Orbit Feedback Trickery at the NSLS VUV ring

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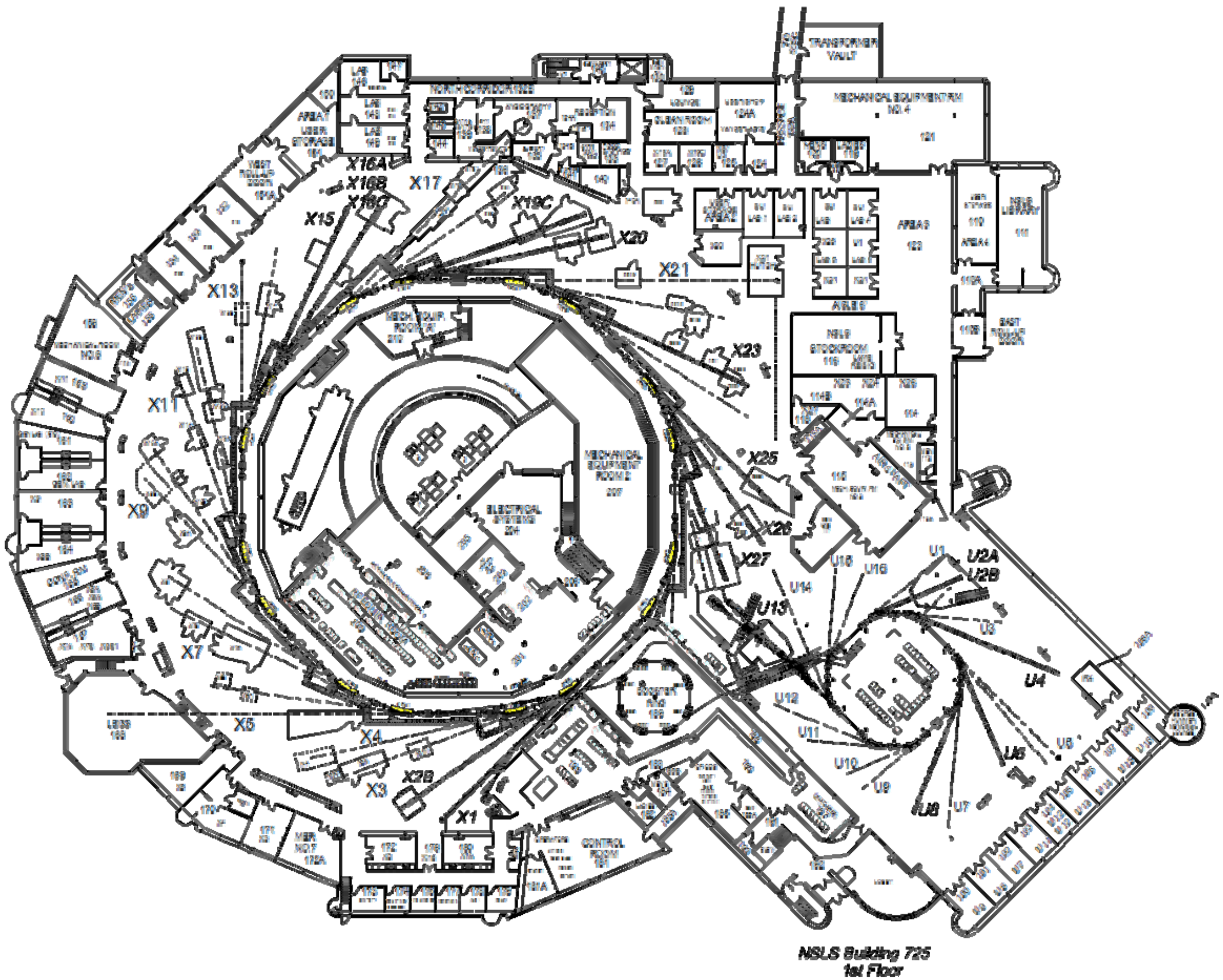
Outline

- Motivation & Introduction (NSLS, VUV ring, why feedback, some history)
- Present Orbit Feedback System & Design Tradeoffs
- Dynamic Orbit Bump
- Outlook

NSLS Accelerators Today



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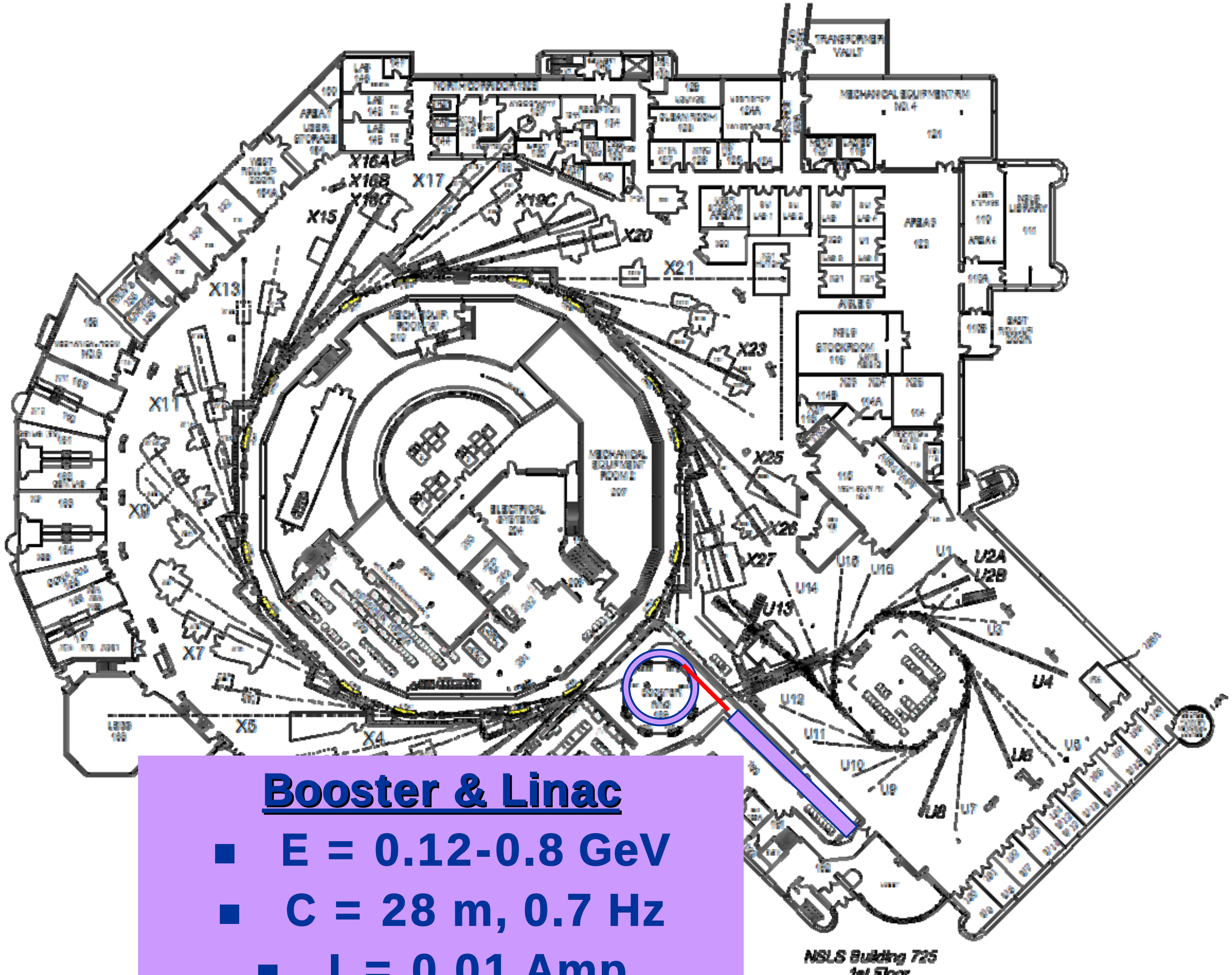

