Introductions to Superconducting Crab Cavities

Kai Tian

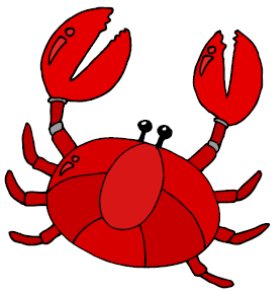
Outline

- Background
- Crab Cavities for Crab Crossing
- Applications beyond Crab Crossing

Status of Crab Cavities

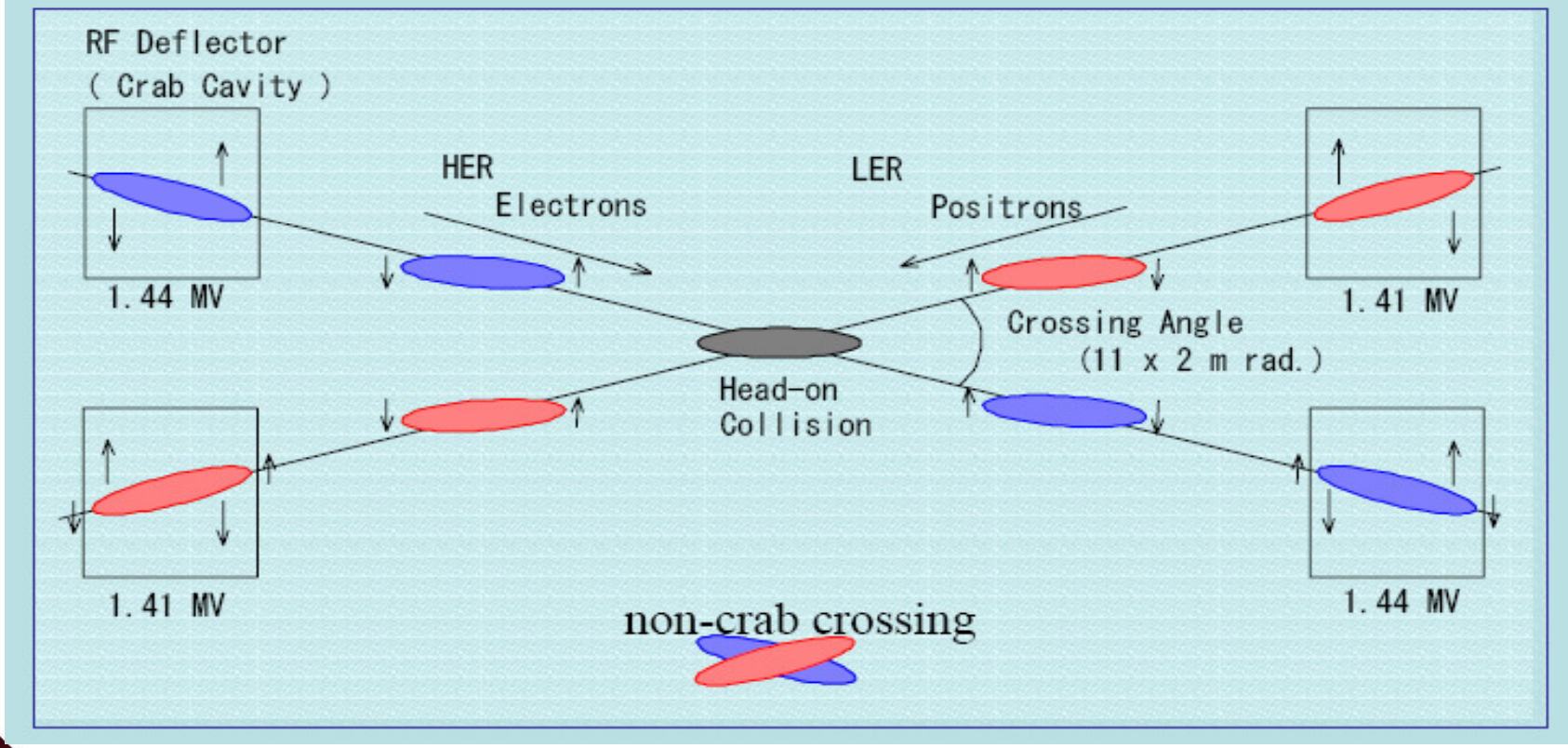
- Existing cavities
  - KEK-B collider
  - ANL-Tsinghua Emittance Exchange Experiment (NC)
  - LOLA (LCLS at SLAC)
  - Diagnostics
- Prototypes
  - FNAL (Kaon separation and ILC) 3.9-GHz multi-cell
  - Cockcroft Institute/DL
  - Tsinghua-LBNL cylindrical symmetric multi-cell
  - ANL-JLAB-LBNL-Tsinghua for APS
- Proposed Cavities
  - LHC

Initial Motivation



Crab crossing scheme in colliders*

- Provide head on collision at IP
- Increase the luminosity
- Beam deflection using high RF fields



* R. B. Palmer, SLAC-PUB-4707,1988; K. Oide and K. Yokoya,SLAC-PUB-4832,1989.

