UK Atomic Energy Authority

V Kiptily et al

On a scientific case for gamma-ray diagnostics at JT-60SA

The work is carried out in close collaboration with ENEA (M. Nocente et al)

9th WPSA Planning Meeting, Budapest, 5th – 9th September 2022

ISTP Consiglio Nazionale delle Ricerche

Università degli Studi di Milano Bicocca

European Commission

Contract for the Operation of the JET Facilities Co-Funded by Euratom
This work was funded by the RCUK Energy Programme [Grant number EP/P012450/1]

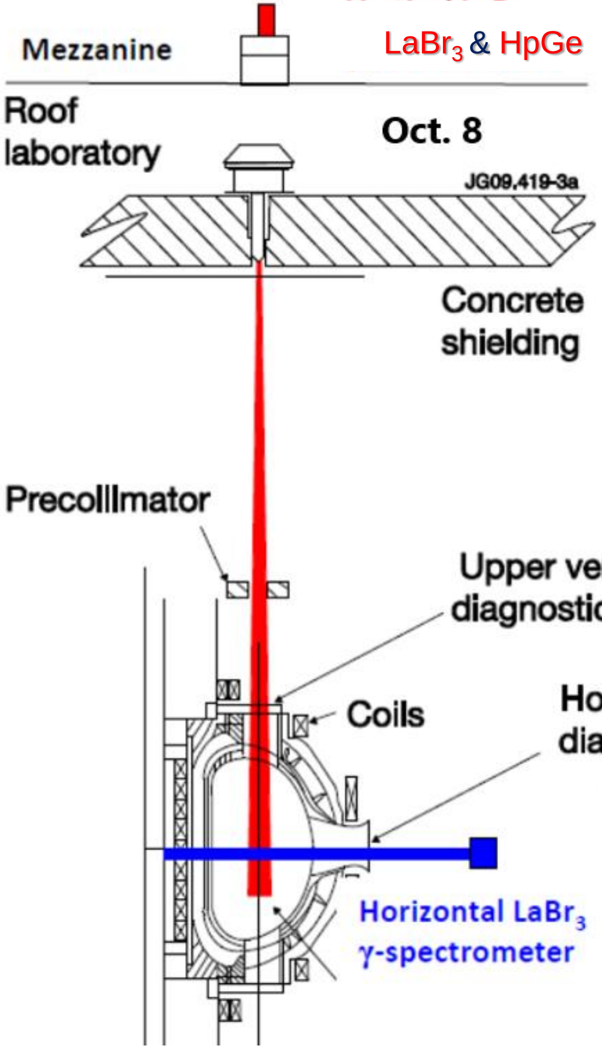
CCFE Culham Centre for Fusion Energy

Gamma-ray spectrometers on JET

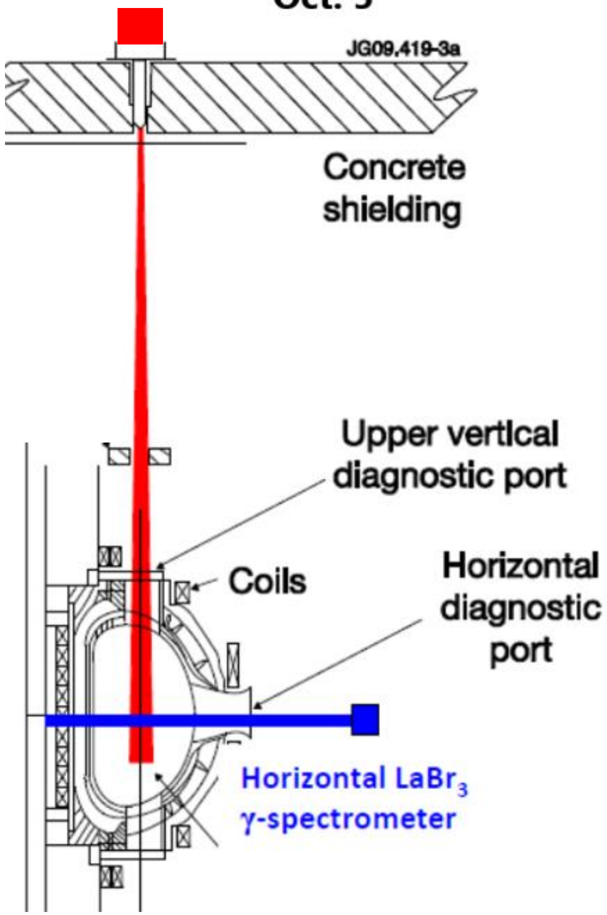
UK Atomic Energy Authority

Vertical spectrometers

LaBr$_3$ & HpGe

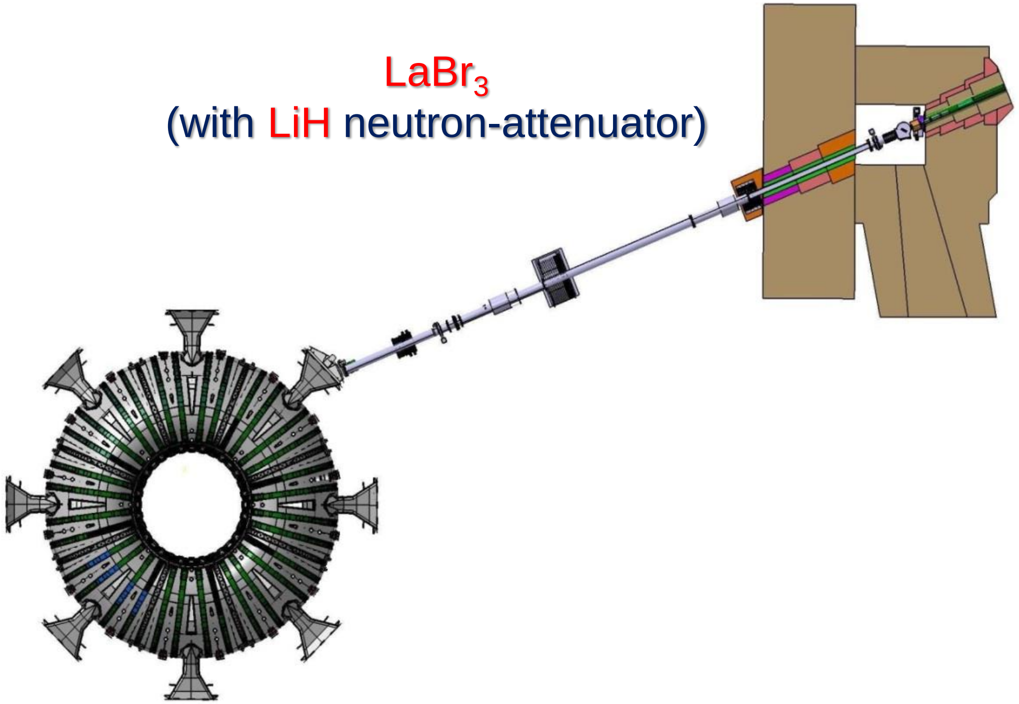


LaBr$_3$
(^{6}LiH + LiH neutron-attenuator)



Horizontal tangential spectrometer

LaBr$_3$
(with LiH neutron-attenuator)

