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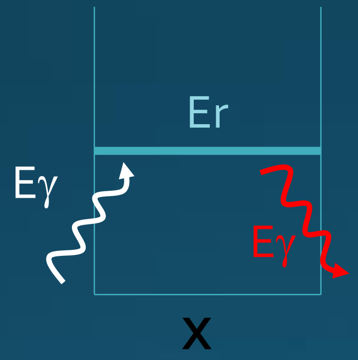
Possible contribution to the GF physics activities: Nuclear Resonance Fluorescence

Outlook

- Nuclear Resonance Fluorescence
- ^{26}Al measurements @ HIγS
- A set-up for γ beams diagnostic
- Other target cases
- Conclusions

Nuclear Resonance Fluorescence

The nucleus is resonantly excited by absorption of a γ ray and decays by emitting a γ ray either back to the ground state or to an excited state.

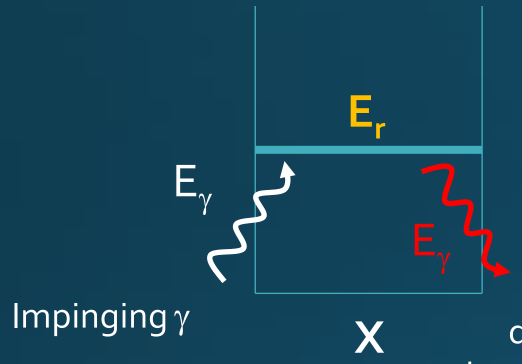


This process is very useful validate resonance properties.
It is used in a wide variety of applications including reaction rate calculations, nuclear astrophysics, nuclear reactor simulations.

Metzger F.R., Progress in Nuclear Physics 7 (1959) 53

Process cross-section

γ ray emission from properly selected nuclear levels of a given nucleus X when resonant condition with the impinging γ ray energy is achieved



decay photons E_γ when the resonant energy E_r is matched

PROCESS CROSS-SECTION

$$\sigma_i^0(E) = \pi\lambda\!\!\!^{-2} \frac{2J_1+1}{2(2J_0+1)} \frac{\Gamma_0\Gamma_i}{(E-E_r)^2+\frac{1}{4}\Gamma^2}$$

- excited level spin
- width for gamma transition to ground state
- width for transition to a specific channel
- Ground state spin
- Level total width

Metzger F.R., Progress in Nuclear Physics 7 (1959) 53

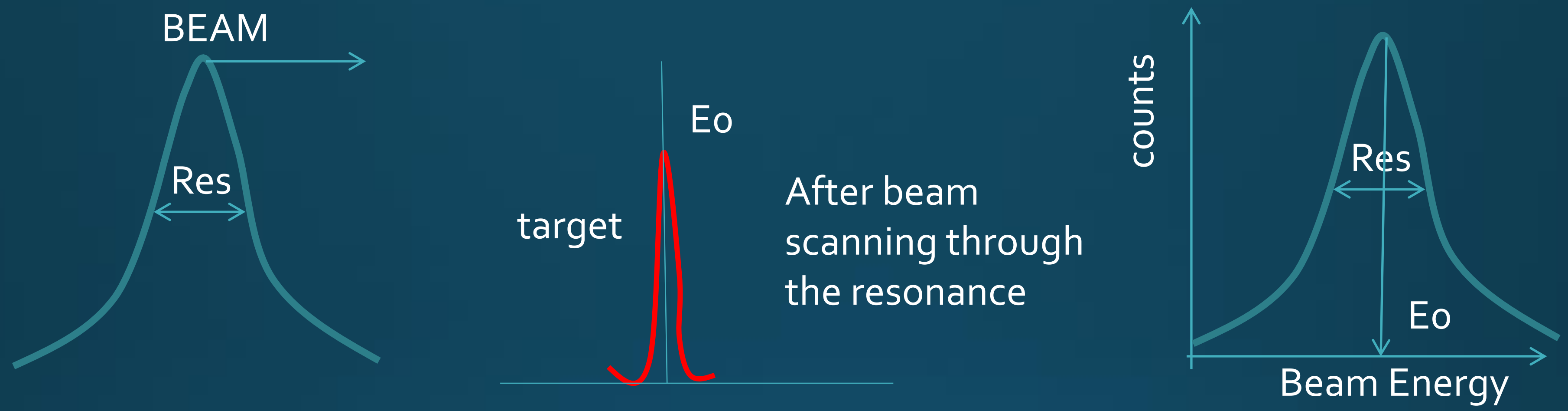
Twofold application

- **Known nuclear levels → Provide an absolute γ beam energy calibration and band-width measurements**
- **Explore unknown nuclear parameters by using a γ ray beam → Find E_r , Γ_i and spin of the level**

