# *Requirements for the crab cavity from BDS*

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2022/02/16

Joint meeting of IDT WG2 crab cavity (WP-3) and BDS group

# *Requirements for the crab cavity from BDS*

***Fill in the table below** as the subject of today's meeting.*

***Requirements for the crab cavity from BDS***

<table>
<tr><th colspan="3"></th><th>Preferable</th><th>Requirement</th></tr>
<tr><td colspan="3">Flange to flange distance</td><td></td><td></td></tr>
<tr><td colspan="3">Horizontal aperture (full gap)</td><td></td><td></td></tr>
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<tr><td rowspan="2">Backup in beamline</td><td>RF source</td><td></td><td></td></tr>
<tr><td>cavity</td><td></td><td></td></tr>
</table>

- *When we change the design of other devices (especially for the final doublet packages), the requirements may also change.*
- *But for the requirement of crab cavity, we will not change the relationship with individual devices based on the present design.*

## *One more question from Peter*

***Question :***

*How much do need to detune CC if it is to be parked, suggestion of >1000 x BW proposed, seems too high. Can BDS team provide some indication of scaling for linac vs circular machine.*

***My personal answer :***

- *I also the number seems too much !*
- *The effect of wakefield is completely different for circular accelerator and beam transport line.*
- *In particular, since the beam energy of ILC is extremely high, the effect of wakefield on a single cavity is not that large, according to the results of past wakefield simulations of ILC BDS.*
- *There may be some orbit drift due to the long-range wakefield, but I believe that can be handled with intra-train IP feedback as well as active cavities.*
- *I think it is enough to have a small detune not to be stored an input RF in the cavity in case of parking.* ***I think it is sufficient to design the tuner considering only the RF aspect.***

***Give me the comments and objections, if you have !***

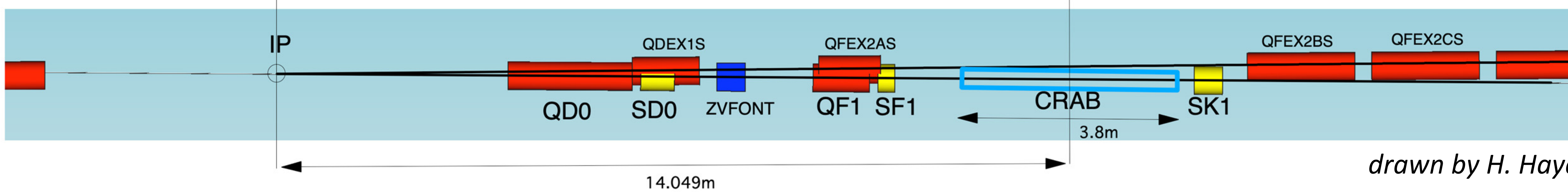
## ***Flange to flange distance***

# Exact length of the crab cavity space

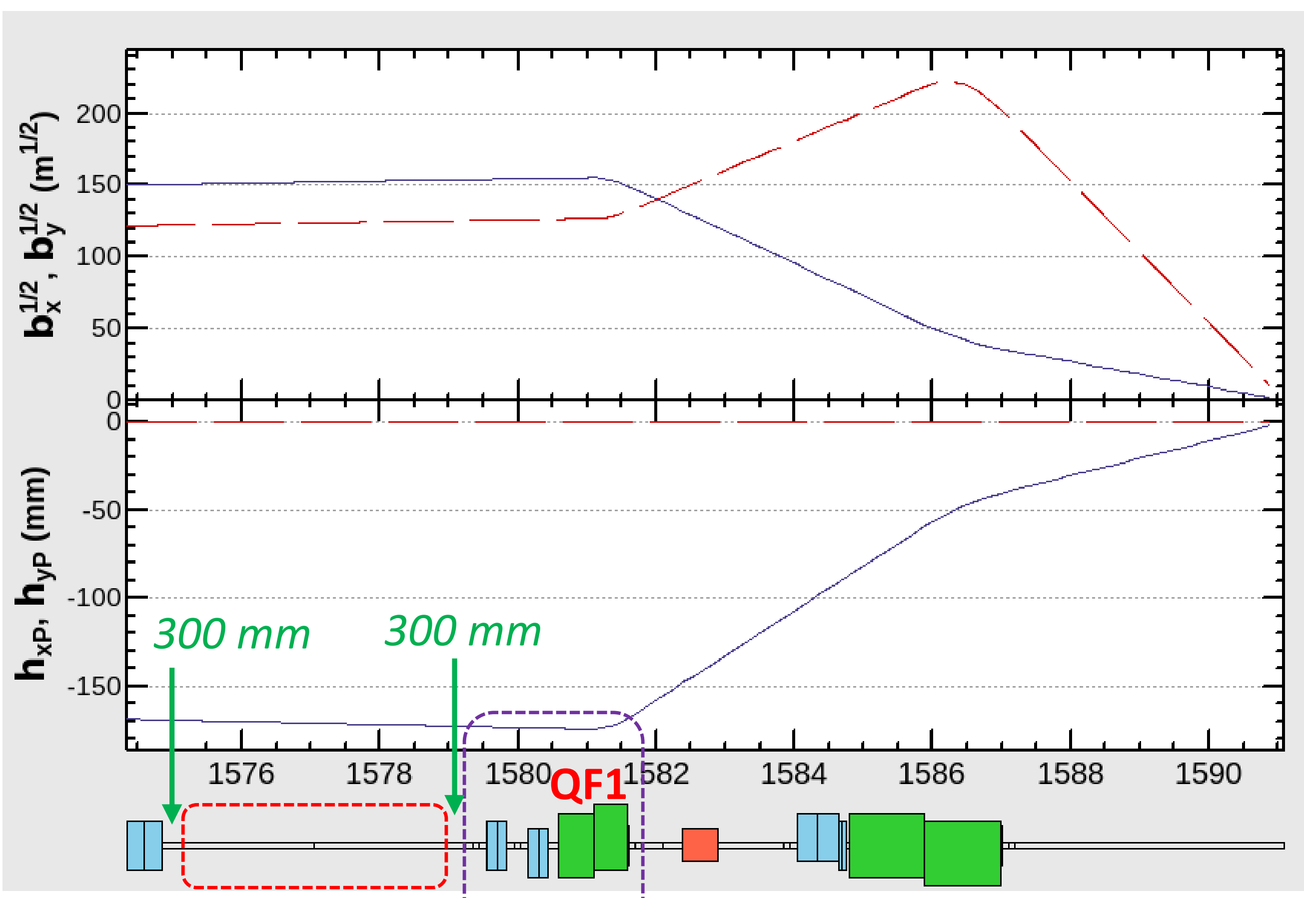
## Crab cavity space

*@Crab cavity meeting (2020/11/24)*

two beamline distance
14.05m x 0.014rad = 197mm




*drawn by H. Hayano*




Space for C.C.
3800 mm

SF1
OC1

*Space for QF1 cryomodule package*

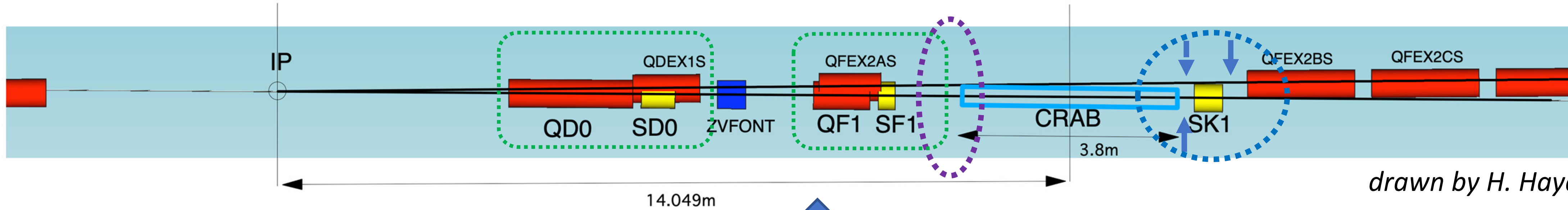
*Length between OC1 end to QF1 cryomostat end plate : 300 mm*

- *Although it is not included in the figure above, there is actually an octupole called OC1 between SF1 and the crab cavity. The magnet including OC1 is included in the QF1 cryostat package.*
- *In the present optics deck, **the distance from the end of OC1 to the end plate of the QF1 cryostat is 300mm**, and the space from there to the space of the crab cavity is also assumed to be 300mm.*
- *The distance from the space of the crab cavity to SK1 is also 300mm.*
- *Some ideas have been proposed, such as winding OC1 on top of SF1, but all present optics designs are based on the assumption of independent coils. The QF1 cryostat has possibility to be shortened in future, but we would like to consider it based on this drawing for now.*

