

# Circular $e^+e^-$ Colliders

Physics at LHC and beyond

Aug 14, 2014 @ Quy Nhon

K. Oide (KEK)

Thank F. Zimmermann and all who provided the materials.

More than 20 circular e+e- colliders have been built and operated since 1962.  
 This is the most experienced and matured scheme in HEP.

Collider	Location	Scheme	Beam Energy (GeV)	Luminosity ( $10^{30} \text{cm}^{-2}\text{s}^{-1}$ )	Year
AdA	Frascati	S	0.25	$\sim 10^{-5}$	1962
ACO	Orsay	S	0.5	0.1	1966
Adone	Frascati	S	1.5	0.6	1969–1993
SPEAR	SLAC	S	4	12	1972–1990
VEPP-2/2M	BINP	S	0.7	13	1974–
DORIS	DESY	D	5.6	33	1974–1993
DCI	Orsay	D	1.8	2	1976–2003
PETRA	DESY	S	19	30	1978–1986
VEPP-4M	BINP	S	7	50	1979–
CESR	Cornell	S	6	1,300	1979–2002
PEP	SLAC	S	15	60	1980–1990
TRISTAN	KEK	S	32	37	1986–1994
BEPC	IHEP	S	2.2	13	1989–2005
LEP	CERN	S	46	24	1989–1994
DAΦNE	Frascati	D	0.7	150	1997–
LEP2	CERN	S	105	100	1995–2000
PEP-II	SLAC	D	3.1 / 9	12,000	1999–2008
KEKB	KEK	D	3.5 / 8	21,100	1999–2010
CESR-c	Cornell	S	1.9	60	2002–2008
VEPP-2000	BINP	S	0.5	120	2006–
BEPC-II	IHEP	D	2.1	710	2007–

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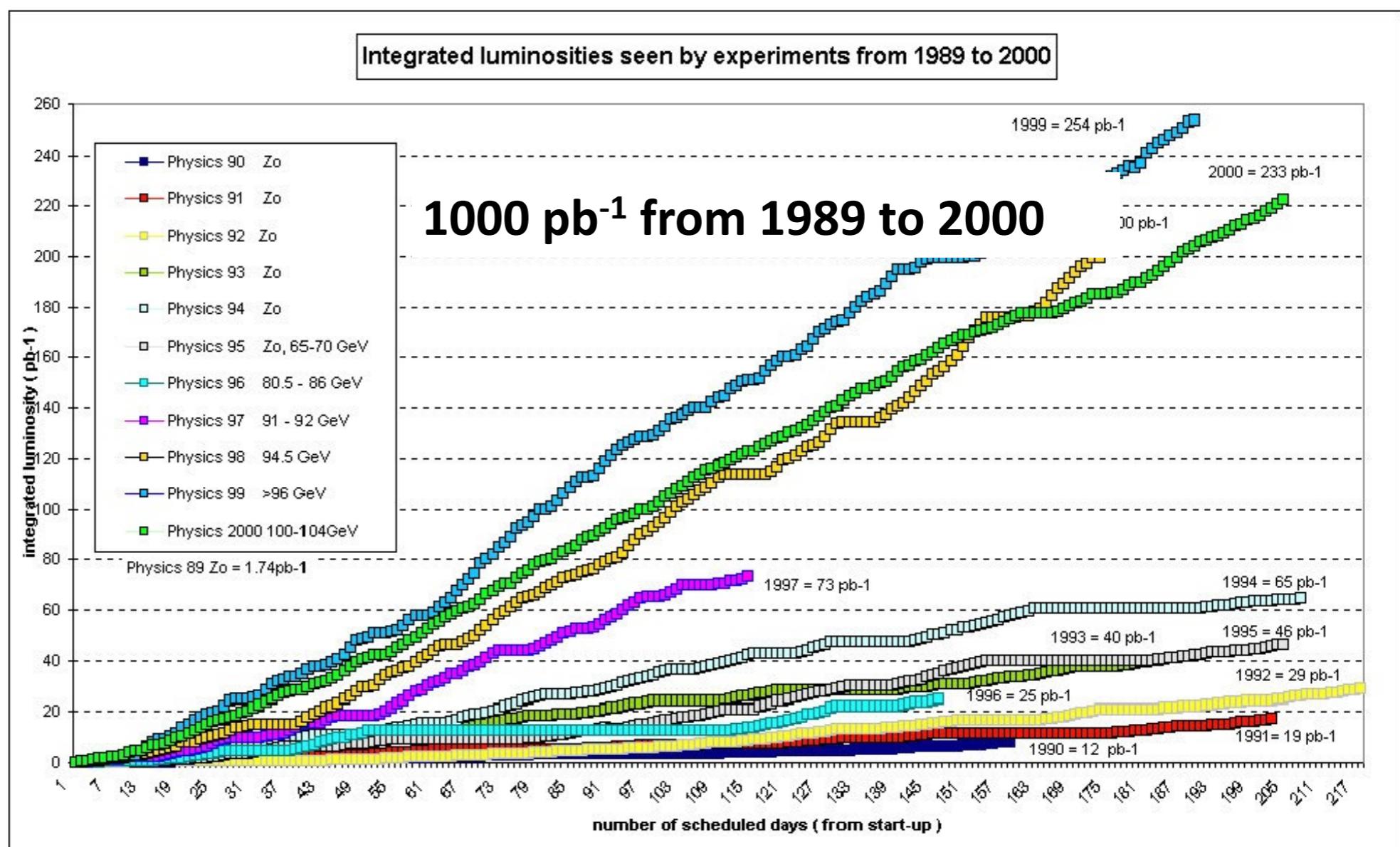
LEP – largest circular  $e^+e^-$  collider so far



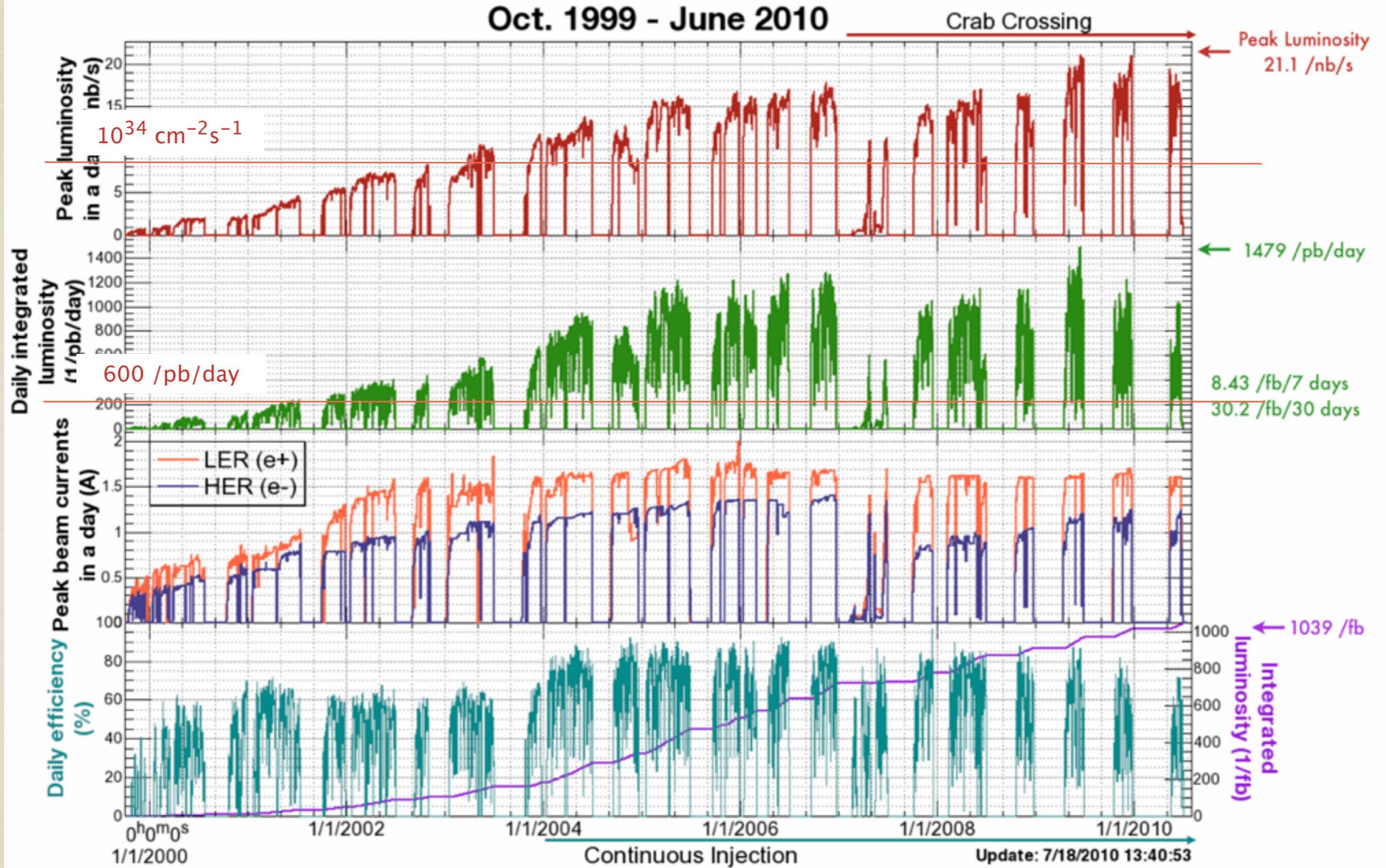
# LEP – largest circular $e^+e^-$ collider so far



R. Assmann, Chamonix 2001



# KEKB – brightest circular $e^+e^-$ collider so far



The next generation  $e^+e^-$  collider must be the largest AND brightest!

# Future high-energy circular colliders

Parameters are indicative and fast evolving, as no CDR yet

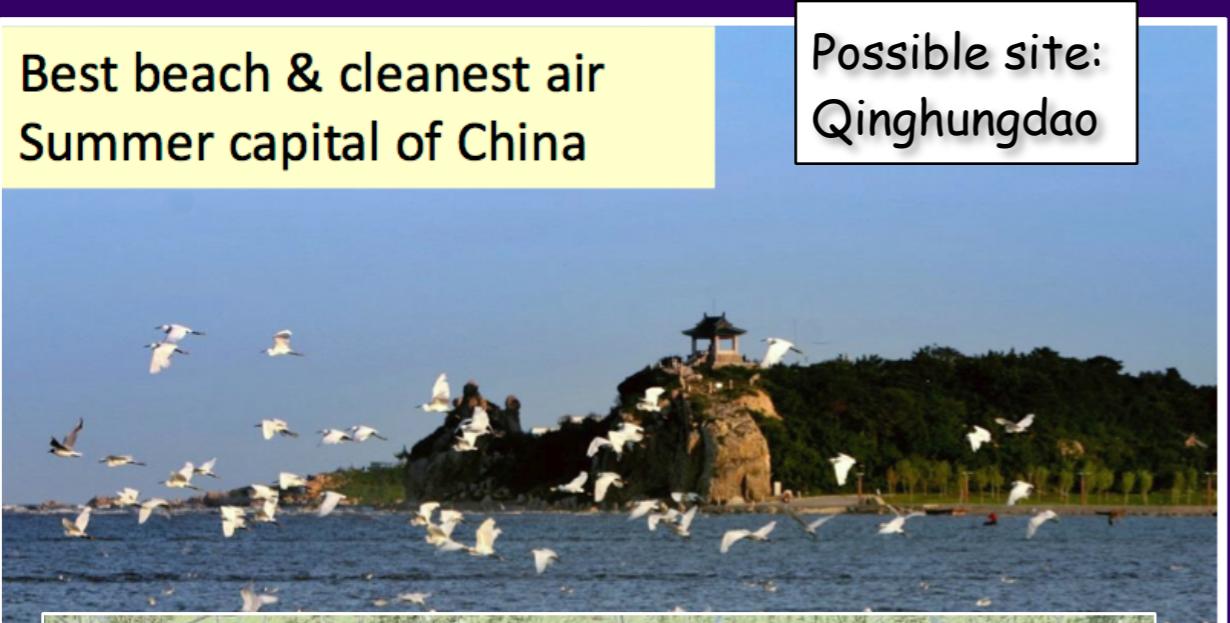
China: 50-70 km  $e^+e^-$   $\sqrt{s}=240$  GeV (CepC)  
followed by 50-90 TeV pp collider (SppC)  
in same tunnel

50 km  $e^+e^-$  machine + 2 experiments:

- pre-CDR: end 2014
- construction: 2021-2027
- data-taking: 2028-2035

Best beach & cleanest air  
Summer capital of China

Possible site:  
Qinghungdao

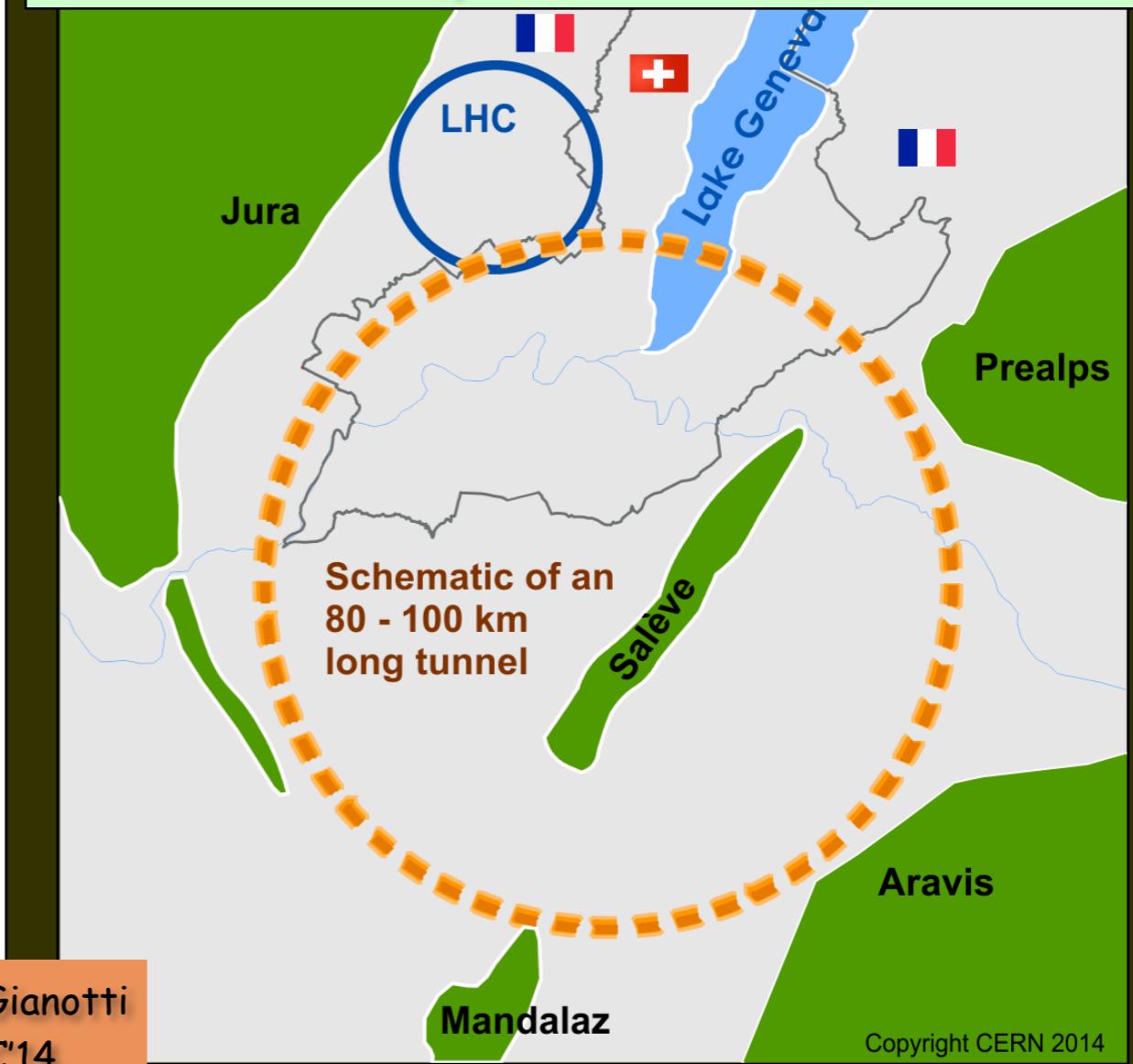


Fabiola Gianotti  
IPAC'14

CERN FCC: international design study for Future Circular Colliders in 80-100 km ring:

- 100 TeV pp: ultimate goal (FCC-hh)
- 90-350 GeV  $e^+e^-$ : possible intermediate step (FCC-ee)
- $\sqrt{s}= 3.5-6$  TeV ep: option (FCC-eh)

Goal of the study: CDR in ~2018.



# Future Circular Collider (FCC) study ; goals: CDR and cost review for the next European Strategy Update (2018)

## International collaboration :

- *pp*-collider (*FCC-hh*) → defining infrastructure requirements

~16 T ⇒ 100 TeV in 100 km

~20 T ⇒ 100 TeV in 80 km

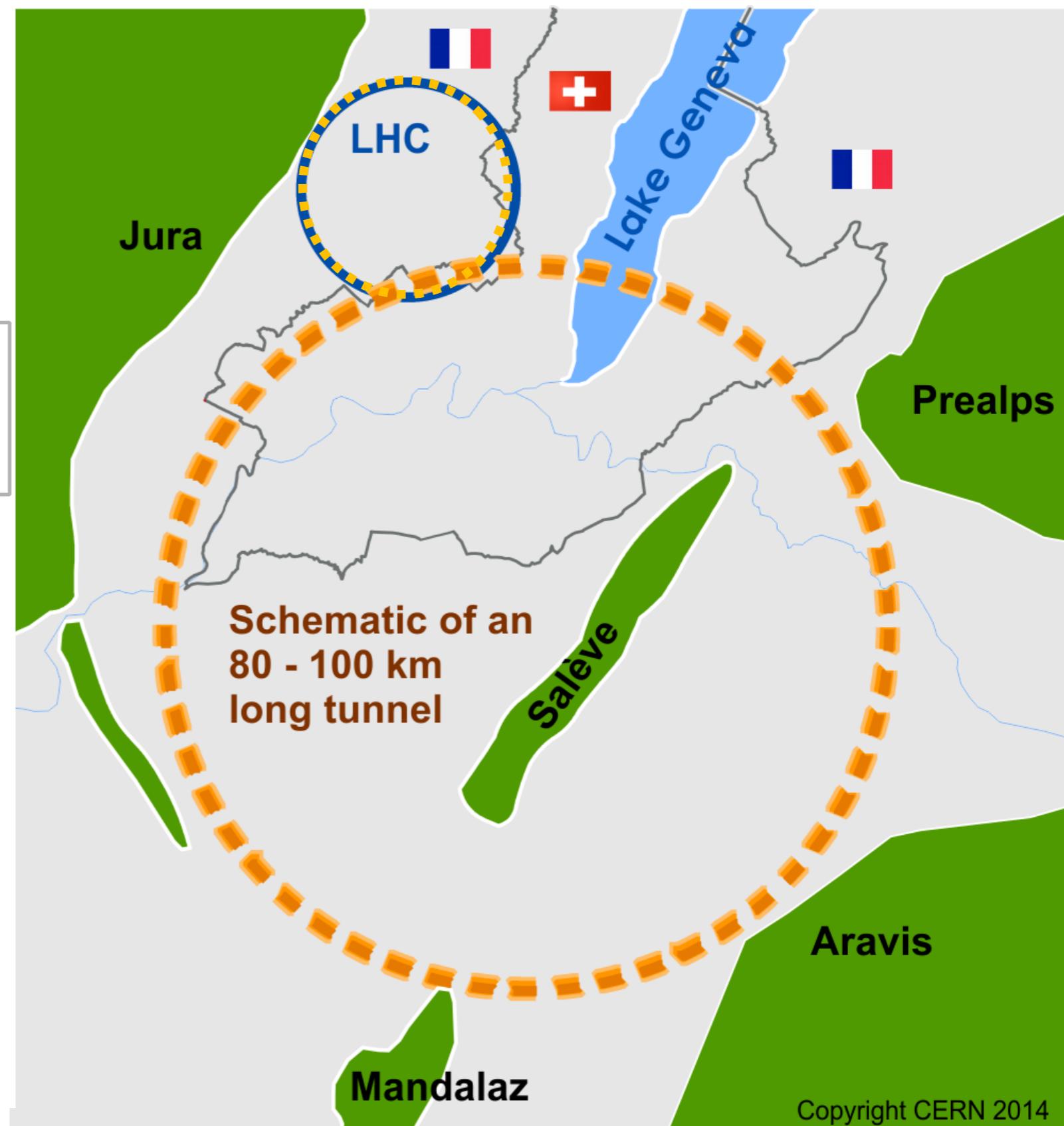
including *HL-LHC* option.

16-20 T in LHC tunnel

- *e<sup>+</sup>e<sup>-</sup>* collider (*FCC-ee/TLEP*) as potential intermediate step

- *p-e* (*FCC-he*) option

- 100 km infrastructure in Geneva area



# CepC/SppC study (CAS-IHEP), CepC CDR end of 2014, e<sup>+</sup>e<sup>-</sup> collisions ~2028; pp collisions ~2042



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parameter	LEP2	FCC-ee					CepC
		Z	Z (c.w.)	W	H	t	
$E_{\text{beam}}$	104	45	45	80	120	175	120
circumference [km]	26.7	100	100	100	100	100	54
current [mA]	3.0	1450	1431	152	30	6.6	16.6
$P_{\text{SR,tot}}$	22	100	100	100	100	100	100
no. bunches	4	16700	29791	4490	1360	98	50
$N_b$	4.2	1.8	1.0	0.7	0.46	1.4	3.7
$\varepsilon_x$	22	29	0.14	3.3	0.94	2	6.8
$\varepsilon_y$	250	60	1	1	2	2	20
$\beta^*$	1.2	0.5	0.5	0.5	0.5	1.0	0.8
$\beta^*$	50	1	1	1	1	1	1.2
$\sigma^*$	3500	250	32	130	44	45	160
$\sigma_{z,\text{SR}}$	11.5	1.64	2.7	1.01	0.81	1.16	2.3
$\sigma_{z,\text{tot}}$	11.5	2.56	5.9	1.49	1.17	1.49	2.7
hourglass factor	0.99	0.64	0.94	0.79	0.80	0.73	0.61
$L$	0.01	28	212	12	6	1.7	1.8

# beam-beam tune shift & energy scaling

tune shift limits scaled from LEP data, confirmed by FCC simulations (S. White, K. Ohmi, A. Bogomyagkov, D Shatilov,...):

$$\xi_y \simeq \frac{\beta_y r_e N}{2\pi\gamma\sigma_x\sigma_y} \leq \xi_{y,\max}(E)$$

$$\xi_{y,\max}(E) \propto \frac{1}{\tau_s^{0.4}} \propto E^{1.2}$$

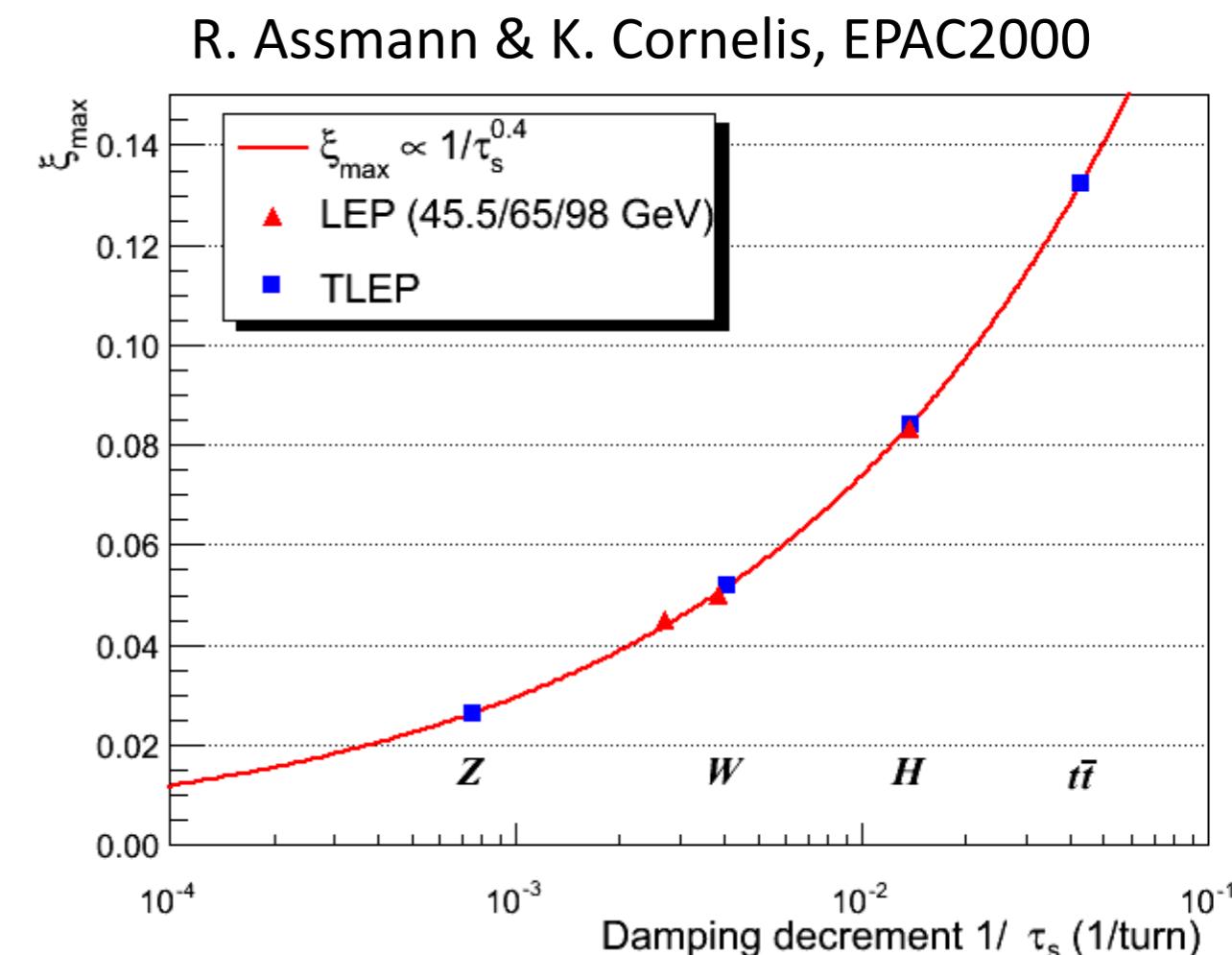
J. Wenninger

→ luminosity scaling with energy:

$$L = n_{IP} \frac{f_{coll} N^2}{4\pi\sigma_x\sigma_y} F_{hg} \propto \frac{\eta P_{SR}}{E^3} \frac{\xi_y}{\beta_y^*} \propto \frac{\eta_{W \rightarrow b} P_{wall}}{E^{1.8}} \frac{1}{\beta_y^*}$$

→ luminosity scaling with energy, incl. beamstrahlung (V. Telnov):  $\frac{N}{\sigma_x^* \sigma_z} < 0.1 \eta \frac{\alpha}{3\gamma r_e^2}$   
 $(30 \text{ minutes lifetime})$

$$\mathcal{L} \approx \frac{I}{2e} \left( \frac{0.1\alpha\eta}{6\pi} \right)^{2/3} \left( \frac{\xi_y}{\gamma r_e^5 \varepsilon_y} \right)^{1/3} \propto \frac{P_{SR}}{E^{3.93} \varepsilon_y}$$



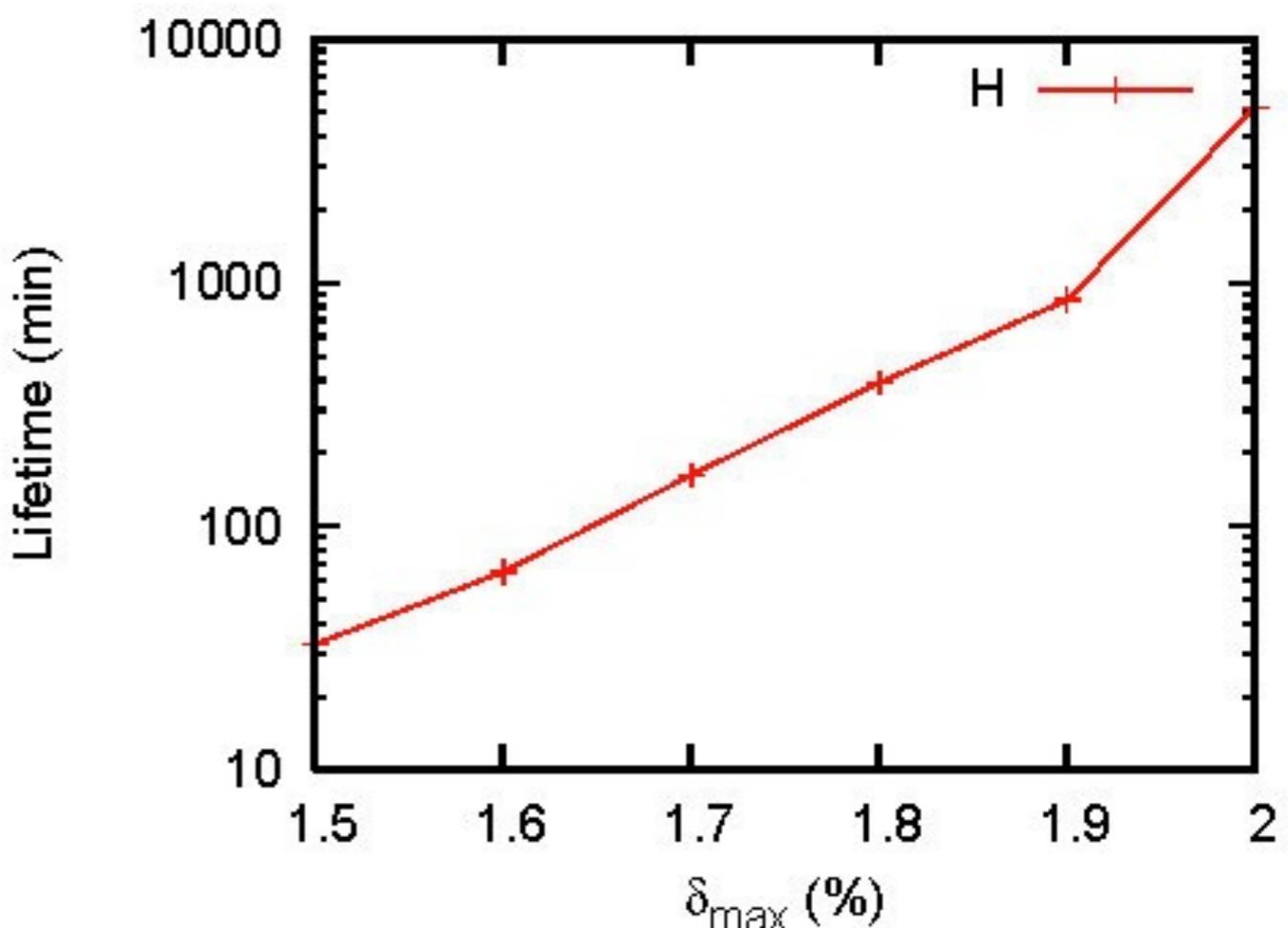
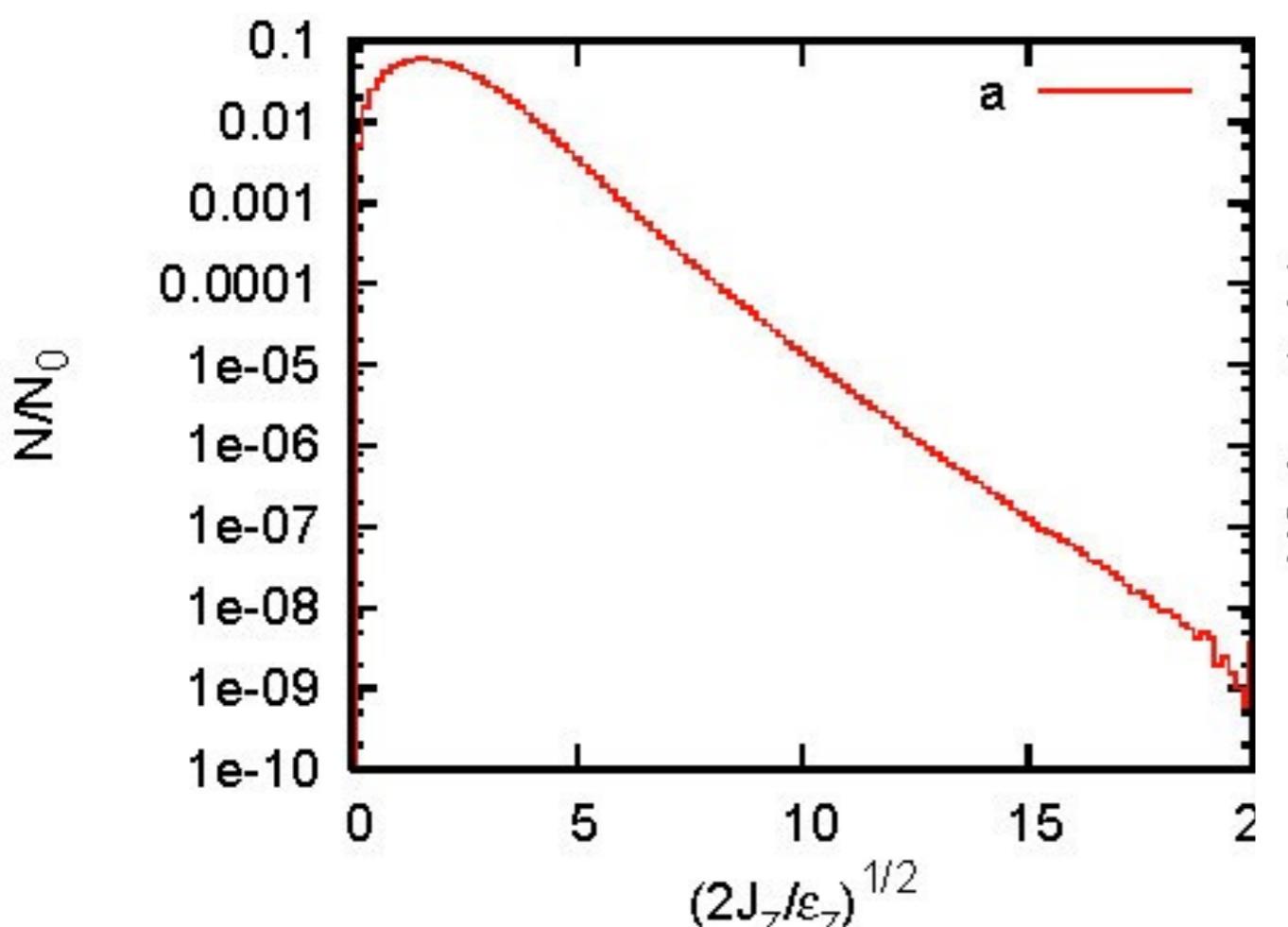
# beamstrahlung lifetime

example: FCC-ee  $H$  (240 GeV c.m.)

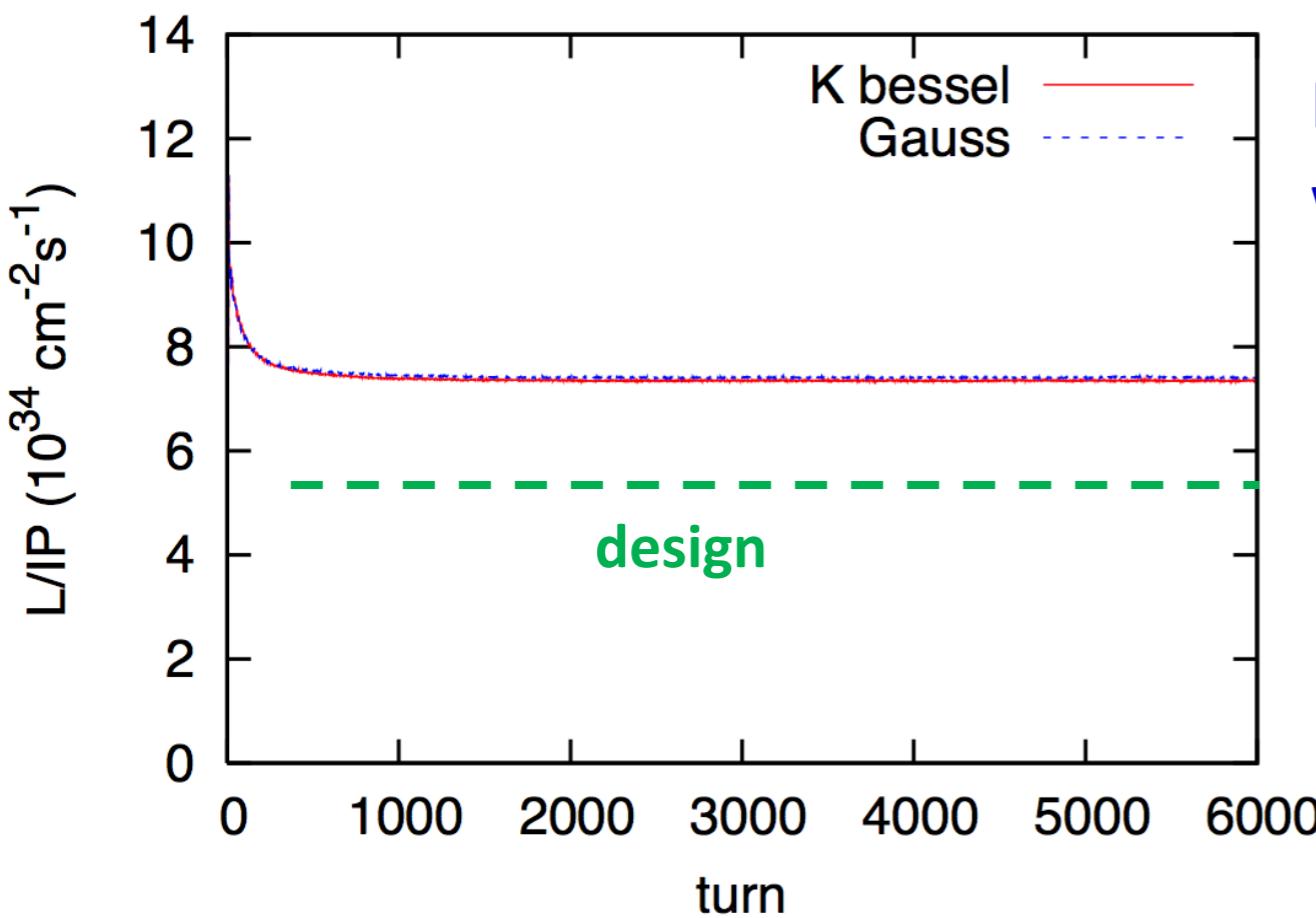
equilibrium distribution w/o  
aperture limit from simulation



lifetime vs. momentum  
acceptance



# *simulations confirm tantalizing performance*



BBSS strong-strong simulation  
w beamstrahlung

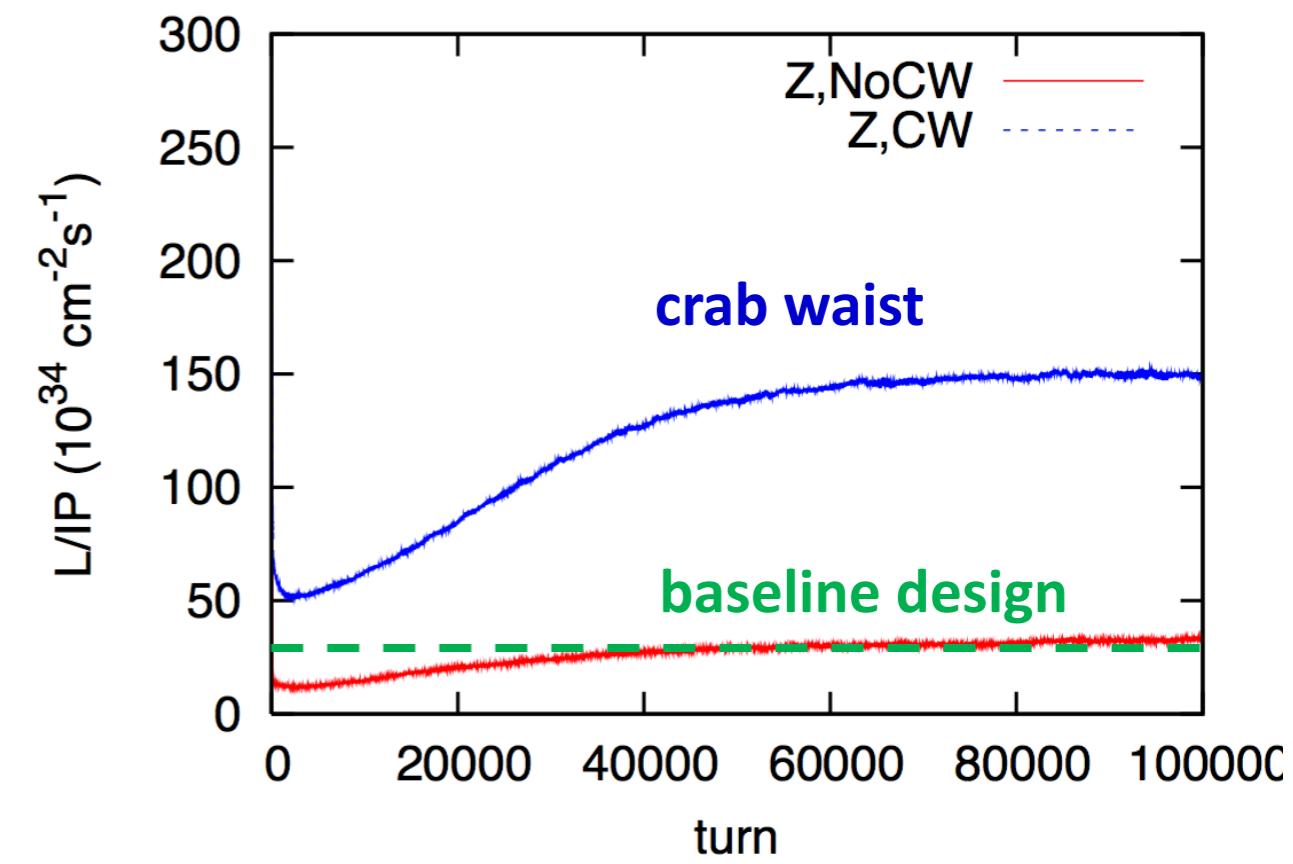
FCC-ee in Higgs production  
mode (240 GeV c.m.):  
 $L \approx 7.5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$  per IP

BBWS crab-strong simulation  
w beamstrahlung

FCC-ee in crab-waist mode  
at the Z pole (91 GeV c.m.):  
 $L \approx 1.5 \times 10^{36} \text{ cm}^{-2}\text{s}^{-1}$  per IP

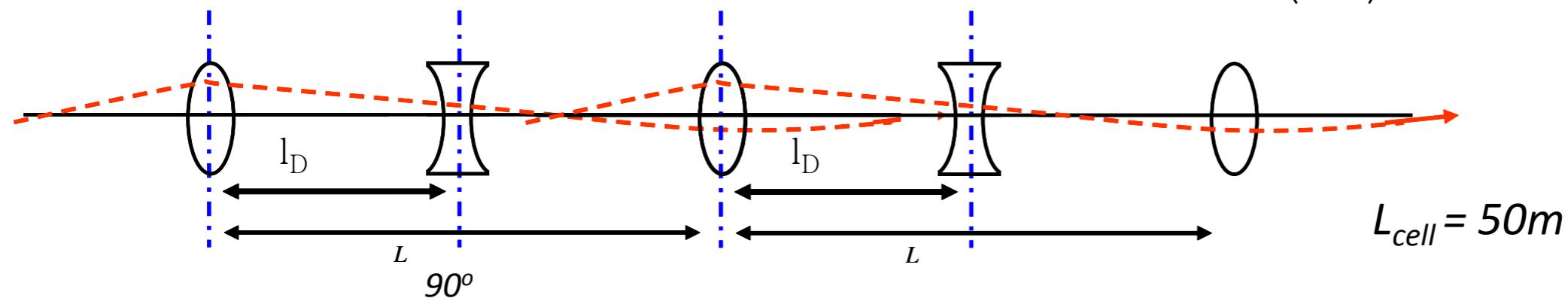
K. Ohmi et al., IPAC2014

A. Bogomyagkov, E. Levichev, P. Piminov, IPAC2014



# Lattice for smaller energies

$$\varepsilon = \left( \frac{\delta p}{p} \right)^2 (\gamma D^2 + 2\alpha DD' + \beta D'^2)$$

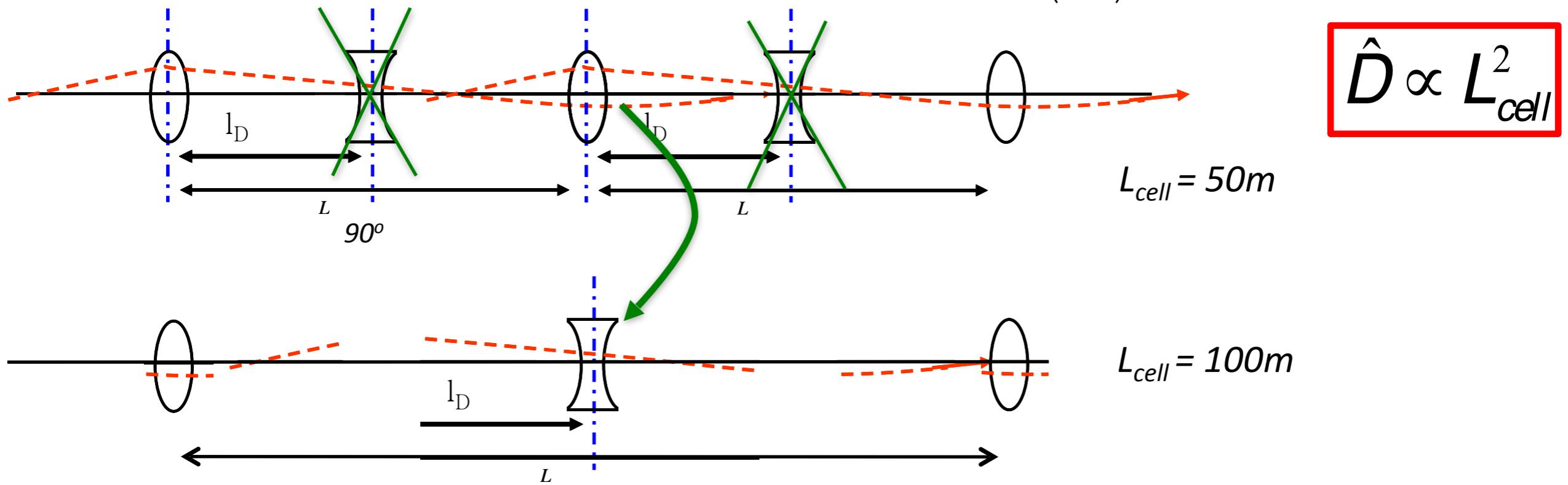


$$\hat{D} \propto L_{cell}^2$$

Court. Bernhard Holzer

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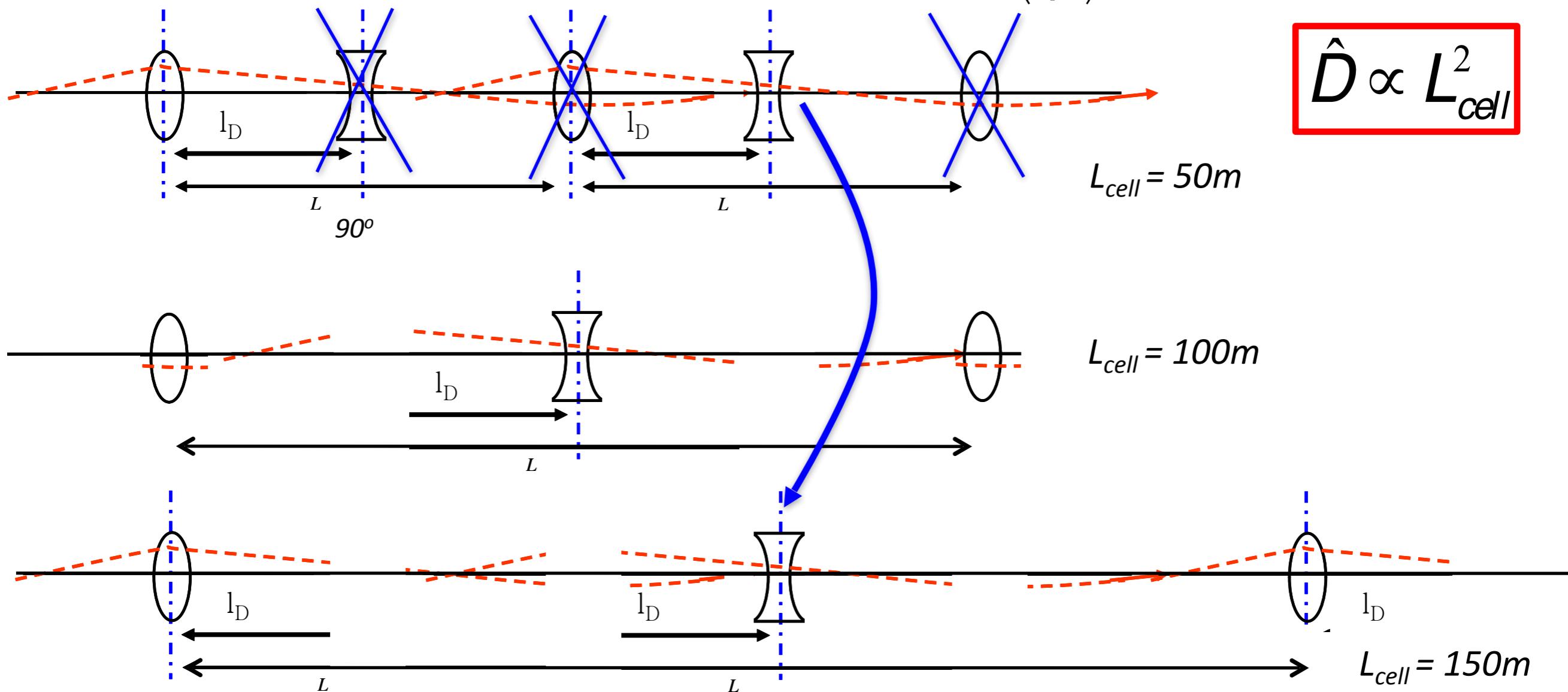
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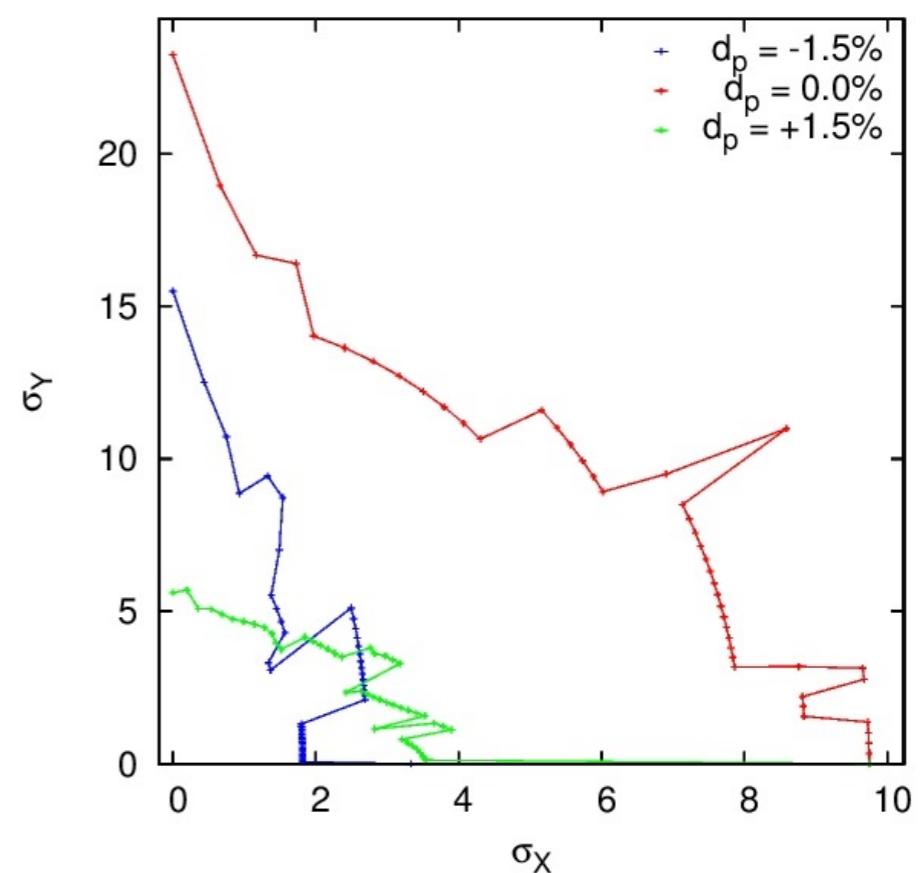
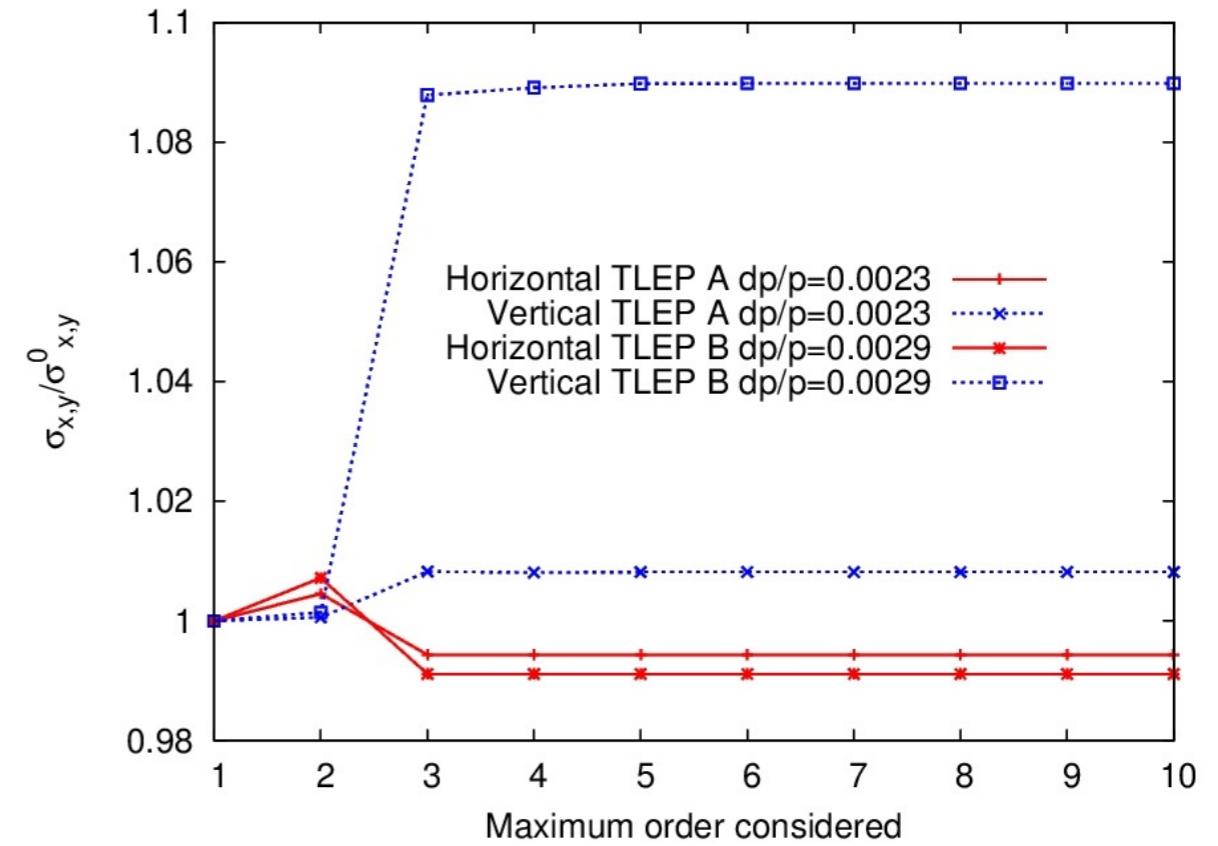
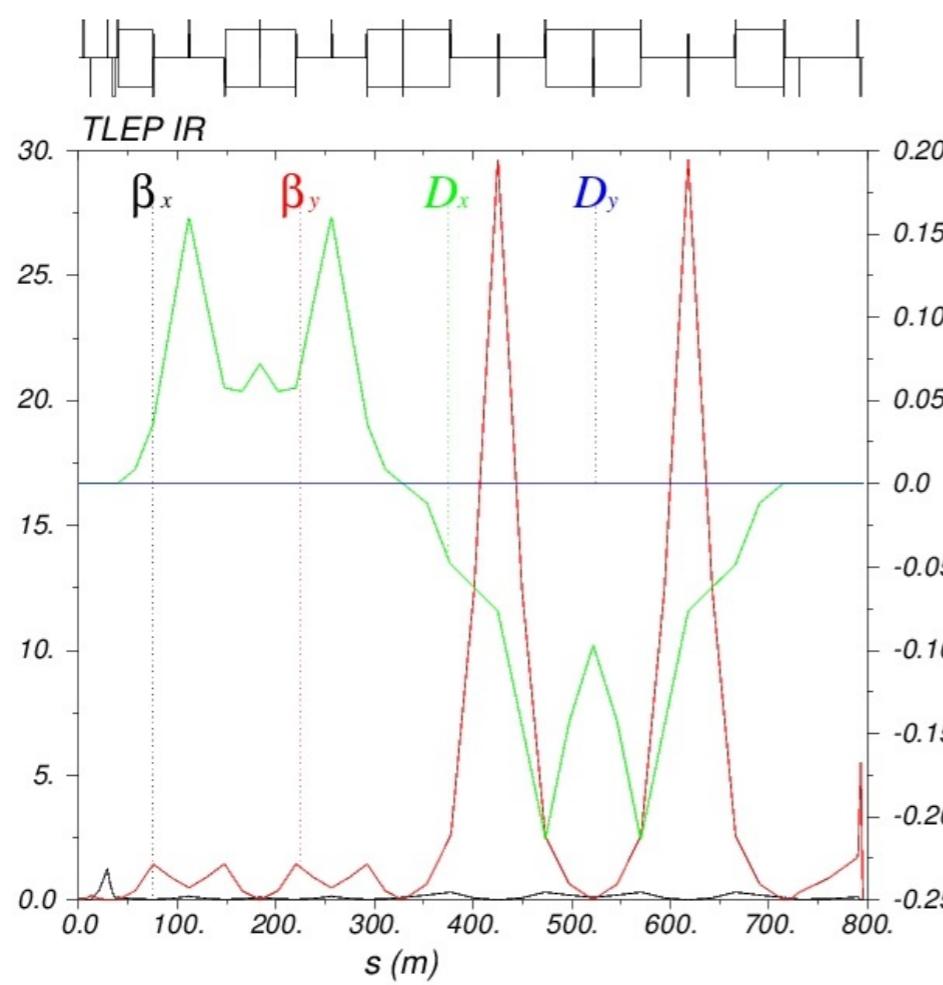
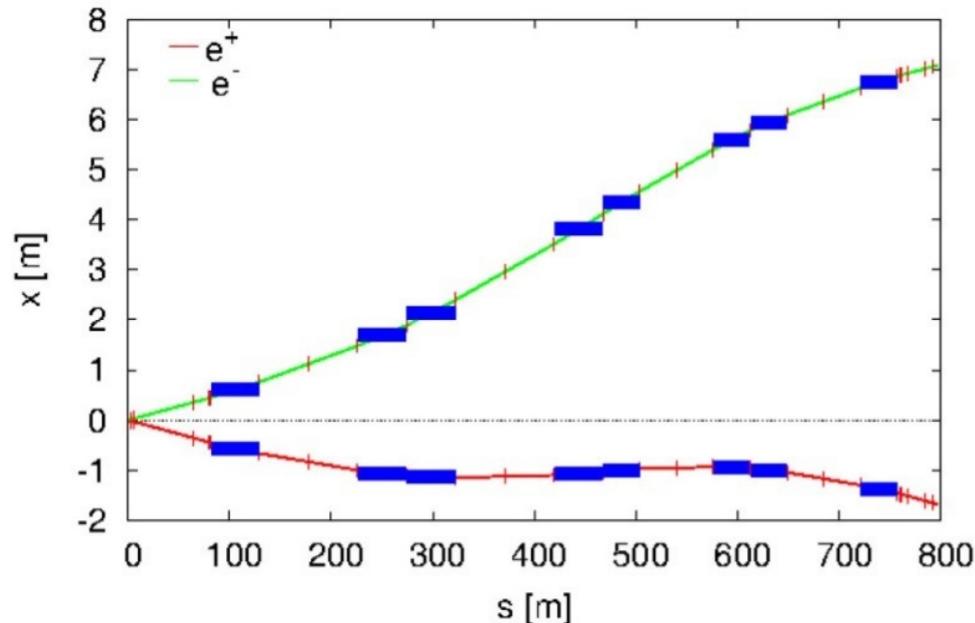
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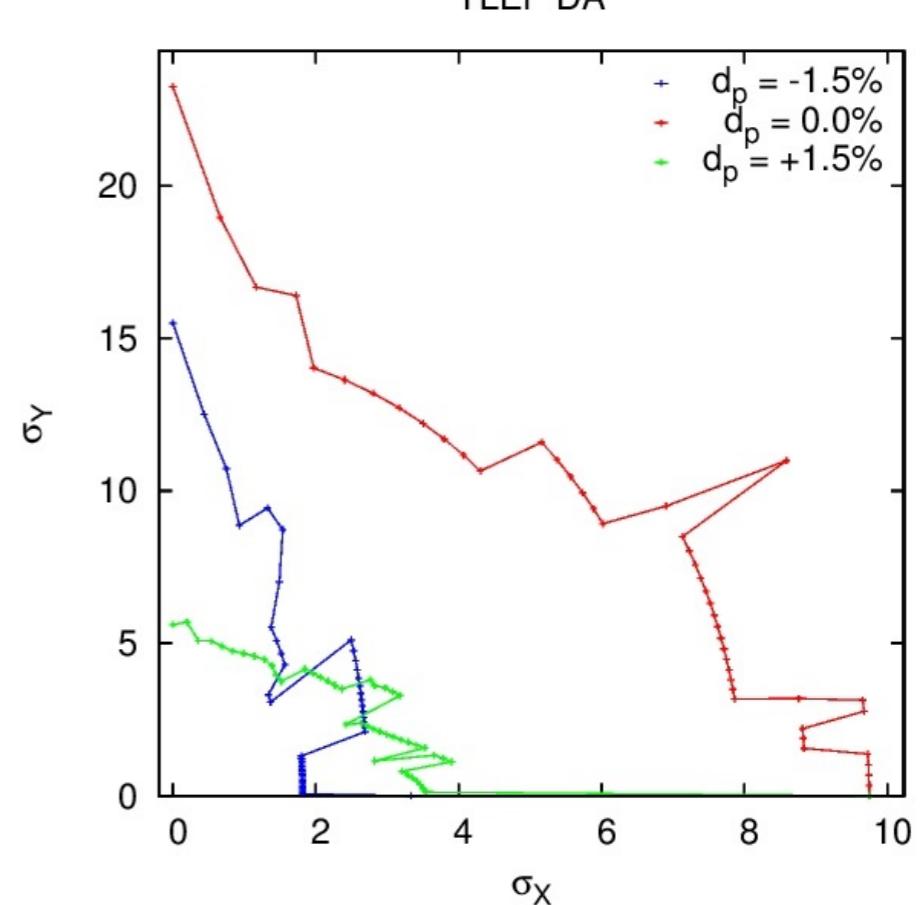
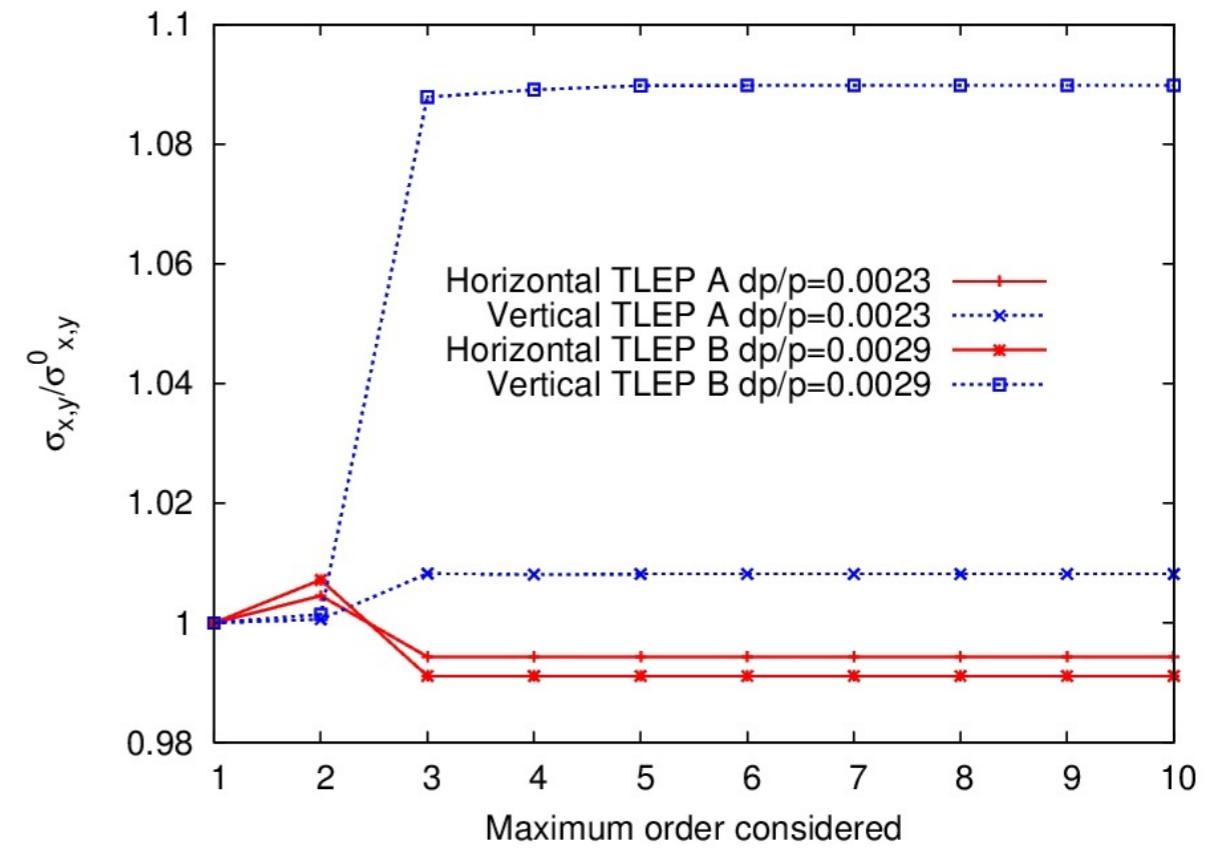
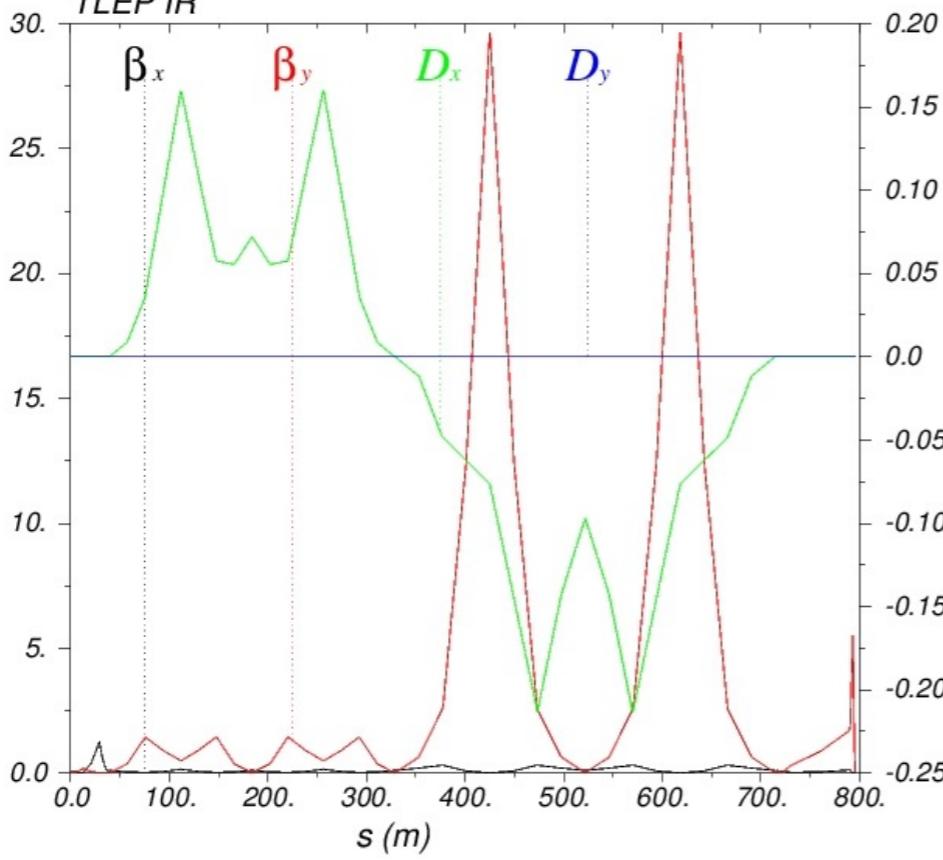
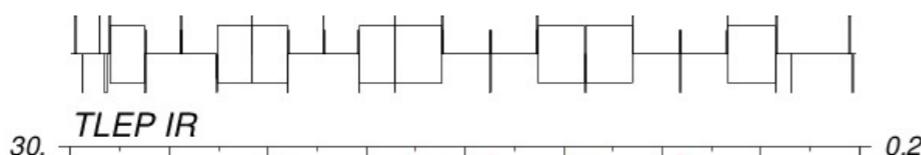
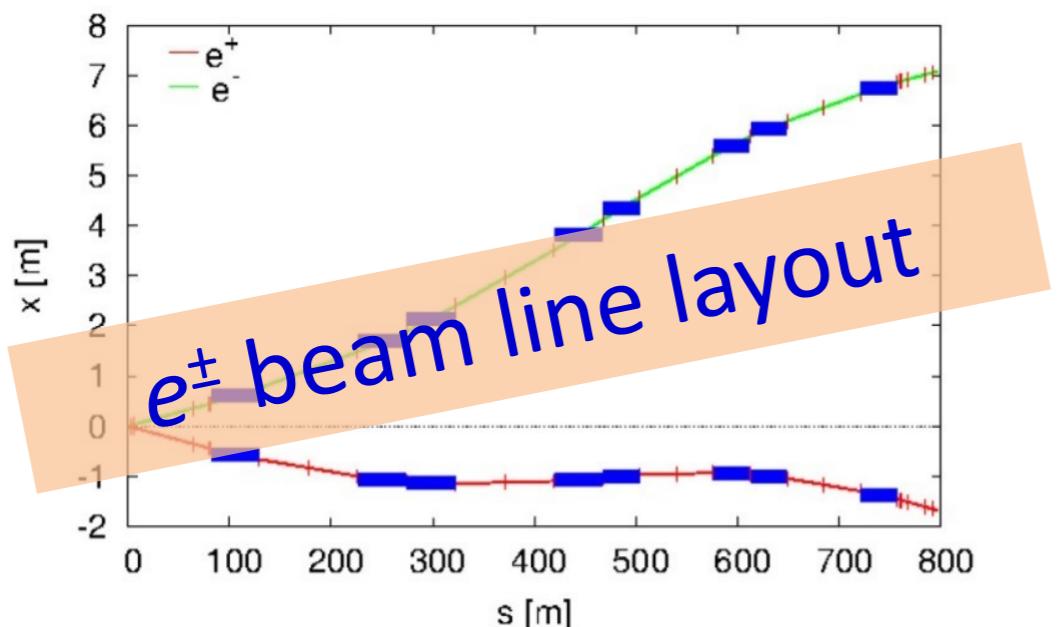


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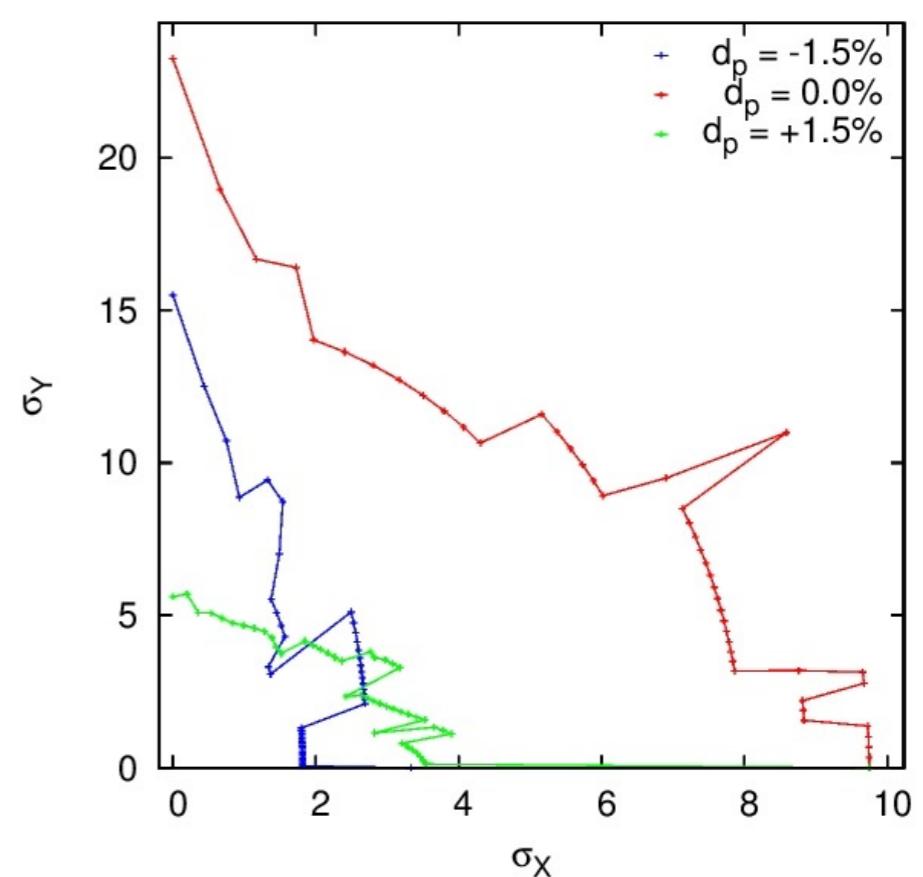
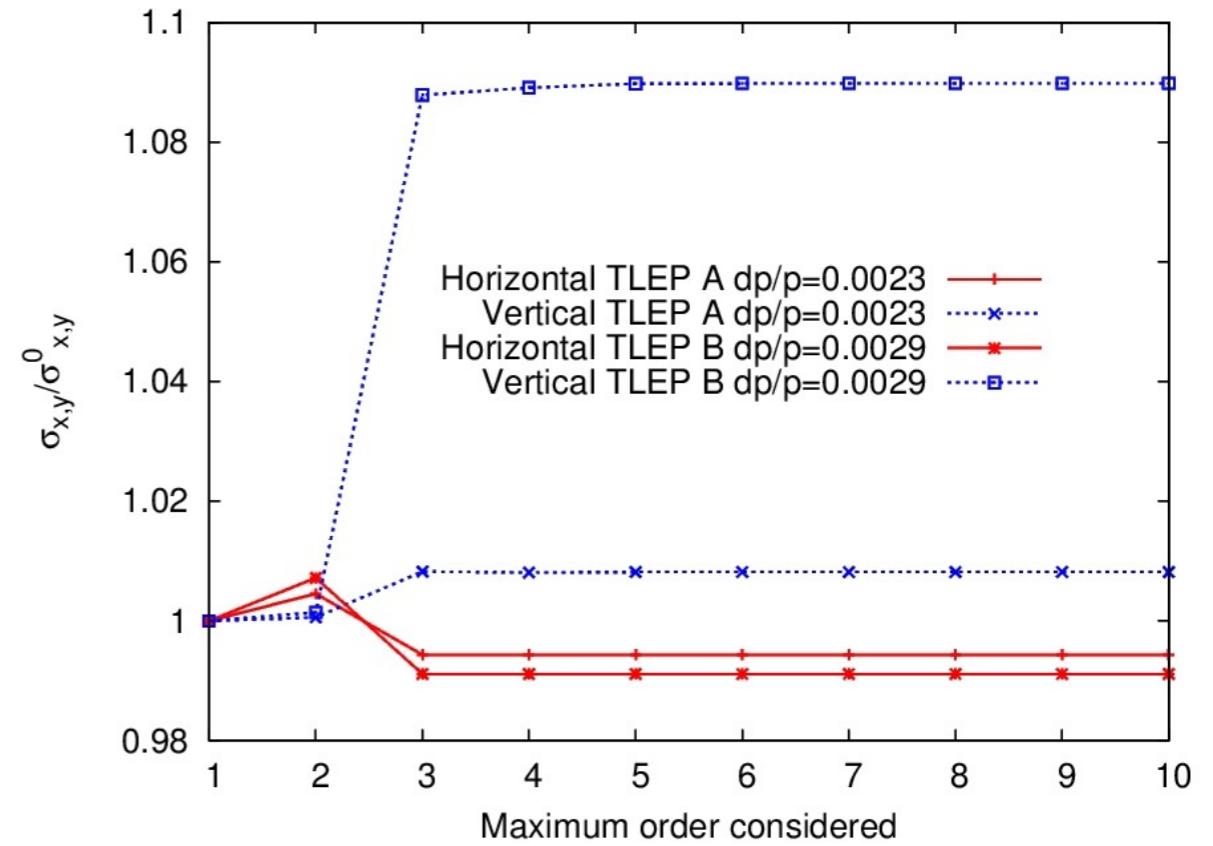
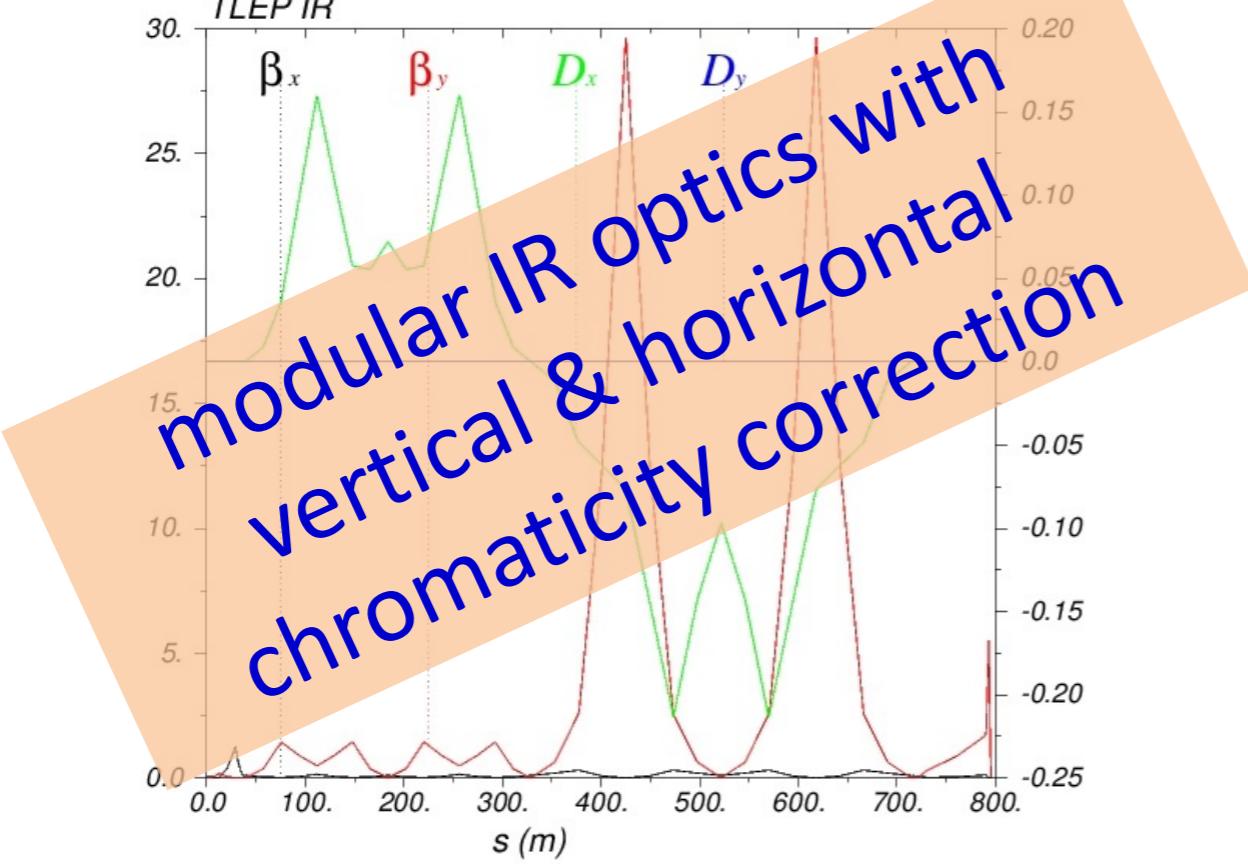
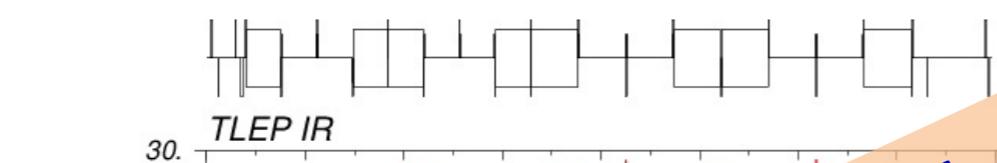
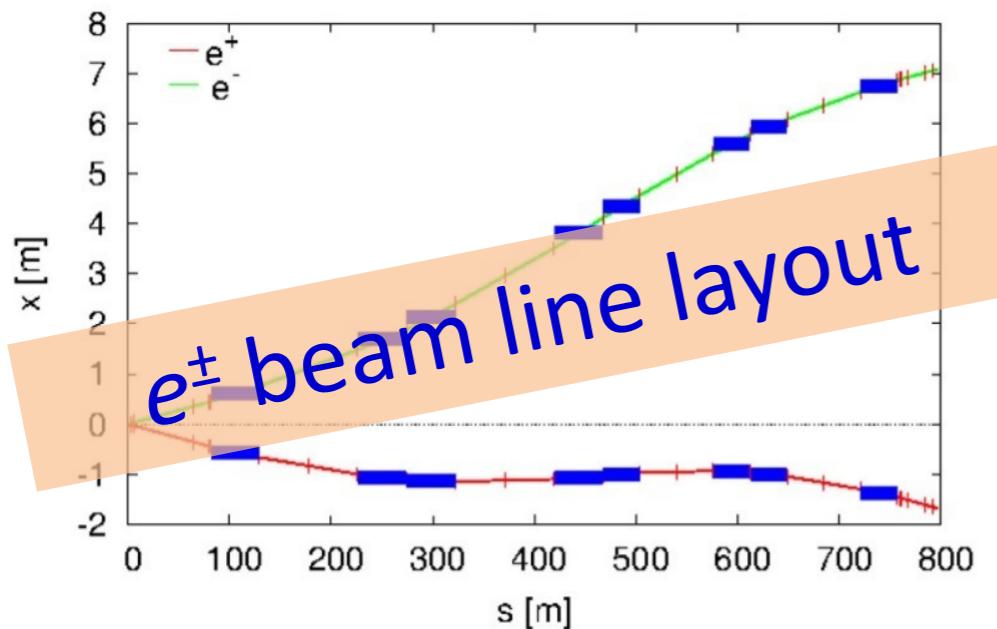
# FCC-ee IR design #1



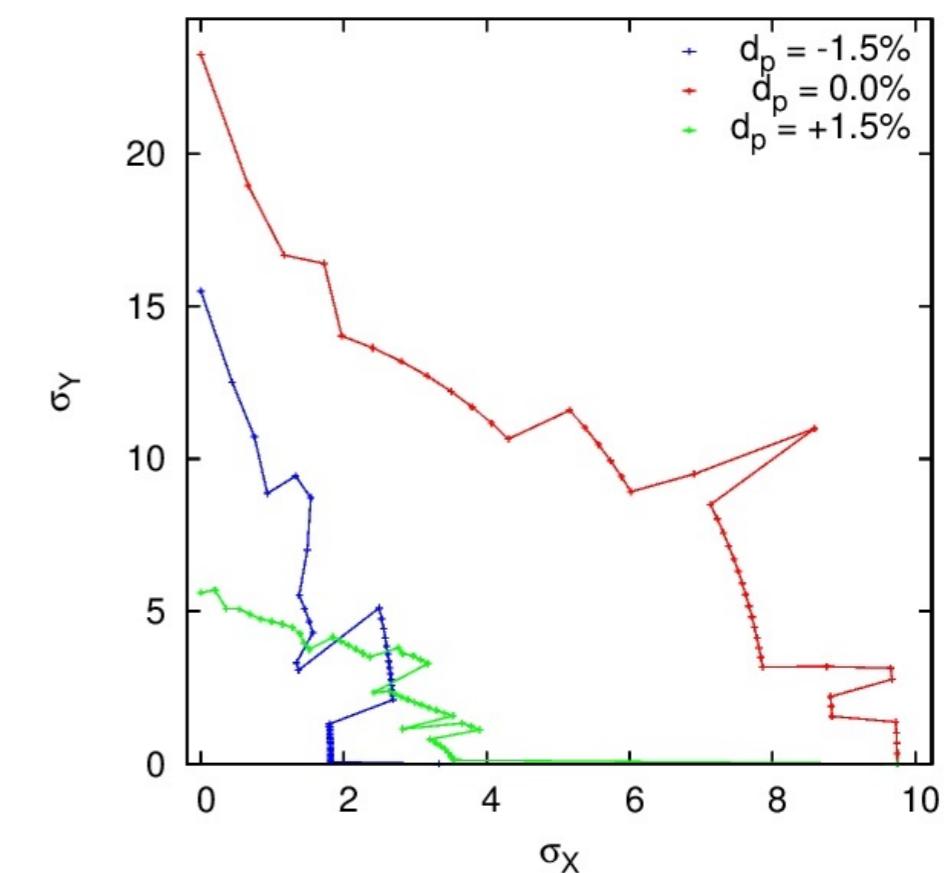
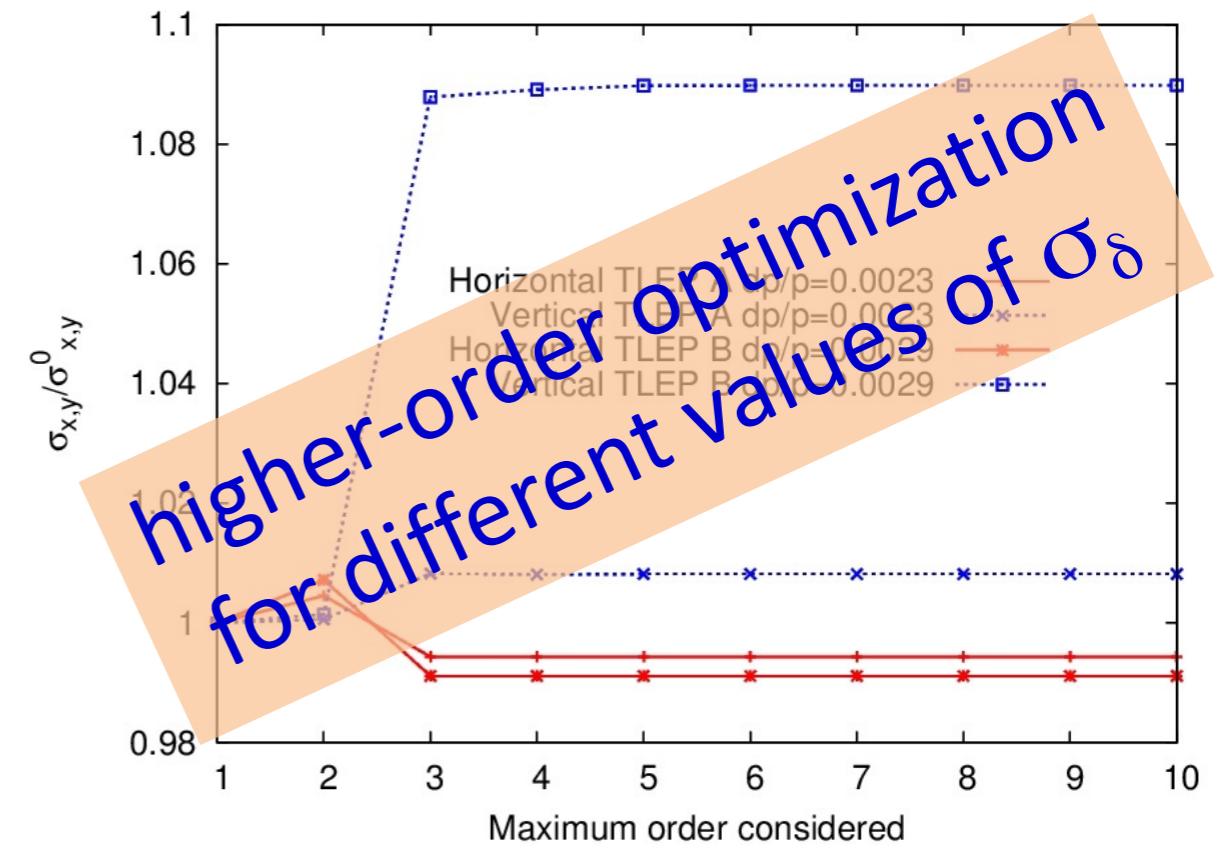
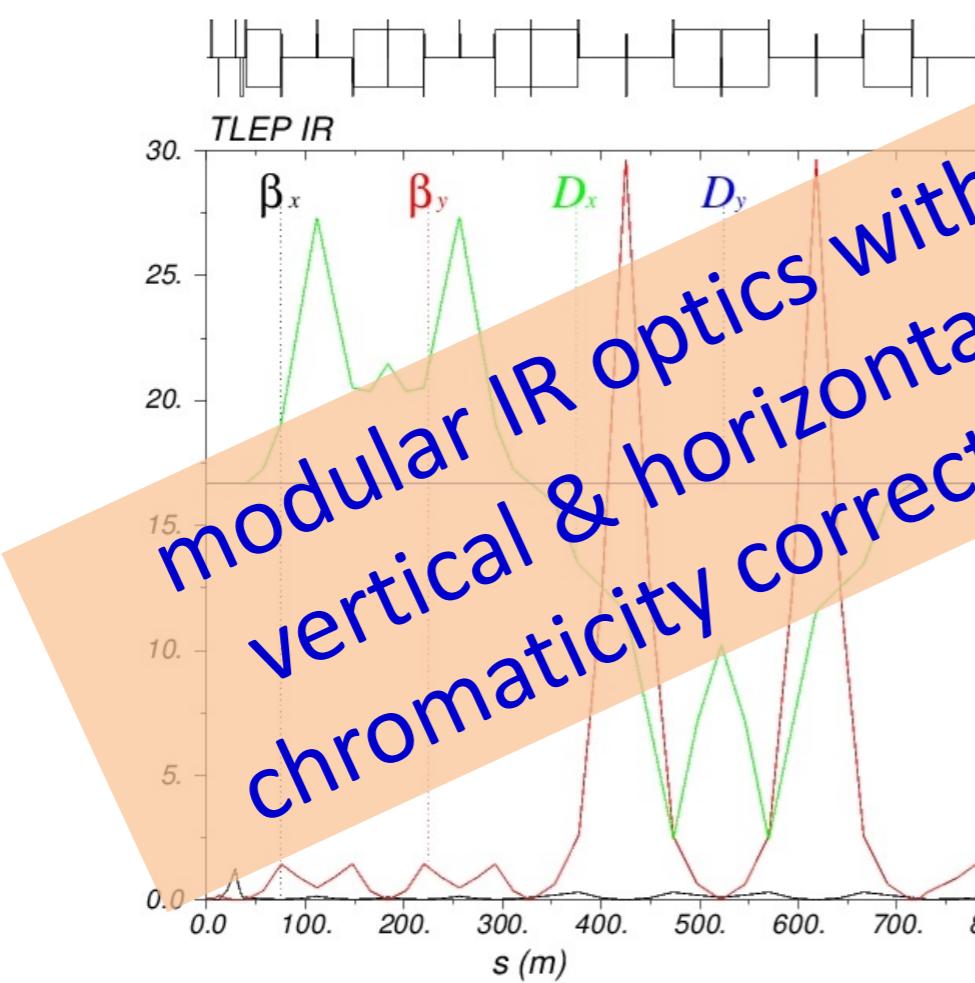
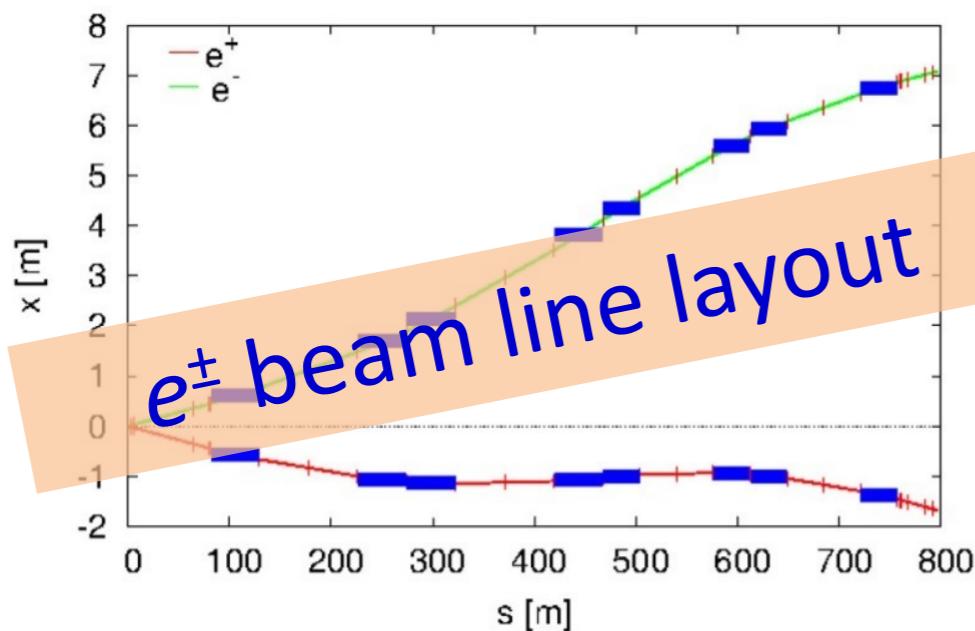
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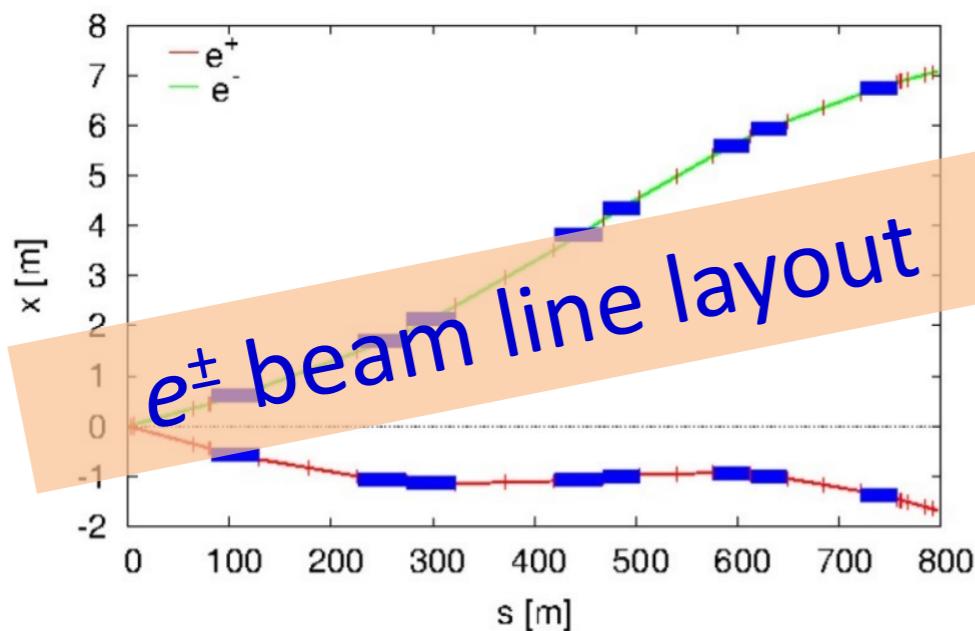
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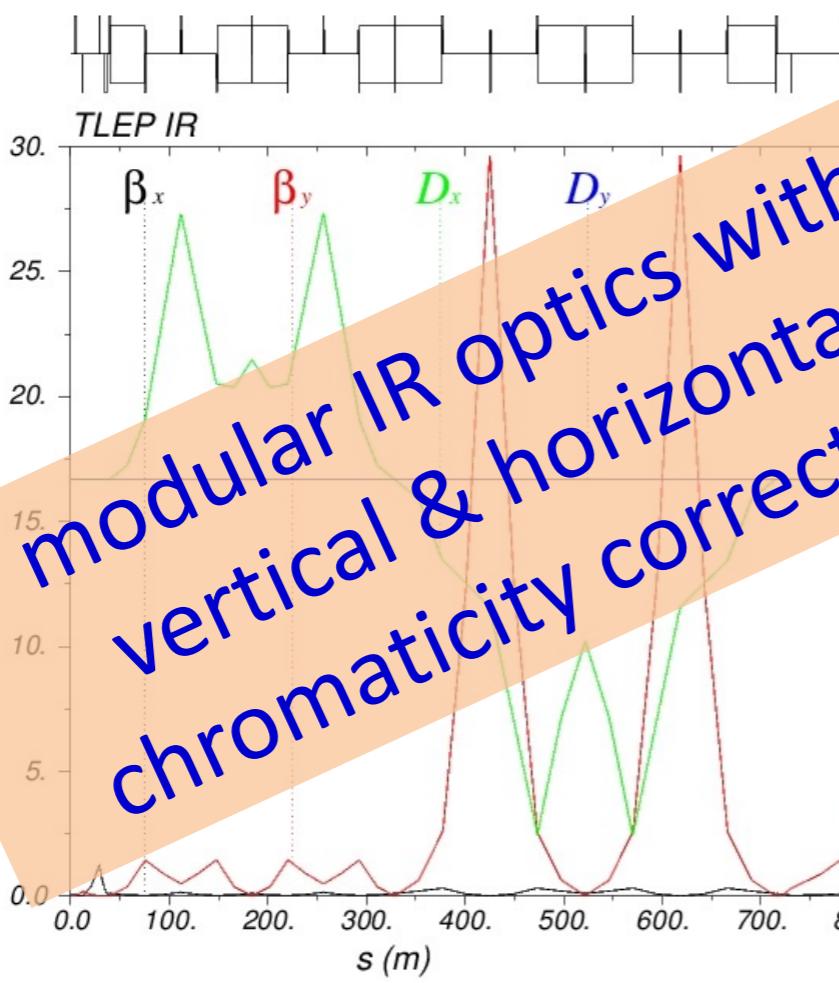
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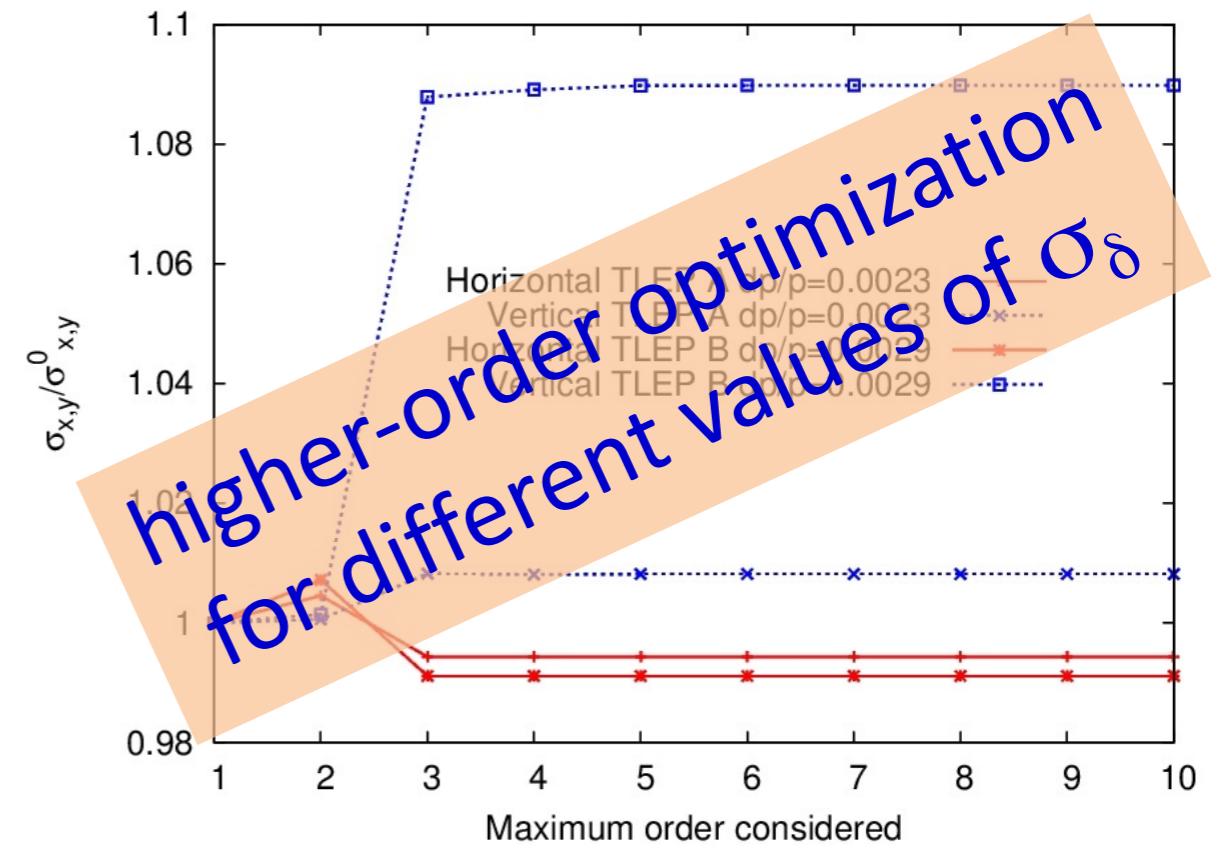
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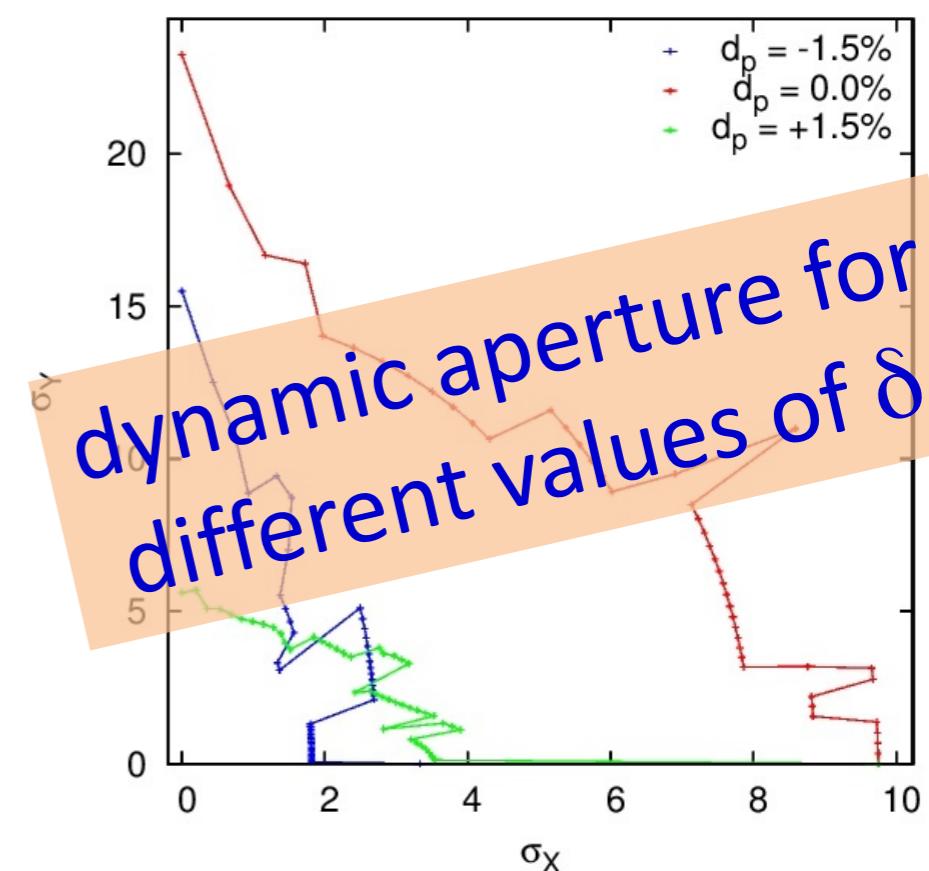
$e^{\pm}$  beam line layout



modular IR optics with  
vertical & horizontal  
chromaticity correction

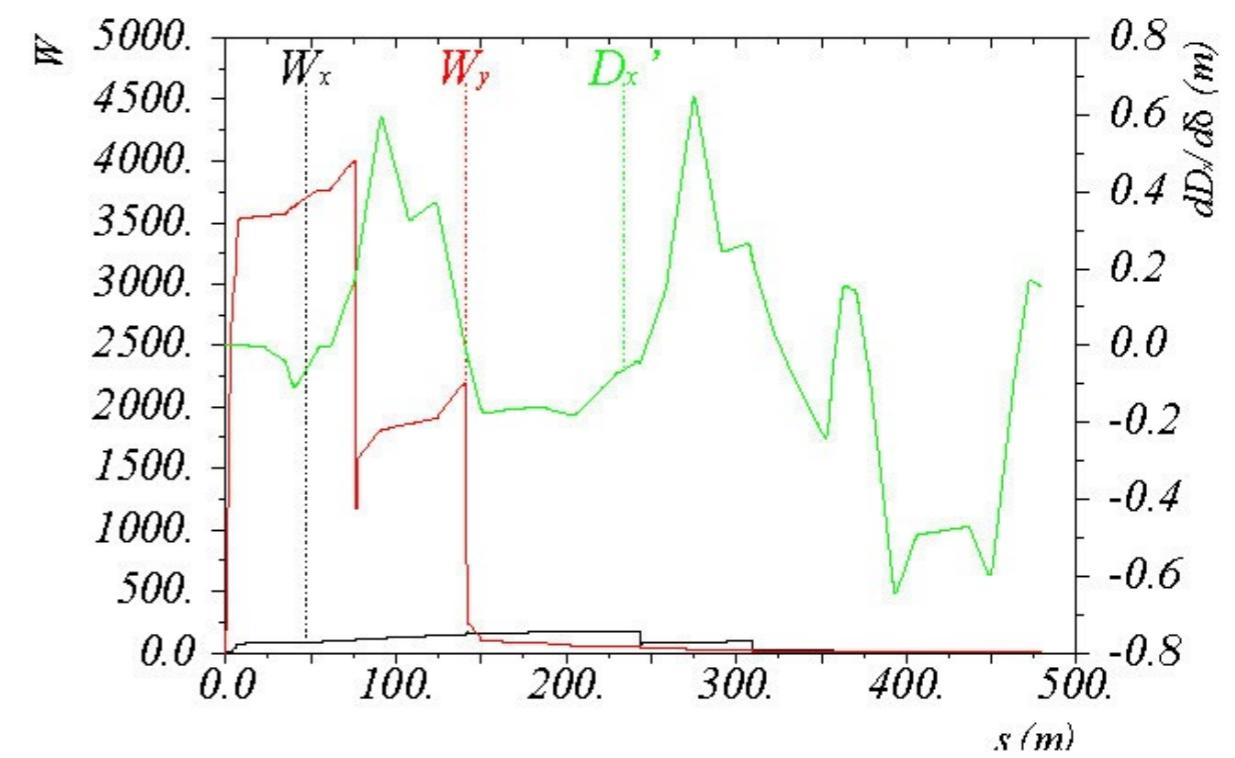
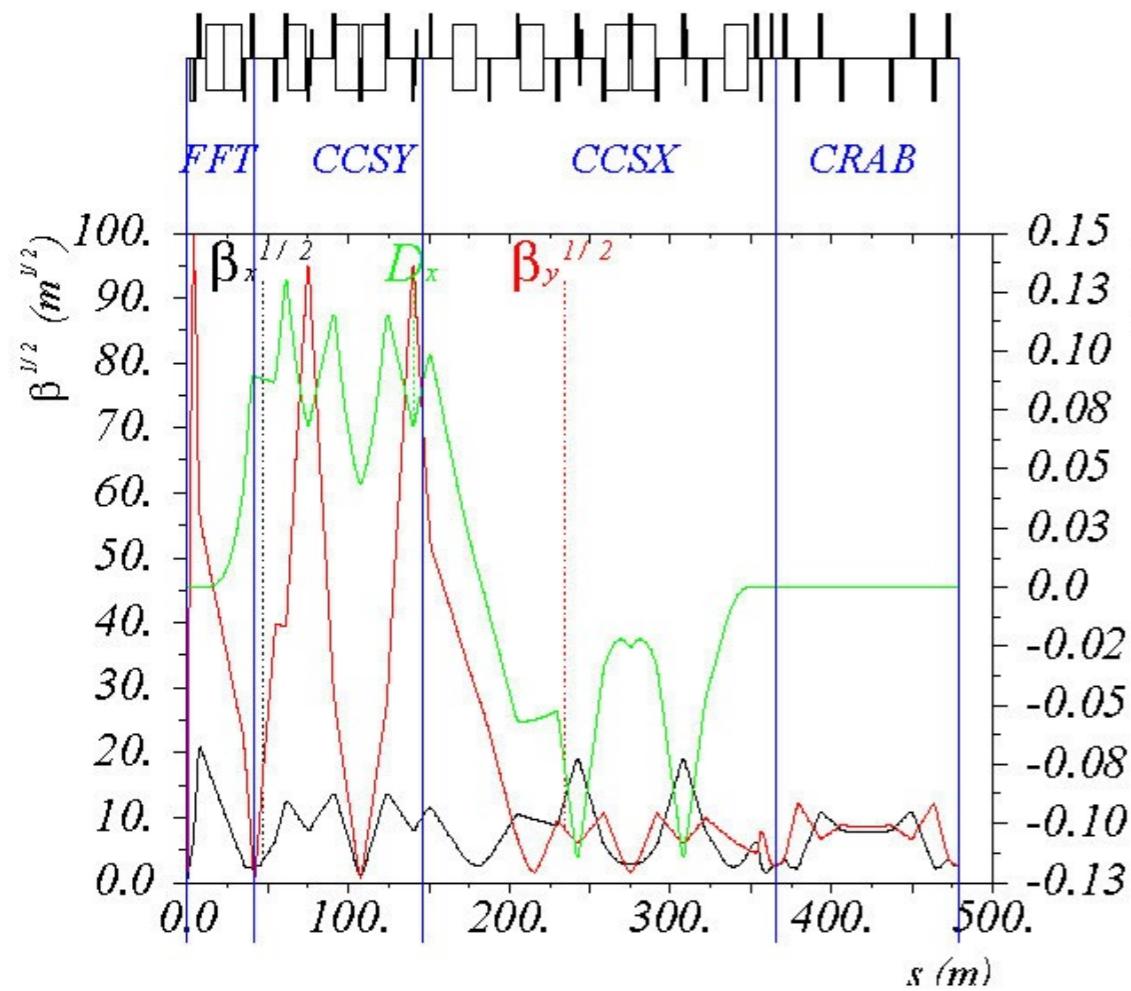
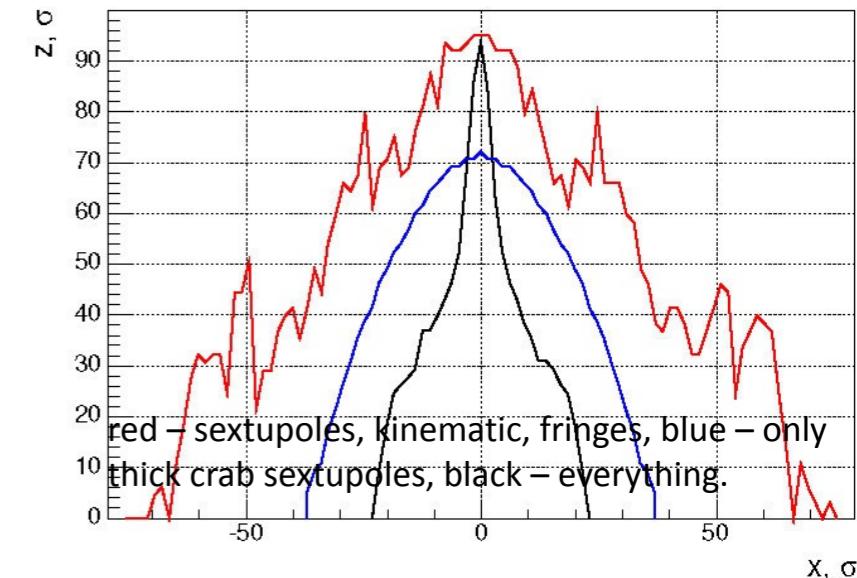
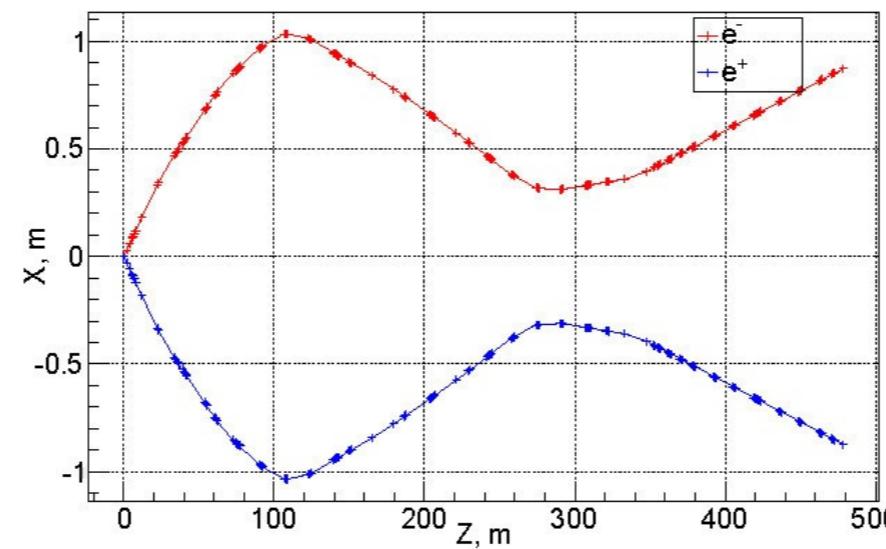
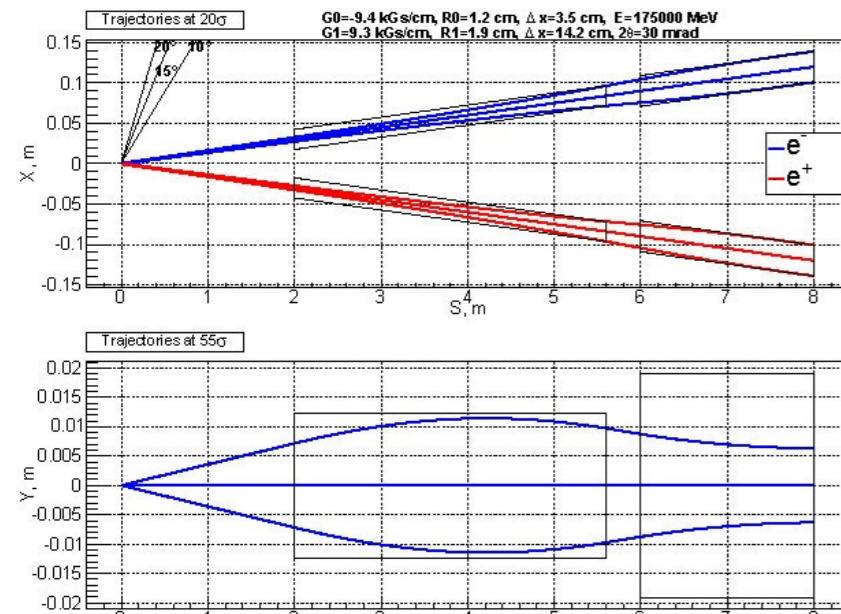


higher-order optimization  
for different values of  $\delta$

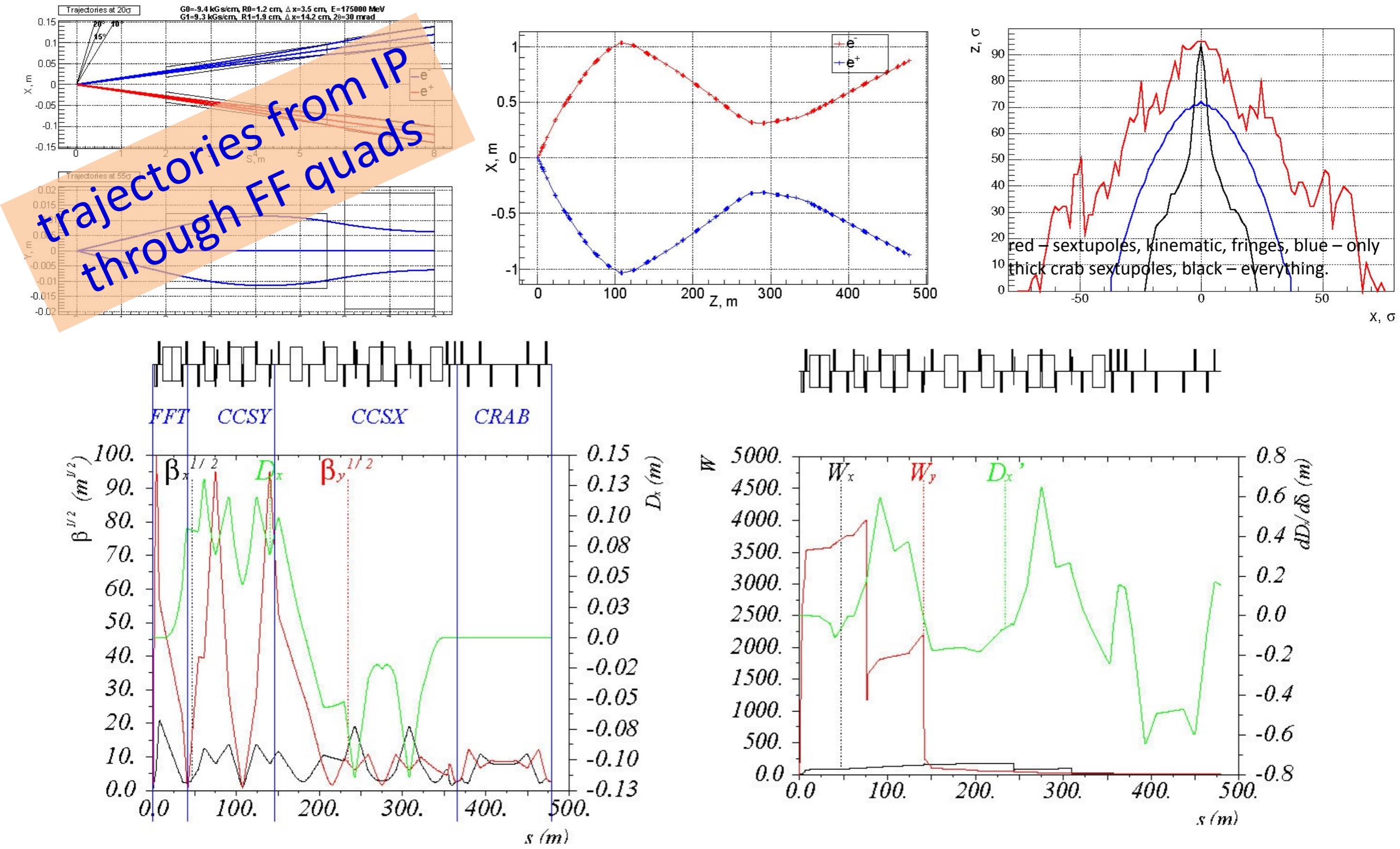


dynamic aperture for  
different values of  $\delta$

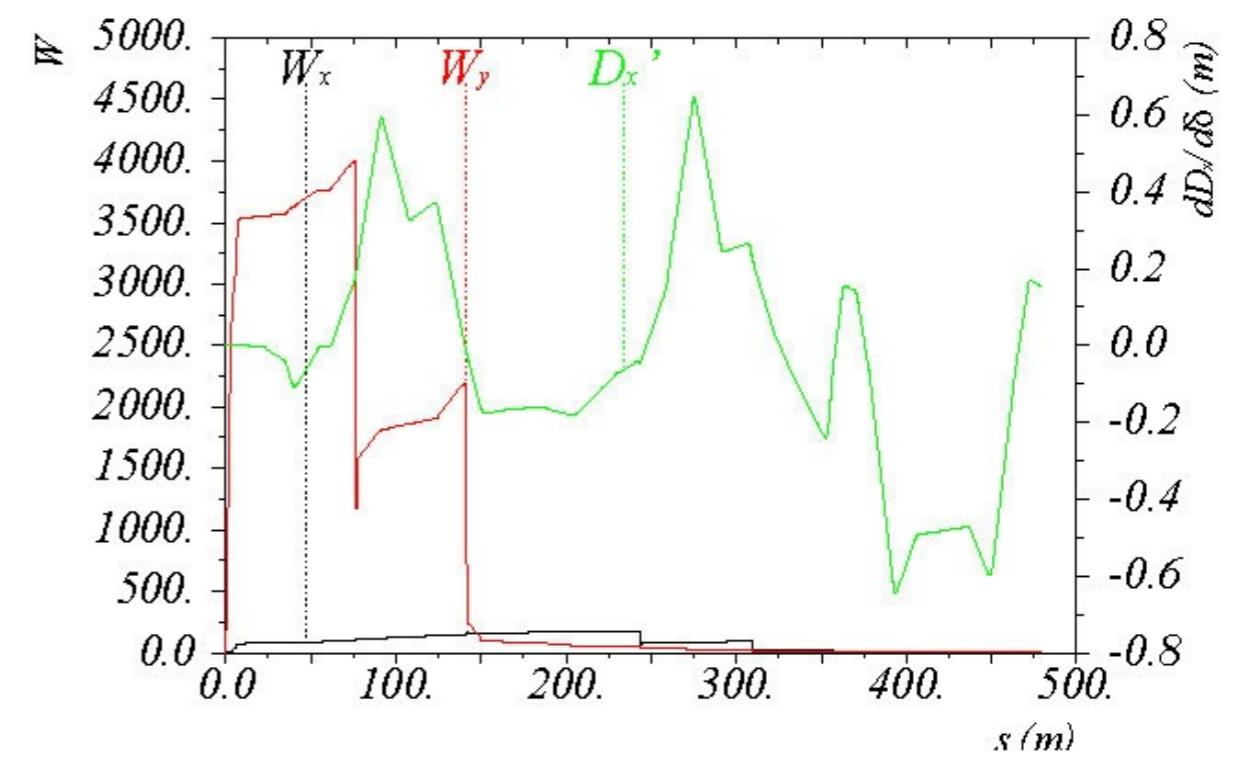
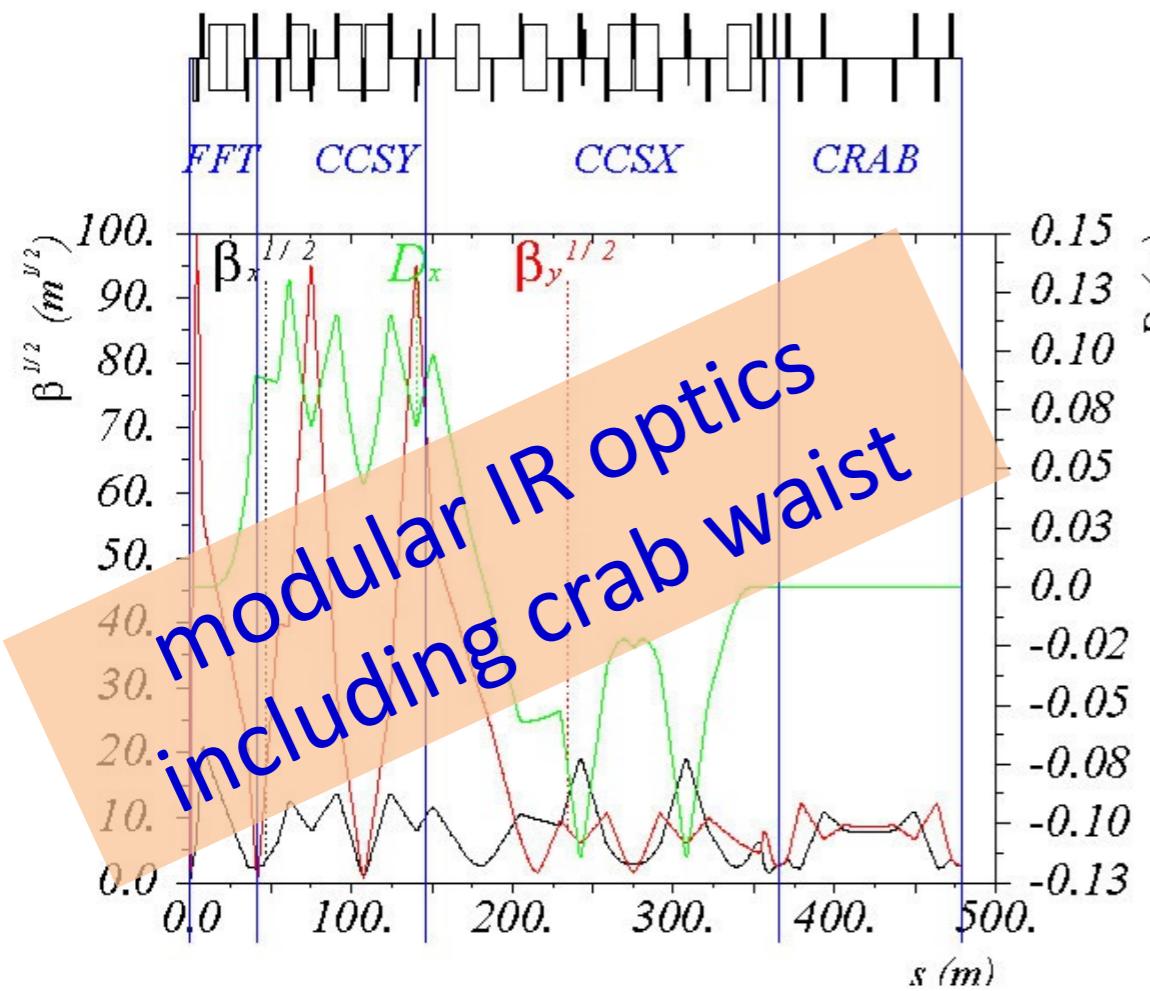
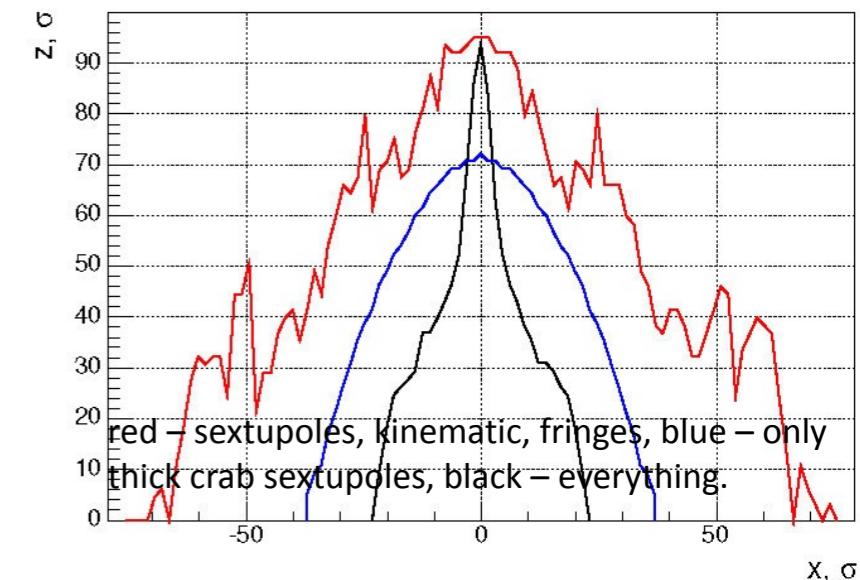
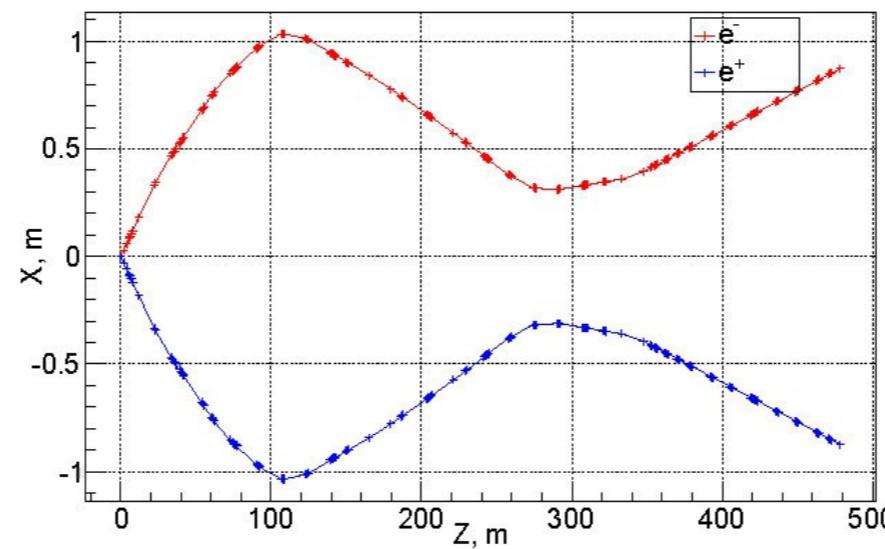
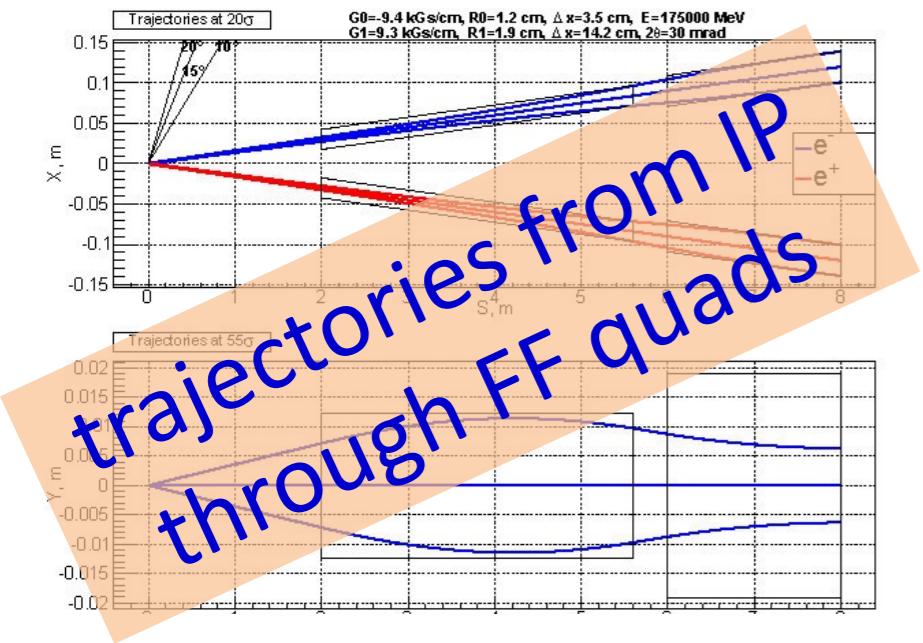
# FCC-ee IR design #2



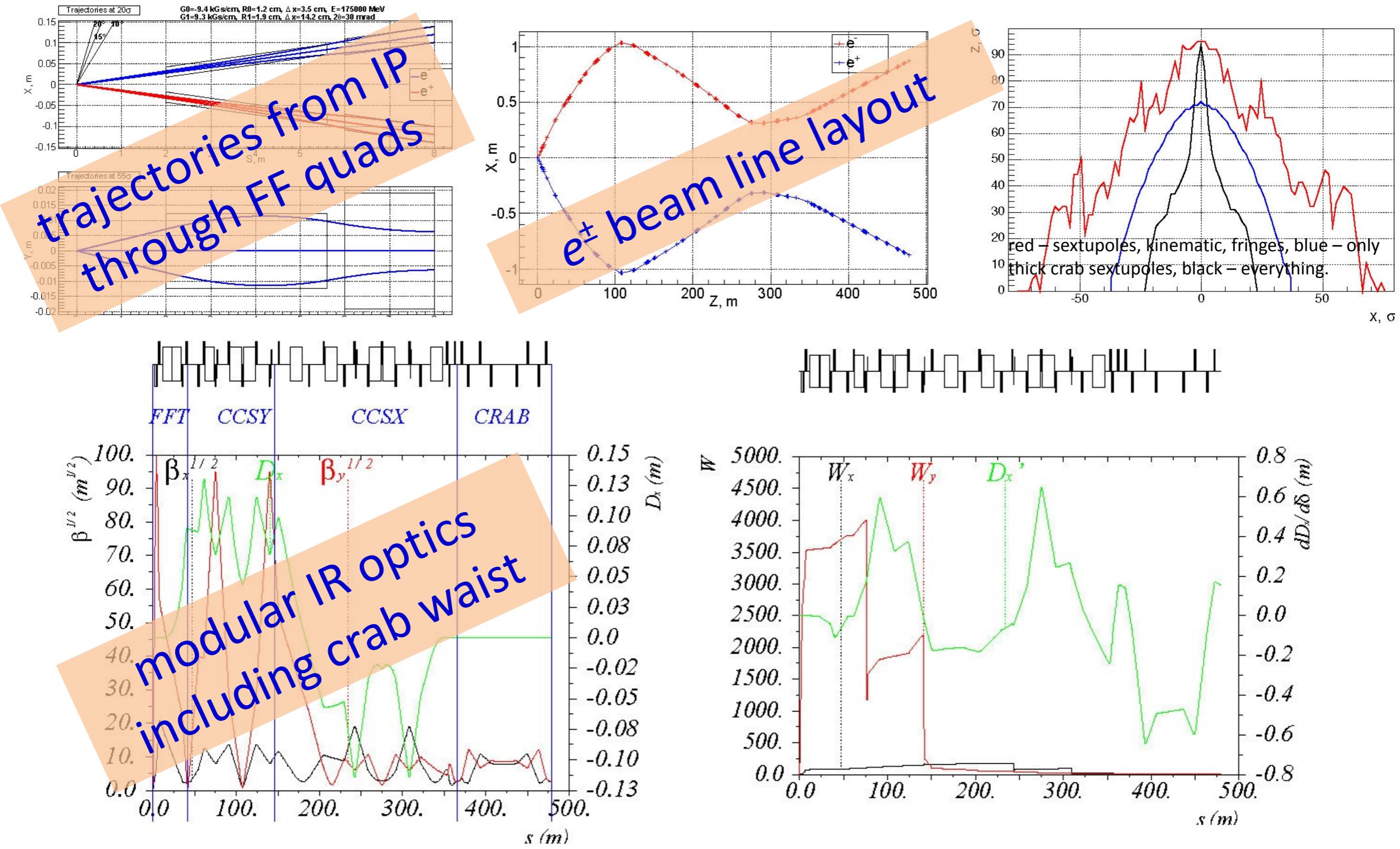
# FCC-ee IR design #2



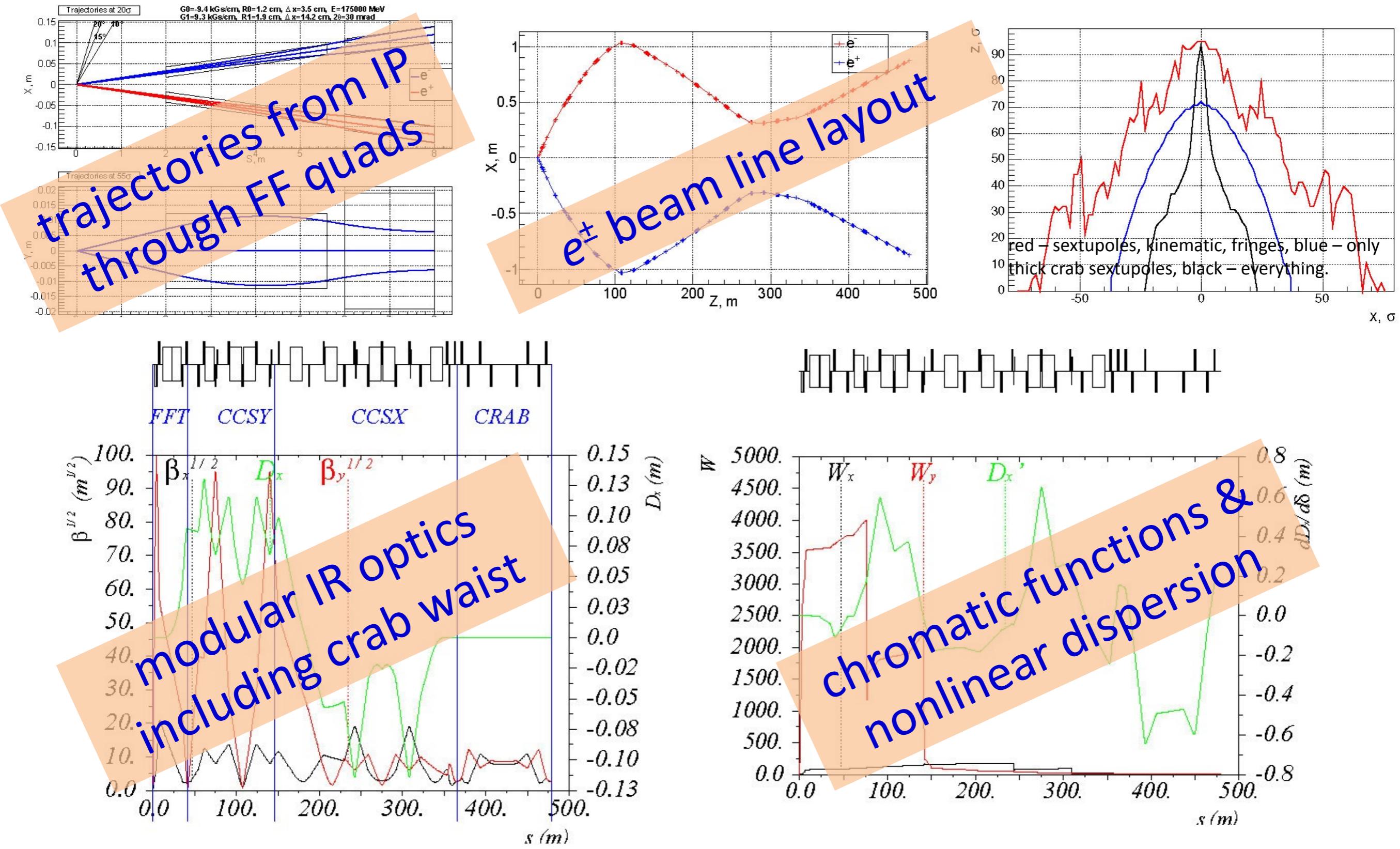
# FCC-ee IR design #2



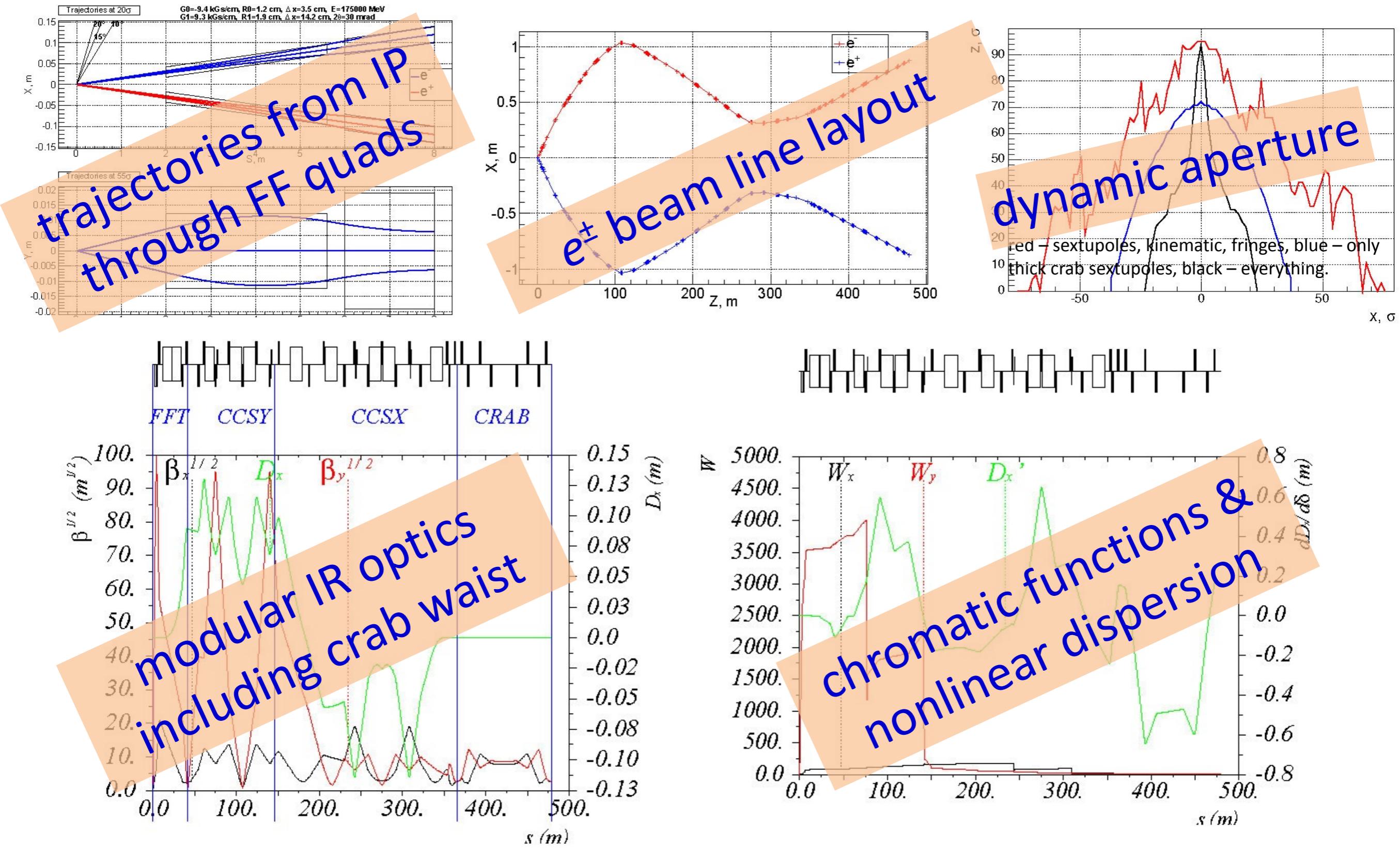
# FCC-ee IR design #2



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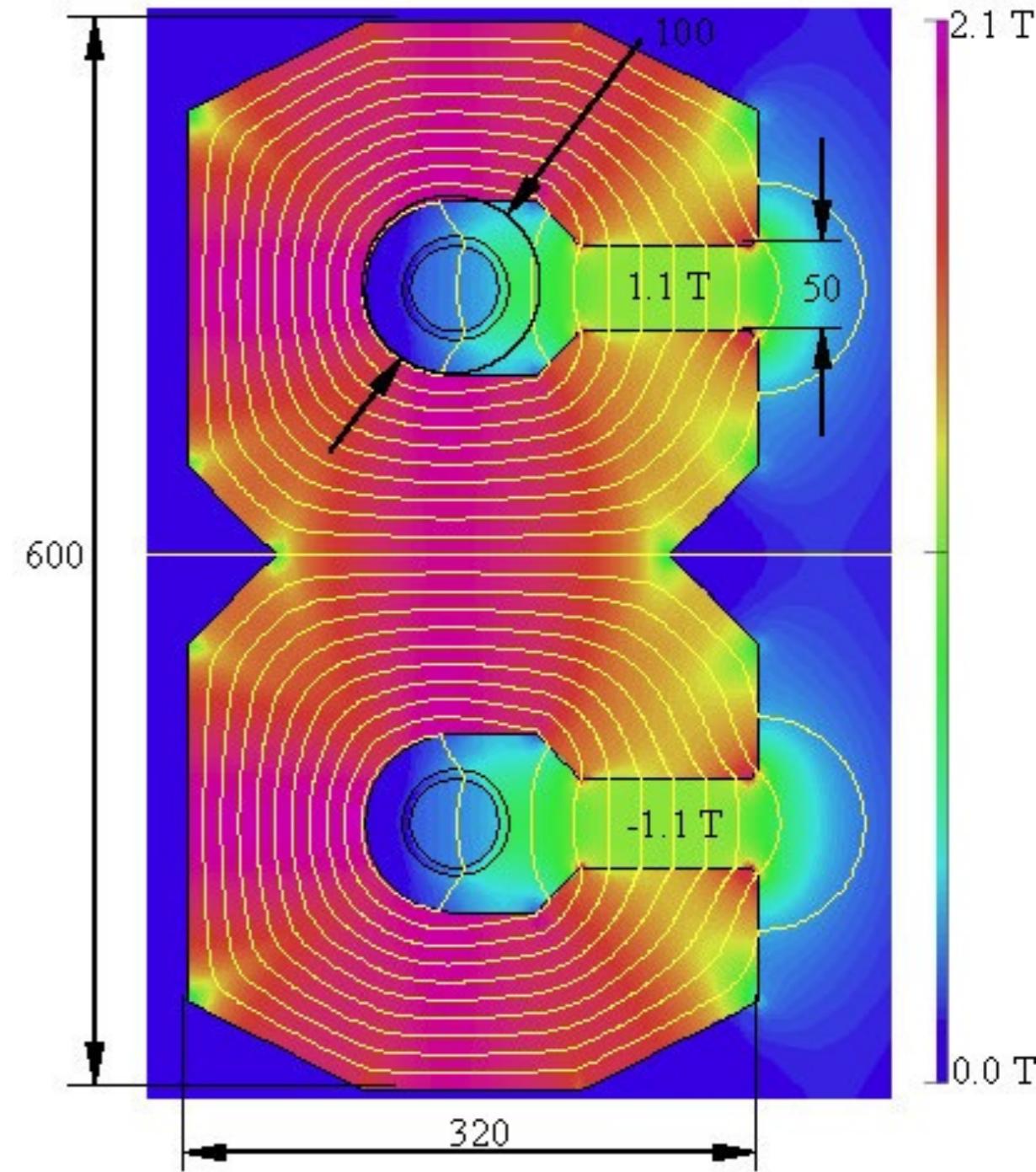


# FCC-ee/hh: hybrid NC & SC arc magnets

twin-aperture iron-dominated,  
compact hybrid “transmission  
line” dipoles - for injector  
synchrotrons in FCC tunnel

- resistive cable  
for lepton machine
- superconducting  
for hadron operation

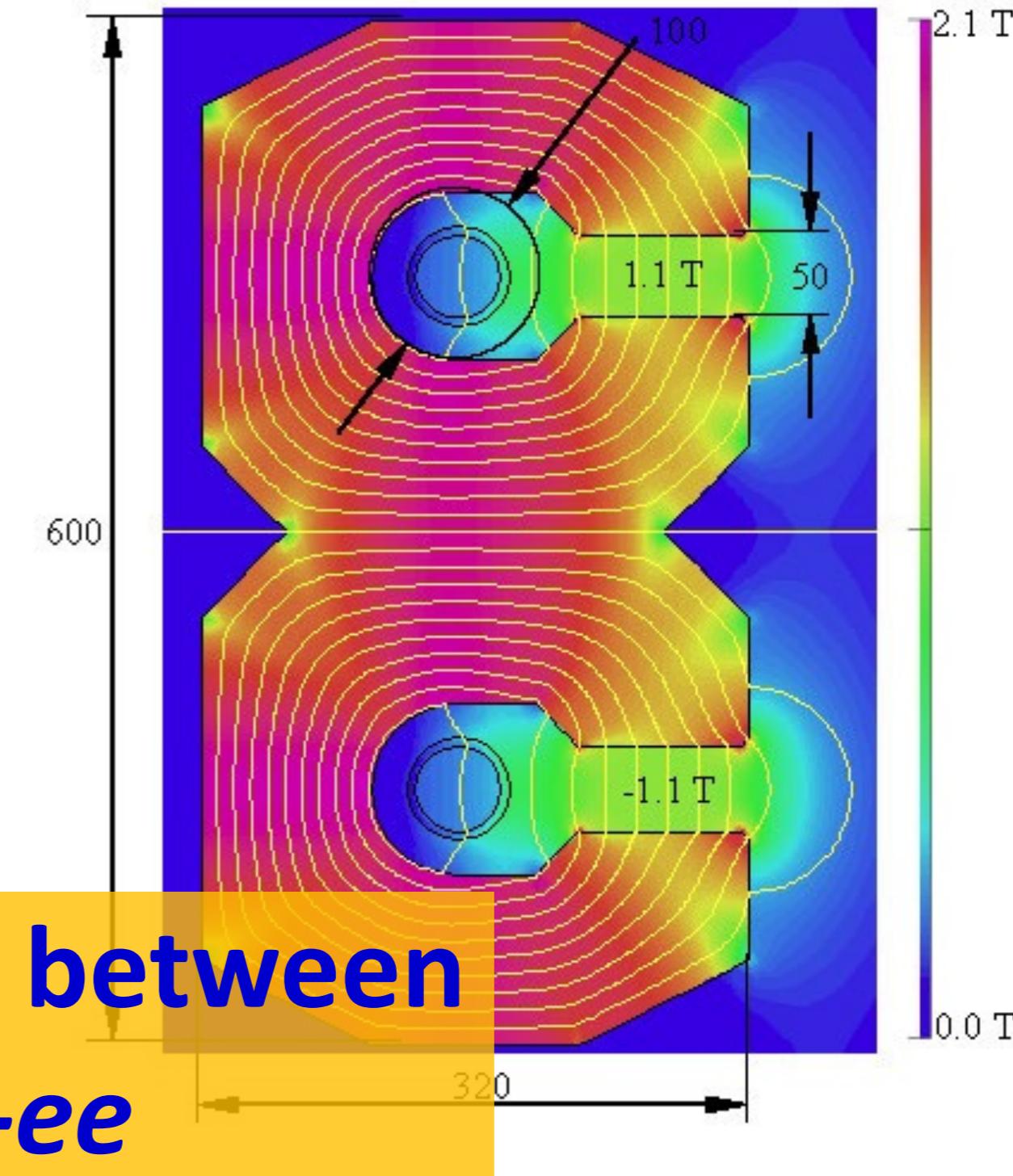
required dynamic range  $\sim 100$   
hadron extraction 1.1 T  
lepton injection: 10 mT



# FCC-ee/hh: hybrid NC & SC arc magnets

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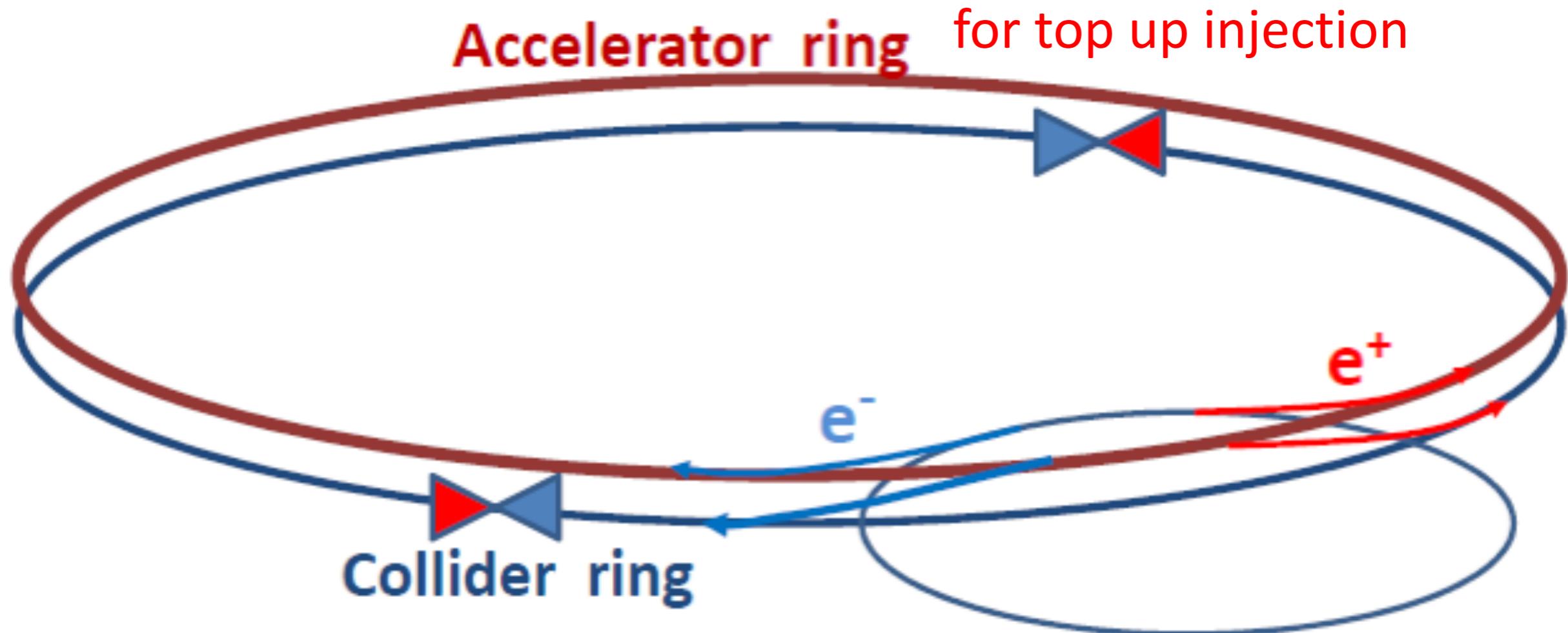


one of many synergies between  
FCC-hh and FCC-ee

# FCC-ee: $e^+e^-$ collider up to 350 (500) GeV

circumference  $\approx 100$  km

A. Blondel

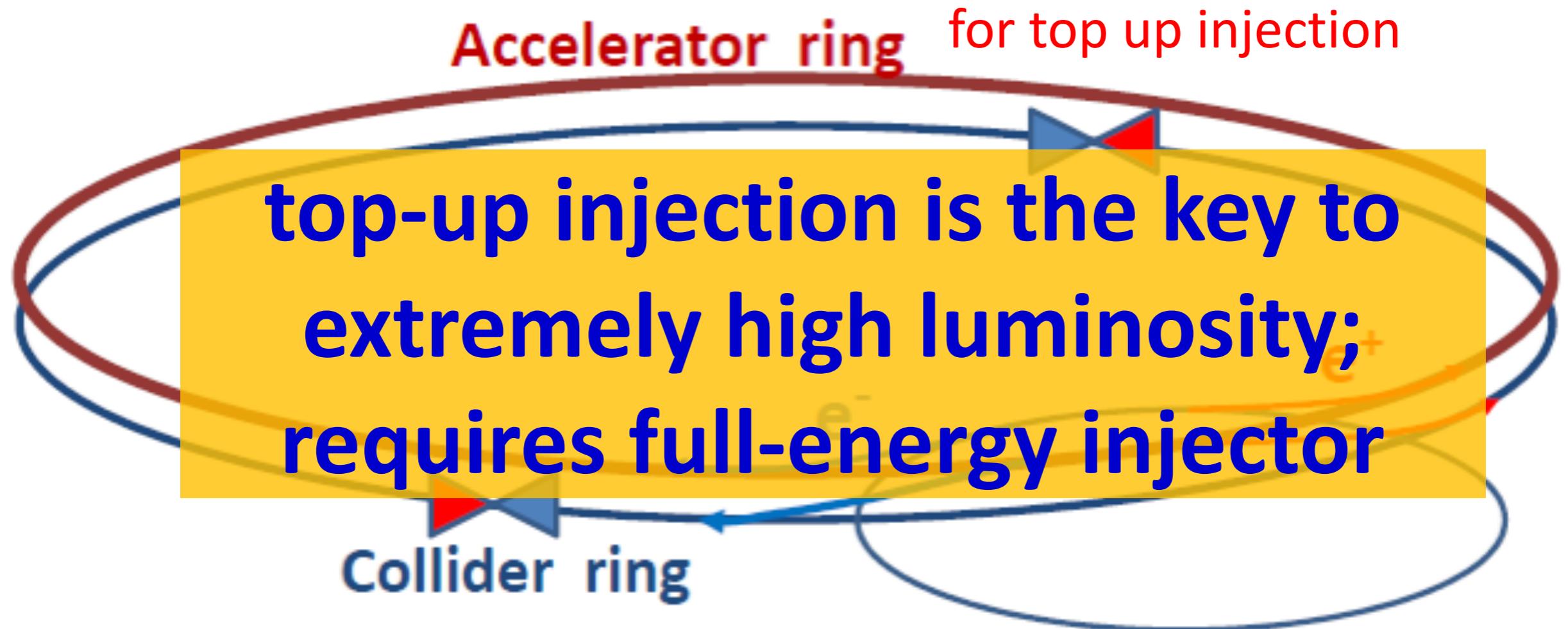


**short beam lifetime** ( $\sim \tau_{\text{LEP2}}/40$ ) due to high luminosity  
**supported by top-up injection** (used at KEKB, PEP-II, SLS,...);  
top-up also avoids ramping & thermal transients, + eases  
tuning

# FCC-ee: $e^+e^-$ collider up to 350 (500) GeV

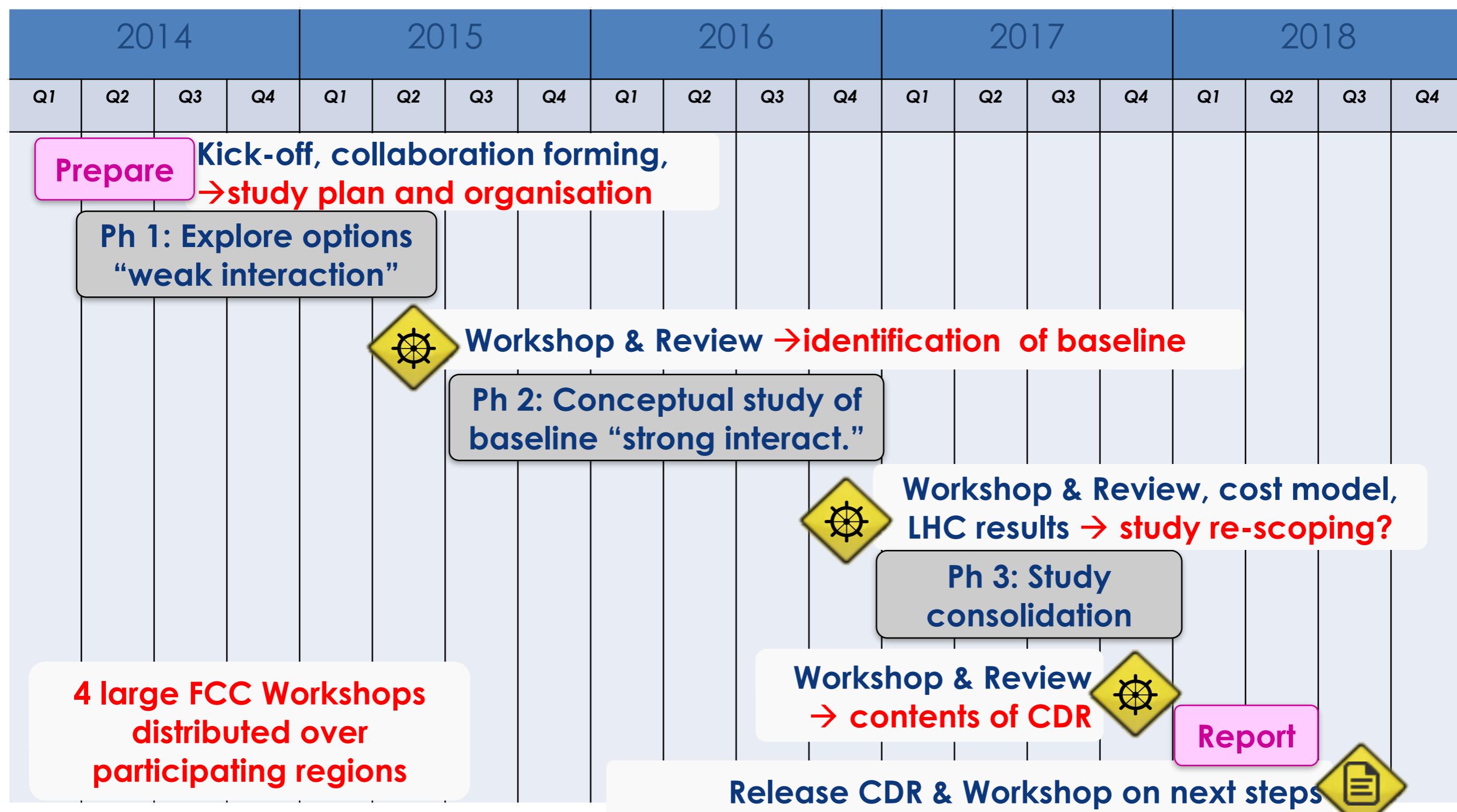
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**short beam lifetime** ( $\sim \tau_{\text{LEP2}}/40$ ) due to high luminosity  
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**top-up also avoids ramping & thermal transients, + eases tuning**

# FCC global design study – time line



- presently discussions with potential partners (MoUs)
- first international collaboration board meeting at CERN on 9 & 10 September 2014

# Reports from SuperKEKB

# Parameter comparison

Rings	FCC-ee Z	FCC-ee tt	KEKB LER / HER	SuperKEKB LER / HER	
Beam energy	46	175	3.5 / 8	4 / 7	GeV
Circumference	100		3		km
Current / beam	1.45	0.0066	~ 1.6/1.3	3.6 / 2.6	A
Bunches / beam	16700	98	~ 1500	2500	
Particles / bunch	1.8	1.4	~ 0.67/0.54	0.90 / 0.65	$10^{11}$
Hor. emittance	29	2	18 / 24	3.2 / 5	nm
Ver. emittance	60	2	~ 150	10 / 15	pm
$\varepsilon_y/\varepsilon_x$	0.2	0.1	~ 0.8/0.6	0.27	%
$\beta_x^*$	500	1000	~ 1200	32 / 25	mm
$\beta_y^*$	1	1	~ 6	0.27 /0.3	mm
Bunch length $\sigma_z$	2.6	1.5	8 / 6	6 / 5	mm
Momentum spread w/BS	6	19	9 / 7	7 / 6	$10^{-4}$
Half crossing angle	?	?	11	41.5	mead
Beam-beam $\xi_x$	0.031	0.092	~ 0.12/0.13	0.003	
Beam-beam $\xi_y$	0.030	0.092	~ 0.13/0.09	0.09	
Luminosity / IP	28	1.7	2.1	80	$10^{34}$

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Parameters of FCC-ee, such as  $\beta^*$  seems easier than SuperKEKB, but...

# ◆ Scaling of final quads



$$k_1 = \frac{B'L_Q}{B\rho} = c_f/L \quad (\text{inverse focal length})$$

$$L_Q = c_Q L$$

$$B'b = B_0 \quad (\text{pole tip field})$$

$$b > \max(\sqrt{2\beta_{x,y}J_{x,y}}) \quad (\text{required acceptance})$$

$$\beta_{x,y} = \beta_{x,y}^* + \frac{L^2}{\beta_{x,y}^*}$$

$$\xi_y = k_1 \beta_y \quad (\text{vertical chromaticity})$$



$$L_0 = \frac{c_f B \rho}{c_Q B_0} \sqrt{\frac{2 J_{x,y}}{\beta_{x,y}^*}}$$

$$L > \frac{L_0}{2} \left( 1 + \sqrt{1 + 4 \frac{\beta_{x,y}^{*2}}{L_0^2}} \right)$$

$$\xi_y = \frac{c_f L}{\beta_y^*}$$

A measure of difficulty in chromaticity correction

# Scaling of final quads (cont'd)

$$L_0 = \frac{c_f B \rho}{c_Q B_0} \sqrt{\frac{2J_{x,y}}{\beta_{x,y}^*}}$$

$$L > \frac{L_0}{2} \left( 1 + \sqrt{1 + 4 \frac{\beta_{x,y}^{*2}}{L_0^2}} \right)$$

$$\xi_y = \frac{c_f L}{\beta_y^*}$$

Rings	SuperKEKB LER	TLEP Z	TLEP tt	
Beam energy	4	46	175	GeV
$B\rho$	13.3	153	584	Tm
$B_0$	0.7		$\Leftarrow$	T
$c_f \equiv k_1 L$	1.56		$\Leftarrow$	
$c_Q \equiv L_Q / L$	0.35	0.35	0.7	
$\beta_x^*$	32	500	1000	mm
$\beta_y^*$	0.27	1	1	mm
$2J_x$	3.7		$\Leftarrow$	$\mu$ m
$2J_y$	10	0.87	0.23	nm
$L_0$	0.935	2.65	3.58	m
$L$	0.935	2.74	3.84	m
$L_Q$	0.33	0.96	2.69	m
$b$	10	7.4	7.4	mm
$\xi_y$	5,400	4,200	6,000	

$J_{x,y}$  assumes similar injected beams.

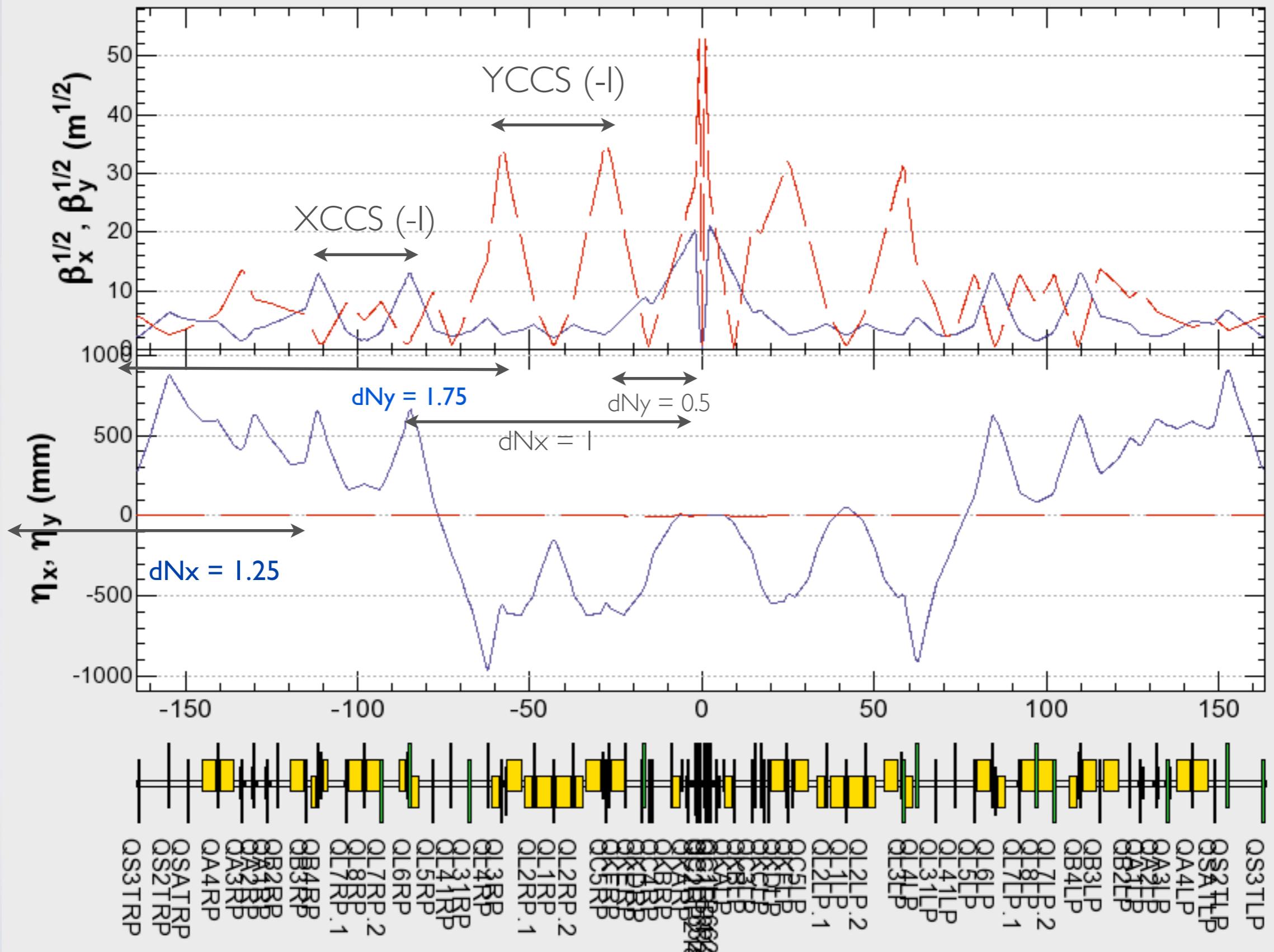
Similar level of difficulty!

If FCC-ee uses a chromaticity correction similar to SuperKEKB, the resulting momentum acceptance will be similar, about  $\pm 1.4\%$ .

More analyzes including nonlinearities have been given by  
A. Bogomyagkov, E. Levichev, P.Piminov.

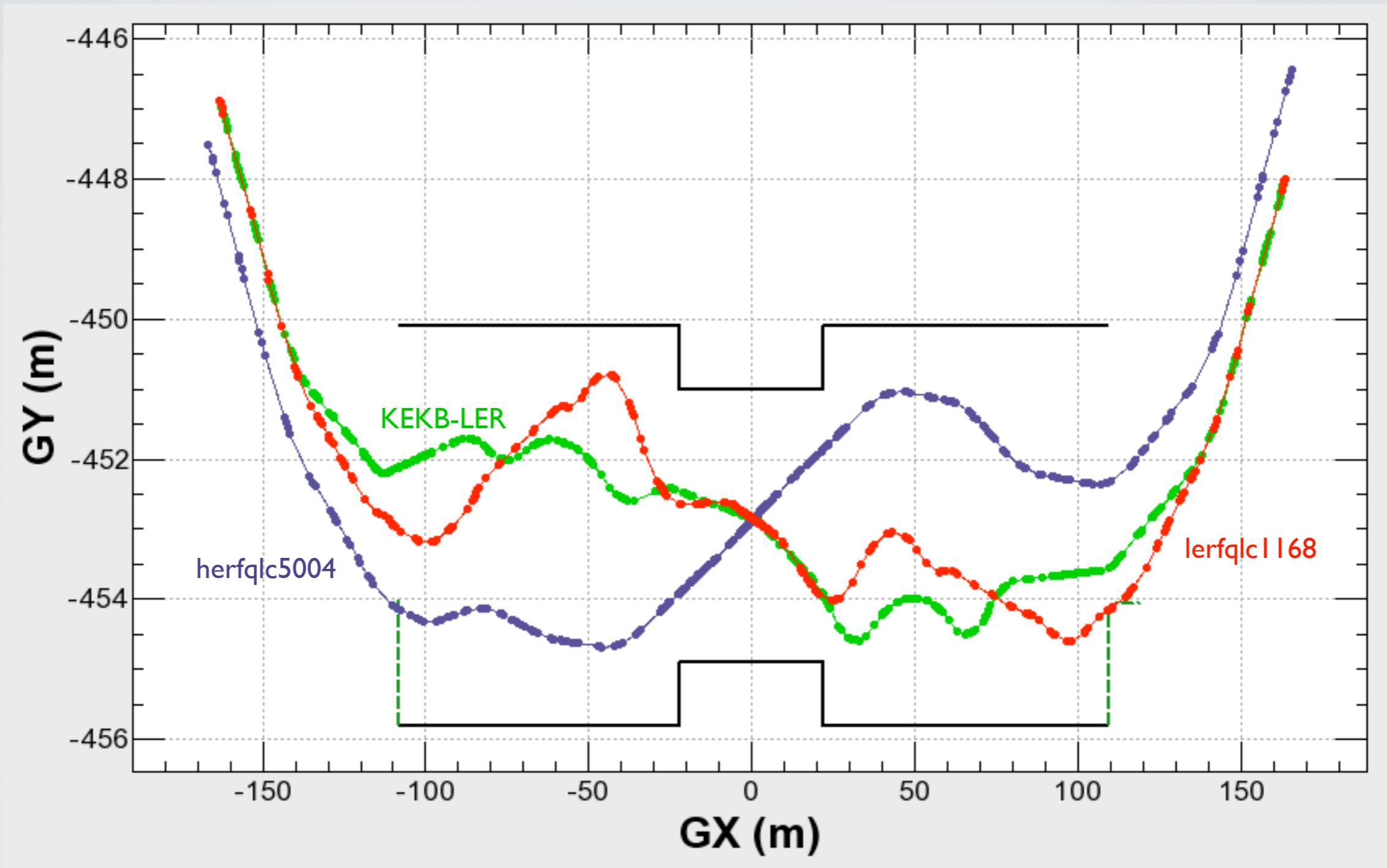
# LER (Semi-)Local Chromaticity Correction

K. Oide



# LER 2-family LCCS

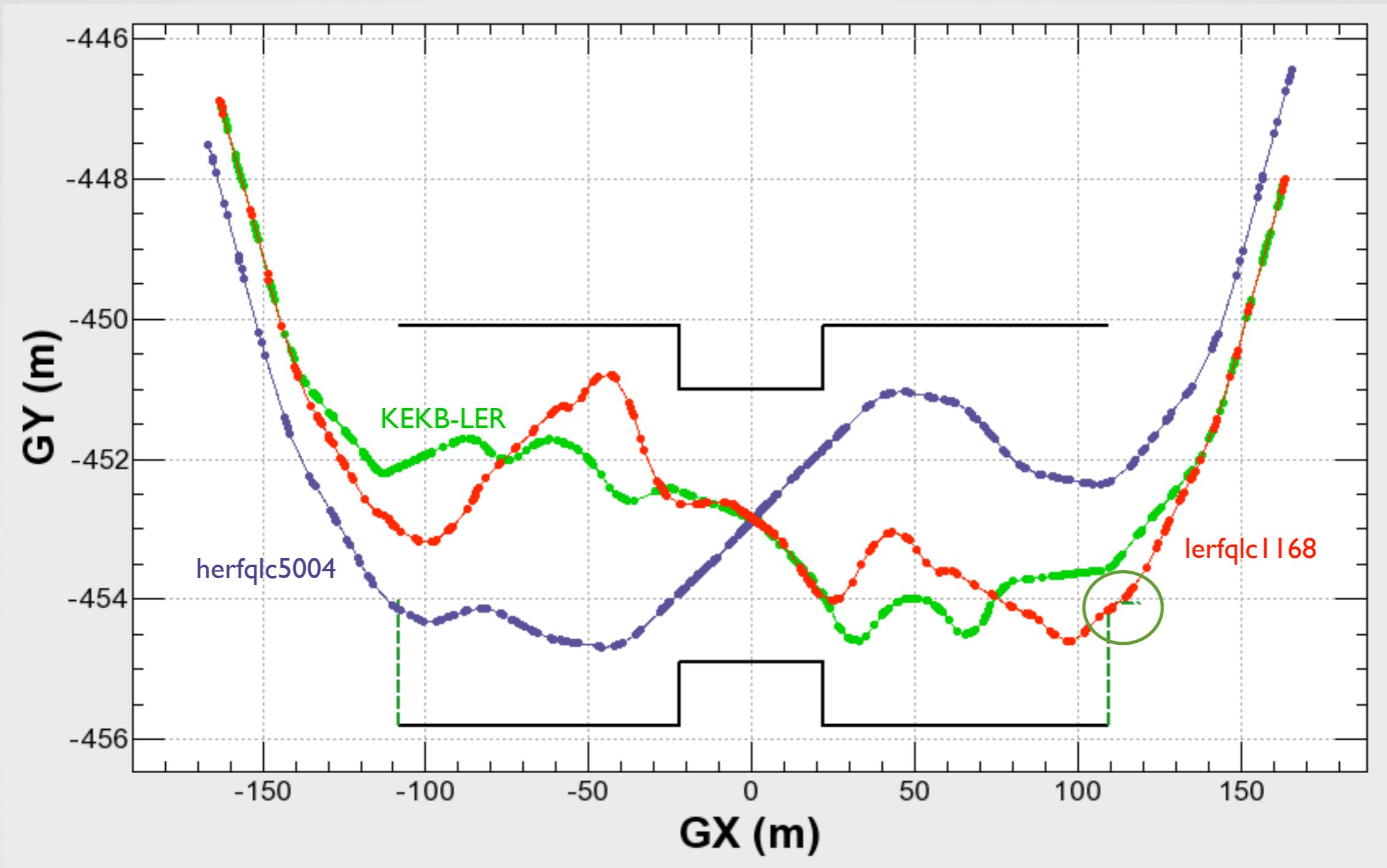
- Such a local CCS wiggles the orbit around the IP -



The design of CCS must be matured before the tunnel.

# LER 2-family LCCS

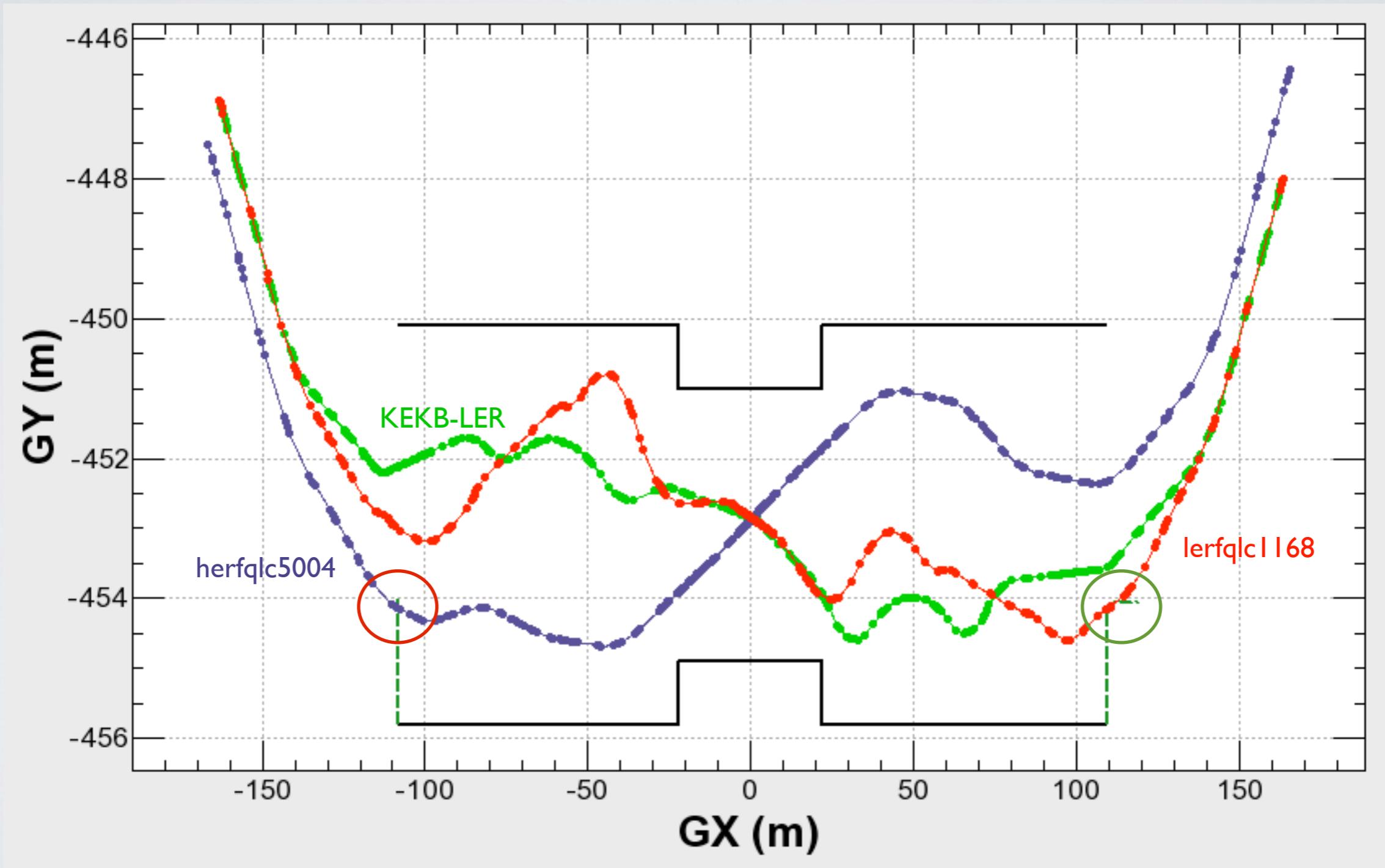
- Such a local CCS wiggles the orbit around the IP -



The design of CCS must be matured before the tunnel.

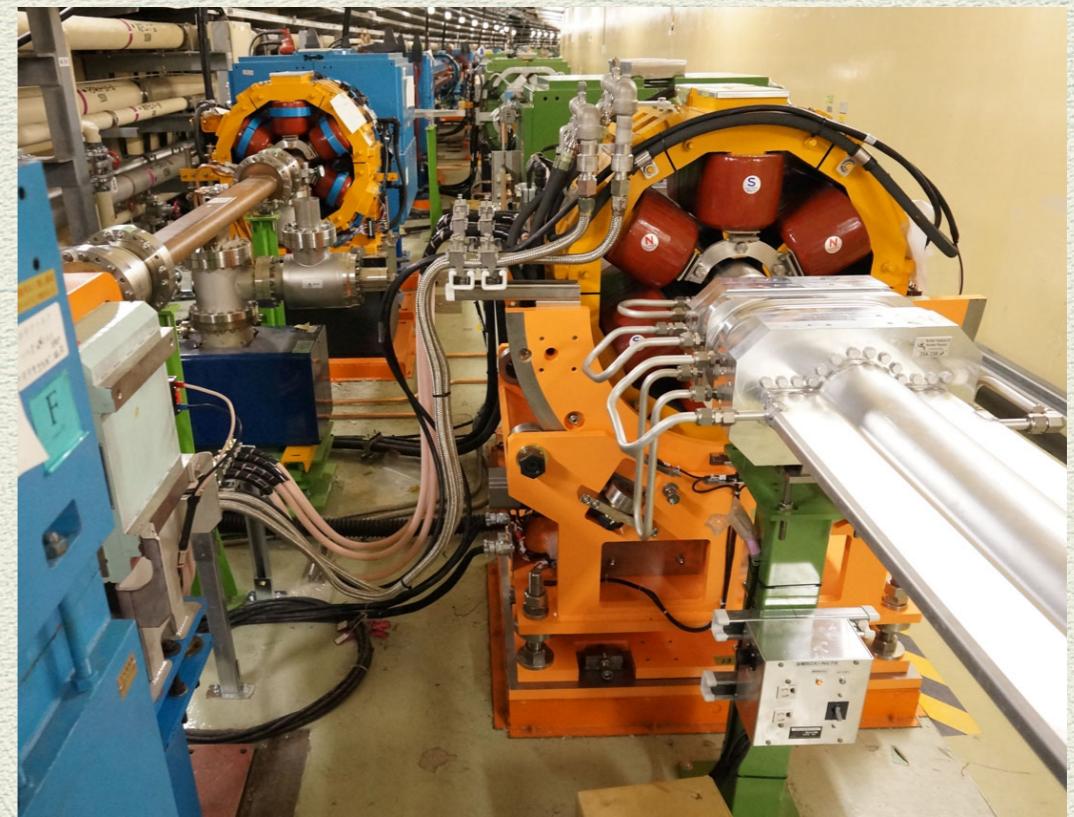
# LER 2-family LCCS

- Such a local CCS wiggles the orbit around the IP -

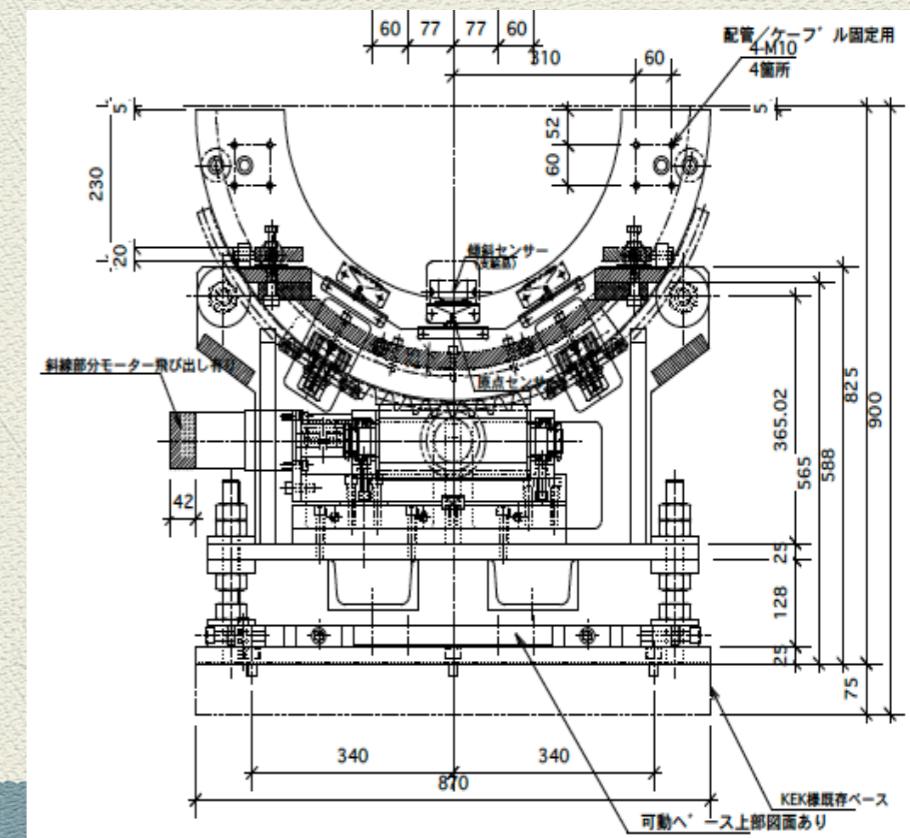


The design of CCS must be matured before the tunnel.

LER sextupoles are sitting on “tilting table” to correct chromatic x-y coupling.

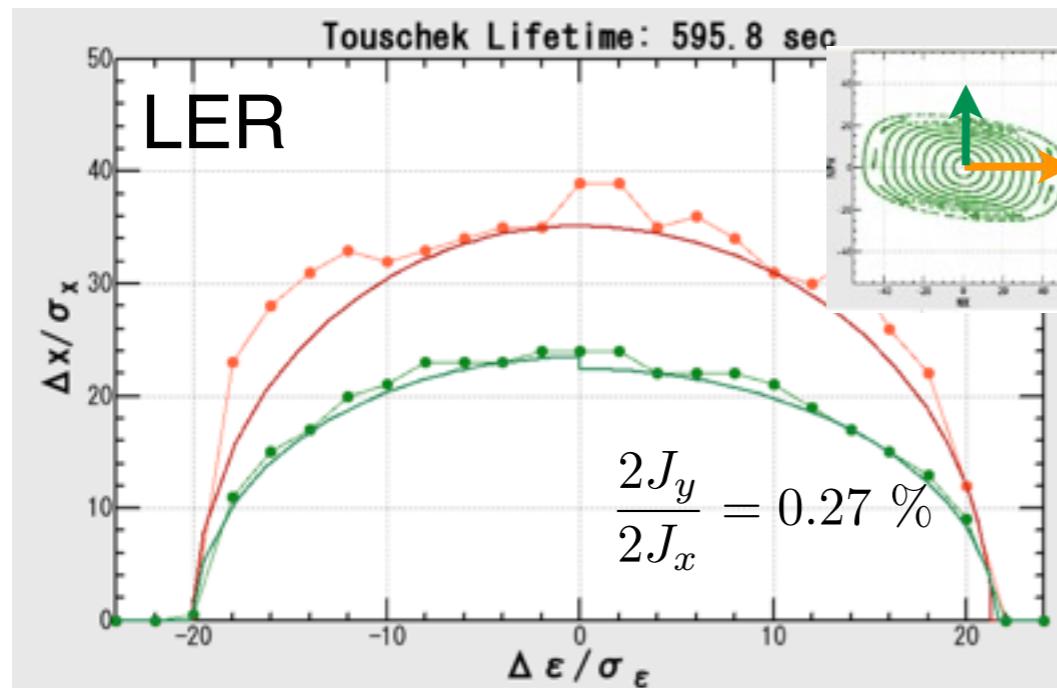


Sextupole magnet on tilting table installed in the beam line.  
Details of the tilting table



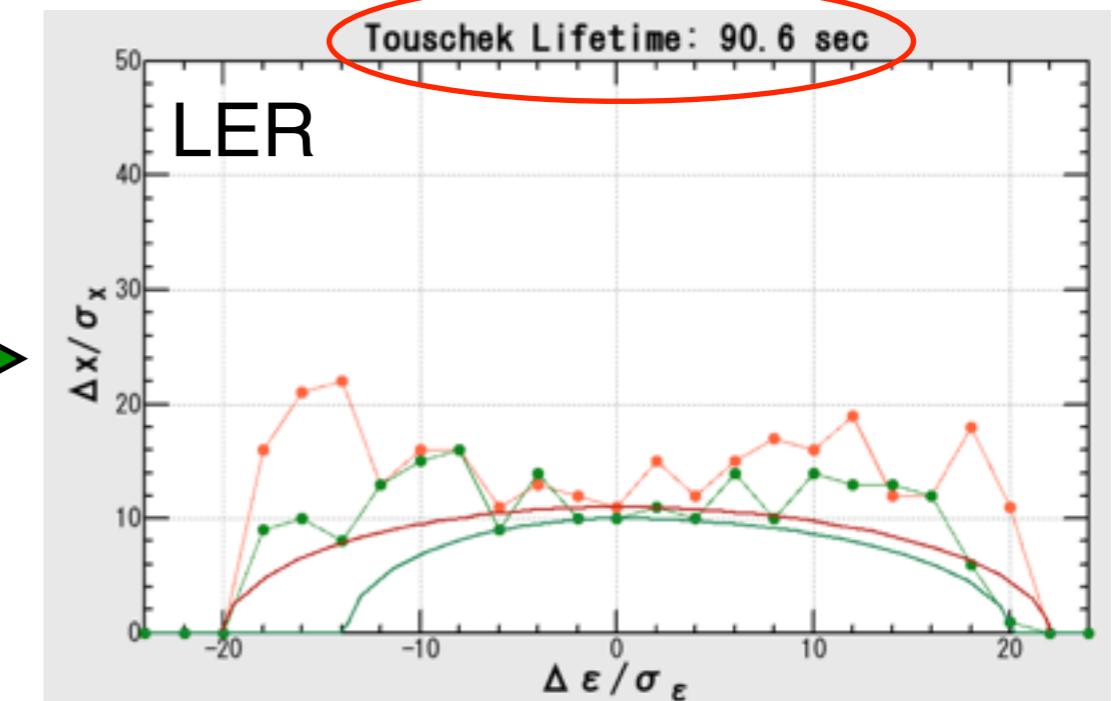
# Reduction of dynamic aperture due to beam-beam

w/o beam-beam

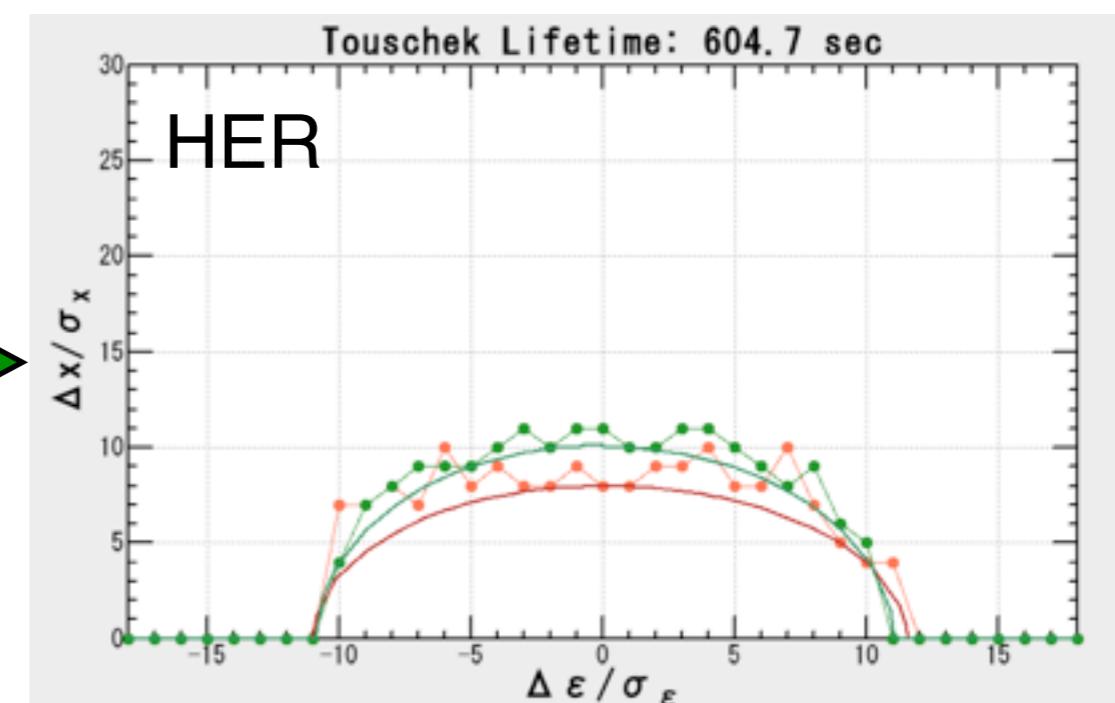
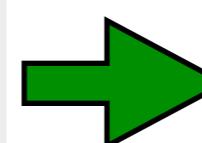
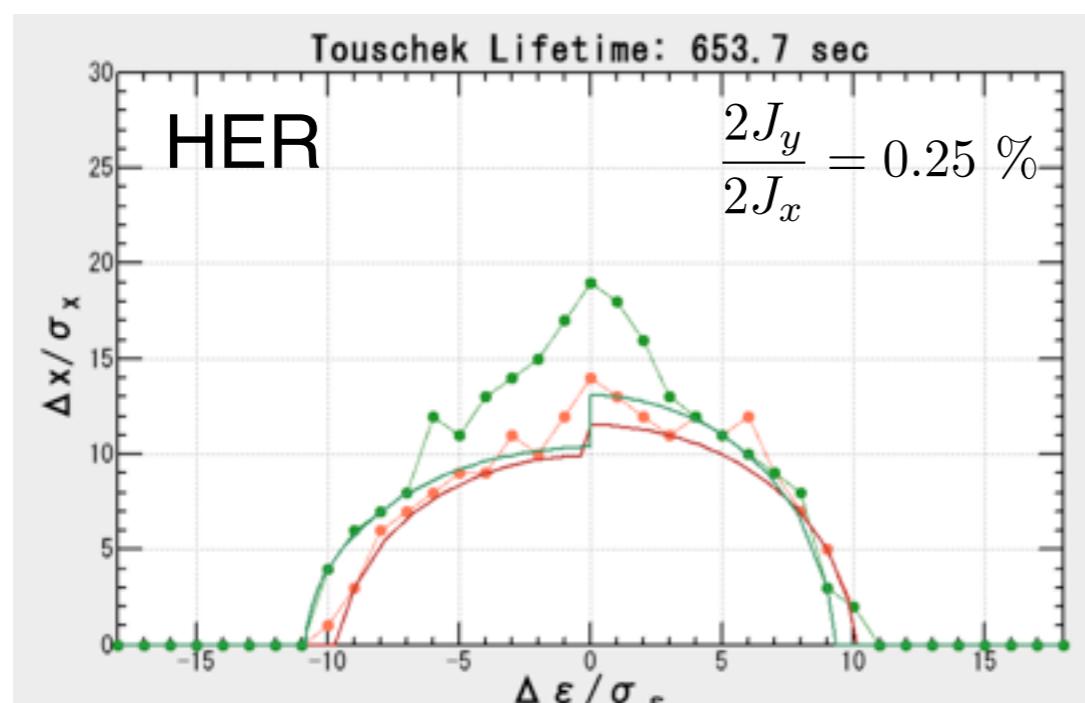


$\Delta p/p = \pm 1.4\%$

with beam-beam

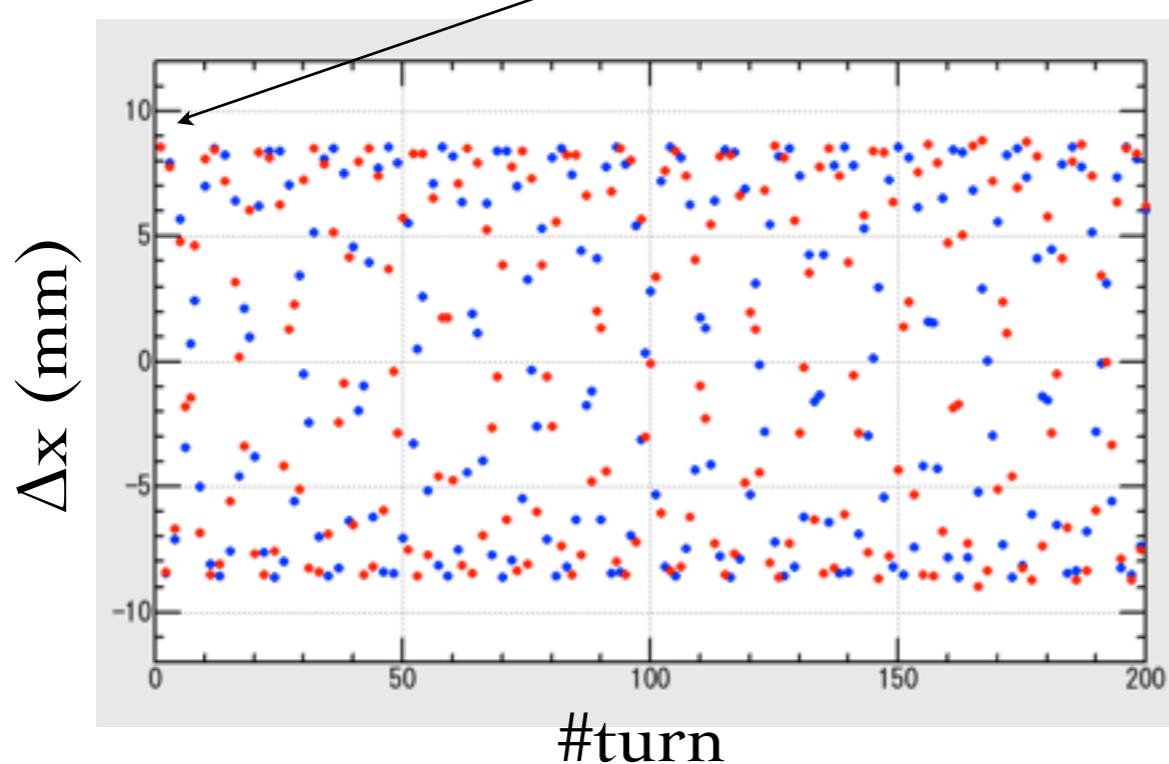


Transverse aperture reduces significantly.



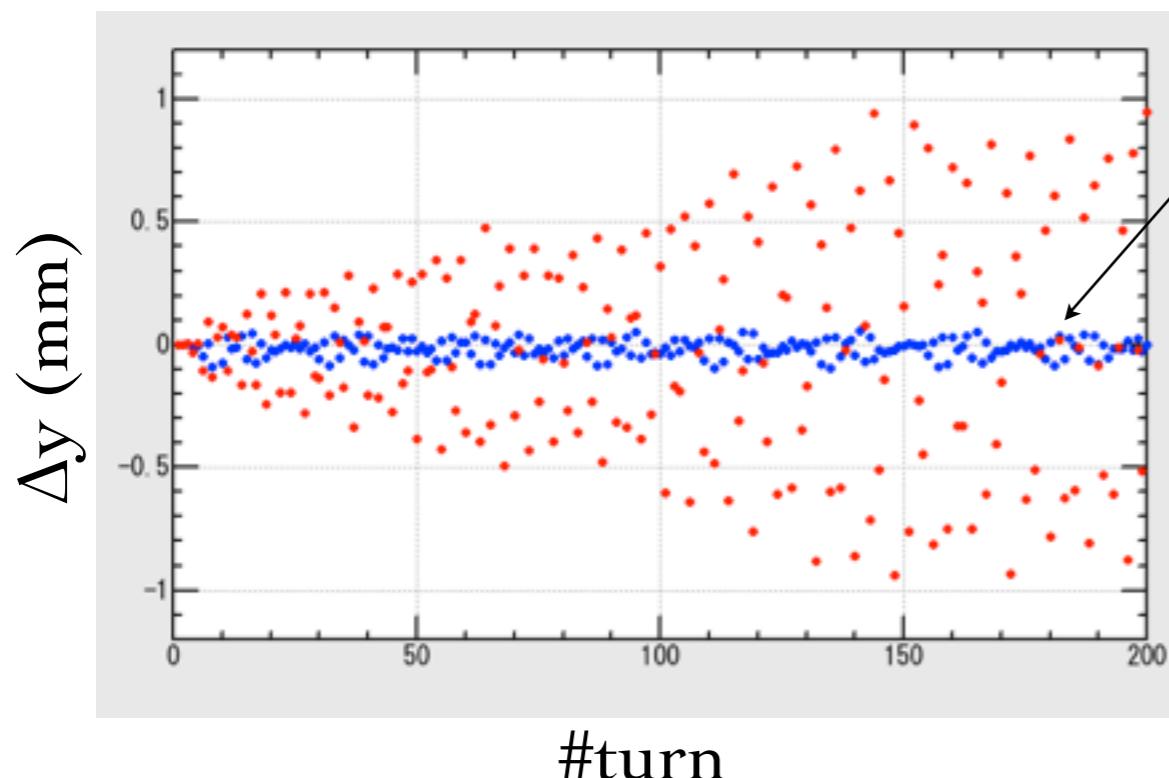
# Tracking simulation: beam-beam effect

Initial orbit is **15 sigmas** in the horizontal direction and **0** for the vertical direction



**blue: no beam-beam**  
**red: with beam-beam**

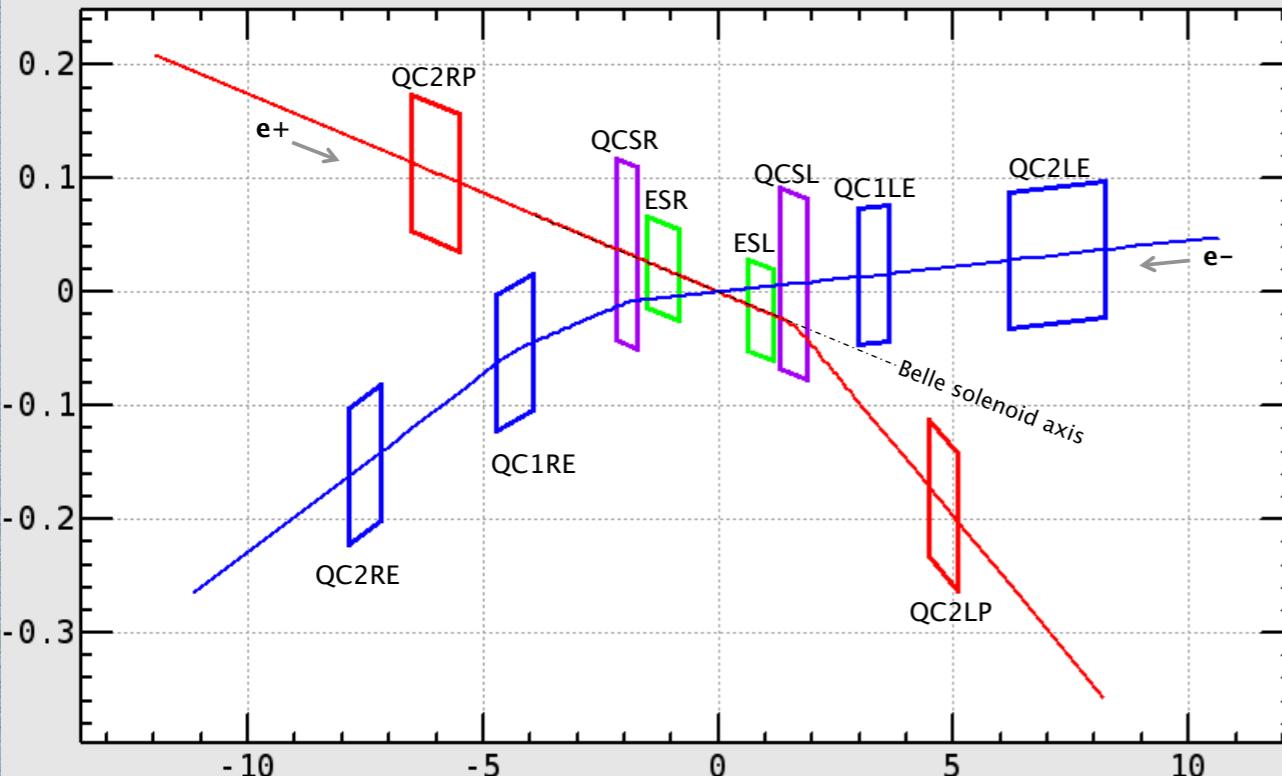
Horizontal betatron oscillation is stable for both cases.



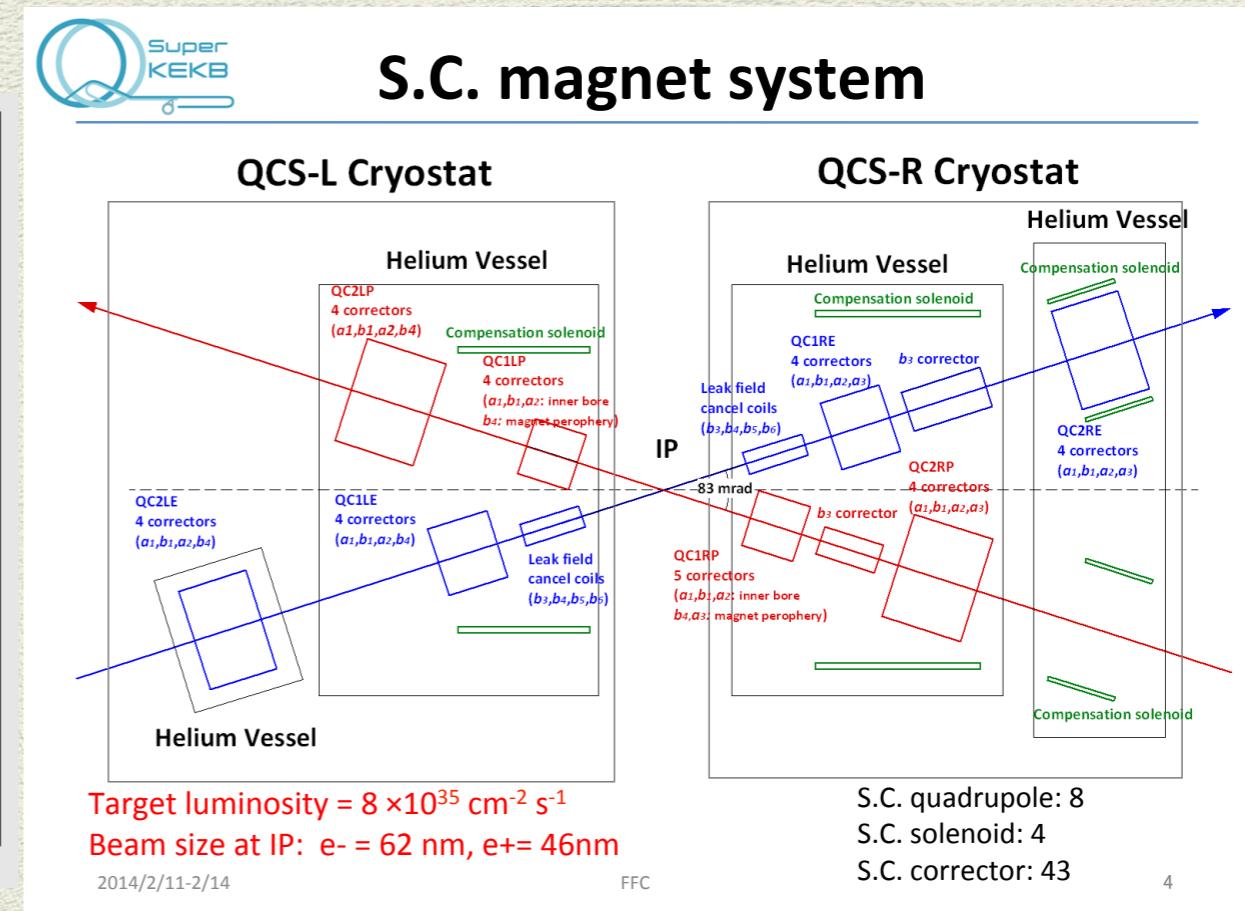
The vertical oscillation exists for the case w/o beam-beam, since there is a X-Y coupling.

**Vertical betatron oscillation is unstable when beam-beam effect is included.**

# Final Focusing Quads

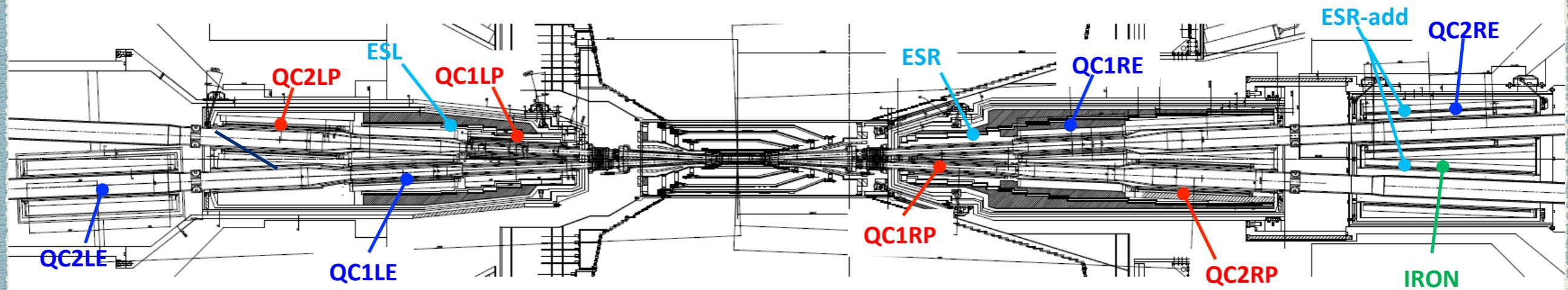


KEKB:  
Common final quads  
with medium crossing angle  
11 mrad x 2



SuperKEKB:  
Separate final quads  
with large crossing angle  
41.5 mrad x 2

# S.C. magnets in SuperKEKB IR



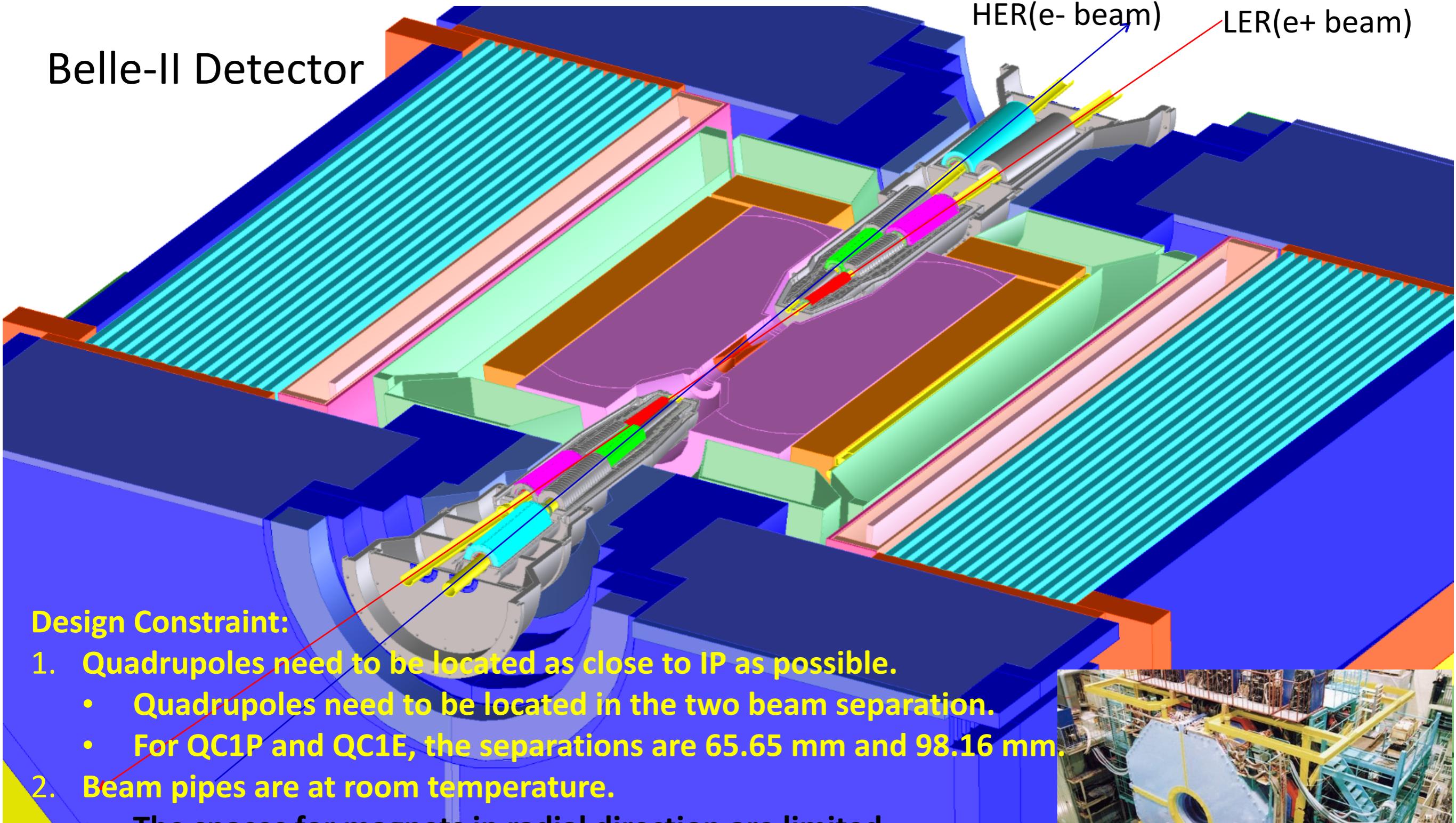
	Integral field gradient, (T/m)·m Solenoid field, T	Magnet type	Z pos. from IP, mm	$\theta$ , mrad	$\Delta X$ , mm	$\Delta Y$ , mm
QC2RE	13.58 [32.41 T/m × 0.419m]	Iron Yoke	2925	0	-0.7	0
QC2RP	11.56 [26.28 × 0.410]	Permendur Yoke	1925	-2.114	0	-1.0
QC1RE	26.45 [70.89×0.373]	Permendur Yoke	1410	0	-0.7	0
QC1RP	22.98 [68.89×0.334]	No Yoke	935	7.204	0	-1.0
QC1LP	22.97 [68.94×0.334]	No Yoke	-935	-13.65	0	-1.5
QC1LE	26.94 [72.21×0.373]	Permendur Yoke	-1410	0	+0.7	0
QC2LP	11.50 [28.05 × 0.410]	Permendur Yoke	-1925	-3.725	0	-1.5
QC2LE	15.27 [28.44×0.537]	Iron Yoke	-2700	0	+0.7	0

# SuperKEKB IR Overview

Belle-II Detector

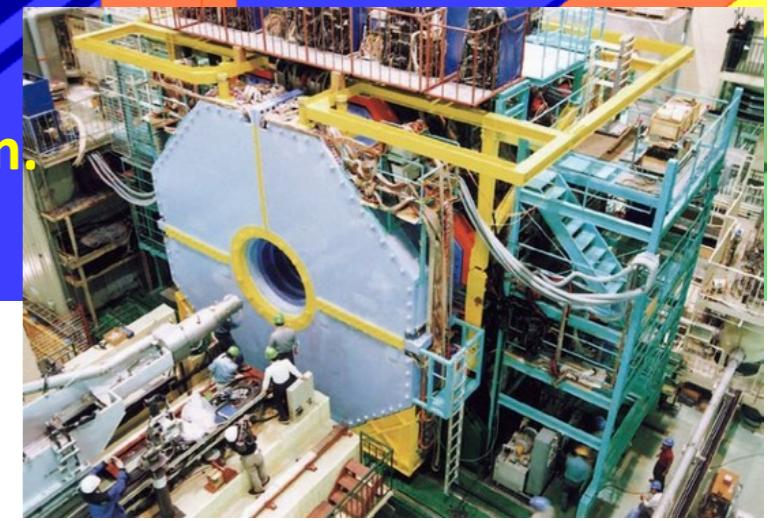
HER(e- beam)

LER(e+ beam)

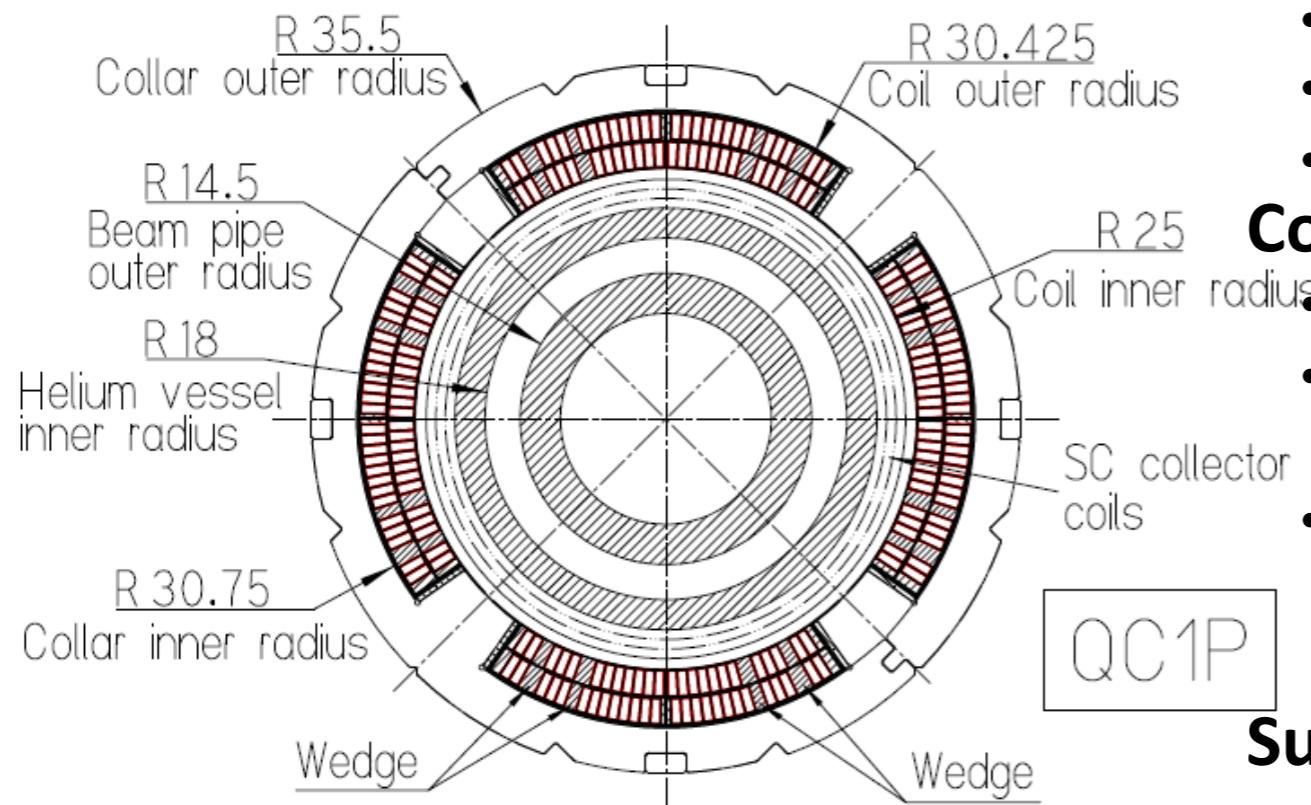


## Design Constraint:

1. Quadrupoles need to be located as close to IP as possible.
  - Quadrupoles need to be located in the two beam separation.
  - For QC1P and QC1E, the separations are 65.65 mm and 98.16 mm.
2. Beam pipes are at room temperature.
  - The spaces for magnets in radial direction are limited.
3. Solenoid magnetic fields are superimposed on QC1P and QC1E.



# QC1P (No iron yoke)



QC1P magnet cross section

## QC1P magnet design (QC1RP, QC1LP)

- Design field gradient = 76.37 T/m @ 1800 A
- Effective magnetic length = 0.3336 m
- Magnet length = 0.4093 m
- $B_p = 4.56$  T (with solenoid field of  $B_z=2.6$  T,  $B_r=1.1$  T)
- Load line ratio at 4.7 K = 72.3 %
- Inductance = 0.88 mH

## Coil design

- 2 layer coils (3 coil blocks for each layer)
- Error field in 2 D cross section @ R=10 mm
  - $b_6 = 0.10$  units,  $b_{10} = -0.21$  units,  $b_{14} = 0.02$  units
- Integral error field in 3D model
  - $b_4 = 0.24$  units,  $b_6 = 0.54$  units,  $b_8 = 0.01$  units ,  $b_{10} = -0.21$  units

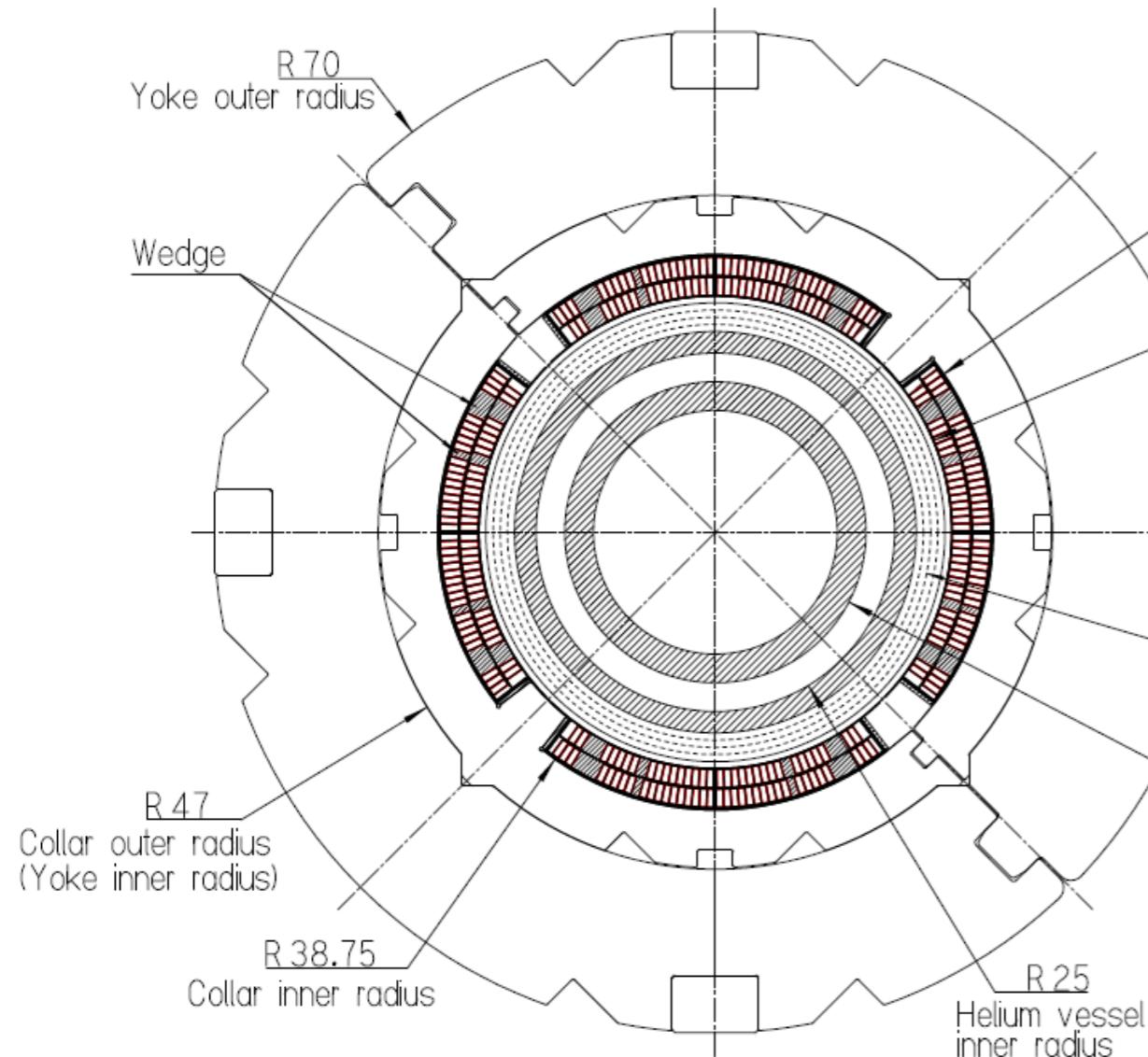
## Superconducting cable

- Cable size : 2.5 mm × 0.93 mm
- Keystone angle = 2.09 degree

## Cryostat

- Cryostat inner bore radius  $R_{in} = 18$  mm
- Beam pipe at R.T. :  $R_{in} = 10.5$  mm,  $R_{out} = 14.5$  mm

# QC1E (Permendur yoke)



QC1E magnet cross section

## QC1E magnet design (QC1RE, QC1LE)

- Design field gradient = 91.57 T/m @ 2000 A
- Effective magnetic length = 0.3731 m
- Magnet length = 0.4554 m
- $B_p = 3.50 \text{ T}$
- Load line ratio at 4.7 K = 73.4 %
- Inductance = 2.19 mH

## Coil design

- 2 layer coils (3 coil blocks for each layer)
- Error field in 2 D cross section
  - $b_6 = -0.06 \text{ units}$ ,  $b_{10} = -0.34 \text{ units}$ ,  $b_{14} = -0.01 \text{ units}$
- Integral error field in 3D model
  - $b_4 = -0.02 \text{ units}$ ,  $b_6 = -0.04 \text{ units}$ ,  $b_8 = 0.05 \text{ units}$ ,  $b_{10} = -0.43 \text{ units}$

## Superconducting cable

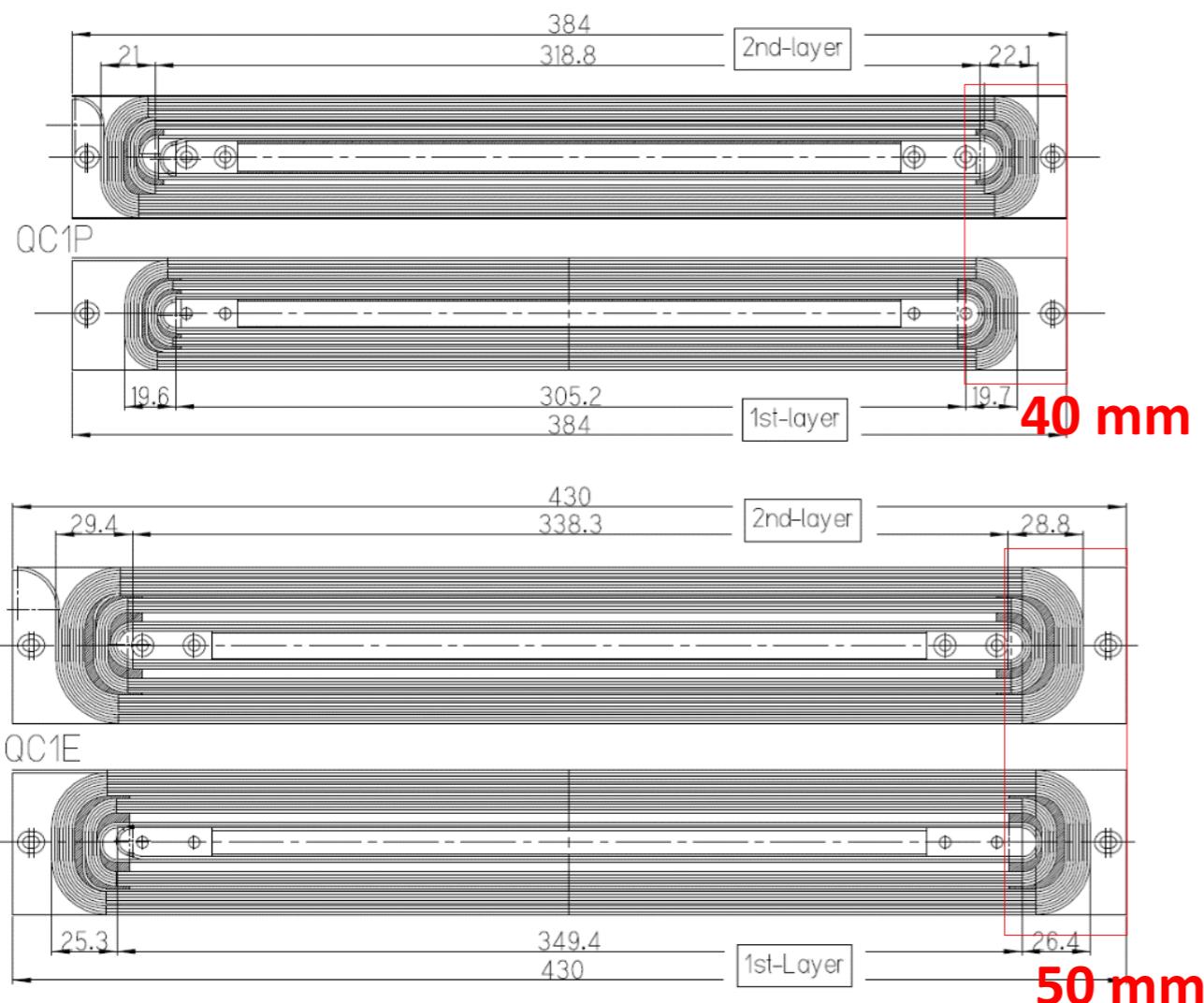
- Cable size : 2.5 mm × 0.93 mm
- Keystone angle = 1.59 degree

## Cryostat

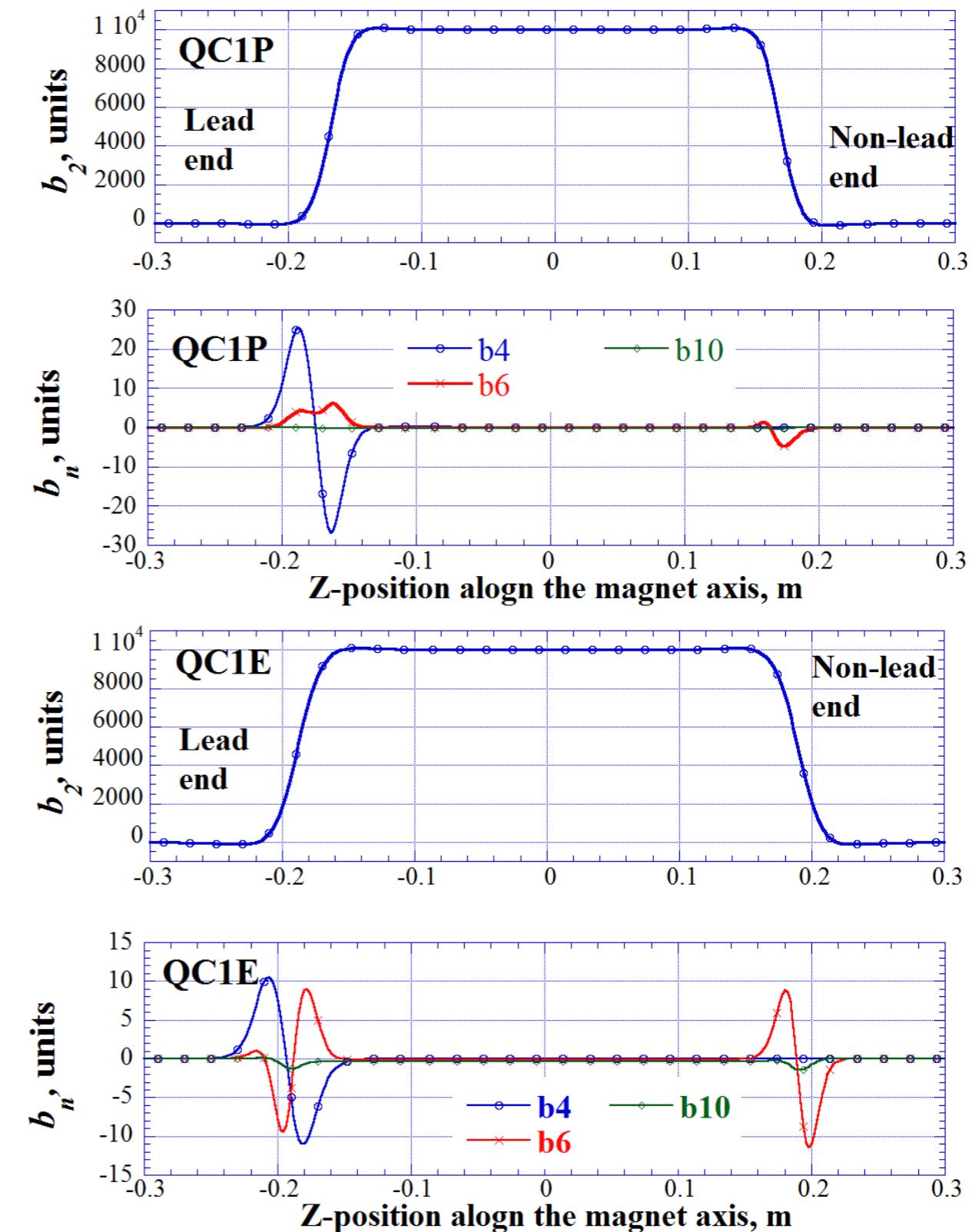
- Cryostat inner bore radius  $R_{in} = 25 \text{ mm}$
- Beam pipe at R.T. :  $R_{in} = 17 \text{ mm}$ ,  $R_{out} = 21 \text{ mm}$

# 3D magnet design of QC1P/1E

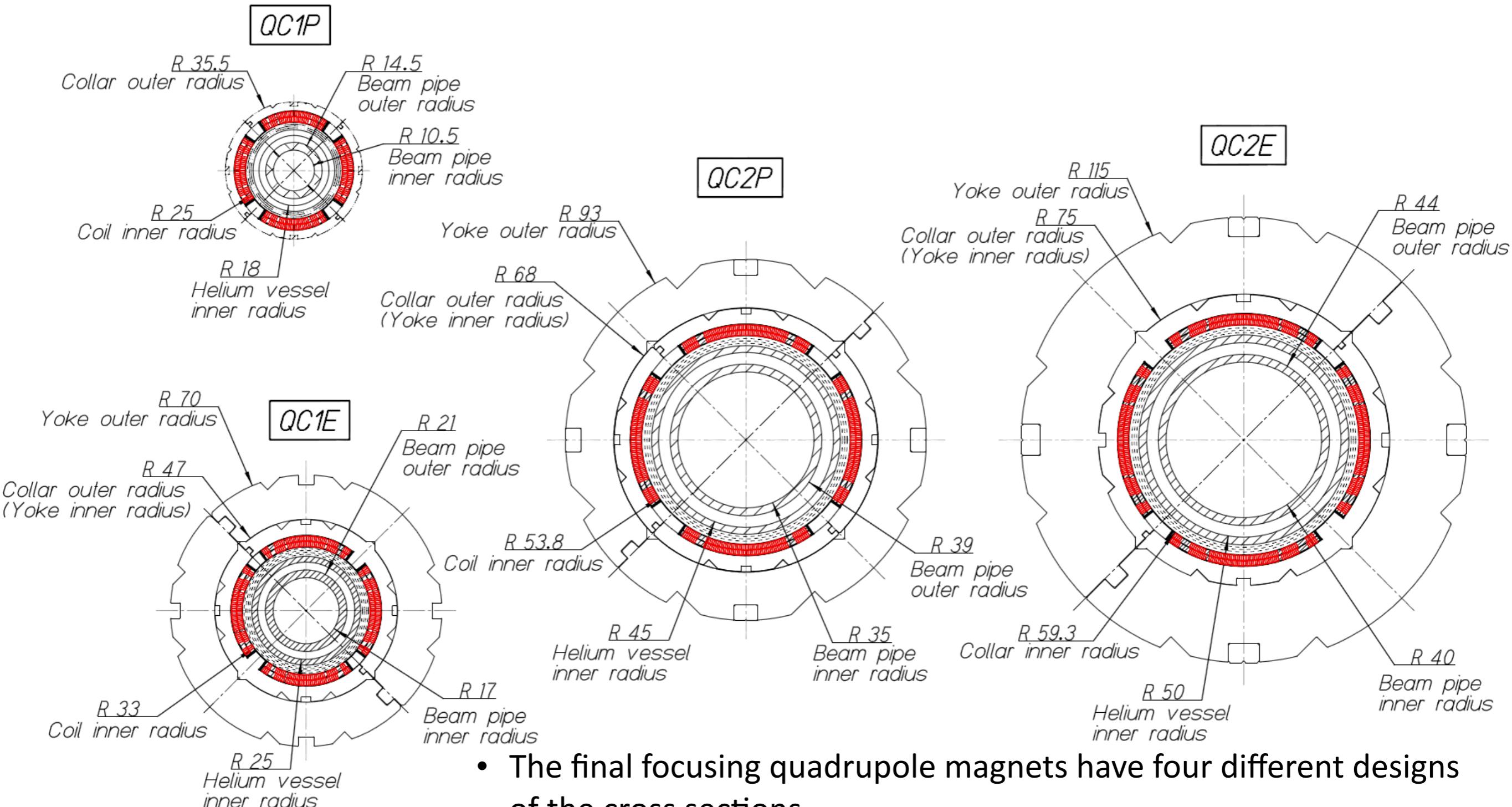
## QC1P/1E coil end design



- The coil ends were designed to be as short as possible.
- In order to exclude the skew components in the lead end, the quadrant coils have mirror symmetry to the neighbor coils.



# Cross section of four quadrupoles

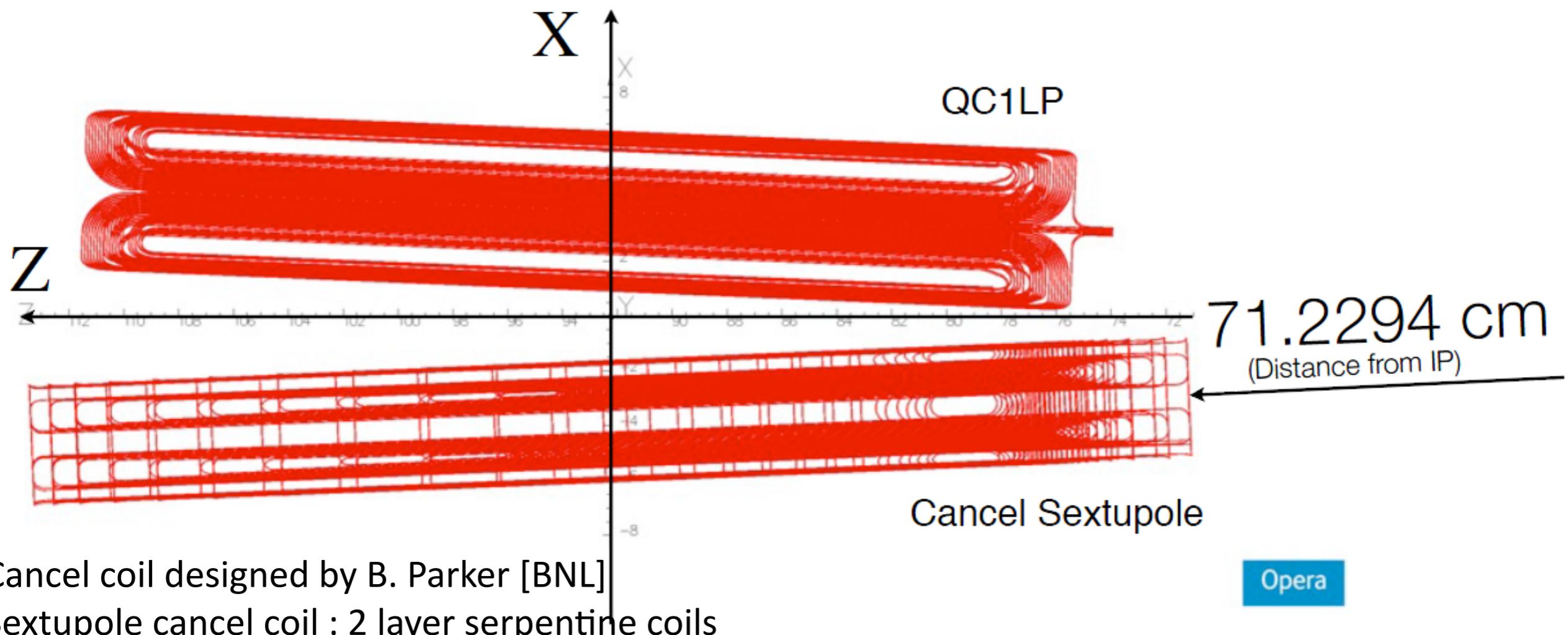


- The final focusing quadrupole magnets have four different designs of the cross sections.
  - QC1P has the smallest inner radius of 25 mm.
  - QC2E has the largest inner radius of 59.3 mm.

N. Ohuchi

# SC leak field cancel coils

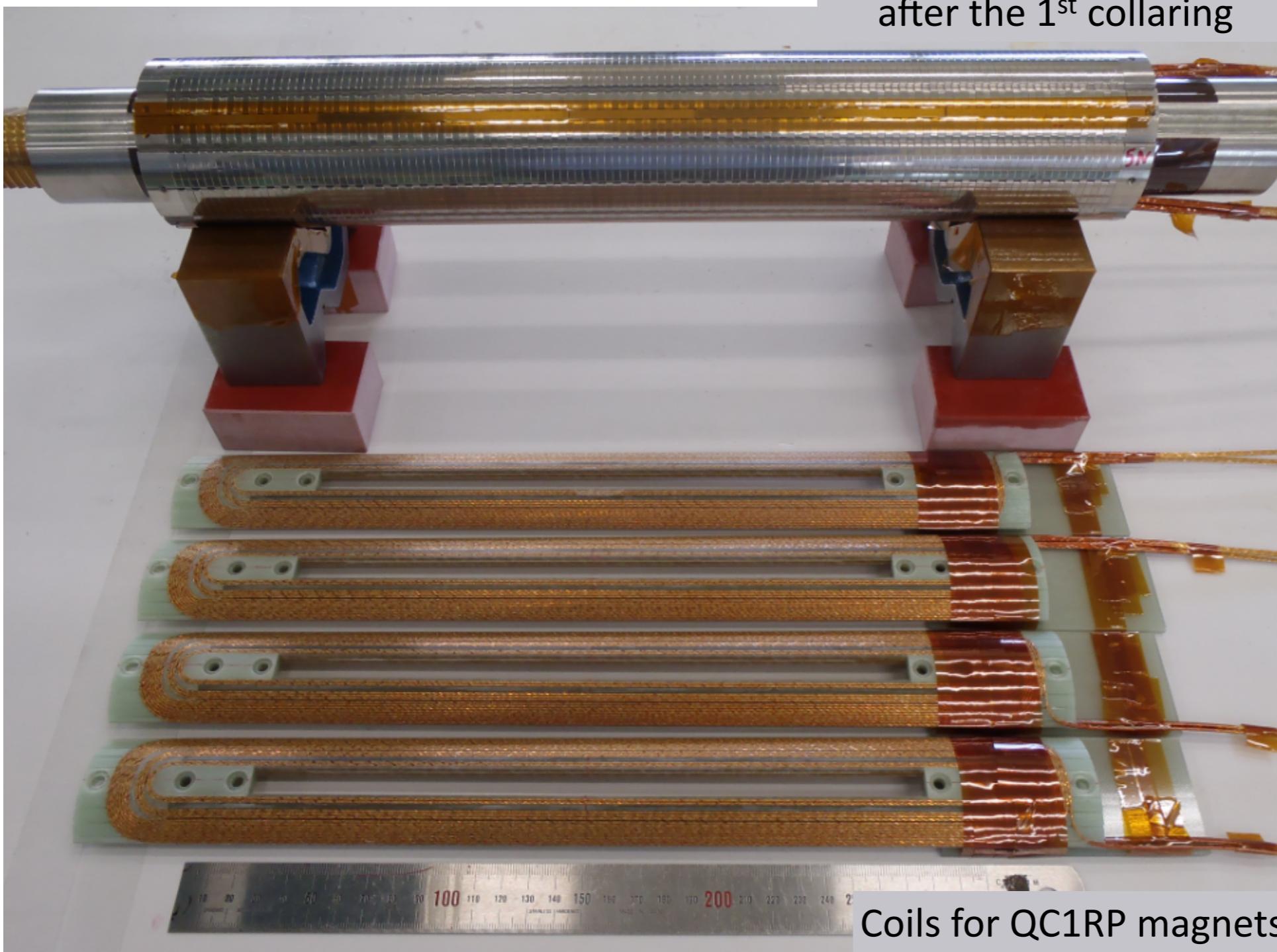
- The leak field cancel coils are now designed and constructed by BNL under the US-Japan research collaboration program.
- The field model is constructed with the collaboration between BNL and KEK.



N. Ohuchi

# Production of quadrupole

## Collared QC1LP magnet



QC1LP field quality after collaring

$@ R = 10$ mm	<i>a</i>	<i>b</i>
n=1	-0.1	-0.4
<b>2</b>	0.0	<b>10000</b>
<b>3</b>	<b>-0.5</b>	<b>5.4</b>
4	-0.0	-1.9
5	0.8	-3.6
6	-0.4	-0.3
7	0.8	0.8
8	-0.4	0.7
9	-0.2	-0.4
10	0.4	-0.1

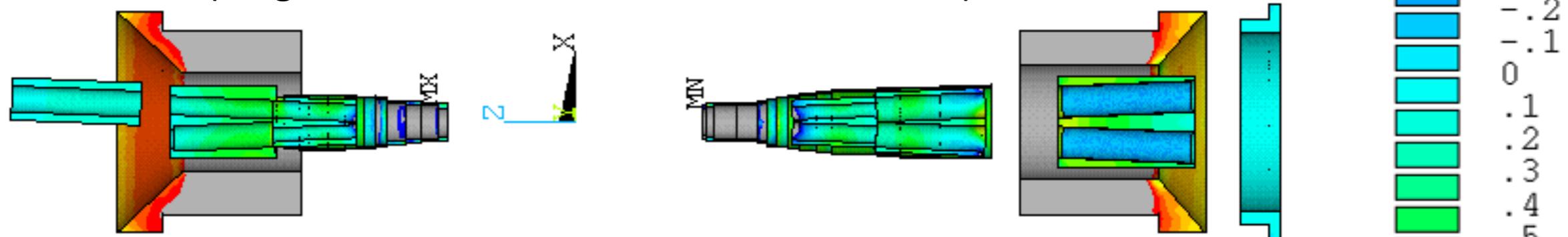
N. Ohuchi

# Magnet design: Permendur yoke

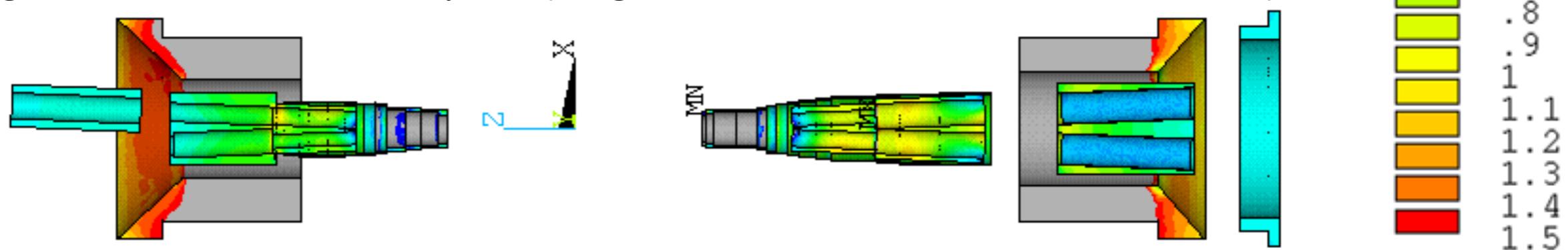
- The final focus system is designed to be operated under the Belle II solenoid field at 1.5 T.
- This field is cancelled with the accelerator compensation solenoids along the beam line. This cancellation is not perfect.

## Field profile in the iron components (3D ANSYS)

Optimized condition (magnetic field in the iron:  $-0.5 \text{ T} < B < 0.5 \text{ T}$ )



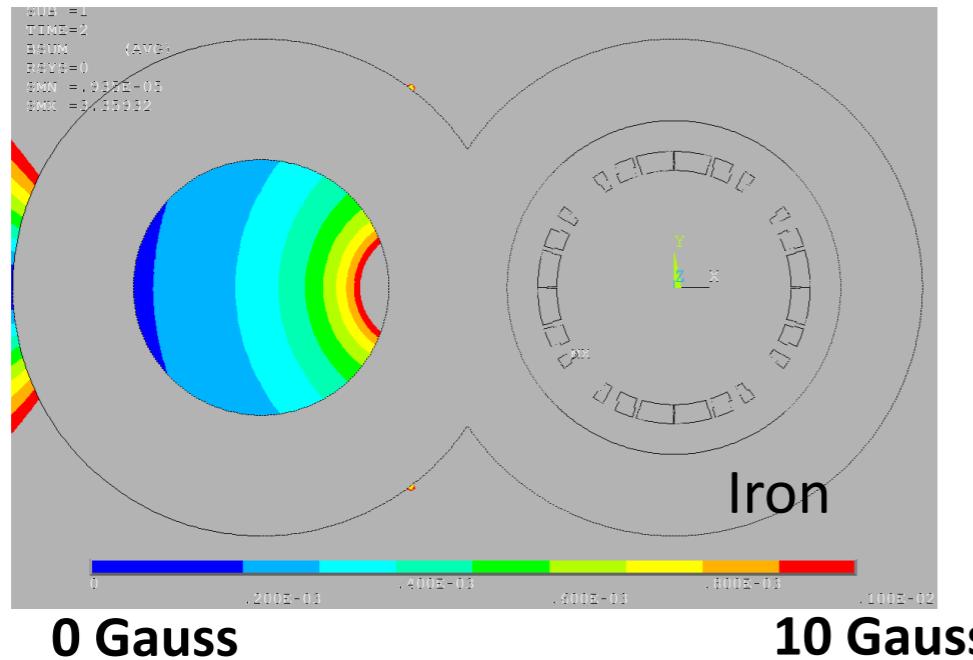
Increasing Belle solenoid current by 1 % (magnetic field in the iron:  $-0.5 \text{ T} < B < 1 \text{ T}$ )



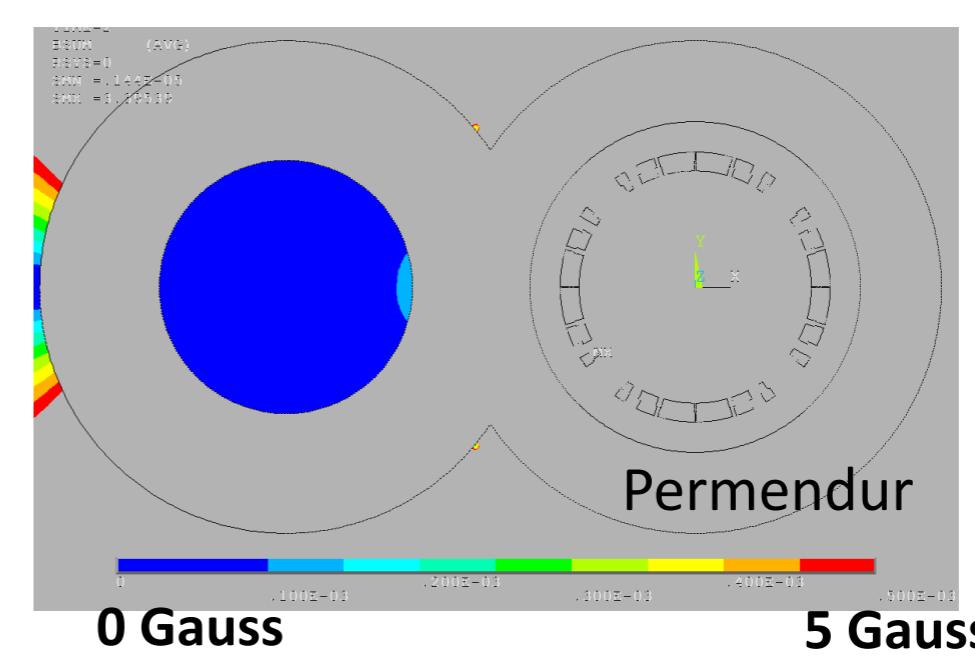
At the good cancelling condition, the insides of iron components have magnetic field at 0.5T .

# Magnet design: Permendur yoke

Leak field in the e+ beam line in case of Iron and Permendur Yokes  
With 0.5 T field in the Yoke

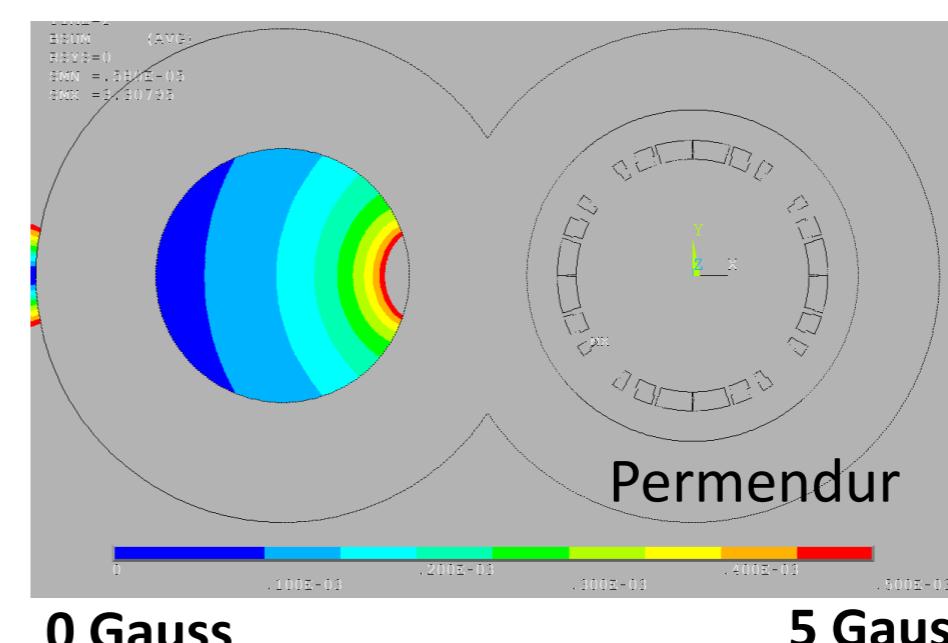
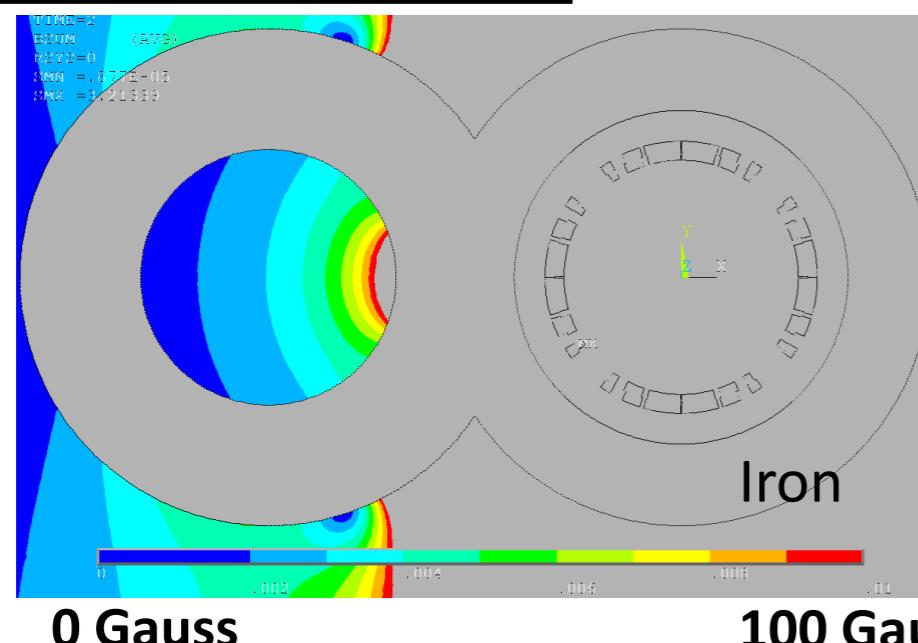


Leak field at e+ center = 3 Gauss



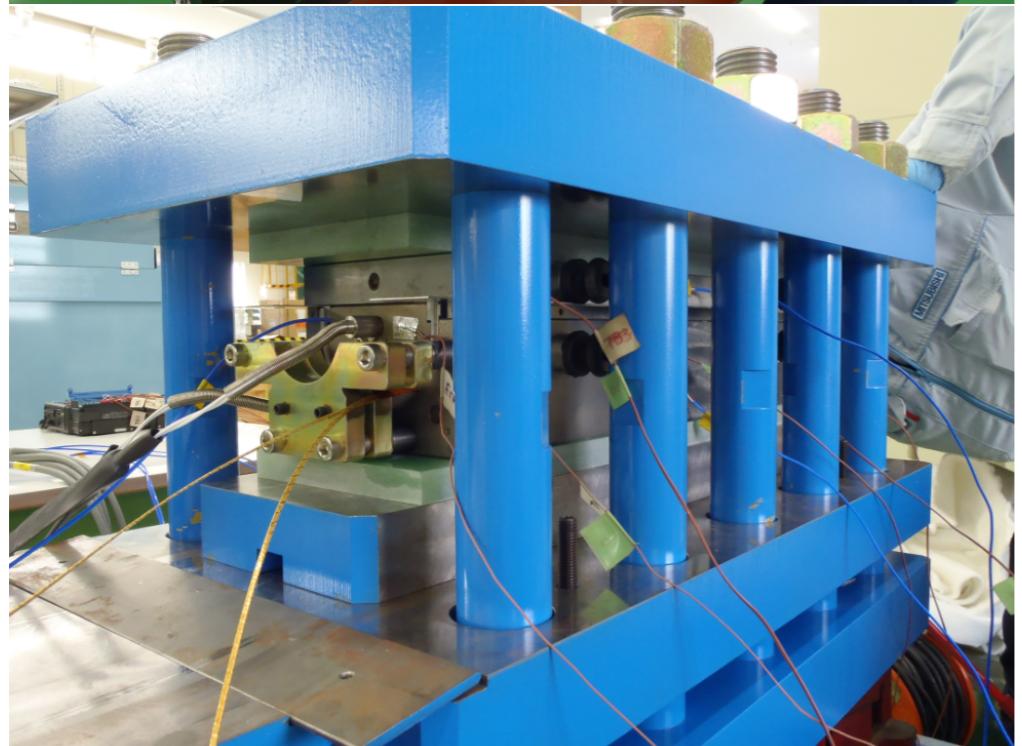
Leak field at e+ center <1 Gauss

With 1 T field in the Yoke



# Construction of QC1P and QC1E

- *Coil Winding and Curing Process*



2014/8/10-8/15

During winging coil, the cable tension was controlled:

- Initial tension at 120N and
- Reducing the tension of 10 N every two turns

Four coils for QC1E



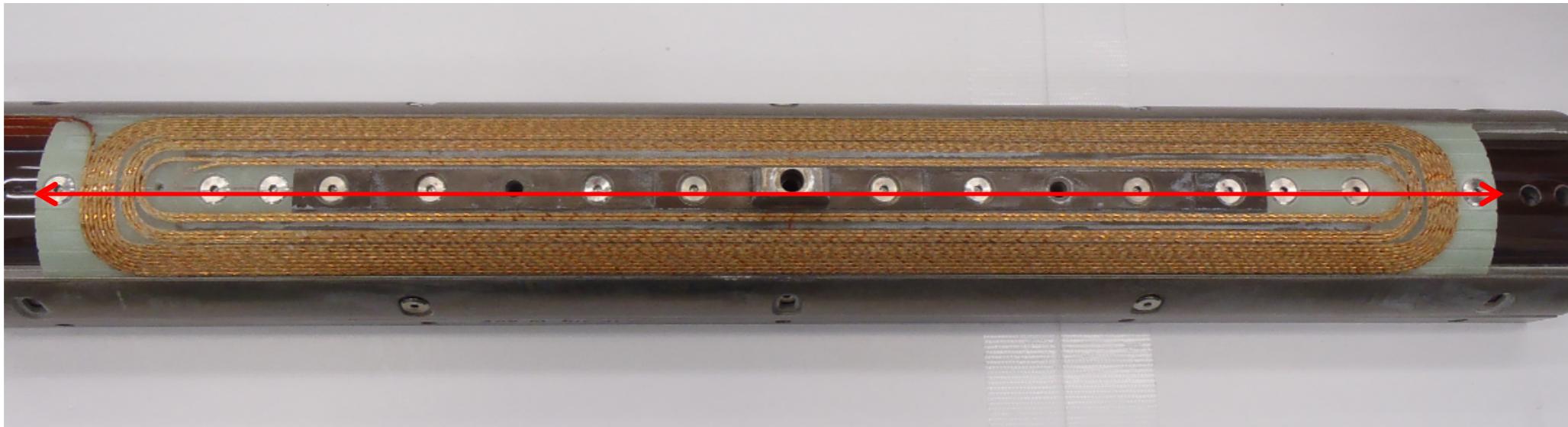
Normal shape

Mirror symmetry shape

After winging the coils, the coils were cured to the design shape with the forming blocks at temperature of 130 degree C and pressure of 20 MPa.

# Coil shapes of QC1P and QC1E

length



Length: distance between the end spacers

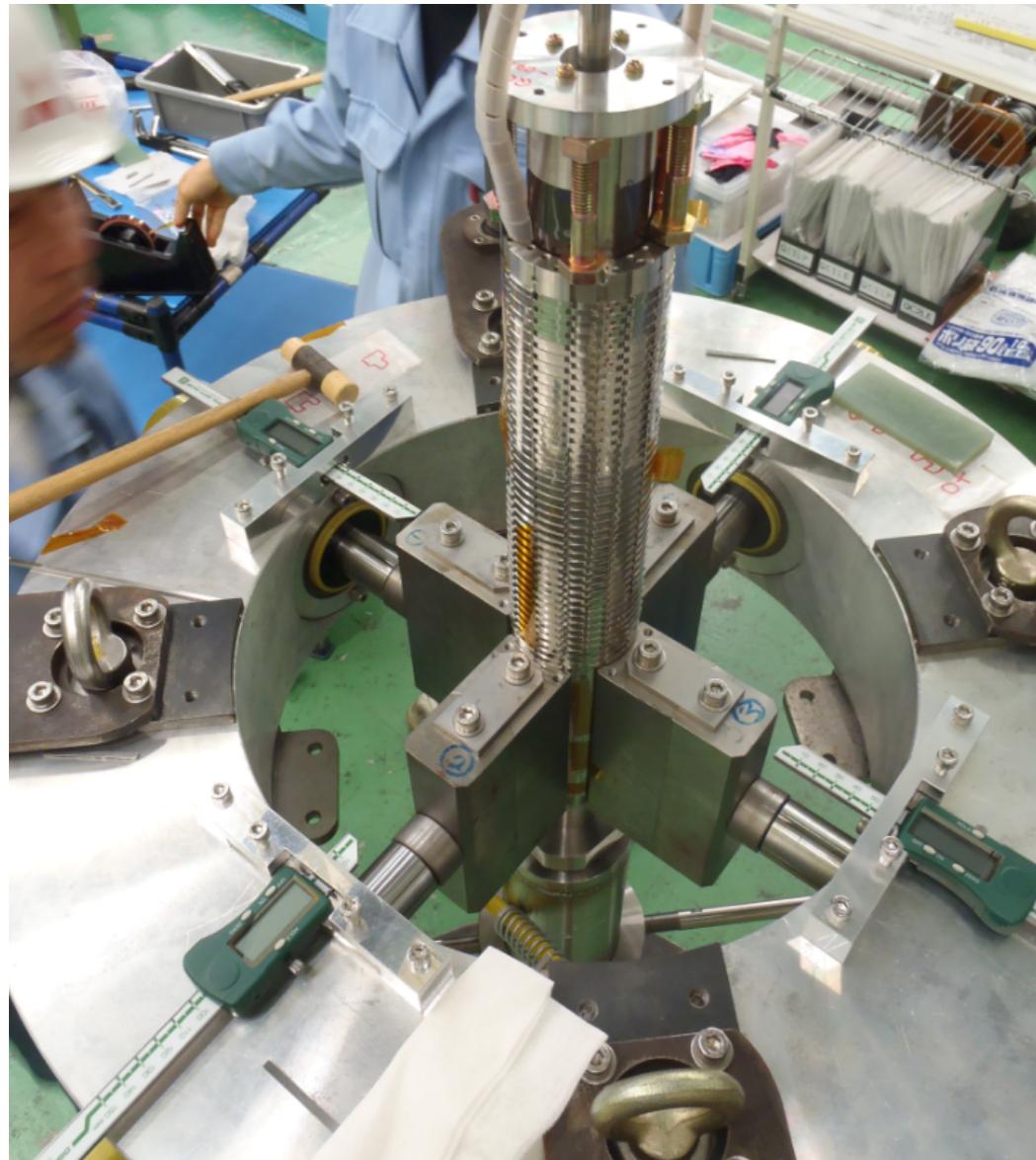
Thickness: two layer coil (1<sup>st</sup> layer and 2<sup>nd</sup> layer)

STD: standard deviation of four coils

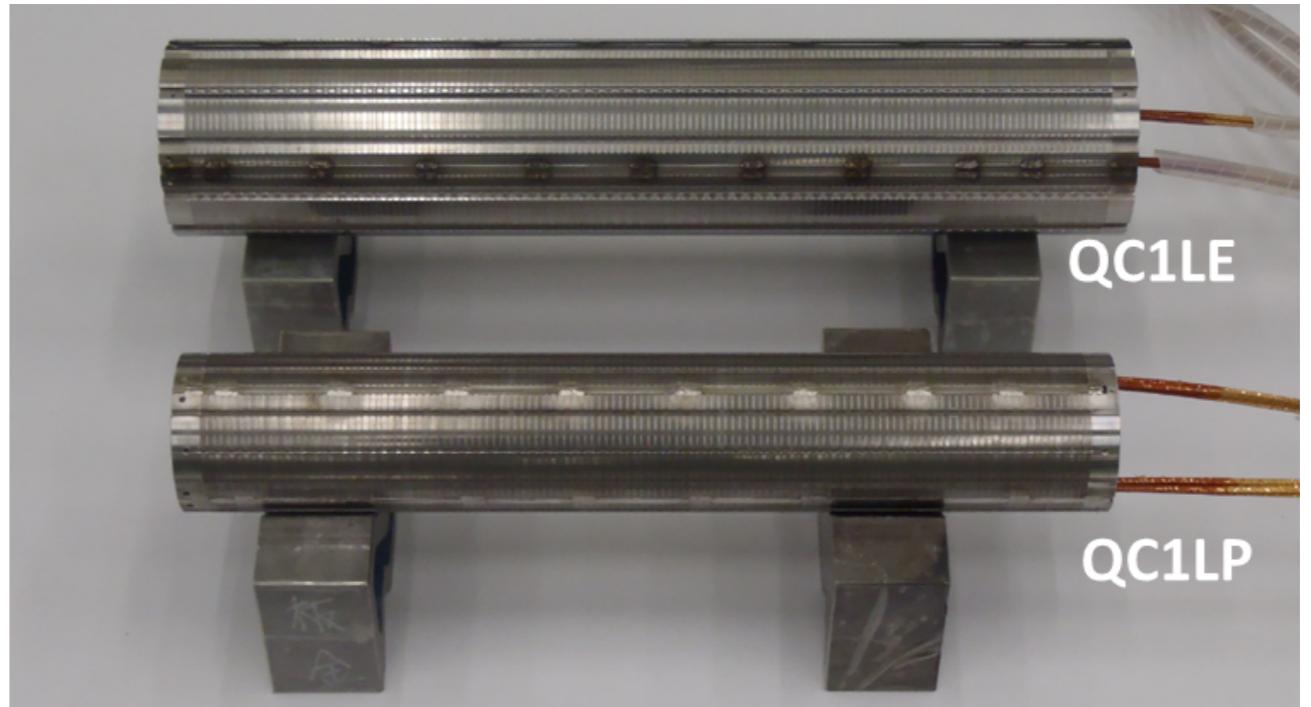
Coil shape	QC1LP	QC1RP	QC1LE	QC1RE
<i>Length, mm (Average, STD) (Design)</i>	<i>384.00, 0.044 (384.0)</i>	<i>383.98, 0.006 (384.0)</i>	<i>429.98, 0.041 (430.0)</i>	<i>429.92, 0.010 (430.0)</i>
<i>Thickness, mm (Average, STD) (Design)</i>	<i>5.418, 0.006 (5.425)</i>	<i>5.423, 0.002 (5.425)</i>	<i>5.425, 0.003 (5.425)</i>	<i>5.418, 0.002 (5.425)</i>

# Construction of QC1P and QC1E

## *Collaring and Yoking*



Collaring press and the QC1LP magnet



QC1LP and QC1LE collared magnets



QC1LE yoked magnet



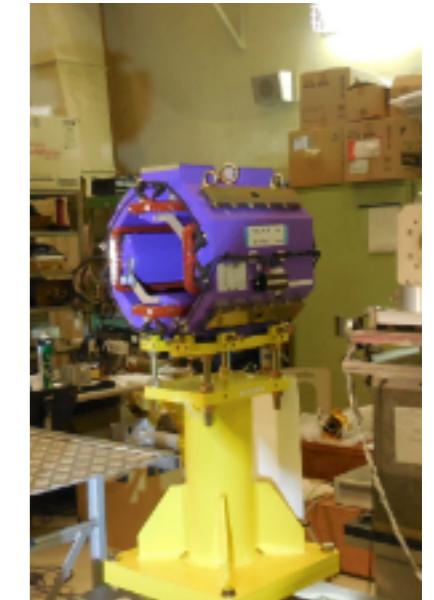
Moving stage for QCSL (H. Yamaoka)



Bends for IR



Vertical  
bend



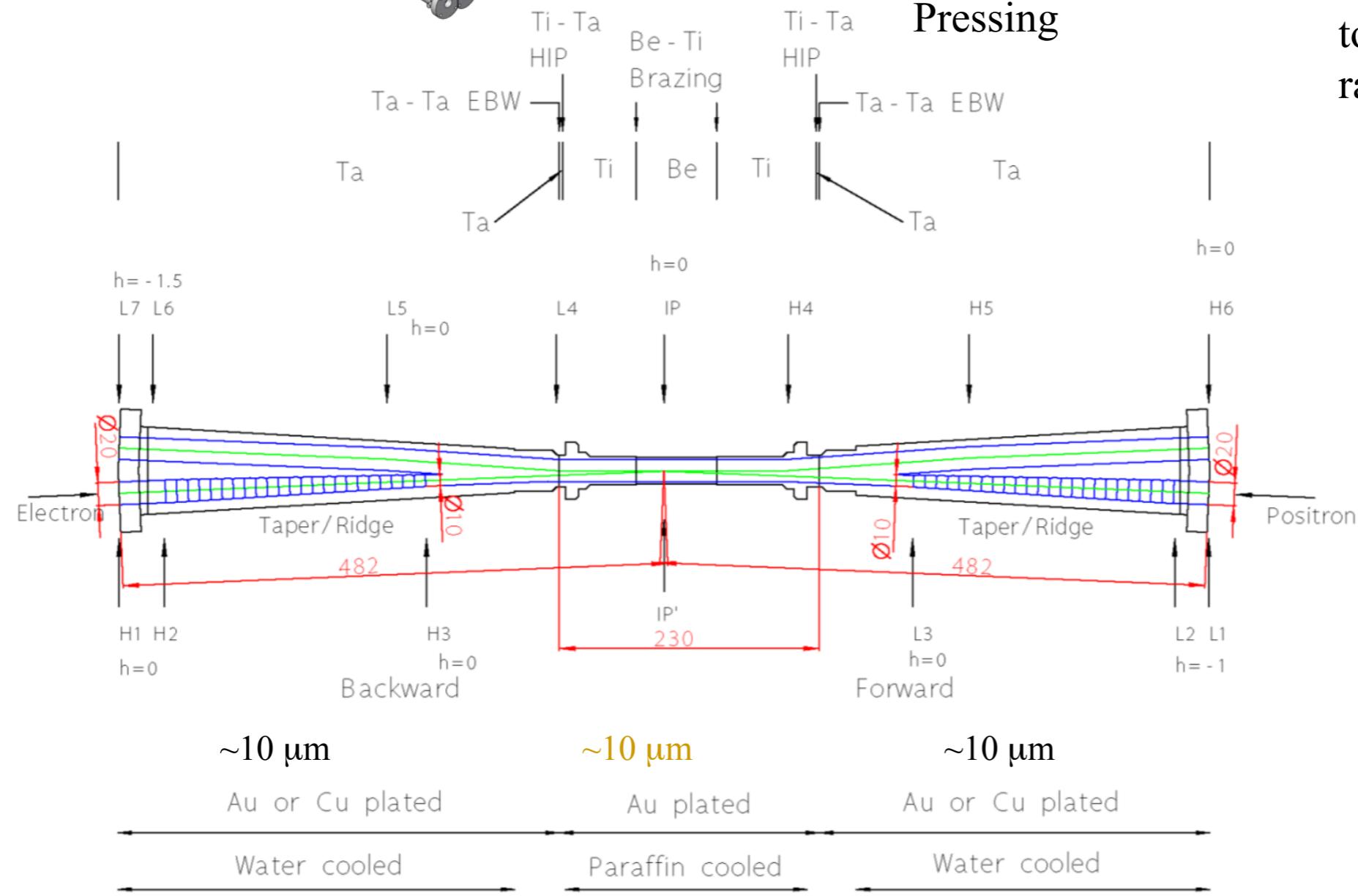
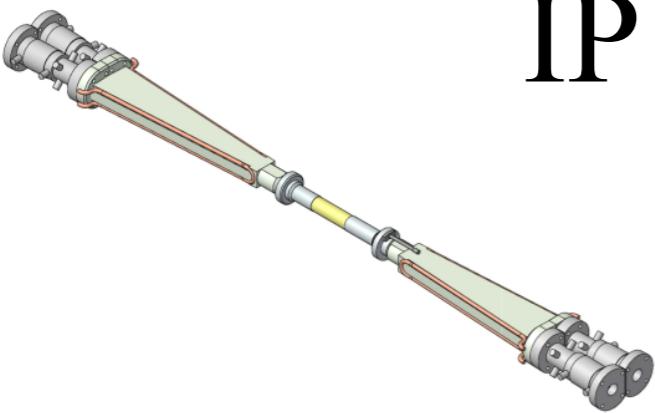
Skew Quad



Beam pipes in containers

Pictures of magnets : H. Iinuma.

# IP Chamber – Design feature



HIP = Hot Isostatic Pressing

Only taper parts are exposed to direct synchrotron radiation.

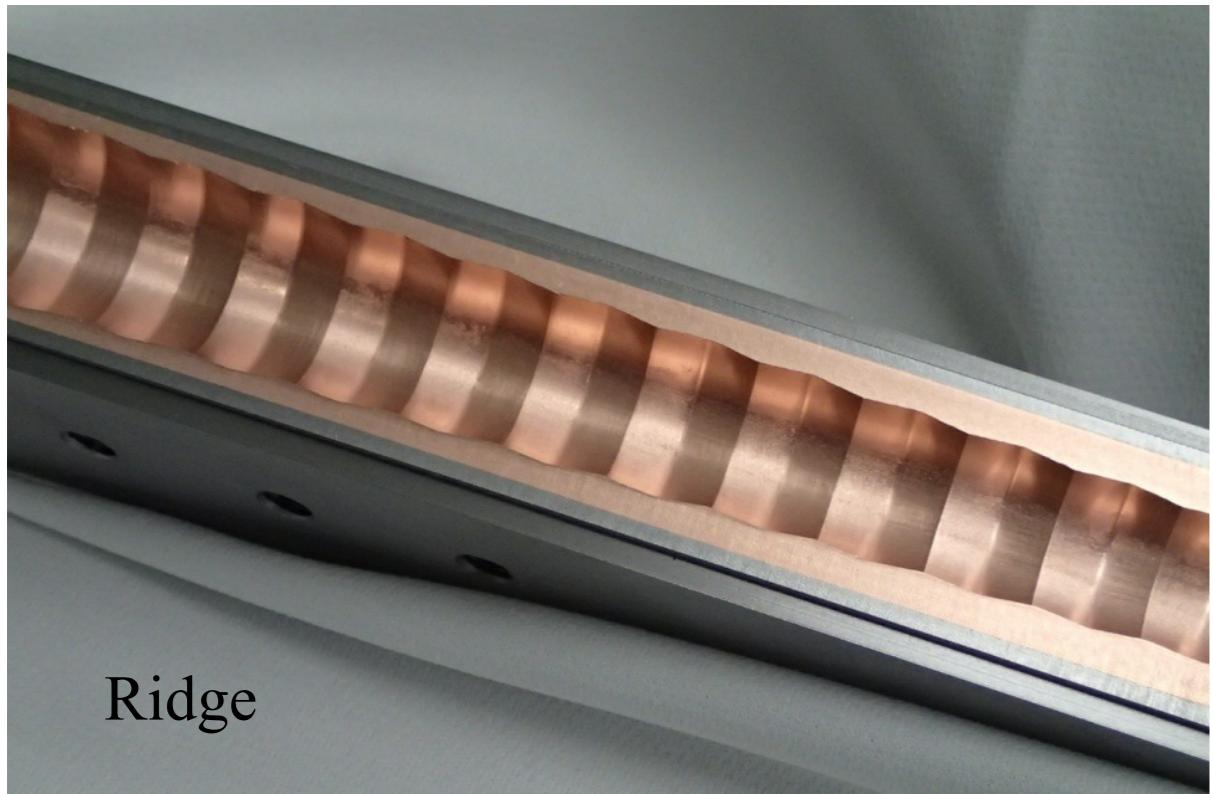
Taper: to reduce the number of photons entering into the central part

+

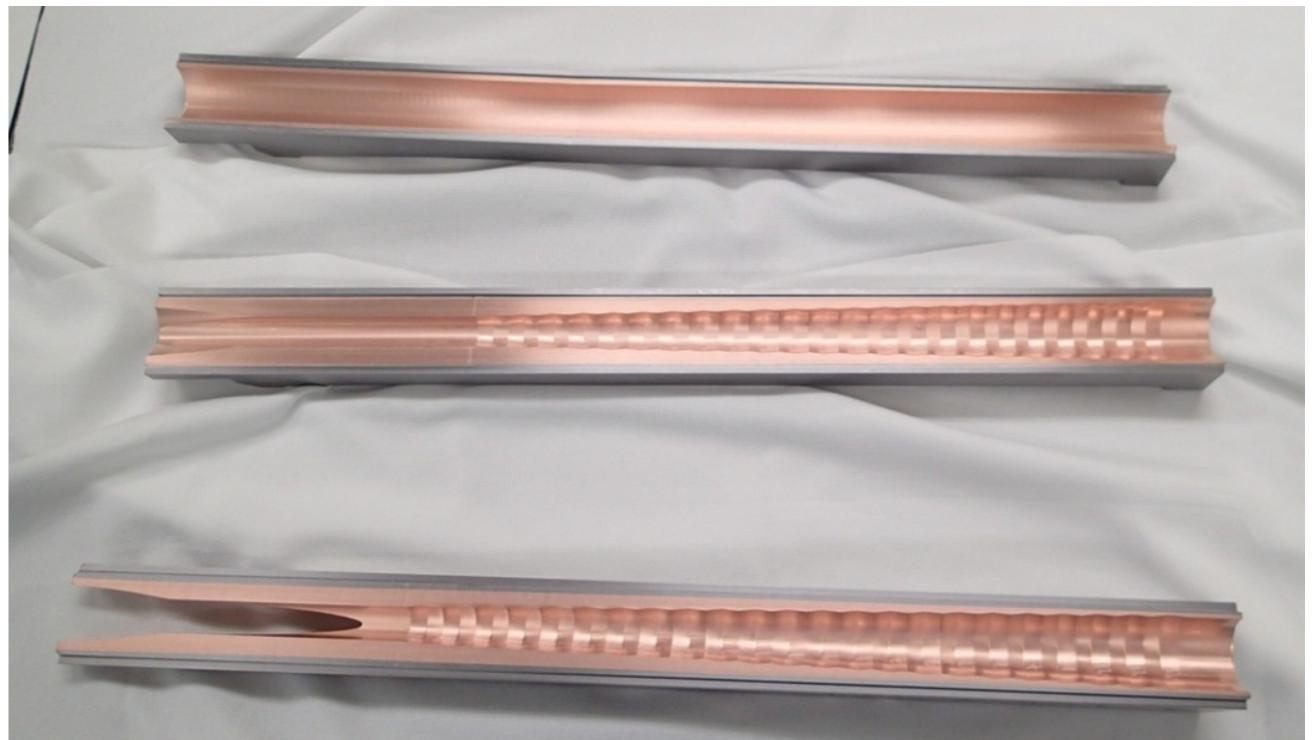
Ridges: to keep the direction of scattered photons away from Be

Negligible trap of HOM at the central part.

# IP chamber (Ta part manufacturing)



Ridge



End flange

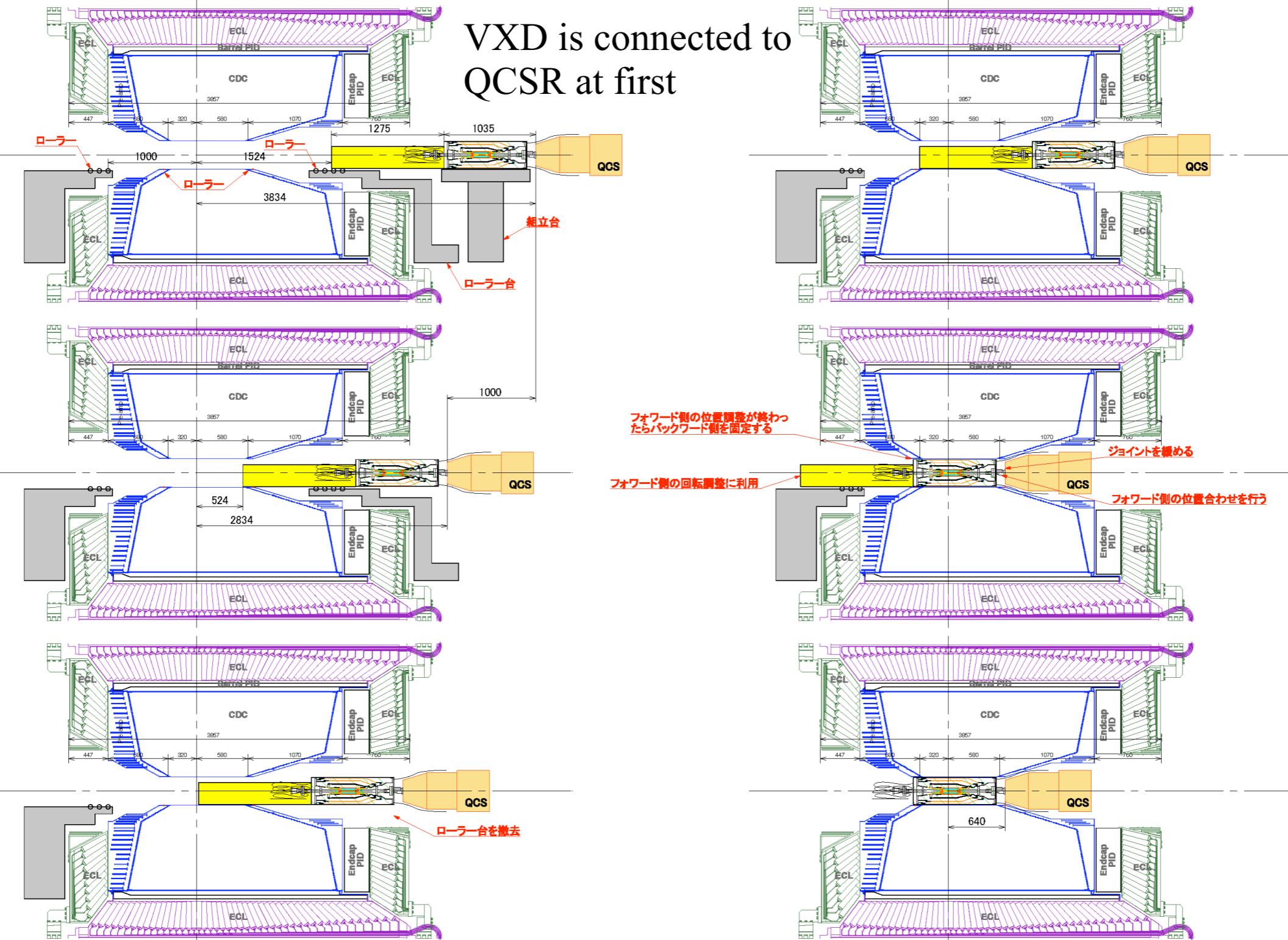


Metal Technology Co., Ltd

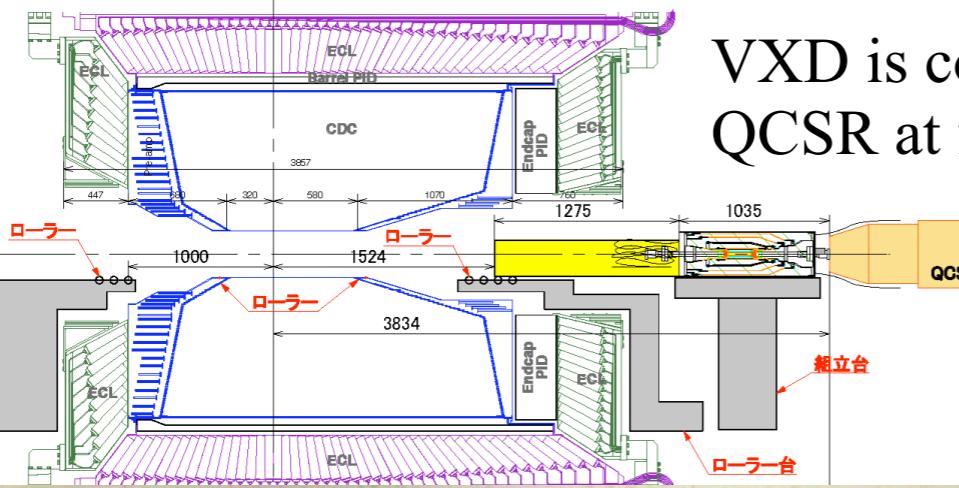
43

K. Kanazawa

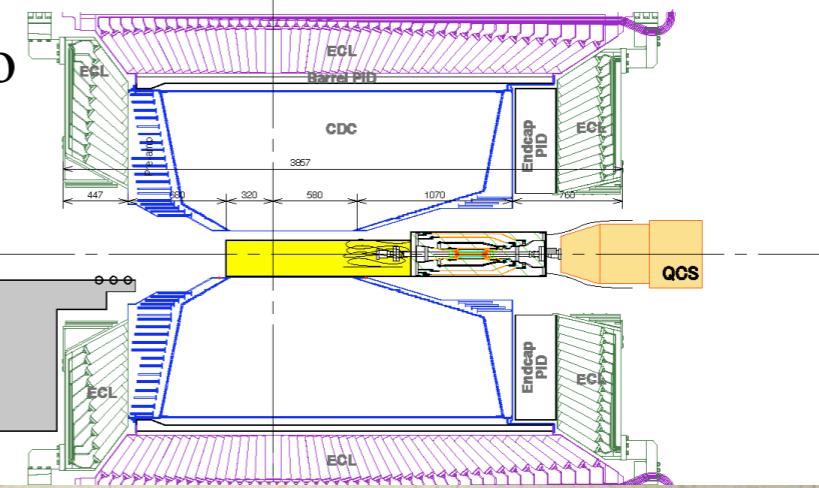
# Installation Scenario - Baseline



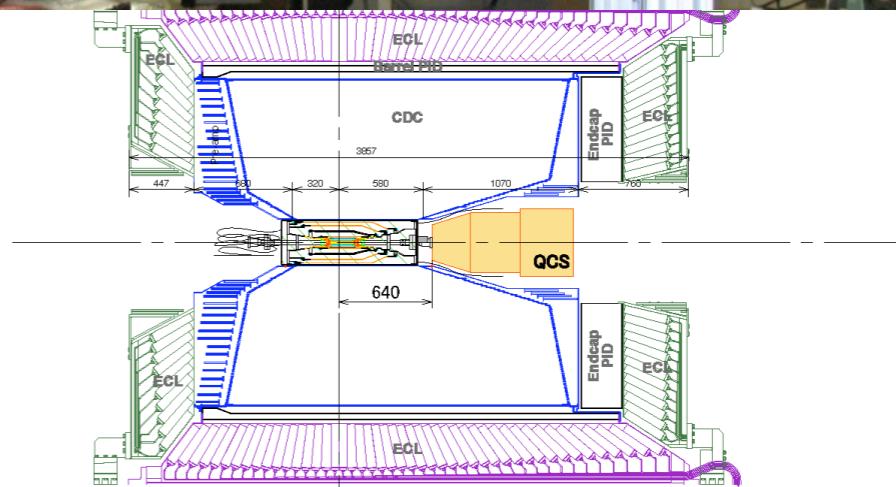
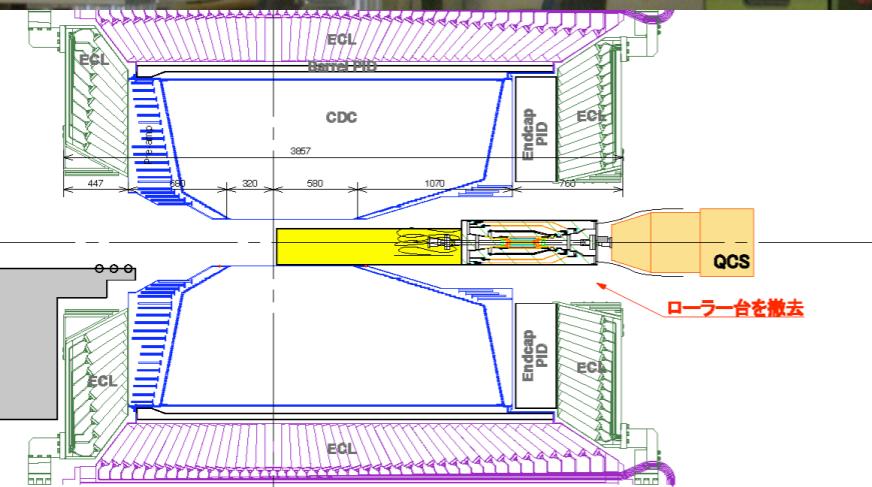
# Installation Scenario - Baseline



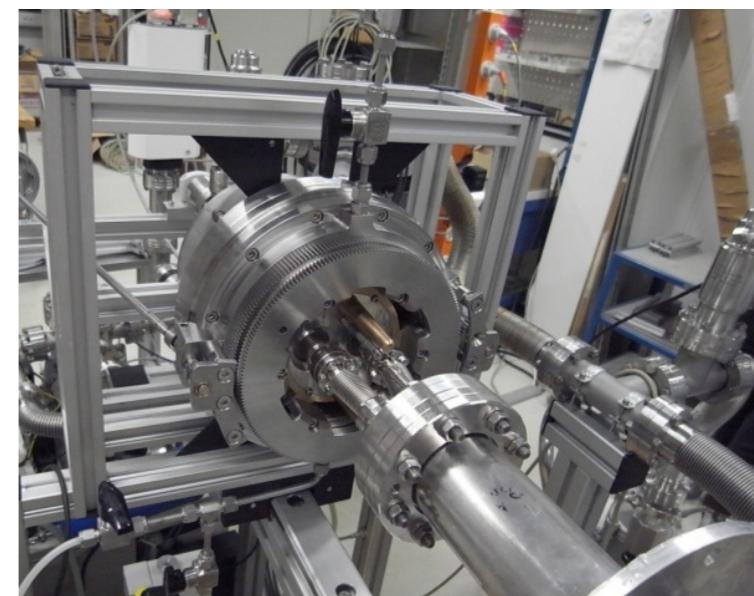
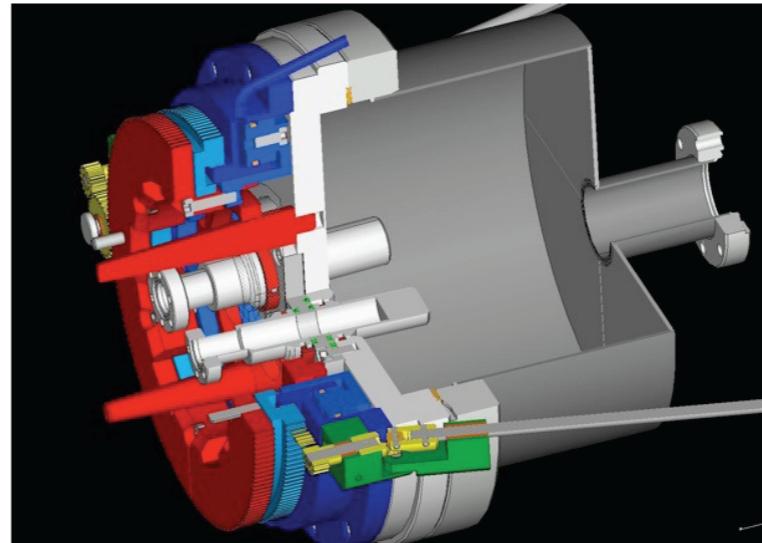
VXD is connected to  
QCSR at first



Mock-up test at KEK



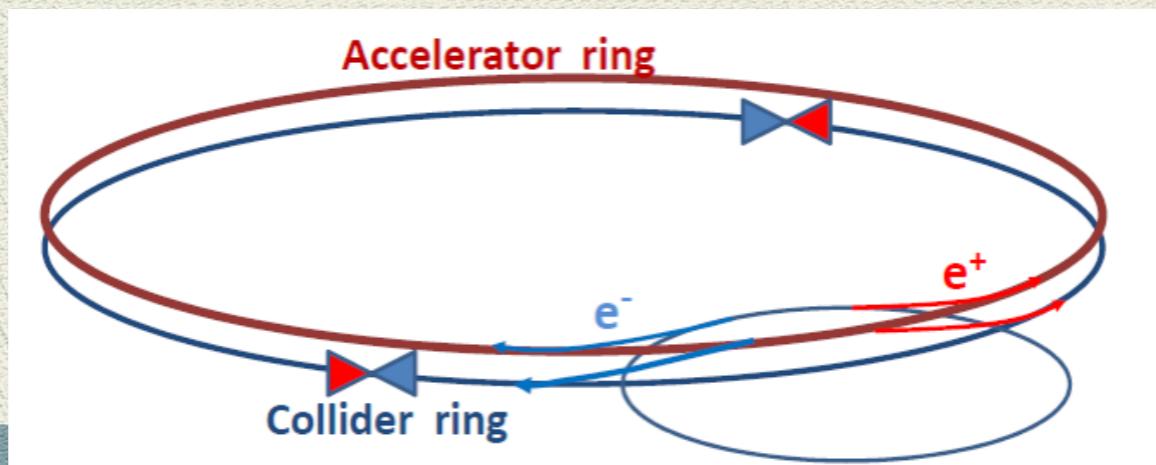
# AIM (Alternative Installation Method)



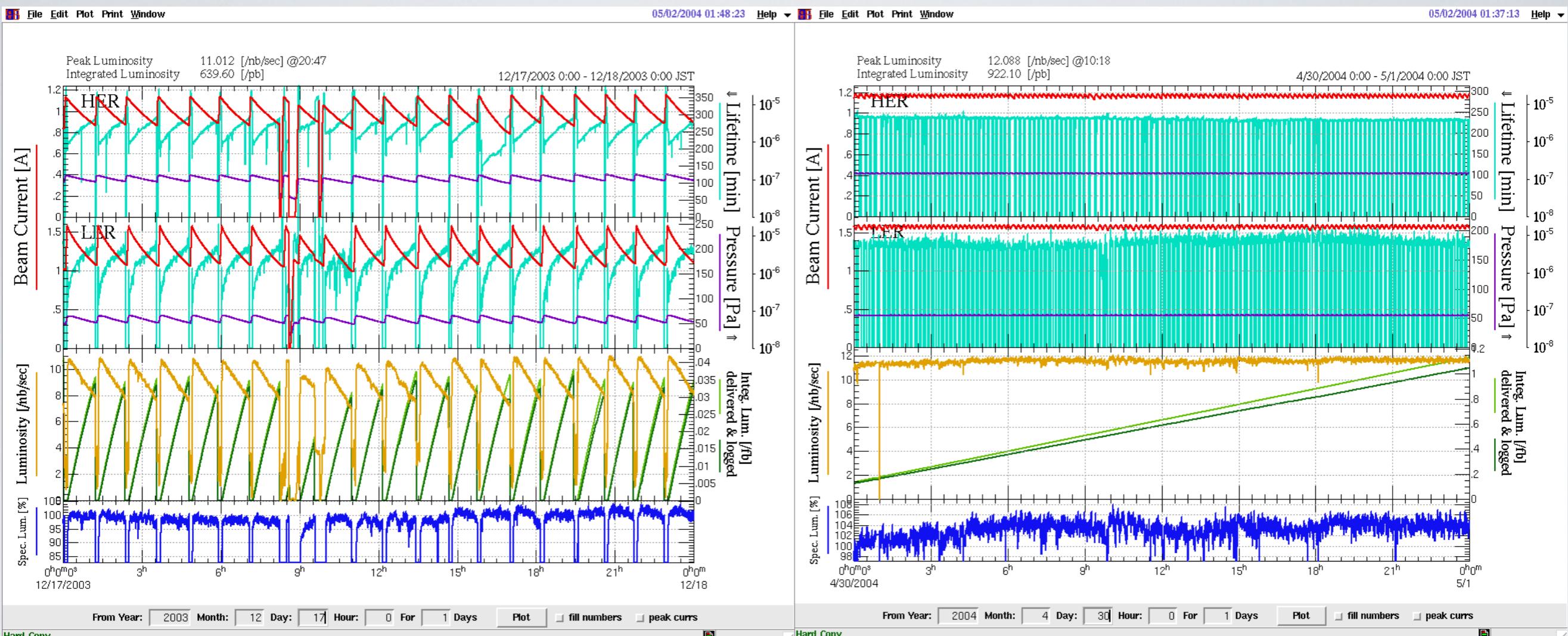
# ◆ Injection parameters for top-up

Rings	TLEP Z	TLEP t	KEKB LER / HER	SuperKEKB LER / HER	
Beam energy	46	175	3.5 / 8	4 / 7	GeV
Current / beam	1.45	0.0066	~ 1.6/1.3	3.6 / 2.6	A
Stored Charge / beam	484	2.2	16 / 13	36 / 26	$\mu$ C
Lifetime	$\sim 400$	$\sim 30$	$\sim 100$	$\sim 3.3/6.7$	min
Injection rate / beam	20	1.2	2.7 / 2.2	180 / 65	nC/s
Linac charge / beam	$\sim 4$	$\sim 2$	1 / 2	8 / 4	nC/pulse
Linac rep./beam	30	30	< 5	< 25	Hz
Synchrotron inj. duty / beam	17	< 2	—	—	%

- ◆ TLEP Z may require an injector comparable to SuperKEKB.
- ◆ The synchrotron dedicates 17% per beam for its injection from the linac in the case of TLEP Z.
- ◆ The intensity imbalance between bunches in the collider rings should be estimated.



# Top-up at KEKB (2004-)

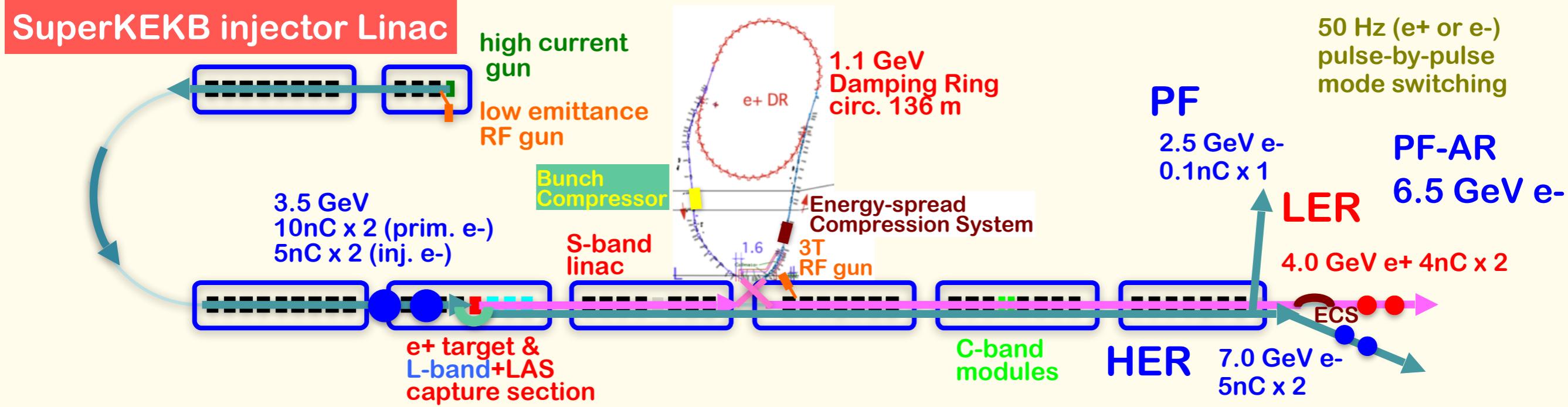
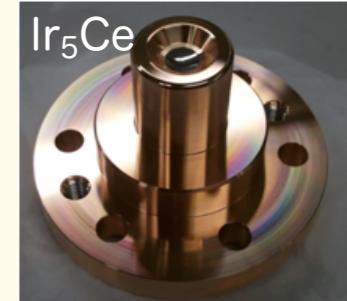


a day before top-up

a day after top-up

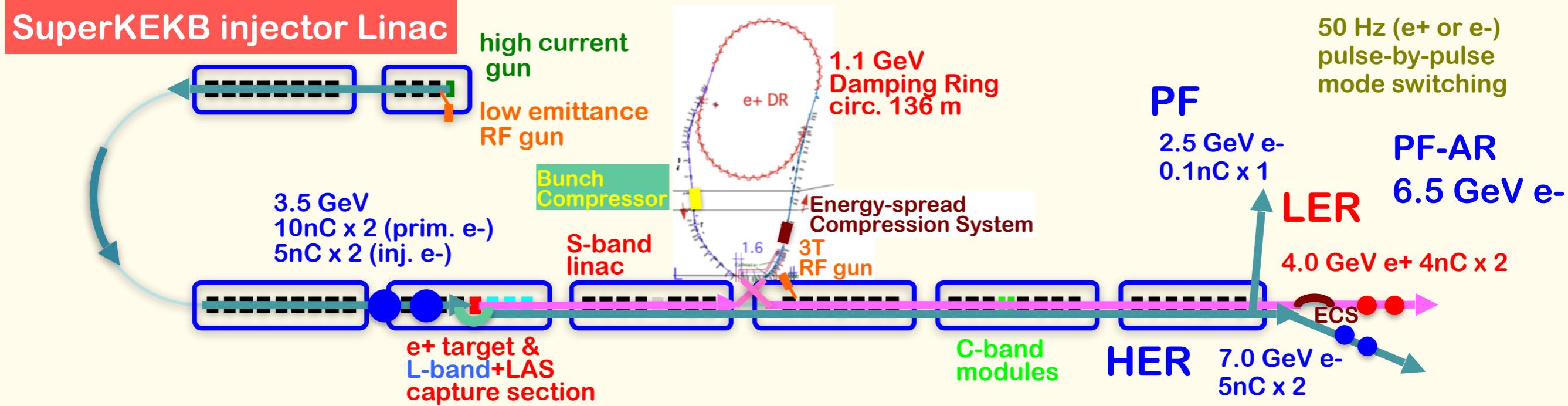
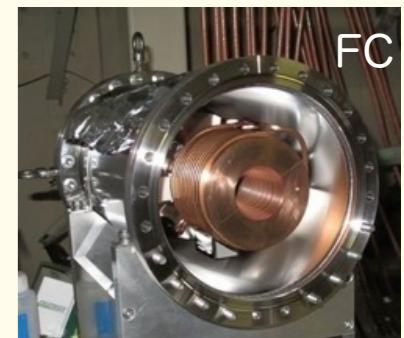
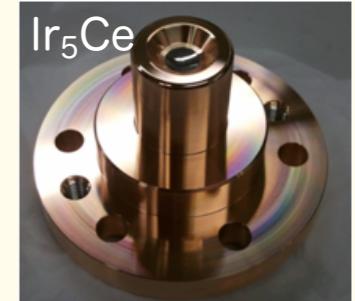
- Top-up improved the integrated luminosity from 640 pb/day to 920 pb/day in 2004 (eventually reached 1480 pb/day in 2009).
- Machine becomes more stable and less aborts, as the stored beam current is nearly constant.
- Thus the luminosity tuning became easier.

# Injector Upgrade for SuperKEKB



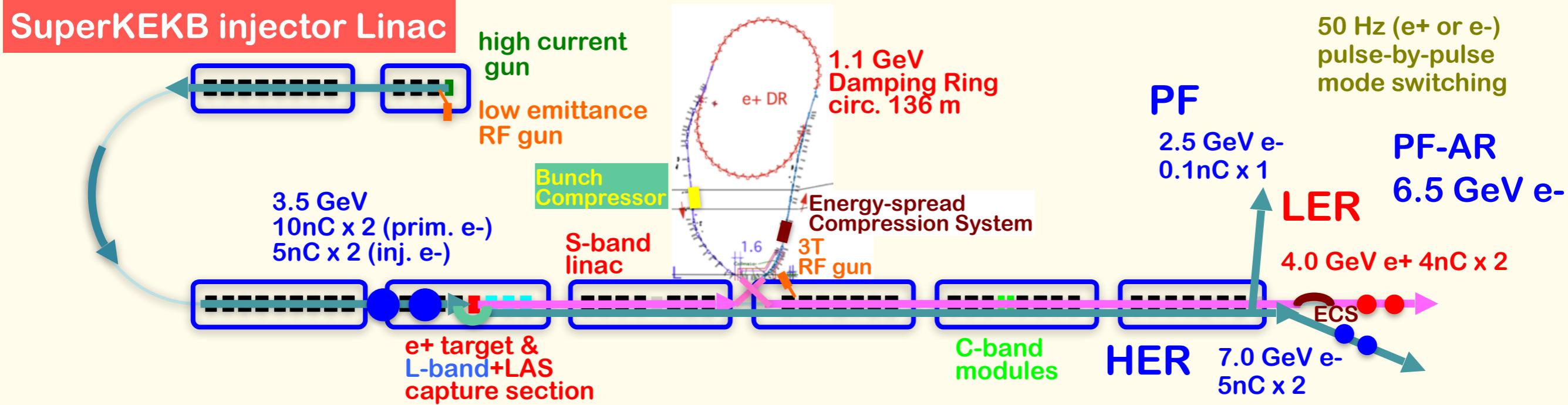
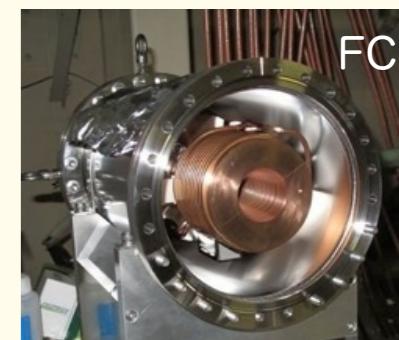
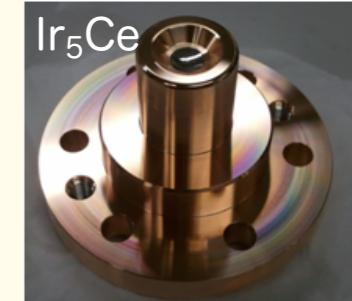
# Injector Upgrade for SuperKEKB

- ◆ Lower-emittance Injection Beam
  - ❖ To meet nano-beam scheme in the ring
  - ❖ Positron with a damping ring, Electron with a photo-cathode RF gun
  - ❖ Emittance preservation by alignment and beam instrumentation



# Injector Upgrade for SuperKEKB

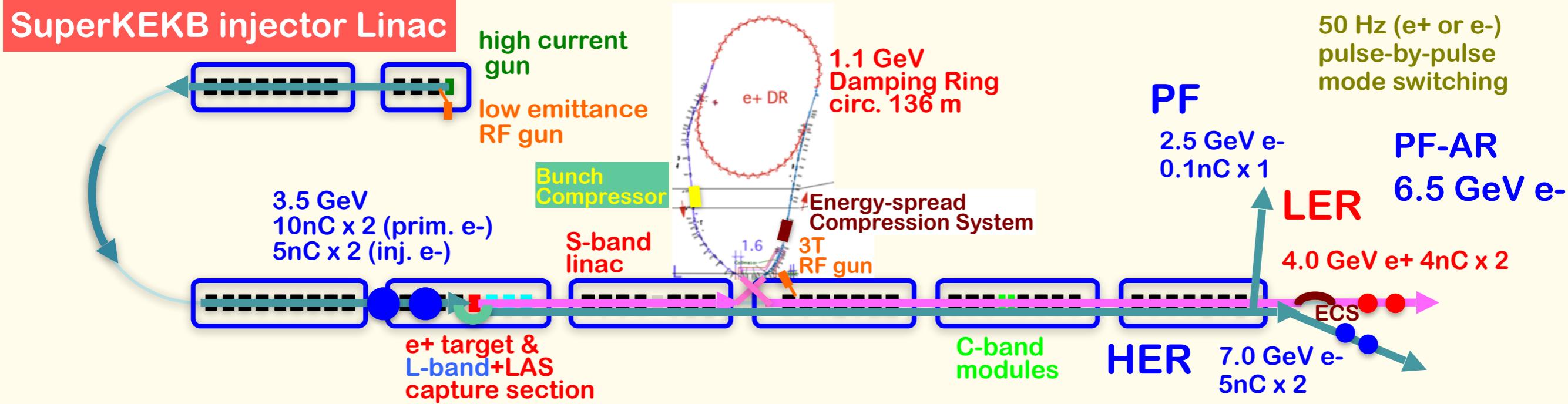
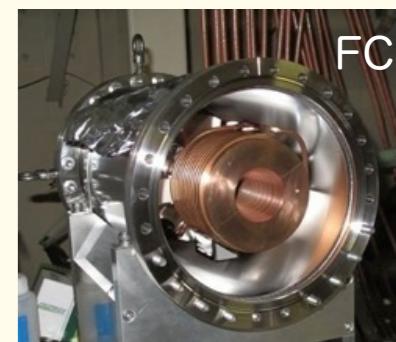
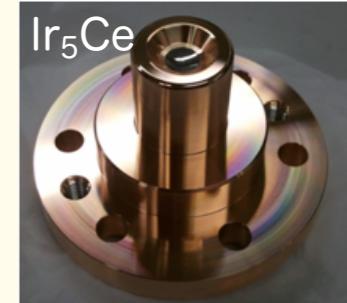
- ◆ Lower-emittance Injection Beam
  - ❖ To meet nano-beam scheme in the ring
  - ❖ Positron with a damping ring, Electron with a photo-cathode RF gun
  - ❖ Emittance preservation by alignment and beam instrumentation
- ◆ Higher Injection Beam Current
  - ❖ To meet larger stored beam current and shorter beam lifetime in the ring
  - ❖ 4~8-times larger bunch current for electron and positron
  - ❖ Reconstruction of positron capture section and electron gun



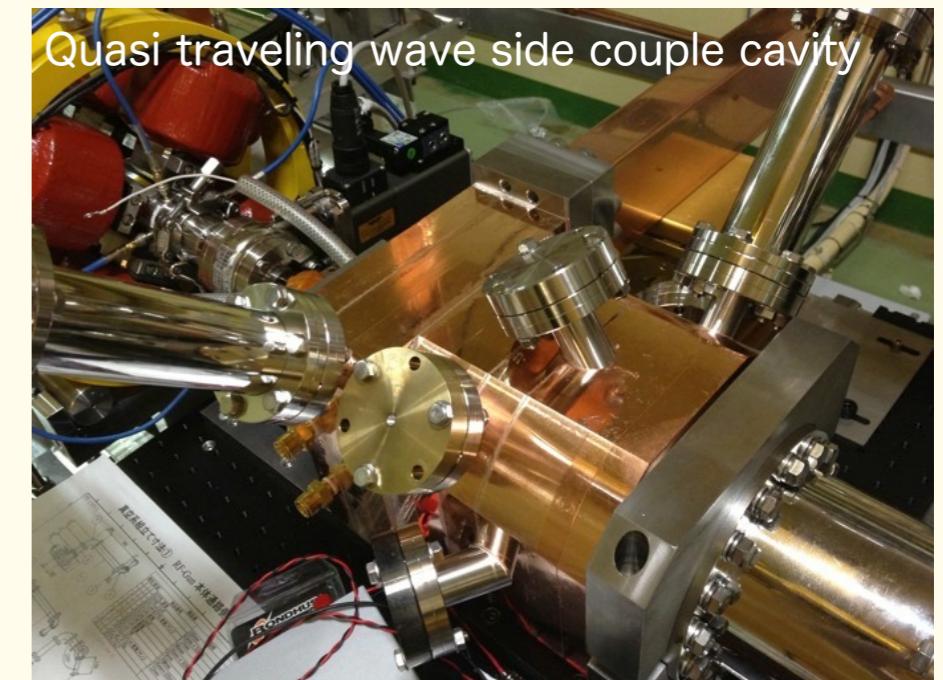
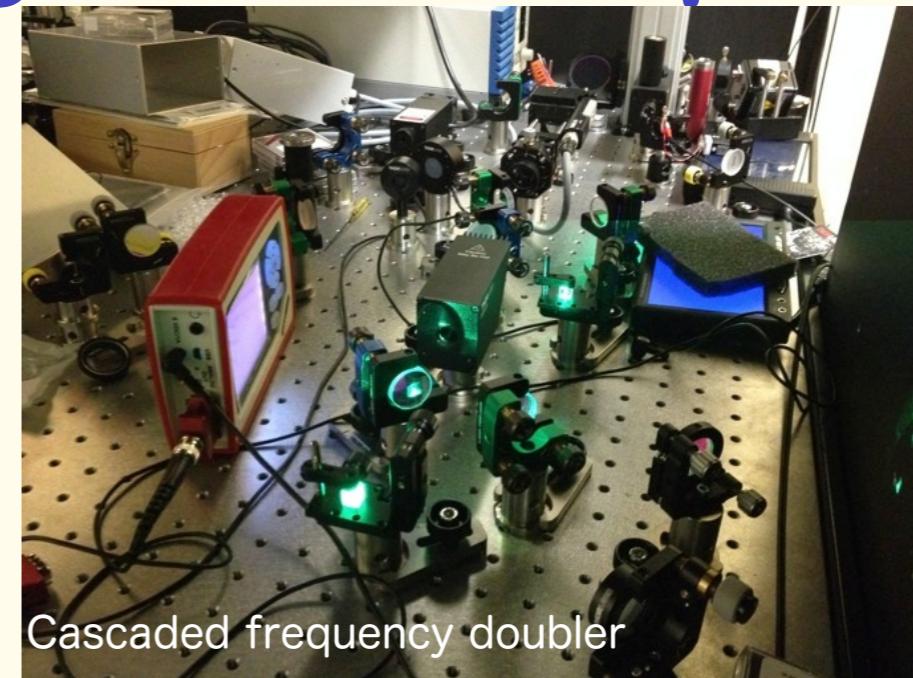
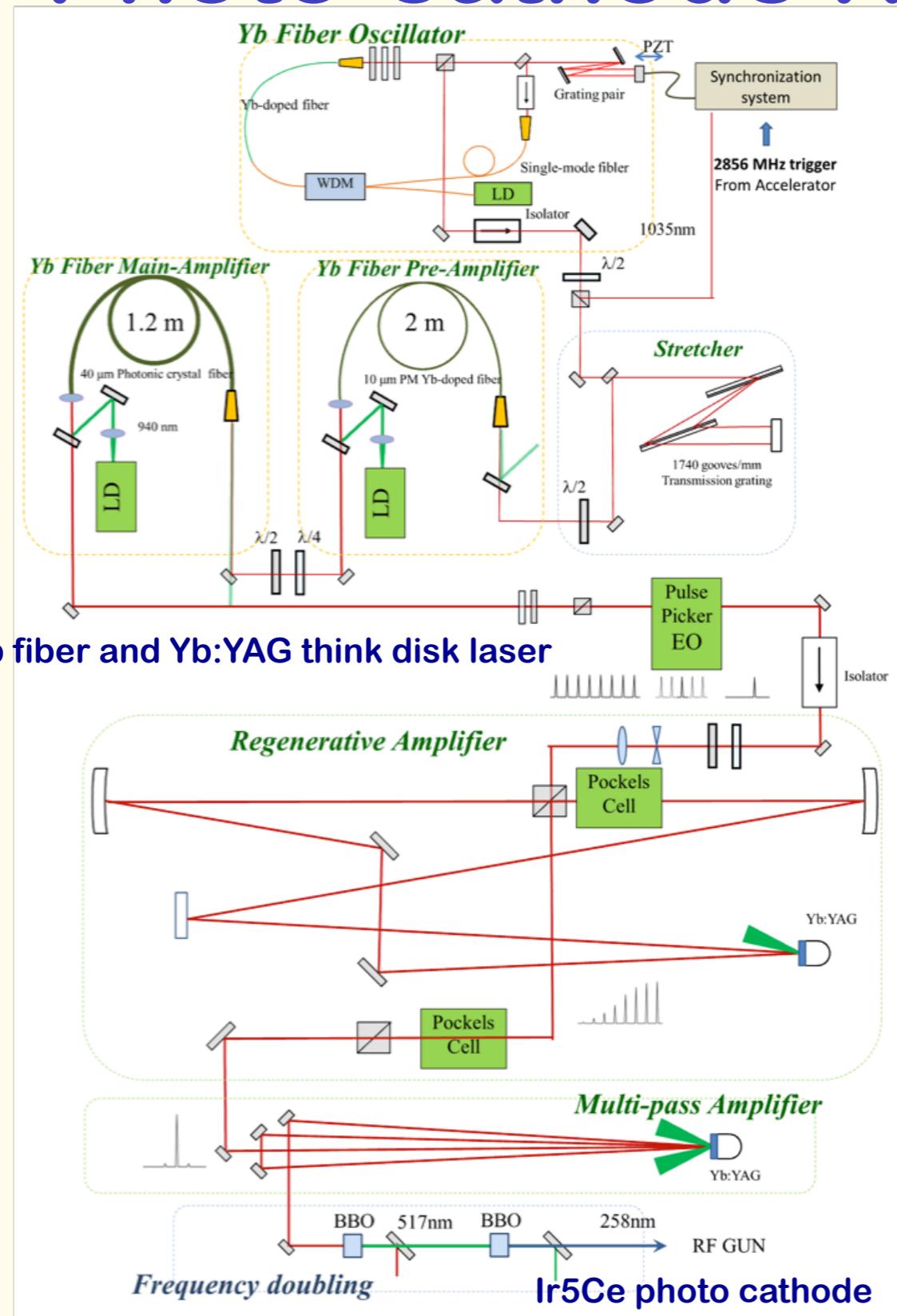


# Injector Upgrade for SuperKEKB

- ◆ Lower-emittance Injection Beam
  - ❖ To meet nano-beam scheme in the ring
  - ❖ Positron with a damping ring, Electron with a photo-cathode RF gun
  - ❖ Emittance preservation by alignment and beam instrumentation
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  - ❖ To meet larger stored beam current and shorter beam lifetime in the ring
  - ❖ 4~8-times larger bunch current for electron and positron
  - ❖ Reconstruction of positron capture section and electron gun
- ◆ Quasi-simultaneous injections into 4 storage rings (PPM)
  - ❖ SuperKEKB  $e^-/e^+$  rings, and light sources of PF and PF-AR
  - ❖ Improvements to beam instrumentation, low-level RF, controls, timing, etc

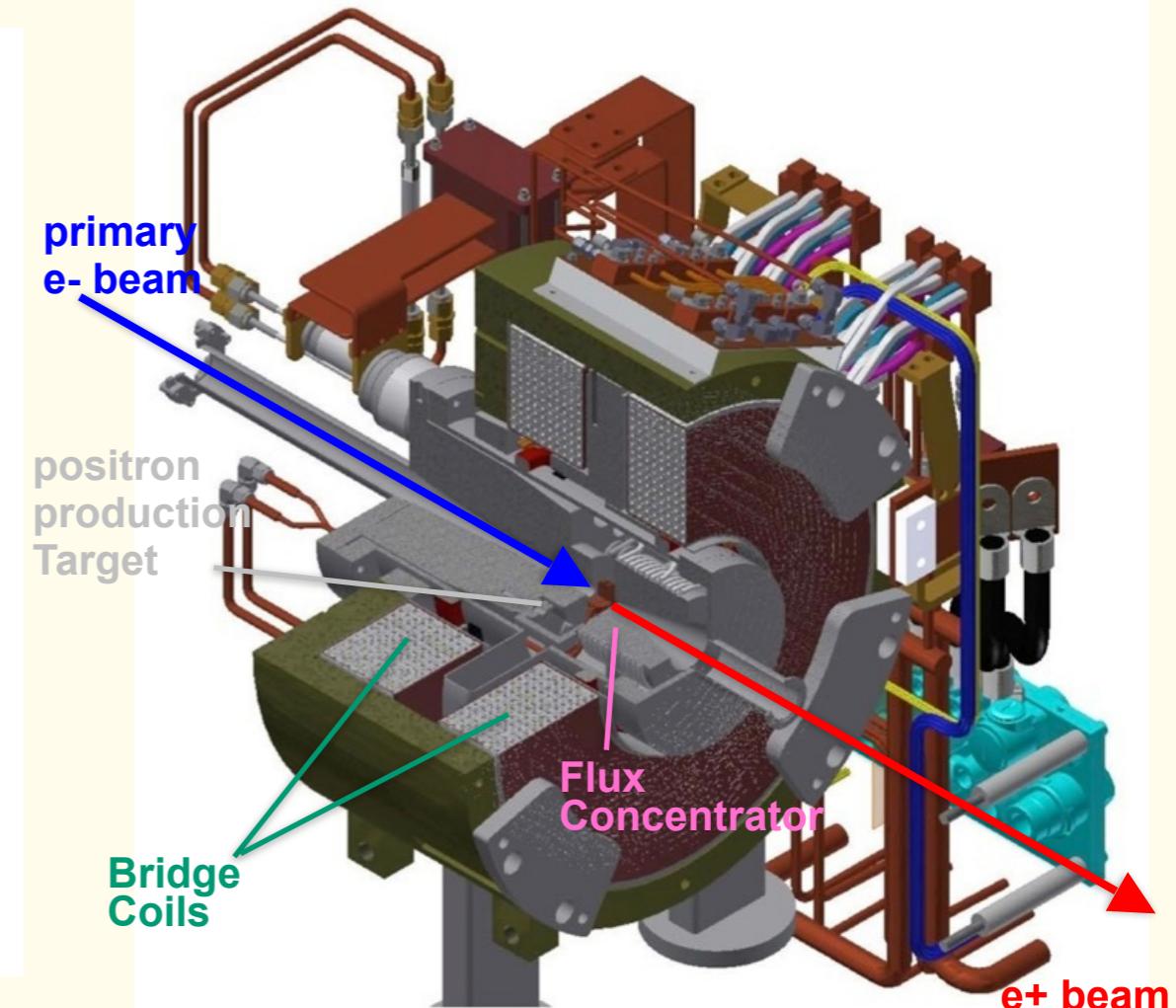
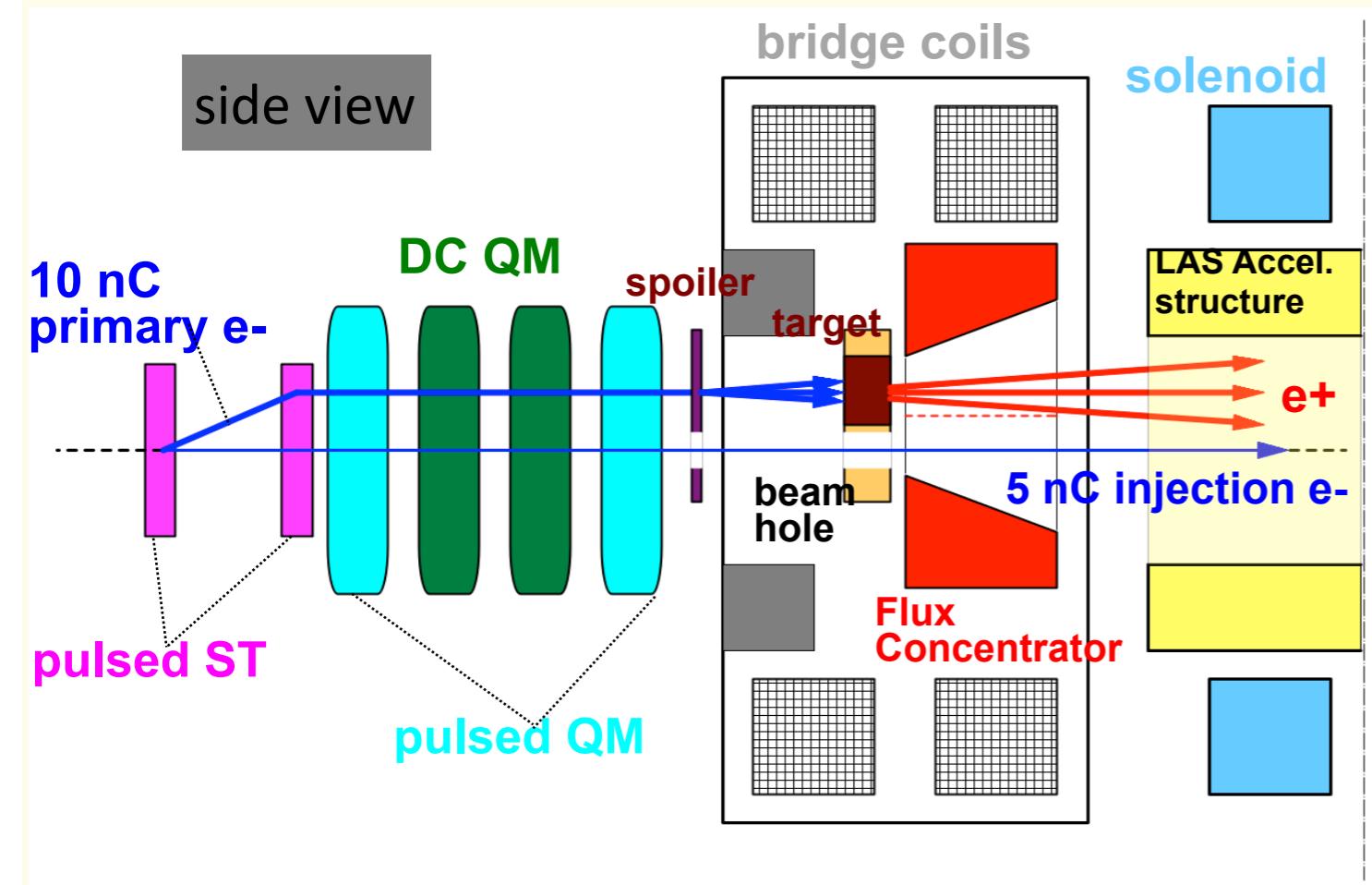


# Photo-cathode RF-gun Development



- ◆ 5.6 nC / bunch was confirmed
- ◆ Next step: 50-Hz beam generation & Radiation control

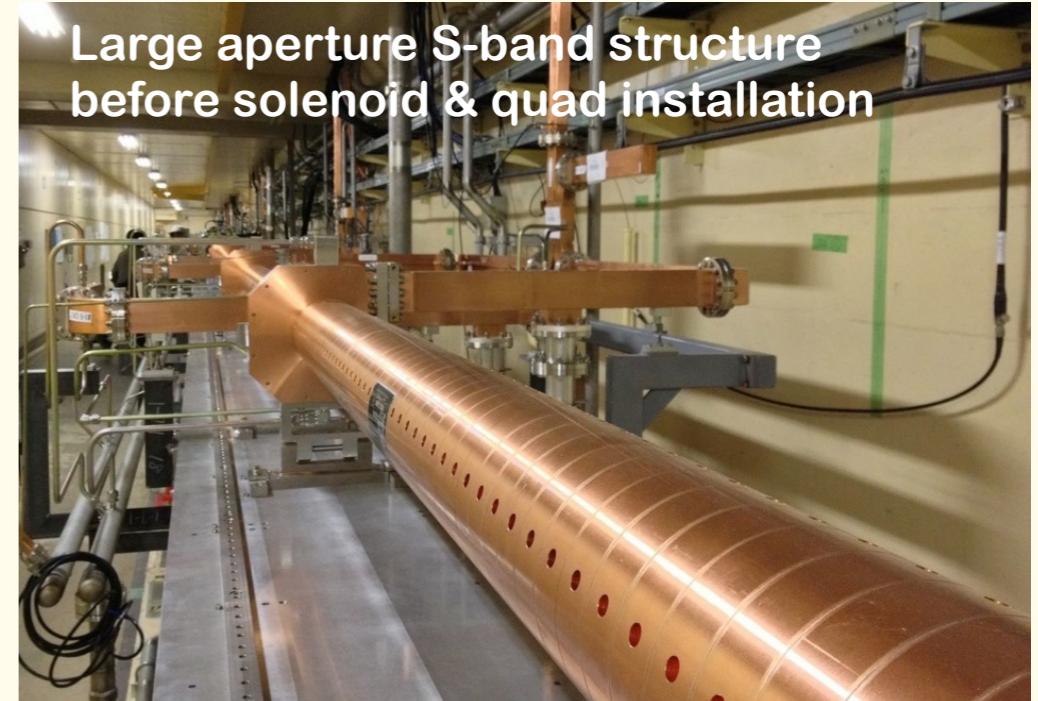
# Positron generation



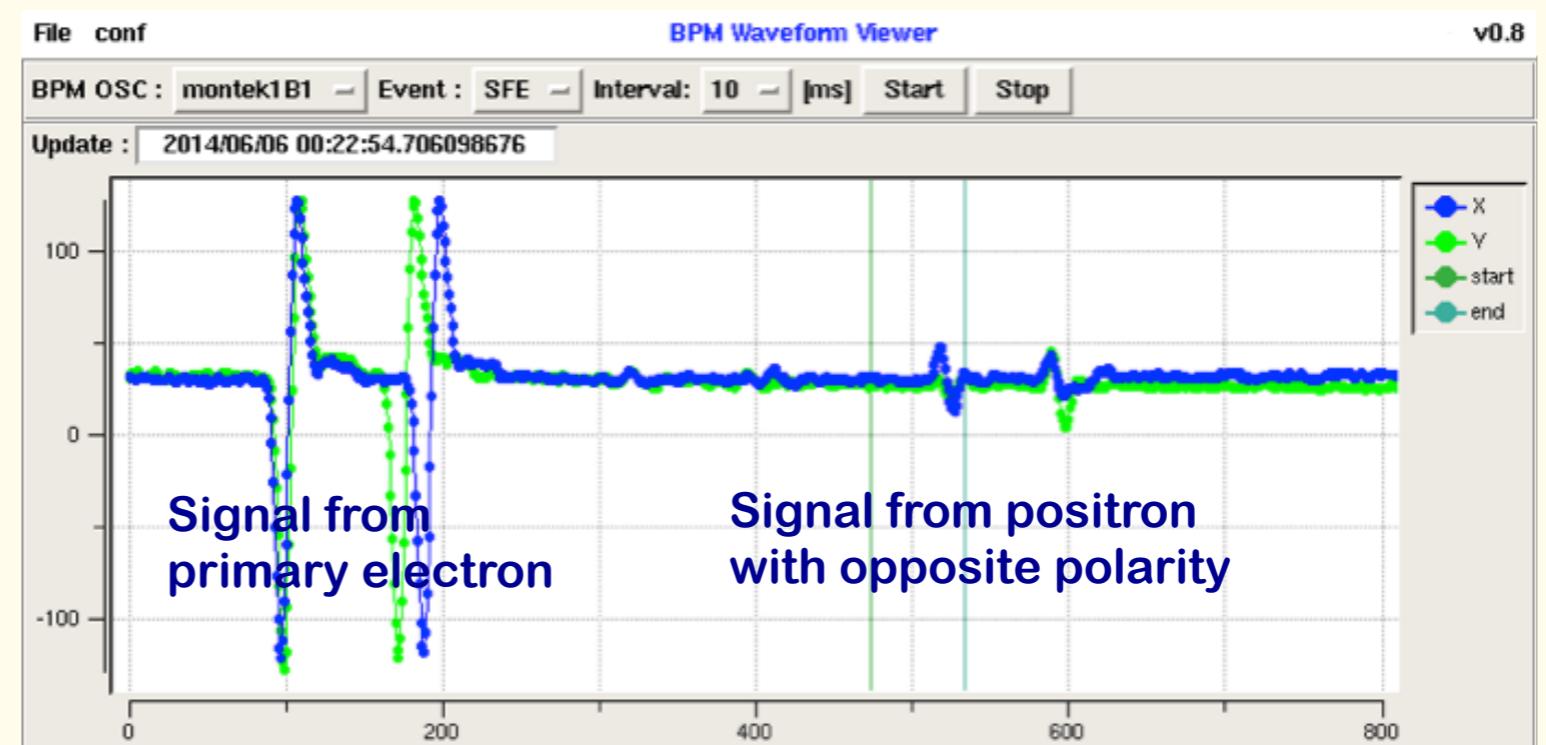
Positron capturing with flux concentrator (FC)  
and large aperture s-band structure (LAS)  
Deceleration field to reduce satellite bunches  
Pinhole beside target for electron beam  
Protection system with beam spoilers

# Positron generation test

- ◆ Beam test started with low magnetic field, low primary beam current in June 2014

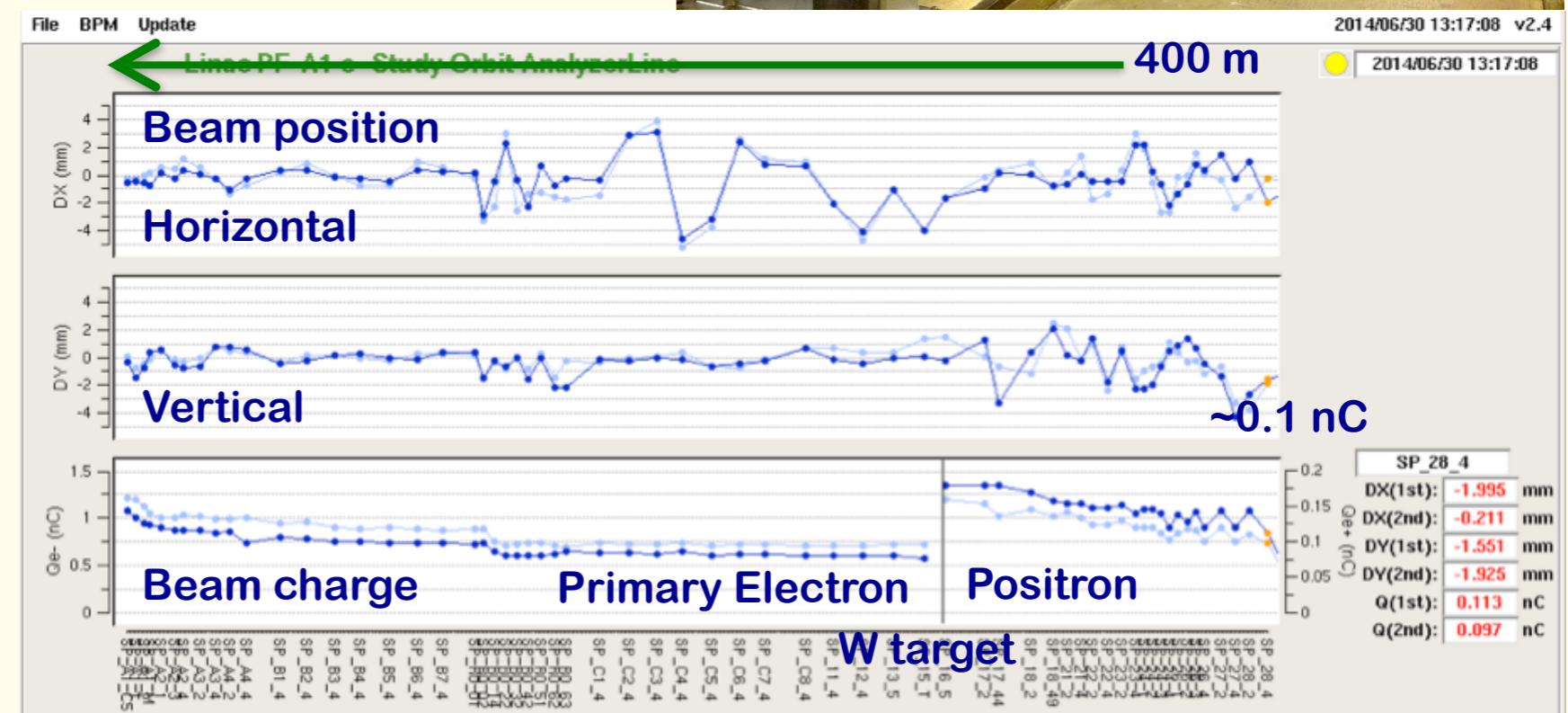


- ◆ Positrons were confirmed after orbit and angle adjustment



# Positron generation test

- ◆ Generated positron  $\sim 0.1\text{nC}$  was transferred to the entrance of damping ring
- ◆ With higher magnetic and electric field, 4-nC positron will be generated
- ◆ Target shield (40cm x 6m long) will be finalized
- ◆ Alignment will be improved  
 $3\text{mm} \rightarrow 0.1\text{mm}$



## ◆ Summary

- ◆ Circular e+e- colliders have been the most experienced & successful scheme worldwide, in the past 50 years.
- ◆ The next gen. machine must be the largest and brightest.
- ◆ Challenges exist both in beam dynamics (optics, dynamic aperture, lifetime, etc.) and hardware (rf, beam pipe, collimation, injector synchrotron, etc.).
- ◆ Despite some nonscientific obstacles, the construction of SuperKEKB has reached the final stage. The first beam will come in 2015.