Polarized synchrotron emission from post-disruption runaway electrons in the JET C38 campaign

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This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission, or ITER Organization.
Outline + main takeaways

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Synchrotron emission polarization and detection
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pitch angle: \( \sin \theta_p \propto |\vec{v} \times \vec{B}| \)

polarization: \( \vec{E} \propto \vec{v} \times \vec{B} \)
Synchrotron measurements depend on…

- **Detector geometry** – known

- **Magnetic geometry** – depends on the runaway current density (unknown)

- **Runaway distribution function** – can be constrained
Polarimeter of the Motional Stark Effect (MSE) diagnostic is used to measure...

- Total **intensity** of polarized light – spatial profile

- **Fraction** (degree) of linear polarization

- Polarization **angle** – measured w.r.t. the vertical
MSE system on JET ($\lambda \approx 660 \text{ nm}, \Delta \lambda \approx 1 \text{ nm}$)
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Polarimeter data can complement fast camera images

Camera (KLDT-E5WE)

λ ≈ 450 – 700 nm

JPN 94552, t = 8.2s

MSE
Measurements from disruption-generated runaway beams in JET
To do…

- I still need to consider reflected light from the metal ITER-like wall

- I use the standard EFIT magnetic geometry, but need to verify its goodness-of-fit/applicability

- I need to justify/verify polarization angle measurements for low polarization fractions (~0)
‘Typical’ runaway beam

- Disruption triggered at $t = 8.0\,\text{s}$.
- Runaway beam forms $\sim500\,\text{kA}$.
- Beam position is vertically stable.
- SPI trigger at $t = 8.4\,\text{s}$ failed.
- MHD activity at $t = 8.6\,\text{s}$.
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![Graph showing the intensity and polarization fraction over time.](image)
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- Polarization is mostly vertical ($0^\circ$).
- Some horizontally-polarized ($90^\circ$) light is seen at $r_{\text{tan}}/a \sim 0.5$,
  but for low polarization fractions $\sim 0$. 
Argon SPI successfully triggered at $t = 8.4$ s.
Does pitch angle scattering cause bright flash? Reduce polarization fraction? Change pol. angle?
Do these data indicate an evolving runaway current density profile?

- D2 SPI triggered at $t = 8.4$ s.
- Runaway current increases!
- Beam suddenly disappears (disrupts?) at $t \sim 8.7$ s.

- Beam appears to decrease in size and intensity as current increases.

- Polarization fraction ~ 0 ‘follows’ radially-inward motion.

- So does transition from vertical-to-horizontal polarization.
  (Caution: low pol. fraction values)
Preliminary results from the synthetic diagnostic SOFT

M Hoppe et al 2018 Nuclear Fusion 58 026032
Synchrotron-detecting Orbit Following Toolkit
M Hoppe et al 2018 Nuclear Fusion 58 026032

Inputs

• Detector geometry
• Magnetic geometry (EFIT)
• Phase space distribution $f(r, p, \theta_p)$ (optional)

Outputs

• Spectra
• Images
• Polarization information
• Detector response function $\hat{G}(r, p, \theta_p)$
Preliminary SOFT results differ slightly from experiment.

Note: We only had time to run SOFT for this early pulse and not for the other pulses shown in this presentation.
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From SOFT:
- Polarization fractions > 0.5 ✗
- All **vertically**-polarized light ✓

→ Discrepancy due to incorrect magnetic geometry from EFIT?

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Detection of horizontal polarization at the edge depends on the safety factor

For MSE channel 10, with line-of-sight

\[ R_{\text{tan}} = 3.43 \text{ m}, \quad r_{\text{tan}}/a = 0.43 \]

what is the detected polarization angle for runaways with a given energy, \( p/mc \)

pitch angle, \( \theta_p \)

and safety factor profile

\[ q(r) = \frac{2q_0}{2 - (r/a)^2} \]
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\[ q(r) = \frac{2q_0}{2 - (r/a)^2} \]

\( q_0 = 1 \)

\( q_0 = 3 \)
Polarization fraction measurements at the edge are highly sensitive to the safety factor $q_0$.

For MSE channel 5, with line-of-sight

$R_{\tan} = 3.63 \text{ m, } r_{\tan}/a = 0.63$

what is the detected **polarization fraction** for runaways with a given energy, $p/mc$

pitch angle, $\theta_p$

and safety factor profile

$$q(r) = \frac{2q_0}{2 - (r/a)^2} ?$$
Polarization fraction measurements at the edge are highly sensitive to the safety factor $q_0 = 1$

For MSE channel 5, with line-of-sight $R_{\text{tan}} = 3.63 \text{ m}$, $r_{\text{tan}}/a = 0.63$

what is the detected polarization fraction for runaways with a given energy, $p/mc$ pitch angle, $\theta_p$

and safety factor profile $q(r) = \frac{2q_0}{2 - (r/a)^2}$?

![Graph showing polarization fraction with safety factor profile $q_0 = 3$. The graph includes a color scale ranging from 0% to 100% and coordinates for $p/mc$, $\theta_p$.](image-url)
Polarization fraction measurements at the edge are highly sensitive to the safety factor

For MSE channel 5, with line-of-sight

\[ R_{\text{tan}} = 3.63 \text{ m}, \frac{r_{\text{tan}}}{a} = 0.63 \]

what is the detected polarization fraction for runaways with a given

energy, \( \frac{p}{mc} \)

pitch angle, \( \theta_p \)

and safety factor profile

\[ q(r) = \frac{2q_0}{2 - (r/a)^2} \]
Main takeaways

• **Synchrotron radiation** from relativistic runaway electrons is (mostly) **linearly-polarized**

• The **intensity**, **fraction**, and **angle** of this polarized light can give insight into the **spatiotemporal evolution** of the runaway **current density** and **pitch angle** distribution

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Outlook using polarization data

If we can understand the evolution of the runaway pitch angle distribution and current profile, then we can…

- Better constrain runaway momentum space dynamics
- Effectively know the runaway density profile
- Compare with forward-evolution models
- Investigate the effects of mitigation (e.g. MGI or SPI), especially on pitch angle scattering
- Better understand the ‘disruptions’ of increasing-current runaway beams (e.g. due to kink instability?)
References

Bonus
Strange runaway beam

- SPI triggered 4 ms after TQ.
- Current first increases, then decreases.
- Really strange spatiotemporal dynamics observed.

- Intensity saturates at $r_{\text{tan}}/a \sim 0.5$, but then falls below the noise floor for $t > 9.8$ s ($I_r < 500$ kA).

- Snakelike pattern observed for polarization fraction $\sim 0$.

- Similar strange evolution in polarization angle.
Fast mitigation

- SPI at $t = 22.5$ s, pellet breaks into three pieces.

- Still measure polarized synchrotron emission during fast runaway loss.

- Intensity is brightest on the high field side.

- Polarization fraction $\sim 0$ everywhere.

- Polarization is primarily horizontal. (Caution: low pol fraction values)
Another increasing runaway beam current

- D2 SPI at $t = 8.4$ s.
- Ne SPI at $t = 8.6$ s.

- Beam appears to decrease in size as current increases.

- Broad region of low polarization fraction.

- Broad region of horizontal polarization, due to view of the top of the runaway beam?
Synchrotron radiation is emitted primarily in the runaway’s direction of motion

linear polarization: \( \vec{E} \propto \vec{v} \times \vec{B} \)