LHC-Crab Cavity R&D

KEK activities of the past one year

and

future prospects

Yoshiyuki Morita, KEK

Outline

- Drastic design change of Super-KEKB
  - High current option to nano-beam option
- LHC crab crossing for luminosity increase
- Crab cavity for LHC, design and construction
  - Baseline design for global crabbing
  - Compact crab cavity for local crabbing
  - Fabrication, surface treatments, cold tests, etc.
- Beam tests for LHC at KEKB
  - Crab noise tests and simulations
  - x-z coupling test
- Beam tests at SPS with KEKB-Crab
  - Transport our crab cavities to CERN
  - Beam test at SPS
- Future prospects

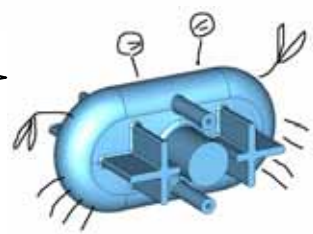
Drastic design change of Super-KEKB
High current option to nano-beam option

Beam Parameters

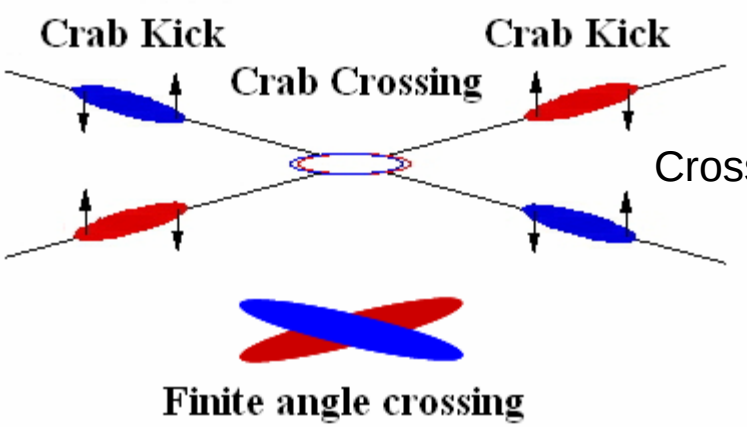
Koiso-san, MAC2010

	KEKB Design	KEKB Achieved : with crab	SuperKEKB High-Current	SuperKEKB Nano-Beam
Energy (GeV) (LER/HER)	3.5/8.0	3.5/8.0	3.5/8.0	4.0/7.0
β_y^* (mm)	10/10	5.9/5.9	3/6	0.27/0.42
ε_x (nm)	18/18	18/24	24/18	3.2/2.4
σ_y(μm)	1.9	0.94	0.85/0.73	0.059
ξ_y	0.052	0.129/0.090	0.3/0.51	0.09/0.09
σ_z (mm)	4	~ 6	5/3	6/5
I_{beam} (A)	2.6/1.1	1.64/1.19	9.4/4.1	3.6/2.6
$N_{bunches}$	5000	1584	5000	2503
Luminosity (10^{34} cm^{-2} s^{-1})	1	2.11	53	80

We have designed a new crab cavity for high current applications. However the nano-beam option needs no crabs.



