First Studies on Machine Learning for the ALS Storage Ring

Simon C. Leemann & Shuai Liu
ALS Accelerator Physics, ATAP Division, Lawrence Berkeley National Laboratory
March 28, 2019

In collaboration with: Alex Hexemer (co-PI), Hiroshi Nishimura, Matthew A. Marcus, David Shapiro, Changchun Sun, Dani Ushizima, Nathan Melton, Greg Penn, Thorsten Hellert

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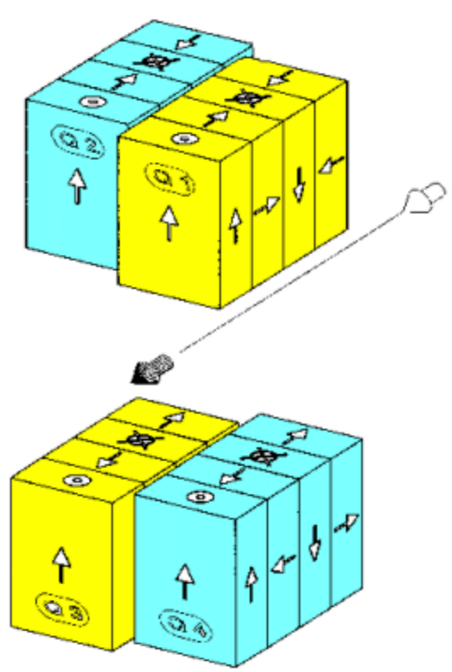
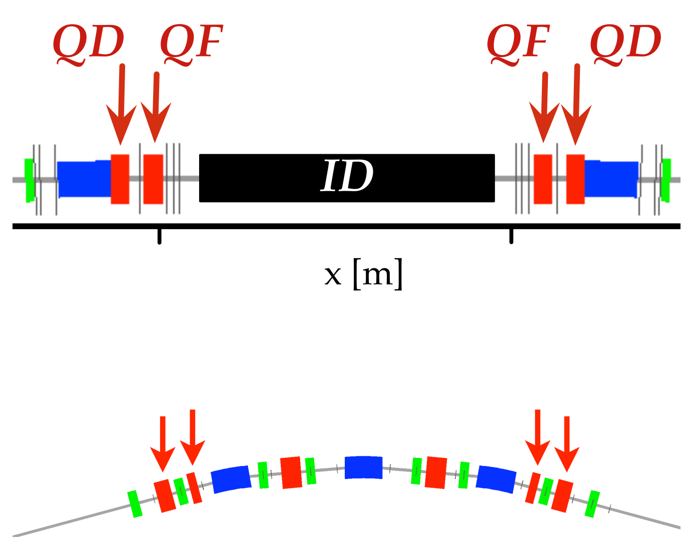
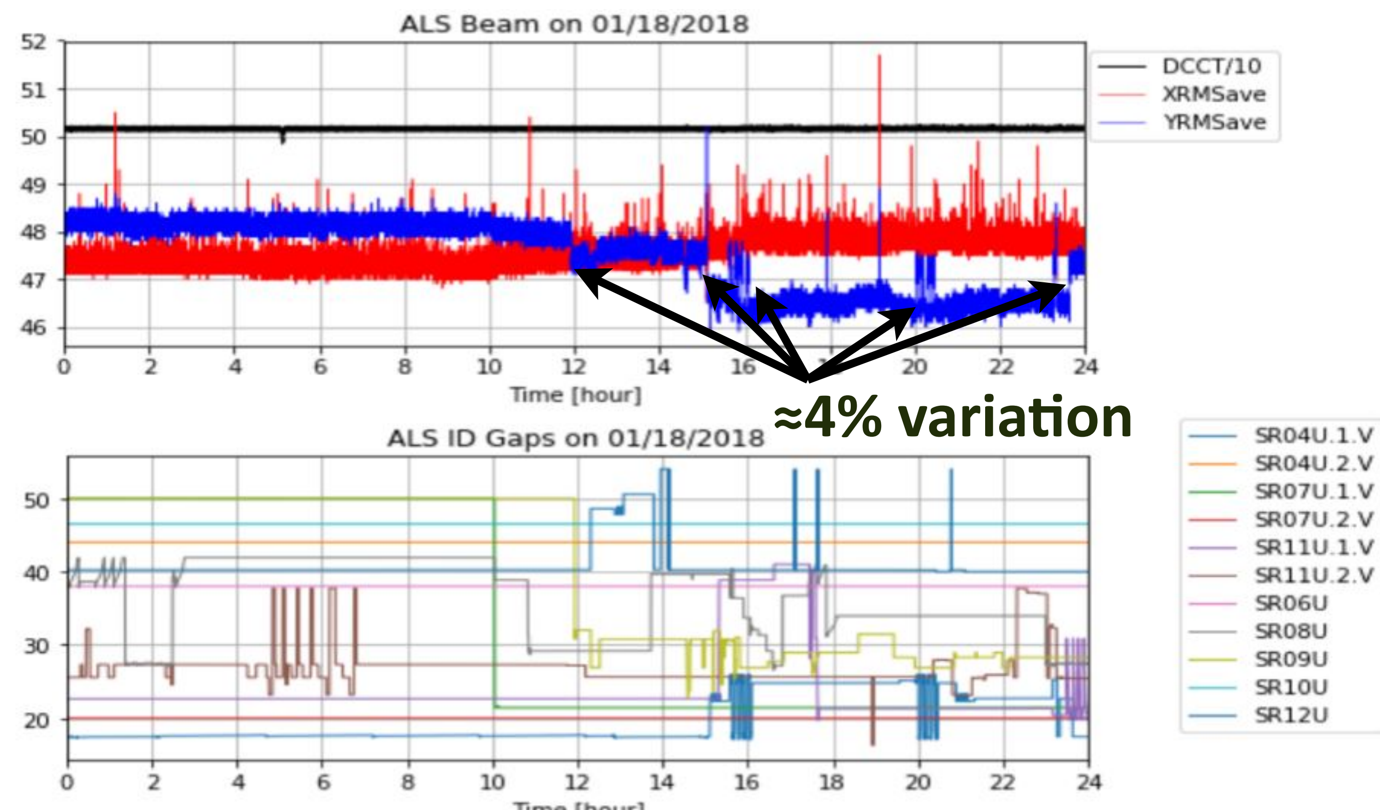
Background

- ALS Storage Ring (SR) orbit is very well controlled up to many tens of Hz
- ALS beam size control is an entirely different matter: depends strongly on plane, local optics tuning, global optics corrections, eg. ID feed-forwards (FFs), tune feedback (FB)
- ID FFs work well, but require look-up tables (≈12 hrs AP shift per EPU to generate two 3D tables) & correction susceptible to machine drift ➔ constantly re-record tables



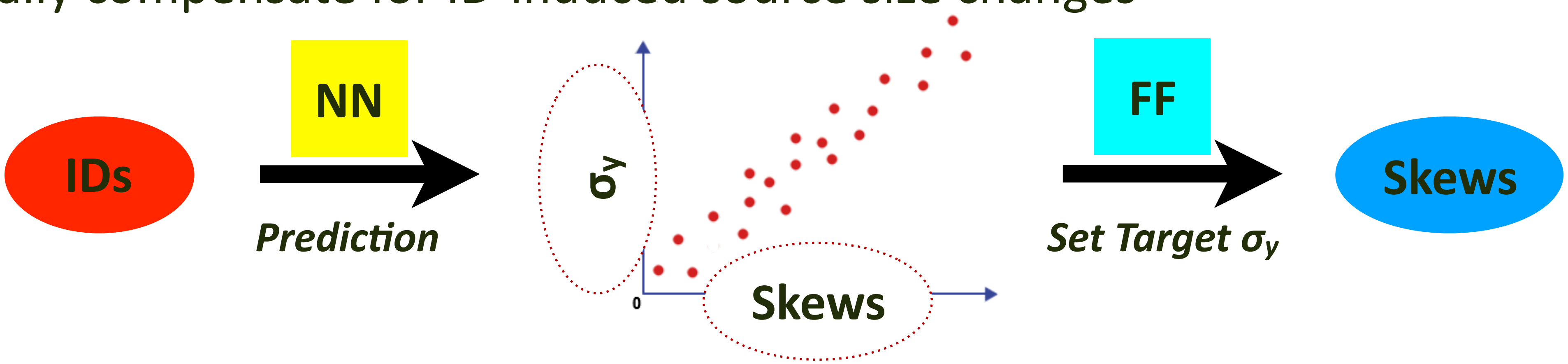




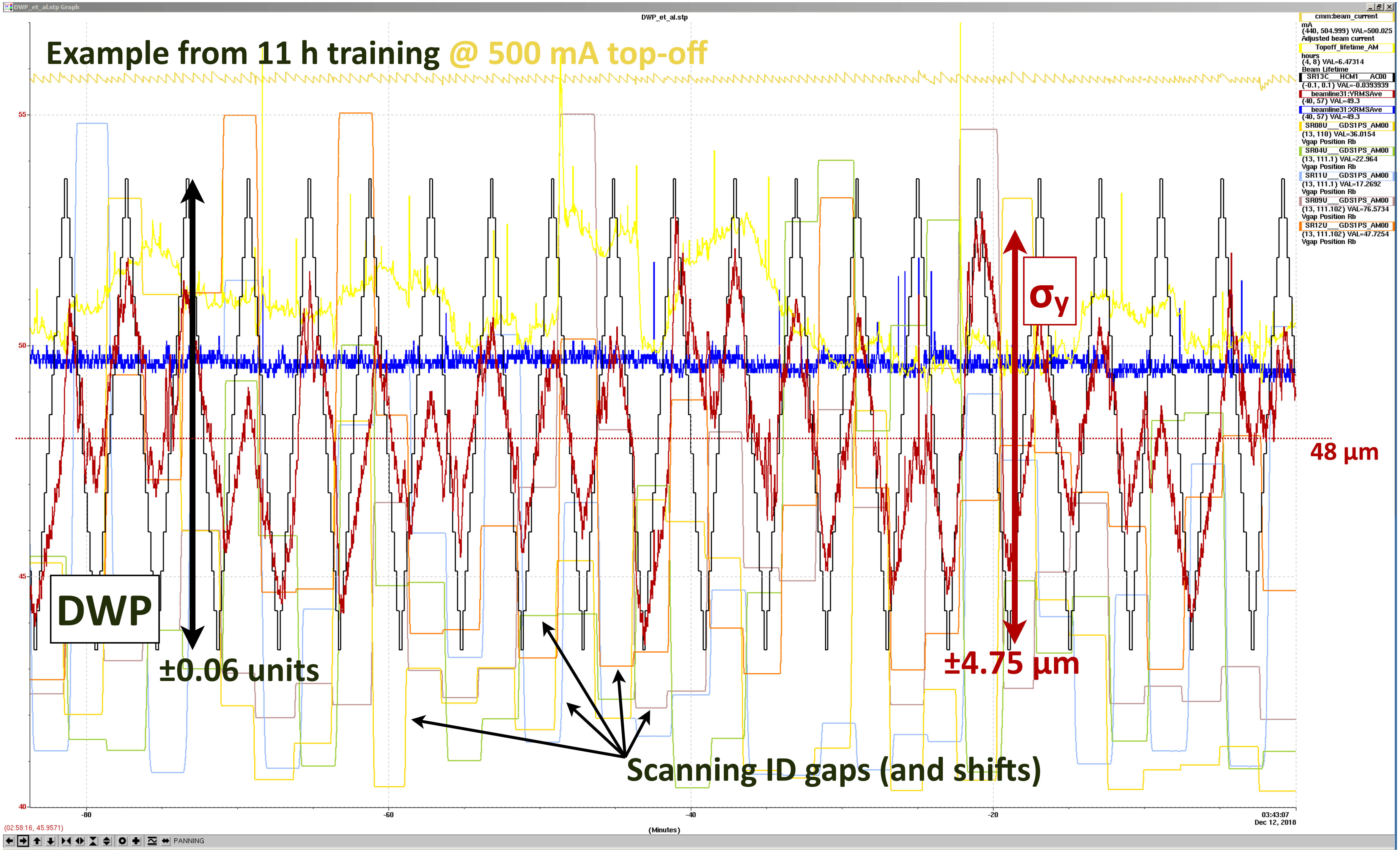
Courtesy: H. Nishimura

Background (cont.)

