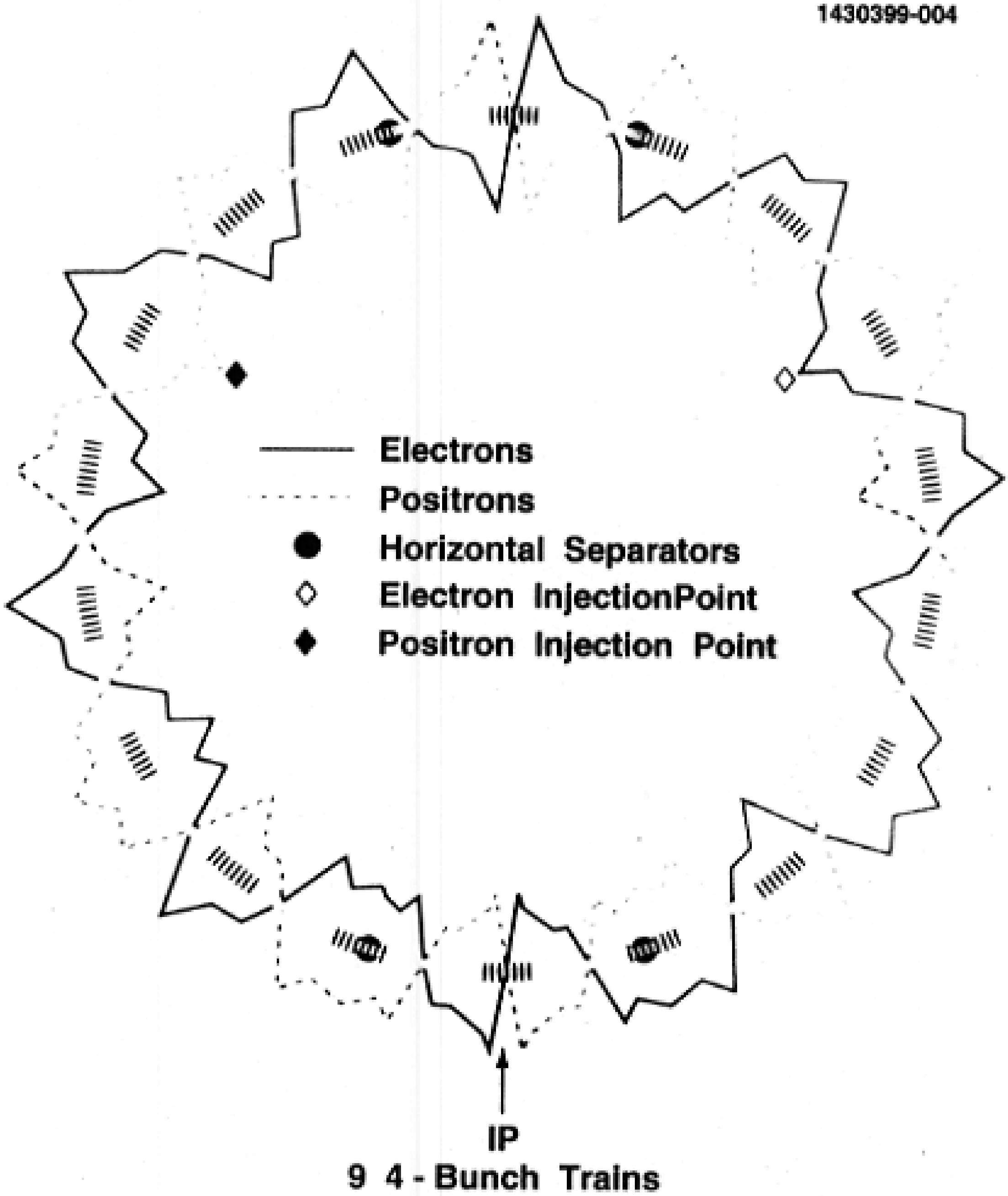
# CESR Configuration - February 99

- Trains of bunches
  - Electrostatic separators powered antisymmetrically.
  - Small horizontal crossing angle at IP.
  - Orbits separated at temporal crossing points of electrons and positrons
  - 9 trains per beam with 4 bunches/train, 14ns spacing


1430399-004
Electrons
Positrons
Horizontal Separators
Electron InjectionPoint
Positron Injection Point
IP
9 4 - Bunch Trains

## Long Range Interactions

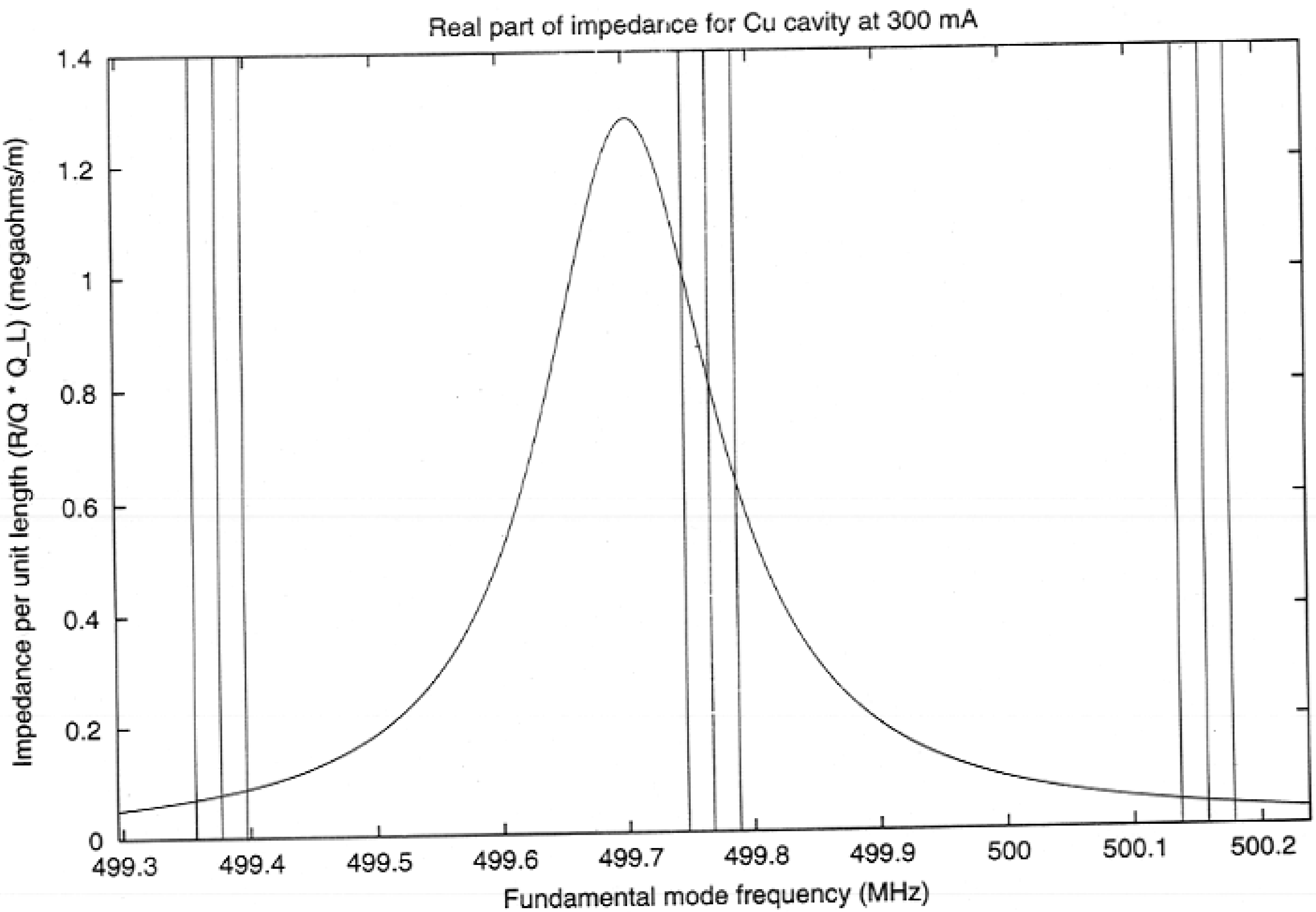
9 trains of four bunches $\Rightarrow$ 71 parasitic crossings/turn

- Optical functions, orbits of one beam depend on current in opposing beam
- Uneven bunch spacing $\Rightarrow$ optical functions, orbits depend on location within train

$\Rightarrow$ luminosity is bunch dependent $\pm 5\%$

# Longitudinal Instability

- High Q parasitic modes in 5-cell cavities
- Instability threshold depends on
  - Bunch spacing
  - Cavity temperature (HOM frequencies)
- Coupled bunch mode excited by cavity fundamental



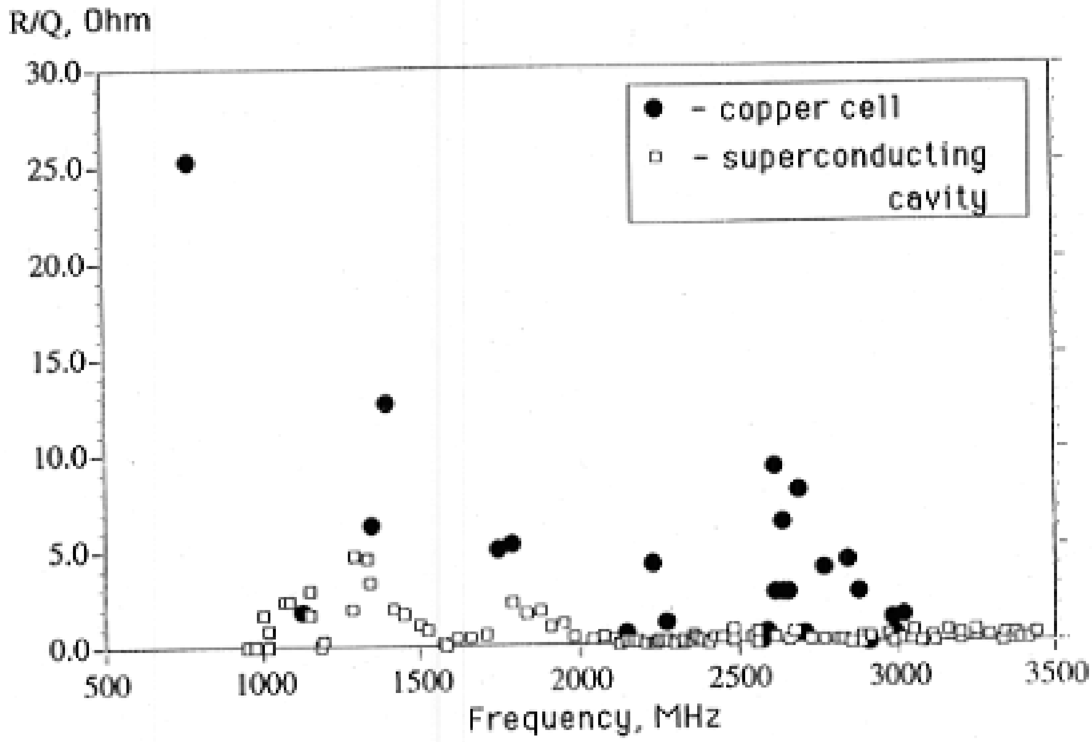
Real part of impedance for Cu cavity at 300 mA
Impedance per unit length (R/Q * Q_L) (megaohms/m)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
499.3
499.4
499.5
499.6
499.7
499.8
499.9
500
500.1
500.2
Fundamental mode frequency (MHz)

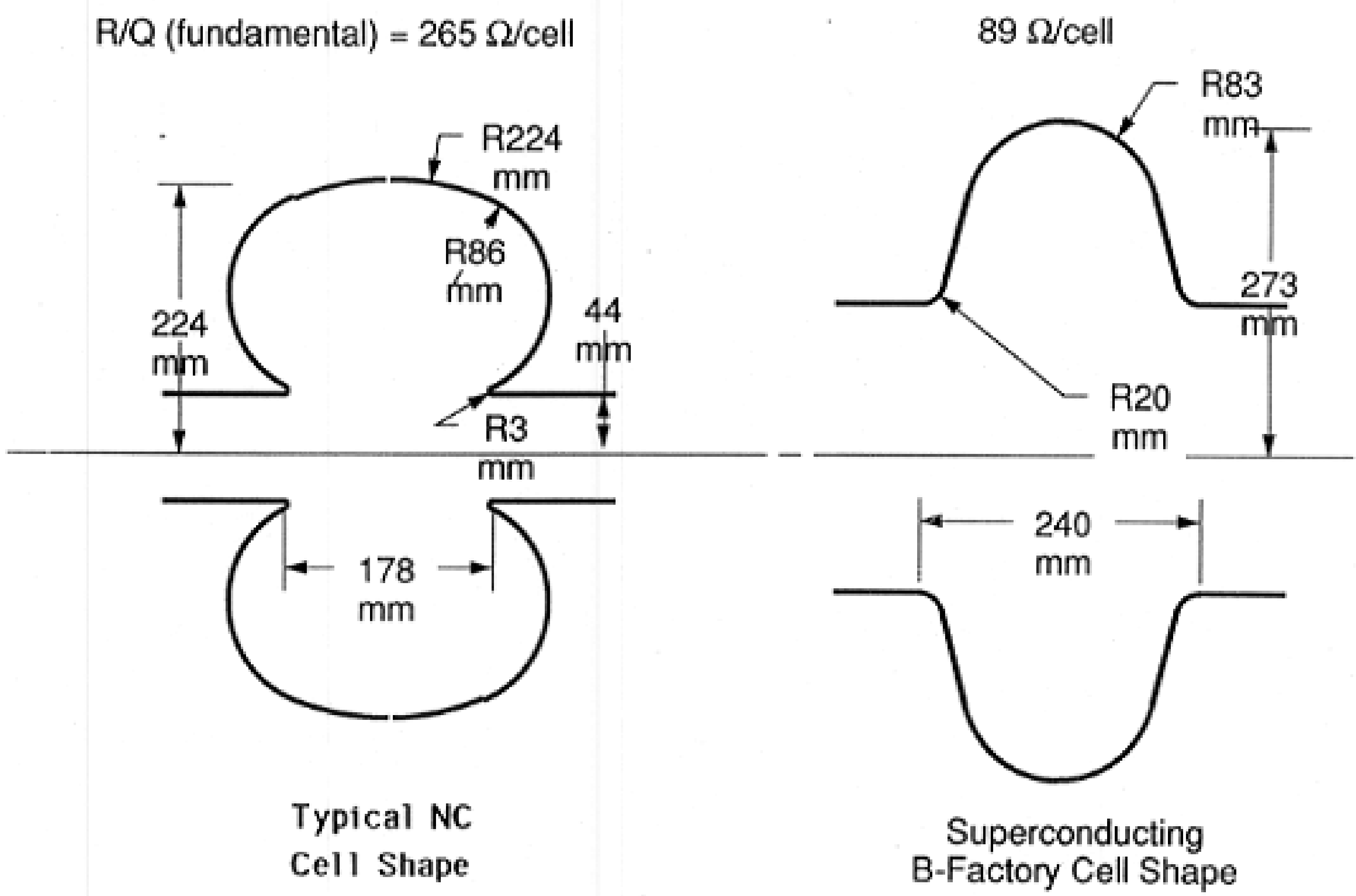
# SUPERCONDUCTING RF

- Single cell superconducting RF cavities replace 5-cell copper cavities
    1. Reduce longitudinal impedance (1/15)
    2. Increase accelerating voltage (reduce bunch length)
    3. More power to beam

# SUPERCONDUCTING RF

- 500MHz
- Open geometry and large beam tube ⇒ R/Q(HOM) small
- Higher order modes propagate along beam tube to ferrite loads outside cryostat
- Waveguide input coupler
- Planar ceramic window
- Designed to operate at 10MV/m and deliver 350kW to beam


R/Q, Ohm
30.0
25.0
20.0
15.0
10.0
5.0
0.0
500
1000
1500
2000
2500
3000
3500
Frequency, MHz
● - copper cell
□ - superconducting cavity

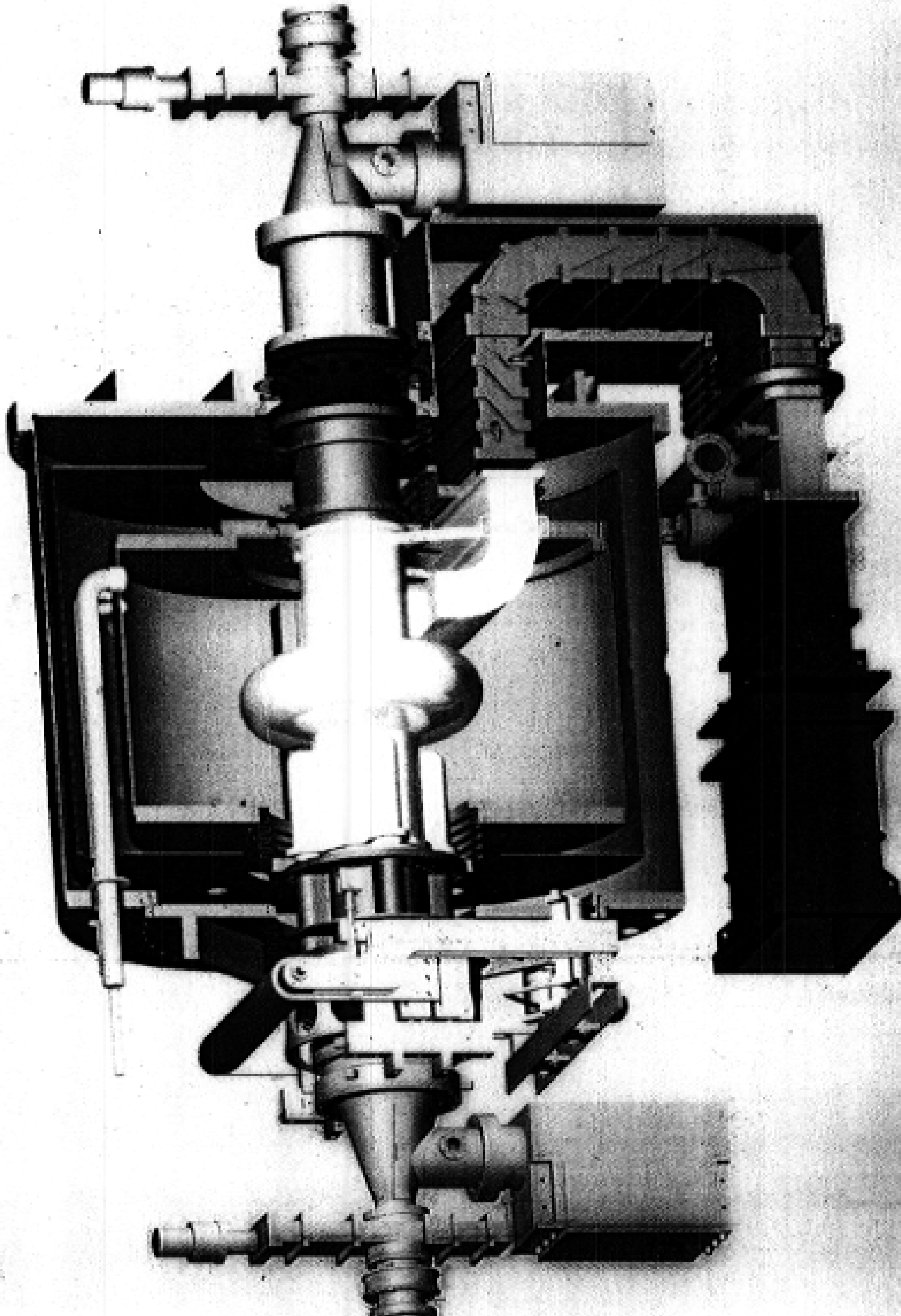

R/Q (fundamental) = 265 Ω/cell
89 Ω/cell
R224 mm
R86 mm
224 mm
44 mm
R3 mm
178 mm
R83 mm
273 mm
R20 mm
240 mm
Typical NC Cell Shape
Superconducting B-Factory Cell Shape

