Reconstruction of the runaway electron energy distribution function by spectral analysis of the HXR emission at JET

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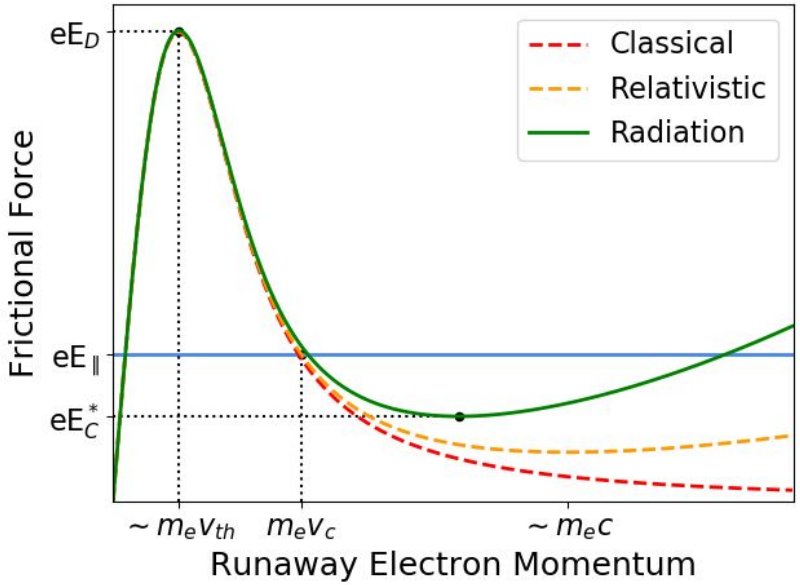
RE HXR Emission

- Runaway electrons radiation losses are mainly caused by **synchrotron** emission and **bremsstrahlung**;

- Since RE at JET can reach energies in the order of 10 MeV, bremsstrahlung is emitted in the **hard X-ray** (HXR) range;



HXR Spectrometers at JET

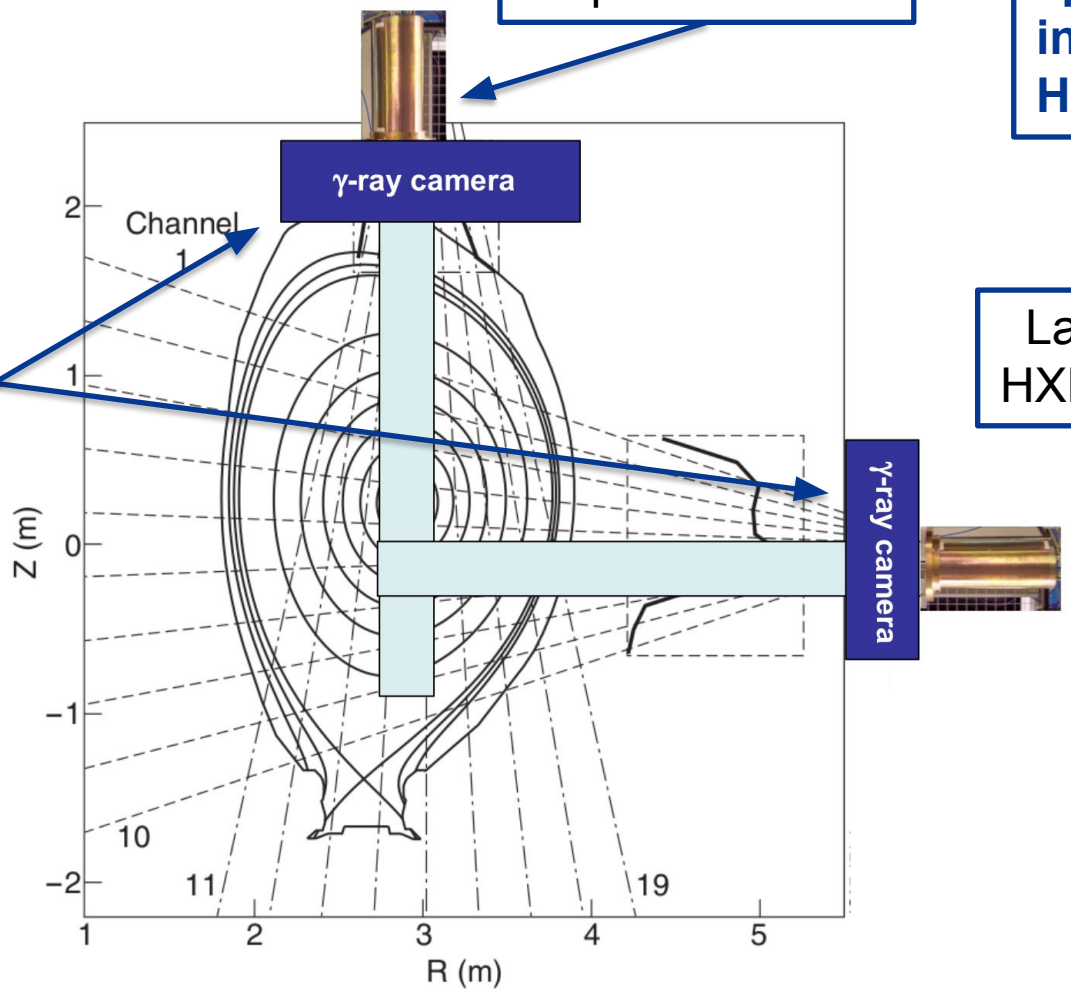
Large radial HXR spectrometer

Detailed spectroscopic information of HXR emission

Gamma Camera (19 LoS)

Spectroscopic and spatial information of HXR emission

Large tangential HXR spectrometer



Forward Model

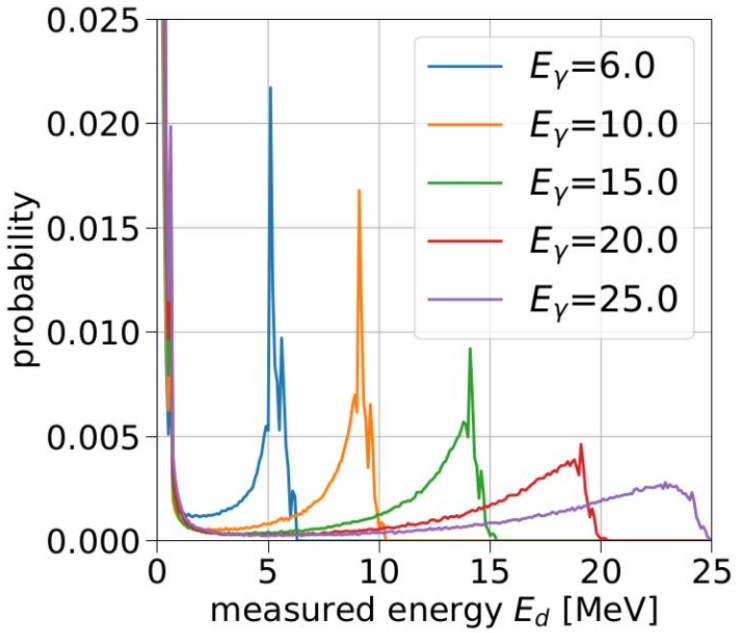
$$S = W \cdot F$$

$W = W_{DRF} \cdot W_E$ is the transfer matrix

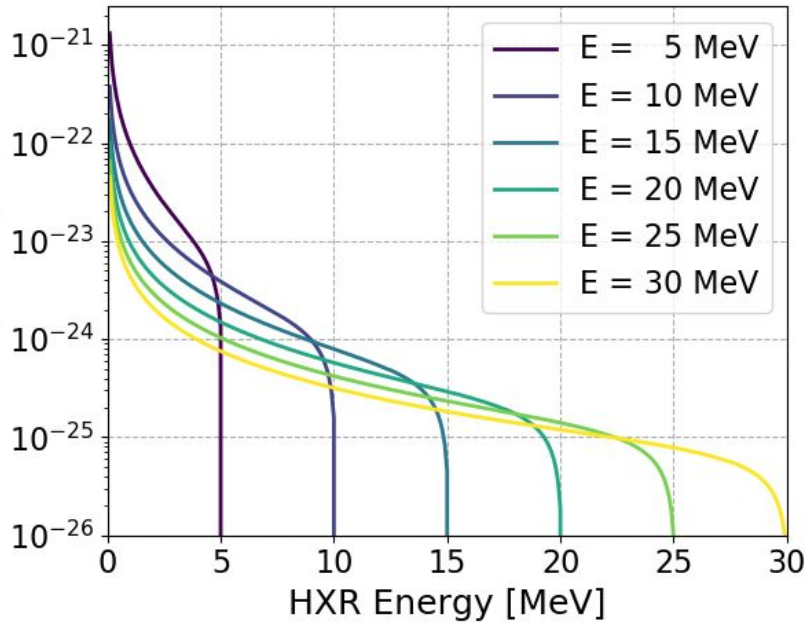
Transfer Matrix (W)