- Early 2018: DOE BES ADRP suggests we form collaboration with SSRL on ***"Beam Based Optimization and Machine Learning for Synchrotrons"***
- DOE BES & ASCR: granted funding Aug 2018 for two years (≈$0.7M @ ALS & similar at SSRL) → S.C. Leemann & A. Hexemer (PIs @ ALS), X. Huang & J. Safranek (PIs @ SSRL)
- Presently in the process of hiring postdoc to work on this full time; in the meantime collaborated with other accelerator (H. Nishimura) and ML experts (N. Melton) on preparing **first ML application for ALS SR**
  - Idea is *not* to replace any existing FBs or FFs, but to use an ***ML-based FF to remove residual fluctuations of vertical source size in ALS SR*** (sub-micron, ALS-U, etc.)
  - Employ NN to predict SR beam size as function of arbitrary ID gap/shift configurations → adjust skew quadrupole excitation ("vertical dispersion wave") to globally compensate for ID-induced source size changes



Training a Neural Network During AP Shift



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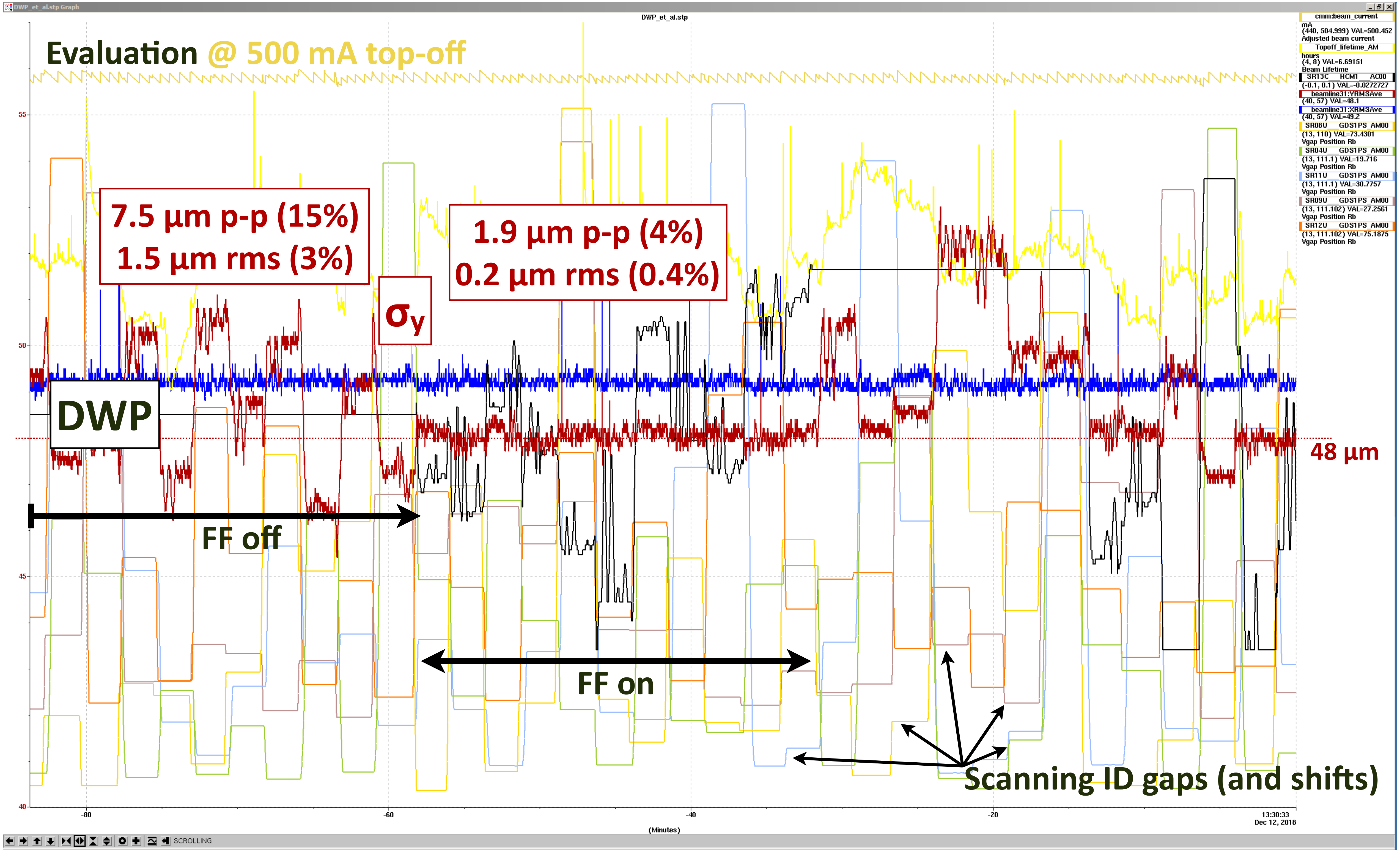
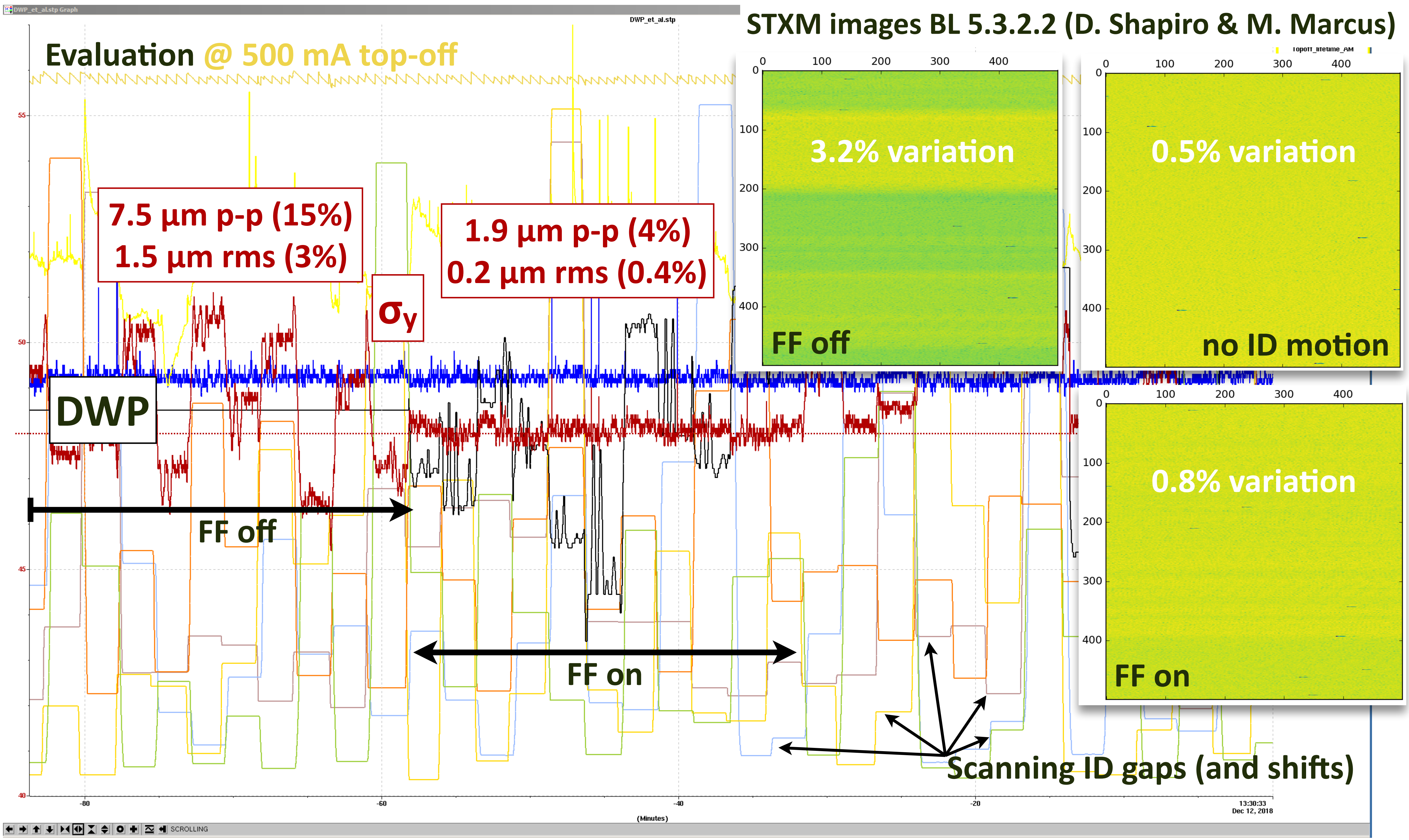
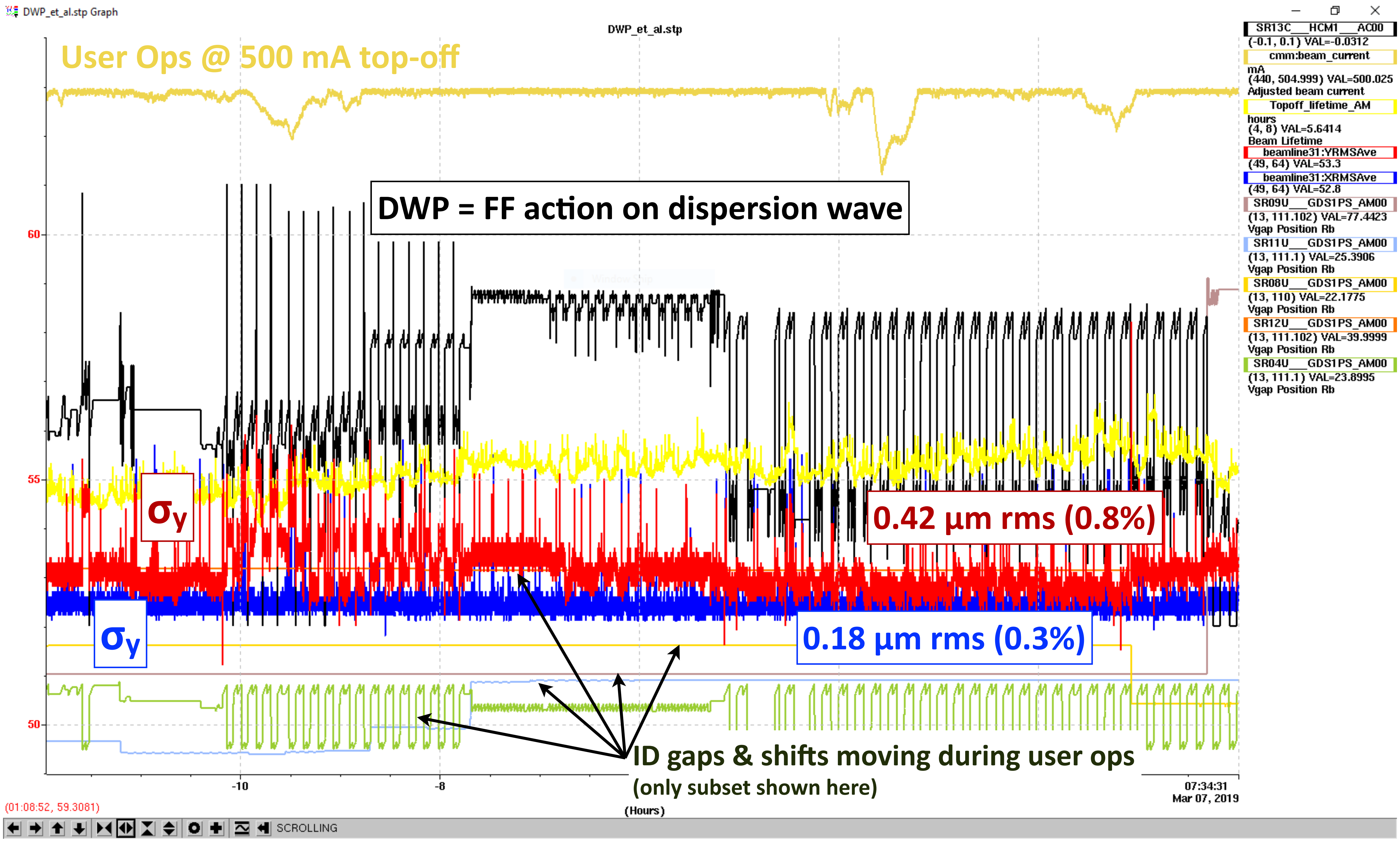
Evaluating NN-Based FF During AP Shift



