Overview of the NSLS-II RF System

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presented by Ernst Weihreter

- System requirements
- 500MHz fundamental RF
- 1500MHz Landau cavity
- Booster RF system

NSLS II Ring Parameters

Beam Property	Required Baseline	Full Capability
Beam Energy	3 GeV	3Gev
Stored Current	500 mA	500 mA
Horizontal emittance	1 nm	0.5 nm
Vertical emitance	0.010 nm	0.008 nm
Energy Loss per turn	1 MeV	2 MeV
Momentum acceptance	3%	>3%
ID Straights for undulators	>21	>25
Electron Beam Stability	1 µm	< 1 µm
Top-off Injection Current stability (Δt > 2 min.)	< 1%	< 0.1%
Momentum Compaction	0.00037	0.00037

NSLS II Design Approach

- Large circumference of 780m (soft bends) for low natural emmittance, ε_0 = 2 nm (144kW beam power)
- 54 m of 1.8 T damping wigglers in zero dispersion straights to further reduce emmitance to 0.5nm. (> 500kW of beam power!)

$$\frac{\varepsilon_w}{\varepsilon_0} = \frac{1+f}{1+\frac{L_w}{4\pi\rho_0}\left(\frac{\rho_0}{\rho_w}\right)^2} \qquad \frac{\delta_w}{\delta_0} = \sqrt{\frac{1+\frac{L_w}{2\pi\rho_0}\frac{4}{3\pi}\left(\frac{\rho_0}{\rho_w}\right)^3}{1+\frac{L_w}{4\pi\rho_0}\left(\frac{\rho_0}{\rho_w}\right)^2}}$$

Only 14m of DW and ~1/2 RF power installed day one due to cost constraints

NSLS-II RF VOLTAGE, POWER REQUIREMENTS

	Baseline Capability with 2 RF Cavity Systems Required Voltage 3.3 MV		Fully Build-out Capability with 4 RF Cavity Systems Required Voltage 5 MV	
	#	P(kW)	#	P(kW)
Dipole	60	144	60	144
Damping wiggler	3 (21 m)	259	8 (56m)	517
Cryogenic-PMU	3	76	6	127
EPU	2	33	4	66
Additional devices	~7	120	~10	200
TOTAL		529		1003
Available RF Power		540		1080

Design Concept/Design Goal

Ring RF system

- Superconducting cavities chosen for ring RF
  - low R/Q better for beam stability
  - higher AC power efficiency
  - Reliability and costs well establish
- CESR-B SCRF considered for baseline design and cost estimate
- KEK-B SCRF cavity as option
  - Higher power per coupler attractive
  - Requires more BNL infrastructure to assemble, test
- 310 kW Klystron amplifiers chosen for baseline:
  - Well established at other LS facilities
  - Reliability and costs well established
  - Combined IOT's as option, possible R&D on Solid State amplifiers
- Passive SCRF Landau cavity
  - Demonstrated performance at SLS, ELLETRA

RF Phase, Energy Stability Requirements

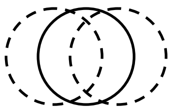
Weiming Guo et al, PAC 2007

$$\sigma_\delta = \sqrt{\frac{1}{2}\left(\frac{\Delta p}{p}\right)^2 + \sigma_{\delta,0}^2} = \sqrt{1+\frac{1}{2}f^2}\,\sigma_{\delta,0}$$

$$f = (\Delta p/p)/\sigma_{\delta,0}$$

$$\sigma_{y'}^2 = \frac{\lambda_n}{2L}\sqrt{1+16n^2N_w^2\sigma_\delta^2} + \varepsilon_y/\beta_y$$