$$W = W_{DRF} \cdot W_E$$

MCNP simulation for a $LaBr_3$ scintillator

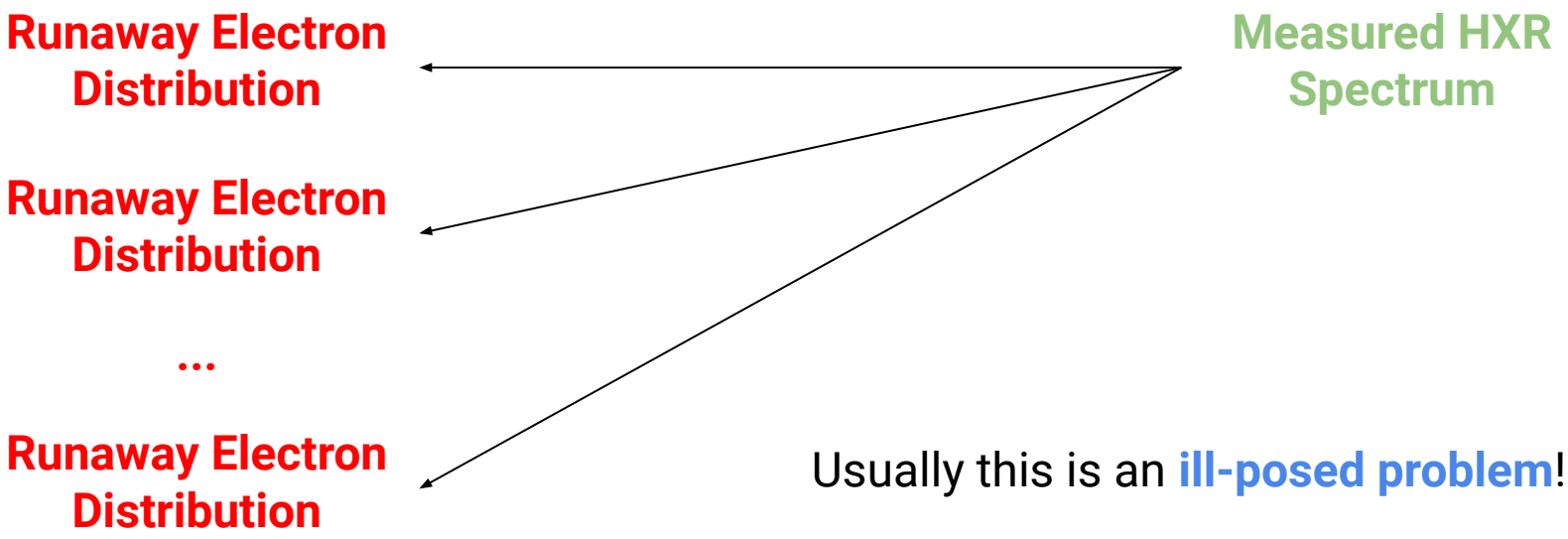


Semiempirical cross section from Salvat 1992



The cross section has been evaluated assuming pitch = 1 for all particles in the RE beam.

Inverse Model



Usually this is an **ill-posed problem**!

Tikhonov Regularization

The strategy is to substitute the ill-posed problem with a closely related well-posed one.

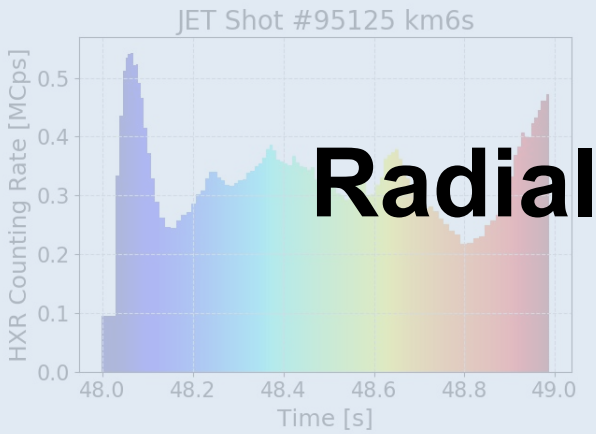
$$F_{tikh} = F \; s.t. \; min_{nnls} \left\| C \cdot F - D \right\|$$

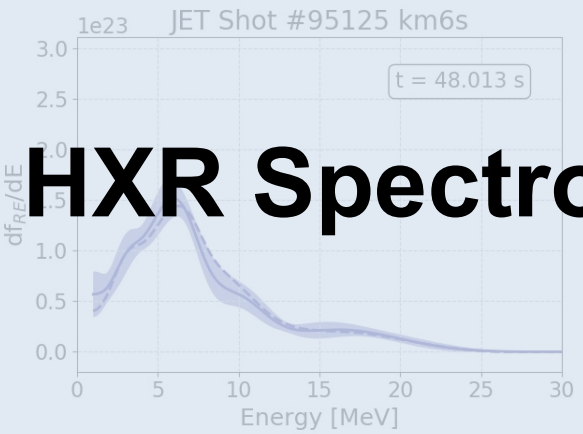
$$C = \begin{bmatrix} W \\ \alpha L \end{bmatrix}; \; D = \begin{bmatrix} S \\ 0 \end{bmatrix}$$

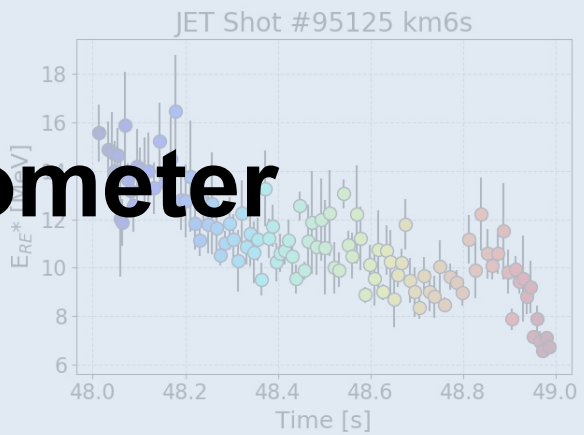
- The L matrix can be used to penalize different solution aspects.
  In our analysis we chose L = L1 (First Order Tikhonov Regularization).
  This is equivalent to favor smooth solutions with low first derivative values.

- The α parameter controls the regularization intensity.