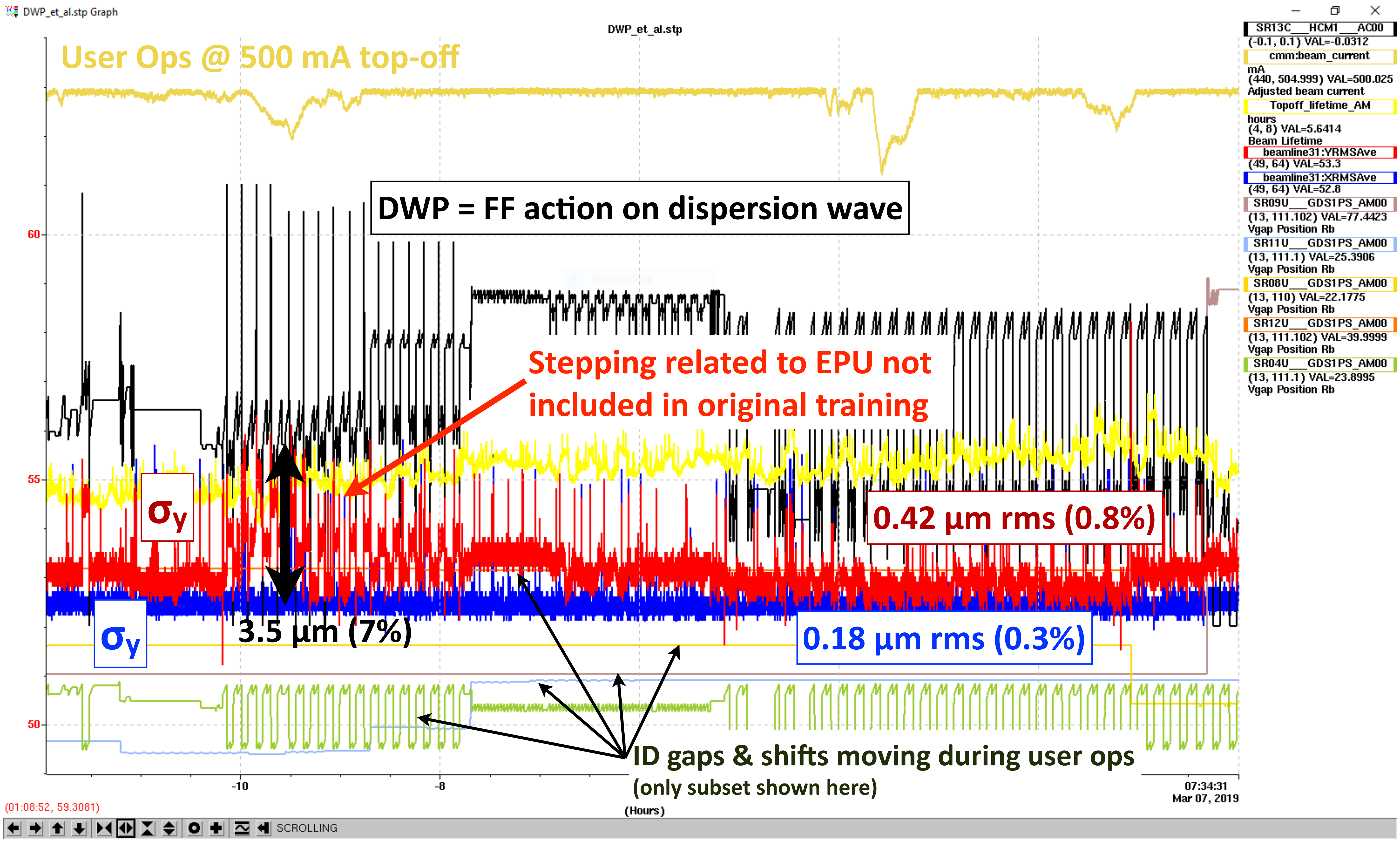
Evaluating NN-Based FF During AP Shift (cont.)



During User Ops: Stabilization Confirmed



During User Ops: Stabilization Confirmed, but...



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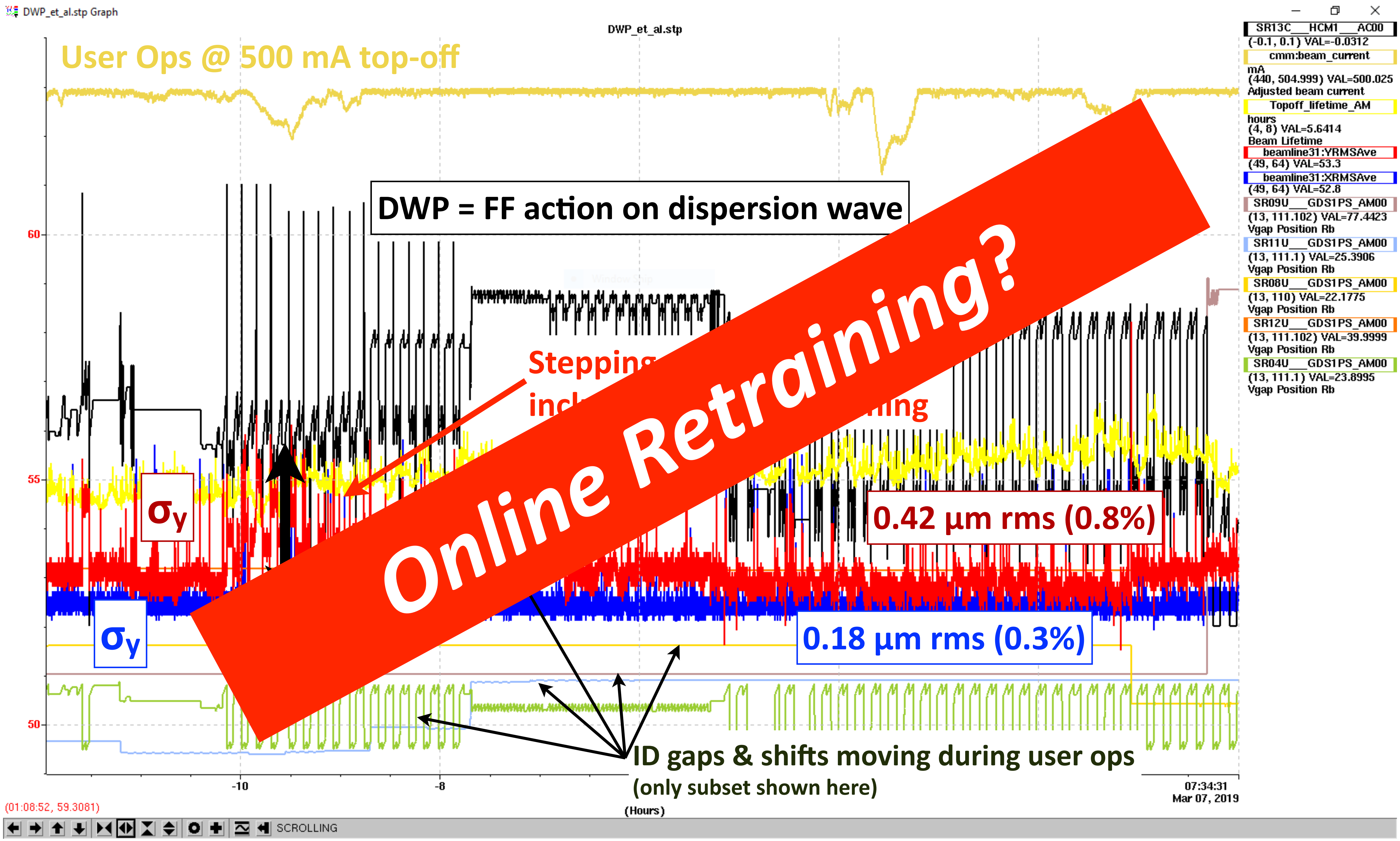
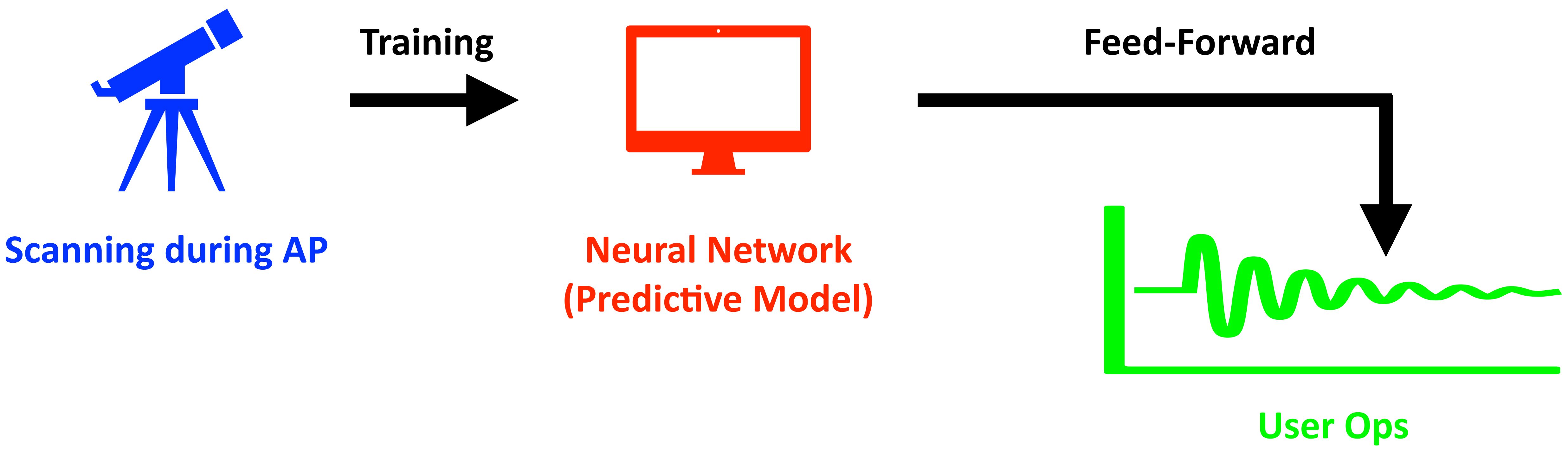