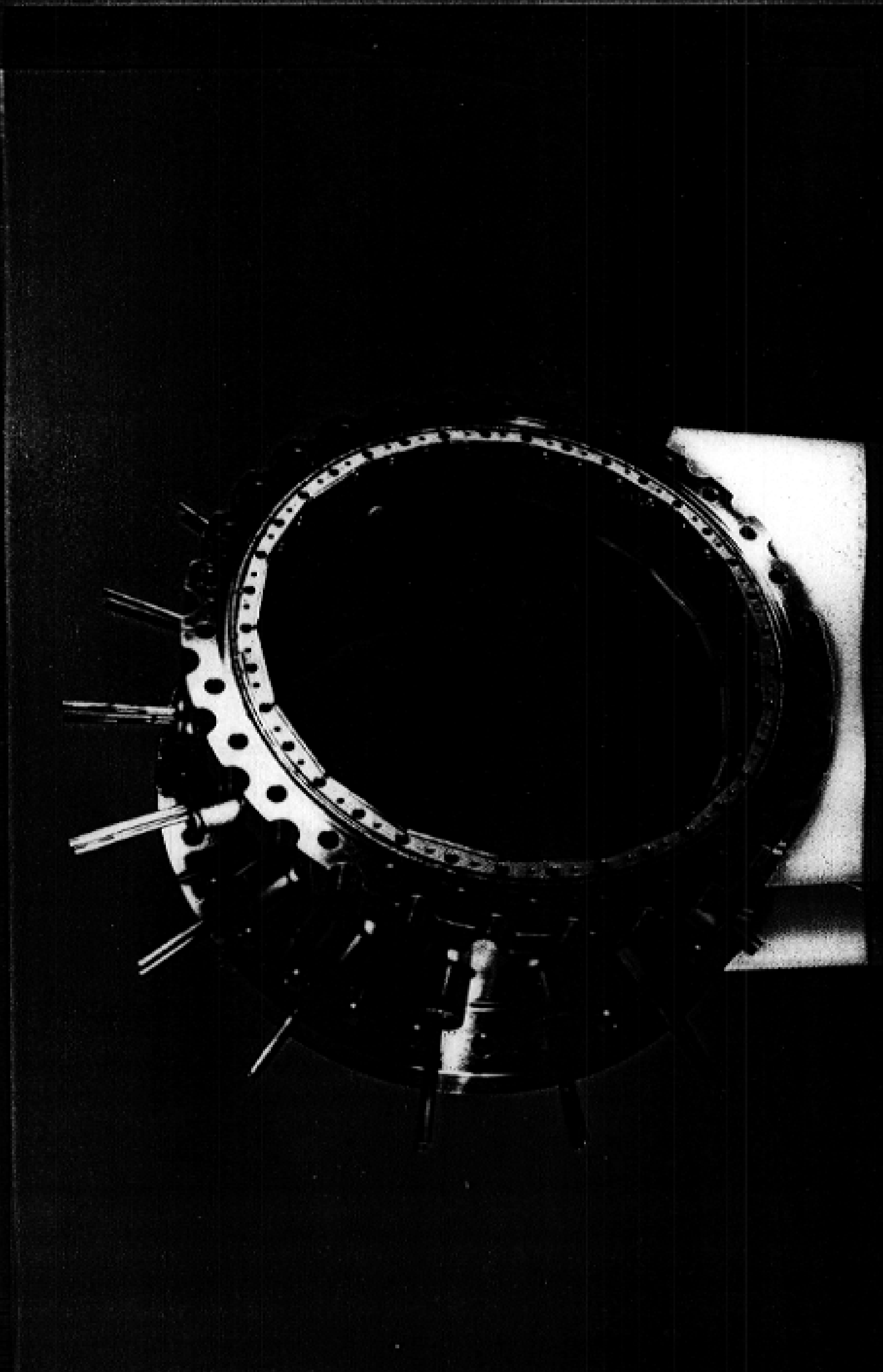
# SRF Operating Experience

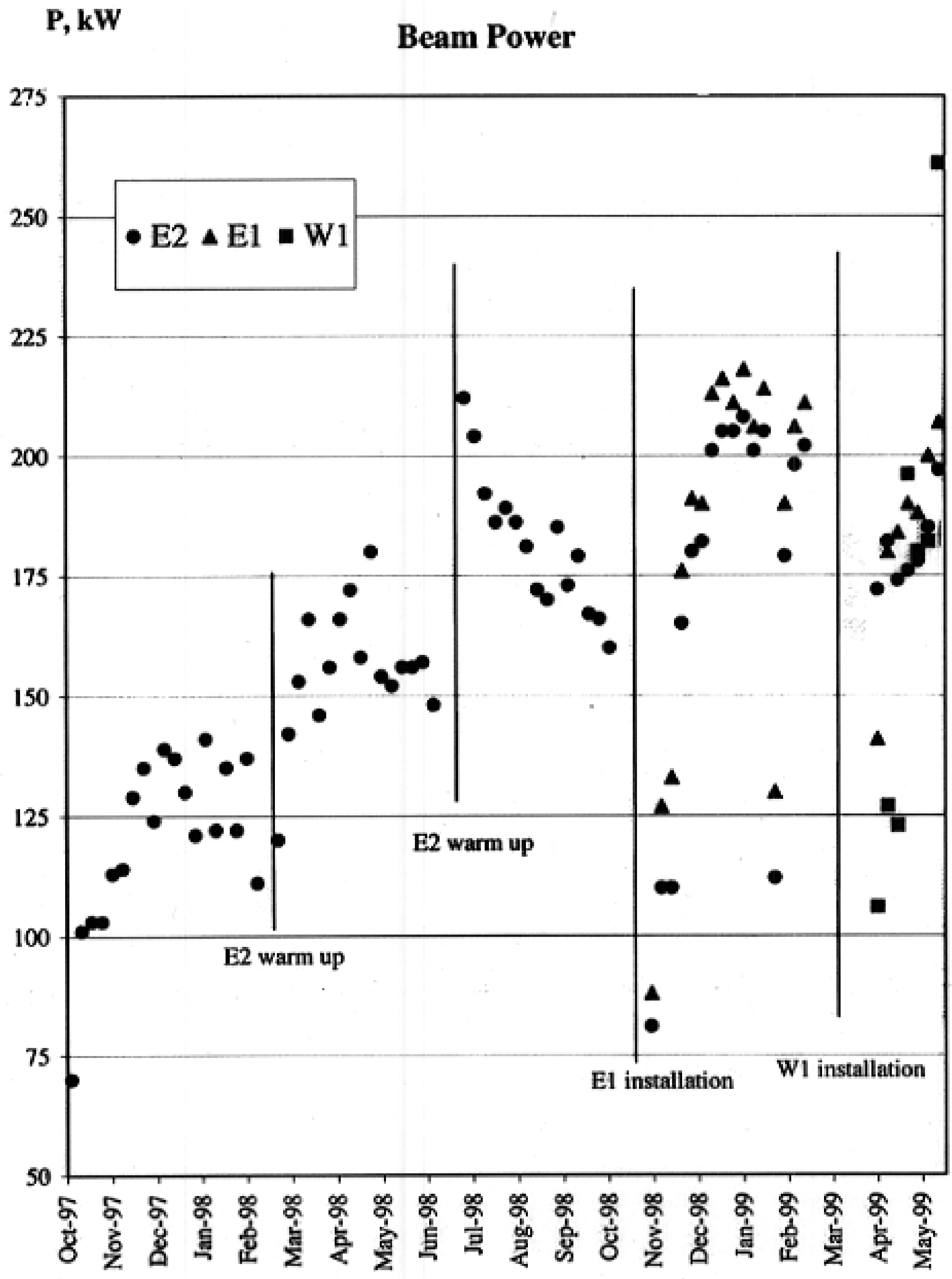
- Cavity installation
  1. September 1997 (+3 5 cell)
  2. October 1998 (+2 5 cell)
  3. April 1999
  4. September 1999
- Accelerating gradient 6.5-8.5 MV/m
- Stored beam current - 550mA (2 + 2)
- Power delivered through superconducting cavity to beam - 260kW (3)
- HOM power extracted by ferrite loads 5-6kW

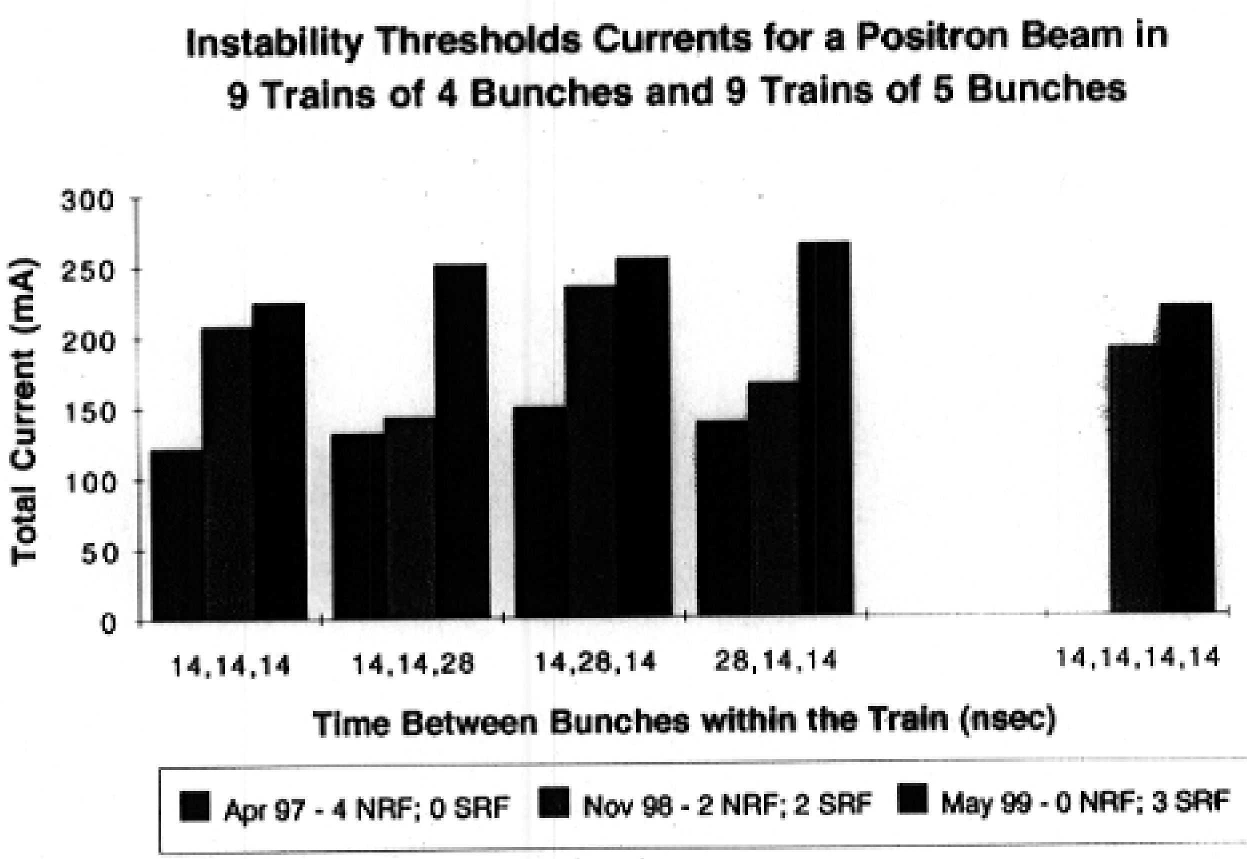
# Longitudinal Feedback

- Receiver - phase detector
  - BPM signal mixed with CESR RF reference
  - Amplified output proportional to arrival time of bunch
- Digital processor operates at 71MHz (14ns bunch spacing)
  - In line pedestal correction
  - Digital low pass and tuneable band pass filters






P, kW
Beam Power
275
250
225
200
175
150
125
100
75
50
E2
E1
W1
E2 warm up
E2 warm up
E1 installation
W1 installation
Oct-97
Nov-97
Dec-97
Jan-98
Feb-98
Mar-98
Apr-98
May-98
Jun-98
Jul-98
Aug-98
Sep-98
Oct-98
Nov-98
Dec-98
Jan-99
Feb-99
Mar-99
Apr-99
May-99



Instability Thresholds Currents for a Positron Beam in
9 Trains of 4 Bunches and 9 Trains of 5 Bunches
Total Current (mA)
300
250
200
150
100
50
0
14,14,14
14,14,28
14,28,14
28,14,14
14,14,14,14
Time Between Bunches within the Train (nsec)
Apr 97 - 4 NRF; 0 SRF
Nov 98 - 2 NRF; 2 SRF
May 99 - 0 NRF; 3 SRF

# Longitudinal Feedback

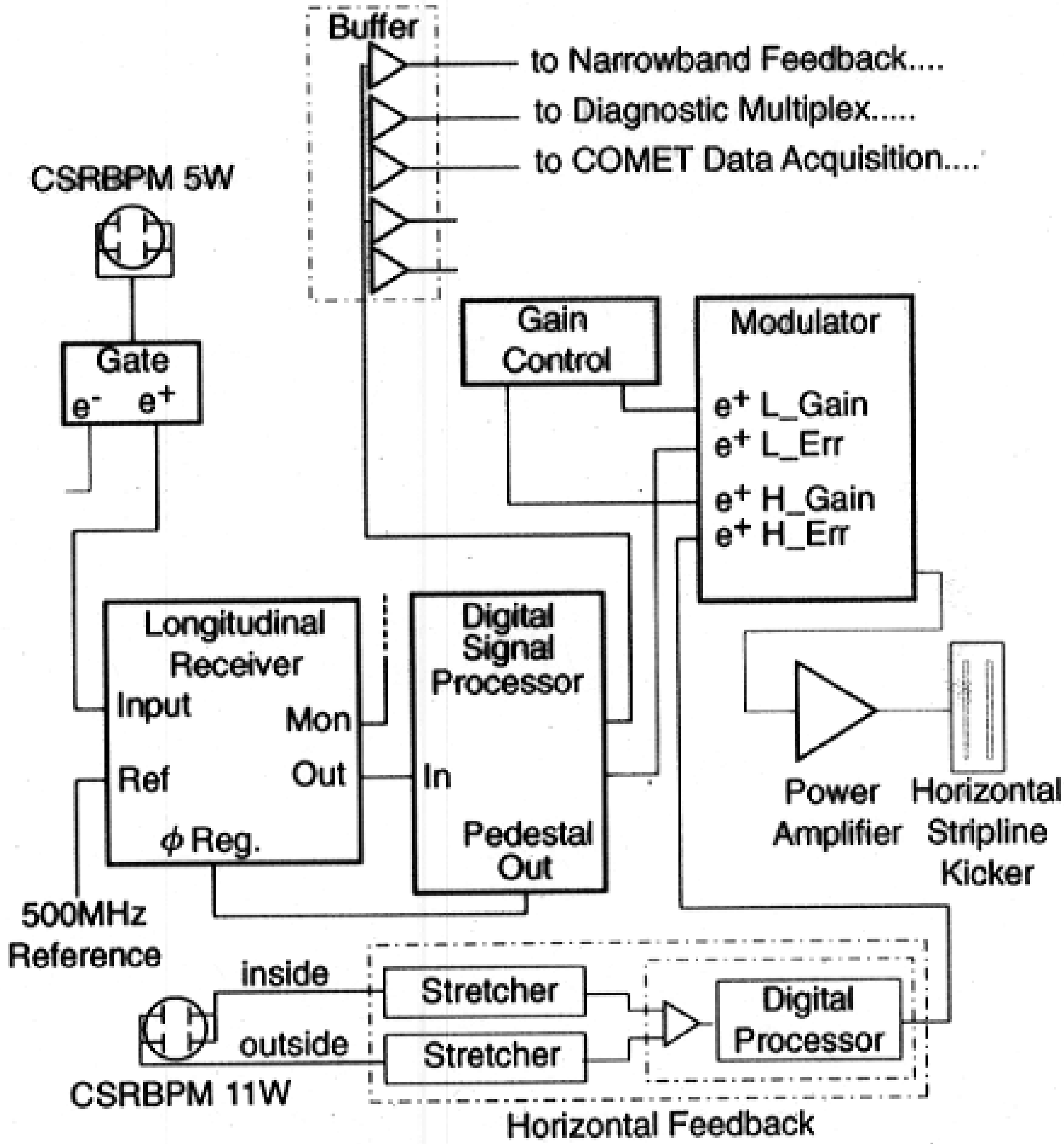
- Horizontal stripline kicker
  - Differential pulse couples to beam via dispersion - pathlength
- Power amplifier
  - Analog broadband amplifier - operations (140V)

# Longitudinal Feedback

- Finally, modulate klystron phase to damp mode excited by fundamental

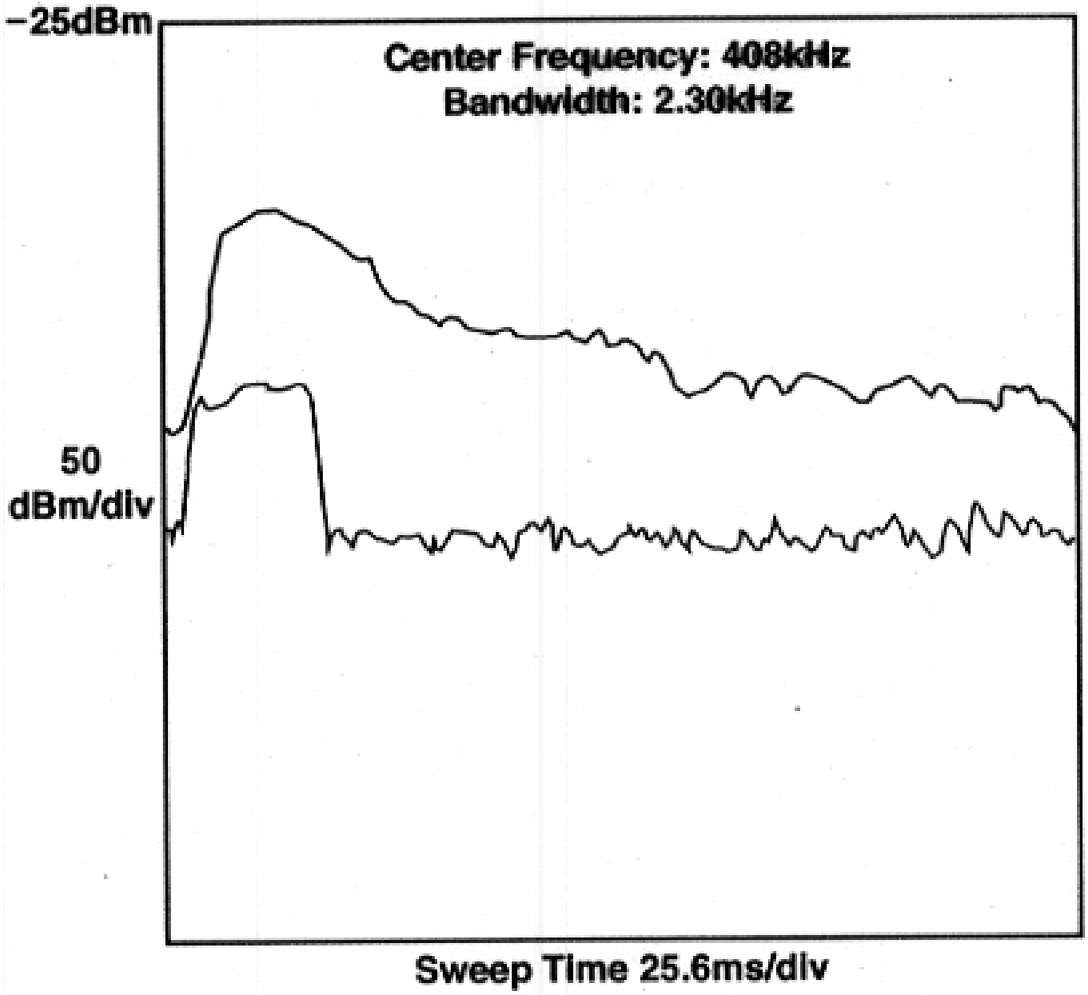
⇒ Instability threshold > 550mA

The longitudinal feedback system has allowed oreating currents to more than double: from **250mA** to over **500mA** total current.




**Block diagram of the longitudinal feedback system at CESR**

The phase error from each bunch is sampled at 71.4 MHz and filtered in a DSP. The result is combined with the horizontal error signal, and sent to a horizontal stripline kicker. The dispersion at the kicker produces a longitudinal impulse.


