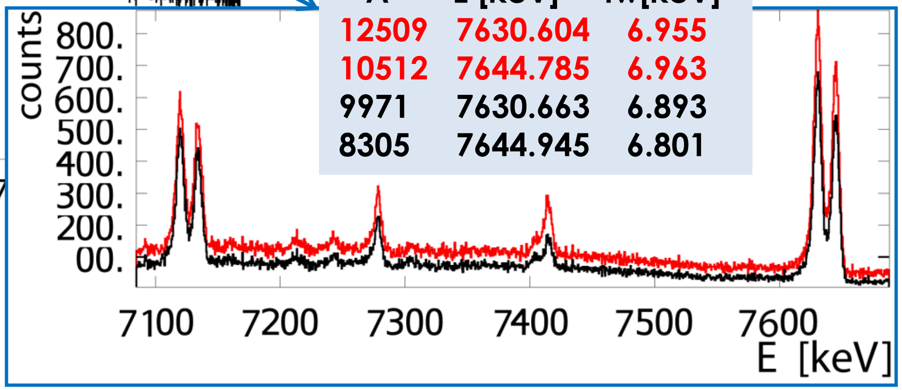


Data analysis
more about tracking

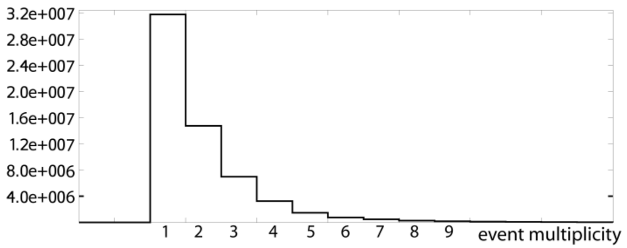


core sum vs **tracking**

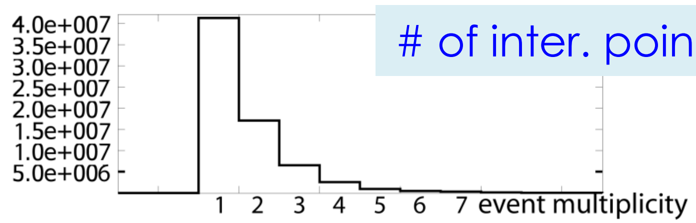
A	E [keV]	fw[keV]
12509	7630.604	6.955
10512	7644.785	6.963
9971	7630.663	6.893
8305	7644.945	6.801



# of points (segments) /event



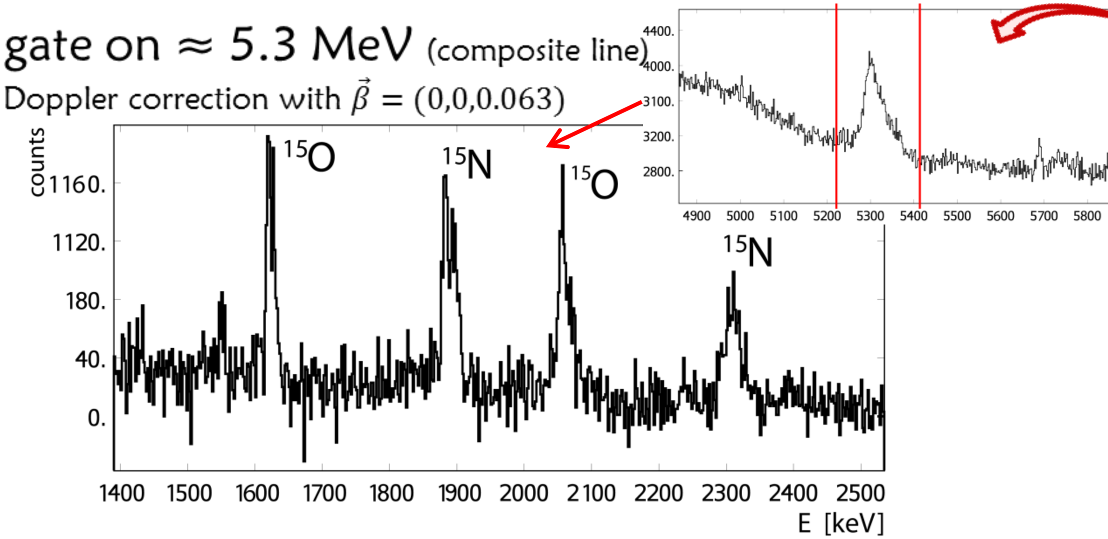
# of inter. points/detector

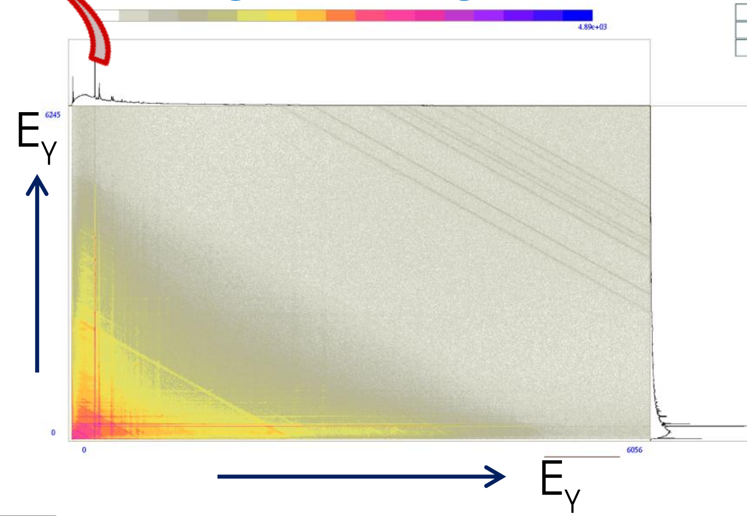


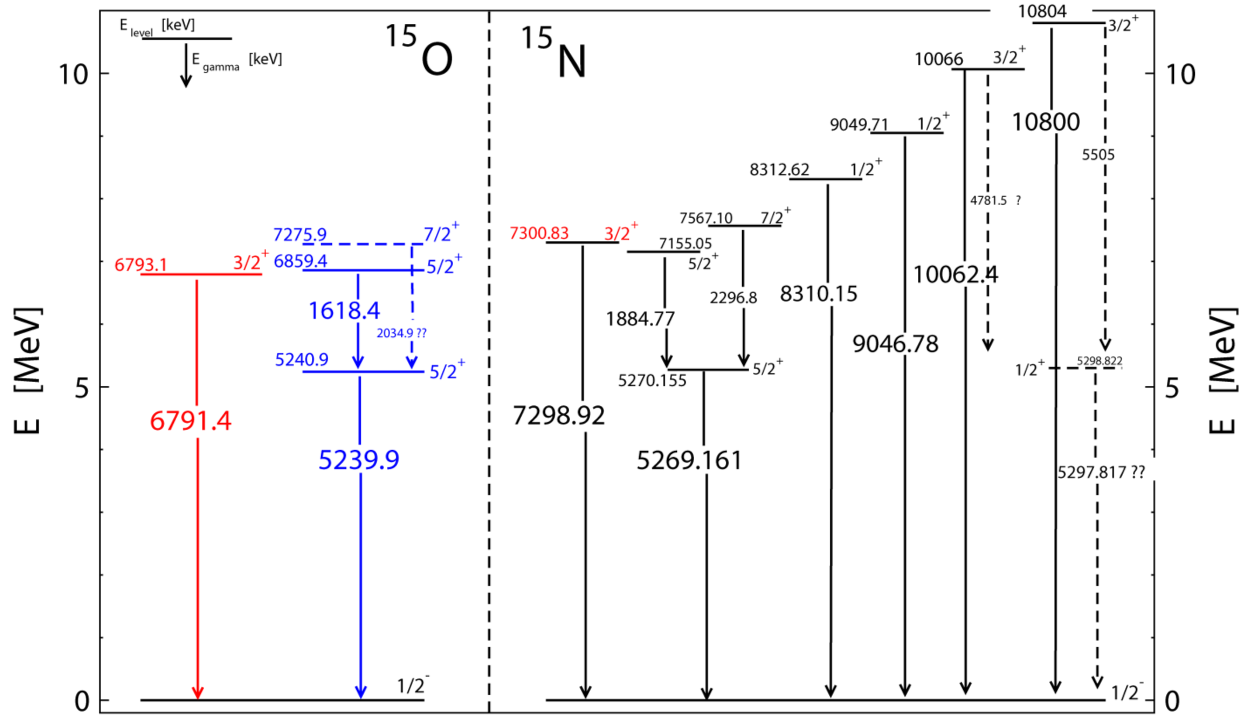
It seems that in case of low gamma multiplicity the best performance are reached by treating AD as a "big calorimeter" but preserving the tracking procedure to obtain the first interaction point

gate on ≈ 5.3 MeV (composite line)

