MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

Wendelstein 7-X

Improvement of a correction algorithm for laser-misalignment effects in TS density profiles at the W7-X stellarator

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EUROfusion

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Outline

Background

- unphysical density profiles — mainly caused by laser movement

Developed Correction Algorithm

- Identify “calibration cell” with Autoencoder
- Retrospective Correction

Improvement & Results

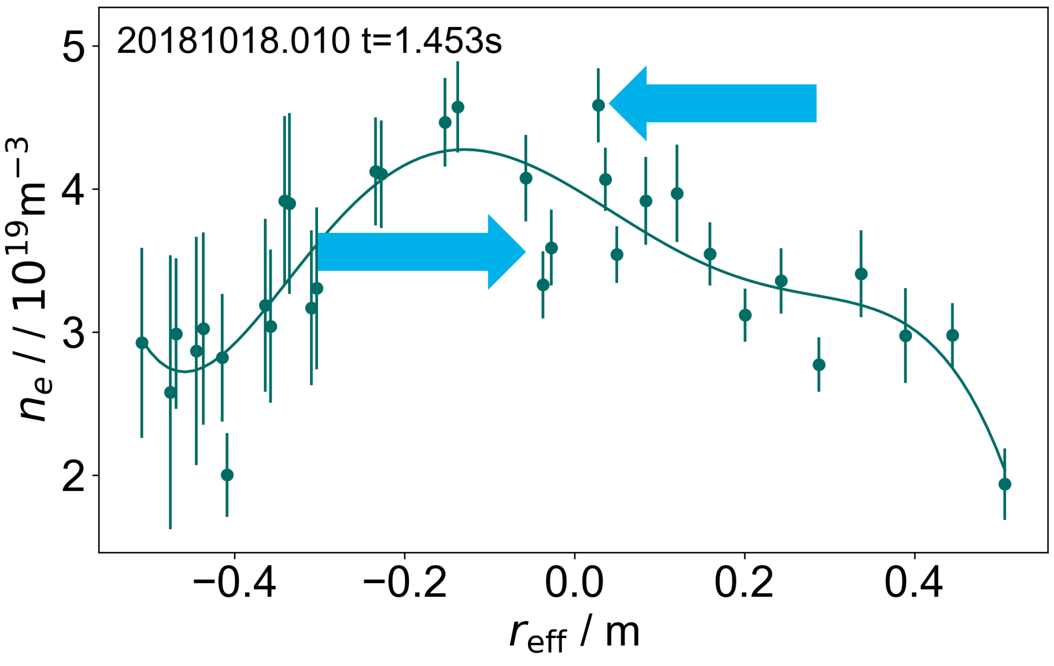
- New way to identify “calibration cell”

Summary and Outlook

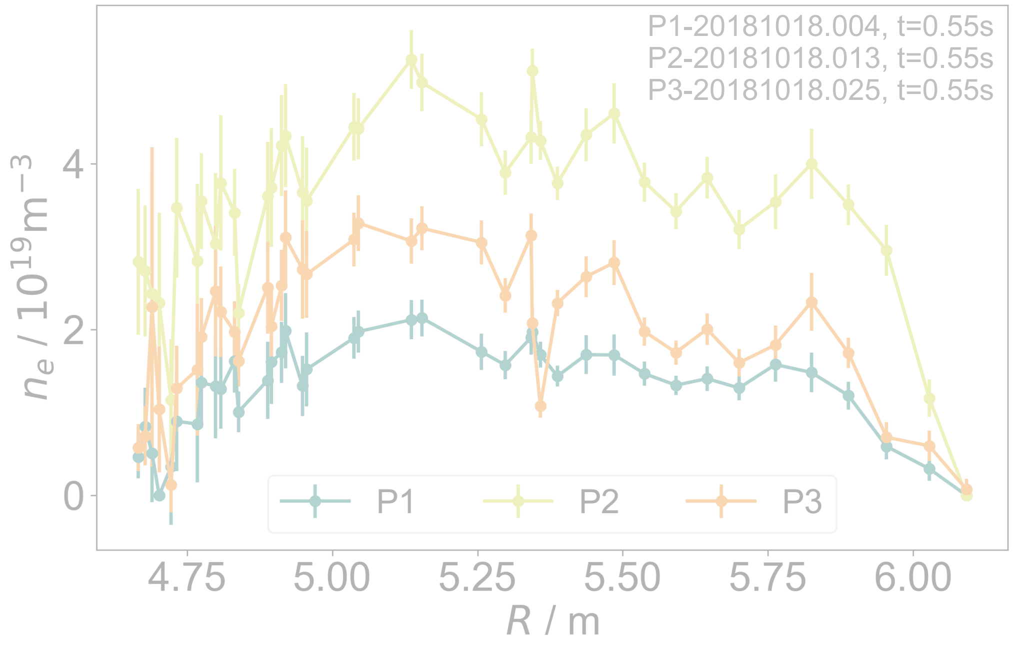
Background

Distorted TS density profiles

- not smooth or symmetric over r_eff



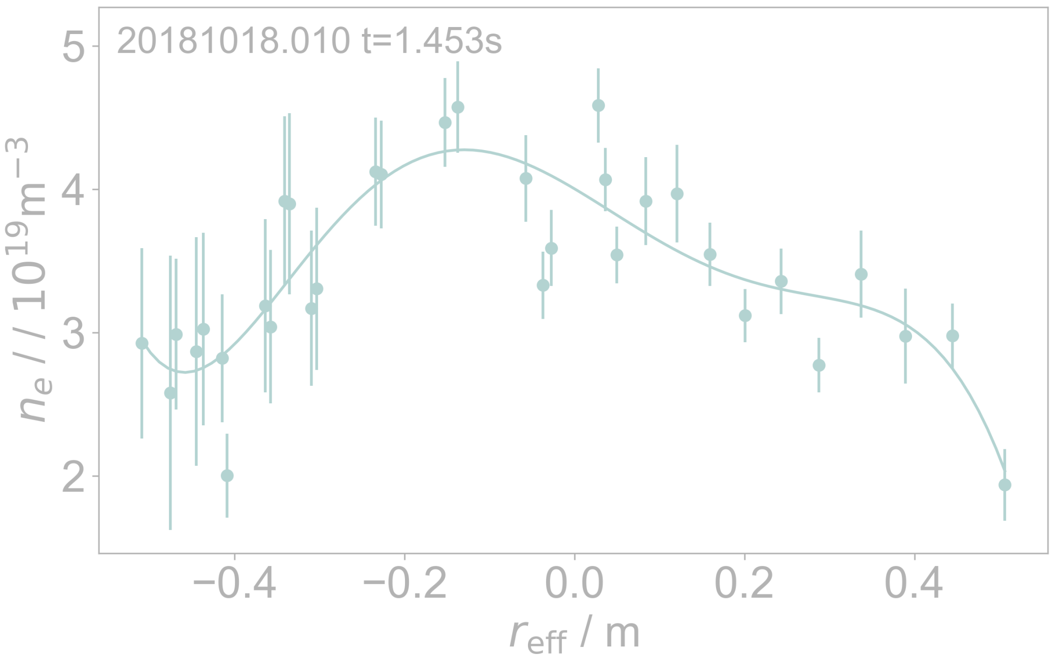
- Measured profiles for similar plasma parameters are very different



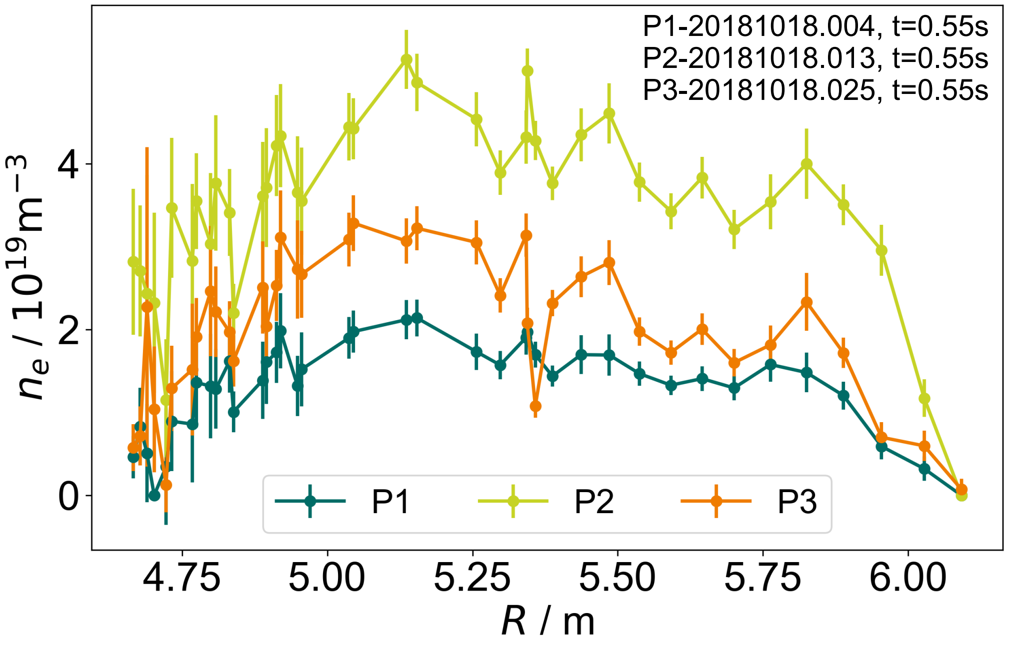
[slide courtesy J. Frank]

Distorted TS density profiles

- not smooth or symmetric over r_eff



- Profiles for similar plasma parameters are very different



[slide courtesy J. Frank]

Error Sources — Laser Movement

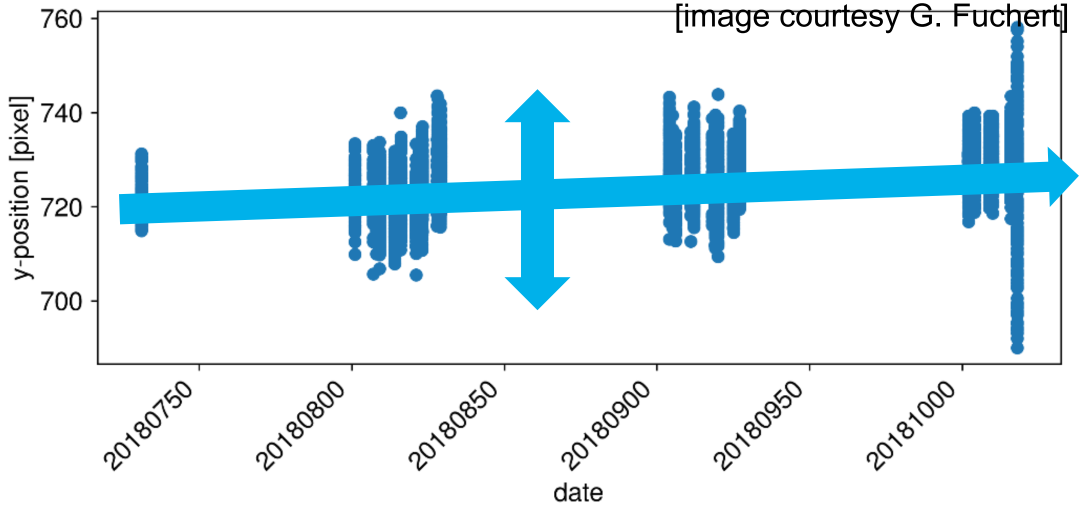
Master's thesis of Philips Nelde:

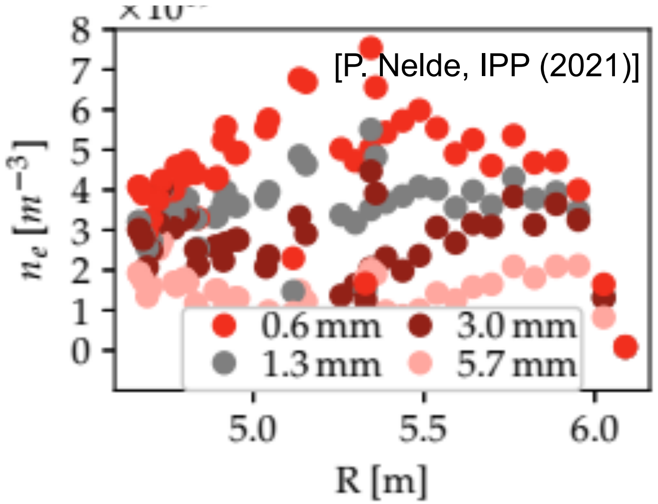
- biggest error source: **unstable laser alignment (drift & vibration)**

  —> variety of different profile shapes

- Even small drifts can reduce the measured density by 90 %

example laser 2





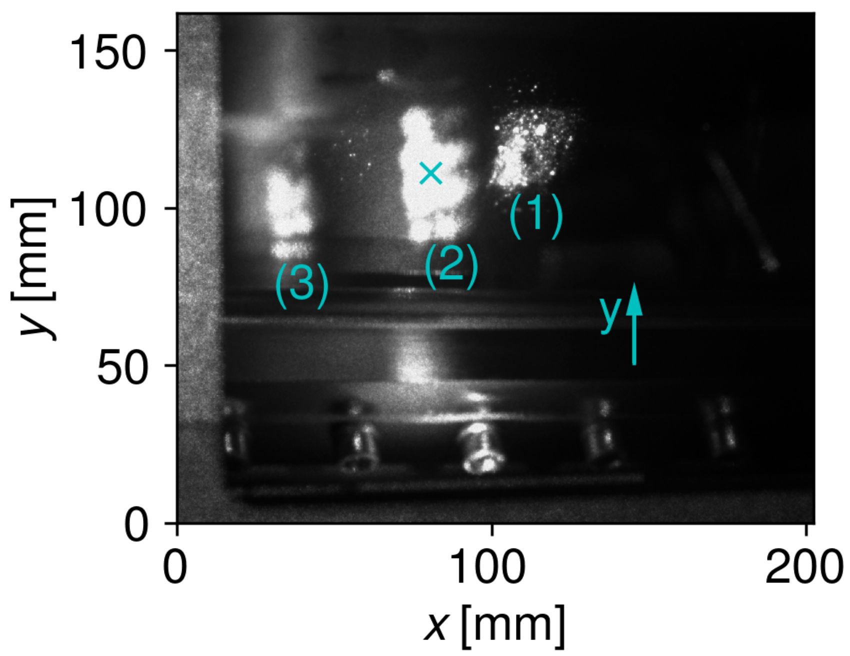
[slide courtesy J. Frank]

