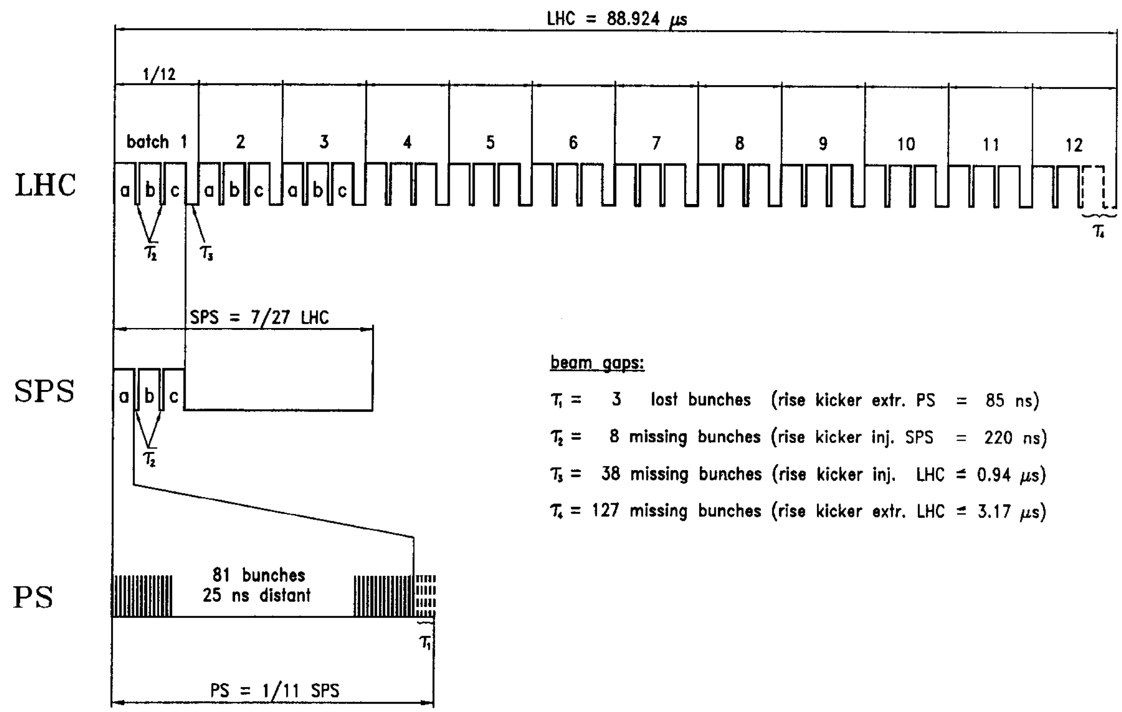
Fast orbit control around interaction points at the Large Hadron Collider

CERN, August, 1997

John Corlett
Lawrence Berkeley National Laboratory
Berkeley, CA 94720

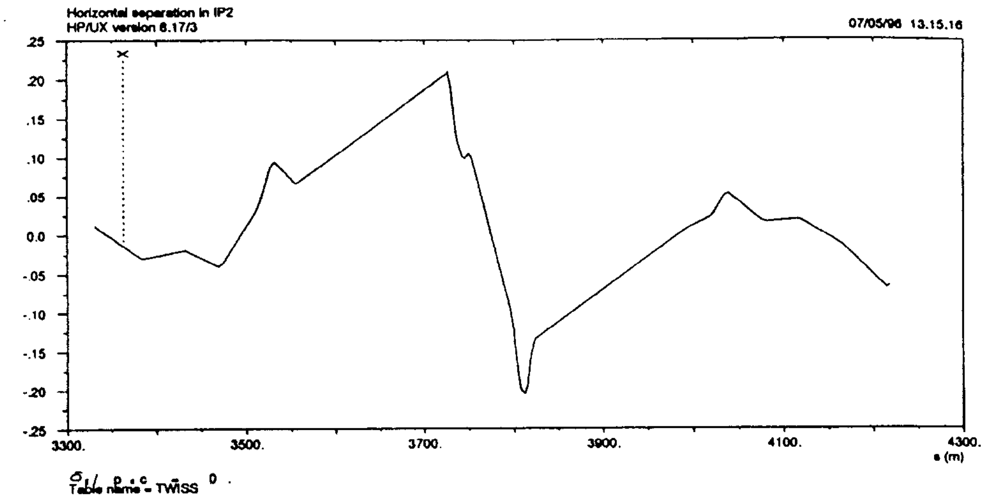
- LHC fill pattern is determined by the rise times of kickers