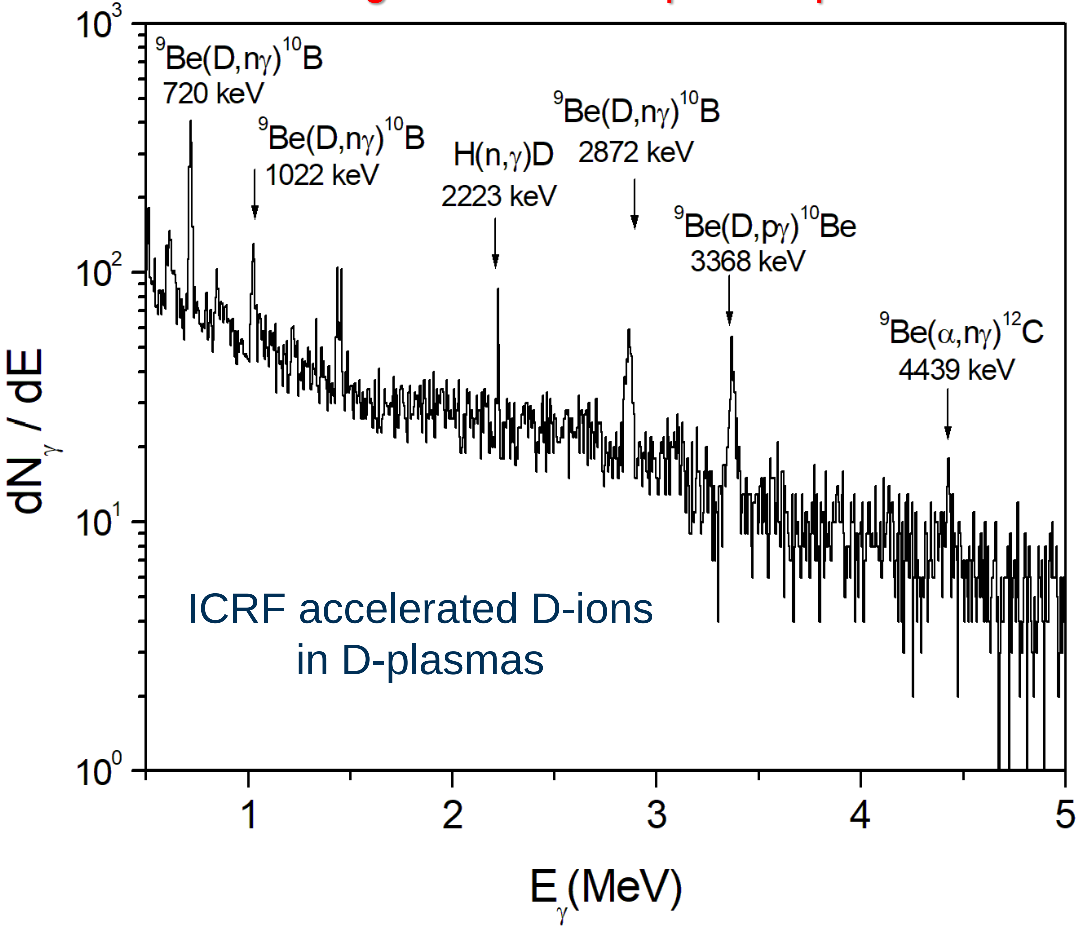


CCFE CULHAM CENTRE FOR FUSION ENERGY

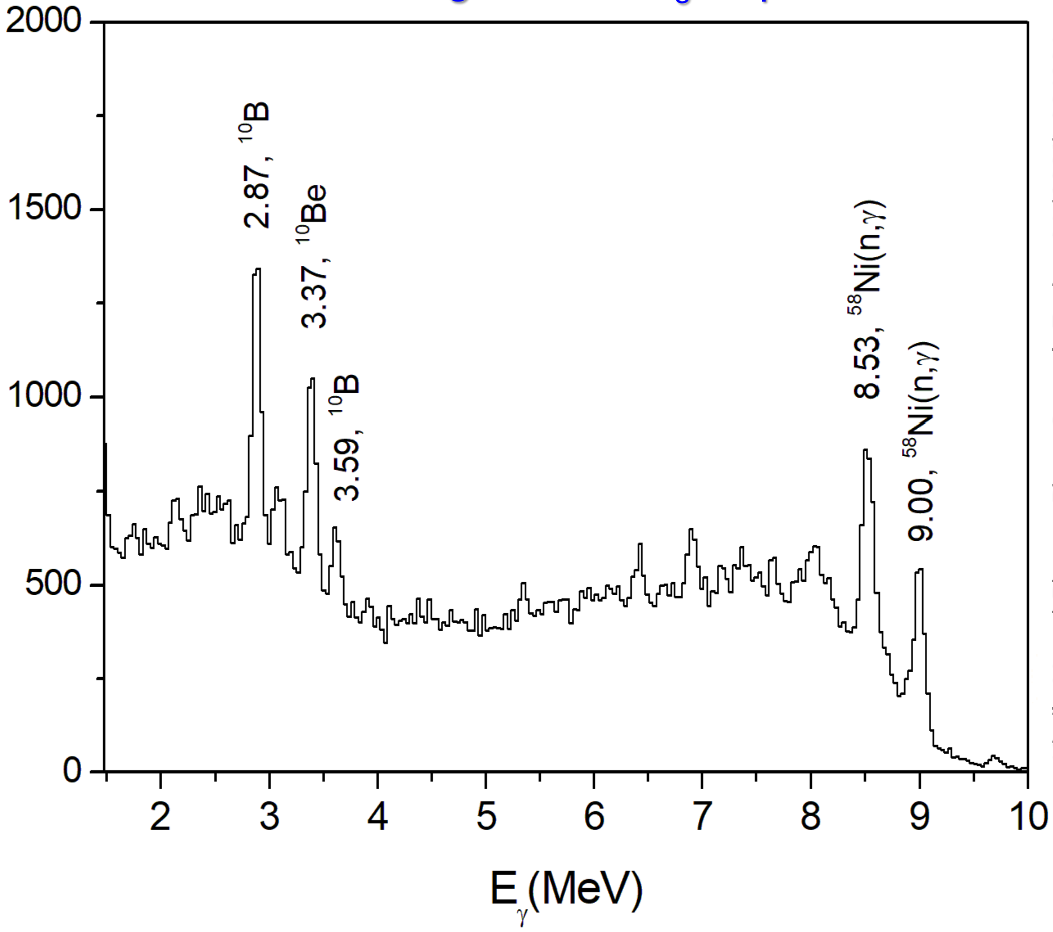
Fast-ion studies on JET:

