SR collimation following the experience in LEP

starting with a bit of history of the CERN **L**arge **E**lectron-**P**ositron Collider

trying to illustrate and summarize key points, that may be of interest for future e+e- colliders including CEPC / FCC-ee

L = 26.659 km

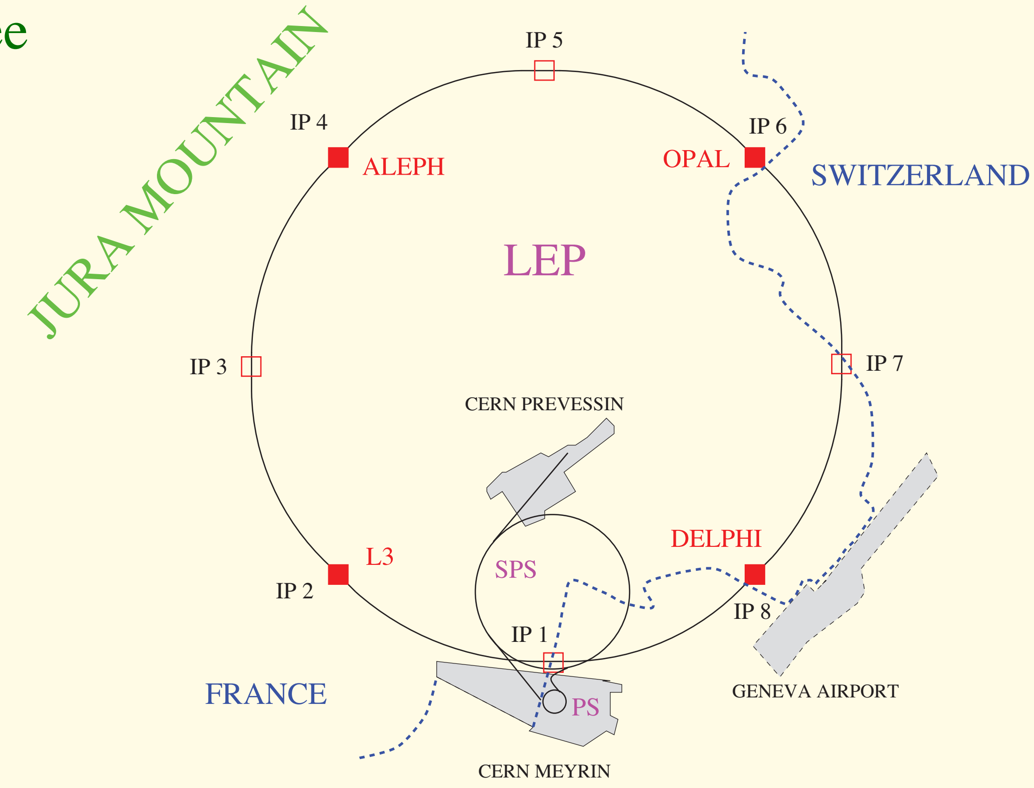
Ecms 89 — 209 GeV

SR Power ≲ 10 MW / beam

Luminosity ~ 10^{32} cm^{-2} s^{-1}

up to ~ 4×10^{11} e+, e- / bunch

min. $\sigma^*_{x,y}$ ~ 150 μm , 3 μm



LEP : tunneling 13/9/1983 - 8/2/1988; installation largely in 1988 + sector test
Pilot run, first Z's, low L, superconducting final focus magnets off : August 1989
Operation : 1990 - 2000 ; then stopped and dismantled for LHC

Changing a lot and "devil in details"

Discussed in Chamonix meetings, well documented in proceedings

Had disappeared, ticket 8/1/2020 RQF1495759 created by me 8/1/2020

Resolved 11 month later : CERN Service Desk 11/12/2020, back online

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1st Workshop on LEP Performance, Chamonix 1991:       https://cds.cern.ch/record/256125
2nd Workshop on LEP Performance, Chamonix 1992:       https://cds.cern.ch/record/260389
3rd Workshop on LEP performance, Chamonix 1993:       https://cds.cern.ch/record/248984
4th Workshop on LEP Performance, Chamonix 1994:       https://cds.cern.ch/record/265955
5th Workshop on LEP Performance, Chamonix 1995:       https://cds.cern.ch/record/277821
6th LEP Performance Workshop, Chamonix 1996:          https://cds.cern.ch/record/289995
7th LEP Performance Workshop, Chamonix 1997:          https://cds.cern.ch/record/312024
8th LEP Performance Workshop, Chamonix 1998:          https://cds.cern.ch/record/330057
9th LEP-SPS Performance Workshop, Chamonix 1999:      https://cds.cern.ch/record/359023
10th Workshop on LEP-SPS Performance, Chamonix 2000:  https://cds.cern.ch/record/394989
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Lesson #1 : seen with LEP — can expect as general feature for large, warm e+e- machines

Very dynamic, very complex, changing all the time, orbit, emittance,

major beam-beam tune shift ($\xi_y = 0.08$/IP) **and** (vertical) **tails; core/halo see different machine**

Requiering continous efforts and follow up

LEP optics changed a lot : 60/60 ('89-'91), 90/90 ('92), 90/60 ('93/97), 102/90 ('98-'00)

Collimation and operational procedures improved, including

adding off momentum collimators in dispersion suppressors - collimate off-momenum BKG

