# Synchrotron Radiation in Interaction Region

Helmut Burkhardt (CERN) and Manuela Boscolo (INFN-LNF)
Contact for detector/experiments : Nicola Bacchetta

**Here : aiming for a short presentation, quick look at**

**synchrotron radiation fans in IR region for the latest BINP+CERN designs**

**at top energy, 175 GeV / beam**

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

| | | | |
|---|---|---|---|
| **Principles and scaling** | **presentation by Manuela** | **Oct. '13** | **at TLEP#6 CERN** |
| **Experience with backgrounds** | **my presentation** | **March' 14** | **at EIC'14 JLAB** |
| **MDI for FCC-ee** | **presentation by Nicola** | **June '14** | **at TLEP#7 CERN** |
| **Losses in IR and Touschek** | **presentation by Manuela** | **Oct.'14** | **at HF2014 Beijing** |
| **Interaction Region Challenges** | **my Vidyo presentation** | **Oct.'14** | **at TLEP#8 Paris** |

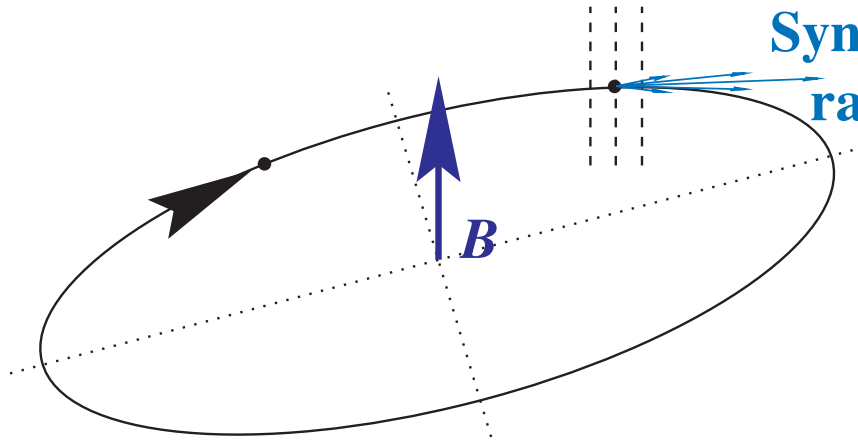
# Synchrotron radiation

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

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

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

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




**Synchrotron radiation**

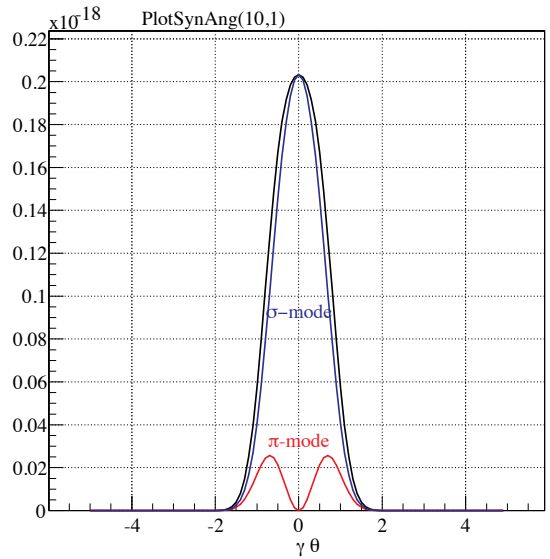
mean free path length λ between radiation

