Performance Measurements with Tracking Arrays

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ACC Meeting June 30th 2016
Performance of tracking arrays

What progress have we made in demonstrating AGATA performance?
Are Tracking performances complete and feasible?

The energy resolution
The absolute photo-peak efficiency
The peak-to-Total ratio
Count rate capability

Emphasis of this talk : Absolute efficiency and P/T
Formalism developed : ANL – CSNSM collaboration
AGATA-GRETINA collaboration

T. Lauritsen, A. Korichi, A.N. Wilson, J. Dudouet, D. Weisshar et al,
Submitted to NIM A 2016
Efficiency and P/T of tracking arrays, *it is complicated*

Observed areas for $^{60}$Co source with

$[N=1, Cs=0]$ for Cccal

$[N=\text{number of crystals and } Cs>0]$ for CCsum

$C_f$ is the angular correlation factor

Correct for the fact that the 1173 can knock out counts in the 1333 line and vice versa.

CR is the correction for random $\gamma$ rays hitting the detector

S is the Number of $\gamma$ rays emitted

LF is the Life Fraction (dead time or other loss)

The probability for a $\gamma$ ray to scatter out of a crystal, to be detected by other crystals in the array and successfully sum up to the photo-peak

$F$: addback factor
Summed Peak Method: SPM \([A(2506)/A(1173)]\)

\[
\epsilon_p(1333) = N \left\{ \frac{A^{obs}(2506)}{A^{obs}(1173)C_f} \right\} / \left\{ 1 - C_s(1333) + \frac{A^{obs}(2506)(1 + C_s(1173))}{A^{obs}(1173)N(P/T)(1333)} \right\}
\]

Calibrated Source Method: CSM \([S\text{ and } L_f\text{ must be known}]\)

\[
\epsilon_p(1333) = \frac{A^{obs}(1333)}{S(1 - C_R)(1 - C_s(1333))} + \frac{(1 + C_s(1173))A^{obs}(2506)}{NS((P/T)(1173))(1 - C_R)(1 - C_s(1173))(1 - C_s(1333))}
\]

External Trigger Method

\[
A^{obs}(1333) = A^{obs}_{ext}(1173) \times \epsilon_p(1333)C_f(1 - C_R)
\]

With CCcal and CCsum: five measurements of the array efficiency
True P/T- true peak Areas (new concepts)

We saw how the observed peak areas relate to the actual array efficiencies.

Once the peak areas have been correctly determined, efficiencies, true peak areas and peak–to–total ratios can be extracted.

\[
A^{true}(1173) \equiv S \epsilon_p(1173)
\]

\[
= \frac{A^{obs}(1173)}{(1 - C_k(1333))(1 - C_R)(1 - C_s(1173))},
\]

\[
A^{true}(1333) \equiv S \epsilon_p(1333)
\]

\[
= \frac{A^{obs}(1333)}{(1 - C_k(1173))(1 - C_R)(1 - C_s(1333))},
\]

\[
A^{true}(2506) \equiv S \epsilon_p(1173)\epsilon_p(1333)C_f
\]

\[
= \frac{A^{obs}(2506)}{(1 - C_R)(1 - C_s(1173))(1 - C_s(1333))}.
\]

\[
(P/T)^{true} = \frac{A^{true}(1173) + A^{true}(1333) + A^{true}(2506)}{A^{true}_\text{tot}},
\]

Include for CCcal and CCsum but not for tracked spectra

\[
A^{obs}_\text{tot} = (1 + C_s)A^{true}_\text{tot}
\]
Performance of AGATA@GSI with $^{60}$Co source

<table>
<thead>
<tr>
<th>Input</th>
<th>Efficiency (%)</th>
<th>$P/T$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGATA (external trigger method)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core Common</td>
<td>2.38(2)</td>
<td>18.3(2)</td>
</tr>
<tr>
<td>Calorimetric</td>
<td>3.30(2)</td>
<td>32.2(3)</td>
</tr>
<tr>
<td>Tracked with single interactions</td>
<td>2.55(3)</td>
<td>37.5(4)</td>
</tr>
<tr>
<td>Tracked without single interactions</td>
<td>2.53(3)</td>
<td>42.3(5)</td>
</tr>
<tr>
<td>Add-back 100 mm</td>
<td>2.86(4)</td>
<td>24.6(2)</td>
</tr>
</tbody>
</table>

$\epsilon_{track} = \frac{A_T(1333)}{S \epsilon_p(1333)}$

$\epsilon_{track} = \frac{A_T(1333)}{A_{obs}(1333)(1-C_R)(1-C_F)} \equiv \frac{A_T(1333)}{A_{true}(1333)}$

$(P/T)^{tracked} = \frac{A_T(1173) + A_T(1333)}{A_{tot}}$
Tracking efficiency and P/T

\[ E'_\gamma = \frac{0.511}{1 + \frac{0.511}{E_\gamma} - \cos(\theta)} \]

\[ FOM = \sum_i \frac{\sqrt{\left(\sum_i (\theta_i^{\text{theo}} - \theta_i^{\text{obs}})^2\right)}}{n_i - 1}; n_i > 1 \]

FOM: a measure of how well the interaction angles and interaction energies follow the Compton scattering formula inside a gamma ray.

