Validation of a Bayesian method

for current tomography

at WEST

J. De Rycke[1], D. Mazon[2], J. Morales[2], P. Moreau[2], G. Verdoolaege[1], and WEST team*

1: Department of Applied Physics, Ghent University, 9000 Ghent, Belgium

2: IRFM, CEA, F-13108 Saint-Paul-Lez-Durance, France

*See https://irfm.cea.fr/en/west/west-team/

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Overview

– Bayesian current tomography at DEMO

– Methodology for WEST

– Systematic error correction

– Validation at WEST and results

– Conclusions and future work

DEMO IDA CURRENT TOMOGRAPHY

– DEMO

  – Synthetic data

  – Exploit diagnostic synergies

– Integrated data analysis

  – Pick-up coils, flux loops, saddle coils

– Current tomography

  – Infer 2D tomogram

   – Calculate plasma parameters of interest
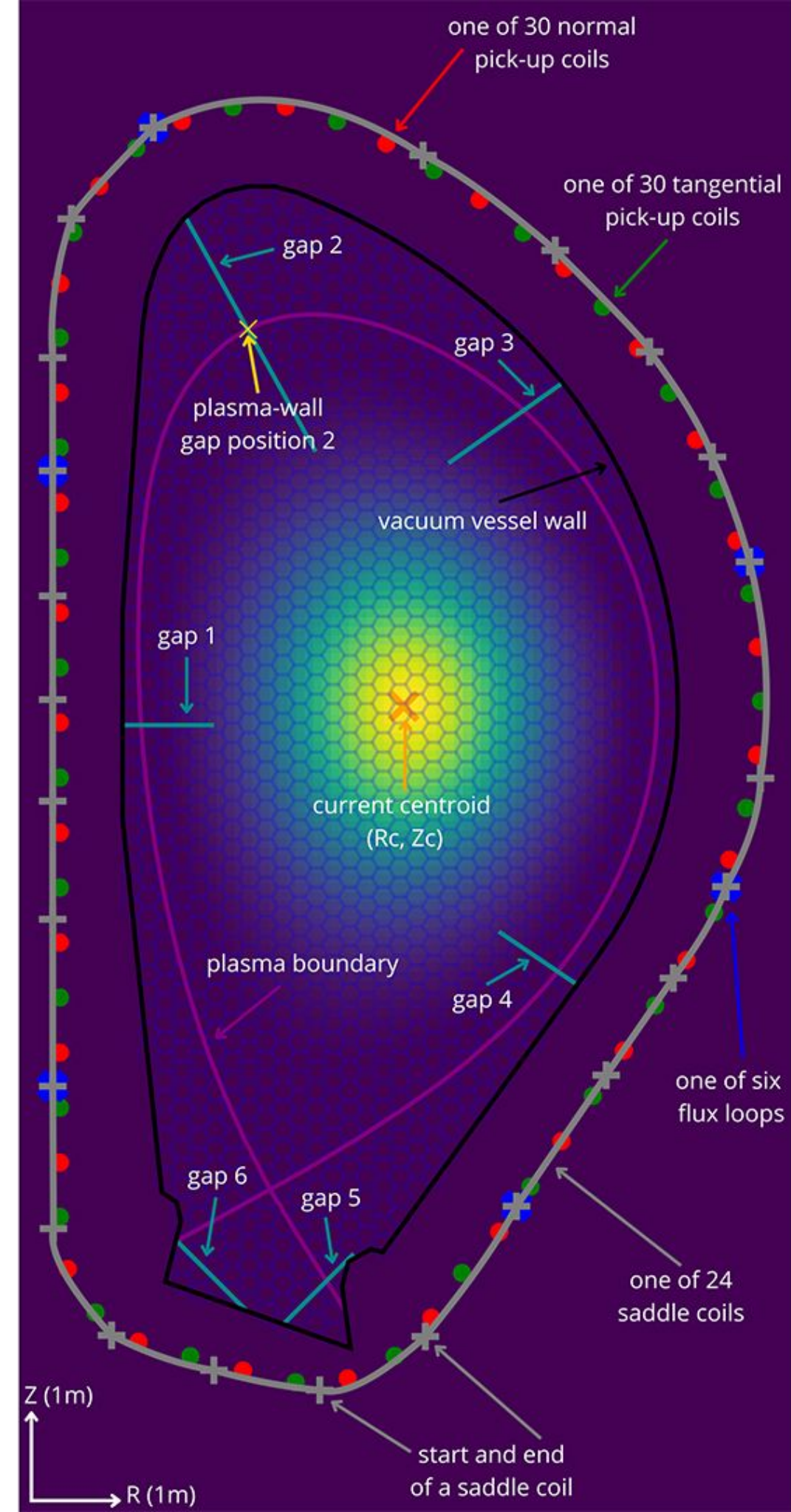
METHODOLOGY FOR WEST

– Data: 110 pick-up coils

  – FM: From current filament to poloidal magnetic field (B)

  – ϵ: error on measurement

– Multiple contributions

  – J: toroidal current density

  – S: active and passive structures

  – IC: iron core

– $\epsilon \sim N,\ \Sigma = \mathrm{diag}(\sigma_1^2, \sigma_2^2, \ldots, \sigma_{110}^2)$

$$B = FM_J \cdot J + FM_{IC} \cdot IC + FM_S \cdot S + \epsilon$$

MAGNETIC FIELD CONTRIBUTIONS

– J needs a prior (Gaussian) distribution
  – Zero mean, blueprint covariance $\Sigma^J_{prior} = (D^T \cdot D)/(N-1)$, $D \in \mathbb{R}^{N \times M}$
  – N previous current tomograms

– IC non-linear effects
  – Model explicitly
  – Zero mean, Gaussian process prior
  – $\Sigma^{IC}_{prior} = \sigma^2 \exp(-(\mathbf{x}_i - \mathbf{x}_j)^2/(2l^2))$