γ-ray spectrometry

Vertical High-resolution HpGe – spectrometer



Horizontal tangential $LaBr_3$ – spectrometer



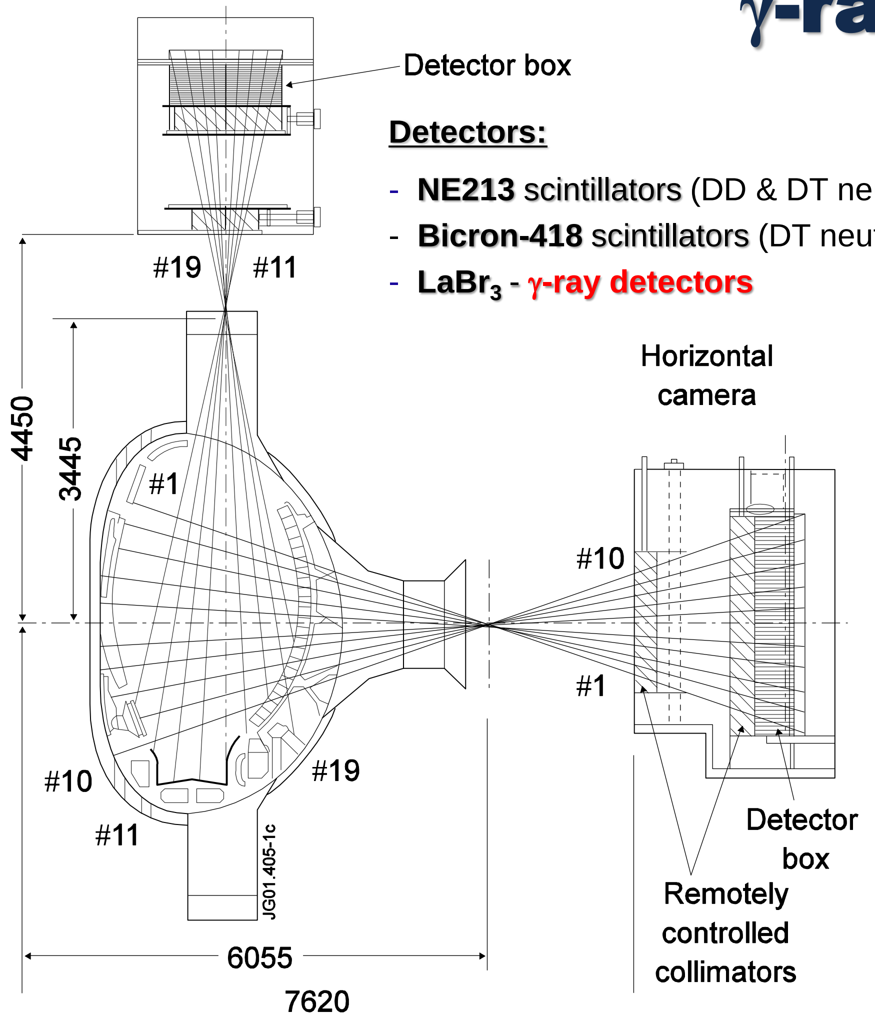
Kiptily V et al Plasma Phys. Control. Fusion 64 (2022) 064001

UK Atomic Energy Authority

CCFE CULHAM CENTRE FOR FUSION ENERGY

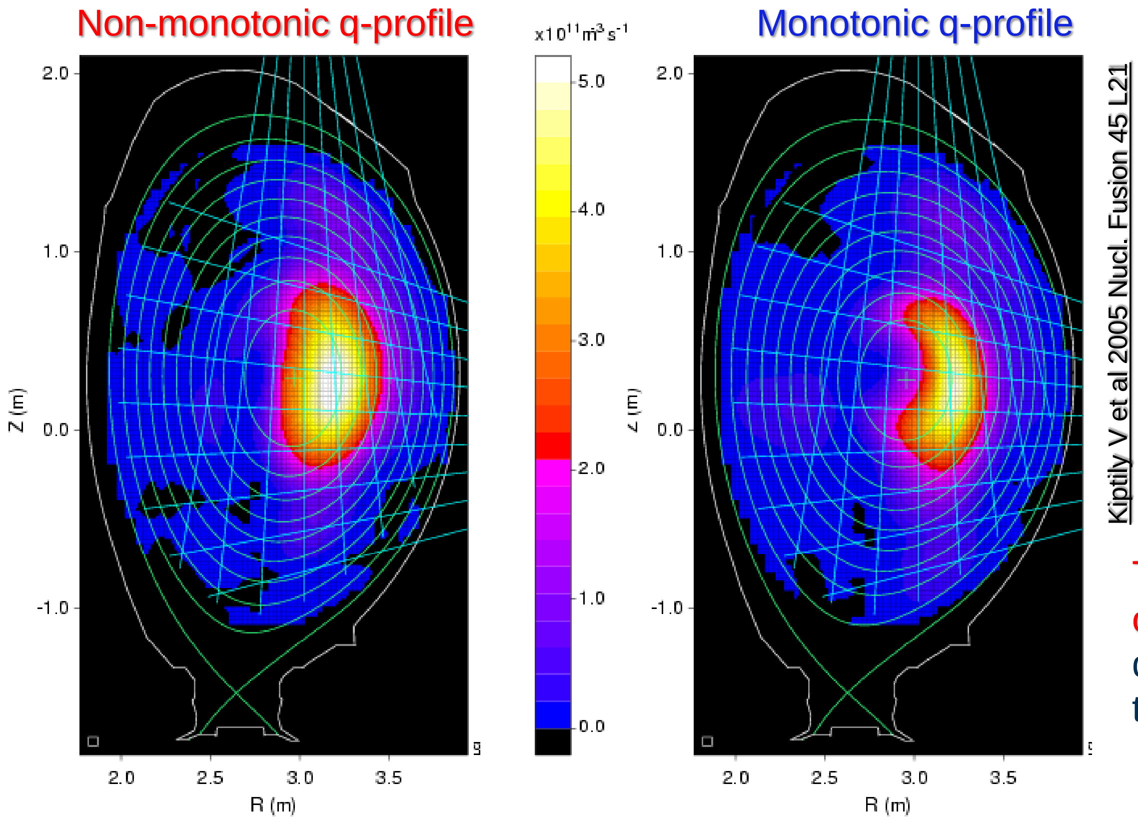
Fast-ion studies on JET:

γ-ray tomography



Detectors:

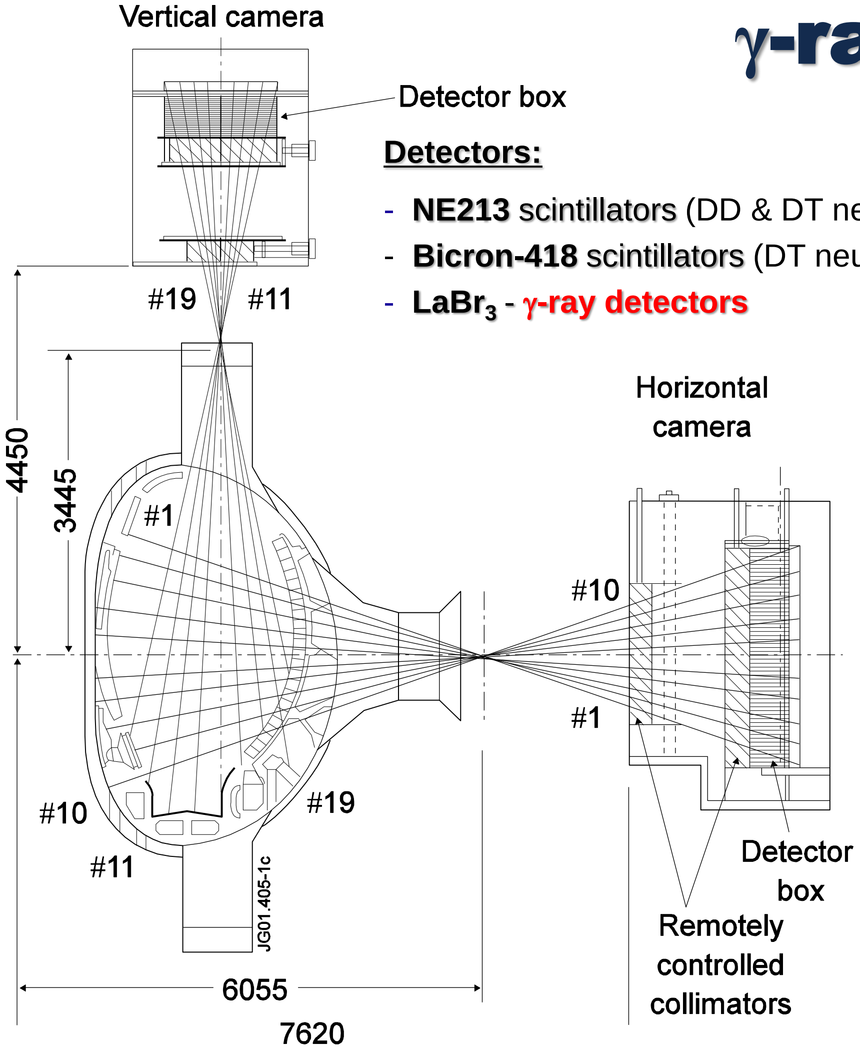
- **NE213** scintillators (DD & DT neutrons)
- **Bicron-418** scintillators (DT neutrons)
- **$LaBr_3$** - **γ-ray detectors**