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

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



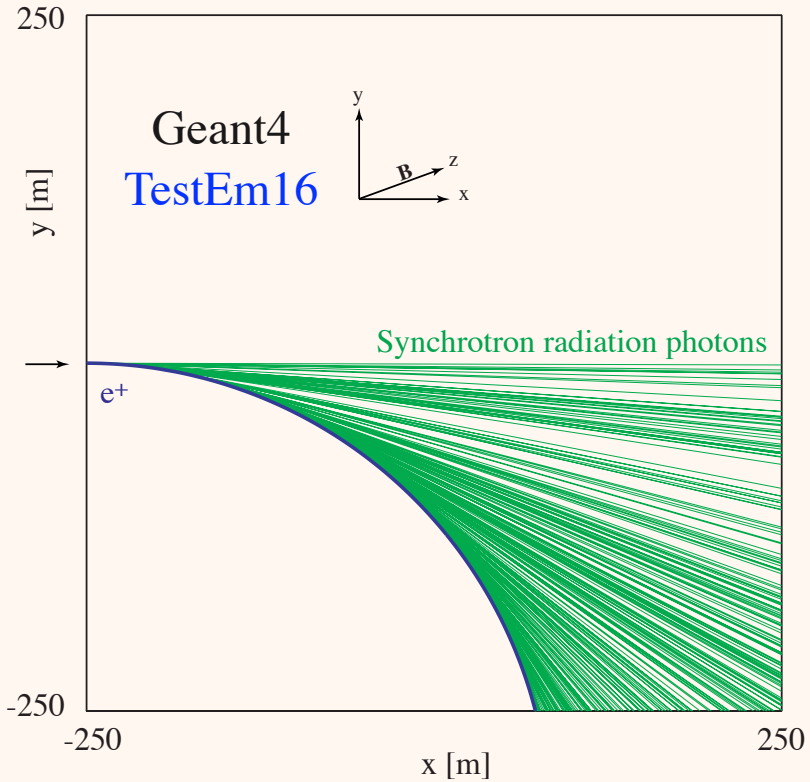

angular distribution (at $E_c$)
~ 1/γ = 3 μrad @ TLEP

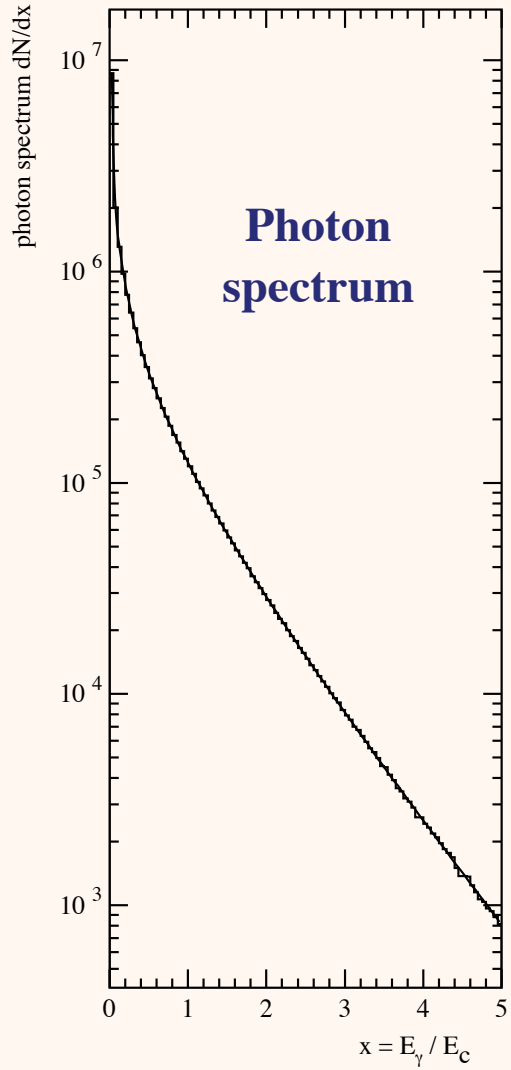
# Spectrum

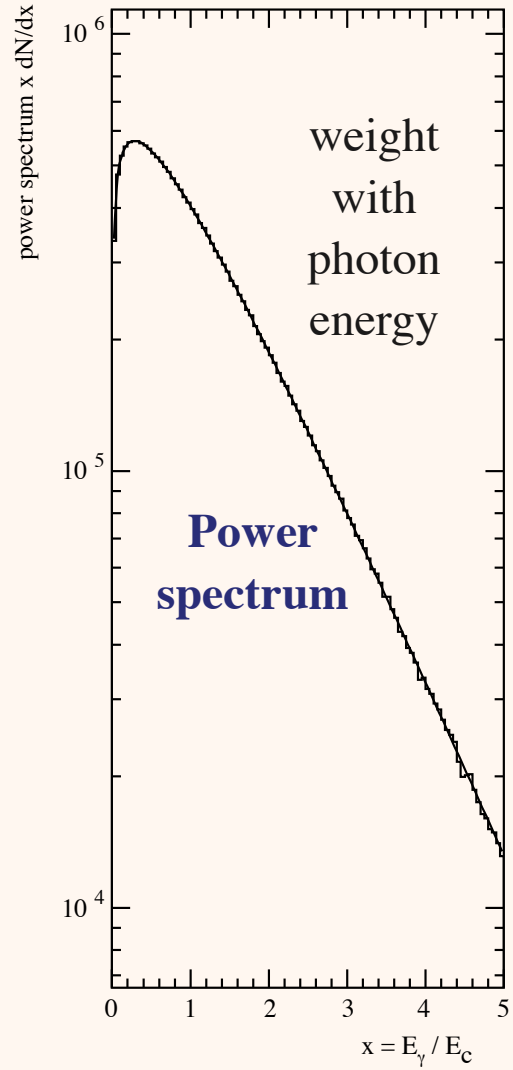
Photon energy in units of the critical energy. $x = E_\gamma / E_c$

