Neutron and gamma-ray diagnostics at JT-60SA: proposed scoping study

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on behalf of the Milano team

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Outline

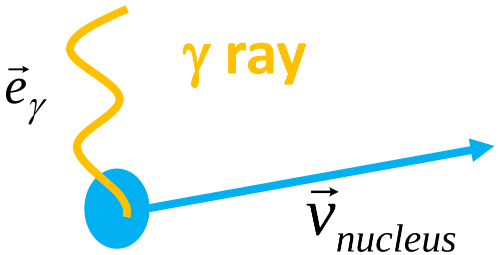
- Gamma-ray spectroscopy: why and how
- Possibilities for JT-60SA
- Neutron spectroscopy: why and how
- Possibilities for JT-60SA
- Proposed activities

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)

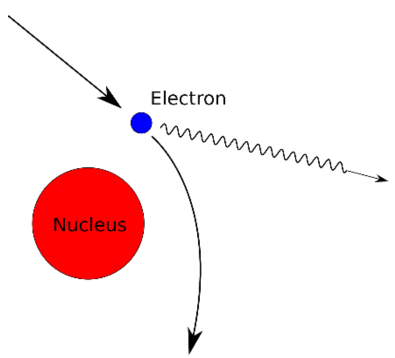


ii) α + ^{9}Be $\rightarrow$ ^{12}C* + n, ^{12}C* $\rightarrow$ ^{12}C + γ (4.44 MeV)
(two step reaction)

