Luminosity calculations and analysis of lattice nonlinearity for SuperKEKB

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SuperKEKB optics meeting

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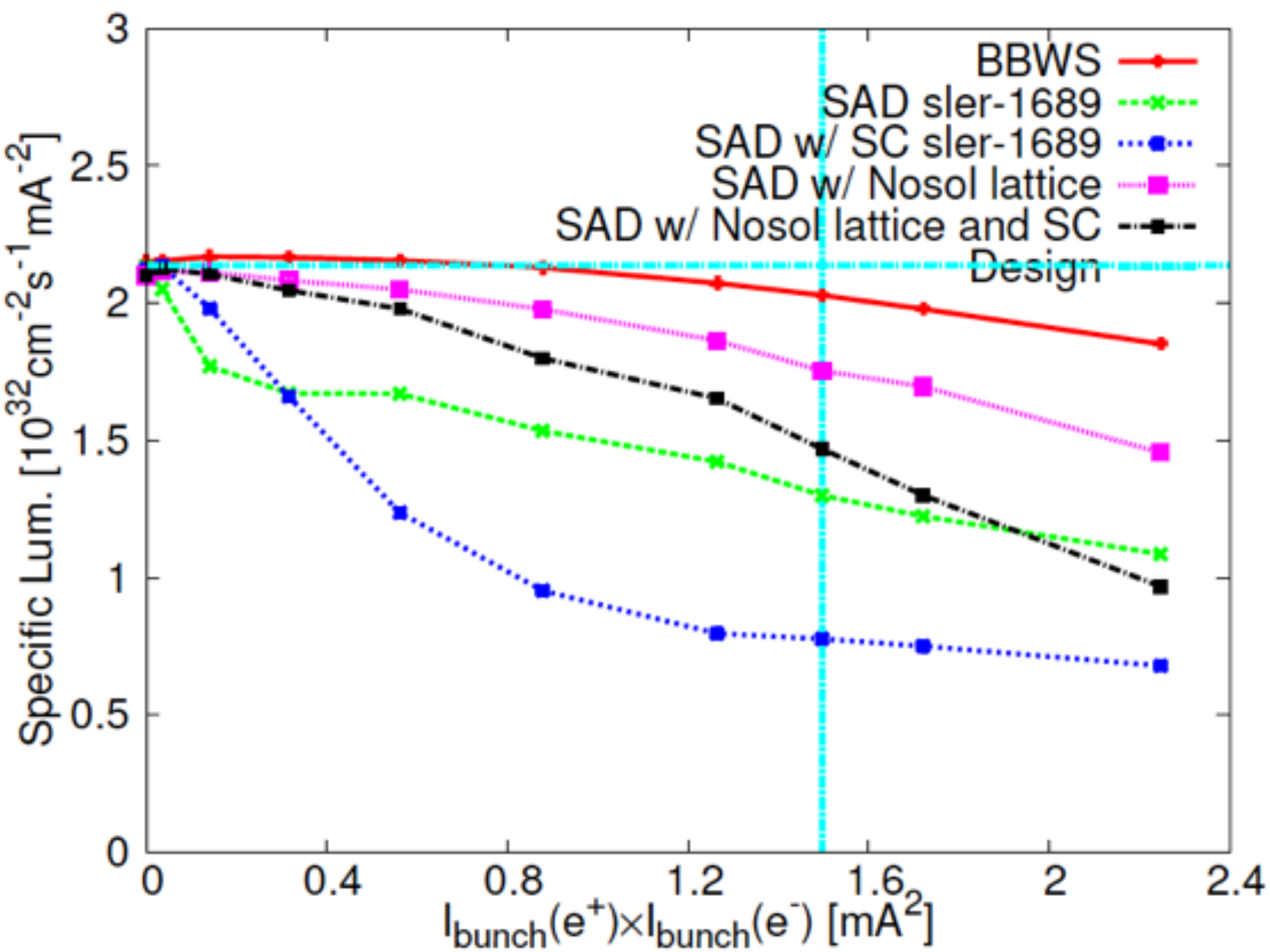
Outline

- ➤ **Lum. calculation with simplified LER lattice**
- ➤ **Y. Zhang's idea about lattice nonlinearity**
- ➤ **Lum. calculation for detuned lattice**
- ➤ **Summary**

1. Lum. calculation: LER: Simplified IR

- ➤ **Simplified lattice by H. Sugimoto**
- ➤ **sler_simple001.sad: no solenoid but preserve main optics parameters**
- ➤ **No significant lim. degradation at low current**
- ➤ **Solenoid is the main source of lattice nonlinearity?**



2. Lattice nonlin.: LER: Y. Zhang's idea

From Y. Zhang

Use Poincare map to see what happens(beam-beam off)

- Initial coordinates (x0, 0, 0, 0, 0, 0)

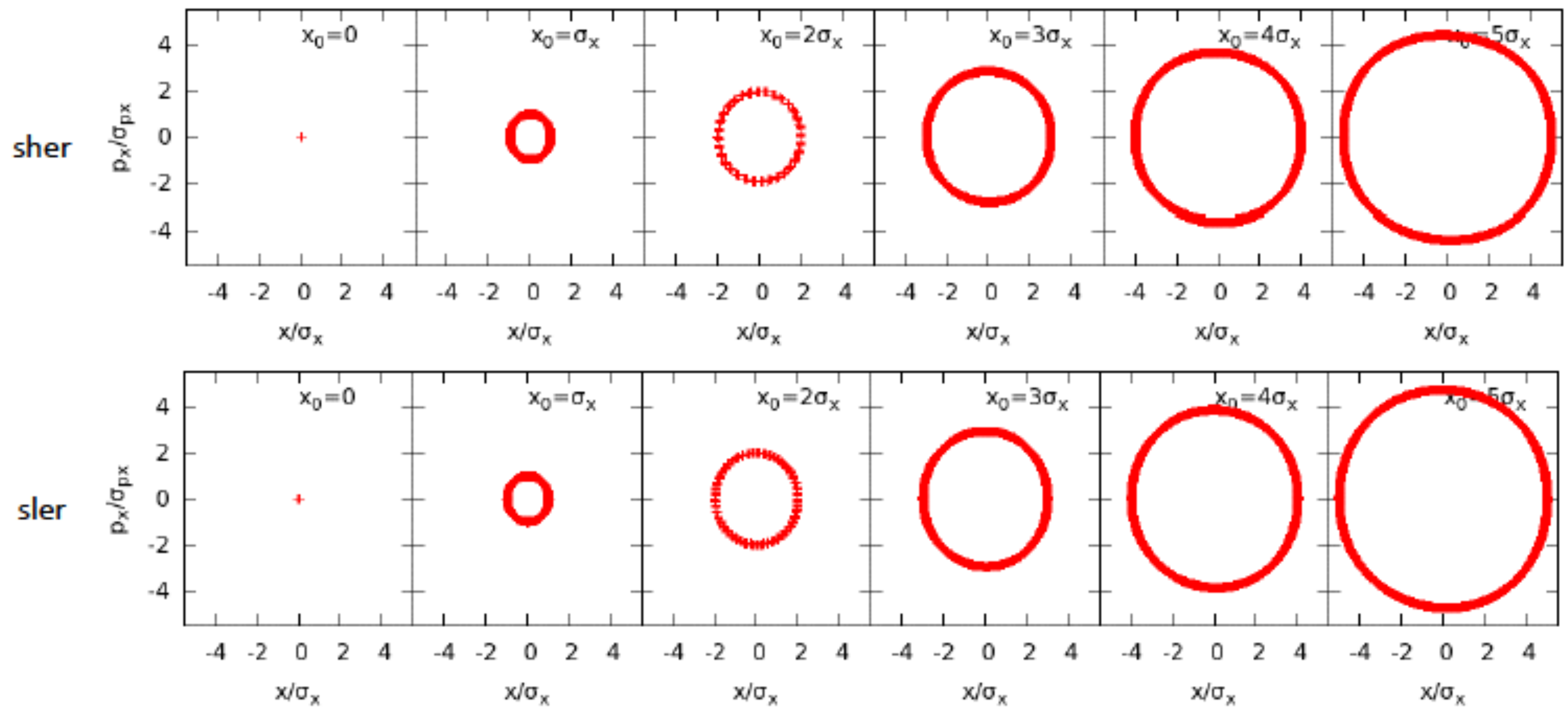
  x0 change from 0 -> $5\sigma_x$
- Watch point is at IP

