Istituto per la Scienza e Tecnologia dei Plasmi

Consiglio Nazionale delle Ricerche

Nefertari

The GEM Soft X-Ray Diagnostics on RFX-mod2

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ISTP - CNR, Milan, Italy

International Conference on Diagnostics for Fusion Reactors

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CONSORZIO RFX
Ricerca Formazione Innovazione

The GEM Soft X-Ray Diagnostic on RFX-mod2

Soft X-Rays in Fusion Plasmas

- Bremsstrahlung
- Cyclotron emission
- Radiative recombination
- De-excitation of atoms or ions

Provide Information On

- Electron temperature
- Electron density
- Suprathermal electron components
- Impurity content and concentration
- Hydromagnetic structures

GEM Detectors Can Measure

- Intensity (counters)
- Location (cameras)
- Energy (spectrometers)

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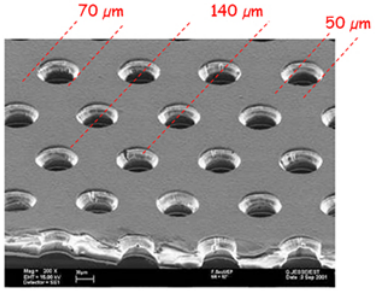
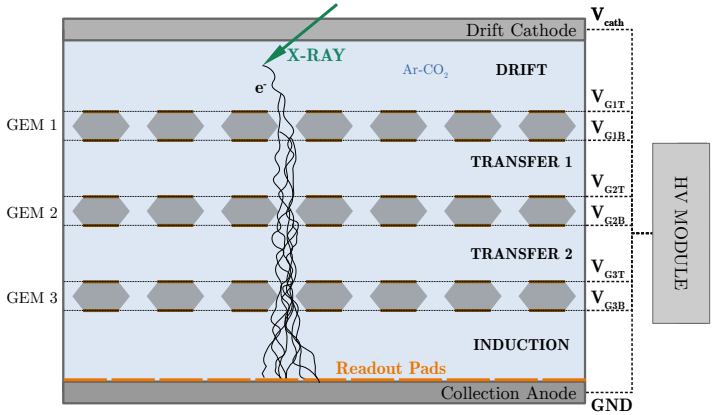
The Gas Electron Multiplier (GEM)

- **Kapton foil** with **copper layers** on both sides, chemically perforated with a high density of **holes**.
- Intense **electric field** in the holes, where **electron multiplication** occurs.
- **Stacks of GEMs** can be used to achieve **higher gain**.
- **Electrical signals** induced on the **readout anode**.





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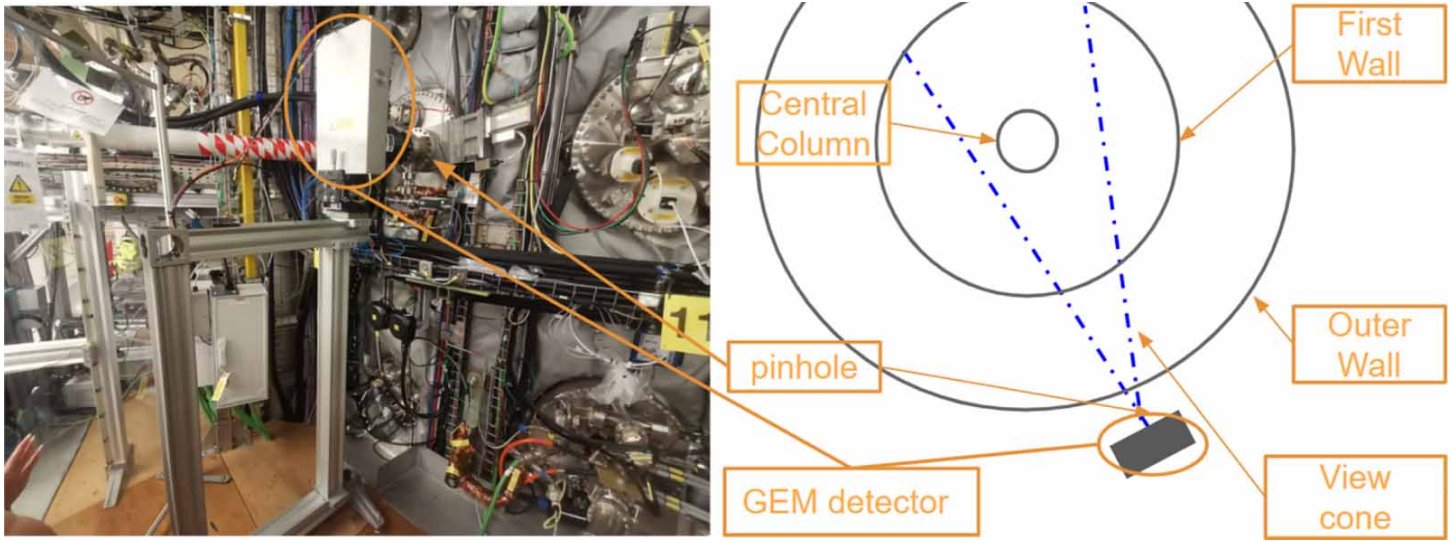
Experience on Fusion Devices

