Beam Backgrounds and IR Design

- Belle experiences -

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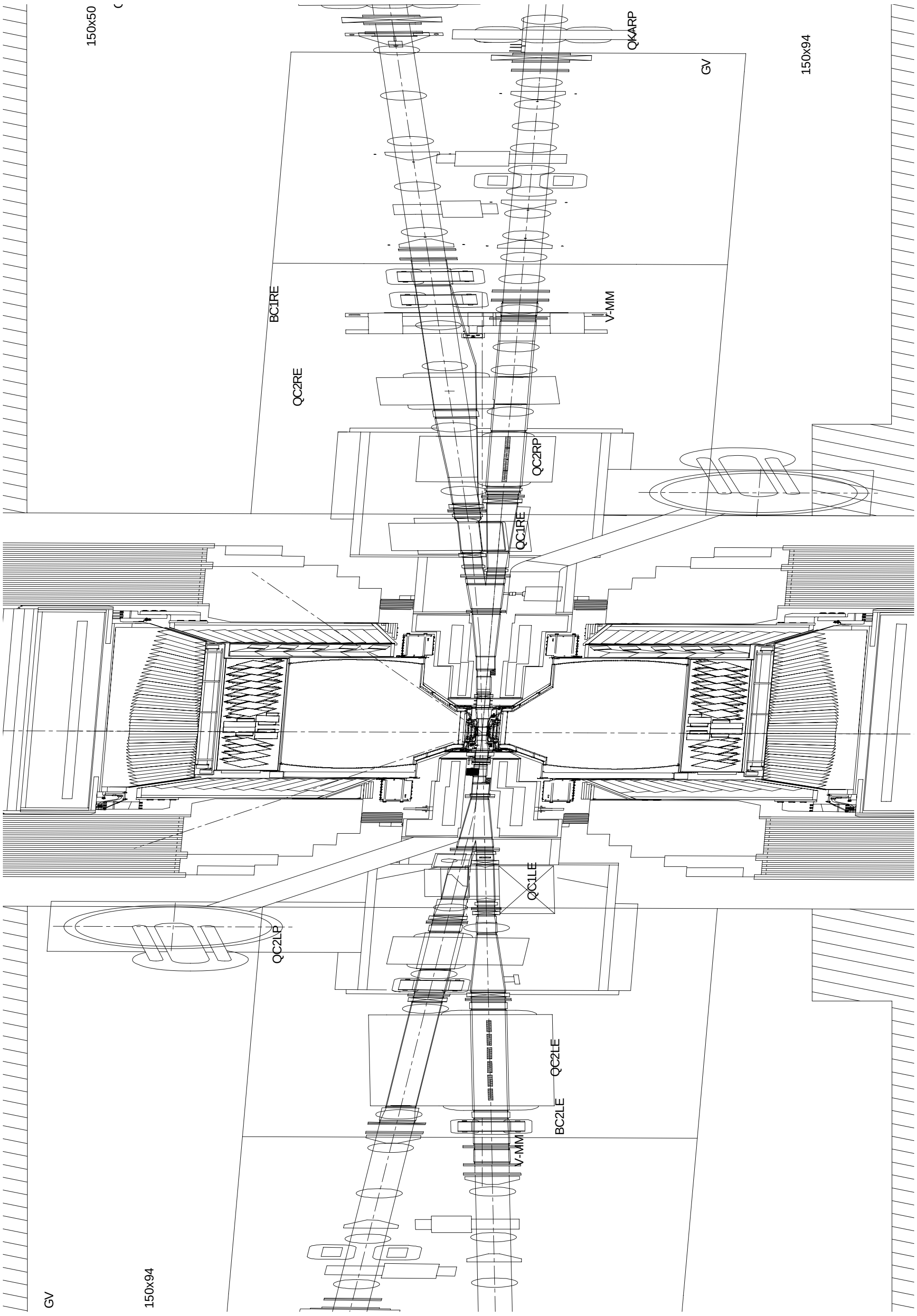
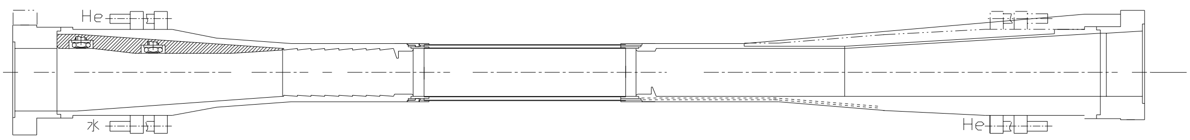
3/26/02 IHEP, Beijing

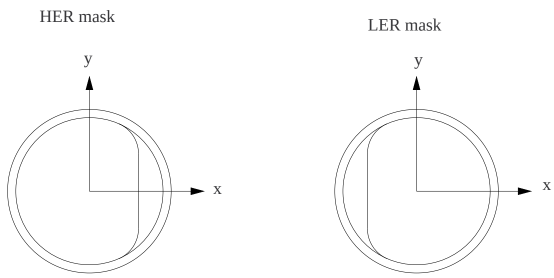
1. Experience with SVD1.x and SVD2.0 Upgrade
   (a) Synchrotron radiation background
   (b) Particle background
2. Mechanical design overview
   (a) Beampipe heating and HOM studies
   (b) Cooling/Mechanical design

Machine configuration near Belle



Versions of SVD1.x IR beampipe.

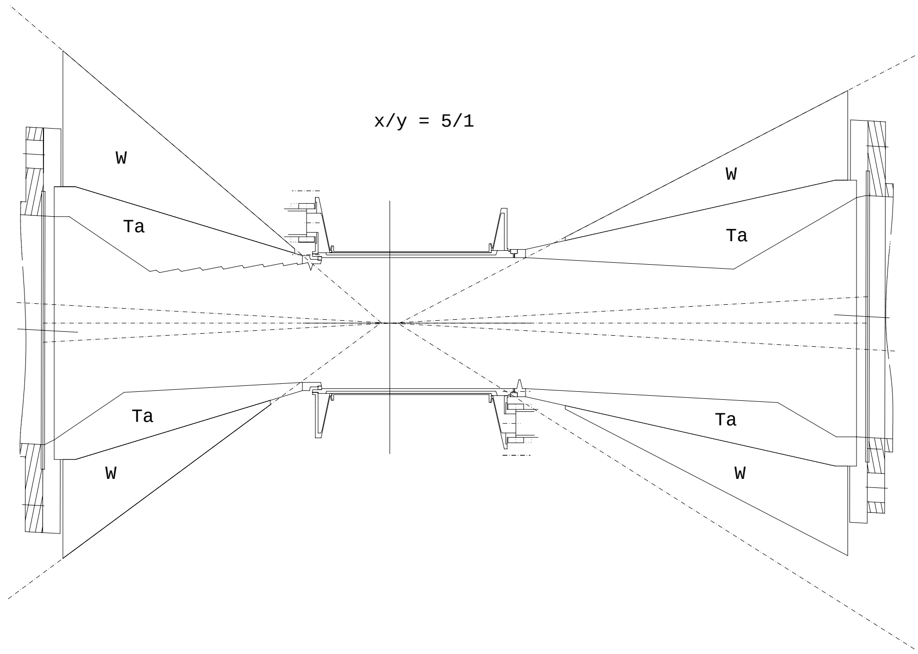




All $r = 2$ cm, Be: He cooled, Cone: Water-cooled.

verision	Period	comment
SVD1.0	6/99→8/99	no gold on Be rad-soft chip (200 kRad)
SVD1.2	10/99→7/00	20 μm gold outside Be rad-soft chip (200 kRad)
SVD1.5	10/00→	10 μm gold inside Be rad-tolerant chip (1MRad, mostly)

SVD2.0 (2002 summer upgrade):
r=1 or 1.5 cm studied. (1.5 cm taken)



Be: liquid-cooled, Cone: water-cooled.
10μm gold inside Be.
Rad-hard chip ($\sim$20 MRad)

SR Backgrounds

Two Sources

- **'Soft' SR background**

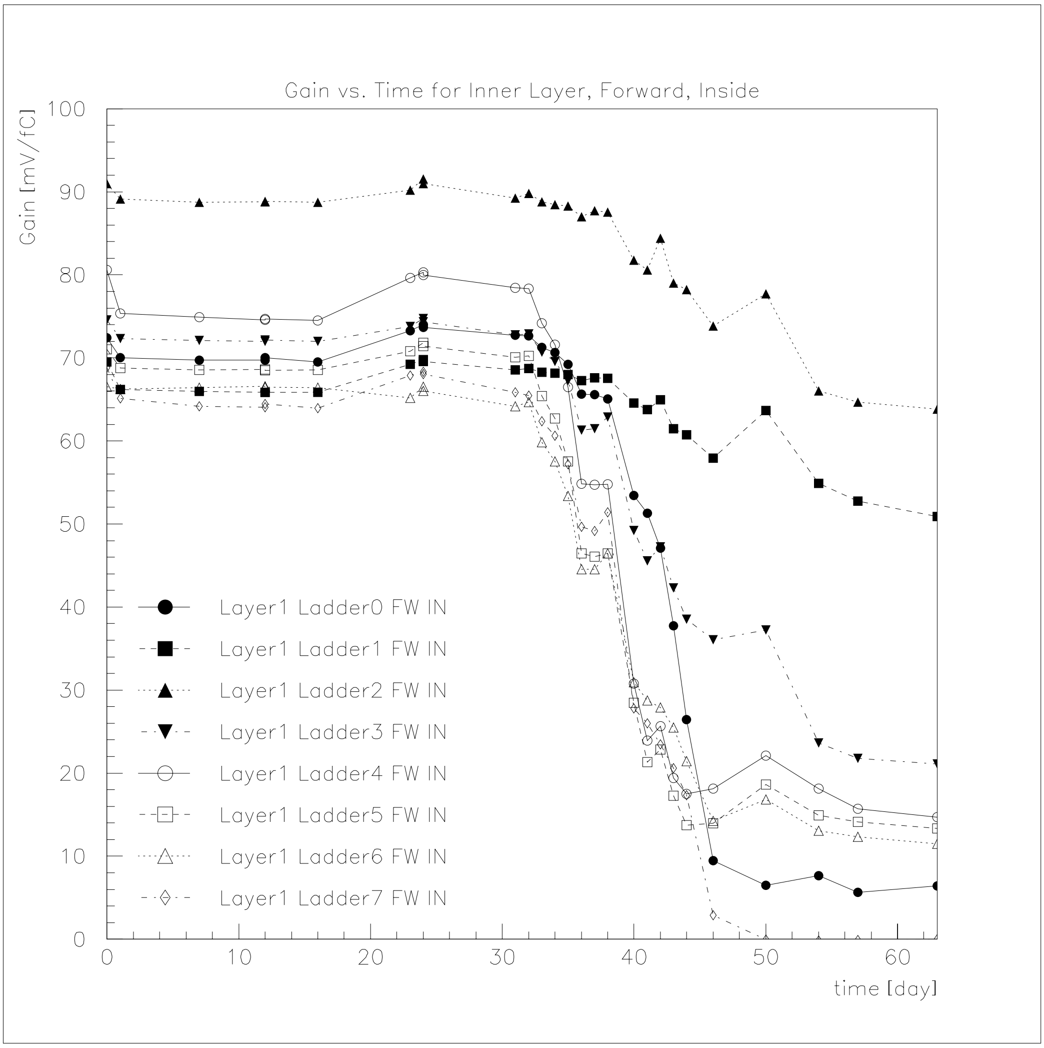
  Caused gain loss of SVD1.0 in summer 1999.
  SR photons from HER upstream.
  + Bare Be beampipe.