Booster & Linac

- E = 0.12-0.8 GeV
- C = 28 m, 0.7 Hz
- I = 0.01 Amp

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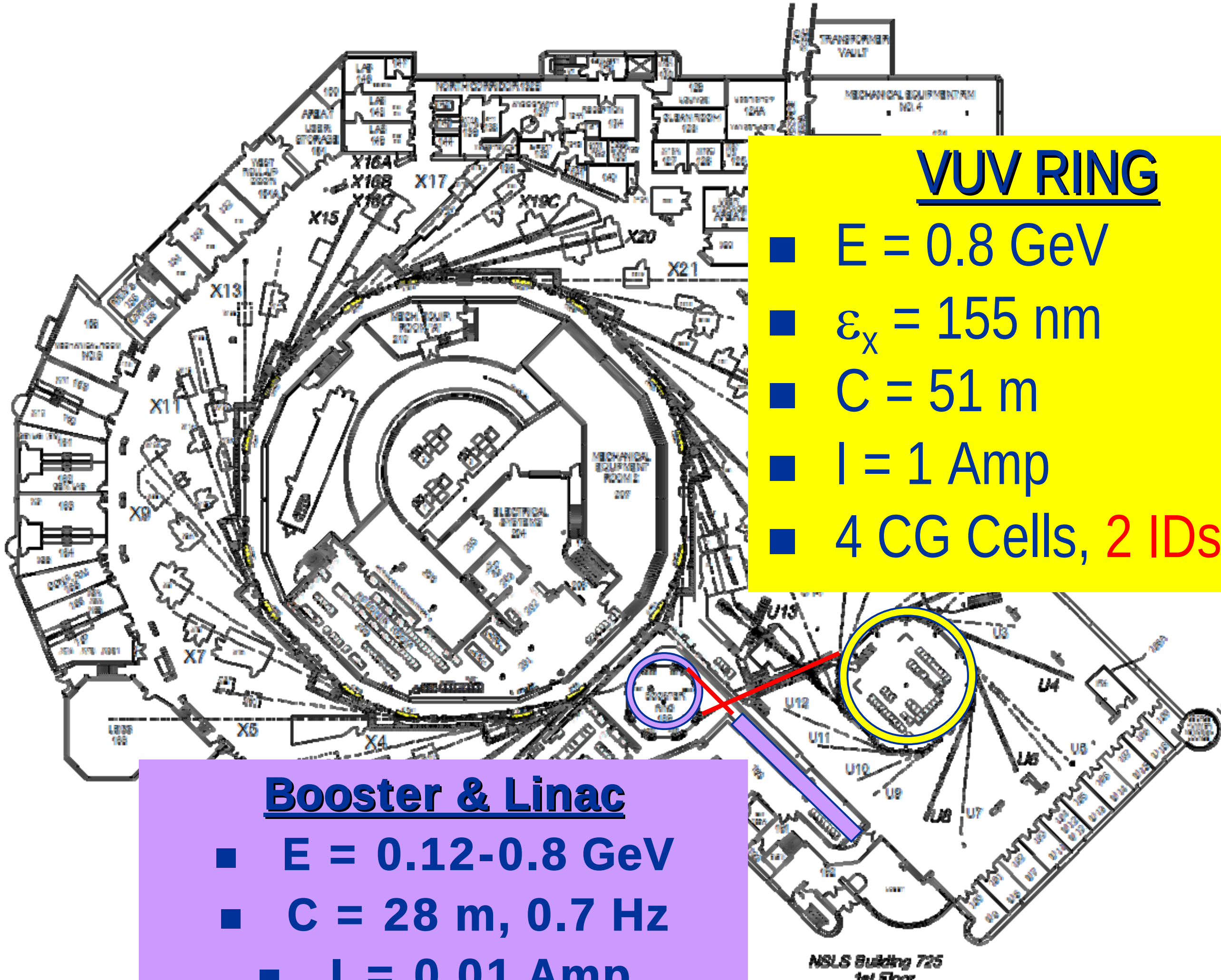

VUV RING

- $E = 0.8$ GeV
- $\varepsilon_x = 155$ nm
- C = 51 m
- I = 1 Amp
- 4 CG Cells, 2 IDs

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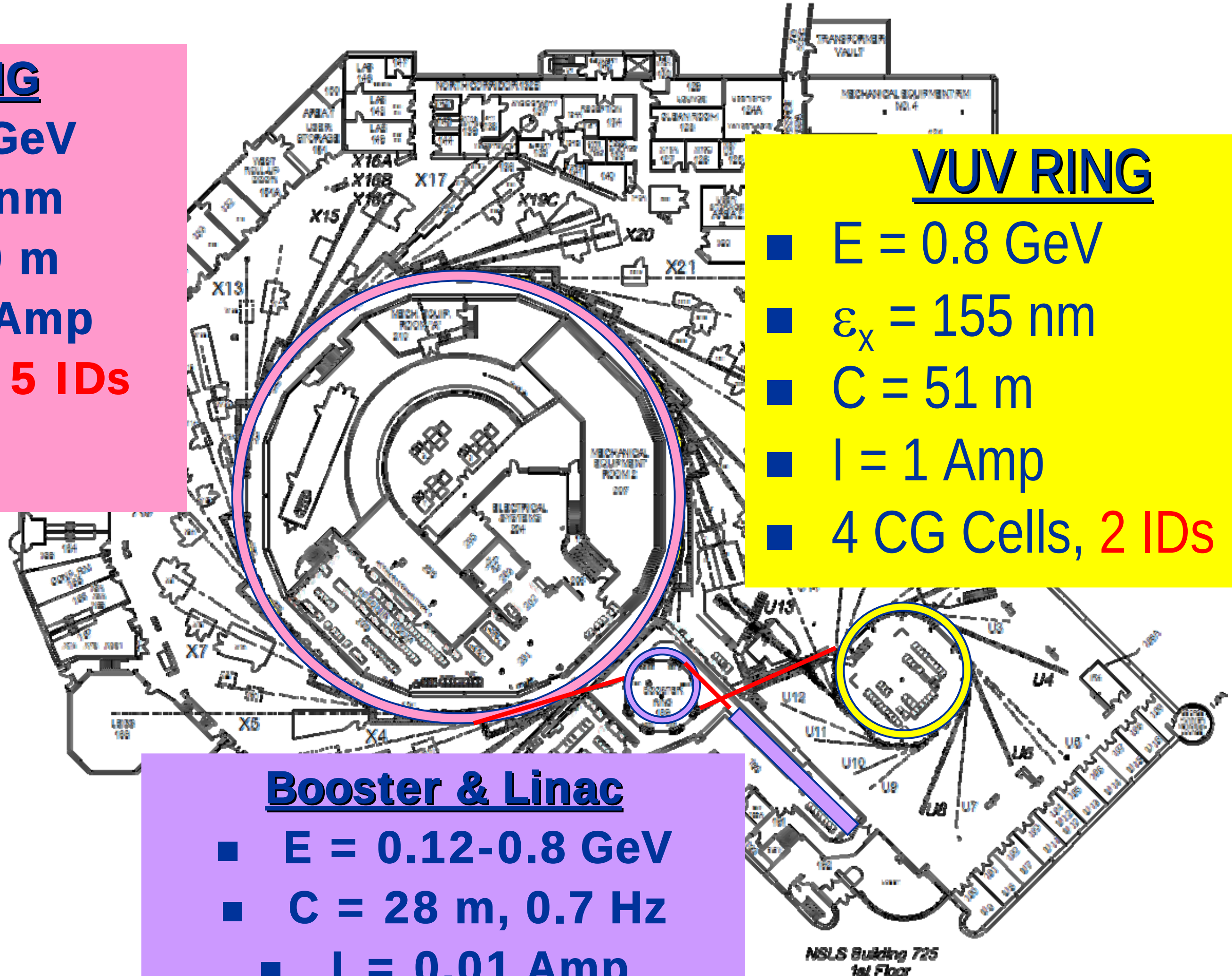