## *Crab cavity space*

*@Crab cavity meeting (2020/11/24)*

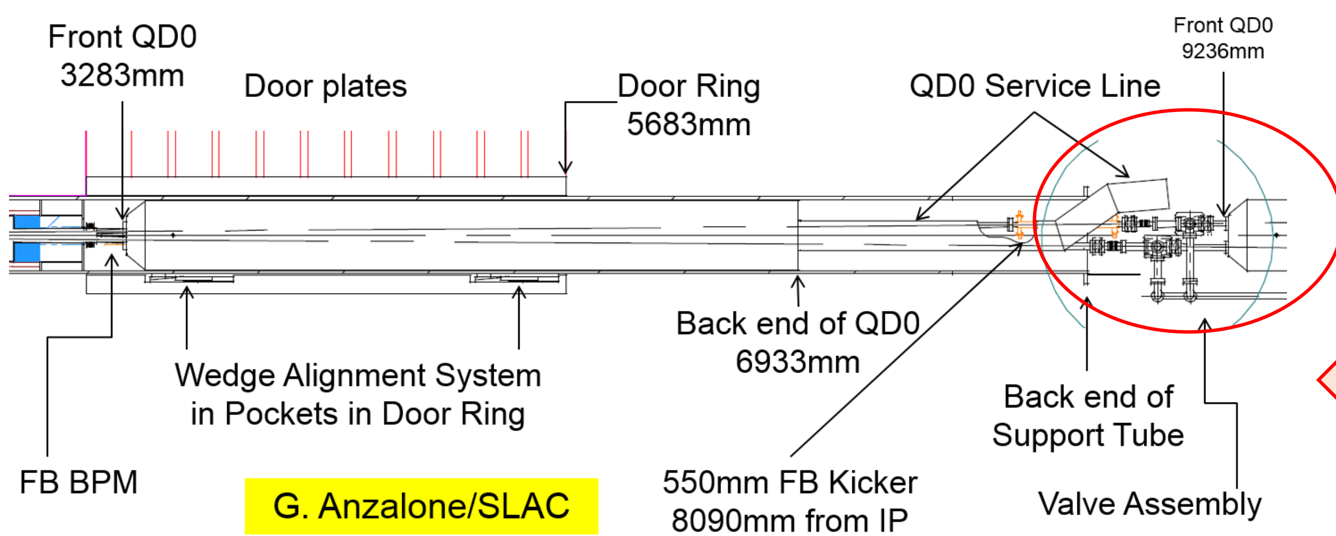
two beamline distance
14.05m x 0.014rad = 197mm




*drawn by H. Hayano*

### *Example : SiD design of QD0-QF1 cryostats connection*

*Tom Markiewicz/SLAC@MDI meeting (2014/09/05)*



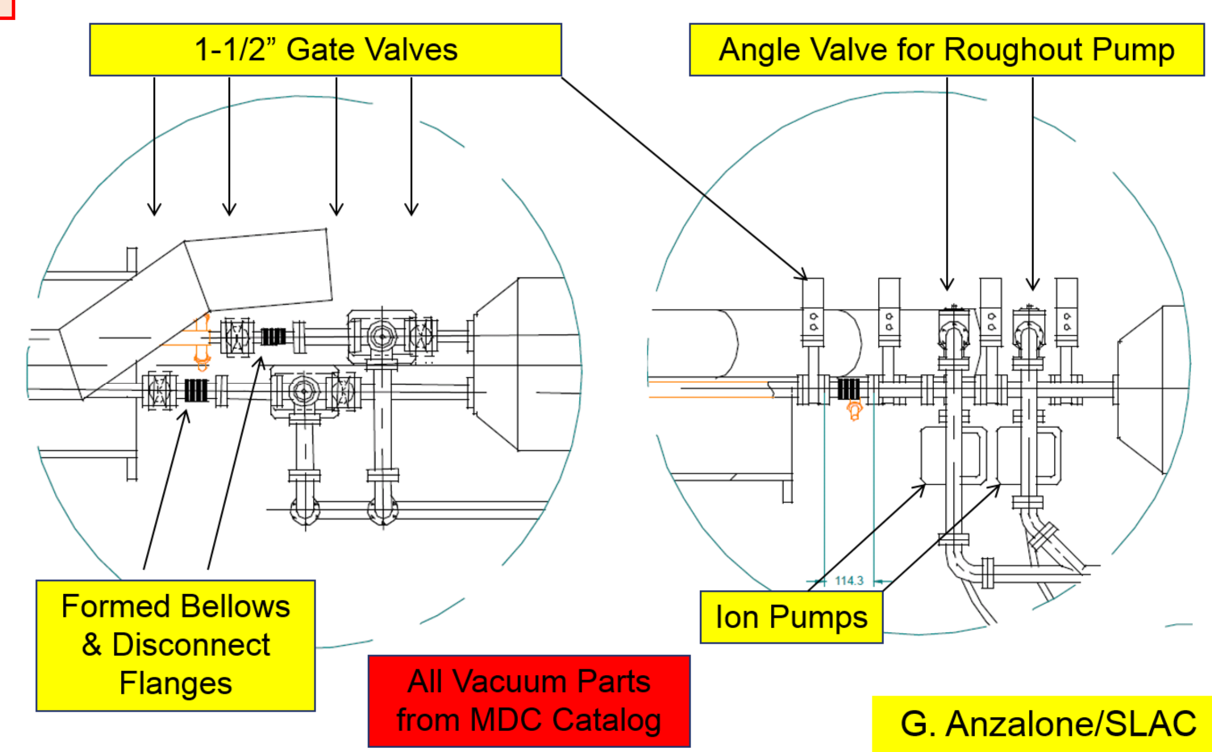

### *Length between C.C. cryostat end plate to SK1*

*no long vacuum tube for extraction line : at least 450 mm*

- 2 vacuum valves
- 2 bellows

*with long vacuum tube for extraction line : at least 300 mm*

- 1 vacuum valve
- 1 bellows




### *Warm section in between cryostats*

- 4 vacuum valves
- 2 bellows
- 2 vacuum pumps

***Length of warm section : 850 mm***

***Correction of the space upstream of the crab cavity***

- *300 mm => 850 mm*
- *The space in the crab cavity will be shortened by 550mm*

***Correction of the space downstream of the crab cavity***

- *If a long vacuum tube is attached to the cryostat of the crab cavity, and the valve on the take-out line side is moved downstream, the current configuration will fit.*

***Space of the crab cavity cryostat***

- ***3800 mm => 3250 mm***
- *Some ideas have been proposed, such as winding OC1 on top of SF1, but all present designs are based on the assumption of independent coils.*
- *If QF1 and crab cavity are placed in the same cryostat, it is possible to make the space longer by the amount of warm section, but it is safer to keep them independent for maintenance.*
- ***However, since we want to retain the ease of maintenance and the flexibility of the QF1cryostat design, we would like to consider something within 3.25m as a higher priority design at present stage.***

# *My proposal for crab cavity flange-to-flange distance*

### *Requirements for the crab cavity from BDS*

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- *The maximum energy requirement, which will be discussed later, will be based on this space length.*

## *Discussion*

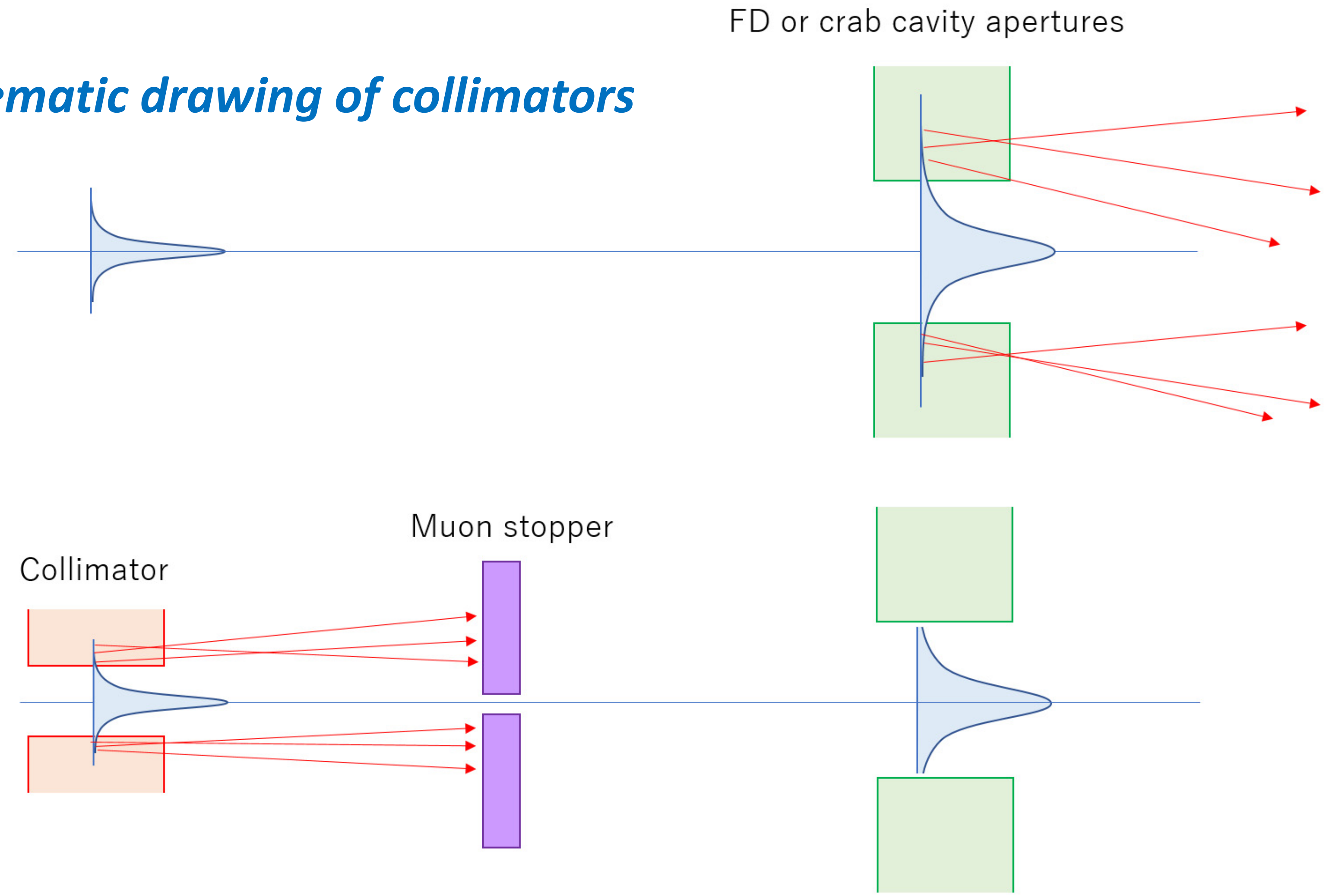
***Give me the comments and objections !***