GEMs on Tokamaks

Installed on FTU, EAST, KSTAR, WEST, **MAST-U**.



A. Celora et al., 2025, Meas. Sci. Technol. 36 016019

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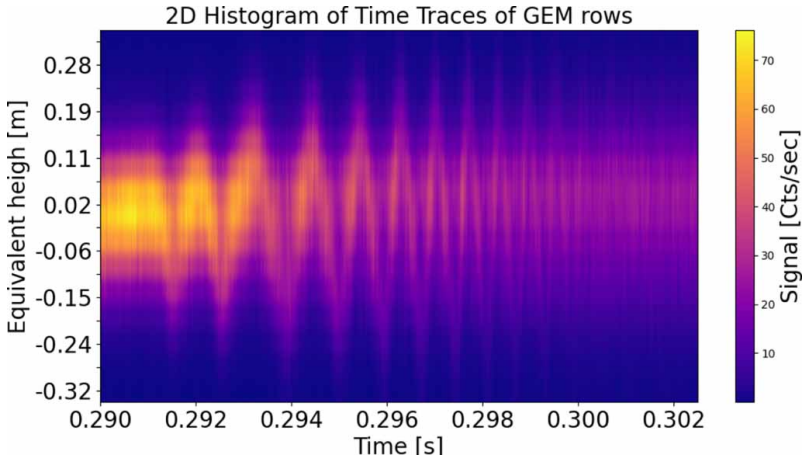
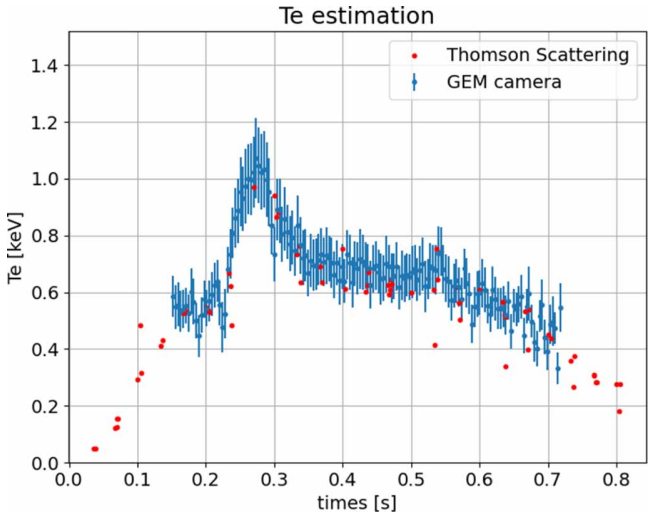
Results on MAST-U

Observation of **MHD** activity: **Snake instability**.



Computation of **electron temperature** from the **Bremsstrahlung spectrum**.



A. Celora et al., 2025, Meas. Sci. Technol. 36 016019

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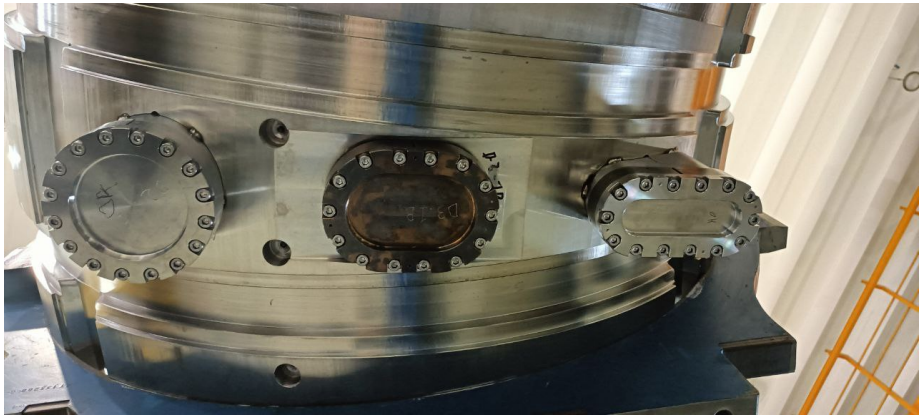
GEM LoS for RFX-mod2

Upper Ports of Sector 12

- 2 GEM cameras.
- Central and external ports.
- Vertical line of sight.
- Views core and edge plasma.
- Pinhole configuration.