Tomographic reconstructions of γ-ray profiles measured in different q-profile phases of the plasma discharge

Fast-ion studies on JET:

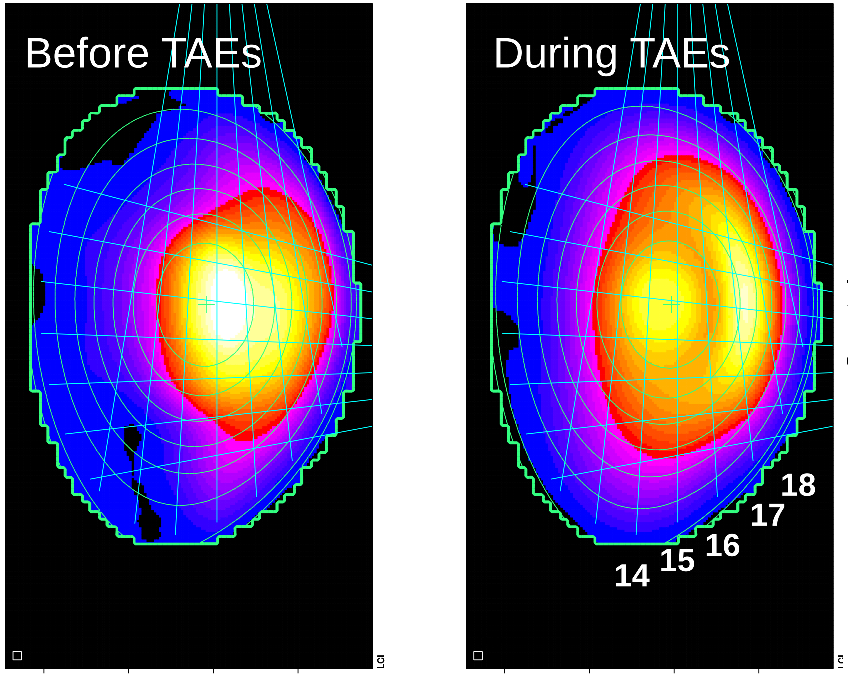
γ-ray tomography

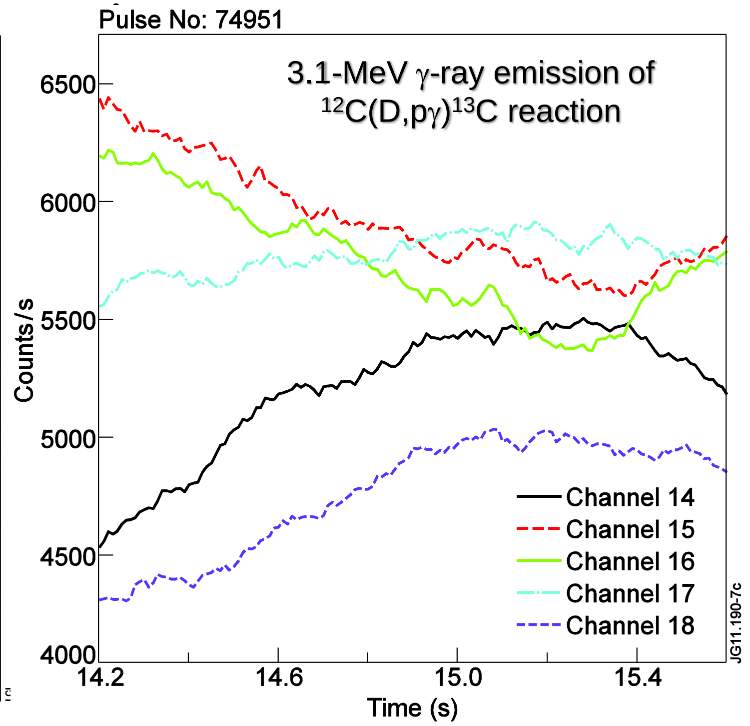


Detectors:

- **NE213** scintillators (DD & DT neutrons)
- **Bicron-418** scintillators (DT neutrons)
- **$LaBr_3$** - **γ-ray detectors**

