Beam-beam issues from the recent PEP-II commissioning

M. Placidi

The fruitful collaboration on this subject with

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(and more...)

is gratefully acknowledged

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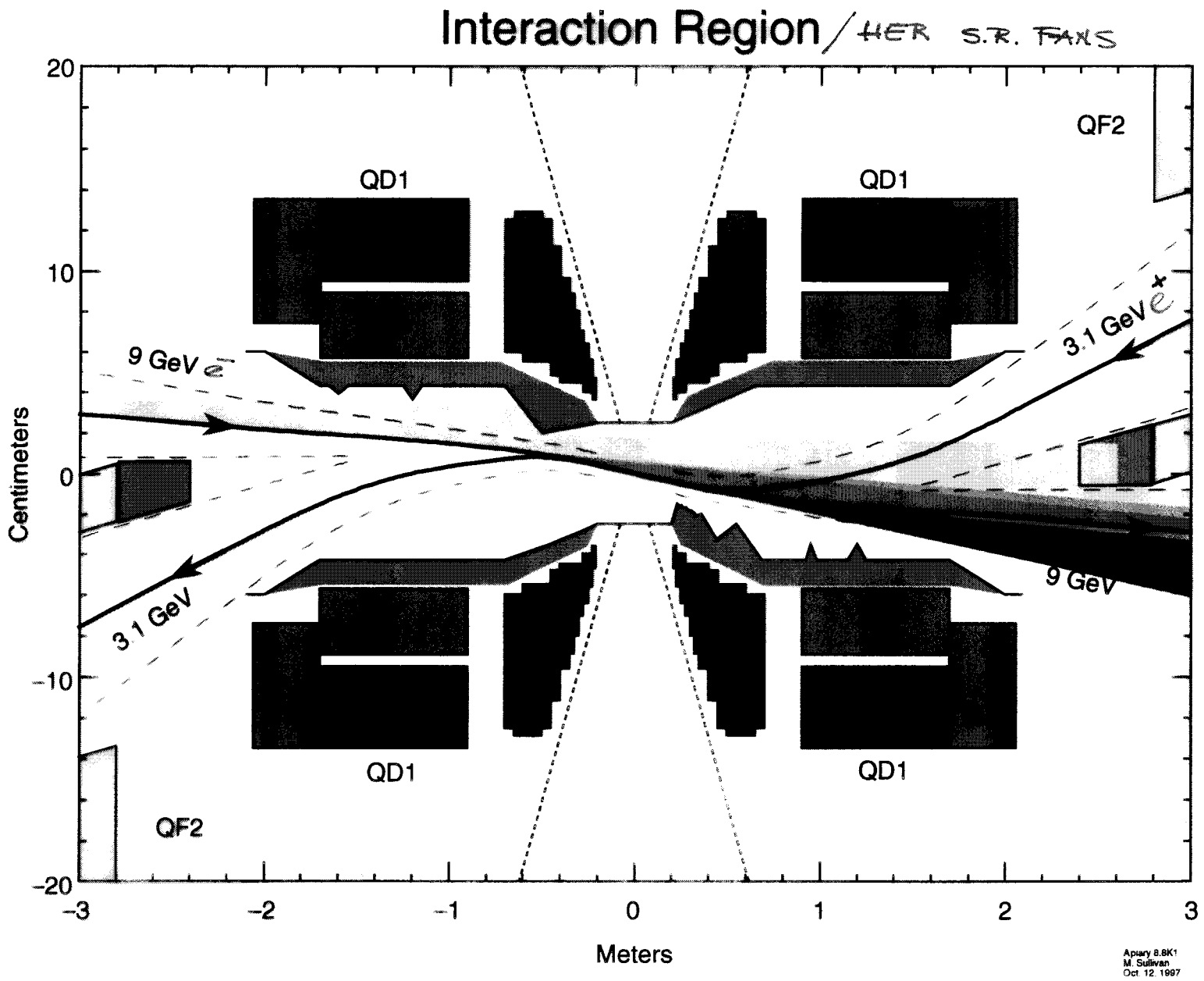
Introduction

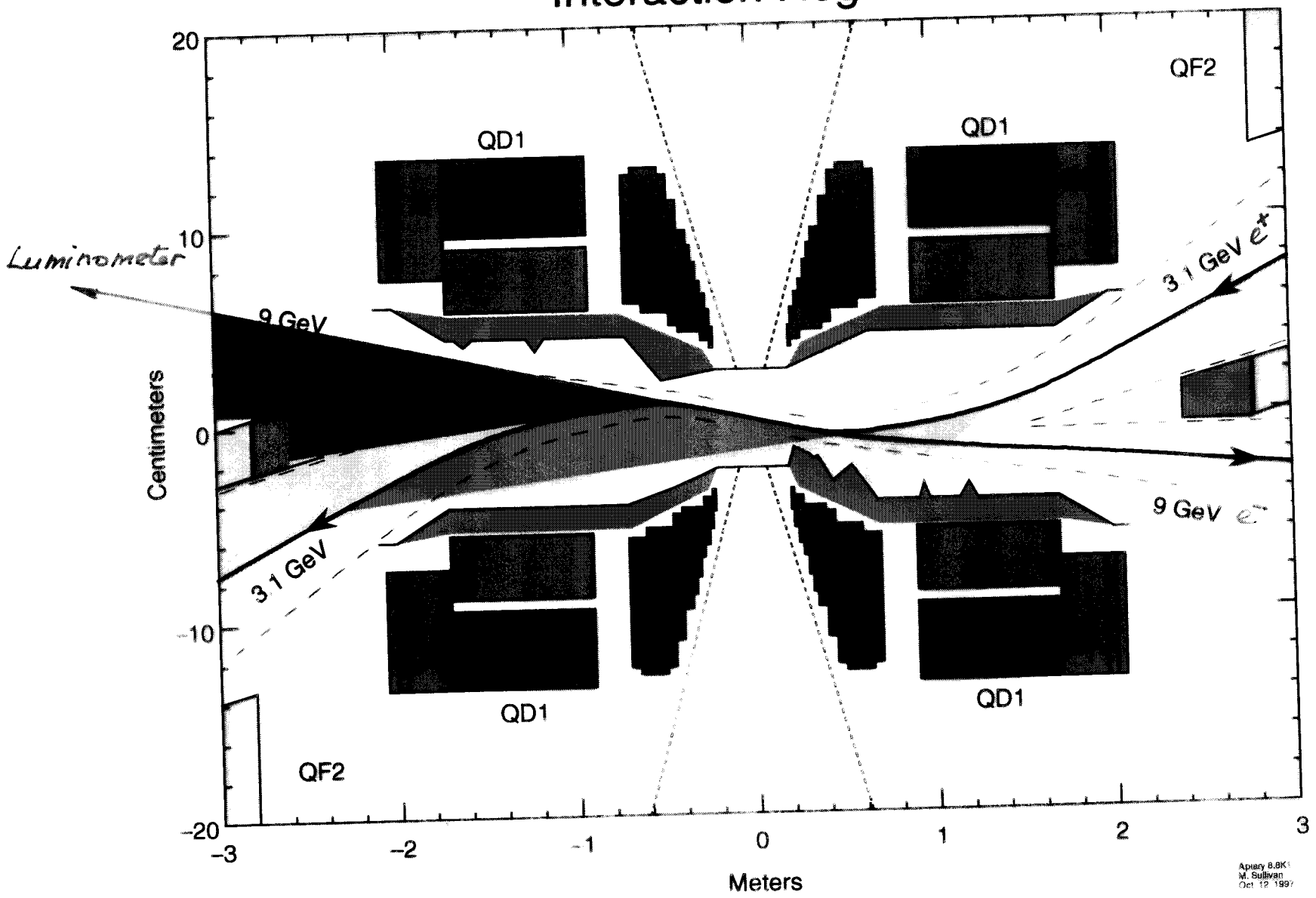
- LER and HER rings **commissioned in parallel** in July, November, December '98 and January, February '99.
- **First collisions** observed in July '98.
- **Four Collision Runs** from December '98 to February '99.
- Developed procedures to bring beam in collision **preserving reasonably small beam sizes at the interaction**
- Commissioned several **feedback loops** to control luminosity and orbits in both planes
- Developed **IP diagnostics techniques and consistency checks** to assess the reliability of the measuring procedures

PEP-II Parameters relevant to the IR

Symbol	Units	LER	HER
E_{CM}	GeV	10.580	
E	GeV	3.1186 / e^+	8.9733 / e^-
r_E		2.8773	
$\varepsilon_{xo} \mid \varepsilon_{yo}$	π nm·rad	49.2 | 1.5	49.2 | 1.5
α_c		1.23×10^{-3}	2.41×10^{-3}
$\nu_x \mid \nu_y$		38.570 | 36.642	24.618 | 23.638
$\tau_x \mid \tau_y \mid \tau_s$	ms	61.5 | 60.3 | 29.9	36.9 | 37.1 | 18.6
$f_{rev} \mid T_{rev}$	kHz | μs	136.3113 | 7.336	
$\beta_x^* \mid \beta_y^*$	m	0.500 | 0.015	
$\sigma_{xo}^* \mid \sigma_{yo}^*$ $(\Sigma_{xo} \mid \Sigma_{yo})$	μm	156.8 | 4.7 (221.8 | 6.7)	
$r = \sigma_{yo}^*/\sigma_{xo}^*$		0.03	0.03
$\kappa = \varepsilon_{yo}/\varepsilon_{xo}$		0.03	0.03
$r_\beta = \beta_y^*/\beta_x^*$		0.03	0.03
$\xi_x \mid \xi_y$		0.03 | 0.03	0.03 | 0.03
f_{RF}	MHz	475.99903	
λ_{RF}	m (ns)	0.630 (2.1)	
σ_E	MeV	2.4	5.5
δ_E		7.7×10^{-4}	6.1×10^{-4}
σ_{so}	mm (ps)	12.3 (40.3)	11.5 (38.2)
ν_s		0.0269	0.0448
$s_b \geq 2\lambda_{RF}$	m (ns)	1.26 (4.2)	
k_b		1658	1658
I_b^+ I_b^-	mA	1.300	0.452
I^+ I^-	A	2.155	0.750
$\mathcal{L}_b$	$cm^{-2}s^{-1}$	1.81×10^{30}	
$\mathcal{L}$	$cm^{-2}s^{-1}$	3.00×10^{33}	


Interaction Region / HER S.R. FANS
QF2
QD1
QD1
9 GeV e⁻
3.1 GeV e⁺
3.1 GeV
9 GeV
QD1
QD1
QF2
Centimeters
Meters
20
10
0
-10
-20
-3
-2
-1
0
1
2
3
Apary 8.8K1
M. Sullivan
Oct. 12. 1997

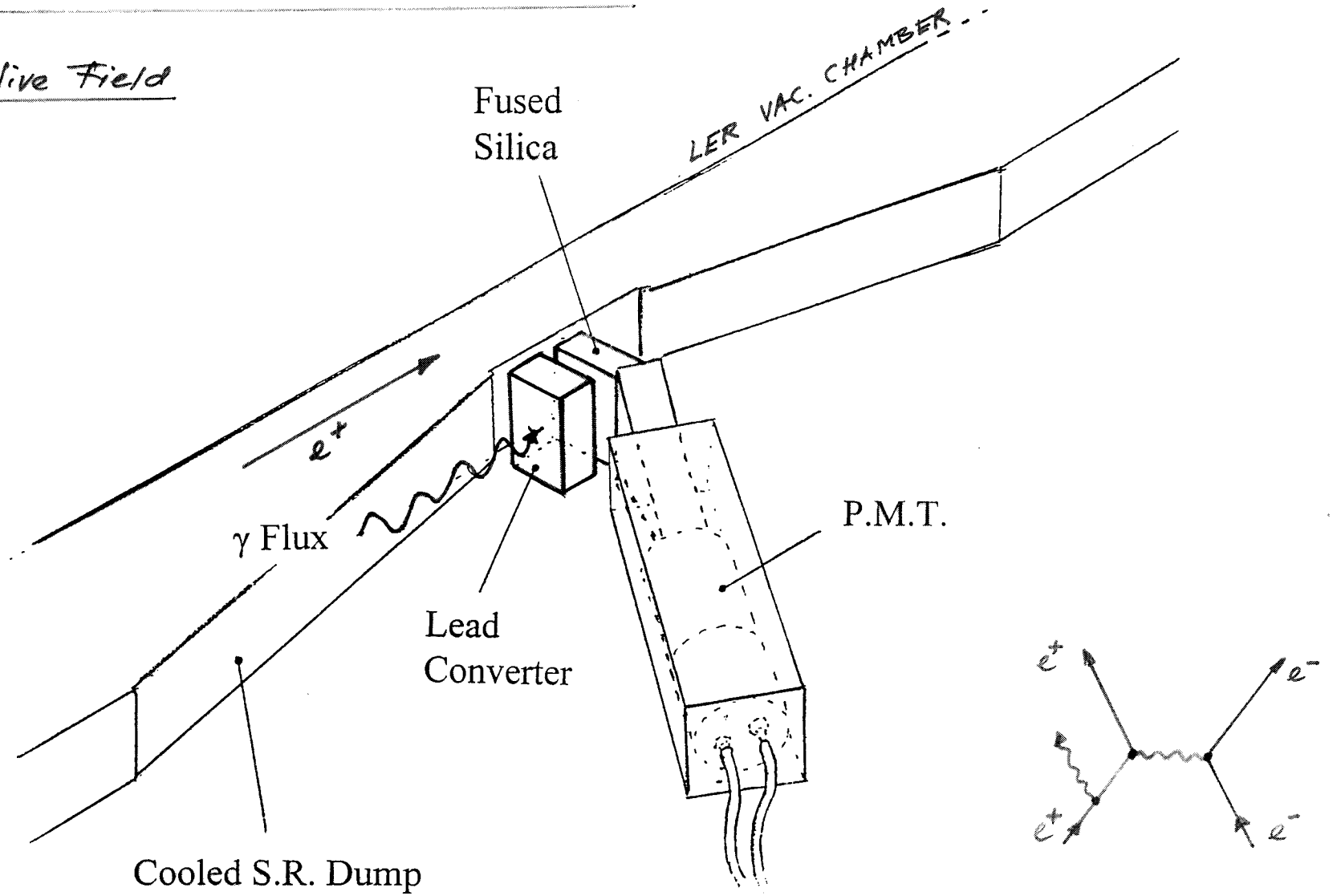
Interaction Region / LER S.R. FANS



Apiary 8.8K
M. Sullivan
Oct 12 1997

Radiated Bhabha Luminometer

Clive Field



— Radiation Shielding Not Shown —

Luminosity and beam sizes at the interaction

Luminosity for Gaussian bunches colliding head-on with **non-zero impact parameter** δz^*:

$$\mathcal{L}(\delta z^*) = k_{\mathrm{b}} \underbrace{f_{rev} \frac{N^+ N^-}{2\pi\, \Sigma_{\mathrm{x}} \Sigma_{\mathrm{y}}}}_{\mathcal{L}_b} \cdot \exp\left[-\frac{1}{2}\left[\left(\frac{\delta x^*}{\Sigma_{\mathrm{x}}}\right)^2 + \left(\frac{\delta y^*}{\Sigma_{\mathrm{y}}}\right)^2\right]\right] \tag{1}$$

$\delta z^* \equiv (\delta x^*\ ,\ \delta y^*)$ **difference** between **bunch centroid offsets at IP**

$\Sigma_{\mathrm{z}} = \sqrt{\sigma_{\mathrm{z}+}^{*2} + \sigma_{\mathrm{z}-}^{*2}}$ **convoluted transverse (un) equal beam sizes** (general case).

