NLC - The Next Linear Collider Project

Parameters of Future Rings

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LBNL

Future Rings

- Greater demands on performance of present and future accelerators
  - Lower emittance
  - Higher current
  - Shorter bunches
  - Top-up mode
  - Bunch trains (gaps)
  - Reduced damping time
    - →
    - →
    - →
- All tend to push limits of beam stability
    - →Single-bunch
    - →Multi-bunch

Comparison of ring parameters

- Synchrotron Light Sources
  - ◊ Existing 3rd generation light sources
    - > ALS, NSLS, ESRF, ELETTRA, APS, …..
  - ◊ New light sources
    - > DIAMOND, SOLEIL, SSRF, ….
- Damping rings for linear colliders
  - > NLC, TESLA, CLIC
    - ⇒Similar to 3rd generation light sources
    - ⇒Pushing some parameters

Comparison of ring parameters

		ALS	ELETTRA	SRRC	NSLS-vuv	SLS	ATF damping ring	SOLEIL	DIAMOND	SSRF	NLC damping ring	CLIC damping ring	TESLA damping ring
Energy	GeV	1.5	2	1.5	0.808	2.4	1.54	2.5	3	3.5	1.98	1.98	5
Momentum compaction	1.00E-03	1.43	1.59	6.78	23.5	0.7	1.93	0.472	8.43	0.71	0.66	0.28	0.12
Energy spread	%	0.08	0.08	0.075	0.05	0.09	0.072	0.0924		0.0923	0.09	0.078	0.13
Bunch length	ps	12	18.7	30	170	13.3	16.7	11.67		16.2	12.7	10	20
Normalized X emittance	m rad	1.20E-05	2.70E-05	6.28E-05	2.14E-04	2.07E-05	4.30E-06	1.47E-05	8.39E-05	8.15E-05	3.00E-06	1.50E-06	8.00E-06
Normalized Y emittance	m rad	1.20E-07	2.20E-07	1.25E-06	4.63E-07		3.00E-08				3.00E-08		
X/Y damping time	ms	17	13	4.9 / 9.4	14	9	6.8 / 9.1	8.73		7.17 / 7.14	5.2	8.3	28
Longitudinal damping time	ms		80	5.7	7	5	5.5	4.35		3.56	2.5		
Number of bunches per train		320	388	150	7		10 - 60	396			95	154	2820
Bunch spacing	ns	2	2	2			2.8 - 5.6	2.84		2	2.8	0.667	20
Multibunch current	mA	400	320	200	1000	400	600	500	300	300	800	820	
Single bunch current	mA	20	30	10	400			10		5			
Particles per bunch		5.00E+09					1 - 3 E+10				1.60E+10	4.20E+09	2.00E+10
Circumference	m	196.8				288	138.6	337	407	384	297	239	17000
Repetition rate	Hz						25				120	150	5
Beam pipe radius	cm	5	10	9	11		1.2	1.25	1	2.3	1.6		

Existing machines — Proposed light sources — Proposed damping rings

Instabilities in rings

- Coupled-bunch motion
  - Bunch-to-bunch energy spread
    - →Broaden undulator harmonics
    - →Energy spread in extracted bunch trains
  - Movement of source point
  - Increase in beamsize
  - Beam loss

> Damp resonances
>
> ⇒ Cavities, BPM’s, septa, kicker magnets, …
>
> Feedback systems
>
> ⇒ Control residual motion

Instabilities in rings

- Single-bunch effects
  - Increase in beamsize (transverse and longitudinal)
    - →Instabilities
      - > Impedance driven, two-beam driven
    - →IBS
  - Beam loss
  - "Bursting" phenomena particularly difficult
    - →SLC - "sawtooth", NSLS - coherent radiation bursts
      - > Severe consequences downstream of damping rings
  - Requires very careful vacuum chamber design
    - > Reduce short-range wakefields
      - ⇒*Understand wakefield / impedance model*
      - ⇒*Understand instability models*