γ-ray images of D-ions
with energies E_D>0.5 MeV

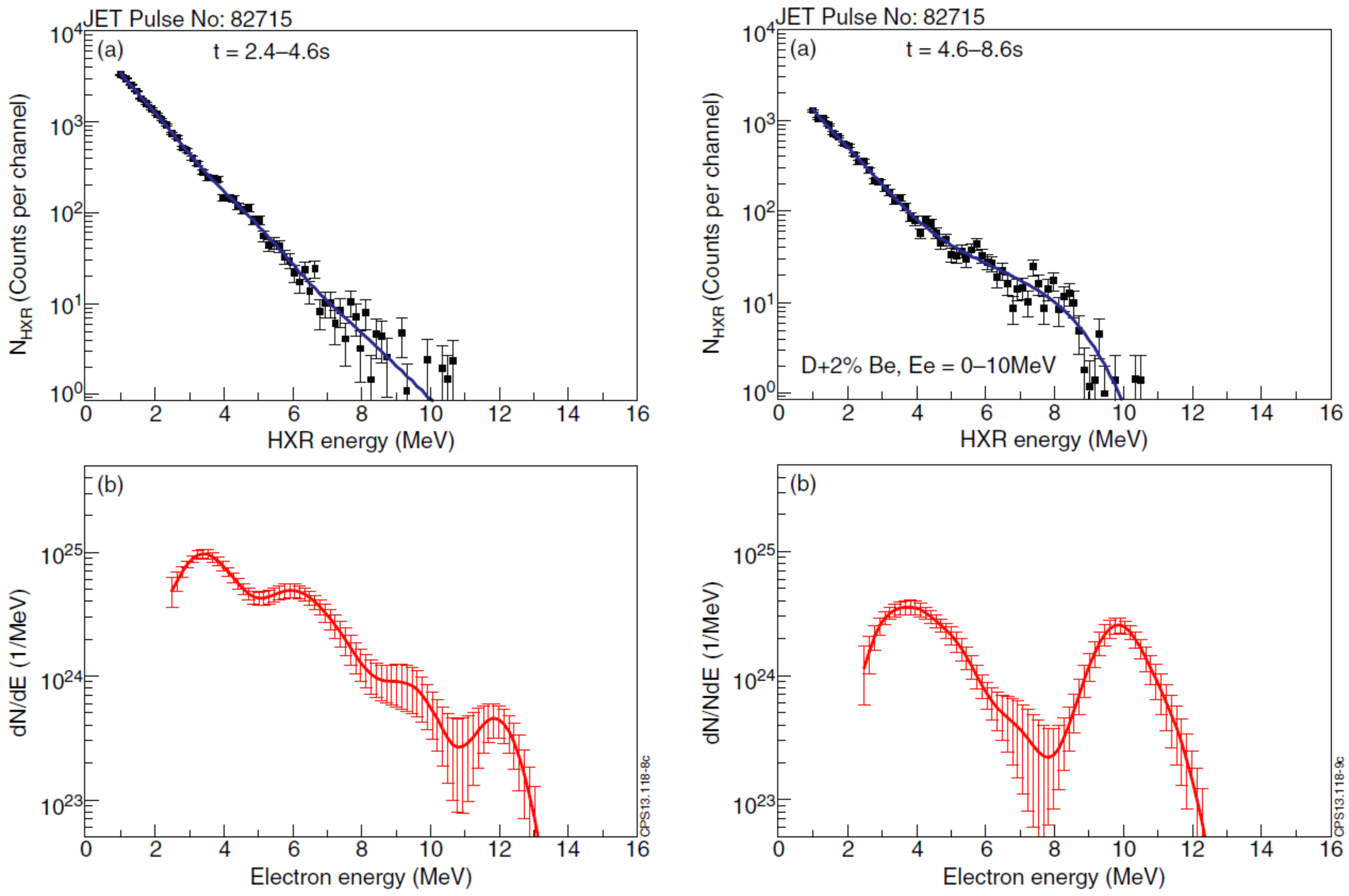




Kiptily V et al 2013 Plasma and Fusion Research: Overview Articles, 8 2502071

Runaways studies on JET:

Start-up runaways



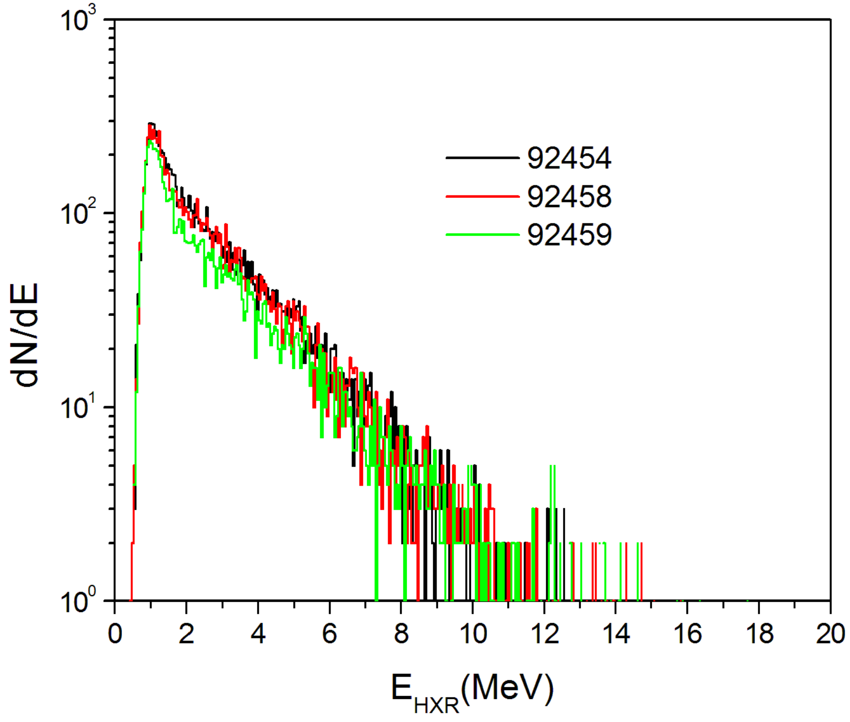
Shevelev A et al 2013 Nucl. Fusion 53 123004

- HXR spectra recorded during start-up of discharges
- RE-beam in the plasmas generated at the X-point creation and continues up to NBI heating
- RE energy distribution reconstructed from recorded HXR spectra based on a electron-impurity interaction model

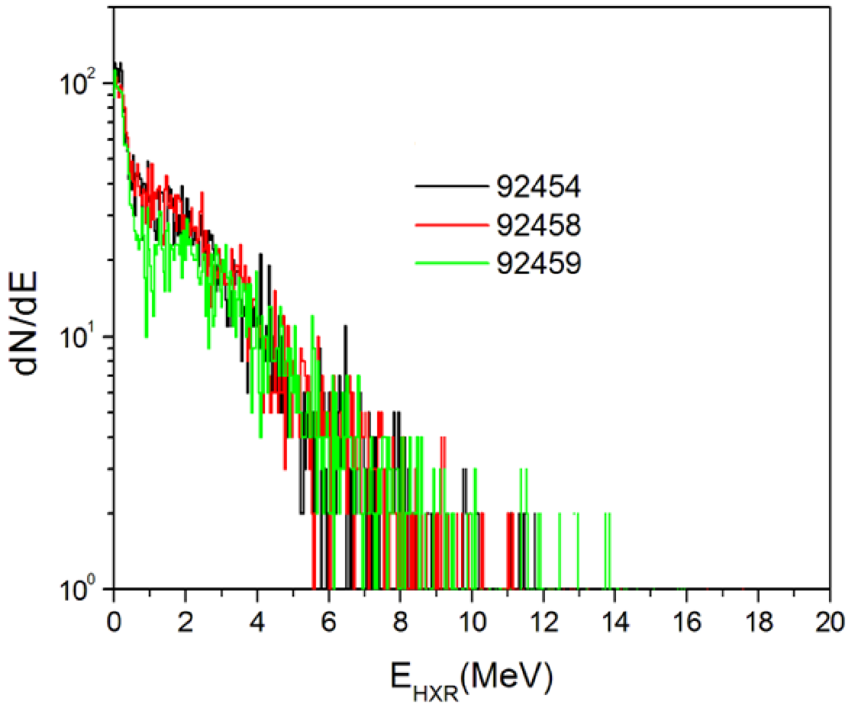
Runaways studies on JET:

Disruption mitigation experiments

Horizontal tangential spectrometer



Vertical spectrometer



Initial Research Phases Priorities & γ-ray diagnostic duty (I)

UK Atomic Energy Authority

Runaway electrons studies

- Current ramp-up scenario development up to full-current operation (H.I.1. Stable operation at high current)
- Basic disruption studies (H.I.2. ITER risk mitigation for non-activated phase)
- Runaway electron study at high current (H.II.3. ITER risk mitigation)
- Disruption avoidance (H.II.3. ITER risk mitigation)

JT-60SA Research Plan, Version 4.0, 2018

CCFE CULHAM CENTRE FOR FUSION ENERGY

Initial Research Phases Priorities & γ-ray diagnostic duty (II)

UK Atomic Energy Authority

Confined Fast Ion studies

- L-H transition studies in hydrogen / helium plasmas (H.I.2. ITER risk mitigation for non-activated phase)
- Energetic particle driven mode studies (H.II.1. ITER scenario development)
- Energetic particle effects on transport and confinement (H.II.1.)
- Fast ion effects on turbulence and transport (H.II.2. Steady-state high beta scenario development)
- Fast particle driven modes instability (H.II.2.)
- Compatibility of RMP with fast ion confinement (H.II.3. ITER risk mitigation)
- Burning plasma simulation experiment (H.II.3.)