-25dBm
Center Frequency: 408kHz
Bandwidth: 2.30kHz
50
dBm/div
Sweep Time 25.6ms/div

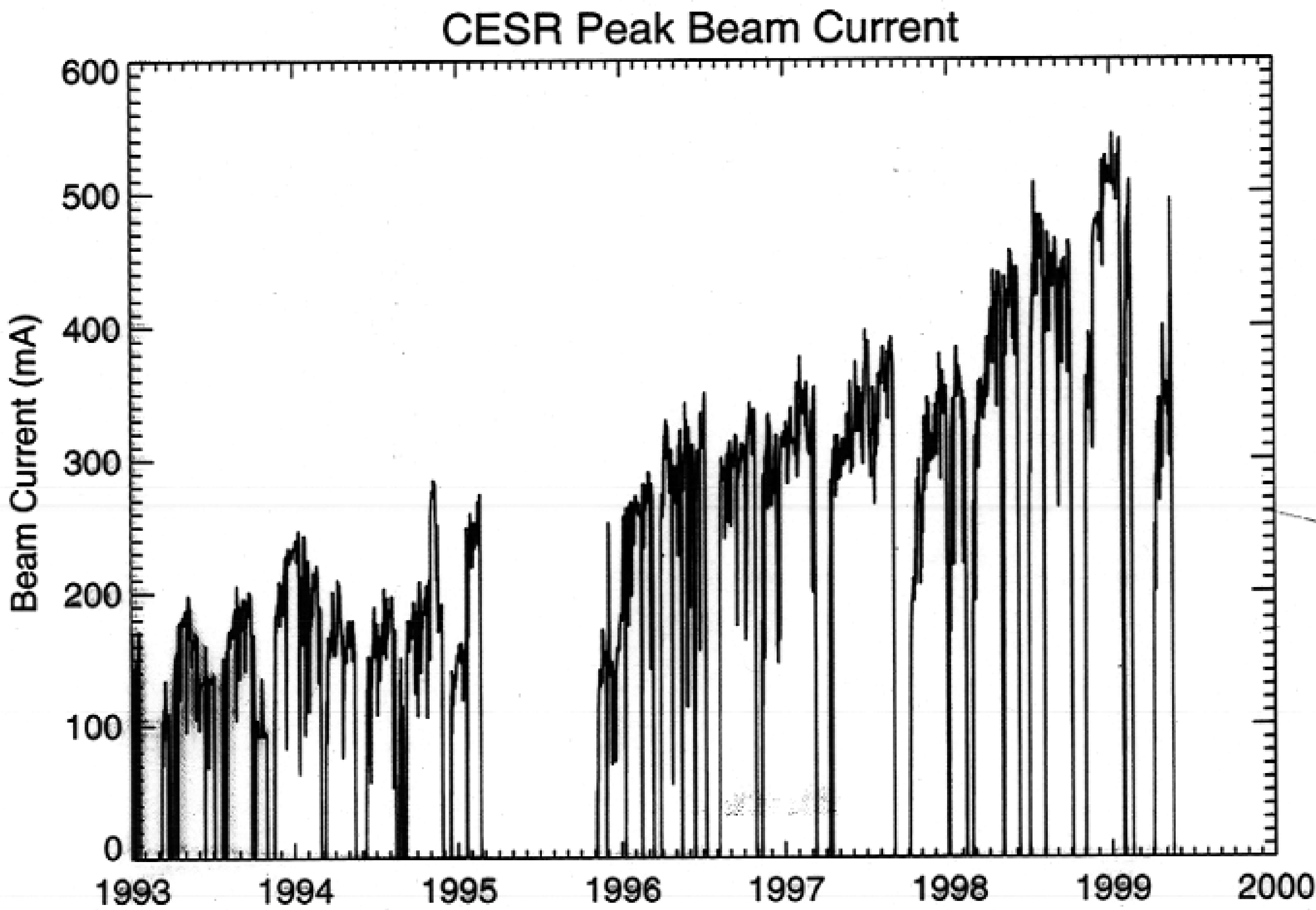
# Current limits

- Synchrotron radiation

  → rebuild chambers for effective masking/cooling

- RF power

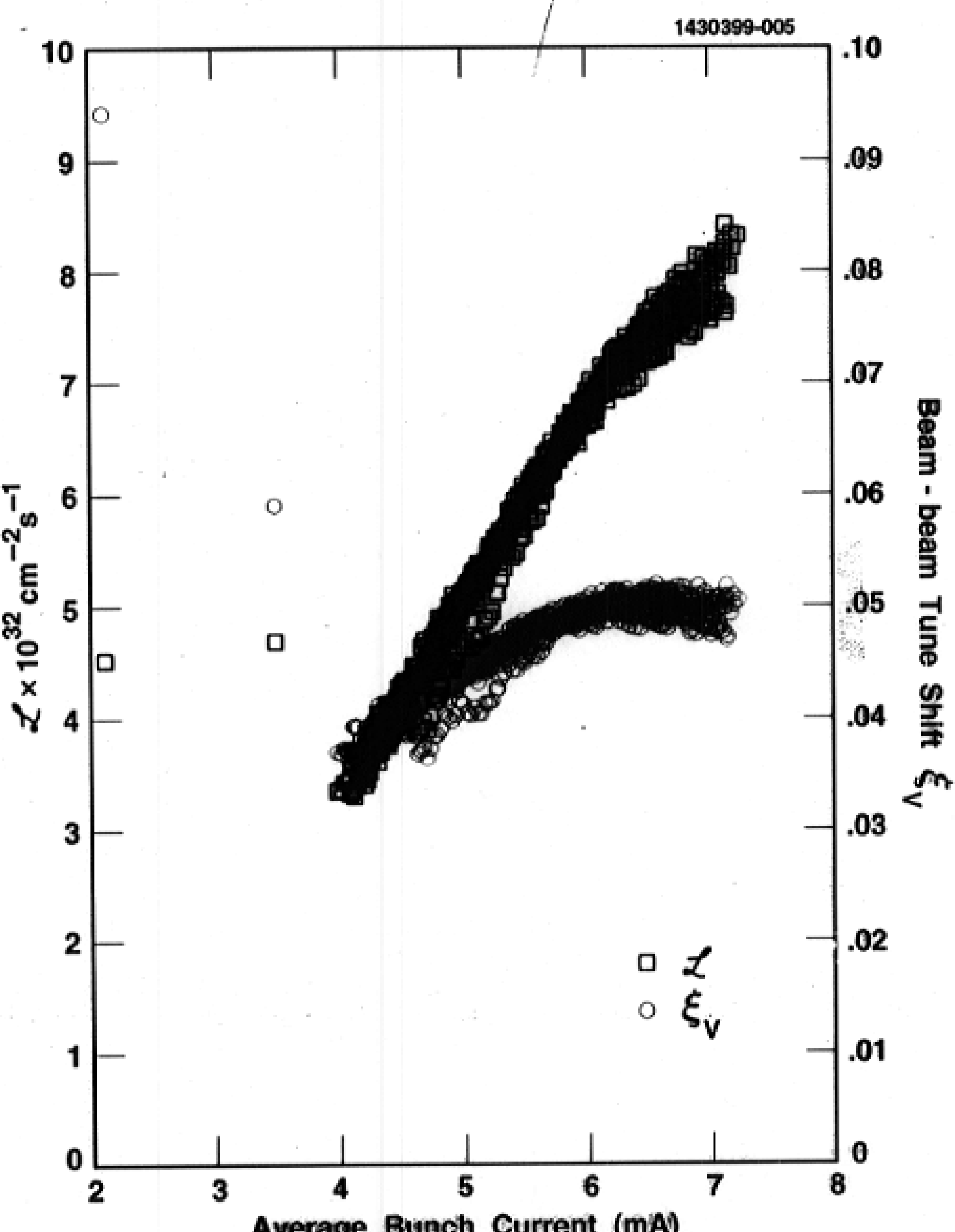
  - Replace 500kW with 800 kW klystron → 2 cavities
  - Power each of remaining two cavities with dedicated 500kW tube


CESR Peak Beam Current
Beam Current (mA)
0
100
200
300
400
500
600
1993
1994
1995
1996
1997
1998
1999
2000

# LUMINOSITY

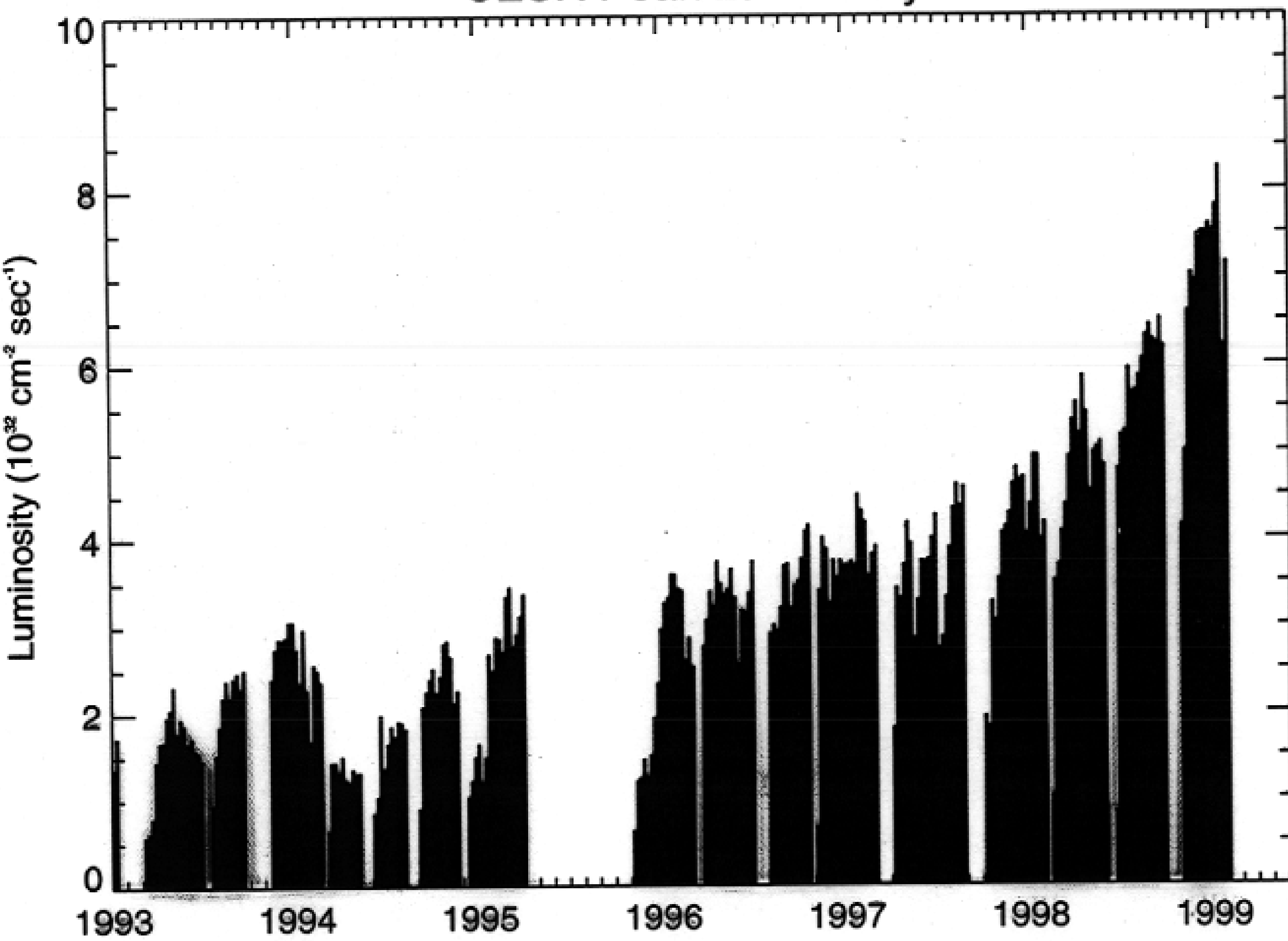
Tune Shift Parameter

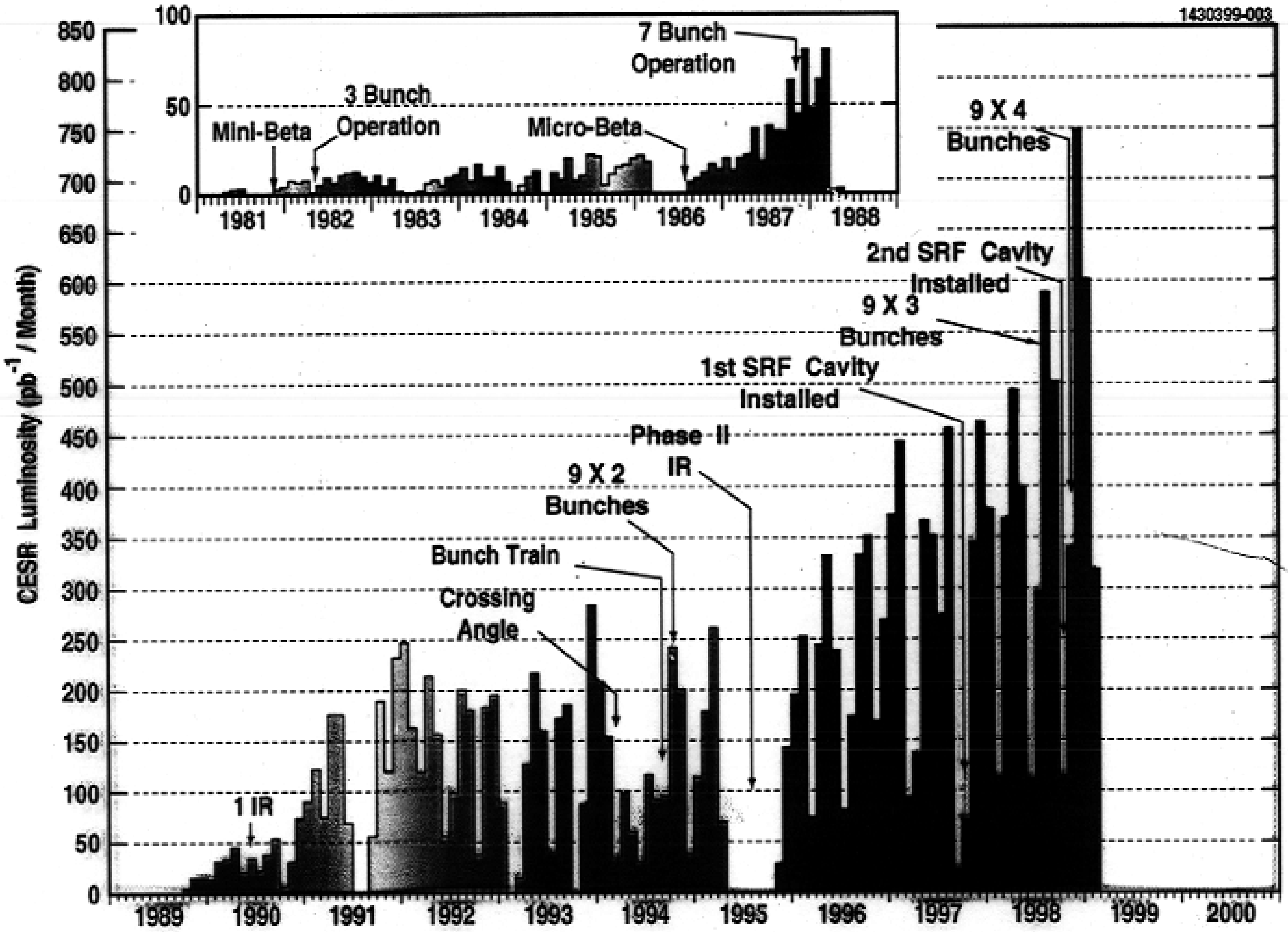
- Optics
  - Develop technique for measuring optical errors
  - Improve model of guide field and calibration of magnet strengths
  - Measure and correct linear optics ⇒
    - Optimal separation at parasitic crossing points
    - Simplifies correction of orbit, coupling, sextupole errors
  - Sextupole design algorithm effectively compensates for energy and amplitude dependence of optics
  - Improved solenoid coupling compensation correction scheme
- Fast, bunch by bunch luminosity monitor ⇒ computer driven optimization



1430399-005
$\mathcal{L} \times 10^{32} cm^{-2}s^{-1}$
Beam - beam Tune Shift $\xi_V$
Average Bunch Current (mA)
$\mathcal{L}$
$\xi_V$
0
1
2
3
4
5
6
7
8
9
10
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10

# CESR Peak Luminosity





1430399-003
CESR Luminosity (pb$^{-1}$ / Month)
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
1 IR
Crossing Angle
Bunch Train
9 X 2 Bunches
Phase II IR
1st SRF Cavity Installed
9 X 3 Bunches
2nd SRF Cavity Installed
9 X 4 Bunches
100
50
0
1981
1982
1983
1984
1985
1986
1987
1988
Mini-Beta
3 Bunch Operation
Micro-Beta
7 Bunch Operation

