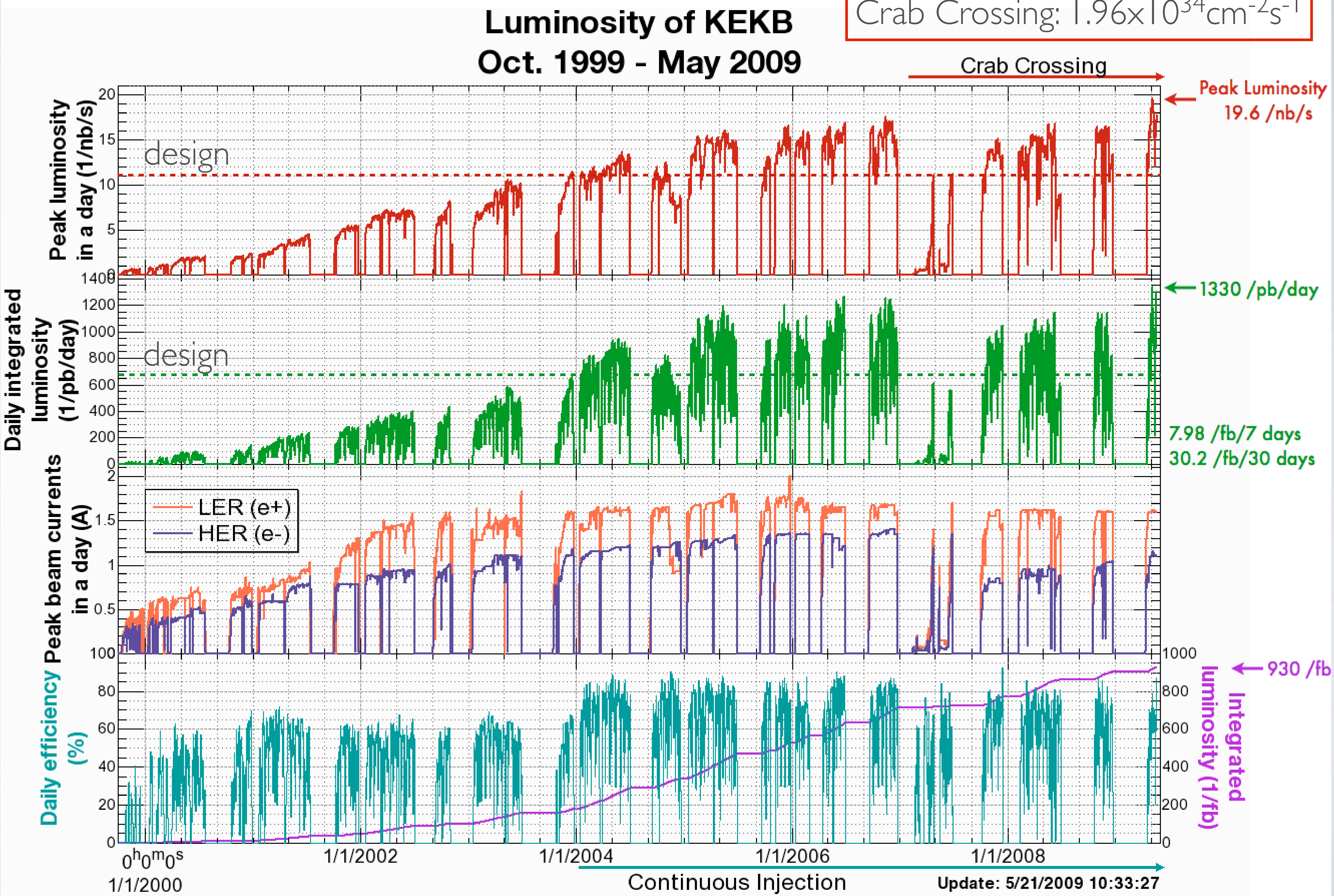
KEKB Upgrade

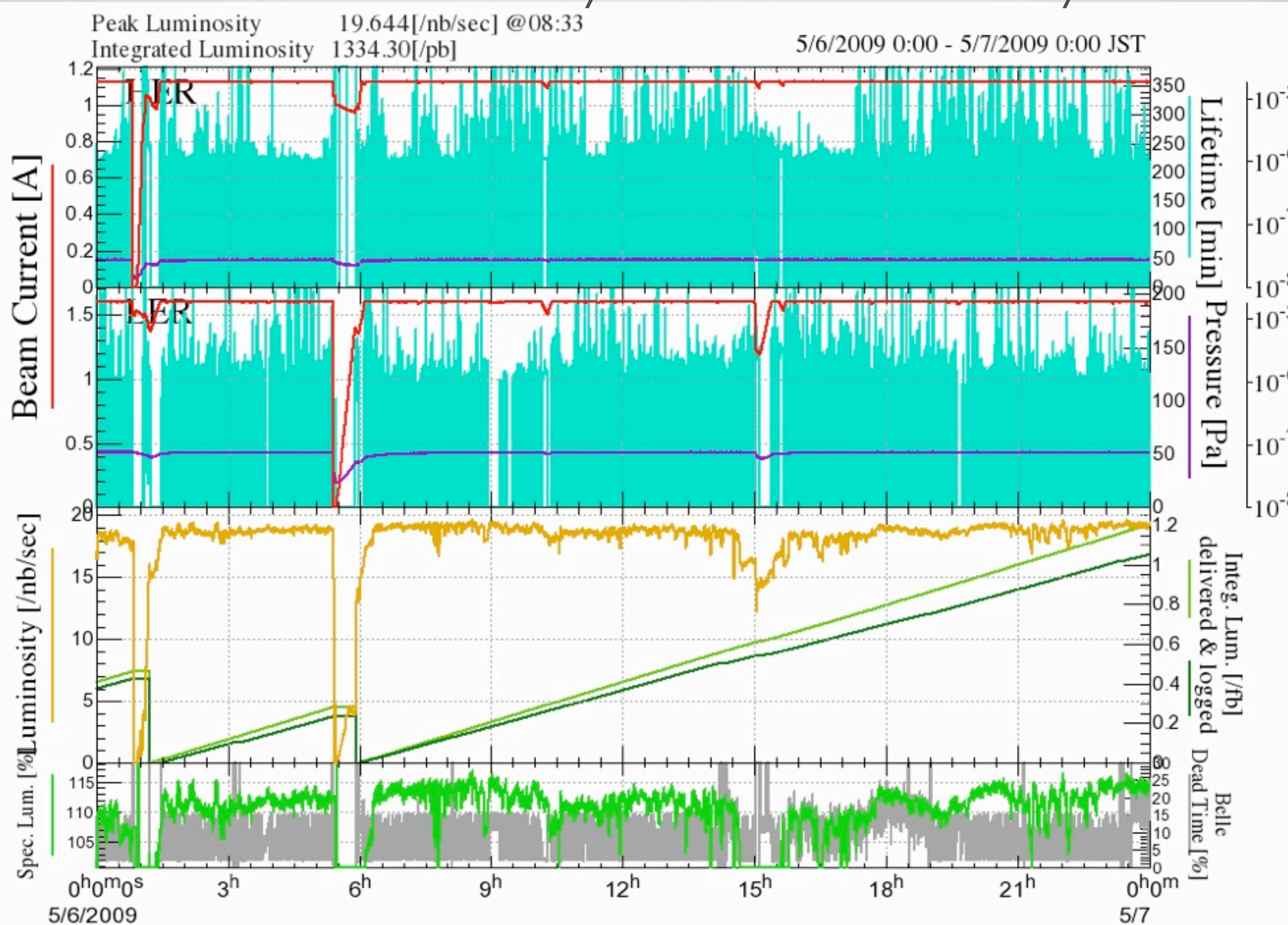
21 MAY 2009 @ HEPAP

K. Oide (KEK)

A new record was made by Crab Crossing: $1.96 \times 10^{34} cm^{-2}s^{-1}$



The Best Day = 1.33 fb^{-1}/day

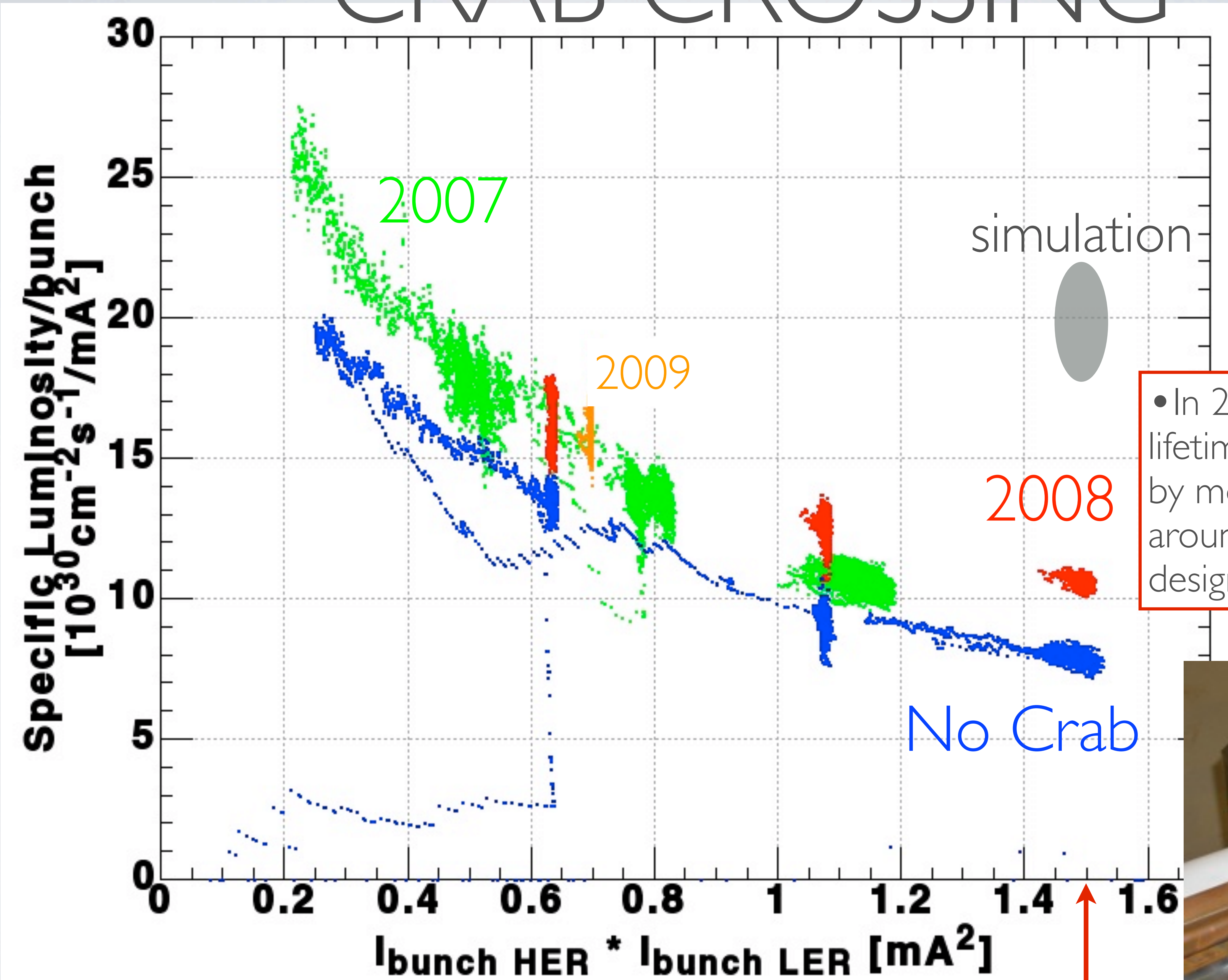


Crab **No Crab**

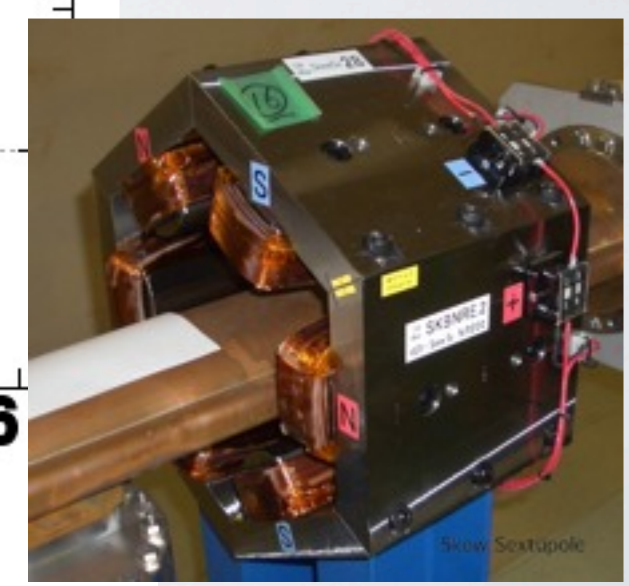
Date	5/6/2009 LER	5/6/2009 HER	11/15/2006 LER	11/15/2006 HER	Design LER	Design HER	
Eff. Crossing angle	0 (crab)		22		22		mrad
Beam current	1.60	1.13	1.65	1.33	2.6	1.1	A
Bunches	1584		1389		5000		
Bunch current	1.01	0.71	1.19	0.96	0.52	0.22	mA
Bunch spacing	mostly 1.8		1.8–2.4		0.6		m
Hor. emittance ε_x	18	24	18	24	18	18	nm
β_x^*	150	150	59	56	33	33	cm
β_y^*	0.59	0.59	0.65	0.59	1.0	1.0	cm
Hor. size @ IP	164	190	103	116	77	77	μm
Ver. size @ IP	0.85	0.85	1.9	1.9	1.9	1.9	μm
Beam-beam ξ_x	0.120	0.099	0.115	0.075	0.039	0.039	
Beam-beam ξ_y	0.123	0.088	0.104	0.058	0.052	0.052	
Luminosity	19.6		17.6		10		/nb/s
$\int$Lum./day	1330		1260		$\sim$ 600		/pb
$\int$Lum./7 days	7.98		7.82		–		/fb
$\int$Lum./30 days	25.68		30.21		–		/fb

Crab crossing has achieved higher luminosity with less beam currents, but the luminosity is still less than expected by simulations.

