

# Synchrotron Radiation in Interaction Region

and comment on BBREM rad. Bhabha lifetime

by **Helmut Burkhardt** (CERN) for the FCC-ee-MDI team  
with **Manuela Boscolo** (INFN-LNF)  
and **Nicola Bacchetta** (INFN) for detector/experiments

## More on MDI for FCC-ee, concepts and generic simulations :

Principles and scaling	<a href="#">presentation by Manuela</a>	Oct. '13	at <a href="#">TLEP#6</a>	CERN
Experience with backgrounds	<a href="#">presentation by Helmut</a>	March' 14	at <a href="#">EIC'14</a>	JLAB
MDI for FCC-ee	<a href="#">presentation by Nicola</a>	June '14	at <a href="#">TLEP#7</a>	CERN
Losses in IR and Touschek	<a href="#">presentation by Manuela</a>	Oct.'14	at <a href="#">HF2014</a>	Beijing
Interaction Region Challenges	<a href="#">presentation by Helmut</a>	Oct.'14	at <a href="#">TLEP#8</a>	Paris via Vidyo
Synchr. Rad. in IR	<a href="#">presentation by Helmut</a>	Dec.'14	at <a href="#">FCC-ee-Acc#11</a> ,	CERN
Progress in SR and tools	<a href="#">presentation by Manuela</a>	Feb'15	at <a href="#">TLEP#9</a>	Pisa
Losses in IR region	<a href="#">presentation by Manuela</a>	later today	at <a href="#">FCC 2015</a>	Washington

**Total e+e-( $\gamma$ ) cross-section relevant for beam lifetime, dominated by very forward rad. Bhabha**

**For free e+e and  $s_b = 2\%$  energy acceptance (bucket height)**

$$\sigma = 0.278 \text{ barn} \quad E_b = 120 \text{ GeV}$$

$$\sigma = 0.285 \text{ barn} \quad E_b = 175 \text{ GeV}$$

$$\sigma = \int_{s_b}^1 \frac{d\sigma}{dk} = \frac{16}{3} \alpha r_e^2 \left[ \left( -\log s_b - \frac{5}{8} \right) \left( \log(4\gamma_e^+ \gamma_e^-) - \frac{1}{2} \right) + \frac{\log^2 s_b}{2} - \frac{3}{8} - \frac{\pi^2}{6} \right]$$

**Actual machine : particles confined to bunches**

**no collisions with very small momentum transfer corresponding to distances larger than**

**d = beam height at collisions ( and distance between particles )**

**Fully simulated (to first order with single photon emission, accurate cross section and spectra)**

**in BBBREM on event by event basis with**

**$t_{\max} = (\hbar c / d)^2$ , reject  $t > t_{\max}$  (hard cutoff) or reduce weight  $t^2 / (t - t_{\max})^2$  (soft cutoff)**

**With cutoff, the cross section becomes  $\sim$  independent of beam energy**

**for  $s_b = 2\%$  and d in the range of 0.1 - 1 mm (log. dependence on cutoff)**

**reduced to  $\sigma = 0.15$  barn, or nearly doubling the lifetime !**

References :

**BBBREM, R.Kleiss and H.B. , Comp.Phys. Comm. 1994**

Altarelli, Buccella, Nuovo Cimento 34 (1964) 1337

H.B., R. Kleiss, Beam Lifetimes in LEP, Proc. EPAC 1994

G.L.Kotkin, V.G. Serbo, Beam-size effect, PRSTAB 2004, JINST 2009

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

**Some key points :**

**Minimize synchrotron radiation in the IR region :**

**Bends** as weak as possible and as far as possible from IP

**difficult with large crossing angle and local chromaticity correction**

**difficult to optimize in single design for Z and top energy**

**Quads** have to be strong and close to IP.

**Minimize offset from quad axis**

**Careful with vertical halo/tails**

**Profit from**

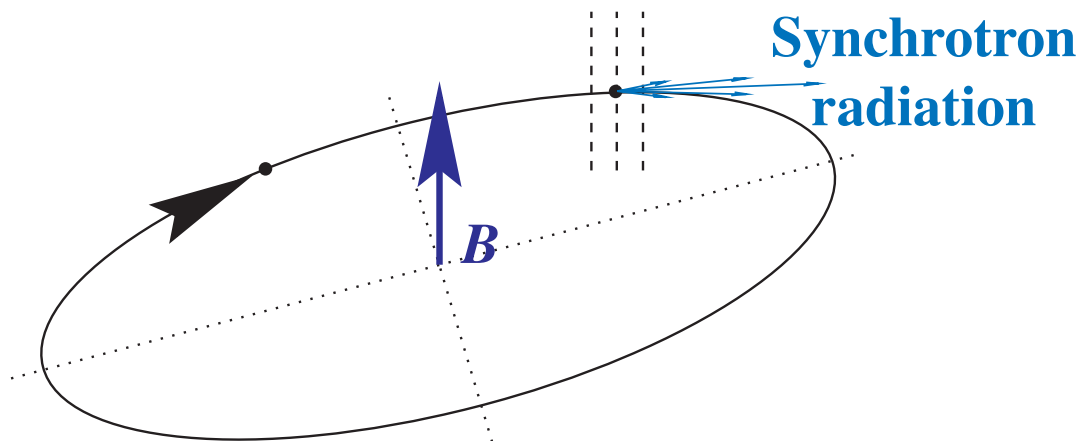
- **LEP and e+e- factory design experience**
- **Progress in technology and computing**

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

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

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

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



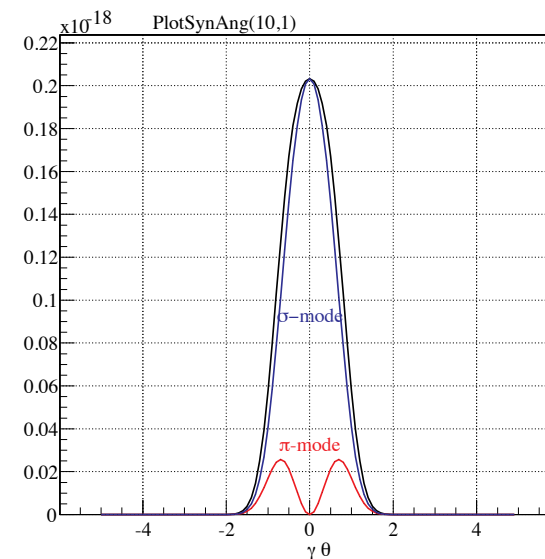
mean free path length  $\lambda$  between radiation

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

LEP2, FCC-ee,  $B \approx O(0.1 \text{ T}) \quad O(1 \text{ m})$

**SynRad cone distribution mostly from bending angle  $O(\text{mrad})$**

+ minor contribution from beam divergence  $O(10 \mu\text{rad})$  and SynRad process

