MDI Status Report

Hongbo Zhu

7 September 2017

Machine Parameters (before)

D. Wang

	Pre-CDR	*Higgs*	*W*	*Z*
Number of IPs	2	2	2	2
Energy (GeV)	120	120	80	45.5
Circumference (km)	54	100	100	100
SR loss/turn (GeV)	3.1	1.67	0.33	0.034
Half crossing angle (mrad)	0	16.5	16.5	16.5
Piwinski angle	0	3.19	5.26	4.29
N_e/bunch (10^{11})	3.79	0.968	0.365	0.455
Bunch number	50	644 (412)	5534	21300
Beam current (mA)	16.6	29.97 (19.2)	97.1	465.8
SR power /beam (MW)	51.7	**50 (32)**	**32**	**16.1**
Bending radius (km)	6.1	11	11	11
Momentum compaction (10^{-5})	3.4	1.14	1.14	4.49
β_{IP} x/y (m)	0.8/0.0012	0.171/0.002	0.2 /0.002	0.16/0.002
Emittance x/y (nm)	6.12/0.018	1.31/0.004	0.57/0.0017	1.48/0.0078
Transverse σ_{IP} (um)	69.97/0.15	15.0/0.089	10.7/0.059	15.4/0.125
ξ_x/ξ_y/IP	0.118/0.083	0.013/0.083	0.0064/0.062	0.008/0.054
RF Phase (degree)	153.0	128	126.8	165.3
V_{RF} (GV)	6.87	**2.1**	**0.41**	**0.14**
f_{RF} (MHz) (harmonic)	650	650	650 (217800)	650 (217800)
Nature σ_z (mm)	2.14	**2.72**	**3.37**	**3.97**
Total σ_z (mm)	2.65	2.9	3.4	4.0
HOM power/cavity (kw)	3.6 (5cell)	0.64(2cell) (0.41)	0.72(2cell)	1.99(2cell)
Energy spread (%)	0.13	0.098	0.065	0.037
Energy acceptance (%)	2	1.5		
Energy acceptance by RF (%)	6	2.1	1.1	1.1
n_γ	0.23	0.26	0.14	0.12
Life time due to beamstrahlung_cal (minute)	47	52		
F (hour glass)	0.68	0.96	0.98	0.96
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	2.04	3.13 (2.0)	5.12	11.9

Machine Parameters (July)

D. Wang

	Higgs	**W**	**Z-low lum.**	**Z-high lum.**
Number of IPs	2	2	2	2
Energy (GeV)	120	80	45.5	45.5
Circumference (km)	100	100	100	100
SR loss/turn (GeV)	1.61	0.32	0.033	0.033
Half crossing angle (mrad)	16.5	16.5	16.5	16.5
Piwinski angle	2.28	3.6	6.33	6.33
N_e/bunch (10^{10})	9.68	3.6	2.3	2.3
Bunch number	420	5700	3510	27000
Beam current (mA)	19.5	98.6	38.8	298.5
SR power /beam (MW)	**31.4**	**31.3**	1.3	**9.9**
Bending radius (km)	11.4	11.4	11.4	11.4
Momentum compaction (10^{-5})	1.15	1.15	1.15	1.15
β_{IP} x/y (m)	0.36/0.002	0.36/0.002	0.36/0.002	0.36/0.002
Emittance x/y (nm)	1.18/0.0036	0.52/0.0017	0.17/0.0038	0.17/0.0038
Transverse σ_{IP} (um)	20.6/0.085	13.7/0.059	7.81/0.087	7.81/0.087
ξ_x/ξ_y/IP	0.025/0.085	0.014/0.068	0.017/0.053	0.017/0.053
RF Phase (degree)	128	134.7	151	151
V_{RF} (GV)	**2.03**	**0.45**	**0.069**	**0.069**
f_{RF} (MHz) (harmonic)	650	650	650	650 (217800)
Nature σ_z (mm)	**2.75**	**2.98**	**2.92**	**2.92**
Total σ_z (mm)	2.85	3.0	3.0	3.0
HOM power/cavity (kw)	0.42 (2cell)	0.38 (2cell)	0.096 (2cell)	0.74 (2cell)
Energy spread (%)	0.096	0.064	0.036	0.036
Energy acceptance (%)	1.1			
Energy acceptance by RF (%)	1.98	1.46	1.2	1.2
n_γ	0.19	0.11	0.12	0.12
Life time due to beamstrahlung_cal (minute)	63			
F (hour glass)	0.93	0.963	0.987	0.987
L_{max}/IP (10^{34}cm^{-2}s^{-1})	2.0	5.6	1.0	7.7