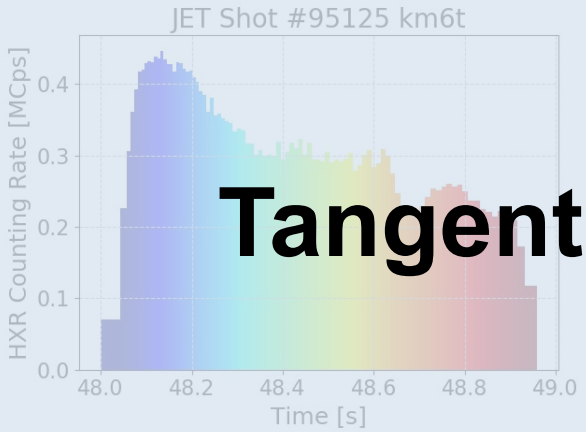
RE Energy Distribution Function

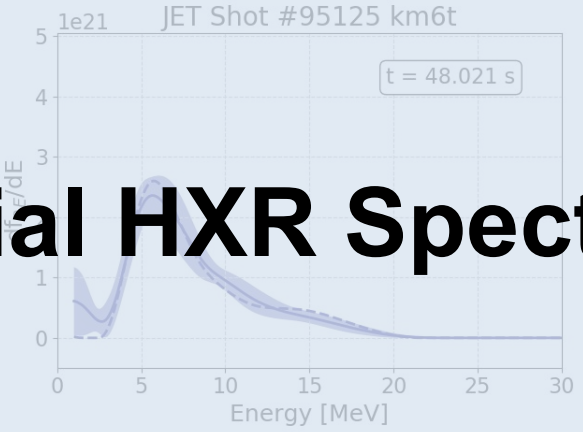


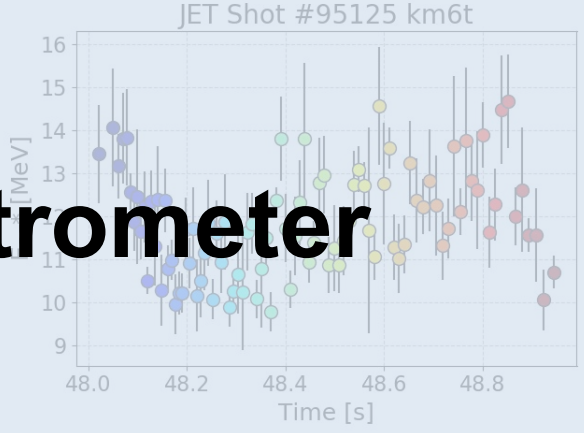




Radial HXR Spectrometer

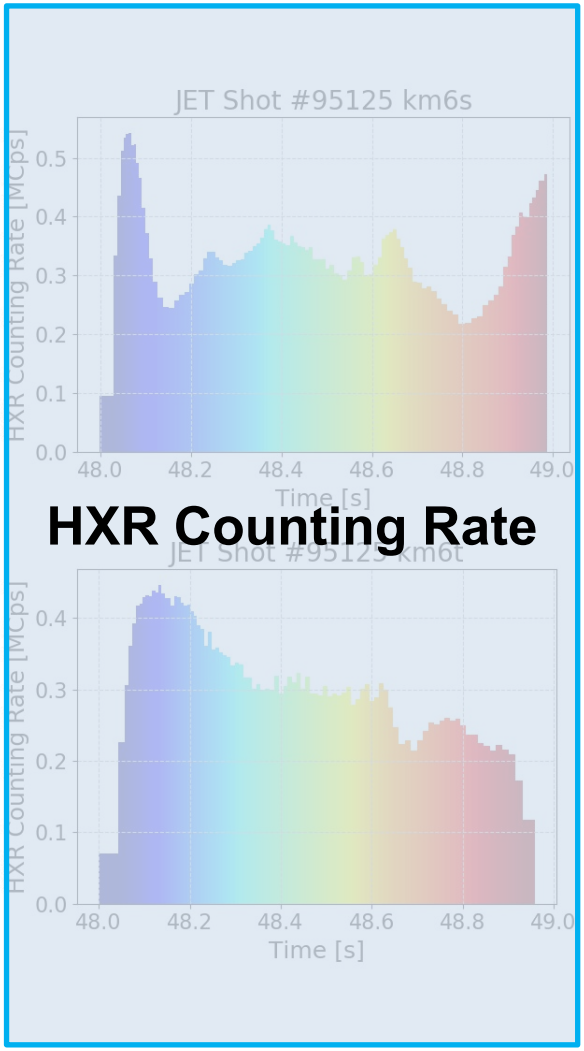


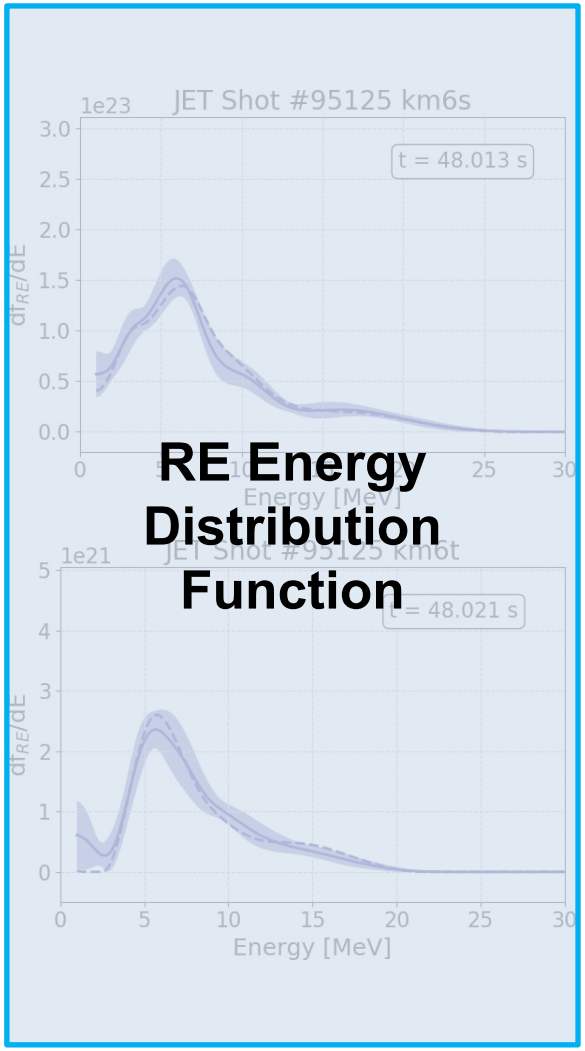


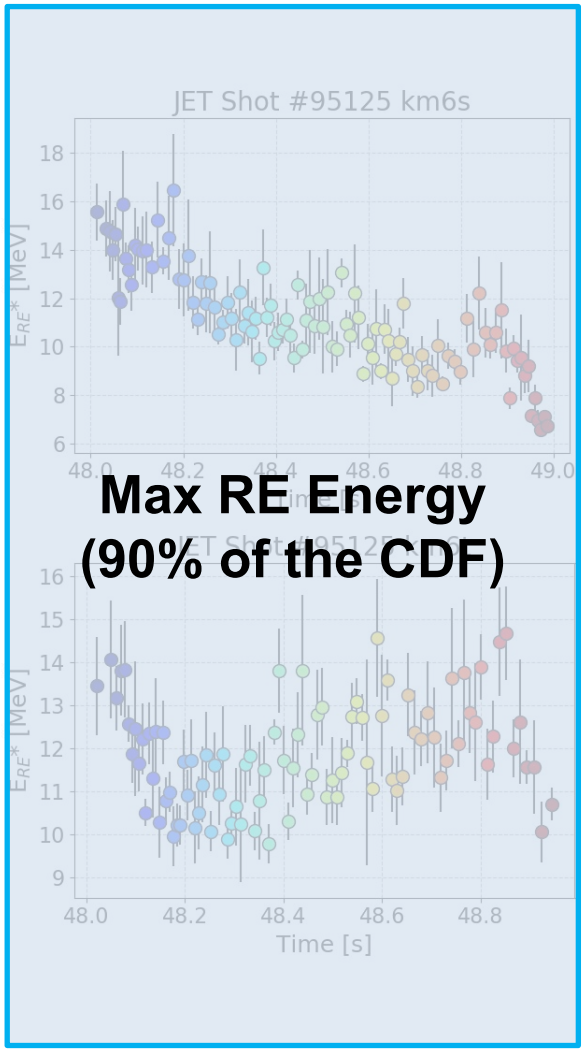


Tangential HXR Spectrometer

RE Energy Distribution Function



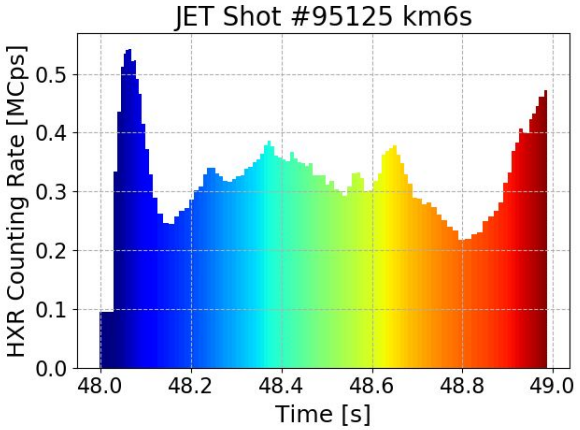


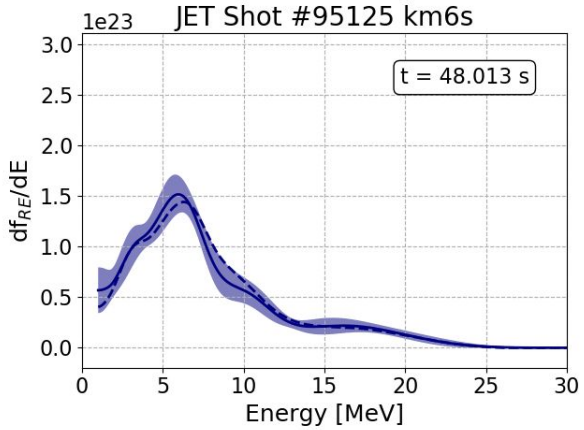


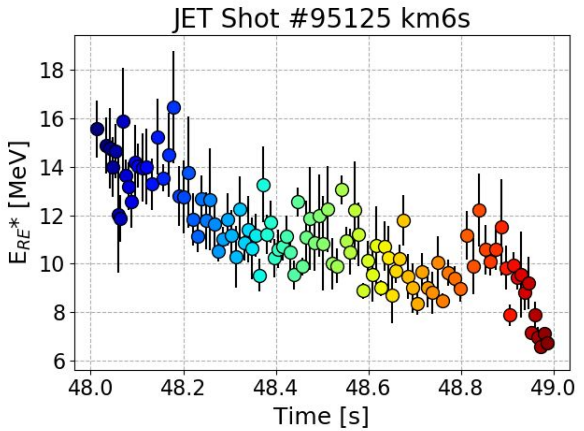