# PERFORMANCE SUMMARY

- Peak Luminosity

  $8.3 \times 10^{32} cm^{-2} s^{-1}$

- Daily integrated luminosity

  $40.2 pb^{-1}$

- Monthly integrated luminosity

  $750 pb^{-1}$

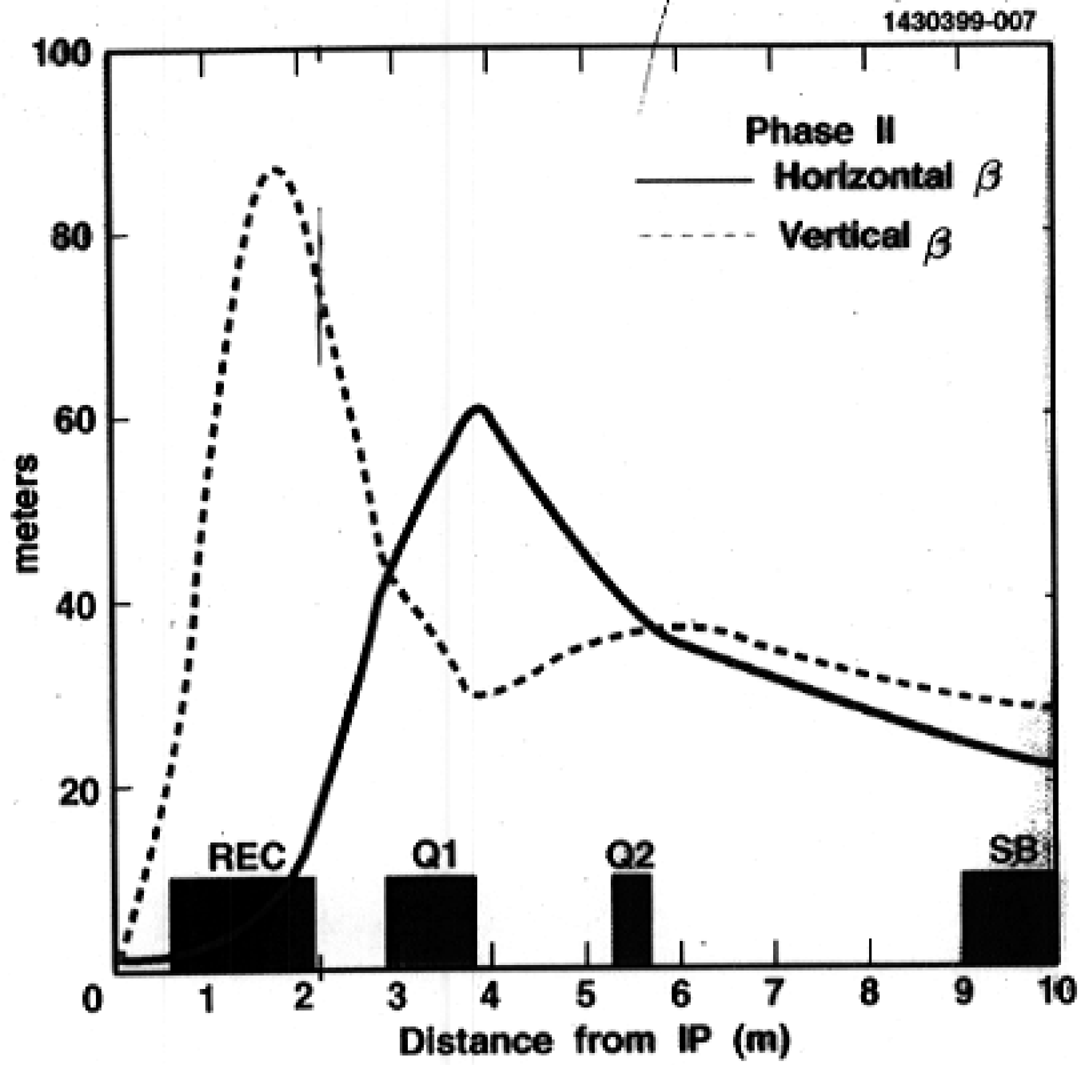
- Yearly integrated luminosity

  $4400 pb^{-1}$ 1998

- Total colliding beam current

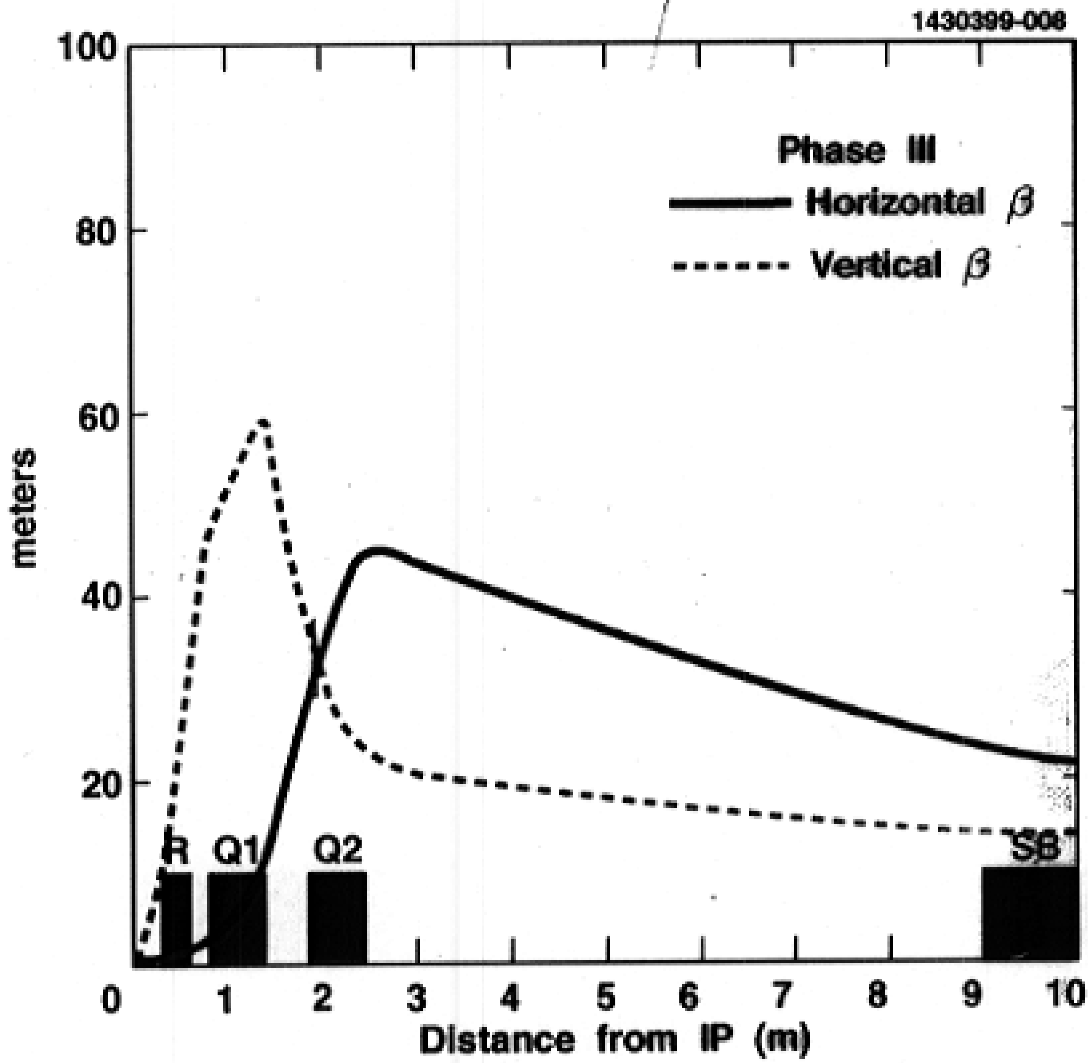
  $560 mA$, $9 \times 4$ bunches per beam

- Beam-beam tune shift parameter $\xi_v = 0.05$




$\beta^*_V = 18$ mm

$\beta^*_H = 1$ m



1430399-008
Phase III
Horizontal β
Vertical β
meters
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
R
Q1
Q2
SB
Distance from IP (m)


$\beta_v^* = 13$ mm

# Phase III Final focus

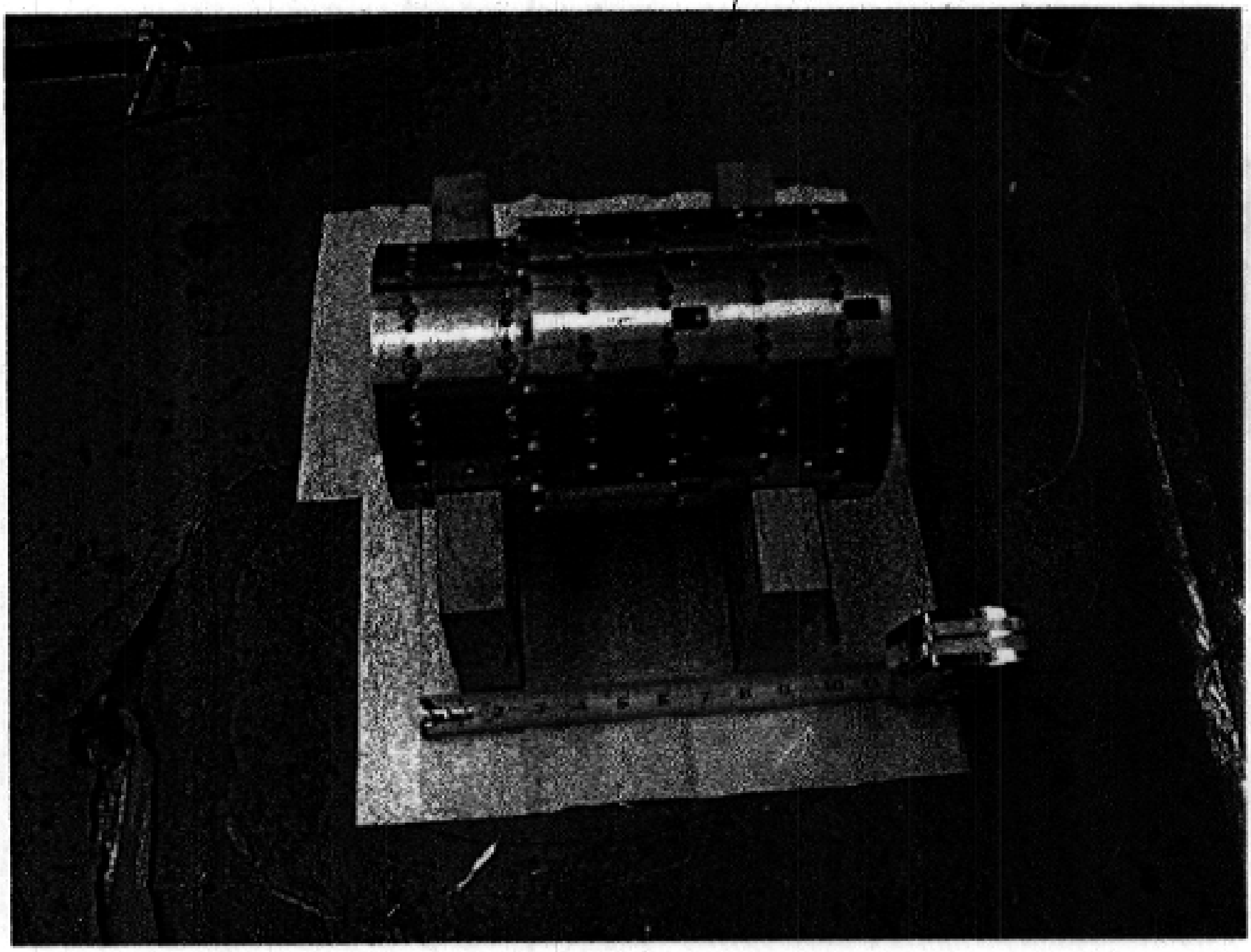
- Objective: Reduce $\beta_v^*$ and minimize $\beta_v$ at near miss 2.1m from IP

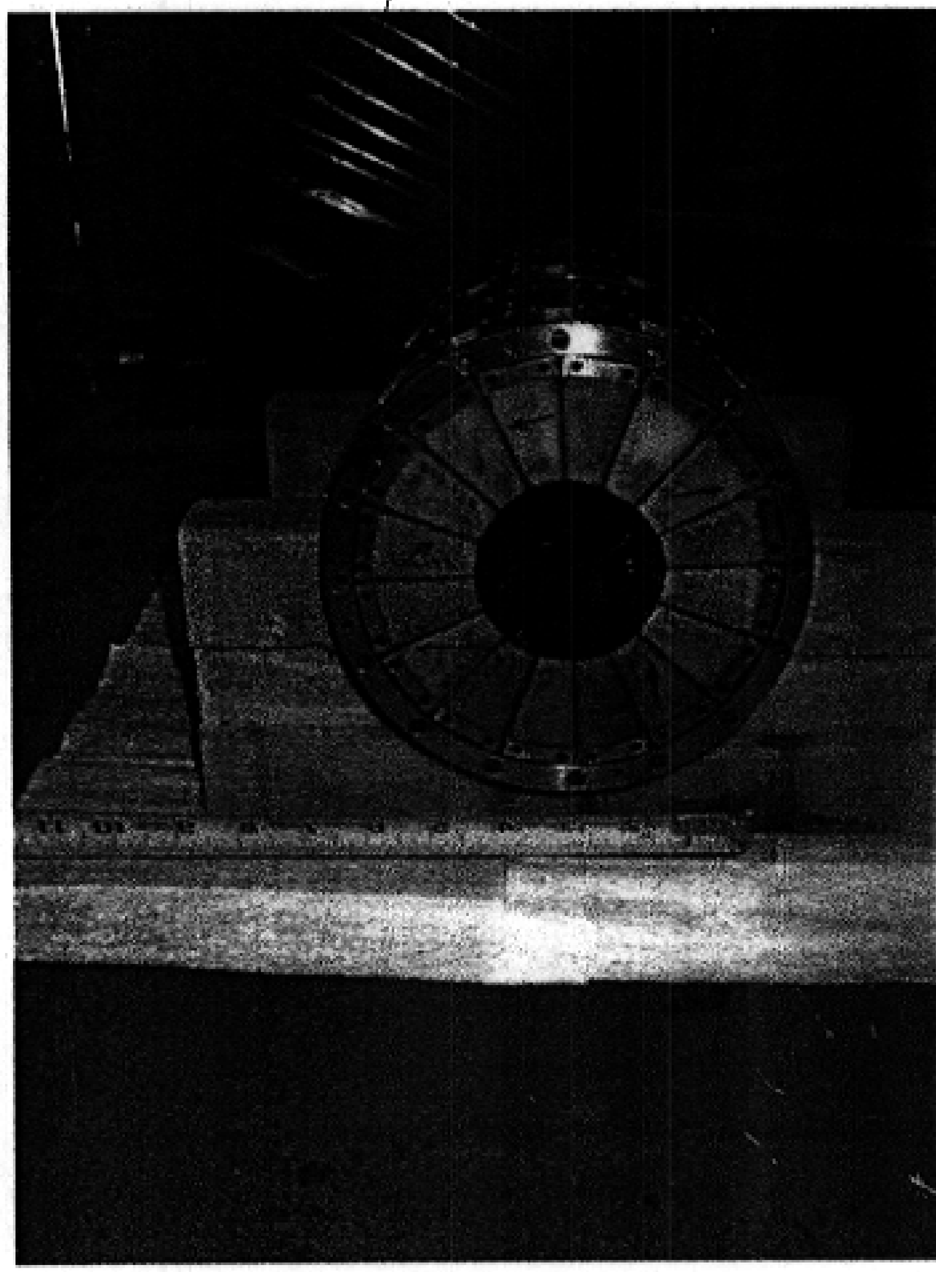
  $\Rightarrow$ High gradient quads close to IP

# Phase III Final focus

Permanent magnet quads

| | section 1 | sections 2 & 3 |
|---|---|---|
| Gradient[T/m] | 29.27 | 31.91 |
| peak field[T] | 9.7 | 10.7 |
| length[m] | 0.093 | 0.093 each |
| distance from IP[m] | 0.33 | 0.423 |





# Phase III Final focus

Superconducting final focus quads-

- Two quadrupoles with skew quad and vertical dipole windings in a cryostat
- Each coil assembly is rotated 4.5° for solenoid compensation

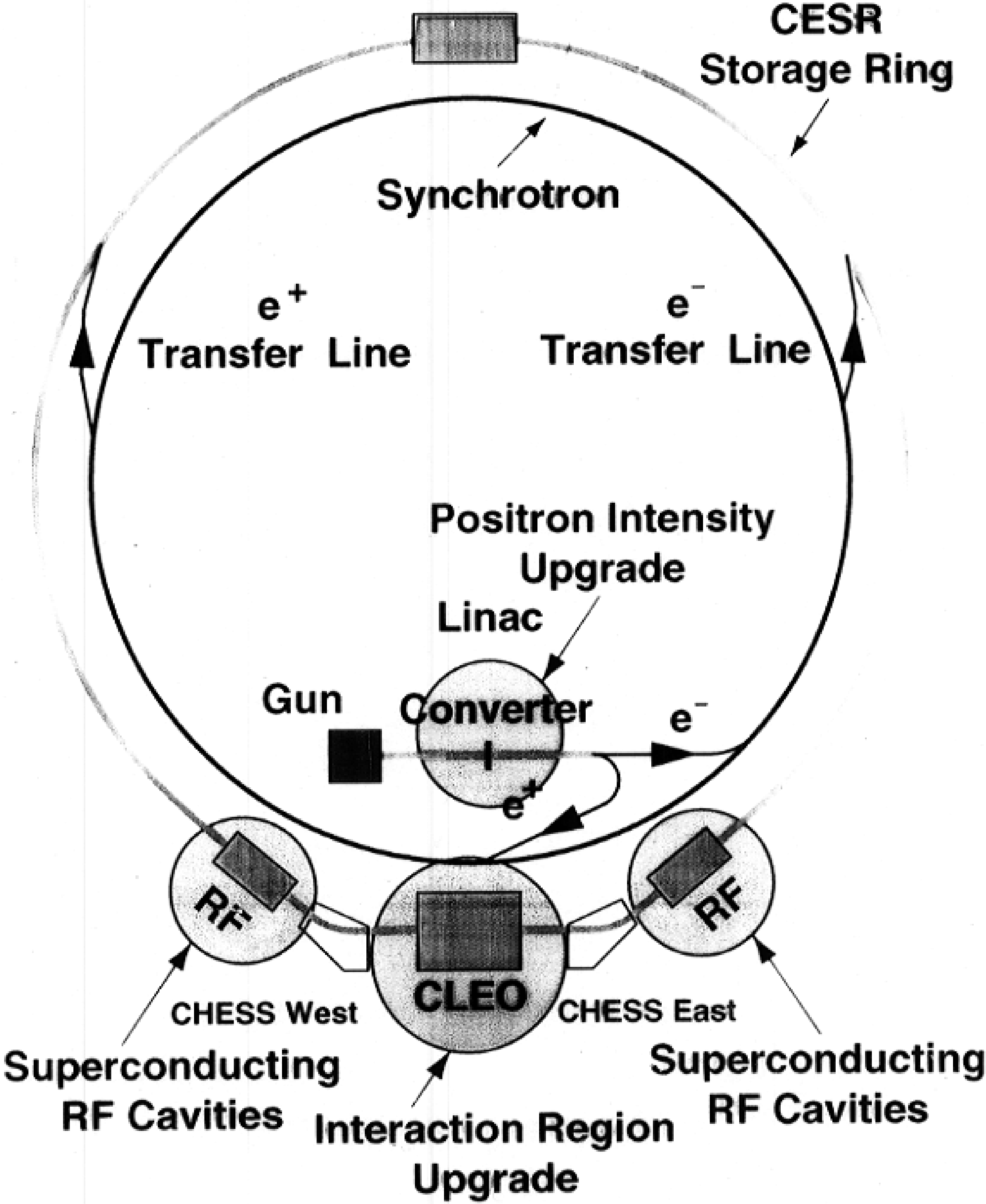
| | Main quad |
|---|---|
| Gradient[T/m] | 48.4 |
| peak field[T] | 6 |
| current[A] | 1225 |
| length[m] | 0.65 |

- Status
  - 3 of 4 coil assemblies tested to over 1225A
  - Expect delivery by the end of 1999
  - Support and alignment of cryostat by eccentric cam bearings

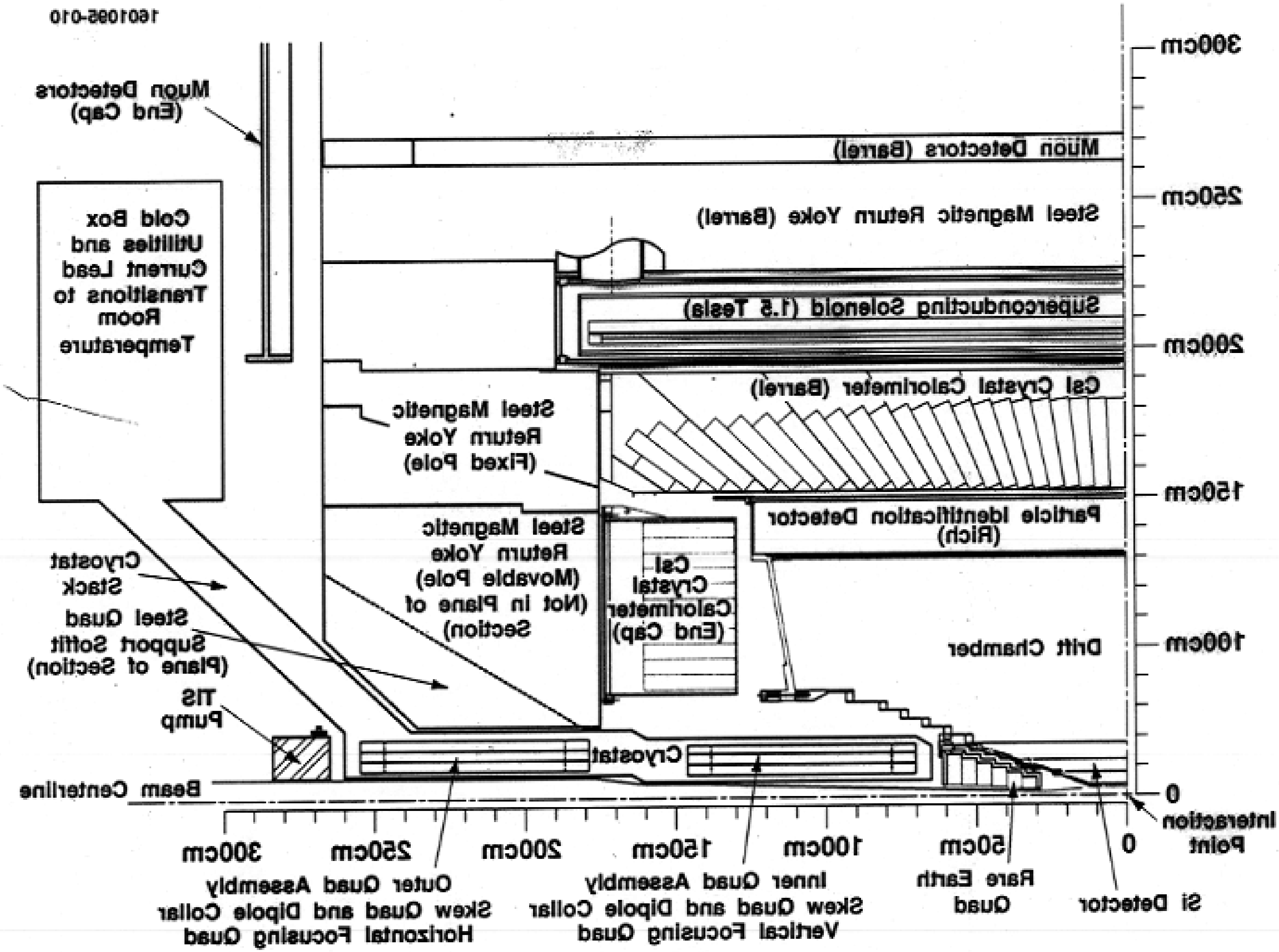
# CESR - CLEO Status

- CESR
  - Bunch trains and crossing angle collisions
  - Longitudinal multibunch instability
  - Superconducting RF
  - Longitudinal feedback
  - Performance
  - Status of upgrade
- CLEO III
  - Drift chamber
  - Particle Identification (RICH)
  - Silicon vertex detector
  - Calorimeter
- CLEO II results