Beam energy scanning

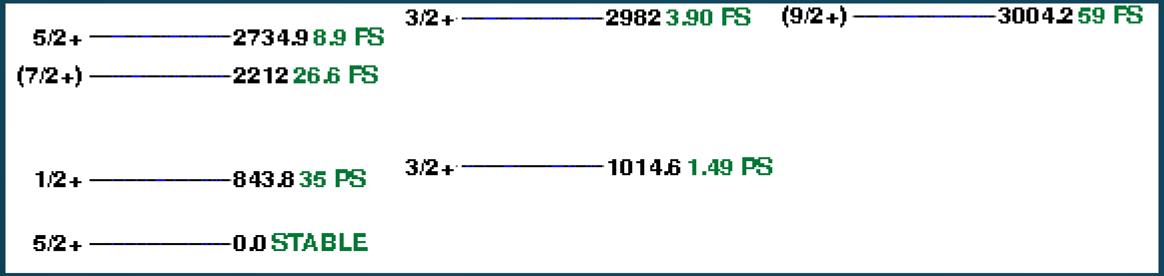
Res=beam resolution   Γ=total level width

Γ < Res



Γ > Res

^{27}Al case



http://www.nndc.bnl.gov/chart/getbandplot.jsp?unc=nds

Pietralla et al. PRC 51 (1995) 1021
Bremsstrahlung facility – Stuttgart Dynamitron accelerator

TABLE I. For six ^{27}Al levels below 4 MeV the nuclear self-absorption was measured. The determined level widths and lifetimes $\tau = \hbar/\Gamma$ confirm the literature values in all cases. The last row displays an error-weighted mean value from the results of this measurement and the literature data (recommended best values). The level energy 2212.01(10) which we obtained deviates from the literature.

E	[keV]	1014.45(3)	2212.01(10)	2734.9(7)	2982.00(5)	3004.2(8)	3956.8(4)
R	[%]	10(12)	26.56(58)	7.1(28)	33.34(59)	5.6(23)	19.9(17)
τ^a	[fs]	> 240	38.1(10)	14(6)	5.63(13)	93(39)	3.94(40)
Γ^a	[meV]	< 2.7	17.29(46)	46(19)	116.9(27)	7.1(30)	167(17)
$\Gamma_{lit}{}^b$	[meV]	0.306(15)	17.14(40)	51(7)	115(6)	7.74(46)	183(15)
Γ^c	[meV]	0.306(15)	17.19(31)	51(7)	116.7(25)	7.74(46)	177(11)

[a]This work.
[b]See [13].
[c]Weighted mean value from a and b.

The high-precision results from Pietralla et al. have been widely used as the standard for flux calibration in NRF experiments

Measured at HIγS – TUNL (USA) to perform spin assignment

^{27}Al case @HIγS

PHYSICAL REVIEW C **90**, 054315 (2014)

