

Fusion power measurement through neutron-independent DT gamma-ray spectroscopy

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D. Rigamonti¹, F. Scioscioli^{1,2}, L. G. Tedoldi² and M. Tardocchi¹



¹Institute for Plasma Science and Technology, CNR, Milan, Italy

²Department of Physics, UNIMIB Milan, Italy



Outline

- Fusion power measurements in DT plasmas

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- Standard method for fusion power measurements

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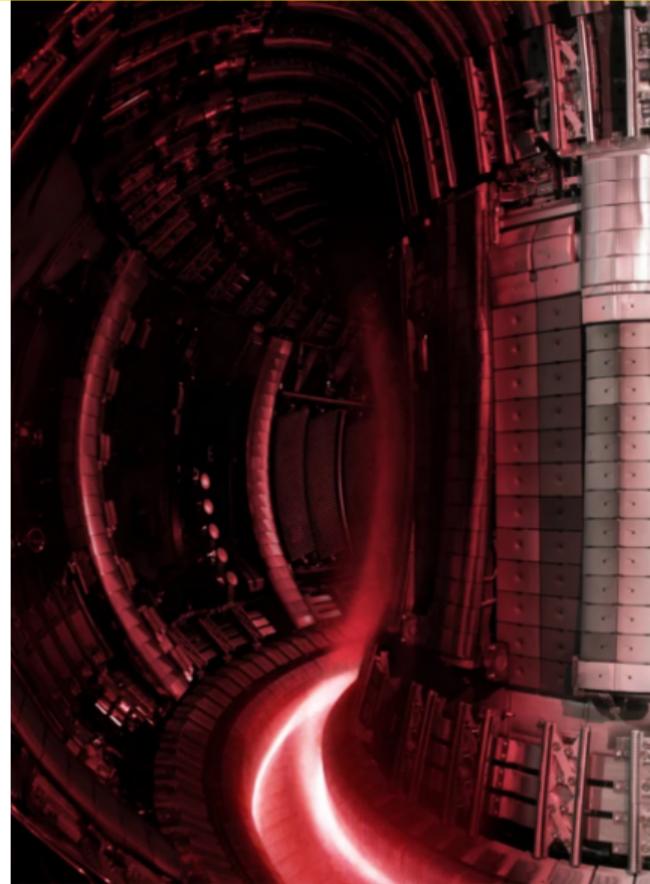
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- Results
- Prospects

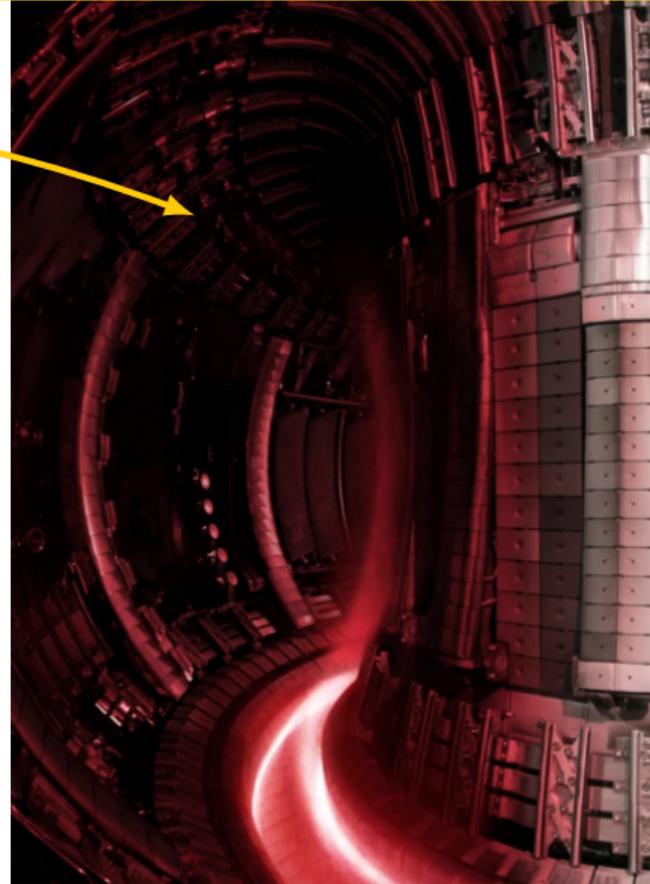
What is Fusion Power?

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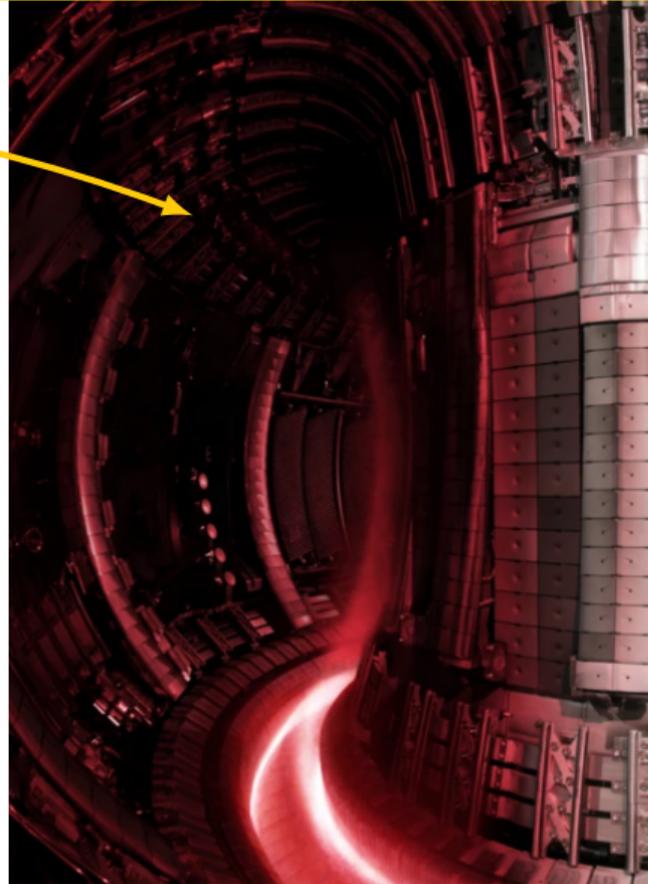
What is Fusion Power?

- Deuterium and Tritium



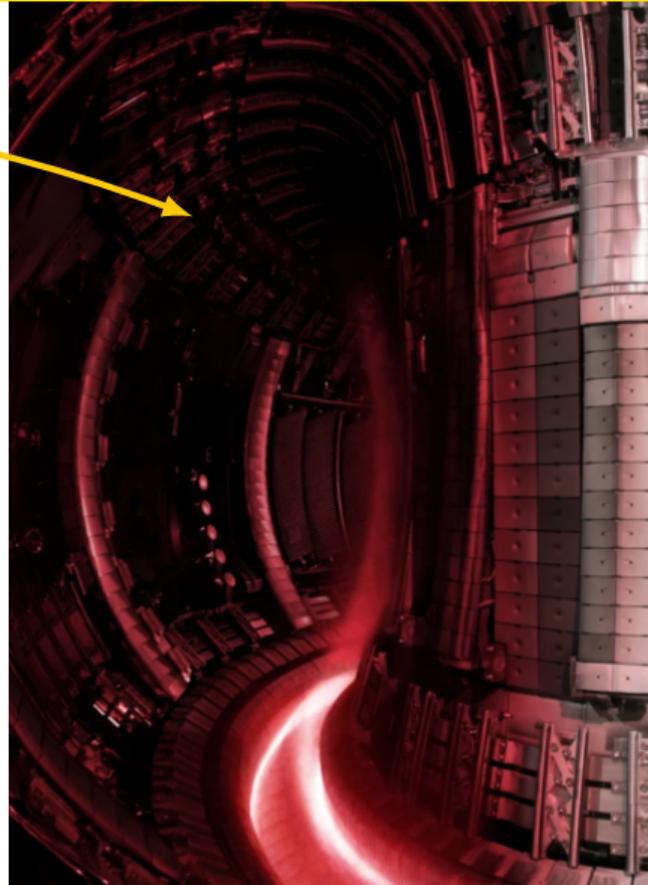
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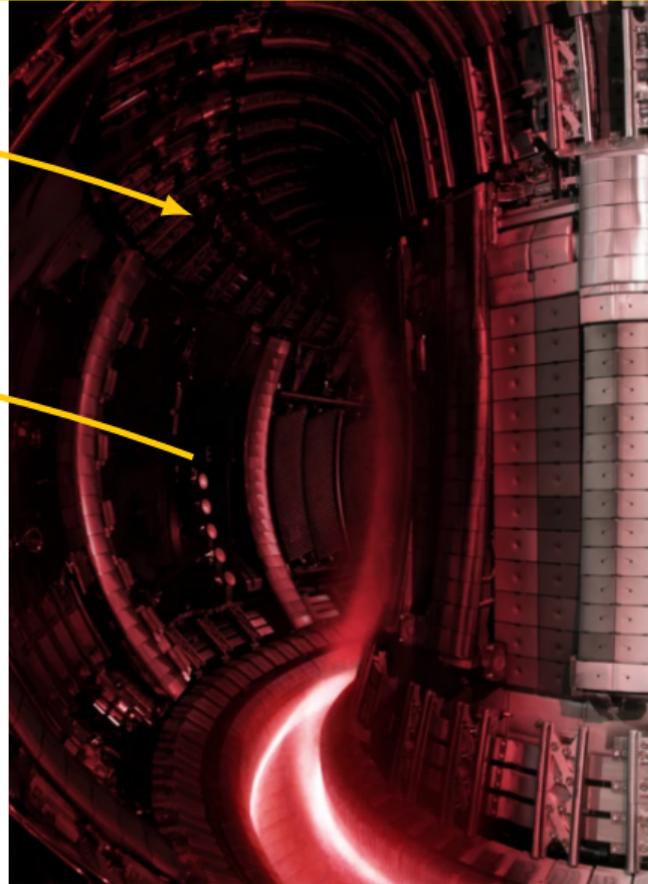
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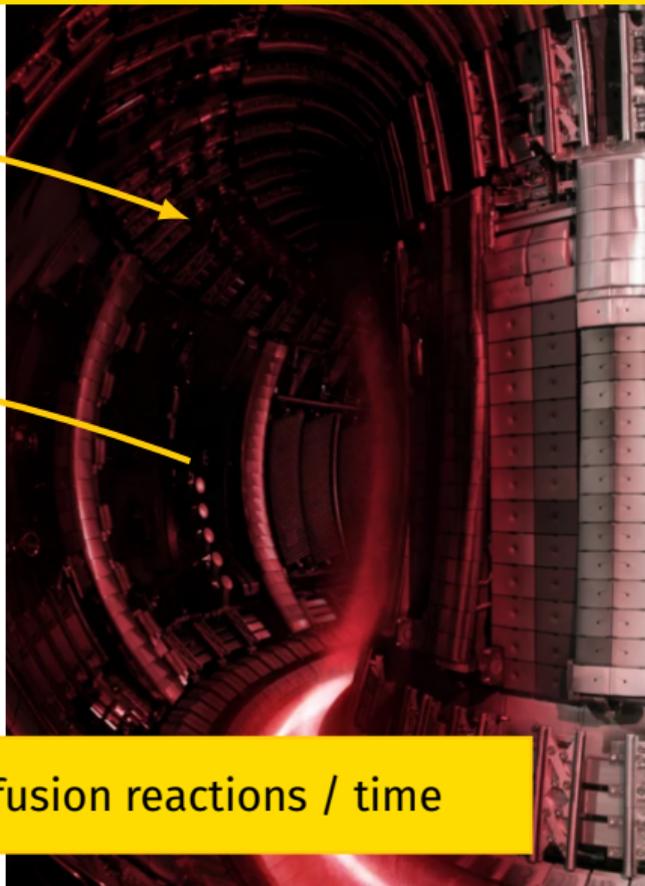
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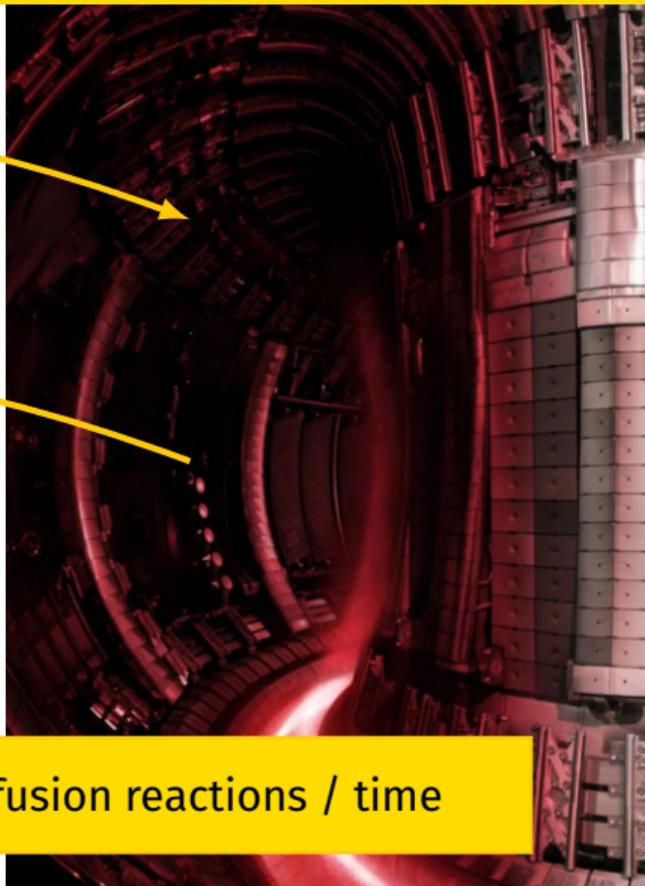
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DT fusion power: DT fusion Q value · number of DT fusion reactions / time

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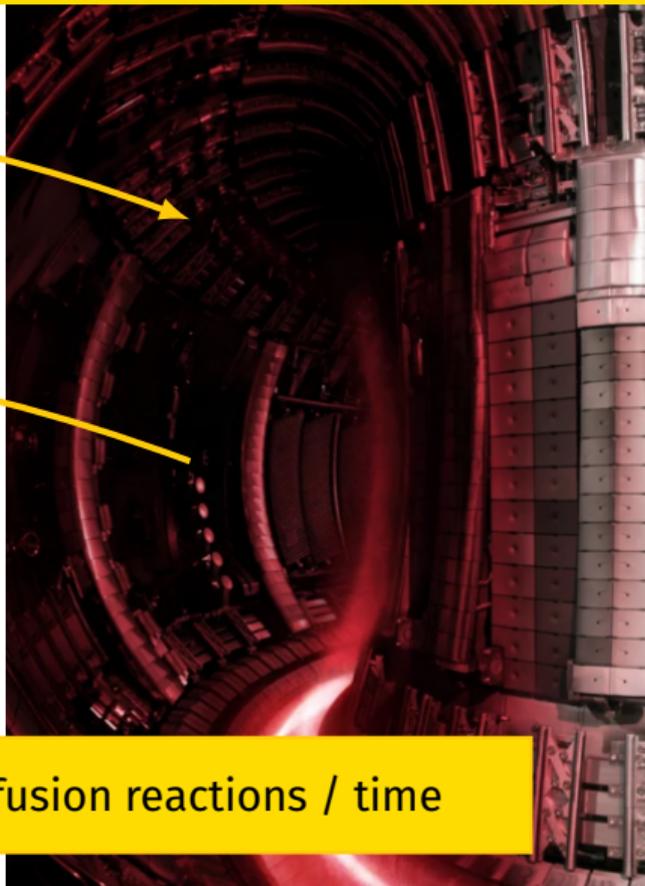
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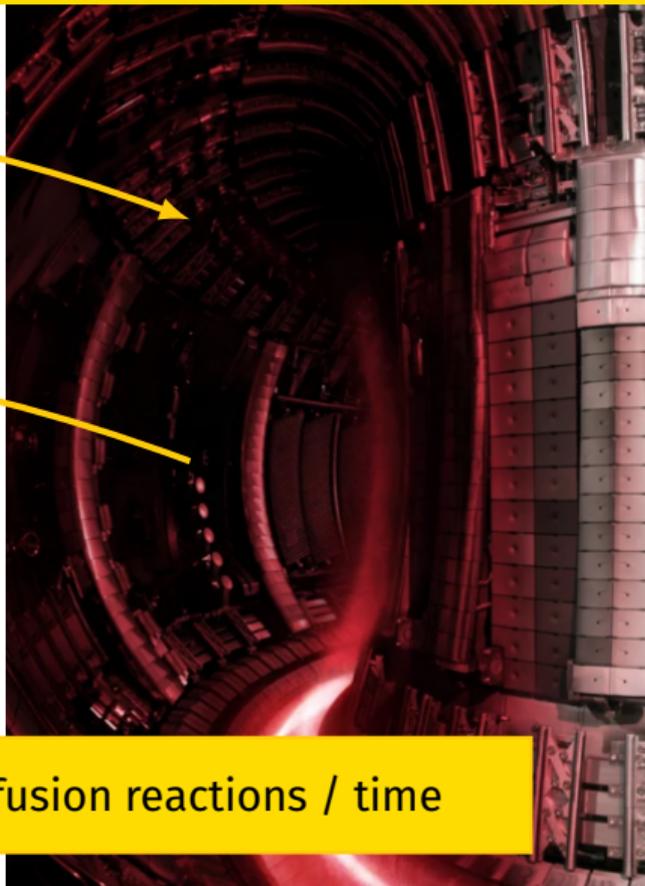
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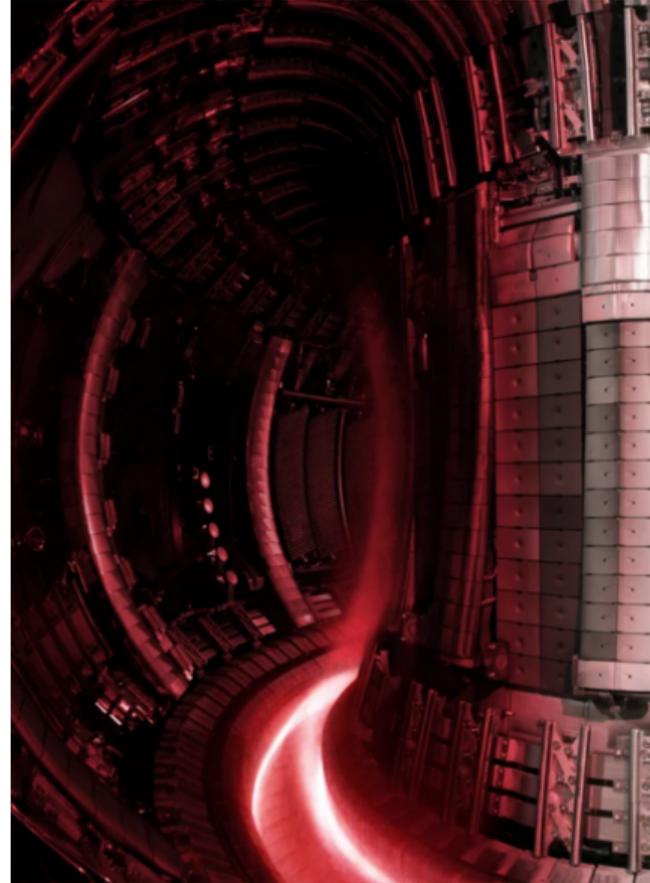
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- Deuterium and Tritium
- Heat it up
- Maintain the plasma (control instabilities)
- Get fusion energy
- Radiation losses
- 14 MeV neutrons
- Lots of scattered neutrons



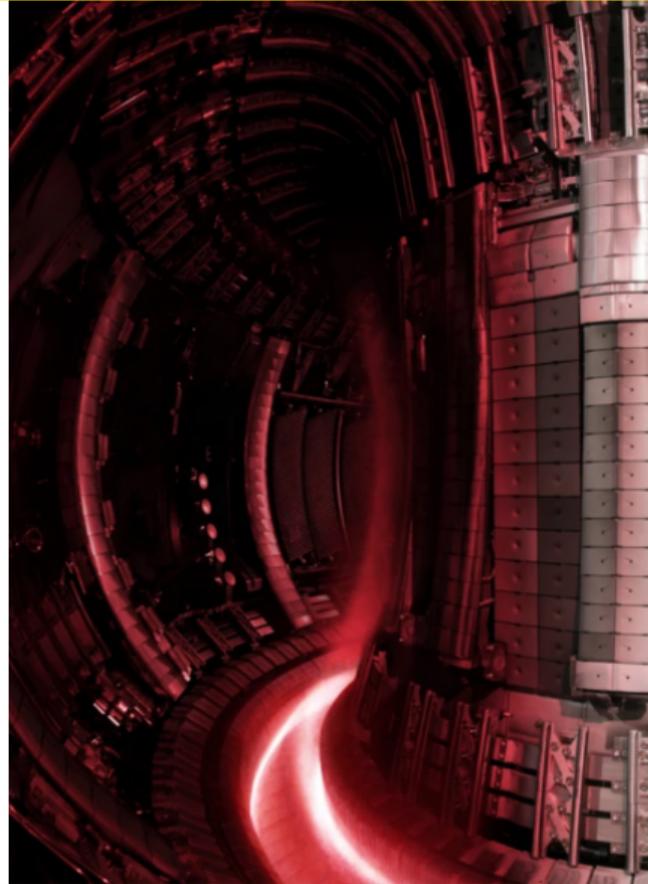
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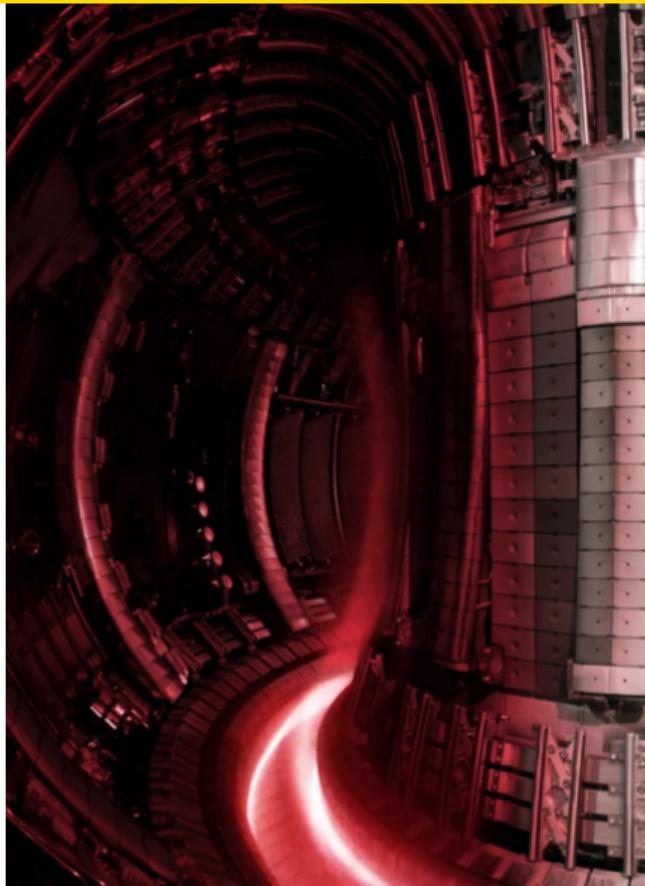
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- Counting fusion products