XRAY RING

- E = 2.8 GeV
- ε_x = 60 nm
- C = 170 m
- I = 0.28 Amp
- 8 CG Cells, 5 IDs

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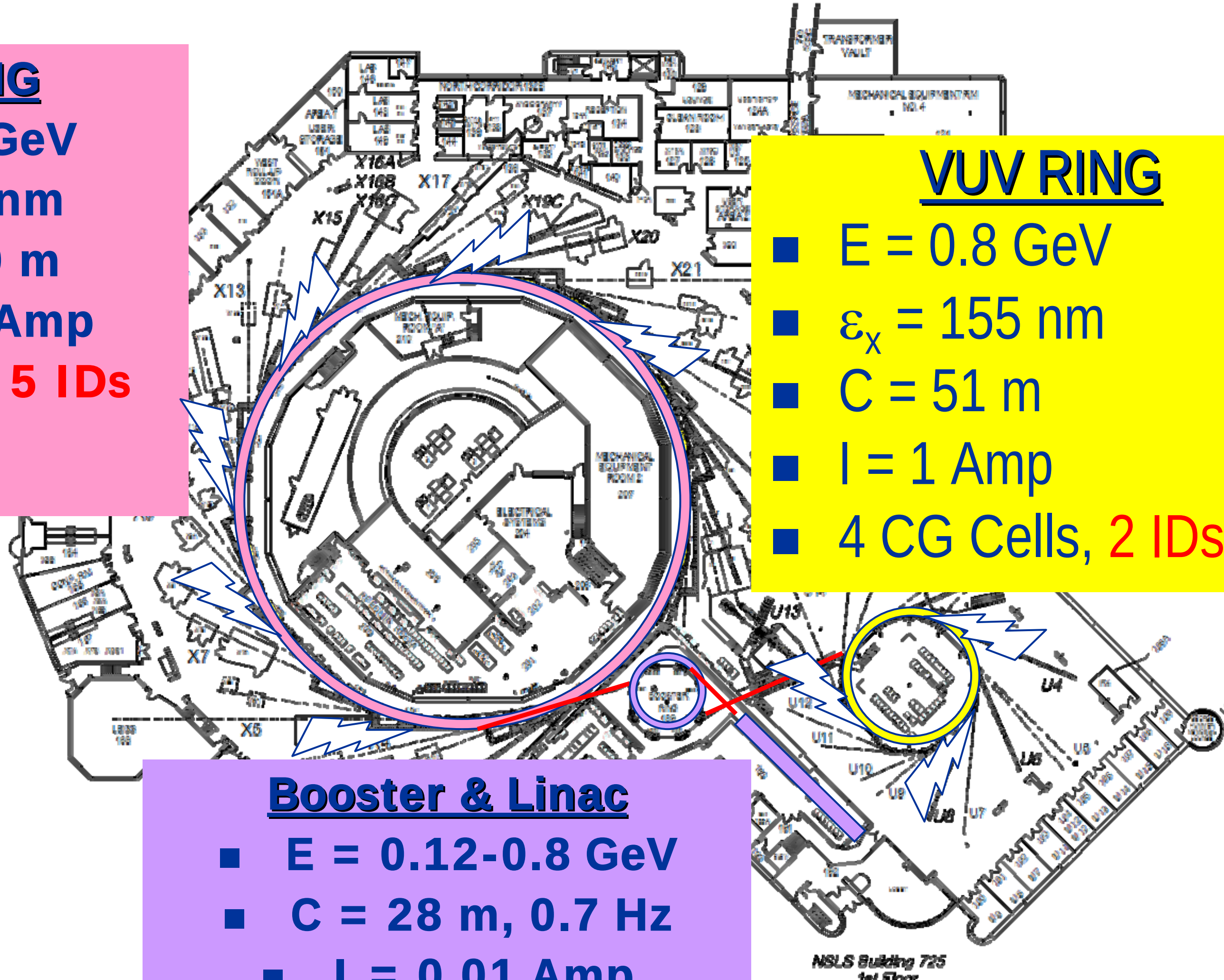

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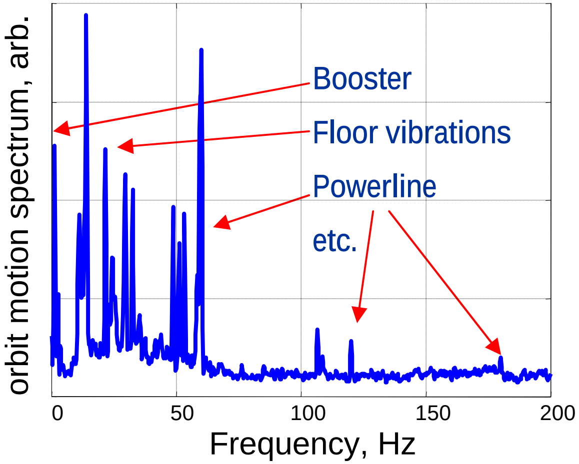
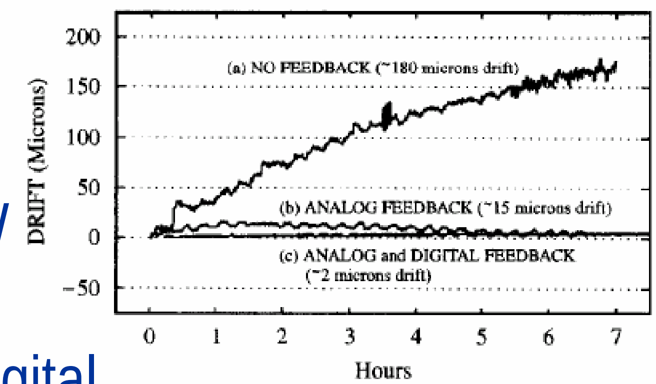
Orbit Feedbacks – Motivation and History

- Environmental noise on the beam
  - Eliminate the source or
  - Build an orbit feedback system



