Electron Cloud Observations and Predictions at KEKB, PEP-II and SuperB Factories

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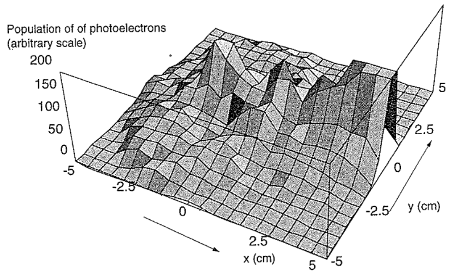
KEKB

- Coupled bunch instability (CBI) caused by the electron cloud was known in the middle of the design stage of KEKB based on the observation at PF and subsequent theoretical work by K. Ohmi.
- A solenoid winding was proposed as a measure against CBI in the design report.
- The design of vacuum chambers was kept to round copper chambers without anteroom.
- At the beginning of the operation, vertical beam size blowup was observed in LER.
- According to the speculation that the blowup was caused by the electron cloud, the solenoids which covered 35% of drift space were wound.
- At the same time a model of the blowup by the electron cloud was proposed by K. Ohmi and F. Zimmermann.
- Luminosity was increased as a result of the solenoid winding.
- The solenoids finally covered 95% of drift space.
- However, decrease of specific luminosity was still observed in 3 RF bucket spacing pattern and not resolved at the end of operation of KEKB.
- In the course of fighting with the electron cloud were carried out many machine studies about CBI, sideband due to the strong head-tail instability, tune shift and tune spectrum, the measurement of the electron cloud density and so on which I will summarize here.

Theoretical works

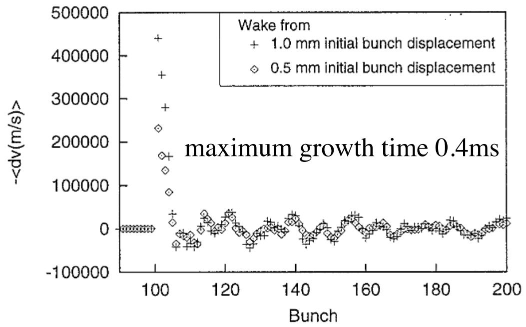
-Coupled bunch instability



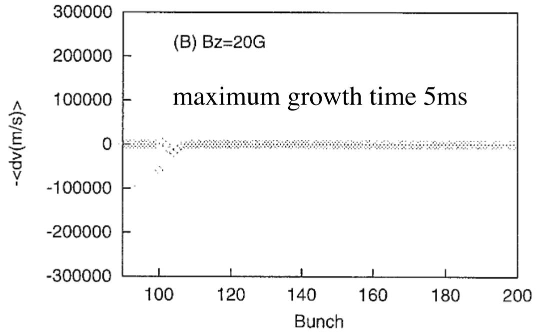
simulated electron cloud distribution

K. Ohmi, KEKB Design Report,
KEK report 95-7

without solenoid



with solenoid

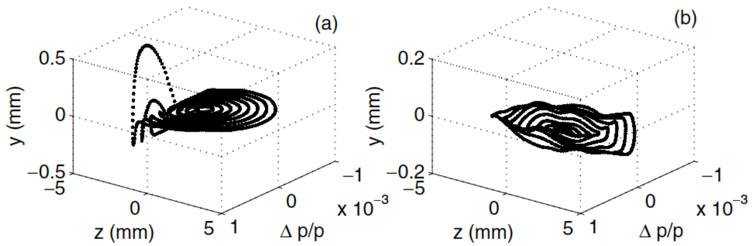


vertical wake force

- Growth time is increased to 5ms with solenoids.

-Single bunch instability

w/o synchrotron oscillation   with synchrotron oscillation



Simulated bunch shape deformation
due to the electron cloud.

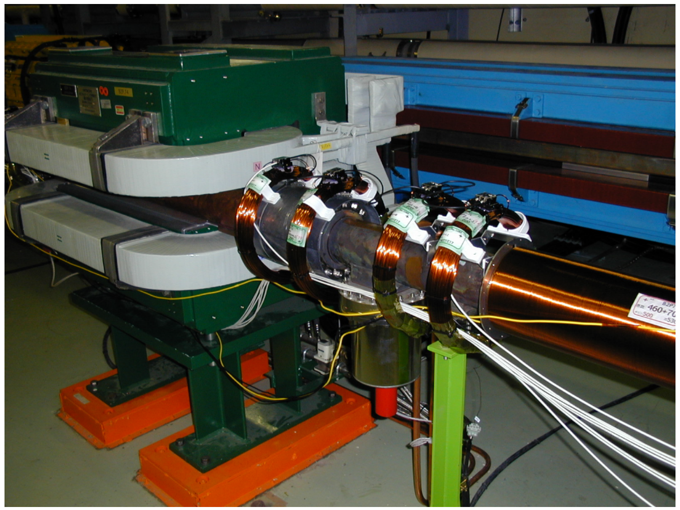
- A rise time by a simulation is of the order of 0.2 ms for ρ_e = ~1 x 10^{12} m^{-3}.
- Analysis of the strong head-tail instability with the two particle model gives a similar threshold of 0.7 x 10^{12} m^{-3}.

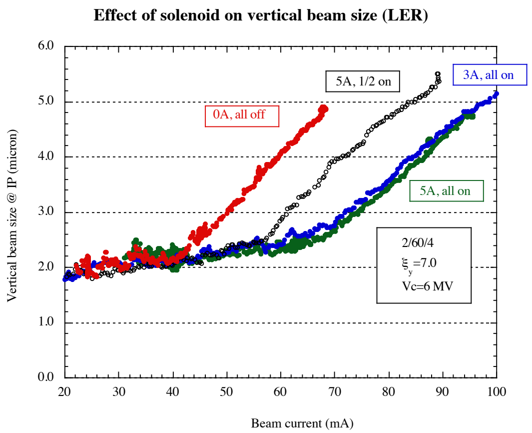
K. Ohmi and F. Zimmermann, PRL, 85, 3821(2000).

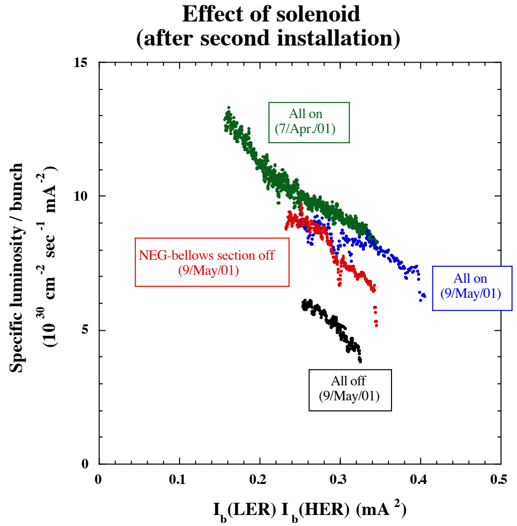
Solenoid

Parameters of solenoids

Type	Length (mm)	Diameter (mm)	Turns	Bz @ 5A (Gauss)
Bobbin	150 - 650	148	250(typ.)	45
Bobbinless	40	220	190, 200	48
Bobbinless	40	250	200	43
Bobbinless	40	300	200	37



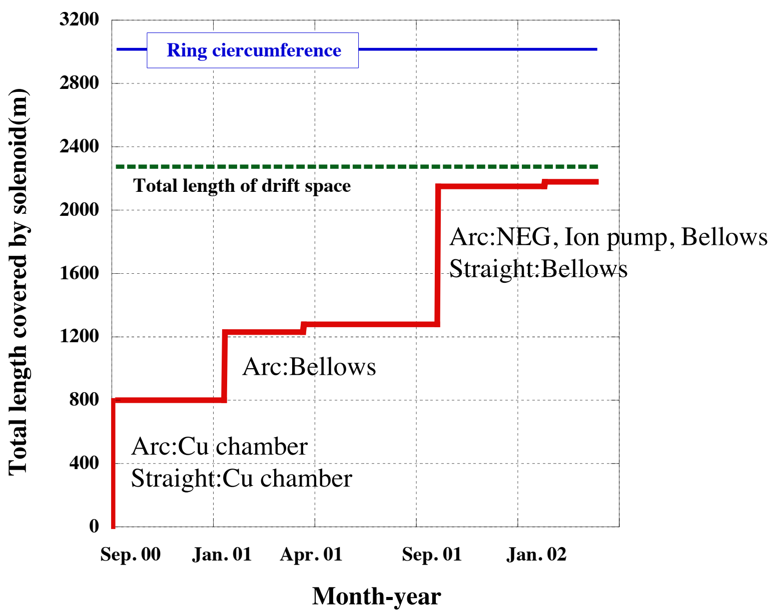




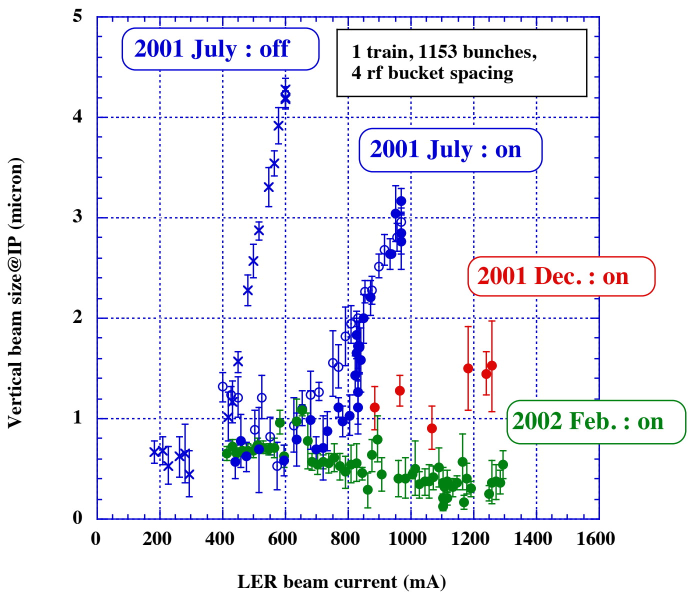
Installation history and beam size blowup

- •Major installation of solenoids finished in early 2002.

  Finally, drift space of 95% was covered by the solenoids.
- •Blowup was relaxed as the winding progressed.
- •Solenoid winding was not enough to suppress the luminosity drop at 3 RF bucket spacing. Place where the remaining electron cloud located was not identified.



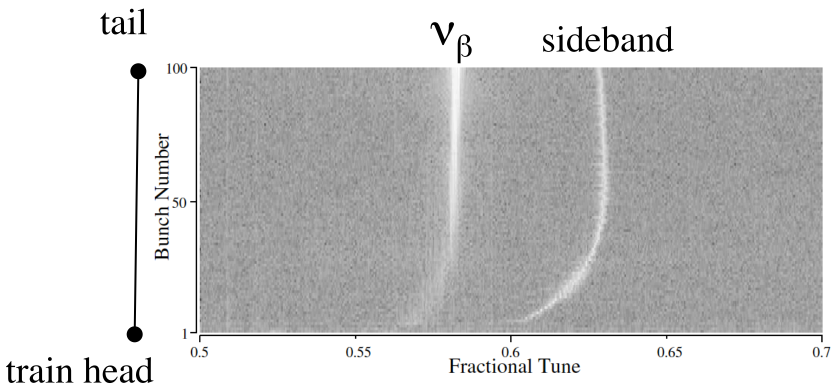
Installation history of the solenoids.