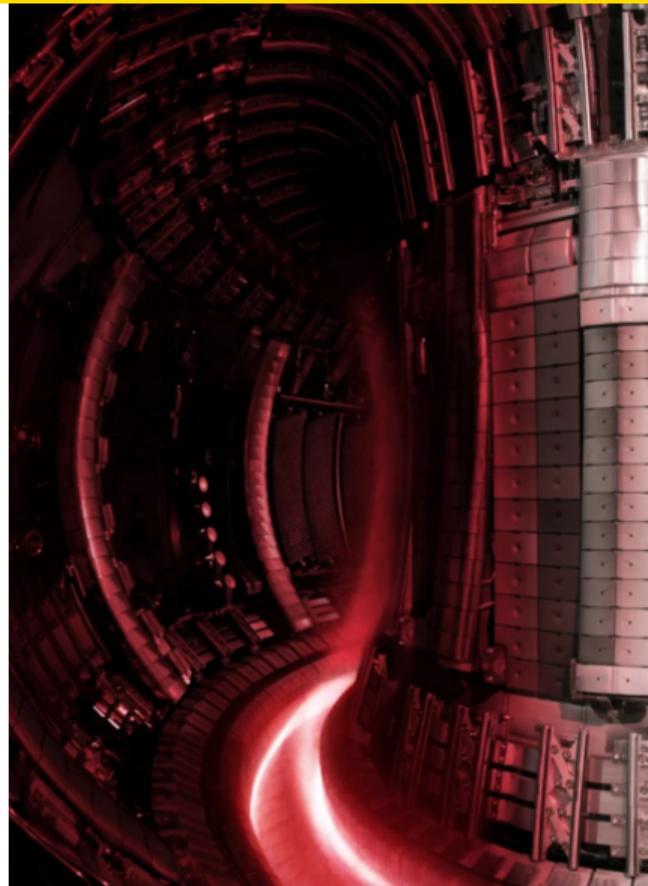
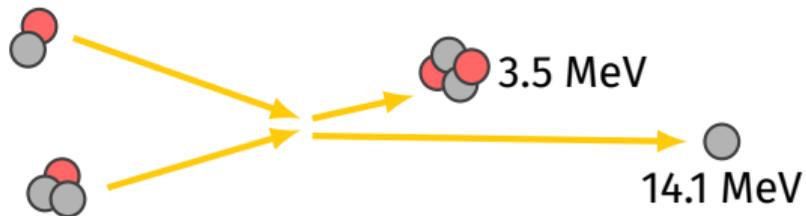
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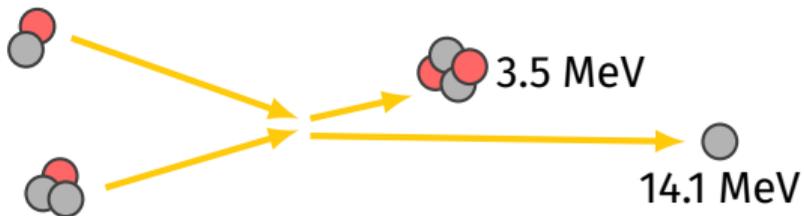
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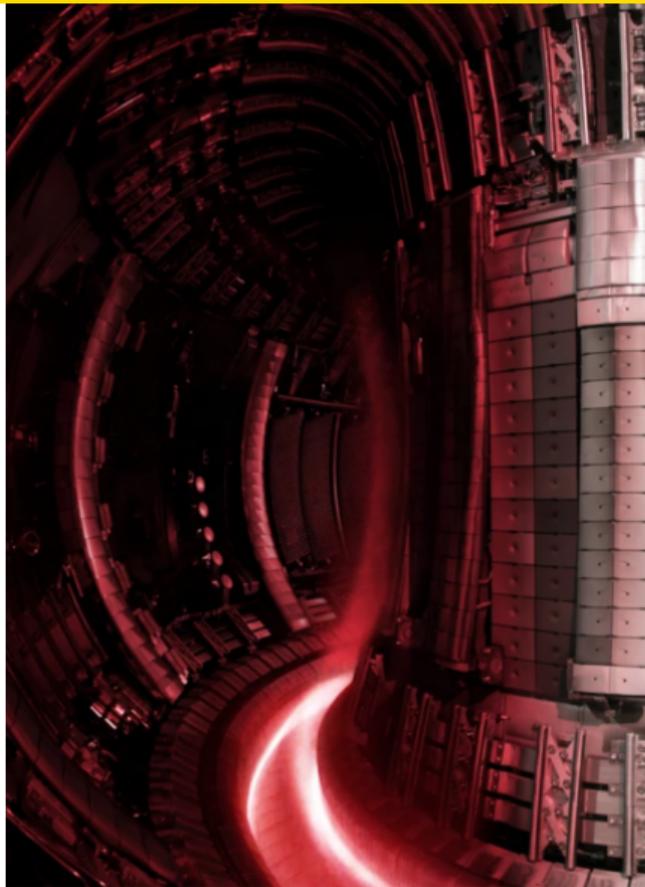


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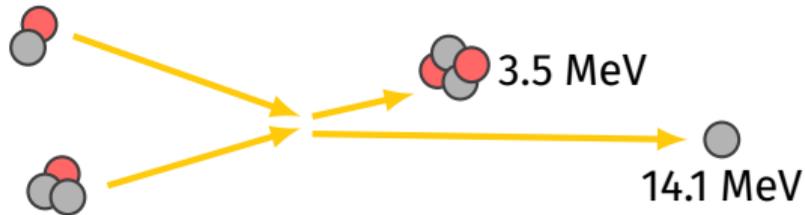


- Alphas are confined

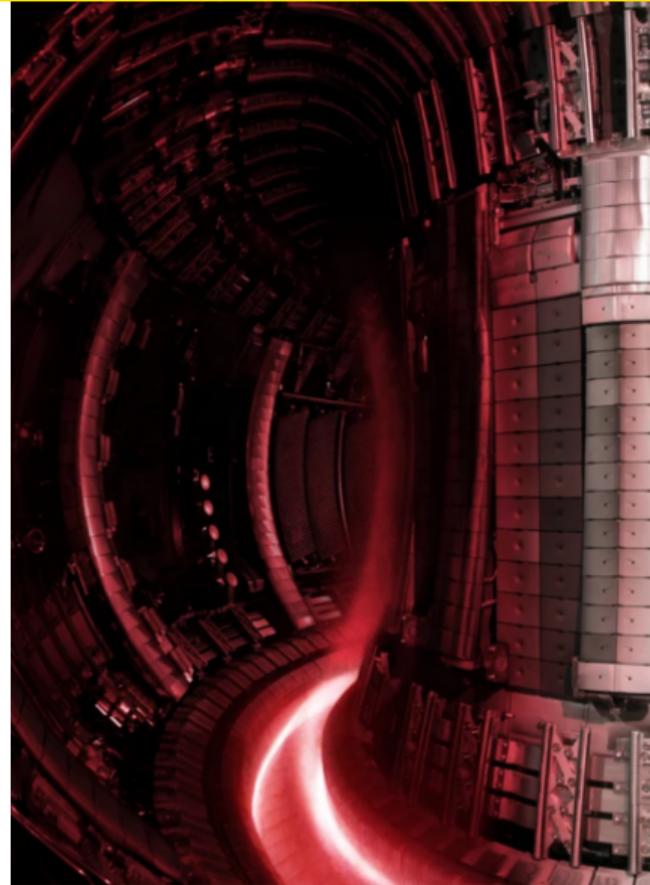


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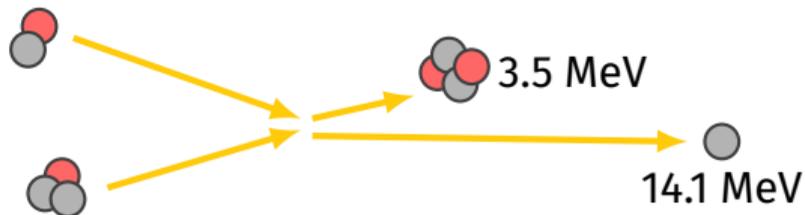


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- Neutrons escape (direct and scattered)

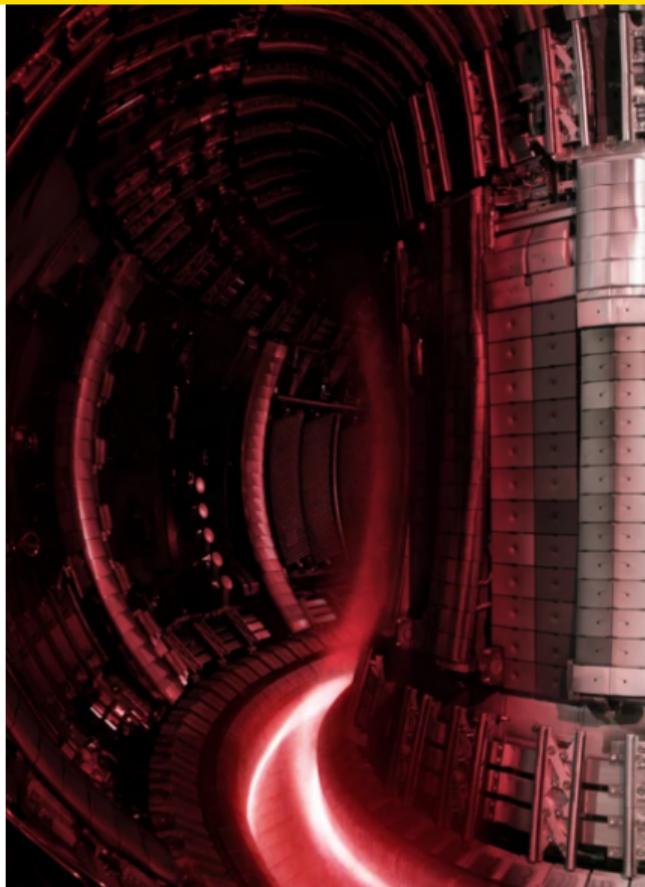


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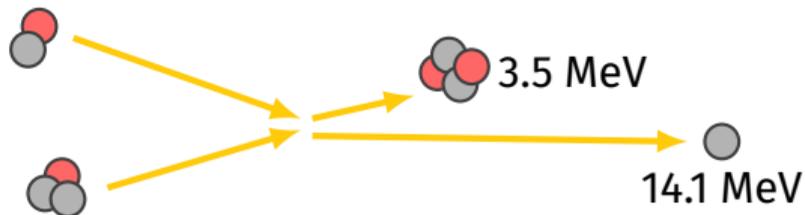


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- $3.5 \cdot 10^{17}$ n/s for 1 MW fusion power



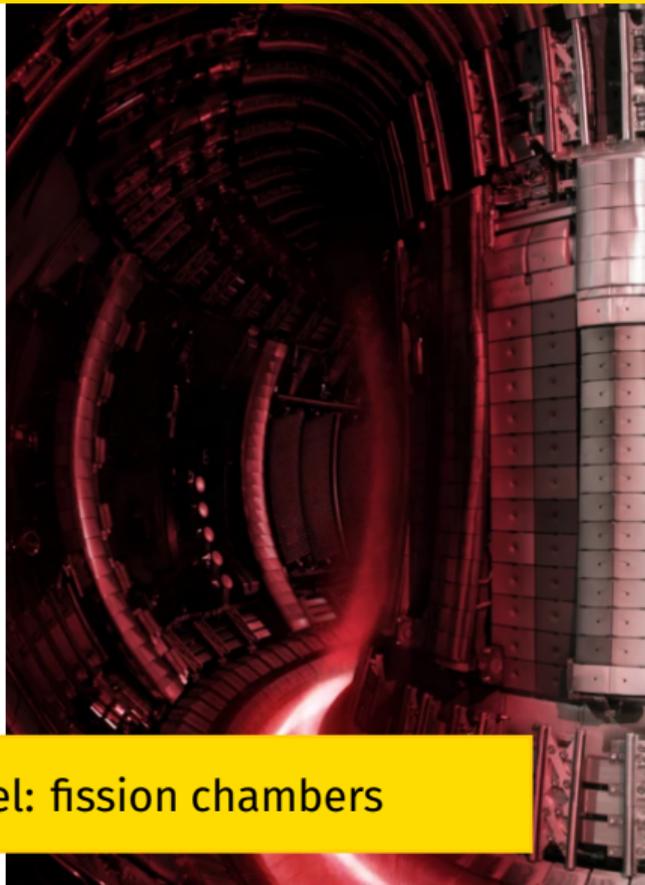
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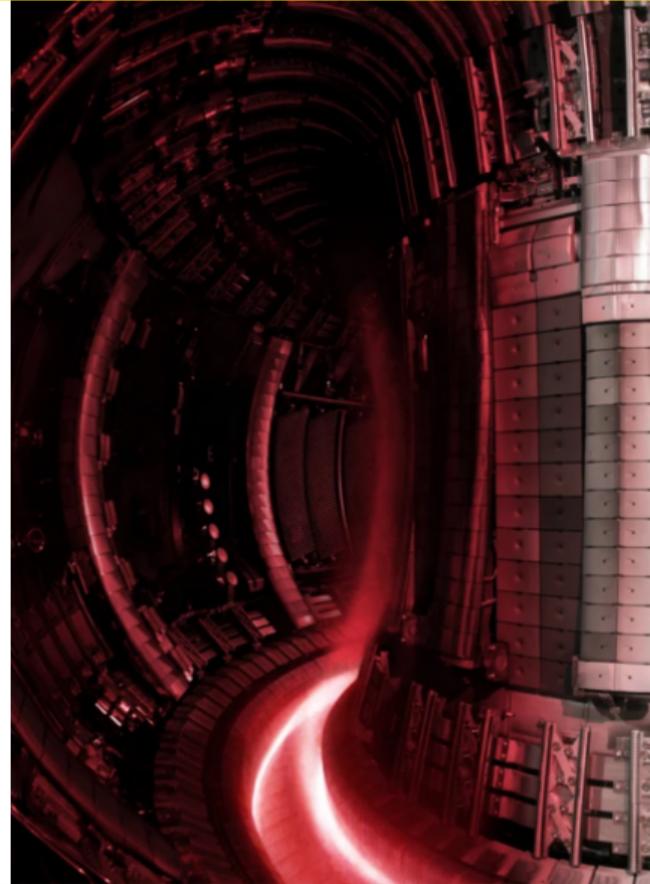


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Locate fast neutron counters outside the vessel: fission chambers