Doppler correction with $\vec{\beta} = (0,0,0.063)$



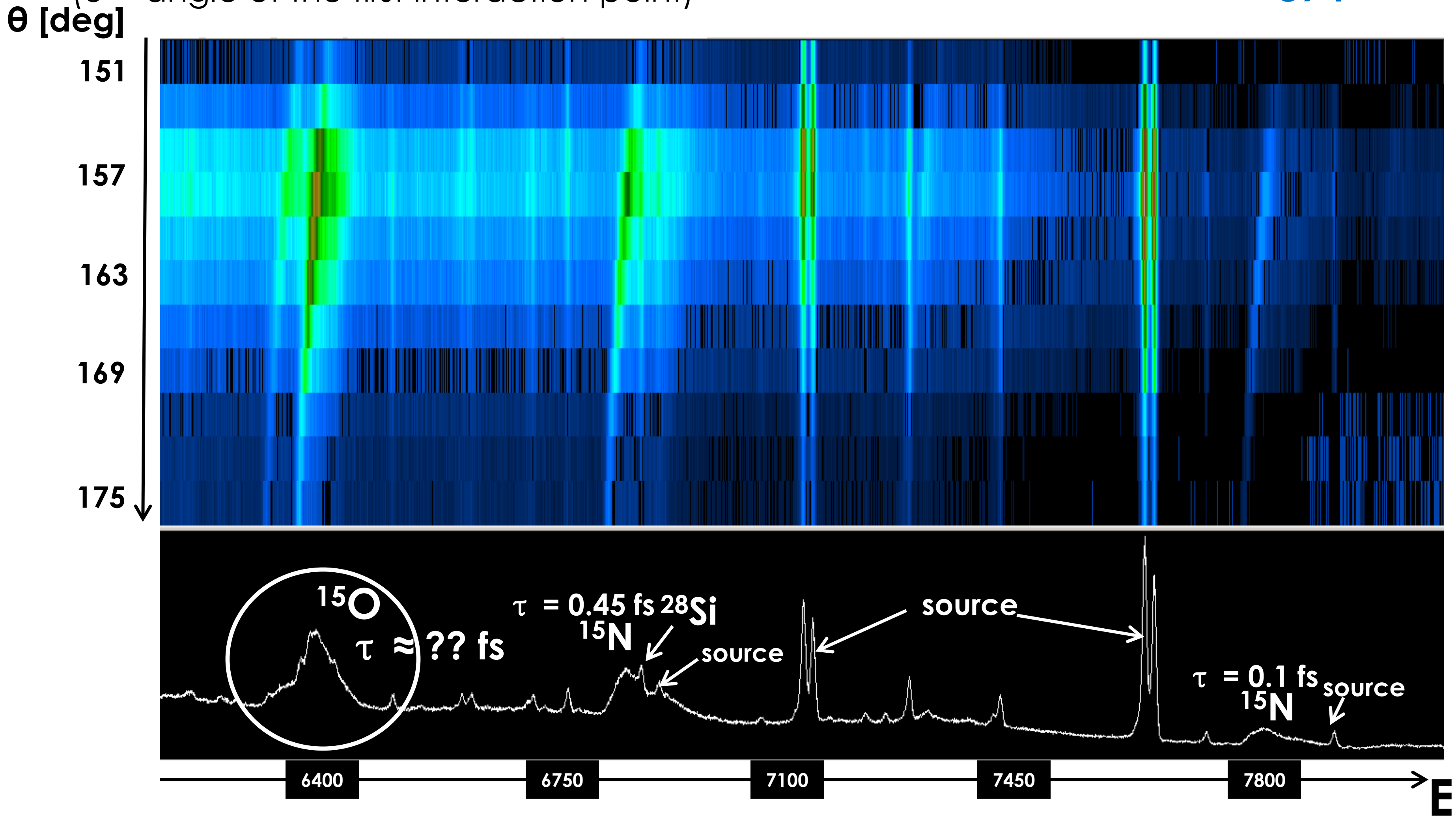




The main reaction channels are ^{15}O (Q = 5072 keV) and ^{15}N (8069 keV)

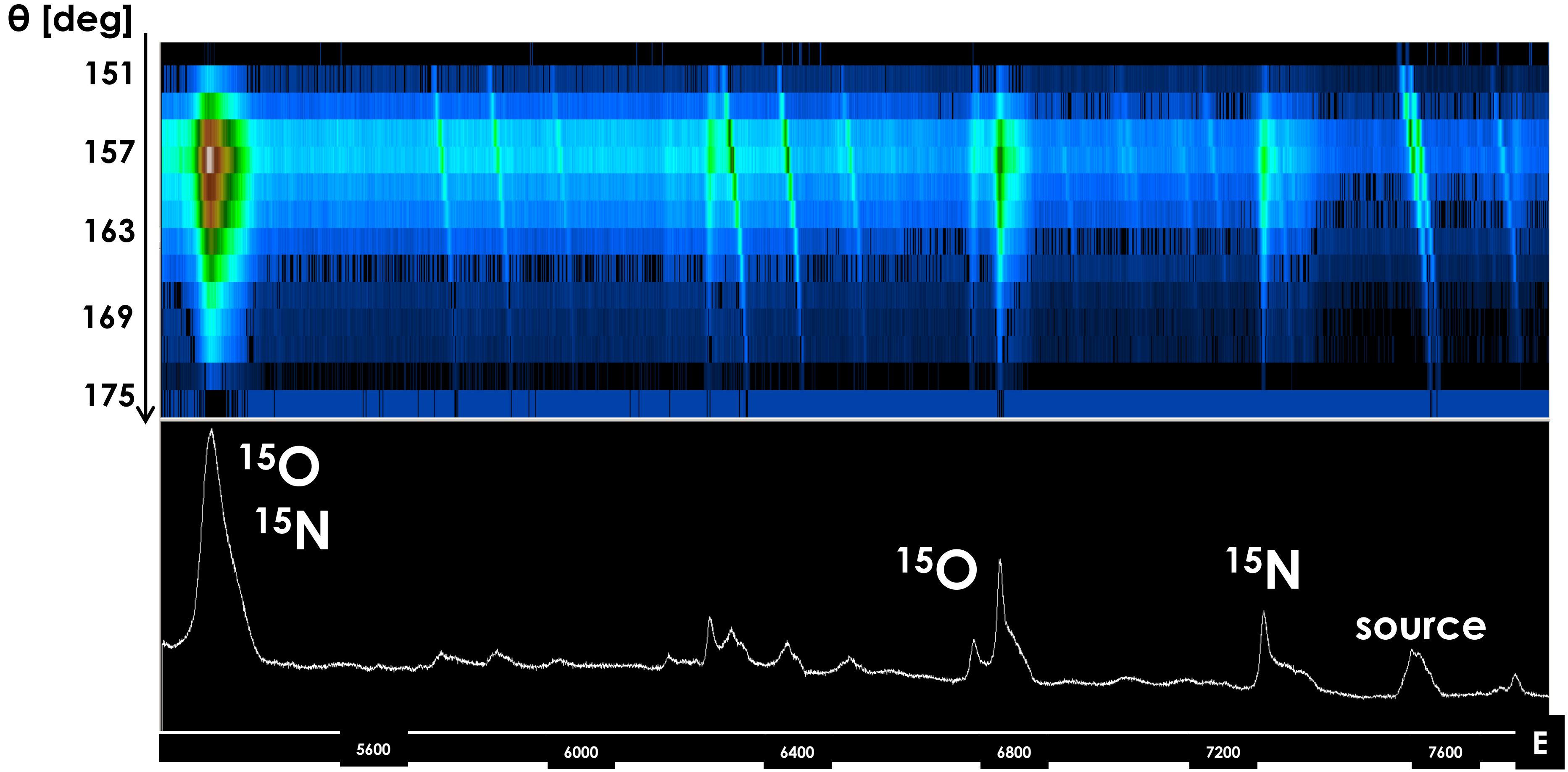
$V_C \approx 2.23$ MeV

(θ = angle of the first interaction point)