- **'Hard' SR background**

  High-pulseheight component of SVD.
  CDC leakage current.
  Backscattering from downstream HER.

SVD gain loss in summer 1999

(gain 1/4 ∼ 0 in 10 days)



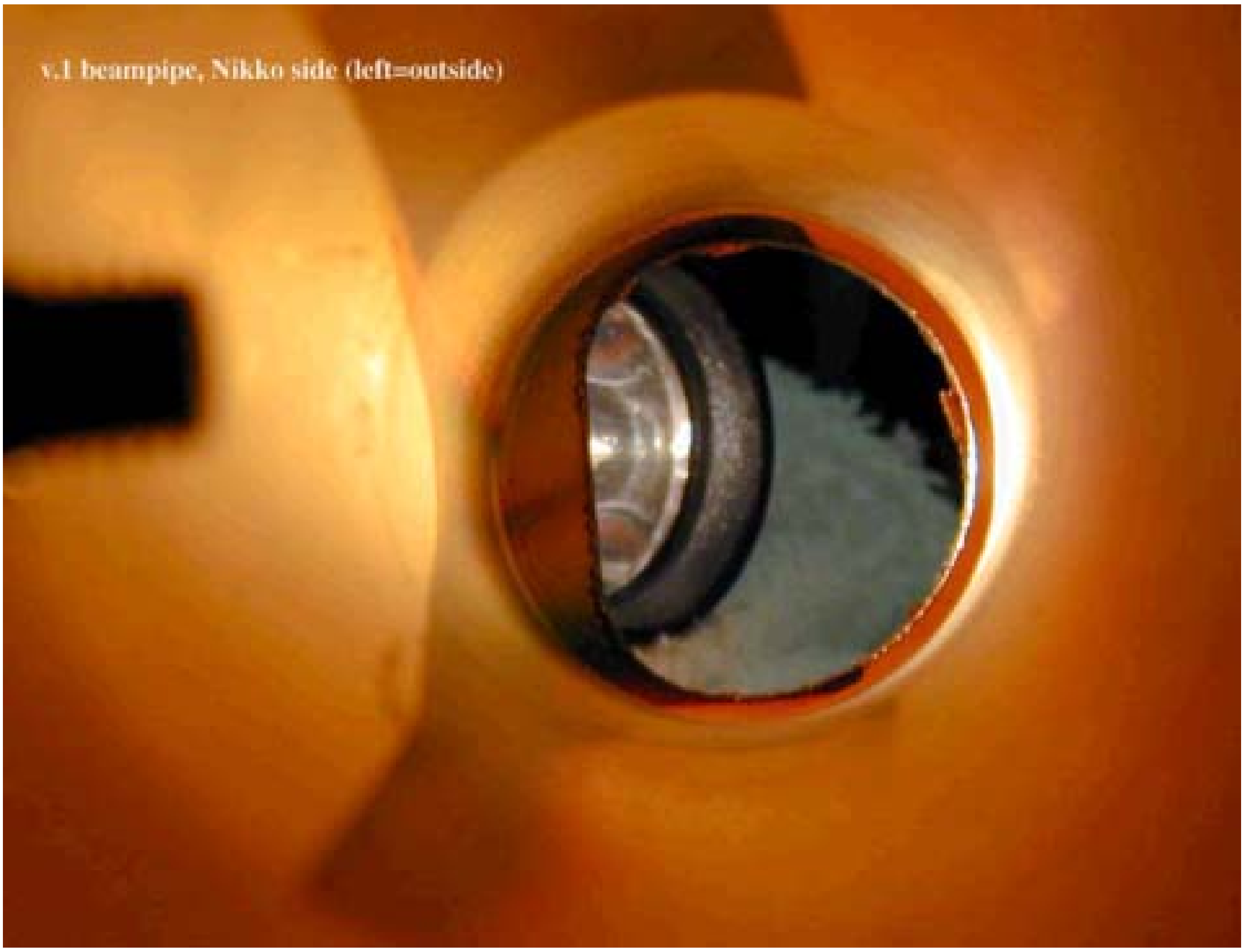
Gain loss is mostly forward side (right side)
Bottom hybrids. Hybrids shaded by other hybrids OK.

v.1 Beampipe SR Burns

Looked from Nikko (HER) side.

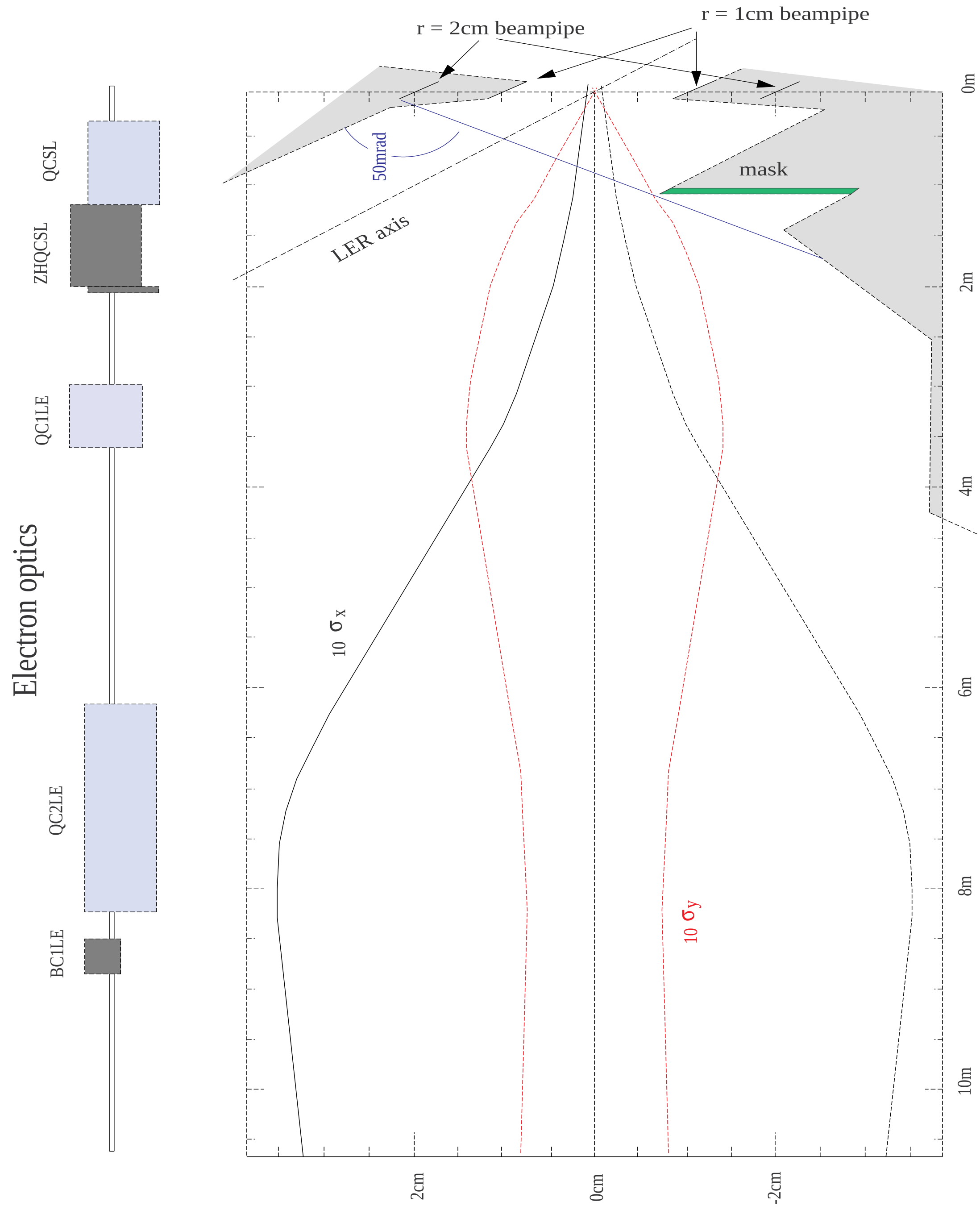
After central Be section had been cut off.

Tungsten mask removed.