Latest Machine Parameters

D. Wang

Last Month

	Higgs	*W*	*Z-low lum.*	*Z-high lum.*
Number of IPs	2	2	2	2
Energy (GeV)	120	80	45.5	45.5
Circumference (km)	100	100	100	100
SR loss/turn (GeV)	1.68	0.33	0.035	0.035
Half crossing angle (mrad)	16.5	16.5	16.5	16.5
Piwinski angle	2.25	3.56	6.26	6.26
N_e/bunch (10^{10})	10.7	3.6	2.3	2.3
Bunch number	348	5240	3550	27000
Beam current (mA)	17.9	90.7	39.2	298.5
SR power /beam (MW)	**30.1**	**30.1**	1.4	**10.4**
Bending radius (km)	10.9	10.9	10.9	10.9
Momentum compaction (10^{-5})	1.14	1.14	1.14	1.14
β_{IP} x/y (m)	0.36/0.002	0.36/0.002	0.36/0.002	0.36/0.002
Emittance x/y (nm)	1.21/0.0036	0.54/0.0018	0.17/0.0039	0.17/0.0039
Transverse σ_{IP} (um)	20.9/0.086	13.9/0.060	7.91/0.088	7.91/0.088
ξ_x/ξ_y/IP	0.028/0.093	0.014/0.067	0.017/0.052	0.017/0.052
RF Phase (degree)	128	134.4	151	151
V_{RF} (GV)	**2.14**	**0.465**	**0.072**	**0.072**
f_{RF} (MHz) (harmonic)	650	650	650	650 (217800)
Nature σ_z (mm)	**2.72**	**2.98**	**2.92**	**2.92**
Total σ_z (mm)	2.84	3.0	3.0	3.0
HOM power/cavity (kw)	0.43 (2cell)	0.35 (2cell)	0.098 (2cell)	0.74 (2cell)
Energy spread (%)	0.098	0.066	0.037	0.037
Energy acceptance (%)	1.2			
Energy acceptance by RF (%)	2.06	1.48	1.2	1.2
n_γ	0.21	0.11	0.12	0.12
Life time due to beamstrahlung_cal (minute)	61			
F (hour glass)	0.93	0.96	0.986	0.986
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	2.0	5.07	1.0	7.6

Relevant Changes

- **Higgs parameters** (*larger βx to improve dynamic aperture*)
  - Ne/bunch: 10.7 (9.68)× 10^{10} → higher background (e.g. stronger beamstrahlung effect)
  - Energy acceptance: 1.2% (1.5%) → higher/lower background? (beam loss particles)
  - Bunch number: 348 (412) → lower background

Counterbalanced in background levels? ***To be evaluated***

  - SR power: 30.1 (32) MW (restricted by the radiation tolerance of permanent magnets) → lower power deposition

- Bunch spacing (according to the updated parameters)
  - Higgs (~0.2 μs), W (~60 ns), Z(~100ns/~12ns)

Updated Magnet Designs

Y. Zhu

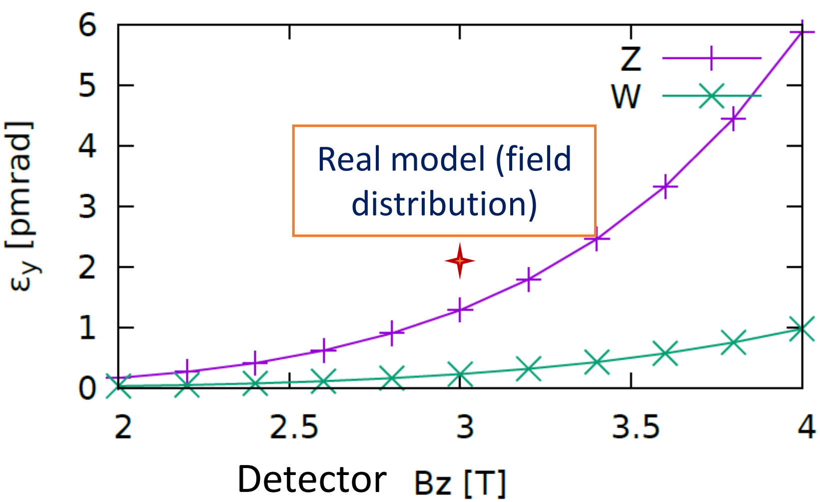
- Parameters of the magnets based on the new L* = 2.2 m and lower detector solenoid of B=3 T (small updates as required for lattice design)