Emittance requirements

- Light sources
  - High brightness radiation beams
    - → $\gamma\varepsilon_x$ " 10 µmrad, $\gamma\varepsilon_y$ " 100 nmrad
- Damping rings
  - High luminosity collisions
    - → $\gamma\varepsilon_x$ " 1 µmrad, $\gamma\varepsilon_y$ " 10 nmrad
  - Extracted beam emittance
    - →Evolves from the injected beam emittance, and the natural equilibrium emittance

$$\varepsilon_{extracted} = \varepsilon_{injected} e^{-2N_\tau t} + \varepsilon_{equilibrium}\left(1 - e^{-2N_\tau t}\right)$$

  - Positron beam requires pre-damping ring
    - →Large emittance from target

- Small beams
- Small vacuum chambers
- *Strong short-range wake*
- *High cut-off frequency*

Ring Parameters

- Luminosity determined by repetition rate of bunch trains
- Damping time determined by required rep rate, # trains, store time per train

$$\tau \text{ Š } \frac{1}{f_{rep}} \frac{N_{train}}{N_{\tau}}$$

  - Three orders magnitude reduction in vertical emittance

- Need E > 2.8 GeV with iron magnets
  - Expensive

    →Increase damping rate using wiggler

$$\tau = \frac{2.88x10^{12}\, T_{orbit}}{B_0\, \gamma^2}$$

- Long, narrow gap insertion device
  - Limiting aperture
  - Increases short-range wakefield

Ring Parameters

- Energy
  - Adequate damping at minimal cost
  - Preserve spin polarization
    - →Spin-tune is half-integer
  - " 2 GeV

$$E = \left(n + \frac{1}{2}\right) 440\ \text{MeV}$$

- Intra-beam scattering
- Instability thresholds

- Bunch trains
  - Continuous injection / extraction
  - Requires very stable and fast injection / extraction kickers
    - →Sets machine circumference

- Transients excite all bunch trains in machine
- Phase transient along bunch train

Ring Parameters

- Small momentum compaction
  - ◊ Sensitivity to orbit changes
    - →Increase RF voltage to maintain short bunches
  - ◊ Incorporate chicane to control circumference ± few mm
    - →Wiggler on / off
    - →Other effects

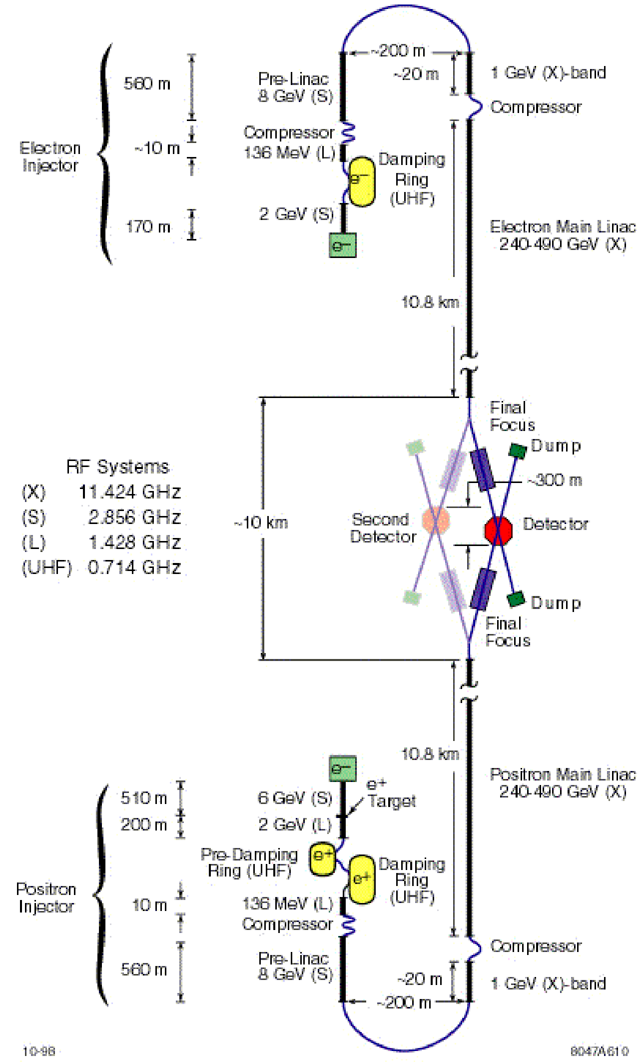
- Decreases instability thresholds

- Bunch length
  - ◊ Short
    - →Maintain peak current below instability thresholds
    - →Avoid excessive intra-beam scattering
      - > Harmonic cavities
        - ⇒Light sources
        - ⇒CLIC