HER side optics near IR

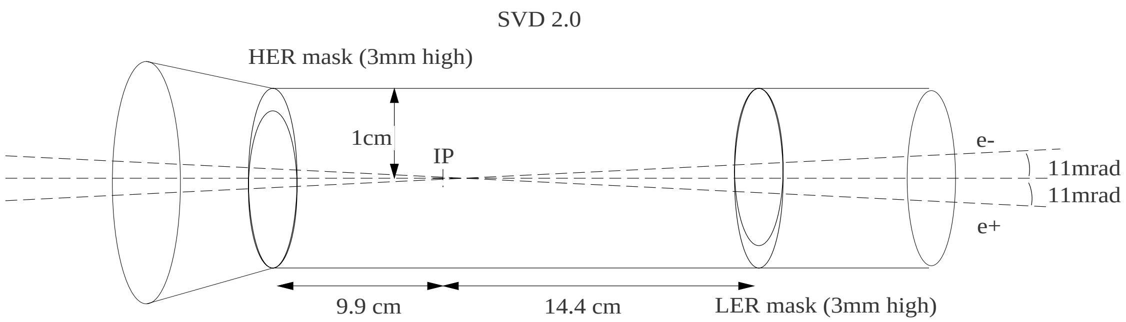
(top view exept red envelope which is vertical)



SR dose estimation

Method

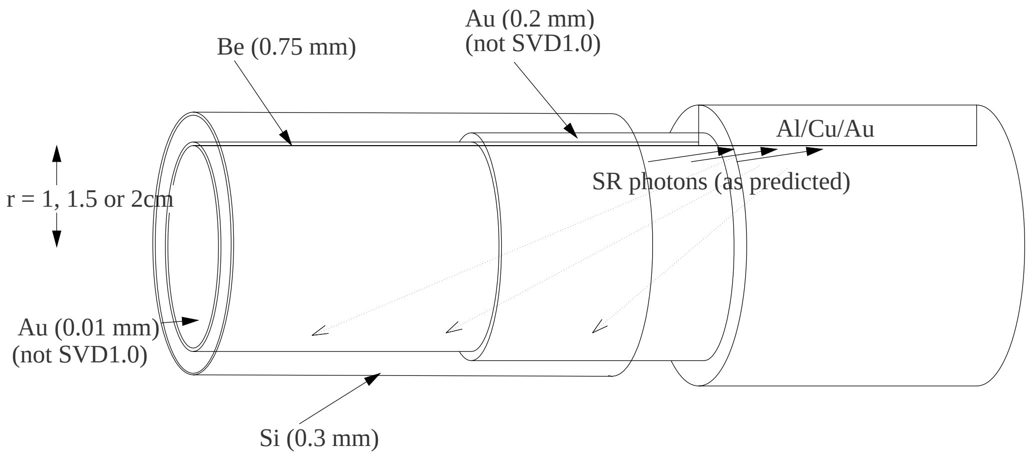
- SRGEN
  Written by S. Henderson.
  Twiss parameters $\longrightarrow$ beam profile.
  Steps through magnetic field.
  Numerically integrates the power spectrum on a given surface.



SR power sprctrum on a bemapipe surface is passed to EGS

- EGS4
  Photons traced down to 1 keV.
  Electrons traced down to 20 keV.
  KEK low-energy improvements
  (L-edge X-rays: important for heavy elements)

EGS geomety example



Sources of possible v.1 Beampipe Burns

In increasing order of devastation
(dose estimation: SRGEN + EGS)

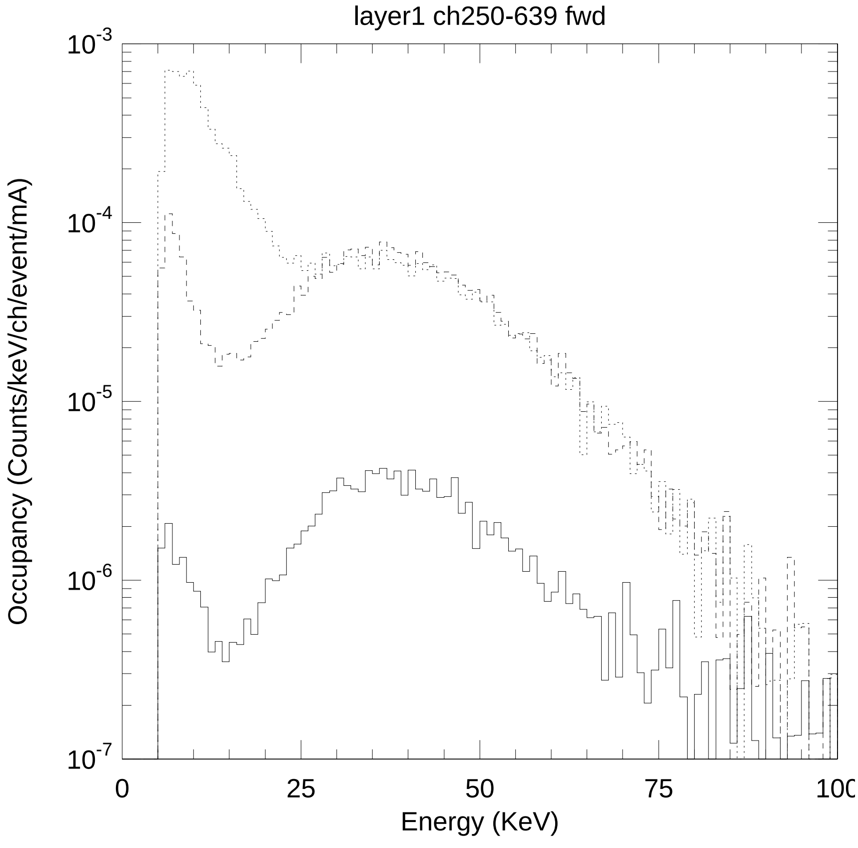
1. Bounced SR from inside QCSL.
   Shade of the tungsten mask tip
   $\longrightarrow$ source is just beyond Uno mask.
   Bounced SR from BH3, QC2?
2. QC2 $\sim$ 50 kRad/10days
   It could hit anywhere on the HER mask depending on steering.
3. BC3 $\sim$ 300 kRad/10days
   BC3 SR Could hit IR if not blocked by the 1.1m mask.
4. QC1 $\sim$ 500 kRad/10days
   If y offset of QC2 causes SR hit on IR, QC1 should also hit.

Measures Taken for Soft SR background

- Limit values of steering magnets.
- Wrap the Be section of beampipe by mylar coated with 20μm gold.
- Protect the readout hybrids by 300μm gold.

File: Generated internally

ID	IDB	Symb	Date/Time	Area	Mean	R.M.S.
119	20	1	991108/1131	1.2813E-04	40.29	17.36
366370	20	2	990916/2021	2.6009E-03	33.97	16.76
358370	20	3	990916/2021	7.7561E-03	18.27	14.67



Backscattered HER SR from QCSR

HER offset $\sim 4.3cm$ in QCSR on exit

$$\rightarrow \begin{array}{l} E_c = 38 \text{ keV} \\ \text{Power} = 25 \text{ kW/A} \end{array}$$

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

Compton backscattering on Al:
1%/str of power (at 38 keV)

Be section is bare $\sim$ transparent.
Cone is Al; $\lambda(Al) = 0.6$ cm
$\rightarrow$ penetrates the cone section.

Measures taken

SVD1.2 (1999 fall): 'SR dump' beampipe: Al $\rightarrow$ Cu ($\times 1/10$ dose reduction)

SVD1.5 (now): In addition, 0.3mm-thick coating inside the LER-sdie Aluminum pipe.

Strategies aginst SR

For HER (LER: $\times 1/10$ for E_c and P)

$$E_c(keV) = 4.27B(kG)$$

$$P(W/A) = 12.68I(A)B^2(kG)E^2(GeV)L(m)$$

element	E_c (keV)	P(kW/A)
QC2LE	1.3 d(cm)	0.16 d^2(cm)
QC1LE	5.6 d(cm)	0.91 d^2(cm)
QCSL,R	8.9 d(cm)	1.71 d^2(cm)

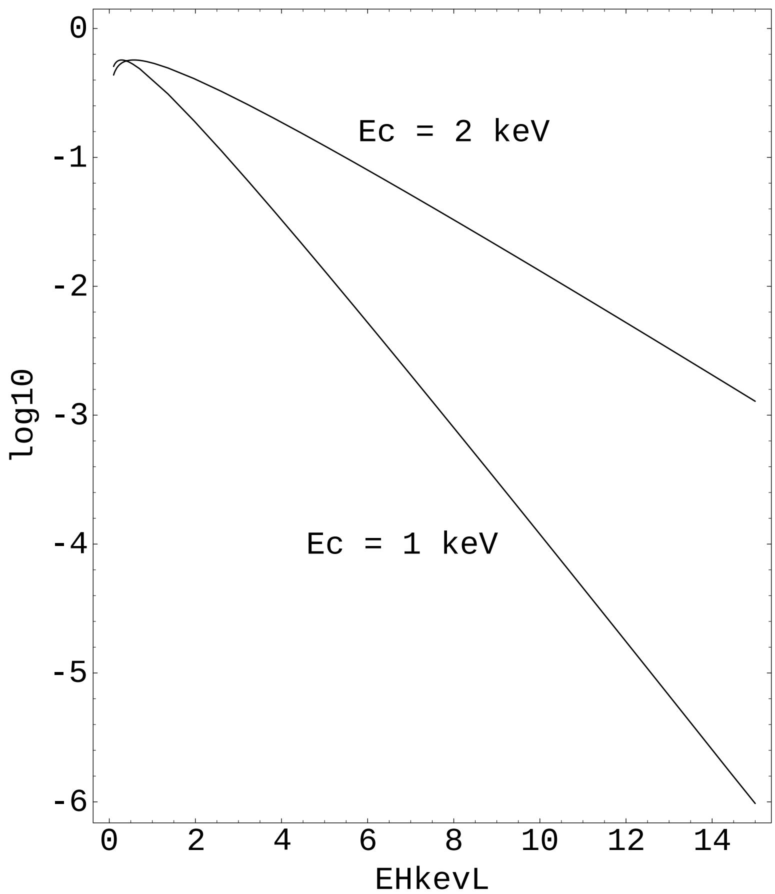
A slight increase in E_c $\rightarrow$ drastic rise in dose.
$\rightarrow$ limit the offsets at upstream Q's
and strengths of steering magnets.

Critical Energy and Si Dose

Typical SR X-ray energy for Si dose
$\sim$ 10 keV

SR pectrum

Ebeam fixed. B field varied.