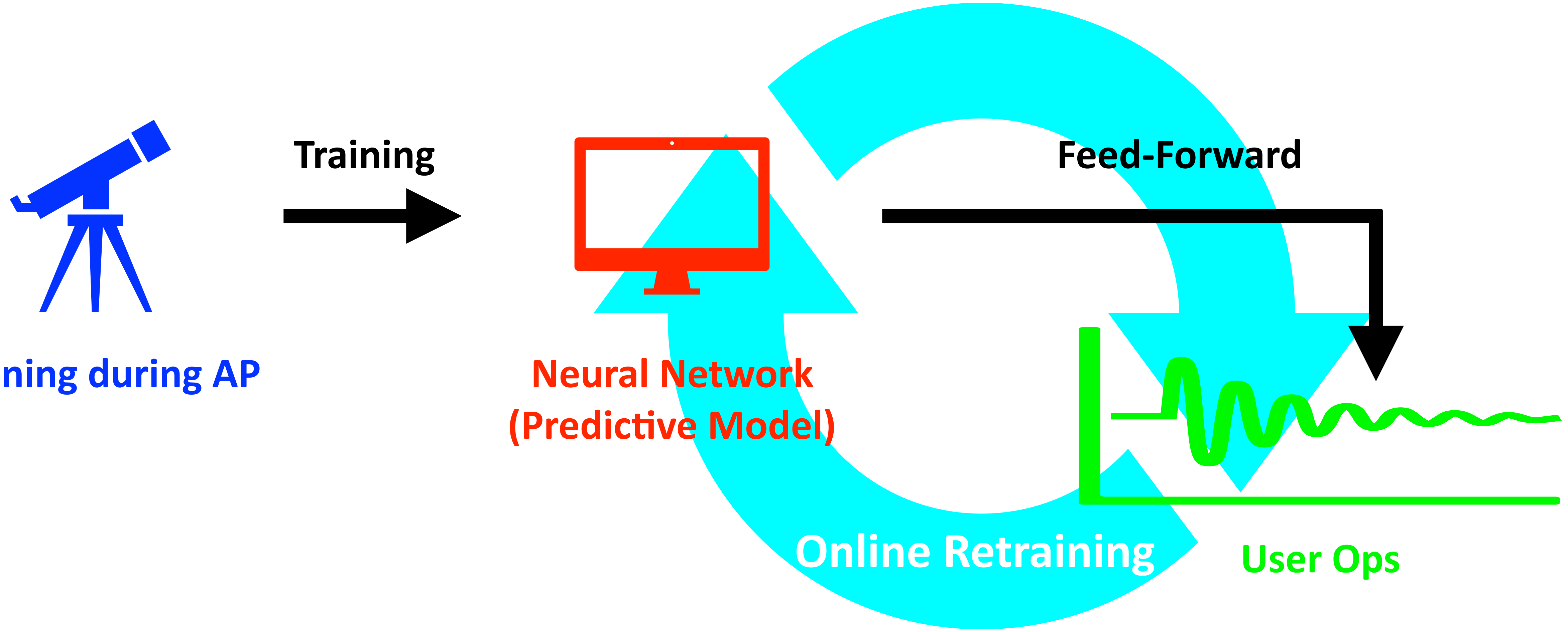
So what's different with online retraining?

"Conventional" Machine Learning



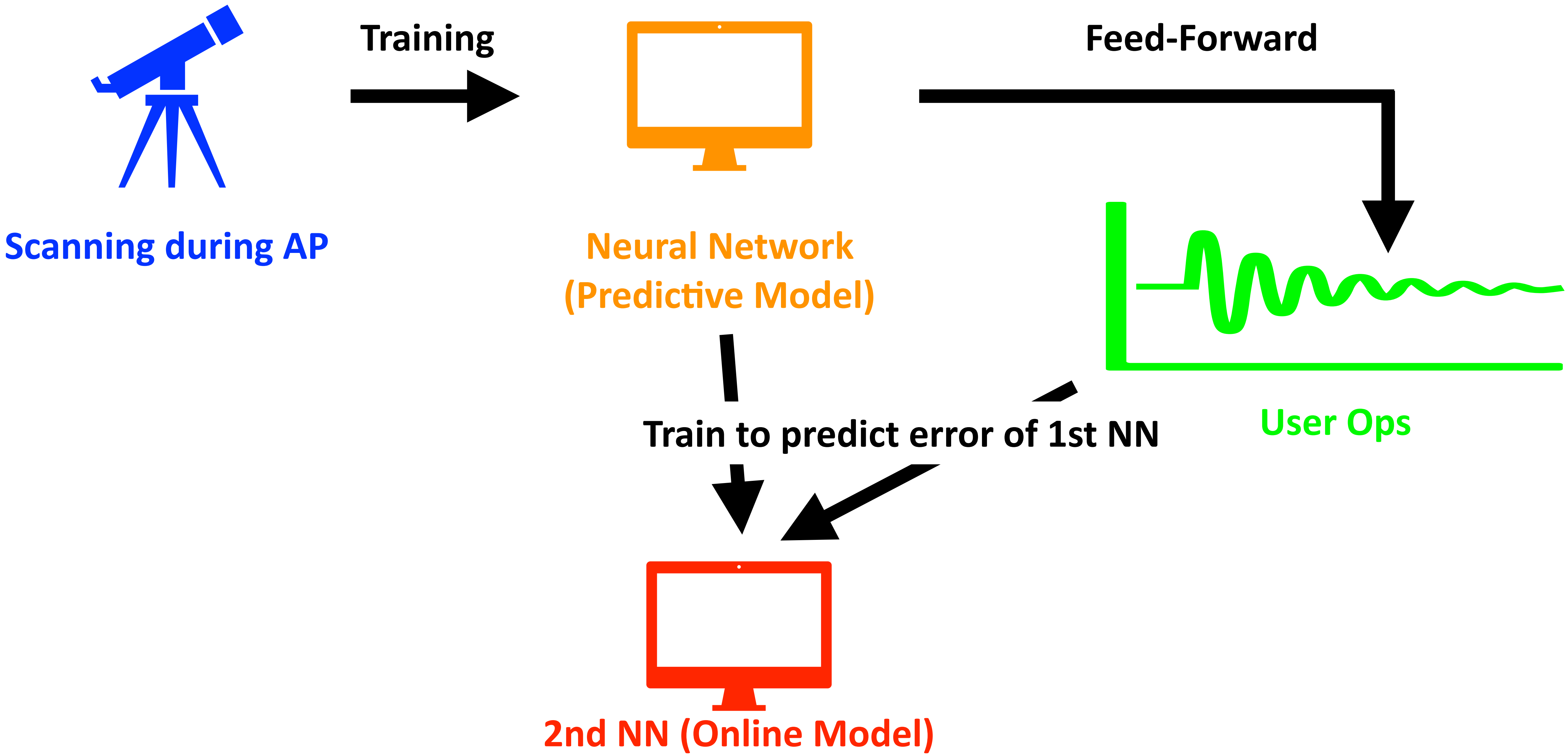
So what's different with online retraining? (cont.)