RE Energy Distribution Function

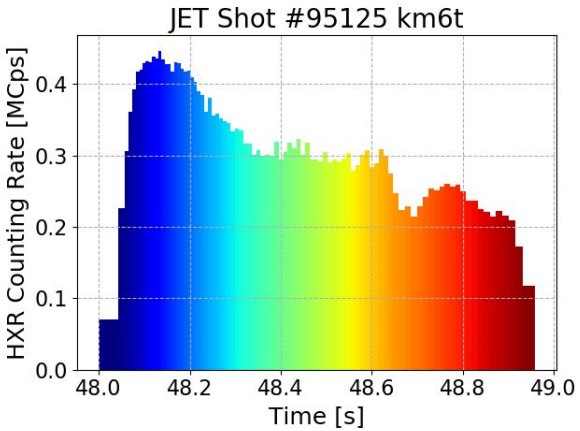
Tikhonov Regularization

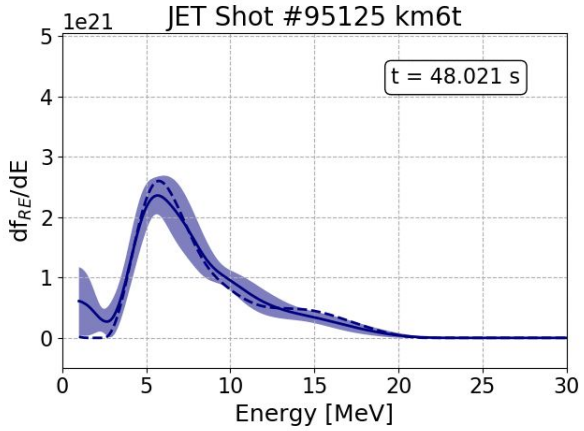
RE Energy Evolution Analysis

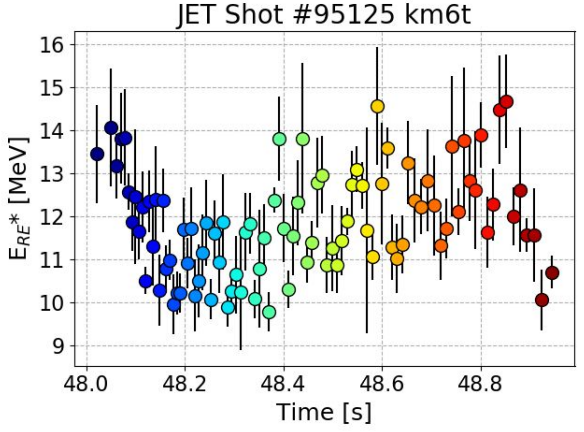




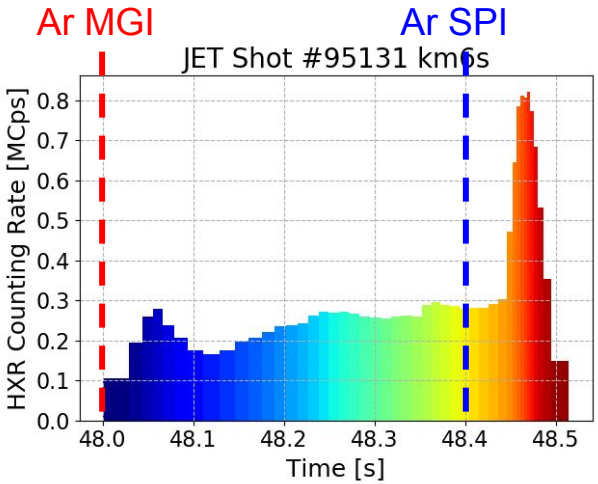


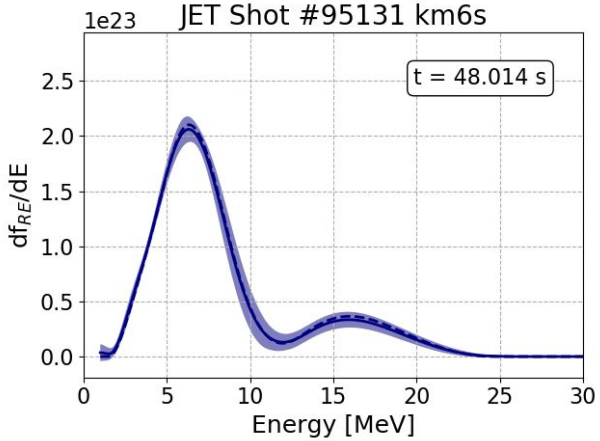


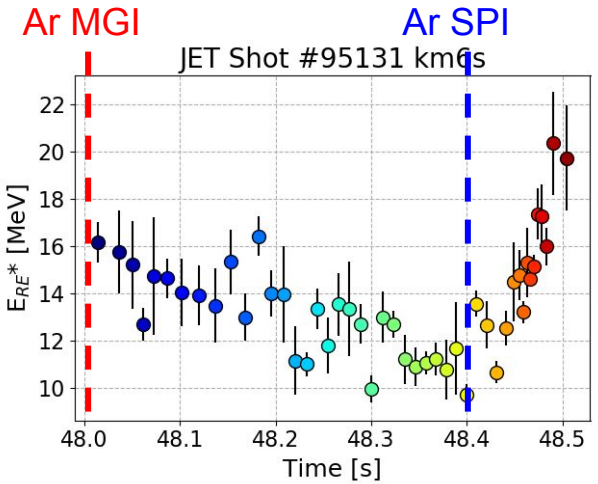


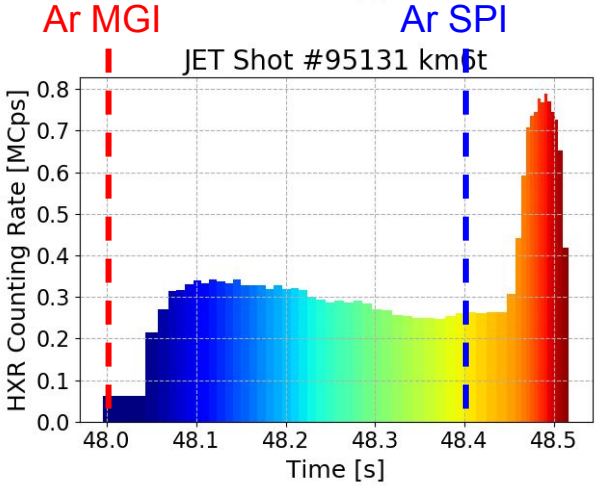


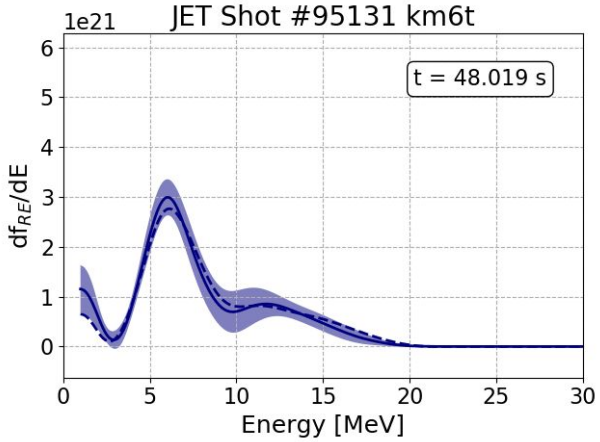
RE Energy Distribution Function

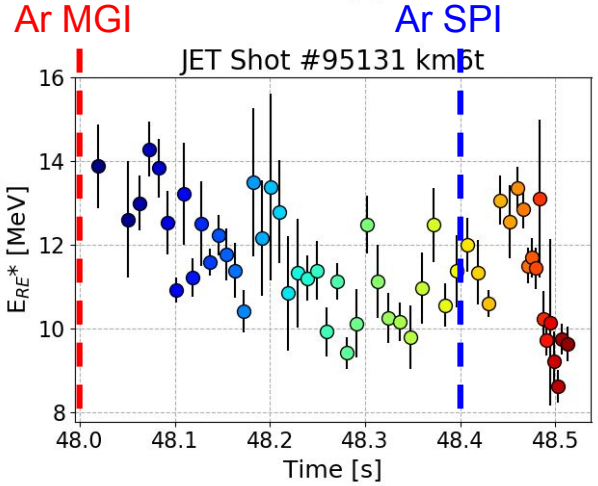