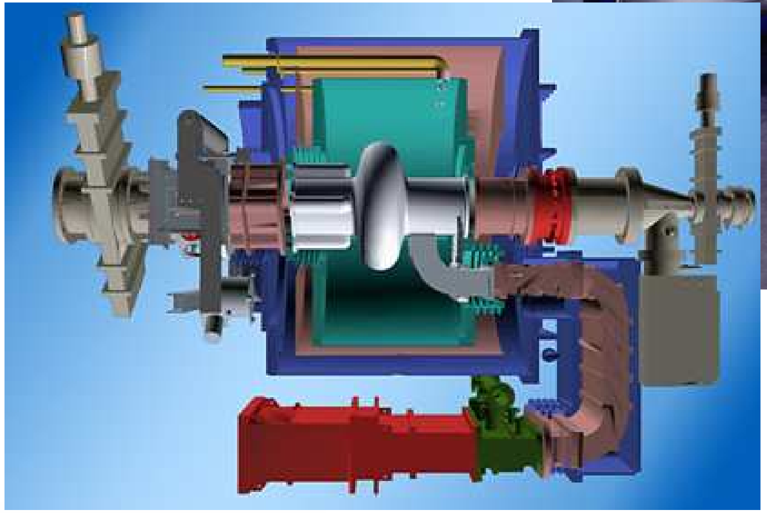
$$y = y_0 + \eta_y\langle\delta\rangle$$



	$\Delta\phi$ (°)	$d\delta$ ($\times10^{-4}$)
Centroid jitter due to Residual dispersion (ID's)	0.81	3
Vertical Divergence (from momentum jitter)	2.4	9
Dipole, TPW (position stability due to momentum jitter)	0.27	1
Timing experiments (5% of 15ps bunch @>500Hz)	0.14	0.5

