Gamma diagnostics

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Contributors

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Outline

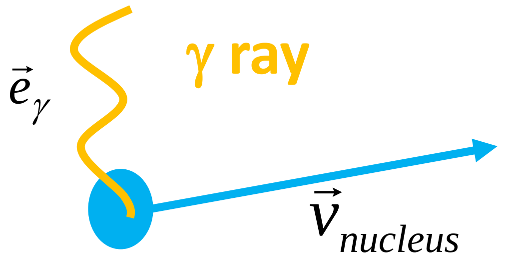
- **Gamma-ray spectroscopy: why and how**
- **Aim of the study**
- **2021 results**
- **Plans for 2022**

Gamma-rays measure fast ions…

γ-rays are produced by **nuclear reactions** between **fast ions** and **impurities**

- They can be produced in **fusion reactions** (I step reaction) **or** result from the **de-excitation of a nucleus** (II step reaction)

i) d + p $\rightarrow$ ^{3}He + γ (5.5 MeV) (fusion reaction)



ii) α + ^{9}Be $\rightarrow$ ^{12}C* + n, ^{12}C*$\rightarrow$ ^{12}C + γ (4.44 MeV) (two step reaction)

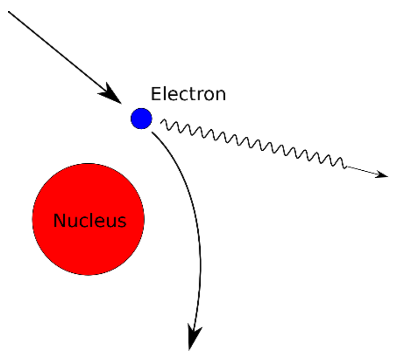
On JT-60SA gamma-rays could diagnose protons and deuterons from NBI heating

… but also fast electrons

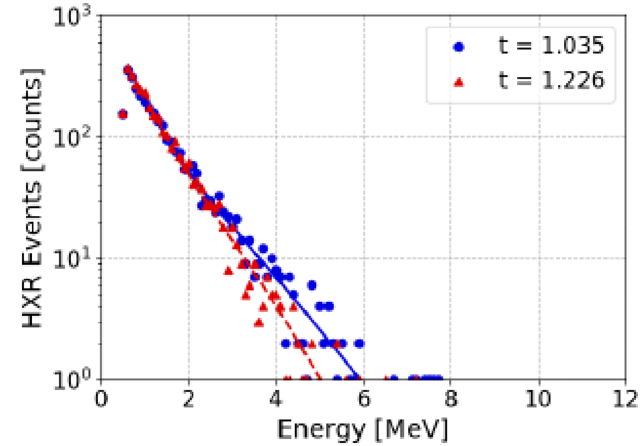
A. Shevelev et al. Nucl. Fusion (2013) 123004
A. Dal Molin, PhD Thesis, University of Milano-Bicocca, 2021

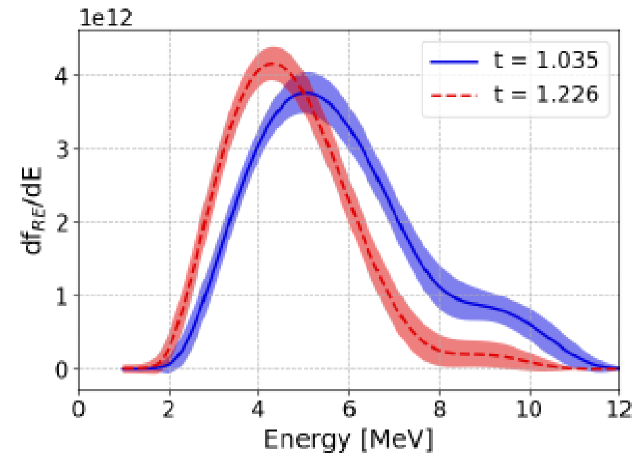
- Measurements of the **bremsstrahlung radiation** spectrum in the MeV range (**γ-rays**) are the natural way to gain information on the RE distribution function

γ-ray



$$E_\gamma <= E_{RE}$$





Runaway electron distribution function can be retrieved by deconvolution of the data

Aim of the activity and contractual information

Aim of the activity:
a feasibility study of gamma-ray diagnostics for JT-60SA

Eurofusion deliverable:
SA.ENH.A3-T001-D001 (owner: M. Nocente)
Build strong scientific case based on scientific goals (JT-60SA, ITER and Demo)
Focus: complement existing/planned diagnostics and studies (fast ions, runaway physics, disruption dynamics,…), in particular by indentifying synergies with neutron diagnostics.

