NLC - The Next Linear Collider Project

Accelerator Test Facility – KEK/ATF

Prototype injector for JLC/NLC

ATF is the only test facility with ~NLC emittance

Marc Ross

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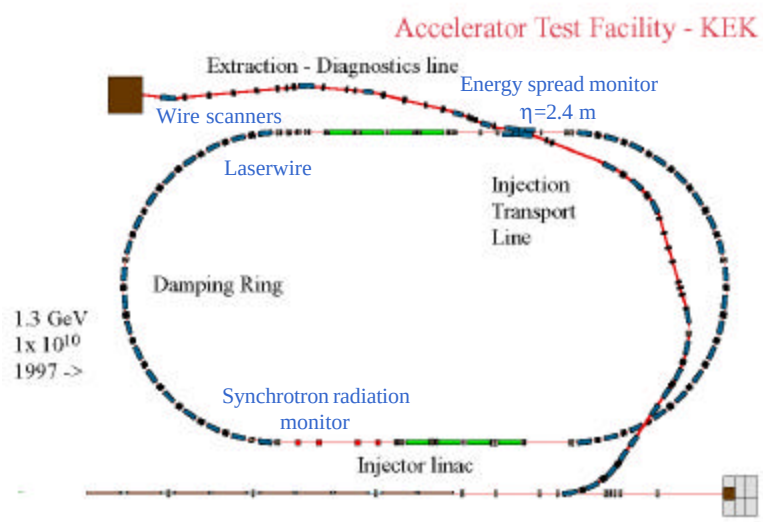
ATF Report

- Single bunch emittance results
  - Evidence for intra-beam scattering
- Emittance measurements
- Single bunch study plans

- Instrumentation RD at ATF
- Multi bunch plans



KEKの敷地内に運転中のJLCのための試験加速器

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Emittance

	γe_x	$g e_y$	
– NLC spec:	3e-6	3e-8 m-rad	
– ATF achieved:	5e-6	6e-8 (5e-6	<1e-8 expected)

– Single bunch; 1.28 GeV; 1e10 ppb (NLC: 1.98 GeV; 8e9)

- What are important emittance effects?
  - ring dispersion / coupling correction
  - intra-beam scattering
  - extraction line optical aberration correction
  - instrument validity

Collective effects – single bunch

- cause either coherent instability or incoherent emittance growth
  - Potential well distortion
  - "Microwave" instability
    - serious problem at SLC
      - worse with 'strong' but still a problem with 'weak'
      - definite threshold observed
  - Intra-beam scattering
    - Key topic of ATF work
    - more studied at proton machines
    - important single bunch emittance driver for NLC
    - no threshold: dependence on bunch volume

Intra-beam scattering

- Similar to synchrotron radiation →
  - growth rate = damping rate at equilibrium
  - collisions involve energy exchange between particles
  - beam temperature in rest frame: 7000:35:1 (x, y, z)
  - SR from bends only; IBS everywhere

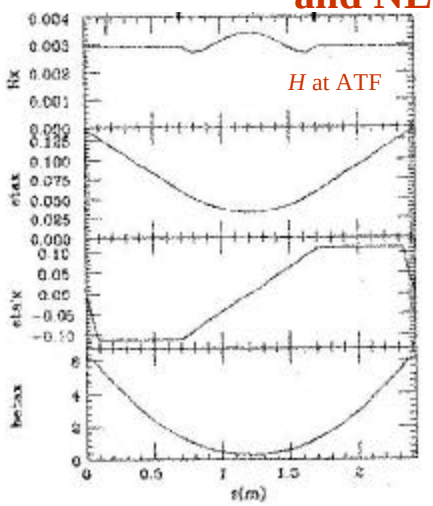
$$\frac{\langle H \rangle_{bends}}{\langle H \rangle} = 1.6 = \frac{(\varepsilon_y - \varepsilon_{y0})/\varepsilon_{y0}}{(\varepsilon_x - \varepsilon_{x0})/\varepsilon_{x0}} \quad \text{(at ATF)}$$