- Short bunch - lower instability thresholds

NLC

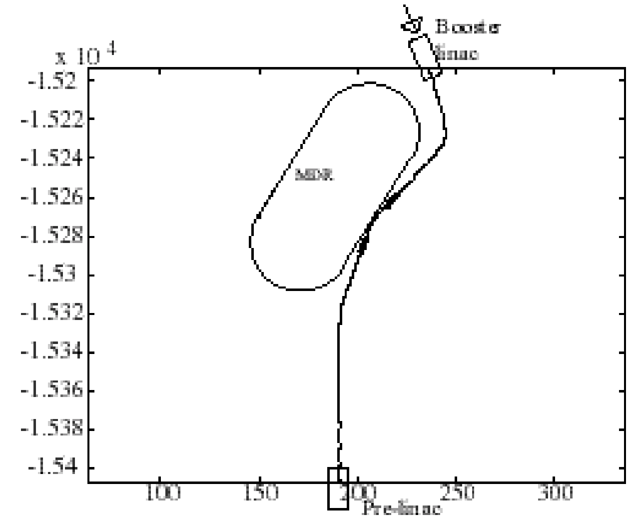
- Consists of:
  - e+ source and polarized e- source to produce high-current bunch trains
  - damping rings for small emittances
  - bunch compressors for short bunches
  - X-band linacs to attain high gradient acceleration for high energy
  - collimation section to remove large amplitude particles
  - final focus for small spots
  - two IPs for alternate experiments

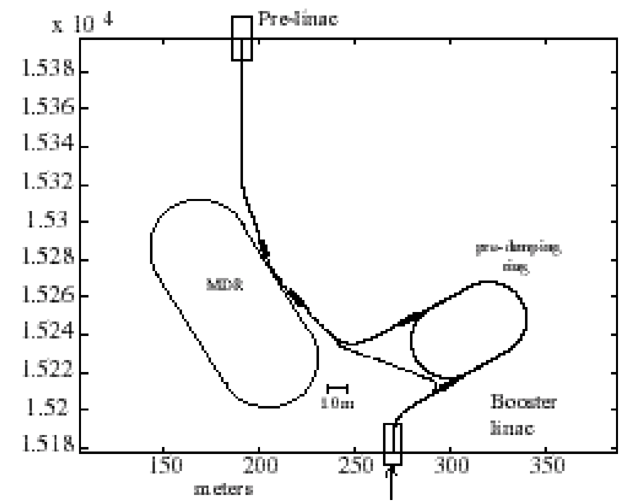


NLC Damping Rings Complex

- Reduce emittance of low-energy e^+ e^-
- Stable platform for injection into linacs
  - Similar to 3rd generation light sources