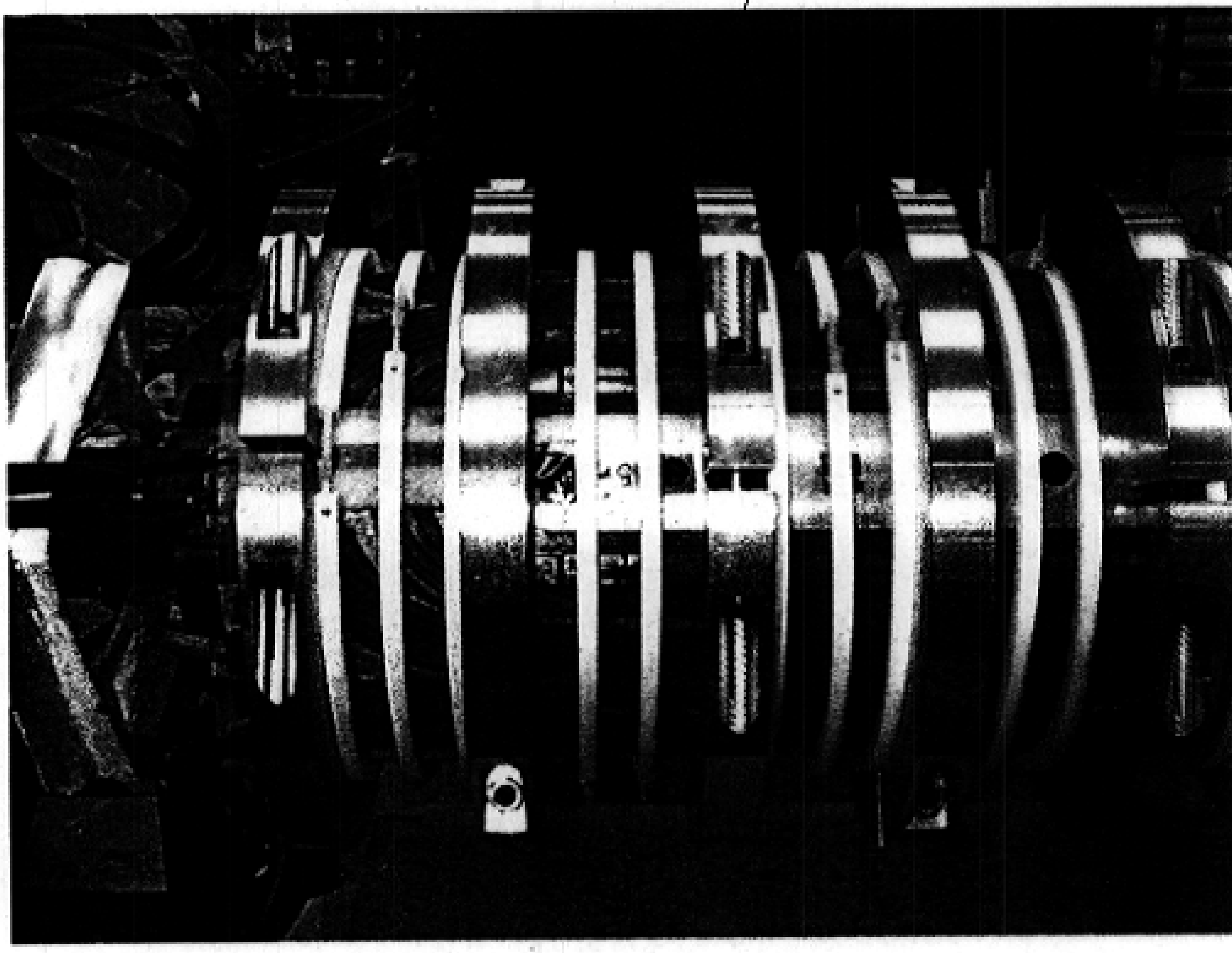
0050399-001



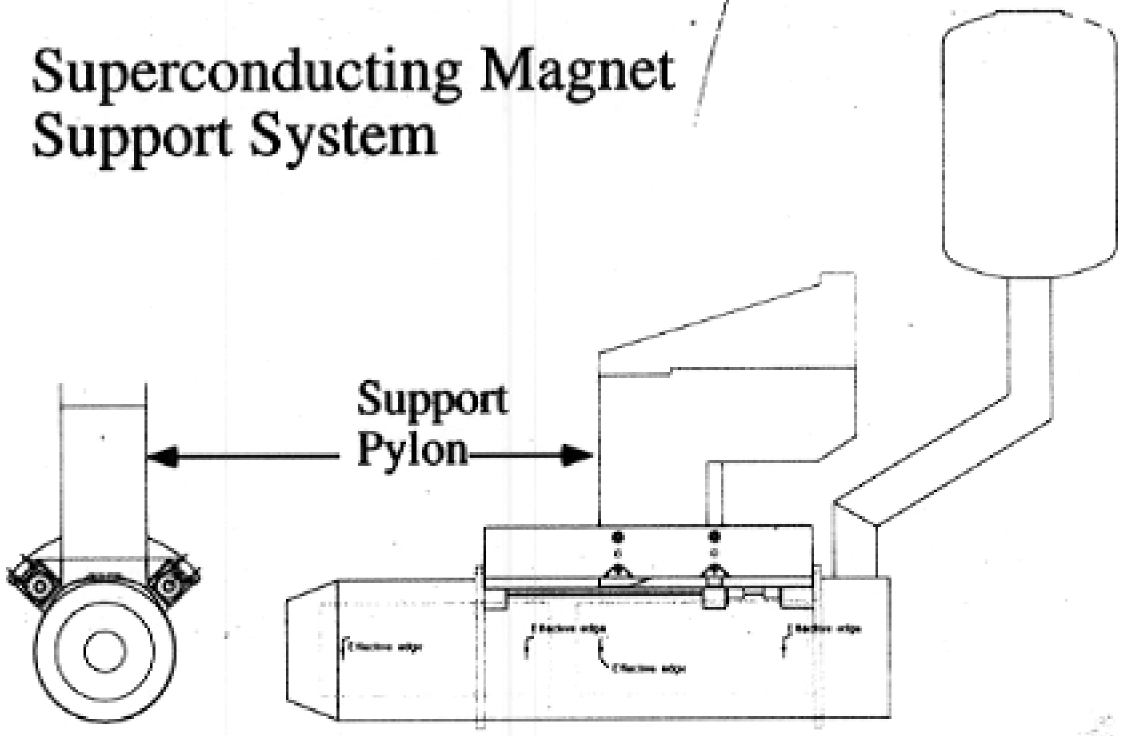
CESR
Storage Ring
Synchrotron
e+
Transfer Line
e−
Transfer Line
Positron Intensity
Upgrade
Linac
Gun
Converter
e−
e+
RF
RF
CLEO
CHESS West
CHESS East
Superconducting
RF Cavities
Superconducting
RF Cavities
Interaction Region
Upgrade

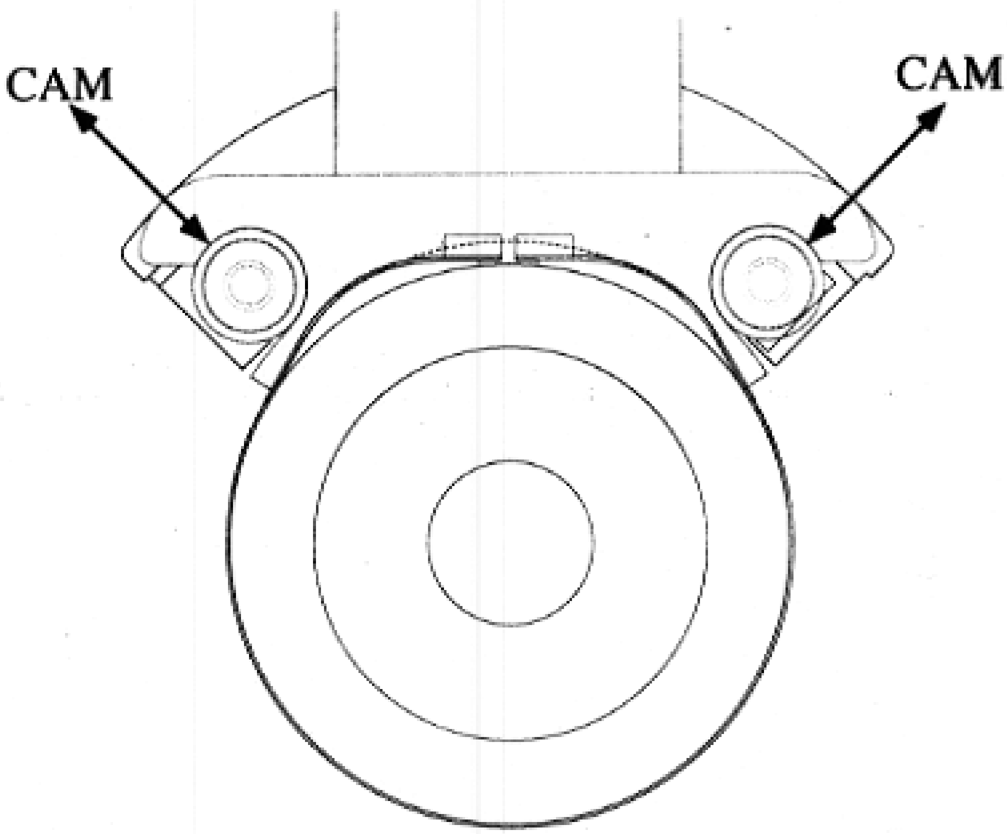

1601095-010
Muon Detectors (End Cap)
Muon Detectors (Barrel)
Steel Magnetic Return Yoke (Barrel)
Cold Box Utilities and Current Lead Transitions to Room Temperature
Superconducting Solenoid (1.5 Tesla)
CsI Crystal Calorimeter (Barrel)
Steel Magnetic Return Yoke (Fixed Pole)
Particle Identification Detector (Rich)
Steel Magnetic Return Yoke (Movable Pole) (Not in Plane of Section)
CsI Crystal Calorimeter (End Cap)
Cryostat Stack
Steel Quad Support Soffit (Plane of Section)
Drift Chamber
TIS Pump
Cryostat
Beam Centerline
Interaction Point
0
50cm
100cm
150cm
200cm
250cm
300cm
Outer Quad Assembly Skew Quad and Dipole Collar Horizontal Focusing Quad
Inner Quad Assembly Skew Quad and Dipole Collar Vertical Focusing Quad
Rare Earth Quad
Si Detector

**CLEO III**



# Superconducting Magnet Support System



CESR Parameters

| | Phase II<br>Jan. 1999 | Phase III<br>Summer 2000 |
|---|---|---|
| beam energy[GeV] | 5.289 | 5.289 |
| 5-cell copper cavities | 2 | 0 |
| single cell SRF cavities | 2 | 4 |
| RF accelerating voltage[MV] | 6.4 | 12 |
| $\beta_v^*$[mm] | 18 | 13 |
| $\beta_h$ 2.1m from IP [m] | 14 | 29 |
| $\beta_v$ 2.1m from IP [m] | 78 | 30 |
| natural bunch length[mm] | 22 | 13 |
| number of bunch trains | 9 | 9 |
| number of bunches/train | 4 | 6-10 |
| bunch spacing [ns] | ~~28~~ 14 | 6-14 |
| peak colliding beam current [A] | 0.550 | 1.0 |
| crossing angle [mrad] | 2.2 | 2.7 |
| vert tune shift param | 0.05 | 0.05 |
| luminosity[$\times 10^{33} cm^{-2} s^{-1}$] | 0.83 | 2.0 |

# INJECTOR

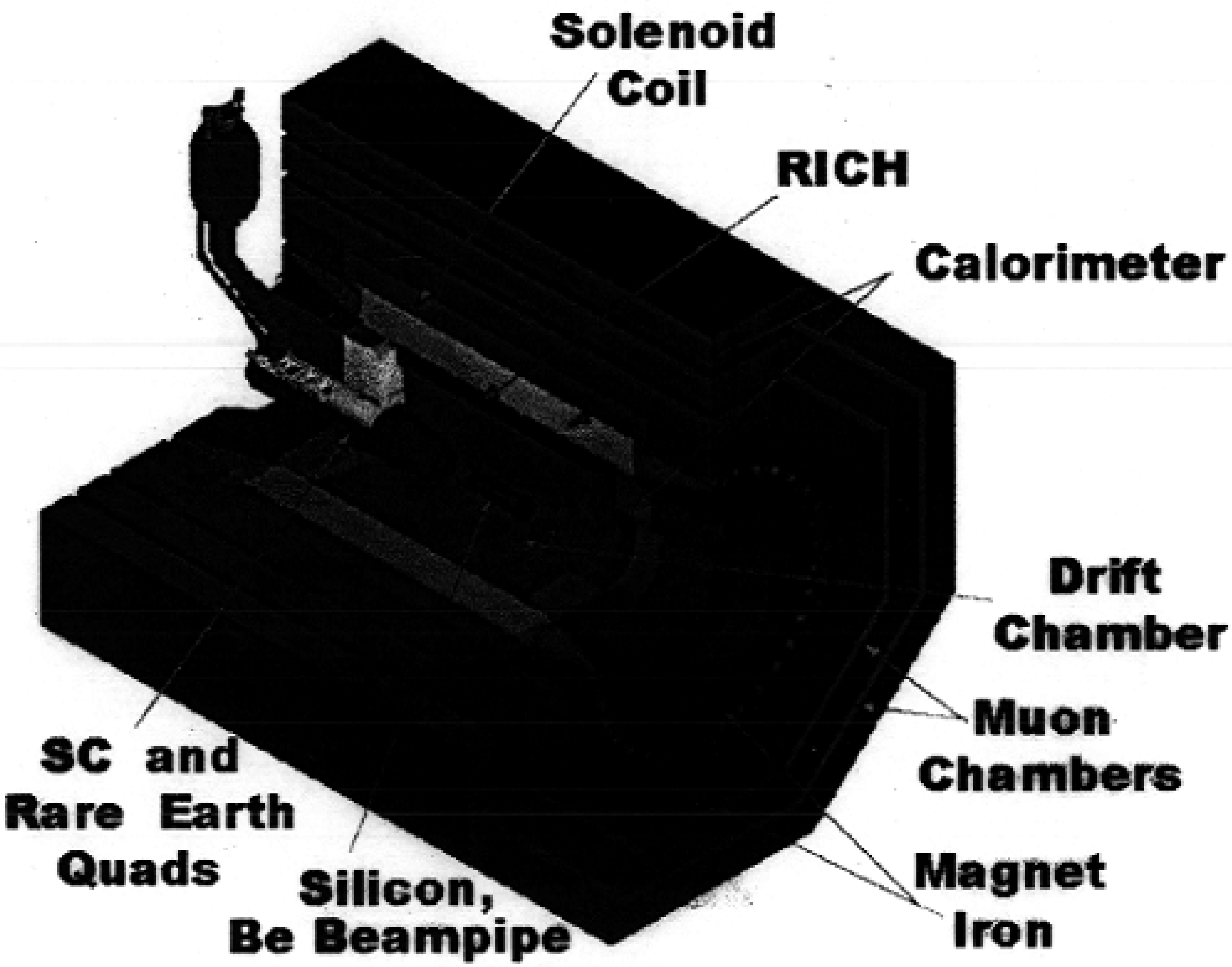
- Linac
  - Replaced chronically leaking accelerating section
  - Replaced weak klystrons
  - Upgraded modulators
  - Improved cooling
- Synchrotron
  - Install strip line BPMs
  - Implement remote magnet moving equipment

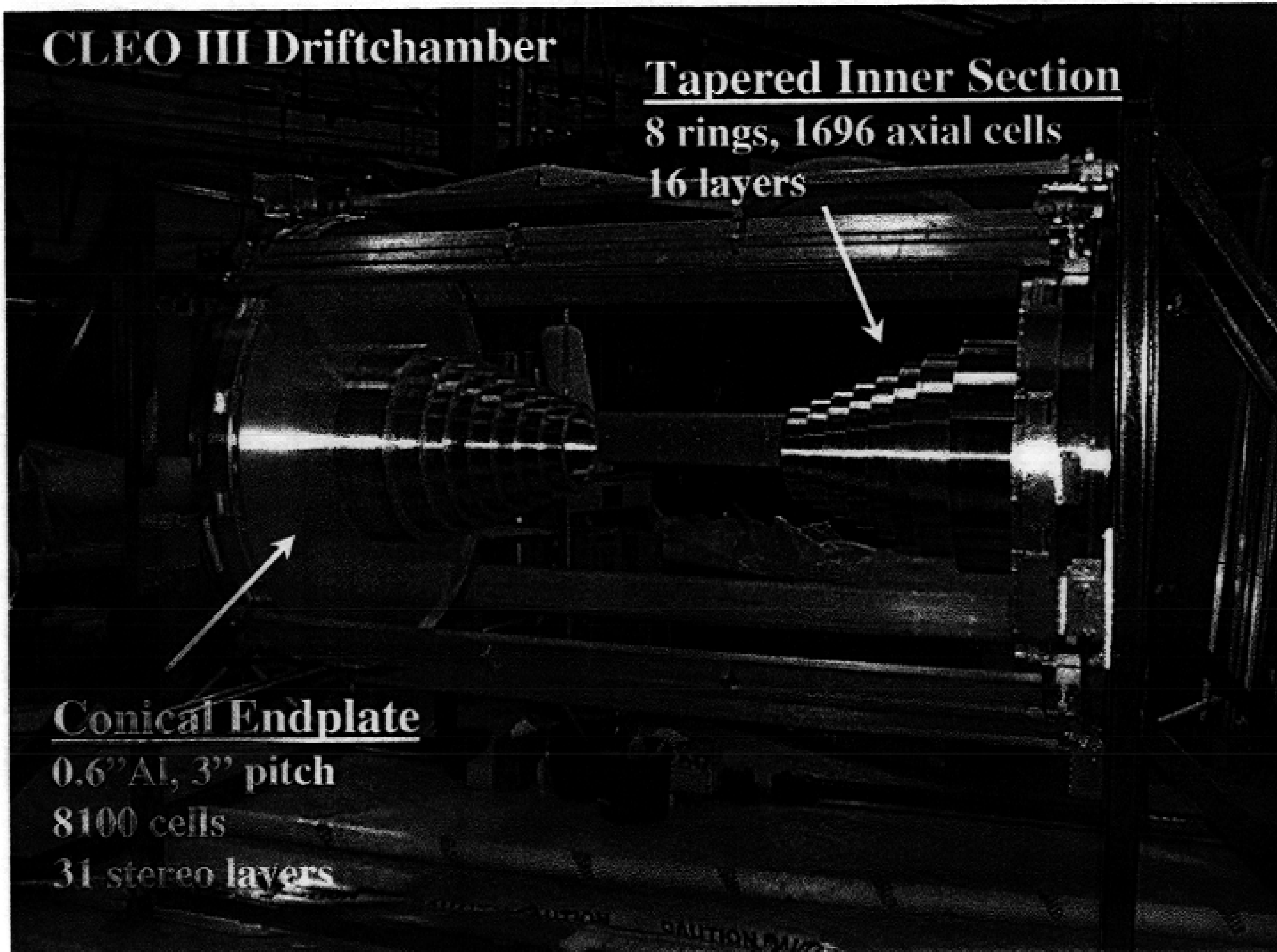
→ Reduce time to refill

## CLEO III

- New drift chamber
  - → space for RICH
  - → and superconducting final focus quads
- Particle Identication (RICH)
- 4 layer silicon vertex detector