- The gaps between bunch trains result in different beam-beam interactions for the bunches near to the ends of a train

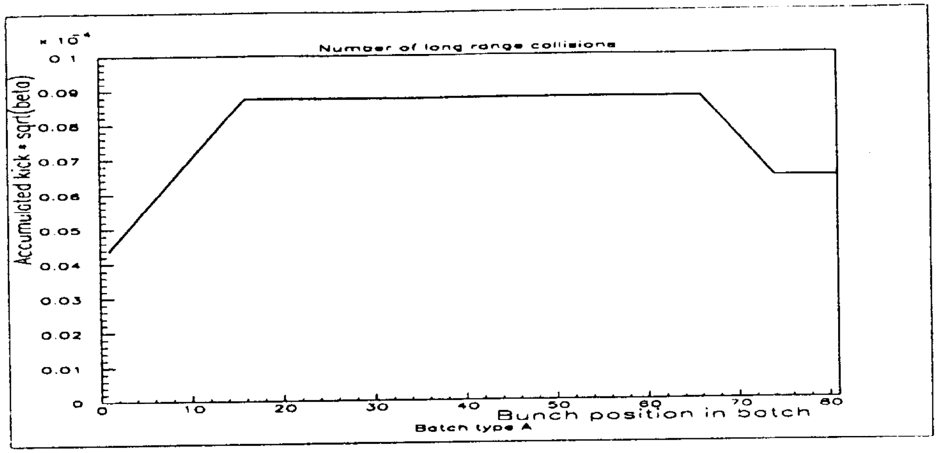
  * different closed-orbit distortion for the PACMAN bunches

- "Effects of PACMAN bunches in the LHC", W. Herr, LHC Project Report 39, August 1996.