Correction by Camera

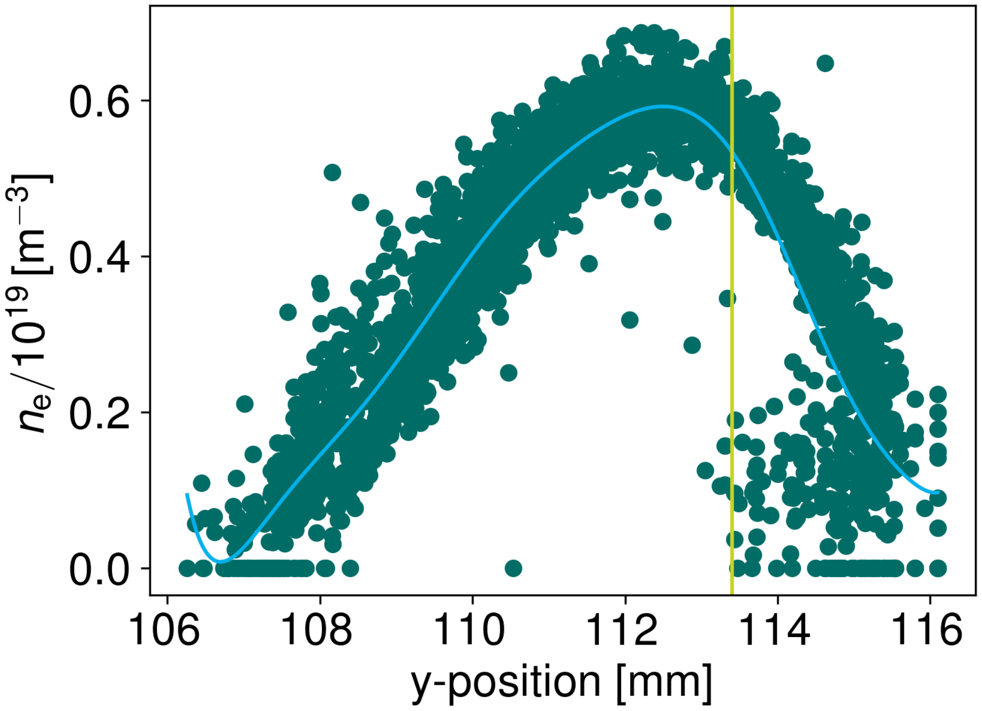
Proof of concept:

- Monitoring of entrance laser position with a camera
- Position dependence from alignment scan - each volume has now a relation between position on camera and measured density

[G. Fuchert, JINST 17, C03012 (2022)]



Monitored position of the laser spot on the entrance window (1) and two reflections (2 and 3)



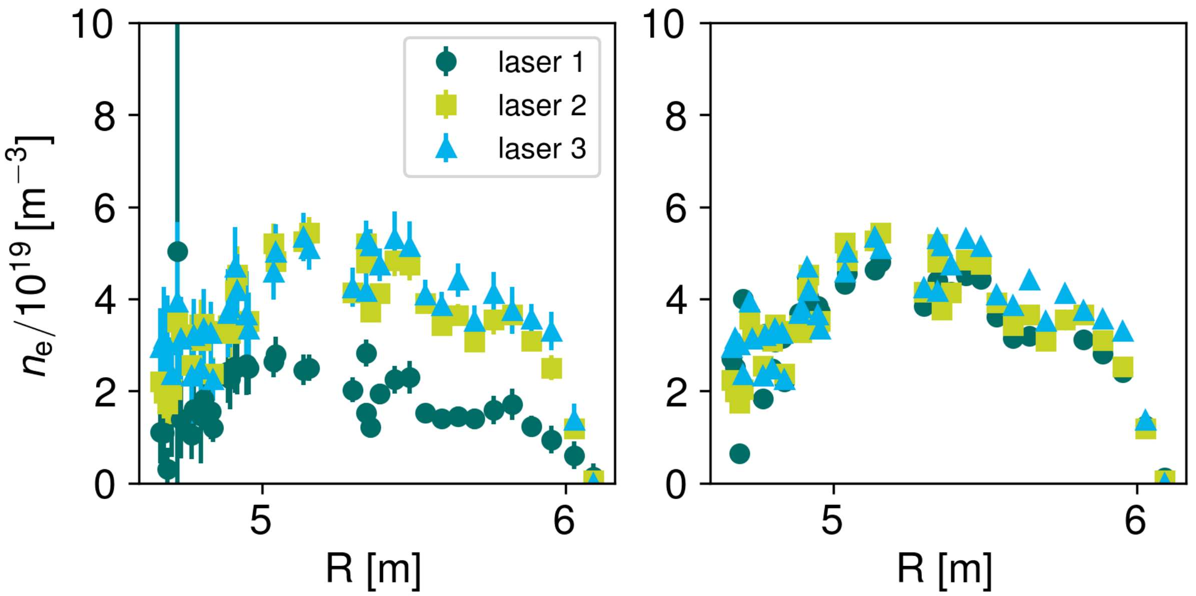
[slide courtesy J. Frank]

Correction by camera

- Correction of profiles influenced by intentional laser misalignment **successful**

Current OP:

- 2 cameras monitoring the laser entrance & exit
  —> all degrees of freedom should be sufficiently covered



… but correction of OP 1.2b data is not possible since there was no camera observation of laser exit

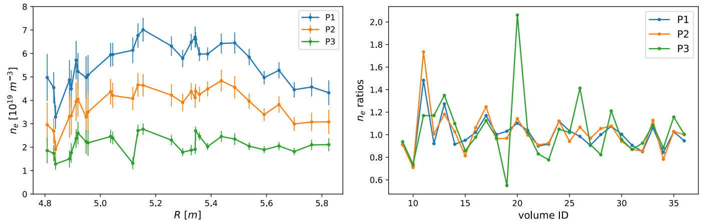
[slide courtesy J. Frank]

Developed Correction Algorithm

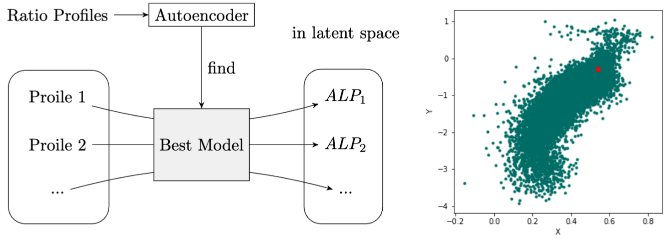
Procedure of the Correction Algorithm

Assume: Raman calibration performed correctly

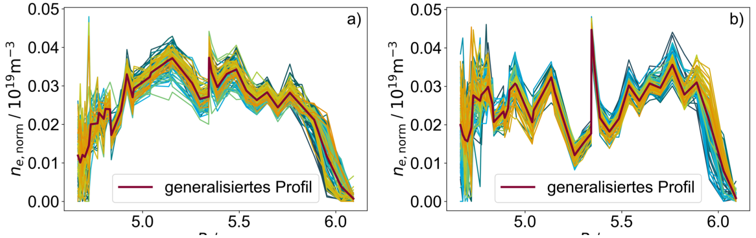
1. Prepare Data



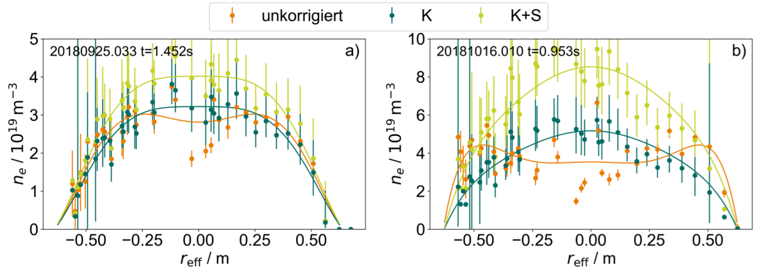
2. Learn “laser position” with *Autoencoder*



3. Identify *the calibration profile* through training result



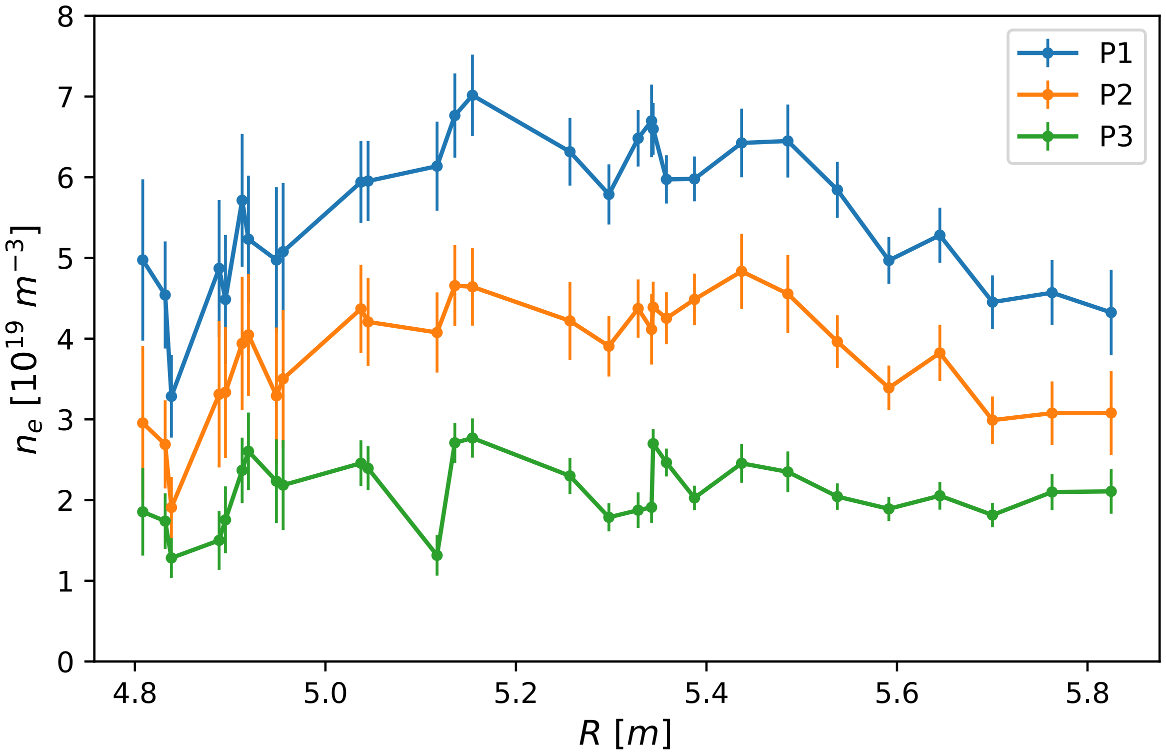
4. Correction



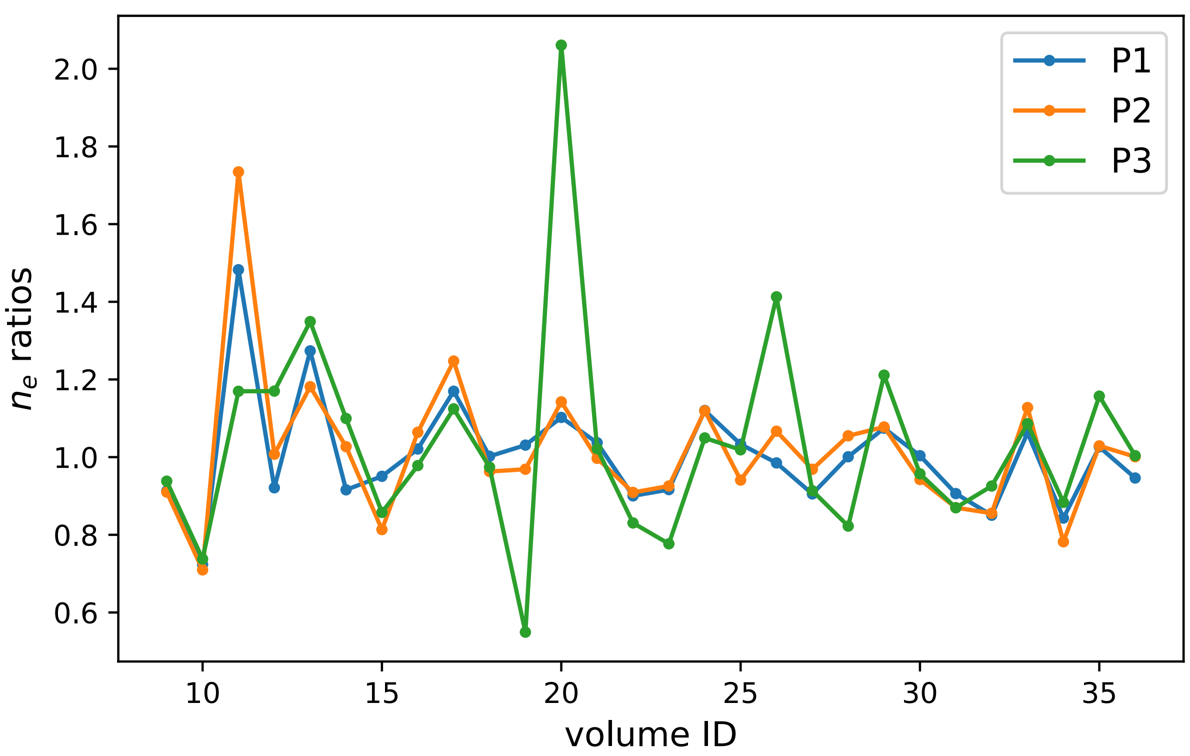
1. Prepare Data for Autoencoder

Ratio Profiles (OP 1.2b V8&10 Sep & Oct): Ratios of n_e measured in adjacent scattering volumes

Original Profile:
influenced by plasma condition & laser fluctuations

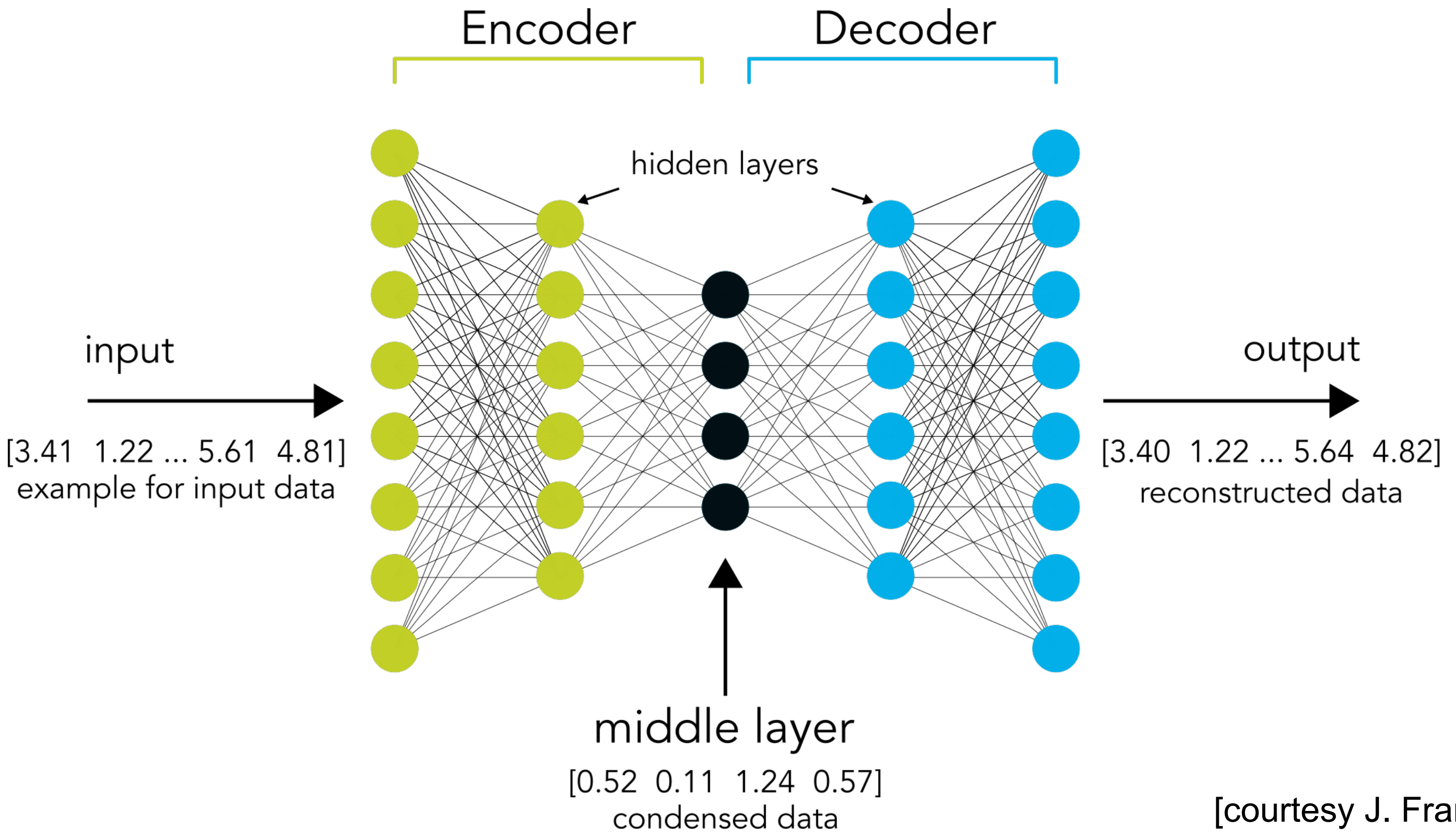


Ratio Profile:
predominantly influenced by laser fluctuations



2. Learn “laser position” with *Autoencoder*

What is an Autoencoder?

