Machine Induced Backgrounds at the FCC-ee

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material: M.B. talk at FCC WEEK15 "Losses in IR Region"

H.B. Oct 14th 2015 review "Interaction region Synchrotron Radiation"

Background design study
general approach

- Simulation of beam background sources → primary losses

- Propagation -interactions and showers- of primary particle losses in and nearby the detectors

  → check for acceptable rates in all detectors

- If detector background budget not satisfactory, readjustments of
  - Shieldings, masks and collimators
  - beam parameters
  - IR design

Machine Detector Interface

Key issue:

- lost particle backgrounds
- Synchrotron radiation backgrounds

- SR heating of vacuum chambers
- radiation damage/lifetime of detectors
- sensor occupancy
- luminosity measurement

Beam Induced Backgrounds

Two Main Classes:

- **Beam particles e^+, e^-, e^+e^- effects**
  - Bhabha
  - Beamstrahlung
  - Beam-gas
  - Touschek
  - Thermal photons
- **Synchrotron Radiation**

- Both aspects deeply studied for present/past machines
- Beam particles effects (better) studied at Factories
- SR manageable extrapolation from LEP experience but FCC-ee is a very challenging machine, dedicated studies needed

Beam Induced Backgrounds

- **Luminosity sources**
  - Beamstrahlung
  - Bhabha (Radiative)
  - 2-photon pair production

    $e^+e^- \to e^+e^- \; e^+e^-$

    $e^+e^- \to e^+e^- \; \mu^+\mu^-$
  - Beam-beam (Halo)
- **Linear with Currents**
  - Synchrotron radiation
  - Beam-gas Coulomb/ Bremsstrahlung (at constant Pressure)
- **Other sources**
  - thermal outgassing due to HOM losses
  - top-up injection background
  - High order modes
  - Compton thermal photons
  - ion or electron cloud
  - single / multiple Touschek scattering

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Some cause backgrounds due to direct beam losses: particle tracking needed.

The impact of these effects is of course dependent on machine parameters (like beam energy, energy acceptance)

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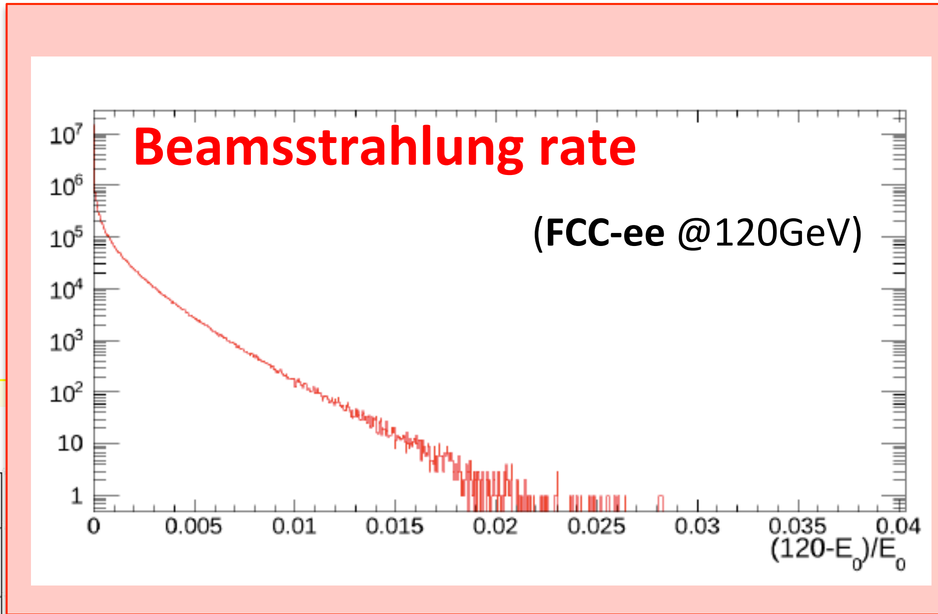
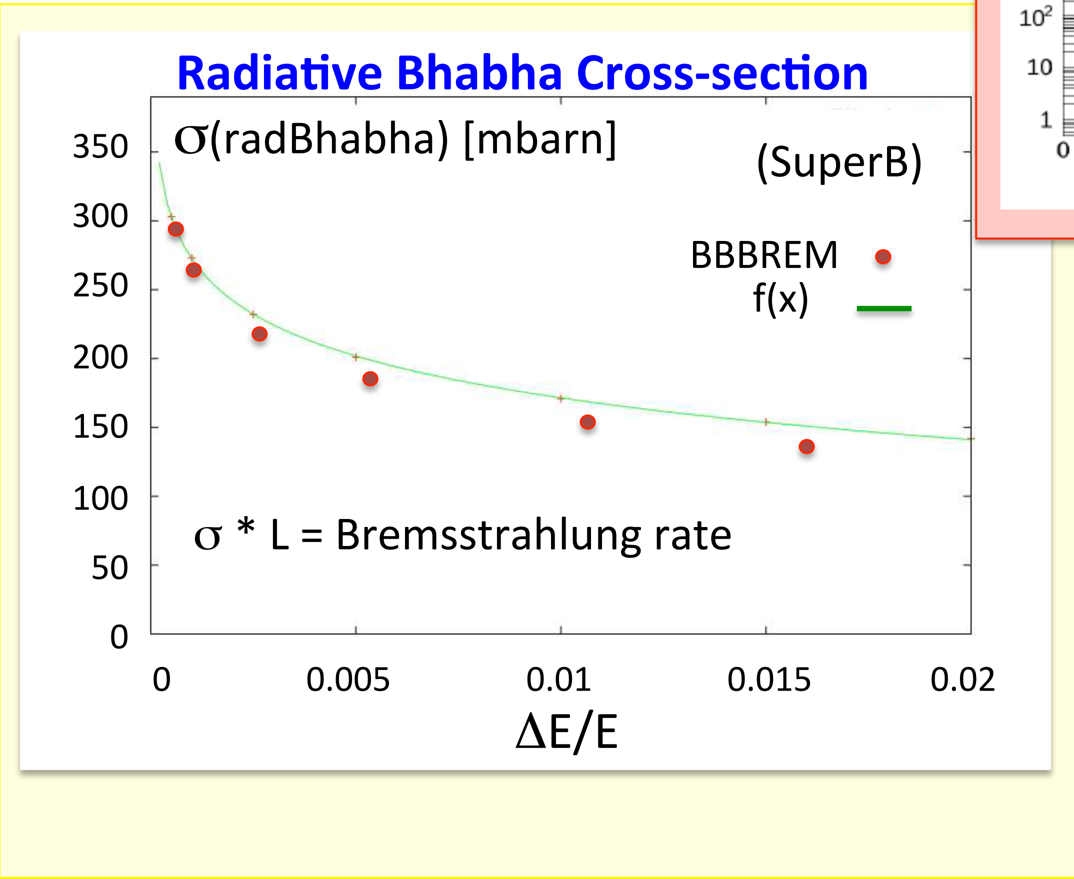
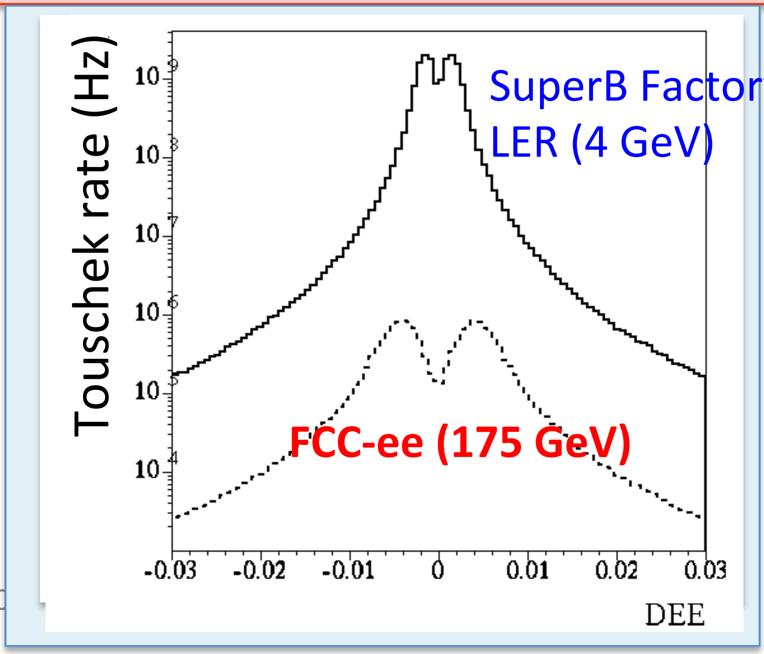
Dependence on Energy Acceptance

