Introduction of discussion at crab cavity group (WG3)

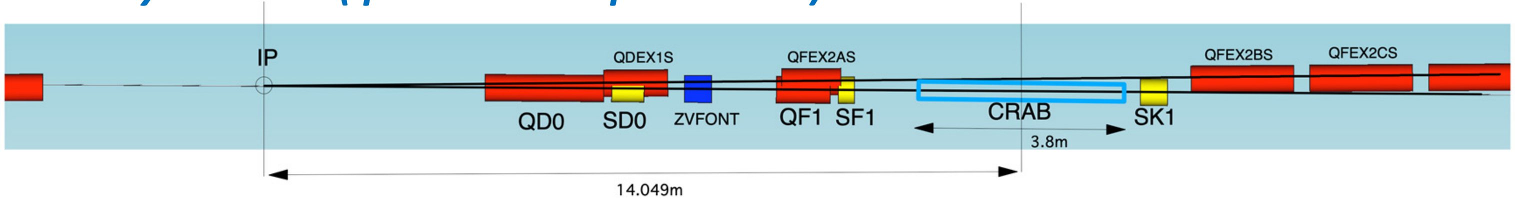
Crab cavity location
Wakefield effect of crab cavity
Technical selection of crab cavity

Toshiyuki OKUGI, KEK
IDT WG2 DR/BDS/DUMP group meeting
2021/12/22

Crab cavity location

Crab cavity location (present ILC optics deck)

two beamline distance
14.05m x 0.014rad = 197mm



Crab cavity location (alternative)

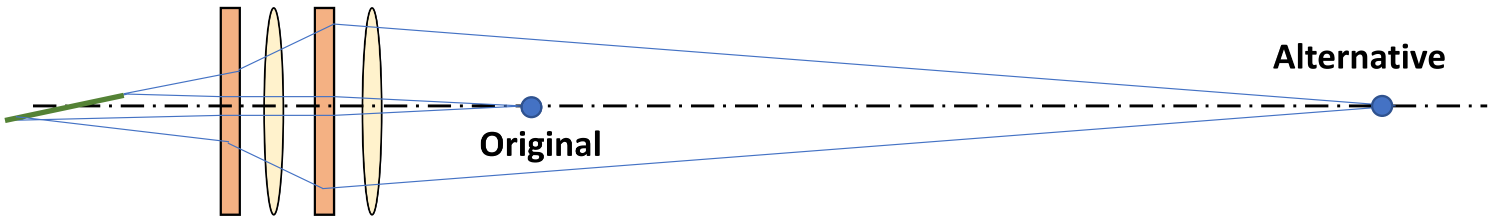
two beamline distance
77m x 0.014rad = 1078mm

drawn by H. Hayano

- *Since lots of magnets will be put in the dump line, the next neighbor candidate to put the crab cavity* ***is 77 m from the IP*** *in order to avoid the positional influence of the magnets in the dump line.*
- *The requirement of the relative RF jitter is independent to the crab cavity location. But the jitter requirement for the next neighbor location is tighter for the distance between the crab cavities (28m and 154m).*

	Present	***Alternative***
Longitudinal distance from IP	14.05 m	77 m
Horizontal distance from dump line	0.197 m	1.078 m
R12 (crab cavity to IP)	17.4 m	12.2 m
relative timing jitter requirement	49 fs rms. (2 % luminosity drop)	

Effect to the luminosity

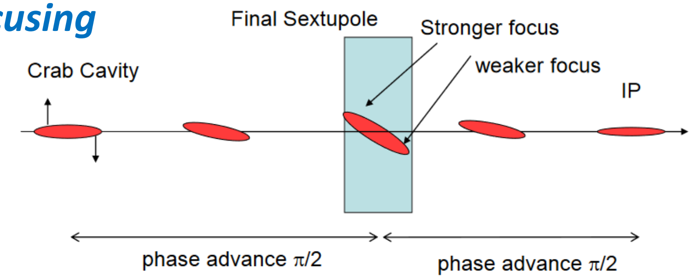


Horizontal beam orbit at FD was changed from the bunch head to the bunch tail

➢ *The vertical focal position was shifted from the bunch head to the bunch tail*

	z	*Present*			*Alternative*		**Beam waist shift**	
		σ_x/σ_{x0}	σ_y/σ_{y0}	Δ_y/σ_z	σ_x/σ_{x0}	σ_y/σ_{y0}	Δ_y/σ_z	
Bunch head	+600 um	1.0010	1.0138	+0.14	1.16	1.45	+1.03	**Weak focusing**
	+300 um	1.0005	1.0044	+0.07	1.05	1.13	+0.51	
⇕	0	1	1	0	1	1	0	⇕
	- 300 um	1.0005	1.0044	-0.07	1.05	1.13	- 0.51	
Bunch tail	- 600 um	1.0010	1.0138	-0.14	1.16	1.45	- 1.03	**Strong focusing**
	Luminosity reduction	0.5 % (geometrical)			16 % (geometrical)		↑	