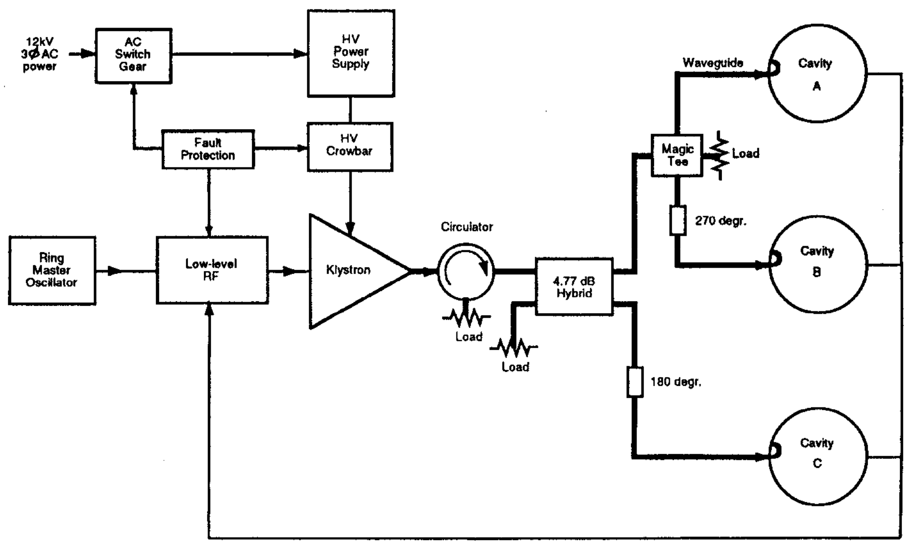
	Pre-damping ring	Main damping rings
Energy (GeV)	1.9 – 2.1	1.9 – 2.1
Circumference (m)	214	297
Bunch spacing (ns)	2.8	2.8
Fill pattern	2 trains 95 bunches 2 gaps 100 ns	3 trains 95 bunches 3 gaps 68 ns
Damping time (ms)	< 5.21	< 5.21
N_{max}/bunch	1.9×10^{10}	1.6×10^{10}
Current (mA)	800	750
Injected emittance X/Y (m-rad)	$< 9 \times 10^{-2}$ (edge)	$< 150 \times 10^{-6}$ (rms)
Extracted emittance X/Y (m-rad)	$< 1 \times 10^{-4}$	$< 3 \times 10^{-6}$ / 0.03×10^{-6}
RF voltage (MV)	2	1.5
Momentum compaction	0.0051	0.00066
Energy spread (%)	0.09	0.09
Bunch length (mm)	8.4	3.8
Wiggler field (T)	2	2
Synch. radiation power per section (kW)	25	25
Vacuum pressure (Torr)	1×10^{-9}	1×10^{-9}
Maximum rep. Rate (Hz)	120	120





