Beam simulations for SPS tests

H. J. Kim, T. Sen

Fermi National Accelerator Laboratory

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Outline

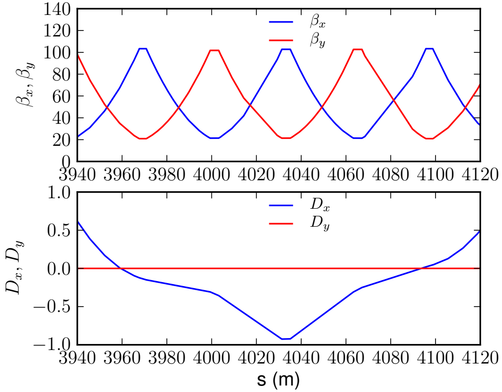
Crab cavity in the SPS

Motivation

- Crab scheme reovers the geometric luminosity loss due to finite crossing angle without increasing bunch intensity.
- Crab cavity proposed by Palmer (1988).
- In CC, a particle gets a transverse deflection and collsion is effectively "head on".
- CERN will persue crab crossing for LHC upgrade: 2020 shutdown – install CC
- SPS test with KEK-B crab cavities is proposed for deciding on a full crab-cavity implementation in LHC.
- Using a weak-strong code BBSIMC, we investigate effects of crab cavity on emittance growth in the SPS.

Crab cavity at COLDEX location

- Longitudinal location: 4009 m
- (β_x, β_y) = (30, 77)
- (μ_x, μ_y) = (15.173, 15.176)
- (η_x, η'_x) = (-0.5, -0.02)
- Crab cavity parameters
  - Voltage: 1.5MV
  - Frequency: 509MHz
  - Wave length: 60 cm
  - Global scheme
  - Horizontal crossing



Crab cavity kicks:

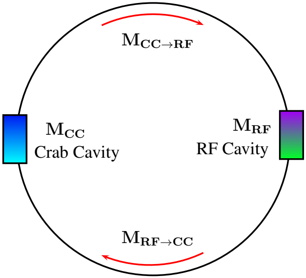
$$\Delta x' = \frac{qV_{cc}}{E_0} \sin(kz), \qquad \Delta \frac{\Delta E}{E} = \frac{qV_{cc}}{E_0} \cos(kz) \cdot kx$$

Stability analysis model

$$T = M_{RF\to CC} \cdot M_{RF} \cdot M_{RF\to CC} \cdot M_{CC}$$

$$M_{CC} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & \xi & 0 \\ 0 & 0 & 1 & 0 \\ \xi & 0 & 0 & 1 \end{pmatrix} \qquad \xi = \frac{qV_{cc}k}{E_0}$$

$$M_{RF} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & \Delta & 1 \end{pmatrix} \qquad \Delta = \frac{qV_{rf}h}{\beta^2 E_0 R}$$



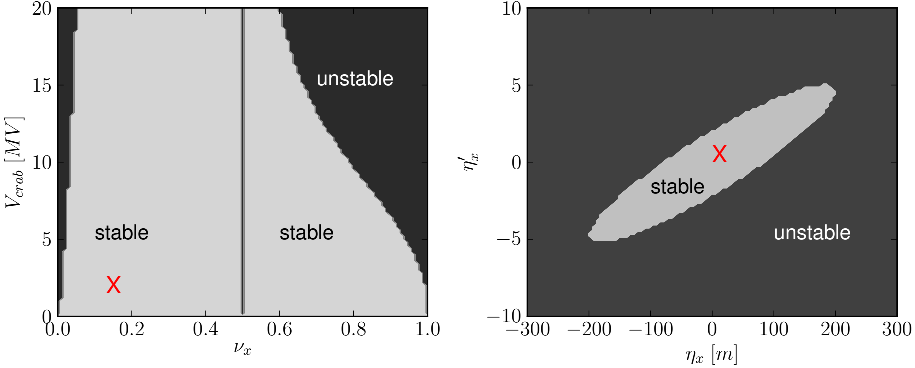
The characteristic polynomial of the matrix T is

$$Q(\rho) = \rho^2 - b_1\rho + b_2, \qquad \rho = \lambda + \frac{1}{\lambda}$$

The stability conditions are

$$\boxed{\mathbf{b_1^2 - 4b_2 > 0, \quad 4 - \left| b_1 \pm \sqrt{b_1^2 - 4b_2} \right| > 0}}$$