History of KEKB Crab Cavity*

0) 1/3 scale model 1.5 GHz 1994

1) Full Scale Prototype Crab Cavity 500MHz 1996

2003

2 Nb Cavities # 1 & # 2
Coaxial Coupler
Prototype Horizontal Cryostat
(# 2 was Installed
into Prototype Horizontal Cryostat for Cool down Test)

Installation of 2 crab cavities in KEKB was decided 2004

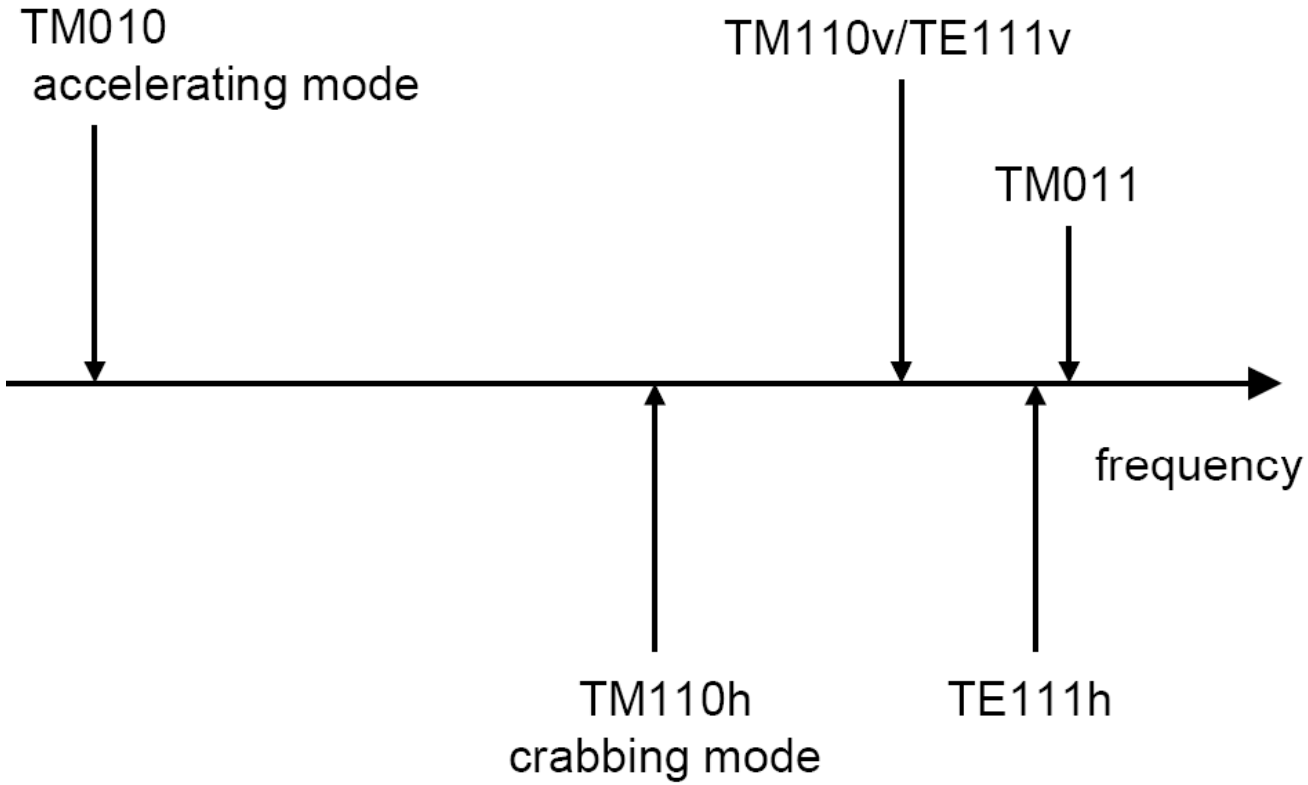
2) KEKB Crab Cavity 509MHz

2 Nb Cavities for LER, HER

Cold Tested in Vertical Cryostat 2005
Assembling and High power test 2006
Installation and Commissioning 2007
Jan. ~

