Updated: 201006

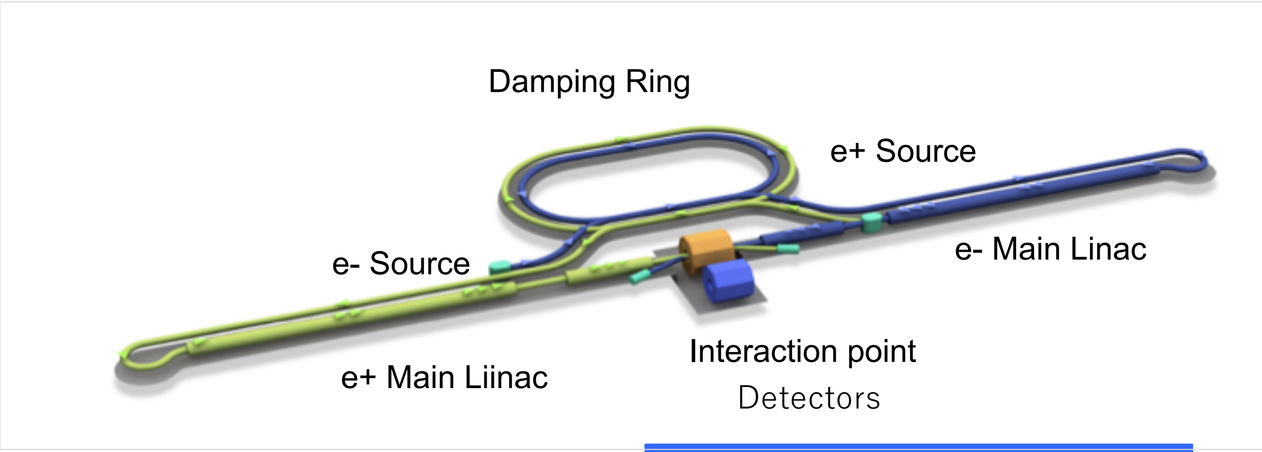
Possible Spanish Contribution to the ILC *focusing on* ML-SCM and Damping Ring

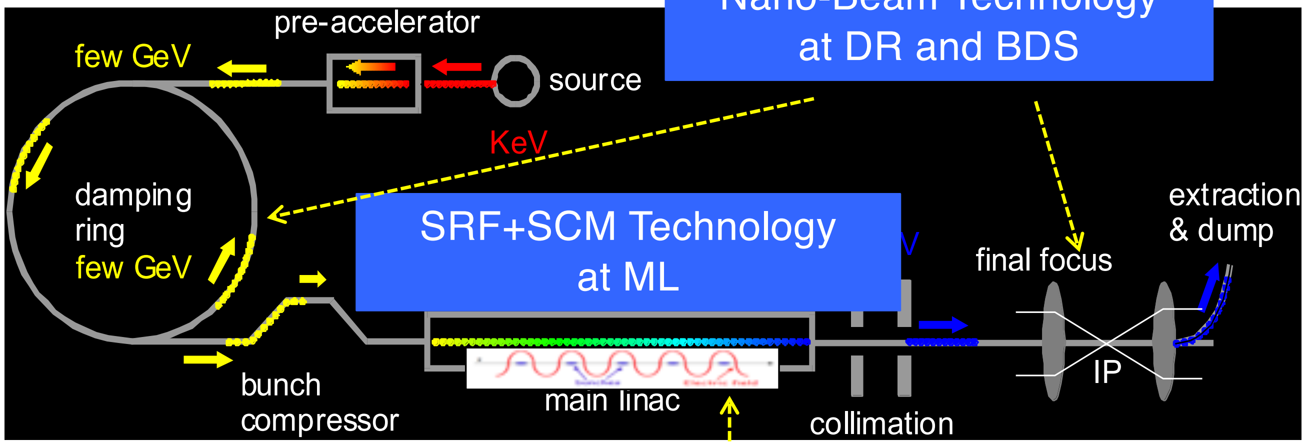
Akira Yamamoto,

Prepared for the ILC-Spain Accelerator Contribution, Online Meeting,

Original: 6 Oct. 2020

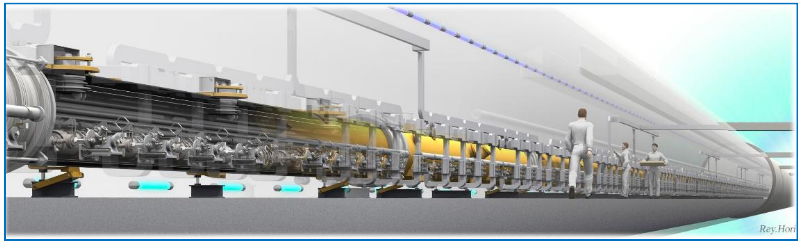
Key Technologies at ILC:





Nano-Beam Technology
at DR and BDS

SRF+SCM Technology
at ML



Parameters	Value
Beam Energy	125 GeV
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Beam size at IR	7.7 nm
ML-SRF, <E> gradient Q_0	31.5 (35) MV/m (+/-20%) $\geq$ 1E10 (1.6E10)
# SRF cavity (9-cell)	~ 8,000 x 1.1
# Cryo-M-a. w/o Q-mag	~ 630
# Cryo-M-b, w **Q-mag**	~ 315
# RF, Klystron	~ 240

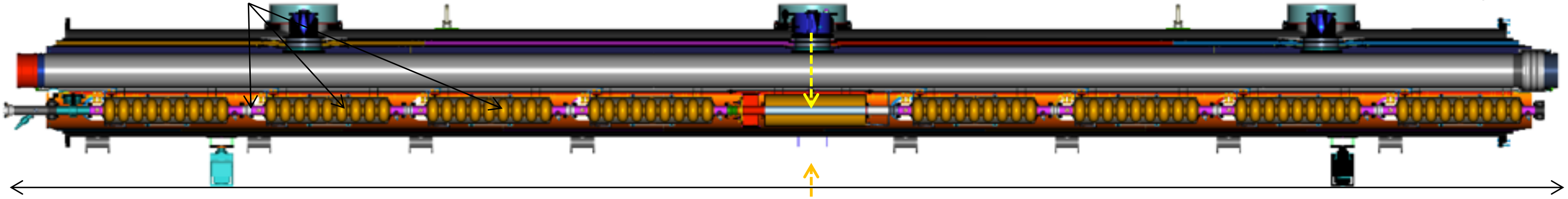
ILC-ML-SCM (SCQ)

SC Quadrupoles and Dipoles for ILC ML

cavities (8)

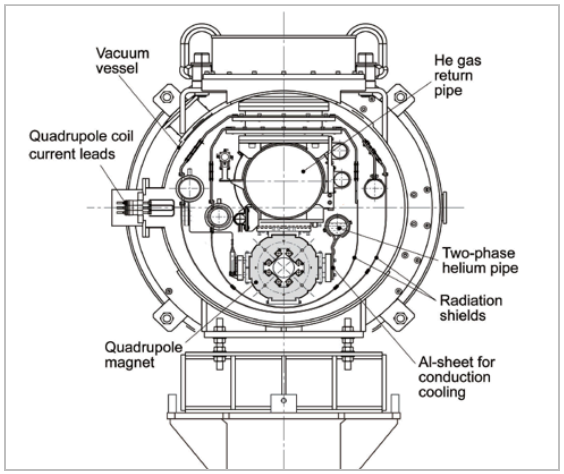
SC quad package (1)

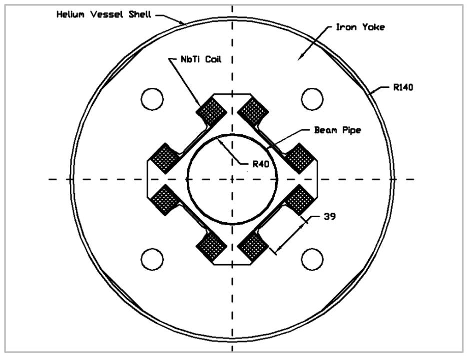
Type-B module
w/ 8 SRF-cavities and 1 SC-Quad. Magnet

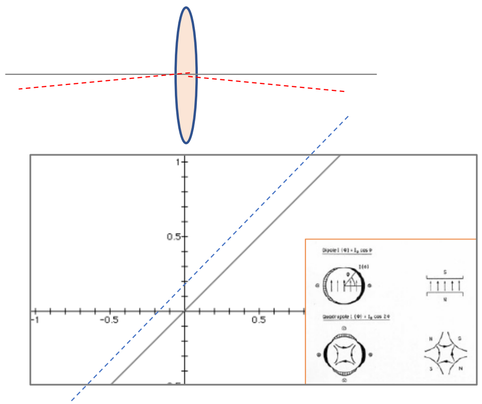


12.652 m

Q: for focusing beam
D: for steering beam and bendingit along the earth surface with $\rho = 6{,}400$ km