For hom. field over formation length : single spectrum

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




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

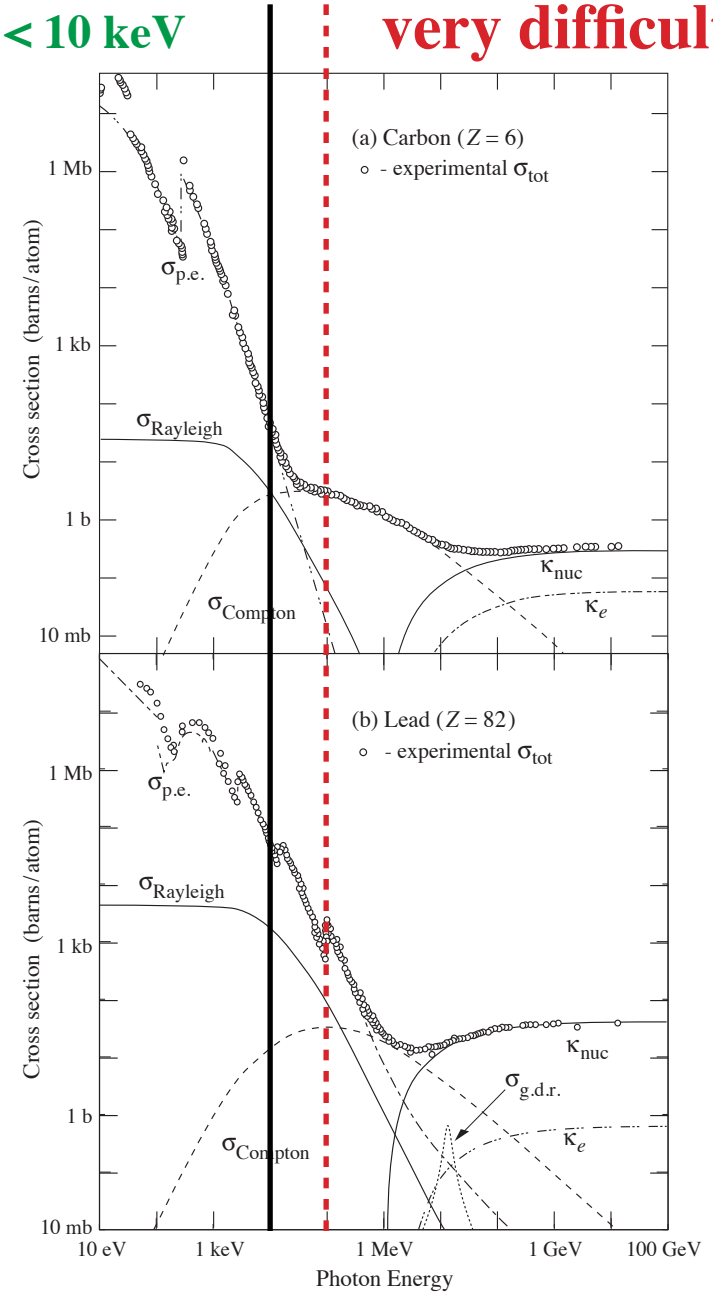
This year : generalized to long live charged particle in Geant4 10.1 released 5/12/2014

Ref. : H.B., CERN-OPEN-2007-018, Geant4 physics-manual Implemented as process G4SynchrotronRadiation

