SLAC SLC 2-Mile S-Band Linear Collider

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SLAC

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U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

SLAC Linear Collider: Questions to Answer

SLC collider topics:

- Constructing the SLAC 2-Mile Linac
- SLC collider parameters
- Project timeline
  - Making 50 GeV
  - Making polarized e- bunches
  - Making charge e+ bunches
  - Damping rings
  - Linac emittance
  - Arcs and Final Focus
- Anticipated and new accelerator physics
- Increasing the luminosity
- Integrated luminosity with Detectors Mark-II and SLD

Many thanks: R. Assmann, J. Clendenin, J. Dorfan, S. Ecklund, R. Erickson, G. Fischer, T. Himel, N. Phinney, B. Richter, M. Ross, J. Sheppard, R. Stiening, and the SLC team

SLAC Linac Tunnel and Klystron Gallery Construction

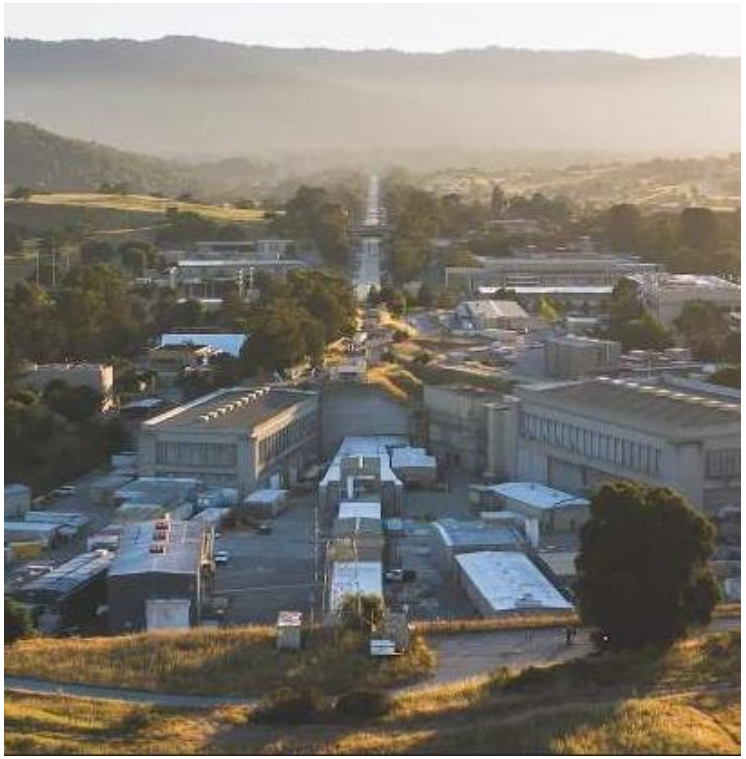
Gallery is ~10 m above
The accelerator tunnel
30 sectors at ~100 m ea =
2 miles or ~3.3 km

Accelerator tunnel tangent to earth
at Sector 30. About 10 m high
at the front end.

SLAC Research Yard

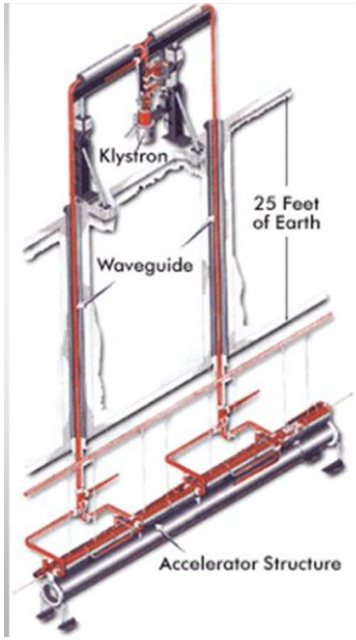
Paleoparadoxia
(14 million year old fossil
related to hippopotamus)

1964



2019

SLAC Klystron Gallery and Accelerator Tunnel

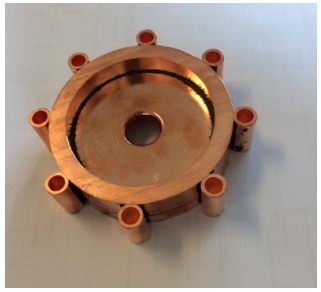


240 klystrons

Construction of the Copper S-band Accelerator 3 m Structures (960+)

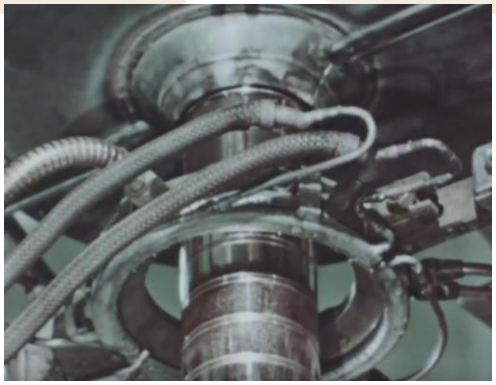
About 1000 precision measurements during construction of a 3 m structure with tolerances about (~0.02 mm)

Cut cylinders

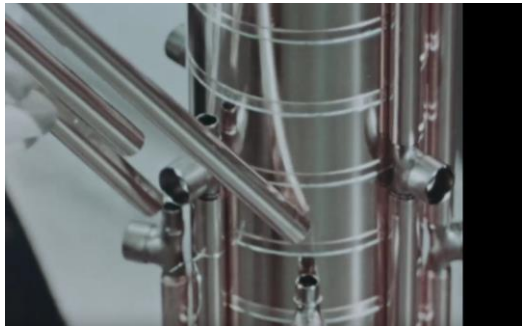


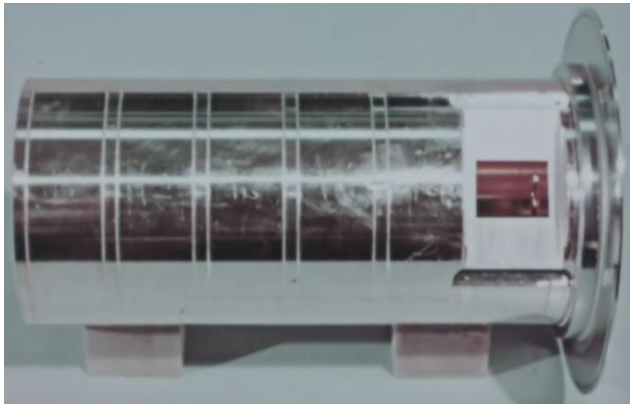
Shape disks

Braze (#3) full 3 m structure



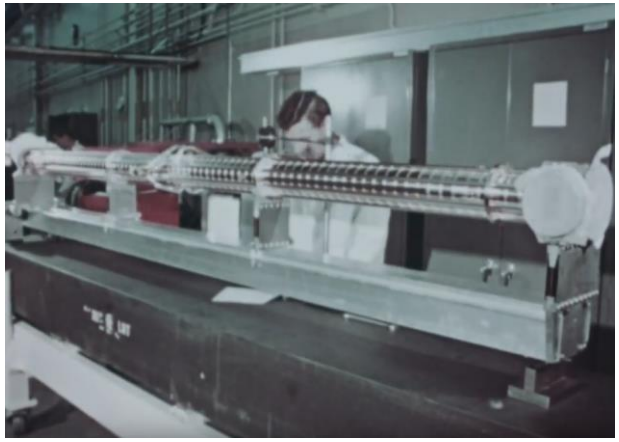
Braze (#4) cooling lines





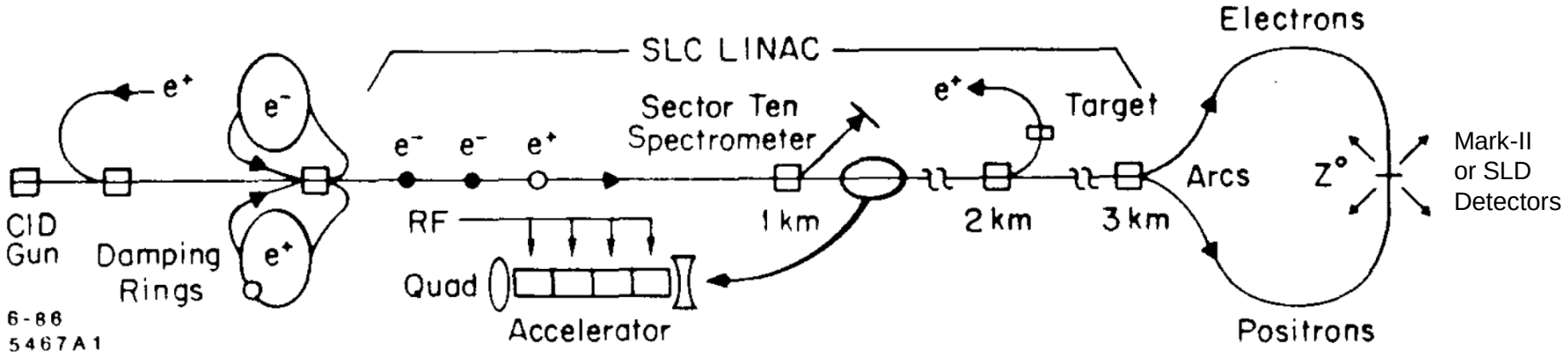
Braze (#1+2) end couplers

Mount DLWG on strong back

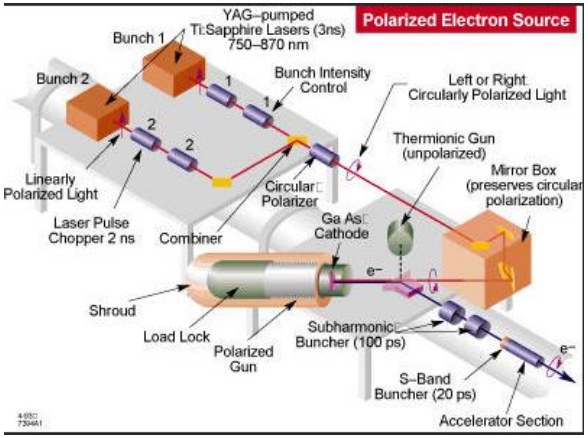


SLAC Linac Overview (~30 GeV in 1975)