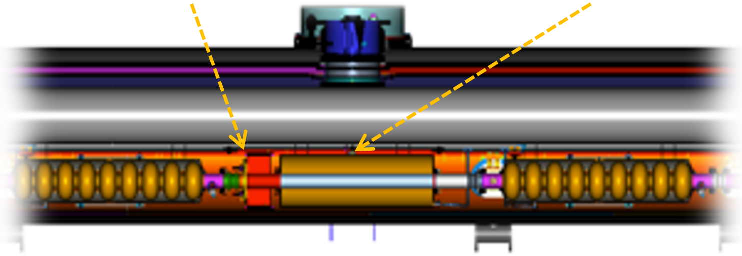


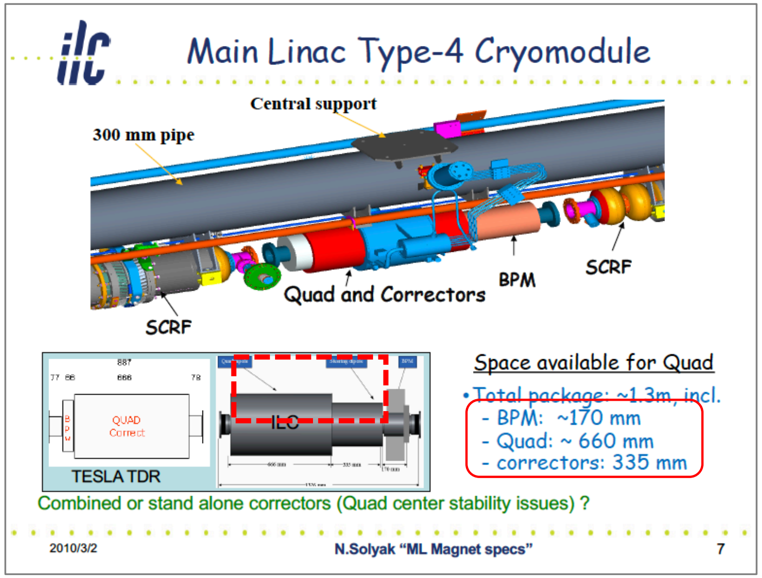


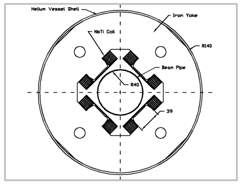
Q and D Combined functioning required for beam focusing and steering

SC Quadruple (SCQ) Design in the ILC TDR
to be updated

Beam Position Monitor (BPM) + SC Quadrupole (SCQ)







Function:

- Beam focusing and the Orbit Steering

Parameter	Value	Unit
Peak gradient	54	T/m
Peak integrated gradient	36	T
Field non-linearity at 5 mm radius	0.05	%
Dipole trim coils integrated strength	0.075	Tm
Aperture	78	mm
Pole-to-pole distance	90	mm
Magnetic stability (20 % field change)	< 5	µm
Peak operating quadrupole current	100	A
Magnet total length	680	mm
SC wire diameter	0.5	mm
NbTi filament size (vendor value)	3.7	µm
Cu:SC volume ratio	1.5	
Superconductor Critical current (5 T and 4.2 K)	200	A
Coil maximum field at 100 A current	3.3	T
Magnetic field stored energy	40	kJ
Quadrupole inductance	3.9	H
Quadrupole coil number of turns/pole	900	
Yoke outer diameter	280	mm

IL-ML SCQ Design Variations

Update: 200717

to be studied

Q-D separated in TDR w/ some updates

Parameters	Separated (Baseline)
Physical Length in total Iron-Pole Radius	0.995 m 0.045 m
Quad(max. at 250 GeV/c): Physical Length Magnetic Length Gradient (G) G-Integral (required) B at pole B-max in Coil	 0.66 m 0.621 m 60 T/m 38 T ~ 2.7 T ~ 3.6 T
Dipoles (max. at 250 GeV/c): Physical Length Magnetic Length B* B-Integral (required)* B-max in Coil	 0.335 m 0.29 m 0.34 T 0.1 T•m ---
B-max at Pole B-max in Coil	2.8 T (tbd)

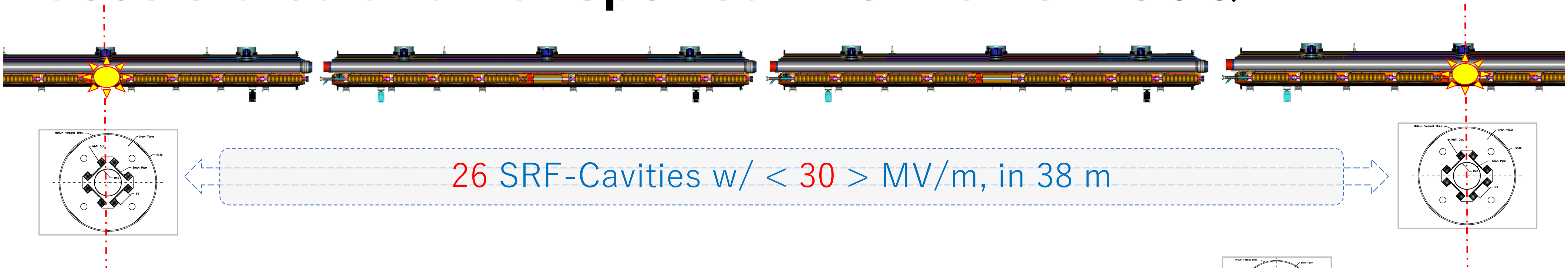
Q-D Combined w/ Two types : in study

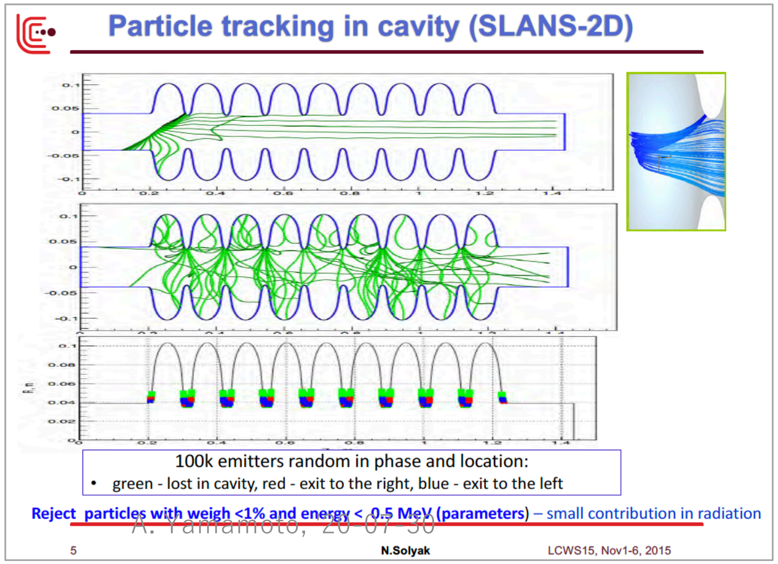
Parameters	Unit	Type - L.E. (5~25 GeV)	Type - H.E. (25~250 GeV)
Dimensions: Physical Length Magnetic Length Iron-Pole Radius	 m m m	 0.25 0.20 0.045	 1.00 0.95 0.045
Quadrupole field: Field Gradient (G) G-Integral (required) B_G at pole	 T/m T T	 19 **3.8** ~ 0.86	 40 **38** ~ 1.8
Dipole field: B_D B-Integral (required)*	 T T•m	 0.05 **0.01**	 0.105 **0.10**
B-max at Pole in Coil	 T T	 **~0.9** < 1.5	 **~ 1.9** < 3

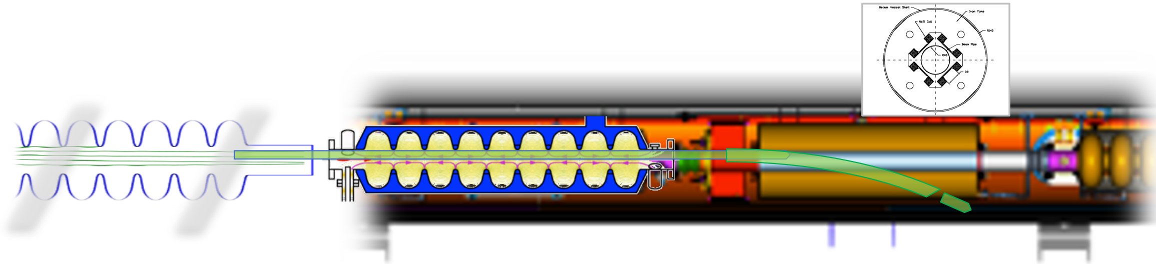
* See: page 13

A. Yamamoto, '20-07-30

An Issue:
Dark-Current Electrons generated in SRF Cavities accelerated and transported into the next SCQ





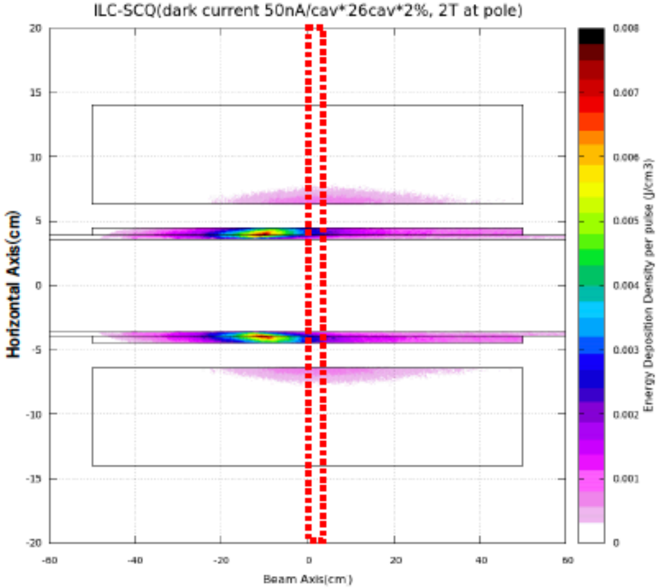


$P_{DC\text{-}e\text{-}} = \sim <0.3>$ GeV/c
$B_{SCQ} = 0 \sim 2$ T $= \sim <1>$ T
$r = \sim 1$ m