2. Lattice nonlin.: LER: Y. Zhang's idea

➤ **Realistic lattice**

From Y. Zhang

sher-5767 vs ler-1689 in X direction

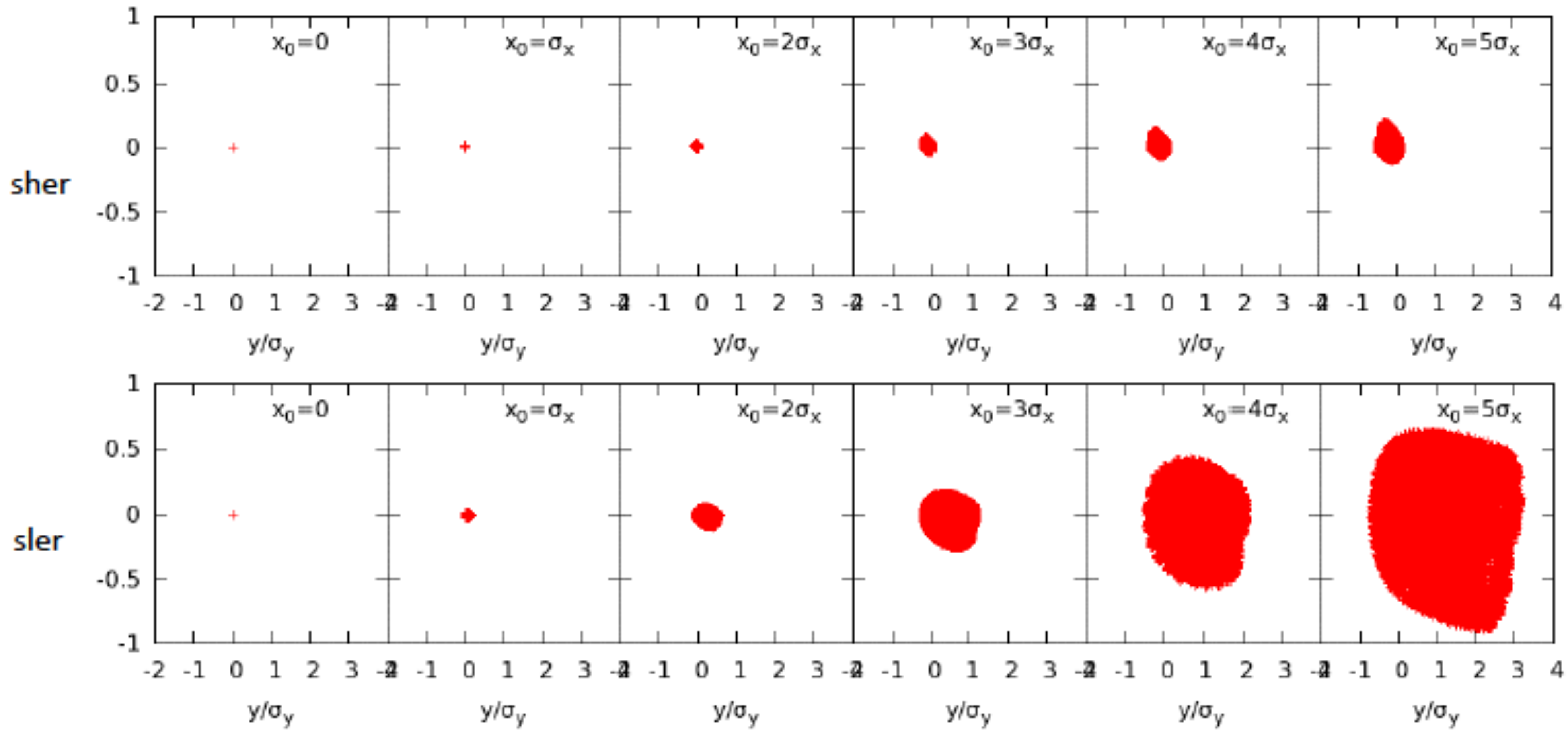


2. Lattice nonlin.: LER: Y. Zhang's idea

- ➤ **Realistic lattice**
- ➤ **Evidence of nonlinear X-Y coupling?**
- ➤ **COD in y direction as function of X offset**

From Y. Zhang

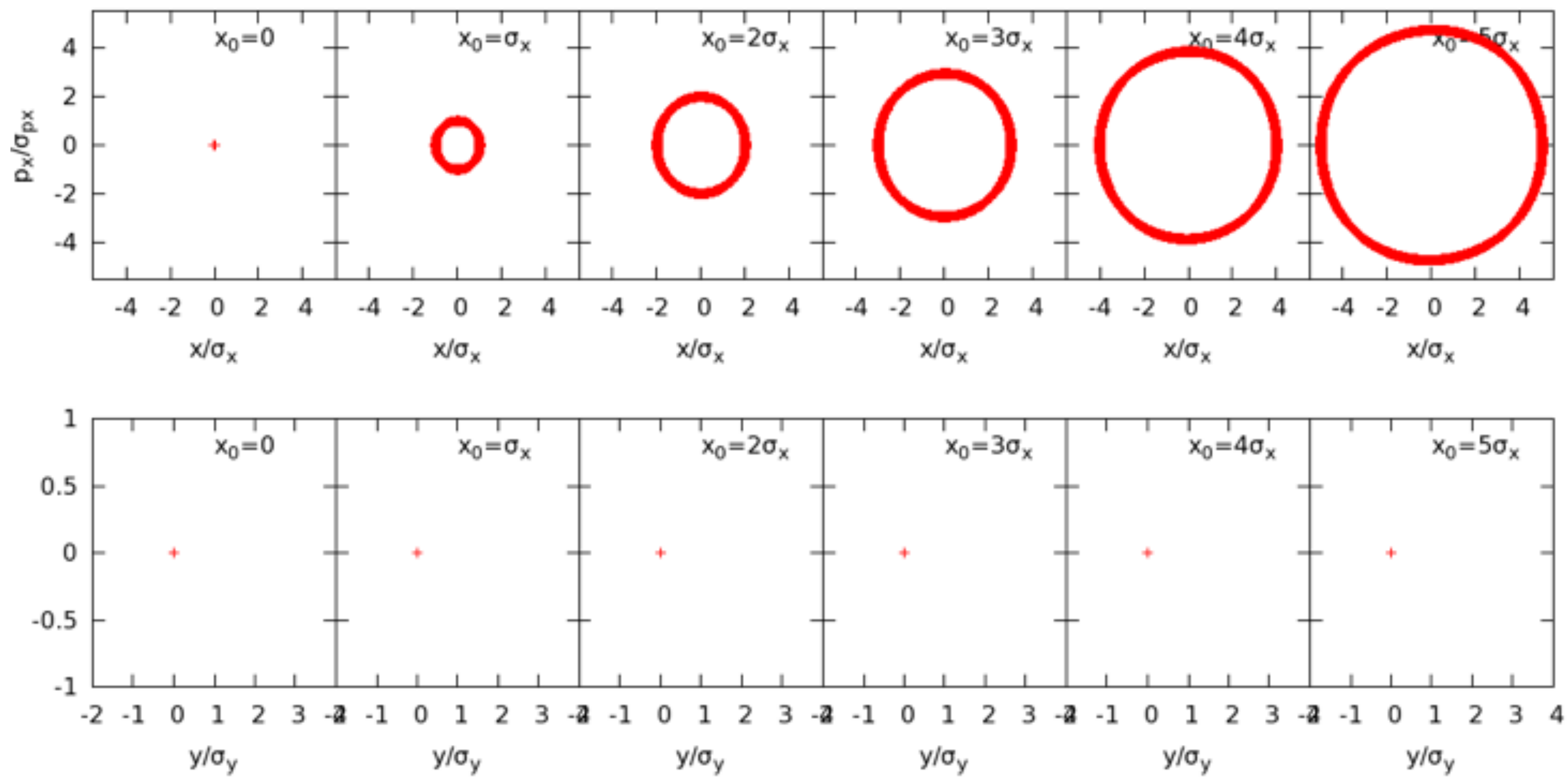
sher-5767 vs ler-1689 in Y direction



2. Lattice nonlin.: LER: Y. Zhang's idea

- Simplified LER lattice (From H. Sugimoto)
- Confirm: solenoid causes nonlinear X-Y coupling

From Y. Zhang



2. Lattice nonlin.: LER: Y. Zhang's idea

From Y. Zhang

It seems

- There exist stronger coupling resonance from horizontal to vertical direction in LER!
- There exist a clear orbit offset in y when horizontal oscillation is large enough ($1\sigma_y$ for $5\sigma_x$) in LER!