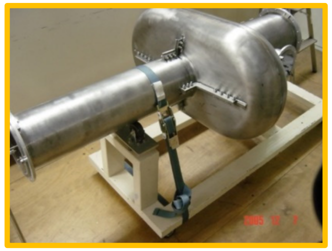
Traveling focusing



The luminosity for the alternative location will be increased than that evaluated as the geometrical luminosity by the traveling focusing of the beam-beam effect.

Requirement of the ILC crab cavity

KEKB crab cavity



Total kick voltage

- *The kick voltage was evaluated* ***for E_{CM}=250GeV ILC (beam energy is 125 GeV).***
- *Total voltage for the crab kick is smaller for the higher RF frequency.*

Cavity gradient

- *Cavity gradient was evaluated* ***by scaling to the KEKB dipole crab cavity as a reference****.*
- *The actual cavity gradient should be evaluated to be design-by-design.*

Relative RF phase jitter

- *Since the requirement of the timing jitter is independent to the RF frequency,* ***the requirement of the phase jitter is severe for the lower frequency.***

Frequency		3.9 GHz	1.3 GHz	
# of cell		9 cell	3 cell	9 cell
Total length (pi/2 mode)		0.346 m	0.346 m	1.038 m
Total kick voltage	***Present location***	0.615 MV	1.845 MV	
	Alternative (s=77m)	0.878 MV	2.633 MV	
Cavity gradient	***Present location***	8.14 MV/m	24.4 MV/m	8.14 MV/m
	Alternative (s=77m)	11.6 MV/m	34.9 MV/m	11.6 MV/m
Relative RF phase jitter		0.023 deg rms. (49 fs rms.)	0.023 deg rms. (49 fs rms.)	

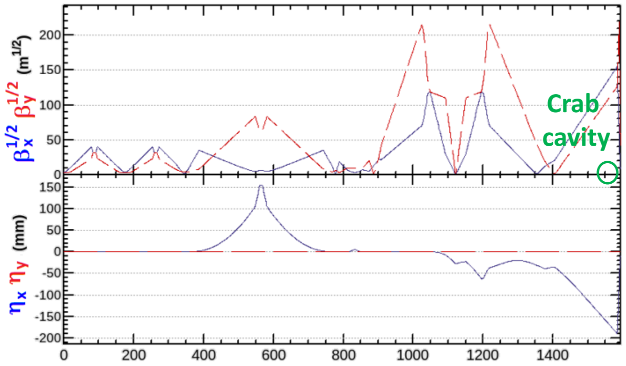
Crab cavity location

- The present alternative position happens to be a condition that satisfies traveling focusing.
- However, it is not possible to change the conditions for traveling focusing and for crab crossing independently.
- In addition, there are several designs of crab cavity that could be placed in the original position, so we decided to consider the position of the crab cavity based on the original position.

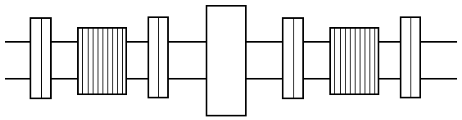
Wakefield effect of crab cavity

Shot-range wakefield of the crab cavity

Beam optics for ILC collimator / final focus

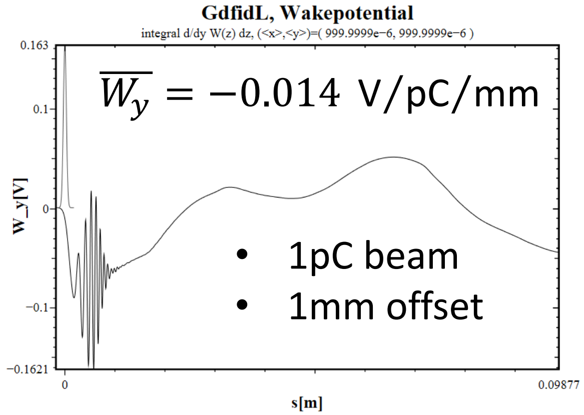


Component arrangement at BPM in simulation



Case 1	**Case 2**
1 BPM	
2 bellows	⇒ masked
4 flanges	⇒ masked

Wakefield calculation by Alexey Lyapin by GdfidL



Case 1 wakefield condition *:*
bellows and flange gaps are not masked.

