Investigating Bremsstrahlung spectral features using multiple lines of sight in runaway electron scenarios at JET

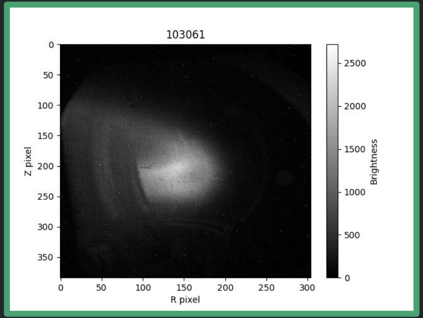
S. Fugazza[1], M. Tardocchi[2], M. Nocente[1]

1: Department of Physics
University of Milano-Bicocca

2: Institute for Plasma Science and Technology
National Research Council

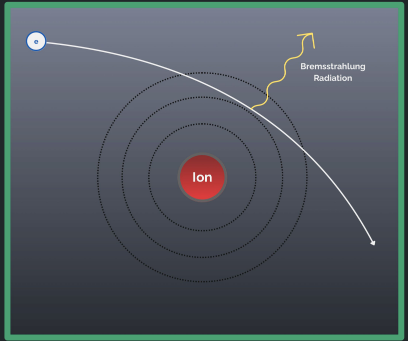
ICFRD 2025 Conference - Varenna

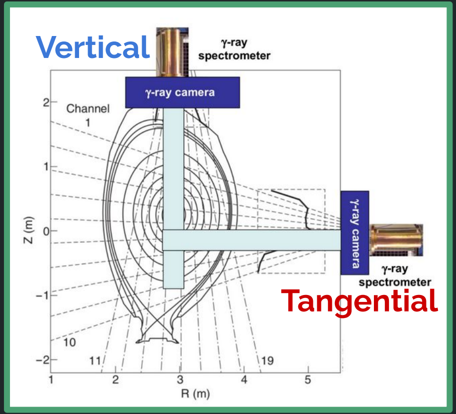
Introduction



- **Runaway Electrons** (REs) are a critical population in tokamaks that **must be controlled.** They can impact on the tokamak wall, causing **severe damage.**

  - During runaway events, strong **bremsstrahlung radiation** is emitted. This emission spans **from a few keV up to several tens of MeV**.

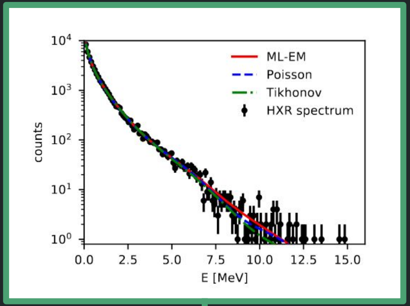




- **JET** was equipped with several **gamma-ray diagnostics**, capable of observing B. emission:
  - Tangential-GRS (line of sight at ~**50°** to the magnetic axis)
  - Vertical-GRS (line of sight at ~**90°** to the magnetic axis)

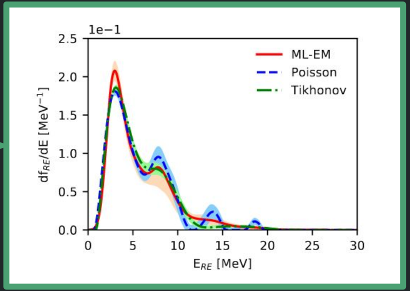
Introduction

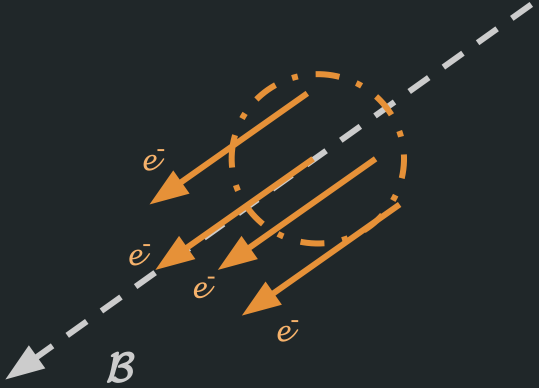
- The **RE distribution** can be inferred from experimental spectra through **inversion algorithms**.
- These studies typically assumed a **strongly co-passing** RE distribution, (emitted at **zero-angle** with respect to the magnetic field)