2. Lattice nonlin.: LER: Y. Zhang's idea

From Y. Zhang

Frequency Analysis

- Linear Normalized Coordinate

$$\hat{x} = \frac{x}{\sqrt{\beta_x}}, \hat{p}_x = p_x * \sqrt{\beta_x}$$

$$\hat{y} = \frac{y}{\sqrt{\beta_y}}, \hat{p}_y = p_y * \sqrt{\beta_y},$$

- Turn-by-Turn data could be represented by (with first order approximation)

$$\hat{x}(m) - i\hat{p}_x(m) = \sqrt{2A_x} e^{i(m\mu_x + \phi_{x,0})} - \sum_{abcd} 2ia f^{(3)}_{abcd} (2A_x)^{\frac{a+b-1}{2}} (2A_y)^{\frac{c+d}{2}} e^{i(b-a+1)(m\mu_x+\phi_{x,0})} e^{i(d-c)(m\mu_y+\phi_{y,0})}$$

$$\hat{y}(m) - i\hat{p}_y(m) = \sqrt{2A_y} e^{i(m\mu_y + \phi_{y,0})} - \sum_{abcd} 2ic f^{(3)}_{abcd} (2A_x)^{\frac{a+b}{2}} (2A_y)^{\frac{c+d-1}{2}} e^{i(b-a)(m\mu_x+\phi_{x,0})} e^{i(d-c+1)(m\mu_y+\phi_{y,0})}$$

2. Lattice nonlin.: LER: Y. Zhang's idea

From Y. Zhang

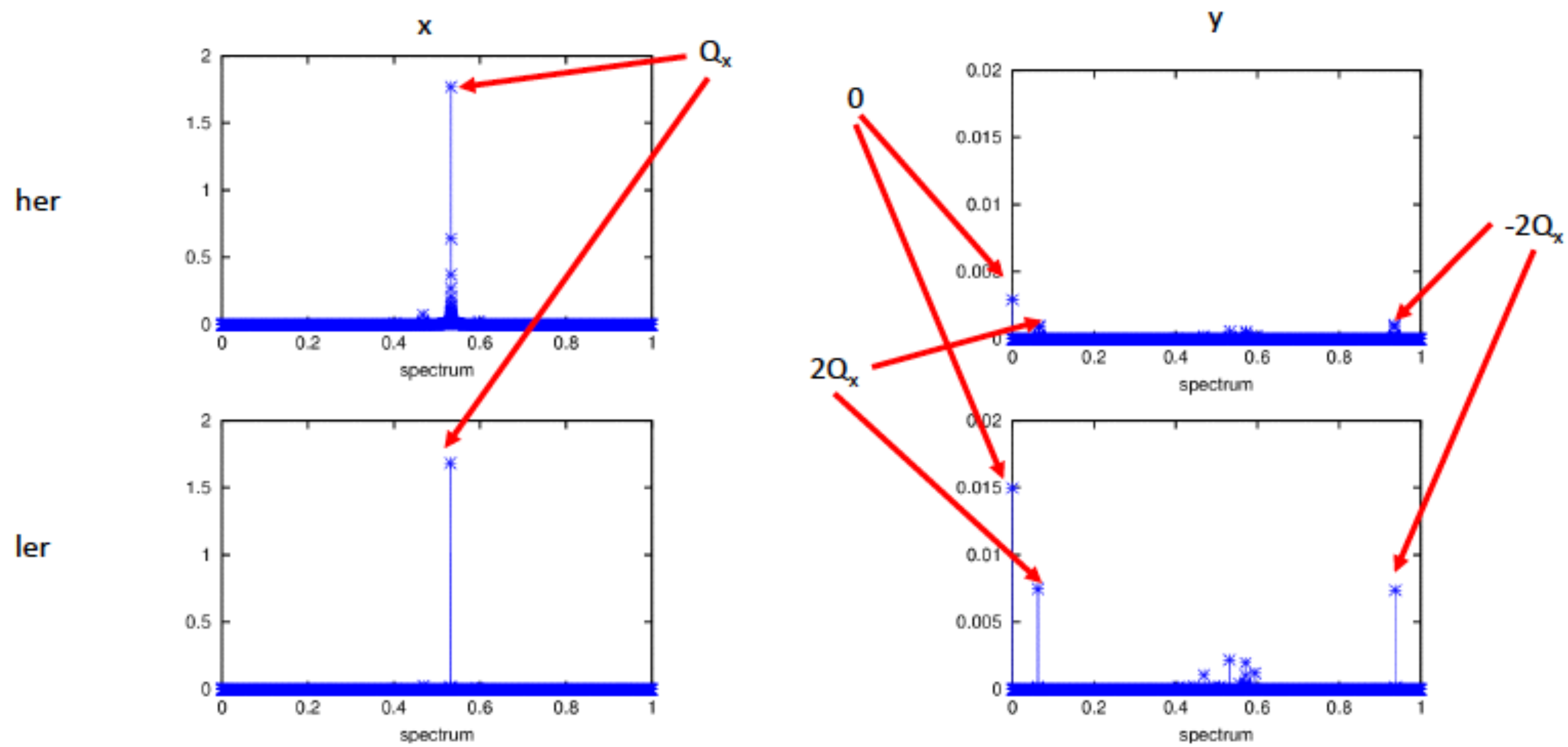
Frequency Analysis (2)

- FFT with
  $\hat{x} - i\hat{p}_x$ in x direction
  $\hat{y} - i\hat{p}_y$ in y direction

2. Lattice nonlin.: LER: Y. Zhang's idea

From Y. Zhang

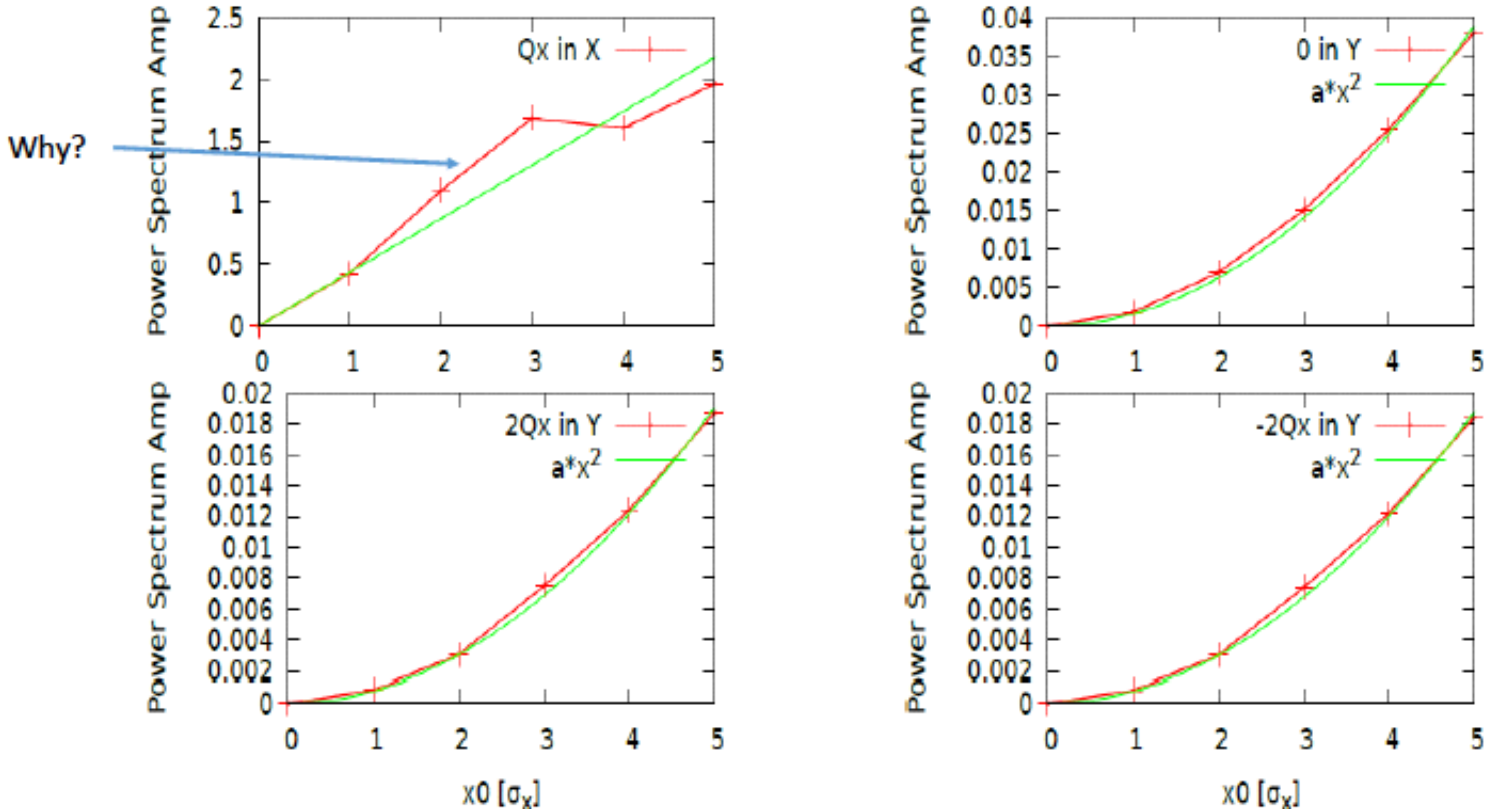
Spectrum (x0=3σ_x)



2. Lattice nonlin.: LER: Y. Zhang's idea

From Y. Zhang

Power spectrum analysis (LER)



2. Lattice nonlin.: LER: Y. Zhang's idea

From Y. Zhang

Sepctrum

- There exist very strong 'oscilation' at 0, 2Qx, -2Qx for LER
- It is suspected the cause is

  f1110 -> 0 in vertical direction, the amplitude is proportional to $(2A_x)$

  f0210 -> 2Qx in vertical direction, the amplitude is proportional to $(2A_x)$

  f2010 -> -2Qx in vertical direction, the amplitude is proportional to $(2A_x)$

All these terms may come from a skew sextupole like magnet.