Optimum overlap ($\delta z^* = 0$) provides **max. Operational and Specific luminosities**:

$$\hat{\mathcal{L}}_{\delta z^*=0} = \frac{k_{\mathrm{b}}}{2\pi\, e^2\, f_{rev}} \frac{I_b^+ I_b^-}{\Sigma_{\mathrm{x}} \Sigma_{\mathrm{y}}} = \frac{\mathrm{A}}{\Sigma_{\mathrm{x}} \Sigma_{\mathrm{y}}} \frac{I^+ I^-}{k_{\mathrm{b}}} \tag{2}$$

$$\hat{\mathcal{L}}^{\star}{}_{\delta z^*=0} = \frac{\hat{\mathcal{L}}_{\delta z^*=0}}{k_{\mathrm{b}}\, I_b^+ I_b^-} = k_{\mathrm{b}} \frac{\hat{\mathcal{L}}_{\delta z^*=0}}{I^+ I^-} \equiv \frac{\mathrm{A}}{\Sigma_{\mathrm{x}} \Sigma_{\mathrm{y}}} \tag{3}$$

Diagnostics with Beam-Beam Deflections / Amplitudes

Pioneered at the SLAC SLC and routinely applied at LEP (J. Wenninger) **the deflections** of the **centroids** of two **flat Gaussian distributions** passing each other at a **normalised offset** $\tilde{z}$

$$\Theta^{*}_{\mathrm{y}\pm}(\tilde{z}) = \hat{\Theta}^{*}_{\pm} \cdot \Re\left[\mathbf{w}\left(\frac{\tilde{x} + \mathbf{i}r\tilde{y}}{d}\right) - \exp\left[-\frac{1}{2}(\tilde{x}^2 - \tilde{y}^2)\right] \cdot \mathbf{w}\left(\frac{r\tilde{x} + \mathbf{i}\tilde{y}}{d}\right)\right] \tag{4}$$

represent a **powerful IR diagnostic tool**:

$\star$ the **maxima** represent a measure of the **horizontal beam sizes at the interaction**

$$|\,\hat{\Theta}^{*}_{\pm}\,| = \frac{r_{\mathrm{e}}\sqrt{2\pi}}{\Sigma_{\mathrm{x}}\sqrt{1-\mathrm{R}^2}}\left(\frac{N^{\mp}}{\gamma^{\pm}}\right) \quad , \quad \mathrm{R} = \frac{\Sigma_{\mathrm{y}}}{\Sigma_{\mathrm{x}}} \tag{5}$$

knowing the energy $\gamma^{\pm}$ of the **deflected** bunch and the population $N^{\mp}$ of the **deflecting** one.

IR Tuning and Diagnostics Procedures

⋆ **Beam finding** : x, y **closed bumps** @ IP

⋆ **Overlap/Luminosity optimisation** : x, x', y, y' **closed bumps** @ IP

⋆ Measure **peak Luminosity** : **Lumi-scans**

⋆ Derive **convoluted beam sizes** : fits of **Lumi- and** *BBD*-**scans**

⋆ Measure e^- *BBD* **slopes** : fit e^- deflections scanning e^+ (better BPM sensitivity)

⋆ Infer **Luminosity** : *BBD* **slopes, convoluted sizes**

⋆ Infer **Horizontal beam-beam parameter** : *BBD* **slopes, convoluted sizes**

⋆ Infer **Vertical beam-beam parameter** : *BBD* **slopes, convoluted sizes, Luminosity**

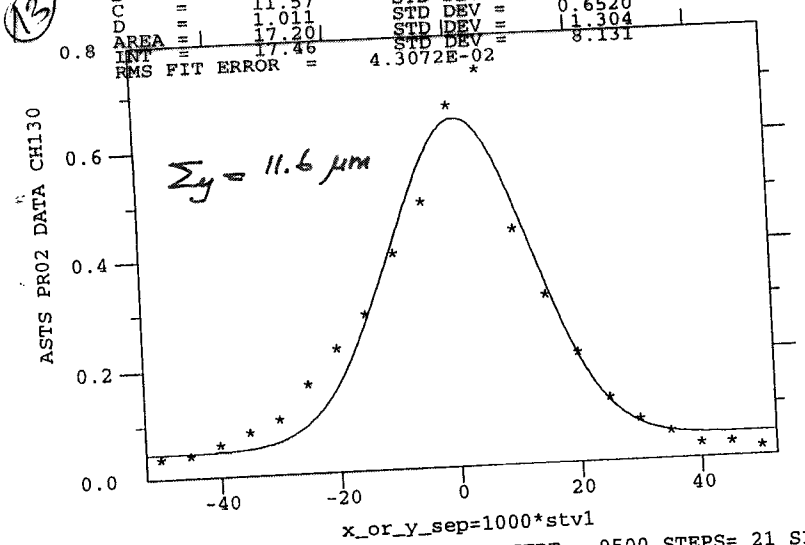
⋆ Compare **measured/inferred** $\hat{\mathcal{L}}$, $\hat{\mathcal{L}}^\star$, Ξ_x, Ξ_y figures to **expected** from **measured colliding currents** and **nominal IP beam sizes**

(13)

Y = A + B * EXP(-(X - D)**2 / (2 * C**2))

A =	4.6629E-02	STD DEV =	1.6231E-02
B =	0.5931	STD DEV =	3.1145E-02
C =	11.57	STD DEV =	0.7909
D =	1.011	STD DEV =	0.6520
AREA =	17.20	STD DEV =	1.304
INT =	17.46	STD DEV =	8.131

RMS FIT ERROR = 4.3072E-02



KNOB (COMMON$ROOT:[MKB]LERIP_Y.MKB.2) STRT=-.0500 STEPS= 21 SIZE= 5

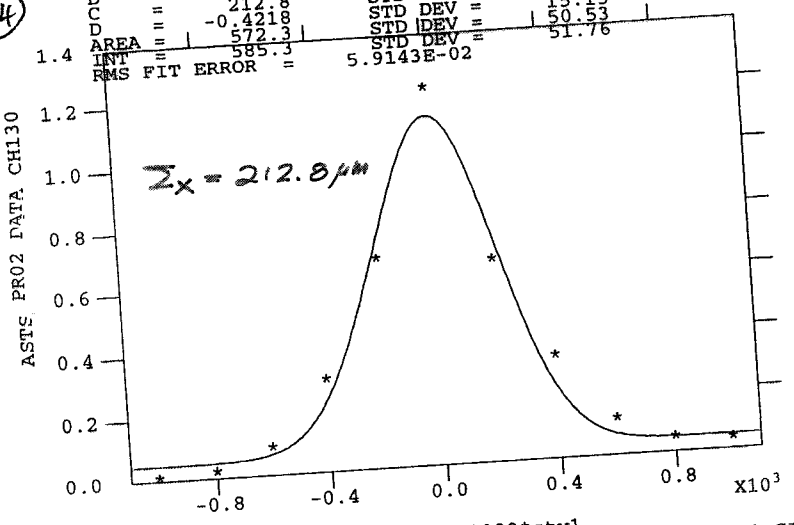
8-DEC-98 23:27:40

(14)

Y = A + B * EXP(-(X - D)**2 / (2 * C**2))

A =	4.8840E-02	STD DEV =	3.2052E-02
B =	1.073	STD DEV =	6.9864E-02
C =	212.8	STD DEV =	17.55
D =	-0.4218	STD DEV =	15.15
AREA =	572.3	STD DEV =	50.53
INT =	585.3	STD DEV =	51.76

RMS FIT ERROR = 5.9143E-02

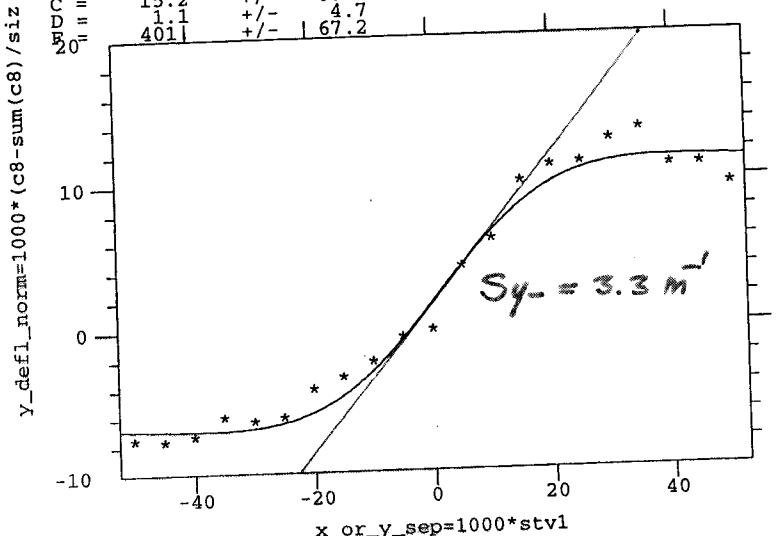


KNOB (COMMON$ROOT:[MKB]LERIP_X.MKB.2) STRT=-1.000 STEPS= 11 SIZE= .20

8-DEC-98 23:34:57

Y = A + B*Z*exp(Z*Z)*erf(Z,Z*F/C)/(X-D); Z = (X-D)/sqrt(2(F*F-C*C

A =	2.2	+/-	1.2	RMS ERROR	1.1
B =	3210.			CHISQ/DOF	1.6
C =	15.2	+/-	6.40		
D =	1.1	+/-	4.7		
E =	401	+/-	67.2		



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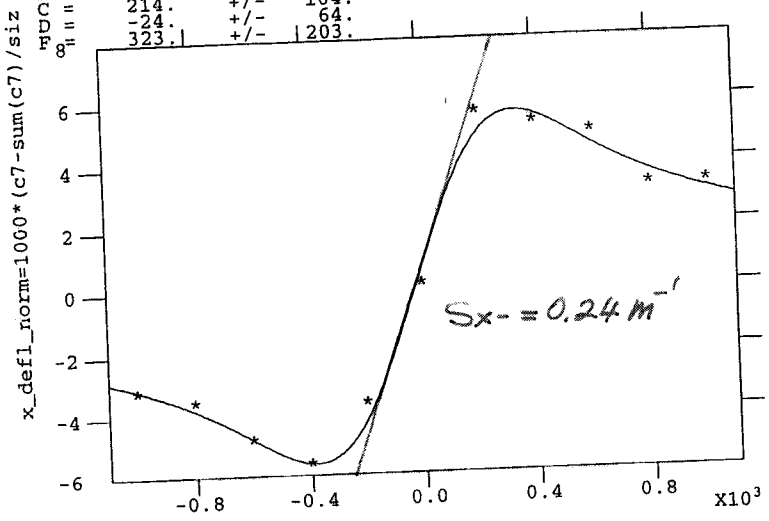
8-DEC-98 23:28:09

Y = A + B*Z*exp(Z*Z)*erf(Z,Z*F/C)/(X-D); Z = (X-D)/sqrt(2(F*F-C*C))

A =	2.10E-03	+/-	0.69	RMS ERROR	0.38
B =	3210.			CHISQ/DOF	0.32
C =	214.	+/-	104.		
D =	-24.	+/-	64.		
E =	323.	+/-	203.		

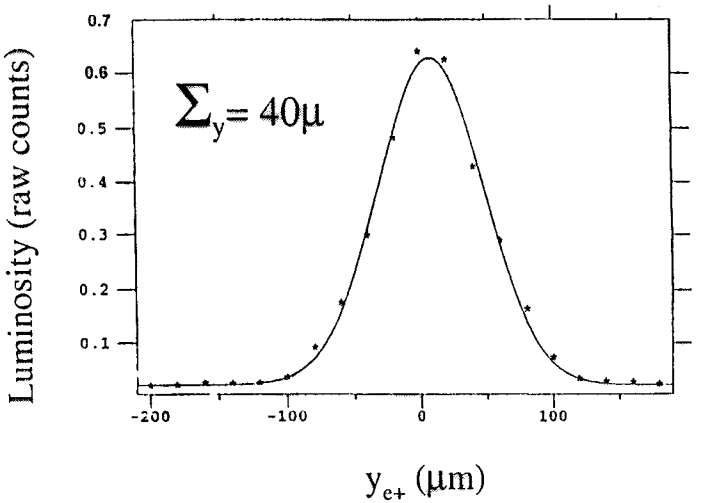


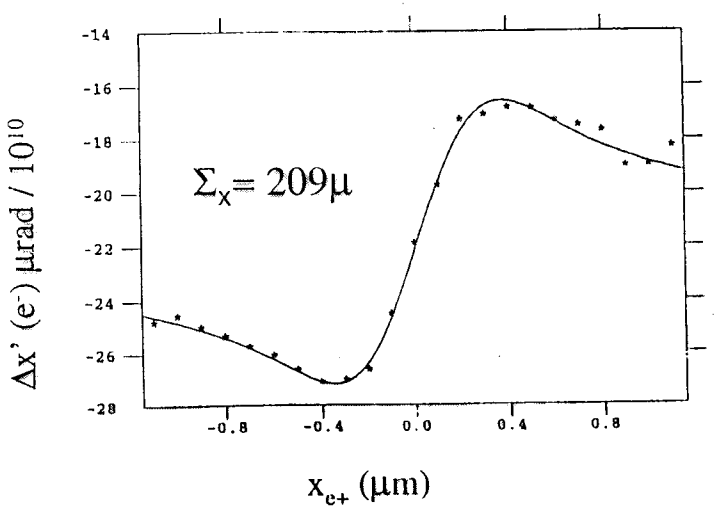
KNOB (COMMON$ROOT:[MKB]LERIP_X.MKB.2) STRT=-1.000 STEPS= 11 SIZE= .20