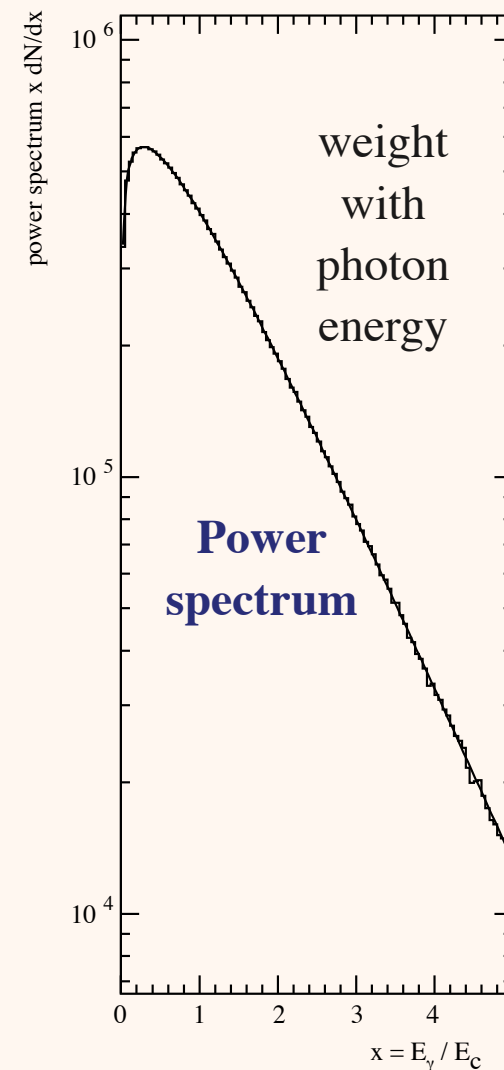
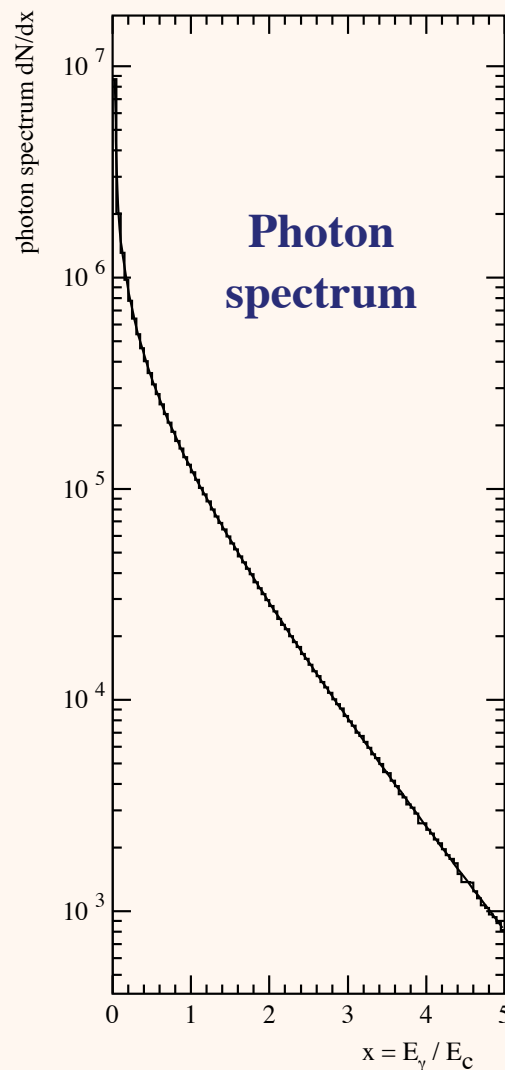
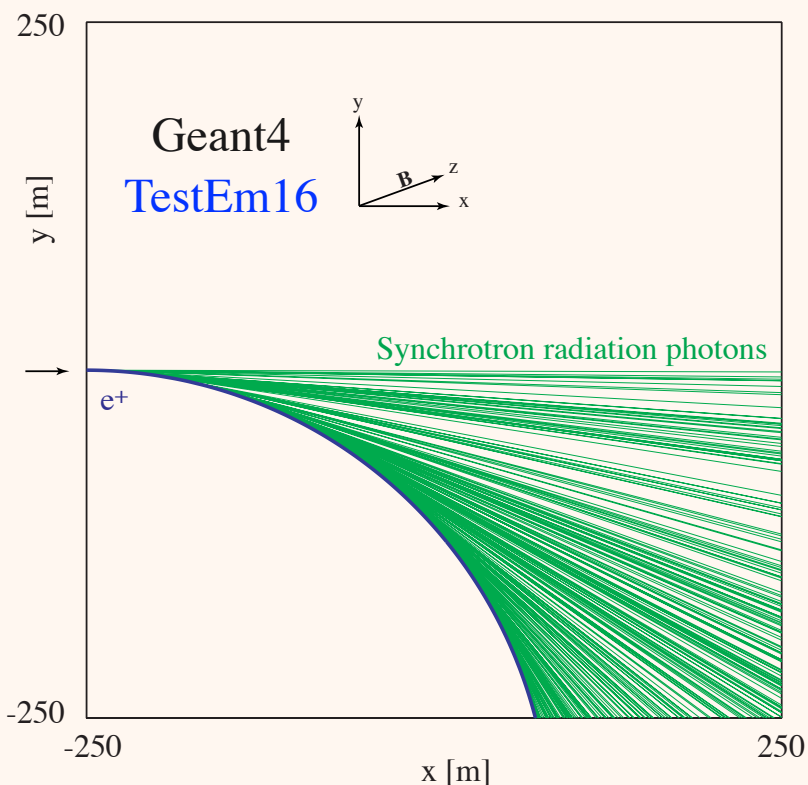


angular distribution (at  $E_c$ )  
 $\sim 1/\gamma = 3 \mu\text{rad} @ 175 \text{ GeV}$

Photon energy in units of the critical energy.  $x = E_\gamma / E_c$

For hom. field over formation length : single spectrum

$$\frac{d^2 N}{ds dx} = \frac{\sqrt{3} \alpha}{2\pi} \frac{eB_\perp}{mc} \int_x^\infty K_{5/3}(\xi) d\xi$$



10 GeV  $e^+$  moving initially in x-direction, bend downwards on a circular path by a 0.1 T magnetic field in z-direction. [Geant4 TestEm16](#)