Magnet	Field Strength	Length (m)	Inner Radius (mm)
QD0	151 T/m	1.73	19
QF1	102 T/m	1.4636	26
Compensating solenoid	6.6 T	1.0	90
Screening solenoid	3 T	1.73	100

- Weaker QD0/QF1 field strengths would lead to less harder SR photons in the IR → easier collimation and less backgrounds
- Lower compensating solenoid makes it possible to construct the magnet with the cutting-edge superconducting magnet technology → motivation to increase L* (+ clearance between electron/positron beam pipes)

Why Lower Detector Solenoidal Field

- Requirement to compensate and screen the detector field (close to full cancelation) to avoid disturbance to the beam
  - Challenging to construct the compensating magnet:
    - High detector field & short magnet (limited space) → 13 T in preCDR (almost impossible with technologies to be developed in coming years);
    - lower filed (3T) & longer magnet (space gained from the larger L* ~2.2) → ~7 T (feasible)
- Might blow up the vertical emittance → significant luminosity loss

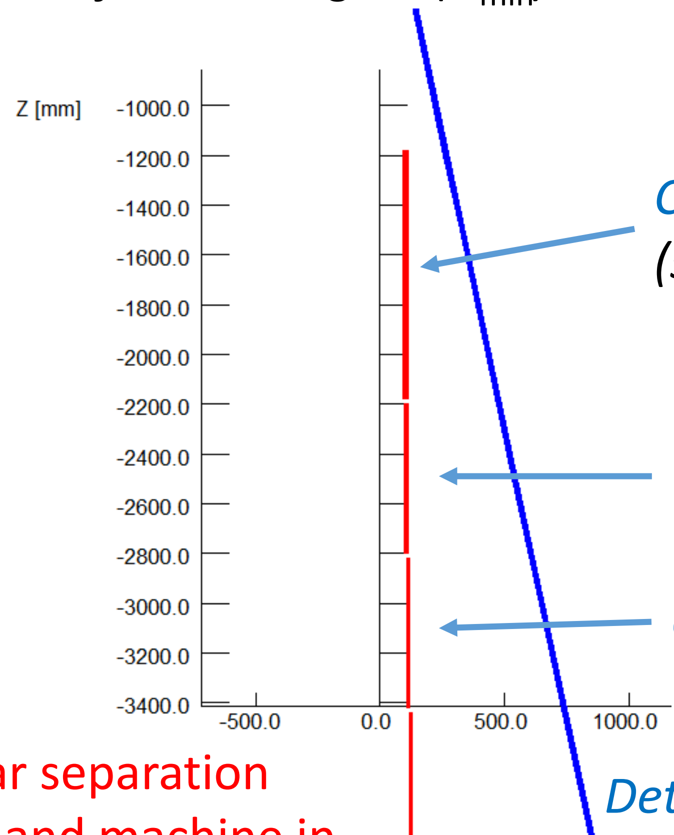


Worst case at Z: increase of 2.2pmrad compared to 3.9pmrad (design parameter) → acceptable

We are less aggressive than FCCee in terms of luminosity at Z → less sensitive to emittance increase, less demanding to lower further the detector solenoid

Magnet Layout

- Magnets along the z-axis, outer radius (including cryogenics and mechanical structure) yet to be estimated → *defining the detector coverage in the forward region (θ_{min})*



Compensating magnet

(space given to LumiCal?)

QD0 + Screening magnet

QF1

We still miss a clear separation between detector and machine in the forward region.

