Frascati
24 Giugno 2015

LNF Mini-Workshop series:
Rewarding Science

"Premio Villi 2014"

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Università degli Studi di Padova

Dipartimento di Fisica e Astronomia

SCUOLA DI DOTTORATO DI RICERCA IN FISICA

CICLO XXV

The lifetime of the 6.79 MeV state in ^{15}O as a challenge for nuclear astrophysics and γ-ray spectroscopy: a new DSAM measurement with the AGATA Demonstrator array

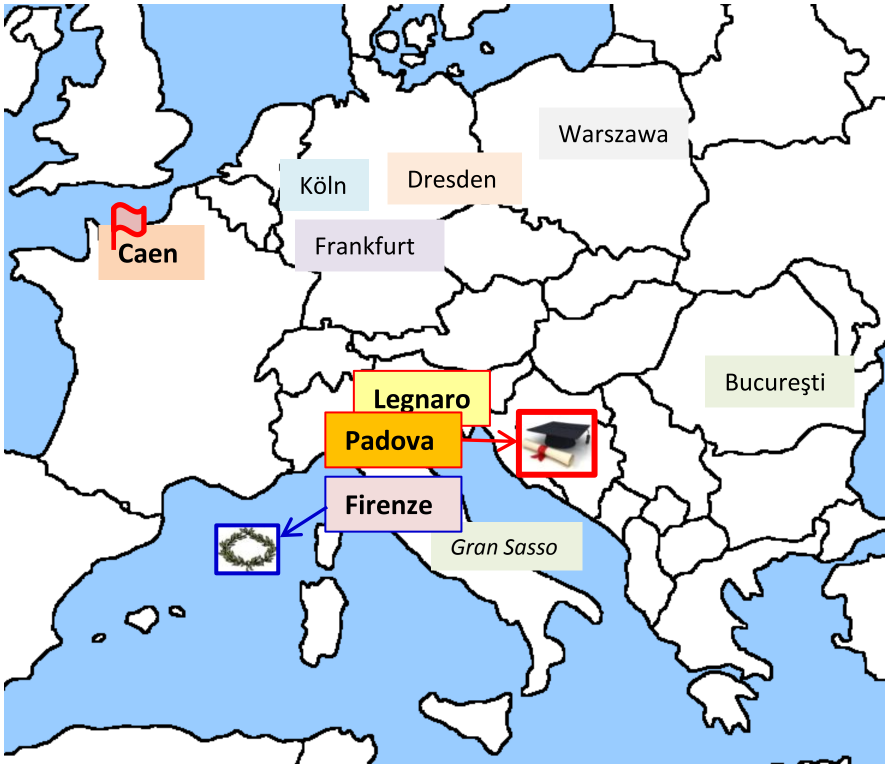
Direttore della Scuola : Ch.mo Prof. Andrea Vitturi

Supervisori : Ch.mo Prof. Santo Lunardi,

Dott. Călin Alexandru Ur

Dottoranda : Caterina Michelagnoli

An international research network!
Collaborations and key institutes for my formation



2008-2009: University and INFN of Florence
Diploma thesis (Prof. P.G. Bizzeti)

2009: INFN fellowship at the
Legnaro National Laboratories

2010-2012: University and INFN of Padova
PhD *(PhD thesis discussion: June 20th 2013)*

2013: Post-Doc
University and INFN of Padova

2013-
at present : Post-Doc CNRS
at GANIL, Caen (FR)
(Grand Accélérateur National d'Ions Lourds)

PhD thesis: use of advanced gamma-ray spectroscopy techniques for the measurement of a key-observable for nuclear astrophysics
(esperimento GAMMA)

The lifetime of the 6.79 MeV state in ^{15}O as a challenge for nuclear astrophysics and γ-ray spectroscopy: a new DSAM measurement with the AGATA Demonstrator array

1. ***(astro-) Physics Motivation:***

→ *the cross section of the ^{14}N(p,γ) reaction at stellar energies*

"E quando miro in cielo arder le stelle;
Dico fra me pensando:
A che tante facelle?"
G. Leopardi
"Canto Notturno di un Pastore Errante dell'Asia"

2. ***Experimental method***

→ *the measurement of femtosecond nuclear level lifetimes with the Doppler Shift Attenuation Method (DSAM)*

3. ***Experimental setup***

→ *use of the Advanced-GAmma-Tracking-Array (AGATA) for the detection of gamma rays*

4. ***Data analysis and results***

→ *"continuous" DSAM: old method, new implementation*

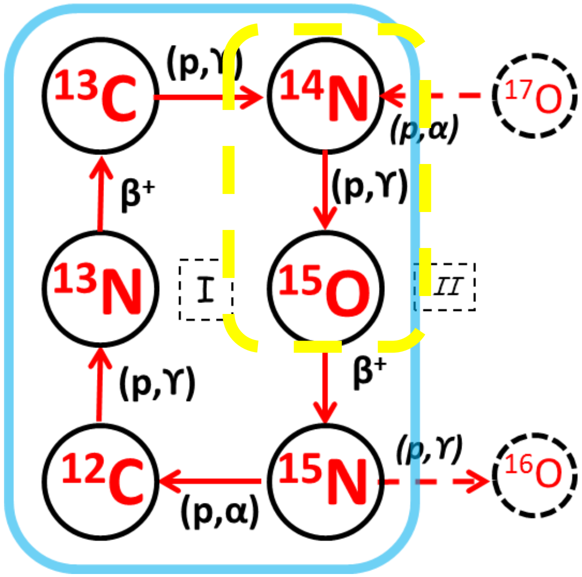
→ *the lifetime of the 6.79 MeV state in ^{15}O and "test nuclear states" in ^{15}N*

→ *new constraints on the ^{14}N(p,γ) reaction cross section at stellar energies*

Conclusions and perspectives

→ *pioneering technique*

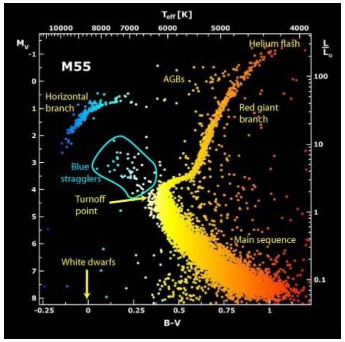
Stellar burning rates: the Carbon-Nitrogen-Oxygen (CNO) cycle and $^{14}N(p,\gamma)^{15}O$ reaction



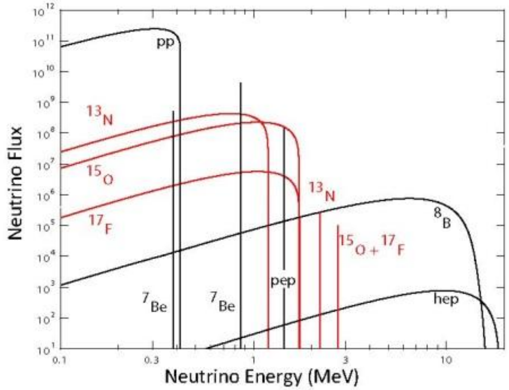
H burning through the CNO cycle

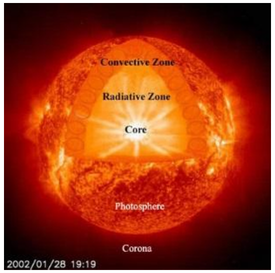
evolutionary path of massive stars

age of globular clusters



+ν fluxes: C,N abundances in the Solar core ➡ *Solar Composition Problem*



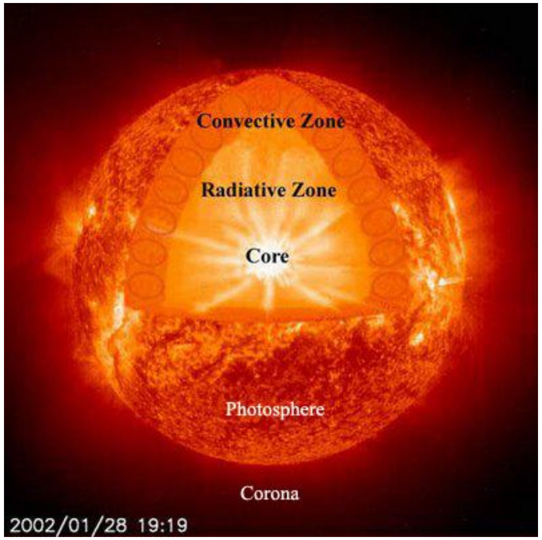


$^{14}N(p,\gamma)^{15}O$ = slowest reaction

⬇

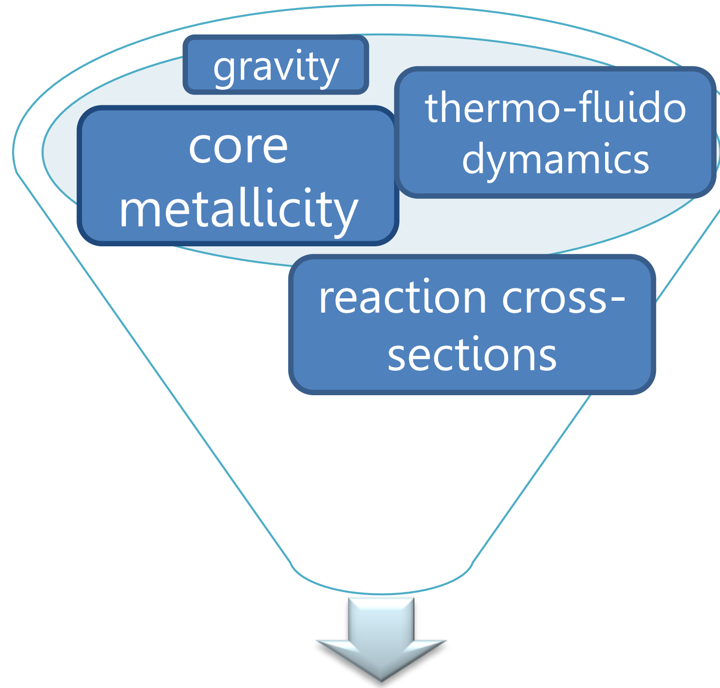
rate-controlling

The *Solar composition problem*



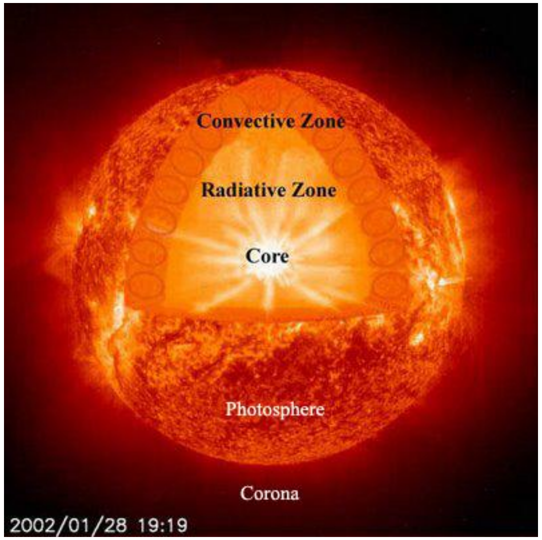
observables:

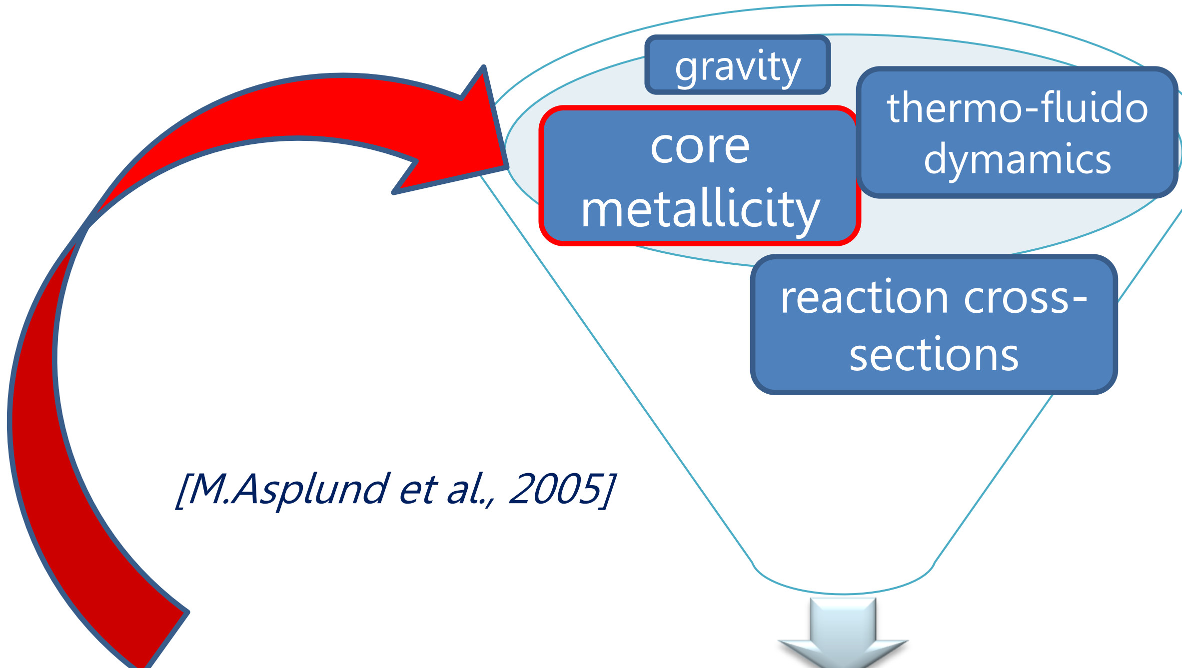
- luminosity
- chemical abundances of the photosphere
- density and sound velocity profiles (helioseismology)



Solar Standard Model (SSM)

The *Solar composition problem*





[M.Asplund et al., 2005]

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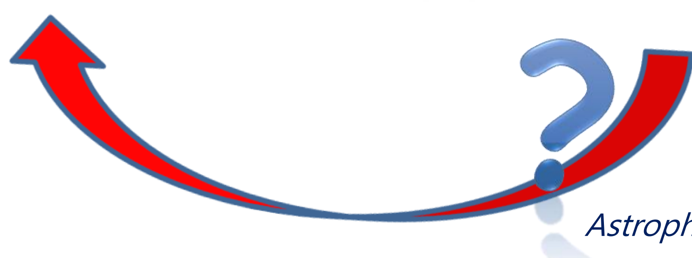
↔ Solar Standard Model (SSM)



the neutrino flux depends linearly on the cross-section:

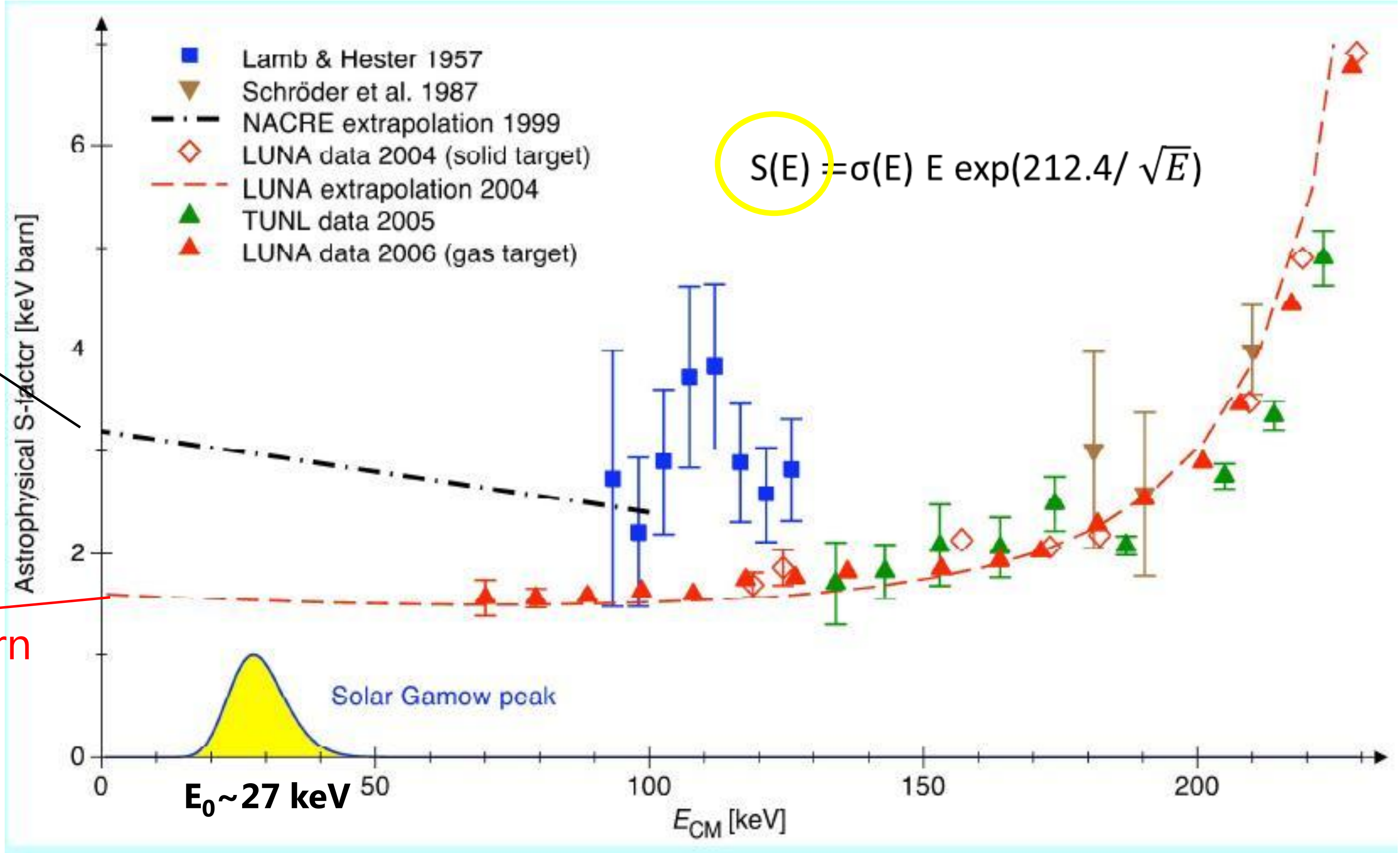
$$\Phi_{\upsilon}^{CNO} = f\,(S_{nuc},T,CN)$$

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

$^{14}N(p,\gamma)^{15}O$ reaction cross-section measurements

NACRE 1999
3.2±0.8 keV barn
σ=2.2 10^{-19}b

LUNA 2008
1.57±0.13 keV barn
σ=1.1 10^{-19}b



CN component of the solar neutrino flux reduced by a factor ~ 2

Globular Cluster ages increased by ~ 0.7-1 Gyr ….

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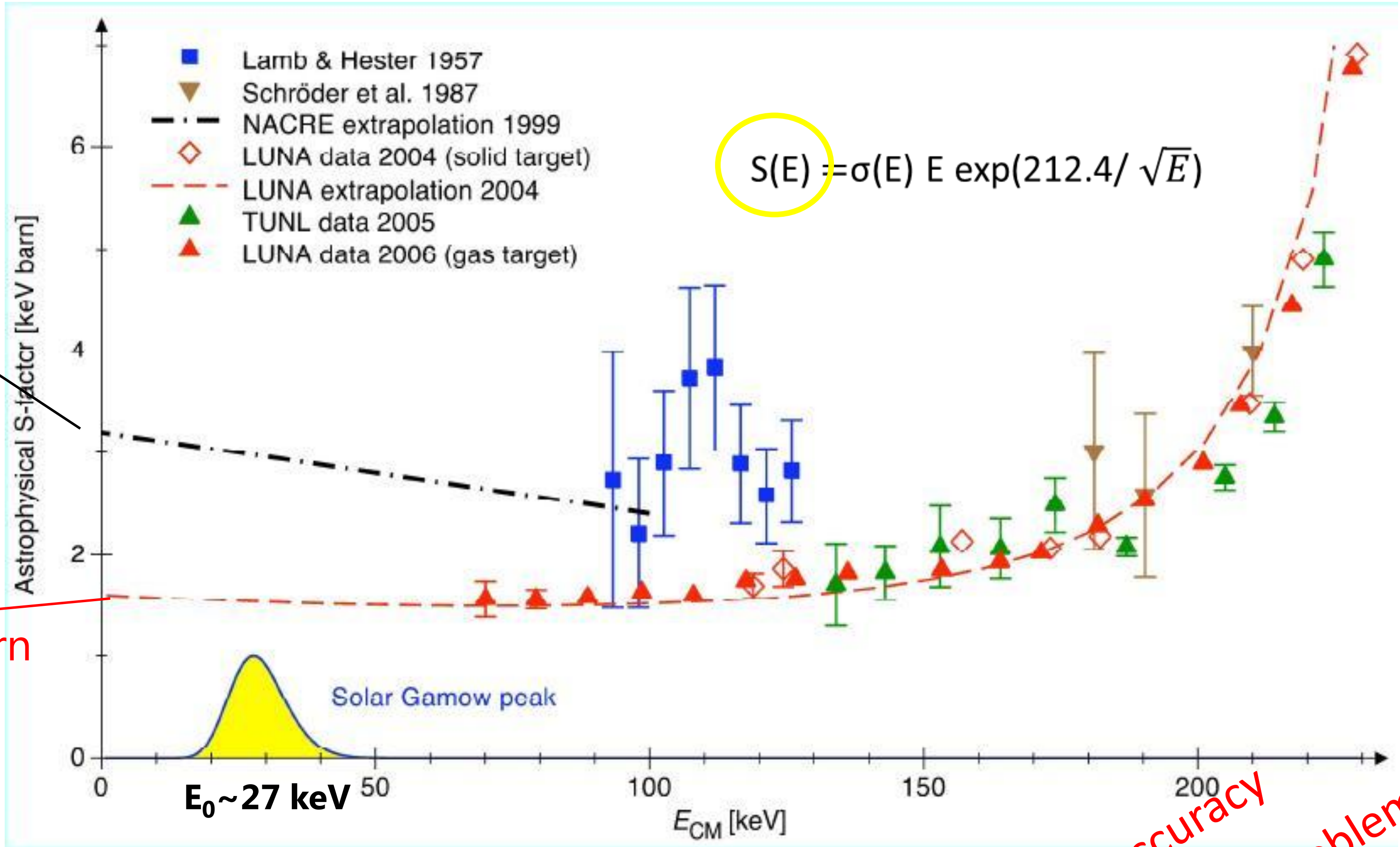

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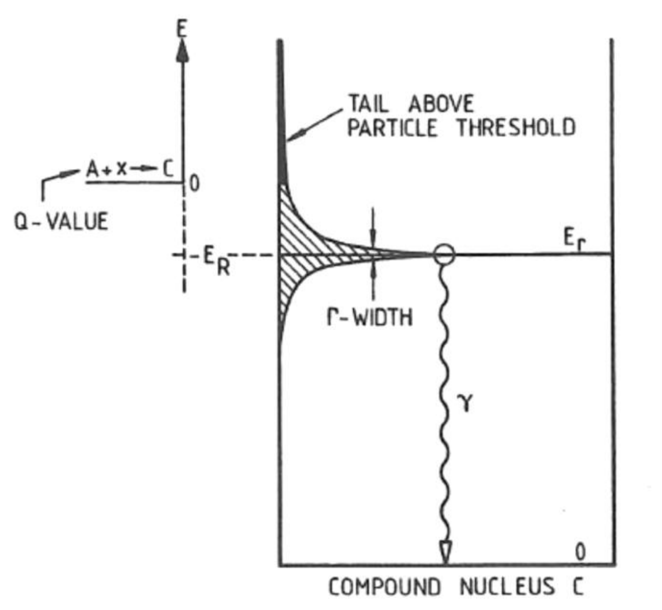
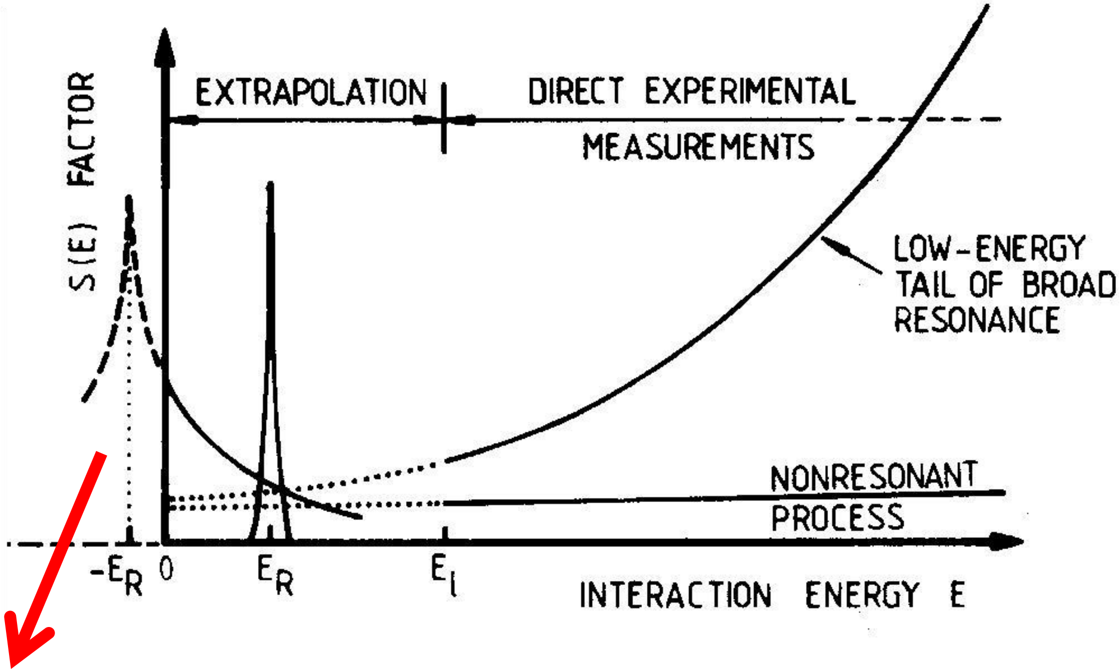
Globular Cluster ages increased by ~ 0.7-1 Gyr ....

still 5% accuracy ⇕ Solar Composition Problem

Extrapolation of the cross-section (astro. S-factor) at stellar energies

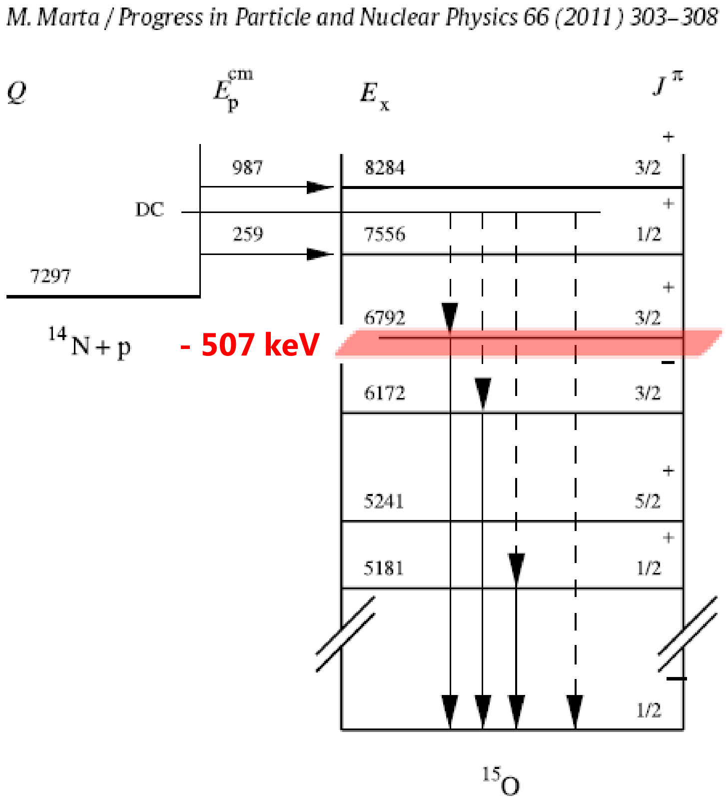
in **extrapolating** the available exp. data to the **Gamow energy** region the occurrence of resonances has to be carefully taken into account, for example with an *R-matrix fit* to the exp. data