CRAB CROSSING



• In 2008, the beam lifetime was improved by modifying optics around CC, to reach the design intensity.



design intensity

M. Masuzawa

• In 2009, skew sextupoles are installed to correct chromatic coupling at the IP to reach 1.96x10^{34} cm^{-2}s^{-1}

Two Options for SuperKEKB

	High-Current (LER / HER)	Nano-Beam (LER / HER)	
I	9.4 / 4.1	3.3 / 1.9	A
ε_x	24 / 18	2.8 / 1.6	nm
$\varepsilon_y/\varepsilon_x$	1 / 0.5	0.84 / 0.46	%
ν_x	0.505	0.530	
β_x^*	400	44 / 25	mm
β_y^*	3 / 6	0.21 / 0.37	mm
ϕ_x	15	30	mrad
σ_z	5 / 3	6	mm
ξ_y	0.2 / 0.3	0.07	
$\mathcal{L}$	~ 4	~ 6	10^{35}

Possible with existing rf system at KEKB

$$\mathcal{L} \propto \gamma \left(\frac{I\xi_y}{\beta_y^*} \right)$$

(half crossing angle)

A conservative choice: does NOT assume Crab Waist

"HIGH CURRENT SCHEME" OF KEKB UPGRADE

$$\mathcal{L} \propto \gamma \left(\frac{I \xi_y}{\beta_y^*} \right)$$

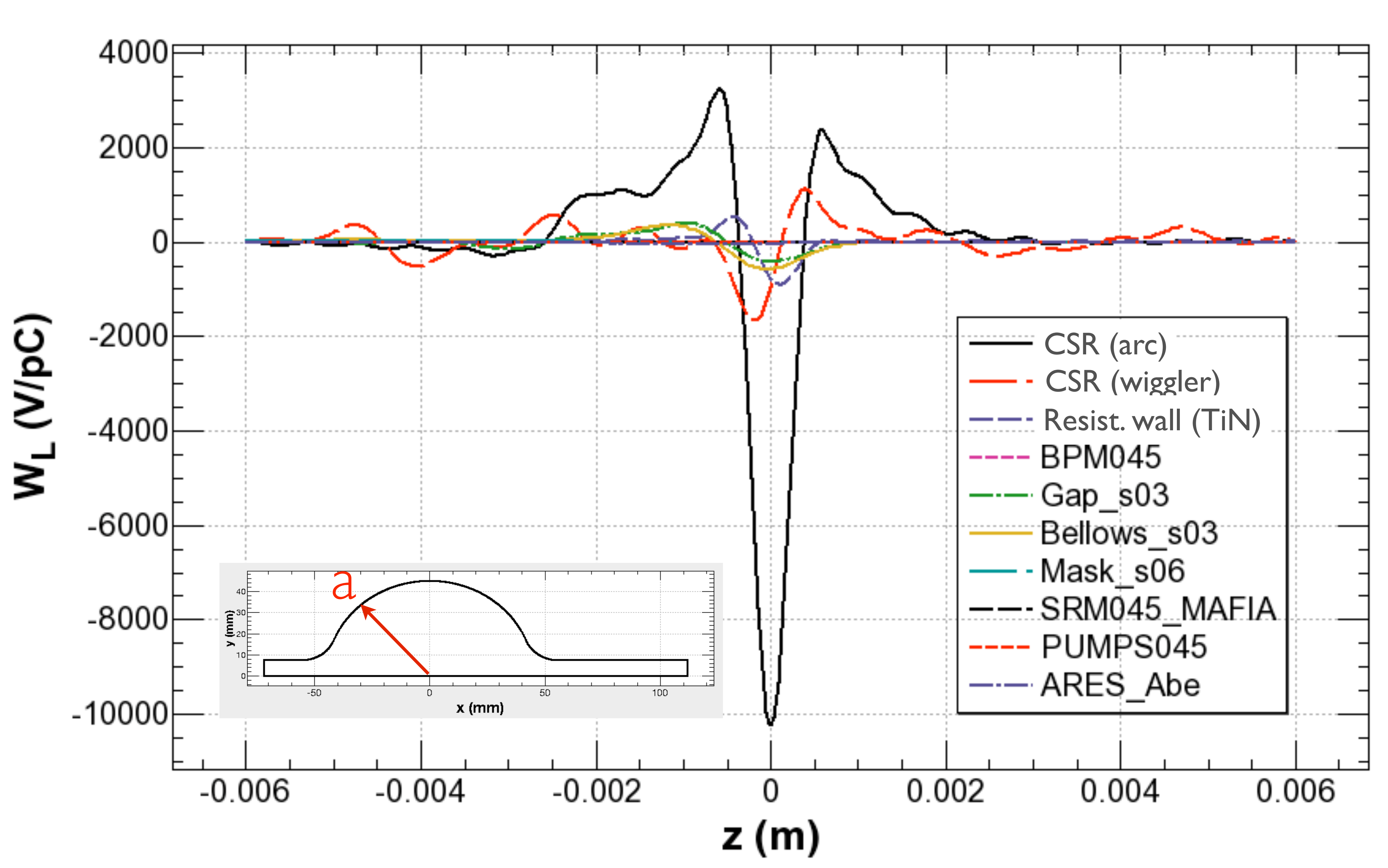
	Present KEKB (LER / HER)	High-Current Scheme (LER / HER)	
Beam energy E	3.5 / 8	3.5 / 8	GeV
Beam current I	1.6 / 1.1	9.4 / 4.1	A
β_y^*	6	3	mm
Vert. beam-beam ξ_y	0.14 / 0.09	~ 0.3	
$\mathcal{L}$	0.19	8	$10^{35} \mathrm{cm}^{-2}\mathrm{s}^{-1}$

Also assumes $\sigma_z \lesssim \beta_y^*$.

CSR REVISITED

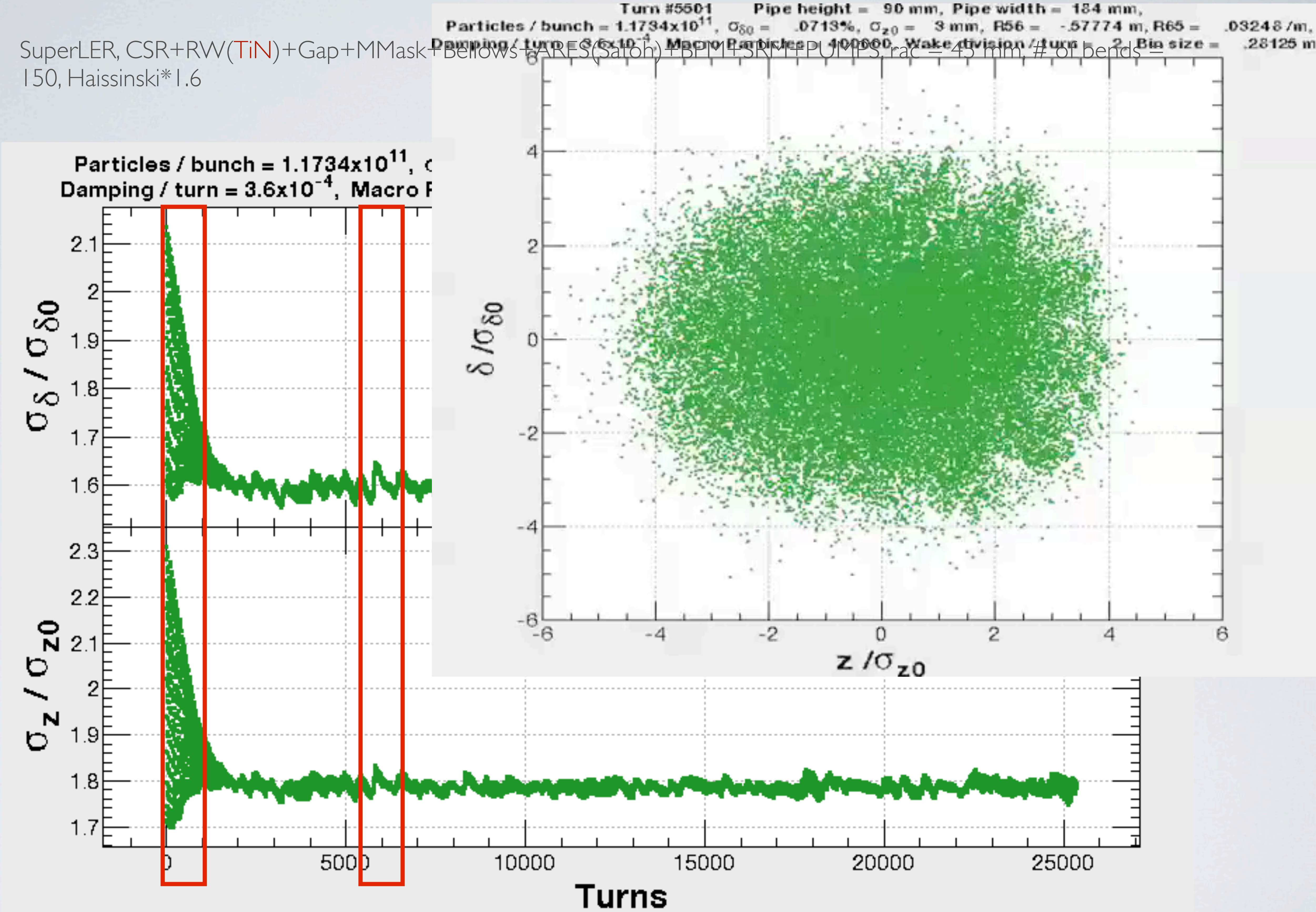
- Coherent Synchrotron Radiation (CSR) in SuperKEKB has been studied by T. Agoh since 2004 as reported at KEKB Accelerator Review Committee. http://www-kekb.kek.jp/MAC/2005/ (2005)
- An independent estimation was done in 2008, which takes realistic shape of the beam pipe and other impedances into account.
- Confirmed the results by T. Agoh.
- This is a heavy impact on the design parameters of SuperKEKB.

a = 45 mm wake functions



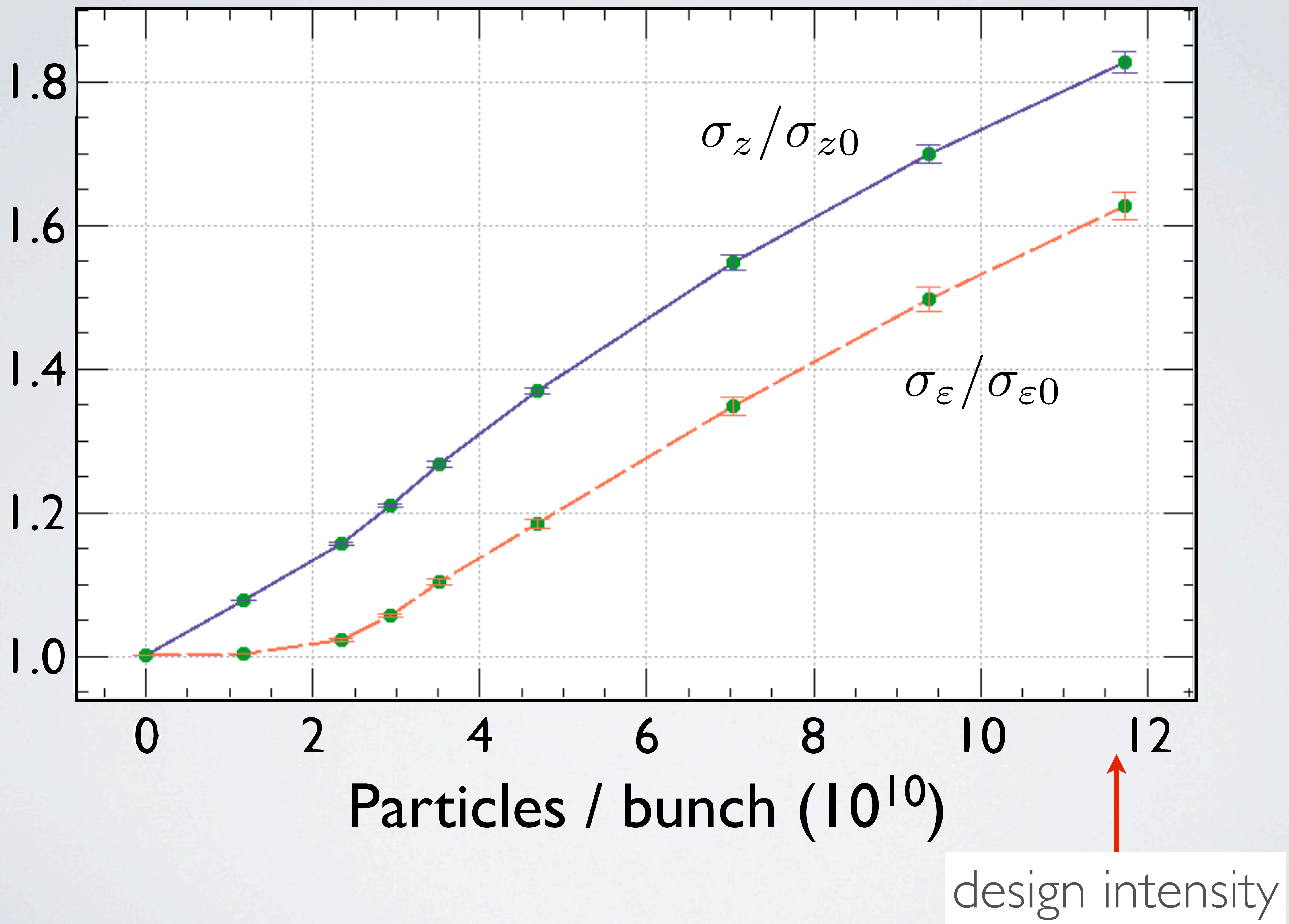
CSR dominates all other wakes.

SuperLER, CSR+RW(TiN)+Gap+MMask+Bellows+ARES(Satoh)+BPM+SRM+PUMPS, rac = 45 mm, # of bends = 150, Haissinski*1.6