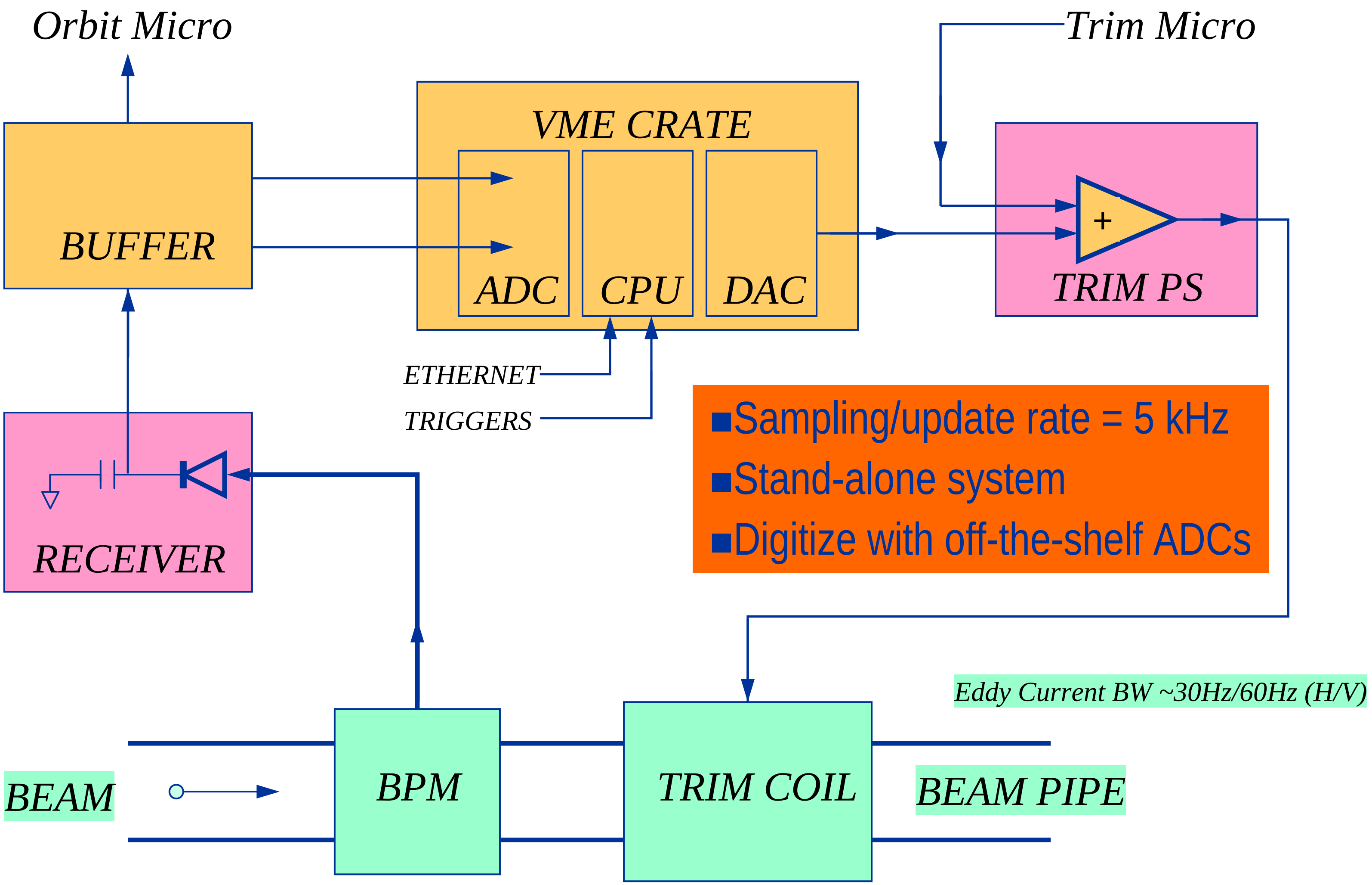
- NSLS efforts
  - Late 80s: Analog local feedbacks in ID beamlines
  - Late 80s: Analog global feedback in VUV & X-ray
  - Mid-90s: Test digital global system in X-ray



O. Singh et al., 1998

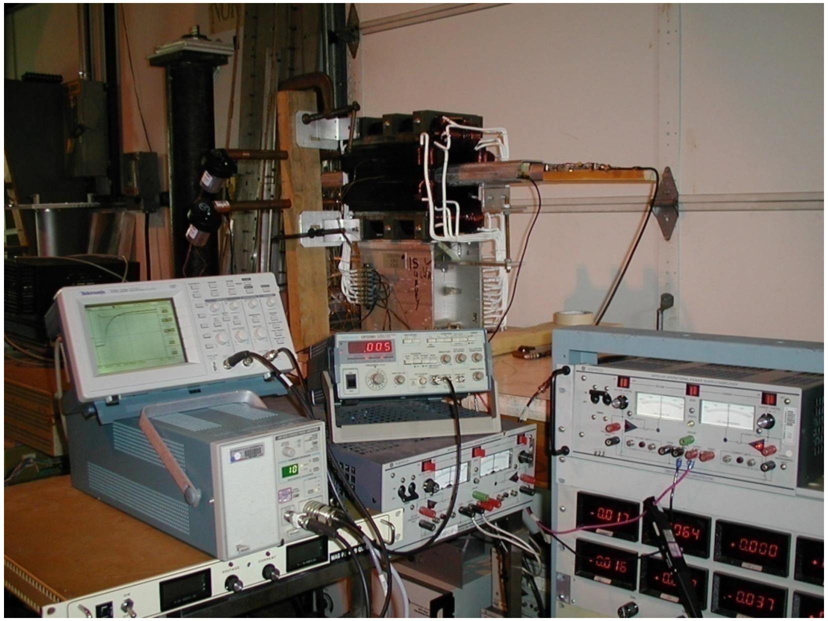
- Test digital system
  - Low sampling rate (15 Hz)-> small BW
  - Slow drift & booster noise reduced
  - Demonstrated the potential of going digital (such as scalability, flexibility, enable/disable, etc.)
- Present 5 kHz digital system – operations early 2000s

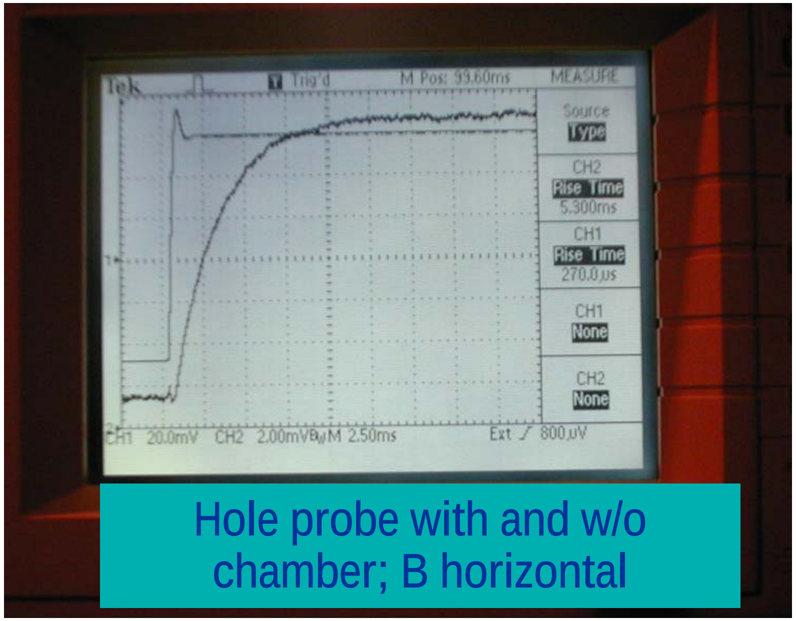
NSLS Orbit Feedback System Design



- Sampling/update rate = 5 kHz
- Stand-alone system
- Digitize with off-the-shelf ADCs