By Y. Morikawa, 200721

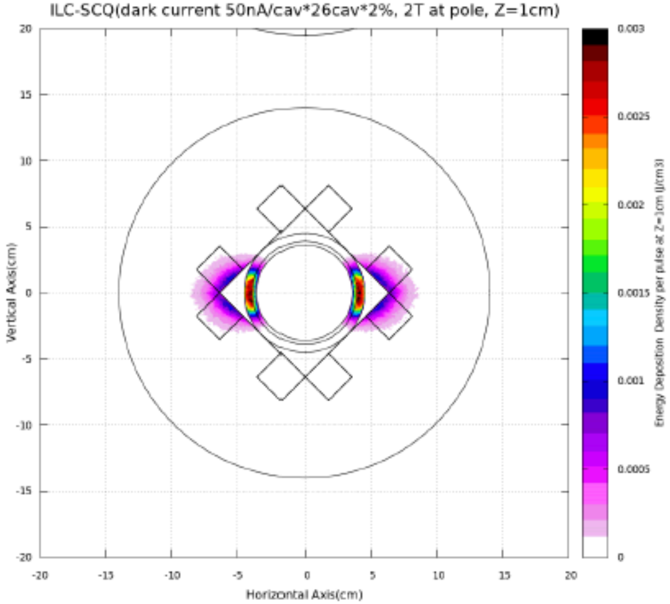
Dark Current absorption Simulation in ILC-ML SCQ (4)

1パルス当たりの発熱密度

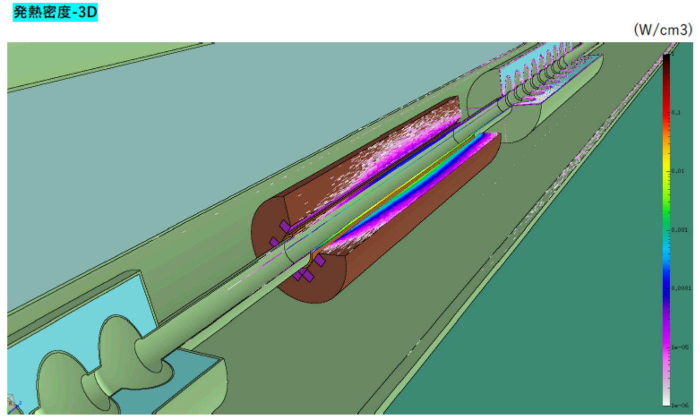


コイル最大発熱部

Z=1cmでのパルス当たりの発熱密度分布



発熱密度-3D

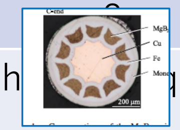


パルス当たりの最大発熱密度

・パイプ部~0.002J/cm3、Absorber部~0.003J/cm3, Coil部~0.001J/cm3

Superconductors to be compared in Basic Study

Item	Unit	NbTi	MgB_2	Nb_3Sn
Critical Temp. @ 0 T and 0A	K	9.2~9.5 K ~ 8 K @ 3 T	39 K TBD K @ 3 T	18.3 K (> ~ 15 K @ 3)
Wire dia. (bare)	mm	0.5	0.55	
# filaments		7242	10	
Filament dia.	μm	3.7	90	
Twisted pitch	mm	25	200	
Cu: SC (ratio)		1.5~2 : 1	1 : 1.2	
RRR (Cu)		50 ~ 100	88 (RT/10 K), 40 (RT/-40K)	
Critical Current	A	204 A @ 5 T, 4.2 K	116, 164, 232, 328 A @ 5, 4, 3, 2 T, @ 4.2K	
Wire dia. (insulated)	mm	0.54 + (0.04~0.10) = ~ 0.61	0.71	
Insulation material		Enamel + (Glass-Fiber)	T-Glass	
Heat Treatment required		< 200 C	~ 600 C	≥ ~ 600 C
Relative cost		1	[illegible]	~5
Availability		Contributed by Fermilab	Purch [illegible] quired	Purchasing required



Possible International Cooperation

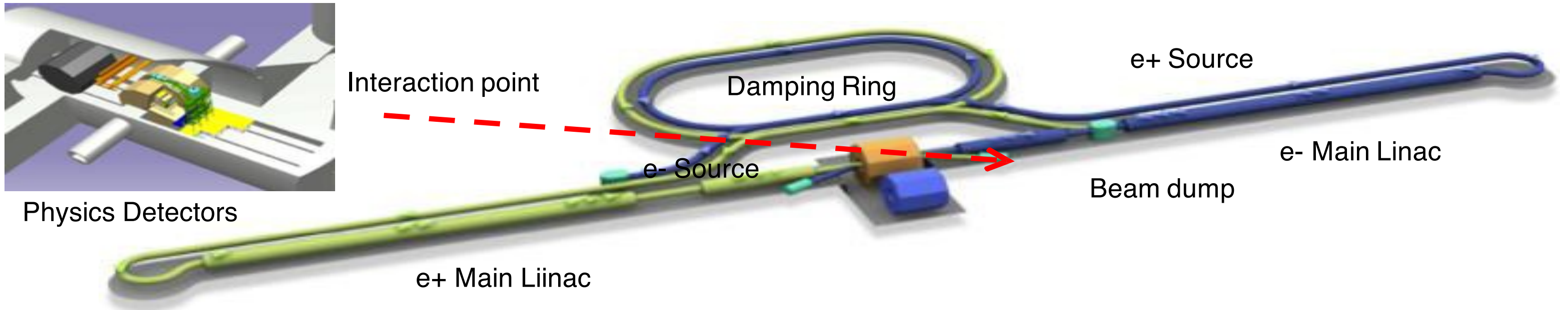
- **Technical options and remaining issues:**
  - A set of {SC quadruple (SCQ)} and {BPM+Beam-pipe (BP)}, assembled
    - Advantage: the best mechanical alignment that is so important at ILC
  - SCQ and BPM+BP, separated
    - Necessary effort: accurate and reliable interface design between SCQ and BPM
  - Sustainability to beam/SR irradiation and mitigation
    - Remaining issue for to find the best solution for magnet protection: collimators/absorbers/etc.

- **Sharing the production:**
  - Each region to be responsible, including overall CM performance test,
  - One (or two) institution(s) to be responsible for the full production and test,
  - Any others,

- **Some personal comment:**
  - The production strategy to be established in the ILC preparation phase,
  - It may be a good plan, in this stage, to develop an industrial prototype to finalize the production magnet design, to be optimized in terms of current, quad/dipole combination, cooling, etc.

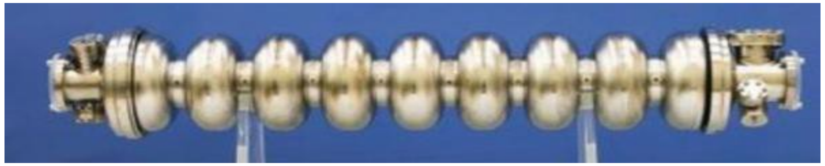
DAMPING RING

ILC Accelerator Technology

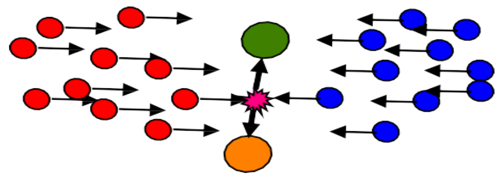


Bunch, consisting of ~10^{10} e+ / e-

- Creating particles - ***Sources***
  - polarized elections/positrons
- High quality beams ***Damping ring (DR)***
  - Low emittance beams
- Acceleration ***Main linac***
  - superconducting radio frequency (SRF)
- Getting them collided ***BDS, Final focus***
  - nano-meter beams
- Go to ***Beam dump***

