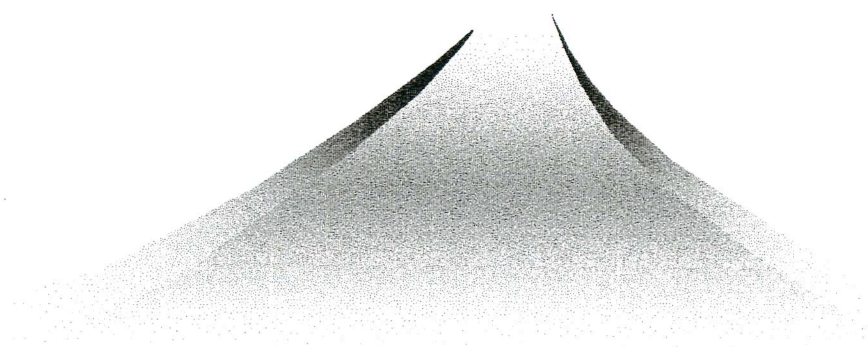
Beam-Beam Effect and Luminosity Issues

Y. Funakoshi (KEK)



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2. History of luminosity upgrade
3. Methods of luminosity tuning
4. Beam–beam simulations
5. Recent machine study
6. Strategy for higher luminosity

Machine parameters of the KEKB

(At the maximum peak luminosity recorded on Feb. 19 /2001)

	LER	HER	
Horizontal emittance	18	24	nm
β_x^* / β_y^*	0.59/0.007 (0.33/0.01)	0.63/0.007 (0.33/0.01)	m
Beam current	677	559	mA
# of bunches/ring	1153 (2700)		
Bunch curret	0.596	0.484	mA
# of trains	1	1	
# of bunches/train	1153	1153	
Bunch spacing	8 (2)	8 (2)	nsec
Bunch length (calc)	5.5@6.0	5.7@11.0	mm@MV
ξ_x / ξ_y	0.052/0.027 (0.039/0.052)	0.038/0.023 (0.039/0.052)	
ν_x / ν_y	45.513/43.574 (45.52/44.08)	44.519/41.617 (44.52/42.08)	
Lifetime	120@677	274@559	min@mA
Luminosity from Belle CsI	$24.7 * 10^{32}$ $(1 * 10^{34})$		/cm^2/sec

Beam–beam performance

- **Beam–Beam Limit**
  - 1152 bunches (at max peak luminosity)
    - ξ_x/ξ_y = 0.038/0.023 (HER)
    - ξ_x/ξ_y = 0.052/0.027 (LER)
  - 188 bunches (at max peak luminosity)
    - ξ_x/ξ_y = 0.030/0.032 (HER)
    - ξ_x/ξ_y = 0.030/0.025 (LER)
- **Specific luminosity**
  - Strong current dependence
  - Beam blowup even at relatively low beam current

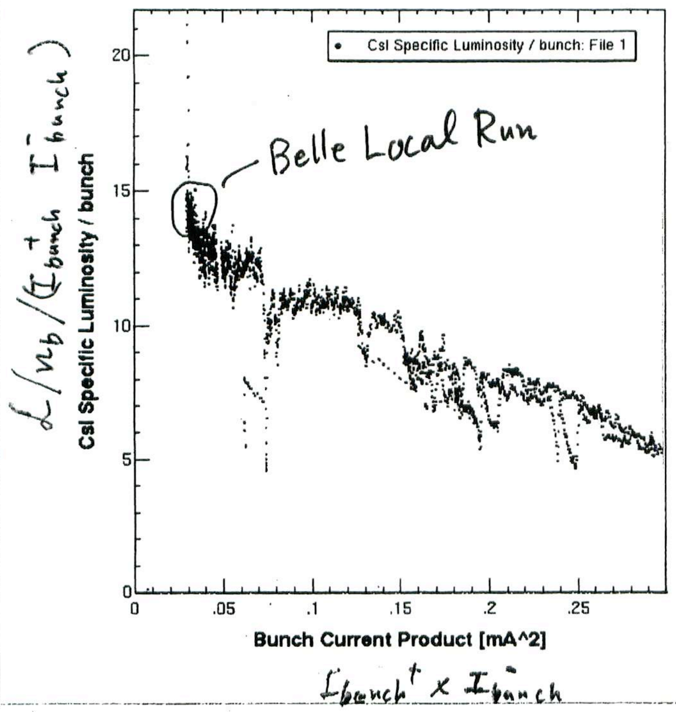
Beam-Beam Log Viewer Ver. 3.3

File Edit Window 02/20/2001 07:49:48 Help

Luminosity History | IBump Display | Beam-Beam Parameters | Correlation Plot

Plot Region

File 1 Multiple files



Plot control

Read File 1

Read Default File 1

From: Lum2001_2_19_23_50_57.dat

To: Lum2001_2_20_6_8_41.dat

Read Multiple Files 1

Read File 2

Auto Update Start (every 30 sec)

Auto Update Stop

Auto Update OFF

Def X

X Axis

c[[22]]: CsI Specific Luminosity / bunch

Y1 Axis

unused

Y2 Axis

Def X	c[[6]]*c[[7]]/c[[38]]^2
Def Y1	Sqrt[c[[10]]^2+c[[11]]^2]
Def Y2	Sqrt[c[[18]]^2+c[[19]]^2]
Cut Y1	
Cut Y2	

Plot 1

Plot 2

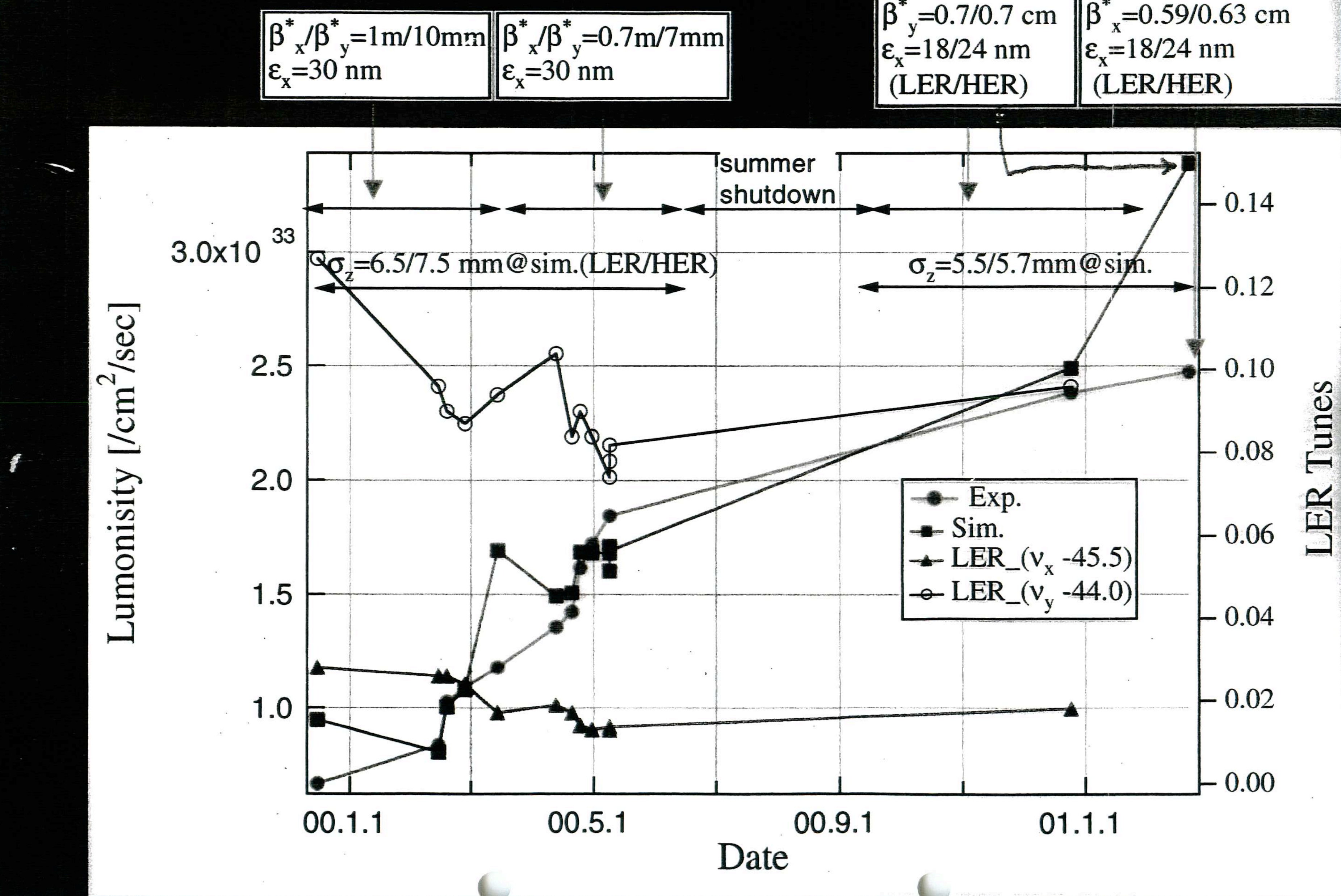
Plot 1&2

Change Label

History of Luminosity Upgrade

- Tune survey
- Squeezing beta functions at the IP
- Optics corrections
- Luminosity tuning
- Increase of beam currents

Luminosity History of KEKB (Exp. & Sim.)



Tune Survey

- Relatively extensive tune survey (mid. 1999)
  - A region around the design tune gave better luminosity.
  - The design tune did not give the best result.
- Summer of 2000 (after accumulation of continuous luminosity tuning)
  - The design tune gave the best luminosity.
- Now
  - A new working point gives slightly better luminosity.