    - (for emittance generated through residual dispersion vv coupling)
  - H is the dispersion invariant $H = \left[\eta^2 + (\beta\eta' + \alpha\eta)^2\right]/\beta$

Intra-beam scattering – theory

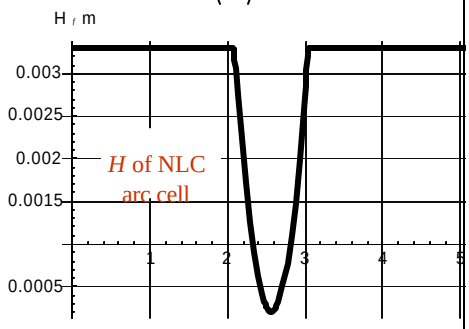
- small transfer approx. of Touschek lifetime
  - limitation in SR sources
- Bjorken&Mtingwa + Piwinski
  - $x - y$ coupling and microwave related σ_z distortion not included in most simulations
- Magnitude
  - overall scale factor usually used (protons…, ALS)
- Tail generation – (should be important for downstream users)
  - cut-off parameter introduced
    - reduces computed 'rms' emittance by 30%

H – dispersion invariant for ATF and NLC design



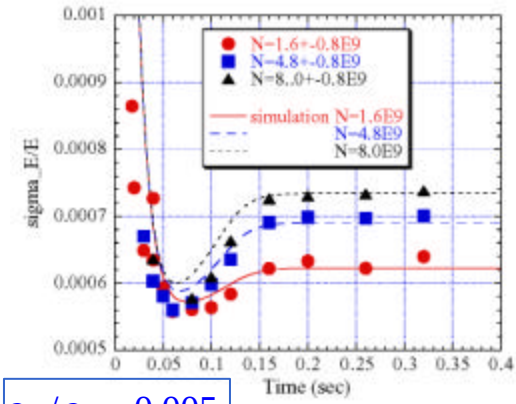
$$\frac{\langle H \rangle_{bends}}{\langle H \rangle} = 1.6 @ ATF$$

$$\frac{\langle H \rangle_{bends}}{\langle H \rangle} = 0.64 @ NLC$$



Evidence for IBS – vertical coupling into s_E

- Vertical still large – no effect on *x* and *E*
- Vertical damped – increase in *x* and *E*
- minimum at 70ms



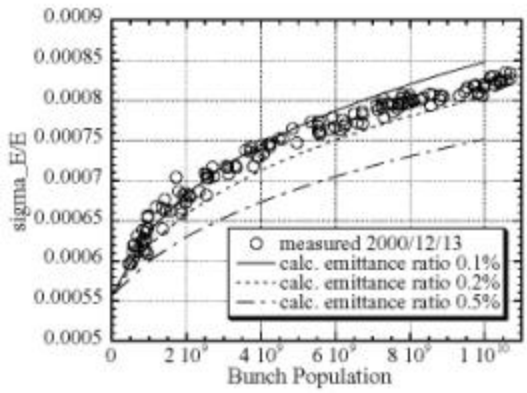
Simulation consistent when coupling →

$\varepsilon_y / \varepsilon_x = 0.005$

Energy spread

- Zero current energy spread ~ 5.5e-4 is close to expected.

$\varepsilon_y / \varepsilon_x \leq 0.002$



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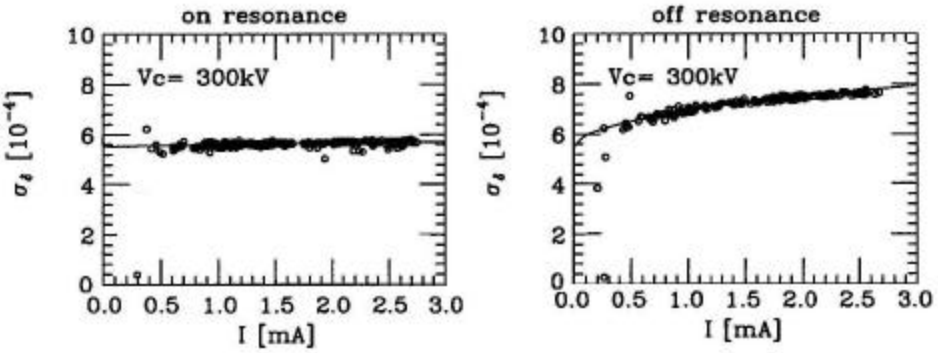
Energy spread on/off difference coupling resonance – showing IBS effect