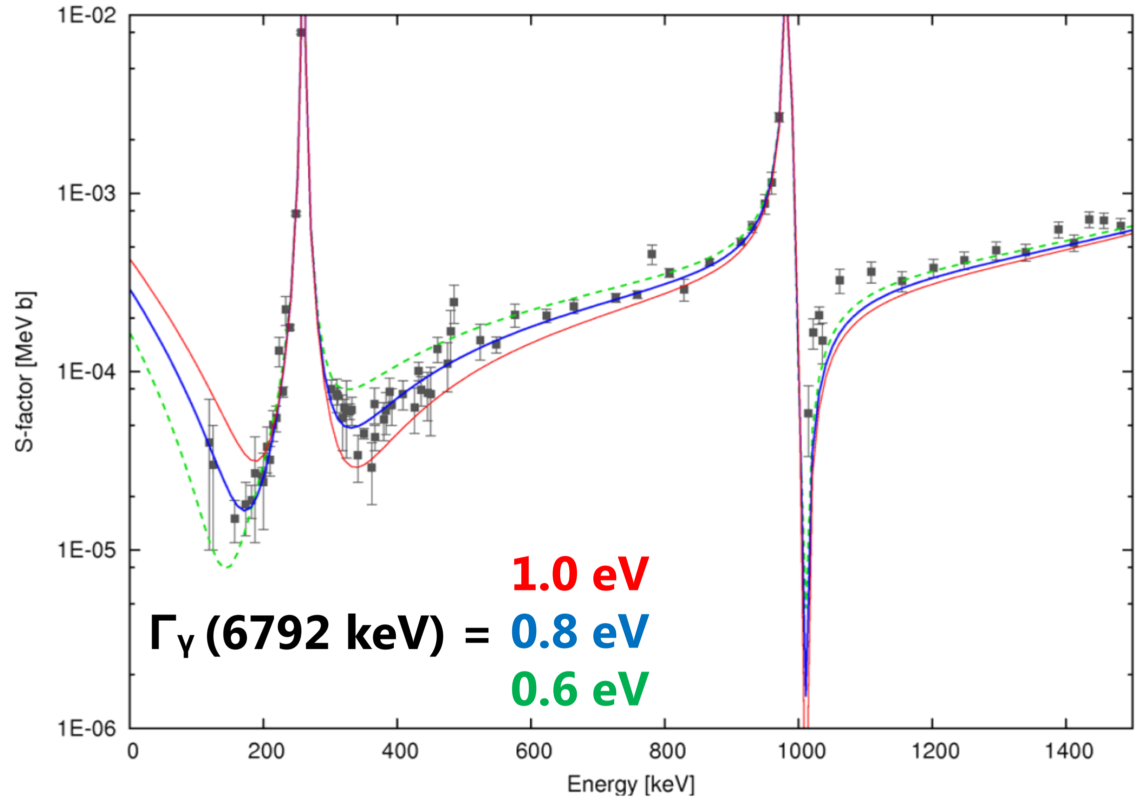




tail(s) of any possible sub-threshold resonances have to be carefully taken into account

$^{14}N(p,\gamma)^{15}O$: the sub-threshold resonance at -507 keV (i.e. the 6.79 MeV state in ^{15}O)





Captures to different excited states in ^{15}O contribute to the cross-section. The capture 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**)

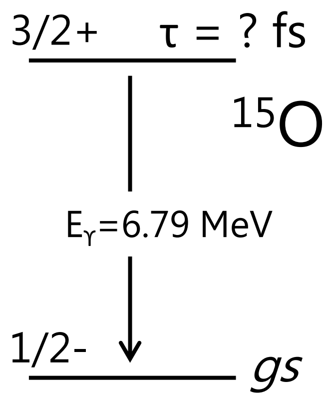
[C.Angulo et al., NP A690 (2001) 755,
M.Marta et al., PR C78 (2008) 022802(R), ...]

Existing literature for the lifetime of the 6.79 MeV state in ^{15}O

$$\Gamma = h/\tau$$

$$n(t) = n_0 \, e^{-t/\tau}$$

group/year (method)	τ [fs]	Γ [eV]	$\Gamma/\Delta\Gamma$ [%]
Oxford 1968 (DSAM, $d(^{14}N,^{15}O)n$)	< 28	> 0.02	-
TUNL 2001 (DSAM, $^{14}N(p,\gamma)^{15}O$)	1.6±0.7	0.41±0.17	44
RIKEN 2004 (CE $^{208}Pb(^{15}O,^{15}O^{*})$)	< 1.8	> 0.36	-
LUNA 2004 (R-matrix fit)	1.1±0.5	0.6±0.3	45
TUNL 2005 (R-matrix fit)	0.3±0.1	2.2±0.7	33
Bochum 2008 (DSAM, $^{14}N(p,\gamma)^{15}O$)	< 0.77	> 0.85	-
LUNA 2008 (R-matrix fit)	0.75±0.20	0.9±0.2 *	26



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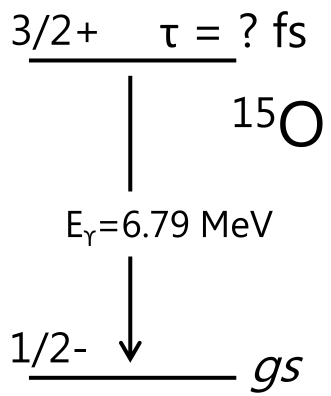


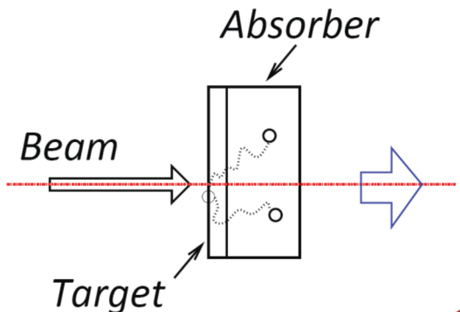
* *adopted value*

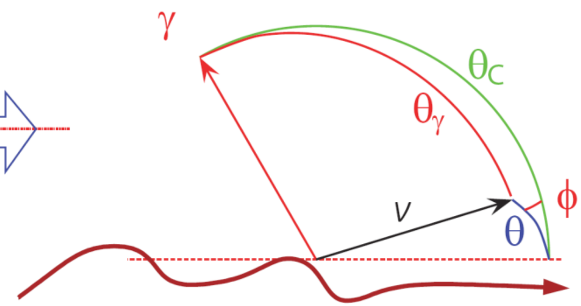
direct lifetime measurement ⇔ Doppler Shift Attenuation Method (DSAM)

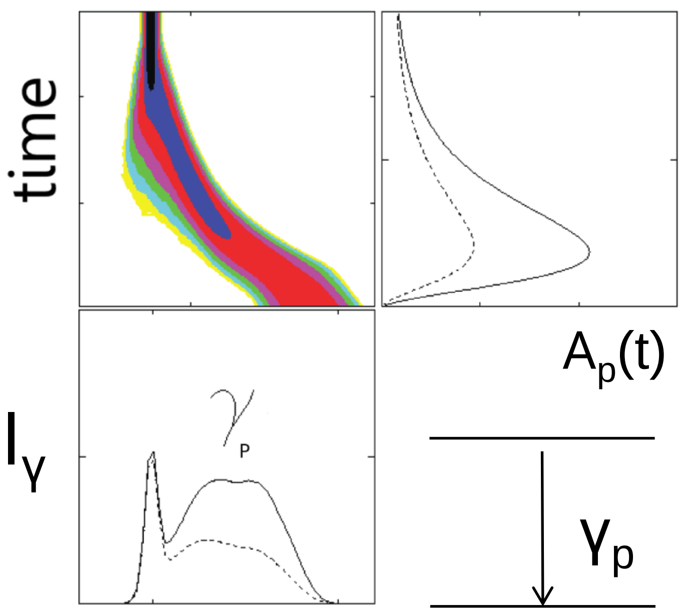
DSAM: suitable down to ~10fs => **>** ARE THESE RESULTS "ROBUST" ENOUGH??
> IS IT POSSIBLE TO IMPROVE THE ACCURACY OF SUCH MEASUREMENT??

Doppler Shift Attenuation (DSA) for the measurement of nuclear level lifetimes

The lifetime of the excited state is compared with the slowing down time of the emitting nucleus in the absorbing material

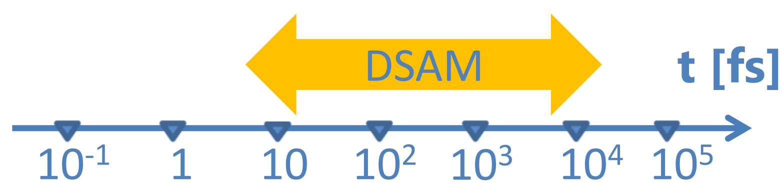






$$\overline{E_\gamma} = E_\gamma \frac{\sqrt{1-\beta^2}}{1-\beta\, cos\theta} \qquad \beta = \left|\frac{\vec{v}}{c}\right|$$

Monte Carlo simulations => lineshape analysis of the peaks observed in the γ spectrum



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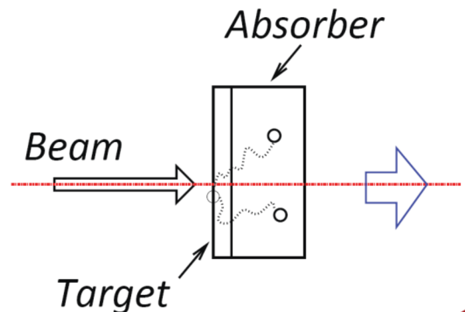

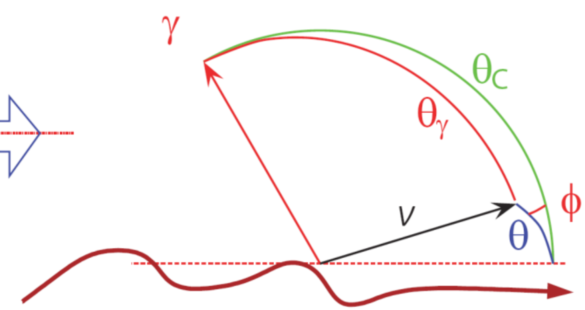

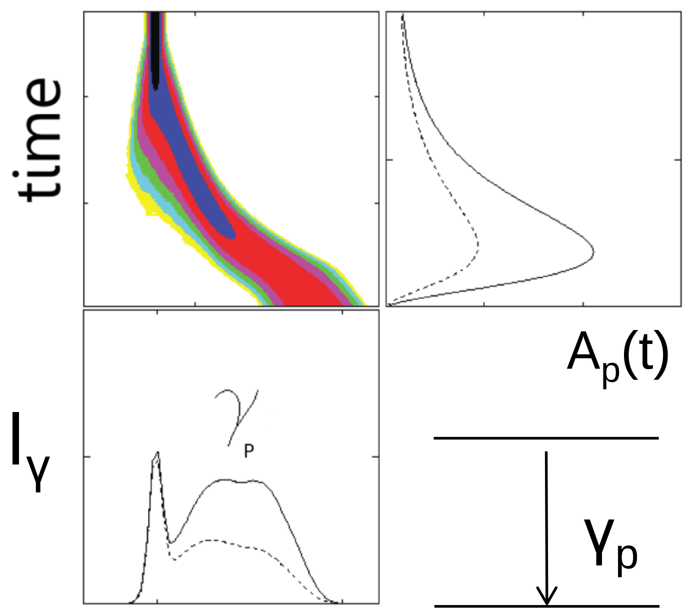

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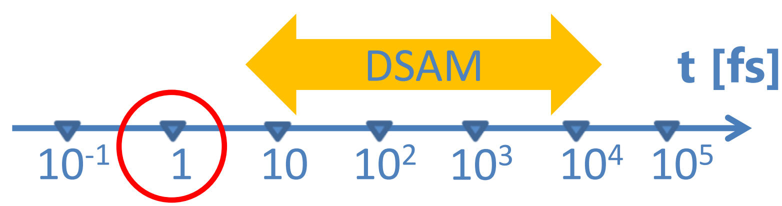


lifetime of the 6.79 MeV level in ^{15}O (?)

Experimental requirements for ~femtosecond lifetimes

1. maximize Doppler shift effects

2. large stopping power of the absorbing material

3. monitor of energy gain instabilities

4. high γ-detection efficiency and resolution
   (good detector response function)

Experimental requirements for ~femtosecond lifetimes

1. maximize Doppler shift effects

inverse kinematics reaction

2. large stopping power of the absorbing material

gold layer

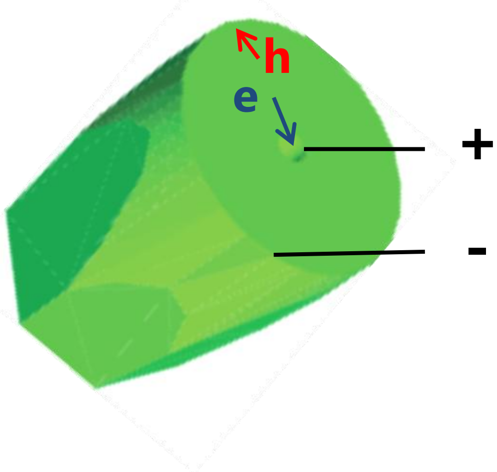
3. monitor of energy gain instabilities

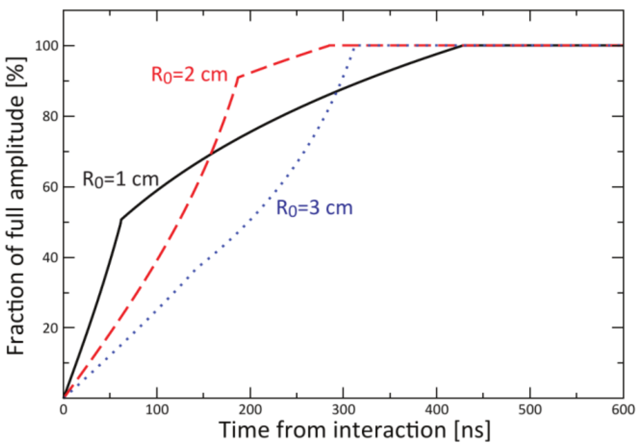
radioactive γ source while beam on target

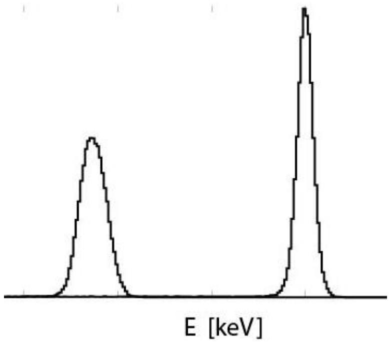
4. high γ-detection efficiency and resolution (good detector response function)

advanced γ-ray detection techniques

γ-ray spectroscopy with standard HPGermanium detectors

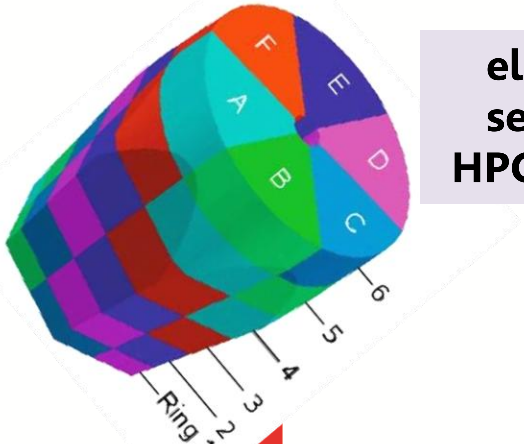






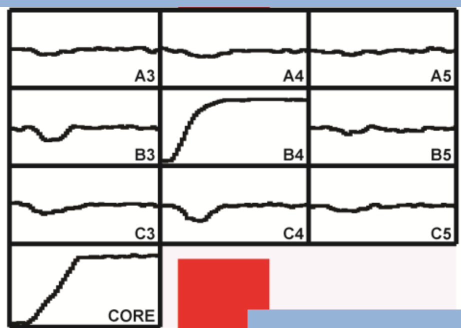
gamma interaction position = center of the detector

γ-ray spectroscopy with segmented HPGermanium detectors



electrically segmented HPGe detector

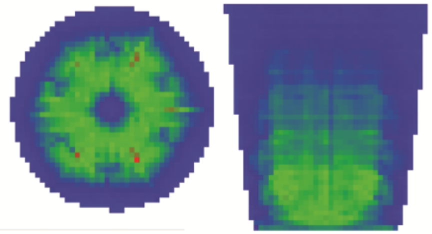
Digital electronics to record and process segment signals



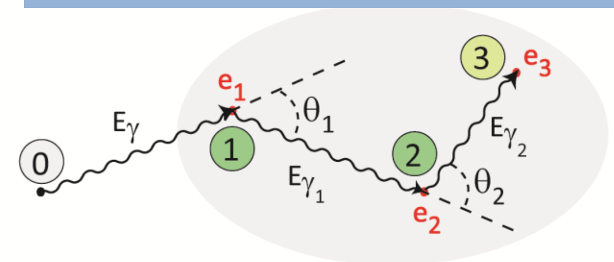
Decomposition of the recorded pulses through comparison with reference signals

Identification of the individual interaction points

$(x,y,z,E,t)_i$



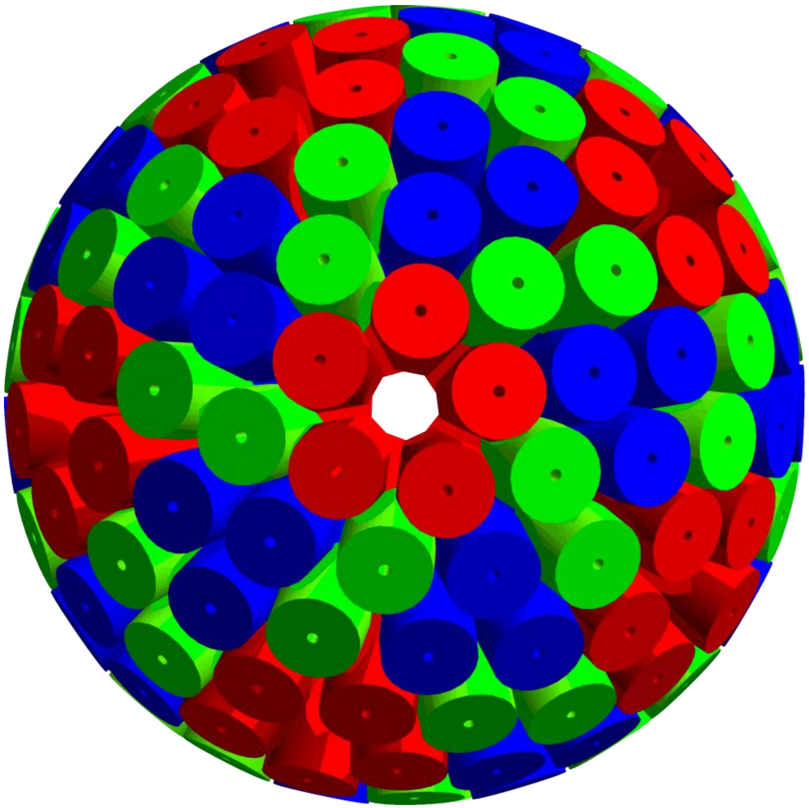
Reconstruction of tracks evaluating permutations of interaction points



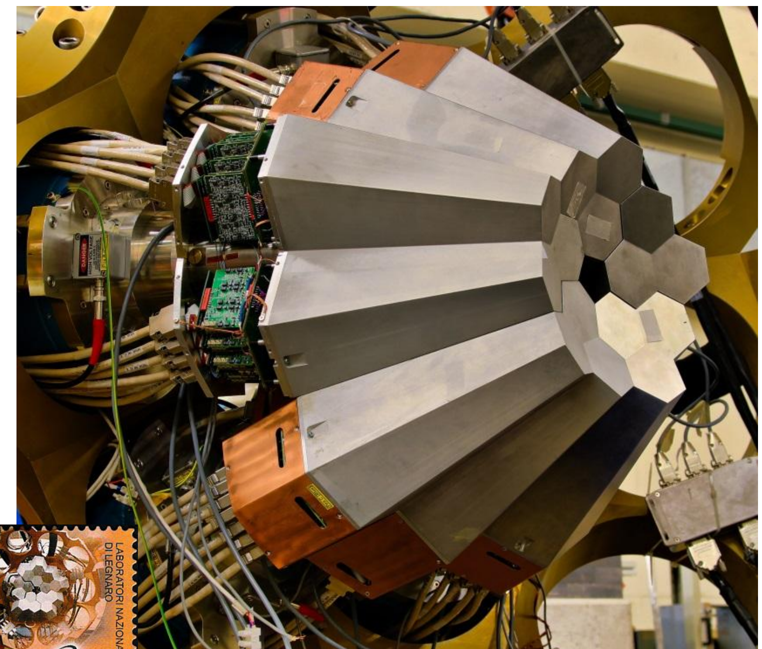
gamma first interaction point within few mm !!

Energy and direction of γ-rays

The AGATA (Advanced-Gamma-Tracking-Array) project



Demonstrator campaign
@ Legnaro National Lab.



180 n-type 36-fold segmented HPGe
--> 60 triple clusters

ε_{ph}=43% P/T=60% <= M_γ=1 @ 1 MeV
ε_{ph}=28% P/T=52% <= M_γ=30 @ 1 MeV

5 triple clusters (15 segmented HPGe)

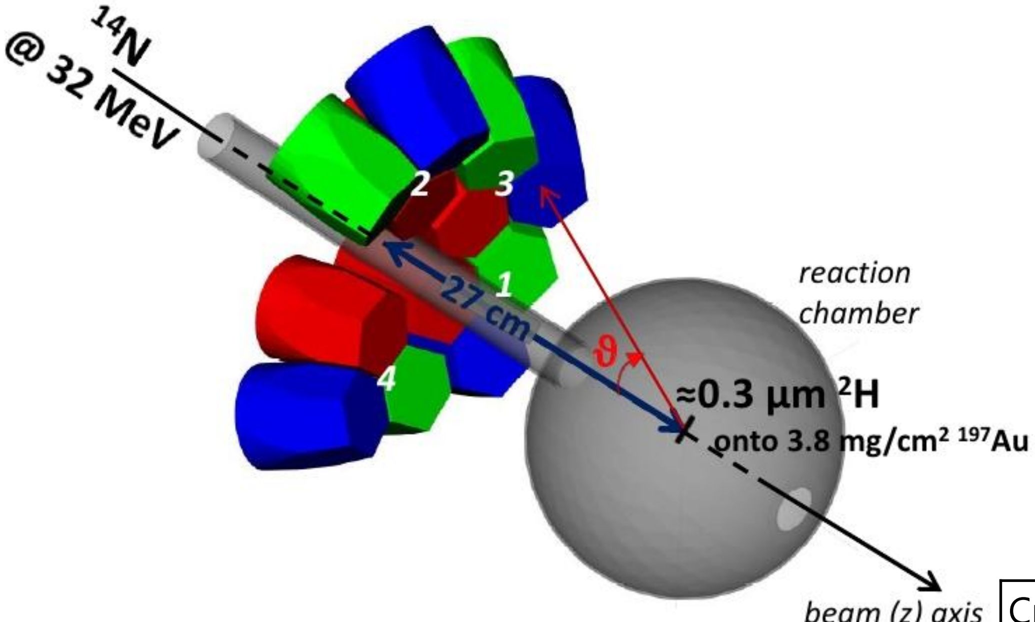
γ spectroscopy campaign @ LNL: 2009-2011

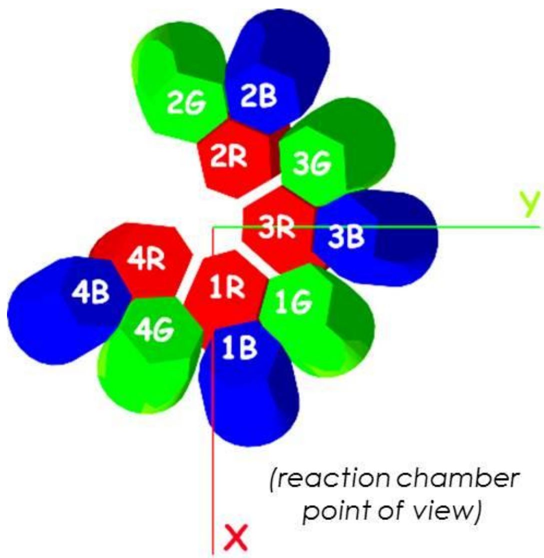
now at GANIL !!