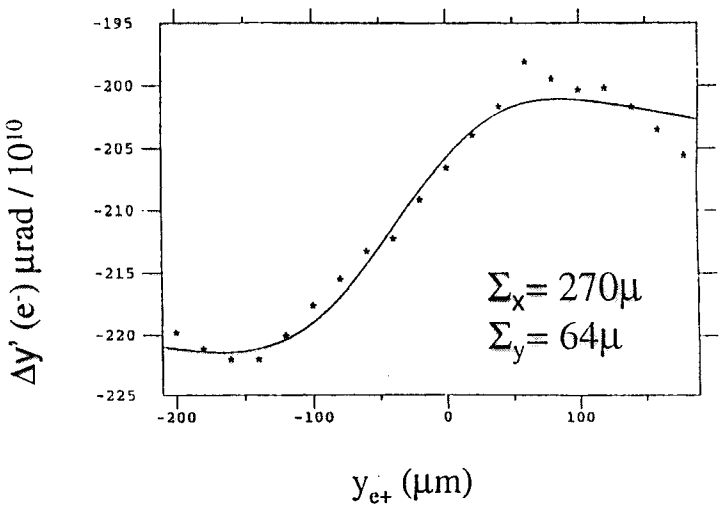
8-DEC-98 23:35:23

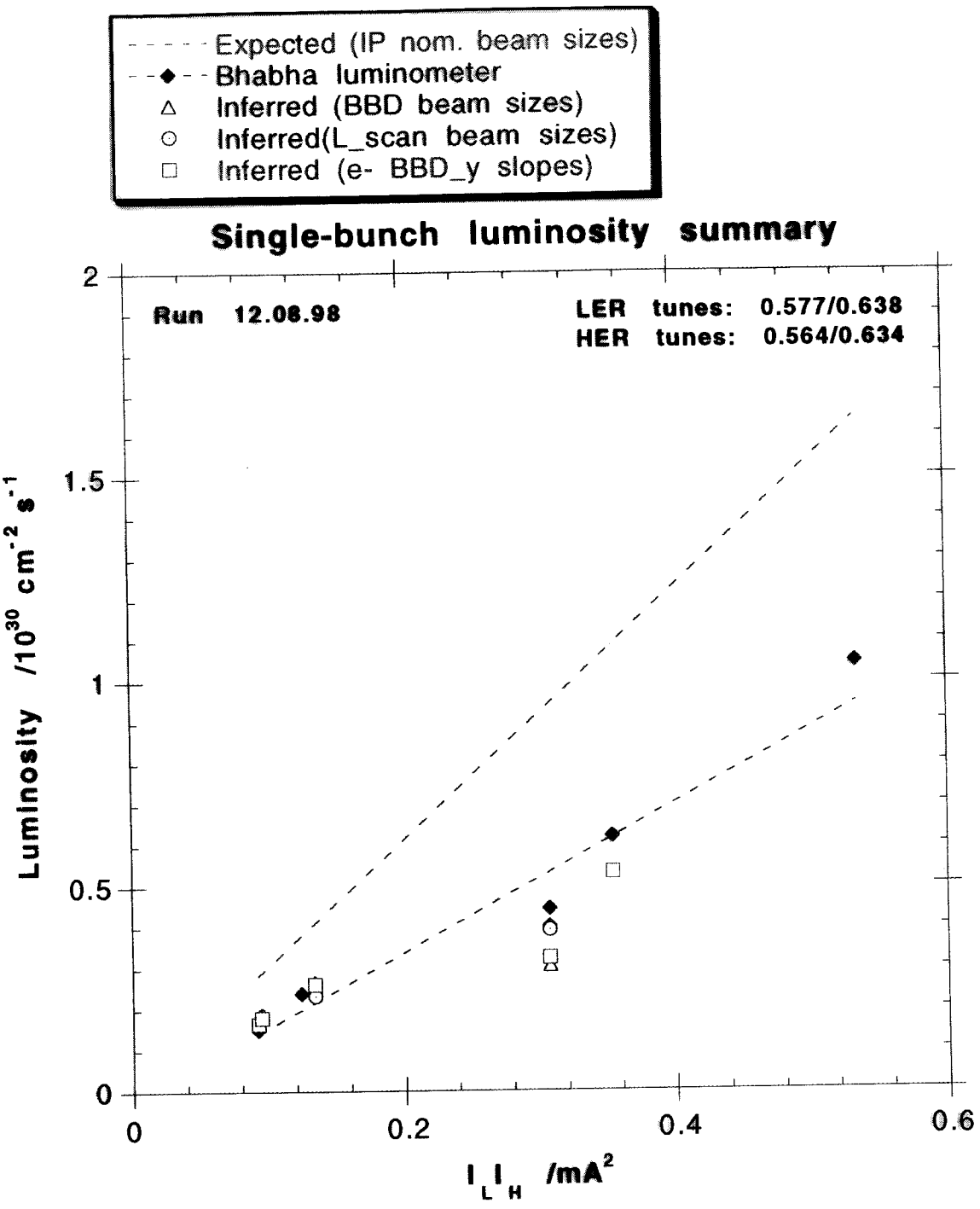
First Measured Luminosity 10 Nov 98

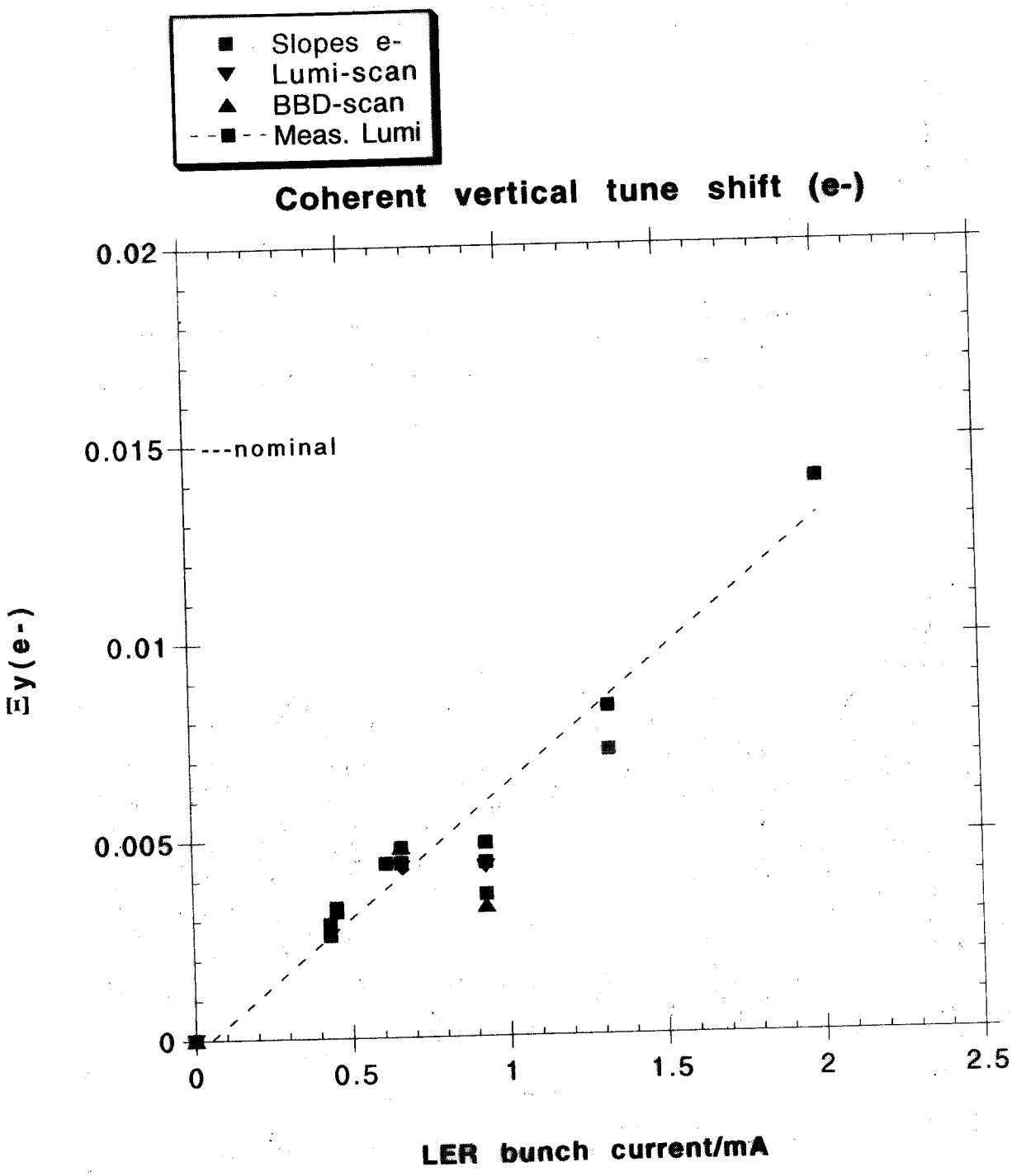
- 0.6 mA in single HER bucket
- 1.3 mA in single LER Bucket
- Stays stored even when not centered
- $\mathcal{L}$ from deflection beam sizes and currents ~ 2 x10^{29}
- $\mathcal{L}$ from radiative Bhabha rate ~ 2.7 x 10^{29}
- 11 Bunches gave ~11 times luminosity