Manpower:
- 3 PM shared between UNIMIB and ISTP
Coordinator: M. Nocente
- 1 PM CCFE
Coordinator: V. Kiptily

Workplan

1) Identify **scenarios** where gamma-ray measurements are necessary (eg. startup runaway monitoring in the initial phases, fast ion studies etc.)

2) Identify **preliminary operational requirements** (eg. need for impurity injection?) and **reactions** that are suitable for gamma-ray measurements at JT-60SA for fast particle studies.

3) Identify **possible locations** for the installation of gamma-ray spectrometers and the associated constraints

4) Preliminary evaluation of the **gamma-ray fluxes** expected at the installation locations

5) Preliminary **definition of the detector types** and dimensions

6) Define a **scientific case supported by the technical evaluations above** for gamma-ray diagnostics at JT-60SA

Activity done in 2021

1) Identification of energetic particles/reactions that could/should be diagnosed in all the research phases of JT-60SA

2) Identification of possible installation locations for gamma-ray diagnostics

3) Preliminary evaluation of gamma-ray fluxes in at least one relevant scenario

List of possible reactions so far for fast ion studies

Reactions suitable for proton studies (eg. 500 keV NBI)

Reaction	Resonance, keV	E_γ, MeV	$\sigma(E_R)$, mb
$^{7}Li(p,\gamma)^{8}Be$	**441**	**17.64**	3.5
$^{11}B(p,\gamma)^{12}C$	**162**	**11.67** & **4.44**	0.152
$^{12}C(p,\gamma)^{13}N$	**457**	**2.365**	0.124

Possible by ***Li – LiH/LiD pellet injection***

Reactions suitable for deuterium studies (eg. 500 keV NBI)

Reaction	Q, MeV	E_γ, MeV	σ(500 keV), mb
$^{6}Li(d,n\gamma)^{7}Be$	3.381	0.429	~75
$^{6}Li(d,p\gamma)^{7}Li$	5.026	0.478	~40
$^{10}B(d,n\gamma)^{11}C$	6.465	2.00, 4.319 & 4.804	~20
$^{10}B(d,p\gamma)^{11}B$	9.230	2.125, 4.444 & 5.021 2.125	~1.5, 7 & 1
$^{11}B(d,p\gamma)^{12}B$	1.145	0.953	~10

Research phases of JT-60SA and possible gamma-ray diagnostics contribution

Research phase	Sub-phase	Timeline	Main plasma species	Positive NBI (P-NBI) power, perpendicular box (85 keV)	Positive NBI (P-NBI) power, tangential box (85 keV)	Negative NBI (N-NBI) power (500 keV)
Initial Research phase	Phase I	2020-2021	H	0	0	0
		2023		3 MW	3 MW	10 MW
	Phase II	2023	D	6.5 MW	7 MW	
		2024-2025		13 MW		
Integrated Research phase	Phase I	2026-2028	D			
	Phase II	2030-	D			
Extended Research phase		>5 y	D	16 MW	8 MW	

Tentative timeline: conceptual design phase ends in December 2022; Detector is finalized and installed by end of 2023: Detector available at JT-60SA before 2024.

We can measure (at the earliest) from the initial research phase II. The headlines which can be addressed are:
H.II.1, H.II.2 and H.II.3

Identification of possible installation locations

Based on the interaction with the QST team during the RCM in October 2021, the detectors could be installaled in **some channels of the existing neutron emission profile monitor**.

Preliminary evaluation of fluxes

A (very) preliminary evaluation of the fluxes has been made with the following assumptions:

1) The source strength is the same as at JET when reactions are the same
2) The signal at the detector scales as $1/d^2$ (d = 23 m at JET vs d=7 m at JT-60SA)
3) For fast ion reactions, cross sections are lower by a factor 100

Result

1) Gamma-ray emission from proton NBI is too weak to measure
2) Gamma-ray emission from deuterium NBI is comparable to typical gamma-ray counting rates at JET (≈kHz)
3) Runaway electrons are easily measured (comparable or higher emission than at JET)

Required input information

- In order to advance the conceptual design we need some input information

1) Information on **the geometry of the neutron profile** monitor, including collimator size, available space etc.
2) Distribution function of deuterons from NBI
3) Distribution function of protons from NBI
4) Some reasonable assumptions on the runaway electrons (eg. RE Current and tentative, good guess for their distribution)

Plans for 2022

1) **Consolidated evaluation of gamma-ray fluxes** at the installation locations

2) Definition of the **detector main specifications**; possibility to use a detector than **combines neutron and gamma-ray spectroscopy** with a single instrument (inorganic scintillators with Clorine, eg. CLYC)

3) Based on the results of 1)+2), **identify the benefits for energetic particle studies** coming from the use of these detectors

THANK YOU FOR YOUR ATTENTION