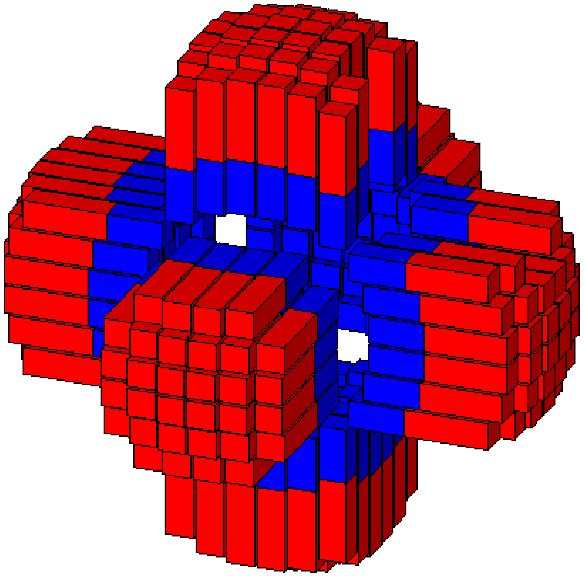
Characterisation of $LaBr_3(Ce)$ Performance for PARIS



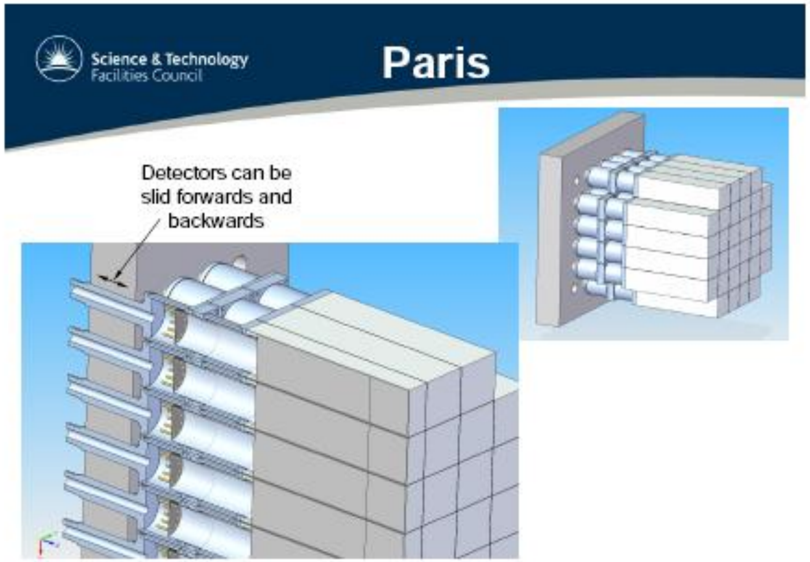
O. J. Roberts

RIKEN SHOGUN Workshop
Tokyo 4-5 February 2011

University of Brighton

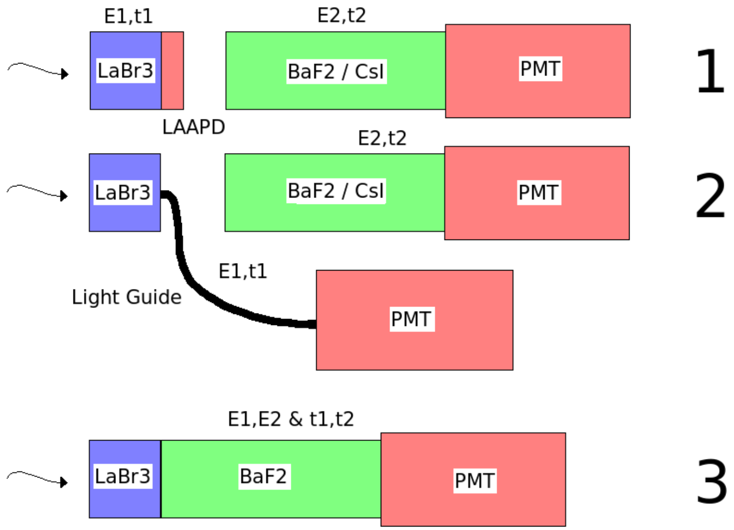
Outline

- Motivation
- SiPM Array
  - Light Response
  - Timing Measurements
  - Temperature Response
- Phoswich Detector
  - Neutron Response
  - Coincidence Timing Measurements
  - Pile Up Measurements
  - $^{27}Al(p,\gamma)^{28}Si$ Beam Test
- Summary & Conclusions



Images courtesy of J.Strachan (STFC)

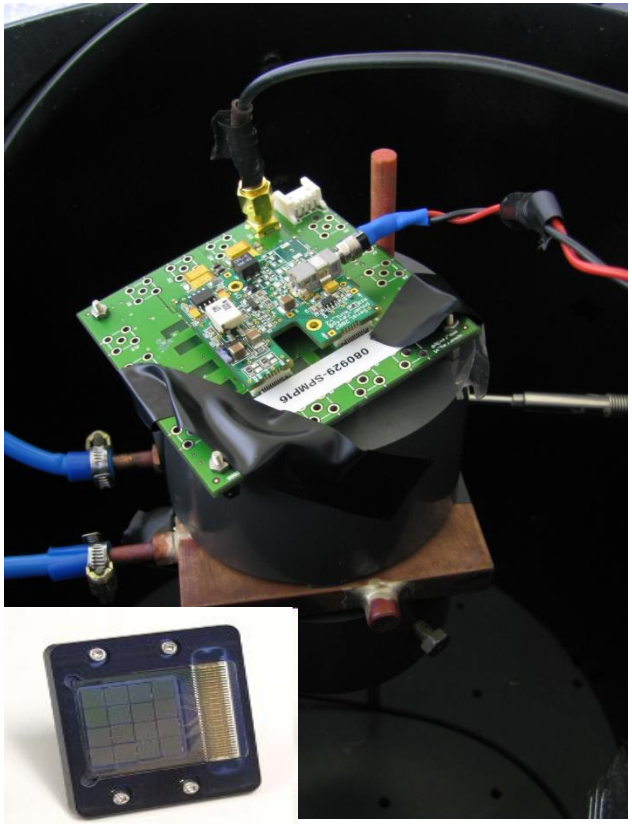
Motivation: PARIS



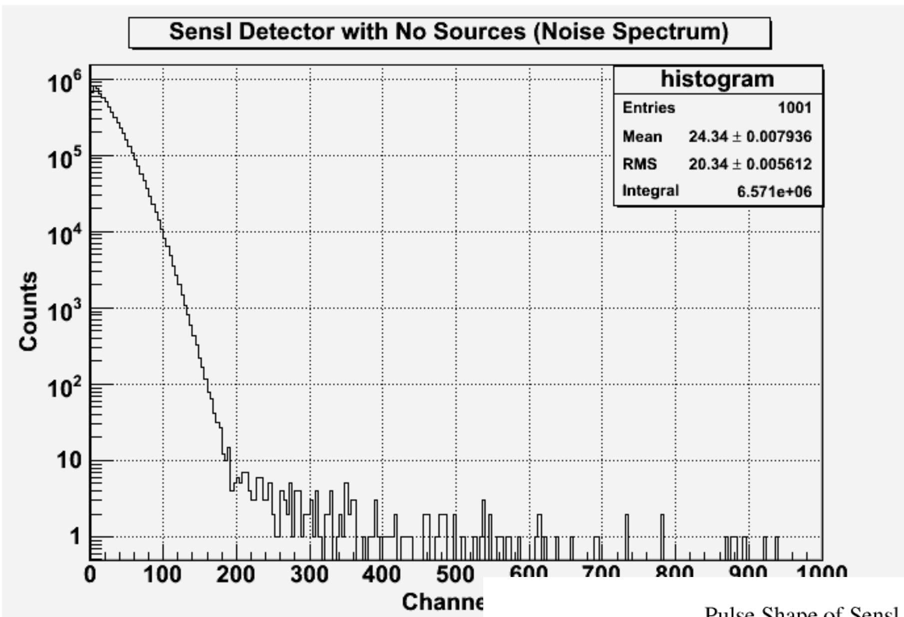
- Energy range between 0.1 and 50 MeV
- Two layers of scintillators in a 4π arrangement: $LaBr_3$(Ce) and BaF_2, or CsI(Na)
- An outstanding question within the collaboration is what set-up to adopt.

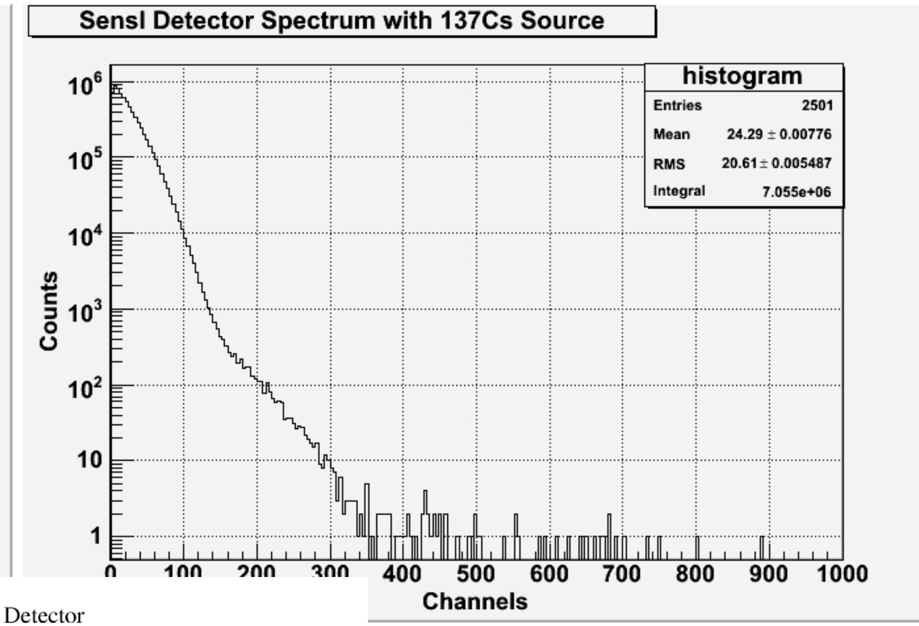
Large Area APD's

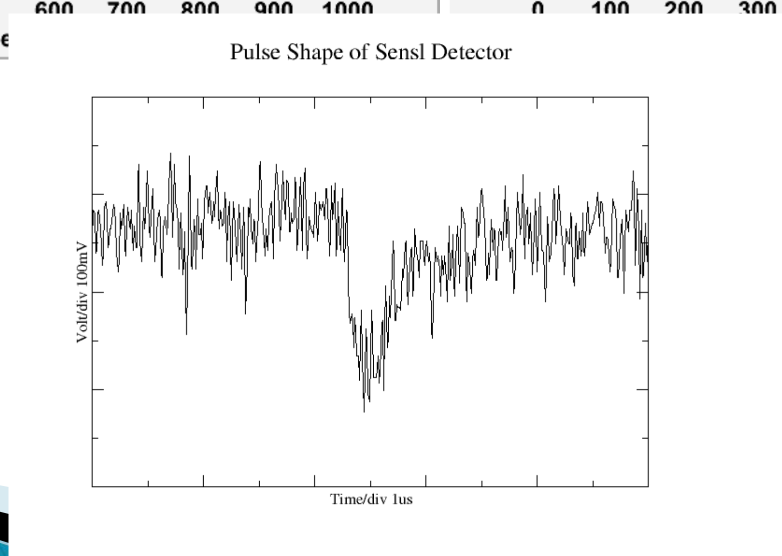
- Novel SiPMs from SensL provide high gain and low dead space
- Built-in preamp takes in 5 V and creates a bias voltage of ~28 V.
- Sensitive from 400-850 nm, peaking at ~ 520 nm.
- 16 pixels, 3.2 x 3.2 mm.
- Collectively, large amount of noise (50-100 mV), small S/N.



SensL Spectra & Pulse

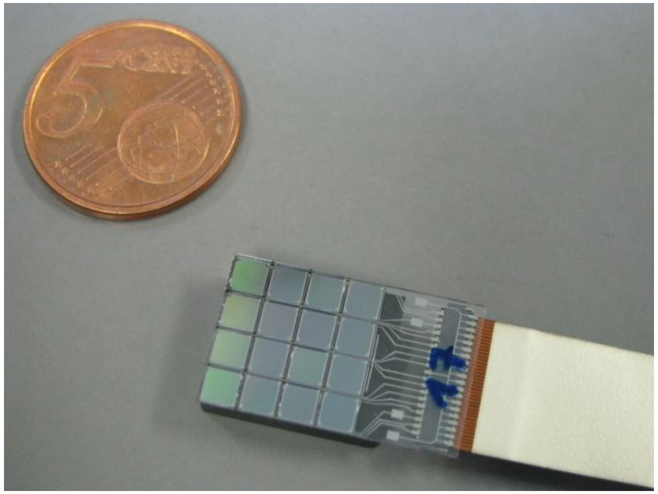


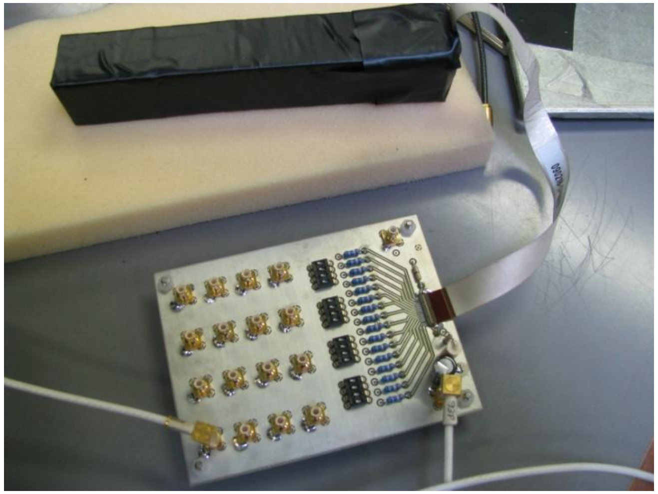




"New" SiPM Array

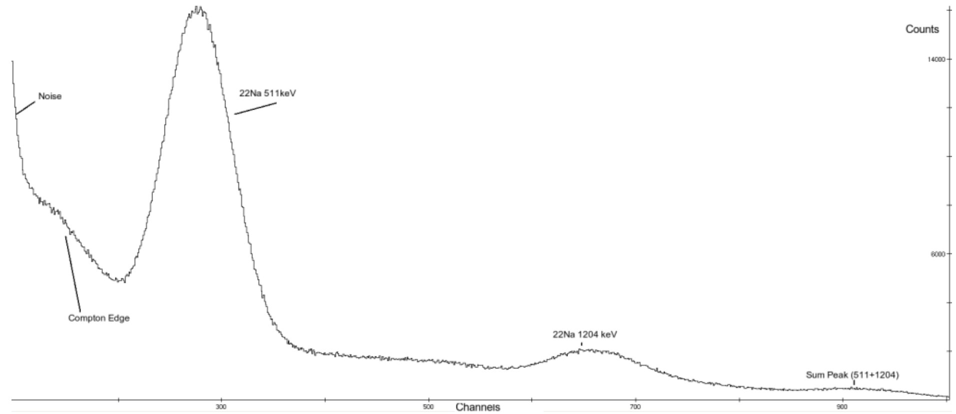
- 4 new SensL arrays with FPC cables were purchased.
- 4 boards were made at the University of York to read off the signal.
- Switches allowed greater flexibility