Speed Limitation due to Eddy Currents in the *Al* Vacuum Chamber



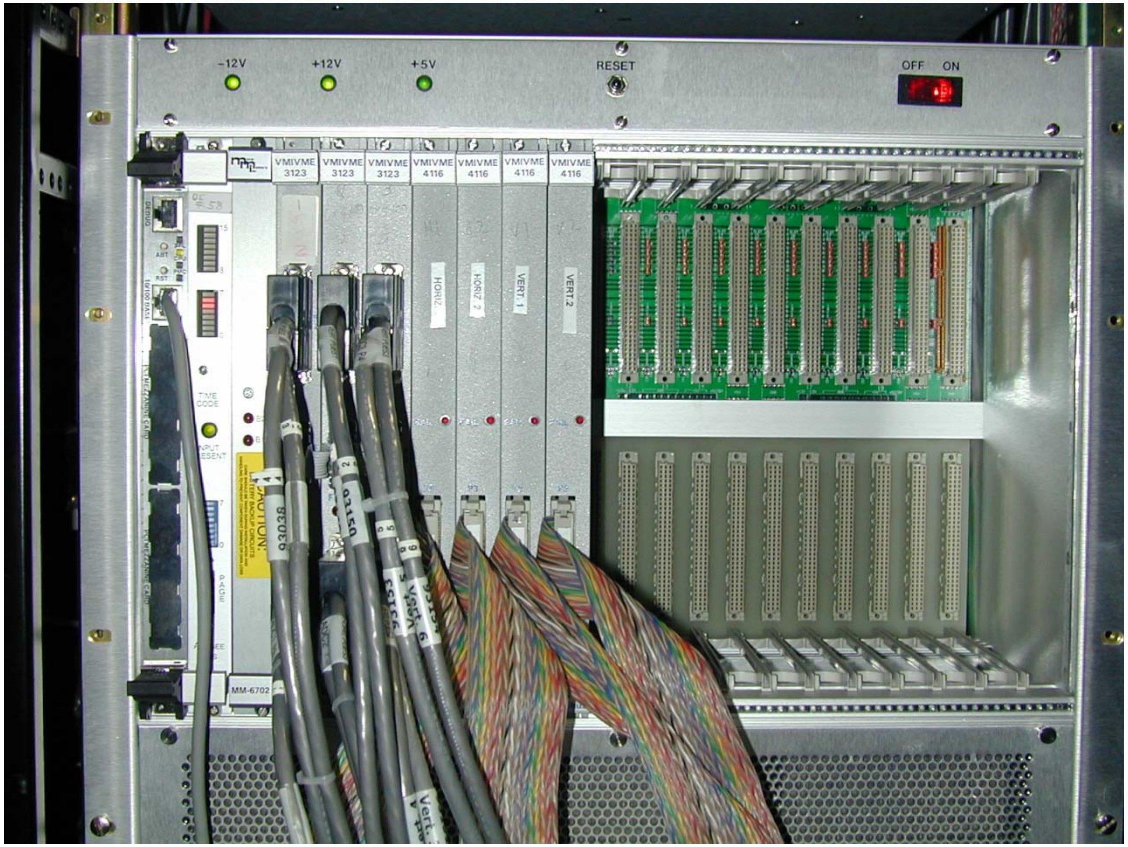


Hole probe with and w/o chamber; B horizontal

- Rounded corner rectangular beam chamber 42x80 mm^2, 4 mm thick
- Chamber dominates (small signal) response, corrector PS, BPMs, sample rate, calculation delays are much faster
- 3dB BW is ~30 Hz (hor), ~60Hz (vert); 10-90% rise-times of 6 & 12 ms
- Limitation on feedback gain*BW product …

NSLS Orbit Feedback System Implementation

VUV Ring Digital Orbit Feedback Crate



Hor. & vert. in one system

Each plane includes

- 24 BPMs and 8 (16) trims
- 8 SVD eigenvectors

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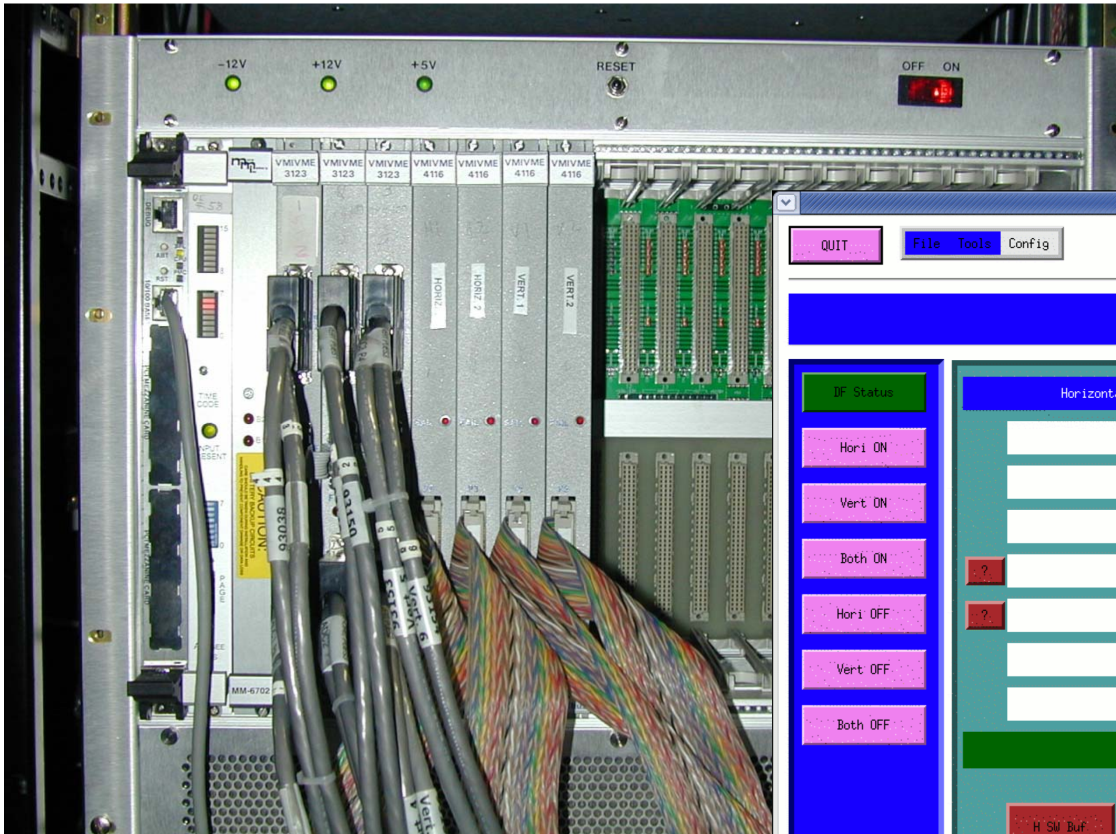

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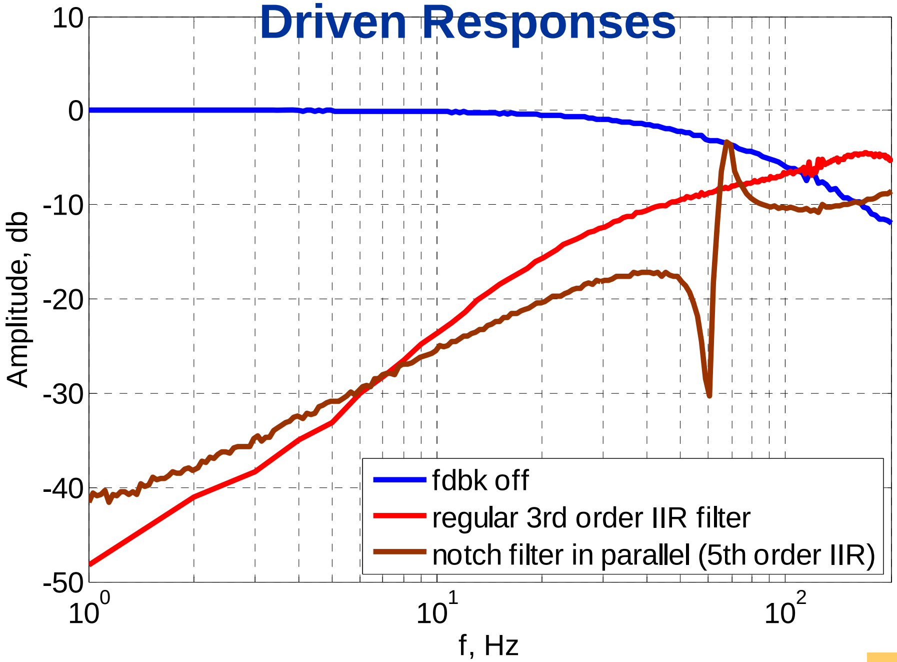
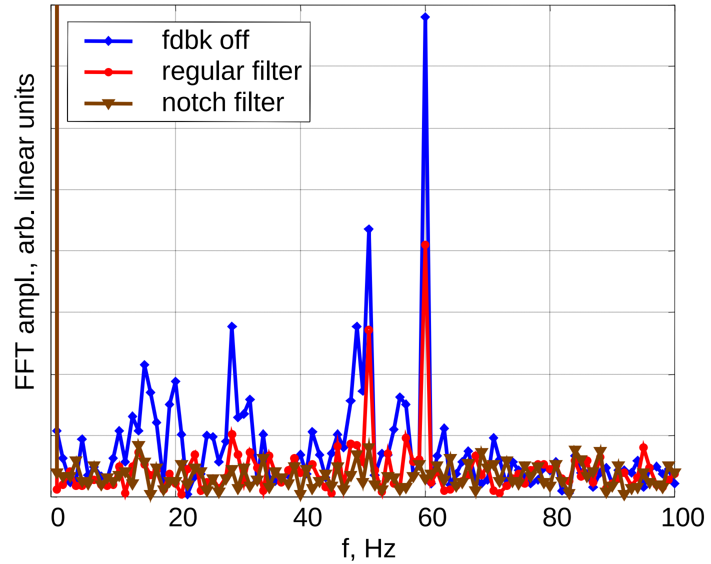
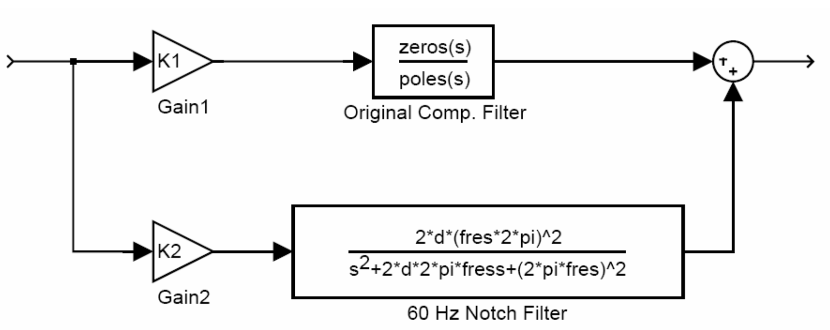
Feedback Performance: High Frequency Orbit Noise Reduction