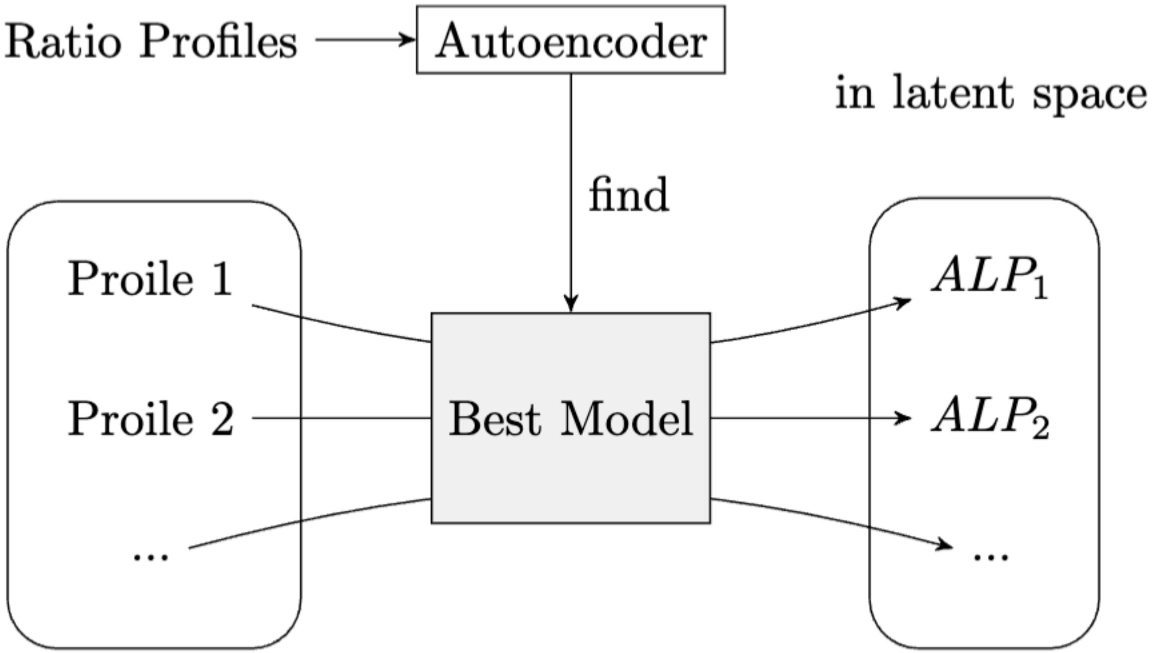


~ actual laser position

[courtesy J. Frank]

2. Learn "laser position" with *Autoencoder*

How?

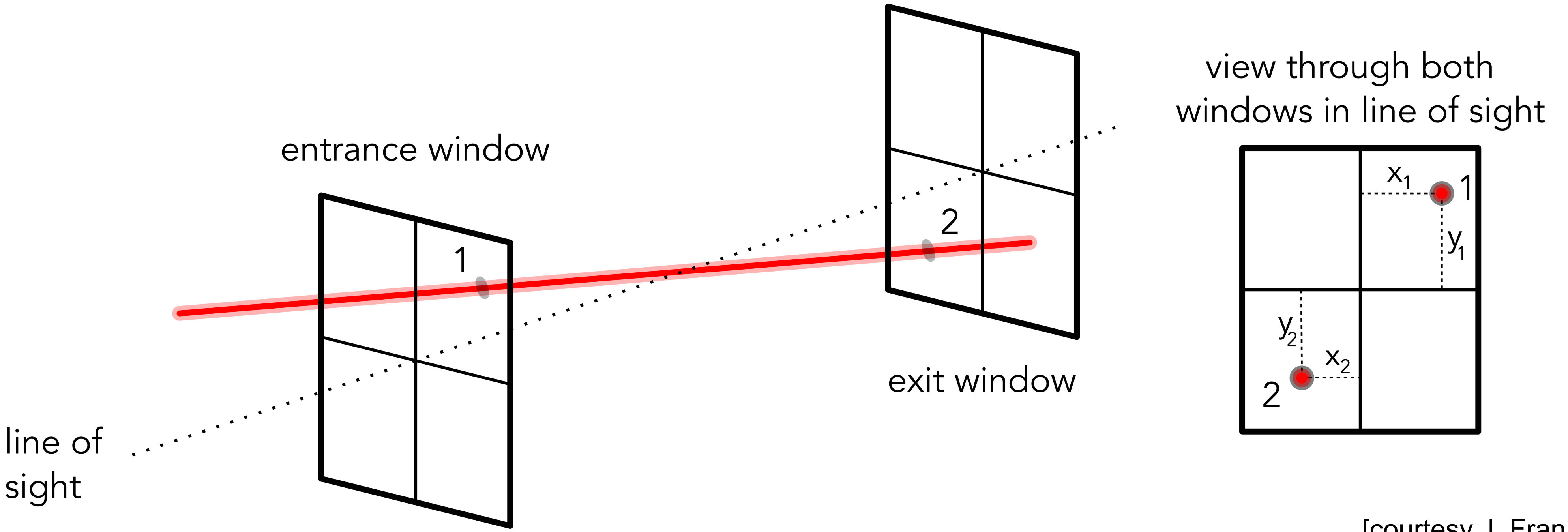


~ actual laser position

Interlude: Degrees of freedom

Expecting **≤ 4** degrees of freedom

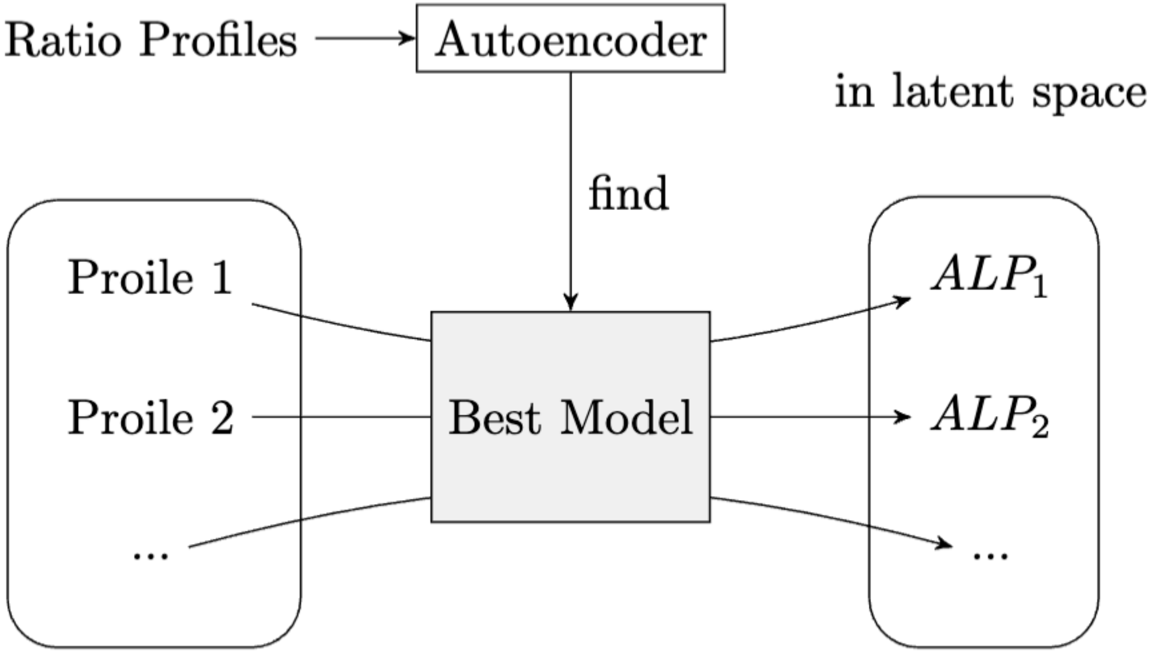
- < 4: Not necessarily all of them influence profile shape
- > 4: probably reconstruct statistical effects

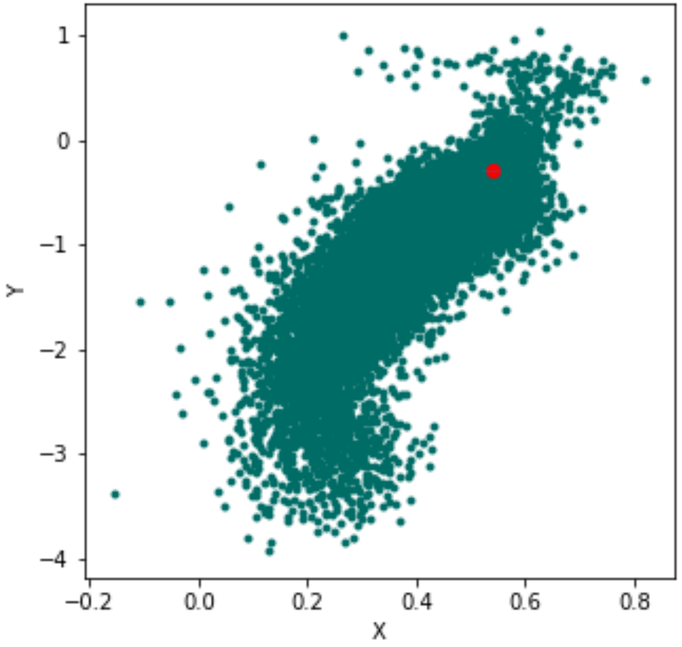


[courtesy J. Frank]

2. Learn "laser position" with *Autoencoder*

How?



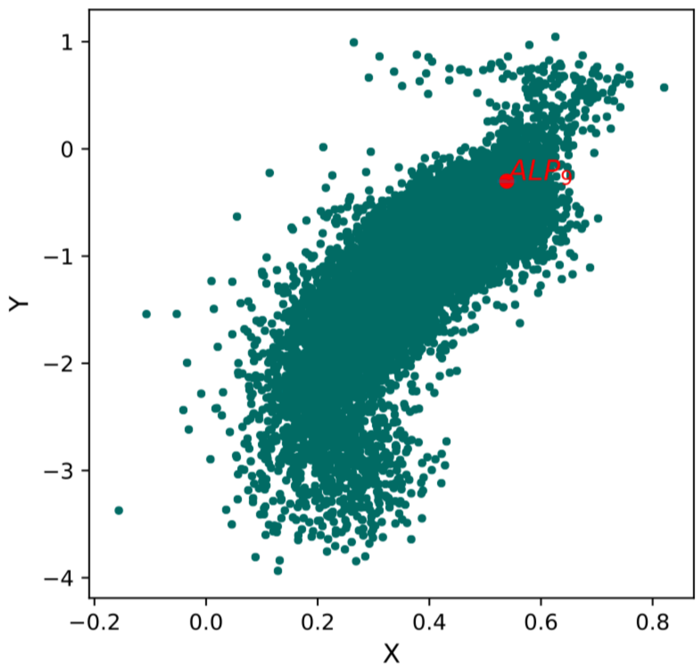


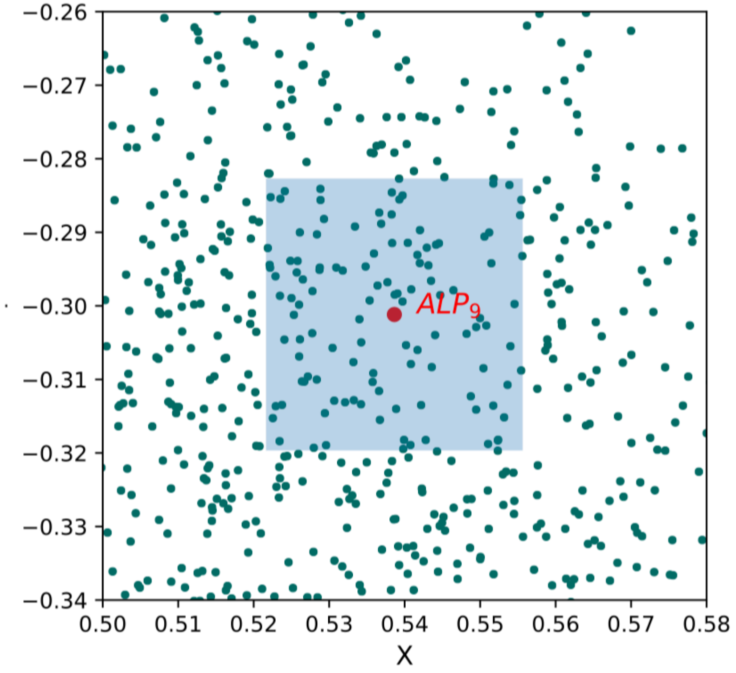
e.g: ALPs in 2D latent space

3. Identify the *best cell* (calibration profile) through *ALPs* (training result)

Assume: profiles measured with similar laser position are close in latent space

3.1 Assign a *cell* to each profile





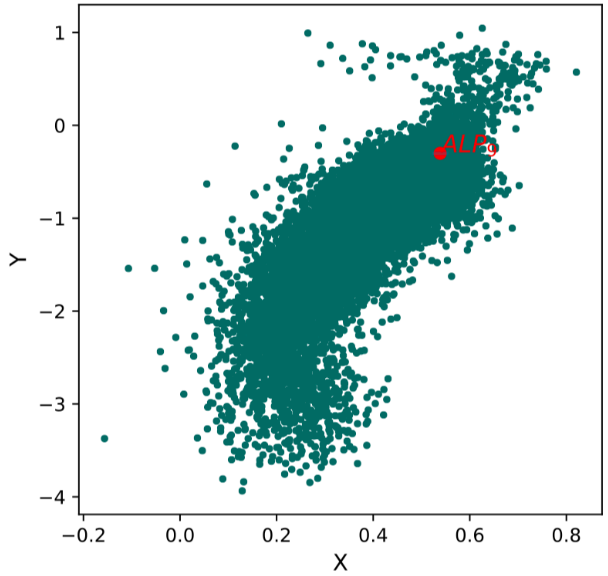
- E.g. Cell of profile 9 in 2D latent space
- Euclidean distance metric:

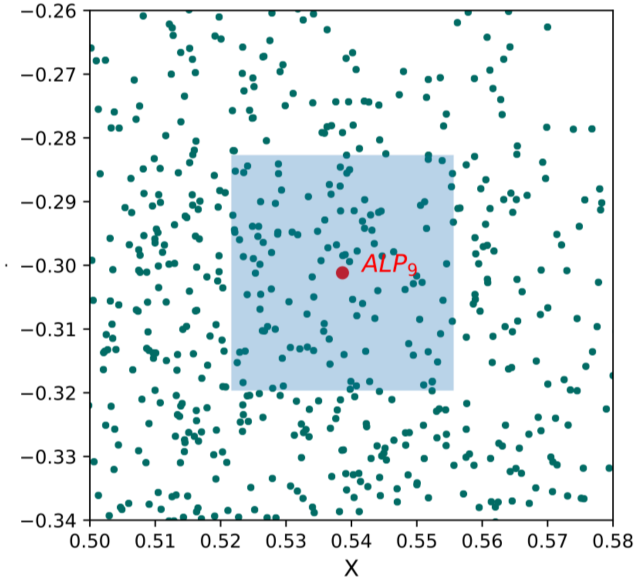
$$d(p,q) = \sqrt{\sum_{i=1}^{N} (p_i - q_i)^2},$$

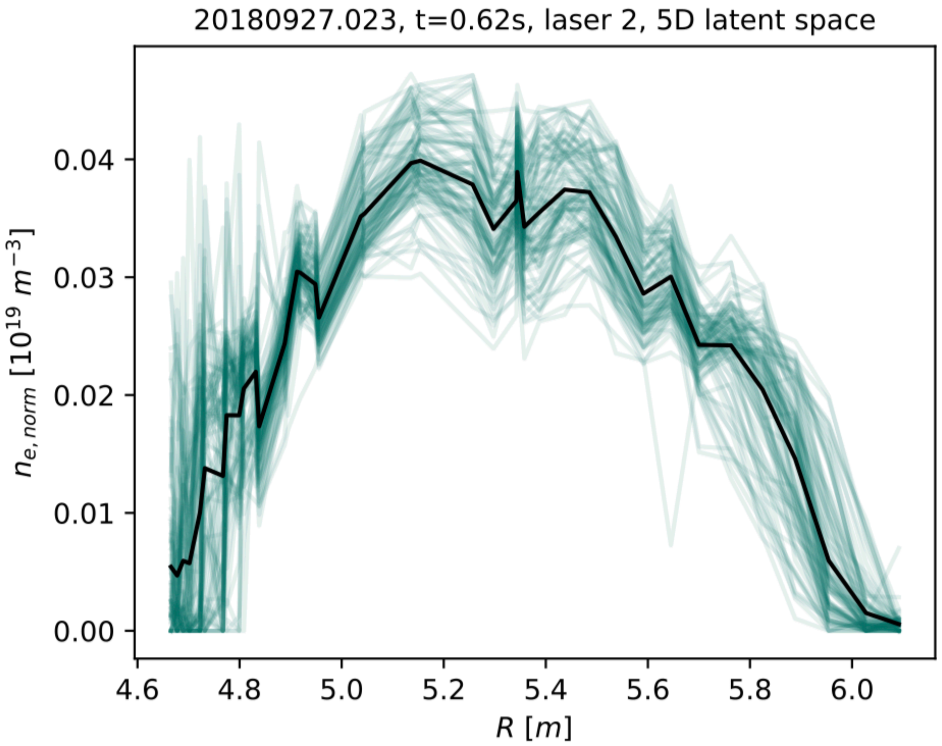
3. Identify the *best cell* though *ALPs*

Assume: profiles measured with similar laser position are close in latent space

3.2 Get *generalised profile*







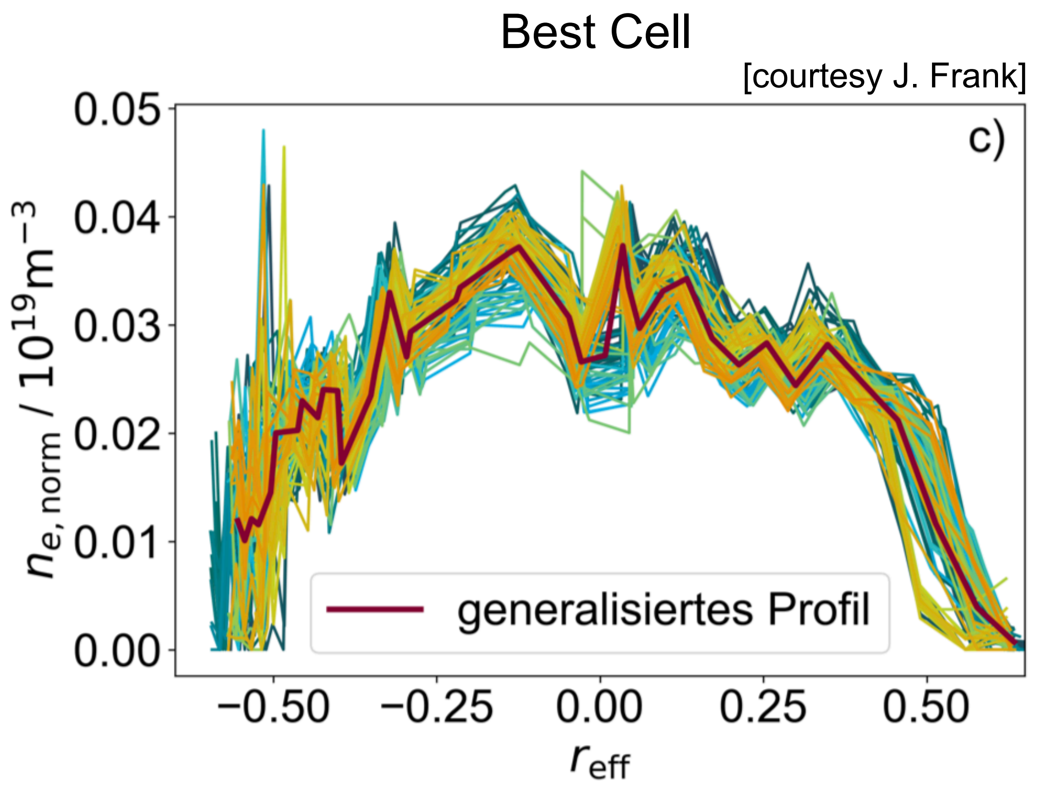
Mean Profile of normalised profiles (*generalised profile*)

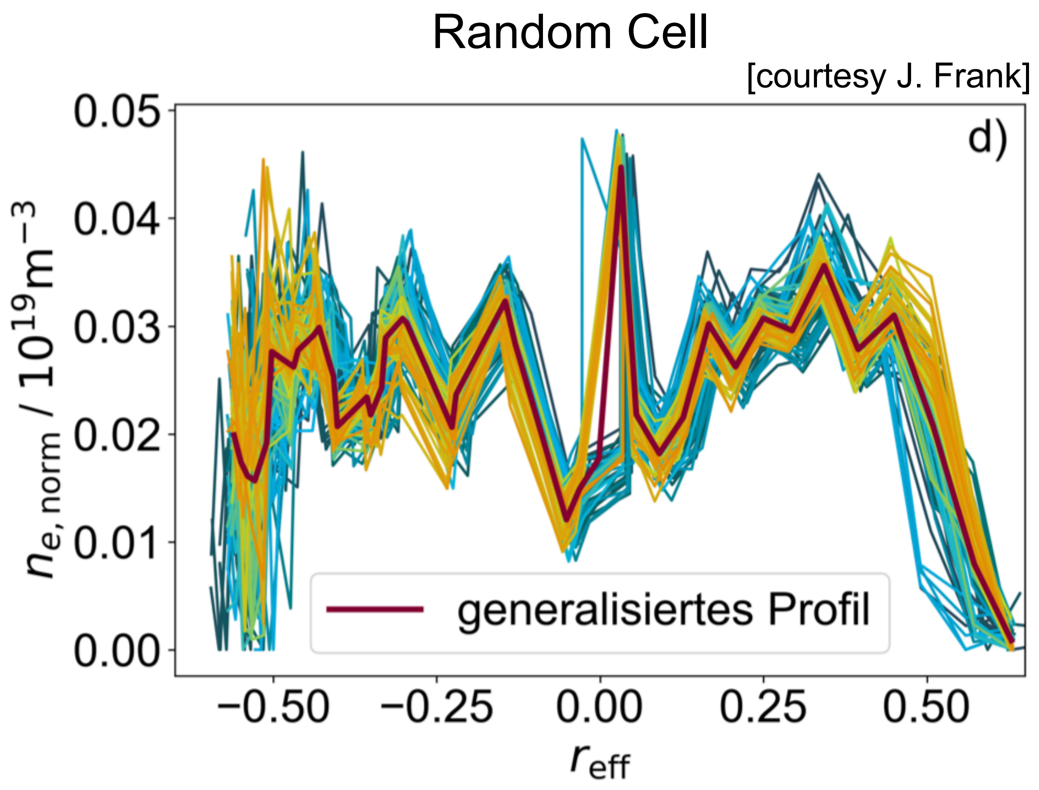
3. Identify calibration position though *ALPs*

Assume: profiles measured with similar laser position are close in latent space

3.3 Identify the best cell

By evaluating how ideal the shape is (Smooth & symmetrical)





3. Identify calibration position though *ALPs*

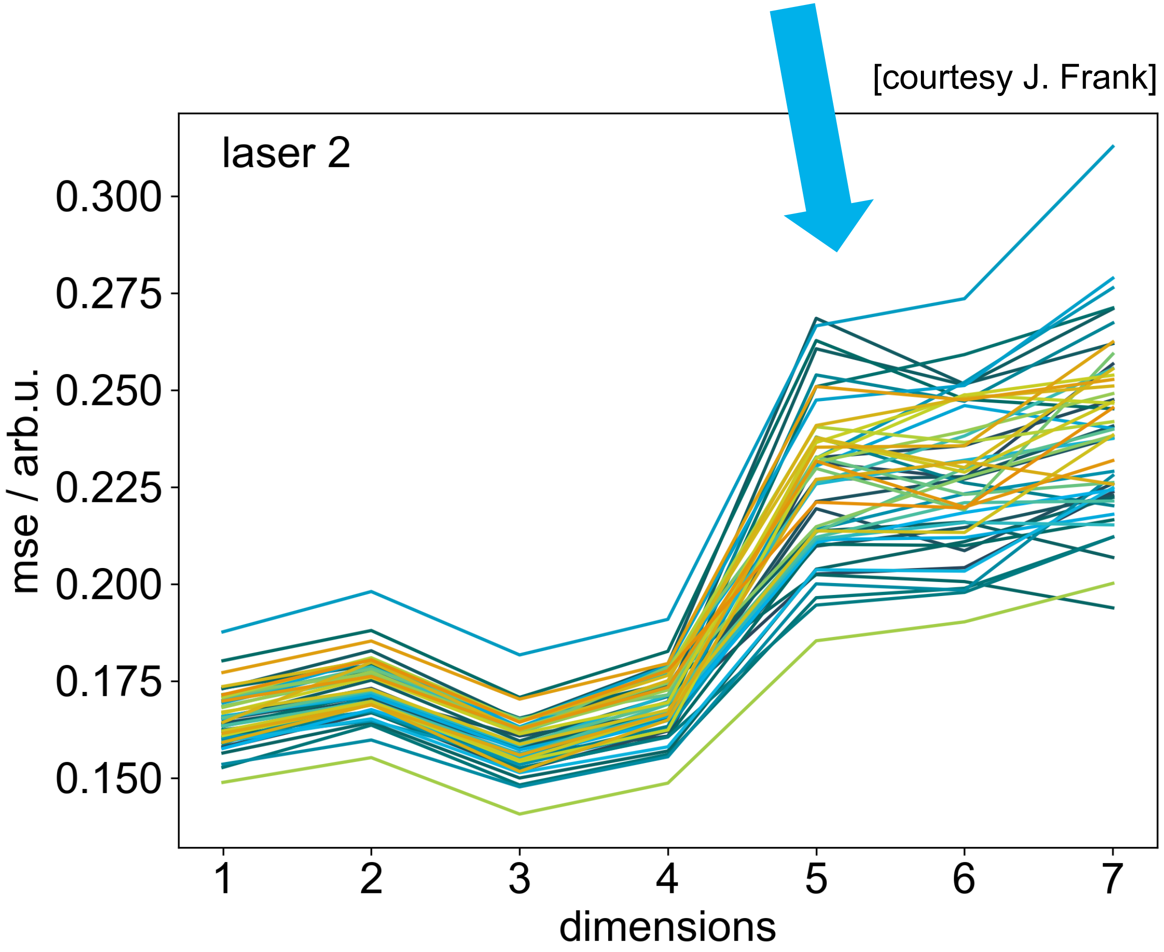
Assume: profiles measured with similar laser position are close in latent space

3.4 Compare best cell of different Dimensionalities

- >4D seem to worsen the correction
- 1-4D are rather similar
- Minimum mse seems to be at **3D**

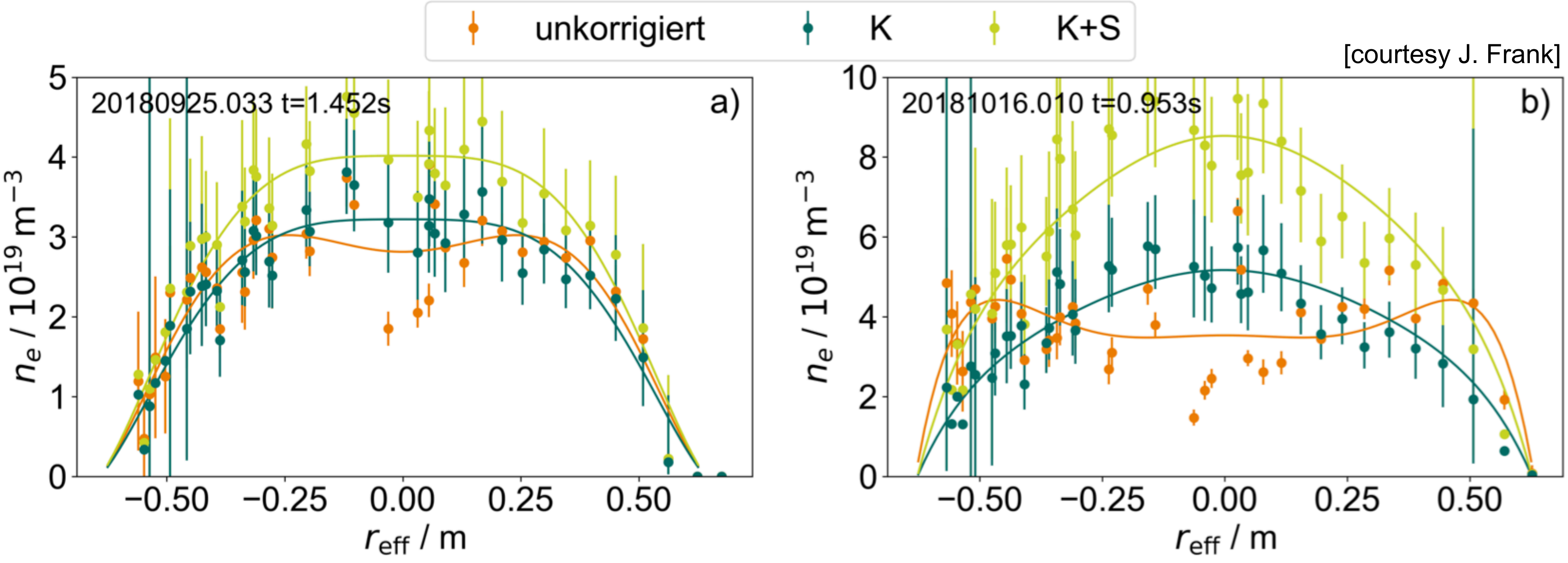
—> Agrees with expectation from geometric configurations