Stability boundary

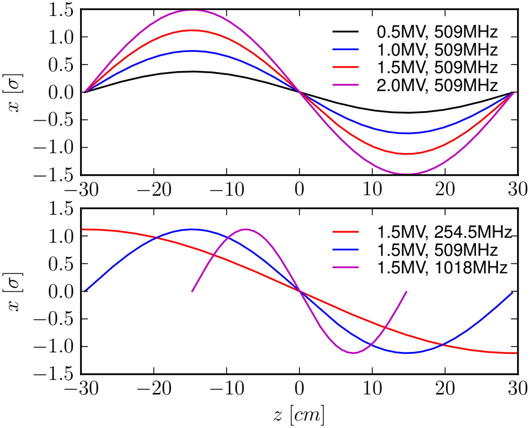


- 55GeV: V_{cc} = 1.5MV, ν_x = 0.13
- Dispersion at crab cavity: η_x = -0.5, $\eta_x^{'}$ = -0.02
- Non-linearities are not included.

Beam-Beam Simulation (BBSIM) code

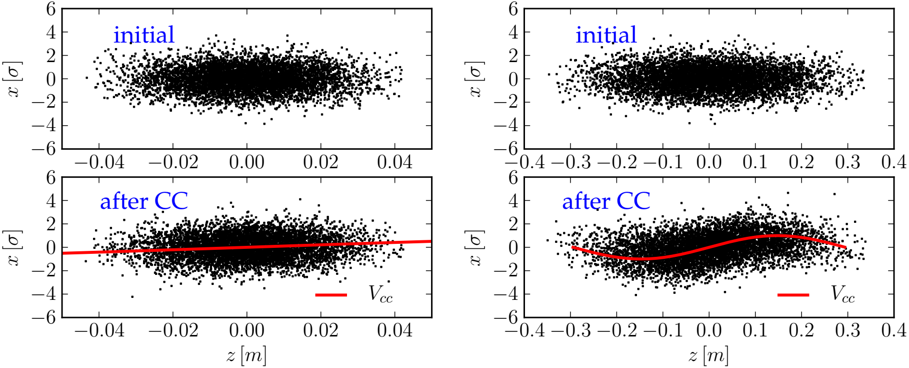
- 6D weak-strong tacking code.
- Linear transfer matrices btwn nonlinear elements + nonlinear kicks at the nonlinear elements (thin lens approximation: dipole, quadrupole, sextupole, mulitpole, etc.).
- Beam-beam force: (1) Gaussian beam profile and (2) Poisson solver with FFT.
- Multiple-slice model for finite bunch length effects.
- Lorentz boost to handle crossing angle collisions.
- Modules: crab crossing, wire and electron lens compensation, etc.
- Fully parallelized with MPI.

Global crab scheme changes closed orbit



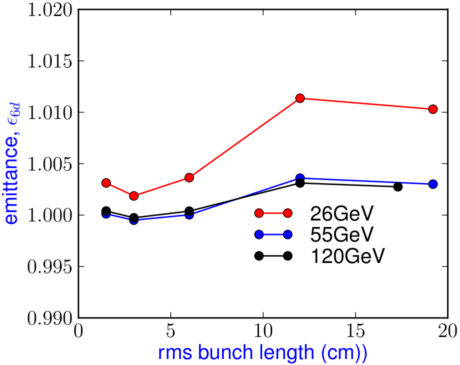
$$\tan\frac{\theta}{2} = \frac{q\omega\sqrt{\beta^*\beta_{CC}}V_{CC}}{c^2 p_s}\left|\frac{\cos\left(\Delta\varphi_0 - \pi Q\right)}{2\sin\left(\pi Q\right)}\right|$$

Large bunch length



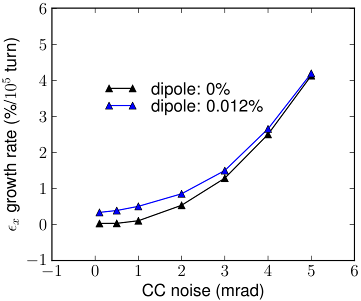
- f_{cc}= 509MHz, λ_{cc} = 60cm
- S-shaped bunch due to CC degrades luminosity.