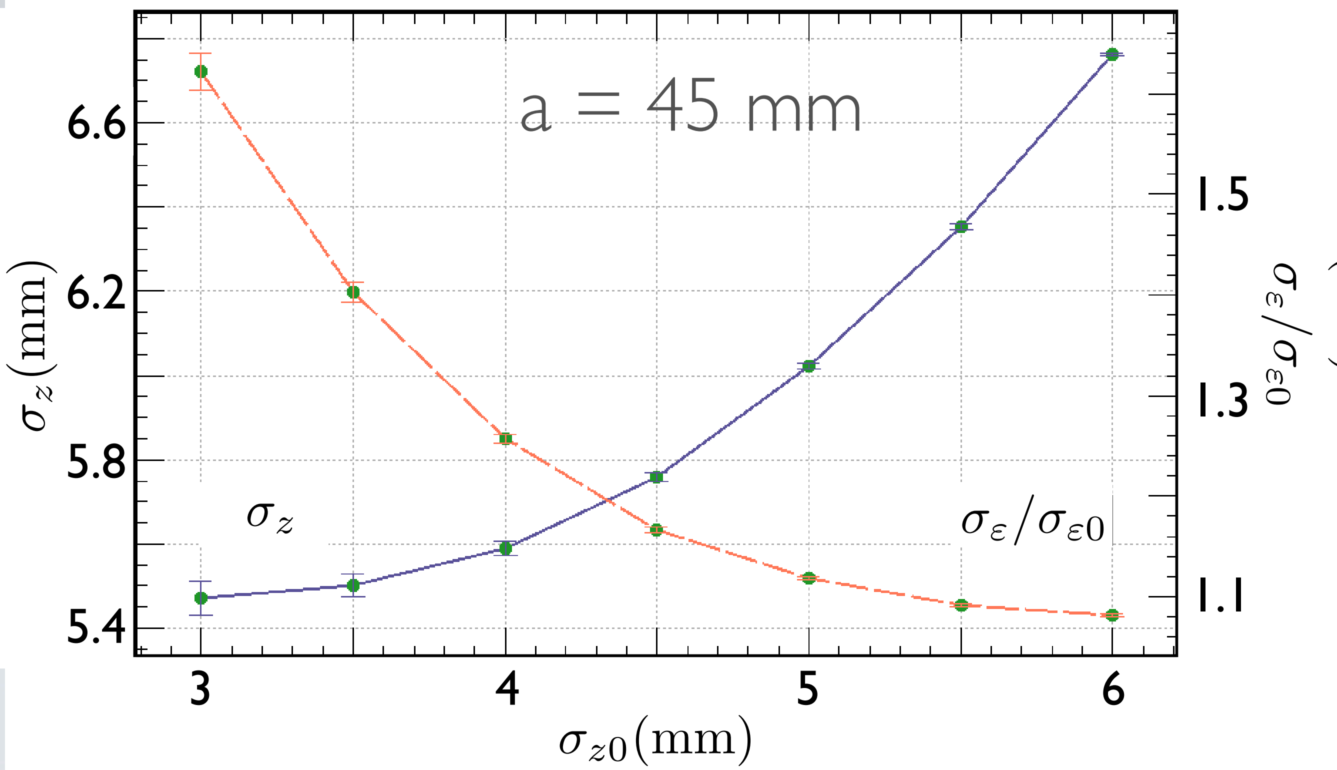


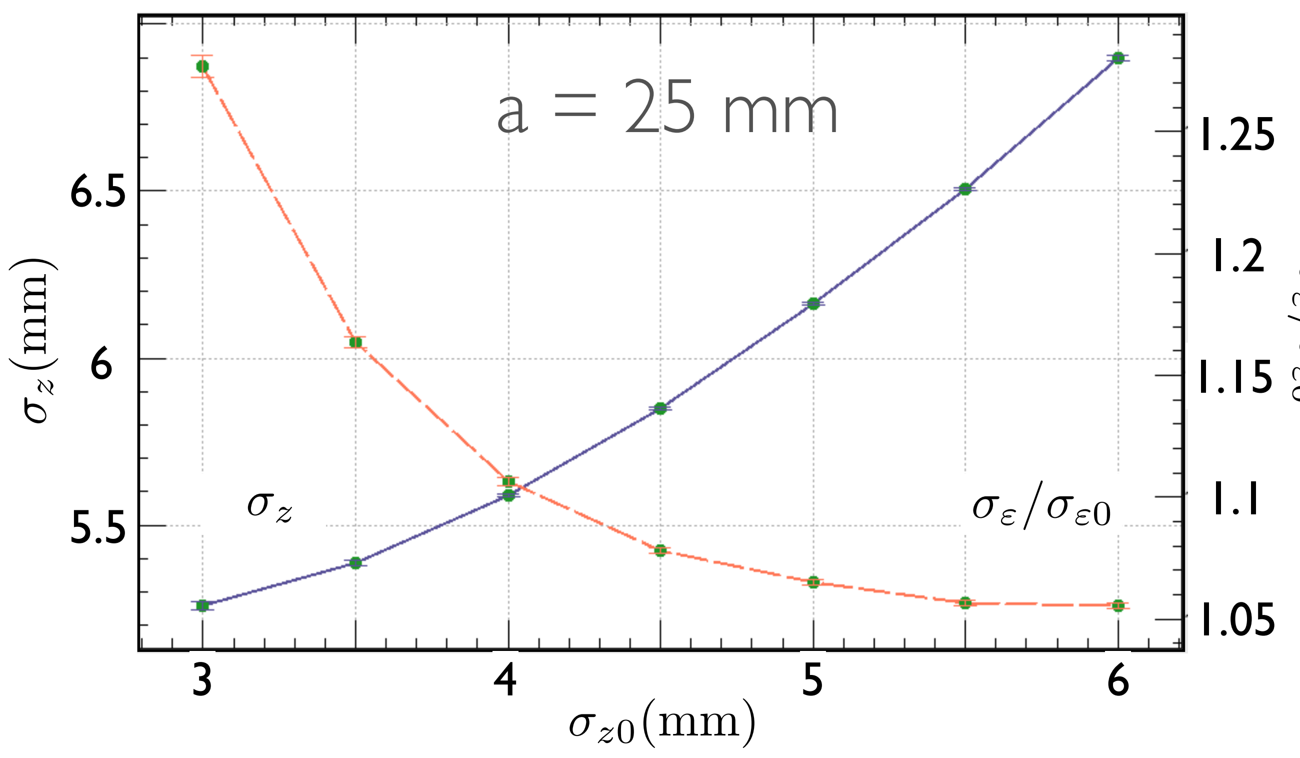
Microwave instabilities: no stable state is reached.

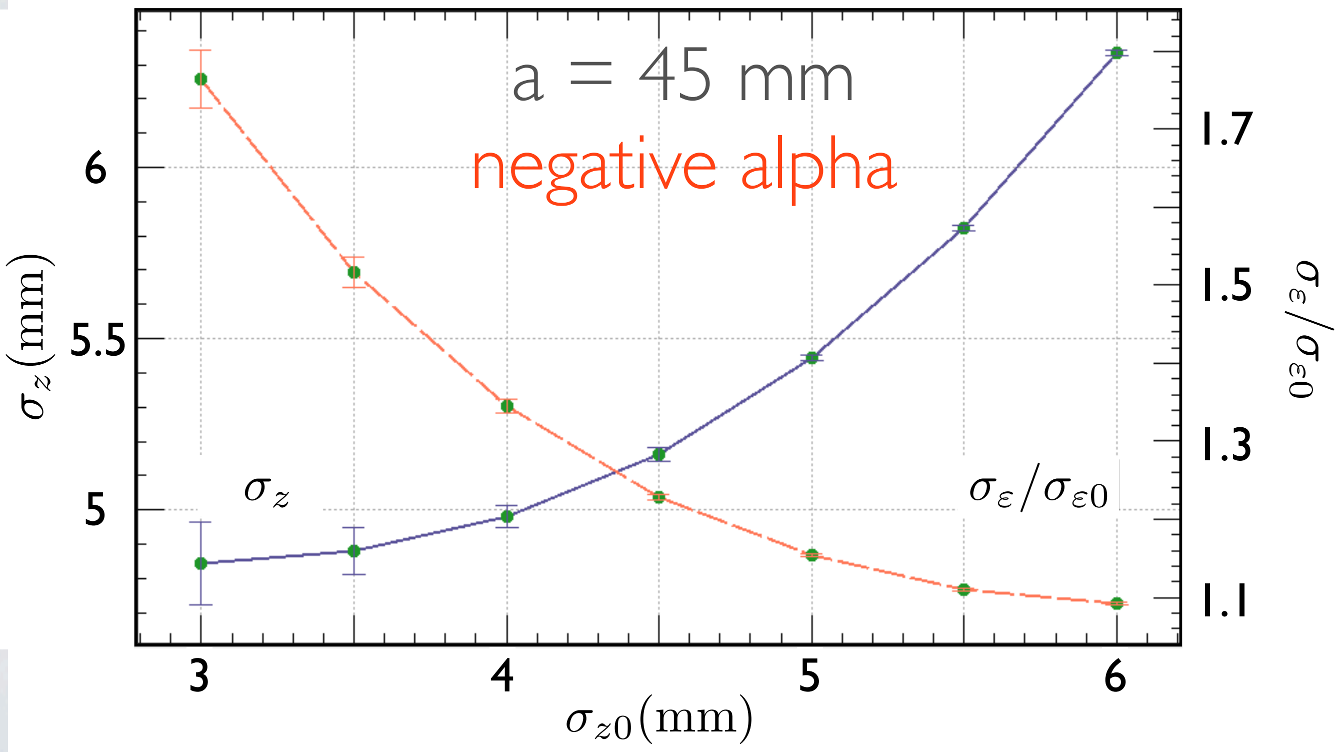
ALL WAKES, INCL. WIGGLERS



• A longer bunch length relaxes the instability.







- a = 25 mm beam pipe is better but does not solve the problem.
- a = 45 mm with negative alpha may be the best choice
- No problem in the HER.

THE MINIMUM ACHIEVABLE BUNCH LENTH

for a = 45 mm beam pipe

		zero bunch current	design bunch current	
LER	σ_z	5	6	mm
	σ_ε	7.1	8.0	10^{-4}
LER neg. alpha	σ_z	**4.5**	**5.3**	mm
	σ_ε	**7.1**	**8.5**	10^{-4}
HER	σ_z	3	3.6	mm
	σ_ε	6.8	7.0	10^{-4}
HER neg. alpha	σ_z	**3**	**3.1**	mm
	σ_ε	**6.8**	**7.7**	10^{-4}

DESIGN OF THE INTERACTION REGION

- Crab crossing needs a horizontal tune very close to a half integer (ν_x = 0.503) to achieve the very high beam-beam parameter $\xi_y = 0.3$.

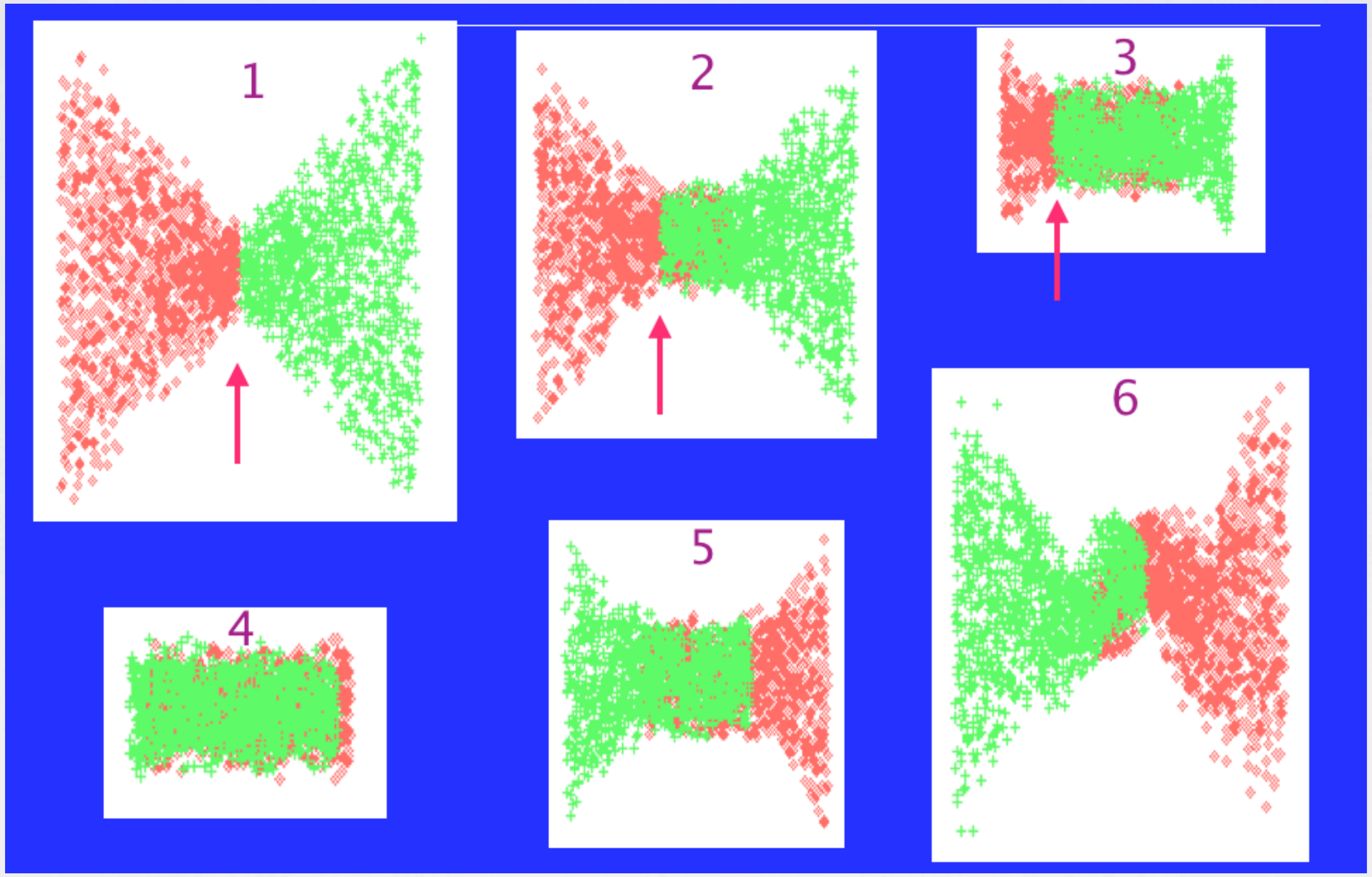
- Such a horizontal tune enhances the dynamic β and dynamic emittance effects to enlarge the bam size at the final quads by more than factor 10.

- No design of the IR has been technically found which is compatible with $\nu_x = 0.503$ and $\beta_x^* = 20$ cm.

- Thus the parameters were relaxed to $\nu_x = 0.505$ and $\beta_x^* = 40$ cm.

TRAVEL WAIST SCHEME

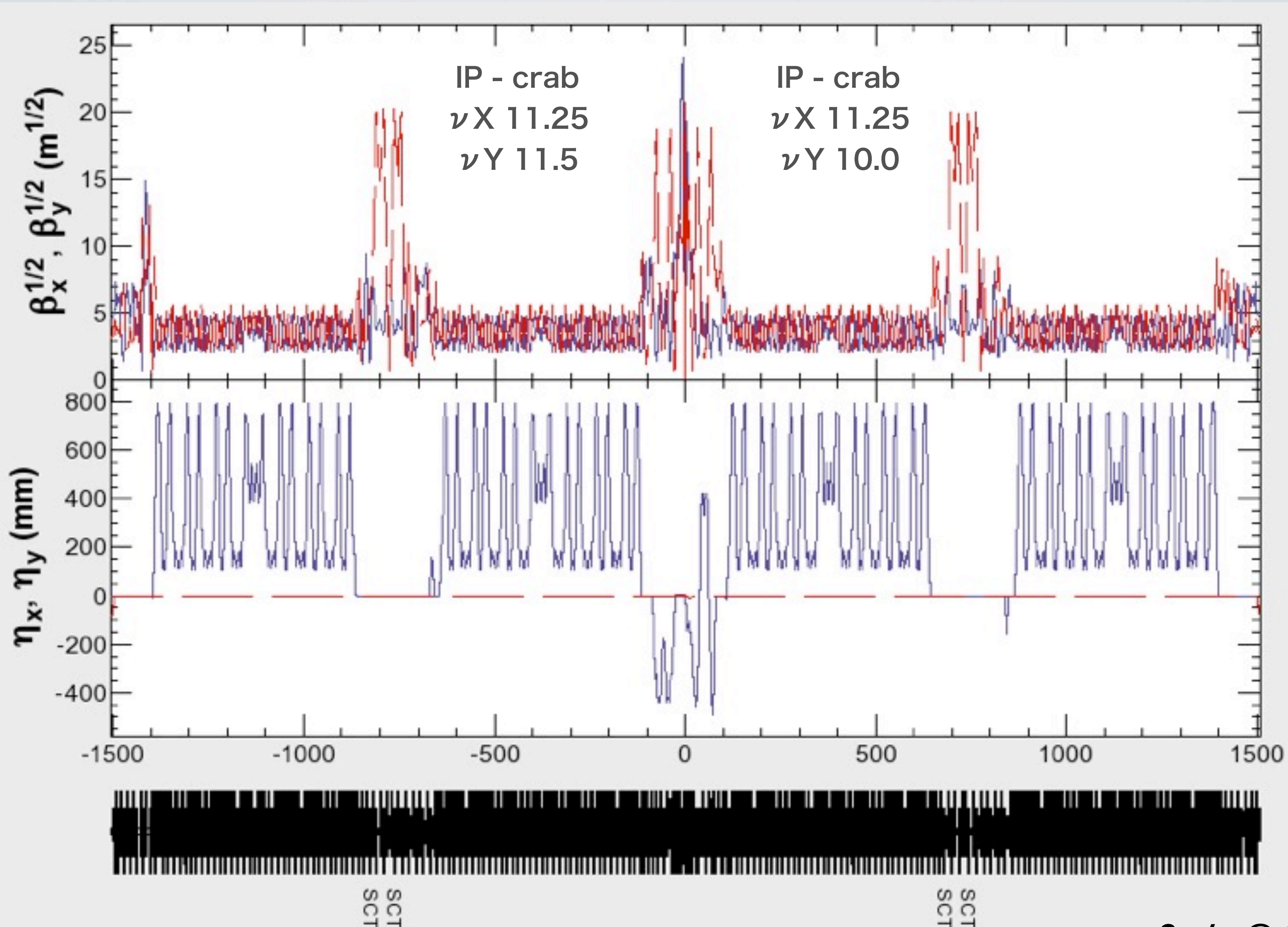
- Known technique for a linear collider (Balakin, et al).
- Move vertical waist backward along z.



N. Walker

- Two crab cavities, each sits in the middle of -I pair of sextupoles, are necessary for a ring.
- Very hard to accommodate them in the HER.

