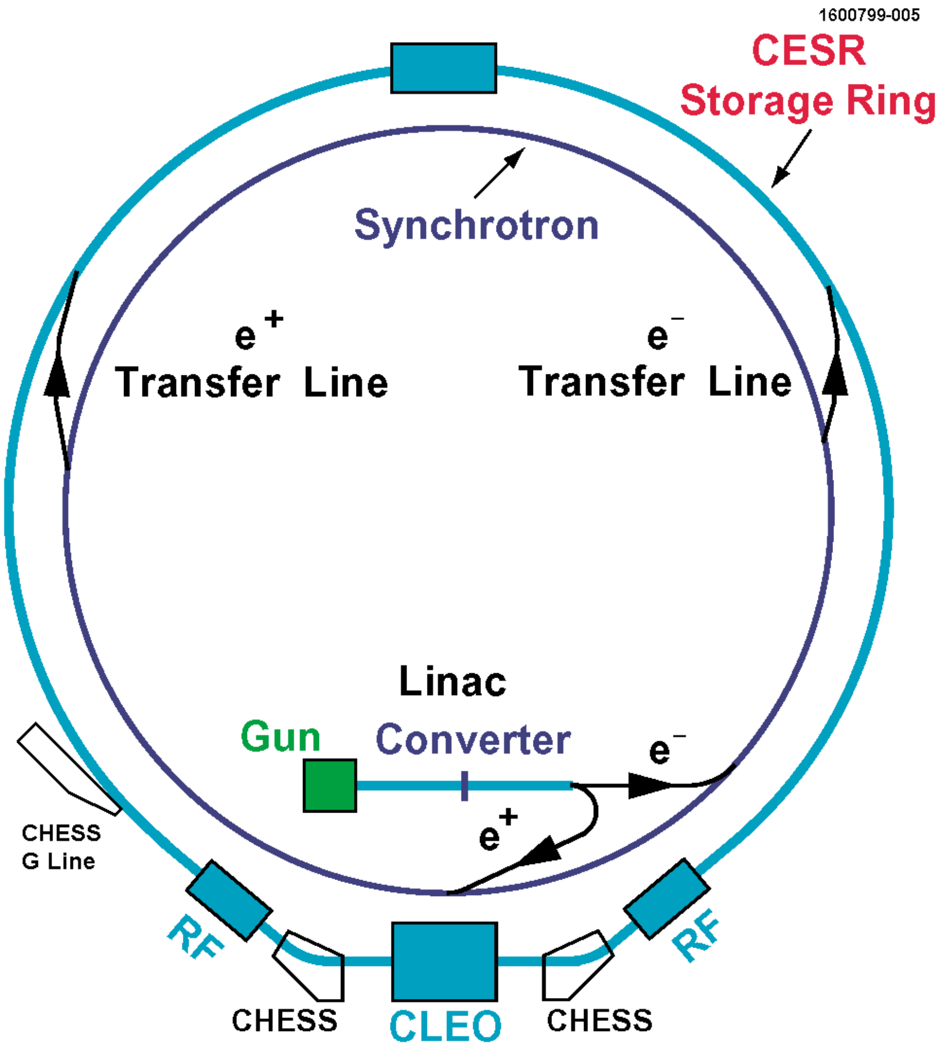
Injection with Pretzels at CESR

Working Group 6 – Injectors & Injection

David Rice
Center for Accelerator-based ScienceS and Education, Cornell University, Ithaca, NY

CESR Complex

- CESR injector is a full-energy synchrotron with e+/e- linac providing a programmable pattern of bunches each 60 Hz cycle.



Cornell University
Laboratory for Elementary-Particle Physics

Injector Parameters

CESR Injector		
	Parameter & Units	**Value**
	Injector repetition rate [/s]	60
	Linac Energy (e+/e-) [MeV]	160/300
	Linac max bunch number	24
	Linac charge/bunch (e+/e-) [nc]	0.01/0.1
	Linac RF frequency [MHz]	2855.77
	Synchrotron Circumference [m]	755.84
	Synchrotron RF frequency [MHz]	713.943
	Highest common frequency [MHz]	71.394
	Smallest common bunch spacing [ns]	14.007

Ring Parameters

(Circa. 2000)