… but also fast electrons

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

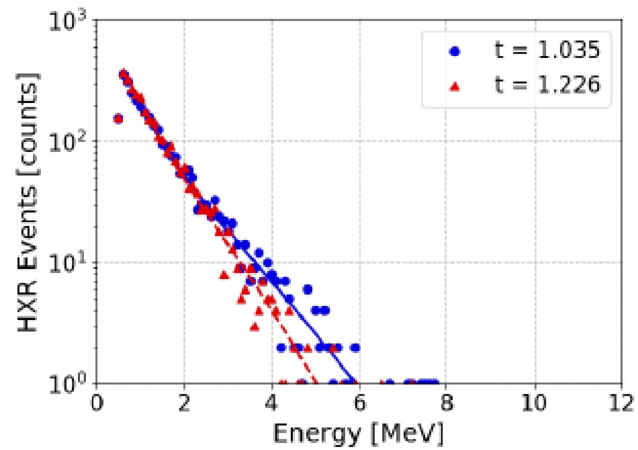
γ-ray

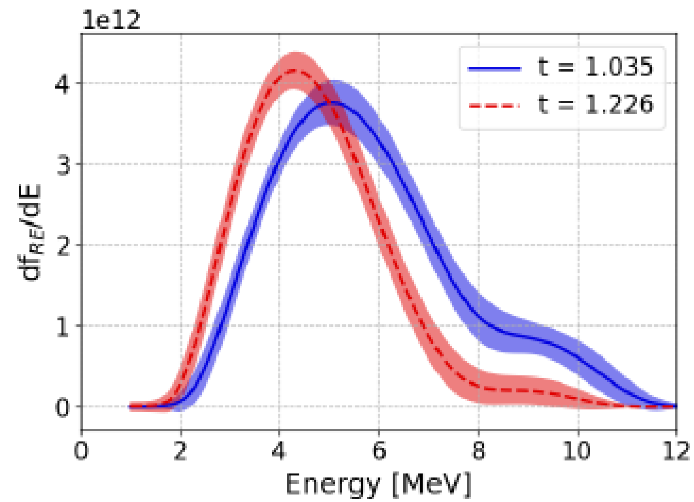


$$E_\gamma <= E_{RE}$$

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

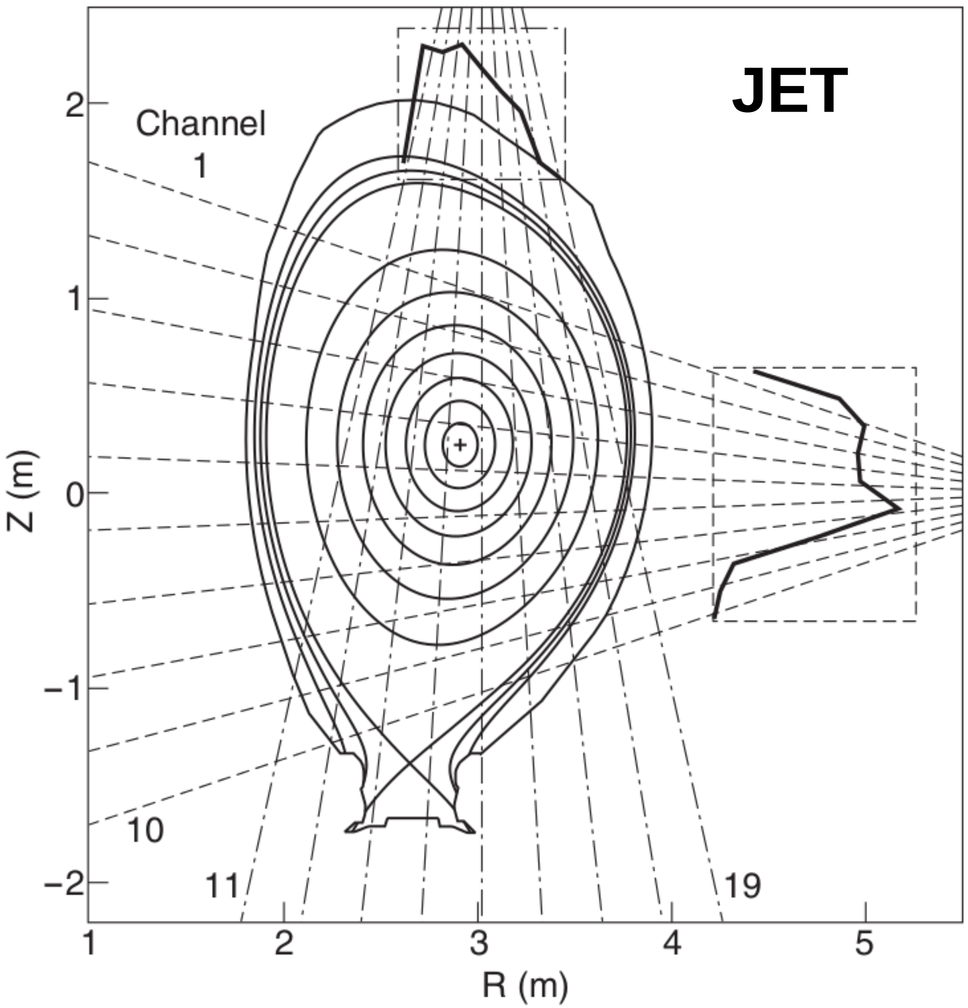
A. Shevelev et al. Nucl. Fusion (2013) 123004
A. Dal Molin, PhD Thesis, University of Milano-Bicocca, 2021