LER TRAVEL WAIST LATTICE



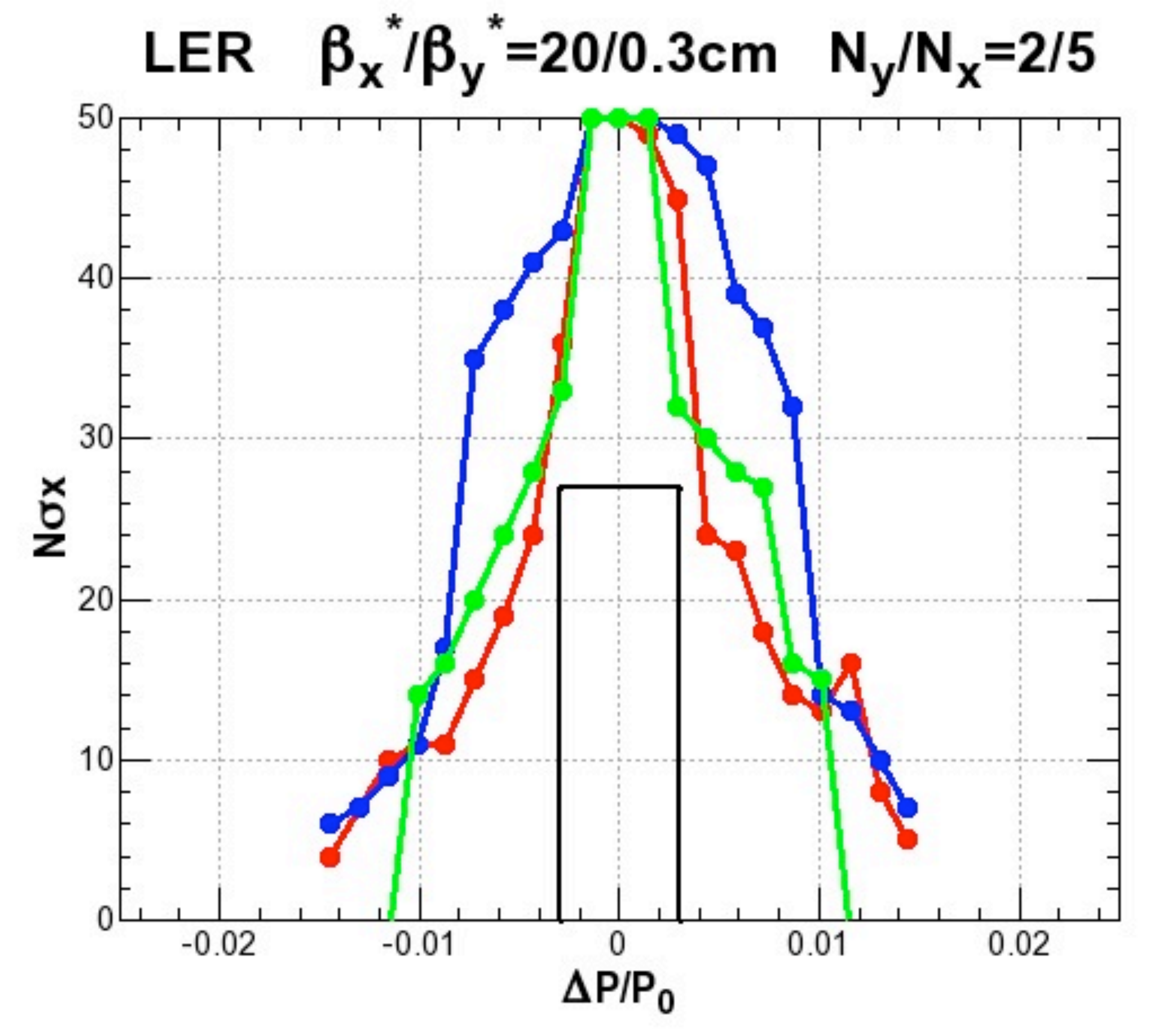
Sext - crab - Sext
Sext - Sext = -I'
K2 = -1.846 m^{-2}

Sext - crab - Sext
Sext - Sext = -I'
K2 = -1.846 m^{-2}

βx/y @ SX = 15/350 m
βx @ crab = 50 m
Vcrab = 1.56 MV

Sextupoles are not strong.

LER DYNAMIC APERTURE WITH TRAVEL WAIST



RF ON
Crab OFF, OFF, ON
sext thickness: 0.334 m
K2= 0, +-1.846

Acceptance
Ax = 7.5e-6 m
Ay = 1.2e-6 m
$\Delta p/p$ = 0.003

The aperture shrinks, but still acceptable.

HOW MUCH IS THE IMPACT ON THE LUMINOSITY?

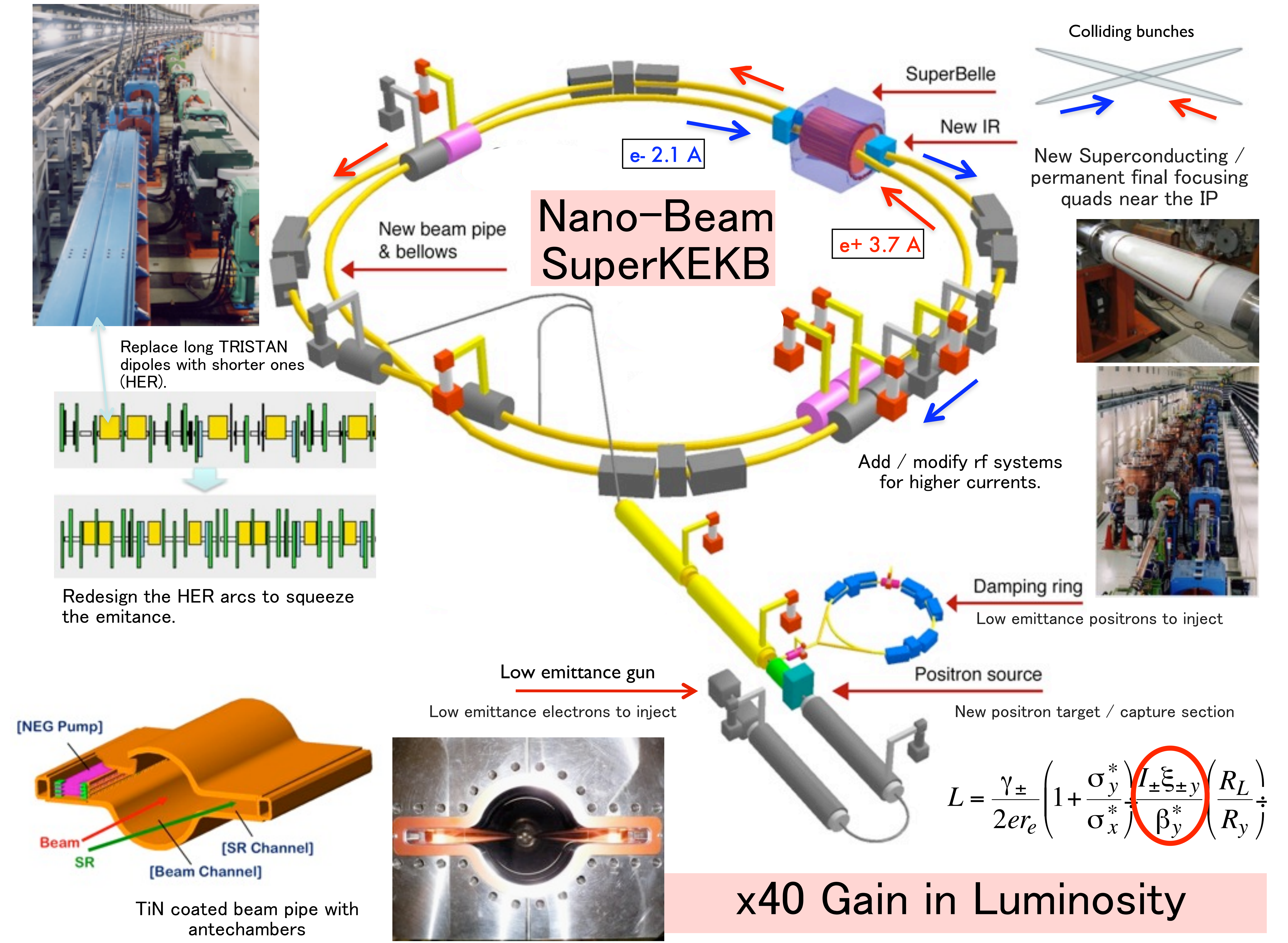
ν_x	β_x^* (cm)	$\sigma_{z,\mathrm{LER}}$ (mm)	$\mathcal{L}$ (10^{35})	
0.503	20	3	8	Original
0.505	40	3	5	+ Possible IR design
0.505	40	5	3	+ CSR
0.505	40	5	4	+ Travel Focus
0.503	20	5	5.5	+ Recovery of the IR design

* All luminosities assume that Crab Crossing works perfectly.

No technical solution has been found yet.

PROGRESS IN THE NANO-BEAM SCHEME

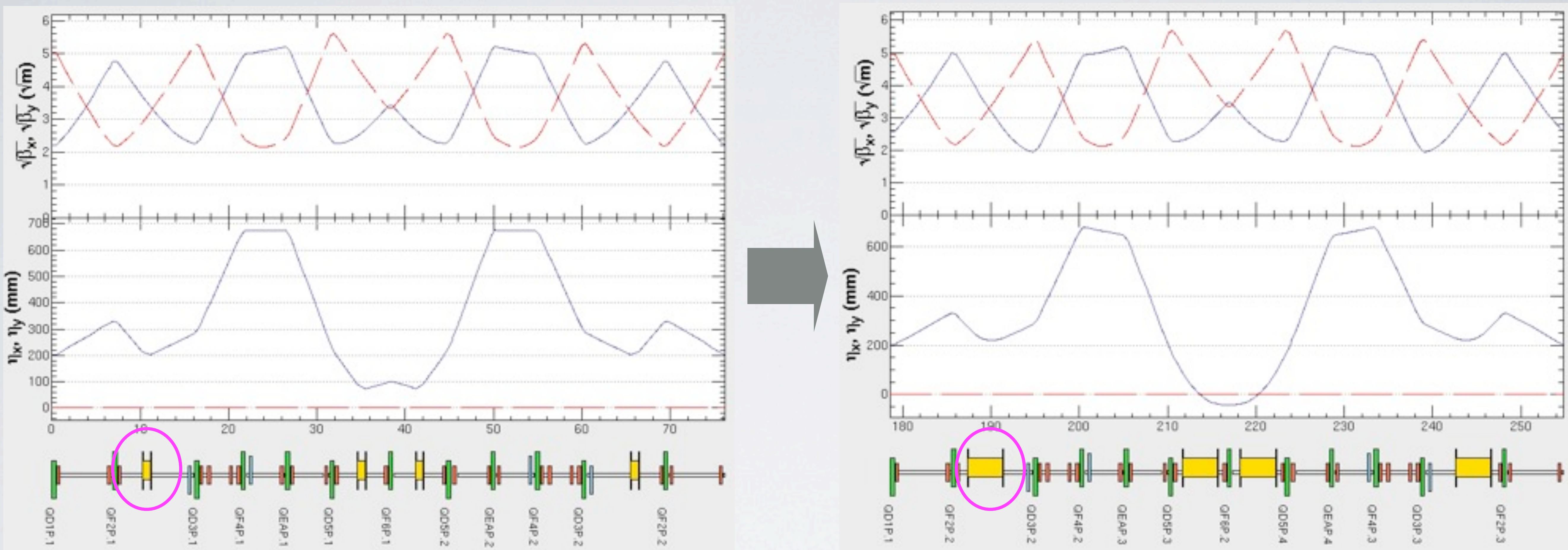
- Lattice: solutions exist, preserving the present tunnel.
- Optimization of dynamic aperture is going on.
- IR: large crossing, independent quads for both beams.
- LER emittance must be higher than 2.5 nm @ 3.5 GeV, considering intra-beam scattering.
- Electron cloud mitigation has been studied at KEKB. Results from CesrTA will be also important.
- Design of e+ damping ring has been done.



$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

LER Nano-Beam Lattice

LER arc cell **Preliminary**



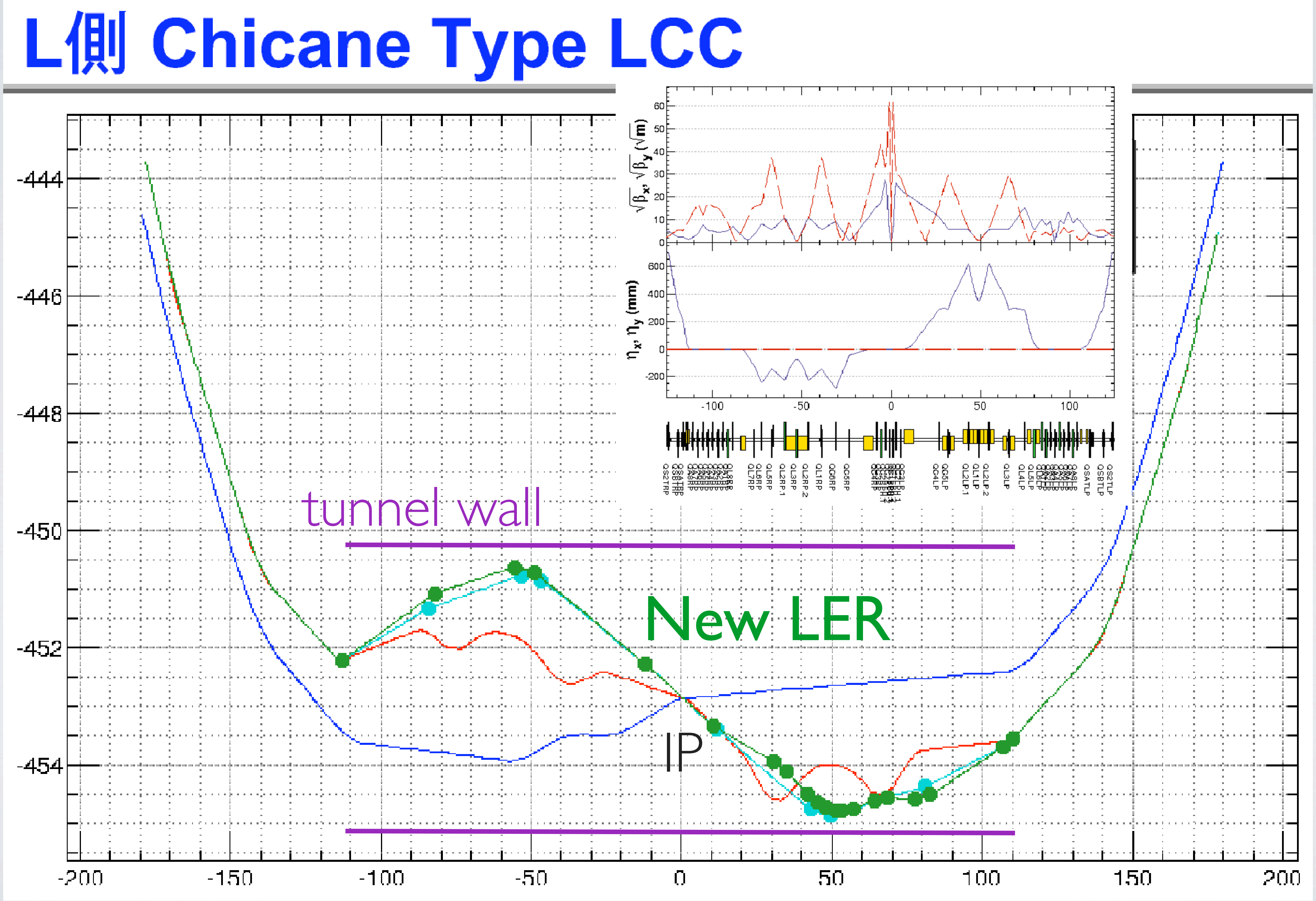
L bend = 0.9 m → L bend = 4.0 m

ε_x = 6.8 nm → ε_x = 2.2 nm

- The arc cell lattice of the KEKB LER (left) can be modified to the low-emittance version (right), by weakening the magnetic field of the dipoles.
- No need for changing other components, beam pipes, geometry.
- The HER's emittance is reduced by replacing the arc cells.