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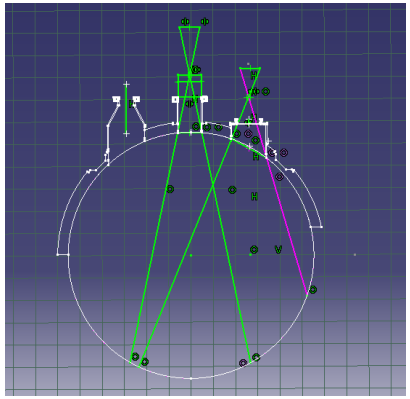
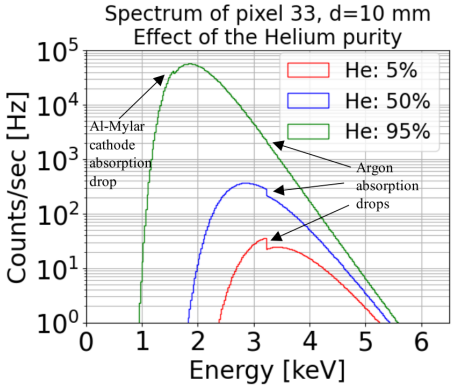
Synthetic Detector Data

Revolt

- **Ray tracing algorithm** for **synthetic** diagnostic **data**.
- **Isotropic** emission from each voxel.
- Includes **attenuators** (Air, Be, ...).
- Includes **detector efficiency**.

F. Guiotto et al., Development of a GEM-Based Diagnostic for Soft X-Ray Measurements Resolved in Space, Time, and Energy at RFX-mod2, submitted to Plasma Physics and Controlled Fusion (2025)





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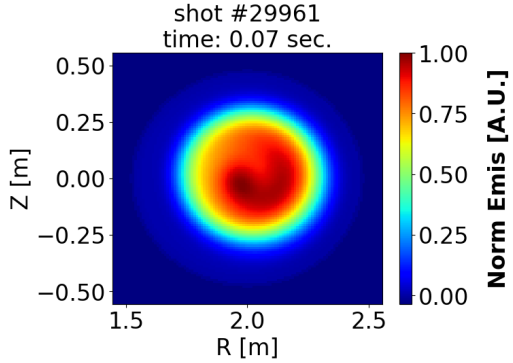
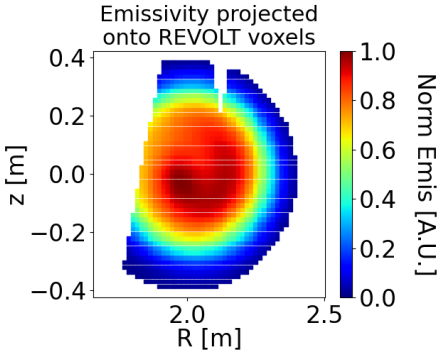
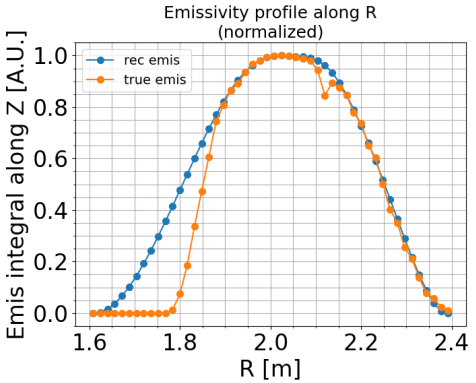
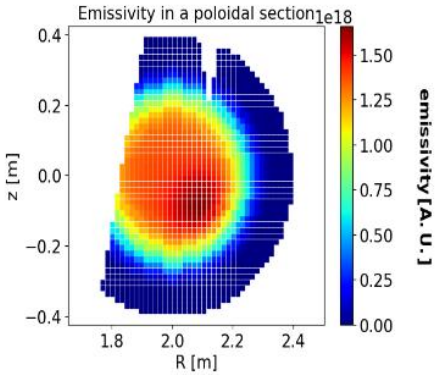
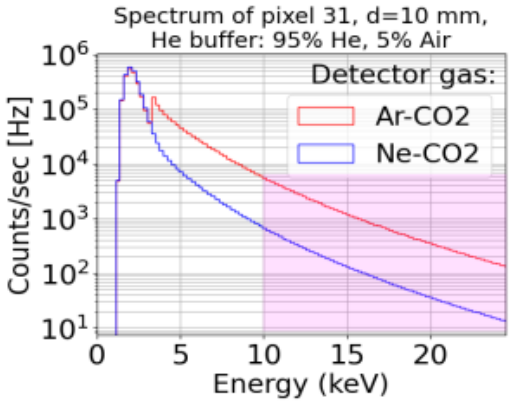
Tomographic Reconstruction