Damping Rings RF Systems

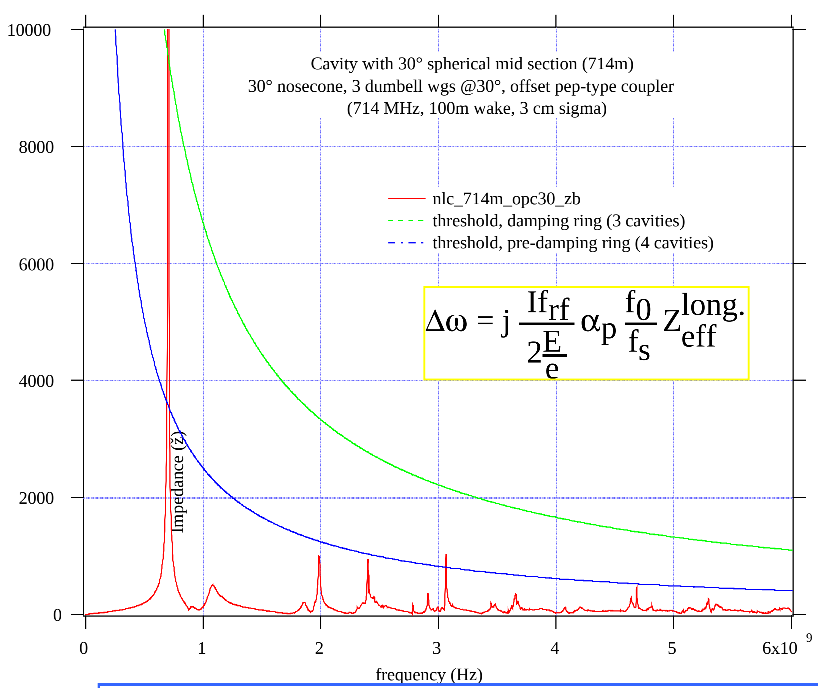
- Main damping rings

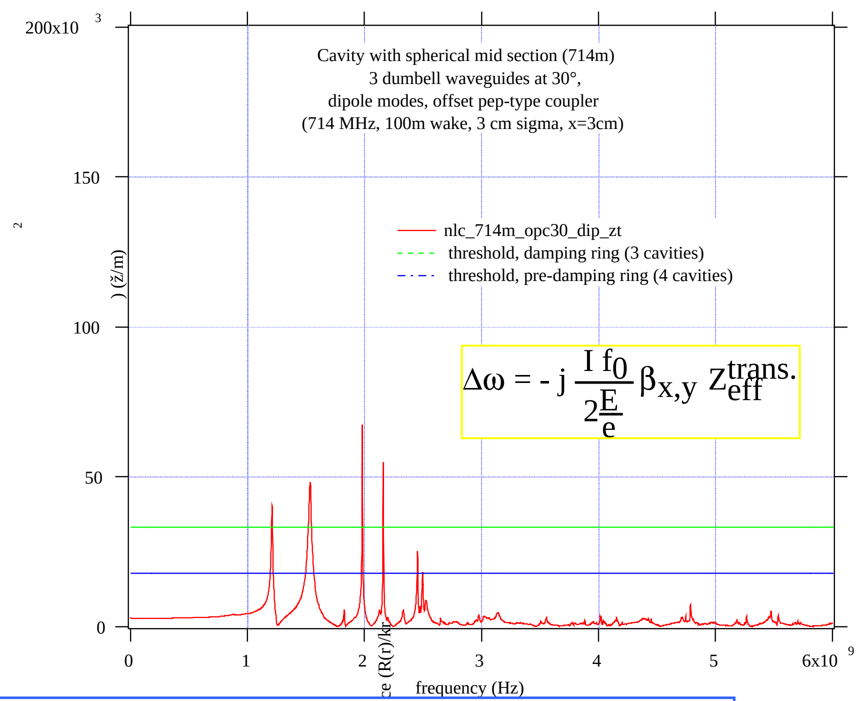


Energy	1.98 Gev
Circumference	297m
RF Frequency	714 MHz
Harmonic Number	708
Bunch spacing	2.8 ns
Beam Current	0.75 A
σ_ε	0.09 %
σ_z	4 mm
α	0.00066
$U_{s.r.}$	750 keV/turn
$U_{HOM's}$	5.6 keV/turn
$U_{parasitic}$	36 keV/turn
V_{RF}	1.5 MV
Number of Cavities	3
Number of klystrons	1
Cavity Wall Dissipation	42 kW/cavity
Klystron Power	1 MW
Shunt Impedance	3.0 MΩ/cavity
Unloaded Q	25500
Coupling Factor	5.8
Synchronous Phase Angle	32°
Optimum Detuning at Full Current	106 kHz
Synchrotron Frequency	6.9 kHz
Loaded Q	3777
Energy acceptance	±1.8%

HOM Damping

- Longitudinal modes
- Transverse modes





→Damp higher-order modes

> *Transverse feedback system required*

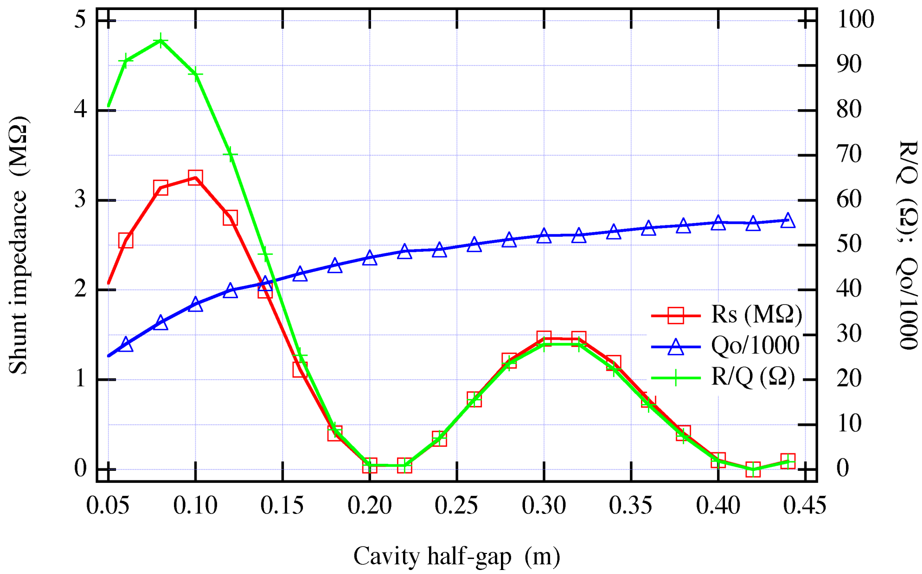
⇒HOM's, two-beam instabilities, and resistive wall