Nano-Beam IR Design: Fitting into existing tunnel

A. Morita

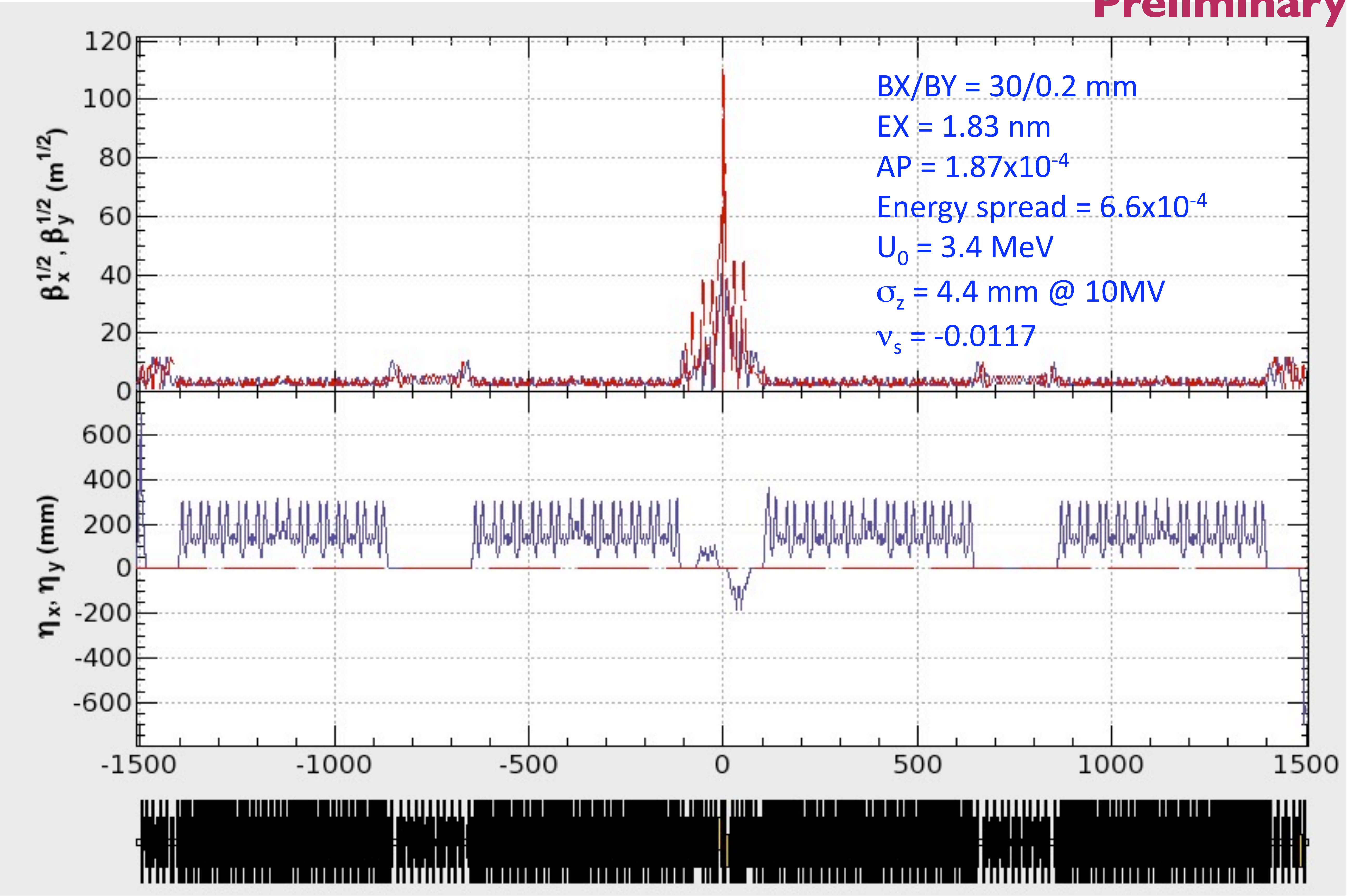


Preliminary

Nano-HER

Y. Ohnishi

Preliminary



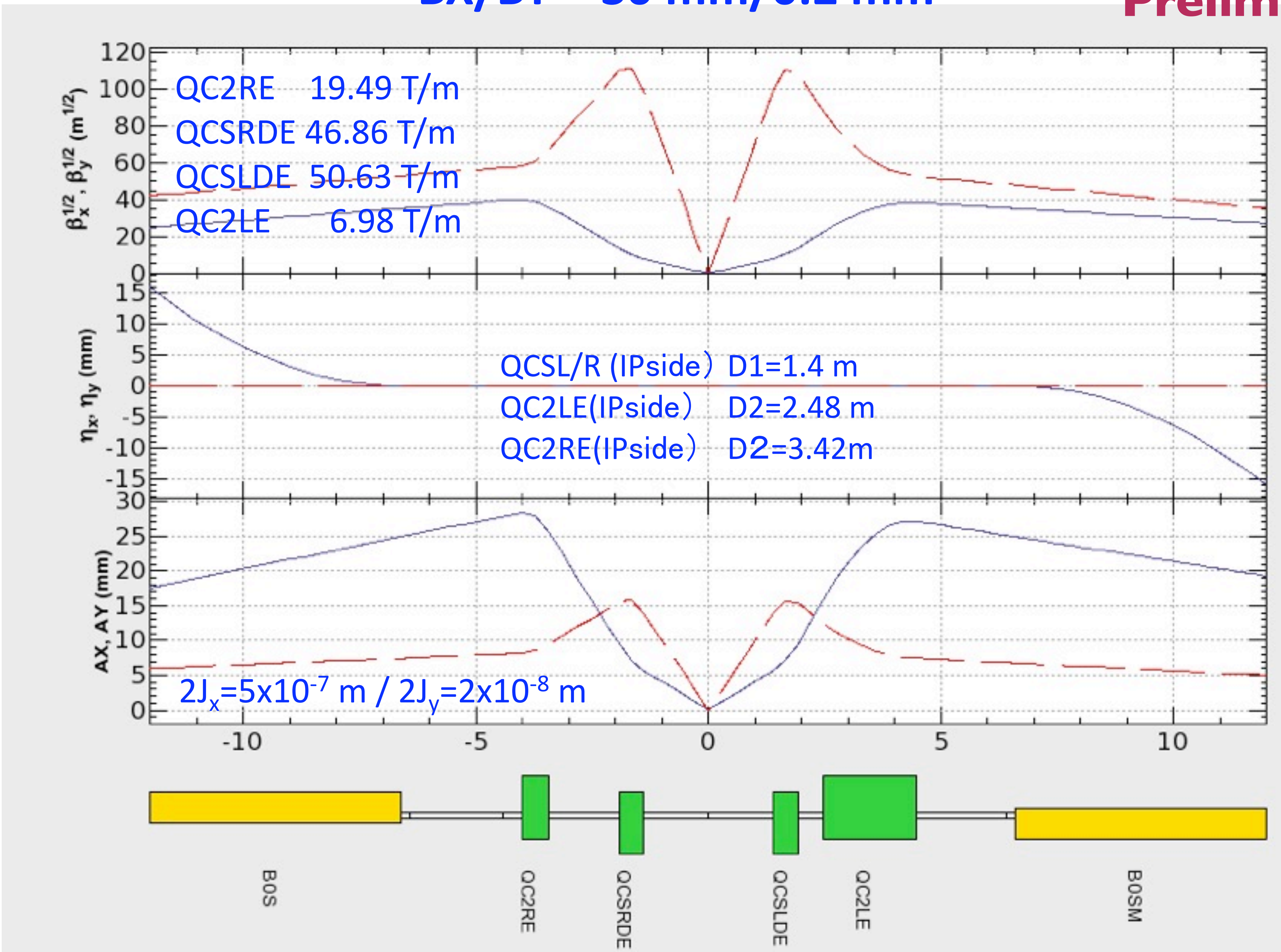
C=3016.2998 m (+38 mm from KEKB-HER)

HER IR

Y. Ohnishi

BX/BY = 30 mm/0.2 mm

Preliminary

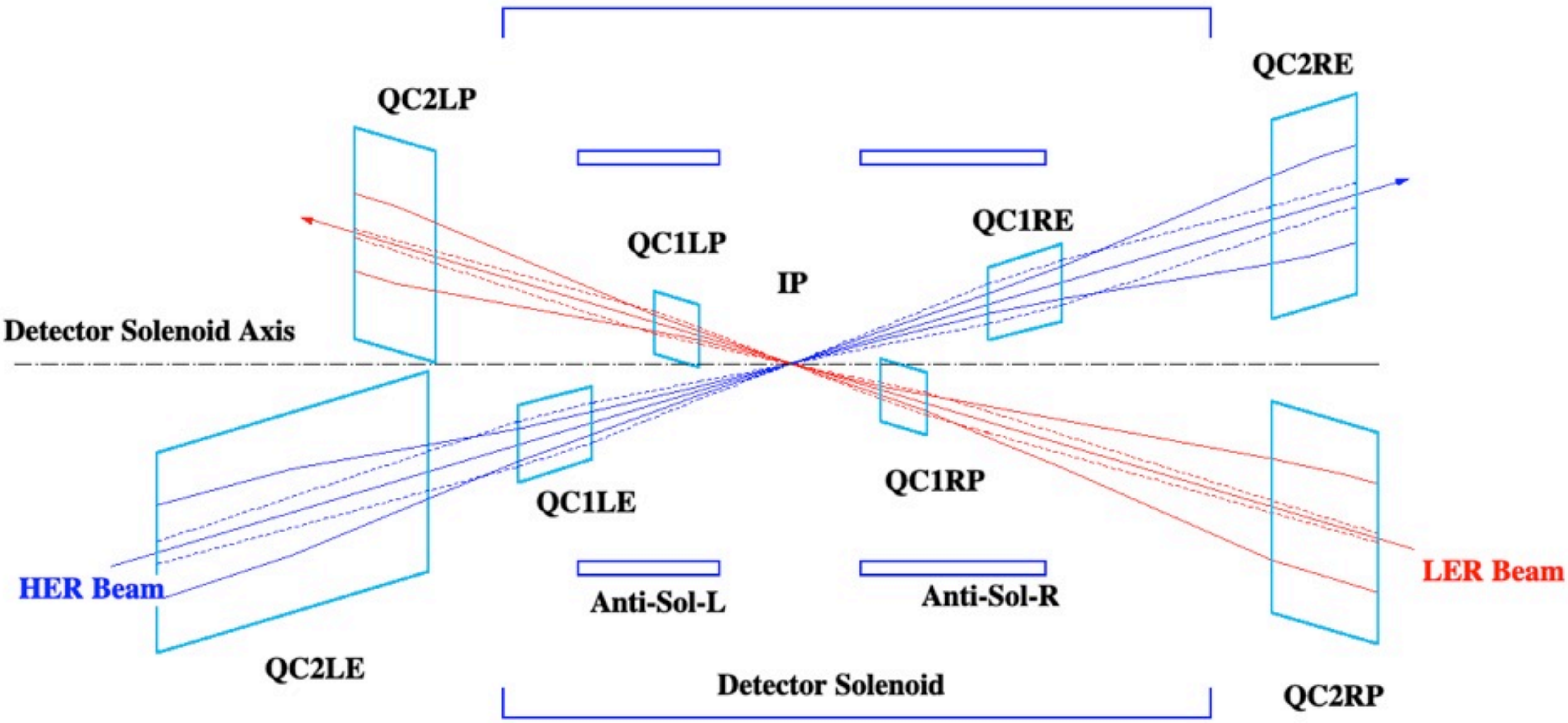


u_c =1.24 keV

u_c =1.24 keV

IR Design: Large crossing angle & independent quads

Preliminary



N. Ohuchi

Design of superconducting final quad for Nano-LER

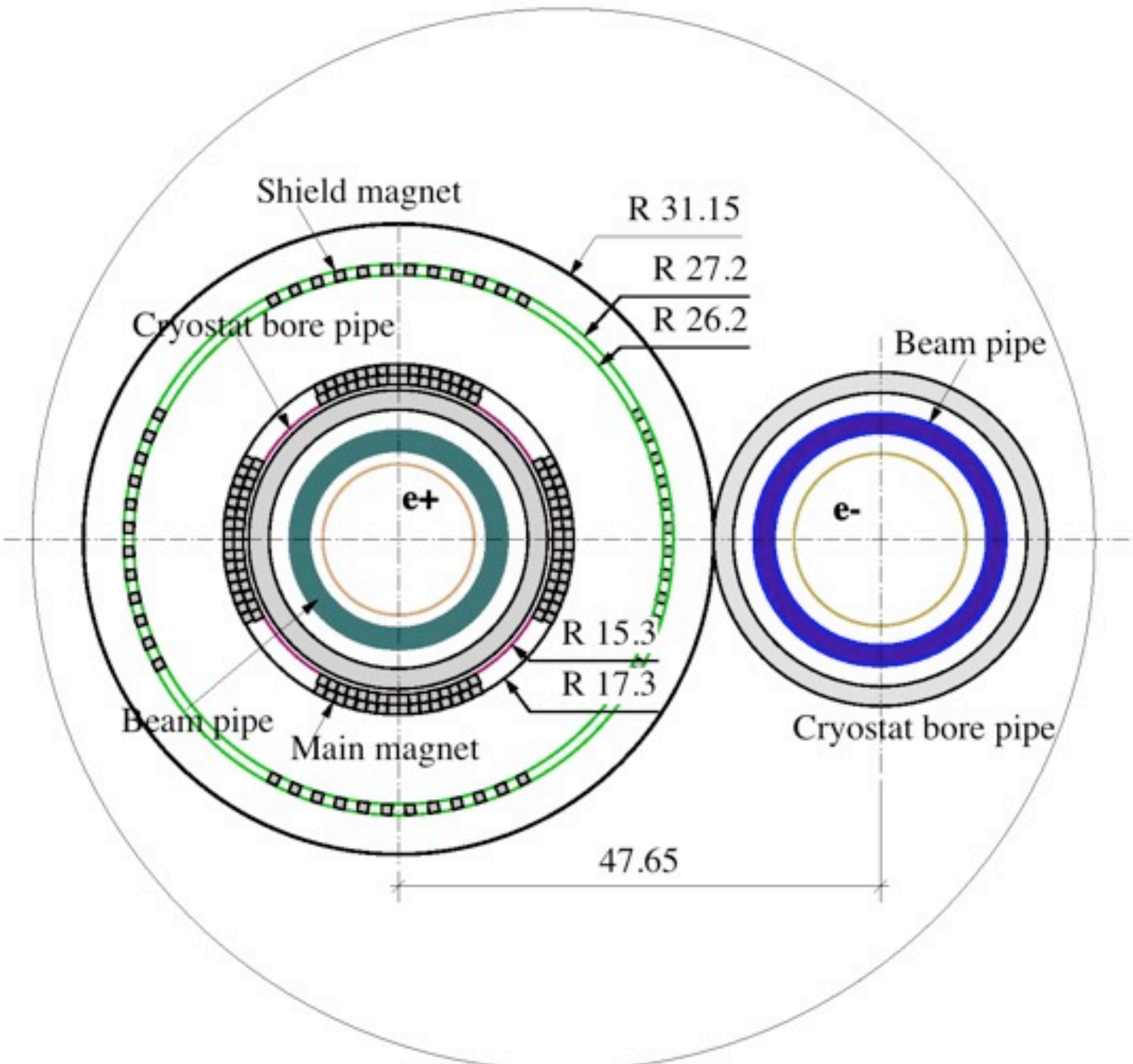


Figure 2: Cross section of QC1RP in the front end
Active shield quadrupole (corn type)

Table: Magnet parameters for QC1RP

Main Coil	Two layers
Inner radius (front/rear end)	15.3 mm/16.97 mm
Outer radius (front/rear end)	17.3 mm/18.97 mm
Turn number/pole	16
Shield Coil	One layer
Inner radius (front/rear end)	26.2 mm/29.05 mm
Outer radius (front/rear end)	27.2 mm/30.05 mm
Turn number/pole	6
Magnet as QC1RP	
S.C. cable / cable size	NbTi/1mm×1mm
S.C. cable Cu ratio	1.2
Operation current	1288.6A
Field gradient (front/rear end)	88.35 T/m/72.95 T/m
Effective magnetic length	0.2238 m
Maximum field in the coil	1.43 T
Operation temperature	4.4 K