Superconducting Accelerator Modules for Storage Rings based on CORNELL Design

SC Accelerator Module with Cryogenic valve box and Control Electronic Racks



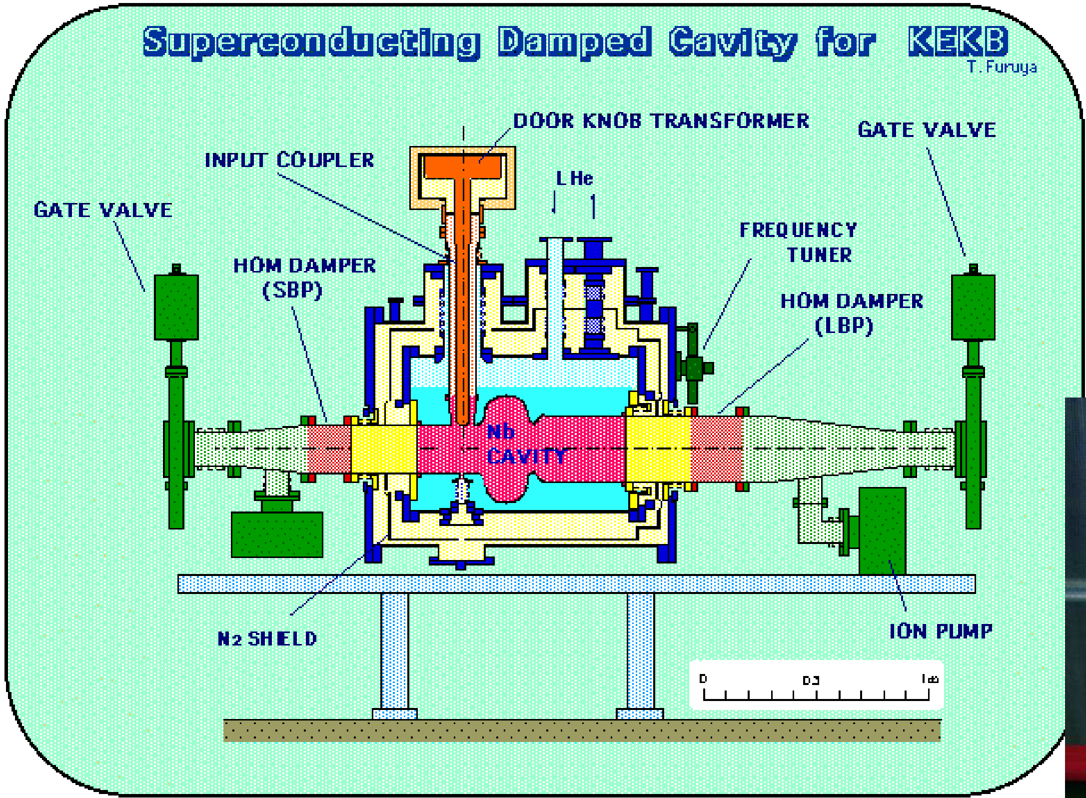
Delivered turn-key

CESR-B Cavity chosen for Baseline

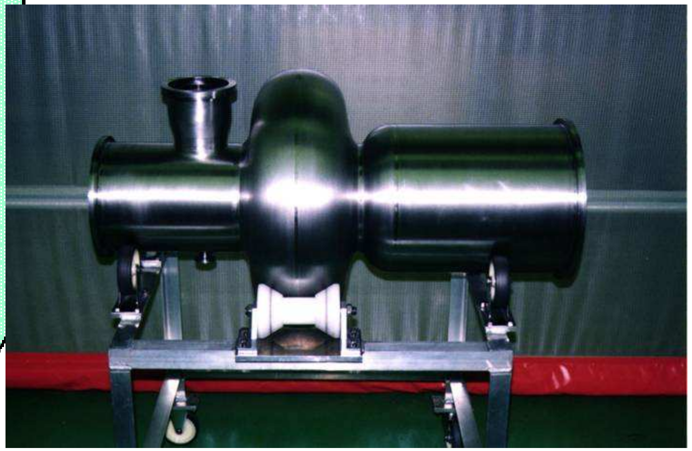
SCRF chosen for lower R/Q, highly damped HOM's, lower operating cost and comparable capital cost Well established commercial production. Units 15 and 16 now being produced by ACCEL. In operations at Cornell (4), CLS(2), Taiwan (2). Diamond (3). Being commissioned at Shanghai (2)

Frequency	**500 MHz**
Beam energy gain/cav	**>2.4 MV**
Eacc	**>8 MV/m**
Unloaded Q	**$>7 \cdot 10^8$**
Standby (static) losses	**<30 W**
Dynamic + static losses	**<120W**
Operating Temperature	**4.5 K**
Max. beam power/cavity	**<250 kW**

KEK-B cavity has been designed and built at 500MHz for BEPC-II



Cavity
***Nb single-cell**
***Frequency: 500* MHz**
***Gap length: 0.243 m**
***R/Q : 93 Ohm**
***Total length: 3.7 m**



