Beam background

H. Nakayama (KEK)

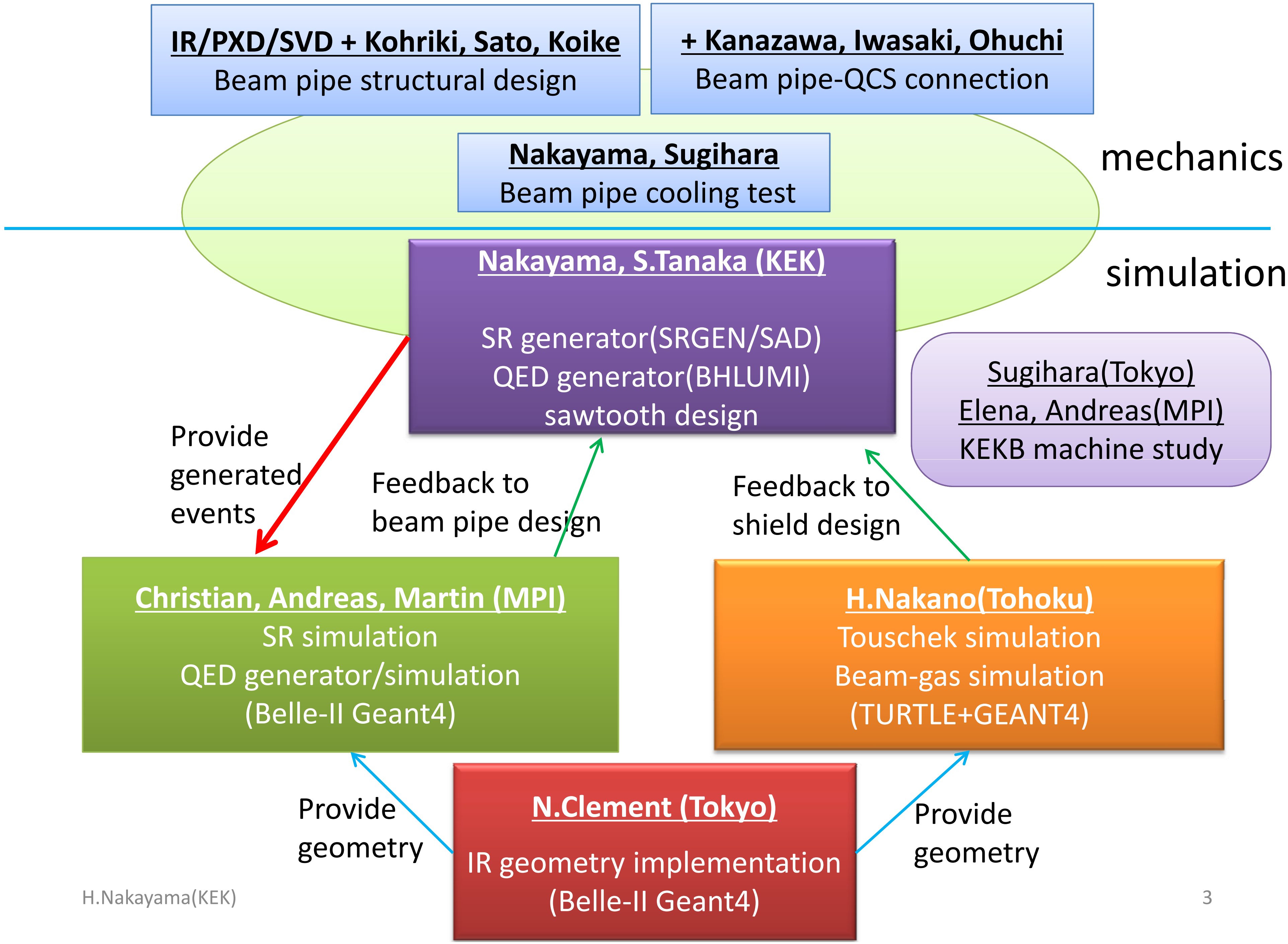
5th DEPFET Workshop Valencia

- BGsim group
- Status overviews on BGsim tasks
- Report on machine study

BG simulation group

Contact parson

- Japan
  - KEK: Hiro Nakayama, (Shuji Tanaka, Takanori Hara)
  - Tokyo: Clement Ng, Shinya Sugihara
  - Tohoku: Hiroshi Nakano (Hitoshi Yamamoto)
- MPI
  - Christian Kiesling, Hans-Guenther Moser, Andreas Moll, Martin Ritter, Elena Nedelkovska,


IR/PXD/SVD + Kohriki, Sato, Koike
Beam pipe structural design
+ Kanazawa, Iwasaki, Ohuchi
Beam pipe-QCS connection
Nakayama, Sugihara
Beam pipe cooling test
mechanics
simulation
Nakayama, S.Tanaka (KEK)
SR generator(SRGEN/SAD)
QED generator(BHLUMI)
sawtooth design
Sugihara(Tokyo)
Elena, Andreas(MPI)
KEKB machine study
Provide generated events
Feedback to beam pipe design
Feedback to shield design
Christian, Andreas, Martin (MPI)
SR simulation
QED generator/simulation
(Belle-II Geant4)
H.Nakano(Tohoku)
Touschek simulation
Beam-gas simulation
(TURTLE+GEANT4)
Provide geometry
N.Clement (Tokyo)
IR geometry implementation
(Belle-II Geant4)
Provide geometry

Introduction: background sources

1. Touschek effect ($\propto$ IxE^{-3})

- Intra-bunch scattering → energy increase & decrease
- Significant in low energy ring (LER)

2. Beam-gas scattering ($\propto$ PxI)

- Collision with remaining gas
- Type 1: Coulomb scattering → direction change
- Type 2: Bremsstrahlung → energy decrease

3. Synchrotron Radiation ($\propto$ E^{2}xB^2)

- Type 1: Upstream (SR hit Be beam pipe directly)
- Type 2: Backscatter (SR hit downward beam pipe, then reflected back to IP)

4. QED process (Radiative Bhabha, 2 photon ,etc…) ($\propto$ Luminosity)

- Type 1: radiated gamma + magnet Fe → neutron, main bkg source for KLM
- Type 2: e+,e- lose energy→off-trajectry→ hit downward beam pipe → shower

5. Beam-beam effect

- Injected particles with a large horizontal oscillation (due to injection error) may be lost

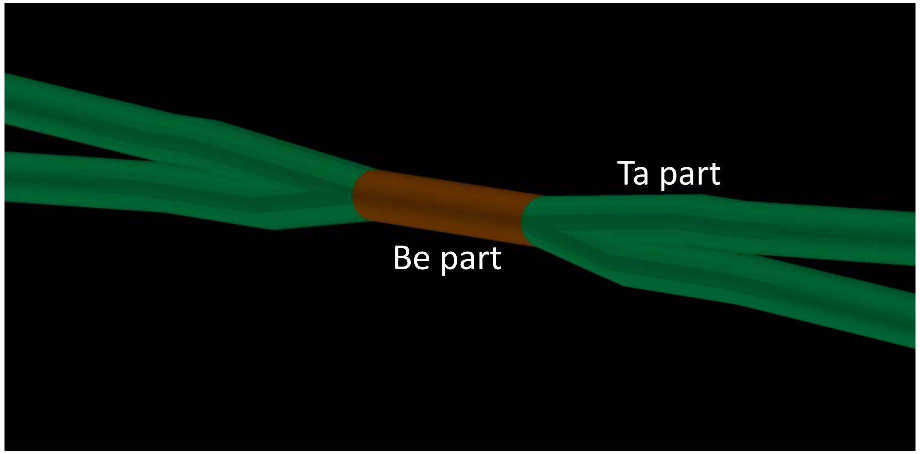
Upgrade from KEKB to SuperKEKB

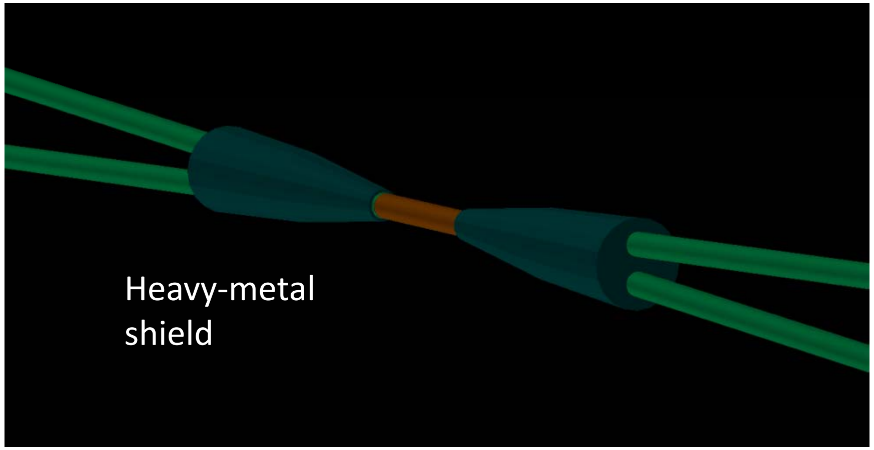
Machine parameter	HER (KEKB)	LER (KEKB)	HER (SuperKEKB)	LER (SuperKEKB)
Vertical beam size	0.94μm	0.94μm	59nm	59nm
Beam current(mA)	1188	1637	2600	3600
luminosity($cm^{-2}s^{-1}$)	2.1×10^{34}		8×10^{35}	

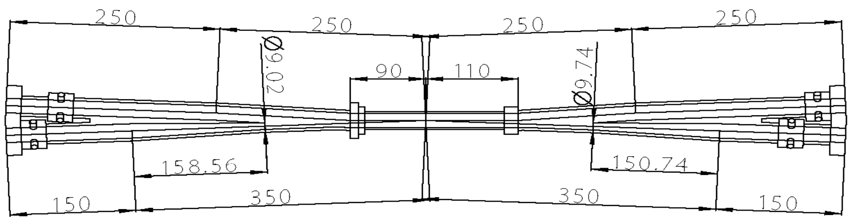
smaller beam size, more current
→ x40 higher luminosity

BG simulation status overview

0. Geant4 implementation (Clement)



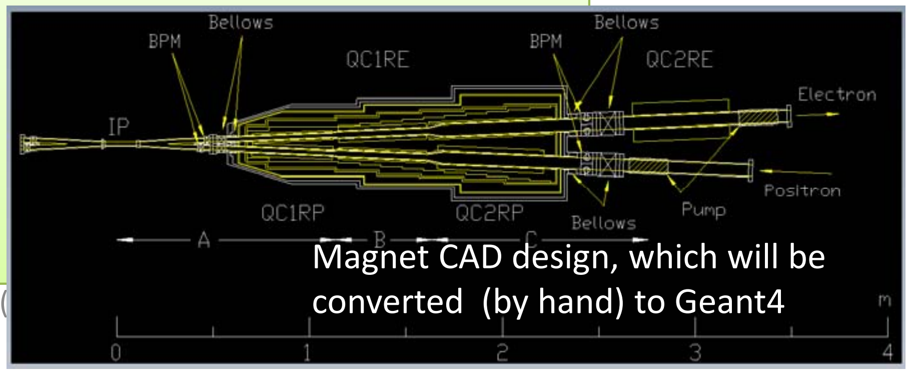




ready	IP +- ~0.1m : Be pipe only
ready	IP +- ~0.5m : add Ta pipe, shield
NotYet	IP +- ~3.0m : add QC1, cryostat

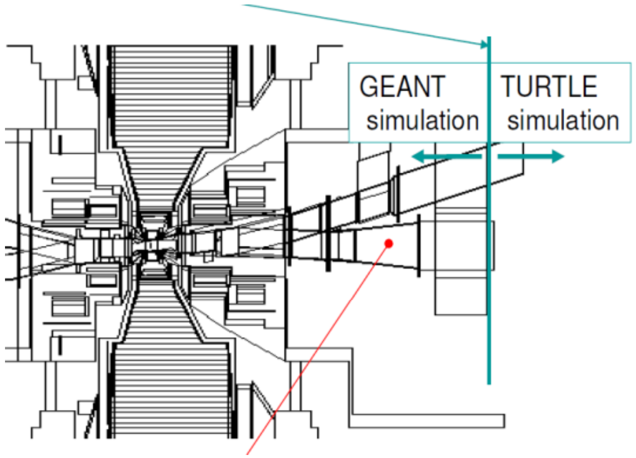
<Status>
- Beam pipe is implemented (June ver.)
- Preliminary heavy-metal shield is also in

<Plans>
- Magnets, cryostat is the next step
- July ver. beam pipe (latest) comes after that



Magnet CAD design, which will be converted (by hand) to Geant4

1,2. Touschek/Beam-gas (Nakano)

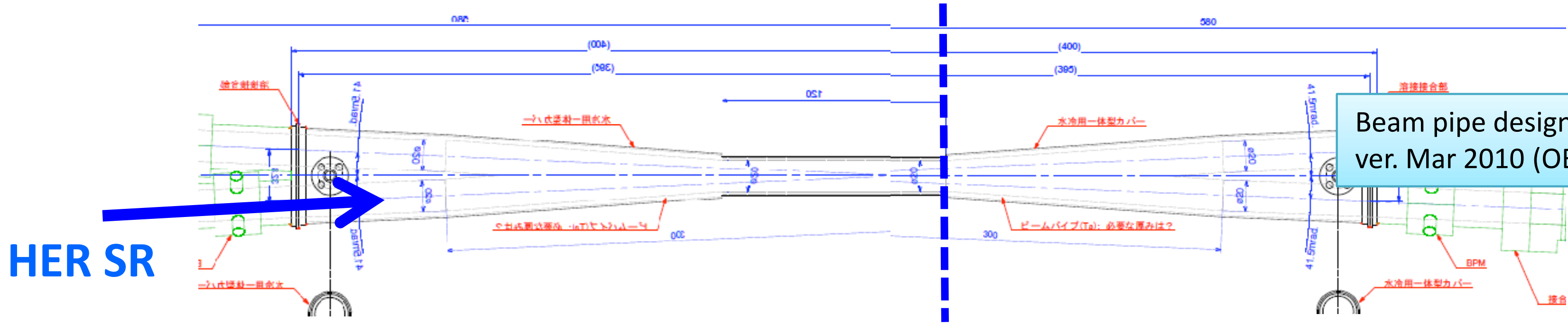


- Simulation framework
  - **TURTLE + Belle-II Geant4**
    - Ring part: matrix calculation by TURTLE
    - IR-nearby: step-by-step tracking by Geant4
- Generator
  - No specific generator used
  - Change direction/energy according to theoretical equation

<Status>
• Finalizing cross-check using KEKB. Start SuperKEKB soon.
• Ohnishi (Accl.Grp.) is also running Touschek simulation based on SAD.
<Plans>
• Heavy metal shield study is urgent.
SVD group will soon make decision on "slant" or "straight".
If "Slant", we have less space for heavy-metal shield. ← OK for us??
• Assuming reasonable flux and start Geant4 simulation from just before the shield.