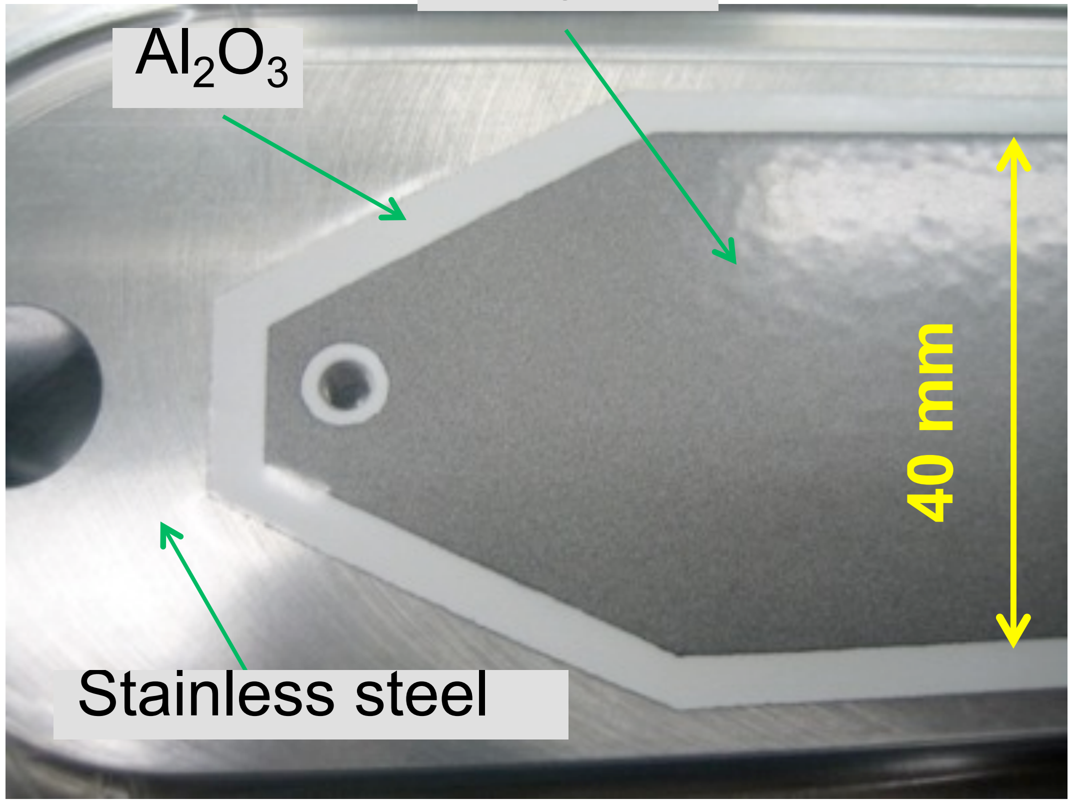
N. Ohuchi

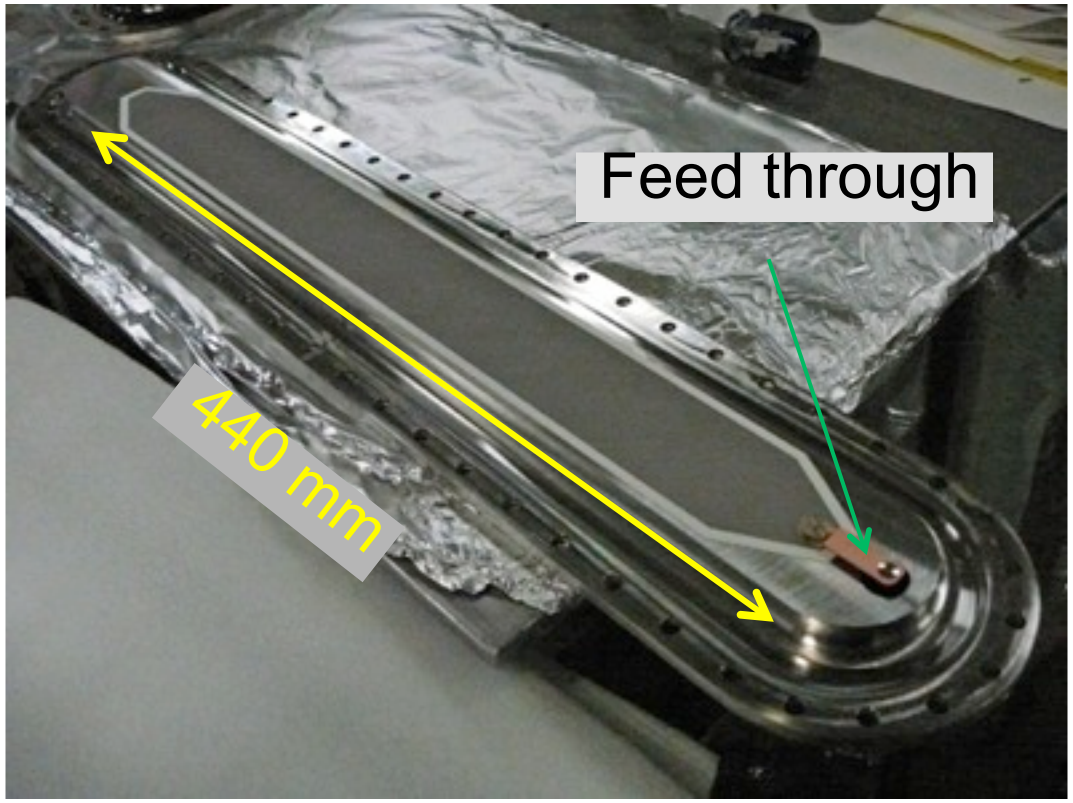
Preliminary

Clearing electrode

- **New strip-line type electrode was developed.**
- **Very thin electrode and insulator;**
  - Insulator: ~0.2 mm, Al_2O_3, by thermal spray.
  - Electrode: ~0.1 mm, Tungsten, by thermal spray.
- **Low beam impedance, high thermal conductivity**
  - Input power ~ 100 W

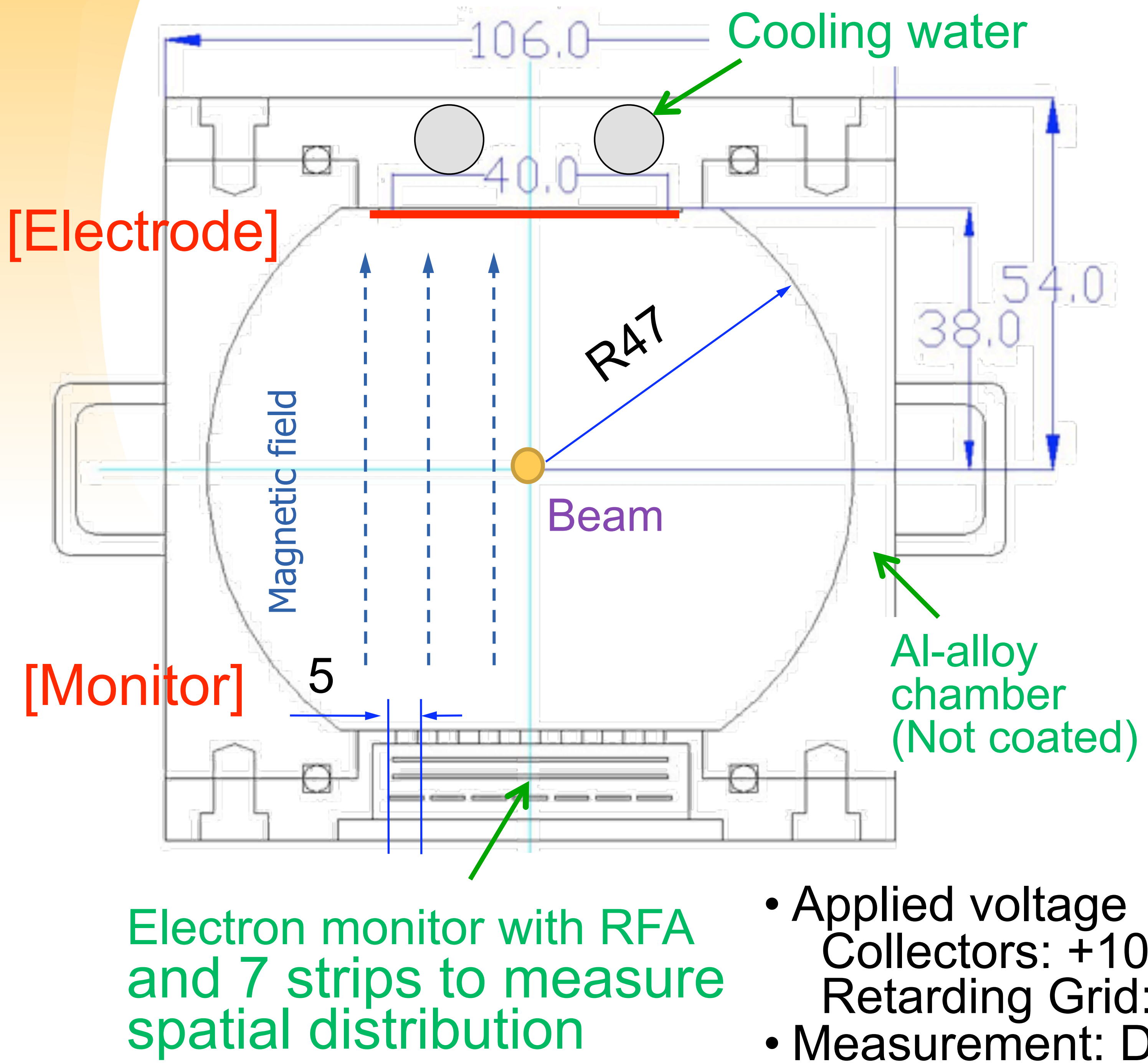
Y. Suetsugu, H. Fukuma, M. Pivi and L. Wang
NIM-PR-A, 598 (2008) 372

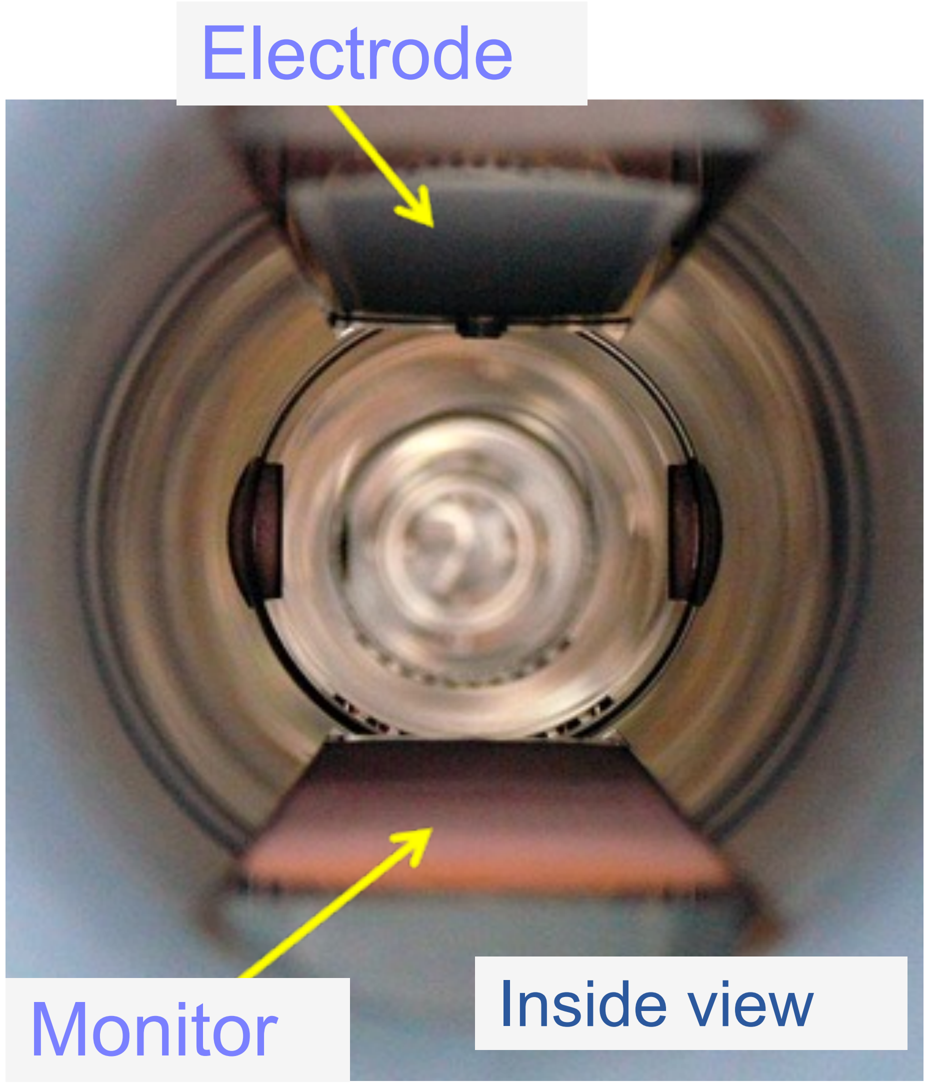




Clearing electrode

- **The electrode and an electron monitor were set face to face in a test chamber.**



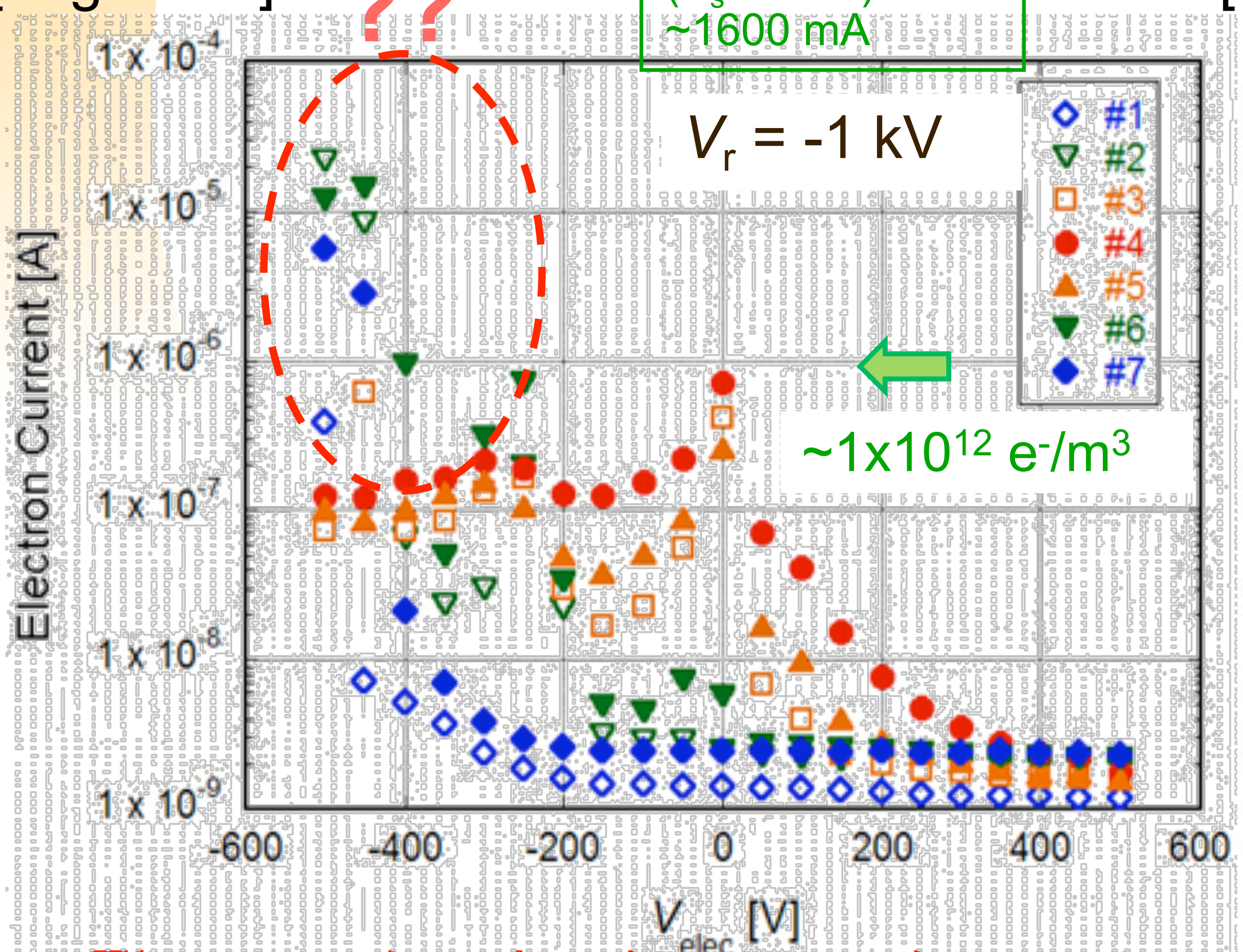


- Applied voltage
  - Collectors: +100V
  - Retarding Grid: 0 ~ -1 kV
- Measurement: DC mode