Luminosity Tuning

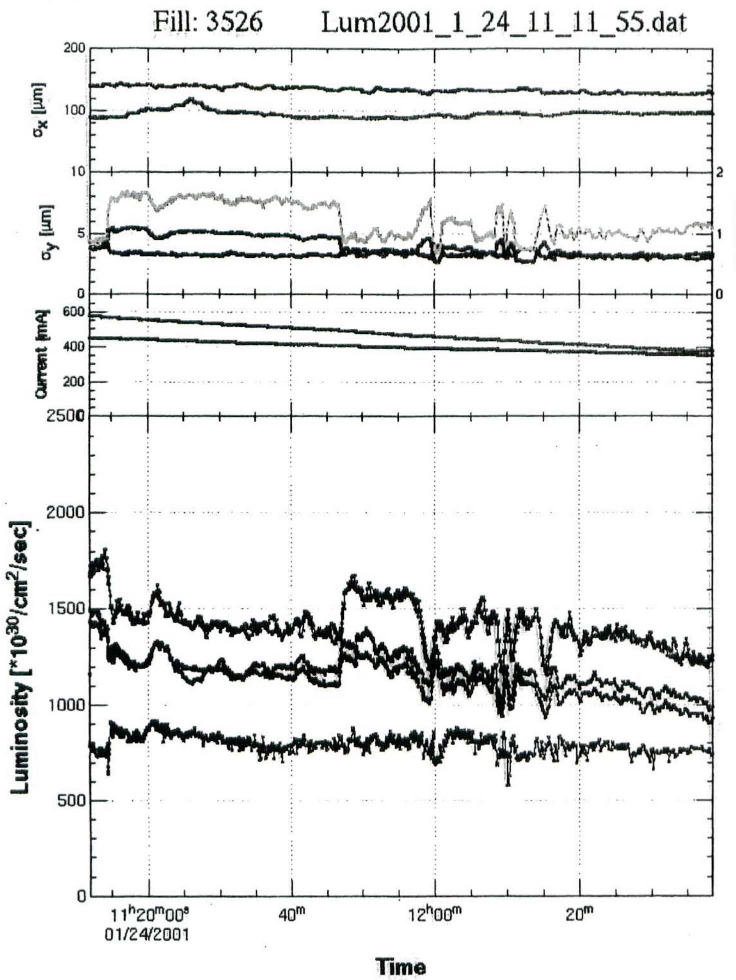
- Method of tuning
  - Feedback
  - Trial and error (during physics run)
- Tuning items
  - IP Orbit Offset (Orbit feedback)
  - Crossing Angle (Orbit feedback)
  - Waist
  - IP x–y Coupling
  - IP Dispersion
  - Beam size ratio (Size feedback)
  - Other parameters related to the energy transparency

Beam size feedback

- Vertical beam size ratio of the two beams is an important tuning parameter.
- LER beam is apt to be blown up in the KEKB.
- The luminosity can be usually increased by intentionally enlarging the HER (vertical) beam size.
- The beam size of HER is controlled by making an orbit bump in HER with a leakage vertical dispersion around the ring.

Beam Parameters Summary | Beam Beam Scan | Luminosity History | Tune History

Luminosity History



Luminosity

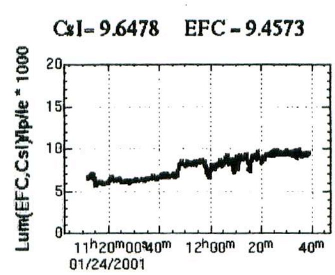
σ_x^* [m] (for Calculation)	1.22E-4
σ_x^* [μm] (LER)	95.5061
σ_x^* [μm] (HER)	128.6659
σ_y^* [μm] (LER)	3.2974
σ_y^* [μm] (HER)	2.9612
Number of Bunches	1152
β_x^* [m]	.7
β_y^* [m]	.007
Luminosity (Acc with σ_x(design))	9.07846E32
Luminosity (Acc with σ_x(meas))	9.71214E32
Luminosity (CsI)	1.22732E33
Luminosity (EFC)	1.24197E33

Start | Stop | Read | Drop1/2 | Ref.

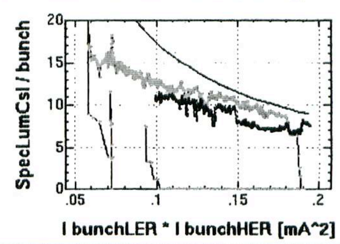
Specific Luminosity

Spec. Lum | LER scan | HER scan

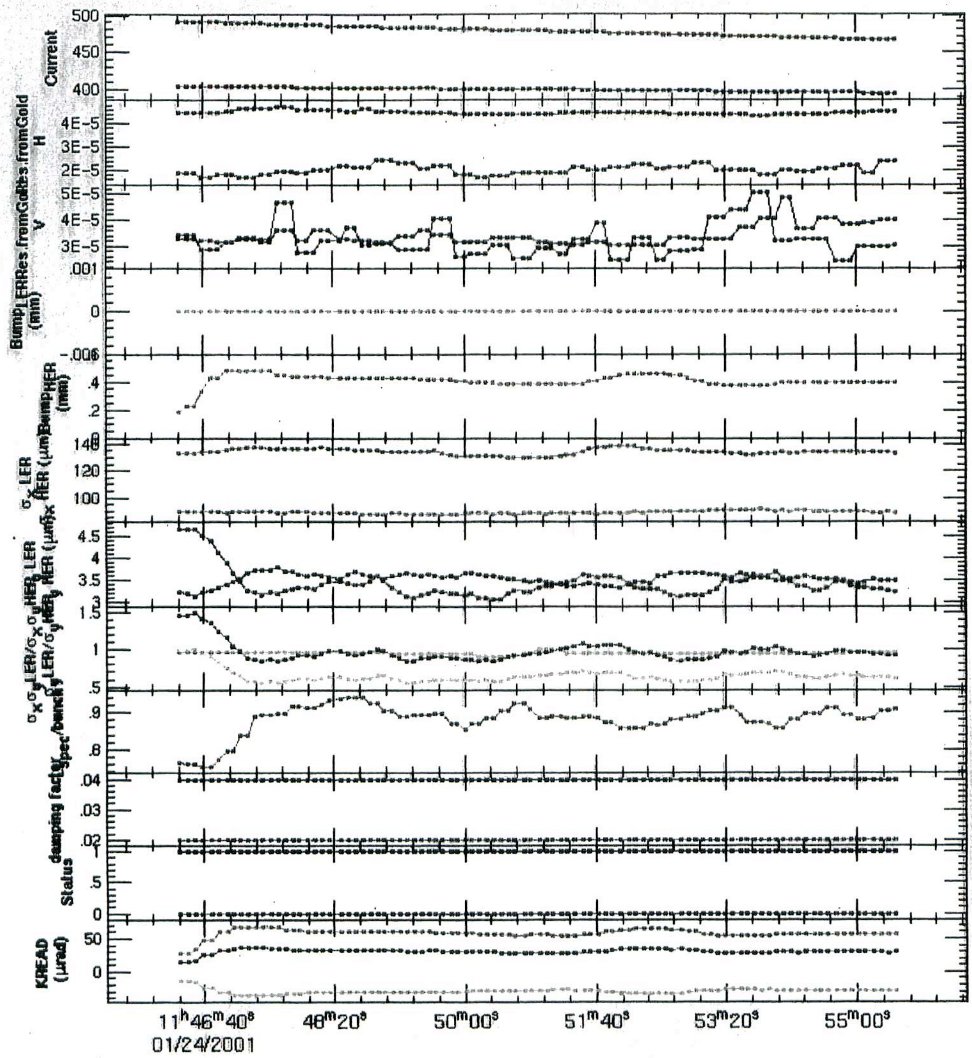
Start L | Stop L | Start H | Stop H | Label L | Label H



Reference: Lum2000_5_9_8_21_34.dat



FBH10.9_2001_1_24_11_46_11.dat



Beam size feedback (cont.)

- The beam size feedback is used to keep the size ratio constant (->target value).
- Target values of the feedback are determined by trial and error so that the luminosity is maximized.
- Optimum target values are usually dependent on the beam current.

Energy transparency

- Beam current ratio
  - The ratio is not inverse of the beam energy ratio.
  - The LER beam is weaker in the usual operation.
- Beam size ratio
  - We need a beam size feedback system.
- Tunes
  - not exactly equal for the two beams.
  - determined by trial and error

Energy transparency (cont.)

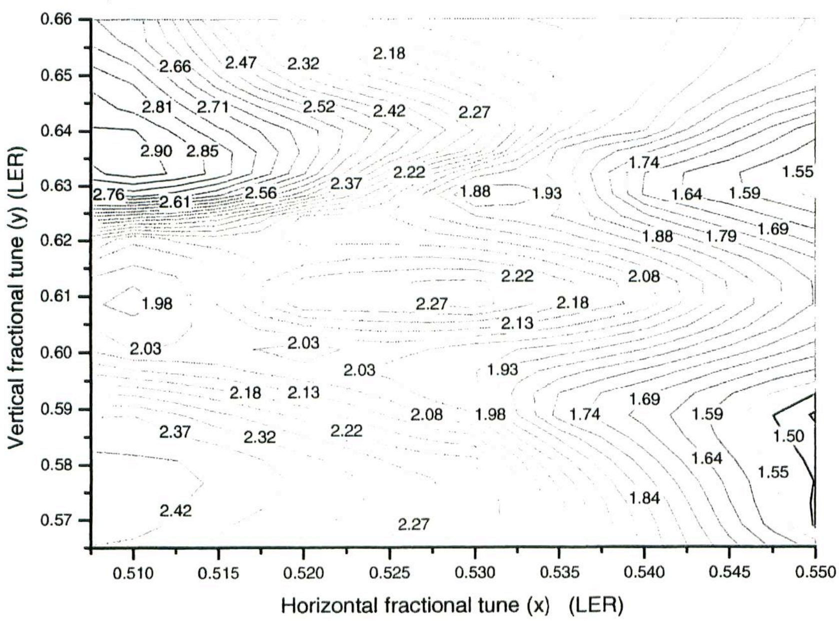
- Emittance and beta functions at IP
  - Not the same values for the two beams
  - Optimized by trial and error
- Radiation damping time
  - equalized with wiggler magnets in LER
  - We do not have much data on their effectiveness.