FOM < ~0.6-0.8 considered GOOD    FOM > ~0.8 considered BAD (Compton events)
**FOM spectrum**, a measure of how well the interaction angles and interaction energies follow the Compton scattering formula inside a gamma ray. Typical spectrum of FOM values (in log):

![Graph showing FOM spectrum with labels for 'Single hits, FOM==0', 'mostly good guys', 'mostly bad guys', 'Single interaction located beyond their range', 'Over flow', 'Typical FOM cut'].

- **Entries**: 4080552
- **Mean**: 0.6166
- **RMS**: 0.586
For single hits: We can improve the tracking by other means:

Looks like a low energy 'single interaction'

Single hits fom=0

Single interaction over range
It Helps!

- $^{122}\text{Sn}(^{40}\text{Ar}[170\text{MeV}],4n)^{158}\text{Er}$
- June 5-6, 2015-

P/T=0.27  P/T=0.34
It Helps!

$^{122}\text{Sn}(^{40}\text{Ar}\,170\text{MeV},4\text{n})^{158}\text{Er}$

June 5-6, 2015-

$P/T=0.27$  $P/T=0.34$
Performance of AGATA@GANIL with $^{60}$Co source

<table>
<thead>
<tr>
<th></th>
<th>SPM cal</th>
<th>CSM cal</th>
<th>SPM sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\epsilon_p$(pure)</td>
<td>4.26(12)%</td>
<td>4.48(13)%</td>
<td>4.00(16)%</td>
</tr>
<tr>
<td>$(P/T)_0^{obs}$</td>
<td>0.328(5)</td>
<td>0.224(5)</td>
<td>0.184(5)</td>
</tr>
<tr>
<td>$(P/T)_1^{true}$</td>
<td>0.371(5)</td>
<td>0.270(5)</td>
<td>0.363(5)</td>
</tr>
<tr>
<td>$\epsilon_{track,nsi}$</td>
<td>82(1)%</td>
<td>81(1)%</td>
<td>82(1)%</td>
</tr>
<tr>
<td>$\epsilon_{track,ws}$</td>
<td>95(1)%</td>
<td>94(1)%</td>
<td>95(1)%</td>
</tr>
<tr>
<td>$C_f$</td>
<td>1.0275</td>
<td>1.0275</td>
<td>1.109</td>
</tr>
<tr>
<td>$C_s$</td>
<td>0</td>
<td>0</td>
<td>0.307(5)</td>
</tr>
</tbody>
</table>

Abs. Eff (External Trigger Method) = 4.29 (10)

Cluster angle = 20 degrees

Abs_Eff_tracked=3.80% P/T=41% FOM cut=1.0
Abs_eff_tracked=3.25% P/T= 49  no_singles (29 crystals )

A Better P/T compared to GSI
But the array Is more compact: 72% versus 68%

But also more passive material: 3 crystals not active at GSI
AGATA GSI & GANIL
Tracked data including single interactions

Cluster angle = 20 degrees

- FOM = 0.8
  - Eff = 3.7%
  - P/T = 41%

- FOM = 0.8
  - Eff = 2.8%
  - P/T = 38%

Scaling:
21/29 * 3.7% = 2.7%
AGATA and GRETINA

29 crystals positioned at 23.5 cm  
28 crystals positioned at 18.5 cm

\[ \frac{4.25\%}{6.4\%} = \frac{29}{28} \left(\frac{18.5}{23.5}\right)^2 \]

Cluster angle = 20 degrees

Tracking codes are doing the job (despite some deficiencies)
Similar performances
Conclusion...

Rate capabilities of AGATA : 50 kHz

Doppler correction capabilities : beautiful for fast beams

Tracking : we Improve some deficiencies for high multiplicity
But dependent of the input data

Problem : PSA?

TBD : process the AGATA (or GRETINA) through the same Decomp( PSA) to conclude

Ideas and suggestions are welcome
First AGATA-GRETINA tracking arrays collaboration meeting
December 5-7, 2016

First Circular

We are pleased to announce the first AGATA-GRETINA collaboration meeting to be held at ANL on 5-7 of December 2016.

The workshop will be devoted to discussions about common challenges related to tracking arrays, including the physics, technical details and analysis of data from these arrays. We intend to organize these workshops on a yearly or bi-yearly basis, alternating between meeting places in the US and EU.

