2nd Crab Cavity Meeting as joint meeting of BDS and SRF subgroups

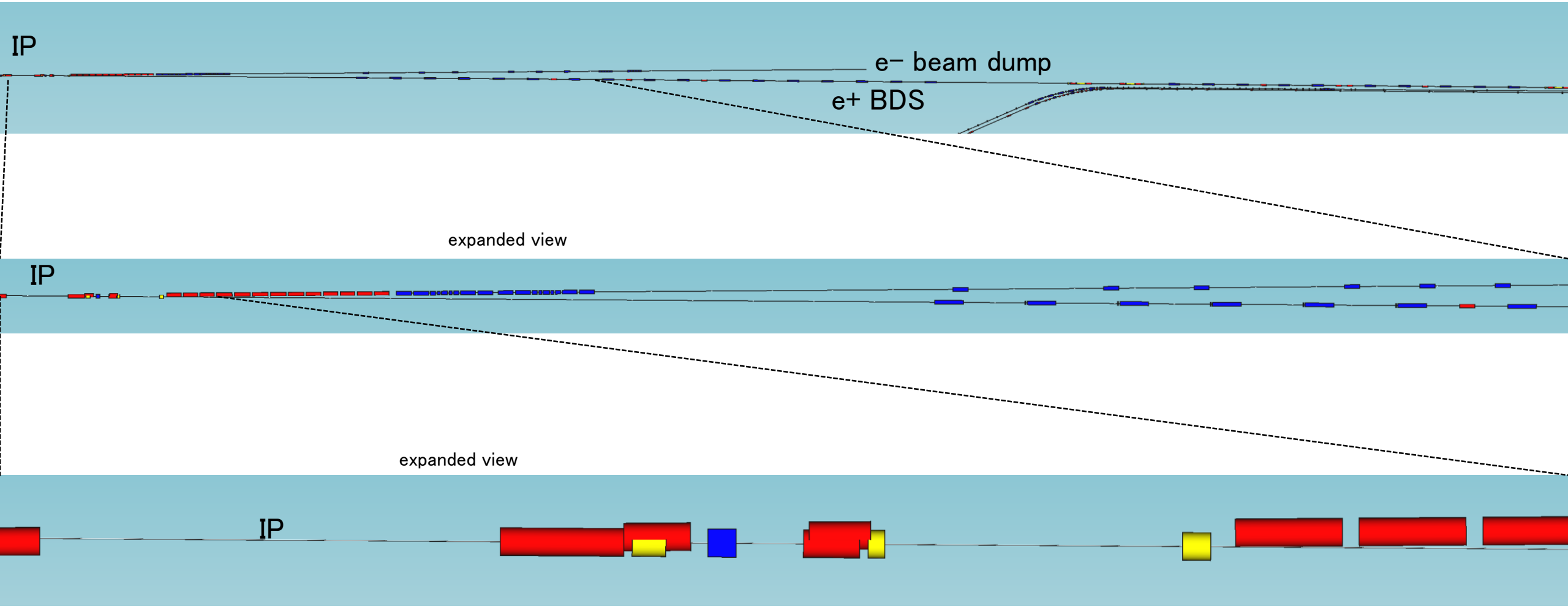
- ✓ Date/time: 30/Nov/2020 22:00~23:55 @JST

- ✓ Agenda:
  - ✓ Introduction
  - ✓ Presentations from Americas and Europe
    - ✓ Presentation by Graeme Burt (20 min)
    - ✓ Presentation by Robert Rimmer (20 min)
    - ✓ Presentation by Rama Calaga (5 min)
  - ✓ Discussions
    - ✓ Travelling focus
    - ✓ Installation space
    - ✓ Timing (may be not so significant)
    - ✓ Task list in technical preparation period
  - ✓ Next meeting

- ✓ Attendees: P. McIntosh, G. Burt, R. Calaga, B. Rimmer, J. Delayen, S. Posen, P. Burrows, A. Lankford, S. Michizono, A. Yamamoto, H. Hayano, Okugi-san, K. Yokoya, Kirk