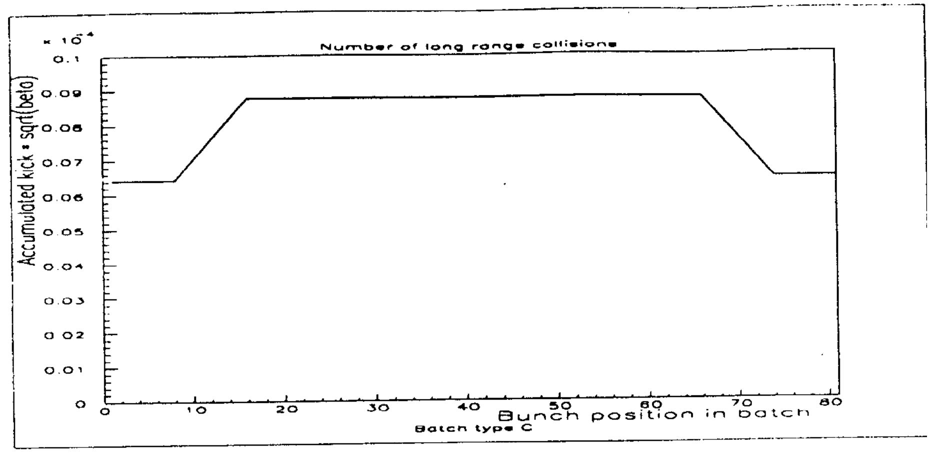


Orbit in the interaction region

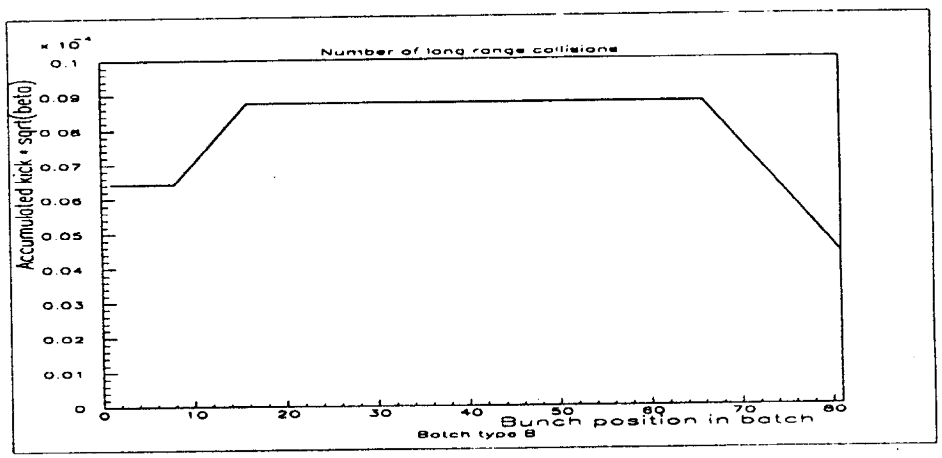
- Closed orbit follows kick shape shown



Accumulated kick, bunch train A



Accumulated kick, bunch train B



Accumulated kick, bunch train C

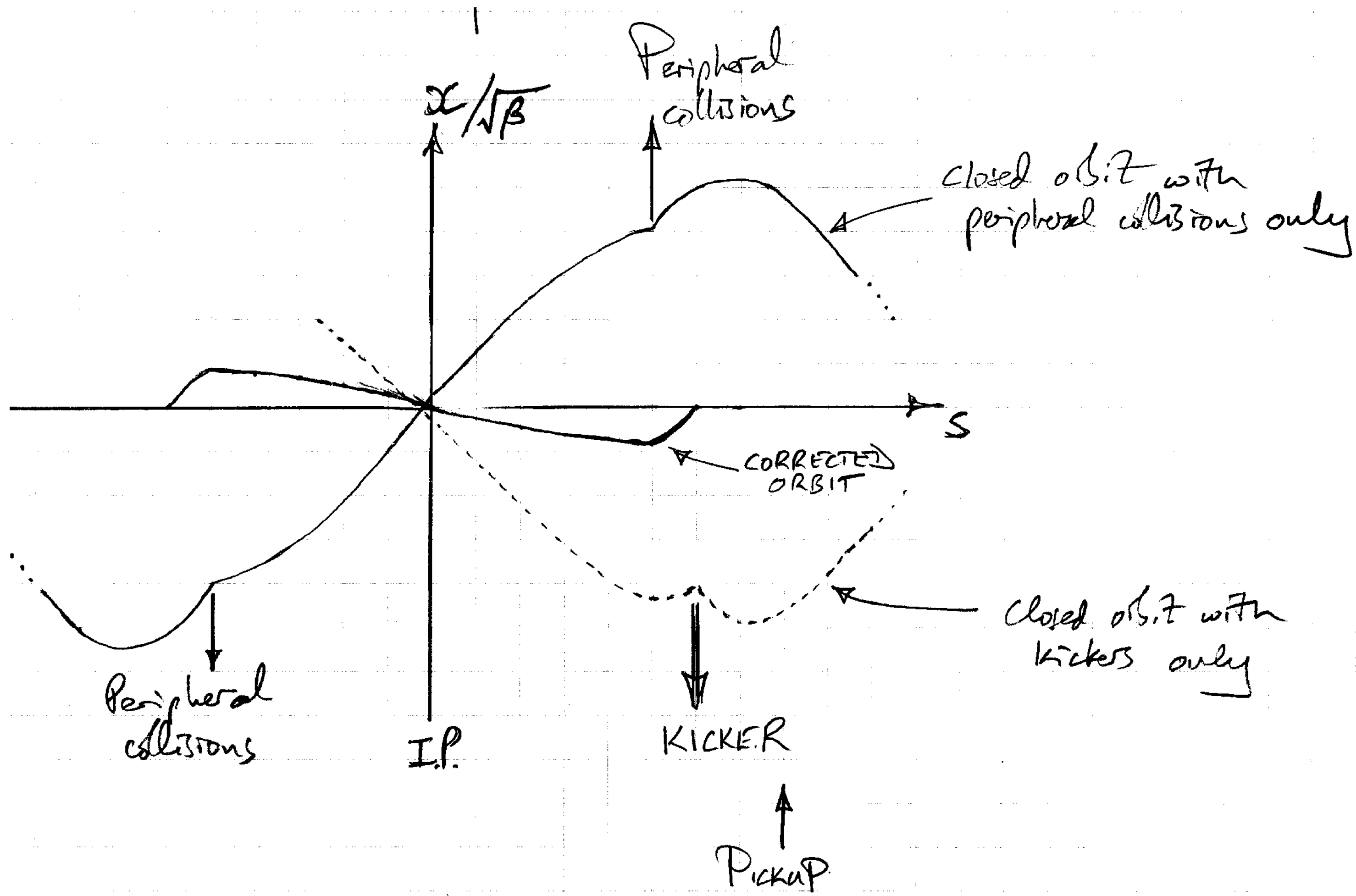
- Orbit can be adjusted to correct for displacement of nominal bunches