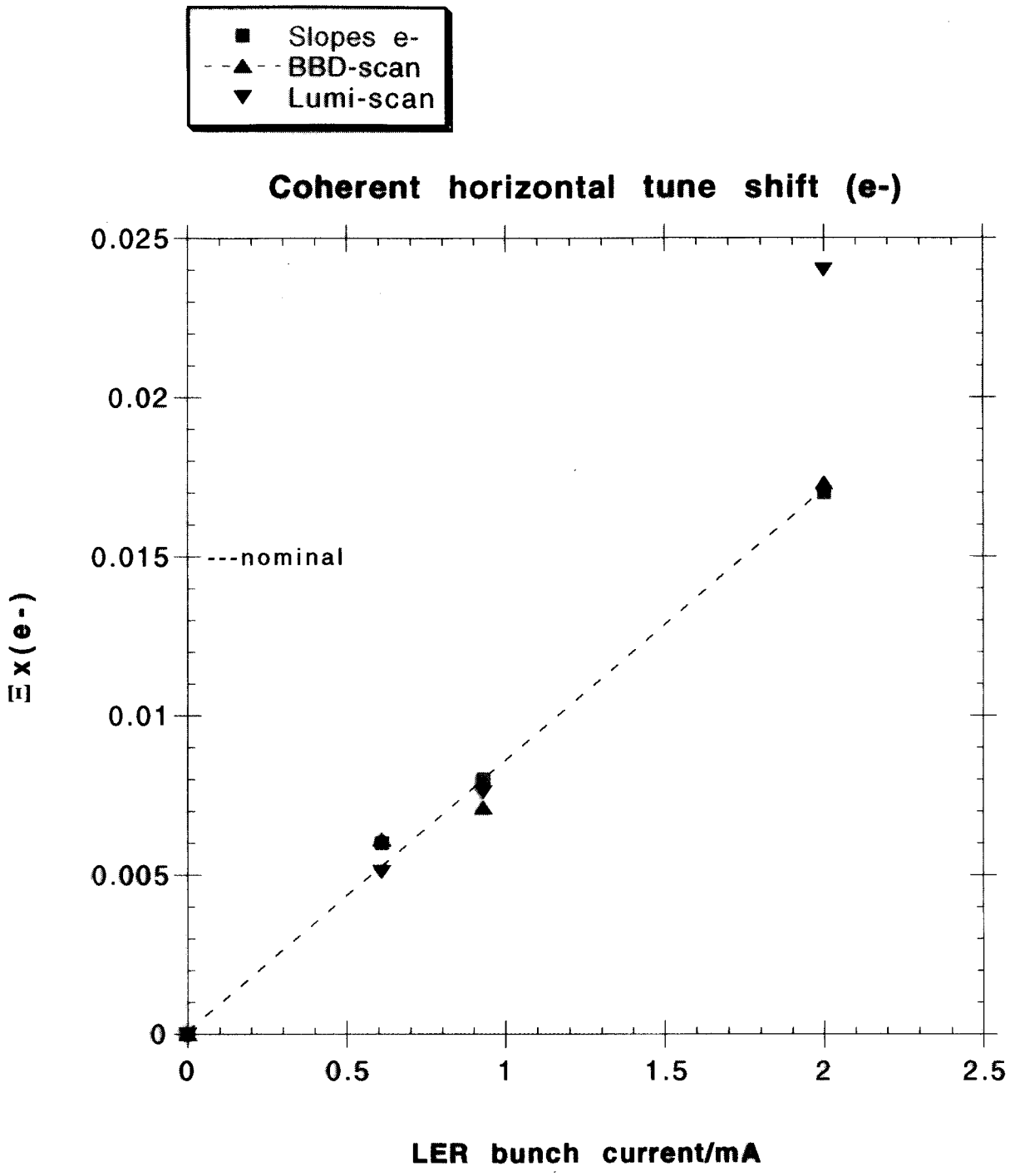


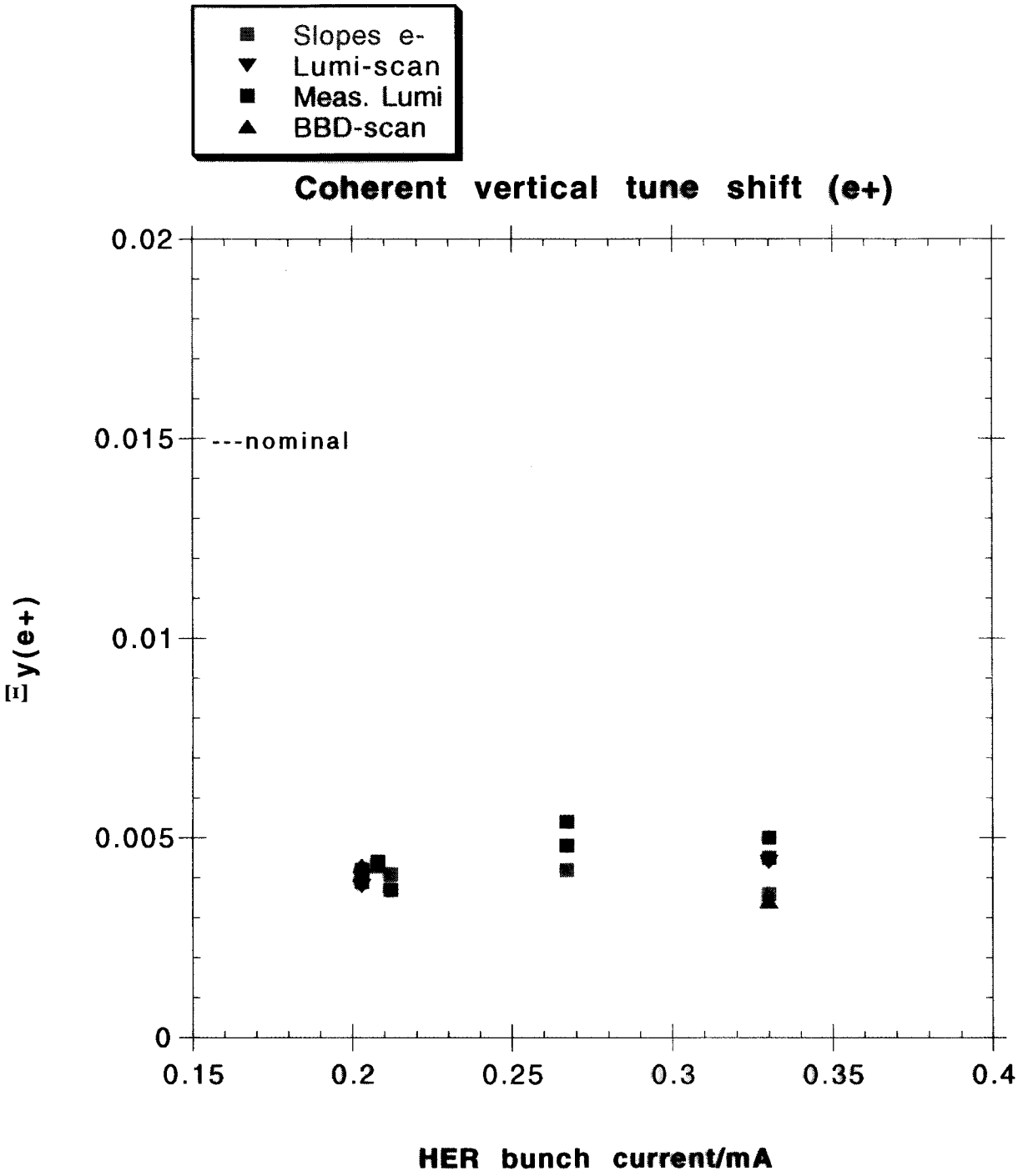


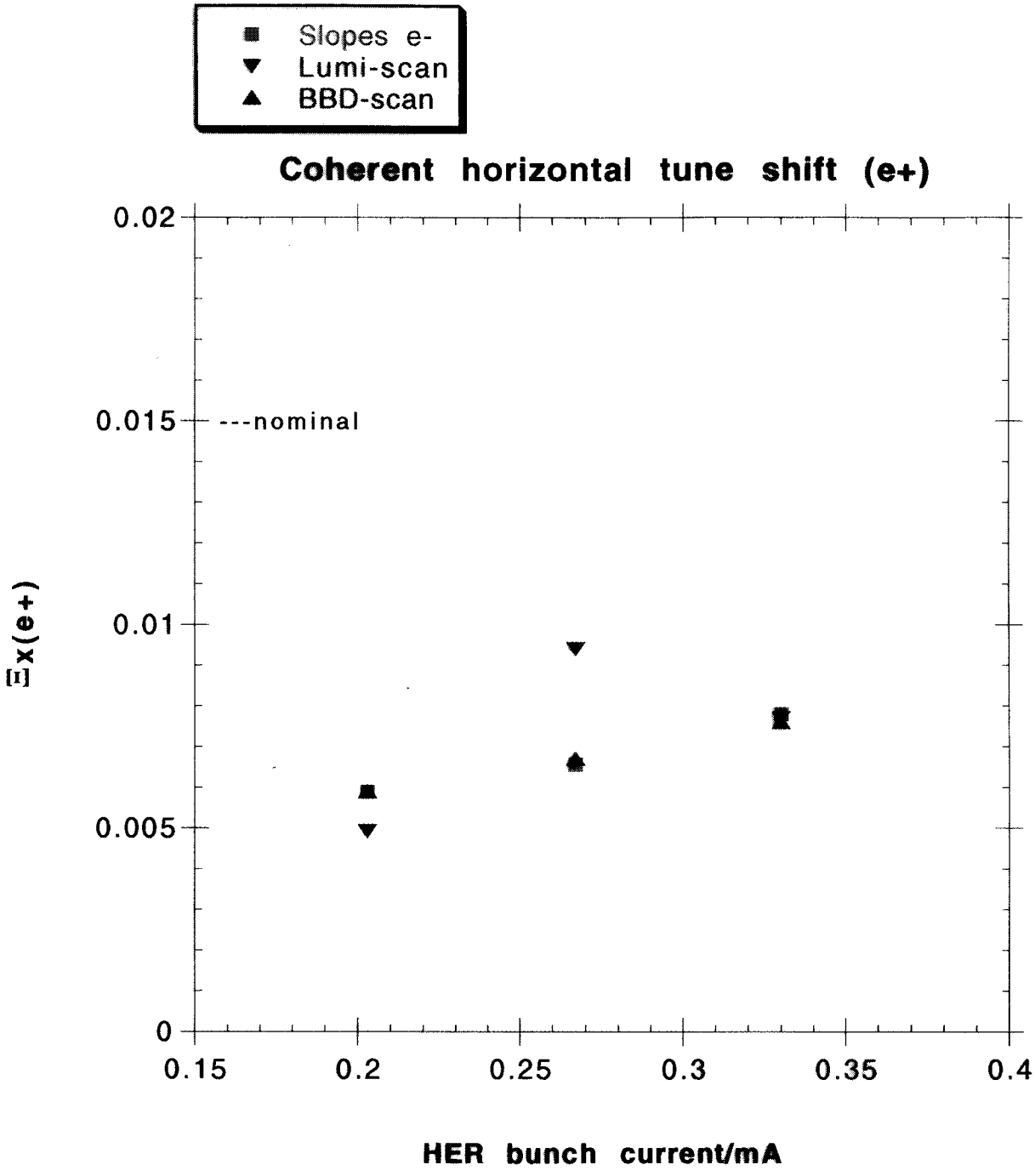



Expected (IP nom. beam sizes)
Bhabha luminometer
Inferred (BBD beam sizes)
Inferred(L_scan beam sizes)
Inferred (e- BBD_y slopes)
Single-bunch luminosity summary
Run 12.08.98
LER tunes: 0.577/0.638
HER tunes: 0.564/0.634
Luminosity /10^30 cm^-2 s^-1
I_L I_H /mA^2
0
0.5
1
1.5
2
0.2
0.4
0.6


Slopes e-
Lumi-scan
BBD-scan
Meas. Lumi
Coherent vertical tune shift (e-)
0.02
0.015
---nominal
0.01
0.005
0
Ξy(e-)
0
0.5
1
1.5
2
2.5
LER bunch current/mA

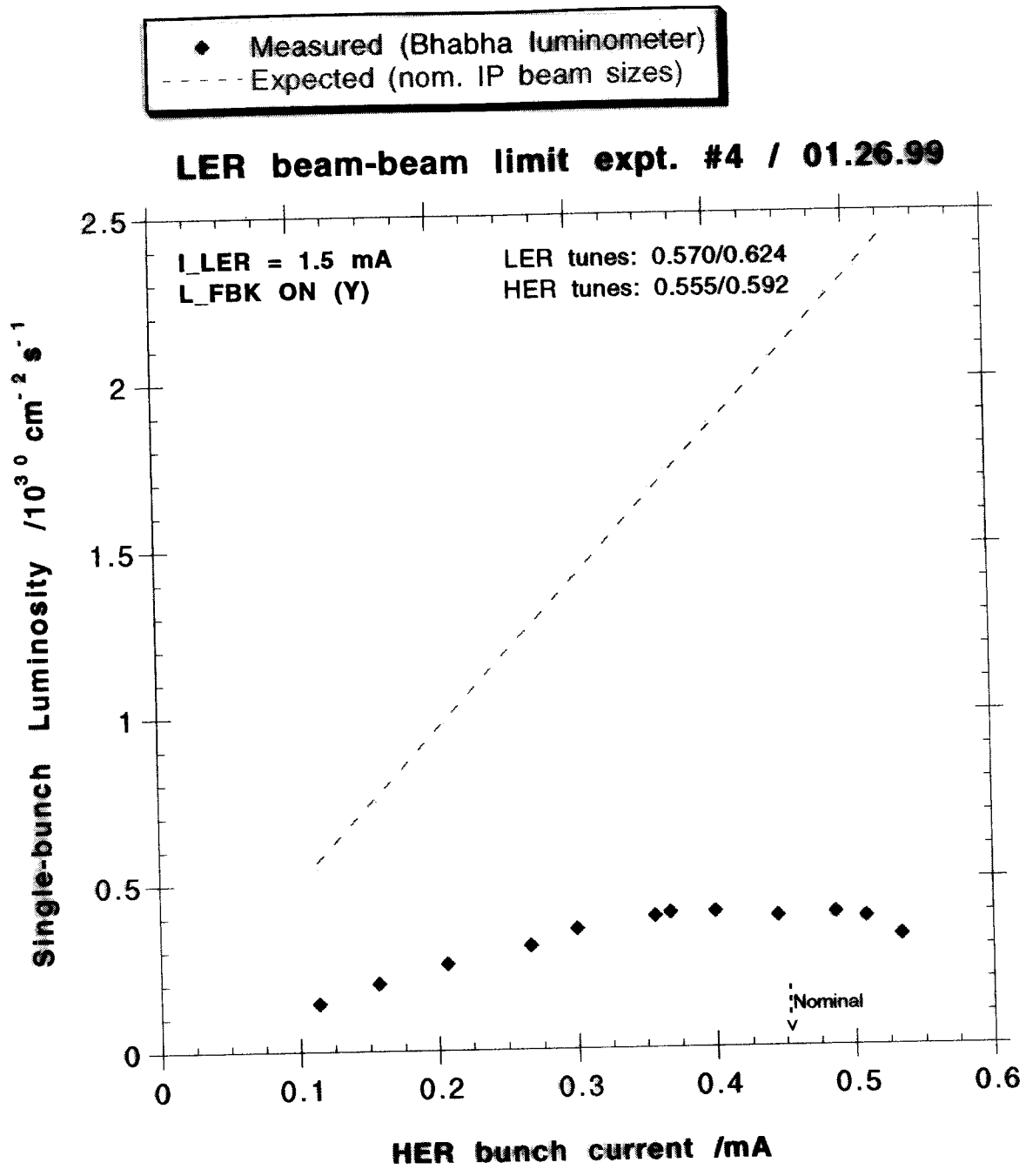

Slopes e-
BBD-scan
Lumi-scan
Coherent horizontal tune shift (e-)
0.025
0.02
0.015
0.01
0.005
0
---nominal
Ξx (e-)
0
0.5
1
1.5
2
2.5
LER bunch current/mA

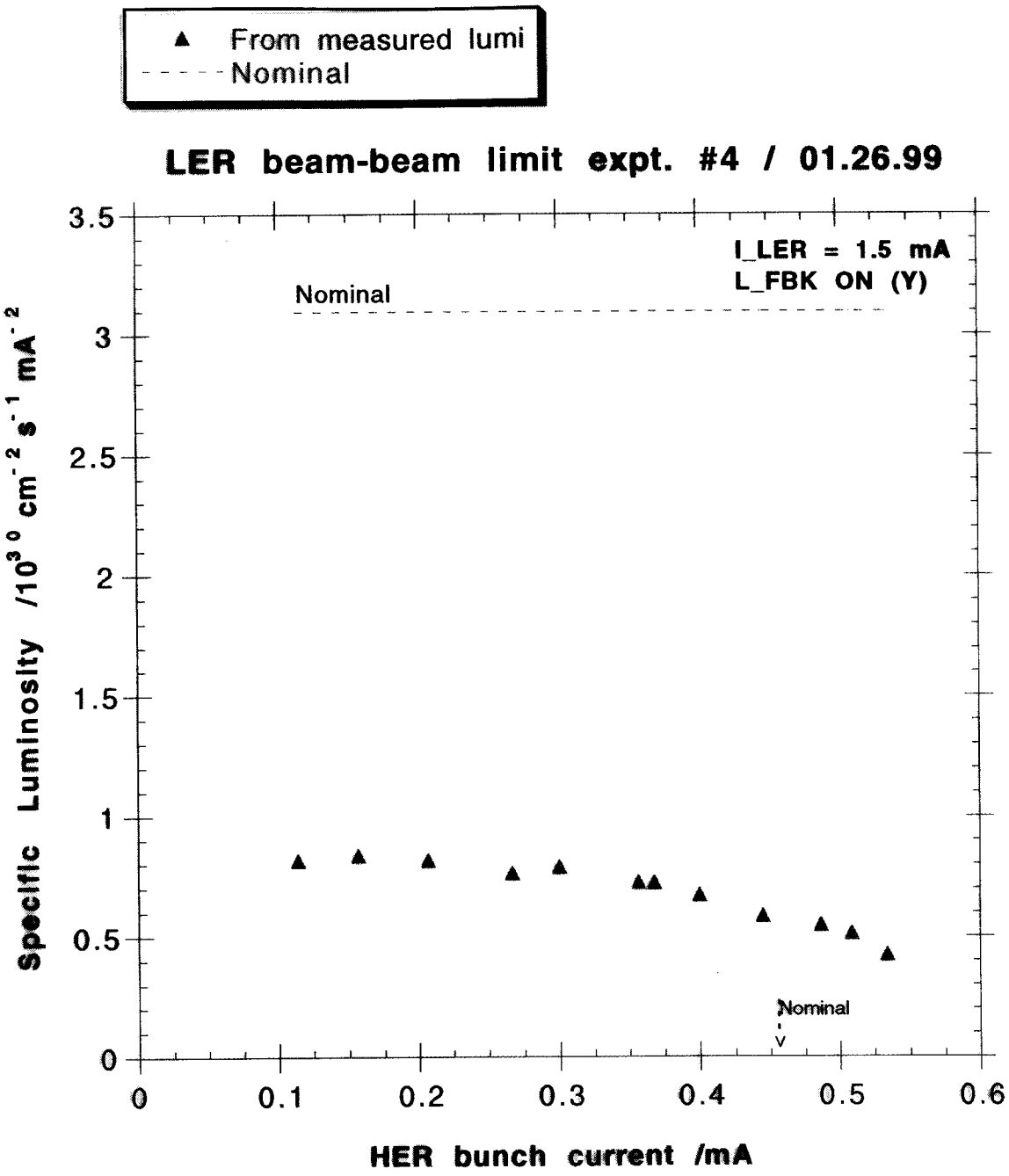

Slopes e-
Lumi-scan
Meas. Lumi
BBD-scan
Coherent vertical tune shift (e+)
0.02
0.015
---nominal
0.01
0.005
0
ξy(e+)
0.15
0.2
0.25
0.3
0.35
0.4
HER bunch current/mA

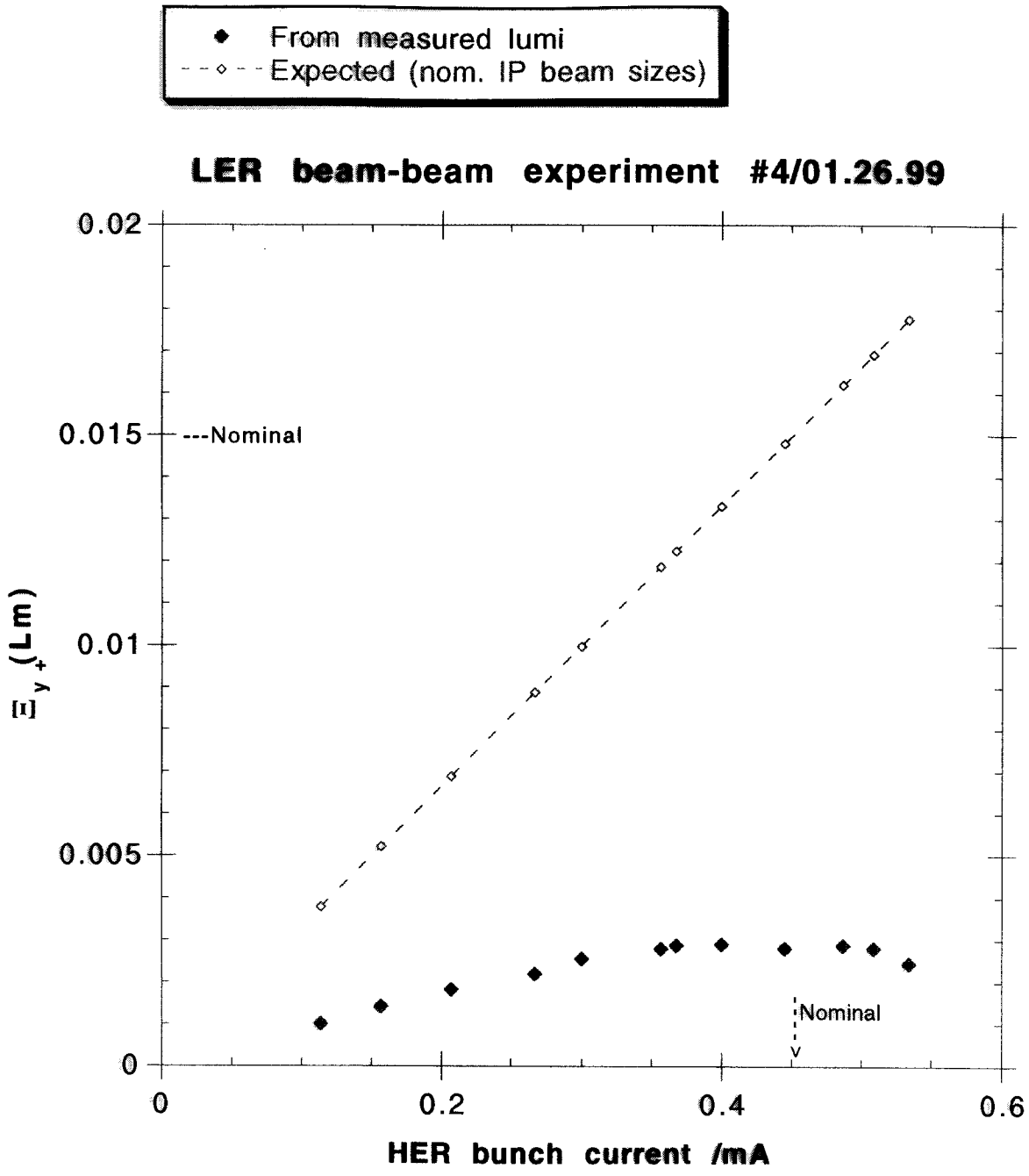

Slopes e-
Lumi-scan
BBD-scan
Coherent horizontal tune shift (e+)
0.02
0.015
---nominal
0.01
0.005
0
ξx(e+)
0.15
0.2
0.25
0.3
0.35
0.4
HER bunch current/mA