## ***Horizontal aperture***

Considerations from beam collimation

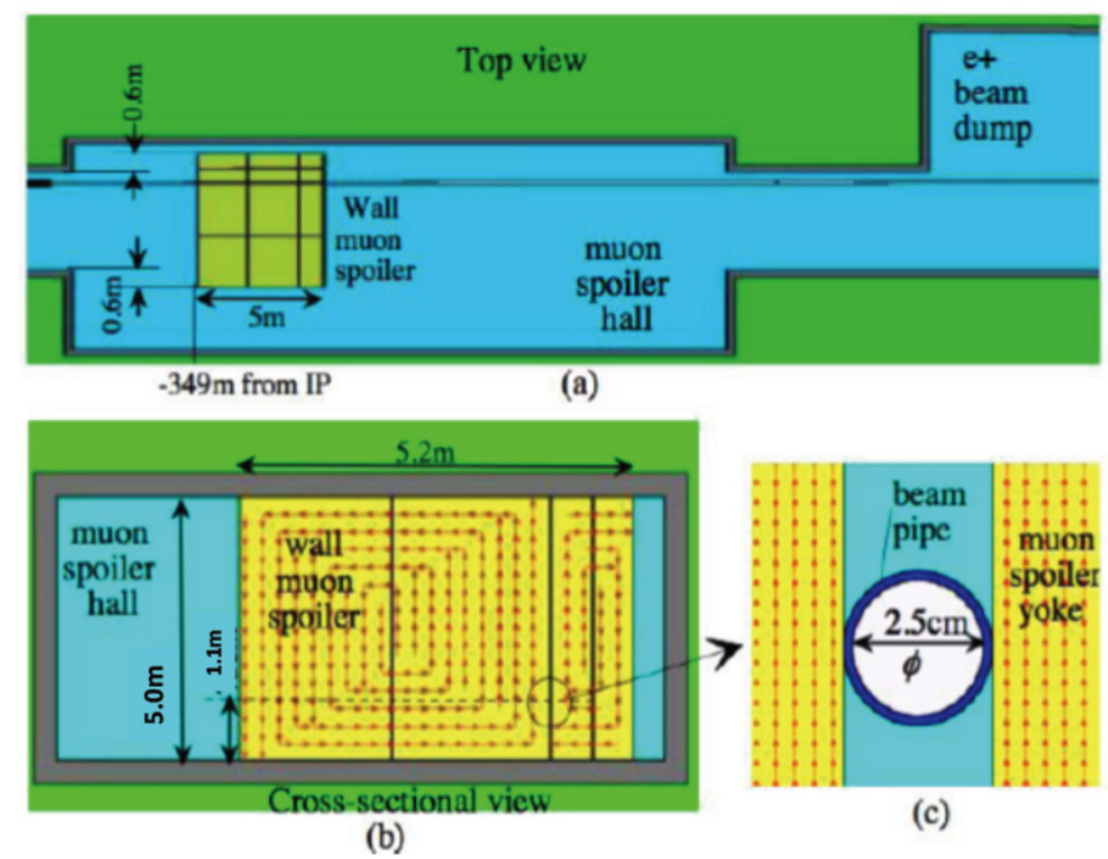
# Concepts of the ILC collimator system

## Schematic drawing of collimators

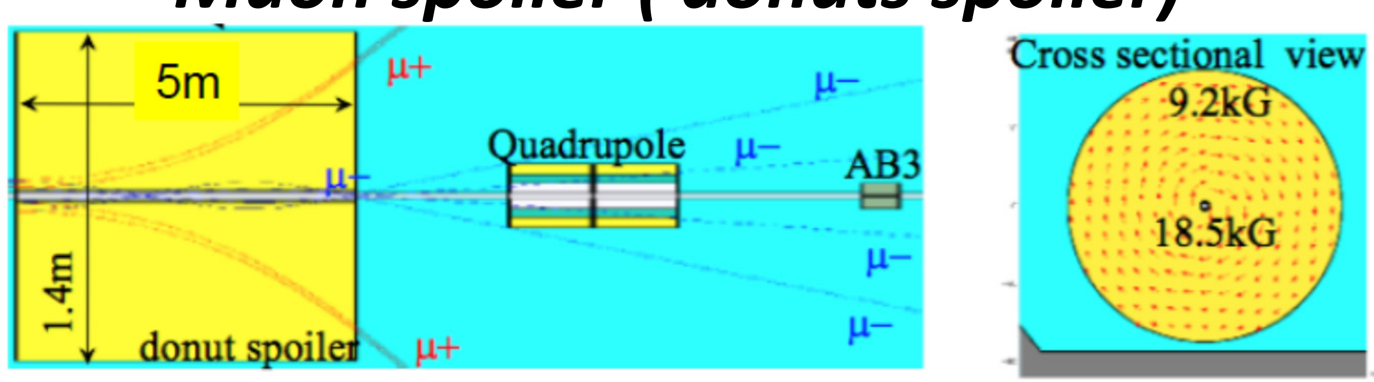



- In ILC, a collimator is placed upstream to prevent the beam halo from hitting the final doublet or crab cavity.
- Since the beam halo hitting the collimator produces a large amounts of secondary particles (muons, etc.), it is necessary to install a large muon stopper to prevent the muons from reaching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

## Muon wall




## Muon spoiler ( donuts spoiler)

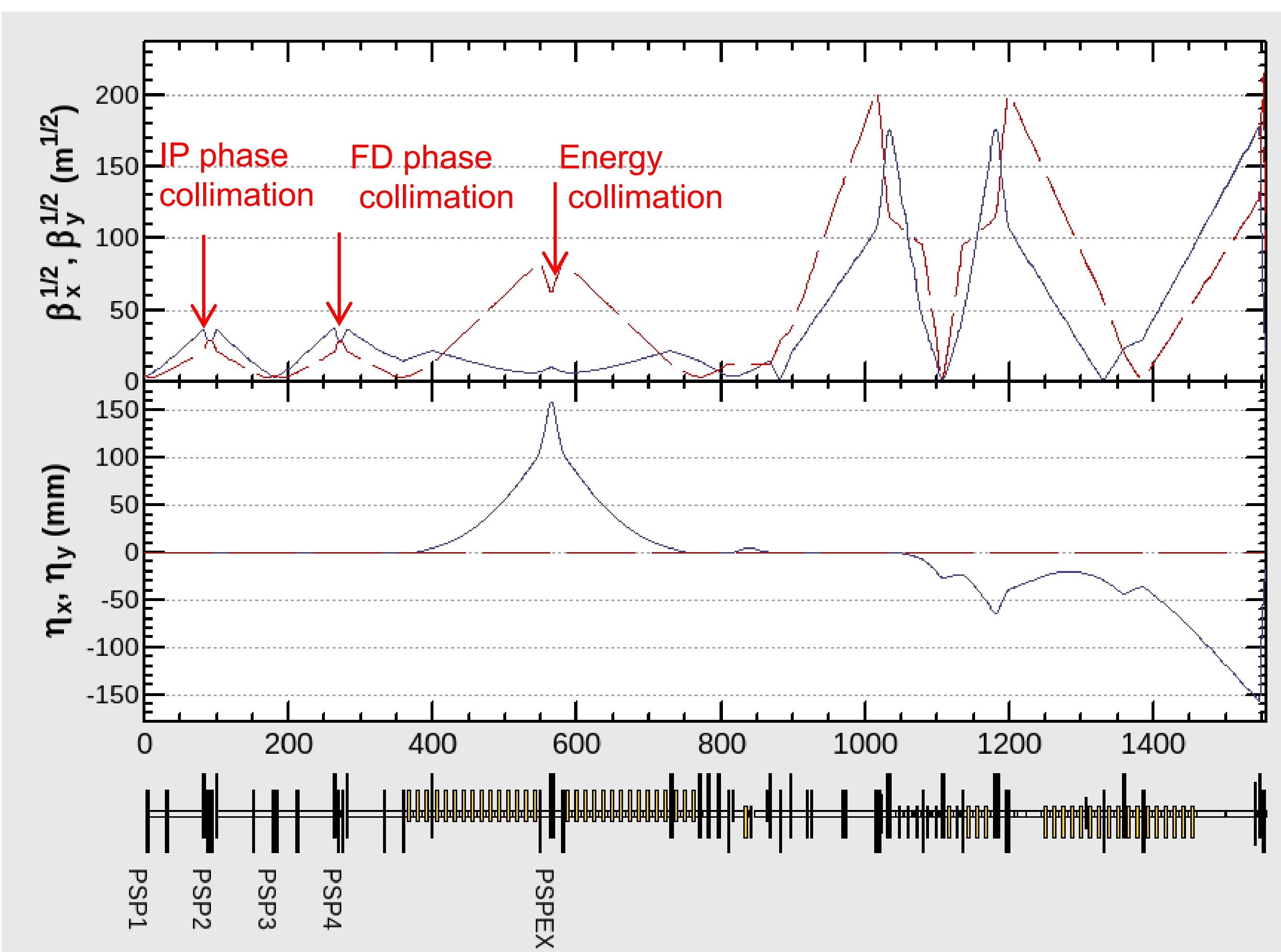


# Consideration of collimation depth

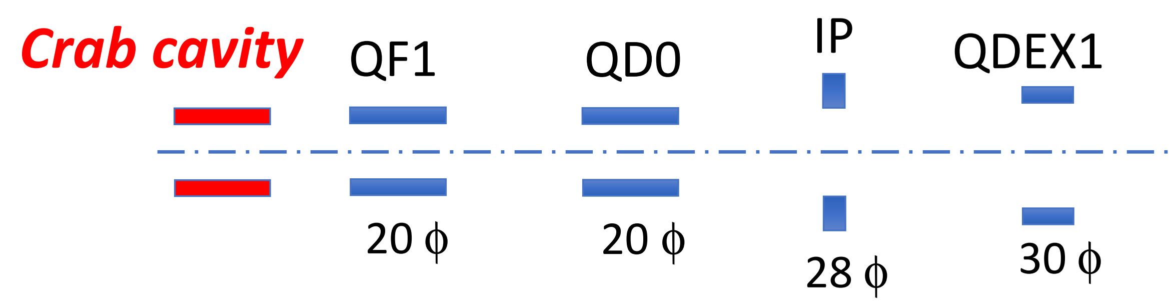
- *The aperture of ILC collimator is determined so that the halo particles and SR generated by the halo particles do not hit the SC device or inner detector.*
- *The collimation depth (aperture of the collimator relative to the beam size) should be larger because the more halo particles are cut at the 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 6$\sigma$ of the beam size horizontally.*