The experiment for the measurement of the lifetime of the 6.79 MeV level in ^{15}O

^{14}N (32 MeV) + ^{2}H → mainly: **^{15}O** (Q_{gs}=5.1 MeV)

(Tandem XTU, LNL) **^{15}N** (Q_{gs}=8.6 MeV)





4 Triple Clusters of the AGATA Demon.

Crystal #	theta [deg]	cos (theta)	$\overline{E_\gamma}$ [keV]
1**R**	168.54	**-0.9800**	6403
1**G**	159.99	**-0.9396**	6417
1**B**	156.57	**-0.9175**	6425

$$\overline{E_\gamma} = E_\gamma(6792\ keV)\ \frac{\sqrt{1-\beta^2}}{1-\beta\ cos\theta} \qquad \beta = \left|\frac{\vec{v}}{c}\right| = 0.06$$

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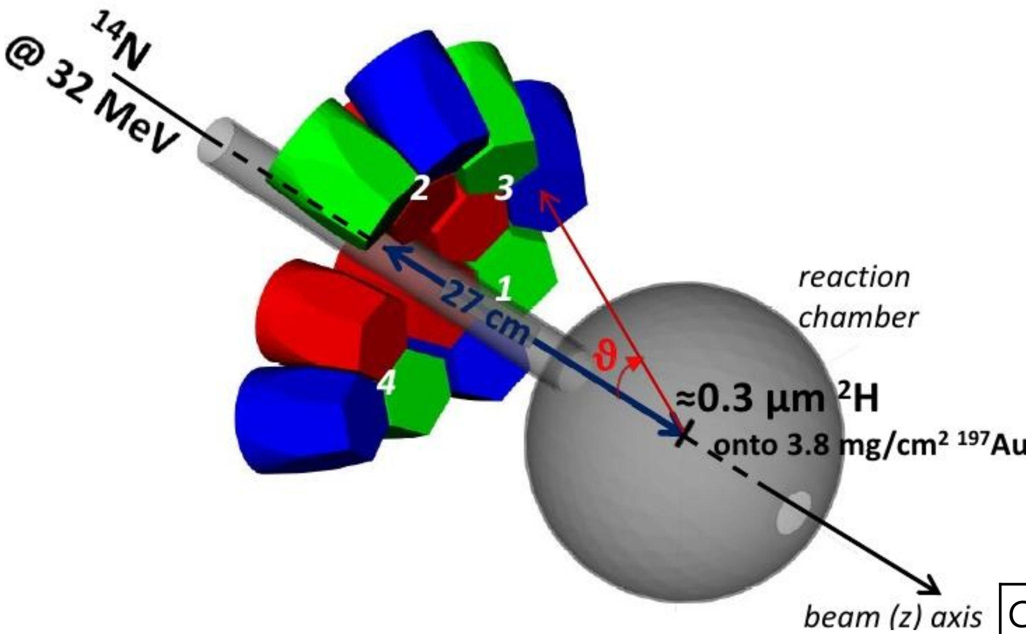
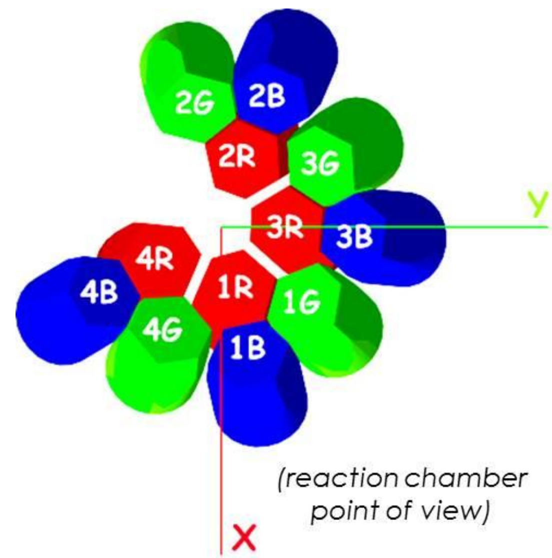
(Tandem XTU, LNL)





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4ATCs → 4 x 3 x (36+2) = 456 channels to be handled in the analysis!!!

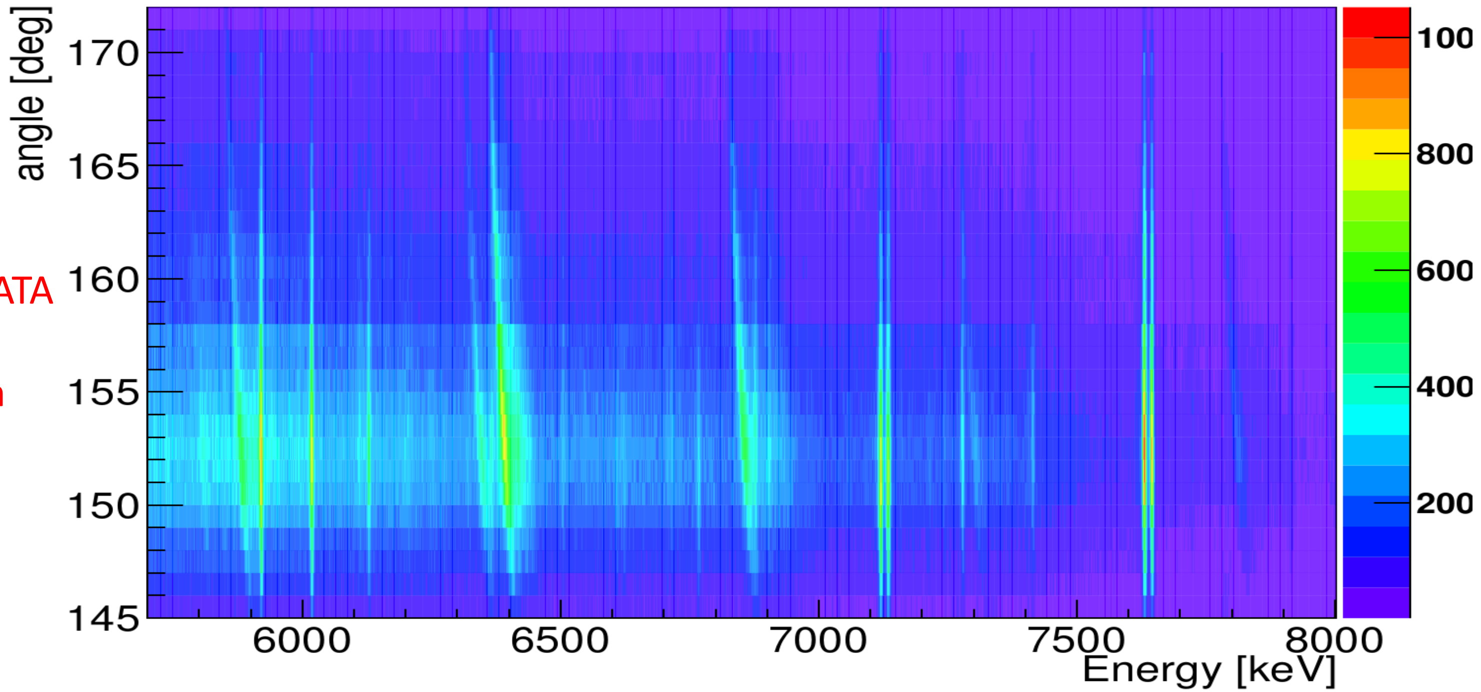
TOT data stored on disk ≈ 6.9 TB

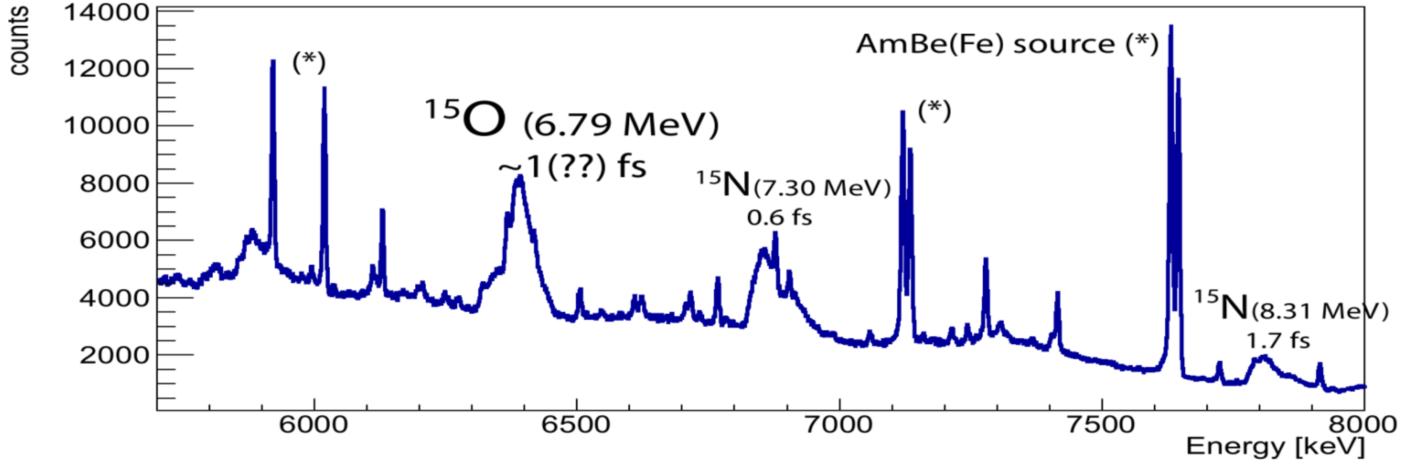
$$\overline{E_\gamma} = E_\gamma(6792\ keV)\ \frac{\sqrt{1-\beta^2}}{1-\beta\ cos\theta} \qquad \beta = \left|\frac{\vec{v}}{c}\right| = 0.06$$

Data sorting: θ of the first interaction point *vs* γ energy

4 mm AGATA position resolution

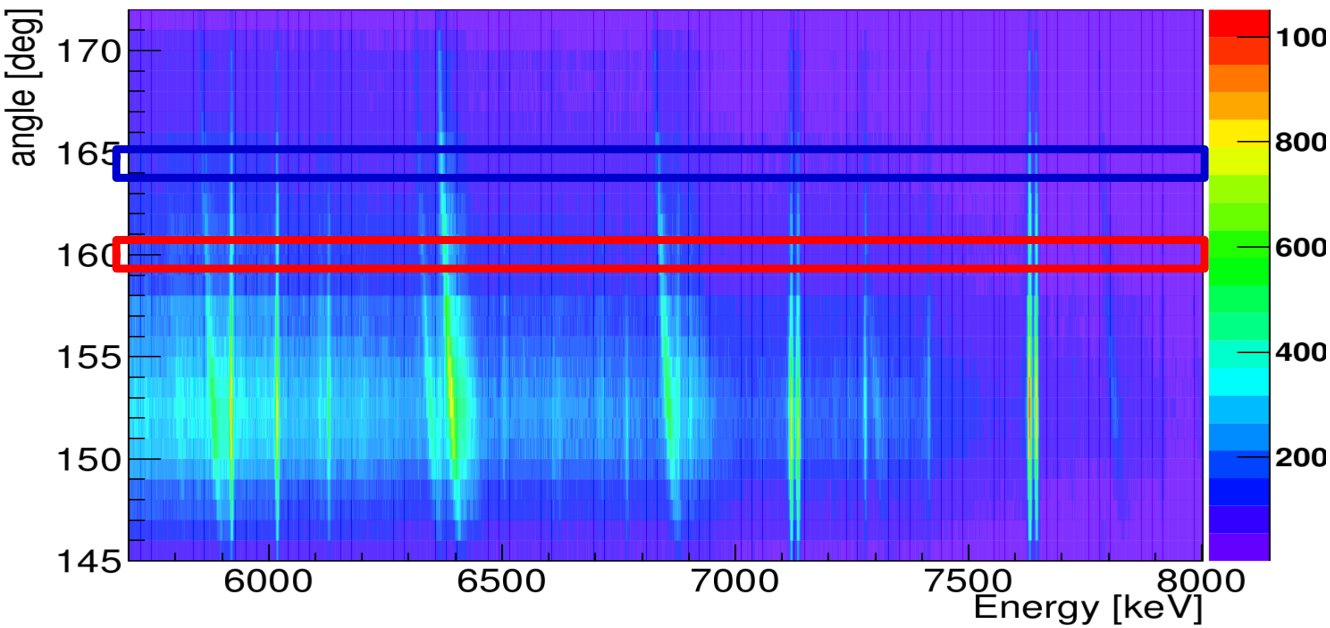
2 degree "θ slices"

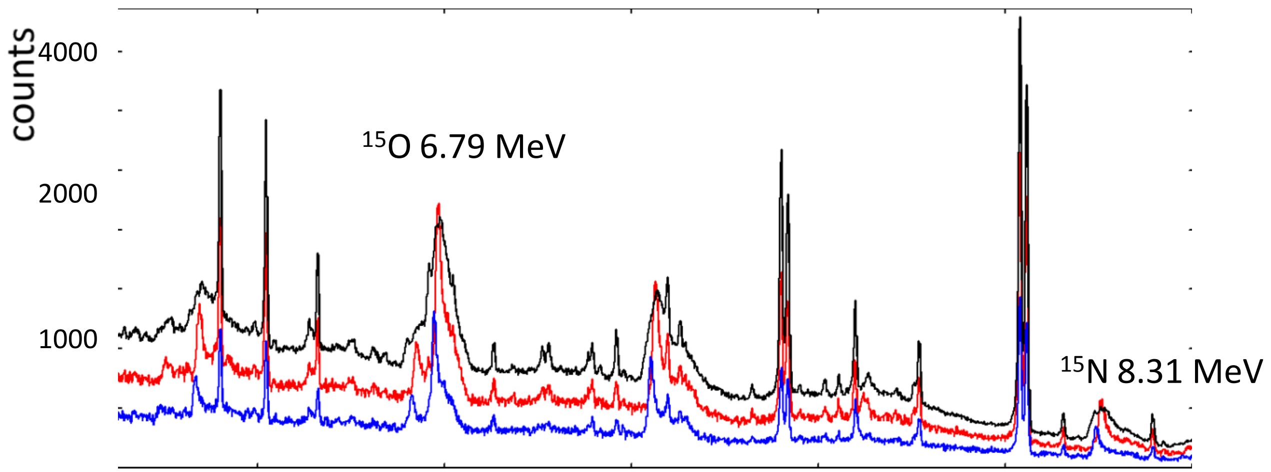




Data sorting: θ of the first interaction point *vs* γ energy

θ slice selection





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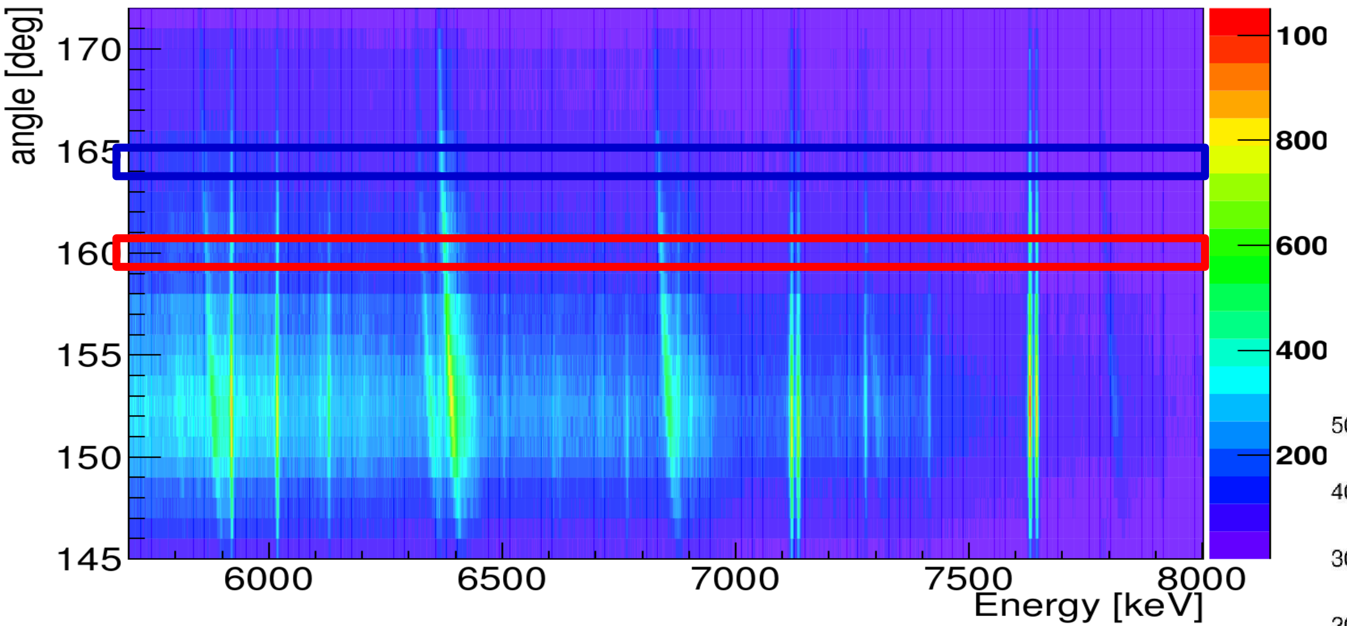

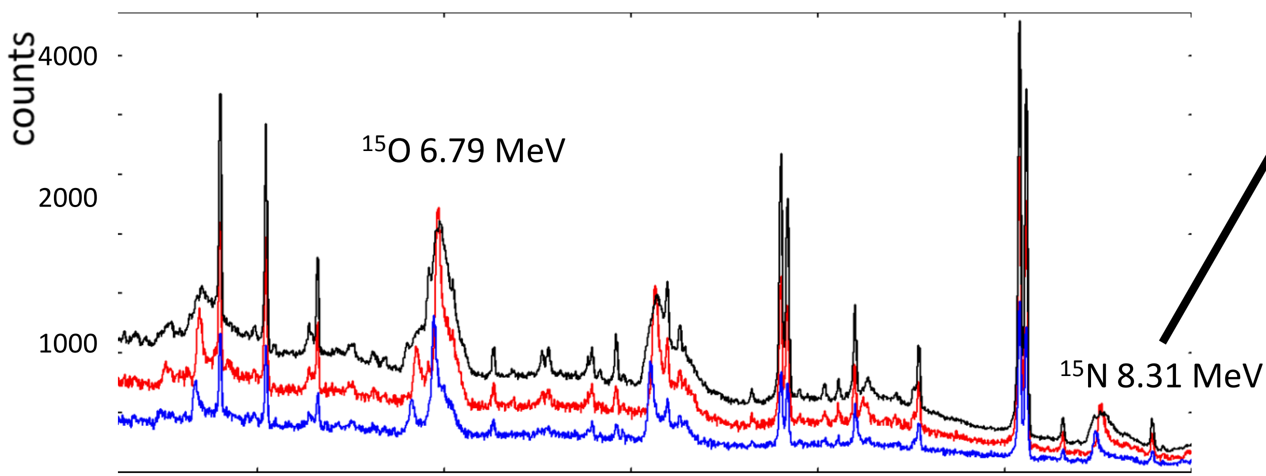

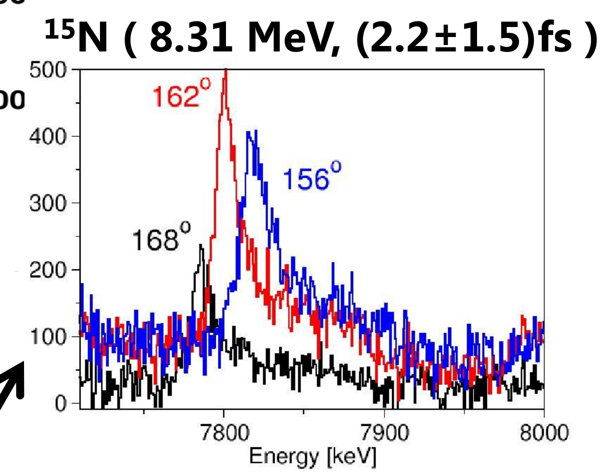

Lineshape analysis ⇔ comparison between simulated and experimental spectra

Monte Carlo simulation inputs

Geant4 simulations for *DS* lifetime measurements

1. geometry of the AGATA Demonstrator
2. deuterium distribution profile
3. nuclear reaction and characteristics of the produced nucleus
4. kinematics of the reaction products
5. level scheme of the emitting nucleus

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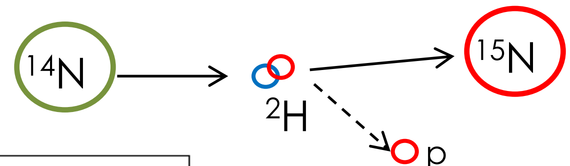
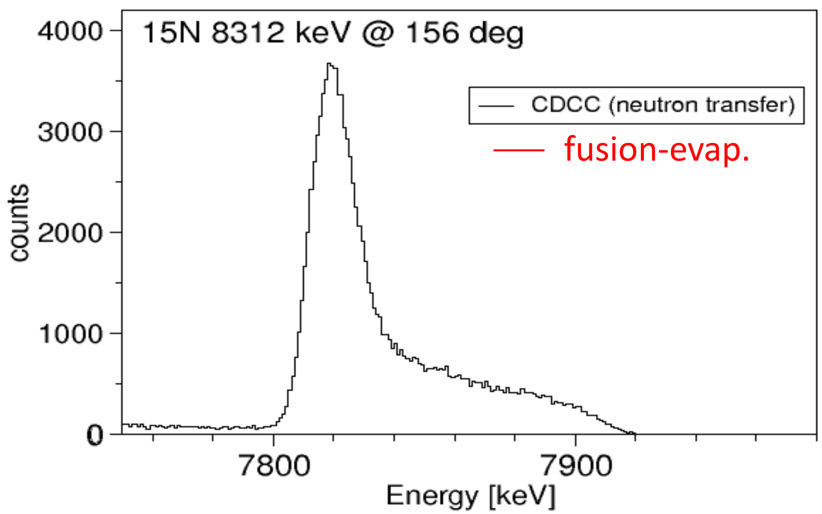
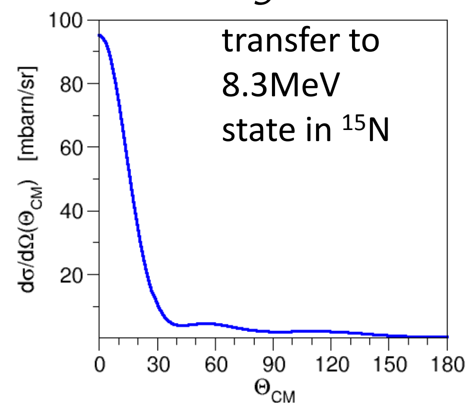
Kinematics of the emitting nuclei

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





center of mass angular distribution:

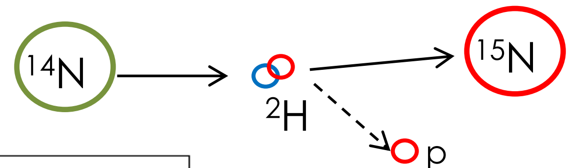


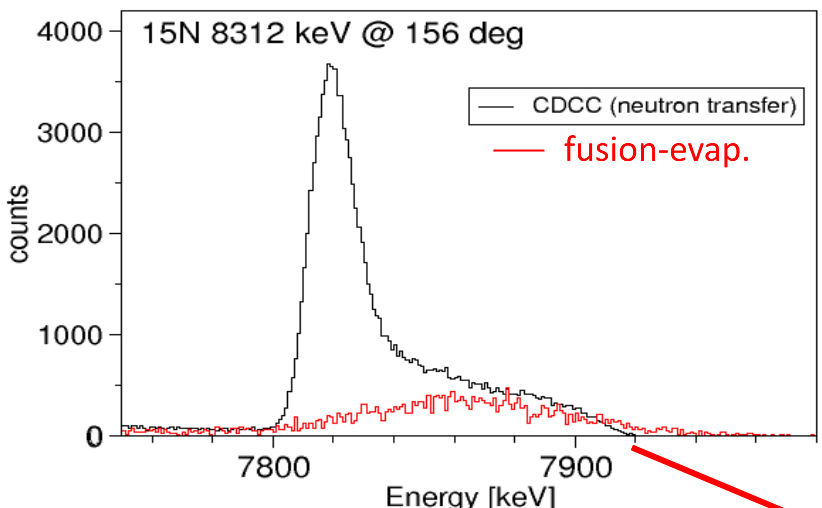
CDCC calculations of the nucleon transfer process by N. Keeley**

***Continuum-Discretized Coupled Channels*

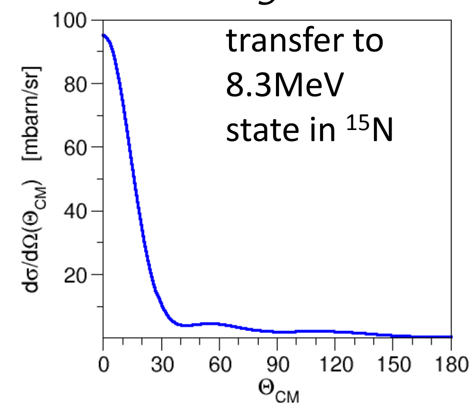
Kinematics of the emitting nuclei

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





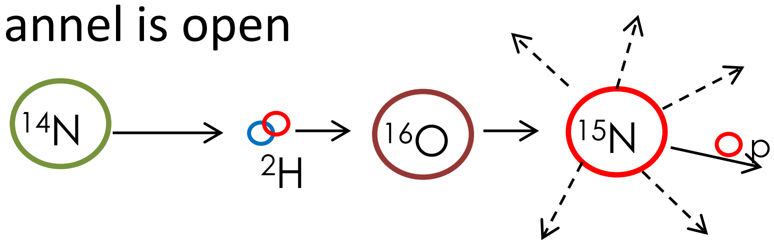
center of mass angular distribution:



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

***Continuum-Discretized Coupled Channels*

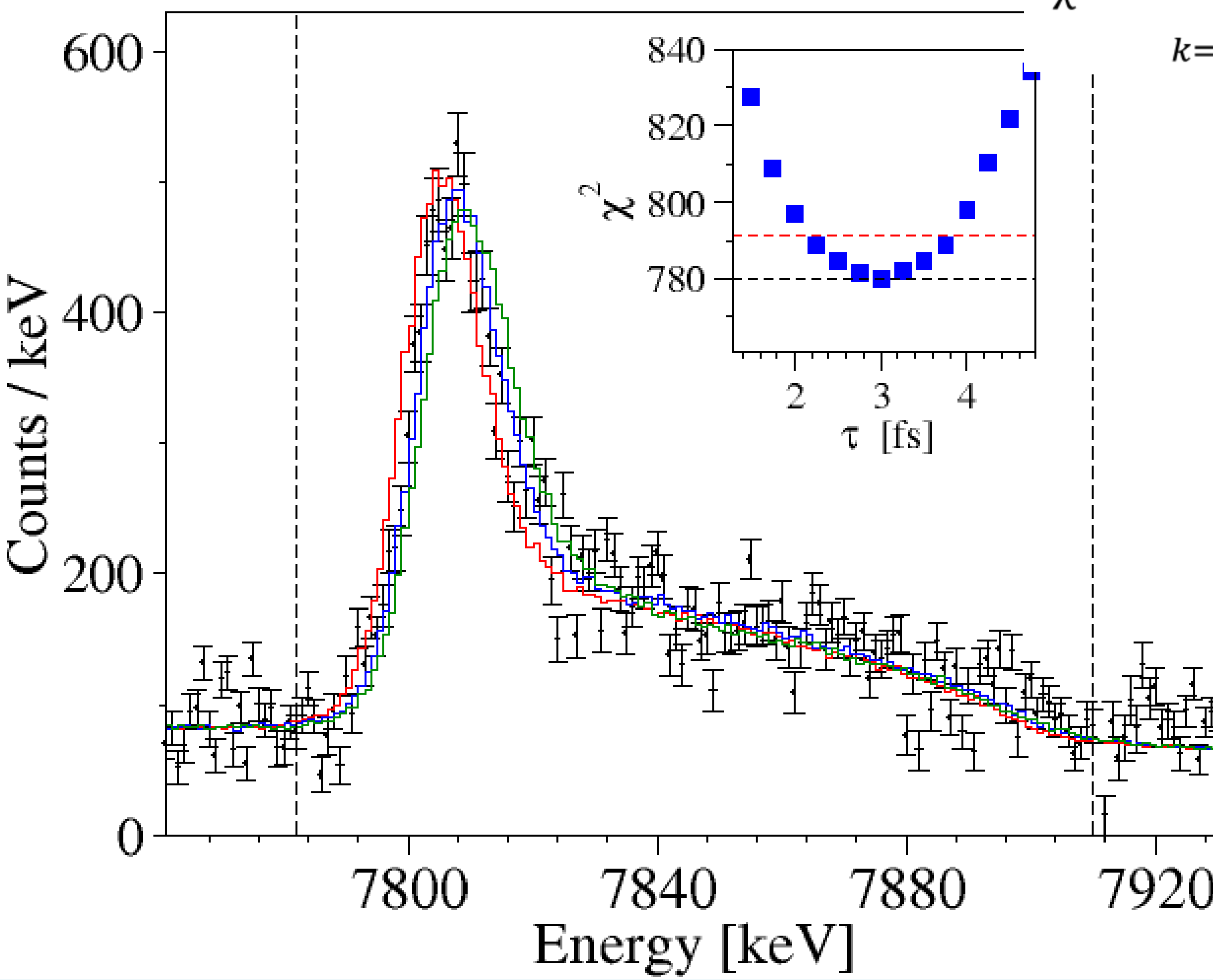
but also the fusion-evaporation channel is open



Lineshape analysis: lifetime of the 8.31 MeV state in ^{15}N

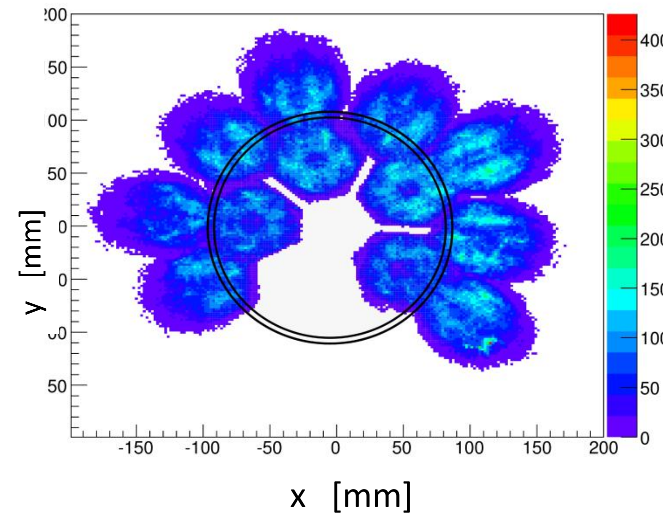
test case !