LHC crab crossing
Geometric luminosity reduction of finite angle crossing

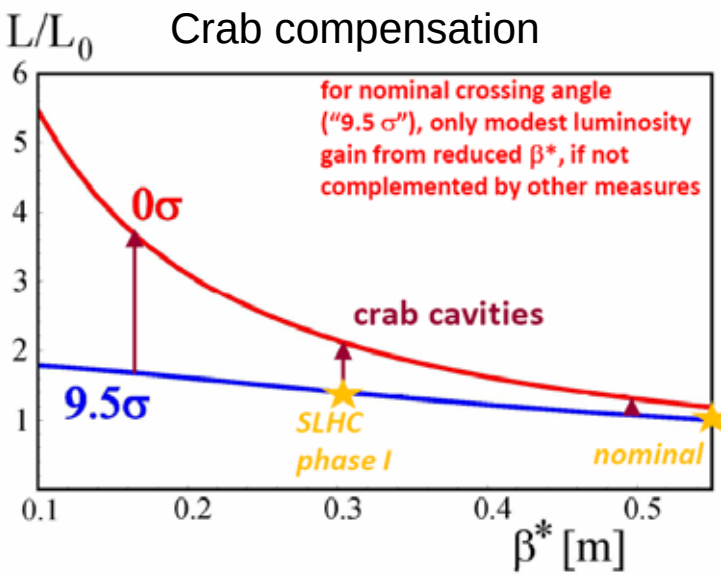


Crossing angle θ_c

Piwinski angle $\Phi = \dfrac{\theta_c \sigma_z}{2\sigma_x}$

Geometric luminosity reduction given by

$$R = \frac{1}{\sqrt{1+\Phi^2}}$$



Frank Zimmermann, LHC-CC09

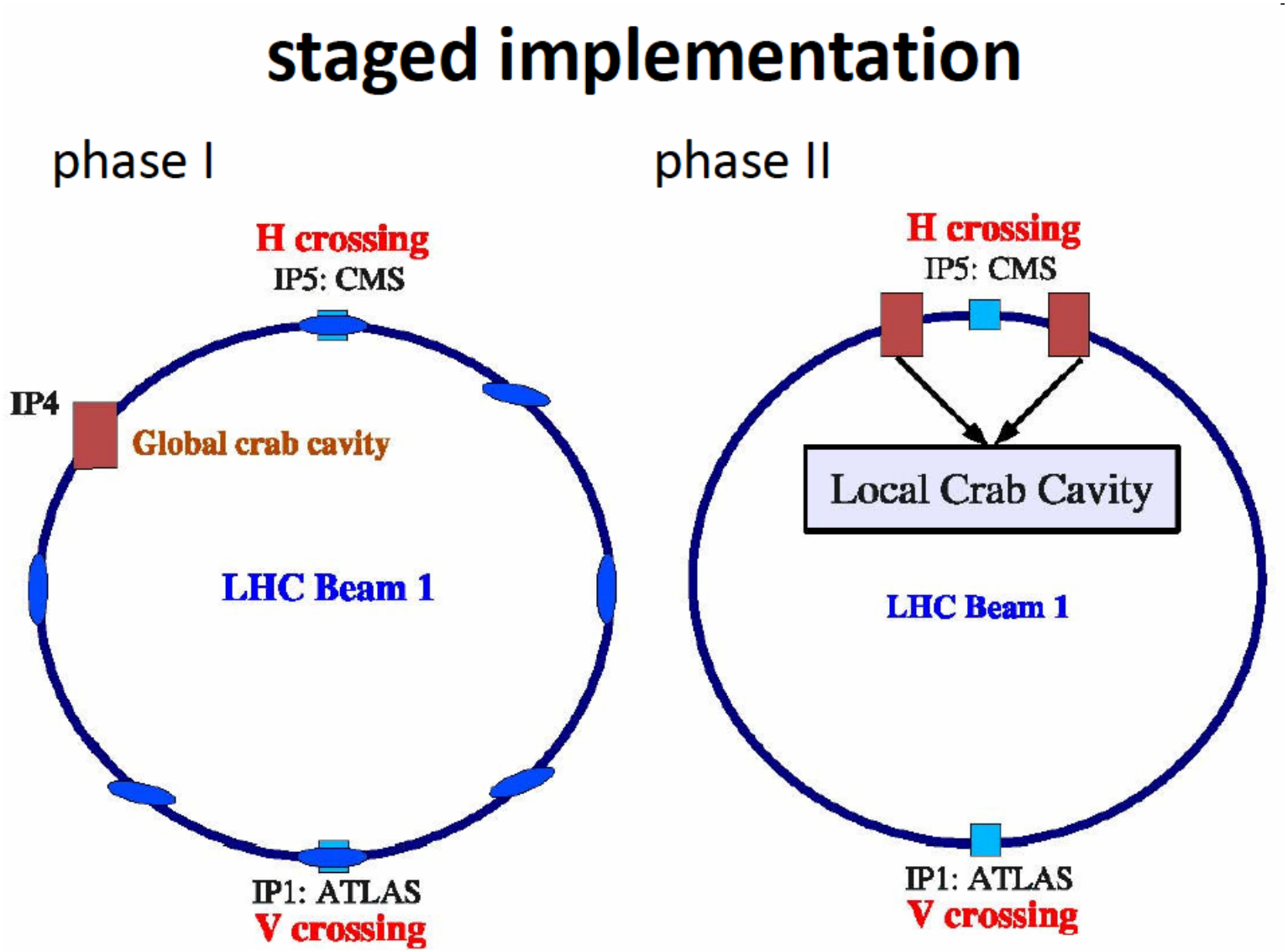
To increase luminosity…
If beta* reduced for nominal crossing angle…

$$\sigma_x \propto \sqrt{\beta^*}$$

If finite angle crossing,
Modest luminosity increase because geometric reduction is large