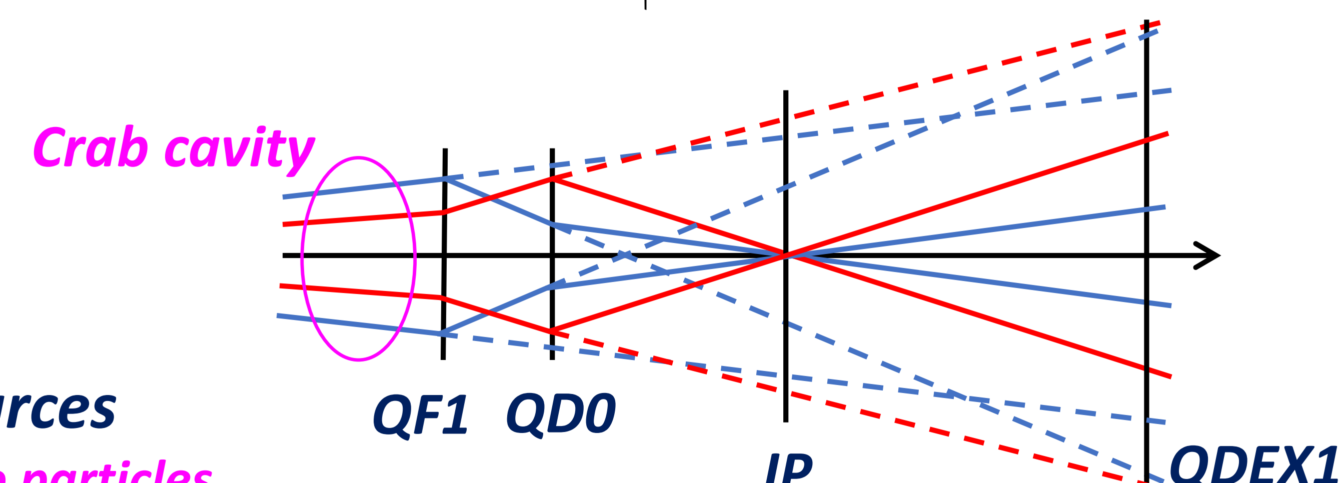
## Arrangement of the Collimators

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 = 0.150m




## Collimation depth are determined by the following apertures




## BG sources

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

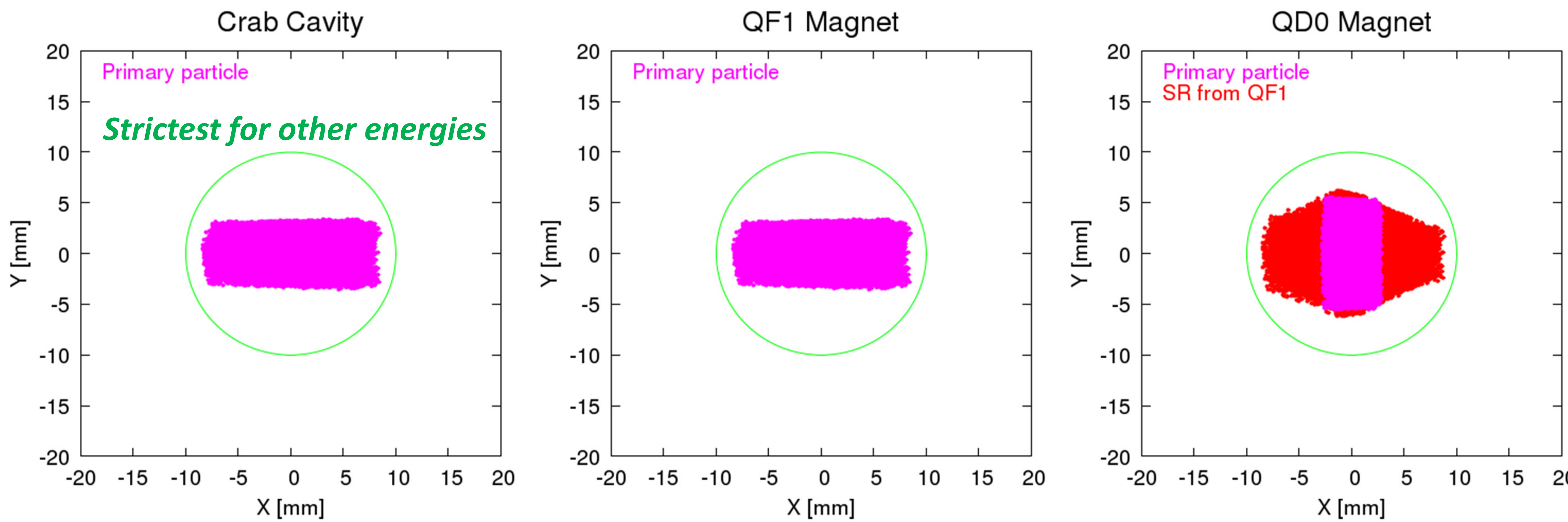
# *ILC IP parameters*

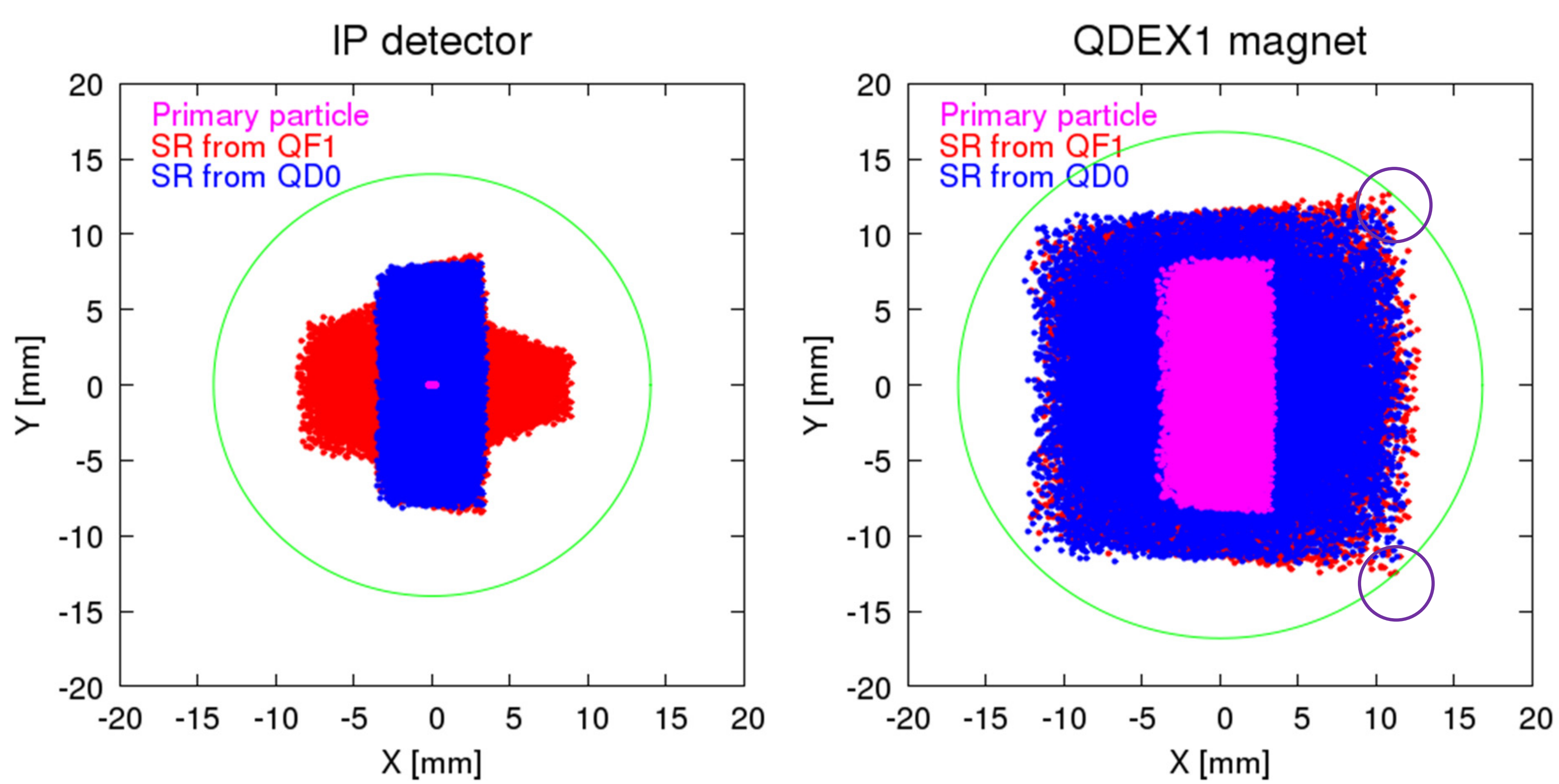
- *The luminosity values were modified from the TDR description in CR-5.*
- *In CR-16, the horizontal emittance was reduced for ECM=250 GeV operation (no other energies were discussed).*