* K. Hosoyama et. al. , ICFA Workshop at Shanghai May, 2008

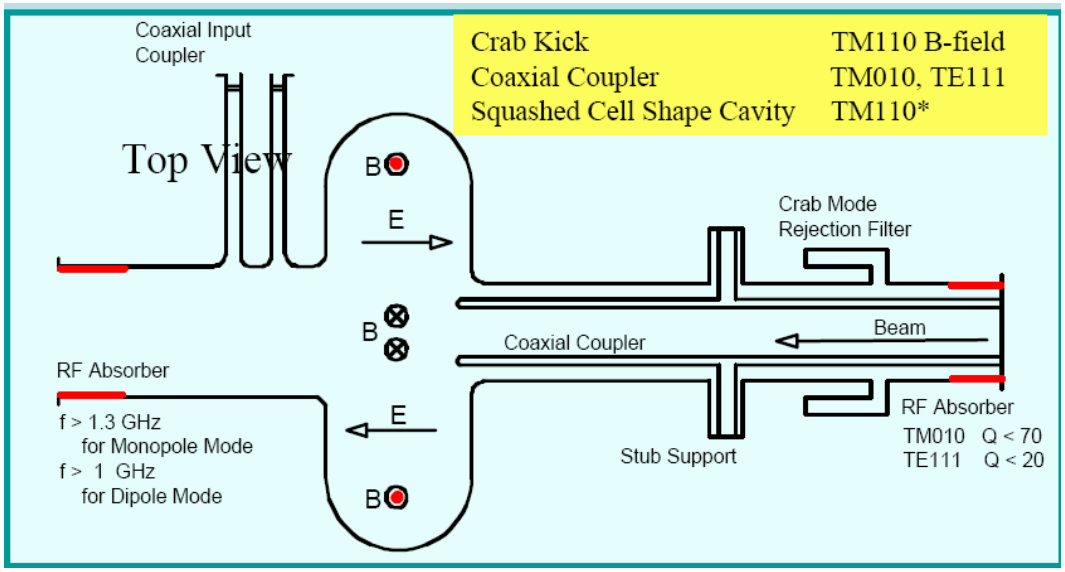
Order of Modes in KEKB Crab Cavities

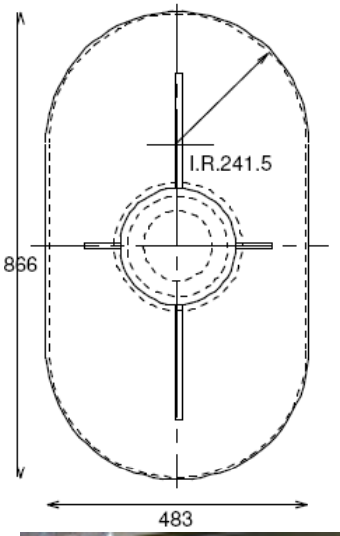


Cavity Design

- •LOM and HOM damping
- •Degeneration of TM110 modes

Base Design of KEKB Crab Cavity





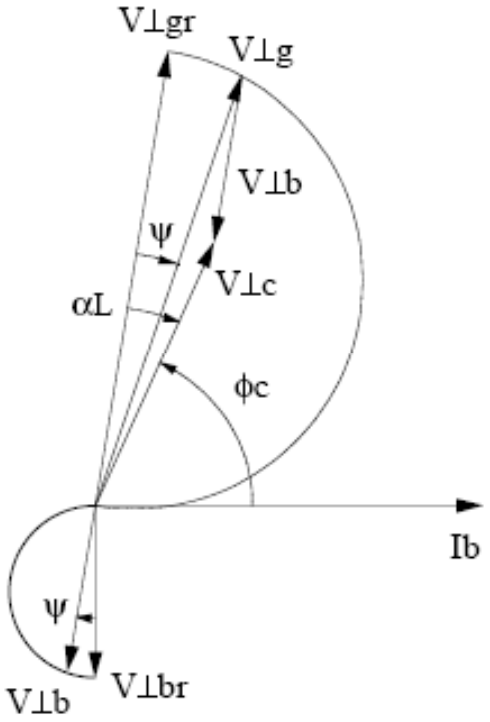
Characteristics:

- **Squashed Cell Shape**
- **Coaxial Coupler to Extract TM010**
- **Large Beam Pipes for Higher Order**

Beam loading on the Crab Cavity

Vector relation for the crabbing mode ($\Delta x > 0$).