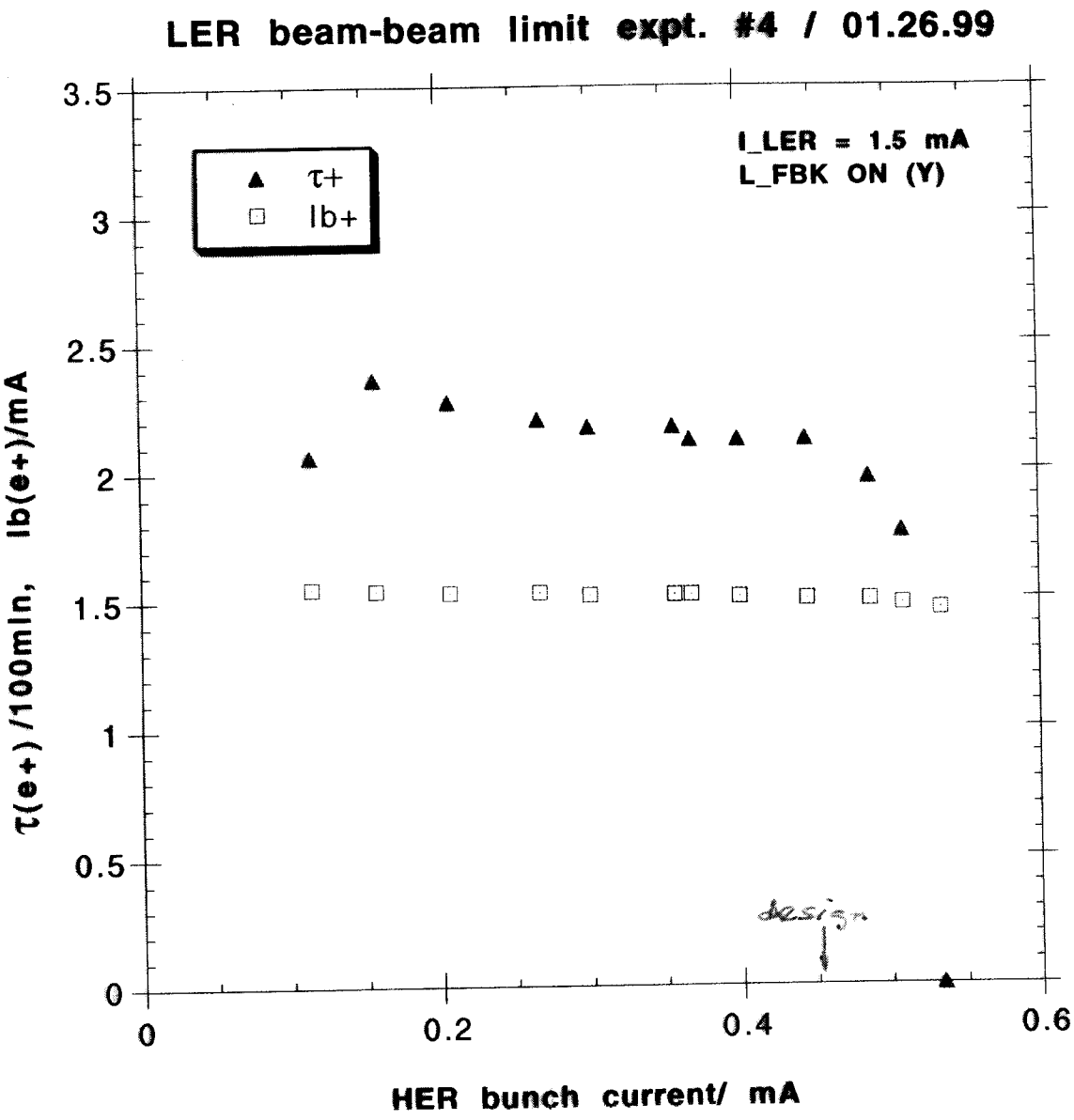
Current limitations / the HER bunch current

- **Observation**: rising the LER bunch current to make the HER unhappy **the LER bunch lifetime went bad!**
- **Possible explanation**: the HER bunch sizes shrink while rising the LER bunch current **increasing the tune shift seen by the LER bunch.** If so it may depend on working point in tune diagram.
- **The LER beam-beam experiment** - determine the maximum HER bunch current which can be collided with the LER without affecting its lifetime
  1. Single-bunch, initial tunes
  2. Multi-bunch, new LER working point


Measured (Bhabha luminometer)
Expected (nom. IP beam sizes)
LER beam-beam limit expt. #4 / 01.26.99
I_LER = 1.5 mA
L_FBK ON (Y)
LER tunes: 0.570/0.624
HER tunes: 0.555/0.592
Nominal
Single-bunch Luminosity /10^30 cm^-2 s^-1
HER bunch current /mA
0
0.5
1
1.5
2
2.5
0.1
0.2
0.3
0.4
0.5
0.6


From measured lumi
Nominal
LER beam-beam limit expt. #4 / 01.26.99
I_LER = 1.5 mA
L_FBK ON (Y)
Nominal
Nominal
Specific Luminosity /10^30 cm^-2 s^-1 mA^-2
HER bunch current /mA
0
0.5
1
1.5
2
2.5
3
3.5
0.1
0.2
0.3
0.4
0.5
0.6

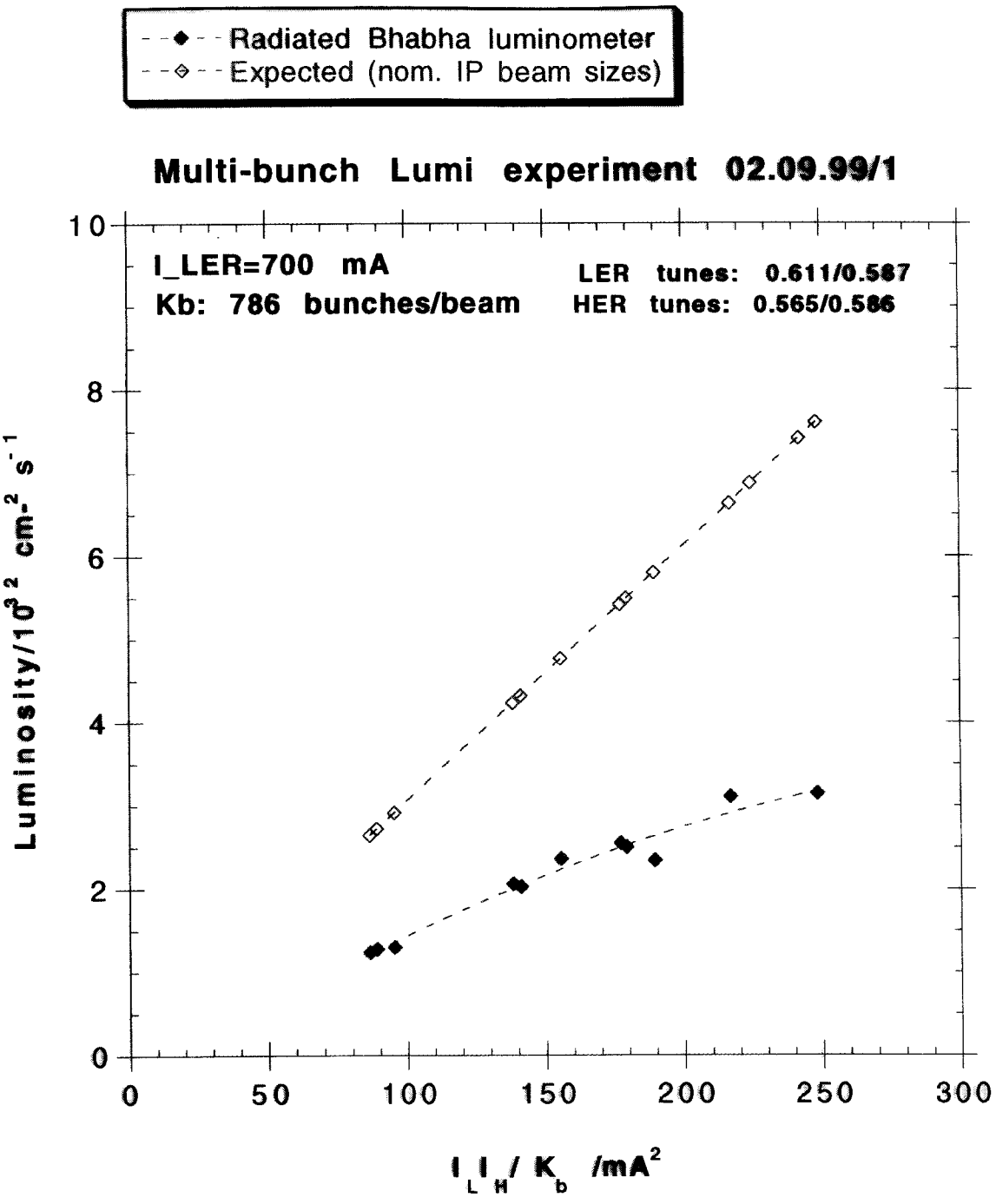

From measured lumi
Expected (nom. IP beam sizes)
LER beam-beam experiment #4/01.26.99
0.02
0.015
0.01
0.005
0
---Nominal
Nominal
[I]y+ (Lm)
0
0.2
0.4
0.6
HER bunch current /mA

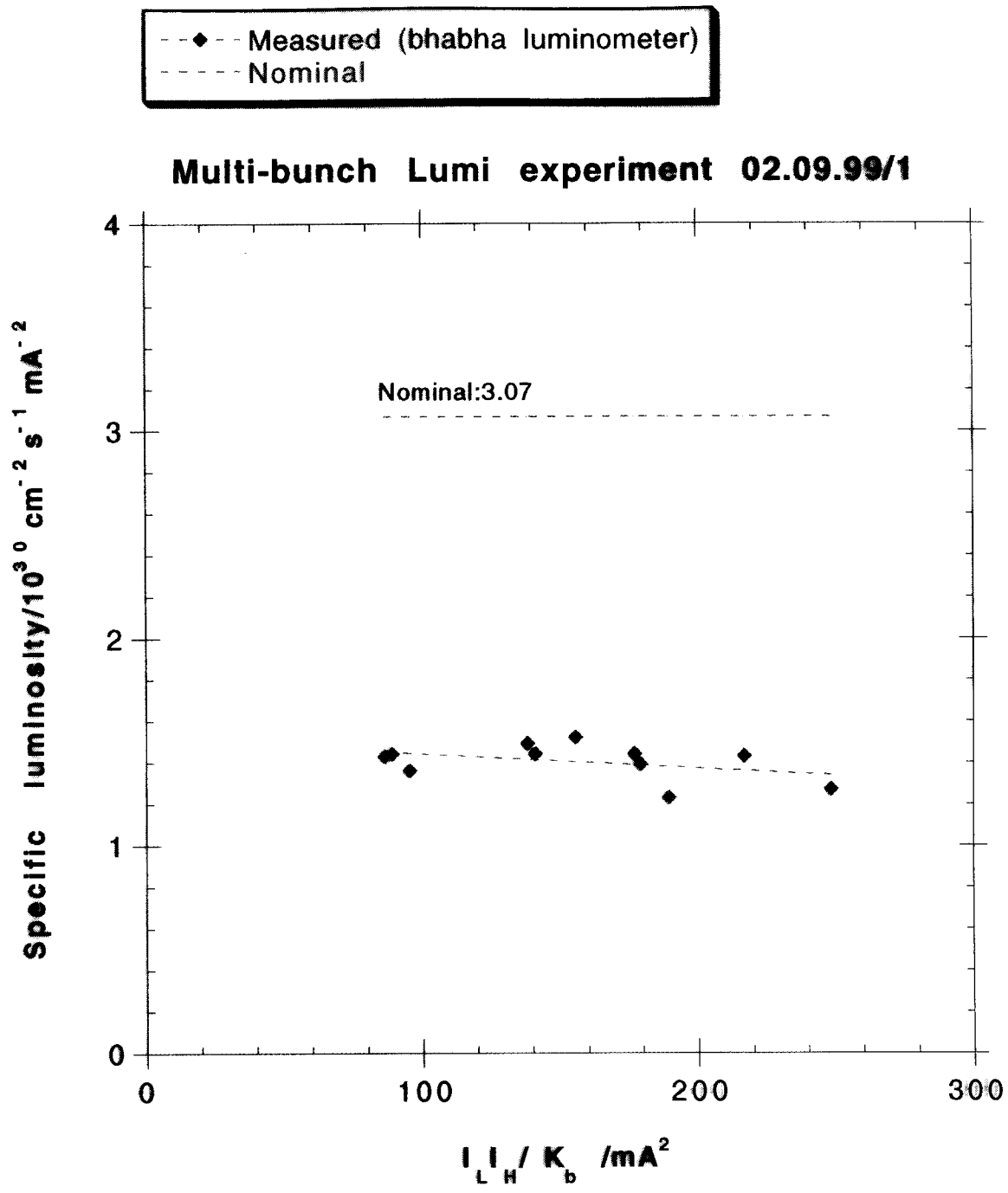

LER beam-beam limit expt. #4 / 01.26.99
I_LER = 1.5 mA
L_FBK ON (Y)
τ+
Ib+
design
τ(e+) /100mIn, Ib(e+)/mA
HER bunch current/ mA
3.5
3
2.5
2
1.5
1
0.5
0
0
0.2
0.4
0.6