Online Retraining (Simple Approach)



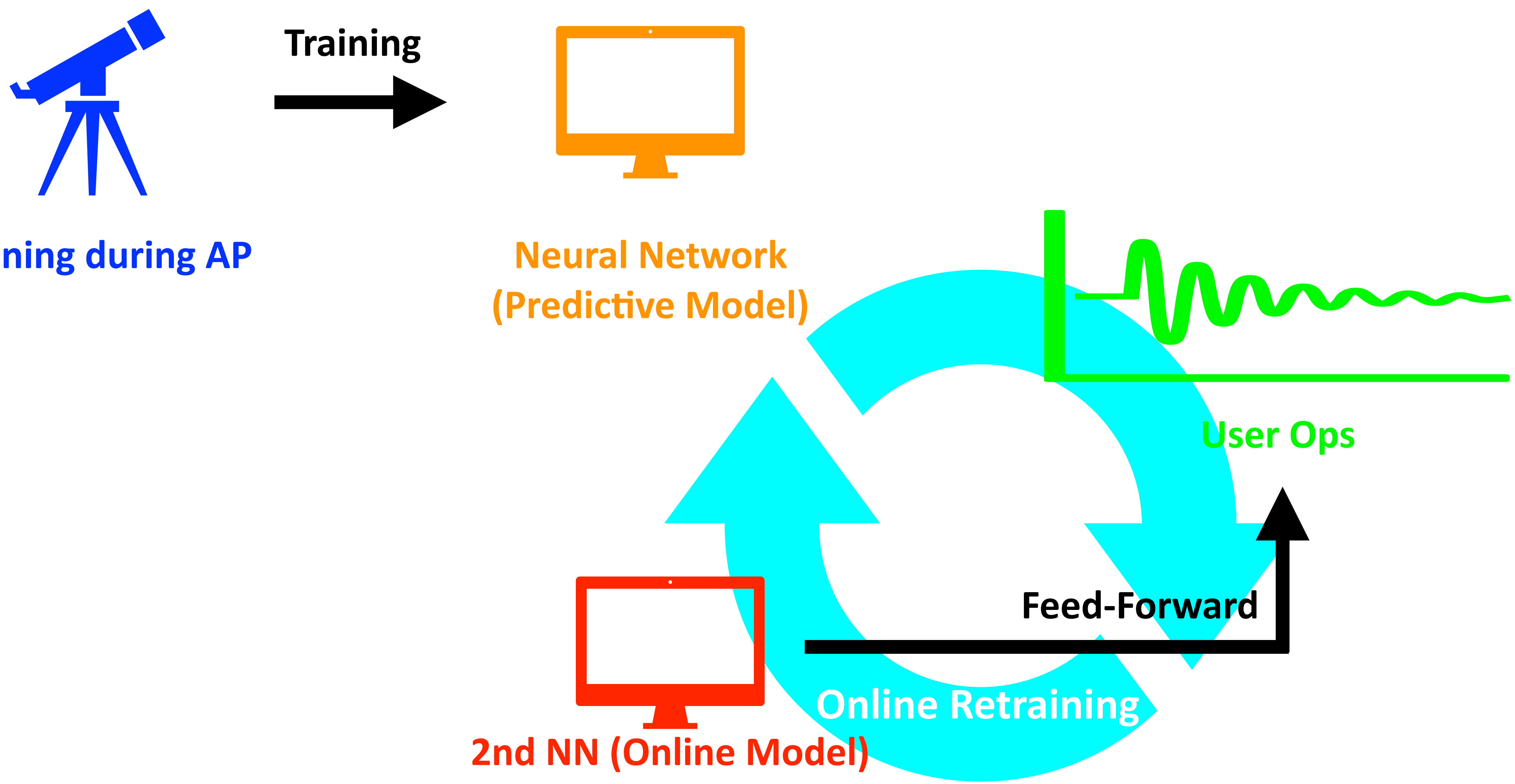
So what's different with online retraining? (cont.)

Online Retraining (Smarter Approach), Step 1



So what's different with online retraining? (cont.)

Online Retraining (Smarter Approach), Step 2



So what's different with online retraining? (cont.)

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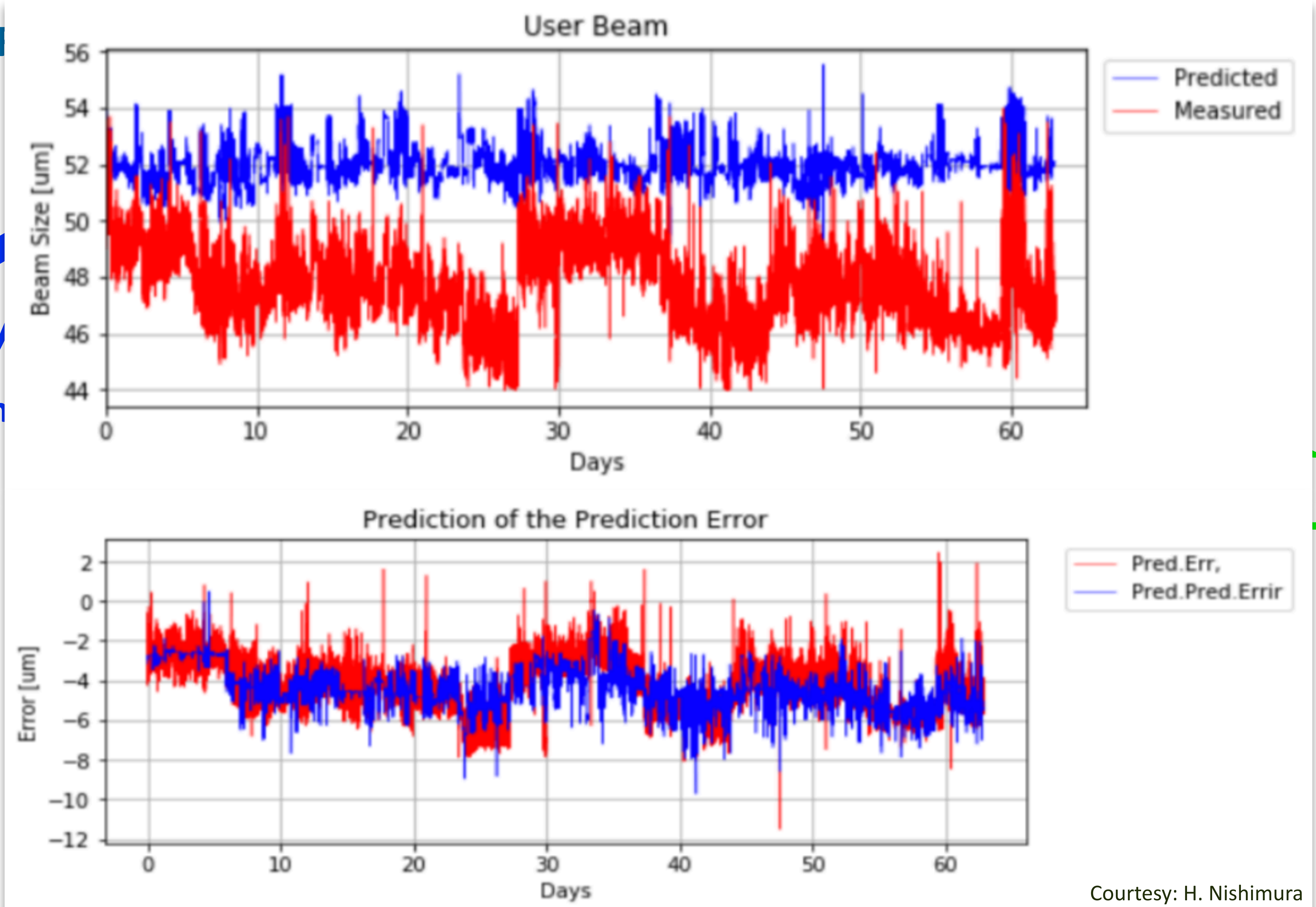
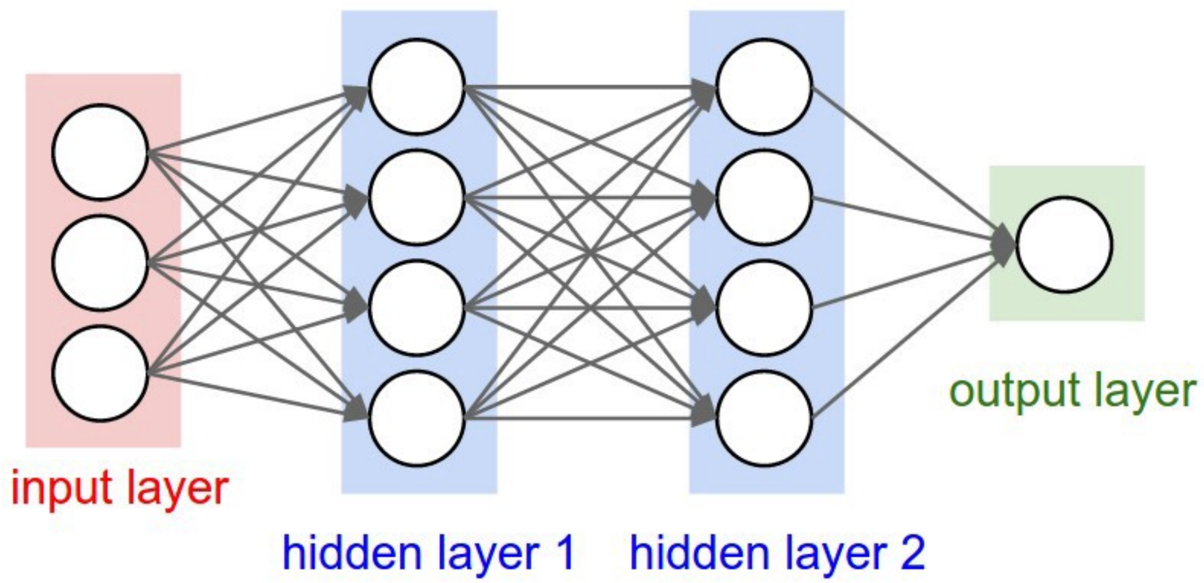
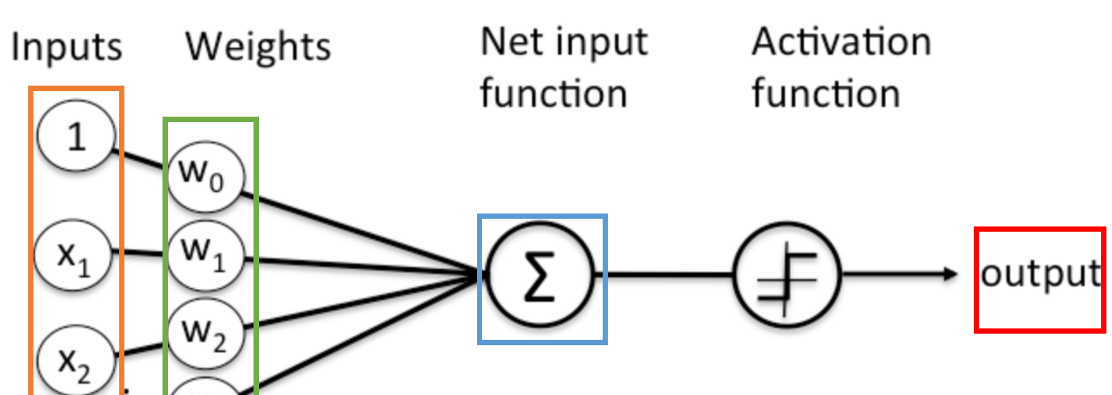


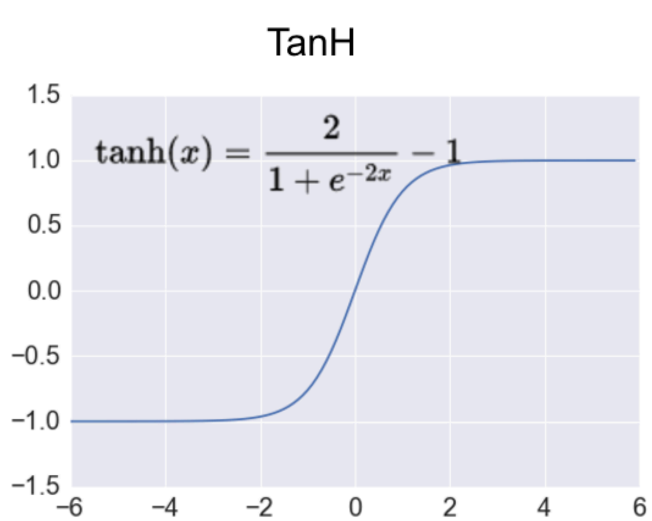
Courtesy: H. Nishimura

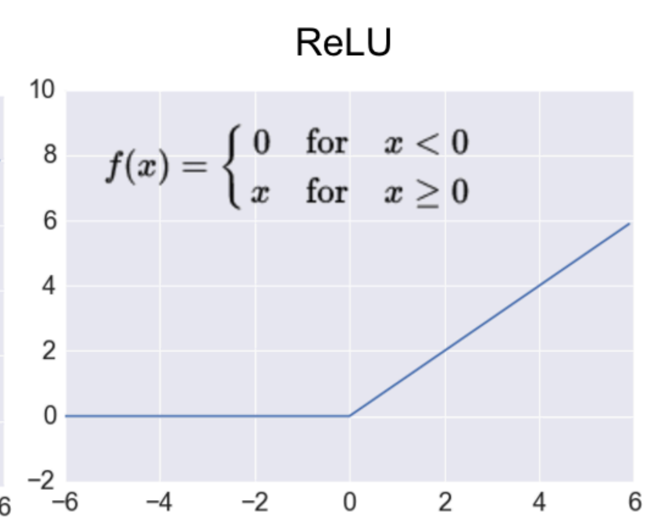
So what does this NN look like in detail?