Validating resonance properties using nuclear resonance fluorescence

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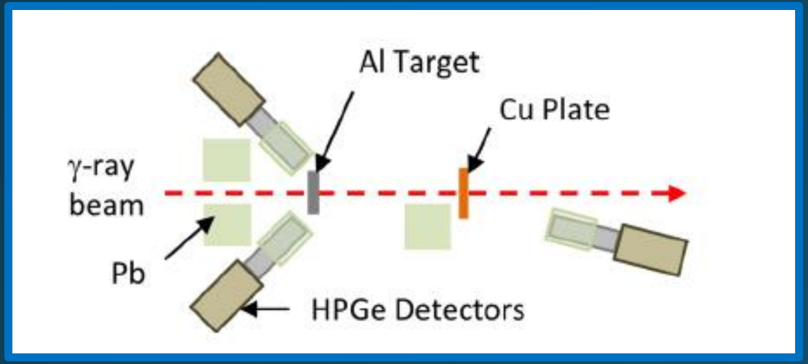
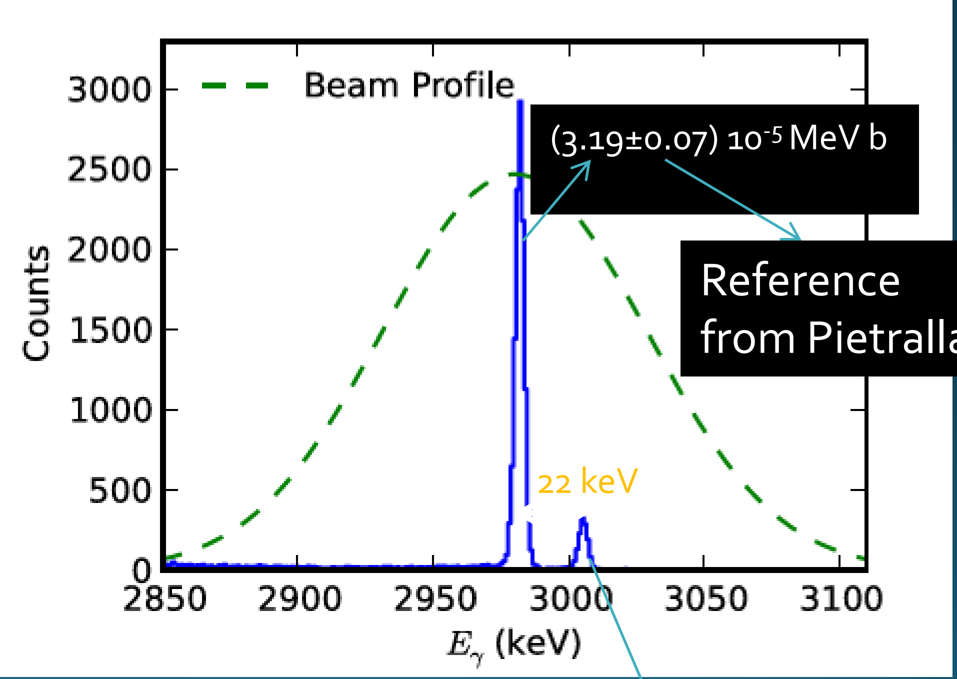
Set-up at HIγS – TUNL (USA)



	HIγS	
Bandwidth (rms)	1.4%	0.3%
FWHM	100 keV	21 keV
Beam intensity	10^8 γ/s	
	10^3 γ/s eV	10^4 γ/s eV
Target thickness	25.3 mm	



