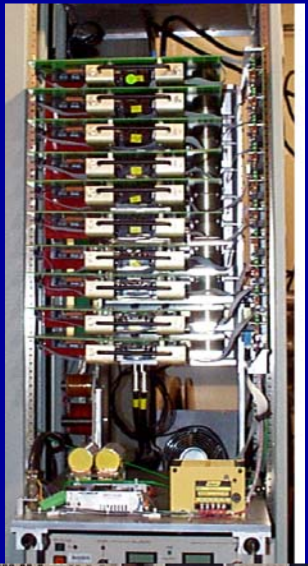
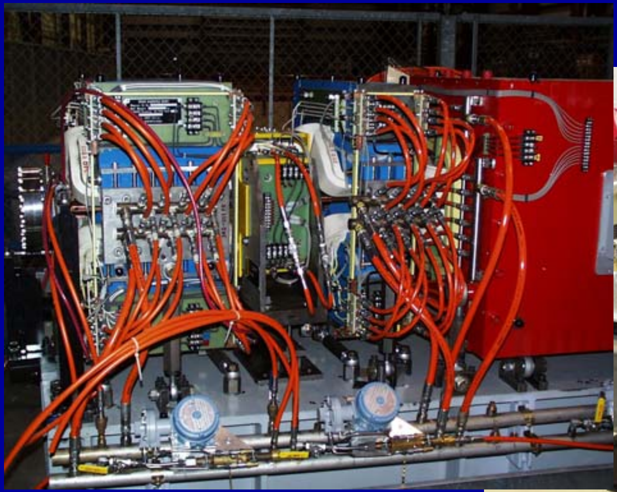


Operational Aspects of the SPEAR 3 Accelerator

J. Corbett

August 7, 2003



SPEAR 3 Design Criteria

Maximize photon beam brightness

small horizontal & vertical beam size (ε_x ~20 nm-rad, β_x ~10 m, β_y ~5 m)

500 mA, 3 GeV, (vs. 3.5 GeV, 260 mA)

short, high field dipoles (hard x-rays)

Maintain tunnel footprint & beam line locations

'standard cells'

'matching cells'

6-month installation

pre-assembled girders

'no-way' schedule

Accelerator Physics Issues

Create a Compact, <u>Buildable</u> Lattice

- chamber bore, radiation slot height
- ε_c, magnet bore, magnet spacing, pole tip fields
- accommodate tunnel beamlines, RF, match booster

Operationally Robust Machine

- tunable, ramp to 3.3 GeV (3.5 GeV debate)
- BSC, photon beam strikes, interlocks

Minimize β_x in straight sections

- dipole layout, cell tunes, 🕘quad strength

Dynamic aperture off-momentum

- cell tunes, global tunes
- chromatic sextupole field pattern

Low Impedance

- copper chamber, PEP-II cavities, DELTA kicker

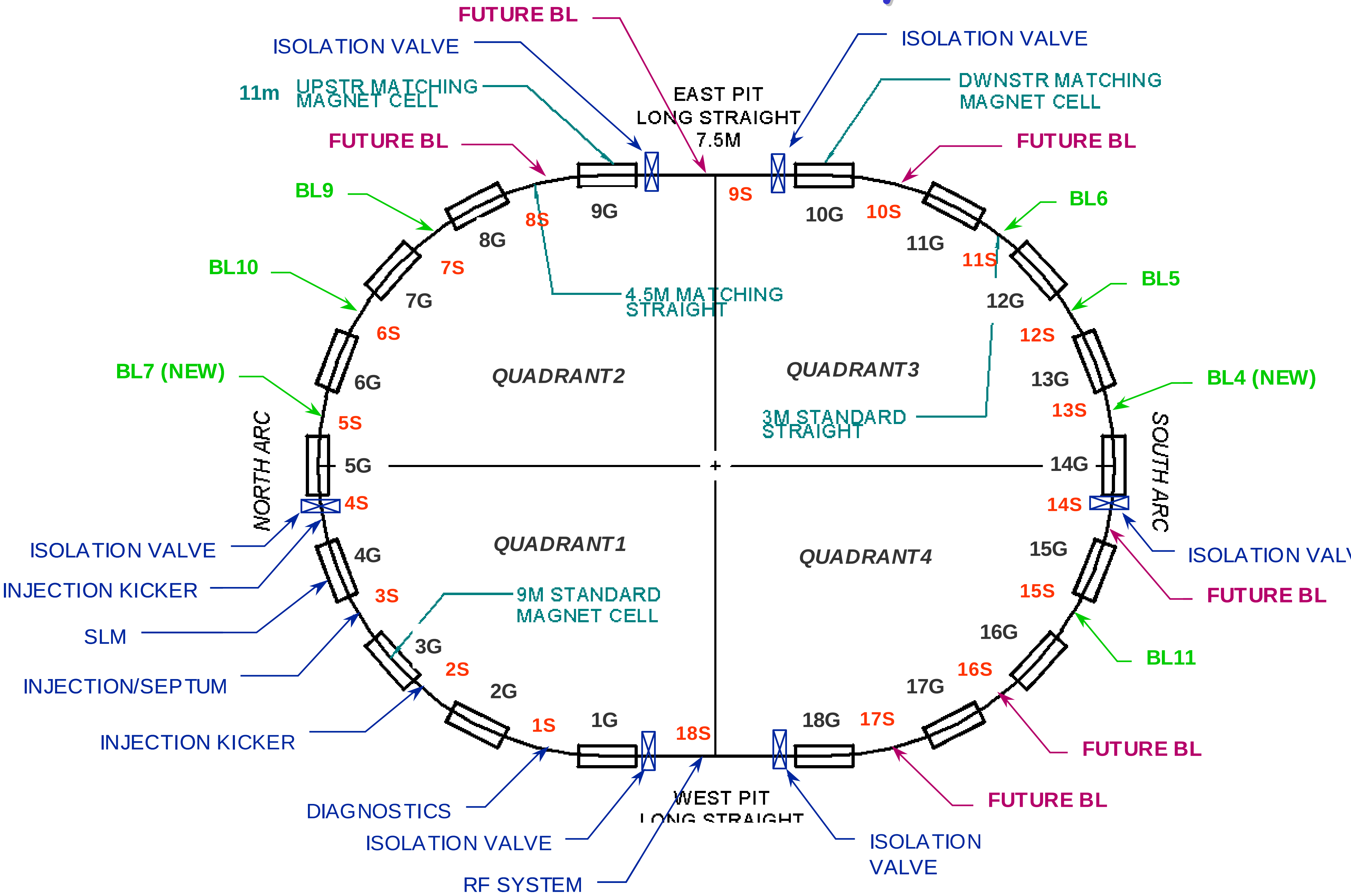
Beam Stability

- BPM & support design, corrector field penetration
- quadrupole modulation, orbit feedback

20 hour lifetime

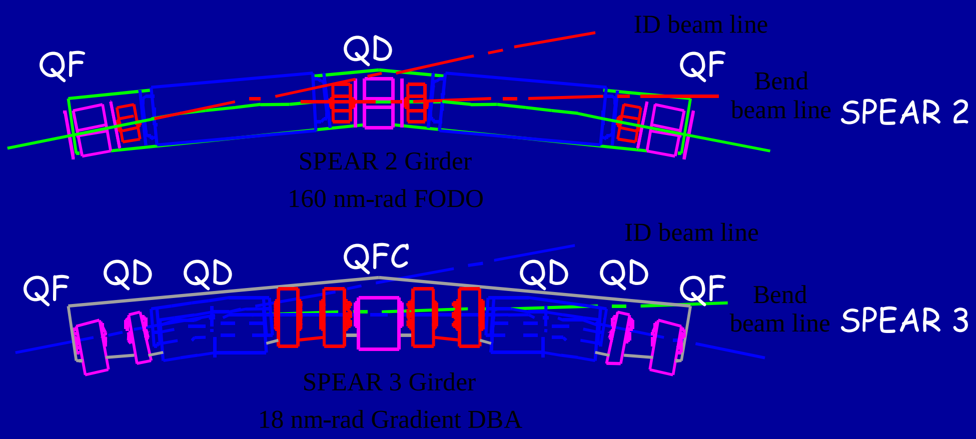
- large BSC
- 1.2nT N_2 equivalent pressure
- V_g = 3.2 MV

SPEAR 3 Girder Layout

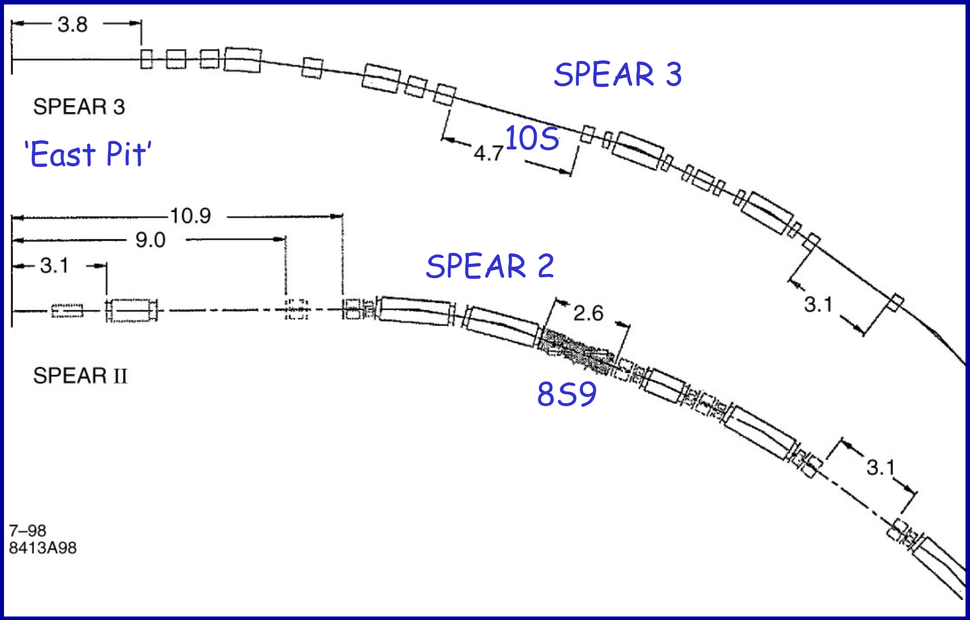


Lattice Conversion from SPEAR 2 to SPEAR 3

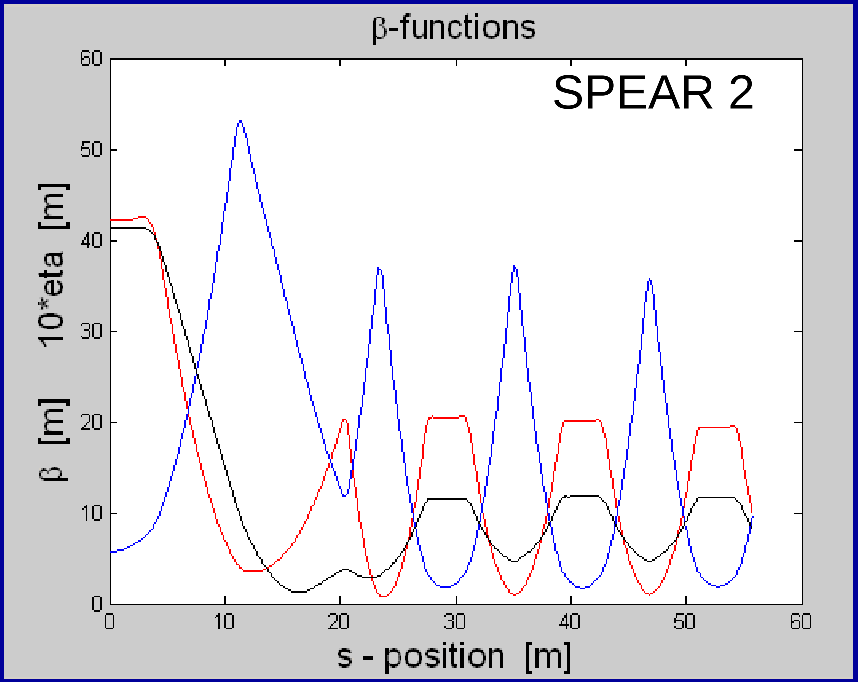
Standard Cells

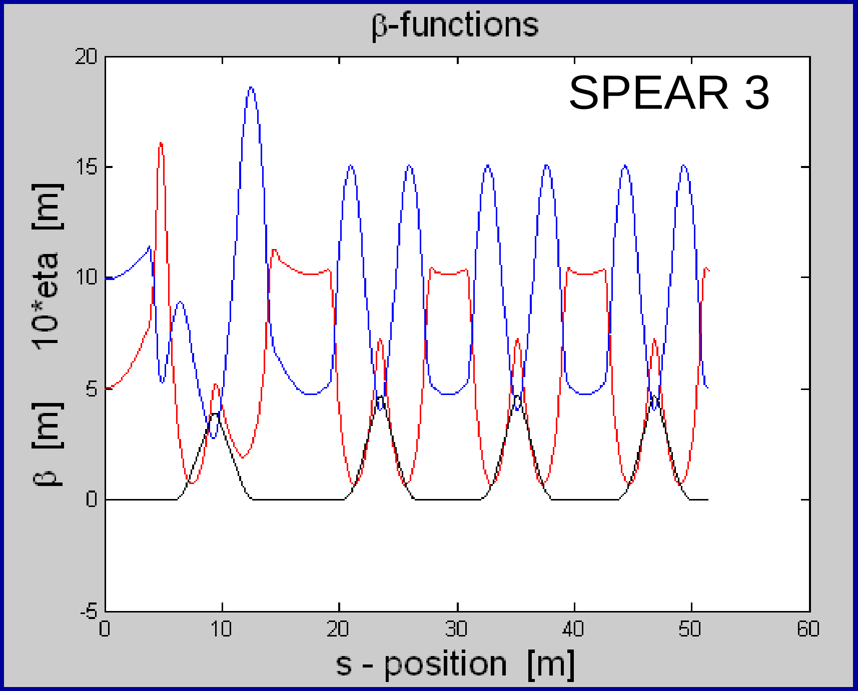


Matching Cells

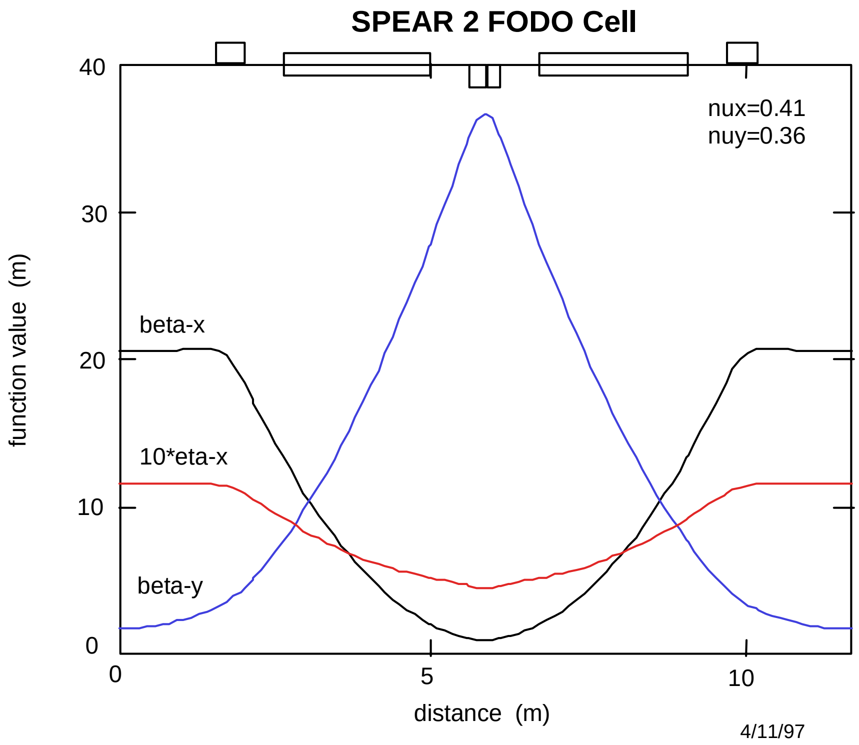


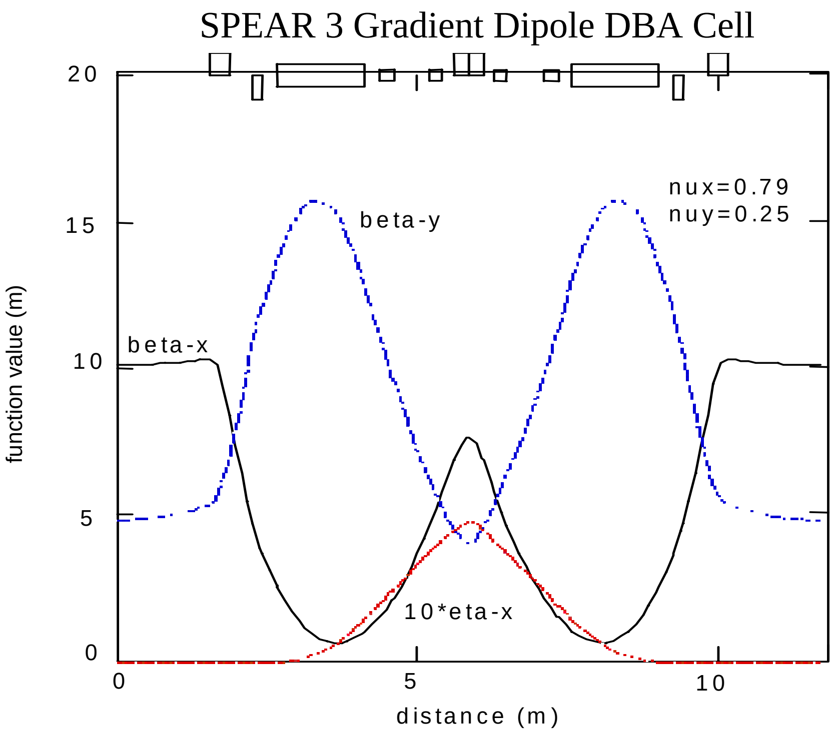
Comparison of Optical Functions



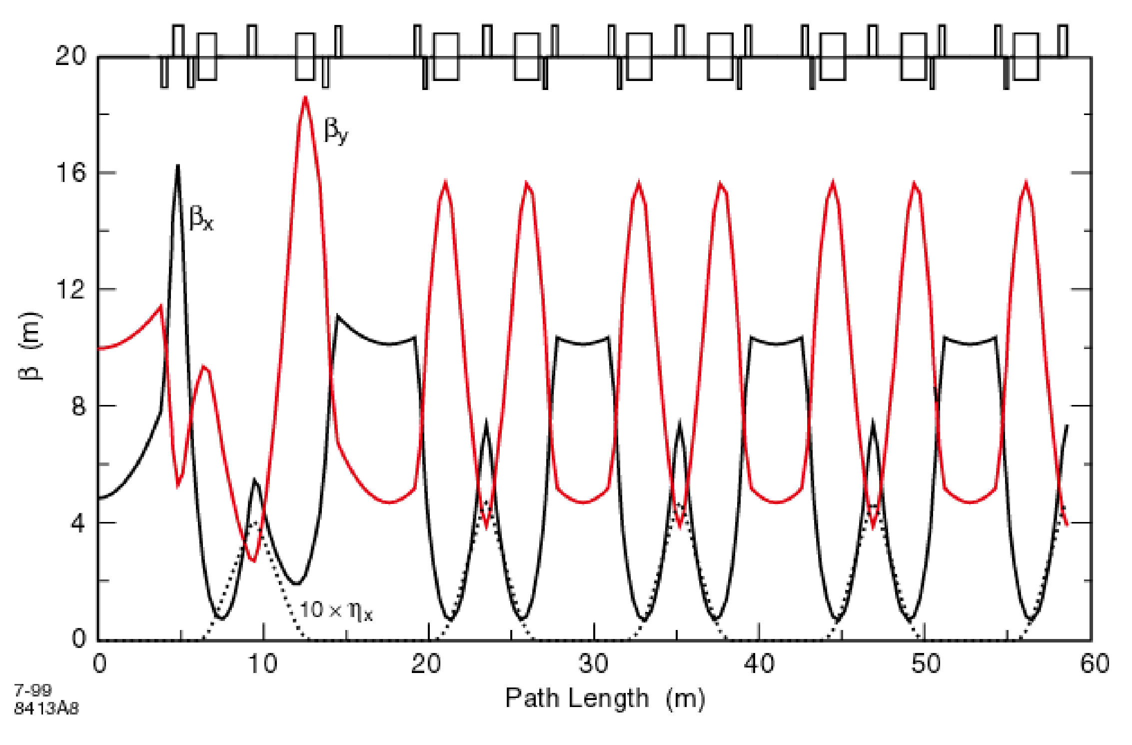


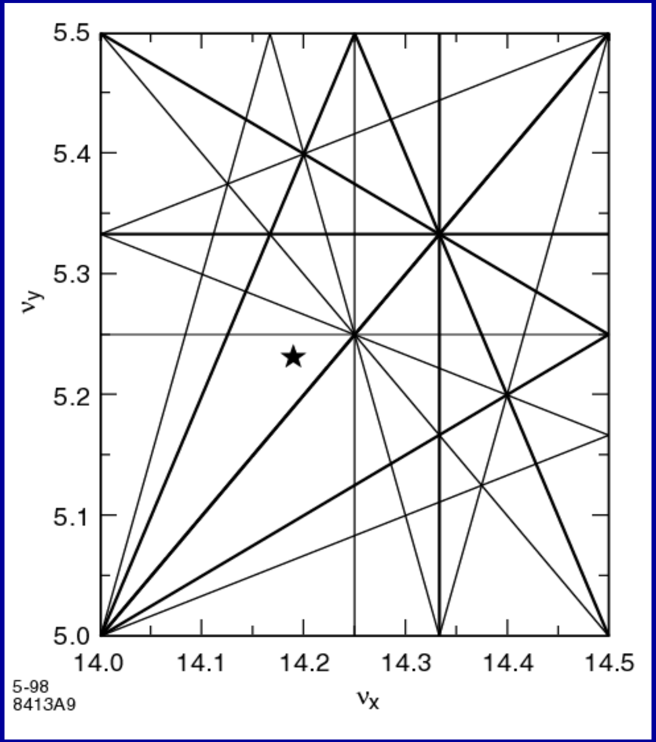
SPEAR Lattice Functions (cont'd)





SPEAR 3 OPTICS (cont'd)

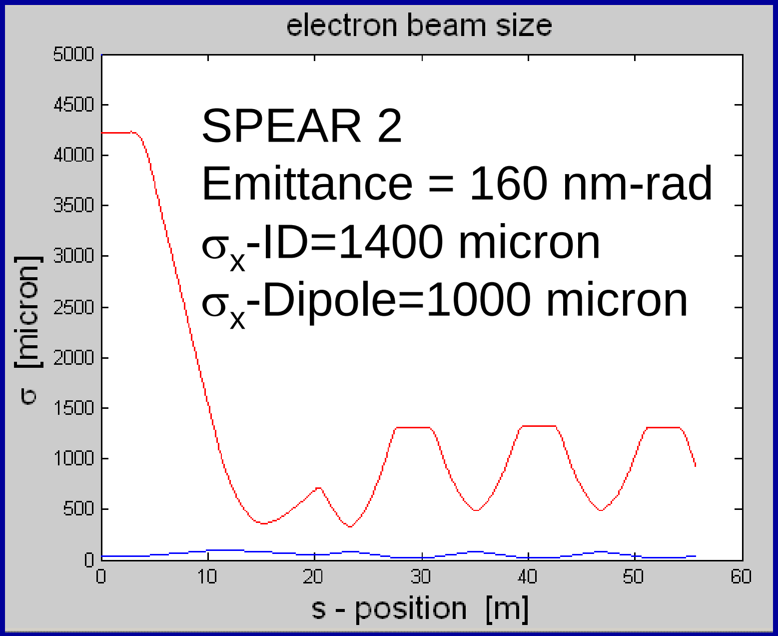


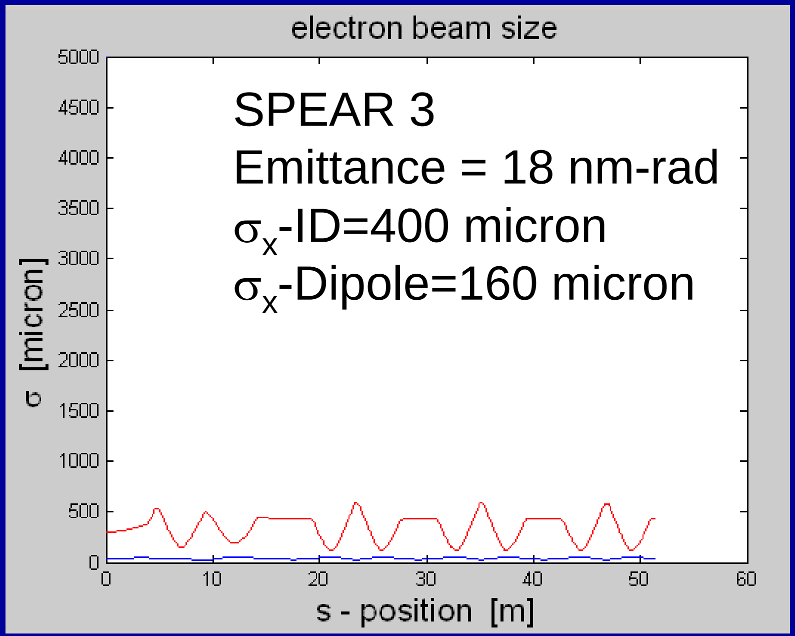


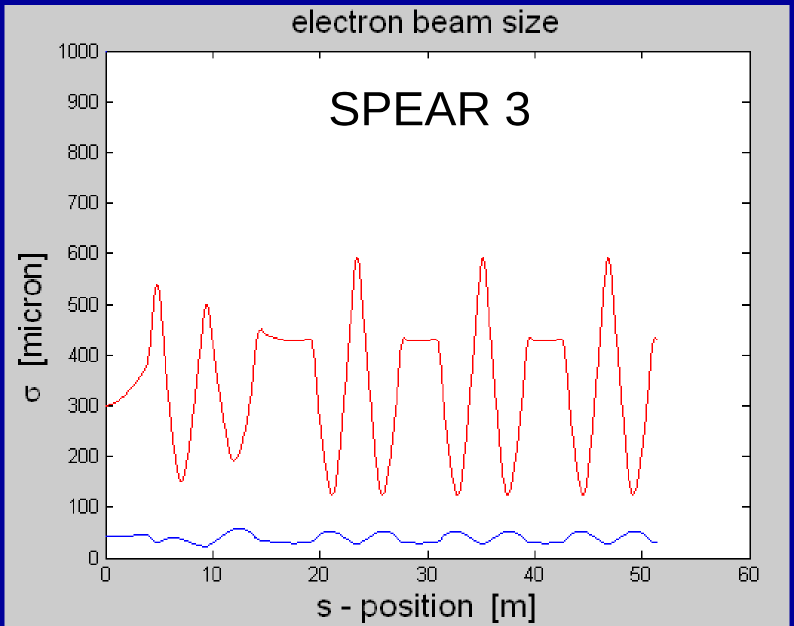
$\nu_x = 14.18$

$\nu_y = 5.23$

Comparison of Electron Beam Size







Photon Beam Size and Stability

	ID Source Point		Dipole Source Point	
	SPEAR 2	SPEAR 3	SPEAR 2	SPEAR 3
σ_x	2000 μm	**427 μm**	790 μm	**160 μm**
$\sigma_{x'}$	2-20 mrad	**2-20 mrad***	mrads	**mrads**
σ_y	53 μm	**30 μm**	200 μm	**50 μm**
$\sigma_{y'}$	142 μrad	**136 μrad***	147 μrad	**136 μrad**
σ_s	23 mm/75 ps	**5.3 mm/19 ps**	23 mm/75 ps	**5.3 mm/19 ps**

