Synchrotron Radiation Background study for Belle

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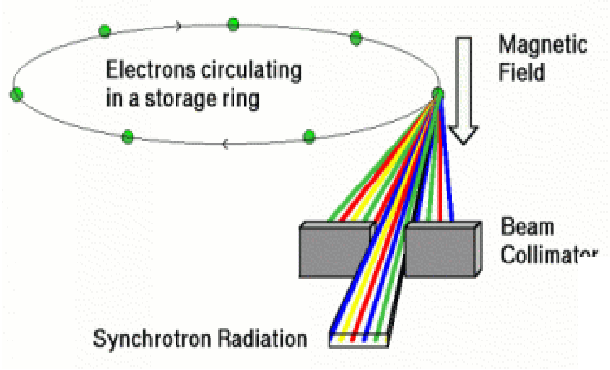


- Accelerator
- BEAST
- Geometry near IP
- SVD killing situation
- Experience with SVD1.0 Beampipe
- Modification for SVD2.0 Beampipe
- Conclusion

B-factories

machine	KEK-B	PEP-II	CESR
detector	Belle	BaBar	CLEO
Circumference(km)	3.016	2.199	0.768
# of rings	2	2	1
E_{e^+}(GeV)	3.5	3.1	5.3
E_{e^-}(GeV)	8.0	9.0	5.3
bunch size (h)	77μm	181μm	500μm
" (w)	1.9μm	5.4μm	10μm
" (ℓ)	1.0cm	0.7cm	1.8cm
crossing angle(mrad)	22	0	±2.3
Luminosity($cm^{-2}s^{-1}$)	10^{34}	3×10^{33}	1.5×10^{33}
#$B\bar{B}$/sec	10	3	1.5

Beam separation

Want collision to occur at one location
→ beam separation
(avoid parasitic crossing)

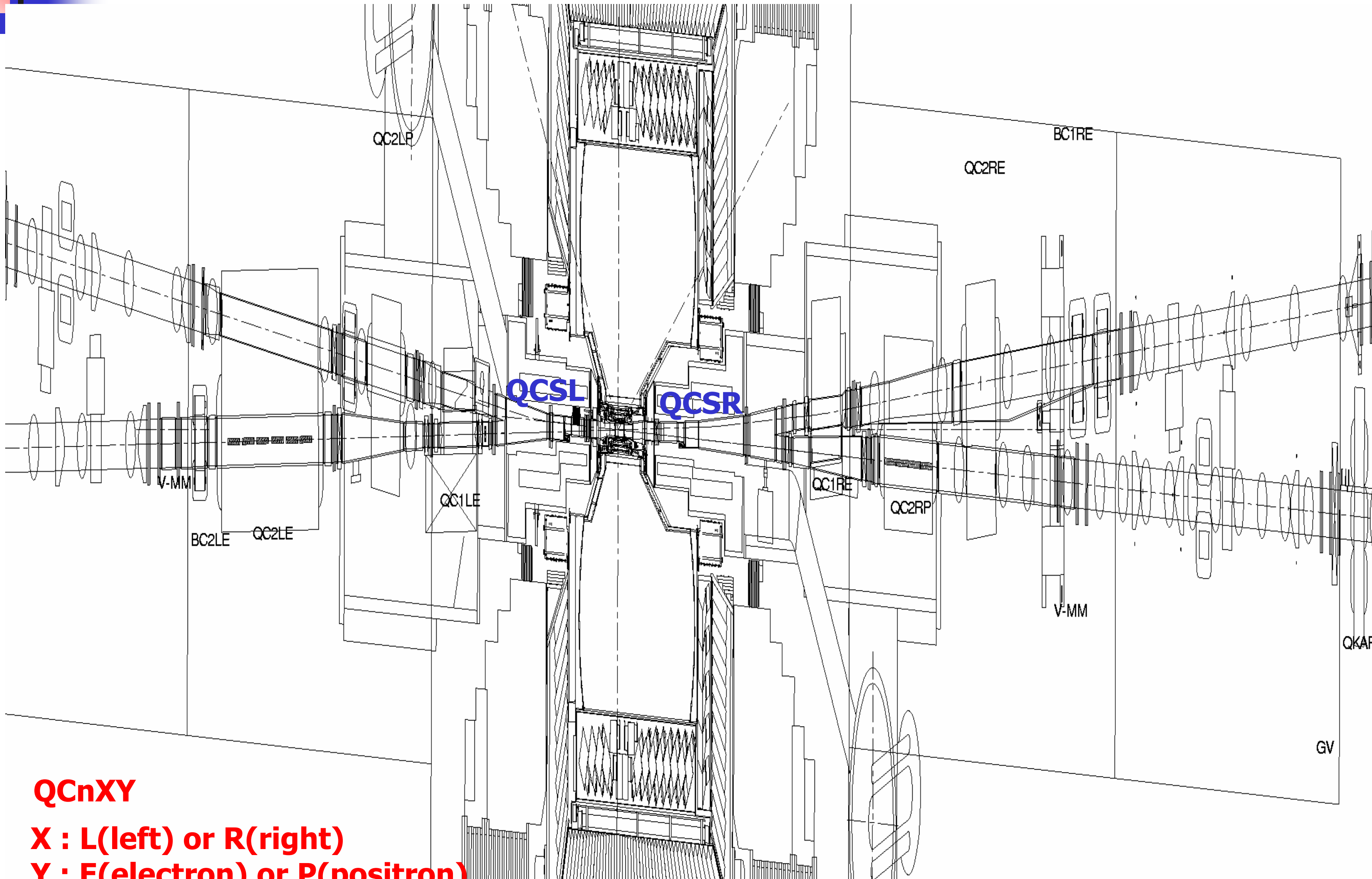
CESR: pretzel orbit
interweaving e^+e^- orbits within a single ring
crossing angle ±2.3 mrad

PEP-II: separation by bending magnet
e^+e^- beams bend differently
head-on collision

KEK-B: finite crossing angle
crossing angle = ±11 mrad

Large crossing angle →Luminosity reduction
(geometrical)

Machine configuration near Belle



QCnXY

X : L(left) or R(right)
Y : E(electron) or P(positron)

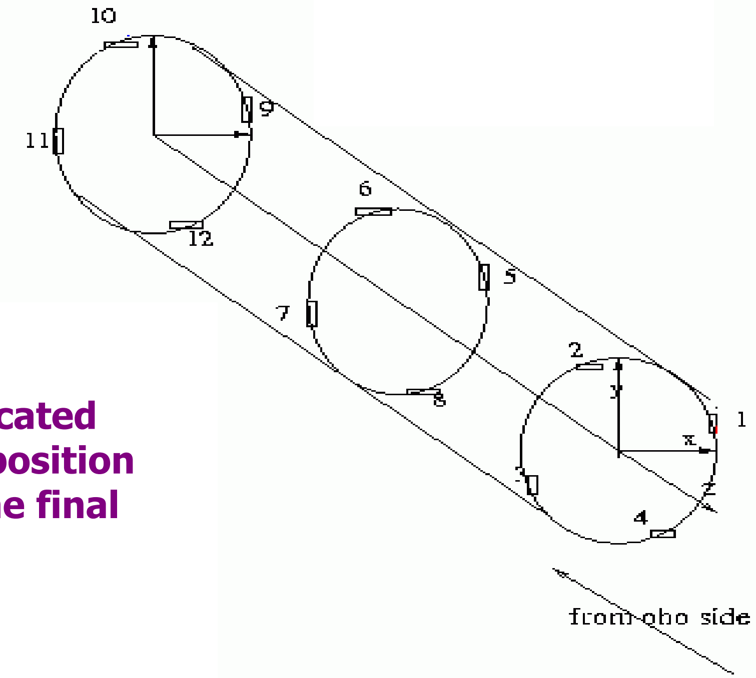
Belle commissioning detector (BEAST)

BEAST : Background Exorcism for A STable Experiment

Goal -> To understand the backgrounds and tune the machine so that backgrounds will be at a tolerable level at the beginning of Belle roll-in and operation

Detector component :

1. PIN diodes
2. MOSFETs to measure integrated doses
3. Small drift tubes to measure single particle rates and leakage current
4. Calorimeter
5. Two ladders of silicon vertex detectors



Some of the diodes are located at the same radial and z-position as silicon electronics in the final Belle detector

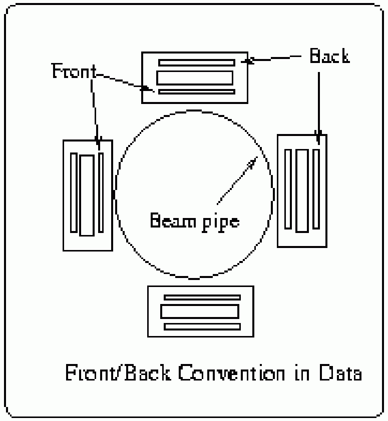
BEAST detector

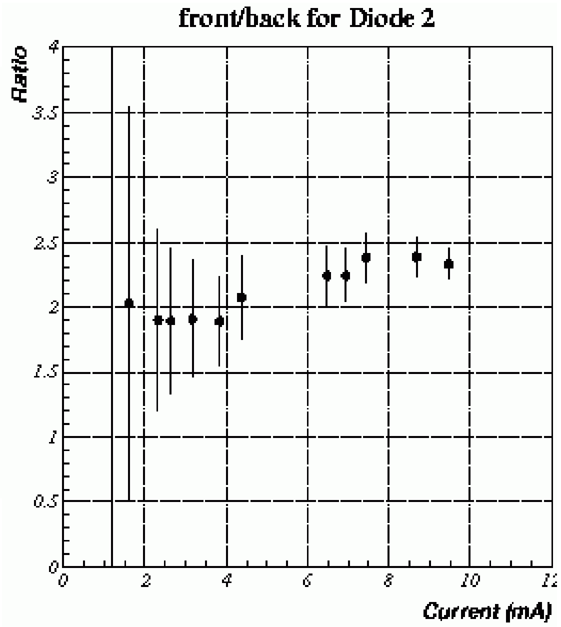
Two diodes separated by 2 mm Pb

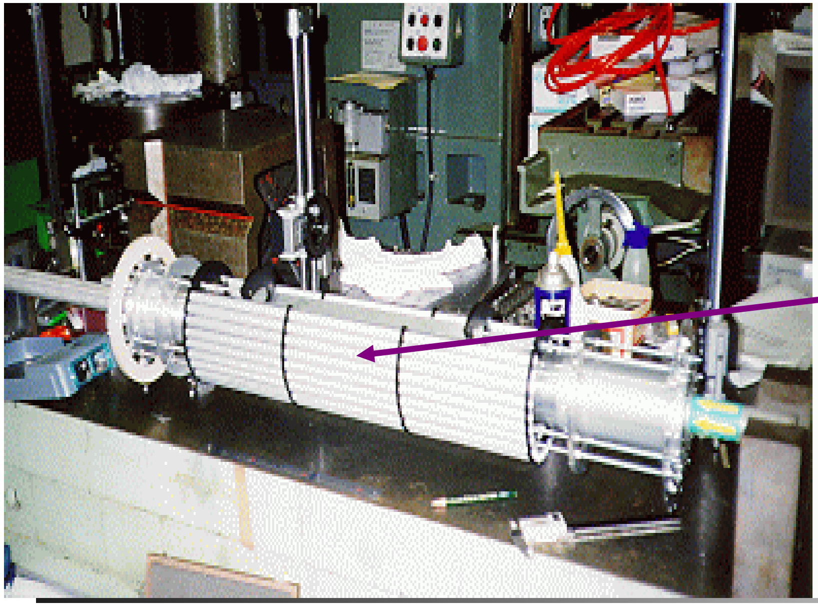
Front/Back energy deposition ratio:

> 1   soft photons/charged particles
< 1   hard photons/charged particles

Ratio from data ~ 2



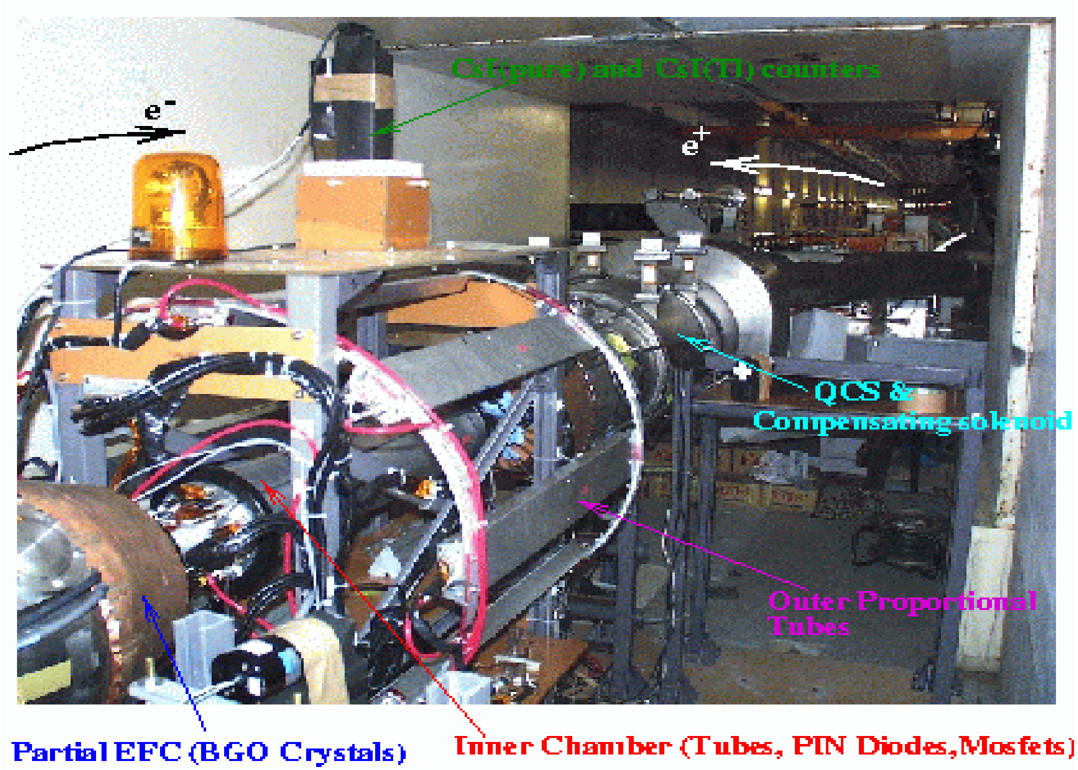




Drift tubes (Al cylinders with a single wire)
53 tubes distributed in two layers of 21 and 32 tubes at radial distance of 7cm and 45 cm