Gap Transient Effects

- Bunch-to-bunch synchronous phase variation
  - Leads to energy variation after bunch compression
  - 4° / 30 ps

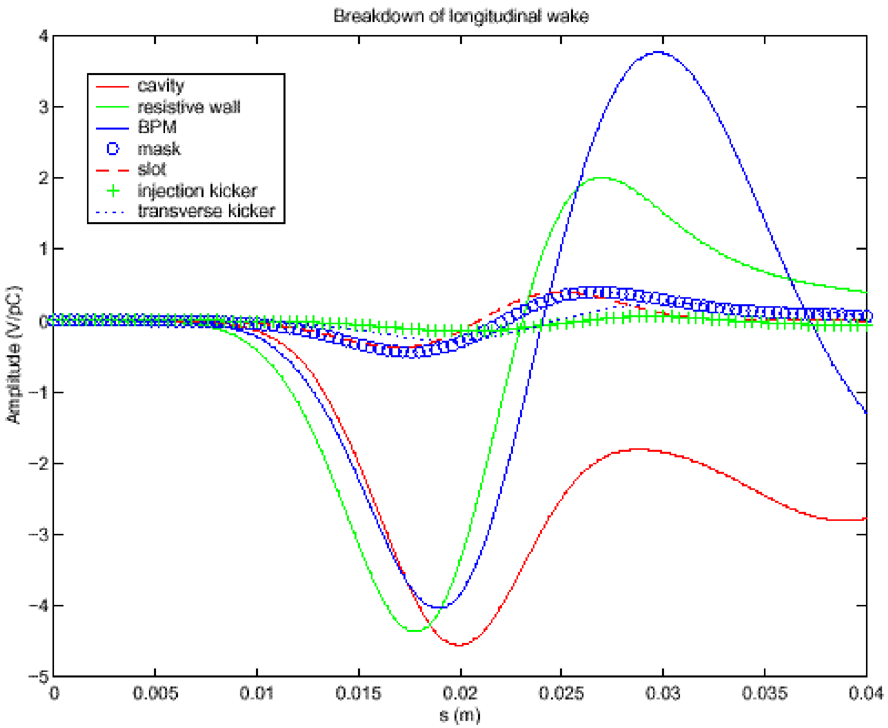
$$\Delta\phi - \frac{2kI_oT_{gap}}{V_{cavity}\sin\phi_{synch}}$$

- Compensation techniques
  - Adaptive-inverse feedforward with broadband klystron (? f " 10 MHz)
  - Harmonic cavities
  - Ring off-frequency (• f " 40 kHz)
  - High-stored-energy cavities



NLC Impedance Model

- Longitudinal wake
  - Major vacuum chamber components
    - →RF cavities
    - →Resistive wall
      - > Small vacuum chamber
    - →BPM's
      - > High-frequency resonances
    - →Ante-chamber slots
    - →Bellows shields
    - →Injection and extraction magnets