Case 2 wakefield condition *:*
cavity BPM wake is only put into beamline.
(bellows and flange gaps are masked.)

> Locations of many wakefield sources are comparable or larger beta-function than crab cavity.

Effect of wakefield with orbit distortion (orbit jitter) was evaluated as

$$\frac{\sqrt{\sigma^2 - \sigma_0^2}}{\sigma_0} \propto \frac{q}{E} \sum W\beta$$

q : bunch charge
W : strength of wakefield
E : beam energy
e : emittance
b : beta-function at wake source

	W[V/pC/mm]* beta [m]
Crab cavity	**-214**
ILC Case 1	-142352
ILC Case 2 (only cavity BPMs in BDS beamline)	-22104

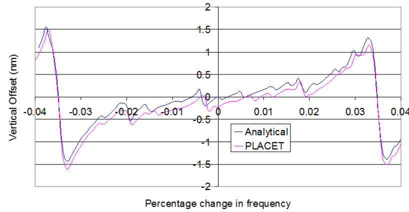
Long-range wakefield of Crab cavity

Calculation of the Impedance Requirements for the ILC Crab Cavity

G. Burt, Lancaster University

Acknowledgements: Leo Bellantoni, Andrea Latina, Amos Dexter, Philippe Goudket, Roger Jones

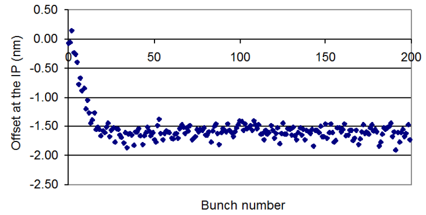
PLACET+GuineaPig



The PLACET results show when the damping tolerances are met with a maximum Q of 1x10^5 the maximum vertical offset is 1.5 nm.

The results give good agreement with the previous analytical results.

The PLACET simulations showed negligible emittance growth showing that offset is the dominant effect



But feedback removes offsets from the main linac?

- Yes FONT can remove offsets in one plane if they are the same bunch to bunch
- Crabs are too close to the IP to do bunch-to-bunch feedback
- Also FONT works in only one plane

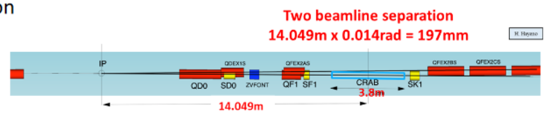
- *It is necessary to consider whether feedback is also necessary in the horizontal direction.*
- *In the current BDS concept, horizontal emittance is getting smaller and horizontal disruption is getting larger. From this point of view, consideration of feedback in the horizontal direction is also necessary.*

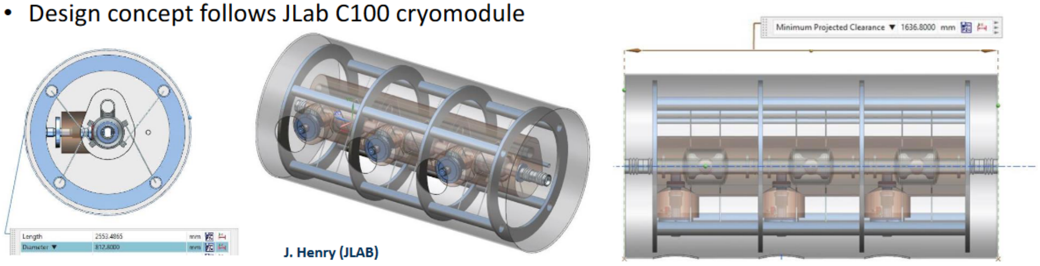
Technical selection of crab cavity

RF Dipole (RFD)

Frequency : 1.3GHz
Aperture : 30mm
Length (1TeV) : **4.9m (3 cryomodule)**

- 1 cryomodule for 1.845 MV at 250 GeV
  - 3 cavities in a single cryomodule allow operation with a cavity failure
- 3 cryomodules for 7.4 MV at 1 TeV
- Cryomodule size: length ~ 1.64 m and diameter ~ 0.82 m
- Design concept follows JLab C100 cryomodule

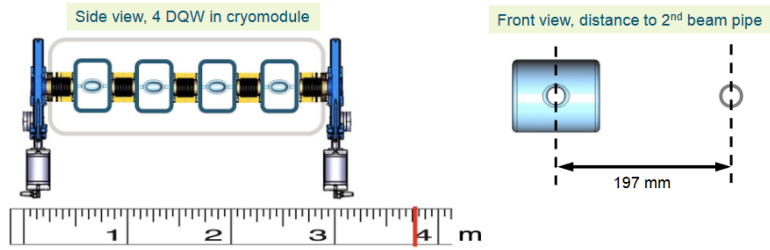




Double Quarter Wave (DQW)