BEAST detector

Simulation: 25 kRad per year at
design current and
1 nTorr pressure
(readout electronics of SVD)

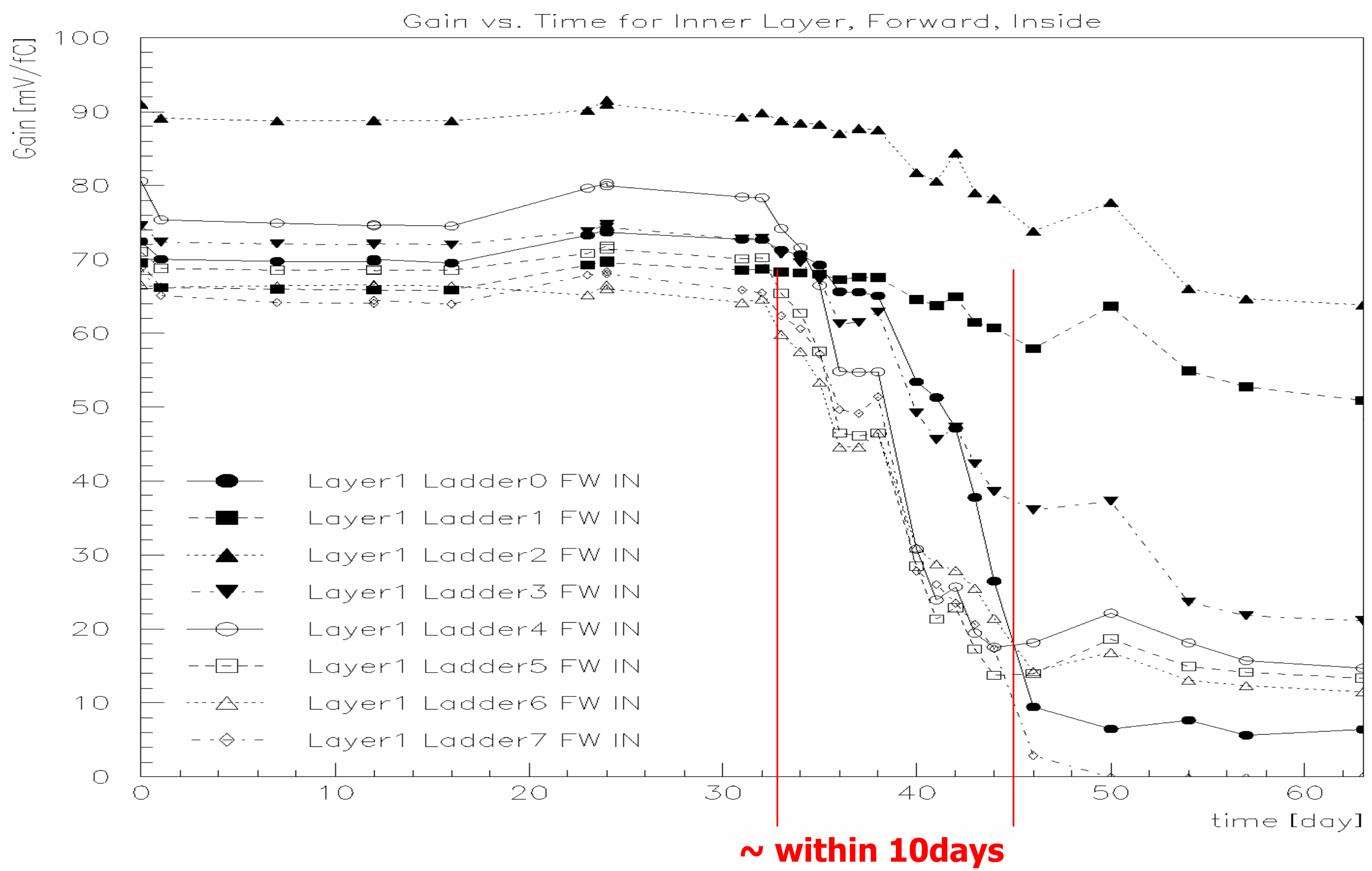


SR background α I
Particle background α I.P

Background measured in BEAST ~10 times more
but
the vacuum pressure and the beam optics fine tuning would improve the situation

SVD gain drop

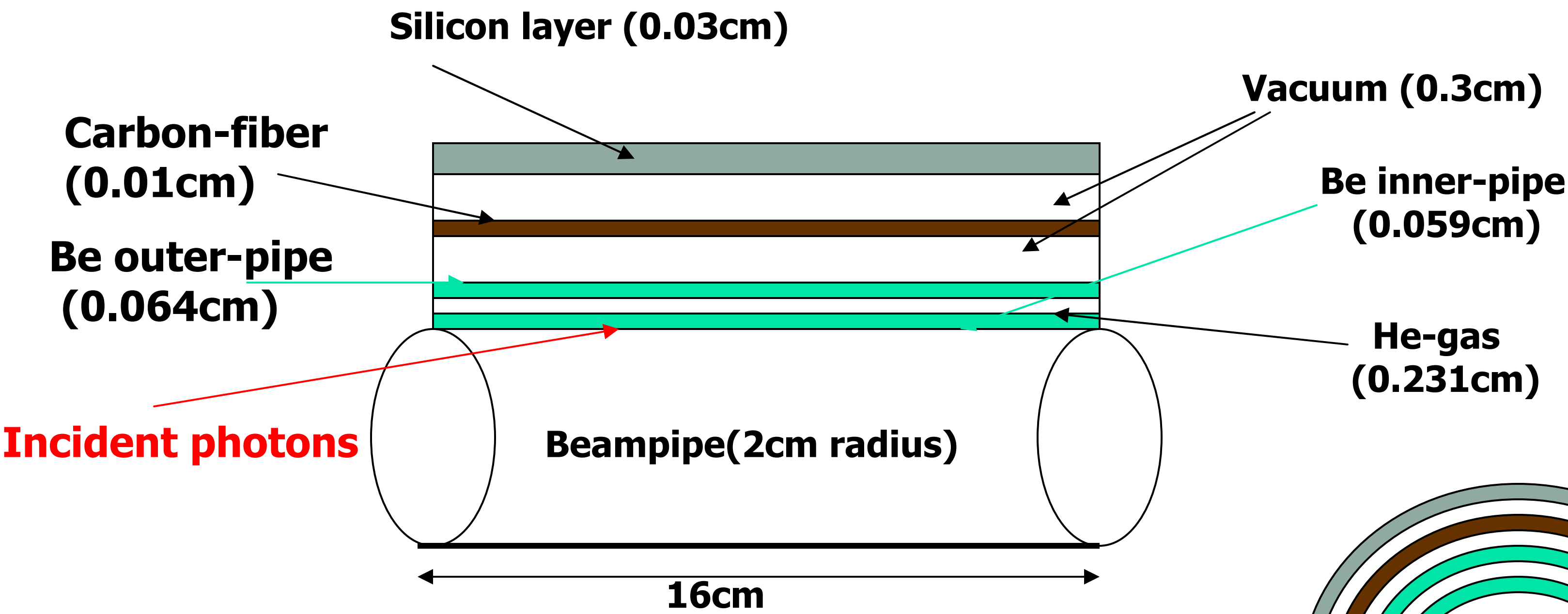
The preamplifier gains in the innermost layer dropped dramatically



Immediate Solutions

EGS4 simulation: To see the effect of SR on silicon detector

Simple geometry used -> small incident angle(~5^0) for photons

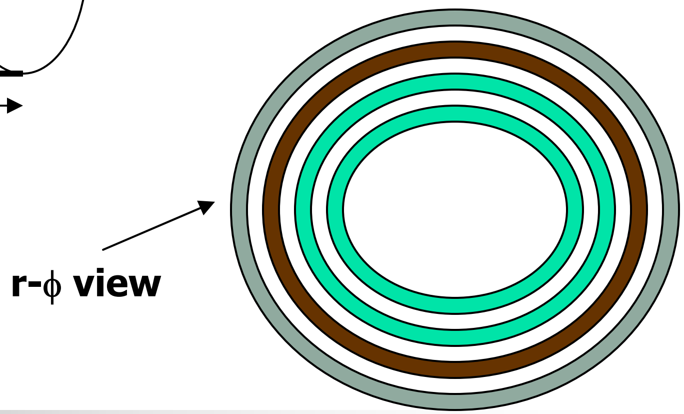


I. 10μm gold inside the Berylium Beam pipe

II. 10μm gold outside the Berylium Beam pipe

III. 20μm gold inside the Berylium Beam pipe

IV. 10μm gold inside the Berylium Beam pipe

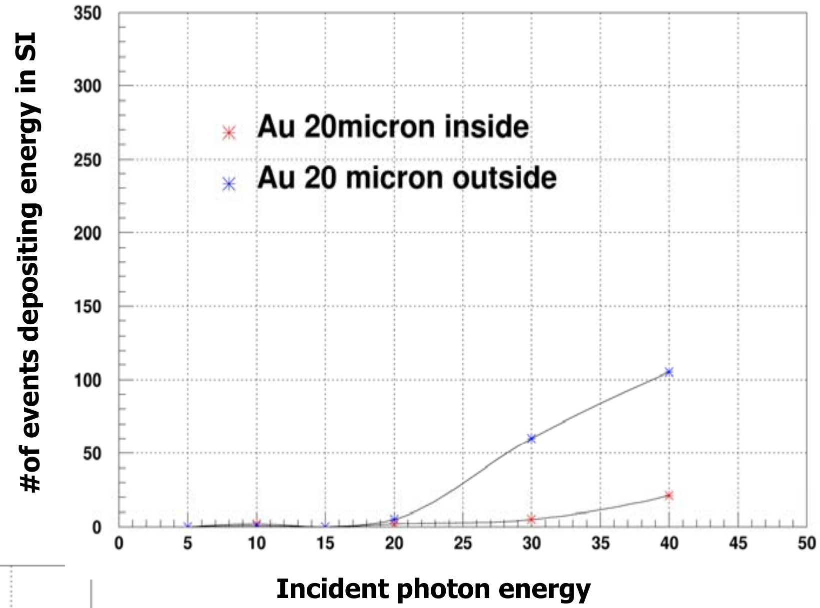


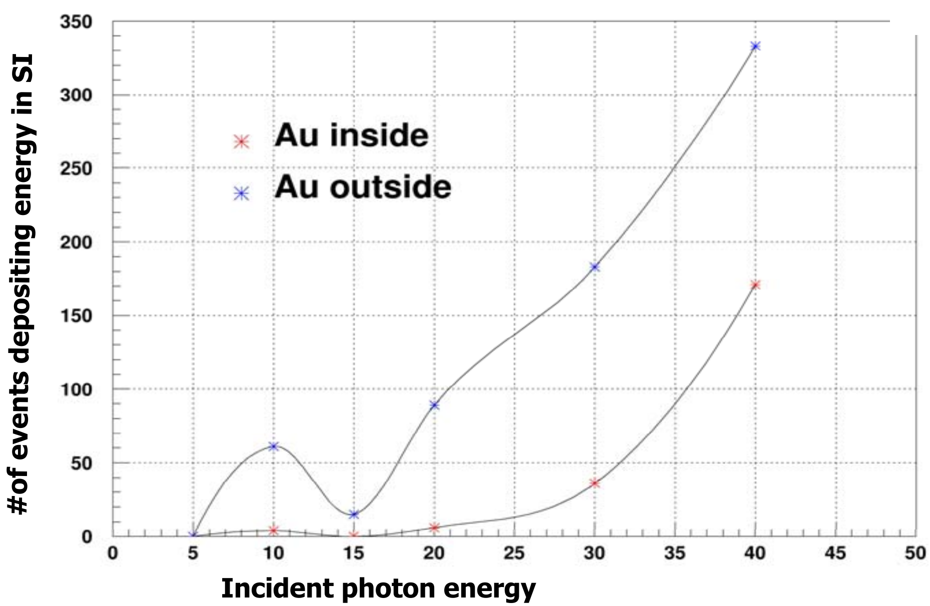
Immediate Solutions

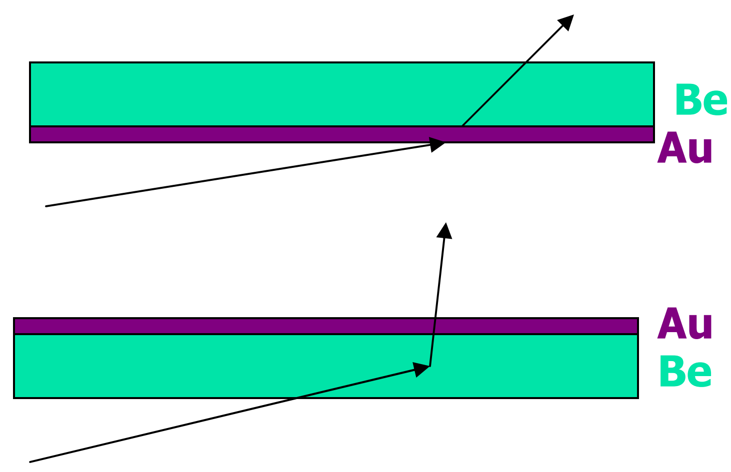
10000 incident photons

20μm gold stops all the Photons with E < 20KeV

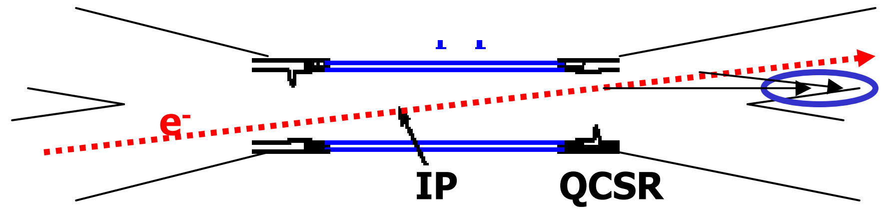
But important:
10μm Au inside Be beam pipe equivalent to 20μm Au outside Be