Driven Responses



Feedback 5 kHz Orbit Data FFT



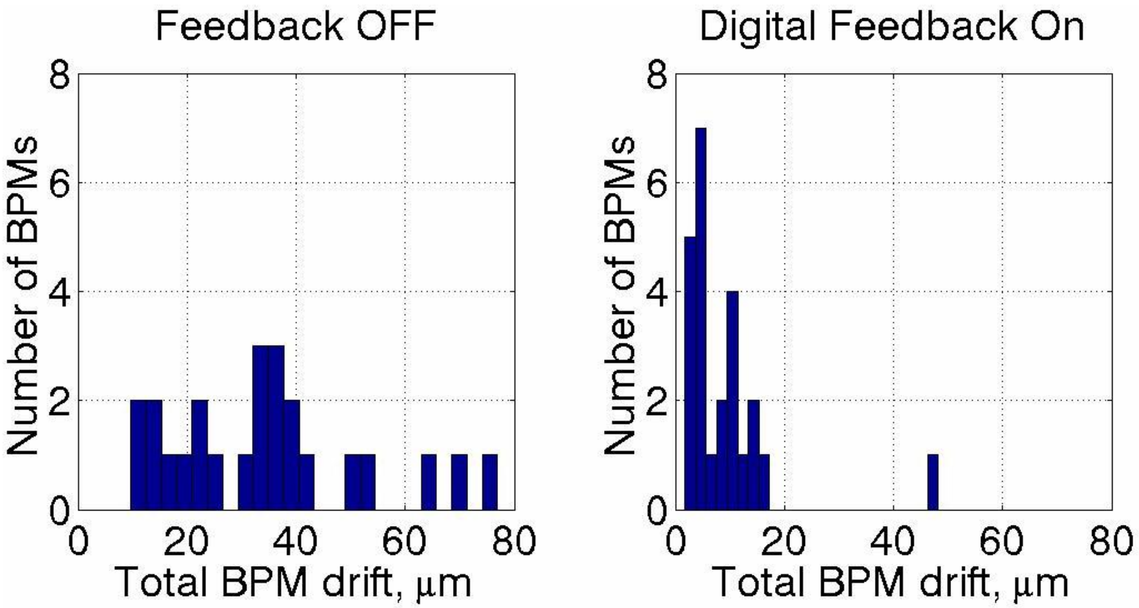


Compensation filter design

- Correction bandwidth of up to 200 Hz possible
- Selective narrow band correction still possible using notch filters
- Control theory tricks to keep system stable
- It works! Provides >25 dB damping @ 60 Hz
- Integrated RMS is reduced to <3% of σ_y

Feedback Performance: Slow Orbit Drift Reduction

Vertical Drift, Standard VUV ops, 5 hr standard fill

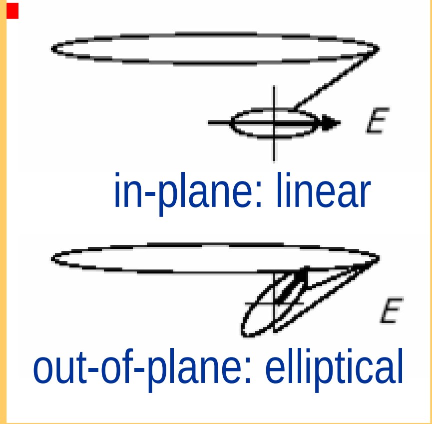


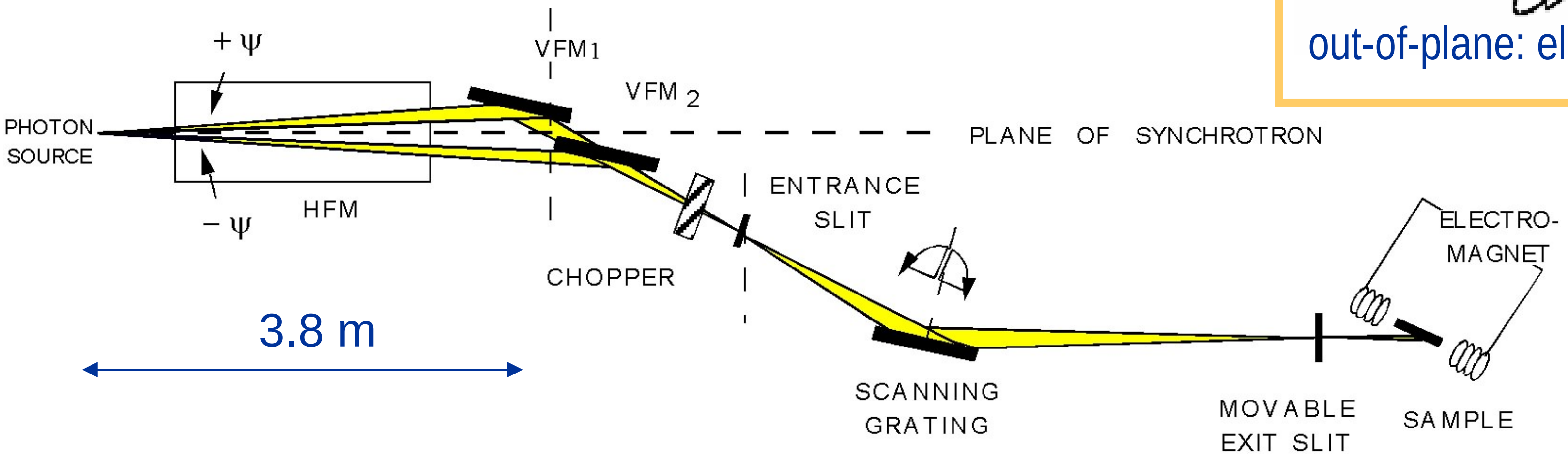
- VUV: Average drift reduced 35 μm -> 6 μm (<3 % beam size); same % in hor.

Feedback works great! Why fix it?