**Recently generalized to all long live charged particles including ions**

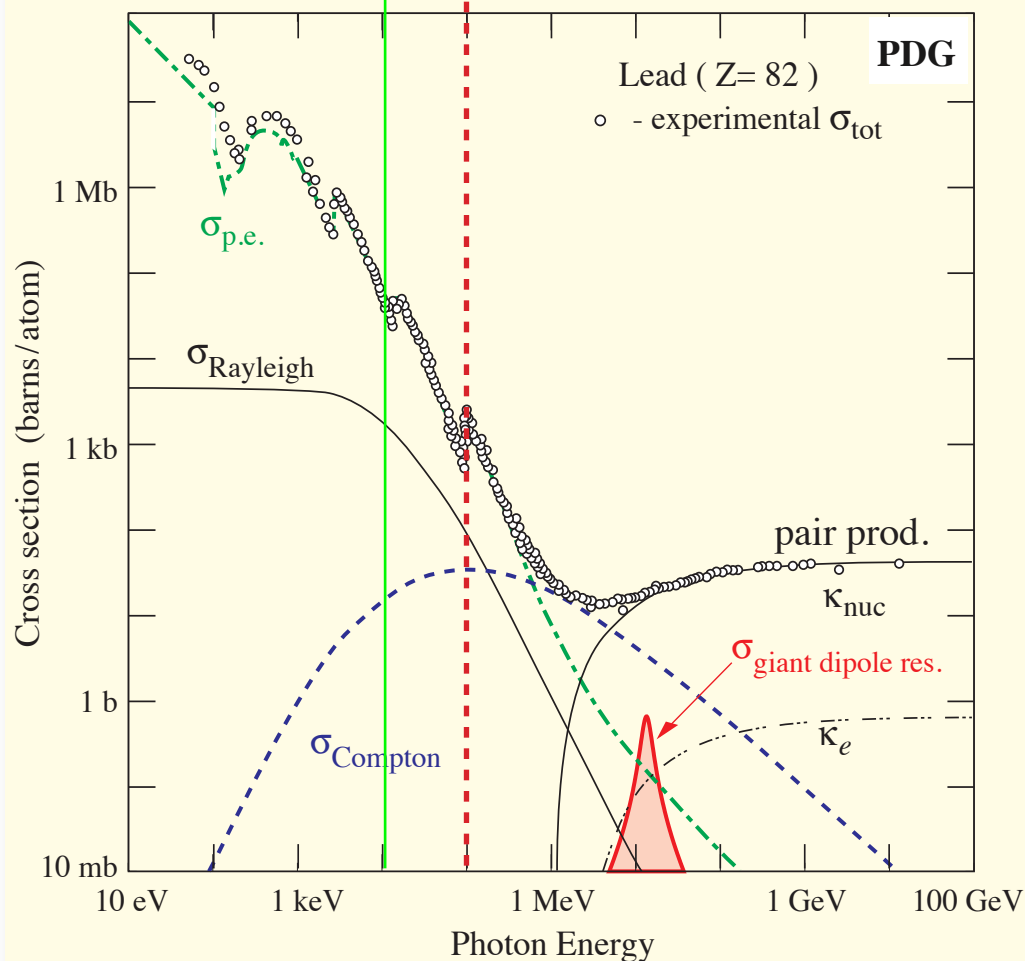
in [Geant4 10.1](#) released 5/12/2014

Ref. : H.B., [CERN-OPEN-2007-018](#), Geant4 [physics-manual](#) Implemented as process G4SynchrotronRadiation

✓ < 10 keV

> 100 keV very difficult

10 MeV significant neutron flux, giant dipole res.



## Critical photon energies

SuperKEKB ~ 2 keV (LER)

FCC-hh ~ 5 keV

LEP1 : 69 keV

LEP2 : 724 keV (arc, last bend 10× lower)

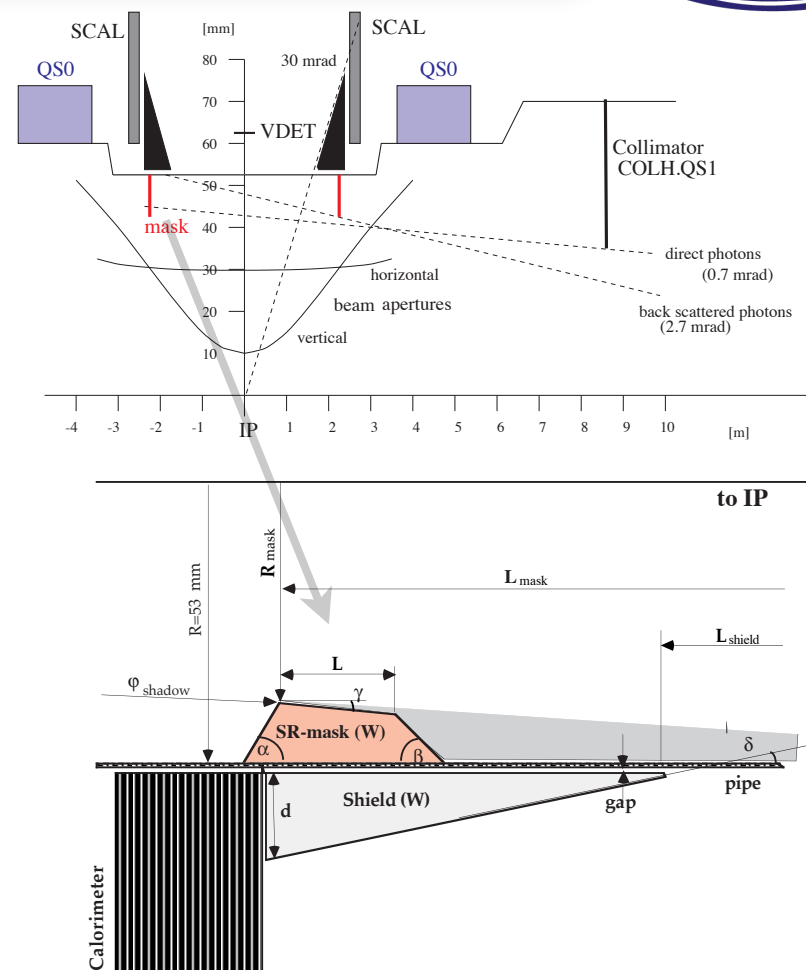
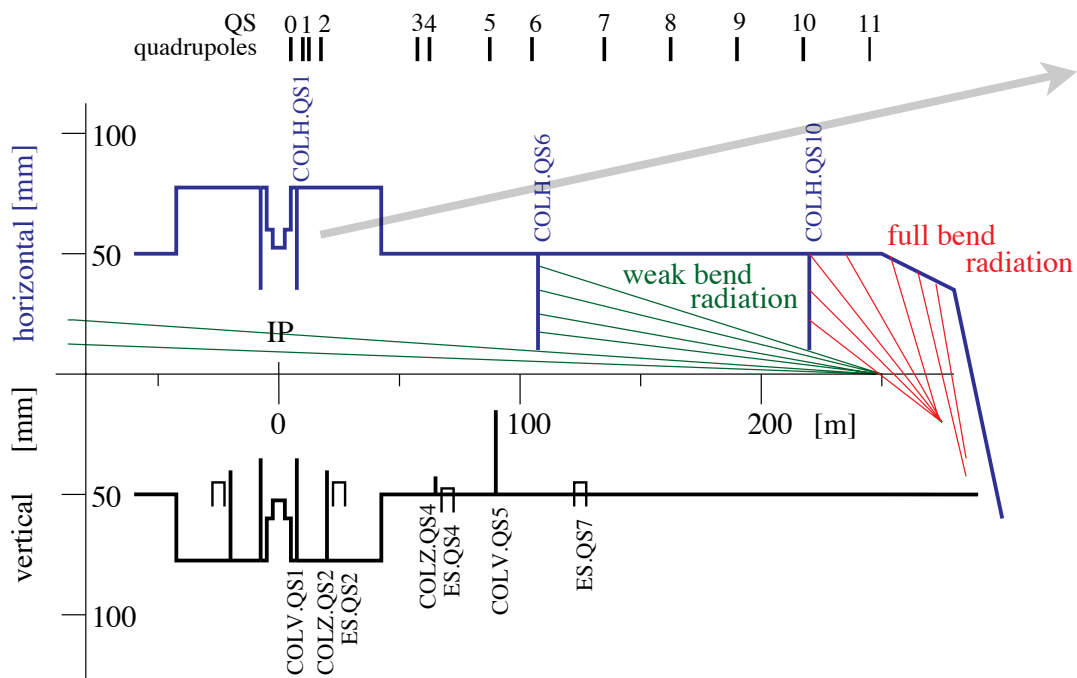
TLEP : ~ 350 keV (arc, 175 GeV)