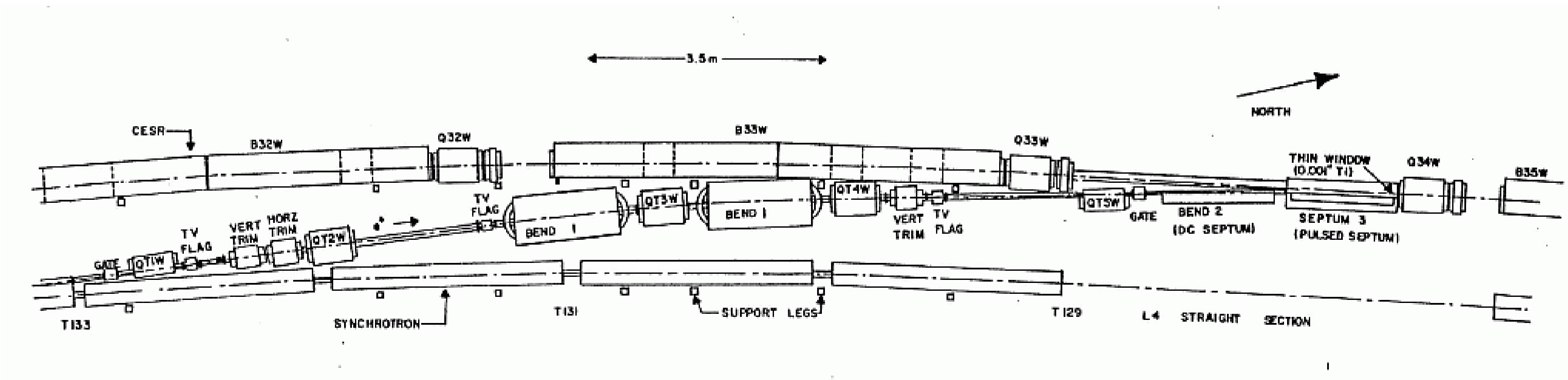
	Parameter & Units	Value
CESR Ring		
	Circumference [m]	768.44
	Operating beam energy [GeV]	1.8-6
	Transverse damping time [ms]	24 (@5.3GeV)
	Current per beam (mA)	375
	Number of bunches	45
	RF Frequency [MHz]	499.7594

Injection Process

- A grid-modulated cathode produces a series of precisely spaced bunches (~24 max – beam loading limit)
- Accelerate in synchrotron ~8 ms (sinusoidal B field)
- Timing system waits variable # turns for alignment with CESR buckets being filled (61/60 circumference ratio)
- Single turn extraction to transfer line through thin (3 mm) septum in CESR chamber in horizontal plane.
- Pulsed, half-sine ~ 3 turn base width, bump magnets bring stored beam next to septum.
- Injected particles damp, sometimes with help of short trim kicker ("pinger")

Synch-CESR Transfer Line

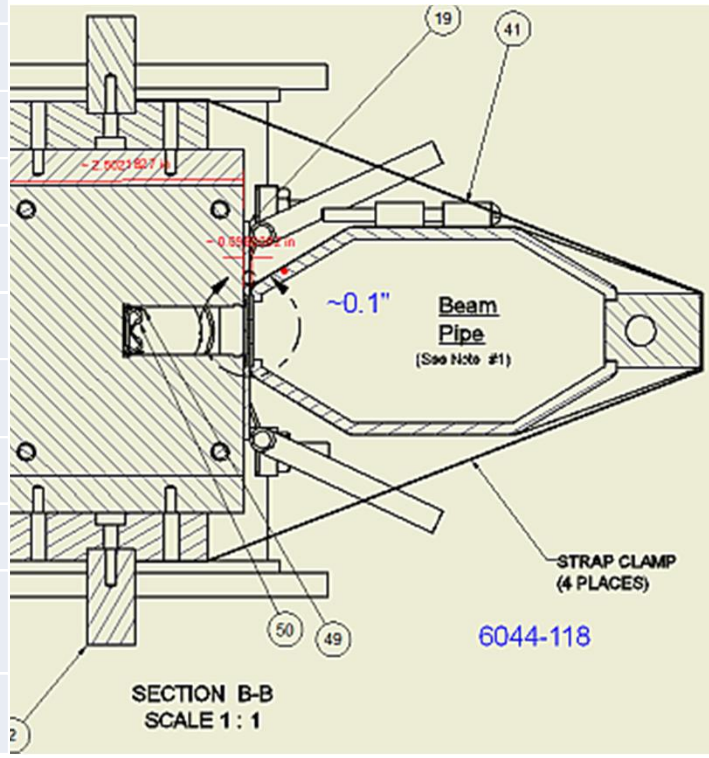
- Transfer lines from synchrotron to CESR
- Recent upgrade with 3 bpm's each to record bunch-by-bunch positions.