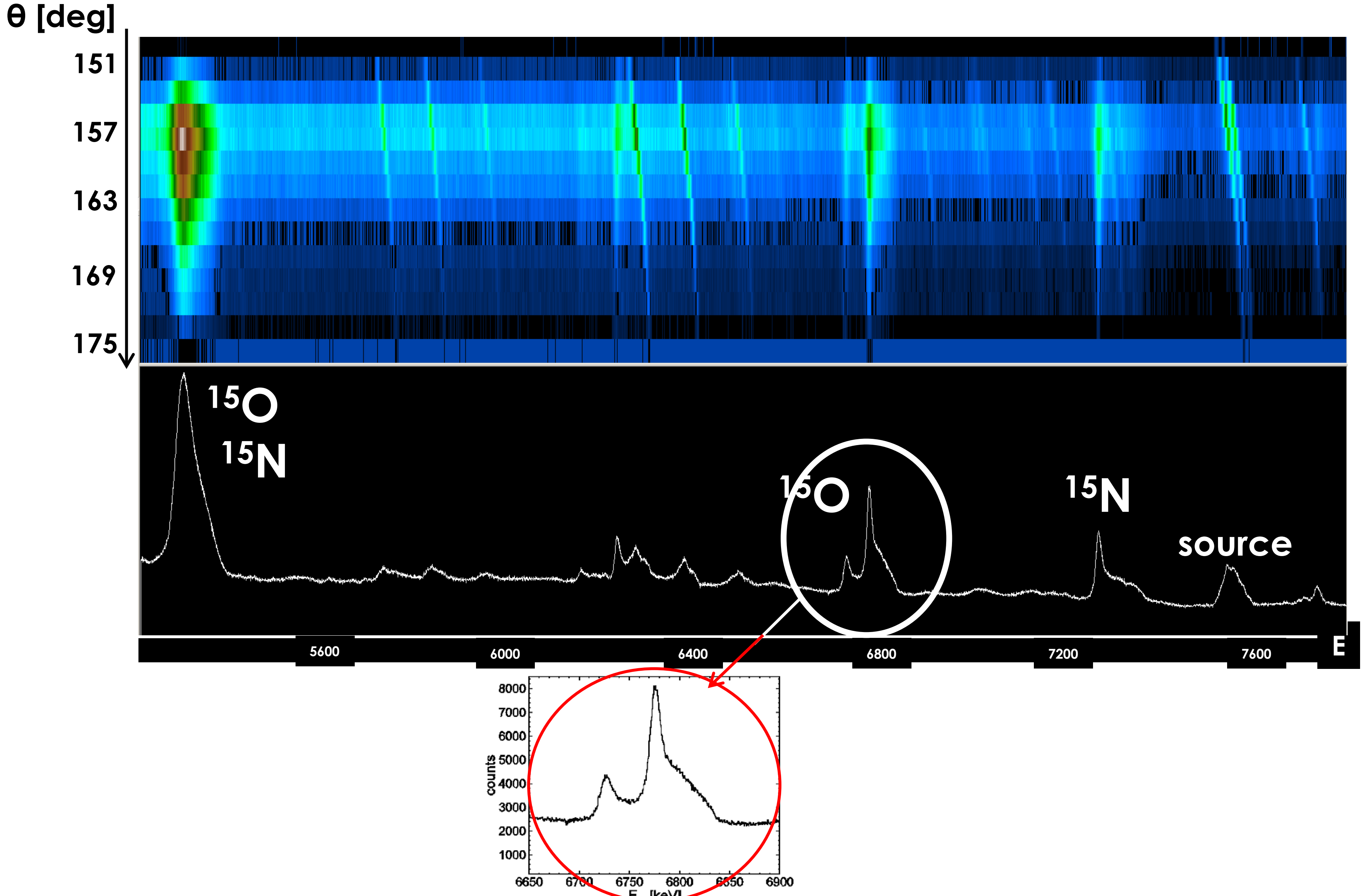
Not Doppler corrected → "vertical straigth lines" ↔ emission at rest

theta vs energy β=0.063

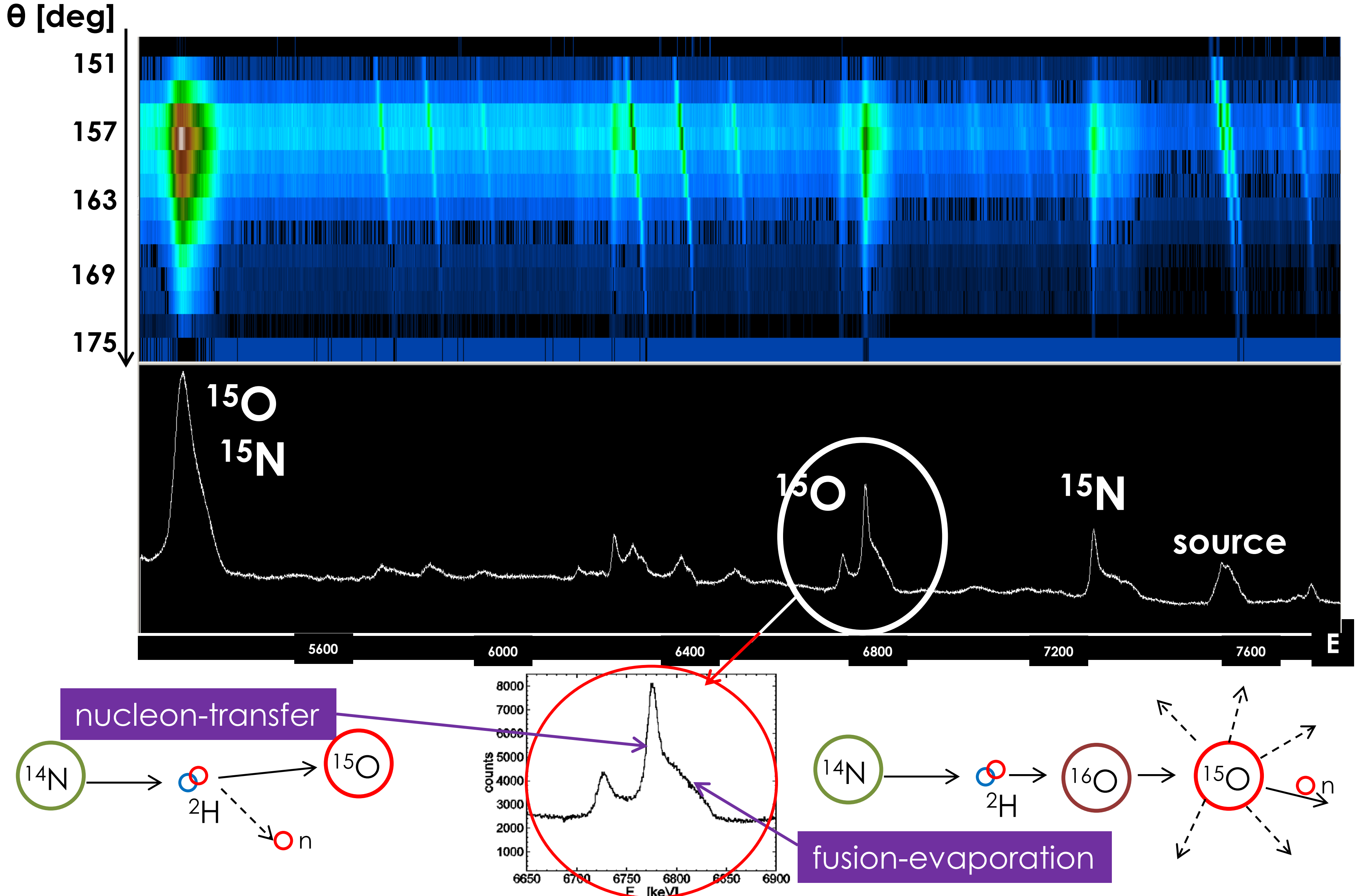


Data analysis

theta vs energy β=0

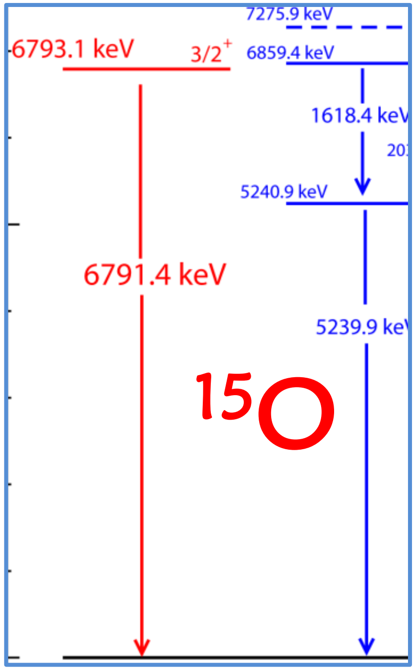


Data analysis
theta vs energy β=0



Simulations

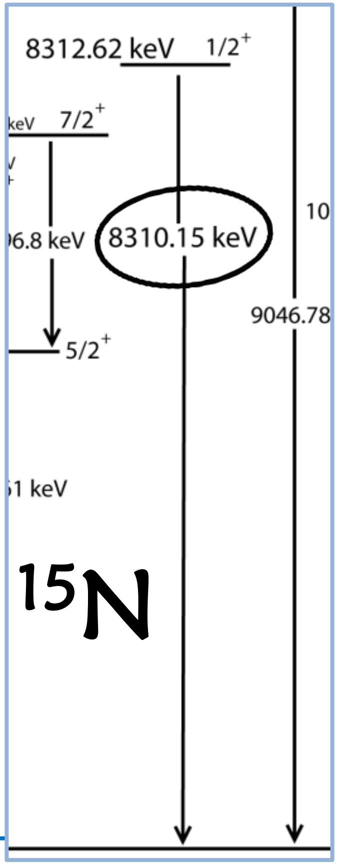
(taken from my Monday talk … ☺)



$\tau \sim$ fs (???)