Emittance growth (bunch length)

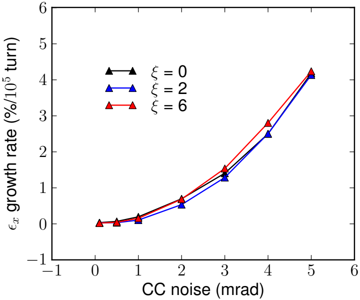


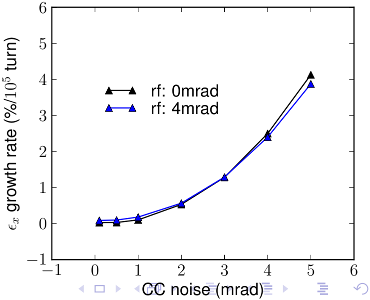
- Emittance growth depends on bunch length (momentum spread).
- Maximum emittance growth for large bunch length.

Emittance growth vs CC noise

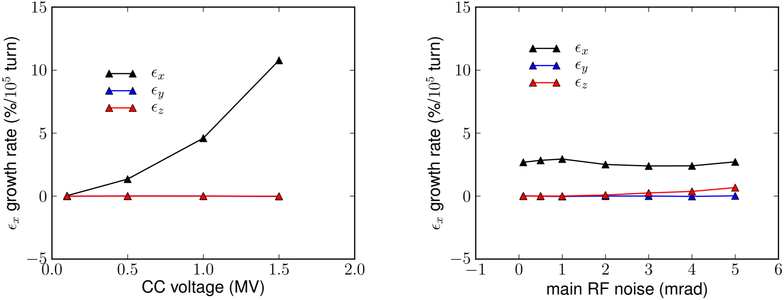


- negligible longitudinal emittance growth





Emittance growth vs CC voltage/RF noise



- Crab cavity noise is set 4mrad. Crab cavity voltage is 0.7MV.

Simulation

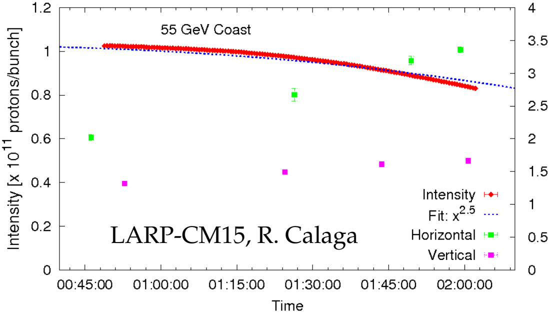
	Horizontal emittance growth rate		
	dipole noise (0.012%) RF noise (1 mrad) no CC	dipole noise (0.012%) RF noise (1 mrad) CC noise (0mrad)	dipole noise (0.012%) RF noise (1 mrad) CC noise (1mrad)
ξ_x=7, ξ_y=4, V_{RF}=4MV	378	375	470
ξ_x=2, ξ_y=2, V_{RF}=4MV	276	349	458
ξ_x=2, ξ_y=2, V_{RF}=2MV	126	180	253

NOTE) noise amplitudes are exagerated to see their impact.