Analogies:
- dependence on energy acceptance
- direct losses







Energy dependent processes: scale law

$$P(\text{Beamstrahlung}) \propto \gamma \cdot \frac{N^2}{\sigma_x \sigma_y}$$

$$P(\text{Bremstrahlung}) \propto \ln\left(\sqrt{s}\right) \cdot L \propto \ln\left(\sqrt{s}\right) \cdot \frac{N^2}{\sigma_x \sigma_y}$$

$$P(\text{Touschek}) \propto \frac{1}{\gamma^3} \frac{N}{\sigma_x \sigma_y \sigma_z}$$

P = Probability function

√s = c.m. energy
L = Luminosity

scaling with the beam energy:

Beamstrahlung is the dominant effect at high energies;

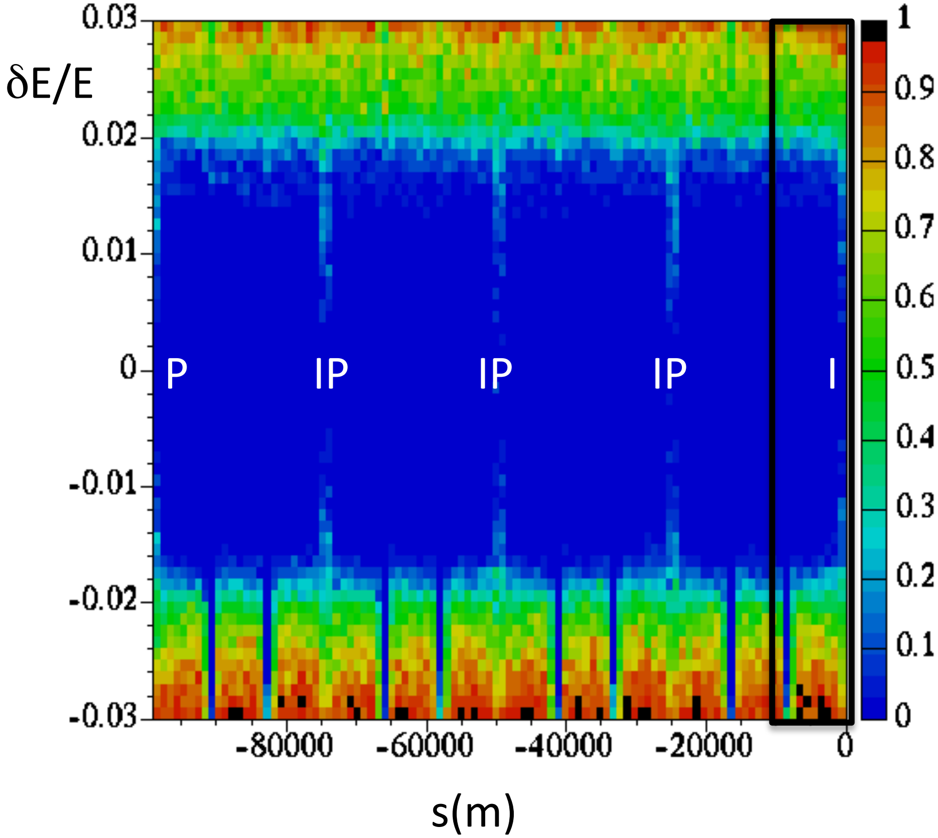
it is strongly dependent on energy acceptance (see previous slide);

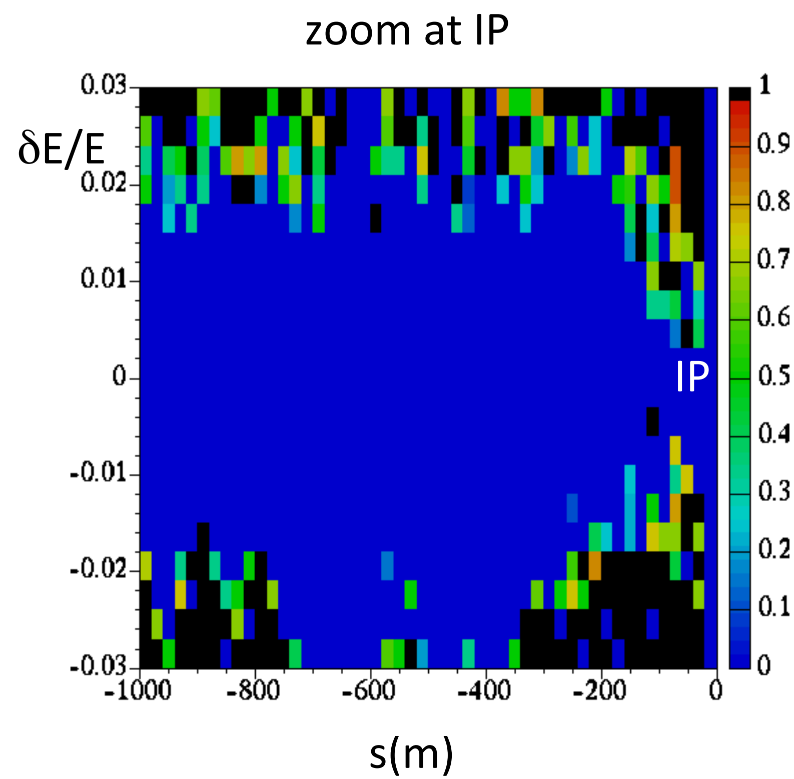
➡ acceptance needed as high as possible

Momentum Aperture of Touschek particles through the ring

(from physical aperture)

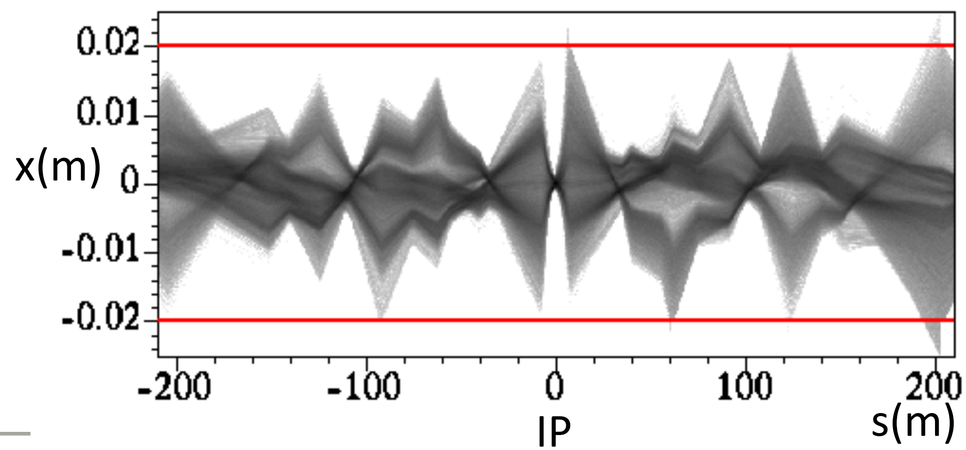
Not simply an *s* dependent momentum aperture: EXAMPLE





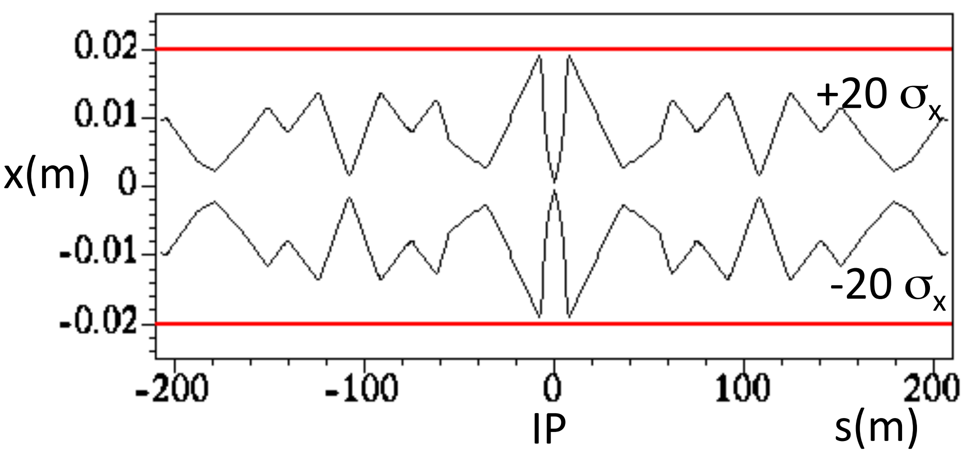
- Crucial for all sources inducing a δE/E like Touschek, rad Bhabha, beamstrahlung (HE)
- Best determined with full tracking
- warning: present optics is much better (optics: TLEP_V14_IR_6-13-2)