New User Requirements for Orbit Control at U4B Source Point

- U4B is the only NSLS beamline providing variably polarized photons from a bend magnet.
- Design (C.T. Chen, early 1990s) uses well-known property of SR

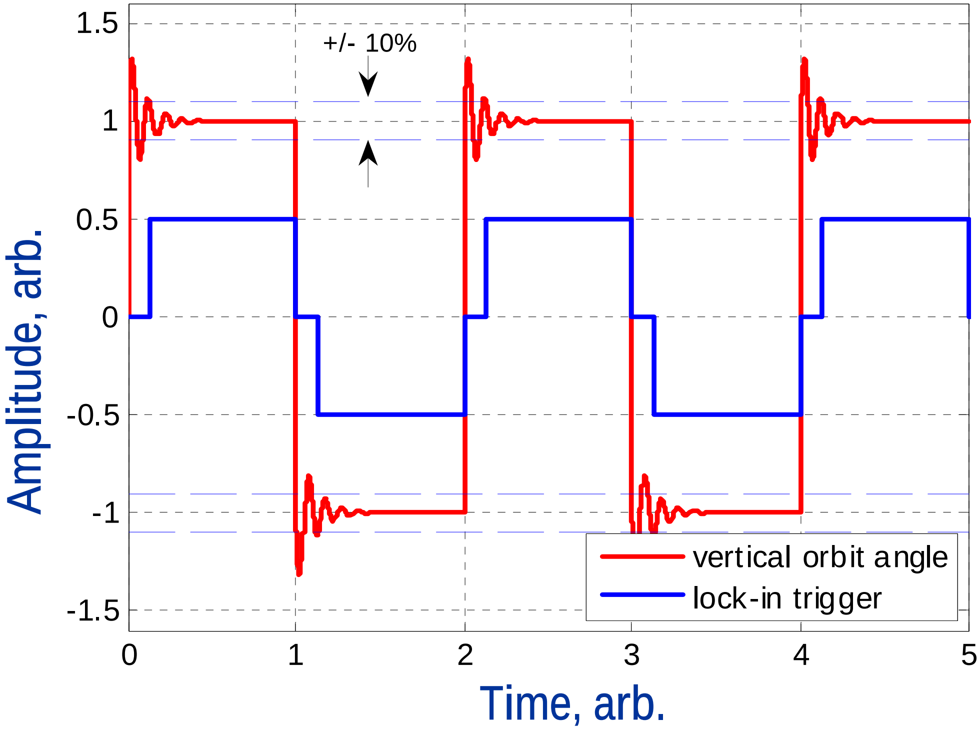




- Linearly or Circularly polarized photons with energy range 20-1500 eV
- Studies of magnetic properties of transition metal & rare earth systems (thin films, alloys)
- Moving VFM wrt to e-beam orbit samples different ellipticity + helicity
- Present work aims to provide faster helicity switching by moving e-beam instead of VFM

U4B User Requirements for Orbit Motion in Detail

- Bipolar periodic angular shifts of +/- 0.25 mrad at the source point
  equivalent +/-0.4/γ ⇔ +/-1 mm on VFM ⇔helicity sign change @ 70% polarization
  +/- 0.4 mm motion on BPMs on either side of the bend magnet
- Frequency -> As High As Possible (present mirror move takes minutes), 10 Hz is the present goal
- Time Dependence:
  - Ideal: square wave (SW)
  - Acceptable: SW w. reduced duty factor (no data taken for zero lock-in trigger)
  - Rise-time (not shown) and ringing reduce the duty factor =>
  - +/- 10% on ringing is O.K.
  - 80% duty factor is O.K.



Dedicated time setup is straightforward

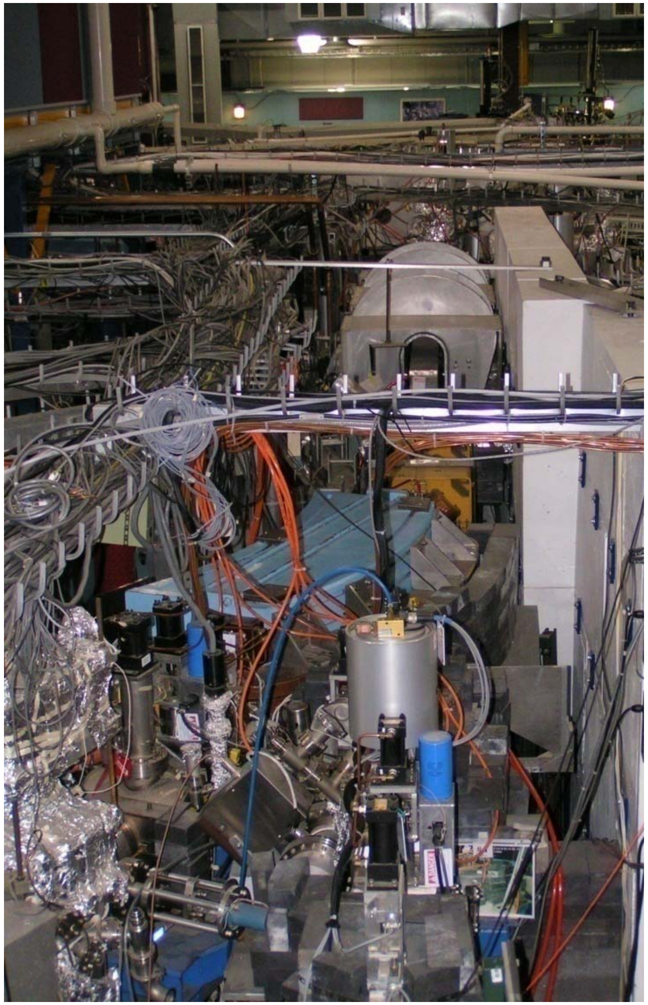
Goal to be part of regular operations

i.e. invisible to the rest of the users

Constrains & General Approach

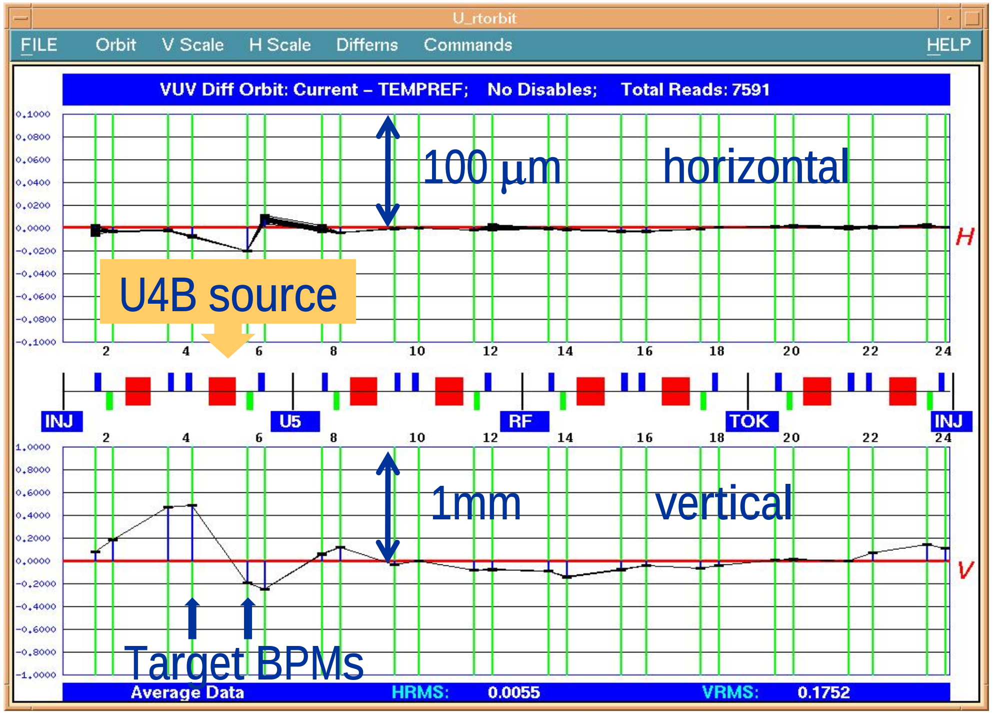
- We are not the first ones to try this out
- Other solutions exist (SLS, TLS, MAX2)
- VUV ring is densely packed with hardware =>
  (Additional/modified hardware is hardly possible)
- We attempt to achieve the goals without new hardware but rather by modifying the existing 5 kHz orbit feedback system
- Establish a local bump desired by U4B users
- Change the fdbk algorithm to vary the reference orbit
- Change the algorithm to include feed-forward
- Feedback corrects for imperfect bump closure

- What is the maximum achievable rate? Is this acceptable to the rest of the users?