- Bunch-bunch orbit differences at an I.P. can be as large as one σ at high luminosity

  * significant reduction in luminosity

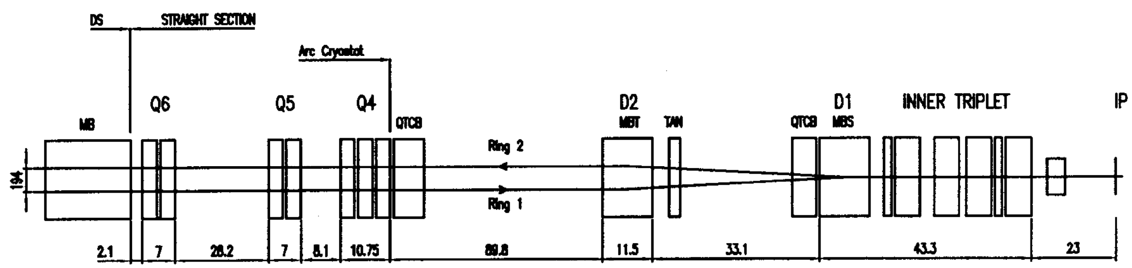
  * ***"fast" orbit control needed for PACMAN bunches***

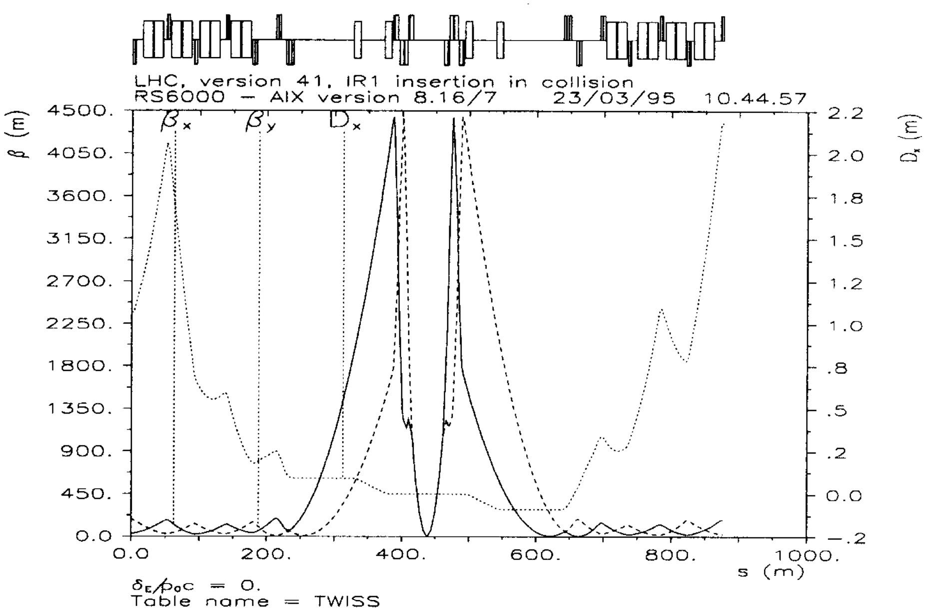
- Correction scheme involves measuring closed orbit deviation around an interaction point and applying a corrective kick to compensate for the different positions of bunches along bunch trains