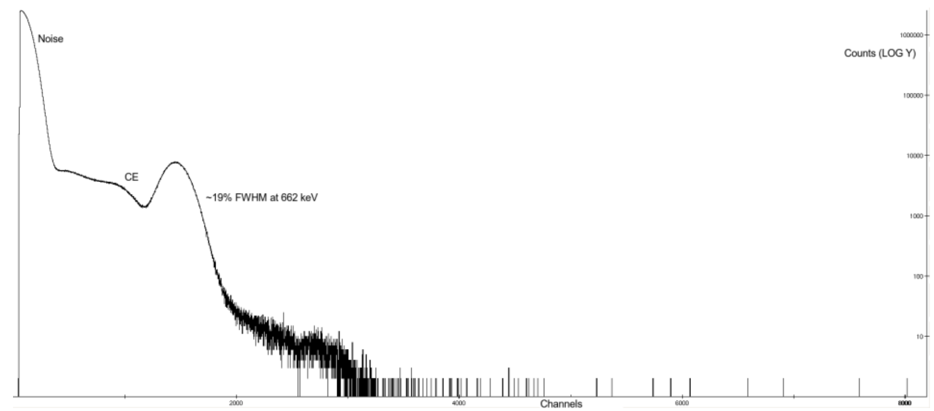




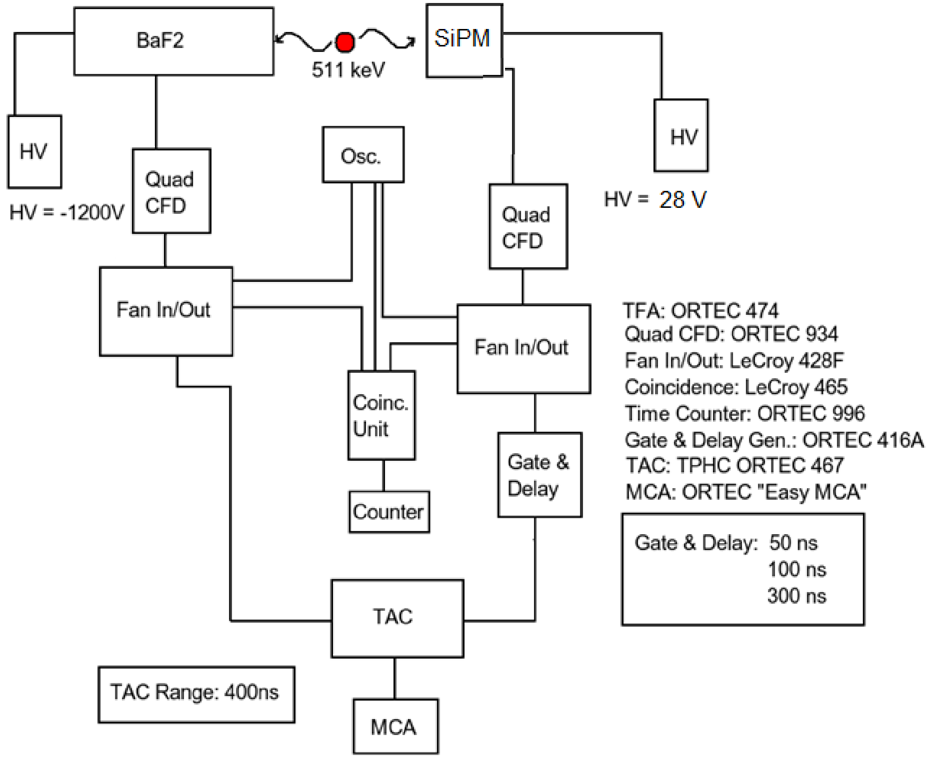
Energy Spectra with New Arrays

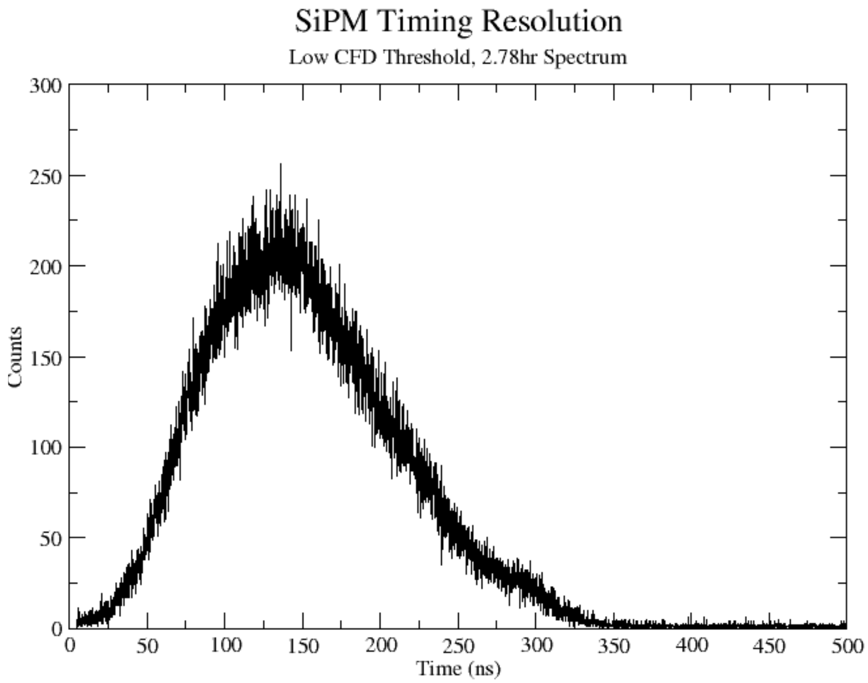
- 1”x1”x6” CsI(Tl) scintillator coupled to the detector produced spectra
- FWHM resolution with a ^{137}Cs source, found to be ~19%
- Similar resolution when measuring the FWHM of the 511 keV photo-peak (~25%)





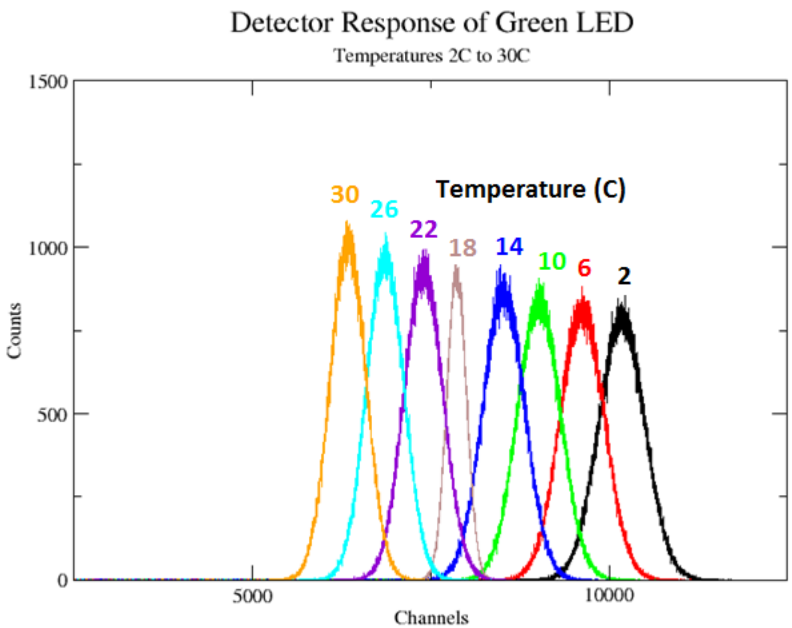
Timing with the SiPM

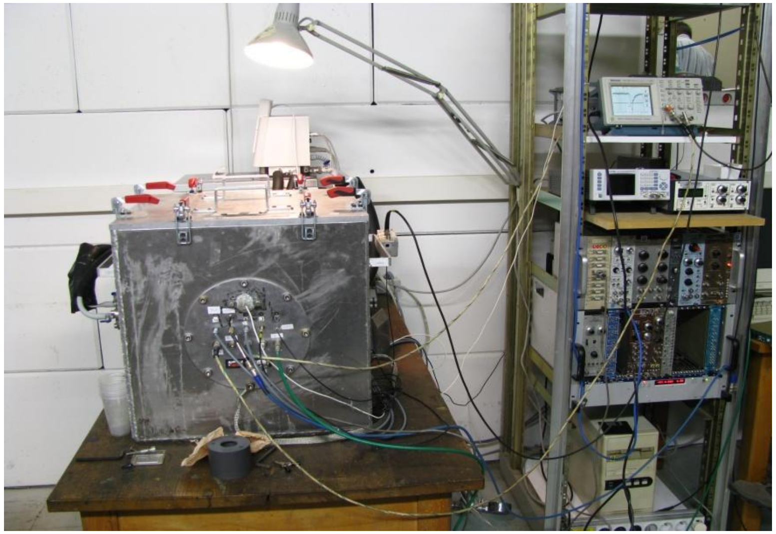




- Start-stop timing coincidence measurement with 1” BaF_2 detector revealed a timing FWHM of ~ 120 ns

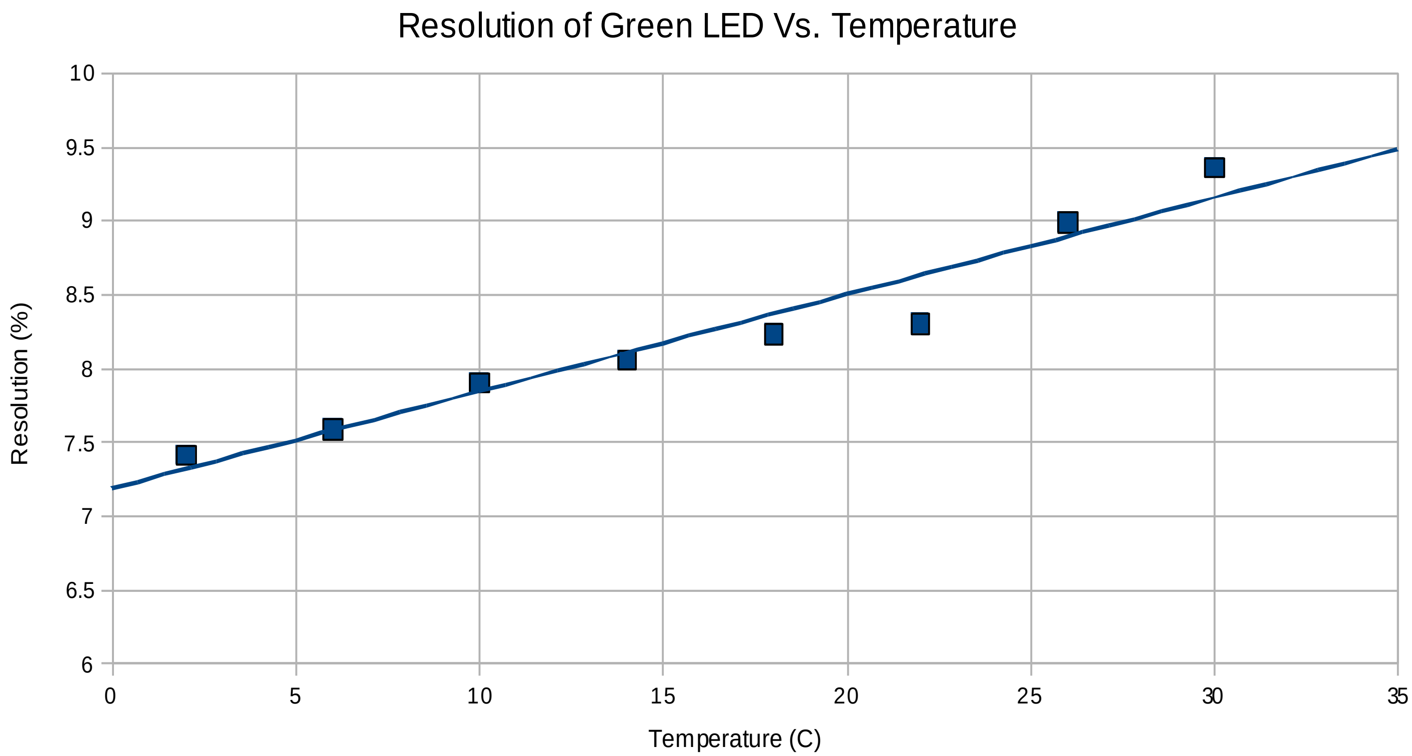
Temperature Response of LAAPD





- Labyrinth in the copper plate is pumped with cooled alcohol
- Temperature tests between 2°C and 30°C shows linear degradation in the FWHM of green LED (565 nm) Signal.

