Accelerator Physics Lecture Modules

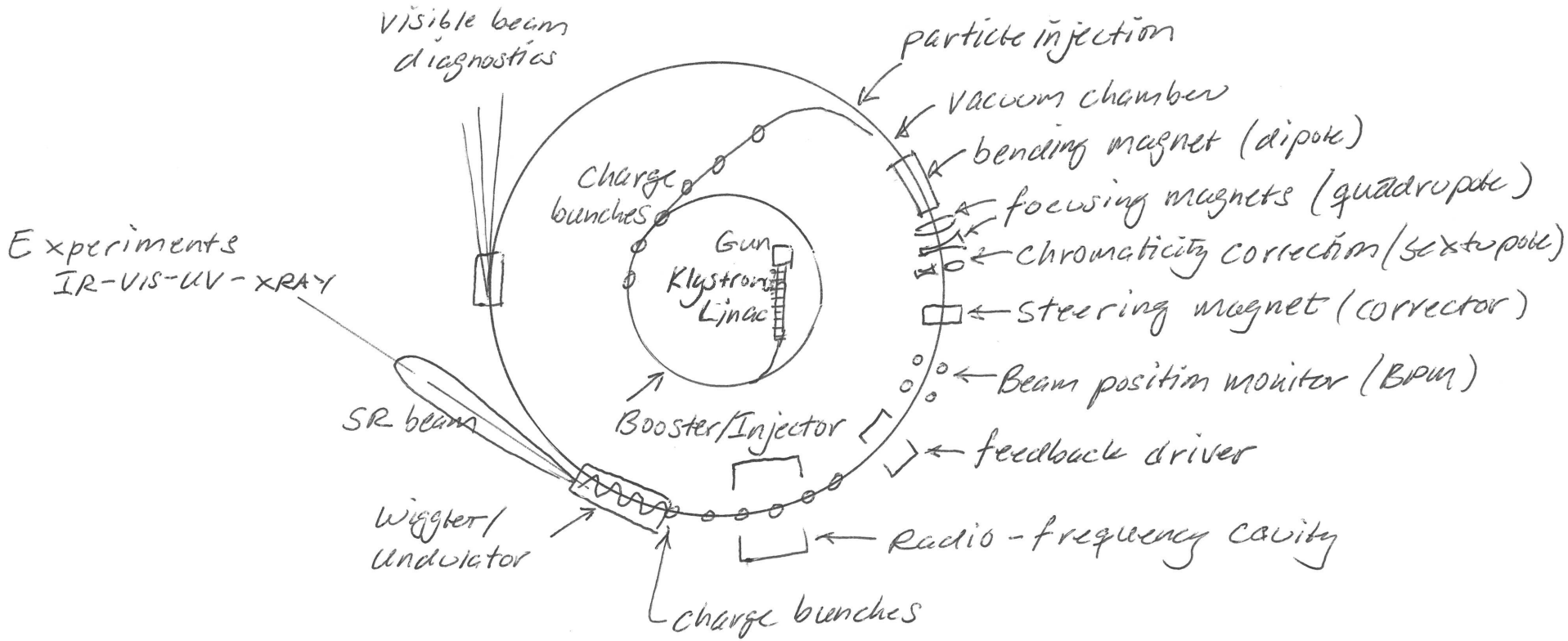
1. Introduction/Timing
2. Beam propagation basics
3. Simple Harmonic Oscillator

4. Betatron oscillations (transverse motion)
5. Dispersion
6. Closed Orbit Distortion

7. Synchrotron oscillations
8. Properties of synchrotron radiation

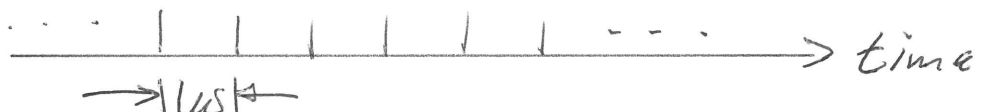
9. Radiation damping
10. Equilibirum emittance

Anatomy of a Synchrotron (aka Storage Ring)