- Pickups and kickers must be outside D1, where the beams are separated

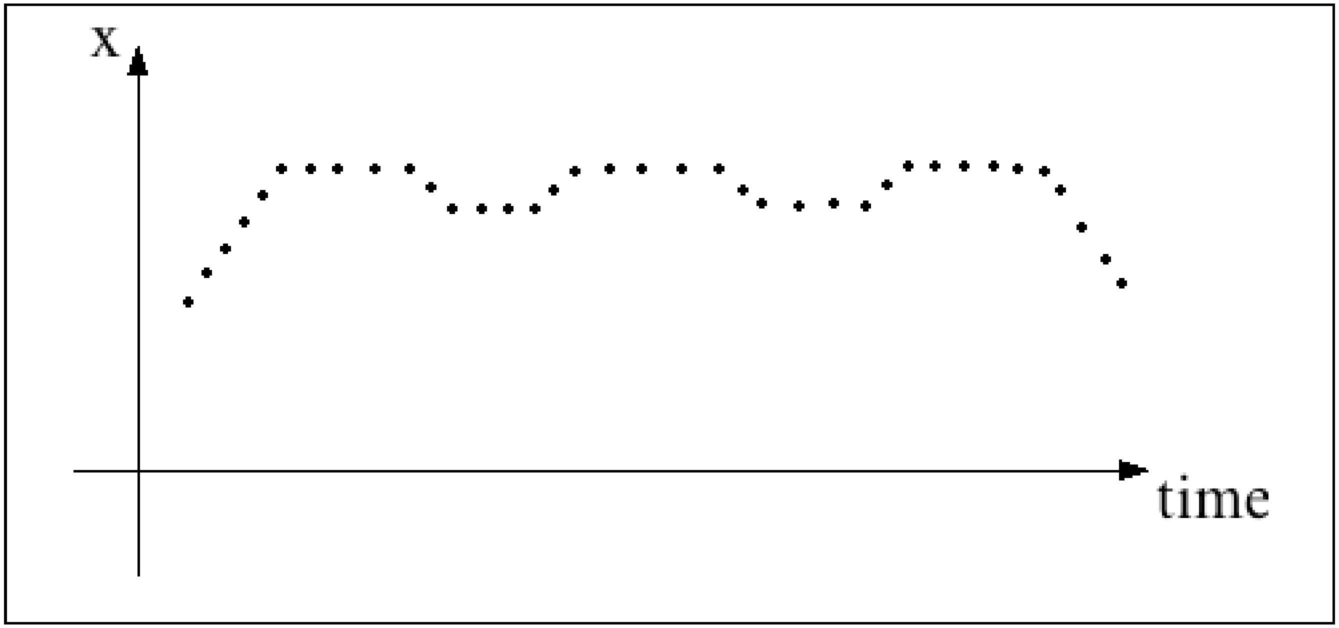
∗ region between D2 and the cryostat is potentially available





Lattice parameters

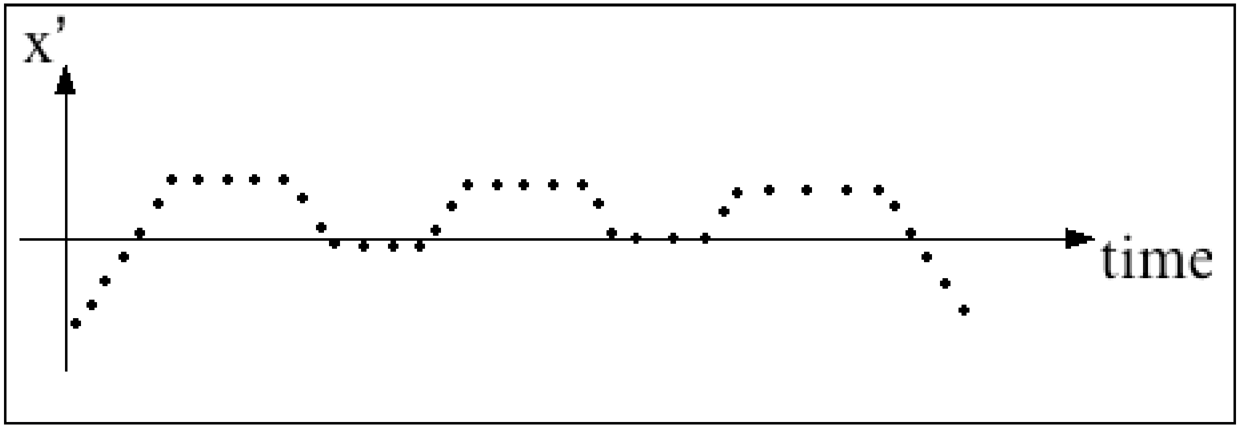
- Measure orbit bunch-by-bunch outside I.P.
- Digitize bunch-by-bunch $I_b\Delta x$ measurement
    - ∗ normalize by I_b to obtain Δx
    - ∗ average over several turns to reduce betatron motion



- Apply corrective kick to kickers around I.P.
  - ∗ correct closed orbit deviation outside I.P.

- Herr calculates normalized maximum total kick from peripheral collisions to be 8.8 e-6 $m^{1/2}$ (half of this per side of the I.P.)