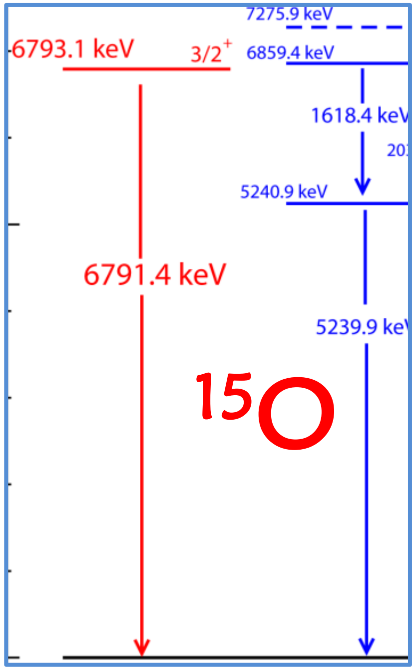
excited nuclear states populated either by fusion-evaporation and nucleon-transfer

τ = 0.45 fs

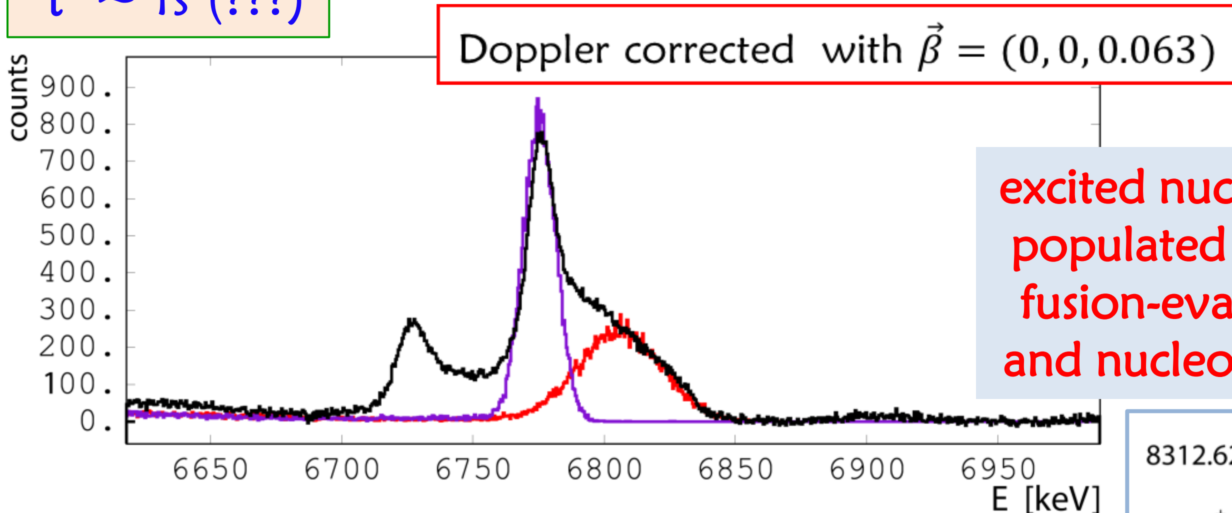


Simulations

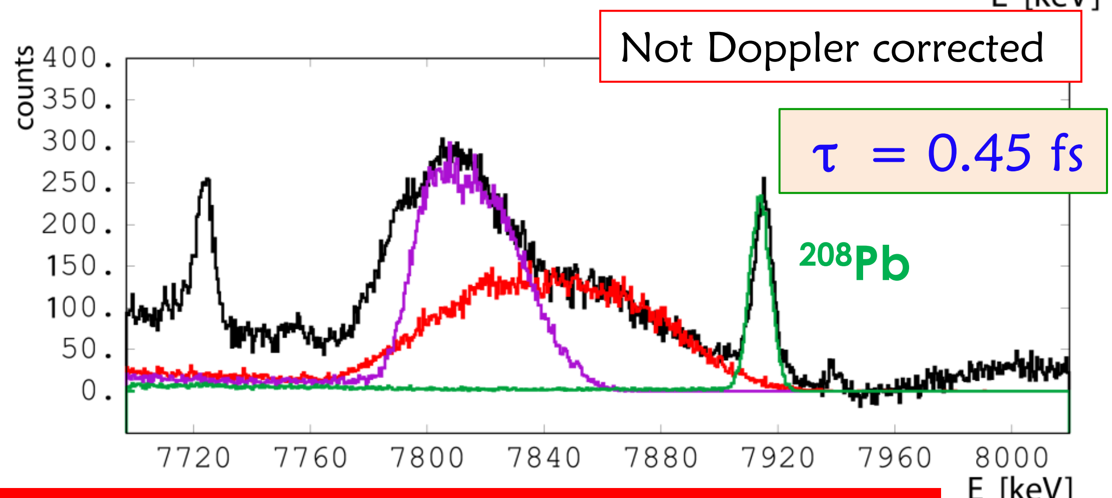
(taken from my Monday talk … ☺)

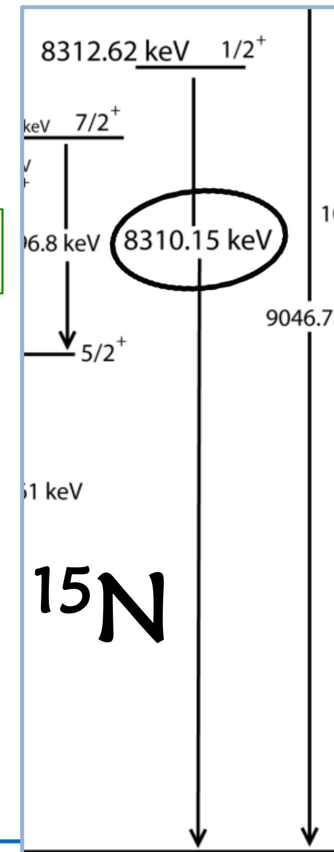


τ ~ fs (???)



excited nuclear states populated either by fusion-evaporation and nucleon-transfer





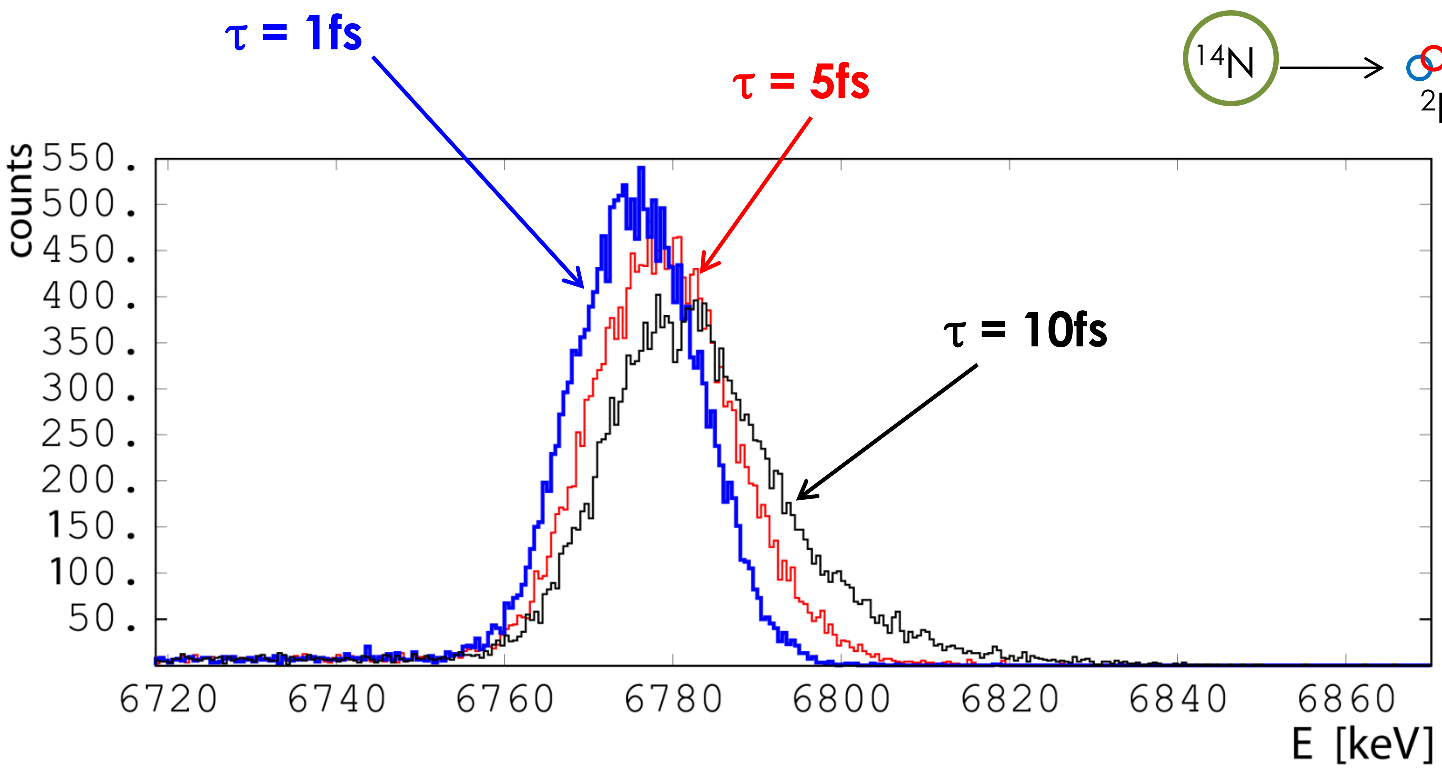
→experimental spectrum

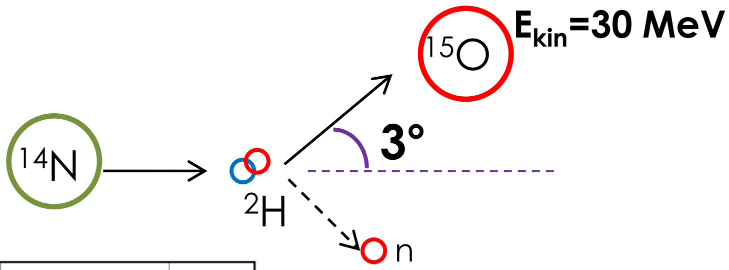
→simulated fusion-evap.