# 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**

# TLEP_V14_IR_6-13-2 BINP

Optics files in /afs/cern.ch/eng/fcc/ee/TLEP_V14_IR_6-13-2/ by Anton Bogomyagkov et al.
as presented by Anton and Dmitry last week, see indico

MDISIM output, bends

| iele | NAME | KEYWORD | S | L | Angle | Emean | ngamBend | rho | B | BETX | SIGX | divx |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | m | m | | keV | | m | T | m | mm | mrad |
| 13 | L.MB0 | SBEND | 22.56 | 10.5 | 0.001 | 348.64 | 3.6071 | 1.05e+04 | 0.055594 | 122 | 0.4646 | 0.02834 |
| 15 | L.MB1 | SBEND | 33.66 | 10.5 | 0.0037 | 1290. | 13.346 | 2.84e+03 | 0.205698 | 14.21 | 0.1586 | 0.02834 |
| 39 | L.MB2 | SBEND | 73.68 | 10.5 | 0.0037674 | 1313.5 | 13.59 | 2.79e+03 | 0.209446 | 78.22 | 0.372 | 0.01655 |
| 59 | L.MB3 | SBEND | 107.2 | 14.5 | 0.0051804 | 1307.9 | 18.686 | 2.8e+03 | 0.208551 | 2.024 | 0.05984 | 0.03686 |
| 65 | L.MB4 | SBEND | 123.5 | 14.5 | 0.0051804 | 1307.9 | 18.686 | 2.8e+03 | 0.208551 | 185.1 | 0.5723 | 0.03686 |
| 91 | L.MB5 | SBEND | 179.7 | 14.5 | 0.00063536 | 160.41 | 2.2918 | 2.28e+04 | 0.025578 | 6.146 | 0.1043 | 0.01713 |
| 105 | L.MB6 | SBEND | 221.5 | 14.5 | 0.0002393 | 60.415 | 0.86319 | 6.06e+04 | 0.00963366 | 84.76 | 0.3873 | 0.005598 |
| 129 | L.MB7 | SBEND | 274.6 | 14.5 | -0.0031537 | 796.19 | 11.376 | 4.6e+03 | -0.126959 | 8.549 | 0.123 | 0.01494 |
| 135 | L.MB8 | SBEND | 291 | 14.5 | -0.0031537 | 796.19 | 11.376 | 4.6e+03 | -0.126959 | 26.96 | 0.2184 | 0.01494 |
| 161 | L.MB9 | SBEND | 345.5 | 14.5 | -0.0028026 | 707.57 | 10.109 | 5.17e+03 | -0.112827 | 19.14 | 0.184 | 0.01956 |
| 235 | L.MB10 | SBEND | 526.5 | 10.5 | 0.0011018 | 384.13 | 3.9743 | 9.53e+03 | 0.0612522 | 18.23 | 0.1796 | 0.02132 |
| 241 | L.MB11 | SBEND | 543.5 | 10.5 | 0.0011018 | 384.13 | 3.9743 | 9.53e+03 | 0.0612522 | 23.68 | 0.2047 | 0.01544 |
| 247 | L.MB12 | SBEND | 571.8 | 10.5 | 0.0011018 | 384.13 | 3.9743 | 9.53e+03 | 0.0612522 | 7.454 | 0.1148 | 0.01544 |
| 253 | L.MB13 | SBEND | 588.8 | 10.5 | 0.0011018 | 384.13 | 3.9743 | 9.53e+03 | 0.0612522 | 86.85 | 0.392 | 0.02132 |
| 273 | MB1.A1C1.DS | SBEND | 686.4 | 10.5 | 0.00048843 | 170.29 | 1.7618 | 2.15e+04 | 0.0271539 | 35.99 | 0.2523 | 0.01122 |
| 275 | MB2.A1C1.DS | SBEND | 697.5 | 10.5 | 0.00048843 | 170.29 | 1.7618 | 2.15e+04 | 0.0271539 | 16.97 | 0.1733 | 0.01122 |
| 282 | MB3.A1C1.DS | SBEND | 711.4 | 10.5 | 0.00048843 | 170.29 | 1.7618 | 2.15e+04 | 0.0271539 | 36.24 | 0.2532 | 0.01122 |
| 284 | MB4.A1C1.DS | SBEND | 722.5 | 10.5 | 0.00048843 | 170.29 | 1.7618 | 2.15e+04 | 0.0271539 | 73.12 | 0.3597 | 0.01122 |
| 292 | MB5.A1C2.DS | SBEND | 736.4 | 10.5 | 0.00048843 | 170.29 | 1.7618 | 2.15e+04 | 0.0271539 | 35.99 | 0.2523 | 0.01122 |
| 294 | MB6.A1C2.DS | SBEND | 747.5 | 10.5 | 0.00048843 | 170.29 | 1.7618 | 2.15e+04 | 0.0271539 | 16.97 | 0.1733 | 0.01122 |