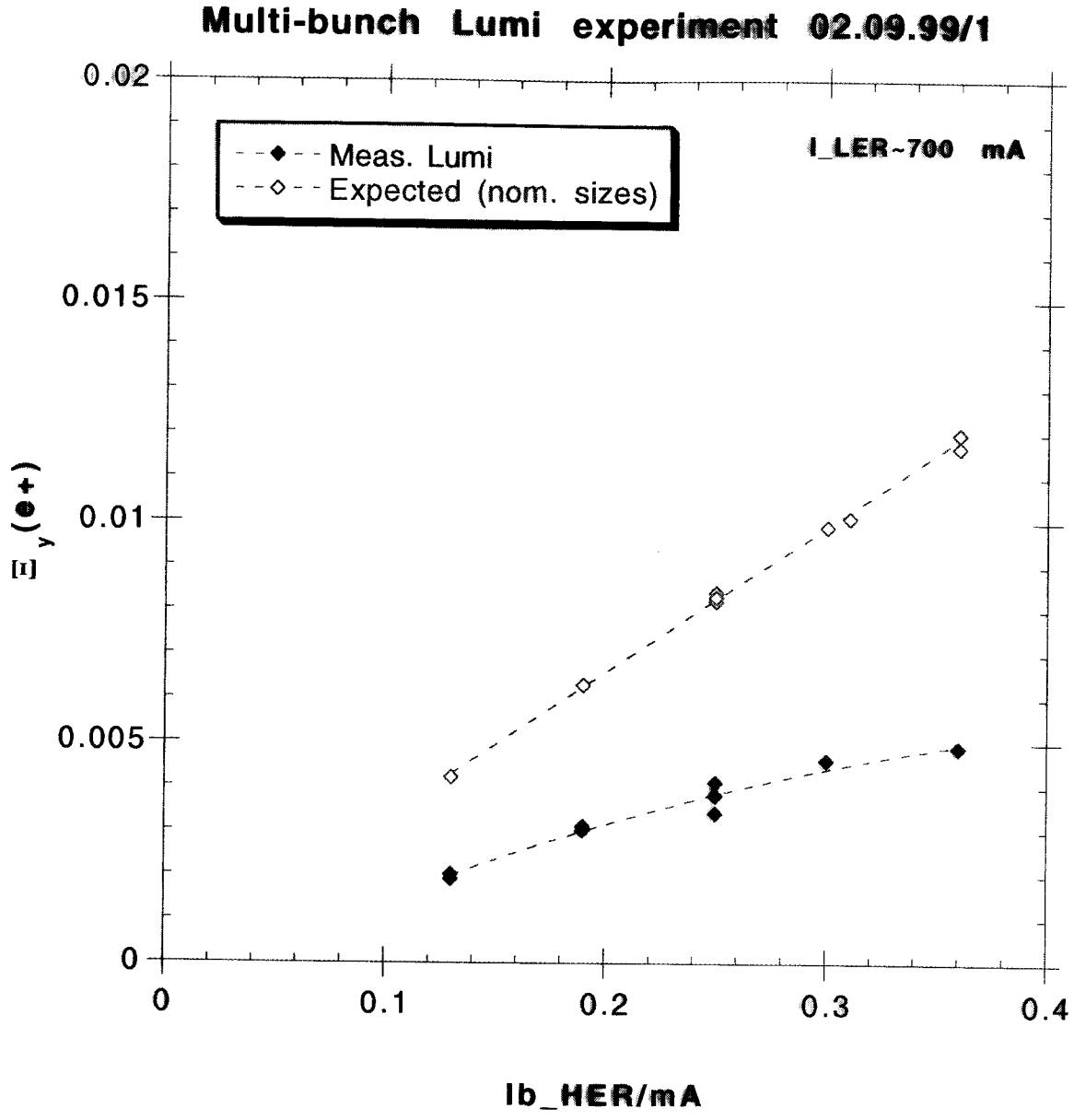
The Betatron Tunes

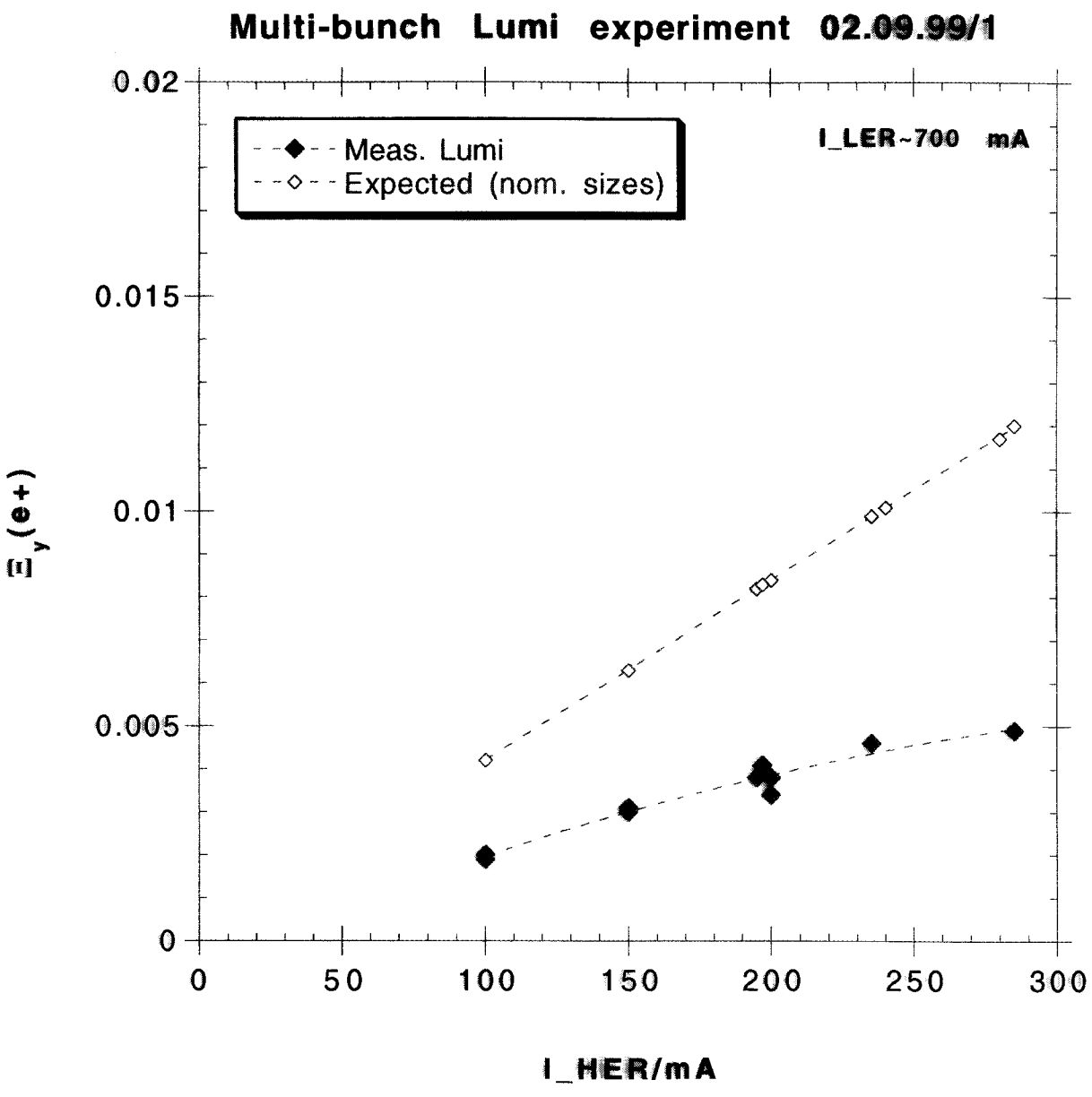
The Dec.'98 data were taken on the **initial working points**, close to the design ones, **sitting above the coupling resonance for both rings**.
A **new LER working point below the coupling resonance** was adopted in the February runs.

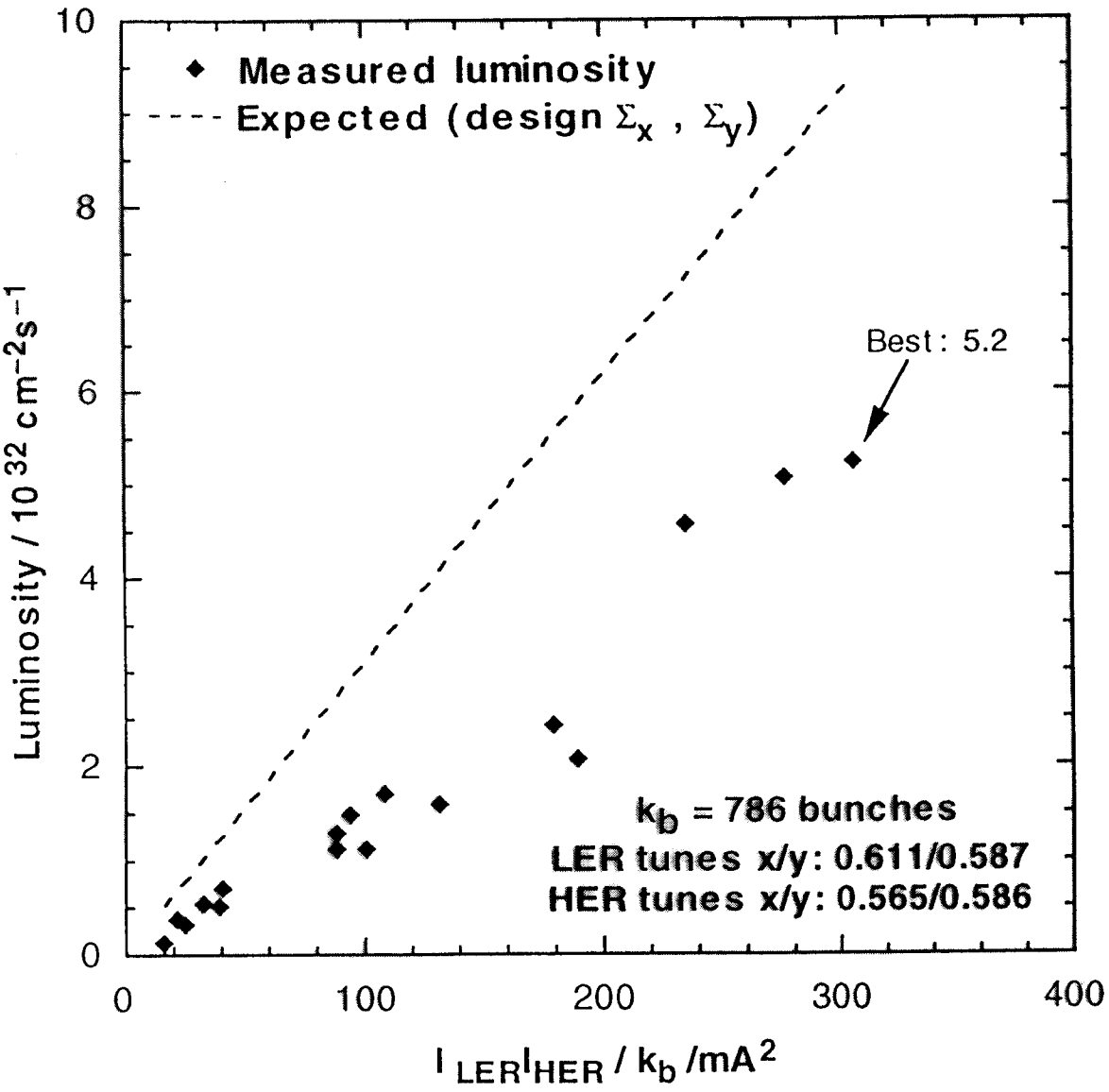
	Design		**Initial**		**Actual**	
	ν_x	ν_y	ν_x	ν_y	ν_x	ν_y
LER	0.570	0.642	0.577 ± 0.01	0.638 ± 0.01	0.610 ± 0.01	0.580 ± 0.01
HER	0.618	0.638	0.564 ± 0.01	0.634 ± 0.01	0.565 ± 0.01	0.585 ± 0.01

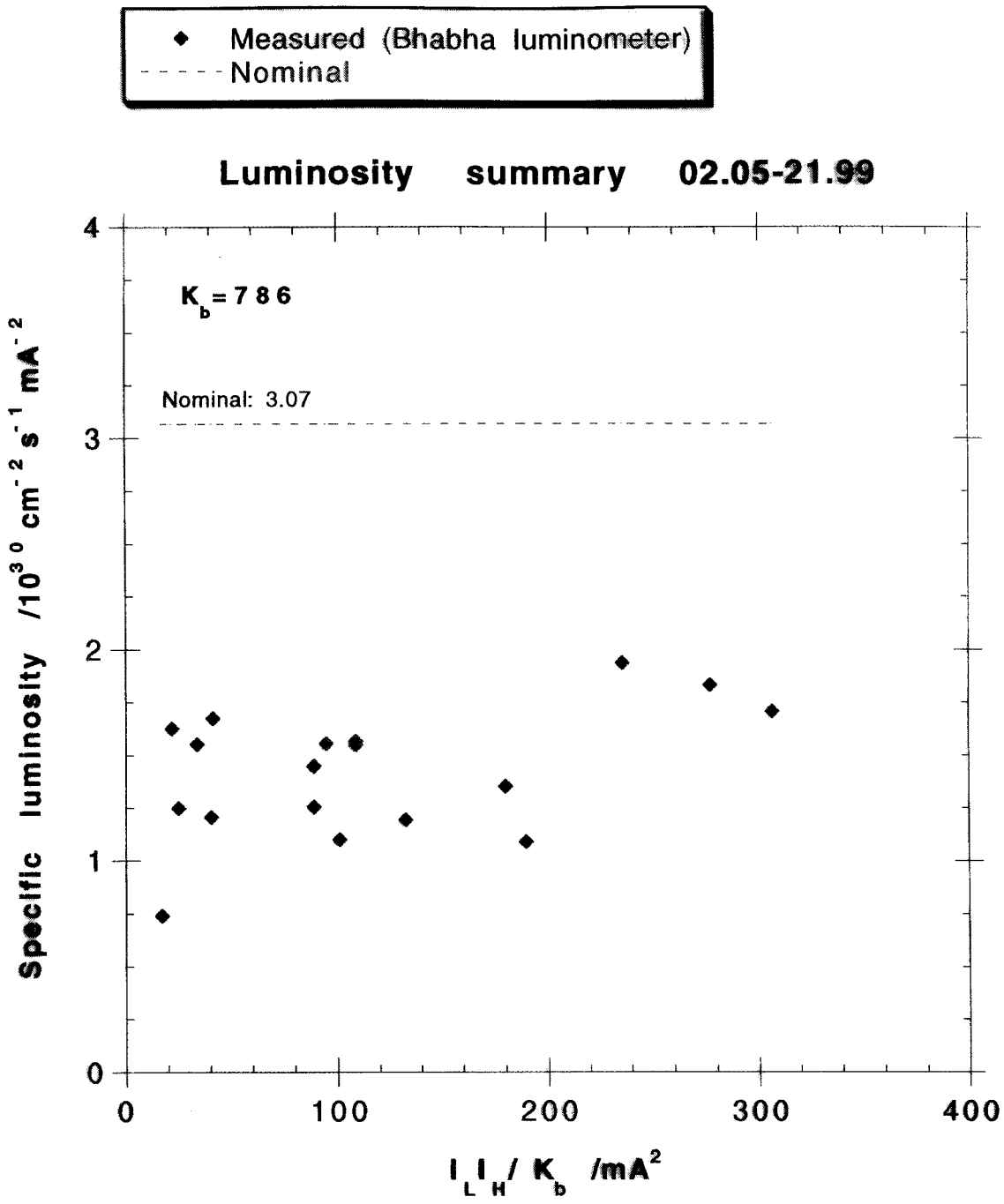

Radiated Bhabha luminometer
Expected (nom. IP beam sizes)
Multi-bunch Lumi experiment 02.09.99/1
I_LER=700 mA
Kb: 786 bunches/beam
LER tunes: 0.611/0.587
HER tunes: 0.565/0.586
Luminosity/10^32 cm^-2 s^-1
I_L I_H / K_b /mA^2
0
2
4
6
8
10
0
50
100
150
200
250
300