We are hoping these workshops will foster collaborations between the AGATA and GRETINA communities and help define and accomplish our common challenges.

Organizing and Advisory committee:

B. Birkenback, IKP-Koeln, Germany.
A. Boston, Liverpool University, UK.
M.P. Carpenter, ANL, USA.
A. Gadea, IFIC-Valencia, Spain.
A. Korichi (co-chair) CSNSM-CNRS, France.
T. Laurissen (co-chair) ANL, USA.
A.O. Macchiavelli, LBNL, USA.
D. Radford, ORNL, USA.
O. Stezowski, IPNL-CNRS, France.
D. Weisshaar, NSCL, USA.
Extra slides
Quasi-online data analysis

Buffer size not adapted to the counting rates and actors spectra enabled
20% of data losses

Buffer size adapted to the counting rates and actors spectra enabled
8% of data losses

Buffer size not adapted to the counting rates and actors spectra disabled

Jérémie Dudouet: dudouet@ipnl.in2p3.fr
AGATA collaboration meeting 2015: 6-7 July 2015
OFT- tracking code

ANL- tracking code from cut=0.6

Tracking codes are doing the job
Tracking 101: determining the interaction sequence and how 'good' a gamma ray is

Cluster, find interaction sequence
Evaluate scattering angle
<--> energy consistency with the Compton scattering formula:

\[ E'_{\gamma} = \frac{0.511}{1 + \frac{0.511}{E_{\gamma}} - \cos(\theta)} \]

FOM < ~0.6-0.8 considered GOOD
FOM > ~0.8 considered BAD (Compton events)

Note: Single interactions cannot be tracked
Tracking codes are doing the job

```
jeremie_nsi.spe  ;P/T= 0.468  ;p1/p2/sum=  1146917/  1084651/  4764551 :: photoeff = 0.045 ;
totaleff = 0.095 ; p2eff = 0.043 ; *=    0.9791

fom_nsi06.spe  ;P/T= 0.488  ;p1/p2/sum=  1247299/  1184123/  4984402 :: photoeff = 0.049 ;
totaleff = 0.100 ; p2eff = 0.047 ; *=    1.1571

fom_nsi08.spe  ;P/T= 0.462  ;p1/p2/sum=  1353925/  1289846/  5722022 :: photoeff = 0.053 ;
totaleff = 0.114 ; p2eff = 0.052 ; *=    1.1288
```
Builder_000.adf  only 28 crystals- counting correctly

**Sum core**

Abs. Efficiency
with error: eff1173= 4.50% +/- 0.12%

with error: eff1333= 4.23% +/- 0.11%

__input P/T is 0.3340
True P/T is 0.3341 +/- 0.0107

__obs P/T is 0.1715 +/- 0.0001

nsi tracking efficiency = 78.59% +/- 0.58%
FOM20_nsi efficiency point is 0.0332 +/- 0.0009
wsi tracking efficiency = 92.43% +/- 0.68%
FOM20_wsi efficiency point is 0.0391 +/- 0.0011

**Calorimetric**

Abs. Eff
with error: eff1173= 4.09% +/- 0.12%

with error: eff1333= 3.88% +/- 0.12%

__input P/T is 0.3315
True P/T is 0.3316 +/- 0.0024

__obs P/T is 0.2907 +/- 0.0002

nsi tracking efficiency = 79.58% +/- 0.82%
FOM20_nsi efficiency point is 0.0309 +/- 0.0010
wsi tracking efficiency = 93.59% +/- 0.97%
FOM20_wsi efficiency point is 0.0363 +/- 0.0012

Builder_0006.adf  29 crystals counting correctly

will show array efficiency
with error: eff1173= 4.73% +/- 0.13%

with error: eff1333= 4.44% +/- 0.12%

__input P/T is 0.3357
__true P/T is 0.3351 +/- 0.0107

__obs P/T is 0.1721 +/- 0.0001

nsi tracking efficiency = 80.35% +/- 0.59%
FOM20_nsi efficiency point is 0.0357 +/- 0.0010
wsi tracking efficiency = 94.20% +/- 0.69%
FOM20_wsi efficiency point is 0.0418 +/- 0.0012

with error: eff1173= 4.24% +/- 0.21%

with error: eff1333= 4.02% +/- 0.20%

__input P/T is 0.3380
__true P/T is 0.3368 +/- 0.0031

__obs P/T is 0.2945 +/- 0.0002

nsi tracking efficiency = 80.08% +/- 1.07%
FOM20_nsi efficiency point is 0.0322 +/- 0.0016
wsi tracking efficiency = 93.84% +/- 1.25%
FOM20_wsi efficiency point is 0.0377 +/- 0.0019