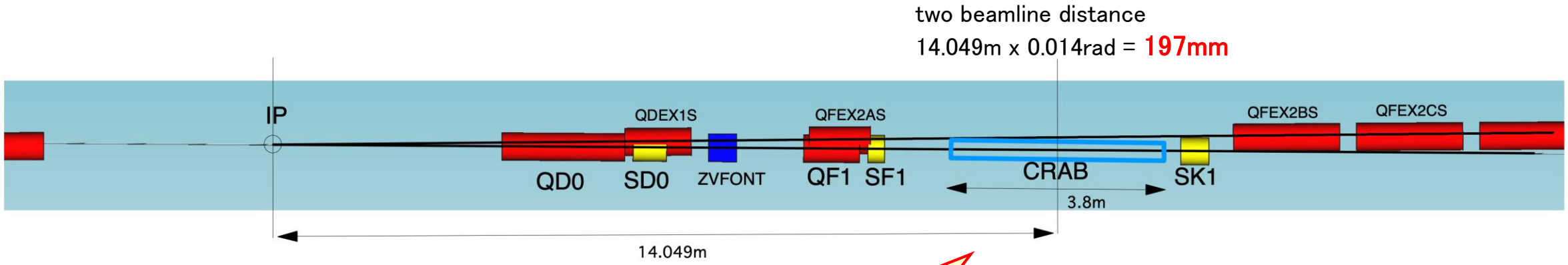
e+ BDS

H. Hayano



Crab cavity position

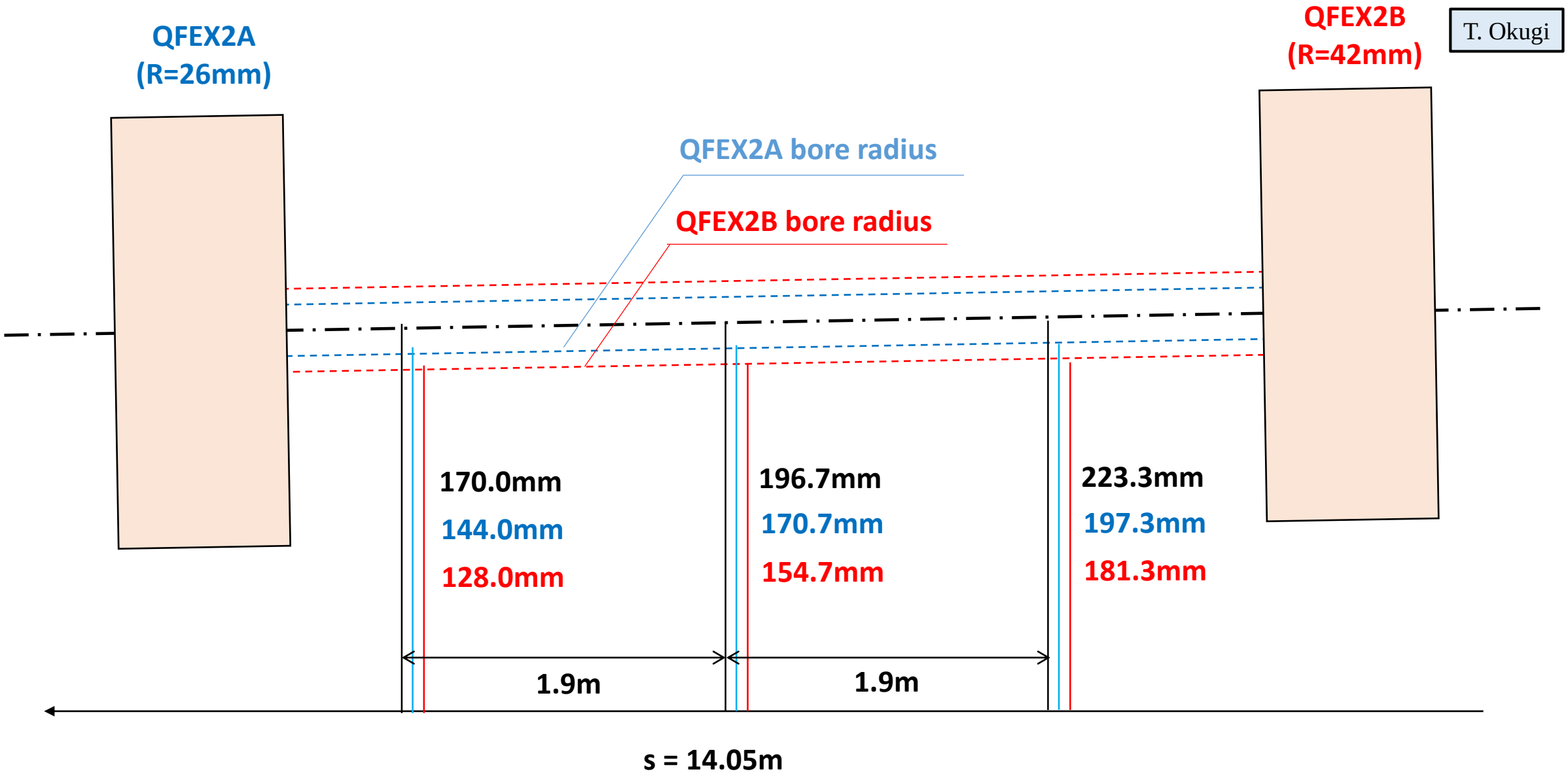
H. Hayano



Here is the original location presented in TDR.
But, there is too narrow space between two beam lines!
More detailed design is necessary.
It looks not impossible.

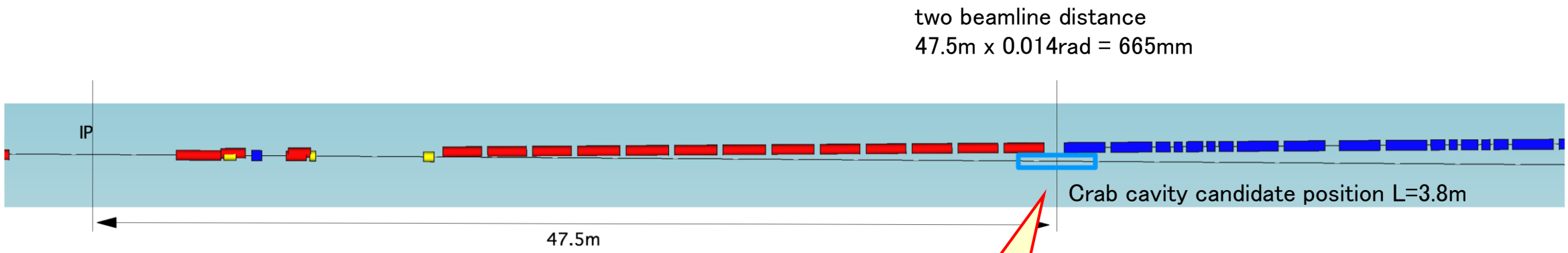
magnet symbol is not real scale.
it is just a symbol.
(logituinal length is scaled, width is not.)

Actual distance between two beam lines at 14 m site



H. Hayano

Crab cavity position : other candidate

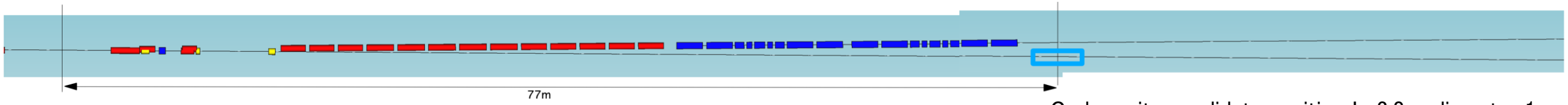


magnet symbol is not real scale.
it is just a symbol.
(logituinal length is scaled, width is not.)