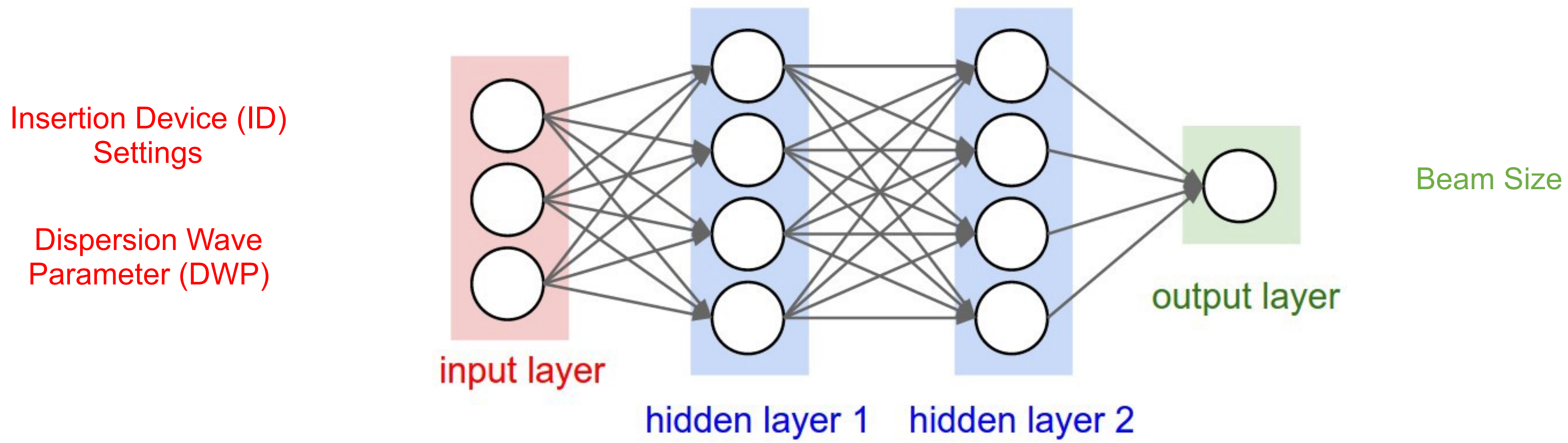


$$x_j^{l+1} = f\left(\sum_j w_{ij} x_i^l\right)$$





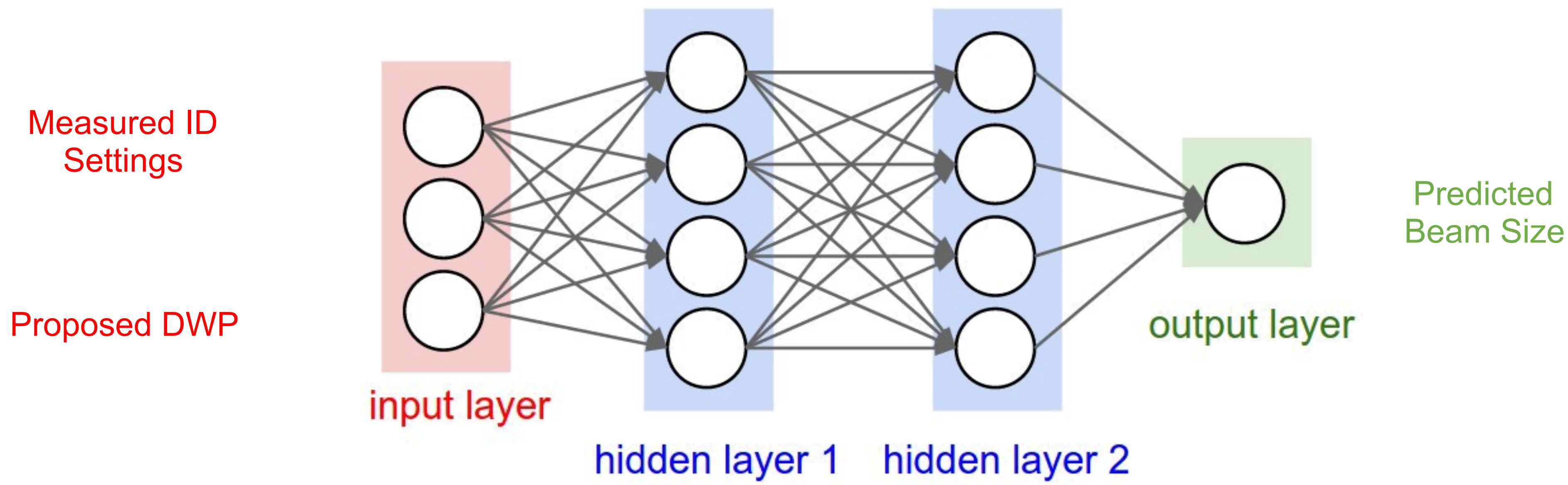
And how is it trained?



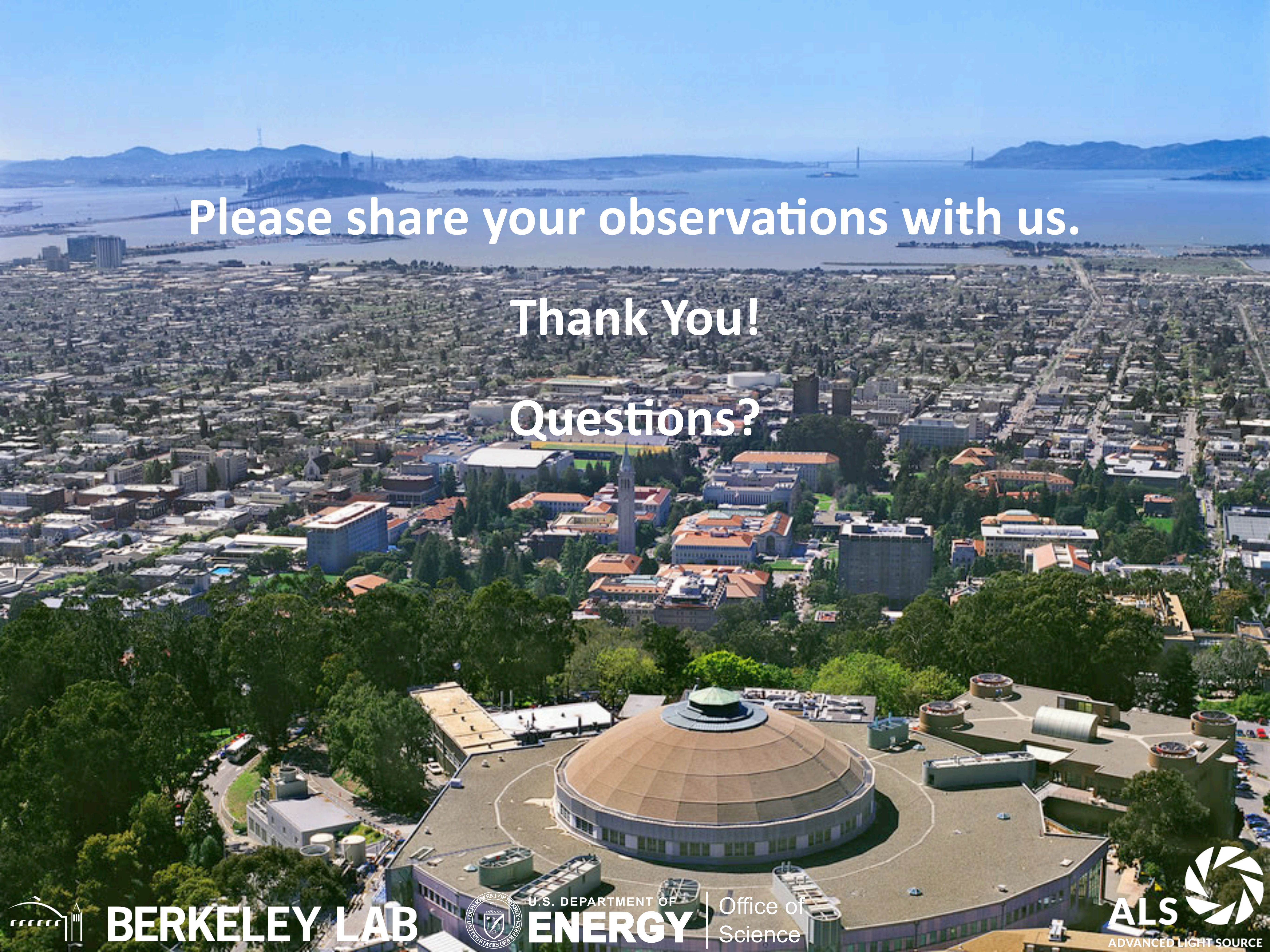
Input Layer: ID settings (22 Dimension) and DWP (1 Dimension)
Three Hidden Fully Connected Layers: 128, 64, 32 neurons in each layer
Output Layer: Vertical Beam Size (1 Dimension)

Regularization: L_2 regularizer with $\lambda = 10^{-4}$
Optimization: Adam Optimizer with learning rate $\alpha = 10^{-3}$

So then how do we use it?



Proposed DWPs		Predicted Beam Sizes		
-0.06		50.3		
….		….		
0	Measured ID Settings → Neural Network	52.1	Compare with Target → Beam Size	Choose proper DWP
…		…		
0.06		54.0		



Please share your observations with us.

Thank You!

Questions?