SLAC SLC Collider Layout (e+e- : 47 GeV x 47 GeV) (begin const. 1984)



Polarized e- Gun



e- bunches = each 8x 10^{10} in 2 ns long
bunch shortened to 3 mm

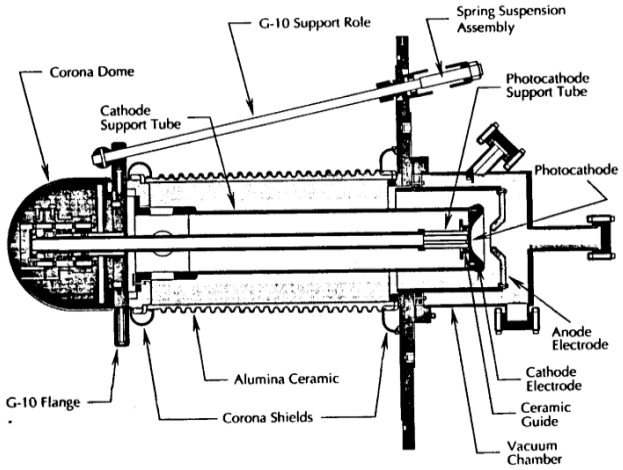
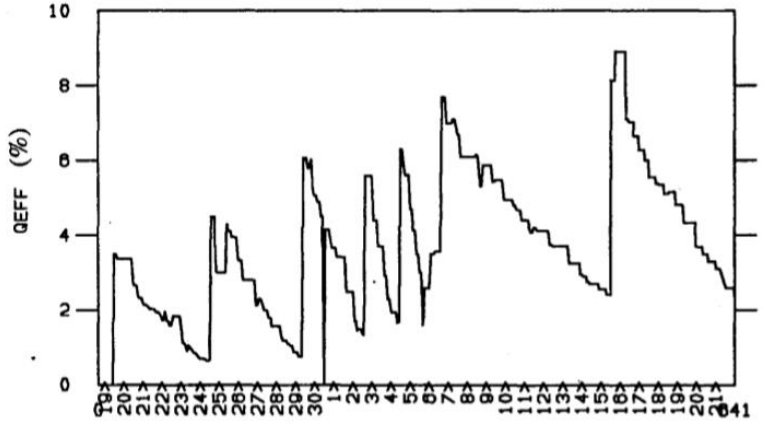


Fig. 2 Schematic diagram of the polarized electron gun at the SLC.



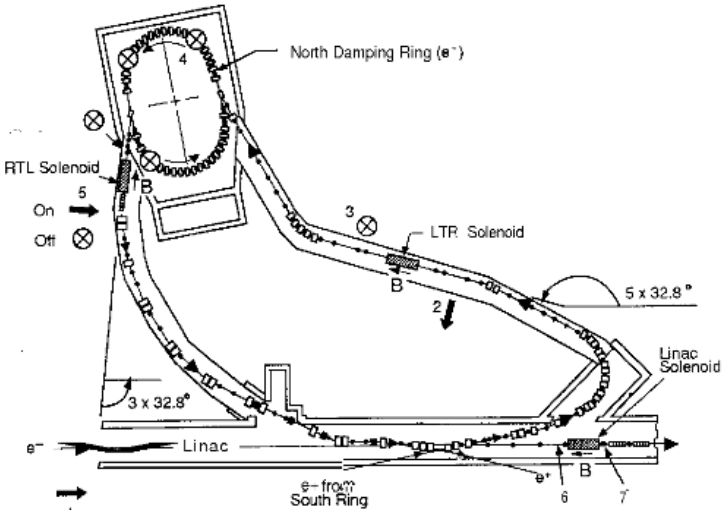
Measured quantum efficiency of the polarized electron source for the first month.

Cathode	Polarization at Cathode
Bulk GaAs at 150° K (715 nm)	42 %
Thin AlGaAs (715 nm)	42 %
Thin GaAs (760 nm)	45 %
Strained lattice [2] (830 nm)	85 %

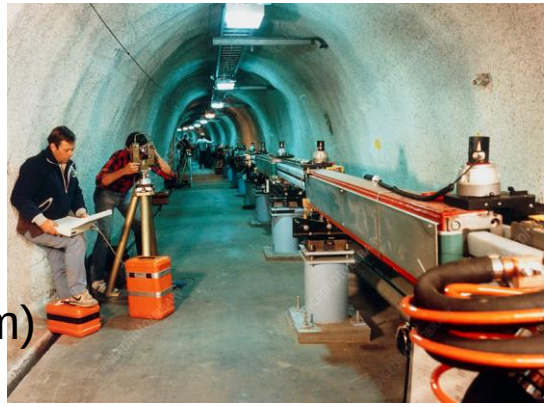
Linac Improvements needed for the SLC Collider

Two damping rings
With spin manipulation

Linac fitted with
New quadrupoles
and dipole correctors



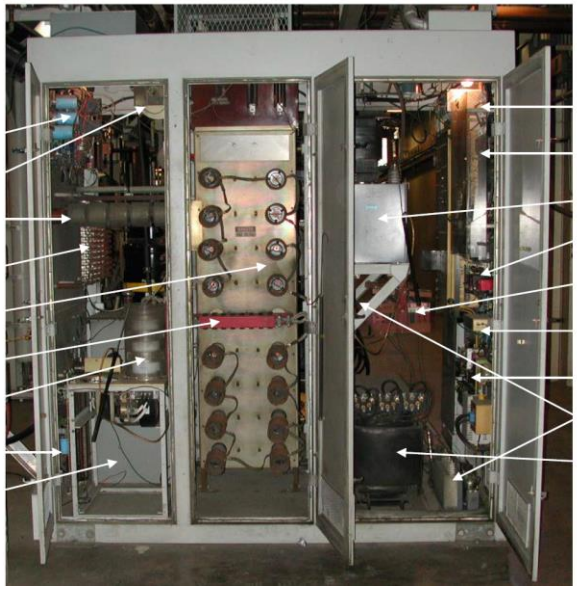
Build two arcs with
combined function
dipole, quadrupoles,
and sextupole fields
(vacuum bore = ~10 mm)



SLC RF Klystron, SLED, and New Modulators

SLED
pulse
doubler

6045
Klystron
(3 micro-sec)



New
Pulsed
Modulator

SLC Collider History

1979	First proposed, began design studies	
1985-87	Construction	
1989	1st Z in Mark II detector on April 11	
	Mark II run to Nov, 1990	~1200 Zs
1991	SLD engineering run	~300 Zs
1992	1st SLD Physics Run	10000 Zs
	Electron polarization	22%
1993	SLD Physics Run	50000 Zs
	switched to Flat Beam optics	
	Strained lattice cathode	62%
1994-5	SLD Physics Run	100000 Zs
	Major upgrades to Damping Rings and Final Focus	
	Thinner layer cathode	77%
1996	Short SLD Physics Run	50000 Zs
	with new Vertex Detector VXD3	
1997-8	Major SLD Physics Run	> 350000 Zs
	with VXD3	

SLC Luminosity Summary

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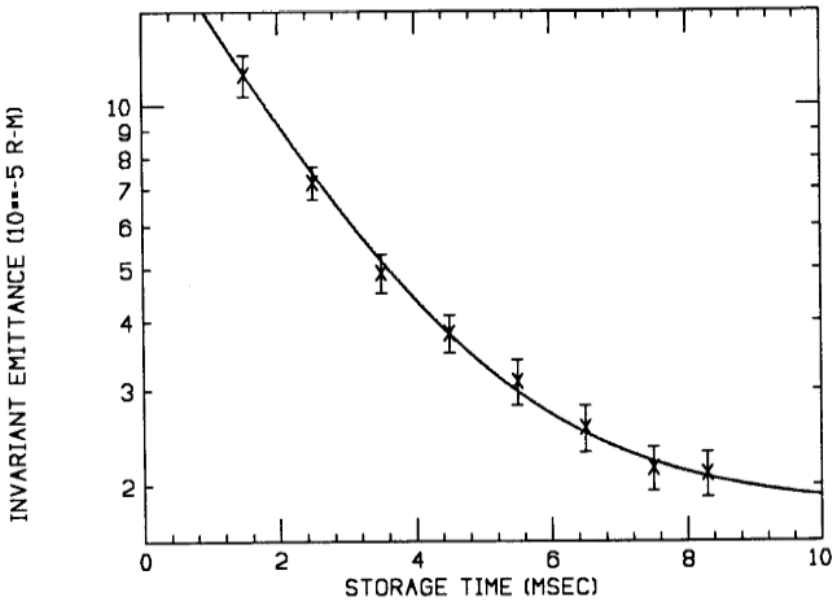
$$L = \frac{N^{+} N^{-} f}{4\pi\sigma_x \sigma_y} H_d$$

Table 1: Design and achieved SLC beam parameters

	Design	Achieved	Units
Beam charge	7.2e10	4.2e10	$e^{\pm}$/bunch
Rep. rate	180	120	Hz
DR ε_x	3.0e-5	3.0e-5	m rad
DR ε_y	3.0e-5	3.0e-6	m rad
FF ε_x	4.2e-5	5.5e-5	m rad
FF ε_y	4.2e-5	1.0e-5	m rad
IP σ_x	1.65	1.4	μm
IP σ_y	1.65	0.7	μm
Pinch factor	220%	220%	Hd
Luminosity	6e30	3e30	$cm^{-2}sec^{-1}$

Damping ring emittance reduction



Measured extracted emittance versus storage time in the electron damping ring.

Low currents are fine.