adding synchrotron masks

As a result : LEP2 backgrounds comparable to LEP1

Detailed info, example of my records

```
Macintosh   HD:Helmut:fortran:MAD:worktwiss.out                                   Page: 1
Friday, 18 July 1997 / 9:27
 twiss=n0520p97v2 Ebeam=45.60 GeV assumed from twiss file name
 IPs at      .000   3332.360   6664.720   9997.080  13329.400  16661.800  19994.200  23326.500 EndLep  2
 emittance in x= 45.000   in y=  4.500 nm    deltaE/E= 1.000E-03
 sawtooth, sign is for positrons, opposite for electrons,  collimator position increased by ABS(SAWT)
 Collimator       dist to IP   beta  disp  number of   sawtooth  sigmabeam opening  nsig  opening /
                     [m]        [m]   [m]  B2 BI bends   [mm]       [mm]     [mm]           disp
 IP1"                .000      25.3   .00  612   12      .00      1.066
 COLH.QL8.R1"     175.458      57.3   .00  612   12      .00      1.605     23.3   14.5
 COLH.QF23.L2"   -637.260     115.7  1.11  782   24     -.74      2.537     32.4   12.5   .029
 COLH.QD20.L2"   -522.170      26.4   .60  791   24     -.41      1.245     16.0   12.5   .027
 COLH.QS17.L2"   -419.630      67.3   .84  798   24     -.58      1.931     24.7   12.5   .030
 COLH.QS15.L2"   -356.600     146.9   .94  802   24     -.66      2.738     34.9   12.5   .037
 COLH.QS10.L2"   -220.540       9.1   .00  808   24      .00       .640      9.3   14.5
 COLH.QS6.L2"    -129.440      31.3   .00  808   24      .00      1.187     17.2   14.5
 COLV.QS5.L2"     -98.660      36.6   .00  808   24      .00       .406     12.2   30.0
 COLZ.QS4.L2"     -66.110     132.0   .00  808   24      .00       .771     23.1   30.0
 COLH.QS4.L2"     -61.970      20.9   .00  808   24      .00       .969     14.0   14.5
 COLZ.QS2.L2"     -21.320      33.1   .00  808   24      .00       .386     11.6   30.0
 COLV.QS2.L2"     -15.150      63.8   .00  808   24      .00       .536     16.1   30.0
 COLH.QS1B.L2"     -8.750     131.1   .00  808   24      .00      2.429     35.2   14.5
 IP2"                .000       2.0   .00    0    0      .00       .300
 COLH.QS1B.R2"      8.750     131.1   .00    0    0      .00      2.429     35.2   14.5
 COLV.QS2.R2"      15.150      63.8   .00    0    0      .00       .536     16.1   30.0
 COLZ.QS2.R2"      21.310      33.1   .00    0    0      .00       .386     11.6   30.0
 COLH.QS4.R2"      61.970      20.9   .00    0    0      .00       .969     14.0   14.5
 COLZ.QS4.R2"      66.110     132.0   .00    0    0      .00       .771     23.1   30.0
 COLV.QS5.R2"      98.660      36.6   .00    0    0      .00       .406     12.2   30.0
 COLH.QS6.R2"     129.440      31.3   .00    0    0      .00      1.187     17.2   14.5
 COLH.QS10.R2"    220.540       9.1   .00    0    0      .00       .640      9.3   14.5
 COLH.QS15.R2"    356.600     146.9   .94    6    0      .64      2.738     34.9   12.5   .037
 COLH.QS17.R2"    419.630      67.3   .84   10    0      .56      1.931     24.7   12.5   .030
 COLH.QD20.R2"    522.170      26.4   .60   17    0      .40      1.245     16.0   12.5   .027
 COLH.QF23.R2"    637.260     115.7  1.11   26    0      .71      2.537     32.4   12.5   .029
 IP3"                .000      25.3   .00  208    0      .00      1.066
 COLH.QF23.L4"   -637.260     115.6  1.11  390    0      .06      2.536     31.8   12.5   .029
 COLH.QD20.L4"   -522.170      26.4   .60  399    0      .02      1.245     15.6   12.5   .026
 COLH.QS17.L4"   -419.640      62.2   .79  406    0      .02      1.850     23.1   12.5   .029
 COLH.QS15.L4"   -356.600     136.8   .88  410    0      .02      2.633     32.9   12.5   .037
 COLH.QS10.L4"   -220.490      17.3   .00  416    0      .00       .883     12.8   14.5
 COLH.QS6.L4"    -108.000      16.8   .00  416    0      .00       .870     12.6   14.5
 COLV.QS5.L4"     -79.180      42.7   .00  416    0      .00       .438     13.1   30.0
 COLZ.QS3A.L4"    -66.110      70.8   .00  416    0      .00       .565     16.9   30.0
 COLH.QS3B.L4"    -56.280      46.9   .00  416    0      .00      1.452     21.1   14.5
 COLZ.QS2.L4"     -21.320      28.8   .00  416    0      .00       .360     10.8   30.0
 COLV.QS2.L4"     -15.150      63.9   .00  416    0      .00       .536     16.1   30.0
 COLH.QS1B.L4"     -8.550     120.1   .00  416    0      .00      2.325     33.7   14.5
 IP4"                .000       2.0   .00  416    0      .00       .300
 COLH.QS1B.R4"      8.520     120.2   .00  416    0      .00      2.326     33.7   14.5
 COLV.QS2.R4"      15.120      63.5   .00  416    0      .00       .535     16.0   30.0
 COLZ.QS2.R4"      21.320      28.2   .00  416    0      .00       .356     10.7   30.0
 COLH.QS3B.R4"     56.320      46.9   .00  416    0      .00      1.452     21.1   14.5
 COLZ.QS3A.R4"     66.120      73.8   .00  416    0      .00       .576     17.3   30.0
 COLV.QS5.R4"      79.220      43.6   .00  416    0      .00       .443     13.3   30.0
 COLH.QS6.R4"     108.020      16.8   .00  416    0      .00       .871     12.6   14.5
 COLH.QS10.R4"    220.520      17.3   .00  416    0      .00       .883     12.8   14.5
 COLH.QS15.R4"    356.620     136.6   .88  422    0      .00      2.632     32.9   12.5   .037
 COLH.QS17.R4"    419.620      62.1   .79  426    0     -.01      1.850     23.1   12.5   .029
 COLH.QD20.R4"    522.120      26.4   .60  433    0     -.01      1.245     15.6   12.5   .026
 COLH.QF23.R4"    637.220     115.8  1.11  442    0     -.04      2.537     31.7   12.5   .029
 COLH.QL13.L5"   -299.100      87.3   .13  622    0     -.04      1.987     24.9   12.5   .187
 IP5"                .000      25.2   .00  624    0      .00      1.066
 COLH.IP5"           .200      25.2   .00  624    0      .00      1.066     13.3   12.5
 COLV1.QL8.R5"    168.400      50.5   .00  624    0      .00       .477     11.9   25.0
 COLV2.QL8.R5"    176.100      60.2   .00  624    0      .00       .520     13.0   25.0
 COLV.QL9.R5"     195.400      20.6   .00  624    0      .00       .305      7.6   25.0
 COLH.QL13.R5"    299.200      87.5   .13  626    0     -.04      1.989     24.9   12.5   .187
 COLV.QD20.R5"    519.300     153.5   .00  641    0      .00       .831     20.8   25.0
 COLV.QD30.R5"    914.300     149.1   .00  671    0      .00       .819     20.5   25.0
 COLV.QD40.R5"   1309.300     142.6   .00  701    0      .00       .801     20.0   25.0
 COLH.QF23.L6"   -637.300     115.5  1.11  806    0     -.69      2.535     32.4   12.5   .029
 COLH.QD20.L6"   -522.200      26.4   .60  815    0     -.38      1.245     16.0   12.5   .027
 COLH.QS17.L6"   -419.600      79.0   .93  822    0     -.61      2.102     26.9   12.5   .029
 COLH.QS15.L6"   -356.600     107.1   .89  826    0     -.59      2.370     30.2   12.5   .034
 COLH.QS10.L6"   -220.500      11.3   .00  832    0      .00       .714     10.4   14.5
 COLH.QS6.L6"    -129.500      26.7   .00  832    0      .00      1.096     15.9   14.5
 COLV.QS5.L6"     -98.700      33.2   .00  832    0      .00       .386     11.6   30.0
 COLZ.QS4.L6"     -66.100     127.7   .00  832    0      .00       .758     22.7   30.0
 COLH.QS4.L6"     -62.000      20.9   .00  832    0      .00       .970     14.1   14.5
 COLZ.QS2.L6"     -21.300      36.2   .00  832    0      .00       .403     12.1   30.0
 COLV.QS2.L6"     -15.300      67.9   .00  832    0      .00       .553     16.6   30.0
 COLH.QS1B.L6"     -8.700     124.6   .00  832    0      .00      2.368     34.3   14.5
 IP6"                .000       2.0   .00    0    0      .00       .300
 COLH.QS1B.R6"      8.700     124.6   .00    0    0      .00      2.368     34.3   14.5
 COLV.QS2.R6"      15.300      67.9   .00    0    0      .00       .553     16.6   30.0
 COLZ.QS2.R6"      21.300      36.2   .00    0    0      .00       .403     12.1   30.0
 COLH.QS4.R6"      62.000      20.9   .00    0    0      .00       .970     14.1   14.5
 COLZ.QS4.R6"      66.100     127.7   .00    0    0      .00       .758     22.7   30.0
 COLV.QS5.R6"      98.700      33.2   .00    0    0      .00       .386     11.6   30.0
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Macintosh   HD:Helmut:fortran:MAD:worktwiss.out                                   Page: 2
Friday, 18 July 1997 / 9:27
 COLH.QS6.R6"     129.400      26.7   .00    0    0      .00      1.096     15.9   14.5
 COLH.QS10.R6"    220.500      11.3   .00    0    0      .00       .714     10.4   14.5
 COLH.QS15.R6"    356.600     107.1   .89    6    0      .60      2.370     30.2   12.5   .034
 COLH.QS17.R6"    419.600      79.0   .93   10    0      .62      2.102     26.9   12.5   .029
 COLH.QD20.R6"    522.200      26.4   .60   17    0      .40      1.245     16.0   12.5   .027
 COLH.QF23.R6"    637.300     115.5  1.11   26    0      .71      2.535     32.4   12.5   .029
 IP7"                .000      25.2   .00  208    0      .00      1.066
 COLH.QF23.L8"   -637.200     115.8  1.11  390    0      .06      2.537     31.8   12.5   .029
 COLH.QD20.L8"   -522.200      26.4   .60  399    0      .02      1.245     15.6   12.5   .026
 COLH.QS17.L8"   -419.600      62.1   .79  406    0      .02      1.850     23.1   12.5   .029
 COLH.QS15.L8"   -356.600     136.6   .88  410    0      .02      2.632     32.9   12.5   .037
 COLH.QS10.L8"   -220.500      17.3   .00  416    0      .00       .883     12.8   14.5
 COLH.QS6.L8"    -108.000      16.8   .00  416    0      .00       .871     12.6   14.5
 COLV.QS5.L8"     -79.200      43.6   .00  416    0      .00       .443     13.3   30.0
 COLZ.QS3A.L8"    -66.100      73.8   .00  416    0      .00       .576     17.3   30.0
 COLH.QS3B.L8"    -56.300      46.9   .00  416    0      .00      1.452     21.1   14.5
 COLZ.QS2.L8"     -21.300      28.2   .00  416    0      .00       .356     10.7   30.0
 COLV.QS2.L8"     -15.100      63.5   .00  416    0      .00       .535     16.0   30.0
 COLH.QS1B.L8"     -8.500     120.2   .00  416    0      .00      2.326     33.7   14.5
 IP8"                .000       2.0   .00  416    0      .00       .300
 COLH.QS1B.R8"      8.600     120.1   .00  416    0      .00      2.325     33.7   14.5
 COLV.QS2.R8"      15.200      63.9   .00  416    0      .00       .536     16.1   30.0
 COLZ.QS2.R8"      21.300      28.8   .00  416    0      .00       .360     10.8   30.0
 COLH.QS3B.R8"     56.300      46.9   .00  416    0      .00      1.452     21.1   14.5
 COLZ.QS3A.R8"     66.100      70.8   .00  416    0      .00       .564     16.9   30.0
 COLV.QS5.R8"      79.200      42.6   .00  416    0      .00       .438     13.1   30.0
 COLH.QS6.R8"     108.000      16.8   .00  416    0      .00       .870     12.6   14.5
 COLH.QS10.R8"    220.500      17.3   .00  416    0      .00       .883     12.8   14.5
 COLH.QS15.R8"    356.600     136.8   .88  422    0      .00      2.633     32.9   12.5   .037
 COLH.QS17.R8"    419.600      62.2   .79  426    0     -.01      1.850     23.1   12.5   .029
 COLH.QD20.R8"    522.200      26.4   .60  433    0     -.01      1.245     15.6   12.5   .026
 COLH.QF23.R8"    637.300     115.6  1.11  442    0     -.04      2.536     31.7   12.5   .029
 COLH.QL8.L1"    -175.500      57.2   .00  612   12      .00      1.605     23.3   14.5
 end of LEP NB2,NBI=   612    12
 there were in total NB2tot=  1640 standard  bends called B2L or B2M or B2R or B2S
 there were in total NBItot=    24 injection bends called BI
 there were in total NBWtot=    32 weak bends called BW1 or BW2 or BW3 or BW4
```

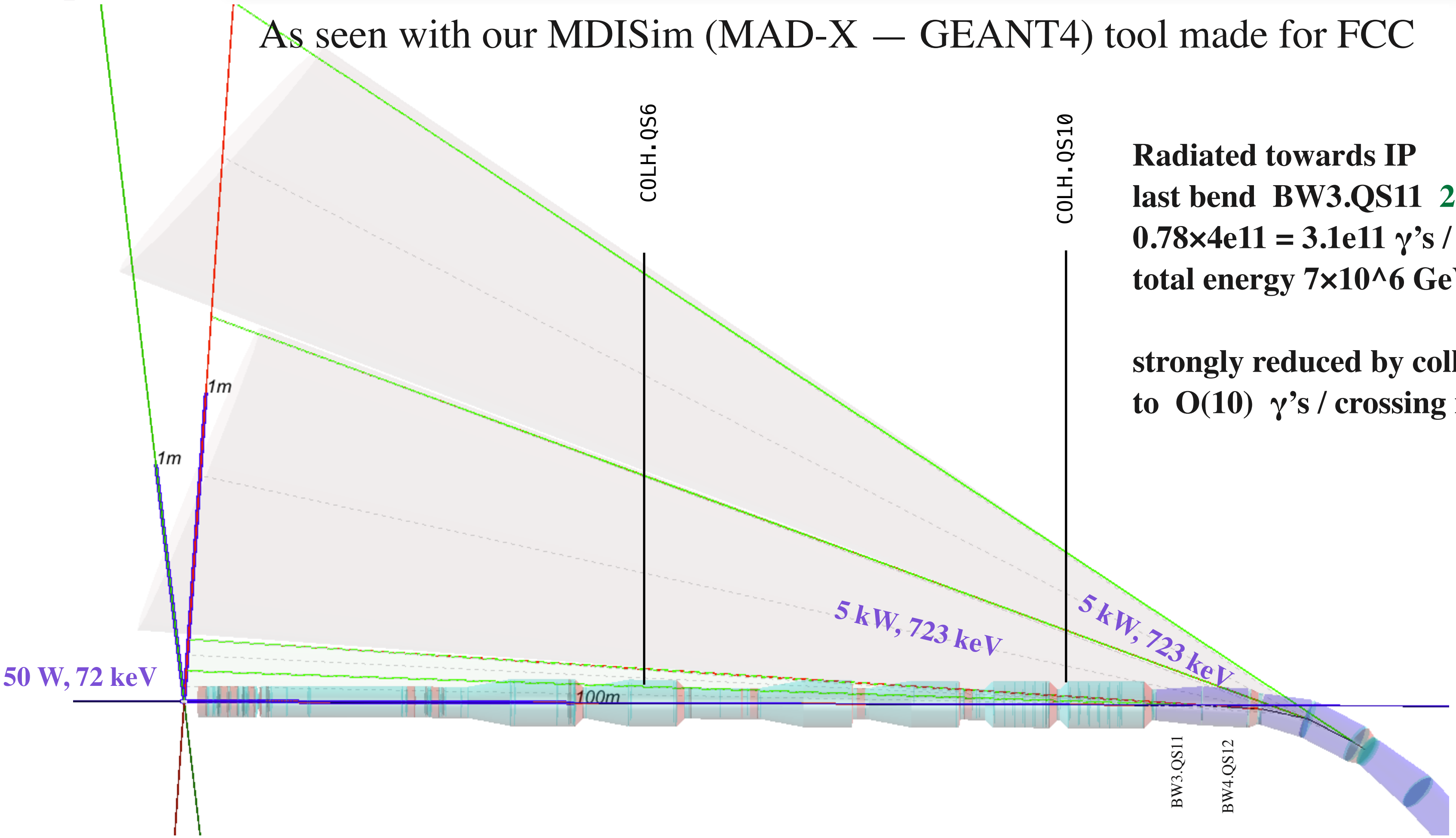
Also kept : full set of LEP mad8 optics files
+ my logging of LEP snapshots avery 15 min

FILL	TIME	Ie+	Ie-	EWIG	e+x	e+y	e-x	e-y	L3	ALEPH	OPAL	DELPHI
6811	11.3794	1.60178	1.63328	.813	.000	.000	.000	.000	3.965	5.047	1.795	5.310