3. Synchrotron Radiation Problem

- Few month ago, we found SR hits the Be beam-pipe seriously, much more than we had thought (thanks to M. Sullivan).



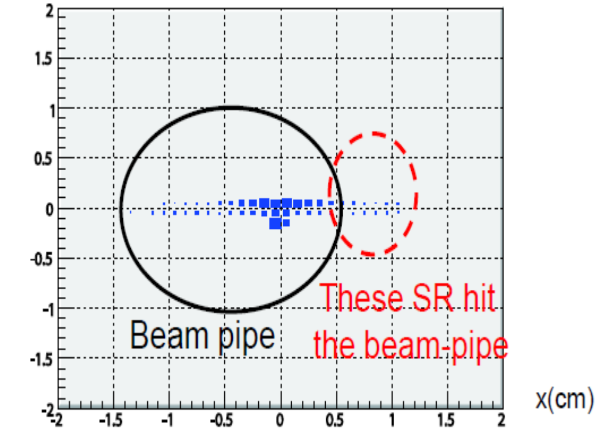
Beam pipe design
ver. Mar 2010 (OBSOLETE)

Scaled for 1 bunch

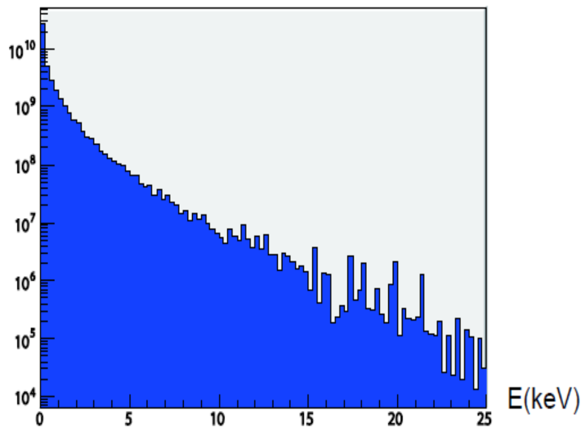
M. Iwasaki(KEK)

SR generation/propagation only. Reflection/scattering on beam pipe is not implemented.

SR x vs y position (cm)



SR energy (keV)



SR/bunch:

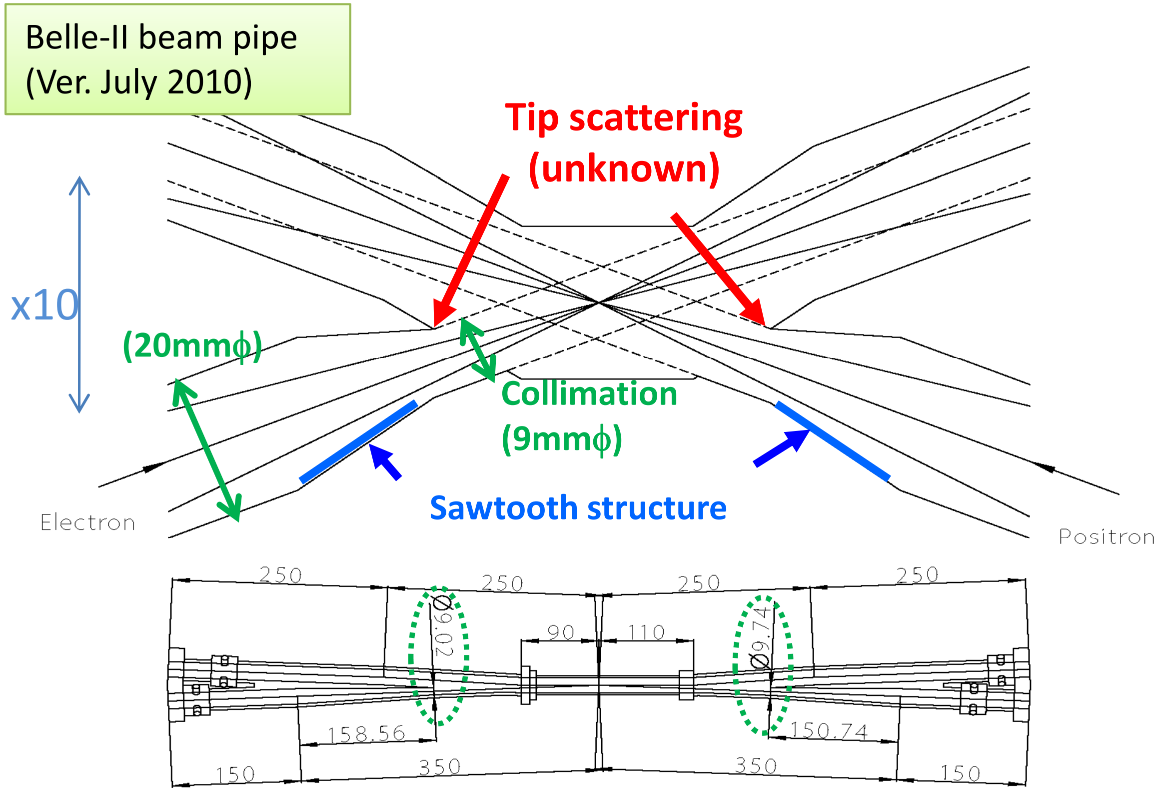
<u>1.6×10^{7}</u>(E>5keV)

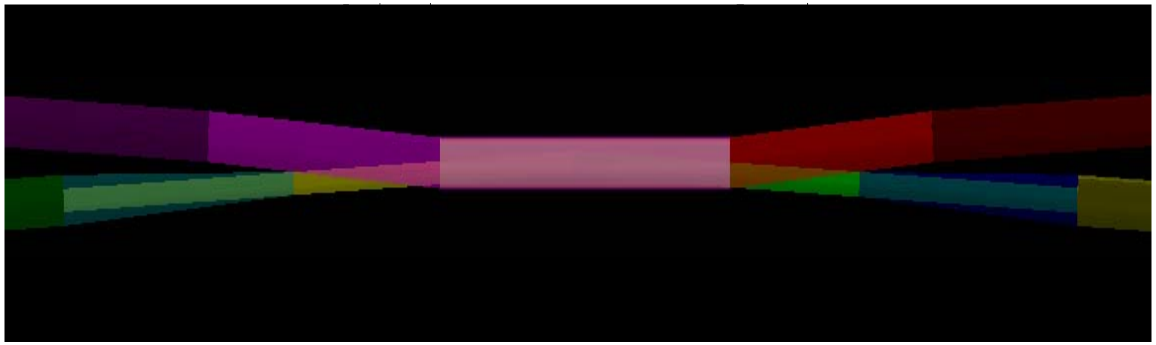
PXD requirement

< ~10^{2}-10^{3}/ bunch

New beam pipe design

K. Kanazawa





☺ Incoming pipes are cone-shaped, collimating SRs to prevent direct hits on Be part.
(1.6×10^{7}→ **8.8×10^{2}**/bunch)

☺ HOM can escape through the pipes for the outgoing beam.

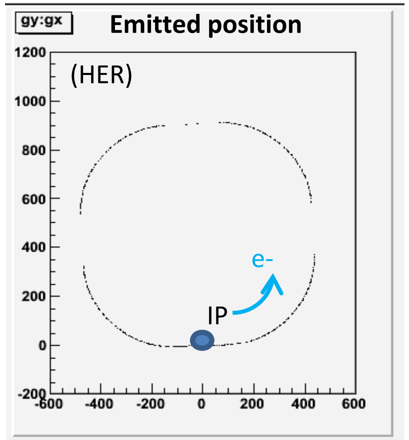
😐 Still suffers from SRs which are not parallel to beam.
😐 Quite sensitive to alignment error (0.5mm error→x100-1000 SR hits)

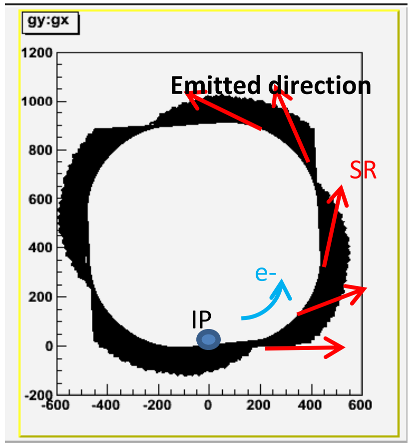
- Tip-scattering or refection on saw-tooth structure is hard to simulate. We are planning a beam test.

More beam pipe details in Shuji's talk tomorrow

3. Synchrotron Radiation (KEK/MPI)

- Simulation framework (MPI)
  - **Belle-II Geant4**
    - simulate SR absorption/reflection by Geant4
      (Geant4 can take care of interaction of very low-energy photon)
    - Surface effect is very difficult to simulate. (EGS?)
- Generator (KEK)
  - A) **SADtoSR** or B) **SRGEN** or C) LCBDS(used by Iwasaki)
  - So far, use A) as baseline (No need for optics conversion)



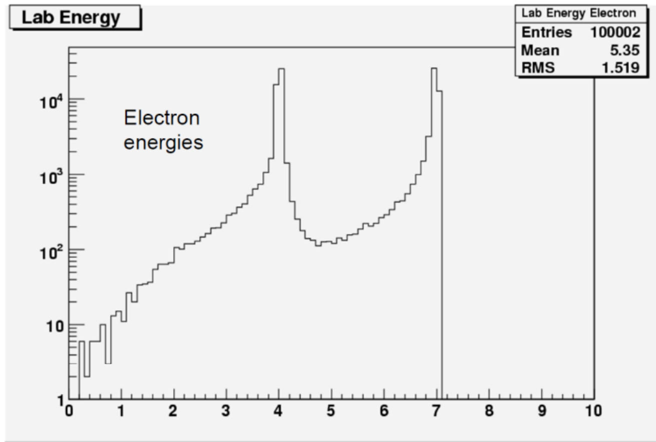


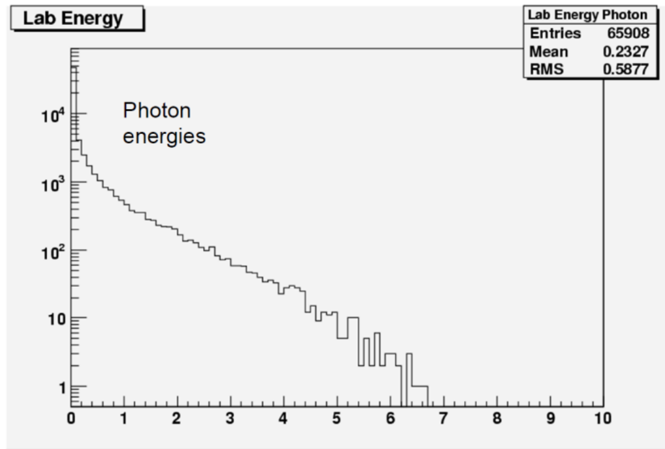
<Status>
- SR 4-vectors from beam center axis are ready
- Need to add beam-size effect

<Plans>
- SADtoSR validation using simple model is necessary
- Cross-check with Iwasaki's LCBDS results

4. QED, Rad. Bhabha (KEK/MPI)

- <u>Simulation framework (MPI)</u>
  - **Belle-II Geant4**
    - simulate interaction of $\gamma/e^+/e^-$ with matter by Geant4
- <u>Generator(KEK/MPI)</u>
  - A) **BHLUMI** or B) **BHWIDE** or c) **BBbrem**
  - Each generator covers different scat. angle





<Status>
• Start running several generators
• Funakoshi's (Accl.grp.) theoretical calculation is quite consistent with our generators
<Plans>
• QED MC results are inconsistent with SuperB's,
  machine study analysis can give answer

Machine study for Touschek/Beam-gas BG

Extrapolation towards BG

I: beam current, τ: life time
k: proportional constant

$$BG = I \cdot \left(k_{Touschek} \cdot \frac{1}{\tau_{Touschek}} + k_{beam-gas} \cdot \frac{1}{\tau_{beam-gas}} + \ldots \right)$$

- KEKB machine study results can be extrapolated for SuperKEKB
- Extrapolation strategy
  - Measure k and τ at KEKB by machine study
  - Assume same $k_{Touschek}$, $k_{beam\text{-}gas}$, $\tau_{beam\text{-}gas}$ at SuperKEKB
  - For $\tau_{Touschek}$ at SuperKEKB, use optics simulation result
  - SR, Rad.Bhabha, beam-beam BG are not included

KEKB machine study (Jun. 2010)

- Single beam(HER/LER only), random trigger
- Vary vertical beam size to see Touschek effect
- Measure SVD,CDC,ECL background level