High currents have instabilities
In the damping rings

(saw-tooth longitudinal) →
Needed new vacuum chambers

Linac oscillations emerge at higher bunch charges

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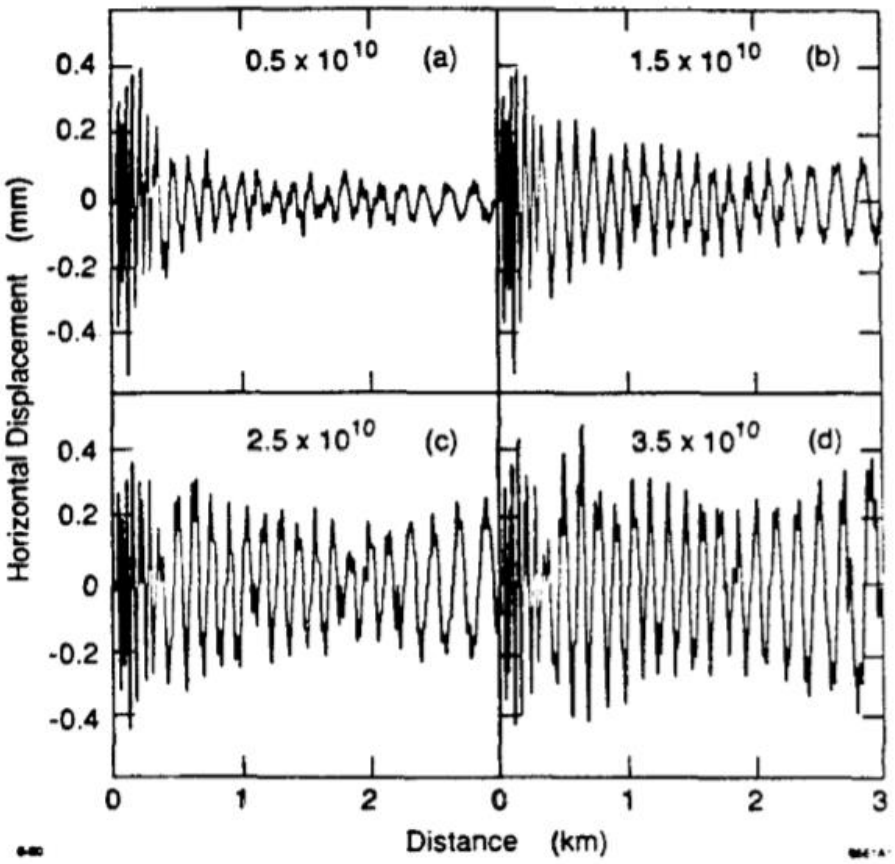
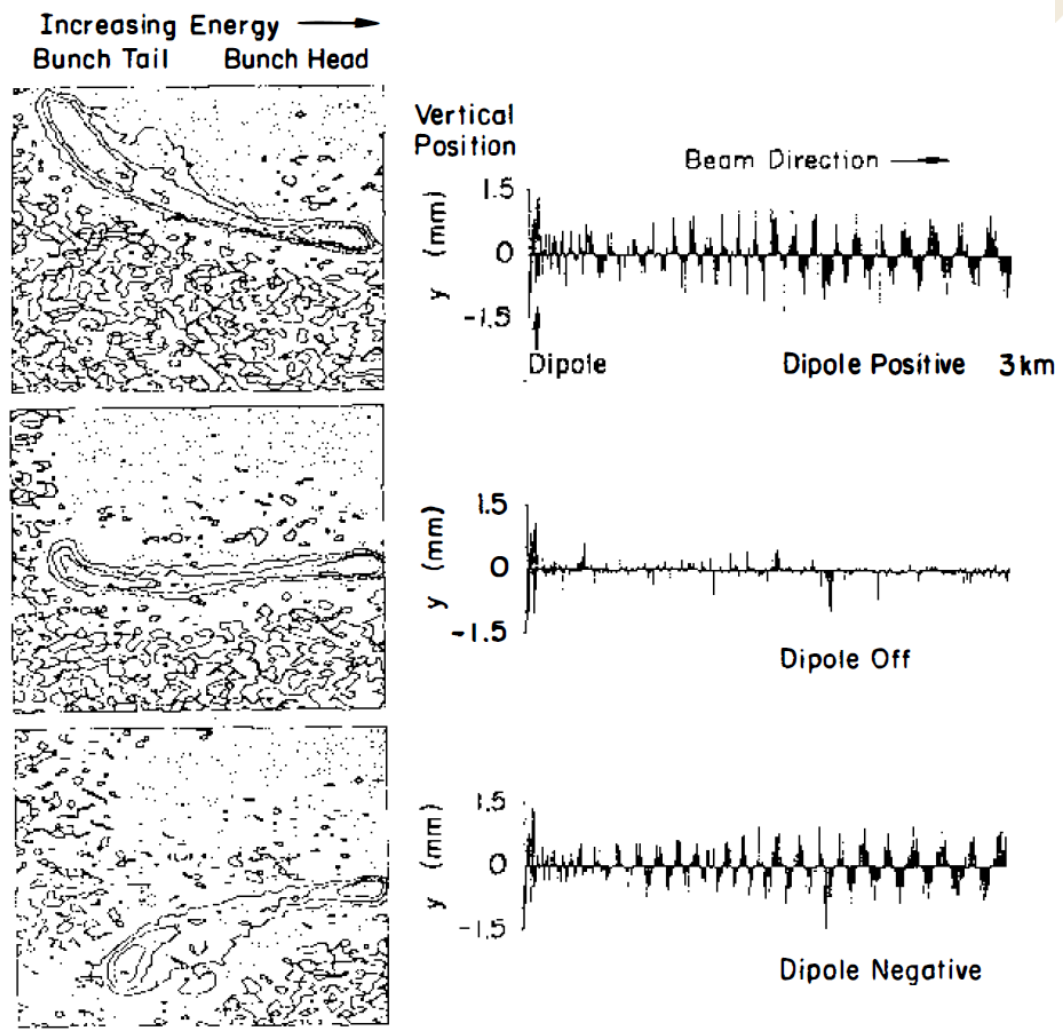


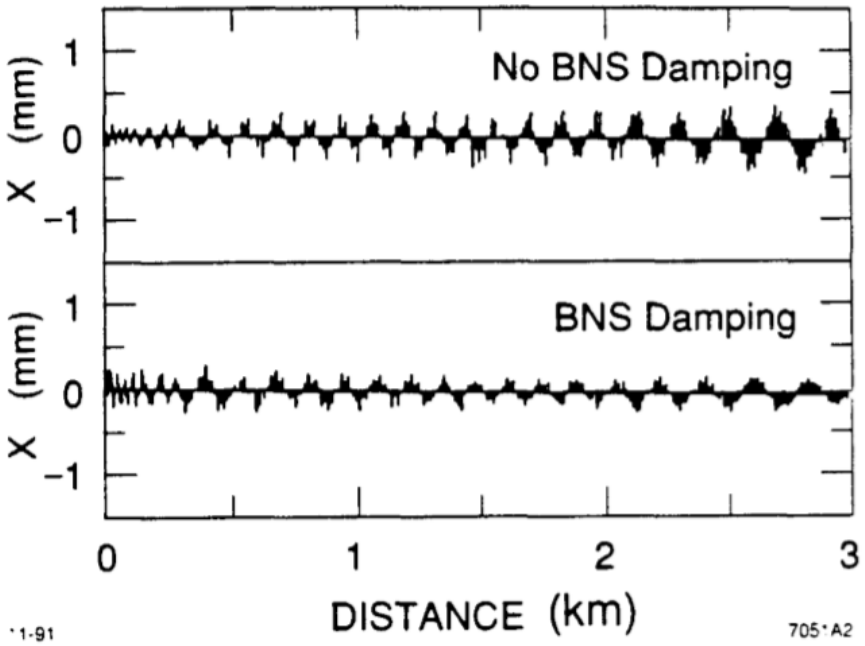
Observed single bunch oscillations along the SLC linac versus charge for identical dipole changes. Standard BNS conditions for 3×10^{10} e^- are used in all cases with the overall linac phase adjusted to make a small energy spectrum at 47 GeV.

SLC Linac Transverse Wakefields over 2 Miles



BNS Damping to reduce emittance growth

Change RF phase in first 1/3 of the linac opposite to last 2/3 of the linac (~few degrees) then scale quadrupoles and re-correct trajectories. (~15 minutes)



Measured oscillations in the SLC linac with and without transverse wakefield damping (BNS). The bunch charges are 2 x 10^{10} e^-. The upper plot shows the exponential growth of the oscillation without BNS damping and the lower plot shows little growth with BNS damping. A factor of ten improvement is observed.