| $E_{CM}$ [GeV] | 250 | | 350 | 500 |
|---|---|---|---|---|
| | **TDR** | **CR-16** | **TDR** | **TDR** |
| $\gamma\varepsilon_x$ [µm] | 10 | 5 | 10 | 10 |
| $\gamma\varepsilon_y$ [µm] | 0.035 | 0.035 | 0.035 | 0.035 |
| $\beta_x^*$ [mm] | 13 | 13 | 16 | 11 |
| $\beta_y^*$ [mm] | 0.41 | 0.41 | 0.34 | 0.48 |
| $\sigma_x^*$ [µm] | 0.729 | 0.515 | 0.684 | 0.474 |
| $\sigma_y^*$ [nm] | 7.66 | 7.66 | 5.89 | 5.86 |
| $D_x$ | 0.26 | 0.51 | 0.21 | 0.30 |
| $D_x$ | 24.50 | 34.50 | 24.30 | 24.57 |
| $\delta_{BS}$ [%] | 0.96 | 1.90 | 1.53 | 4.50 |
| $L$ [$\times 10^{34}$] | 0.82 | 1.35 | 1.00 | 1.79 |

**The collimation depths shown below are calculated based on the parameters of this latest ILC.**

# *Result of simulation for collimation depth evaluation (ECM=250GeV)*



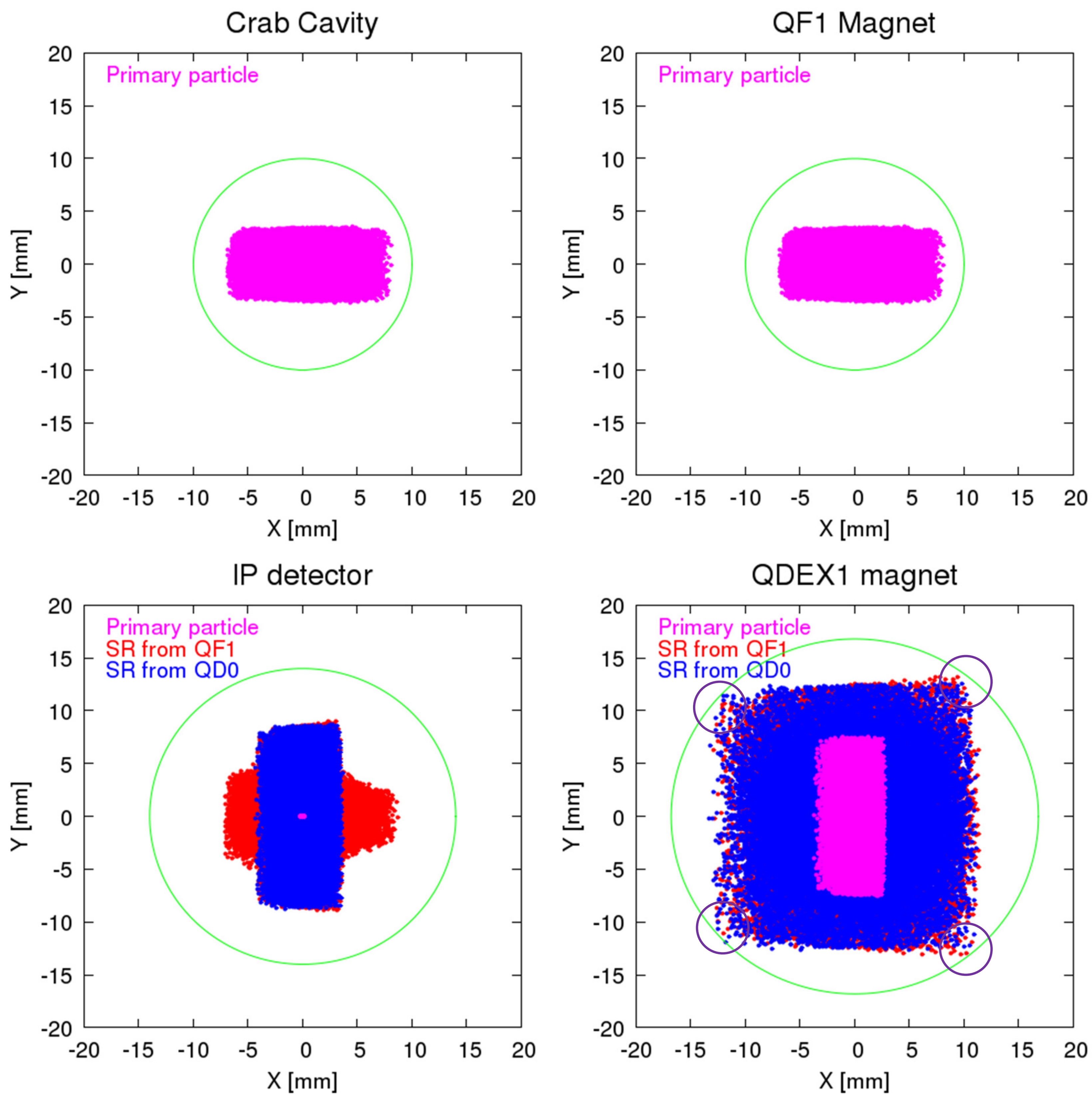

***Maximum collimator full aperture***

X : 3.06 mm

Y : 3.10 mm

- Collimator aperture is limited by SR from QF1 and QD0 to QDEX1
- The tightest apertures for the primary particle are the crab cavity and QF1.

# *Result of simulation for collimation depth evaluation (ECM=350GeV)*



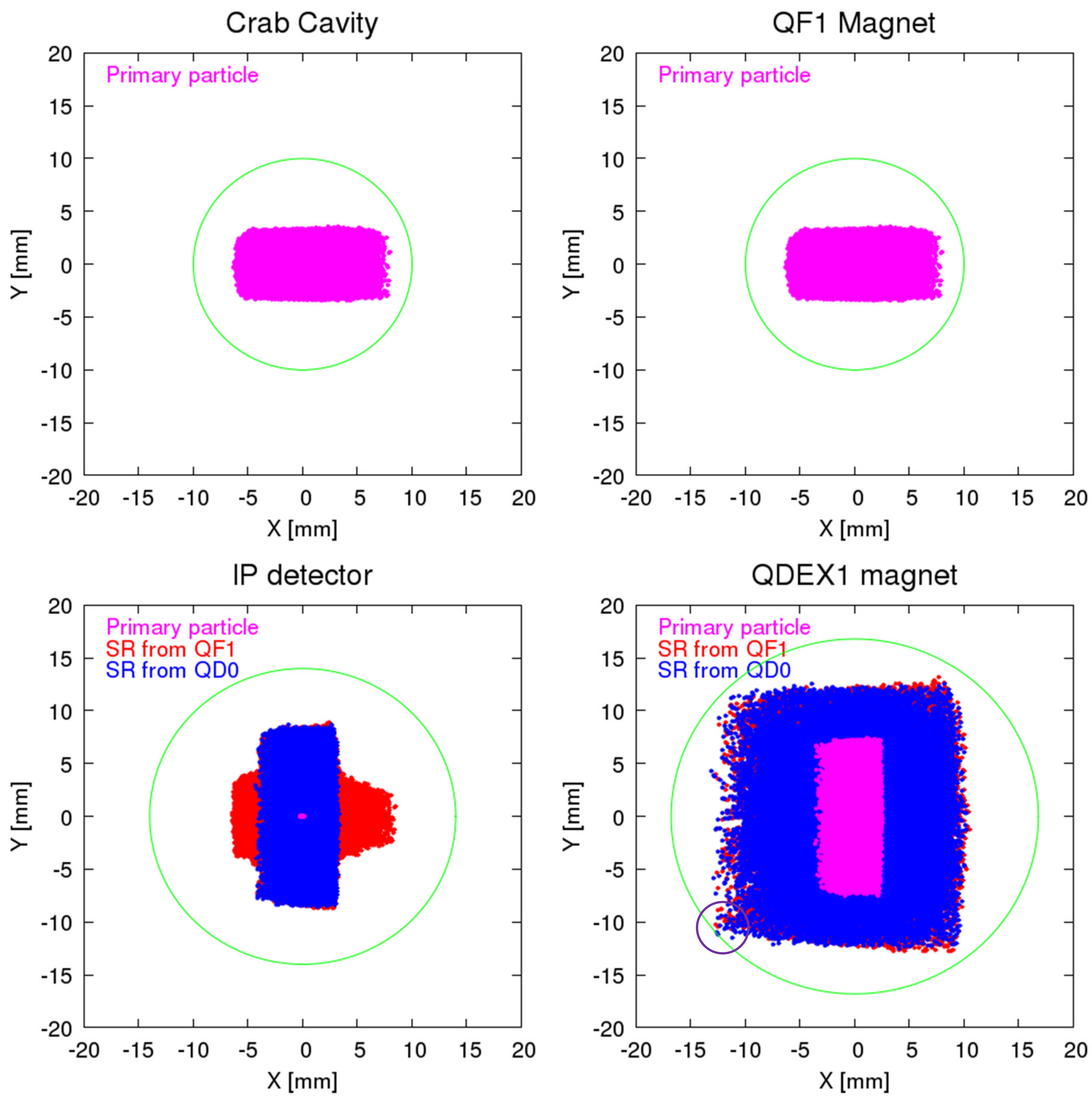

***Maximum collimator full aperture***

X : 2.74 mm

Y : 2.56 mm

- Collimator aperture is limited by SR from QF1 and QD0 to QDEX1
- The tightest apertures for the primary particle are the crab cavity and QF1.