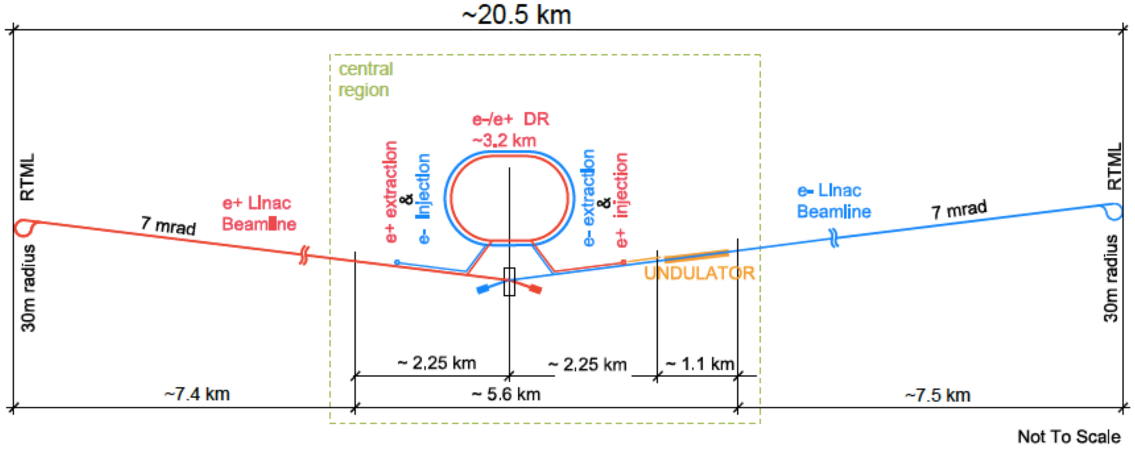


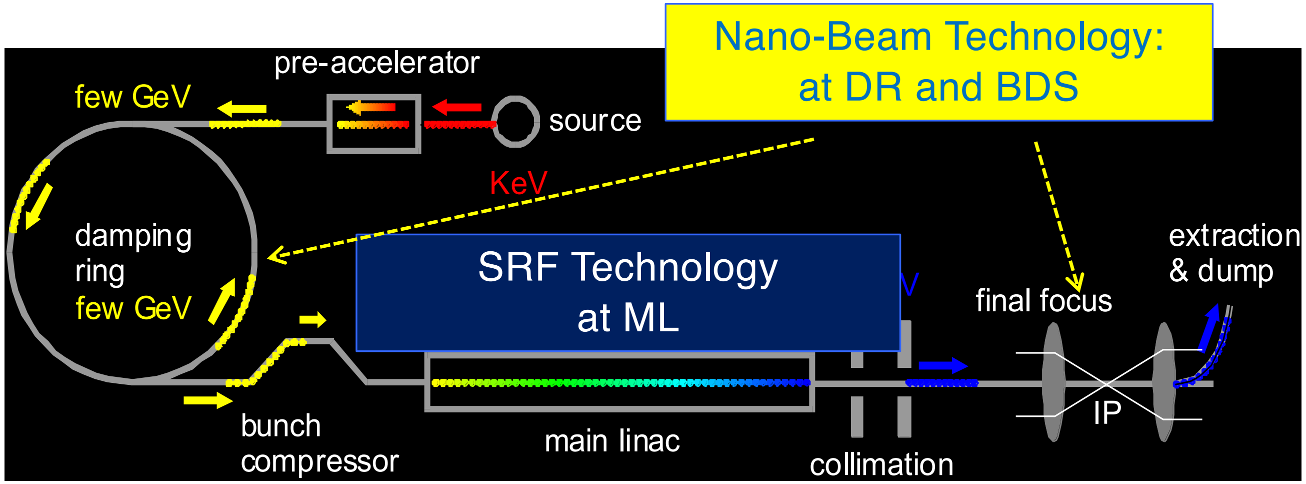
SRF Technology



Nano-beam Technology

ILC Configurations and Parameters:





Parameters	Value
Dimensions: Overall Damping Ring ML + RTML (in part) Undulators BDS	20.5 km 3.2 km ~ 2 x (5.5 + 2) km ~1.1 km 2 x 2.25 km
Beam Energy	125 GeV
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Beam sizes at IR	**7.7 nm (V)** **729 nm (H)**
ML-SRF, <E> gradient Q_0	31.5 (35) MV/m (+/-20%) ≥ 1E10 (1.6E10)

Status of DR Design and Technology

- ILC DR beam optics/lattice design has been matured with the ILC-TDR-500, and **no reasons to change** for ILC-250; i.e., from e+/e- Source to Main Linac.

- One update after TDR has been done for the DR **main dipoles** (weaker and longer), to **reduce the horizontal emittance** for the possible luminosity-upgrade option.

- Low emittance beam technology for the ILC-DR has been sufficiently advanced with worldwide efforts, particularly for electron storage rings **for light sources** in photon science projects.

- Nano-beam technology required for the ILC-DR/BDS has been well demonstrated with the **ATF/ATF-II** collaboration and the facility hosted at KEK.

ILC Damping Ring (TDR)

Table 6.1
Nominal parameters of injected and extracted beams for the baseline configuration.

Parameter	Electron Beam	Positron Beam
Train repetition rate [Hz]	5.0	
Main Linac Bunch separation [ns]	554	
Nom. # bunches per train	1312	
Nom. bunch population	2×10^{10}	
Required acceptance†		
Norm. betatron amplitude $(a_x + a_y)_{max}$ [m rad]	0.07	
Long. emittance $(\Delta E/E \times \Delta l)_{max}$ [% × mm]	0.75×33	
Extraction Parameters:		
Norm. horizontal emittance $\gamma\epsilon_x$ [μm rad]	5.5	
Norm. vertical emittance $\gamma\epsilon_x$ [nm rad]	20	
RMS relative energy spread σ_p/p [%]	0.11	
RMS Bunch length σ_z [mm]	6	
Max. allowed transfer jitter $[\sigma_{x,y}]$	0.1	

† specified for the positron damping ring

Damping Ring

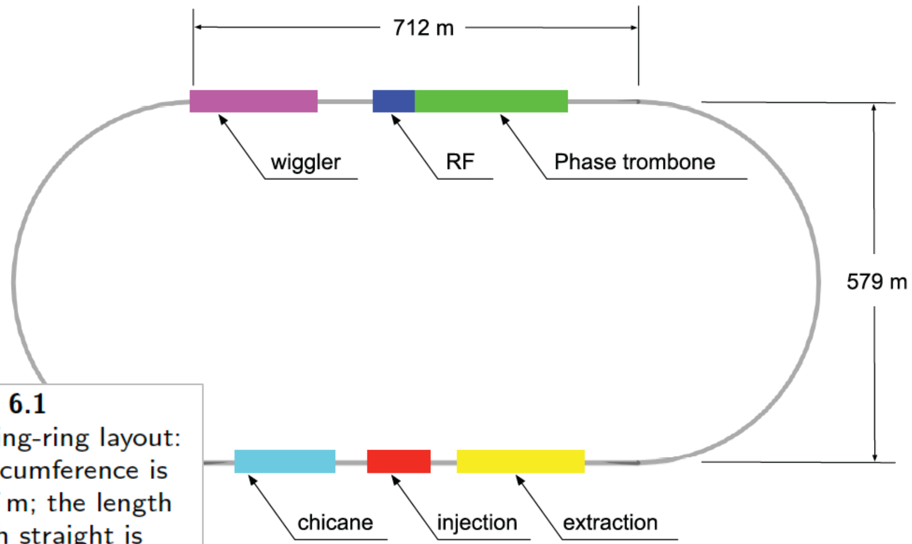


Figure 6.1
Damping-ring layout: the circumference is 3238.7 m; the length of each straight is 710.2 m.

ILC DR Parameters and the potential Upgrade

Table 6.2
Damping ring lattice parameters for 5 Hz *Low Power* (baseline) and *High Luminosity* (upgrade) operating modes and 10 Hz repetition rate (baseline) operation [98].

Parameter	5 Hz Mode Low Power	5 Hz Mode High Lumi	10 Hz Mode Positrons	10 Hz Mode Electrons
Circumference [km]	3.238		3.238	
Number of bunches	1312	2625	1312	
Particles per bunch [$\times 10^{10}$]	2	2	2	
Maximum beam current [mA]	389	779	389	
Transverse damping time τ_x, τ_y [ms]	23.95		12.86	17.5
Longitudinal damping time τ_z [ms]	12.0		6.4	8.7
Bunch length σ_z [mm]	6.02		6.02	6.01
Energy spread σ_E/E [%]	0.11		0.137	0.12
Momentum compaction factor α_p [$\times 10^{-4}$]	3.3		3.3	
Normalized horizontal emittance $\gamma\epsilon_x$ [µm]	5.7		6.4	5.6
Horizontal chromaticity ξ_x	−51.3		−50.9	−51.3
Vertical chromaticity ξ_y	−43.3		−44.1	−43.3
Wiggler Field [T]	1.51		2.16	1.81
Number of Wigglers	54		54	
Energy loss/turn [MeV]	4.5		8.4	6.19
RF Specifications:				
Frequency [MHz]	650		650	
Number of cavities	10†	12	12	
Total voltage [MV]	14.0		22.0	17.9
Voltage per cavity [MV]	1.40	1.17	1.83	1.49
RF synchronous phase [°]	18.5		21.9	20.3
Power per RF coupler [kW]‡	176	294	272	200

† The baseline RF deployment for positrons is 12 cavities to support 5 and 10 Hz modes.
‡ Power/coupler computed as (Max. Current) × (E loss/turn)/(No. cavities).

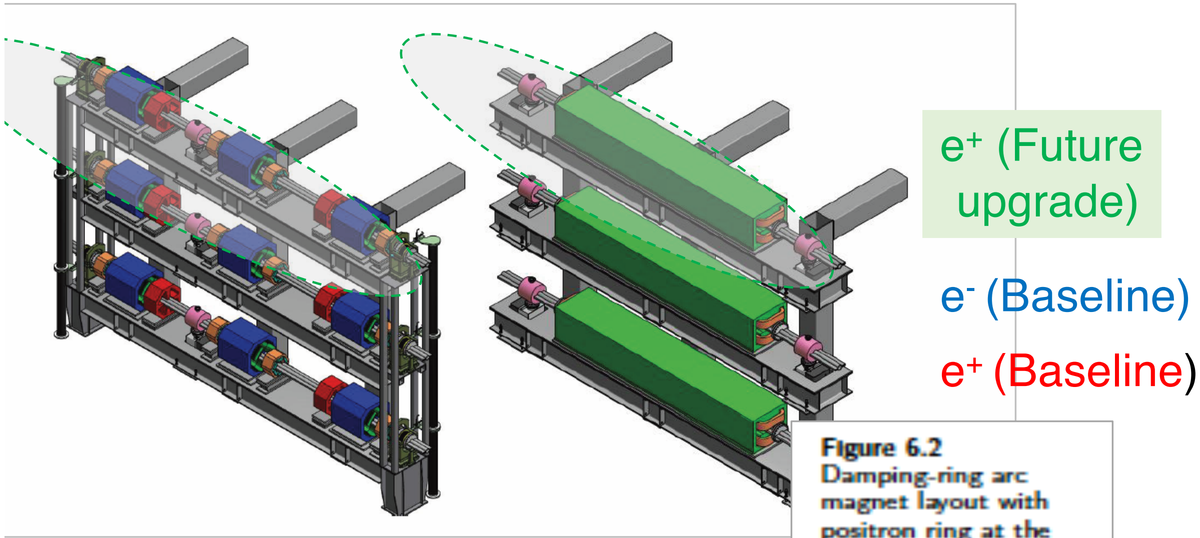
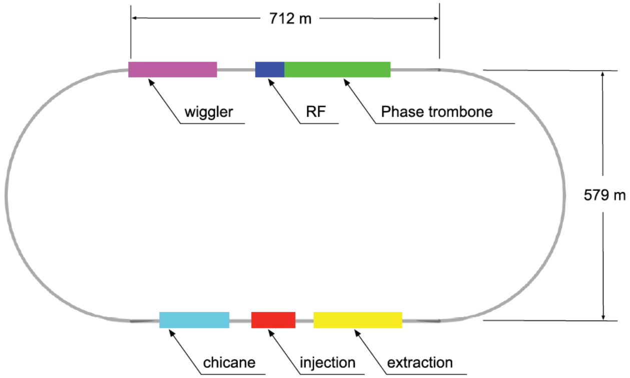


Figure 6.2
Damping-ring arc magnet layout with positron ring at the bottom and electron ring directly above. A second positron ring would be placed above the electron ring if required: (a) quadrupole section layout and (b) dipole section layout.