FCC-ee Touschek Off-energy trajectories



Horizontal Physical Aperture =2 cm constant

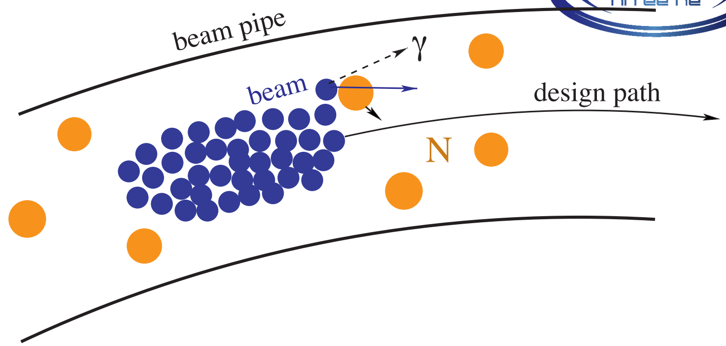
Trajectories of off-energy Touschek particles with an initial $\Delta E/E$ in the range between 0.3 - 4 %



on-energy particles:
Beam envelope at 20 σ_x

(optics: TLEP_V14_IR_6-13-2)

Beam-gas scattering



- Mainly Coulomb and Bremsstrahlung interactions with residual gas molecules in the beam pipe
- As a start: the estimate based on LEP2 rates and rescale for beam currents

- For a more quantitative and accurate estimate the lattice description is needed

  TOOLS:

  – PLACET, HTGEN (Helmut)
  – MCGAS Monte Carlo developed for SuperB and Italian τ-charm (Manuela)

Beam-gas Coulomb scattering

		B-Factories				
LER parameters	**unit**	**KEKB**	**SuperKEKB**	**SuperB**	**LEP**	**FCC-ee (KO) (175GeV)**
V beam pipe @QD0	mm	35	13.5	6		
β_y (max) @QD0	m	600	2900	1497	**150 m**	**5.236 km**
Coulomb lifetime	hr/min	>10 hrs	35 min	24 min		

- Coulomb rate decreases quadratically with energy ➡ beneficial for FCC-ee
- Coulomb rate increases linearly with β_{ave} ➡ worse for FCC-ee
- Losses happen vertically at $\boldsymbol{\beta_y}$**(max)** (i.e. at QD0) larger by 1 order of magnitude with respect to SuperB Factories, at LEP there was no high beta close to the IP ➡ worse for FCC-ee should be found a trade off for this value

Beam-gas Bremsstrahlung

- At **LEP** off-energy particle background was largely dominated by beam-gas Bremsstrahlung along the straight sections [τ_B= 430 hrs with P=10^{-10} Torr, NIM A 403 (1998) 205-246]
- From 45 GeV to 65 GeV dynamic pressure increased by a factor 5

⇓

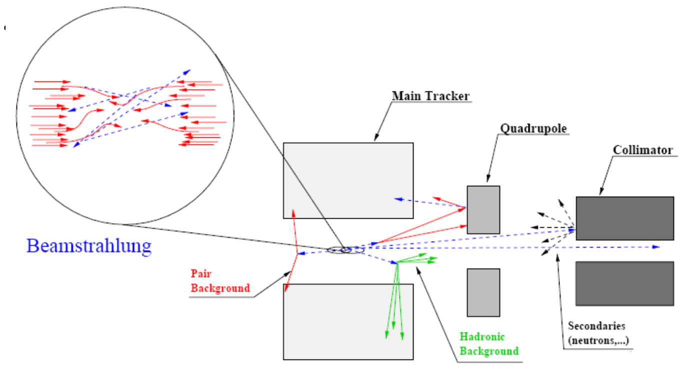
- At FCC-ee Beam Losses needs to be studied with particle tracking
- General requirement: P < 1.E-9 Torr

Radiative Bhabha

- ***Large* energy loss/angle** => lost almost immediately, closeby detectors
  - almost independent on machine lattice but the Final Focus
  - BBBREM generator [R. Kleiss, H.Burkhardt](collinear), BABAYAGA, BHWIDE(low angle)
- ***Small* energy loss/angle** => may be lost after few machine turns
  - multi-turn tracking with a dedicated Monte Carlo simulation with BBBREM generator for the weights of the tracking particles
- Cross-section almost independent on sqrt(s)
- **Lifetime** depends essentially on energy acceptance at IP and on Luminosity
- **Multi-turn particle losses** best calculated by tracking

Beamstrahlung

- Beamstrahlung is synchrotron radiation in the field of the opposing beam
  - ➔ energetic photons are emitted -> produce background
  - ➔ –(ΔE/E) bunch particles get lost in
    - -> Backgrounds from debris
    - -> Luminosity drops
    - -> beam energy spread affected

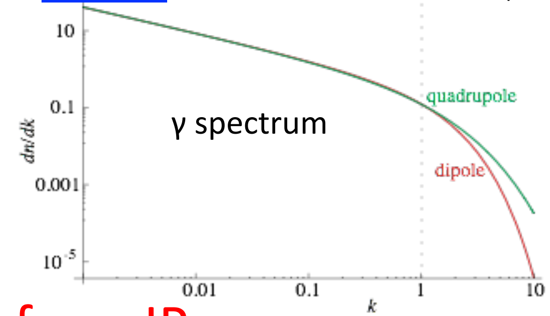


Many analogies (dependence on energy acceptance at IP, direct losses) with Radiative Bhabha but Beamstrahlung is the dominant effect at FCC-ee high energy

Approach for FCC-ee SR : IR challenges

Challenge: maximize performance (integrated luminosity) for experiments **for good** or at least tolerable **experimental (background, stability) conditions.**

H.B. Chapter 5.2 Landolt-Börnstein New Series I/21C



γ-energy / Ecrit.

Some key points :

Minimize synchrotron radiation in the IR region =>

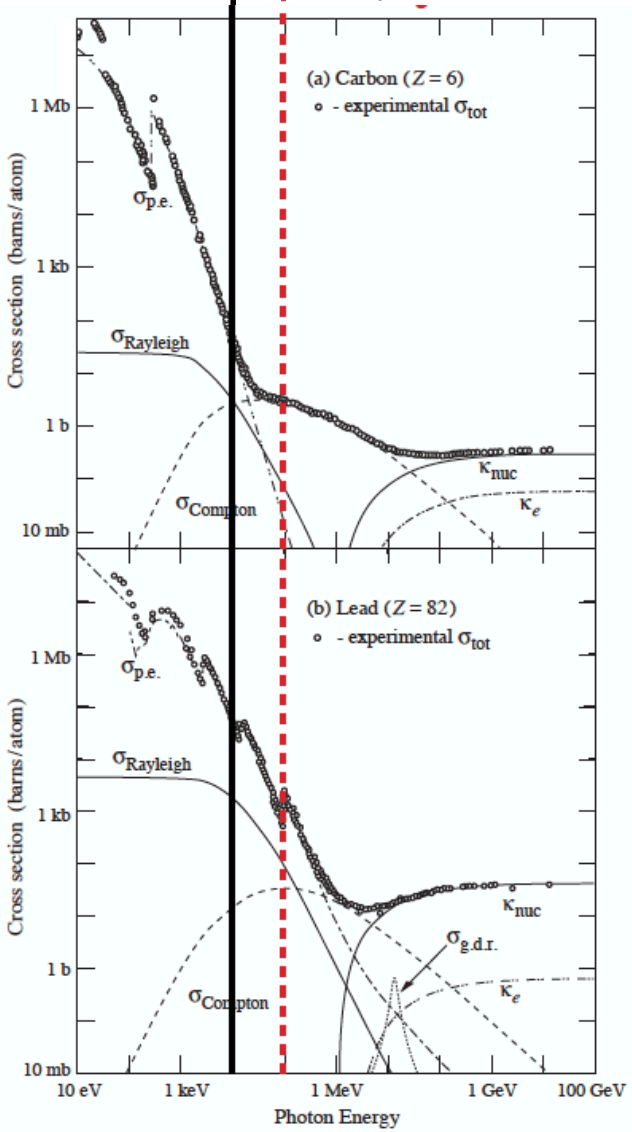
- **Bends** as weak as possible and as far as possible from IP
- **Quads** have to be strong and close to IP,
  Minimize offset from quad axis
  Careful with vertical halo/tails

SR Monte Carlo : H.B. CERN-OPEN-2007-018 **integrated in G4**

- **For FCC the approach has been to start developing the software tools**

Spectrum and absorption

✔ < 10 keV | very difficult above 100 keV



Typical mean (0.3 E_c) photon energies

B-factories (and **FCC-hh**) mostly below 10 keV

LEP1 : 21 keV
LEP2 : 320 keV (arc, last bend 10× lower)

TLEP : ~ 350 keV (arc, 175 GeV)
-> very similar to LEP2
difficult to collimate

Enormous photon flux, MWs of power
can get kW locally, melt equipment, detectors..