Δx is the horizontal displacement of the beam



- Transverse kick voltage: $V_{\perp c}$
- Transverse shunt impedance: $\bar{R}_\perp \equiv \frac{V_{\perp c}^2}{P_c}$
- Beam-induced voltage:

$$V_{\perp b} = V_{\perp br}\cos\psi e^{j\psi}$$

$$V_{\perp br} = -j\frac{I_b \bar{R}_\perp}{1+\beta}k\Delta x,$$

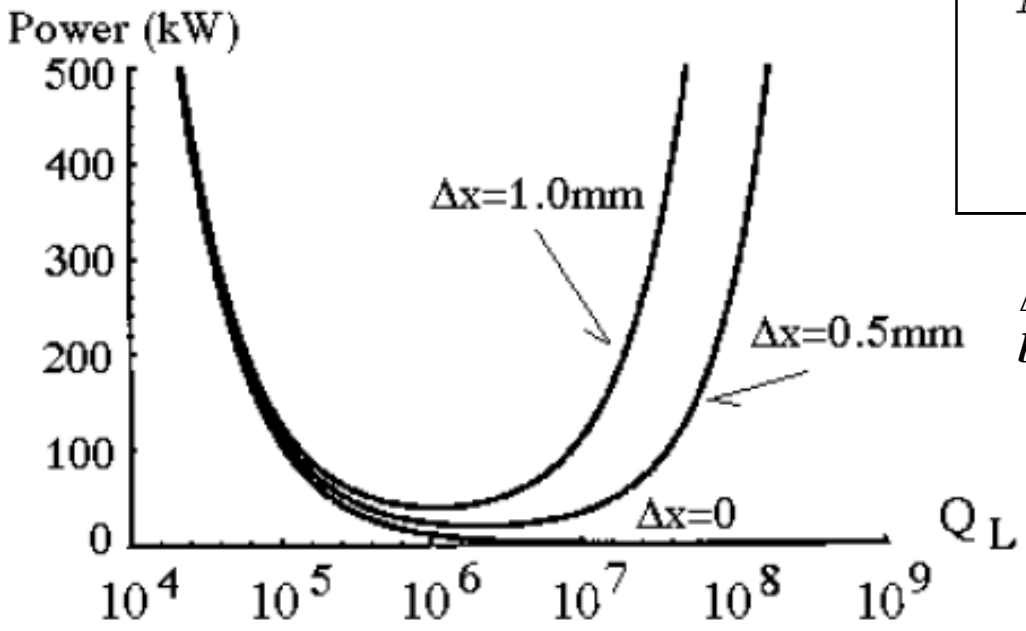
- Generator voltage at resonace

$$|V_{\perp gr}| = \frac{2\sqrt{\beta}}{1+\beta}\sqrt{\bar{R}_\perp P_g}$$

$$P_g = \frac{(1+\beta)^2}{4\beta\bar{R}_\perp} \times \left\{\frac{1}{\cos\alpha_L}\left(|V_{\perp c}| + \frac{I_b\bar{R}_\perp}{1+\beta}k\Delta x\sin\phi_c\right)\right\}^2.$$

Beam Loading (contd)