→simulated nucleon-transfer

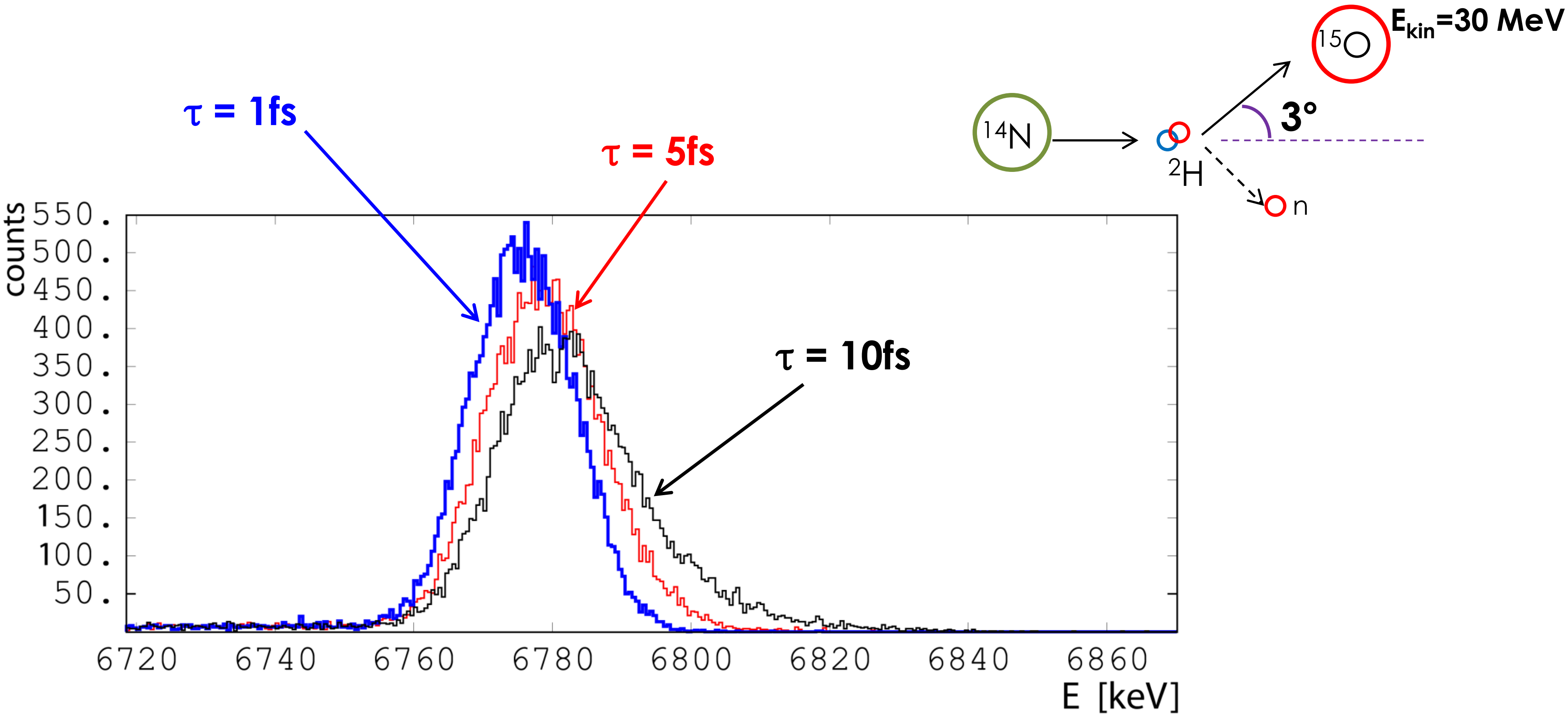
With all these different and independent contributions to the peak of interest in the γ spectrum are we sensitive to (~fs) lifetime???

Indeed, the shape of the peak correspondent to the de-excitation of the nucleon-transfer product may be sensitive to the level lifetime...





Indeed, the shape of the peak correspondent to the de-excitation of the nucleon-transfer product may be sensitive to the level lifetime...



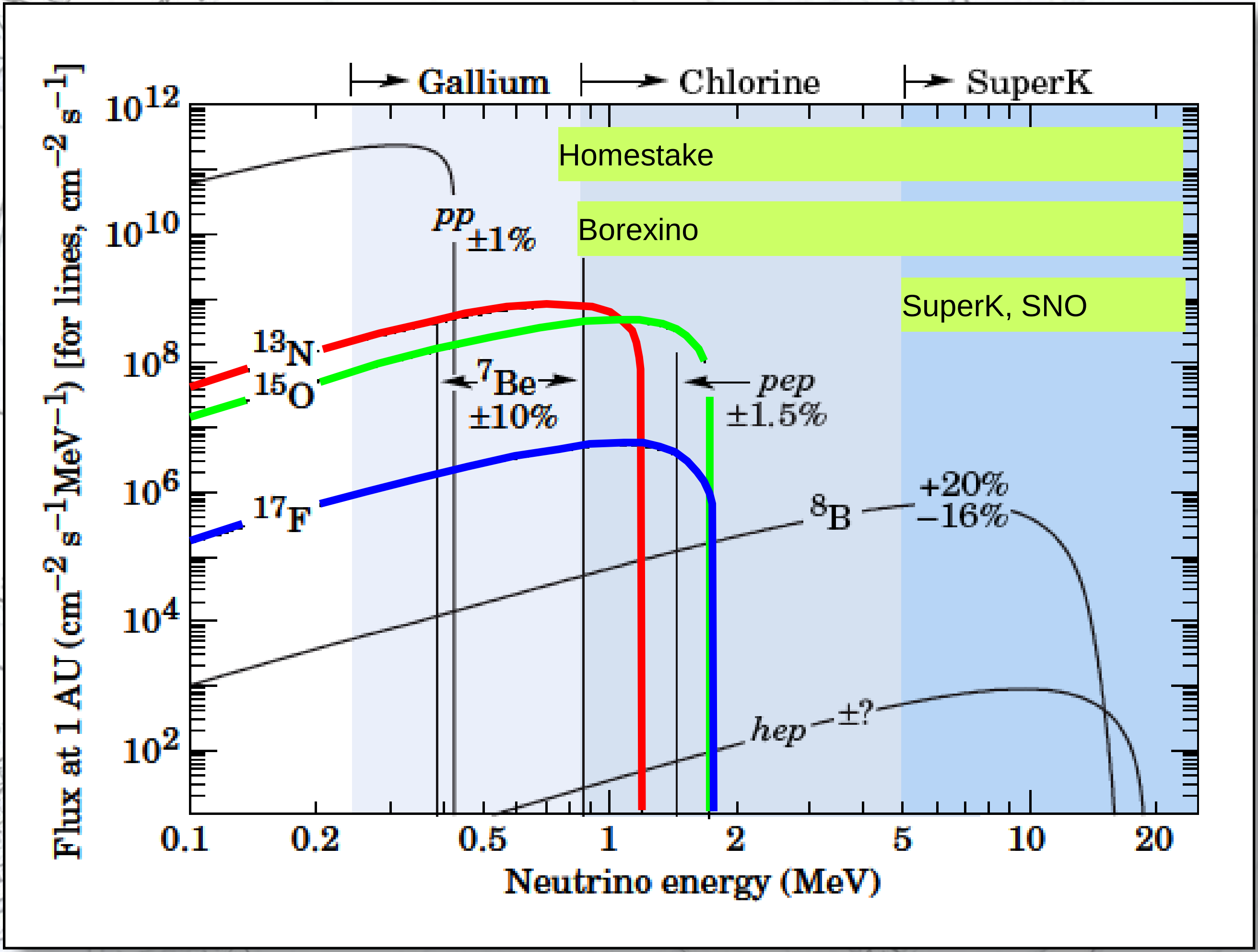
Accurate calculations of the reaction x-sections and kinematics are needed (G. Pollarolo, S. Silzner)