Frequency : 1.3GHz
Aperture : 20mm
Length (1TeV) : 3.3m (4 DQW)

- For 1 TeV CoM beam scenario, **4 or 5 DQW cavities** are sufficient to **provide a 7.4 MV crabbing kick at 1.3 GHz**. Adding a 5th cavity could reduce the V_t/cavity to 1.5 MV.
- Length available of **3.8 m enough for crab cavities and other necessary components** (cold-warm transitions, gate valves, etc.).
- Sufficient **clearance to 2nd beam pipe for coupler integration**.



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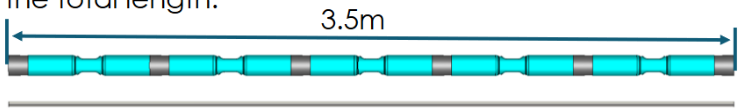
S. Verdú-Andrés (BNL) | ILC Workshop 2021 | Slide 14

Wide open waveguides (WOW)

Frequency : 1.3GHz
Aperture : 20mm
Length (1TeV) : 3.5m (5 cryomodule)

- Simple design with single cell cavities and BLAs between cavities.
- Total length 3.5m.
- Use 2 cavities for 125GeV first, depending on the operational experience, choose either 4 or 5 cavities for 500GeV.
- Reducing the beampipe diameter can further reduce the total length.



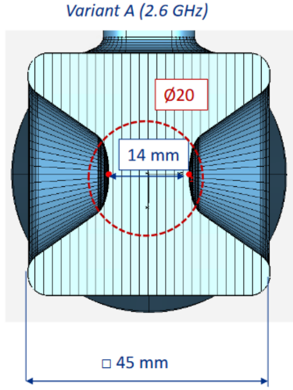
Gate valves, bellows and cryomodules not shown here, they will not occupy extra length though.

QMiR cavity

Frequency : 2.6GHz
Aperture : **14mm? (<20mm)**
Length (1TeV) : 1.0m (2 cavity)

ILC CC Aperture Limit is < Ø20 mm (?)

Variant A (2.6 GHz)



- **QMiR Deflecting Cavity has two opposite electrodes**
- **Smaller distance between electrodes provides a larger transverse kick**
- **The SR halo causes the heating of the electrodes**
- **The total area of SR interception is < 20% of the "effective" aperture**
- **Can we tolerate a smaller than 20mm distance?**
  - **ILC BDS group input is needed**
- **What is a safe maximal SR power dissipation?**
  - **For a front pair of electrodes with dT<0.5K:**

    $P_{max} \approx 2K_{NB}S_e dT/(DF*h_e) \approx 100W$

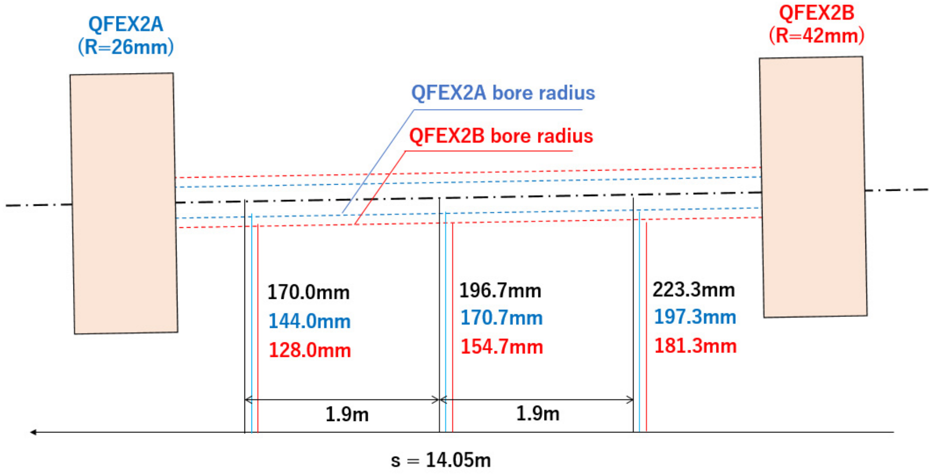
    K_{NB} = 10 W/m/K - thermal conductivity