Temperature Response of LAAPD

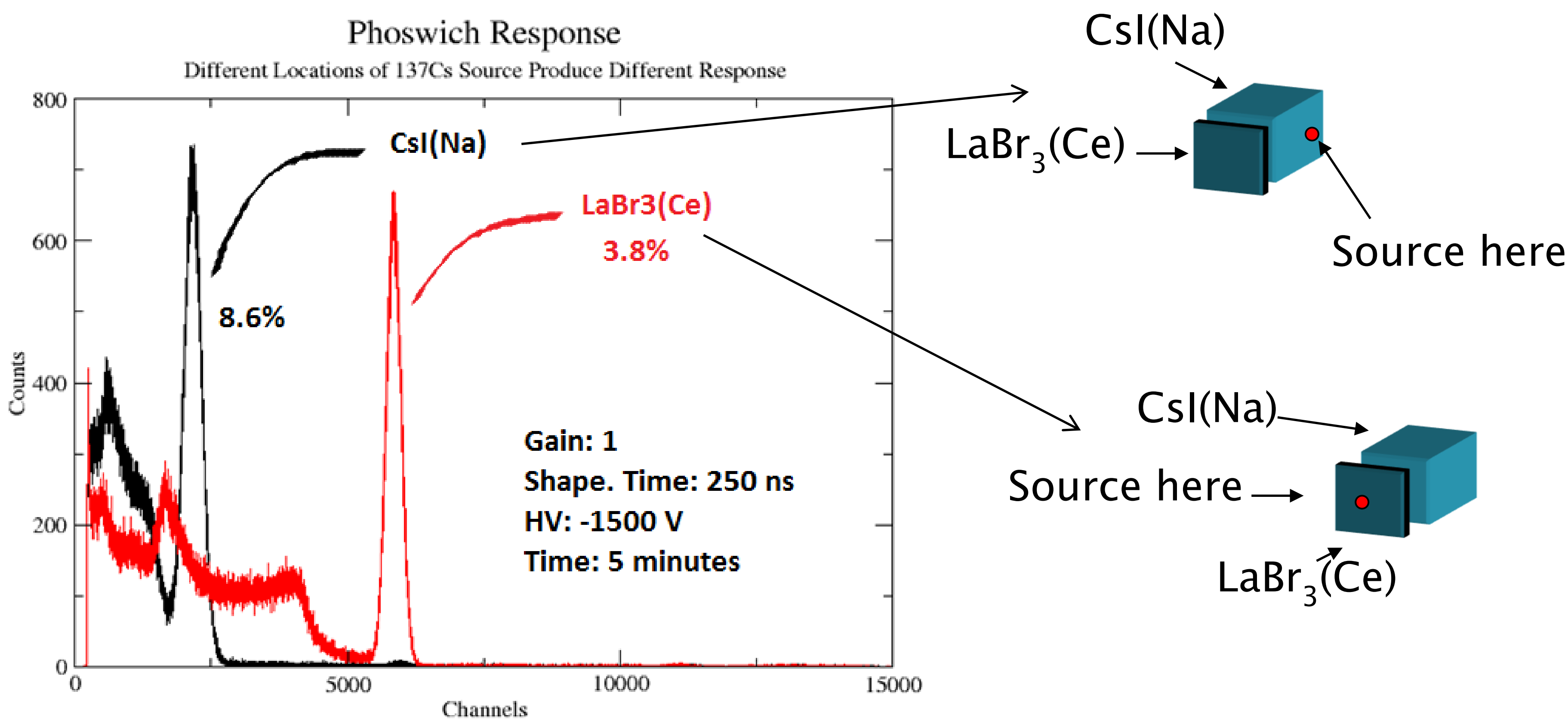


- Temperature and energy resolution is linear.
- Resolution with scintillator still not optimised.

SiPM Conclusions

- SiPM Array
  - Light Response – Very good with a green LED. Newer models give a spectrum of poor energy resolution when used with a 6” CsI(Tl) scintillator.
  - Timing Measurements – Timing resolution with respect to a 1” BaF_2 in a start-stop set-up was poor when used with a CsI(Tl) crystal (~120 ns)
  - Temperature Response – Energy resolution responded linearly with temperature. Lower energy resolutions recorded at lower temperatures.
  - Tests reveal several shortcomings that might be improved with an alternative method.

Phoswich Tests



- The signal is read out on one device (i.e. PMT).

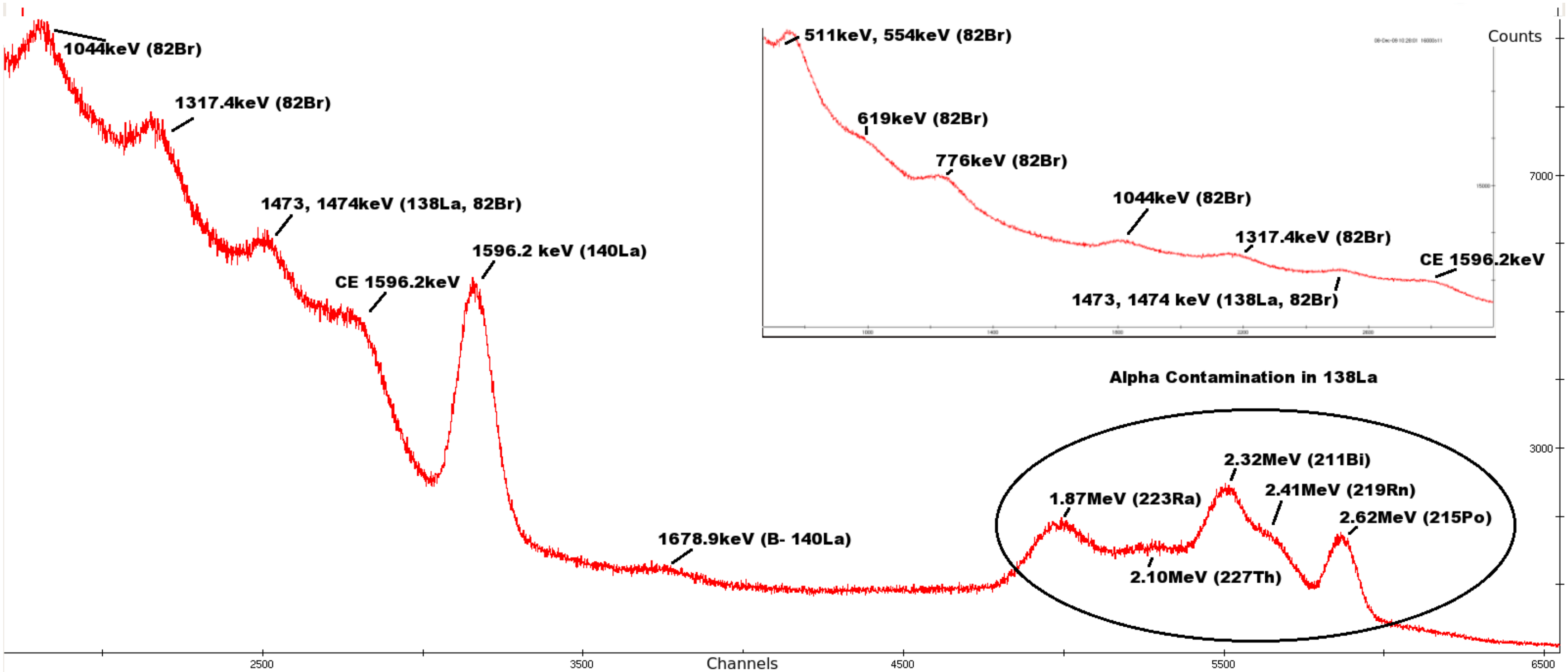
Neutron Response

- Neutron response of the phoswich detector was observed with a 10.5 GBq $^{241}Am/^{9}Be$ source.

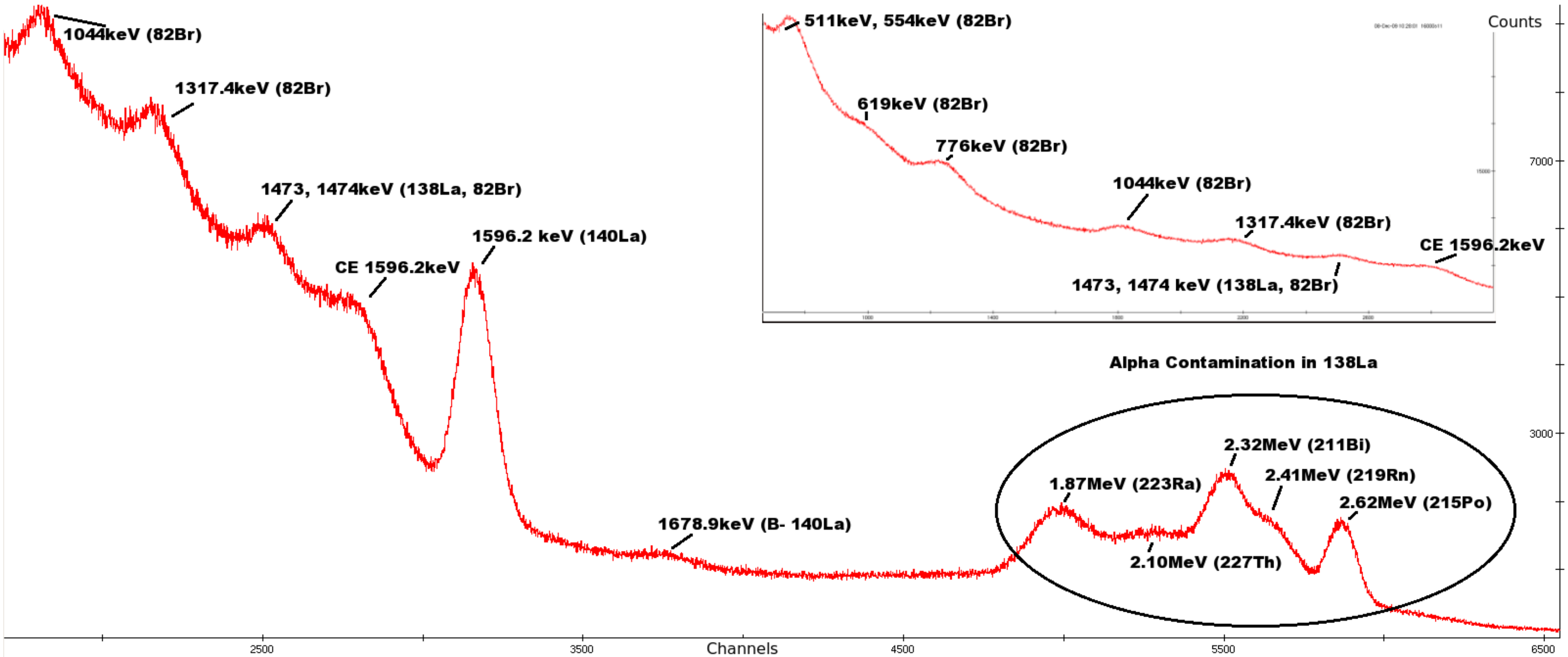
- Large thermal n-capture cross-section from ^{139}La, ^{79}Br, ^{81}Br.

- Is PSD between gammas and neutrons possible?