JT-60SA Research Plan, Version 4.0, 2018

CCFE CULHAM CENTRE FOR FUSION ENERGY

Integrated & Extended Research Phases priorities & γ-ray diagnostic duty (III)

UK Atomic Energy Authority

Confined Fast Ion studies

- Fast ions & fusion products confinement and MHD effects in the high-β steady-state operation with high-power long-pulse discharges
  - in the carbon JT-60SA
  - W-coated carbon first wall and divertor

JT-60SA Research Plan, Version 4.0, 2018

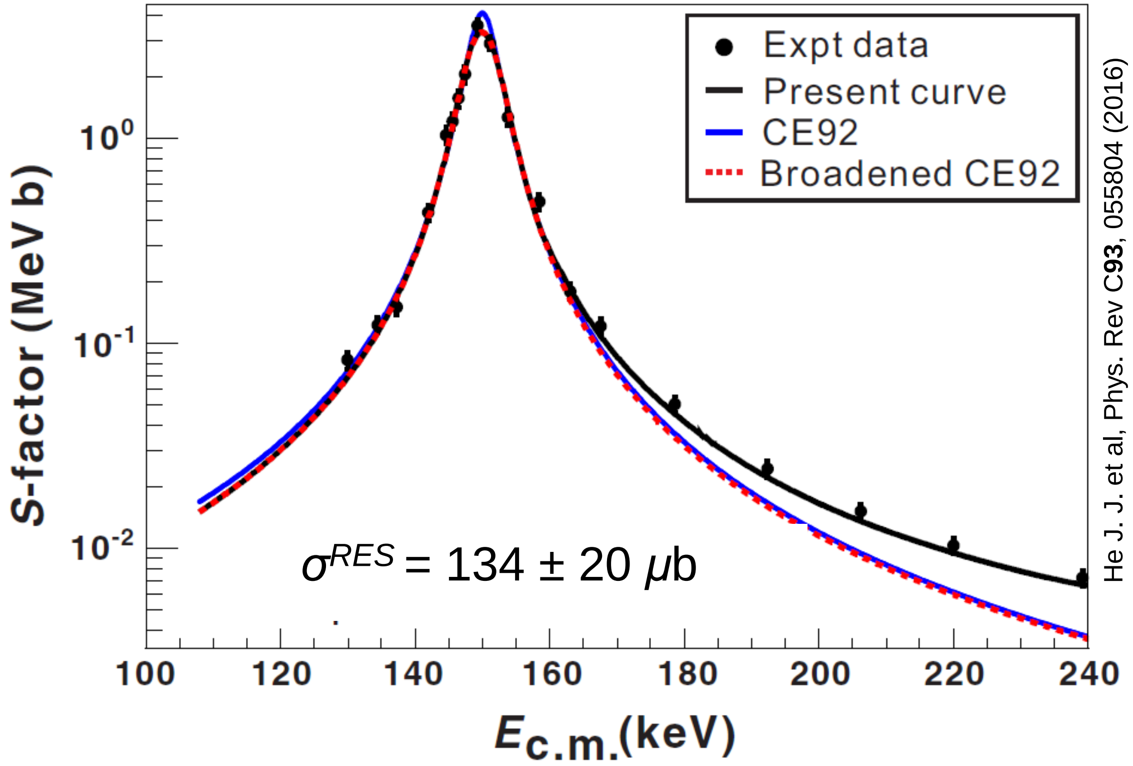
CCFE CULHAM CENTRE FOR FUSION ENERGY

Gamma-rays for fast-ion studies (I)

Hydrogen N-NBI & *boron* / *carbon* impurities

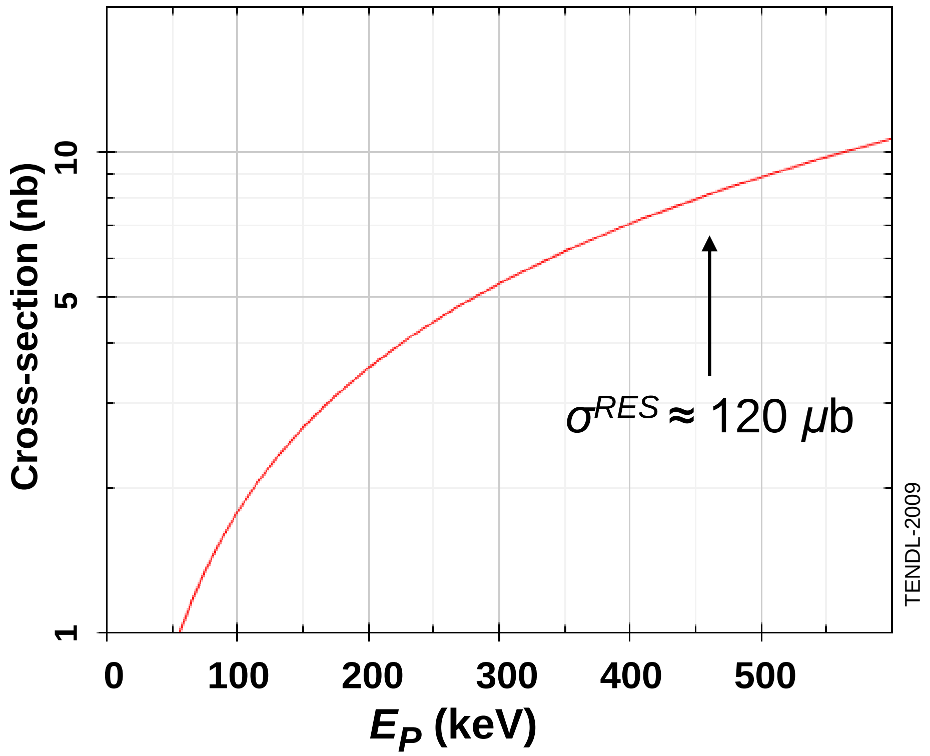
Analysis of γ-ray spectra => beam deposition, slowing down, fast-ion distribution

$^{11}B(H,\gamma)^{12}C$, Q=15.96 MeV, E_{RES} = 162 keV



He J. J. et al, Phys. Rev C93, 055804 (2016)