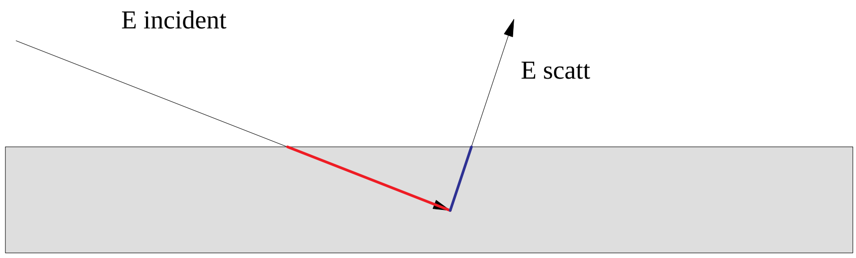


EGS: $E_\gamma > 8keV$ contributes to dose.
Ec = 2keV has $\sim$100 times more Si dose
than Ec = 1keV.

Scattering of X-rays

Photo electric effect	$E_{\text{scatt}} = E_{\text{K,Ledges}}$
Compton scattering	$E_{\text{scatt}} \sim E_{\text{incident}}$
Rayleigh scattering	$E_{\text{scatt}} = E_{\text{incident}}$

Reflection rate and angular distribution:
interplay of how deep the scatteing occur and how much is absorbed before exit.

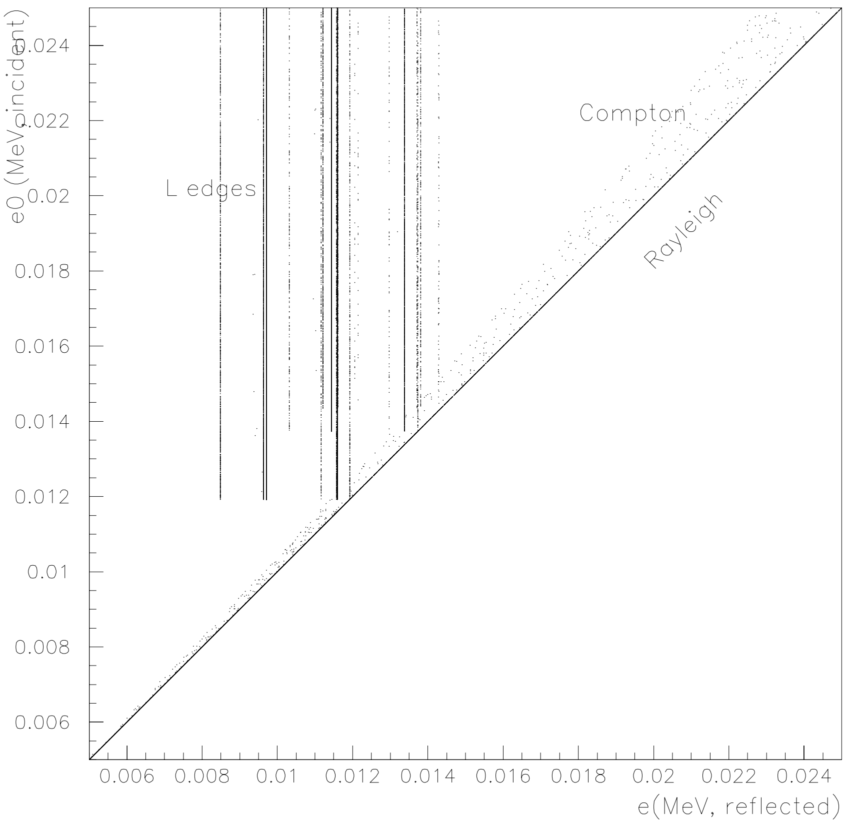


e.g. Photoelectric effect photons yield large for small incident angles.

Example: Scattering of X-rays on Gold

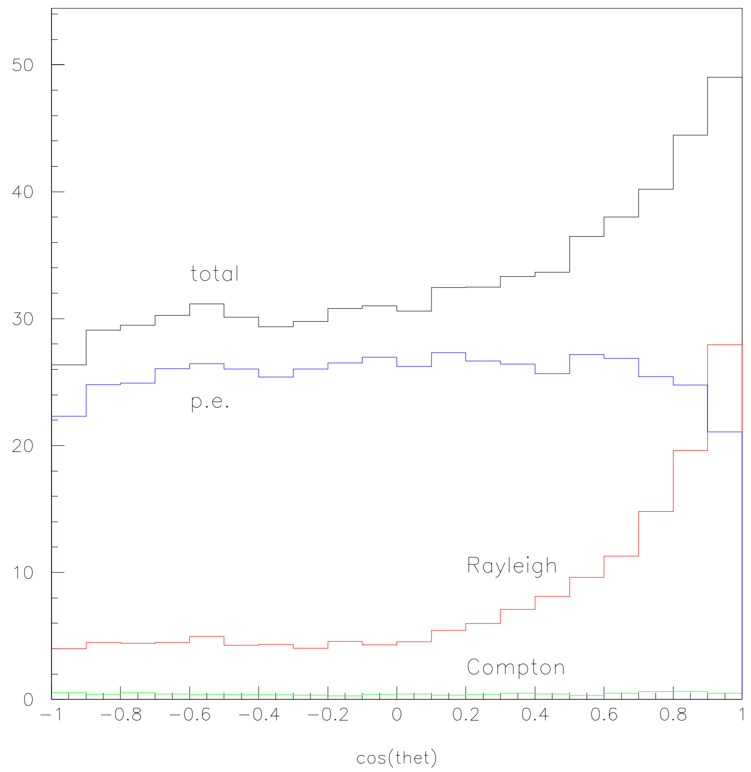
Incident angle = 40 mrad

Uniform power between 5 and 25 keV



Scattering angle distributions

(incident: 5-25 keV, 40 mrad)

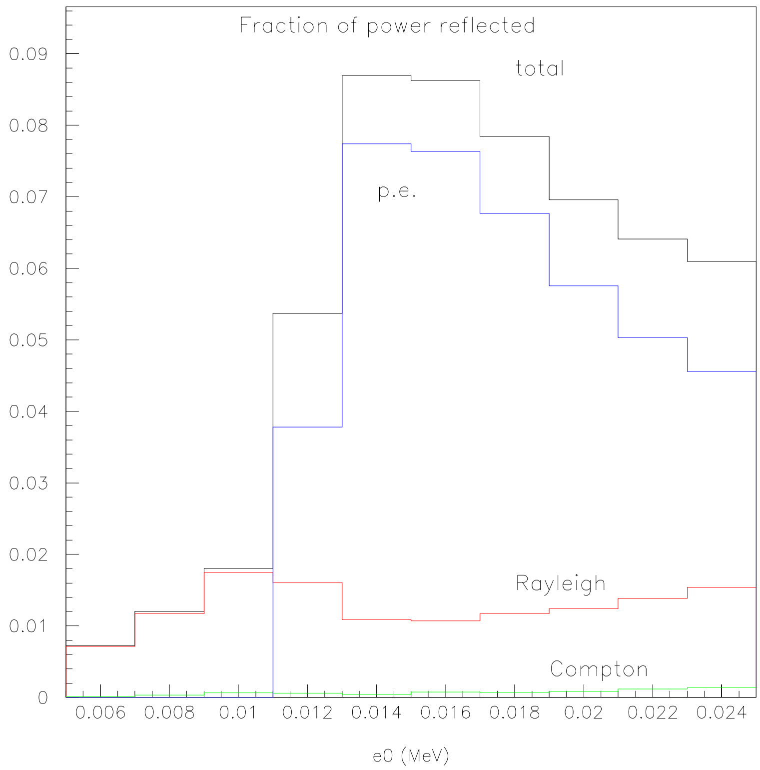


Apart from the forward Rayleigh scattering roughly uniform in 2π str.

Fraction of Reflected Power

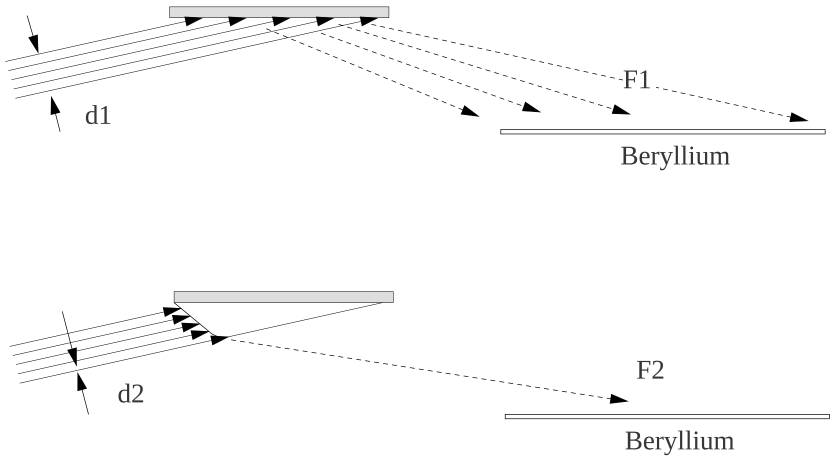
(incident: 5-25 keV, 40 mrad)

(Power reflected in 2π str)/(Power incident)



Typically, 1%~0.1% per str of power is reflected.

Sawtooth Structure



d1,2: flux of photons shining on the surface that can see Beryllium.

Reduction of flux on Beryllium:

$$\frac{F2}{F1} \sim \frac{d2}{d1}$$

Depends on the radius of the tip.

Typically reduces dose by 10^{-2}.

SVD2.0 Design for 'Soft' SR

Based on the recommendation of the last SVD review,
pursue r=1cm possibility.
(r=1.5cm as backup)

- Tilt 11mrad w.r.t. Belle axis.
  - Smaller masks $\rightarrow$ less HOM.
  - Be section and cones on axis.
  - Space for cooling tubes for Be section.
- Sawteeth on HER side (varying angle).
  Surface scattering $\rightarrow$ tip scattering.
  $\sim 1/50$ dose reduction.
- Masks away from fiducial region.
  $\sim 1/10$ backscattering dose per 5cm.
  (300μm Au foil)
- Expected dose on silicon:
  QC1 Backscat. at LER-side Ta mask
  0.5 kRad/yr (yoff = 0 mm)
  67 kRad/yr (yoff = 3 mm)

  Depends on the orbit
  $\rightarrow$ orbit tracking/online alarm (in progress)

SVD2.0 Design for 'Hard' SR

- Use Tantalum for the cone section.
  (backscattered QCSR 40 keV X-rays)
- LER side mask ?
  Blocks backscattered X-rays for
  $E_\gamma < 100keV$ $\rightarrow$ negligible dose.