FILL	TIME	LEP_MODE	ENERGY	BETA_Y	TWISS_NAME	BUN
6811	03-04-00 09:52:04	filling	22.100	10	g1020b99_v1	8
6811	03-04-00 10:41:14	acceleration	22.100	10	g1020b99_v1	8
6811	03-04-00 10:45:26	acceleration	45.620	5	g0520b99_v1	8
6811	03-04-00 10:45:33	adjust	45.620	5	g0520b99_v1	8
6811	03-04-00 11:14:57	physics	45.620	5	g0520b99_v1	8

Possible bench marking with LEP, here Eb=100 GeV

As seen with our MDISim (MAD-X — GEANT4) tool made for FCC



Radiated towards IP
last bend BW3.QS11 248.7 - 260.2 m
0.78×4e11 = 3.1e11 γ's / crossing
total energy 7×10^6 GeV

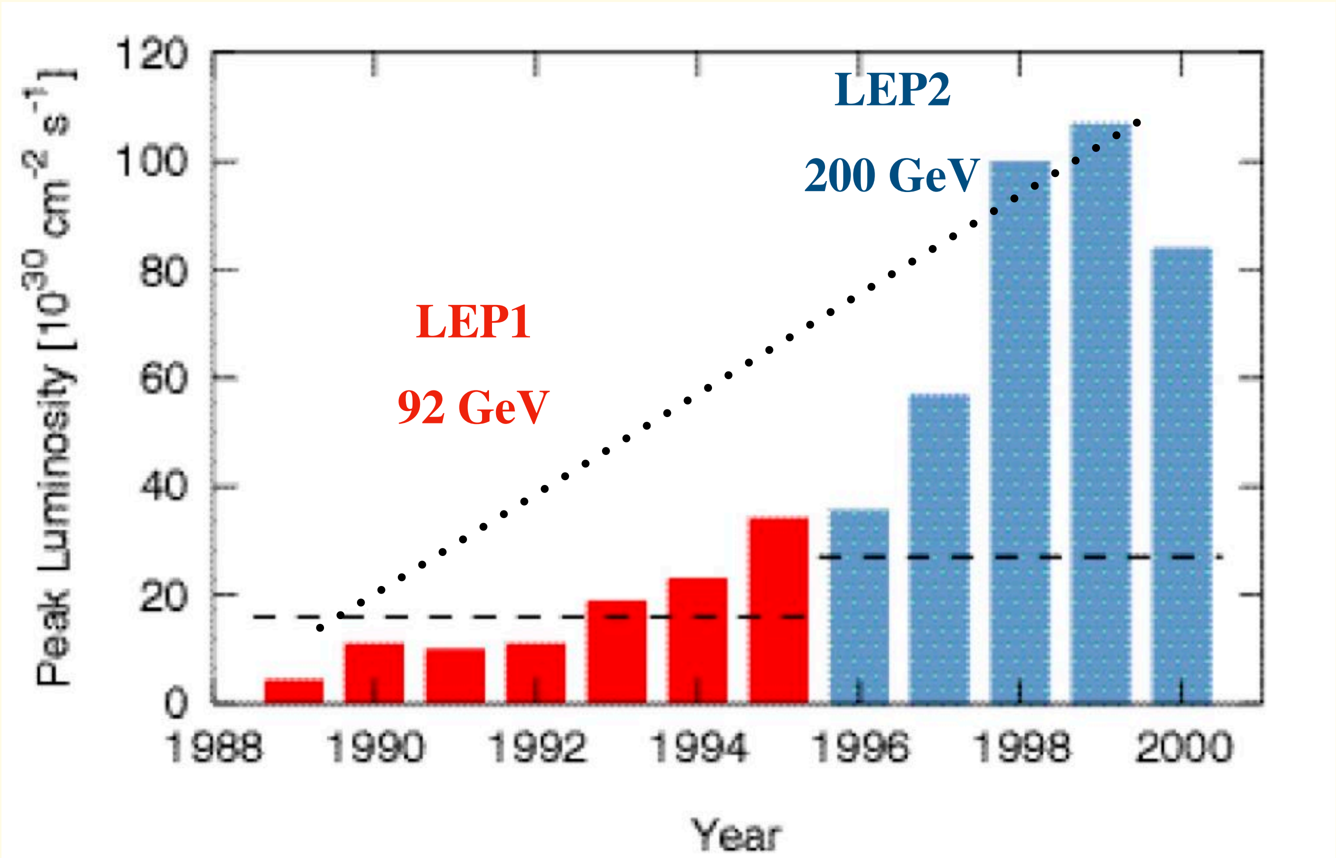
strongly reduced by collimation and masks
to O(10) γ's / crossing interacting in TPC

iele	NAME	KEYWORD	S	L	Angle	Ecrit	ngamBend	rho	B	BETX	SIGX	divx	Power	frac>10MeV
			m	m		keV		m	T	m	mm	mrad	kW	
162	BW3.QS11.R2	RBEND	260.2	11.55	0.0003768	72.37	0.7767	30652.0	0.0109	45.5834	1.4262	0.0379	0.04989	2e-62
164	BW4.QS12.R2	RBEND	272.1	11.55	0.0003768	72.37	0.7767	30652.0	0.0109	33.8668	1.2293	0.0379	0.04989	2e-62
172	B2L.QS12.R2	RBEND	287.3	11.55	0.003768	723.7	7.767	3065.2	0.1088	88.0931	1.9827	0.0637	4.989	6.5e-08
174	B2R.QS13.R2	RBEND	299.2	11.55	0.003768	723.7	7.767	3065.2	0.1088	163.5957	2.7019	0.0636	4.989	6.5e-08

Quads, at 1 sigmax, horizontal

iele	Element	s	L	betx	sigx	divx	K1L	k0	x	Angle	Ecrit	ngam	Power
		m	m	m	mm	mrad	m-2	m-1	mm		keV		kW
2	QS0.R2	5.7	2	27.8	1.115	0.04003	-0.327	0.0003474	-0.0524	0.0006948	770.7	1.432	0.9798
10	QS1B.R2	11.2	2	226	3.176	0.01405	0.06314	0.0001918	-0.1377	0.0003836	425.5	0.7907	0.2987
12	QS1A.R2	13.7	2	278	3.523	0.01267	0.06314	0.0002129	-0.1509	0.0004259	472.4	0.8778	0.3681
20	QS2.R2	18	1.6	276	3.507	0.01272	0.01788	6.006e-05	-0.1471	9.61e-05	133.2	0.1981	0.023423
36	QS3.R2	59	2	39.4	1.326	0.03366	0.01879	2.45e-05	-0.02171	4.9e-05	54.35	0.101	0.004873

Peak performance



Performance increased steadily (slowly) over many years

not injector limited - beams accumulated, strong (SR) damping, equilibrium emittance

minimum β* and maximum tune shift were limited in LEP

by the need of the experiments for stable low background running conditions

LEP peak performance parameters

Table 3. LEP beam parameters corresponding to the best performances at three different energies. The luminosities and beam–beam tune shifts are averaged over a time interval of 15 min. For each beam energy, the first line corresponds to the horizontal, the second line to the vertical plane.

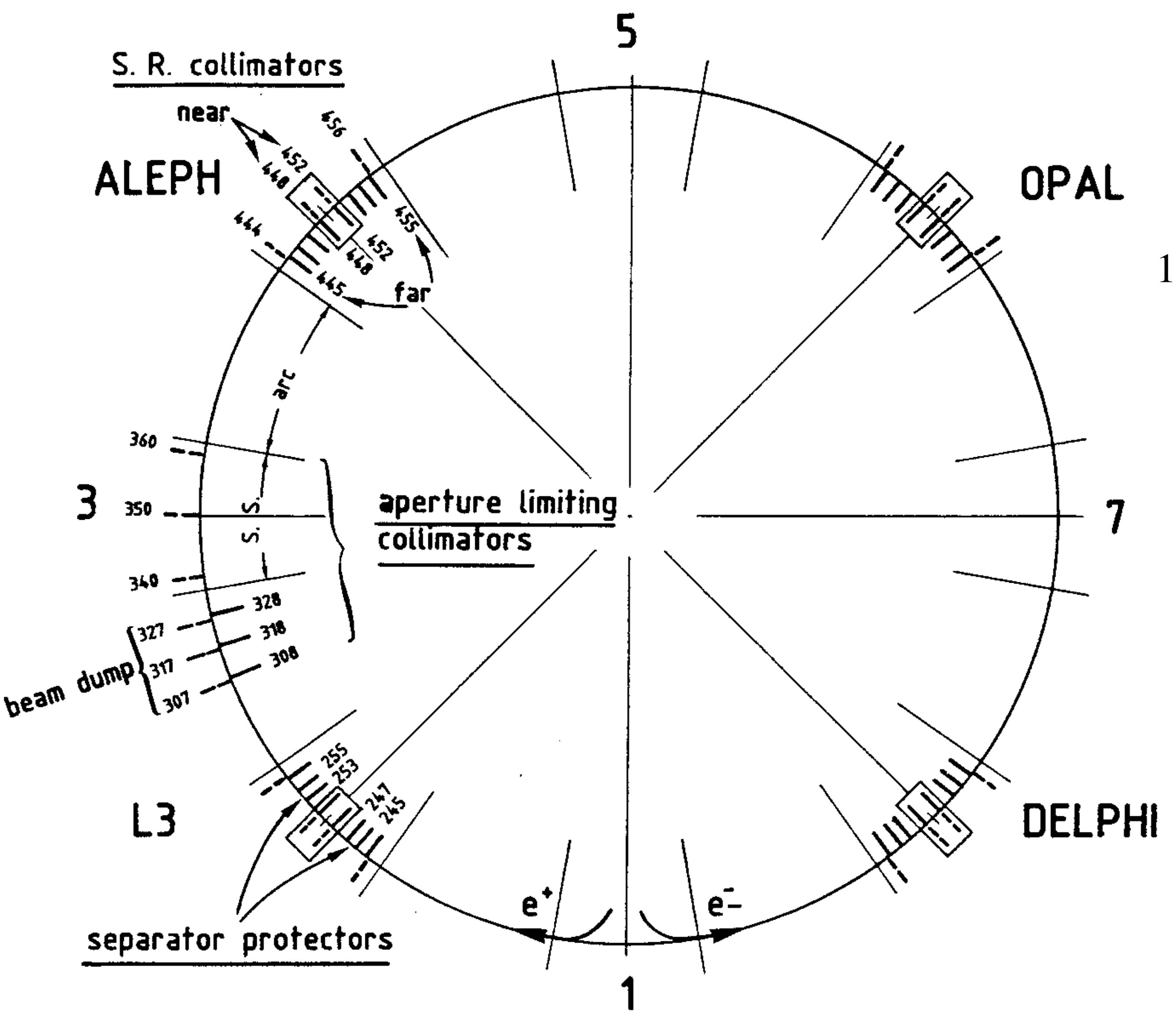
E_b (GeV)	N_b ($\times 10^{11}$)	k_b	$\mathcal{L}$ (cm^{-1} s^{-2})	Q_s	Q	β^* (m)	ϵ (nm)	σ (μm)	ξ
45.6	1.18	8	1.51×10^{31}	0.065	90.31	2.0	19.3	197	0.030
					76.17	0.05	0.23	3.4	0.044
65	2.20	4	2.11×10^{31}	0.076	90.26	2.5	24.3	247	0.029
					76.17	0.05	0.16	2.8	0.051
97.8	4.01	4	9.73×10^{31}	0.116	98.34	1.5	21.1	178	0.043
					96.18	0.05	0.22	3.3	0.079

Table 6. Overview of LEP (instantaneous) peak performance 1989–99. $\int \mathcal{L}\,dt$ is the luminosity integrated per experiment over each year. The design luminosity at 45 GeV is 17×10^{30} cm^{-2} s^{-1}.