similar to LEP2

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

Very difficult but not impossible as  
demonstrated in LEP2

as long as no hard synchrotron radiation  
is generated towards experiments in the IR !!



$E_b = 45 \text{ GeV}$  to  $105 \text{ GeV}$  the closest we got to FCC-ee

Machine induced backgrounds, MIB in LEP ~ 100 collimators to reduce MIB

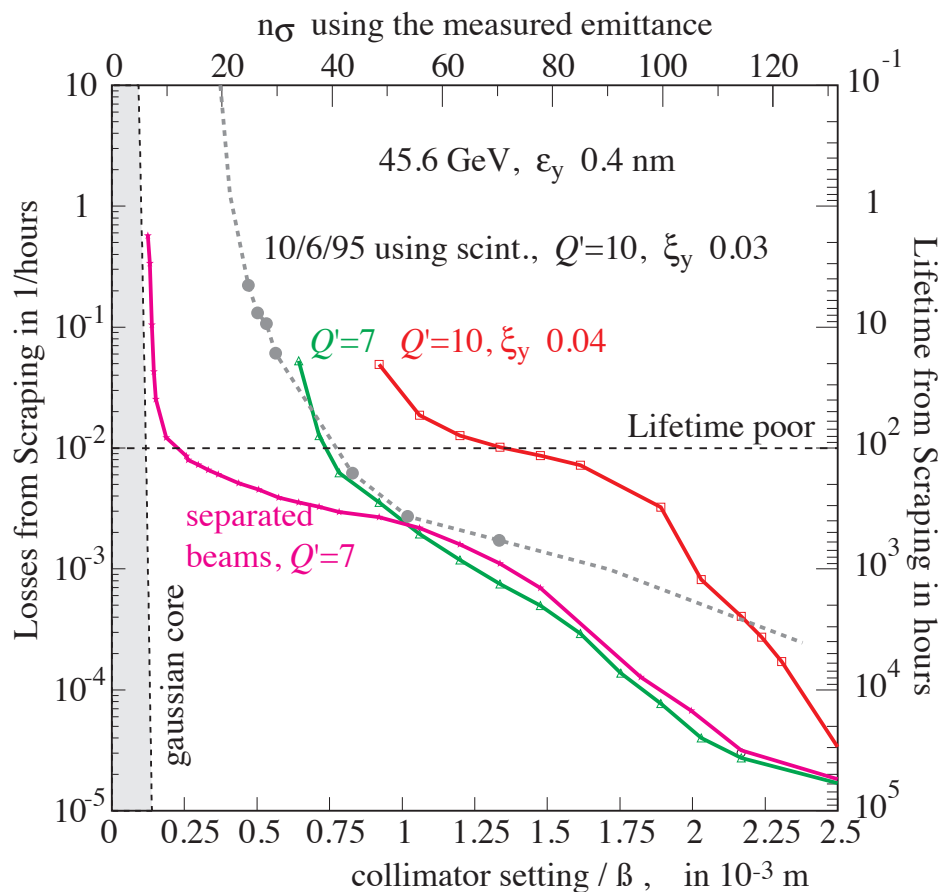
flat, symmetric machine, no crossing angle, few (4-12) bunches

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

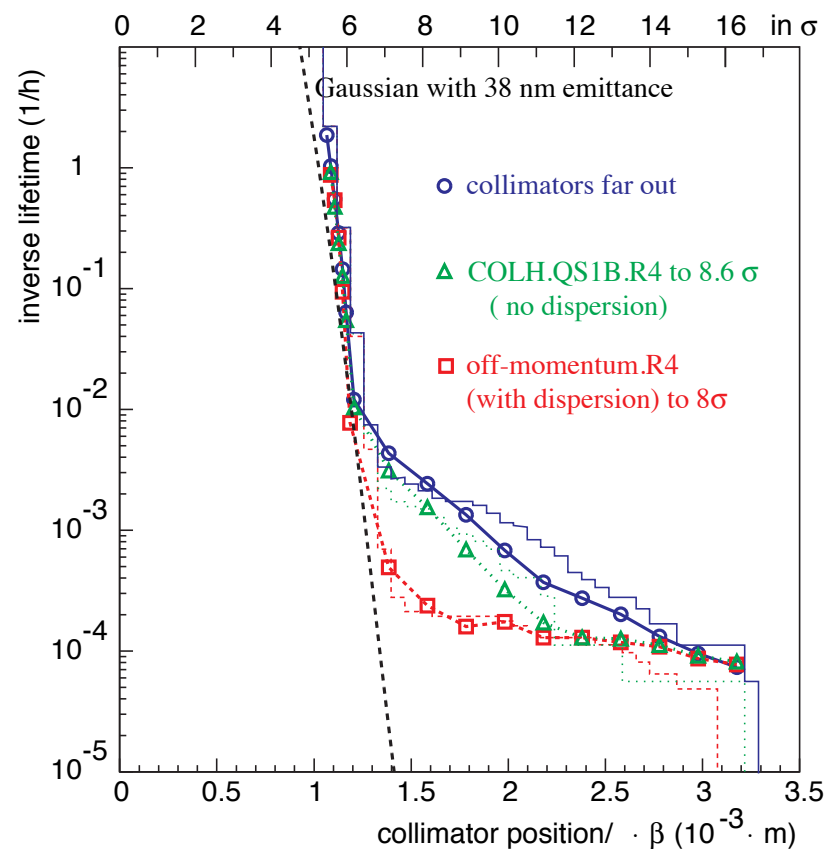
**Off-momentum** beam-gas and thermal photon