Vertical beam size transferred to I.P. measured by an interferometer.

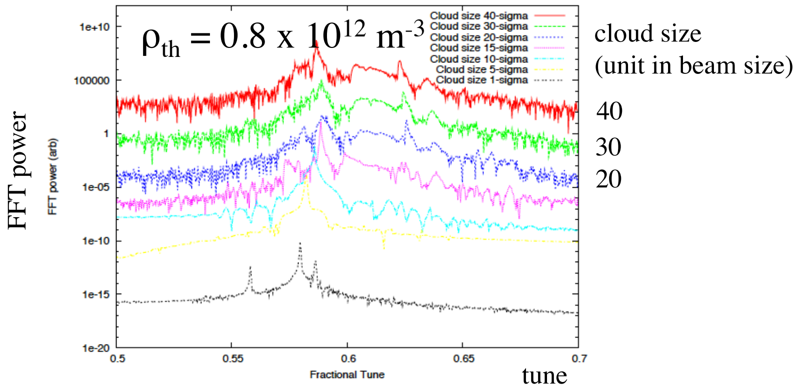
Observation of sideband

- A vertical sideband, which is an indication of the single bunch instability by the electron cloud, was observed in the signal of transverse dipole oscillation of bunches.
- Sideband appeared at upper side of ν_β.



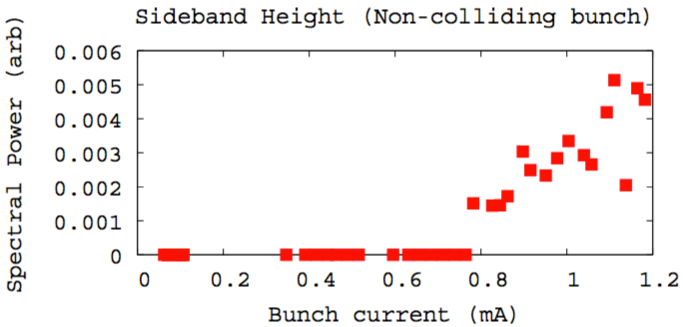
J.W. Flanagan et al., PRL 94 (2005).

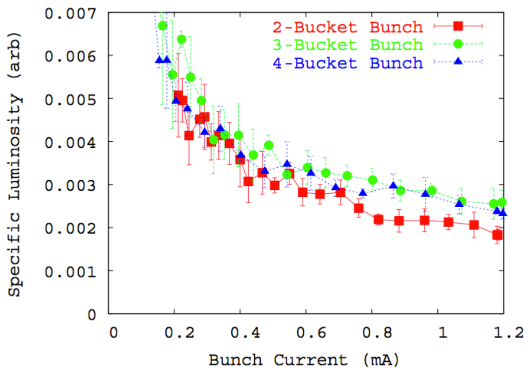
- A simulation successfully reproduces the sideband in case cloud size is 20 times larger than the beam size.

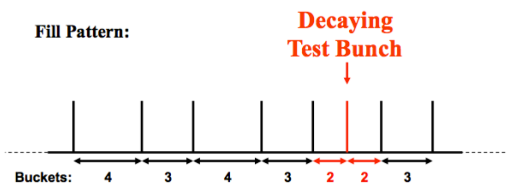


E. Benedetto et al., PAC07.

Sideband and Luminosity







J.W. Flanagan et al., ECLOUD07.

- Appearance of the sideband coincided with a drop of the specific luminosity.

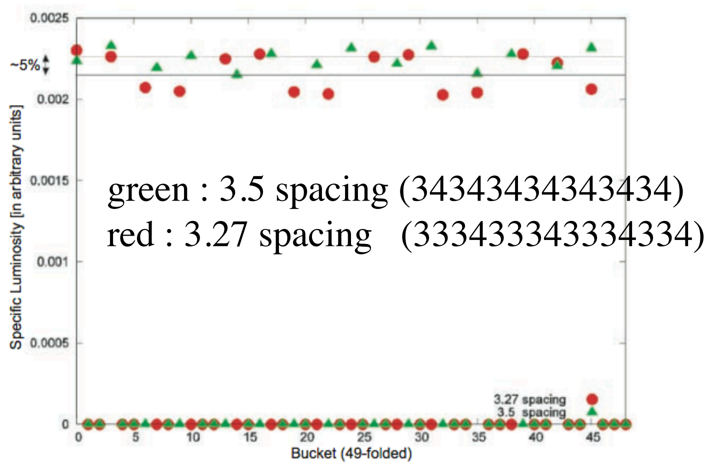
Fill pattern and luminosity

- At the end of operation without crab cavities a fill pattern was straight 3.5 bucket spacing where 3 RF bucket and 4 RF bucket spacing were repeated alternately.

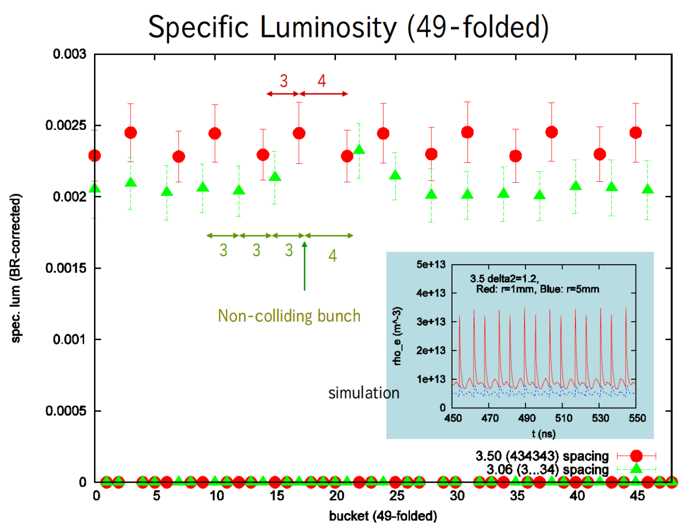
- 3.27 bucket spacing, where sequence of bunch spacing was (333433343334334 buckets), was tried. The result showed that the specific luminosity with 3.27 spacing is about 5 % lower than that with 3.5 bucket spacing.

- A single beam measurement showed that bunches which had the lower specific luminosity had higher betatron sideband peaks.

- Degradation of the luminosity by the electron cloud was not completely resolved in 3 RF bucket spacing.



Y. Funakoshi et al., EPAC06



J. Flanagan et al., ECLOUD07

Coupled bunch instability (CBI)

Solenoid off

- Mode spectrum of CBI was totally different with and without solenoid field, which shows CBI was caused by the electron cloud.

- Observed mode spectrum without solenoid field was consistent with simulation assuming that photoelectrons were produced uniformly around chamber wall.

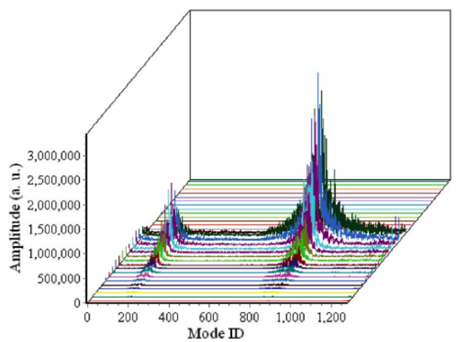
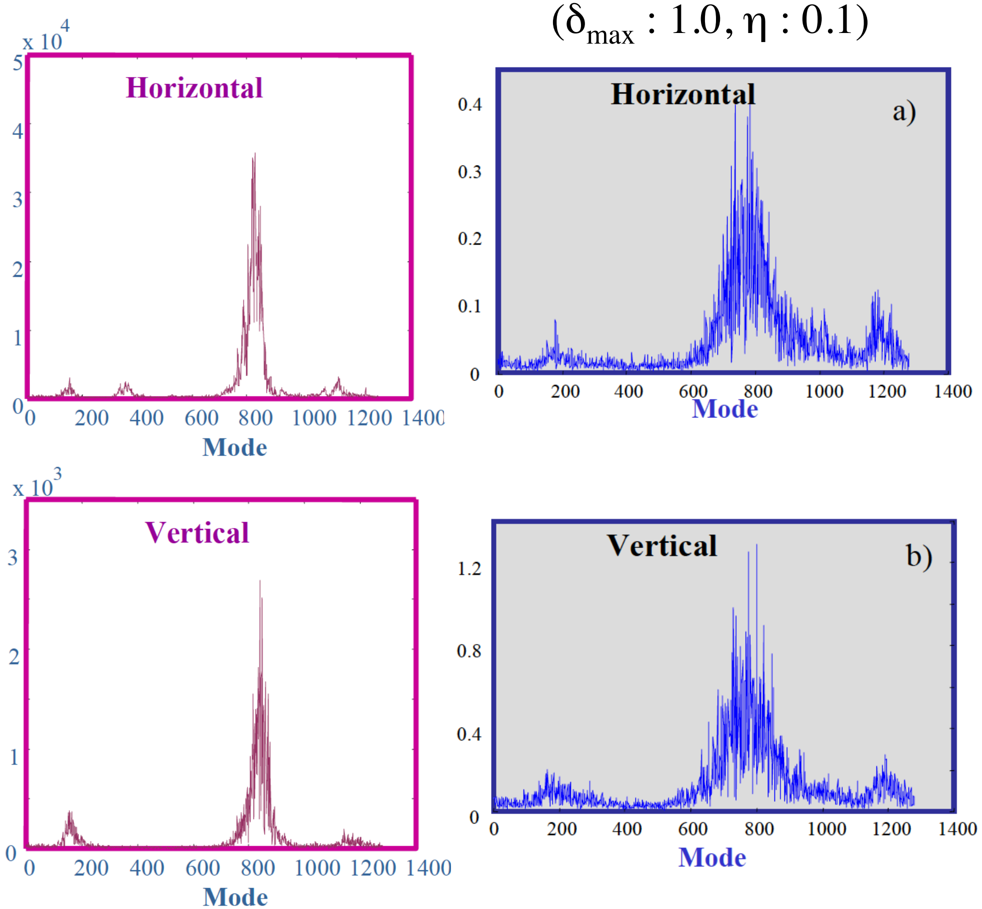


FIG. 5. (Color) Time evolution of horizontal unstable modes from mode 0 to 1279.

M. Tobiyama et al., PRSTAB(2006).

Experiment

Simulation by PEI
(δ_{max} : 1.0, η : 0.1)



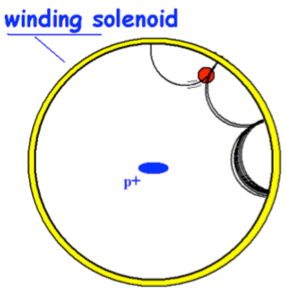
bunch current : 0.52mA, bucket spacing : 4 rf buckets, number of bunch : 1153

S. S. Win et al., ECLOUD'02.

Solenoid on

- Simulated mode spectrum assuming the solenoid field of 10 G explains the observation although 45 G was applied. (Electrons may stay nearer to the beam position than the chamber surface.)
- The mode frequency is low.
- The low mode frequency is explained by the rotation frequency of the spiral trajectory along the chamber surface.