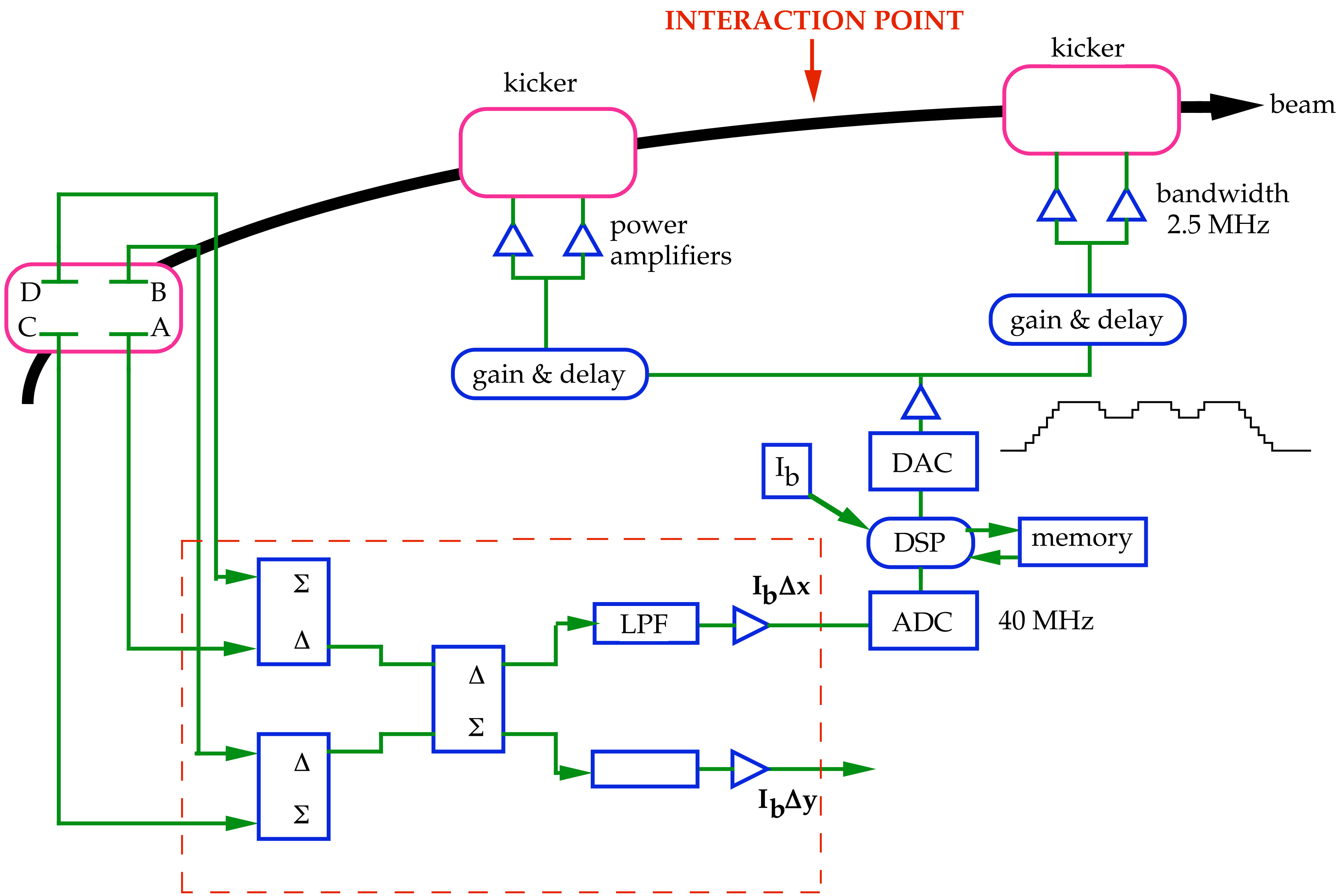
- Using an AC coupled system and a DC bump through the I.P. we need only about 1/4 of this normalized kick to correct for *deviations* in the bunch train about the average



- Kicker placing is not optimal for correcting the betatron motion induced by peripheral (beam-beam) kicks