– S values are provided
  – $\Sigma^S = \text{diag}(\sigma_1^2, \sigma_2^2, \ldots, \sigma_s^2)$
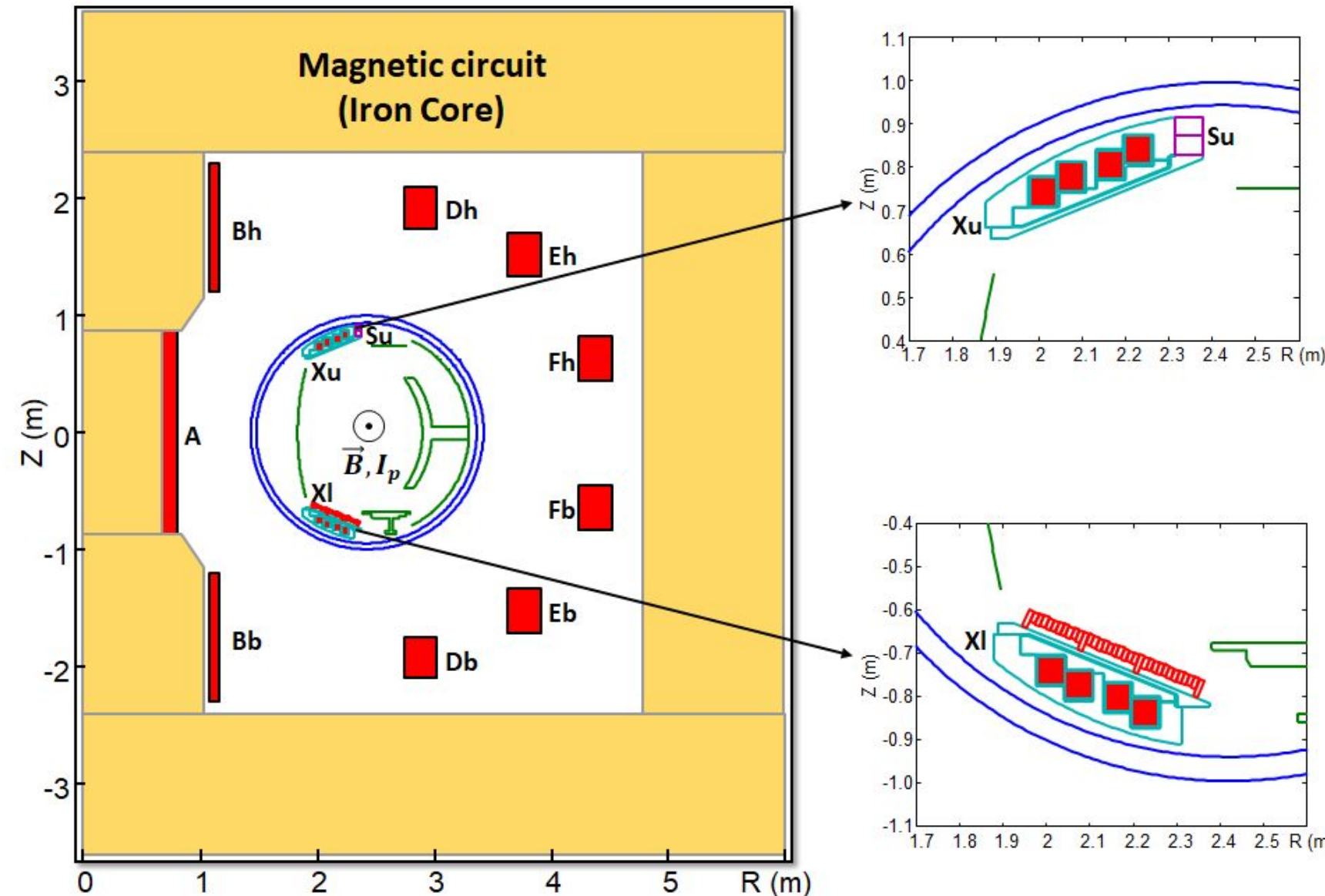
$$B = FM_J \cdot J + FM_{IC} \cdot IC + FM_S \cdot S + \epsilon$$

BAYESIAN INFERENCE

$$P(A|B) = P(B|A) \cdot P(A) / P(B)$$

$$P(A) \sim N(\mathbf{0}, \Sigma_{prior})$$

$$B' = B - FM_S \cdot S, \quad \Sigma_{meas'} = \Sigma_{meas} + FM_S \cdot \Sigma^S \cdot FM_S{}^T$$

Gaussian measurements + linear FM => Gaussian P(B|A)

Gaussian P(B|A) and Gaussian P(A) => Gaussian P(A|B)

$$\Sigma_{post} = (FM^T \cdot \Sigma_{meas'}{}^{-1} \cdot FM + \Sigma_{prior}{}^{-1})^{-1}$$

$$\mu_{post} = \mu_{prior} + \Sigma_{post} \cdot FM^T \cdot \Sigma_{meas'}{}^{-1} \cdot (B' - FM \cdot \mu_{prior})$$