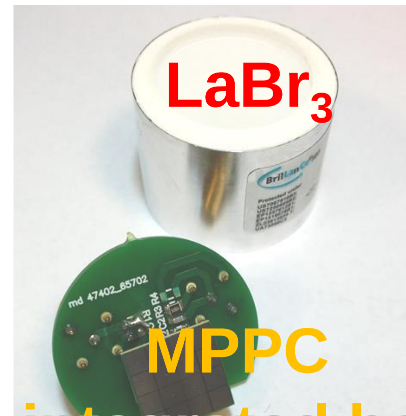


Common instrumentation for both applications

Compact detectors to measure the fast ion/runaway electron spatial distribution



D. Rigamonti et al. Rev Sci Instrum 89 10I116 (2018)

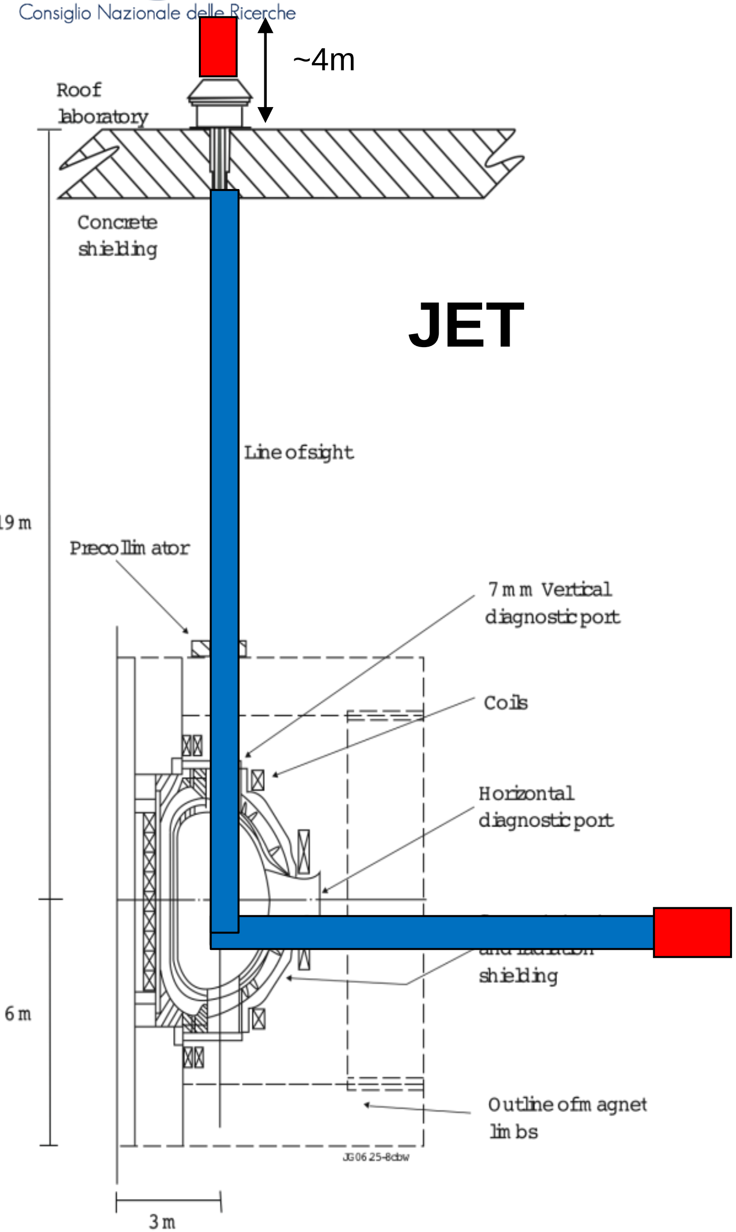


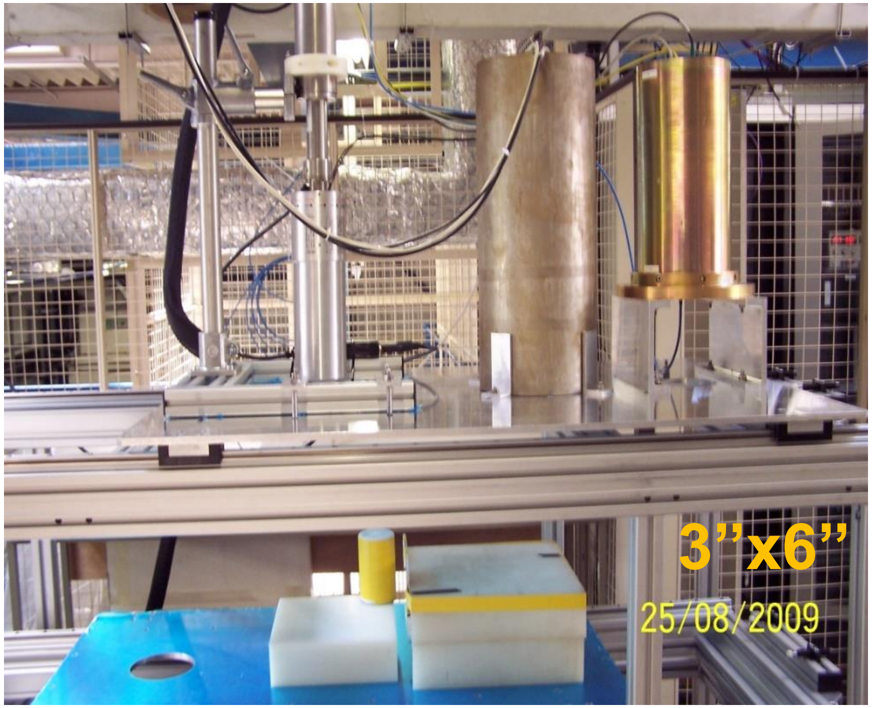
+ integrated board

Developed for the JET ***Gamma-ray Camera Upgrade*** project

- **Fast (≈ 200 ns FWHM)**
- **Compact (1”x1”)**
- **Insensitive to magnetic fields**
- **Can be placed in an already existing neutron camera**