[courtesy J. Frank]



4. Retrospective Correction

$$n_{k,corrected} = n_k \cdot v_k \cdot s \qquad v_k = \frac{n_{k,gen,cali}}{n_{k,gen}} \qquad s = \frac{\int n_{cali}}{\int n}$$

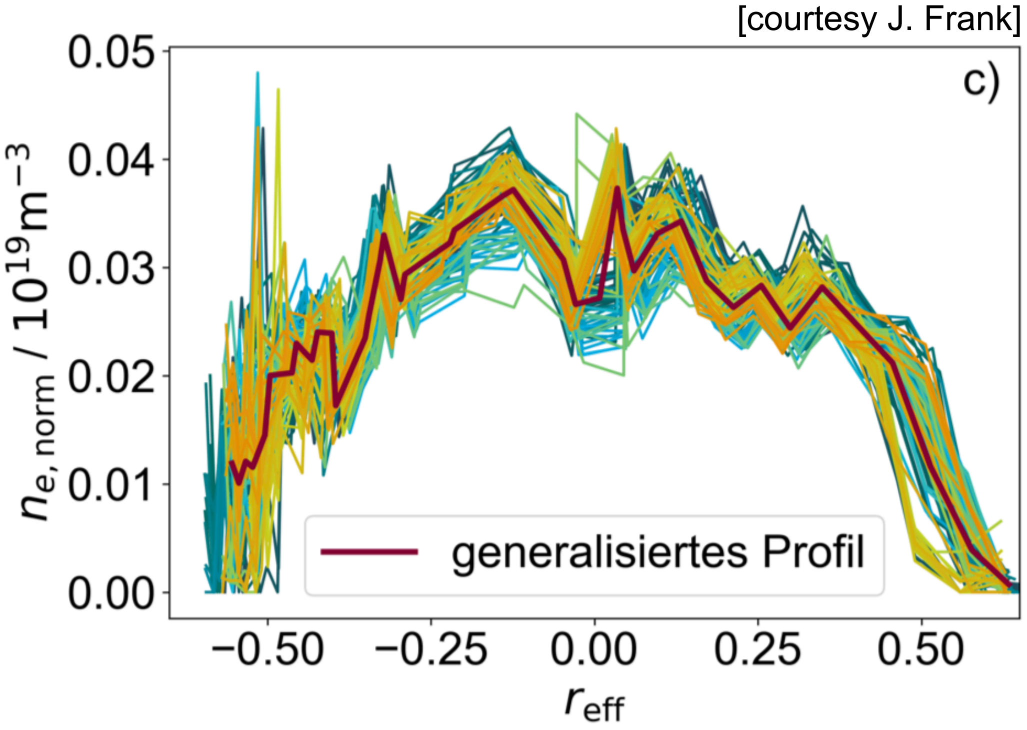


[courtesy J. Frank]

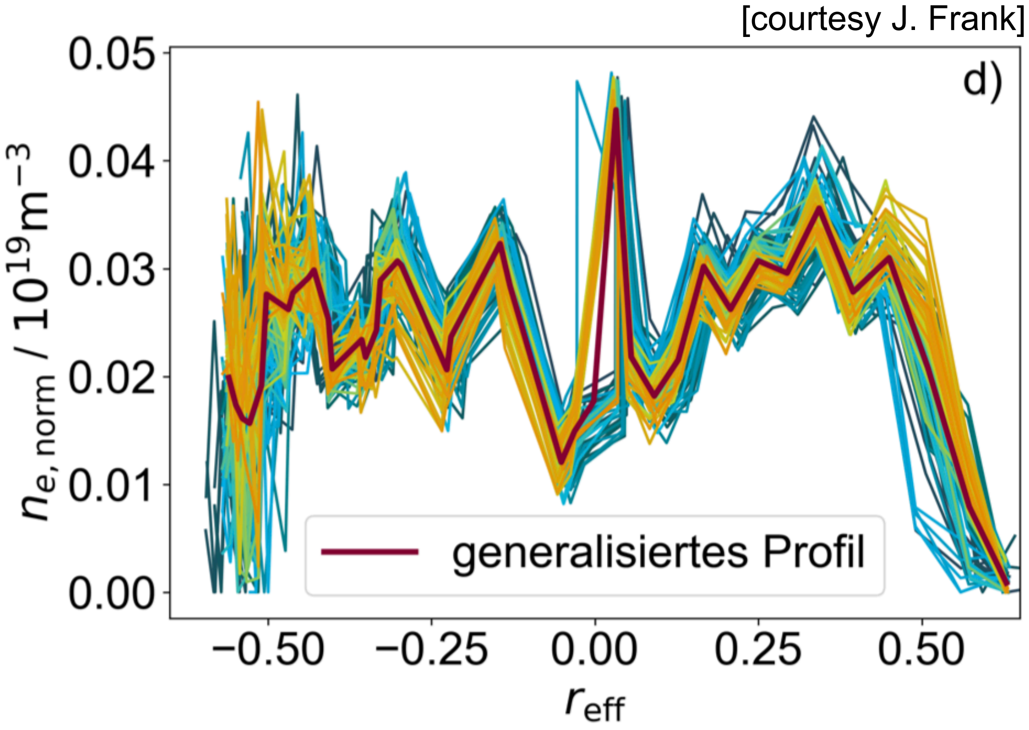
Instability in the Existing Method (Calibration Cell Selection)

Possible result:

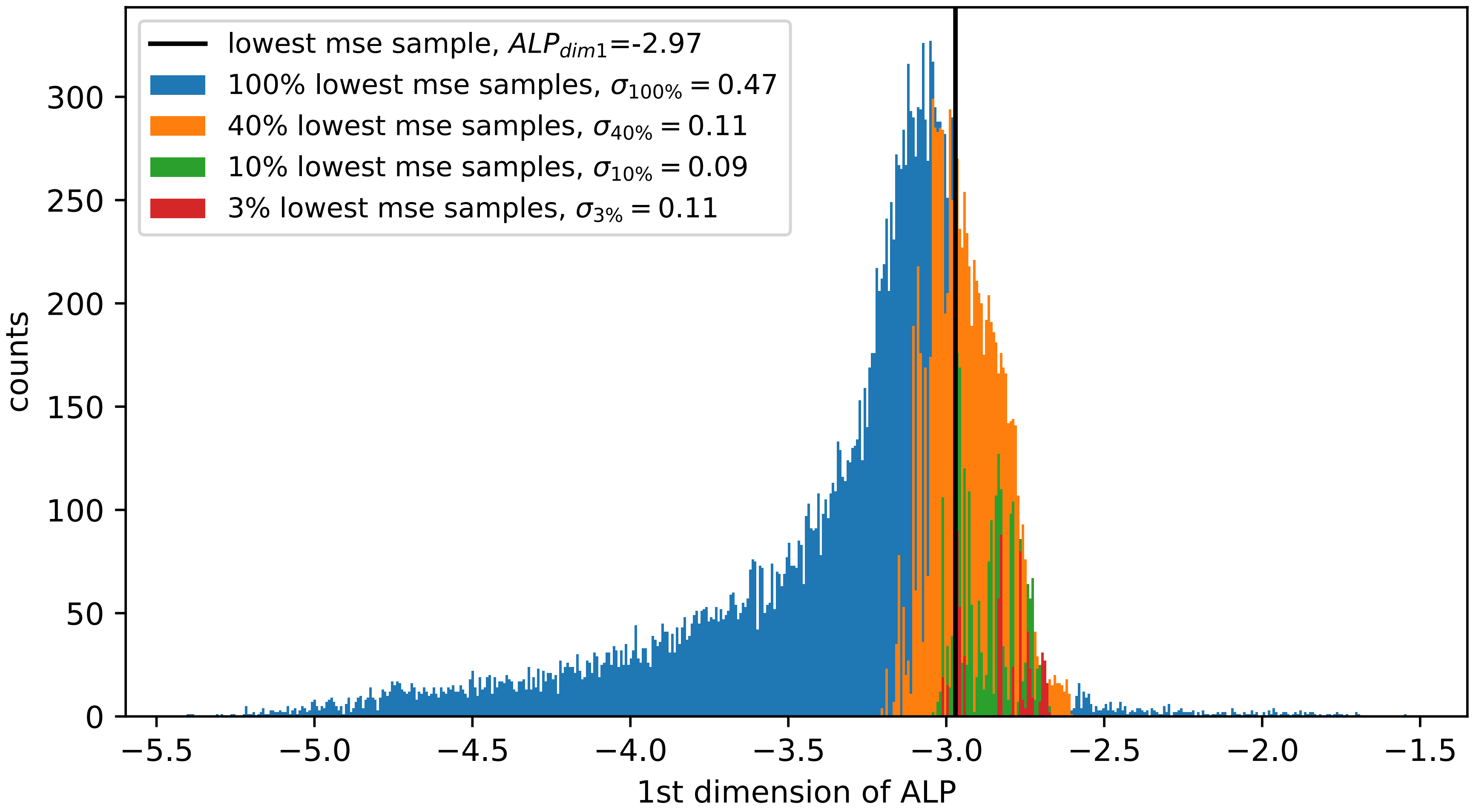
Random Cell



Best Cell



Color-coded histogram (what?)



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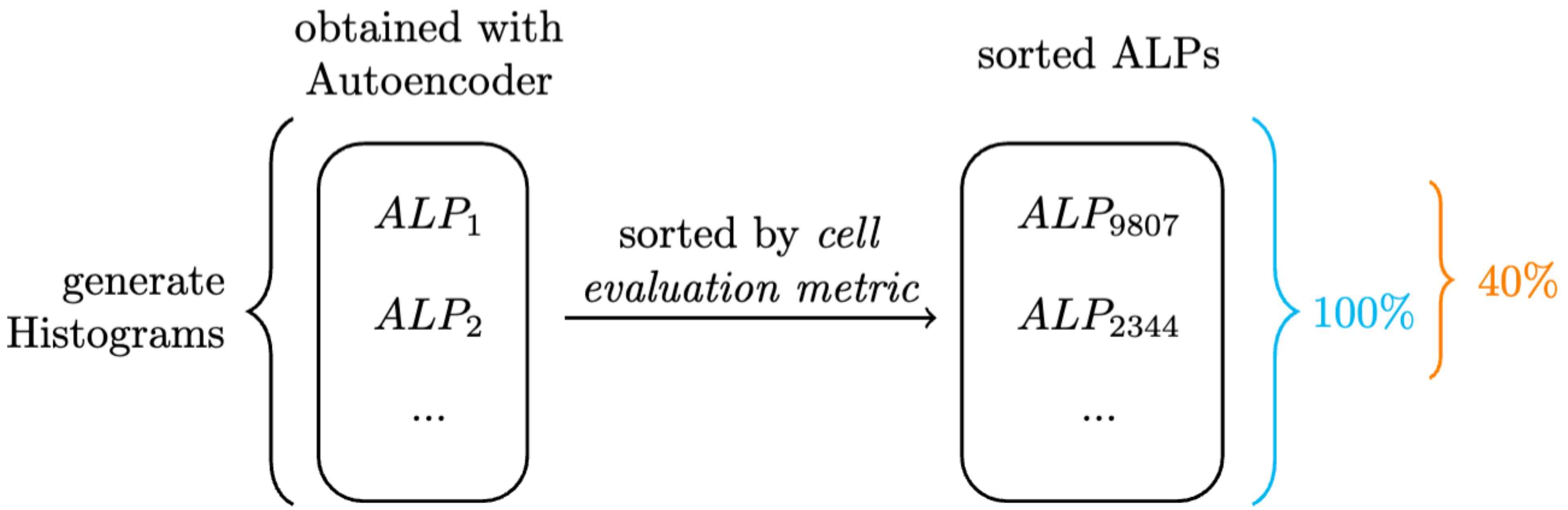

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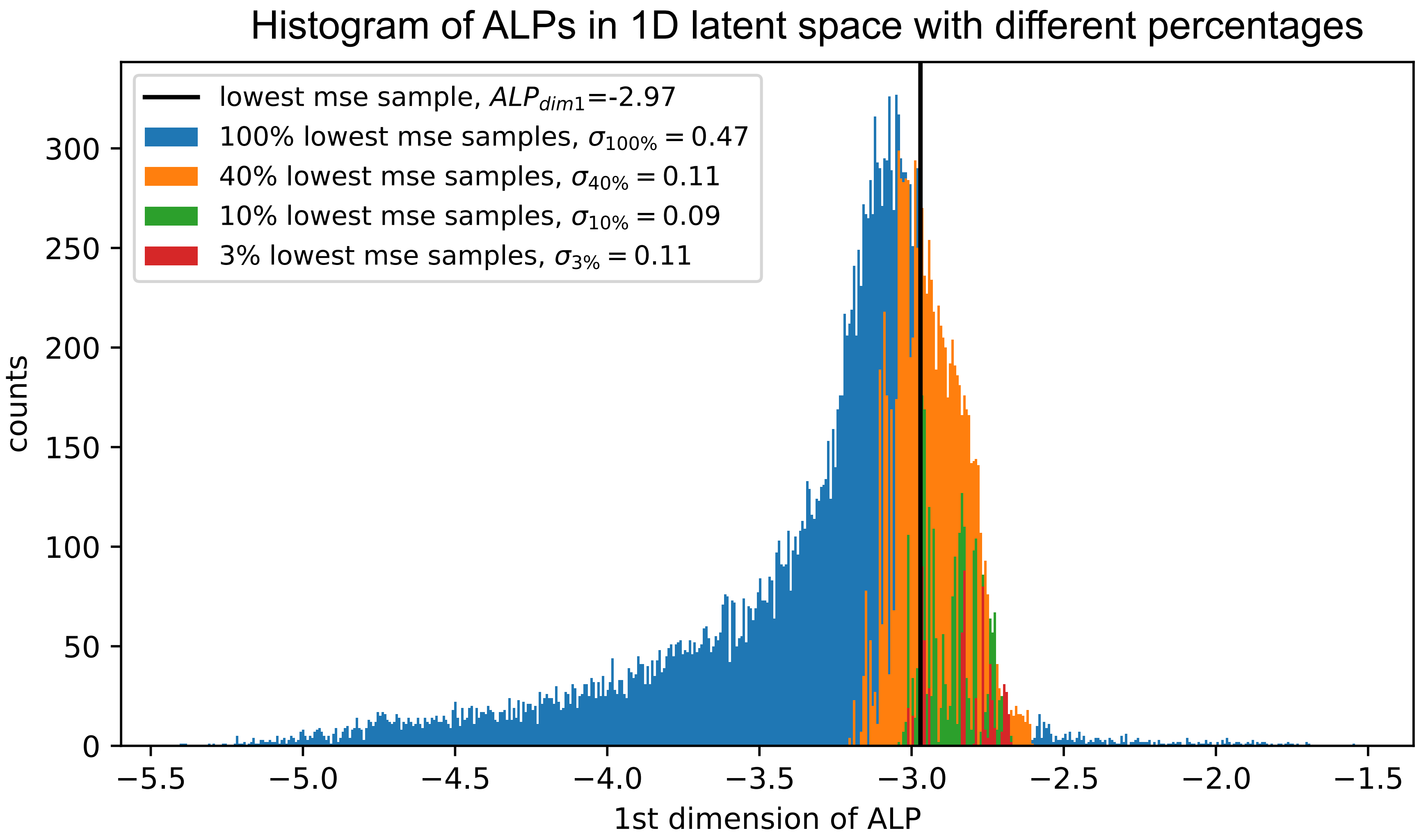
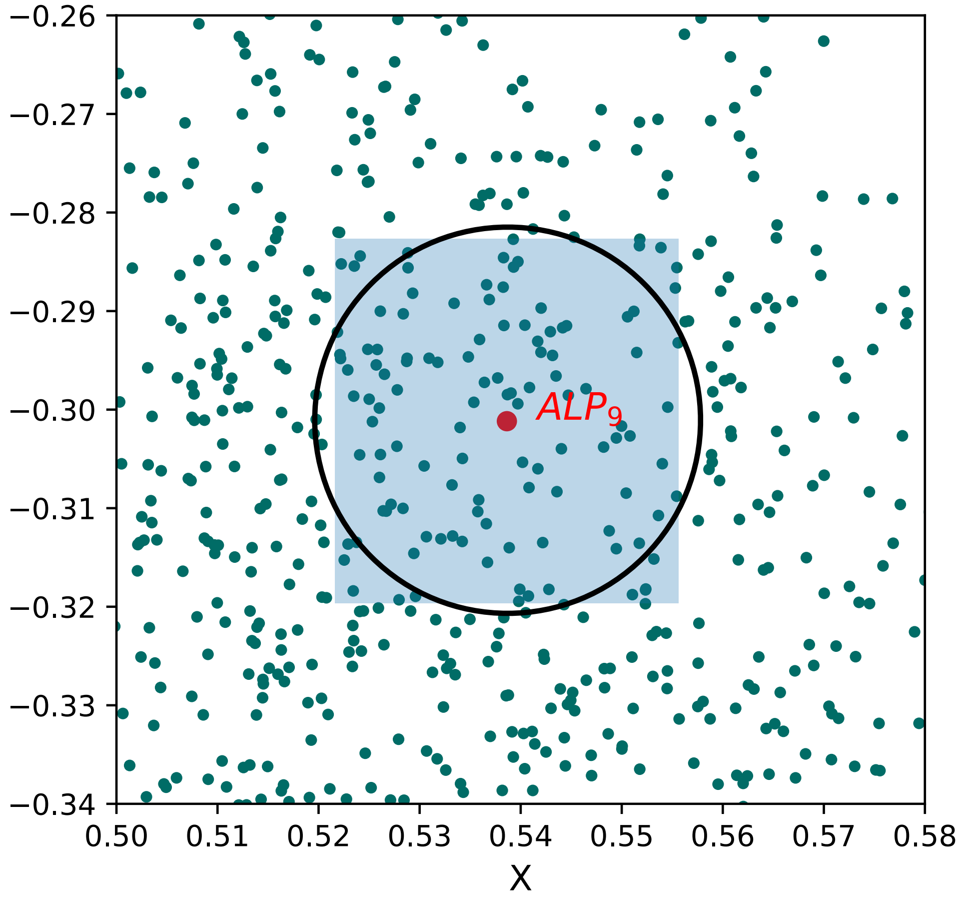