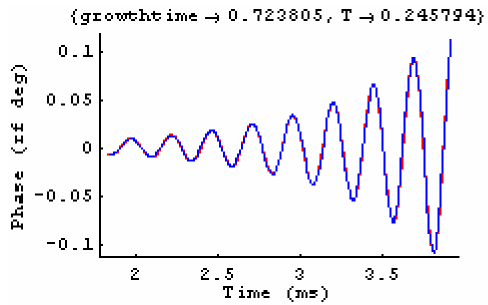
Landau Cavity

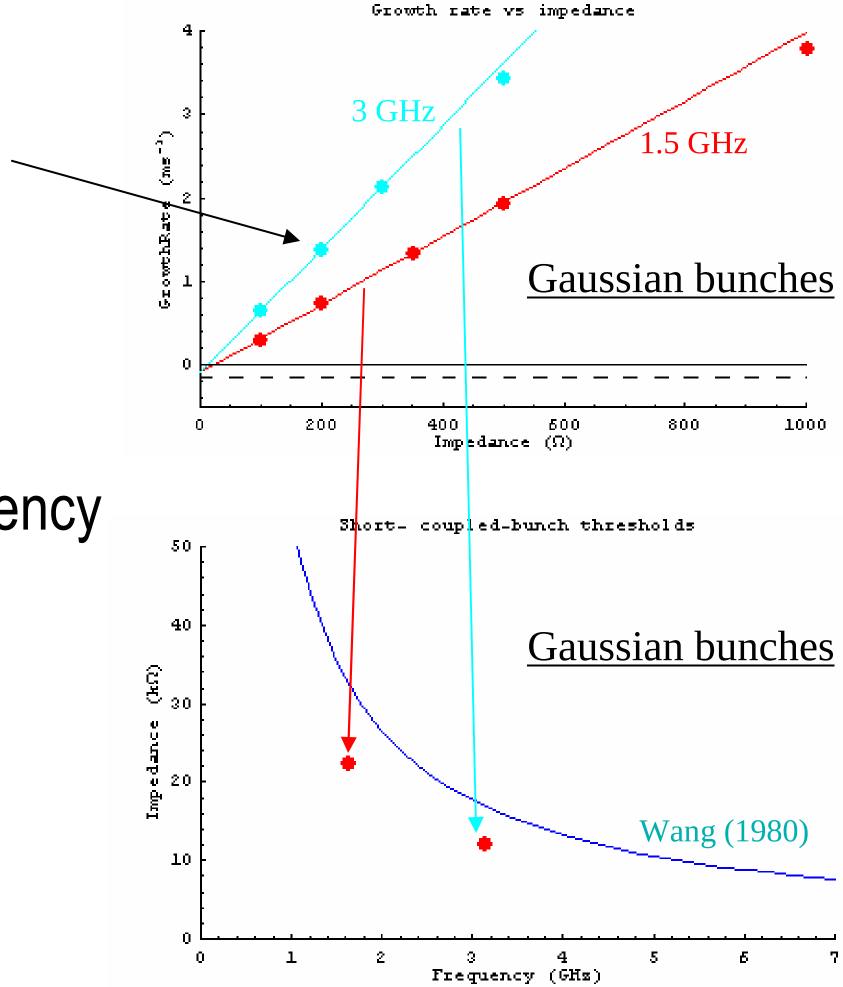
- **Super3HC cavity developed by SLS/ELETTRA/CEA-Saclay-CERN collaboration meets baseline requirements, 2nd cavity for fully built out system**
  - Longitudinal HOM impedance (7k-ohm) marginal for bare lattice, short bunches
  - Pursuing contacts with SLS/ELETTRA/CEA/SOLEIL/CERN
  - ACCEL commercial production?

- **DoE SBIR request for proposals due in September will include 1500MHz passive HOM damped cavity for future light sources:**
  - 2-cell, beampipe HOM damped cavity
  - $100k first year
  - Up to $750k additional 2 years
  - AES Inc. , Niowave Inc., both interested, capable