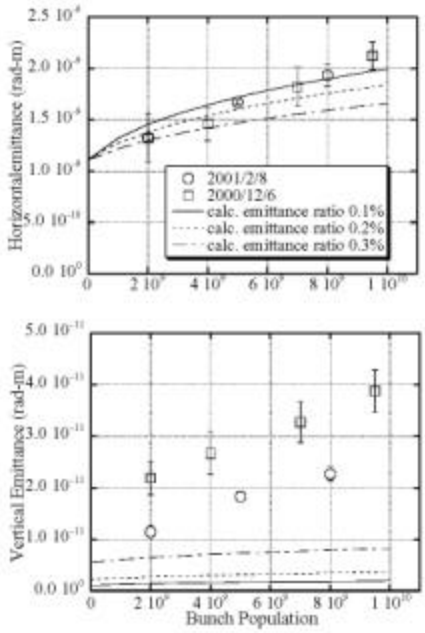
Energy spread in extraction line on/off coupling resonance



Emittance vs intensity

- Extraction line wire scanner emittance
- Simulation uses zero current ε_x

$\varepsilon_y / \varepsilon_x \leq 0.002$



Emittance results

- Growth ratio is well measured
- ε_y0 is poorly understood
- Observed energy spread/ horizontal emittance growth indicates a 6x smaller vertical emittance than observed

Table of emittance measurements: (e-9/e-11 *x/y*; not normalized)

		e_x0	e_x	e_y0	e_y	r
extracted	wires 4/00	1	1.85	1	3	2.35
extracted	Dec-00	1.1	2.2	1.7	4	1.35
extracted	Feb-01	1.1	2.2	0.7	2.8	3.00
extracted	Apr-01	1	2.4	1.2	2.5	0.77
ring	L wire	1.1	2.2	0.7	1.9	1.71

- measurements made 4/00 to 4/01
- IBS: $1 < r < 1.6$

$$r = \frac{(\varepsilon_y - \varepsilon_{y0})/\varepsilon_{y0}}{(\varepsilon_x - \varepsilon_{x0})/\varepsilon_{x0}}$$

Constraints on measurement/optical errors from estimate of *r*

- for example – a coupled mixture as would be generated by a skew quad

$$\varepsilon_{y\text{meas}} = \varepsilon_{y\text{real}} + k\varepsilon_x$$ (*k* independent of I)

- → only makes sense if:

$$\frac{\varepsilon_y}{\varepsilon_{y0}} < \frac{\varepsilon_x}{\varepsilon_{x0}}$$

- not so for 00/01 data

Orbit correction/emittance optimization

Simulated vertical emittance after each correction

- Random seed 'SAD' simulation results

	Average	<1.1E-11 rad-m
COD	2.28 (E-11 rad-m)	20 %
V COD-dispersion	1.67	51 %
Coupling	0.58	91 %