Detector/machine separation requires more careful considerations

(NB. FCC-ee θ = 100 mrad)

Background Estimation

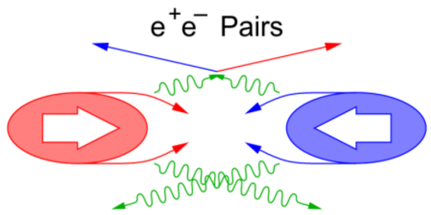
- Beamstrahlung → pair production, hadronic backgrounds
- Synchrotron radiation → power/energy deposition in IR, photon flux forming detector backgrounds (beam halo)
- Beam loss particles → radiative Bhabha scattering (initial + off-orbit particles back to IR), beam-gas interactions

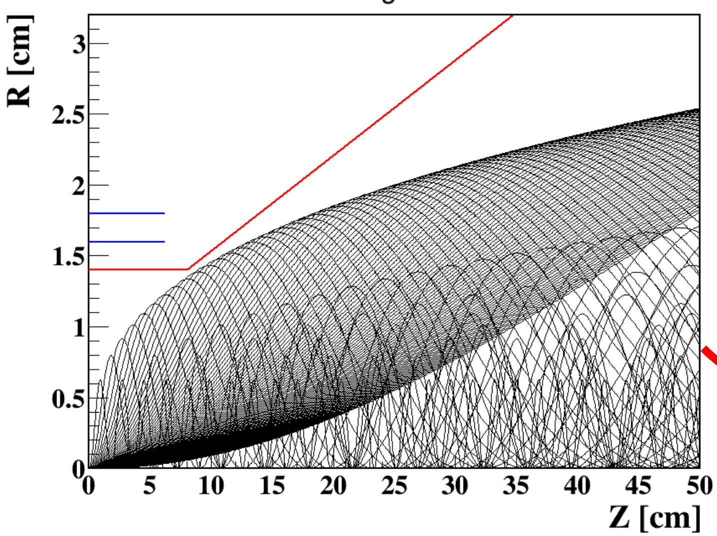
Mostly based on the framework (MDIToolkit) developed by Q. Xiu

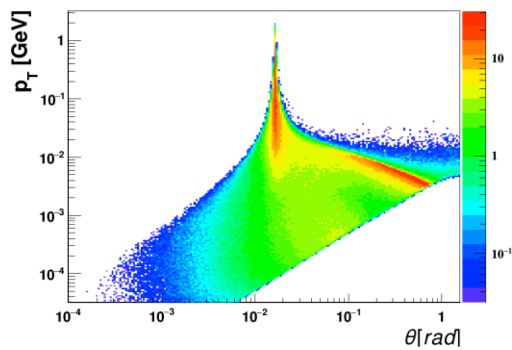
Beamstrahlung

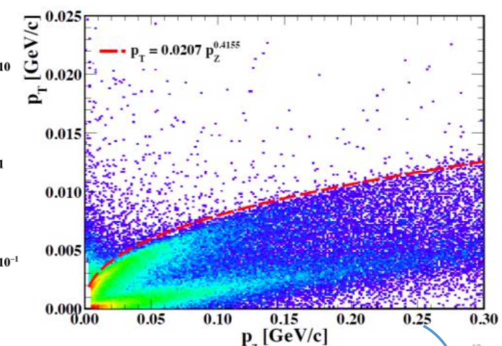
X. Wang & W. Xu

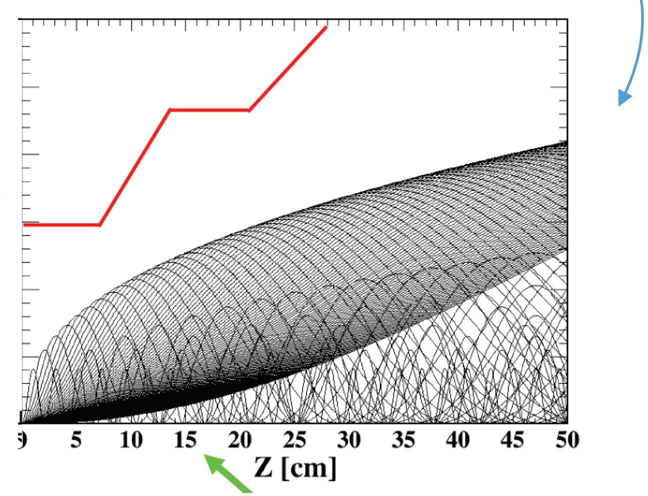
- Helixes formed by the electrons/positrons from the kinematic edge of pair production out of the beamstrahlung
- Knowledge transfer to newcomers, code-debugging/cross-check …