Modification for SVD1.2 and SVD1.5



FOR SVD1.2 :

Limit the beam parameter : offset less than 3mm

20μm gold coating outside the beampipe

300μm gold coating outside the fiducial region (protect hybrids)

HER downstream is changed to Copper (but it produces 8keV x-rays)

FOR SVD1.5 :

Limit the beam parameter : offset less than 3mm

10μm gold coating inside the beampipe

300μm gold coating outside the fiducial region

Expected does: 15kRad/year (without 300μm gold coating)
: 0.5 kRad/year with gold coating

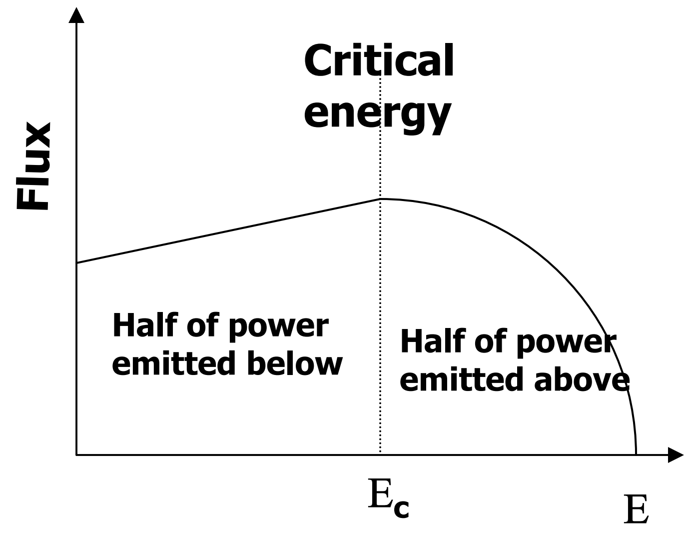
Dose will be 100 times more if no gold coating inside beampipe

Critical energy and Silicon dose

E_C (keV) = 4.27 B (kG)

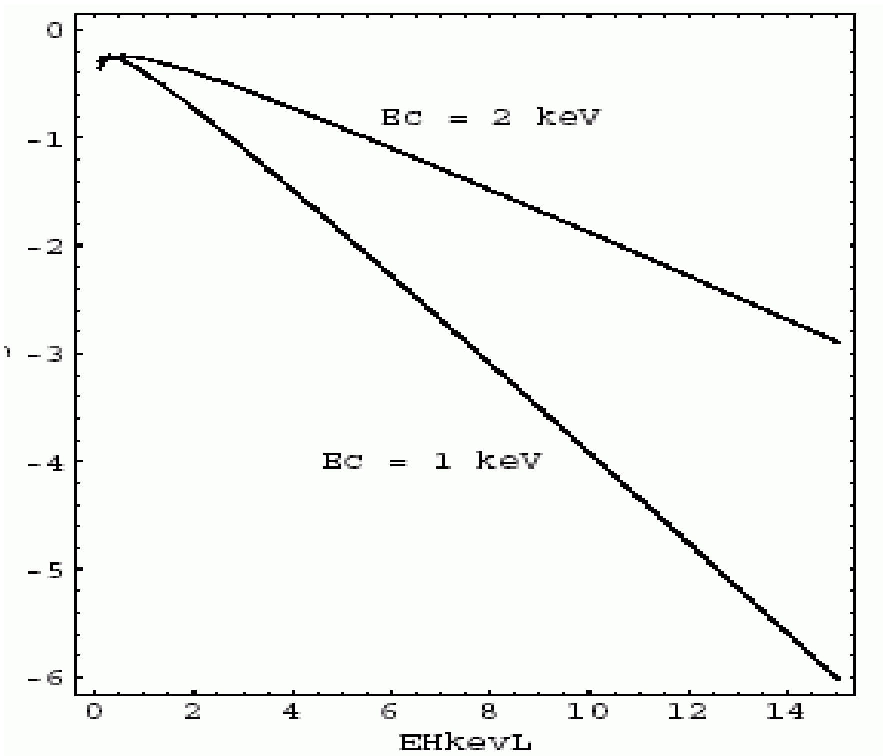
P(W/A) = 12.61 I(A) B^2(kG) E^2(Gev) L(m)

A slight increase in E_c -> drastic rise in dose



SR spectrum

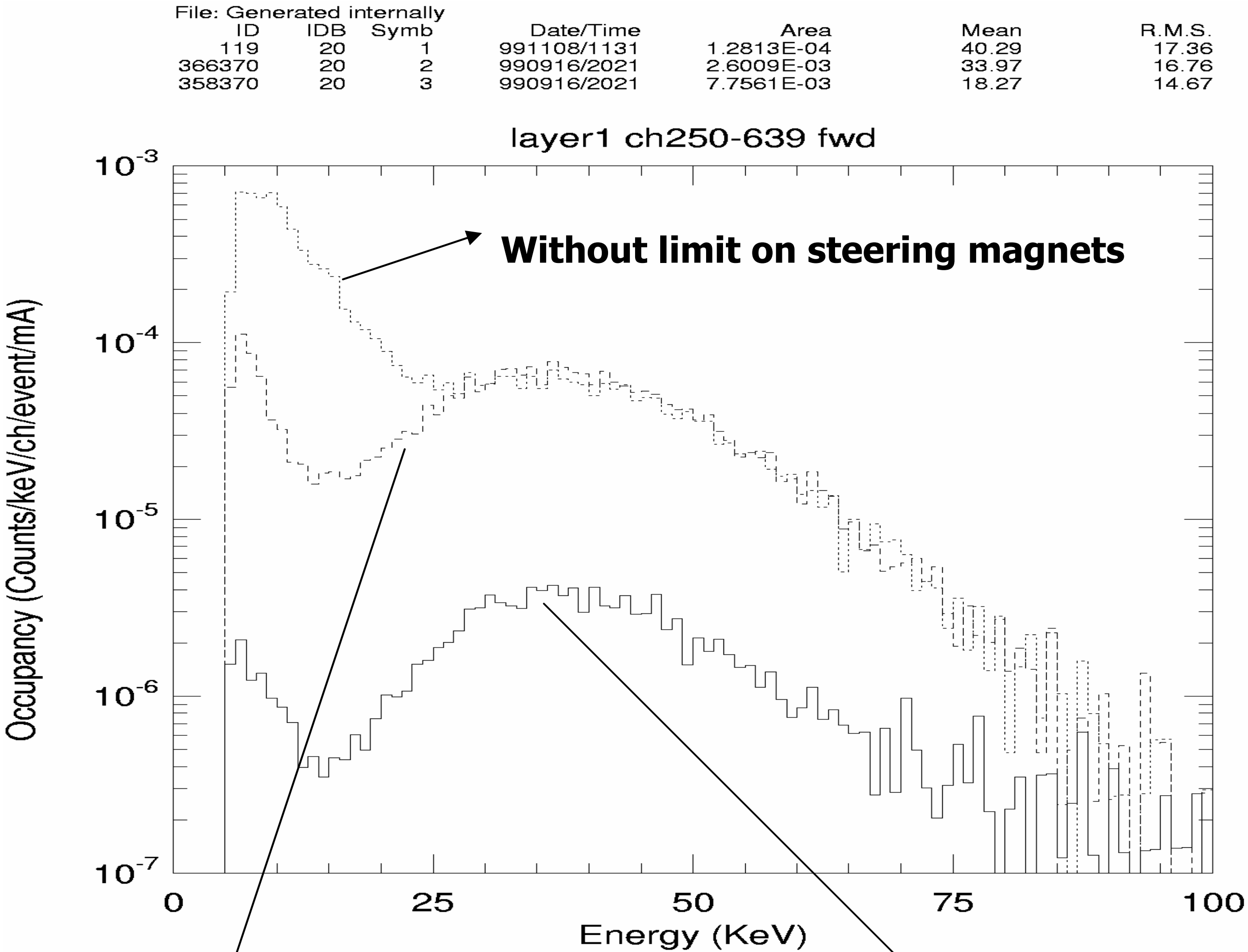
E_{beam} fixed , B field varied



E_c =2keV has ~100 times more Silicon dose than E_c=1keV

Limit the offsets at upstream Q's
And strengths of steering magnets

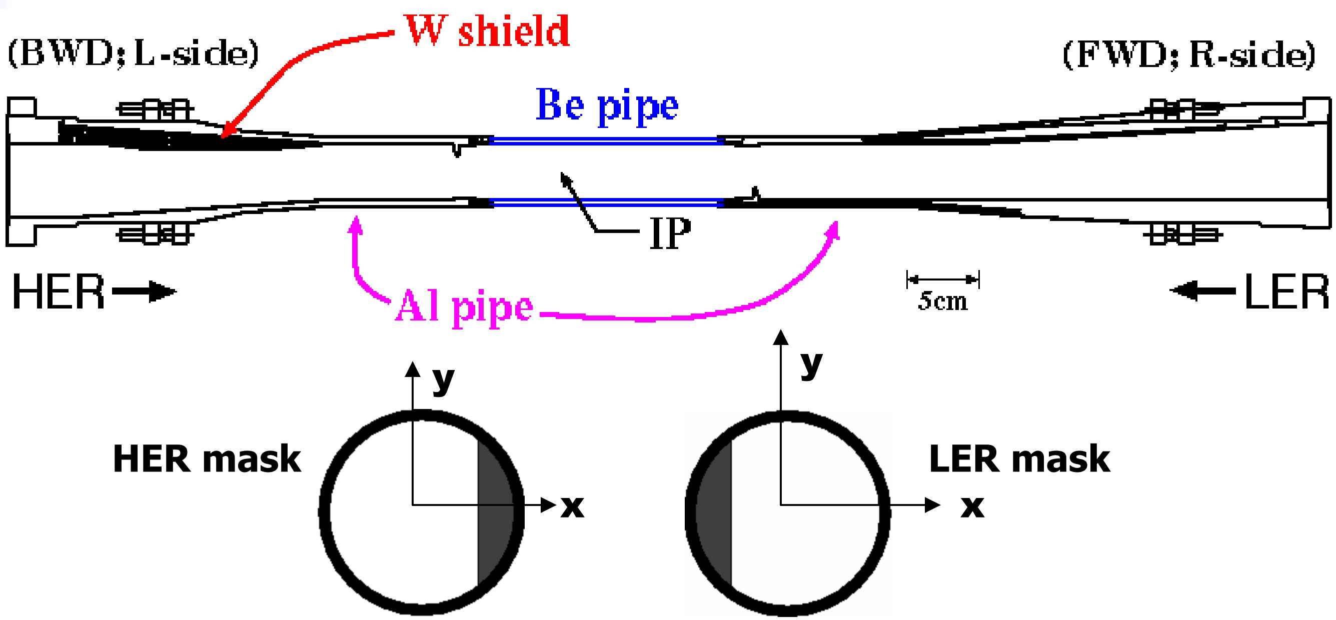
Pulse height distribution of SVD hits (single bunch mode)



With limits on steering magnets

With SVD1.2 modification (20μm gold outsideand 300μm gold outside fiducial region)