S. S. Win et al., PRSTAB(2005).

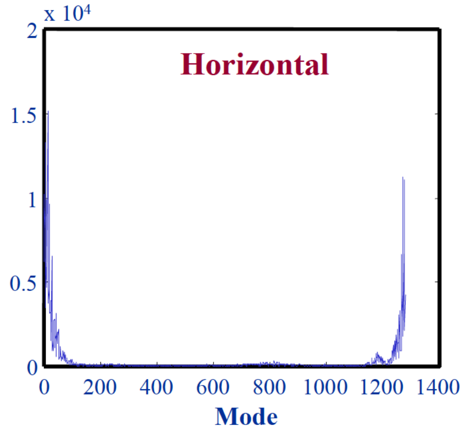


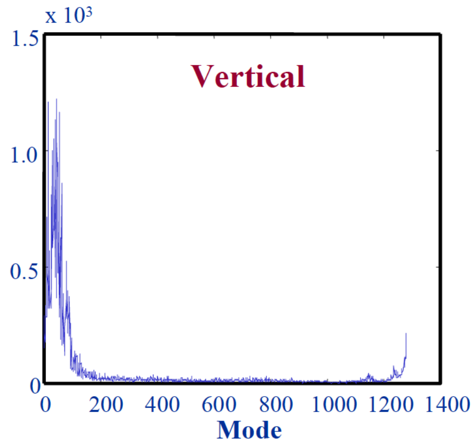
K.C. Harkay, ep feedback collaboration meeting, 2004.

- Maximum vertical growth time is 0.4ms which is consistent with a simulation assuming low SEY of 1.0.

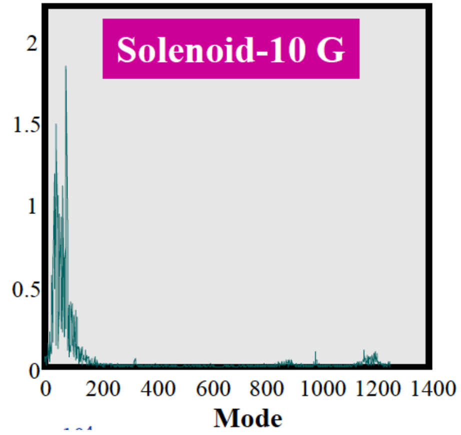
M. Tobiyama et al., PRSTAB(2006).

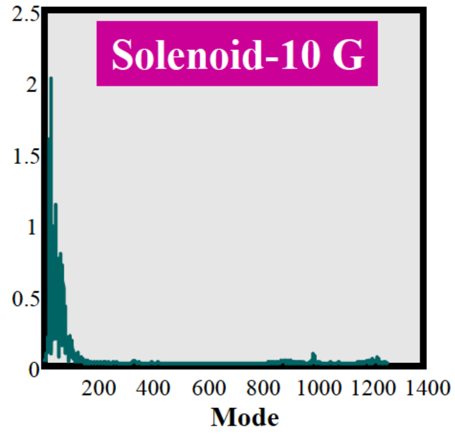
Experiment





Simulation by PEI





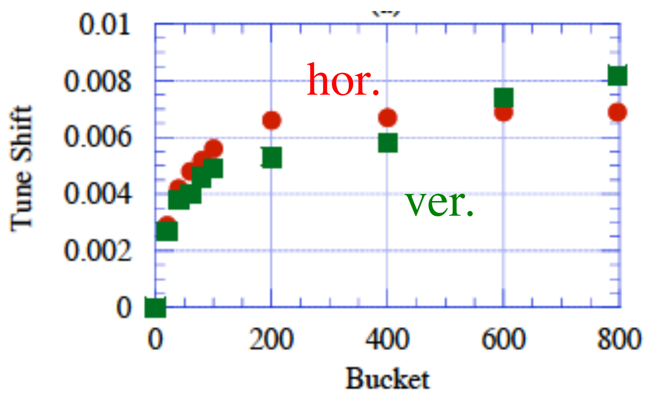
S. S. Win et al., ECLOUD'02.

Tune shift by the electron cloud

•Tune shift gives an estimate of the electron density (K. Ohmi et al., APAC2001).

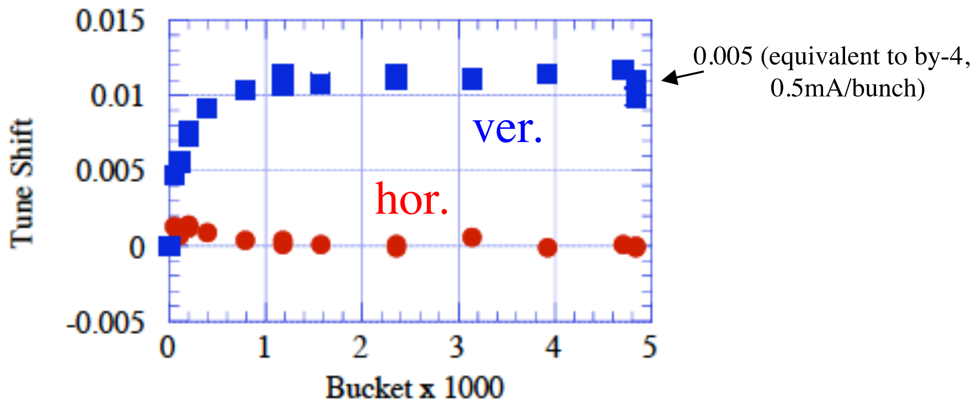
$$\Delta\nu_{x,y} = \frac{r_e}{2\gamma}\langle\beta_{x,y}\rangle\rho_e L \quad \text{for round electron cloud,} \qquad \begin{cases}\Delta\nu_x = 0 \\ \Delta\nu_y = \frac{r_e}{\gamma}\langle\beta_{x,y}\rangle\rho_e L\end{cases} \quad \text{for horizontally flat electron cloud.}$$

Solenoid off



4 rf bucket spacing, 0.5mA/bunch

Solenoid on



3.5 rf bucket spacing, 1mA/bunch

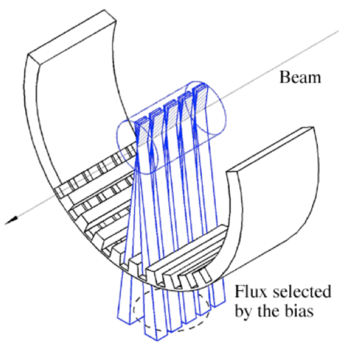
T. Ieiri et al., ECLOUD'07, EPAC06, PAC07, IPAC'10.

•In case of solenoid-off, the electron distribution seems round which is consistent with the observation of CBI. The estimated electron density from the the tune shift at saturation is 1.1 x 10^{12}m^{-3} which is roughly consistent with a simulation.

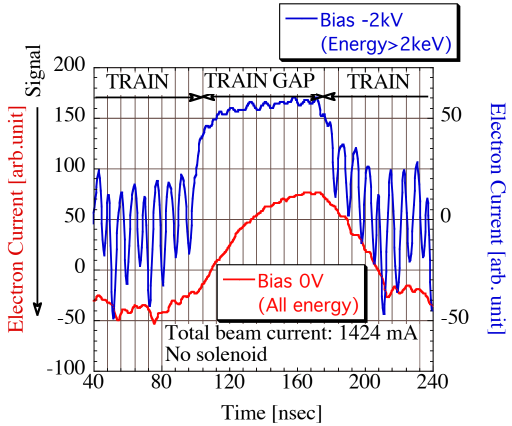
•In case of solenoid-on, the horizontal tune shift was reduced to almost zero while the vertical one was reduced only by 40 %. The reason of the different effect of solenoids in horizontal and vertical planes is not understood yet. This may imply the distribution of the cloud changed flatter.

Measurement of electron cloud density

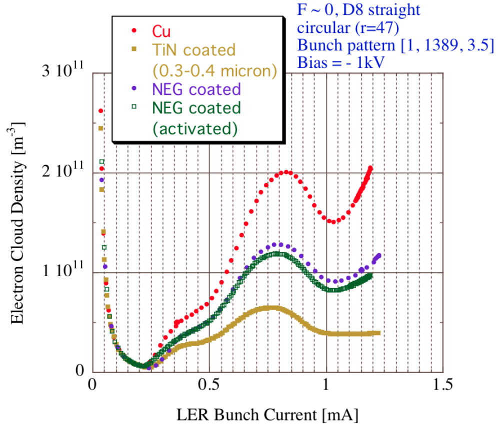
- A method measuring electron cloud density near beam was proposed then employed to KEKB.
- Applying bias voltage to RFA (retarding field analyzer) selects near-beam electrons which have relatively high energy due to strong kick by the beam.
- The method was useful for the development of vacuum components for removing the electron cloud.



Conceptual drawing of the method

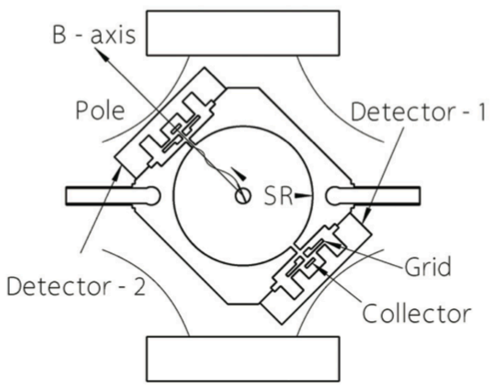


Electron current observed by the RFA with the MCP.

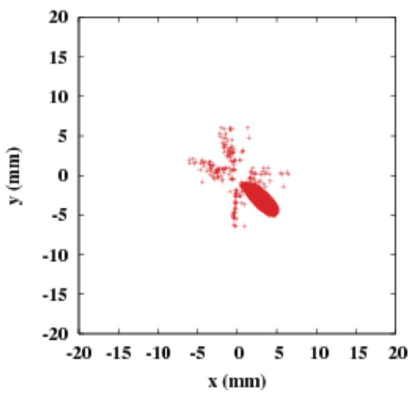


Example : Electron cloud density in coated vacuum chambers.

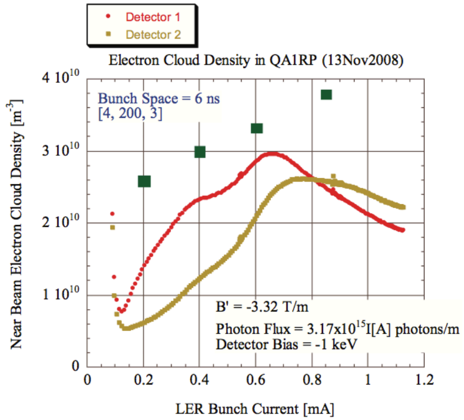
- The method was applied to the measurement of the electron cloud density in a quad and a solenoid.



RFA in a quadrupole.



The observed area in a quadruple magnetic field. Retarding bias is 1kV.



Electron cloud density in a quadrupole.

K. Kanazawa and H. Fukuma, IPAC'10.

PEP-II

- CBI by the electron cloud was studied by M. Furman and G. Lambertson at the design stage of PEP-II.
- According to their study, arc chambers were coated by TiN to reduce the secondary electrons.
- At the beginning of operation, non-linear pressure rise in straight sections accompanied by the beam size blowup was observed. Droop on the luminosity along the train were also observed.
- Solenoid winding and optimization of fill pattern with mini-gaps were main measures against the electron cloud.
- After completion of winding, the mini-gaps in by-2 pattern (i.e. 2 RF bucket spacing) were gradually reduced and eventually eliminated.

  Making a large tune space by tuning might help eliminate the mini-gaps .

  "We believed that reducing and eventually eliminating the mini-gaps helped the tune space of the LER ring. The tune footprint for each bunch should become more equal and that should give us an overall smaller footprint. "-Mike Sullivan, private communication.