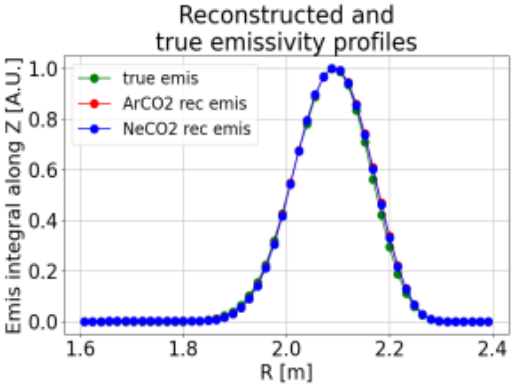












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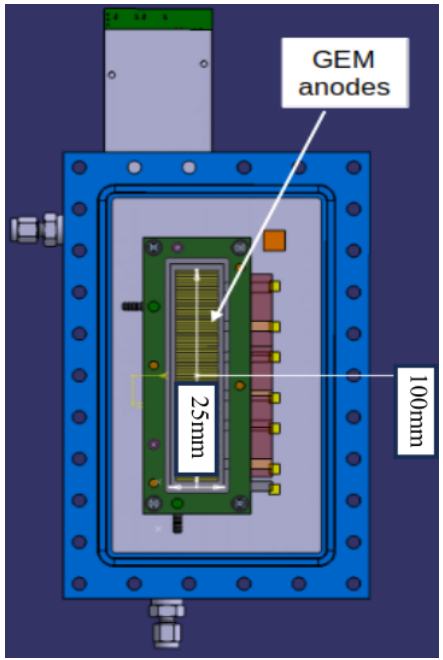
Detector Design

Detector Parameters

- 3 GEM foils ($110 \times 25\text{mm}^2$) @ $350\,\text{V}$.
- Drift region $3\,\text{mm}$ @ $1\,\text{kV}\,\text{cm}^{-1}$.
- Transfer regions, $1\,\text{mm}$, $2\,\text{mm}$ @ $3\,\text{kV}\,\text{cm}^{-1}$.
- Induction region $1\,\text{mm}$ @ $5\,\text{kV}\,\text{cm}^{-1}$.
- **Ar-CO_2** (70%-30%) at atmospheric pressure.
- **Padded** anode array 1x64.
- **Beryllium** window $200\,\mu\text{m}$ thick.
- Variable pinhole diameter $0.1\,\text{mm}$ to $10\,\text{mm}$.
- Helium buffer.
- Readout electronics: **GEMINI ASIC** and **FPGA**.