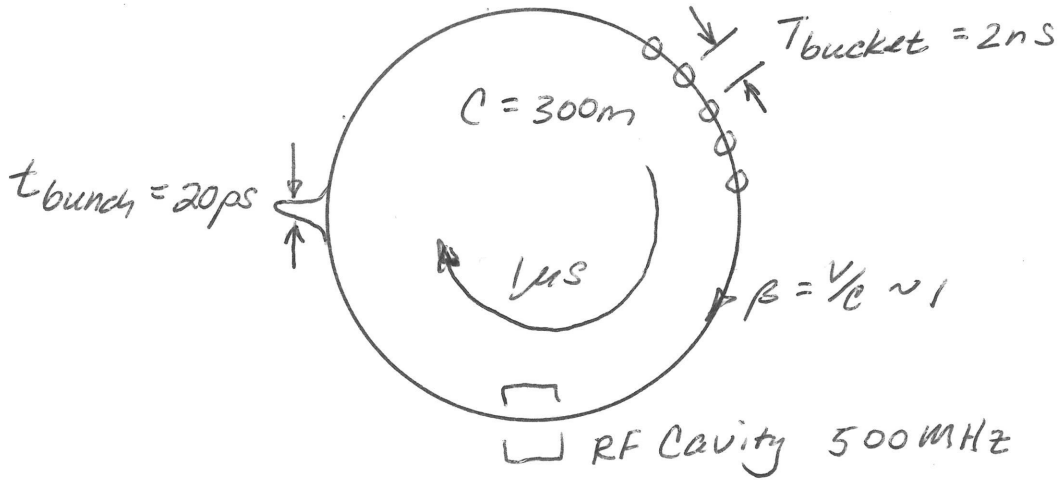
Typical circumference $L = 300\,m$

Revolution time $t = L/c = \frac{3\times10^{2}}{3\times10^{8}} = 10^{-6}\ sec\ (1\,\mu s)$



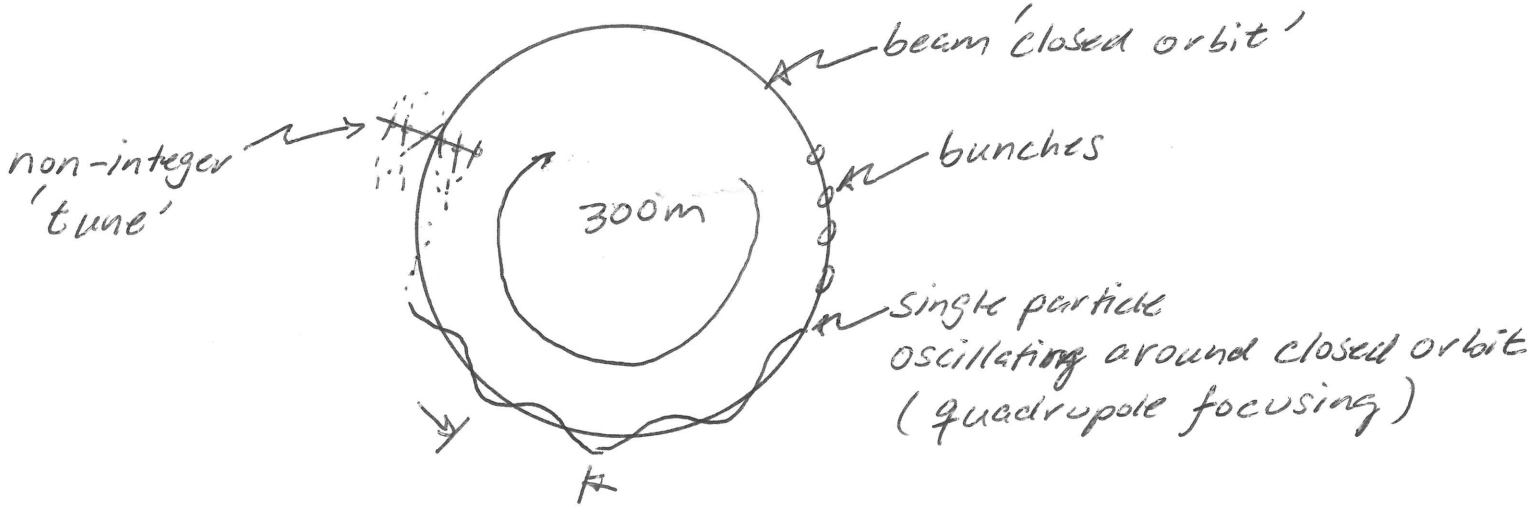
SROC = 1 MHz Heartbeat for many systems

Characteristic Time Scales 1 - Hardware



	time	distance	frequency
T_{rev}	1 μs	300m	1 MHz
T_{bucket}	2 ns	0.6m	500MHz
T_{bunch}	2 ps	6 mm	50GHz
T_{camera}	20ms		50Hz
T_{BPM}	100μs		10kHz
T_{Build}	4 yr		
$T_{operate}$	25yr		