* For 100-period undulator: $\sigma_{x'}$ = 42 μrad, $\sigma_{y'}$ = 15 μrad

Transverse Stability:

<10% of beam dimensions

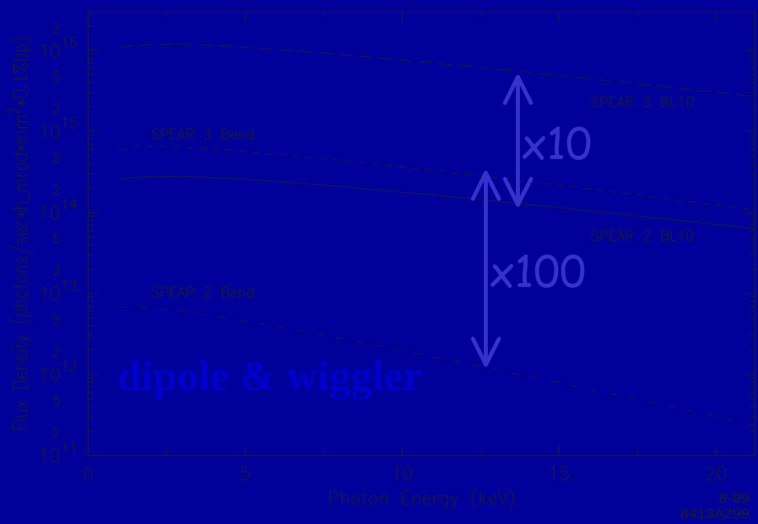
⇒ **< 20 μm H, < 5 μm V** at stable BPMs
<1.4 μrad vertical for 100-period ID

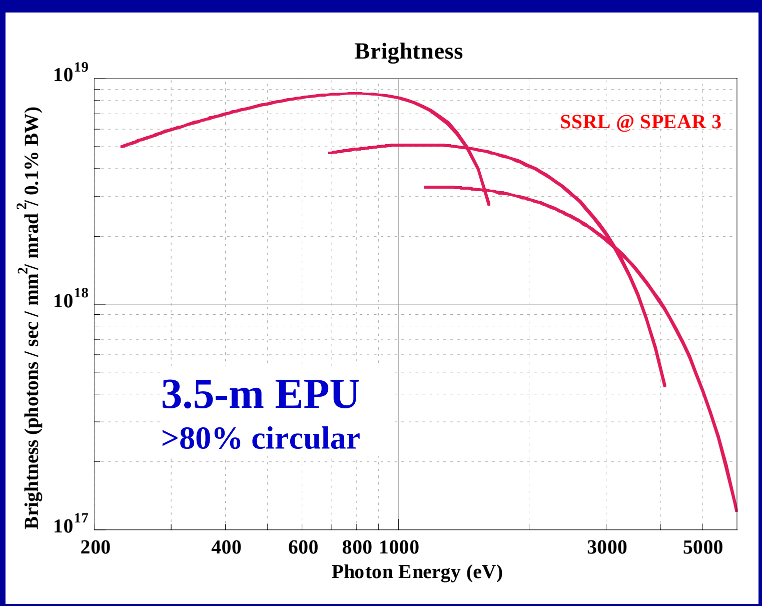
⇒ **< 0.02%** coherent E oscillations (dipole sources)

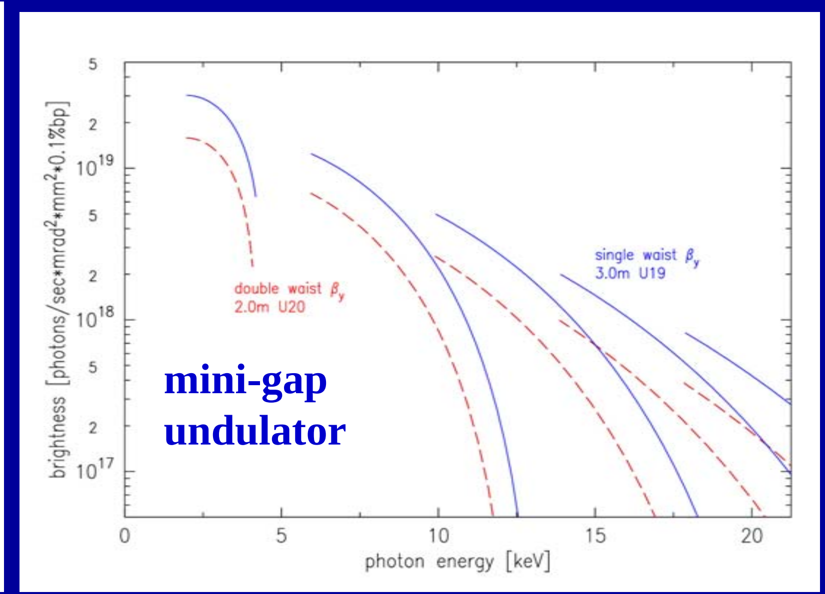
Longitudinal Stability:

< 0.01% coherent E oscillations ($\Delta\phi < 0.3^o$)
for 10^{-4} stability of 5^{th} undulator harmonic

Photon Beam Spectra

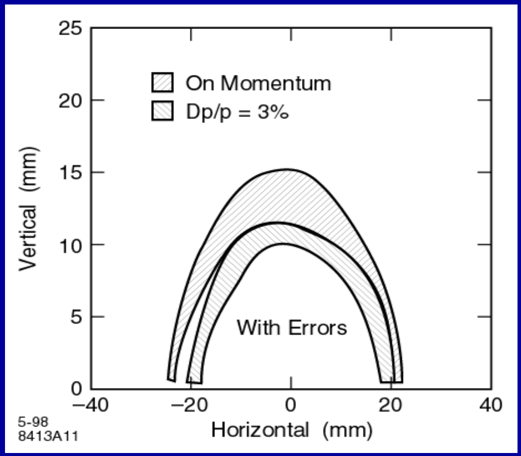




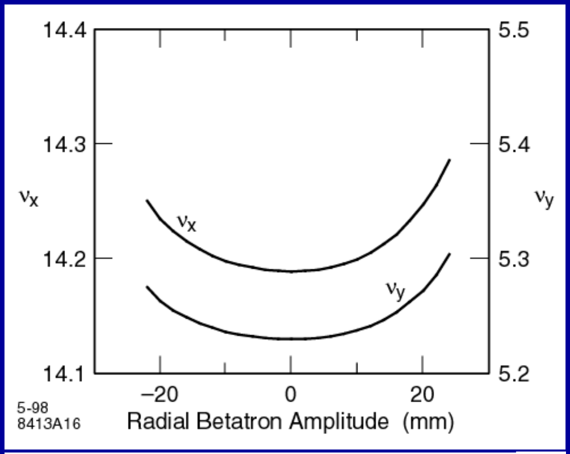


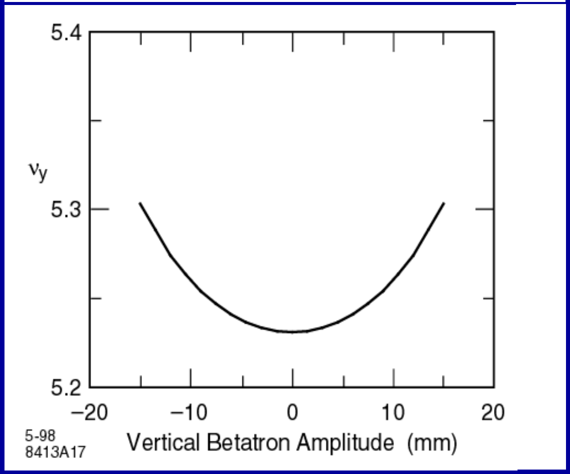
SPEAR 3 Lattice Properties

Dynamic aperture:

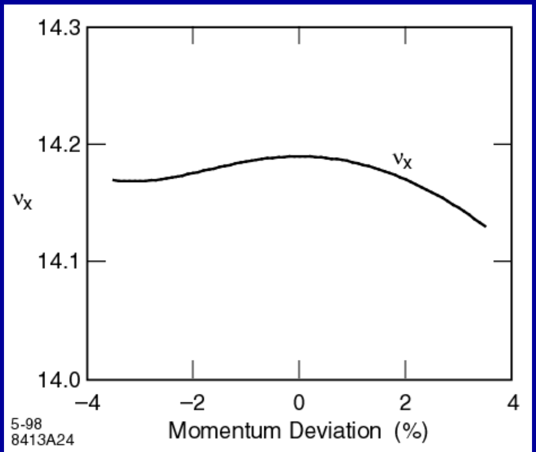


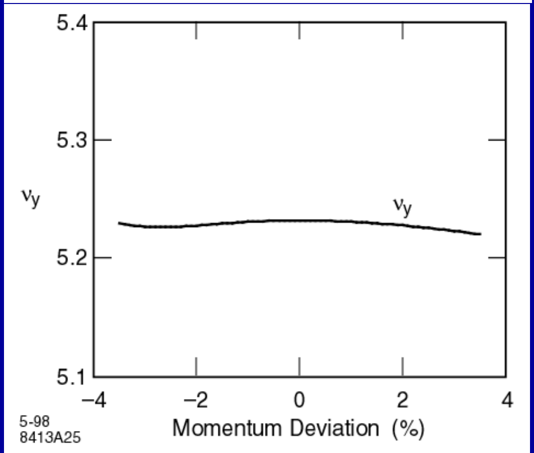
Tune with amplitude:



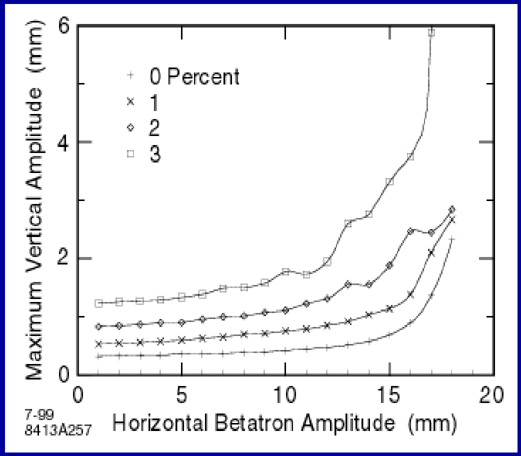


Tune with momentum:





Coupling with amplitude:



Electron Beam Lifetime

Gas Scattering: 28 h @ 500 mA

- Coulomb: **89 h**
- Bremsstrahlung: **41 h**

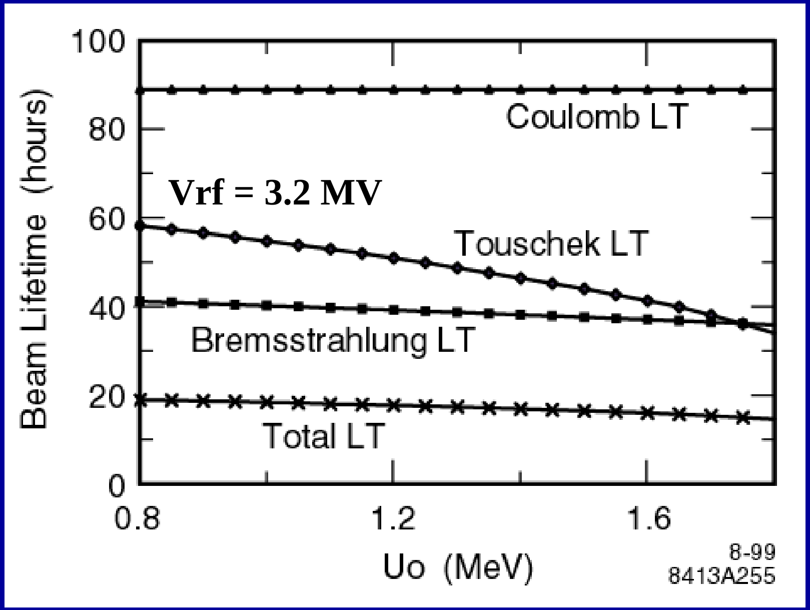
1.8 nTorr N_2-equivalent (conservative), 3% energy acceptance (not conservative)

Intrabeam Scattering: 53 h @ 500 mA

1% coupling, 3.2 MV RF, 3% energy acceptance, 279 bunches

Total: 18 h @ 500 mA

- higher if pressure <1.8 nTorr
- **45 h** @ 200 mA



Machine Parameters

	SPEAR 2	SPEAR 3
Energy	3 GeV	3 GeV
Current	100 mA	500 mA
Emittance (with IDs)	160 nm-rad	18 nm-rad
Circumference	234.126 m	234.144 m
Betatron tunes (x,y)	7.18, 5.28	14.19, 5.23
Nat. chromaticity (x,y)	-12, -14	-22, -14
Critical energy	4.8 keV	7.6 keV
RF frequency	358.533 MHz	476.300 MHz
RF gap voltage	1.6 MV	3.2 MV
Synchrotron tune	.019	.007
Momentum compact.	.015	.0011
Energy spread	0.07%	0.1%
Average ring pressure	1 nTorr	1.8 nTorr
Lifetime at max. curr.	~40 h	~20 h
Beam size (x,y) - ID	2.0, .05 mm rms	0.43,.03 mm rms
Beam size (x,y) - bend	.79, .20 mm rms	.17, .05 mm rms
Bunch length	75 ps rms (23 mm)	17 ps rms (5 mm)
Straight sections	12 x 3.1 m 4 x 2.7 m 2 x 4.7 m	12 x 3.3 m 4 x 4.8 m 2 x 7.6 m

SPEAR 3 Design (cont'd)

In-house Technology (PEP-II B-Factory/Richter)

Magnet Design, Manufacture & Measure

Power Supply Design

MCOR30

Kicker pulsers (NLC)

Copper Vacuum Chamber

e-beam welder, masks, bellows, etc

RF

cavities, tube(s), controls, personnel

Communications

EPICS, bitbus, cards, etc

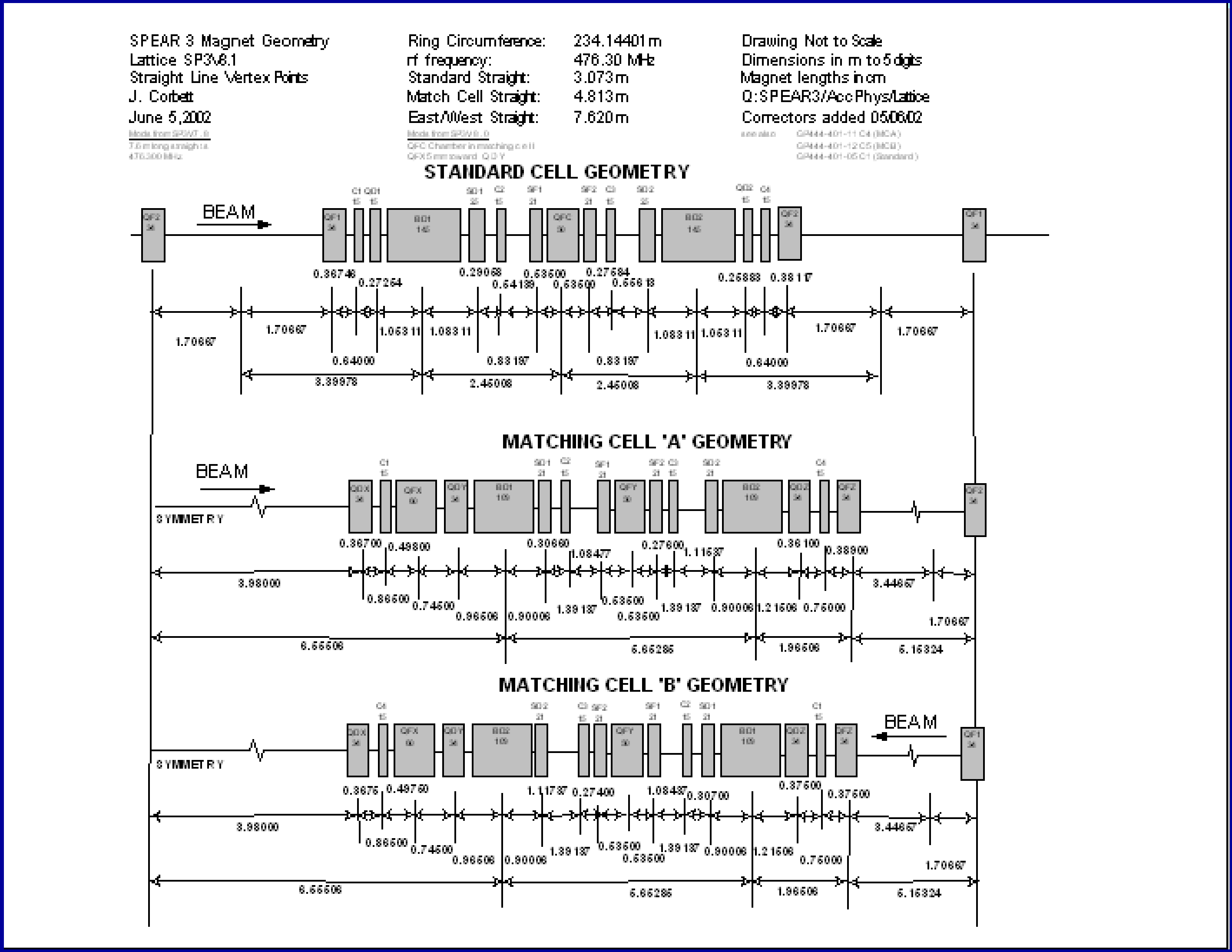
Operational reliability, performance

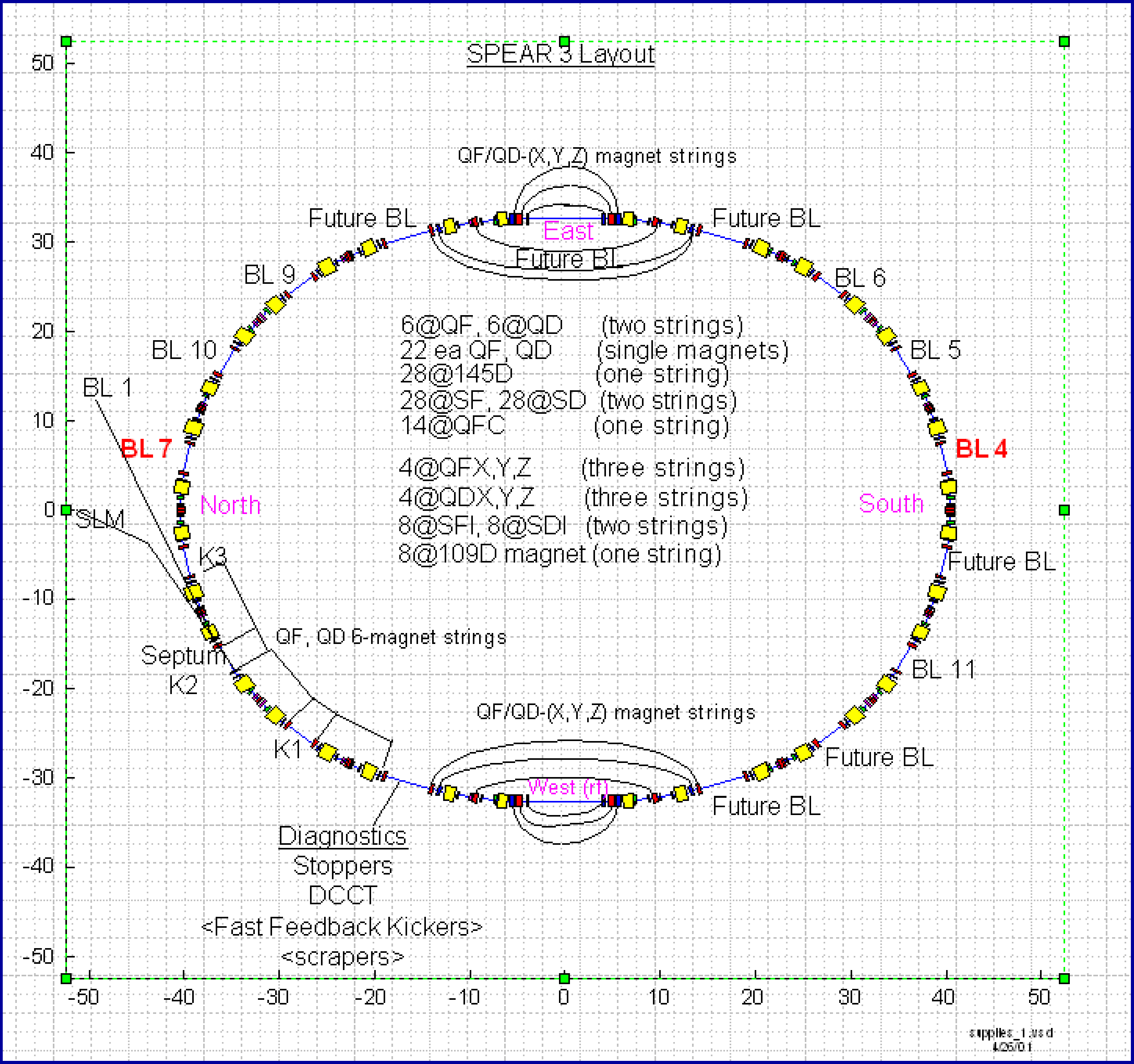
at-energy injection

reliable, effective controls, power supplies, etc

high performance diagnostics

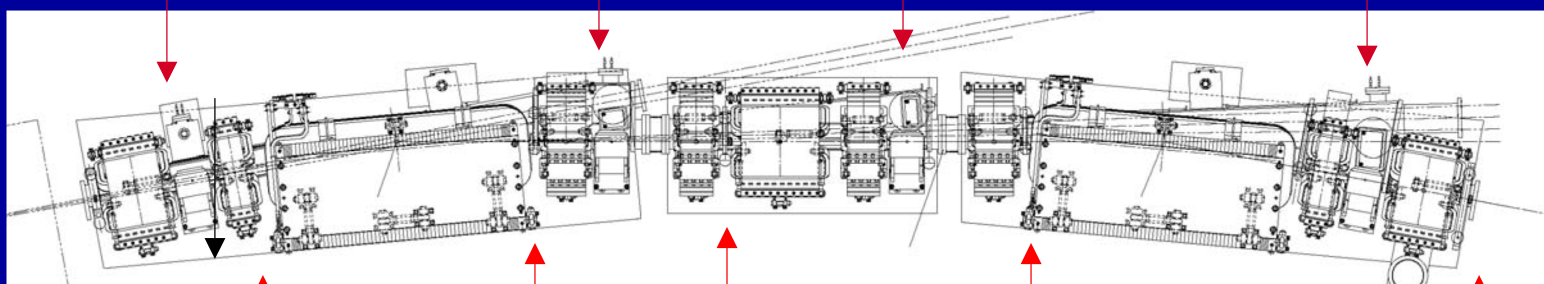
Magnet Nomenclature




SPEAR 3 Layout
QF/QD-(X,Y,Z) magnet strings
Future BL
East
Future BL
Future BL
BL 9
BL 6
BL 10
BL 5
BL 1
BL 7
BL 4
North
South
SLM
K3
Future BL
6@QF, 6@QD (two strings)
22 ea QF, QD (single magnets)
28@145D (one string)
28@SF, 28@SD (two strings)
14@QFC (one string)
4@QFX,Y,Z (three strings)
4@QDX,Y,Z (three strings)
8@SFI, 8@SDI (two strings)
8@109D magnet (one string)
QF, QD 6-magnet strings
Septum
K2
BL 11
QF/QD-(X,Y,Z) magnet strings
K1
Future BL
West (rf)
Future BL
Diagnostics
Stoppers
DCCT
<Fast Feedback Kickers>
<scrapers>
50
40
30
20
10
0
-10
-20
-30
-40
-50
-50
-40
-30
-20
-10
0
10
20
30
40
50

BPM and Corrector Locations (std cell)

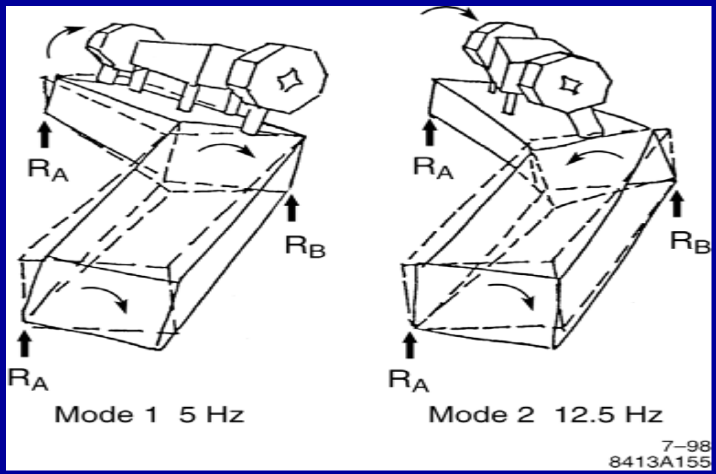
Corrector locations (72 total 54 X & 54 Y)

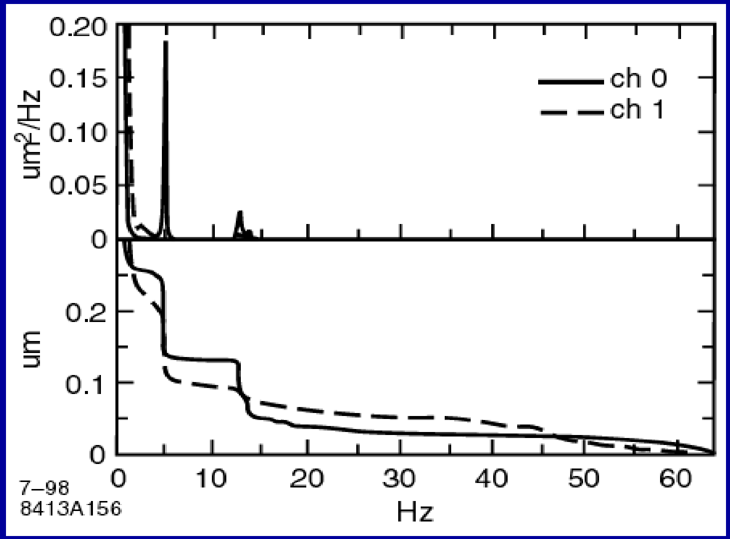


BPM locations (104 total)