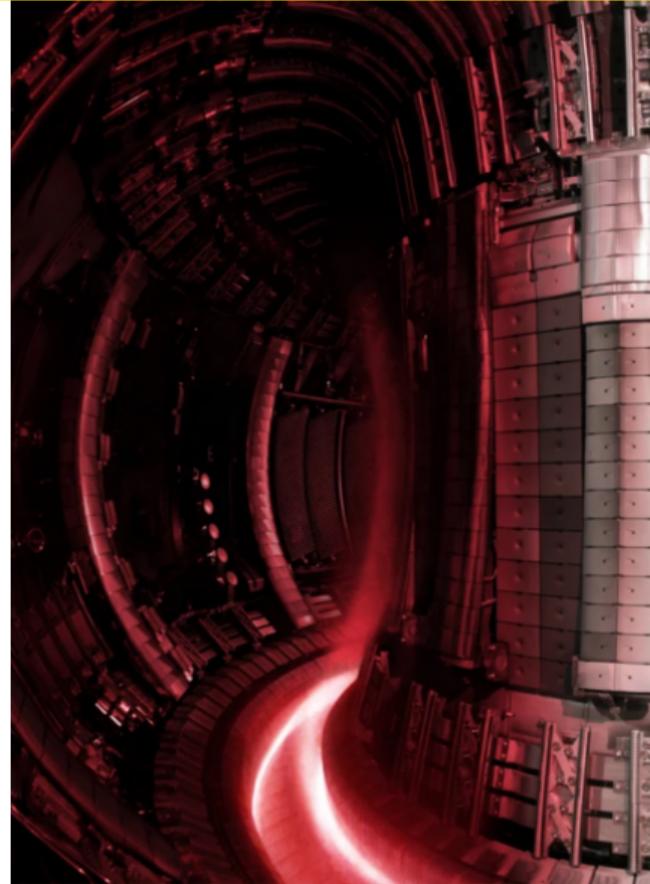


The neutron activation system



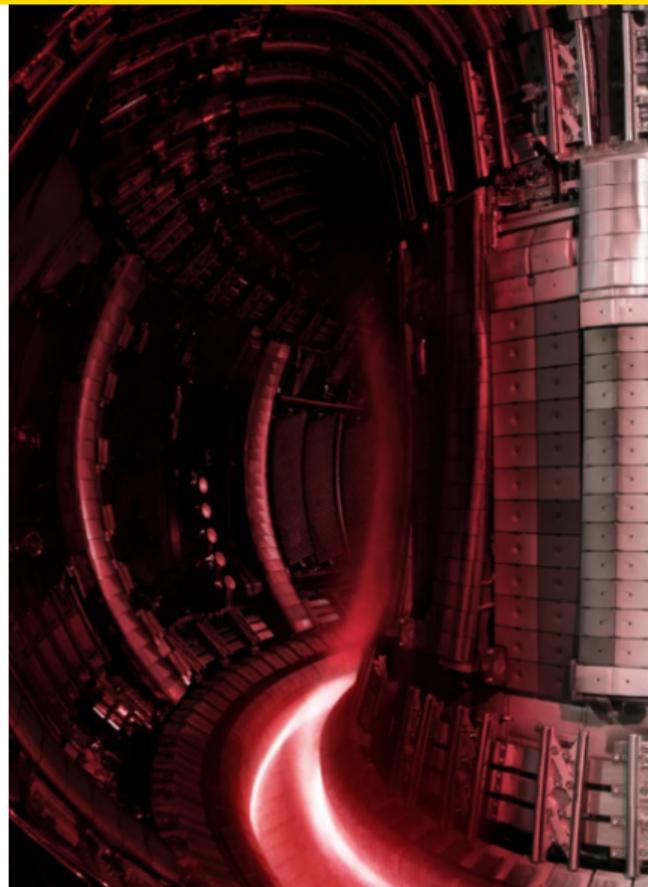
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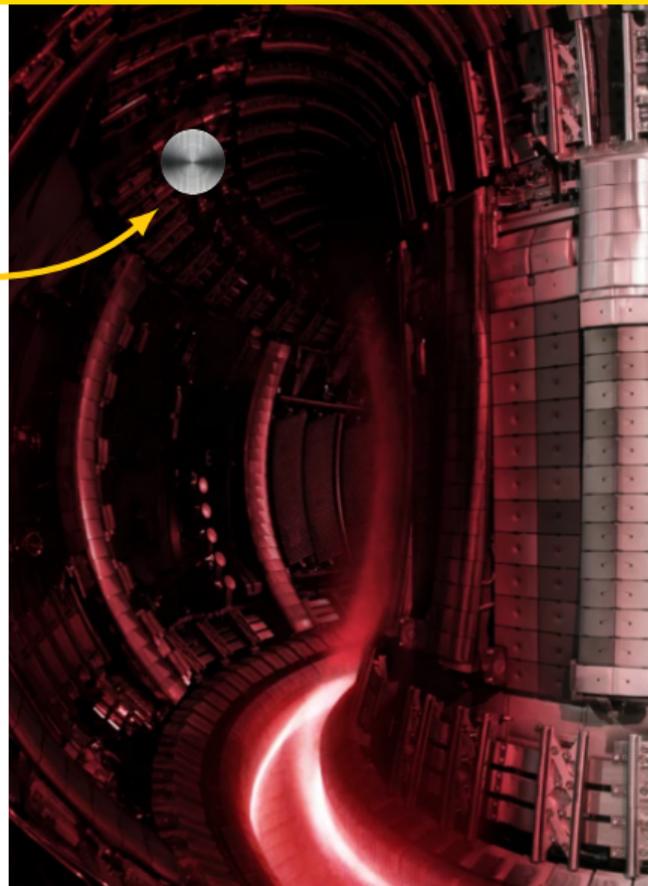
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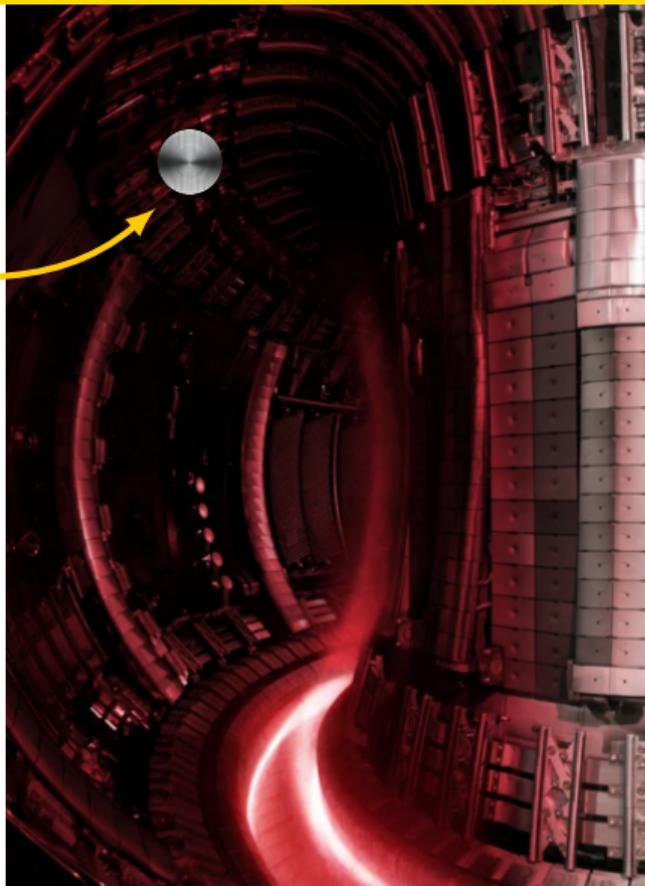
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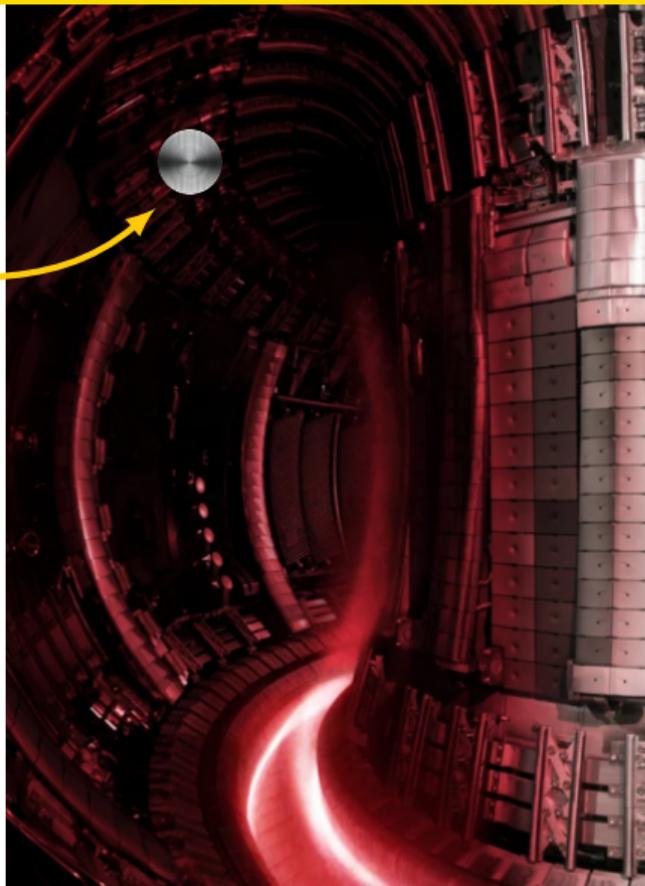
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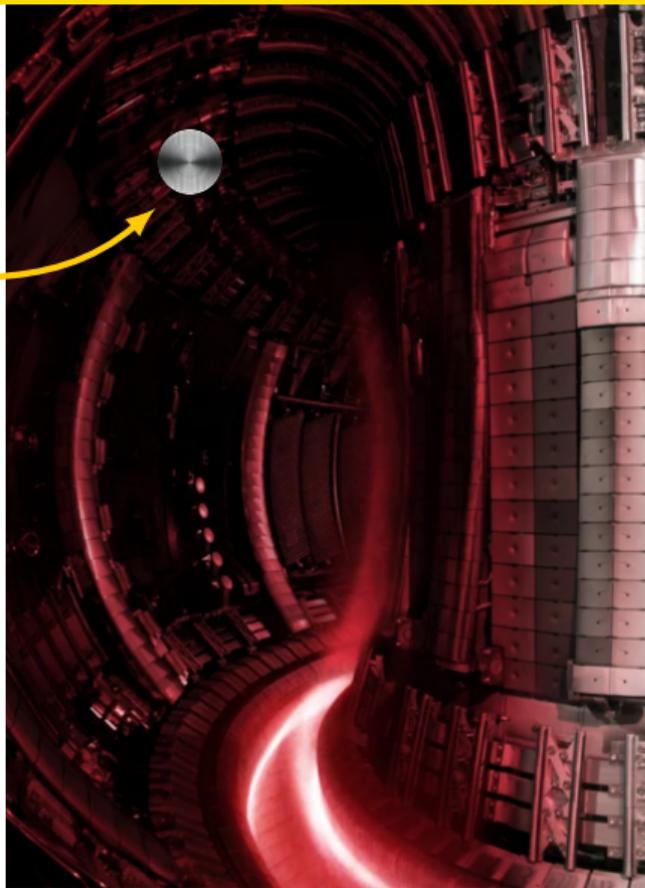
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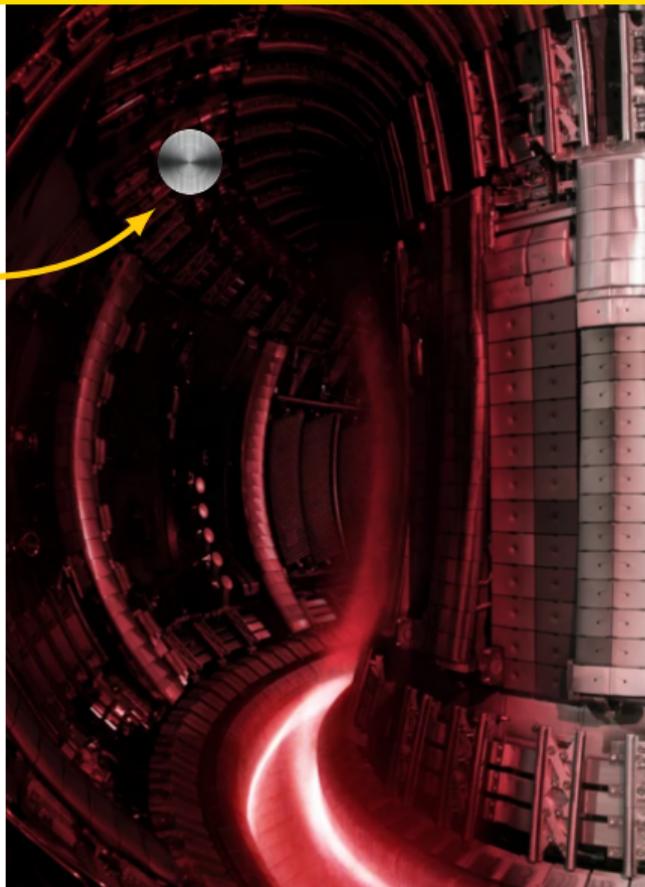
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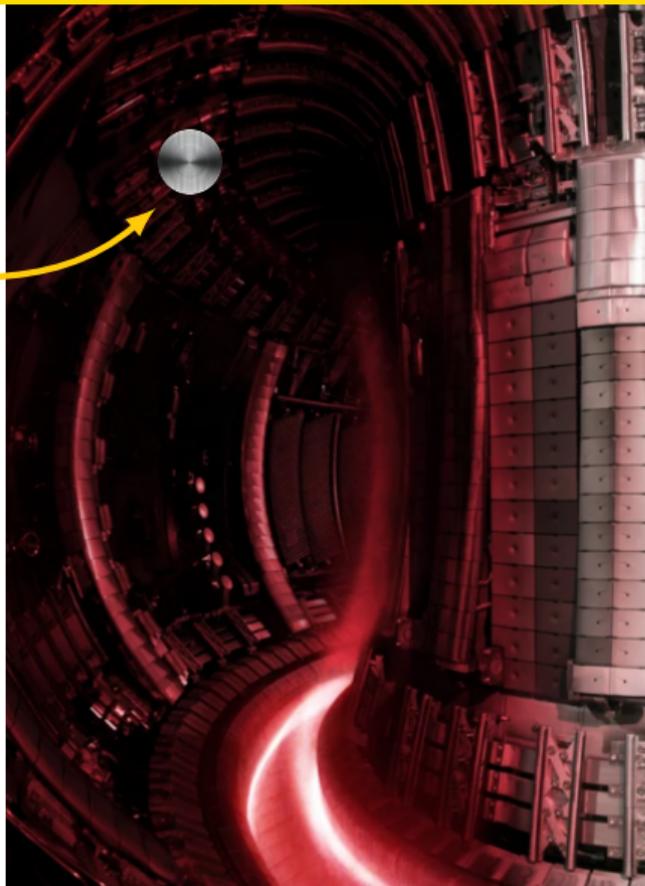
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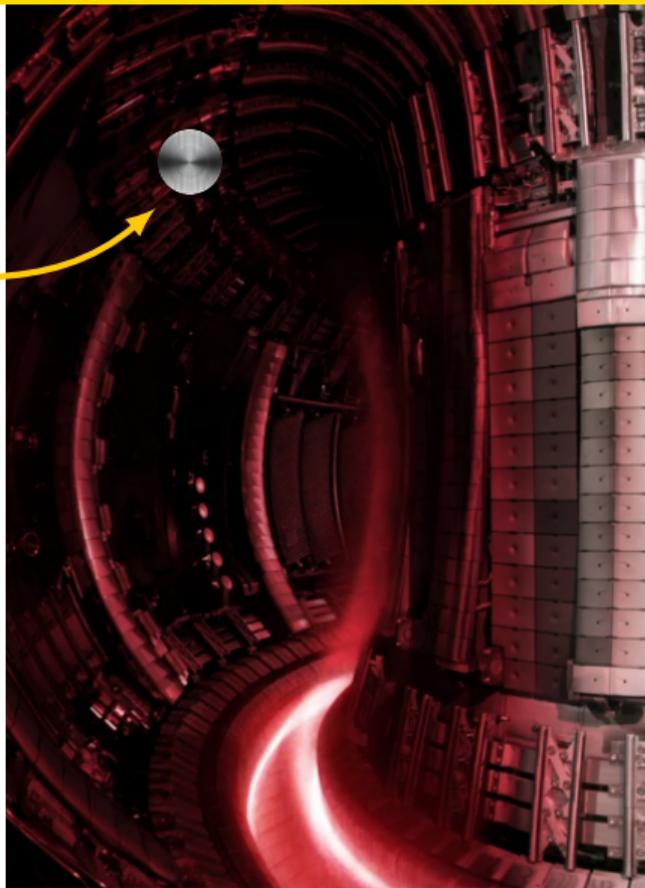
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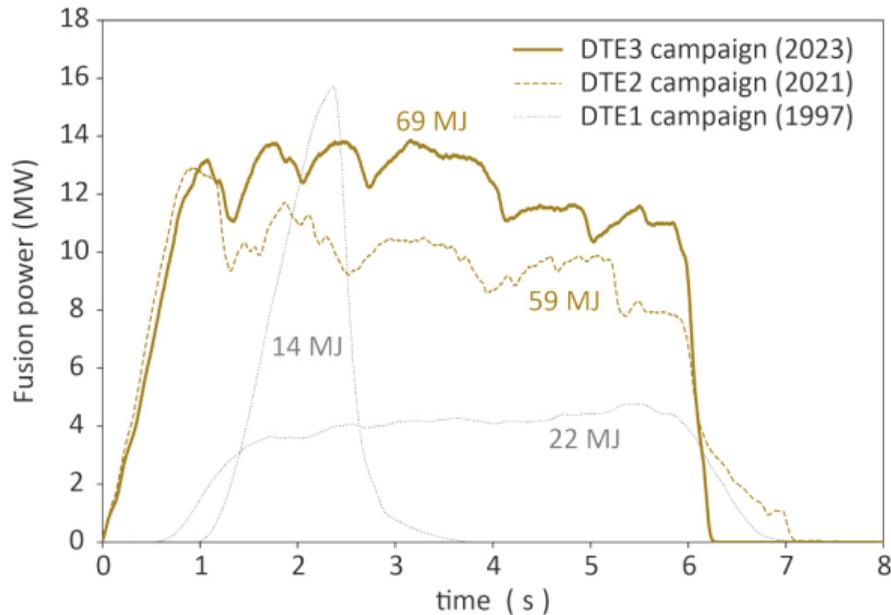
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as frequently as possible)



Fusion power measurements at JET

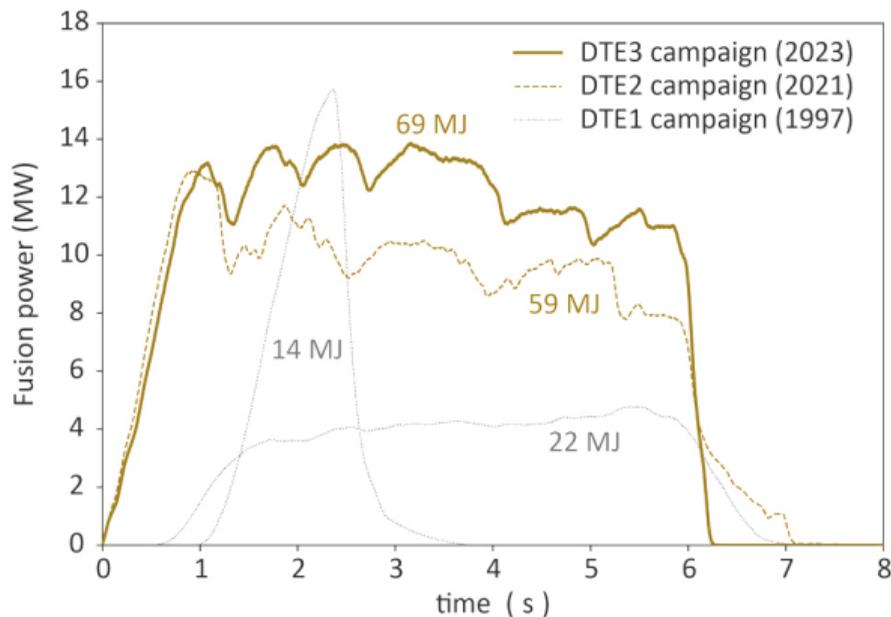
Fusion power measurements at JET

- JET energy records from DT campaigns:



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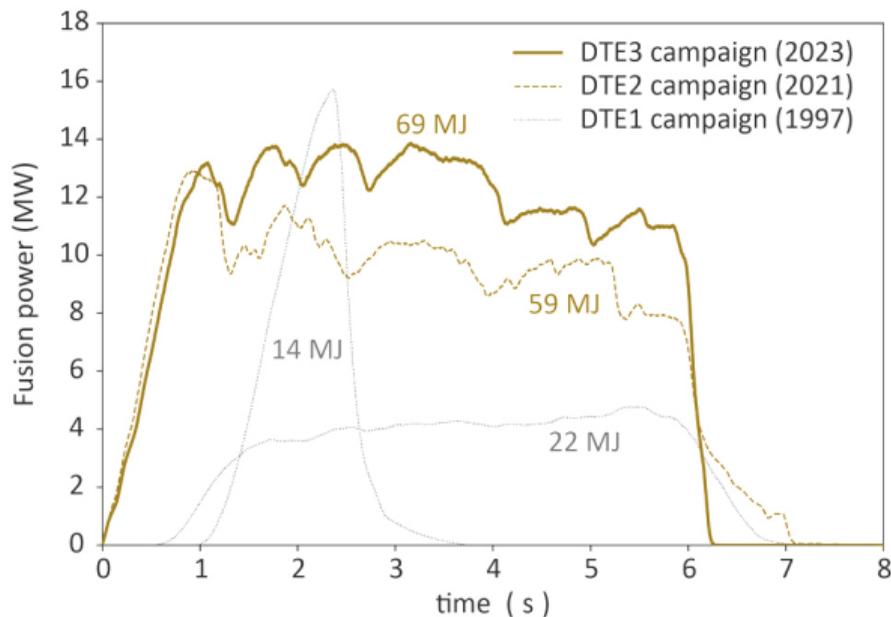
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Fusion power from neutron rate

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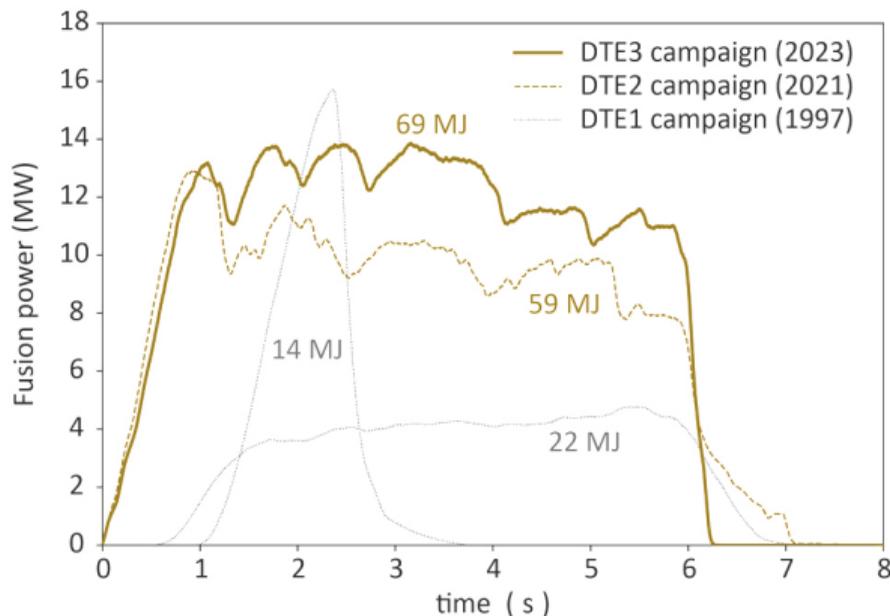
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Fusion power from neutron rate
7-10% accuracy, $\Delta t = 10$ ms

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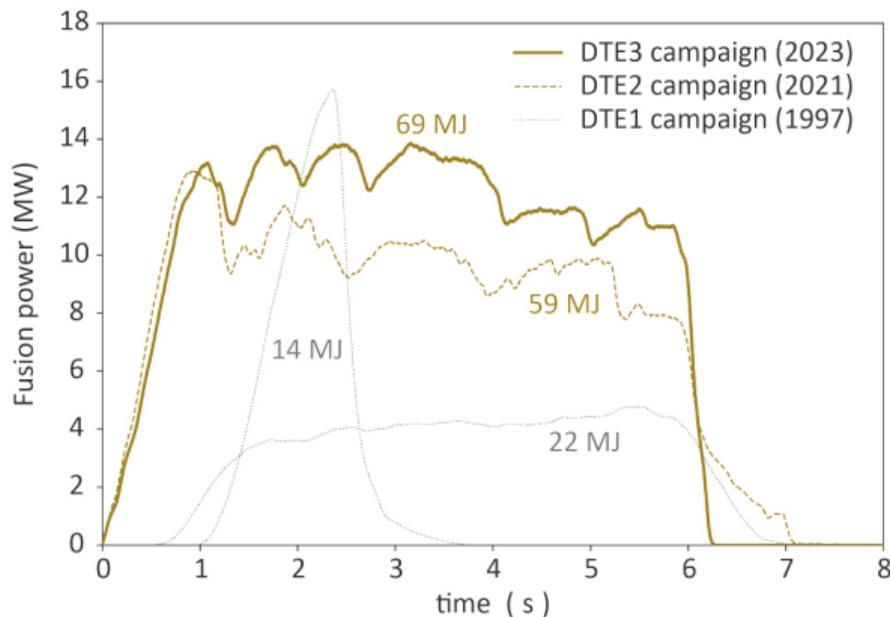


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Unique method available
for DT plasmas

Fusion power measurements at JET

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Fusion power from neutron rate
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Unique method available
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Similar approach
also adopted at ITER

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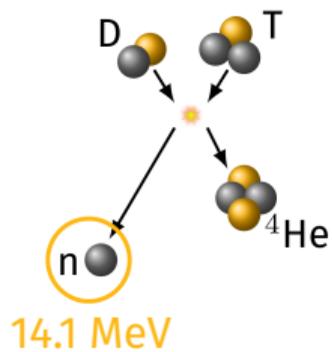
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 - Reduce fusion power uncertainties
 - Operate closer to legal limit: higher efficiency

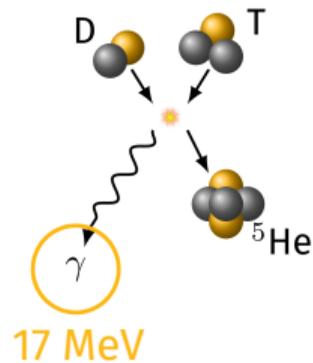
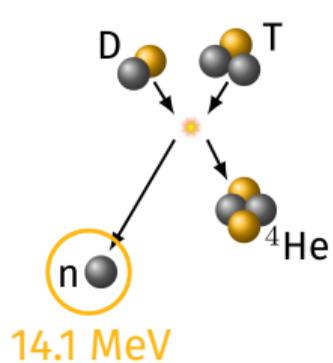


We also have fusion gammas!