Characteristic Time Scales 2 – Transverse Particle Motion



horizontal ~ 1 oscillation per 10–15 m

Vertical ~ 1 oscillation per 30–45 m

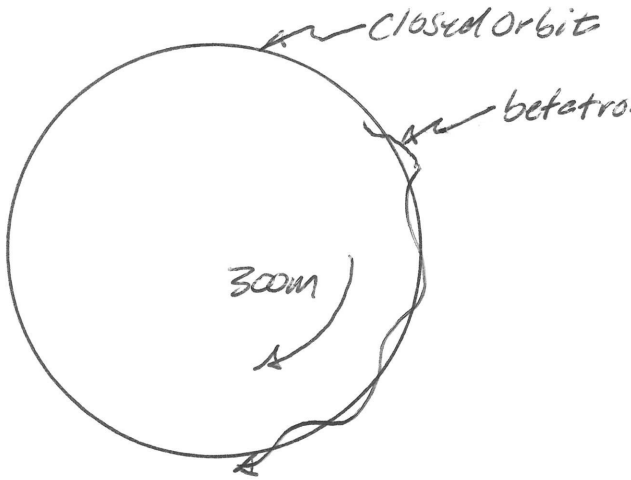
$Q_x \cong 30.15$

$Q_y \sim 15.2$

integer tune

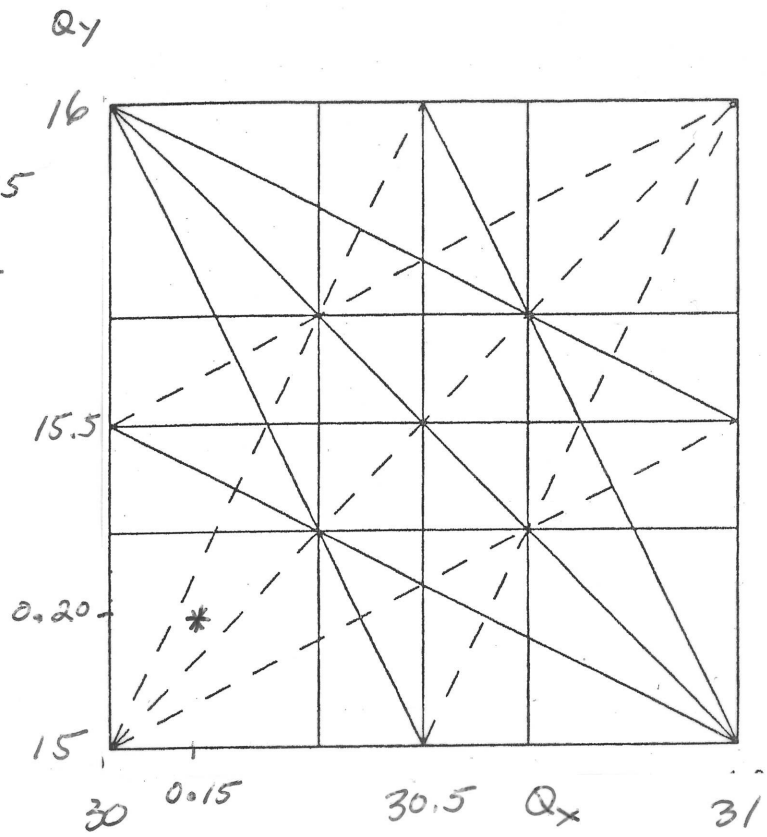
fractional tune

Transverse Particle Motion (cont'd)



$Q_x \sim 30.15$

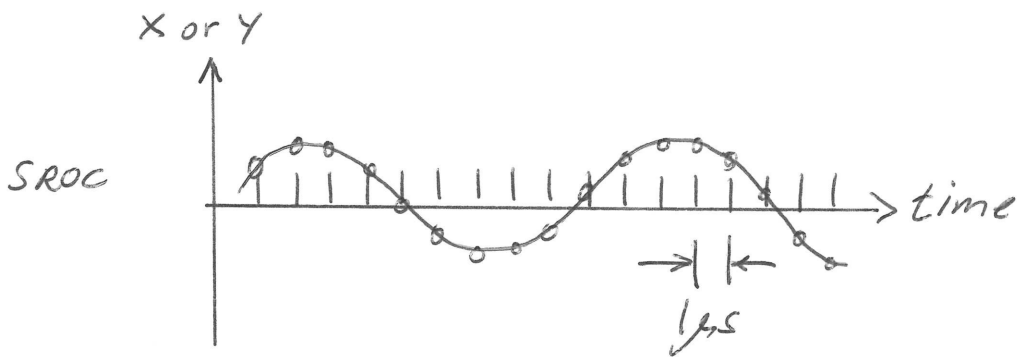
$Q_y \sim 15.2$



Measured 'tune'