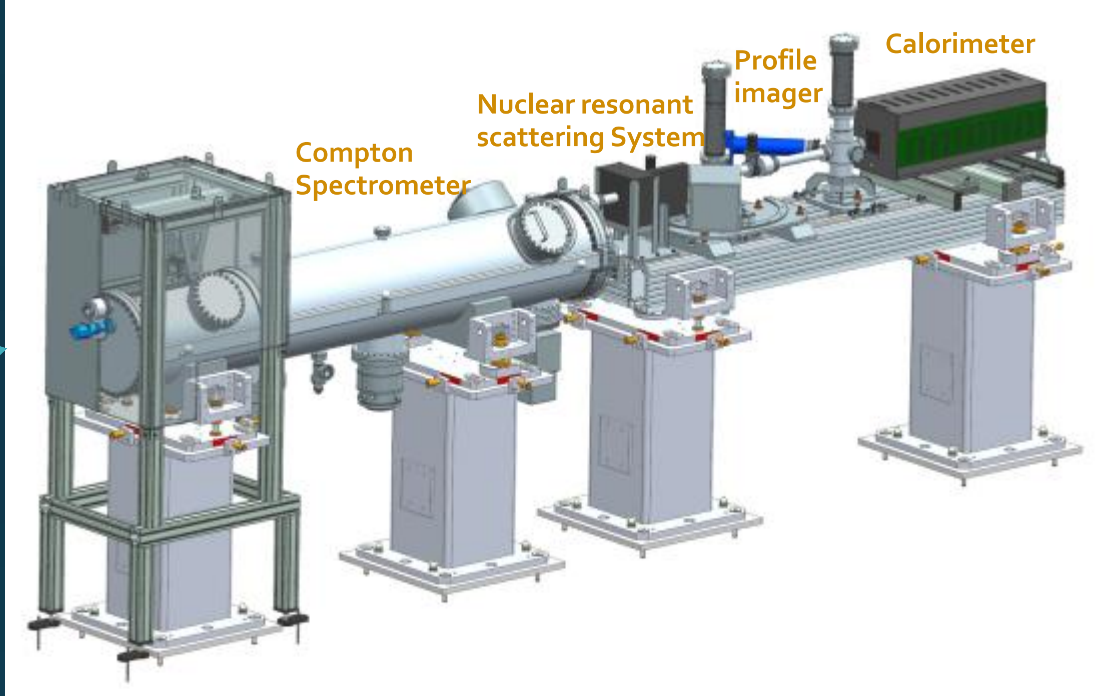
$(3.19 \pm 0.07)\ 10^{-5}$ MeV b

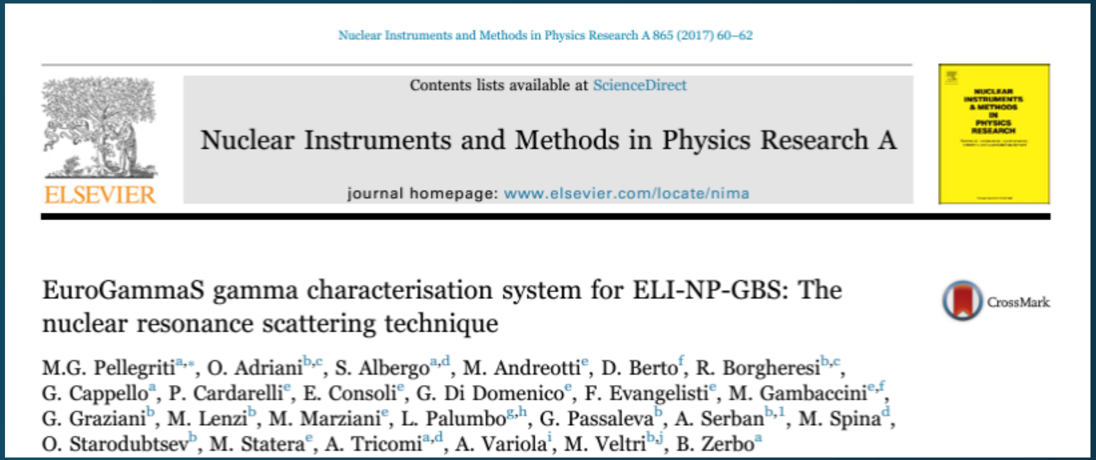
Reference
from Pietralla et al.

$3.30 10^{-6}$ MeV b
Measured @ HIγS

A system for Gamma beam characterization

γ-beam

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ELSEVIER

EuroGammaS gamma characterisation system for ELI-NP-GBS: The nuclear resonance scattering technique

M.G. Pellegriti[a,*], O. Adriani[b,c], S. Albergo[a,d], M. Andreotti[e], D. Berto[f], R. Borgheresi[b,c], G. Cappello[a], P. Cardarelli[e], E. Consoli[e], G. Di Domenico[e], F. Evangelisti[e], M. Gambaccini[e,f], G. Graziani[b], M. Lenzi[b], M. Marziani[e], L. Palumbo[g,h], G. Passaleva[b], A. Serban[b,1], M. Spina[d], O. Starodubtsev[b], M. Statera[e], A. Tricomi[a,d], A. Variola[i], M. Veltri[b,j], B. Zerbo[a]