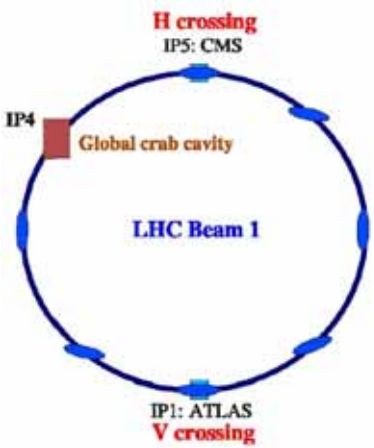
If crab crossing applied…
Large geometric reduction can be recovered

LHC crab crossing
Global crabbing and local crabbing

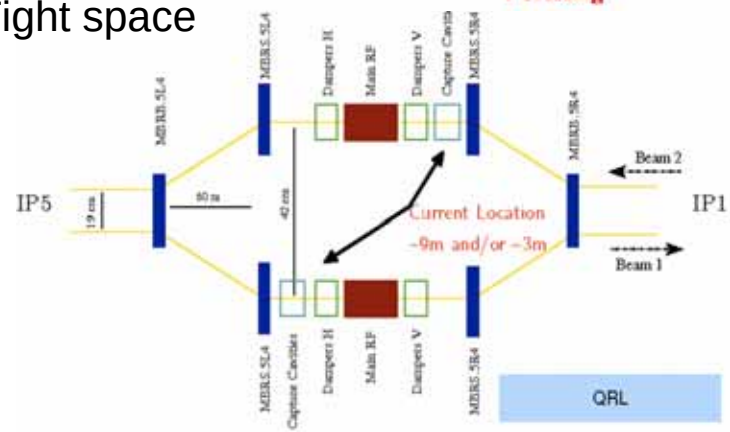


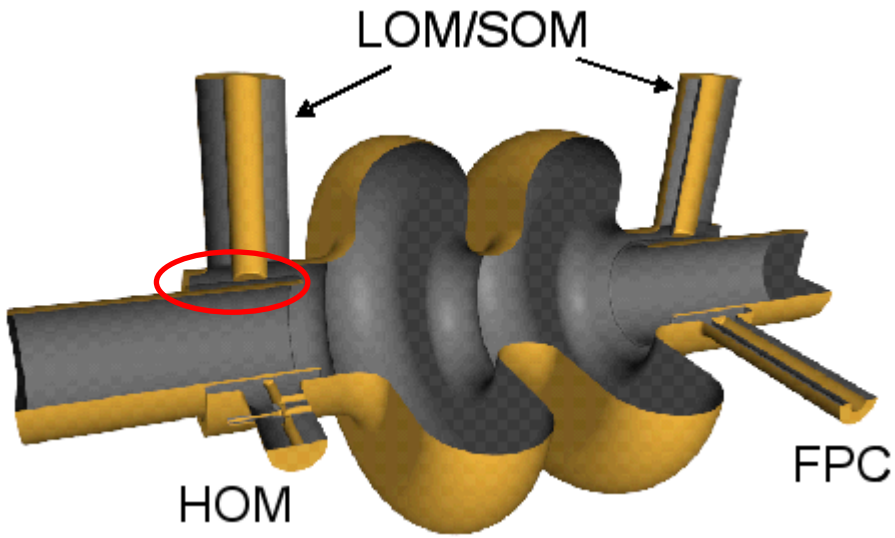
Baseline design (Squashed cell)
US-LARP

Global crabbing

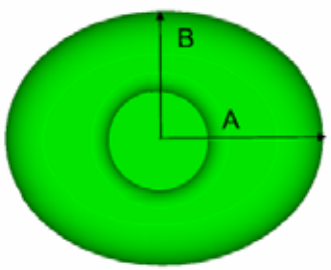


Tight space





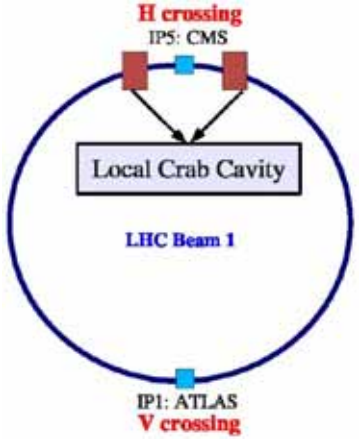
Liling Xiao and Zenghai Li, SLAC



Baseline cavity design
for global crabbing scheme

Squashed two-cell cavity
Coaxial structure for LOM damping
RF frequency: 800 MHz
Crabbing voltage: 2.5 MV
Long axis: A=24.5cm