$Q_x = (0.15)(1MHz) = 150kHz$

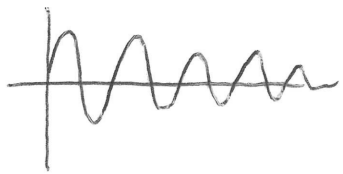
$Q_y = (0.2)(1MHz) = 200kHz$



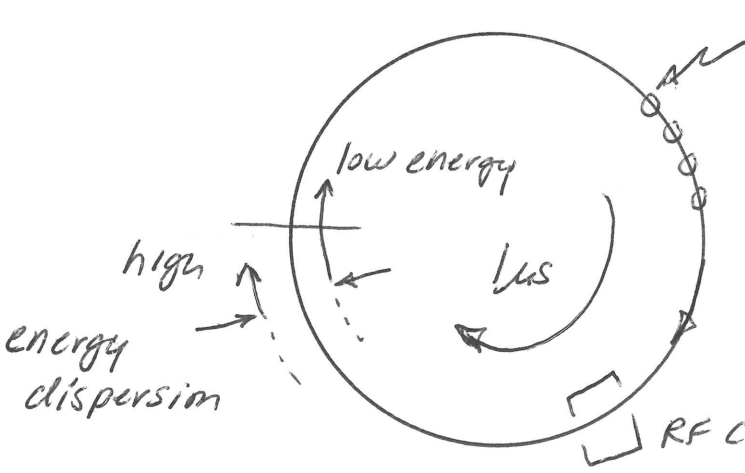
$$\ddot{x} + 2\alpha\dot{x} + \omega_\beta^2 x = 0$$