- Loaded Q and required power

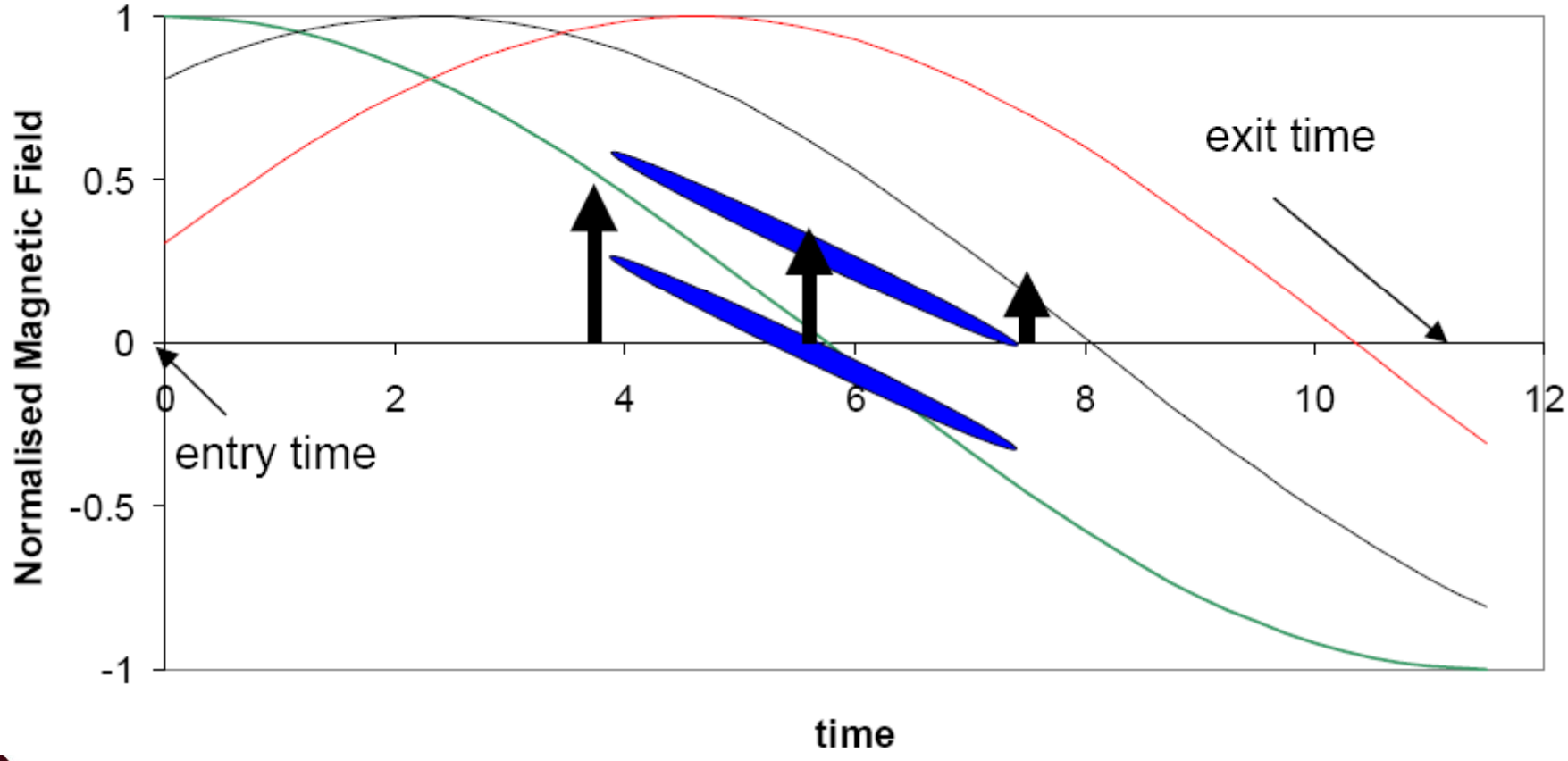


$$P_g = \frac{(1+\beta)^2}{4\beta \bar{R}_\perp} \times \left\{ \frac{1}{\cos\alpha_L} \left(\mid V_{\perp c} \mid + \frac{I_b \bar{R}_\perp}{1+\beta} k \Delta x \sin\phi_c \right) \right\}^2 .$$