Aim as for LEP2 :
do not generate hard synchrotron radiation anywhere close to the IR

[Helmut Burkhardt]

Optics MDI design - SR criteria

Stimulated by the request of Katsunobu Oide to provide simple criteria to make synchrotron radiation effects tolerable :

My proposal, based on LEP2 :

1. Ecr < 100 keV within 250 m of IP. Weak dipoles in IR LEP2 72 keV at 260 m from IP

2. Ecr < 1 MeV in ring, to avoid n-production LEP2 0.72 MeV

Should be considered as guidelines, neither guarantee nor hard limit. Possible to compromise :

1. Ecr < 100 keV important for SR directed to IP, outgoing beam could be higher

2. Ecr > 1 MeV ---> consequences of neutron production to be evaluated in detail

Turned out to be possible to design an optics including crab waist with these criteria :

`/afs/cern.ch/eng/fcc/ee/Oide/Lattices/FCCee_t_45_16_cw_nosol.seq` from 31/08/2015

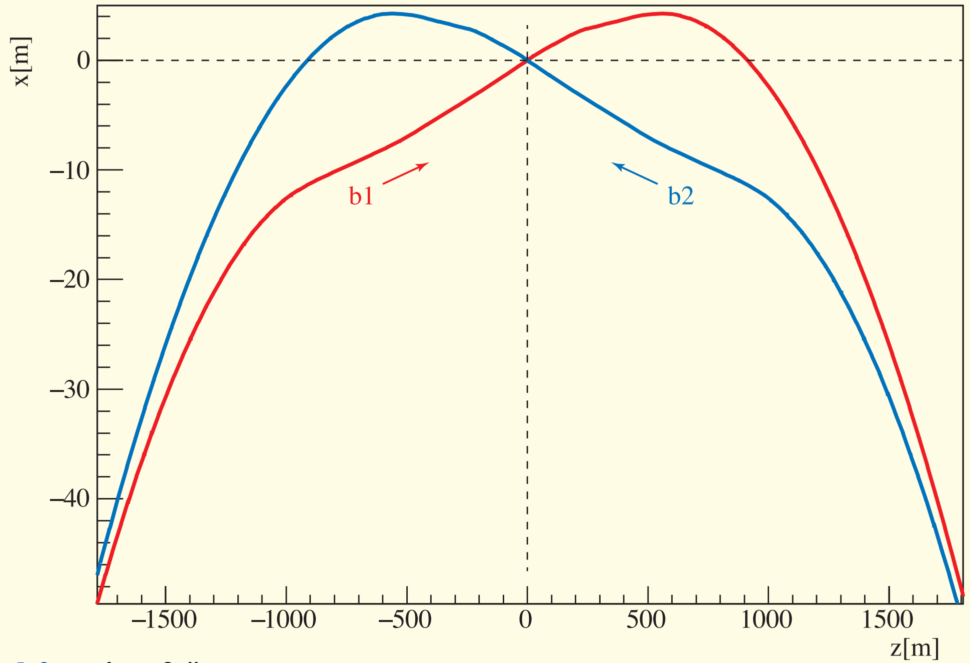
Look at these optics using our generic MDISim tools, guided by LEP2 --->

[Helmut Burkhardt]

1. step : MAD-X twiss and survey

FCCee_t_45_16_cw_nosol.seq is complete ring, but only single beam
make 2nd beam and introduce crossing on survey level

```
beam, particle = positron, npart=2.3e11, kbunch=60, energy = 175, radiate=false;
twiss, chrom,          file="fcc_ee_t_45_16_cw_nosol_b1_twiss.tfs";
survey, theta0 = +0.015, file="fcc_ee_t_45_16_cw_nosol_b1_survey.tfs";
```




```
seqedit, sequence=L000005; ! construct beam2
 cycle, start=L000005$END; ! start at end
 reflect;
endedit;

twiss, chrom,          file="fcc_ee_t_45_16_cw_nosol_b2_twiss.tfs";
survey, theta0 = - 0.015, file="fcc_ee_t_45_16_cw_nosol_b2_survey.tfs";
```


[Helmut Burkhardt]

KO lattice FCCee_t_45_16_cw SR tables

Based MAD-X tfs files

Eb=175 GeV L = 99938 m RFHV= 9.6 GV Harm=133343

Qs=0.0818654 frev = 2.99978 kHz fRF= 400 MHz ibeam=6.63253 mA SR Power / beam =47.1606 MW

Bend radiation incoming

iele	NAME	S	L	Angle	Ecrit	ngamBend	rho	B	BETX	SIGX	divx	Power	frac>10MeV
		m	m		keV		m	T	m	mm	mrad	kW	
12	BWL.2	91.89	49.56	-0.0004168	100	1.504	118886.3	-0.0049	1323.550	1.5582	0.0140	0.3071	8.927e-46
16	BC1L.2	194.5	98.99	-0.0008327	100	3.004	118886.3	-0.0049	376.0960	0.8306	0.0076	0.6134	8.927e-46
29	BC3L.4	526.4	51.41	-0.001794	414.9	6.472	28651.0	-0.0204	54.1165	0.3151	0.0072	5.485	1.681e-12
33	BC3L.3	581.4	51.41	-0.001794	414.9	6.472	28651.0	-0.0204	203.3444	0.6108	0.0072	5.485	1.681e-12
52	BL.2	914.4	34.41	0.002923	1010	10.54	11771.7	0.0496	18.4651	0.1840	0.0105	21.75	3.874e-06
63	B1.1264	980.2	28.62	0.00246	1022	8.875	11633.3	0.0502	20.1072	0.1921	0.0108	18.52	4.379e-06
67	B1.1263	1012	28.62	0.00246	1022	8.875	11633.3	0.0502	99.4930	0.4272	0.0108	18.52	4.379e-06

PowSum=47.1606 MW first 250m PowSum250 = 920.491 W

Outgoing

iele	NAME	S	L	Angle	Ecrit	ngamBend	rho	B	BETX	SIGX	divx	Power	frac>10MeV
14	BC1.1	71.39	46.57	0.003134	800	11.3	14860.8	0.0393	54.6903	0.3167	0.0084	18.47	2.56e-07
27	BC3.1	211.7	28.81	0.003169	1308	11.43	9091.2	0.0642	17.8242	0.1808	0.0113	30.53	4.212e-05
31	BC3.2	244.1	28.81	0.003169	1308	11.43	9091.2	0.0642	104.6386	0.4381	0.0113	30.53	4.212e-05
50	BS.1	481.8	31.4	0.003155	1195	11.38	9951.7	0.0587	20.3199	0.1931	0.0104	27.77	1.951e-05
60	BG1.1	559	33.23	0.002495	892.5	8.999	13320.1	0.0438	22.7827	0.2044	0.0101	16.4	9.89e-07
64	BG1.2	594.9	33.23	0.002495	892.5	8.999	13320.1	0.0438	115.2035	0.4597	0.0101	16.4	9.89e-07