fractional tune 150KHz

damping 5ms

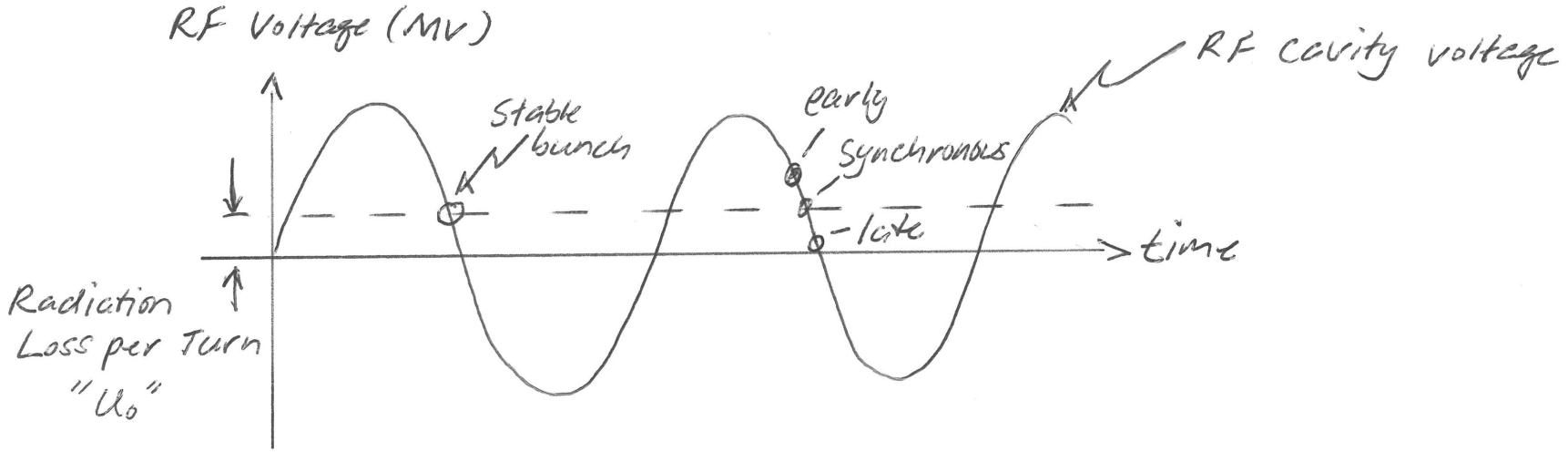


Characteristic Timescales 3: Longitudinal Particle Motion

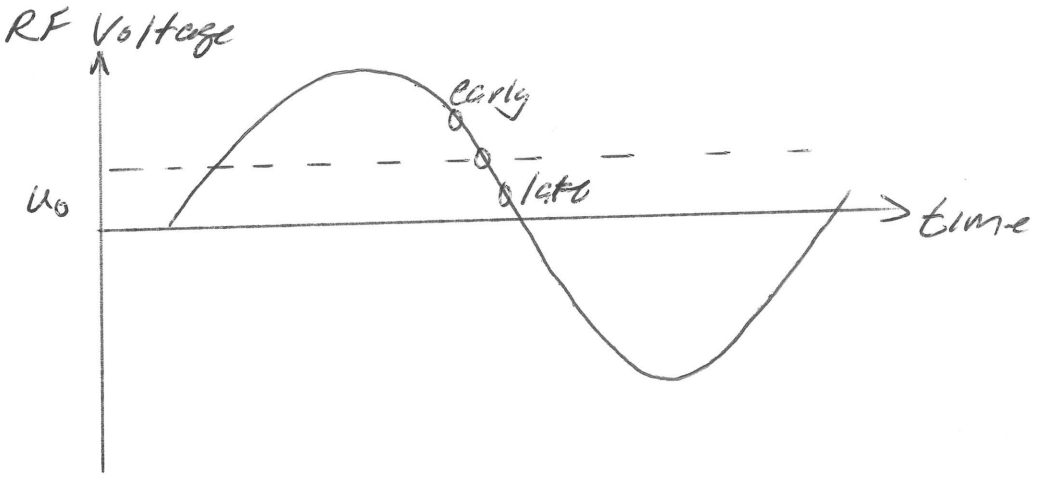


h = harmonic number $= \frac{T_{rev}}{T_{RF}} = \frac{1\mu s}{2ns} = 500$

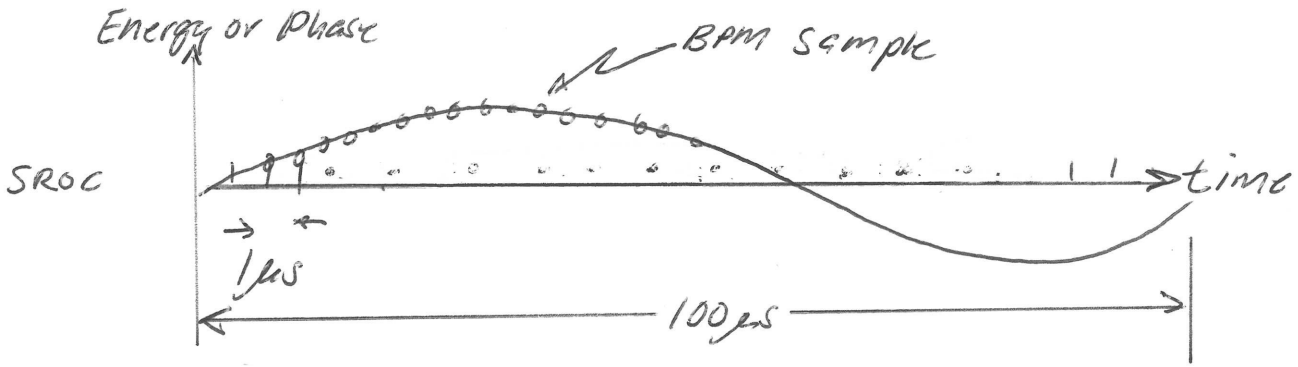
I = beam current $= \frac{Q}{T_{rev}} = \frac{500 \cdot 10^{10}}{1\mu s} \Rightarrow 500mA$

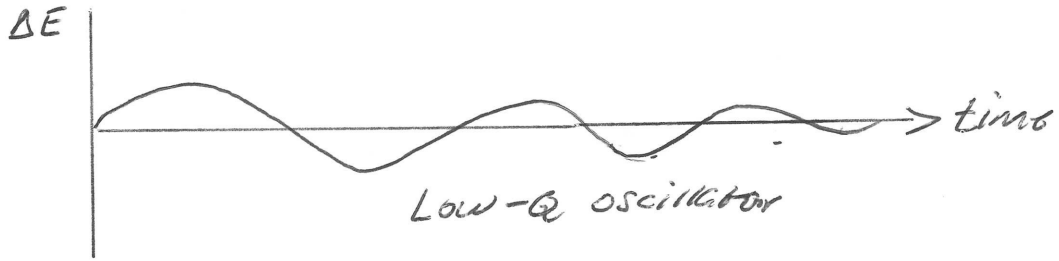


Longitudinal Particle Motion (cont'd)



RF Voltage Restoring Force – phase focusing (1947)