- PEP-II finally achieve a straight by-2 pattern at 3.2A.

  "The electron cloud instability (ECI) in the LER for e+ needed ~30 gauss solenoids on the straight section stainless steel vacuum chambers. About 1.8 km of solenoid was wound. This proved very successful. The LER Arc chambers with ante-chambers, photon stops and TiN coatings worked well against ECI as designed. In the end, ECI did not degrade the peak luminosity " -J. T. Seeman, EPAC08.

Simulation of electron cloud buildup

- Code POSINST

  Sophisticated model of secondary electron emission

  Elliptical cross section of a chamber

  Space-charge forces from the electron cloud

- Average density

  Pumping Straight $\sim 4.1\times10^{11}$ electrons/m^3

  Bend $\sim 1.1\times 10^{12}$ electrons/m^3

  L_{PS}/L_B =7.15m/0.45m

  Pumping Straight makes major contribution.

- The growth time for the CBI is in the range 1–2 ms.

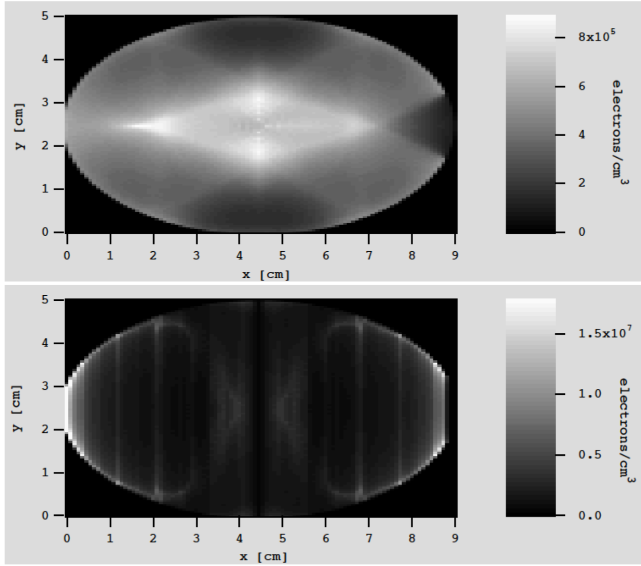
TiN coated ante-chamber (δ ~1.1)

I=2.14A, No. of bunches=1746

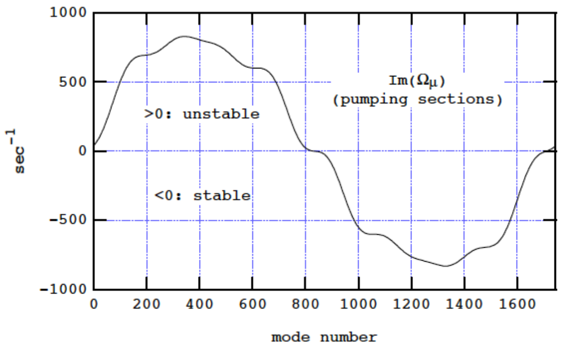
photon reflectivity R =1

Pumping straight

Bend



Growth rate of CBI (vertical)

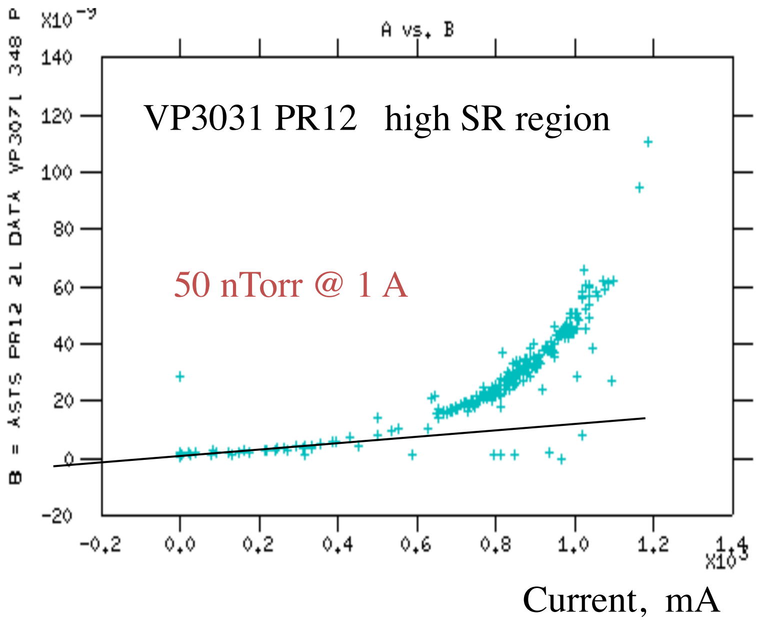


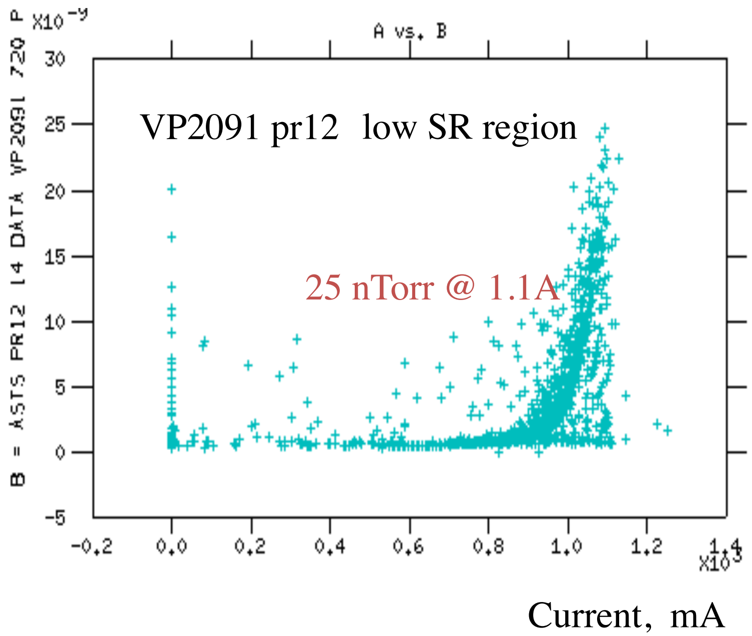
M. A. Furman and G. R. Lambertson, EPAC96, PAC97, MBI97(Tsukuba).

Nonlinear pressure rise (electron multipacting)

- Early in LER commissioning, a sharp nonlinear pressure increase with the beam current was observed at straight sections.
- LER straight sections except for IR had stainless steel round vacuum chambers.
- Increase of pump current came mostly from multipacting electrons entering the pump from the beam chamber.
- Electron multipacting has been detected in all drift sections of the LER straights, independent of the level of synchrotron radiation.

LER straight sections, Feb. 2000





A.Kulikov et al., ECLOUD'04.

Solenoid

- The last section in the straights was energized 16-Mar-01 (54 total).
- Solenoids in the LER arcs: the first - 23-Apr-01, the last - 9-Feb-02.

- Summer 2003 improvements:
  - -Additional 50 Gauss solenoids for all straight sections drift chambers.
  - -Double the field at pumping T-s, transitions and small drift chambers for all LER straight sections.
  - -Additional solenoids for “no sextupole” girders in all LER arcs.

Kulikov, ECLOUD04

PEP-II Solenoid Parameters

Parameter	LER Straights	LER Arcs
Chamber size (mm)	115 dia.	95x465
Wire gauge	#10	#10
Wire material	Cu	Cu
Wire package	Single cond.	Four cond. in parallel
Solenoid field (gauss/A)	2.4	0.57
Return wire	#10	#6
Power supply voltage (V)	30	200
Power supply current (A)	12	55
Max. Field (gauss)	29	31
Sol. length/pow. sup. (m)	10-15	80
Number of power supplies	54	12
Available drift length (m)	600	960
Soln. length installed (m)	600	960
Chamber material	SS	AL (TiN coating)

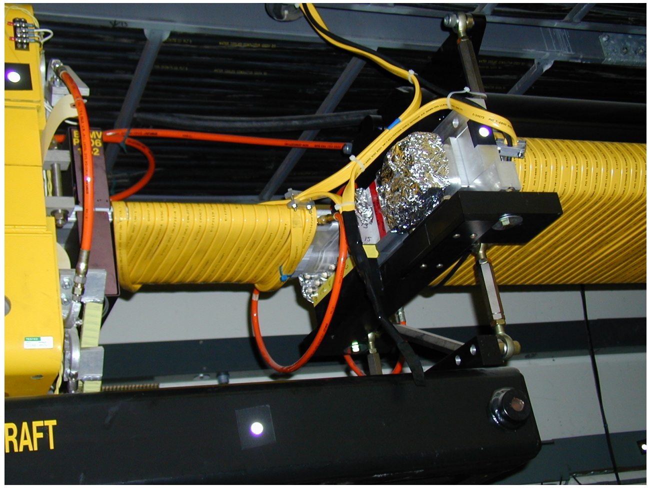
U. Wienands, A. Kulikov, ICFA WS BNL, Nov. 2003.

- Major solenoid windings finished for ECI reduction in 2003.