Version of SVD1.x beampipe



All r=2 cm, Be: He cooling

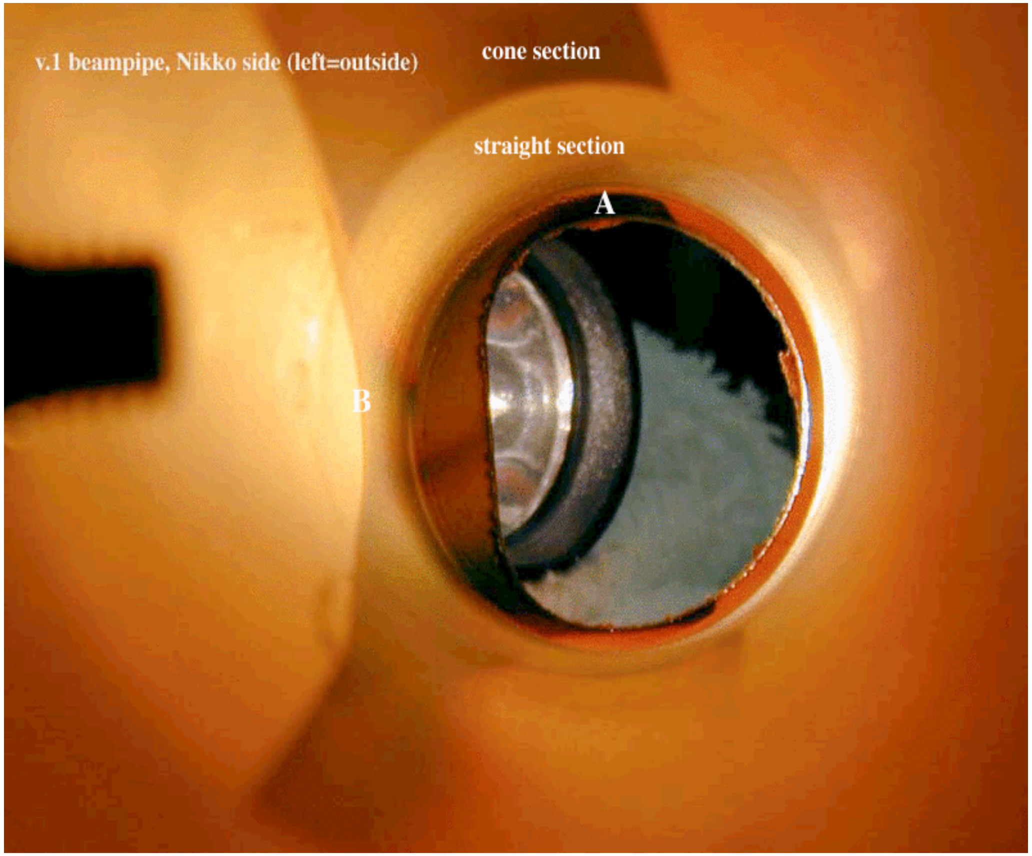
version	period	comment
SVD1.0	6/99 → 8/99	No gold on Be Rad-soft chip (200kRad)
SVD1.2	10/99 → 7/00	20 μm gold outside Be Rad-soft chip (200kRad)
SVD1.5	10/00 → 8/03	10 μm gold inside Be Rad-tolerant chip (~1MRad)

SVD1.0 beampipe SR burns

Looked from HER upstream side -> along the electron beam

After central Be section has been cut off

Tungsten mask removed



SR dose estimation (method)

1. SRGEN

Twiss parameters -> beam profile
Steps through magnetic field
Numerically integrates the power spectrum on a given surface

SR power spectrum on beam pipe surface is passed to

2. EGS4

Photons traced down to 1keV
Electrons traced down to 20 keV
KEK low-energy improvements (L-edge X-rays)

SRGEN Package

SRGEN is a synchrotron radiation generation code. It tracks a beam through the magnetic elements and accumulates spectra on surfaces in the interaction region. The vacuum chamber in the IR is described by a set of elliptical defining apertures. Between each aperture is a surface which smoothly joins the two apertures. Each aperture is describes by semi-major and semi-minor axes of the ellipse and horizontal and vertical offsets of the center of the ellipse w.r.t the magnetic axis. SR is collected on the surface and these surfaces are referred by number.

To run SRGEN:

.lat : magnetic lattice
lattice.init : machine lattice initialization file
apertures.ap : Aperture input file
.in : Initialization file

Input files for SRGEN

.lat file specifies the magnetic lattice near the IR

Mag1_mnemonic type length start k_or_rho

Mag2_mnemonic type length start k_or_rho

Mag1_mnemoni : name of the first magnet
Type : kind of magnet (dipole or quad)
length : magnetic length of the element in meter
start : the position of the +s end of the magnetic element
k_or_rho : k [m^{-2}] for quad or rho[m] for dipole

k >0 horizontal focussing

Example:

BC3	dipole	0.3444	-25.7265	-499.0000
QC2	quad	2.0652	-6.1671	+0.116325
QC1	quad	0.647	-2.9762	-0.494062
QCS	quad	0.4843	-1.3578	-0.753225

Input files for SRGEN

.init file contains lattice specification, the starting and ending positions for the SR generation, and the initial trajectory and Twiss parameters at the starting point

Easy way: start at IP and track outward from there

s_start = 0.0 s_stop = -8.23
x_{off} = 0.0 x_{ang}= 0.0 y_{off} = 0.0 y_{ang} =0.0 ds = -0.001
β_h = 0.7 β_v = 0.007 α_h = 0.0 α_v = 0.0
ι_h = 0.0 ι_v = 0.0 ι_h' = 0.0 ι_v' = 0.0
ε_h = 3.0e-08 ε_v = 3.0e-10

Line-1: starting and ending positions along the trajectory over which to calculate SR flux

Line-2: Initial horizontal displacements and angles
ds ->step size to be used in twiss parameter evolution

Line-5: Emittance

SRGEN input file description

.ap file specifies the vacuum chamber in the IR and defines the shapes of those surfaces on which SR lands

Number_of_apertures
ap1_number horiz_radius horiz_offset vert_radius vert_offset z_location material surface_type

ap1_number : argument to label surface numbers
horiz_radius : half aperture in horizontal direction
horiz_offset : horizontal offset of the aperture from magnetic axis
z_location : z location of the aperture
material : name of the material (important for SRSIM)
surface_type : scattering surface this represents

appear in decreasing order of z
region between aperture 0 and 1 is surface 0

```
8
0  0.01300  0.0015328  0.0130  0.0   0.1494
1  0.01000  0.0010919  0.0100  0.0   0.0993 copper pipemask
2  0.00850 -0.0004092  0.0085  0.0   0.0992 copper pipemask
3  0.01000  0.0010897  0.0100  0.0   0.0991 copper pipemask
4  0.01000 -0.001582   0.0100  0.0  -0.1439 beryllium beampipe
5  0.00850 -0.000083   0.0085  0.0  -0.1440 copper backmask
6  0.01000 -0.001584   0.0100  0.0  -0.1441 copper backmask
7  0.01000 -0.002684   0.0100  0.0  -0.2441 copper backmask
```

SRGEN input file description

SRGEN commands (.in) file

number_of_magnets mag1_mnemonic mag2_mnemonic ... magN_mnemonic
number_of_surfaces
surf1 surf2 surf3 ... surfN

number_of_magnets : number of magnets for which to perform the integration
mag1_mnemonic : mne_monic as specified in .lat file
number_of_surfaces : number of vacuum chamber surfaces on which to accumulate SR hits
surf1 surf2 surf3 ... : list of surface numbers

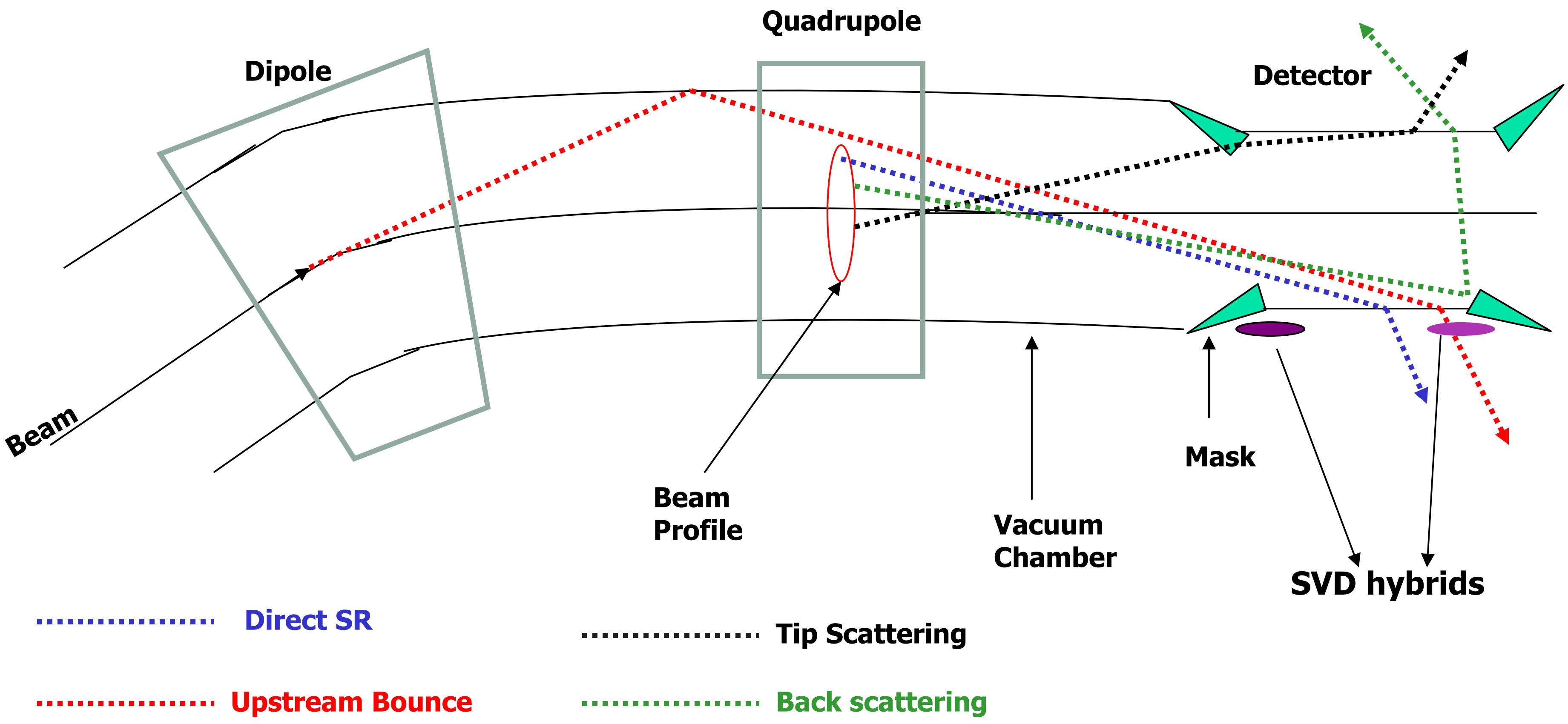
Example :
3 QCS QC1 QC2
2
0 1

SR to be calculated for 3 magnets and collected on two surfaces with surface number 0(beampipe) and 1 (pipe mask).

Final Command to run code and generate histograms:

srgen ph.init ph.ap ph.in ph_test

SVD killing situation(1999 summer) and new beam-pipe



Sources of possible v.1 Beampipe Burns

In increasing order of devastation
(dose estimation: SREGN + EGS4)

1. Bounced SR from inside QCSL

Shade of tungsten mask tip
-> source is just beyond uno mask
Bounced SR from BH3, QC2 ?

2. QC2 forward scattering ~ 23kRad/10days

It could hit anywhere on HER mask
depending on steering

2. QC2 backward scattering from LER ~ 23kRad/10days

4. BC3 ~ 270kRad/10days

BC3 SR could hit IR if not blocked by 1.1m mask

5. QC1 ~ 480kRad/10days

If y offset of QC2 causes SR hit on IR
QC1 should also hit

The 1.1m mask blocks SR of about 1/3 on the inside at HER mask

Two sources of SR backgrounds

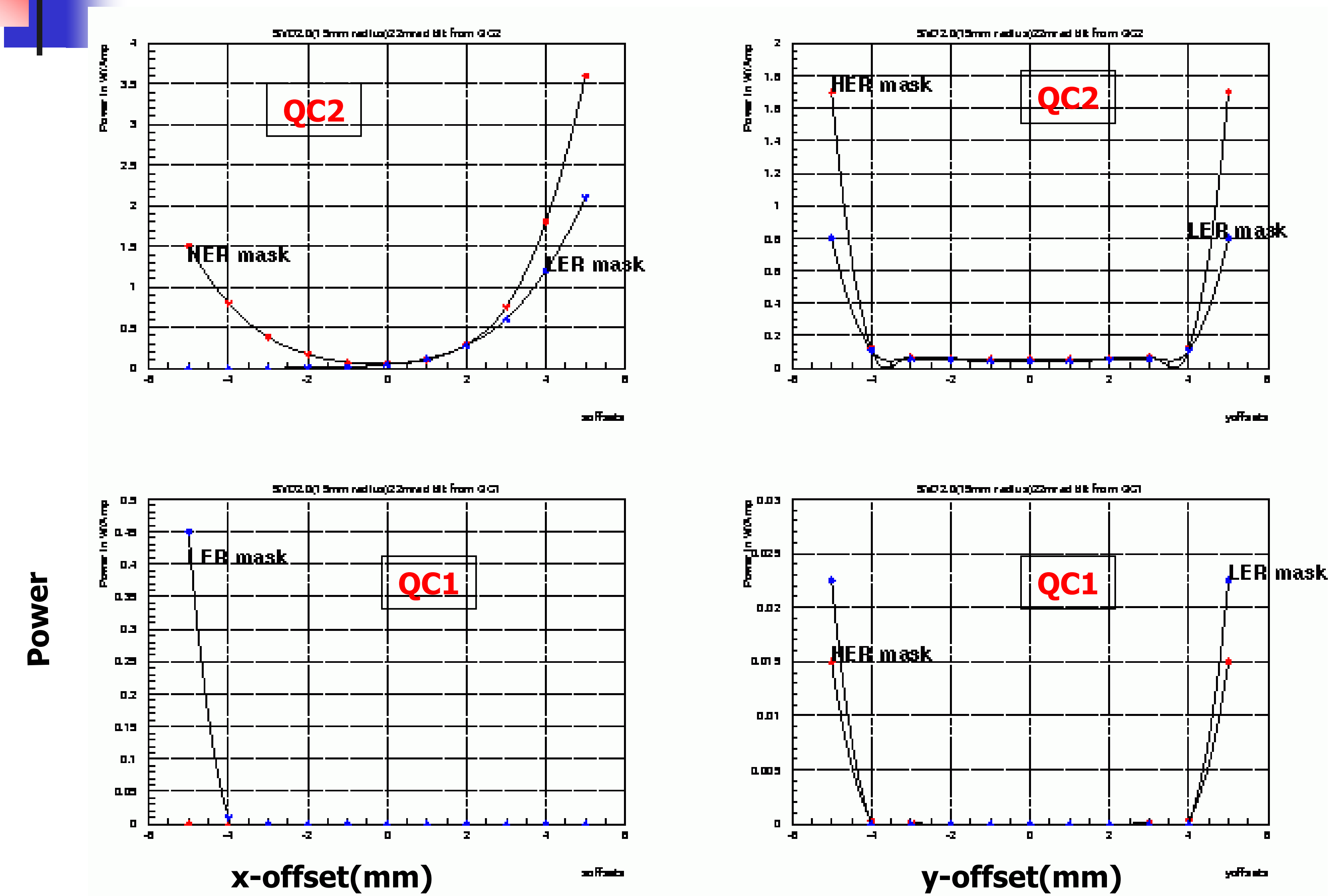
- **'Soft' SR background**

  Caused gain loss of SVD1.0
  SR photons from HER upstream
  + Bare Be beampipe

- **'Hard' SR background**

  High-pulse height component of SVD
  CDC leakage current
  Back-scattering from downstream HER