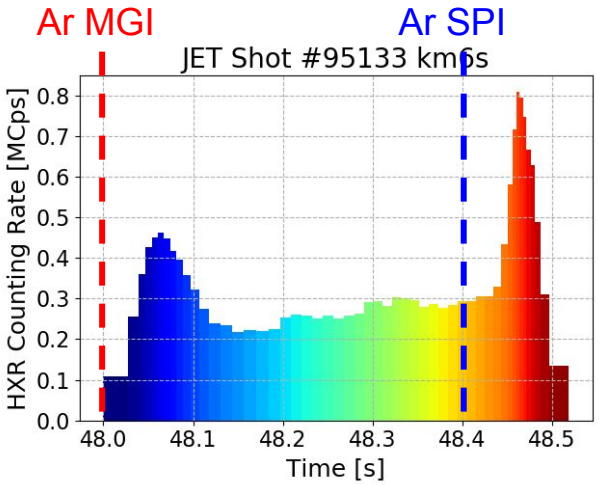


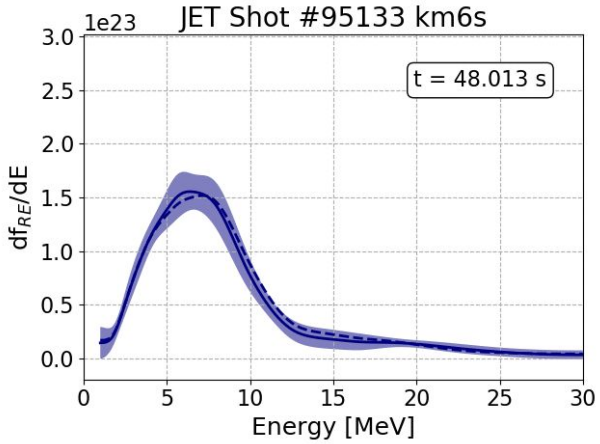


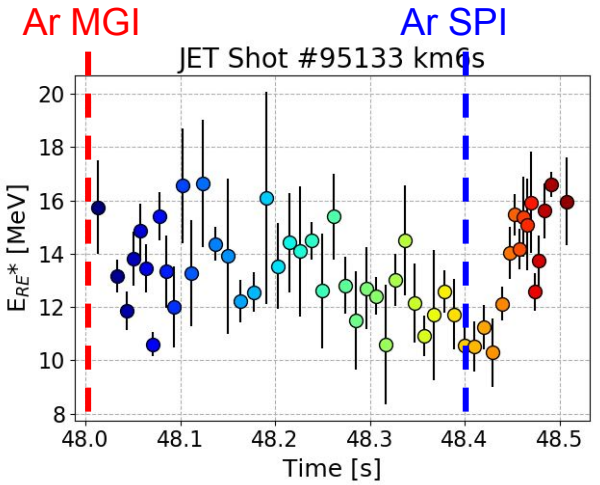


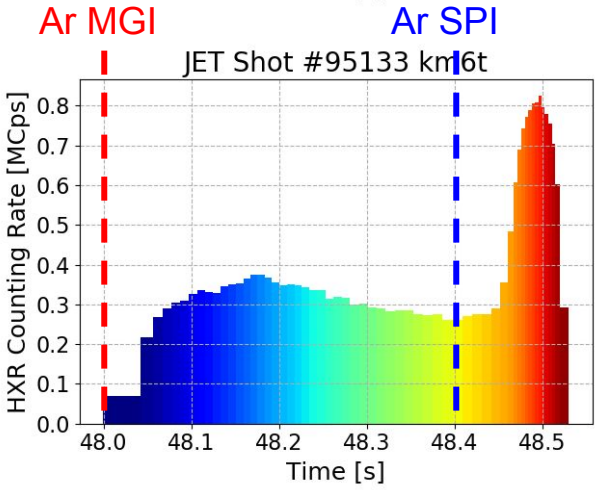


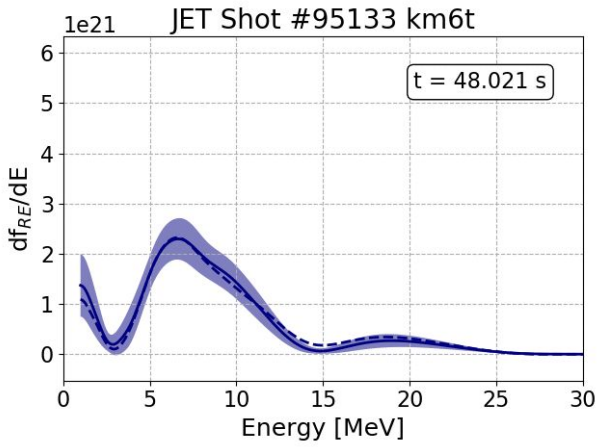
RE Energy Distribution Function

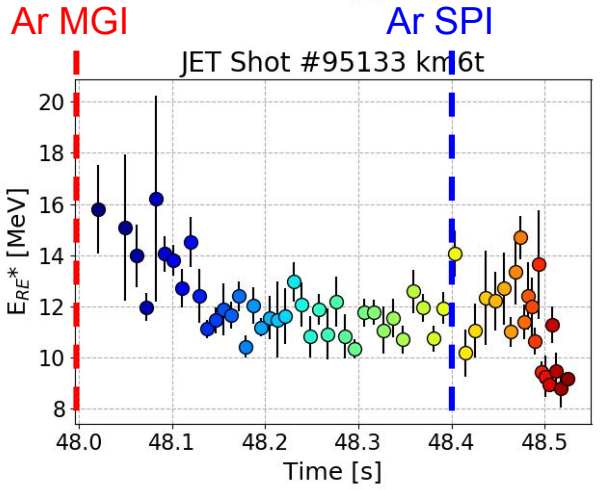












RE Energy Distribution Function

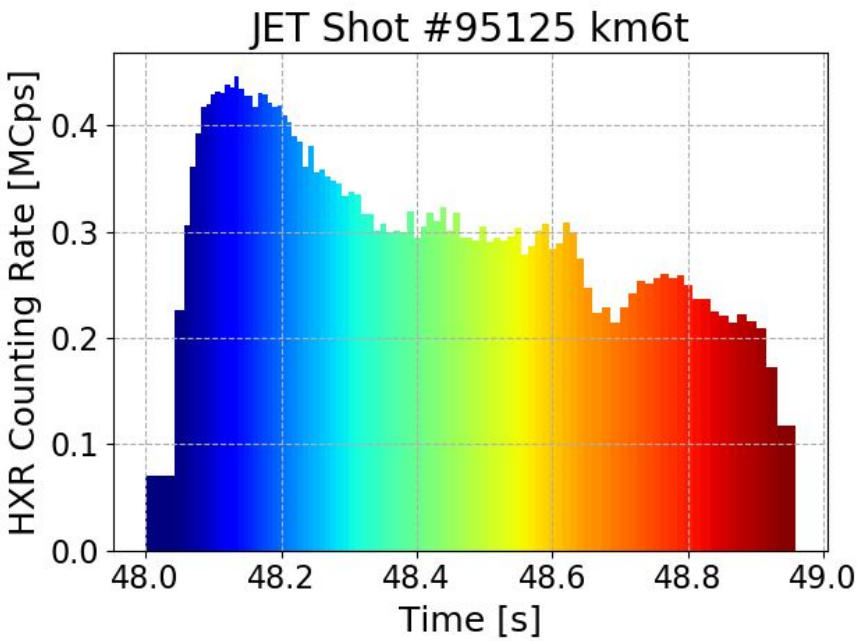
Analysis performed

95125, 95727, 95729, 95733, 95774, 95131, 95132, 95133, 95134, 95135, 95136, 95776