    S_e, h_e - electrode cross-section and height

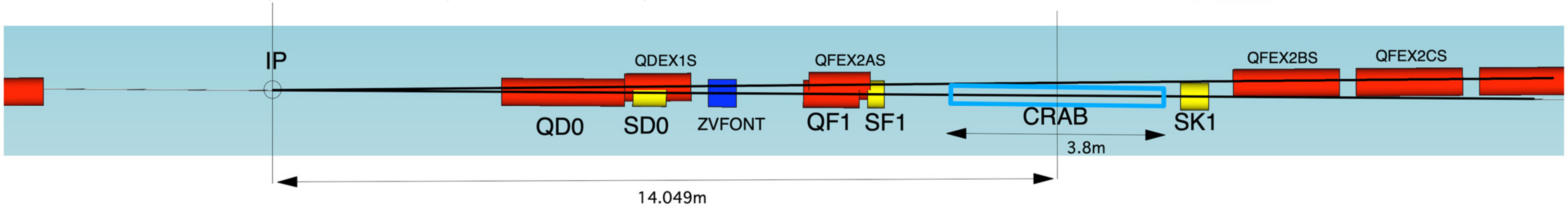
    DF = $3.6*10^{-3}$ – duty factor
- **We can easily redesign QMiR to a lager aperture**
  - **in progress ...**

Requirements for the geometry of the crab cavity

Interference with extraction line



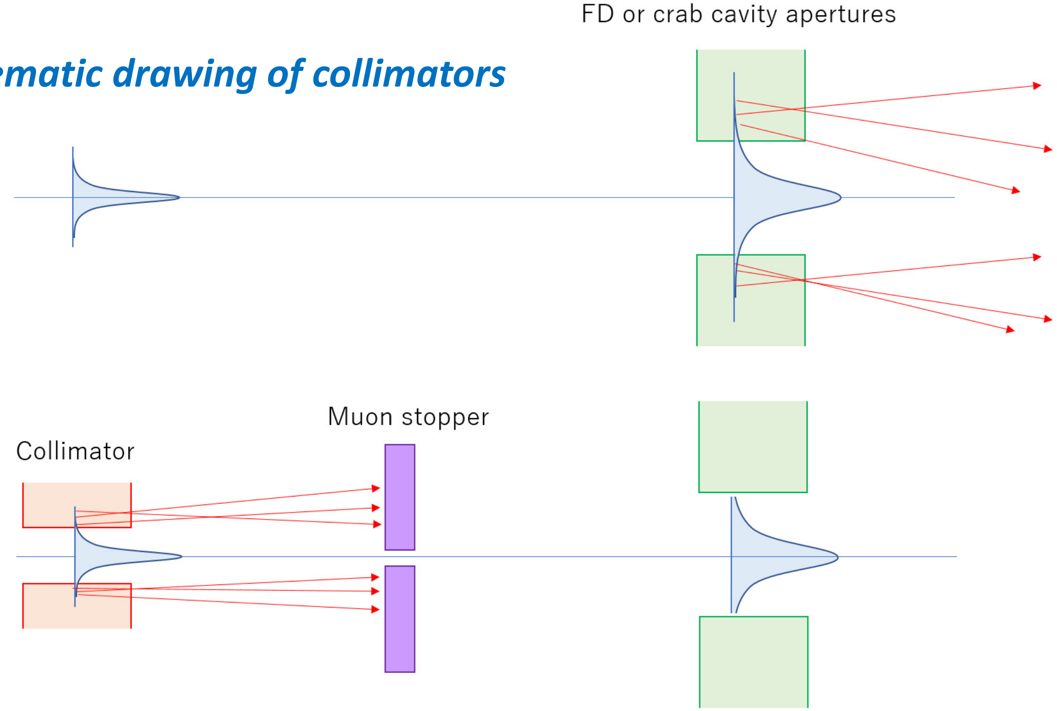
Crab cavity location (present ILC optics deck)



- Up to what energy must the crab cavity for the beam be contained in a 3.8 m space?
  - ➢ Should we give priority to the technology that can fit up to 1 TeV in 3.8 m?
  - ➢ Is it enough if the beam is stable up to ECM=250 GeV?
    - ✓ In that case, we will adopt a different technique when we move to higher energies.
- Contingency ?