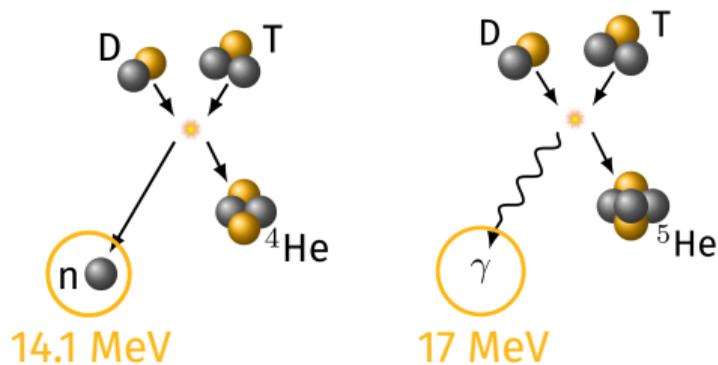
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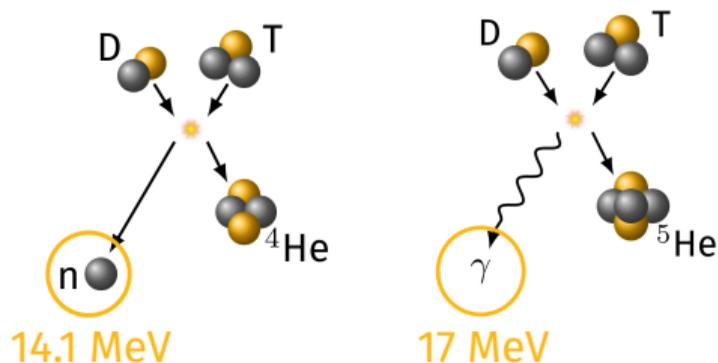


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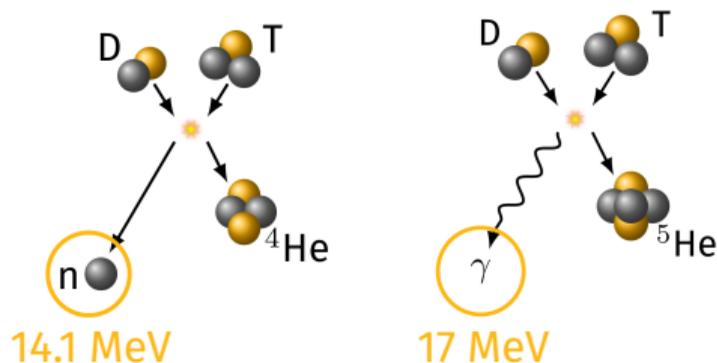
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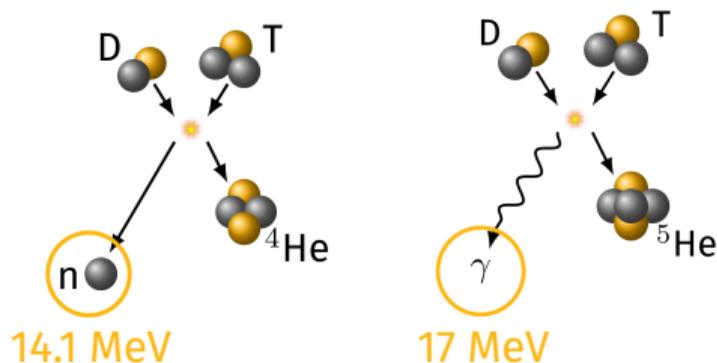
- One 14 MeV n for each DT fusion reaction
 - Standard neutron-based method

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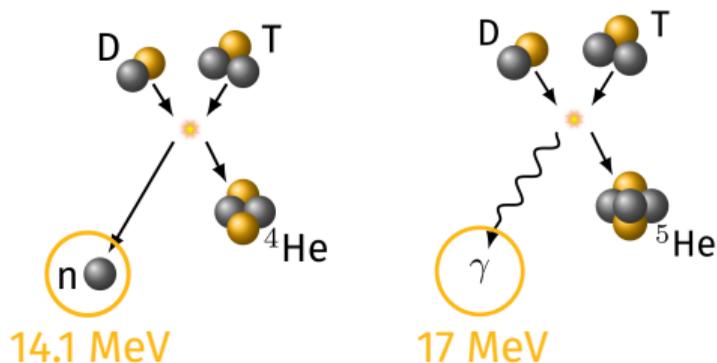
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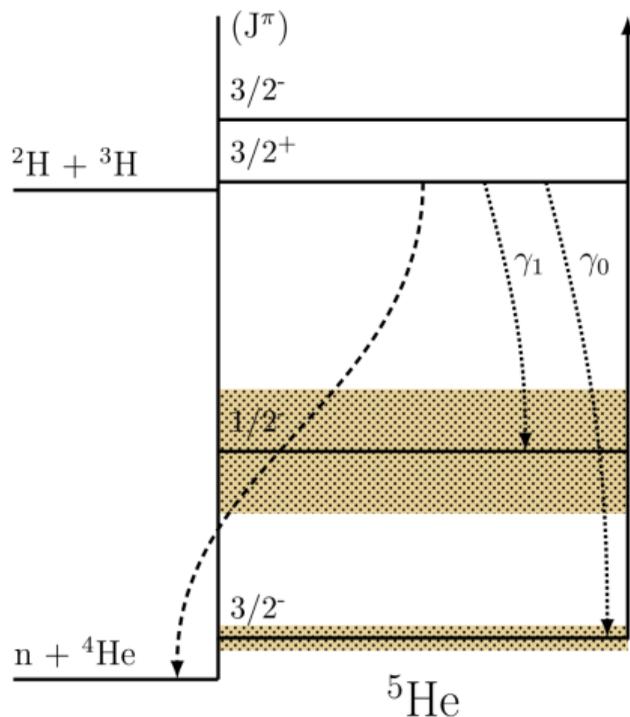


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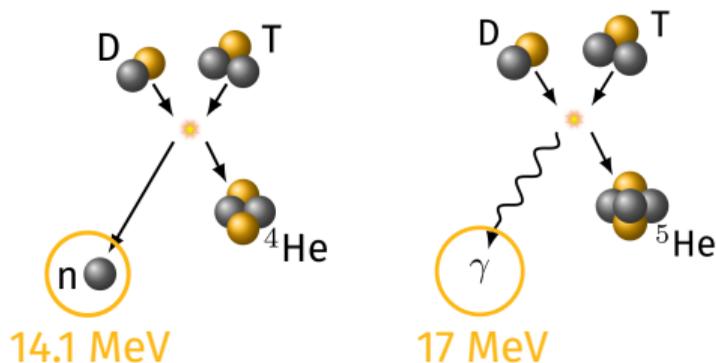
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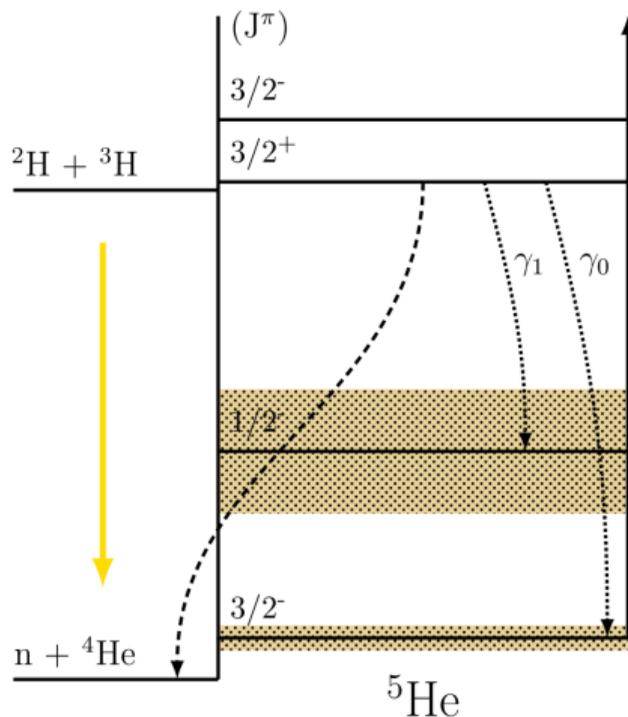
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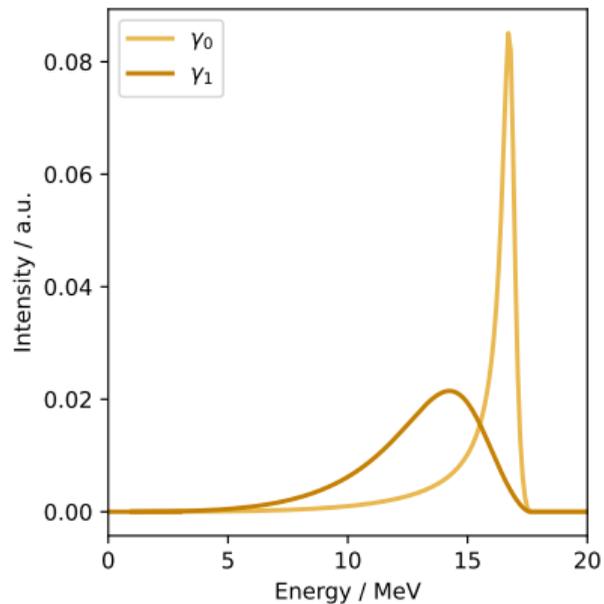
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DT fusion gamma-rays

DT fusion gamma-rays

DT gamma-rays spectrum

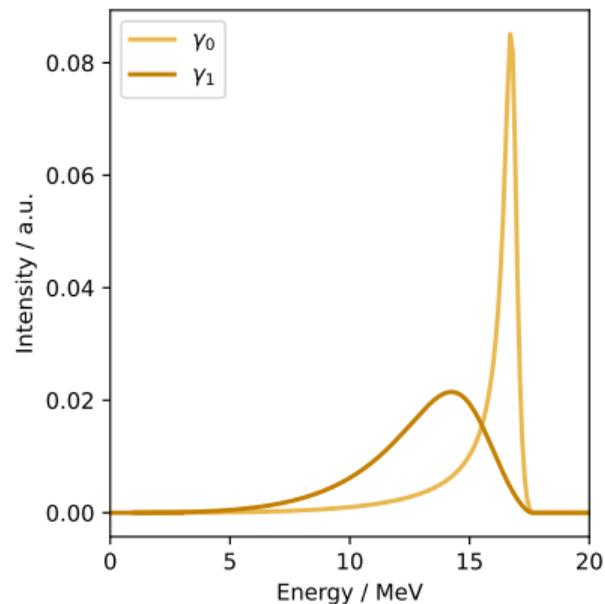


(from R-matrix theory)

DT fusion gamma-rays

DT gamma-rays spectrum

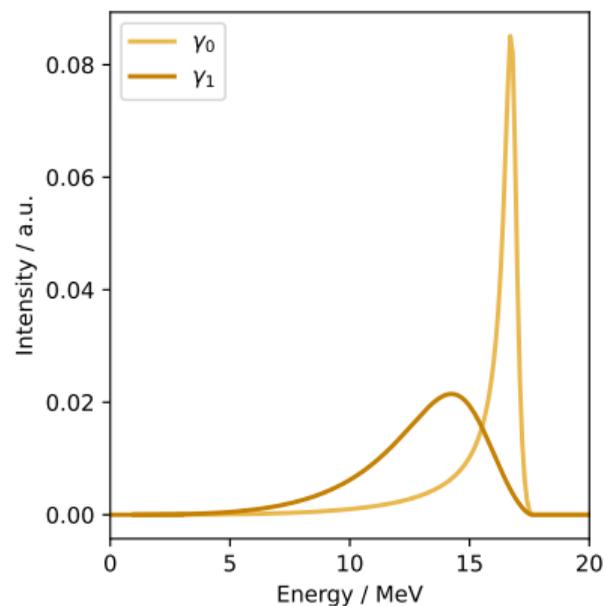
● No complete spectral infos before JET DTE2



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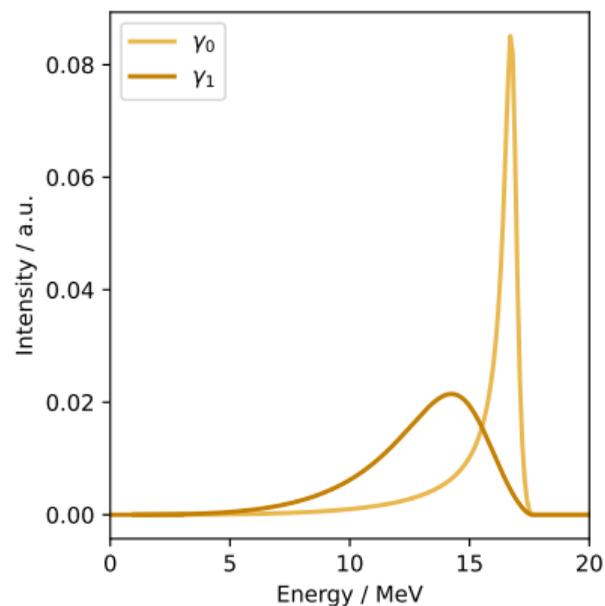


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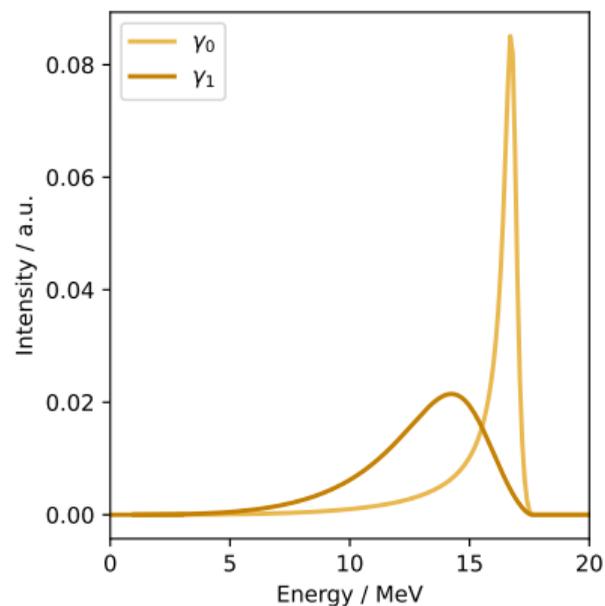


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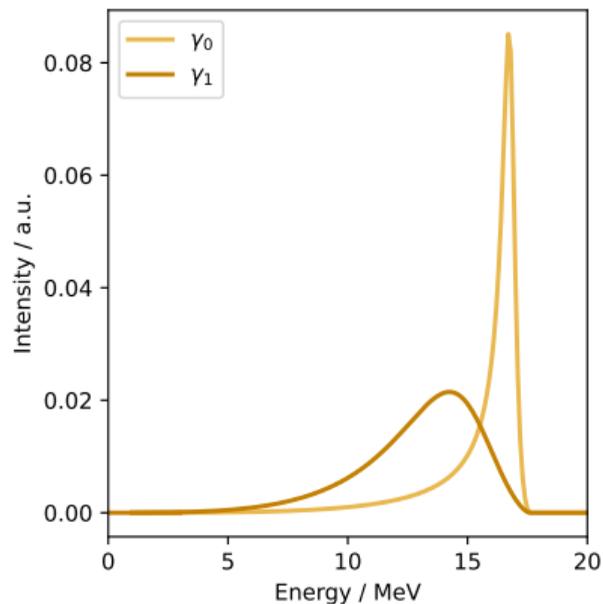
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Unusable for now...

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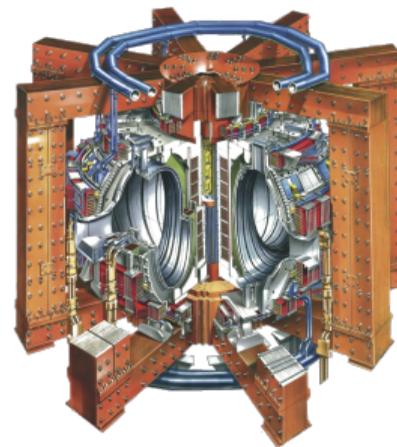


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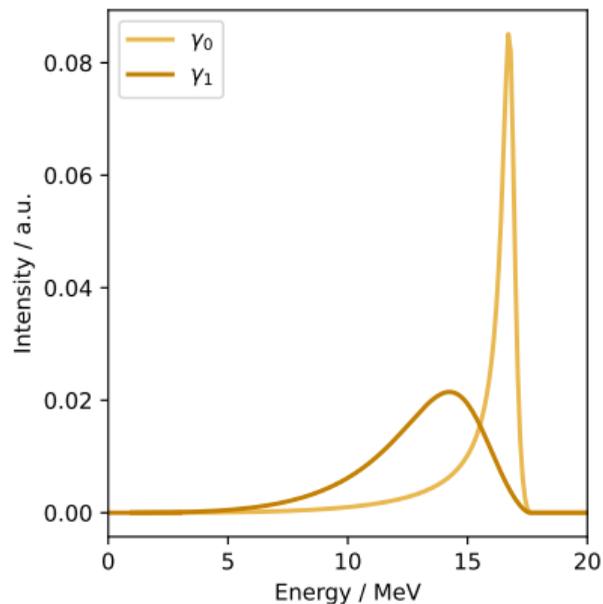
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Measured at JET
during DTE2
with
Tangential Gamma-Ray
Spectrometer



DT fusion gamma-rays

DT gamma-rays spectrum

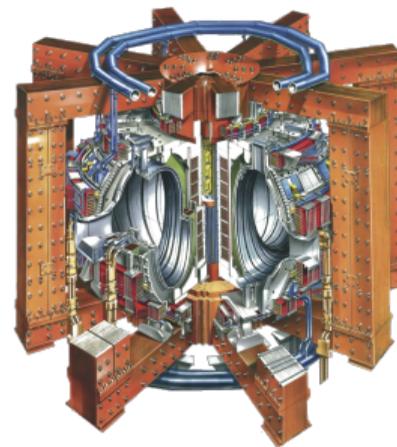


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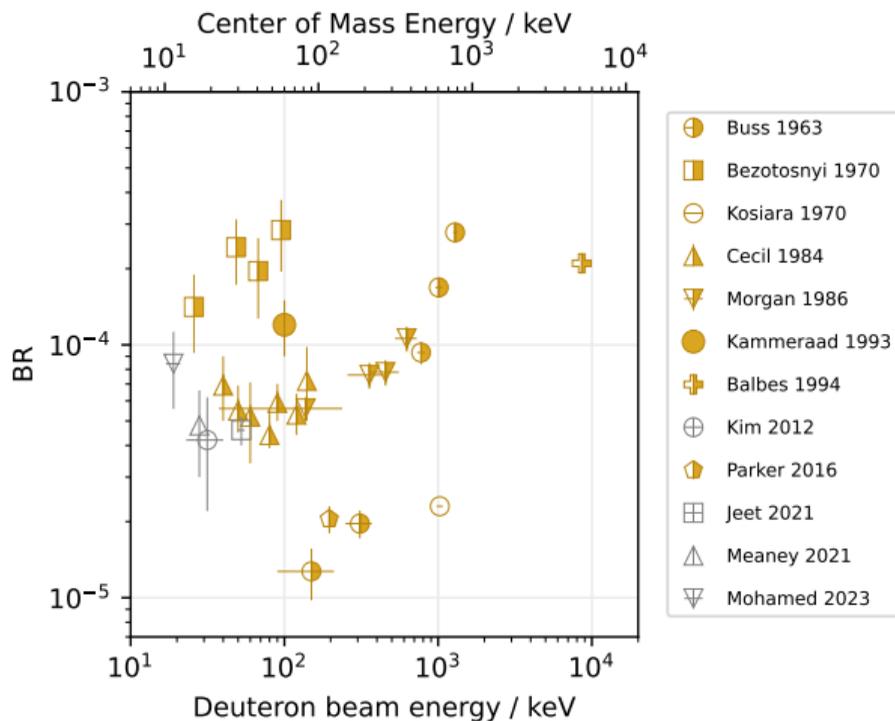
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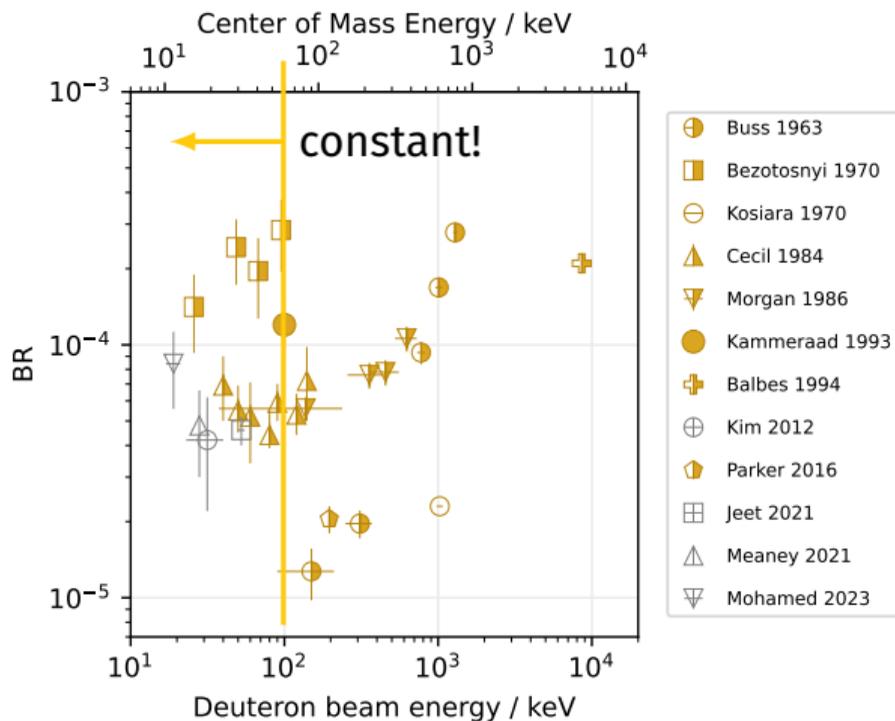
Measured at JET
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Tangential Gamma-Ray
Spectrometer



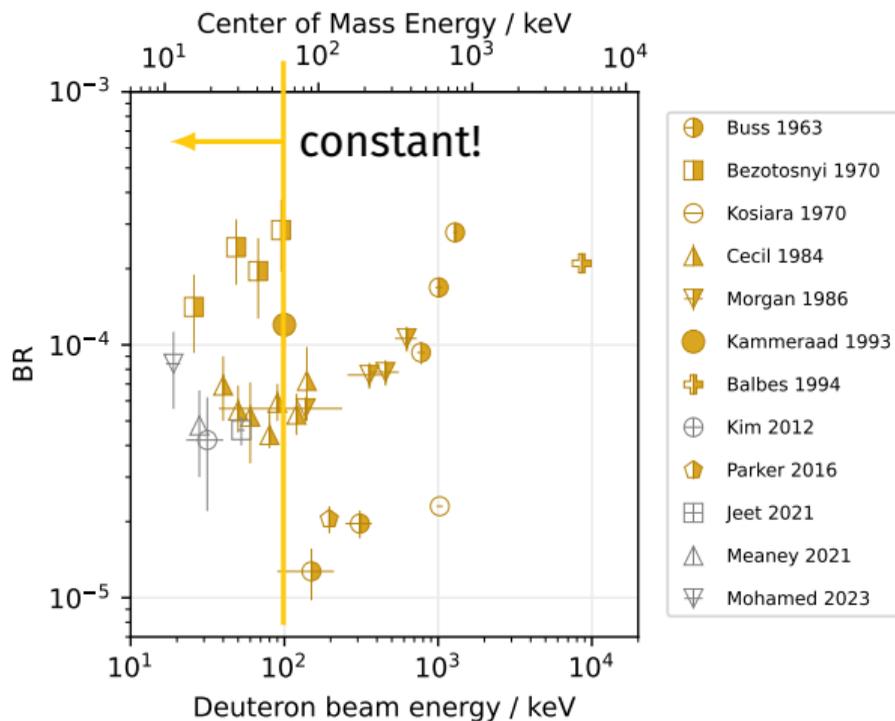
DT gamma-rays: the branching ratio



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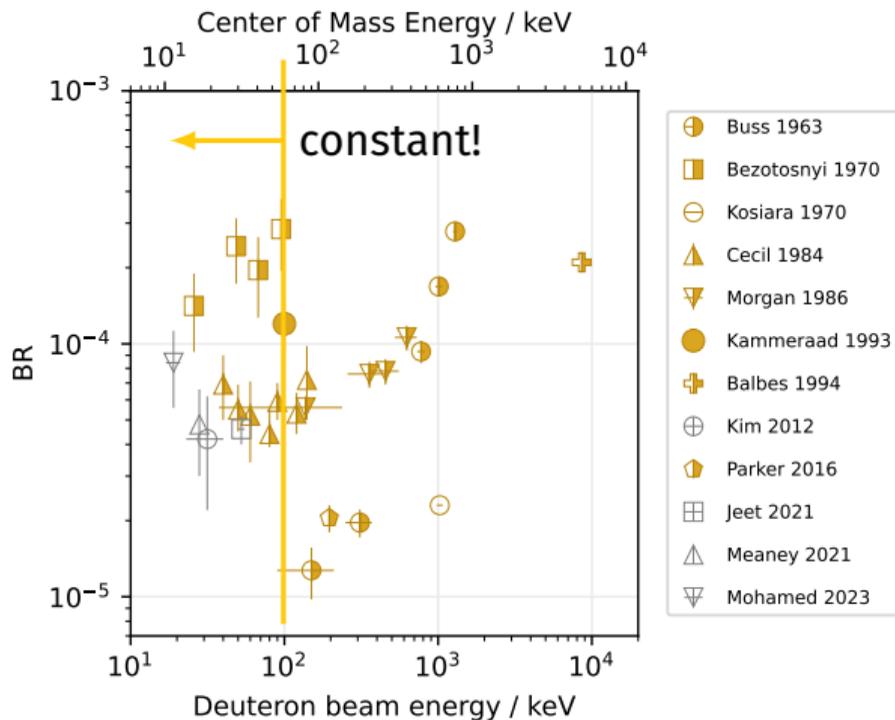