Magnet Girders

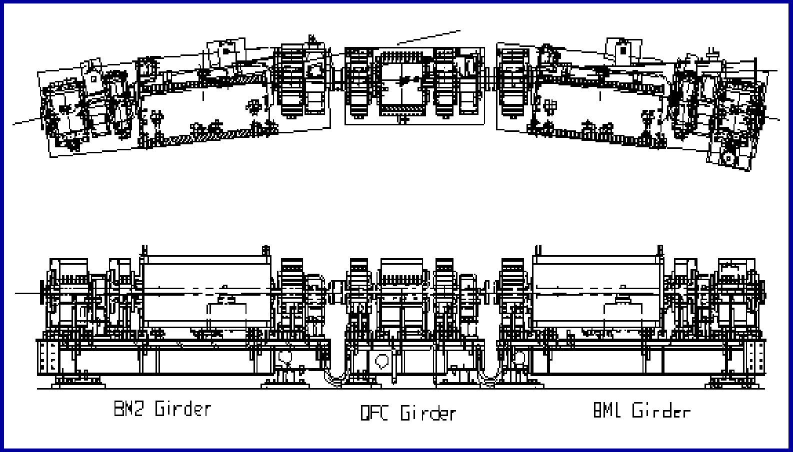
Concrete girder motion



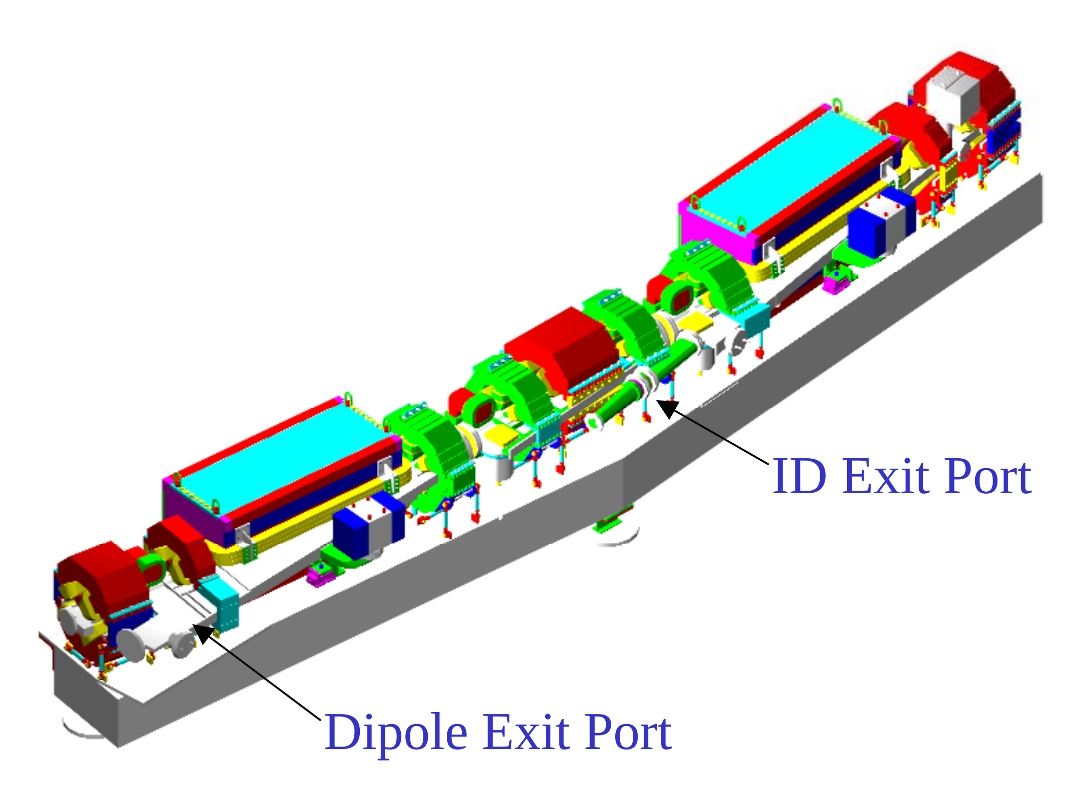


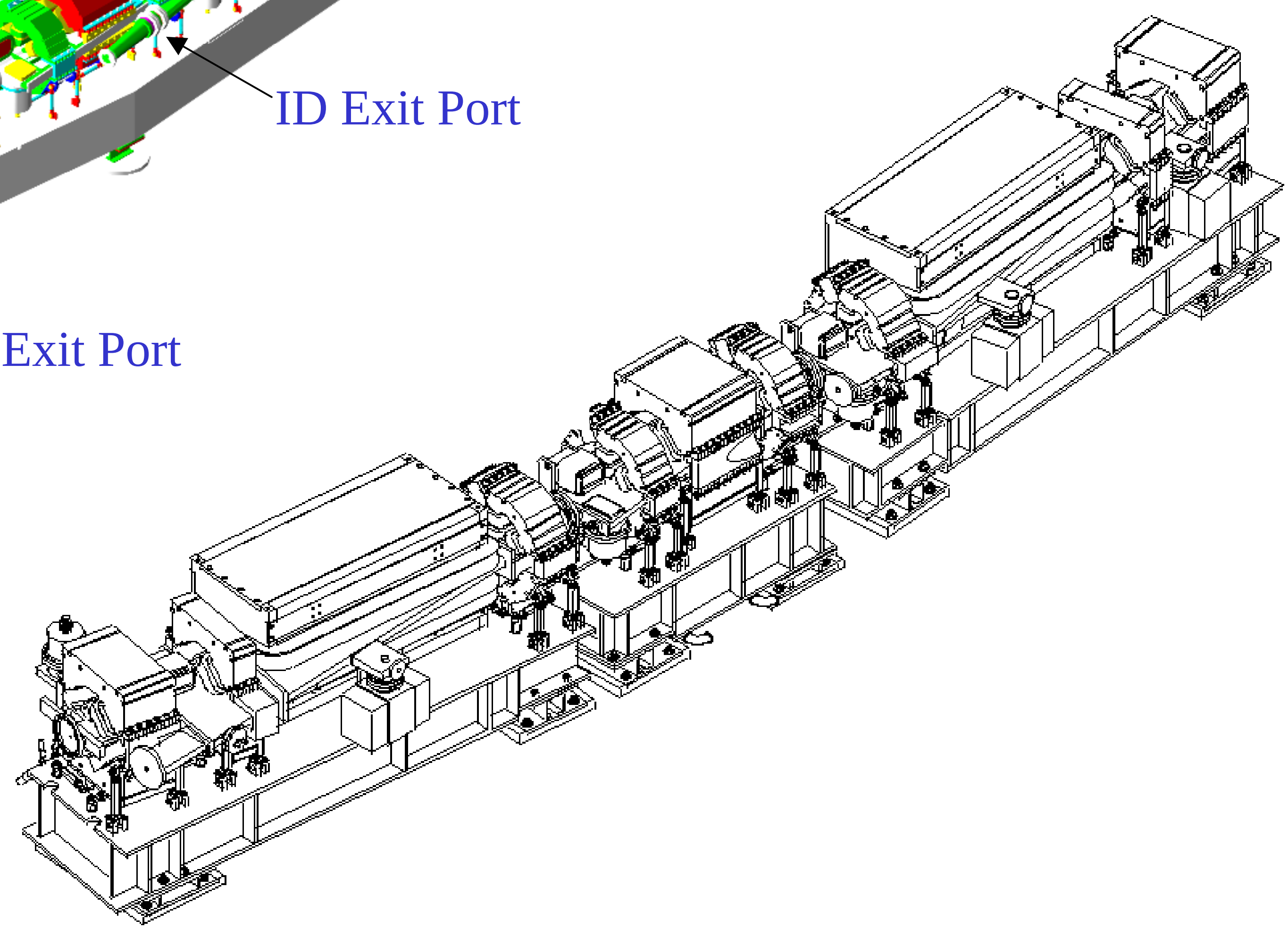
SPEAR 3 - Option 1

SPEAR 3 - Option 2 (new concrete floor)

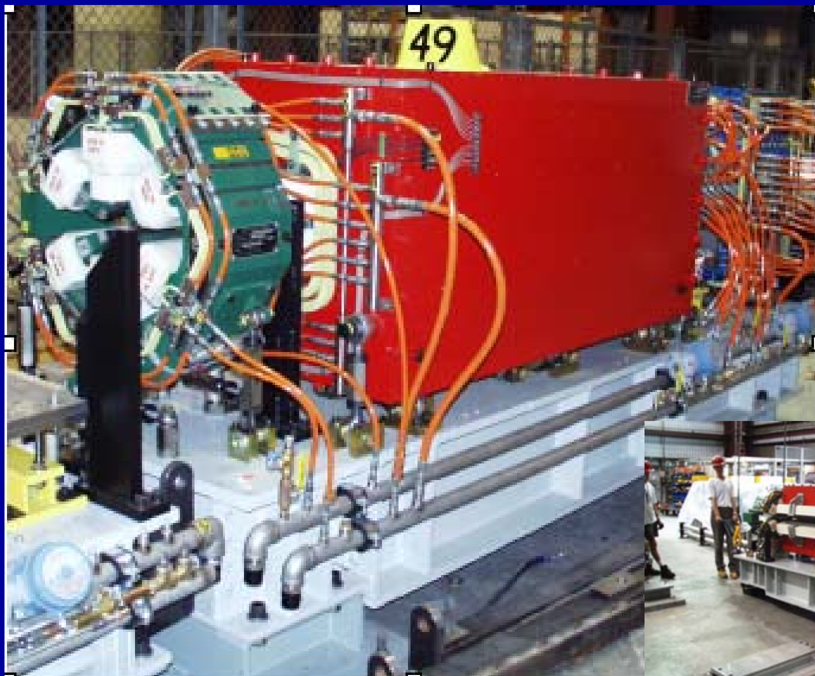


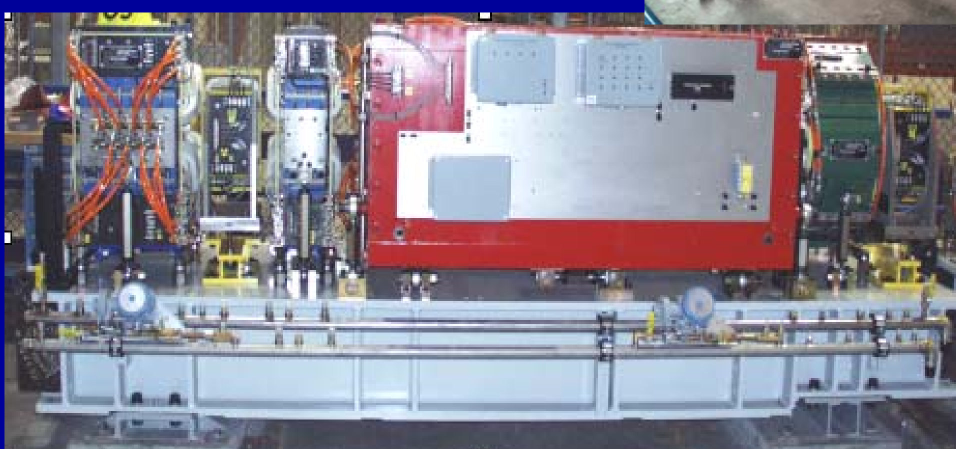
'Standard' Cells (North/South arcs)



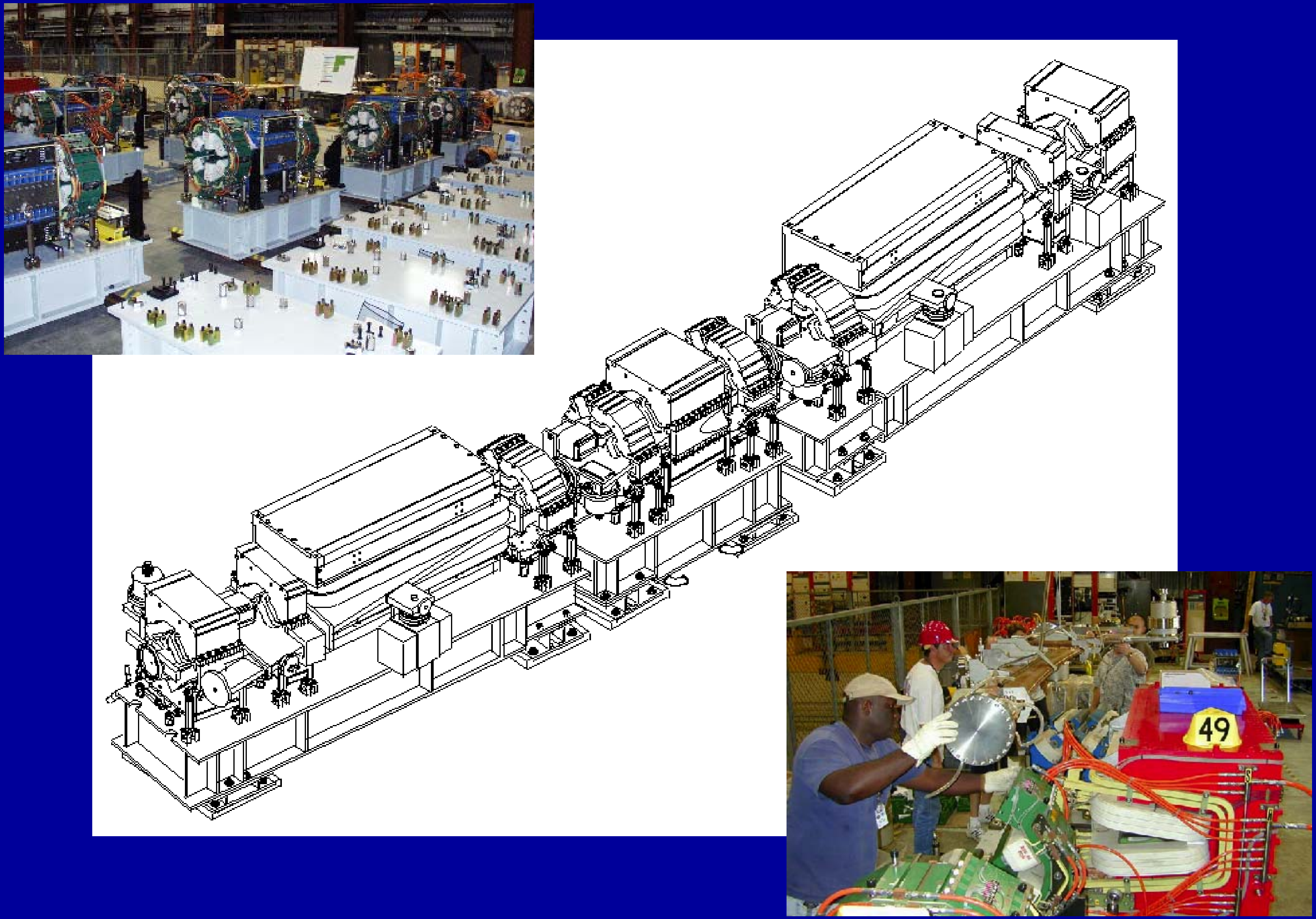


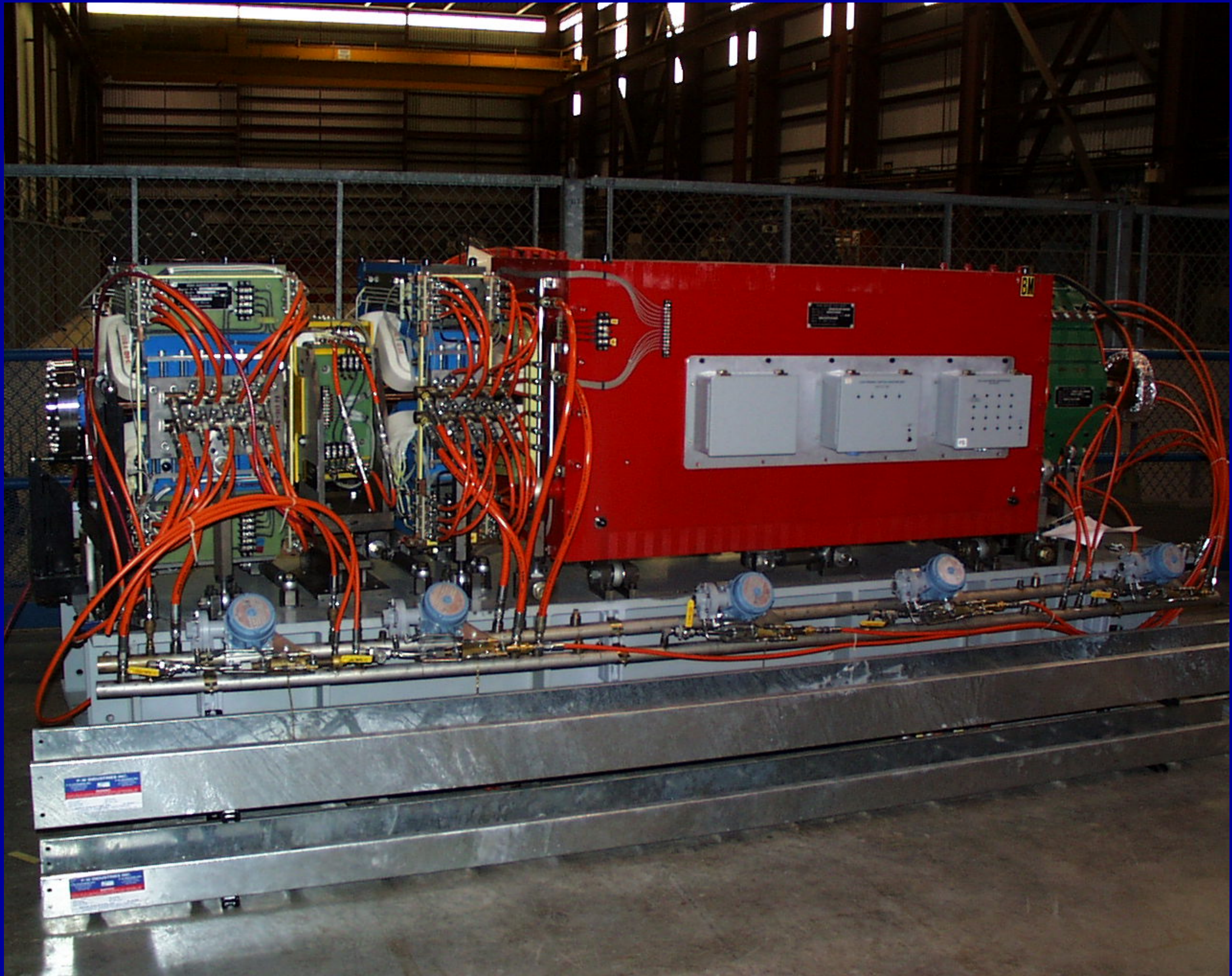
Magnet Raft Assembly

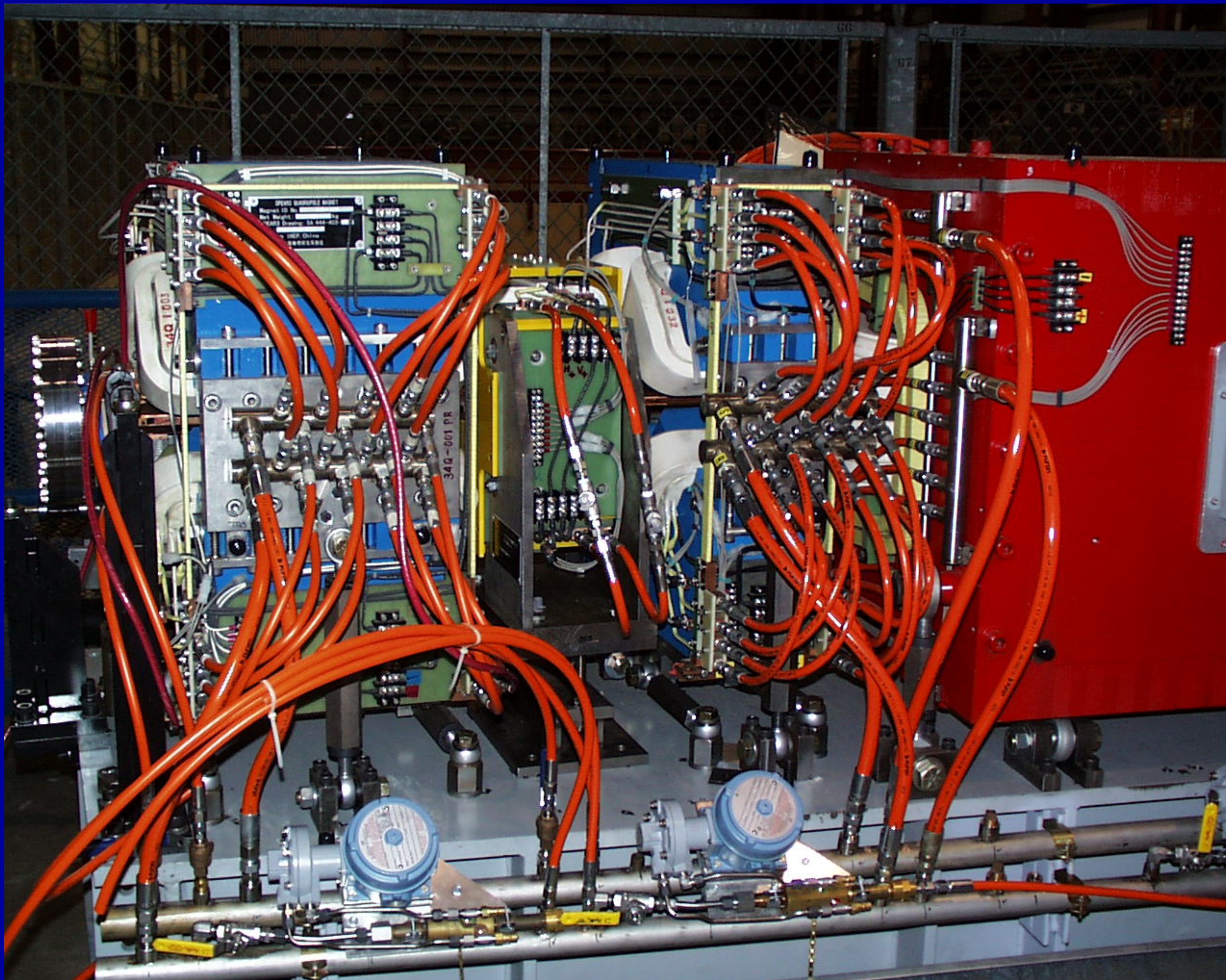




Magnets and Supports

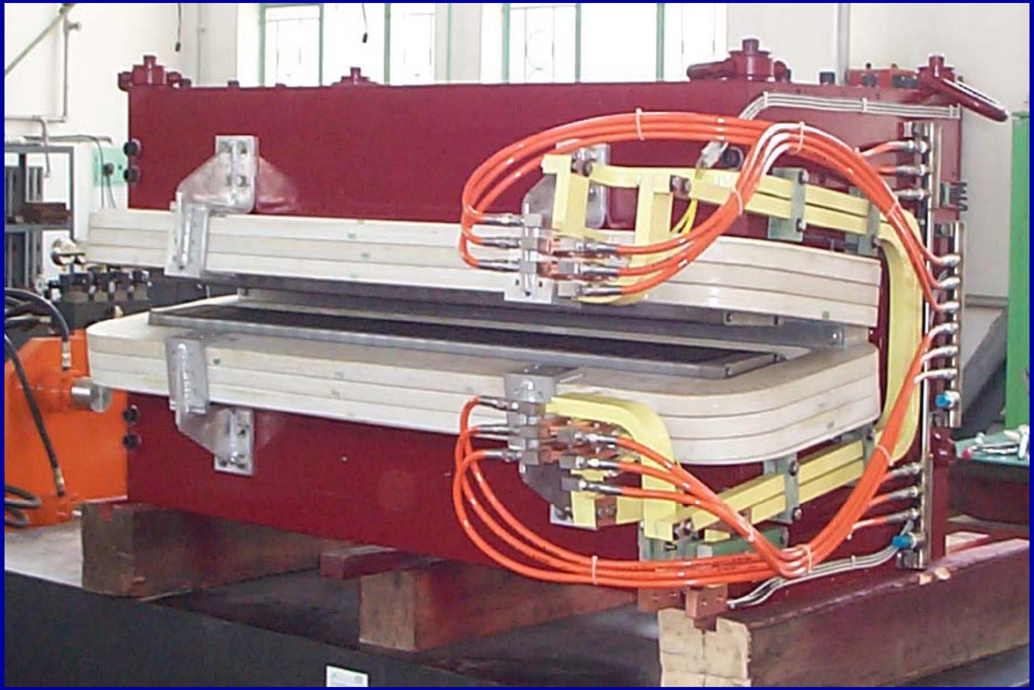




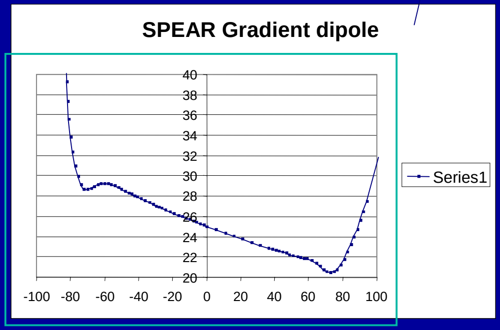


Magnet Production at IHEP, Peking

Gradient Dipoles



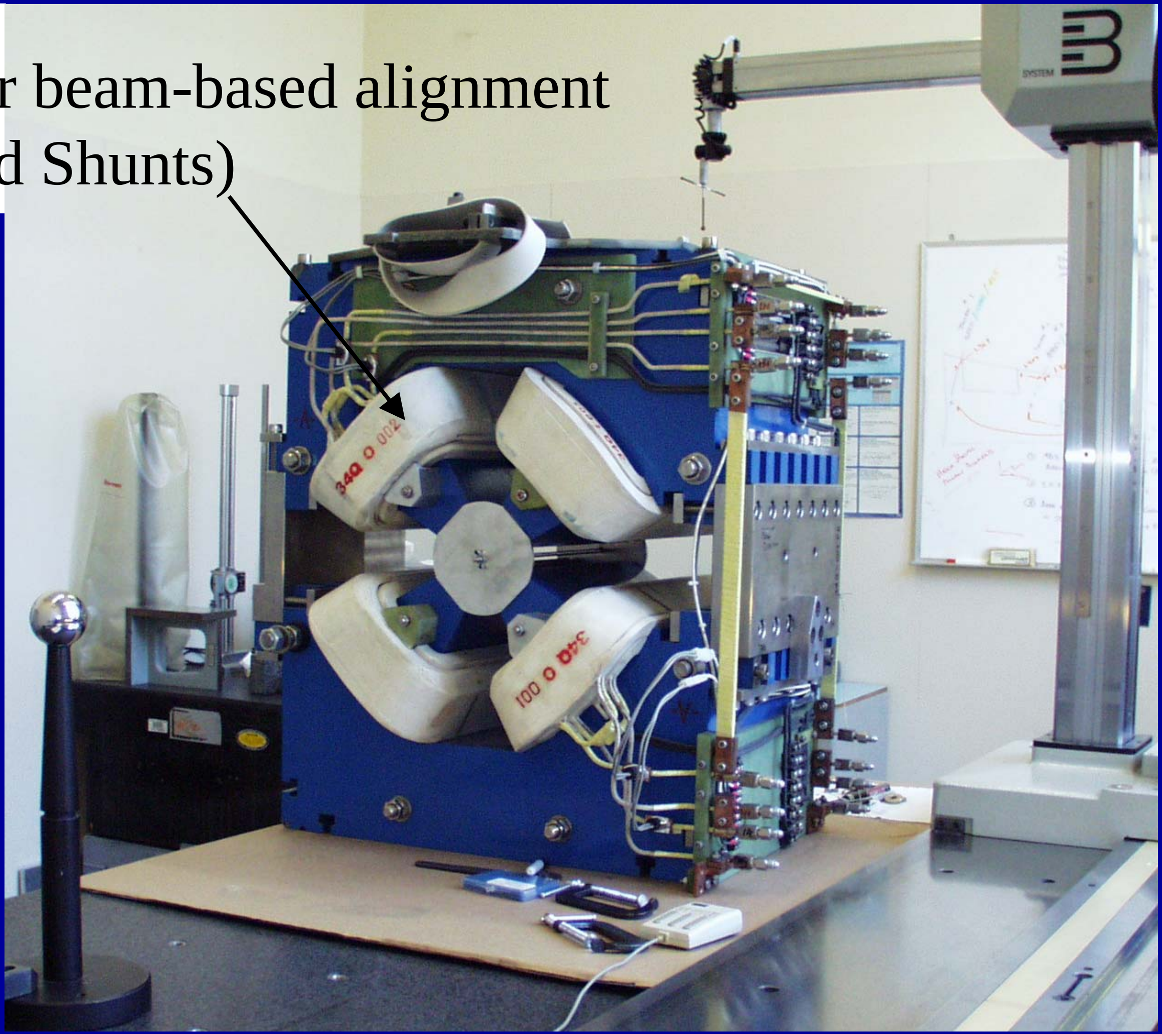
pole chamfer



- 1.42 T + 3.63 T/m @ 3 GeV
- 1.45 m long, 50 mm aperture
- 2% trim coils
- 6-strut supports
- 32 ea. full-length
- 4 ea. 3/4-length