  20 kRad/yr without the mask.
  (no resonant HOM: take this choise)

Injection SR Background

Ta backscattering dominant

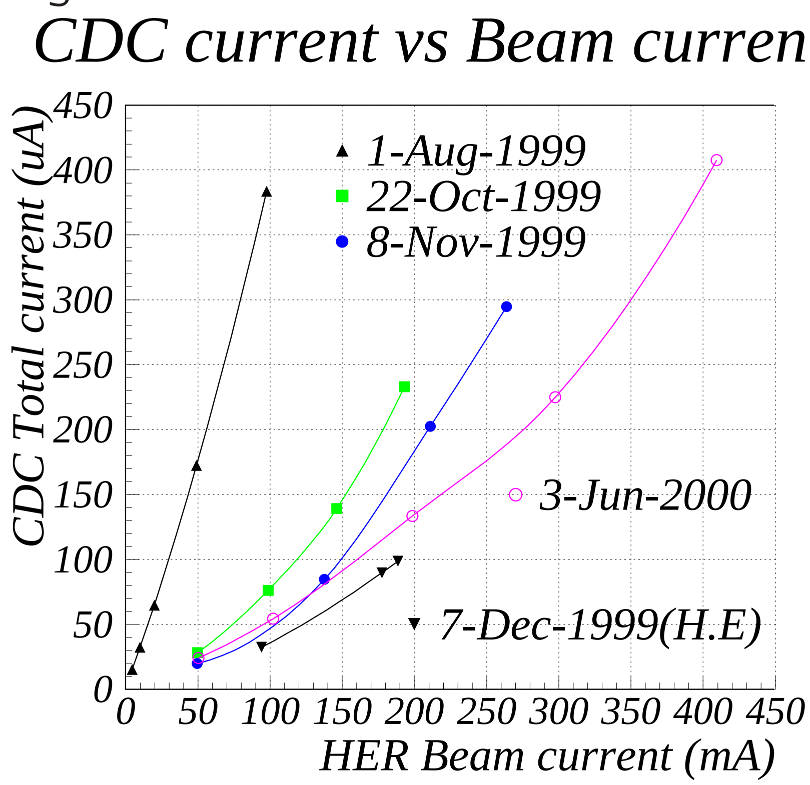
Fast component (feedback dumping 1ms):
6.7 kRad/yr
Slow component (normal dumping 40ms):
1/40 kRad/yr

Overall, SR does not seem to be a problem.

Particle Background vs SR Background

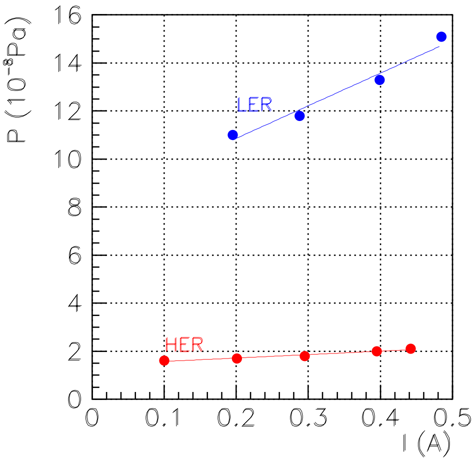
- Particle background $\propto$ I*P
- SR Background $\propto$ I

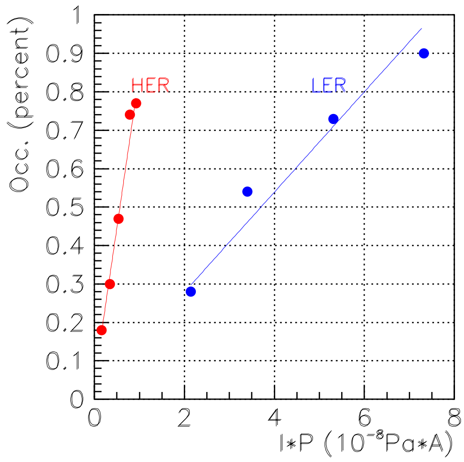
CDC leakage current as a function of HER current.



Quandratic component larger after
the summer 1999 shutdown?

Pressure, Current, SVD Occupancy





Vacuum pressures:
average of readings near upstream of IP.

- HER vacuum linear in I
  SVD occupancy linear in $I \cdot P$ for HER

- LER vacuum non-linear in I
  SVD occupancy non-linear in $I \cdot P$ for LER

LER: related to photoelectron effect
(or multi pacting effect)

Particle background dominant now.

Particle Background

Simulation:

- Beam-gas scatterings from the entire ring.
  (Bremsstrahlung + Coulomb)

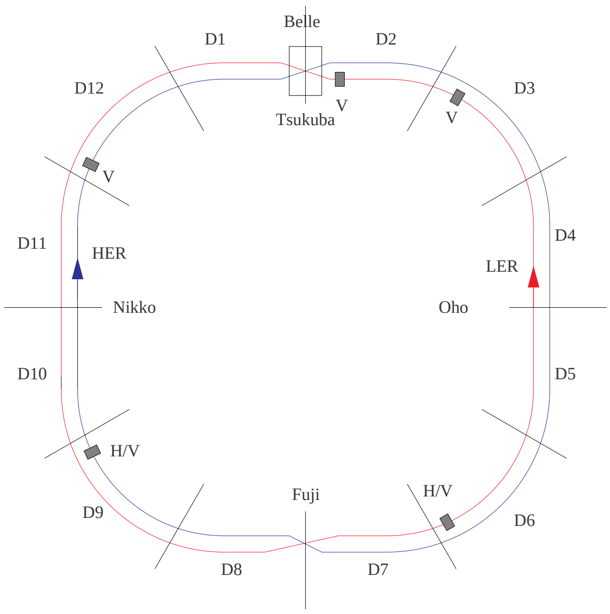
- GEANT simulation up to $\pm$7m of IP.
  (Up to QC2's)

- Touschek effect (Touschek generator written)
  Strongly depends on beam size.
  Consistent with observed Touschek lifetimes and Touschek background (w/i x2).
  (0-half of bkg is due to Touschek)

- Inner-mask shape optimization (r=1cm/1.5 cm)
  SR mask + beam-stay-clear $\rightarrow$ optimum shape.
  r=1.5cm significantly superior to r=1cm.

- Movable masks.

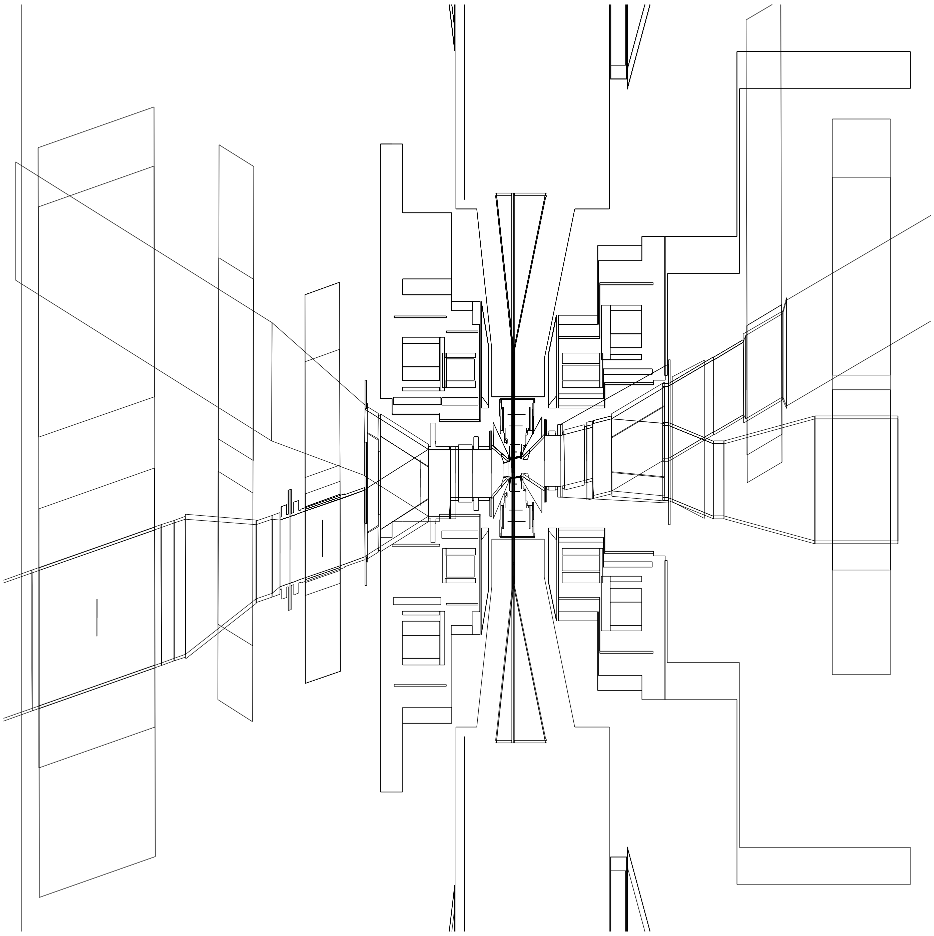
Simulation of Movable Masks



Effective masks: vertical masks ($\pm$3mm)
1 $\sim$ 2 orders of mag. change in bkg.

W/O masks, vertical aperture limit is QC1 ($25\sigma_y$)
$\pm$3mm$\equiv 19\sigma_y$ at the masks.