- **Compton Scattering Spectrometer**

high–precision measurements of **single** Compton scattering from thin target

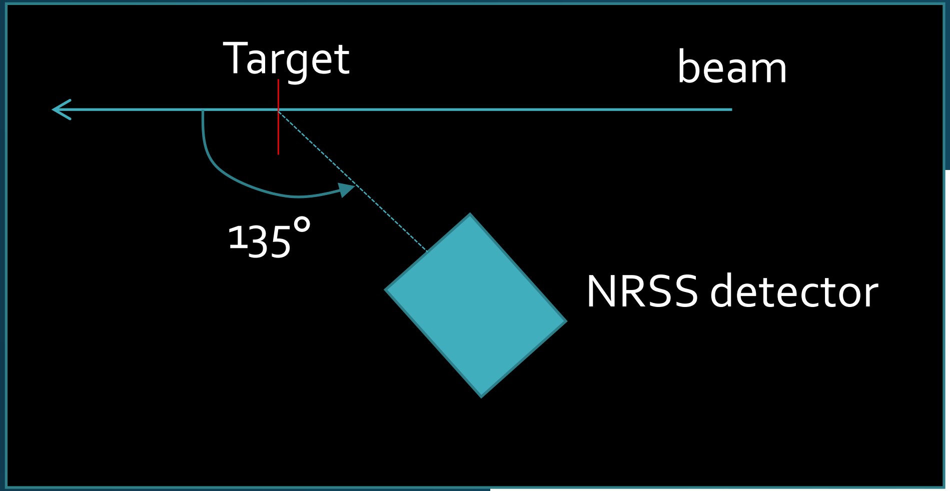
- **Absorption Calorimeter**

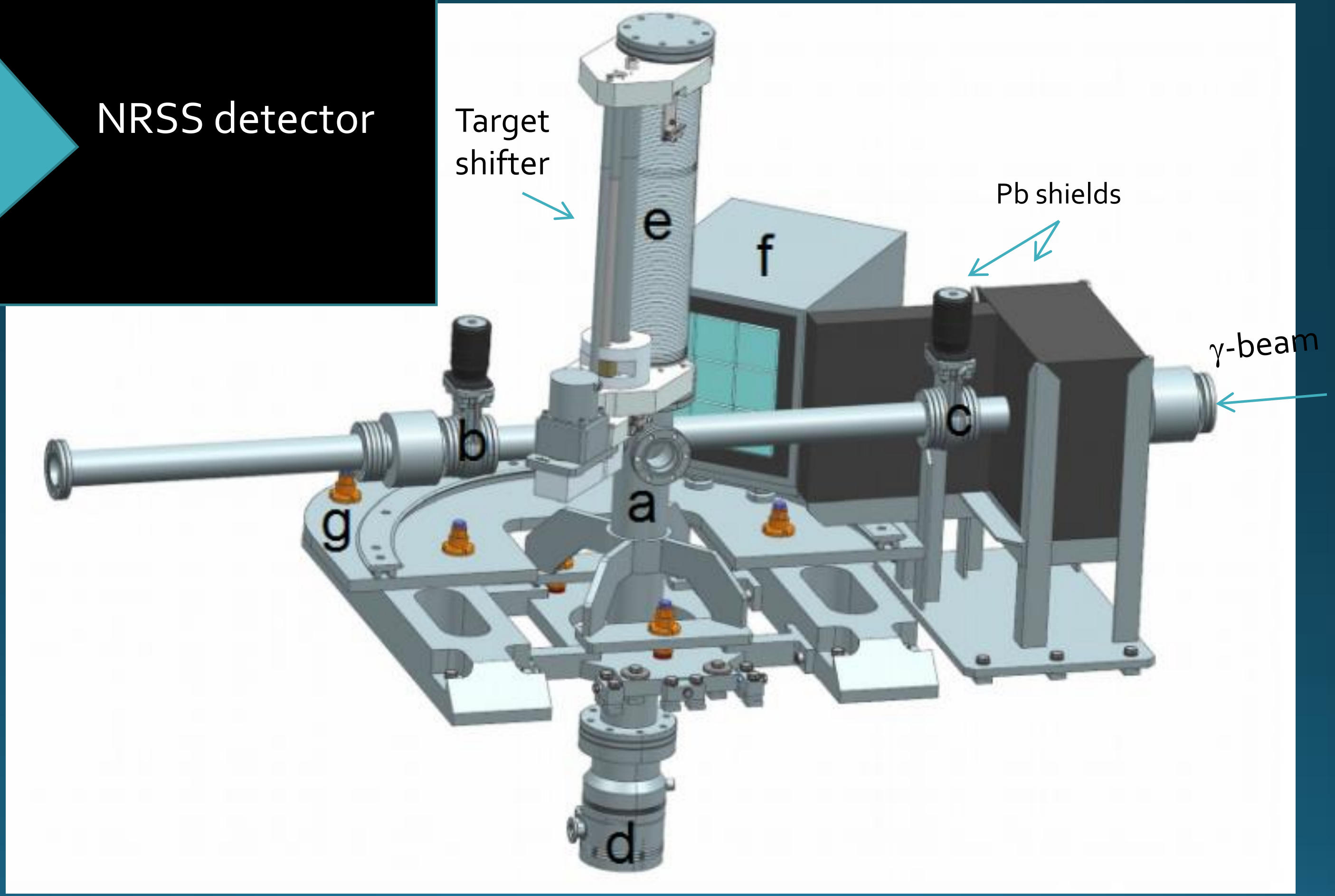
calorimetric, **total absorption** technique