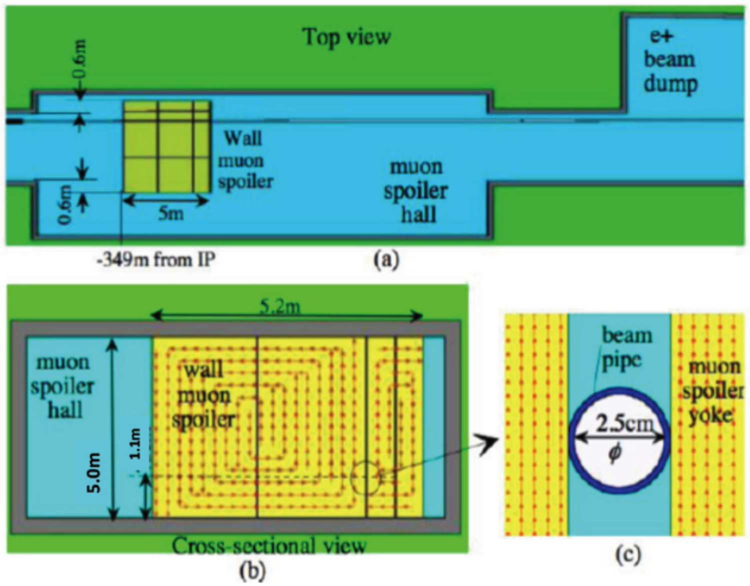
Aperture Issue

Schematic drawing of collimators

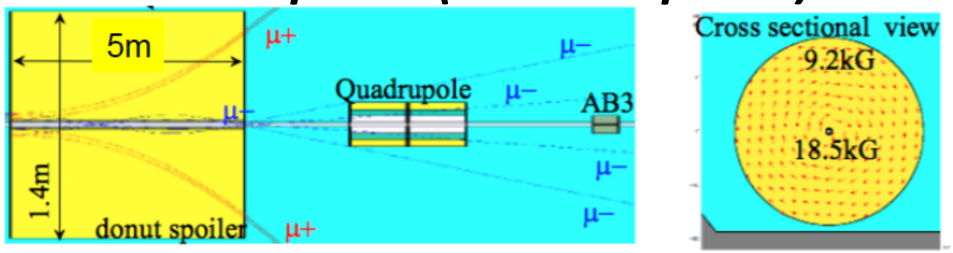


- *In ILC, a collimator is placed upstream to prevent the beam halo from hitting the final doublet or crab cavity.*
- *Since the beam halo hitting the collimator produces a large amounts of secondary particles (muons, etc.), it is necessary to install a large muon stopper to prevent the muons from reaching the detector.*

Muon wall



Muon spoiler (donuts spoiler)