[Panontin E., PhD Thesis, Univ. Milano-Bicocca (2020)]

Inversion Algorithms



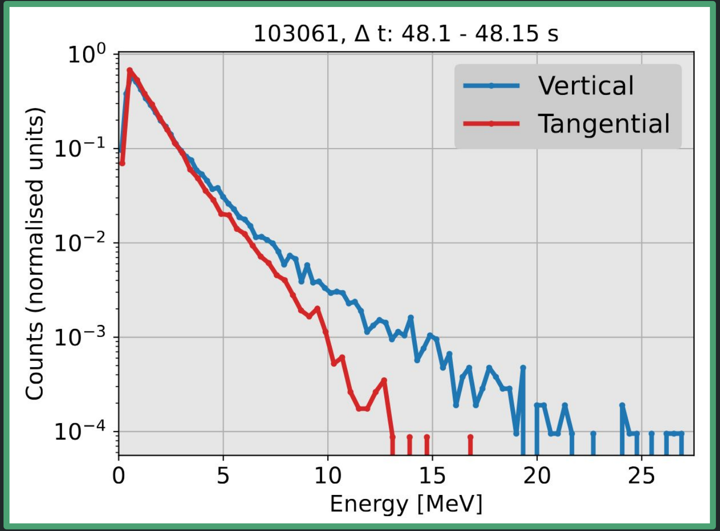


Introduction

- In several **JET experiments**, Bremsstrahlung spectra have **shown differences** when observed from **distinct viewing angles.**

- The origin of this effect is still not fully understood.

[O. Ficker et al. IAEA FEC 2023]



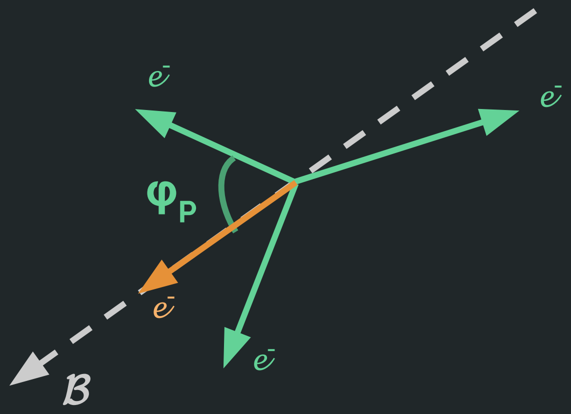
Our Question

- Could the RE distribution itself directly **affect the spectral shape** - particularly when it is **not fully co-passing**, i.e., not perfectly aligned with the magnetic axis?

★ Goal of this work:

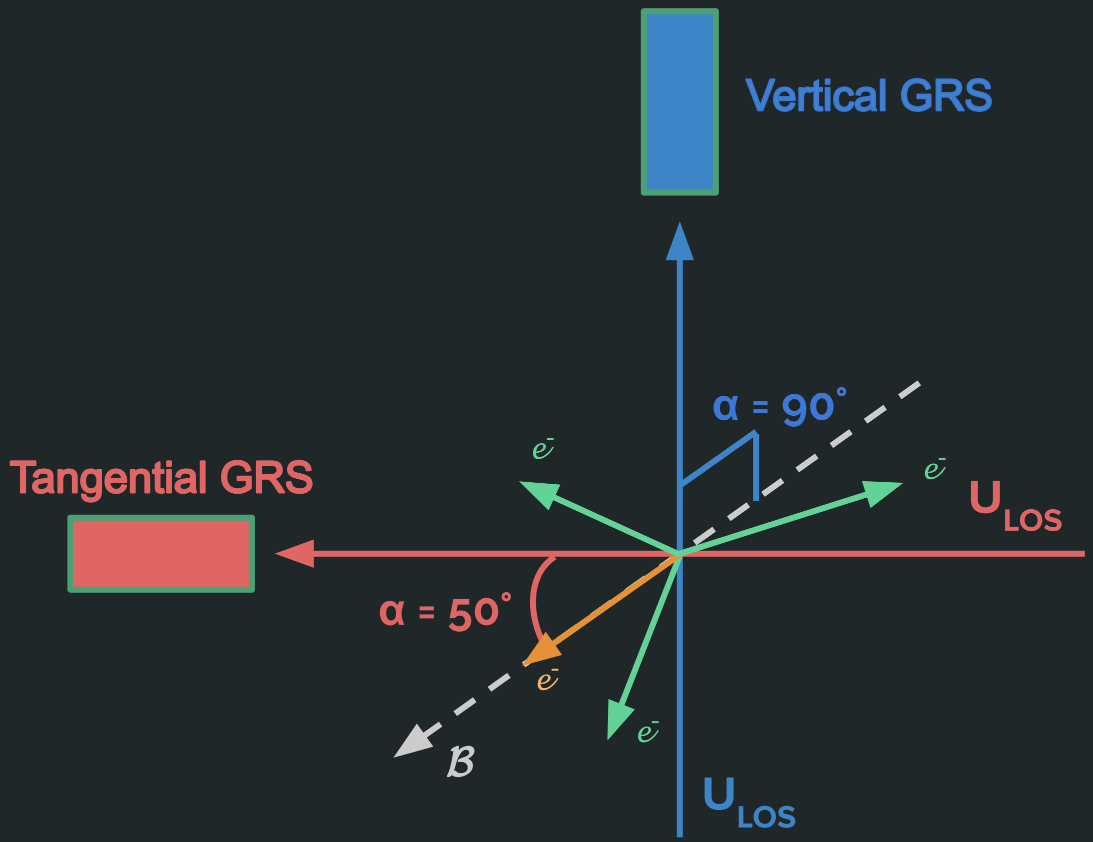
To explore how the Bremsstrahlung spectrum varies with different RE pitch-angle distributions, and how it changes when the plasma is observed with multiple lines of sight.

- co-passing runaway electrons
- runaway electrons with non-zero pitch-angle φ_P



Emission Anisotropy

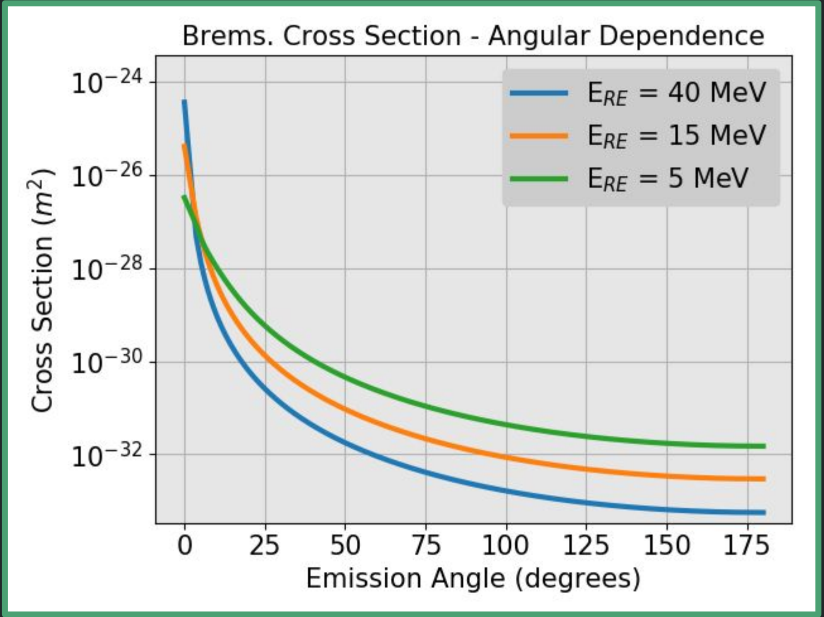
- The Bremsstrahlung emission is **anisotropic**
- Each detector will experience a **different sensitivity** for electrons emitted at **specific angles**