DT gamma-rays: the branching ratio



Unique opportunity:
JET equipped with
absolute neutron monitors

DT gamma-rays: the branching ratio



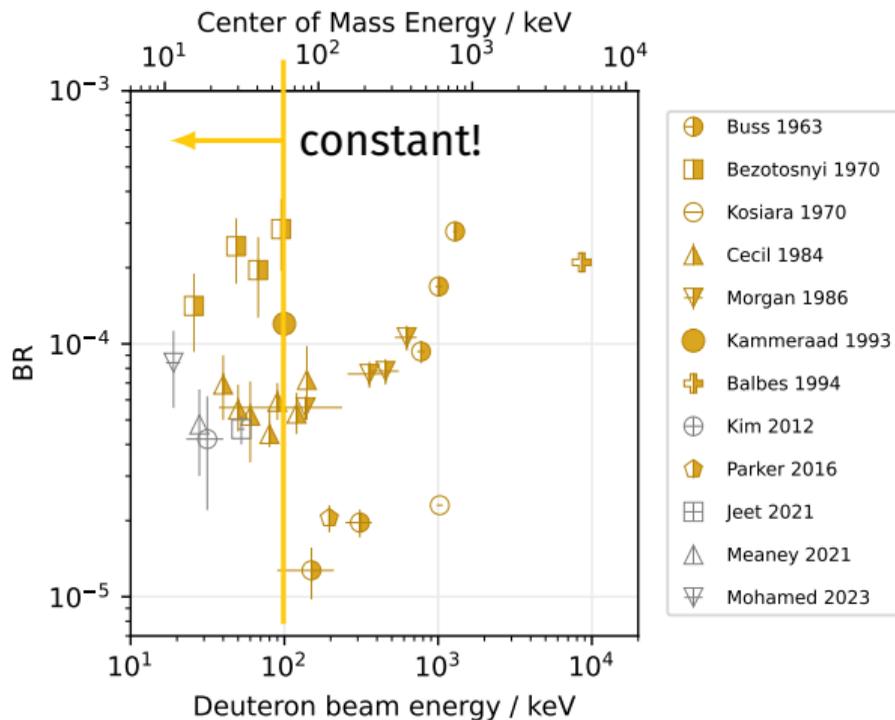
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$$BR_{\gamma} = \frac{R_{\gamma}}{R_{\gamma} + R_n}$$

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novel method

JET

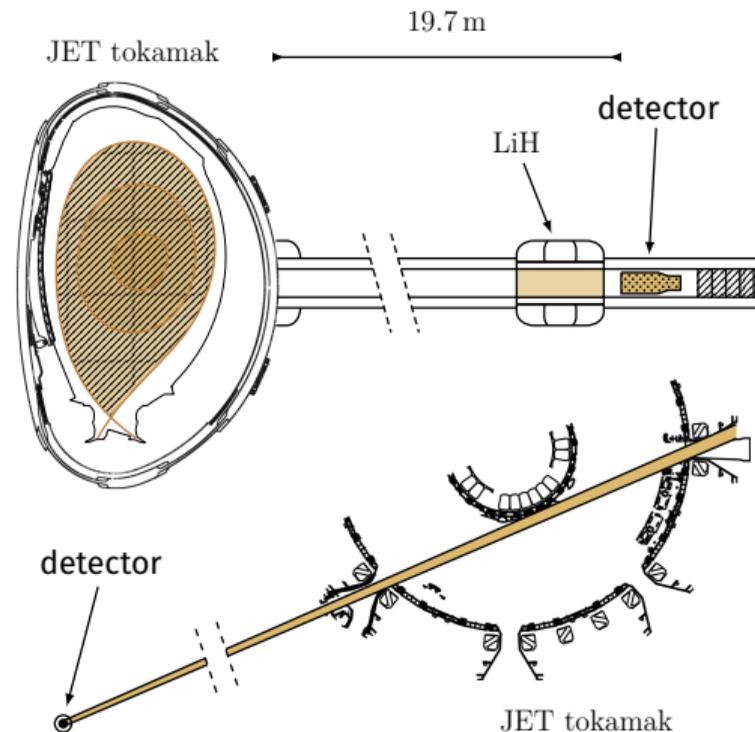
Fusion gamma-rays measurement at JET

- Tangential gamma-ray spectrometer

Fusion gamma-rays measurement at JET

■ Tangential gamma-ray spectrometer

- equatorial LoS
- **tangent** to central column
- 20m from the plasma



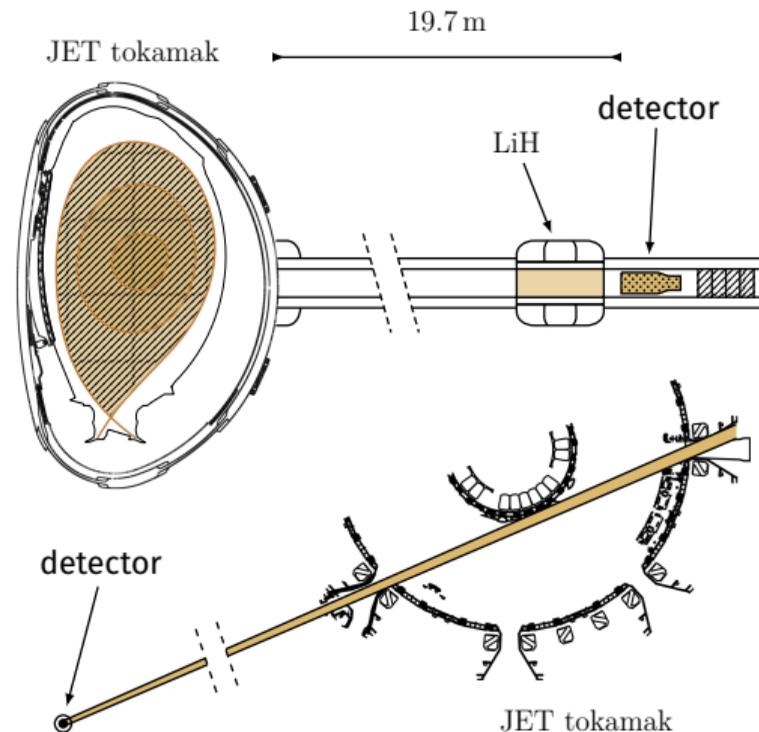
RSI - 2021 - M. Nocente et al.
Jinst - 2021 - G. Marcer et al.

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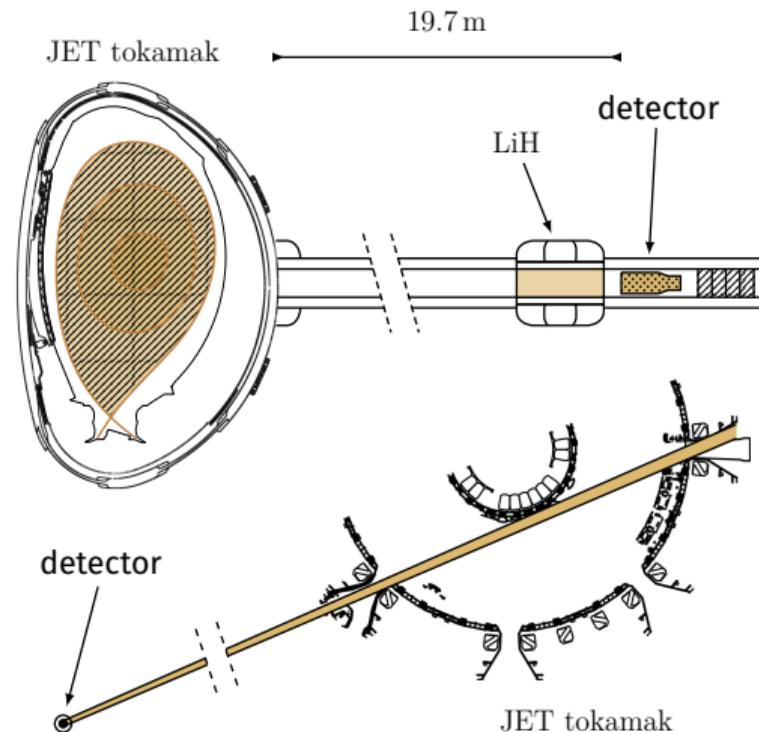
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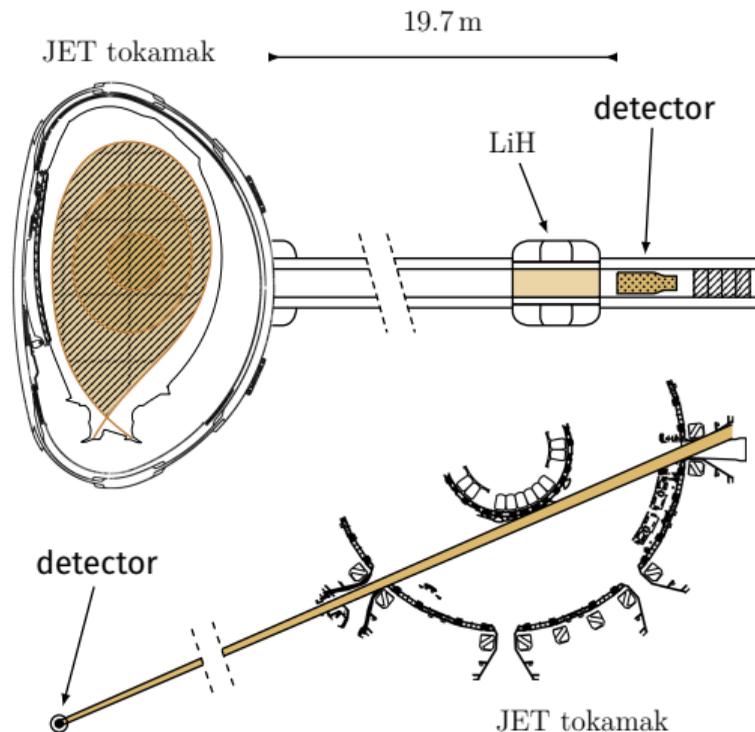
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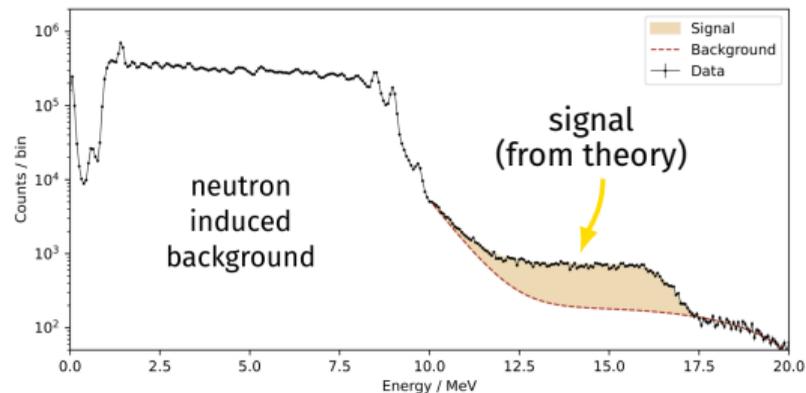
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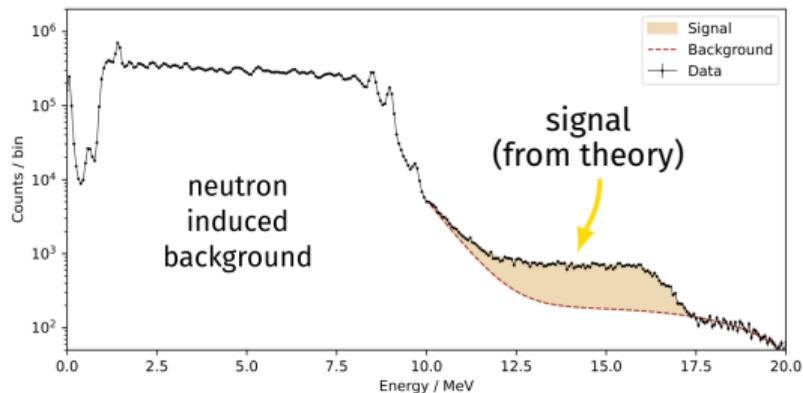
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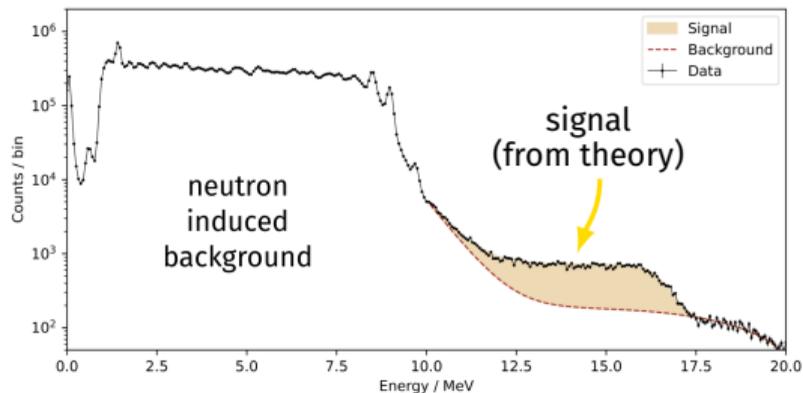
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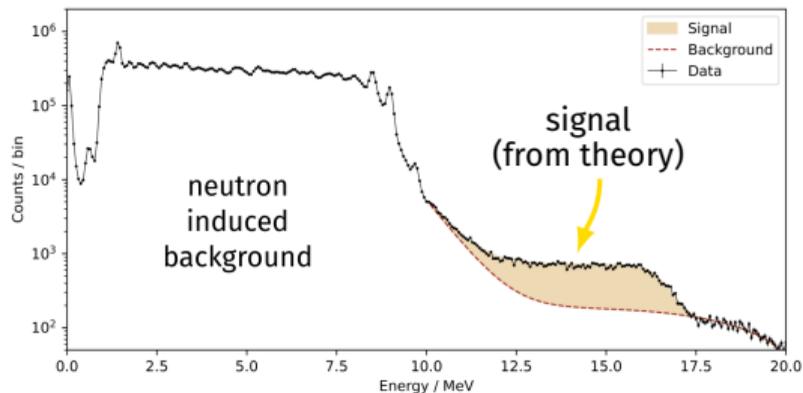
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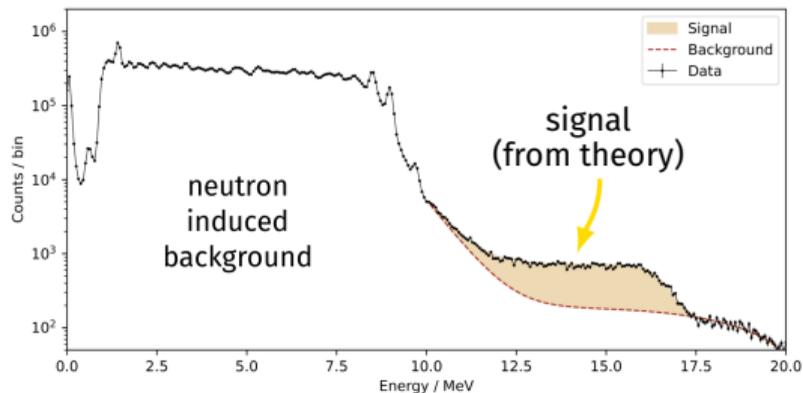


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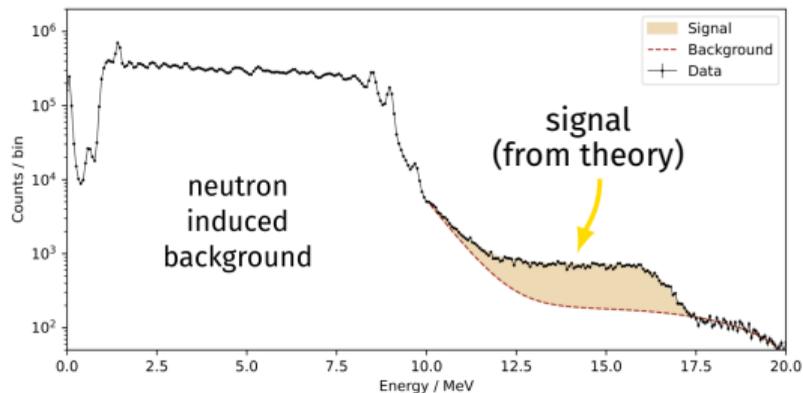
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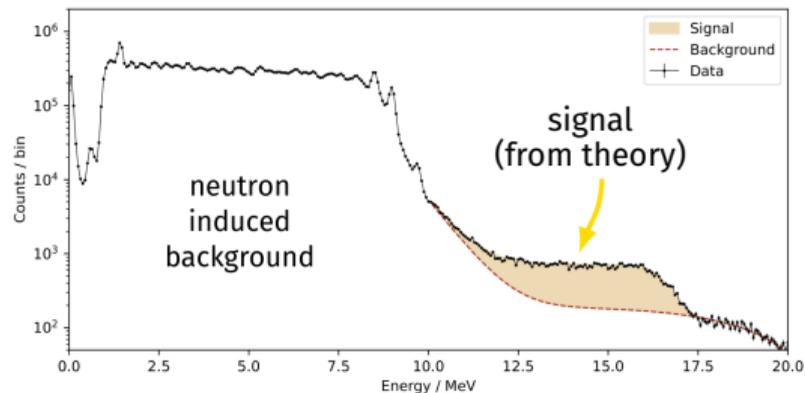
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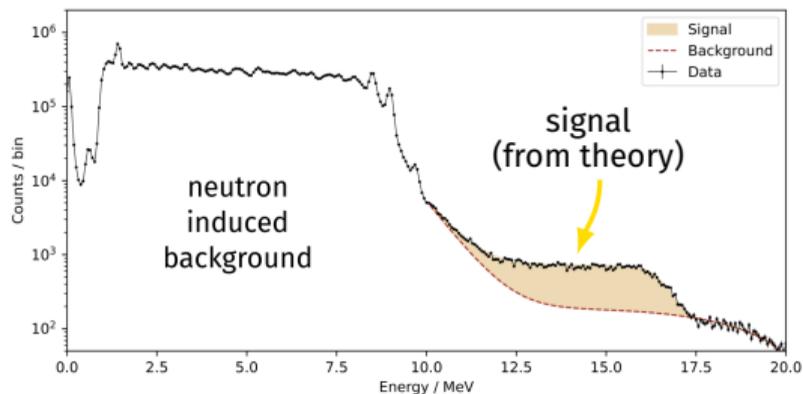
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spectroscopic capabilities!