GEANT Simulation



Data vs MC

Unit = kRad/yr (1yr = 10^7 sec)
(Normalized to 1.1A/2.6A, 1nTorr CO)

Data: SVD lyr 1
(PIN diodes. LER/HER separately taken.)

	dose
HER	24 kRad/yr
LER	82 kRad/yr

MC: SVD ly1 1

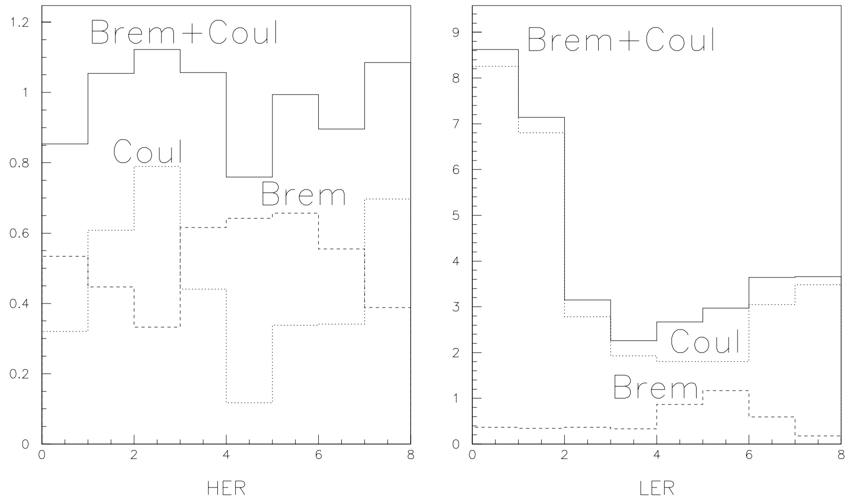
LER Particles entering GEANT just outside of b.p.
depends strongly on materials around b.p.
The numbers in (), such contributions set to 0.

	Brem/Coul	Touschek	total
HER	40.5	-	40.5
LER	35.2(23.3)	56.5(6.5)	91.7(29.8)

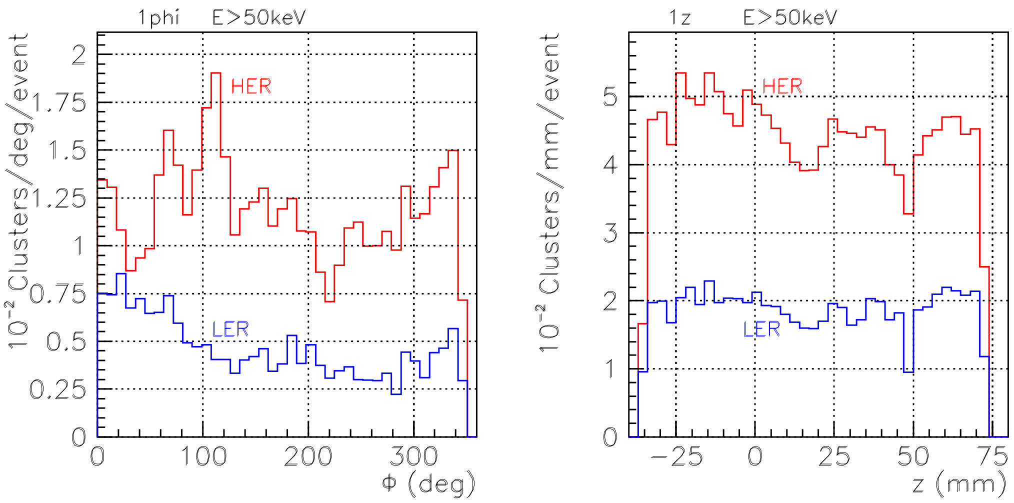
Data/MC agreement is reasonable.

ϕ distribution of hits

MC



Data



Pressure bump study

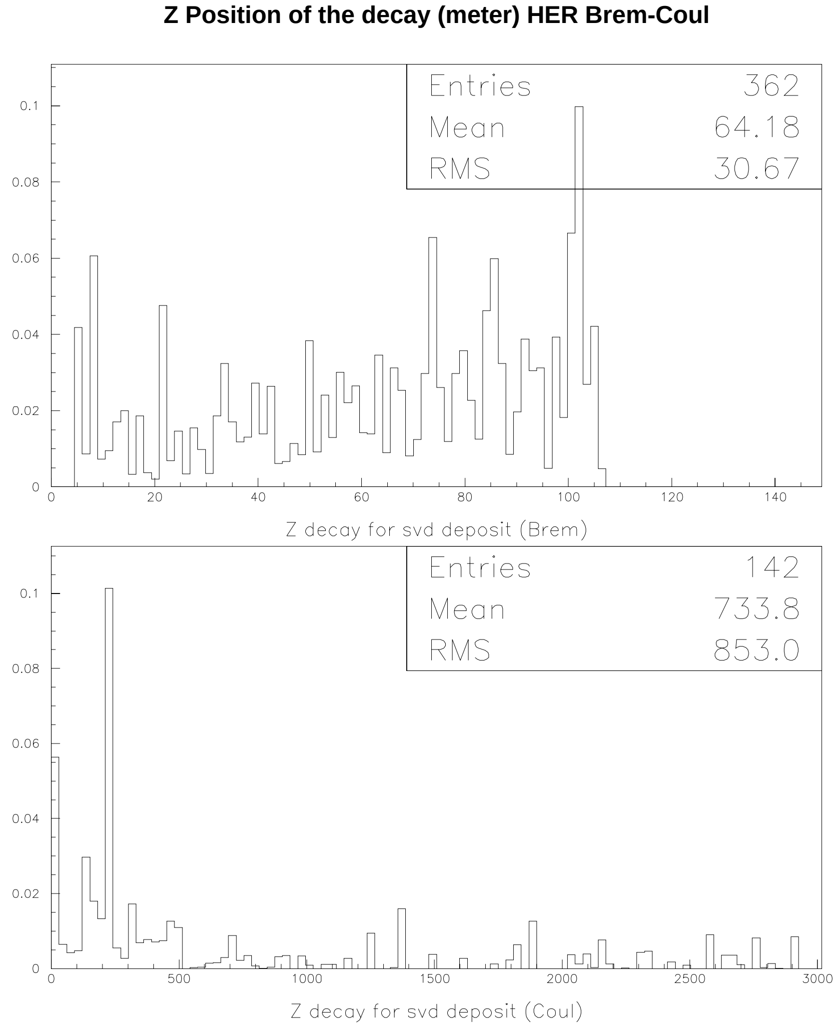
Pressure raised locally by turning off ion pumps and activating NEG pumps.

Pressure rise 'measured' by beam lifetime change. (Touscheck effect was not large)

name	length (m)	ΔP_{eff} (10^{-7} Pa)	Δbkg/ΔP_{eff} (arb.)
HER			
D1 str	65	2.0	120
D1 arc	166	0.22	187
D6 arc	240	2.6	0.4
D2	174	3.2	$\sim$0
D7/8	482	19	0.83
No bump	3016	0.7(500mA)	7
LER			
D10/11	192	3.8	0.8
D2 str	95	1.0	15
D7 str	70	1.7	2.5
No bump	3016	0.8(600mA)	5

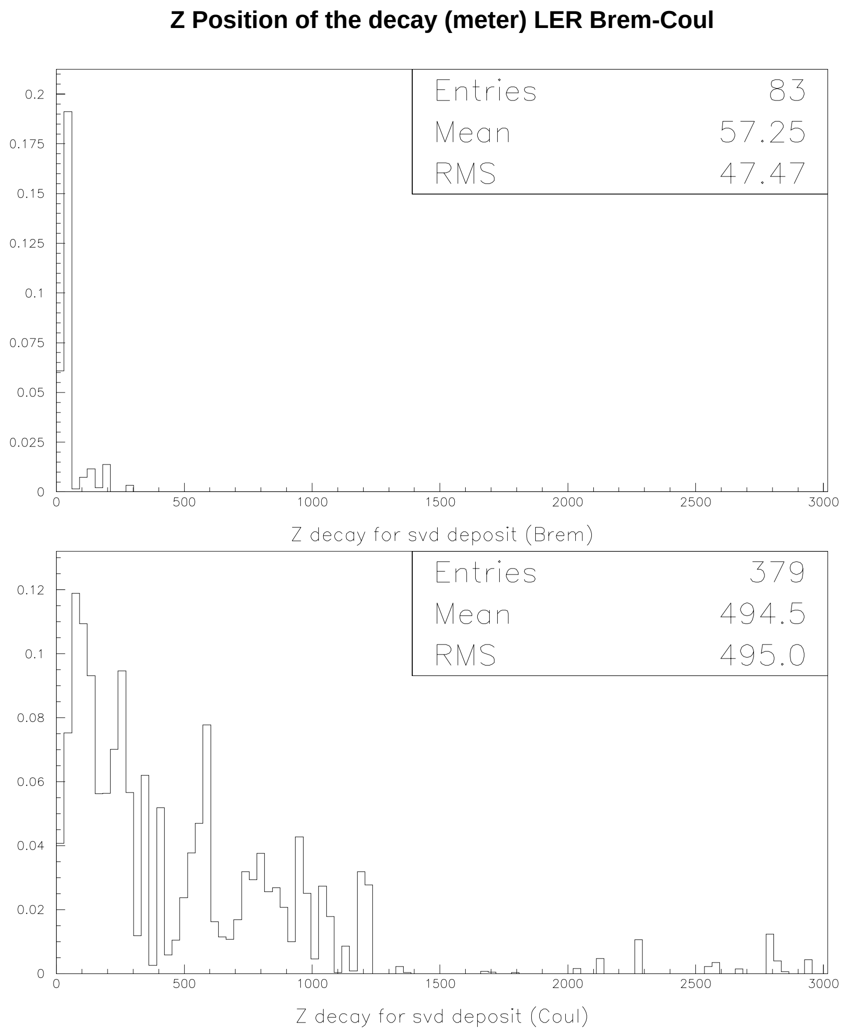
MC location of scatt. depositing energy in SVD

HER Top: Brems, Bottom: Coulomb



MC location of scatt. depositing energy in SVD

LER Top: Brems, Bottom: Coulomb



MC Results for Versions

SVD1.4 $r = 2cm$

r		$L1$ $3cm$	$L2$ $4.5cm$	$L3$ $6.0cm$
HER Brem		5.9	3.2	2.0
HER Coul		34.6	13.9	7.4
LER Brem		20.4(8.5)	9.0(3.1)	4.8(1.3)
LER Coul		14.8	6.3	1.7
Touscheck		56.5(6.5)	32.3(3.6)	16.9(2.0)
Sum		132(70)	65(30)	33(14)