first 250m PowSum250=79.5272 kW

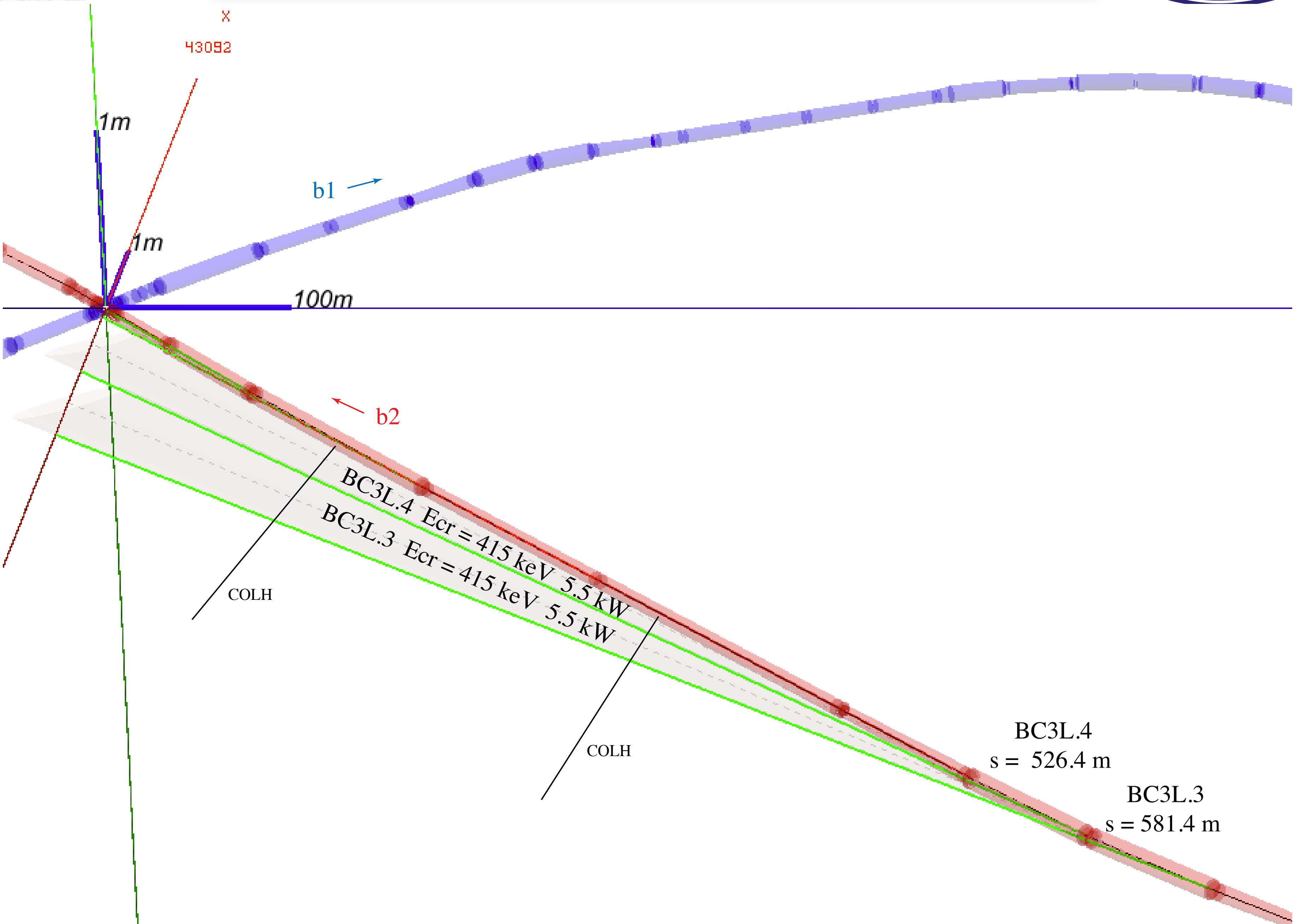
red color : critical energy over 100 keV, Power > 1kW and within 250 m of IP, here only on outgoing beam

Quads, at 1 sigmax, horizontal, incoming beam

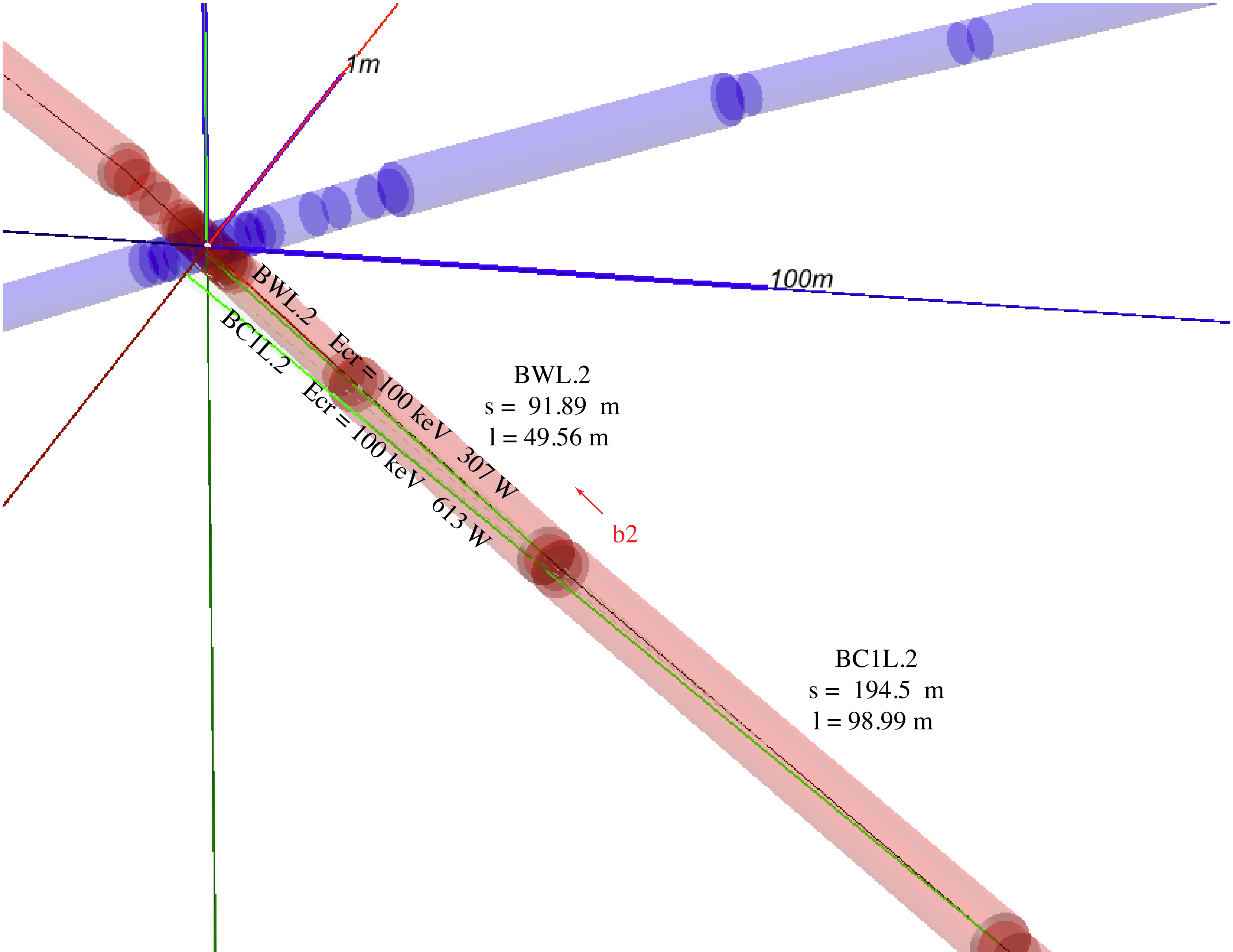
iele	Element	s	L	betx	sigx	divx	K1L	k0	x	Angle	Ecrit	ngam	Power
		m	m	m	mm	mrad	m-2	m-1	mm		keV		kW
3	QC1L1.2	3.8	1.6	20.9	0.1957	0.009375	-0.2665	5.215e-05	1.849e-25	8.344e-05	620	0.301	0.3811
4	QC1L2.2	5.4	1.6	77	0.3759	0.00488	-0.2665	0.0001002	3.157e-25	0.0001603	1191	0.5782	1.406
6	QC2L1.2	6.95	1.25	180	0.5743	0.003194	0.1318	7.569e-05	4.643e-25	9.461e-05	899.8	0.3413	0.6271
7	QC2L2.2	8.2	1.25	219	0.6335	0.002896	0.1318	8.348e-05	5.024e-25	0.0001043	992.4	0.3764	0.7629
10	QC3L.2	42	3	406	0.8634	0.002125	-0.008585	7.412e-06	4.331e-25	2.224e-05	88.12	0.08021	0.01444
14	QC4L.2	95.2	3	1.35e+03	1.572	0.001167	0.01369	2.152e-05	-1.059e-18	6.456e-05	255.9	0.2329	0.1217
18	QC5L.2	198	3	370	0.8236	0.002227	-0.01383	1.139e-05	-7.785e-18	3.418e-05	135.5	0.1233	0.03411
20	QC6L.2	293	3	798	1.21	0.001516	0.01137	1.375e-05	-2.684e-17	4.126e-05	163.5	0.1488	0.0497
22	QC7L.2	415	3	21.8	0.1999	0.009175	-0.0177	3.539e-06	-1.509e-17	1.062e-05	42.08	0.0383	0.003292
27	QY2L.4	475	3	205	0.6127	0.002994	0.02518	1.543e-05	-2.407e-17	4.628e-05	183.4	0.167	0.06254