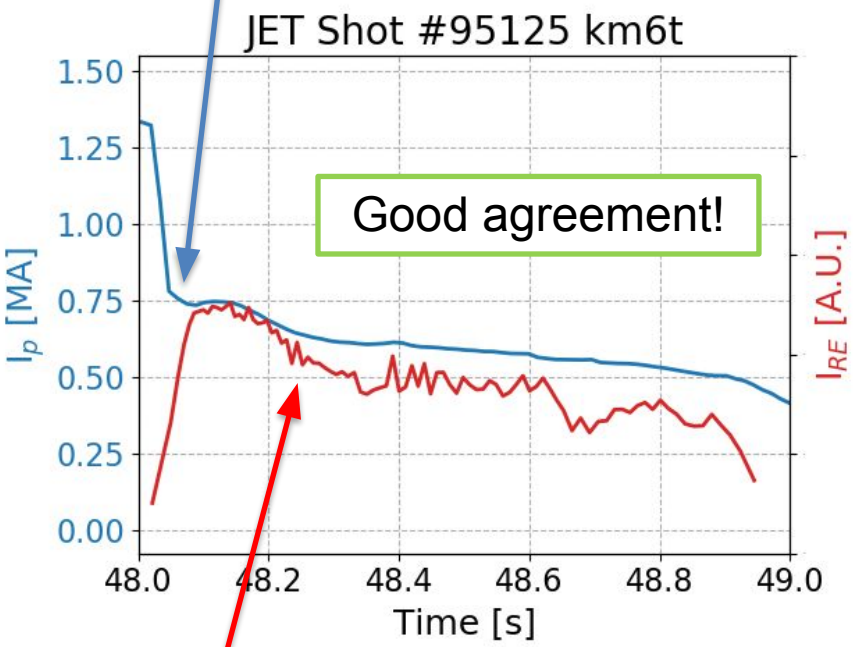
Work in progress

95775, 95137

Runaway Current Reconstruction



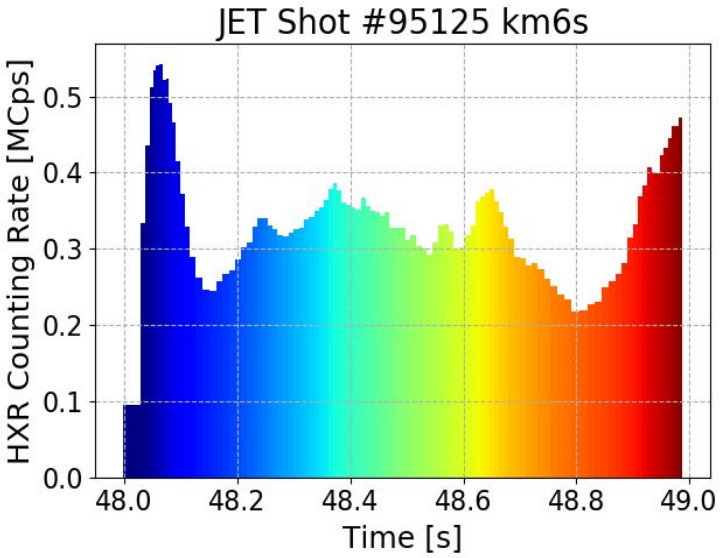
Plasma current measured at JET after the disruption

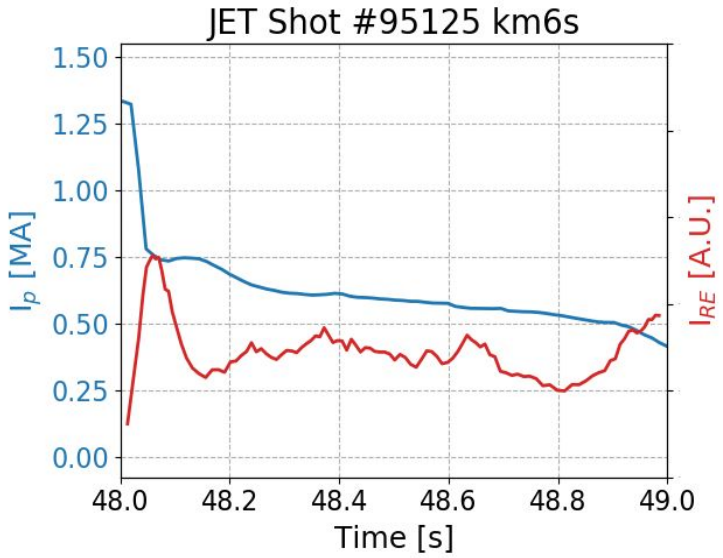


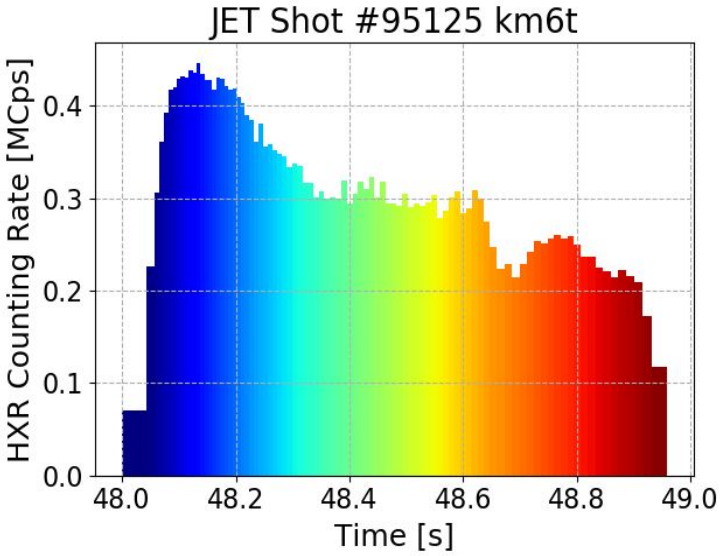
Good agreement!