(A. Novokhatski et al)

Induced Oscillations to reduce Linac exit emittances

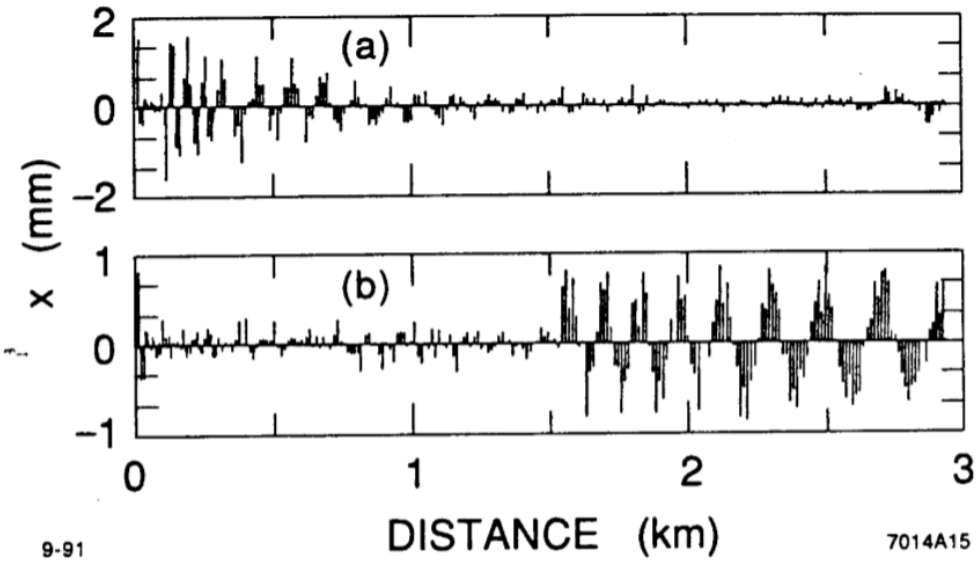
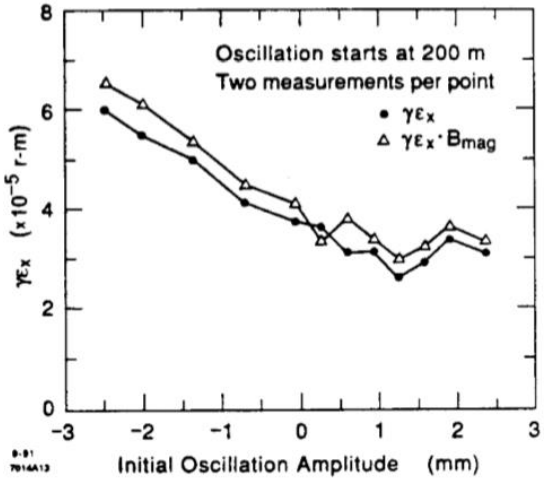
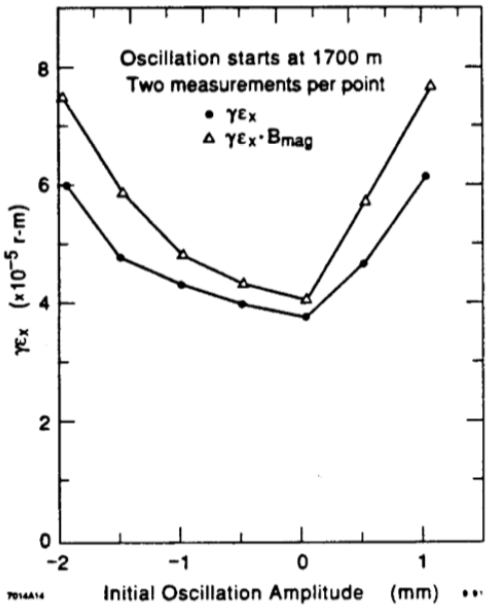
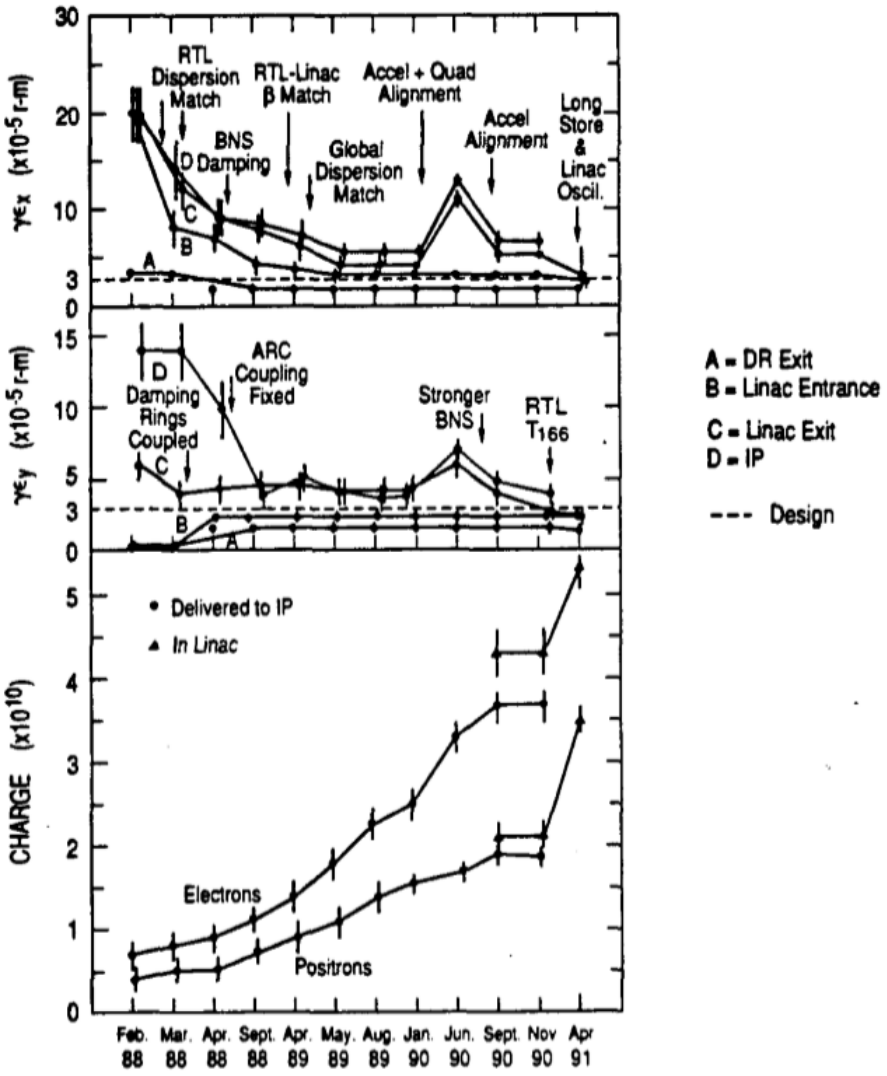


Fig. 12 Two typical induced oscillations in the SLC accelerator used to cancel accumulated wakefields and dispersion errors in the linac (see Fig. 13).





SLC Bunch Charges versus Time



Time evolution of the SLC beam emittances and intensities.

SLC emittance versus ARC corrections (steering, rolling, moving)

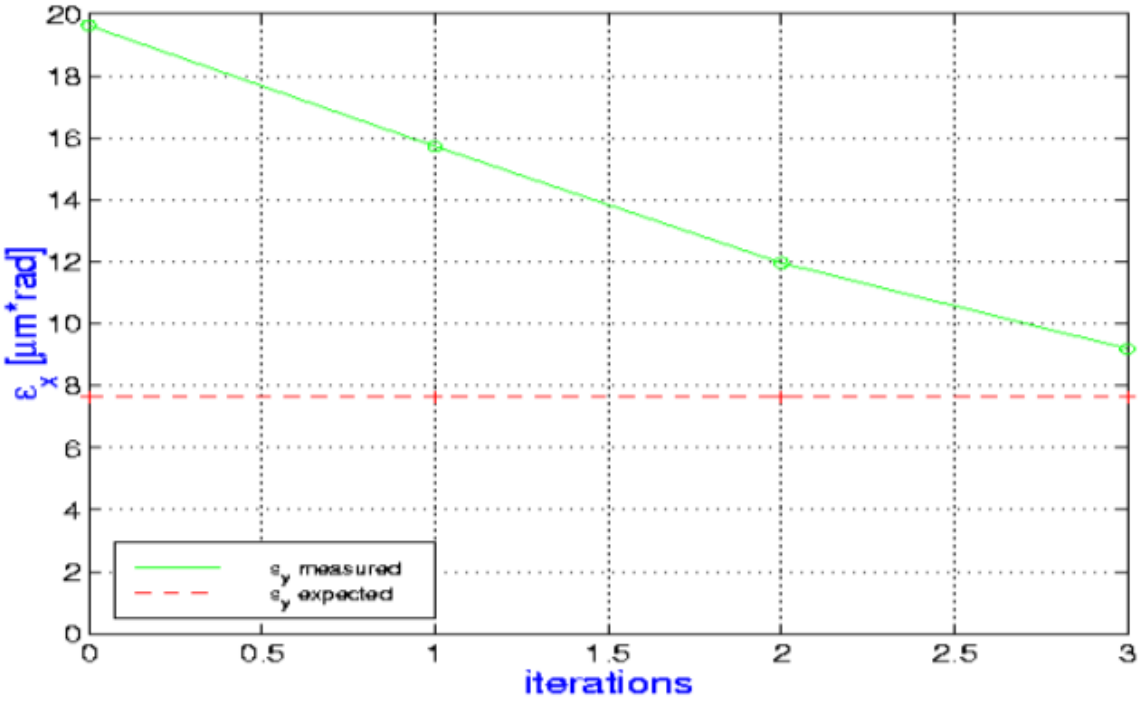
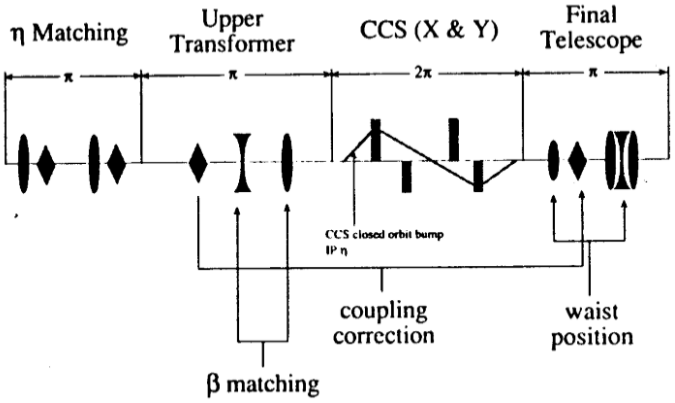


Fig.4: FF vertical emittance as function of Arc-tuning iterations. The expected value comes from the measurement at the end of the Linac plus the contribution from the synchrotron radiation in the Arc

Final focus layout and beam-beam deflection measurements



Schematic view of the SLC Final Focus System indicating tuning regions.