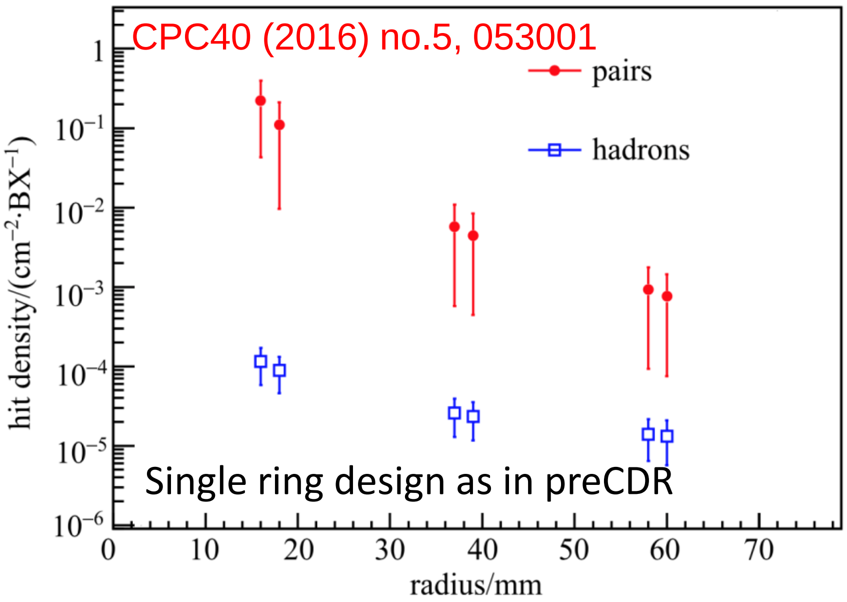


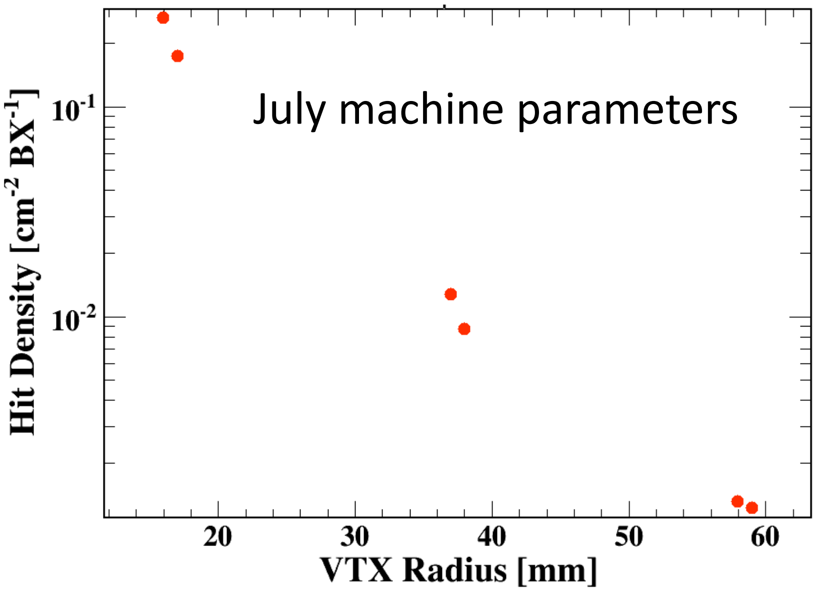




Single ring + 3.5 T → Double ring +3.0 T

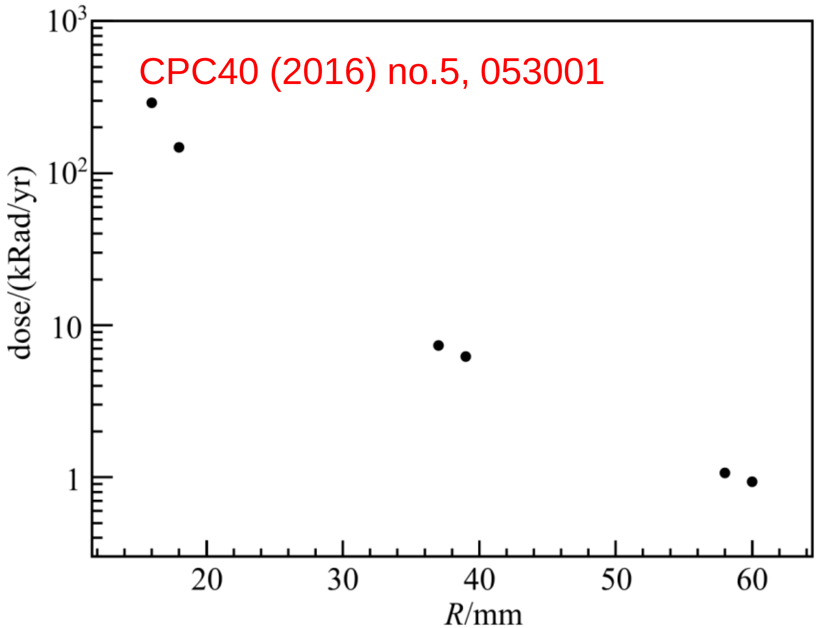
Hit Density

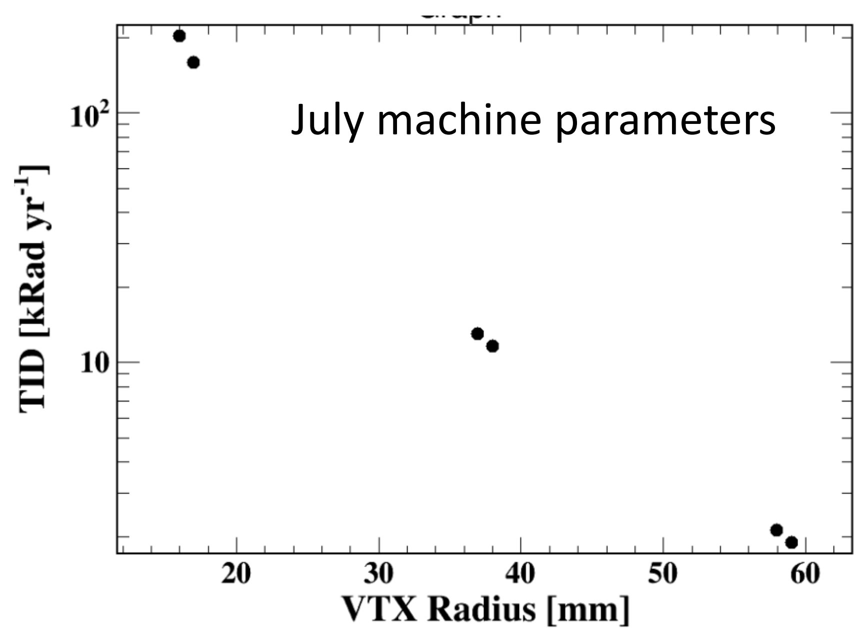




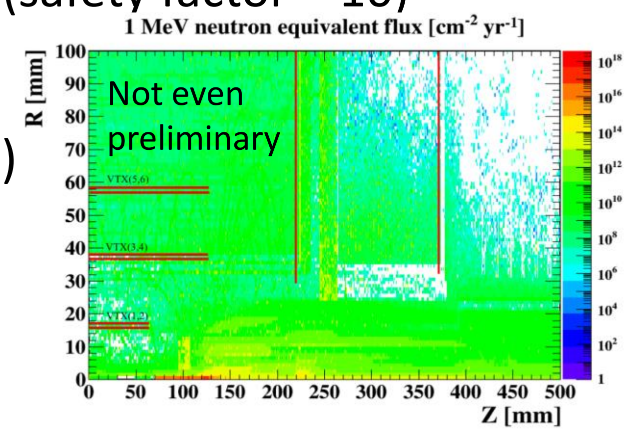
- 0.25 hits/(cm^2·BX) at the 1st vertex detector layer (No safety factor); *updating