SVD2.0 $r = 1cm$

r	$L1$ $1.5cm$	$L2$ $2.2cm$	$L3$ $4.25cm$	$L4$ $6.15cm$
HER Brem	27.5	18.7	5.7	3.3
HER Coul	35.1	21.7	6.5	4.2
LER Brem	67.2(62.8)	38.2(36.9)	9.4(8.9)	4.2(3.1)
LER Coul	51.5	18.2	7.2	2.1
Touscheck	474(464)	245(239)	57(52)	23(18)
Sum	655(641)	361(335)	86(82)	37(31)

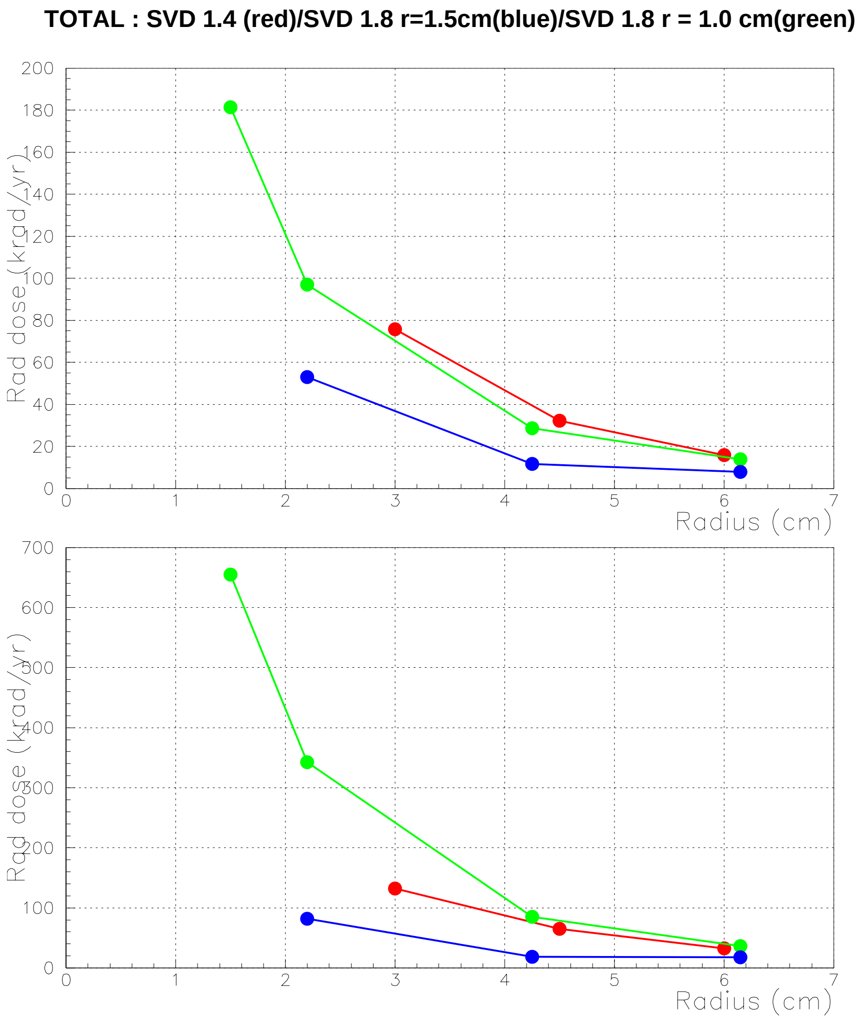
SVD2.0 $r = 1.5cm$

HER Brem		12.5	3.0	1.9
HER Coul		13.4	3.9	3.5
LER Brem		13.1(9.0)	3.4(2.0)	1.6(0.6)
LER Coul		14.0	1.4	1.0
Touscheck		28.8(9.0)	6.7(1.3)	9.7(0.9)
Sum		82(58)	18(12)	18(8)

Particle Bkg Comparisons

Top: w/o Touscheck, Bottom: w/ Touschek

- SVD1.4 (r=2cm)
- SVD2.0 (r=1.5cm)
- SVD2.0 (r=1cm)



Choice of IR beampipe radius

- Occupancy ratio (Now→SVD2.0 design current):
  $= (\text{dose ratio})\times 3(I_{beam})\times\frac{1}{2}(\text{shaping time reduction})$

SVD innermost lyrs:

$$\frac{(\text{r1cm})}{(\text{r2cm})} = 7.5(14)\,, \qquad \frac{(\text{r1.5cm})}{(\text{r2cm})} = 0.9(1.2)$$

( ): w/o 'just outside b.p.'

r=1cm is not promissing as it is (Touschek!).
r=1.5cm looks good

- CDC rates of innermost lyrs (at same currents)

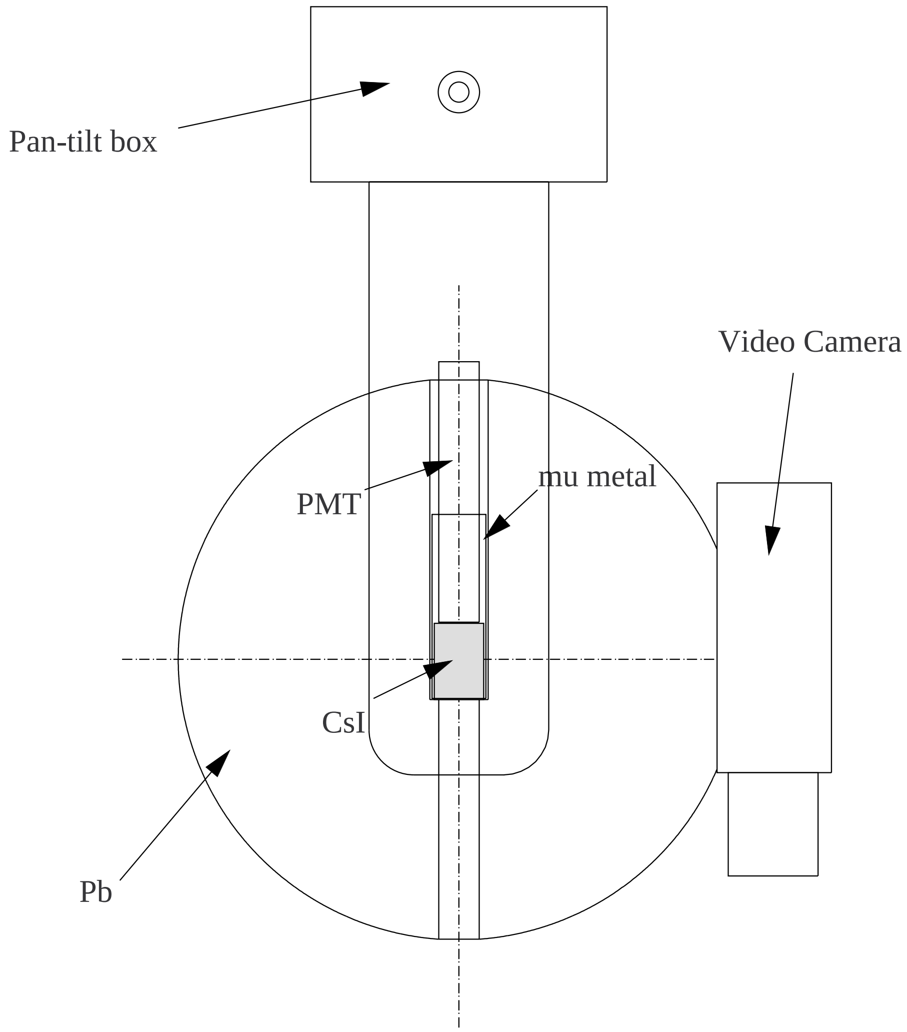
$$\frac{(\text{r1cm})}{(\text{r2cm})} = 1.2\,, \qquad \frac{(\text{r1.5cm})}{(\text{r2cm})} = 0.5$$

$\times 3(\text{current}) < 8$ **(OK)**

Executive Board Decision:
→ use r=1.5 cm for the 2002 upgrade.

1. 3 times more current, smaller radius, but about the same noise level.
2. $\sim$ 25% improvement in vertex resolution exptected.

STARBALL



- Directional radiation detector.
- Pan-tilt remote control.
- Runs along beamline on crane rail.
- Camera to see where it is pointing.

StarBall

Preliminary run located hot spots correcponding to MC prediction.

IR Beampipe Heating Sources

1. Synchrotron Radiation
   Concern: SR heating of mask tip
   (SS, not cooled)

   SVD2.0: QC2 3.5 W on HER mask.
   ~6K temperature rise at the tip.

   Au coating tested at Photon Factory - OK

2. Image current
   (μ: permeability, σ conductivity)

   $$\text{Heat } U(W) \propto n_b Q_b^2 \sqrt{\frac{\mu}{\sigma_z^3 \sigma}} \cdot \frac{L}{r}$$

   SVD2.0 (r=1.5cm, L=20cm):
   $\rightarrow$ 17 W total on Be section.
   Avoid bare SS surface.

3. HOM
   Incoherent and resonant: Dominant source

Incoherent HOM Heating Simulation

1. MAFIA
   Non-cylindrical geometry. CPU intensive.
   HOM of a mask is determined by
   the area of mask aperture.

2. ABCI
   Cylindrical geometries only.
   Estimates trapped modes $\rightarrow$ heating.

Heat generated on the Beryllium section.
(P_{heat}: estimated by ABCI)

measurement	current	n_b	P_{meas}	P_{heat}
BEAST	e^+ 300 mA	648	7W	8W
BEAST	e^- 350 mA	921	10W	8W
SVD1.2	e^+ 450 mA	1146	10.5W	11W

ABCI estimate works reasonably well.

