Low *vs* High Q Cavity BPMs

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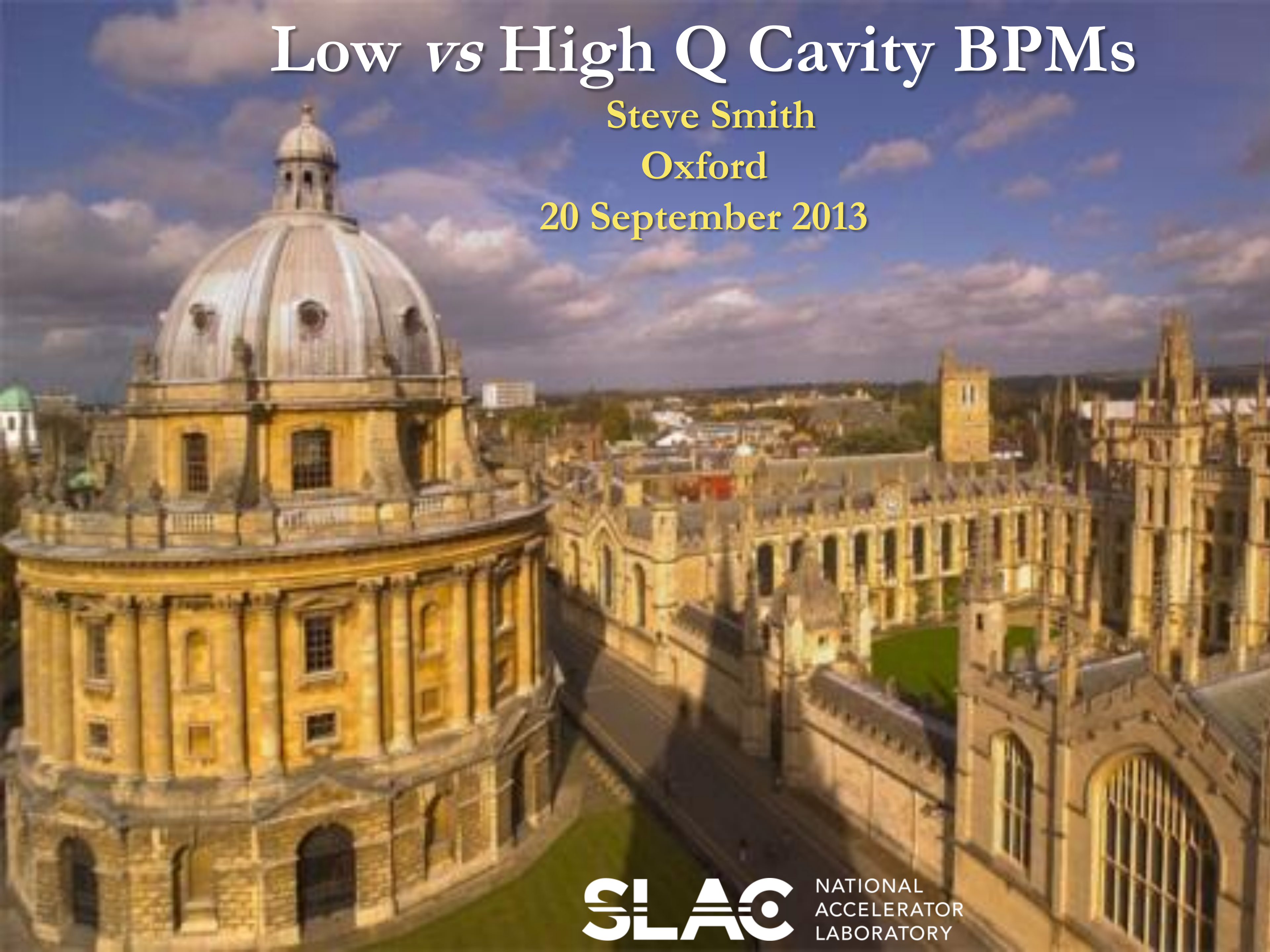

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What do we need from a BPM?

- Application dependent, cannot make completely general statements
- Resolution
- Stability
- Calibrateability

Resolution

- Relatively easy to estimate from specs, theory
- Usually easy to achieve near theoretical resolution
- At least for nominal beam, near center.
- But we need specified resolution over some dynamic range in
  - Position
  - Beam charge
  - Adjacent bunches

Stability

- Stability vs
  - Beam Charge
  - beam phase
  - Temperature
  - Charge, position of previous bunch
- Requires linearity
  - So that signals add cleanly
  - So that we can calibrate (independent of phase, amplitude)

Mode Leakage

- Mode selective pickups reduce leakage of monopole mode into dipole mode.
- But isolation is not perfect.
- Ratio of mono/dipole signal
  - At their respective mode frequencies, at $1\sigma_x$ = 100nm, Xband
    - ~ 10^5 = 100 dB
    - Tail of mono at dipole frequency
    - $\sim 10^5 (F_{110}-F_{010})/F_{010}/Q \sim 10^5/50 = 2\cdot 10^3$ for Q=200
    - So a 40 dB rejection of monopole mode gets a 20 sigma contamination
    - $\sim 10^5 (F_{110}-F_{010})/F_{010}/Q \sim 10^5/500 = 200$ for Q=2000
    - → 40 dB monopole mode rejection yields 2 sigma contamination
  - Quadrupole mode leakage similar
    - BUT no rejection from coupler(!)
- Low Q → greater mode contamination

Signal Aliasing

- Sampling Theorem:

  If we periodically sample band-limited signal we can fully reconstruct input waveform

- Band-limiting to a single Nyquist band:
  - difficult if we try to use most of Nyquist band (low Q)
  - Easy if signal naturally confined to small part of Nyquist (high Q)
- Achieving 12 effective bits in ADC requires aliased tail energy ~76 dB down from signal.
- Requires very high-order filter if we're using half of Nyquist for signal
  - Lossy
  - Large,
  - Expensive
  - Drifts with temperature
  - Maybe not so bad with multiple downconversion with high 1st IF
    - Careful filtering at 2nd IF before ADC

What Limits Dynamic Range?

- Usually weakest link is the digitizer
- e.g. a good 16 bit ADC @ 125 Msamples/sec has ~12 effective bits
- $\sigma_v/V_{pp}=2^{-12}/\sqrt{12}$ or $\sigma_v/V_p=1/6000$
- If we want 100nm resolution, it sounds like we only need a single sample to cover a position dynamic range of 600 microns.
- But if you are an engineer signing off on a spec that says your system covers "X" micron dynamic range at charge "Q"
- Then you better leave engineering margin
  - on the signal level at charge Q (maybe 3 dB)
  - And on the theoretical system noise (maybe 6 dB)
- Now we're down to 200 micron dynamic range

Processing gain

- Very inefficient to use the dynamic range limiting component only once when it can take data at 125 Msamples/sec
- Get processing gain ~$\sqrt{N}$ for N samples of a signal
- Effective bits increased by log2(N)/2
- ➔ increase Q to get more samples into ADC

Linearity