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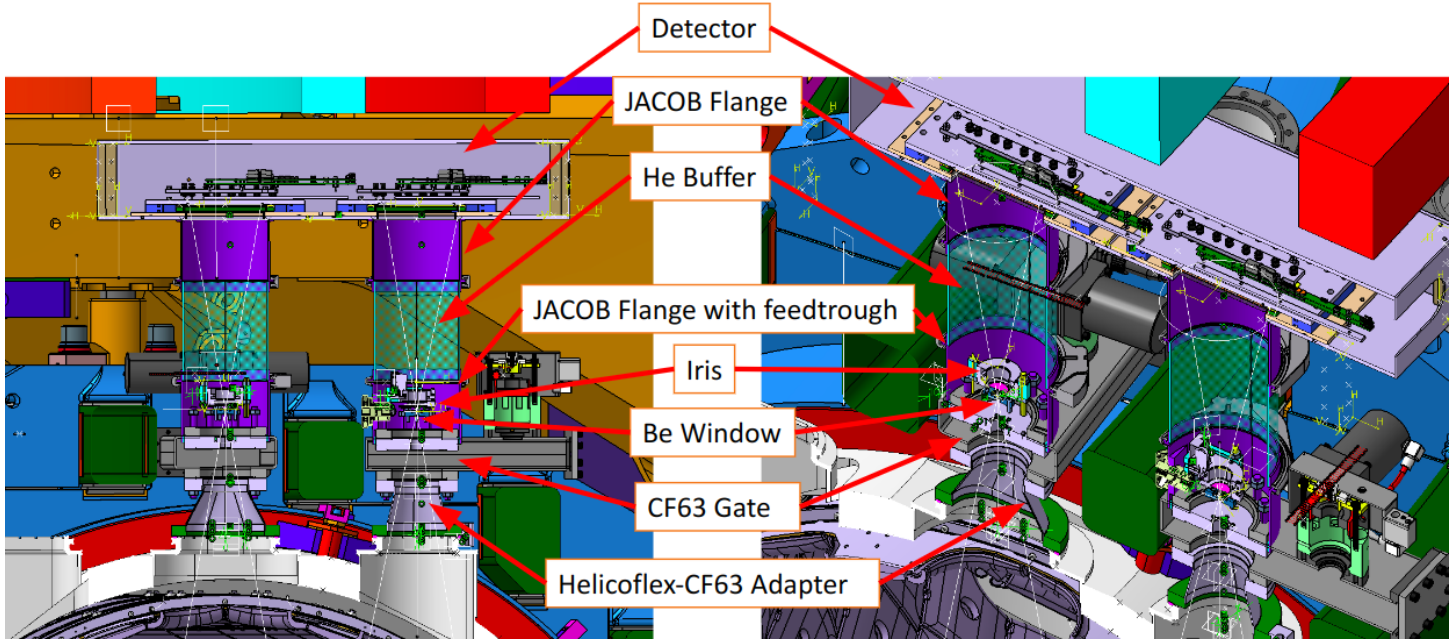
Detector Installation



- GEMs are located between the vessel and the magnetizing coils.
- The magnetic field in the GEM region is **non-negligible** (up to $0.3\,\mathrm{T}$).

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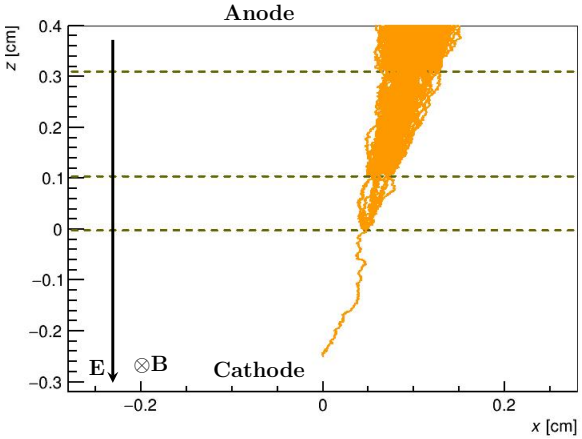
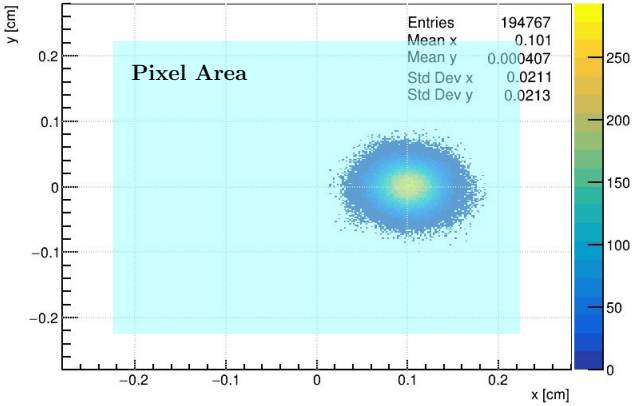
Magnetic Field Considerations

- **Garfield++** simulations of the electron paths in the GEM.
- The electron drift is negligible for $B < 0.5\,T$.
- Revision of the **readout electronics** to avoid interference with the magnetic field.





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Conclusions

- GEM foils have been manufactured.
- Padded anodes are in production.
- New readout electronics are under development.
- Assembly and testing of the detectors in 2025.
- Installation on RFX-mod2 in early 2026.

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