Vlasov simulations of CB modes

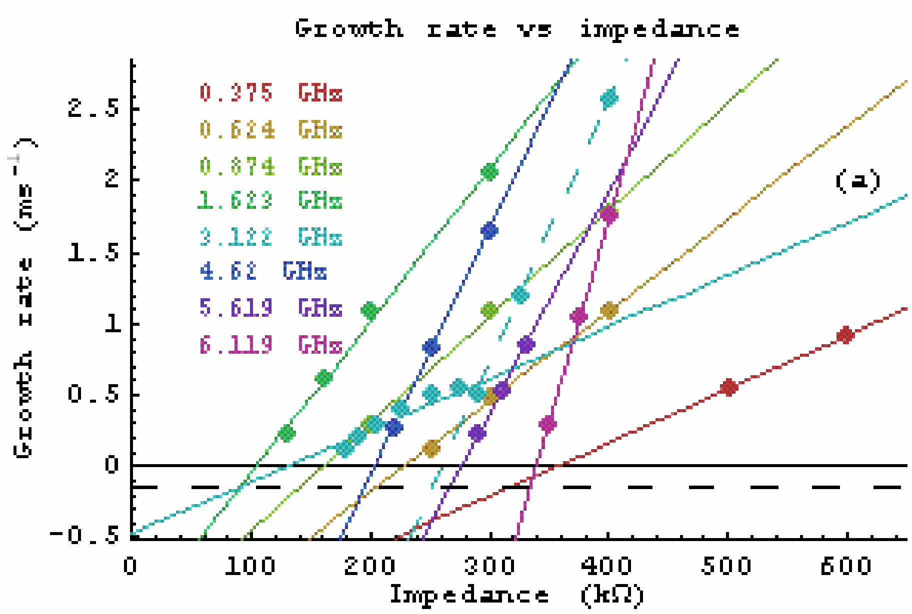
N. Towne

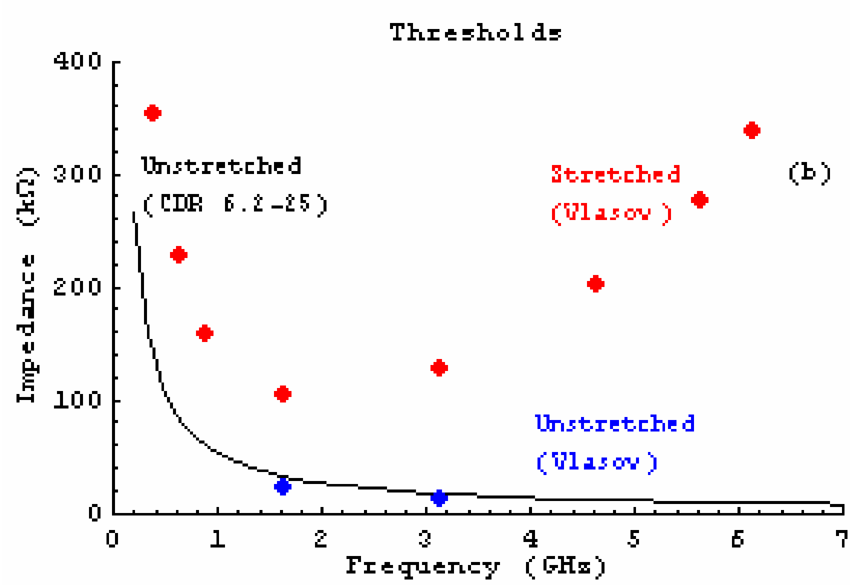




- At a given HOM frequency and impedance, the motion of the bunch centroid is fit to exponentially growing oscillation, and growth rate and frequency are extracted.
- Growth rates extracted from runs at different impedances but the same frequency are fit to a line, and the fit extrapolated to the zero-growth impedance.

CB modes in stretched bunches: results





- **With unstretched bunches impedance thresholds between 3-7 GHz were a concern since ferrite losses decreasing**
- **Thresholds increase to comfortable margins with stretched bunches.**

- **Short bunch operation must still be analyzed**

Transmitter

- Thompson transmitter consisting of ~310kW klystron (up to 400kW) 54kV, 12A DC power supply, controls, circulator with load, Siemens P7 PLC controls similar as for CLS
- May wish to increase to 400kW if KEK-B cavity will be chosen

Klystron RF stability vs. DC supply:

- **RF phase variation vs. beam voltage (constant mod. Anode voltage) 12 degrees/%**
- **RF power vs. beam voltage 0.2dB/%**