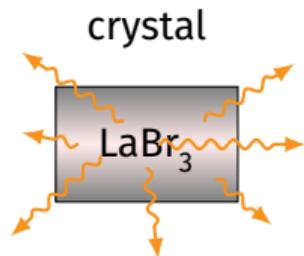


Developed solutions

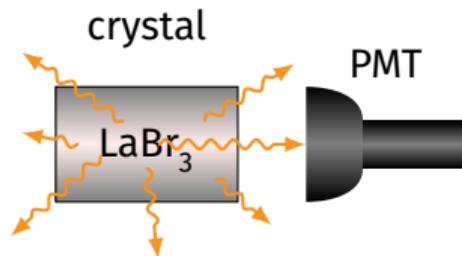
crystal



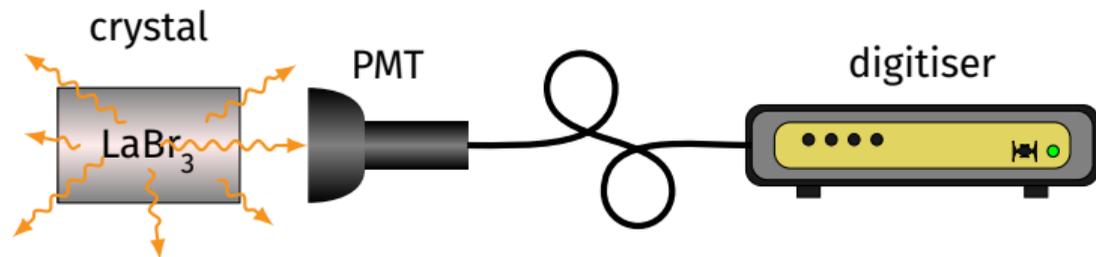
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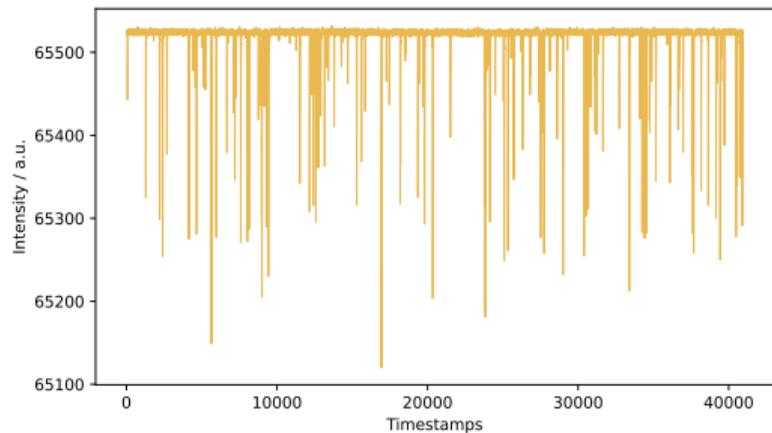
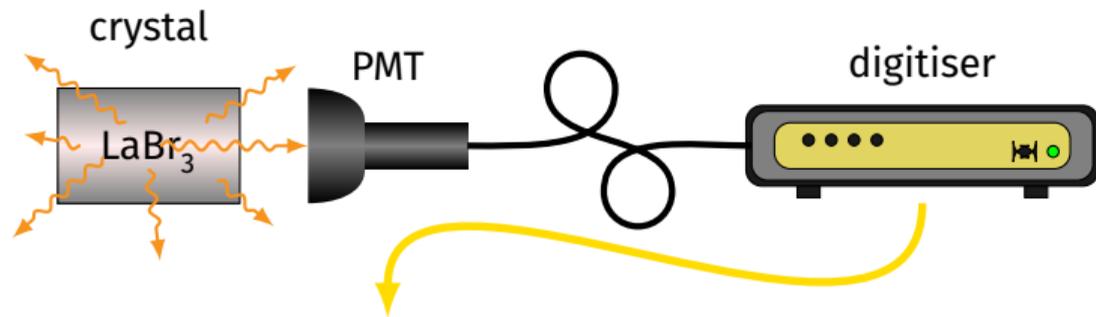
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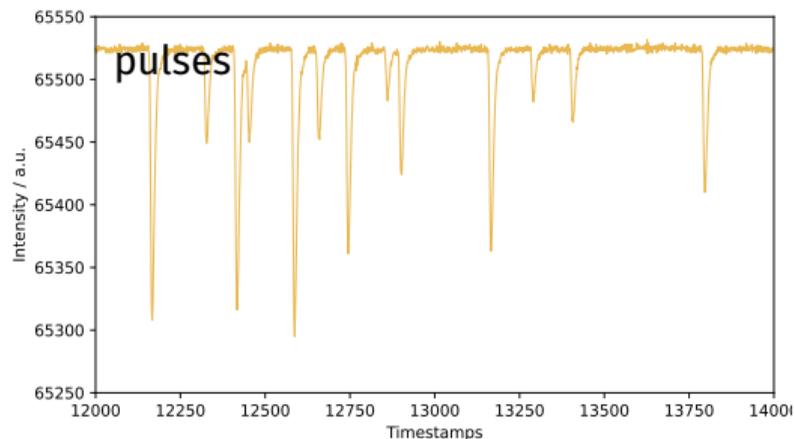
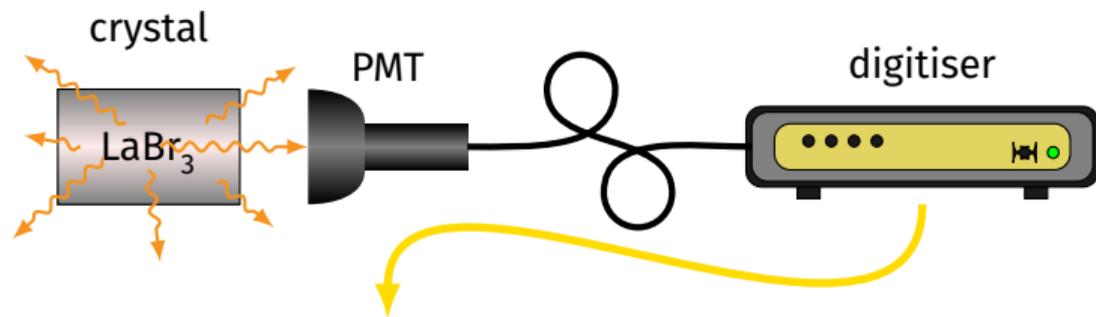
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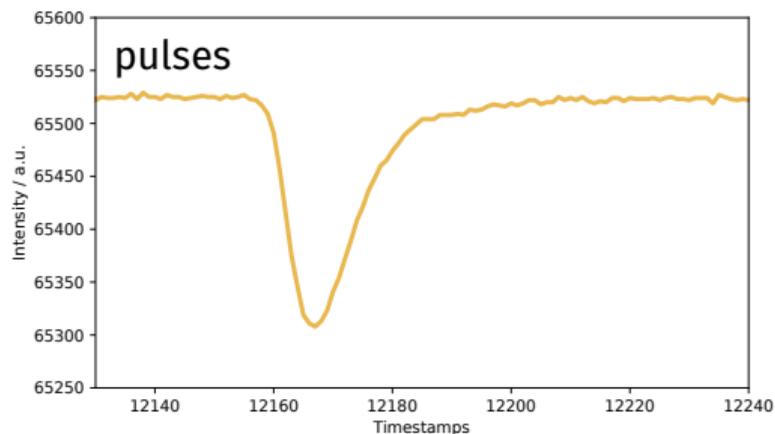
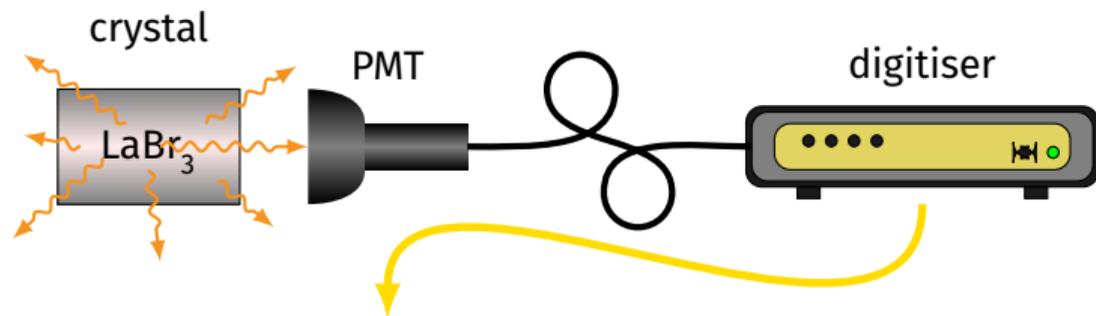
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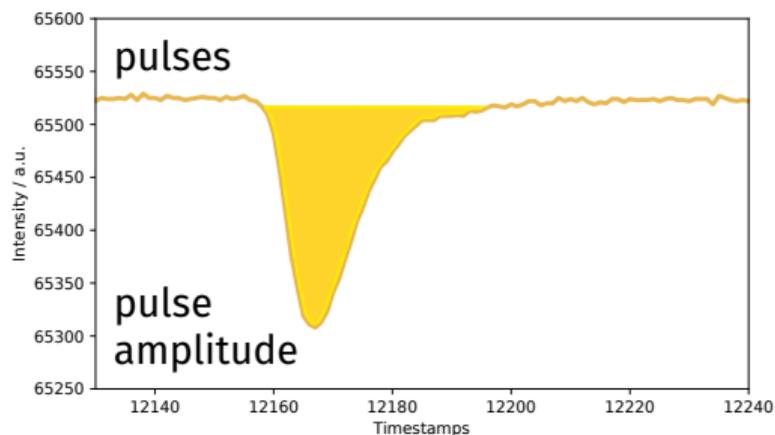
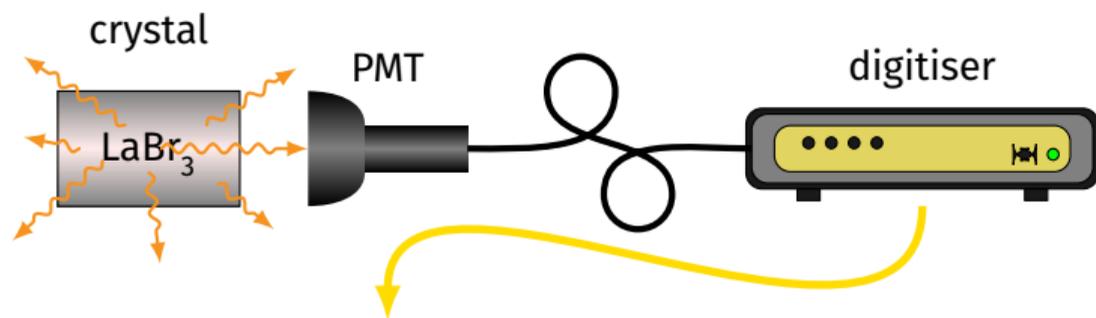
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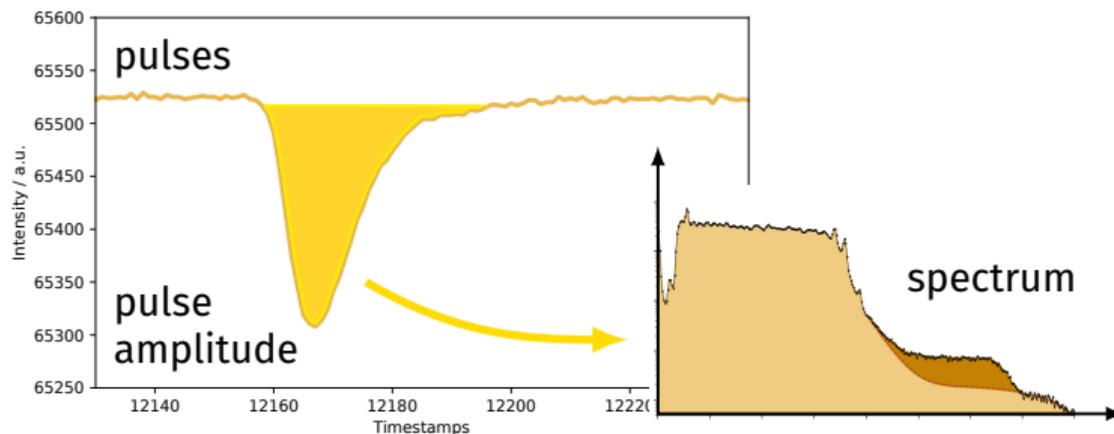
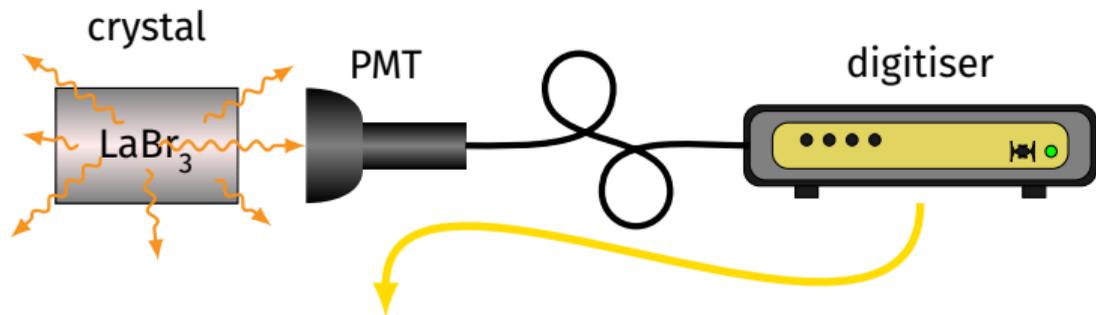
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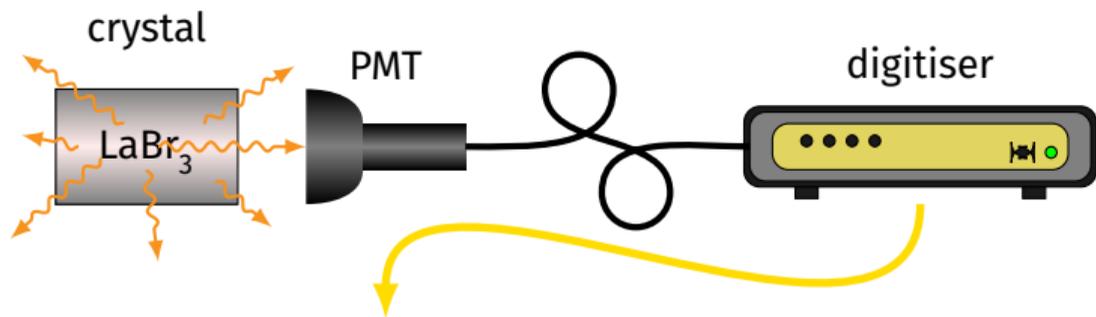
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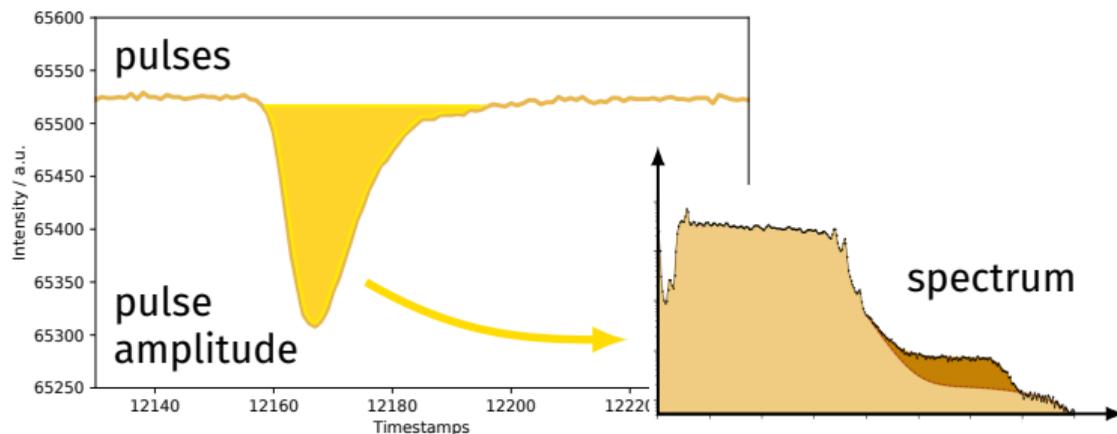
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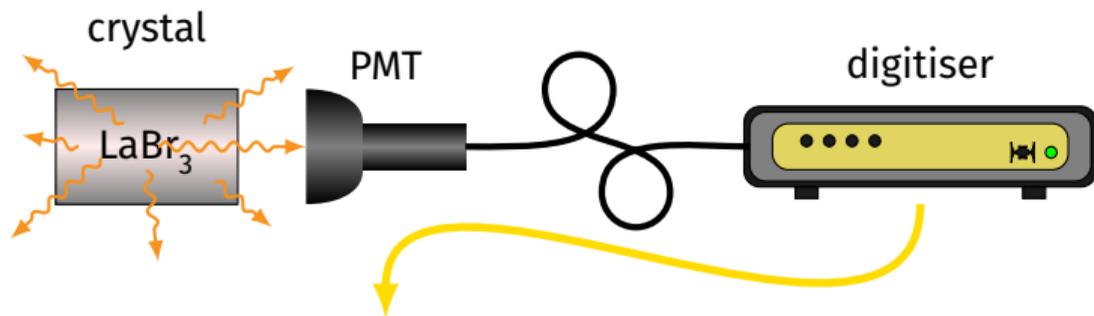
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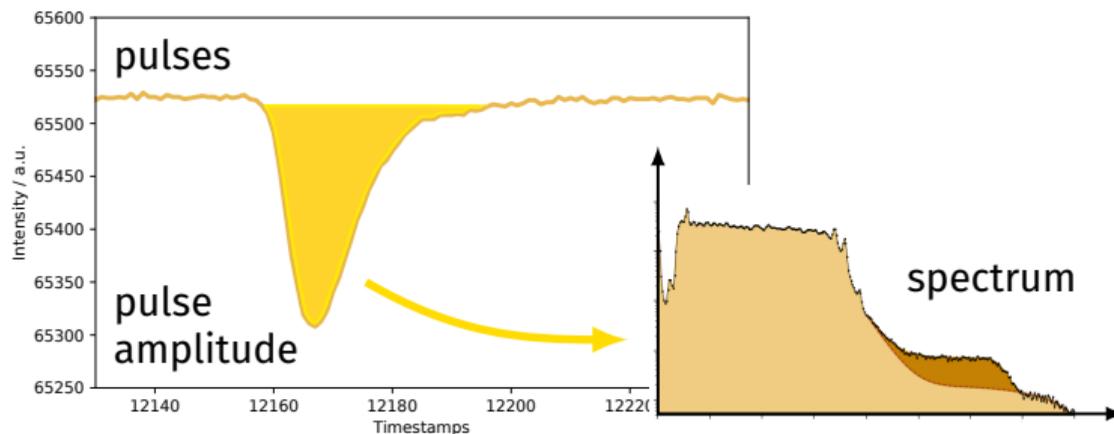
crystal + PMT



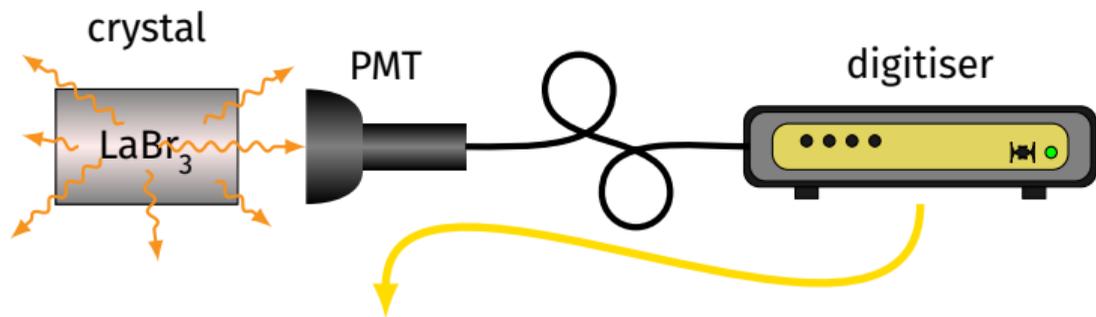
Developed solutions



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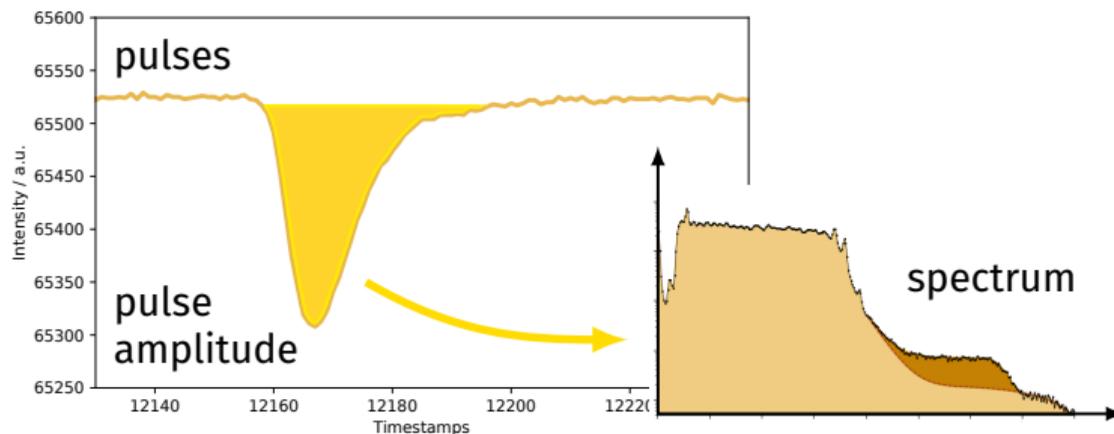
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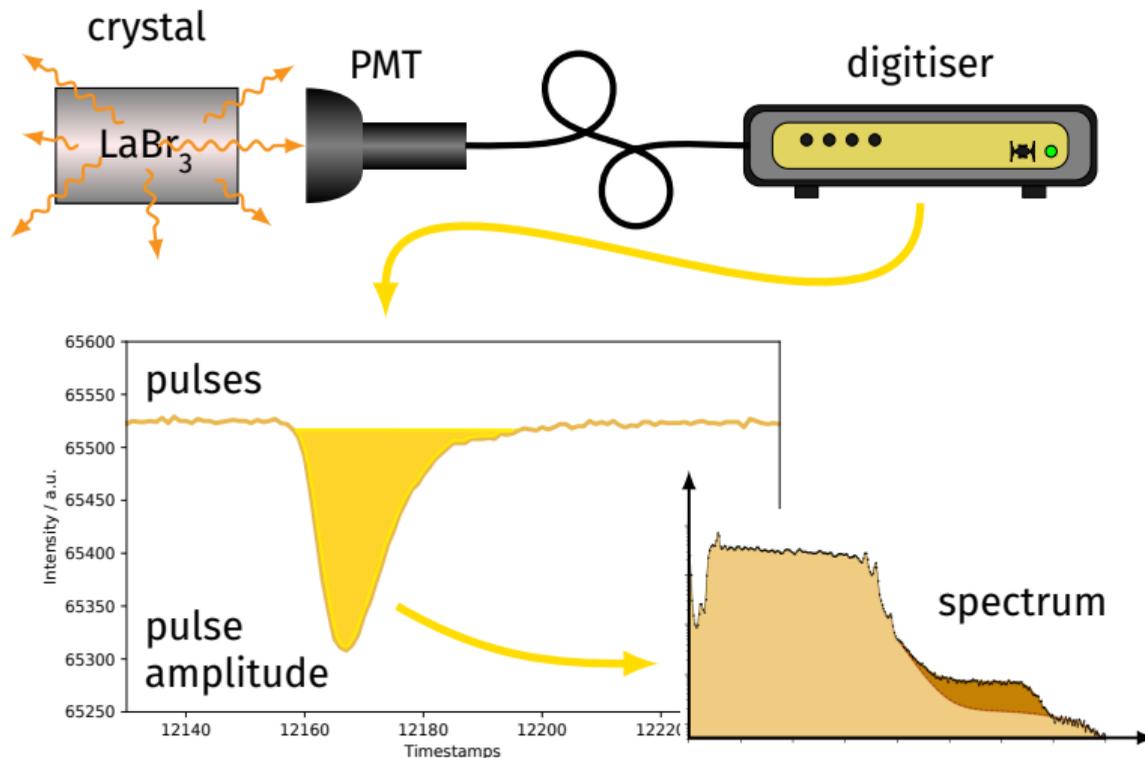
crystal + PMT
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dead-time
pile-up
PMT stability



Developed solutions

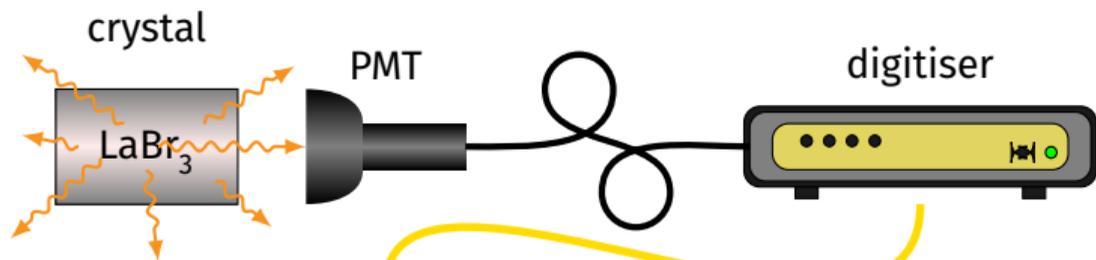


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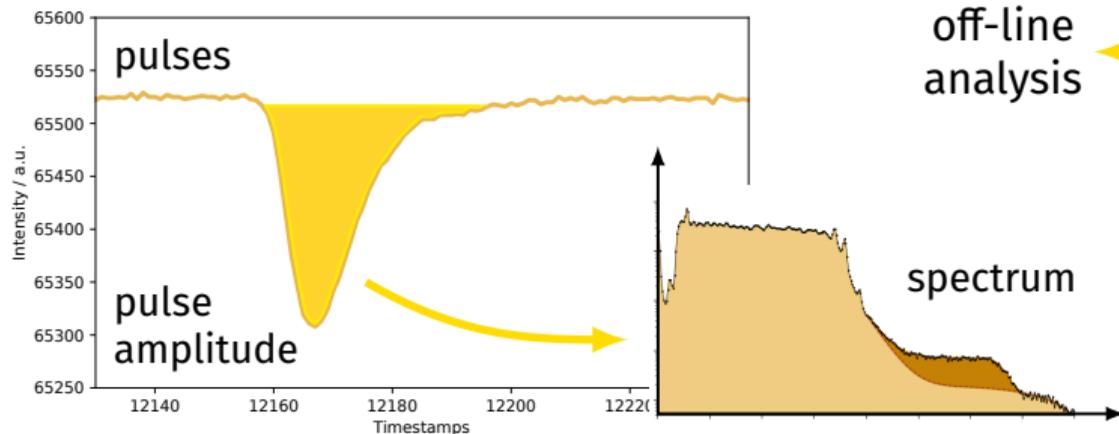
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From counts to absolute measurement