measured by scraping with loss monitors

vertical plane, colliding beams



horizontal plane  
reproduced by simulation



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

**Background spikes, enhanced synchrotron radiation from quadrupoles**



**Basis :** MAD-X lattice and survey (geometry) description, if available with apertures

**ROOT** as main geometry and interface tool

**With extra library to read MAD-X tfs files and calculate derived machine parameters (SynRad)**

**Step 1 :** Construct tables (ntuples) with detailed information element by element

**transformation of Courant-Snyder machine coordinates to Euclidian detector coordinates**

optionally scale up transverse dimensions

```

NtupleRoot nt_b1( ReadAndMerge(Optics_tfs,Survey_tfs) ; // Optics and survey tfs tables from MAD-X
Beam b1(Optics_tfs); // get Energy and synchr integrals from optics twiss header
double nsig=1; // quad radiation from sawtooth + beam size. 0 is sawtooth only
EmitRatio=0.001; // as a start
CalcBeamSizeDivergence(nt_b1,b1.ex,b1.ey,verbose); // calculate beam sizes and divergences and add to ntuple
CalcSynrad(nt_b1,b1,verbose,nsig); // calculate synchrotron radiation for bends and quads

```

**Step 2 :** visualize geometry using root, look at S.R. cones

```

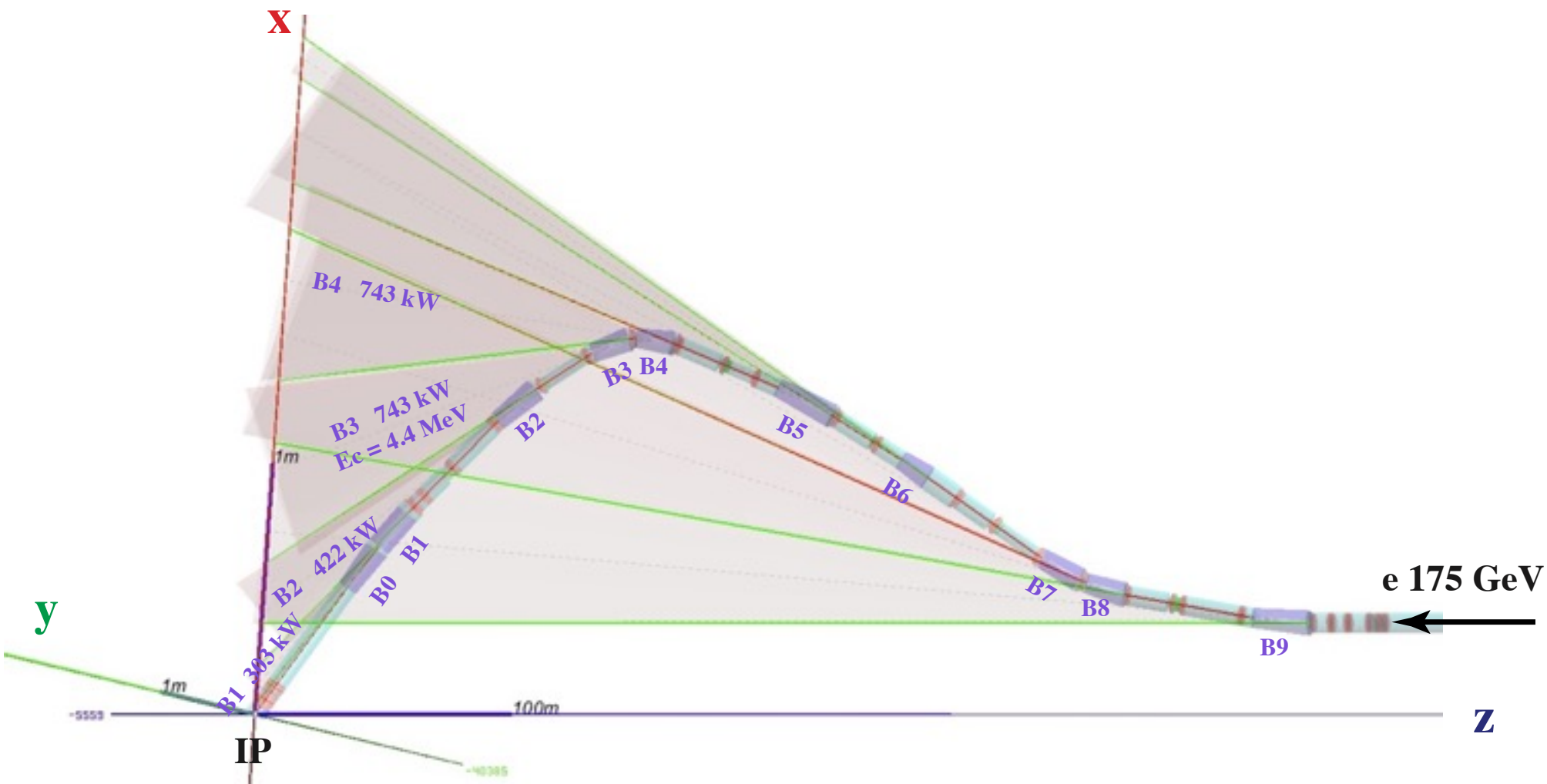
Ntuple2Geom ; // construct geometry in root, export in various formats, root, gdm1..
StartEveWithGeomDisplay(ResolveHome("~/www/Geom/TLEP_V14_IR_6_14_3.root"));
Plot_Bend_SR_Cones(nt_b1,b1,zmin,zmax,Scale_xy,verbose,goto_CM_units,-1);

```

**Step 3 :** tracking and shower Monte Carlo, various options, import geometry to Geant4 (via SGML) or BDSIM..

## SynRad bend cones for TLEP\_V14\_IR\_6-13-2 BINP IR

MDISIM/root/ 3d-OGL display



**Synchrotron radiation into IR major challenge : 2.3 MW / beam of MeV  $\gamma$ 's into detector region**

Optics files from /afs/cern.ch/eng/fcc/ee/TLEP\_V14\_IR\_6-14-3 by Anton Bogomyagkov et al. from 2/5/2015 as presented by Anton 9/2/2015 at CERN, see [indico](#)