[Helmut Burkhardt]

KO lattice FCCee_t_45_16_cw



KO lattice FCCee_t_45_16_cw zoomed



AB lattice FCC_arc_17_IR_8, SR

Based on `/afs/cern.ch/eng/fcc/ee/FCC_arc_17_IR_8/FCC.seq` by Anton Bogomyagkov et al. from 25/09/2015

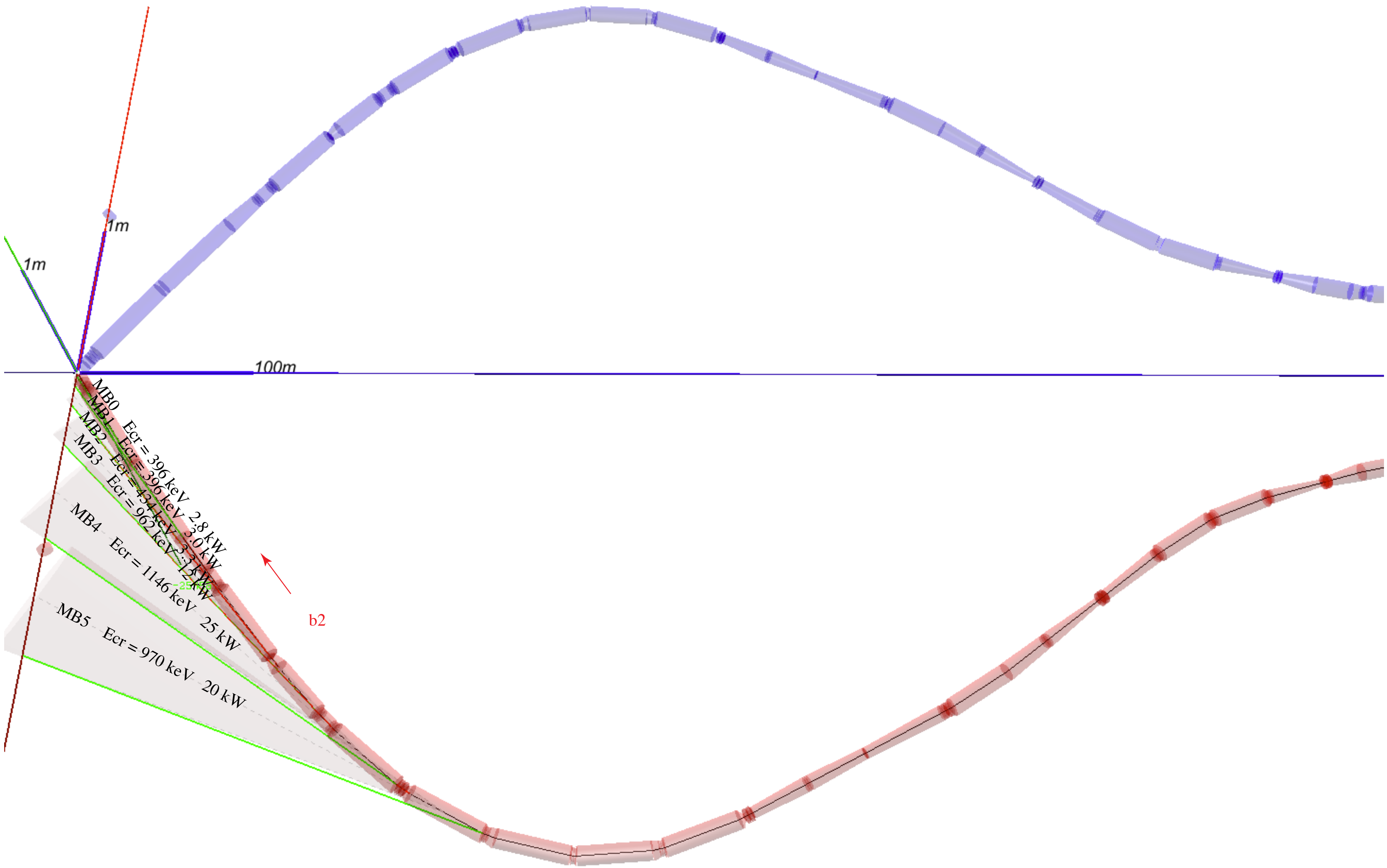
Single beam, symmetric ring, not completely closed, but sufficient for a **first look at SR levels.**

```
Eb=175 GeV l = 101268 m  RFHV=     11 GV Harm=66666  x2
frev = 2.96038 kHz fRF=197.357 MHz x2    ibeam=6.26083 mA
```

iele	NAME	S	L	Angle	Ecrit	ngamBend	rho	B	BETX	SIGX	divx	Power	frac>10MeV
		m	m		keV		m	T	m	mm	mrad	kW	
11	L2.MB0	39	30	-0.001	396.3	3.607	30000.0	-0.0195	222.1822	0.5440	0.0072	2.756	5.281e-13
13	L2.MB1	74	33	-0.0011	396.3	3.968	30000.0	-0.0195	77.0254	0.3203	0.0072	3.031	5.281e-13
23	L2.MB2	127.8	30	-0.0011	435.9	3.968	27272.7	-0.0214	24.9903	0.1825	0.0073	3.334	5.495e-12
29	L2.MB3	155.4	22	-0.00178	961.9	6.421	12359.6	-0.0472	53.9202	0.2680	0.0073	11.91	2.305e-06
39	L2.MB4	198.5	33	-0.00318	1146	11.47	10377.4	-0.0563	42.5753	0.2382	0.0071	25.33	1.335e-05
55	L2.MB5	242.5	37	-0.003019	970.2	10.89	12253.7	-0.0476	157.2048	0.4576	0.0071	20.37	2.531e-06
61	L2.MB6	285.6	37	-0.003056	982.1	11.03	12105.4	-0.0482	16.8422	0.1498	0.0095	20.87	2.885e-06
67	L2.MB7	325.6	37	-0.003056	982.1	11.03	12105.4	-0.0482	136.5402	0.4265	0.0095	20.87	2.885e-06
73	L2.MB8	368.6	37	-0.003019	970.2	10.89	12253.7	-0.0476	45.0495	0.2450	0.0071	20.37	2.531e-06
109	L2.MB12	508.6	30	-0.0023	911.5	8.296	13043.5	-0.0448	31.0986	0.2035	0.0072	14.58	1.261e-06
133	L2.MB15	628.1	30	0.00235	931.3	8.477	12766.0	0.0457	44.4201	0.2433	0.0076	15.22	1.611e-06
139	L2.MB16	661.4	30	0.00235	931.3	8.477	12766.0	0.0457	25.9592	0.1860	0.0076	15.22	1.611e-06
159	L2.MB17	736.7	20	0.001456	865.5	5.252	13736.4	0.0425	10.3423	0.1174	0.0133	8.763	6.86e-07
165	L2.MB18	767.8	20	0.001456	865.5	5.252	13736.4	0.0425	138.9058	0.4302	0.0151	8.763	6.86e-07
211	MBDS2	1029	10	0.0005865	697.2	2.115	17051.0	0.0342	38.9571	0.2278	0.0090	2.844	3.781e-08

```
PowSum=50.0496 MW first 250m PowSum250= 66.734 kW
```

AB lattice FCC_arc_17_IR_8, SR



Too much SR from FCC_arc_17_IR_8 optics to IR

Conclusions

- We need to check all beam loss effects, but priority is given to:
    - Bhabha (radiative)
    - Beamstrahlung
- First FCC-ee Touschek Losses simulation done, need progress with:
    - Multi-turn
    - Check at all energies (especially at the Z)
    - Keep-up with Lattice and parameters updates
- Beam-gas Losses similar studies to be done
- Benchmarking with e+e- machines (SuperKEKB, DAFNE)
- Top-up injection losses
- Muon backgrounds