Experimental (black dots) vs simulated (2fs,3fs,4fs) lineshapes



$$\chi^2 = \sum_{k=lowlim}^{uplim} \left(\frac{Exp(k) - Sim^{\tau, fe}(k)}{\sigma_{Exp}} \right)^2$$

@ 160°

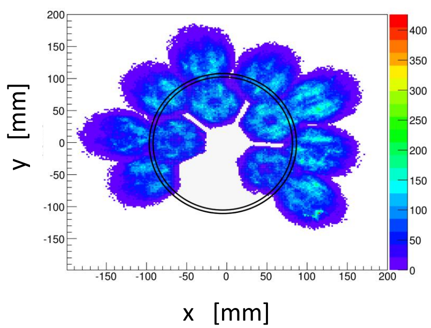


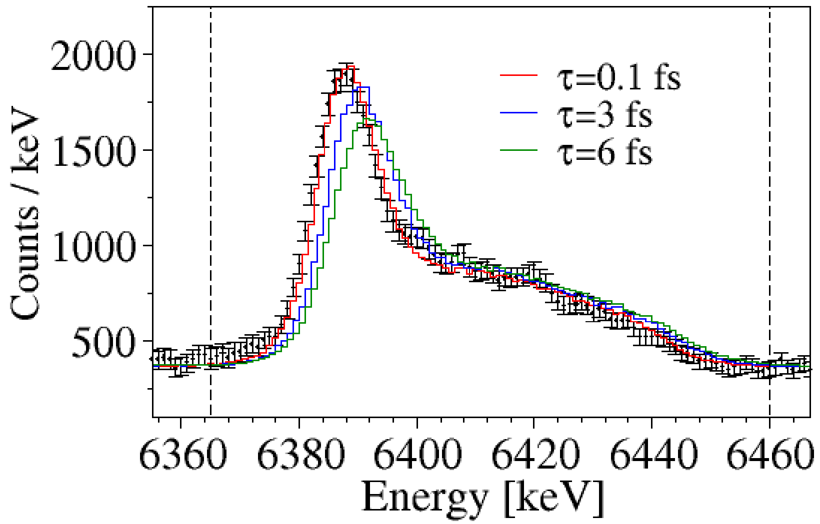
this work: τ = (3.0 ± 0.9) fs

Moreh et al.: τ = (2.2 ± 1.5) fs

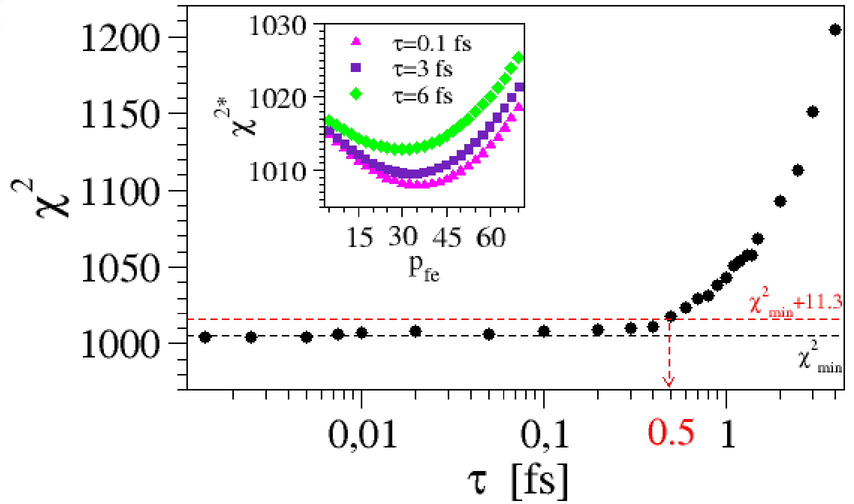
Lineshape analysis: lifetime of the 6.79 MeV state in ^{15}O

@ 160^{O}





Experimental vs simulated lineshapes



Result (independent from the fraction of fusion-evaporation to nucleon-transfer, p_{fe}):

τ < 0.5 fs (99% C.L.)

(τ < 0.4 fs (90% C.L.))

⇩

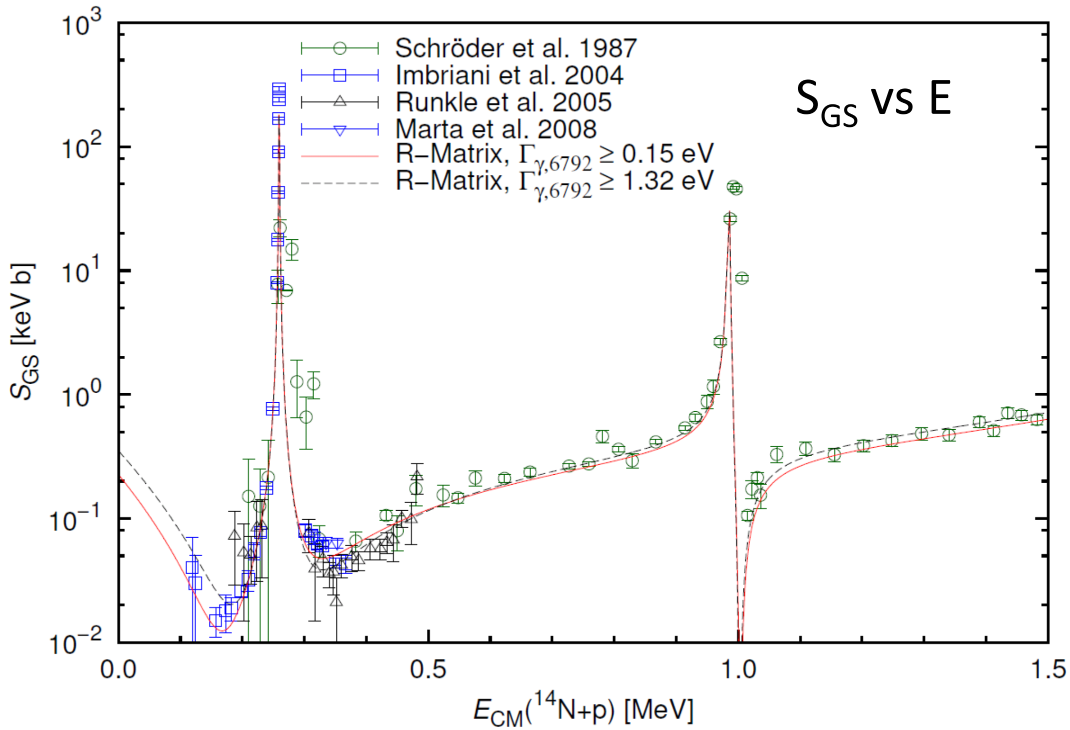
Γ > 1.32 eV (99% C.L.)

C. Michelagnoli et al., "Solar hydrogen burning probed via DSAM lifetime measurement in ^{15}O", submitted to Physical Review Letters

New limit, new R-matrix S factor calculations

TABLE I: Results of direct measurements of the lifetime of the 6.79 MeV state in ^{15}O and corresponding $\Gamma_{\gamma,6792}$ values.

Group	Technique	τ [fs]	$\Gamma_{\gamma,6792}$ [eV]
Oxford 1968 [17]	DSAM ^{14}N+^{2}H	<28	>0.02
TUNL 2001 [18]	DSAM p+^{14}N	$1.60^{+0.75}_{-0.72}$	$0.41^{+0.34}_{-0.13}$
RIKEN 2004 [19]	Coulex		$0.95^{+0.60}_{-0.95}$
Bochum 2008 [20]	DSAM p+^{14}N	<0.77 (68.3%CL)	>0.85
TRIUMF 2014 [21]	DSAM ^{16}O+^{3}He	<1.8 (68.3%CL)	>0.37
Present work	DSAM ^{14}N+^{2}H	<0.5 (99%CL) <0.4 (90%CL)	>1.32 >1.65



Direct lower limit on the formal R-matrix width, and, hence, on the ^{14}N(p,γ) reaction, for the first time. $S_{GS}(0) > 0.05$ keV b (99% C.L.)

C. Michelagnoli et al., "Solar hydrogen burning probed via DSAM lifetime measurement in ^{15}O", submitted to Physical Review Letters

Conclusions

- The data analysis of the first experiment in which advanced γ-ray tracking techniques are applied to high-energy γ ray of astrophysical interest have been performed.
- The first Doppler Shift Attenuation analysis of tracked γ rays has been performed.

  Done for this purpose:
  - modification of the existing AGATA simulation code (Geant4)
  - development of an analysis tool for DSAM for a "continuous" angular distribution of the detected γ rays
- A gain in sensitivity to ~femtosecond lifetimes has been obtained by exploiting the position resolution provided by PSA and γ-ray tracking techniques.
- The method has been tested on levels of known lifetime in ^{15}N.
- A new upper limit on the lifetime of the 6.79 MeV state in ^{15}O has been determined, $\tau < 0.5$ fs (99% C.L.) corresponding to $\Gamma > 1.32$ eV (99% C.L.)
- A direct lower limit on the formal R-matrix width, and, hence, on the $^{14}N(p,\gamma)$ reaction, has been obtained for the first time → Open road to the determination of Stot(0) at better than 5% → solution of the *Solar Composition problem* !

Perspectives

- Still accurate value of the lifetime of the 6.79 MeV state in ^{15}O is needed … :

  Coulomb excitation of radioactive ^{15}O beam at GANIL (SPIRAL1) using AGATA for the detection of the gamma rays

- The sensitivity to femtosecond lifetimes of AGATA is really promising!

  Other astrophysical application:

  the lifetime of the 7.786 MeV state in ^{23}Mg (novae explosions) → accepted experiment by the last GANIL Program Advisory Commitee

Perspectives

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<u>Grazie</u> a tutti coloro che hanno reso questo lavoro possibile! In paricolare …

Dino Bazzacco, INFN Padova
Santo Lunardi, Università e INFN Padova
Calin Ur, ELI-NP (Romania), INFN Padova
Carlo Broggini , INFN Padova
Daniel Bemmerer , H-R, Dresden
Roberto Menegazzo, INFN Padova
…

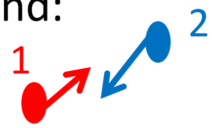
Grazie Enrico

Extra slides

stellar burning rates

$T_c \approx 16 \cdot 10^6\ K \qquad \rho_c \approx 153\ g/cm^3$

number of interactions per second:

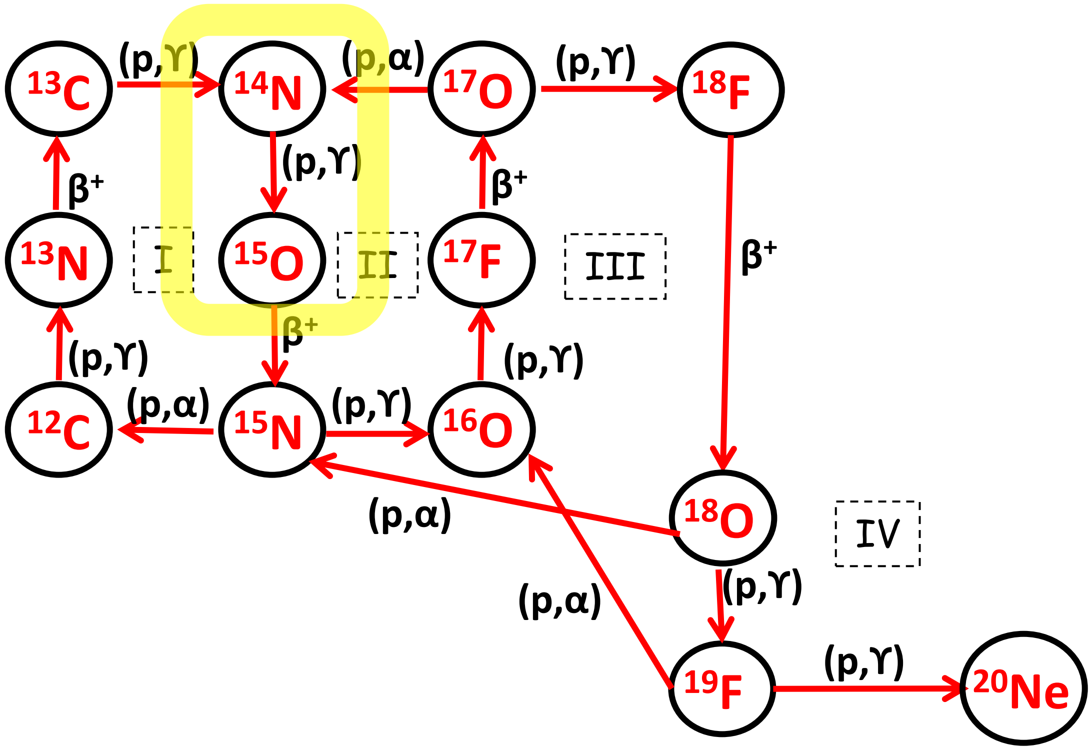


$$r_{12} = \frac{n_1 n_2}{1 + \delta_{12}} \langle \sigma v \rangle_{12}$$

$$\langle \sigma v \rangle_{12} = \sqrt{\frac{8}{\pi \mu (kT)^3}} \int_0^\infty E\ \boldsymbol{\sigma(E)}\ exp\left(-\frac{E}{kT}\right)\ dE$$

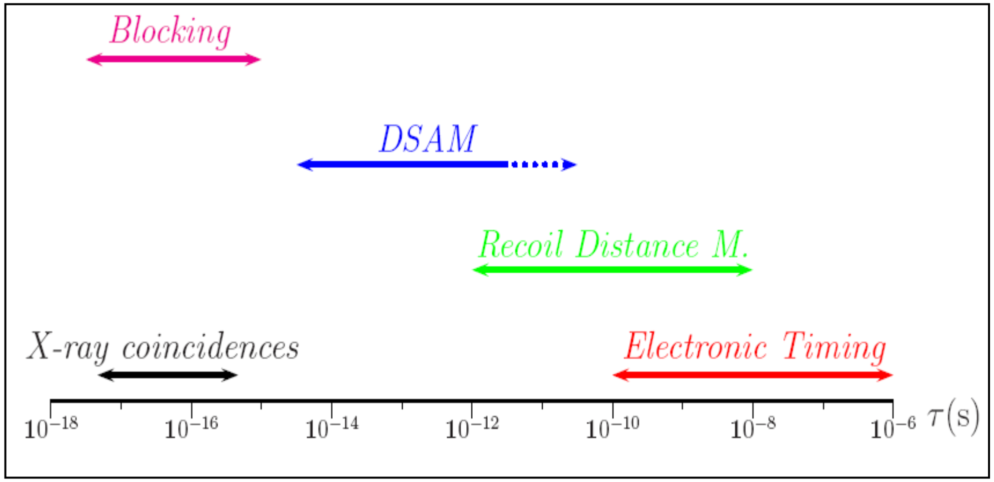
$$kT_{Sun} \approx\ 1\ keV$$

CNO cycle



13C
14N
17O
18F
13N
15O
17F
12C
15N
16O
18O
19F
20Ne
I
II
III
IV
(p,ϒ)
(p,α)
β+

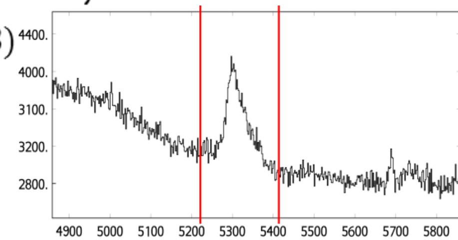
Range of lifetimes typical of different direct techniques:

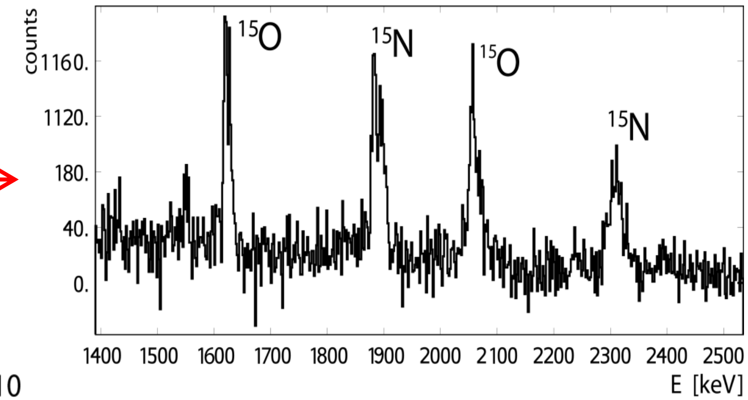


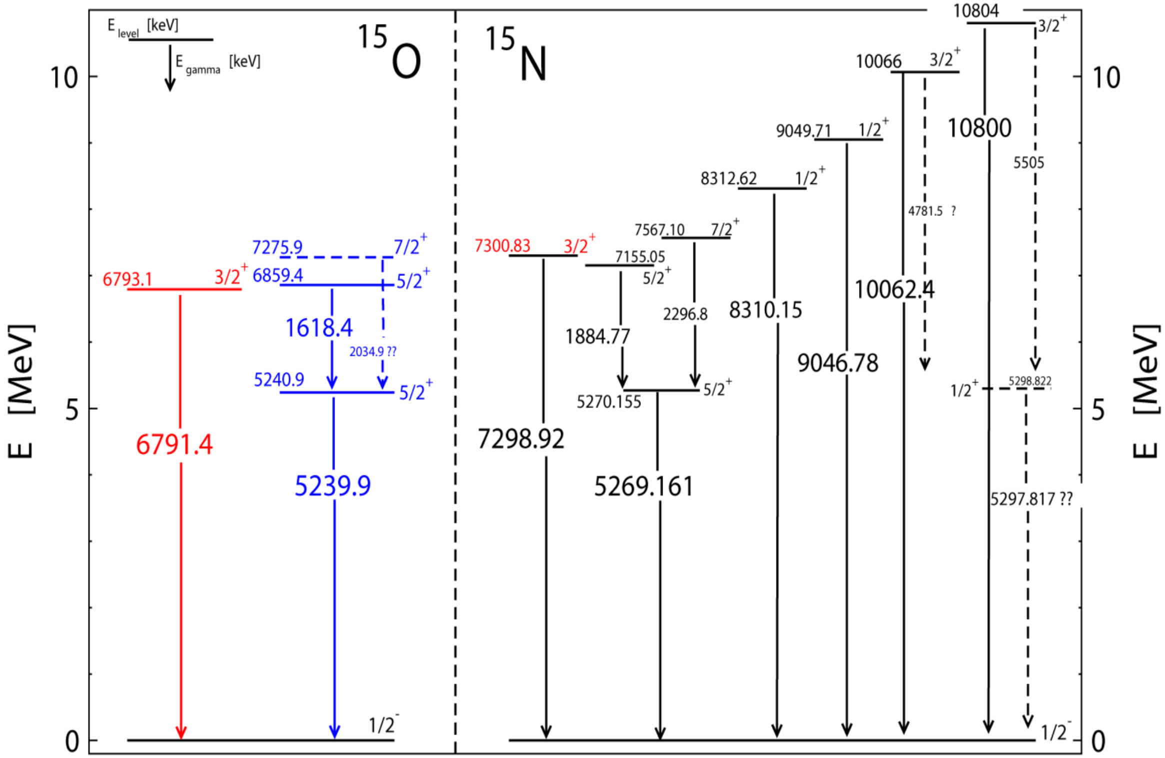
data analysis:
populated excited levels

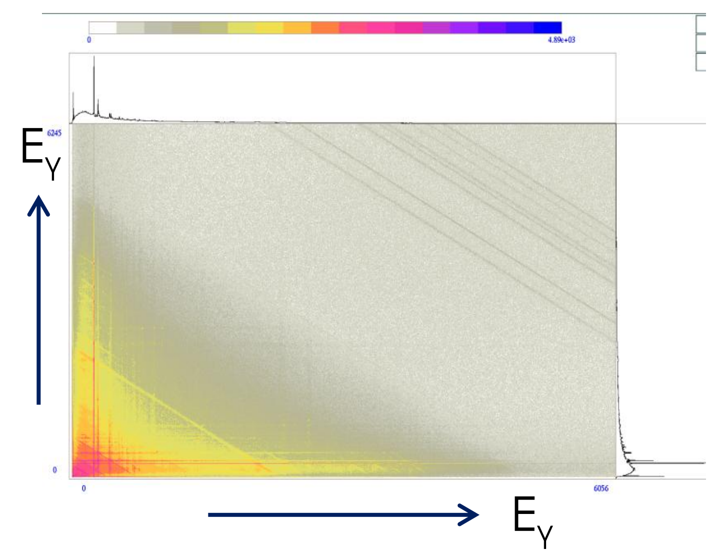
gate on ≈ 5.3 MeV (composite line)