$H \sim 3x^2y - y^3$

2. Lattice nonlin.: LER: Y. Zhang's idea

➤ **Test by inserting a map of H=K*x^2y into the LER lattice**

```
GetMAIN["/ldata/SuperKEKB/Lattice/LER/sler_1689.sad"];
USE ASC;
b=ExtractBeamLine[];
b=Prepend[Drop[b,2],BeamLine[IP,BMBMP,SKEWSEXT]];
```

From Y. Zhang

```
!!! Define external maps of skew sextupole (from Y. Zhang)
lambda=-66.6;
cosx = Cos[-1.571];
sinx = Sin[-1.571];
cosy = Cos[-1.351];
siny = Sin[-1.351];
 ExternalMap["TRACK",LINE["POSITION","SKEWSEXT"],nt_,x_]:=(
  normalx = x[[1]]/Sqrt[32e-3];
  normalpx = x[[2]]*Sqrt[32e-3];
  normaly = x[[3]]/Sqrt[0.27e-3];
  normalpy = x[[4]]*Sqrt[0.27e-3];

  xxsext = cosx * normalx + sinx * normalpx;
  pxsext =-sinx * normalx + cosx * normalpx;
  yysext = cosy * normaly + siny * normalpy;
  pysext =-siny * normaly + cosy * normalpy;

  xx=xxsext;
  px=pxsext - 6*lambda * xxsext * yysext;
  yy=yysext;
  py=pysext - 3*lambda * xxsext * xxsext;
```

← **Phase advance from IP** (cosx … siny)

← **Normalized coordinates** (normalx … normalpy)

← **Phase shift** (xxsext … pysext)

← **skew-sext. kick** (px, py)

```
  normalx  = cosx * xx - sinx * px;
  normalpx = sinx * xx + cosx * px;
  normaly  = cosy * yy - siny * py;
  normalpy = siny * yy + cosy * py;

  xx = normalx*Sqrt[32e-3];
  px = normalpx/Sqrt[32e-3];
  yy = normaly*Sqrt[0.27e-3];
  py = normalpy/Sqrt[0.27e-3];

  zz=x[[5]];
  dd=x[[6]];
  fl=x[[7]];
  Return[{xx,px,yy,py,zz,dd,fl}];
);
```

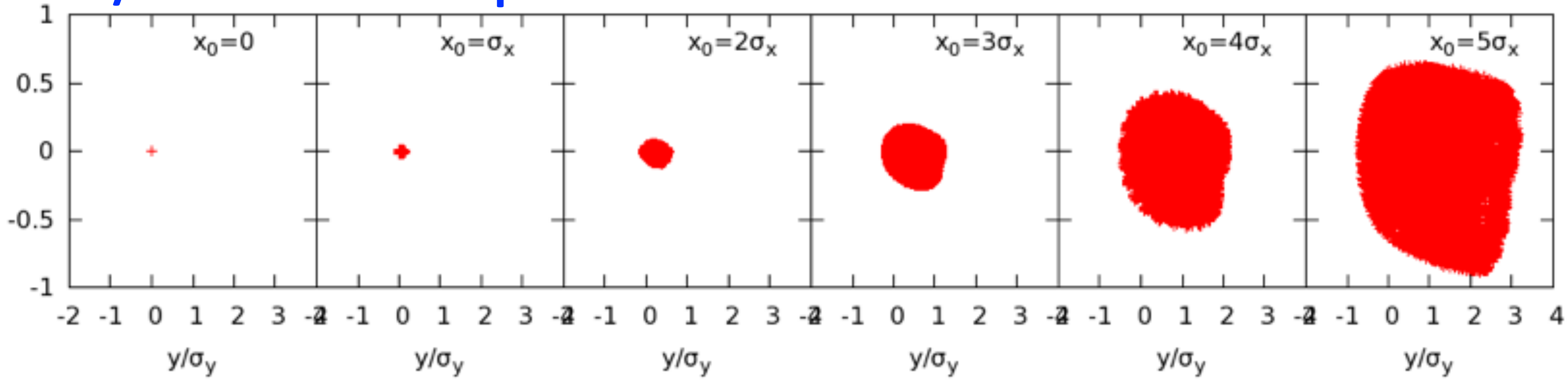
2. Lattice nonlin.: LER: Y. Zhang's idea

➤ **Test by inserting a map of $H=K*x^2y$ into the LER lattice**

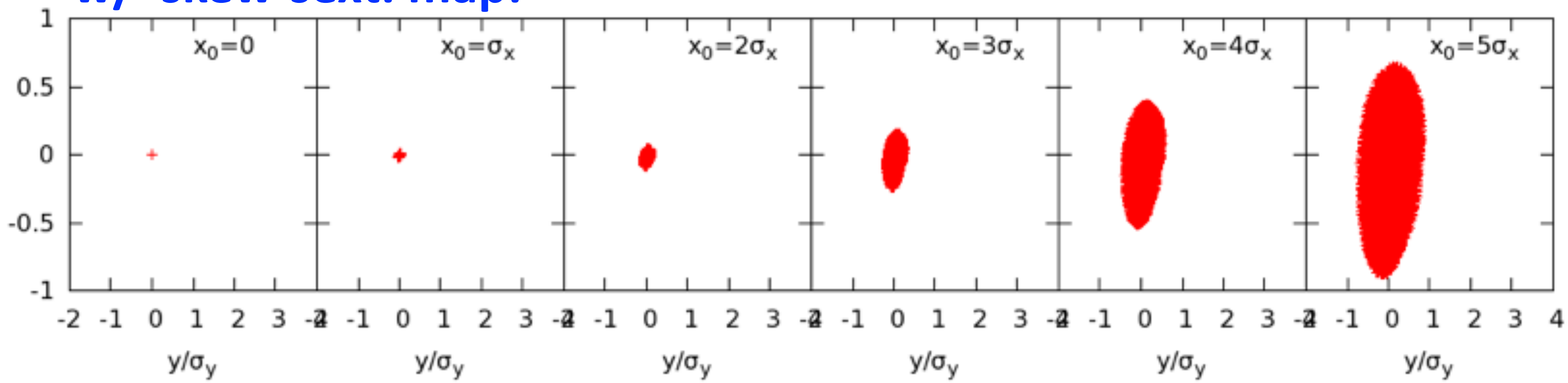
➤ **COD and oscillation amplitude in y are well suppressed as expected**

From Y. Zhang

w/o skew-sext. map:

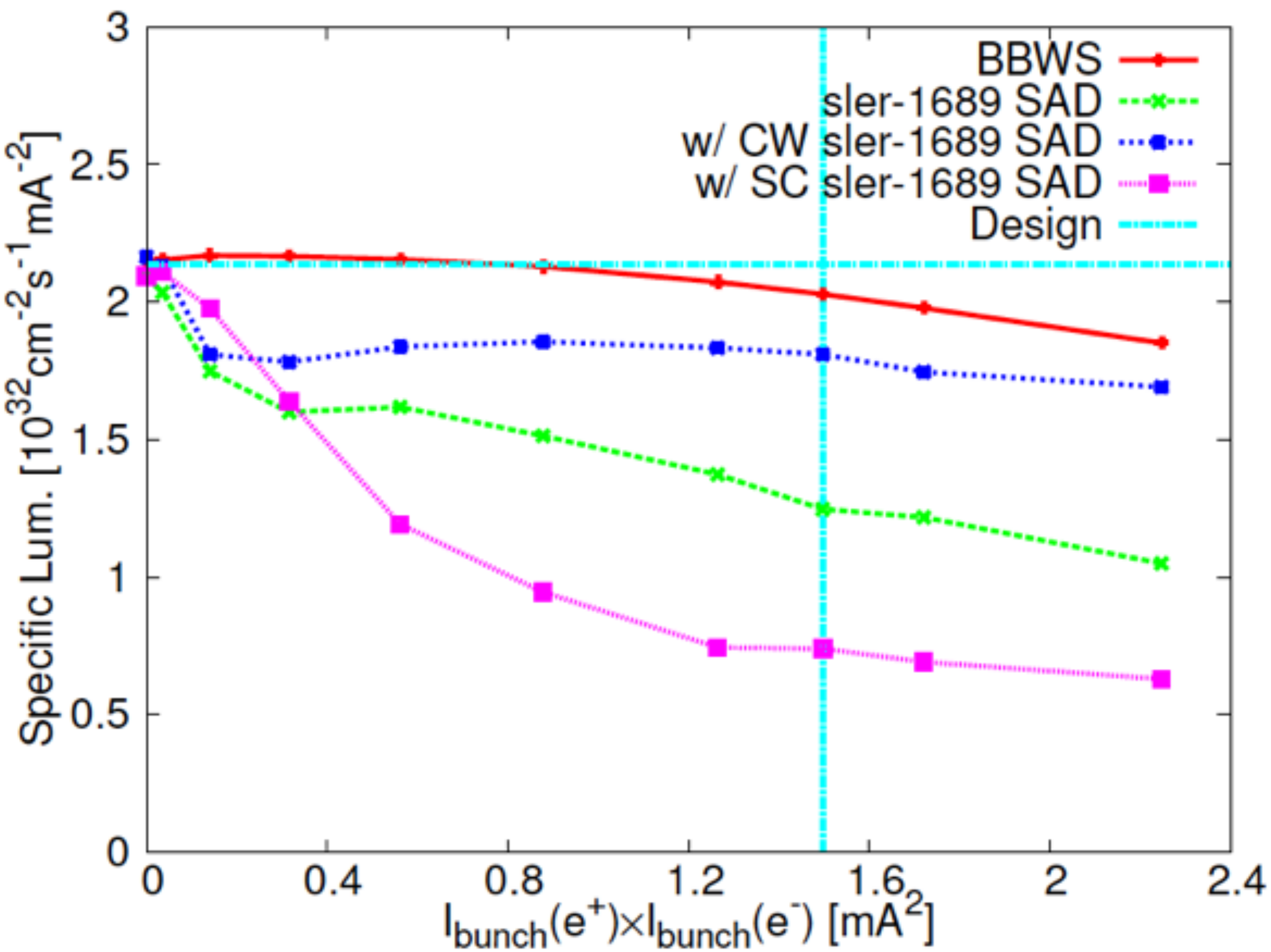


w/ skew-sext. map:



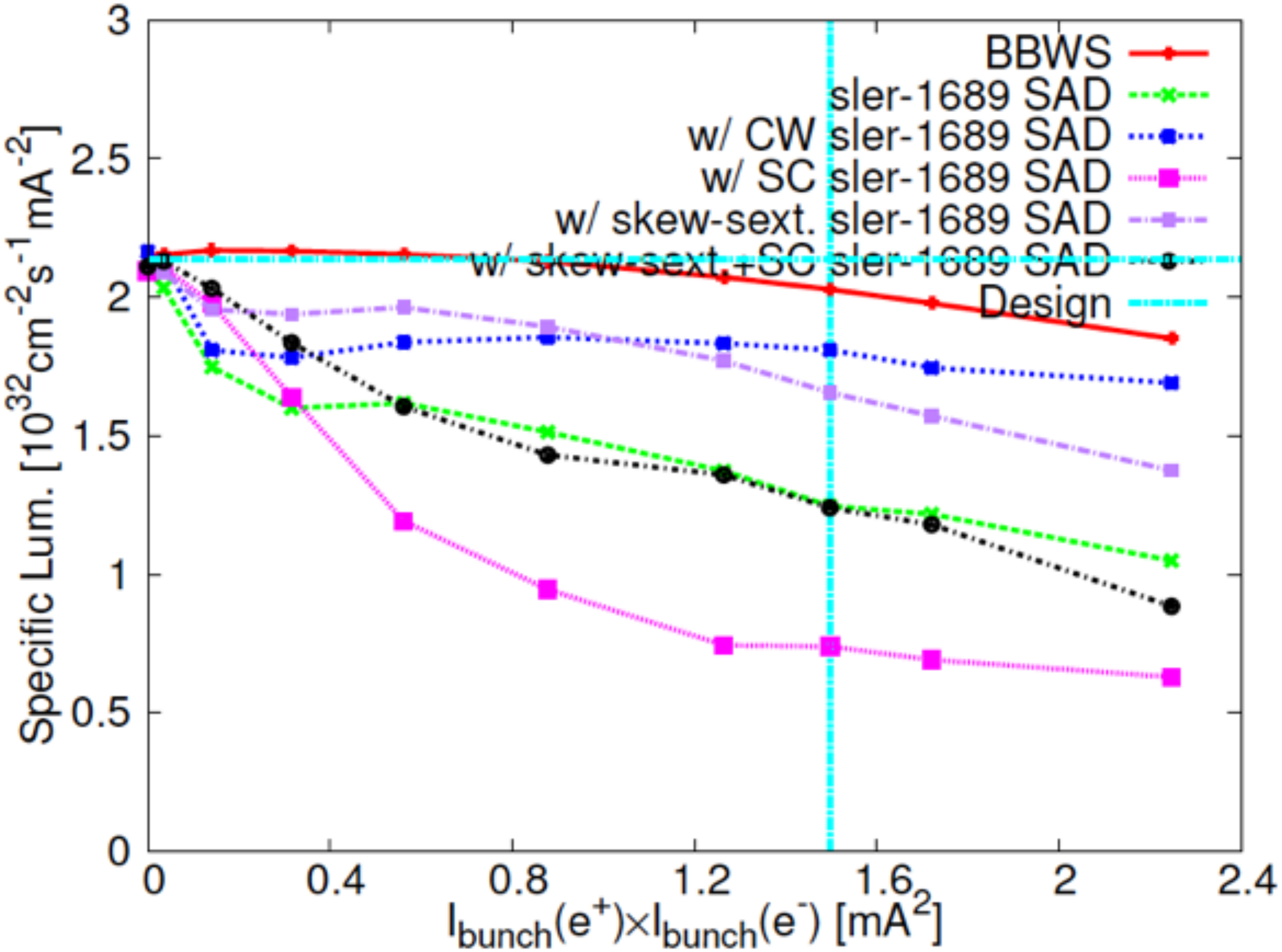
2. Lattice nonlin.: LER: Lum. calculation

- ➤ **Realistic lattice: lum. drops at low beam currents**
- ➤ **Crab-waist:**
  - **to cancel beam-beam driven resonances**
  - **work well at high currents, but not well at low currents**



2. Lattice nonlin.: LER: Lum. calculation

- **Test by inserting a map of $H=K^*x^2y$ into the LER lattice**
- **Skew-sext. map:**
  - **to cancel the nonlinear term from solenoid**
  - **work well at both low and high currents**
  - **interplay of SC and lattice nonlin. also mitigated partially**

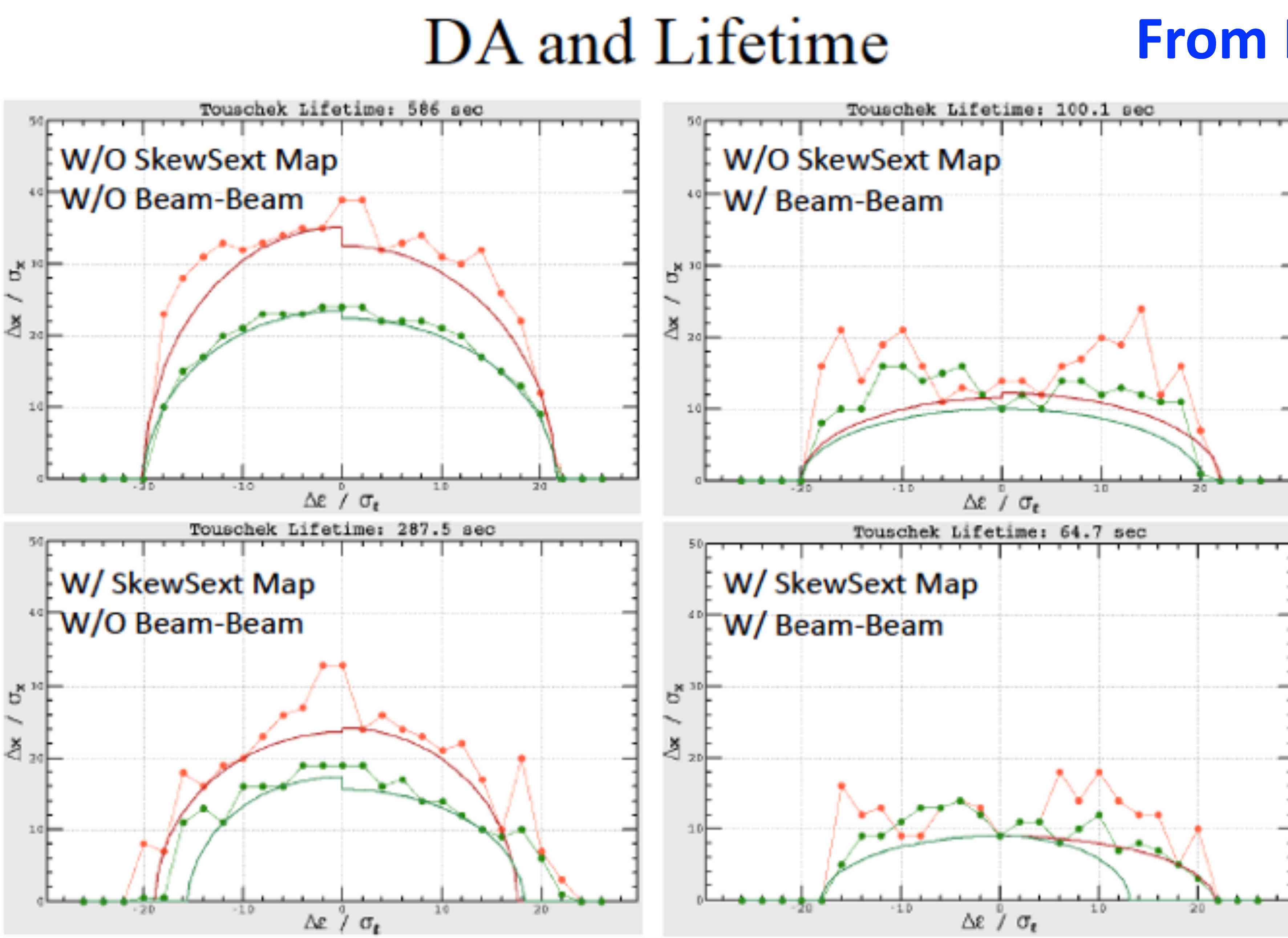


2. Lattice nonlin.: LER: DA and lifetime

- **Test by inserting a map of $H=K*x^2y$ into the LER lattice**
- **Skew-sext. map:**
  - cause loss in DA and lifetime (to be understood)