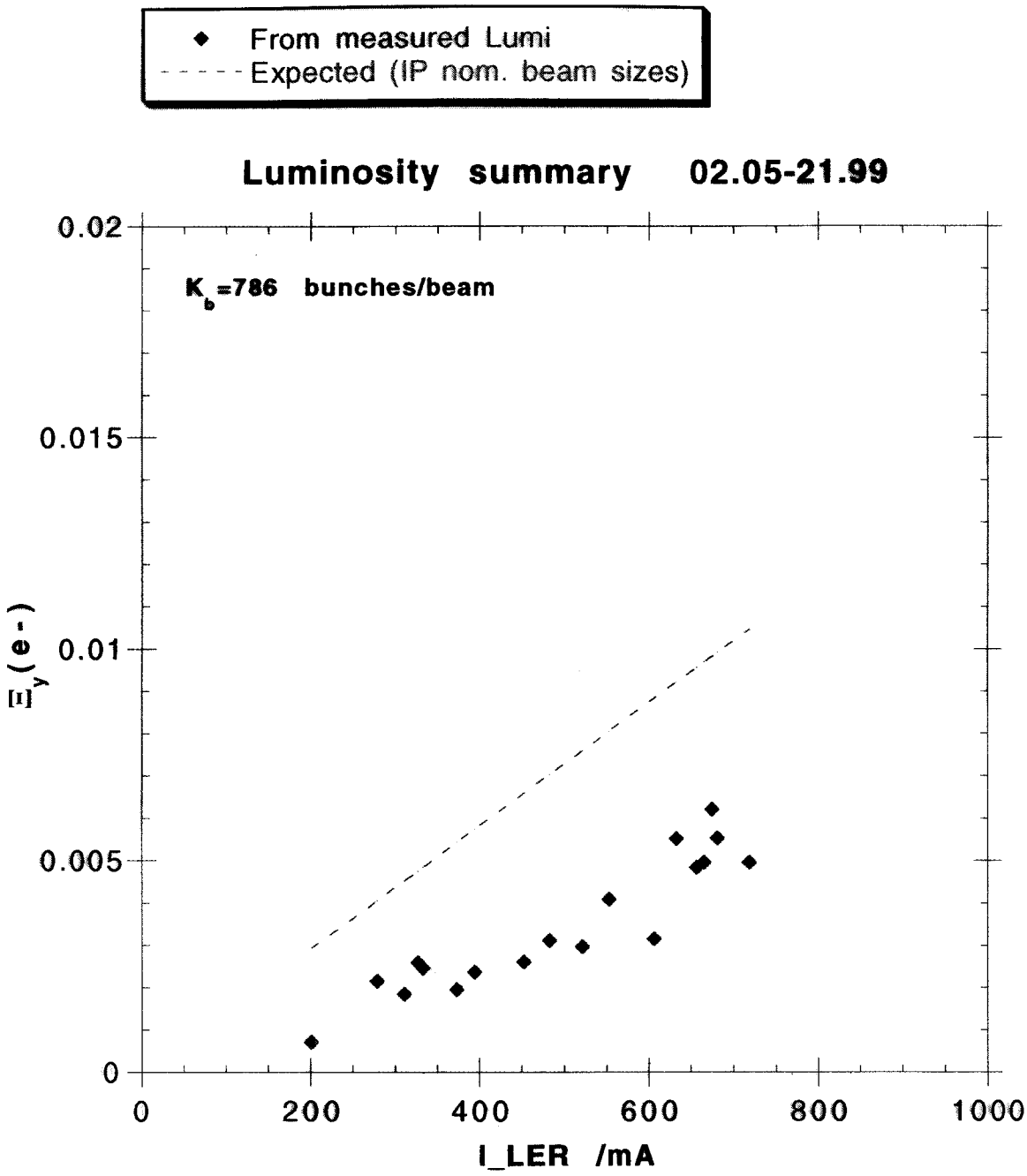

Measured (bhabha luminometer)
Nominal
Multi-bunch Lumi experiment 02.09.99/1
Nominal:3.07
Specific luminosity/10^30 cm^-2 s^-1 mA^-2
I_L I_H / K_b /mA^2
0
1
2
3
4
0
100
200
300

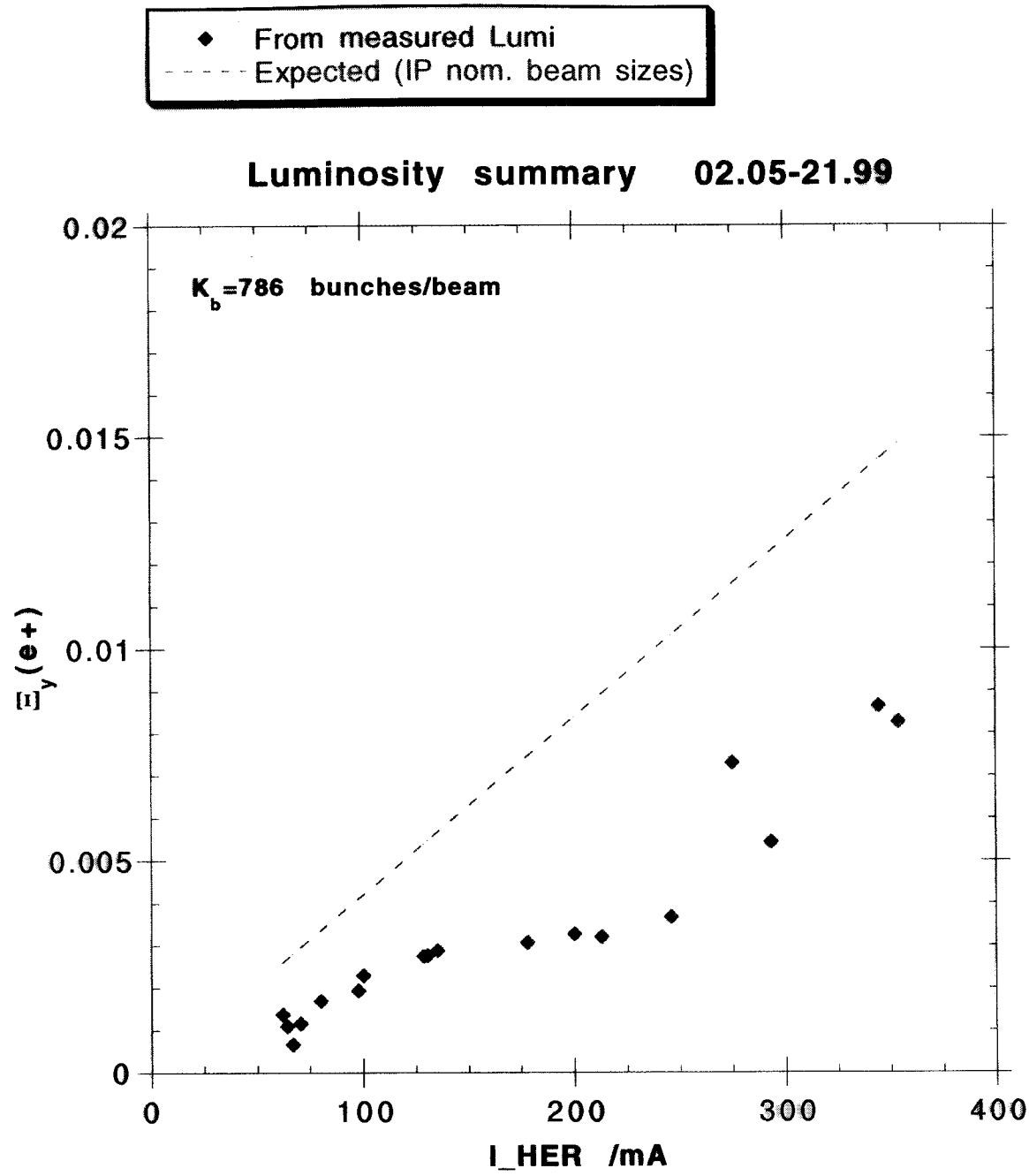

Multi-bunch Lumi experiment 02.09.99/1
Meas. Lumi
Expected (nom. sizes)
I_LER~700 mA
0.02
0.015
0.01
0.005
0
0
0.1
0.2
0.3
0.4
Ib_HER/mA

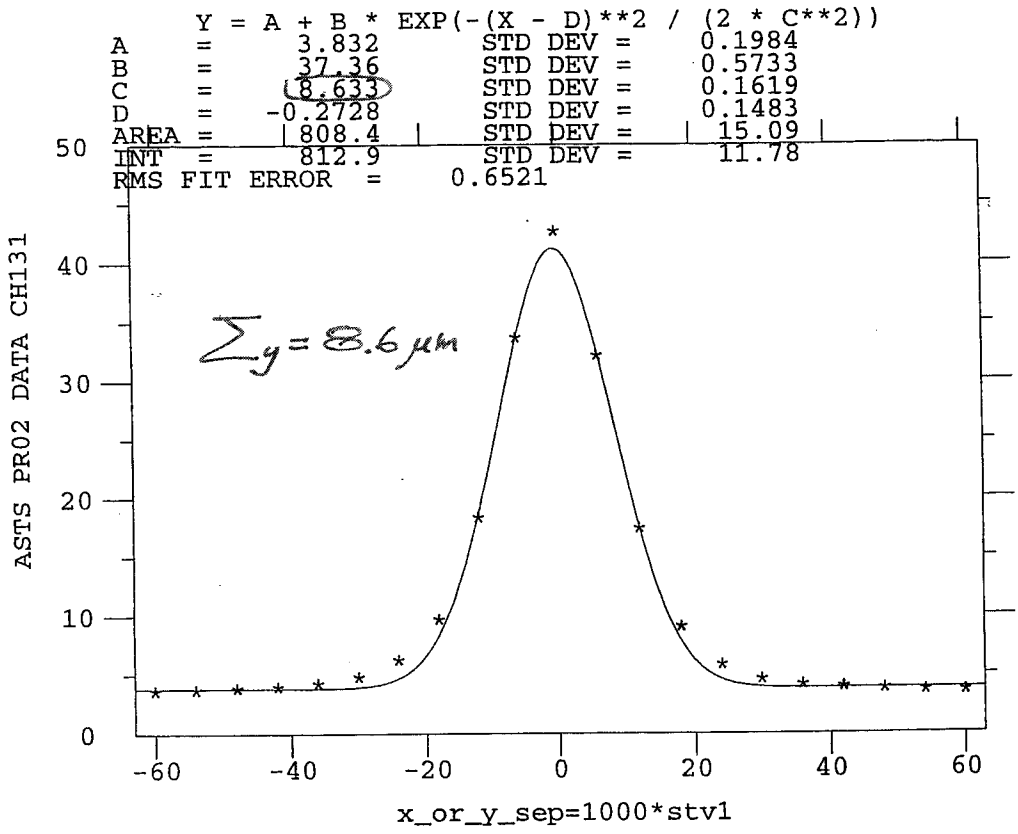

Multi-bunch Lumi experiment 02.09.99/1
Meas. Lumi
Expected (nom. sizes)
I_LER~700 mA
0.02
0.015
0.01
0.005
0
$\Xi_y(e+)$
0
50
100
150
200
250
300
I_HER/mA


Measured luminosity
Expected (design Σ_x , Σ_y)
Best : 5.2
k_b = 786 bunches
LER tunes x/y: 0.611/0.587
HER tunes x/y: 0.565/0.586
Luminosity / 10^{32} $cm^{-2}s^{-1}$
$I_{LER}I_{HER}$ / k_b /mA^2
0
2
4
6
8
10
0
100
200
300
400


Measured (Bhabha luminometer)
Nominal
Luminosity summary 02.05-21.99
K_b = 7 8 6
Nominal: 3.07
Specific luminosity /10^{30} cm^{-2} s^{-1} mA^{-2}
$I_L I_H / K_b$ /mA^2
0
1
2
3
4
0
100
200
300
400

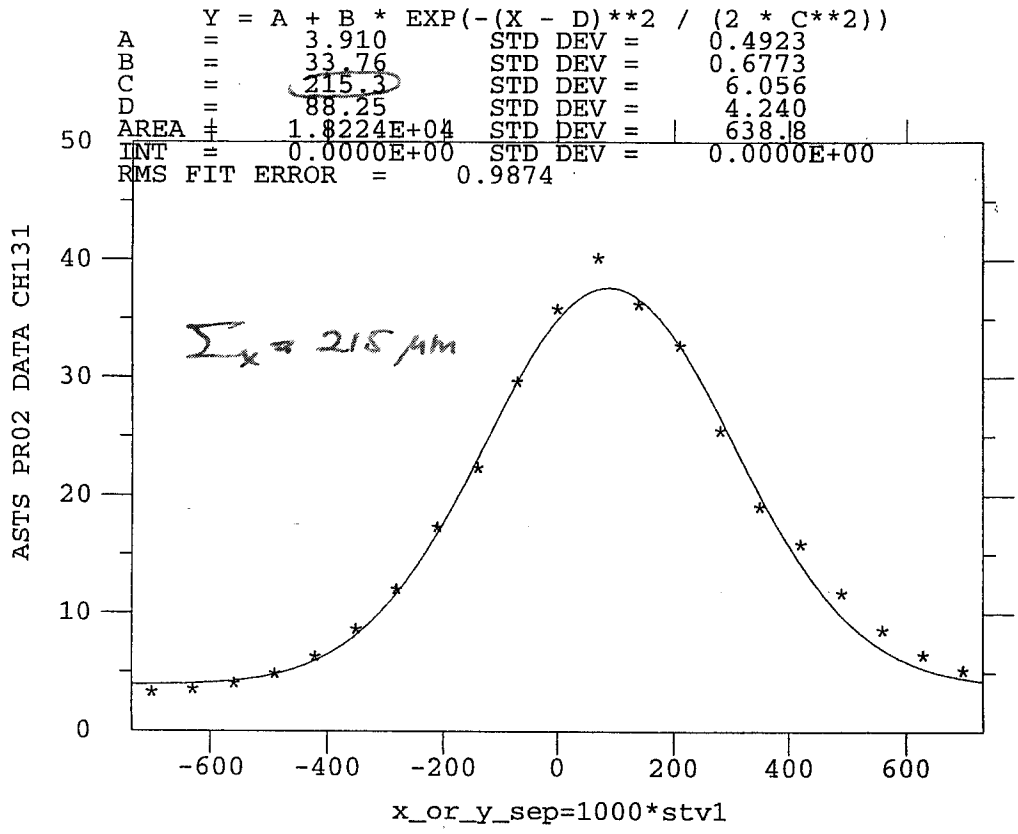

From measured Lumi
Expected (IP nom. beam sizes)
Luminosity summary 02.05-21.99
K_b=786 bunches/beam
0.02
0.015
0.01
0.005
0
[I]_y (e-)
0
200
400
600
800
1000
I_LER /mA


From measured Lumi
Expected (IP nom. beam sizes)
Luminosity summary 02.05-21.99
K_b=786 bunches/beam
0.02
0.015
0.01
0.005
0
[I]_y (e+)
0
100
200
300
400
I_HER /mA



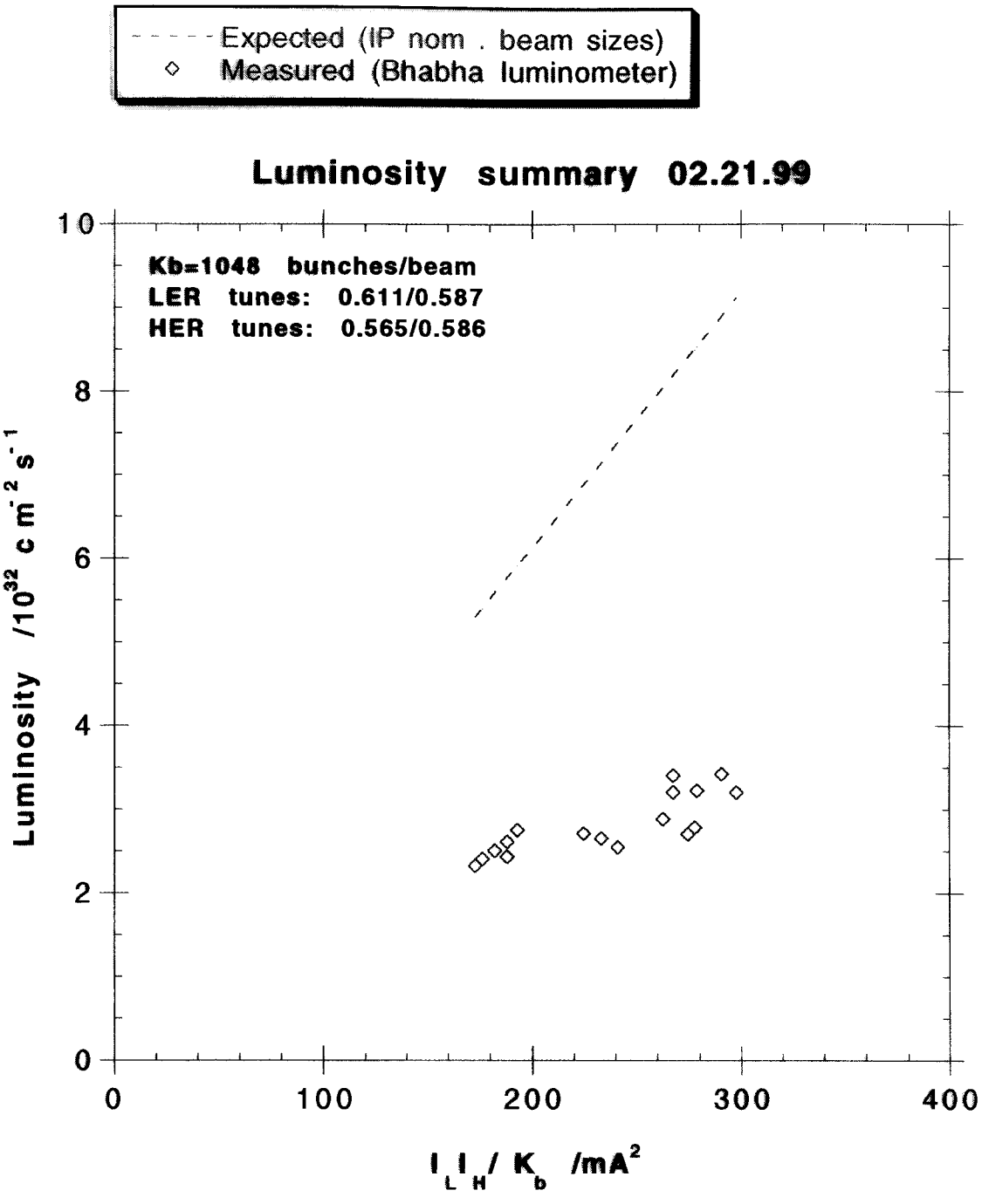
KNOB (COMMON$ROOT:[MKB]LERIP_Y.MKB.3) STRT=-.0600 STEPS= 21 SIZE= 600-5