Neutron Activated Spectrum

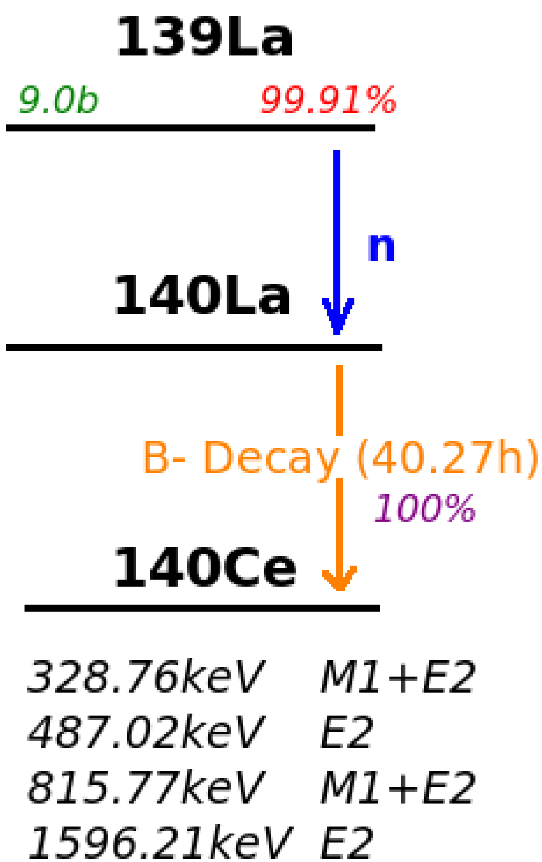


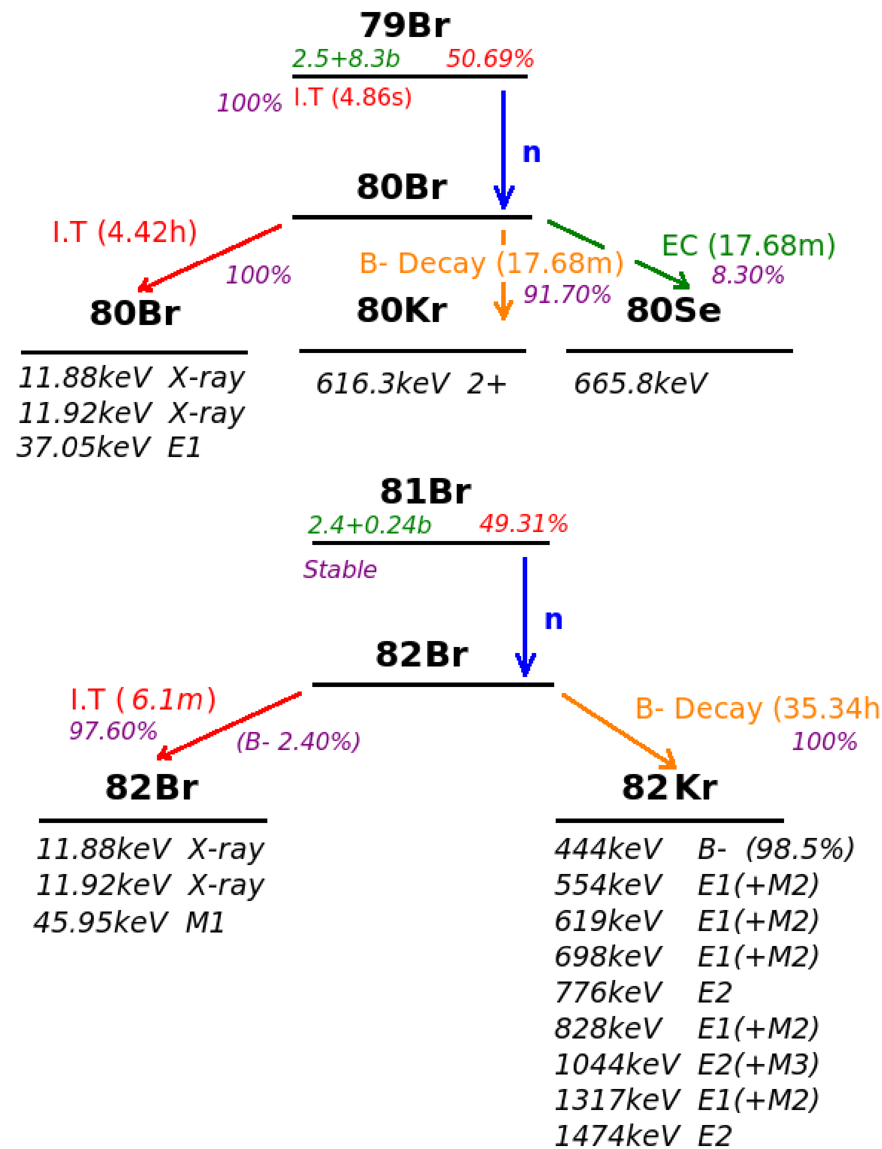
In-beam spectrum showing the lower energy regions up to 1MeV in the inset.



In-beam spectrum showing the lower energy regions up to 1MeV in the inset.

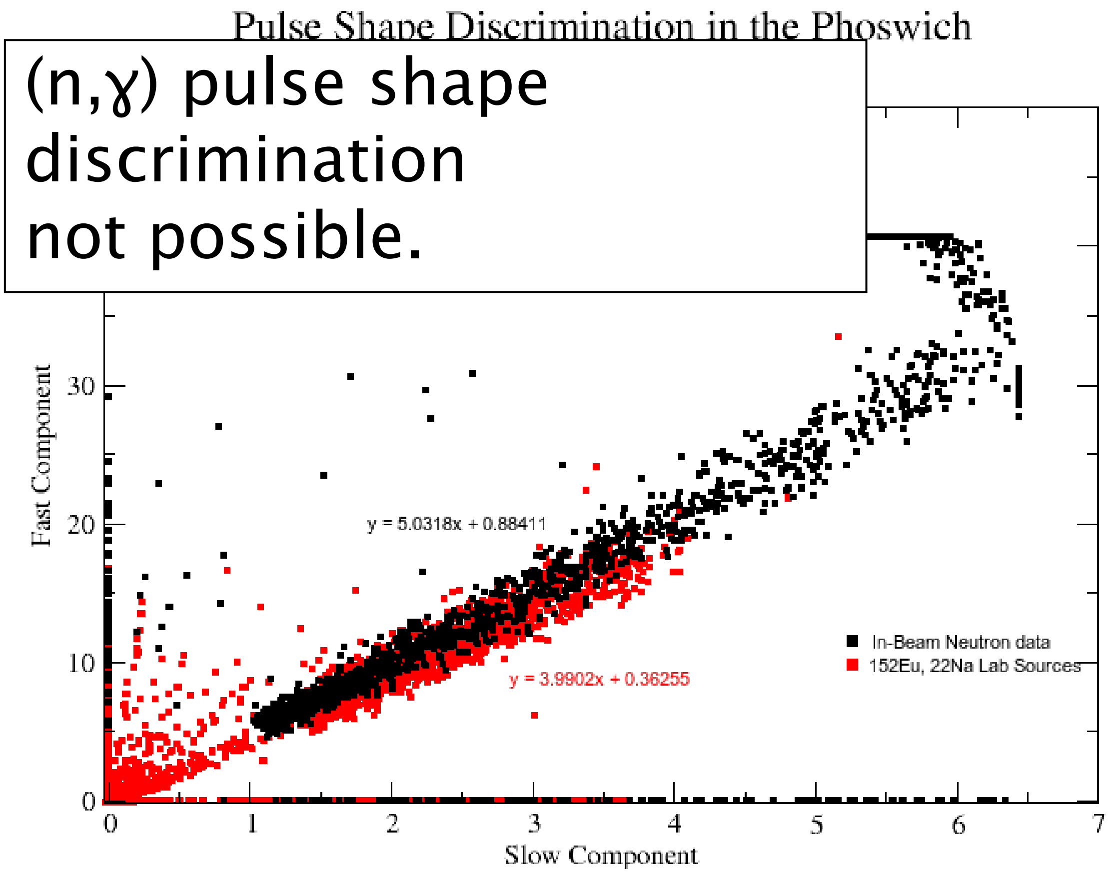
n-Response

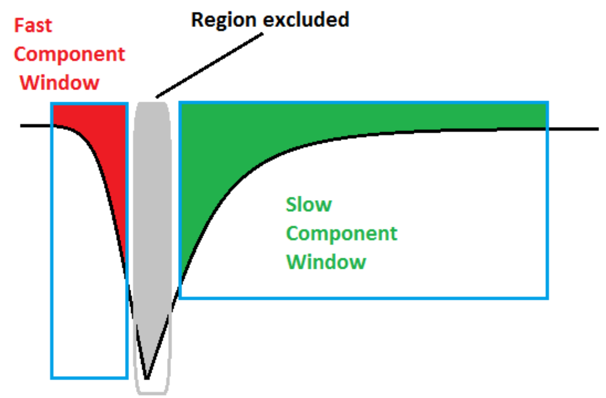

139La
9.0b
99.91%
n
140La
B- Decay (40.27h)
100%
140Ce
328.76keV M1+E2
487.02keV E2
815.77keV M1+E2
1596.21keV E2

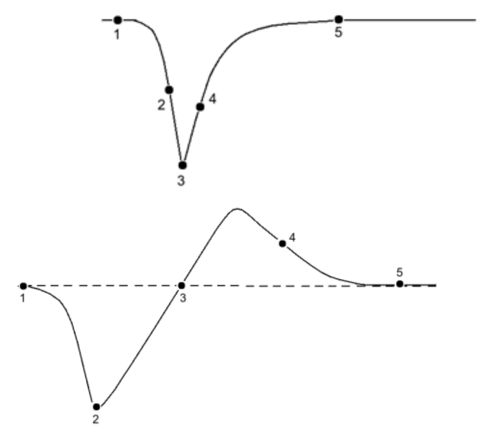

79Br
2.5+8.3b
50.69%
100%
I.T (4.86s)
n
80Br
I.T (4.42h)
100%
B- Decay (17.68m)
91.70%
EC (17.68m)
8.30%
80Br
80Kr
80Se
11.88keV X-ray
11.92keV X-ray
37.05keV E1
616.3keV 2+
665.8keV
81Br
2.4+0.24b
49.31%
Stable
n
82Br
I.T (6.1m)
97.60%
(B- 2.40%)
B- Decay (35.34h)
100%
82Br
82Kr
11.88keV X-ray
11.92keV X-ray
45.95keV M1
444keV B- (98.5%)
554keV E1(+M2)
619keV E1(+M2)
698keV E1(+M2)
776keV E2
828keV E1(+M2)
1044keV E2(+M3)
1317keV E1(+M2)
1474keV E2

Pulse Shape Analysis for $LaBr_3(Ce)$

(n,ɣ) pulse shape discrimination not possible.

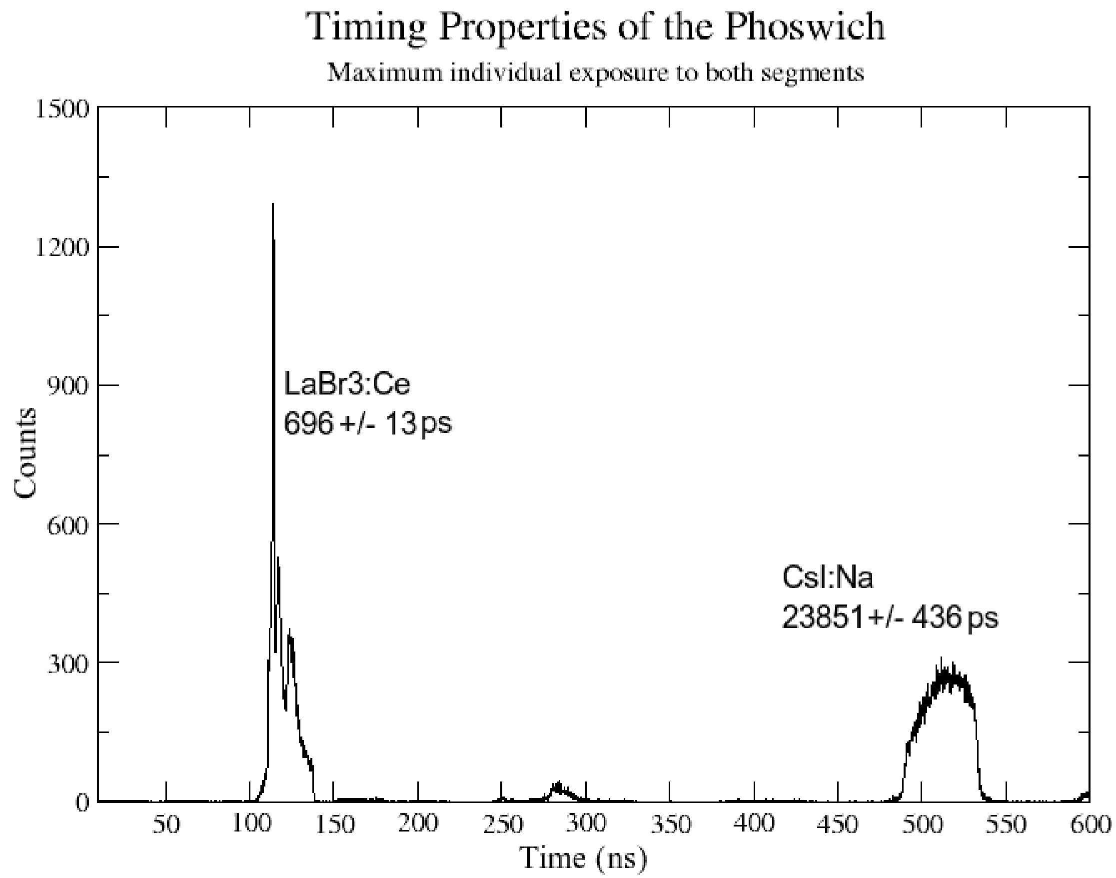






Timing Coincidence Measurements

- Set-up involved irradiating a 1 inch Bicron BaF_2 scintillator formed the “start” channel.
- Front-end timing resolution of 696 $\pm$ 13 ps, and CsI(Na) has a timing resolution of 24 $\pm$ 1 ns.



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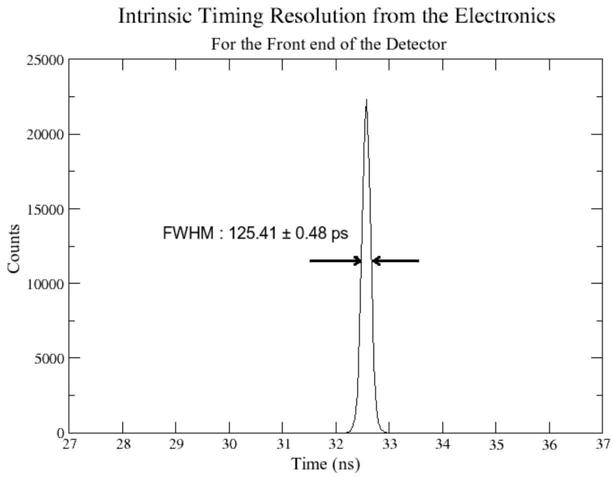
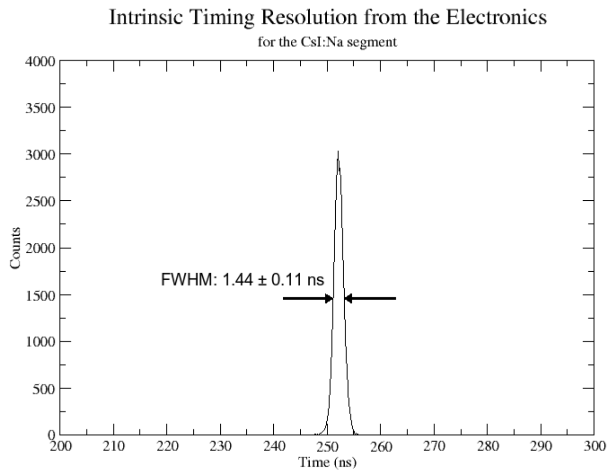
Electronics Timing Resolutions

- Timing Resolutions of the electronics are shown opposite.
- ~125 ps and 1.44 ns for the $LaBr_3(Ce)$ and CsI(Na) segments respectively.





Improving the Timing Measurements

- Optimisation of the timing loop resulted in a marginal improvement to 665 ± 2 ps. Therefore, the timing is constrained by the fast component of BaF_2 (~600 ps).