- **Profile Imager**
- **Nuclear Resonant Scattering calibration System**

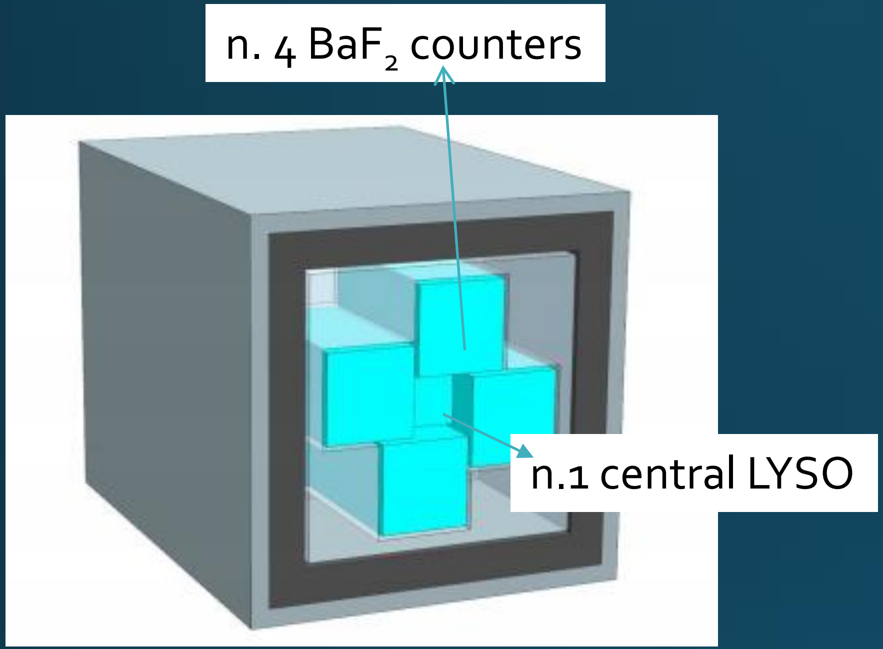
high-precision energy measurement at selected energy values for **absolute energy calibration**