Δx is the horizontal displacement of the beam

Q_L~10^6 is the best choice

Cavity Symmetry and Phase Stability

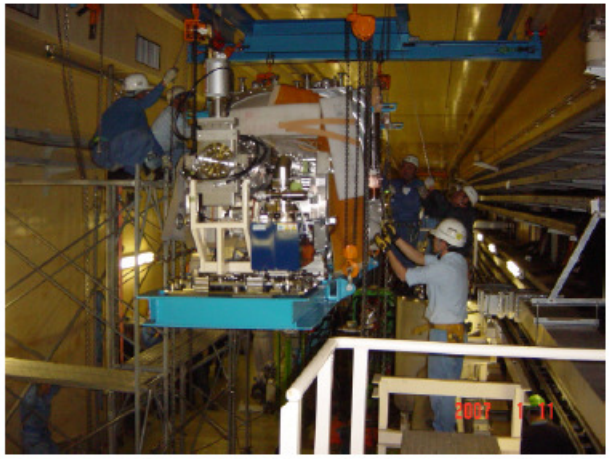


Installation & Commissioning of KEKB Crab Cavities

Installation of Crab Cavities
for HER Jan. 8, 2007,
for LER Jan. 11, 2007

Crab Cavity for HER

Cool-down of Crab Cavities
Jan. 29 , 2007
Beam Operation Start
Feb. 13

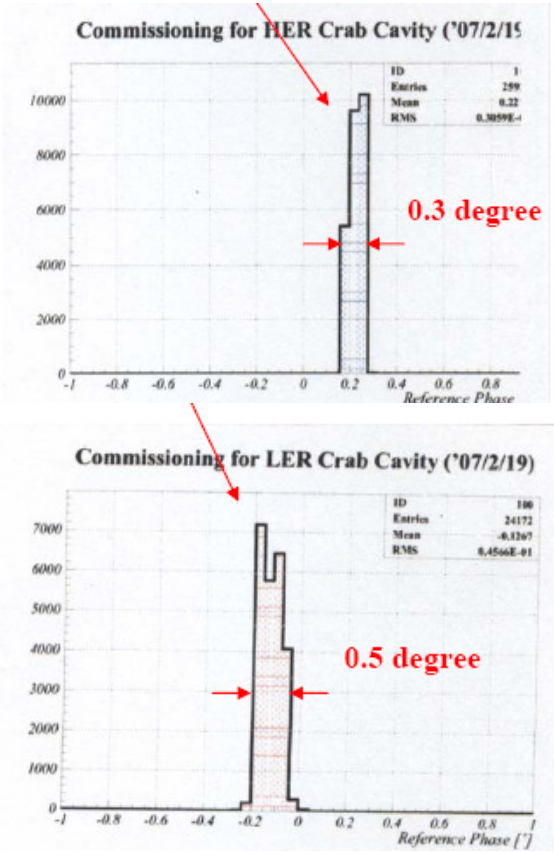


Carrying the Crab cavity using crane track

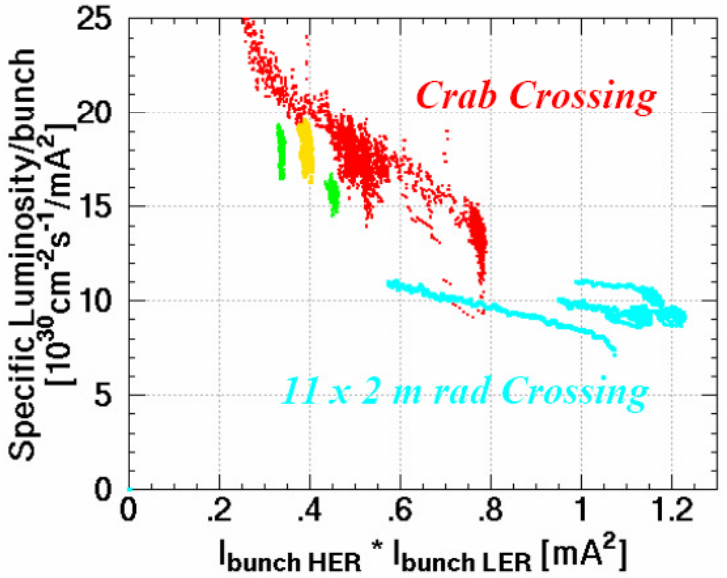
Crab Cavity for LER

Performance of KEKB Crab Cavities

Phase stability



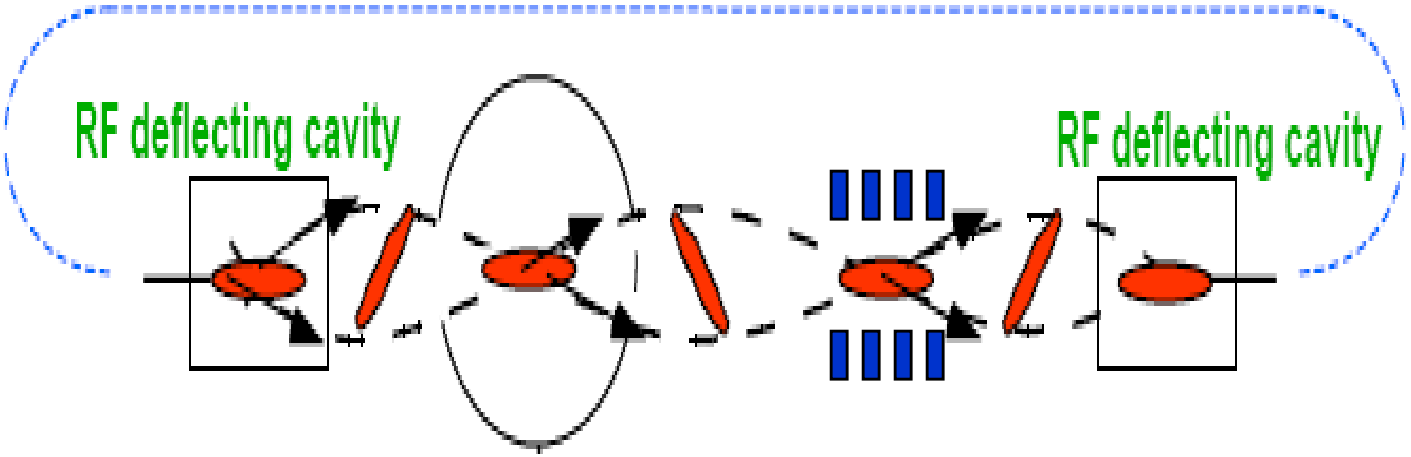
Specific Luminosity of KEKB



Applications beyond Crab Crossing

- Short pulse light source
- Beam diagnostics
- Emittance exchange

Crabbing Scheme for Light Source†



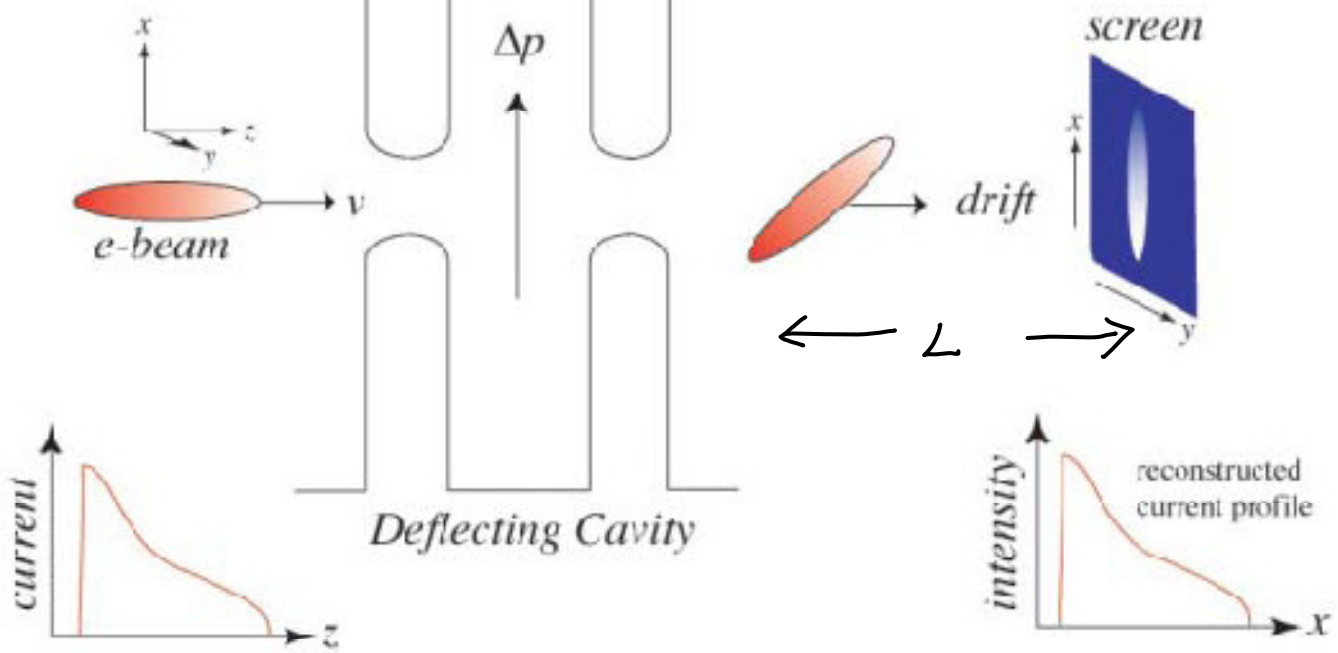
- Deflecting cavity introduces angle-time correlation into the electron bunch, "crabbing" the beam. B_x kicks head and tail of the bunch in opposite directions in the vertical plane.
