

# EN-003 Fusion Density Under Ambiguity v1.0 - Release Package

This directory contains Engineering Note EN-003 and its reproduction package: the script that recomputes every [N] value of the note, its pinned dependencies, and the complete output of the reported run.

**DOI:** [10.5281/zenodo.23105860](https://doi.org/10.5281/zenodo.23105860)

**Version:** 1.0

**Publication date:** 2026-10-02

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**Scale-Time Dynamics LLC**

## Contents

- `EN-003_Fusion-Density-Under-Ambiguity.pdf` — engineering note.
- `en003_reproduce.py` — reproduction script described in Appendix B.
- `requirements.txt` — pinned dependencies of the reported run.
- `reference_output.txt` — complete output of the reported run.
- `LICENSE.txt` — copyright and CC BY 4.0 reuse terms.
- `SHA256SUMS` — SHA-256 checksums for every other release file.

Generated caches, bytecode, virtual environments, logs, and operating-system metadata such as `.DS_Store` are intentionally excluded.

## Recommended citation

Dupke, André (2026). *Fusion Density Under Ambiguity: Preserving Useful Density Under Unresolved Fringe Counts — A Density-Risk Decision for Two-Color Interferometer-Polarimeter Systems in Magnetic-Confinement Fusion* (Engineering Note EN-003, Version 1.0). Zenodo.

<https://doi.org/10.5281/zenodo.23105860>

## Verified environment

- CPython 3.11.15
- NumPy 2.4.4
- SciPy 1.17.1

The reported run took about four minutes on two processor cores, with a peak memory use of about 4 GB.

## Verification

From this release directory, using a temporary environment outside the package:

```
python3 -m venv /tmp/en003-release-verify
/tmp/en003-release-verify/bin/python -m pip install -r
requirements.txt
/tmp/en003-release-verify/bin/python en003_reproduce.py >
/tmp/en003-output.txt
diff reference_output.txt /tmp/en003-output.txt && echo "EN-003:
output identical to the reference"
```

In the verified environment the output matches `reference_output.txt` line by line. The random streams are fixed by seeds, and the deterministic values (lattices, parity dimensions, constants, bounds for zero events) are independent of the platform. On other platforms or BLAS builds, floating-point rounding can move individual decisions that lie at a decision boundary, so event counts may differ by a few. Other numpy versions can change the random streams themselves; the stochastic values then move within the intervals stated in the note.

Validate package integrity from the release directory with:

```
shasum -a 256 -c SHA256SUMS
```

## Deposit metadata

- **Resource type:** Publication, technical note
- **Title:** Fusion Density Under Ambiguity: Preserving Useful Density Under Unresolved Fringe Counts — A Density-Risk Decision for Two-Color Interferometer–Polarimeter Systems in Magnetic-Confinement Fusion
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- **Version:** 1.0 (Engineering Note EN-003)
- **Publication date:** 2026-10-02

- **Language:** English
- **License:** Creative Commons Attribution 4.0 International (CC BY 4.0)
- **Keywords:** fusion plasma diagnostics; two-color interferometry; polarimetry; fringe jump; wrapped phase; integer ambiguity resolution; marginalization; density control; ITER TIP; DIII-D; risk-coverage; Scale-Time Theory
- **Related works (cites):**  
Scale-Time Theory 11.0, [10.5281/zenodo.21221364](https://doi.org/10.5281/zenodo.21221364);  
EN-001, [10.5281/zenodo.18904052](https://doi.org/10.5281/zenodo.18904052);  
Wrapped Phase, Protected Qubits 2.0.1, [10.5281/zenodo.21760092](https://doi.org/10.5281/zenodo.21760092);  
EN-002, [10.5281/zenodo.21833505](https://doi.org/10.5281/zenodo.21833505)
- **Description:** the abstract of the note, in a formula-free form for the deposit form:

Interferometers that measure the line-integrated electron density of magnetically confined fusion plasmas observe a wrapped phase. The whole number of fringes accumulated since the start of a discharge is absent from the data and has to be restored by assumption; when refraction, pellets or disruptions interrupt the signal, the restored count can jump by whole fringes, and the density supplied to plasma control inherits the error. Current practice treats such an event as integer recovery: select a branch, correct the count, report the density.

This note proposes a decision placed on the quantity the control loop consumes. For the two-color interferometer-polarimeter topology that ITER uses as its primary density-control diagnostic, the estimator marginalizes the posterior over integer hypotheses and continuous uncertainty, reports the probability that the density error exceeds a stated tolerance through a conservative bound, and declares the density available when the bound stays within a chosen risk level, with or without a resolved fringe count. The note supplies the measurement model, the slip lattices of the DIII-D prototype and of the ITER design, a joint decision margin in the metric of density and path priors, and an observability accounting that counts nuisance drifts and priors explicitly.

In a Gaussian model of the prototype with assumed priors and phase noise, the most probable fringe count is wrong in 29 % of decisions and the count confidence stayed below 99 % in every simulated decision, so a rule that waits for a resolved count withholds every density; the marginalized estimate keeps every density available and lowers the rate of total density errors beyond a 0.05-fringe tolerance from

$6.6 \times 10^{-5}$  to  $1.7 \times 10^{-5}$ . For the ITER wavelength pair the estimate gains nothing, and withholding uncertain densities lowers the error rate about a hundredfold. With the estimate held fixed, the density-risk gate and a count-confidence gate accepted identical decisions in both configurations. The demonstrated benefit is therefore one of estimation: marginalization preserves useful density despite unresolved counts, while an advantage of gating on the density over gating on the count remains a research question. All results are model-conditional and depend on stated search bounds.

Operational reliability, real-time feasibility and any consequence for fusion performance remain open. The note therefore specifies how others can test the decision on measured data: implementation tests, raw-signal replay and bench optics with independent truth; comparison at matched availability against hard branch selection, integer-aperture acceptance, deployed correctors and machine-learning baselines, with estimate and gate compared separately; named falsifiers, invalidators and a retirement criterion. It is offered for evaluation by groups with access to interferometer–polarimeter records.