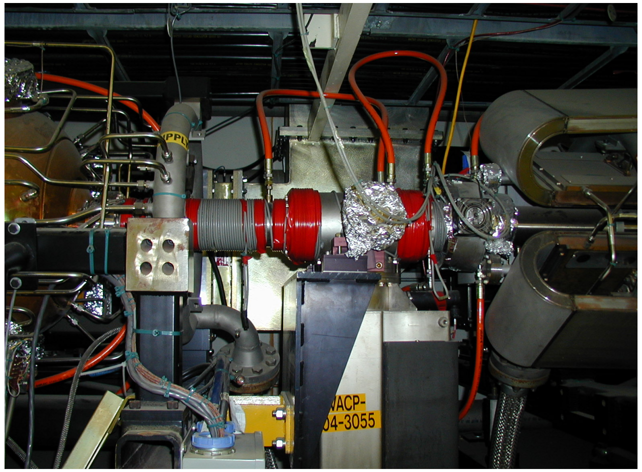
Arc solenoid

50 Gauss solenoid section

"No sextupole" chamber



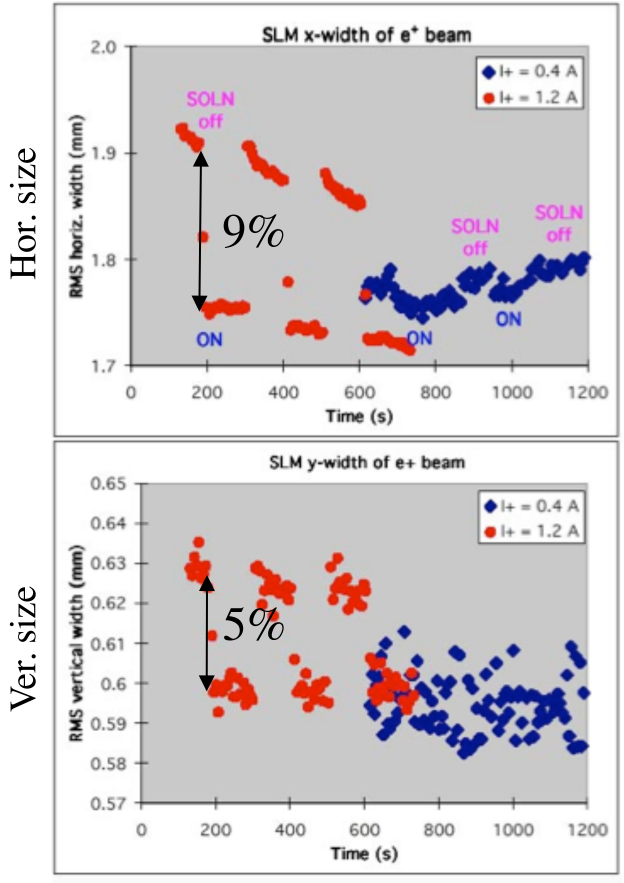
Pumping T



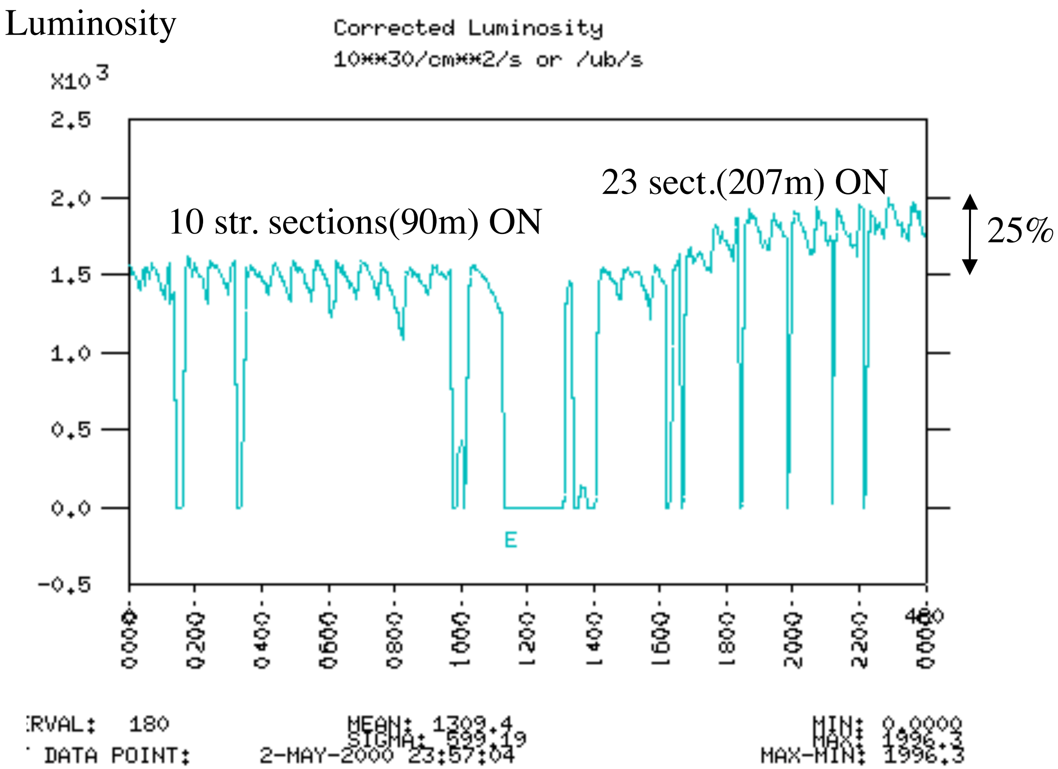
Small region might be important.

Effect of solenoids in straight sections

- It was understood that the straight sections of the ring were the dominant parts that had electron cloud effects.
- Luminosity increased by about 25% when 120m straight solenoid sections were energized.



300m straight solenoids on/off



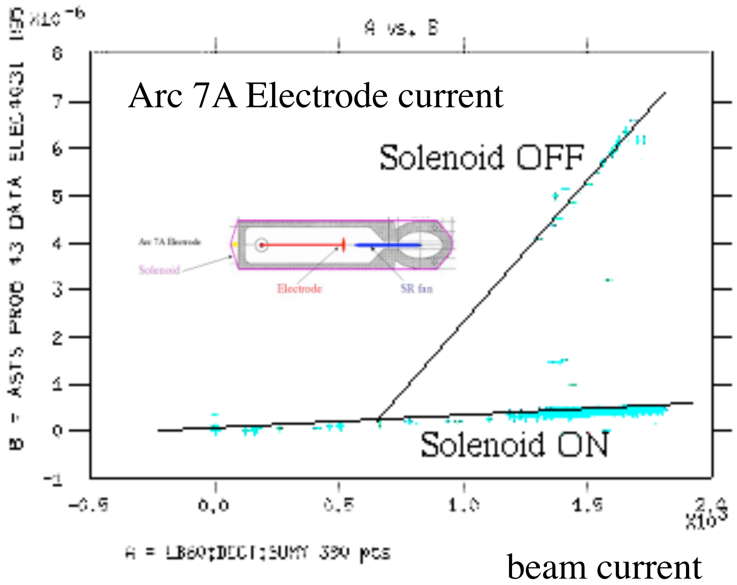
A.Kulikov et al., ECLOUD'04.

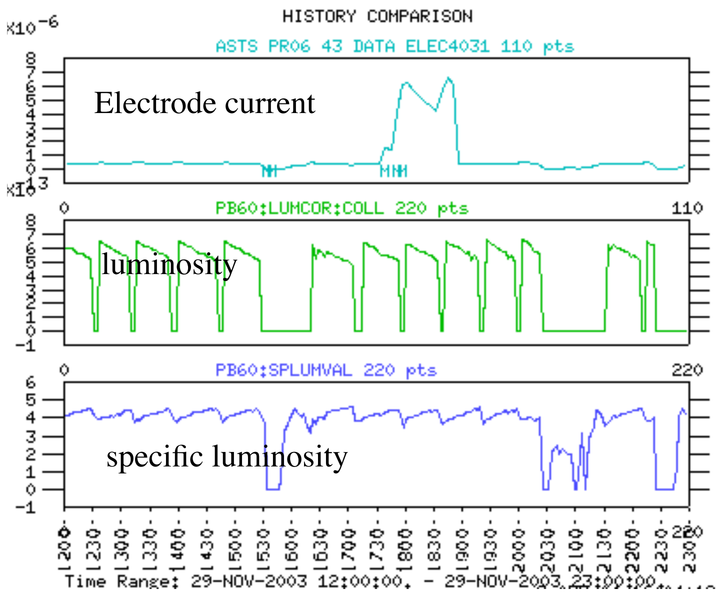
Effect of Arc solenoids

- Arc chambers were TiN coated ante-chambers.
  Were solenoids needed even if chambers were prepared to reduce electrons ?

  Arc 7A solenoid ON-OFF

Arc 7A solenoid: total length ~100 m (~5% of the ring circumference).





A.Kulikov et al., ECLOUD'04.

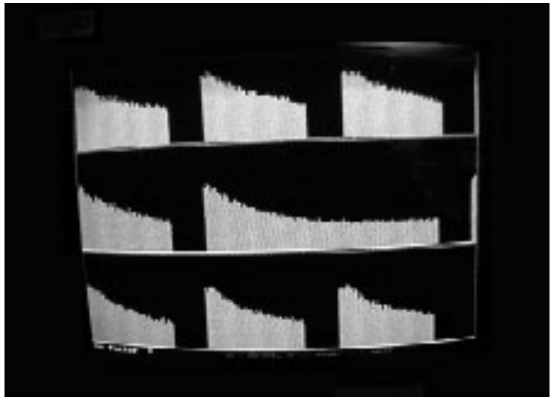
- Without solenoid field, electrode current increased linearly with a threshold in the TiN coated arc vacuum chamber. Was this an indication of multipacting ?
- Turning off solenoids over 100 m did not degrade the luminosity.

Fill pattern

- The bunch spacing was reduced and the mini-gaps were gradually reduced and finally eliminated to achieve a straight by-2 pattern.

Luminosity along a train

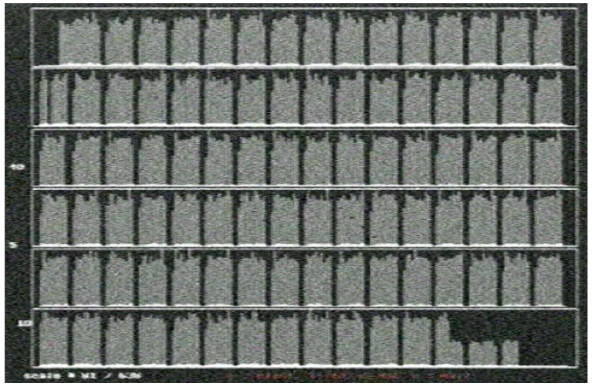
PAC2001



by 4 with additional big gaps.

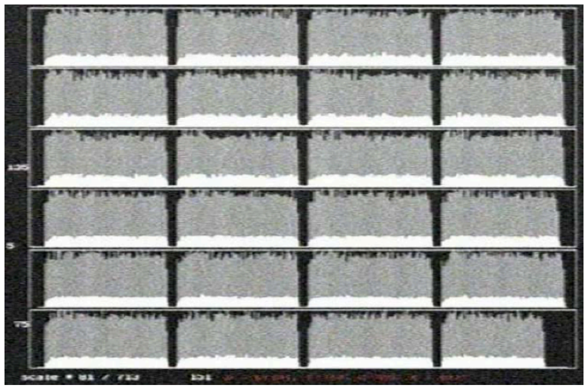
mini-gap

PAC2003

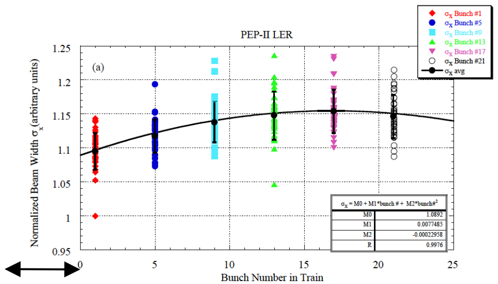


by 3 with mini-gaps of about 5 RF buckets.

EPAC2004

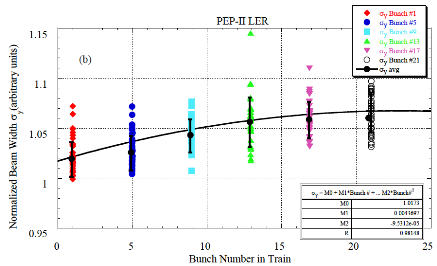


by 2 with mini-gaps of about 3 RF buckets.



mini-gap

horizontal



vertical

Effect of mini-gap on beam size.

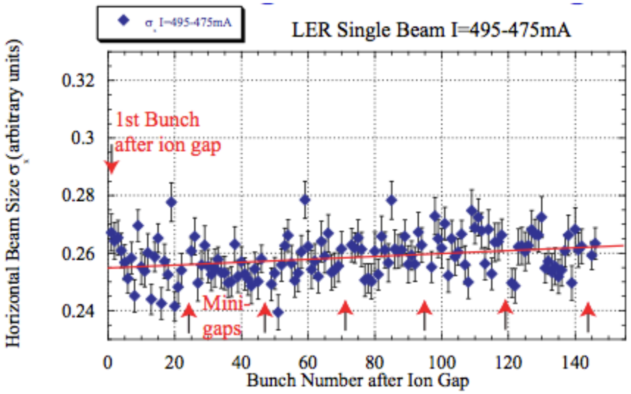
by 4 with 22 bunches/train.