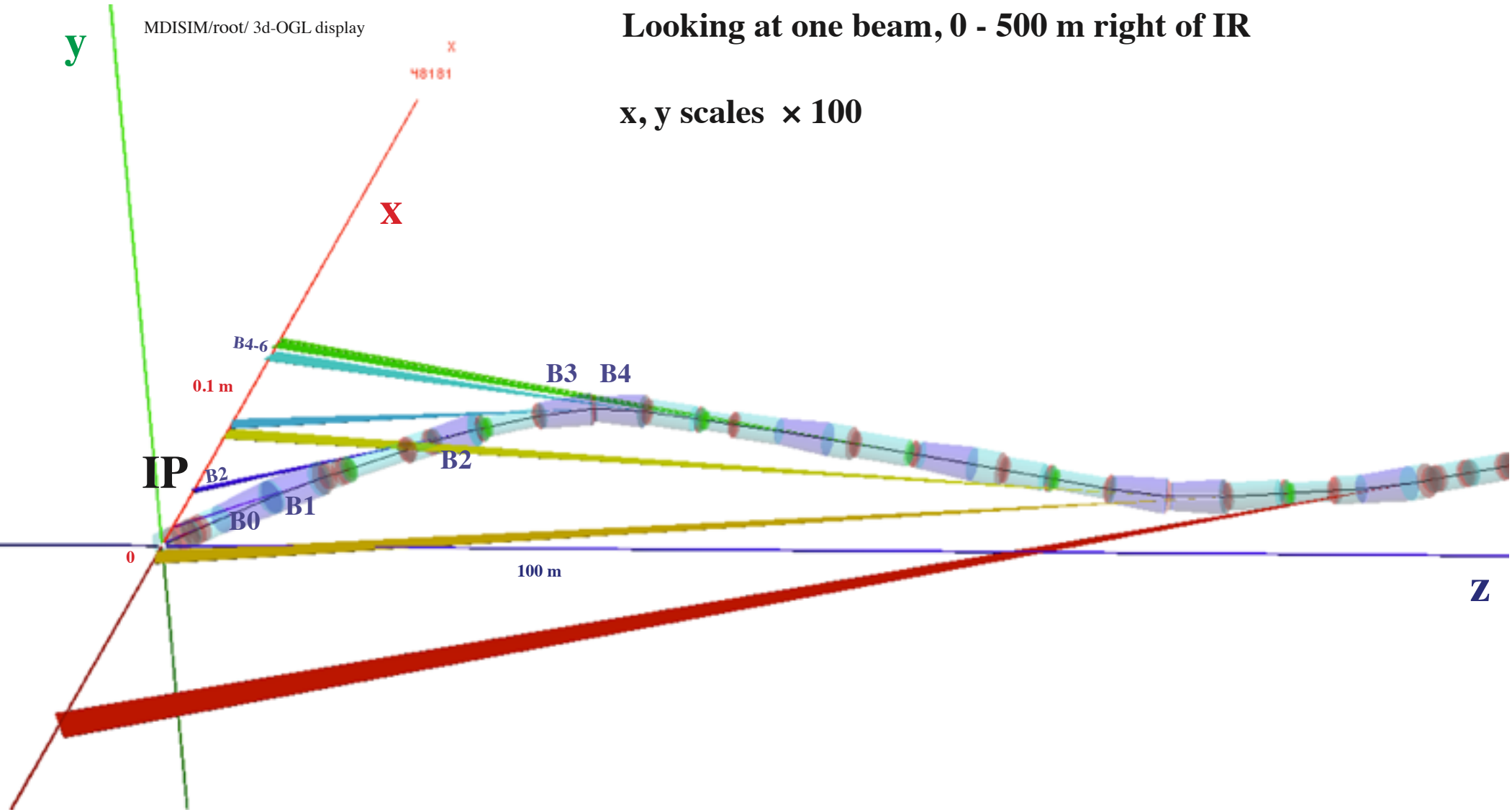
from summing up energy loss the 1660 bends U0sum=2.149 GeV