sler_1689

From H. Sugimoto



3. Lum. calculation: Detuned lattice

➤ **Detuned lattice: sler_1689_d4-8/sher_5767_d4-8**

From Y. Ohnishi

Parameters	symbol	Phase 2.x		Phase 3.x		unit
		LER	HER	LER	HER	
Energy	E	4	7.007	4	7.007	GeV
#Bunches	n_b	2500		2500		
Emittance	ε_x	2.2	5.2	3.2	4.6	nm
Coupling	$\varepsilon_y/\varepsilon_x$	2	2	0.27	0.28	%
Hor. beta at IP	β_x^*	128	100	32	25	mm
Ver. beta at IP	β_y^*	2.16	2.4	0.27	0.30	mm
Beam current	I_b	1.0	0.8	3.6	2.6	A
Beam-beam	ξ_y	0.0240	0.0257	0.088	0.081	
Hor. beam size	σ_x^*	16.8	22.8	10	11	μm
Ver. beam size	σ_y^*	308	500	48	62	nm
Luminosity	L	1×10^{34}		8×10^{35}		$cm^{-2}s^{-1}$

LER

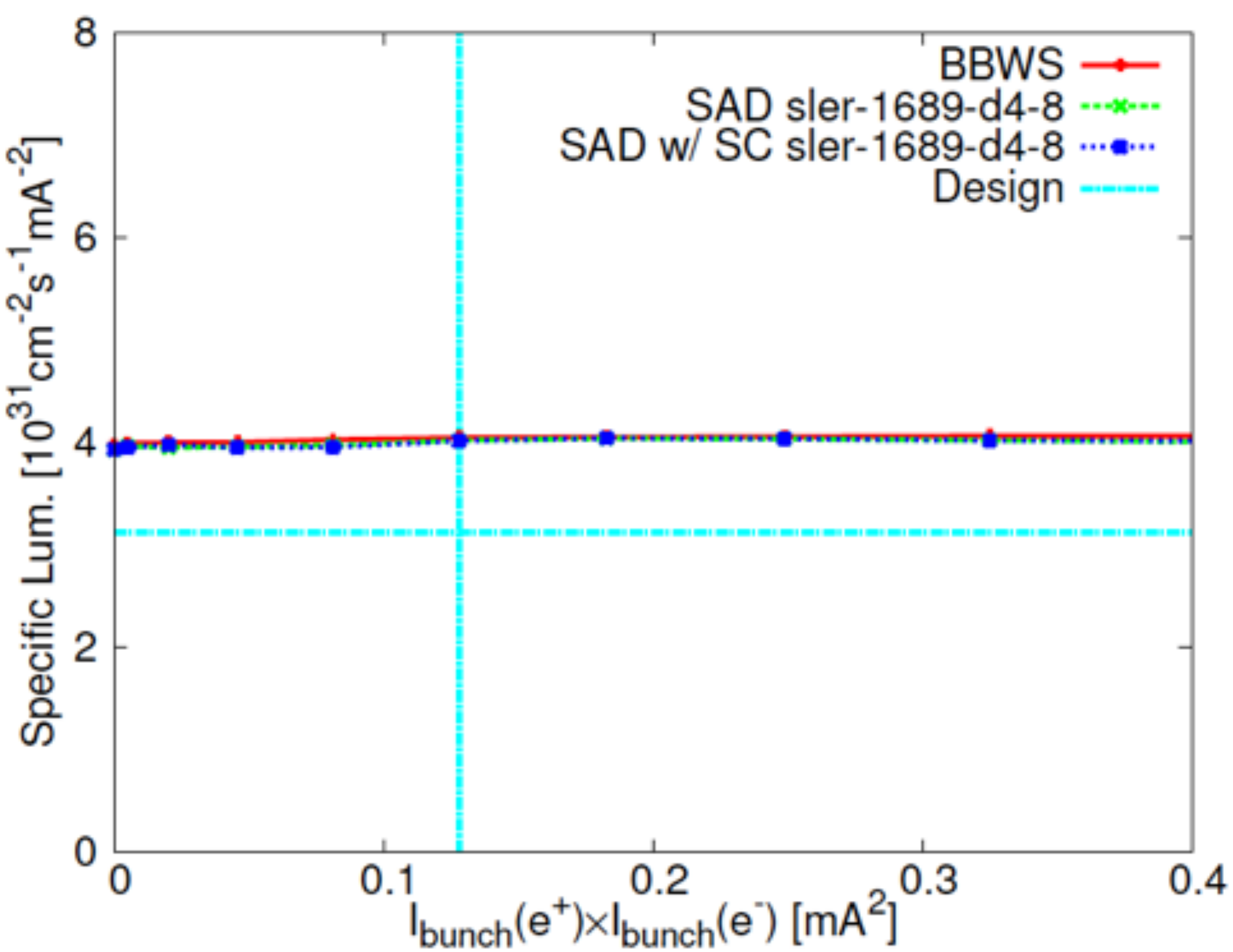
β_x at IP	128	mm
β_y at IP	2.16	mm
I_b	1	A
n_b	2500	
ε_x	1.75	nm
$\varepsilon_y/\varepsilon_x$	2	%

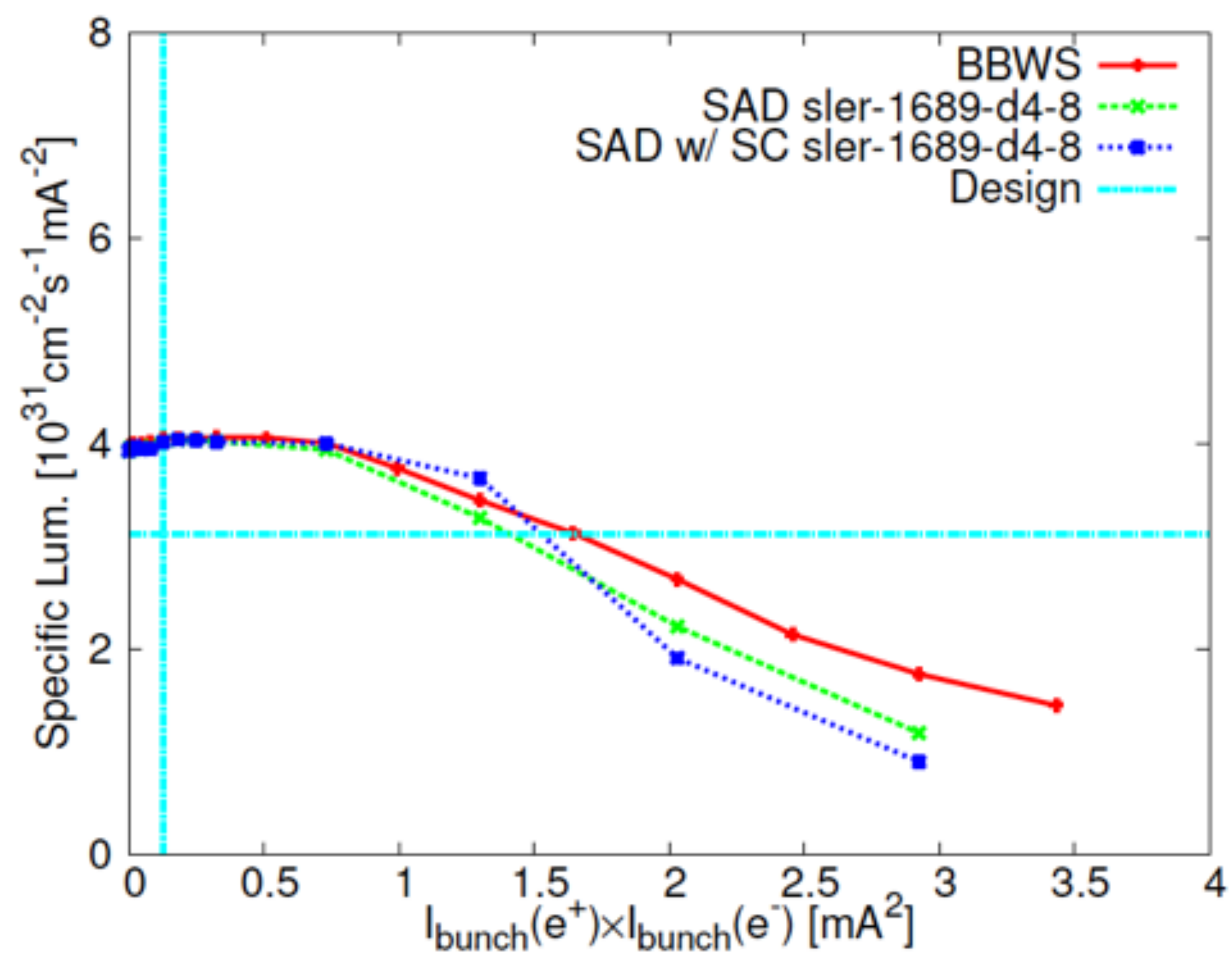
HER

β_x at IP	100	mm
β_y at IP	2.40	mm
I_b	0.8	A
n_b	2500	
ε_x	4.5	nm
$\varepsilon_y/\varepsilon_x$	2	%