iele	NAME	S m	L m	Angle	Ecrit keV	ngamBend	rho m	B T	BETX m	SIGX mm	divx mrad	Power kW	frac>10MeV
13	L.MB0	43.5	10.5	0.001	1132	3.607	10500.0	0.0556	60.2966	0.2771	0.0130	33.61	1.e-05
15	L.MB1	55	10.5	0.003	3397	10.82	3500.0	0.1668	16.9198	0.1468	0.0130	302.5	0.007505
39	L.MB2	104.2	14.5	0.004167	3416	15.03	3480.0	0.1677	22.4885	0.1692	0.0105	422.6	0.007653
59	L.MB3	141.7	15	0.005586	4428	20.15	2685.1	0.2174	6.8157	0.0932	0.0151	734.3	0.01695
65	L.MB4	159.5	15	0.005586	4428	20.15	2685.1	0.2174	63.5433	0.2844	0.0152	734.3	0.01695
91	L.MB5	224	21.5	0.002202	1218	7.943	9763.7	0.0598	20.1852	0.1603	0.0083	79.6	2.e-05
105	L.MB6	262.5	10.5	0.0007305	827.1	2.635	14373.7	0.0406	34.6148	0.2099	0.0061	17.94	4.e-07
129	L.MB7	321.8	14.5	-0.00273	2238	9.847	5311.4	-0.1099	16.4972	0.1449	0.0104	181.4	0.001329
135	L.MB8	339.1	14.5	-0.00273	2238	9.847	5311.4	-0.1099	15.8610	0.1421	0.0105	181.4	0.001329
165	L.MB9	411.4	21.5	-0.001812	1002	6.536	11864.8	-0.0492	37.2633	0.2178	0.0097	53.9	4.e-06
253	MB1.A1C1.DS	640.5	10.5	0.0004884	553	1.762	21497.4	0.0272	36.5415	0.2157	0.0093	8.019	8.e-10
255	MB2.A1C1.DS	651.6	10.5	0.0004884	553	1.762	21497.4	0.0272	17.8663	0.1508	0.0093	8.019	8.e-10

PowSum = 56.6759 MW bends full ring. 2.3 MW within 250 m to IP

Quads, at 1 sigmax, horizontal

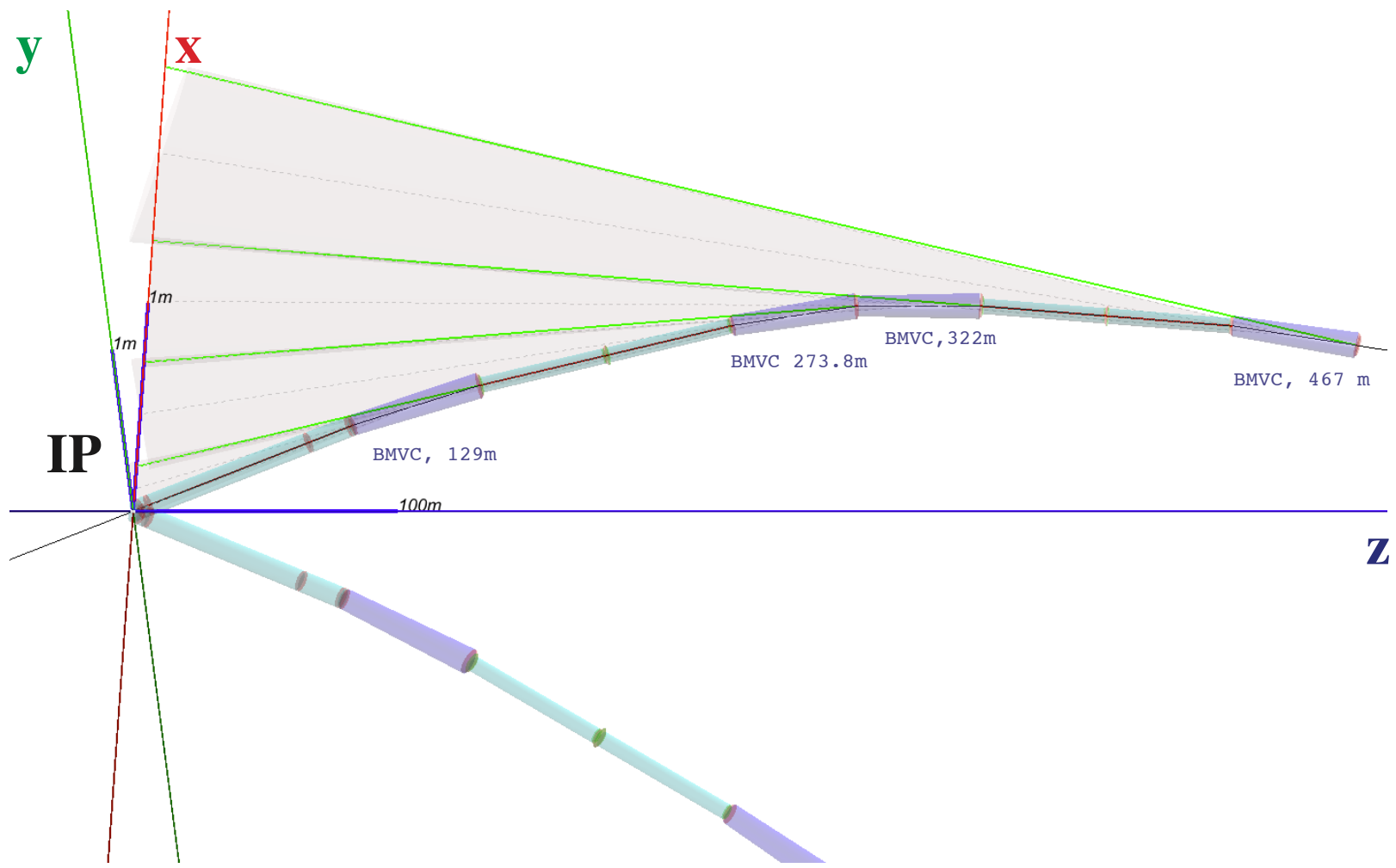
iele	Element	s m	L m	betx m	sigx mm	divx mrad	K1L m-2	k0 m-1	x mm	Angle	Ecrit keV	ngam	Power kW
5	L.MQ0_1	3.8	1.8	39.7	0.2248	0.005664	-0.2848	6.724e-05	0.01133	0.000121	799.4	0.4366	2.873
7	L.MQ0_2	5.6	1.8	172	0.4682	0.00272	-0.2848	0.0001401	0.02379	0.0002522	1666	0.9097	12.47
9	L.MQ1_1	7	1	370	0.6868	0.001854	0.1502	0.0001084	0.03497	0.0001084	1289	0.3911	4.149
11	L.MQ1_2	8	1	416	0.7282	0.001749	0.1502	0.000115	0.03711	0.000115	1367	0.4147	4.665
17	L.MQ2_1	58	1	12	0.1238	0.01028	-0.04789	6.14e-06	0.004413	6.14e-06	73	0.02215	0.01331
19	L.MQ2_2	59	1	12.4	0.1256	0.01014	-0.04789	6.202e-06	0.003951	6.202e-06	73.73	0.02237	0.01357