Beam-beam simulations

- Strong-strong simulation code
  - Coded by K. Ohmi
  - Simulation workers:
    - K. Ohmi, M. Tawada, Y. Wu (IHEP)
- Simulations
  - Tune survey
  - Bunch length dependence
  - Current dependence
  - Effect of machine errors

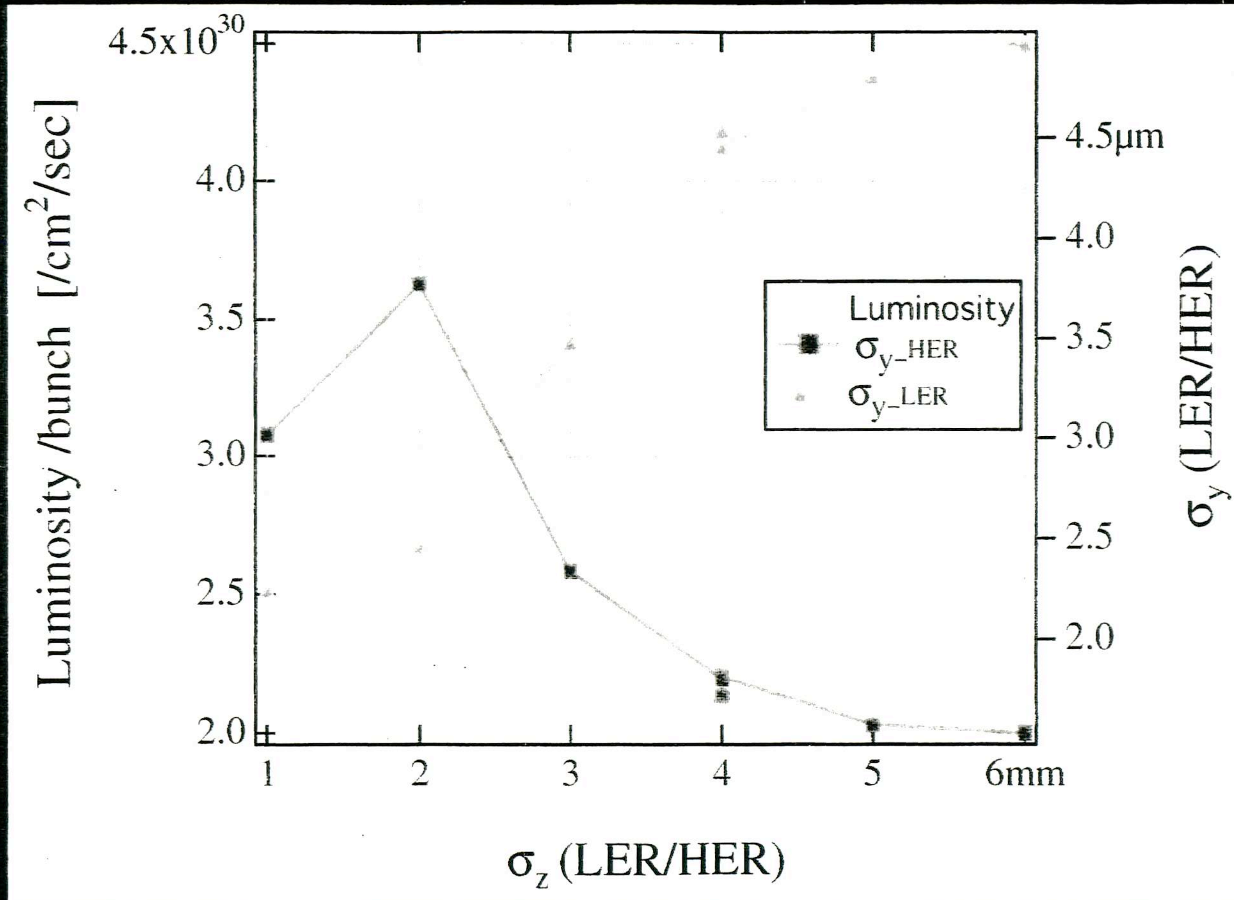
Simulation result for the new parameters

	LER	HER	
Horizontal emittance	**18**	**24**	**nm**
ßx*/ ßy*	**63/0.7**	**80/0.7**	**cm**
Emittance ratio $\epsilon x/\epsilon y$	**2**	**1**	**%**
Beam current	**760**	**580**	**mA**
No. of bunches/ring	**1152**	**1152**	
Bunch length	**5.5@6.0**	**5.7@11**	**mm@MV**

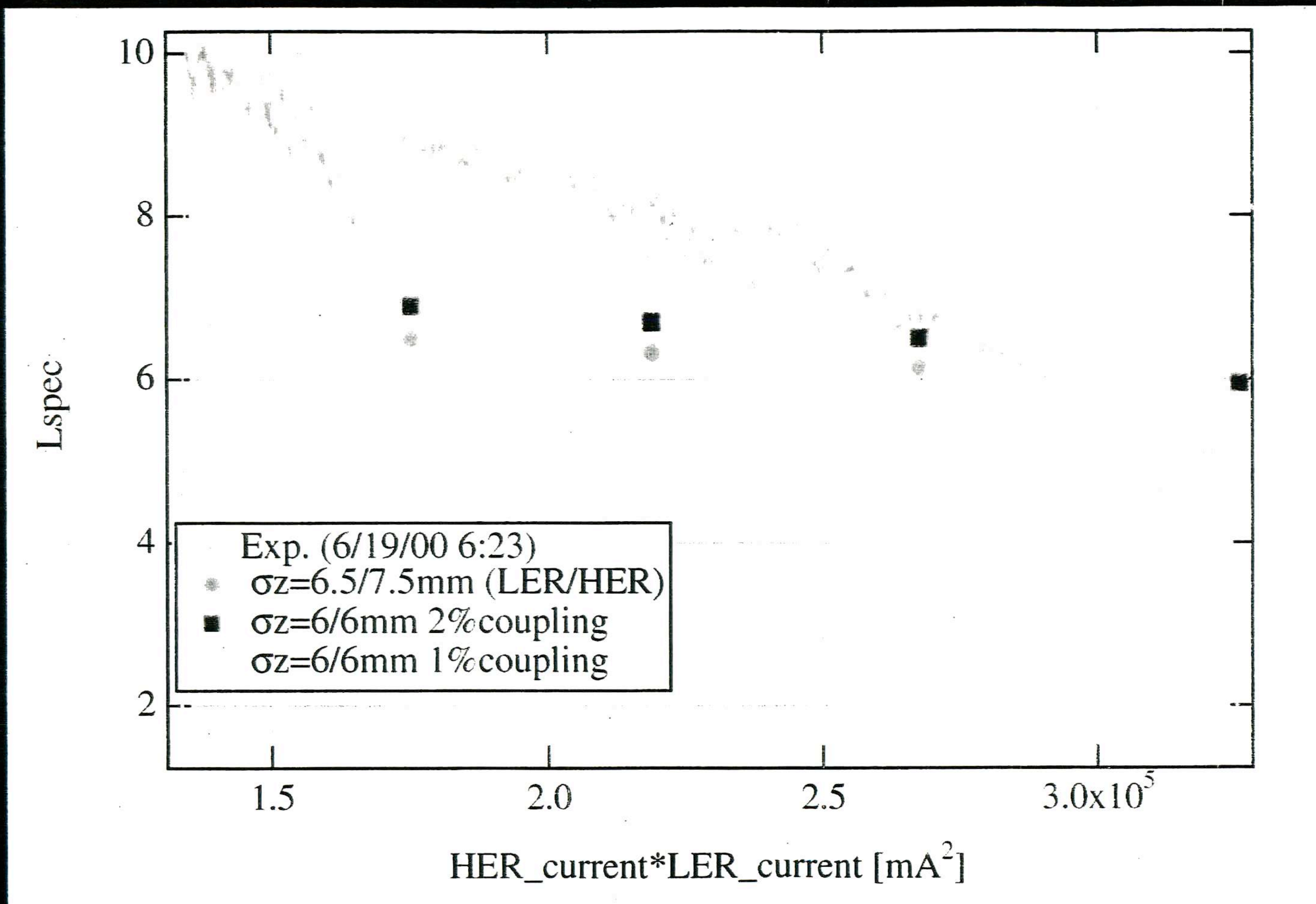


In this set simulation, the HER tunes are fixed as ν_x =44.52, ν_y =41.625, and the LER fractional tunes $\delta\nu_x$ = 0.51~0.55, $\delta\nu_y$ = 0.57~0.66 are covered. The results show that the single bunch luminosity of 2.94 x $10^{30}cm^{-2}s^{-1}$ could be reached at LER tunes of ν_x= 45.510, ν_y= 43.630.

Bunch length dependence (Sim.)



The current dependence of Lspec (Exp. & Sim.)