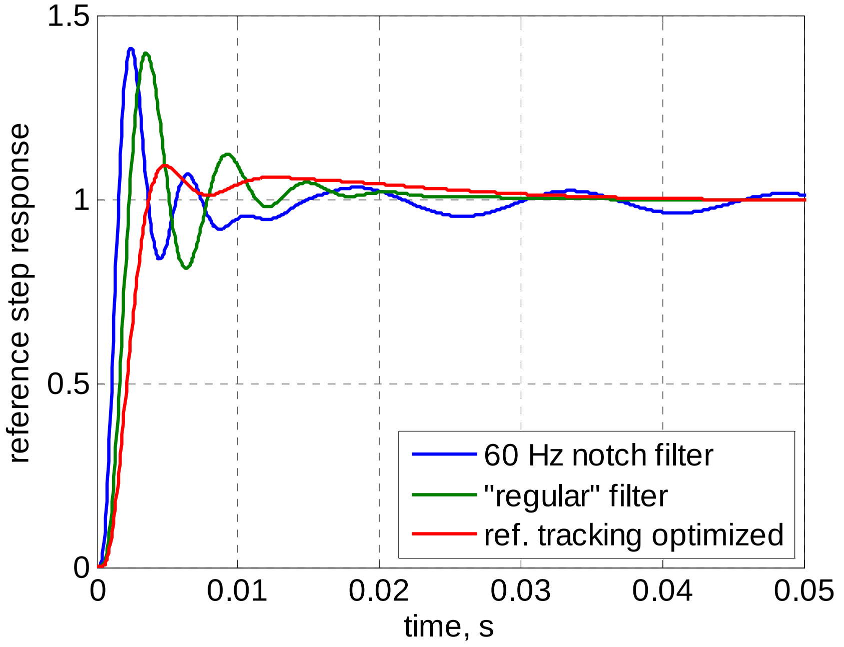
Static Bump

- Local bump was established
- Helicity, polarization checked by U4B group
- There are other users “inside the bump” in addition to U4B
- They will experience higher noise levels => rms comparable to the beam size => O.K. for some but not all
- Coupling is not a problem
- Trim power supplies are driven up to +/- 100% of their allowed range => large signal behavior becomes important…



Control Aspects of Dynamic Bump

- Original control design through loop shaping taking into account
  - User requirements
  - Noise spectrum & corr. capabilities
- Reference orbit was assumed fixed => never paid attention to “reference tracking”; as a result the tracking is quite poor =>
- Well-known control design trade-off: disturbance rejection vs. reference tracking
- Optimization is in progress, settling times of <10 ms are feasible (esp. if give up notch filter) => 10 Hz bump rate O.K.



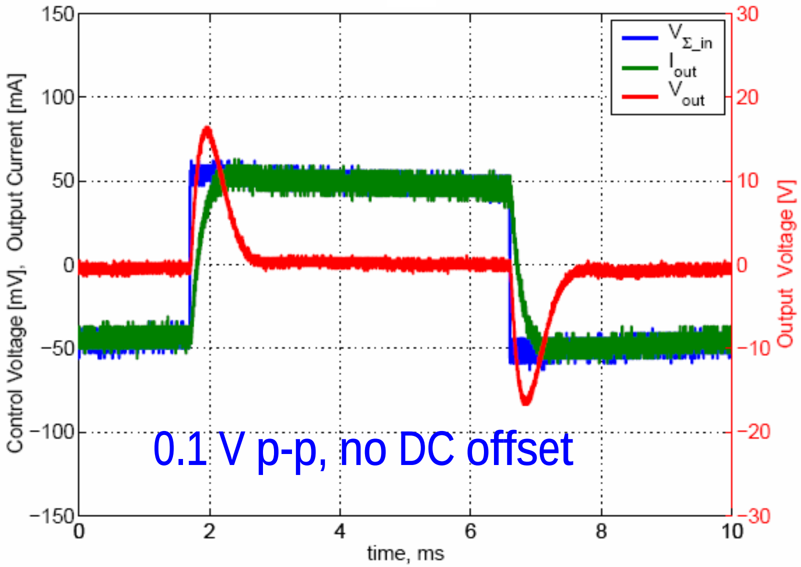
Better tracking is possible at the expense of bandwidth (and give up notch filter)

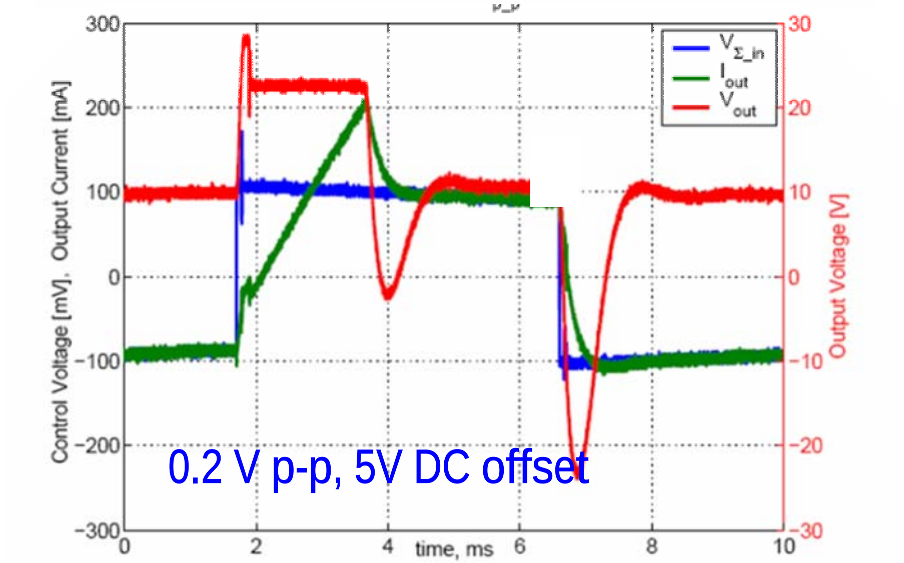
160 Hz, 100 Hz, 80 Hz

and hence 60 Hz rejection

30 dB, 7 dB, 2 dB

Corrector Power Supply Limitations





- Trim coils are inductive, *L* up to ~40 mH
- Large signal PS response is sub-optimal - "spiky" output if hit slew rate or voltage limits
- Impose limitation for amplitude/speed of dynamic orbit bump; $L*\Delta I/\Delta t<V_{max}$ (ΔI=5A, V_{max}=10V) gives Δt>20 ms, hence bump rate < 5 Hz
- Next steps are trying gradual ramps as well as adding matching networks at the PS output

Conclusions and Outlook

- We built 5 kHz digital orbit feedback systems for NSLS VUV (and X-ray) rings. The systems have unique architecture; they are compact and simple yet highly effective in suppressing orbit disturbances (up 100+ Hz) and are useful as diagnostics.
- New user requirements at U4B bend magnet beamline call for large amplitude dynamic orbit bump at their source point.
- Original control design for fixed reference orbit was done emphasizing disturbance rejection (vs. dynamic tracking); this is easily correctable and is not a severe limit on bump rate.
- Orbit bump rate is limited due to sluggish and non-linear large signal step response of trim power supplies; we estimate that rates < 5 Hz should be possible w/o hardware modifications.
- Further tests and user observations are planned for late 2008.

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