red color : critical energy over 100 keV, Power > 1kW and within 250 m of IP

## Looking at one beam, 0 - 500 m right of IR

x, y scales  $\times 100$



MDISIM/root/ 3d-OGL display



Based on tlep\_v12a\_cern\_full\_ring.madx from Roman Martin

received by email on

10/12/2014

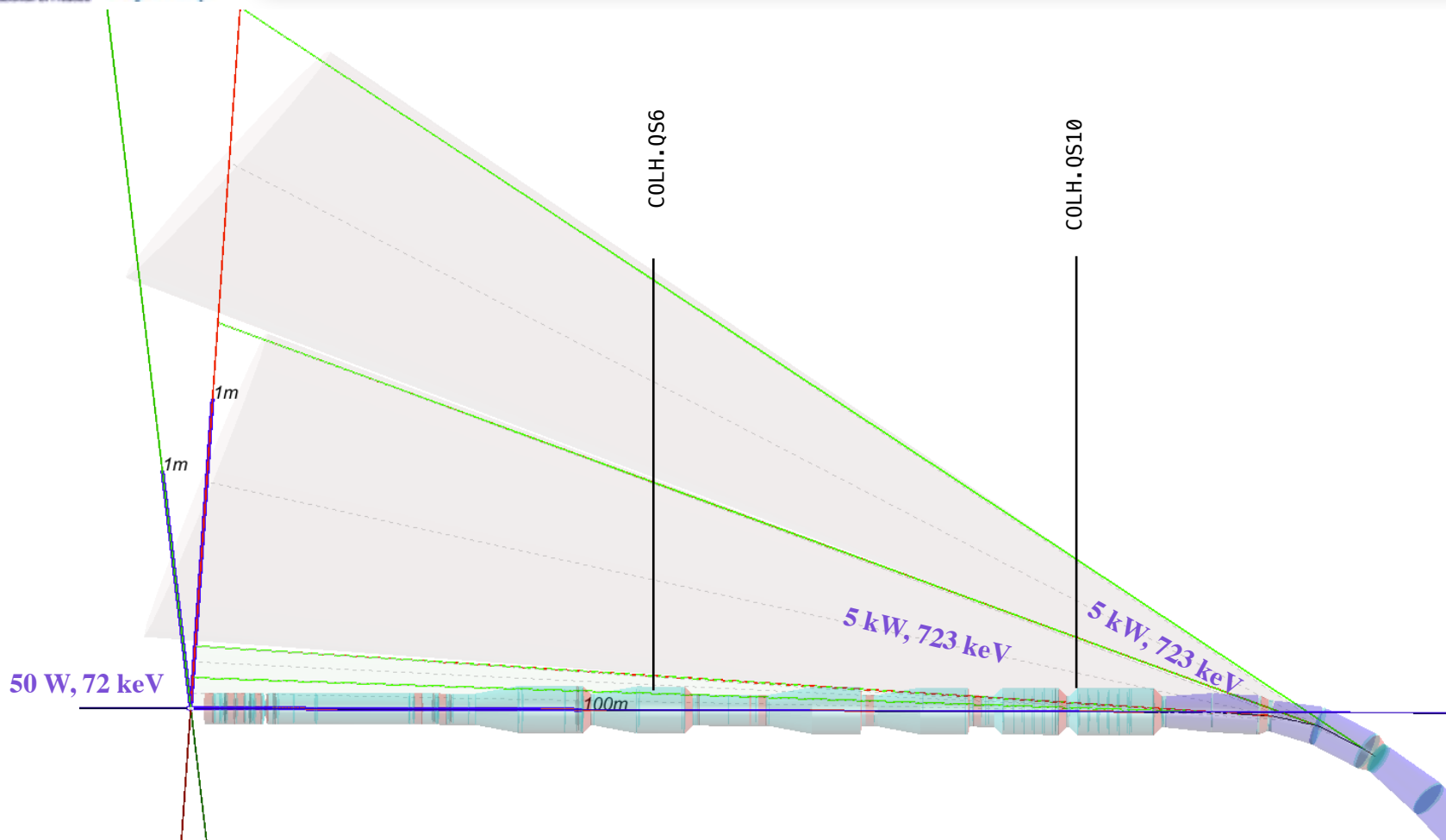
iele	NAME	KEYWORD	S	L	Angle	Ecrit	ngam	Bend	rho	B	BETX	SIGX	divx	Power	frac>10MeV
			m	m		keV			m	T	m	mm	mrاد	kW	
14	BMVC	SBEND	129	47.26	0.002	503.1	7.214	23629.2	0.0247	315.4373	0.5597	0.0056	7.368	1.3e-10	
24	BMVC	SBEND	273.8	47.26	0.002	503.1	7.214	23629.2	0.0247	101.8127	0.3180	0.0056	7.368	1.3e-10	
26	BMVC	SBEND	322.1	47.26	0.002	503.1	7.214	23629.2	0.0247	315.4341	0.5597	0.0056	7.368	1.3e-10	
36	BMVC	SBEND	466.8	47.26	0.002	503.1	7.214	23629.2	0.0247	101.8127	0.3180	0.0056	7.368	1.3e-10	
39	BMHC	SBEND	503	35.19	-0.002	675.6	7.214	17596.9	-0.0332	21.7132	0.1468	0.0070	9.893	2.3e-08	
49	BMHC	SBEND	611.6	35.19	-0.002	675.6	7.214	17596.9	-0.0332	100.0721	0.3153	0.0070	9.893	2.3e-08	
51	BMHC	SBEND	647.8	35.19	-0.002	675.6	7.214	17596.9	-0.0332	21.7132	0.1468	0.0070	9.893	2.3e-08	
61	BMHC	SBEND	756.4	35.19	-0.002	675.6	7.214	17596.9	-0.0332	100.0721	0.3153	0.0070	9.893	2.3e-08	
79	MB1.A3C1.DS	SBEND	808.8	10.5	0.0004958	561.4	1.789	21176.5	0.0276	36.2019	0.1896	0.0082	2.038	1.1e-09	
81	MB2.A3C1.DS	SBEND	819.9	10.5	0.0004958	561.4	1.789	21176.5	0.0276	17.5910	0.1322	0.0082	2.038	1.1e-09	
88	MB3.A3C1.DS	SBEND	833.8	10.5	0.0004958	561.4	1.789	21176.5	0.0276	36.2604	0.1898	0.0082	2.038	1.1e-09	
90	MB4.A3C1.DS	SBEND	844.9	10.5	0.0004958	561.4	1.789	21176.5	0.0276	71.8237	0.2671	0.0082	2.038	1.1e-09	
98	MB5.A3C2.DS	SBEND	858.8	10.5	0.0004958	561.4	1.789	21176.5	0.0276	35.4975	0.1878	0.0083	2.038	1.1e-09	
100	MB6.A3C2.DS	SBEND	869.9	10.5	0.0004958	561.4	1.789	21176.5	0.0276	17.0396	0.1301	0.0083	2.038	1.1e-09	
107	MB7.A3C2.DS	SBEND	883.8	10.5	0.0004958	561.4	1.789	21176.5	0.0276	36.3660	0.1900	0.0084	2.038	1.1e-09	
109	MB8.A3C2.DS	SBEND	894.9	10.5	0.0004958	561.4	1.789	21176.5	0.0276	73.1527	0.2695	0.0084	2.038	1.1e-09	