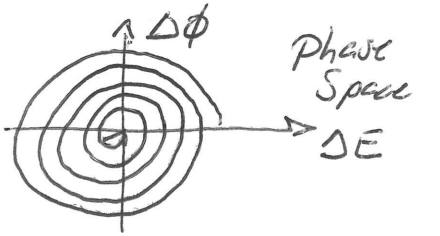




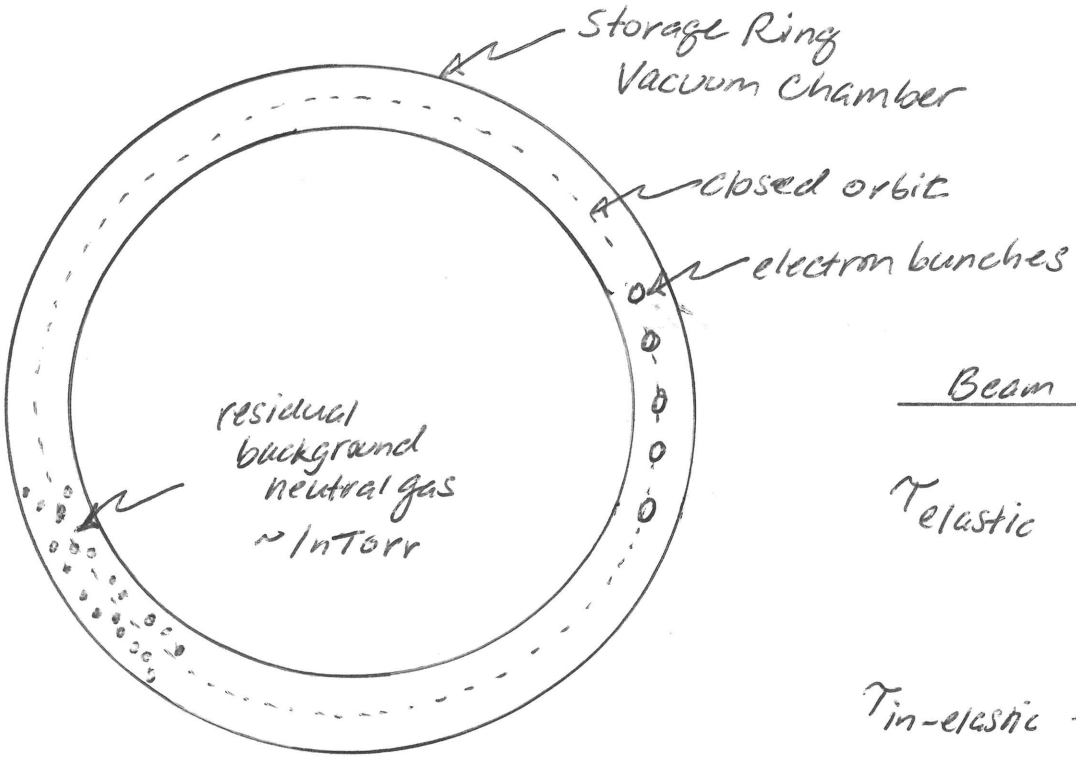
$$\ddot{E} + 2\alpha_s \dot{E} + \omega_s^2 E = 0$$