Effect of beam parameters (limit offsets)



SVD2.0 Design for SR

'Soft' SR component:

- **Tilt 11mrad w.r.t Belle axis**
  - **smaller masks -> less HOM**
    3mm high masks (HER and LER)
  - **masks are made of heavy metal (used to be SS , no cooling)**
  - **Be section and cones on axis**
  - **space for cooling tubes for Be section**

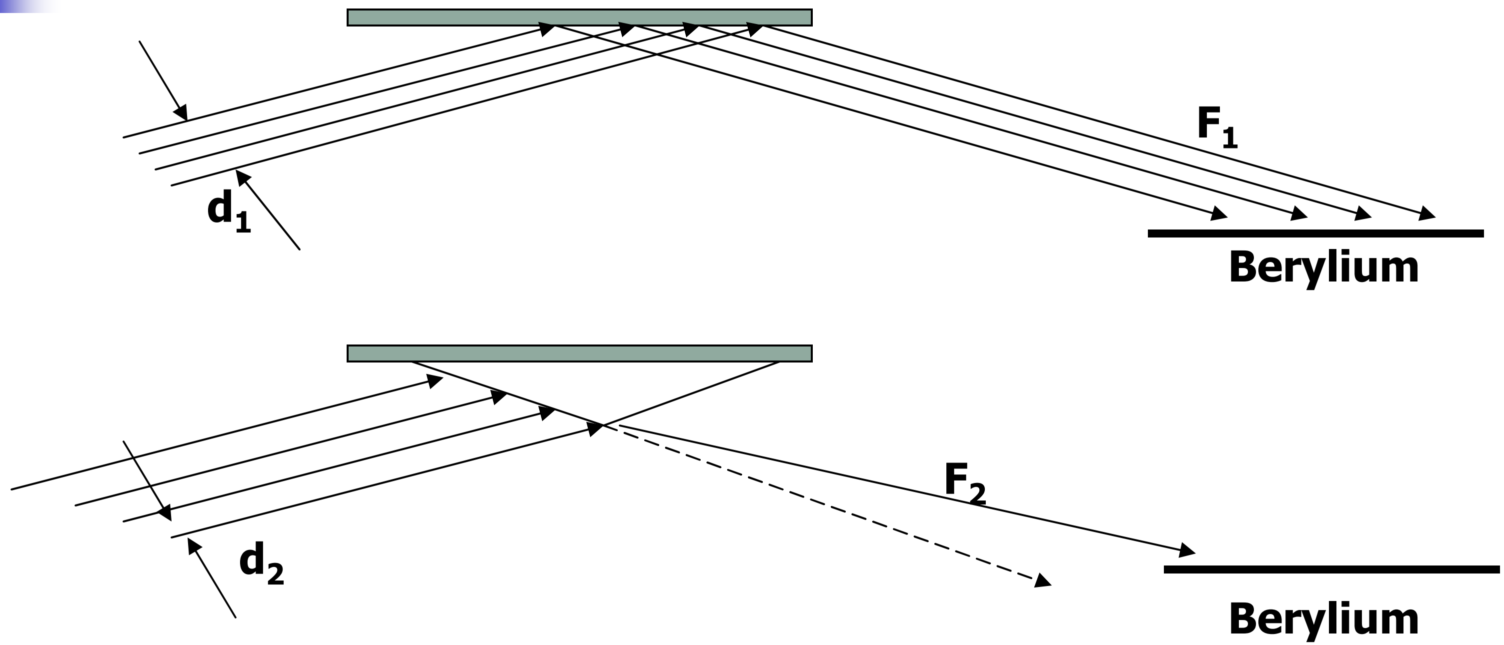
- **Sawteeth on HER side**
  - **surface scattering -> tip scattering**
  ~ 1/50 dose reduction

- **Masks away from feducial region**
  ~ 1/10 backscattering dose
  (300μm Au foil)

'Hard' SR component:

- **LER masks made by heavy metal (Blocks backscattered X-rays)**
- **Use Cu or W in cone section**

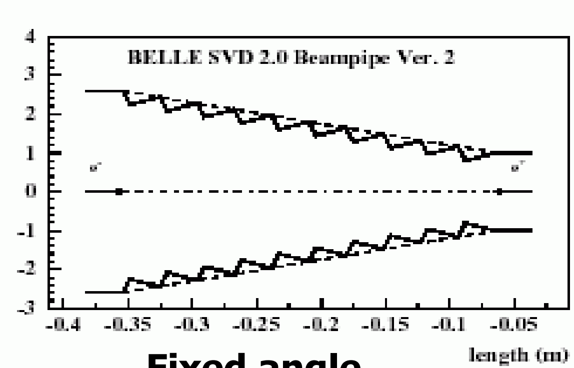
Sawtooth structure



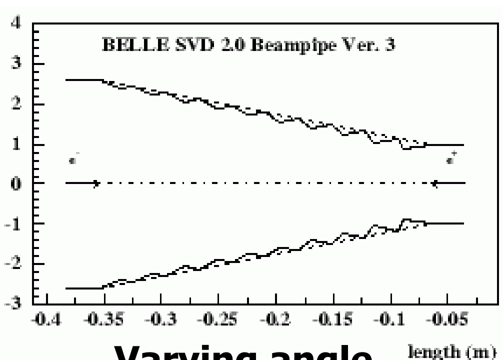
$D_{1,2}$: flus of photons shining on the surface that can see Berylium

Reduction of flux on Berylium

Depends on radius of the tips (smaller the better)