$^{12}C(H,\gamma)^{13}N$, Q=1.94 MeV, E_{RES} = 457 keV

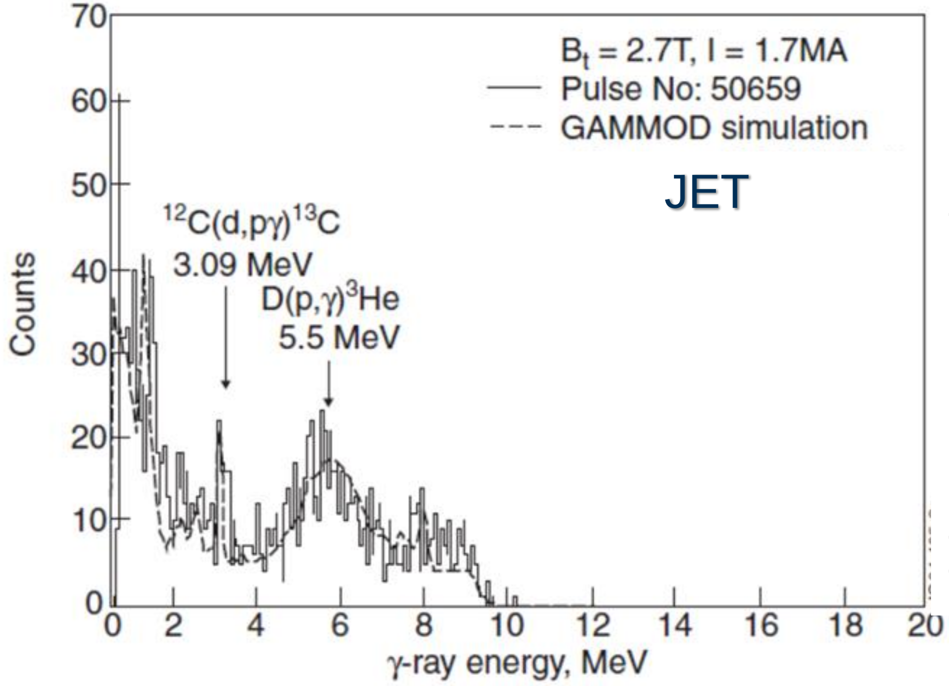


Gamma-rays for fast-ion studies (II)

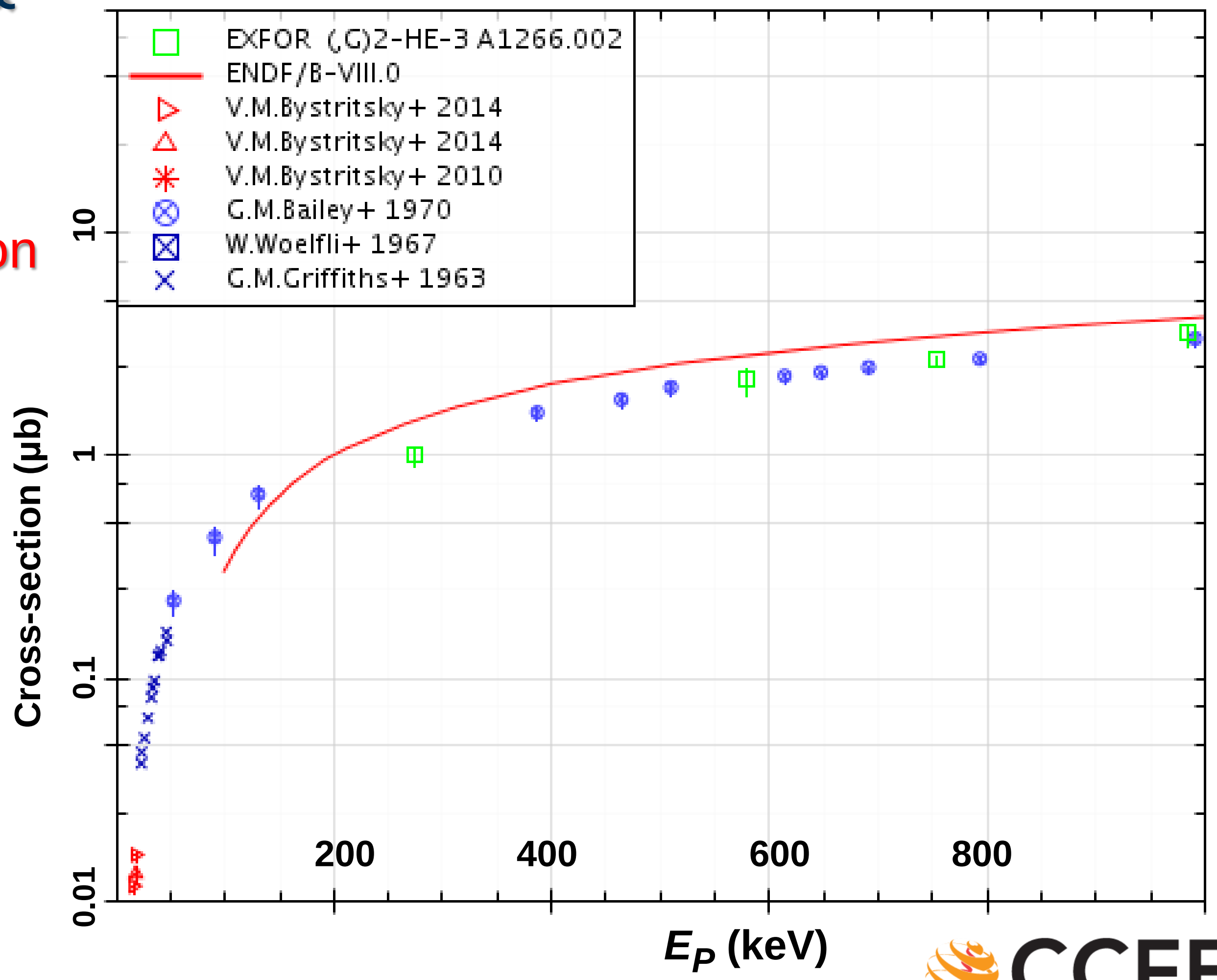
Deuterium N-NBI in *H*-plasmas &
Hydrogen N-NBI in *D*-plasmas

H(D,γ)^{3}He & D(H,γ)^{3}He, Q=5.49 MeV

Analysis of broadened spectra => fast-ion distribution



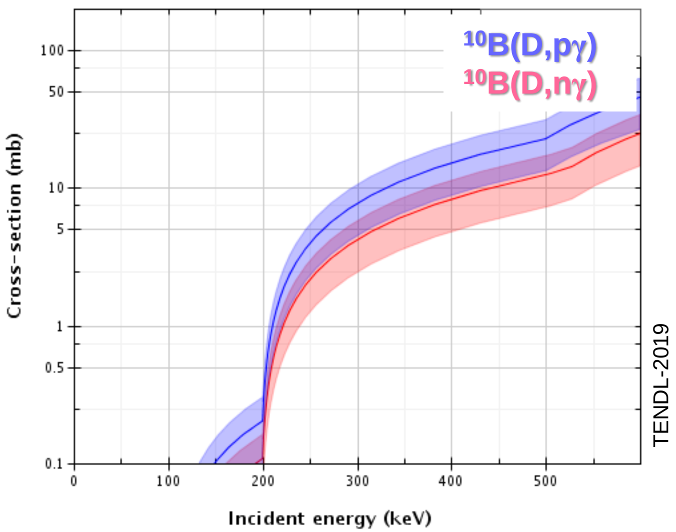
Kiptily et al 2002 Nucl. Fusion **42** 999