PLASMA PARAMETERS OF INTEREST

– Total current

  – Conventient benchmark

– Current centroid

  – Barycentre of current tomogram

– X-point

  – Saddle point: poloidal magnetic field vanishes

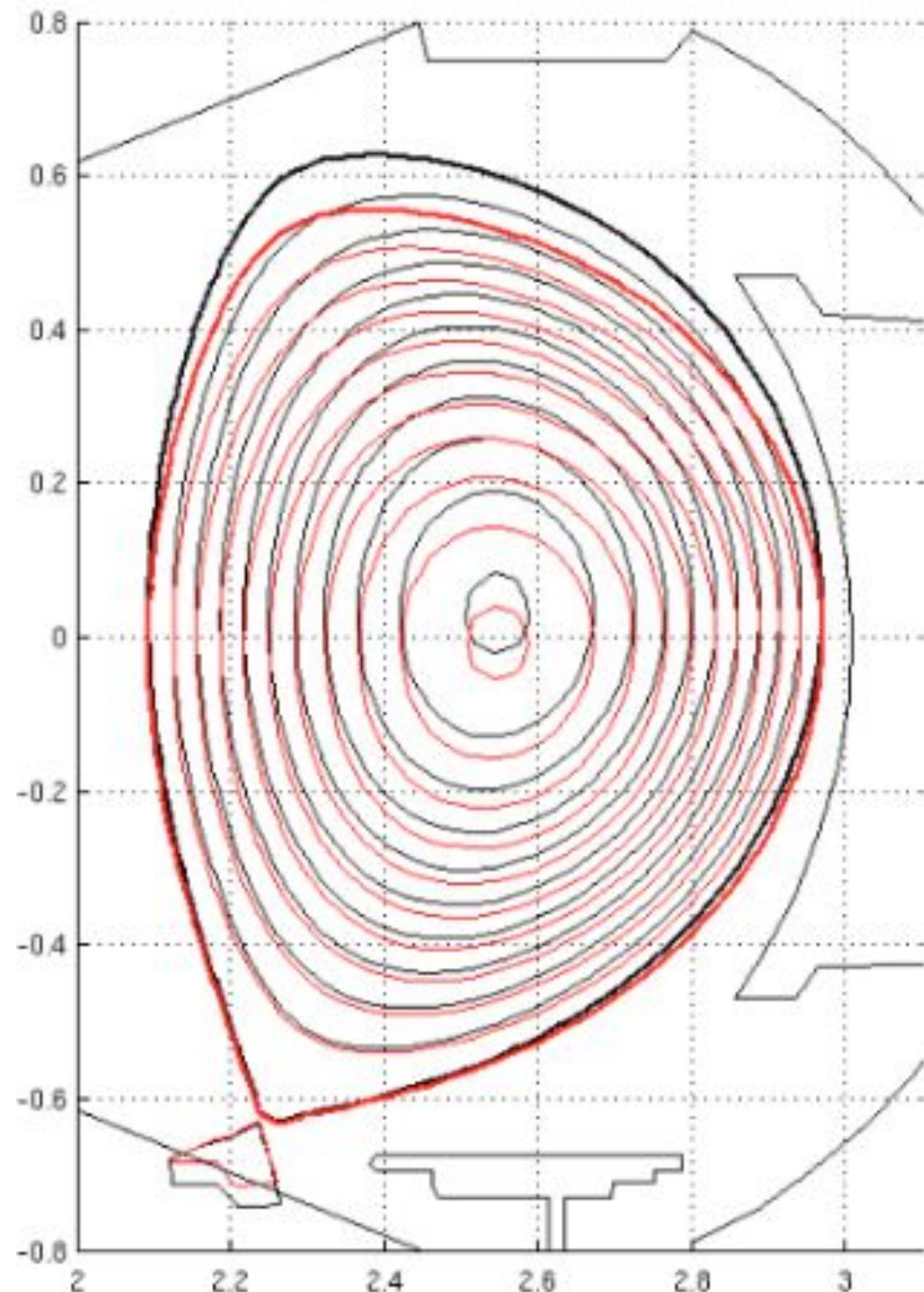 – Indicates last closed flux surface

INFERENCE TRACKS (shot 60000)

– Plasma stable at time index 50-90

  – Use NICE current tomograms 50-59 for construction of prior

– Infer current tomogram at time index 60

  – Save the inferred current tomogram

– Continue with NICE 51-60 for index 61   (NICE-driven)
– Also use NICE 51-59 + OWN 60 for index 61   (Inference-driven)