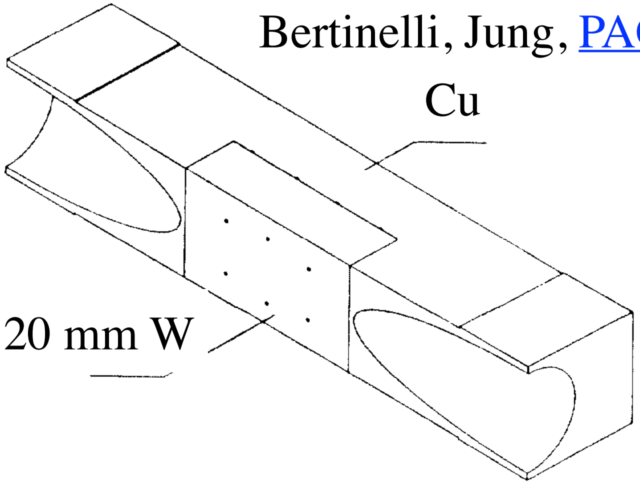
Year	$\int \mathcal{L}\,dt$ (pb^{-1})	E_b (GeV/c^2)	k_b	$2k_b I_b$ (mA)	$\mathcal{L}$ (10^{30} cm^{-2} s^{-1})	ξ_y
1989	1.74	45.6	4	2.6	4.3	0.017
1990	8.6	45.6	4	3.6	7	0.020
1991	18.9	45.6	4	3.7	10	0.27
1992	28.6	45.6	4/8	5.0	11.5	0.027
1993	40.0	45.6	8	5.5	19	0.040
1994	64.5	45.6	8	5.5	23.1	0.047
1995	46.1	45.6	8/12	8.4	34.1	0.030
1996	24.7	80.5–86	4	4.2	35.6	0.040
1997	73.4	90–92	4	5.2	47.0	0.055
1998	199.7	94.5	4	6.1	100	0.075
1999	253	98–101	4	6.2	100	0.083

from Ref 7

LEP movable collimators, essential for background



Bertinelli, Jung, PAC97



settings of order
Aperture H 15.5 σ
Experim. H 18 σ

Vertical
~ 30 nominal σ
~ 100 measured σ

nominal :
10% coupling
σ E = 1.e-3

as originally designed,

G. von Holtey. LEP main ring collimators. EP-BI-87-03

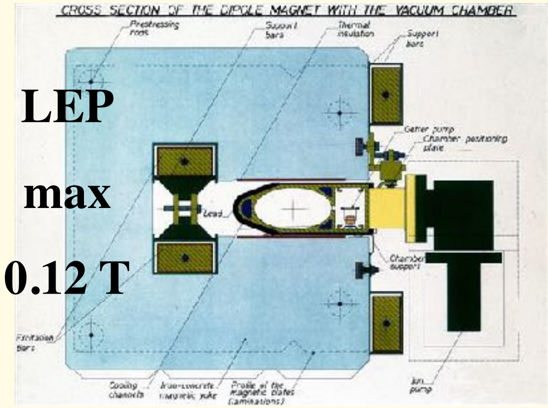
later modified (AP. limit IP5) and upgraded

Comparison of key parameters

Energy in beam			damping time, turns	U0
LHC	362 MJ	3.2e14 p/ beam 7 TeV	1.e9	
FCC-ee	21 MJ	2.8e15 e/ beam 45.6 GeV	1200 Z, 20 tt	9 GeV tt
LEP1	7 kJ	2e12 e/beam 45.6 GeV	360	0.13 GeV
LEP2	27 kJ	3e12 e/beam 100 GeV	30	3 GeV

Synchrotron radiation (SR) power

LHC	8 kW / beam
FCC-ee	50 MW / beam
LEP 2	10 MW / beam



LEP comparable to safe beams LHC, machine protection not a major issue provided by aperture limiting collimators in pt.5

LEP1 operated intially without dedicated beam dump and without loss monitors

Will be much more important for future e+e- colliders — more similar to LHC

(not subject of this talk)

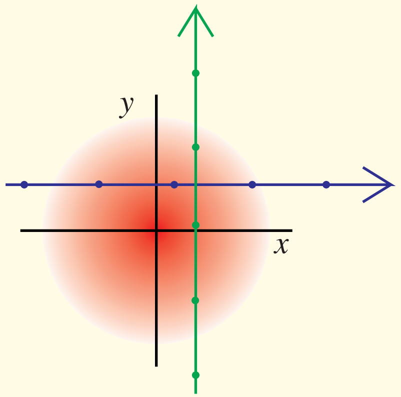
Optimize collisions (1/2)

LEP beam separated

during injection

ramp & squeeze

using electrostatic separators



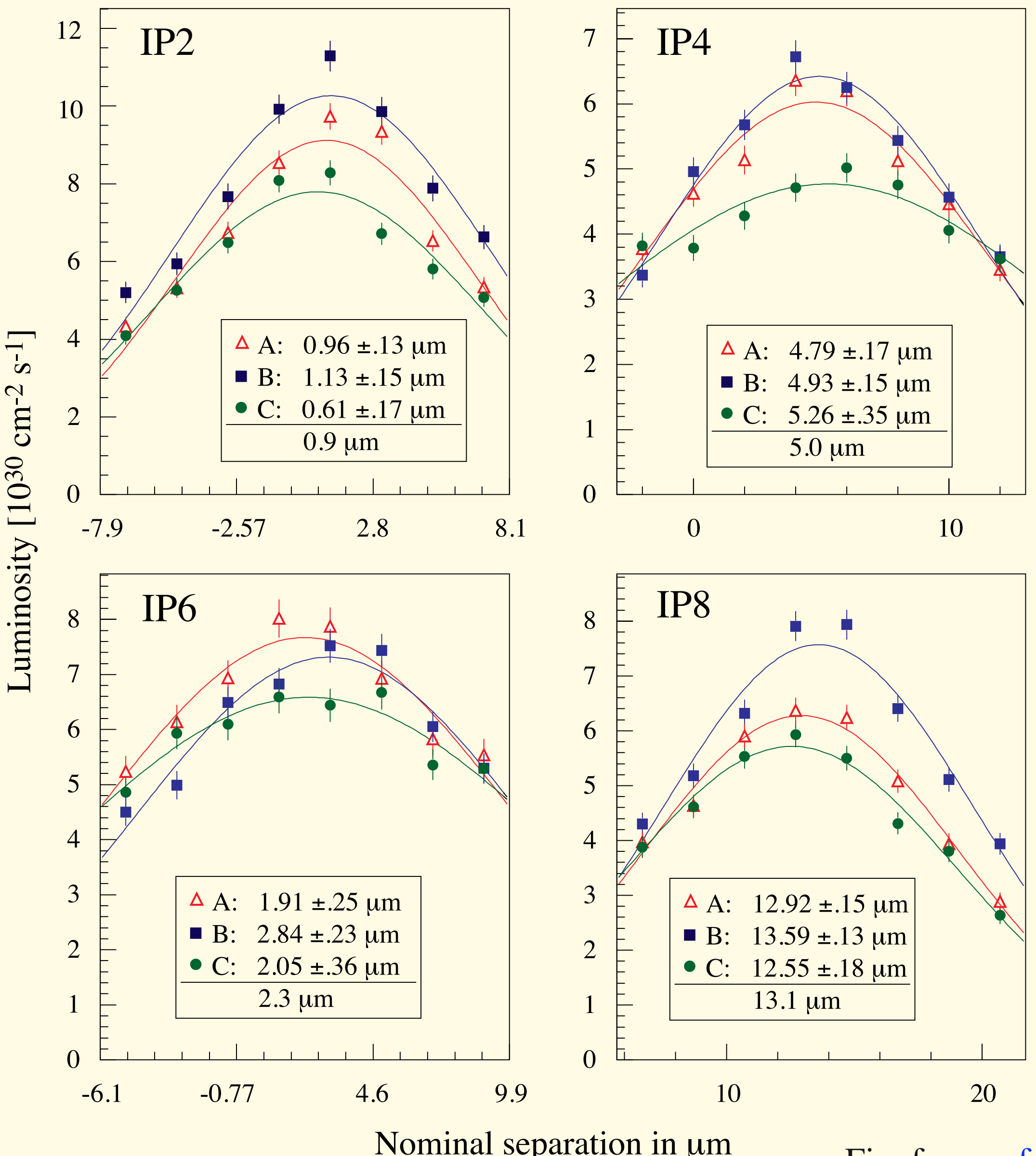


Fig. from ref. [7]

Collisions optimized initially

by separation scans

based on luminosity

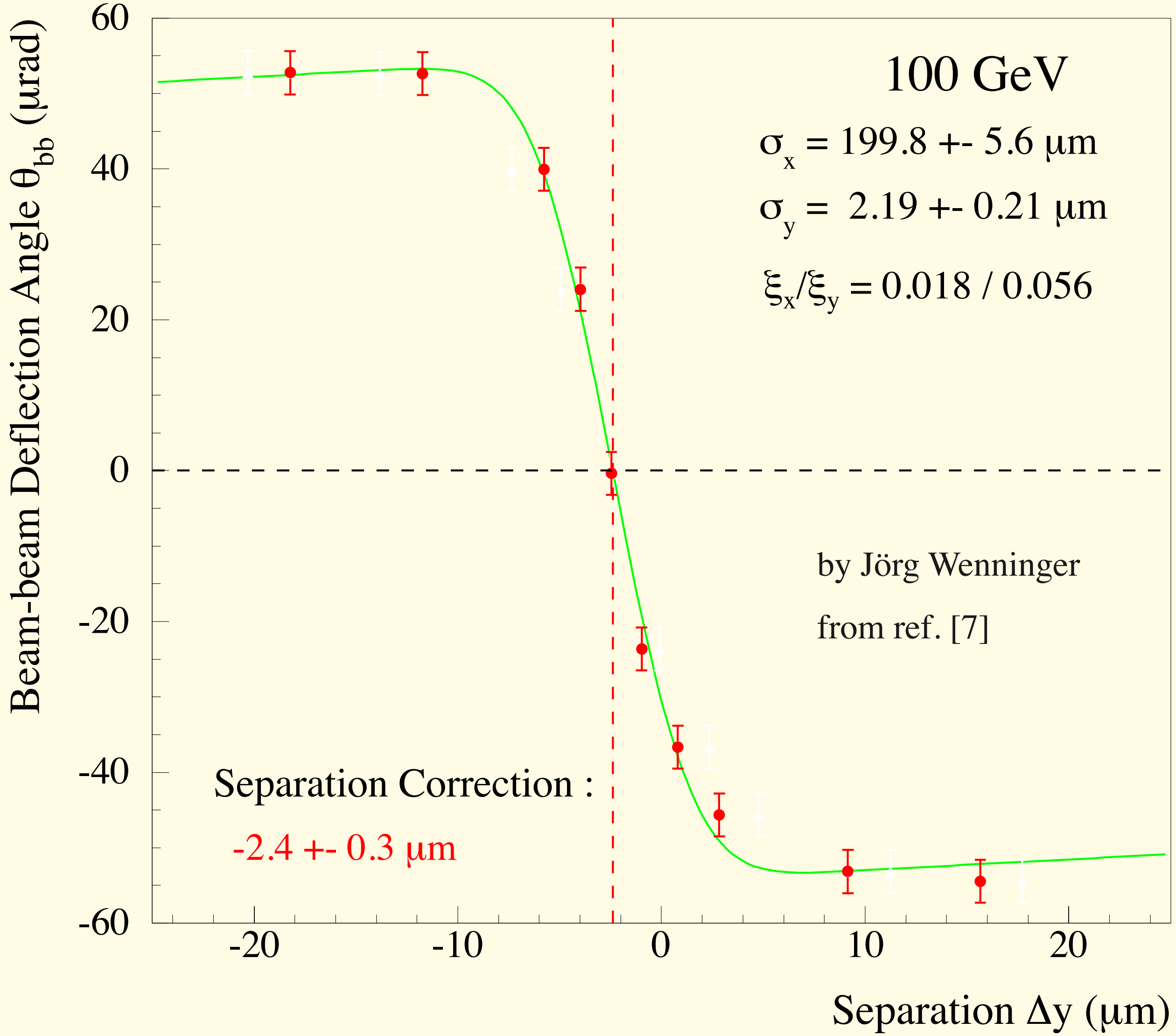
avoid partial separation :

reduces luminosity, can trigger coherent beam-beam, flip-flop, increase halo

Later LEP operation with improved orbit monitoring and control :