Recent machine studies

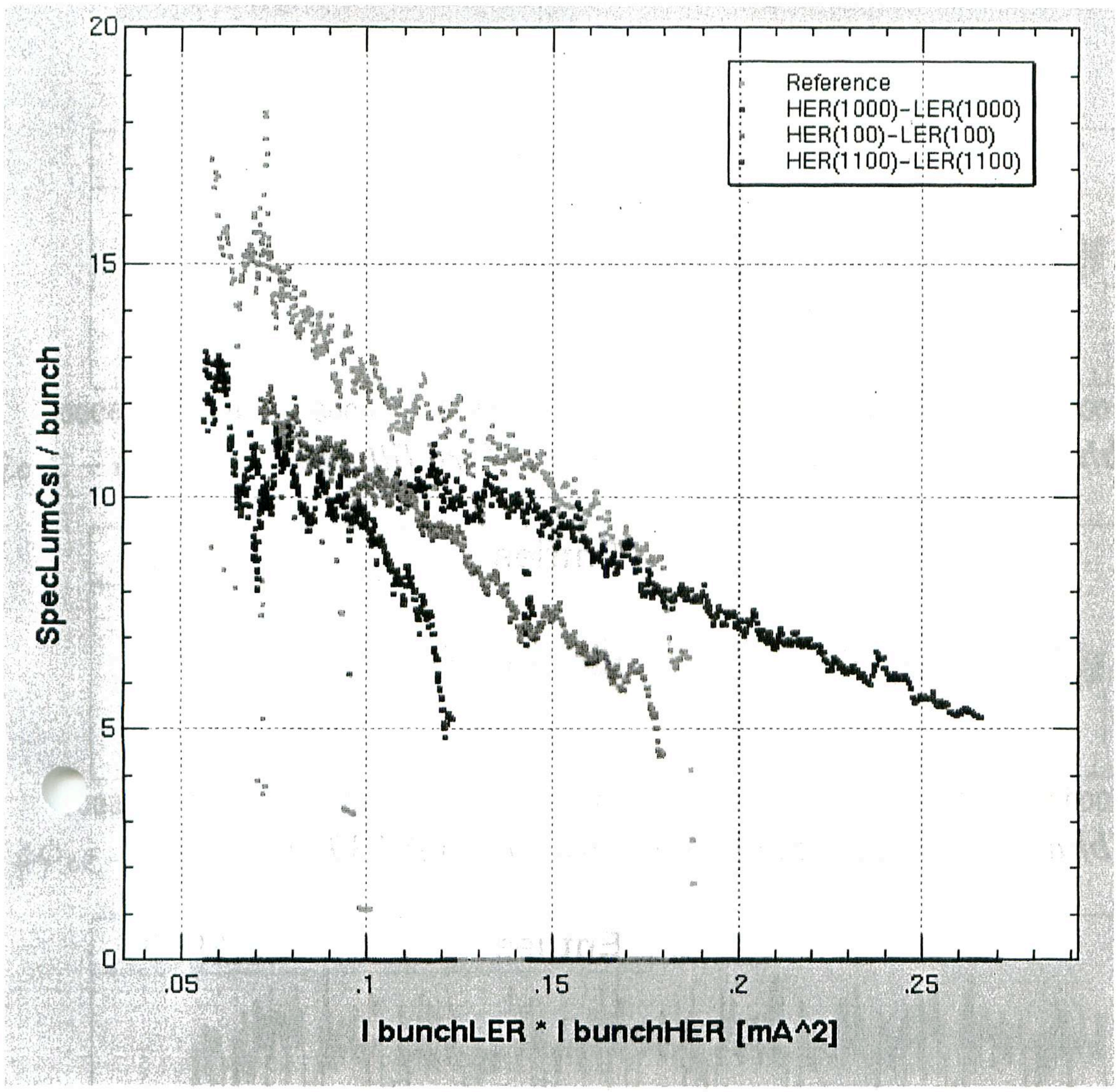
- **Motivation**
  - To increase luminosity by increasing the number of bunches (increasing beam current)
- **Study items**
  - Specific luminosity vs. Fill pattern
  - LER beam size measurements (single beam)
  - Collision with missing partner bunches
  - LER beam size measurements (during physics run with two beams separated)
  - Effect of solenoid magnets
  - Measurement of bunch dependent luminosity

Fill pattern

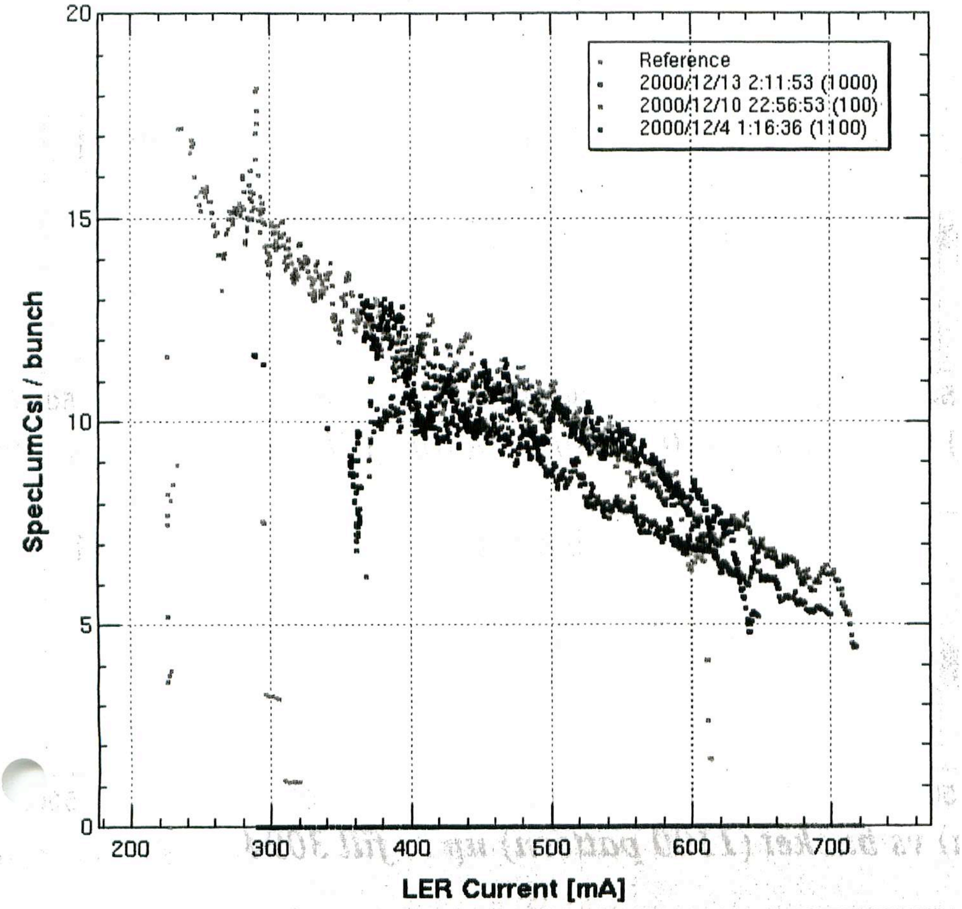
- Number of RF buckets in a ring
  - harmonic number = 5120
- Abort gap
  - 10% of the whole ring = 512 buckets
  - -> Maximum number of bunches = 4608
- Usual physics operation
  - every 4th RF bucket (4 RF bucket spacing) -> (1000)
  - Number of bunches = 1152
- Other options
  - (100) (3 RF bucket spacing)
  - (1100)
  - (10...0) (24 RF bucket spacing)

Specific luminosity vs. Fill pattern

- The longer bunch spacing, the better specific luminosity
- At low beam current the difference is small.
- It seems that the specific luminosity is determined by the LER total beam current not depending on fill patterns.



Reference
HER(1000)-LER(1000)
HER(100)-LER(100)
HER(1100)-LER(1100)
SpecLumCsI / bunch
I bunchLER * I bunchHER [mA^2]
20
15
10
5
0
.05
.1
.15
.2
.25

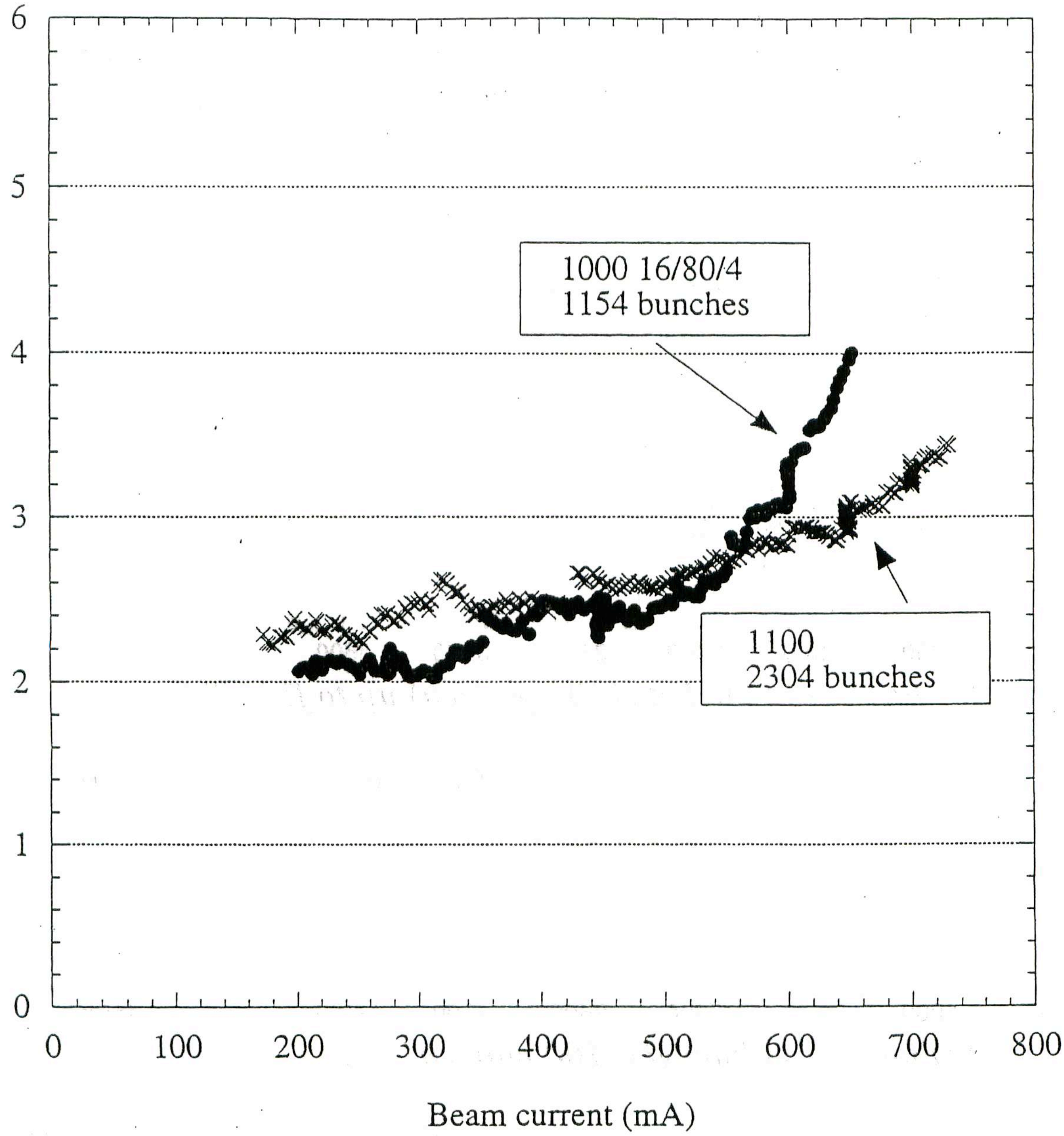


Reference
2000/12/13 2:11:53 (1000)
2000/12/10 22:56:53 (100)
2000/12/4 1:16:36 (1100)
SpecLumCsI / bunch
LER Current [mA]
0
5
10
15
20
200
300
400
500
600
700