Improvement & Results

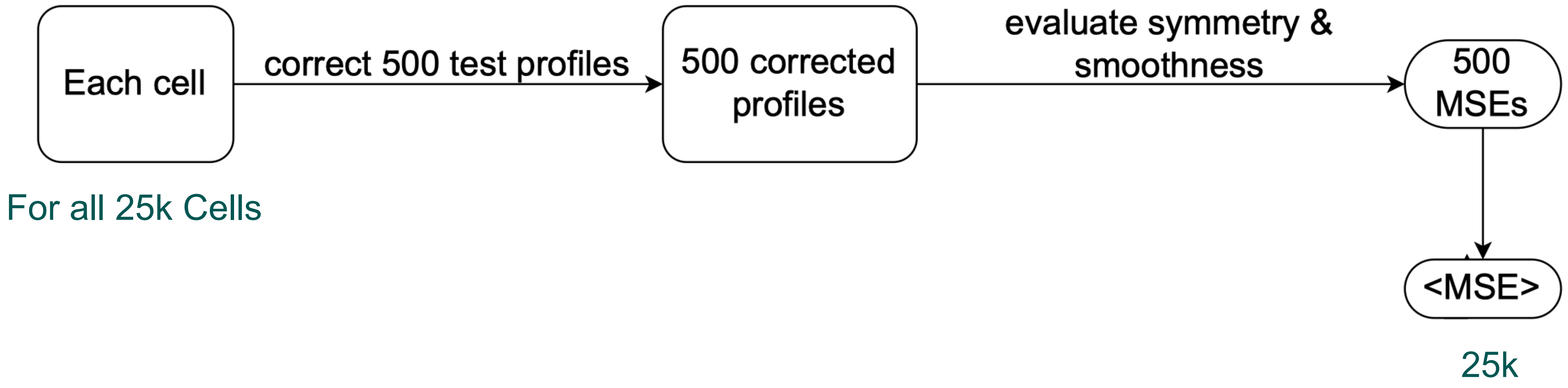
Spherical Cell Definition

- Change cell geometry from n-cube to n-ball
- Same distance metric
- Computation time has been reduced **from up to 2 weeks to only 6h** (on 4 CPU cores)



Correction-Based Calibration Cell Selection

Based on **how well** each cell corrects.



Correction-Based Calibration Cell Selection

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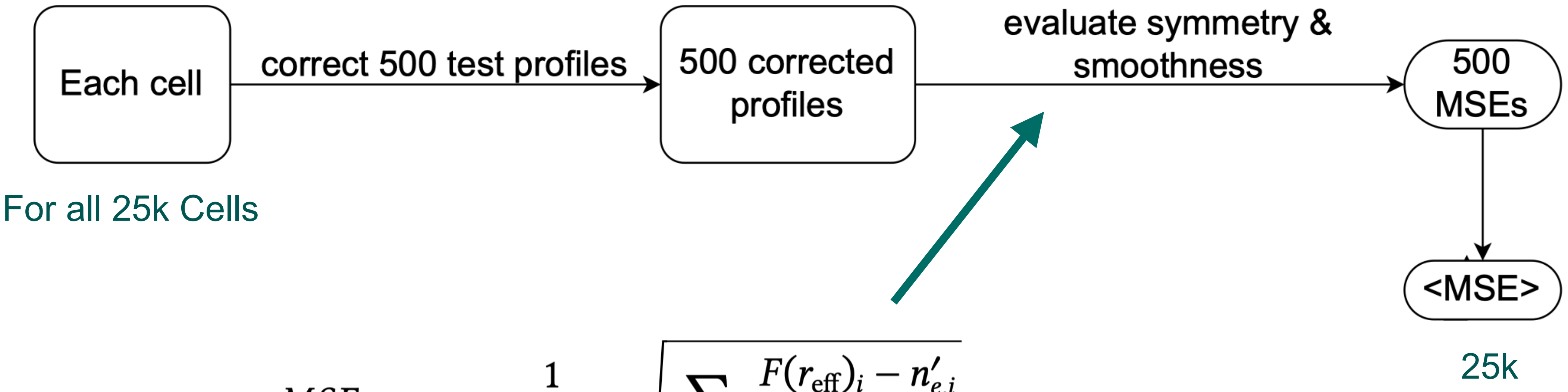
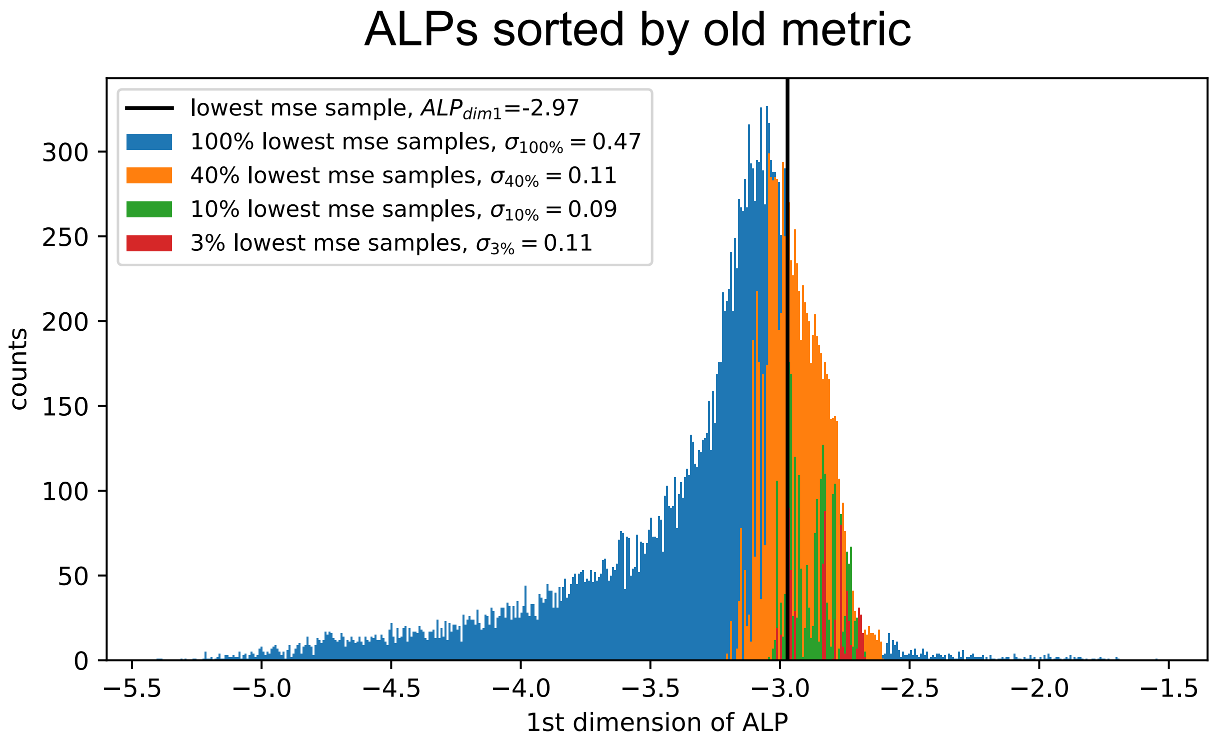
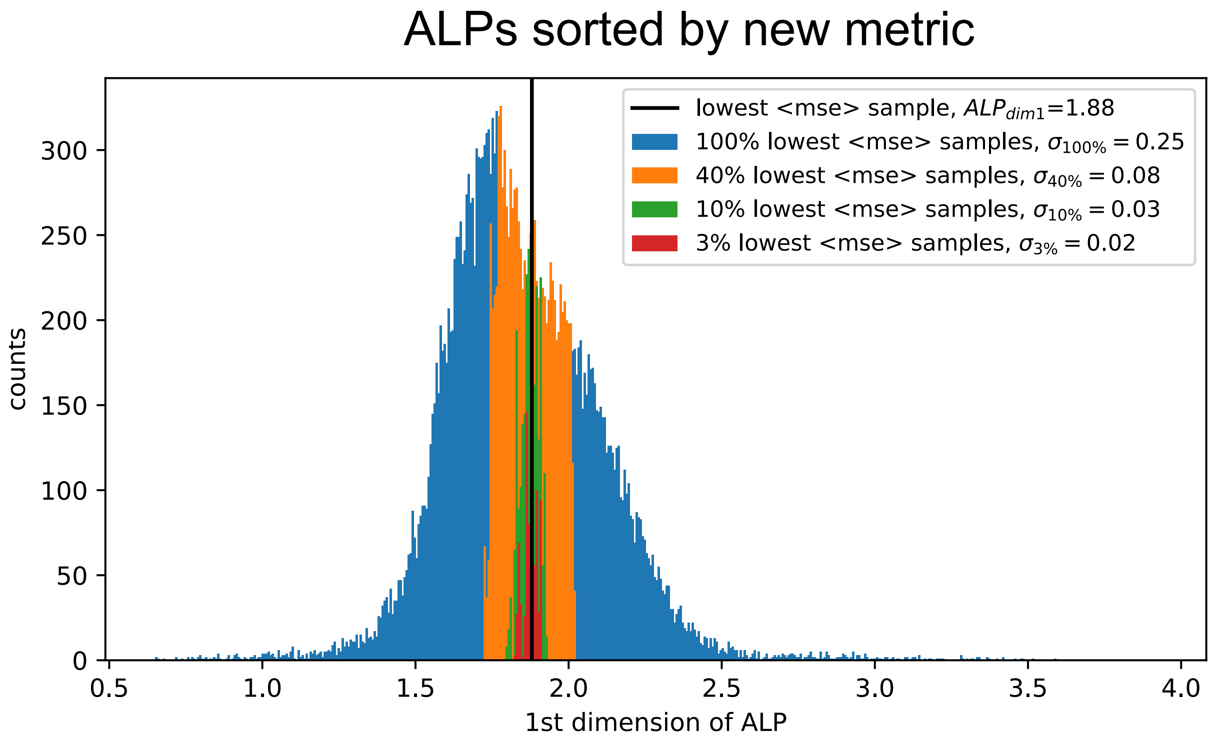


$$MSE_{in/out} = \frac{1}{S(I_{in/out})}\sqrt{\sum_{i \in I_{in/out}} \frac{F(r_{\text{eff}})_i - n'_{e,i}}{F(r_{\text{eff}})_i}}$$

$$< MSE >= \frac{1}{2}(MSE_{in} + MSE_{out})$$

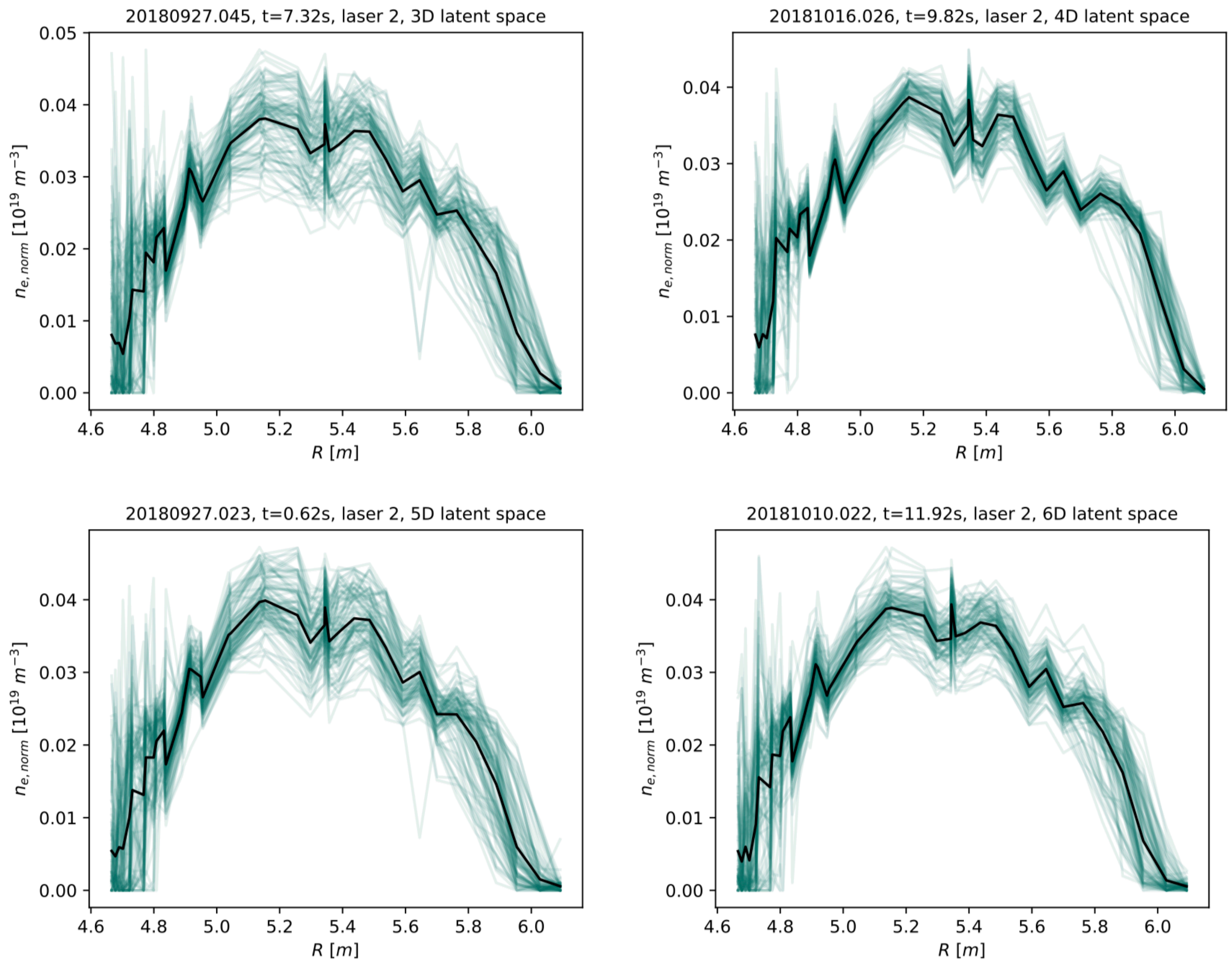
Correction-Based Calibration Cell Selection