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

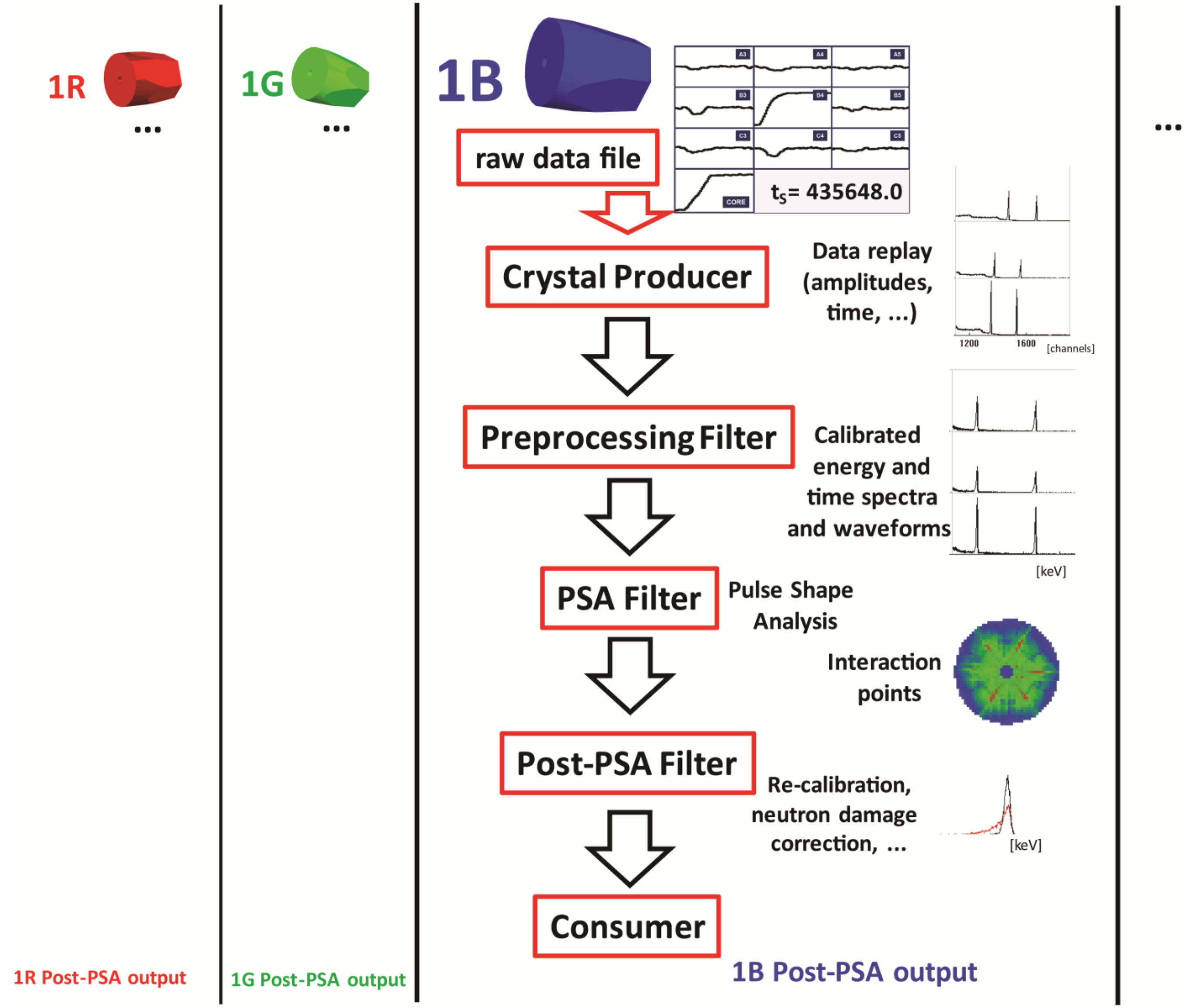






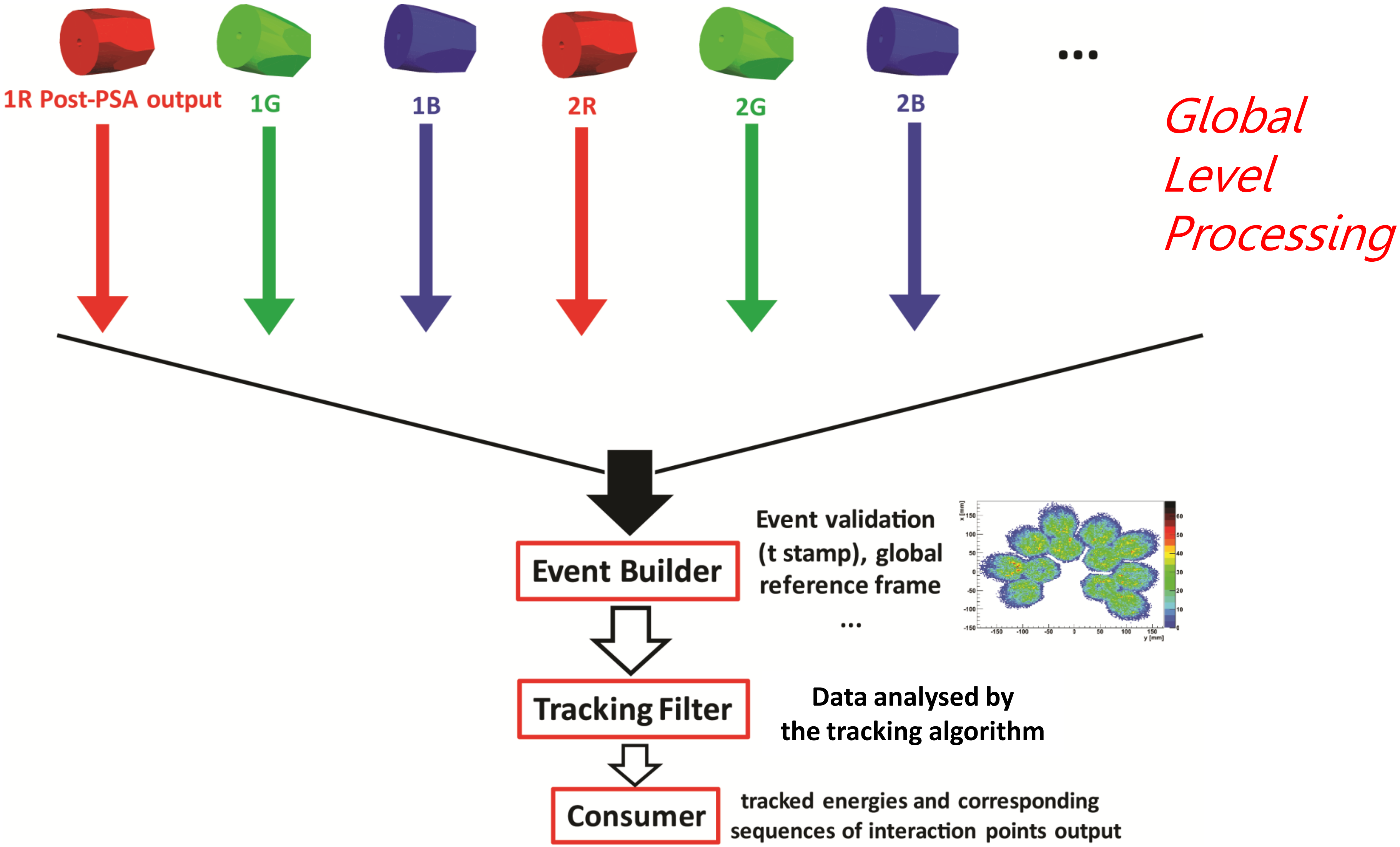


Data replay: from the raw waveforms to the PSA hits

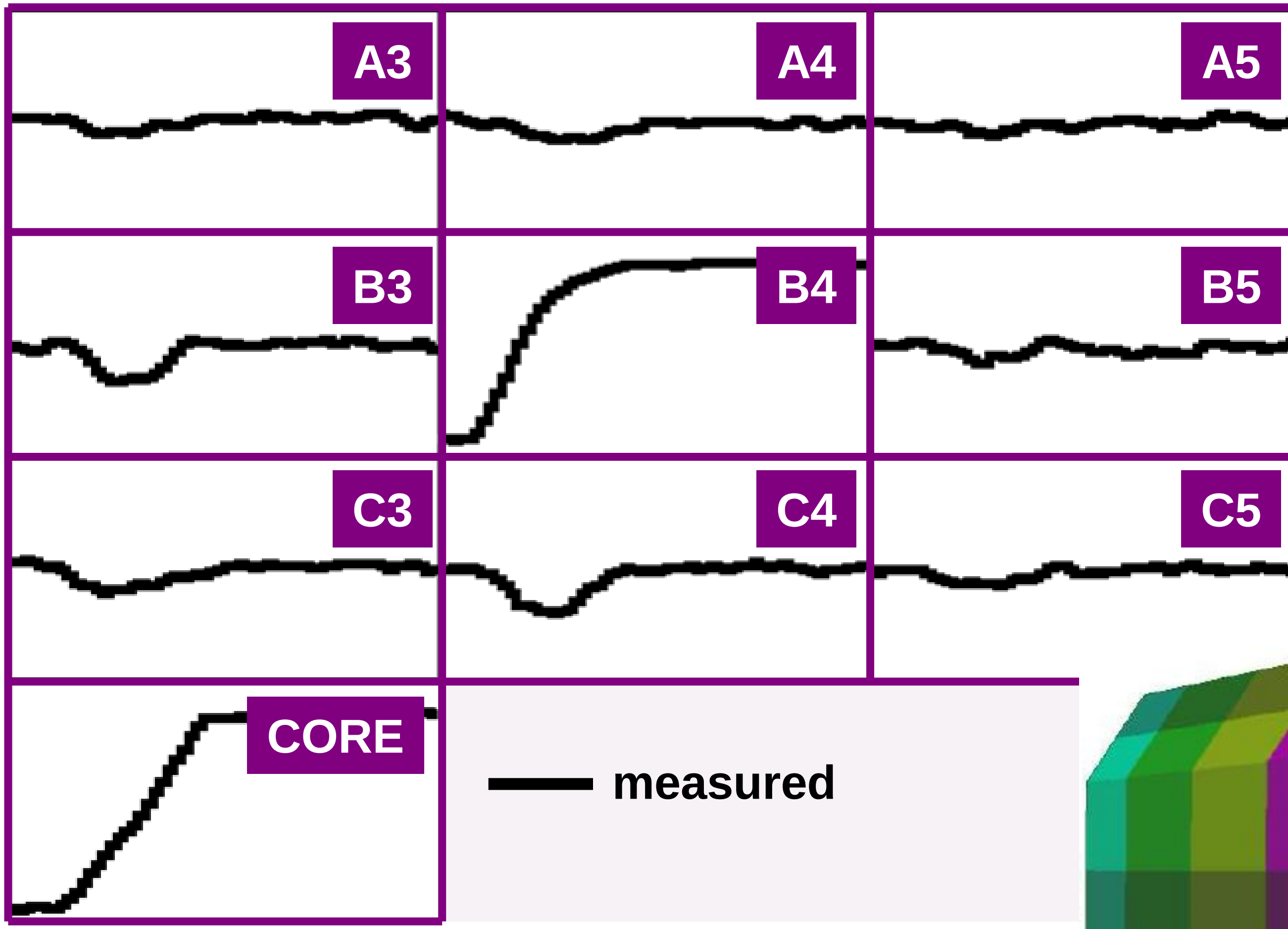


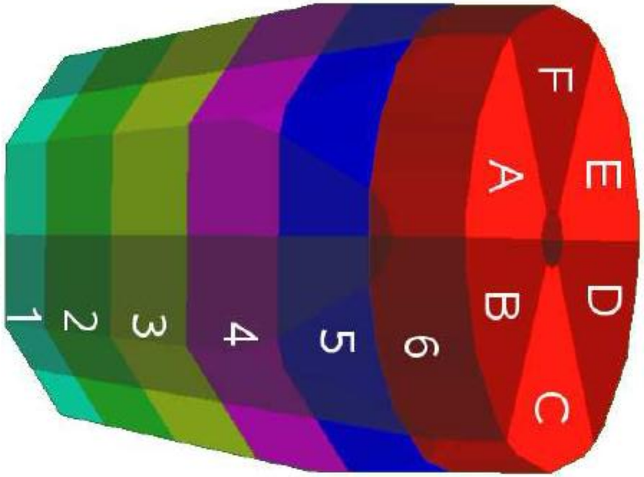
Local Level Processing

Data replay: from the PSA hits to the tracked γ events



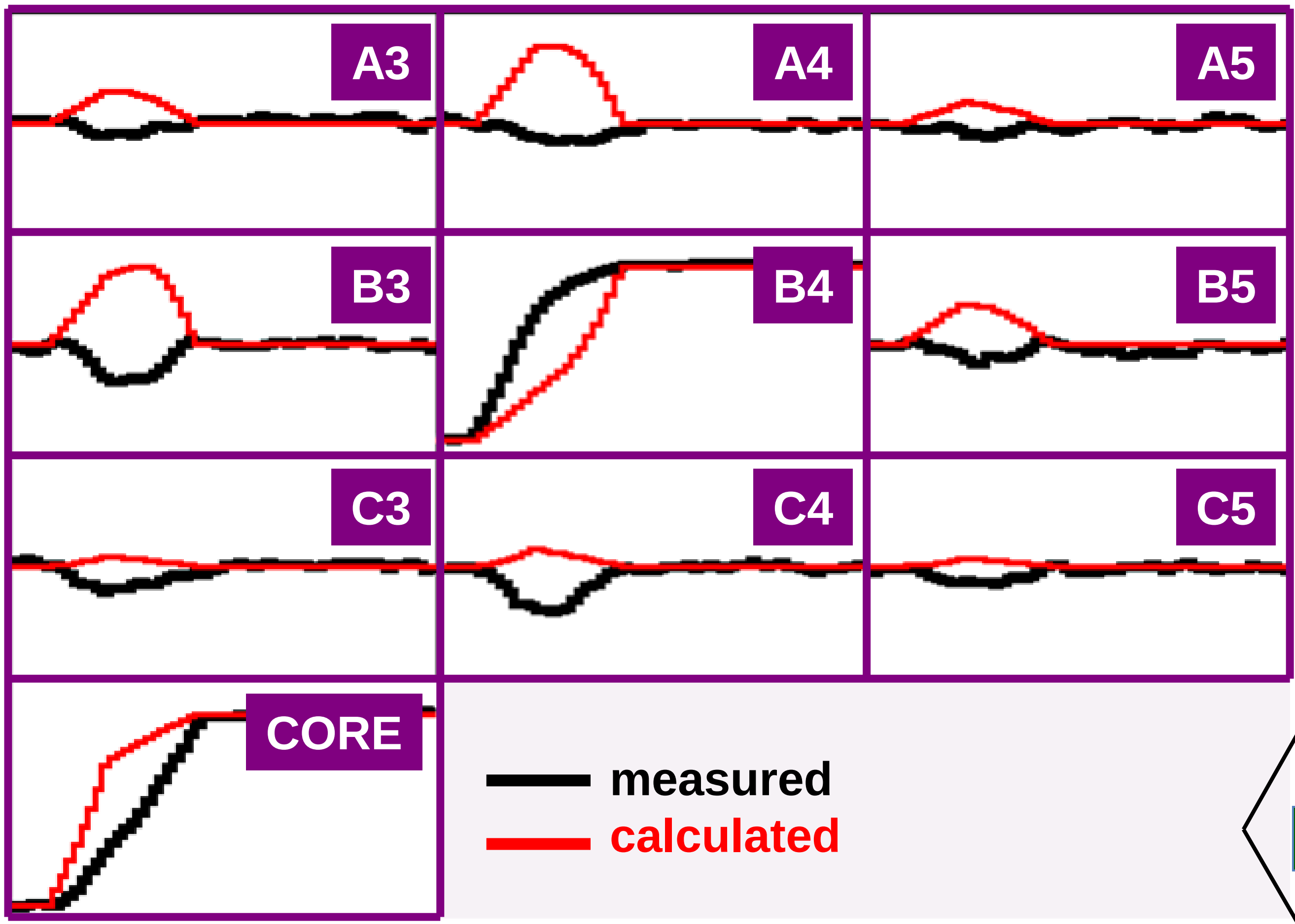
Pulse Shape Analysis concept

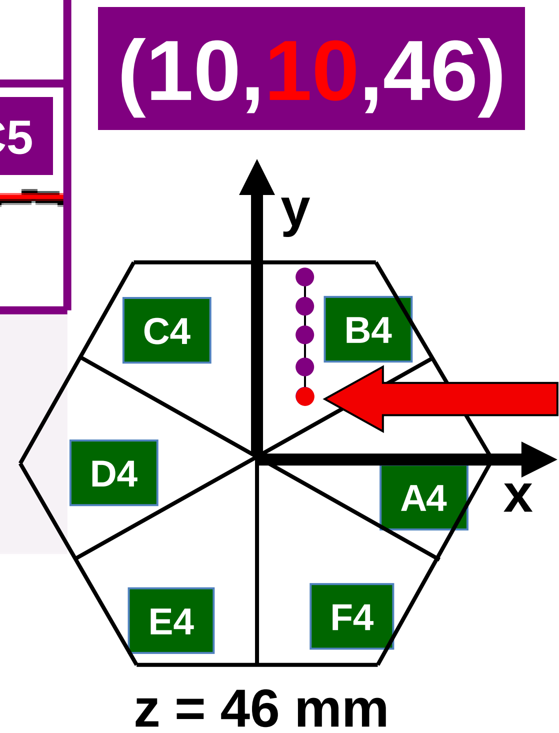




791 keV deposited in segment B4

Pulse Shape Analysis concept





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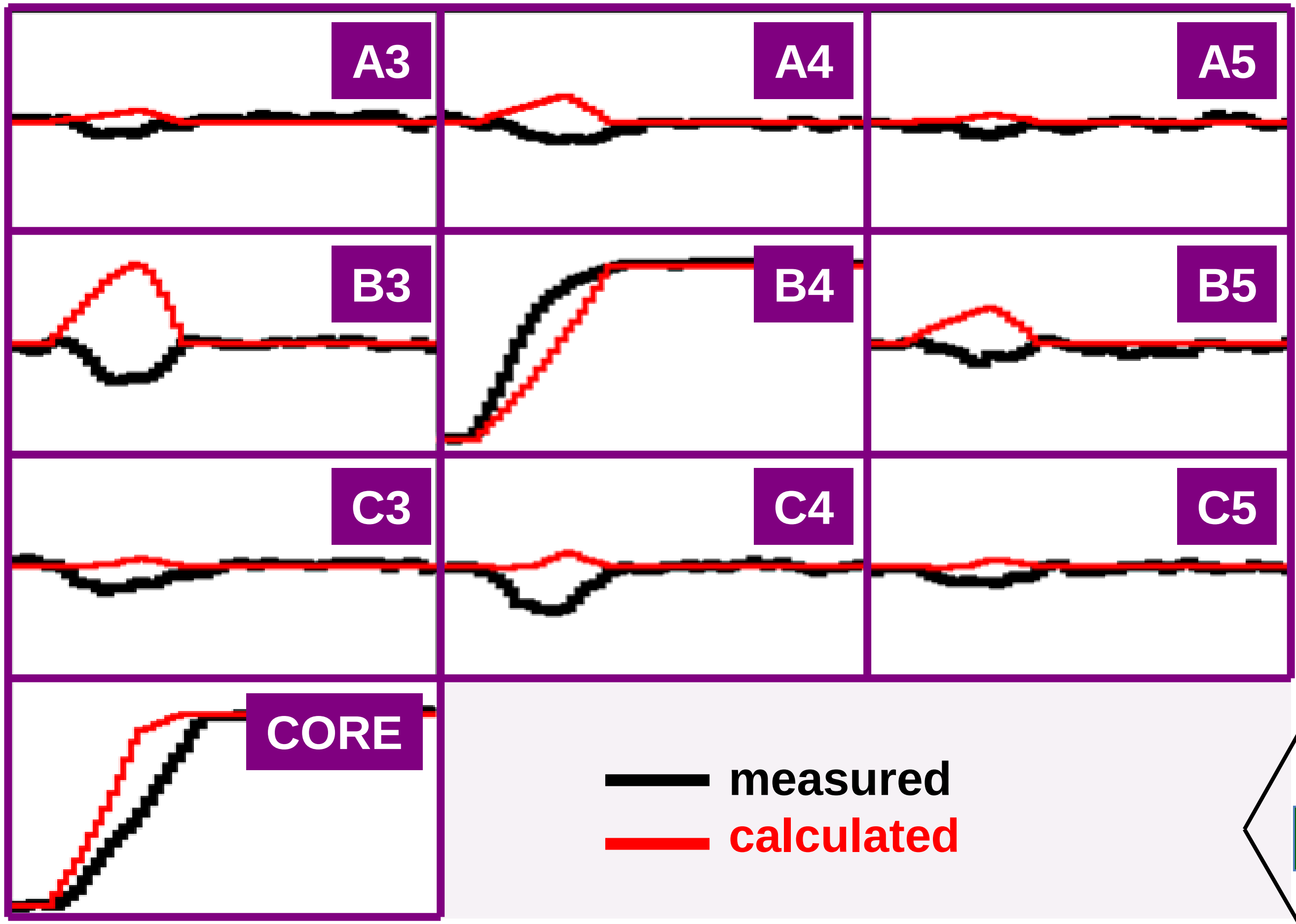
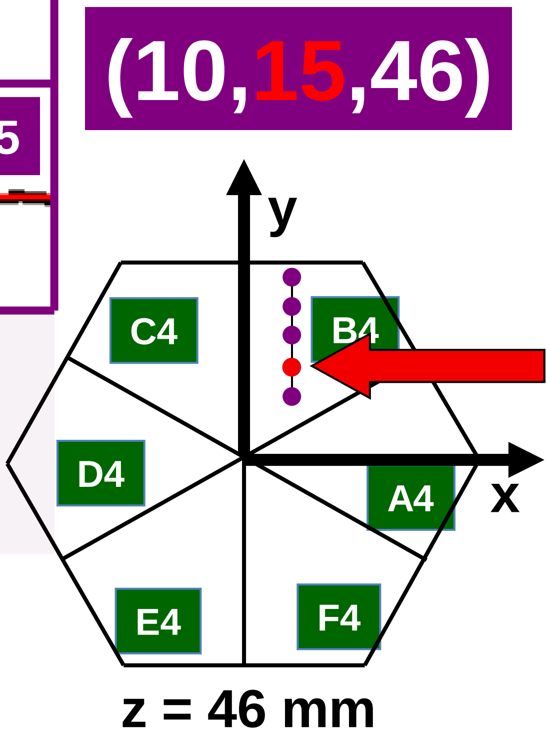
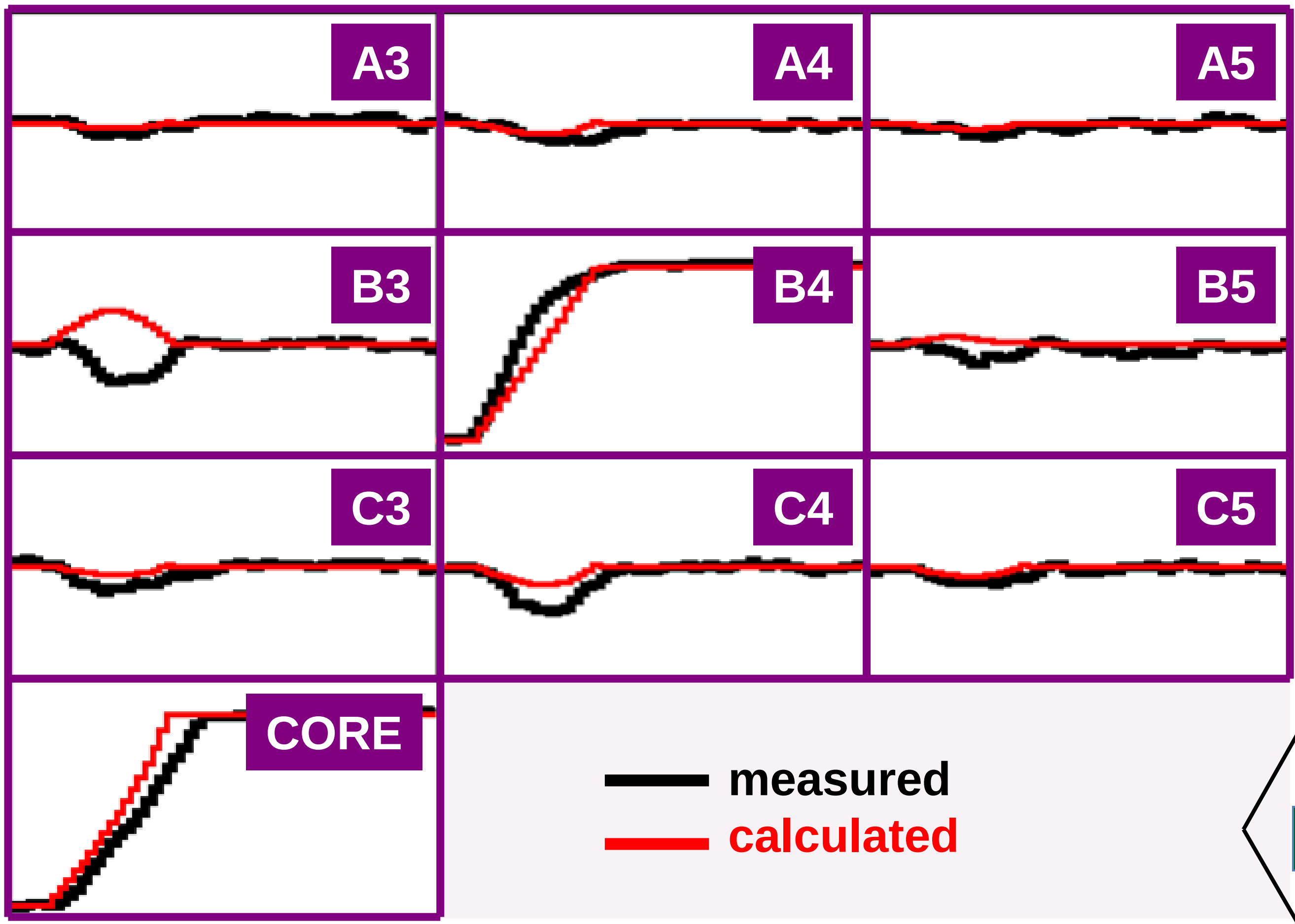


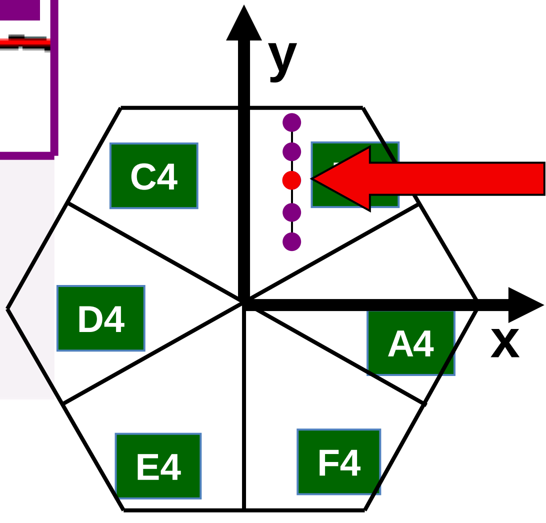


791 keV deposited in segment B4

Pulse Shape Analysis concept



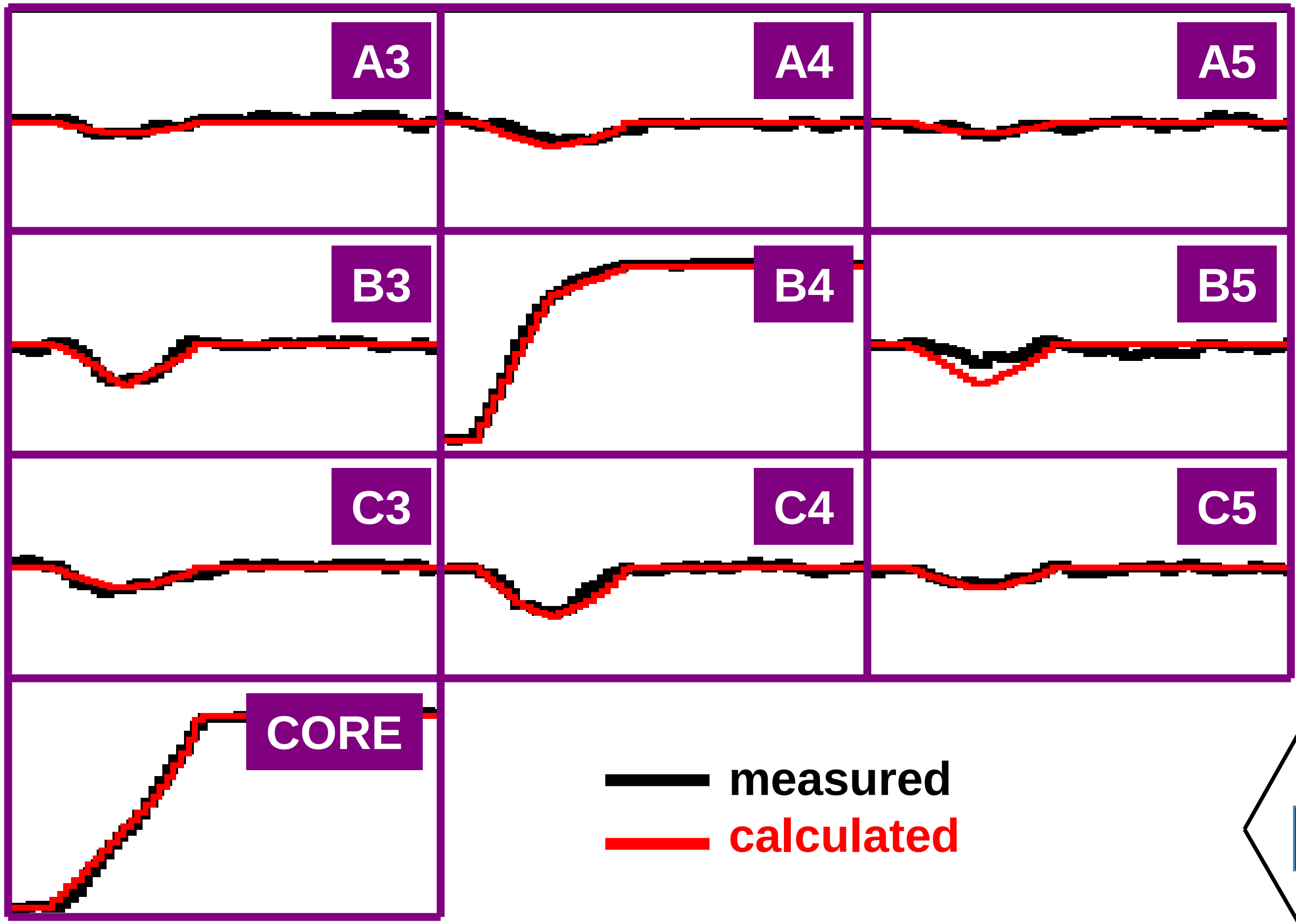
(10,20,46)