Possible explanation of fill pattern dependence of specific luminosity

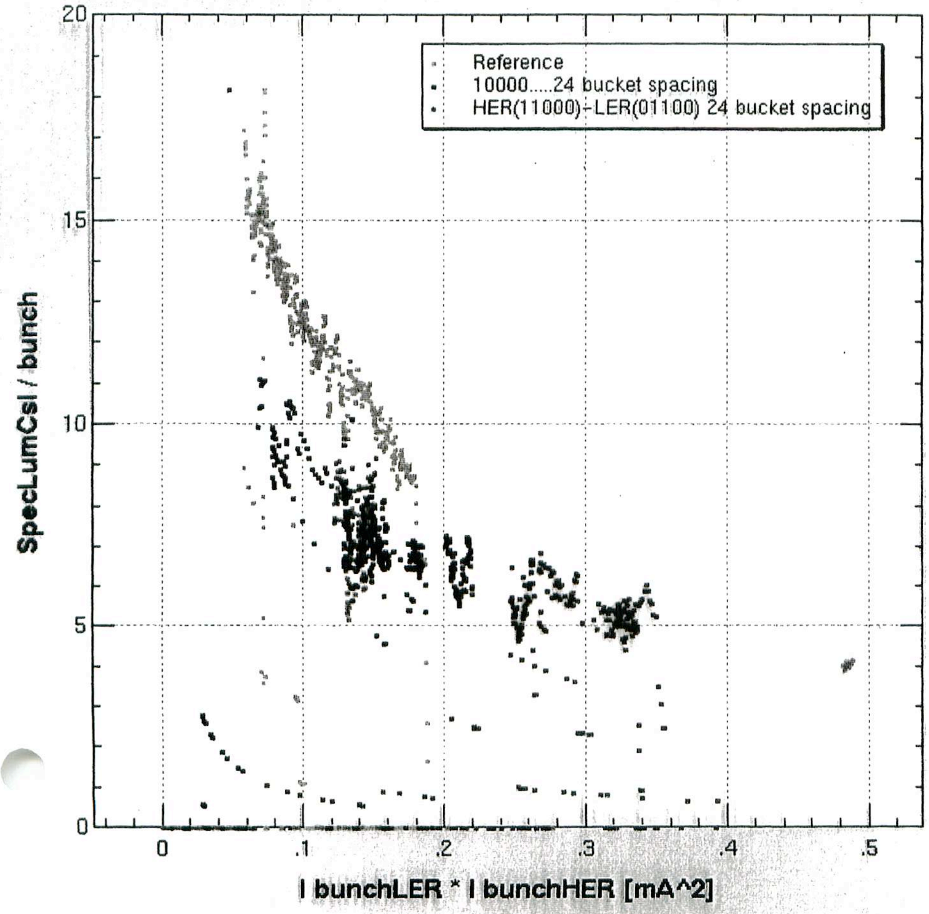
- Photoelectron effect
  - 1) Single beam blowup
  - 2) Incoherent optics modulation by photoelectron cloud
  - 3) Coherent effect (tune spread in a bunch ...)
- Parasitic collision
  - 1) beam–beam blowup
  - 2) bunch dependent COD
- Long range wakefield
  - 1) bunch dependent COD
  - 2) bunch dependent phase
  - 3) coupled bunch oscillation
  - 4) bunch lengthening

Fill pattern



Collision with missing partner bunches

- (1000)(HER) – (1000)(LER)
- (1100)(HER) – (1000)(LER)
- (1000)(HER) – (1100)(LER)
- (100…0)(HER) – (100…0)(LER)
  (24 RF buckets spacing)
- (110…0)(HER) – (0110…0)(LER)
  (fill patter is repeated in every 24 RF buckets)



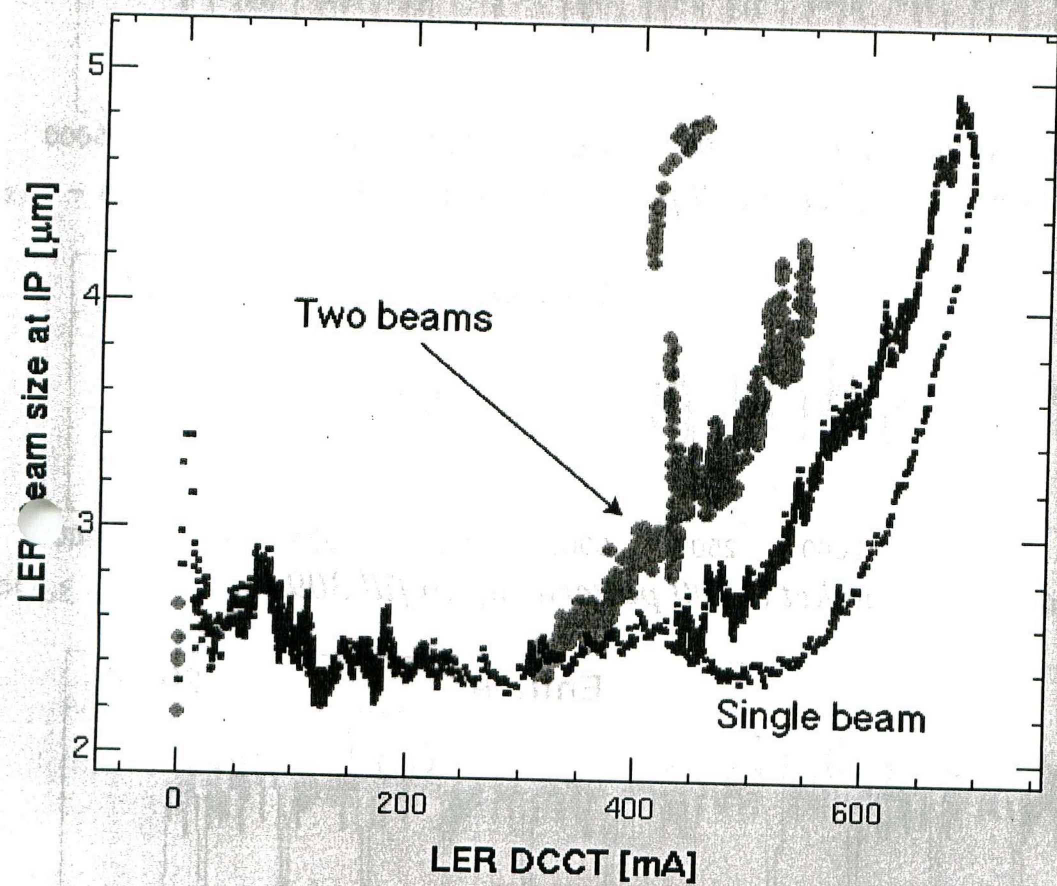
Reference
10000.....24 bucket spacing
HER(11000)-LER(01100) 24 bucket spacing
SpecLumCsI / bunch
I bunchLER * I bunchHER [mA^2]
0
5
10
15
20
.1
.2
.3
.4
.5

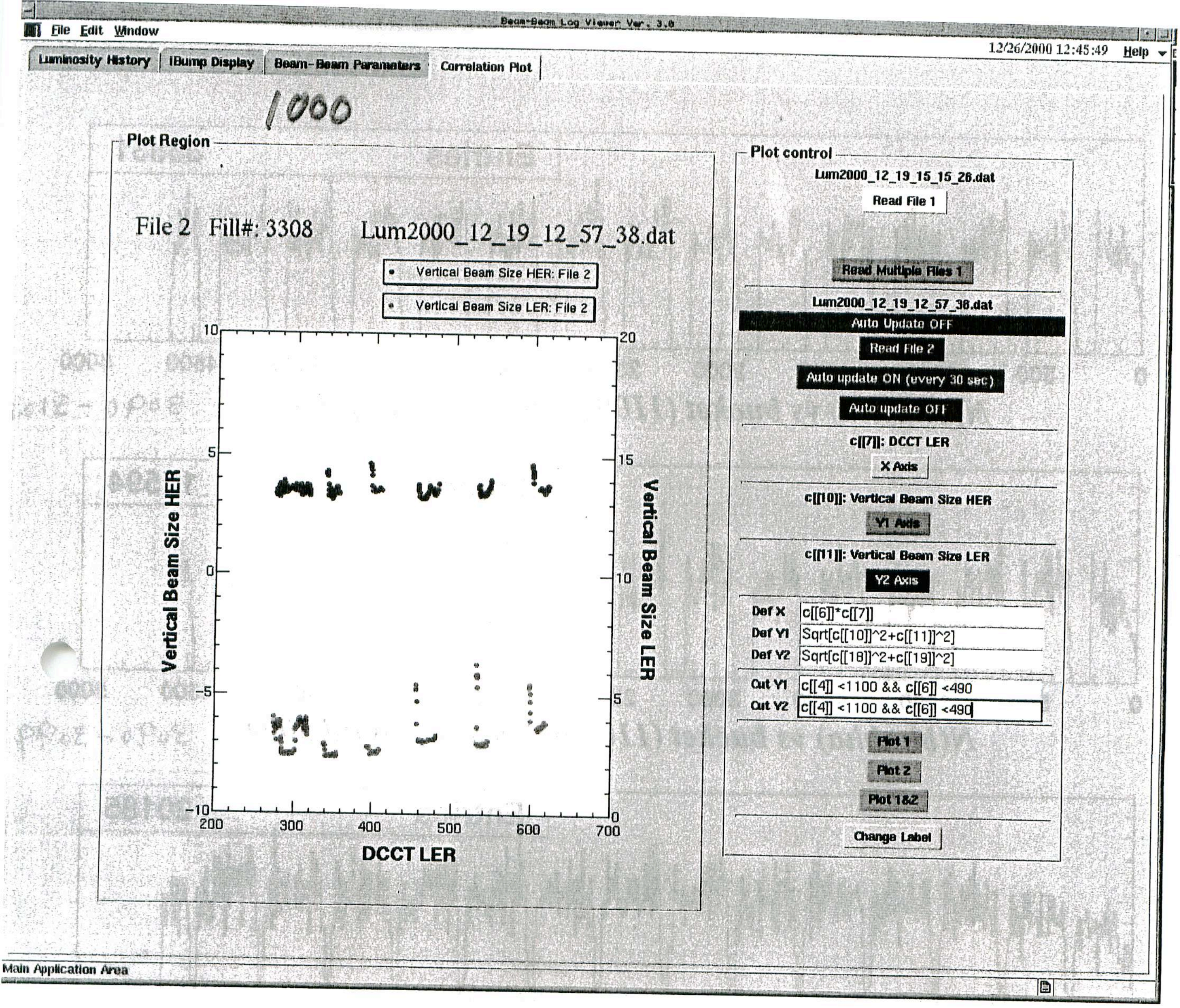
LER beam size measurements during physics run with two beams separated