Fast centering using beam-beam deflections scans

also providing good estimate of core beam sizes (emittance, bb tune shift)



LEP, example of background particle tracking

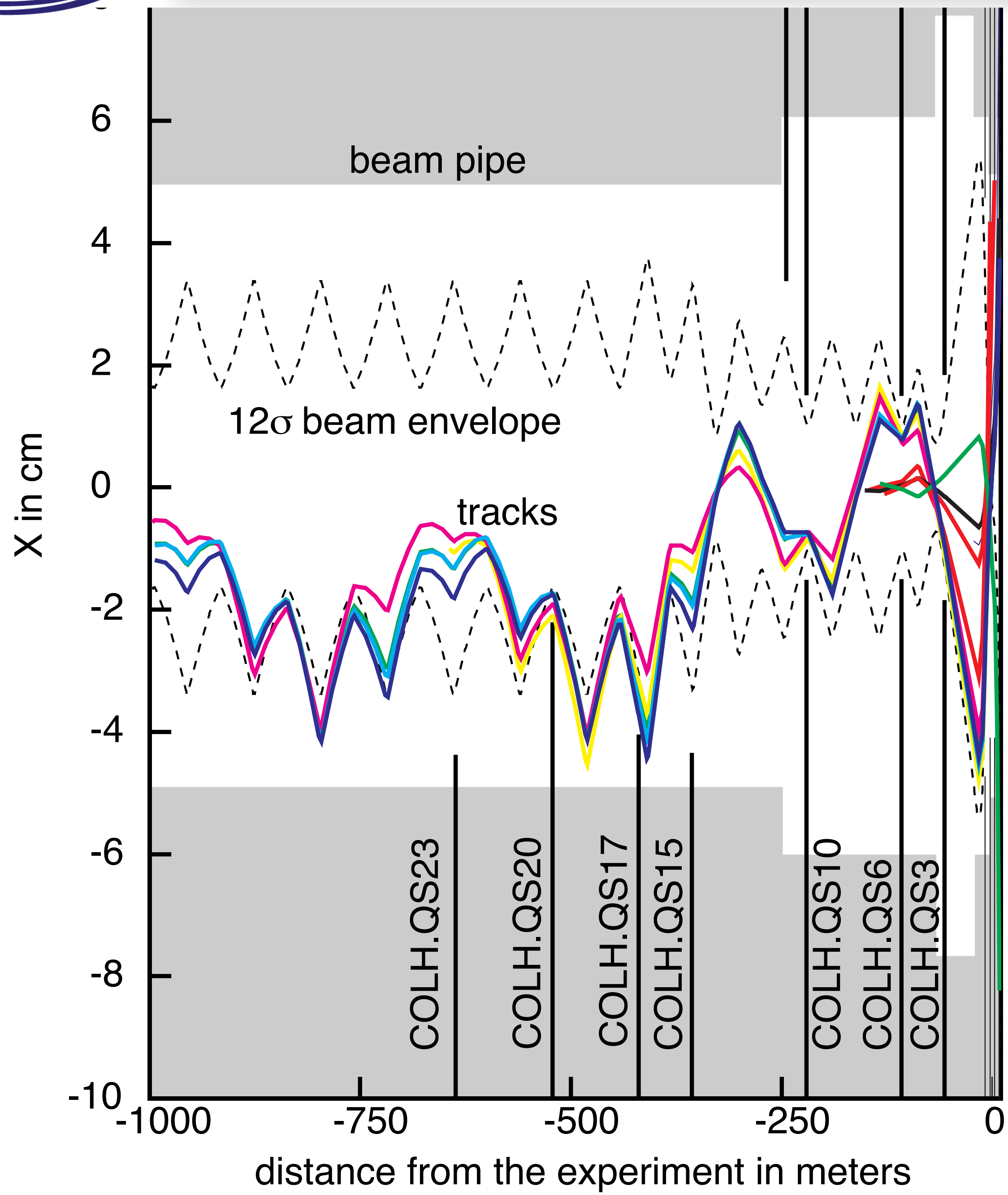


Illustration of beam particle tracking through the LEP lattice over 1000 meters up to an experimental region (cs coordinates).
The distance X from the nominal orbit is given in cm units.
The tracks are for particles that are lost within ±9 m from the interaction point.
The 12σ beam envelope is shown as broken line.
The physical aperture limitation given by the beam pipes is shaded.
The position of collimators (called COLH.QS15, COLH.QS17..) as used in LEP physics runs is shown as vertical straight lines.

Codes : MAD8, Turtle, DIMAD, EGS
+ "own generators" beam gas, thermal, SR, radiative Bbhabha

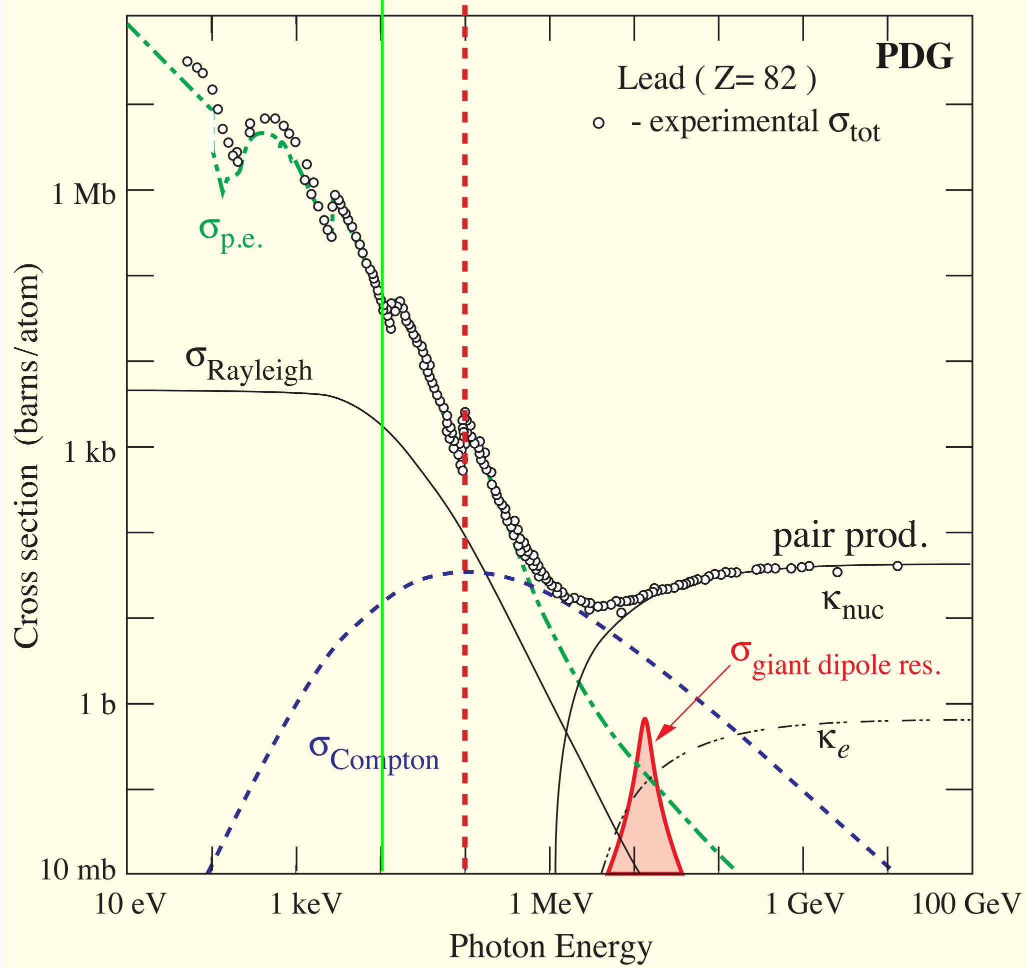
plot from my simulation for the 1998 LEP background paper Ref [6]

Major challenge synchrotron radiation : Photon shielding

✔ < 10 keV

\> 100 keV very difficult

10 MeV significant neutron flux, giant dipole res.



Critical photon energies - bending magnets

SuperKEKB ~ 2 keV (LER)

FCC-hh ~ 5 keV

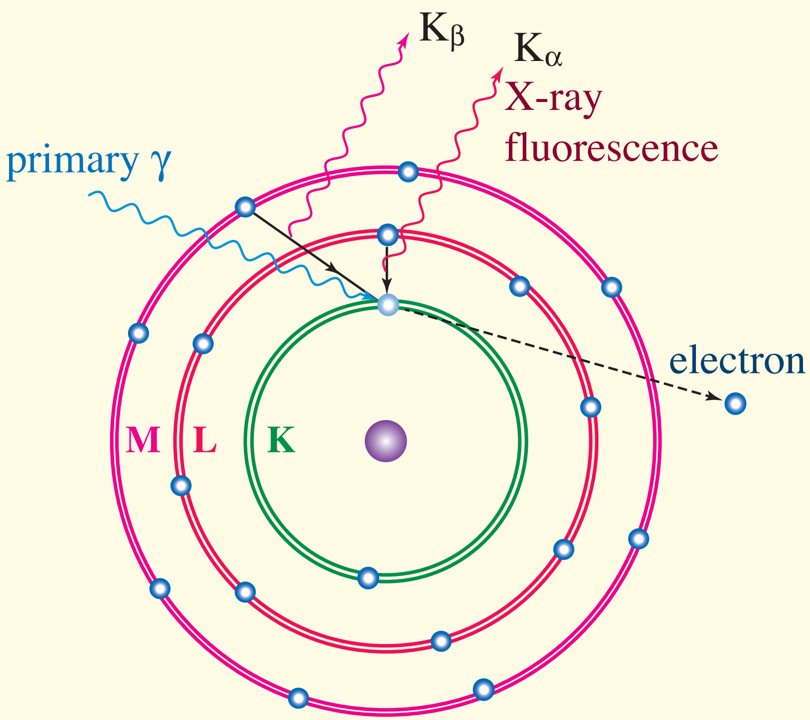
LEP1 : 69 keV

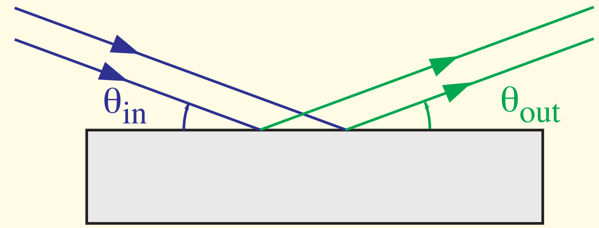
LEP2 : 725 keV (arc, last bend 10× lower)