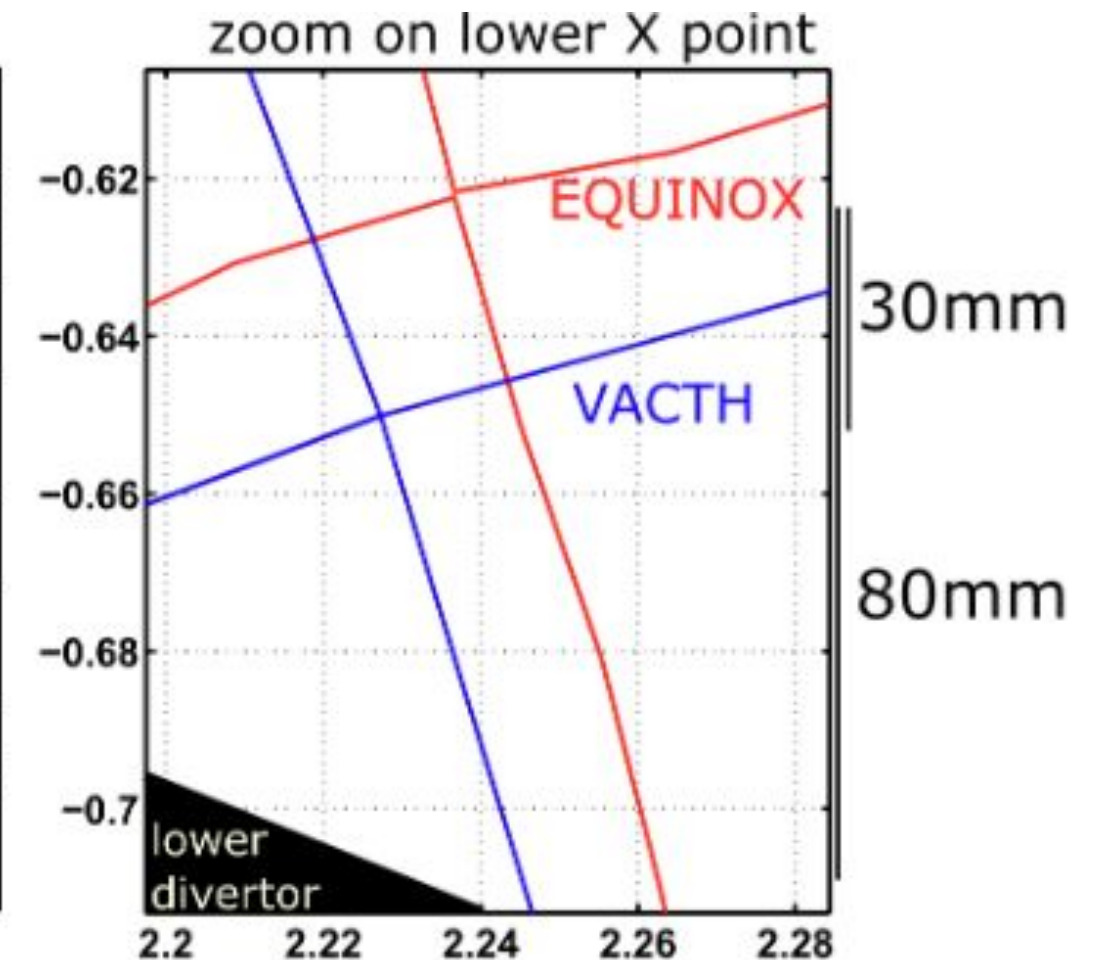– Continue until time index 90
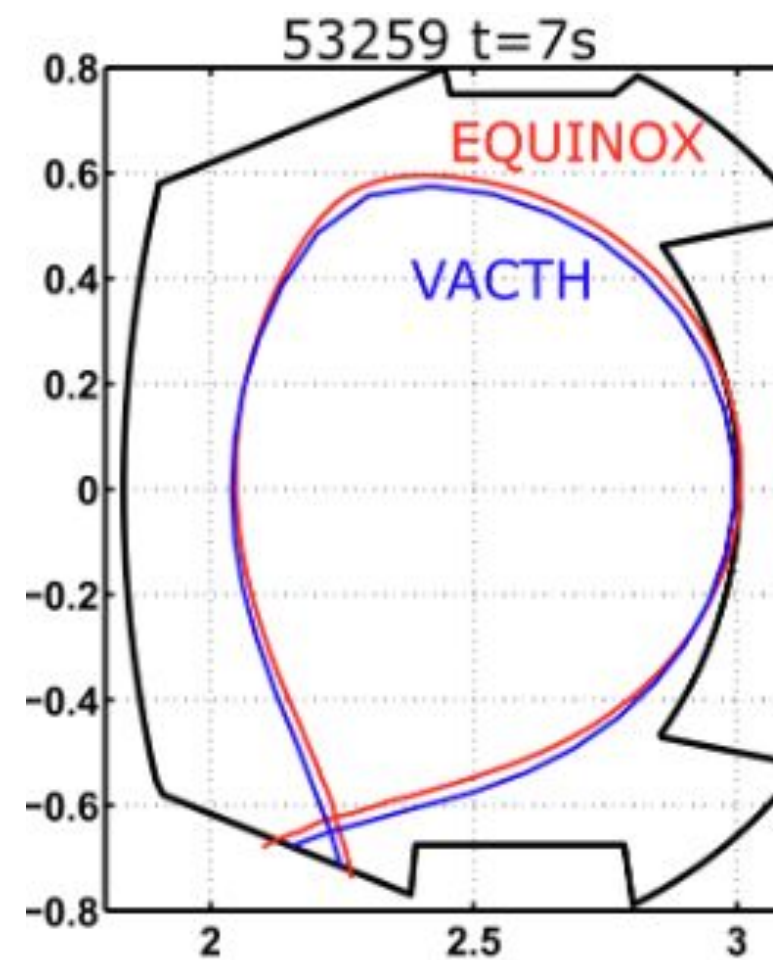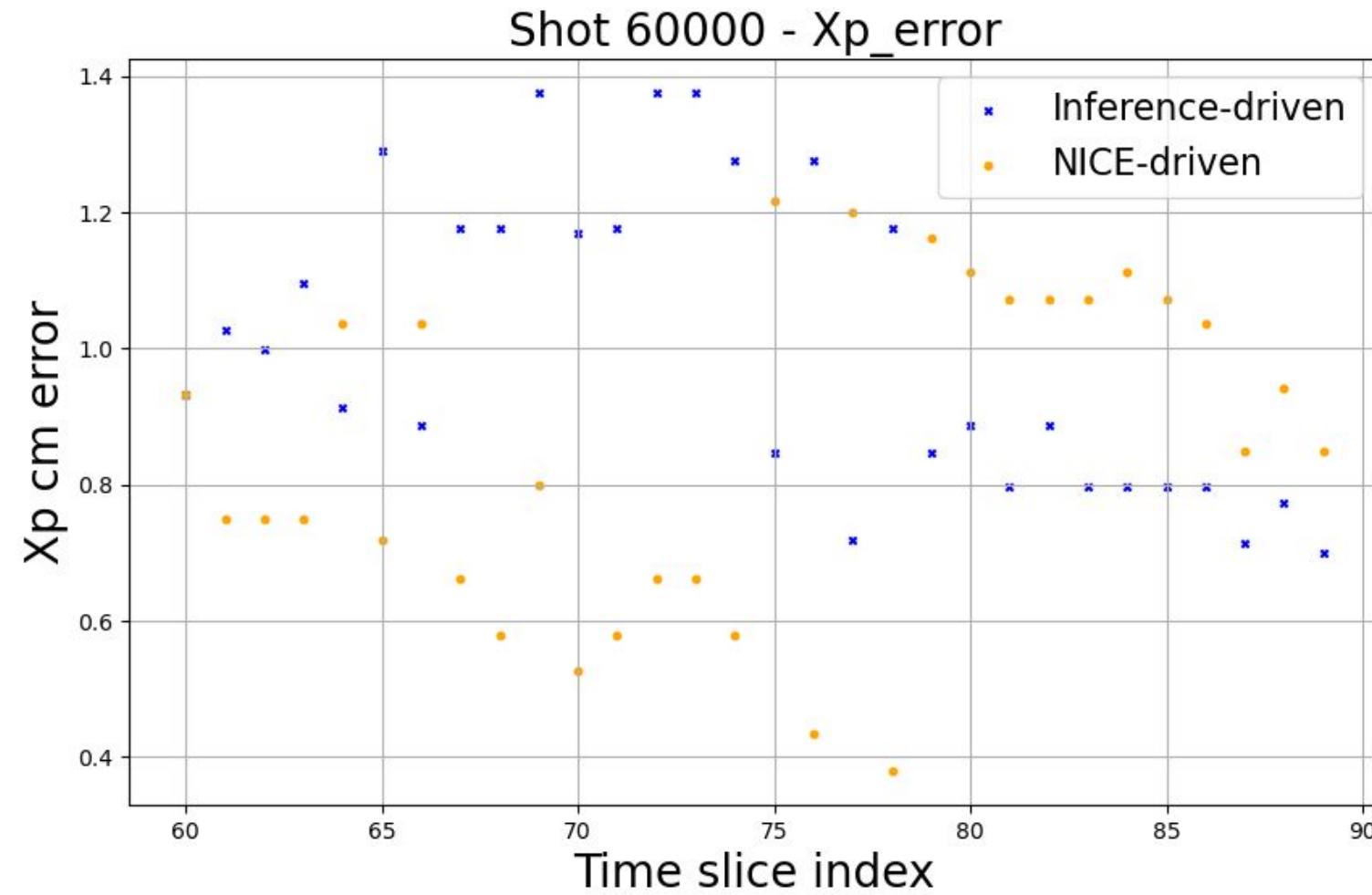
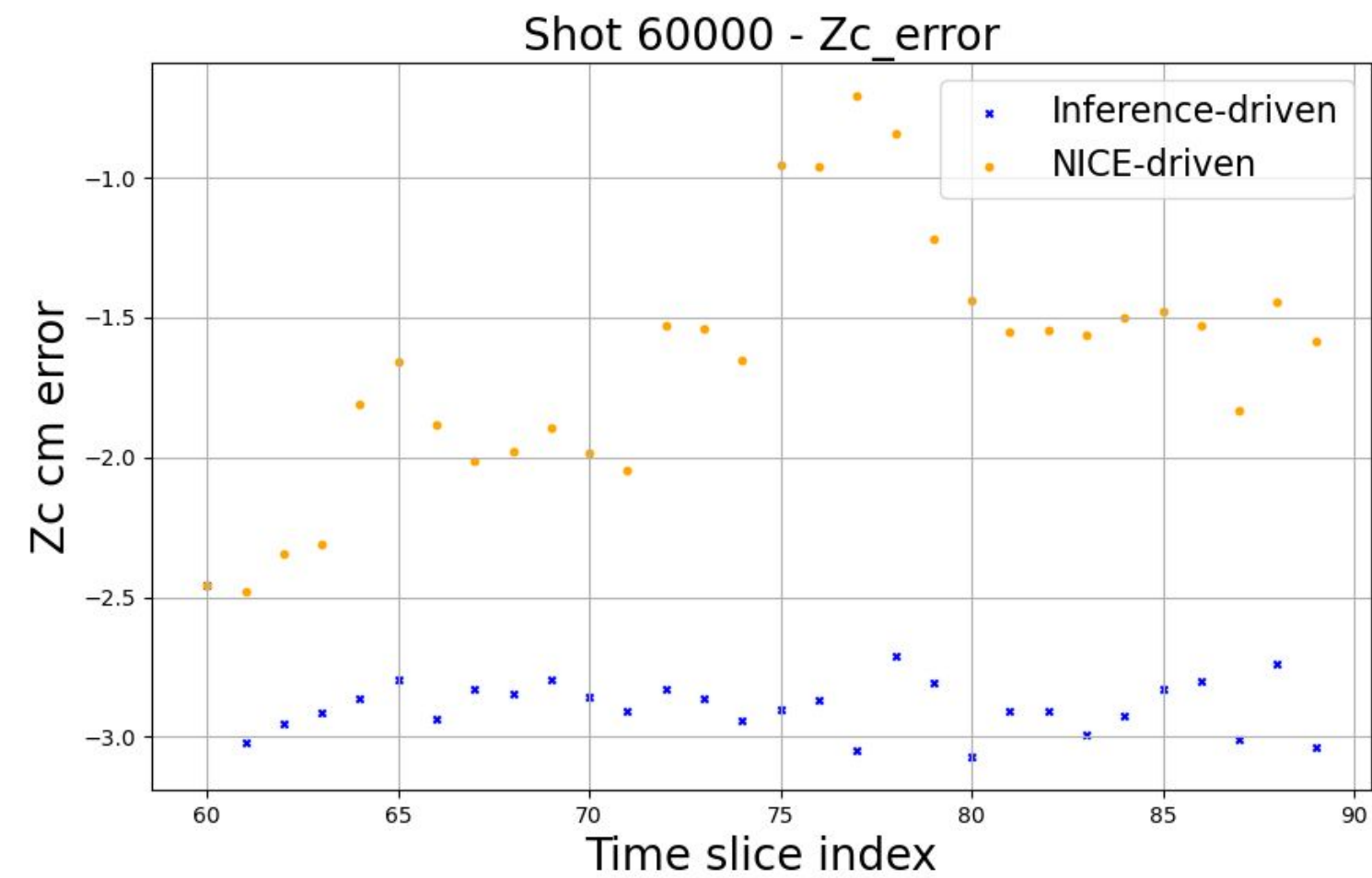# SYSTEMATIC ERROR CORRECTION