- **More concentrated**
- **Std decrease with lower <MSE>s**
- **Groups nested (Red enclosed in green in orange)**

Calibration Cell e.g. laser 2, 3 − 6 neurons in latent space



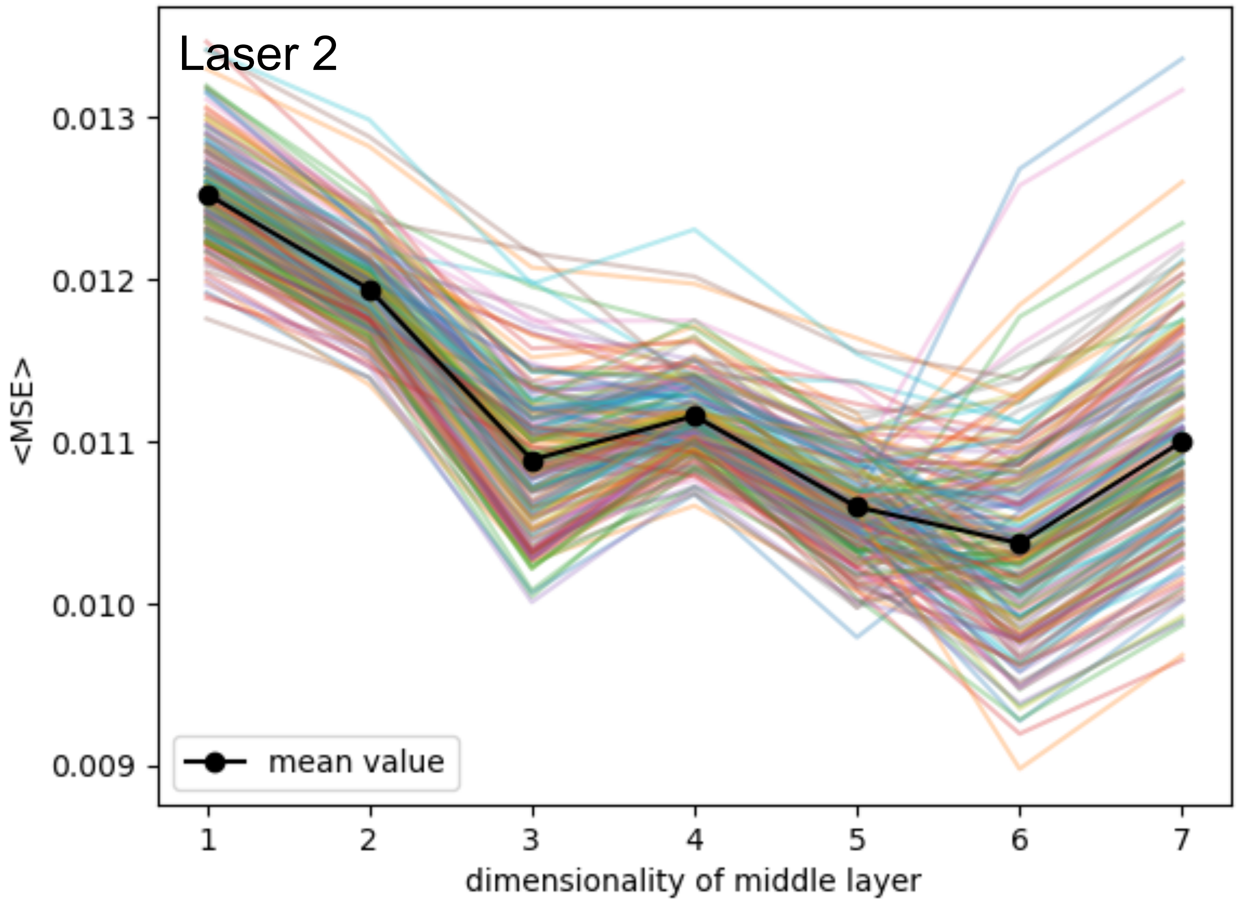
- similar
- Peaks in the centre — assumption not perfectly valid (smoothness)
- 3D & 5D: more dispersed compared to the others
- **4D**: concentrated — optimal

Dimensionality of the Latent Space

<MSE>: how well the best cell within 1-7D latent space corrects

- Run 200 times — reduce noise; represent stability
- <MSE> — similar as in cell selection
- **Lower <MSE>** ~ smoother & more symmetrical

  corrected profile **—>** ideal Dimensionality



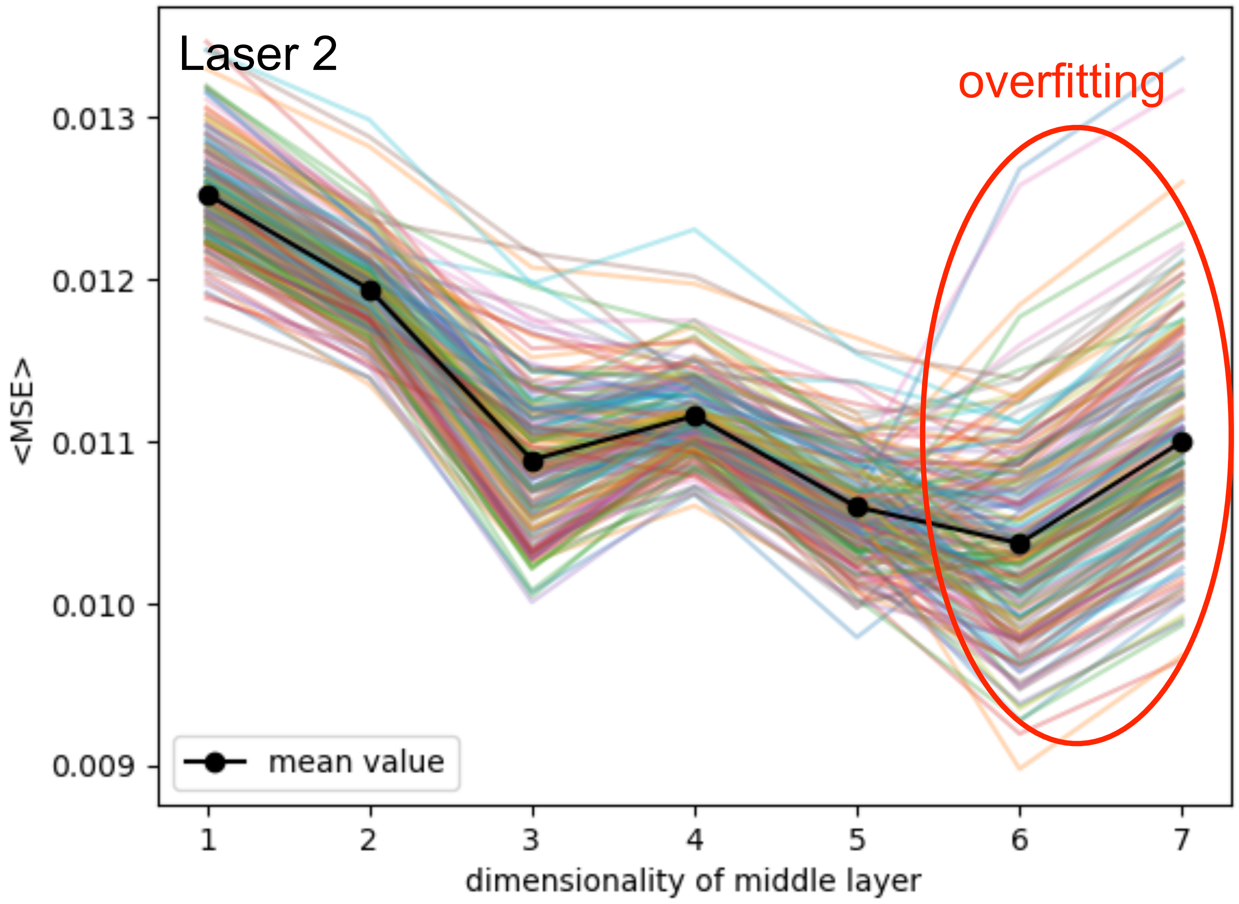
Dimensionality of the Latent Space

<MSE>: how well the best cell separately identified with networks with 1D-7D latent space corrects

- Run 200 times — reduce noise; represent stability
- <MSE> — similar as in cell selection
- **Lower <MSE>** ~ smoother & more symmetrical corrected profile —> ideal Dimensionality

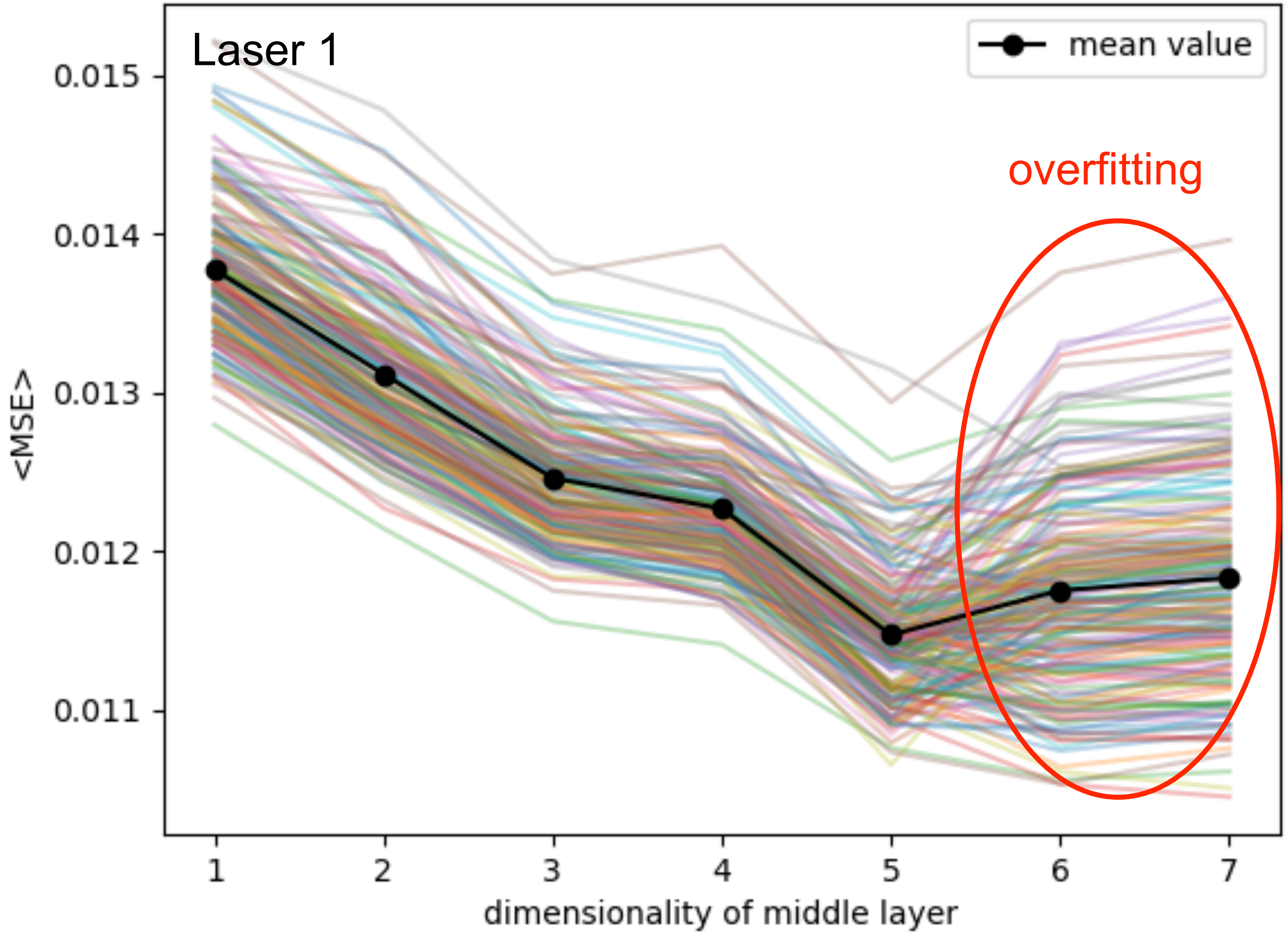
For laser 2:

- Low in 3D-7D
- Possible overfitting for ≥ 6D

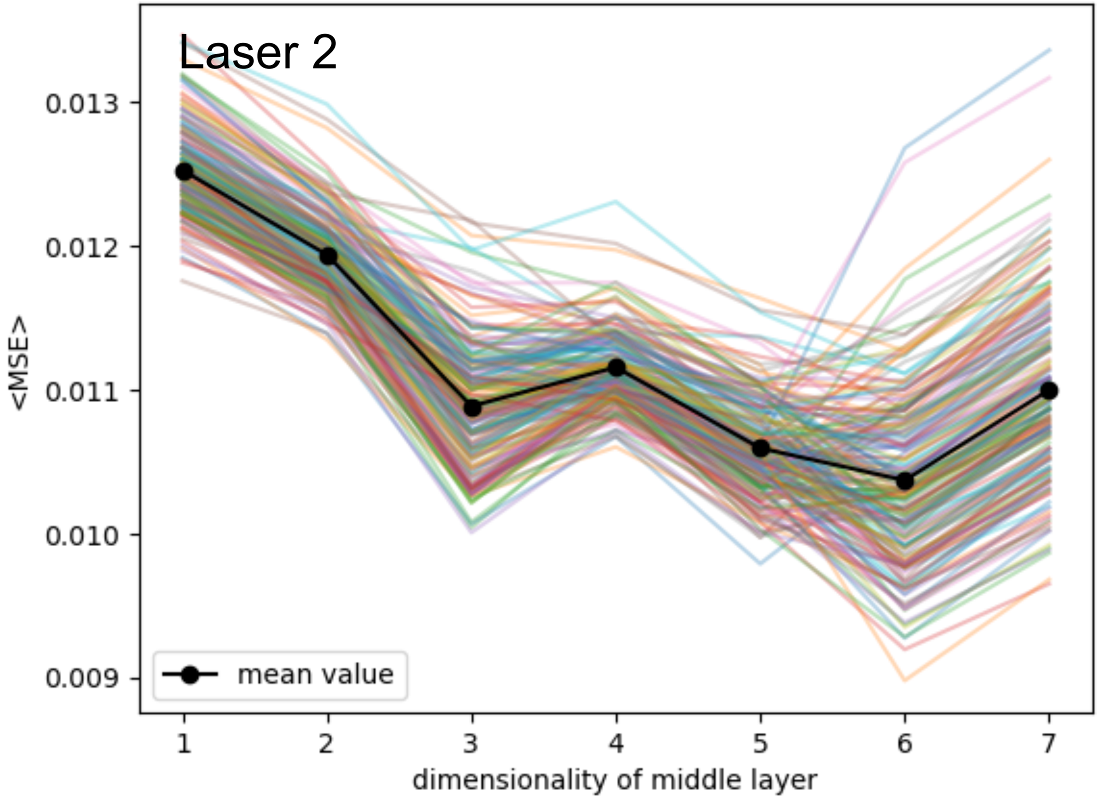


Dimensionality of the Latent Space

<MSE>: how well the (newly identified) best cell of networks with dimensionality 1-7 corrects