Injection Oscillation Amplitude

- Spreadsheet example:

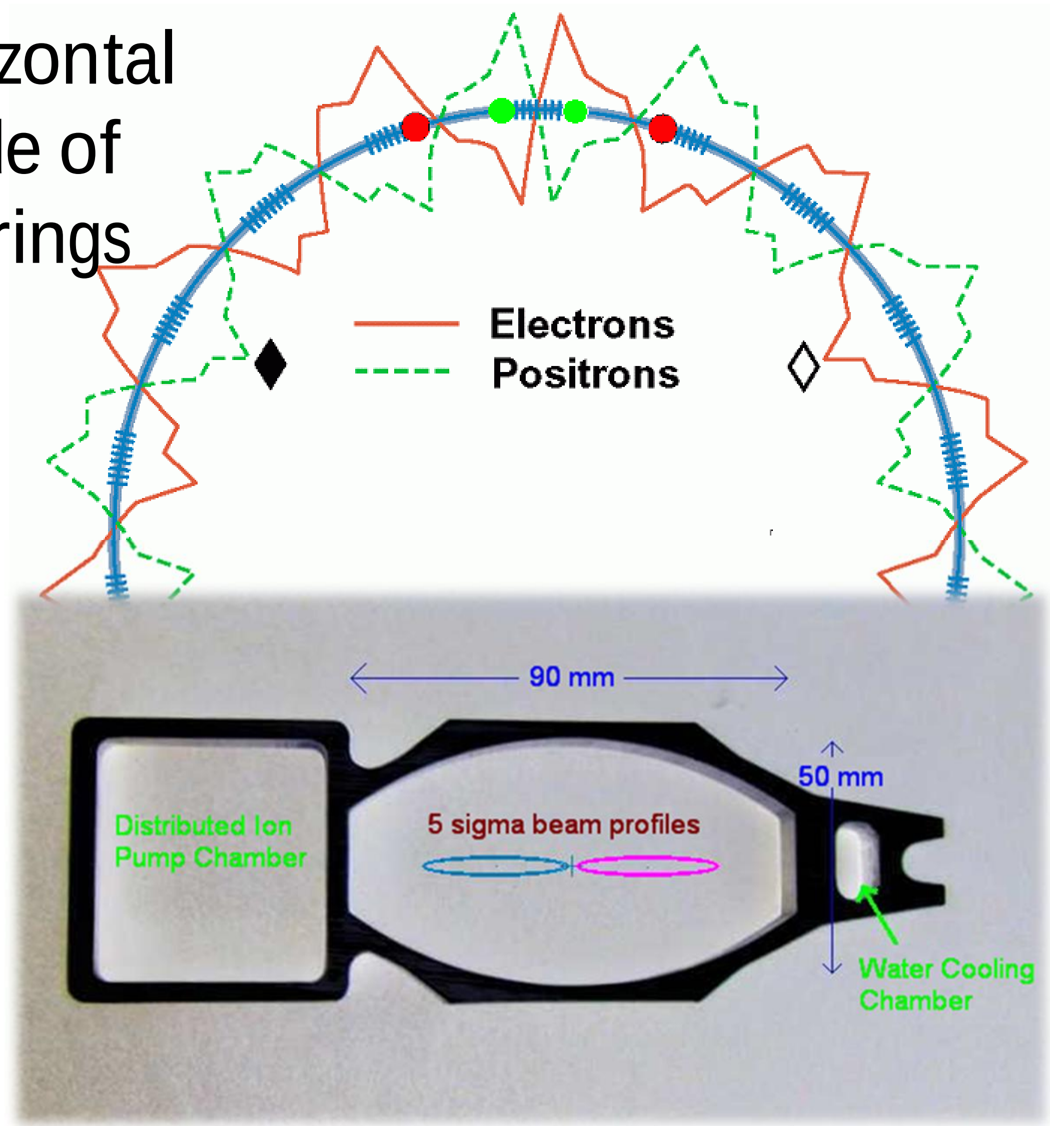
Septum wall thickness	3	mm
Synch beam radius:	3	mm
CESR beam H emit	5.10E-08	m
CESR sigE/E	6.20E-04	
CESR 34W betaH	32.13	m
CESR 34W etaH	1.62	m
CESR 34W sigH	1.63	mm
Min wall clearance	4	sigH
Inj-Stored beam displace.	12.51	mm
Betatron amplitude	9.77	sigma
Betatron amplitude	2.21	mm/√β