  * corrective kick ≈ 1/2 peripheral collision kick

- Schematic of fast orbit correction control scheme



- $\beta_{x,y} \approx 200$ m (lower value) near D2

  - ∗ need kick $\Delta x'$ of approximately

$$\Delta x' = \frac{8.8e\text{-}6}{4\sqrt{200}} = 0.16 \text{ mrad}$$

  - ∗ kick voltage V_{kick} (@ $\beta_{x,y} \approx 200$ m) = 1.1 MV

$$V_{kick} = \frac{E}{e}\Delta x' = 7e12\,\frac{8.8e\text{-}6}{4\sqrt{200}} = 1.1 \text{ MV}$$

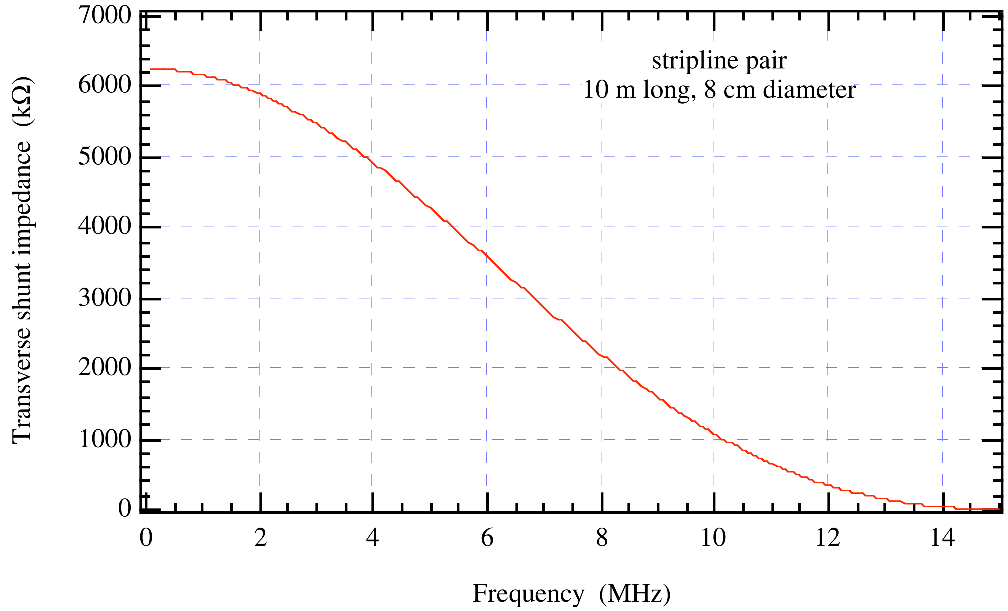
- $\beta_{x,y} \approx 900$ m (upper value) near D2

  - ∗ kick voltage V_{kick} (@ $\beta_{x,y} \approx 900$ m) = 0.5 MV

- Electromagnetic kicker (stripline pair)

$$R_{\perp}T^2 = 2\, Z_L \left(g_{\perp} \frac{2}{kh} \right)^2 \sin^2\Theta$$

Z_L = stripline impedance
$g_{\perp}$ = coverage factor
$k = \omega/c$
h = separation between electrodes, scales as sqrt(β)
l = length of electrodes
$\Theta = k\, l$



- System bandwidth determined by tolerance to overshoot
  - ∗ ≈ 400 ns “rise time” during passage of PACMAN bunches
  - ∗ bandwidth ≈ 2.5 MHz

- 10 m kicker shunt impedance
  - ∗ 26 MΩ @ 2.5 MHz for 3.8 cm aperture (β = 200m)

* 5.7 MΩ @ 2.5 MHz for 8 cm aperture ($\beta = 900$m)

* power requirement P_{kick} (@ $\beta_{x,y} \approx 200$ m) = 23 kW

$$P_{kick} = \frac{V_{kick}^2}{2\,R_{shunt}} = \frac{(1.1e6)^2}{2 \text{ x } 26e6} = 23 \text{ kW}$$

* power requirement P_{kick} (@ $\beta_{x,y} \approx 900$ m) = 22 kW

- Use two kickers, fed by 1/4 power calculated above to obtain the same kick angle

- Per beam, per plane, for one I.P., need four 6 kW amplifiers

  * cost ≈ $15/Watt

- Per beam, per plane, for one I.P., cost of RF power ≈ 360 $k

- Kickers cost ≈ 50 $k each

- Electronics cost ≈ 75 $k per plane, per beam

- Total cost for one plane, for one I.P. = 1.27 $M

  * use magnetic kicker or electrostatic kicker?