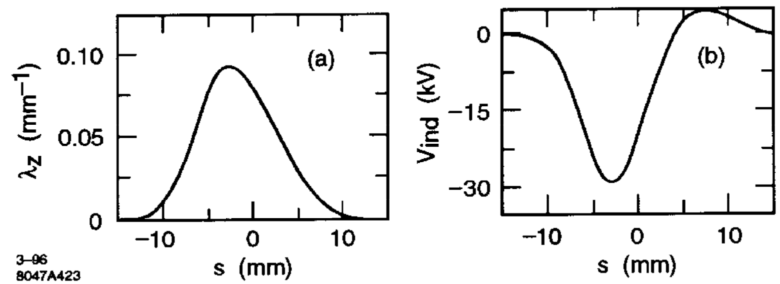


- Similar impedance model for transverse wake

⇒Cho Ng talk

ZDR - Longitudinal single-bunch

- ♦ Potential well distortion



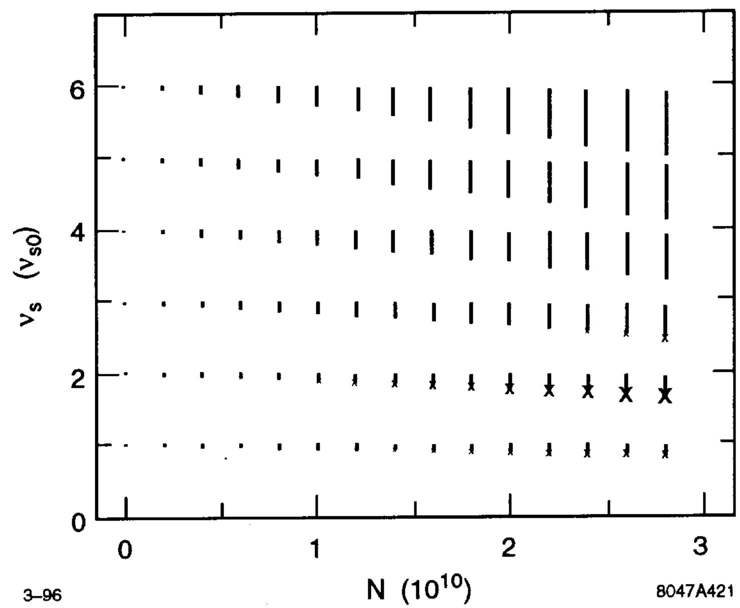
- ♦ Microwave instabilities
  - ◊ Z/n " 0.025 !
  - ◊ Strong threshold estimate

$$I_p = \frac{2\pi\,|\eta|\left(\frac{E}{e}\right)\left(\beta\sigma_p\right)^2}{\left|\frac{Z_{\|}}{n}\right|_{eff}}$$

→Threshold " 2 x operating current

  - ◊ Simulations

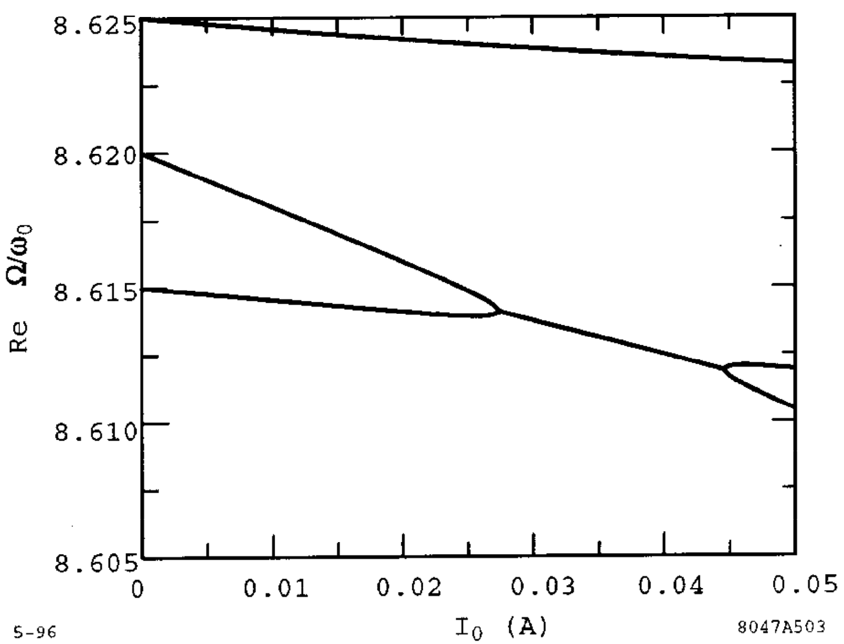
→Threshold " 4 x operating current



ZDR - Transverse single-bunch

- Transverse mode coupling instability (TMCI)
  - Simulations

$$I_b = \frac{4\left(\frac{E}{e}\right)\nu_s}{\left\langle \mathrm{Im}(Z_\perp)\,\beta_\perp \right\rangle R}\,\frac{4\sqrt{\pi}}{3}\,\sigma_l$$