the results with the latest machine parameters*

TID





- 200 kRad/year at the 1st vertex detector layer (safety factor = 10)



- NIEL calculation requires re-coding (on-going)

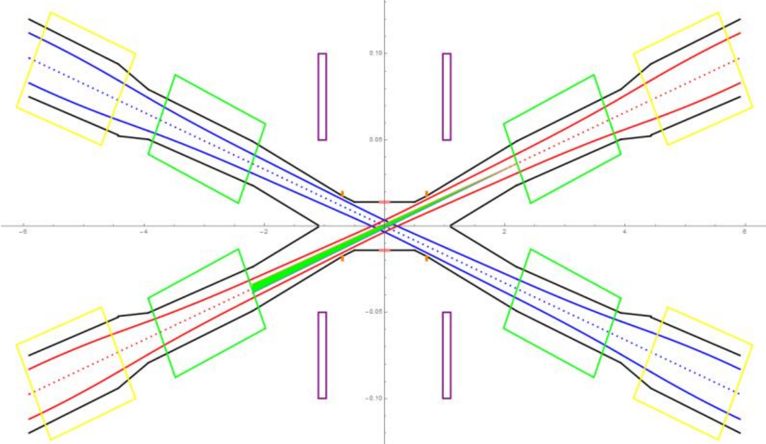
Continue to debug the code and double-check the machine parameters; close to produce the first set of results this week