Dedicated high resolution γ-ray spectrometers





M. Nocente et al. Rev. Sci. Instrum. 81 (2010) 10D321

- Improved **energy resolution**
- Improved **detection efficiency**
  - Required for **advanced analysis** (eg. Doppler shape)
  - **Dedicated** line of sight

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Studies of fast ions by gamma-ray spectroscopy at JT-60SA

Courtesy V. Kiptily 2018

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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

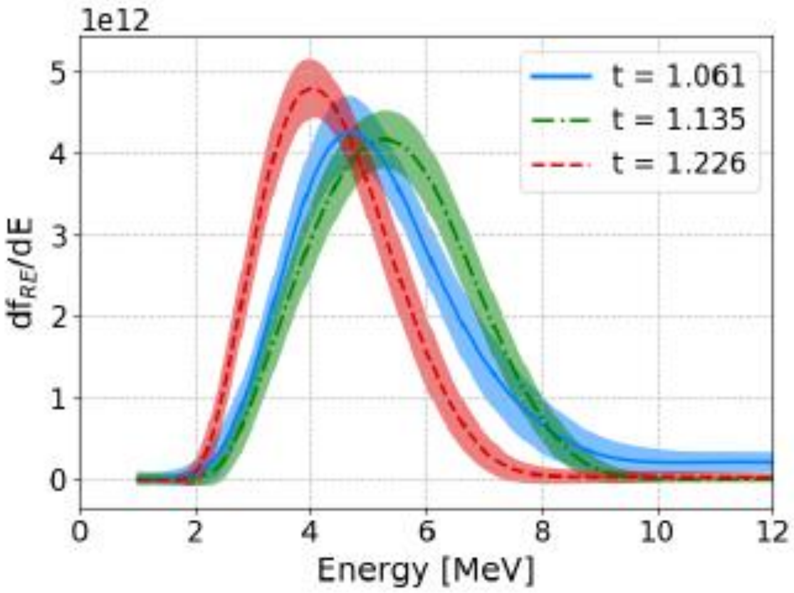
+ runaway electrons

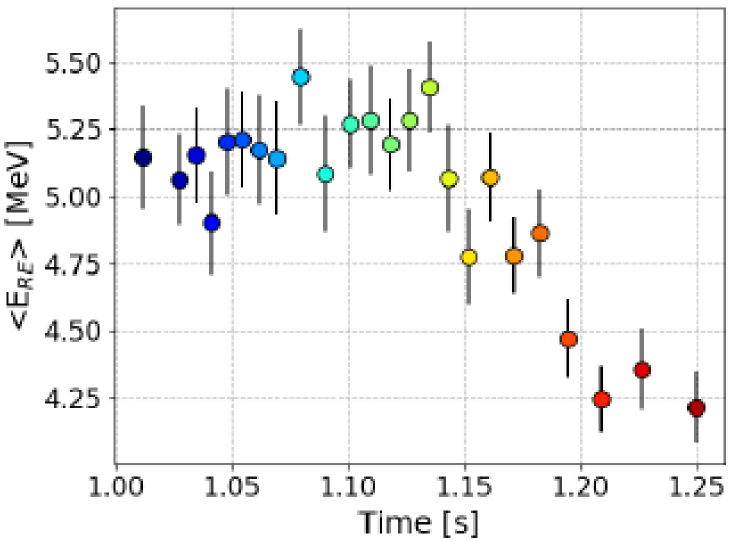
Possible by ***Li – LiH/LiD pellet injection***

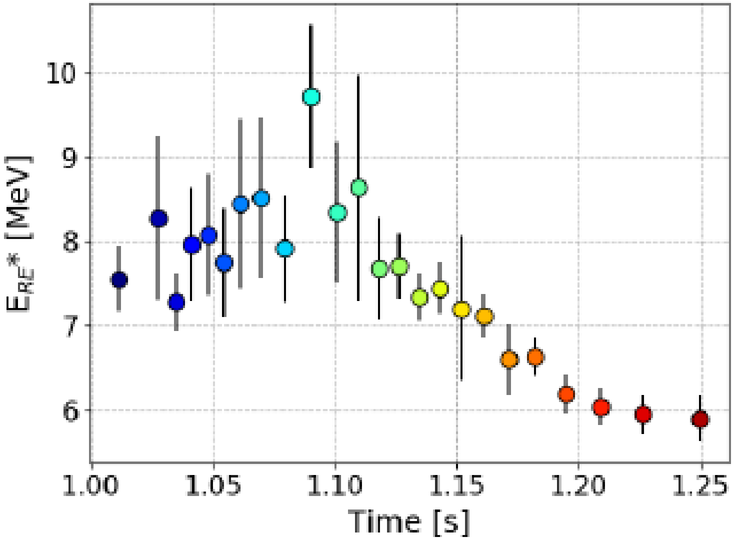
Reactions suitable for deuterium studies (eg. 500 keV NBI)