Compress   Shift

Assumes Xpoint to be correct   Focus on current centroid

Shot 60000 - Rc_error

Shot 60000 - Zc_error

Shot 60000 - Xp_error

ADJUSTING BIASED PRIORS WITH DIAGNOSTICS

- Add large values to diagonal of prior covariance
  - Less informed prior

- Less informed prior -> higher effect from diagnostic values

- Use centroid reconstruction error to shift AND scale entire distribution

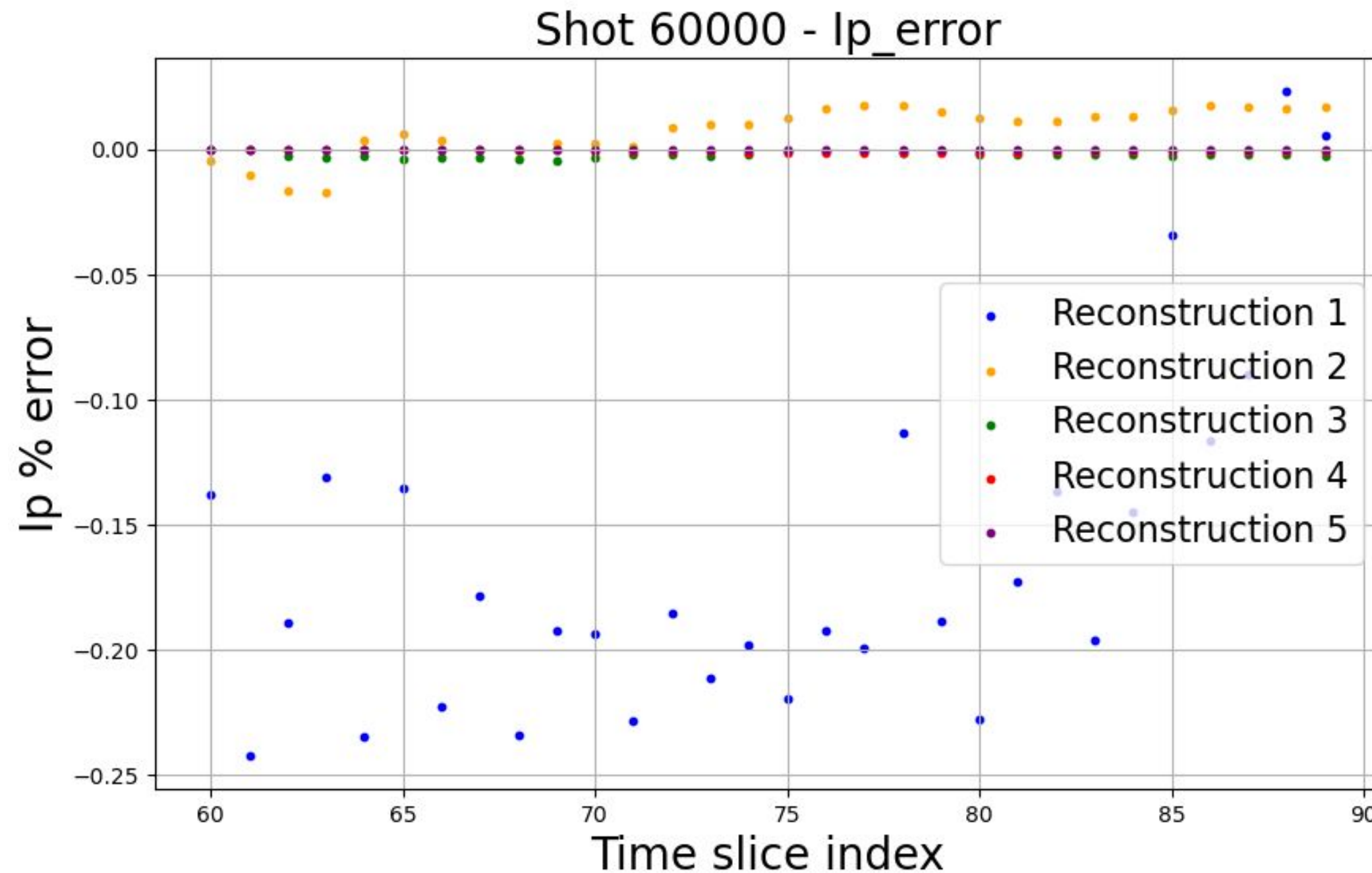$$P(A|B) = \frac{P(B|A)\ P(A)}{P(B)}$$

CONVERGENCE OF CENTROID ERROR

– Repeat until convergence
  – Shows that "simply shifting" is not entirely correct
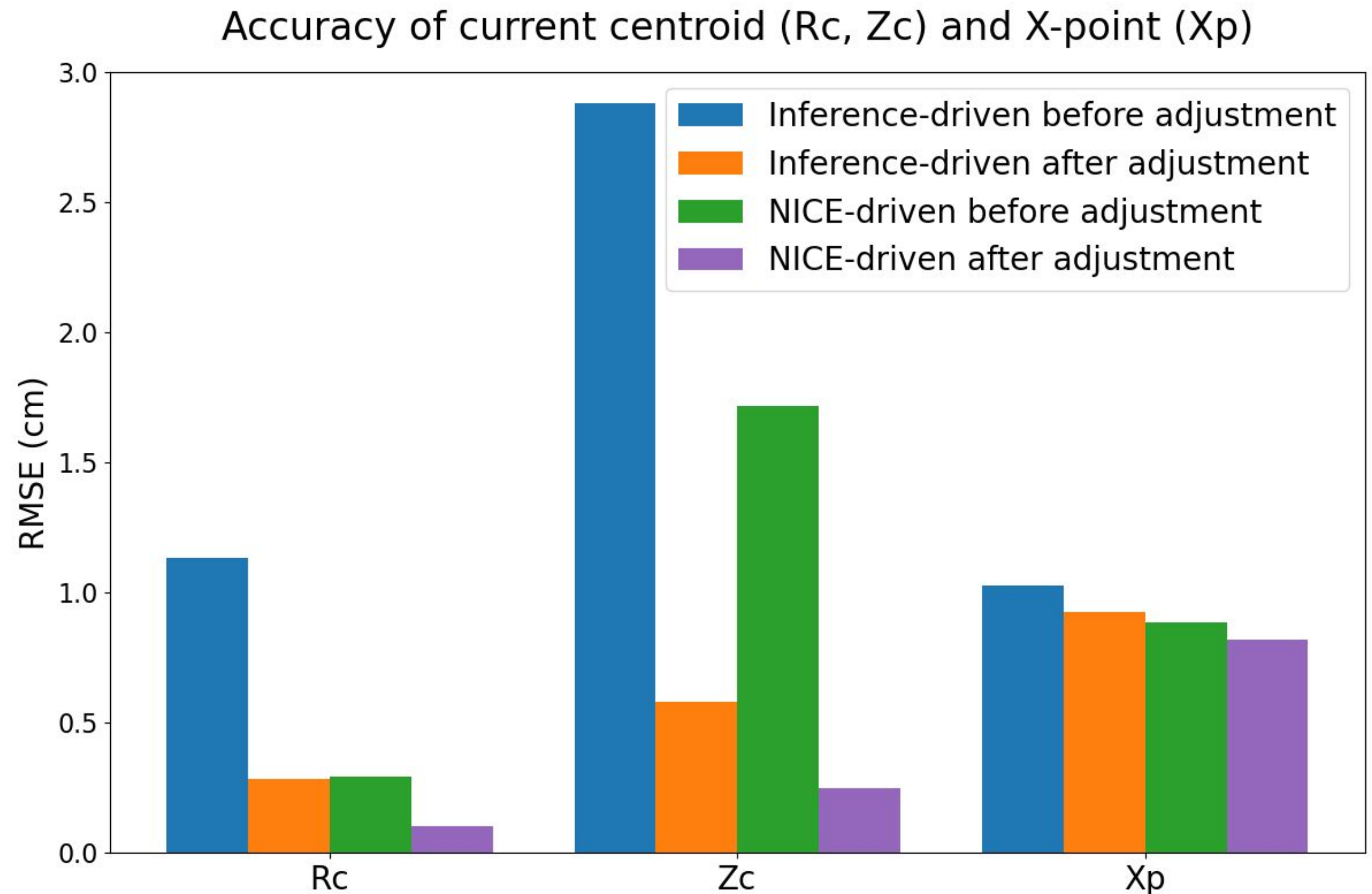 – Total mean shift in cm (Rc, Zc) = (0.94, -2.61)
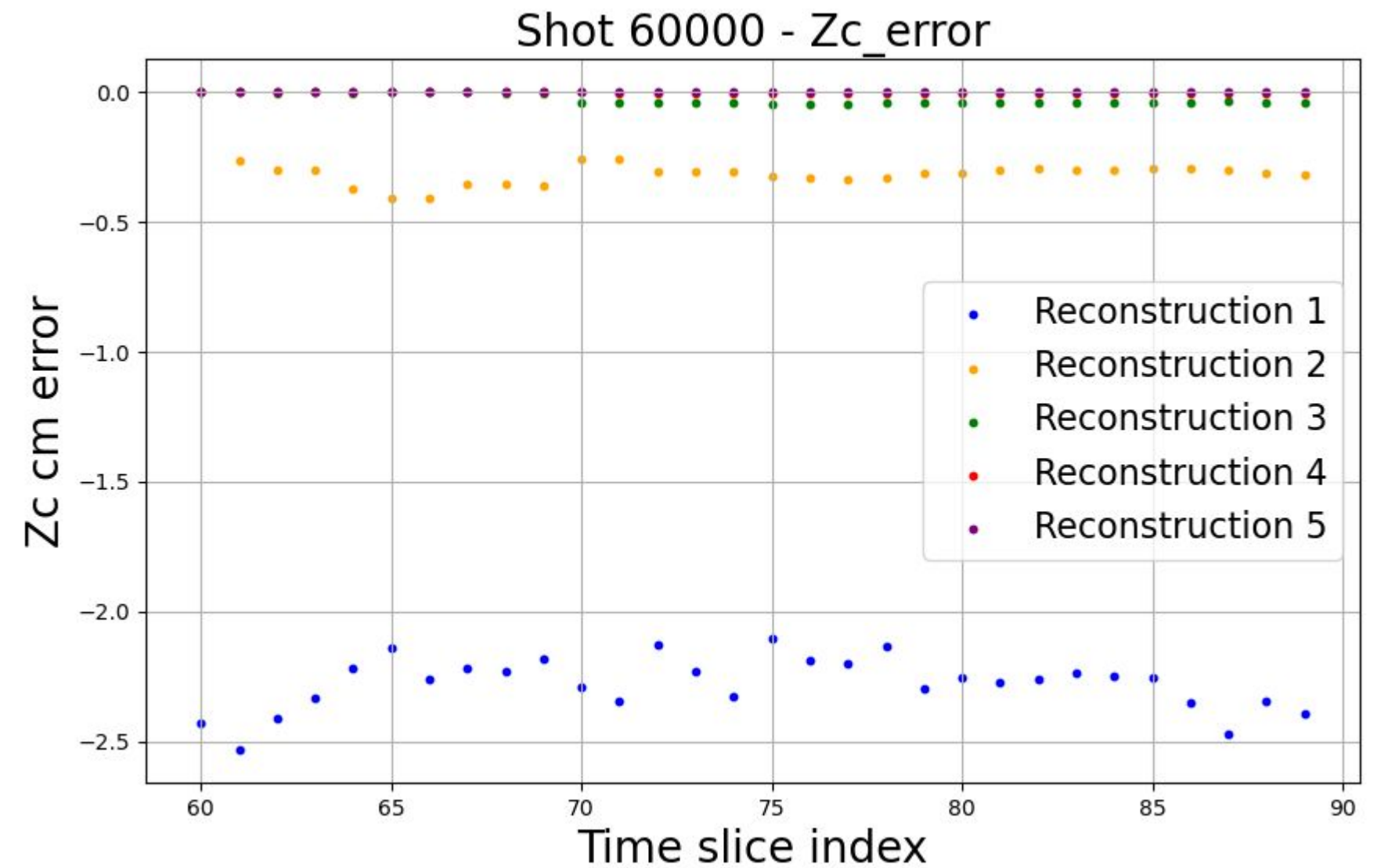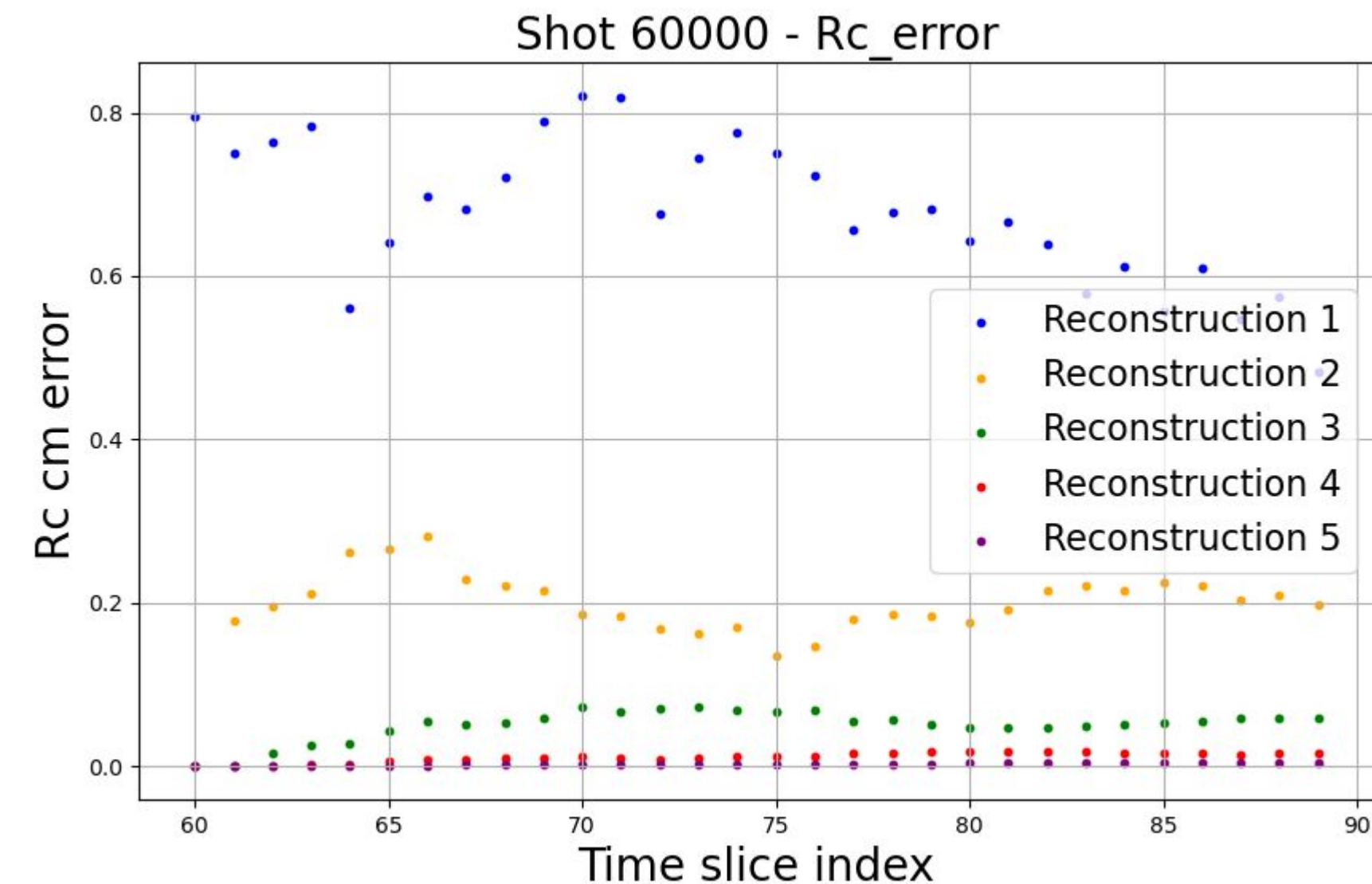
CONVERGENCE OF TOTAL PLASMA CURRENT