H. Hayano

Crab cavity position : other candidate 2

two beamline distance
77m x 0.014rad = **1078mm**



Crab cavity candidate position L=3.8m, diameter 1m

Optional site

magnet symbol is not real scale.
it is just a symbol.
(logituinal length is scaled, width is not.)

Task list in technical preparation period

- ✓ Specification to be reconfirmed before design
- ✓ Decision of installation site, to be reconfirmed availability of cryogenics/RF stations
  - ✓ To be confirmed stabilization of reference signal/cavity phase
- ✓ Design of cavity, coupler, tuner, CM
- ✓ Production of cavity, coupler, tuner, CM
- ✓ Testing cavity, coupler, tuner
- ✓ Assembly of CM and test incl. harmonized operation with two cavities

And also, we have to put the budget request and human resources incl. FTE

Next meeting

From the next time, discussions on crab cavities will be held at SRF subgroup meeting.
If necessary, we will have a joint meeting with BDS.
Those who are interested are always welcome to participate.

22/Dec (Tue) ?

CERN is already shut down because of Christmas holidays

Questions/Discussions/Comments (memorandum) @2nd meeting

Translation by Kirk

- Presentations from UK, US, CERN
  - **3.9 GHz 9-cell cavity is still the baseline design for crab cavity as a good candidate**
  - **Two klystrons are available to drive two crab cavities as better RF control system**
  - RFD has lower R/Q, but not a major issue, may be available, stiffening is necessary for multi-cell design
  - JLEIC and EIC need crab cavity, various designs under consideration,
  - 1.3 GHz DQW is larger at 14 m site, 3.9 GHz may be available?
  - Damping LOM/SOM/HOM should be well-considered
- Travelling focus (problematic for only the other installation space than 14 m site)
  - Long discussions…
  - Phase stability tolerance?
- Installation space (not so challenging)
  - New information about actual distance between two beam lines at 14 m site
  - **14 m site is the best location not only timing but beam dynamics incl. travelling focus**
    - **Extraction line can go through the CM, as demonstrated at HL-LHC**
  - More compact design can be considered
  - 44 m and 77 m are optional
- Timing (not so significant)
  - 37 fs achievements in J-LAB, cable length is not clear
  - CERN can provide for HL-LHC crab cavity data
    - Several hundred meters available as optical link?
- Combination of cavity/CM/klystron as total RF system (electron/positron)
  - Two crab cavities (one cavity in each CM) driven by one klystron as baseline scheme (2/2/1)
  - Two cavities driven by two klystrons (2/2/2), Four cavities (dependence on kick voltage) driven by two klystrons (4/2/2), Four cavities with four CMs (if smaller-size CM is better) driven by two klystrons (4/4/2)
- Technical preparation period
  - How many CMs produced? One or Two? If one, two cavities installed into one CM? If two, one cavity installed into each?
  - Discussion is necessary, but it depends on the budget and human resources
- **3.9 GHz 9-cell cavity design is still the first candidate, the other designs are second**
- UK and US can lead the activity of crab cavity, similar to GDE era
  - For more detailed investigation of design, we need some students, and more funding
    - We can wait for the technical preparation period
    - UK and US will submit the budget request
  - CERN can also join, necessary to discuss with Steiner
- In next LCWS, we can/may have the session of crab cavity

Chats @2nd meeting

- Sam Posen: 10:29 PM
  - https://www.sciencedirect.com/science/article/pii/S1875389215015795
- Graeme Burt: 10:34 PM
  - The requirement was around 3 MV at 3.9 GHz so 9 MV at 1.3 GHz. And the required power was 2.5 kW per cavity. Sorry its been 12 years so I was struggling to remember
- Rama Calaga: 10:45 PM
  - WEPWO048 - IPAC13
- Sam Posen: 11:01 PM
  - I have to switch to another meeting, thanks everyone
- McIntosh, Peter (STFC,DL,AST): 11:27 PM
  - Apologies I have to leave, just wanted to mention that Steiner has scheduled an SRF technology meeting on Friday 4th with European interested groups, the meeting will also include an assessment of crab cavity/CM systems and groups who have an interest in contributing. I will send Steiner your proposed task list to incorporate in the discussion.
- Kirk: 11:28 PM
  - Thanks a lot, Peter.
- Rama Calaga: 11:31 PM
  - I agree