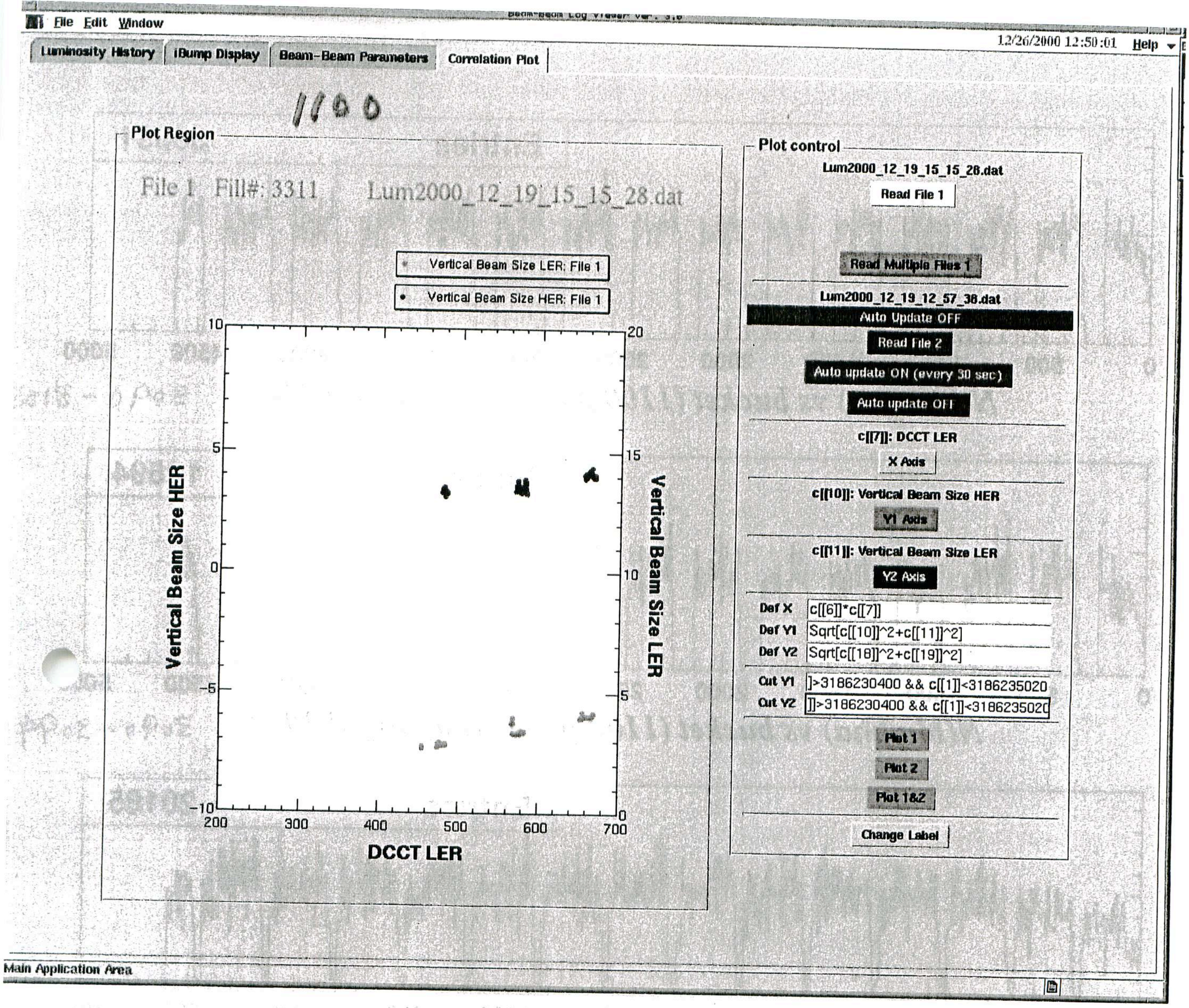
- In the single beam measurement, some "hysteresis" of the beam size has been observed.
- Beam sizes measured during physics run with two beams separated were larger than those measured in single beam mode during injection.
- These data might indicate that there is anther mechanism which brings relatively slow blowup.

Single beam: mons_11_02_2000_22:21:36.dat
(16/80/4)

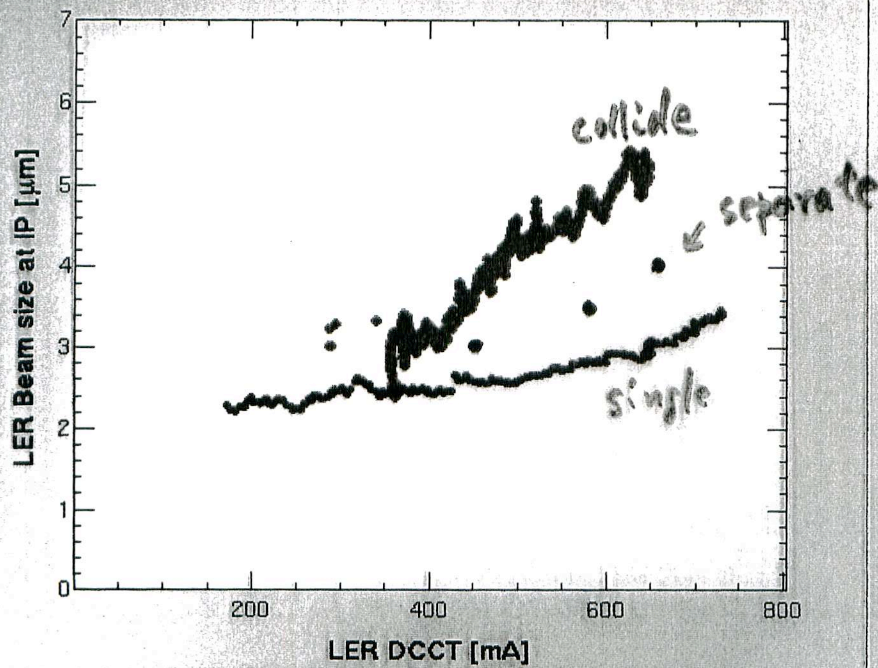
Two beams: Lum2000_11_2_7_58_11.dat
(16/80/4)




Beam-Beam Log Viewer Ver. 3.0
File Edit Window
12/26/2000 12:45:49
Help
Luminosity History
IBump Display
Beam-Beam Parameters
Correlation Plot
1000
Plot Region
File 2 Fill#: 3308 Lum2000_12_19_12_57_38.dat
Vertical Beam Size HER: File 2
Vertical Beam Size LER: File 2
Vertical Beam Size HER
Vertical Beam Size LER
DCCT LER
Plot control
Lum2000_12_19_15_15_26.dat
Read File 1
Read Multiple Files 1
Lum2000_12_19_12_57_38.dat
Auto Update OFF
Read File 2
Auto update ON (every 30 sec)
Auto update OFF
c[[7]]: DCCT LER
X Axis
c[[10]]: Vertical Beam Size HER
Y1 Axis
c[[11]]: Vertical Beam Size LER
Y2 Axis
Def X c[[6]]*c[[7]]
Def Y1 Sqrt[c[[10]]^2+c[[11]]^2]
Def Y2 Sqrt[c[[18]]^2+c[[19]]^2]
Cut Y1 c[[4]] <1100 && c[[6]] <490
Cut Y2 c[[4]] <1100 && c[[6]] <490
Plot 1
Plot 2
Plot 1&2
Change Label
Main Application Area


File Edit Window
12/26/2000 12:50:01
Help
Luminosity History
iBump Display
Beam-Beam Parameters
Correlation Plot
1100
Plot Region
File 1 Fill#: 3311 Lum2000_12_19_15_15_28.dat
Vertical Beam Size LER: File 1
Vertical Beam Size HER: File 1
Vertical Beam Size HER
Vertical Beam Size LER
DCCT LER
Plot control
Lum2000_12_19_15_15_28.dat
Read File 1
Read Multiple Files 1
Lum2000_12_19_12_57_38.dat
Auto Update OFF
Read File 2
Auto update ON (every 30 sec)
Auto update OFF
c[[7]]: DCCT LER
X Axis
c[[10]]: Vertical Beam Size HER
Y1 Axis
c[[11]]: Vertical Beam Size LER
Y2 Axis
Def X c[[6]]*c[[7]]
Def Y1 Sqrt[c[[10]]^2+c[[11]]^2]
Def Y2 Sqrt[c[[18]]^2+c[[19]]^2]
Cut Y1]>3186230400 && c[[1]]<3186235020
Cut Y2]]>3186230400 && c[[1]]<3186235020
Plot 1
Plot 2
Plot 1&2
Change Label
Main Application Area

1100



Luminosity cut

Lum2000_12_4_1_16_36.dat

Read Luminosity Log File

mons_11_15_2000_20:06:50.dat

[redacted]