The Nuclear Resonant Scattering System set-up





Nuclear Resonant Scattering System – Detector Design



Fast component: 0.88ns; Slow component: 600ns

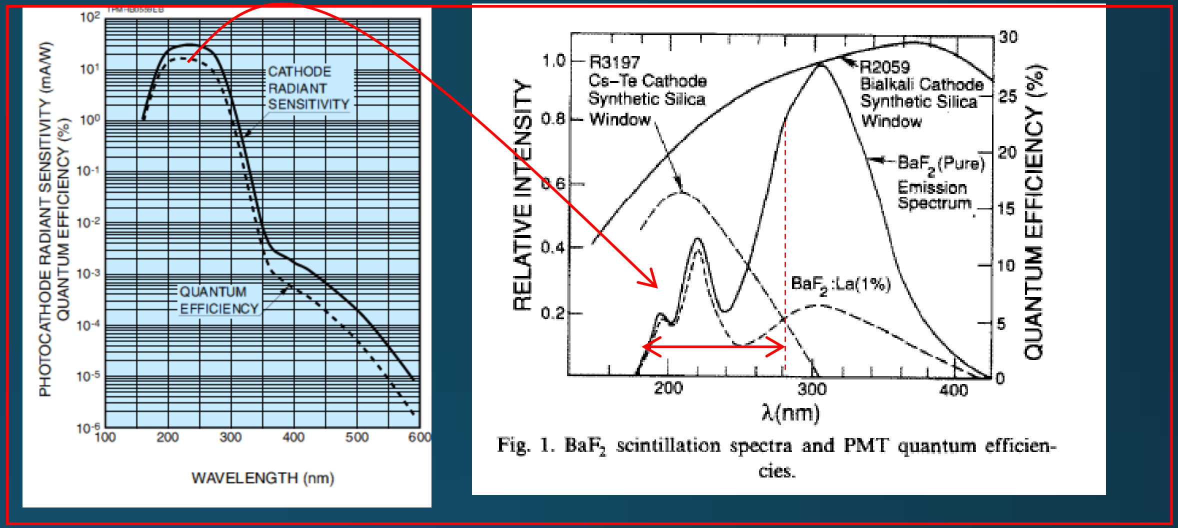
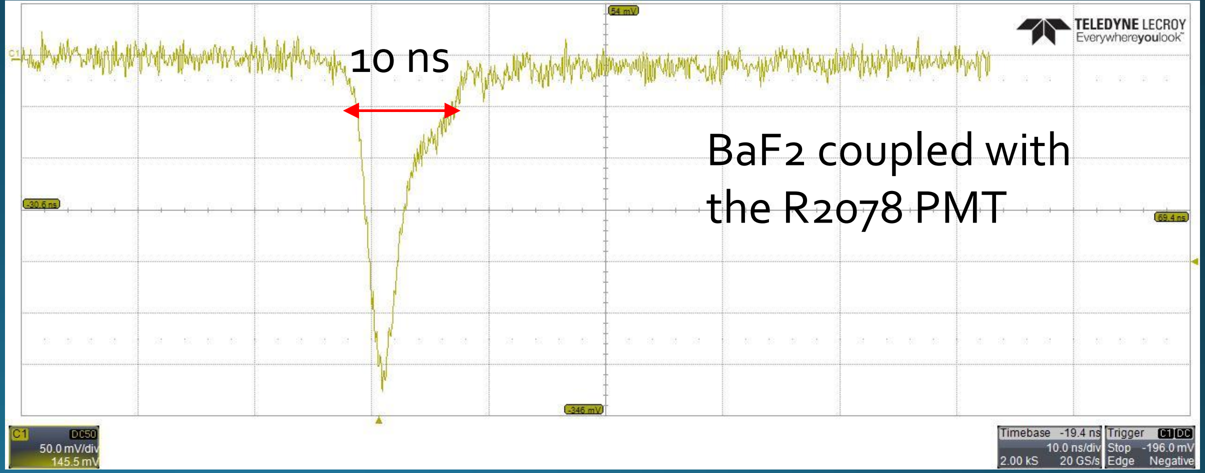


Fig. 1. BaF_2 scintillation spectra and PMT quantum efficiencies.