# The CLEO III Detector

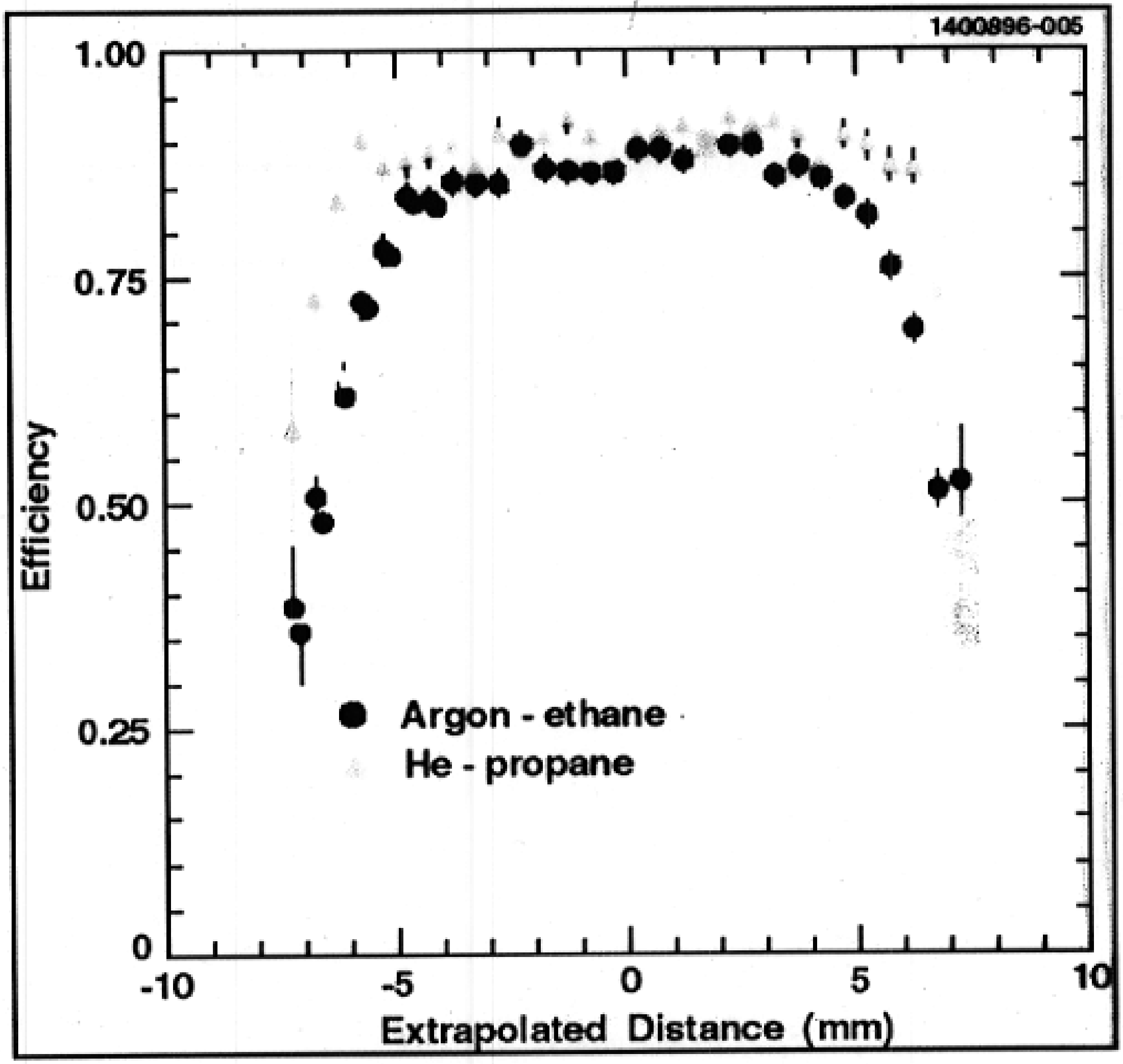


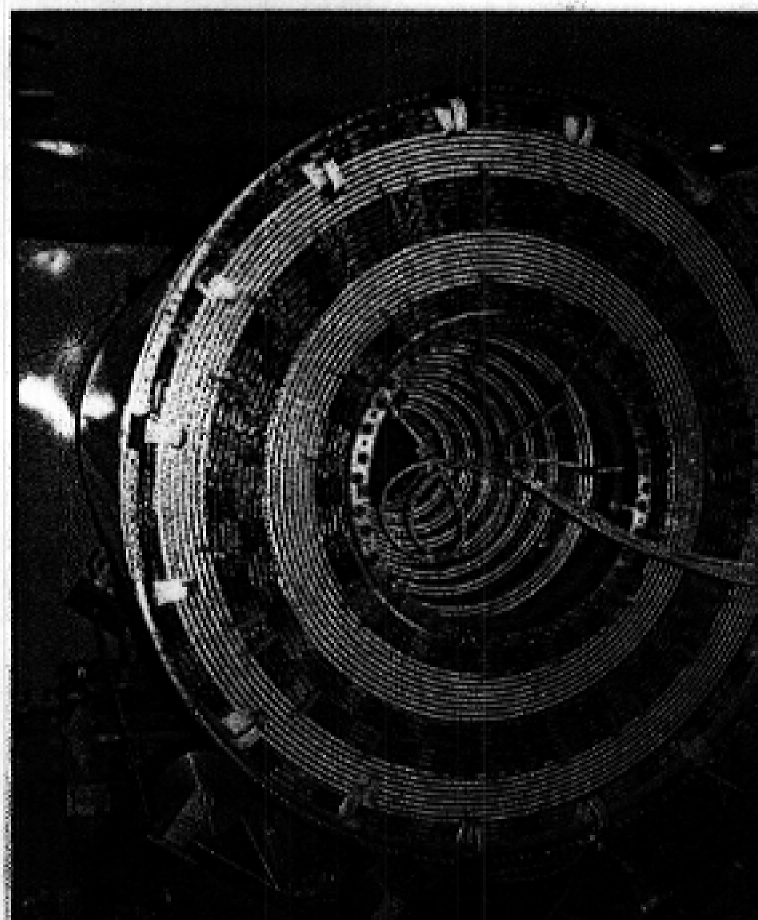

CLEO III Driftchamber
Tapered Inner Section
8 rings, 1696 axial cells
16 layers
Conical Endplate
0.6"Al, 3" pitch
8100 cells
31 stereo layers

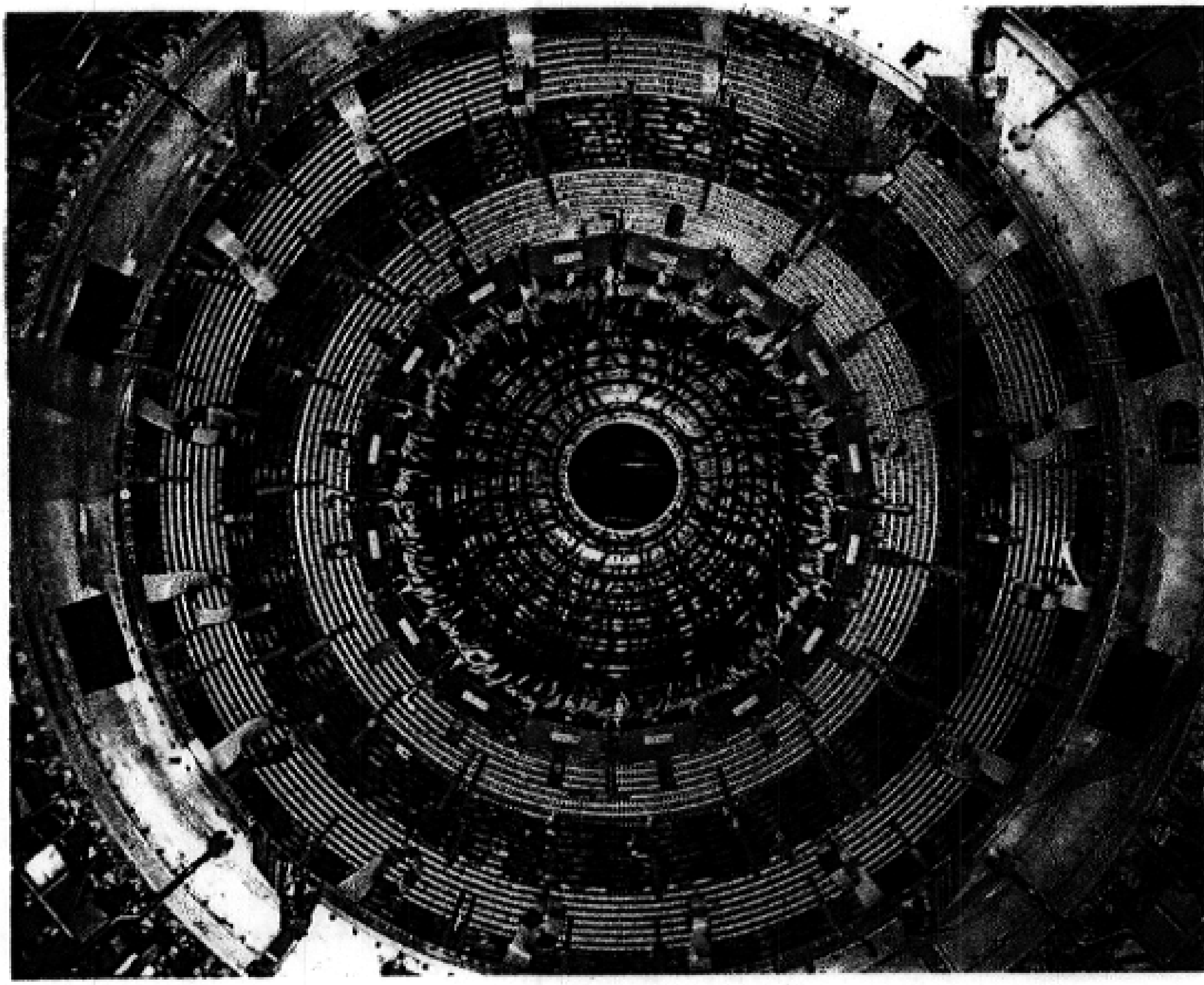
# DRIFT CHAMBER

Reduced multiple scattering

- Inner gas seal
  - 2.5mm Rohacell with 20$\mu$m Al skins
  - $X_0$ <0.15%
  - No support function
- He based gas mixture
  - He:Propane 60:40
    - $X_0 > 330$m
    - Lorentz Angle (@1.5T) < 46°
  - Ar:Ethane 50:50
    - $X_0 = 165$m
    - Lorentz angle (@1.5T) < 69°
- Test beam results (CLEO II.5)
  - Improved efficiency
  - Improved resolution (122$\mu$m $\rightarrow$ 112 $\mu$ m)
  - Improved dE/dx


1400896-005
1.00
0.75
0.50
0.25
0
Efficiency
-10
-5
0
5
10
Extrapolated Distance (mm)
Argon - ethane
He - propane

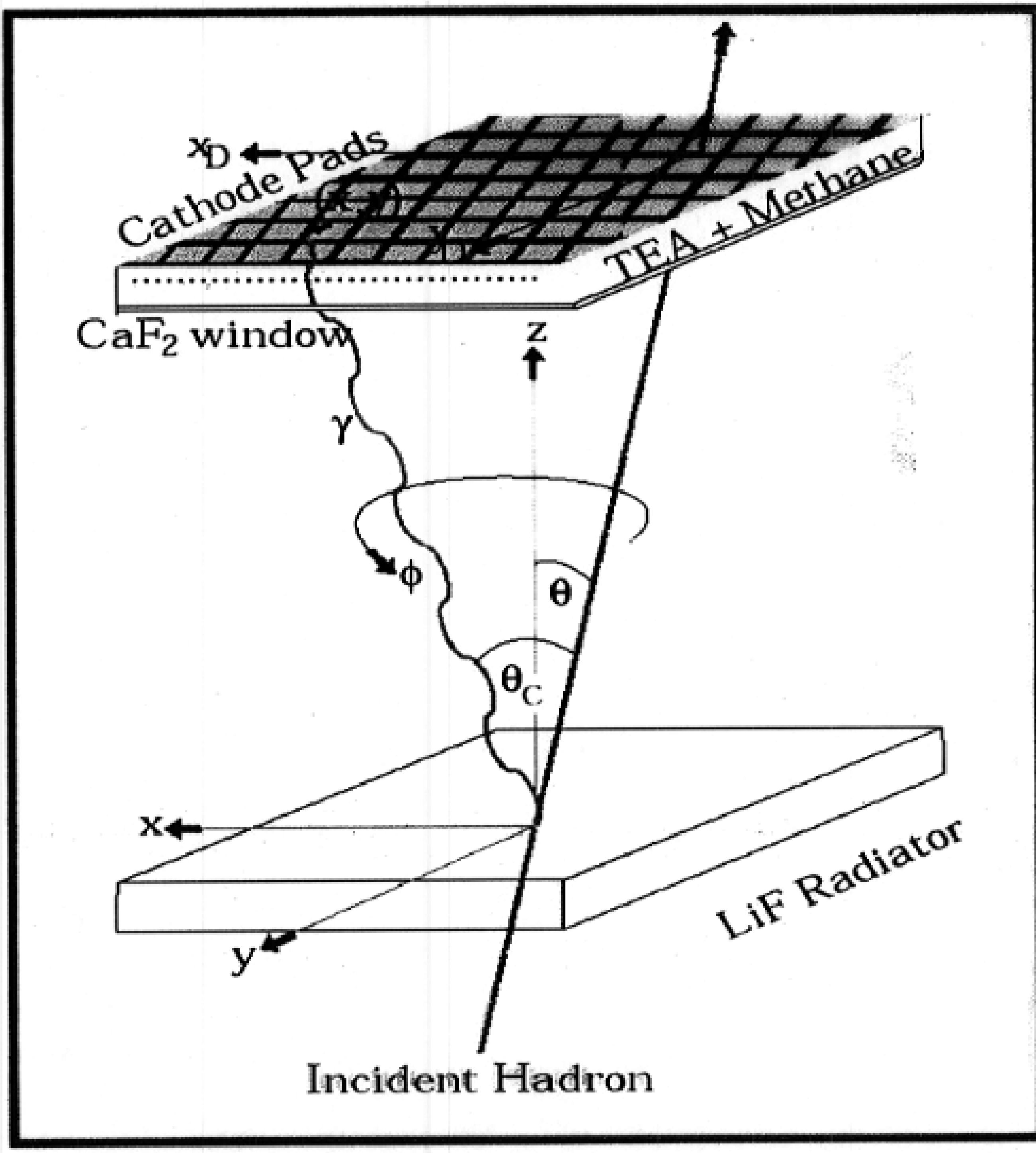




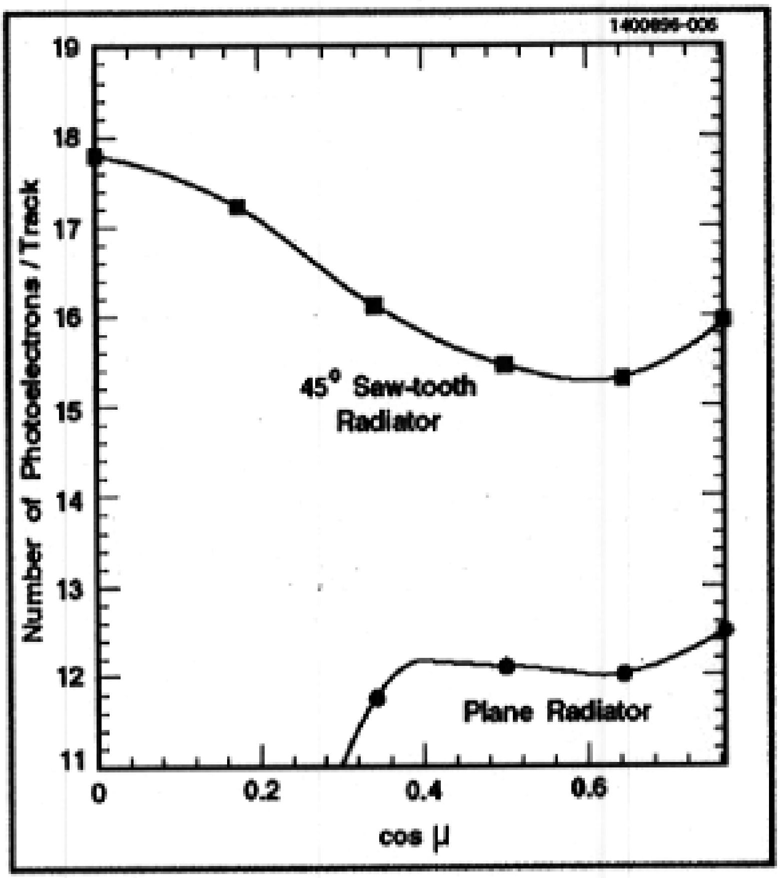
# Particle Identification

- RICH
  - $4\sigma$ $K/\pi$ separation at 3GeV
  - LiF radiator, saw tooth + plane
    - 420 LiF radiators
      300 Plane
      120 Saw-tooth
      17.5 x 17 x 1cm$^3$
    - UV transparent
      135-165nm
  - $N_2$ expansion volume (16cm)
  - TEA/$CH_4$ based photo detector
    - MWPC + Pad Readout
    - $\sim 230,000$ pads, (8mm $\times$ 7.5mm)

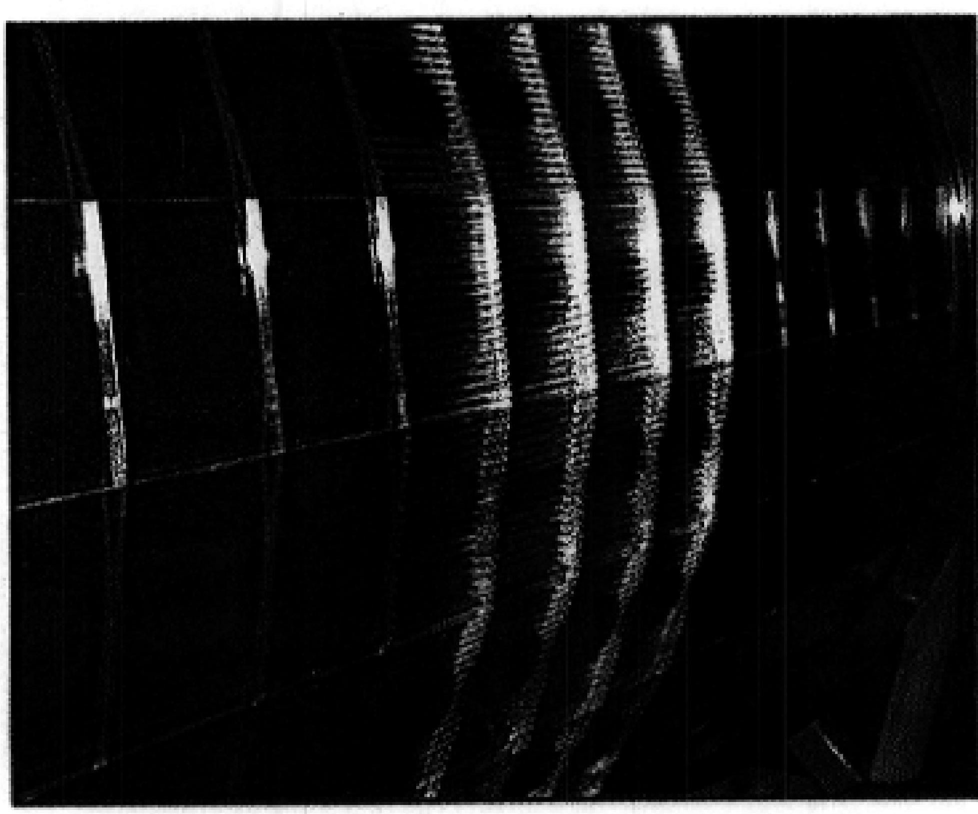
# RICH

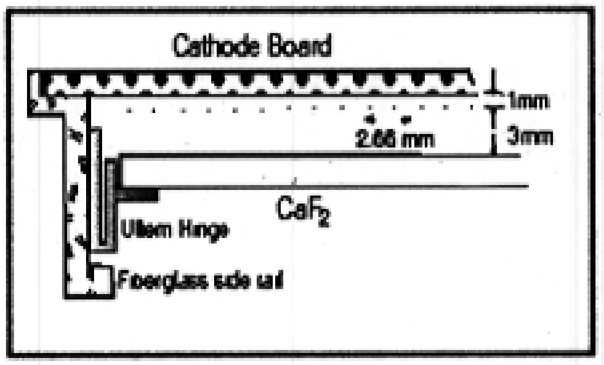


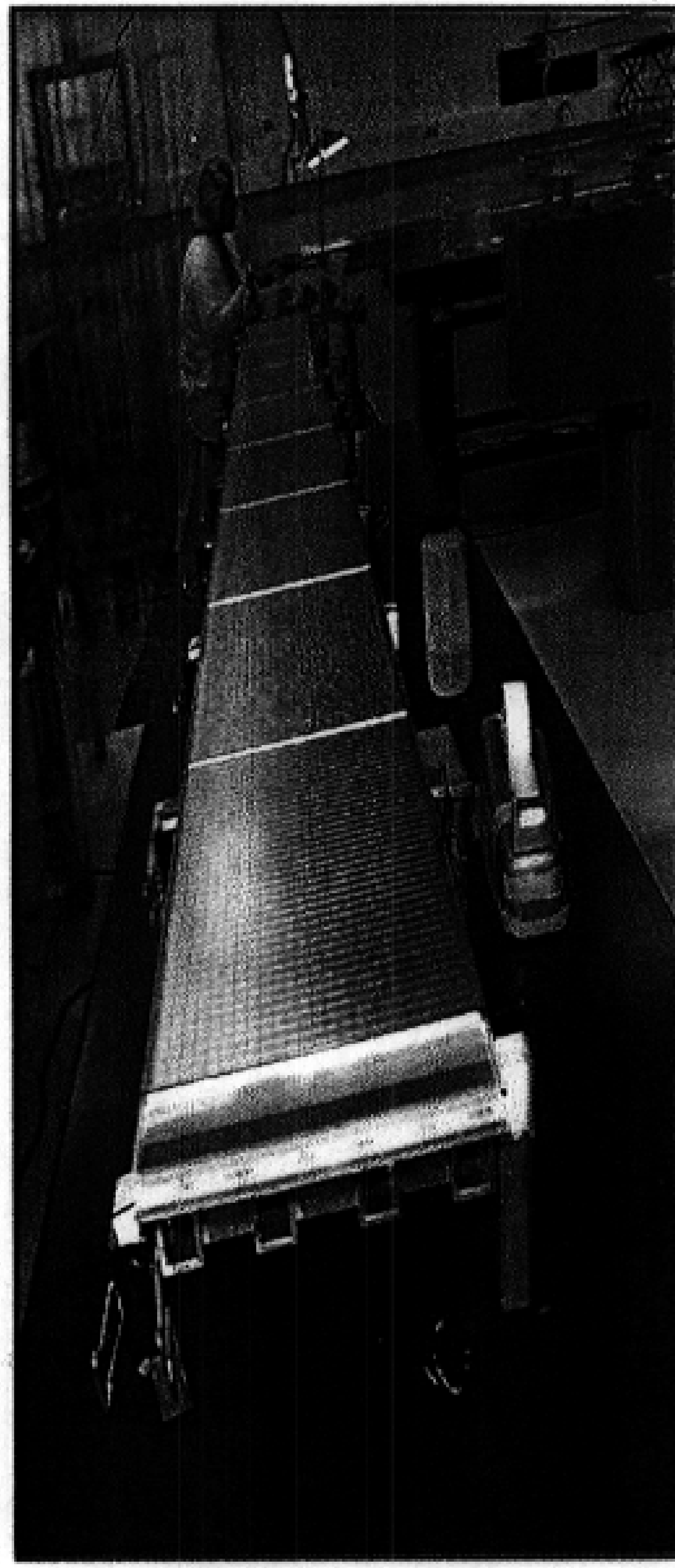
$x_D$
Cathode Pads
TEA + Methane
$CaF_2$ window
z
γ
φ
θ
$\theta_C$
x
y
LiF Radiator
Incident Hadron