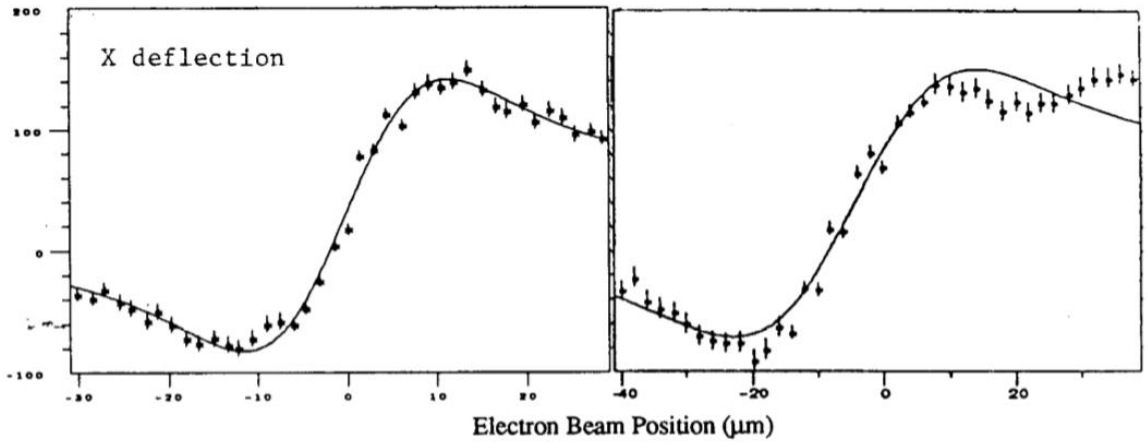
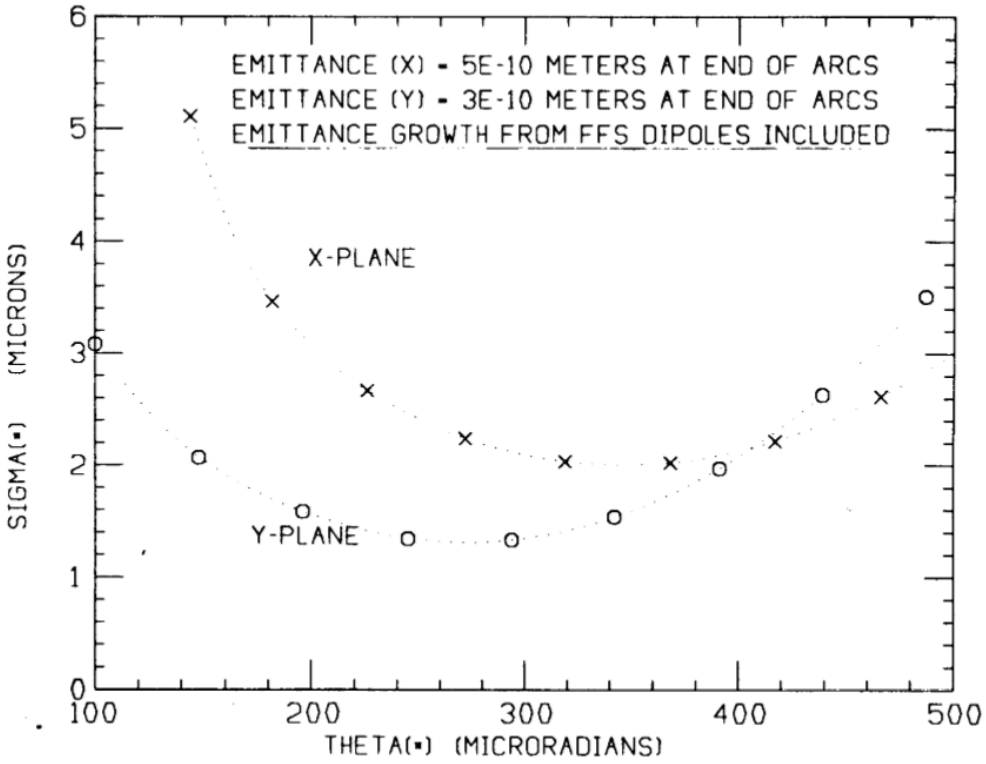


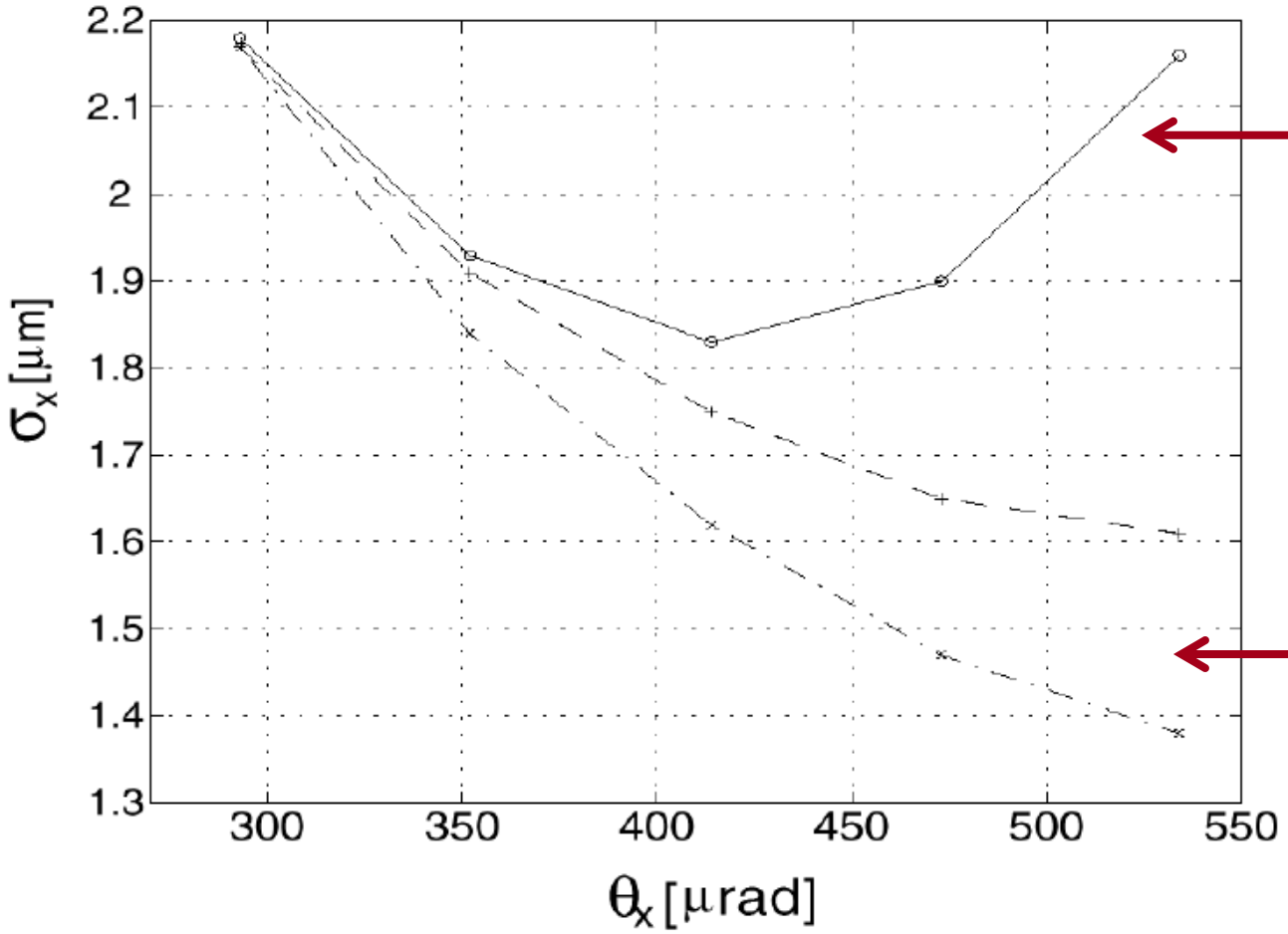
Fig. 20 Observed beam-beam deflections at the SLC Final Focus for about 2.5 x 10^{10} particles per bunch. The left data are for symmetrical beam profiles and the right data are for beams with non-Gaussian transverse tails.

SLC Chromatic Corrections

The theoretical FF performances are limited by spot size dilution due to synchrotron radiation from the bends in the Chromatic Correction Section (CCS) and high order chromo-geometric aberrations.