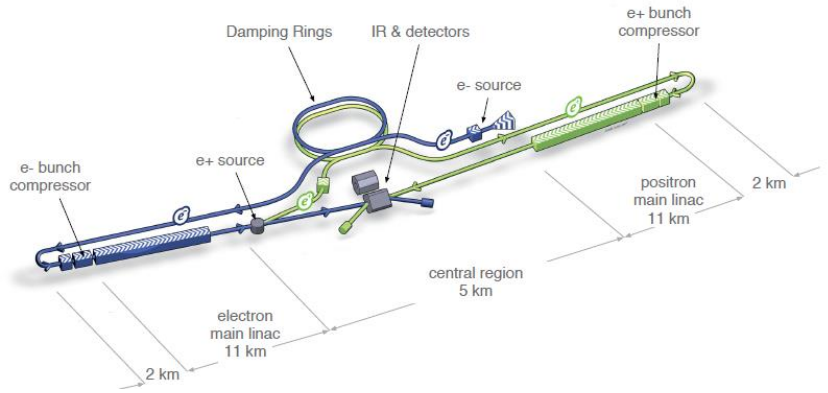
Recent specification for crab system after TDR

Item	Recent specification (after TDR)	
Beam energy	125 GeV (e^-)	
Crossing angle	**20 mrad**	
Installation site	14 m from IP	
RF repetition rate	5 Hz	
Bunch train length	727 μsec	
Bunch spacing	554 nsec	
Operational temperature	2.0 K (?)	
Cavity frequency	3.9 GHz	1.3 GHz
# of cell	9-cell	3-cell/9-cell (?)
Total kick voltage	0.615 MV	1.845 MV
Relative RF phase jitter	0.069 deg rms (49 fs rms)	0.023 deg rms (49 fs rms)

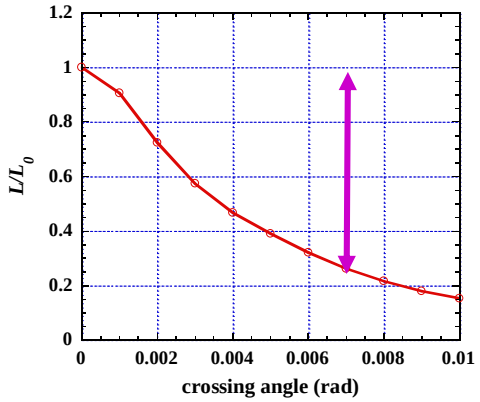
Backup slides

Introduction

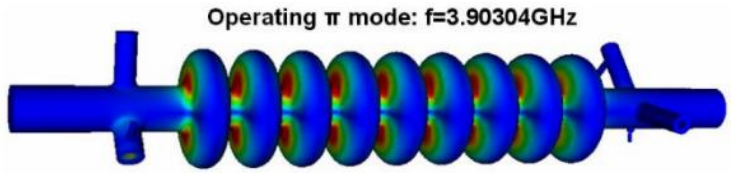
- Crab cavity system is indispensable for ILC
- No progress after TDR
- Prototype CM is necessary (Nomura Research Institute, Ltd. considered not-matured technology)
  - During the technical preparation period, prototype CM should be constructed and tested
  - Budget request is necessary (crab cavity is listed as third issue in SRF technical preparation)
    - **We have to complete the draft of budget request until 22/Dec**
- To be reconfirmed requirements from beam dynamics and timing by Okugi-san
- To be checked installation space based on the recent civil engineering design around IP and beam dynamics



ILC RDR parameter, by CAIN simulation



Cavity design presented in TDR



Not using crab cavities reduces luminosity by 80%!