Concluding remarks

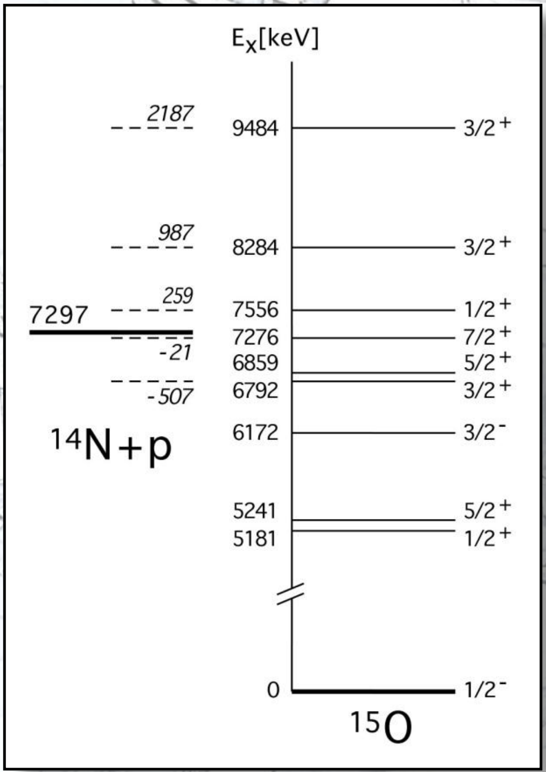
- Data obtained from the 14N+2H reaction @ 32 MeV (week 29 2010) have been processed and analysis is on going.
- Spectra and "E-ϑ" matrices are ready to be compared with detailed simulations.
- Monte Carlo simulations suggest that the level of interest (3/2+ 15O, 6.79 MeV) is populated via two different reaction processes (fus.-evap. and nucleon-transfer), so that to draw some conclusions about the level lifetimes we have to wait for detailed calculations of the x-sections and kinematics (G. Pollarolo, S. Silzner).
- A high-energy gamma source has been used to perform calibrations of the segments and core signals of the 4 ATCs used, as well as to provide an "internal" monitoring of the gain stability of the system during the in-beam run.
- In order to overcome the problems related to the strong non linearity of the segments in low-gain mode and to the effects of the neutron damage, only the CC signals are taken into account in the analysis.
- The shape (baricentre shift) of the peak of interest is a result of many independent factors: data can be analysed with the help of detailed simulations.
- Could we plan a "better" experiment with the gained experience???