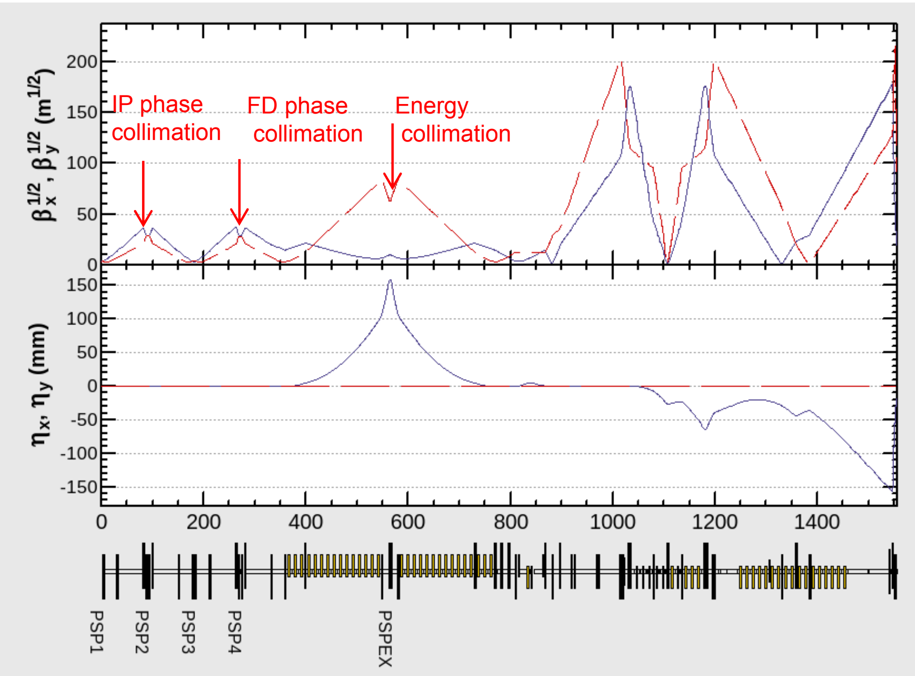


Consideration of collimation depth

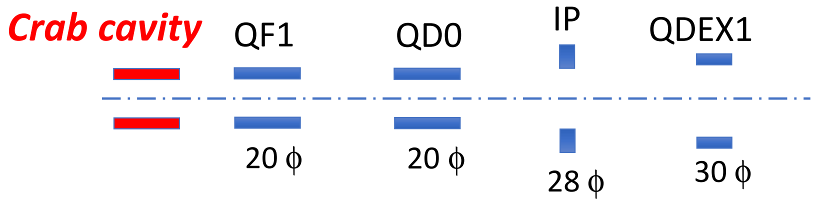
- *The aperture of ILC collimator is determined so that the halo particles and SR generated by the halo particles do not hit the SC device or inner detector.*
- *The collimation depth (aperture of the collimator relative to the beam size) should be larger because the more halo particles are cut at the collimators and much number of the muon background is generated for the smaller aperture of the collimator.*
- *The current design is limited by the aperture of the SC magnets before and after the detector, which is only 6σ of the beam size horizontally.*

Arrangement of the Collimators

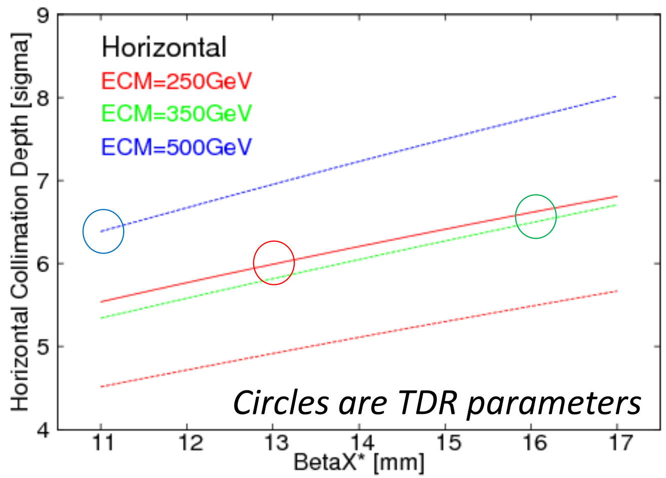
Beta Function at SP2/SP4 = (X; 1000m / Y; 1000m)
Phase Advance (SP2/SP4) = (X; 0.5 pi / Y; 1.5 pi)
Phase Advance (SP4/ IP) = (X; 5.5 pi / Y; 4.5 pi)
EtaX at SPEX = 0.158m