Check items before cavity/cryomodule design

- ✓ Design optimized to “real” installation site
  - ✓ How much space can crab cavity use?
    - ✓ Magnets/beam monitors are symmetrically installed between electron and positron?
  - ✓ How to install CM into real site?
  - ✓ Cryogenics/RF distribution system are available?
    - ✓ Where are the cryogenic and RF stations around IP?
  - ✓ Need to investigate the impact on luminosity, especially 47 m/77 m site
    - ✓ Effect by SX magnet is not negligible
    - ✓ Beam simulation is still under progress
  - ✓ Requirements for timing
    - ✓ Driven by two klystrons based on the same RF reference signal may be available
    - ✓ Signal transfer is independent from length of optical fiber
    - ✓ To be checked the achievements in ERL at J-LAB

Requirement of the ILC crab cavity

Toshiyuki OKUGI, KEK

2020/11/24

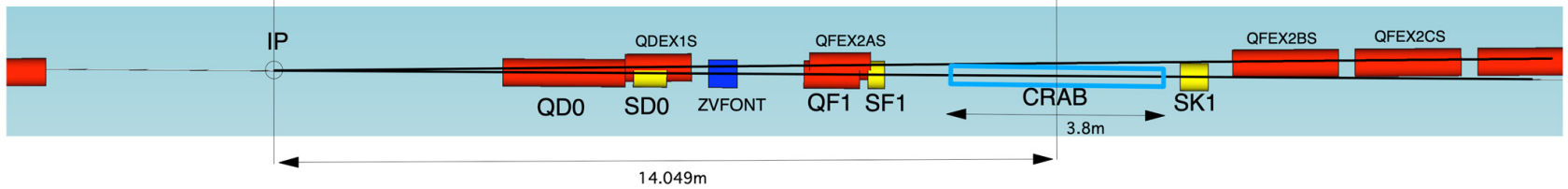
IDT WG2 SCRF, BDS joint subgroup meeting

Crab cavity location

T. Okugi

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

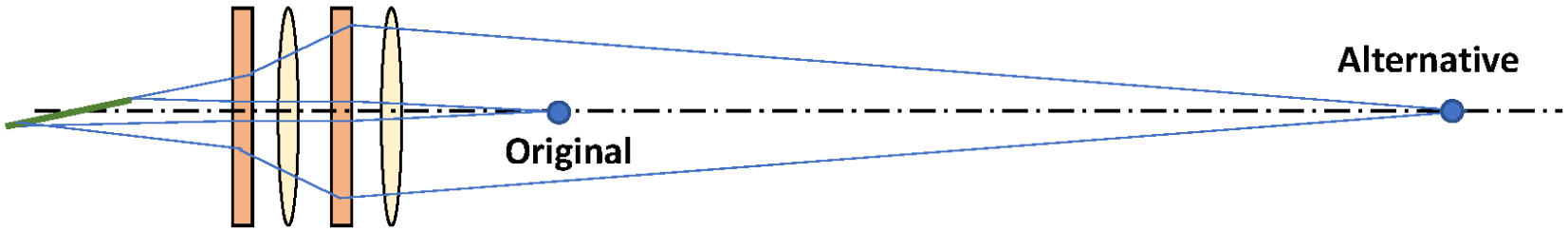
drawn by H. Hayano

- *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

T. Okugi



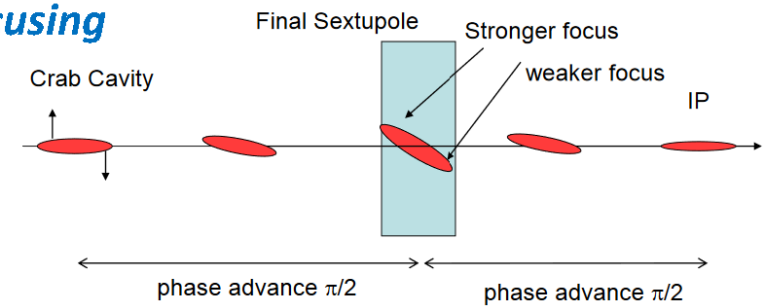
Horizontal beam orbit at FD was changed from the bunch head to the bunch tail