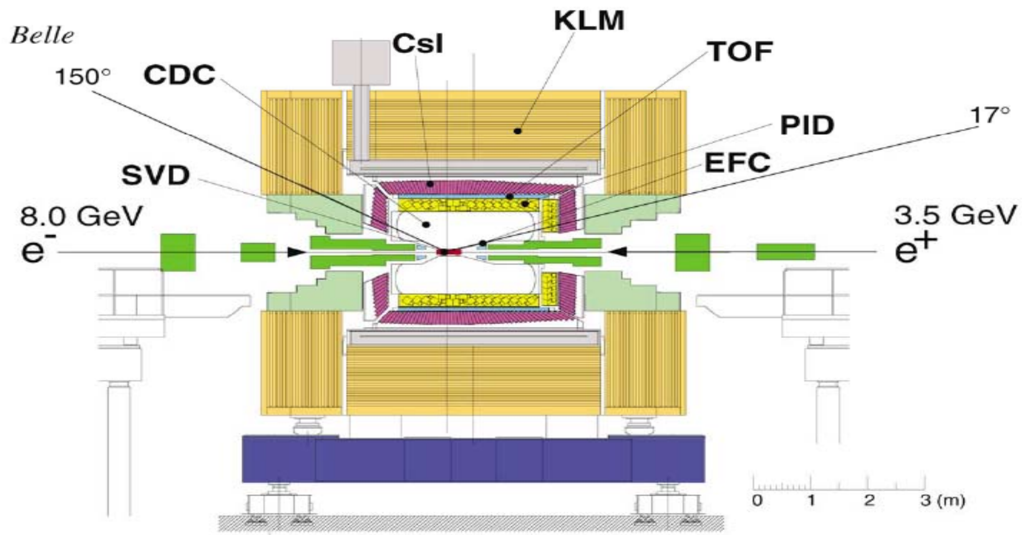
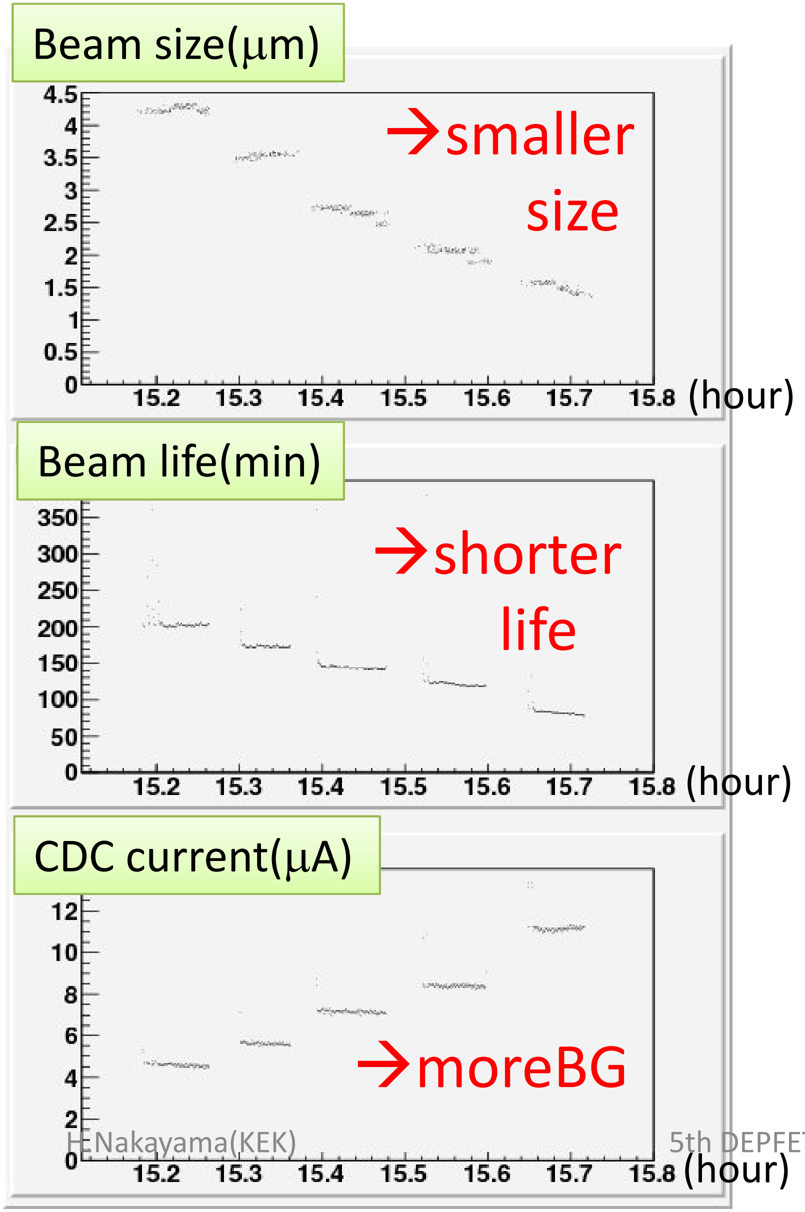
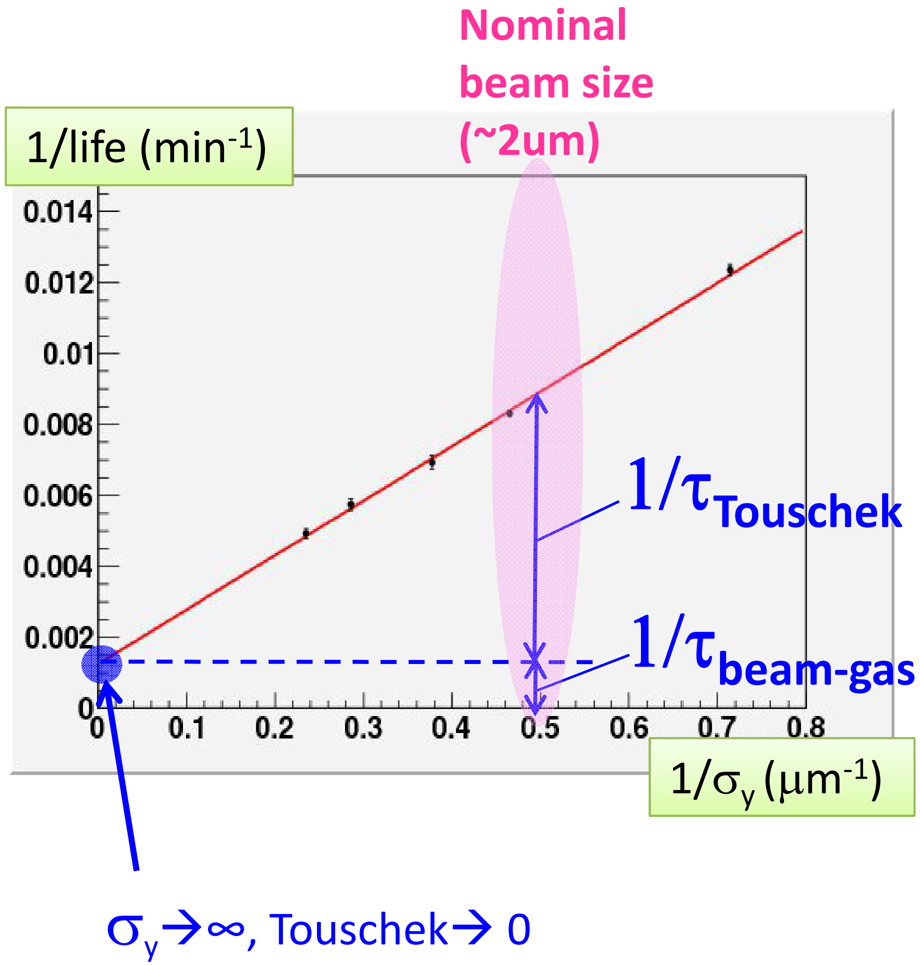


Fig. 1. Side view of the Belle detector.

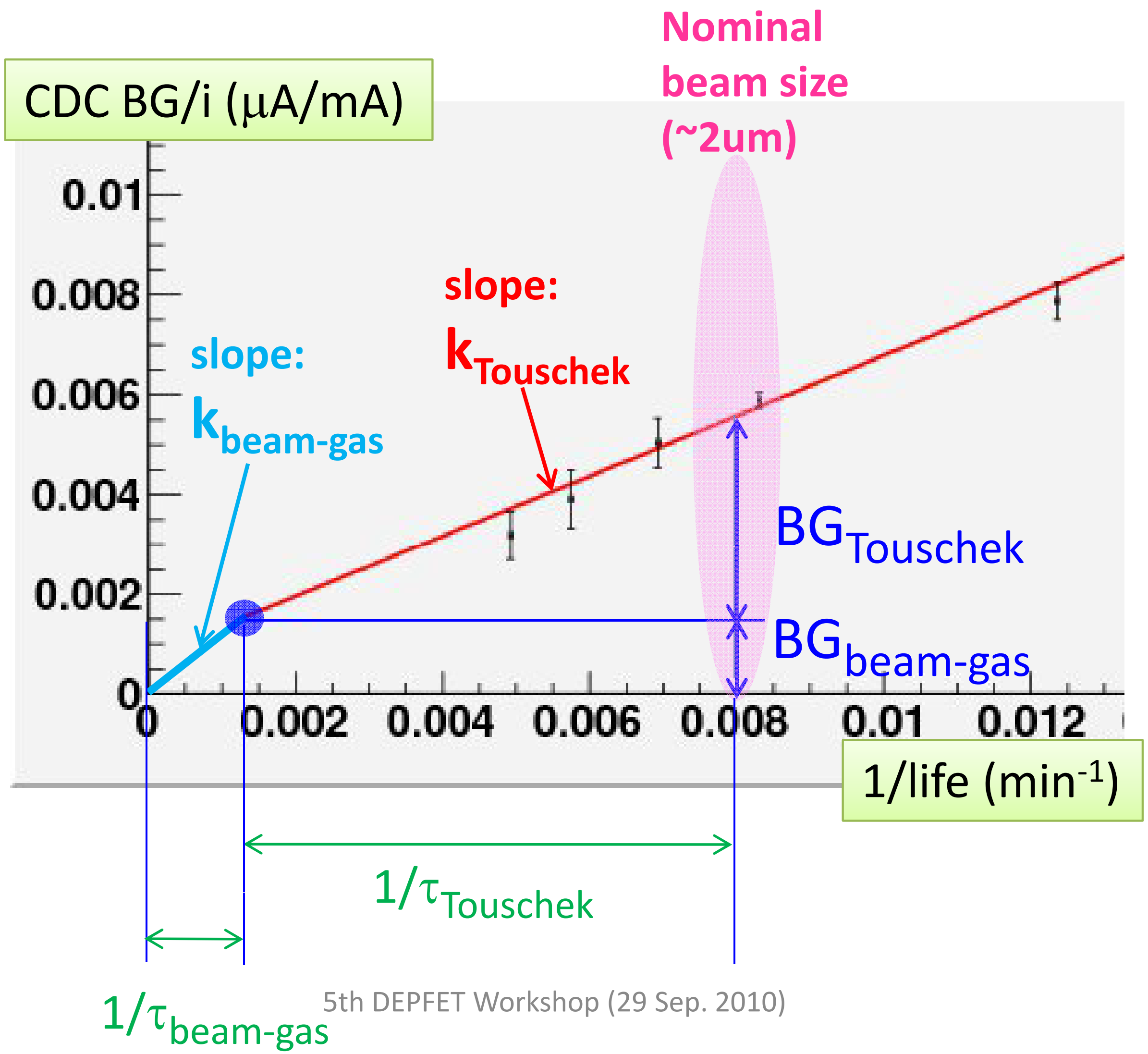
Belle detector

How to measure $\tau_{Touschek}$, $\tau_{beam\text{-}gas}$





How to measure $k_{Touschek}$, $k_{beam\text{-}gas}$



BG estimation at SuperKEKB

Assumptions:

- Use $\tau_{Touschek}$ from optics simulation: 8.7min(LER), 15.3min(HER)
- Use same $\tau_{beam\text{-}gas}$ from KEKB machine study: 800min(LER), 3400min(HER)
- Use same $k_{Touchek}$, $k_{beam\text{-}gas}$ from KEKB machine study

CDC 400+-40 uA (cf. ~20uA@2003)

→ ~120 kHz/wire or less at layer 6 or outer

ECL 60+-5 GeV/event

→ wave form fitting (x1/7) → ~9 GeV/event

SVD 6000+-600 event/trigger

→ shorter integration time (2μs→75ns)

→ ~400 event/trigger, occupancy: 2.7%+-0.3% <10% (SVD2)

PXD (estimated from SVD)

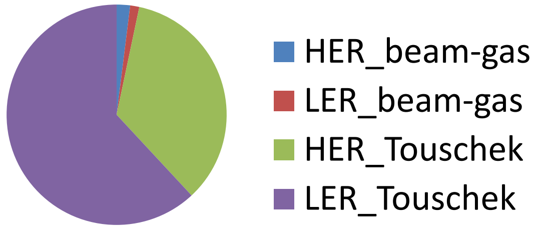
→ 3.2M pixels in 1st layer, shaping time: 20μs

→ Occupancy = 1.5±0.1%

(not including low-pt tracks or <few keV gammas)

PXD 1st: 14mm
SVD2 1st : 30mm

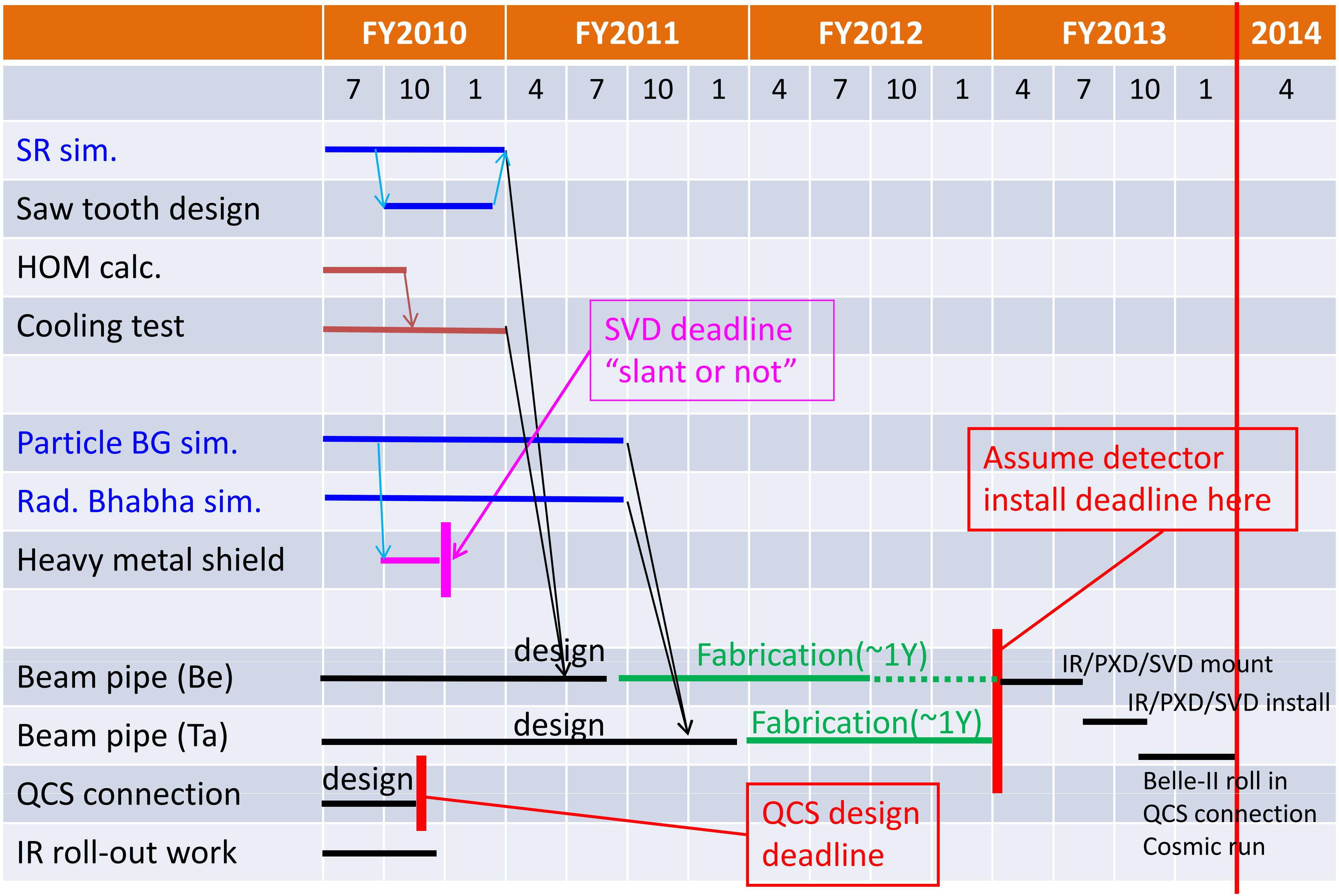
CDC



LER/total: 60~70%,
Touschek/total: >90%

SR, Rad.Bhabha, beam-beam BG are not included

Schedule (draft)