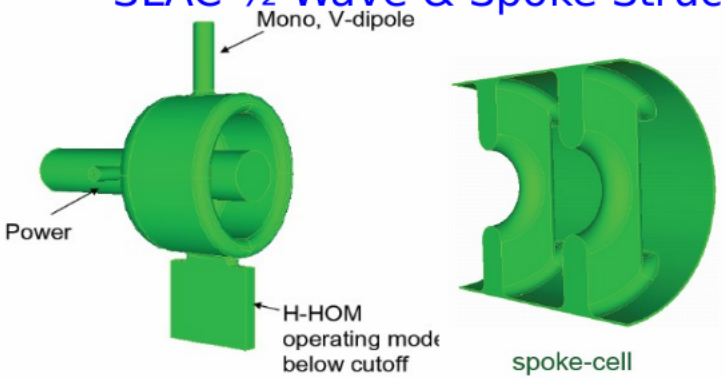
Compact cavity
US-LARP, EUCard, KEK
for future local crab scheme



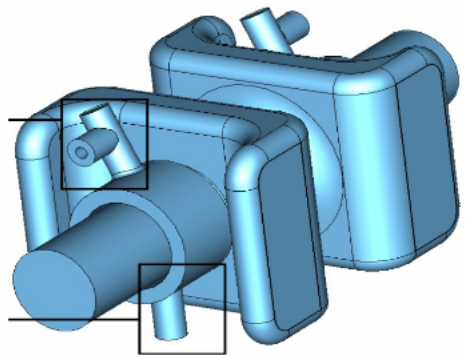
Local crabbing

Tight space at IP

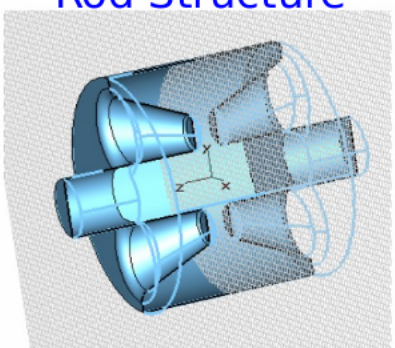
SLAC ½ Wave & Spoke Structures



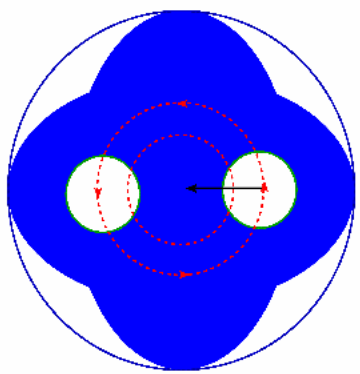
FNAL Mushroom Cavity



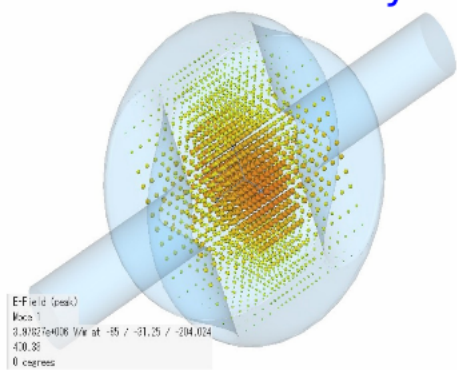
EUCard,UK-JLAb Rod Structure



BNL TM010, BP Offset



KEK Kota Cavity



TEM-type Delayen and Wang

Requirements for LHC-Crab

- High crabbing voltage (2.5MV for global crabbing)
- High reliability (low trip rate)
- Invisible when no crabbing
  - Not to disturb LHC operation

- To develop the LHC-crab cavity
  - Need cavity R&D for high fields and low trip rate
    - Establish surface treatments for complicated structures
  - Need beam tests
    - To confirm reliability