RE current computed from the reconstructed RE energy distribution

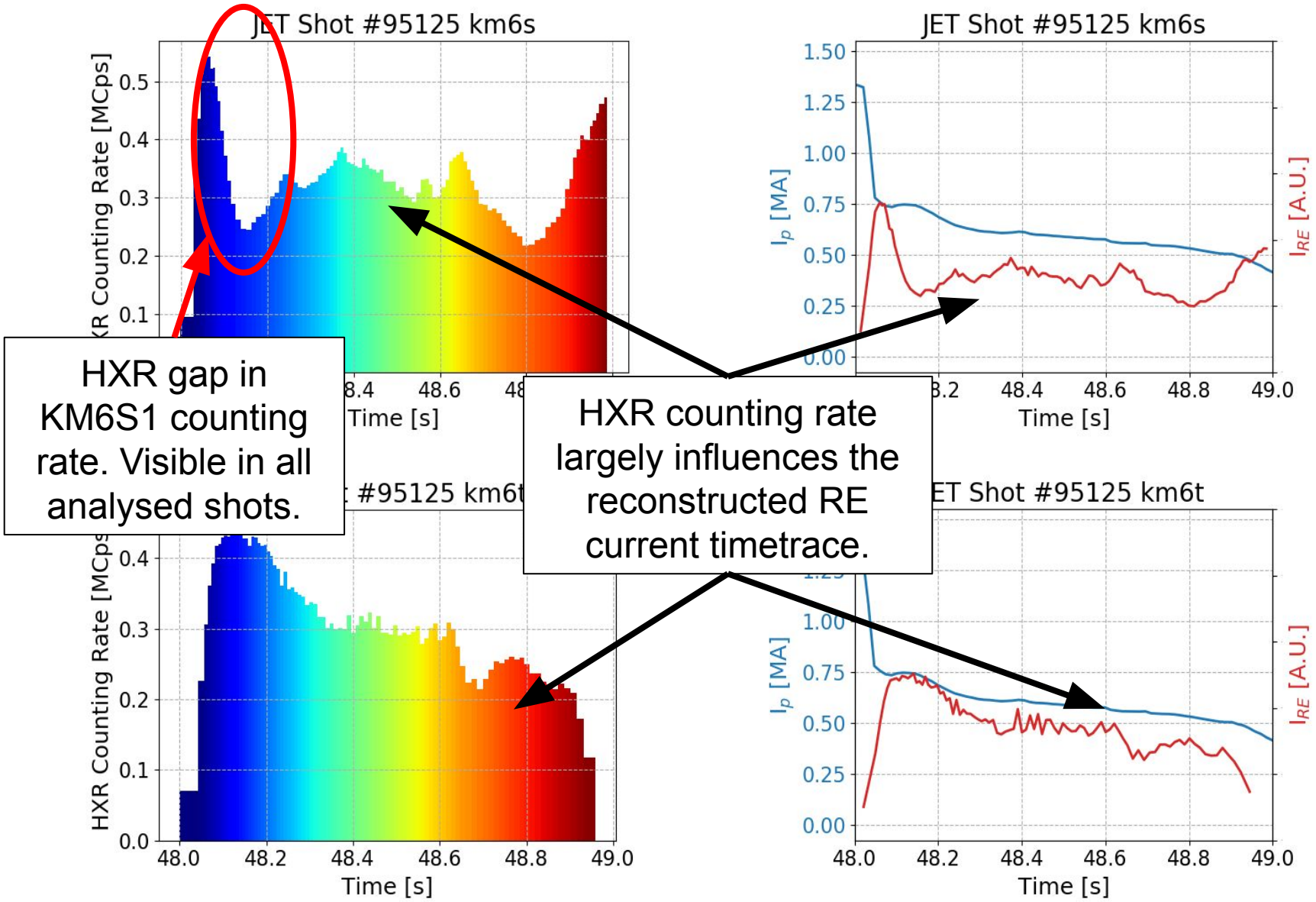
Runaway Current Reconstruction







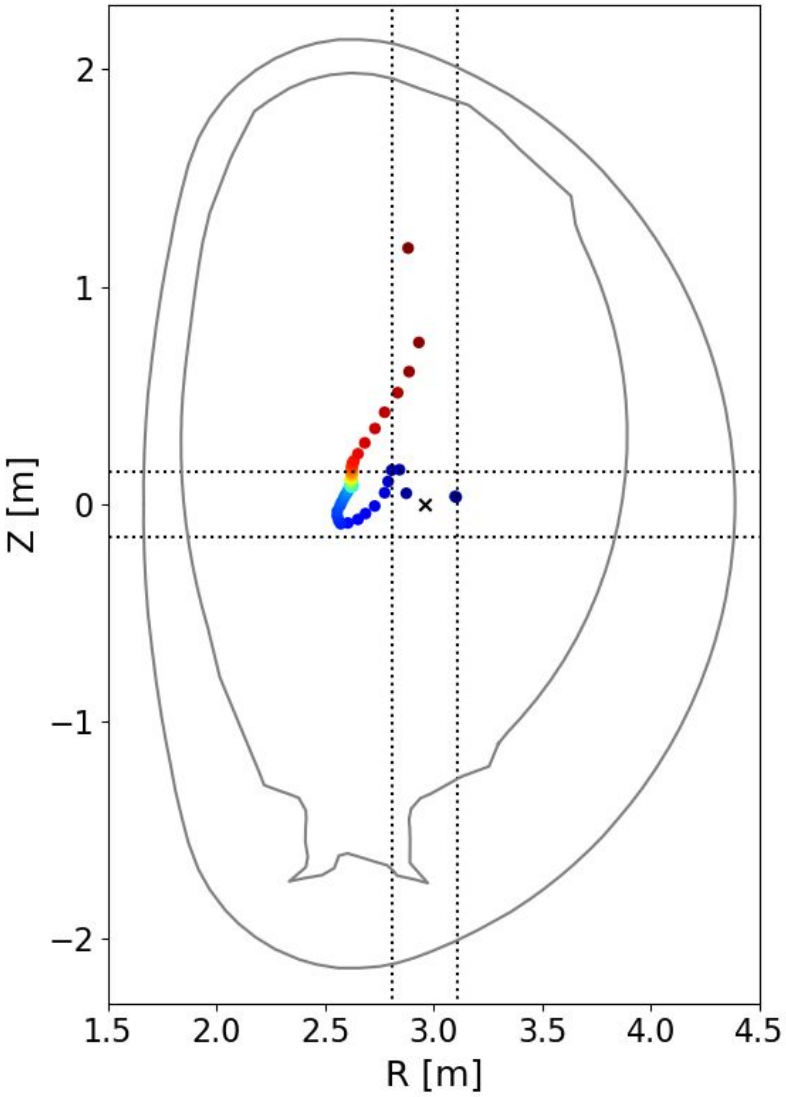
Runaway Current Reconstruction

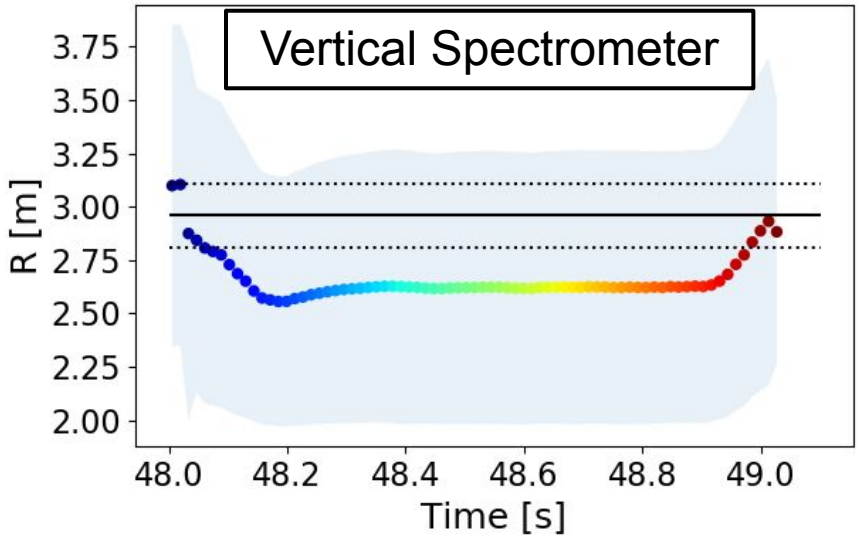


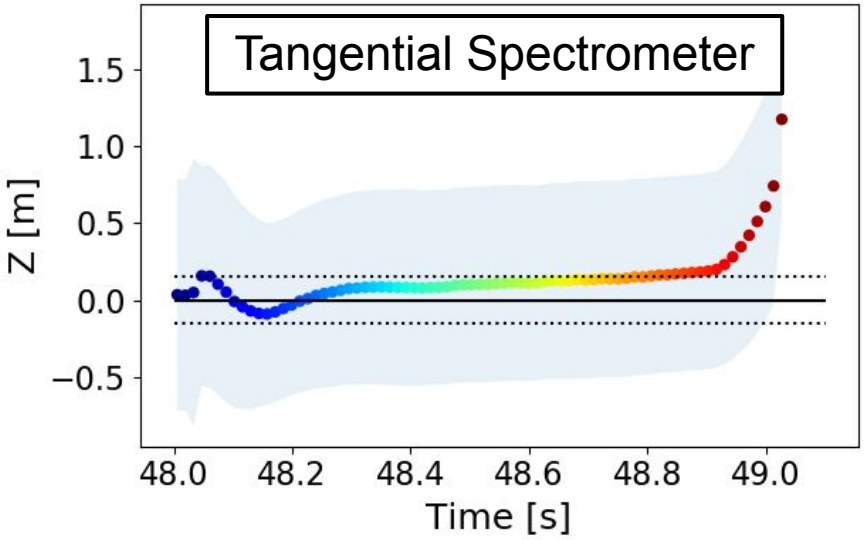
HXR gap in KM6S1 counting rate. Visible in all analysed shots.

HXR counting rate largely influences the reconstructed RE current timetrace.