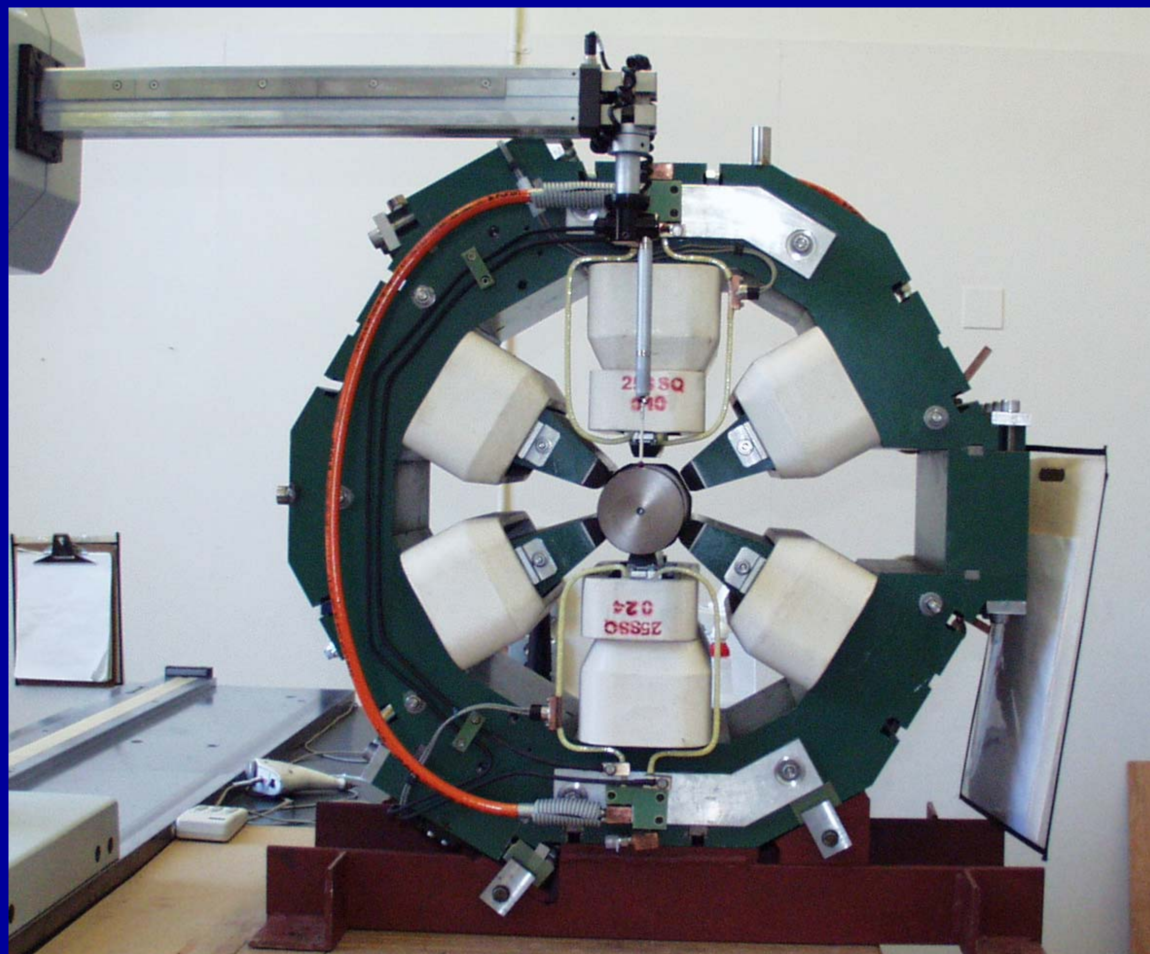
Quadrupole Fiducialization on SLAC CMM

Trim Coil for beam-based alignment
(Quad Shunts)



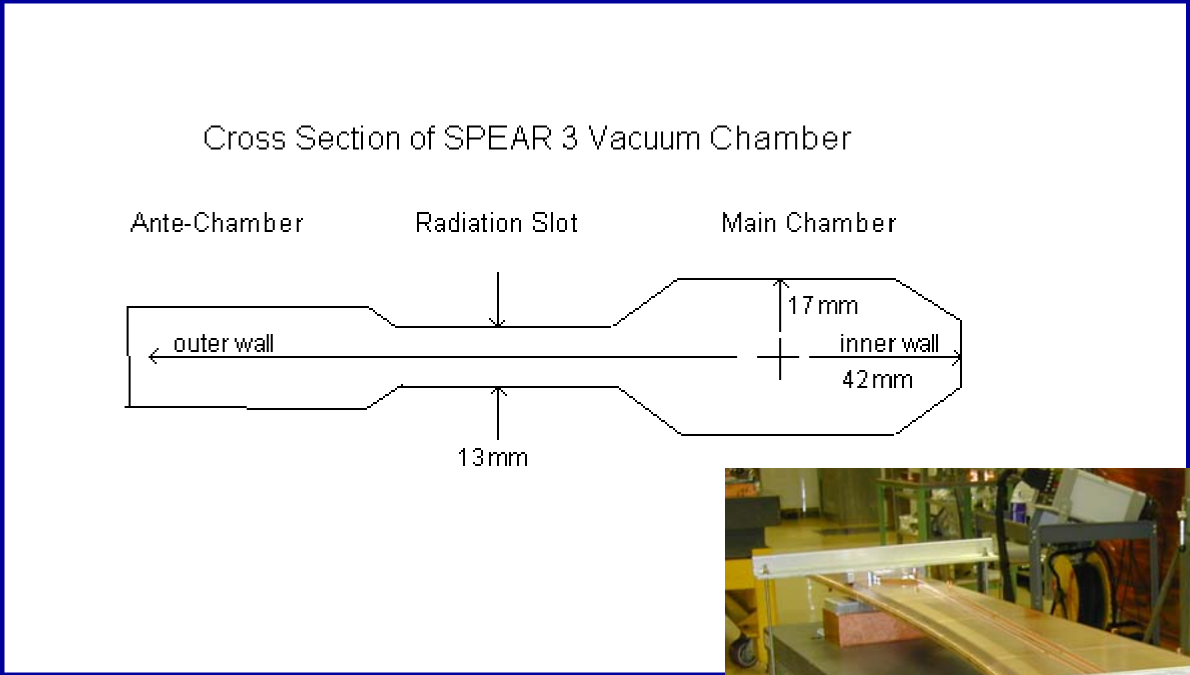
Sextupole Fiducialization on SLAC CMM

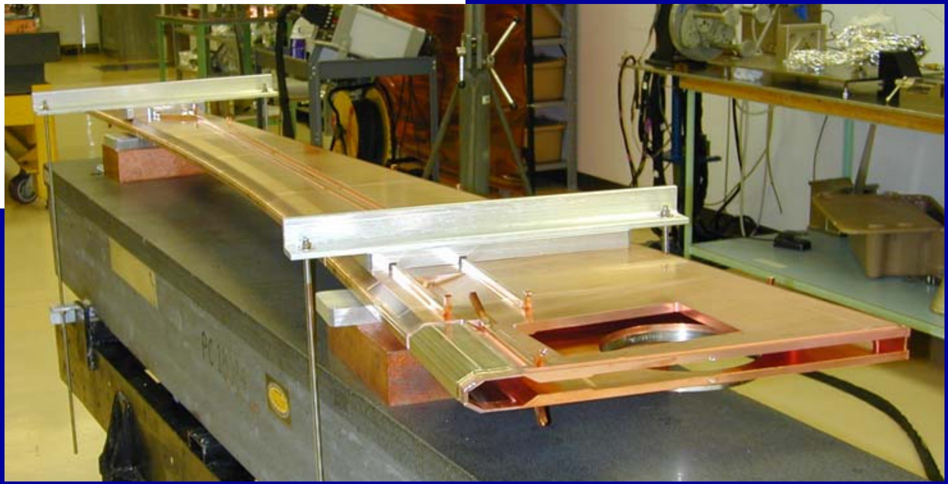
'Wagonwheel'



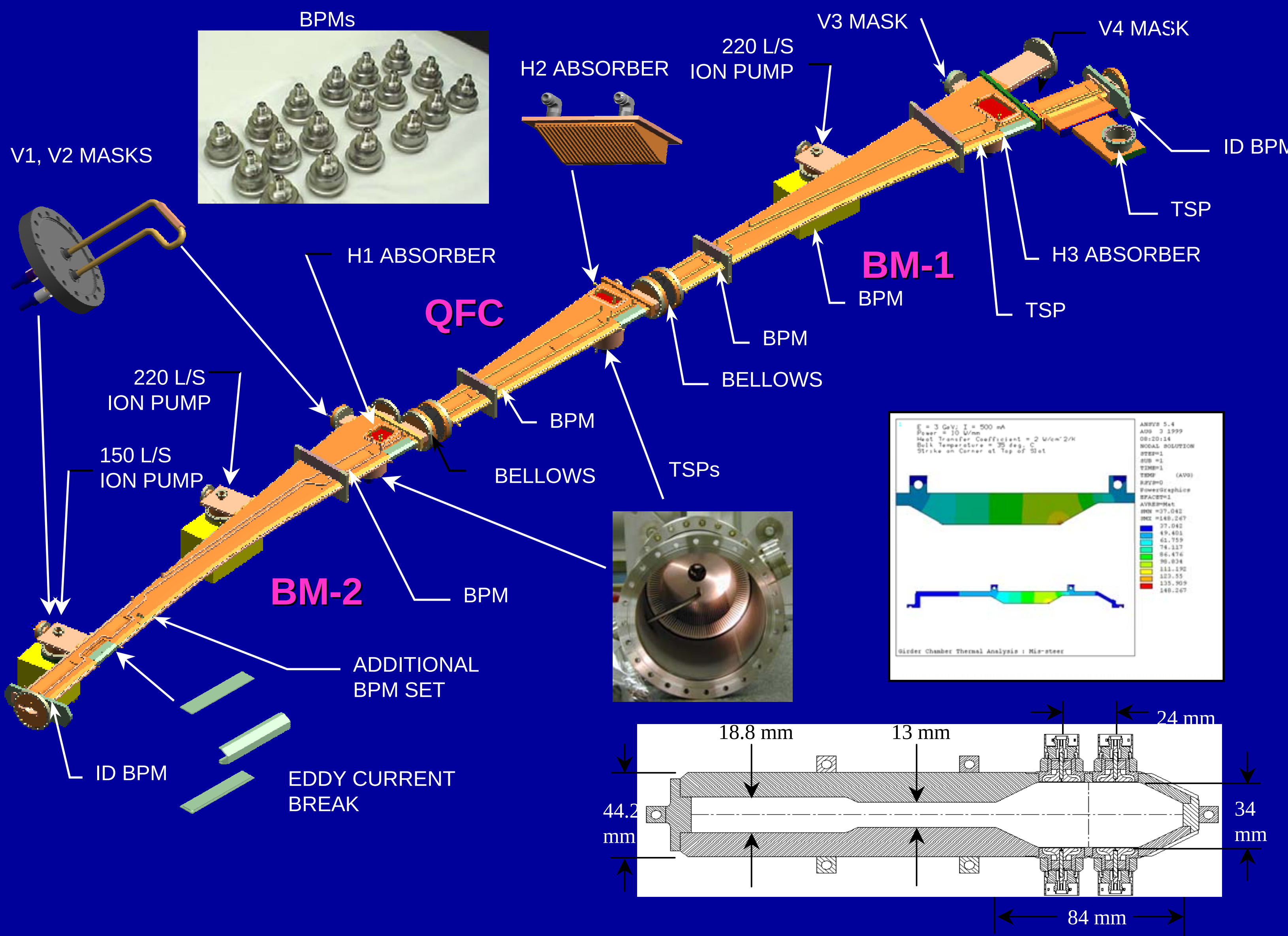
Copper Vacuum Chamber

Passively safe to dipole radiation >500 mA
Lower resistive wall impedance
High thermal conductivity -> Beam Stability
SLAC In-house construction

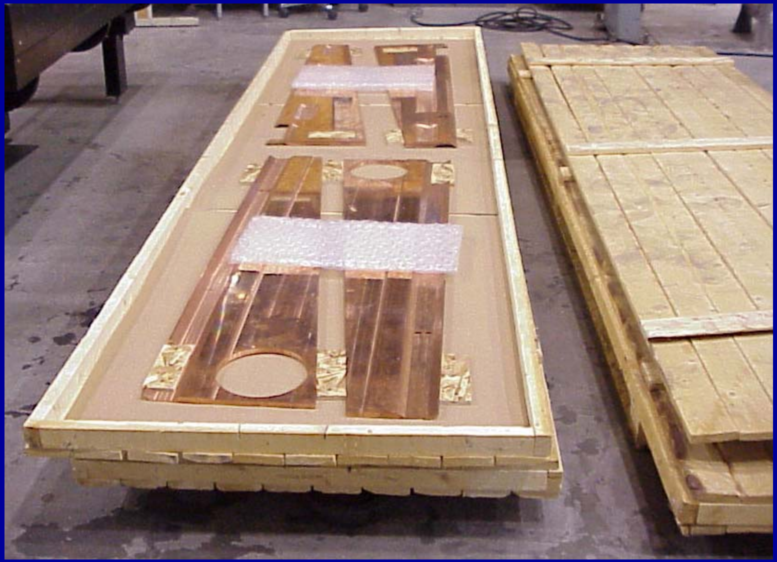




Vacuum System Schematic

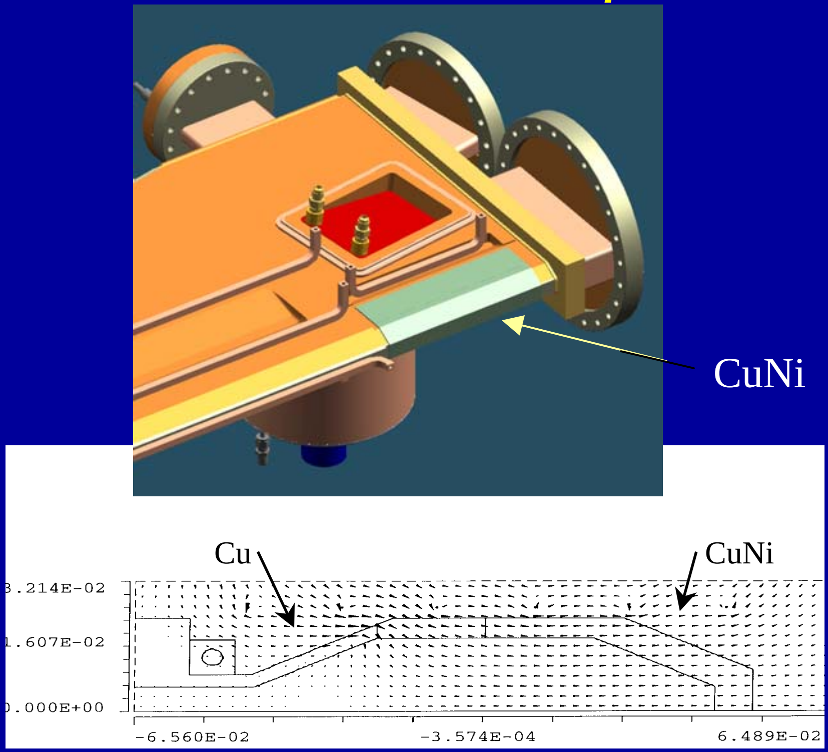


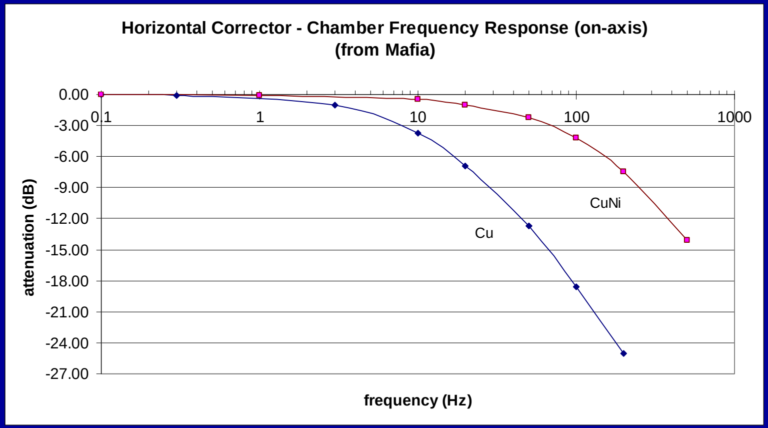
Clamshell Chamber Fabrication

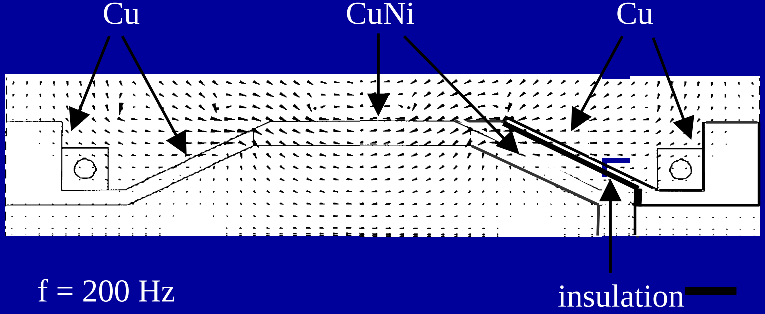


'CuNi' Eddy Current Break

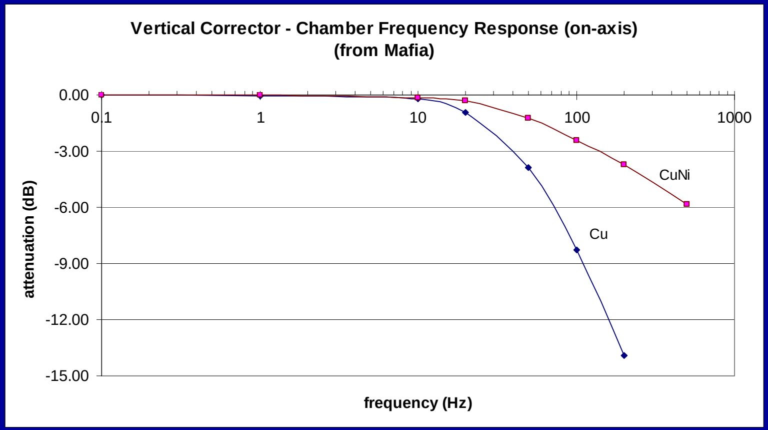
-allows fast corrector field penetration-

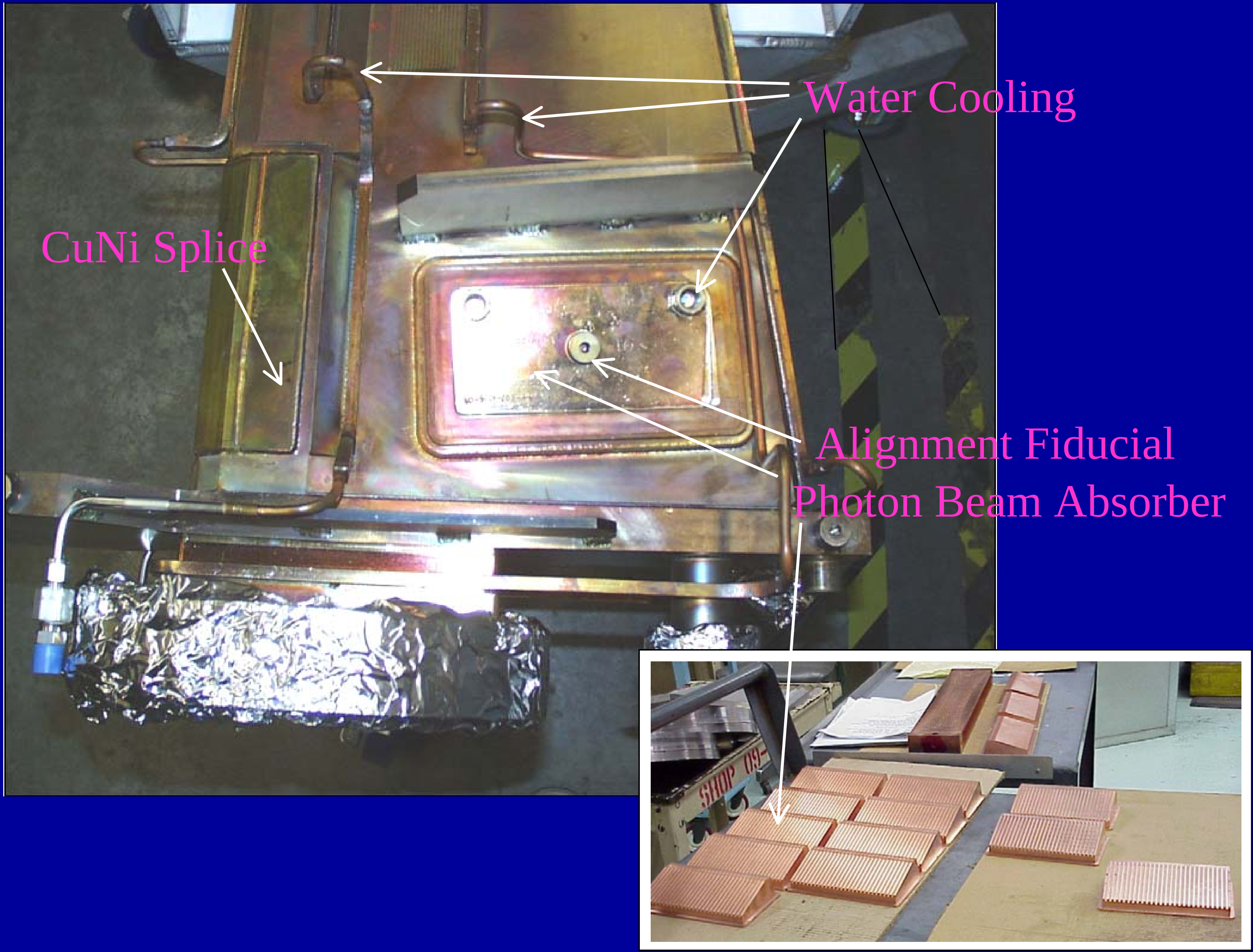




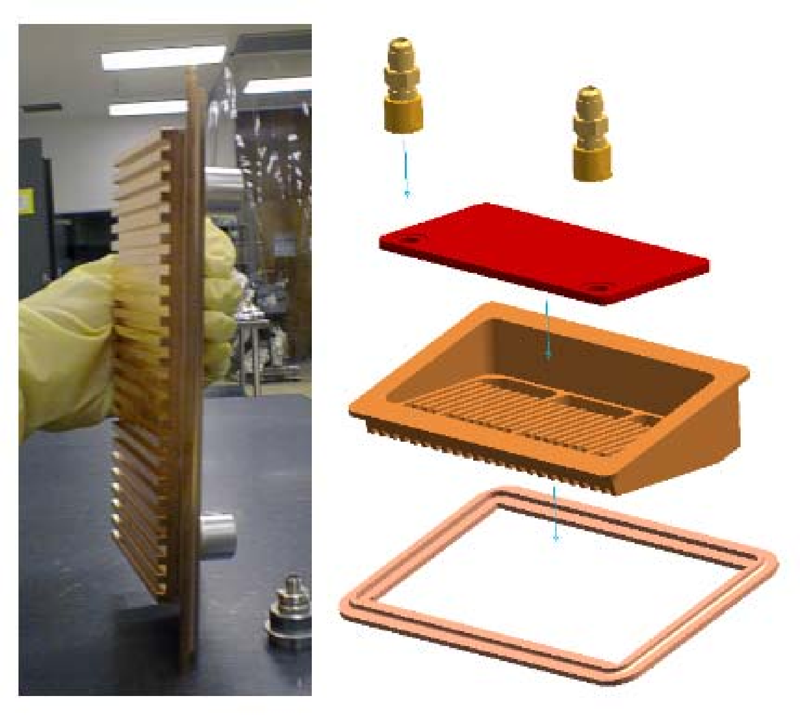


f = 200 Hz




Water Cooling
CuNi Splice
Alignment Fiducial
Photon Beam Absorber

Vacuum System (cont'd)