Synchrotron Radiation

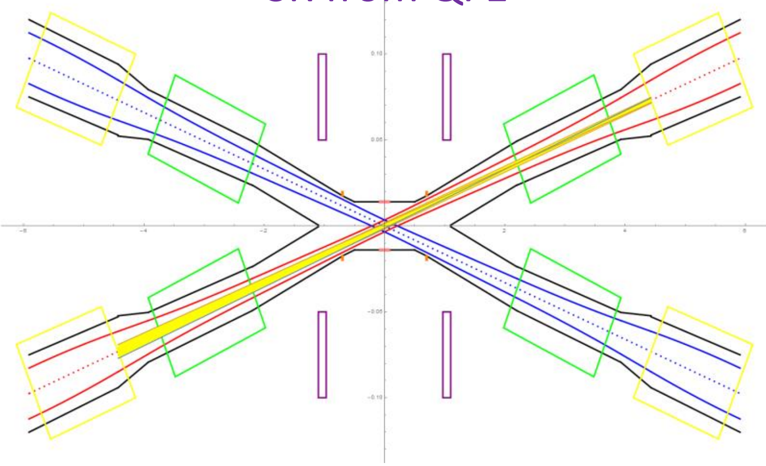
S. Bai

- SR photon flux (**beam core**) estimated based on the latest lattice design

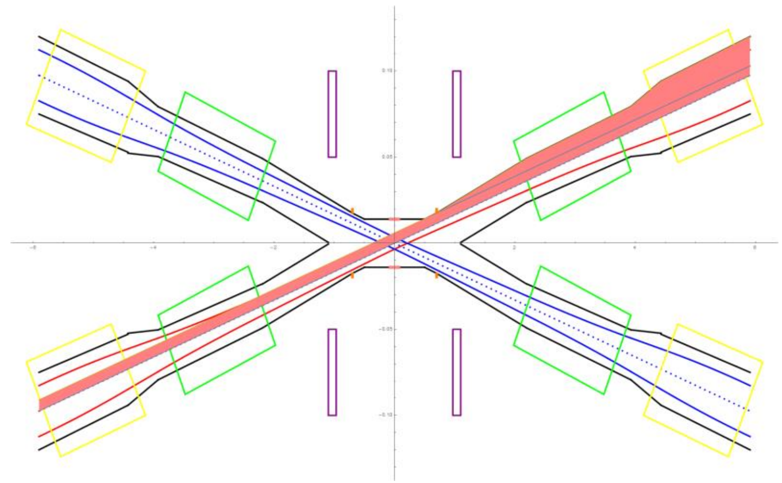
SR from QD0



SR from QF1



SR from B, FD

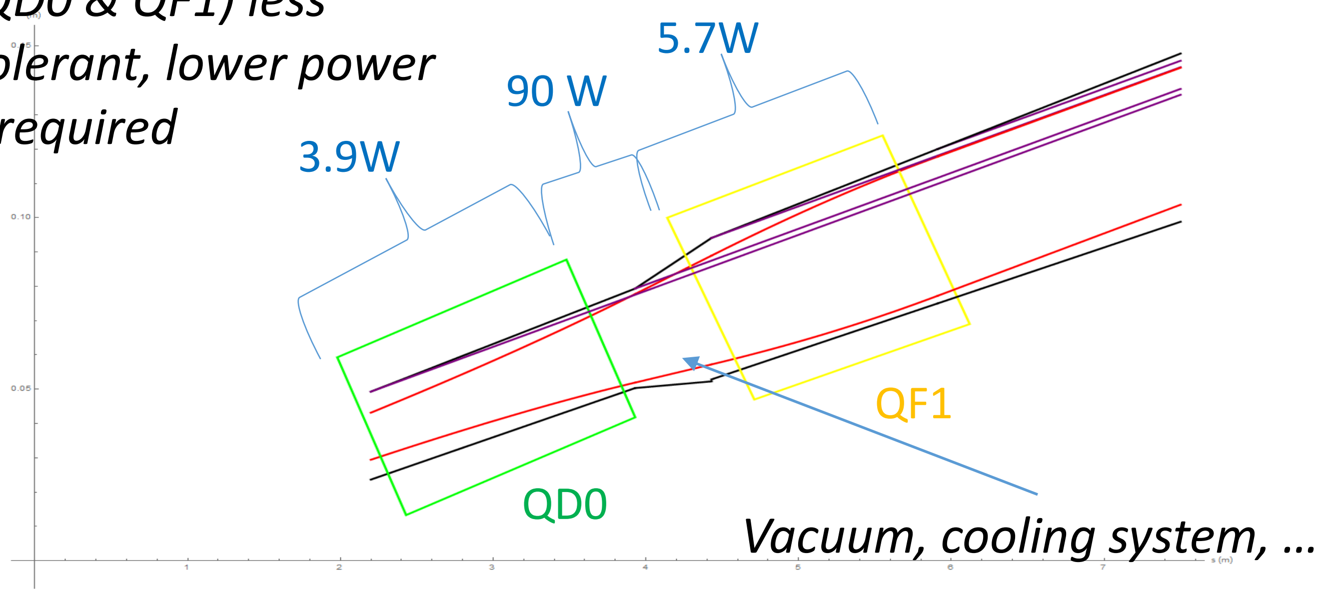


Beam Halo to be considered, but less critical for power deposition calculation

SR Power Deposition

- Power deposition of SR photons along the z-axis

Magnets (QD0 & QF1) less radiation tolerant, lower power deposition required



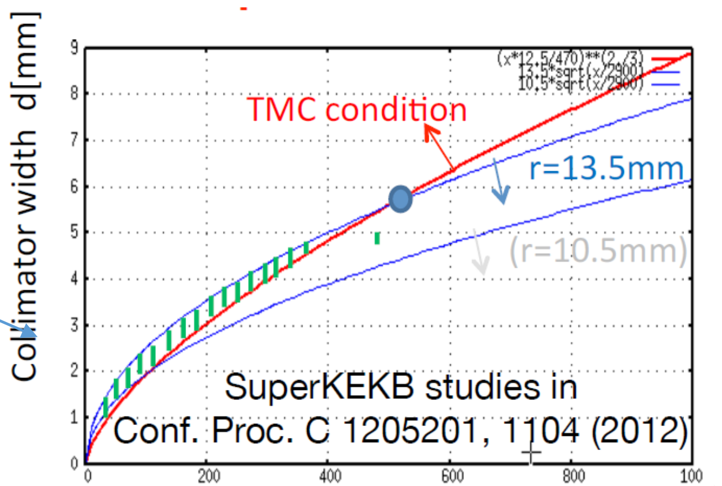
SR induced backgrounds to be estimated with **Bdsim** based on Geant4 (easy handling of geometries and particle interactions with material) → Managed to run through the code; waiting for the latest lattice (+ code debugging) to produce preliminary results → X. Wang (detector) + S. Bai (accelerator)

Detector background: main contribution from Beam Halo

Beam Loss Particles

- **Radiative Bhabha scattering**: particles from the initial interaction (physics process) + off-orbit electrons/positions returning to the IR and bombing machine components, e.g. QD0 → **critical background**
  - BBBREM (small angle radiative Bhabha scattering) → SAD (particle tracking along the ring) → Mokka/Marlin (hit reconstruction)
  - Waiting for the SAD results (relying on the lattice design) from S. Bai
  - Additional challenge: where to place collimators if needed?

Difficult to find the overlapping region with the current machine design



- Beam-gas interaction: less critical but we *have not yet worked it on.*

S. Hou, K. Zhu, S. Lukic et al.

LumiCal

- Combing knowledge and expertise from LEP LumiCal (S. Hou) and LC Fcal (S. Lukic, et al.) designs;
- Bi-weekly meetings called by K. Zhu

See the dedicated talk by Ivanka

CDR Writing

- **Topics to be covered**: interaction region, magnets, radiation backgrounds, luminosity measurement, beam monitor, energy measurement (?), integration (?), beam pipe (?)

- **Editors**: S. Bai (accelerator) + H. Zhu (detector), with inputs of texts & plots from all people involved in MDI studies
  - Similar chapter in the ACC CDR but with consistent designs but focusing slightly different topics -- **to be available earlier** (review in November)

- Preliminary results and texts will hopefully be ready by the end of this month (very difficult) and shall be continuously updated and improved toward CDR.