Conclusions

- The design of the IR is a critical issue for the success of a collider
- Careful trade-off machine / detector constraints

detector constraints:

- Physics acceptance from the nominal beam axis
- Smallest possible beam pipe radius
- Thinnest possible beam pipe wall
- Solenoidal detector
- Separation scheme
- L* key parameter

- In this frame simulations of all the effects that induce machine backgrounds –as realistic as possible- are essential

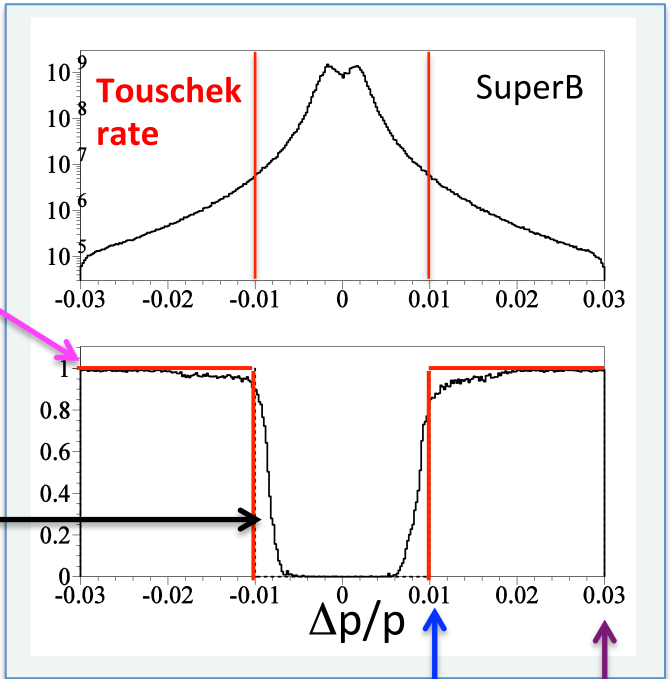
Back-up

Evaluation of Touschek Effect

1. **Touschek lifetime: usually evaluated by the formula, that is dependent on the momentum acceptance, so either**
   - Give the machine momentum acceptance as input, and calculate the formula of the Touschek lifetime averaging on the whole lattice *(rough evaluation)*
   - Calculate the local momentum acceptance through the lattice elements and calculate the formula for each small section of the lattice and then sum up *(more precise evaluation)*

Probability Loss is a step function when machine momentum acceptance is given as an input (resulting from Dynamic Aperture calculation)

Touschek Probability Loss function resulting from particle tracking (consistent, slightly worse, resulting about 0.6-0.8%)



rf acceptance 3%

mom. acceptance (Dyn. Ap.) 1%

The importance of this approach is more important if the distribution vs ΔE/E is very nonlinear (as for Touschek)

Evaluation of Touschek Effect

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2. **Touschek Beam Losses: particle tracking needed along the ring**
   - Macro-particles are tracked through each small slice of elements for many turns (slicing needed for a correct estimate of the Touschek scattering rate to take into account changes of beam density and for proper tracking)
   - Non-linear kicks included in the tracking.
   - **From the total particle losses it is possible to derive the lifetime**

     lifetime (s) = N(beam) / Rate Beam Losses (s)

⇒ (approach used for DAΦNE, SuperB, Italian Tau/C) [Ref. PRST-AB 15 104201 (2012)]

Touschek Tracking code Monte Carlo: some details

- Lattice imported from MAD-X
- A randomly chosen set of macro-particles are launched out of a Gaussian bunch for each small segment of the ring -small enough not to have meaningful Twiss functions changes- and tracked trough the ring for few machine turns or until they are lost.
- These macro-particles are off-energy, as have undergone Touschek scattering, each one has weight proportional to the energy spectrum of the Touschek effect (very nonlinear and lattice dependent)
- once per turn the macroparticle's energy deviation is compared to rf acceptance.
  - Disadvantage: loss location due to rf acceptance exceed not determined
  - Advantage: 4-D tracking in the transverse dimensions for smaller machine turns
- Will interface output with ROOT (plotting and primaries handling)

Perspectives for Software Development

- Presently the Monte Carlo reads MAD-X output (tfs file), produce the input for the MC, that recalculates optics matrices needed both for tracking and twiss functions

We foresee:

- Tracking directly using MAD-X matrices->
- Touschek routine in ROOT or interfaced with ROOT –
- ROOT as a graphical interface similarly to MDISIM
- BBBrem + MC Tracking
- other effects (Beamstrahlung)

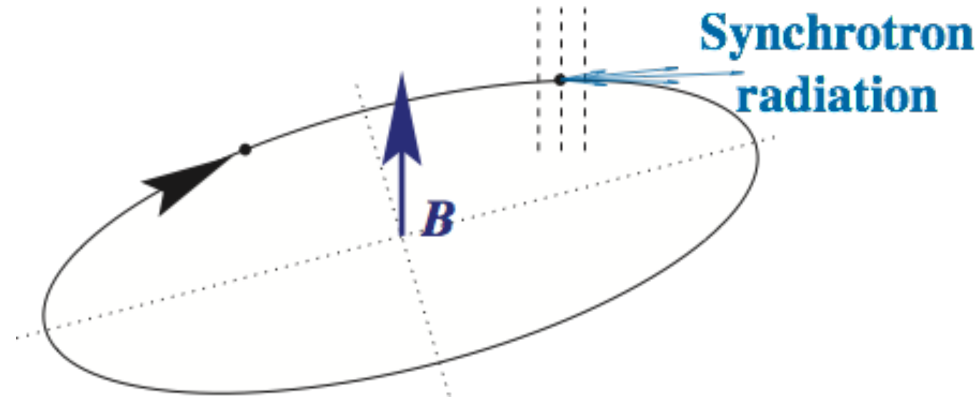
Synchrotron Radiation

$$E_c = \frac{3}{2}\frac{\hbar c\,\gamma^3}{\rho} = 2.96\times 10^{-7}\mathrm{eV\,m}\,\frac{\gamma^3}{\rho}$$

$$\langle E_\gamma\rangle = \frac{8}{15\sqrt{3}}\,E_c \approx 0.308\,E_c$$

$$U_0 = \frac{e^2}{3\epsilon_0}\frac{\gamma^4}{\rho} \approx 6.0317\cdot 10^{-9}\ \mathrm{eV\,m}\ \ \frac{\gamma^4}{\rho}$$

$$P_b = \frac{U_0\, I_b}{e}$$



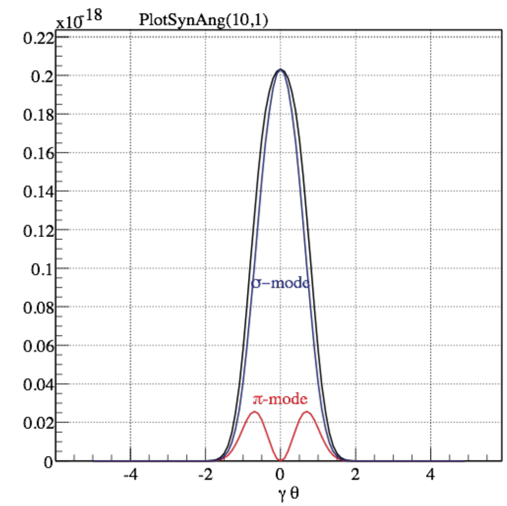
mean free path length λ between radiation

$$\lambda = \frac{\lambda_B}{B_\perp} \qquad \text{where} \quad \lambda_B = \frac{2\sqrt{3}}{5}\frac{mc}{\alpha e} = 0.16183\,\mathrm{Tm}$$

LEP2, TLEP, B ≃ O (0.1 T) O (1 m)

SynRad cone distribution mostly from bending angle O(mrad)