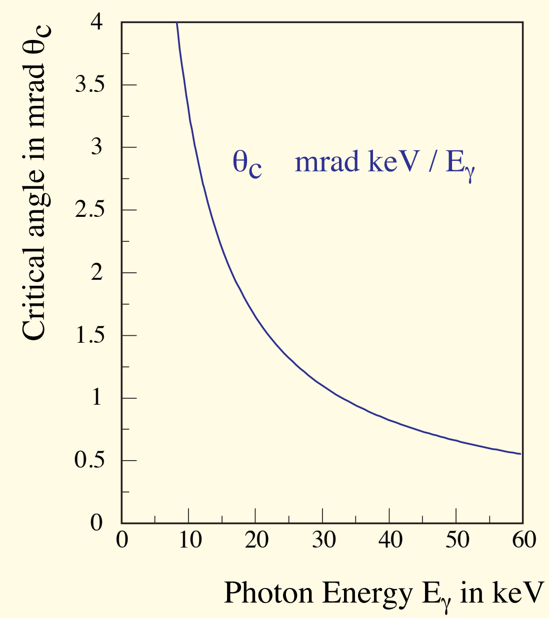
FCC-ee : 1.3 MeV (arc, 182.5 GeV)

important for LEP - and linear colliders :
SR from quadrupoles, dominated by
non-Gaussian tails

X-Ray - Fluorescence and Specular Reflection







below below θ_c
nearly 100 %
very quickly dropping above

Make sure these are included in simulations

Fluorescence was expected and is well simulated with Geant,

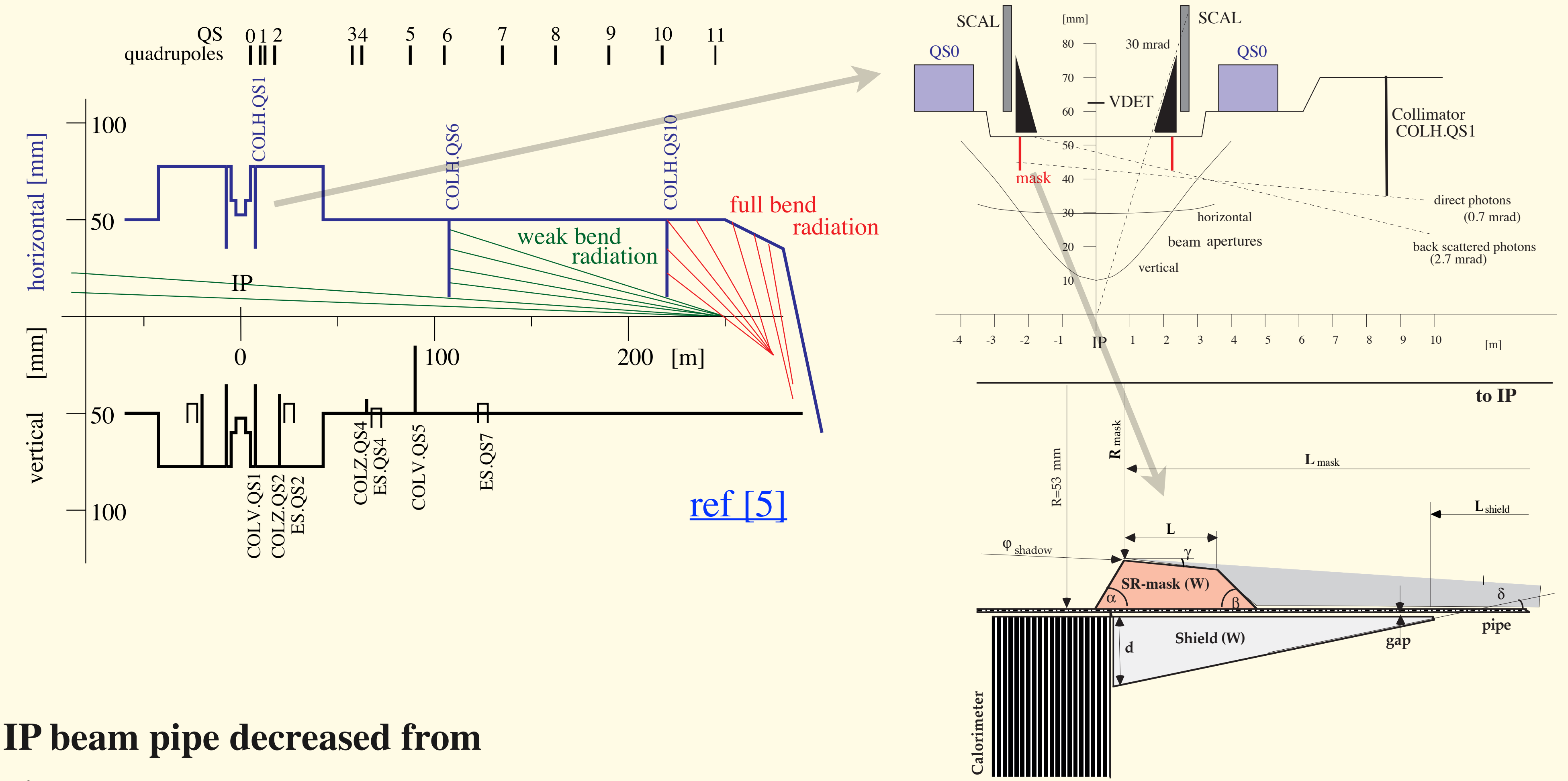
was mitigated for LEP absorbers by surface coating

Reflection in principle known from textbooks (less known for hard γ, depends on surface quality)

like Batterman and Bilderback in Handbook on Synchrotron Radiation Vol.3 Eds G.S.Brown, D.E.Moncton

came as a surprise in LEP, mitigated with COLH.QS6 at 120 m

LEP IR by design minimizing SR backgrounds



ref [5]

IP beam pipe decreased from

Ø = 156 mm Al to 106 mm Be after 1y runnig

~ 100 movable collimators to reduce machine induced backgrounds

flat, symmetric machine, no crossing angle, few (4-12) bunches

Synchrotron radiation - no direct and single reflected radiation to experiments in IP region

Experiments providing continuous background monitoring to LEP control room ref [3]

Evolution of key parameters, LEP1

Showing Fill 2420

one of our best

8+8 bunch (Pretzel)

fills from 9 October 1994

injection energy 22 GeV / beam

physics 45.6 GeV / beam

Luminosity

e+, e- currents

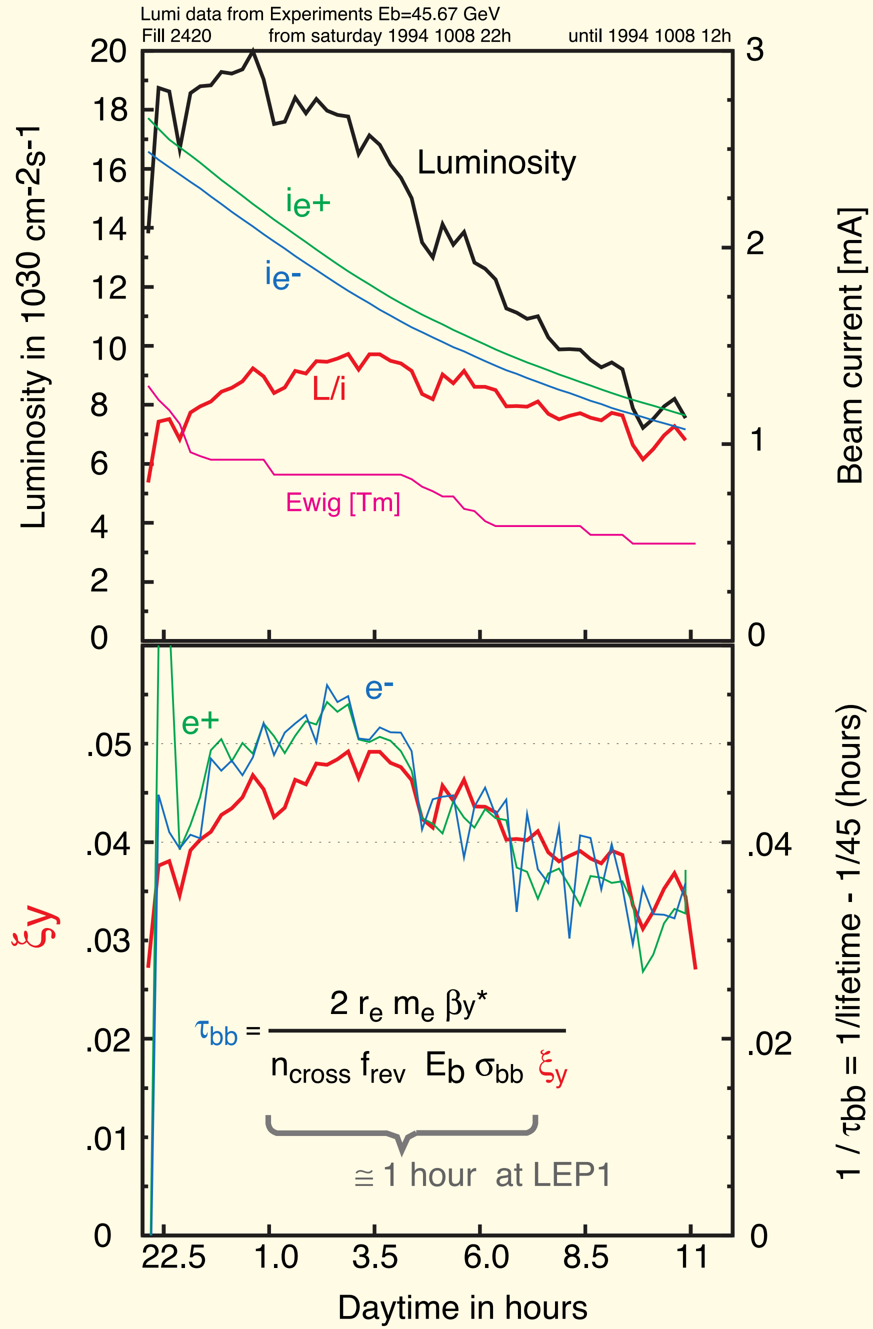
emittance wiggler strength (ε_x adjust)

ξ_y vertical beam-beam tune shift ~ L / i

~ beam loss (inverse lifetime)

from *"burn-off"* by radiative Bhabha

(Beam-beam Bremsstrahlung)