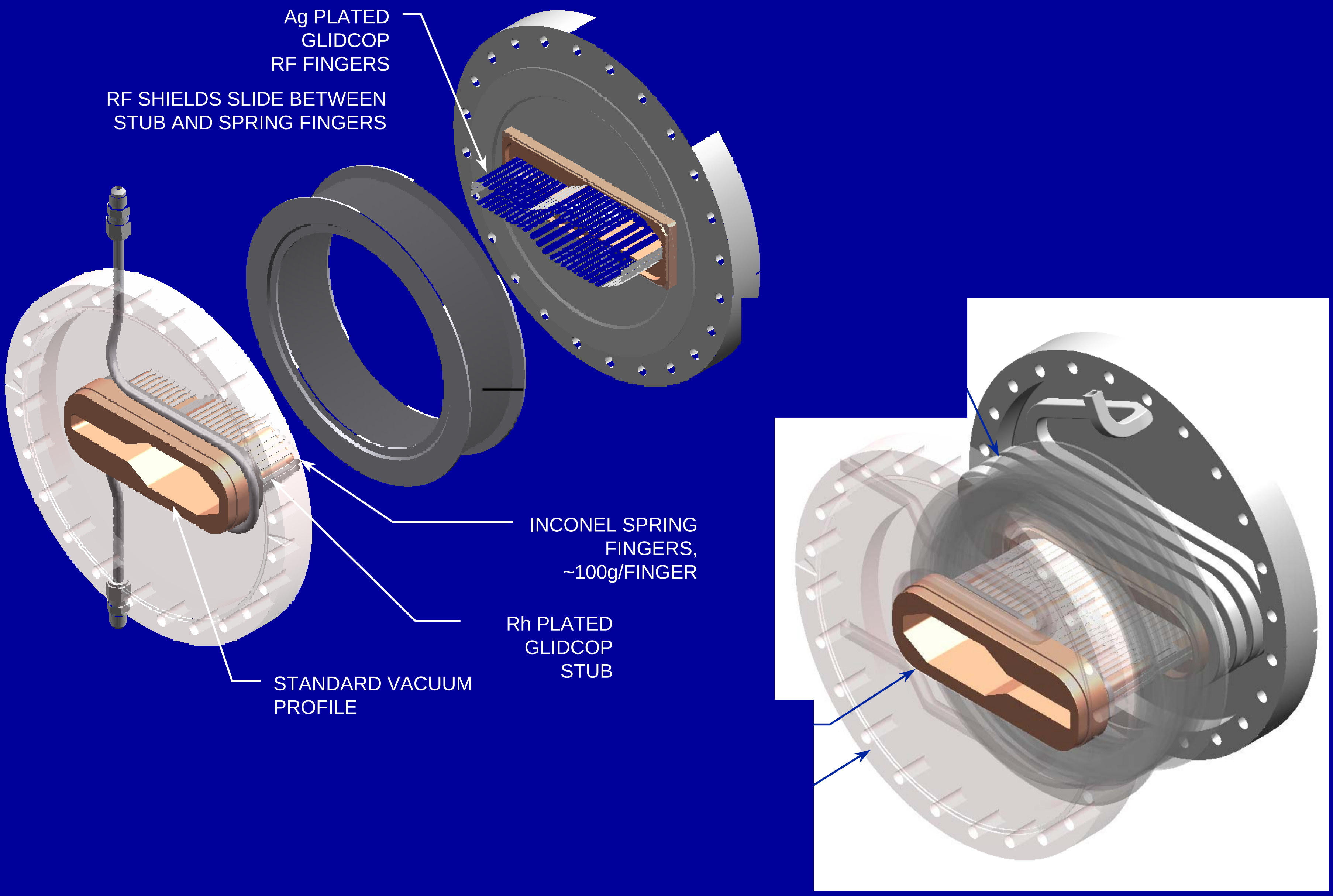


BM-1 bakeout

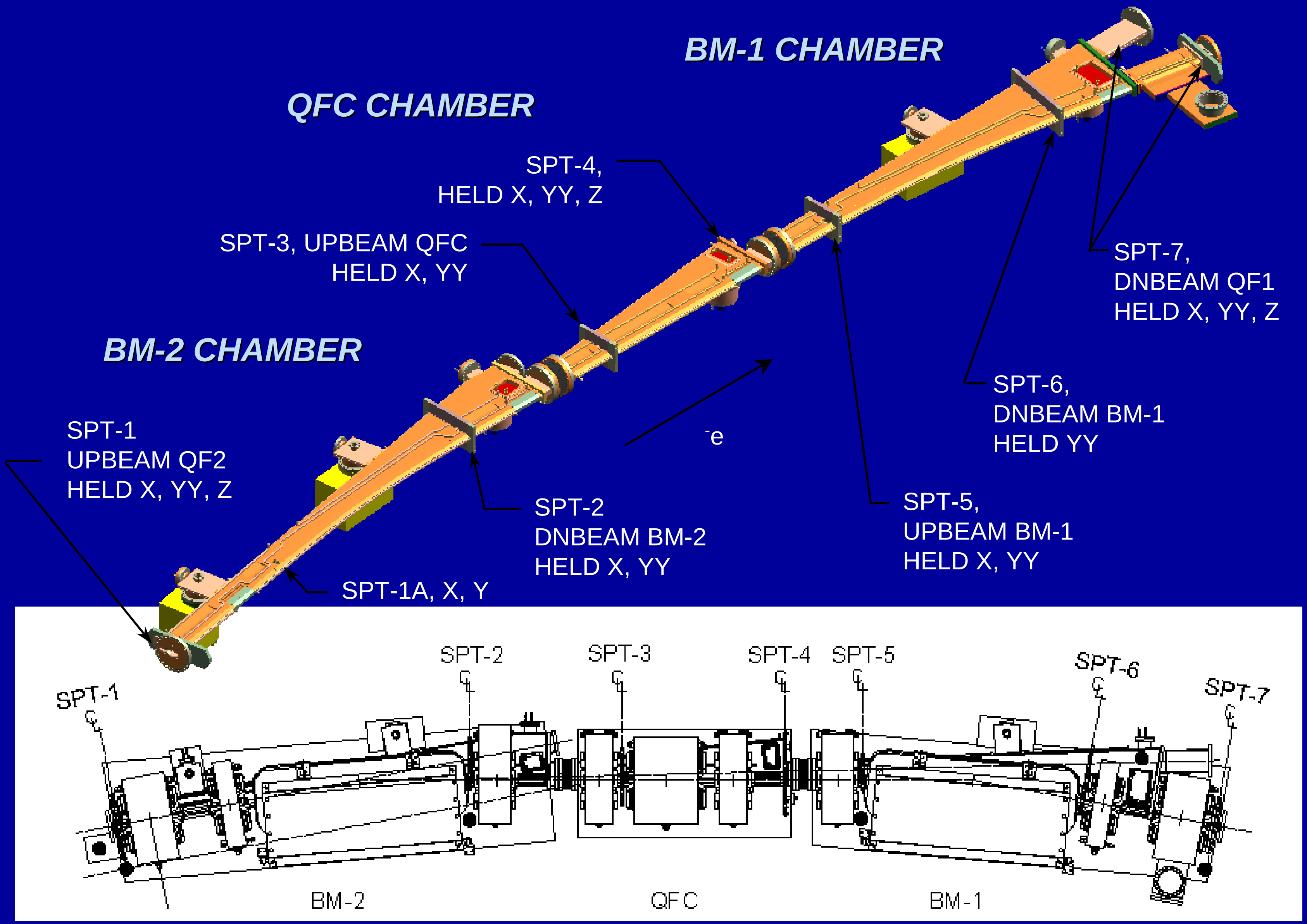
BM-1 chamber installation

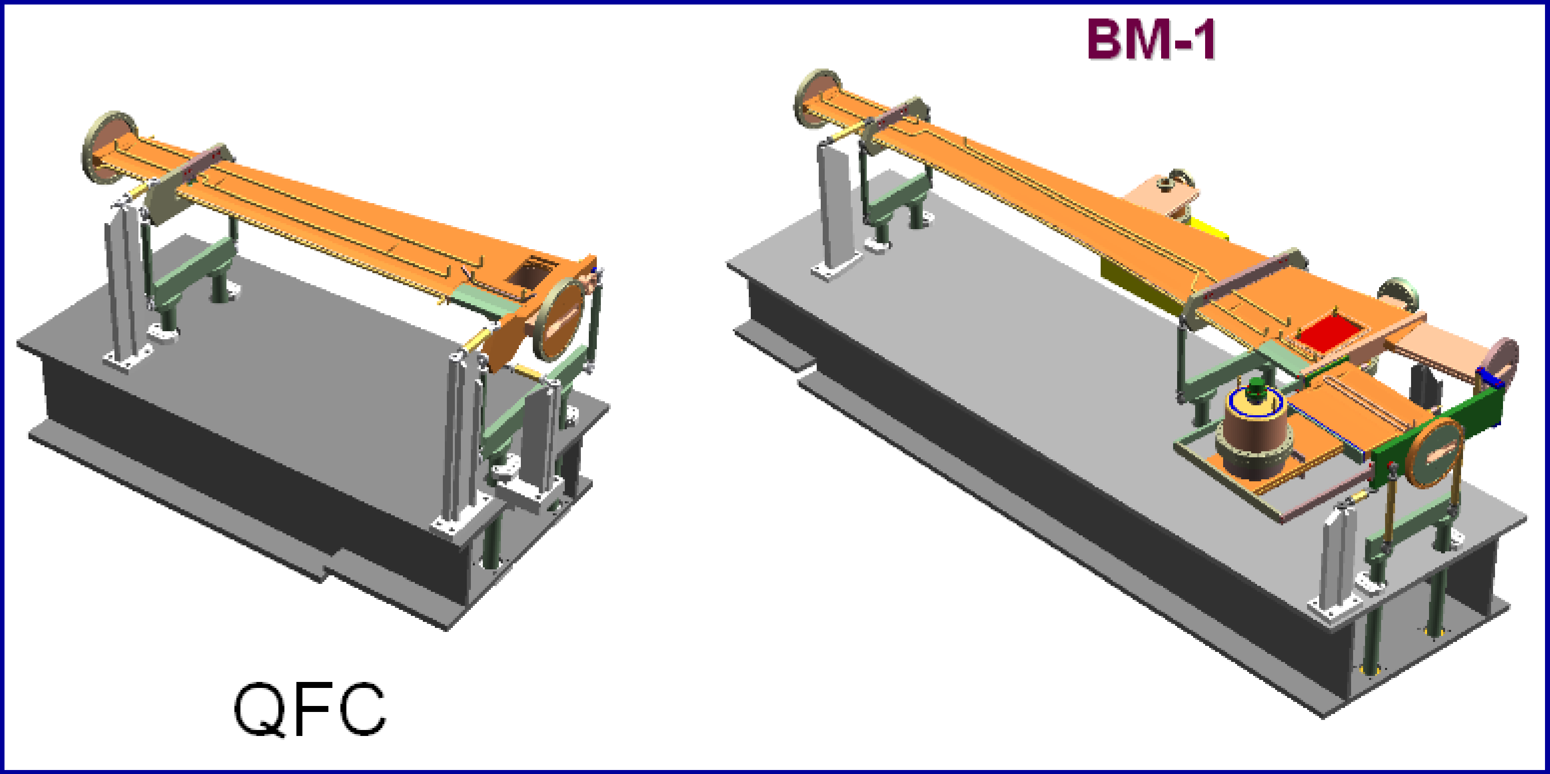
Fiducialization of BM-2 chamber

SPEAR 3 Bellows Modules (PEP-II)

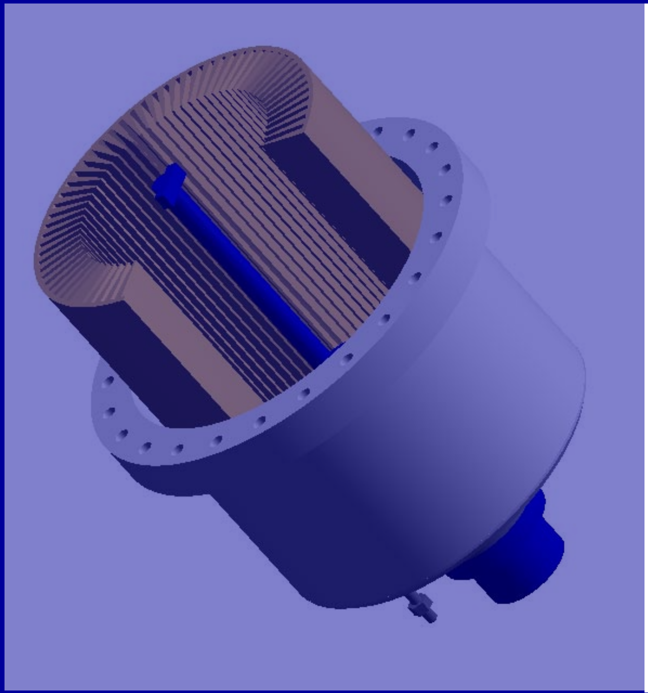


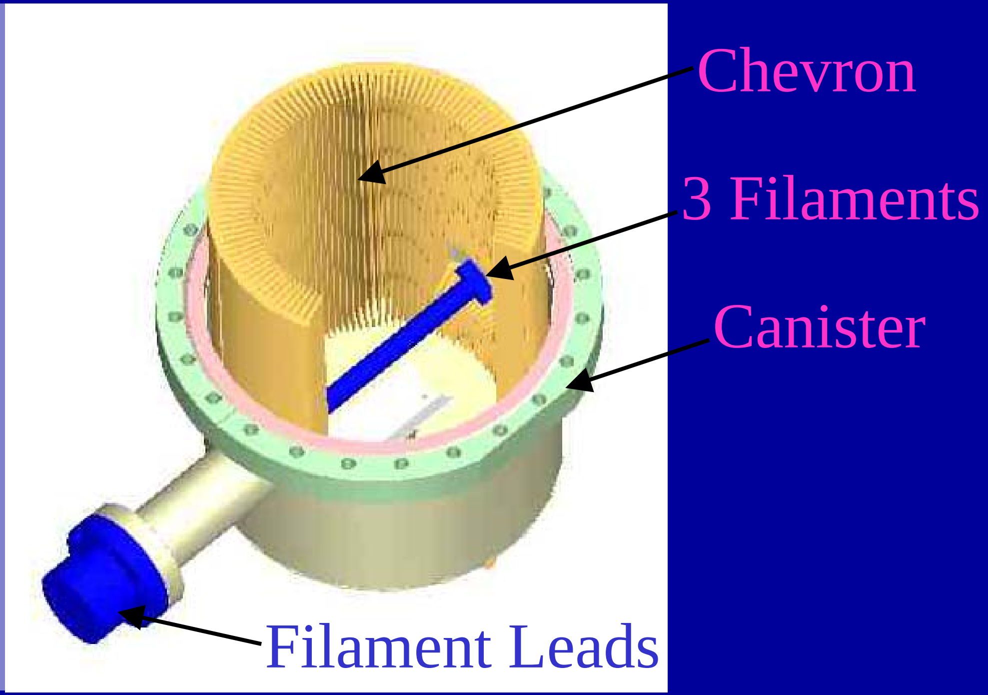
Vacuum Chamber Supports

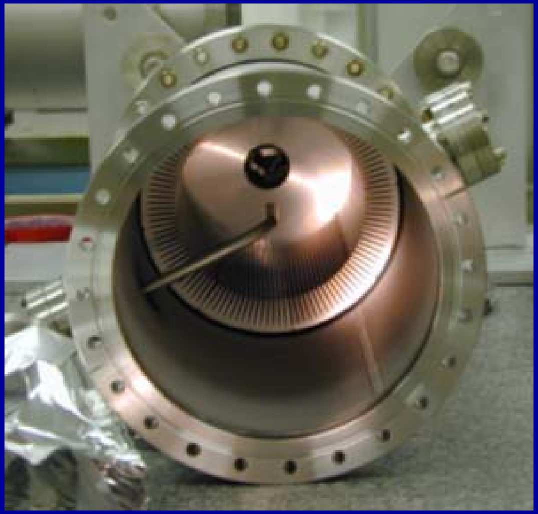


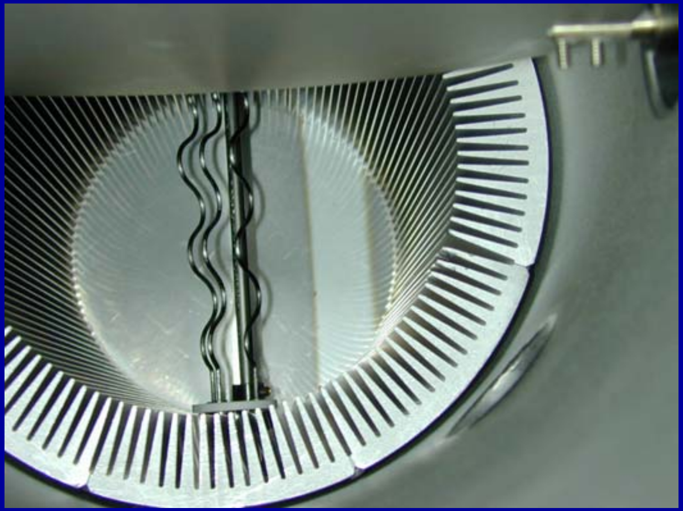

BM-1
QFC

Titanium Sublimation Pumps



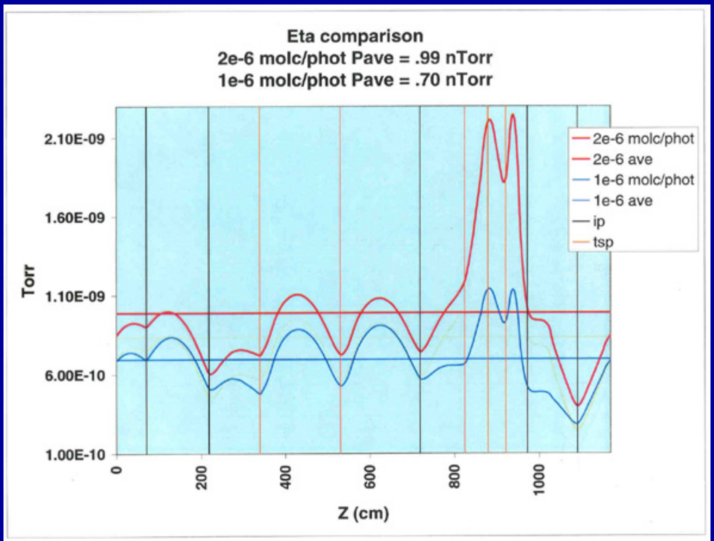


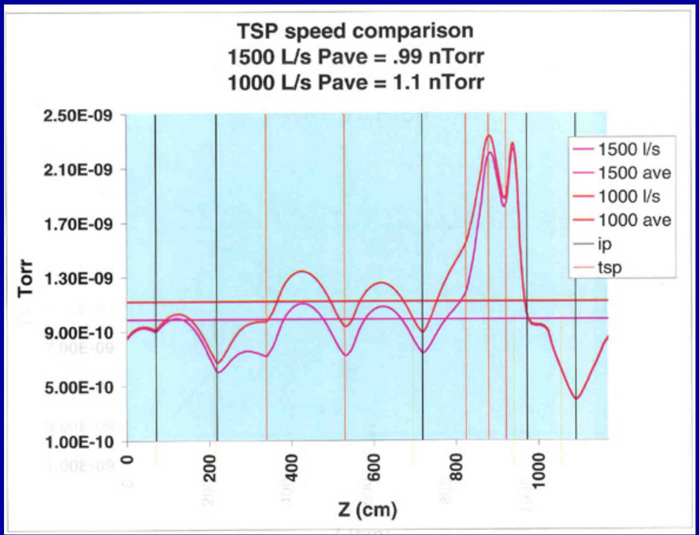




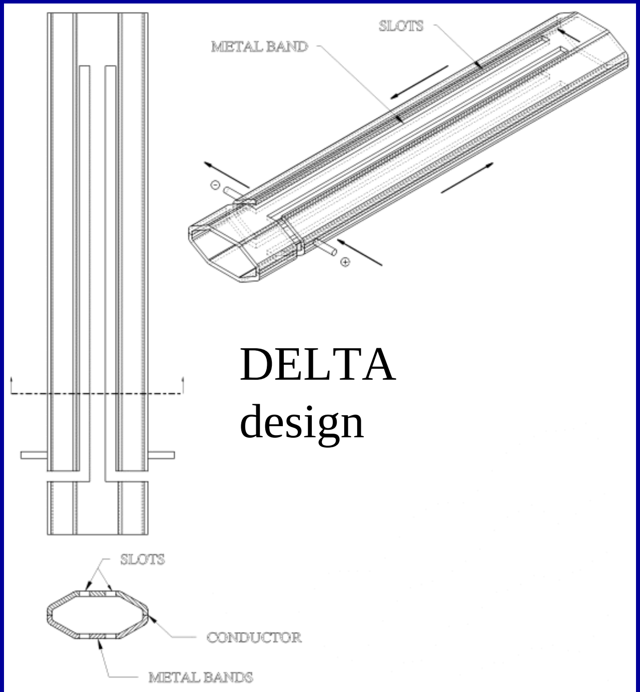
Titanium Sublimation Pumps (cont'd)

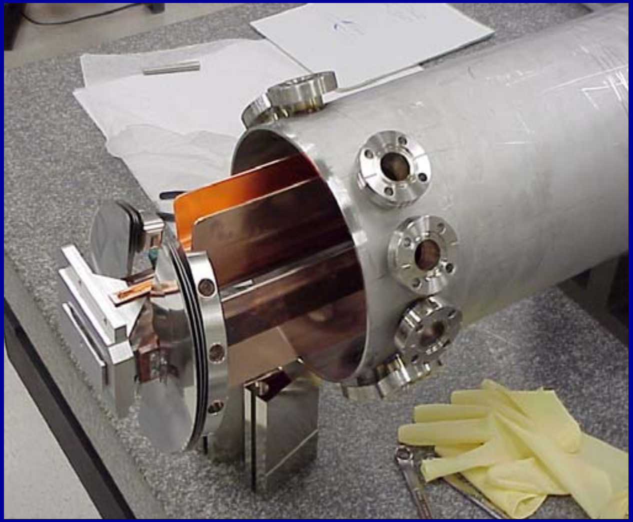
- Testing
  - Filament lifetime,
    - 150 – 400 flashes per filament,
    - 3 filaments per pump, 10 year lifetime.
  - Engineering estimate based on η=2.0E-6 is ~ 4 days at 500mA,
    - PEP-II and ALS - estimates are conservative by factor of 3-4.
      - Minimal data for η rates with > 100 A-hr, gas species, chemistry, pump interaction.
  - <P> < 1.8 nTorr (requirement) at 500 mA,
    - Calculations assume a 75% pumping speed

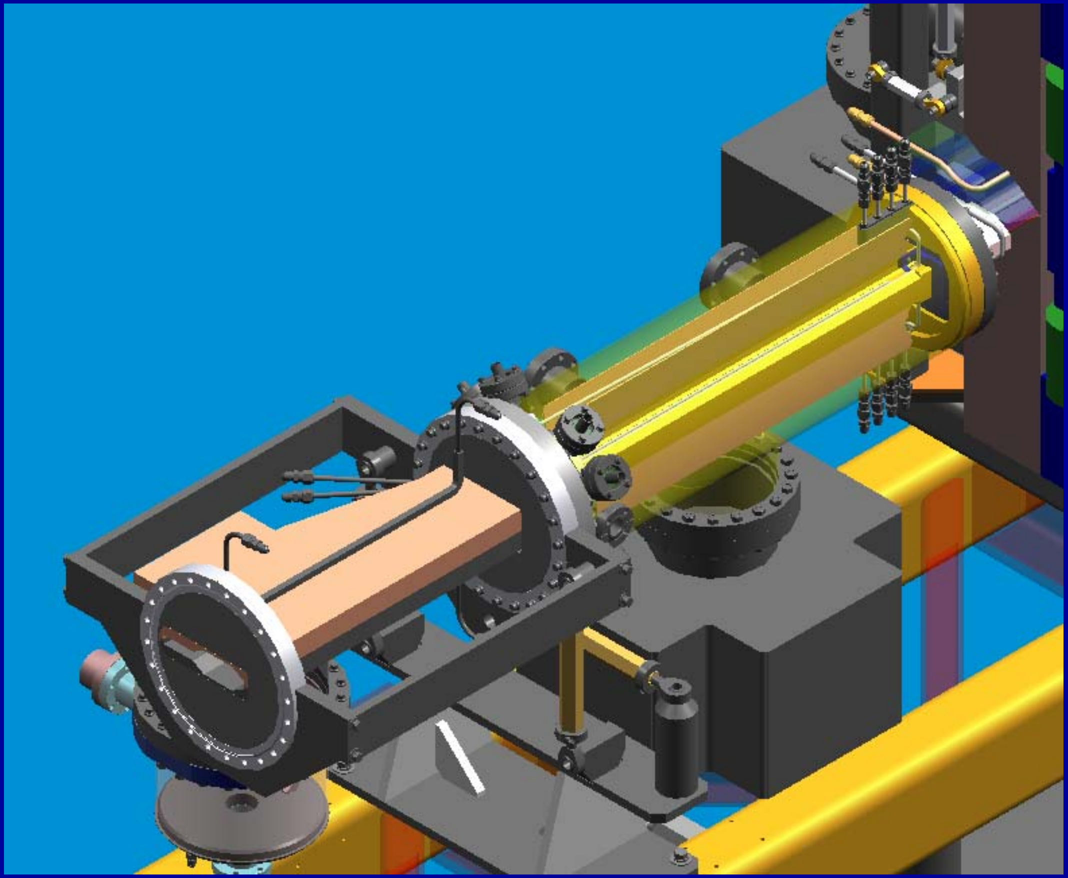




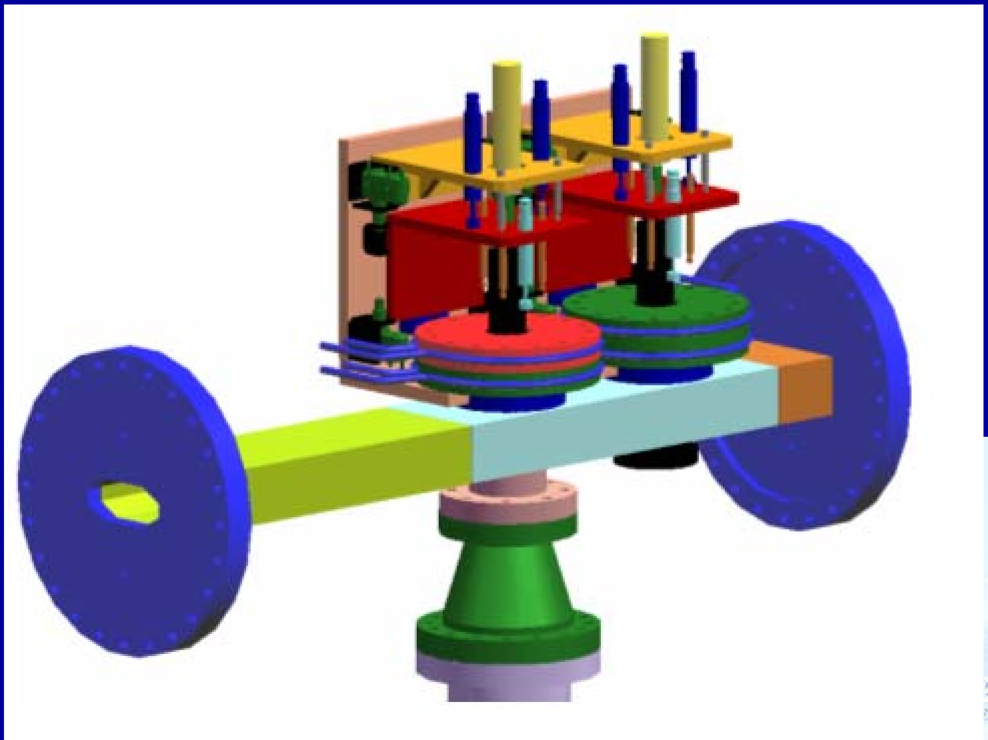
Stripline Injection Kickers







SPEAR 3 Stopper Module

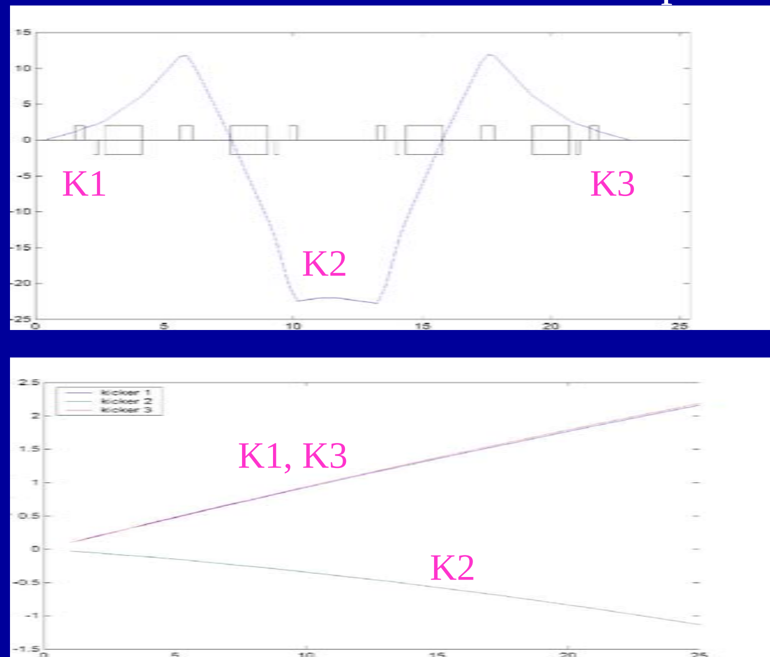


Injection Kickers (cont'd)

Operational goal: -22 mm at 3.0 Gev
10% margin: kick to -25 mm septum wall
10% margin: operate at 3.3 GeV
Low impedance DELTA design

Beam Displacement (mm)

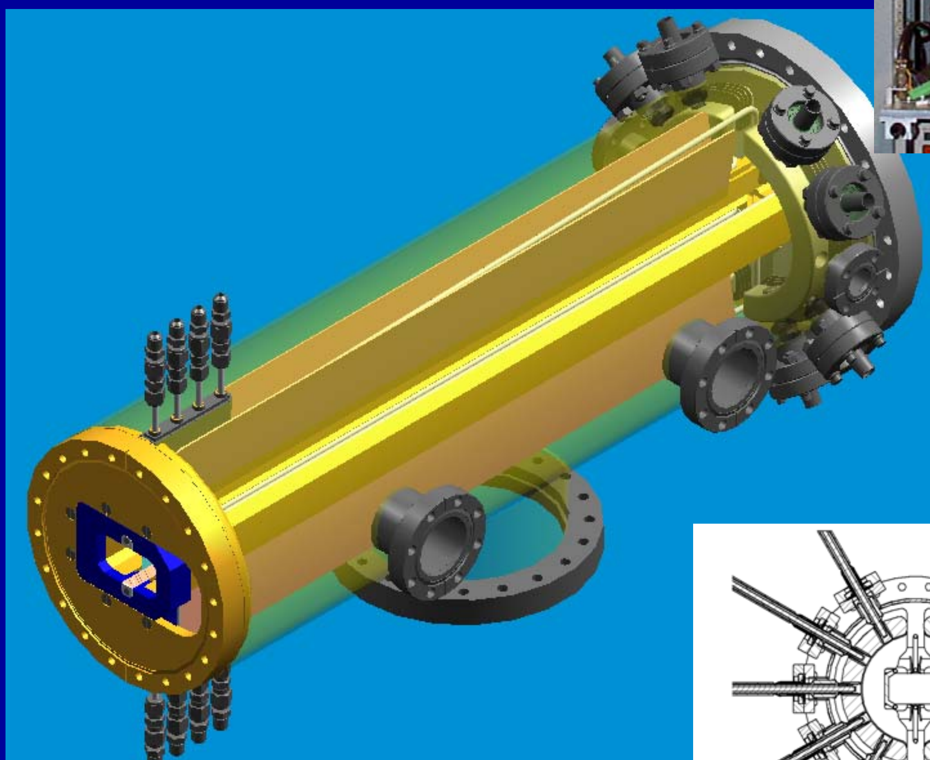
Kicker Strength (mrad)