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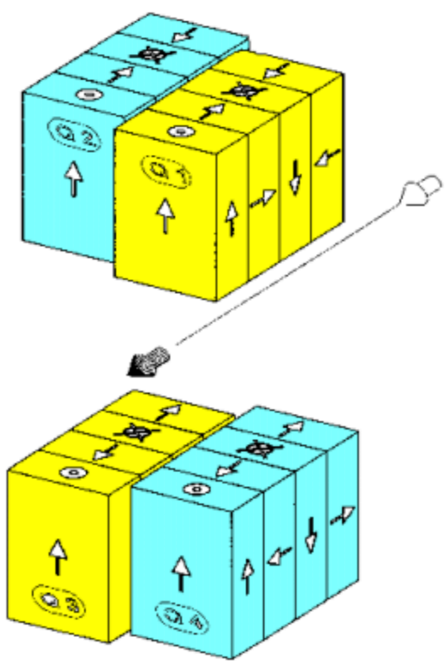
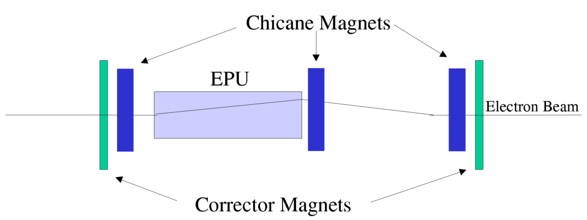
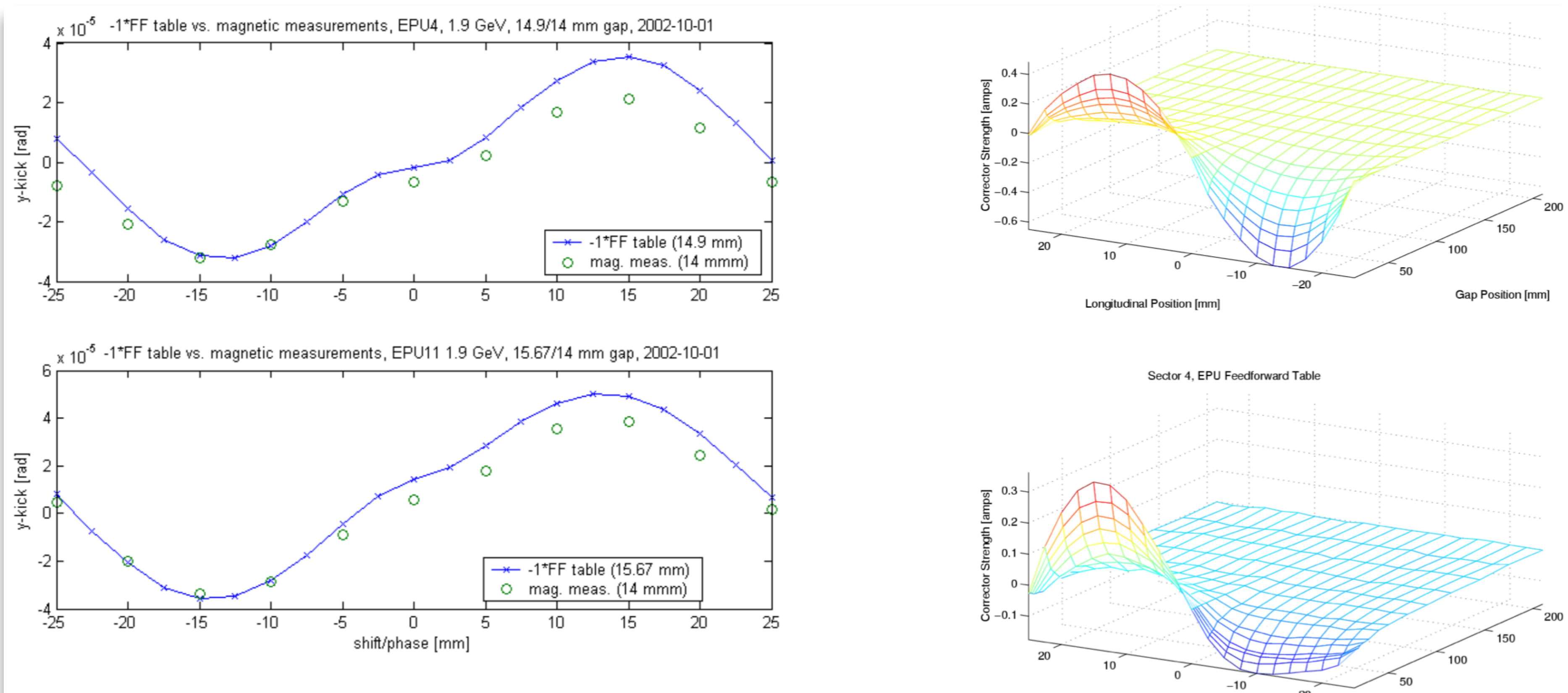
Backup Slides

Errors Caused by IDs & Required Corrections

- Orbit distortions
  - caused by on-axis variation of field integrals (with gap or EPU phase)
    - corrected by shims (magic fingers) & local orbit correctors (FF, 200 Hz)
    - corrected by ring corrector magnets (FB, ≈1 Hz SOFB & 1.1 kHz FOFB)







EPAC 2004, MOPKF071, p.479

Errors Caused by IDs & Required Corrections

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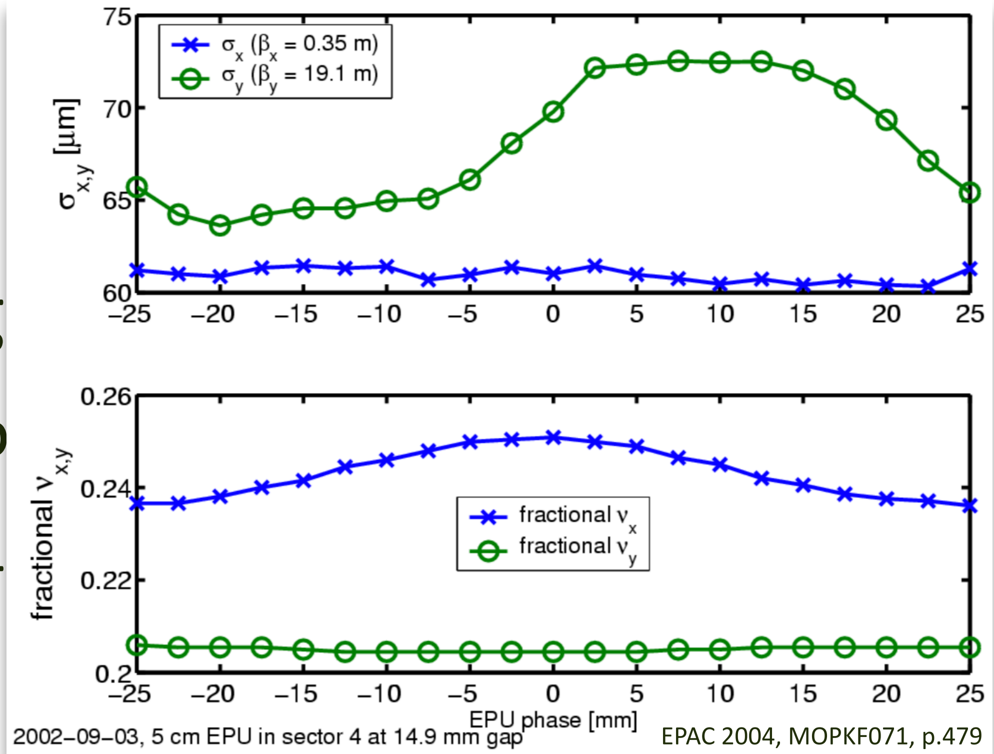
- Beam size (primarily vertical)
  - caused by variation of ID focusing terms (with gap or EPU phase)
    - corrected by local quad trims and global quad adjustment (FF & FB)



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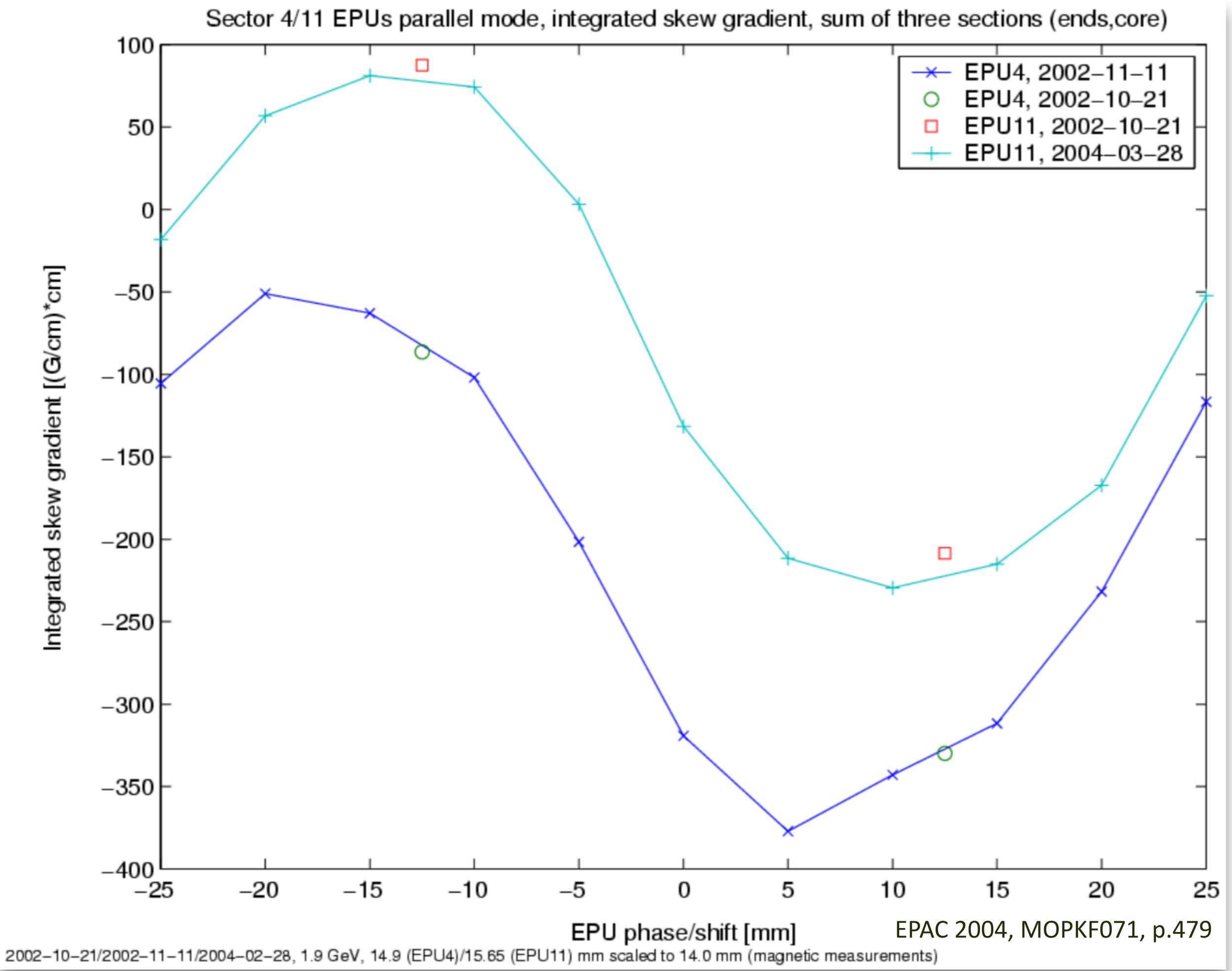