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

	z	Present			Alternative		
		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
	+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
	Luminosity reduction	0.5 % (geometrical)			16 % (geometrical)		↑

Weak focusing ⇕ Strong focusing

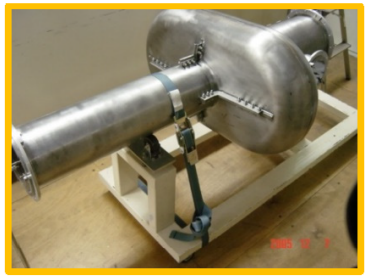
Traveling focusing



The luminosity for the alternative location will be increased that 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

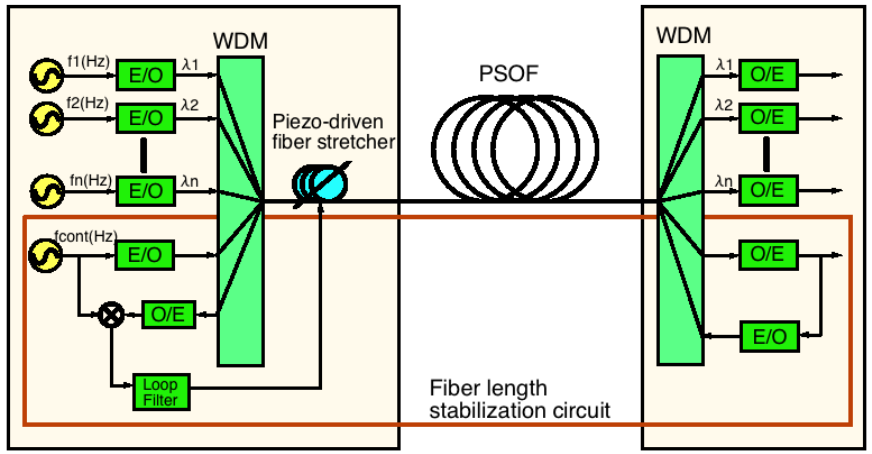
- ✓ *Since the requirement of the timing jitter is independent to the RF frequency,* ***the requirement of the phase jitter is severe for the lower frequency.***

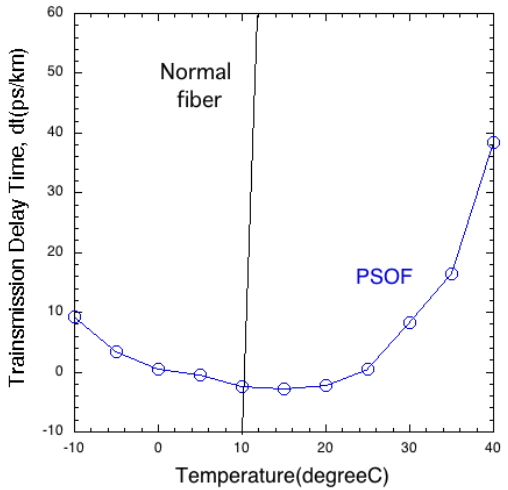
Frequency		3.9 GHz	1.3 GHz	
# of cell		9 cell	3 cell	9 cell
Total length (pi/2 mode)		0.346 m	0.346 m	1.038 m
Total kick voltage	***Present location***	0.615 MV	1.845 MV	
	Alternative (s=77m)	0.878 MV	2.633 MV	
Cavity gradient	***Present location***	8.14 MV/m	24.4 MV/m	8.14 MV/m
	Alternative (s=77m)	11.6 MV/m	34.9 MV/m	11.6 MV/m
Relative RF phase jitter		0.069 deg rms. (49 fs rms.)	0.023 deg rms. (49 fs rms.)	