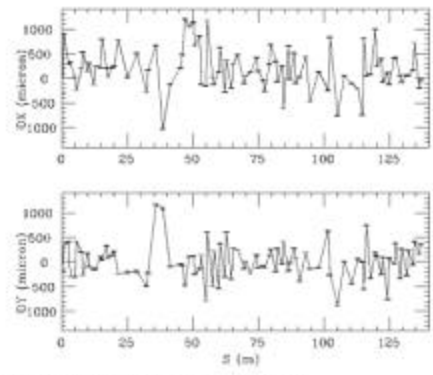
Misalignment : as measured

+ random 30 micron offset

+ random 0.3mrad. rotation

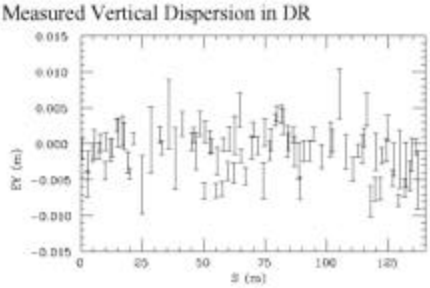
BPM error : offset 300 micron, rotation 0.02rad.

Ring orbits



- Raw BPM readings
- Energy spread measurement an excellent practical indicator of convergence

Measured Vertical Dispersion in DR



$$\eta_{rms} \approx 3mm$$

Summary – single bunch low emittance

- relative growth not explained by aberrations in extraction line
- ring simulation indicates unreasonably small vertical emittance
- ring tuning relies on poorly optimized BPM system
- simulation input somewhat unrealistic

- Plans:
  - complete ring beam based alignment
  - BPM system improvements
    - extraction line (RF dipole mode BPM's)
    - ring

Single bunch study plans

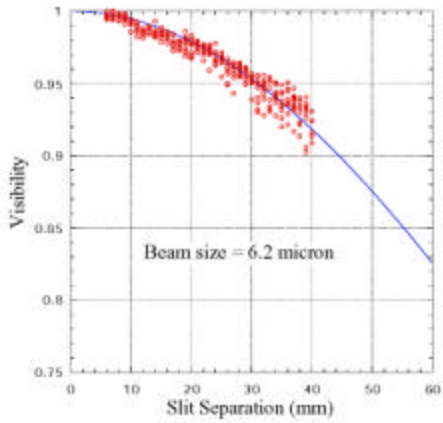
- ZDR prediction for 2 GeV: ~ 20% growth at 1e10
  - What is the impact of the ATF result on the NLC damping ring design?
- ε_{yo} is too high
  - coupling and dispersion correction
  - BPM resolution and beam based alignment
  - understanding of low intensity, low emittance instrument resolution

Emittance measurements

- wire scanners - in the extraction line…
  - few micron beam size resolution
  - 2-3 micron beam jitter
  - control of eta to few mm
- laserwire – in the ring…
- energy spread – extraction line optics
- SR monitor (results not included)

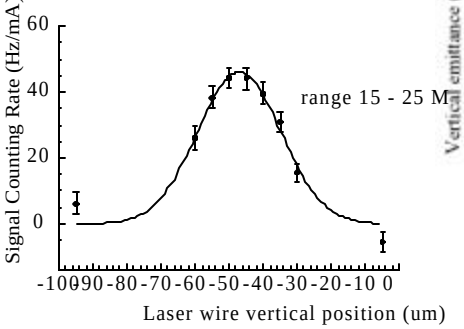
Synchrotron radiation interferometer

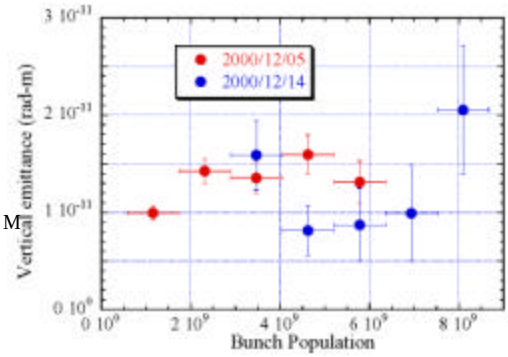
- measure depth of 2 slit modulation vs slit spacing
- 6.2 um
- ε_y ~ 1.6 e-11
- beats diffraction limit by ~ 6x



Ring Laserwire monitor

- Resonant cavity close to focus cut-off
  - uses CW laser
  - cavity gain 300
  - measurement ~ 1 hour