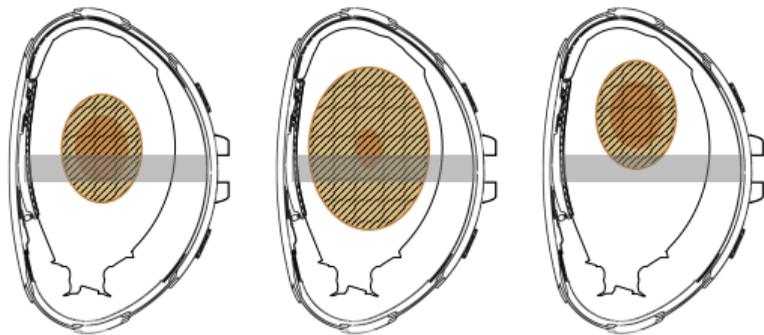
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From counts to absolute measurement

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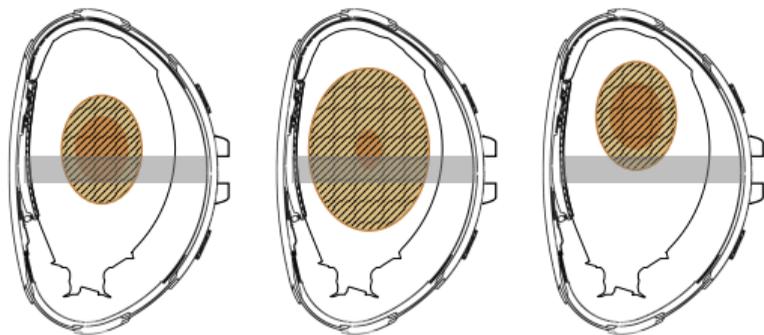
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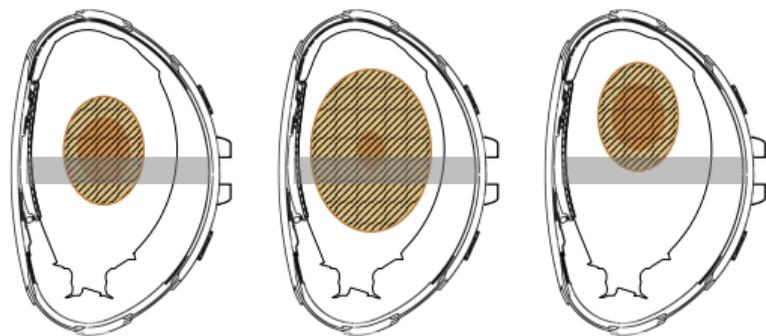
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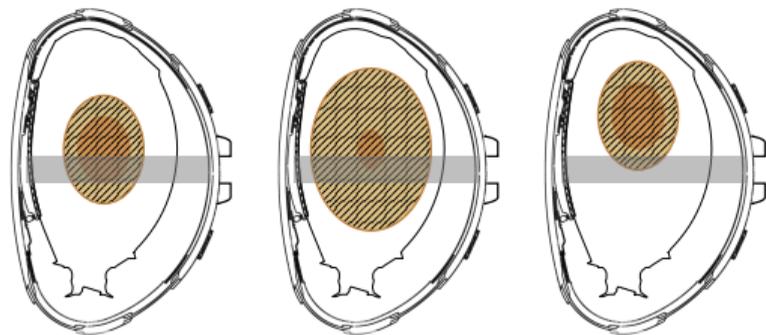
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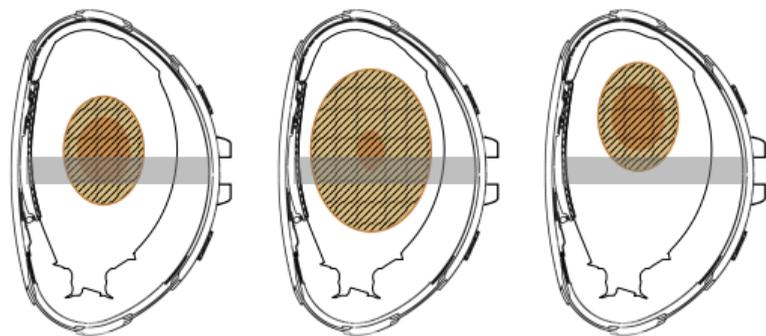


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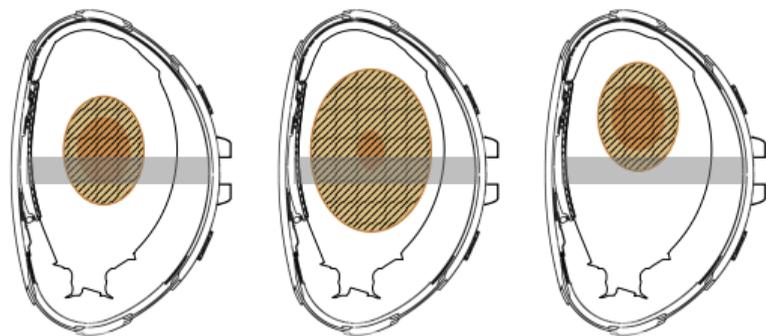
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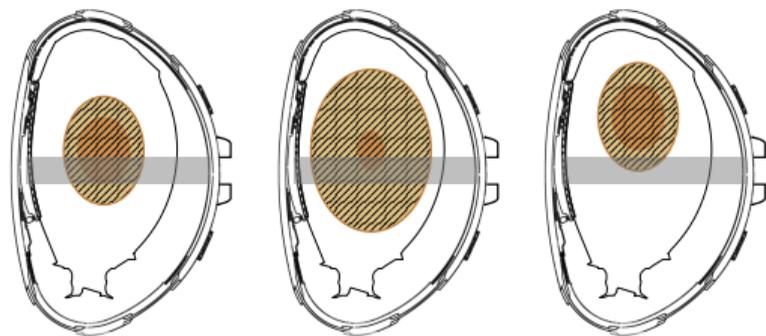


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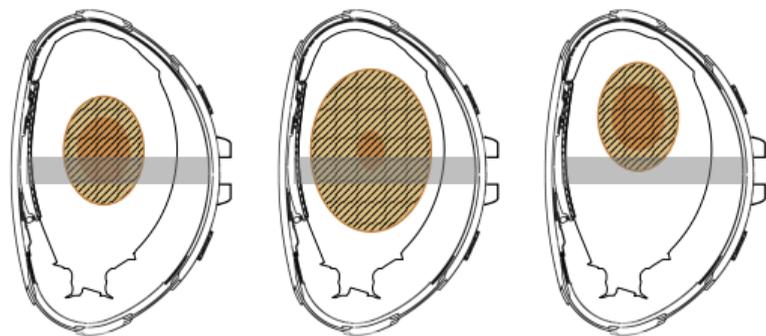
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- Infos from JET Neutron Camera

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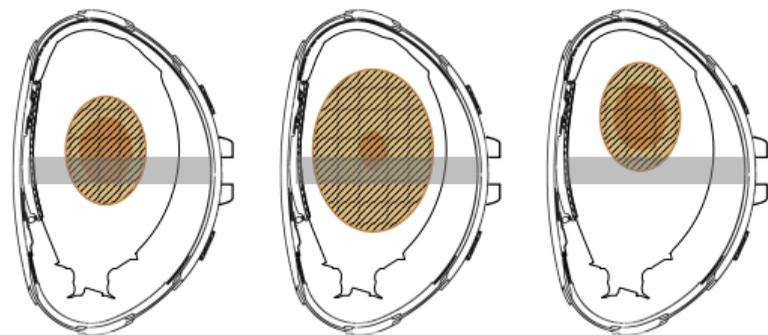


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Jinst - 2023 - G. Marcer et al.
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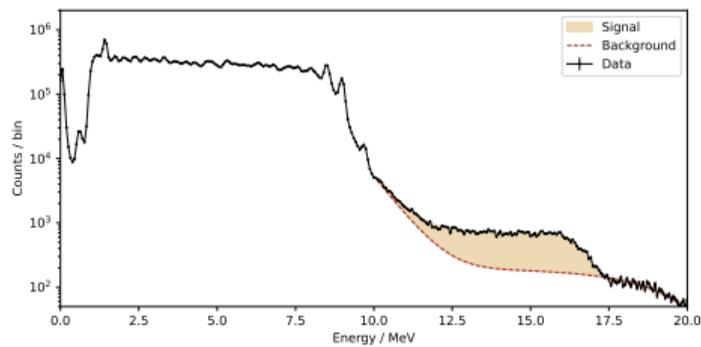


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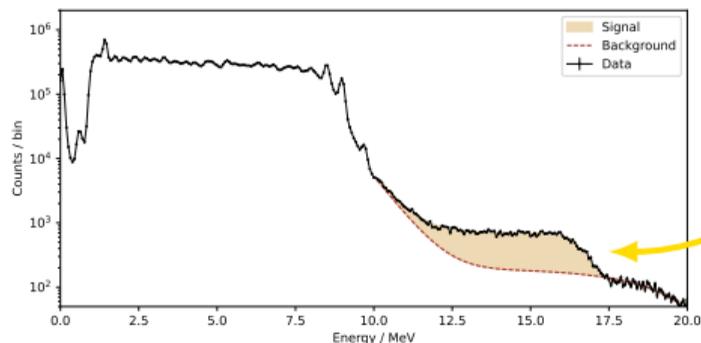
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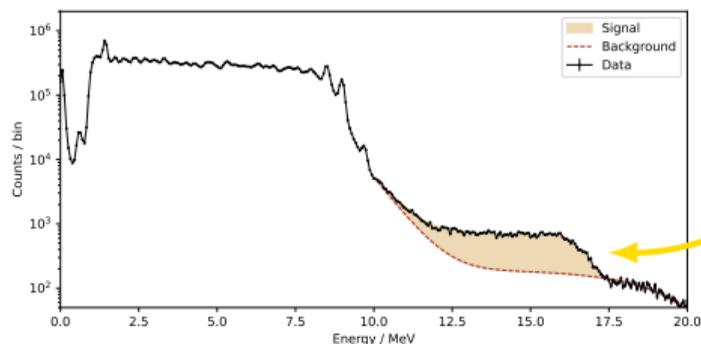
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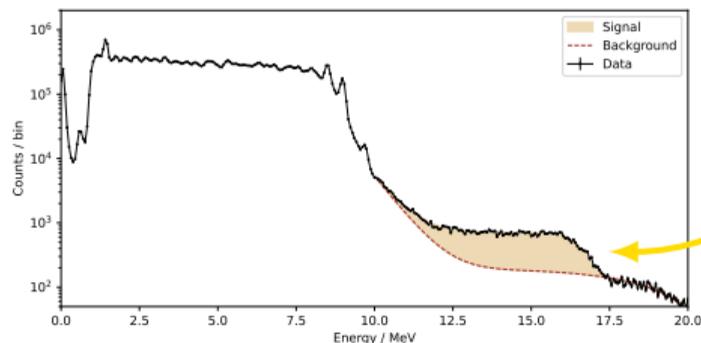
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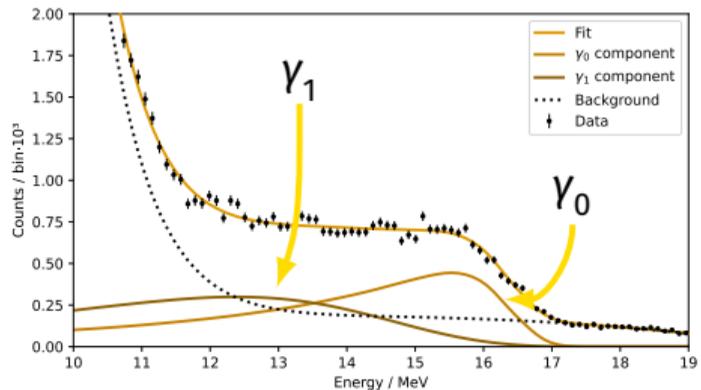
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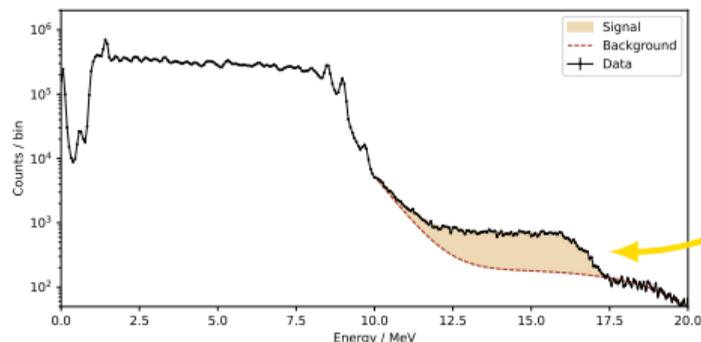


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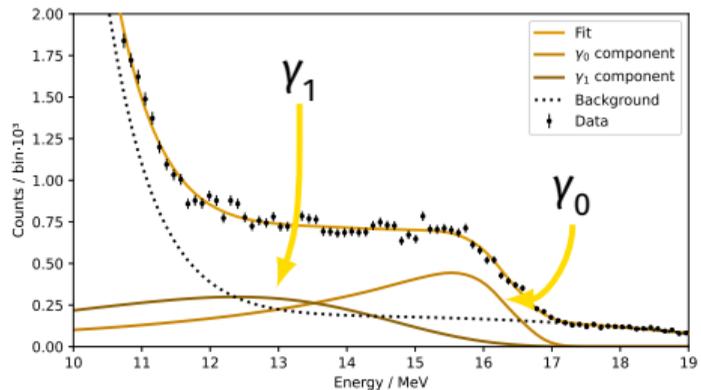


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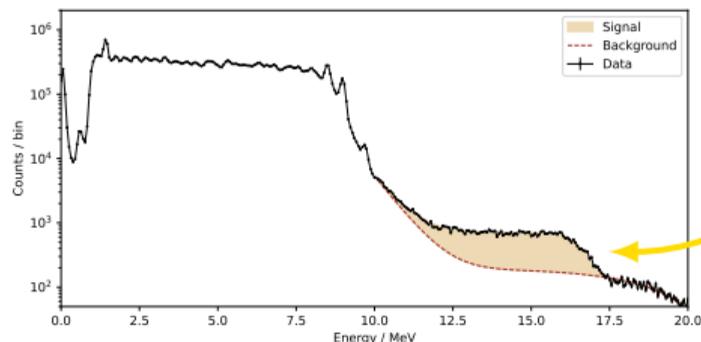


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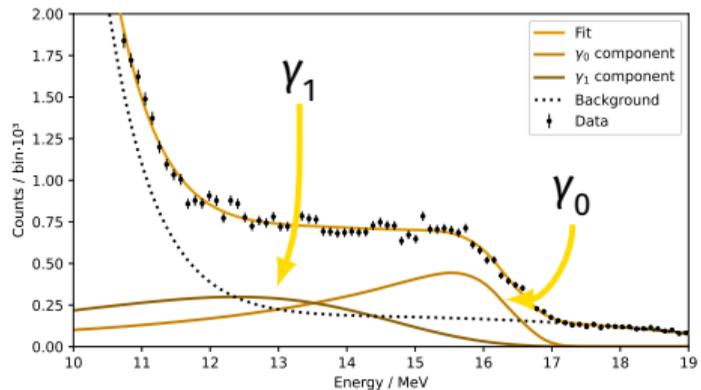
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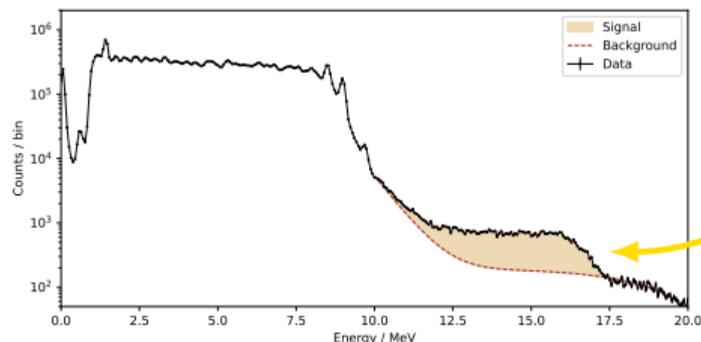
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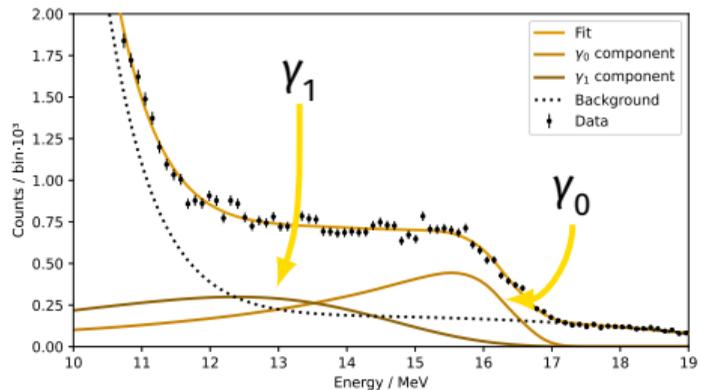


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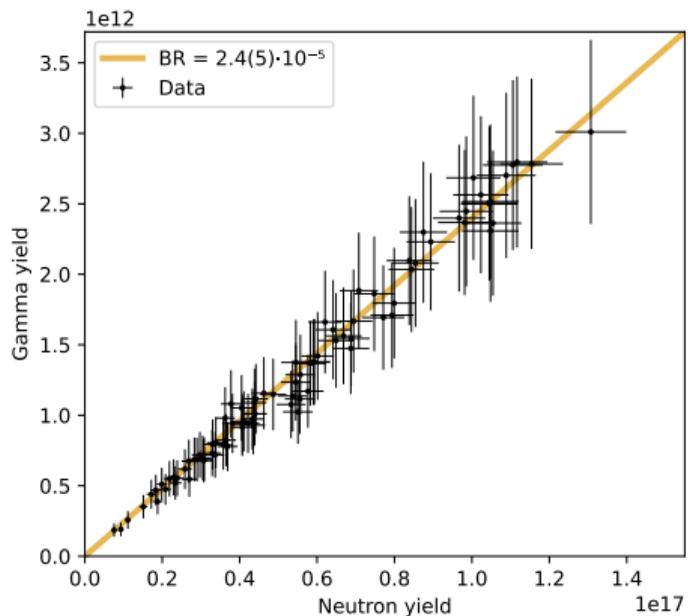
***first ever
spectroscopic measurement!***

M. Rebai et al, PRC, 2024, 10.1103/PhysRevC.110.014625

Results: branching ratio

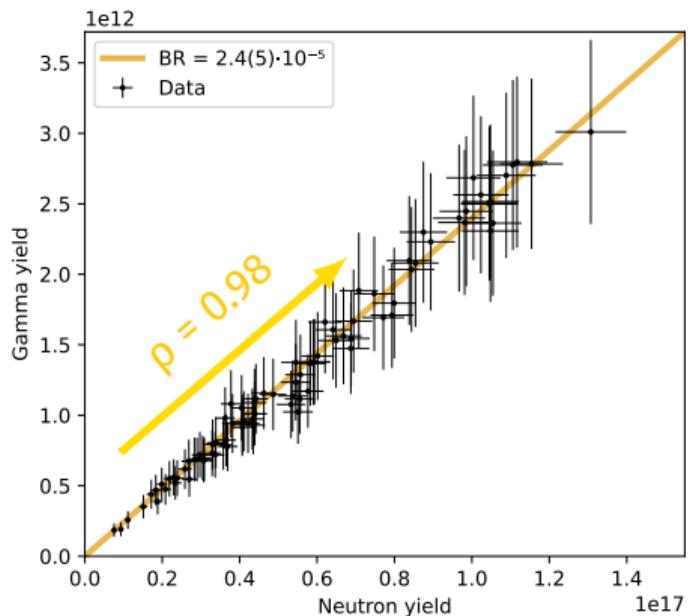
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Measured DT gamma yield vs JET DT neutron yield