Synchrotron tune ~10 kHz

damping 2.5 ms

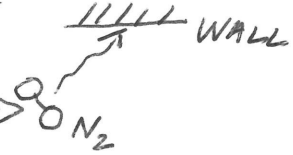


Characteristic Timescales 4: Quantum Events

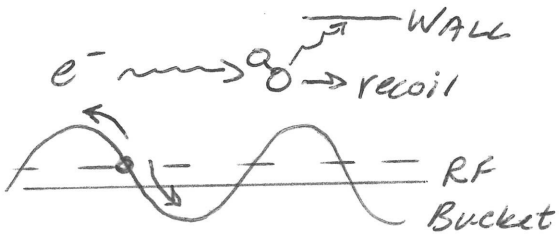


Beam Scattering Lifetime

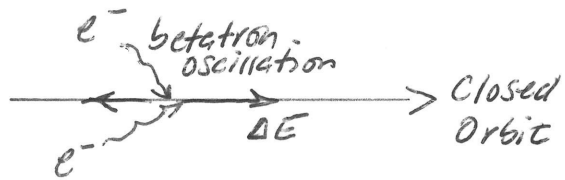
$\tau_{elastic}$ ~ 100hr



$\tau_{in\text{-}elastic}$ ~ 100hr



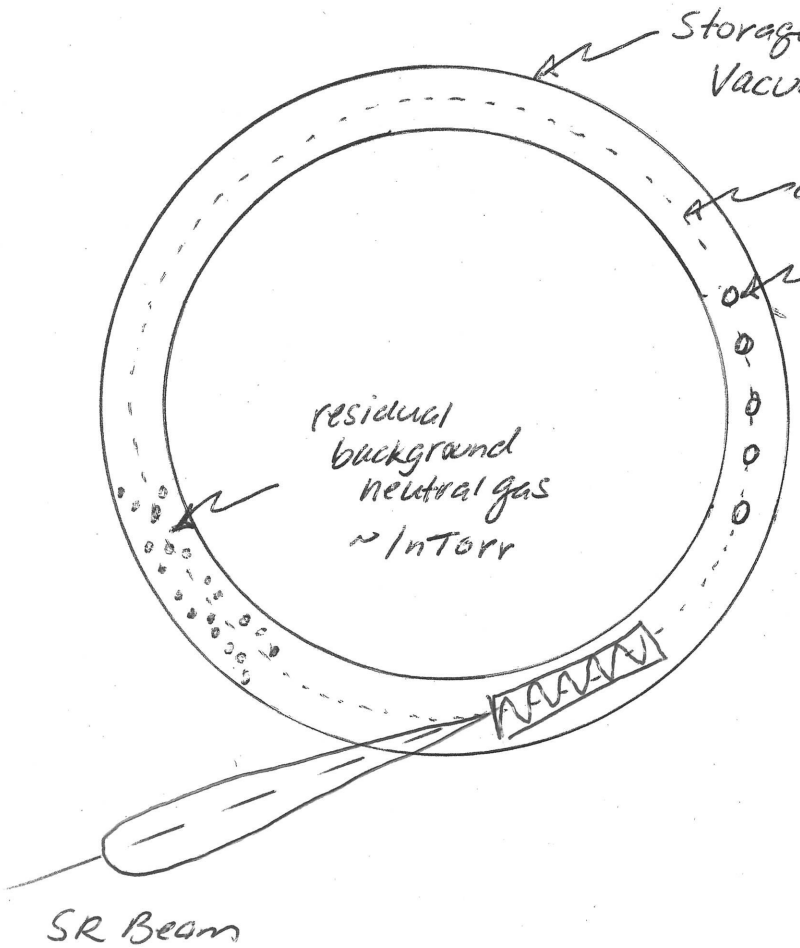
$\tau_{intra\text{-}beam}$ ~ 10hr



$\tau_{quantum}$ ~ 1000hr

$\tau_{top\text{-}up}$ ~ 100 sec

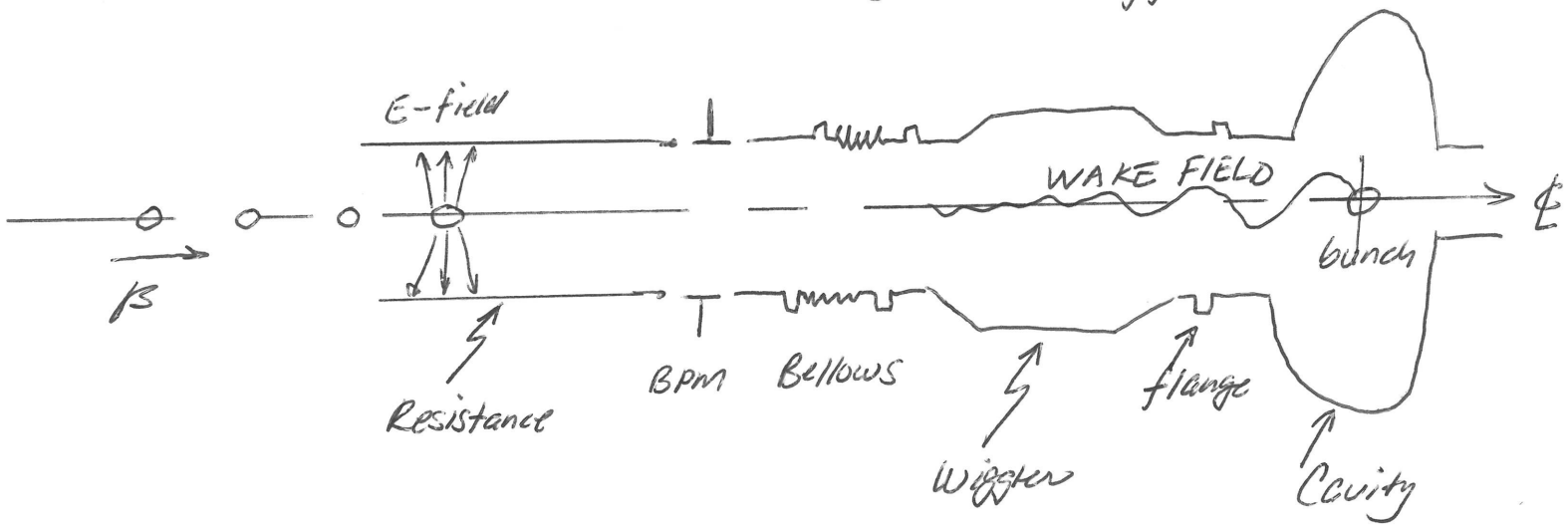
Characteristic Timescales 4: Quantum Events



Synchrotron Radiation

$T_{visible}$	~ 1fs	10^{+15} Hz
$T_{x\text{-}ray}$	~ 10^{-19} sec	10^{+19} Hz
T_{pulse}	20ps	
$T_{rep\text{-}rate}$	500MHz	

Characteristic Timescales 5 ; Collective Effects



Vacuum Chamber has characteristic <u>Impedance</u>

$$Z_{\parallel}(\omega) = R_{\parallel}(\omega) + i L_{\parallel}(\omega)$$

$$Z_{\perp}(\omega) = R_{\perp}(\omega) + i L_{\perp}(\omega)$$

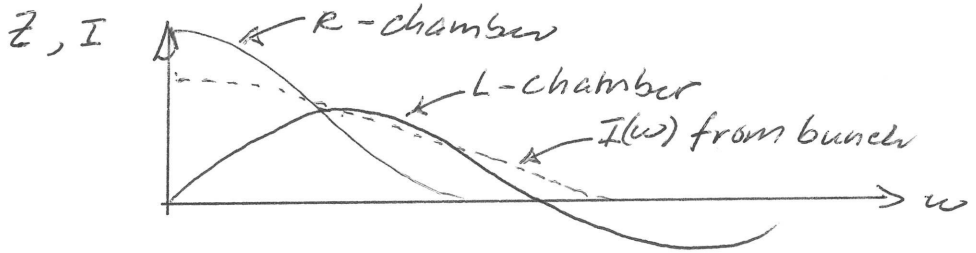
$\parallel$ → longitudinal field (axial direction)
$\perp$ → transverse field
ω → frequency of interest