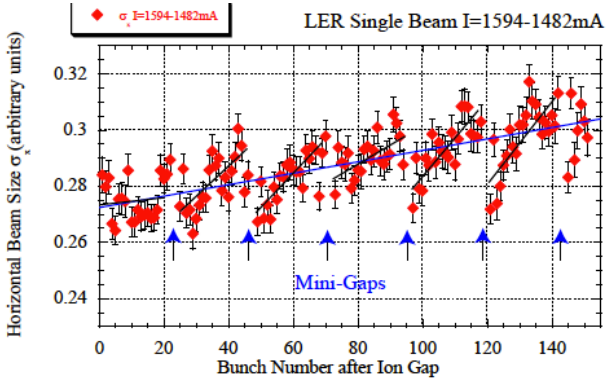
R. Holtzapple, Two-Stream Instabilities, 2001.

Measurement of single beam size blowup

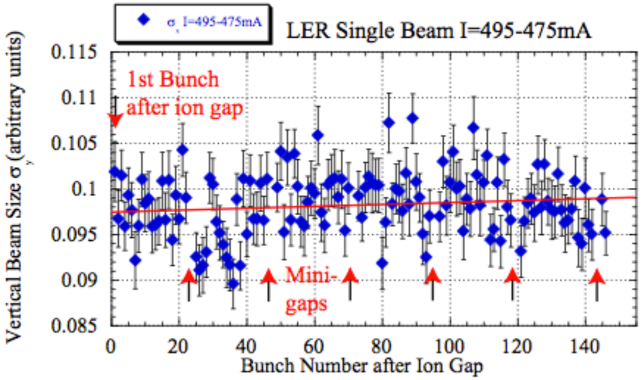
Ibunch~0.6mA | Ibunch~2.0mA

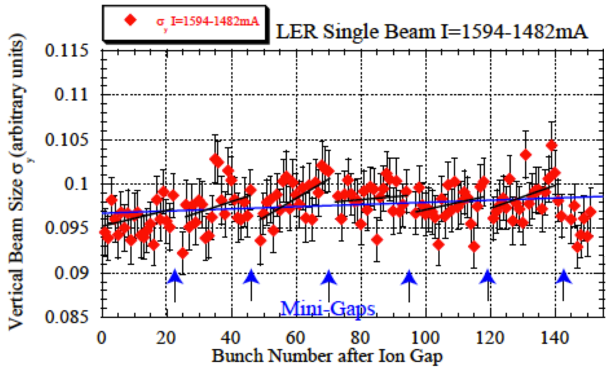
Horizontal





Vertical





F. J. Decker, ECLOUD'02.

by 4 with 22 bunches/train

Simulation

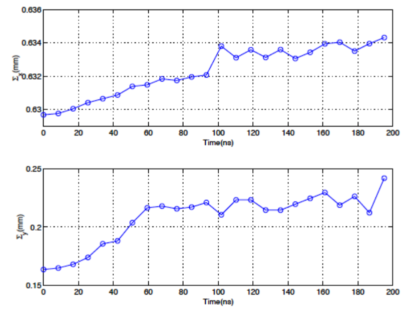


Figure 5: Beam size increase along a bunch train with 8.5ns bunch spacing.

Yunhai Cai, ECLOUD'02.

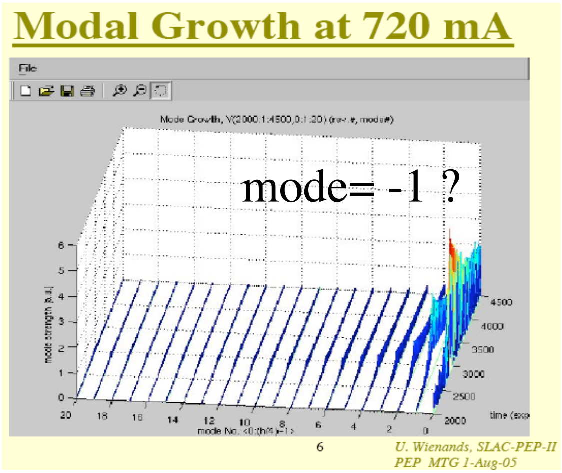
- Beam size growth was evident in the horizontal plane, while the blowup always occurred in the vertical plane in the simulation.

I think the reason of this discrepancy was not explained.

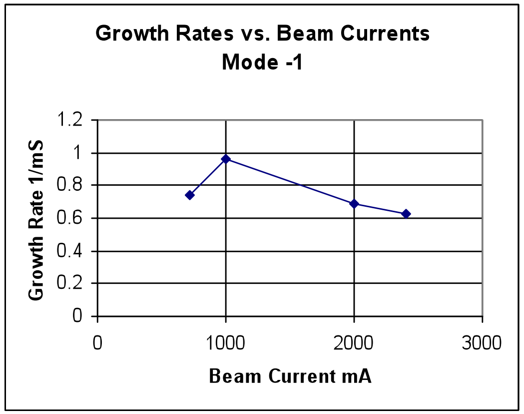
Coupled bunch instability (CBI)

- Reported data are few.
- Growth rate is consistent with a simulation.
- Mode spectrum does not agree with a simulation. Solenoid effect ?

CBI spectrum and growth rate (vertical)



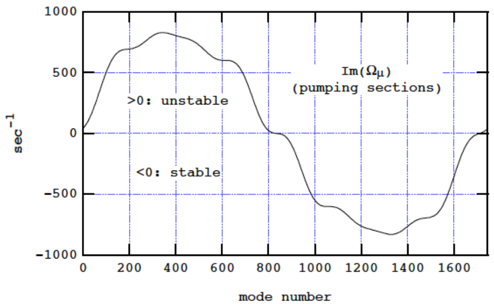
Fill pattern by-2 ?
Solenoid on ?



R. Akre et al., PEP-II MAC 2006.

Simulation

Mode of CBI (vertical)



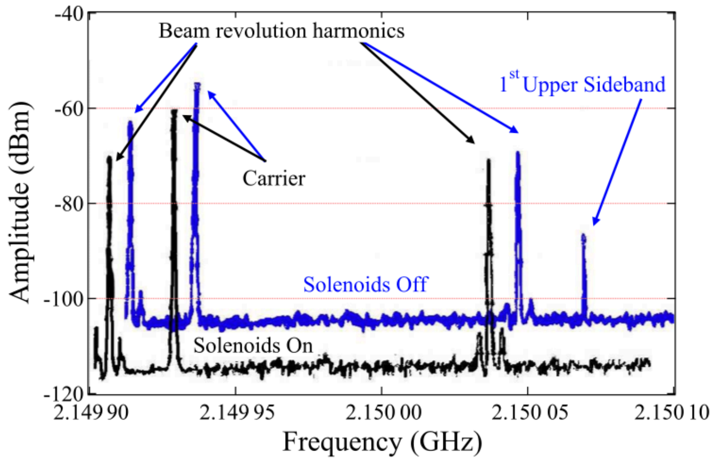
The growth time : 1–2 ms
for I=2.14A.

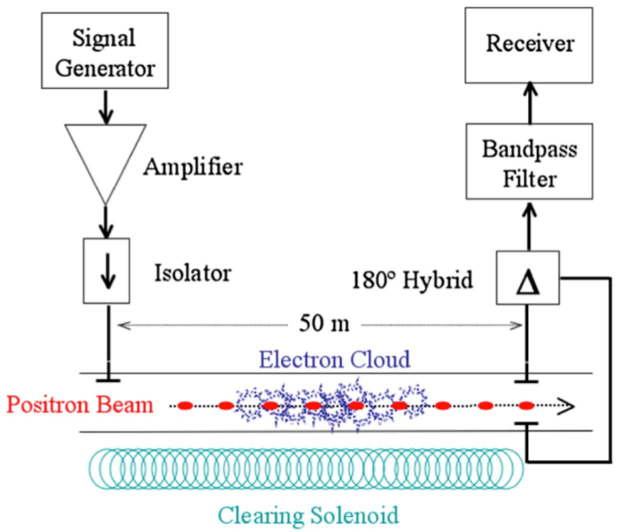
Microwave transmission measurement

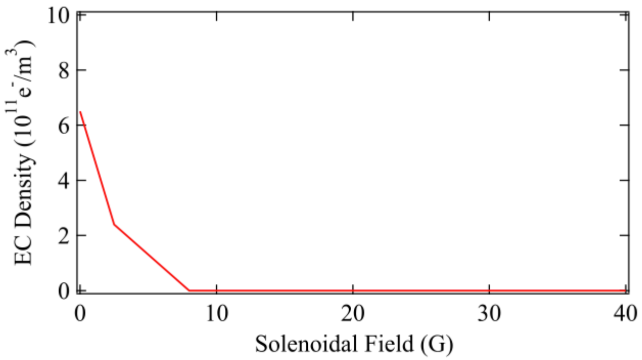
- The electron cloud (i.e. electron plasma) affects the propagation of the EM wave. The resulting phase shift is proportional to the electron density.
- The train gap modulates the electron density at the revolution frequency. The modulation appears as sidebands of the EM carrier.

phase modulation

$$s(t) = A\cos[\omega_{car} t + \Delta\varphi(t)]$$







S. De Santis et al.,PRL 100(2008), J. Byrd et al., BIW08.

*The method was initially developed by F. Caspers, T. Kroyer et al. at CERN (T. Kroyer et al., ECLOUD04, PAC2005).

SuperB

Details will be given by T. Demma's talk.

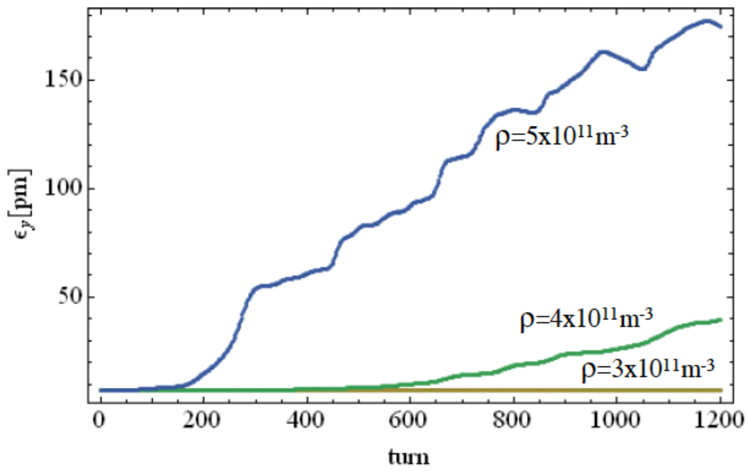
Single bunch instability

- Threshold of the single bunch instability was estimated by the strong-strong code CMAD (M. Pivi).

Instability threshold $\rho_e = 4 \times 10^{11} m^{-3}$

Table 1: Input parameters for CMAD simulations.

Parameter	Unit	Value
Beam energy E	GeV	6.7
circumference L	m	1370
bunch population Nb	-	$5.74 \cdot 10^{10}$
bunch length σ_z	mm	5
hor. emittance σ_x	nm	1.6
vert. emittance σ_y	pm	4
hor./vert. bet. tune Qx/Qy	-	40.57/17.59
synchrotron tune Qz	-	0.01
hor./vert. av. beta function	m	20/20
momentum compaction α	-	$4.04 \cdot 10^{-4}$



T. Demma, IPAC'10.

Electron cloud buildup

- The SuperB typically do not have long field free regions. For the most part of the ring the beam pipe is surrounded by magnets.

  Fractions that the dipoles cover the ring = 0.5

- Electron density in arc bend regions was evaluated by ECLOUD.