# *Result of simulation for collimation depth evaluation (ECM=500GeV)*




***Maximum collimator full aperture***

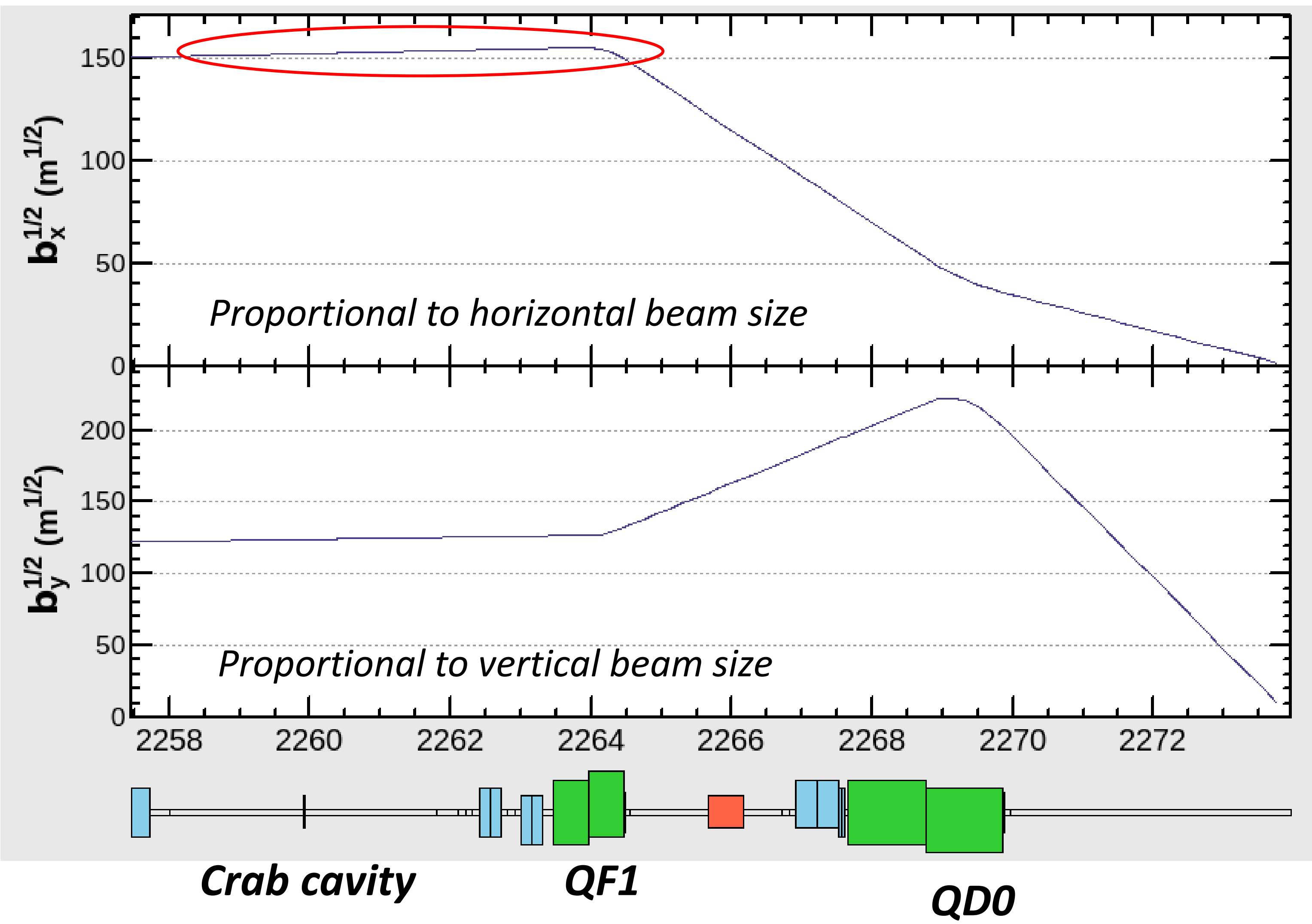
X : 2.06 mm

Y : 2.96 mm

- Collimator aperture is limited by SR from QF1 and QD0 to QDEX1
- The tightest apertures for the primary particle are the crab cavity and QF1.

# Halo particle at  crab cavity

### Beta functions around IP

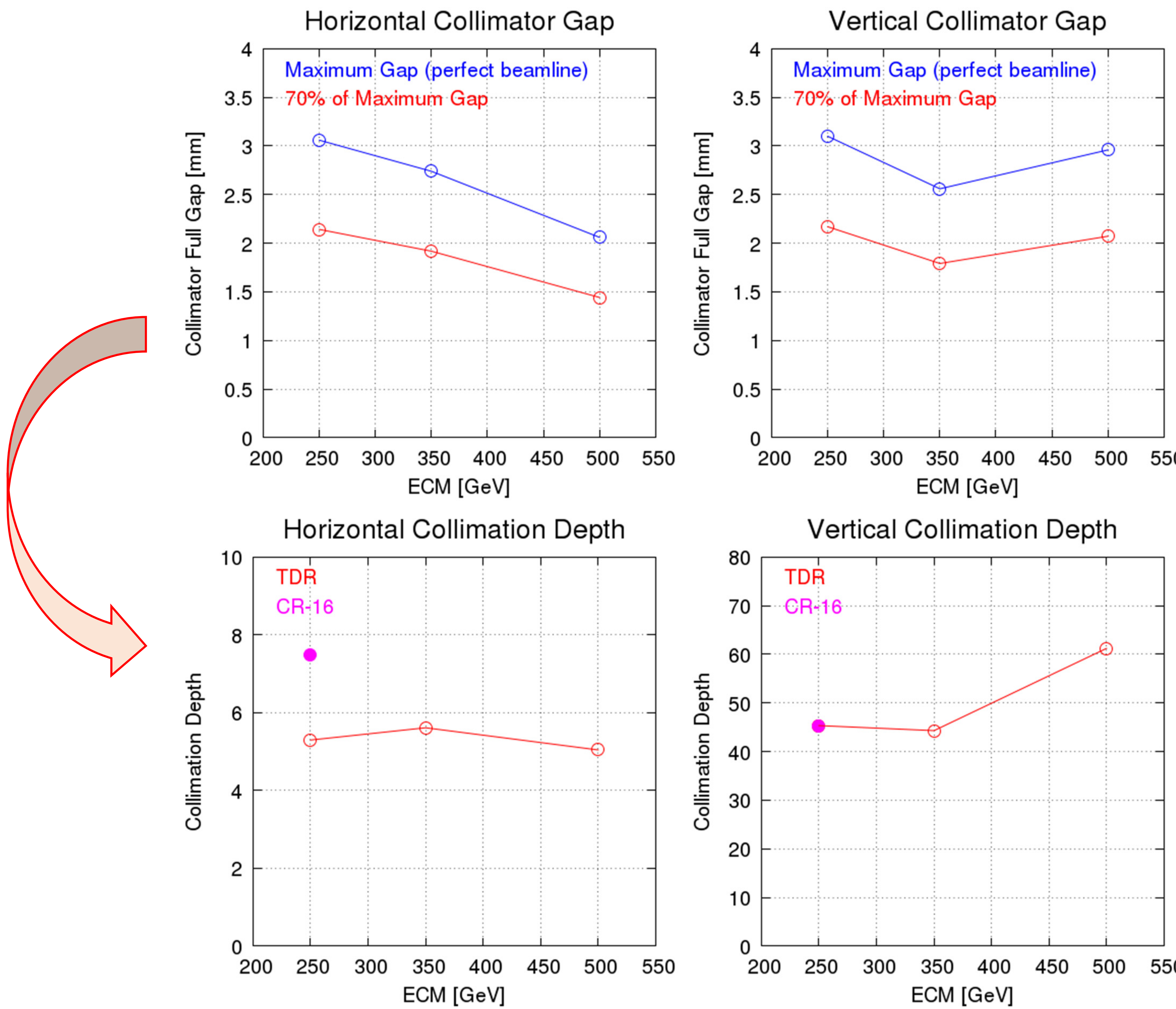



- *Since horizontal beam size at crab cavity is comparable to that at QF1, the distribution of halo particles in the horizontal direction is almost the same.*
- *Although the aperture of the Crab cavity and QF1 do not directly define the collimation depth,* ***the aperture of the Crab cavity and QF1 is not so generous when the collimator aperture is set  just not to hit the QDEX1****.*
- *Furthermore,* ***the tightest apertures for the primary particle are the crab cavity and QF1*** *for all beam energies.*
- *In the present design of the ILC, the diameter of the FD is 20mm up to ECM=500GeV.*
- ***From the point of view of the protection of the crab cavity****, it is not desirable to make the crab cavity narrower than the QF1.*