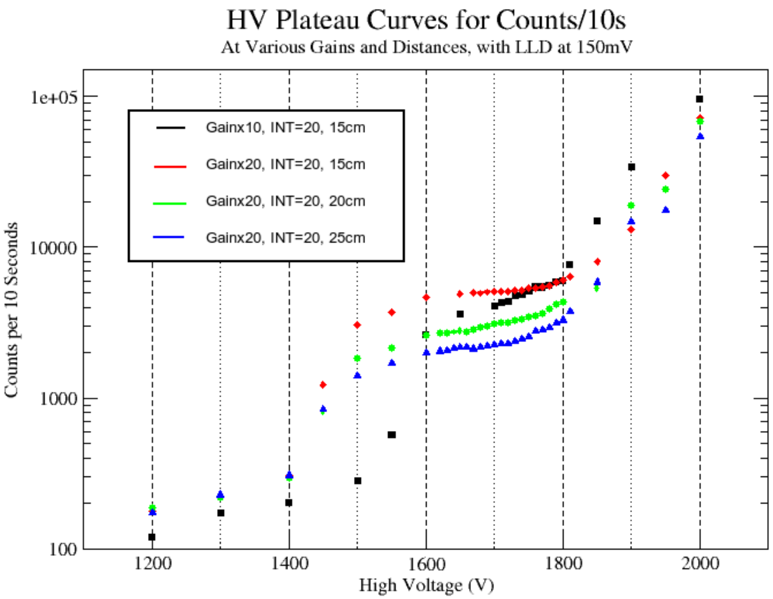
- Need to test with another detector with a comparable time match eg. $LaBr_3$(Ce).

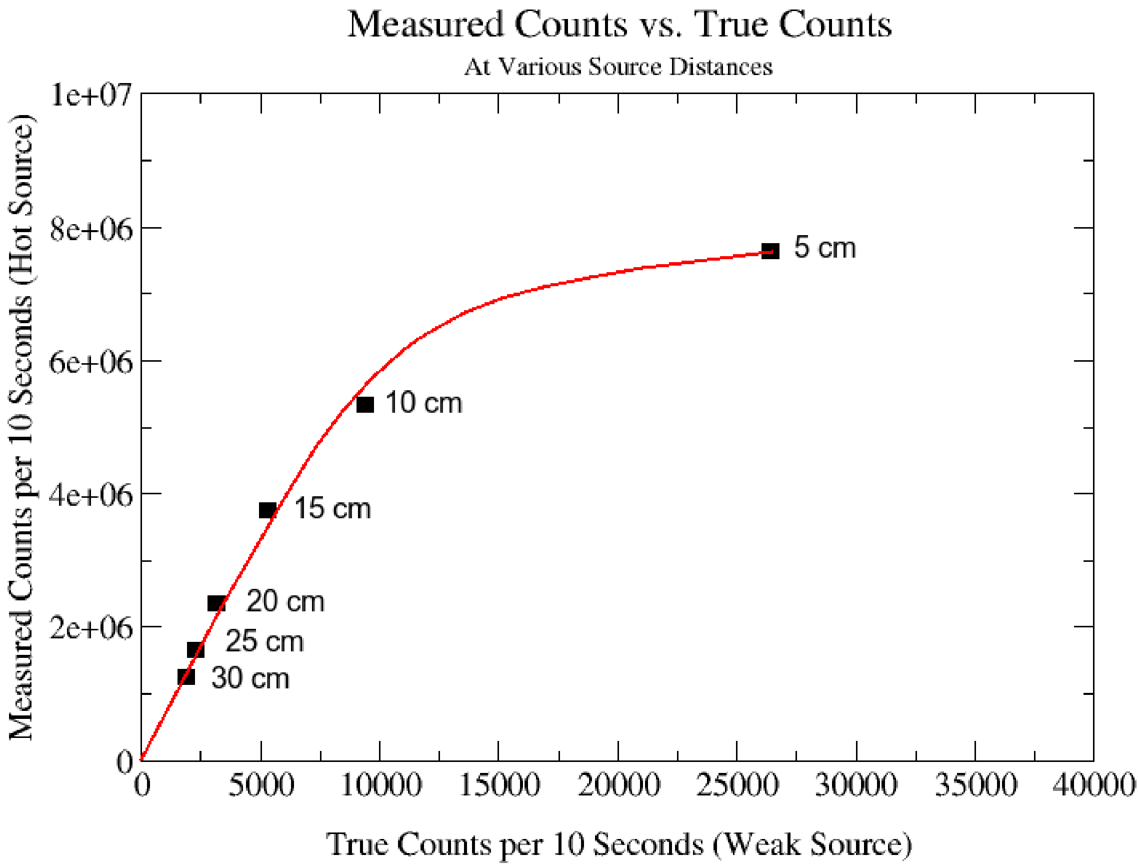
Segment	Int. Timing Res.	Timing(ps)/ch	Intrinsic Timing Res.	Delay (ns)	TAC Range (ns)
$LaBr_3$:Ce	696 ± 13	45.0 ± 0.1	685 ± 13	100	400
Front Elec.	125 ± 1	45.0 ± 0.1	125 ± 1	100	400
CsI:Na	23851 ± 434	167 ± 4	23810 ± 426	400	2000
Back Elec.	1436 ± 110	167 ± 4	1436 ± 110	400	2000

Pile-Up Measurements

- HV plateau had to be determined by altering the CFD LLD and TFA settings.
- Two ^{57}Co sources of different strengths were used; one hot source (4.2 mCi) and one weaker source (3.9 µCi).
- Results were generated based on ratios between “Measured” and “True” counts.

Pile-Up Measurements





Rate found to be ~ 800 kHz, primarily from $LaBr_3(Ce)$

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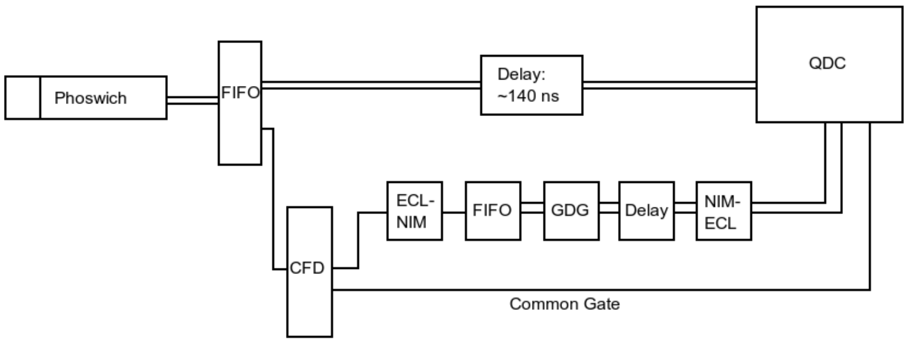
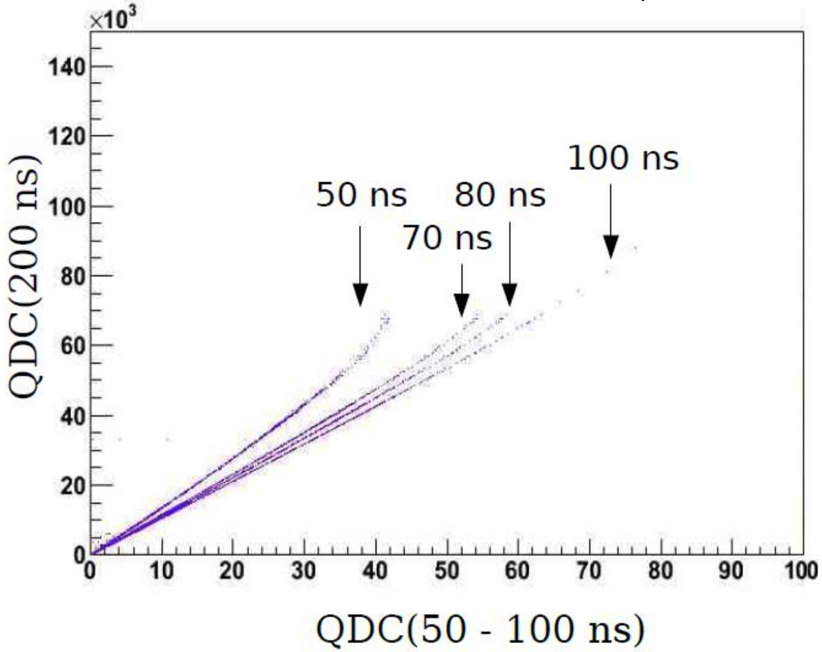
$^{27}Al(p,\gamma)^{28}Si$ Experiment

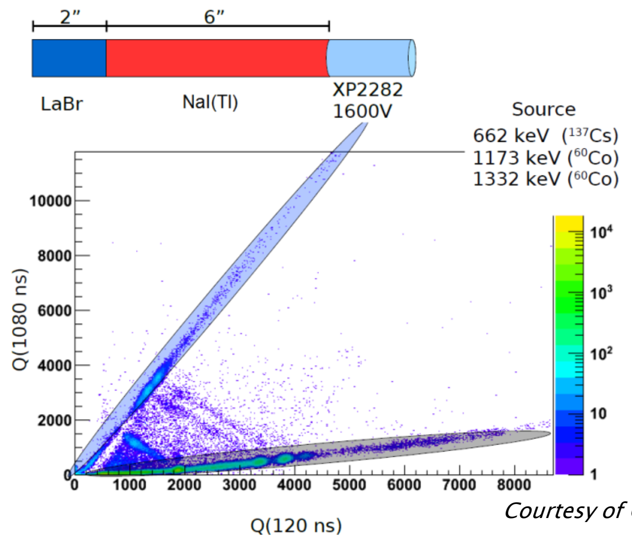


- Proton beam incident on 100μgcm^{-2} ^{27}Al target.
- Purpose to look at resonant capture and observe performance of phoswich under laboratory conditions.
- Several QDC modules used with the phoswich

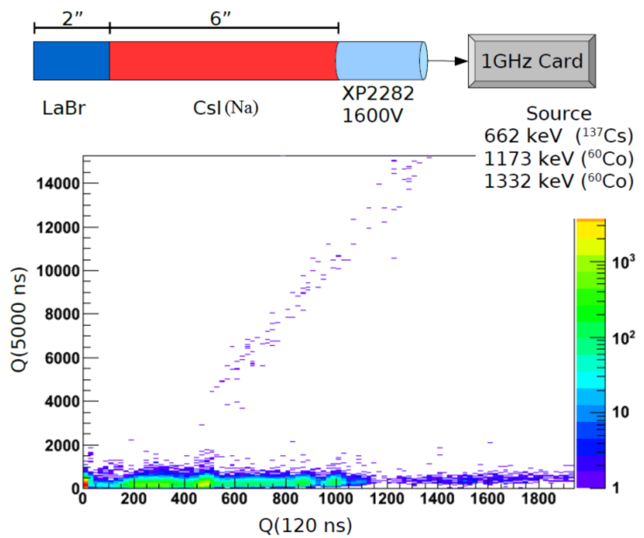
Calibration Tests

Courtesy of O.Dorvaux





Courtesy of O.Dorvaux



Courtesy of O.Dorvaux

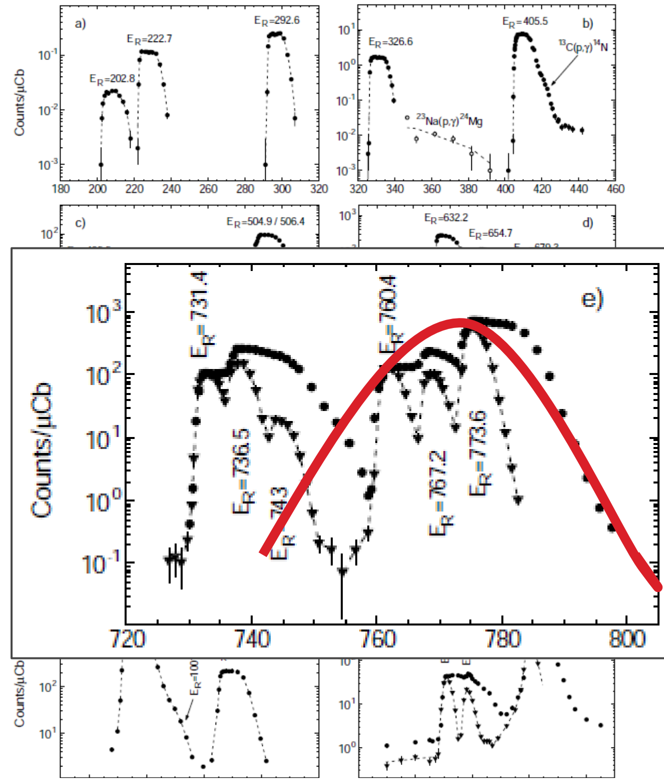
Calibrations with lab sources were used to determine the appropriate gates used with the QDCs to maintain linearity.

Yields and Resonance Strengths

E_R (keV)	Y_∞ (Counts/μC)	$\omega\gamma$ (eV)
202.8	0.094(13)	$1.10(15)\times10^{-5}$
222.7	0.40(3)	$5.0(4)\times10^{-5}$
292.6	1.9(1)	$2.80(15)\times10^{-4}$
326.6	13.3(7)	$2.10(11)\times10^{-3}$
405.3	58(3)	$1.04(5)\times10^{-2}$
446.7	9.4(7)	$1.80(15)\times10^{-3}$
504.9	151(19)	$3.1(4)\times10^{-2}$
506.4	204(24)	$4.1(5)\times10^{-2}$
611.5	26(3)	$5.8(7)\times10^{-3}$
632.2	1296(130)	0.29(3)
654.7	538(53)	0.12(1)
679.3	249(26)	$5.8(6)\times10^{-2}$
731.4	591(34)	0.142(8)
736.5	726(52)	0.175(15)
743.0	94(10)	$2.30(25)\times10^{-2}$
760.4	556(39)	0.14(1)
767.2	802(57)	0.200(15)
773.6	1696(170)	0.42(4)
887.8	44(5)	$1.20(15)\times10^{-2}$
923.0	551(55)	0.145(15)
937.3	721(72)	0.19(2)
991.9	7308(517)	2.00(15)
1025.3	1318(132)	0.36(4)
1089.7	303(22)	$8.4(6)\times10^{-2}$
1097.3	150(16)	$4.2(4)\times10^{-2}$
1118.6	2978(298)	0.85(9)

Eur. Phys. J. A 9, 479–489 (2000)

- Resonance Strengths and yields at resonance energies.