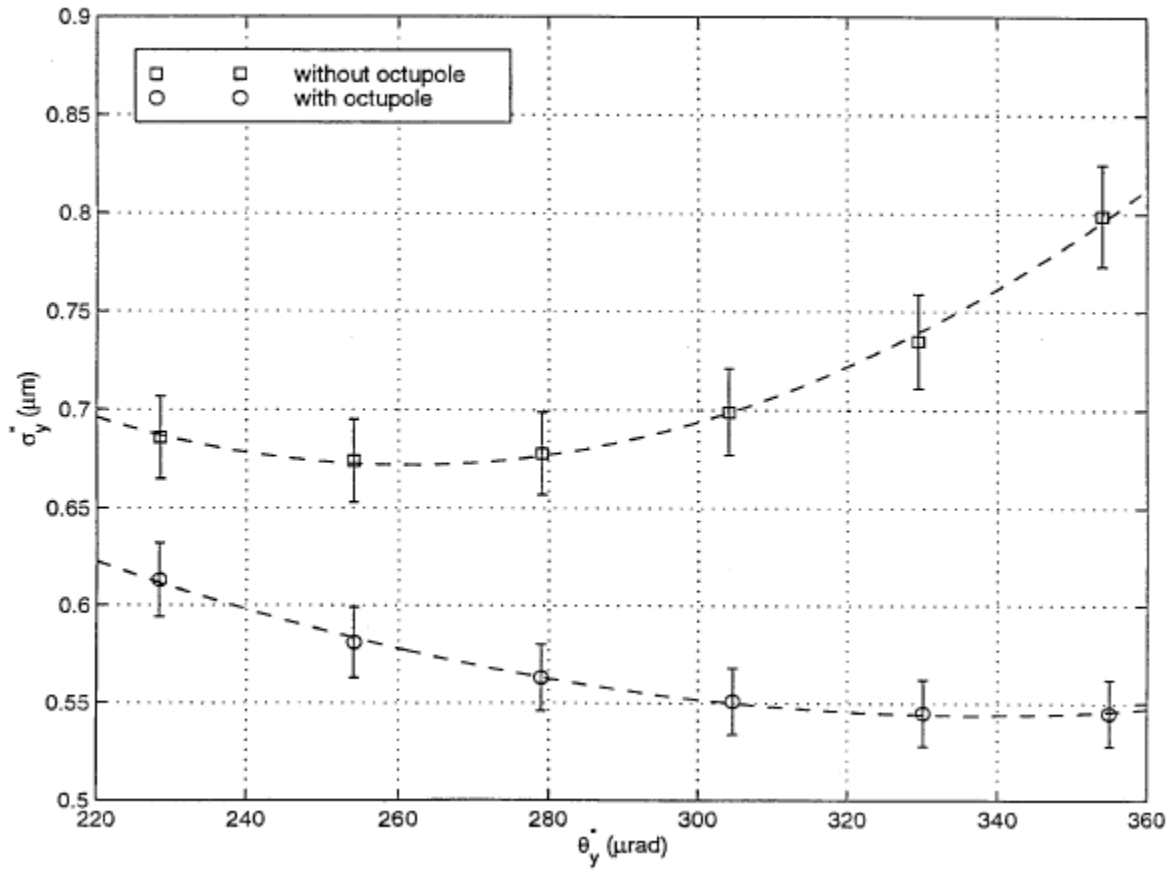
SLC IP horizontal beam size versus divergence angle



1996 optics

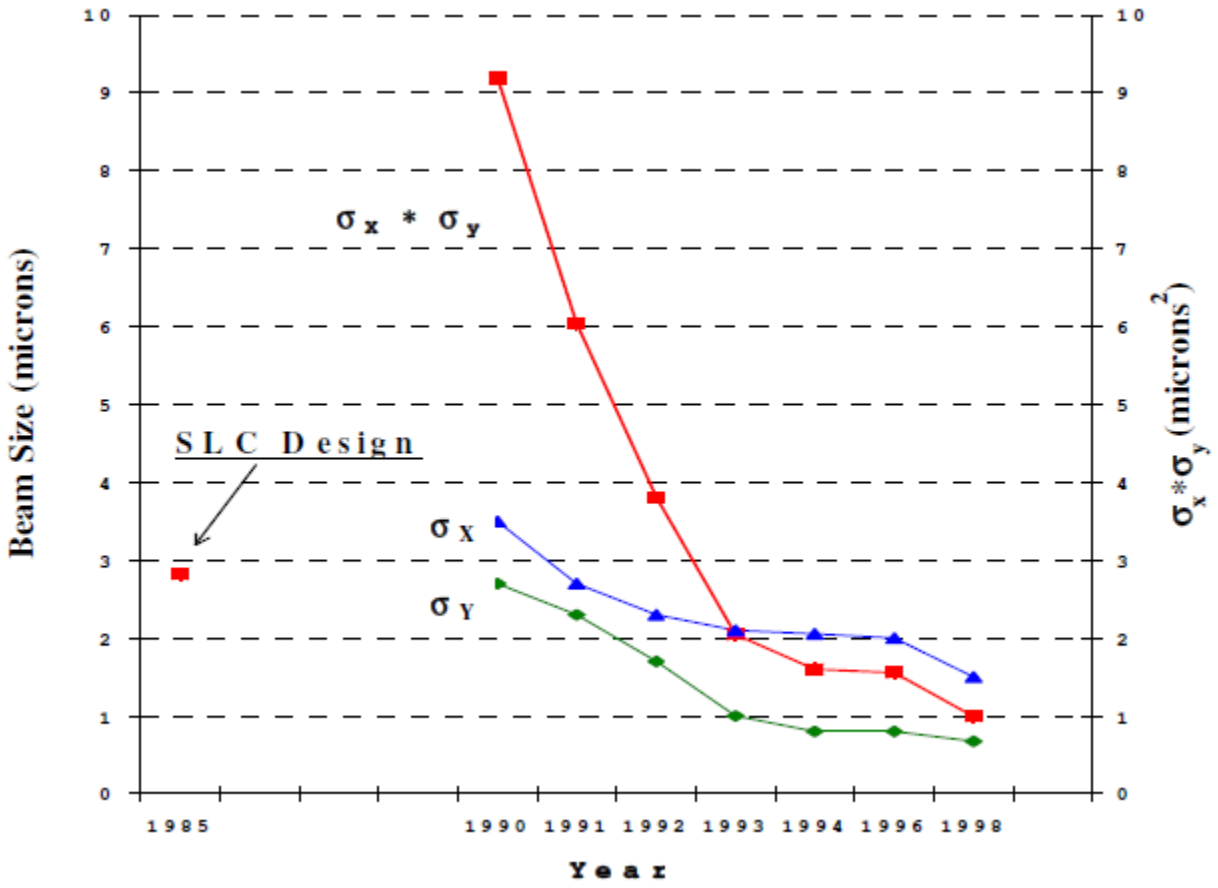
1998 optics

SLC IP Vertical Beam Size versus vertical divergence



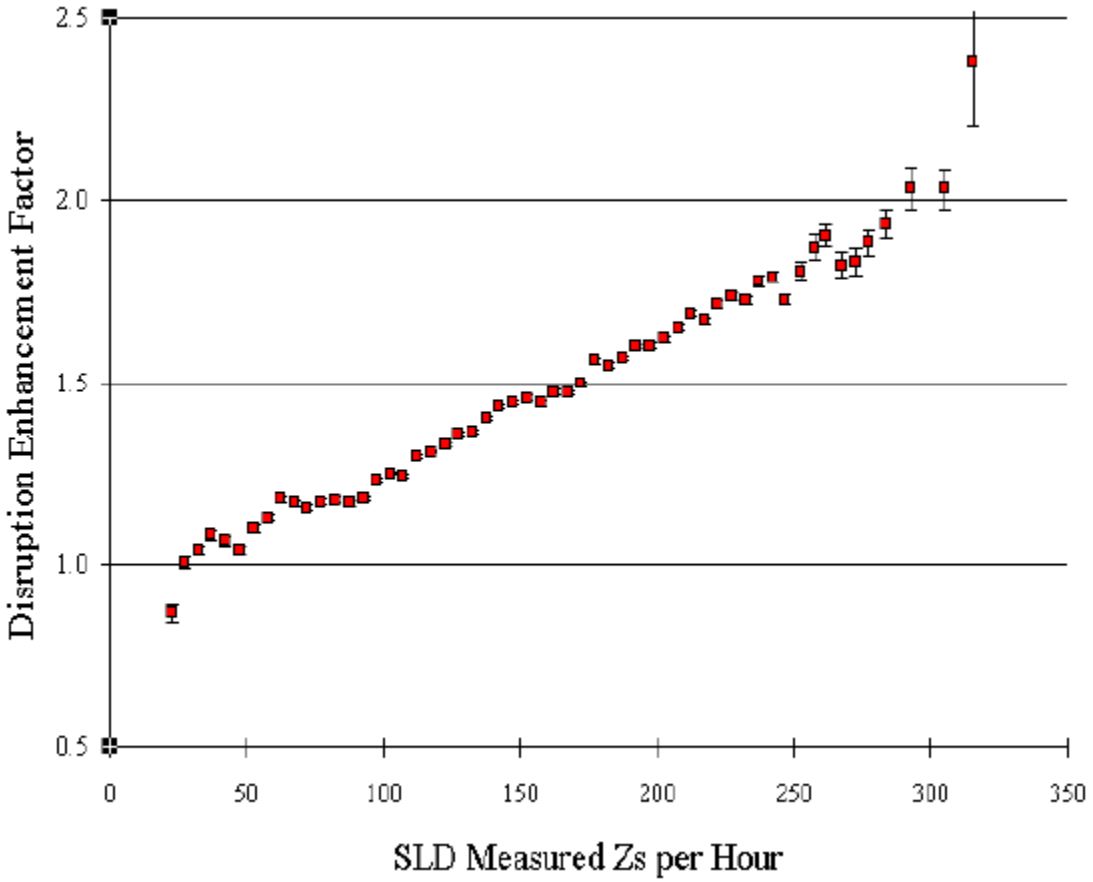
Phinney

SLC Spot Size versus time (Final = 1/3 design)