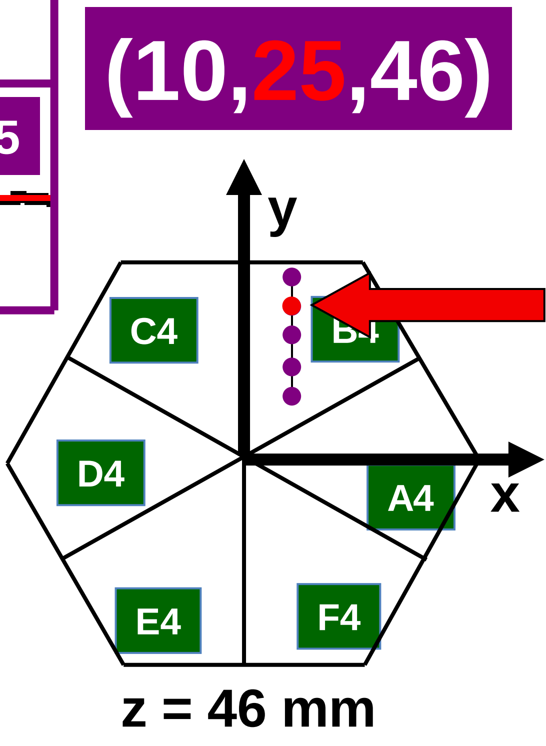


z = 46 mm

791 keV deposited in segment B4

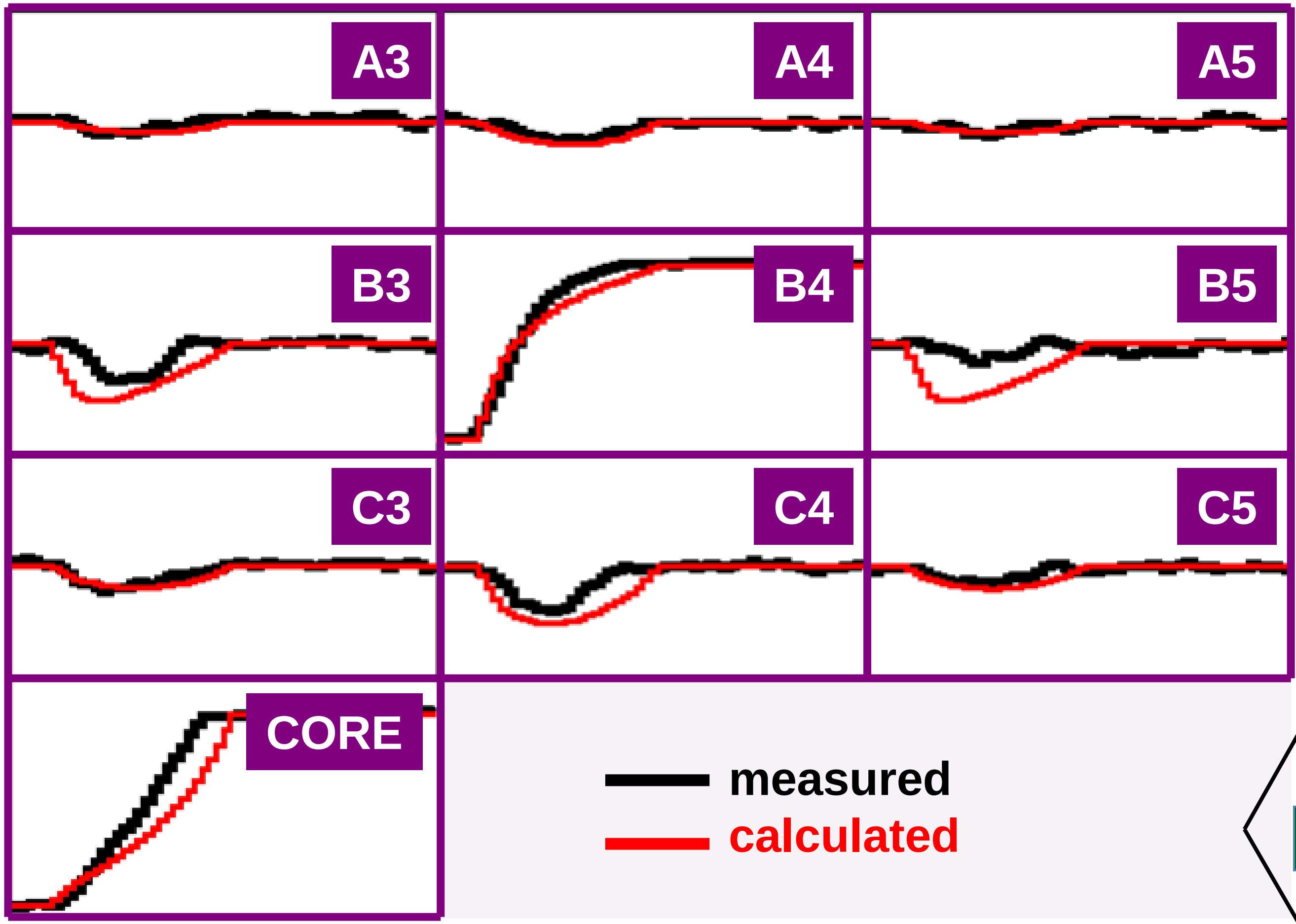
Pulse Shape Analysis concept



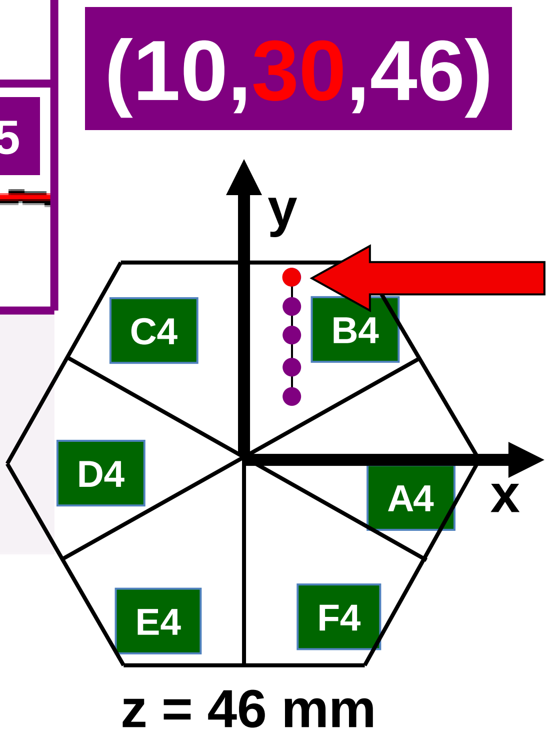


791 keV deposited in segment B4

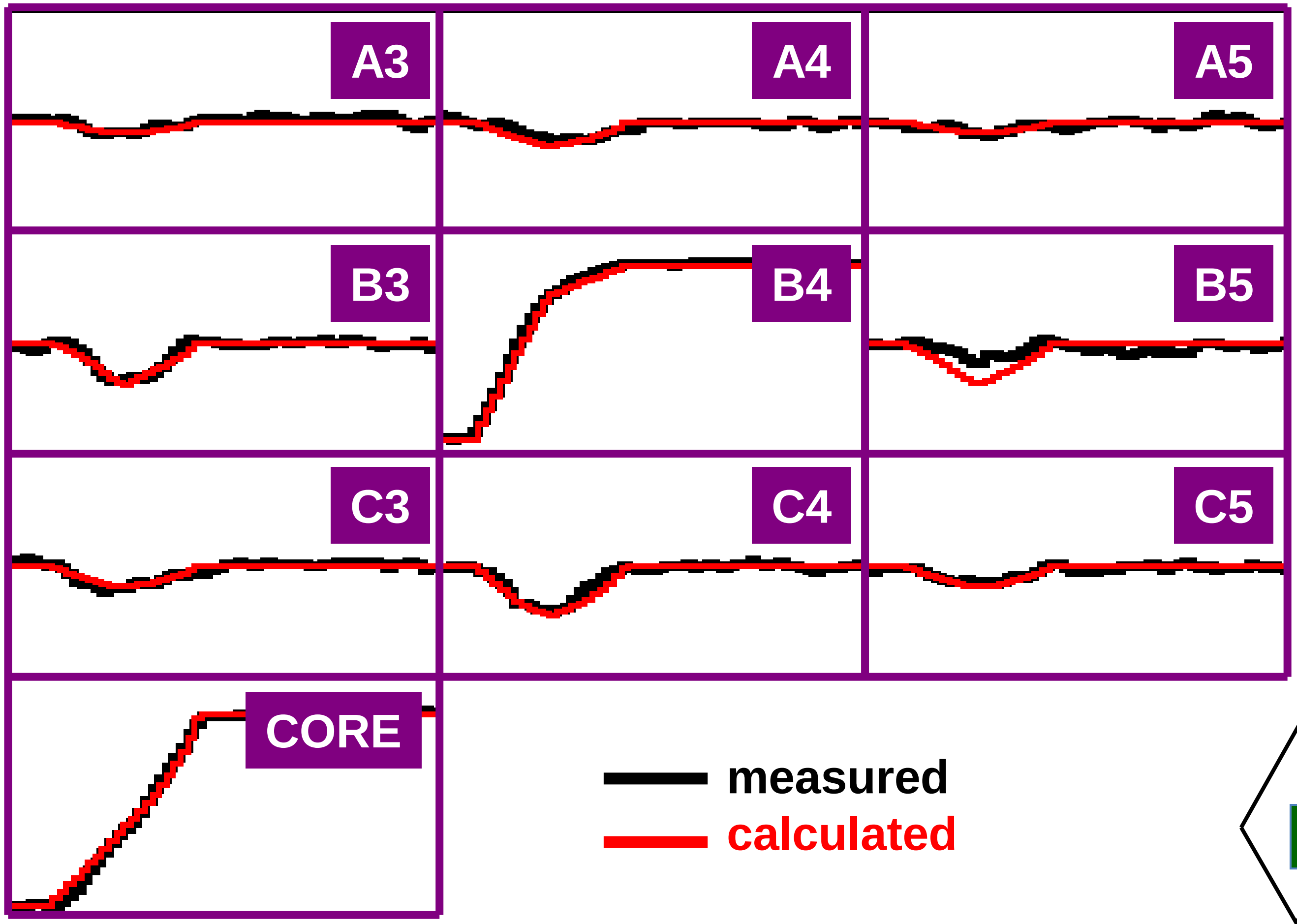
Pulse Shape Analysis concept



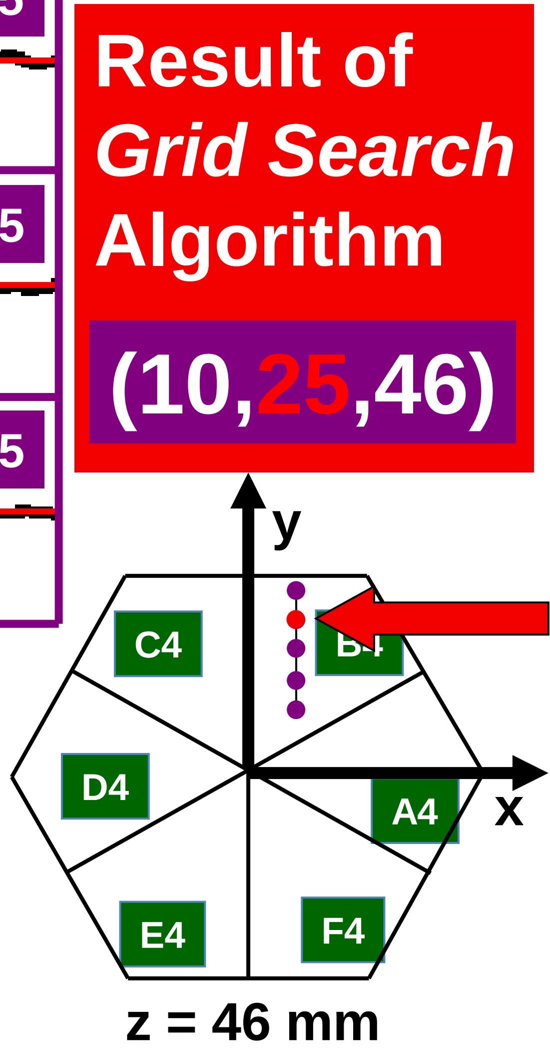
791 keV deposited in segment B4



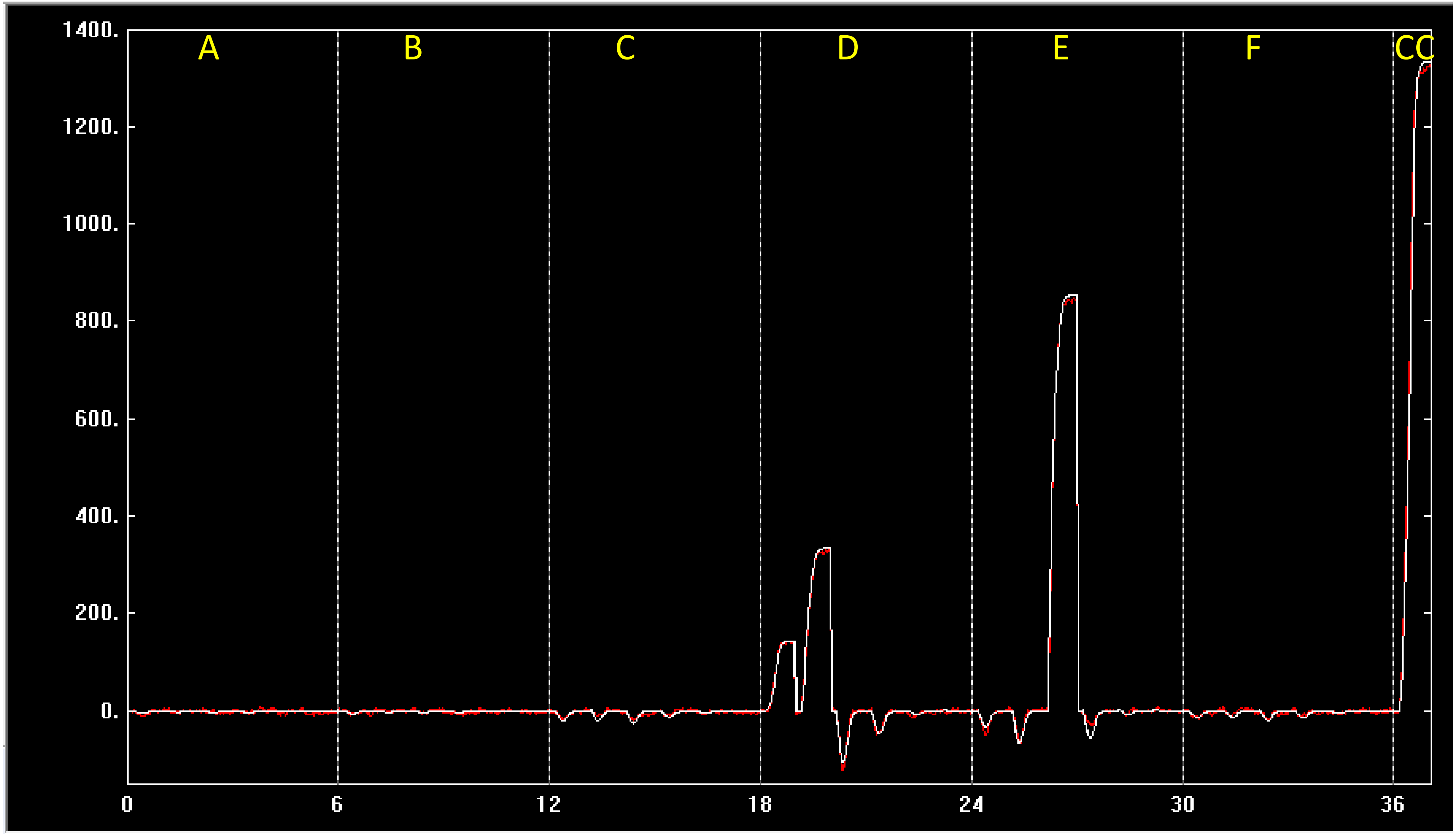
Pulse Shape Analysis concept



791 keV deposited in segment B4

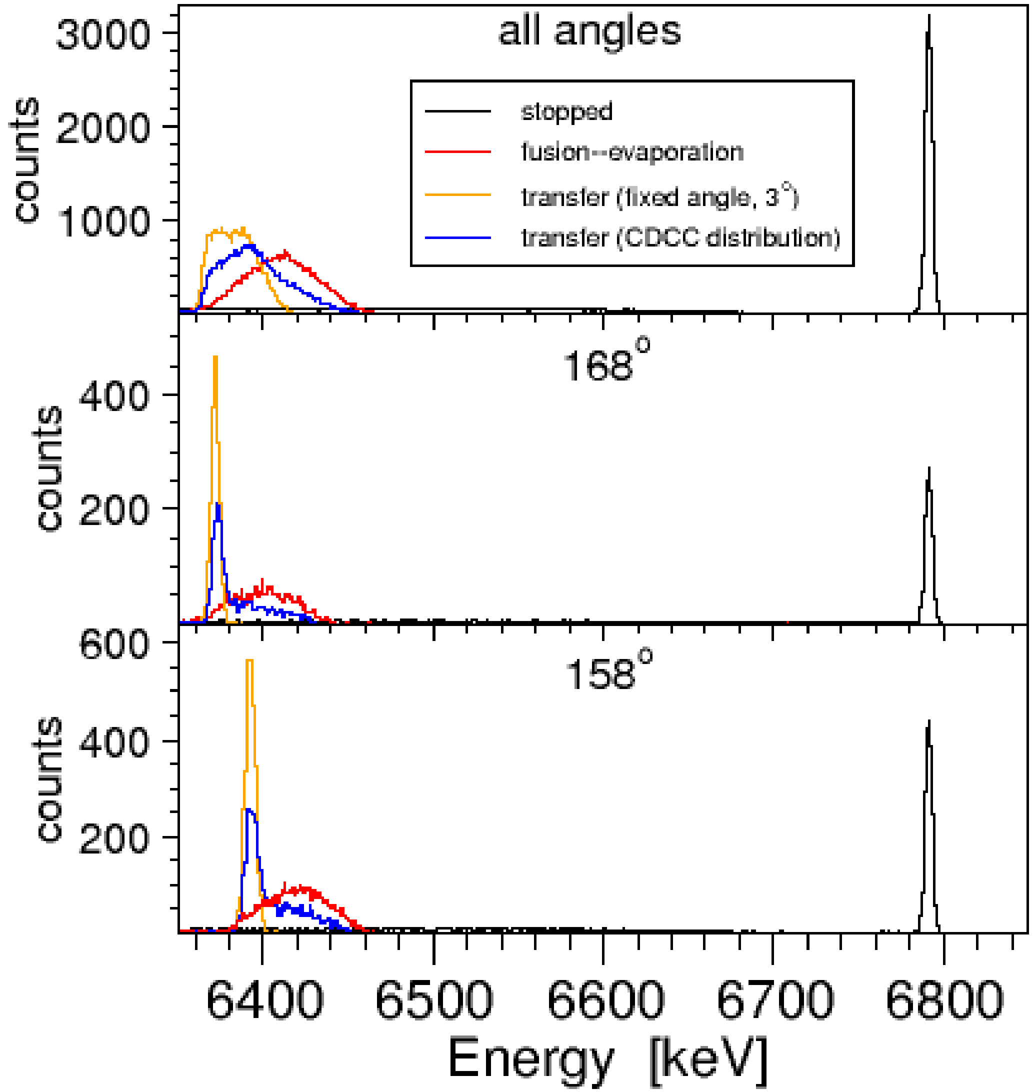


Adaptive Grid Search in action

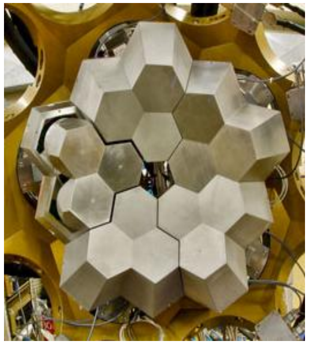


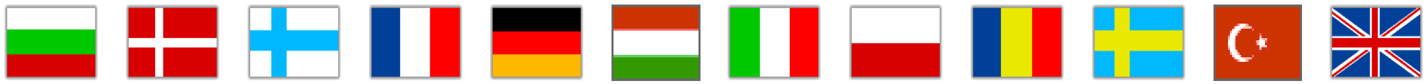
6 Final Result

Kinematics of the emitting nuclei
effect on the γ lineshape

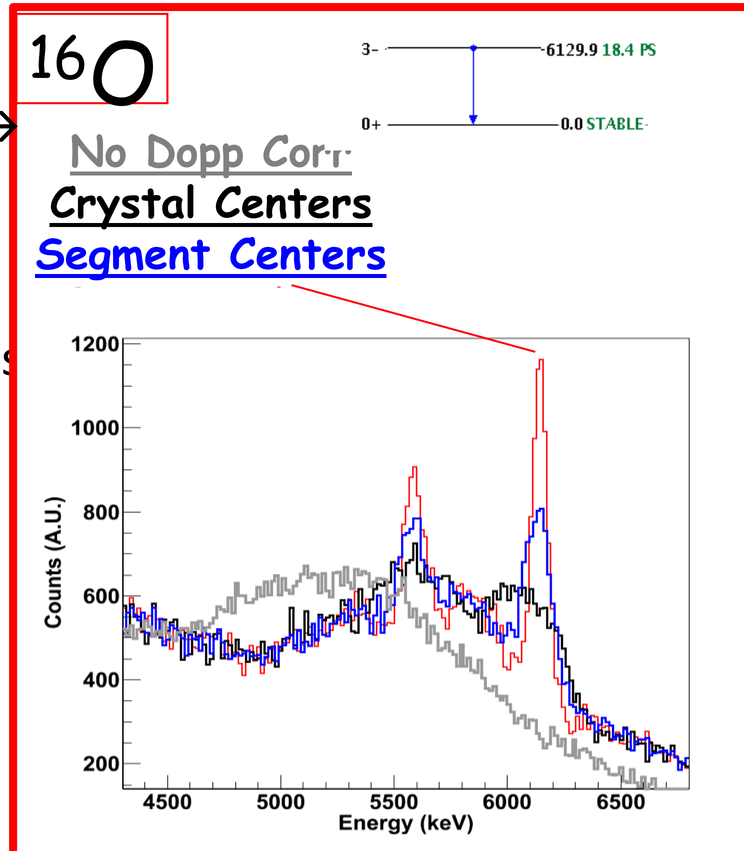


AdvancedGAmmaTrackingArray Demonstrator at LNL





an example of the performance →



Inelastic scattering
17O @ 20 MeV/u on 208Pb
Courtesy of R.Nicolini, D.Mengoni

4 (**nowadays 5**) asymmetric triple-clusters:

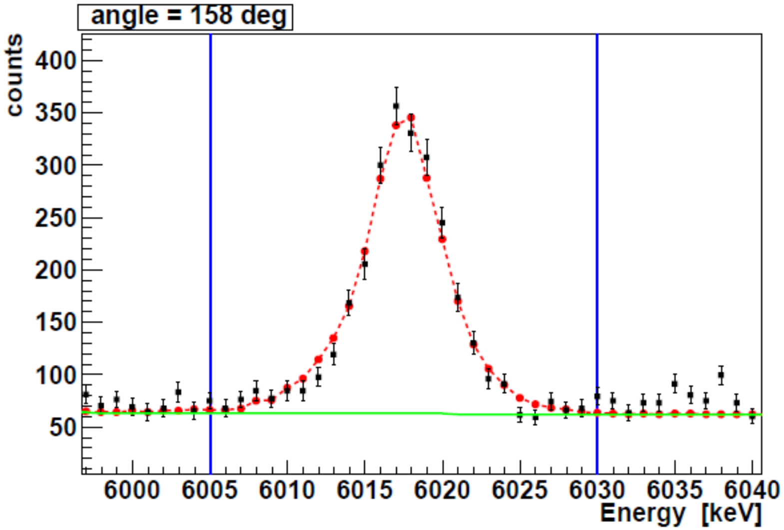
- 12(15) 36-fold segmented crystals
- 432(540) segments
- 444(555) high-resolution digital-channels

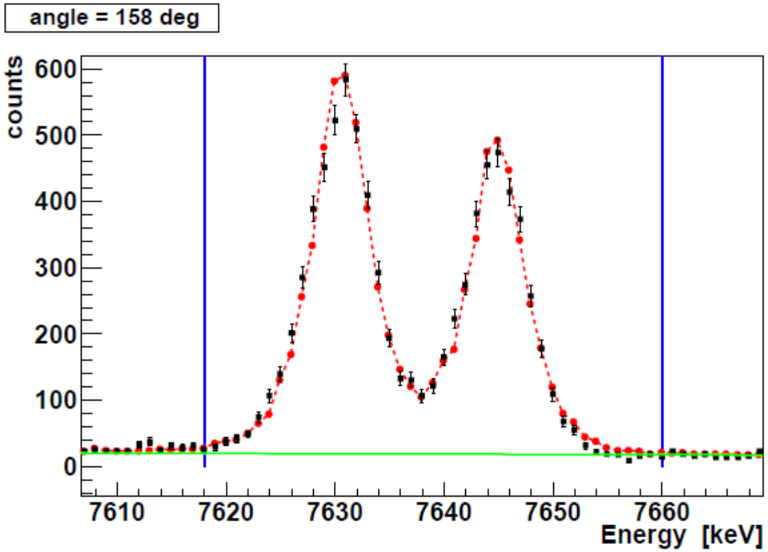
Real time operation: Pulse Shape Analysis
ϒ-ray Tracking