Injection efficiency 60-80% with single beam – but …

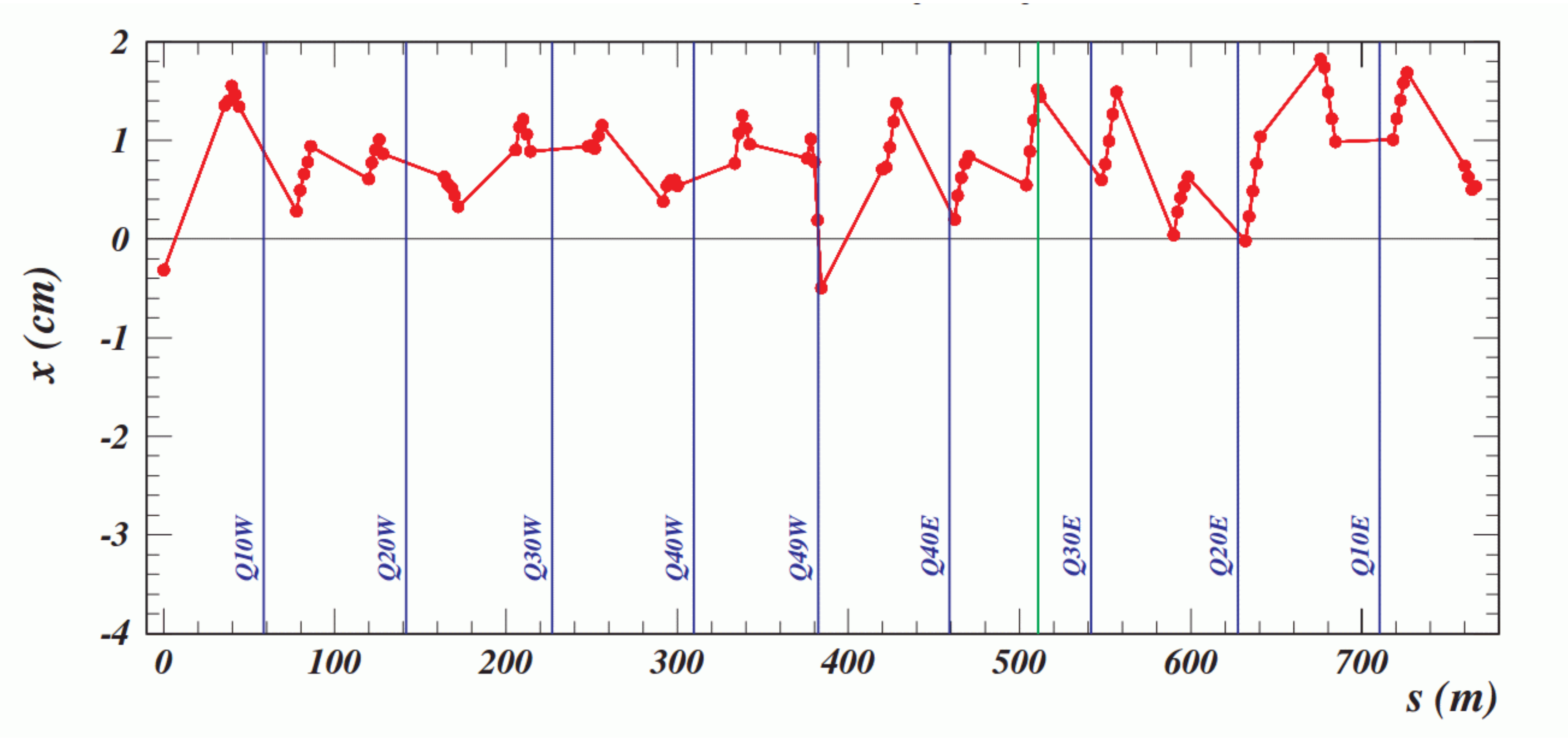
Horizontal Pretzel

- This ~10 sigma horizontal oscillation amplitude of injected particles brings them into core of counter-rotating beam.
- Injection efficiency now 10-30%, requiring frequent maintenance.