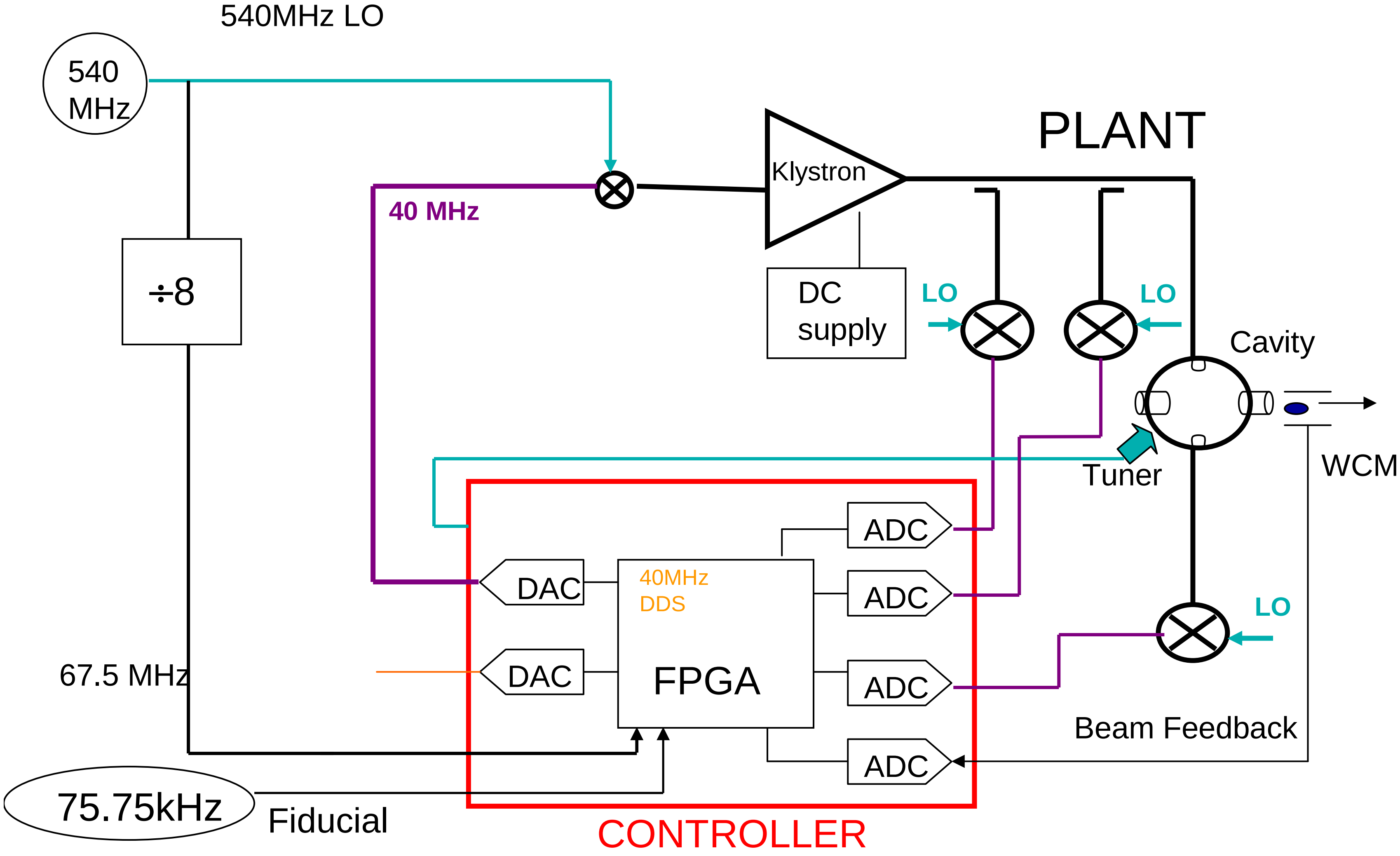
PSM power supply typical performance (54kV,12A)

- **Full range < 1% pk-pk**
- **75V from 1kHz-2kHz (0.14%) = 1.7 degrees**
- **15V from 2kHz-4kHz**
- **3V from 4kHz-12kHz**
- **50V for >12kHz**