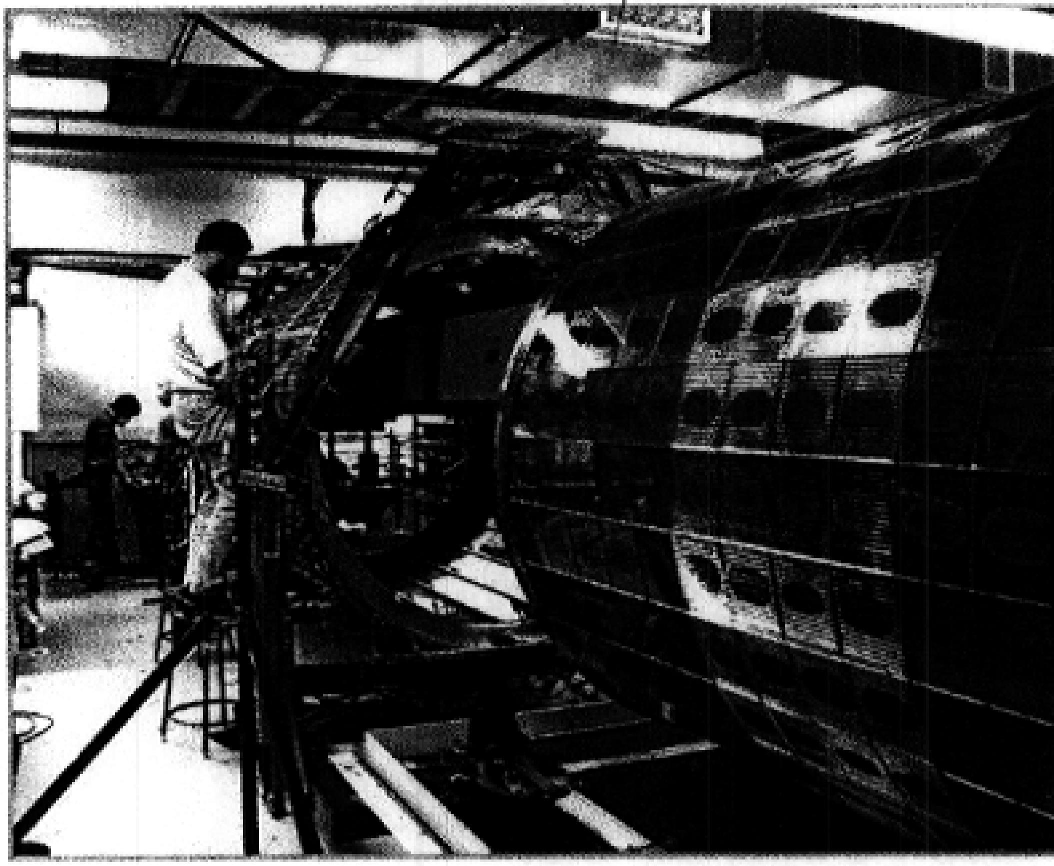
1400896-006
Number of Photoelectrons / Track
cos μ
45° Saw-tooth Radiator
Plane Radiator
19
18
17
16
15
14
13
12
11
0
0.2
0.4
0.6

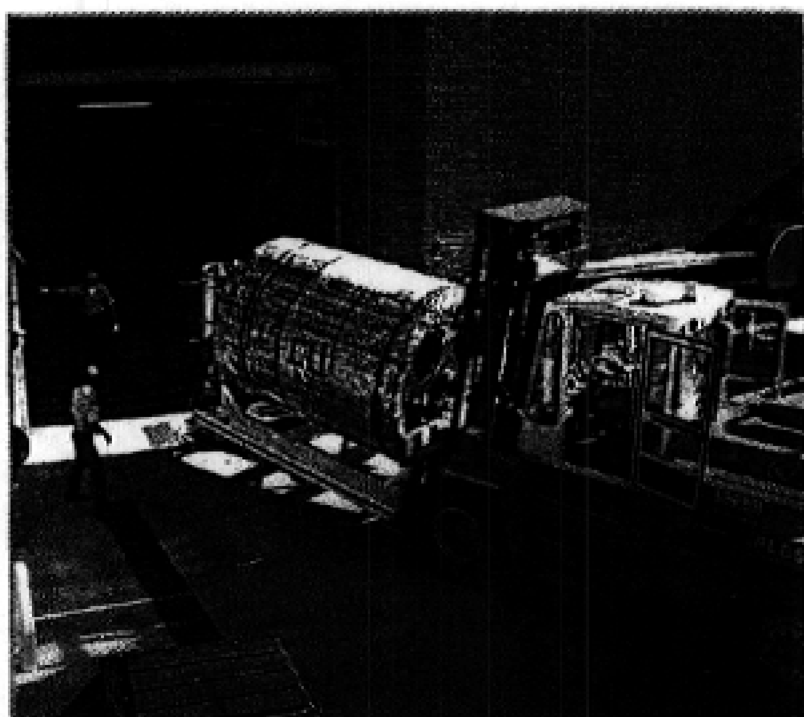




Cathode Board
1mm
2.66 mm
3mm
$CaF_2$
Ultem Hinge
Fiberglass side rail



# RICH Assembly



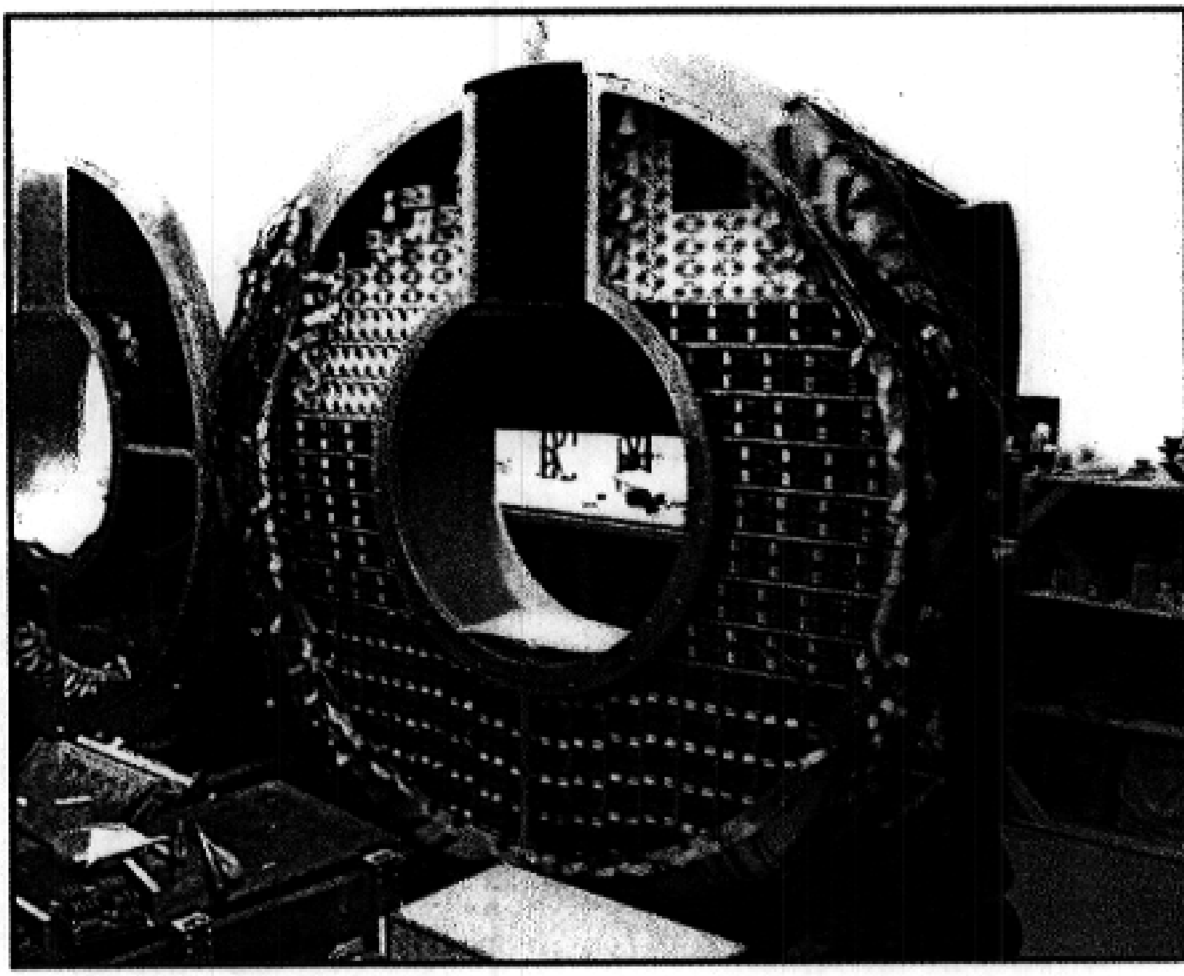


**Arrival at Wilson Lab**

# ELECTROMAGNETIC CALORIMETER

- CLEO pioneered use of CsI calorimeter
- 7800 crystals
- 2% energy resolution at 1 GeV
- 4mr angular resolutio at 1 GeV
- no radiation damage observed
- reduced material in front of endcaps

# Electromagnetic Calorimeter



**Re-Stacking the Calorimeter Endcap**

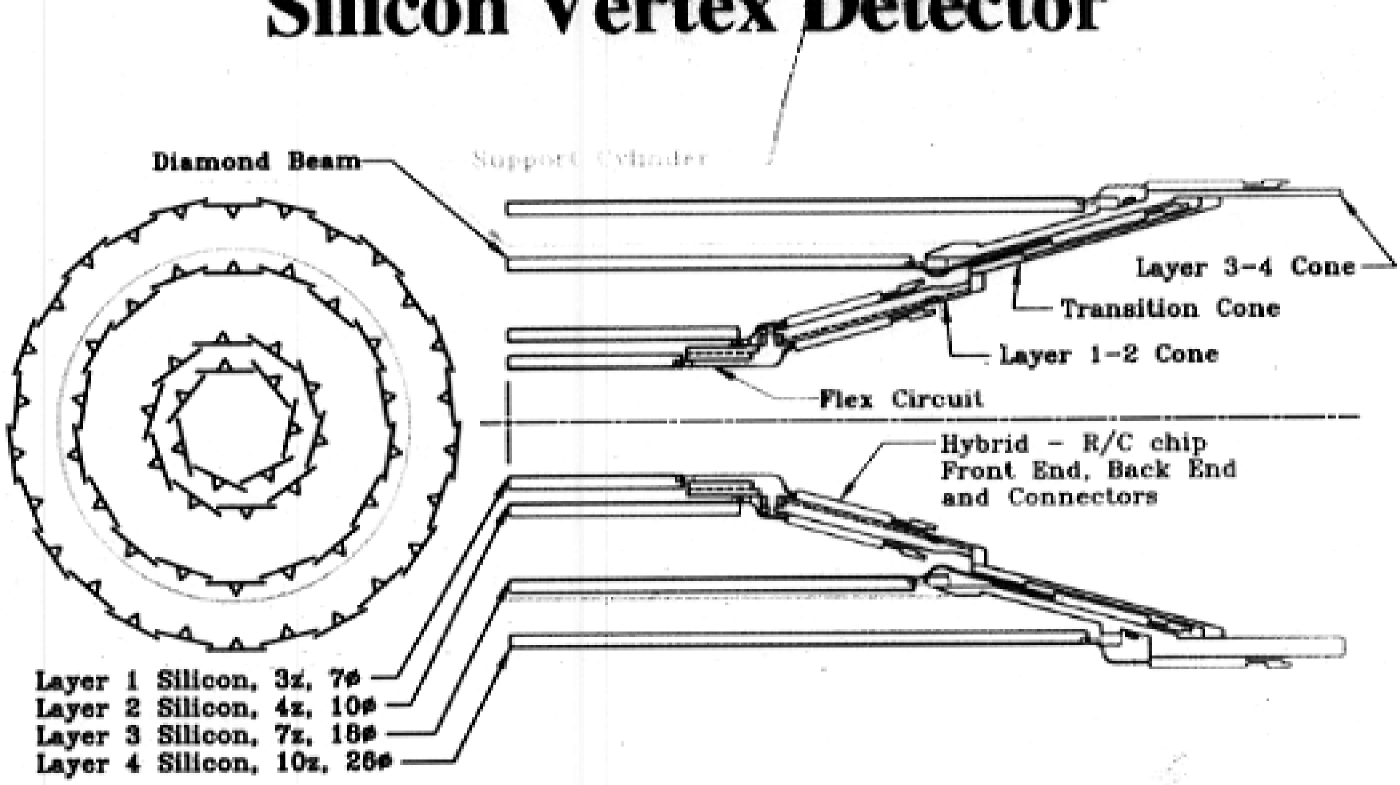
# Silicon Vertex Detector

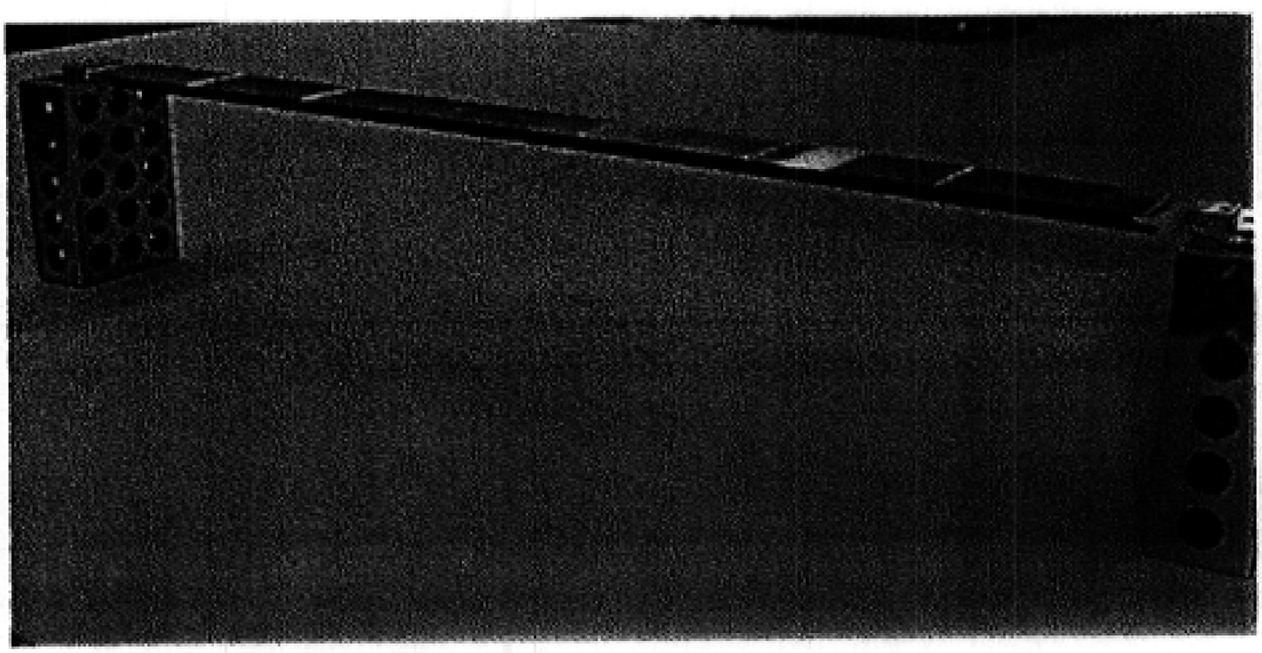
- 4 layers of double sided silicon detectors, 300 $\mu$m thick
- Only active elements and minimal support material in detector fiducial region
- No support structure outside outermost silicon layer
- Conical support structure to maximize acceptance

Readout Electronics

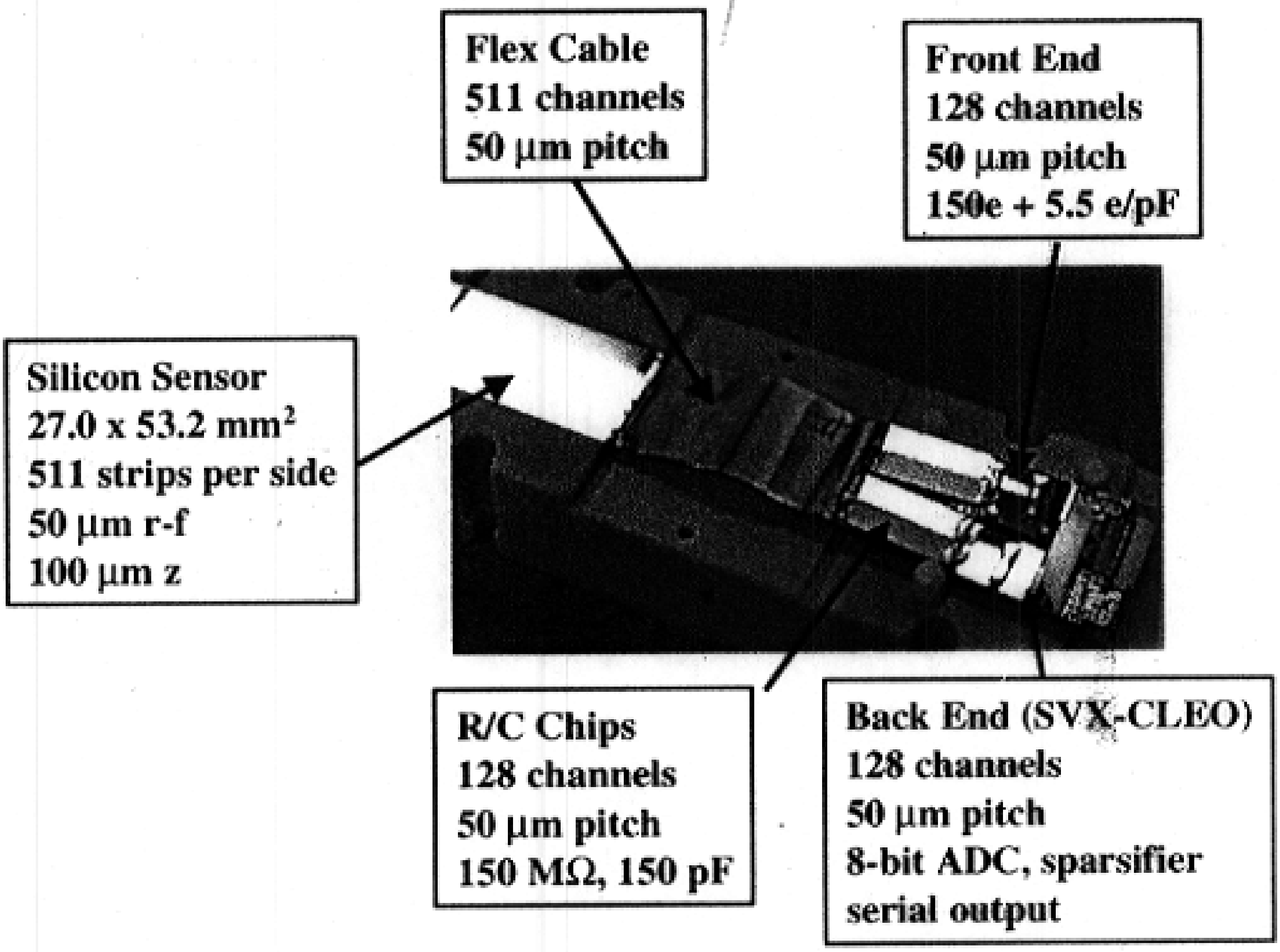
- Up to 5 silicon sensors daisy-chained to one readout
- Radiation hard (100kRad)
- Very low noise, Viking based Front-End chip
- Back-End chip based on SVX II
- BeO Hybrids mounted on copper cones (cooling)
- S/N>15:1 (worst case)