- Electrons oscillate along the orbit.
- Bunch evolution through the lattice results in electrons and photons correlated with vertical momentum along the bunch length.
- Second cavity at $n\pi$ phase cancels "kick"; rest of the storage ring unaffected.

†A. Zholents, P. Heimann, M. Zolotorev, J. Byrd, NIM A 425, 385, (1999).

Deflecting Cavity for Longitudinal Phase space diagnostics

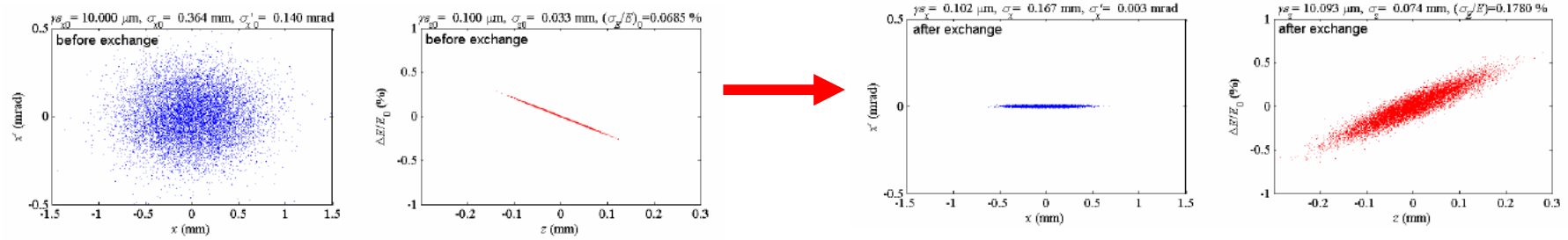
Temporal resolution

$$\Delta t = \Delta x \frac{2mc^2\gamma}{L\,\omega\, e\, V_\perp}$$



Emittance Exchange

- **Emittance Exchange (EEX)**: Complete exchange of x- and z-phase spaces: $(\varepsilon_x,\varepsilon_z) \rightarrow (\varepsilon_z,\varepsilon_x)$



- **Applications**

  - To improve performance of high-gain FEL… Reduce transverse emittance at the expense of longitudinal

  - To obviate electron damping ring in linear collider
    Photocathode gun →flat beam transformation →EEX

  - $(\varepsilon_x, \varepsilon_y, \varepsilon_z)=(1, 1, 8)\rightarrow(50,0.02, 8)\rightarrow(8, 0.02,50)$ μm