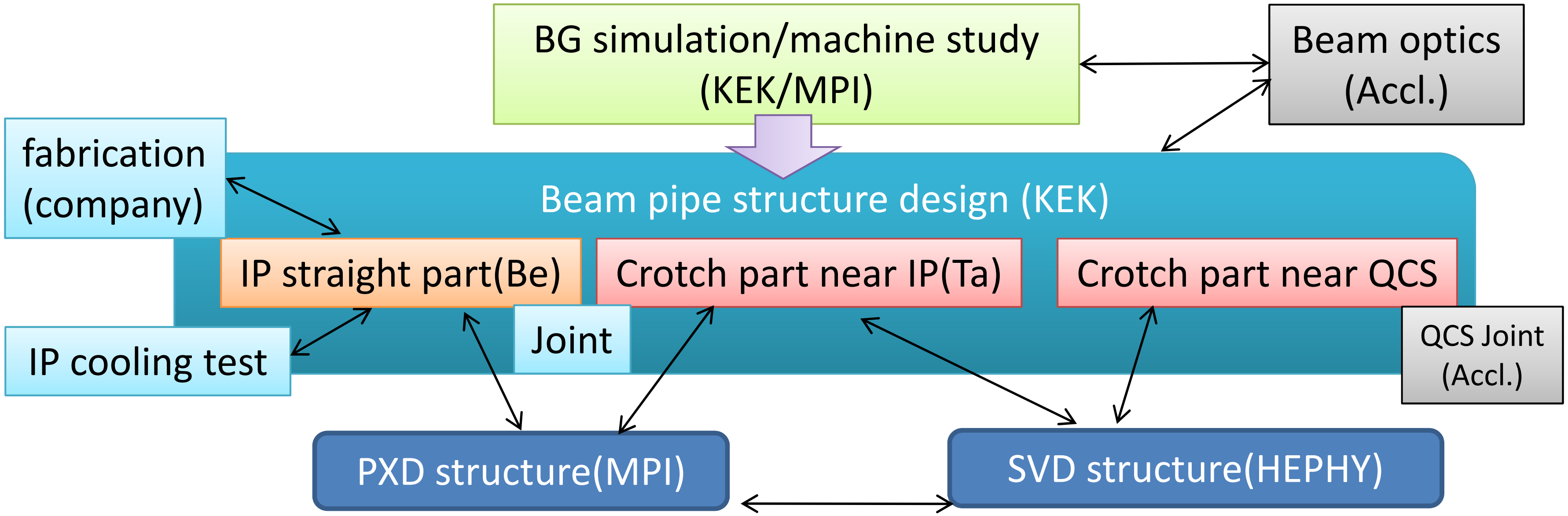


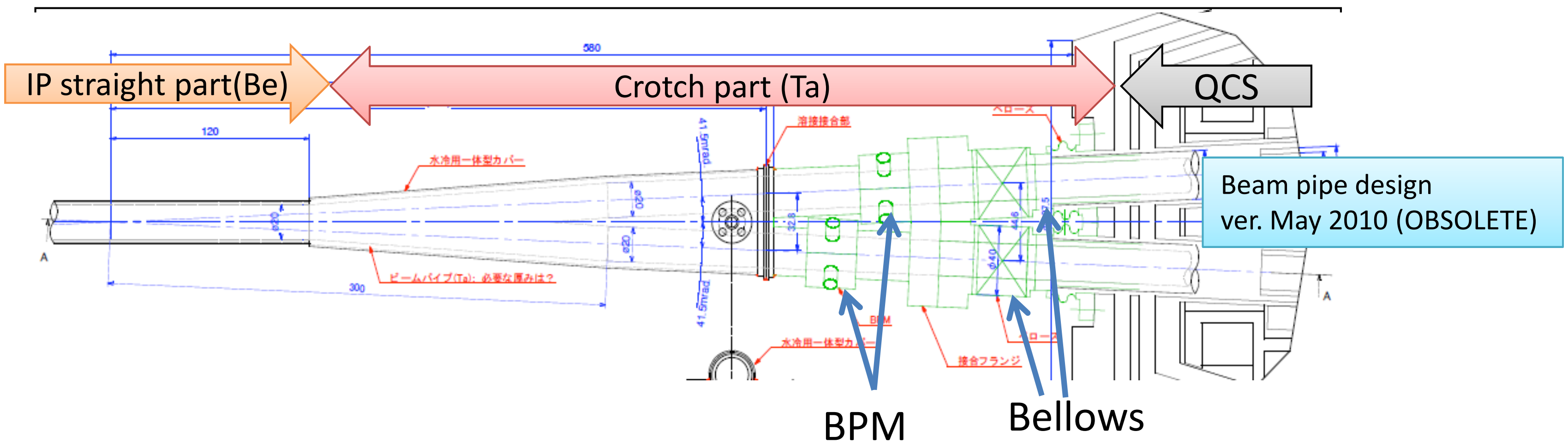
backup

IR tasks

- **BG simulation**
  - Particle BG (Touschek, Beam-gas)
  - Radiative BhaBha
  - SR (upstream, back-scatter)
  - IR geometry implementation
- **BG study**
  - Touschek, Beam-gas study
  - QED study
- **Beam-pipe structural design**
  - Be center part (strength, cooling, fabrication method)
  - Ta crotched part (SR stopping, cooling, fabrication method)
  - QCS connection (BPMs, flanges, bellows, fastening method)
- **Other beam-pipe design**
  - Al mockup test for return cooling
  - Saw tooth design
  - HOM calculation
  - Heavy-metal shield design
  - Mirror current heating estimation
  - Vibration

Beam pipe design & BG estimation

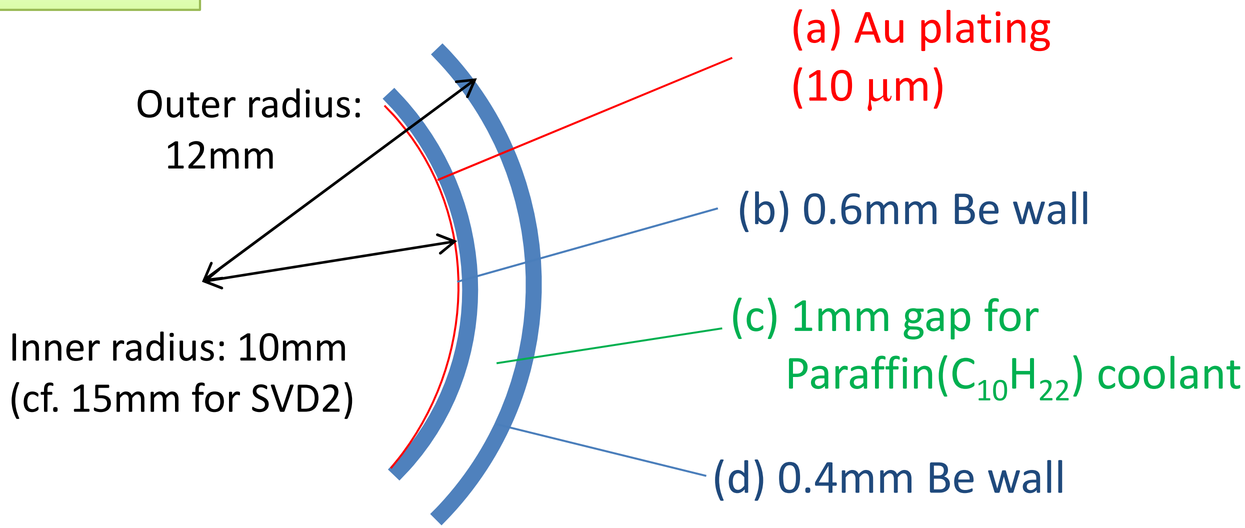




Beam pipe design

Beam pipe parameters

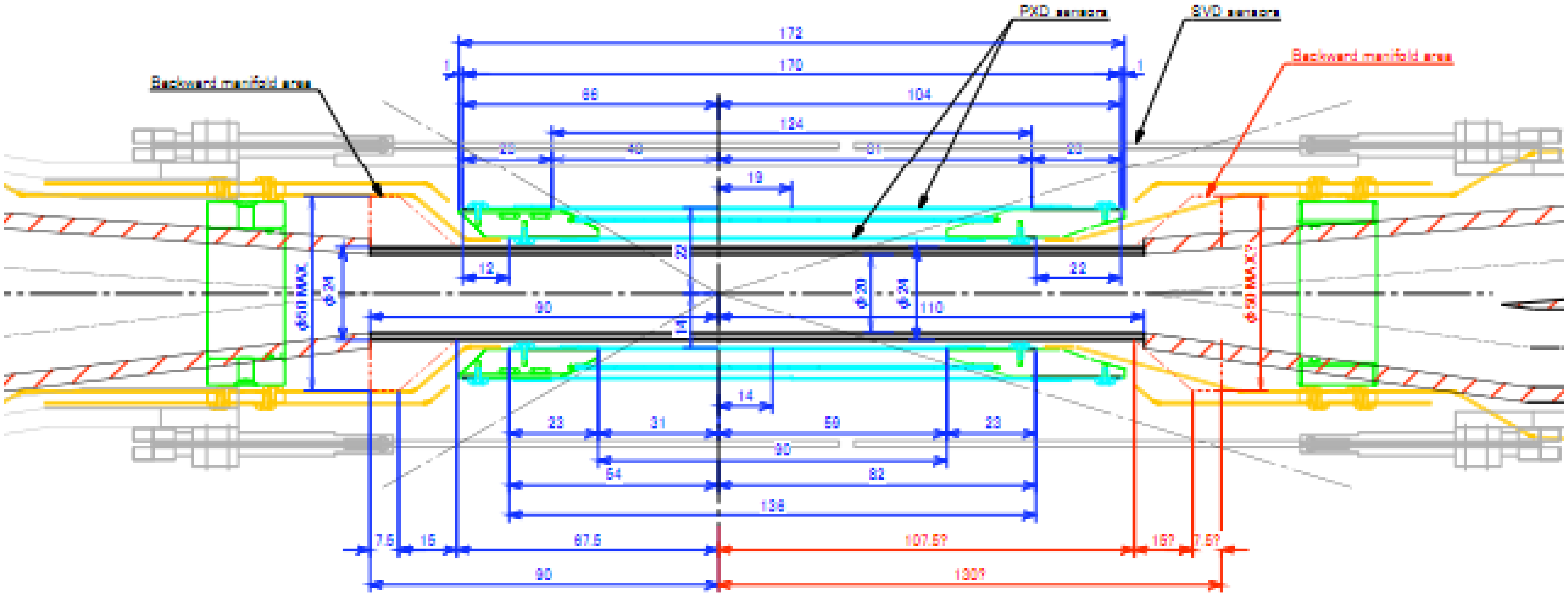
Be center part



Ta crotch part

Inner radius: 10mm
Ta thickness: 4mm
Au plating on inner surface
Dig drains on outer surface to put water cooling pipes
Saw tooth structure to prevent reflected SR lights to hit Be part

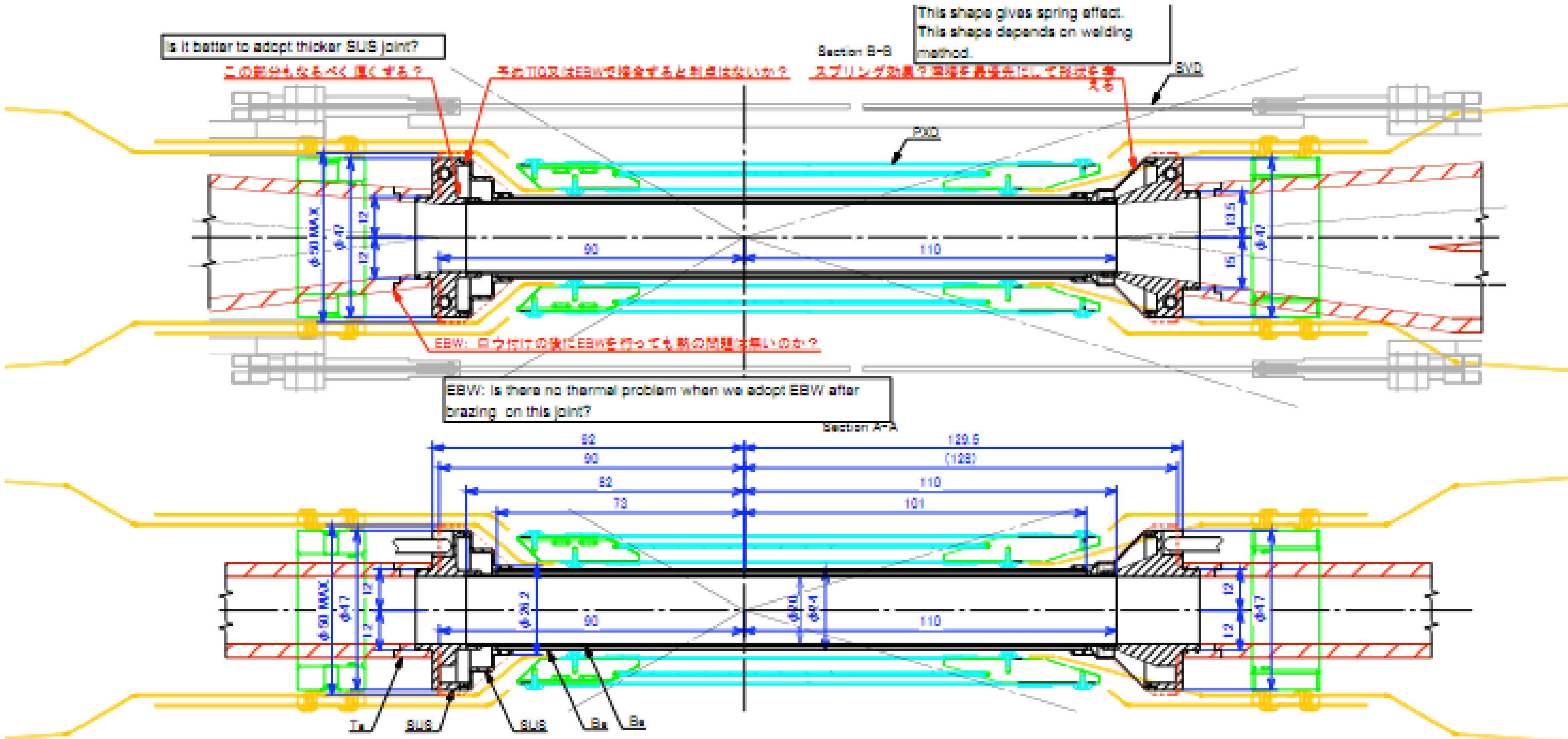
Current Space assignment near IP



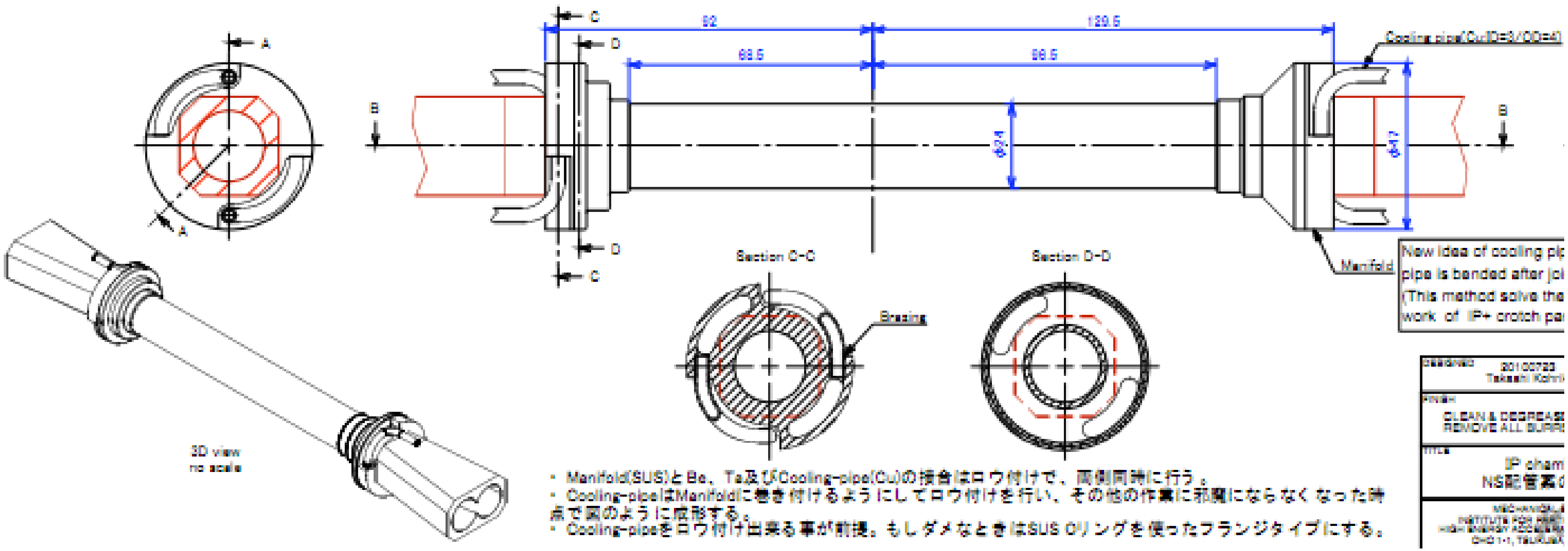
The manifold of left side (backward) shows acceptable space by PXD group requirement.
Red line region is not fixed yet.

- PXD左側（ Backward）の台形はIP chamber manifoldに当てられるスペースを示す。
- PXD右側（ Forward）の台形もIP chamber manifoldに当てられるスペースを示すが、確定ではない。
- 赤字は未定を示す

Current Space assignment near IP



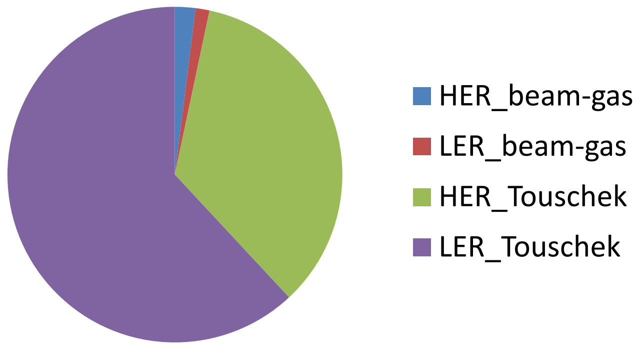
Cooling pipe connection on IP chamber



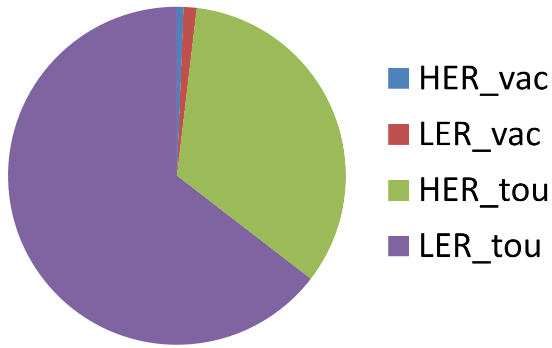
Touschek/Beam-gas machine study

Estimated BG fraction at SuperKEKB

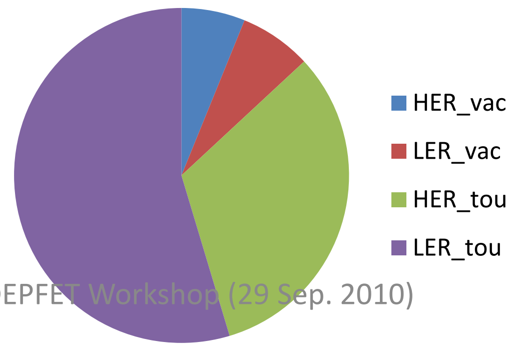
CDC



SVD



ECL

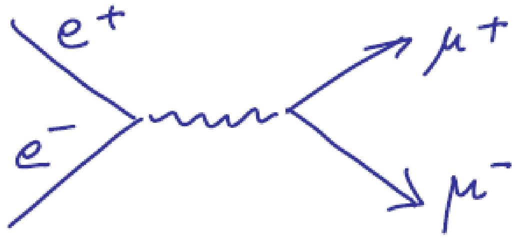


QED machine study

C. Kiesling

1. QED process

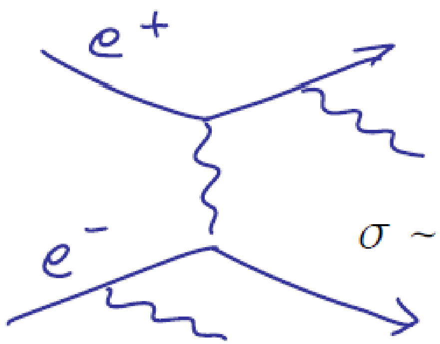
Cross sections for s-channel processes fall like 1/s



Rate ~ 600 ev/s

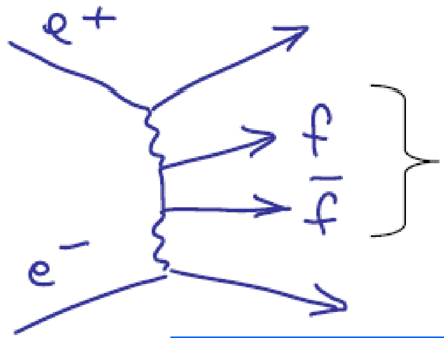
@10^3 / nb s

Cross sections for t-channel processes are largely independent of s



$\sigma \sim 50$ nb

Bhabha scattering



e^+e^- :

$\sigma \sim O(10^7\,\mathrm{nb})$

2-photon-processes

C. Kiesling, VI Open Meeting of the Belle II Collaboration Meeting, July 5-7, 2010

3

C. Kiesling

QED BG estimation

- SuperB QED simulations : 10MHz/cm2

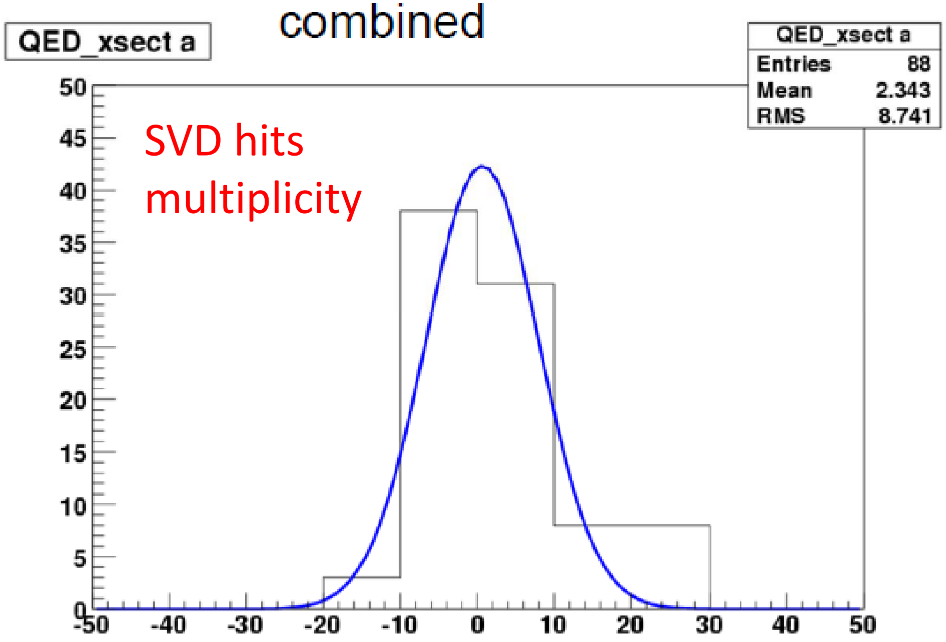
  → ~1.5 % occupancy for PXD, which is close to our limit (2%)
- However, our simulation shows ~0.1% occupancy
  - Our generators (BDK/KW/Grace) show consistent results

- Find out the correct answer by KEKB machine study .
  - Collide two beams (LER and HER)
  - Vary luminosity by varying beam separation, beam size, or beam current.

C. Kiesling

Machine study results

all layers (z and phi) combined



Gauß-Fit including all layers:

$$N_{hits} = 0.7 \pm 7.3$$

Expected hits from KoralW (averaged over the layers):

$$< N_{hits} >= 0.65$$

Cross check analysis:

$$N_{hits} = -5.8 \pm 9.9$$

$$< N_{hits} >= 10.4$$

(SuperB MC)

C. Kiesling, VI Open Meeting

Further analysis is on-going using CDC information

Touschek simulation using SAD
by Ohnishi (Accel.grp.)

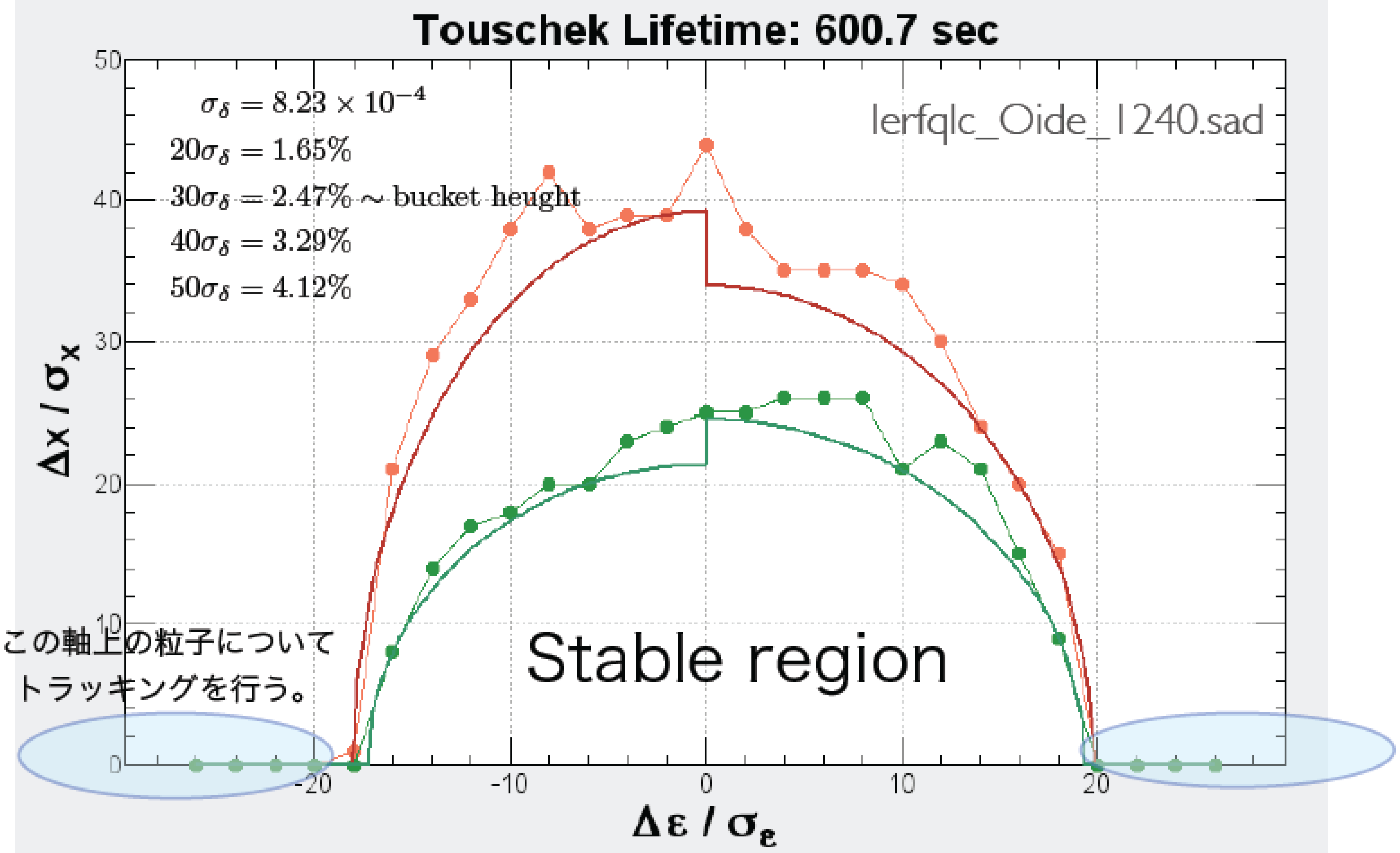
LER Touschek Effect

- SuperKEKB-LER のTouschek lifetimeを600 secと仮定する。
- 蓄積電流3.6 Aの時のロス率は、-6 mA/s。

$$\frac{dI}{dt} = -\frac{I}{\tau}$$

- 1450 mAのとき、垂直ビームサイズを2ミクロンとした場合、Touschek lifetimeは153 min。ロス率は-0.158 mA/s。(中山さんらのマシン・スタディより)
- 従って、SuperKEKBにおけるTouschek lifetimeは、このときの38倍のロス率となる。

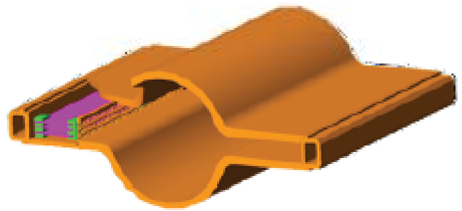
LER Dynamic Aperture



a11: 18.0058	b11: 39.2428	a12: 19.8082	b12: 33.9254	(887.182 sec)
a21: 17.2599	b21: 21.3303	a22: 19.3494	b22: 24.5299	(454.022 sec)

Tracking Simulation

- Physical aperture
  - IP : radius = 5 mm (tighter than realistic case)
  - QC1 : radius = 10 mm
  - QC2 : radius = 30 mm
  - vacuum chamber radius = 45 mm/ante-chamber
    - ante-chamber : inner=-63 mm, outer=+110 mm, height=14 mm



- Single-particle tracking
  - Particle energy changes due to Moller scattering
  - The particle loses energy with the whole ring. Amount of the energy loss is fixed during tracking simulation. Several kinds of energy loss is evaluated. Cross section should be multiplied later.

Touschek Scattering

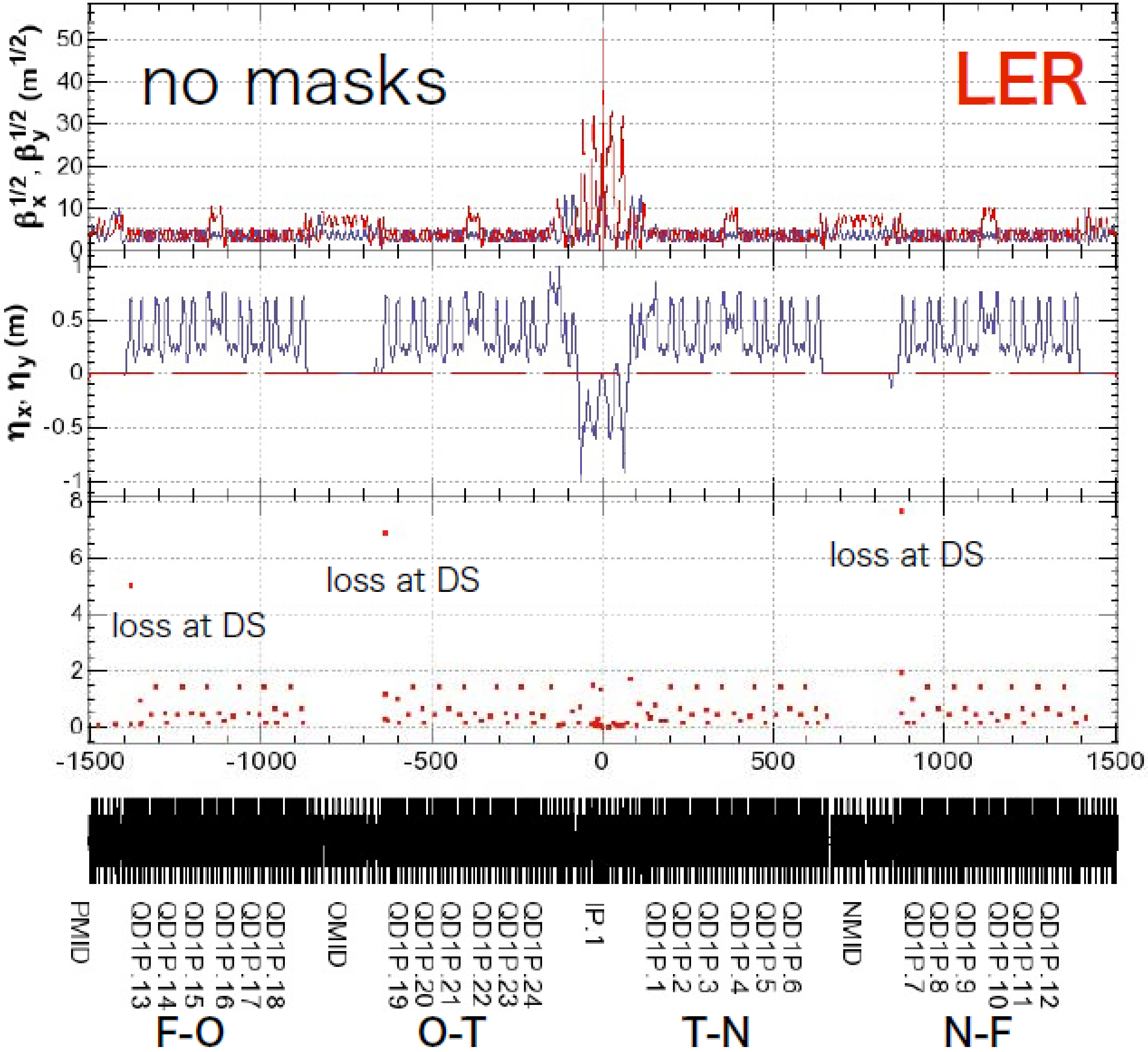
- リング全周についてトラッキングを行う。
  - ドリフト空間の入口でメラー散乱を起こす
  - 粒子ロス判定の場所は散乱場所と同じ集合
- 散乱確率は、場所sの関数

$$P(s) \propto \frac{\Delta s}{\sigma_x(s)\sigma_y(s)}$$

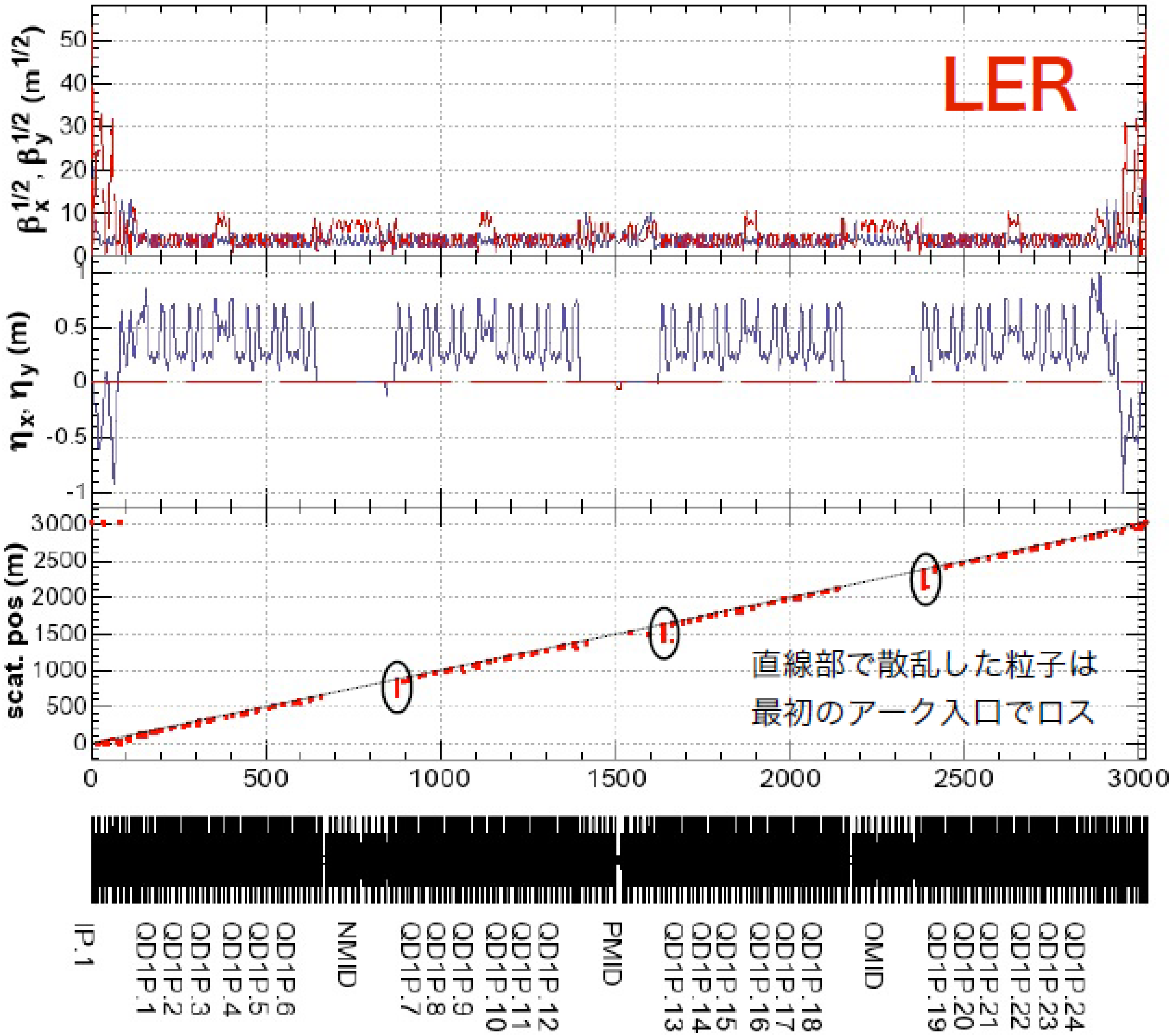
$$\sigma_{x,y}(s) = \sqrt{\varepsilon_{x,y}\beta_{x,y}(s) + (\eta_{x,y}(s)\sigma_\delta)^2}$$

  - 散乱場所における散乱確率を考慮して集計

$-100\sigma_\delta$ $(-8.23\ \%)$



$-100\sigma_\delta$ (−8.23 %)



Horizontal Mask

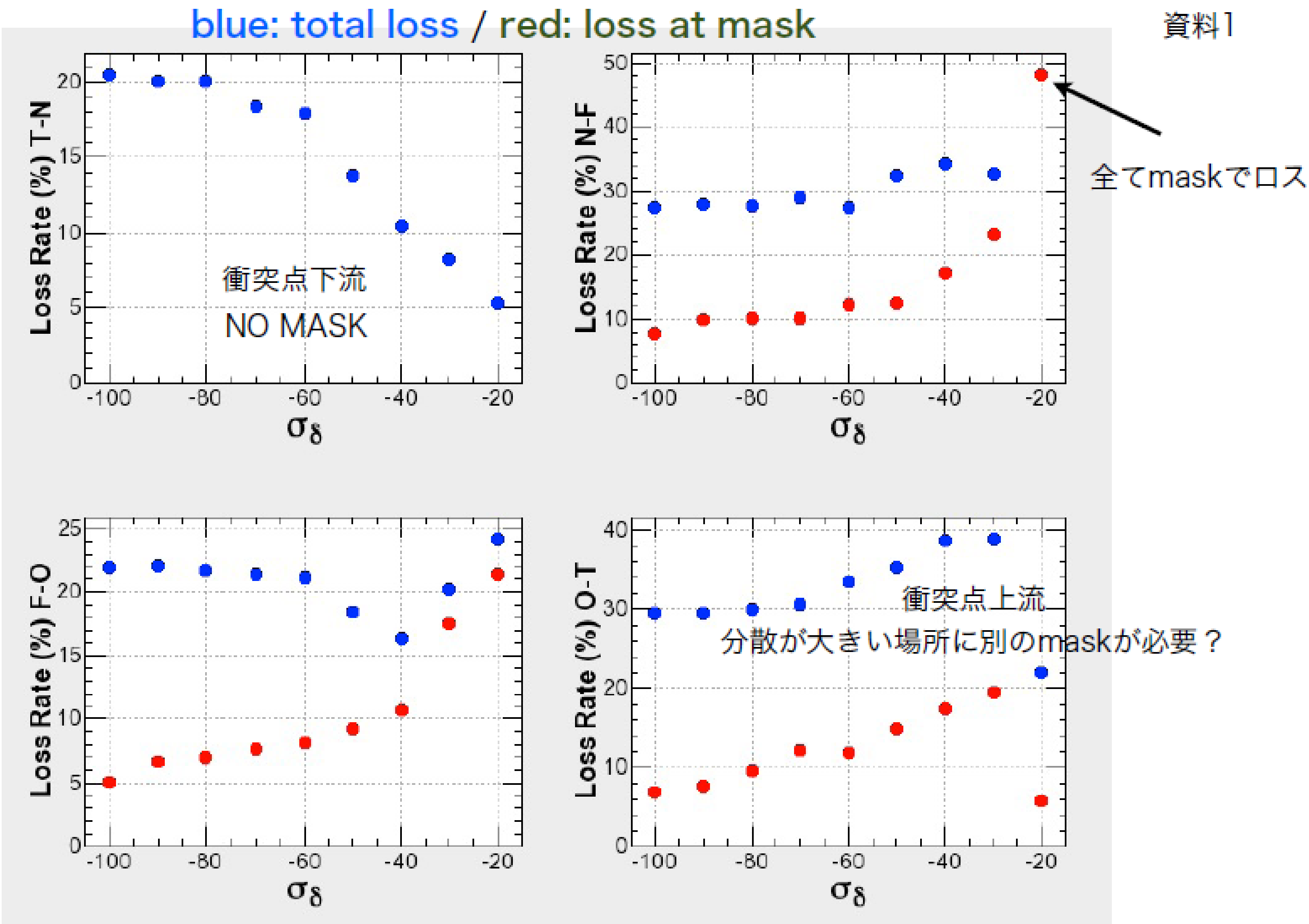
mask 条件

case 1	$2J_x = 7.01 \times 10^{-6} m$ $\delta = 0.25\%$	injection
case 2	$2J_x = 5.12 \times 10^{-6} m$ $\delta = 1.8\%$	$2J_x$=40 sigmas (Touschek Lifetime)

各アーク部先頭部のQF4Pの前にHマスクを置く。
case 2で評価する。

Particle Loss at Each Arc

資料1



Loss Rate

資料2

Touschek lifetimeが600 secと仮定した場合、
エネルギー変化ごとのロス率

$\Delta E/\sigma_E$	loss rate(ΔE)/loss rate(600 s)	integral
20	0.20000	0.20000
30	0.05330	0.25350
40	0.01942	0.27292
50	0.00845	0.28138
60	0.00413	0.28551
70	0.00219	0.28770
80	0.00124	0.28893
90	0.00073	0.28966
100	0.00045	0.29011

Particle Loss

Touschek Lifetimeを600 sec(-6 mA/s)とし、20シグマ以上のエネルギー変化ごとの寄与を積分して求めた**アーク部**での粒子ロス量。（資料1、資料2より）

Arc	Arc except for mask		mask	
	%	nC	%	nC
T-N	1.98	1.20	-	-
N-F	1.16	0.70	11.39	6.87
F-O	1.04	0.63	5.56	3.35
O-T	5.06	3.05	2.75	1.66
total	9.23	5.57	19.69	11.89

Summary

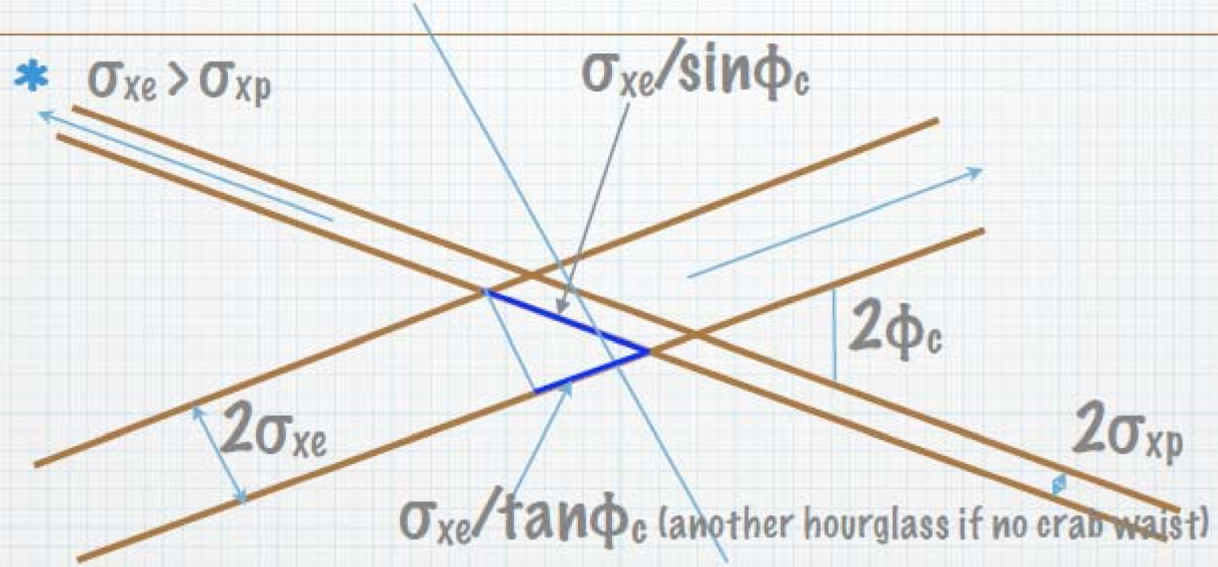
- 20シグマ以上のエネルギーのずれた粒子に対してロス率の評価を行った。
- アーク部のmask以外でロスする量は全体の9.2 %。但し、maskをかすめて散乱した場合は考慮していない。
- H-mask(energy cut)で落とせるロス率は19.7 %。

Beam-beam background
(Funakoshi’s talk)

Beam-beam effect on the beam injection

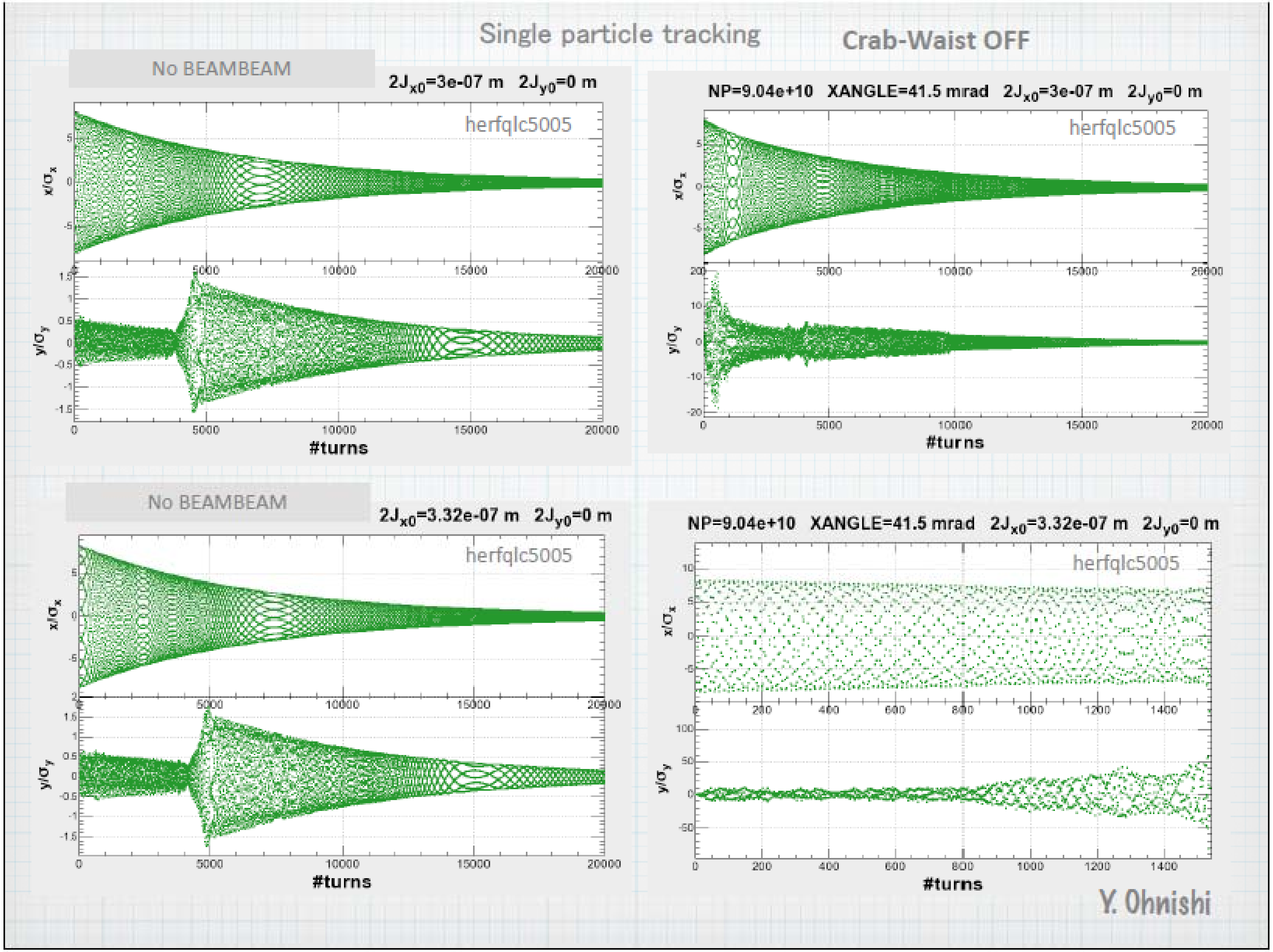
- Phenomena (found by the simulation)
  - In the Nano-Beam scheme, a particle with the horizontal displacement at the IP collides with the other beam at the position where the vertical beta function is larger than its minimum value.
  - Due to this effect, an injected particle with a large horizontal oscillation (due to injection error) may be lost.
  - This effect is serious in HER (due to smaller physical acceptance)
- Counter-measures
  - Crab waist scheme
  - Synchrotron injection

Hourglass condition for the NanoBeam scheme

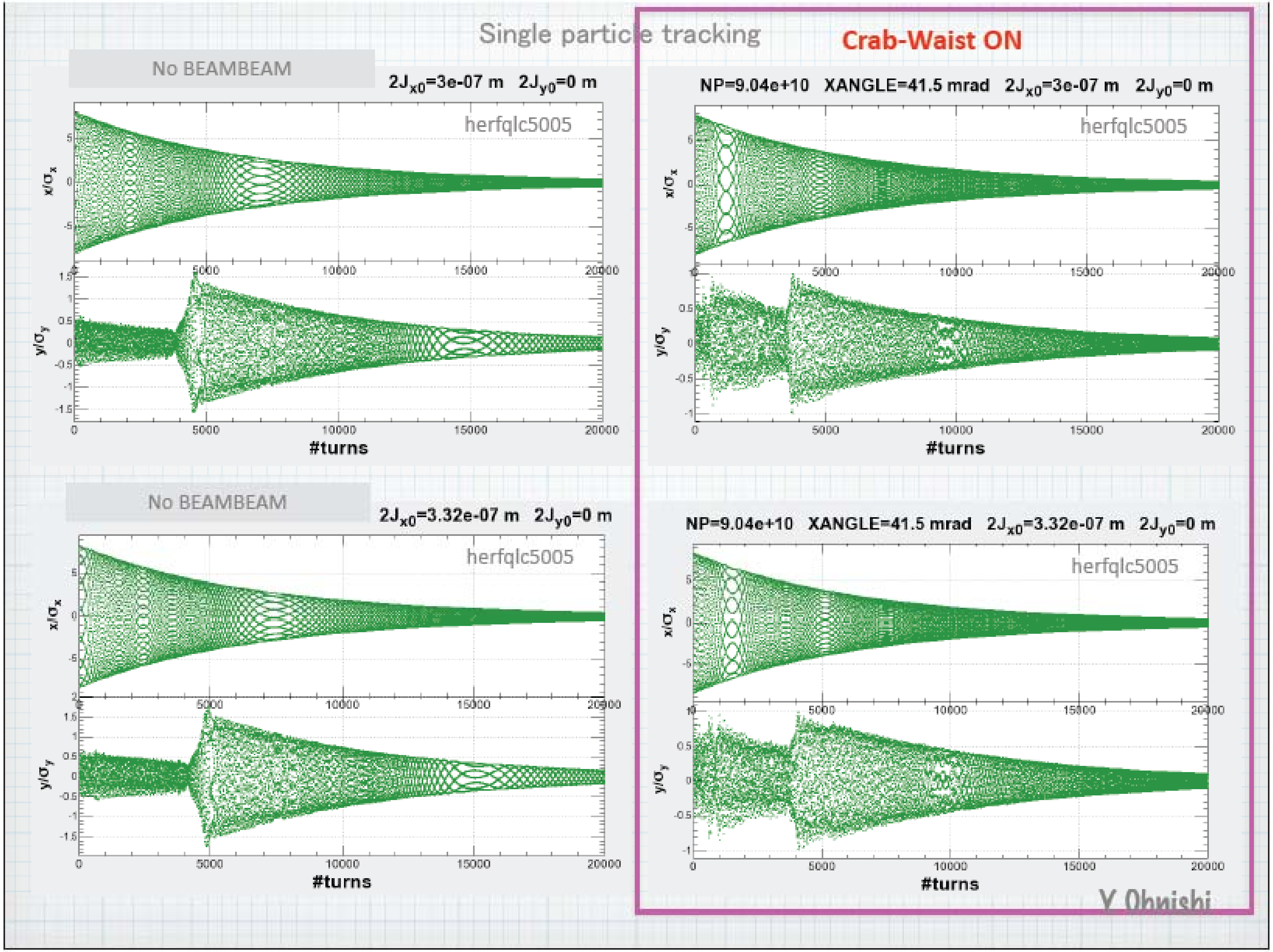


$$\beta_{yp}^{*} \gtrsim \sigma_{xe}/\sin\phi_c = 2\sigma_{ze}^{effective} = 2(\sigma_{xe}/\sin 2\phi_c)$$

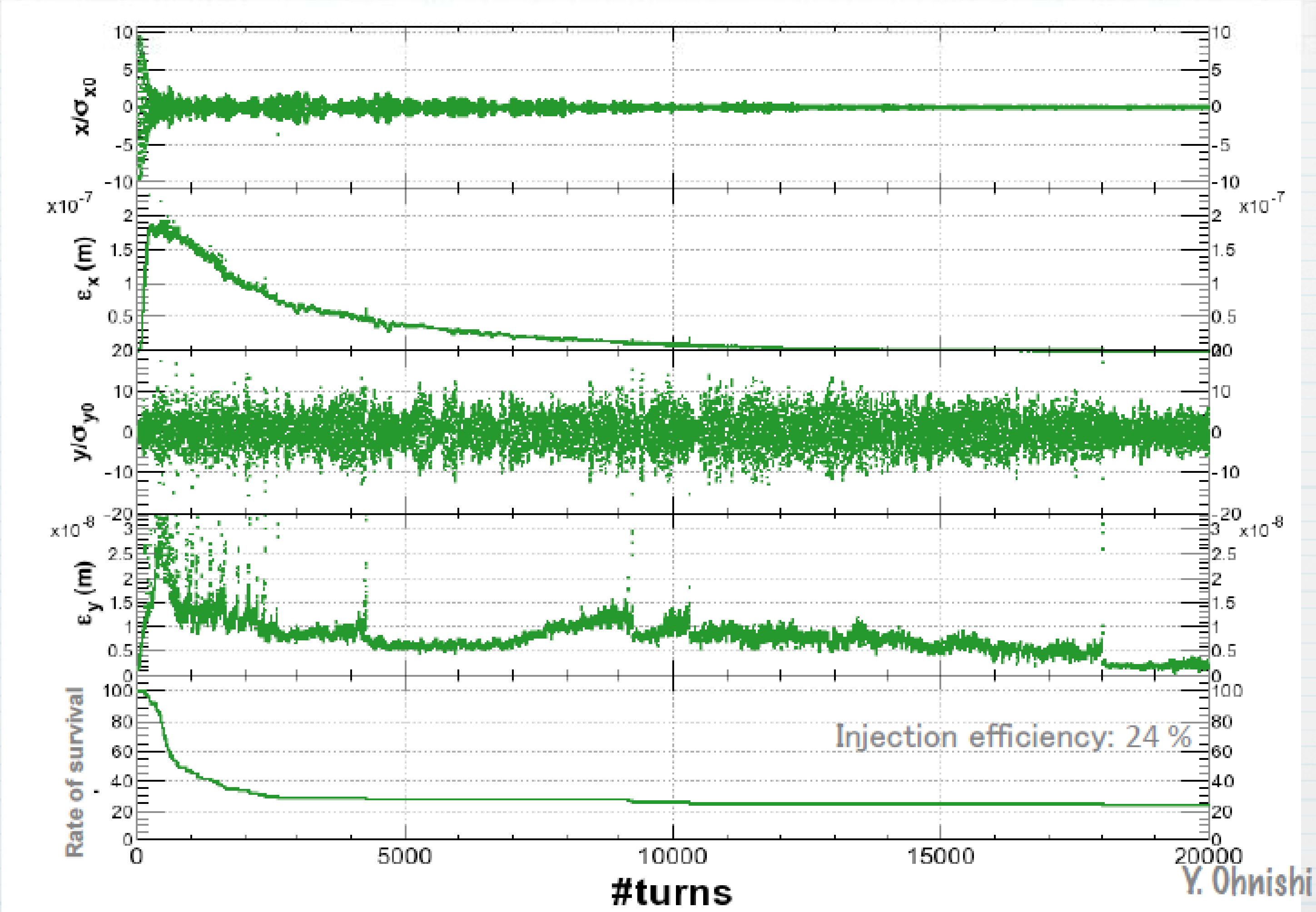
$$\beta_{ye}^{*} \gtrsim \sigma_{xp}/\sin\phi_c = 2\sigma_{zp}^{effective} = 2(\sigma_{xp}/\sin 2\phi_c)$$



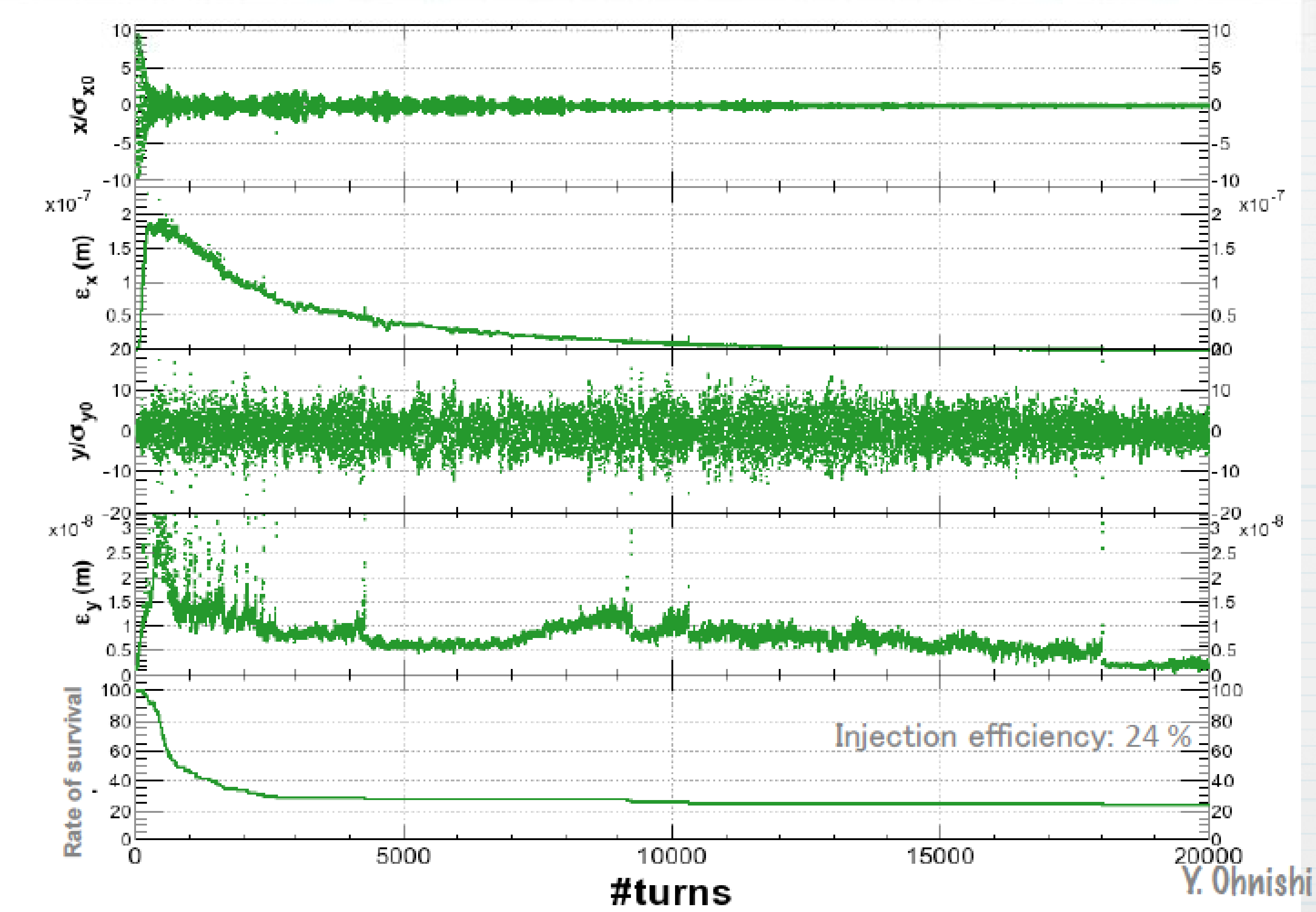
Single particle tracking
Crab-Waist OFF
No BEAMBEAM
$2J_{x0}$=3e-07 m $2J_{y0}$=0 m
herfqlc5005
NP=9.04e+10 XANGLE=41.5 mrad $2J_{x0}$=3e-07 m $2J_{y0}$=0 m
herfqlc5005
#turns
#turns
No BEAMBEAM
$2J_{x0}$=3.32e-07 m $2J_{y0}$=0 m
herfqlc5005
NP=9.04e+10 XANGLE=41.5 mrad $2J_{x0}$=3.32e-07 m $2J_{y0}$=0 m
herfqlc5005
#turns
#turns
Y. Ohnishi


Single particle tracking
Crab-Waist ON
No BEAMBEAM
2Jx0=3e-07 m 2Jy0=0 m
NP=9.04e+10 XANGLE=41.5 mrad 2Jx0=3e-07 m 2Jy0=0 m
herfqlc5005
x/σx
y/σy
#turns
No BEAMBEAM
2Jx0=3.32e-07 m 2Jy0=0 m
NP=9.04e+10 XANGLE=41.5 mrad 2Jx0=3.32e-07 m 2Jy0=0 m
Y.Ohnishi

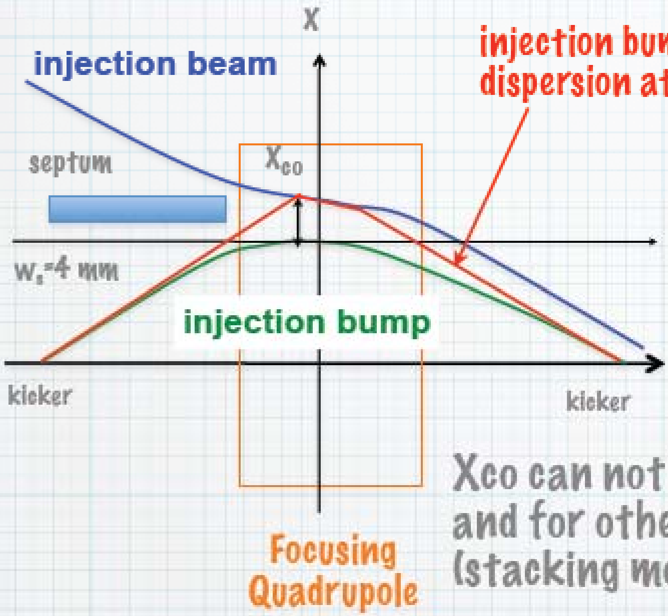
With Beam-Beam (No Crab-Waist)



With Beam-Beam (No Crab-Waist)



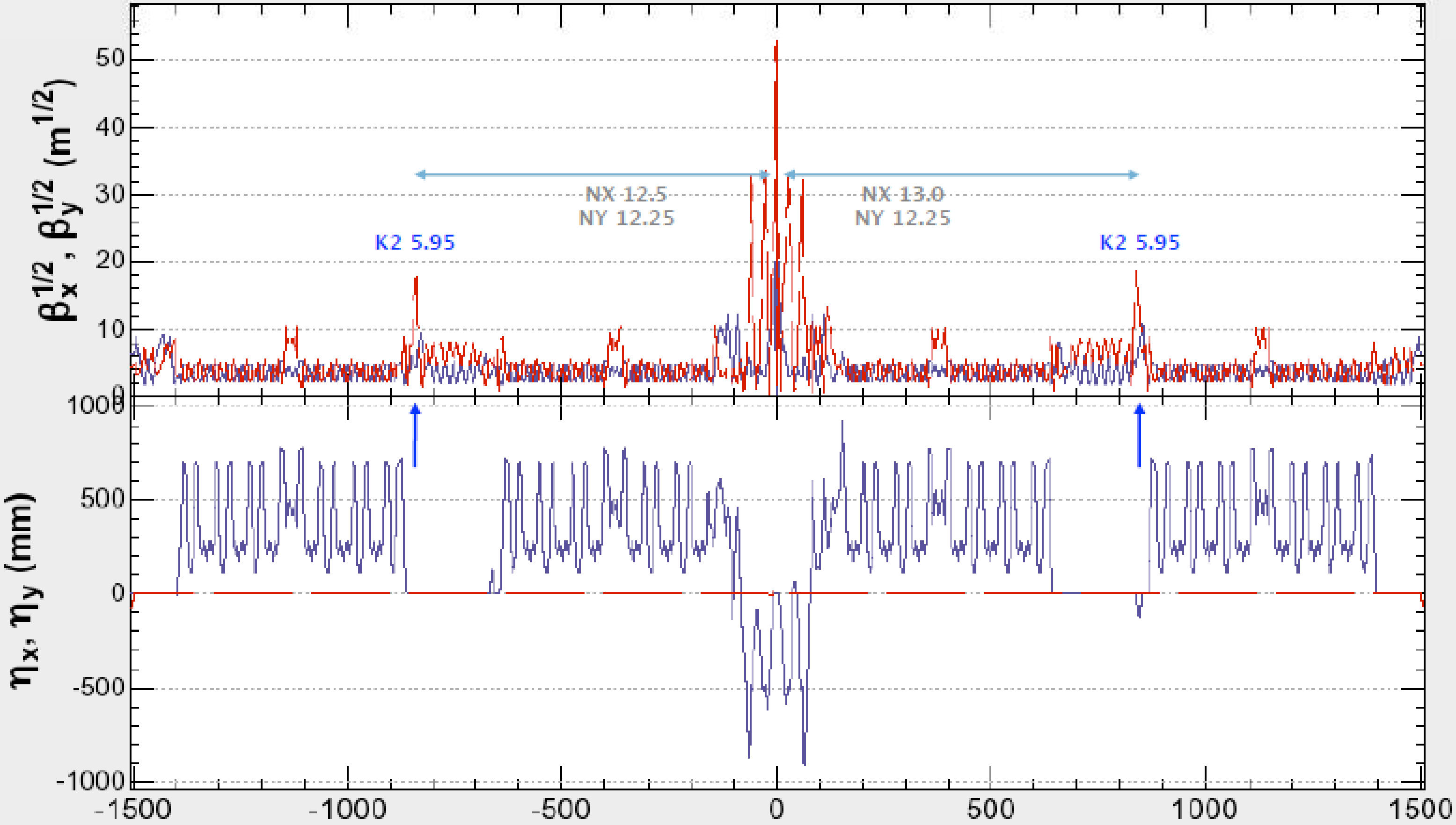
Beam injection scheme



Xco can not be set zero due to thickness of the septum magnet and for other reasons in case of the usual betatron injection (stacking mode).

In case of synchrotron injection, Xco can be zero but the synchrotron oscillation is induced, since the energy of the injected beam should be different from that of the stored beam.

SuperKEKB LER Crab waist



IR: lerfqlc_Oide_1137.sad

H. Koiso