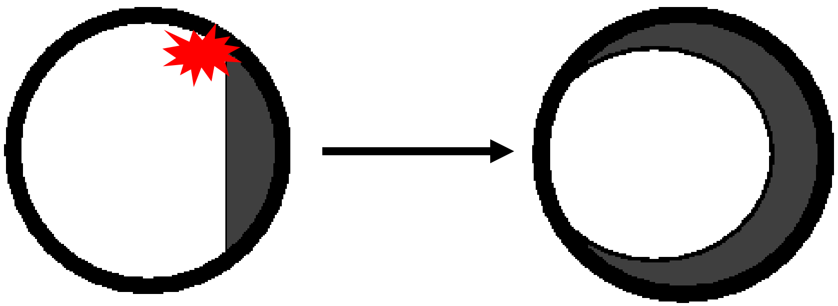


Fixed angle



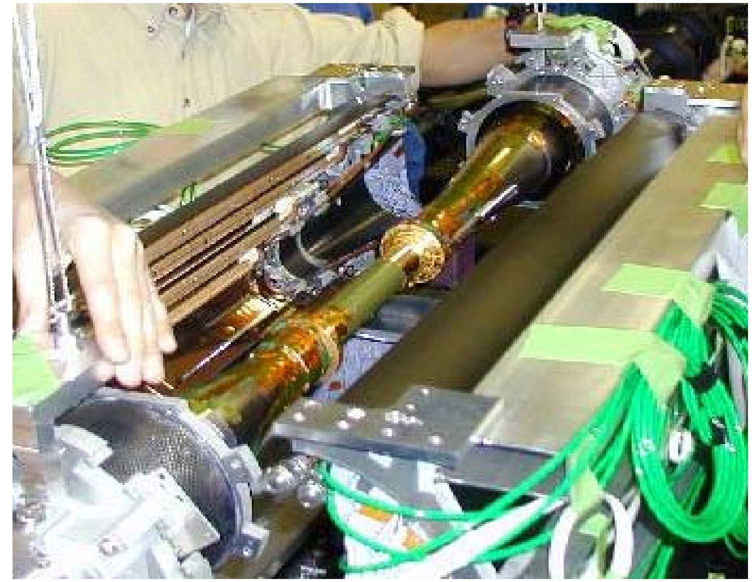
Varying angle

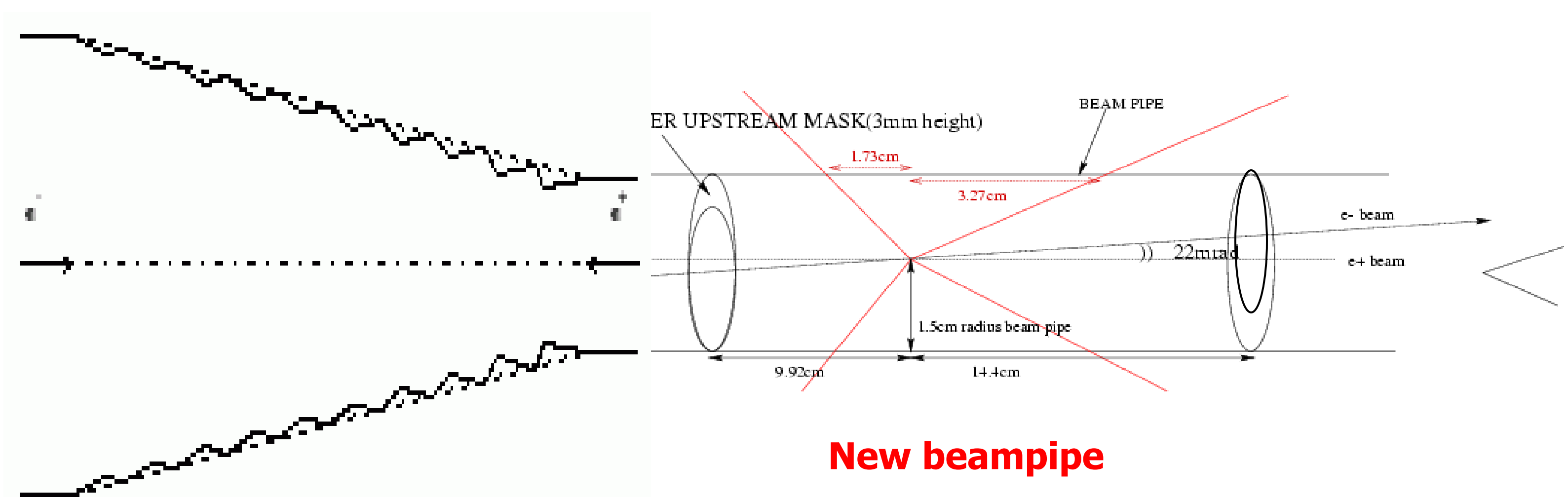
Upgraded beampipe



Old Mask

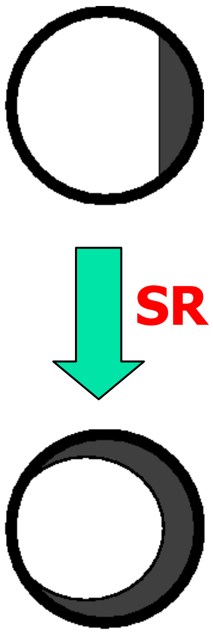
New Mask

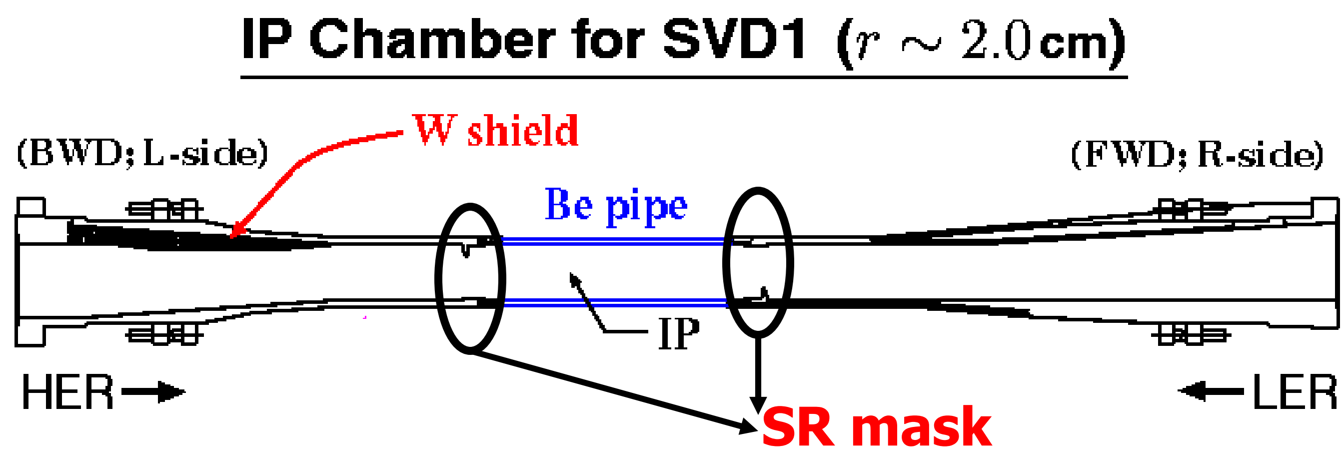


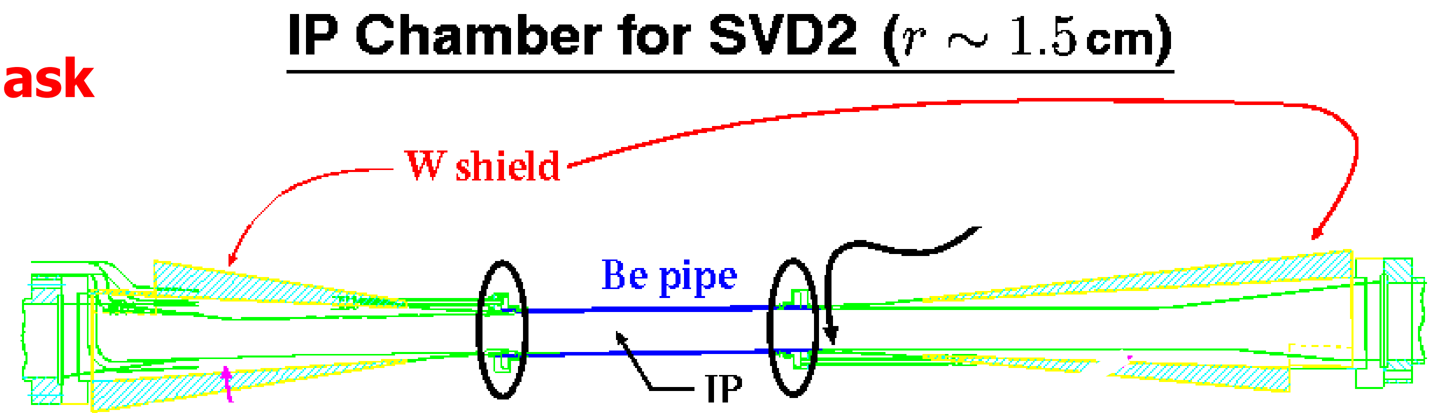


New beampipe

Upgrades-II







New beam-pipe is longer , 16*cm* $\rightarrow$ 24*cm*

HER downstream and upstream modification

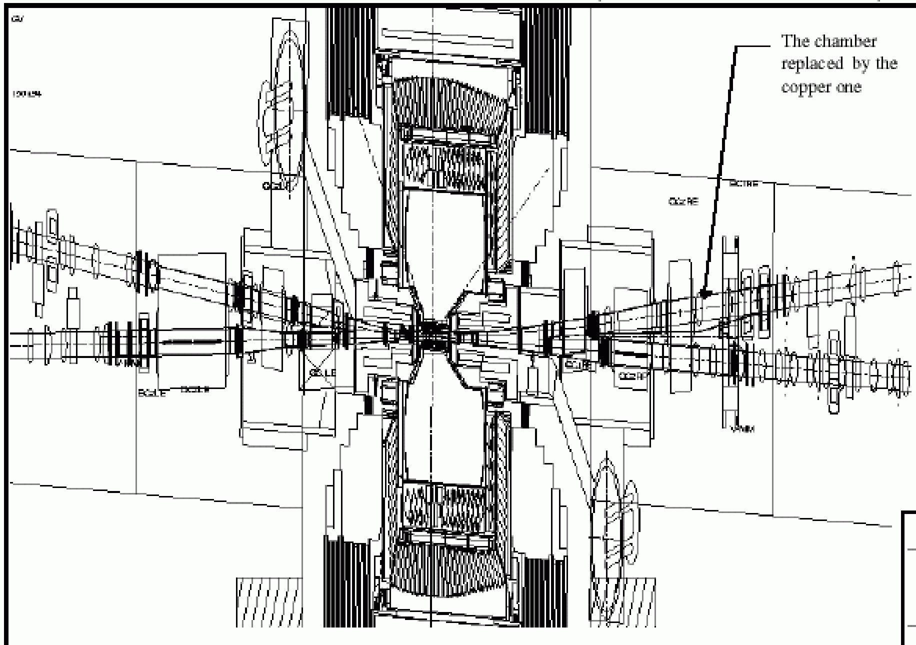
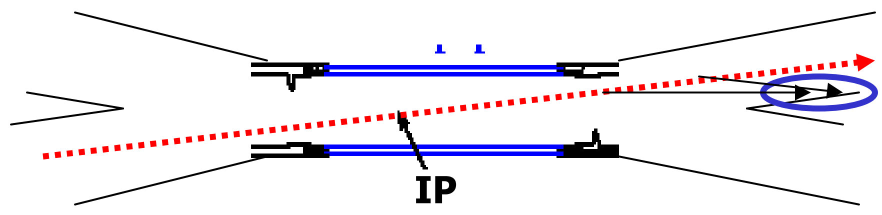


Fig. 2 KEKB IR close up. Horizontal scale is reduced by 5 times smaller than vertical

Downstream chamber is changed



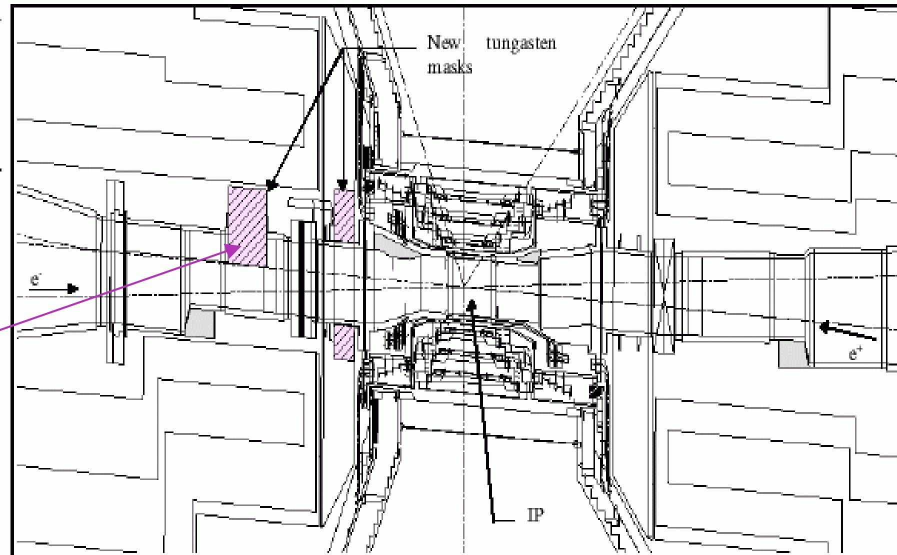


Fig. 6 Clos up view of IP. Horizontal scale is 5 times smaller than vertical one. Hatched area indicates the new masks installed in the last summer shutdown.

Upstream HER is better masked from particle background (better shielding)

Expected dose for SVD2.0

Dominant source of SR background is from QC2

For 1Amp HER beam, the dose due to tip scattering at HER mask is ~ 0.01kRad/year

If no saw tooth : tip scattering -> surface scattering dose ~ 50 times larger

LER mask back scattering ~ 0.001kRad/year

Without LER mask protection for Be beampipe ~ 28kRad/yr

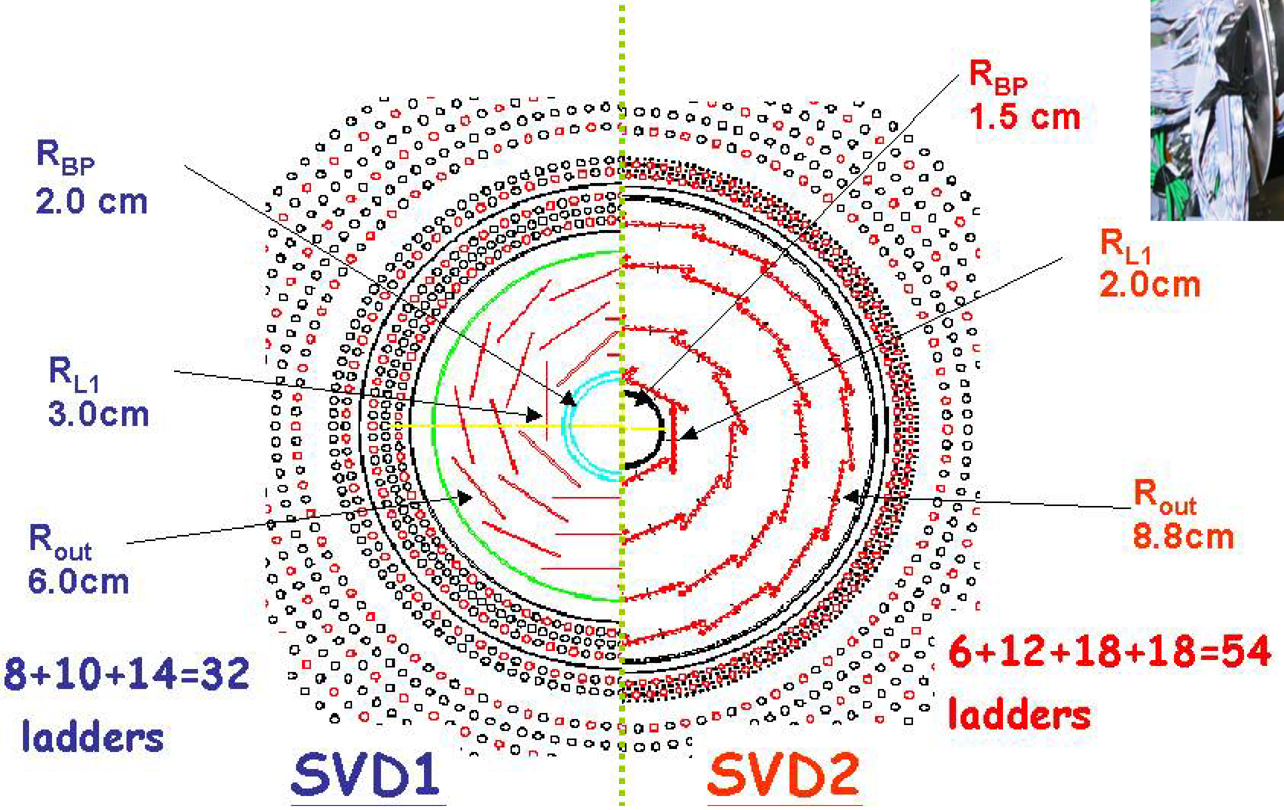
If the 'blast' condition that killed SVD1.0 happens again and continues for one year ~ 12 kRad/year

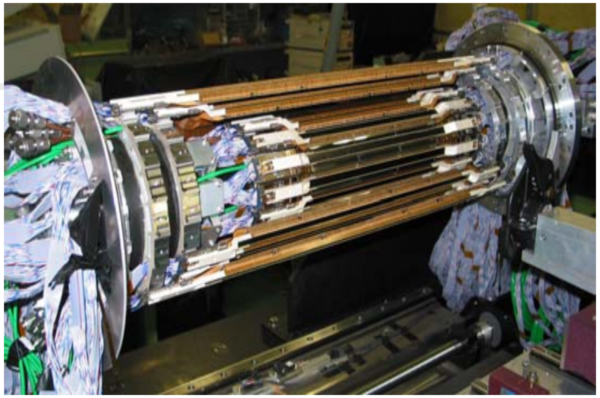
For SVD1.5 ~ 470 kRad/year with 300μm gold foil

Overall, SR does not seem to be a problem.

Upgrades-III

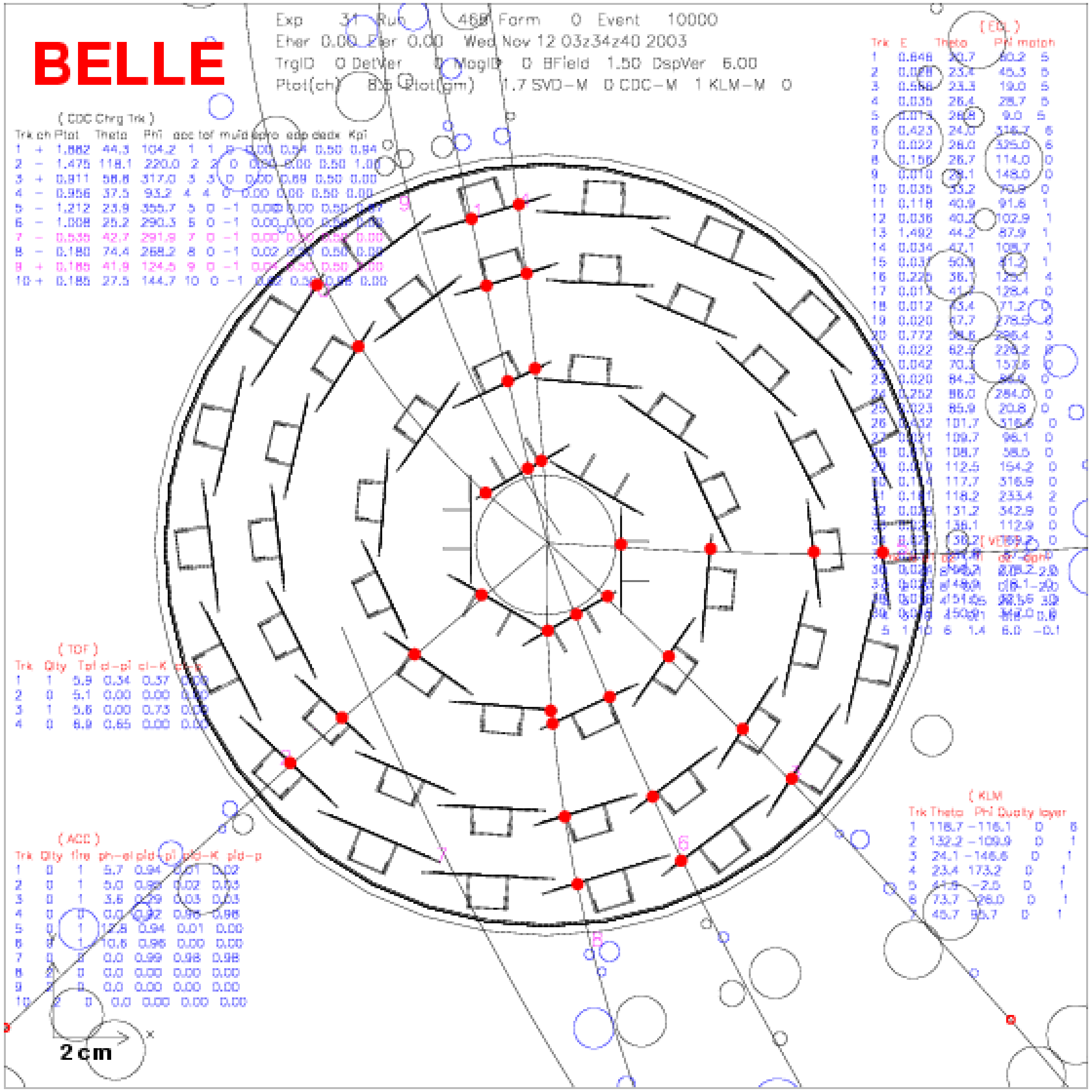
View from beam line





- **Increase the number of layers , 3 layers → 4 layers**
- **smaller radius for inner-most layer**
- **Better vertex resolution (α 1/distance 1st detection layer)**