+ minor contribution from
beam divergence O(10 μrad)
and SynRad process

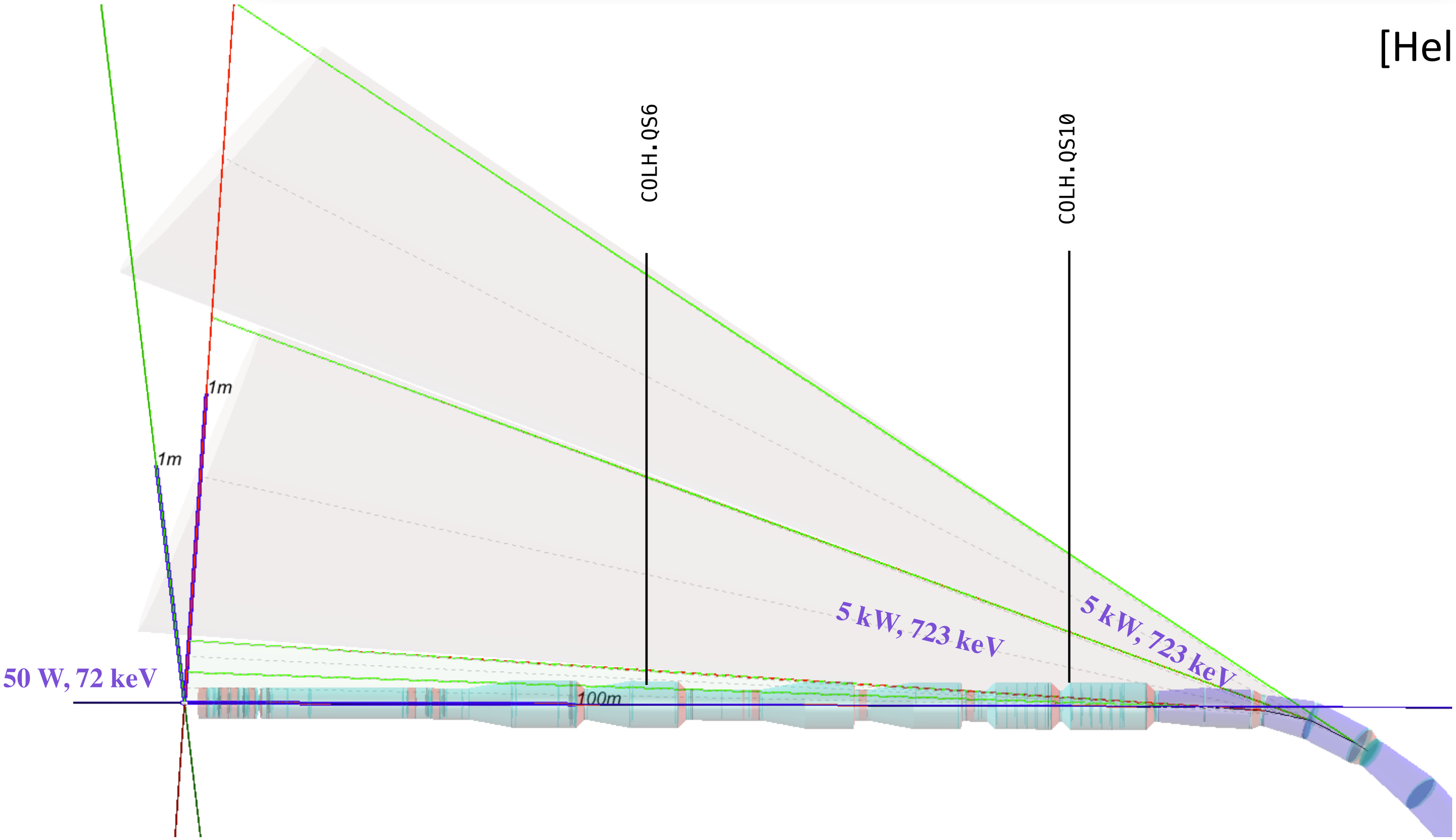


angular distribution (at E_c)
~ 1/γ = 3 μrad @ TLEP

[Helmut Burkhardt]

MDISim run LEP2 100 GEV

[Helmut Burkhardt]



iele	NAME	KEYWORD	S m	L m	Angle	Ecrit keV	ngamBend	rho m	B T	BETX m	SIGX mm	divx mrad	Power kW	frac>10MeV
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

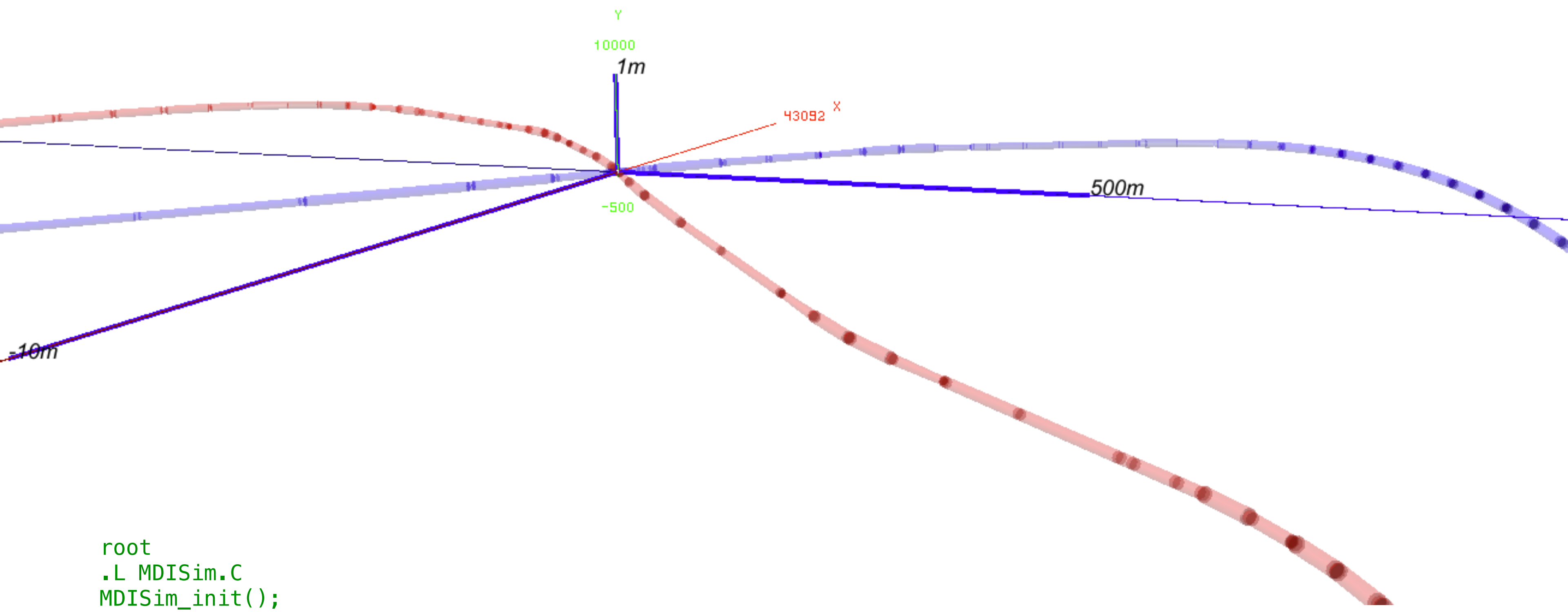
iele	Element	s m	L m	betx m	sigx mm	divx mrad	K1L m-2	k0 m-1	x mm	Angle	Ecrit keV	ngam	Power kW
2	QS0.R2	5.7	2	27.8	1.115	0.04003	-0.327	0.0003474	-0.0524	0.0006948	770.7	1.432	0.9798
10	QS1B.R2	11.2	2	226	3.176	0.01405	0.06314	0.0001918	-0.1377	0.0003836	425.5	0.7907	0.2987
12	QS1A.R2	13.7	2	278	3.523	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

KO lattice FCCee_t_45_16_cw

2. step : Generate Geometry, ROOT with EVE and OpenGL, 3d display

MyNtuple2Geom -acsV -- fcc_ee_t_45_16_cw_nosol IP -zmin zmax scalefac=100 icolb1=600
fcc_ee_t_45_16_cw_nosol_b1_twiss.tfs + b1_survey.tfs icolb2= 632 fcc_ee_t_45_16_cw_nosol_b2_twiss.tfs + b2_survey.tfs

no apertures specified, use default apertures, RF = 6 cm, bend r = 5cm, quad r = 4 cm, sext r =3 cm to make geometry visible




```
root
.L MDISim.C
MDISim_init();
StartEveWithGeomDisplay("http://hbu.web.cern.ch/hbu/Geom/fcc_ee_t_45_16_cw_nosol.root");
Plot_axis_arrows(-10,1,500);
```


[Helmut Burkhardt]