– Discrepancy between reported total current, and "summing the pixels"
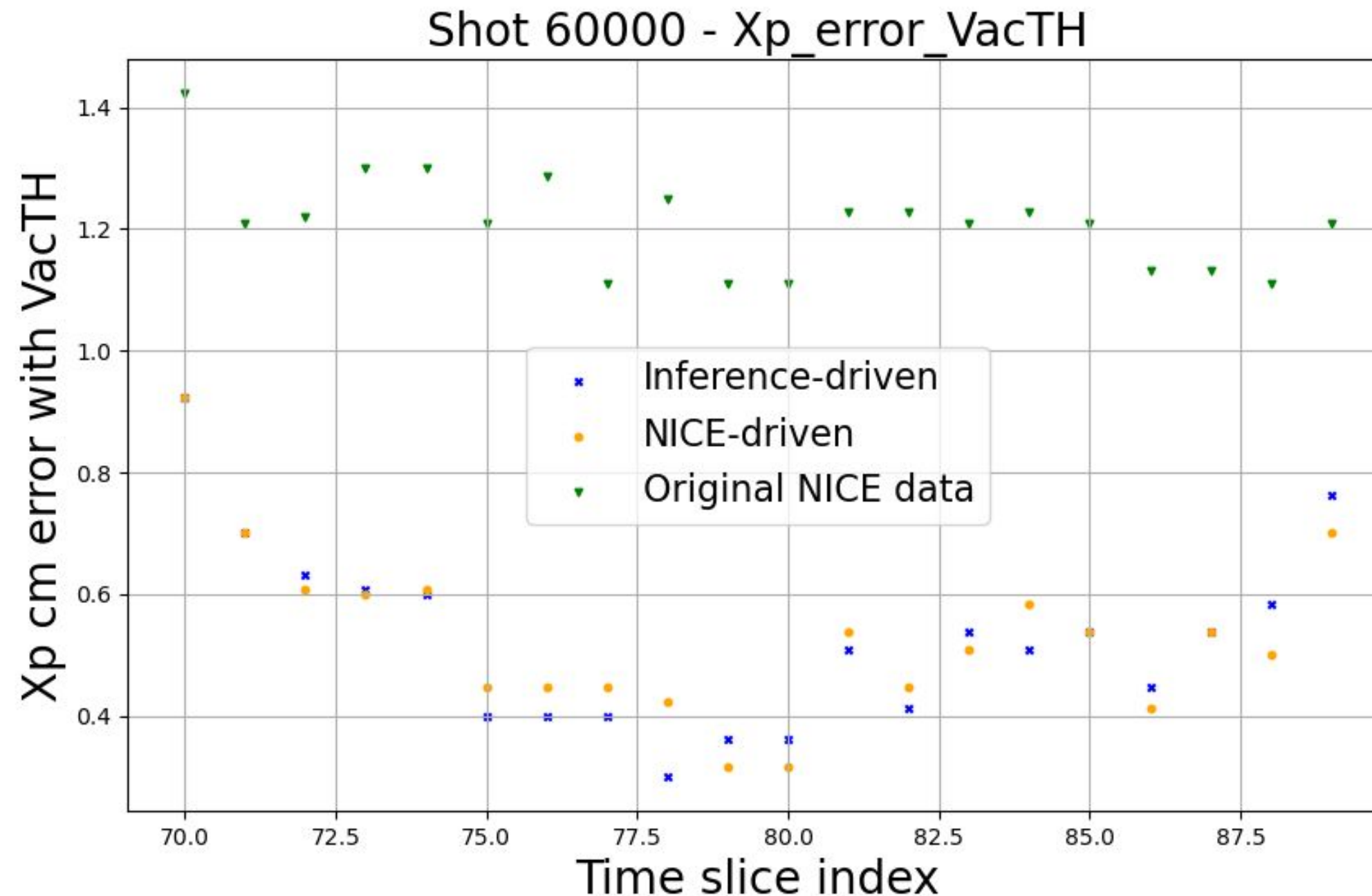
– Has effect on current centroid