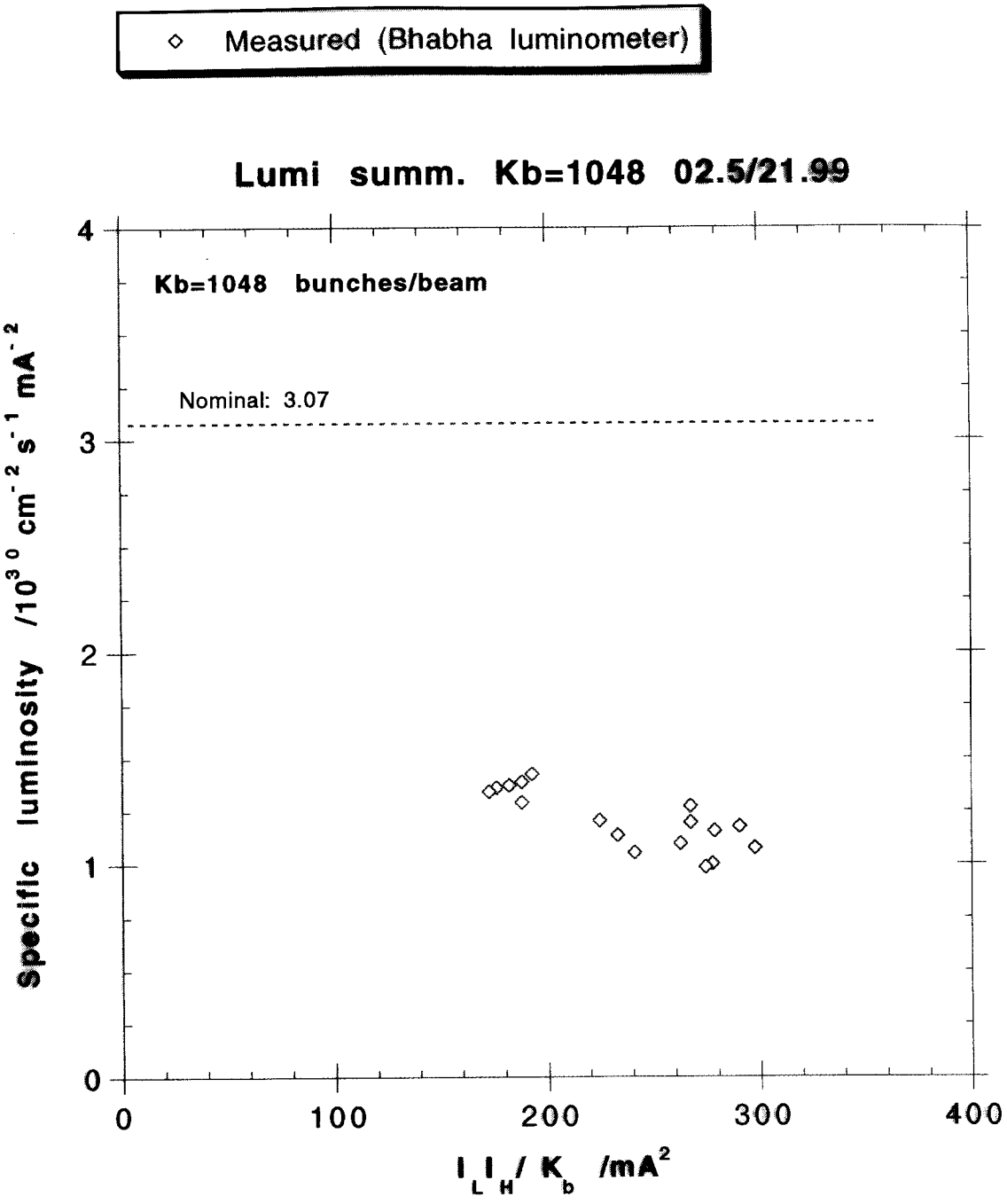
21-FEB-99 05:02:25



KNOB (COMMON$ROOT:[MKB]LERIP_X.MKB.2) STRT=-.7000 STEPS= 21 SIZE= .0700

21-FEB-99 05:05:32

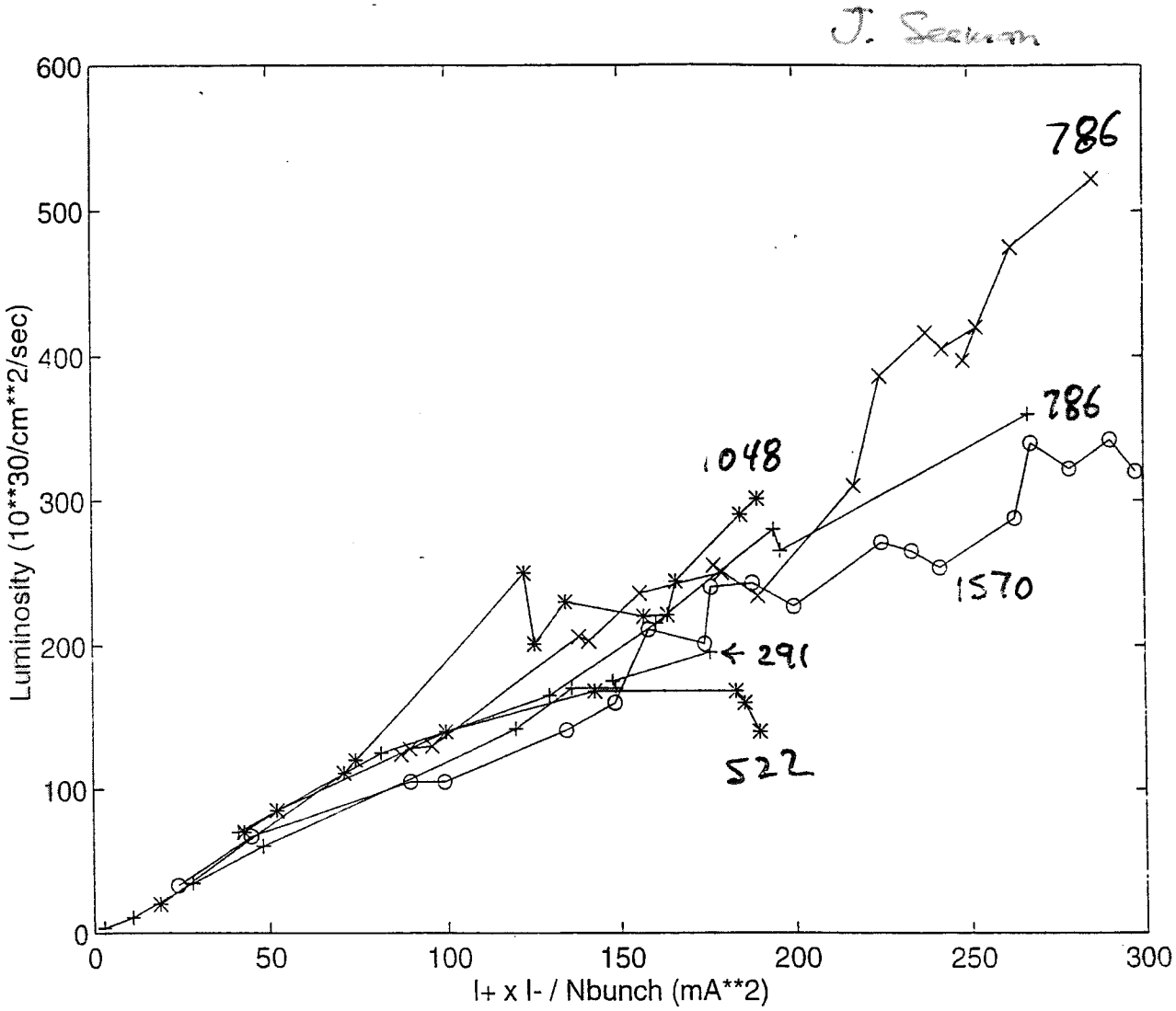

Expected (IP nom . beam sizes)
Measured (Bhabha luminometer)
Luminosity summary 02.21.99
Kb=1048 bunches/beam
LER tunes: 0.611/0.587
HER tunes: 0.565/0.586
Luminosity /10^32 c m^-2 s^-1
I_L I_H / K_b /mA^2
0
2
4
6
8
10
0
100
200
300
400


◇ Measured (Bhabha luminometer)
Lumi summ. Kb=1048 02.5/21.99
Kb=1048 bunches/beam
Nominal: 3.07
Specific luminosity /10^30 cm^-2 s^-1 mA^-2
I_L I_H / K_b /mA^2
0
1
2
3
4
0
100
200
300
400

Beam-beam tune shift summary

Best beam-beam tune shifts from the PEP-II '98 / '99 Winter Run

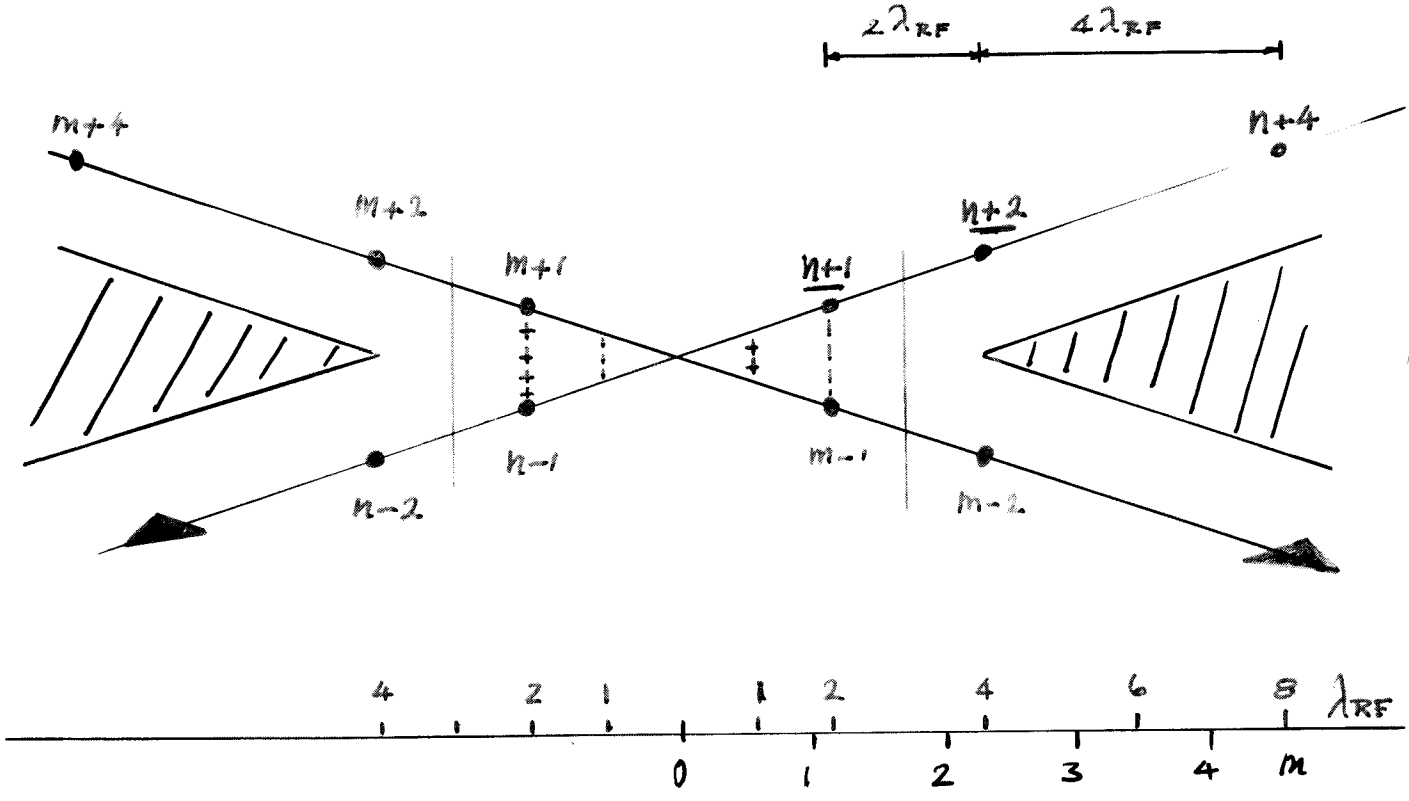
	Achieved				Design	
	Ξ_x	Ξ_y	ξ_x	ξ_y	ξ_x	ξ_y
LER	0.0075	0.009	0.015	0.018	0.030	0.030
HER	0.017	0.014	0.034	0.028	0.030	0.030


J. Seeman
786
786
1048
1570
291
522
Luminosity (10**30/cm**2/sec)
I+ x I- / Nbunch (mA**2)
0
100
200
300
400
500
600
0
50
100
150
200
250
300

Filling patterns / Parasitic Crossings

k_b	bunch spacing	comments
262	12 λ_{RF} (7.6 m)	regular spacing ($\sim 10\%$ ion gap)
524	6 λ_{RF} (3.8 m)	"
786	4 λ_{RF} (2.5 m)	"
1570	2 λ_{RF} (1.25 m)	"
1050	2 λ_{RF} (1.25 m)	regular spacing (large gap)
1048	2 - 4 - 2 - 4 $\cdots$	interleaved (two families)

The $k_b = 1048$ bunches pattern



Outlook

⋆ IP diagnostic procedures helped in fixing discrepancy on measured Luminosity

⋆ New LER working point improved performance (and freedom for the operator's green thumb)

⋆ Peak Luminosity = 5.2×10^{32} cm^{-2} s^{-1} a factor of 2 below expected with intentionally limited beam currents

⋆ Peak Specific Luminosity = 2×10^{30} cm^{-2} s^{-1} mA^{-2} a factor of 1.5 below expected for nominal beam sizes at IP

⋆ Vertical beam sizes affected by coupling and vertical dispersion introduced during IP steering. Developed colliding procedures to minimise

⋆ Beam-beam tune shifts close to design for **electrons**, still low for positrons

⋆ And now...**BaBaR is in place: BACK TO THE FUTURE ?!**

/massimo/private/tex/talks/lhc_whshp0499.tex / April 12, 1999