Collective Effects (cont'd)

$$Z(\omega) = R(\omega) + L(\omega)$$

R, L from vacuum chamber (or SR)

- Short-range wakefield acts back on bunch
  - broadband, low-Q



$$V(\omega) = I(\omega) \cdot Z(\omega)$$

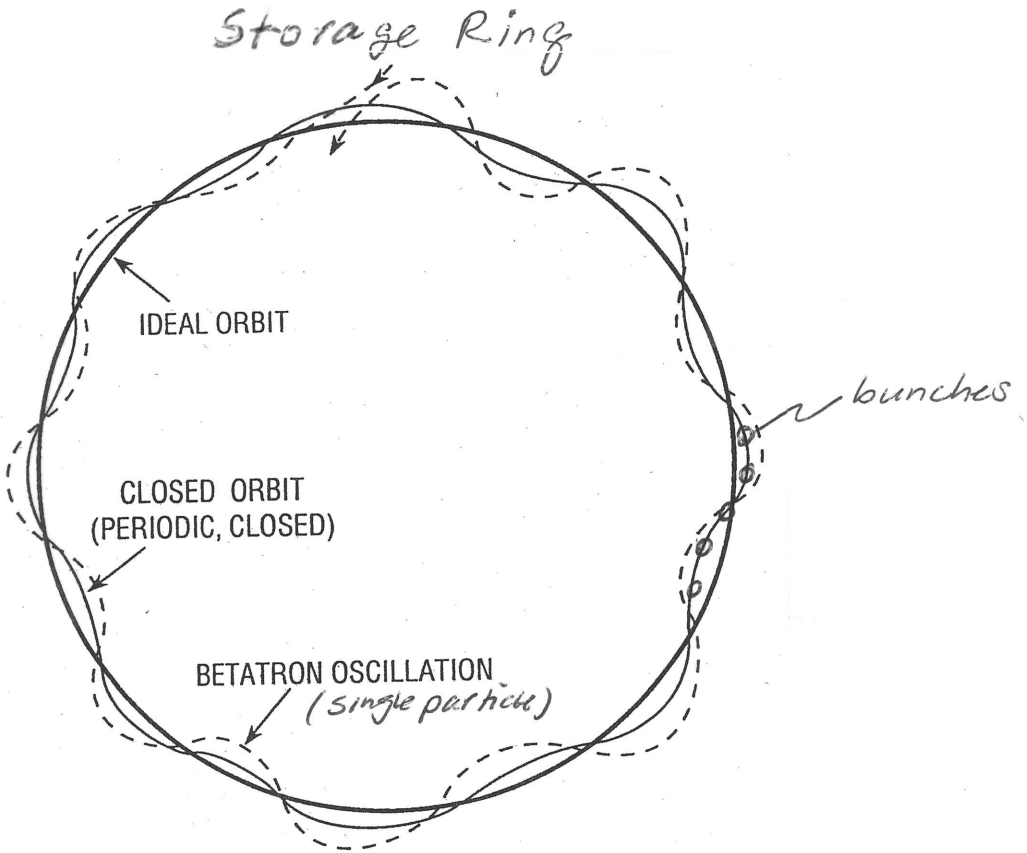
bunch chamber

~ns, GHz

- Long-range wakefield acts on trailing bunches
  - narrowband, high-Q

multi-bunch instability
modes
eigenmodes
Q.M. analogy
μs, MHz

Review - I



Storage Ring

- Closed orbit
- closed orbit distortion (COD)
- Bpms, correctors

- RF System
  - Buckets
  - Bunches
  - synchrotron oscillations
- Betatron Oscillations
  - tune (integer, fractional)
  - damping

- Orbit dispersion
  - energy deviations
  - change in Trev
  - change in tune (chromaticity)

Review - II

- Beam Lifetime
  - elastic scattering (neutral gas)
  - inelastic
  - intra-beam (Touschek)

- Collective Effects
  - Beam-chamber interaction
  - Frequency dependence
  - Resistance/Reactance
  - Instabilities

- Synchrotron Radiation
  - Intense (250kw radiated power)
  - Highly Collimated (laser-like)
  - Broadband Spectrum IR-VIS-UV-X-ray
  - Pulse (pump/probe)
  - Polorized (magnetization studies)