3. Lum. calculation: Detuned lattice

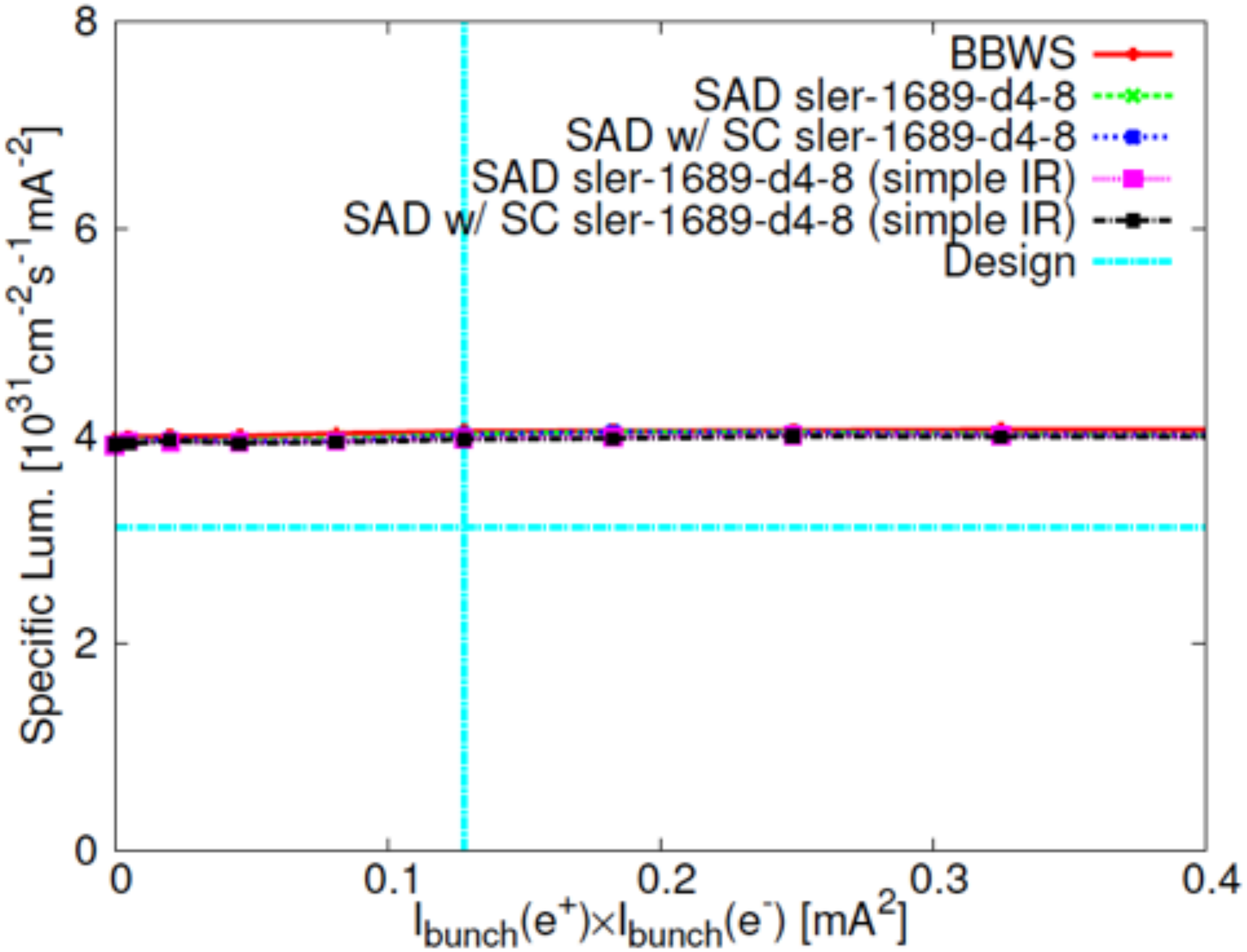
- Assume: ε_x=1.75nm, coupling = 2%
- Space-charge is not important
- Lattice nonlinearity is not very important
- $L=1\times10^{34}cm^{-2}s^{-1}$ is promising
- $L=10\times10^{34}cm^{-2}s^{-1}$ is possible by increasing beam currents?

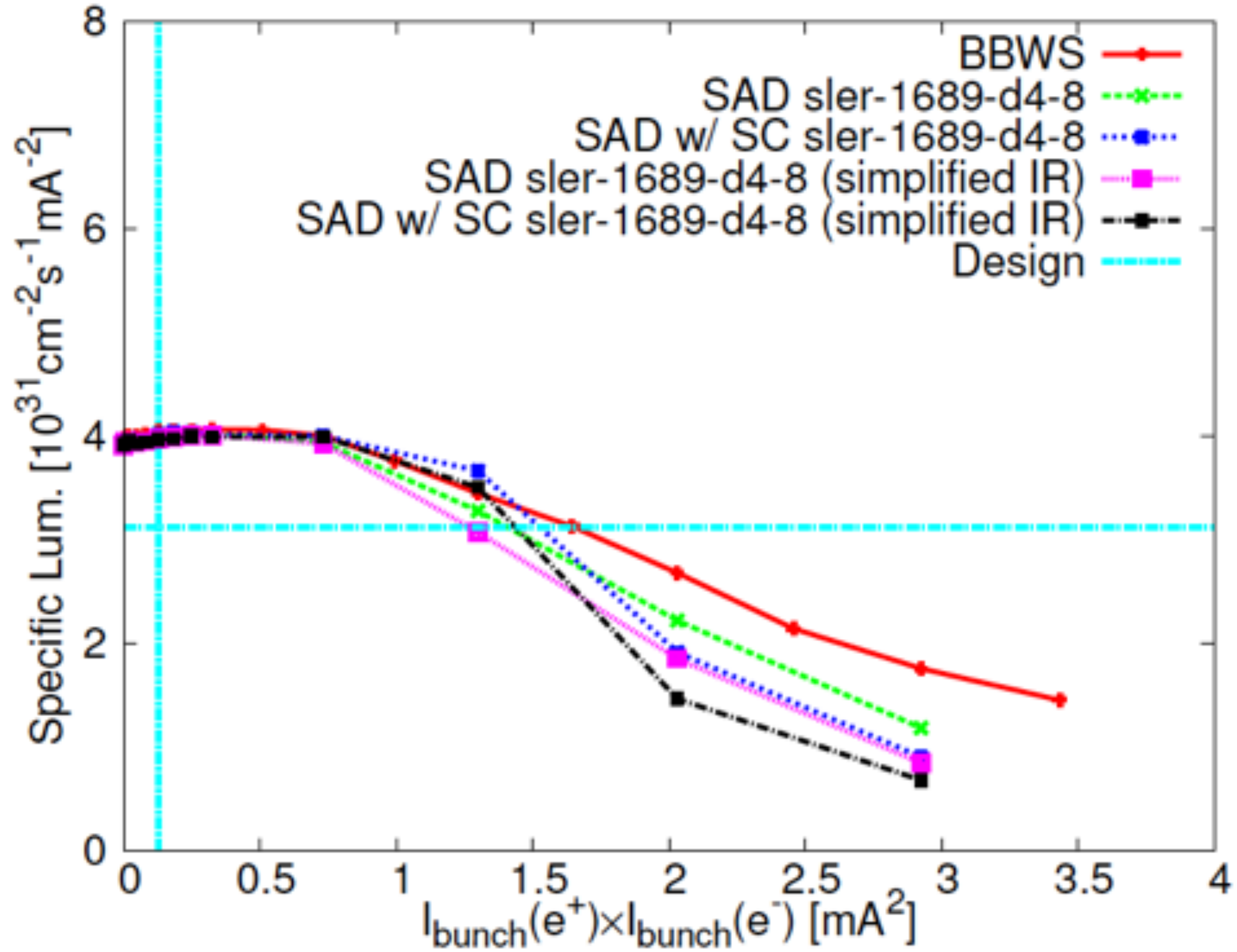




3. Lum. calculation: Detuned lattice

- ➤ Assume: ε_x=1.75nm, coupling = 2%
- ➤ Compare with the case of simplified IR
- ➤ Solenoid not to cause lum. loss





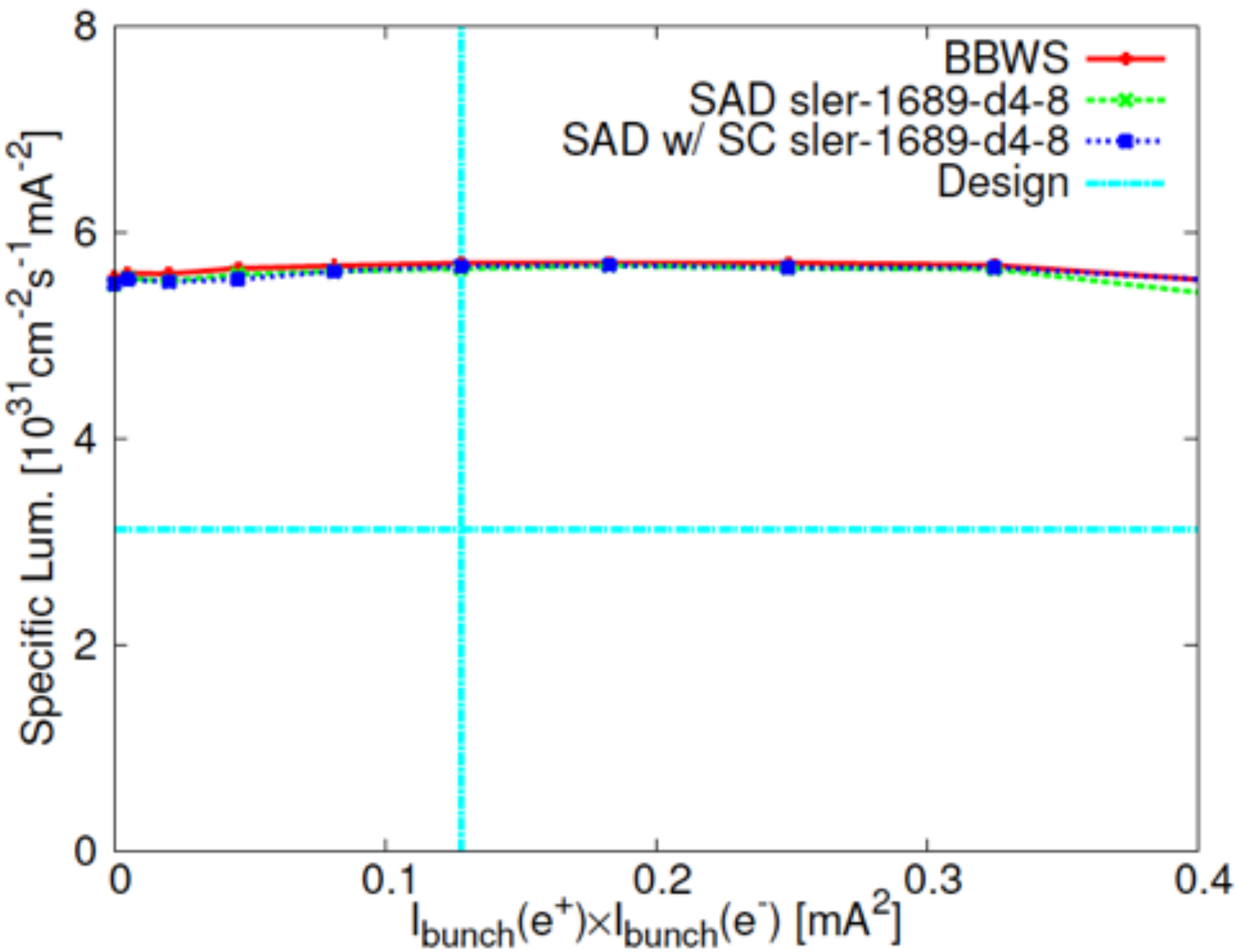
3. Lum. calculation: Detuned lattice

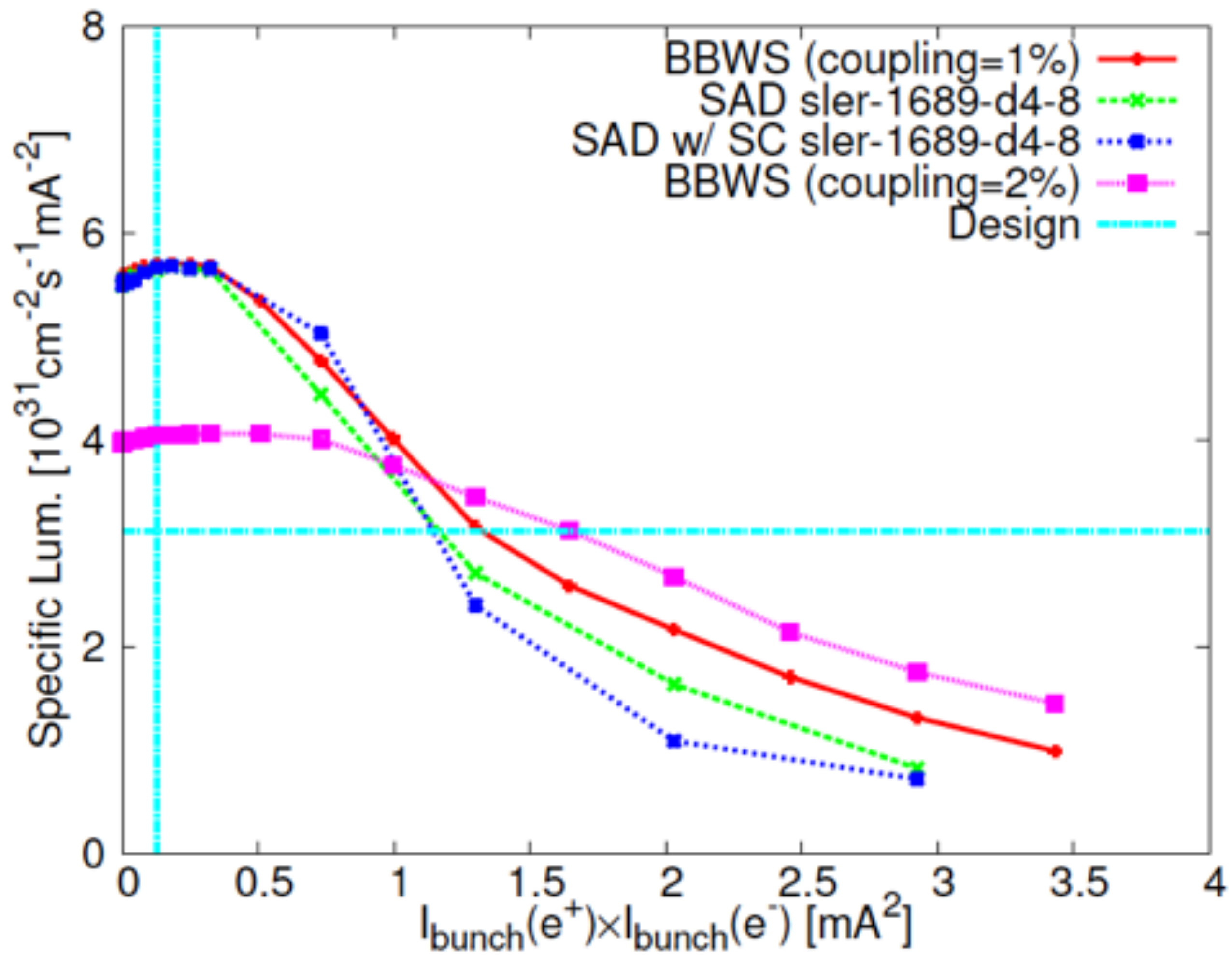
➤ **Assume: ε_x=1.75nm, coupling = 1%**

➤ **Space-charge is not important at low currents**

➤ **Lattice nonlinearity is not very important**

➤ **Decreasing coupling => Lum. gain but beam-beam limit appears at lower beam currents**





4. Summary

- **Lum. calculation with simplified IR (LER)**
  - No significant lum. loss at low beam currents
  - Solenoid is likely to be the main source of LN
- **Analysis of LN in LER by Y. Zhang and relevant simulations**
  - Dominant nonlinear term: skew-sext. $K(x^2y-y^3)$
  - This term not to appear in simplified lattice
  - Lum. can be partially recovered by inserting a skew-sext. map into the lattice
  - But the skew-sext. map does not improve DA and lifetime
- **Lum. calculation for detuned optics**
  - Space-charge and LN likely not to cause lum. loss
  - $L=1\times10^{34}cm^{-2}s^{-1}$ is promising
  - $L=10\times10^{34}cm^{-2}s^{-1}$ is possible?