→Threshold " 10 x operating current

ZDR - Fast ion instability

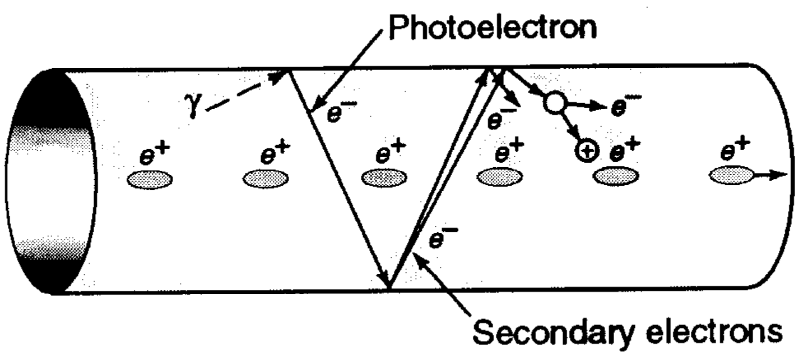
- Interaction between intense electron beam and ions gives rise to fast transverse instability
- Growth time <" 1 ms
- Experimental evidence from ALS and PLS

> ◊ Maintain average pressure < 1 nTorr
> ◊ Bunch-by-bunch feedback system
> ◊ Additional gaps in bunch trains

ZDR - Electron cloud instability

- Intense positron beam produces cloud of photoelectrons and secondary electrons
- Experimental evidence at BEPC
- Desorbs gas from surfaces
- Interaction between positron beam and electron cloud gives rise to fast transverse instability

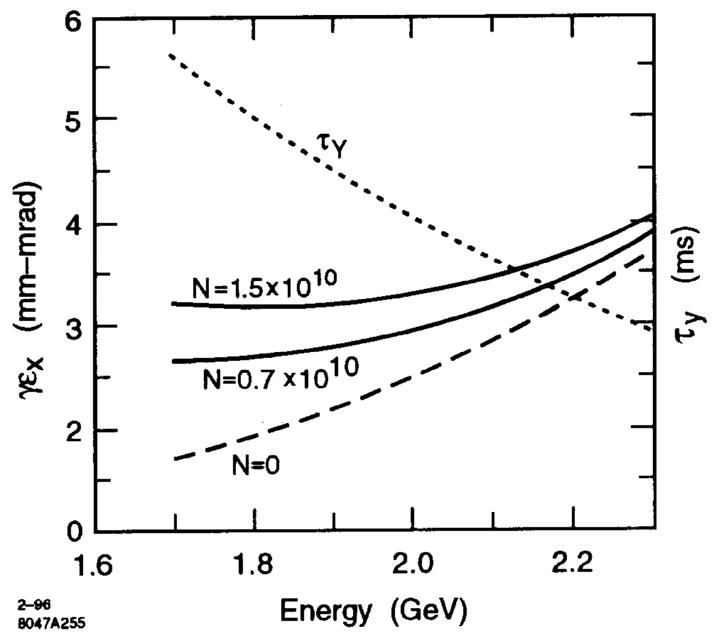
◊ Low secondary emission coatings
◊ Bunch-by-bunch feedback system
◊ Solenoidal magnetic fields



ZDR - Lifetime and IBS

- Gas-scattering lifetime several hours
- Touschek lifetime few minutes
  - Increase bunch volume for commissioning studies
- Intra beam scattering (IBS)
  - significant at lower energies

→Higher energy preferable
> Reduced growth from IBS
> Reduced damping time



Conclusions

- Damping rings and synchrotron light sources face similar problems with collective effects
  - Intense beams
  - Small vacuum chambers

→How good is the impedance model?

→How good are the impedance calculations and measurements?

→How good are the instability models and analyses?

⇒*Subjects of this workshop*