– Before correction:
strong absolute difference
between Inference-
and NICE-driven

– After correction:
Strong improvement
centroid error
Improvement Xpoint error

– Xpoint improves
– Also systematic error

Accuracy of current centroid (Rc, Zc) and X-point (Xp)

Legend:
- Inference-driven before adjustment
- Inference-driven after adjustment
- NICE-driven before adjustment
- NICE-driven after adjustment

– Are the corrected tomograms actually "better"?

 – Compare to VacTH X-points

Shot 60000 - Xp_error_VacTH

Accuracy of the reconstructed X-point compared to VacTH
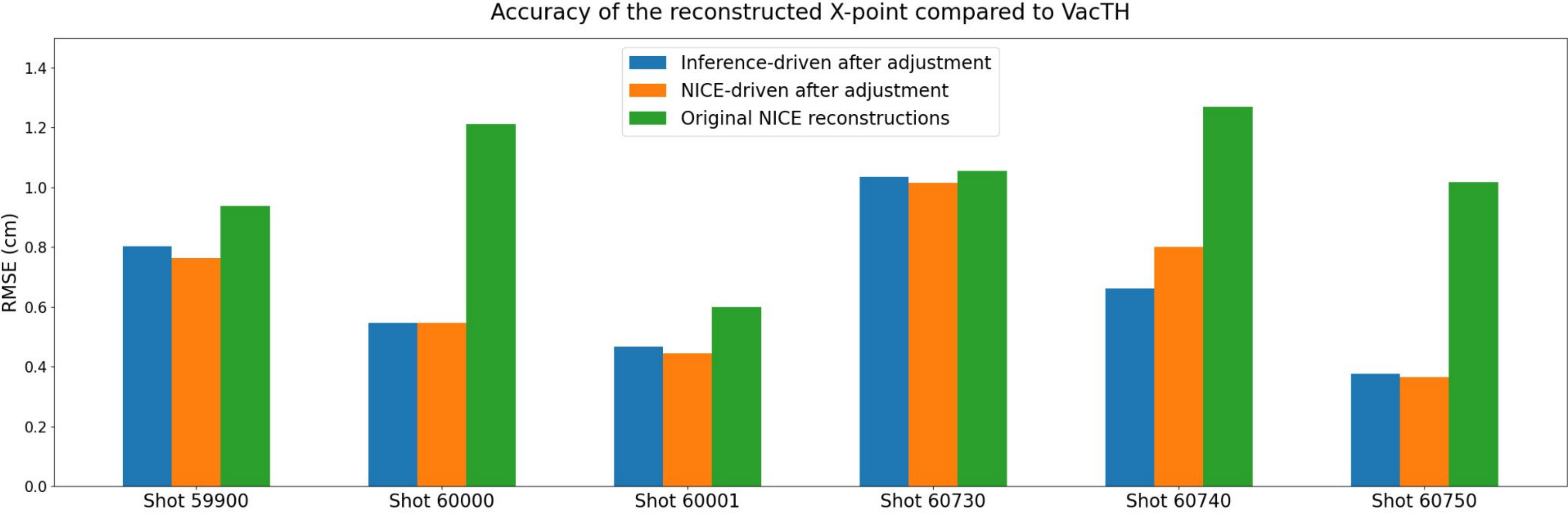
CONCLUSION

– Expanded prior space to let "data" take over

– Global shift not entirely correct. But neither is keeping Xpoint fixed

– EQ correction lets Inference- and NICE-driven reconstructions align

– Better correspondence to VacTH than NICE

– DEMO methodology confirmed to work (on WEST)

Jeffrey De Rycke
PhD Student
FWO Fellowship grant 1SH6424N

RESEARCH UNIT NUCLEAR FUSION

E   Jeffrey.DeRycke@ugent.be
M +32 474 10 53 89

nuclearfusion.ugent.be/jeffrey-de-rycke

FACULTY OF ENGINEERING AND ARCHITECTURE

GHENT UNIVERSITY

infusion fwo

cea