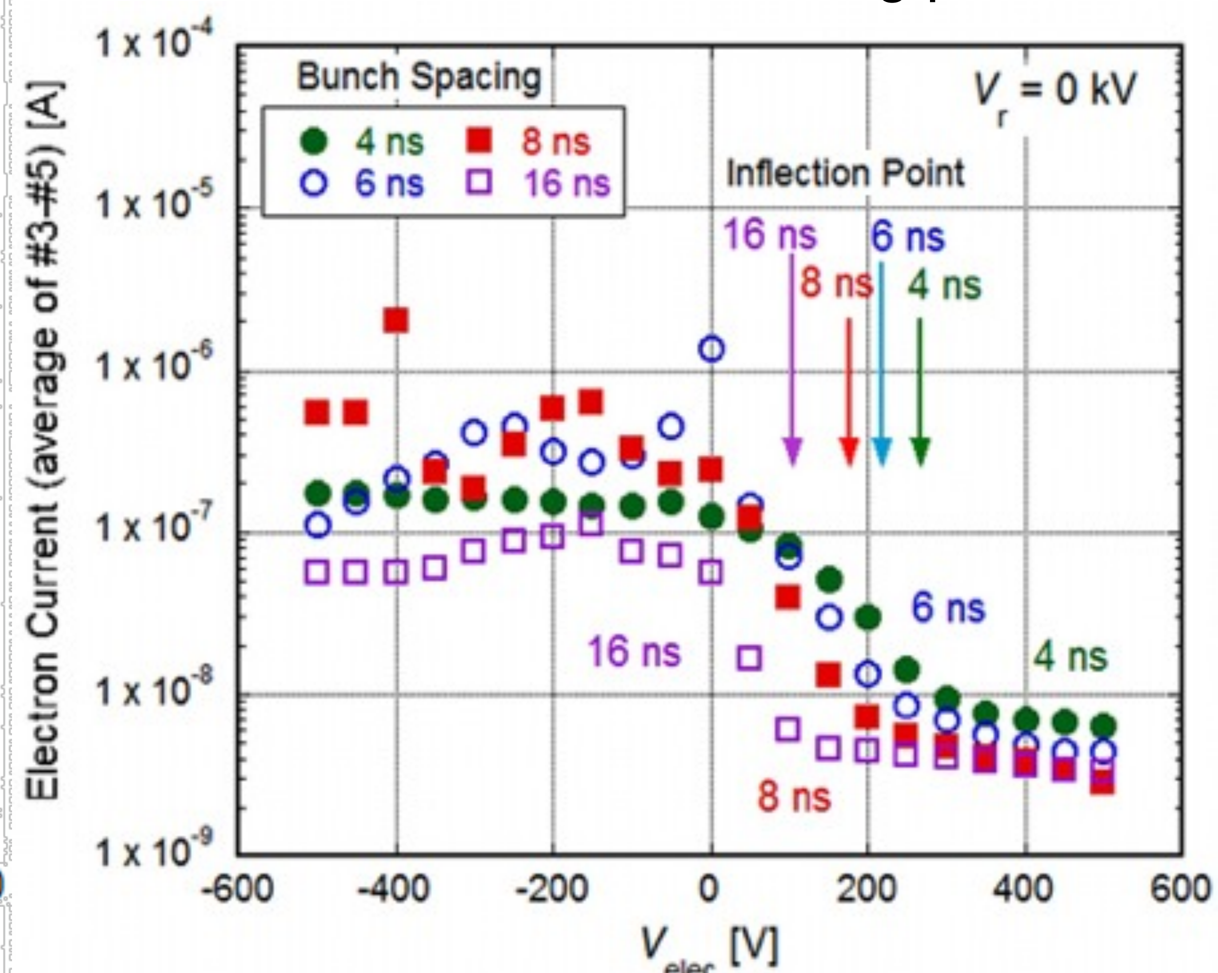
Clearing electrode

- **Effect of electrode voltage (V_{elec})**
  - Smooth decrease in density for positive V_{elec}
  - Effective for various bunch filling patterns

[Log scale]



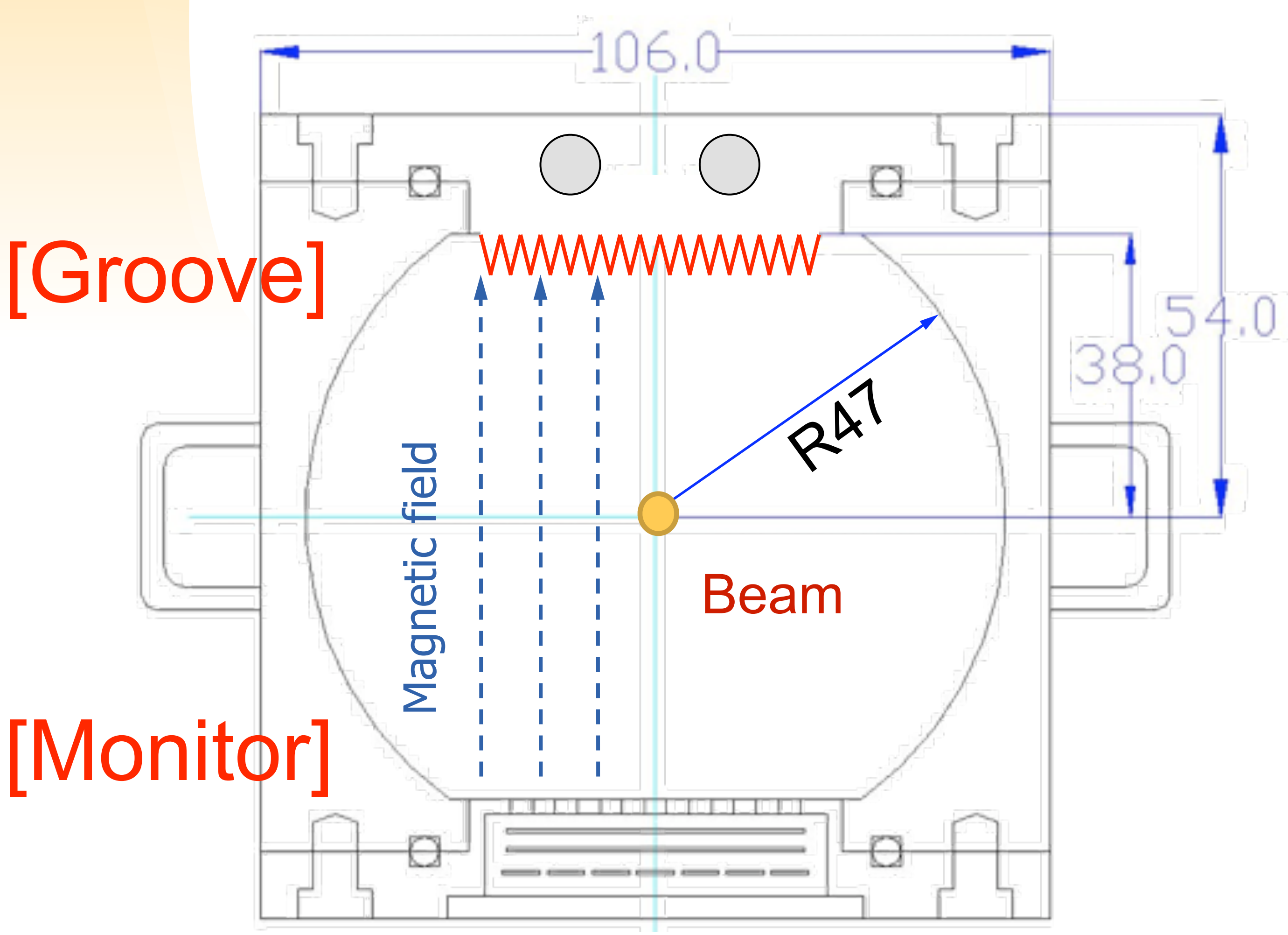
[Log scale] Different bunch filling patterns



Electron density decreased to
1/10 at V_{elec} = + 100 ~ 200 V, 1/100 at V_{elec} = + ~ 500 V

Groove

- **The experiment was carried out under collaboration with SLAC (M. Pivi and L. Wang)**
- **EC was measured at the same condition to that for clearing electrode.**
  – The same experimental setup used in the case of electrode



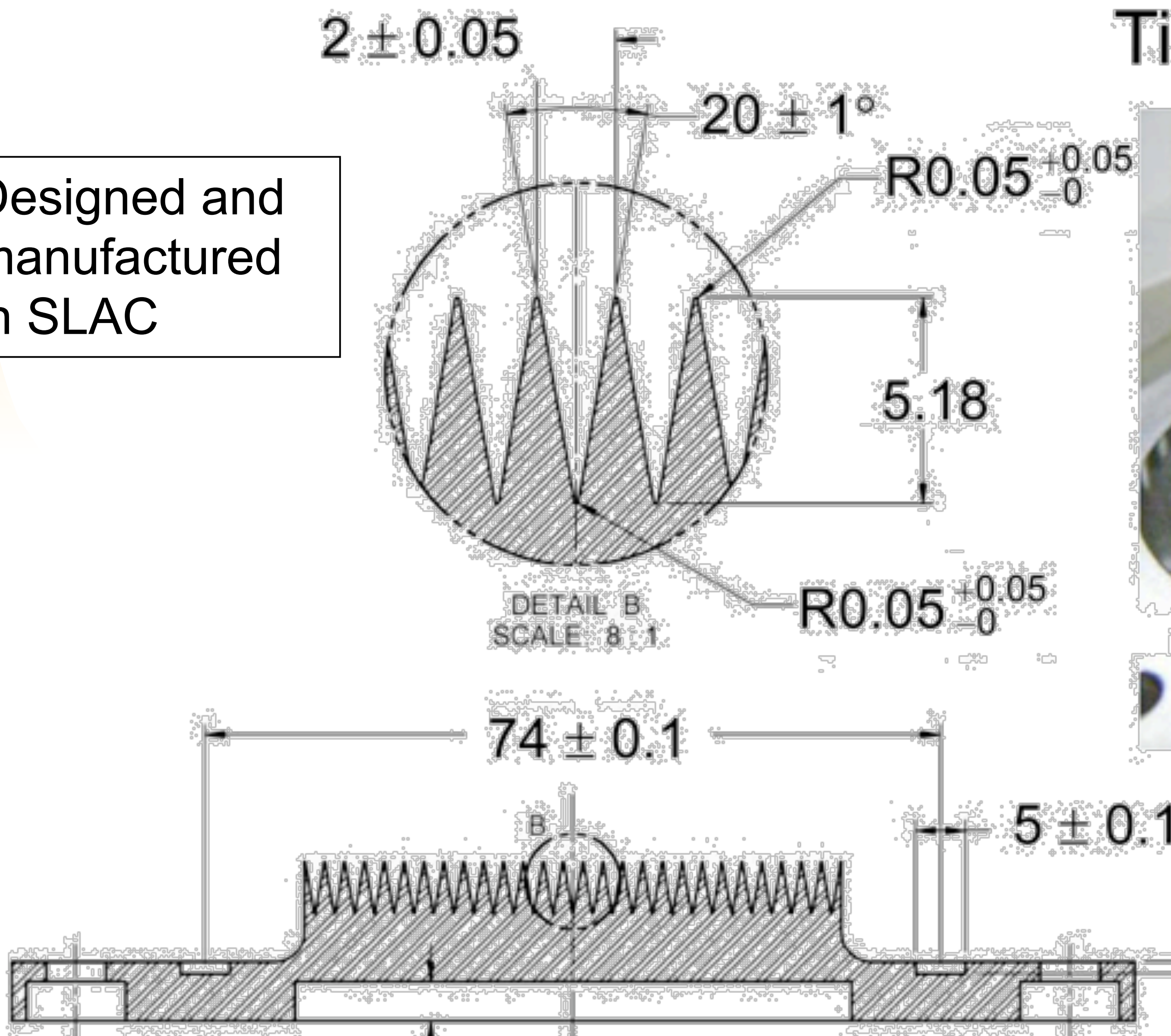
Y. Suetsugu, H. Fukuma, M. Pivi and L. Wang
To be published in NIM-PR-A

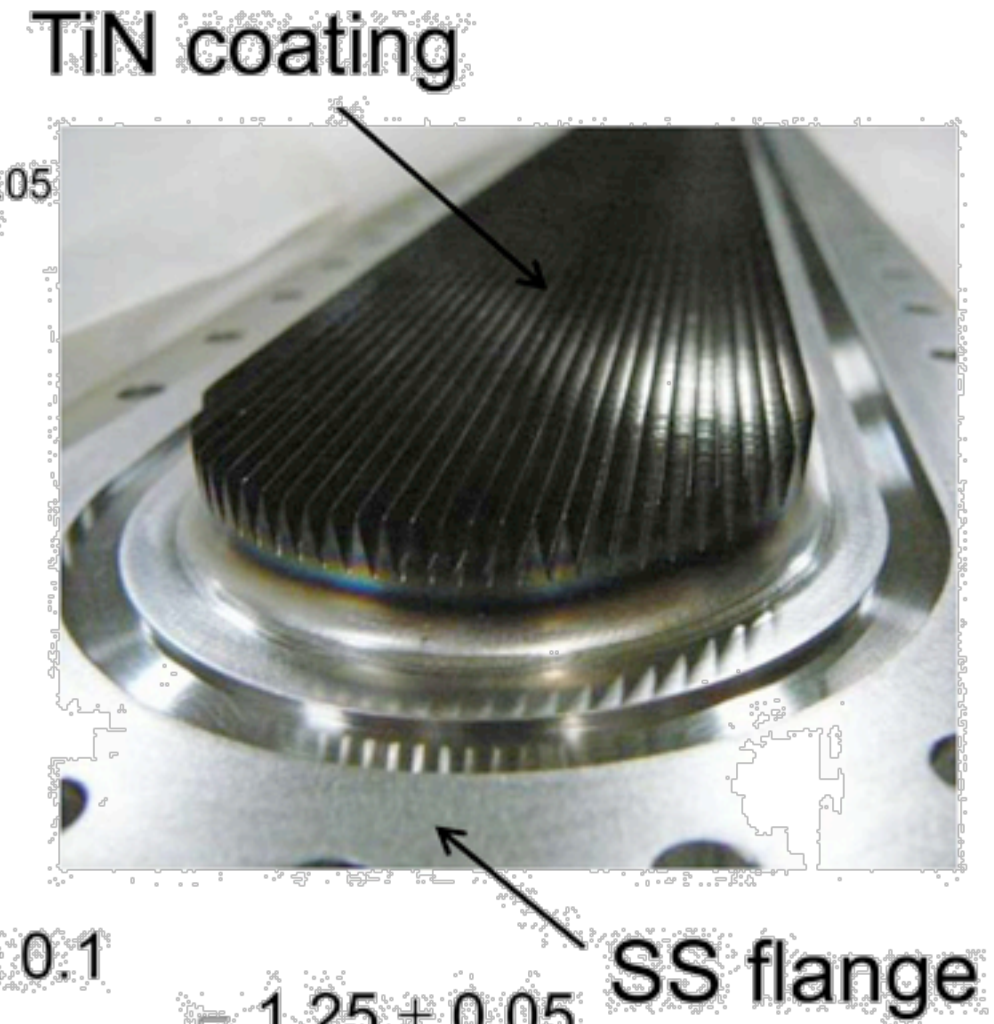
Wiggler magnets
B = 0.77 T

Groove

- **Triangular-type groove structure, with TiN coating**
- **Compared with the data for a flat surface (TiN) and clearing electrode (W)**