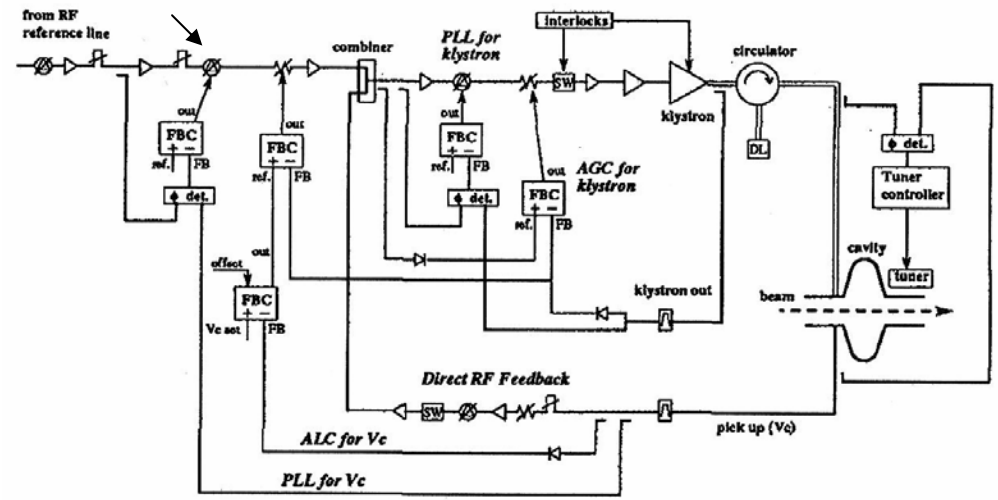
Beam tests for LHC at KEKB

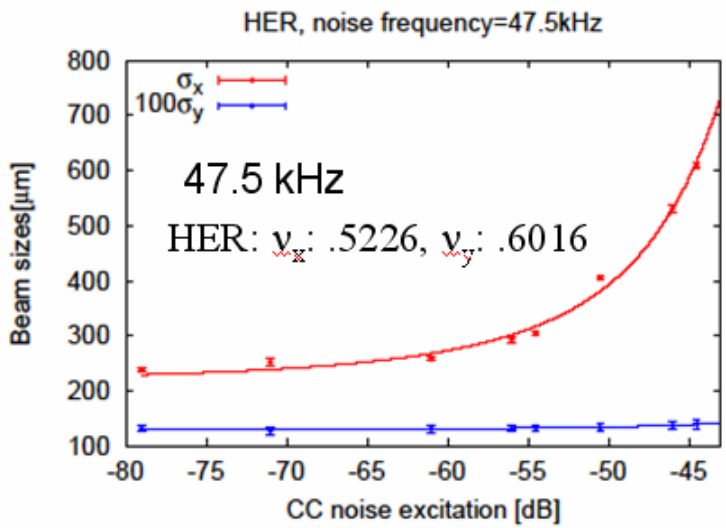
- Several beam tests were proposed
- Tow beam tests were conducted using the KEKB machine
  - Controlled RF noise study with the KEKB crab
  - Longitudinally kicked beam with crab cavities