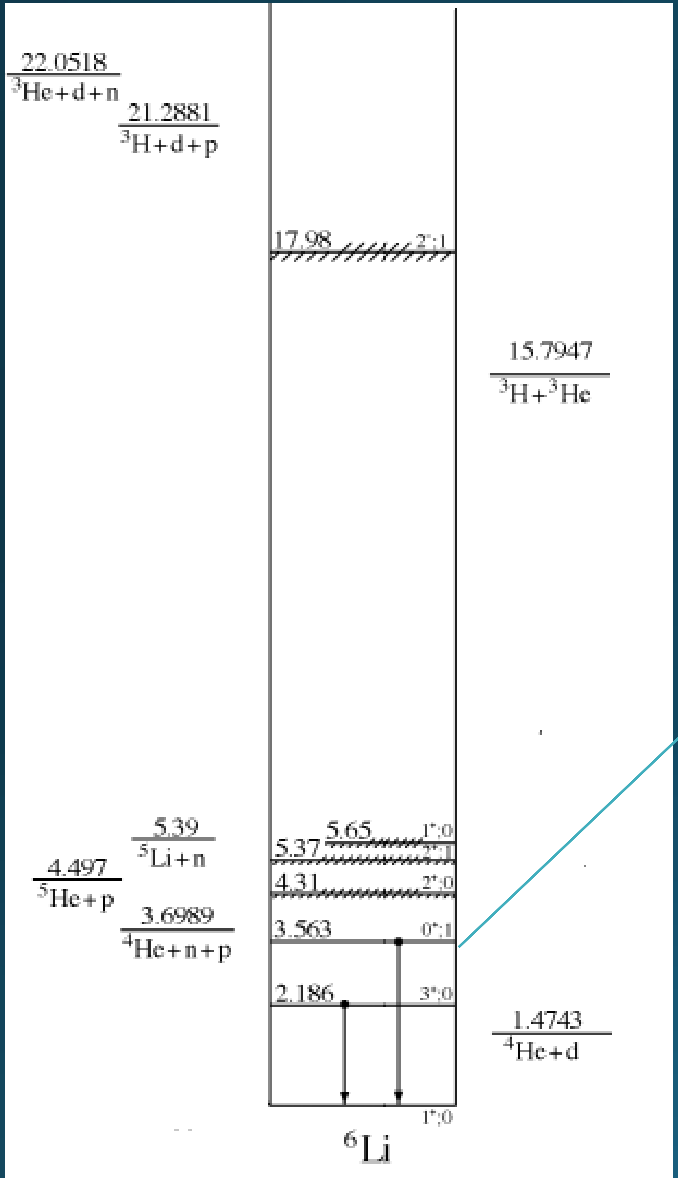
Detector working modes

1) Fast Counter Mode (FC Mode)
Fast beam energy scan, giving a prompt information on the establishment of the resonance.
→External BaF_2 crystals.

2) Energy Spectrometer Mode (ES Mode)
Slower measurement for the later redundant level identification.
→Internal LYSO with the external BaF_2 working as Compton shield.



Other target examples that can be used for calibration



Integrated cross-section

$$\sigma_{int} = \int \sigma(E)dE = \sigma^0_{max}\Gamma\frac{\pi}{2}$$

^{A}X	E$_r$(MeV)	J$_0$	J$_i$	Γ(MeV)	Γ_0(MeV)	σ^0_{max}(b)	σ_{int}(b·MeV)
^{6}Li	3.56288	1	0	$8.2\cdot10^{-6}$	$8.19\cdot10^{-6}$	64	$8\cdot10^{-4}$
^{11}B	2.124693	3/2	1/2	$1.17\cdot10^{-7}$	$1.17\cdot10^{-7}$	270	$5\cdot10^{-5}$
^{11}B	4.44498	3/2	5/2	$5.5\cdot10^{-7}$	$5.5\cdot10^{-7}$	190	$2\cdot10^{-4}$
^{11}B	8.92047	3/2	5/2	$4.374\cdot10^{-6}$	$4.15\cdot10^{-6}$	42	$3\cdot10^{-4}$
^{12}C	4.43891	0	2	$1.08\cdot10^{-8}$	$1.08\cdot10^{-8}$	620	$1\cdot10^{-5}$
^{12}C	15.110	0	1	$4.36\cdot10^{-5}$	$3.85\cdot10^{-5}$	25	$2\cdot10^{-3}$

M.G.P. for EuroGammaS Design Report (2015)

Conclusions

- Nuclear Resonance Fluorescence is an interesting tool
  - To be used for investigating nuclear properties needed for reaction rate calculations, nuclear astrophysics, nuclear reactor simulations
  - To be used for γ ray beam characterization