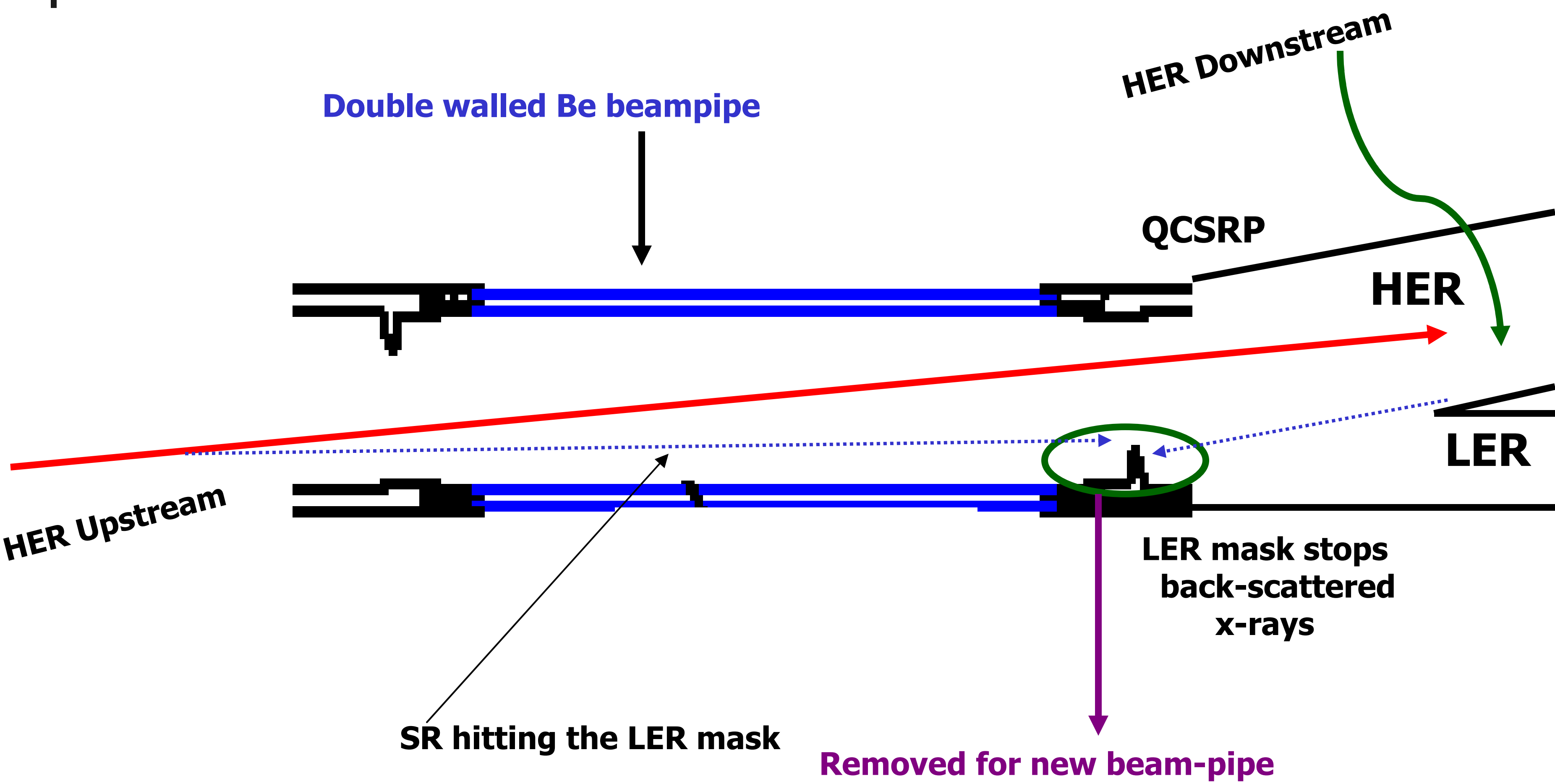
An event with new vertex detector



Summary

- **SR background does not seem to be a problem**
- **The radiation dose is now as predicted by SRGEN+ EGS4**
- **For high radiation dose region ->Radiation alarm**
- **particle background is now protected with better masking system**
- **HOM heating was the next concern but not that much problem because of varying angle**

Upgrade (fall-2003): New beam-pipe



Backscattered HER SR from QCSR

HER offset ~4.3cm in QCSR exit

E_c = 38keV

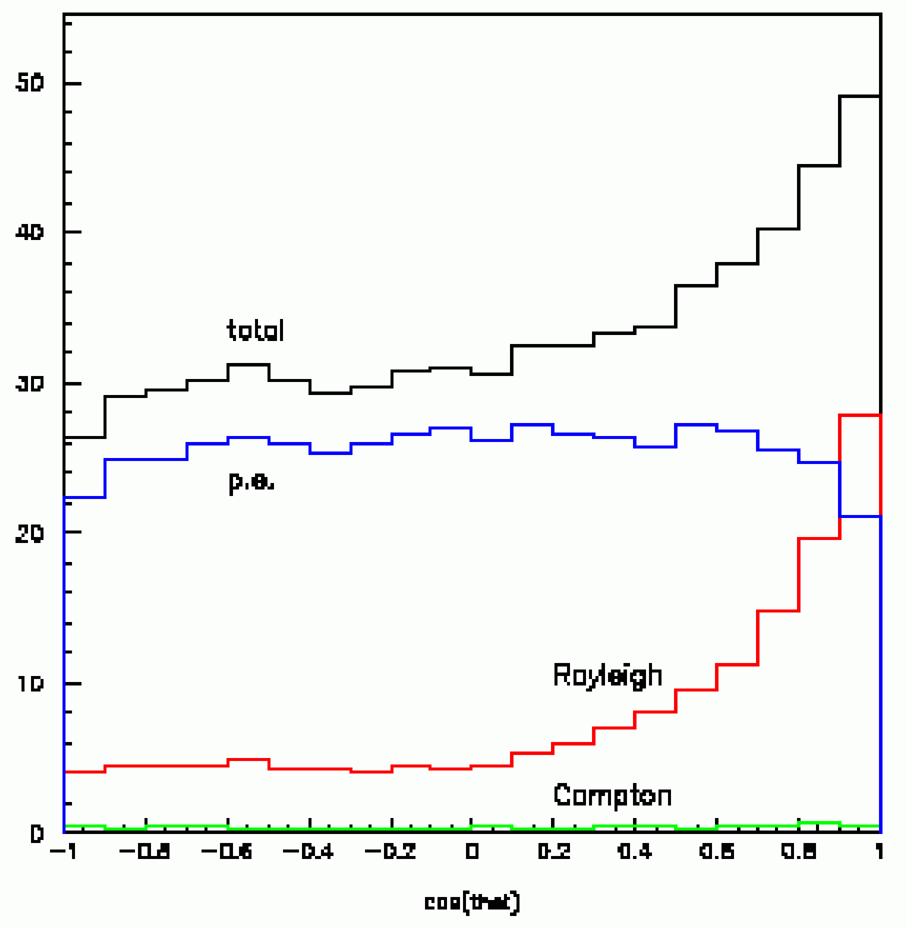
Power = 25 kW/A

Dumped on a beampipe surface that has direct line of sight to IR beam pipe

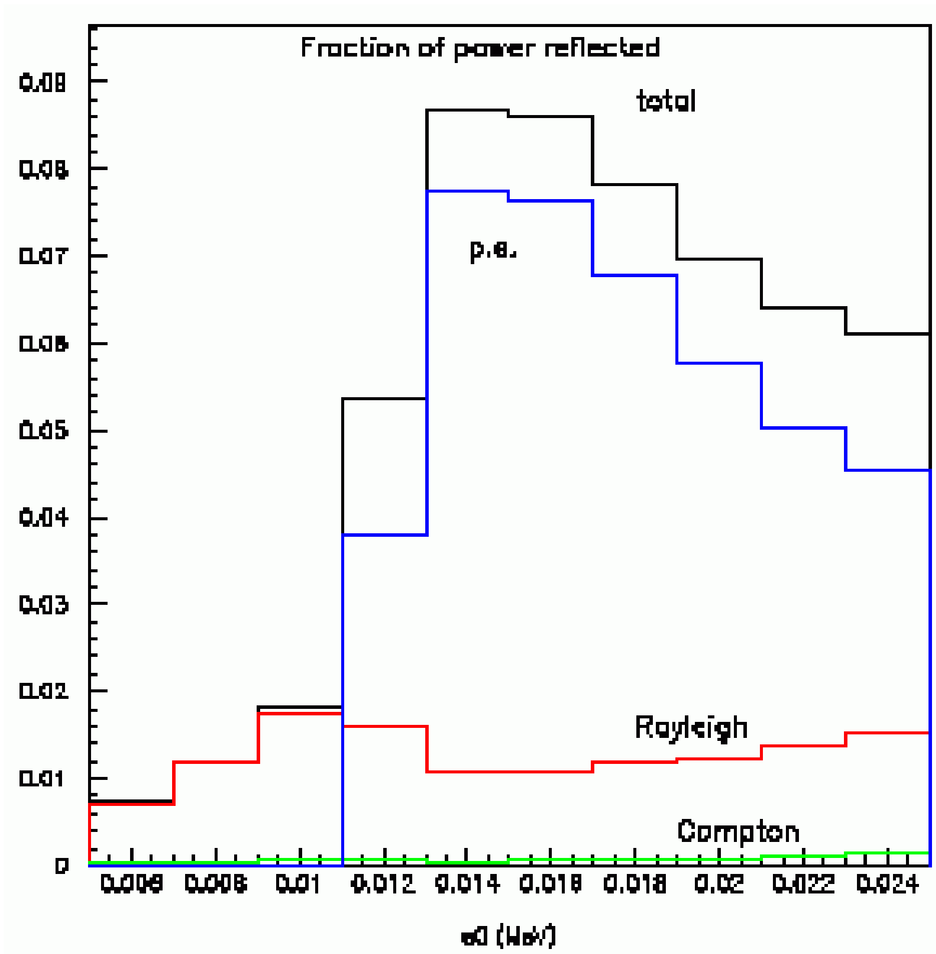
Be section is bare ~ transparent
Cone is AL; λ(Al)= 0.6cm
-> penetrates the cone section

Measure taken for SVD1.2 (1999 fall)
'SR dump' beam pipe Al -> Cu (1/10)
(also extra Pb masks around upstream beam pipe for particle backgrounds)