N. Phinney et al

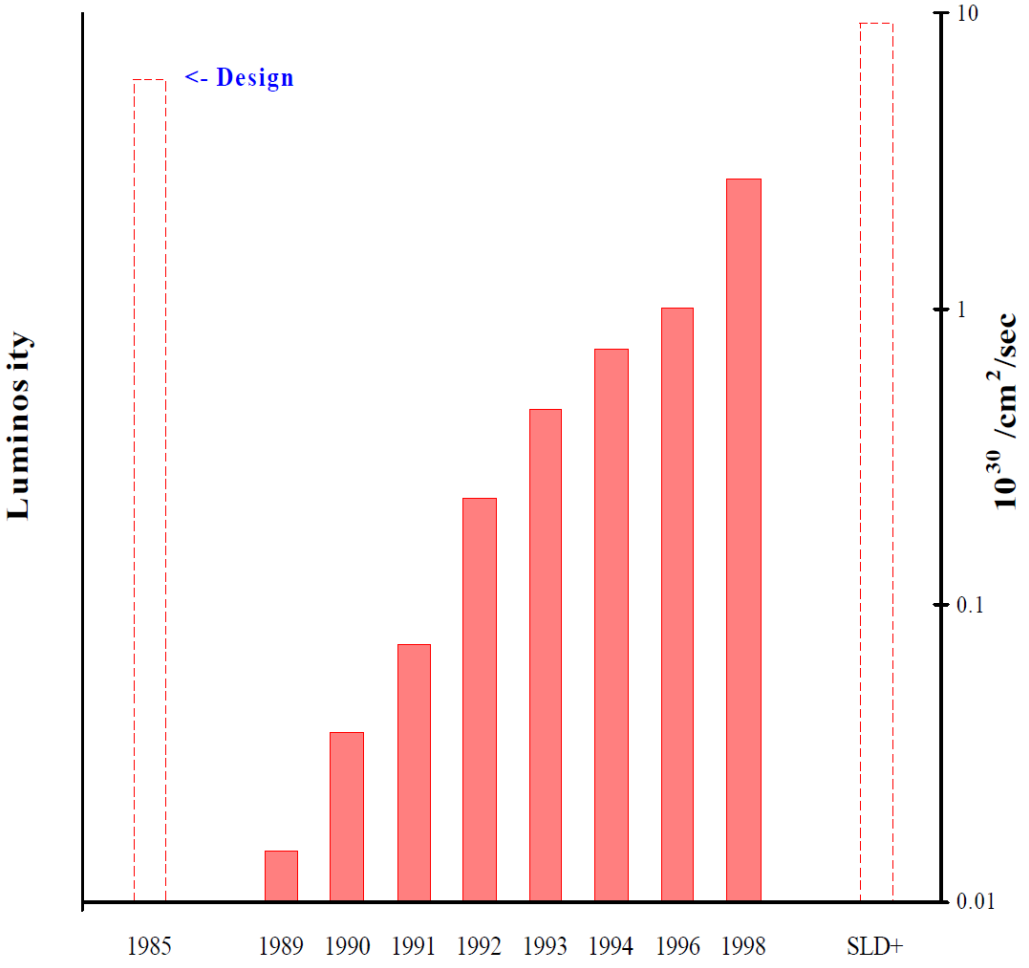
Disruption Enhancement Parameter versus Luminosity



$$D_{x,y} = \frac{2Nr_e\sigma_z}{\gamma\sigma_{x,y}(\sigma_x+\sigma_y)}$$

N. Phinney et al

SLC Luminosity (exponential growth!)



Phinney

Mark-II measured the mass and width of the Z (1989)

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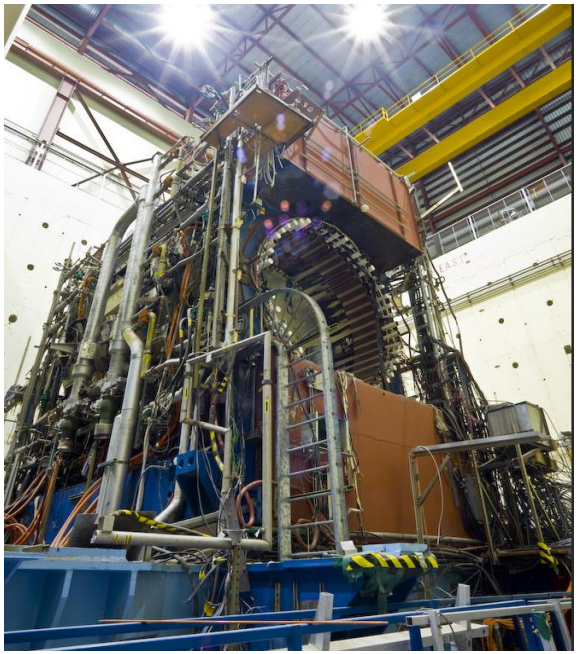
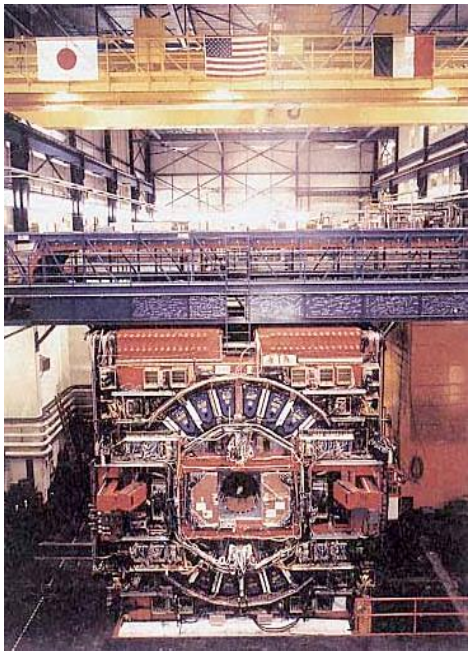
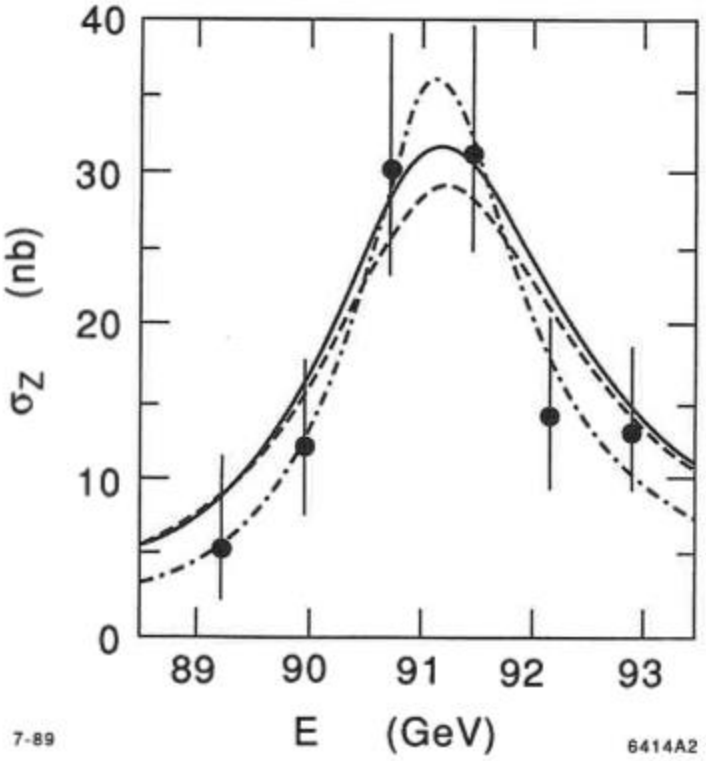
MARK-II at SLC (1988-1991)

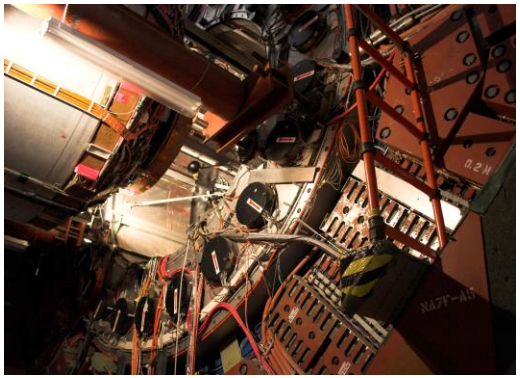


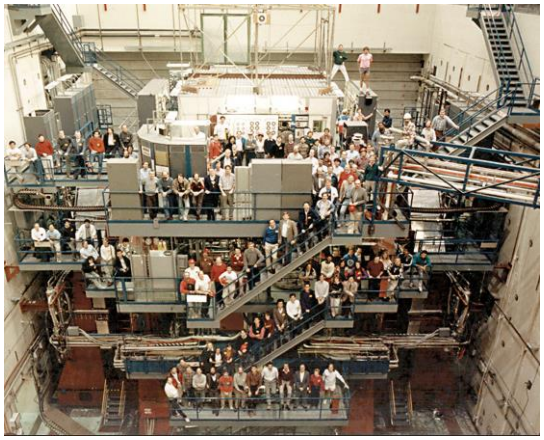




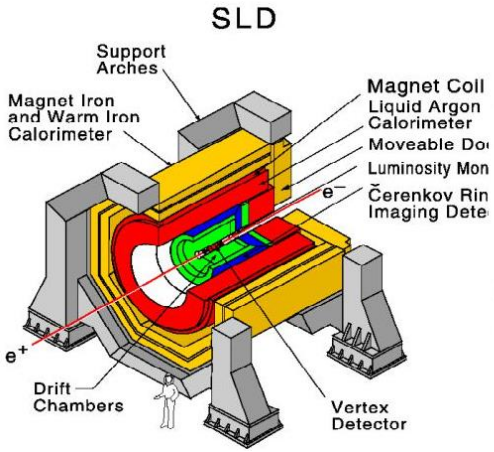
First Z Mass measurement 1989

SLD (1991-1998)