- The number of primary electrons was adjusted in order to take into account the reduction of electron yield by the ante-chamber.

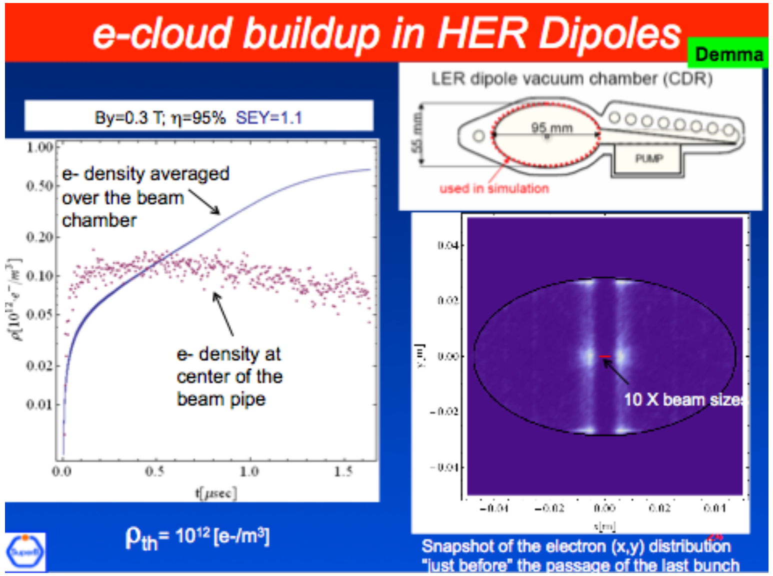
quantum efficiency

Number of primary electrons/m/e+

$$e^-/e^+/m = \frac{dn_\gamma}{ds} Y(1-\eta)$$

average number of emitted photons/m/e+

the percentage of photons absorbed by the antechambers.



M. Biagini,
Epiphany 2012 Conference
Krakow, January 9-11, 2012.

Table 2: Electron cloud densities from ECLOUD simulations.

SEY	η	$rho_e[10^{12}e^-/m^3]$
1.1	95%	0.4
1.1	99%	0.09
1.2	95%	0.9
1.2	99%	0.2
1.3	95%	8.0
1.3	99%	4.0

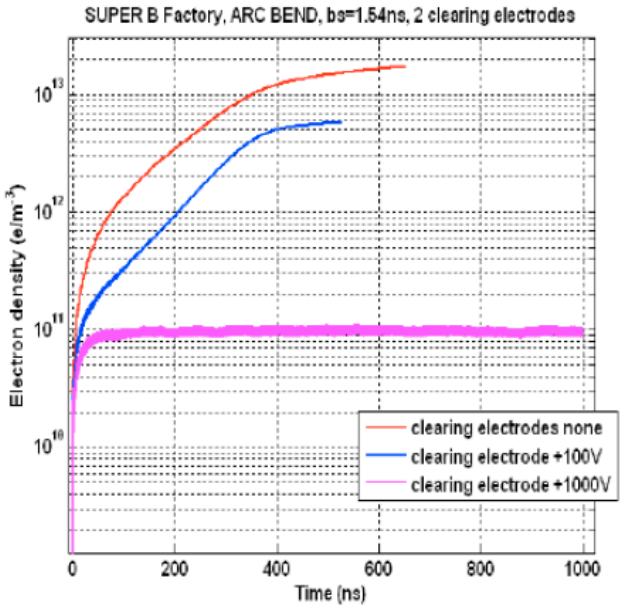
cloud density close to the instability threshold.

By = 0.5T T. Demma, IPAC'10.

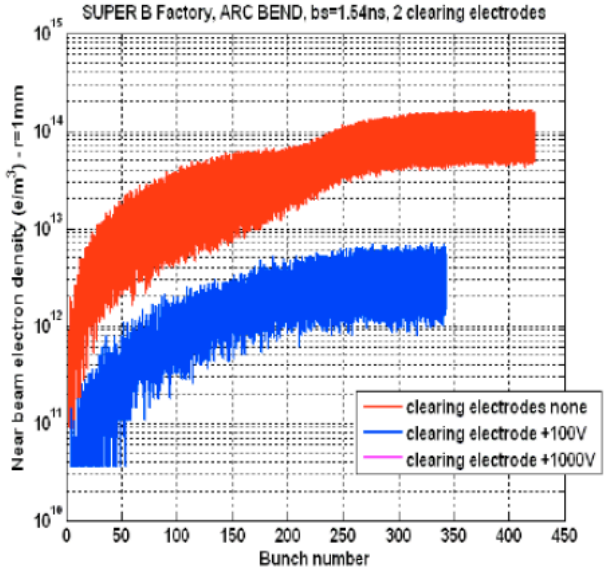
Effect of clearing electrode

- A clearing electrode is considered as one of mitigation methods.
- A simulation was done by POSINST(?).

2×10^{10} particles/bunch, bunch spacing of 1.5 ns



Average density



Central density

- A bias voltage of 1 kV is sufficient to suppress electron cloud formation.

Super*B* Progress Reports, 2010.

SuperKEKB

Single bunch instability

- Threshold electron density estimated by a stability condition is $2.7\text{x}10^{11}$ m^{-3}.

$$\rho_{e,th} = \frac{2\gamma\nu_s\omega_e\sigma_z/c}{\sqrt{3}KQr_0\beta L}$$

$$Q = \min(Q_{nl}, \omega_e\sigma_z/c)$$

$$\omega_e = \sqrt{\frac{\lambda_p r_e c^2}{\sigma_z(\sigma_x+\sigma_y)}}$$

Parameters of Super KEKB LER

Circumference (m)	3016
Energy (GeV)	4.0
Beam current (A)	3.6
Number of e^+ /bunch (10^{10})	9
Emittance H/V (nm)	3.2/0.01
Momentum compaction (10^{-4})	3.5
Bunch length (mm)	6
RMS energy spread (10^{-3})	0.8
Synchrotron tune	0.026
Damping time (ms)	43
Bunch separation (ns)	4

- $Q_{\rm nl}$ depends on the nonlinear interaction
- K characterizes cloud size effect and pinching
- Use $K=\omega_e\sigma_z/c$ *and* $Q_{\rm nl}=7$ for analytical estimation

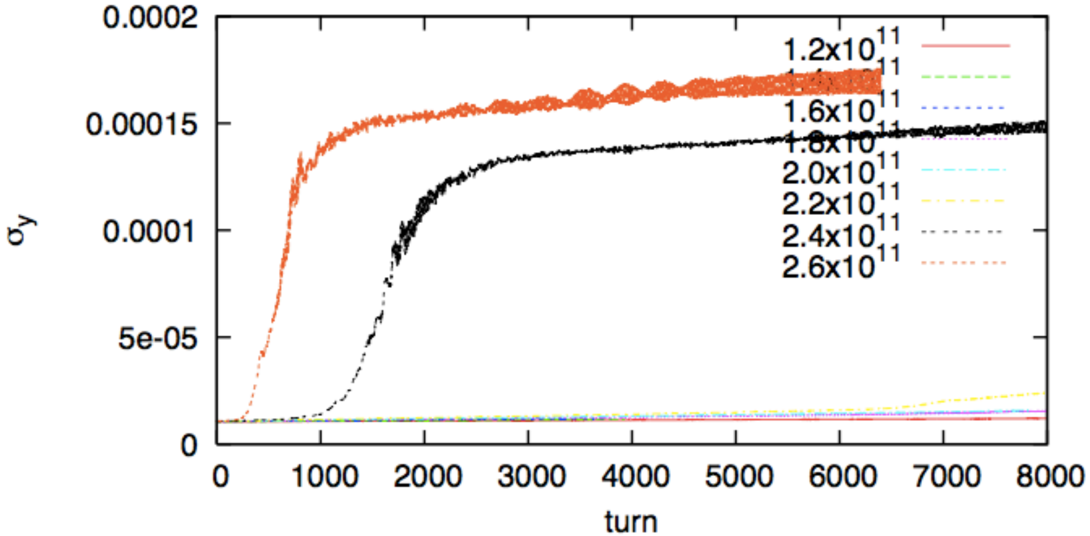
Analytic estimates

Electron frequency $\omega_e/2\pi$ (GHz)	150
Phase angle $\omega_e\sigma_z/c$	18.8
Threshold density (10^{12}m^{-3})	0.27

K. Ohmi, a seminar at Fermilab, June 14, 2011.

•Analytic estimate is consistent with a simulation.

Simulation



K. Ohmi, a seminar at Fermilab, June 14, 2011.

Threshold electron density

Simulation ρ_{th}=2.2x10^{11} m^{-3}

Analytic ρ_{th}=2.7x10^{11} m^{-3}

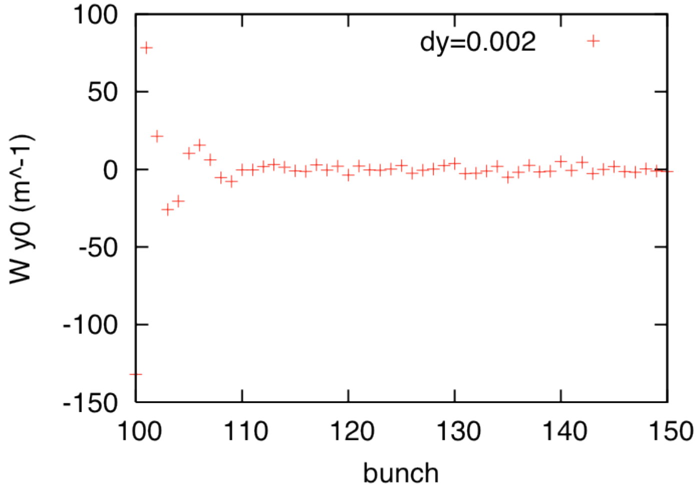
Coupled bunch bunch instability

•Growth time was estimated when the electron density was a threshold of the single bunch instability. The result was 50 turns. The instability could be damped by the bunch feedback system.

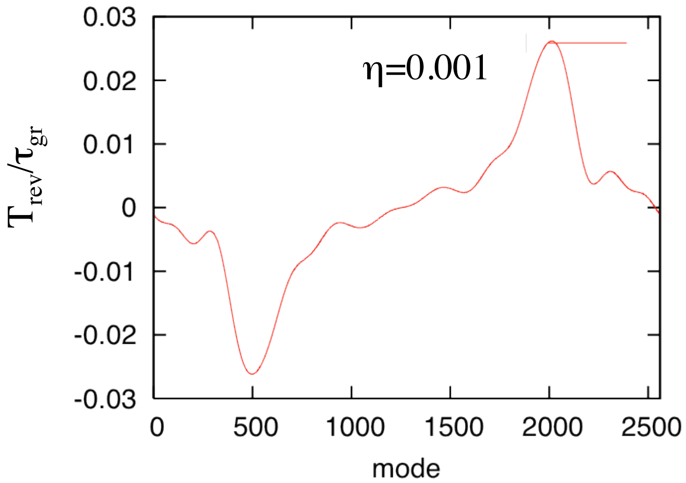
•Therefore single bunch and the coupled bunch instability will be suppressed if the electron density is less than 2.2×10^{11} m^{-3}.

Target electron density near beam against EC instabilities < 1×10^{11} m^{-3}

Wake



Growth rate



Y. Susaki and K. Ohmi, IPAC10.

Measures to be taken against electron cloud effect

- Estimated electron density near beam is 5 x 10^{12} m^{-3} without any cures.
- Main contribution comes from drift space.