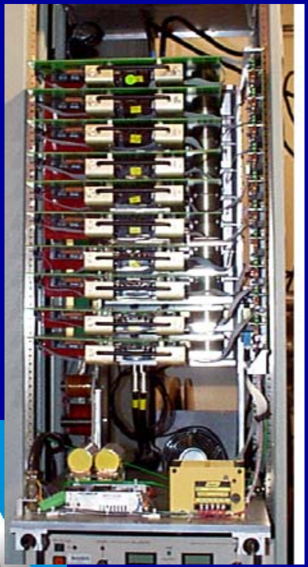


Beam Displacement at Septum (mm)

parameter	K1	K2	K3
Length (m)	1.2	0.6	1.2
Strength (mrad@3.3GeV)	2.2	1.4	2.2
Field Uniformity	n/a	-25 mm	n/a
Pulse Period	<780 ns	<780 ns	<780 ns

Injection Kickers (cont'd)





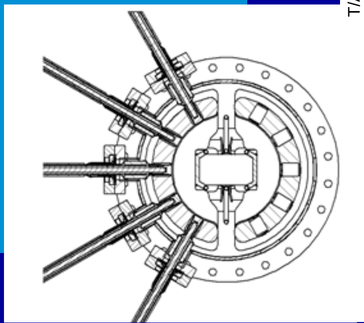
NLC pulser

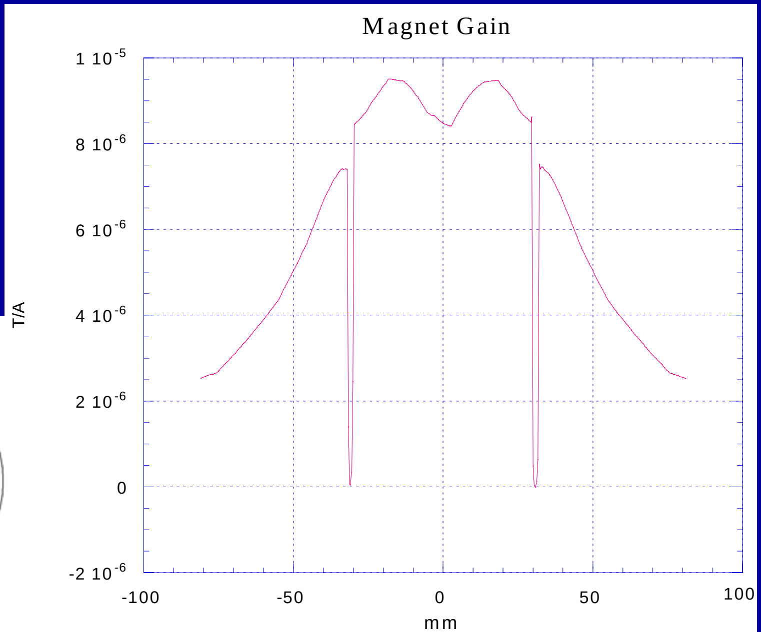
Kicker Specs

K1, K3: 2.2 mrad, 20 mT, 1.2 m long
2.4 kA, 15 kV, 574 nH

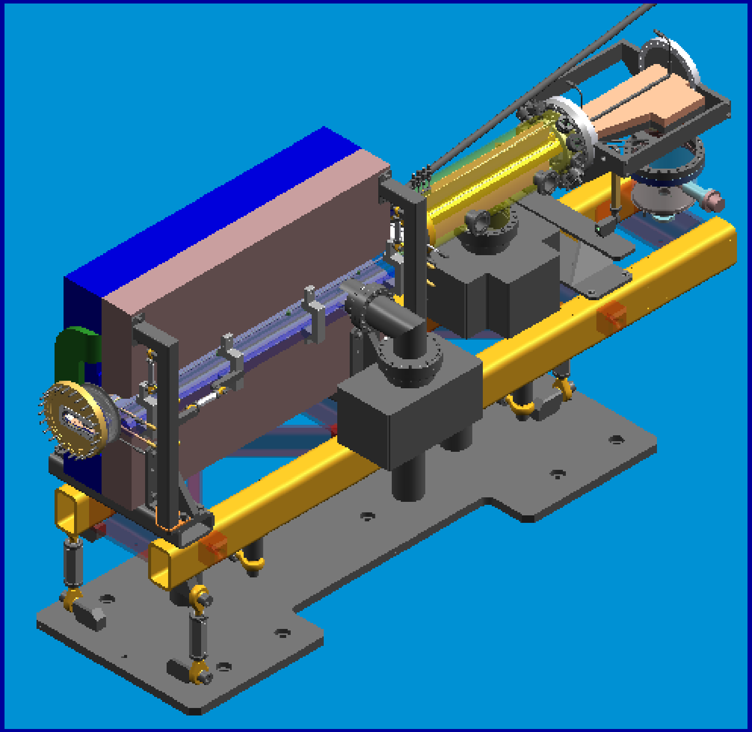
K2: 1.2 mrad, 22 mT, 0.6 m long
2.6 kA, 7.4 kV, 286 nH

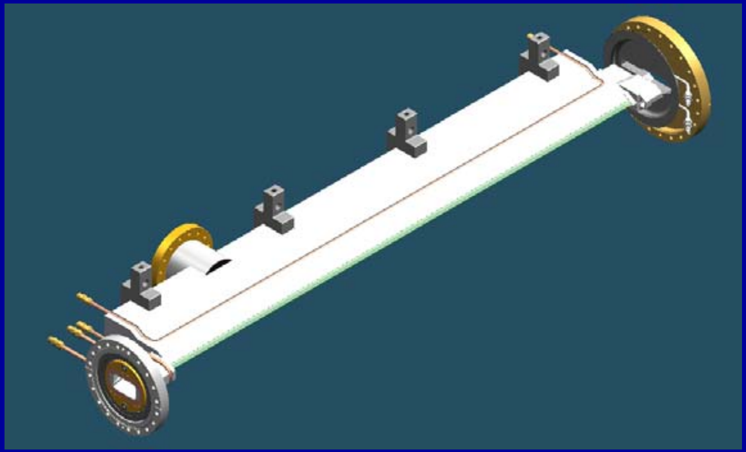
pulse width: 750 ns
rise/fall time: < 375 ns

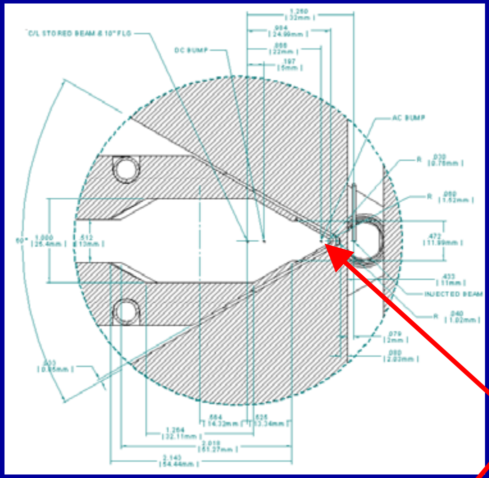




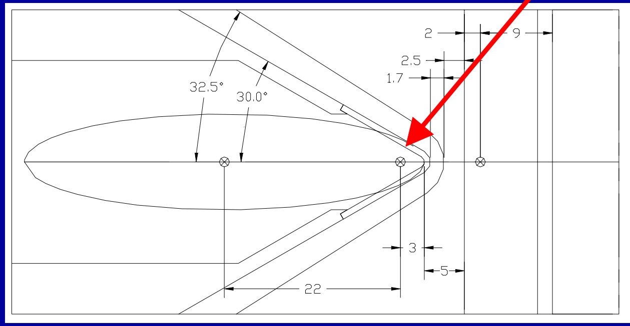
Injection Septum





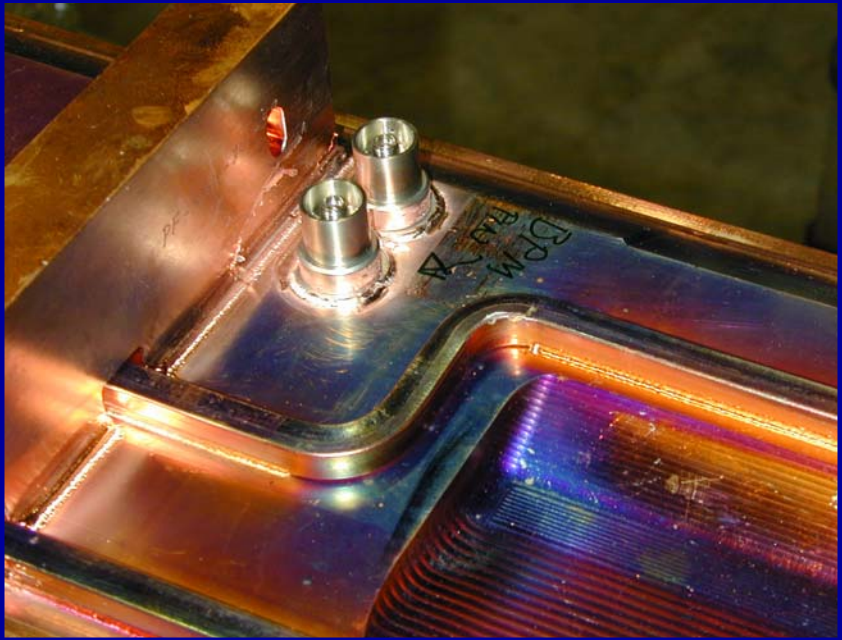


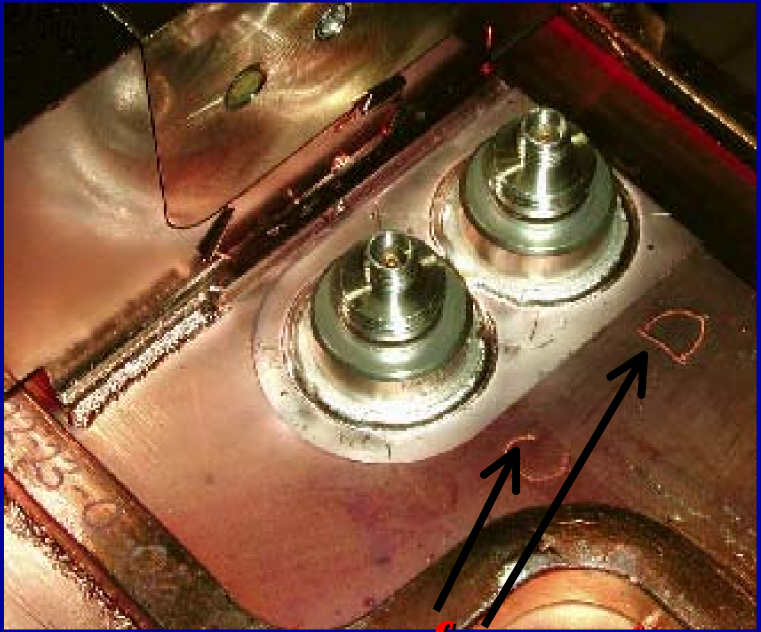
Achtung!



Beam Position Monitor System

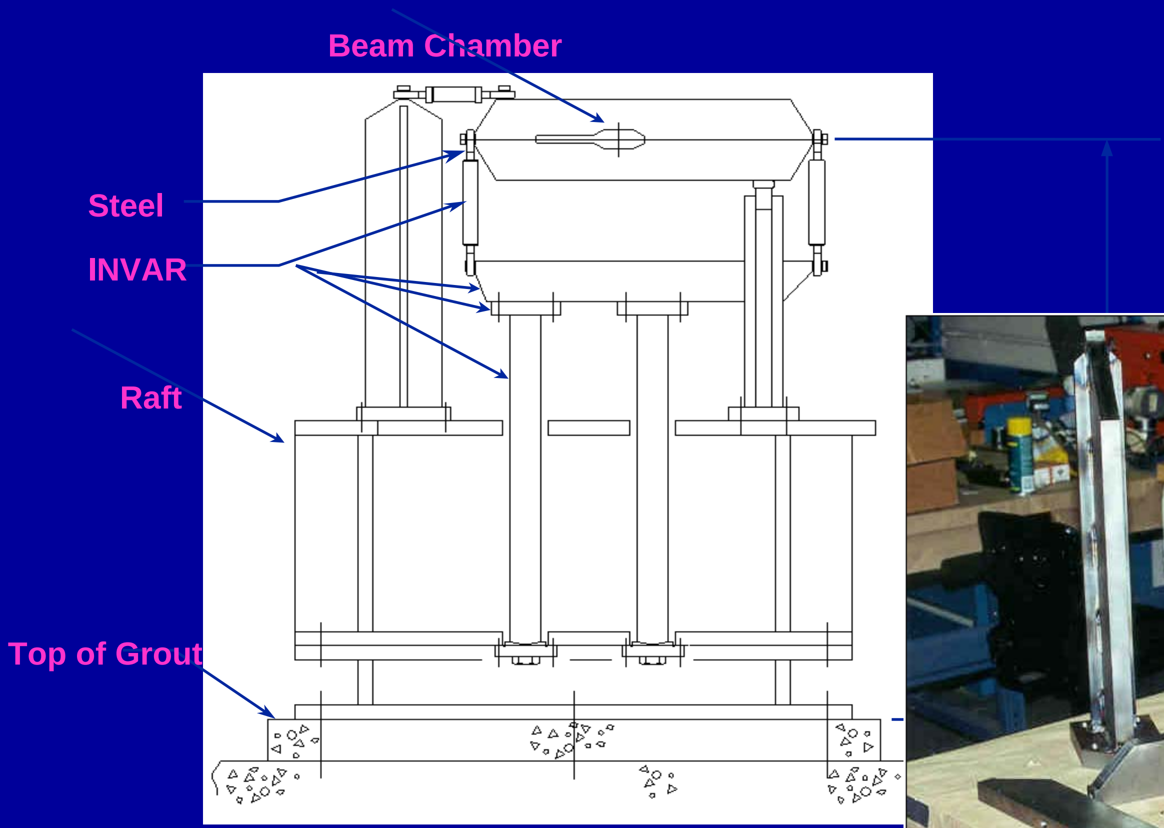
iu =inner/upper
ou= outer/upper
il = inner/lower
ol = outer/lower





nfg

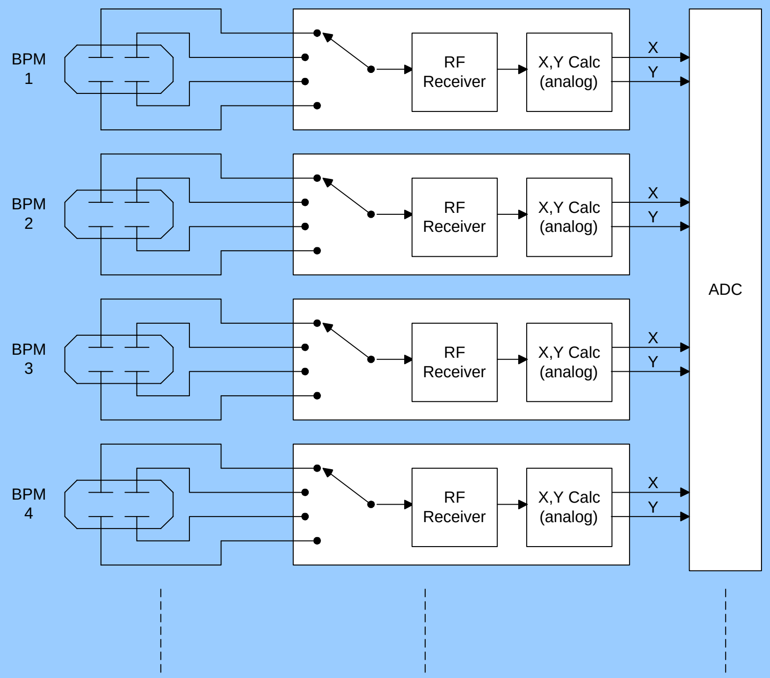
BPM Supports



BPM Processors

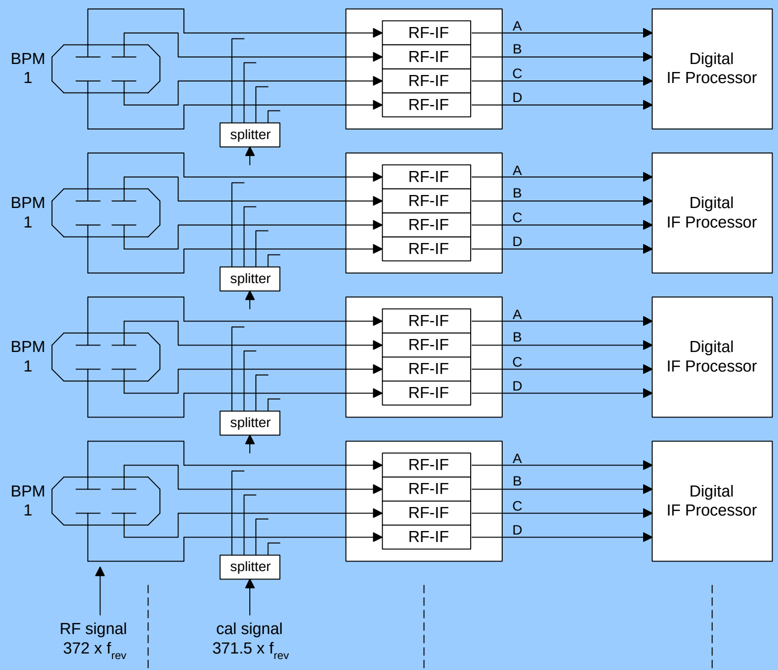
4:1 button MUX (Bergoz)

multi-turn BPM measurement
(~100-200 Hz BW)

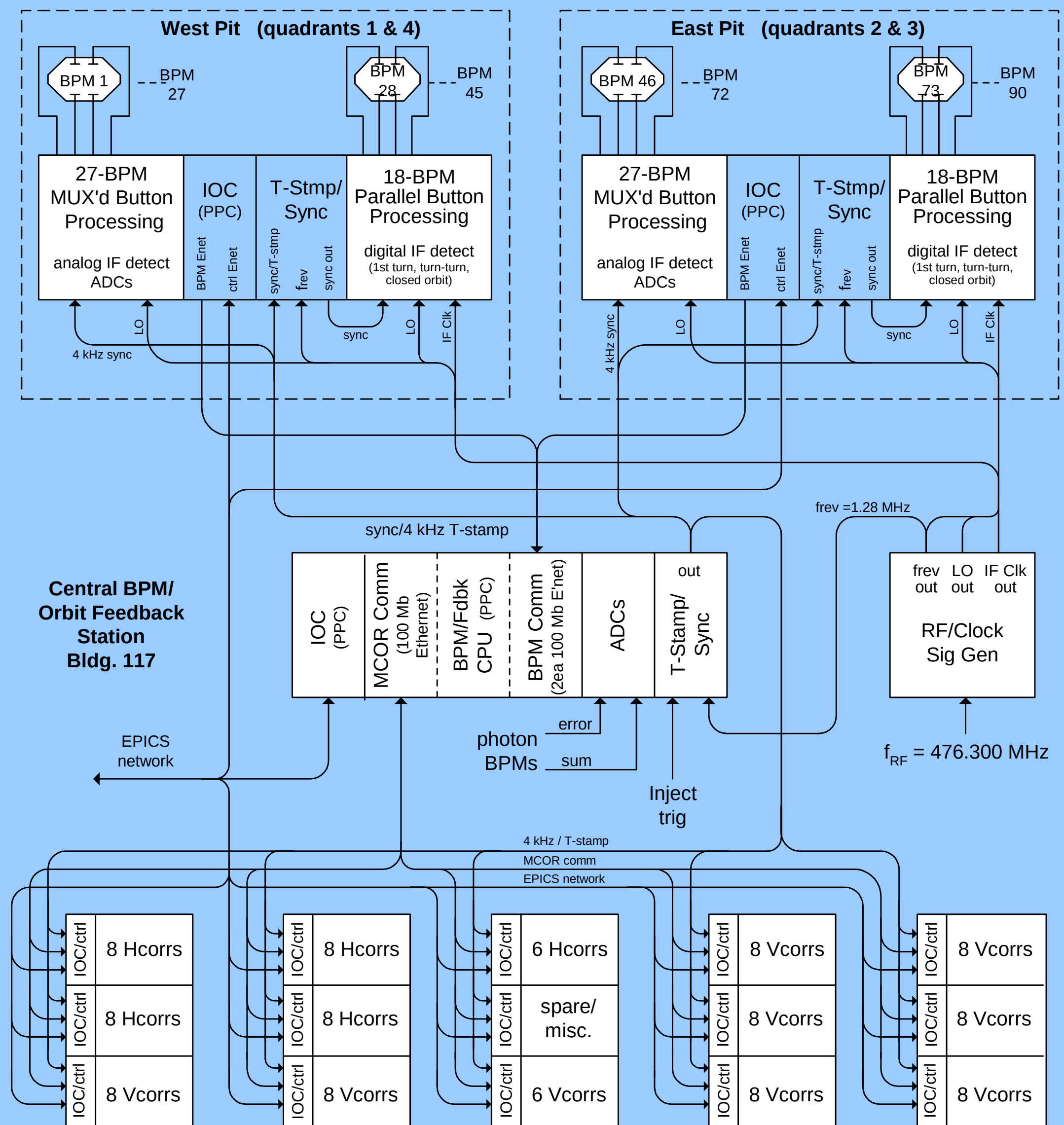


parallel processing (Echotek)

1st turn/single-turn/multi-turn BPM measurement



BPM Processing and Orbit Feedback System (no servos!!!)



Corrector Power Supplies - Bldg. 118

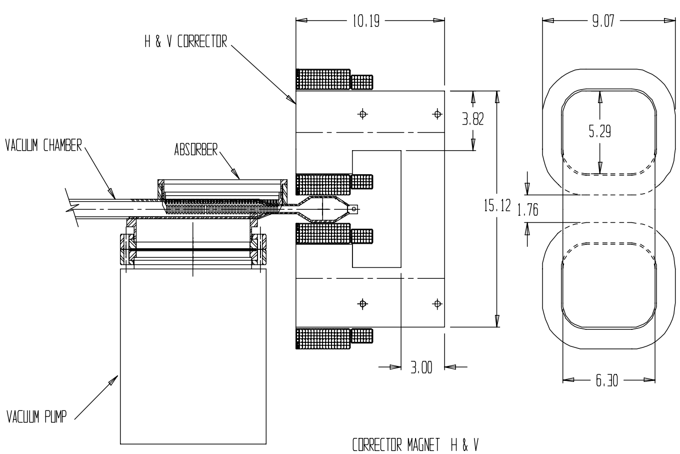
rev. 12/17/02

BPM Processing (cont'd)

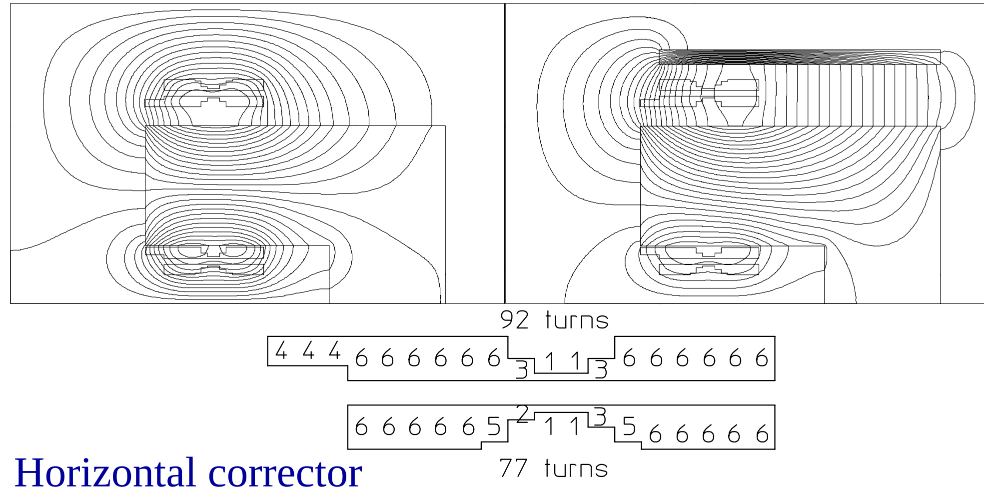
# BPMs		96	
Resolution	1st turn:	1.8 mm	(0.03 mA)
	turn-turn:	13 μm	(> 5 mA)
	feedback:	1 μm	(160 avg)
Current range		5-500 mA (<13 μm turn-turn res)	
Current dependency		< 3 μm	
Orbit acquisition rate		4 kHz for feedback	

Bergoz Processors

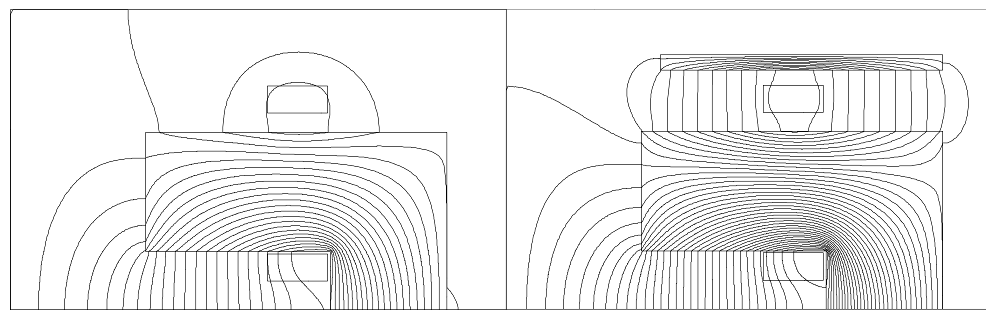
Orbit Correction- Combined-Function Magnets