Beam test 1
Controlled RF noise study with the KEKB crab

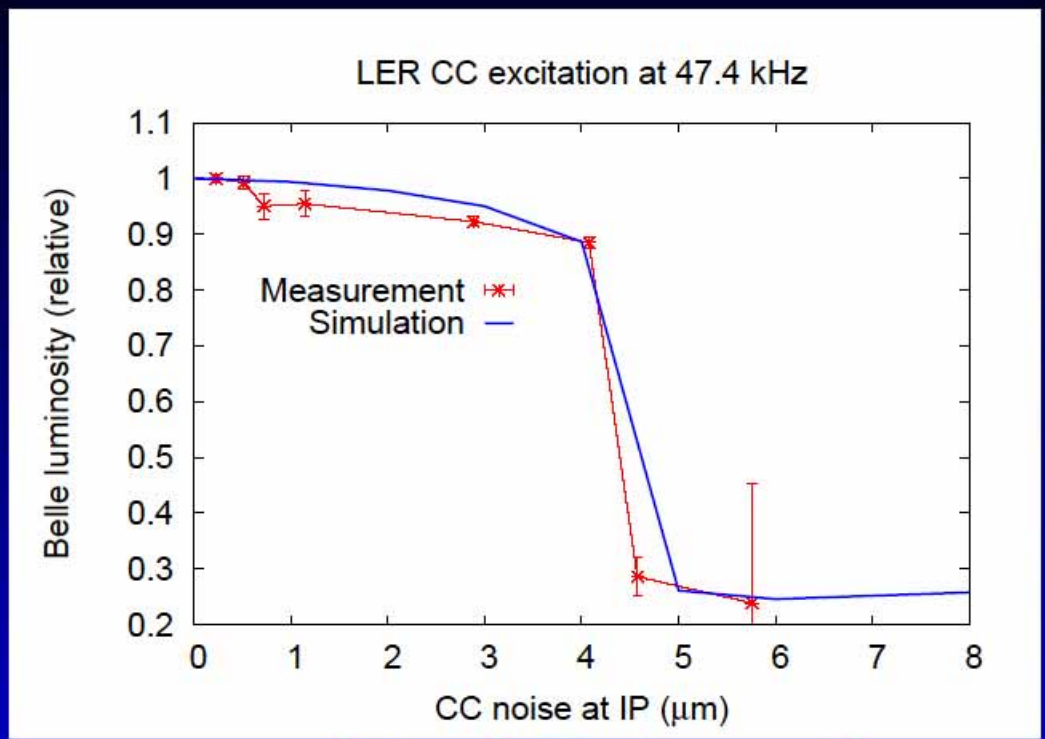
- Add controlled RF noise to the crab cavity
- Measure beam size and luminosity
- Controlled noise
  - Single frequency
  - Close to the horizontal betatron tune: ν_x (~50kHz)
  - Far away from ν_x
- Beam conditions
  - Single LER beam with a beam current of 100 mA
  - Single HER beam (100 mA)
  - Colliding beams (HER/LER: 65/100 mA)

Controlled noise





LER CC noise close to Q_x (exp. vs sim.)



→Measurement and simulation in excellent agreement!

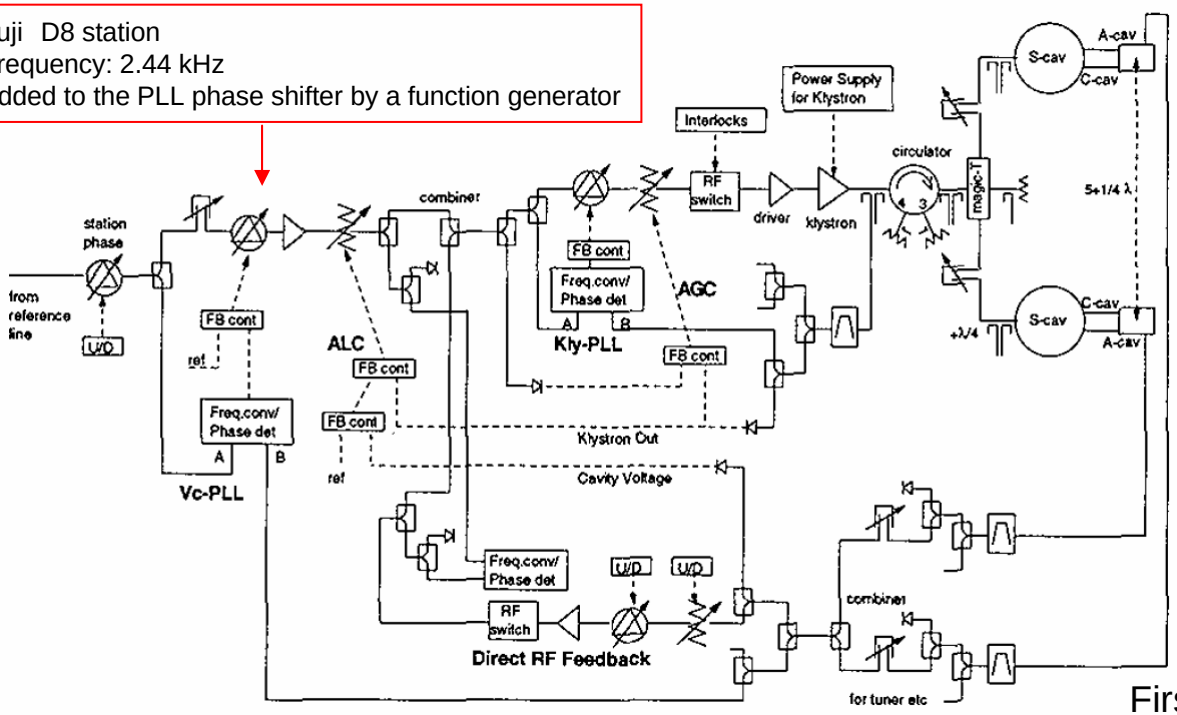
→Shocking abrupt luminosity loss at $4.5\mu\text{m} \approx 0.02\sigma_x^*$