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

Example of runaway studies at ASDEX Upgrade







- Time trace of $<E_{RE}>$ or $E_{RE}*$ can be provided from HXR spectroscopy data
- Time resolution: few ms or less
- Can a similar measurements be performed at JT-60SA?

Possible locations

Courtesy
V. Kiptily
2018

- Sector P4, upper:
  - NPA, neutron and γ-ray profile monitors
  - An efficient γ-ray spectrometer (MeV gammas) could be installed behind of NPA, as in ITER
- Sector P8, horizontal:
  - NPA
  - An efficient γ-ray spectrometer (MeV gammas) could be installed behind of NPA, as in ITER
- Sector P10, horizontal:
  - neutron and γ-ray profile monitors

- In the neutron profile monitor the γ-ray detectors could be setup (1) with independent collimators (a favourable option); (2) on slider in front of neutron detectors as on JET (a restricted use of the diagnostics)
- Behind NPA a large volume (high efficiency) γ-ray detectors could be useful
- On JET, we use $LaBr_3$ and $CeBr_3$ fast scintillators that provide high energy/time resolution at several MHz count rate

(*Existed diagnostics, Table D-6 on pp.148-150, are in blue; proposed – in red*)

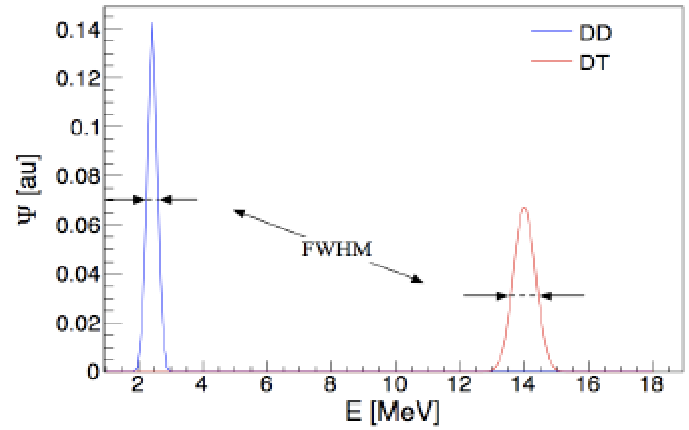
Neutron spectroscopy

In a plasma in thermal equilibrium, the particles are distributed according to a Maxwellian distribution Neutron spectrum is well approximated as a Gaussian centered at 2.45 MeV (or 14.0 MeV) and with FWHM (W)

Ion Temperature T_i

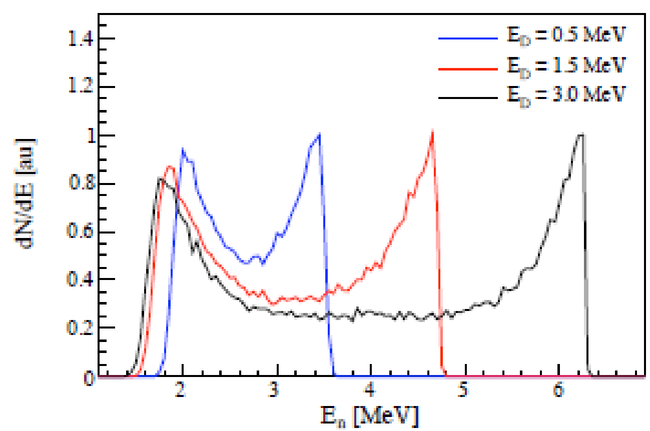
$W = 82.5 \cdot \sqrt{T}$ for DD emission

$W = 177 \cdot \sqrt{T}$ for DT emission



Fast fuel ions can be well diagnosed with NES due the enhanced reactivity

δ(E)-spectra



Requirements for the ideal spectrometer

Energy resolution ($\Delta E_n/E_n$<5%)
Time resolution (count rate capability, >100 kHz)

Development of dedicated instrumentation

Neutron spectroscopy at JT60-SA

- Main application of **neutron spectrometry** at JT-60SA: studies of the **deuterium population** (eg. beam current drive, fast ion driven MHD)

- Best instrument: **time of flight neutron spectrometer** (eg. TOFOR at JET or TOFED at EAST)

- Cons: a time of flight instrument requires **important efforts** in terms of interfaces with the machine, availability of space, cost etc.