# *Summary of collimation depth for ILC BDS*

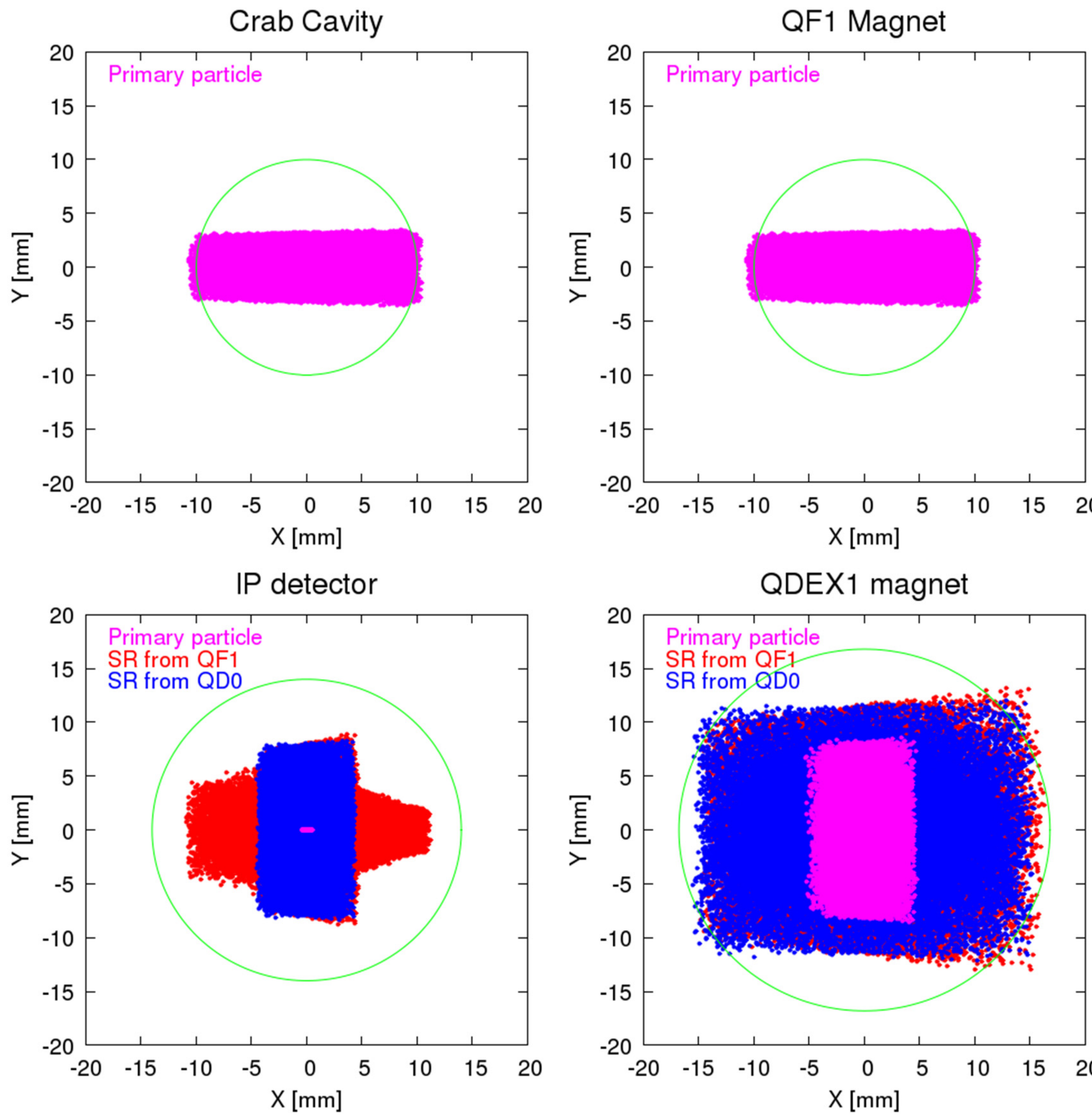
- *The collimation depth is calculated assuming that the collimator is assumed to be* ***30% narrower than the ideal aperture****, because the actual accelerator is affected by alignment errors and other non-ideal conditions.*

- *At ECM=250 GeV, the* ***horizontal emittance was reduced by half in CR-16****, so the collimation depth is larger than the other energies due to this effect (****the collimator aperture does not change even if the emittance is reduced****).*



# My homework ( last crab cavity meeting )

*When the collimator is set to 10 sigma, calculate the distribution of halo particles and synchrotron photons (ECM=250GeV).*




*At the present aperture setting, they hit all superconducting magnets, not just QDEX1.*

*Even if the aperture of the crab cavity is increased to satisfy this condition, the collimation depth will not be increased unless the apertures of the other superconducting magnets (QF1, QD0, QDEX1) are increased as well.*

- ***The optimization of the crab cavity parameters should be done within the range that does not affect other devices.***

*In addition,* ***the crab cavity is the strictest parameter for the primary particle along with QF1****, so it is better not to set the parameter too close to the limit.*

# *My proposal for horizontal aperture (ECM=250GeV)*

***Requirements for the crab cavity from BDS***

| | | | Preferable | Requirement |
|---|---|---|---|---|
| Flange to flange distance | | | | |
| **Horizontal aperture (full gap) at ECM=250 GeV** | | | **as large as possible (*)** | **≧ 20 mm diameter** |
| Maximum beam energy | | | | |
| Contingency | Field margin for max. beam energy | | | |
| | Backup in beamline | RF source | | |
| | | cavity | | |

*(*) as a point of view for the crab cavity protection*

***Horizontal aperture for higher beam energy***
***and***
***maximum beam energy***

# *ILC IP parameters for higher beam energy*

- *The actual specification of the parameters is not the subject of this meeting (**it should be discussed by other members such as ADI**).*
- *If we can achieve a horizontal emittance of 5um at ECM=250GeV, we should be able to find the best IP parameters for energies other than 250GeV, assuming the horizontal emittance at IP.*

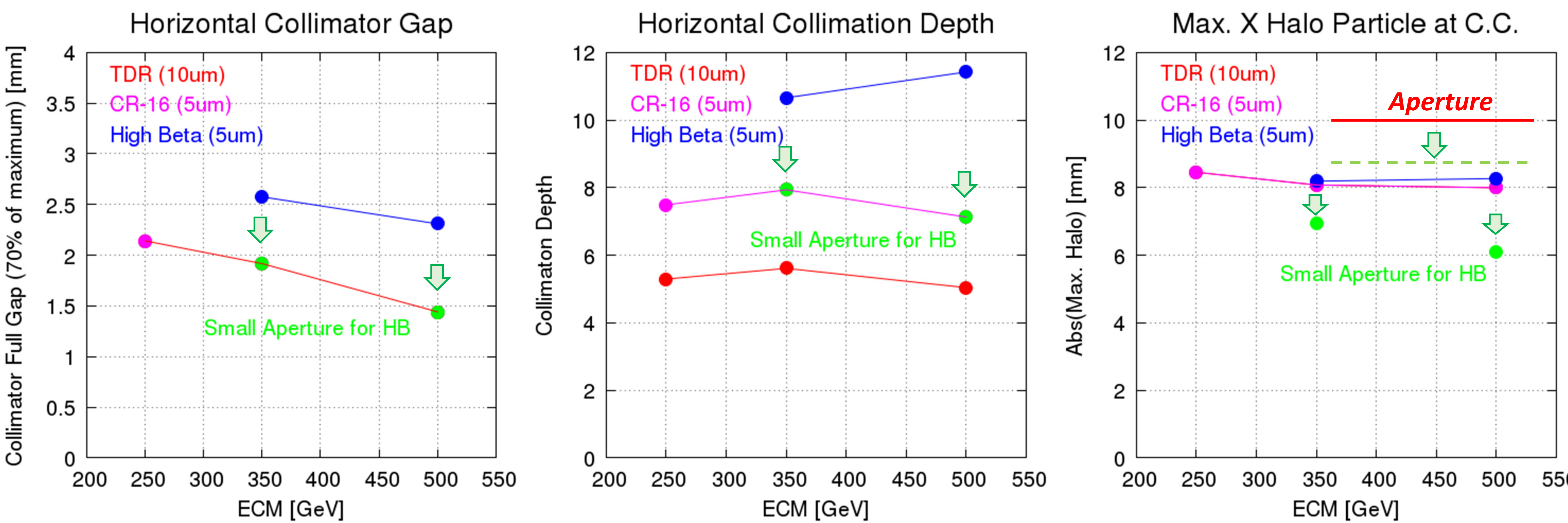
### *Lower horizontal emittance*

- *Luminosity is increased. (factor 1.6 for ECM=250GeV )*
- *Disruption is increased. => it makes collision (FB) difficult.*
- *Energy loss by beamstrahlung is increased. => Large energy spread at collision*

| $E_{CM}$ [GeV] | 250 | | 350 | | | 500 | | |
|---|---|---|---|---|---|---|---|---|
| | **TDR** | **CR-16** | **TDR** | **CR-16** | **High beta** | **TDR** | **CR-16** | **High beta** |
| $\gamma\varepsilon_x$ [μm] | 10 | 5 | 10 | 5 | 5 | 10 | 5 | 5 |
| $\gamma\varepsilon_y$ [μm] | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 |
| $\beta_x^*$ [mm] | 13 | 13 | 16 | 16 | 32 | 11 | 11 | 22 |
| $\beta_y^*$ [mm] | 0.41 | 0.41 | 0.34 | 0.34 | 0.34 | 0.48 | 0.48 | 0.48 |
| $\sigma_x^*$ [μm] | 0.729 | 0.515 | 0.684 | 0.483 | 0.684 | 0.474 | 0.335 | 0.474 |
| $\sigma_y^*$ [nm] | 7.66 | 7.66 | 5.89 | 5.89 | 5.89 | 5.86 | 5.86 | 5.86 |
| $D_x$ | 0.26 | 0.51 | 0.21 | 0.42 | 0.21 | 0.30 | 0.60 | 0.30 |
| $D_x$ | 24.50 | 34.50 | 24.30 | 34.24 | 24.30 | 24.57 | 34.57 | 24.57 |
| $\delta_{BS}$ [%] | 0.96 | 1.90 | 1.53 | 3.04 | 1.53 | 4.50 | 8.92 | 4.50 |
| $L$ [$\times 10^{34}$] | 0.82 | 1.35 | 1.00 | | | 1.79 | | |