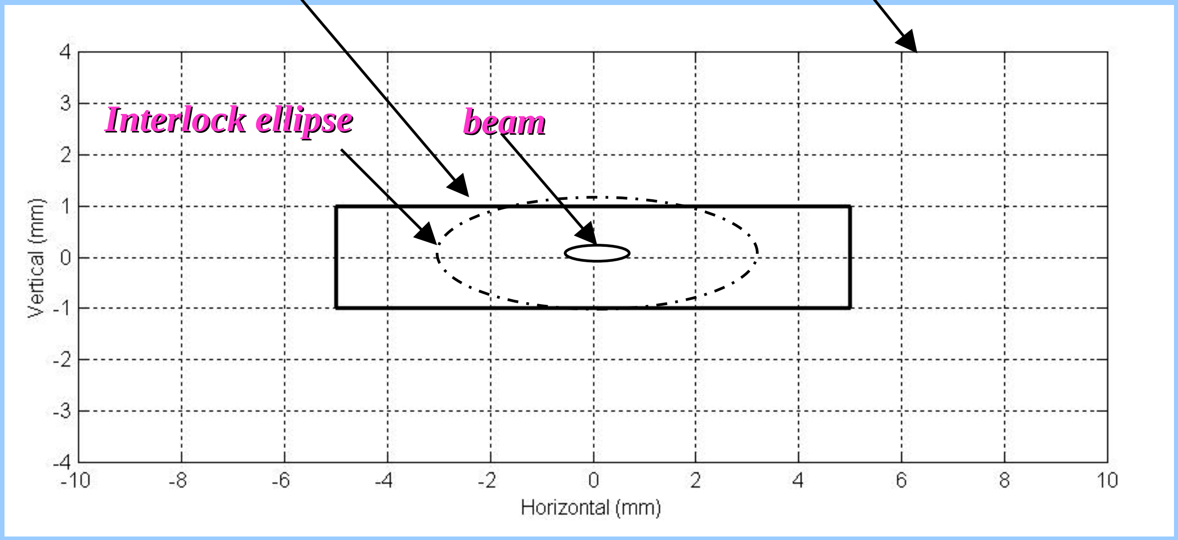
Vertical corrector



Horizontal corrector



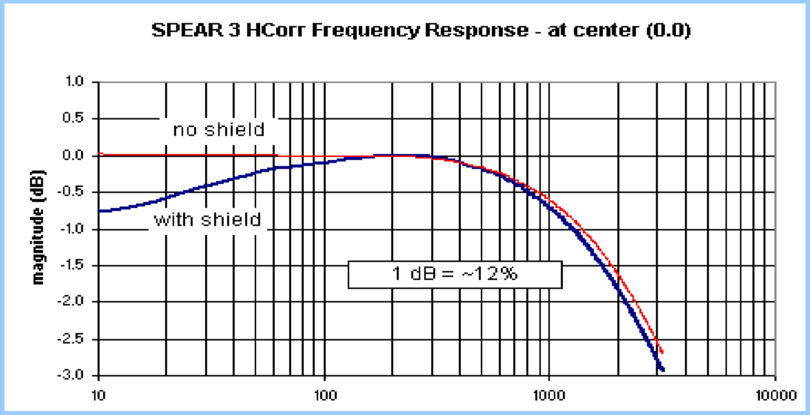
Corrector Magnet Field Quality



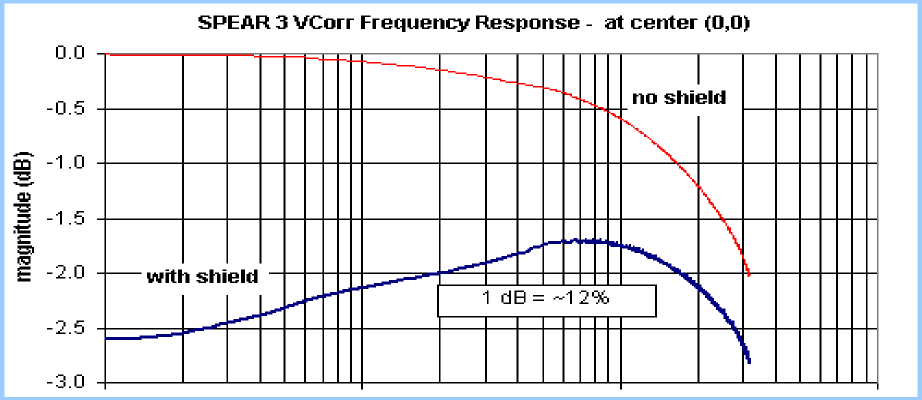
DC fields: <2% in |10| x |4| mm box

AC fields: <1% in |5| x |1| mm box @ ~200Hz

-3dB @ ~100Hz



iron dominated



1 kHz air dominated

Fast Corrector Power Supplies

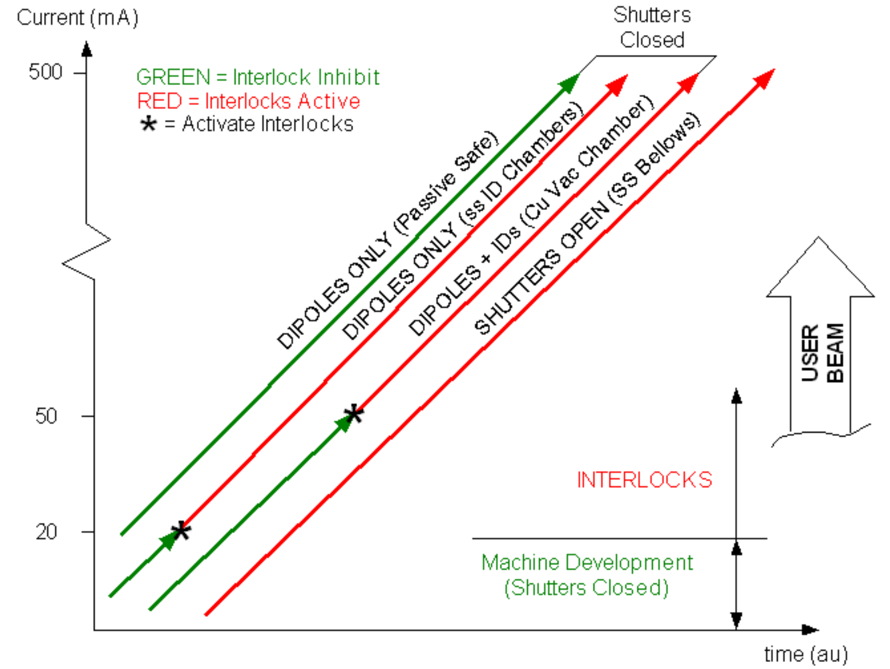
MCOR 30
crate

MCOR 30 and
controller
daughter card

rear panel
Frankenbride board

MCOR control
Frankenboard
+ VME CPU

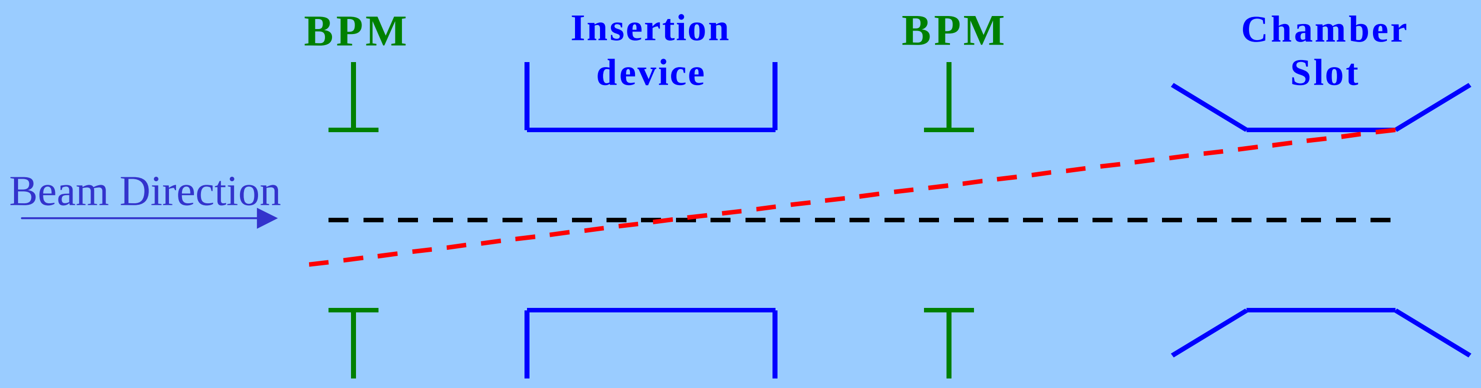
Orbit Interlock System (MPS)



Notes:

1. Shutters Closed for Injection
2. Interlocks on for Injection above I = 20 - 50 ma
3. Injection Rate ~ 50 ma/min

Single Interlock Channel



$$|y + y'L| < g/2 - \Delta_{mech} - \Delta_{\sigma_y}$$

(y,y') = (position,angle) at center of ID

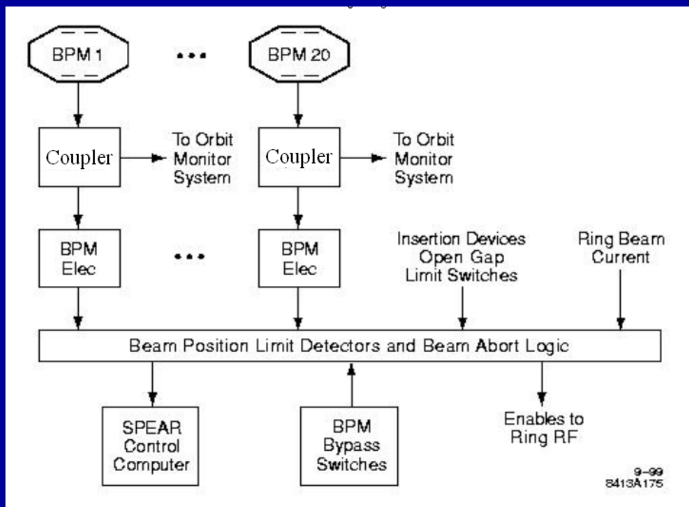
***g* = 13 mm** **Δ_{mech} = 1.5 mm** **$\Delta\sigma_y$ = 2.2 mm**

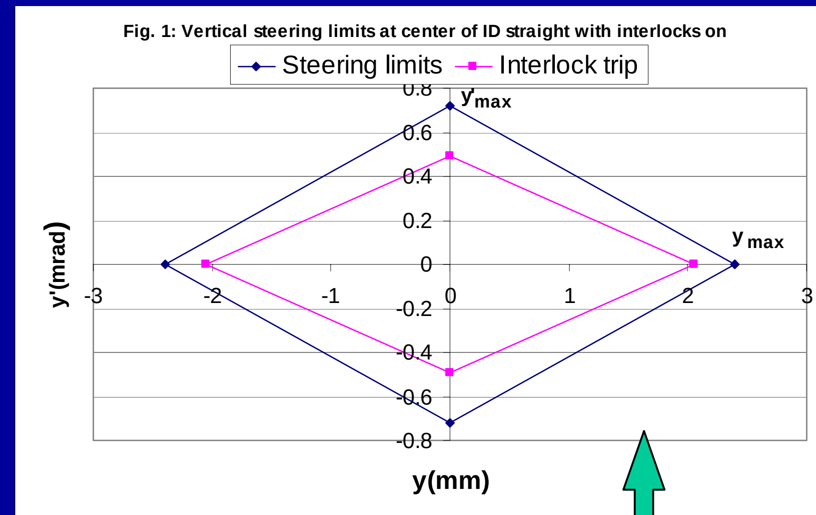
***L* = distance at which photons exit slot = 3.9 m**

$$|y| + |y'|L < g/2 - \Delta_{mech} - \Delta_{\sigma_y} \quad \Rightarrow \quad \frac{|y|}{2.8mm} + \frac{|y'|}{0.72mrad} < 1$$

2.4 mm (accounting for ID focusing)

Orbit Interlock (cont'd)



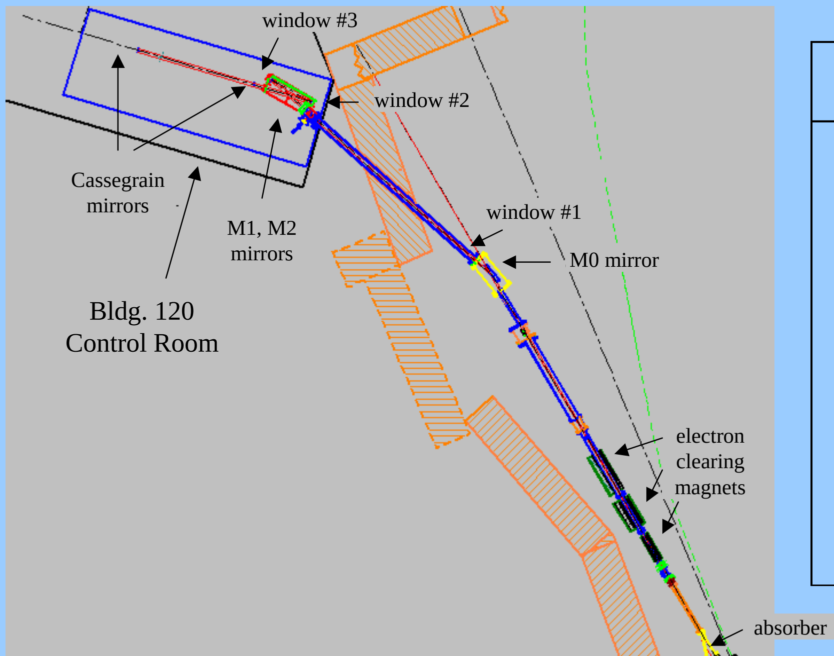


Phase-Space Diamond
Kurita
Safranek
Terebilo
Yotam
Boussina

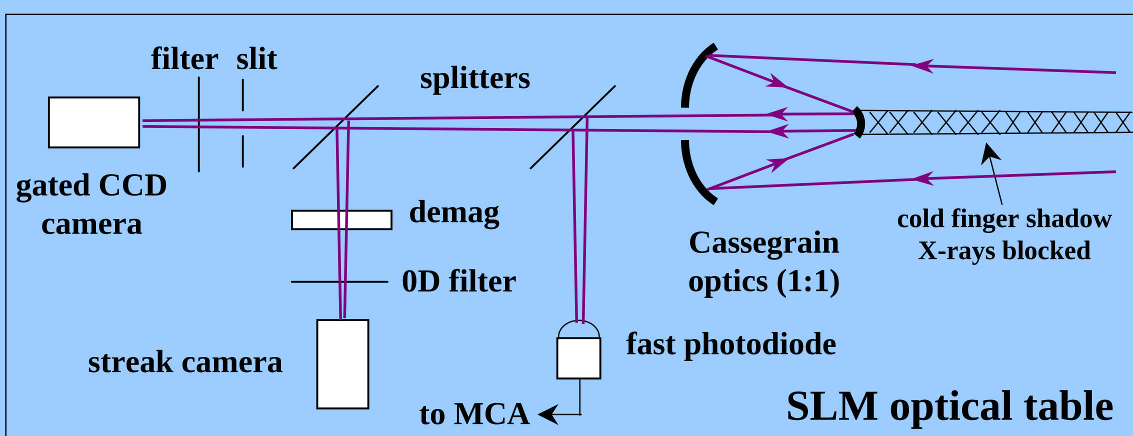
System Specifications

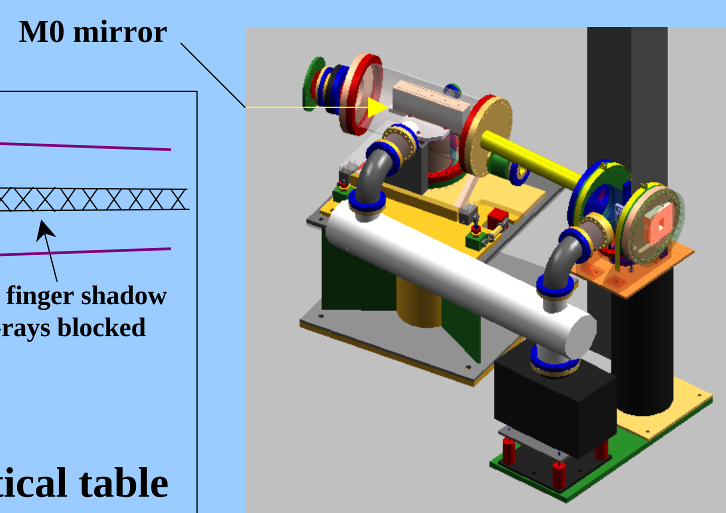
Number of BPMs	20
Processing frequency	476.3 MHz
Beam current range (nom) 5-500 mA	
Resolution (>5 mA)	<50 μm
Accuracy (wrt quad center, after QMS; >5 mA)	<100 μm
Dynamic range (intensity)	>60 dB
Channel isolation	>60 dB
Beam abort time (via RF system)	<1 ms

Synchrotron Light Monitor



Parameter	Value
Radius of curvature in dipole ρ	7.86 m
Critical energy in dipole E_c	7.62 keV
Critical wavelength in dipole λ_c	0.163 nm
Measurement wavelength λ	210 nm
Opening angle $(1/\gamma)$ at λ_c	0.17 mrad
Opening angle at λ for both polarizations	1.87 mrad
Diffraction spot size σ_d	15 μm rms
Electron beam size σ_x	183 μm rms
Electron beam size σ_y	51 μm rms
Vertical image size σ_{image} (1:1 image)	53 μm rms





Synchrotron Light Monitor- Physics Parameters

Frequency Spectrum

$\lambda \sim$ 250 nm (4.9 eV)
UV vs. visible (diffraction effects)

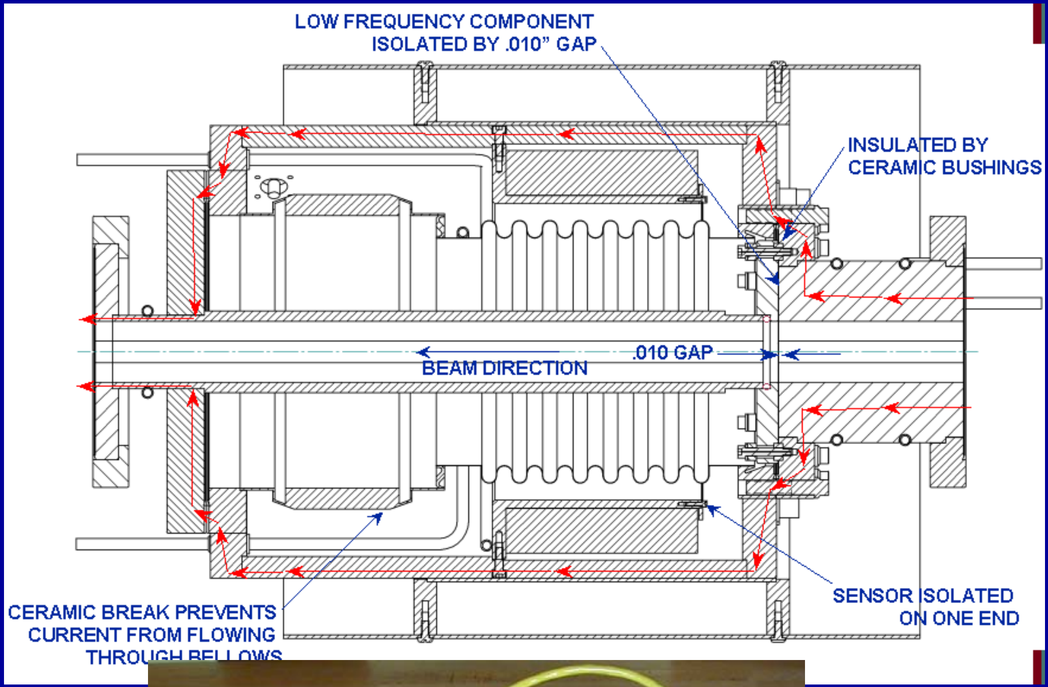
Beam Size (dipole source)

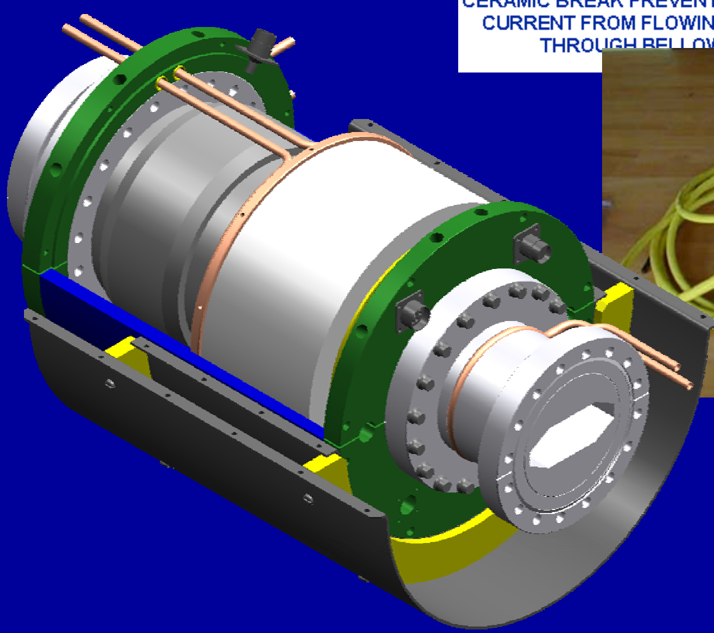
σ_x = 182 μm ,
σ_y = 50.8 μ m (K=1%)
resolution: ~ 40 μm at l = 250 nm
UV monitor magnification X3 (CCD pixel size)

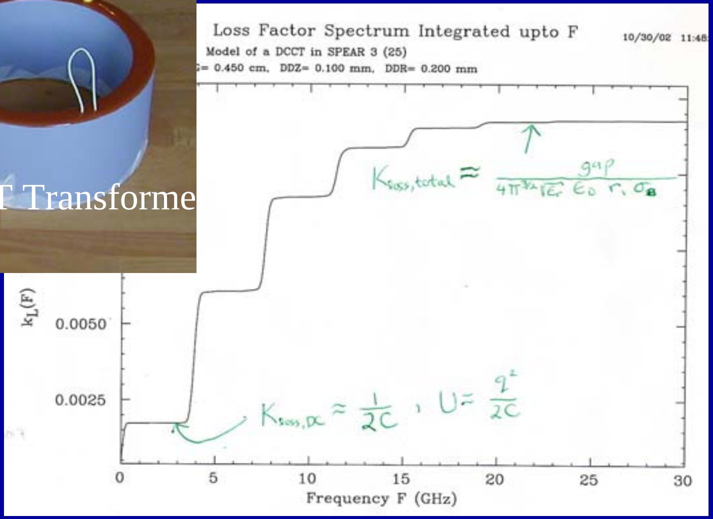
System Functions

Spirocon broadcast to floor
Transverse beam size
Coupling studies
Bunch-to-bunch stability
Streak camera (X2 demag)

High Precision DCCT & Housing

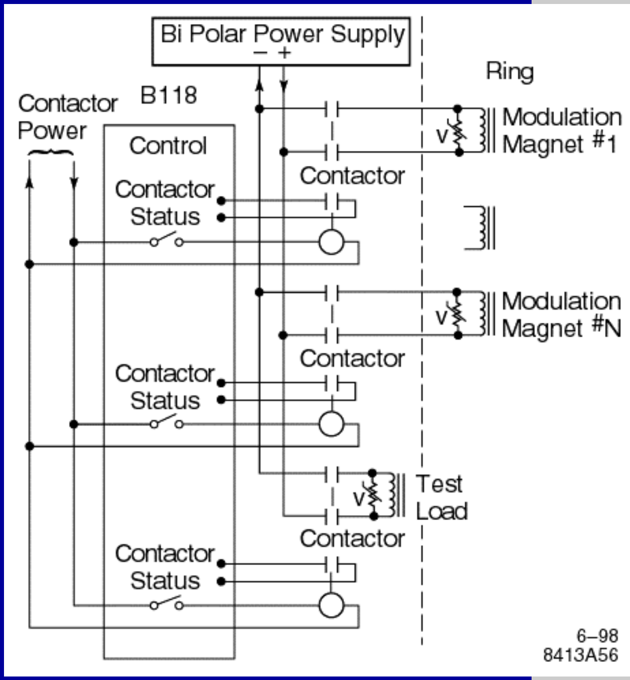




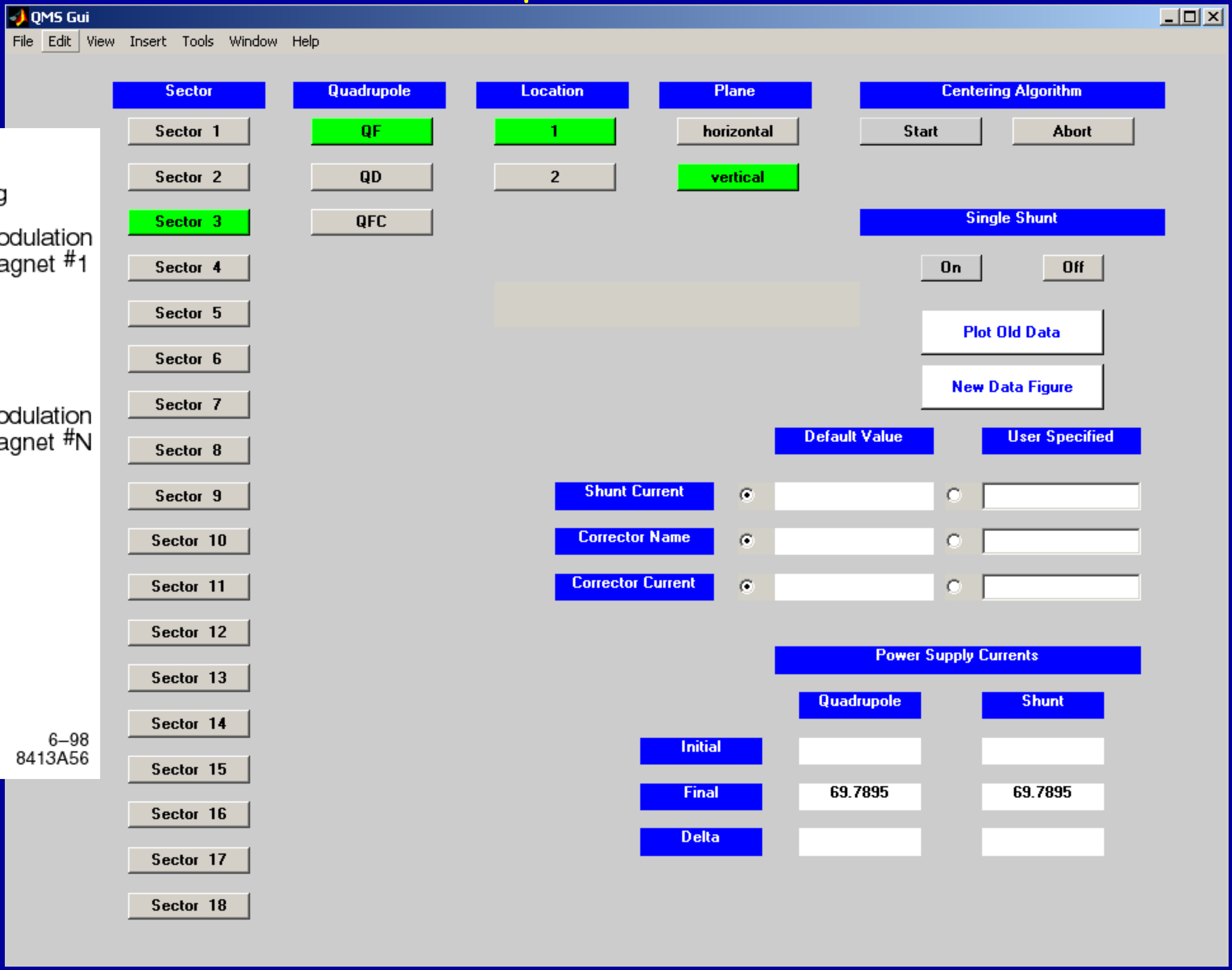


Quadrupole Modulation System - 'Quad Shunts'