Emission Anisotropy

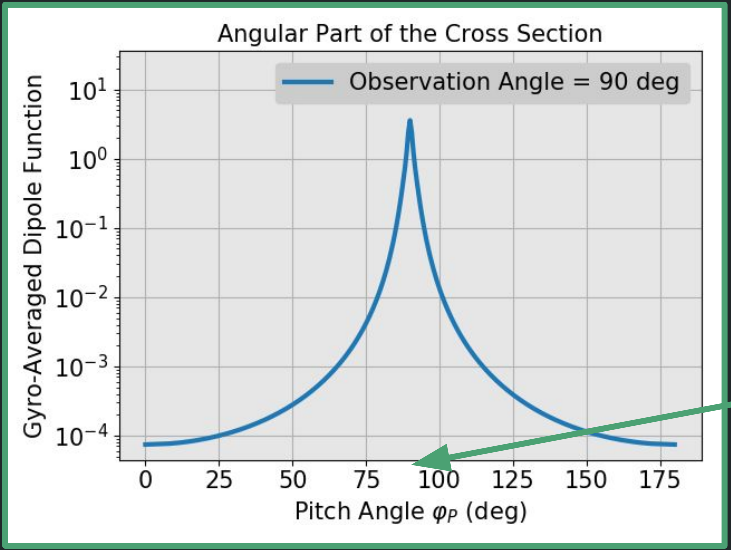
- The reason why two diagnostics observes different spectral features is related to the **bremsstrahlung cross section.**

- **Maximum emissivity** occurs along the RE velocity direction (Emission angle = 0°) and **decreases progressively** as one moves away from it.

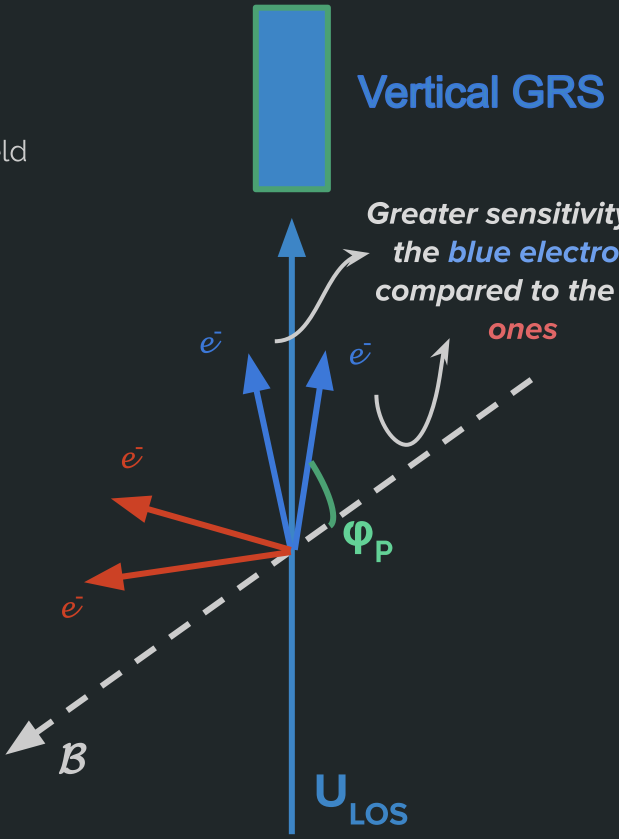


Emission Anisotropy

- **Pitch angle φ_P**: angle between the **electron direction** and the magnetic field
- **Observation angle α**: angle between the **observation direction** and the magnetic field