# Yokoya-san's suggestion in the previous meeting

- *In high energy operation with a large horizontal beta function, the collimation depth becomes large, so it may be acceptable to reduce the collimator aperture up to a certain collimation depth.*
- *At that time, the spread of halo particles in the crab cavity will be smaller, so the aperture of the crab cavity can be reduced.*
- *Since 250 GeV and 500 GeV may have different requirements for the aperture of the crab cavity, we should design the technology for 250 GeV energy only at the first stage.*

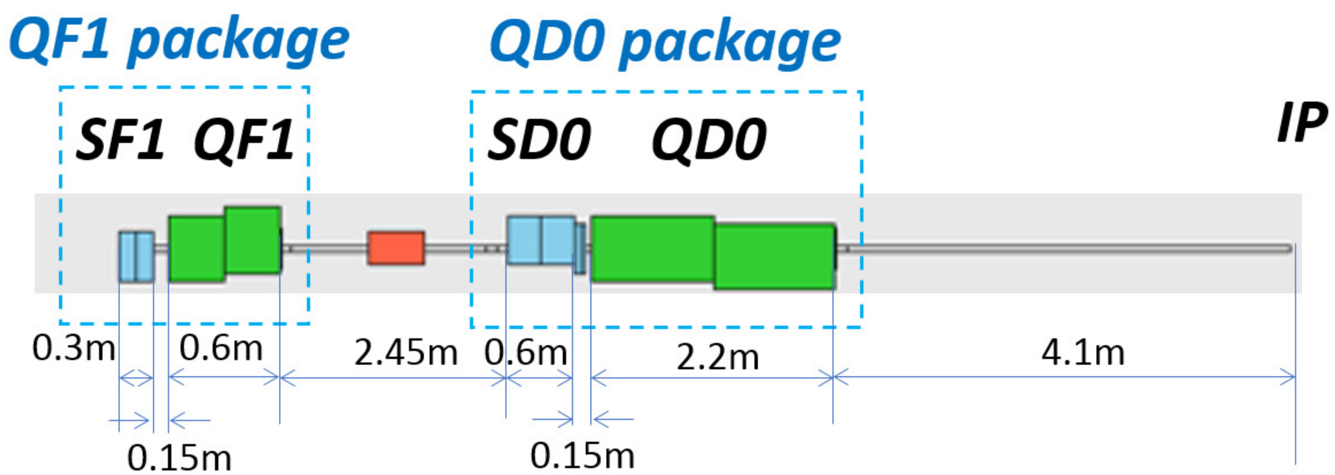



- *Tolerance of collimator setting*
- *Wakefield effect of collimator*
- *etc.*

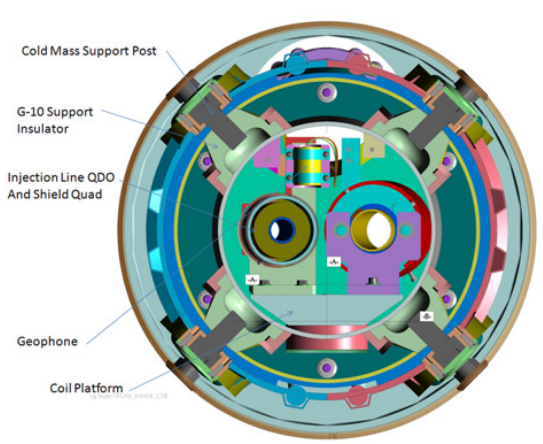
- *Amount of muon background (detector background)*

- *Safety margin to hit particles (protection of crab cavity)*

# Final doublt design




## QD0 Cryostat




***QD0 cryostat is the package of QD0, SD0 and extraction quadupole QDEX0.***

*Outer radius of the cryostat is 110mm.*

*Inner radius of beam pipe for QD0, SD0 is 10mm.*
*Inner radius of beam pipe for QDEX0 is 13mm.*

# Field strength of FD magnets

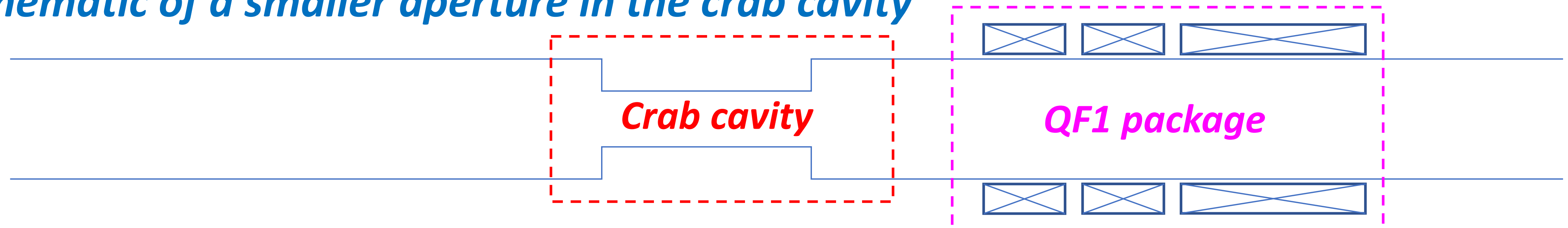
***List of FD magnets for (QF1 L*)=9.1m, (QD0 L*)=4.1m***

| $E_{CM}$ [GeV] | MAGNET | L* [m] | Length [m] | B [(1)] or 2B[(2)] | B at coil [T] (*) |
|---|---|---|---|---|---|
| 250 | QD0 | 4.10 | 1.10 | 124.23 | 1.739 |
| | SD0 | 6.45 | 0.60 | 2597.3 | 0.2545 |
| | QF1 | 9.10 | 0.50 | 134.81 | 1.887 |
| | SF1 | 10.25 | 0.30 | 2774.1 | 0.2719 |
| 500 | QD0 | 4.10 | 2.20 | 124.66 | 1.745 |
| | SD0 | 6.45 | 0.60 | 4310.5 | 0.4224 |
| | QF1 | 9.10 | 1.00 | 144.40 | 2.022 |
| | SF1 | 10.25 | 0.30 | 4395.5 | 0.4308 |
| 1000 | QD0 | 4.10 | 2.20 | 249.32 | 3.491 |
| | SD0 | 6.45 | 0.60 | 8563.0 | 0.8392 |
| | QF1 | 9.10 | 1.00 | 288.79 | 4.043 |
| | SF1 | 10.25 | 0.30 | 8892.1 | 0.8714 |

*(*) Evaluated with simple scaling with R=0.014m, actual field will be larger than this simple scaling*

- *The design of the Final doublet assumes that it can handle up to 500 GeV using the same magnets.*
- *However, I believe a significant modification is needed for 1TeV operation.*
- *So that we can handle the final doublet for any energy upgrade scenario up to about 500GeV.*
- ***As for the crab cavity, I think it is desirable to have a technology that assumes an energy upgrade to about 500 GeV.***

*Schematic of a smaller aperture in the crab cavity*




- In the present design of the ILC, the diameter of the FD is 20mm up to ECM=500GeV.
- When we adjust the beam, we make the collimator wider, so particles are more likely to hit where the aperture is narrower than others.
- **From the point of view of the protection of the crab cavity**, it is not desirable to make the crab cavity narrower than the FD.
- It is not decided (nor discussed) what IP parameter will be used except for ECM=250GeV (***It is not the focus point of today's discussion***).
- Even if any IP parameter is chosen,
  - ✓ ***The larger the collimation depth, the better***, because we do not know what kind of halo particle distribution the beam will have.
  - ✓ ***The larger the diameter of the collimator, the better.***

*I believe that the aperture of the crab cavity should be more than 20mm of the FD aperture up to 500GeV.*

# *My proposal for horizontal aperture and maximum beam energy*

- *The final doublet, which is a device designed for energy upgrade to 500 GeV, will be used from the first operation (250 GeV).*
- *Since the FD aperture is 20mm diameter up to 500GeV, **the crab cavity should not be less than 20mm from a protection standpoint.***
- ***The FD aperture design may change at higher energies, so there is no point in thinking about it now.***
- *As a minimum requirement, the corresponding energy of the crab cavity should be 250 GeV, but if it can be applied up to 500 GeV, it is desirable because **it can be used for any energy upgrade scenario up to 500 GeV**.*

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<tr><td colspan="3">Maximum beam energy</td><td>ECM 500 GeV</td><td>ECM 250 GeV</td></tr>
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*(*) as a point of view for the crab cavity protection*

***Contingency***

# *Basically, no idea for me*

- *I am not sure how much field margin should be provided for contingencies, as I do not have any expertise in this area.*
- *However, ILC accelerator has several devices such as FDs that have to be shut down if they fail, and I think the crab cavity is one of them, so I don't think we need to assume a backup in case of failure.*

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<tr><td rowspan="3">Contingency</td><td colspan="2">Field margin for max. beam energy</td><td>No idea</td><td>No idea</td></tr>
<tr><td rowspan="2">Backup in beamline</td><td>RF source</td><td>No idea</td><td>No idea</td></tr>
<tr><td>cavity</td><td>No idea</td><td>No idea</td></tr>
</table>

## *Discussion*

***Give me your comments !***

# Summary

## *Requirements for the crab cavity from BDS*

| | | | Preferable | Requirement |
|---|---|---|---|---|
| Flange to flange distance | | | 3.25 m | |
| Horizontal aperture (full gap) up to ECM=500GeV | | | as large as possible (*) | ≧ 20 mm diameter |
| Maximum beam energy | | | ECM 500 GeV | ECM 250 GeV |
| Contingency | Field margin for max. beam energy | | | |
| | Backup in beamline | RF source | | |
| | | cavity | | |

*(*) as a point of view for the crab cavity protection*