Contributions expected for the ILC-DR design and technology

- Beam optics/dynamics:
- Magnets:
  - Note: **permanent magnet** applications much interested (see Appendix)
- Wigglers, Fast-Kickers, and RF:
- PS, Control, and Diagnostics:
  - Note: **precision** alignment/control and **stability** critically important
- Vacuum: and
- Others

ILC-DR Arc Cells, Magnets, BPMs (in TDR)



Each cell contains :

1 - 3m (to be longer) dipole, θ = π/75

3 – quadrupoles

4 - sextupoles

3 - corrector magnets

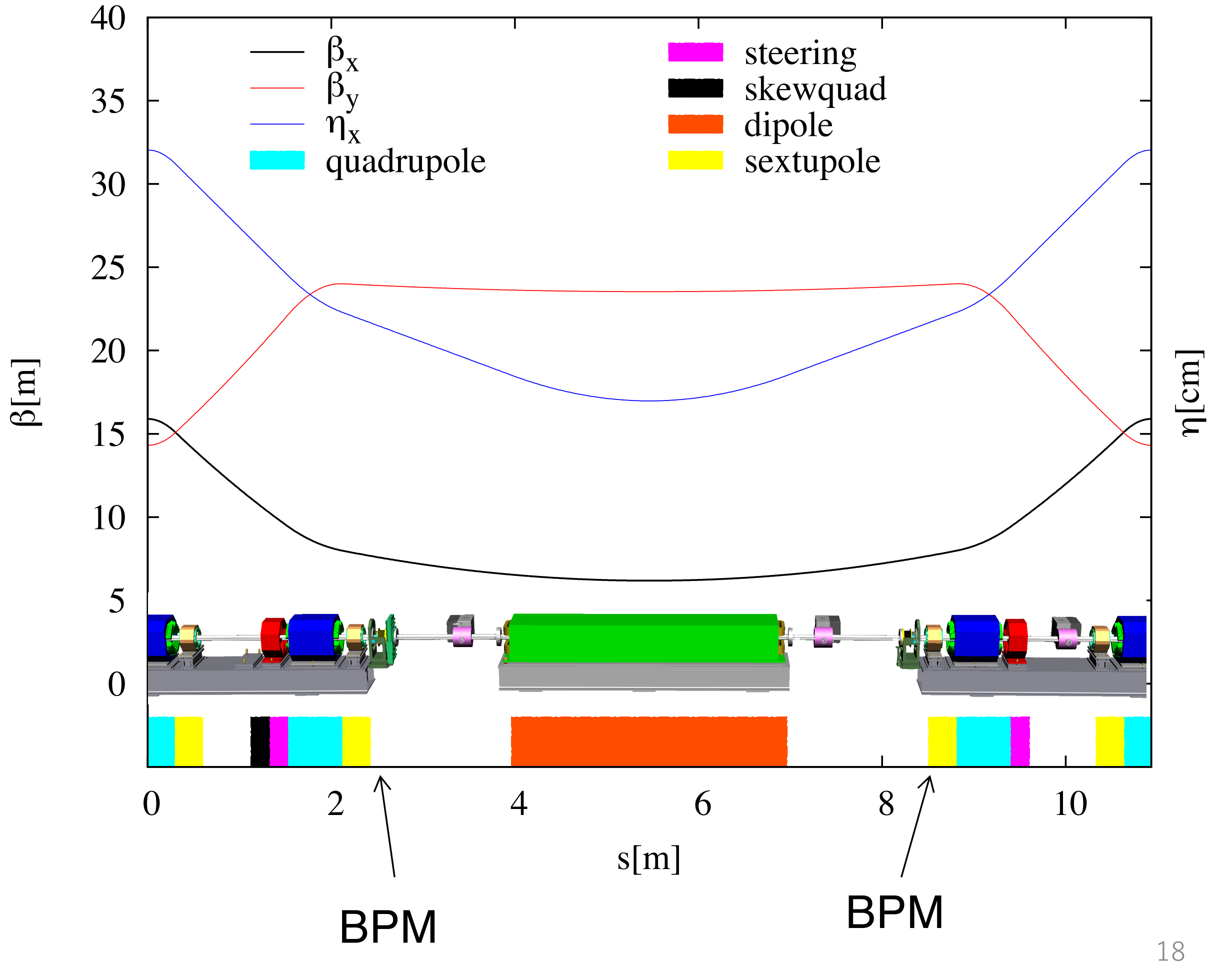
  1-horizontal steering

  1-vertical steering

  1- skew quad

2 beam position monitors

75-cells/arc



ILC-DR Arc Cell Optics Updated

LINEAR COLLIDER COLLABORATION
Designing the world's next great particle accelerator

ilc

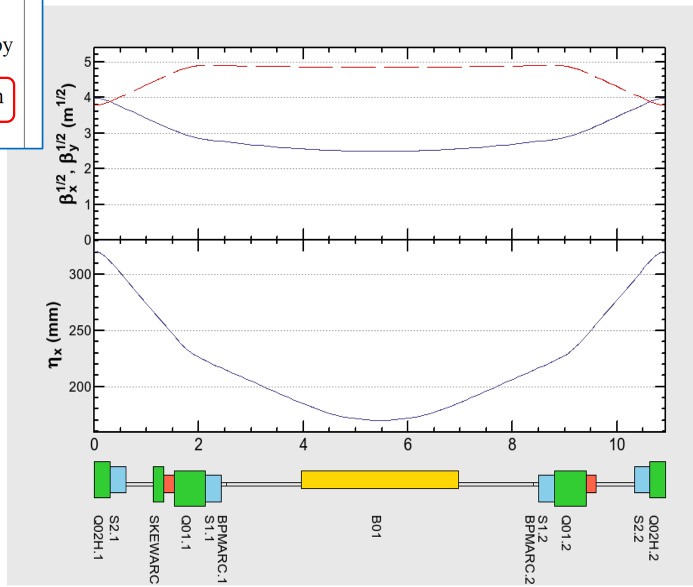
CHANGE REQUEST NO. ILC-CR-0016	EDMS No: **D*1159725**	Created: **14/9/2017** Last modified: **25/9/2017**

LUMINOSITY IMPROVEMENT AT 250GEV CM

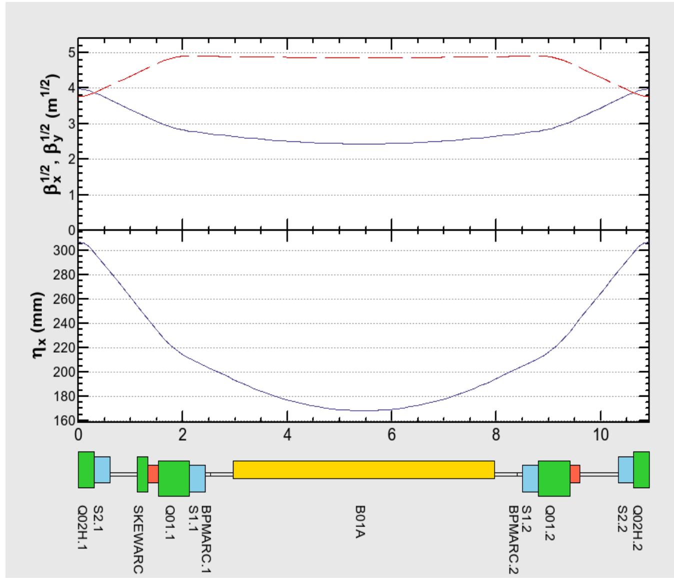
The luminosity at the center-of-mass energy 250GeV can be improved by factor ~1.65 by adopting the horizontal emittance at IP factor 2 smaller than in the TDR. This is achieved by modifying the damping ring design slightly.