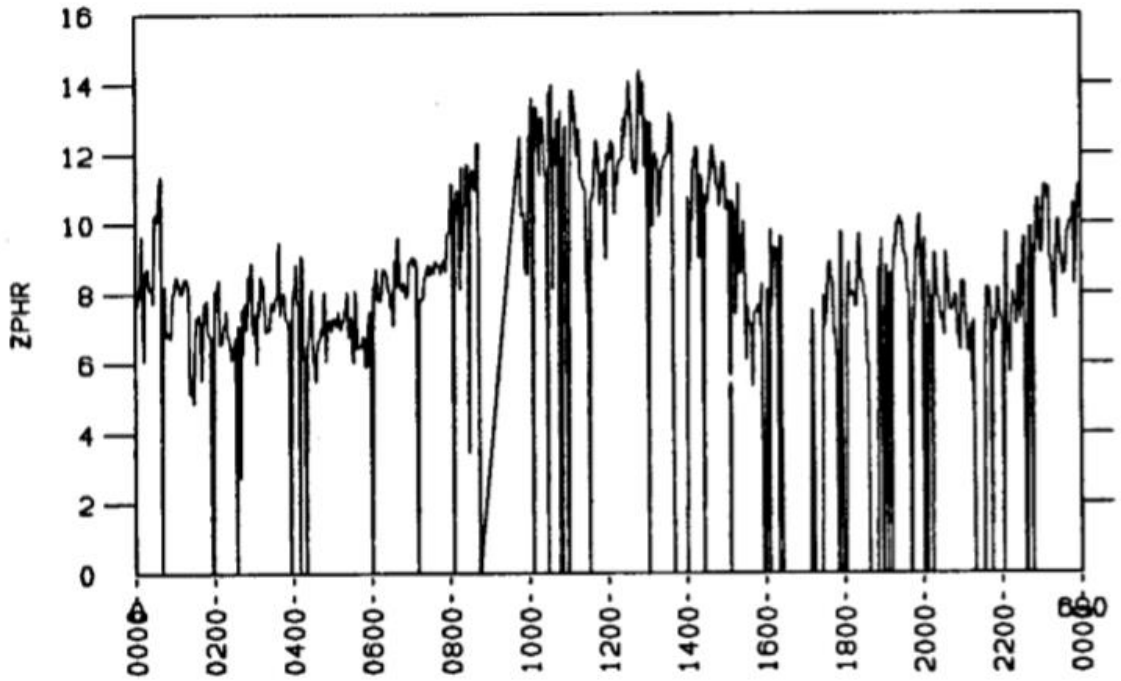
Upside down building



- Precision CCD Vertex Detector
- Central Drift Chamber (CDC)
- Cherenkov Ring Imaging Detector (CRID)
- Liquid Argon Calorimeter (LAC)
- Warm Iron Calorimeter (WIC)
- Compton Polarimeter

	SLC Estimated	SLD on Tape	Ratio
1991	1500	330	22%
March	2900	1000	35%
May	2000	1000	50%
June	4000	2200	55%
July	7000	4500	67%
August 1–15	3800	2600	69%

SLC Luminosity time variation over 24 hours (1992)



Instantaneous luminosity in the SLC for a 24 hour period on April 5, 1992.

SLC Integrated Luminosity

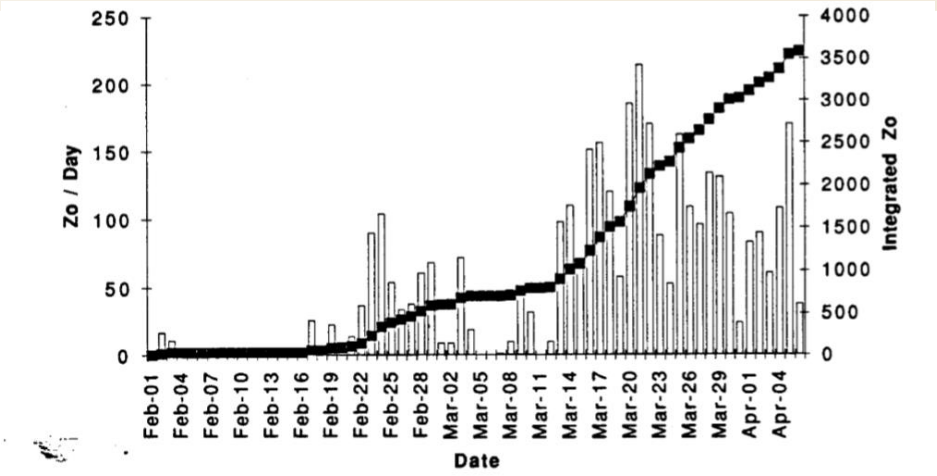
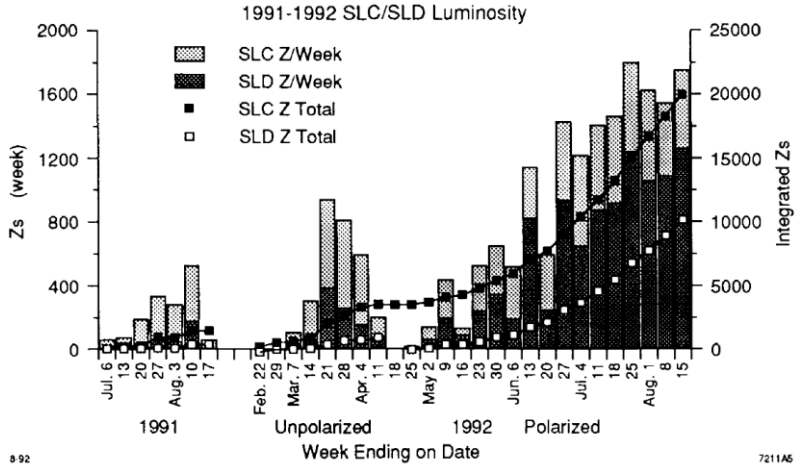


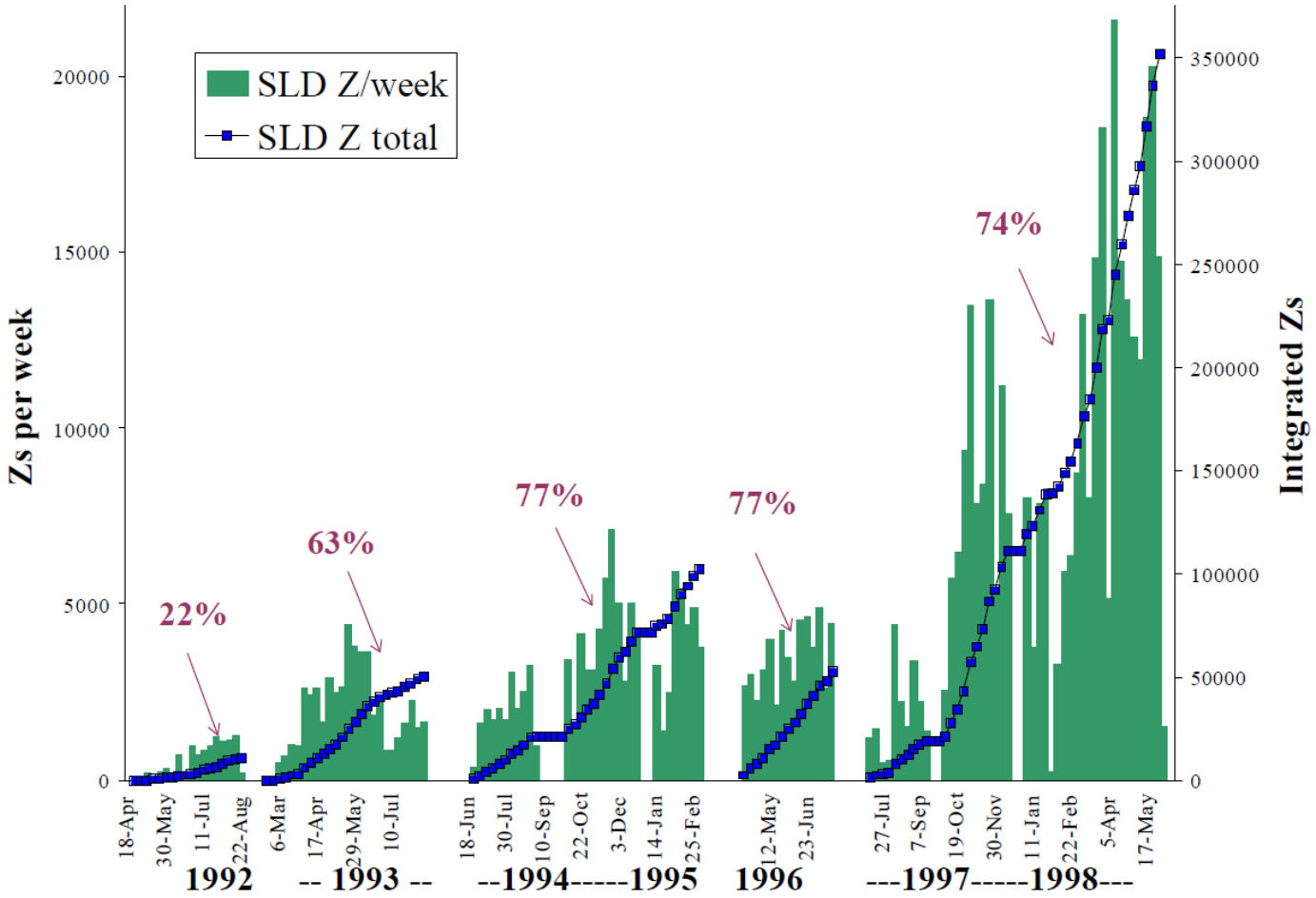
Fig. 23 Delivered Z^0 equivalents per day by the SLC to the SLD detector from February 1 to April 06, 1992. Over 200 Z^0 per day have been delivered.

Daily luminosity
→ Reliability is important



Weekly integrated luminosity

SLC SLD Integrated Luminosity



SLC Conclusions

SLAC

Exciting first “Linear Collider”!

The SLC builders “solved all known issues” while the SLC was being built.

However, many new accelerator physics effects were discovered, studied, and then mitigated.

Accelerator reliability quickly became very important (e.g. no beams coasting in the SLC).

Thus, excellent “proof-of-principle” accelerator for a future linac collider.

The SLC machine has been the first of his kind and most of the problems encountered to reach the design performances are related to the new physics of this collider. Through the years of operation there has been a continuos increasing of the beam intensities and an improving of the beam qualities. The limits to this process are mainly due to three reasons:

1) Intrinsic design limitation of many subsystems in handling higher beam powers, like the gun, the Damping-Rings RF, the Linac RF, the positron target etc. In addition high radiation levels and damage have limited the total peak and integrated beam charge through the machine even more.
2) Intrinsic design limitation in the emittance dilution of many subsystems like the Ring-To-Linac transport lines, the main Linac, the Arcs, the FF.
3) Lack of understanding the new physics of the Linear Colliders. In particular the emittance optimization in the whole machine and the FF optimization.

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