Simlulations of SPS MD

Motivation

- During 2010 MD in the SPS, large transverse emittance growth rate has been observed

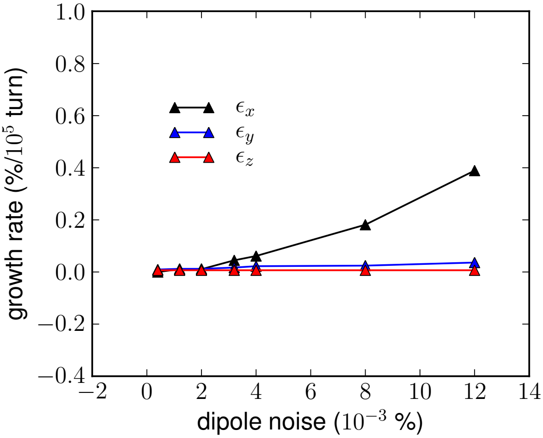


- Dipole voltage ripple, RF phase noise, chromaticity, IBS, ... contribute to the emittance growth.

Parameters

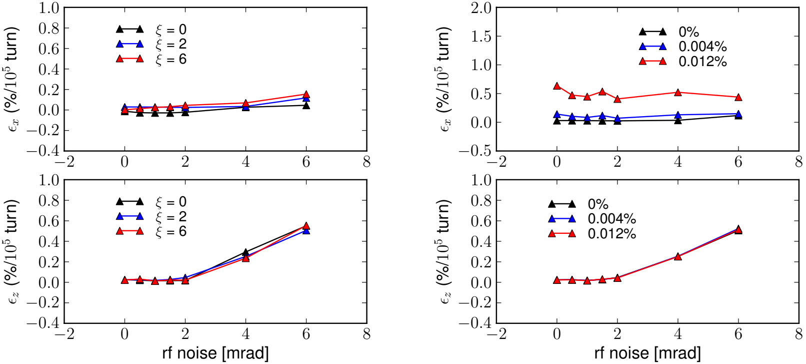
quantity	unit	value
energy	GeV	55
transverse emittance	mm-mrad	3.5
longitudinal emittance	eV-s	0.35
betatron tunes (ν_x, ν_y)		(0.13, 0.18)
chromaticity		2
beta function	m	(103.5, 20.9)
RF voltage	MV	4

Emittance growth vs dipole noise

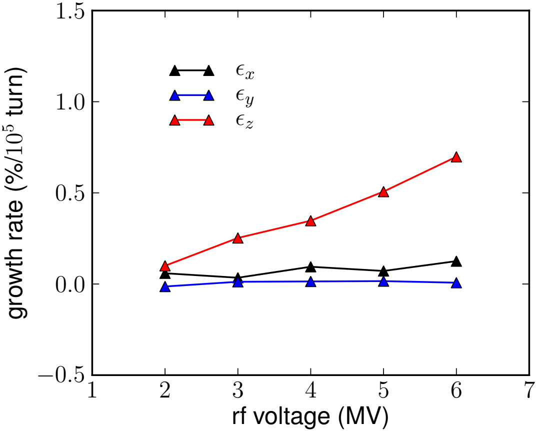


Note) voltage ripple of LHC after active filtering is 2.5×10^{-3}%.

Emittance growth vs RF noise



Emittance growth vs RF voltage



- main RF noise is 4mrad. chromaticity is 2. No dipole noise.

Measurement and simulation

	Horizontal emittance growth rate	
	Measured†	dipole noise (0.012%) rf noise (1 mrad)
ξ_x=7, ξ_y=4, V_{RF}=4MV	110	378
ξ_x=2, ξ_y=2, V_{RF}=4MV	41	276
ξ_x=2, ξ_y=2, V_{RF}=2MV	256	126

† "SPS Emittance Growth in Coast", G. Arduini et al, MSWG, Nov 11, 2010

Summary

- Linear stability model has been studied. Current SPS parameters are far away from unstable boundaries.
- Emittance growth rate studies for crab cavity noise, crab cavity voltage, and main RF noise.
    - Emittance growth depends on bunch length (momentum spread).
    - Crab cavity noise affects on the horizontal emittance growth.
    - Emittance growth is proportional to crab cavity voltage.
- Emittance growth rate for dipole noise, main RF noise, main RF voltage.