Expected electron density without any cures
(Estimated from experiments so far at KEKB. A circular Cu pipe (ϕ 94mm), 4 ns spacing, 1 mA/bunch, No solenoid.)

Sections	L [m]	L [%]	n_e [e^-/m^3]	n_ex L [%]
Total	3016	100	Ave.5E12	100
Drift space (arc)	1629 m	54	8E12	78
Steering mag.	316 m	10	8E12	15
Bending mag.	519 m	17	1E12	3.1
Wiggler mag.	154 m	5	4E12	3.6
Q & SX mag.	254 m	9	4E10	0.063
RF section	124 m	4	1E11	0.072
IR section	20 m	0.7	5E11	0.063

Y. Suetsugu, ARC2010

Comparison among mitigation techniques

- Various measures were investigated and developed at KEK.

Comparison among mitigation techniques

– Based on the experiments so far. Standard = Cu (circular pipe)

Materials, methods	**Relative effect**	**Notes**
Al	~20	Coatings are indispensable.
Cu (Circular pipe)	1	
Solenoid [Drift space]	~1/50	~50 G, considering gaps (<1/1000 if uniform)
Antechamber	~1/5	<1/100 for photoelectrons
Cu (Al) +TiN coating	~3/5	Relatively high gas desorption
Groove (β~20°) [in B]	~1/10	Top and bottom
Electrode [in B]	~1/100	Most effective against EC. Expensive?

Y. Suetsugu, ARC2010

Measures against electron cloud effect

- Following measures are to be applied at SuperKEKB.

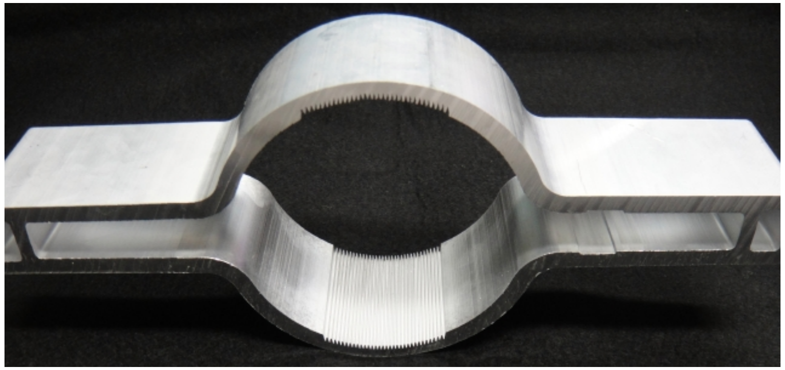
Sections	L [m]	L [%]	Countermeasure	Material	n_e [e^-/m^3]	n_exL [%]
Total	3016	100			3E10	100
Drift space (arc)	1629 m	54	TiN coating + Solenoid	Al (arc)	3E10	68
Steering mag.	316 m	10	TiN coating + Solenoid	Al	3E10	13
Bending mag.	519 m	17	TiN coating + Grooved surface	Al	2E10	14
Wiggler mag.	154 m	5	Clearing Electrode	Cu	4E9	1.5
Q & SX mag.	254 m	9	TiN coating	Al (arc)	8E9	2.8
RF section	124 m	4	(TiN coating +) Solenoid	Cu		
IR section	20 m	0.7	(TiN coating +) Solenoid	Cu or ?		

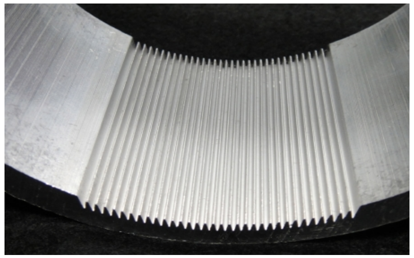
Y. Suetsugu, ARC2011

Electron density near beam less than 1.0×10^{11} e^-/m^3 is expected.

Vacuum components concerning the electron cloud mitigation in SuperKEKB

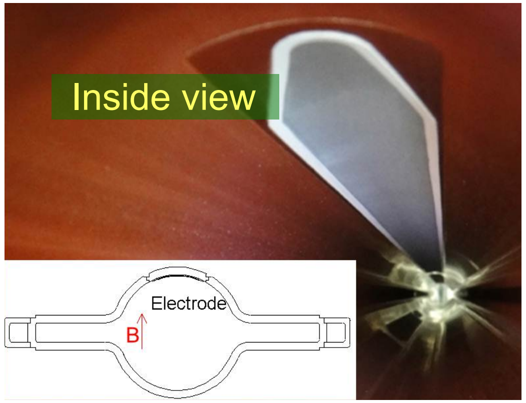
Aluminum beam pipe with grooves





Details will be given by K. Shibata's talk.

Clearing electrode



Y. Suetsugu, ARC2012

Damping ring (DR)

Original parameters	
Circumference (m)	135.5
Energy (GeV)	1.0
Emittance (m)	$1.26\ 10^{-8}$
Coupling (%)	5
Tune H/V/Z	12.24/4.265/0.004
Beta H/V (m)	2.5/6.5
Bunch length (mm)	5.0
# of bunch	4
Bunch separation (ns)	98
# of positron/bunch	$5\ 10^{10}$
Pipe radius (mm)	16
Bend (T)	1.27
Quad (T/m)	7.78
Solenoid (G)	45

SEY	
δmax	2.0/1.0
Emax (eV)	250
Reflection	0.3

- A simulation showed that the threshold of the single bunch instability at DR was near the estimated electron density without any cares.

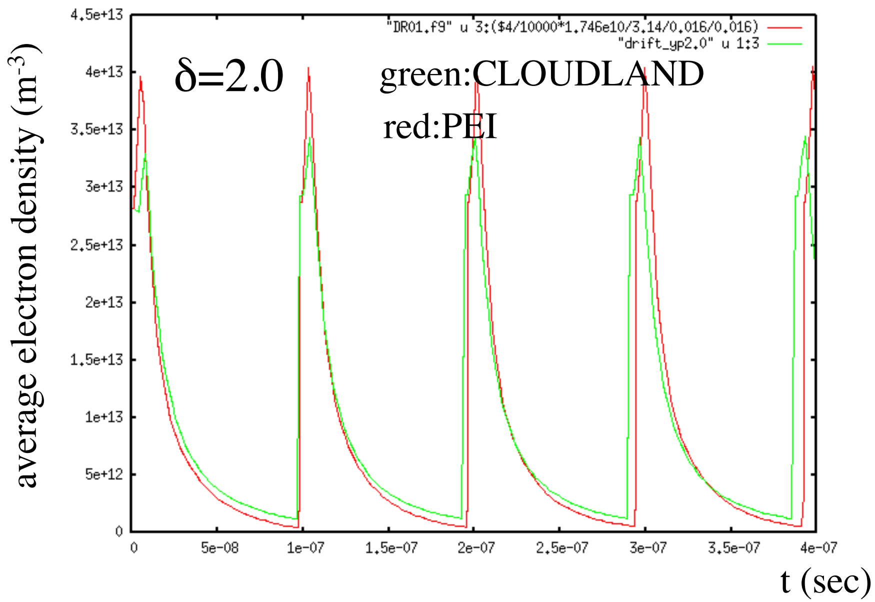
Electron density by simulation

$$\rho_e \cdot L = 1.35\ 10^{14}\, m^{-2}$$

Threshold of the single bunch instability (analytic estimation)

$$\rho_{e,th} \cdot L = 1.57\ 10^{14}\, m^{-2}$$

Cloud buildup (drift space)



• In order to keep enough margin against the electro cloud instability, TiN coating was considered as well as increasing the synchrotron tune ν_s from 0.004 to 0.015.

(Increase of ν_s is necessary for mitigating CSR instability in any case.)

Cloud density: ρ

		Drift	Bend	Q+SX	
Length		73.2	36	26.8	m
δ_{MAX}=2	SR=1	1.3	0.6	0.5	$\times10^{12}$m^{-3}
δ_{MAX}=1	SR=1	0.4	0.5	0.15	$\times10^{12}$m^{-3}
	SR=0.1	0.15	0.11	0.03	$\times10^{12}$m^{-3}

(SR=0.1 means primary electrons are reduced to 1/10 emulating the ante-chamber.)

Integrated electron density for δ_{max}=1 and SR=1 : 0.51×10^{14} m^{-2}.

$\rho_{th}=1.1 \times 10^{13}$ m^{-3} in optics with raised $\nu_{s.}$ (Energy was also changed to 1.1GeV.)

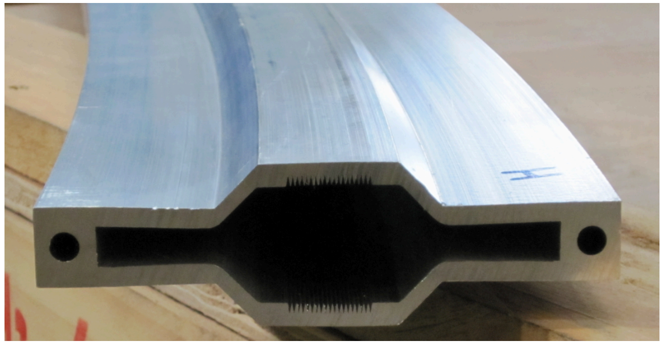
➡ Threshold $\rho_{th} L = 15.0 \times 10^{14}$ m^{-2}

The electron density is well below the threshold.

Measures to be taken against the electron cloud at the damping ring

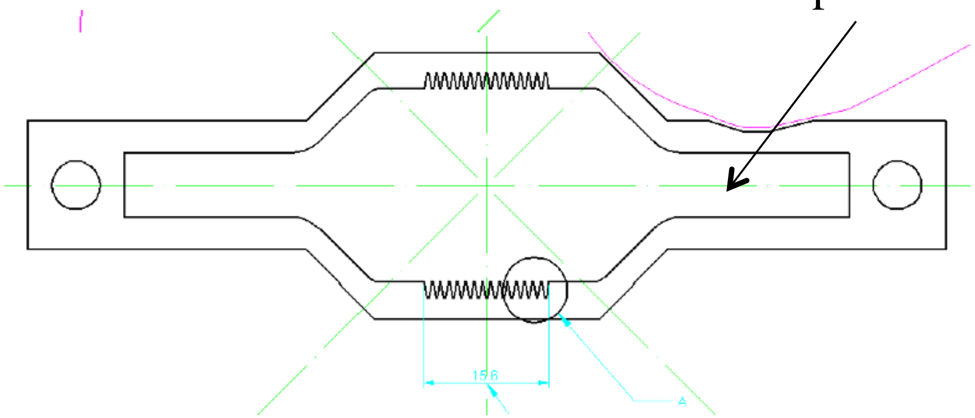
- Al chamber with TiN coating
- Groove on the wall of bend chamber
- Solenoid at straight sections
- Ante-chamber

  Ante-chamber is needed for installing photon masks anyway.



A prototype of a vacuum chamber with groove

A photon mask is placed here.



Comment and Acknowledgments

- I apologize that I do not talk SEY measurements, studies for ILC at PEP-II such as cyclotron resonance and R&D of vacuum components at DAFNE, KEK and SLAC, and so on due to lack of time.

- I thank T. Demma, K. Ohmi, M. Pivi and L. Wang for informing me several materials which I referred in this talk.

- I especially thank M. Sullivan for providing me information of PEP-II operation which I could not clearly understand from available materials.