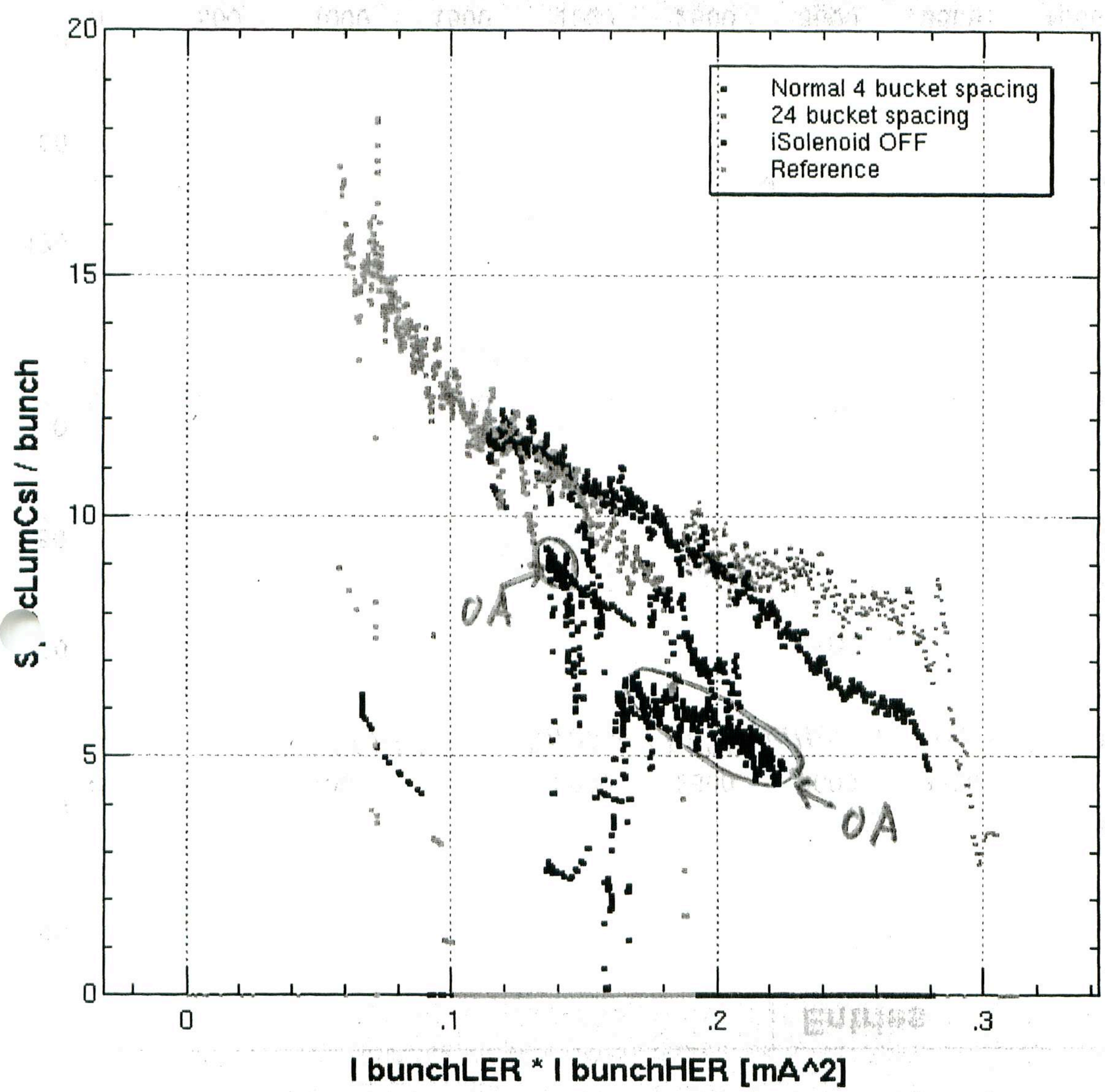
Plot Luminosity Log Data

Plot Mons Data

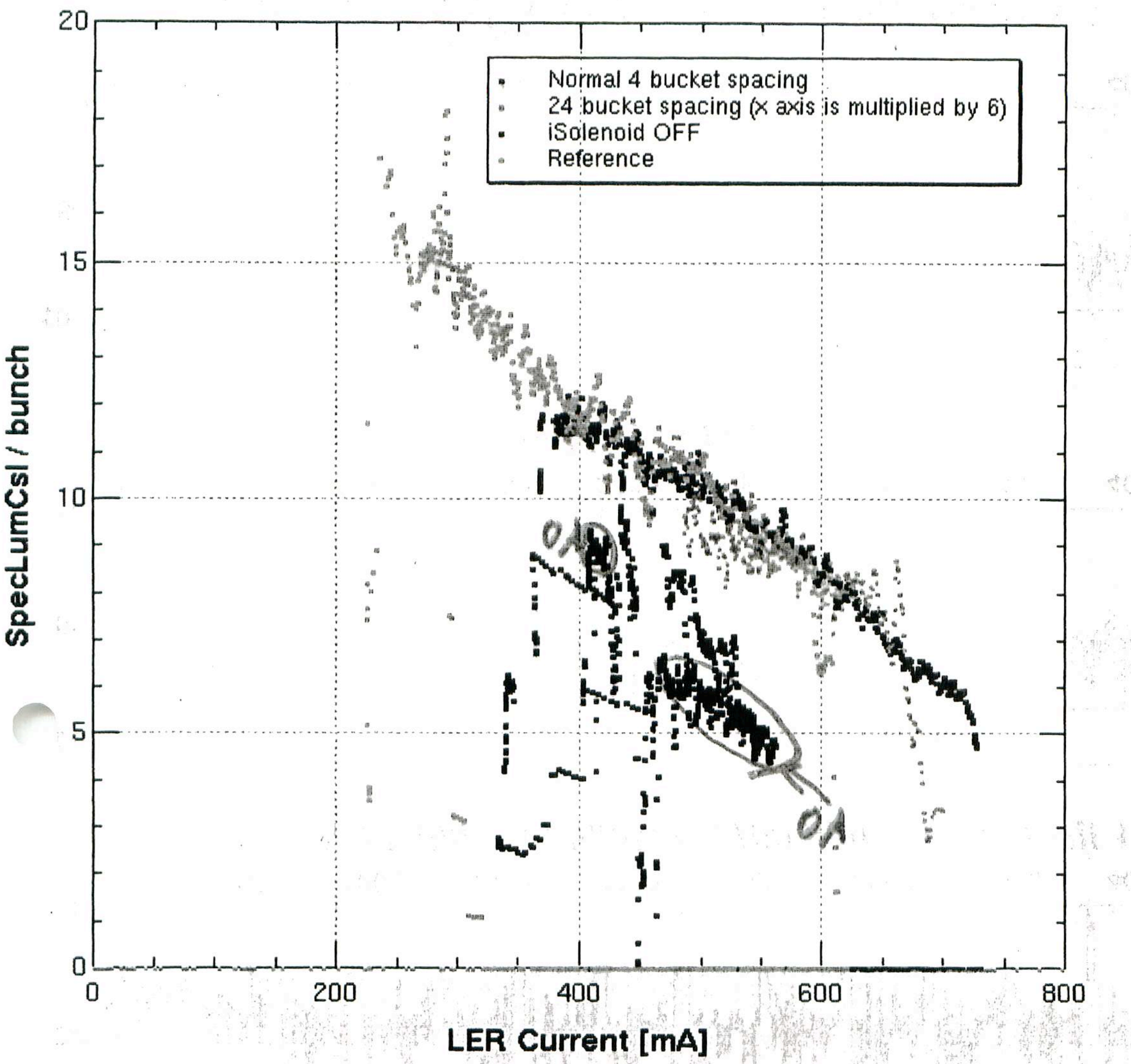
Plot Both

LER beam size measurements during physics run (cont.)

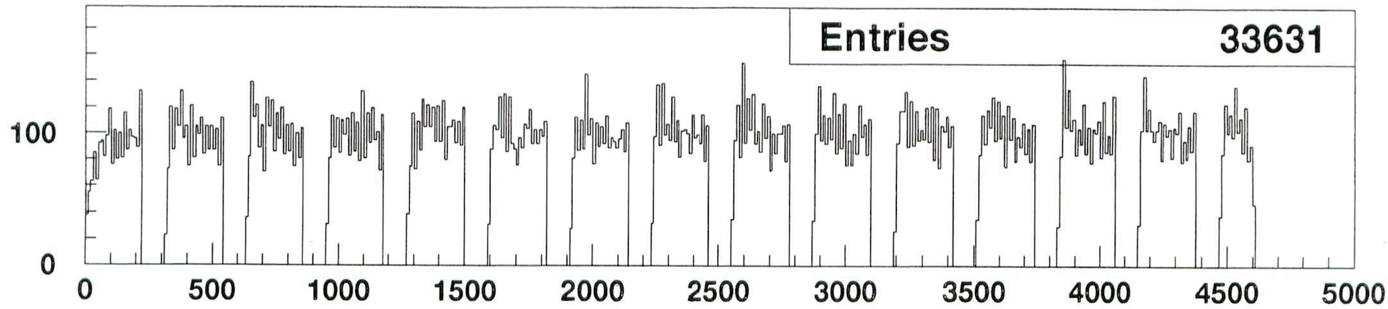
- Some data seem to indicate that the blowup is determined by a total beam current not depending on fill patterns.
- If so, the luminosity might be increased by increasing bunch spacing and increasing bunch current.
- Experiment data are very poor (need more study).