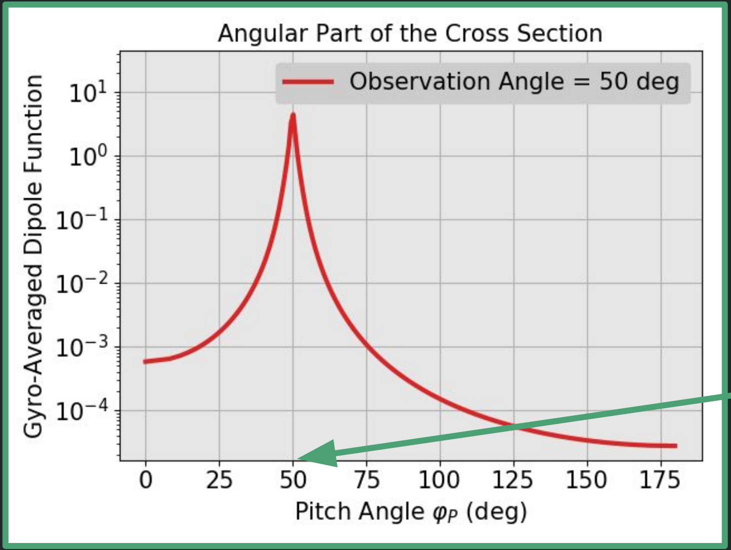


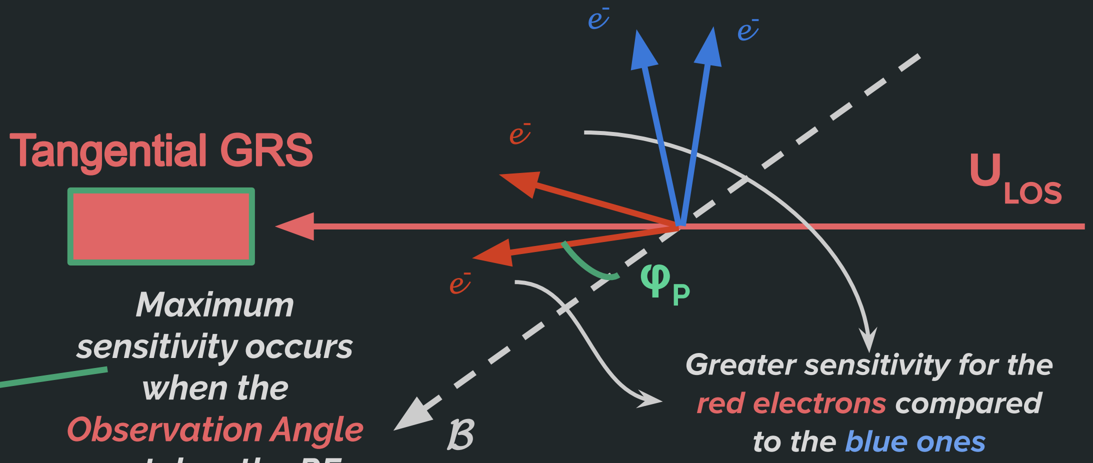
Maximum sensitivity occurs when the Observation Angle <u>matches</u> the RE Pitch Angle



Emission Anisotropy

- **Pitch angle φ_P**: angle between the **electron direction** and the magnetic field
- **Observation angle α**: angle between the **observation direction** and the magnetic field



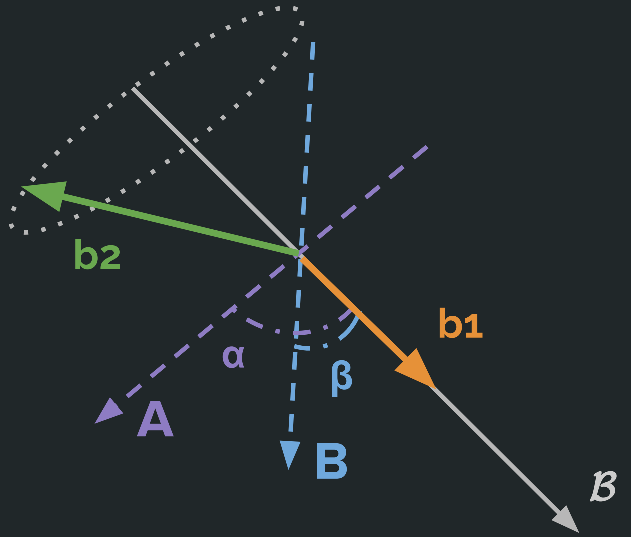


Maximum sensitivity occurs when the Observation Angle matches the RE Pitch Angle

Greater sensitivity for the red electrons compared to the blue ones

A Simple Case

- Consider **two distinct RE beams**, equally populate:
  - **b1: E_{RE} = 15 MeV, P_{RE} = 1.0** (co-passing)
  - **b2: E_{RE} = 25 MeV, P_{RE} = -0.5**
- The plasma is observed with **2 gamma diagnostics**:
  - **A**: observation angle **α = 90°**
  - **B**: observation angle **β = 50°**