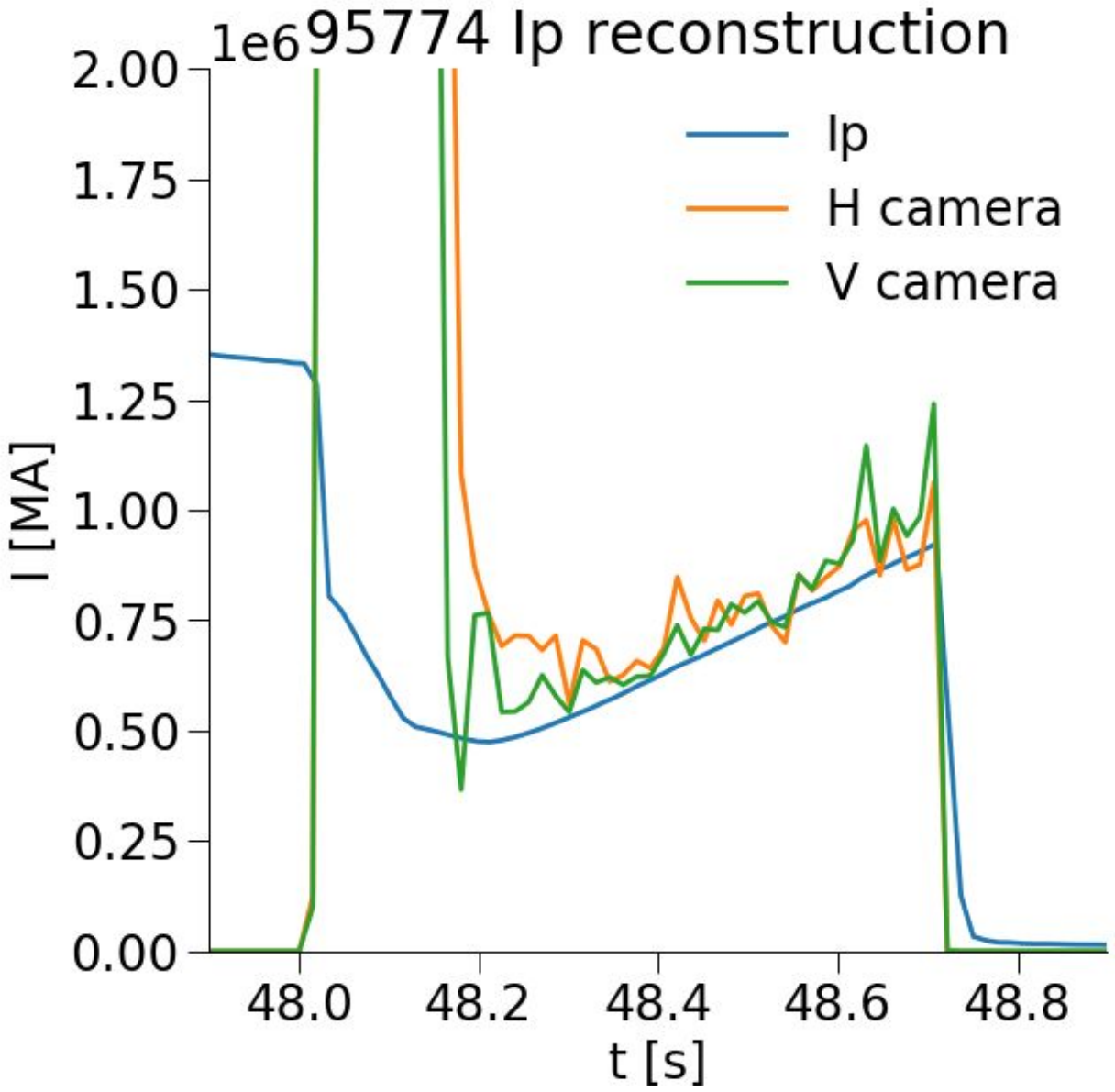
Beam Geometry





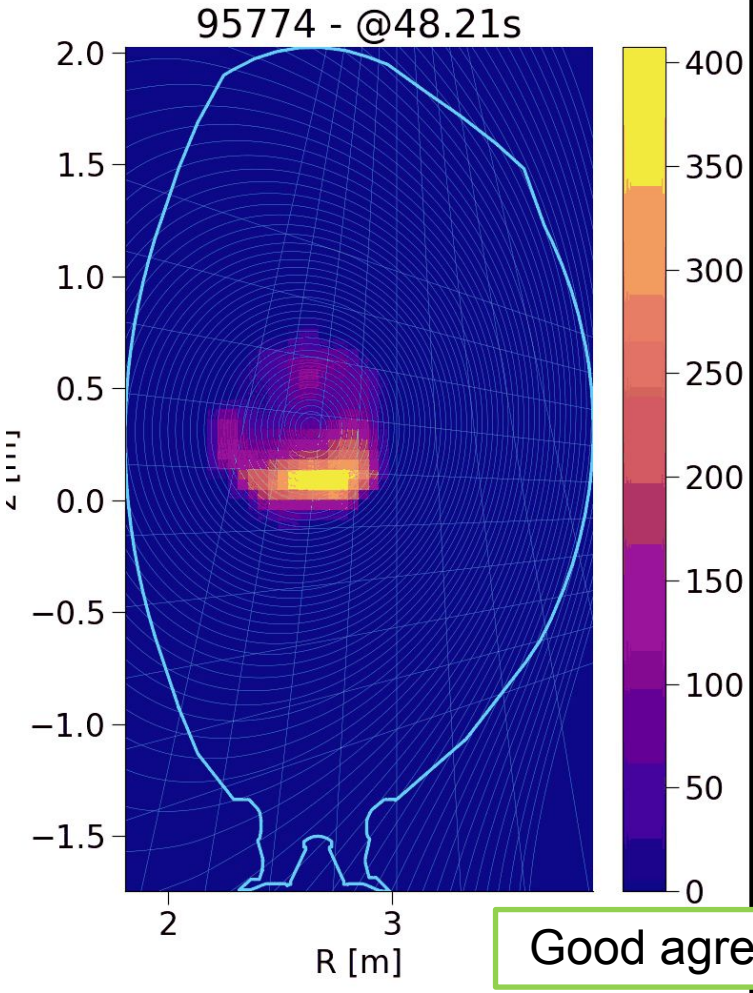


Beam Geometry

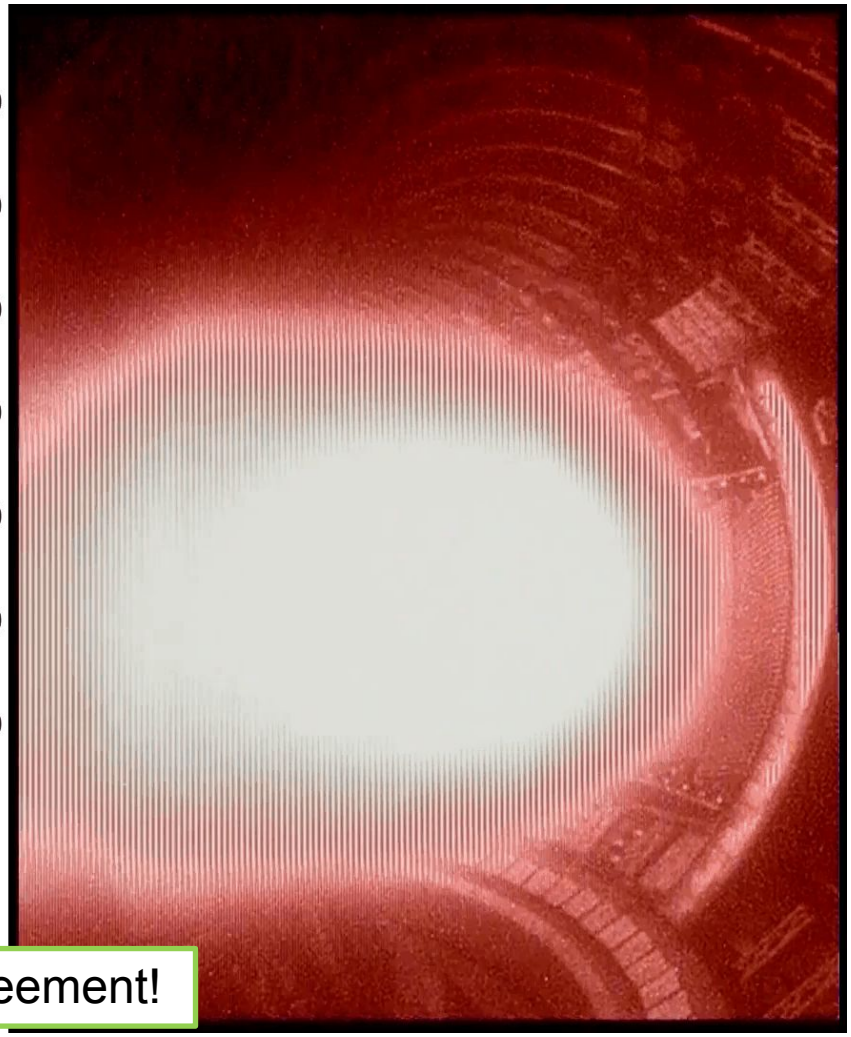


Tomographic Reconstruction

Tomographic reconstruction of the gamma camera data



JET Camera



Good agreement!

Conclusions

- It is possible to recover the **RE energy distribution function** from the measured HXR spectra with ~10 ms time resolution.
- First **tomographic reconstructions of the RE beam** show good agreement with other diagnostics.
- Systematic **analysis of the JET discharges** is currently undergoing.