Energy Loss: 20.35 keV

A 9, 479–489 (2000)

- Yield Curves: 10μgcm^{-2} (▼) 50μgcm^{-2}(●)

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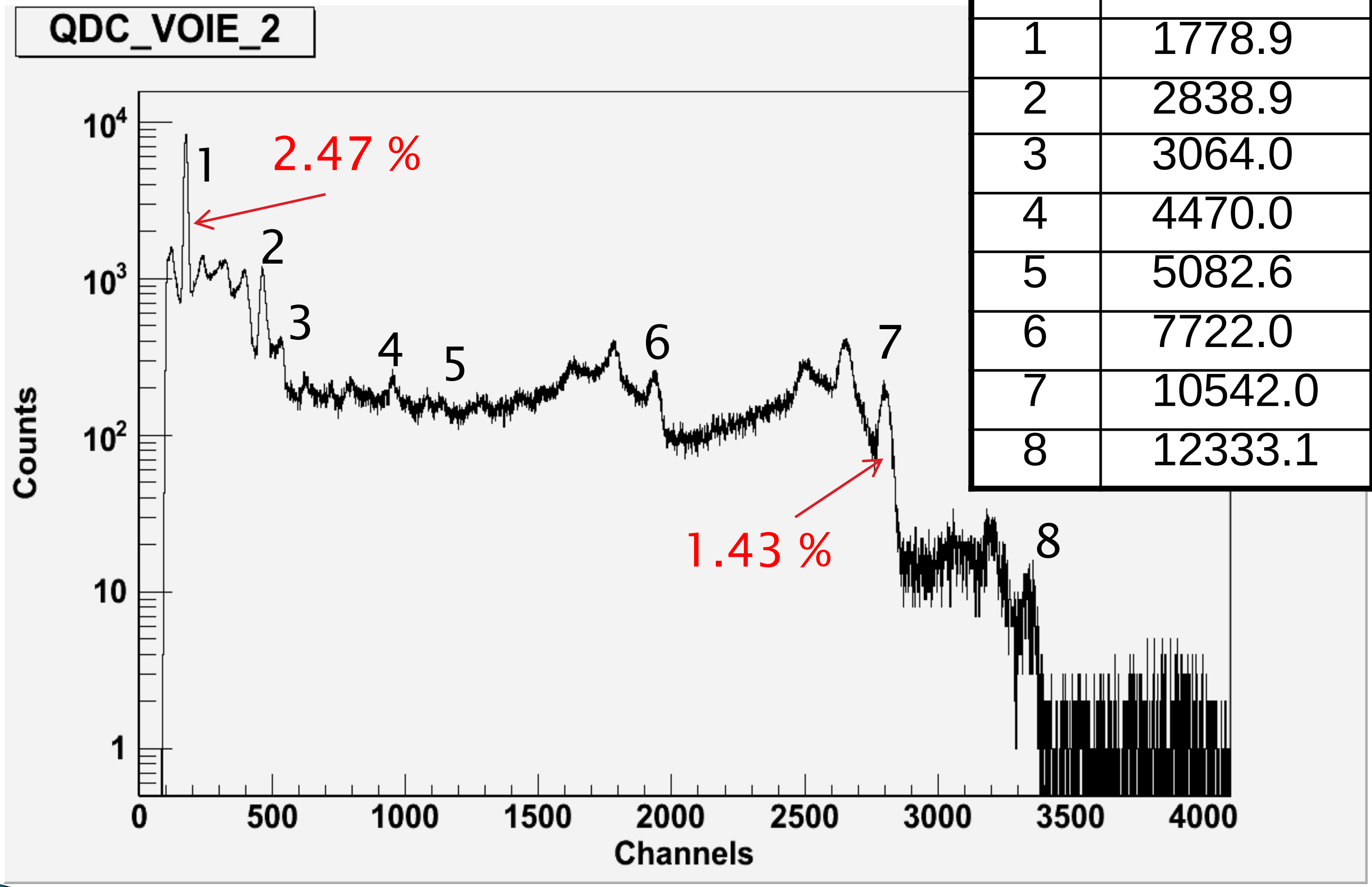
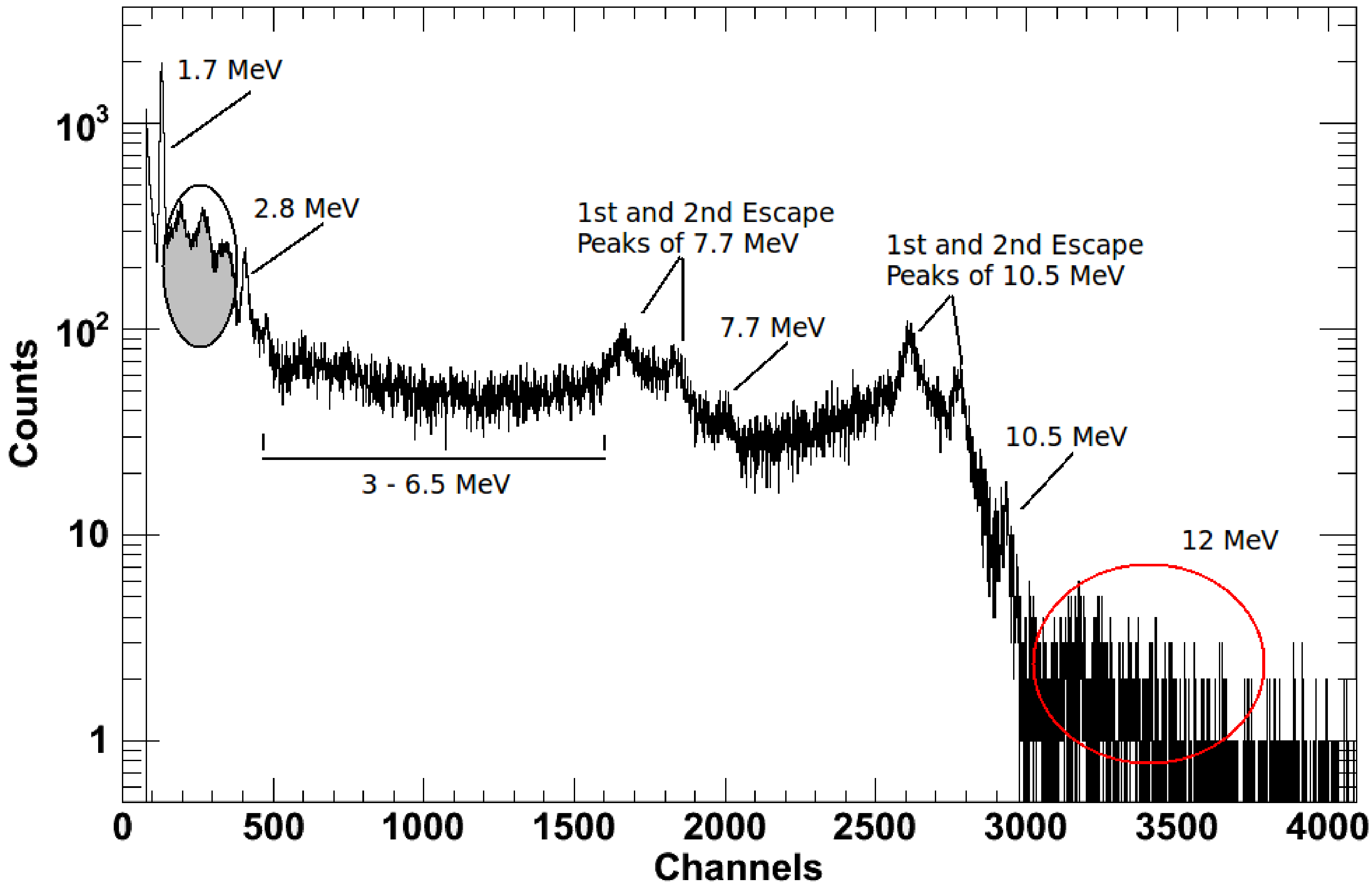
$^{27}Al(p,\gamma)^{28}Si$ Reaction



#	Gamma (keV)	Spin & Parity
1	1778.9	$2^+ - 0^+$
2	2838.9	$4^+ - 2^+$
3	3064.0	R-9479
4	4470.0	$3^+ - 2^+$
5	5082.6	$3^- - 2^+$
6	7722.0	$R - 4^+$
7	10542.0	$R - 2^+$
8	12333.1	$1^- - 0^+$

QDC 0, Phoswich Response



Summary

- SiPMs were very noisy, but eventually generated a spectrum. Although, a poor timing resolution of ~120 ns for a 6" CsI(Tl) scintillator was recorded, they displayed a very linear trend in energy resolution with respect to temperature.

- Neutron activation observed due to isotopes with large thermal neutron cross-sections in Lanthanum and Bromine.

- (n,γ) pulse shape discrimination not possible.

- Phoswich timing resolutions of ~0.7 and 24 ns for $LaBr_3$(Ce) and CsI(Na) with respect to the BaF_2 scintillator, were limited due to poorly time matched BaF_2 in start channel.

- Pile-up rate found to be ~ 800 kHz, primarily from $LaBr_3$(Ce).

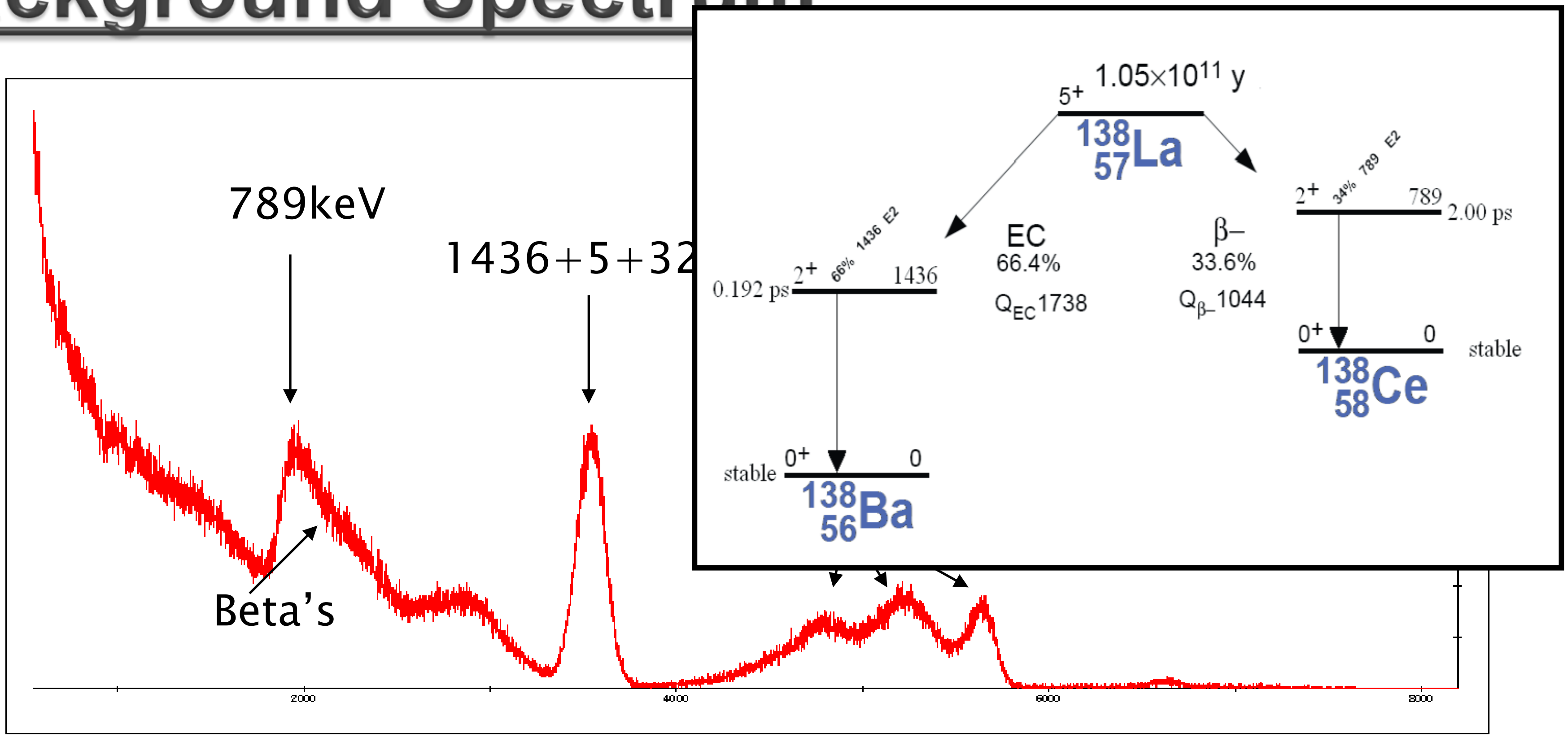
- $LaBr_3$(Ce)/CsI(Na) Phoswich produced poor spectra in-beam, where gain matching the CsI(Na) scintillator proved to be extremely difficult.