A Simple Case

- It follows that **4 spectral components** arise (one for each beam–detector pairing):

$$S_A(b_1)$$

Beam-1
seen by Diagnostic-A

$$S_B(b_1)$$

Beam-1
seen by Diagnostic-B

$$S_A(b_2)$$

Beam-2
seen by Diagnostic-A

$$S_B(b_2)$$

Beam-2
seen by Diagnostic-B

A Simple Case

$$S_A(b_1)$$

$$S_A(b_2)$$

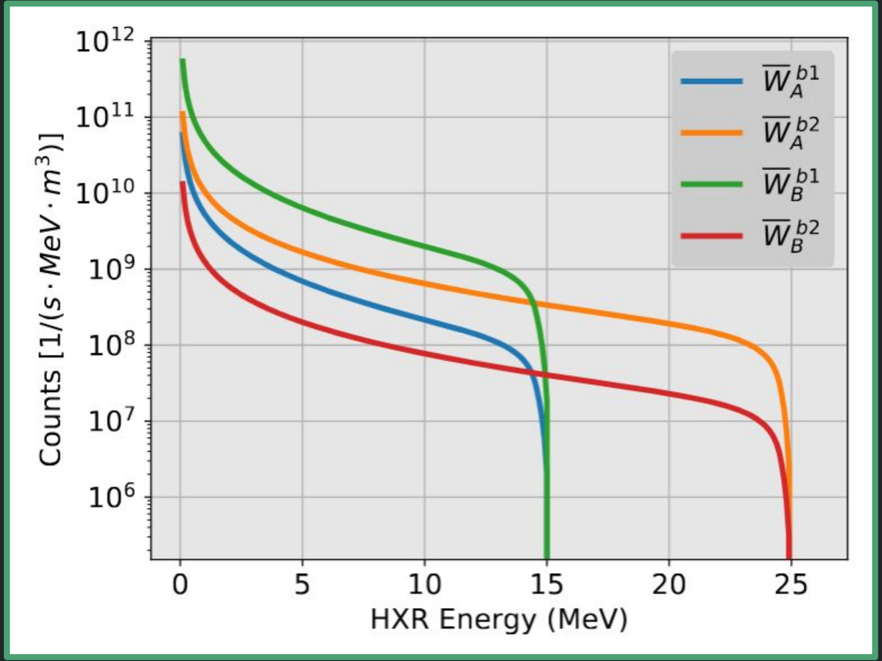
$$S_B(b_1)$$

$$S_B(b_2)$$

b1: E = 15 MeV , P = 1.0

b2: E = 25 MeV, P = -0.5

A: 90° - B: 50°



A Simple Case

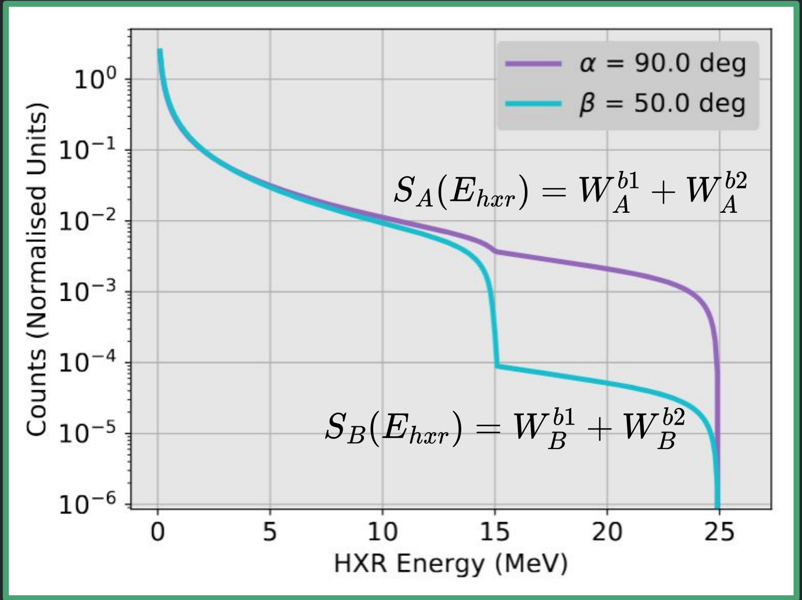
- The **two final spectra** becomes:

Diagnostic-A:

$$S_A = S_A(b_1) + S_A(b_2)$$

Diagnostic-B:

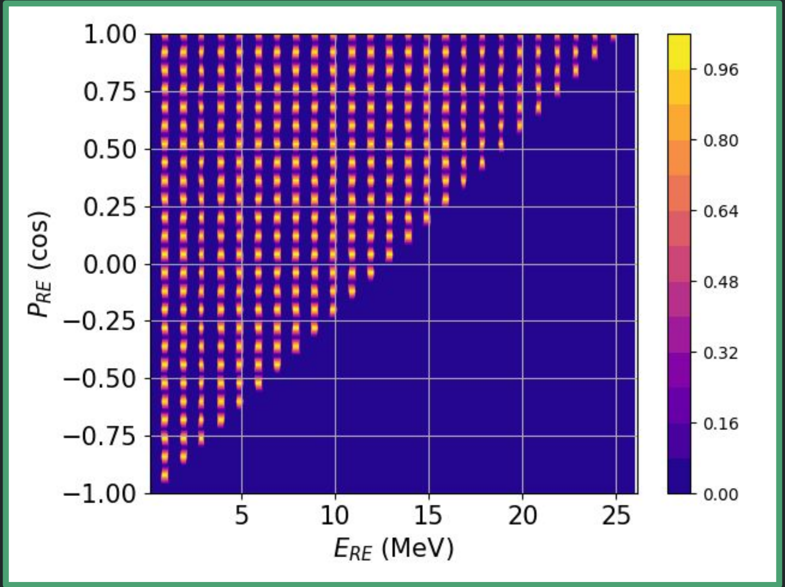
$$S_B = S_B(b_1) + S_B(b_2)$$

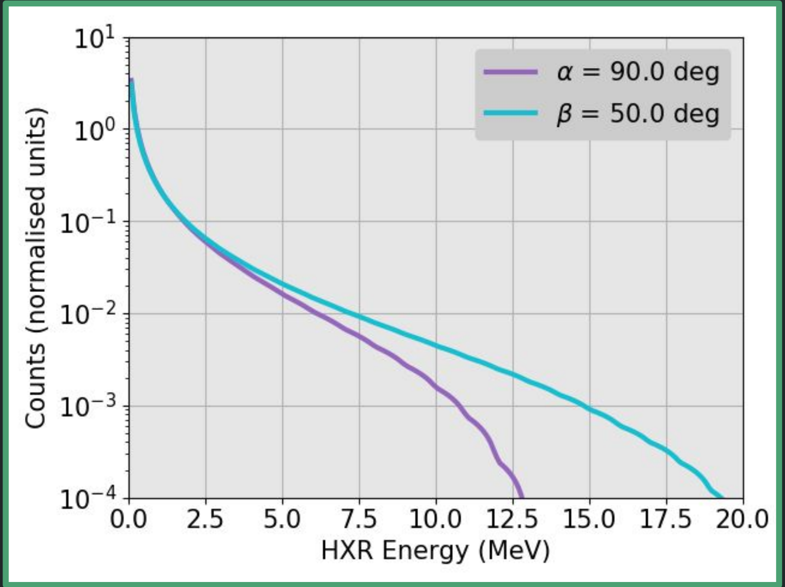


- The two resulting spectra show **clear differences** between the two observation angles, **mainly in the high energy region**

A Simple Case

- A more complex example, where a tentative distribution is used:





- The resulting Bremsstrahlung spectrum mimics better the experimental case

Conclusion

- If the RE distribution is **not fully co-passing**, **different viewing angles** observe **different Bremsstrahlung spectra**.
- This effect arises from the Bremsstrahlung cross section and is mainly driven by the **coupling between energy and pitch angle**. Specific energy–pitch distributions can further enhance these differences.
- These findings may help **improve our understanding** of the different spectral slopes observed at JET.
- For more details, please visit me at my poster presentation.

Thank you for your attention!