Quads, at 1 sigmax, horizontal

| iele | Element | s | betx | sigx | divx | K1L | k0 | L | x | Angle | Emean | ngam |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | m | m | mm | mrad | m-2 | m-1 | m | mm | | keV | |
| 5 | L.MQ0_1 | 3.8 | 41.5 | 0.2709 | 0.006531 | -0.29142 | 7.8947e-05 | 1.8 | 8.6833e-32 | 0.000142104 | 289.004 | 0.512589 |
| 7 | L.MQ0_2 | 5.6 | 183 | 0.5684 | 0.003113 | -0.29142 | 0.00016565 | 1.8 | 1.7717e-31 | 0.000298166 | 606.395 | 1.07553 |
| 9 | L.MQ1_1 | 7 | 393 | 0.8338 | 0.002122 | 0.15977 | 0.00013321 | 1 | 2.5822e-31 | 0.000133211 | 487.651 | 0.480509 |
| 11 | L.MQ1_2 | 8 | 433 | 0.8752 | 0.002022 | 0.15977 | 0.00013984 | 1 | 2.7024e-31 | 0.000139835 | 511.902 | 0.504405 |
| 17 | L.MQ2_1 | 35.7 | 7.16 | 0.1126 | 0.01571 | -0.06095 | 6.8626e-06 | 1 | 5.8903e-20 | 6.86259e-06 | 25.1222 | 0.0247543 |
| 19 | L.MQ2_2 | 36.7 | 5.8 | 0.1013 | 0.01747 | -0.06095 | 6.1735e-06 | 1 | 7.0102e-20 | 6.17354e-06 | 22.5998 | 0.0222688 |

**red color : energy over 100 keV, and within 200 m of IP**

# SynRad bend cones, TLEP_V14_IR_6-13-2 BINP




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

**x, y scales × 100**

# TLEP_V12A CERN

Based on tlep_v12a_cern_full_ring.madx from Roman Martin received by email on 10/12/2014