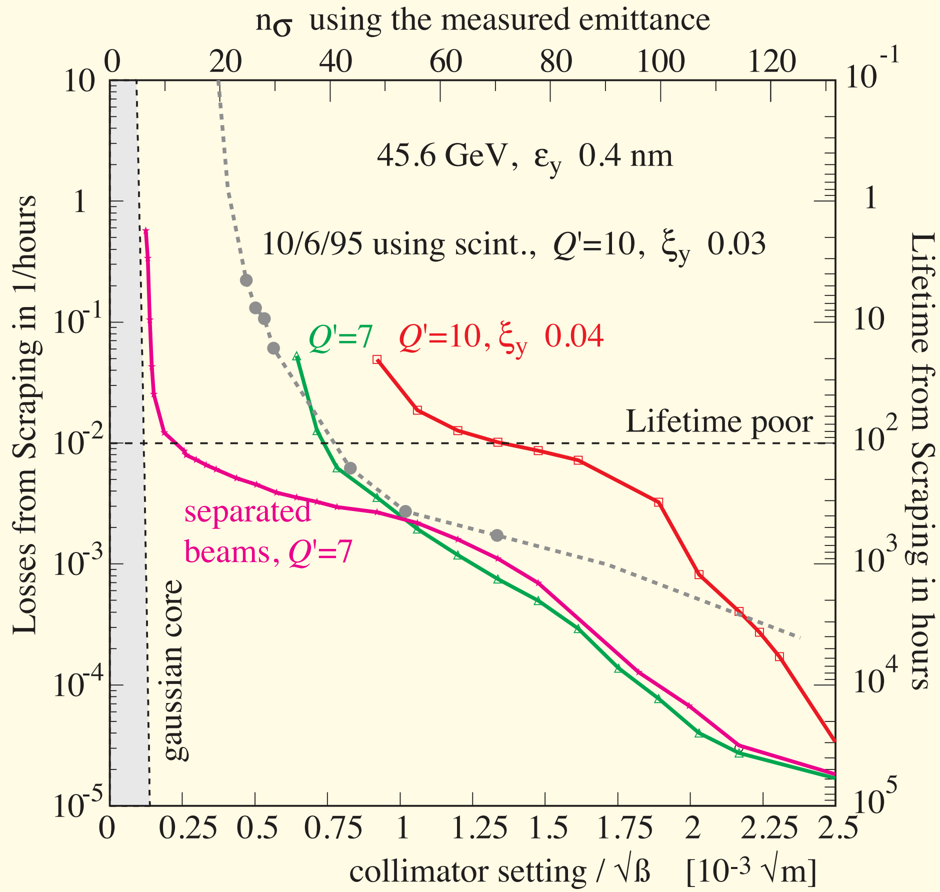


from my presentation / writeup for e+e- factories KEK 1999

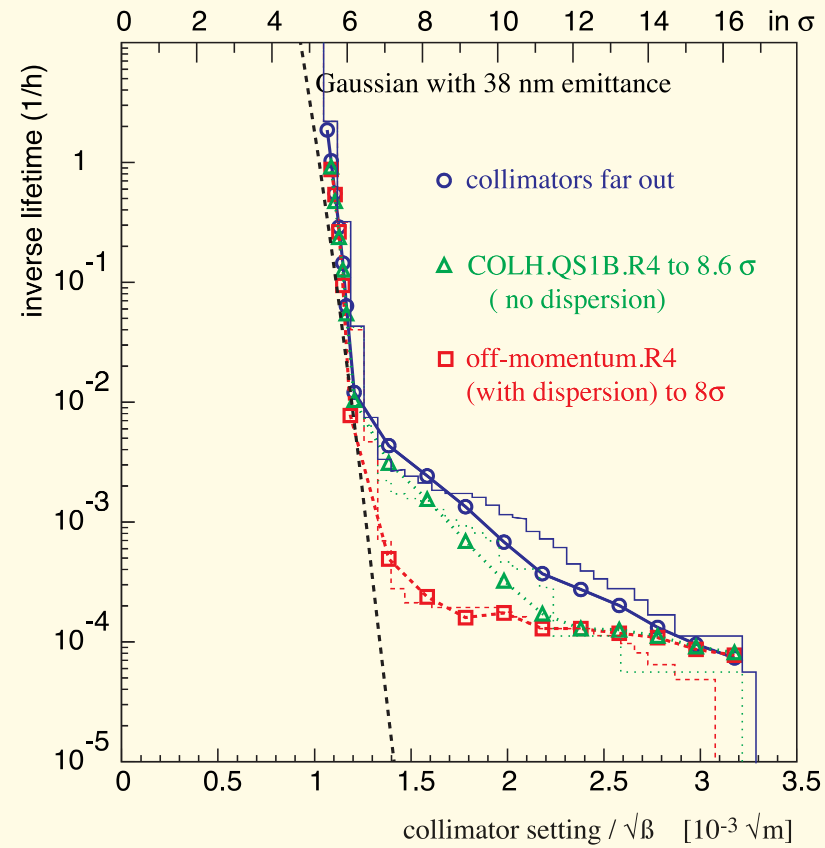
non-Gaussian tails, LEP

measured with loss monitors; scraping with aperture collimators

vertical plane, colliding beams



horizontal plane
reproduced by simulation



Tails from :   beam-beam, high chromaticity, particle scattering

Background spikes, enhanced synchrotron radiation from quadruples

H.B. I. Reichel, G. Roy, Transverse beam tails due to inelastic scattering in LEP, PRSTAB, 3:091001, 2000; I. Reichel, CERN-Thesis-98-017
H.B. "Beam lifetime and beam tails in LEP." Ref [6]

Importance of SR collimation, FCC-ee, CEPC

SR background minimization by design, movable collimators (~ half of the 100 special for SR)

+ local masks, was essential for the LEP detectors to permit precision physics in a clean machine

Background spikes - non-Gaussian tails, tripping detectors, most critical for large wire chambers

roughly requiering << 100 γ / crossing in the detector acceptance

Should be much less ciritical for modern semiconductor based radiation hard detectors, as

used very successfully at LHC with ~ 40 MHz bunch crossing each with ~ 60 visible collisions

However compared to LEP we want :

~ 20 000 more luminosity ~2000 more bunches

5 × smaller beam pipe at the experiment

+ additional challenges from : crossing angle, crab-waist, Beamstrahlung, top-up injection

SR background minimization can be expected to be as for LEP very important and could

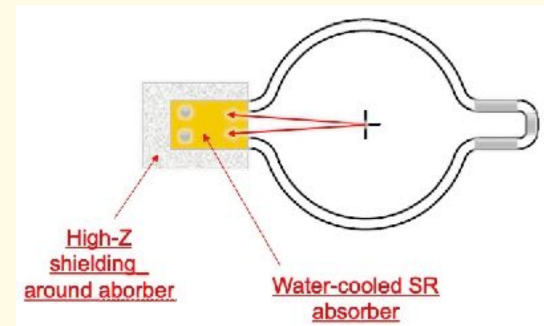
(at times) limit performance or precision

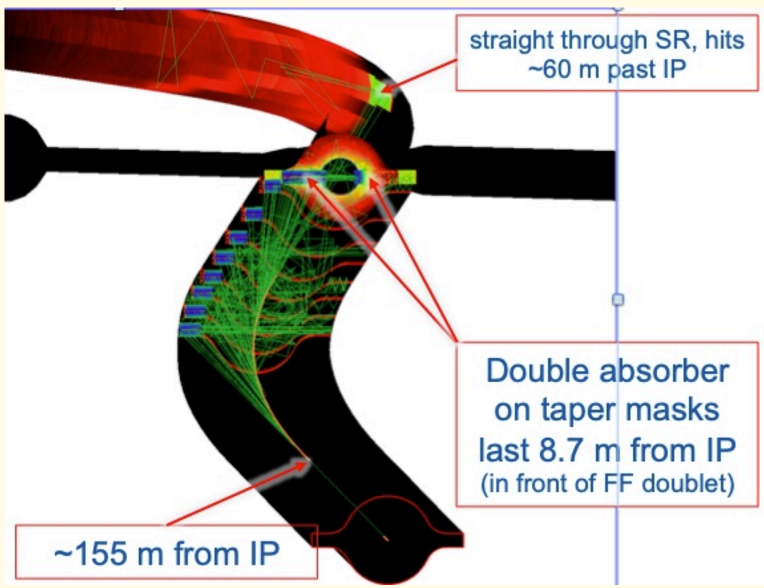
SR Power / length — difficult, but within factor 2 of what worked for LEP

- **LEP had up to 18 MW, 27 km 0.67 kW/m Ecr = 0.725 MeV (LEP2)**
- **FCC 2 × 50 MW, 97 km 1.0 kW/m Ecr = 1.3 MeV (182.5 GeV)**

Ring SR studied by the vacuum group Roberto Kersevan et al.