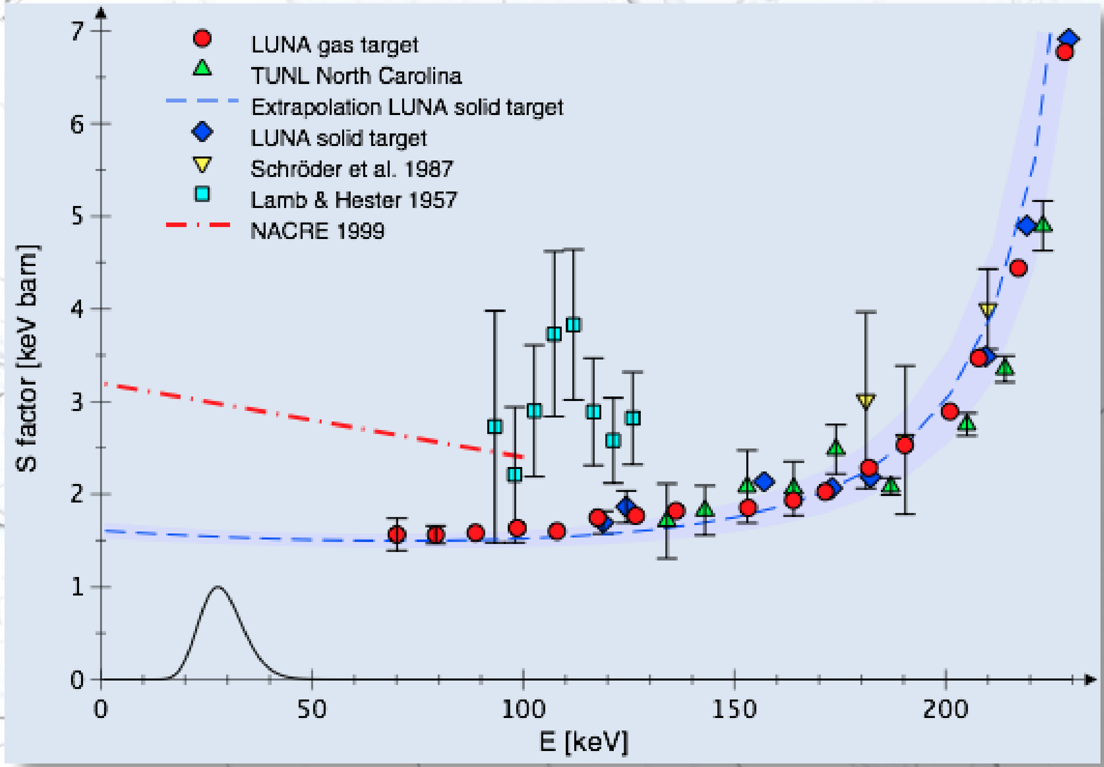
extra slides

physics case



physics case

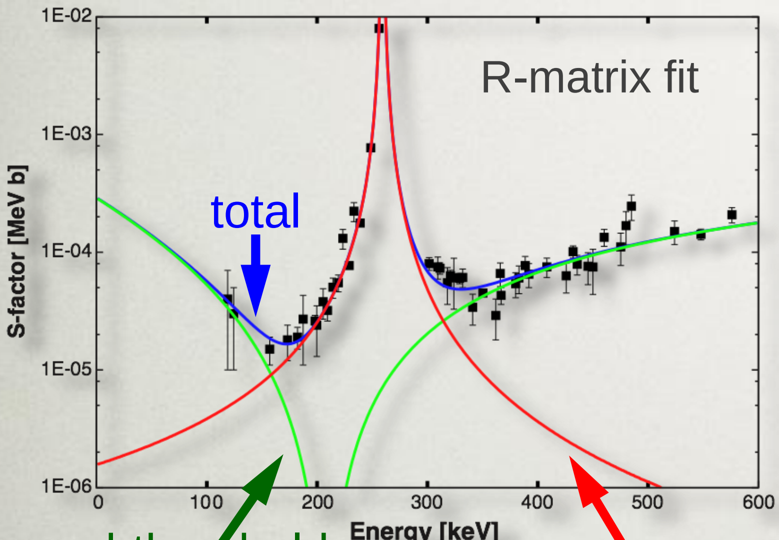


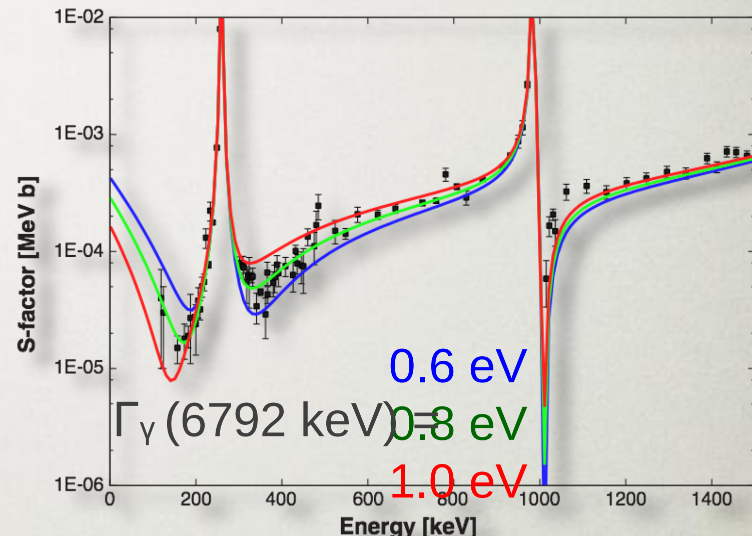


$S_{tot}(0) = 1.57 \pm 0.13$ keV◊b

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

Capture to the ground state of ^{15}O





subthreshold resonance + external contribution

259 keV resonance alone

NACRE 1999
1.55 ± 0.34 kev◊b

Adopted Γ_γ (6792 keV)= 0.9 ± 0.2 eV

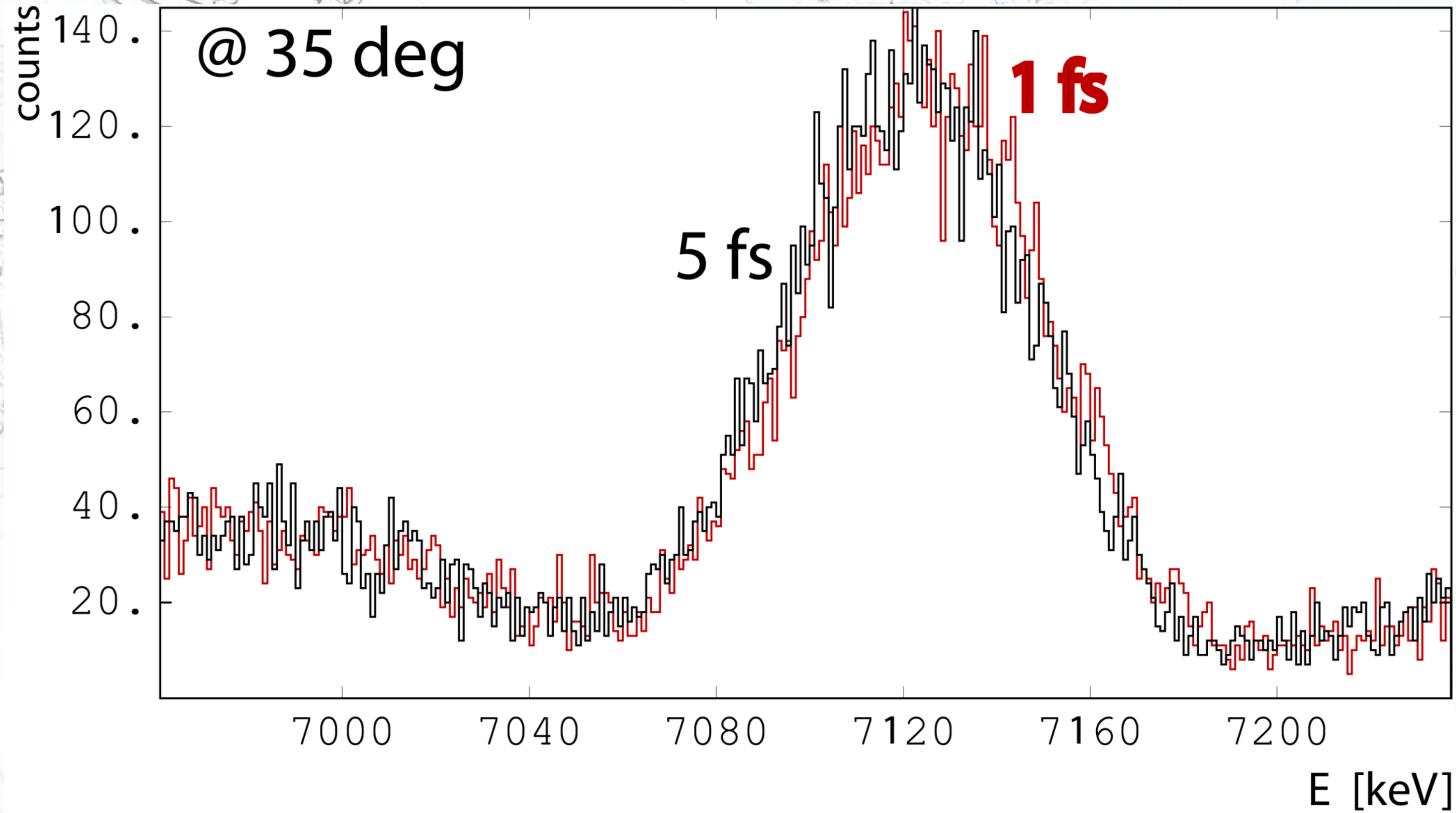
$S_{GS}(0)$ = 0.20 ± 0.05 keV◊b

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

- Improved nuclear physics uncertainties in the ^{13}N and ^{15}O neutrino fluxes from 15% to 8% (**desired 5%**)
- C and N abundance in the solar core possible from Borexino/SNO+ measurements

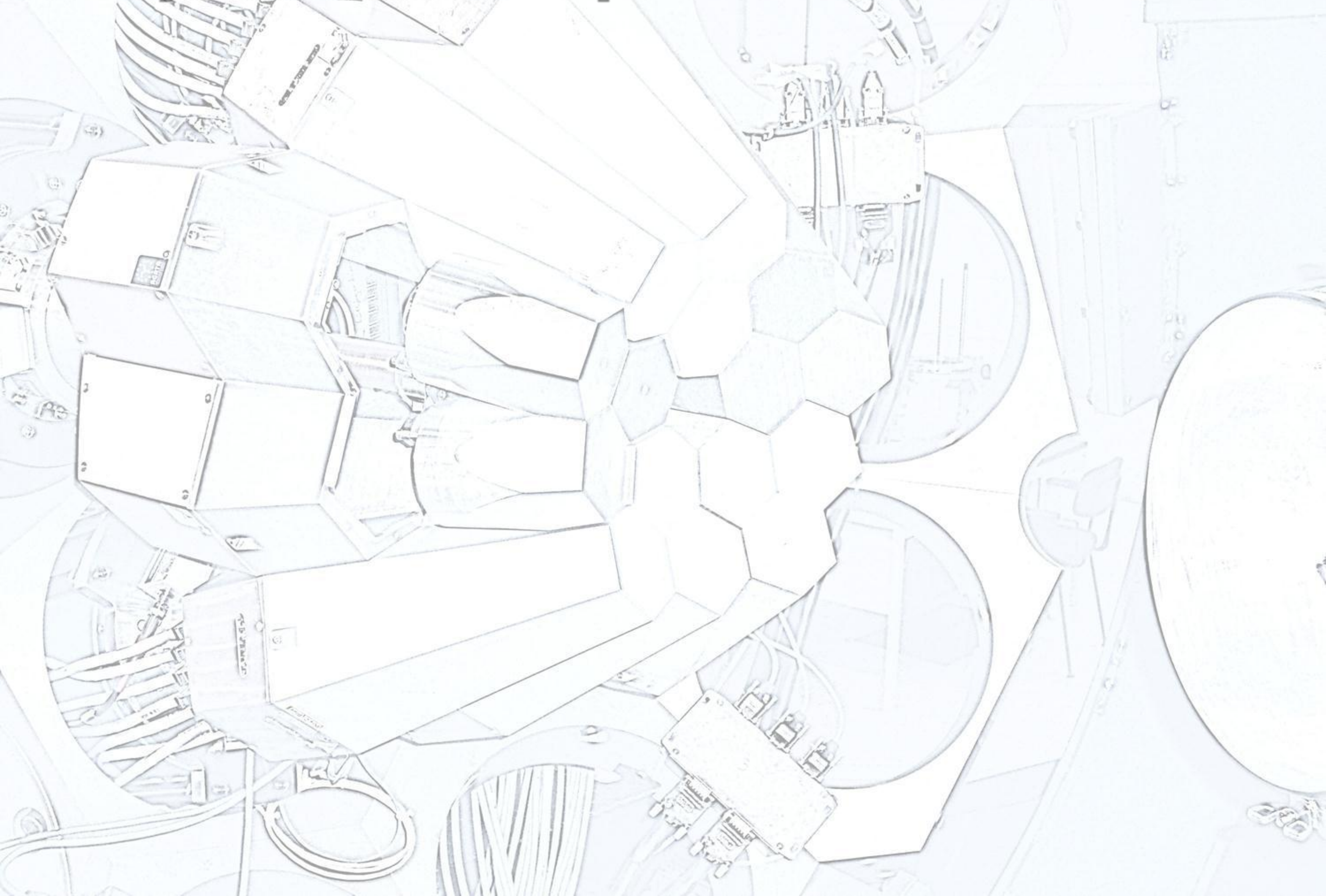
W. Haxton & A. Serenelli, Astrophys. J. 687, 678 (2008)

if we use GASP...



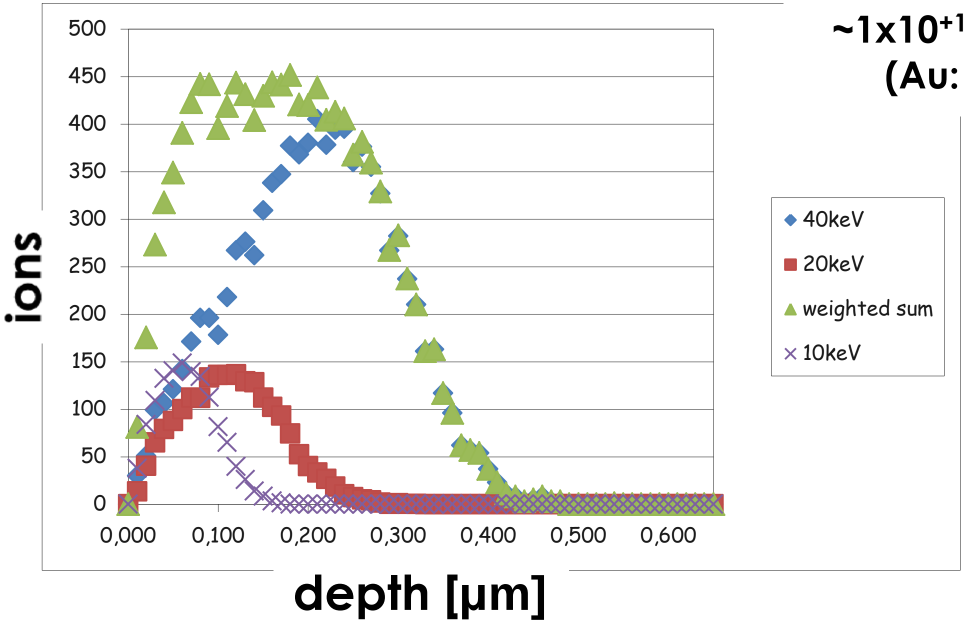
fusion-evaporation + theta=2° kin en=30 MeV

desync. of t-stamps from run 48 on…



target = deuterium implanted in a Au backing (~3.8 mg/cm^2)

following consecutive deuterium implantations at energies between 30 and 100 keV:

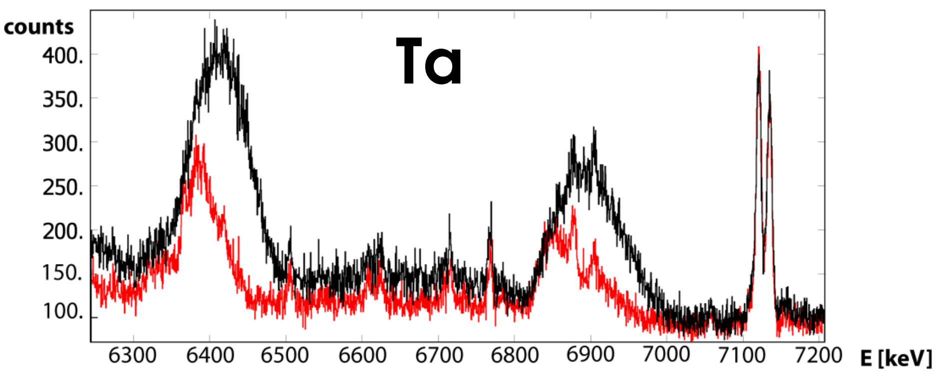


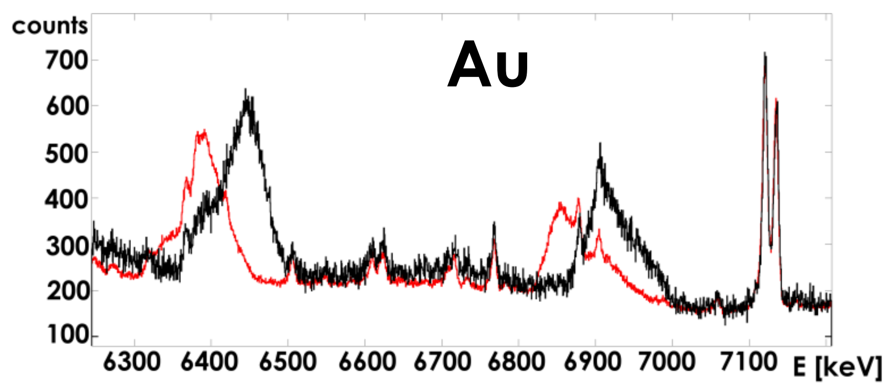
~1x10^{+18} atoms/cm^2
(Au: ^{2}H ~2.6:1)

Targets are being analysed
(SIMS @ Padova, ERDA @ LNL)
The first results reveal that deuterium did not drift during the experiment

Implantation on Tantalum substrate had some problems…

back-side
front-side



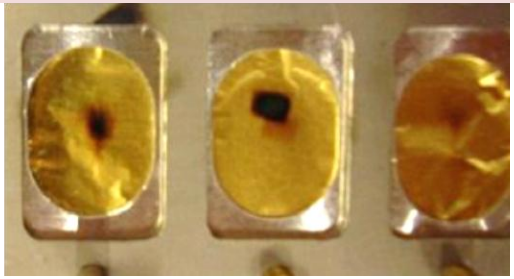


RUN #	DURATION [hh:mm]	TARGET	TRACES ON DISK [GB]	COMMENTS
38	04:35	Au Front (3)	232	
39	01:15	Au Front (3)	68	
42	00:57	Ta Front	42	
43	01:04	Ta Back	47	
44	04:33	Ta Front	197	
45	11:56	Au Front (4)	527	
46	08:31	Au Front (4)	415	
47	07:04	Au Front (4)	331	"Hardware" re-boot of DAQ system
48	01:45	Au Front (4)	86	Beam re-focused
50	04:10	Au Front (4)	221	"Manually" recovered
51	16:50	Au Front (3)	716	New target holder configur
52	06:27	Au Front (3)	283	
53	07:34	Au Front (1)	326	
54	21:14	Au Front (1)	1059	Beam re-focused
55	09:40	Au Front (1)	469	Beam re-focused
56	03:28	Au Front (1)	171	
58	09:05	Au Front (1)	465	
59	10:15	Au Back (1)	496	
62	22:18	-	772	Activity + AmBe source

TOT = 6923 GB

I(Cup7) ~13 enA
Ge single ~450 Hz
Ge single (beam off) ~400 Hz (!)

Low reaction rate ... but the beam was indeed there !!! :

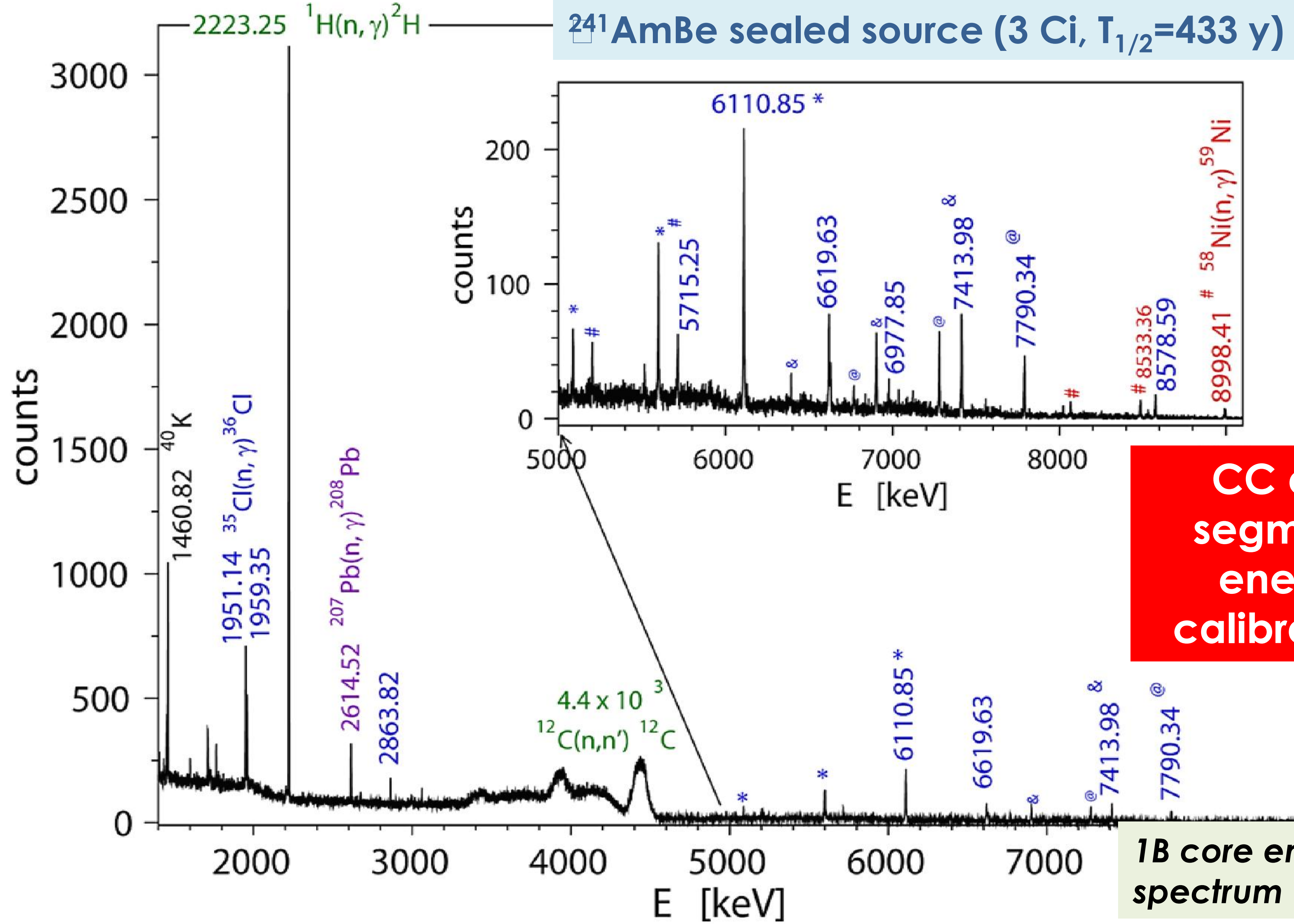


main problems:

- **beam instabilities**
- **from run 48 on: desync. of time stamps (for some crystals –due to a non correct system re-set (?))**
- **non linear calibrations (low gain)**
- **understanding of what was going on ... !!!!**

High energy gamma rays *ATC* test (week 26-27 2010)

^{241}AmBe sealed source (3 Ci, $T_{1/2}$=433 y) + Ni



CC and segments energy calibrations

1B core energy spectrum