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  - caused by variation of ID-induced coupling (usually with EPU phase)
    - corrected by local skew quad coils (FF)

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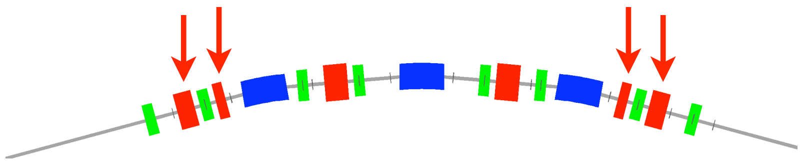
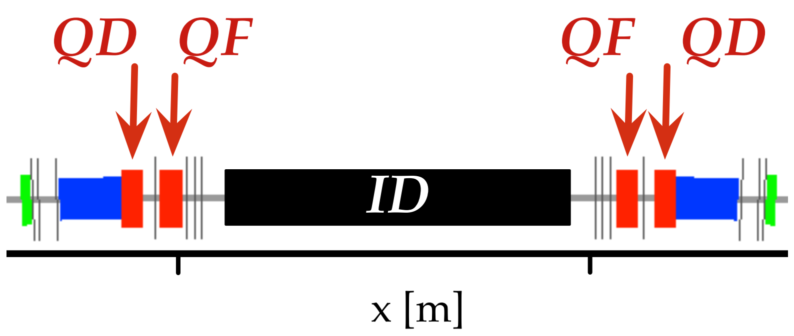
- Beam size (primarily vertical)
  - caused by variation of ID focusing terms (with gap or EPU phase)
    - corrected by local quad trims and global quad adjustment (FF & FB)
  - caused by variation of ID-induced coupling (usually with EPU phase)
    - corrected by local skew quad coils (FF)
- Reduced injection efficiency & lifetime (nonlinear beam dynamics)
  - caused by higher-order ID effects (eg. field roll-off) → sets requirements for ID design and machine optics

ID Focusing Corrections Implemented in ALS ID FF

- Global Corrections
  - tunes (using lattice quads: 24 QF & 24 QD)
  - in addition: **tune FB** using same quads



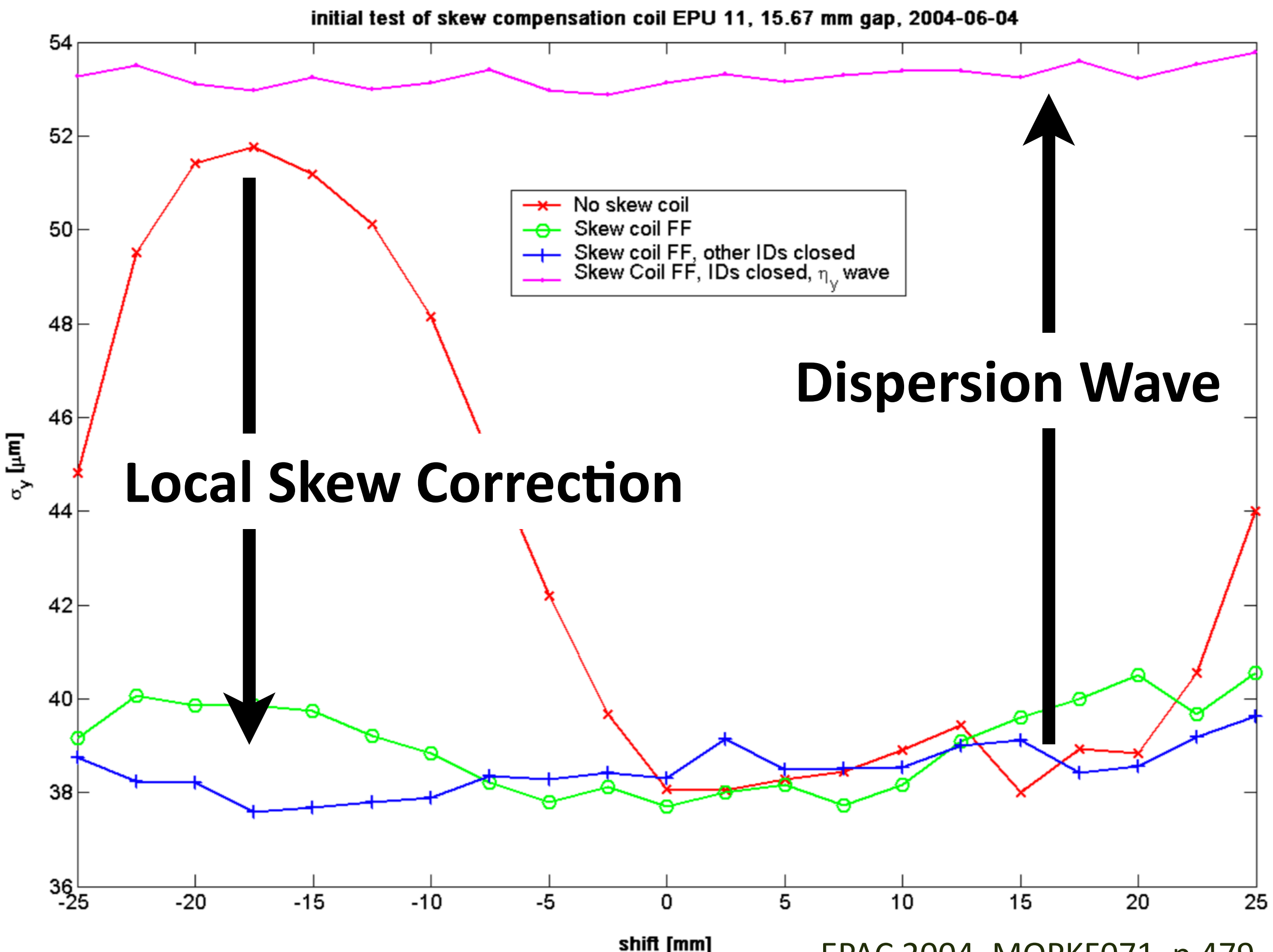
- Local Corrections for all IDs
  - β_y beat (using 2 QF & 2 QD locally) ➔ slightly increases $\Delta\nu_y$ ➔ can be removed by global tune correction



- Local Corrections for EPUs only
  - β_x beat (using 2 QF & 2 QD locally) ➔ locally also corrects $\Delta\nu_x$ since $\beta_x \approx 21$ m

Vertical Dispersion Wave Determines Effective ε_y

- Vertical source size is determined by
  - optics and coupling (local)
  - vertical emittance (global) consisting of
    - natural contribution (emission of SR is quantum process)
    - imperfections (unavoidable in real machines)
    - systematic η_y contributions (Dispersion Wave)



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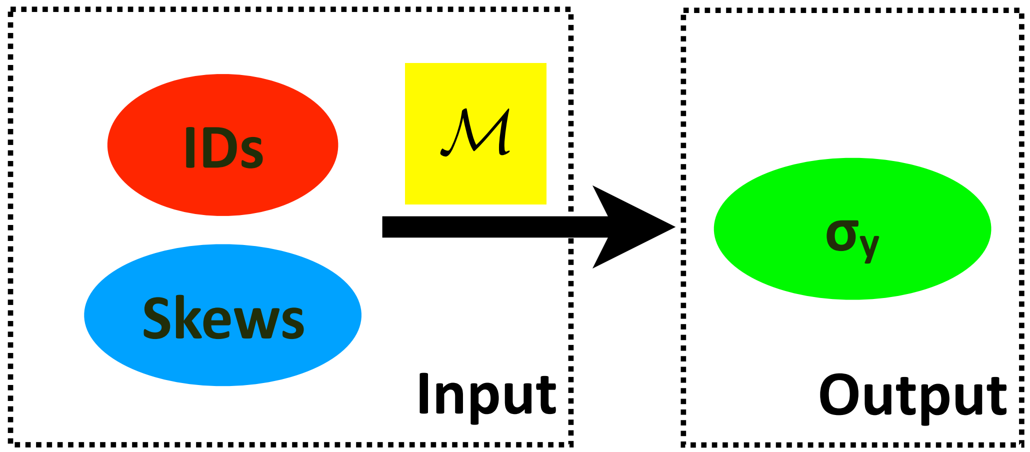
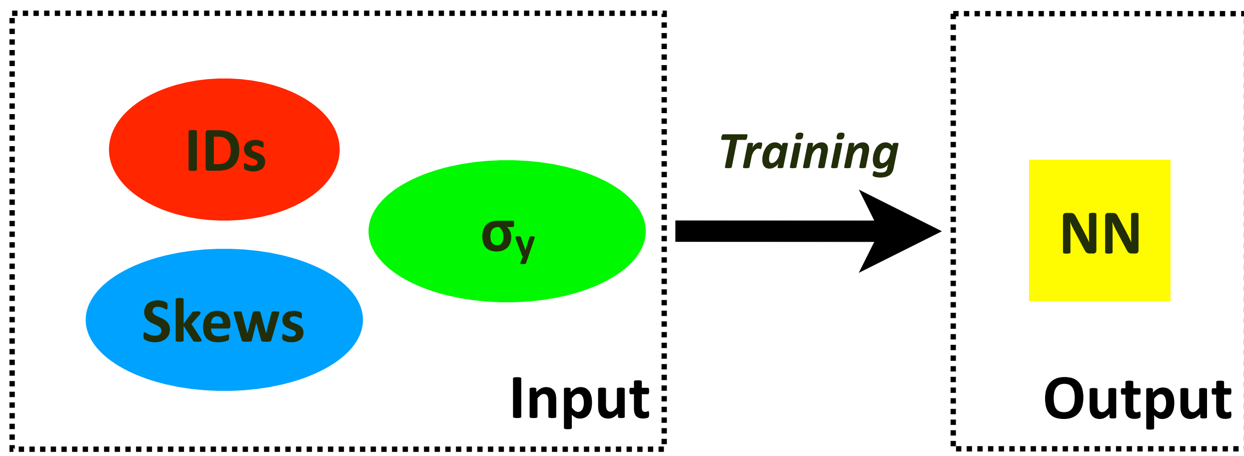
For Accelerators Deep Learning is a Paradigm Shift

Traditional Approach



- *Requires physics/model knowledge*
- *Tends to rely on many (sometimes poor) assumptions*

Deep Learning



- *Requires only large amounts of data & reproducibility*

Application during ops: