Background Estimation

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SuperKEKB international review

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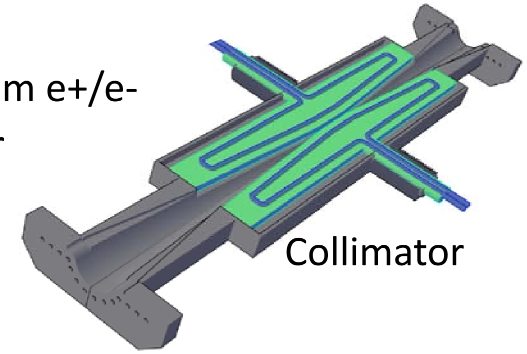
Introduction

- At SuperKEKB with 40 times higher luminosity of KEKB, detector background will also increase drastically.
  - Nano-beam(0.94um→0.048/0.062nm), higher current(x~2), smaller radius of inner-most detector (r_{min}=18mm→14mm)
- To protect detector from background, we carefully design
  - collimators in arc sections
  - IR beam pipe optimized to stop SR light
  - heavy-metal shield on IR beam pipe to stop showers
  - Polyethylene shield to stop neutrons
  - etc…

Background sources at SuperKEKB

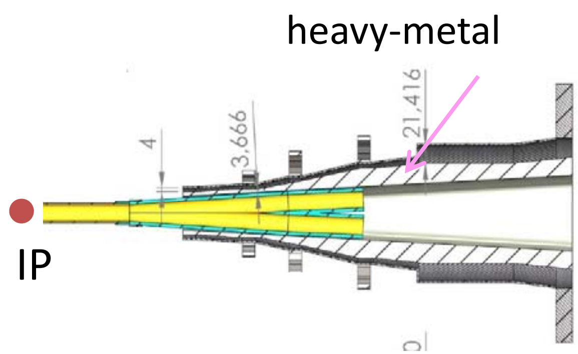
1. Touschek effect

– Intra-bunch scattering, Rate $\propto$ (beam size)$^{-1}$, $\propto E^{-3}$ → mainly LER
– Dominant background at SuperKEKB (nano-beam)
– Scattered beam particles hit beam pipe →create shower →reach detector
– Countermeasures :
  - Horizontal collimator on both (inner/outer) side to stop off-momentum e+/e-
  - Heavy-metal on IR beam pipe to protect inner detector from shower



2. Beam-gas scattering

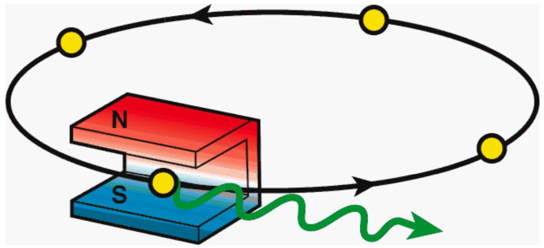
– Scattering by remaining gas, Rate $\propto$ IxP
– Vacuum level at SuperKEKB will be similar to KEKB except for IP region.
– Particles scattered in IP region will be lost at downstream, therefore will not be detector background



Background sources at SuperKEKB (cntd.)

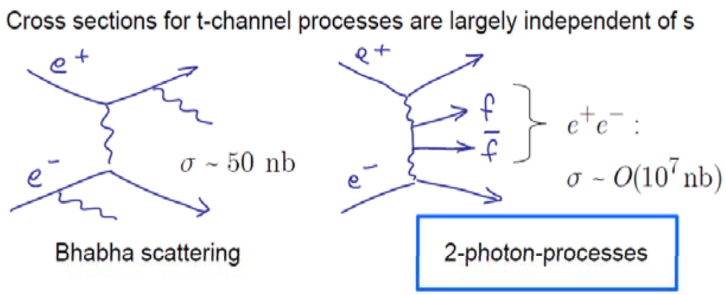
3. Synchrotron radiation

- Rate ∝ E^2B^2: mainly from HER
- Photons are emitted on final focusing magnet
  → hit IP beam pipe (Be) and penetrate → reach PXD
- Countermeasures:
  - collimate beam pipe radius just before IP
  - "ridge (saw-tooth)" on beam-pipe inner wall
    to prevent reflected photons to hit Be pipe



4. QED process

- Physics process, Rate∝Luminosity
  - Rad. Bhabha: Gammas emitted in forward direction
    → hit magnet iron →create neutron: to be simulated
  - 2-photon: e+e- pair will hit PXD: confirmed OK



0.1%(<<1%) occupancy on PXD

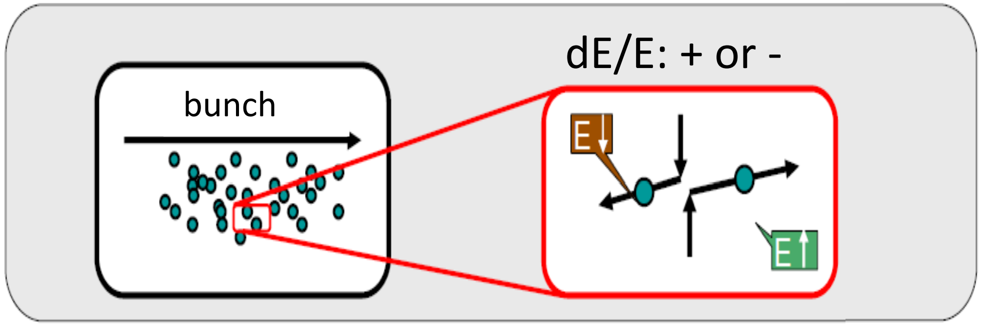
5. Beam-beam interaction

- Scattered at IP, by field of the other beam
- To be simulated

Background tasks

- Simulation
  - Prepare background flux (generate scattering, propagate to IR)
  - Implement IR geometries into GEANT4 models
    - Beam-pipe, QC1/2 magnet, cryostat, non-uniform magnetic field, etc.
  - Full-detector GEANT4 simulation
- KEKB data analysis
  - Compare with KEKB simulation, validation of simulation scheme
  - Extrapolation toward SuperKEKB
- Feedback to structural design
  - Shape of beam-pipe, heavy-metal shield on beam-pipe
  - Collimator
  - Cooling system of IP beam pipe
  - etc…

1. Touschek/Beam-gas



- ☑ Extrapolation of KEKB data
- ☑ KEKB: simulation validity check with data
- ☑ SuperKEKB: Flux simulation
- ☐ SuperKEKB: GEANT4 simulation

1-1. Extrapolation from KEKB data

- KEKB machine study (Jun. 2010)
  - Single beam (no collision), measure detector background
  - Separate Touschek and beam-gas, using beam-size dependence
    - $k_{beam\text{-}gas}$, $\tau_{beam\text{-}gas}$, k_{Tou}, τ_{Tou} are measured

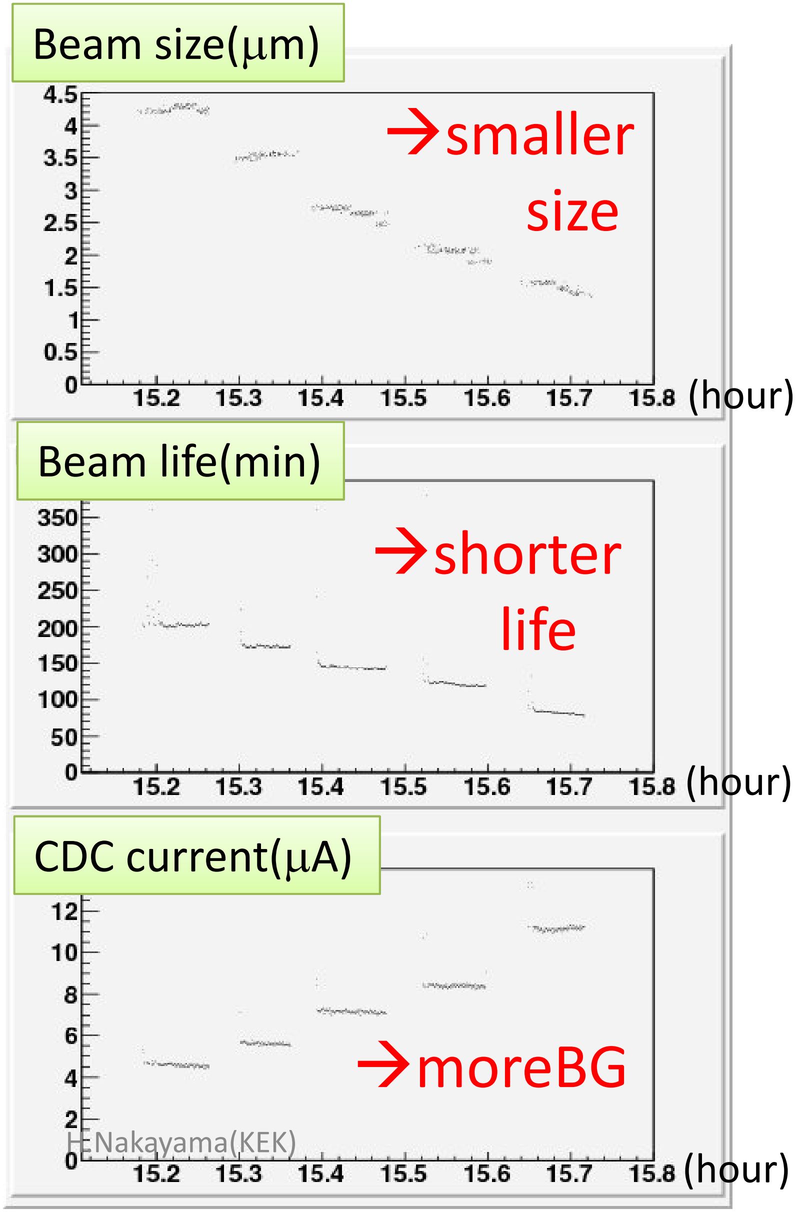
$$BG = -I(k_{Beam-gas} * \frac{1}{\tau_{Beam-gas}} + k_{Tou} * \frac{1}{\tau_{Tou}} + ...)$$

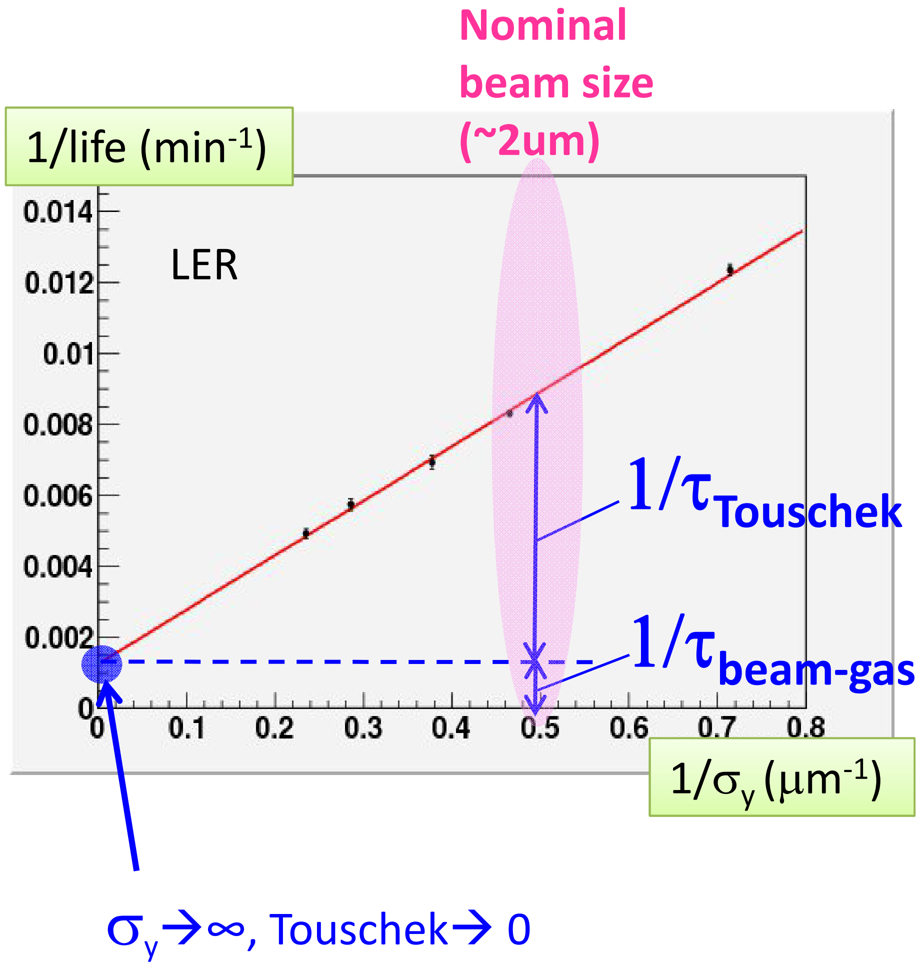
I:beam current , τ:beam life time
k :proportional constant

"k_{Tou}, $k_{beam\text{-}gas}$ are the probability of scattered particle to reach detector and becomes background. It should depend on collimator settings, heavy metal shield amount, and detector performance.

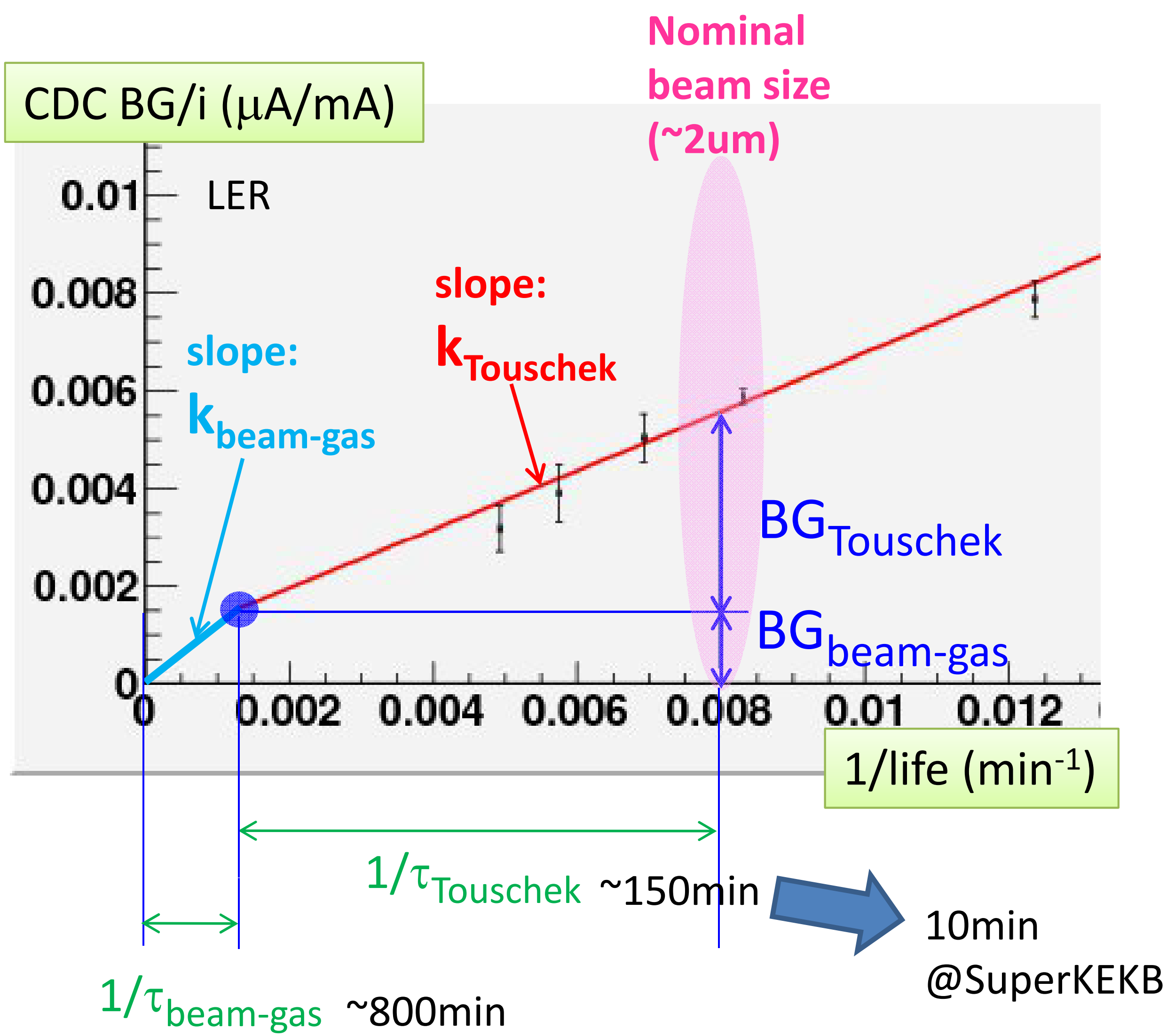
  - Extrapolation strategy for SuperKEKB :
    - The KEK value is assumed for $k_{beam\text{-}gas}$, k_{Tou},and $\tau_{beam\text{-}gas}$.
    - For τ_{Tou} , SuperKEKB design Value (10min) is used.
    - Other background (SR,QED,beam-beam,..) are not considered.

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



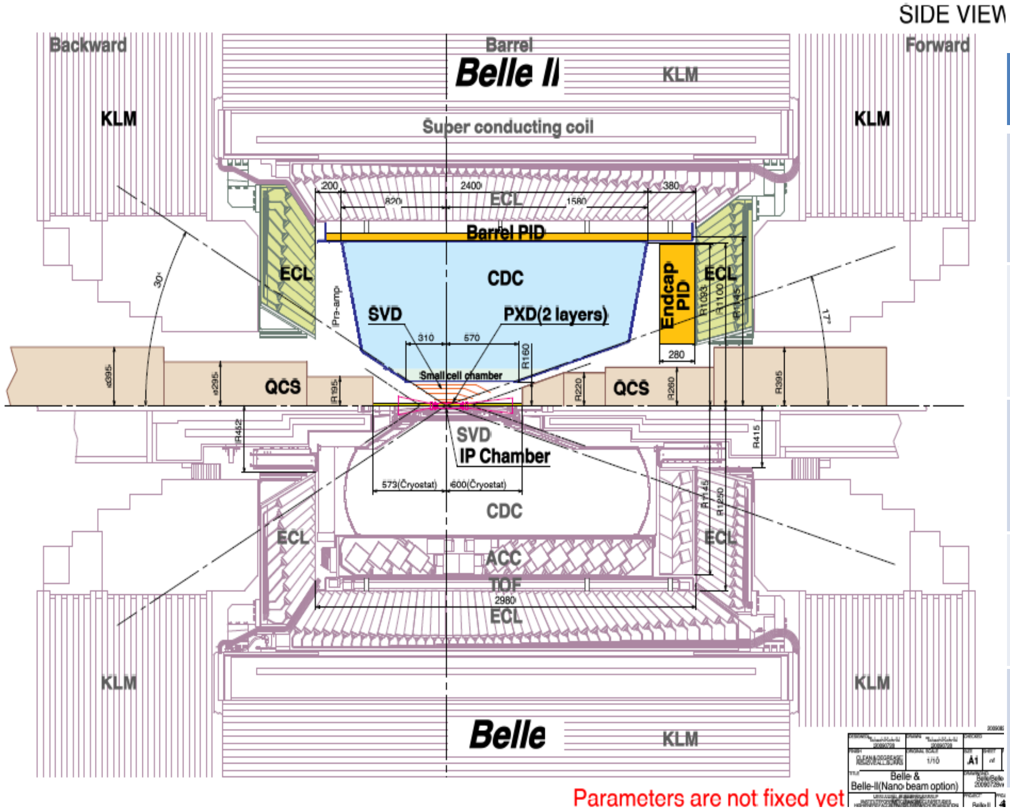


How to measure $k_{Touschek}$, $k_{beam\text{-}gas}$



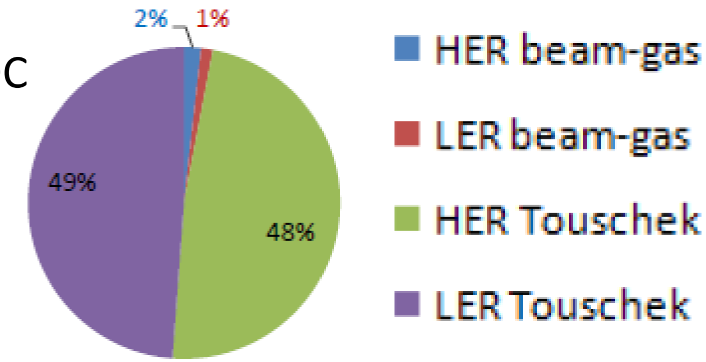
Sugihara(Tokyo)

Extrapolated background at SuperKEKB



	Extrapolated BG (Belle-II+SuperKEKB)
ECL	~9 GeV/event, OK (introduce 5us time window)
TOP	~2.9MHz (=~3MHZ) TOF rate eqiv., ☺ (replaced from current TOF)
CDC	~84kHz/wire (<200kHz/wire), OK (larger radius, more cell number)
SVD	~1.2% occupancy (<10%), OK (shorter integration time)
PXD	~2.0% occupancy (>1%), ☹ (not including low pt particle & few keV gamma)

CDC



Note that only Touschek and beam-gas BG are considered. Other BGs are not included (SR, QED, beam-beam, etc…).

Nakano(Tohoku)

1-2. Simulation vs. Data (KEKB)

Nakano, B2GM7 parallel

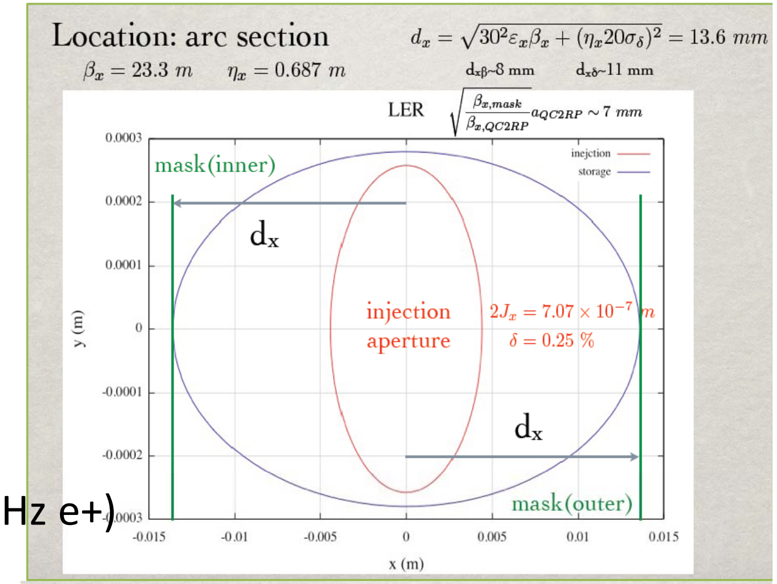
Layer 1	1 Occupancy		2 Dose [krad/yr]	
	Simulation	Data	Simulation	Data
LER				
Touschek	0.47%	0.47±0.07%	32	
Gas	2.24%±0.16% Could be x1/10	0.19±0.07%	40	
HER				
Touschek	0.09%±0.001%	0.006±0.002%	9	
Gas	1.4%±0.1% Could be x1/10	0.49±0.003%	31	
HER+LER	4.2%±0.2%	1.2±0.1%	112±2	100~200

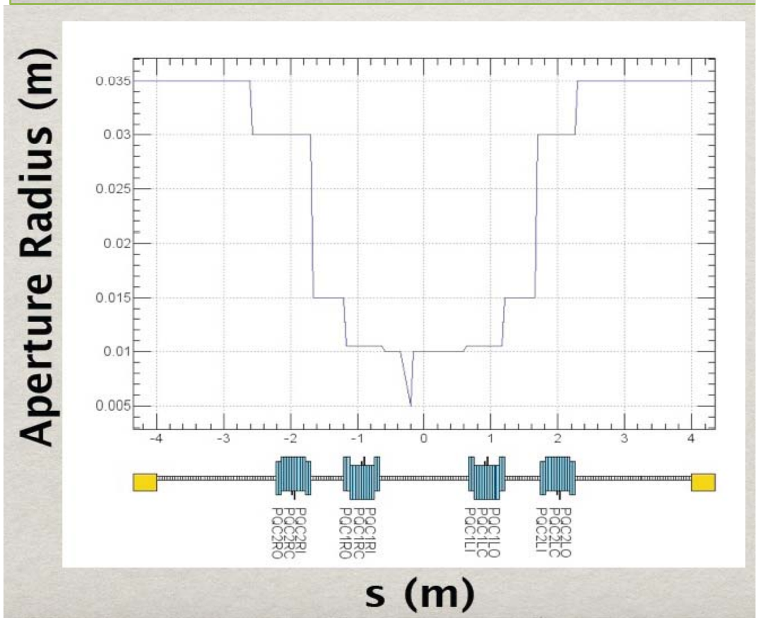
Assumption for simulation:
- 1nTorr CO (0.1~1nTorr?)
- Uniform Touschek in the ring
- 10^7 seconds/year (dose)
- etc..

TURTLE+GEANT simulation is consistent with experimental data.

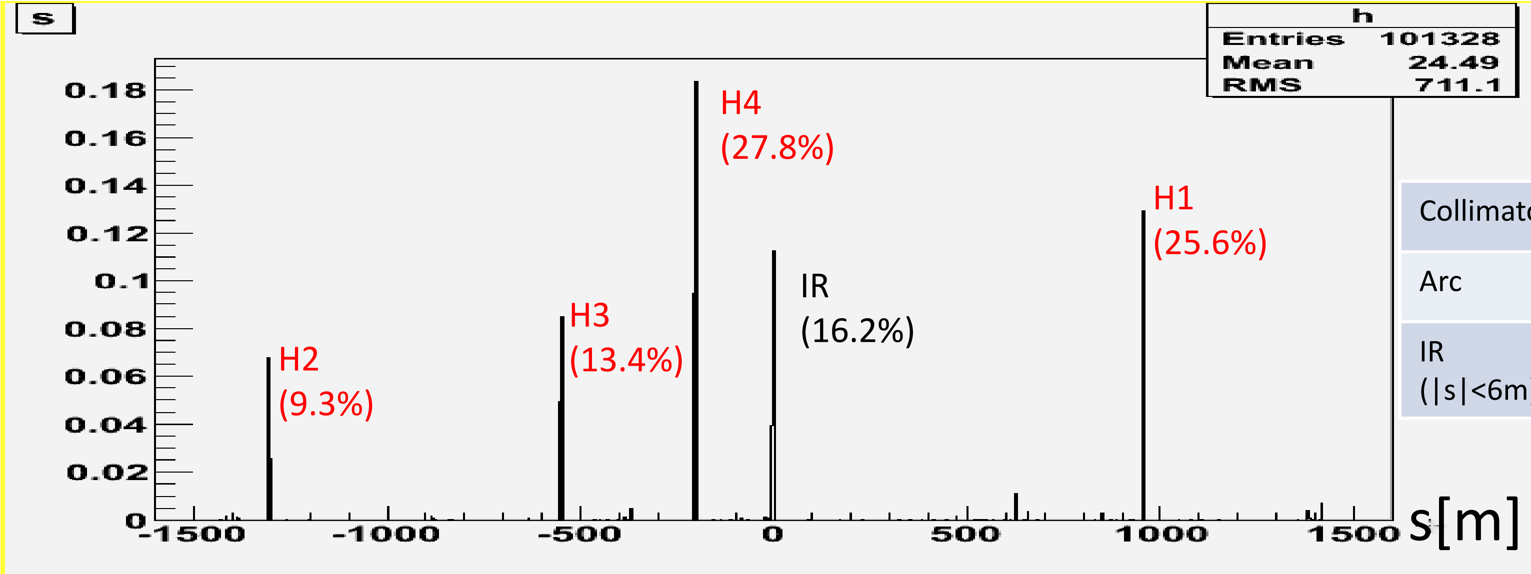
1-3. SuperKEKB simulation

- LER Lattice: ler1354f.sad
- Scattering probability depends on:
  - Scattering position: $\propto \sigma_x(s_0)^{-1}\sigma_y(s_0)^{-1}$
  - |dE/E|: 14~100sigma(1.1 % ~ 8 %)
- I=3.6A, Touschek life=600sec
  - Total loss: -6mA/sec, 240W, 380GHz e+
    (cf KEKB: 1.7A, life=7000sec, Total loss=8W, 12GHz e+)
- Collimator setting (preliminary)
  - 4 collimators in arc section
    - s=-2060m, -1300m, -550m, -200m
  - horizontal: both side (inner/outer)
    (KEKB: inner only)
  - +-13.6mm from beam center
    (we can further close collimators to ~12mm without losing Touschek lifetime)
- Beam-pipe aperture in IR (preliminary)
  - Updated after this simulation





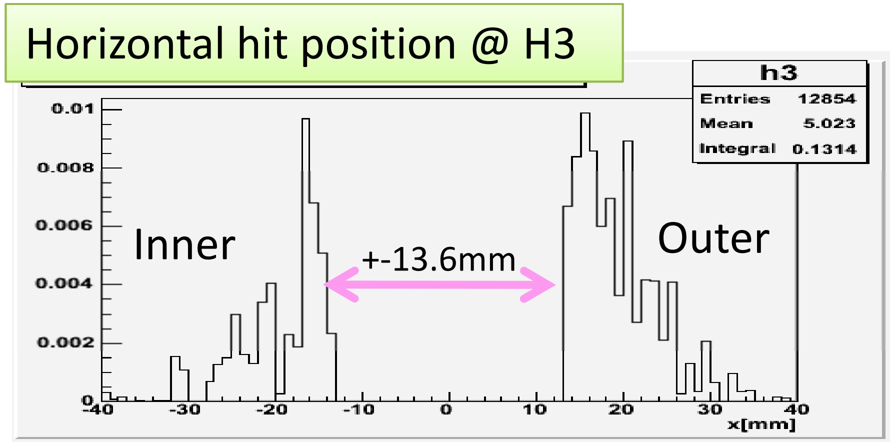
Loss distribution (ring)



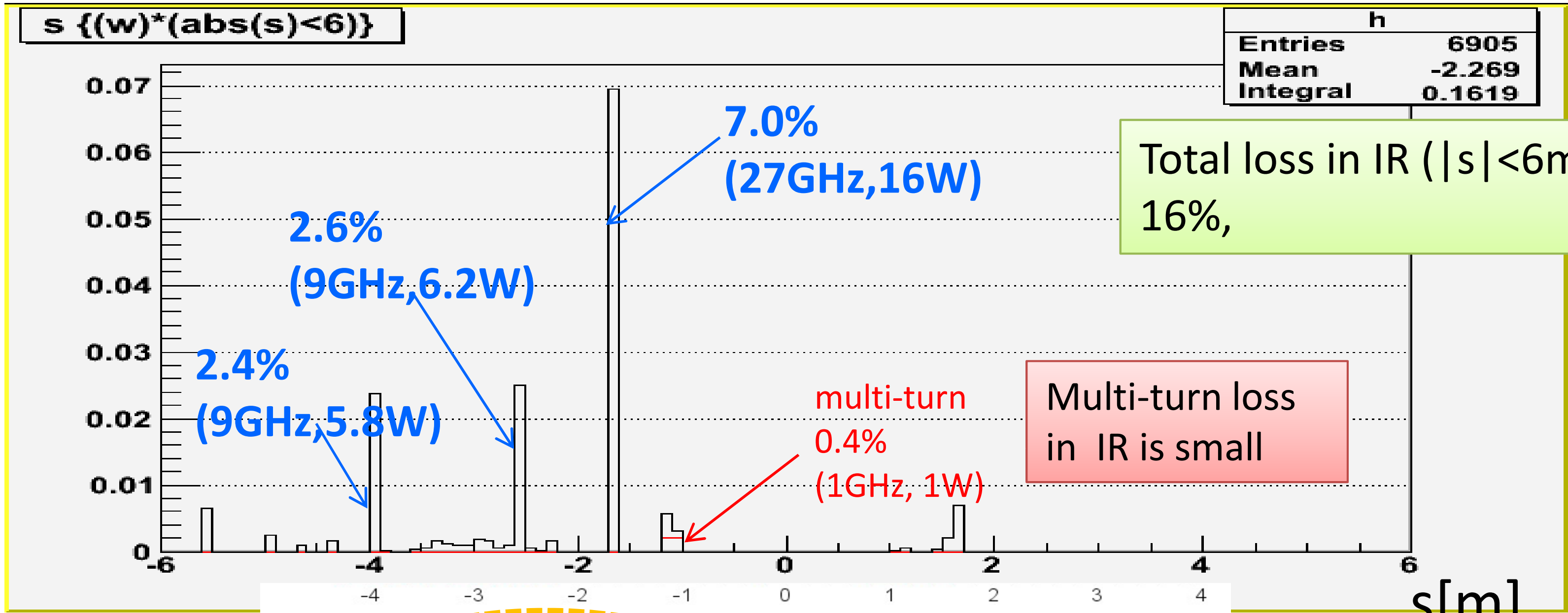
Collimators	**76.2%**
Arc	7.6%
IR (|s|<6m)	**16.2%**

Collimators stop ~76% of Touschek loss.
Outer collimator seems effective.
~16% reaches to IR region(|s|<6m).

More loss at masks can be achieved by narrowing collimators(→+-~12mm), without losing Touschek life time.



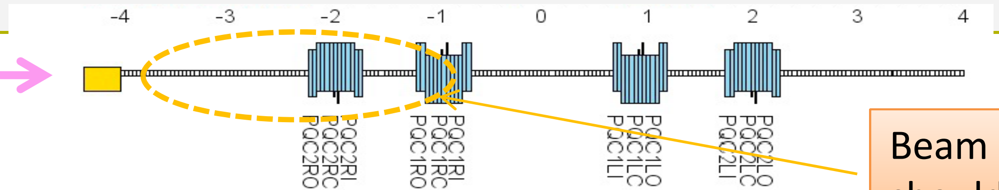
Loss distribution (IR)



Total loss in IR (|s|<6m): 16%,

Multi-turn loss in IR is small

4GeV e+



Beam pipe material of this part should be heavy, such as Ta

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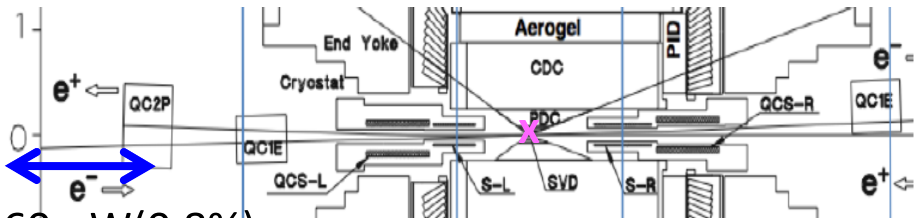
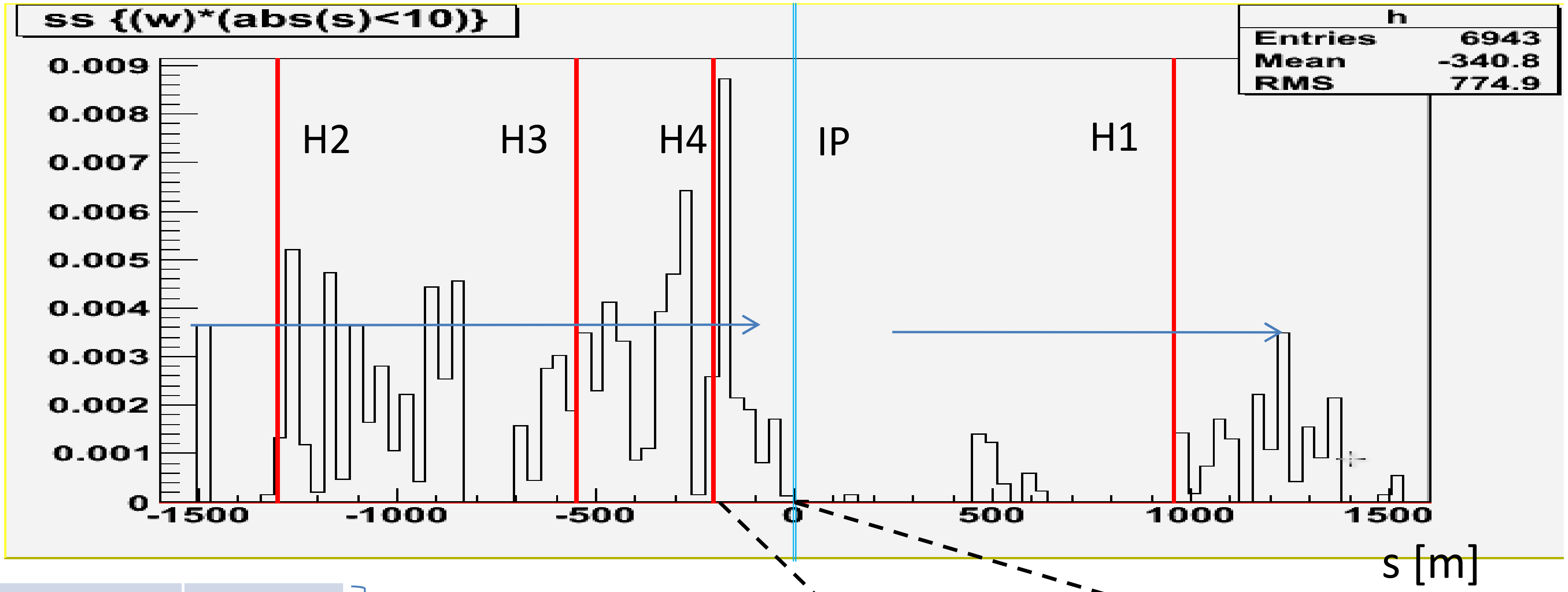
cf. KEKB
Main source of Touschek background is loss at QC2(s=-6~-10m), 60mW.



60mW(0.8%)
(6~10m)

KEKB: W shield inside QCS

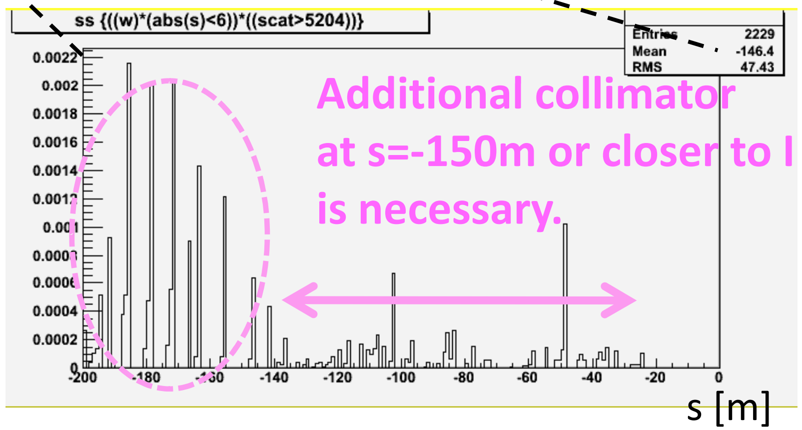
Scattered position of IR loss



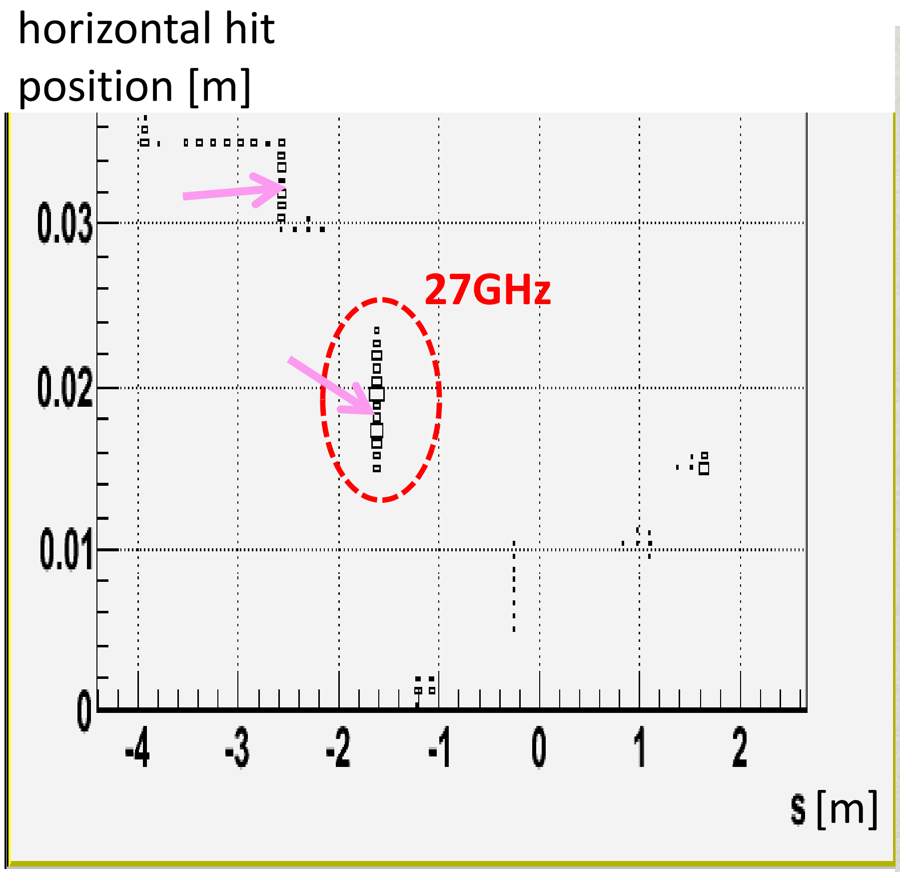
Before H1	0.5%
Before H2	2.9%
Before H3	6.0%
Before H4	4.3%
After H4	**2.2%**
Total	**12.0%**

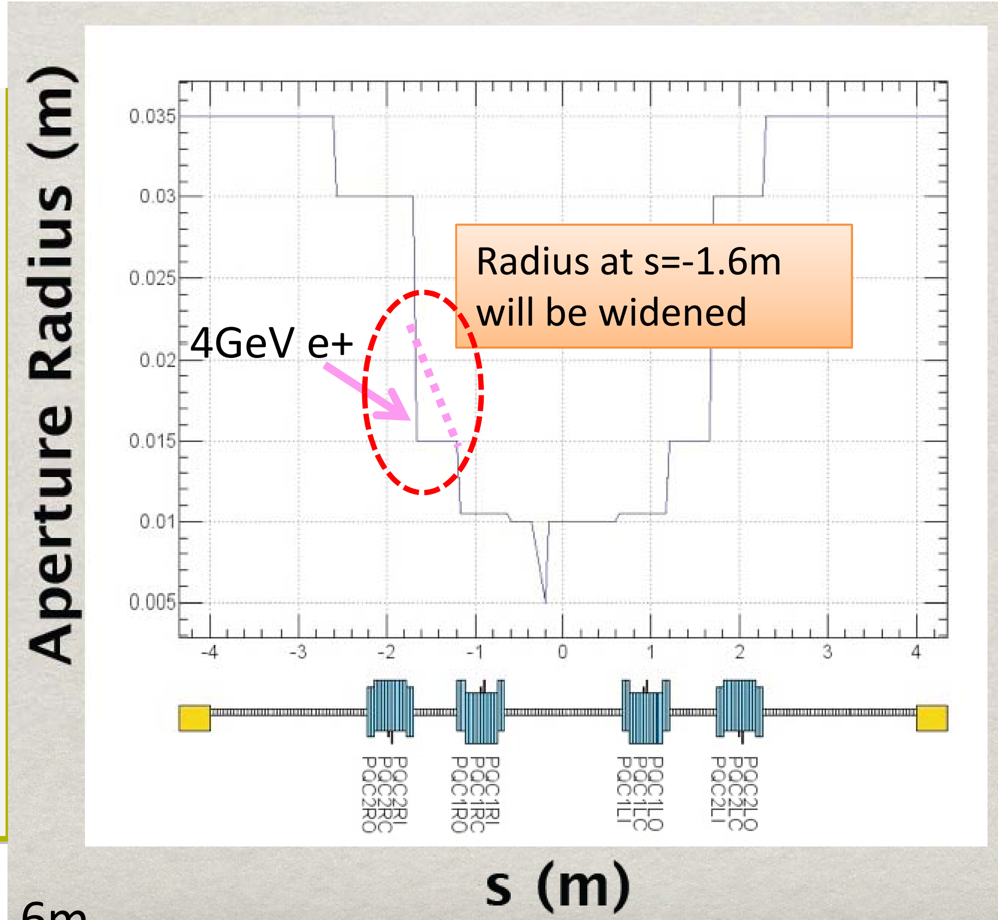
These can be reduced with narrower collimators.

To reduce this, additional collimator closer to IP is necessary.

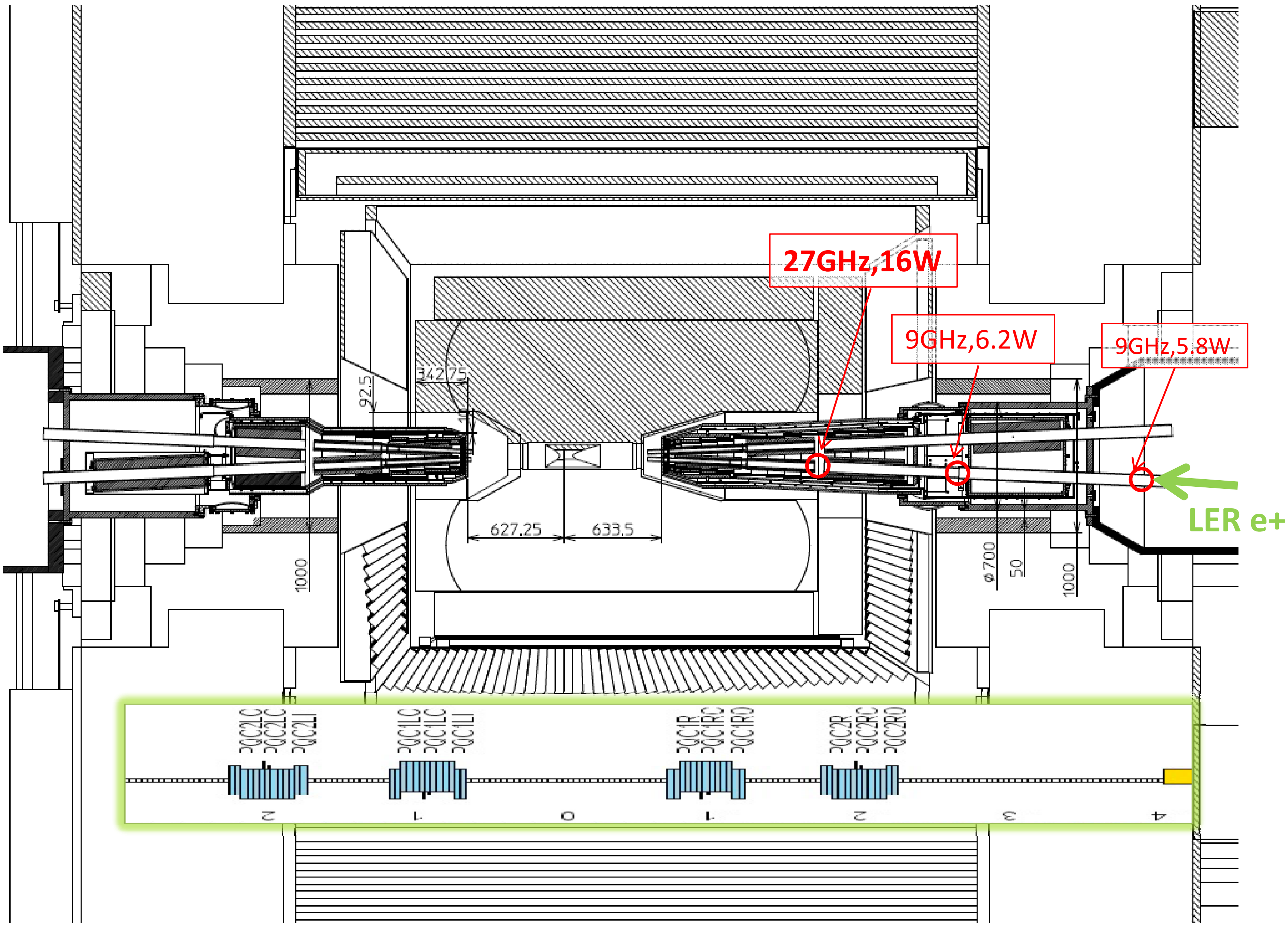


Beam-pipe physical aperture





particles lost at s=-1.6m
will be lost closer to IP, or go through (not lost)
→ to be simulated



27GHz,16W
9GHz,6.2W
9GHz,5.8W
LER e+
627.25
633.5
92.5
1000
1000
50

Touschek: KEKB vs. SuperKEKB

ler1354f.sad

	KEKB(LER)	SuperKEKB(LER)
Beam energy	3.5 GeV	4.0 GeV
Beam current	1.7A	3.6A
Touschek lifetime	~7000 sec	600 sec
Loss rate(Total)	8W, 12GHz e+	240W, 380GHz e+
IR/Total	0.7%	16%
Loss rate(IR)	**60mW, 0.1GHz e+**	**40W, 60GHz e+**
IR loss position	s=-6m~10m	s= -1.6m-4m

x30: almost fixed

x20: to be improved

$I=eNf_0$

$f_0=v_{e+}/3000m =10^5[Hz]$

$R= I/(ef_0)/\tau$ [Hz]

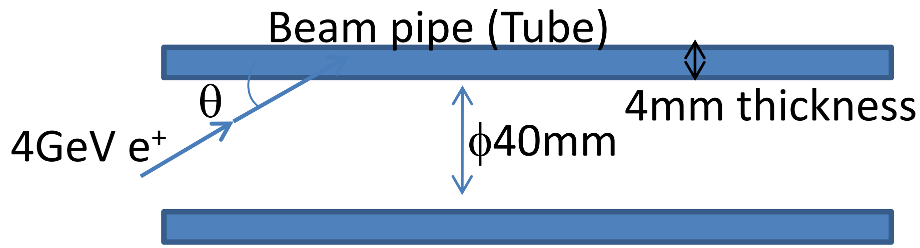
$W= RE=IE/(ef_0)/\tau$ [W]

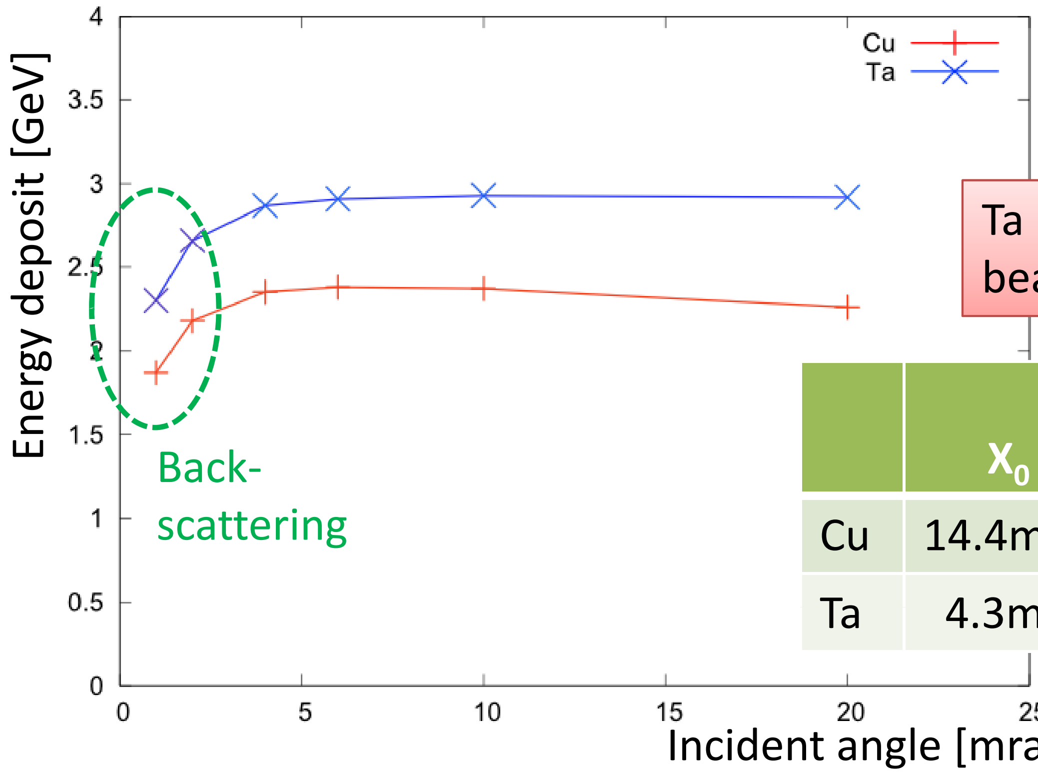
- Need narrower collimators (13.6mm→~12mm)
- Need additional collimator at s=~-150m or closer to IP

- Loss position should be moved to upstream for shielding showers

Toy GEANT simulation

- 4GeV positron
- Beam pipe material: Cu, Ta
- Beam pipe shape: simple tube
- Incident angle: θ=1,2,4,6,10,20 mrad

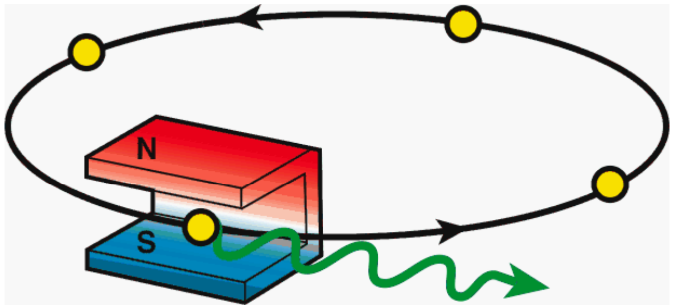




Ta is preferable for beam-pipe material

	X_0	Energy deposit on 4mm thick
Cu	14.4mm	~60% deposit
Ta	4.3mm	~70% deposit

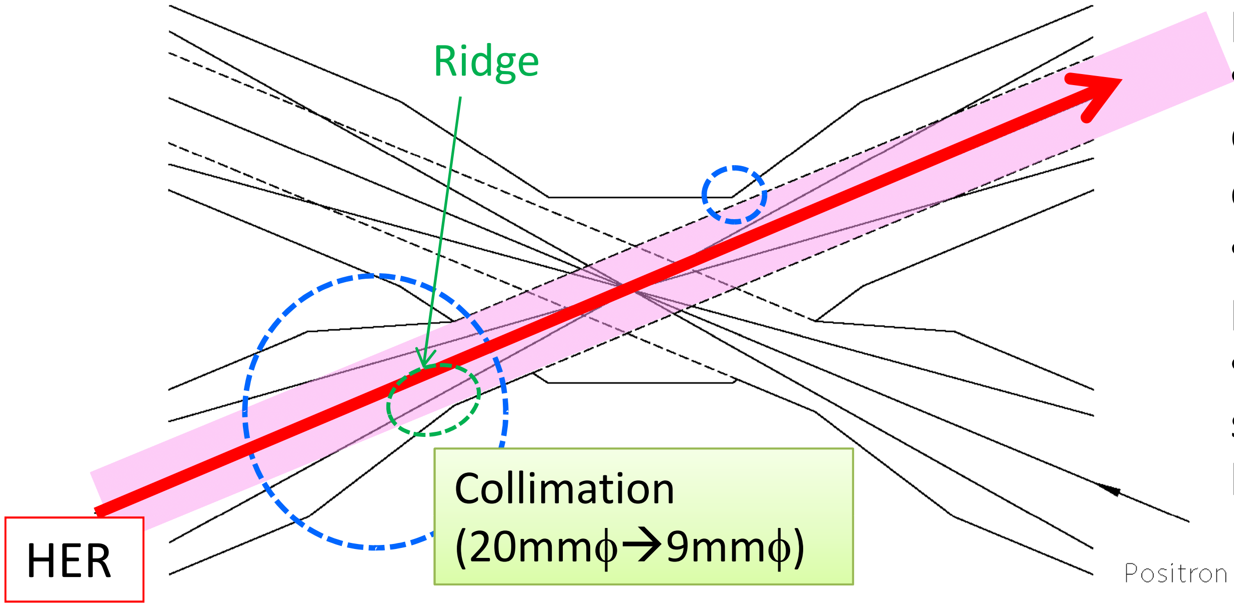
2. Synchrotron Radiation

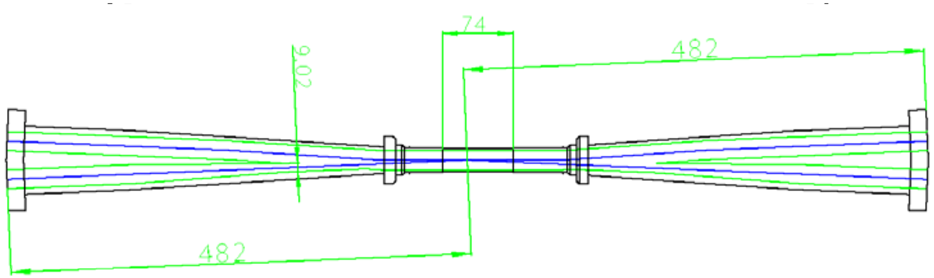


☑ Flux simulation
☐ GEANT4 simulation

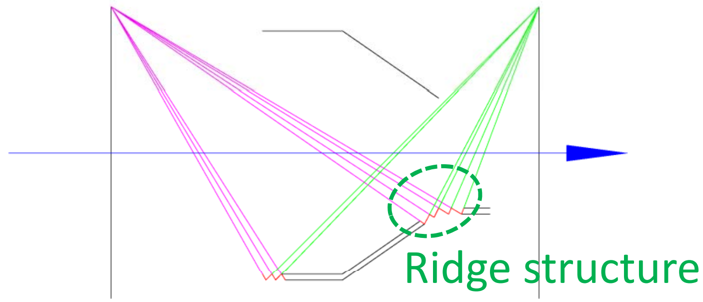
Latest beam pipe design

Proposed at last B2GM, by K. Kanazawa





- Collimation part of incoming pipe stops most of SR.
- The minimum distance of the duct wall from the beam stay clear is 2 mm.
- HOM can escape through the pipes for the outgoing beam.
- “Ridge” structure on inner surface of collimation part to hide IP from reflected SR.

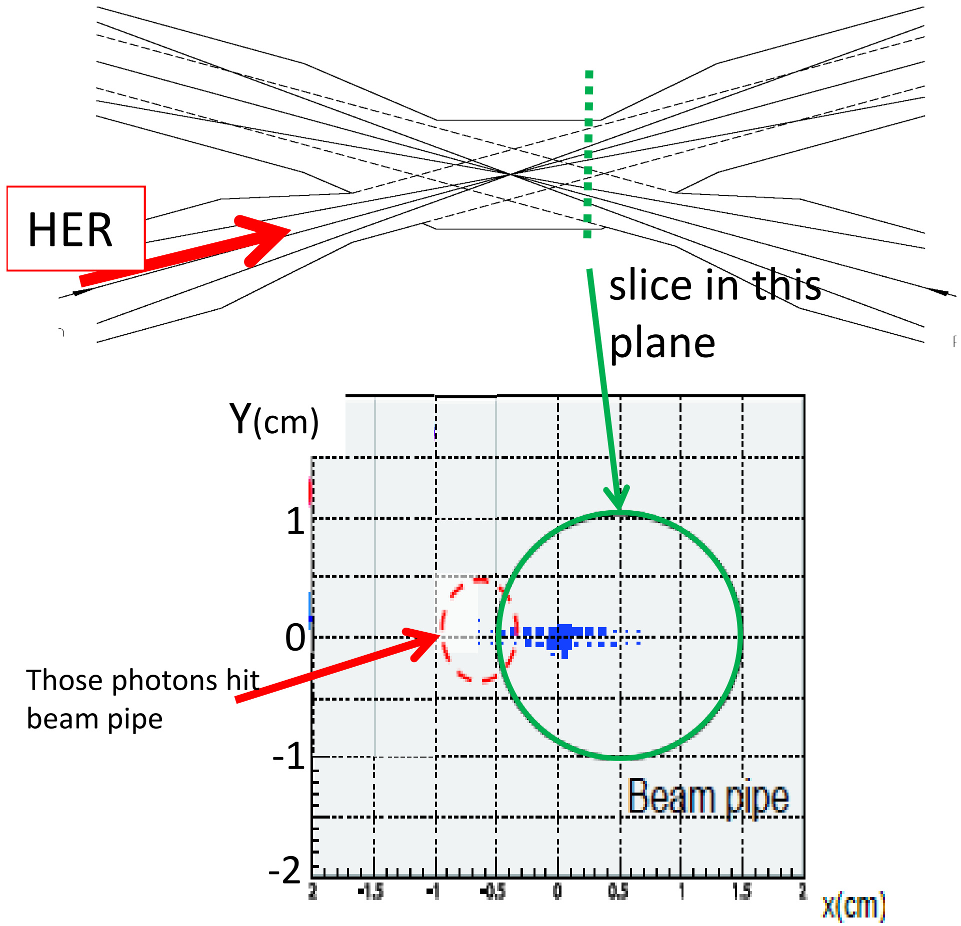


See Kanazawa’s talk

M. Iwasaki

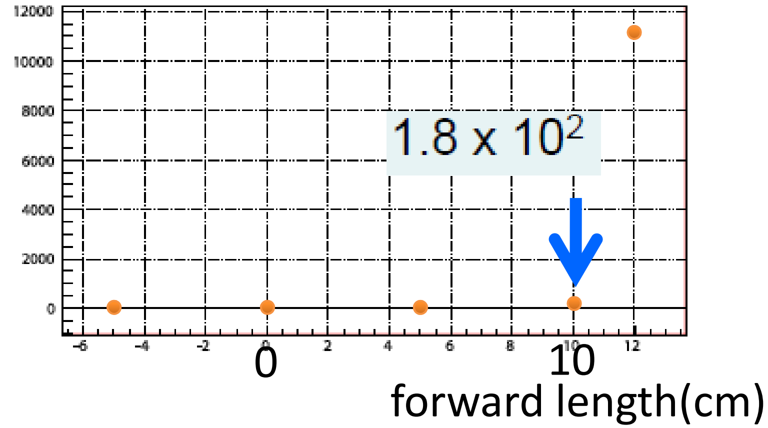
Synchrotron radiation

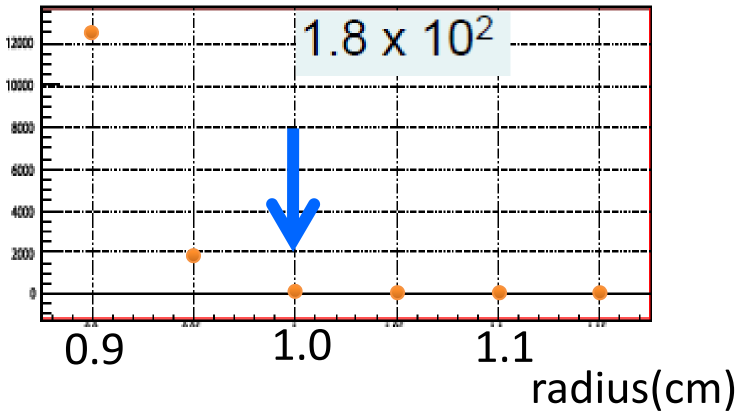
HER(5252a)



1.8x10^2/bunch (>5keV) photons hit straight part of beam pipe.

#photon vs. beam pipe geometry

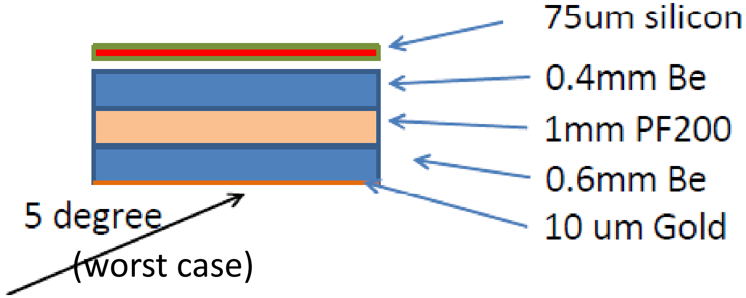




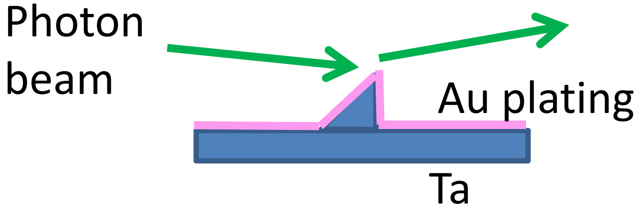
Gives requirements for fabrication accuracy and alignment

GEANT4 toy study

Simple beam-pipe model



E (keV)	Survive rate
1	<1x10^-6
5	<1x10^-6
10	<1x10^-6
20	~3x10-6
30	~30x10^-6



Quick GEANT4 study
- 5 degree(worst case), 1-30keV photon
- After passing through the beam-pipe, 3x10^(-6) will survive for 20keV and less for lower energy

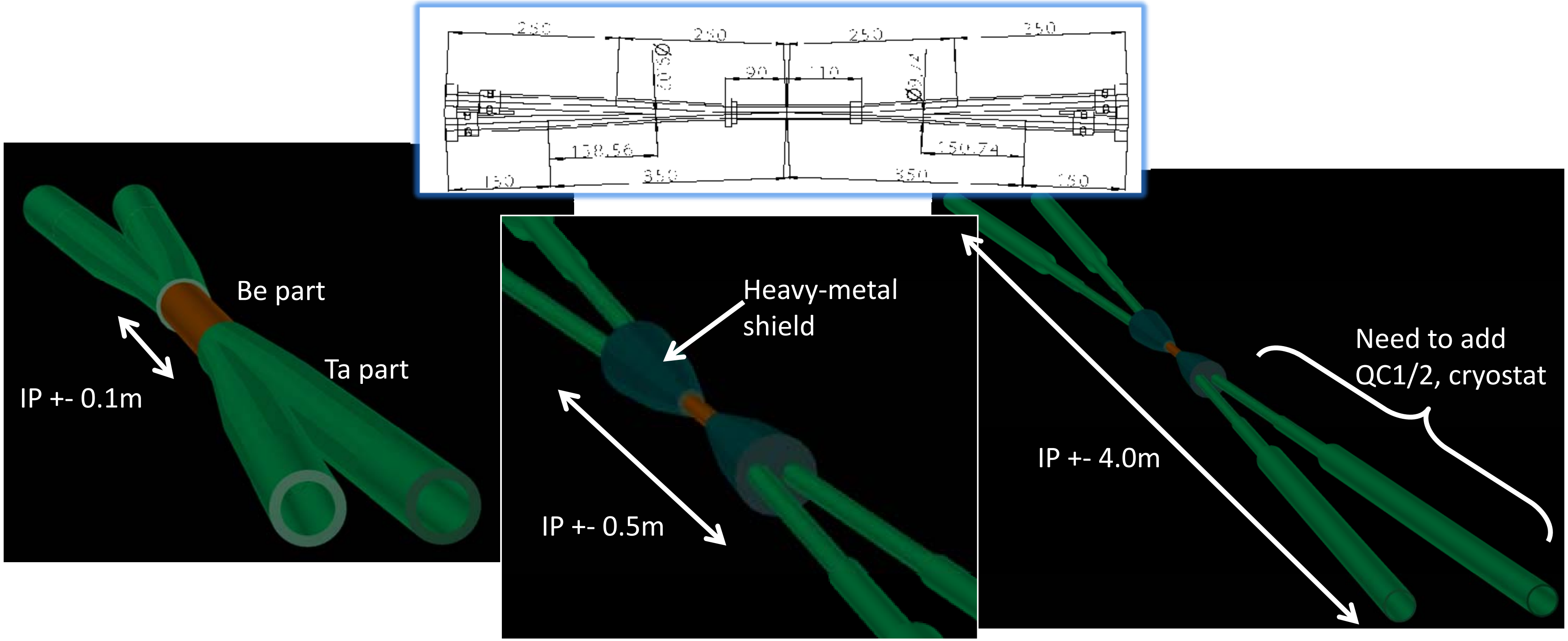
PXD requirement:<1% occupancy
⇔ <6.4 hits/bunch on PXD

- SR hits on beam pipe: O(10^3)/bunch
  → <<1hits/bunch on PXD→OK!
- Back-scattering effect (for high energy SR) should be checked with realistic beam pipe geometry.
- SR depends on leak field distribution.
- Reflection/tip-scattering at "ridge" structure on collimation part is not easy to simulate
  → Beam-test is planned.

3.GEANT4 simulation

Clement(Tokyo)

IR beam pipe in GEANT4

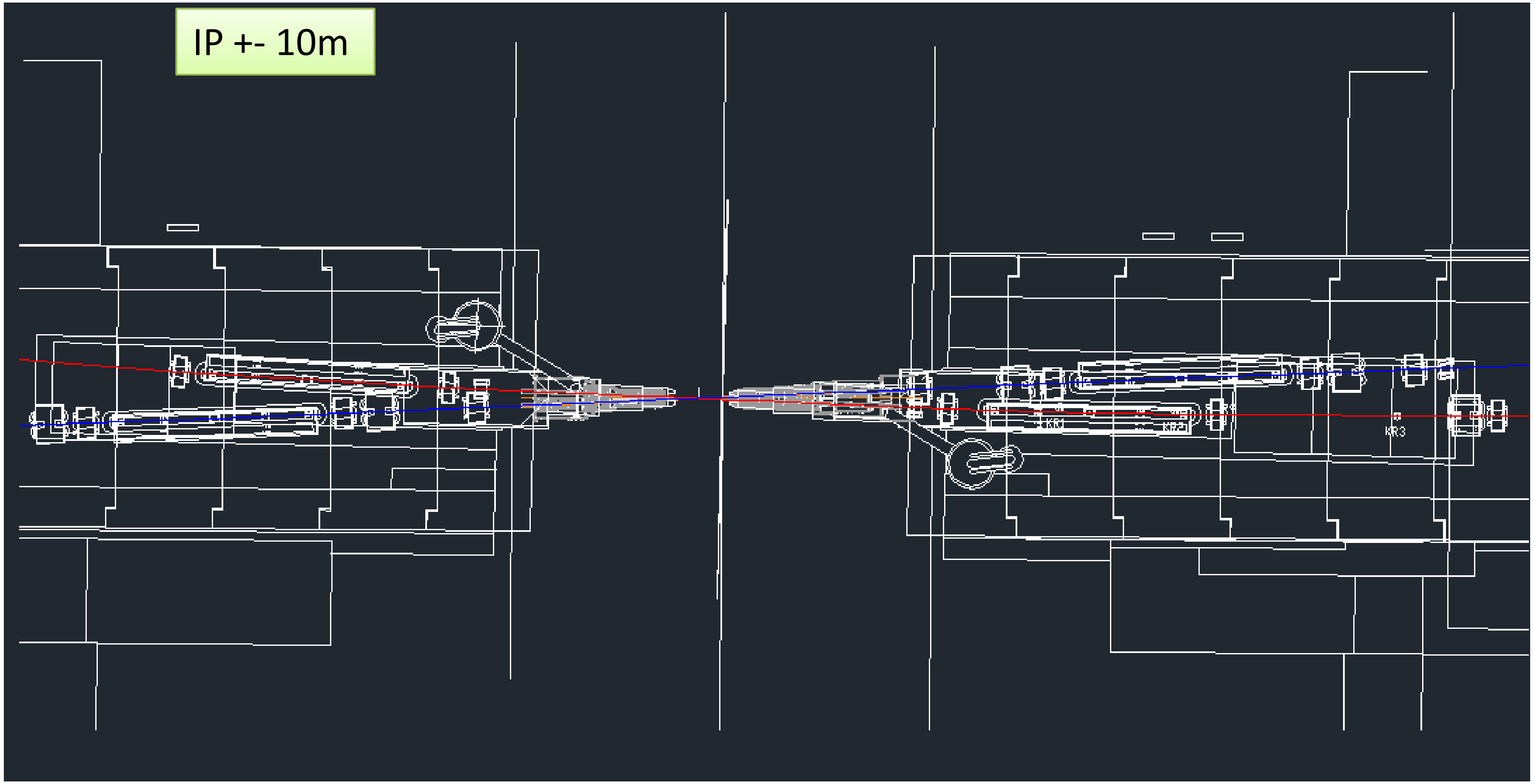


Beam-pipe, heavy-metal shield is implemented.

QC1/2 magnets, cryostat, non-uniform magnetic field will be implemented soon.

Further IR geometry

Provided by Masuzawa

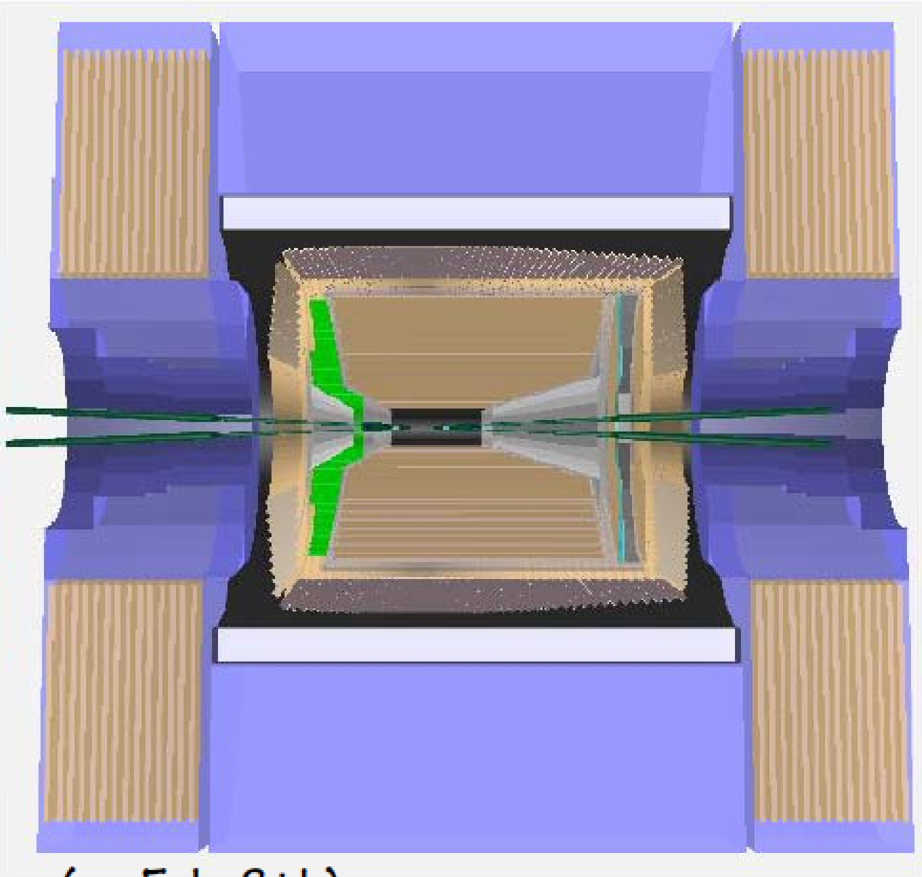


Implementation will be step-by step,
from IP to far from IP+-10m

geant4 sim w/ basf2

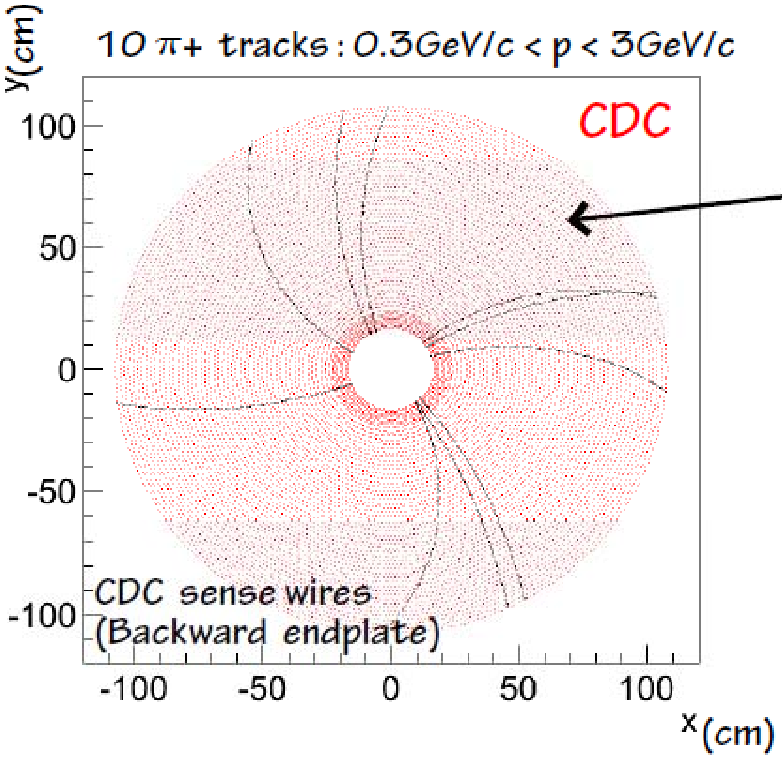
Det. part	Geom.	Digitization
IR	pipe + shield	–
PXD	sensors	first version
SVD	sensors	first ersion
CDC	wires + others	hits
TOP	quartz + PMT	optics treat
ECL	scintilator	will start
A-RICH	aerogel+HAPD	optics treat
EKLM	sensor + iron	debug
BKLM	not yet	not yet
Structure	solenoid+yoke	–

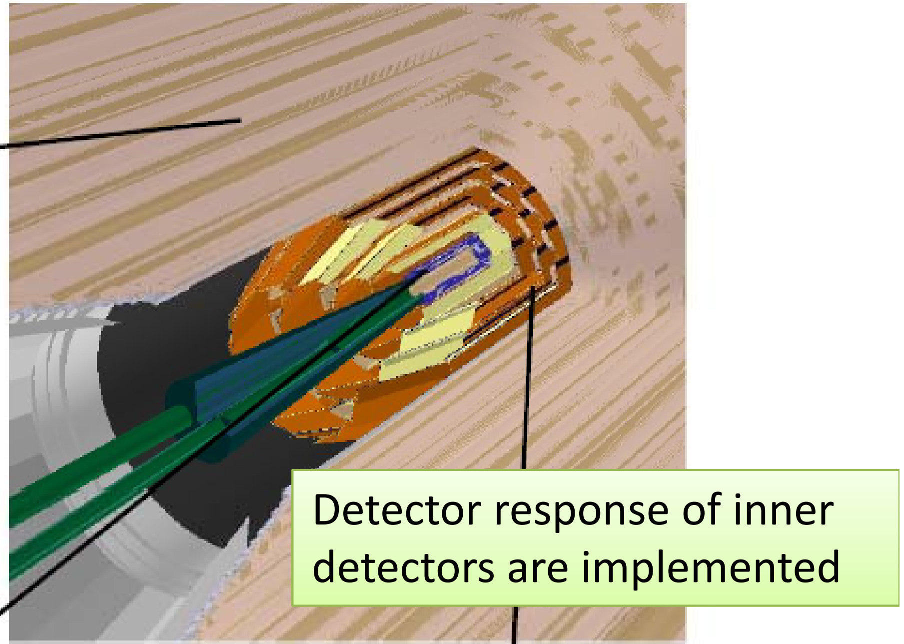
IR: more precise geom. up to +-10m? (now: +-50cm)
QCS magnets
non-uniform B-field



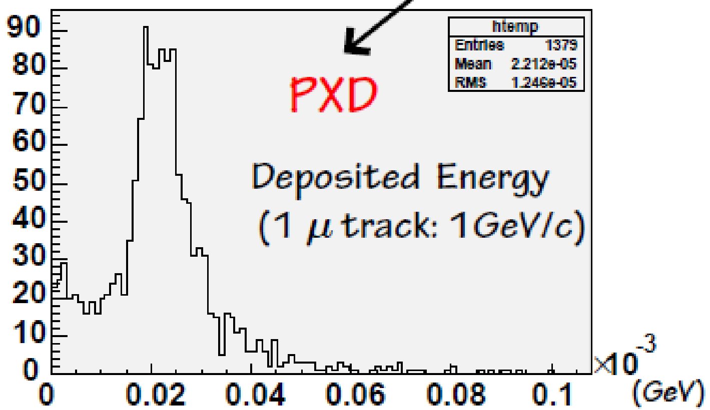
all available sub-detectors are included
in the first release of the Belle II library (on Feb. 8th)

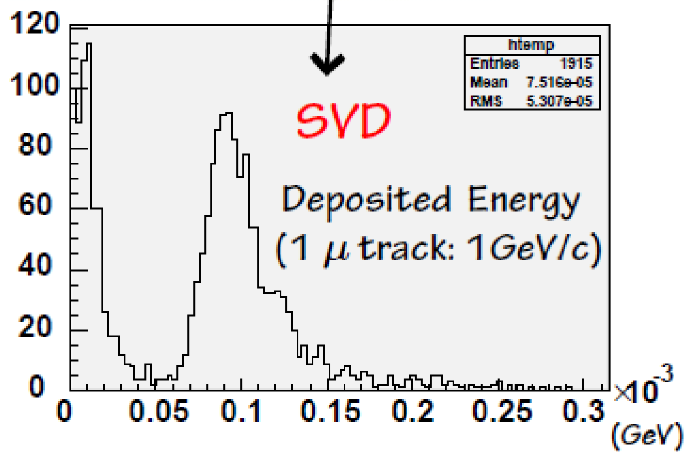
geant4 sim w/ basf2





. particle Gun
. hepevt
. TouschekReader





Summary

Touschek

- Extrapolation of KEKB data toward SuperKEKB is performed.
  - Expected background meets requirement for SVD,CDC,TOP,ECL.
- Simulation validity is confirmed.
  - KEKB simulation results are consistent with KEKB data.
- Preliminary SuperKEKB simulation is performed.
  - ~40W loss in IR region (cf.60mW@KEKB), but we have a room to improve: ex. narrower/additional collimators, wider IR beam-pipe aperture

Synchrotron radiation

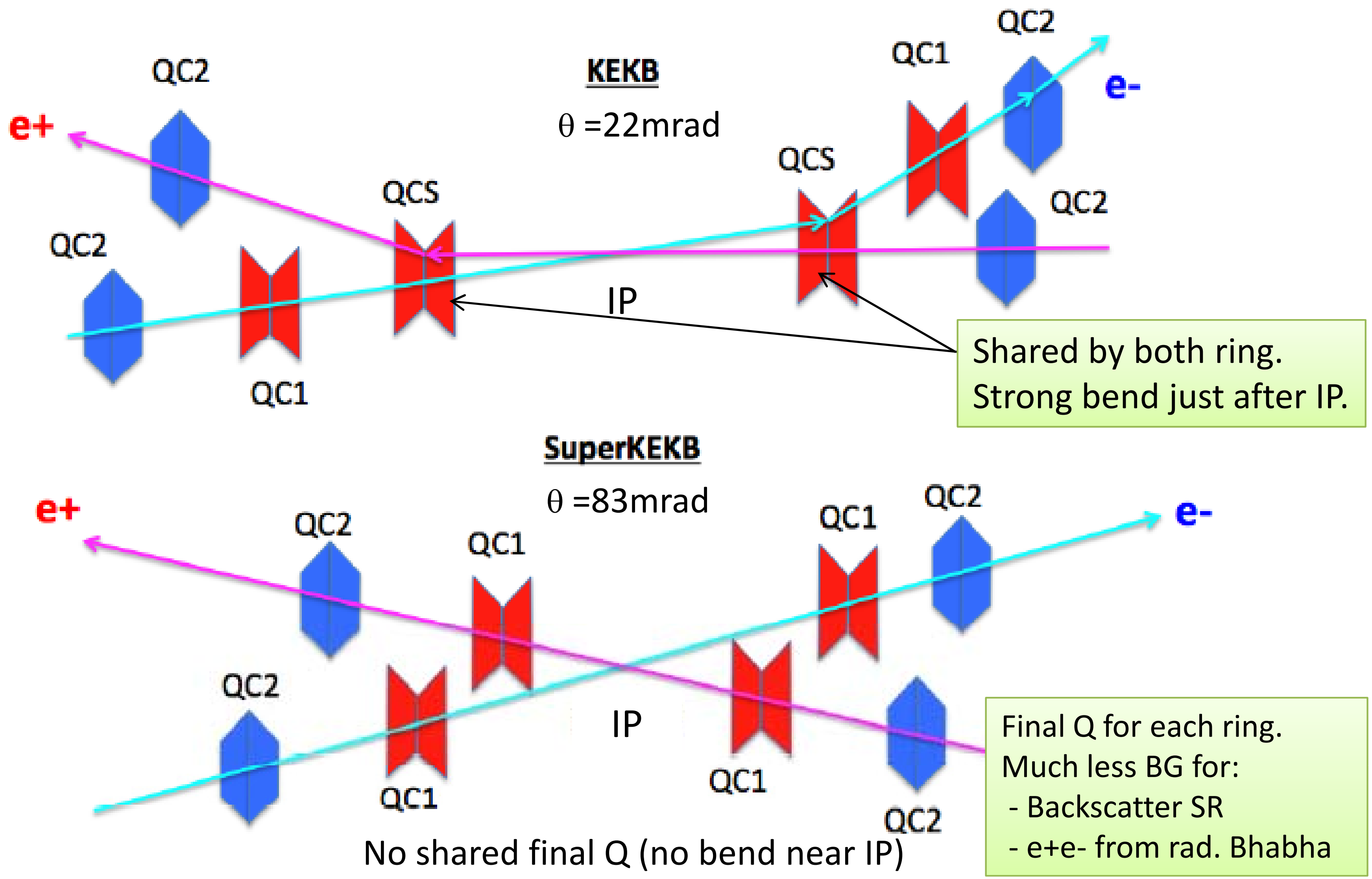
- Collimation part on incoming beam-pipe stops most of SR.
- Simple simulation shows expected PXD occupancy meets requirement.
- Back-scattering effect for high energy SR, tip-scattering on collimation part should be checked. Leak field dependency should be also checked.

GEANT4 simulation

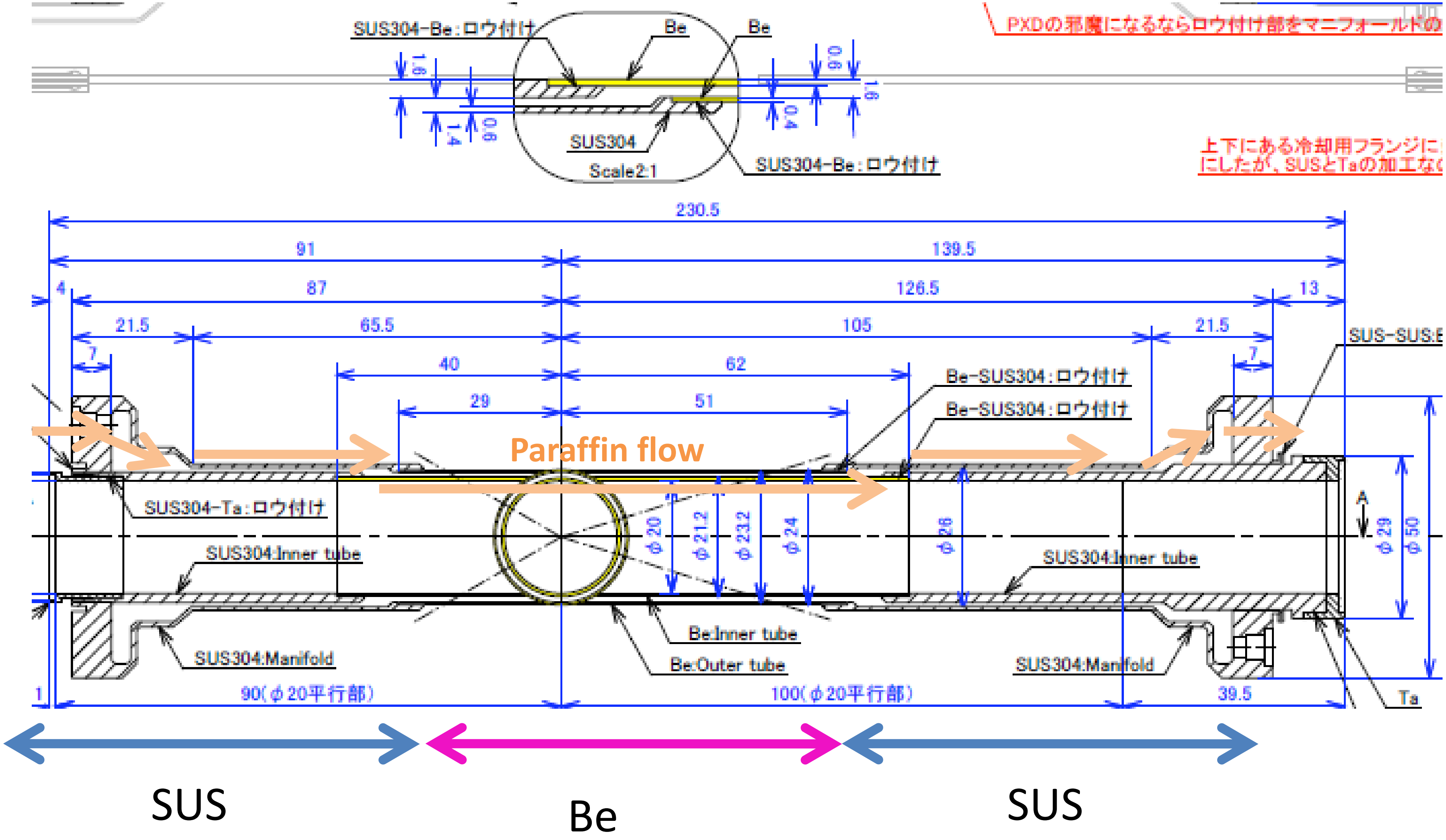
- Full detector simulator is released recently.
- IR magnets, cryostat geometry is missing: should be implemented a.s.a.p.

backup

Final focusing magnets



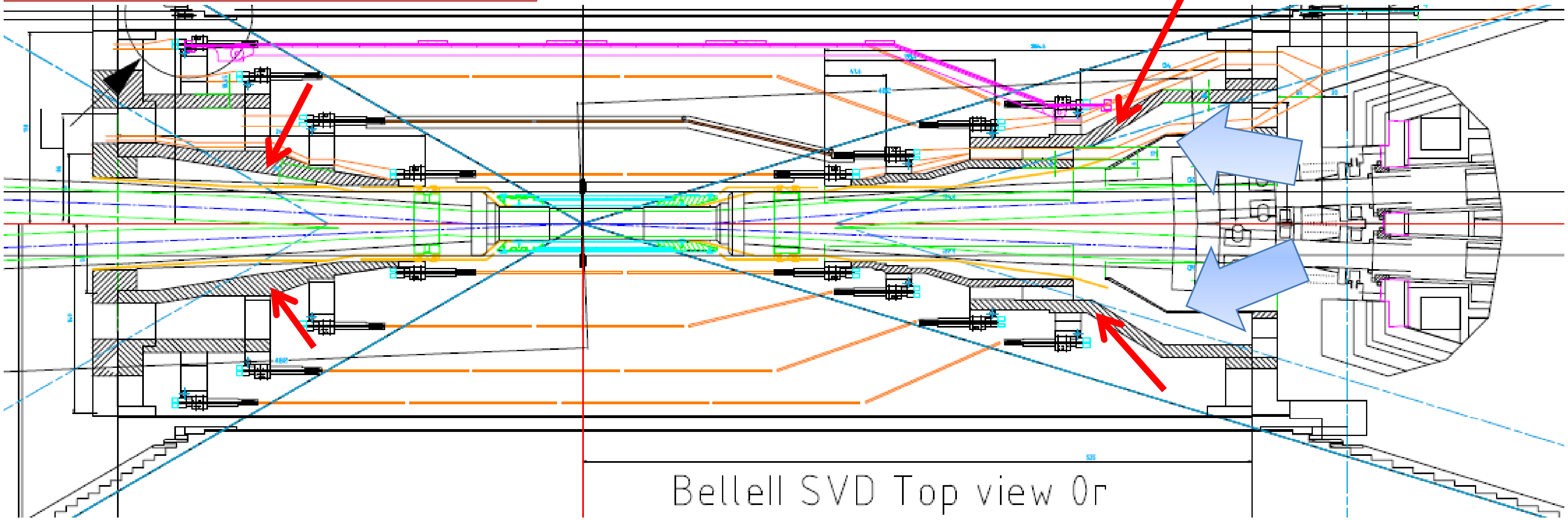
Latest beam-pipe design



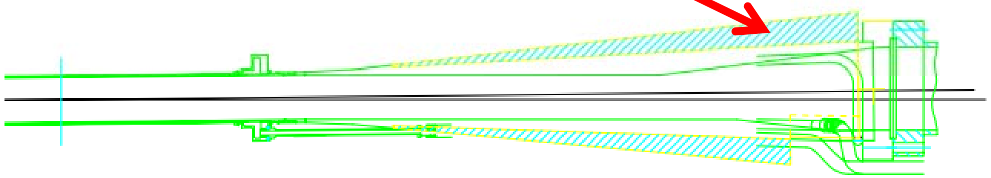
Heavy-metal shield (SuperKEKB)

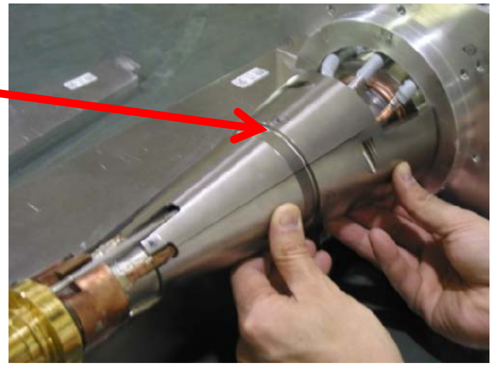
Belle-II IR design(Preliminary)

Heavy-metal shield to protect PXD/SVD from showers coming from upstream.

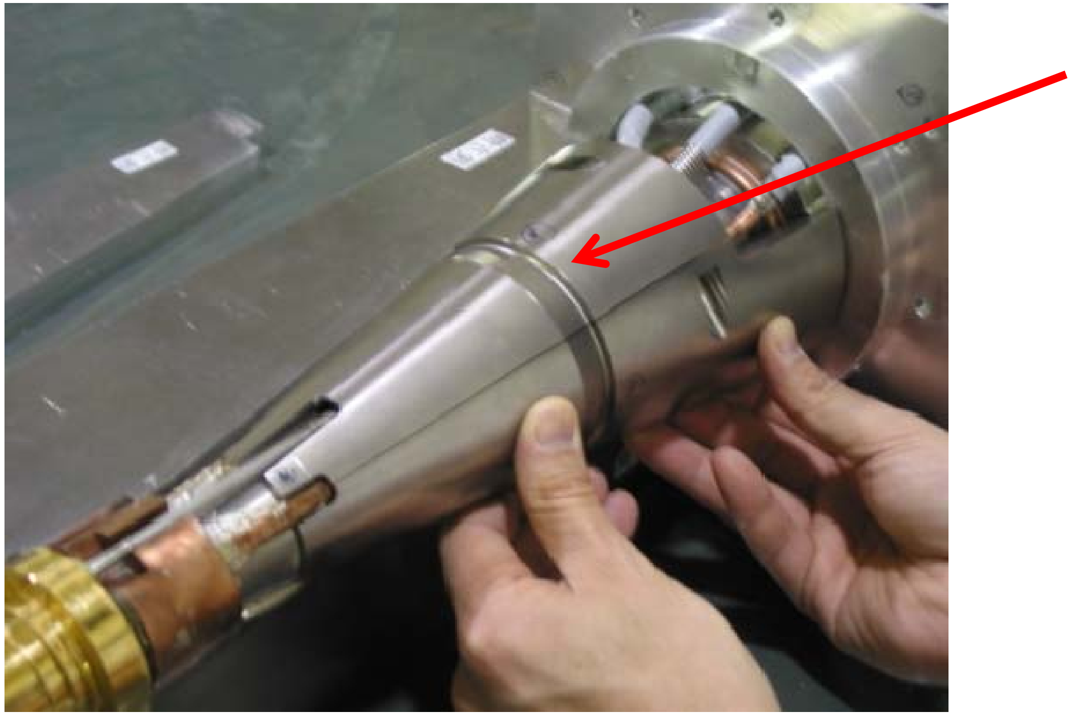


cf. Heavy-metal shield @ Belle



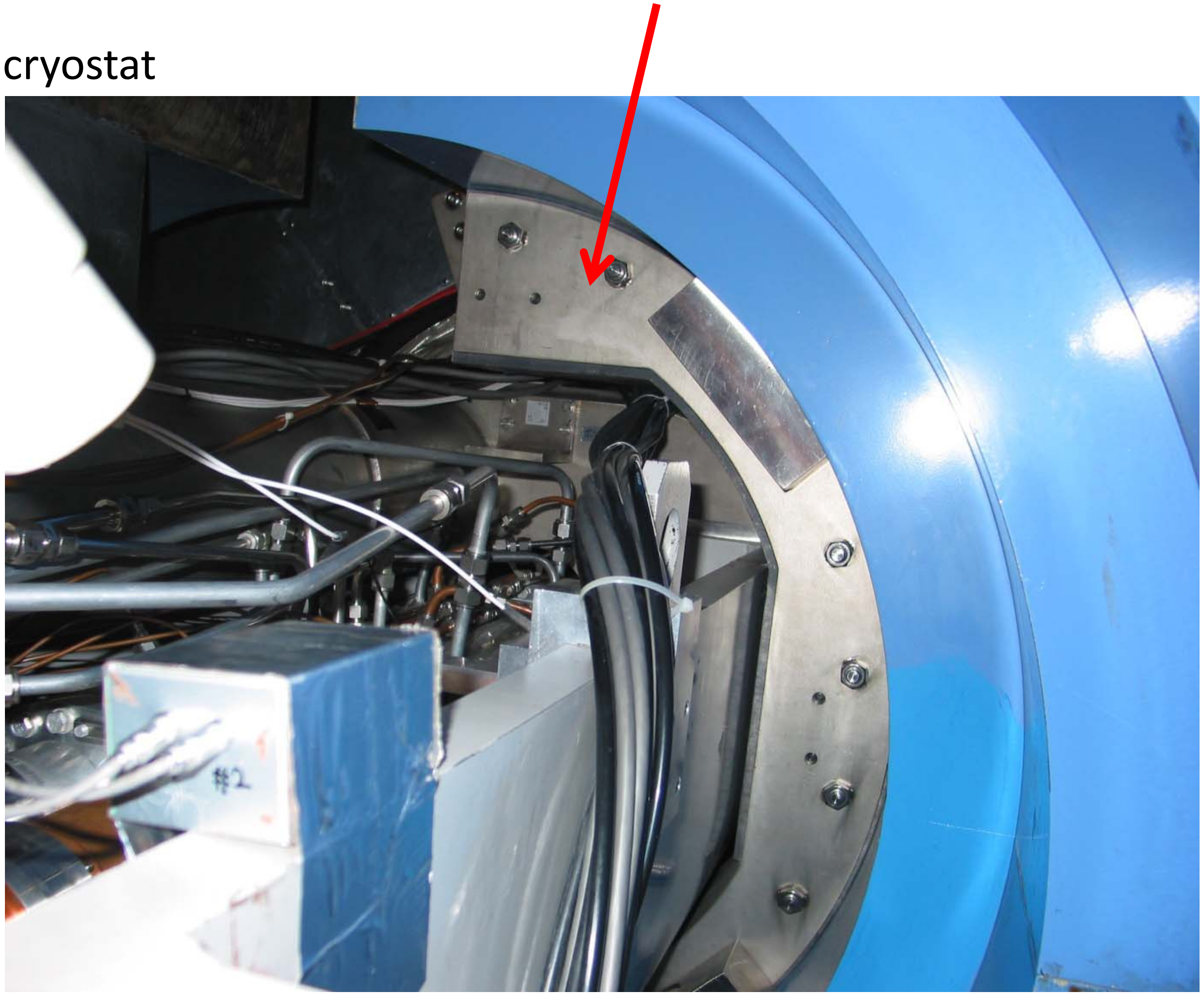


Heavy-metal shield(KEKB)



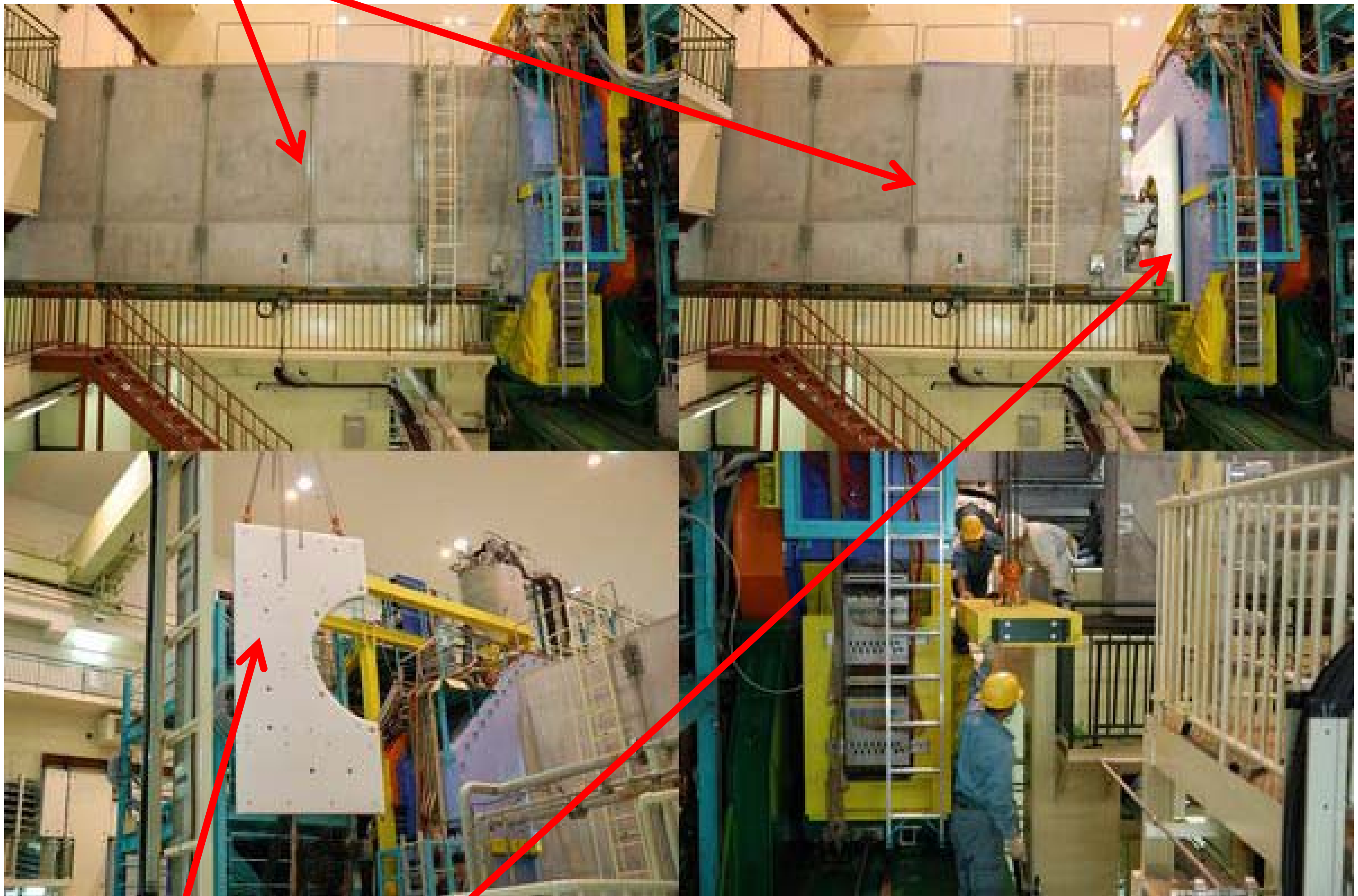
Lead shield in QCS cryostat (KEKB)

QCS-L cryostat



Neutron shield (KEKB)

Concrete wall



Polyethylene shield

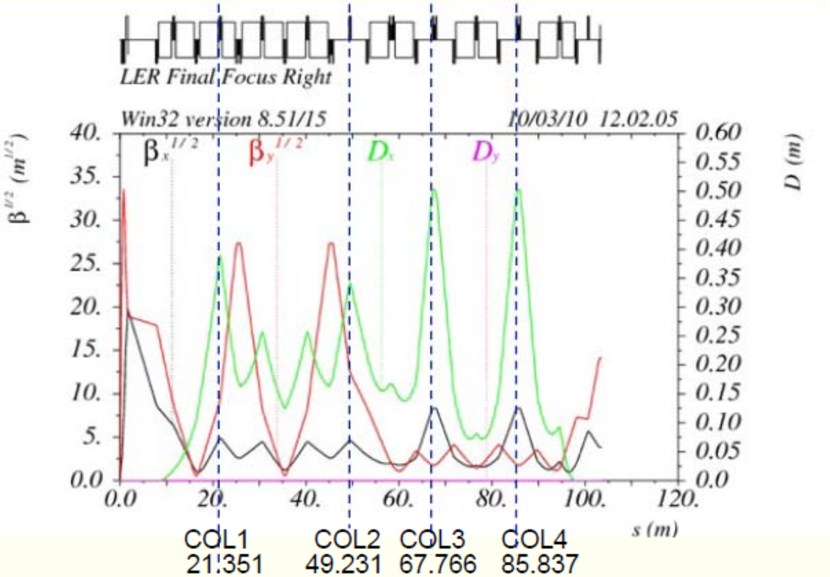
SuperB estimations

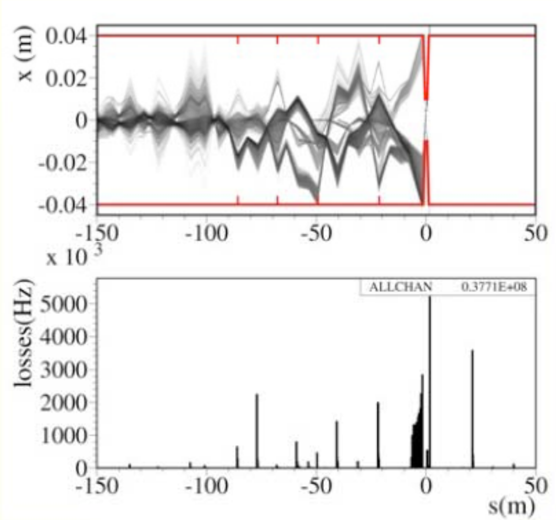
Touschek

Paoloni, XIV SuperB Meeting @ INFN-LNF

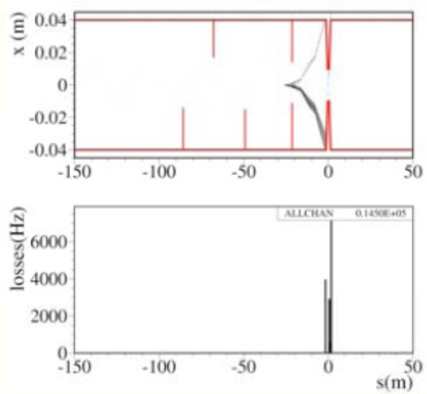
τ_{TOU} = 356 s (5.9 min)

IR losses = 8.6 MHz |s|≤2 nt =1-5
(open jaws)





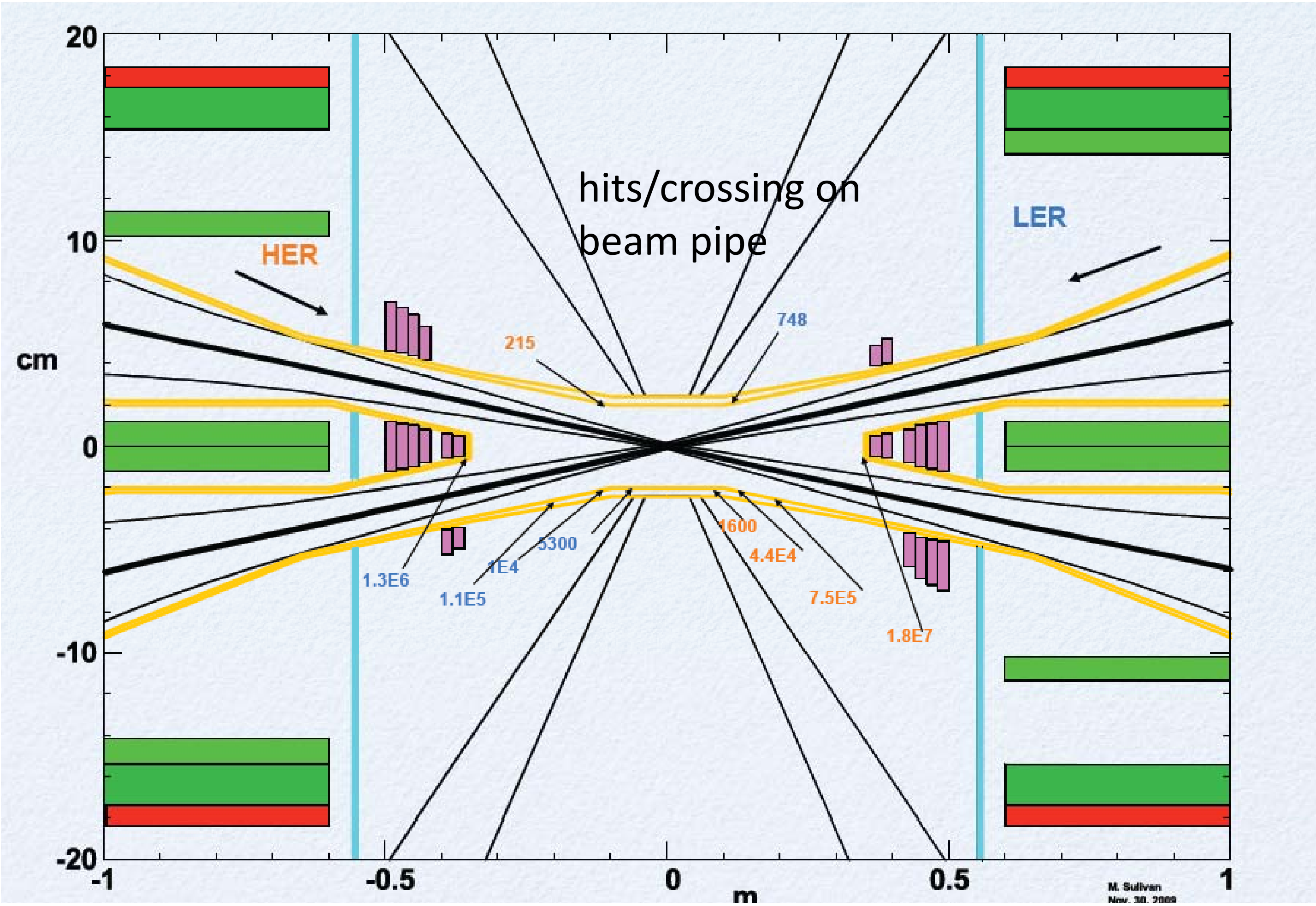
IR losses = 14.5 kHz/bunch
nt =1-5 (jaws closed)



Touschek is not a big problem for SuperB.
Large dispersion at some position→ movable mask is effective there

SR

Paoloni, XIV SuperB Meeting @ INFN-LNF



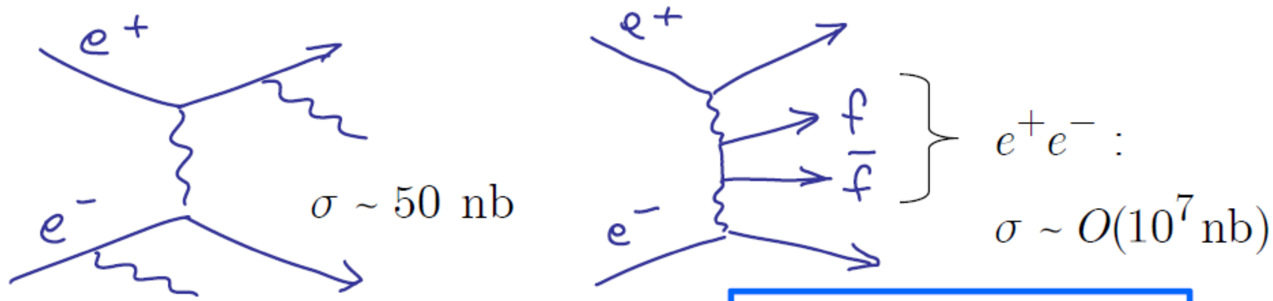
SR is similar for SuperB.

Other background sources

	Cross section	Evt/bunch xing	Rate @ 10^{36}Hz/cm^2	Generators
"Radiative" Bhabha e^+e^- to $e^+e^-\gamma$	~340 mbarn ($E\gamma/E_{beam} > 1\%$)	~850	0.3THz	BBBrem
e^+e^- pair production	~7.3 mbarn	~18	7GHz	Diag36
e^+e^- pair (seen by L0 @ 1.5 cm)	~0.3 mbarn	~0.8	0.3GHz	
Elastic Bhabha	O(10^{-4}) mbarn (Det. acceptance)	~250/Million	100KHz	BHwide
$\Upsilon(4S)$	O(10^{-6}) mbarn	~2.5/Million	1 KHz	
	Loss rate	Loss/bunch pass	Rate	
Touschek (LER)	4.1kHz / bunch (+/- 2 m from IP)	~3/100	~5 MHz	Star (Manuela Boscolo's code)

2 photon process

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

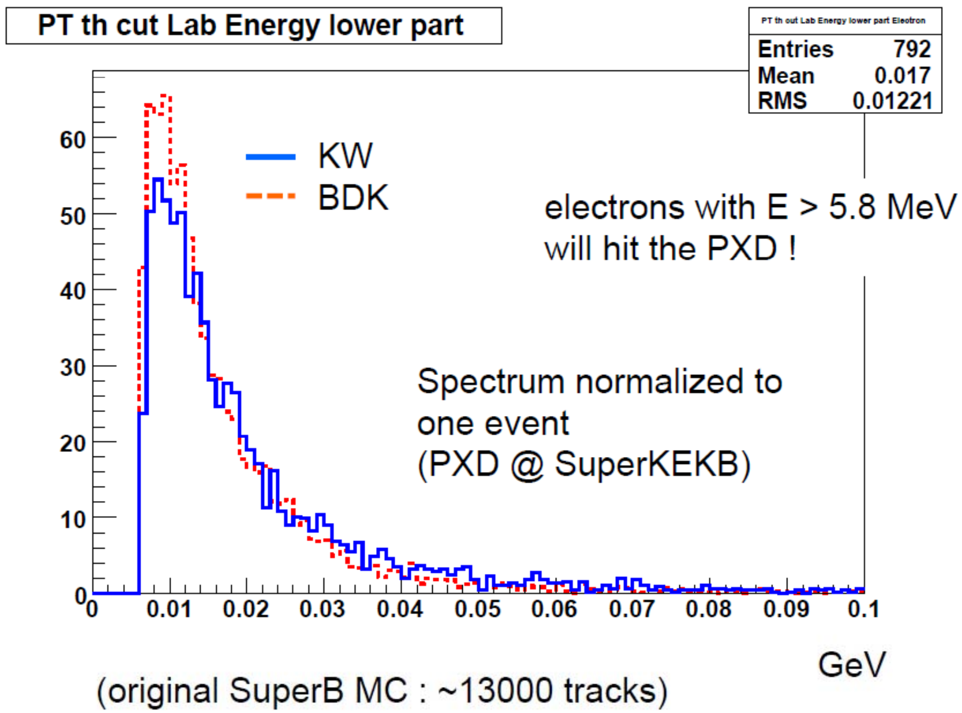


Bhabha scattering

2-photon-processes

Christian(MPI)

Which is correct?



-	SuperB (private communication)	BDK (Simulation)	KW (Simulation)
Tracks	13800	~800	~800
Occupancy	1.3 % ⟷	0.07 %	0.1 %

Christian(MPI)

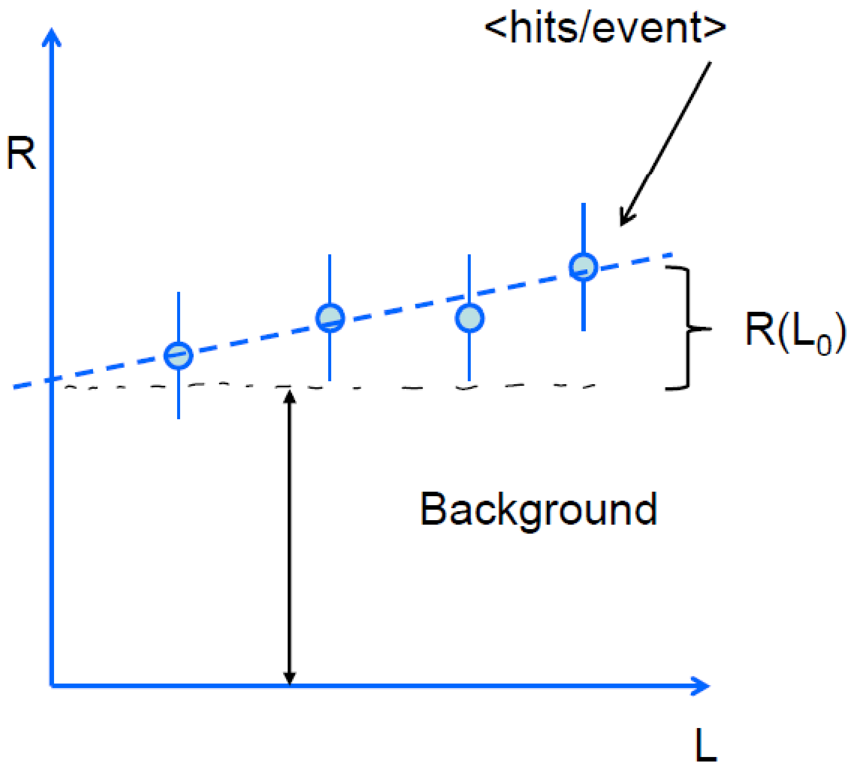
Machine study might give answer

Measure R=<hits/event>
as function of luminosity
(given by Bhabha events)

Extrapolate to L=0 to get
„non-QED“ background

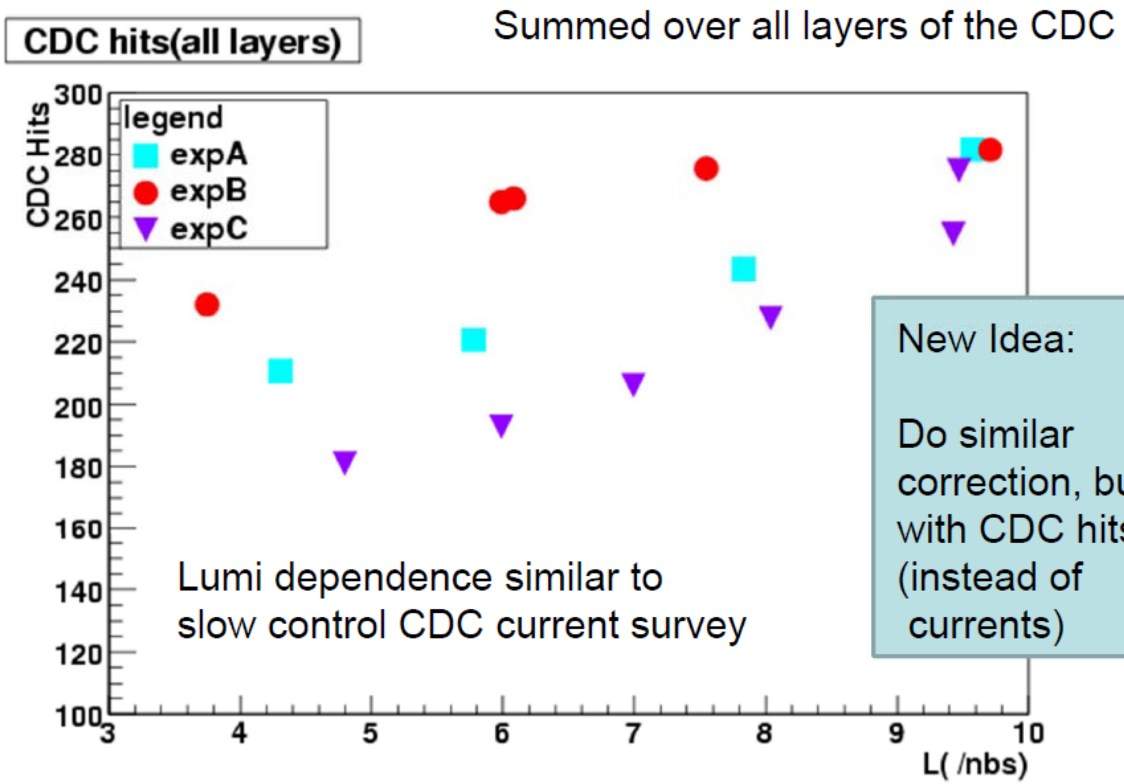
Difference = QED rate

Vary the luminosity in
different ways to control the
systematics.



Christian(MPI)

Luminosity correction by CDC BG



New Idea:

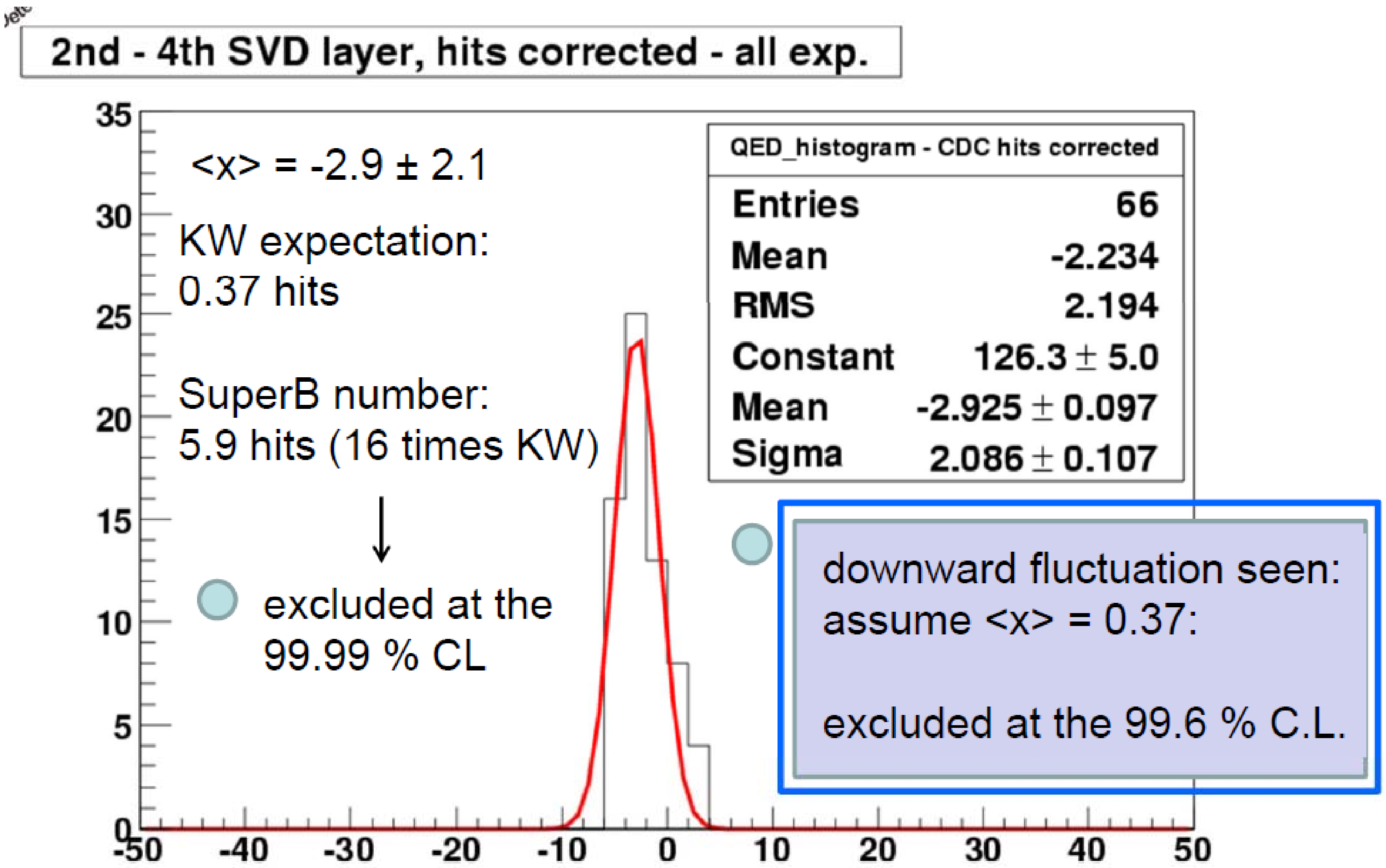
Do similar correction, but with CDC hits (instead of currents)

We expected no luminosity dependence for CDC BG, since 2-photon QED cannot reach CDC.

However, we found dependence→ Use corrected luminosity with CDC hits rate.

Christian(MPI)

SVD hits

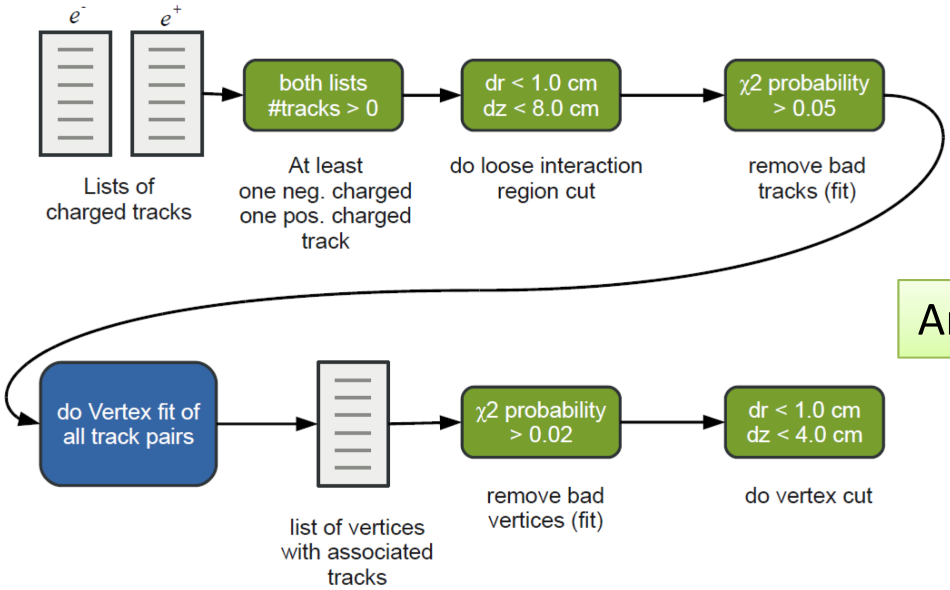


SVD multiplicity coming from QED-2photon process, scaled by corrected luminosity with CDC hit rate

Christian(MPI)

QED summary

- We have excluded SuperB value with machine study.
- Another analysis using reconstructed tracks are planned.



Andreas(MPI)

- We will start GEANT4 simulation soon.