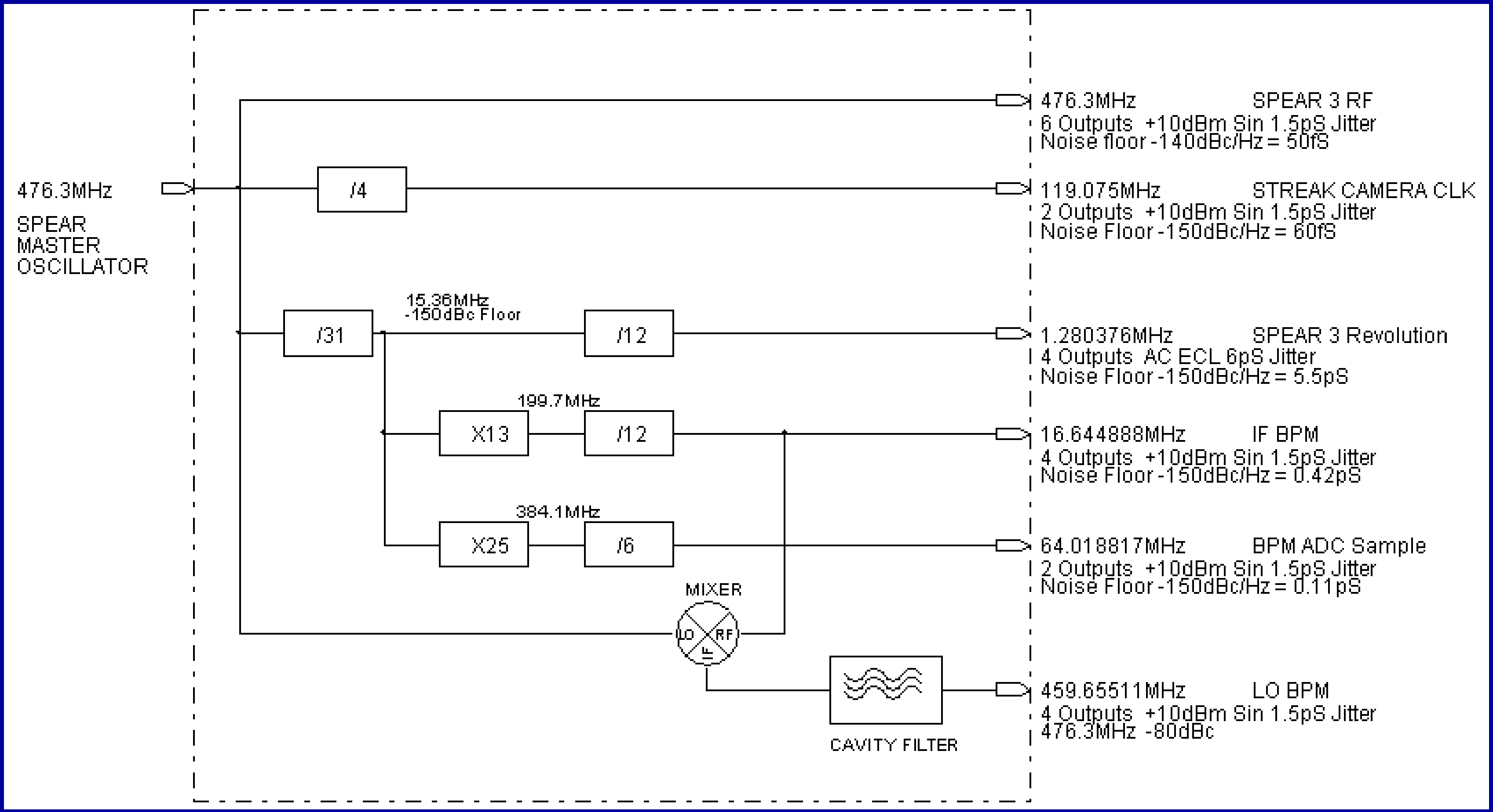
Switchgear



Operator Interface



Timing and RF Signal Generator System



SPEAR RF:

$f_{SPrf} = 372 \times f_{SPrev} = 476.300$ MHz

Booster RF:

$f_{Brf} = 280 \times f_{SPrev} = 358.505$ MHz

SPEAR revolution freq:

$f_{SPrev} = 1.2804$ MHz

BPM LO:

$f_{LO} = 359 \times f_{SPrev} = 459.655$ MHz

BPM IF:

$f_{IF} = 13 \times f_{SPrev} = 16.645$ MHz

IF digitizing clk:

$f_{IFclk} = 50 \times f_{SPrev} = 64.020$ MHz

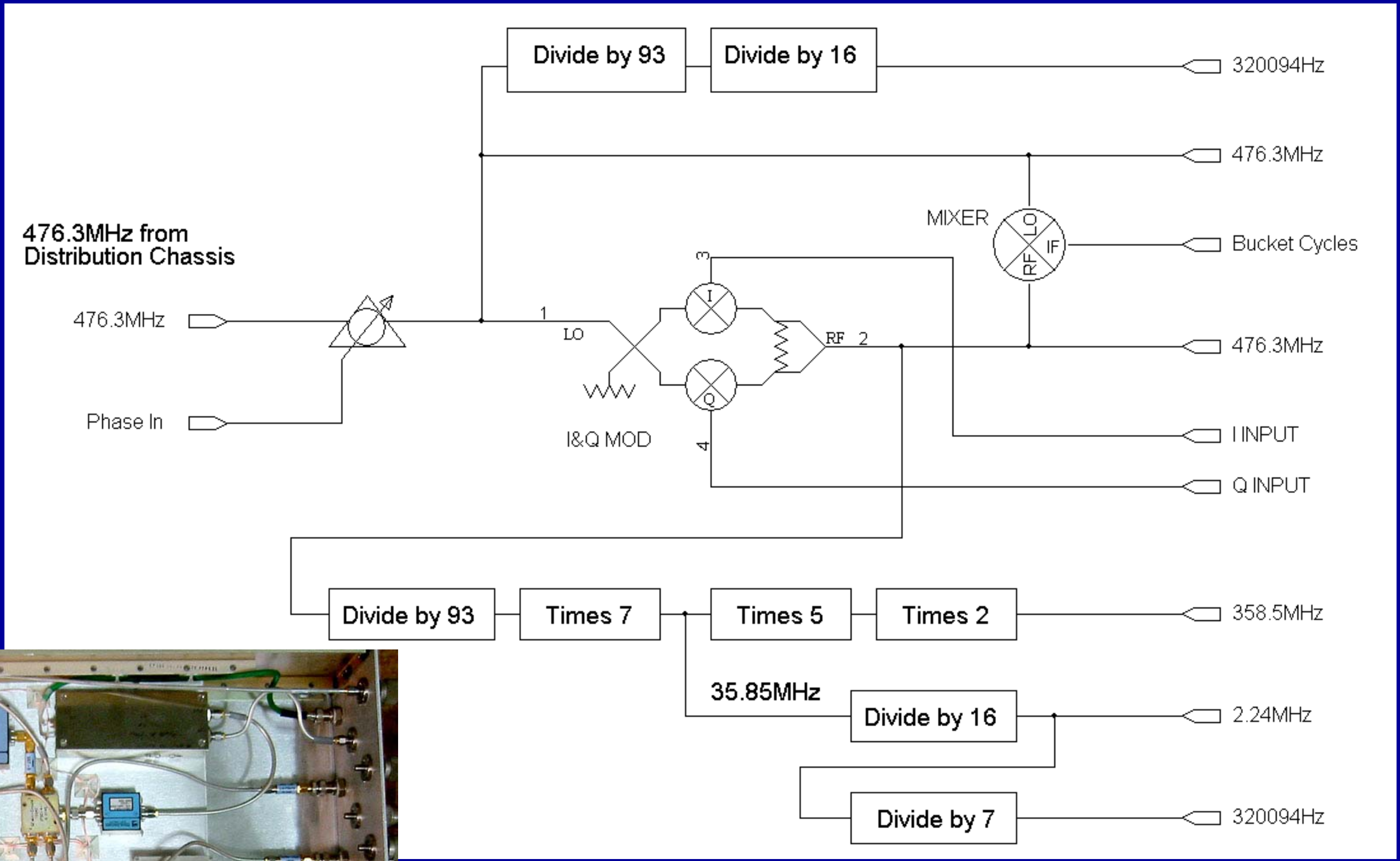
Streak camera clk:

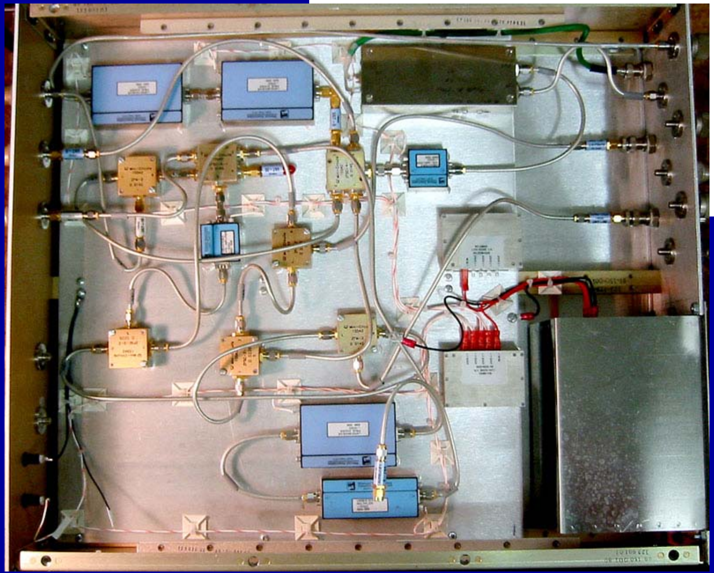
$f_{SC} = f_{SPrf}/4$

$= 93 \times f_{SPrev}$

$= 119.075$ MHz

Booster RF Generator and Timing Modulator





Match of SPEAR ring to Booster

Cogwheel timing requires:

$$\frac{L_{SPEAR}}{L_{BOOSTER}} = \frac{234.1260\ m}{133.7863\ m} = \frac{7}{4}$$

But $L_{BOOSTER} = 133.7986$ (~12 mm too long)

Booster alignment costly, time-consuming

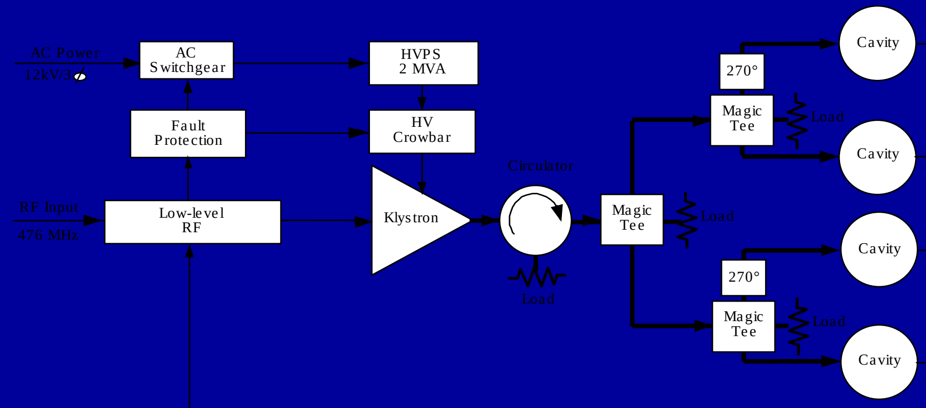
Booster performs well at 358.500 Mc (vs.533)

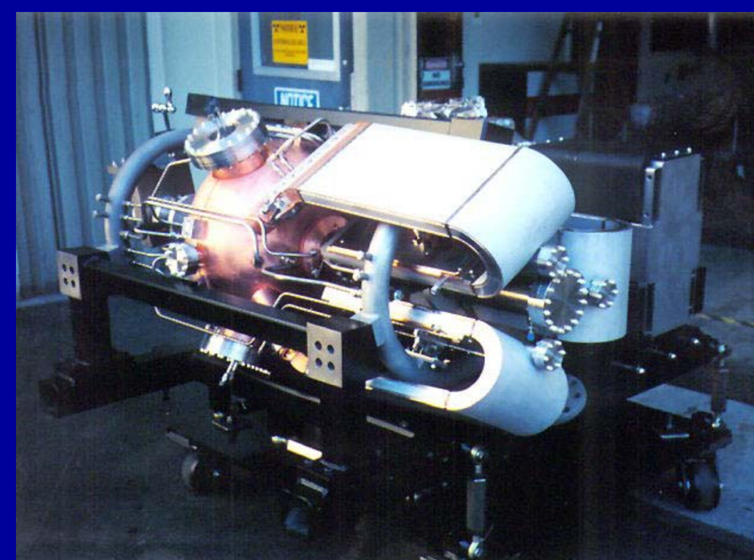
Sol'n: Adjust SPEAR 3 circumference to 234.1442 m

$$f_{RF} = 476.300\ MHz$$

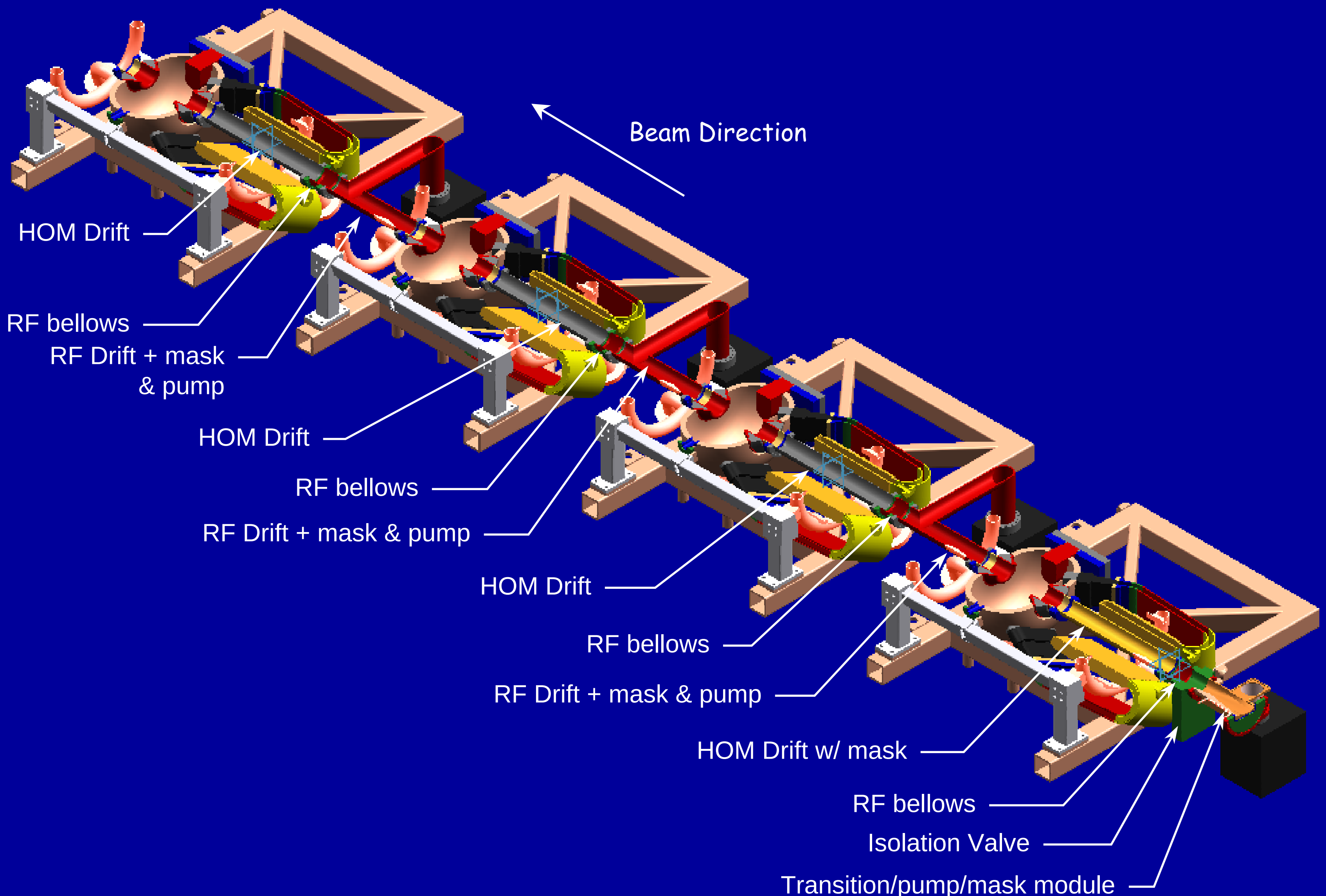
NOTE: round number for rf frequency

PEP-II Style RF System





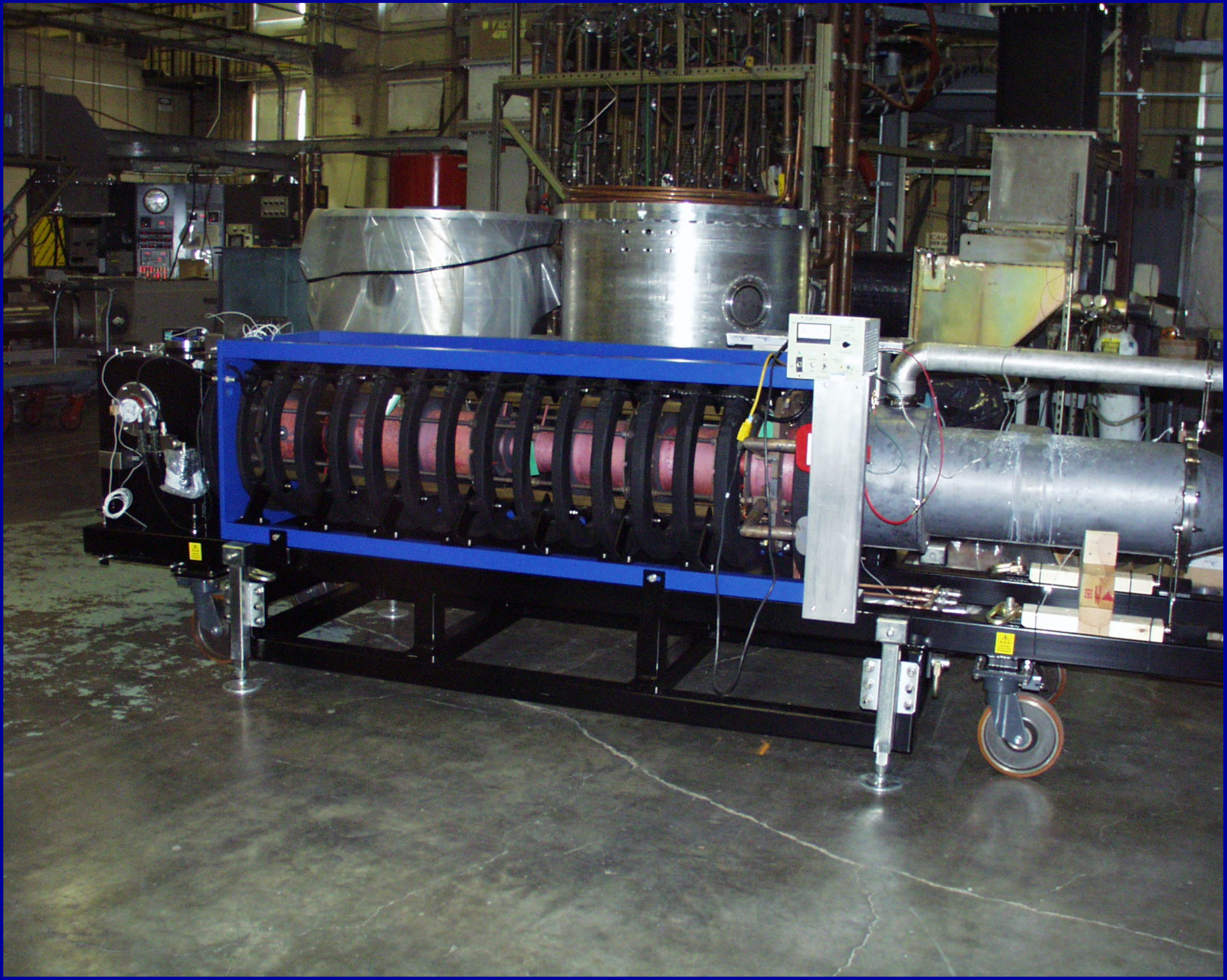
West RF Straight (4 Cavities)



RF Cavity Fabrication

(Accel Inc, Germany)

476.3 MHz, 1.2 MW CW 'Big Daddy' Klystron



Benefits of the PEP-II RF System

Power for 500 mA operation (vs. ~250 mA)
High-order mode damping systems
Single cell vs. 5-cell cavity construction
No 'fine-tuning' of operating point
Robust modern technology
New Klystron
New feedback systems
Temperature control
EPICS Operator interface

RF System Parameters

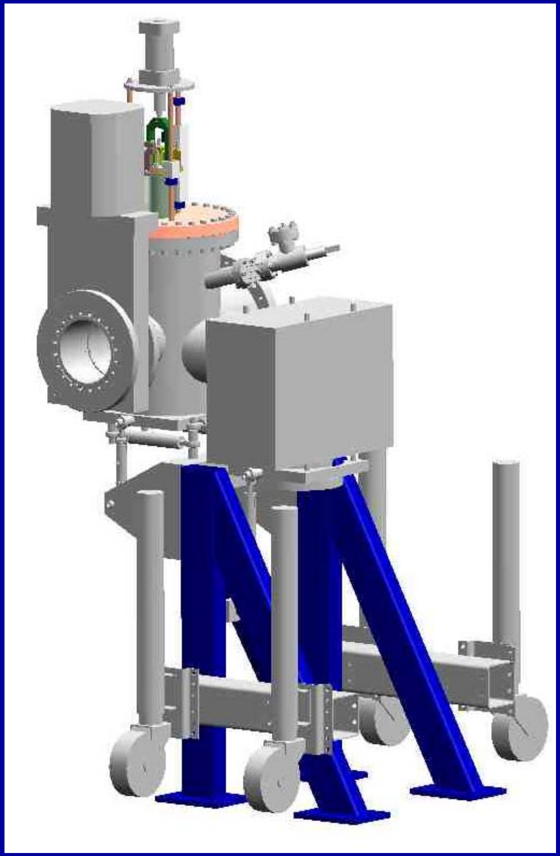
Parameter	Value (2003)	Comments
Beam energy	3.0 GeV	
Beam current I_b	500 mA	
Bend radius	7.86 m	
Total ID strength	42.4 T^2m	100 T^2m by 2020
Energy loss per turn	1.18 MeV	1.5 MeV/turn by 2020
Ring circumference	234.126 m	
RF frequency	476.337 MHz	Booster RF is 358.533 MHz
Harmonic number	372	
Number of klystrons	1	
Number of cavities	4	1-cell, mode-damped
Total shunt impedance	30 MΩ	$R_s=V_g^2/P_{rf}$
Total gap voltage Vg	3.2 MV	
Overvoltage factor	2.7	2.33 @ V_g = 2.75 MV
Tot. cavity wall power	341 kW	252 kW @ V_g = 2.75 MV
Synchrotron rad. power	580 kW	1.04 MW with new IDs by 2020
Misc. losses	108 kW	78 kW @ V_g = 2.75 MV
Total RF power loss	1.03 MW	0.91 MW @ 2.75 MV; 1.2 MW @ 3.2 MV by 2020
Klystron power	1.13 MW	1.0 MW @ 2.75 MV; 1.3 MW @ 3.2 MV in 2020
Available klystron pwr	1.2+ MW	1.6 MW with SLAC-built klystron

SPEAR 3 Project Cost

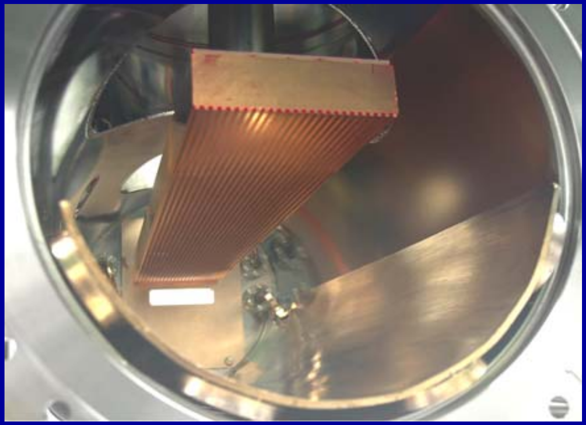
			prelim est 1/97
1.0	Project Management, Accelerator Physics	3.8 M$	0.6
1.1	Magnets and Supports	8.4	4.3
1.2	Vacuum System	10.3	6.3
1.3	Power Supply System	3.1	0.7
1.4	RF System	3.9	3.1
1.5	I&C and Protection Systems	3.5	1.3
1.6	Cable Plant	2.2	---
1.7	Beam Line Front Ends	1.0	---
1.8	Facilities	2.5	0.8
1.9	Installation and Alignment	3.0	1.5
	Total direct cost:	**41.7** (FY99 $)	**18.6** (FY97 $)
	indirect cost:	5.8	
	escalation:	2.5	
	contingency:	8.0	3.7
	TOTAL COST:	***58.0 M$***	

New Beam Line Components (~$35M)

ID's for BL 4,7
Permanent Magnet
Compensation Tables
11 mm chambers



500 mA BL front ends



500 mA BL front end mask

Major Reviews and References

Nov 3-5, 1997	Director's Review		
July 28-30, 1998	Department of Energy (Lehman Review)		
Sept 14-15, 1999	"	"	"
June 13-14, 2000	"	"	"
July 24-25, 2001	"	"	"
July 16-18, 2002	"	"	"

SPEAR 3 Design Report August 1999

SPEAR 3 Quarterly Reports http://www-ssrl.slac.stanford.edu/spear3/spear3_main_page.htm

SPEAR 3 Publications " " " "

SPEAR 3 Technical " " " "

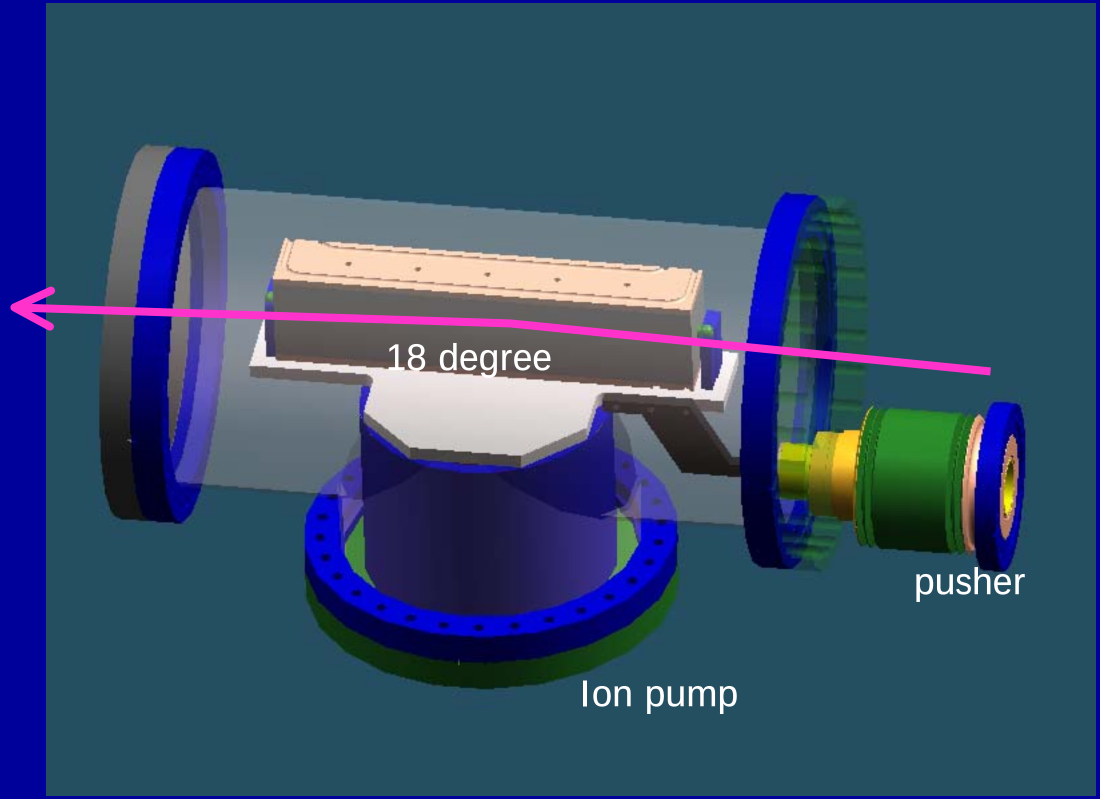
Magnet Photo Gallery http://www-ssrl.slac.stanford.edu/~nli

Vacuum Photo Gallery logon slacnt, winsan1, ssrl-sp3/transfer/sp3vacshop

Power Supply .xls q:groups/accel/supplies

RF System Particle Accelerator Conferences (Schwarz, Rimmer, Hill, Allison, Corredoura)

SLM – First Mirror (M0)



- Flat Si mirror with Rh coating
- 9.50m from source, 9 degrees incidence
- 31.4 cm x 13.3 cm (5 mrad horizontal, ± 3.5 mrad vertical)
- 50 cm x 8 cm mirror
- Rotates in y, translate in x
- 360 W total, 0.4 W/mm^2