See:
Appendix 2 and 3

Original (TDR)

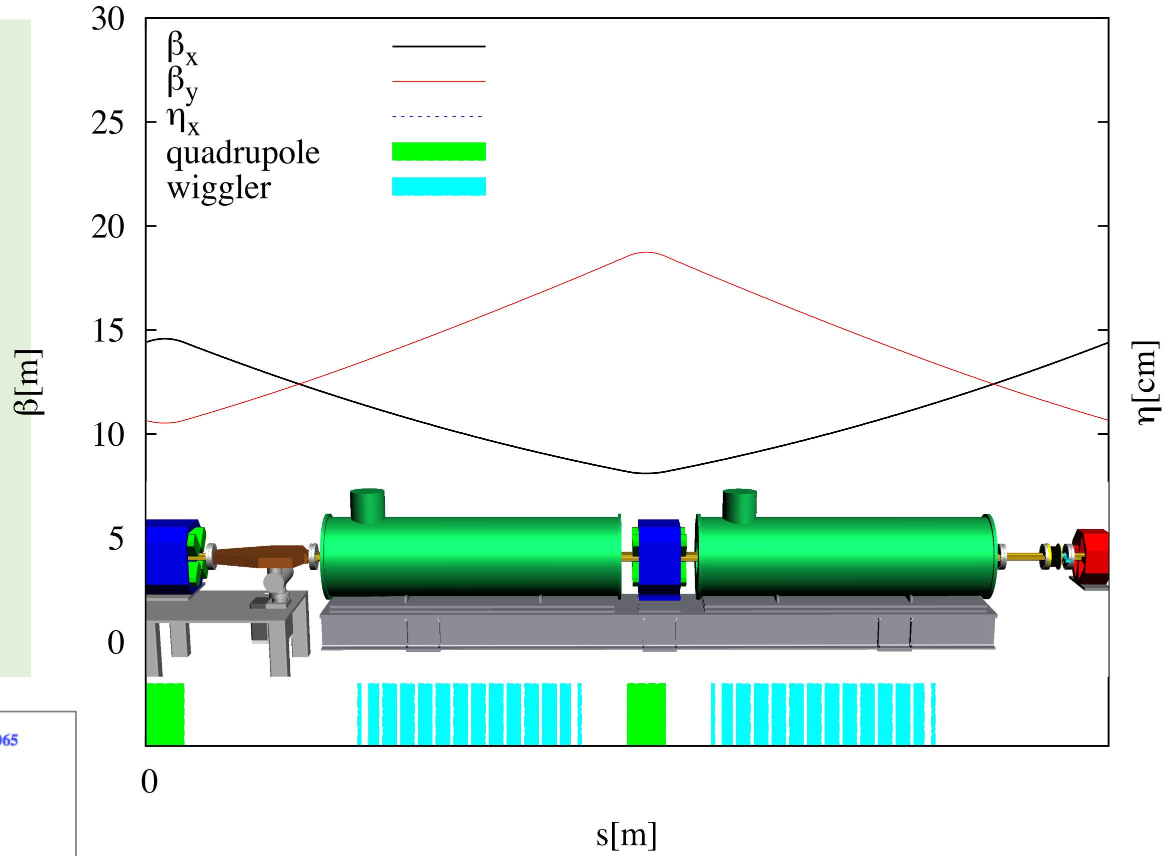


New (long bend)



ILC-DR Damping Wigglers

- Wiggler straight
  - 2 wigglers/cell
  - 30 cells
  - 2.1 m wiggler
  - 1.5T< B_{peak}< 2.2T
  - 54 @ 2.16T => τ_x =13ms (10Hz)
  - 54 @ 1.51T => τ_x = 25ms (5Hz)
  - 3 empty cells will accommodate 6 additional wigglers if required
  - H&V dipole corrector and BPM adjacent to each quad



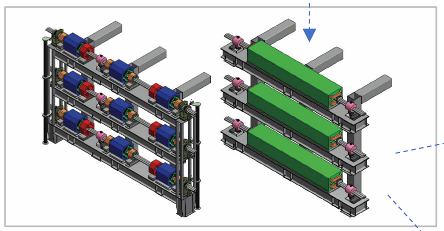
Proceedings of IPAC2012, New Orleans, Louisiana, USA TUPPR065

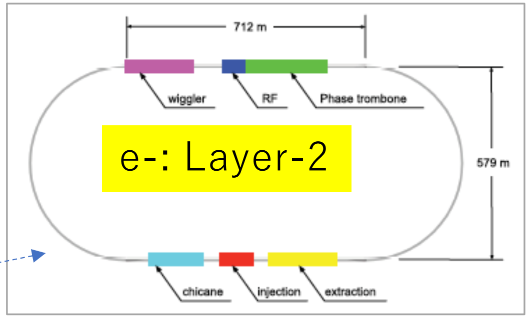
WIGGLER MAGNET DESIGN DEVELOPMENT FOR THE ILC DAMPING RINGS

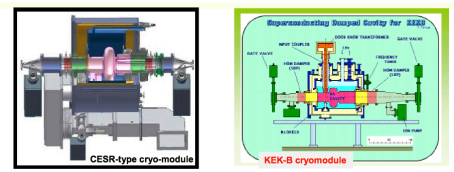
J.A. Crittenden, M.A. Palmer, D.L. Rubin
CLASSE,* Cornell University, Ithaca, NY 14850, USA

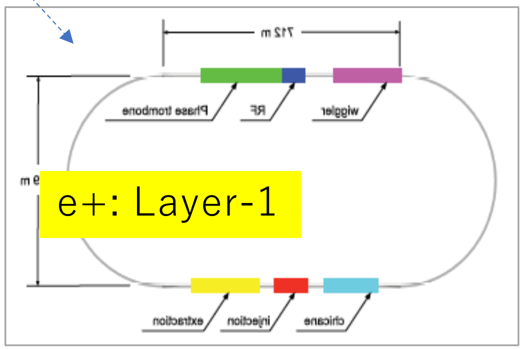
ILC-DR RF System

e+ (future)