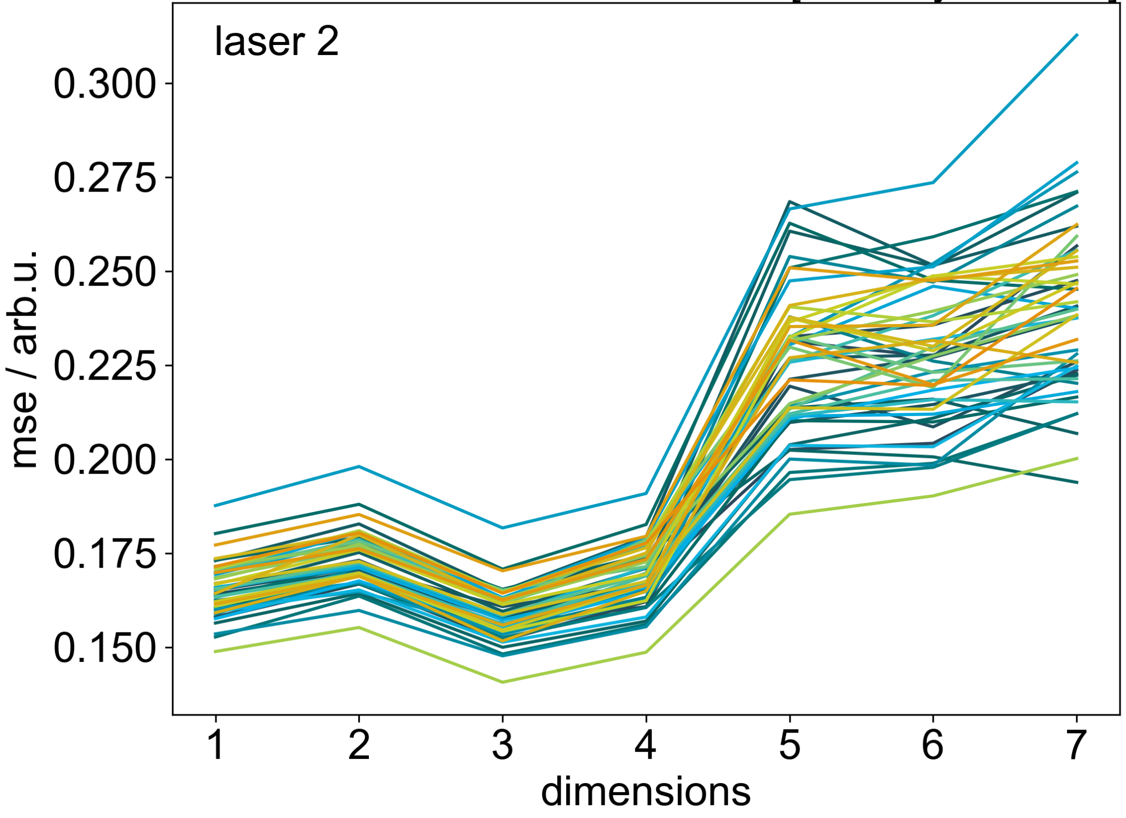


Dimensionality of the Latent Space



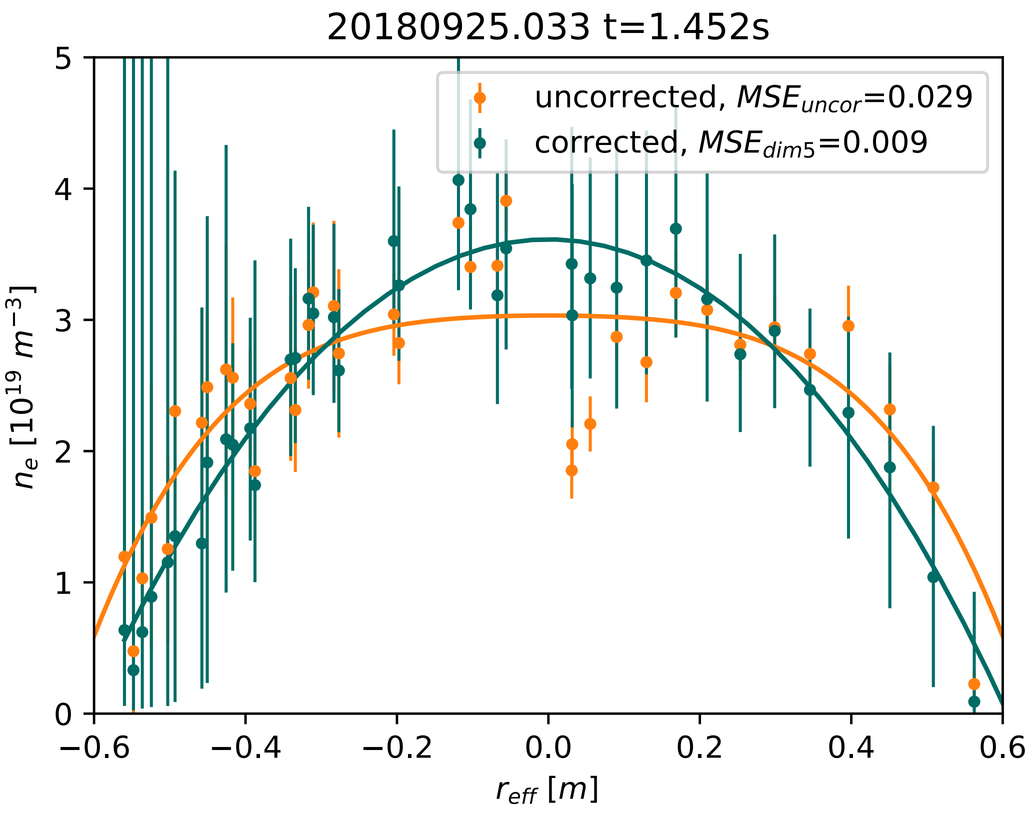
Best now: 5D

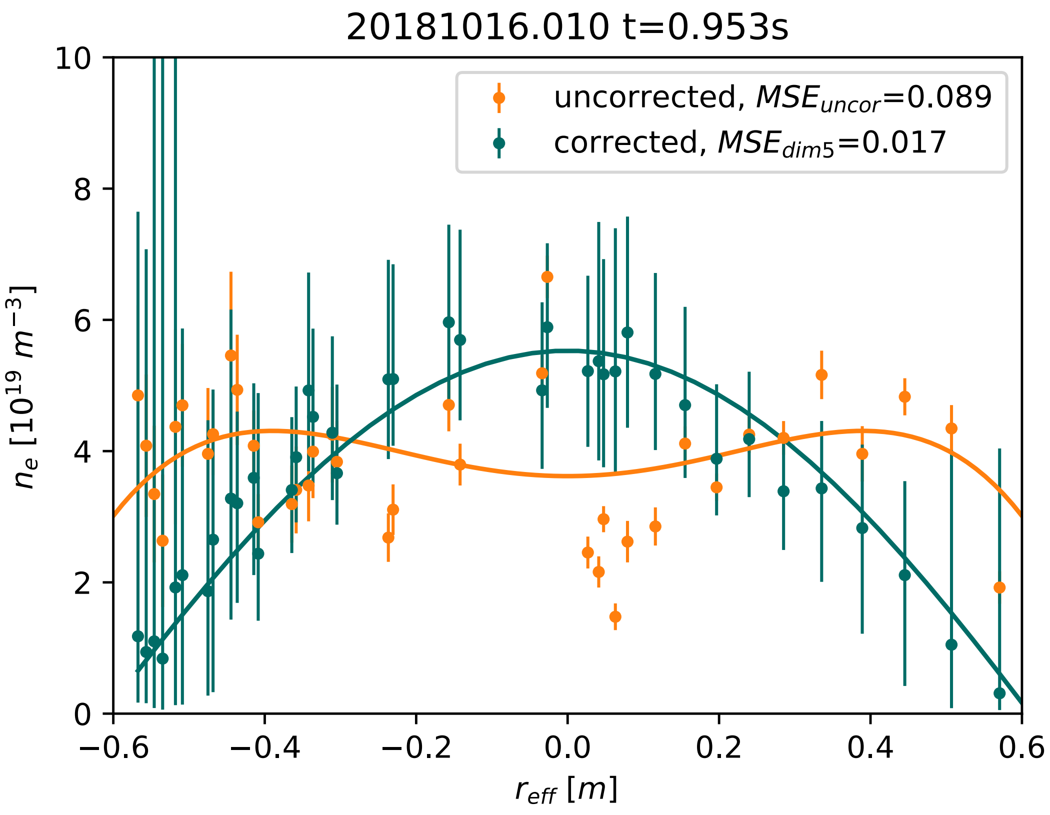
[courtesy J. Frank]



Best previously: 2/3D

Corrected Profile Shapes

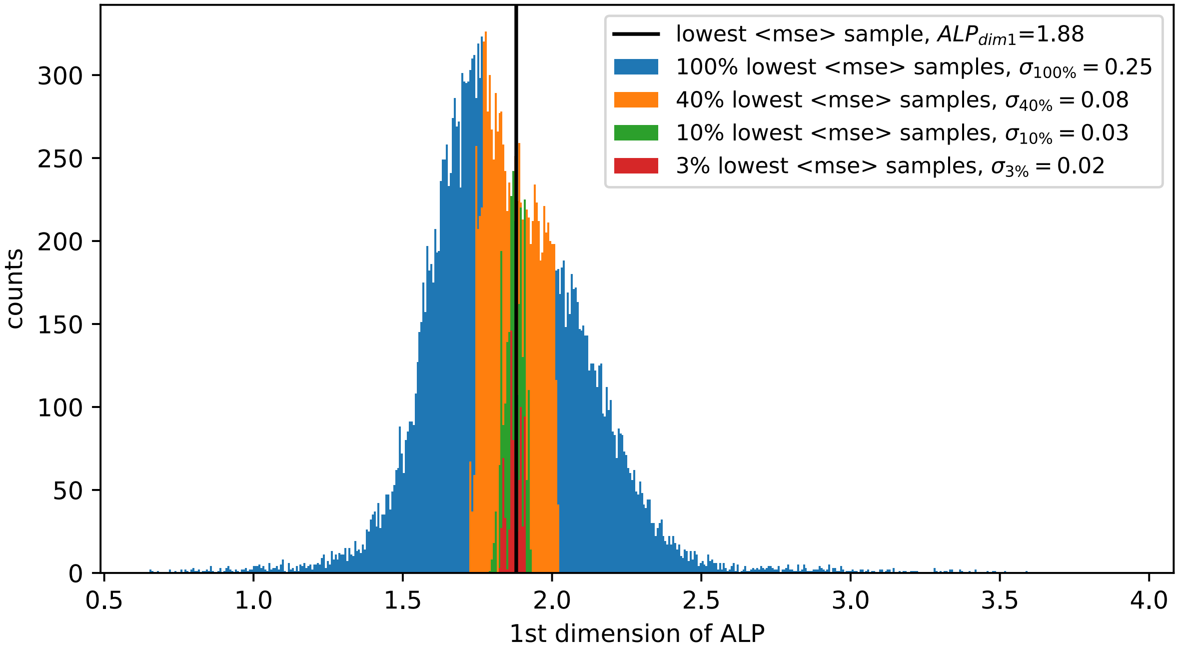


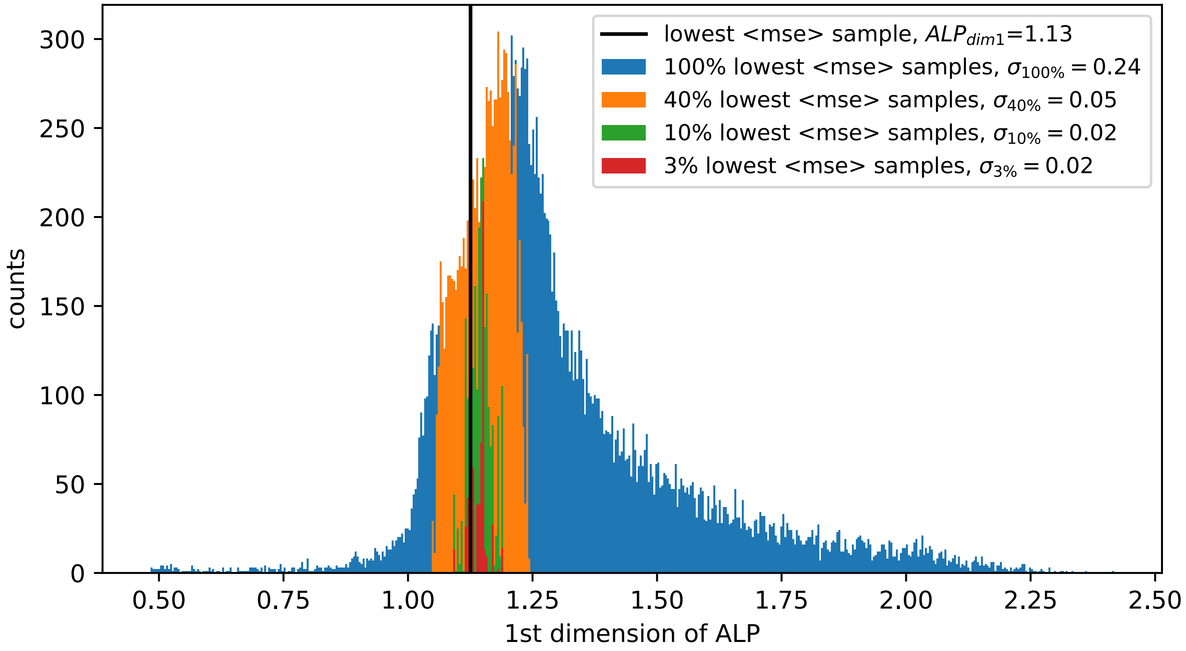


- **Similar result** as the previous method — possible same calibration cell is chosen
- but more confident — **more reliable**

Reproducibility

Evaluation results from the 2 runs (laser 2, 1D latent space)





- **Qualitatively different as expected**
- **Similar contraction effects**

Summary and Outlook

Summary

- Main focus: **more stable Calibration Cell identification —>** more reliable correction
- Significantly reduced computing time by changing the geometry of a cell —> **more efficient**
- Best latent space dimensionality: 4/5 — different as the previous study (3D) and expectation ($\leq$ 4D), reason unclear
- Now: The entire process takes about a week to compute on 4 CPU cores per laser per latent space dimensionality. (Training 3-4d, evaluation 3d)

Limitation & Outlook

- not very obvious which **dimensionality for the latent space** is most suitable

  — probably can be improved with a **new cell clustering method** for different latent spaces

- only partial absolute correction has been achieved — solution needed (have ideas)