Beam test 2
Longitudinally kicked beam with crab cavities

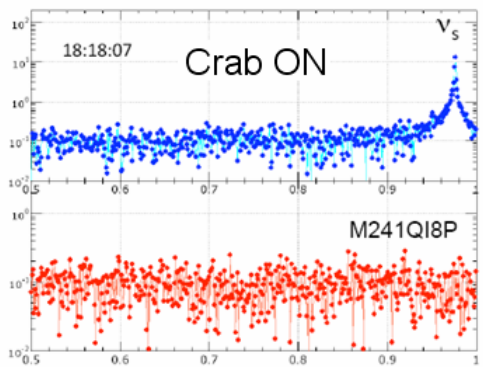
- Longitudinal beam kick with ARES cavities
- Monitor beam position by Turn-by turn BPM (by Ohnishi-san)
  - BOR for backup (by Flanagan-san and Fukuma-san)

LLRF of the ARES normal conducting cavity

Fuji D8 station
Frequency: 2.44 kHz
Added to the PLL phase shifter by a function generator



LER single beam: single bunch with 1 mA
Turn-by-turn BPM at no dispersion



First obserbation of x-z coupling at Crab

General Remarks & Outlook

- Very fruitful experimental collaboration on Crab Cavities (thanks KEK for the beam!)
- Further analysis ongoing
- More experiments in KEK? (Funakoshi san just asked!)

Crab noise study for LHC was conducted by Funakoshi-san on Dec. 23, 2009.
Several beam studies are under consideration in the next machine time 2010.

Beam tests at SPS with KEKB-Crab

- Required RF frequency: 510.6 or 511.0 MHz
  - KEKB-Crab: 508.887MHz
  - Can be tuned
- Required external Q: Qext=10^6
  - KEKB-Crab: Qext=1.3-1.6 x 10^5
  - Spare coupler~10^6
- Transport KEKB-CC to CERN?
  - When?
  - How?
  - Cost?

KEKB-Crab

	KEKB-Crab	@ SPS	comments
RF frequency (MHz)	508.9	510.6 or 511.0	Can be tuned
Qext	1.3-1.6 x 10^5	~10^6	Spare coupler~10^6

Beam tests at SPS with KEKB-Crab

Beam dynamics issues (global cc)

	Simulation	KEKB	SPS	LHC w/o cc	Tevatron
Optics preparation	seems OK	-	-	-	-
▲ b-b limit w/ x-angle	OK	~0.06	OK	-	OK
▲ Ramping w/ beam	OK (w/b-b?)	○	●	-	-
◎ Crab phase noise	Done?	OK	●	-	-
▲ Impedance	tolerance	OK	●	-	-
Dynamics aperture	OK	OK	●	-	-
DA w/ long-range BB	OK	-	-	-	-
S-B resonances	OK	OK	●	-	-
Physical aperture	+ 0.5σ	-	●	-	-
▲ Beam collimation	Maybe OK	-	●	-	-
Coherent oscillation	To be done	solved	-	-	-
Luminosity leveling	promising	○	-	-	-
AC dipole	OK 800MHz?	-	●	○	?
Head-tail osci. like crabbing	?	-	?	○	?

○: can be tested, ●: can be tested if cc is brought

Future prospects

- Crab cavity
  - Fabrication, surface treatments and cold tests
    - Need to establish surface treatments
    - A new electro-polishing equipment is being constructed at KEK
    - Developing 800 MHz RF system for LHC-Crab R&D
  - How about funds?
    - Director of accelerator laboratory supports the activity
    - We are applying a scientific research grant in Japan
- Beam tests for LHC at KEKB
  - Discussing several beam tests at the next machine operation
    - Ramp-up of the crab cavity voltage with beam?
    - Variation of crab voltage for luminosity leveling?
- Beam tests at SPS with KEKB-Crab
  - Beam studies of crabbing with proton beams
  - Many beam studies with sufficient machine time ?
    - Without disturbing LHC operation

終わり