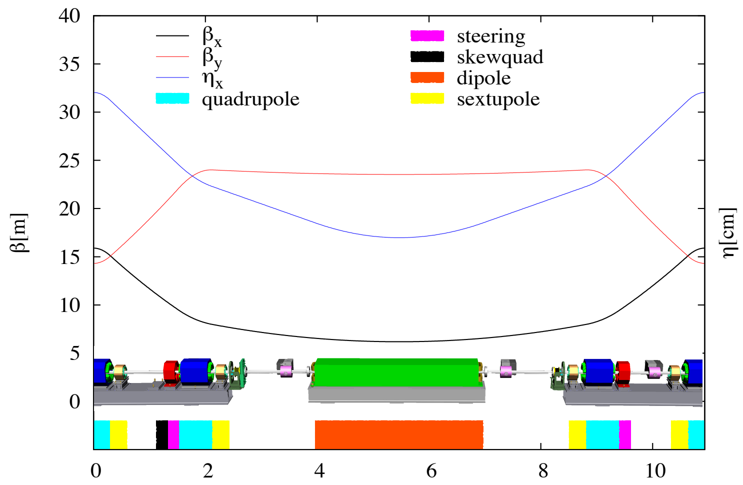




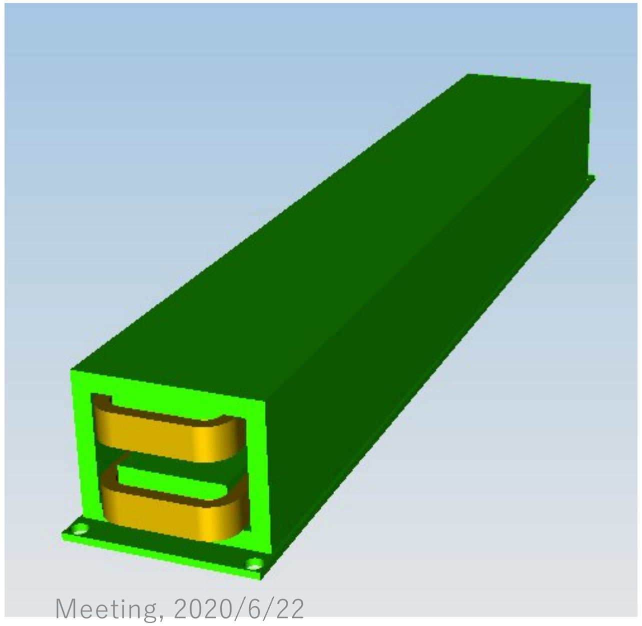


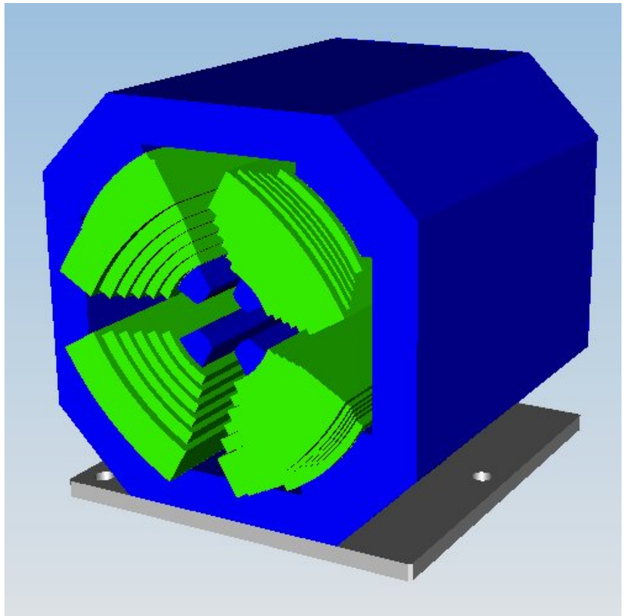
CESR, KEK-B
for References

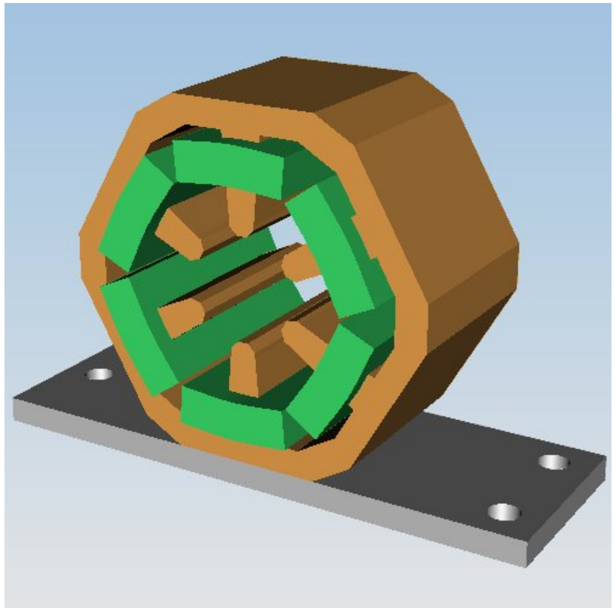
Parameter	Unit	Nominal 5 Hz	10 Hz mode e^+ ring	Luminosity upgrade
Frequency	MHz		650	
Total RF voltage	MV	14	22	14
Overvoltage factor		2.94	2.49	2.94
Active cavity length	m		0.23	
R/Q	Ω		89	
Q_0 at operating gradient	10^9	1	0.6	1
Number of cavities/ring		10	12	12
Cavity RF voltage	MV	1.4	1.83	1.17
Cavity average gradient	MV/m	6.1	8.0	5.1
Beam power per cavity	kW	185.5	287	309
Input coupler Q_{ext}			68×10^3	
Cavity tuning		stationary	fixed	stationary
RF reflected power	%	8.0	11.4	2.6
HOM Power	%		5	
Total RF power	MW	2.00	3.83	3.80
Number of klystrons/ring		5	6	6
Klystron peak power (10% overhead)	kW	441	703	698
Operating temperature	K		4.5	
RF cryogenic losses per cavity	W	15	50	15
Number of SC modules per ring		10	12	12
Static cryo losses at 4.5 K	W		30	
Total cryo losses per ring	W	450	960	540



ILC-DR
Dipole, Quad., & Sext. Magnet Concepts







ILC-DR Magnets

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Conventional Magnets

The damping ring has conventional electromagnets for the dipole, quadrupole, sextupole, and corrector magnets. This technology choice offers flexibility for tuning and optimizing the rings as well as for adjusting the operating beam energy by a few percent around the nominal value of 5 GeV. Magnet counts are shown in Table 6.8. Table 6.9 gives the key magnet parameters and maximum higher-order harmonic content specifications.

Table 6.8
Magnet types and counts for a single ILC Damping Ring using the baseline lattice. These counts do not include magnets, kickers, and septa associated with the damping ring abort beam dump located in the RTML (see Chapter 7). Wiggler magnets are superconducting, all others are normal conducting. In the engineering style designation, which is of the form *MxxLyyy*, *M* indicates the magnet type, *xx* indicates the bore diameter in millimetres, and *yyy* indicates the physical length in millimetres [127].

Magnet	Type	Eng. Style	Qty	Power Method
Dipoles:	Corrector	D60L250	304	Individual
	Chicane	D60L940	28	String
	Disp. Supp.	D60L1940	10	String
	Arc	D60L2940	150	String
Quadrupoles:	Arc	Q60L480	482	Individual
	Straight	Q60L700	121	Individual
	Wig/Inj/Ext	Q85L309	50	Individual
	Wiggler	Q85L600	30	Individual
Skew Quads	Corrector	Q60L250	158	Individual
Sextupoles	—	SX60L250	600	Individual
Wigglers	—	WG76L2100	54	Individual
Kickers	Inj/Ext	Striplines	42	Individual
Thin Pulsed Septa	Inj/Ext	—	2	Individual
Thick Pulsed Septa	Inj/Ext	—	2	Individual

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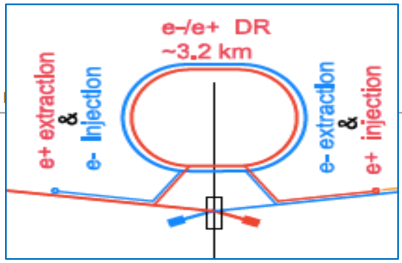


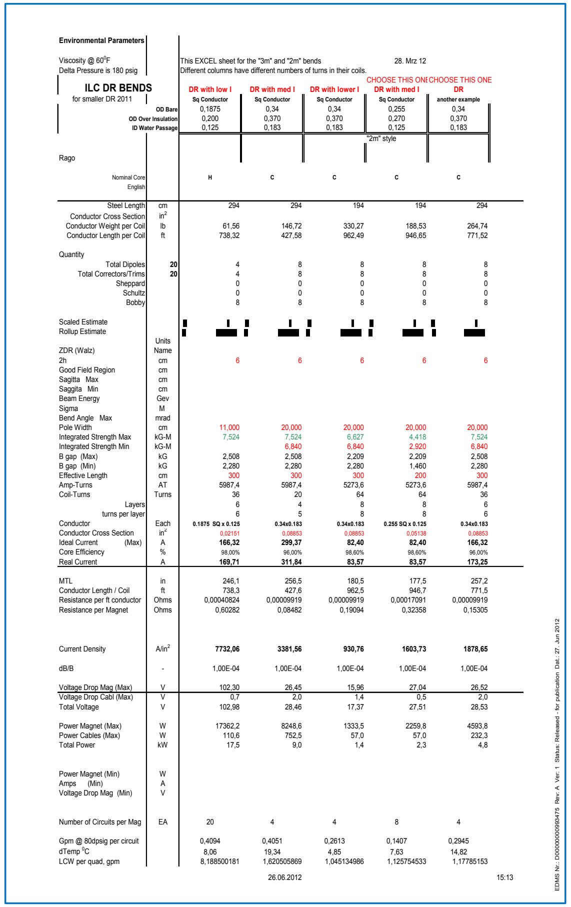
Parameters for the Major Magnets

	Gap, Ap. h x w, d [mm]	L [mm]	B, G [T, T/m]	I [A]	V [V]	Qty for 2-Ring
D60L250 (Corrector)	60x100	250	0.133	9.6	14.8	2 x 304
D60L2940 (Arc)	71x286	2940	0.251	173.3	26.5	2 x 150
Q60L480 (Arc)	60	480	11.8	58.5	--	2 x 480
Q60L700 (Straight)	60	730	4.11	17.9	--	2 x 121
QS60L250 (Skew C.)	60	250	2.2	9	--	2 x 160
SX60L150? (Corrector)	60	150	--	--	--	2 x 600

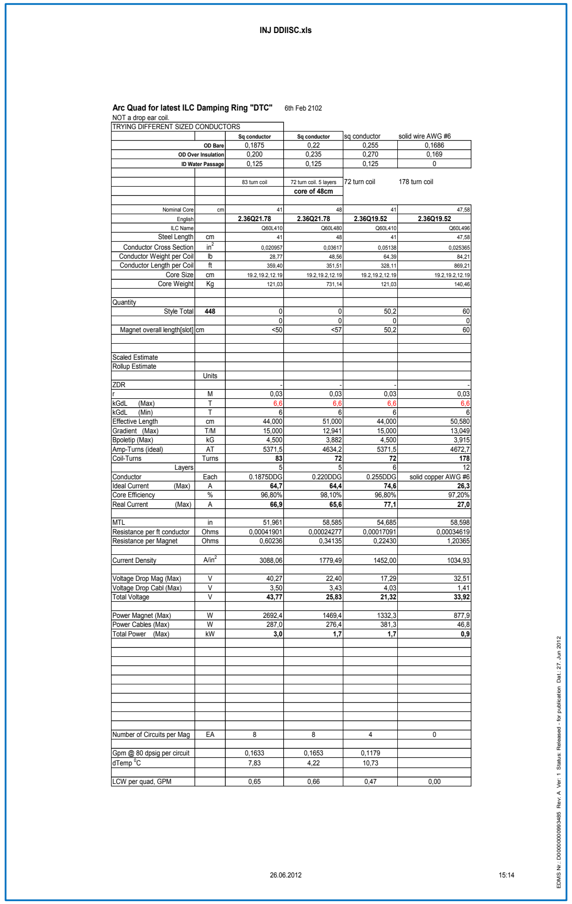
ILC magnet specs. xls, (N. Terunuma)

ILC-DR Magnet Parameters

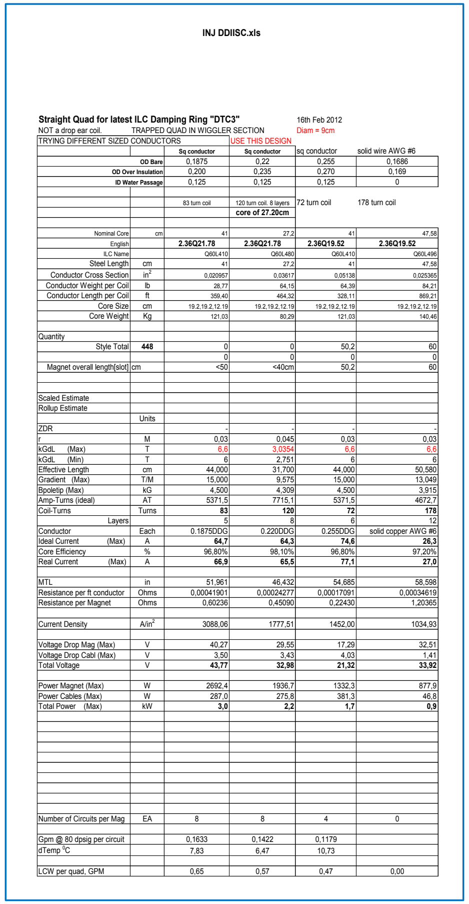
3m-Dipole



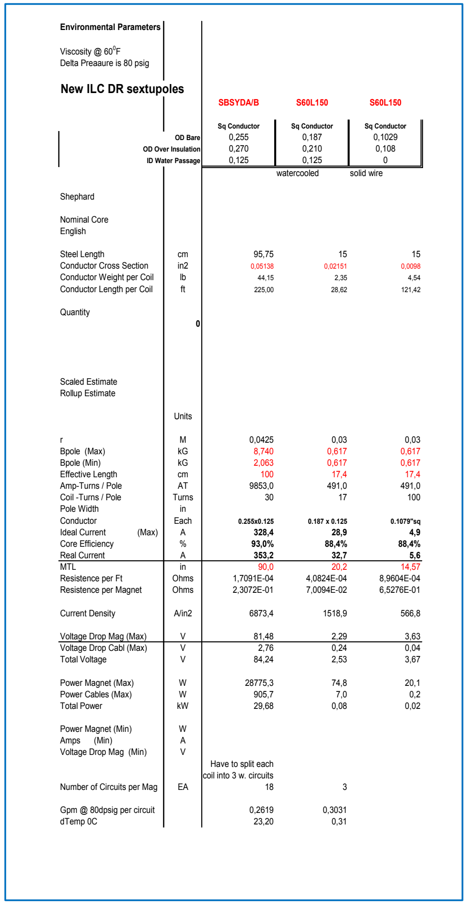
Longer Q,



Straight Q,



Sextupole



ILC-DR Magnets:
Field Tolerance and Stability required for

ILC-TDR, Vol. 3, Part II, 6.