Acknowledgement of Collaborators

P. Joshi[1], D. Jenkins[1], O. Dorvaux[2], M. Rousseau[2], Christian Finck[2,] , M.Ciemala[3], D. Lehertz[5], A. Maj[3], I. Matea[4], J. Pouthas[4], J. Strachan[6], A. Smith[7], R.Wadsworth[1], and the rest of the PARIS collaborators

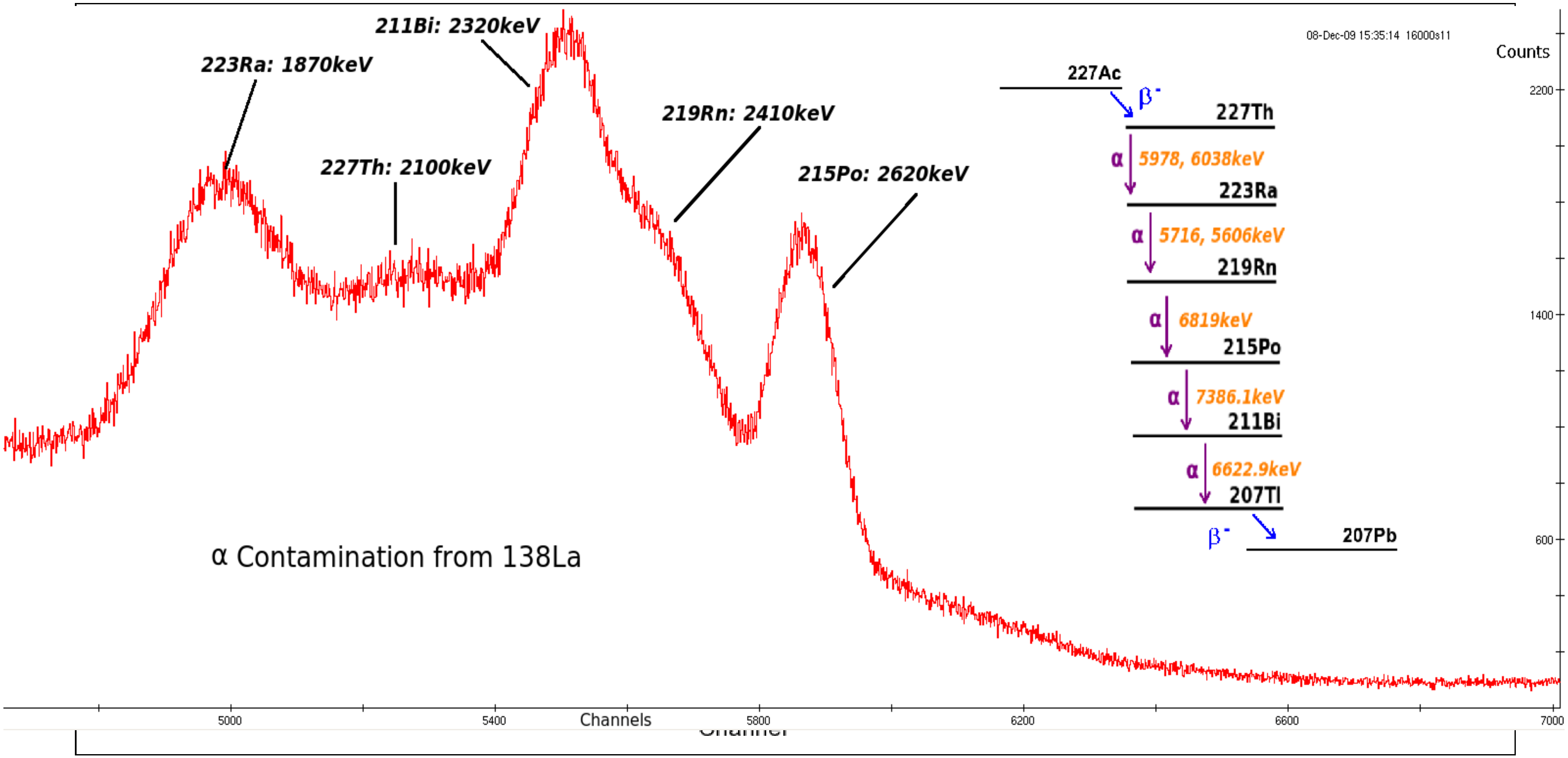
[1]University of York, United Kingdom
[2]IPHC Strasbourg, France
[3]IFJ PAN Krakow
[4]IPN Orsay, France
[5]GANIL, Caen, Frace
[6]STFC Daresbury, United Kingdom
[7]University of Manchester, United Kingdom

Background Spectrum



- Lower channels cut due to K-Shell X-Rays Intensity.
- FWHM @ 1436keV is 169.10keV, Resolution 4.77%

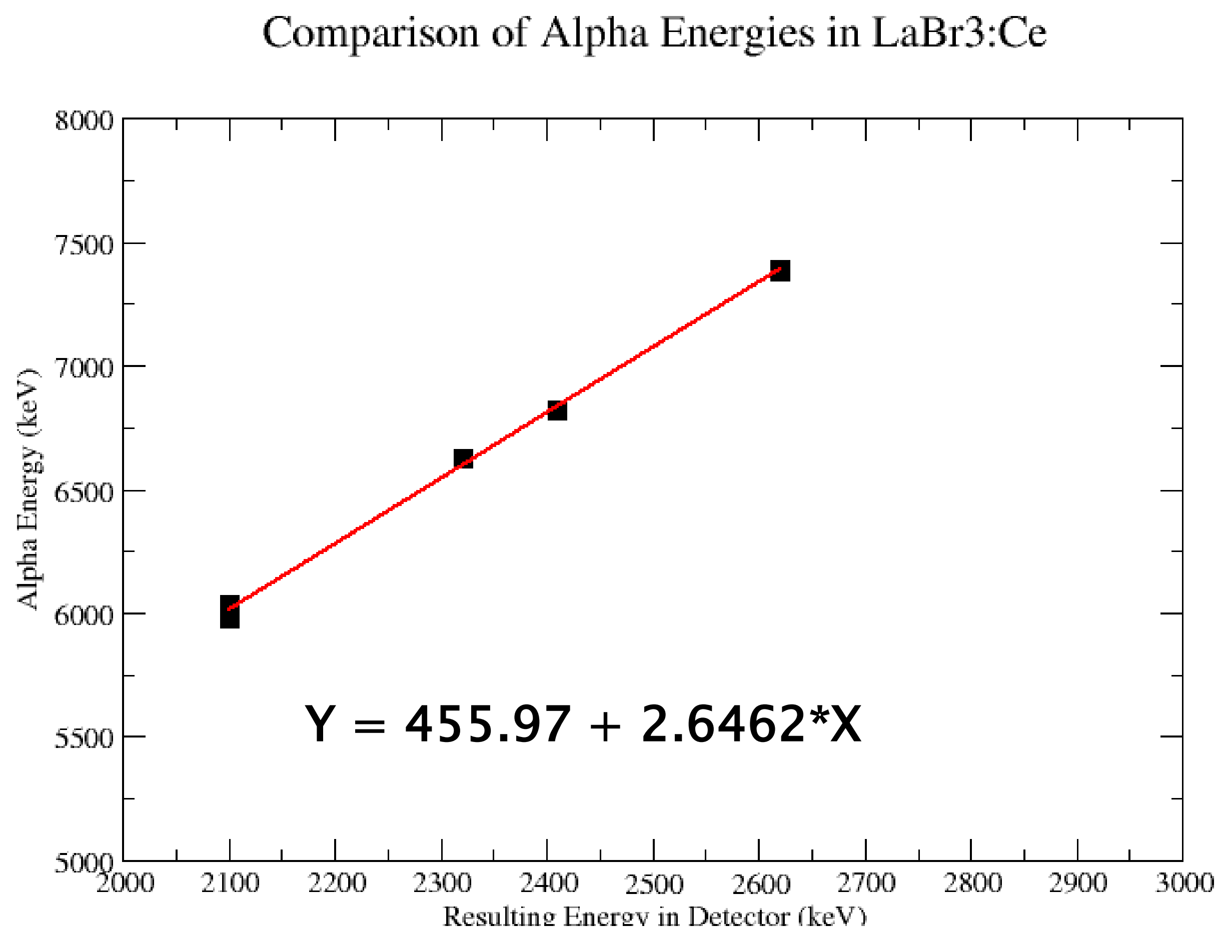
Alpha Contamination



- ^{227}Ac ($t_{1/2}$=21.2yrs), in the same group (IIIB) as Lanthanum

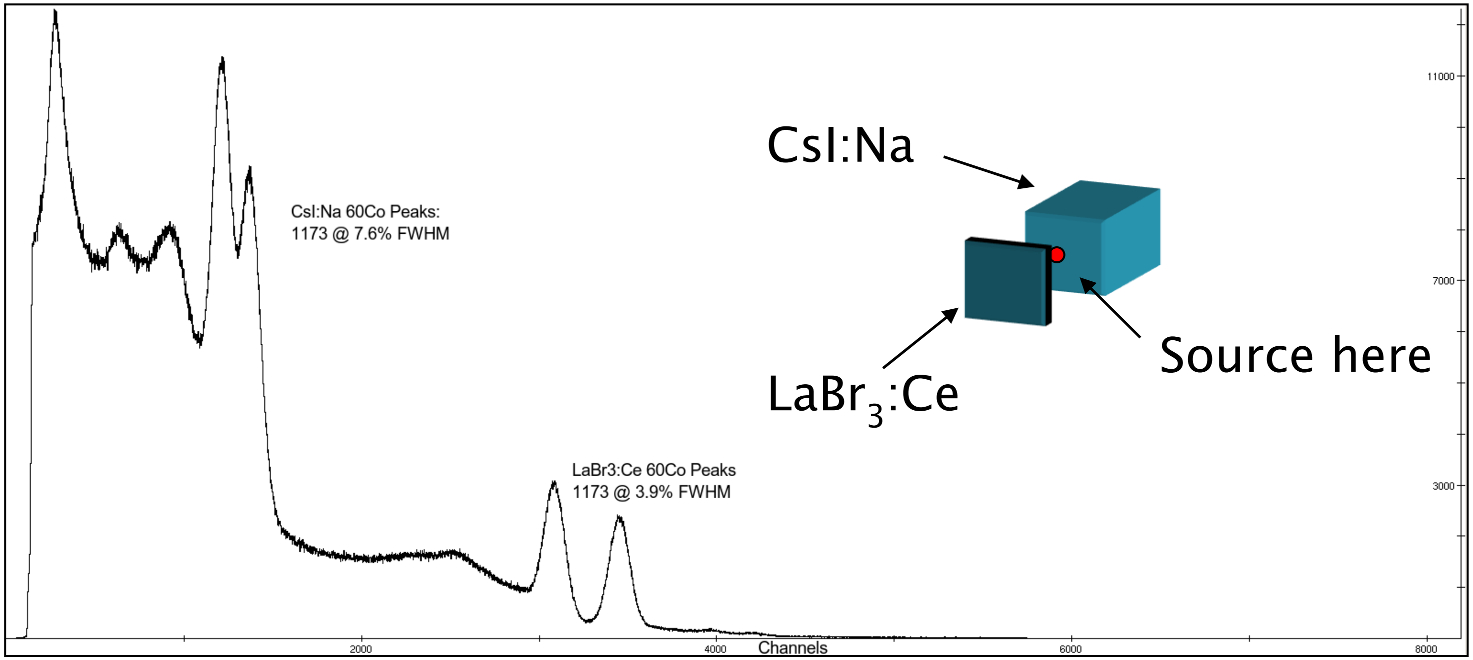
Alpha Scintillation Properties

- Ratio between the two is 0.35.
- Alphas emit 65% less light.
- In agreement with $LaCl_3$ measurements by Hartwell and Gehrke*



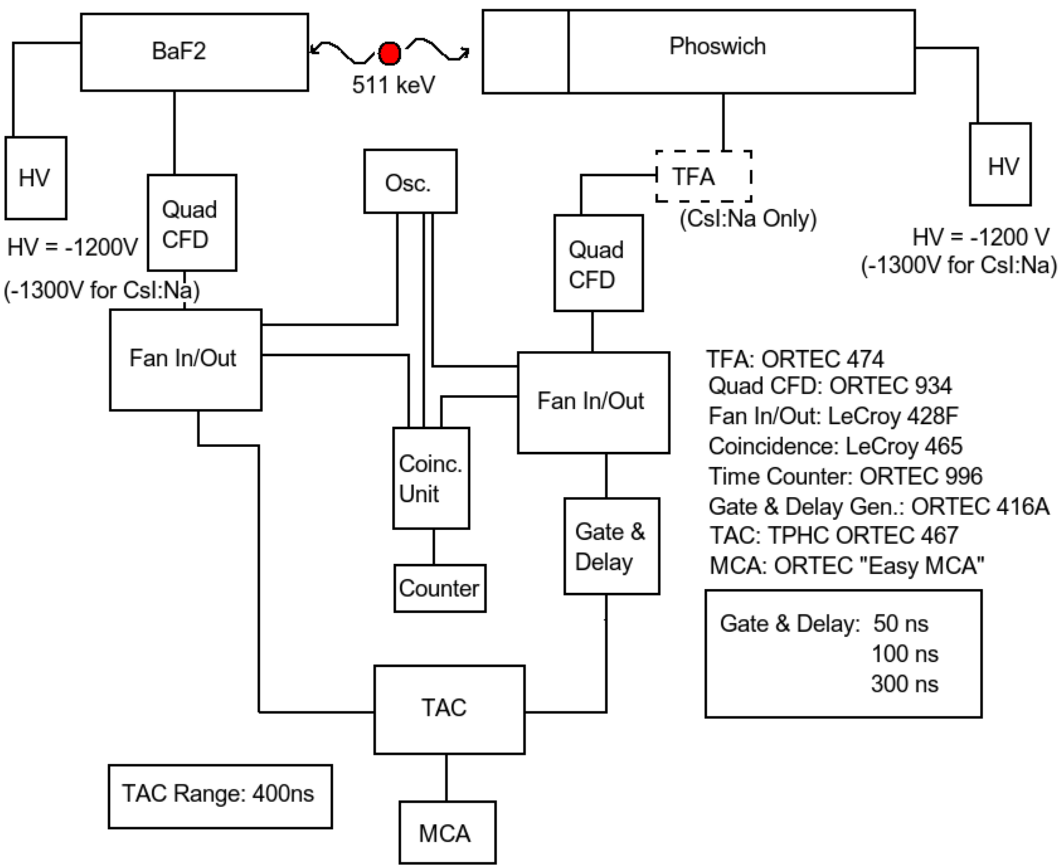
* J.K.Hartwell, R.J.Gehrke, Appl. Radiat. Isot. 63 (2005) 223.