MDISIM output, bends

| iele | NAME | KEYWORD | S | L | Angle | Emean | ngamBend | rho | B | BETX | SIGX | divx |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | m | m | | keV | | m | T | m | mm | mrad |
| 14 | BMVC | SBEND | 129 | 47.26 | 0.002 | 154.92 | 7.2143 | 2.36e+04 | 0.024704 | 315.4 | 0.5597 | 0.005639 |
| 24 | BMVC | SBEND | 273.8 | 47.26 | 0.002 | 154.92 | 7.2143 | 2.36e+04 | 0.024704 | 101.8 | 0.318 | 0.00564 |
| 26 | BMVC | SBEND | 322.1 | 47.26 | 0.002 | 154.92 | 7.2143 | 2.36e+04 | 0.024704 | 315.4 | 0.5597 | 0.005639 |
| 36 | BMVC | SBEND | 466.8 | 47.26 | 0.002 | 154.92 | 7.2143 | 2.36e+04 | 0.024704 | 101.8 | 0.318 | 0.00564 |
| 39 | BMHC | SBEND | 503 | 35.19 | -0.002 | 208.03 | 7.2143 | 1.76e+04 | -0.0331727 | 21.71 | 0.1468 | 0.006974 |
| 49 | BMHC | SBEND | 611.6 | 35.19 | -0.002 | 208.03 | 7.2143 | 1.76e+04 | -0.0331727 | 100.1 | 0.3153 | 0.006973 |
| 51 | BMHC | SBEND | 647.8 | 35.19 | -0.002 | 208.03 | 7.2143 | 1.76e+04 | -0.0331727 | 21.71 | 0.1468 | 0.006974 |
| 61 | BMHC | SBEND | 756.4 | 35.19 | -0.002 | 208.03 | 7.2143 | 1.76e+04 | -0.0331727 | 100.1 | 0.3153 | 0.006973 |
| 79 | MB1.A3C1.DS | SBEND | 808.8 | 10.5 | 0.00049583 | 172.87 | 1.7885 | 2.12e+04 | 0.0275653 | 36.2 | 0.1896 | 0.008248 |
| 81 | MB2.A3C1.DS | SBEND | 819.9 | 10.5 | 0.00049583 | 172.87 | 1.7885 | 2.12e+04 | 0.0275653 | 17.59 | 0.1322 | 0.008248 |
| 88 | MB3.A3C1.DS | SBEND | 833.8 | 10.5 | 0.00049583 | 172.87 | 1.7885 | 2.12e+04 | 0.0275653 | 36.26 | 0.1898 | 0.008233 |
| 90 | MB4.A3C1.DS | SBEND | 844.9 | 10.5 | 0.00049583 | 172.87 | 1.7885 | 2.12e+04 | 0.0275653 | 71.82 | 0.2671 | 0.008233 |
| 98 | MB5.A3C2.DS | SBEND | 858.8 | 10.5 | 0.00049583 | 172.87 | 1.7885 | 2.12e+04 | 0.0275653 | 35.5 | 0.1878 | 0.008334 |
| 100 | MB6.A3C2.DS | SBEND | 869.9 | 10.5 | 0.00049583 | 172.87 | 1.7885 | 2.12e+04 | 0.0275653 | 17.04 | 0.1301 | 0.008334 |
| 107 | MB7.A3C2.DS | SBEND | 883.8 | 10.5 | 0.00049583 | 172.87 | 1.7885 | 2.12e+04 | 0.0275653 | 36.37 | 0.19 | 0.008385 |
| 109 | MB8.A3C2.DS | SBEND | 894.9 | 10.5 | 0.00049583 | 172.87 | 1.7885 | 2.12e+04 | 0.0275653 | 73.15 | 0.2695 | 0.008385 |
| 119 | MB9.A3C3 | SBEND | 908.8 | 10.5 | 0.00099166 | 345.74 | 3.5771 | 1.06e+04 | 0.0551306 | 36.11 | 0.1894 | 0.008386 |
| 121 | MB10.A3C3 | SBEND | 919.9 | 10.5 | 0.00099166 | 345.74 | 3.5771 | 1.06e+04 | 0.0551306 | 17.09 | 0.1303 | 0.008386 |
| 130 | MB11.A3C3 | SBEND | 933.8 | 10.5 | 0.00099166 | 345.74 | 3.5771 | 1.06e+04 | 0.0551306 | 36.29 | 0.1898 | 0.00838 |
| 132 | MB12.A3C3 | SBEND | 944.9 | 10.5 | 0.00099166 | 345.74 | 3.5771 | 1.06e+04 | 0.0551306 | 72.99 | 0.2692 | 0.00838 |

Quads, at 1 sigmax, horizontal

| iele | Element | s | betx | sigx | divx | K1L | k0 | L | x | Angle | Emean | ngam |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | m | m | mm | mrad | m-2 | m-1 | m | mm | | keV | |
| 3 | Q4 | 3.07 | 16.7 | 0.129 | 0.007701 | -0.6072 | 7.8304e-05 | 1.0741 | 3.9205e-21 | 8.41039e-05 | 286.651 | 0.303374 |
| 5 | Q3 | 6.31 | 127 | 0.3545 | 0.002801 | 0.27506 | 9.7521e-05 | 1.2351 | 1.3913e-20 | 0.00012045 | 356.999 | 0.434479 |
| 8 | Q2 | 65.4 | 28.7 | 0.1688 | 0.005882 | -0.038944 | 6.5752e-06 | 1 | 2.412e-20 | 6.5752e-06 | 24.0701 | 0.0237176 |
| 10 | Q1 | 80.8 | 101 | 0.3168 | 0.003135 | 0.033179 | 1.0511e-05 | 1 | 4.0143e-20 | 1.05115e-05 | 38.4799 | 0.0379163 |
| 13 | QDV | 81.8 | 102 | 0.318 | 0.003123 | -0.014755 | 4.6918e-06 | 0.5 | 4.0051e-20 | 2.34588e-06 | 17.1753 | 0.00846191 |
| 15 | QFV2 | 130 | 312 | 0.5568 | 0.001784 | 0.02951 | 1.6431e-05 | 1 | 5.3019e-18 | 1.64308e-05 | 60.149 | 0.0592681 |
| 19 | QDV2 | 178 | 8.04 | 0.08934 | 0.01112 | -0.02951 | 2.6363e-06 | 1 | 8.399e-18 | 2.63629e-06 | 9.65078 | 0.00950944 |
| 23 | QFV2 | 227 | 315 | 0.5597 | 0.001774 | 0.02951 | 1.6517e-05 | 1 | 2.2837e-17 | 1.65167e-05 | 60.4635 | 0.059578 |
| 25 | QDV2 | 275 | 102 | 0.318 | 0.003123 | -0.02951 | 9.3835e-06 | 1 | 1.0464e-17 | 9.38351e-06 | 34.3507 | 0.0338476 |