7.4 kW within 250 m to IP

Quads, at 1 sigmax, horizontal

iele	Element	s	L	betx	sigx	divx	K1L	k0	x	Angle	Ecrit	ngam	Power
		m	m	m	mm	mrاد	m-2	m-1	mm		keV		kW
3	Q4	3.07	1.07	16.7	0.129	0.007701	-0.6072	7.83e-05	3.92e-21	8.41e-05	930.9	0.3034	0.5733
5	Q3	6.31	1.24	127	0.3545	0.002801	0.2751	9.752e-05	1.391e-20	0.0001204	1159	0.4345	1.022
8	Q2	65.4	1	28.7	0.1688	0.005882	-0.03894	6.575e-06	2.412e-20	6.575e-06	78.17	0.02372	0.003763
10	Q1	80.8	1	101	0.3168	0.003135	0.03318	1.051e-05	4.014e-20	1.051e-05	125	0.03792	0.009618
13	QDV	81.8	0.5	102	0.318	0.003123	-0.01475	4.692e-06	4.005e-20	2.346e-06	55.78	0.008462	0.0009581
15	QFV2	130	1	312	0.5568	0.001784	0.02951	1.643e-05	5.302e-18	1.643e-05	195.3	0.05927	0.0235
19	QDV2	178	1	8.04	0.08934	0.01112	-0.02951	2.636e-06	8.399e-18	2.636e-06	31.34	0.009509	0.000605
23	QFV2	227	1	315	0.5597	0.001774	0.02951	1.652e-05	2.284e-17	1.652e-05	196.4	0.05958	0.02375
25	QDV2	275	1	102	0.318	0.003123	-0.02951	9.384e-06	1.046e-17	9.384e-06	111.6	0.03385	0.007664

red color : critical energy over 100 keV, Power > 1kW and within 250 m of IP



iele	NAME	KEYWORD	S	L	Angle	Ecrit	ngam	Bend	rho	B	BETX	SIGX	divx	Power	frac>10MeV
			m	m		keV			m	T	m	mm	mmrad	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	mmrad	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

**Keeping synchrotron radiation at tolerable level in the IR regions of FCC-ee is very challenging**

**Photon energies and power comparable to LEP2**

**where S.R. backgrounds in the IR were acceptable with weak bends, far from IR and using ~100 collimators and local masks, (  $L \sim 1.e32cm^{-2}s^{-1}$  )**

**High luminosity low energy e+e- factory inspired FCC-ee IR designs with large crossing angle and local chromaticity correction tend to generate too high S.R. power and energy**

**High energy e+e-**

**Need for optics and layout which simultaneously optimize luminosity and keep synchrotron radiation at tolerable levels**

# Backup



## ROOT

```
gGeoManager->Export("Geom.gdml"); // export the whole geometry in gdml, or xml, C, root
```

**GEANT4, straightforward to import ROOT geometry - which can be full machine**

```
in DetectorConstruction.cc
G4GDMLParser parser ; parser.Read("FCC-hh.gdml");
fBox=parser.GetWorldVolume();
```

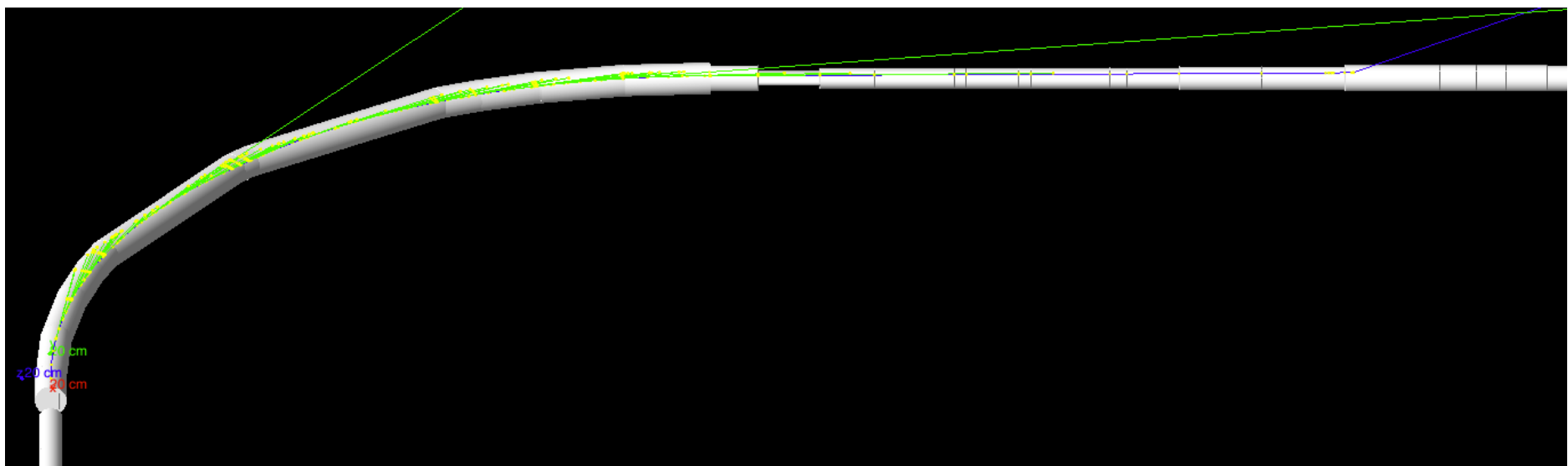
**Loop over imported volumes and set magnetic field and additional parameters if required**

```
G4LogicalVolumeStore* lvs = G4LogicalVolumeStore::GetInstance();
for( auto lvciter = lvs->begin(); lvciter != lvs->end(); ++lvciter ) // loop over imported geometry modules
{
    G4MagField* ThisField = new G4MagField(localfieldValue); // set the local field
    G4FieldManager* fLocalFieldManager = new G4FieldManager(ThisField);
    fLocalFieldManager->SetDetectorField(ThisField);
    if(localfieldValue!=0)
    {
        fLocalFieldManager->CreateChordFinder(ThisField);
        fLocalFieldManager->GetChordFinder()->SetDeltaChord(accuracy); // adjust field tracking accuracy
    }
    else fLocalFieldManager->SetDetectorField(NULL);
    G4bool forceToAllDaughters = true; // use field for daughter modules
    if(VolName=="top") forceToAllDaughters=false; // except for top volume which cover all other volumes
    lvciter->SetFieldManager(fLocalFieldManager, forceToAllDaughters);
}
```

**Essential information -- directly available on MDISim level**

- **root display of synchrotron radiation cones**
- **energy flow tables**

**already set up to be complemented by full shower simulation**



**Geant4 tracking with synchrotron radiation generation and absorption --  
directly from MDISim generated root geometry imported via gdml to Geant4  
Test shown here shown here for a small (LEIR) geometry**