Table 6.9
Target field tolerances used for error simulations at a reference radius of 30 mm for damping-ring magnets. For the wigglers, the field quality is specified by the observed roll-off for a horizontal displacement from the beam axis by the indicated distance. The maximum KL-value specifies the nominal strength of the strongest magnet of each magnet type.

Type	Unit	Max Field Max KL	Error
Dipoles	mrad	41	2×10^{-4}
Quadrupoles	m^{-1}	0.35	2×10^{-4}
Sextupoles	m^{-2}	1.23	2×10^{-4}
H correctors	mrad	2	5×10^{-3}
V correctors	mrad	2	5×10^{-3}
Skew quads	m^{-1}	0.03	3×10^{-3}
Wigglers		–	3×10^{-3}

ILC-DR Vacuum

Figure 6.1
Damping-ring layout: the circumference is 3238.7 m; the length of each straight is 710.2 m.

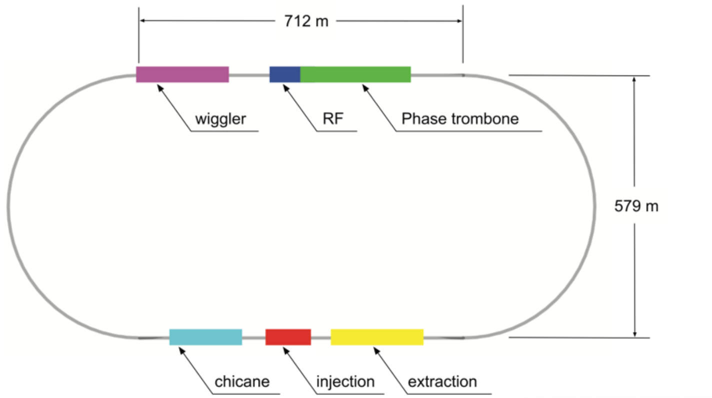
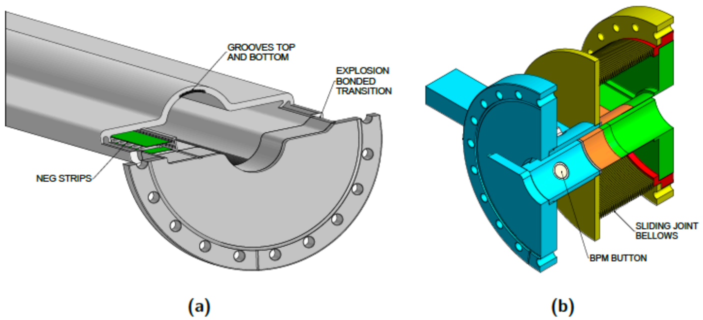


Figure 6.9
(a) Dipole Chamber with grooved top and bottom surfaces, radially inside antechamber with NEG strips, and radially outside antechamber with sloped wall. (b) BPM and sliding joint assembly. [116].



Chapter 6. Damping Rings

Figure 6.10
(a) Wiggler vacuum chamber with clearing electrode and 20 mm tall antechambers with recessed NEG strips. (b) Wiggler section photon stop showing sloping and grooved photon-absorbing walls [116].

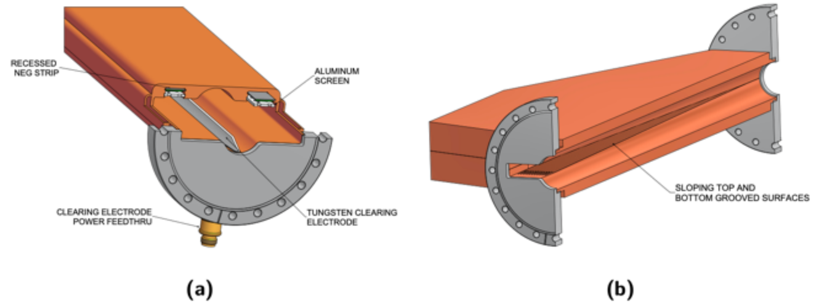
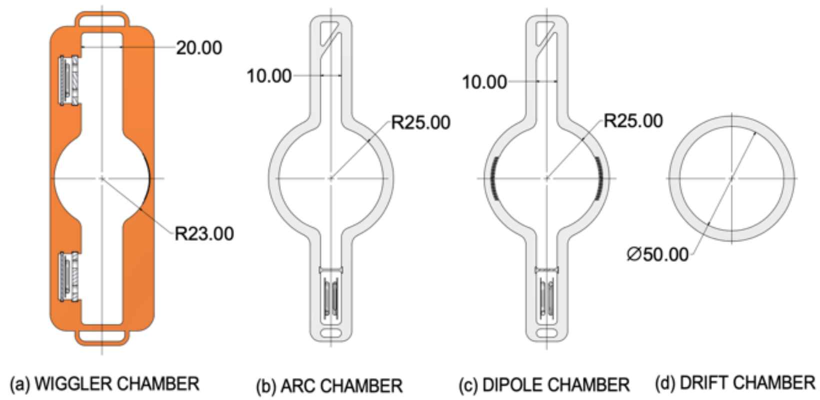


Figure 6.11
Side-by-side comparison of ILC DR vacuum chamber profiles. Dimensions are in millimeters [116].



Summary

- **ML-SCM (SCQ)** may be a very appropriate contribution in harmonization of Spanish institute and industry cooperation**.**

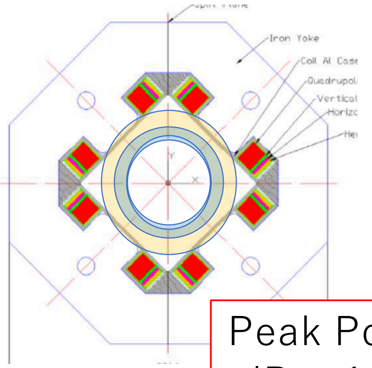
- **Damping Ring (DR)** may be a very effective contribution with a common technical prospect of the **ultra-low emittance** beam and ultra-precision beam control.

- ILC-250 accelerator sub-systems focusing on Damping Ring, including, beam dynamics, various components for the DR. have been described. These are very **efficient technical areas** to share the common objectives and benefits.

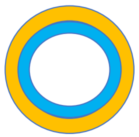
- **Further potentials** will be further investigated and discussed.

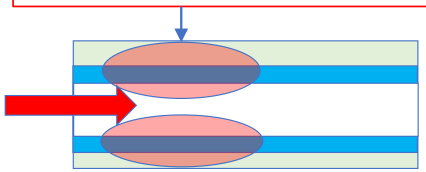
Appendix

Heat Absorption in the SCQ



Peak Power loss:
dR ~ 10 mm, Lz = 30 cm





Power loss distribution (assumption):
Cyl-V. at r = 0.045m, t = 0.01m, L = 0.3m,
$V = 2\pi \times 0.045 \times 0.01 \times 0.3 = 0.9 \times 10^{-3}\ m^3$
M (Mass assuming Cu) = V x d (Cu) = 8 kg

Conduction-cooling along beam-pipe+:
Cyl-pass @ r = 0.04m, t = 0.002m, L = 0.5m,
k_{Cu} = 1,000 W/m•K
$S/L = 2\pi \times 0.04 \times 0.002 / 0.5 = 0.0016$ [m]
dQ/dT = k x S/L = 10^3 x 0.0016 = ~ 1.6 W/K

Assumption of Power/Energy Deposition into SCQ

- Dark current / cavity: **≤ 50 nA**
- Power deposition in SCQ : 1.35 W @ 125 GeV ---> **P ≤ 5 W** @ 500 GeV
- E = **1 Joule / 1 ms** (with an interval time of 200 ms, or 5Hz)
- Cold mass (Beam-Pipe + Yoke + Coil) for energy deposition : ~ **8 kg**

Temperature rise (ΔT) due to Energy Deposition, if no-cooling

- $\Delta T = (E/M) / c_{\text{-}Cu}$ (assuming Cu@ 5 K)
  = (1J / 8kg) / ~0.1 J/kg/K = 1.3 K / pulse (1 ms),
  ≤ (5J / 8kg) / ~0.1 J/kg/K < 6.5 K / sec,

Magnet sustainability in ~ 1 sec (for detection and beam-off):

- MgB_2 Coil (Tc ~ 15 K, at 3 T) stay in superconductivity,
- NbTi Coil (Tc ~ 8 K, at 3 T) require suff. beam absorber & cooling

ILC Accelerator: Images