Development of a transition radiation profile monitor - OTR

- some controversy over minimum resolvable beam image
  - achieved 7um (12/00) well beyond purported limit
  - smallest OTR spot imaged to date
- theoretical limit: ~ λ
- Parameters for ATF OTR (built at SLAC)
  - resolution – 2um
  - field of view – 300 x 200 um (or ~2x)
  - depth of field – 8 um vertical displacement
  - OK light for normal camera – 5e9 ppb
- Instrumentation RD

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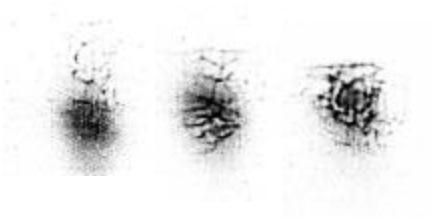
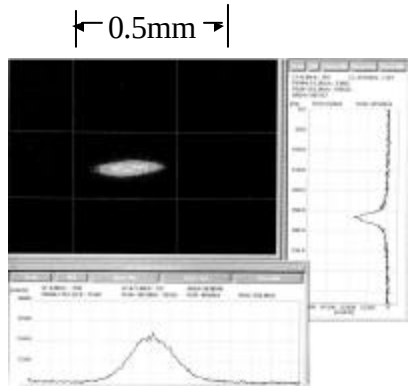
OTR image

- 10 μm σ
- successive images illustrating damage process





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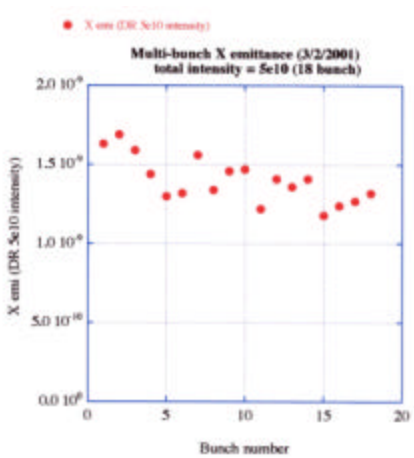
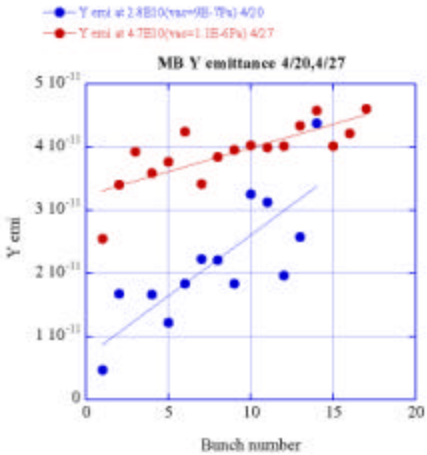
Multi-bunch operation

- 20 bunches; typical single bunch Imax ~ 2.5e9 (4x lower than single bunch
- ε_y increases 1.5x from 1st to 20th bunch (10e-8 normalized avg.)
- vacuum system to be improved 2001





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ATF Operation

- ATF operates 20 weeks/year for a 4 1/3 day block /week
  - ~ 2 wks on/ 2 wks off (end effects are large)
- Users (~ students) get about 1/4 time
  - Effective uptime ~ 55 days/year
- Stability is critical for ~10 pm emittance
- Typical beam sizes are 50 x 8 µm
- BPM resolution single shot is ~15µm
- Beam pulse rate is 1.5 Hz

- Precise measurements require long periods of checking/setup

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ATF Plans

- Operation is limited by funds (KEK) and manpower (KEK)
  - ~10 physicists (6 FTE) + 8 grad. students
  - SLAC participation began 1997
    - 1 FTE average by ~ 8 SLAC staff
    - ~100K$
  - Contributions from Japanese universities and BINP/Protvino
  - Minimal involvement from other labs

SLAC contributions significant

ATF is the only LC test facility with capability for transverse beam dynamics studies
  - collective effects, tolerances, optimization, control, stability, technology