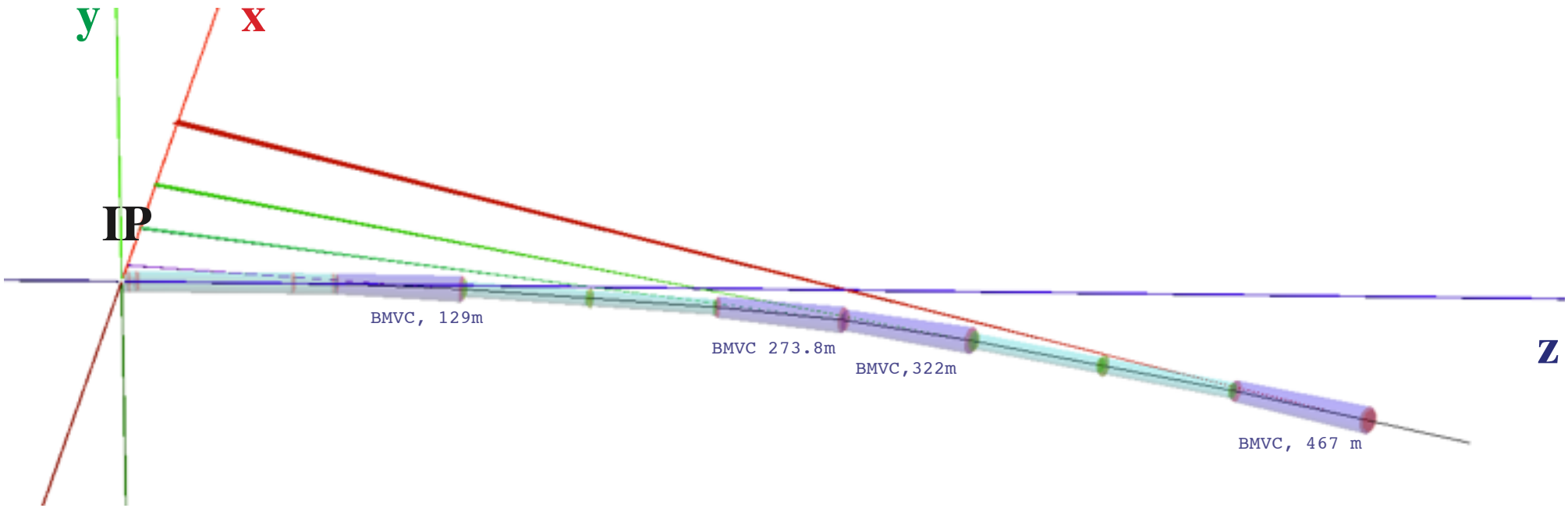
**red color : energy over 100 keV, and within 200 m of IP**

# SynRad bend cones, TLEP_V12A CERN

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

MDISIM/root/ 3d-OGL display

**x, y scales × 100**



# Conclusion

**Synchrotron radiation in the IR region is a major issue for TLEP @ top energy**

**Photon energy very similar to LEP2 where this was acceptable with IRs designed for low synrad + ~100 collimators and local masks, ( L ~ 1.e32cm-2s-1 )**

**Work for FCC-ee / TLEP only started --- much more to do**