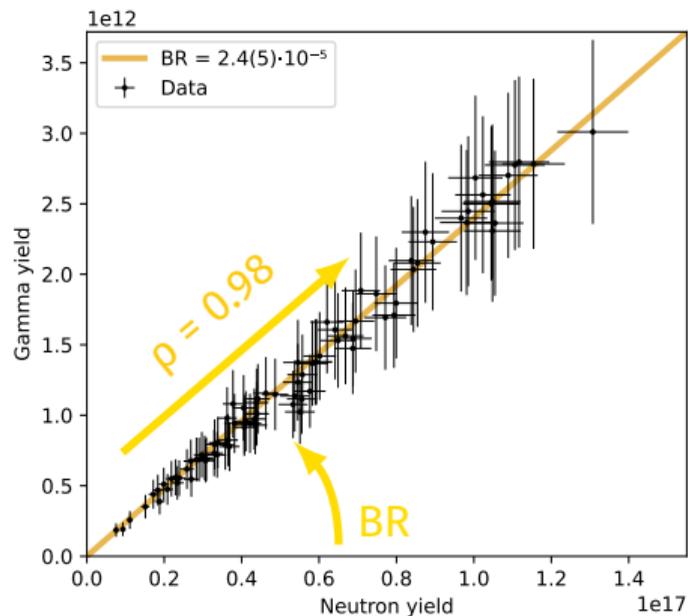
Results: branching ratio

Measured DT gamma yield vs JET DT neutron yield



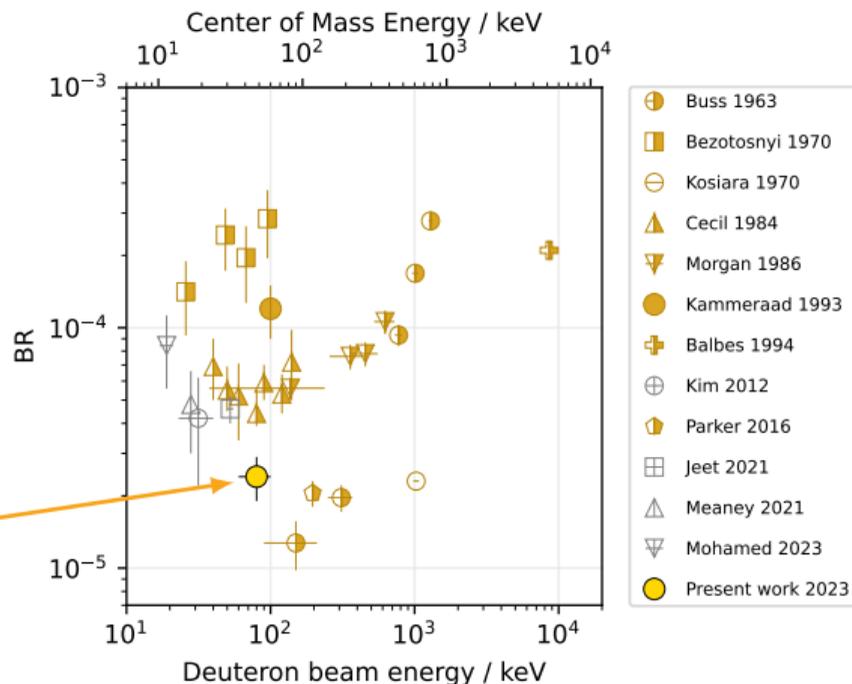
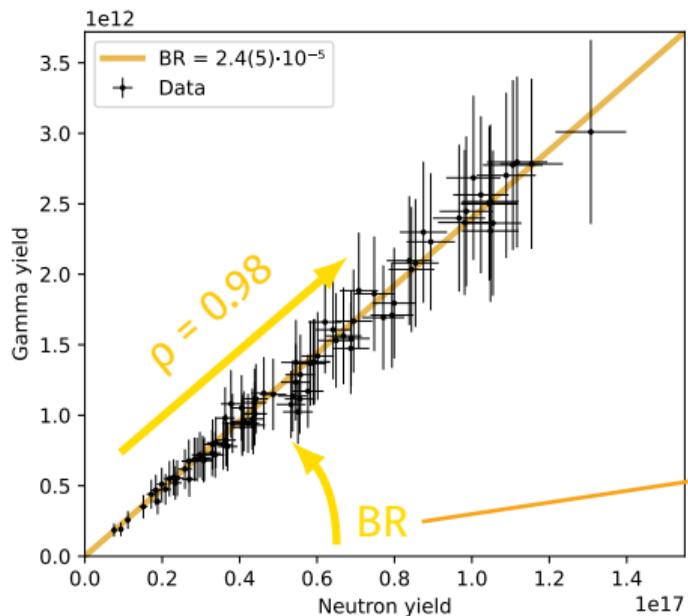
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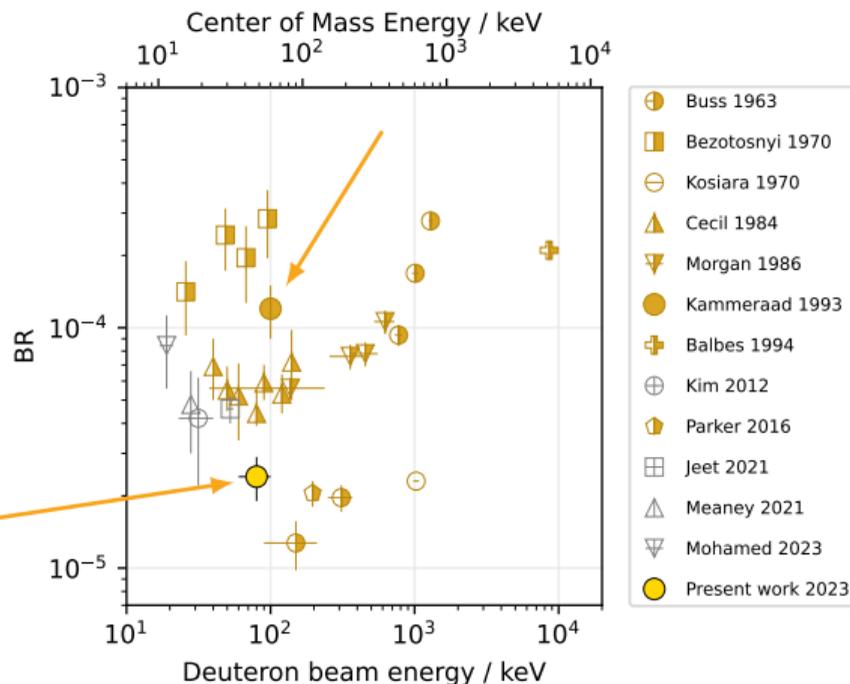
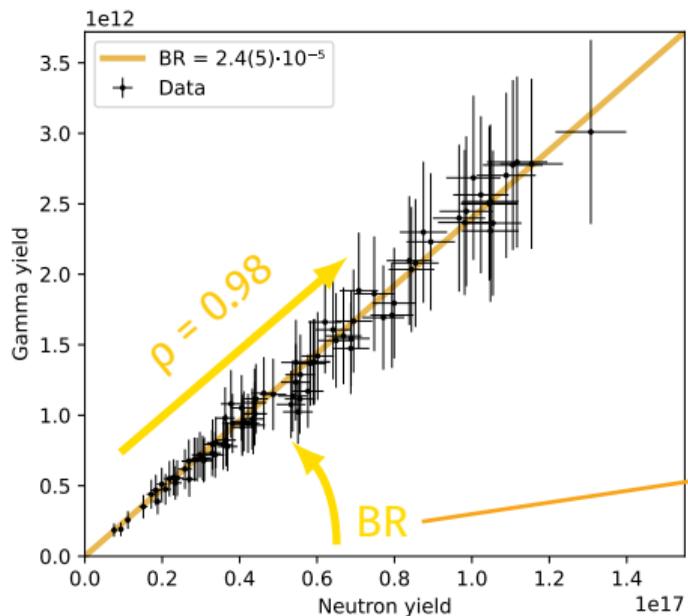
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A. Dal Molin et al, PRL, 2024

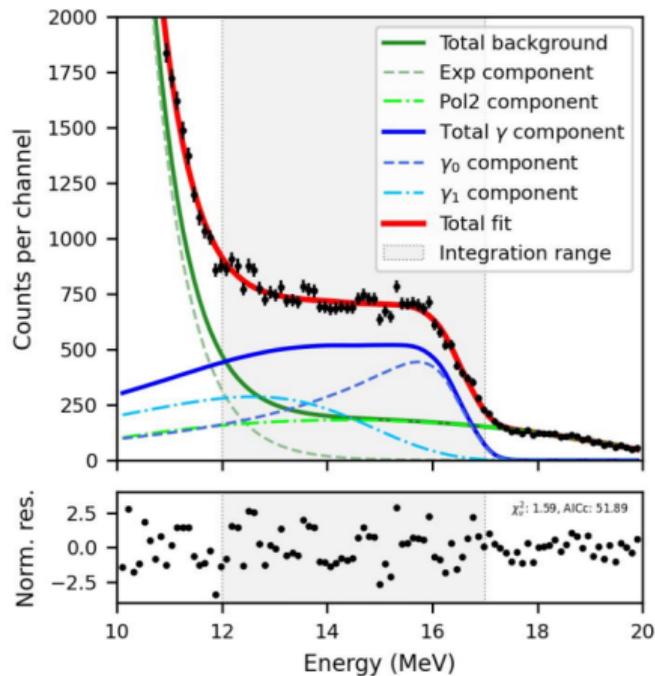
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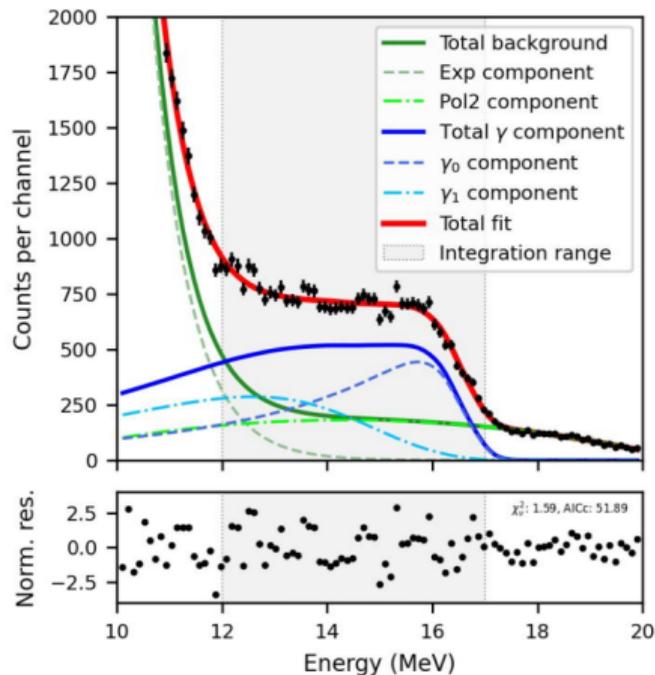


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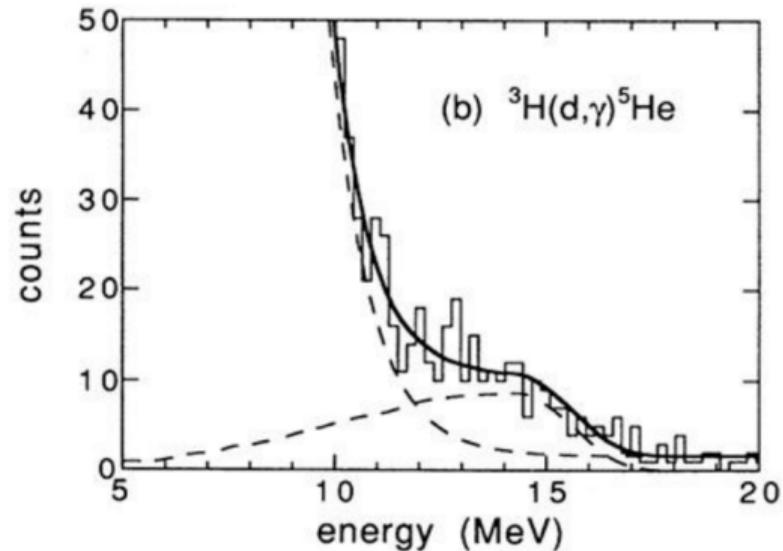
Results: Comparison with Kammeraad et al.



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Best spectroscopic measurement in previous literature



J. E. Kammeraad et al., Phys. Rev. C 47 (1), 29 (1993)

Pros and cons

standard method (n)

novel method (γ)

Pros and cons

standard method (n)

- 10% achieved uncertainty from 40 years experience at JET



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novel method (γ)

- 20% **improvable** uncertainty at first attempt



Pros and cons

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- **Intense signal** (10^{16} - 10^{20}) neutrons/s at JET ✓

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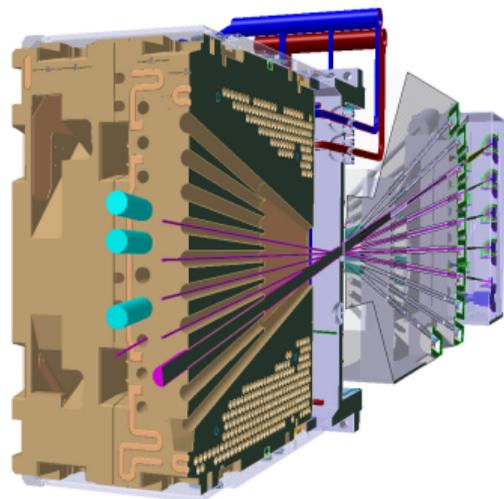
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Apply the method to other DT machines?

Future applications: ITER

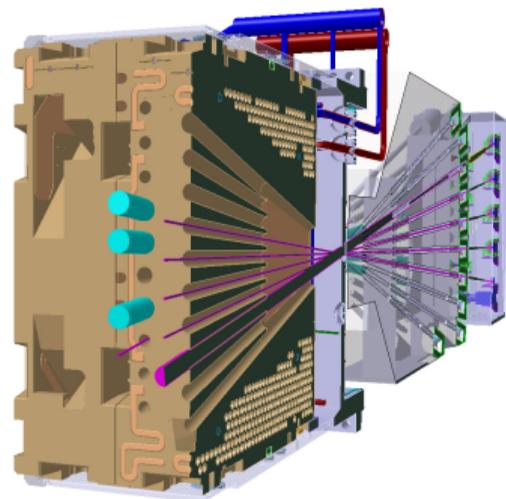
Future applications: ITER

- Multiple LoS Radial Gamma-Ray Spectrometer



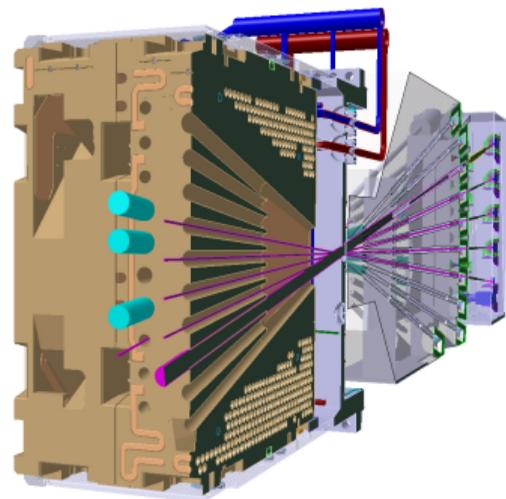
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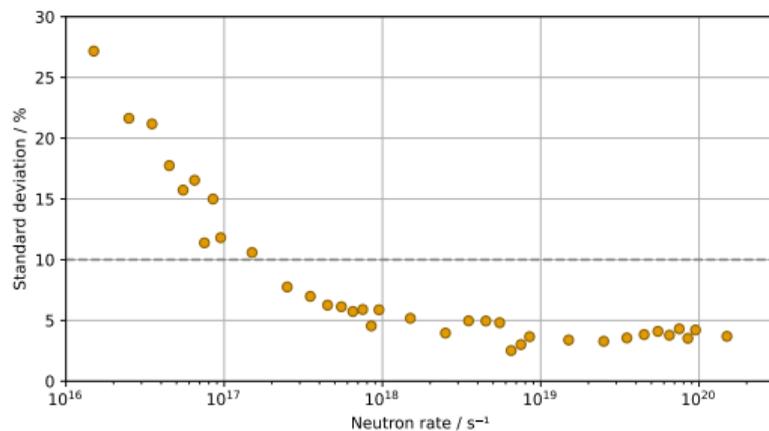
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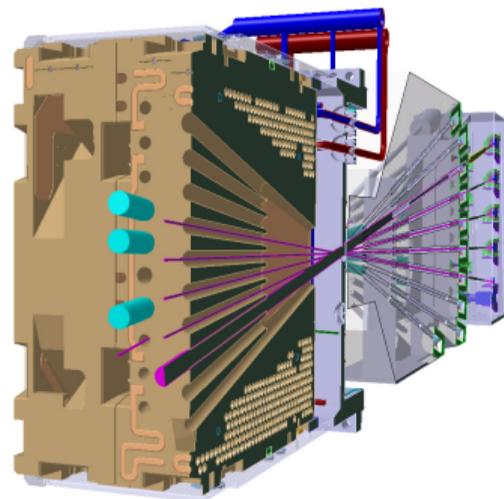


Future applications: ITER

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- Preliminary results

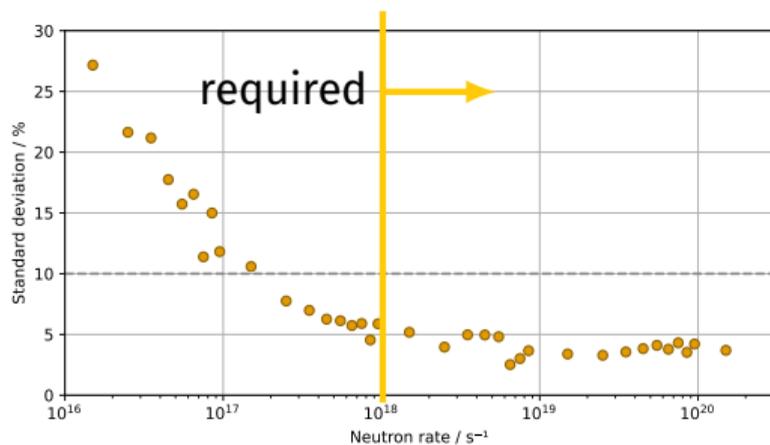


RSI - 2024 - G. Marcer et al. Energy & AI - 2025 - C. Landsmeer et al.

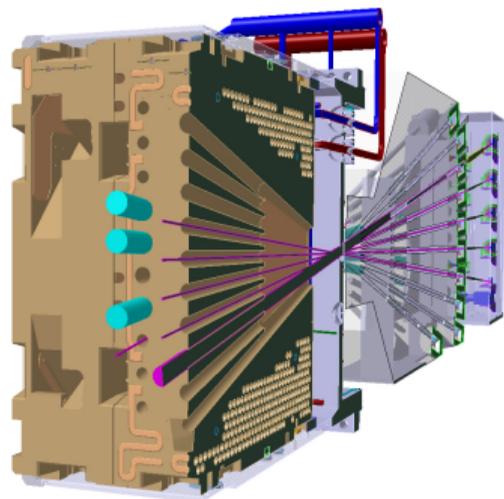


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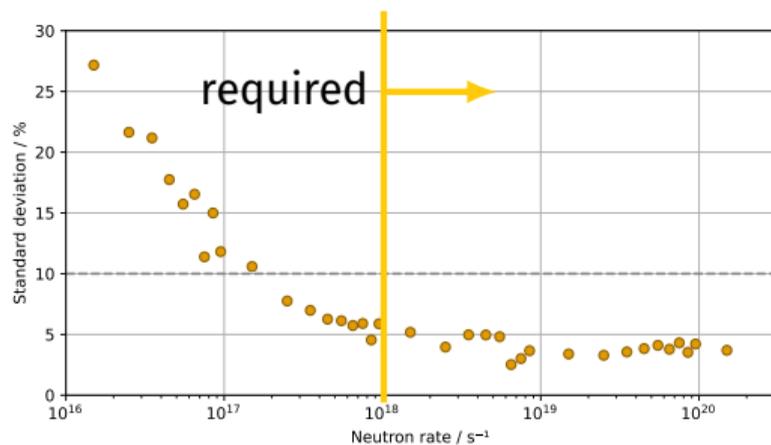


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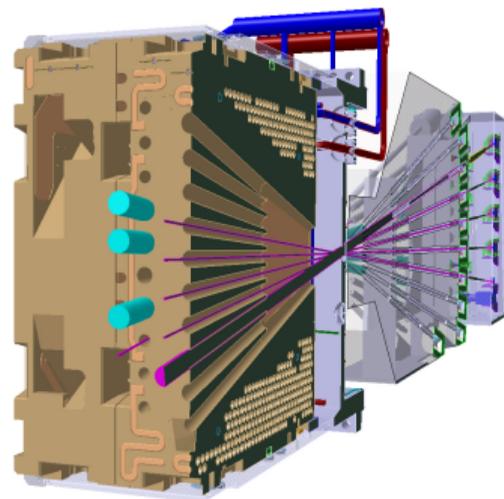


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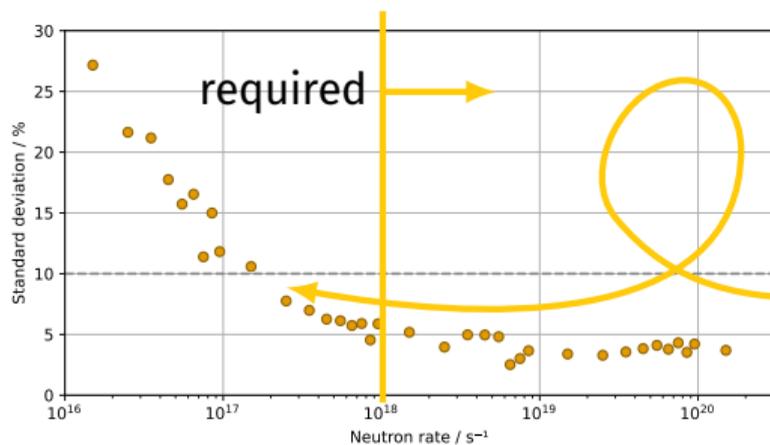
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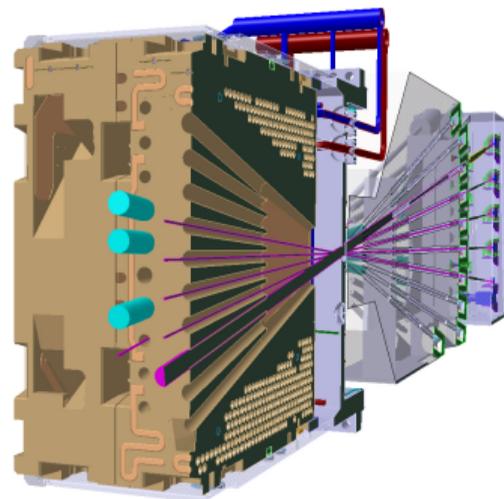
- Assuming BR is known

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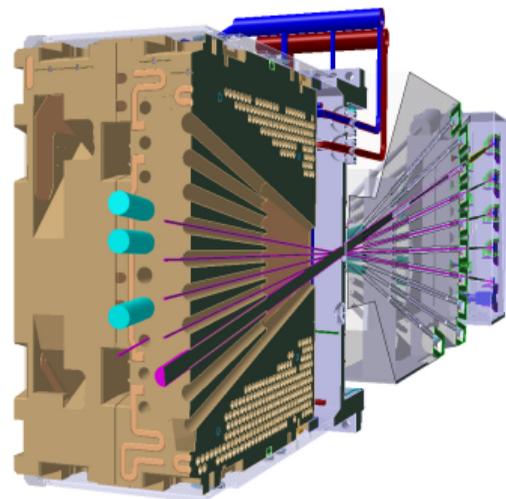
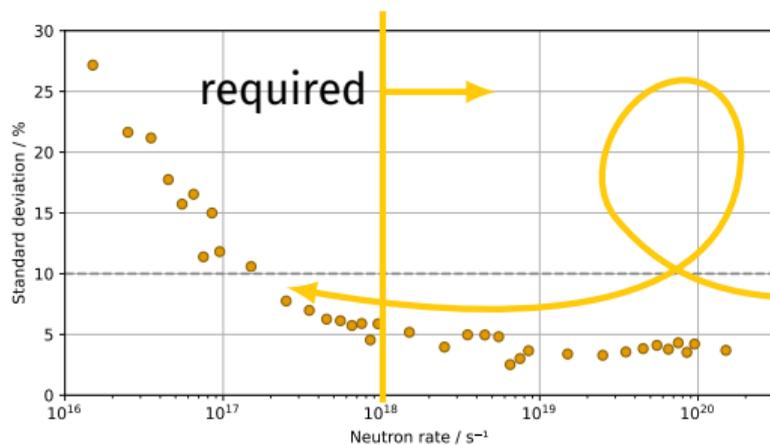
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- Assuming BR is known
- Good above $2 \cdot 10^{17}$ n/s

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- Assuming BR is known
- Good above $2 \cdot 10^{17}$ n/s
- Suitable for ITER requirements

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Thank you!