Collimation depth are determined by the following apertures

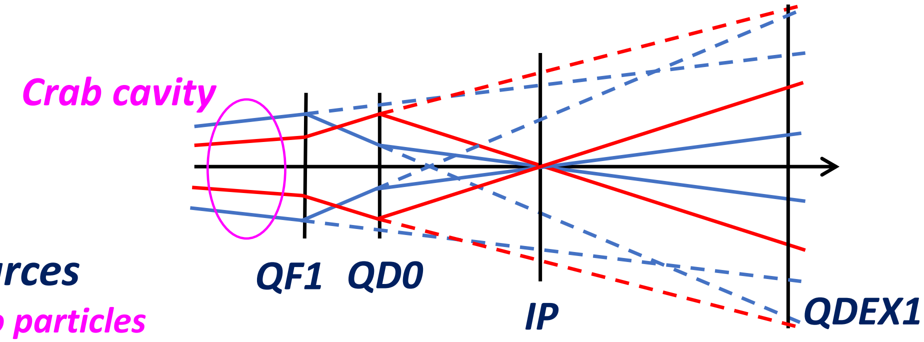


Present ILC design collimation depth



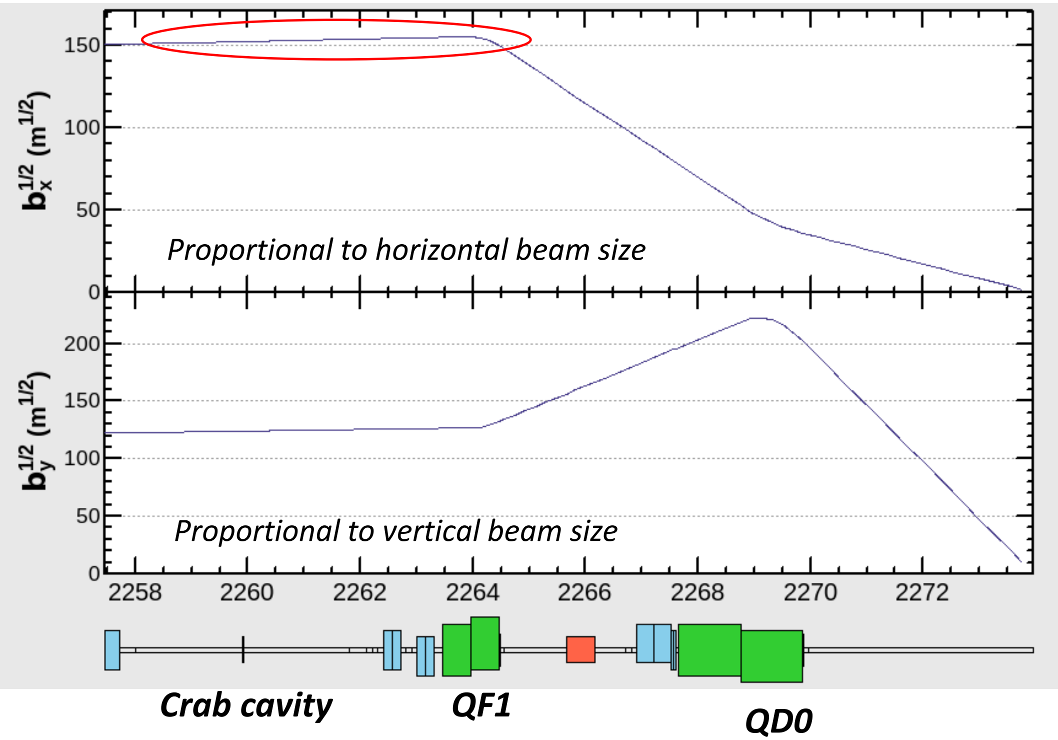
BG sources around IP area

- *The collimation depth is limited by the aperture of QF1, QD0, and QDEX1.*
- *In QF1, it is limited in the horizontal direction by whether the beam halo hits the pipe or not, and the condition is the same for crab cavity.*
- *Since the beam size is the same in the crab cavity and QF1, if the aperture of the crab cavity is smaller than the 20 mm diameter of QF1, the aperture of the crab cavity limits the collimation depth.*



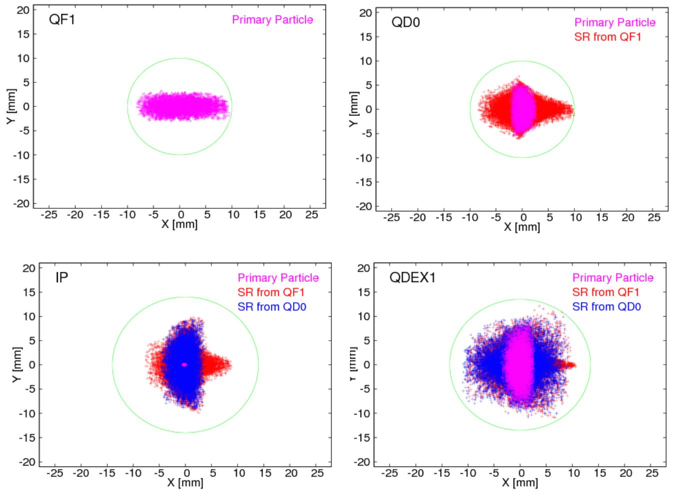
Beta functions around IP

Horizontal beam size at crab cavity is comparable to that at QF1.



BG sources

1) **Halo particles**
2) **SR, generated by halo particles at QF1**
3) **SR, generated by halo particles at QD0**



Summary of the crab cavity aperture

- *The collimation depth (aperture of the collimator relative to the beam size) should be large because the smaller the aperture of the collimator, the more halo particles are cut at the collimators and much number of the muon background is generated at the collimators.*

- *In the ILC present design, it is considered sufficient to install several donut spoilers in the beamline.*

- *However, if the amounts of muons increase more than now, we will need to install a larger muon wall, so the collimator diameter should be as large as possible.*

- *When the horizontal aperture of the crab cavity is smaller than 20mm diameter, the aperture of the crab cavity will limit the collimation depth (**14mm of the vertical aperture is acceptable for crab cavity**).*

Preparations for 2nd Design Workshop (22nd June 2022)

- Assess and compare CC EM designs, not likely finally optimised:
  - Cavity,
  - HOMs,
  - Couplers,
  - Multipacting,
  - Tuning.
- Clarifying then next steps to perform first CC down-selection on 27th Sept 2022:
  - All EM design aspects complete, including pressure stability and fabrication assessment.
  - Down-select 2 optimum CC designs for future prototype development (external review).
- Final CC down-selection, post-prototype validation at ~18-months later (Mar 2024).

Before the technology selection of Crab cavity,
it will be necessary for the BDS side to present guidelines on what to focus on by next spring.

Especially,

- ***Up to what energy must the crab cavity for the beam be contained in a 3.8 m space?***
- ***Contingency ?***