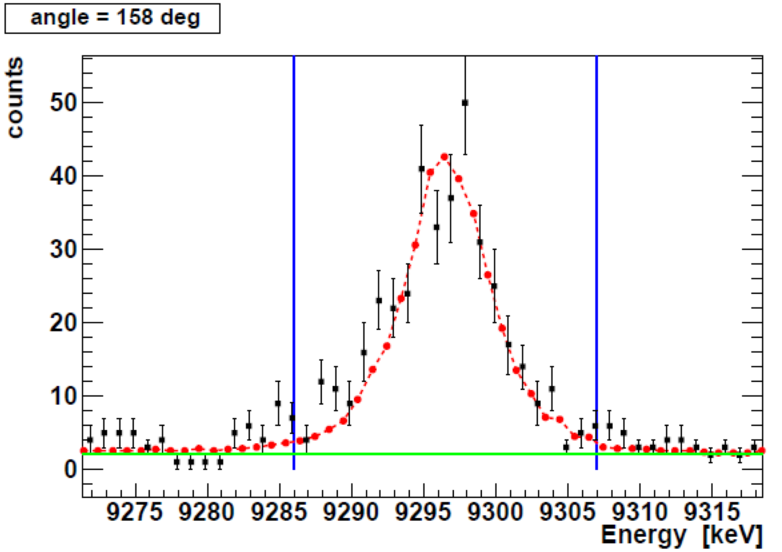
Efficiency and Energy resolution

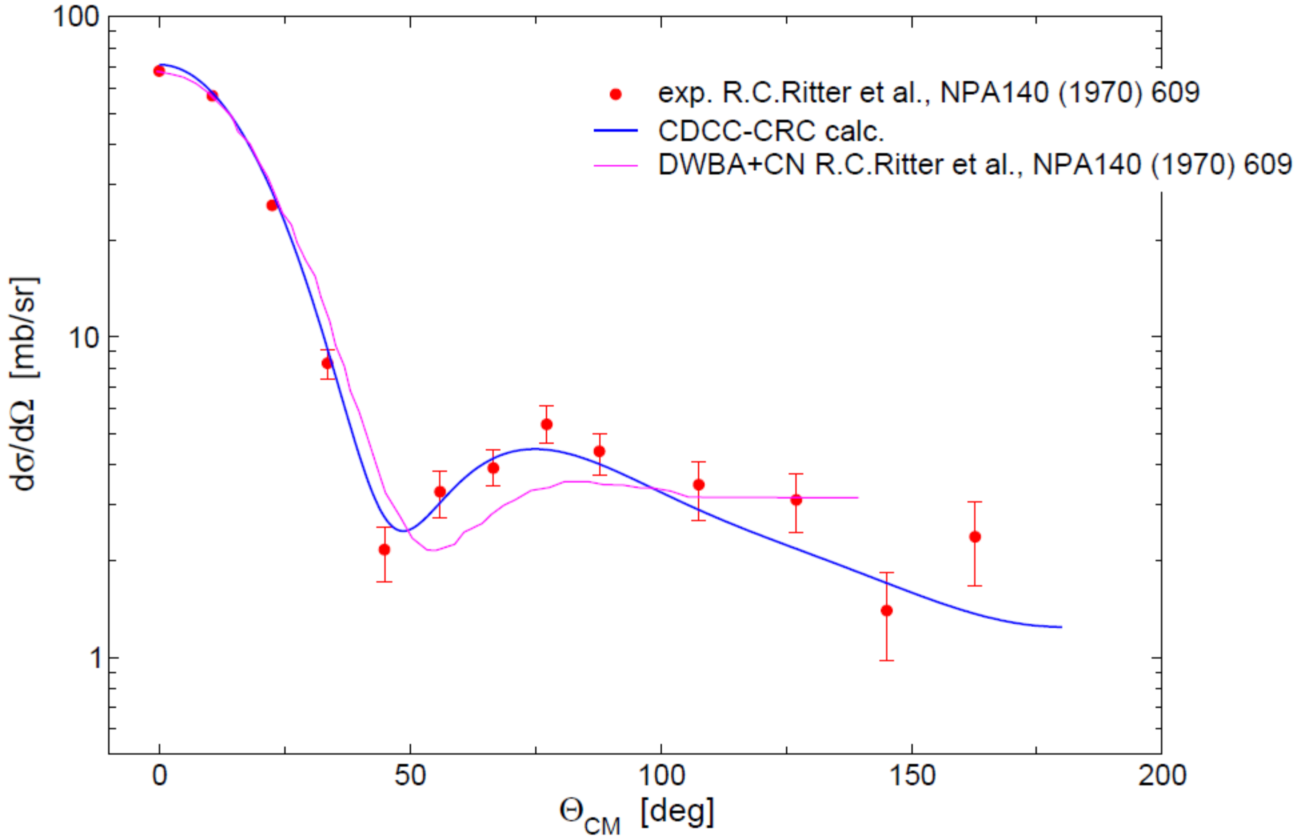
@ 1.3MeV : ≈2% (≈2.7%), 2.5 keV

@ 7 MeV : ≈0.5% (≈0.7%), 4.8 keV

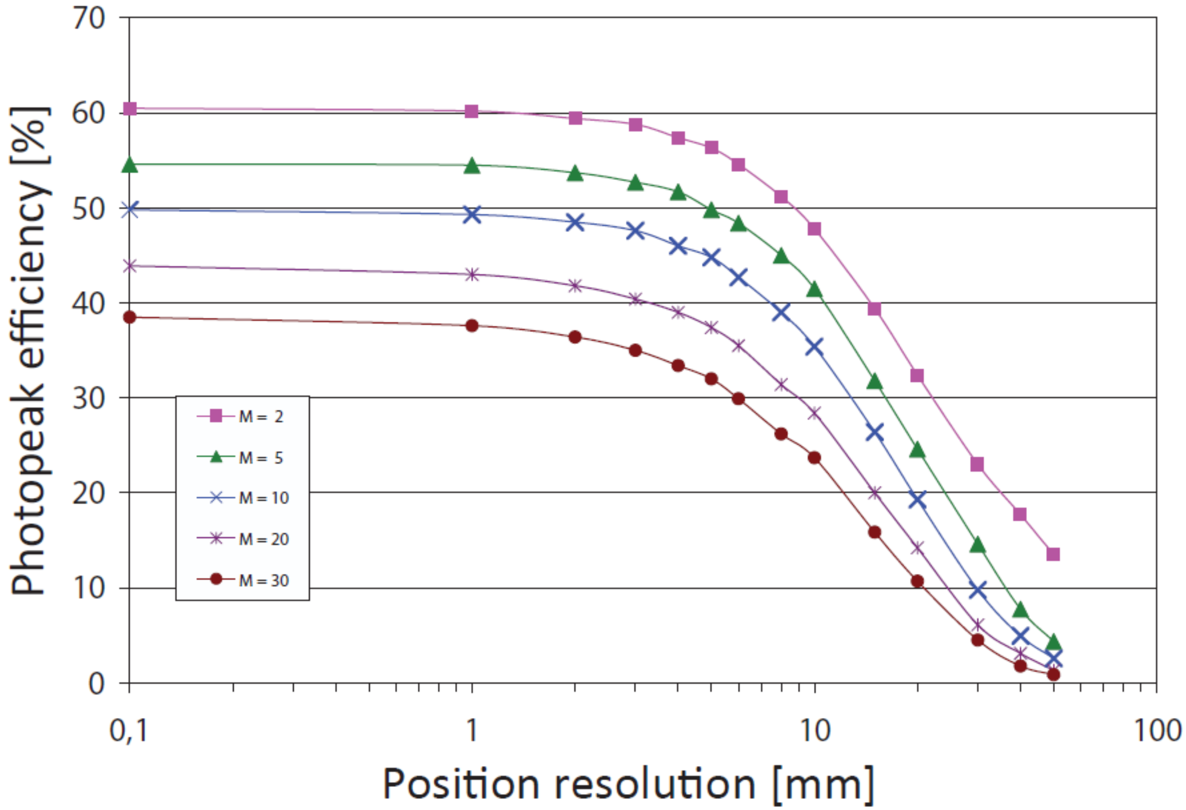

angle = 158 deg
counts
Energy [keV]


angle = 158 deg
counts
Energy [keV]


angle = 158 deg
counts
Energy [keV]

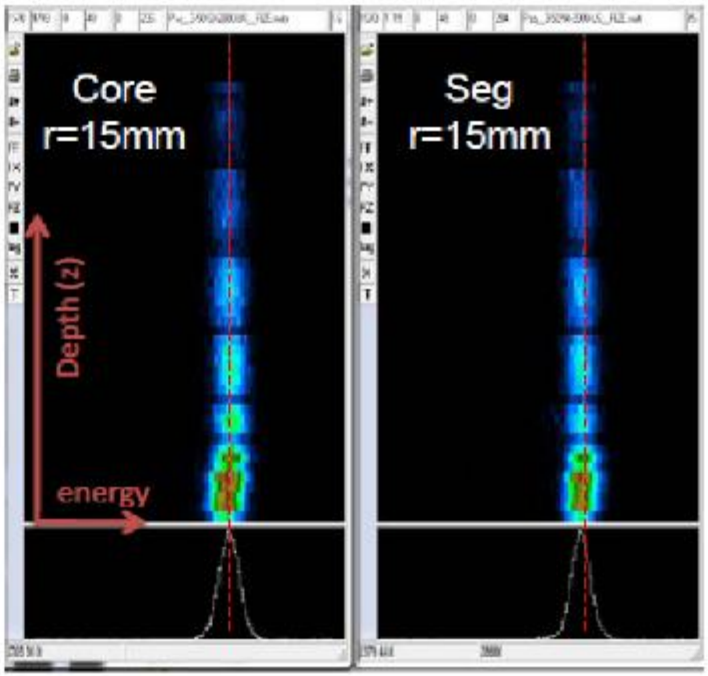


exp. R.C.Ritter et al., NPA140 (1970) 609
CDCC-CRC calc.
DWBA+CN R.C.Ritter et al., NPA140 (1970) 609
dσ/dΩ [mb/sr]
100
10
1
0
50
100
150
200
Θ_CM [deg]

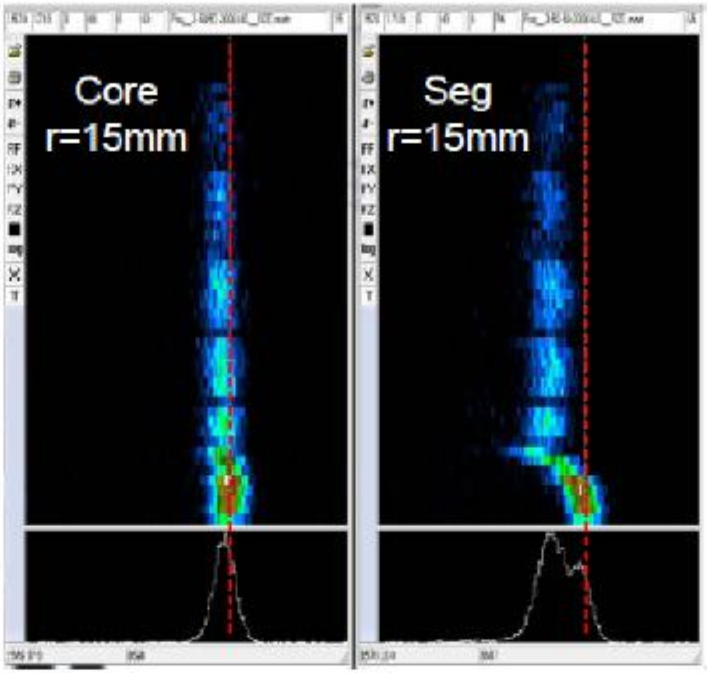


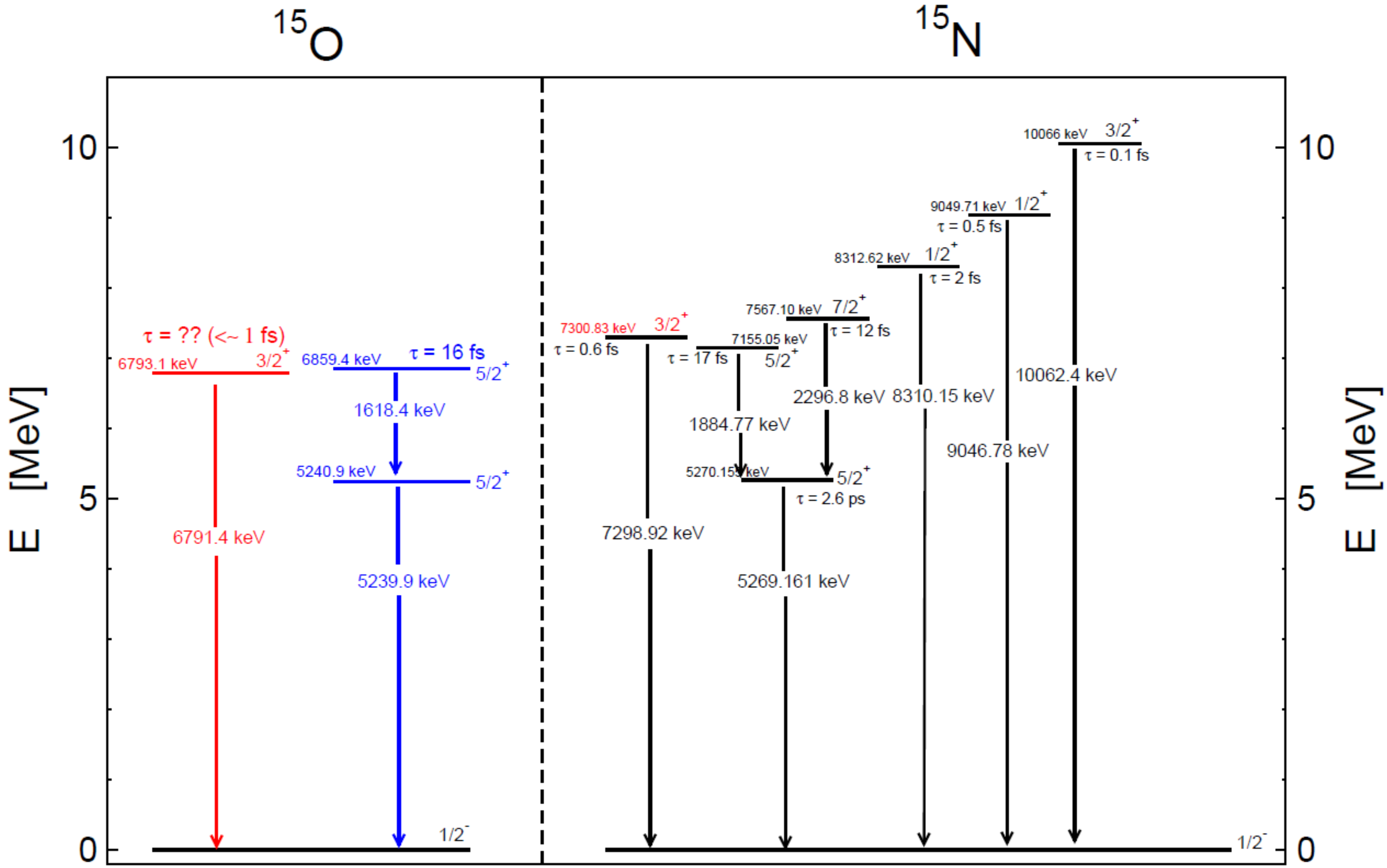
Photopeak efficiency [%]
Position resolution [mm]
0
10
20
30
40
50
60
70
0,1
1
10
100
M = 2
M = 5
M = 10
M = 20
M = 30

April 2010

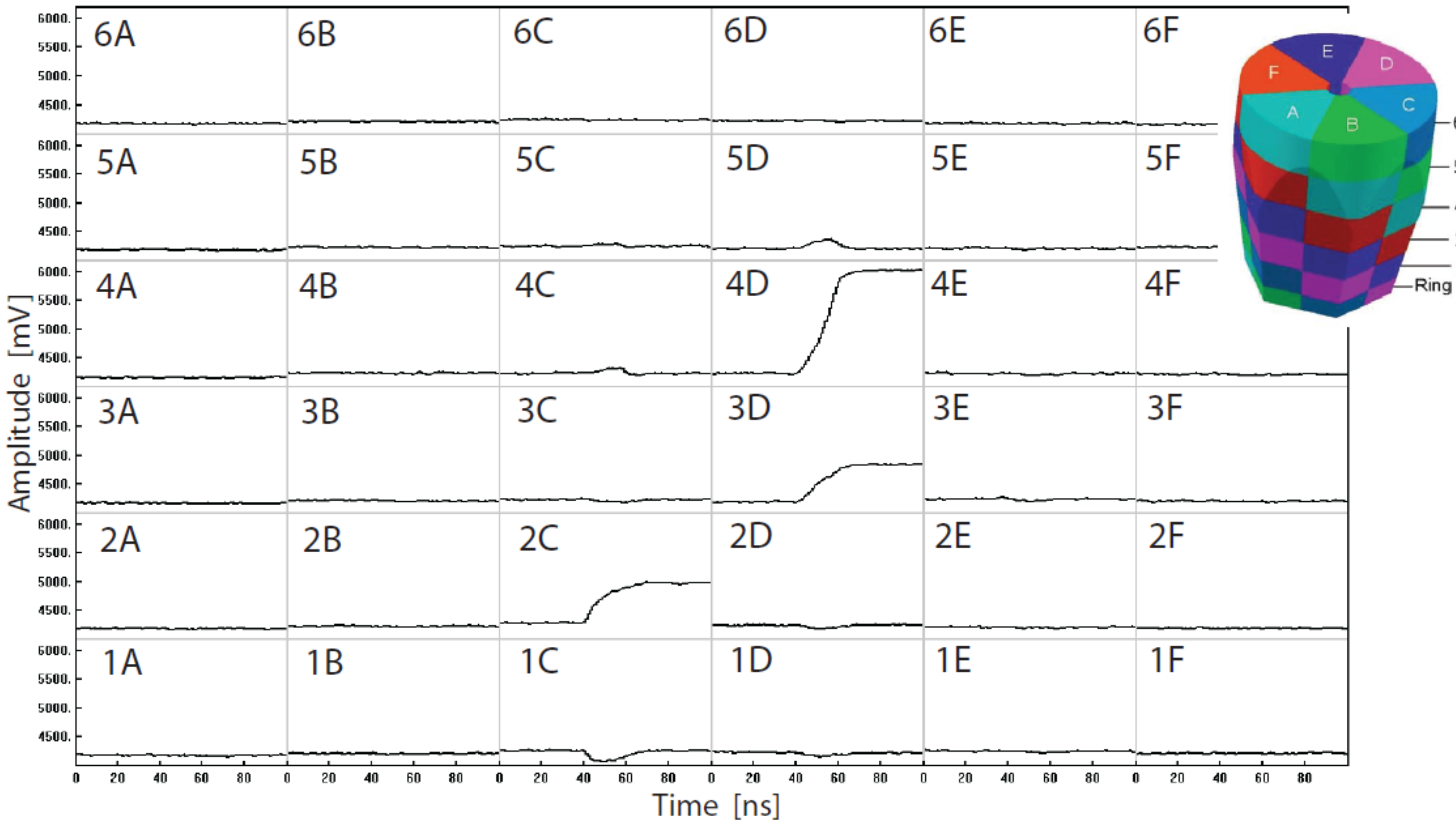


July 2010

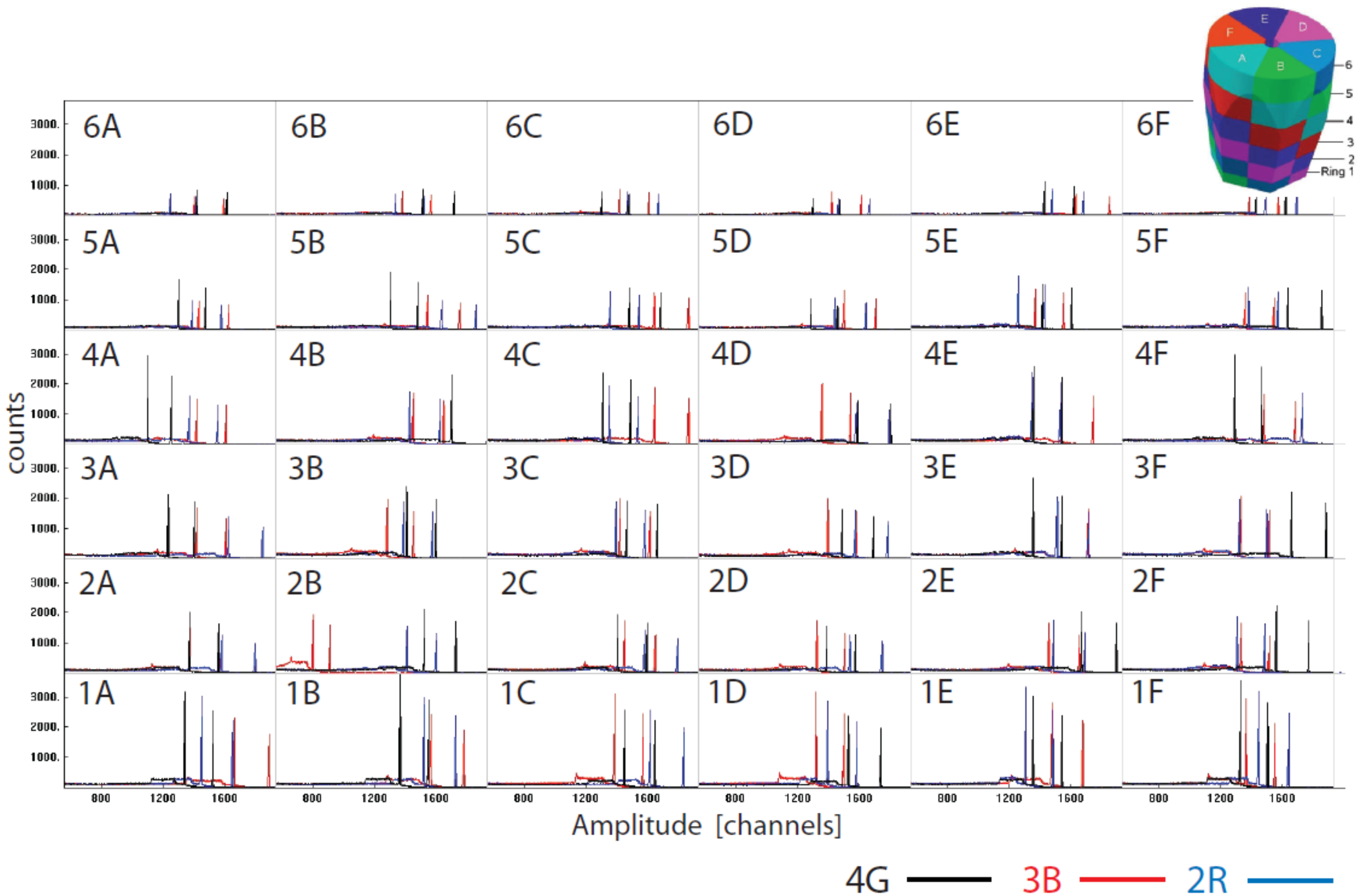




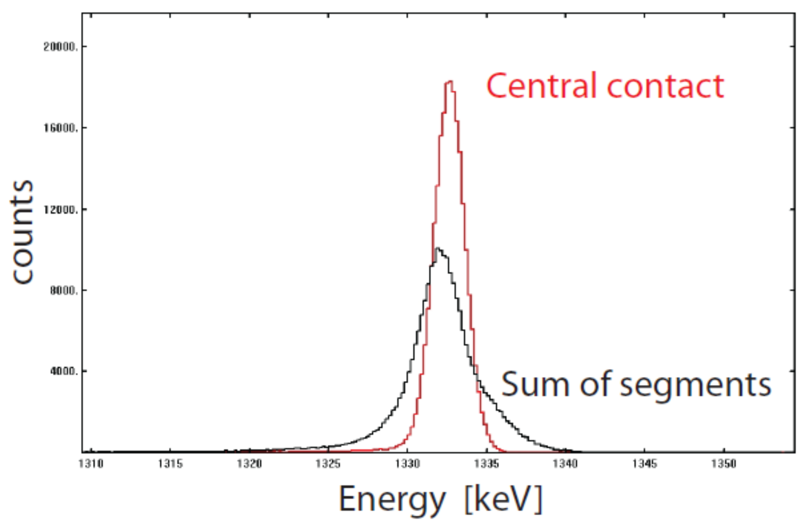
15O
15N
E [MeV]
0
5
10
τ = ?? (<~ 1 fs)
6793.1 keV
3/2+
6859.4 keV
τ = 16 fs
5/2+
1618.4 keV
5240.9 keV
5/2+
6791.4 keV
5239.9 keV
1/2-
7300.83 keV
3/2+
τ = 0.6 fs
7155.05 keV
τ = 17 fs
5/2+
7567.10 keV
7/2+
τ = 12 fs
8312.62 keV
1/2+
τ = 2 fs
9049.71 keV
1/2+
τ = 0.5 fs
10066 keV
3/2+
τ = 0.1 fs
10062.4 keV
2296.8 keV
8310.15 keV
1884.77 keV
9046.78 keV
5270.155 keV
5/2+
τ = 2.6 ps
7298.92 keV
5269.161 keV
1/2-

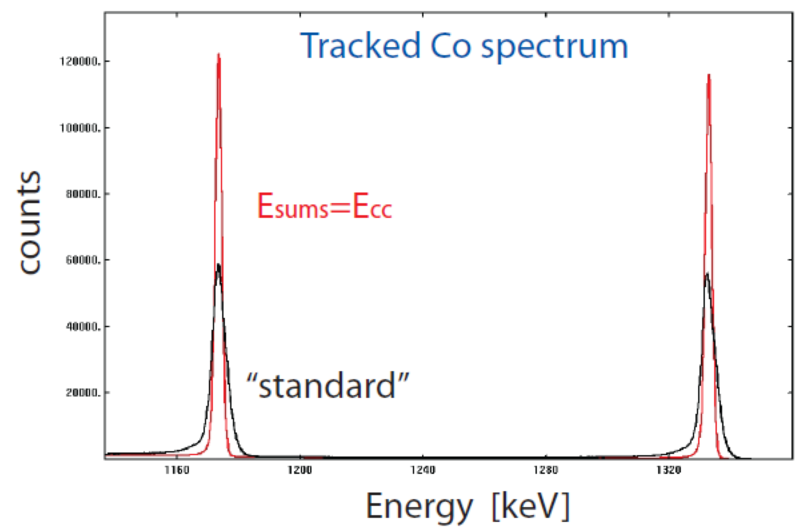


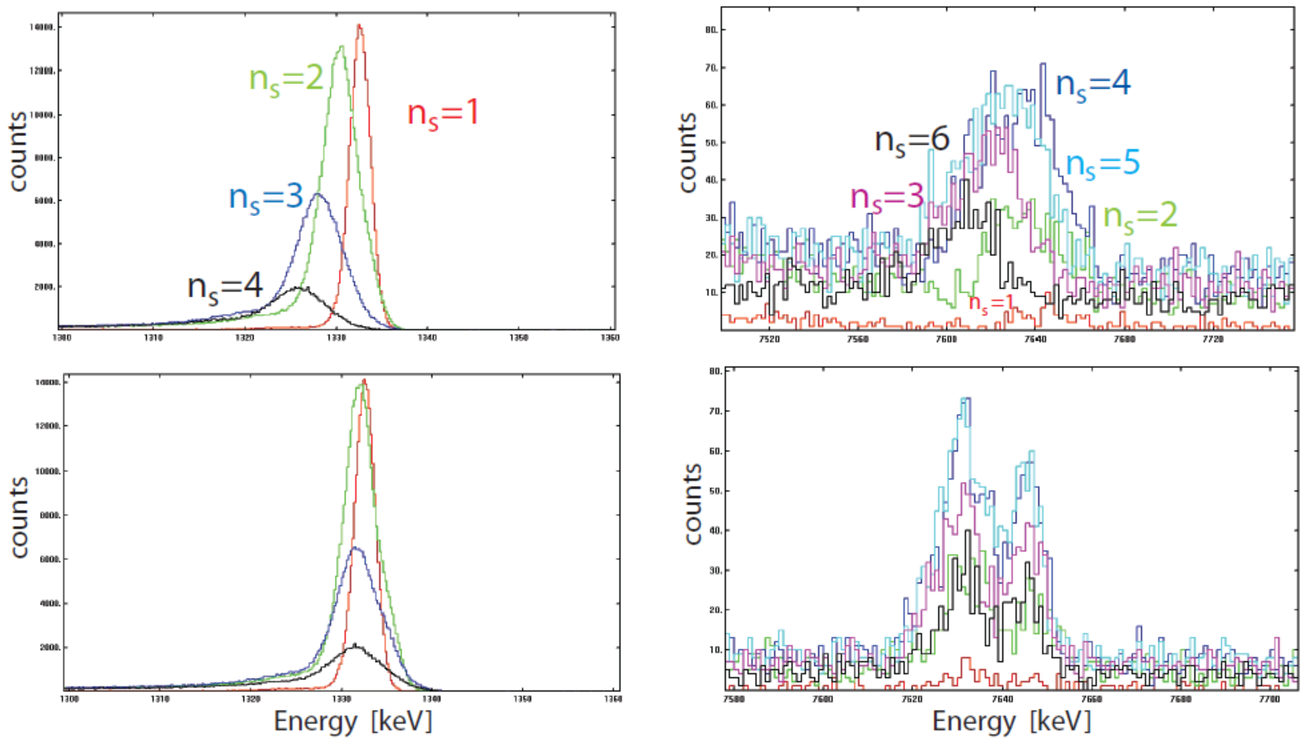
6A
6B
6C
6D
6E
6F
5A
5B
5C
5D
5E
5F
4A
4B
4C
4D
4E
4F
3A
3B
3C
3D
3E
3F
2A
2B
2C
2D
2E
2F
1A
1B
1C
1D
1E
1F
Amplitude [mV]
Time [ns]
A
B
C
D
E
F
6
5
4
3
2
Ring 1