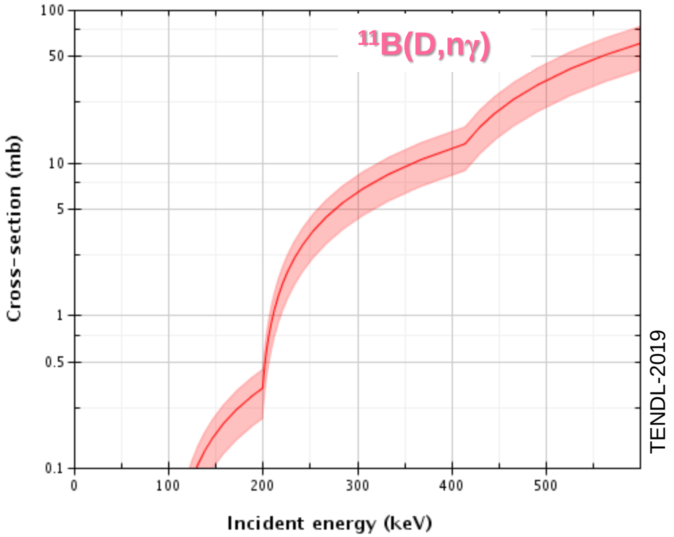


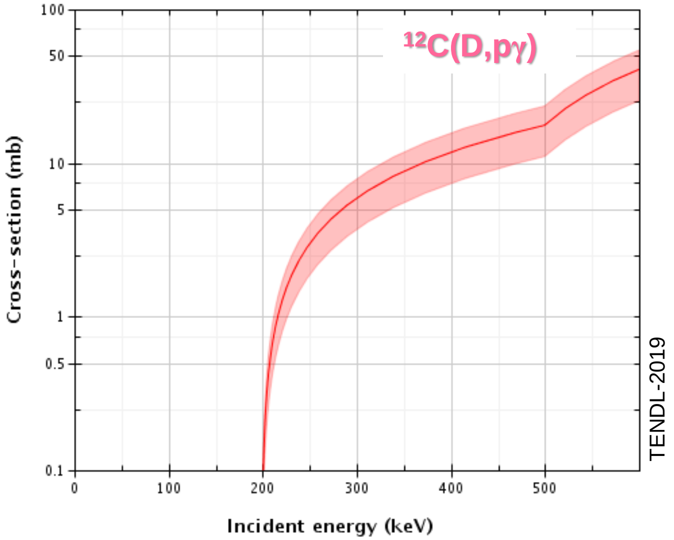
Gamma-rays for fast-ion studies (III)

Deuterium N-NBI in high-performance *D*-plasmas

Reaction	Reaction energy, Q (MeV)
$^{10}B(d,n\gamma)^{11}C$	6.465
$^{10}B(d,p\gamma)^{11}B$	9.23
$^{11}B(d,n\gamma)^{12}C$	13.73
$^{12}C(d,p\gamma)^{12}B$	2.72



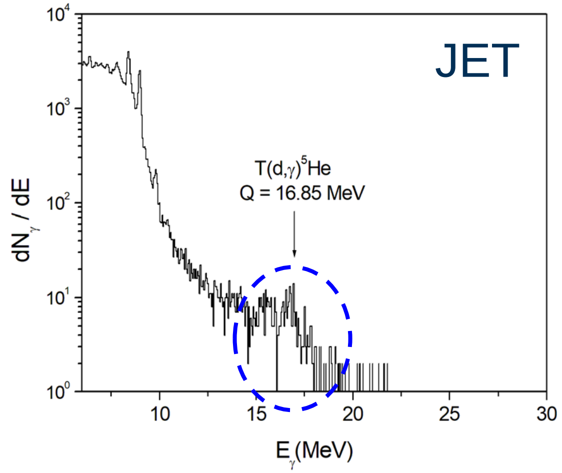




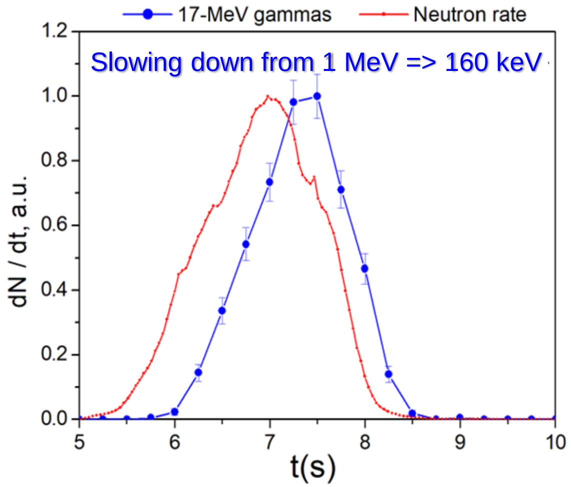
Gamma-rays for fast-ion studies (IV)

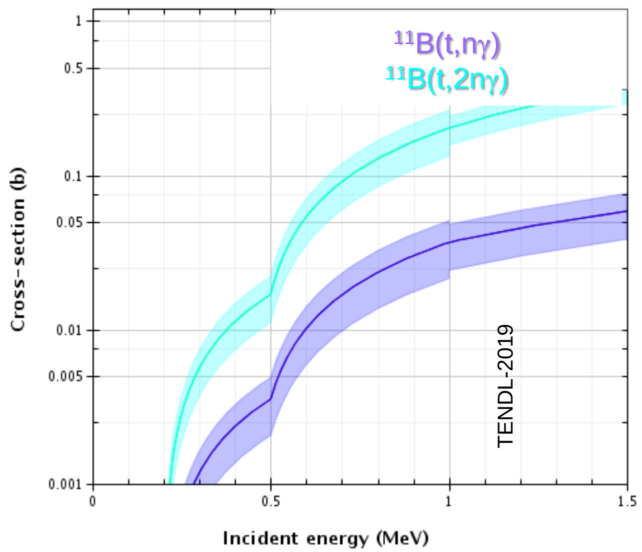
UK Atomic Energy Authority

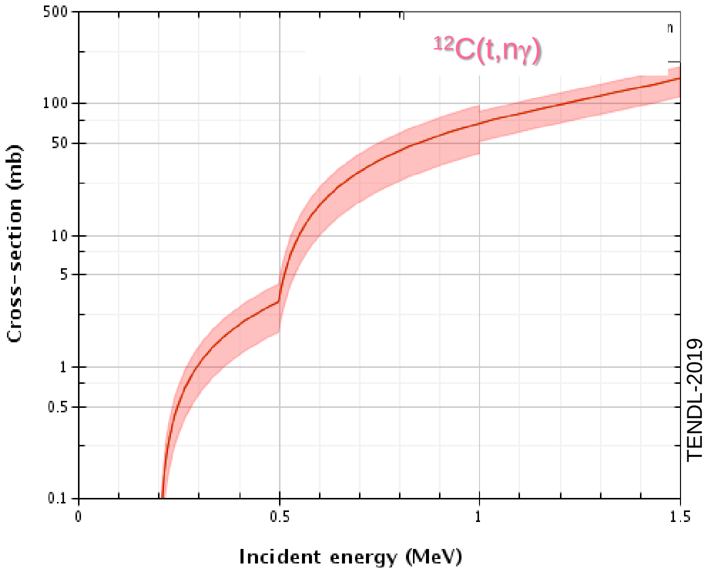
Triton burn-up in high-performance *D*-plasmas



Reaction	Reaction energy, Q (MeV)
$D(t,\gamma)^5He$	16.85
$^{11}B(t,n\gamma)^{13}C$	12.42
$^{11}B(t,2n\gamma)^{12}C$	7.48
$^{12}C(t,n\gamma)^{14}N$	3.97







CCFE CULHAM CENTRE FOR FUSION ENERGY

A preliminary work plan 2022

UK Atomic Energy Authority

- Using experience of JET γ-ray diagnostics, make assessments of
  - *HXR generation by runaway electron beams during*
    - *start-up / rump-up*
    - *disruptions*
  - *nuclear reaction rates and most useful/intensive γ-ray emissions to study of*
    - *hydrogen N-NB / protons*
    - *deuteron N-NB*
    - *DD fusion tritons*
- Report on the scientific case for γ-ray diagnostics on JT-60SA

CCFE CULHAM CENTRE FOR FUSION ENERGY

Thank you
for your attention