Source Position Sensitivity



- What happens when we place it in the centre of the two detectors? See 4 Peaks for ^{60}Co!

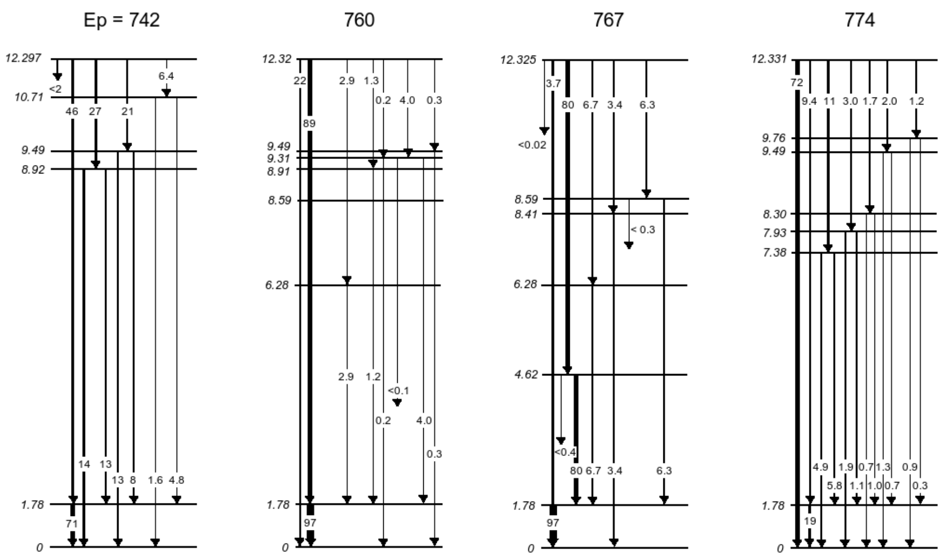
Timing Coincidence Measurements



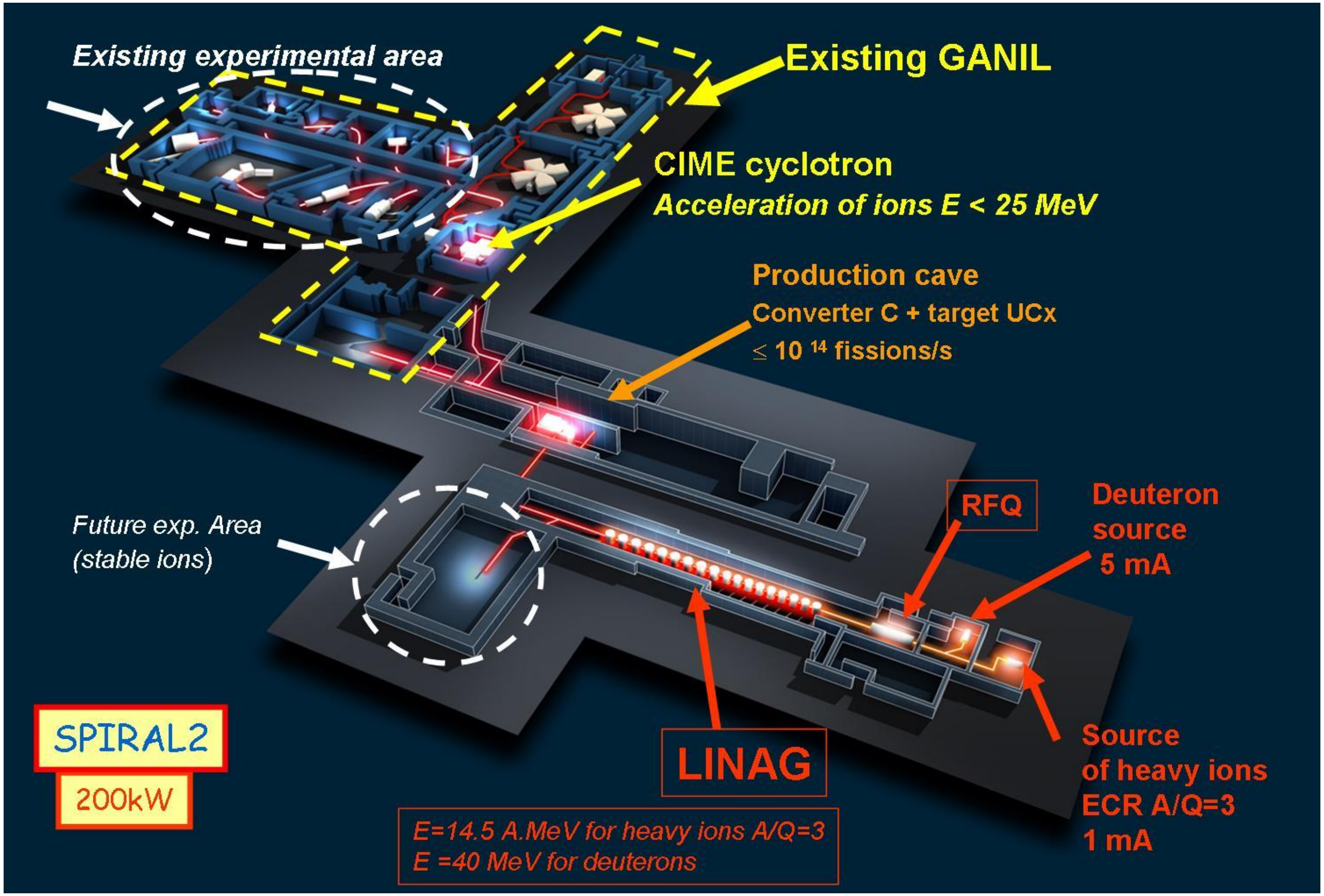
- Set-up involved irradiating a 1” Bicron BaF_2 scintillator formed the “start” channel.
- Both channels were triggered by the coincidence unit externally.
- Timing measurements were taken from the CsI(Na) and $LaBr_3$(Ce) segments.

$^{27}Al(p,\gamma)^{28}Si$ Reaction

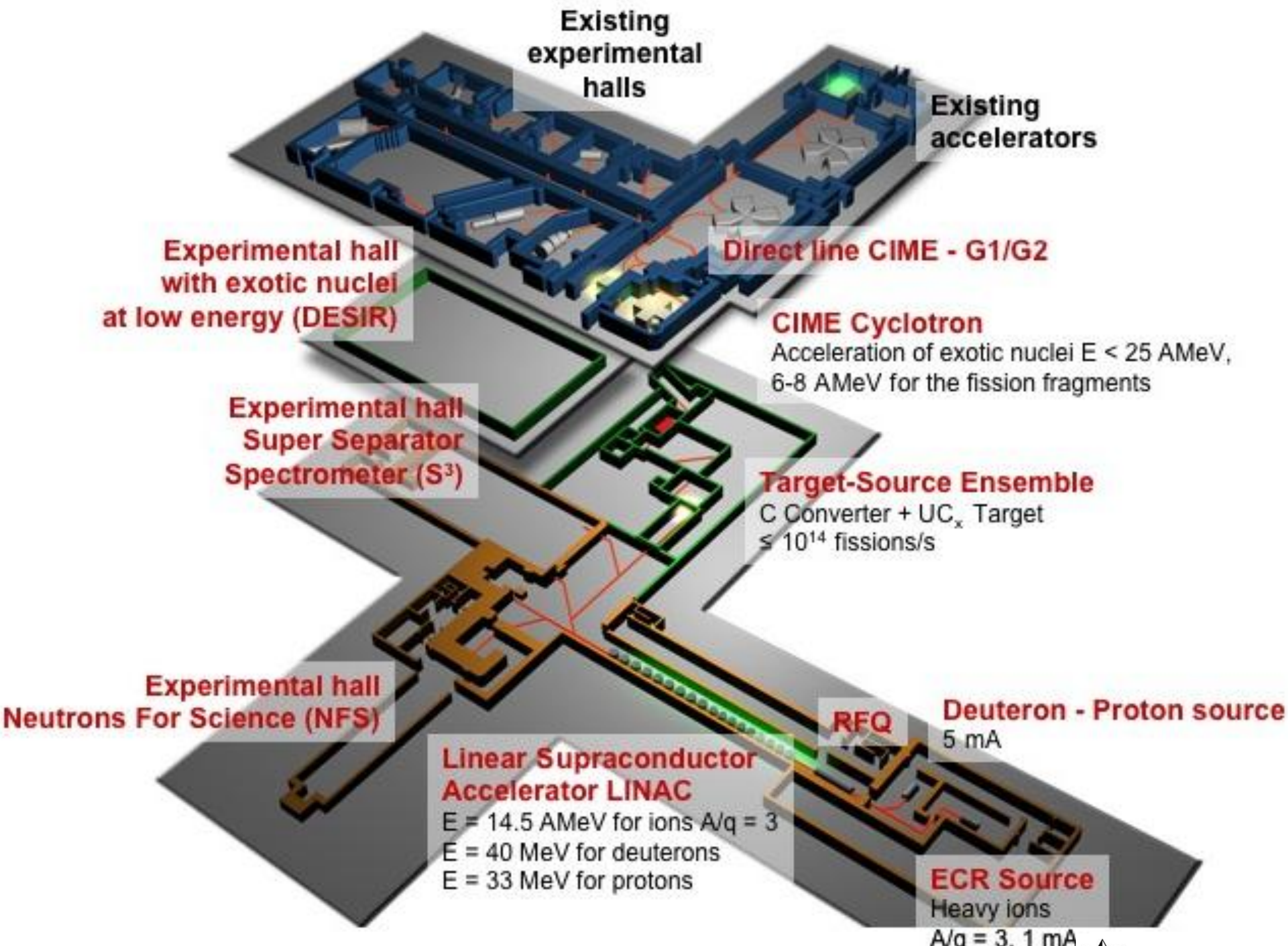
- Population of 742, 760.4,767, and 773.6 keV resonances observed due to $\Delta E << \Gamma$.
- Resonance strength ωγ, is high for 760.4–773.6, with 773.6 the strongest.
- FWHM resolution of 2^{+}–0^{+} with 2”x2”x4” $LaBr_3(Ce)$ crystal = 2.47%
- 10.54 MeV transition with the same detector produced a FWHM of 1.43%



SPIRAL2



Courtesy of http://irfu.cea.fr


Existing experimental halls
Existing accelerators
Experimental hall with exotic nuclei at low energy (DESIR)
Direct line CIME - G1/G2
CIME Cyclotron
Acceleration of exotic nuclei E < 25 AMeV, 6-8 AMeV for the fission fragments
Experimental hall Super Separator Spectrometer (S^3)
Target-Source Ensemble
C Converter + UC_x Target
$\leq 10^{14}$ fissions/s
Experimental hall Neutrons For Science (NFS)
RFQ
Deuteron - Proton source
5 mA
Linear Supraconductor Accelerator LINAC
E = 14.5 AMeV for ions A/q = 3
E = 40 MeV for deuterons
E = 33 MeV for protons
ECR Source
Heavy ions
A/q = 3, 1 mA

Physics Case	Recoil	v/c (cmns^{-1})	E_γ range (MeV)	$\Delta E_\gamma / E_\gamma$ (%)	$\Delta\Sigma_\gamma^{sum}/\Sigma_\gamma^{sum}$ (%)	ΔM_γ (units)	Ω coverage (sr) (finally)	ΔT_{of} (ns)	Ancillaries (prototype scenario)	Miscellamesous
Jacobi transition	A~ 40-150	up to 10%	[0.1-30]	6	< 5	< ~5	2π - 4π	< 1	γ-calorimeter* AGATA ** HI spectro	High efficiency Beam rejection ?
Shape Phase Diagram & Hot GDR in n-rich nuclei	A~ 180	up to 11%	[0.1-30]	6	~ 3 < 5	< ~5	2π - 4π >10% /4π	< 1	γ-calorimeter HI spectro	High efficiency Beam rejection ?
Isospin mixing	A~ 60-100	up to 7%	[5-30]	6	-	-	up to 4π	< 1	γ-calorimeter HI spectro	High efficiency Beam rejection ?
Reaction dynamics	A~ 160-220	up to 7%	[0.1-25]	6-8	< 8	~ 4	up to 2π	< 1	γ-calorimeter n detector FF detector	Complex coupling
Collectivity vs. multifragmentation	A~ 120-200	up to 8%	[5-25]	5	-	-	up to 2π	< 1	γ-calorimeter LCP detector HI detector	Complex coupling

Courtesy of Ch. Schmitt (GANIL), May 2008

Physics Case	Recoil	v/c	E_γ range (MeV)	$\Delta E_\gamma / E_\gamma$ (%)	$\Delta\Sigma_\gamma^{sum}/\Sigma_\gamma^{sum}$ (%)	ΔM_γ (units)	Ω coverage (sr) (finally)	ΔT_{of} (ns)	Ancillaries (prototype scenario)	Miscellamesous
Radiative Capture	A~ 20-30	up to 3%	[1-30]	< ~4	< 5	rough	~ 4π	< 1	HI spectro	High efficiency High current ?
Multiple (normal) Coulex	A~ 40	up to 7%	[2-6]	~ 5	-	-	up to 2π	< 1	AGATA CD detectors	Complex coupling
Astrophysics	A~ 16-90	< 0.2%	[0.1-6]	-	< 5	rough	~ 4π	< 1	γ-calorimeter	High efficiency Background
Shell structure at ntermediate energies	A~ 16-40	up to 40%	[0.5-4]	~ 3	-	-	up to 4π	<< 1	γ-calorimeter HI analyzer	High efficiency - very low I_{beam} - γ-γcoincidence
Relativistic Coulex	A~ 40	up to 50-60%	[1-4]	~4	-	ideally, $M_\gamma = 1$	forward with ~ π /3 aperture	<< 1	AGATA HI analyzer	Angular distribution Lorentz boost

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