Reference Line Stabilization

T.Naito

Reference signal distribution using PSOF and phase feedback

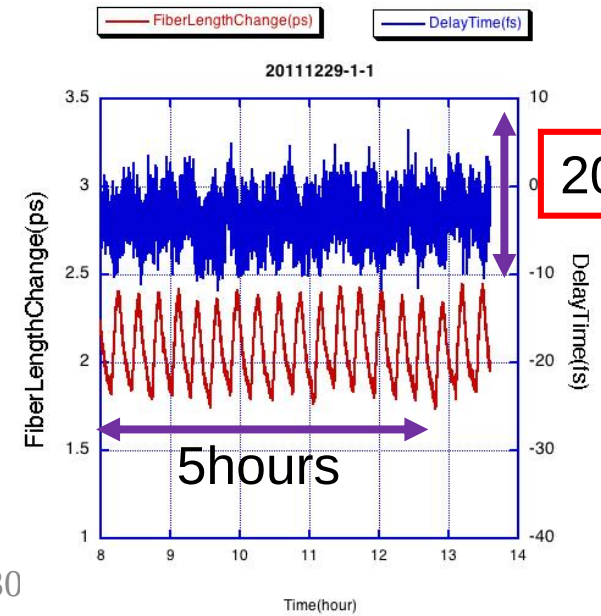




Phase stabilized optical fiber(PSOF)
5ps/km/degC

Requirements:
- Stability of reference signals between electron and positron crab cavities
- Phase stability in each cavity

Achievements:
- 20 fs (peak-to-peak) achieved
- From viewpoint of 3.9 GHz LLRF,
  0.1° (70 fs) → no problem
  0.01° (7 fs) → probably no problem



S-band(2856MHz) signal transmission test:
Red line shows the fiber length change and Blue line shows the timing change at the output. The signal could keep the stability less than 20fs.

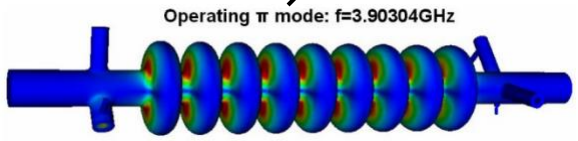
If we use 1.3 GHz crab cavity, these requirements will be more relaxed

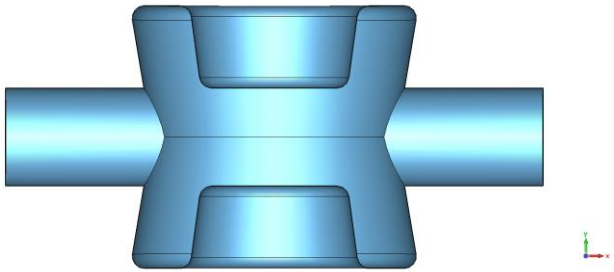
Next meeting

We will have the next meeting (2 hours!) on **30/Nov (Mon)**.
22:00@Japan, 14:00@EU Central, 13:00@UK, 8:00@US Eastern, 7:00@US Central, 5:00@US Pacific

Are you convenient?

Please consider whether each type of crab cavity can be installed in each installation location (14, 47, 77 m)





Courtesy of Rama-san

New idea?

Questions/Discussions/Comments (memorandum) @1st meeting

Translation by Kirk

- Japan was involved with crab cavity in TDR around 2012?
  - No. At that time, UK and US teams were responsible for that
- About luminosity degradation
  - How about β function, bunch length, dispersion at crab cavity?
  - Still don't understand why luminosity is so degraded
  - More simulation is necessary to check it
- Two crab cavities for electron and positron are simultaneously driven by **one** klystron. If the distance between them is too far, timing for harmonization would become difficult. At present, 14 m site is the best. 20 fs is not so easy for 3.9 GHz.
  - **It looks available even in 3.9 GHz from KEK's investigation**
- 14 m site
  - It looks available for installation of crab cavity, if the optimized re-design is done. Recently, a lot of designs are considered for application of crab cavity. It may be possible.

- Next meeting
  - Everybody is convenient on 30/Nov
  - Necessary to sort out the issues
  - Necessary to make the draft of budget request
  - FNAL and J-LAB will join, of course other laboratory is welcome
  - **If you have any idea and suggestion, please send us them by e-mail before the meeting**