HOM Heating Estimate of SVD1.2 and 2.0

HOM loss and trapped modes (heating)
for entire IR beampipe (LER I=2.6A, :

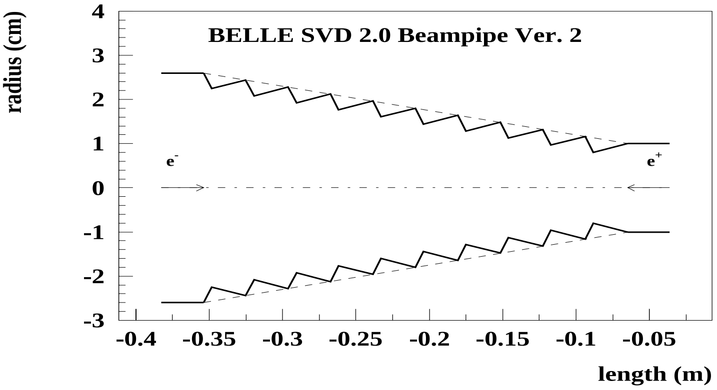
measurement	P_{HOM} (W)	P_{heat} (W)
SVD1.2	6800	300
SVD2.0 (fixed angle)	6250	770
SVD2.0 (varying angle)	2560	68

Assuming 1/3 is deposited on Beryllium section,
Heat(Beryllium) = 100 W for SVD1.2

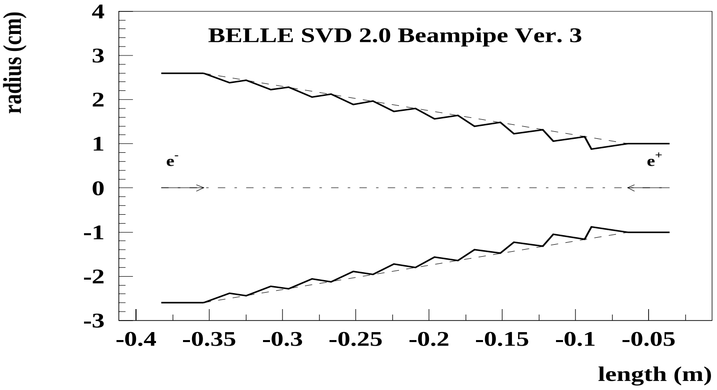
For SVD2.0 also, assume 100W on the Beryllium section, and 100W on each cone.

Sawtooth Designs

Fixed angle



Varying angle

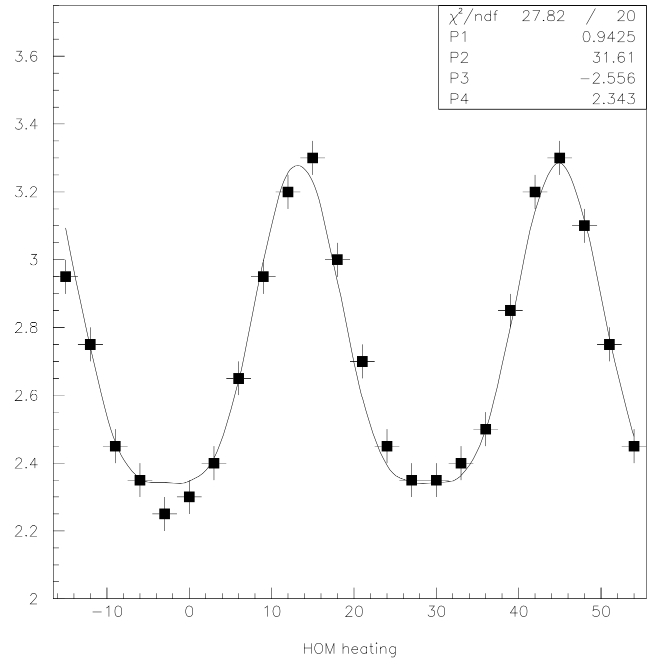


Resonant HOM

1. Normal×10 heating of the IR beampipe observed with 5-bunch mode.

2. Simulation can predict dangerous modes:

   $e+/e-$ RF phase-shift study



Period = 31.61° (TM011: 31.54° expected)

- One could thus design to avoid resonances.

  However:

  Requires fabrication accuracy near limit.
  Limits bunch pattern flexibility.

- We chose to remove masks on the LER side (i.e. no cavity) $\rightarrow$ No resonances.

  Accept the hard X-ray background.
  ($\sim$20kRad/yr)

Be Beampipe Coolant Selection

SVD1.2: He cooling close to allowed stress limit

Water cooling: used by CLEO/BaBar
but corrosion risk
(sulfide, chroride, etc.)

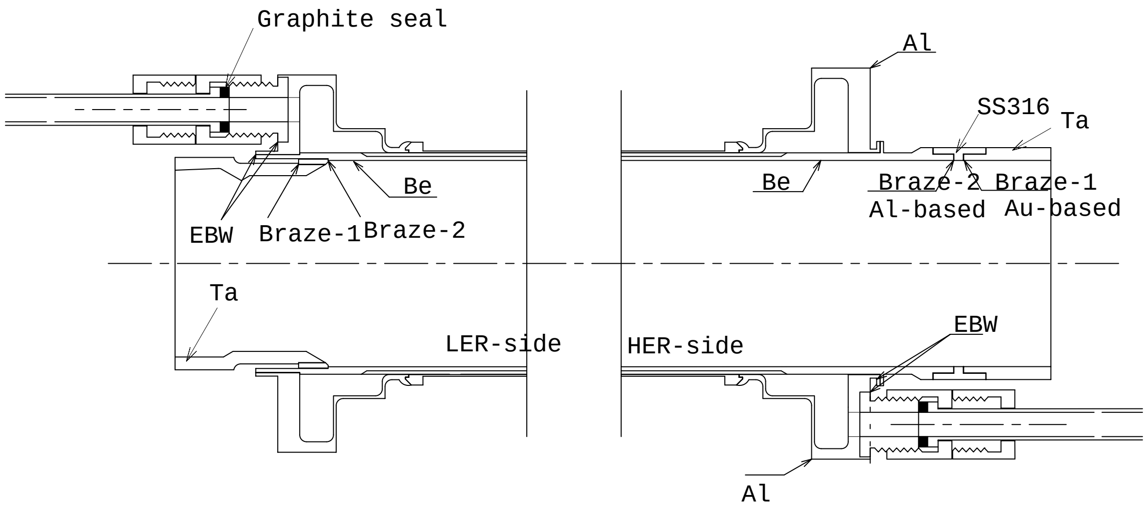
PF200 widely used by CLEO including Be beampipe
well tested on bare Be
(no need to coat)

	water	PF200
density (g/cc)	1.0	0.78
viscosity (g/cm·s)	0.010	0.019
th.cond. (W/cm·K)	0.0062	0.0016
sp. heat (J/g·K)	4.2	2.3

Reasonable cooling power → use PF200.

Still, avoid direct liquid-to-vacuum braze.

Be pipe end section design



Make the SS piece small (attached to Ta)

1. No exposed SS → unlikely to have SR melting. Also better cooling.
2. Better HER backscat. shield (Ta>SS).
3. No need to build each Ta cone in two pieces. (Cooling tube connection: mess)
4. Ta-SS braze extensively tested.
5. Diaphram-shaped PF200 manifold to reduce stress on EBW.

Cooling tube connection:
graphite seal - extensively tested.

Stress analysis

Simply supported at flanges.
Analytical estimation.

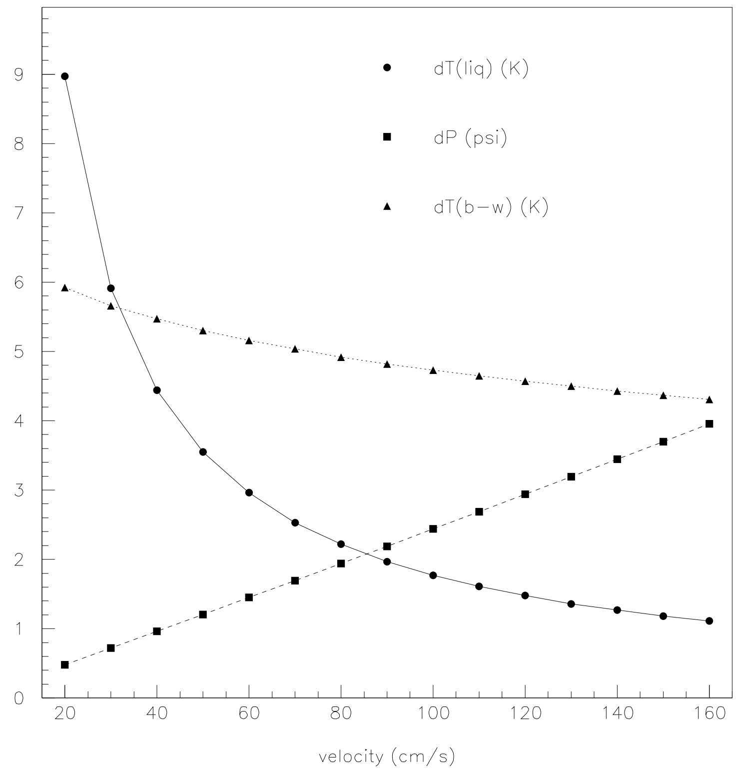
location	moment (kg mm)	stress (kg/mm^2)	allowed (kg/mm^2)
Ta weld(L)	2235	1.96	3.4
Ta (thin)	2252	3.78	5.6
Be (max)	2447	5.73	8.3
Ta weld (R)	2502	1.81	3.4

- allowed = 1/4 (ultimate tensile strength)
- x 0.6 if welding joint.

sag = 0.4 to 0.5 mm at center.

Be Beampipe

- Inner cylinder 0.5mm thick.
- Outer cylinder 0.25mm thick.
- Gap for PF200 0.5mm.
- 6 ribs
- One inlet, one outlet.
- To be facbricated by Brush-Wellman.



Temp rise of inner Be: $\sim 1/5$ of He cooling.

Al Model Flow/Cooling Test

- r=1.5cm mockups were built with Al.
  (cone & diaphram manifold)
  Same gap thickness (0.5mm), same number of ribs (6), $\sim$ same length as the real Be beampipe.

- Pressure drop is as calculated for the cone manifold (at 0.5 l/s):
  Measured: 0.04 atm
  Calculated: 0.037 atm
  Diaphram: $\times$2.5 pressure drop: still OK.

- Temperatures are also as expected.
  Flow is uniform in azimuth.

Summary

- The beam backgrounds of the current configuration are reasonably understood.
- The extrapolation to r=1.5cm and particularly to r=1cm involves uncertainties due to vacuum pressure, importance of Touscheck effect, exact geometry in MC.
- The r=1.5cm version has a good margin of error, and thus taken as the 2002 upgrade.
- Mecnahical reuiremnts are tough, but seems to be manageable.
- The answer will be found this fall.