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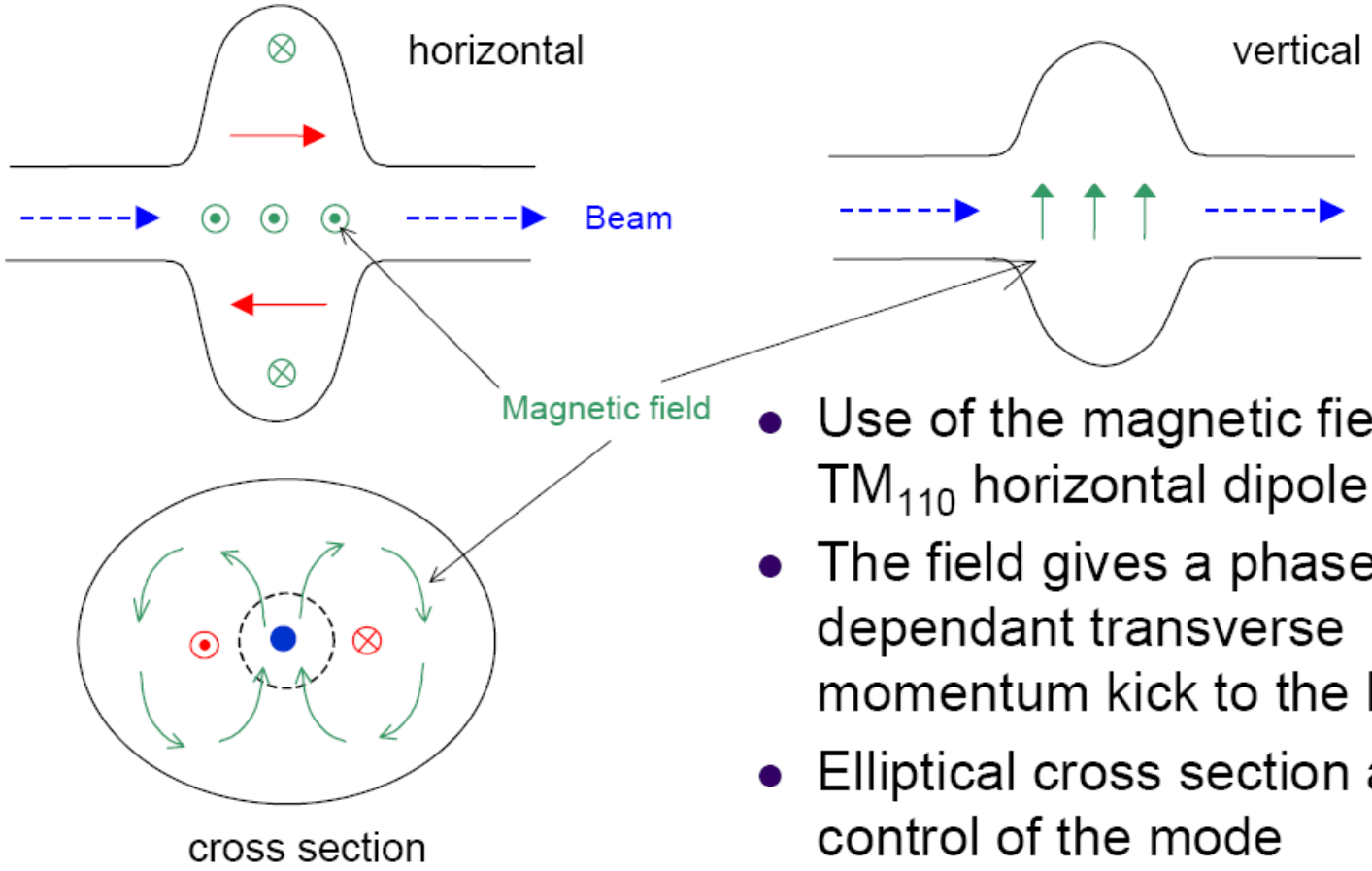
- G. Burt, Problems associated with the Crab Cavity, Crab Cavity Meeting at the Cockcroft Institute, 2005
- Private Communication with Dr Jean Delayen

Extras

Applications

- Crab-wise crossing in Colliders
  - KEK-B cavity
  - LHC and ILC
- Short X-ray Pulse Generation
  - ALS at LBNL
  - APS at ANL
  - SSRF in China
- Other
  - Emmitance exchange
  - Temporal beam diagnostics

Crab cavity basics



- Use of the magnetic field of a TM_{110} horizontal dipole mode
- The field gives a phase-dependant transverse momentum kick to the beam
- Elliptical cross section allows control of the mode polarization.

Cockcroft Institute

Jefferson Lab

JSA