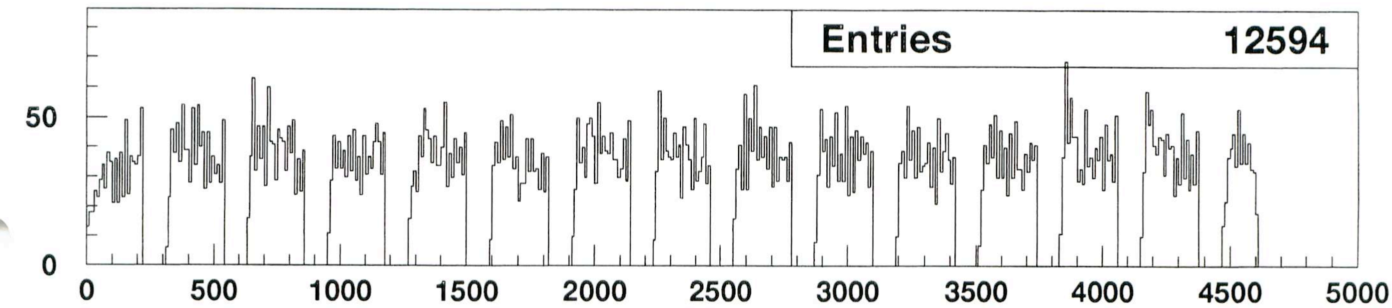
Normal 4 bucket spacing
24 bucket spacing
iSolenoid OFF
Reference
0A
0A
I bunchLER * I bunchHER [mA^2]



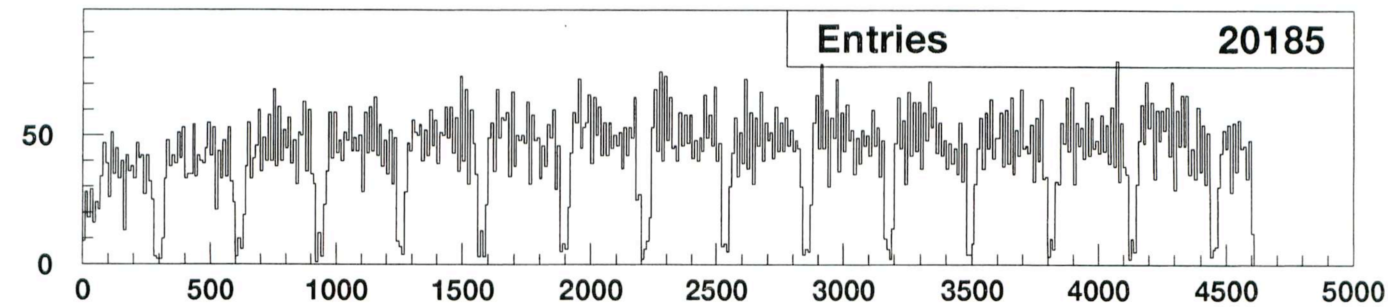
Normal 4 bucket spacing
24 bucket spacing (x axis is multiplied by 6)
iSolenoid OFF
Reference
SpecLumCsI / bunch
LER Current [mA]
0
5
10
15
20
0
200
400
600
800
0A
0A



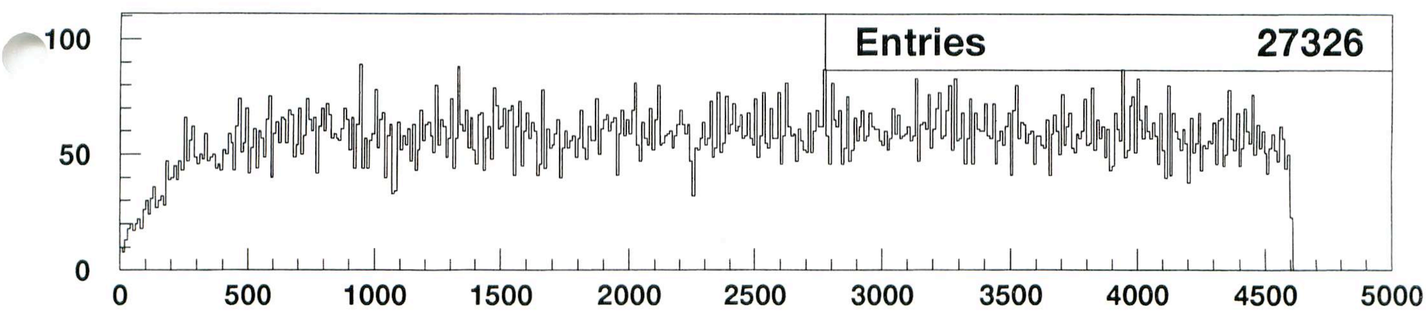
N(bhabha) vs bucket (1100 pattern) before fill 3103 3090 - 3103



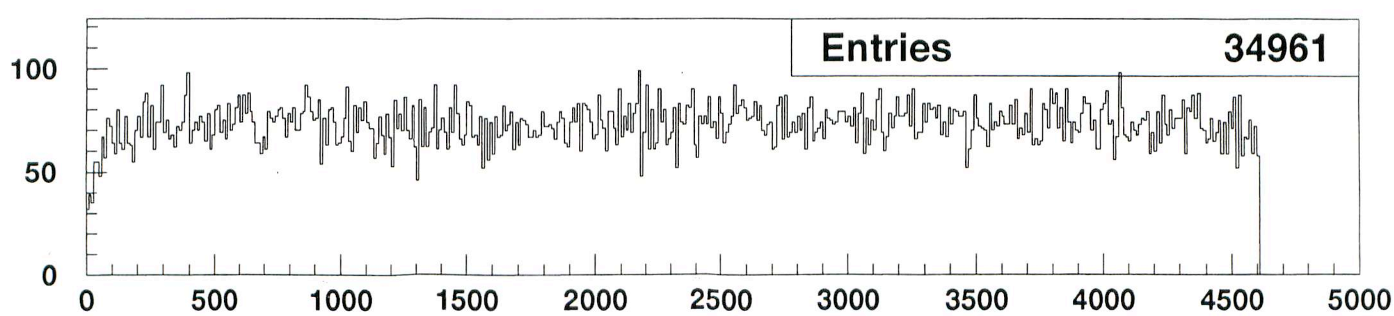
N(bhabha) vs bucket (1100 pattern) up to fill 3094 3090 - 3094



N(bhabha) vs bucket (1100 pattern) after fill 3107

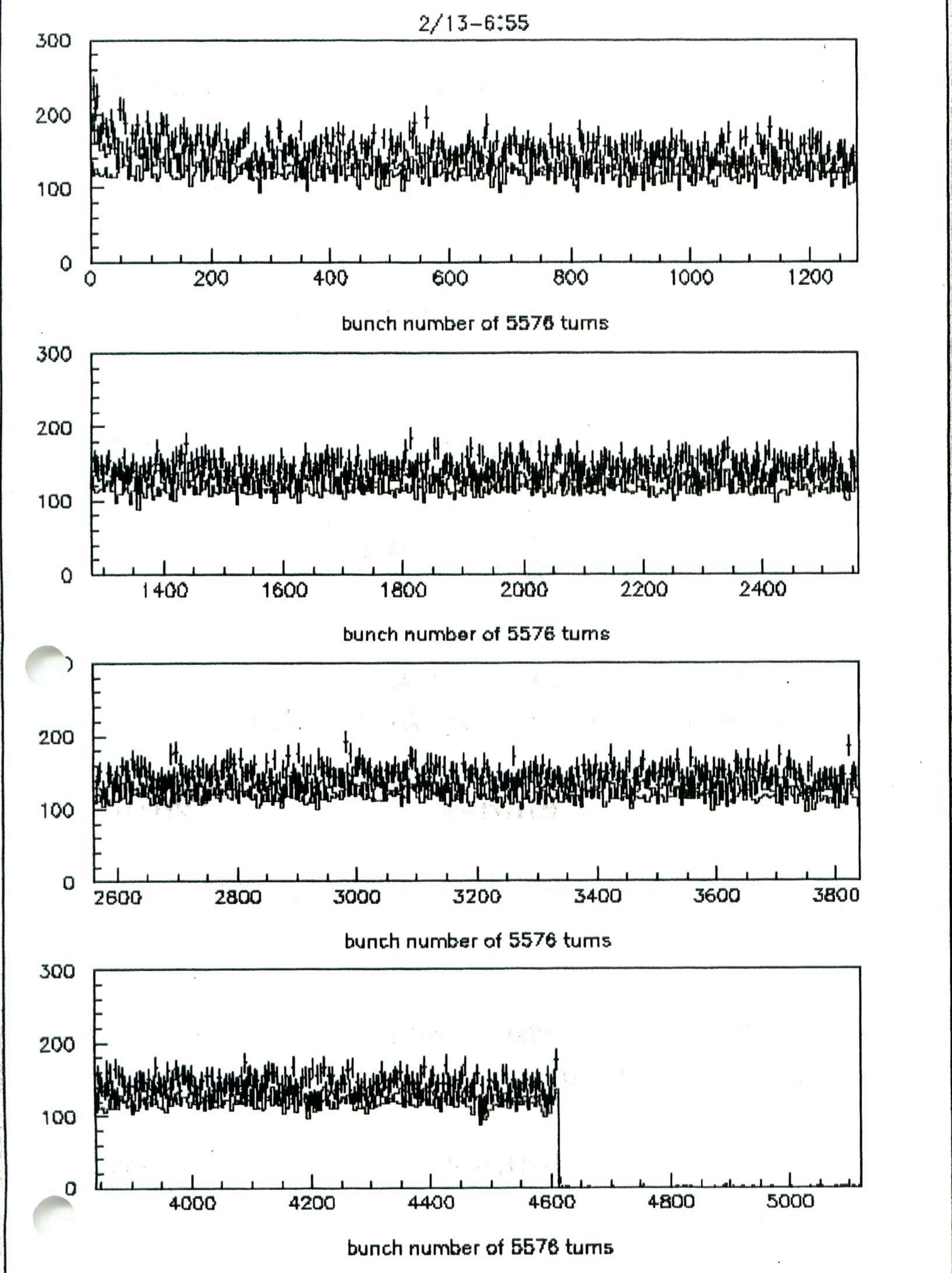


N(bhabha) vs bucket (100 pattern)



N(bhabha) vs bucket (1000 pattern)

Bunch Luminosity measured by ZDLM



Strategy for higher luminosity

- Sources of luminosity limitation
  - LER single beam blowup
  - LER single beam blowup (delayed)
  - Beam–beam blowup (mainly LER)
  - Beam current limitation
    - Heating of HER movable masks
- Ways of getting higher luminosity
  - Suppression of LER single beam blowup
    - More solenoid?, Ante chamber, Switch e– and e+ beams
  - Operation with fewer number of bunches
  - Shorter bunch length
  - Replacement of HER movable masks (for higher beam current)