# Silicon Vertex Detector



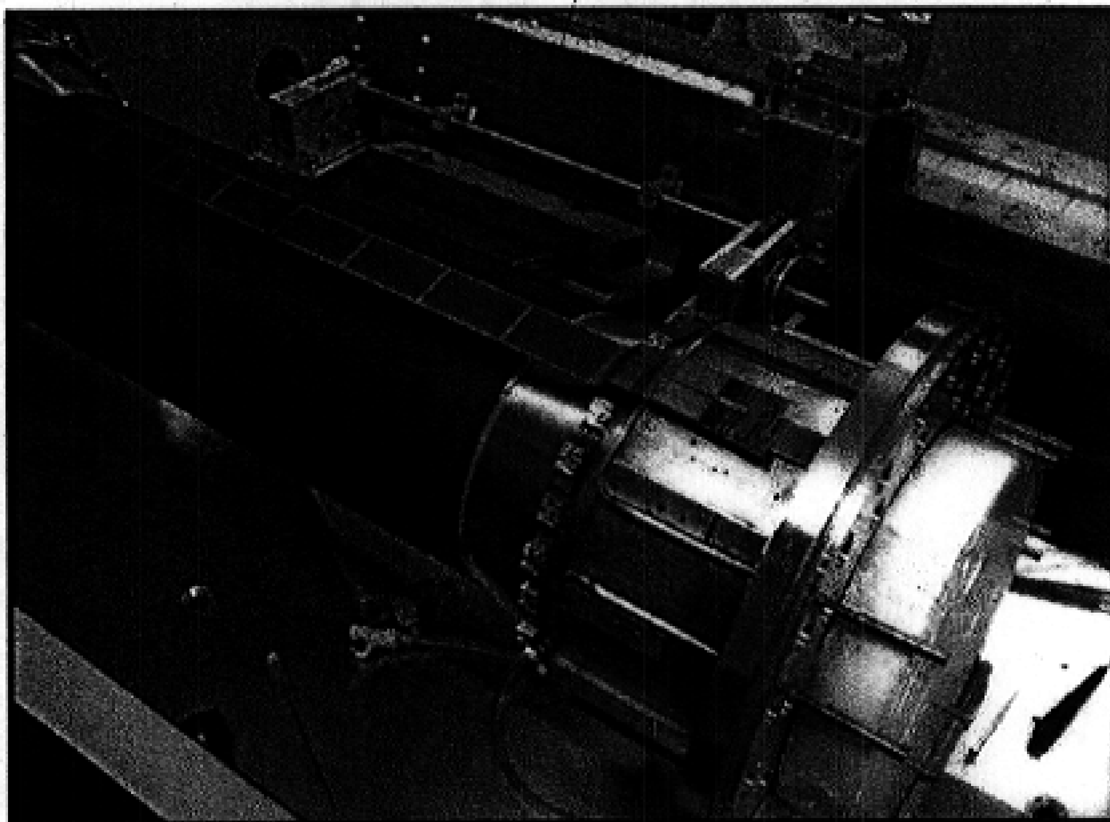



# Read Out Electronics

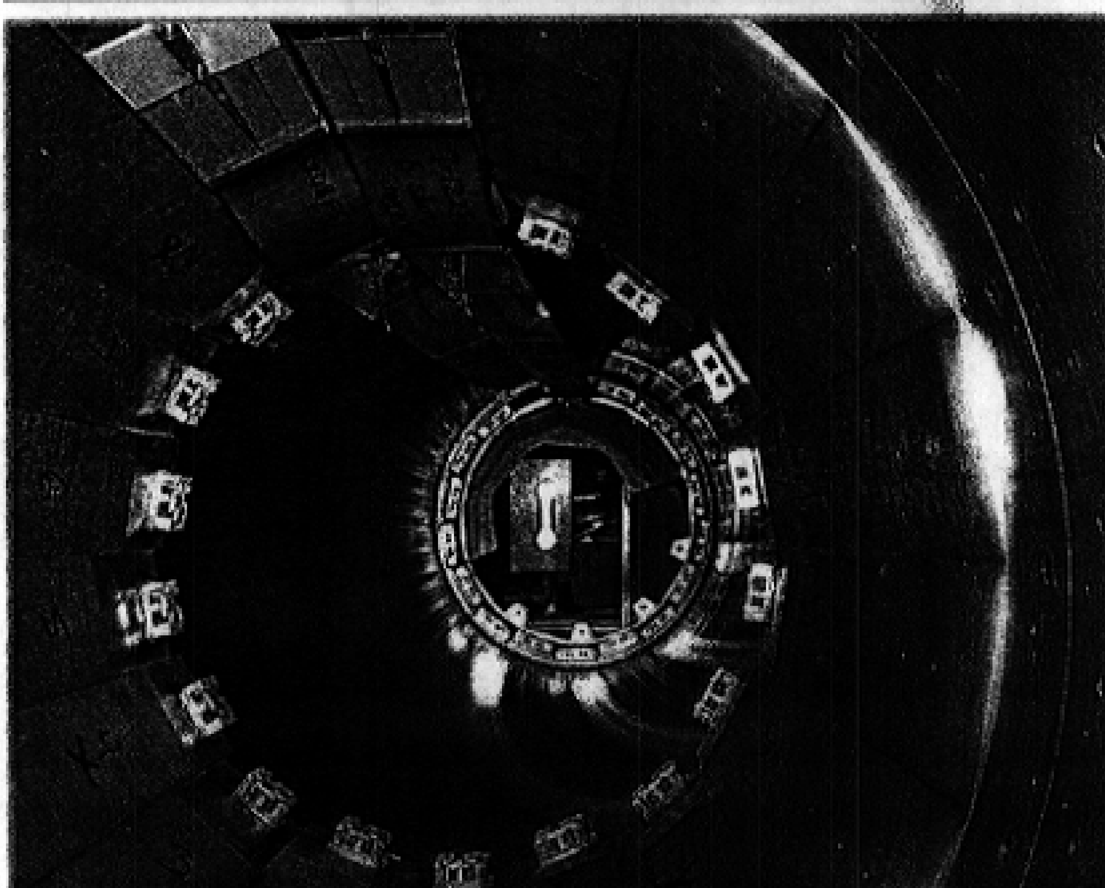


# Vertex Detector Assembly

Layer 4



Layer 3

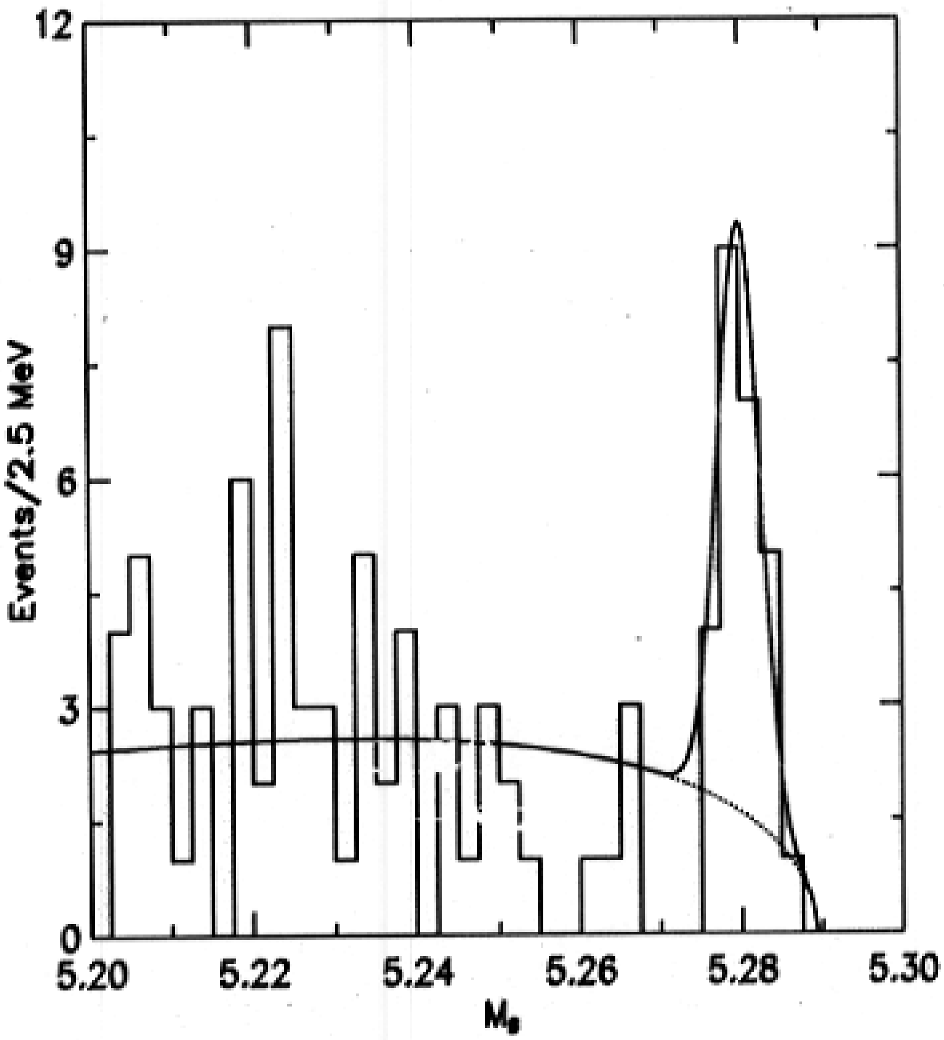


# CLEO II PHYSICS

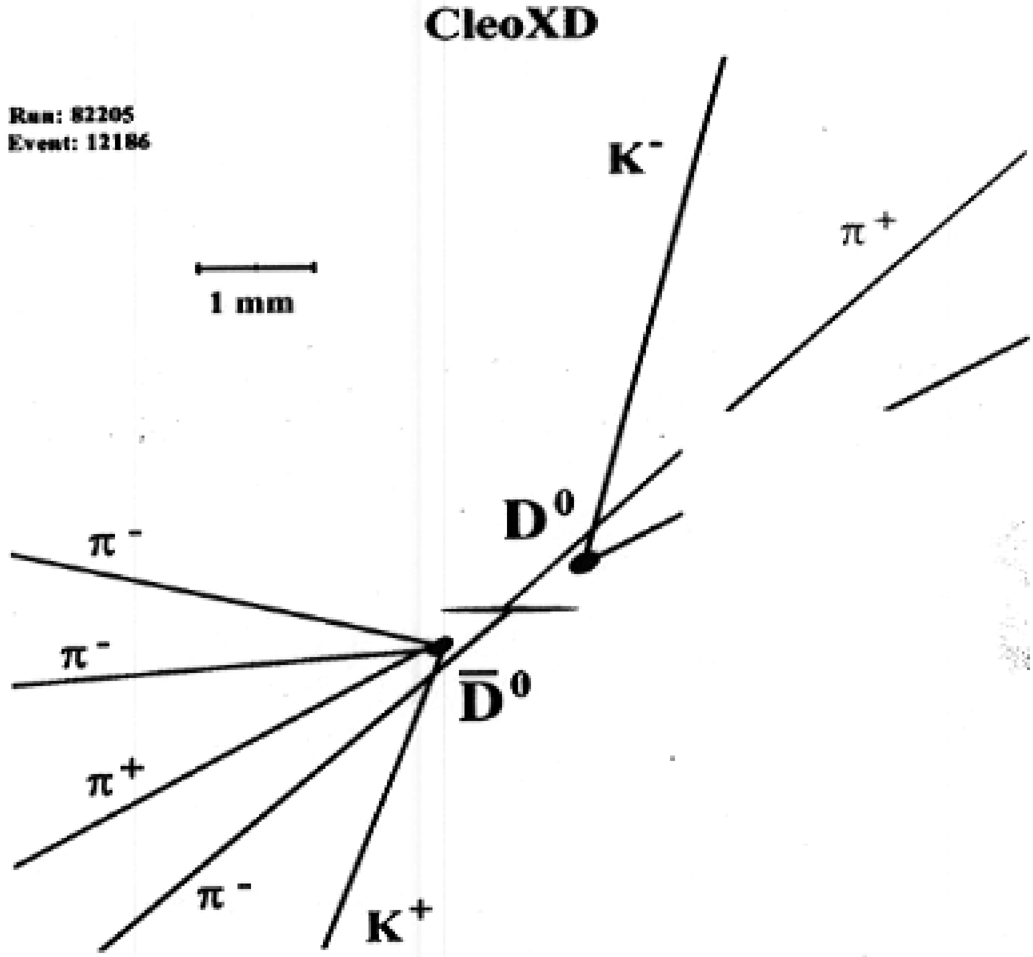
$\sim$ 10 million $B\bar{B}$ pairs $\Rightarrow$

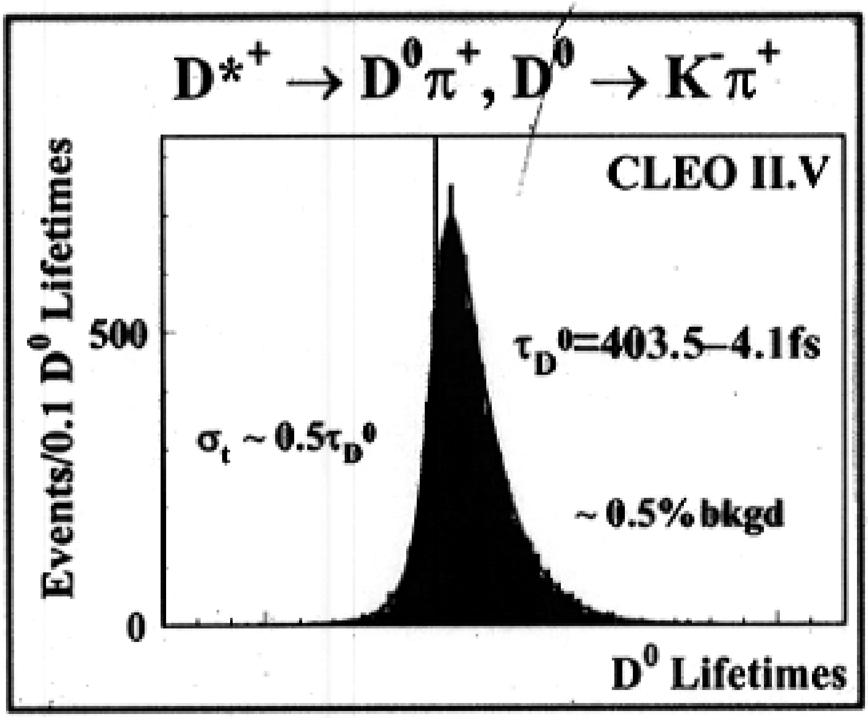
- Branching fractions for rare charmless hadronic decays
  - $B^0 \to K^+\pi^- = 1.9 \times 10^{-5}$
  - $B^0 \to \pi^+\pi^- = 4.7 \times 10^{-6}$
  - Measurment of 14 charmless decay rates $\to \gamma = 113^{+25}_{-23}$ degrees. $(V_{ub} = |V_{ub}|e^{-i\gamma})$
- $D^0 - \bar{D}^0$
  - $R_{ws} = \frac{D^0 \to K^+\pi^-}{\bar{D}^0 \to K^+\pi^-} = (0.34 \pm 0.07 \pm 0.06)\%$
  - Measurement of rate vs decay time $\Rightarrow$ amplitudes that describe mixing consistent with 0
    - $(1/2)x'^2 < 0.05\%$ and $-5.9\% < y' < 0.03\%$

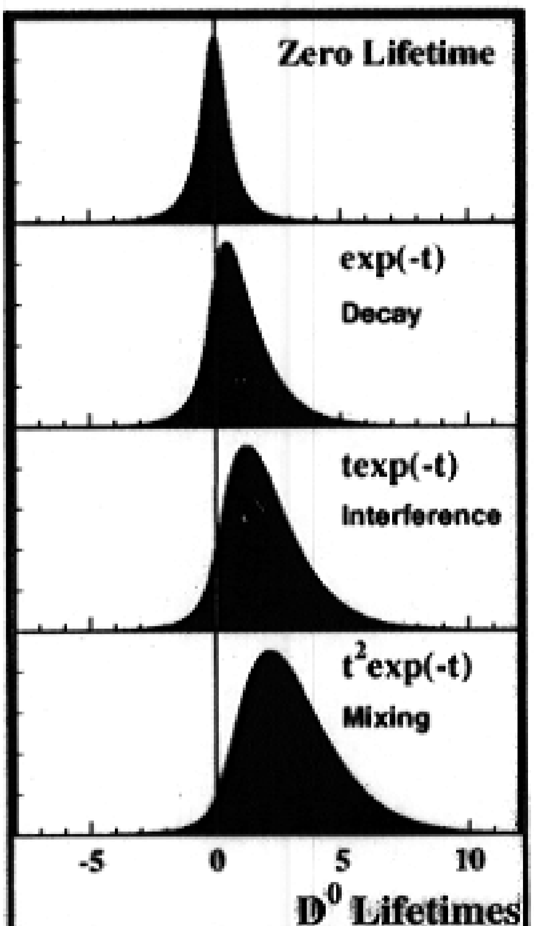
$K\pi$

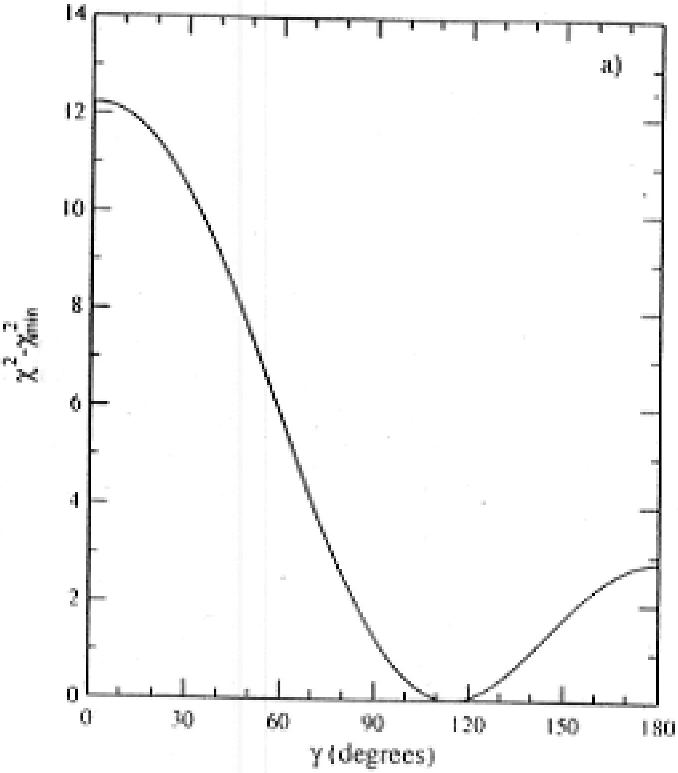


# Charged Particle Tracking




D*+ → D0π+, D0 → K-π+
CLEO II.V
Events/0.1 D0 Lifetimes
500
0
τD0=403.5–4.1fs
σt ~ 0.5τD0
~ 0.5% bkgd
D0 Lifetimes


Zero Lifetime
exp(-t)
Decay
texp(-t)
Interference
t2exp(-t)
Mixing
-5
0
5
10
D0 Lifetimes



14
12
10
8
6
4
2
0
a)
$\chi^2 - \chi^2_{min}$
0
30
60
90
120
150
180
γ (degrees)