Separattion at PC's

- Clearance to counter-rotating bunches for injected bunch(s) calculation (9 trains x 5 bunches, 2.1 GeV):



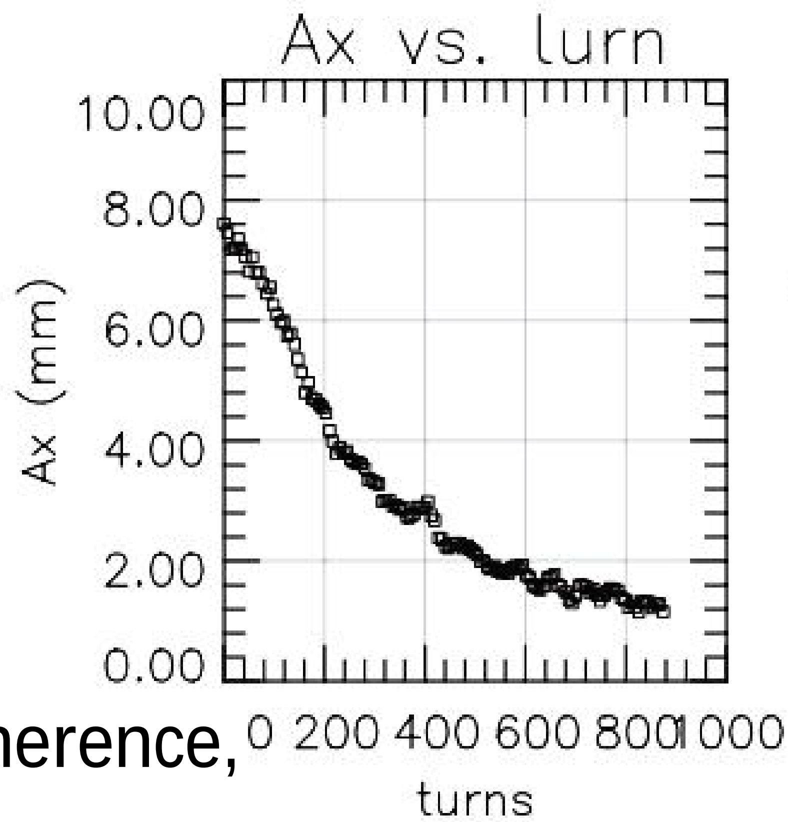
Minimization of Injection Losses

- Several steps in design and operation have been taken to minimize injection losses.
  - Optics design – maximize minimum separation at crossings
  - Use sextupoles to split e+ / e- tunes, minimize coherent effects ($\Delta Q \approx 0.025$) –two more knobs beyond Q_x, Q_y
  - Move close to coupling resonance to increase σ_y of strong beam (not good for luminosity)
  - Use a one-turn kicker (“pinger”) within a few turns of injection to reduce oscillation amplitude of injected bunches - small increase in stored beam oscillations.
  - Energy mismatch tuned for best filling efficiency
  - Filling one beam $\approx$ halfway, then the second and return to the first can keep bunch population more even.
  - Usual tuning of steering, closed orbit bumps, chromaticity…

Cornell University
Laboratory for Elementary-Particle Physics

Amplitude Measurement

- Turn-by-turn measurements* of beam position suggest an amplitude of ~8 mm of the injected bunch.
- Translated to σ_x, smaller amplitude than calculated, likely reflects the agressive bumping of stored beam (3-4 σ_x rather than 5) and similar positioning of the injected beam w.r.t. the septum.
- The fast decay reflects decoherence, not actual damping.



* Billing et al., PAC 2005, p. 1229

Energy dependence

- When CESR HEP began Charm studies (1.8-2.2 GeV vs. 5.3 GeV beam energy) the PC effects became more severe as expected.
  (note – damping time increased only x2 due to 1.8 T wigglers)
- Filling current limits dropped from 375 ma/beam to 75 mA .

Summary

- Injecting against counter-rotating beam adds challenges and (at least at CESR) is the most difficult aspect of multi-bunch operation, usually determining current limits.
- Once bunch populations become very uneven it can be difficult to recover "good" injection conditions.
- Several tuning tactics have been presented.
- For a ground-up design, careful simulation of the injection process, parasitic crossings, lattice nonlinearities and errors will be essential to a robust design.

Thank you for your attention.