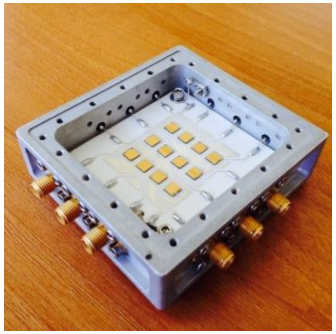
- Valuable information may also come from **relatively inexpensive compact spectrometers.** Cons: a TOF will likely do better.

Compact neutron spectrometer possibilities

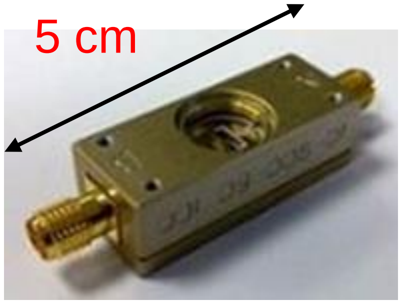
Synthetic diamond detectors

VNS matrix at JET

A. Muraro et al. Rev. Sci. Instrum. 87 11D833 (2016)



Standalone oblique diamond detector at JET



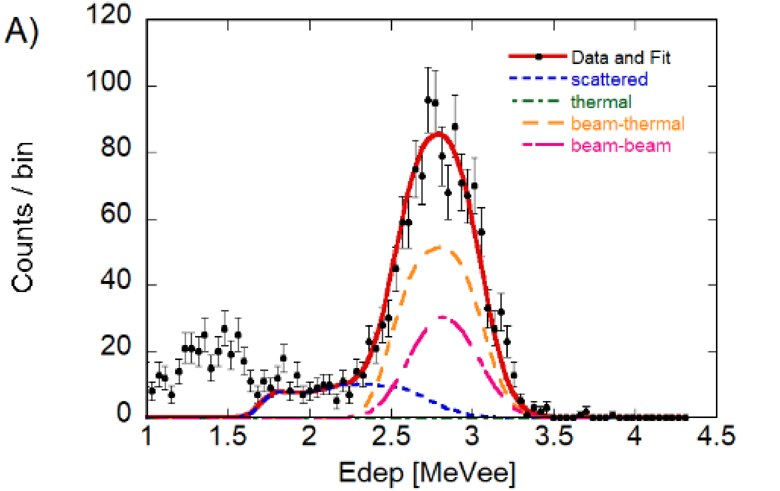
Development of a matrix of synthetic ***diamond detectors*** at JET (VNS project) as well as standalone detectors

Main application at JT60-SA:
integration in the ***neutron camera***

Inorganic scintillators with neutron spectroscopy capabilities (e.g. CLYC-7)

Most recent technology. ***Neutron/gamma-ray discrimination capabilities****. Counting rate capability up to a few 100 kHz. Tested at* ***EAST****. Under development for* ***ASDEX Upgrade*** (COSMONAUT project).

D. Rigamonti et al. JINST 14 C09025 (2019)



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2021/22 scoping study: from list of ideas down to hard numbers

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- Identify ***available positions*** where neutron/gamma-ray diagnostics could go
- Calculate ***neutron spectra and fluxes*** for relevant fast ion scenarios at the available positions
- Calculate ***gamma-ray spectra and fluxes*** for relevant fast ion scenarios at the available positions. Are gamma-ray measurements for fast ion studies feasible at all?
- Evaluate ***HXR emission*** from runaway electrons
- Evaluate pros and cons of each ***technology solution*** (e.g. TOF/CLYC/diamond?) depending on the results of the calculations above. Estimate ***costs*** and ***interface*** requirements.
- Determine what is ***most promising*** for ***further detailed design*** and, eventually, installation. I.e. provide input for an ***informed decision on the next steps***.