with simulations using SYNRAD+, beam pipe minizes scattering

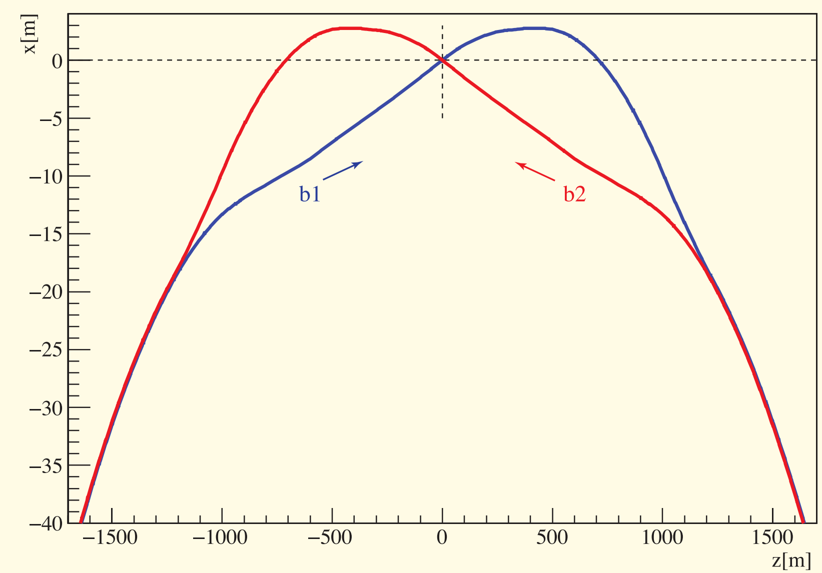




used also to test

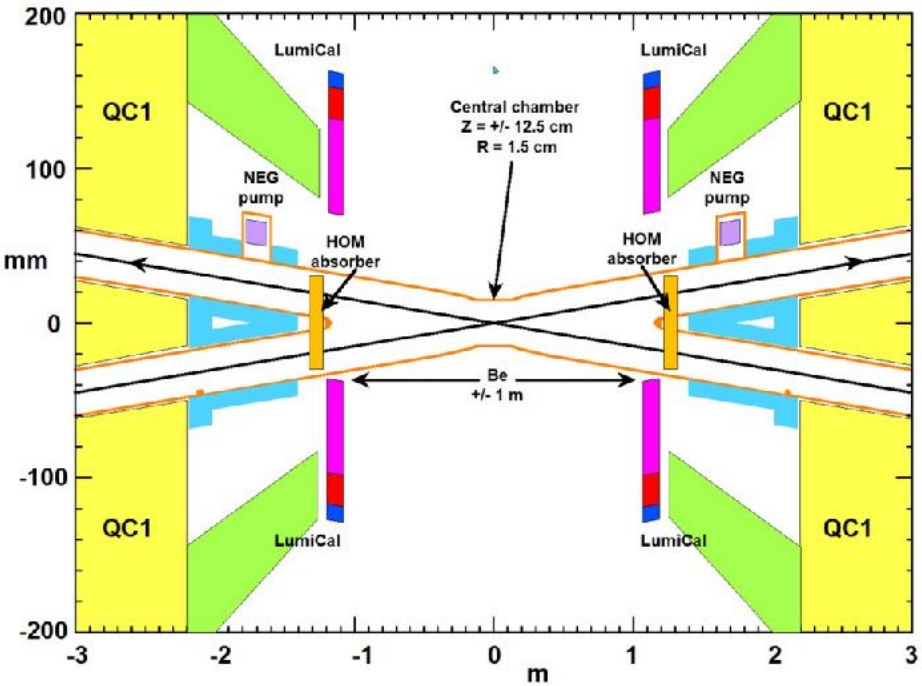
and complement

our MDI simulation studies



Keep Ecr < 100 keV 500 m incoming side to IP

IR layout, experiments in shadow of SR



IR layout, also profiting from e+e- factory experience

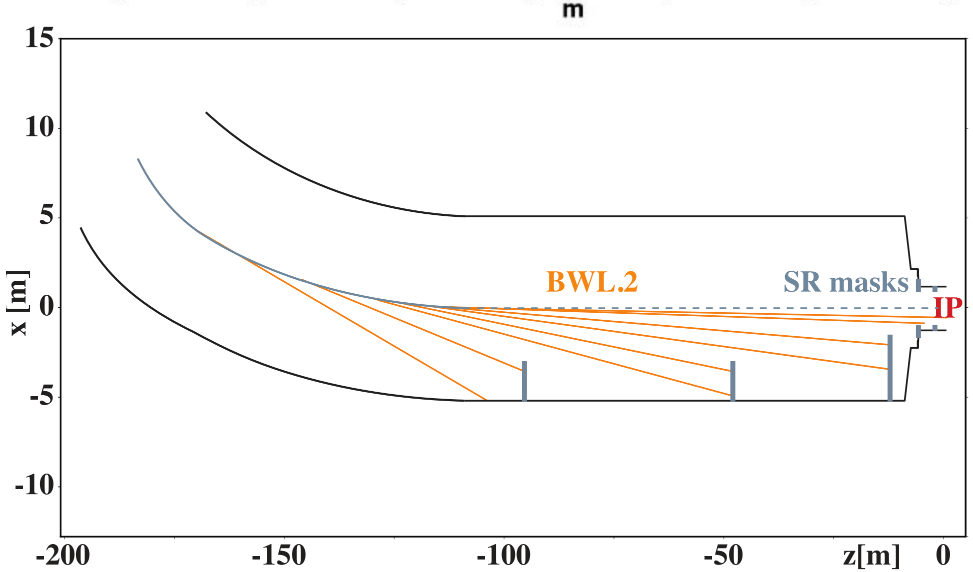
Mike Sullivan / PEP-II

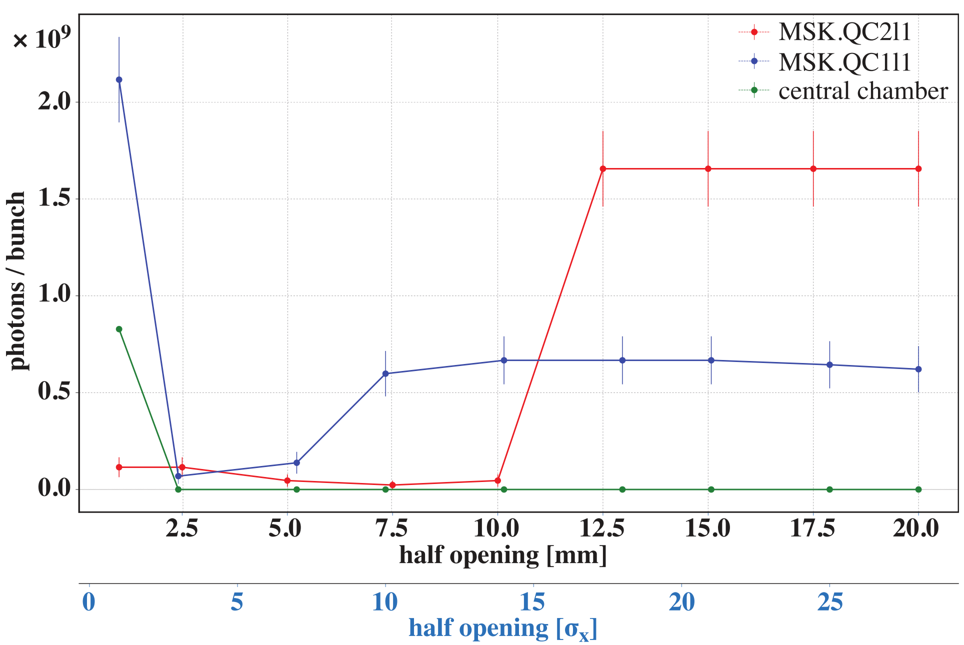
Manuela Boscolo / Daphne

Katsunoby Oide / KEK-B, SuperKEKB

SR from last magnets intercepted by

SR collimators and mask





Detailed simulations by Marian Lückhof, described in his thesis (successful defense 12/3/2021 HH & DESY)

Selected references

[1] *Study of beam induced particle backgrounds*.., G.v. Holtey, A.Ball et al., NIM A403, 1998

[2] *Beam Lifetime and Beam Tails in LEP,* H.B., SL-99-061-AP, Proc. e+e- Factories, 1999

[3] *Accelerator Physics at LEP*, D. Brandt, H.B., M. Lamont, S. Myers, J. Wenninger, Rept.Prog.Phys.63, 2000

[4] FCC-ee CDR, Eur. Phys.J.ST 228 (2019)

[5] *Tools for Flexible Optimisation of IR Designs with Application to FCC*, H.B. + Manuela Boscolo, IPAC 2015 **tupty031**

[6] Background Processes Affecting the Machine-Detector Interface at FCC-ee with Focus on Synchrotron Radiation at 182.5 GeV Beam Energy Marian Lückhof CERN-THESIS-2020-335

[7] IR challenges and MDI at FCC-ee, M. Boscolo, H.B., K.Oide, M. Sullivan, Eur.Phys.J.Plus 136 (2021)

Closing comments

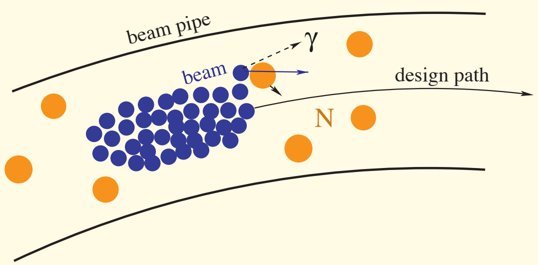
SR principles are well understood; we have plenty of experience from earlier machines, powerful computers for simulations and several detailed, rather independent simulation codes

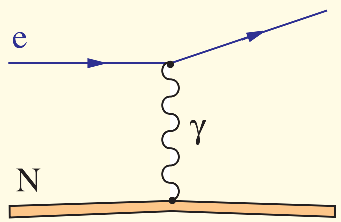
My impression is that this is well taken into the account in the FCC-ee (and I assume also CEPC) design such that SR will not keep us to fully profit from the excellent physics potential and very high precision reachable with future high energy e+e- rings ; a first early SR collimation study has been performed for FCC-ee with promising results but also confirmed the critical dependence on non-Gaussian halo and quadrupole SR strongly depending on alignment and tolerances

Experience has also shown that backgrounds depend on many details and require continues efforts throughout all design phases and later commissioning and operation in close collaboration with the experiments

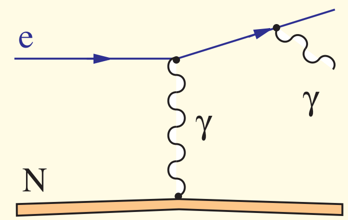
Backup

background sources for loss of e+, e-

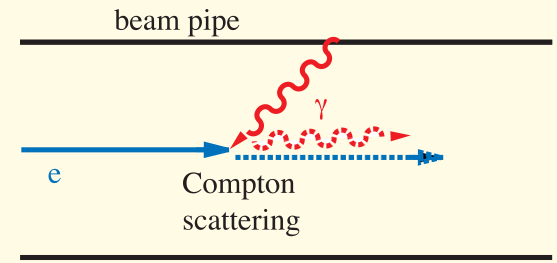




e-N elastic, Coulomb



e-N inelastic, Bremsstrahlung



elastic scattering very small

at LEP energies

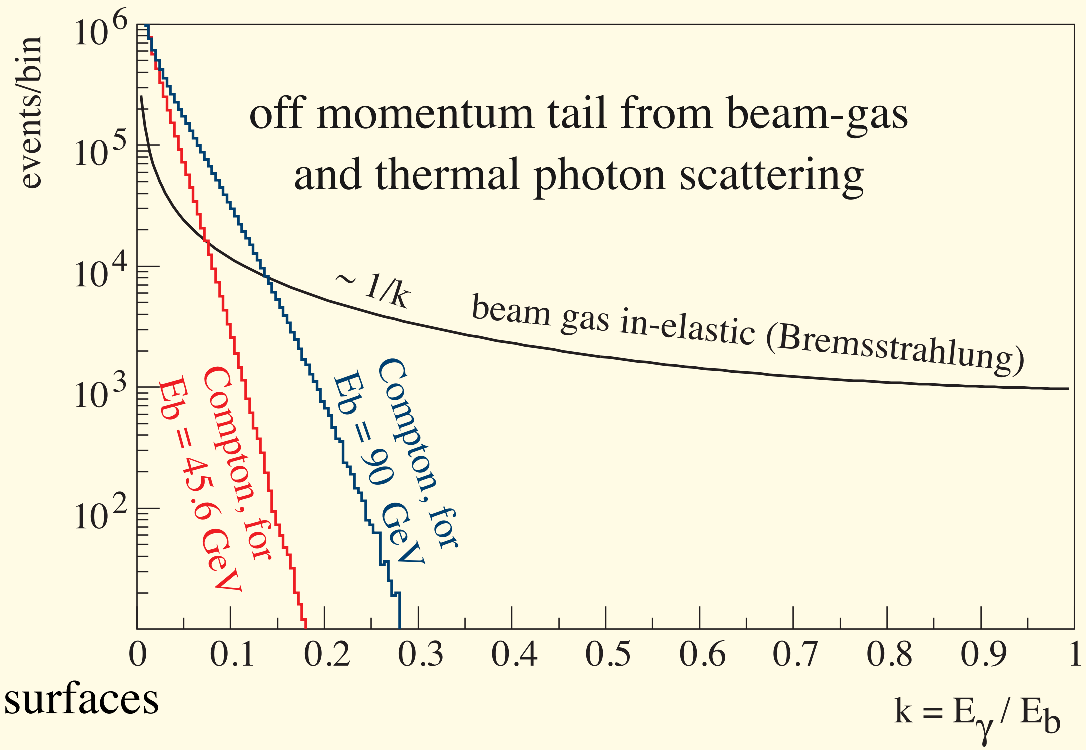
inelastic generated by beam-gas

and thermal photon well visible

but not a major problem

(<< 1 electron lost at IR / crossing)

thanks to



- **excellent vacuum** — SR helps to back out surfaces
- **powerful momentum collimation** both in dedicated collimation section + local each IR

Thermal γ : First described in 1987 by V. Telnov , main single beam lifetime limitation in LEP, well measured and simulated using the algorithm described in SL/Note 93-73

spectrum softer then beam-gas, only small fraction lost in low angle lumi. monitors

Different beam energies

Even more than at LEP, the impact of SR will change a lot from the lowest to the highest physics energy.

Eb GeV	#bun	#e/bun	Xiy	Ibeam mA	U0 GeV	Ecr keV	P MW
LEP							
45.6	12	1.4e11	0.04	4	0.126	70	0.5
100	4	4.2e11	0.08	3	3.0	733	9
FCC-ee							
45.6	16640	1.7e11	0.13	1390	0.036	21	50
182.5	48	2.3e11	0.13	5.4	9.2	1320	50

Lowest energy : major challenge of beam power and heating + as seen in LEP likely more issues with halo/tails, instabilities, background spikes

In LEP1 we used a wiggler to increase the emittance to stabilise beams at beginning of fills

Highest energy : major stream of hard photons that will scatter and reflect and be more difficult to absorb to be mitigated by refined system of collimators + masks