Designed and manufactured in SLAC





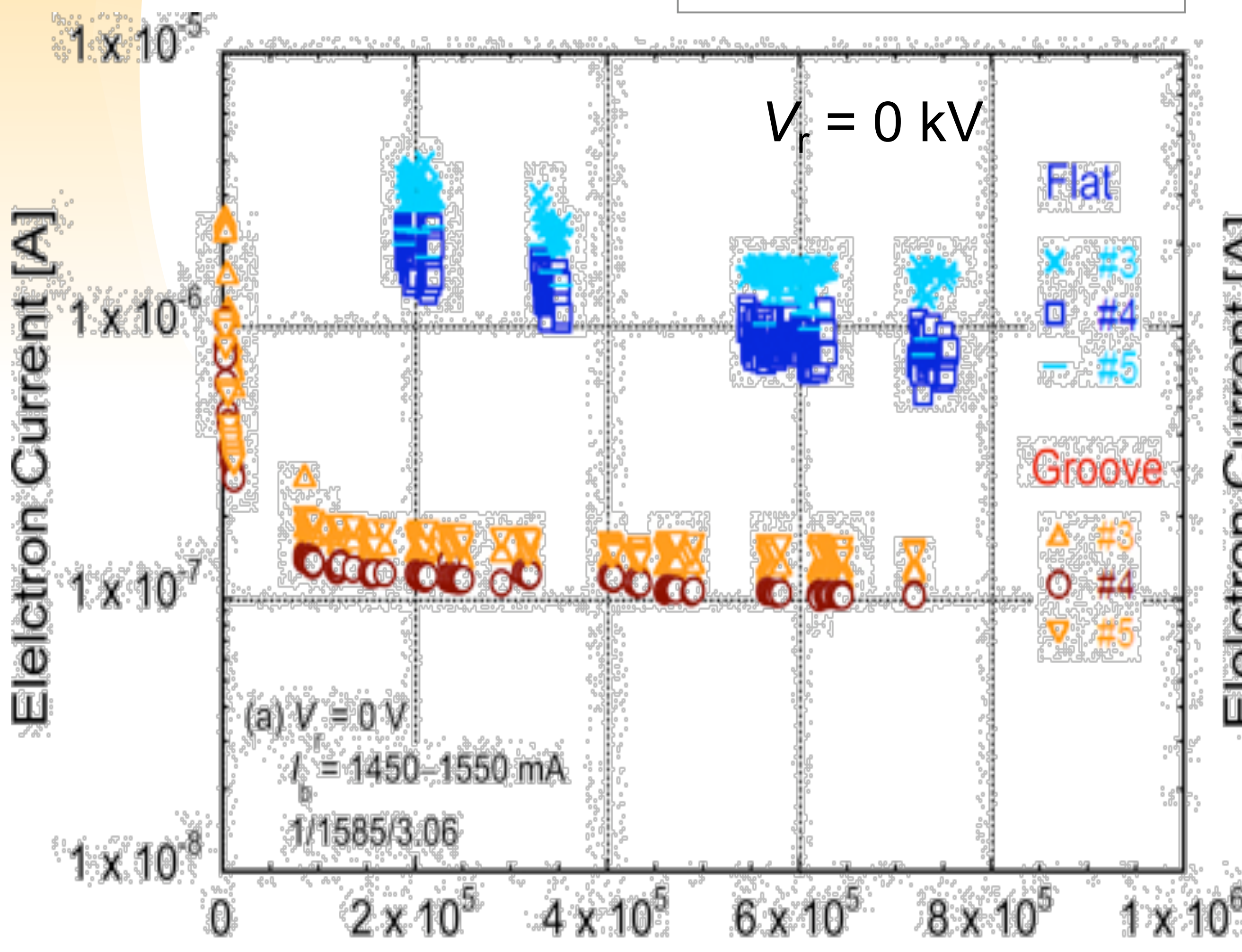
Groove

- **Electron density for the groove was lower than that for the flat surface by ~ one order.**
- **Aging was still proceeding, if plotted by electron dose (integrated electron current).**

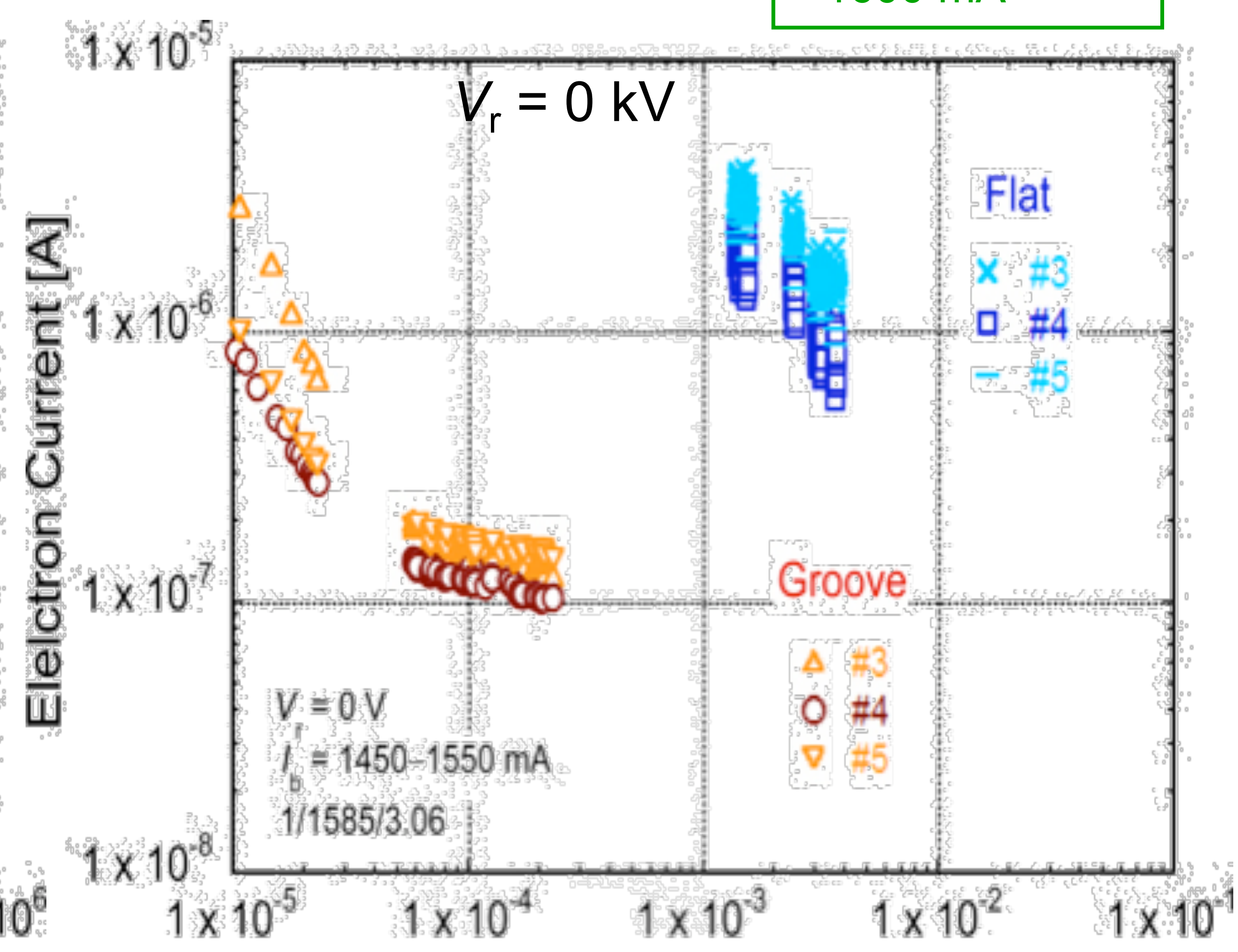
1585 bunches
(B_s ~ 6 ns)
~1600 mA

[Log scale]

Preliminary result



Integrated Beam Current [mA h]

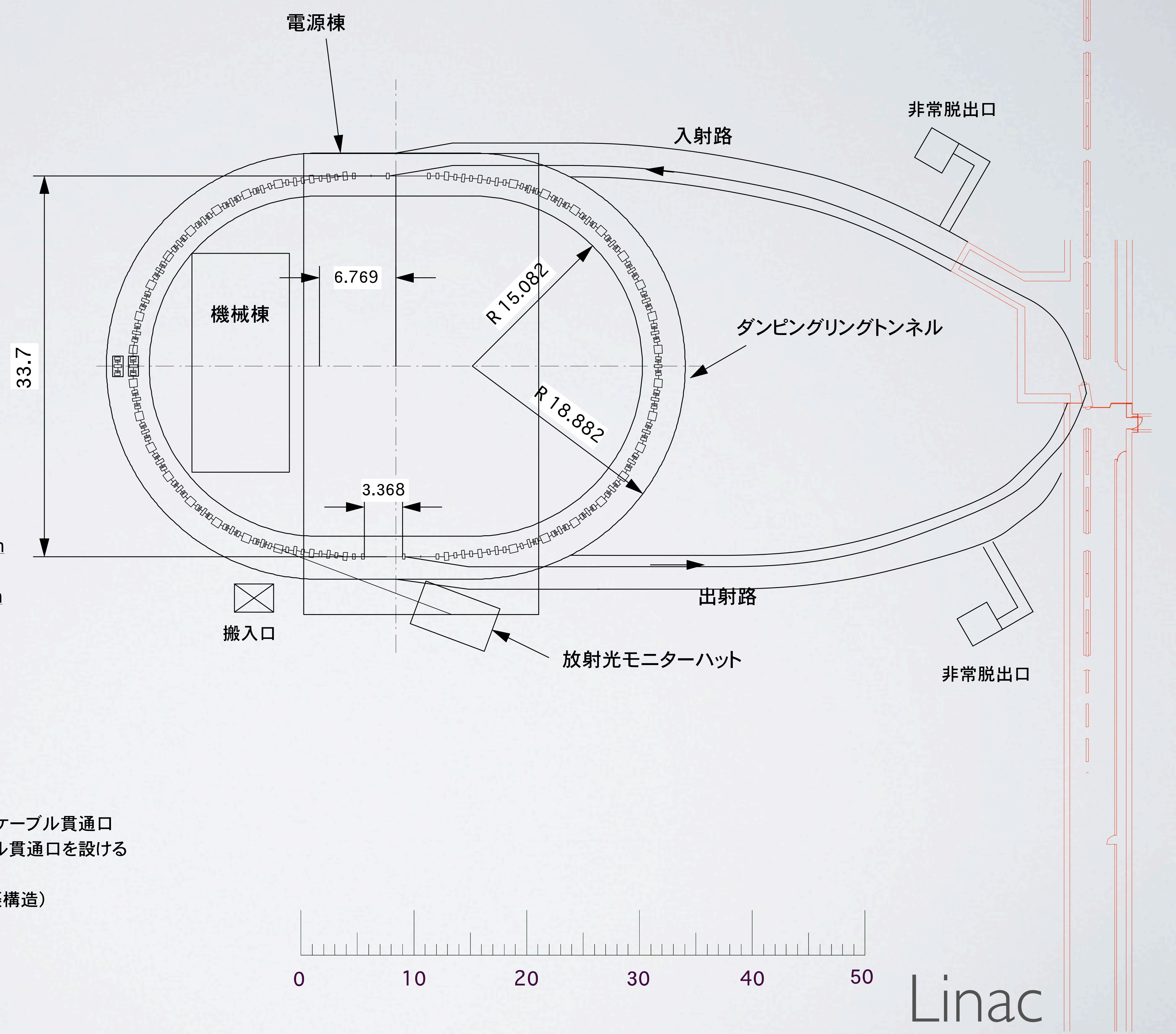


Integrated Electron Current [mA h]

M. Kikuchi

1 GeV e+ Damping Ring

Circ. = 132 m



陽電子用ダンピングリング トンネル構造

1. リング部全長 132 m
   1.1 内空断面(標準部) W 3.8 m H 2.7 m
2. BT部全長 136 m
   2.1 内空断面(標準部) W 3.5 m H 2.7 m

3. 要求性能
   3.1 ビームレベル FL+1.2 m
   3.2 インストール: エアパレット搬送
   3.3 空調性能: 25℃±1℃
   3.4 冷却水性能:往 30℃ 復 ℃

4. その他考慮すべき点など
   4.1 Linacとの接続部の構造; ビーム及びケーブル貫通口
   4.2 直線部に導波管用貫通口及びケーブル貫通口を設ける
   4.3 放射光モニターハット(7×4m2)を
   ビームラインと同一レベルに設ける(耐振構造)
   4.4 機器搬入口 1箇所
   4.5 非常脱出口合計3箇所
   4.6 土盛り上部は周辺監視区域
   4.7 エレベータを設置する

Construction Schedule (preliminary)

K. Akai

Japanese government has allocated ~27 M$ for R&D of SuperKEKB, as a part of stimulative package.

	KEKB高度化 年次計画	JFY2009				2010				2011				2012				2013				2014			
		H21年度				H22年度				H23年度				H24年度				H25年度				H26年度			
		4月	7月	10月	1月	4月	7月	10月	1月	4月	7月	10月	1月	4月	7月	10月	1月	4月	7月	10月	1月	4月	7月	10月	1月
	全体計画	(H21補正予算等)				▽建設開始														▽ビーム運転開始					
	ライナック・BT Linac																			Beam Operation →					
施	Aセクター最上流部建屋増築						▽開始		◆完成	▽RF電子銃設置															
施	加速管組立て室増築(Jアーク南東側)						▽開始		◆完成																
	陽電子源改造						▽試験機設置																		
施	陽電子源等用冷却水・電気						▽開始		◆完成																
施	第三スイッチヤード冷却水増強															◆完成									
	ダンピングリング Damping Ring									Linacと接続															
施	トンネル		▽設計				▽開始			◆	◆完成														
施	電源棟・制御室		▽設計								▽開始		◆完成												
施	機械棟		▽設計								▽開始		◆完成												
施	受電ヤード		▽設計								▽開始		◆完成												
施	冷却水		▽設計								▽開始		◆完成												
	リング各種機器設置													▽開始			▽運転開始								
	メインリング Collider Rings																								
施	電磁石電源室										▽開始		◆完成				▽電源設置								
施	電磁石保管棟						▽開始		◆完成																
施	モニターLC棟増設(未定:検討中)										▽開始		◆完成												
施	真空蒸着準備棟						▽開始		◆完成																
施	真空チェンバー等保管庫						▽開始		◆完成																
施	QCS用コンプレッサー棟										▽開始		◆完成												
施	電源棟床防振・耐震工事										▽開始		◆完成												
施	K2K跡地クレーン設置						▽開始		◆完成																
施	冷却水システム増強(機械棟)						▽開始		◆完成																
施	冷却水システム増強(配管)											▽開始	◆完成												
	真空チェンバー製作 (LER)				(試作)	▽製作開始							◆完成												
	TiNコーティング(LER)							(装置据付)		▽開始			◆完了												
	真空チェンバー据付 (LER)											▽開始(外)			▽(内)	◆完了									
	真空チェンバー製作 (HER)									▽製作開始							◆完成								
	真空チェンバー据付(HER)													▽開始(外)		▽(内)	◆完了								
	真空チェンバー製作 (直線部・IR)													▽製作開始			◆完成								
	TiNコーティング(直線部)																▽開始								
	真空チェンバー据付(直線部・IR)																	▽開始	◆完了						
	電磁石・チェンバー搬出		▽測量			▽開始																			
	電磁石据え付け(ベースプレート含む)									▽開始							◆完成	▽精密測量							
	RF地上部配置変更・増設					▽開始											◆完成								

SUMMARY

- The High-Current Scheme for upgrading KEKB has a few issues which are not easy to be conquered: CSR, IR design, high ξ_y with crab crossing, and construction/operation costs for high current.
- Mitigation such as Travel Waist may work, but also introduces more complexity.
- More attention has been paid for the Nano-Beam Scheme, and the design work is on going in that direction.
- KEKB needs collaboration with accelerator scientists in the world for the success of the challenging project.