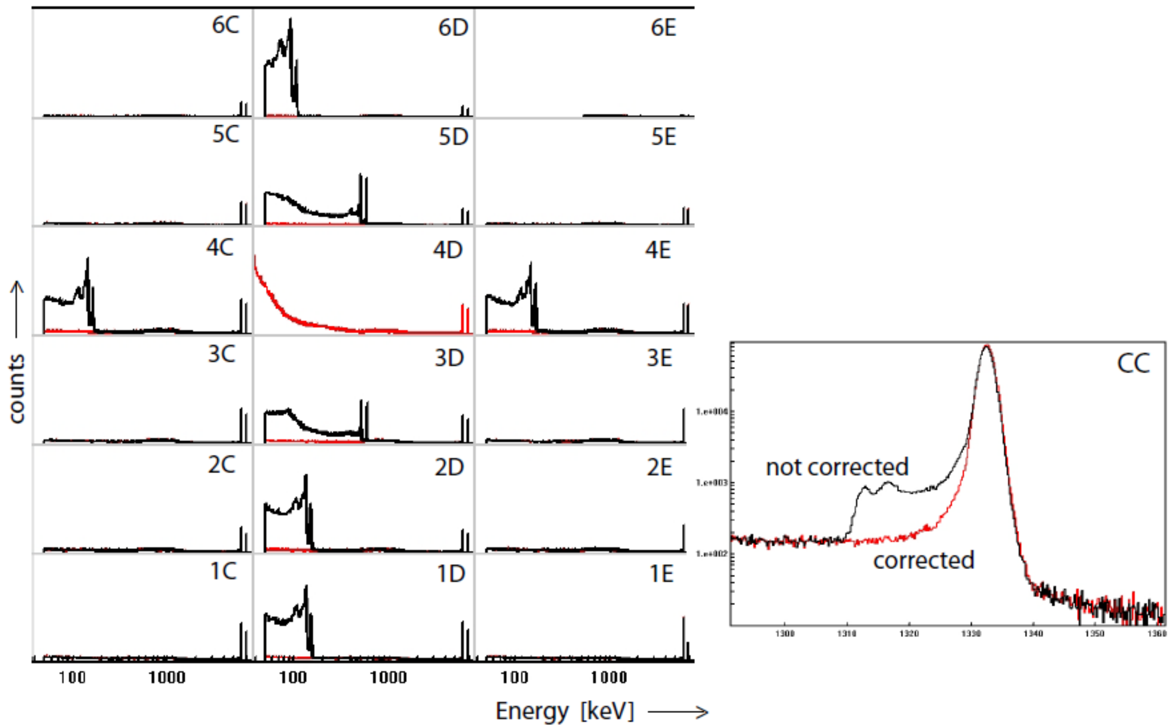
6A
6B
6C
6D
6E
6F
5A
5B
5C
5D
5E
5F
4A
4B
4C
4D
4E
4F
3A
3B
3C
3D
3E
3F
2A
2B
2C
2D
2E
2F
1A
1B
1C
1D
1E
1F
counts
Amplitude [channels]
4G
3B
2R
Ring 1

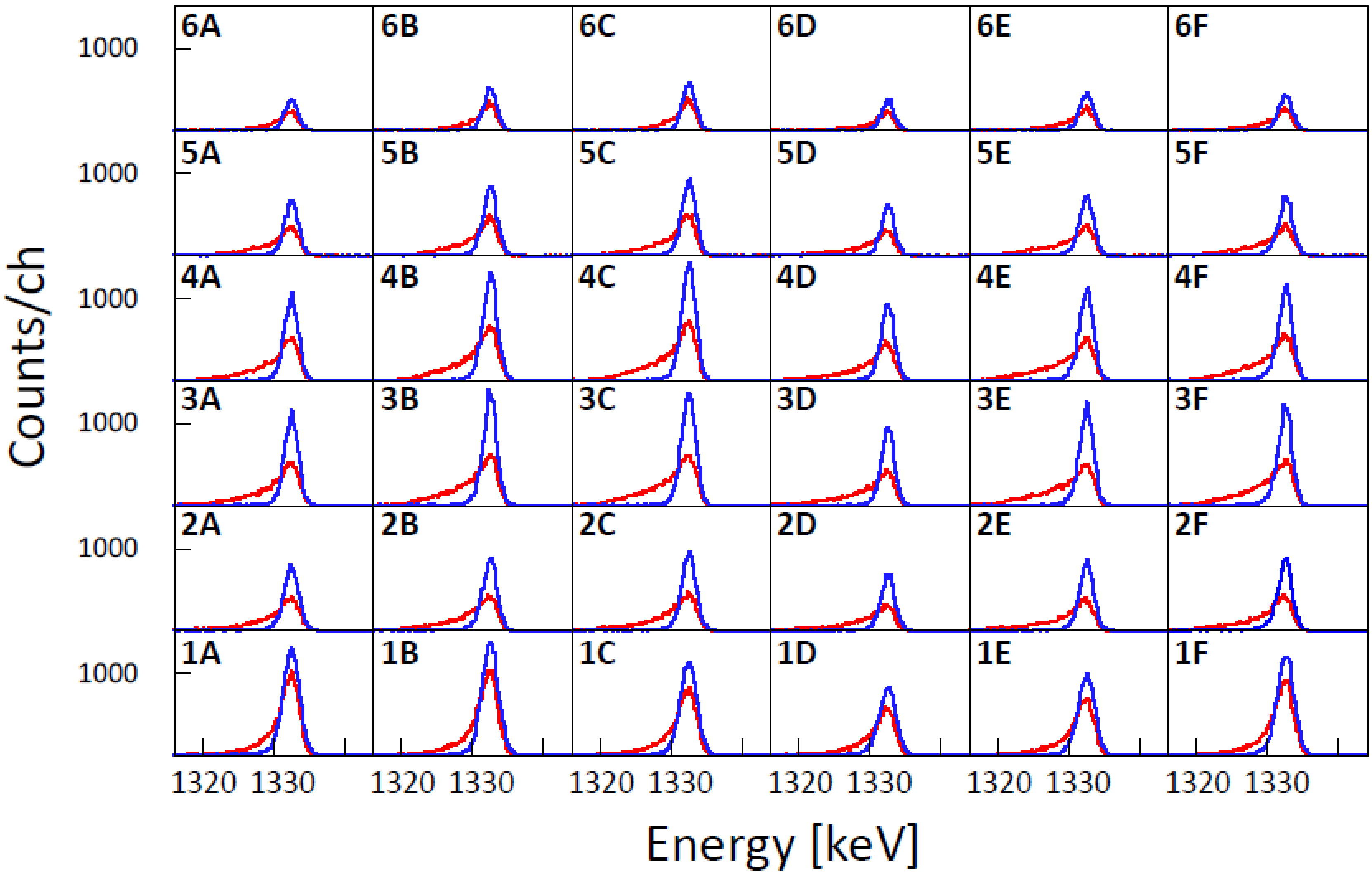

Central contact
Sum of segments
counts
Energy [keV]
20000.
16000.
12000.
8000.
4000.
1310
1315
1320
1325
1330
1335
1340
1345
1350


Tracked Co spectrum
Esums=Ecc
"standard"
counts
Energy [keV]
120000.
100000.
80000.
60000.
40000.
20000.
1160
1200
1240
1280
1320

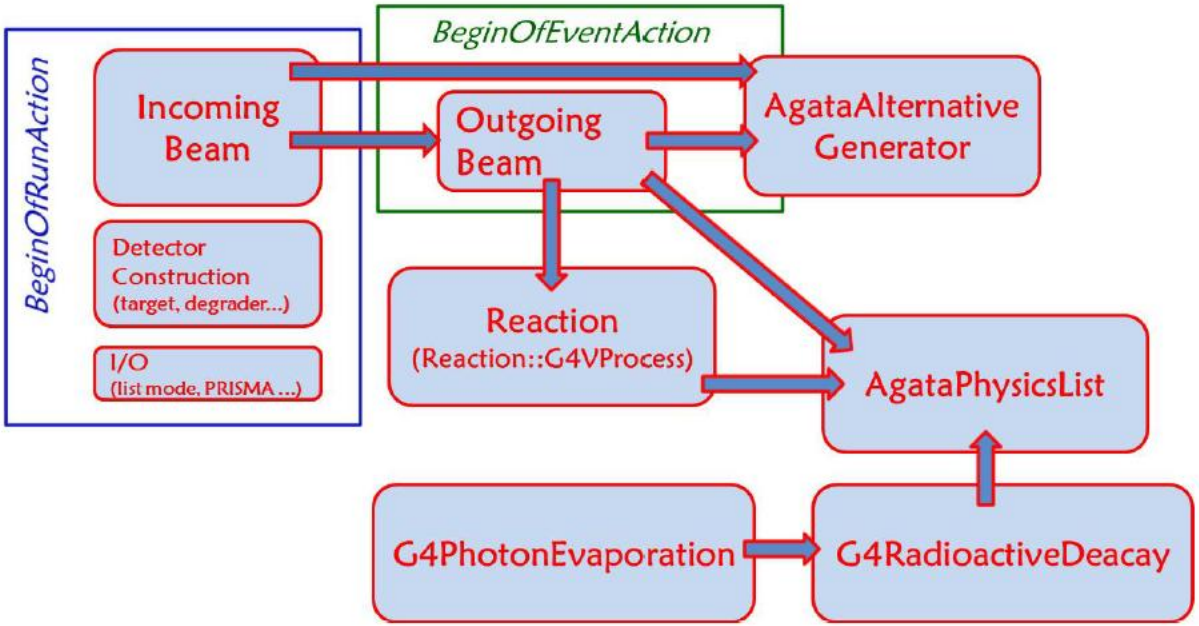


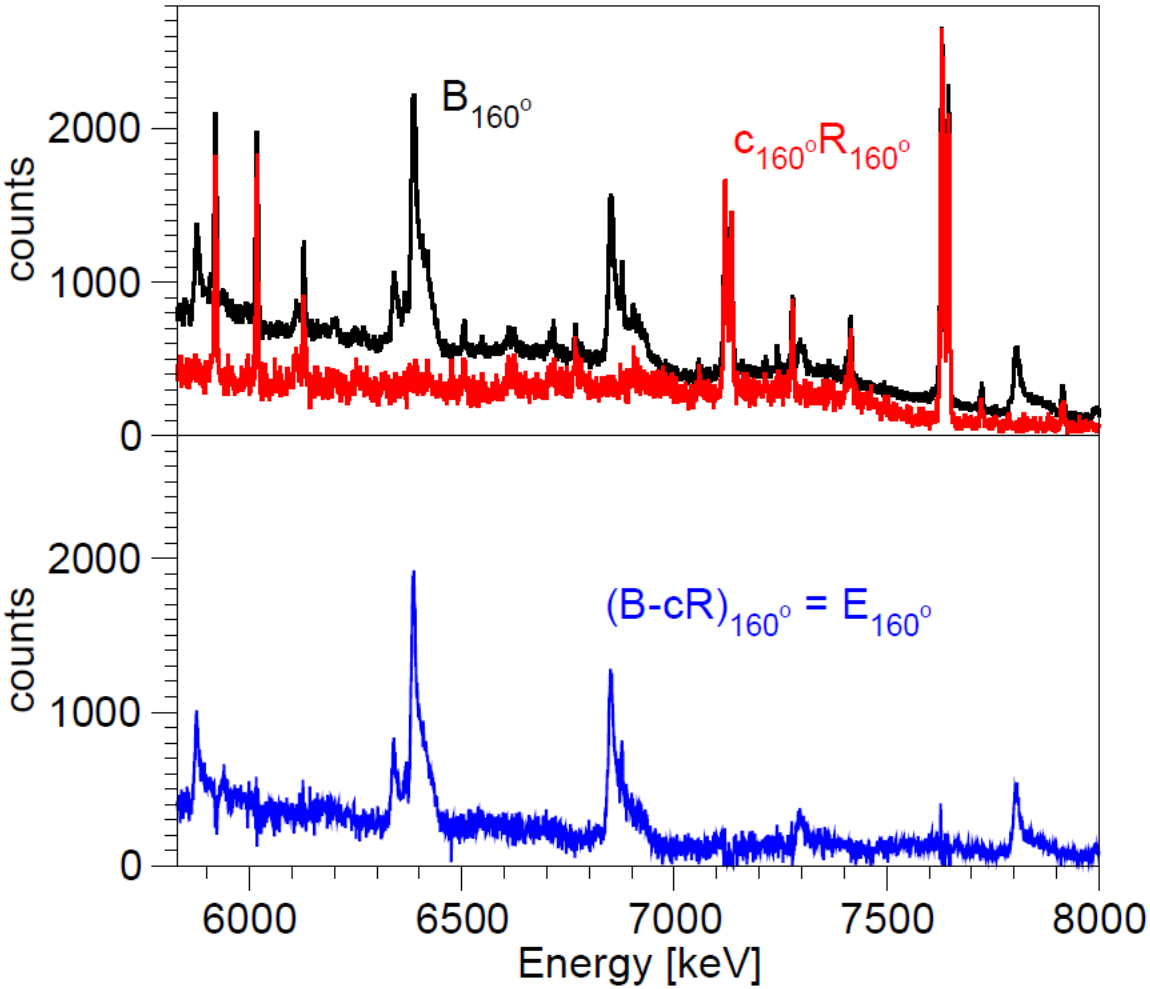
n_s=2
n_s=1
n_s=3
n_s=4
counts
n_s=4
n_s=6
n_s=5
n_s=3
n_s=2
n_s=1
counts
counts
Energy [keV]
counts
Energy [keV]


6C
6D
6E
5C
5D
5E
4C
4D
4E
3C
3D
3E
2C
2D
2E
1C
1D
1E
counts
100
1000
100
1000
100
1000
Energy [keV]
CC
not corrected
corrected
1300
1310
1320
1330
1340
1350
1360

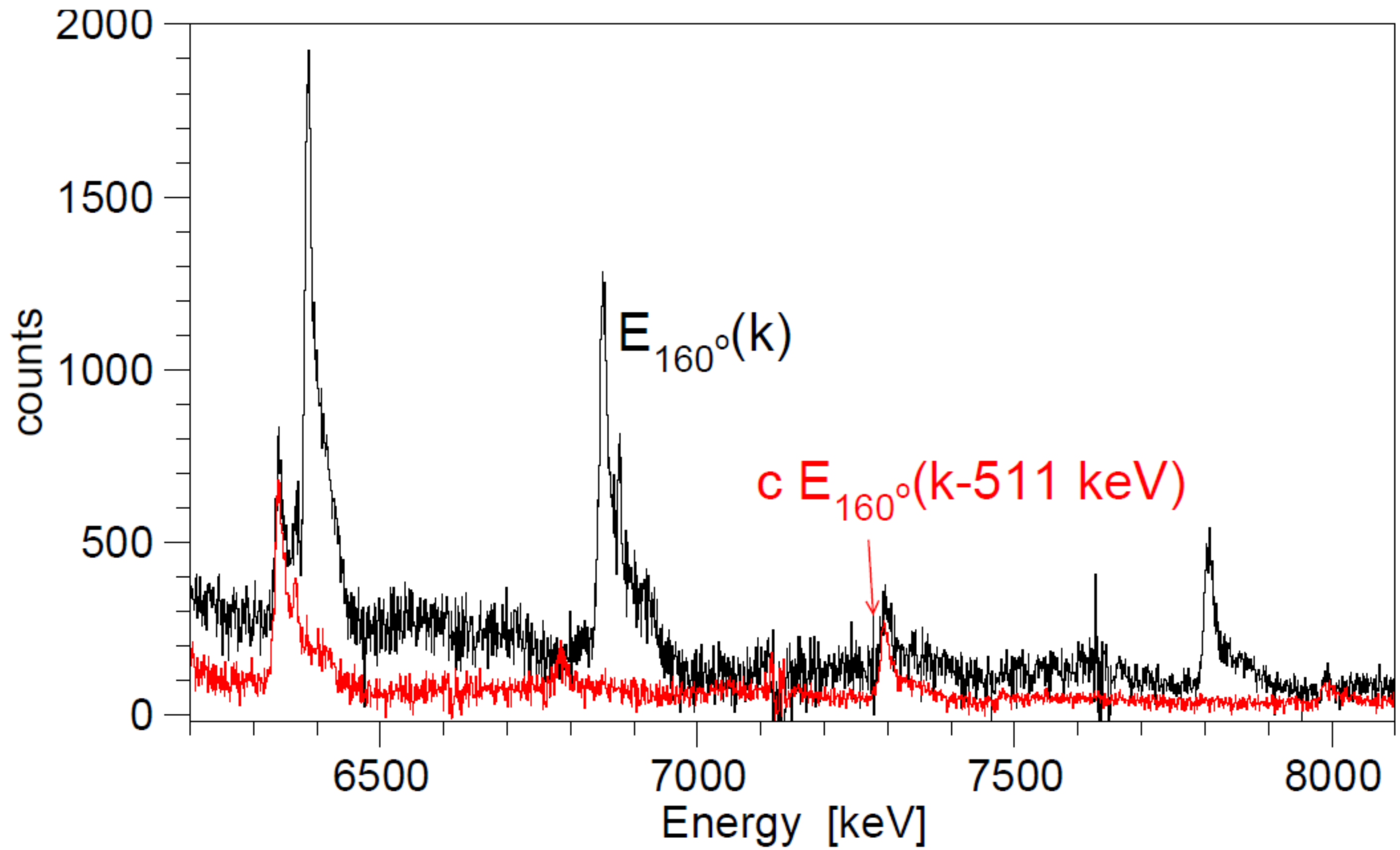


6A
6B
6C
6D
6E
6F
5A
5B
5C
5D
5E
5F
4A
4B
4C
4D
4E
4F
3A
3B
3C
3D
3E
3F
2A
2B
2C
2D
2E
2F
1A
1B
1C
1D
1E
1F
1000
Counts/ch
1320
1330
Energy [keV]


BeginOfRunAction
BeginOfEventAction
Incoming Beam
Outgoing Beam
AgataAlternative Generator
Detector Construction (target, degrader…)
I/O (list mode, PRISMA …)
Reaction (Reaction::G4VProcess)
AgataPhysicsList
G4PhotonEvaporation
G4RadioactiveDeacay

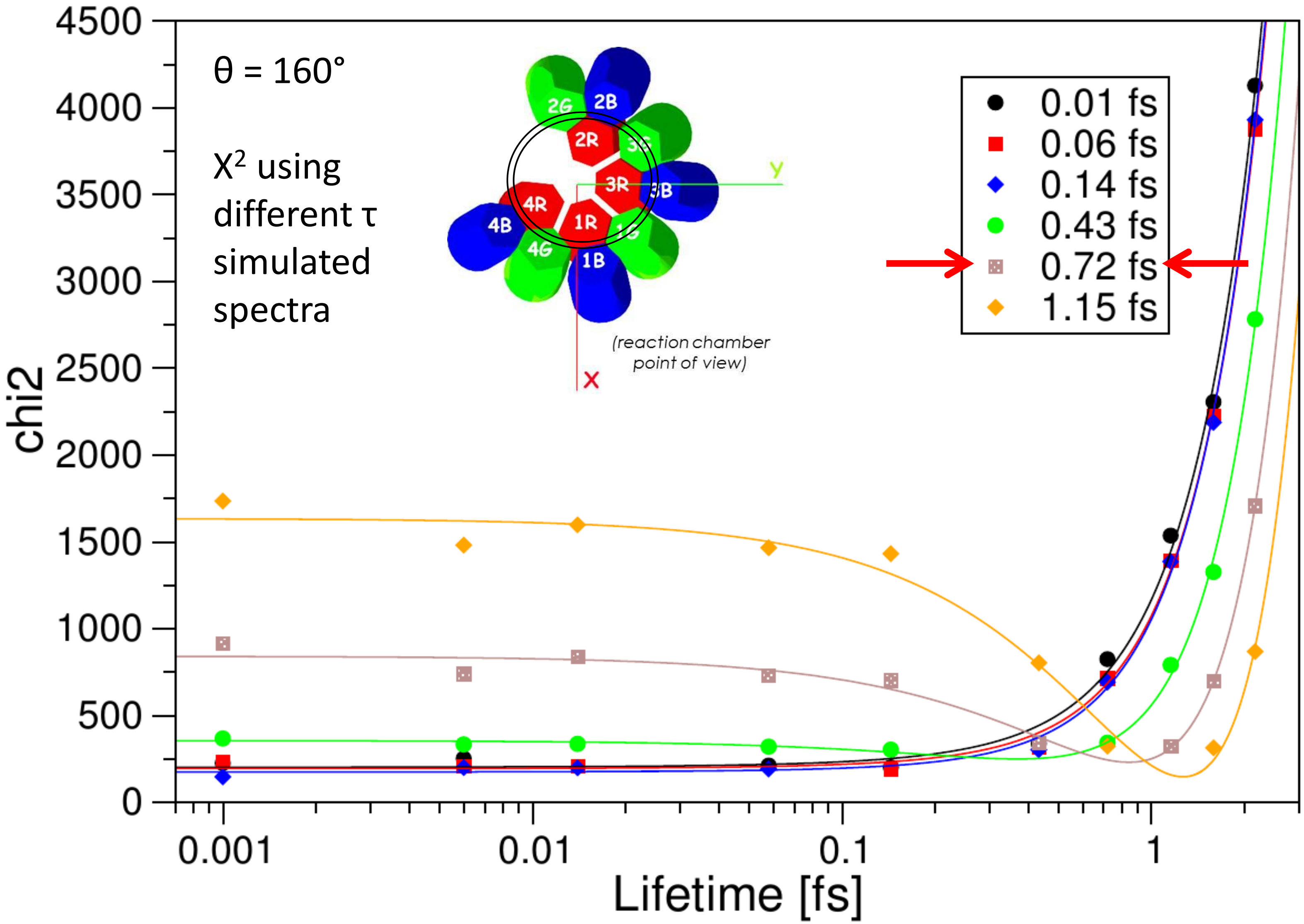


B160°
c160°R160°
(B-cR)160° = E160°
counts
counts
2000
1000
0
2000
1000
0
6000
6500
7000
7500
8000
Energy [keV]

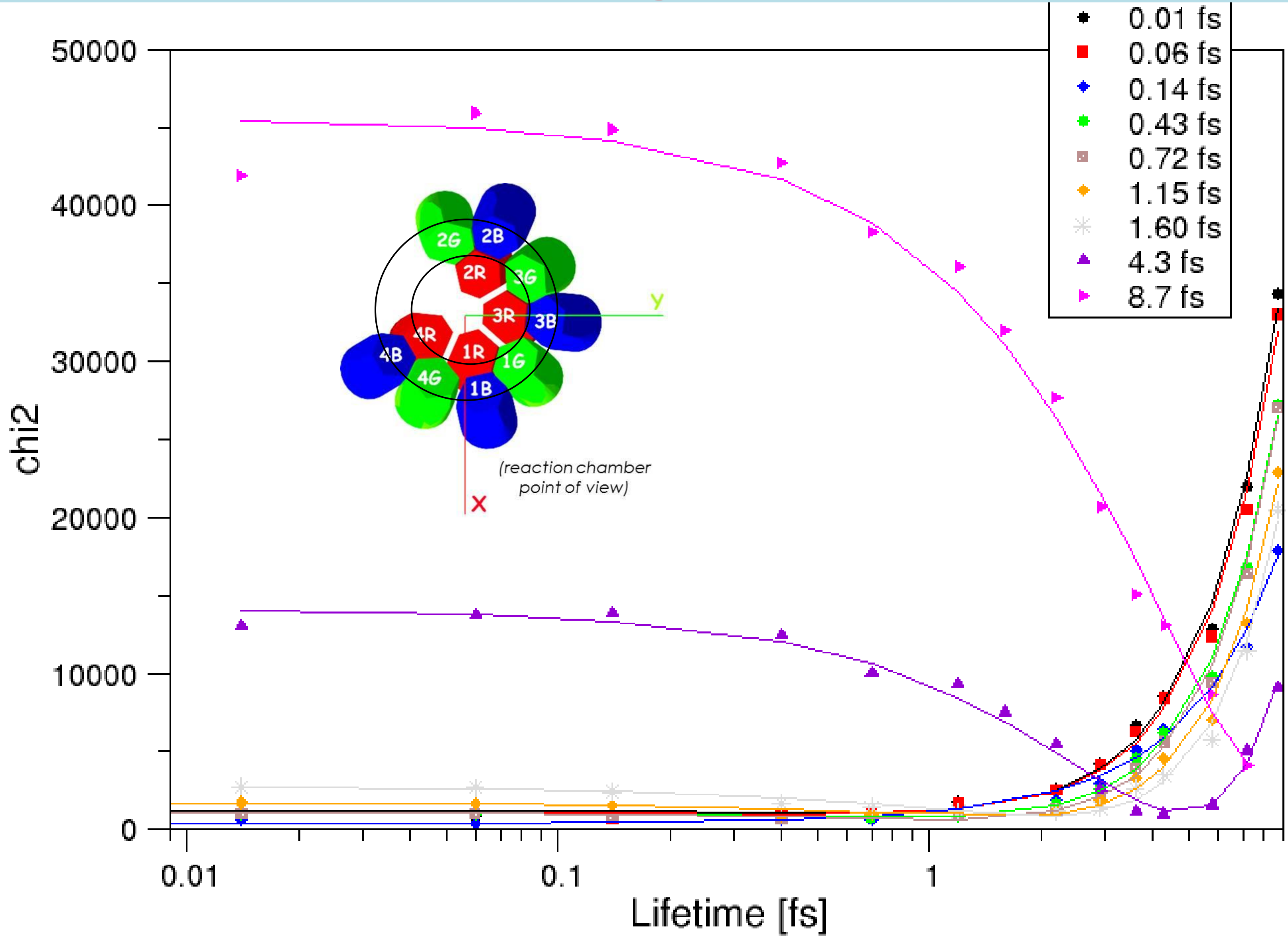


2000
1500
1000
500
0
counts
E160°(k)
c E160°(k-511 keV)
6500
7000
7500
8000
Energy [keV]

Estimation of the sensitivity: when selecting a θ slice



Estimation of the sensitivity: when considering "standard" HPGe



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