SVD killing situation(1999 summer) and new beam-pipe



SVD killing situation(1999 summer) and new beam-pipe



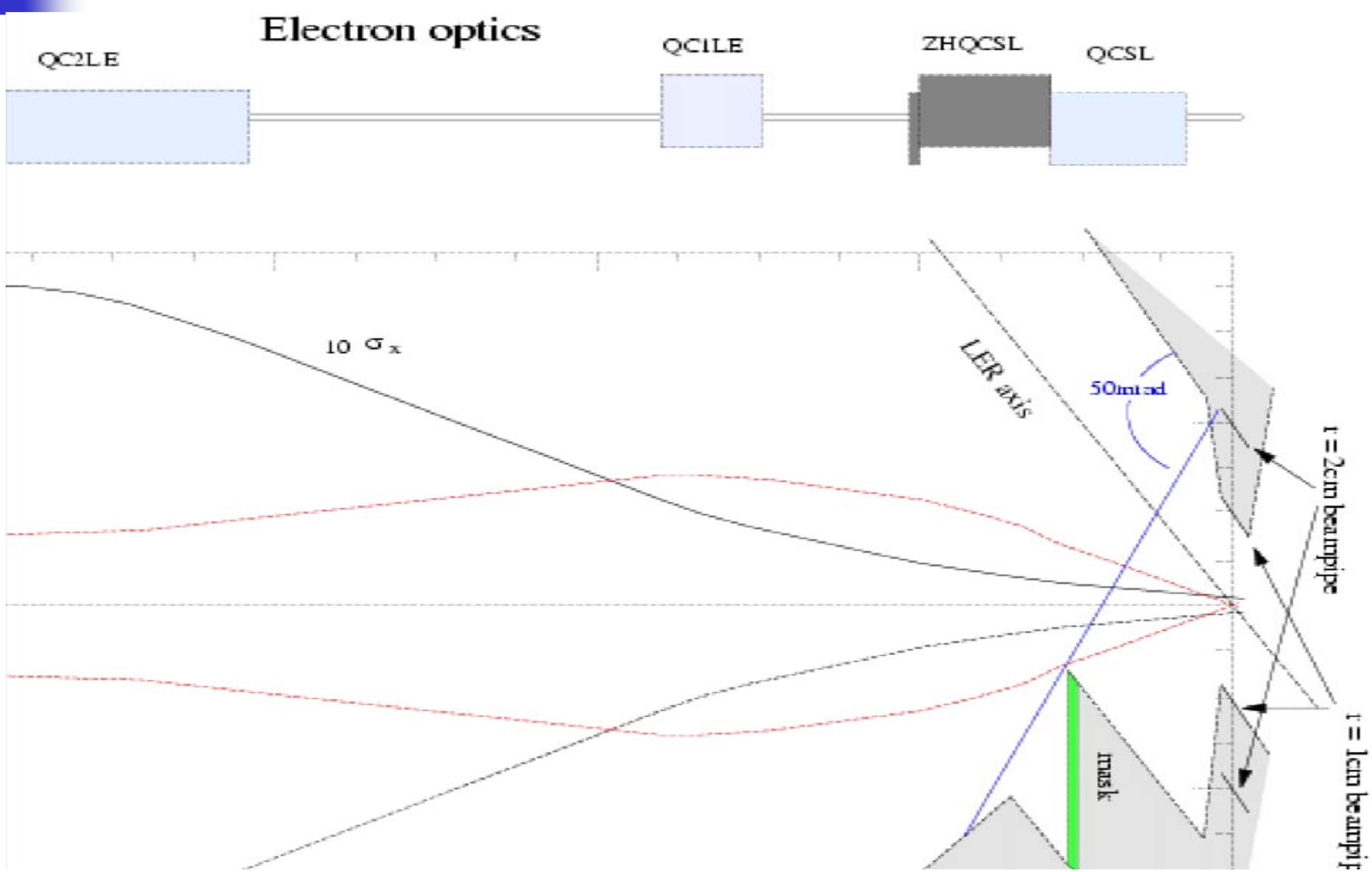
SVD2.0 Design for 'hard' SR

- **Use Cu or Au for cone section**
  (back scattered QCSR 40keV X-rays)

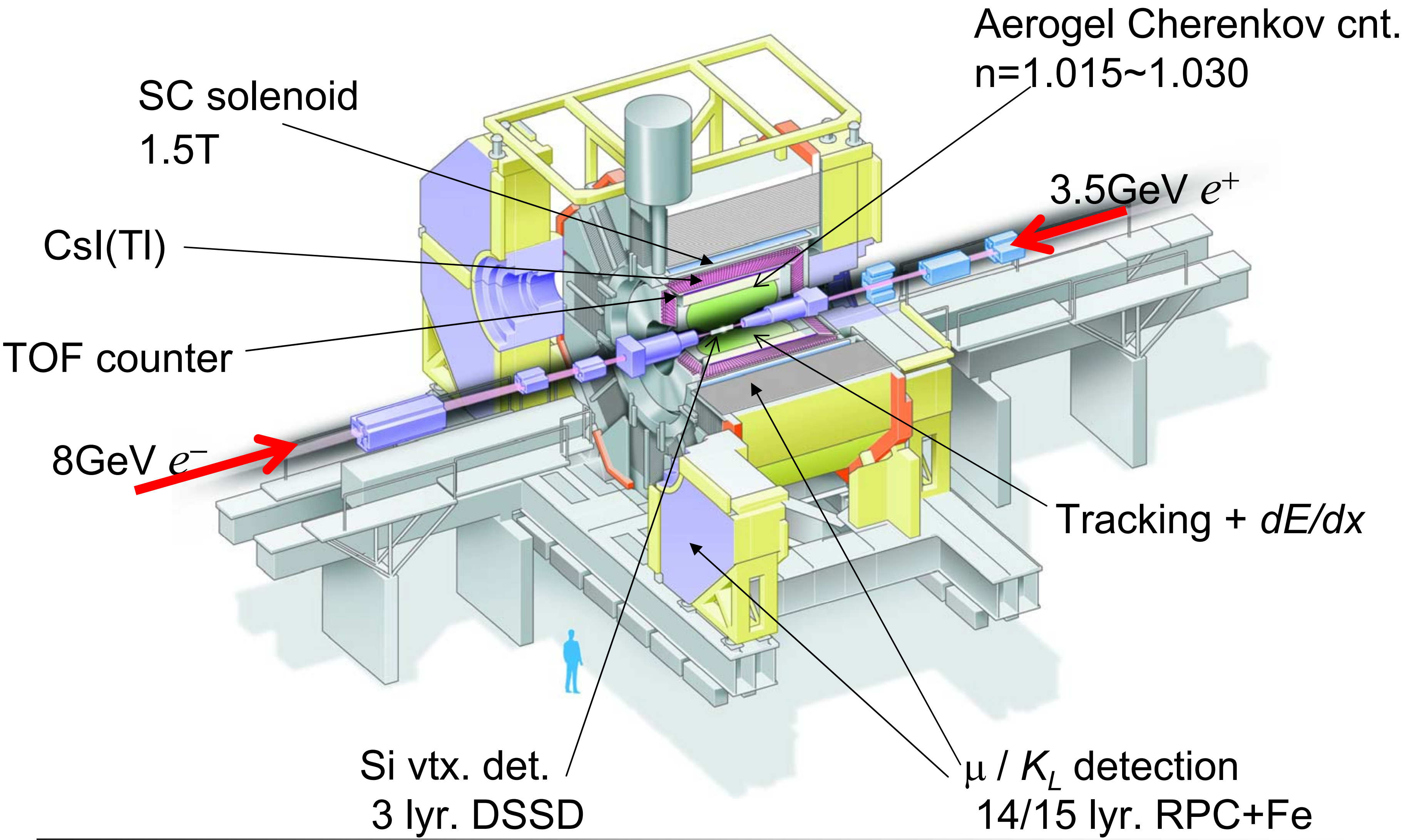
- **LER side mask made 'heavy' metal**
  Blocks backscattered X-rays for
  E_γ < 100keV

Overall, SR does not seem to be a problem.
Dominant: backscattered hard SR ~10kRad

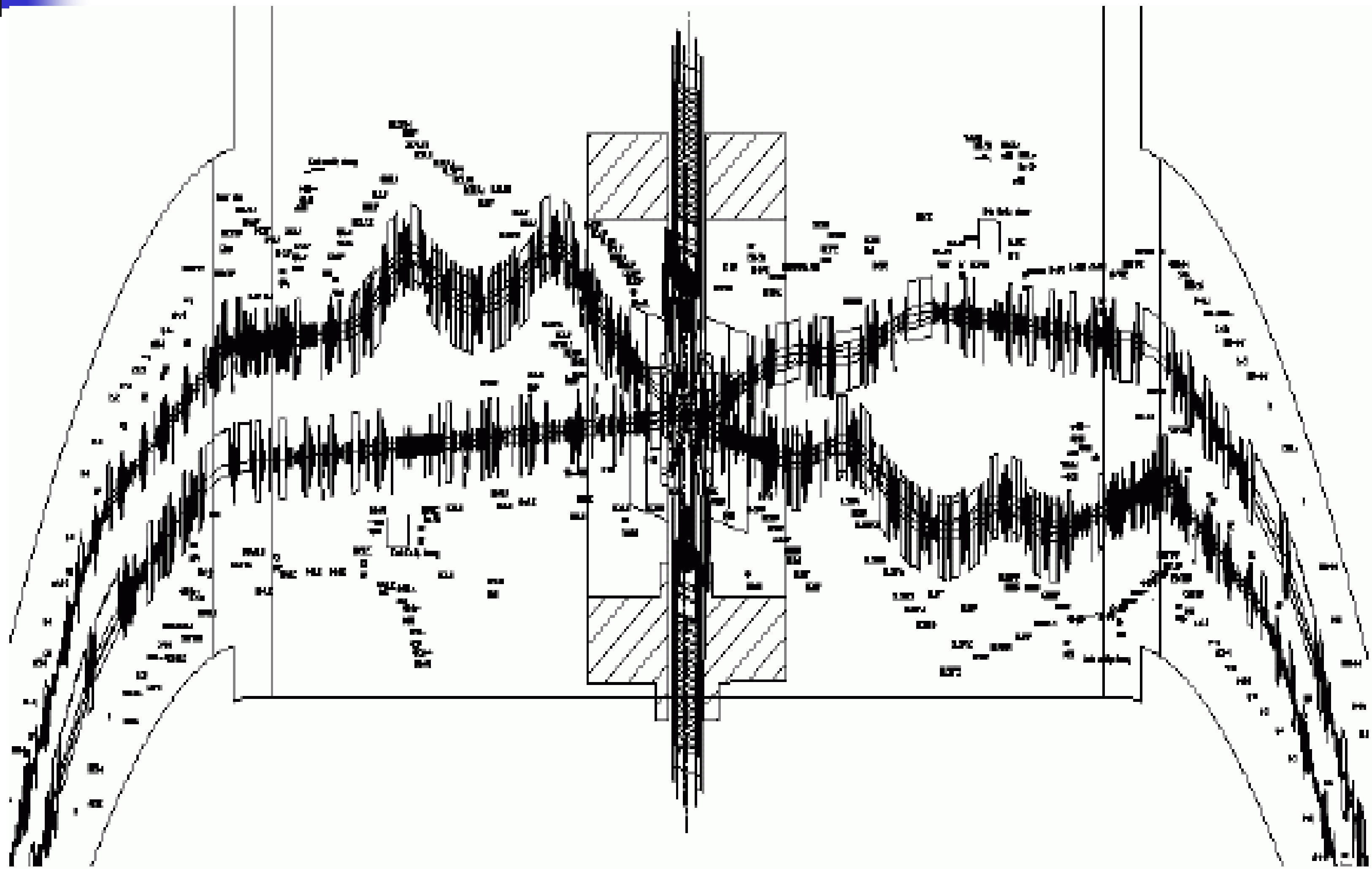
HER side optics near IR



Belle Detector



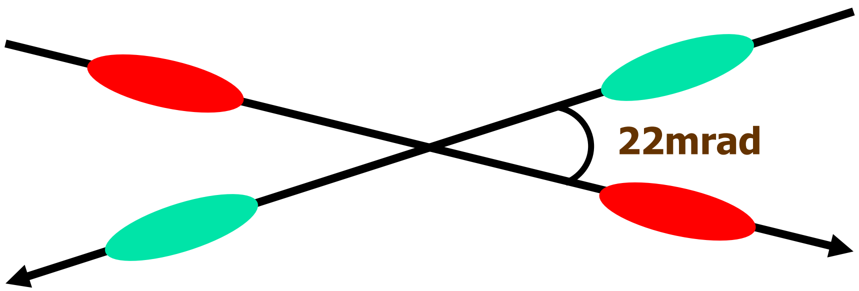
Outline of KEKB straight sections



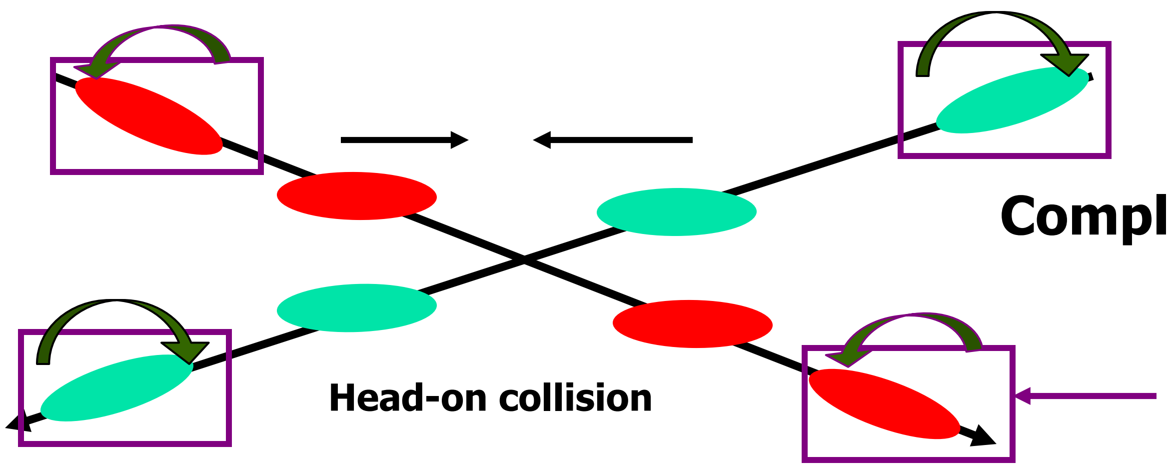
Future upgrade planned for 2005 [luminosity:factor of 2]

For a finite crossing angle → Geometrical luminosity loss
→ Beam instability

Without crab cavities:



With crab cavities:



Scattering of X-rays

Photo electric effect $E_{scatt} = E_{k,L\ edges}$

Compton scattering $E_{scatt} = E_{incident}$

Rayleigh scattering $E_{scatt} = E_{incident}$

Reflection rate and angular distribution:
Interplay of how the scattering occur
and how much is absorbed before exit