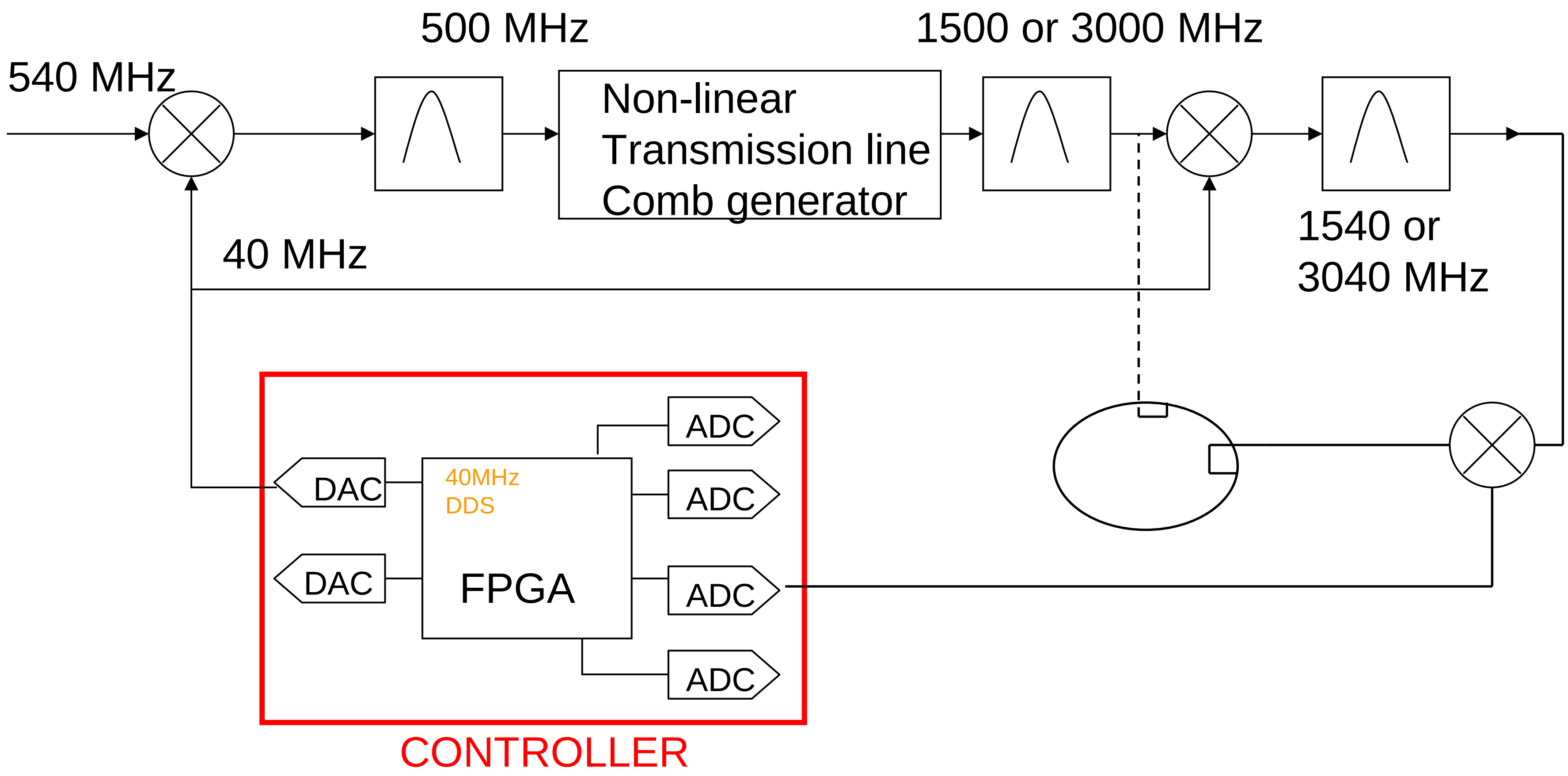
This is limiting factor in APS, ~1 degree phase jitter after feedback using mod-anode

Need fast scalar phase feedback!

RF System LLRF Architecture

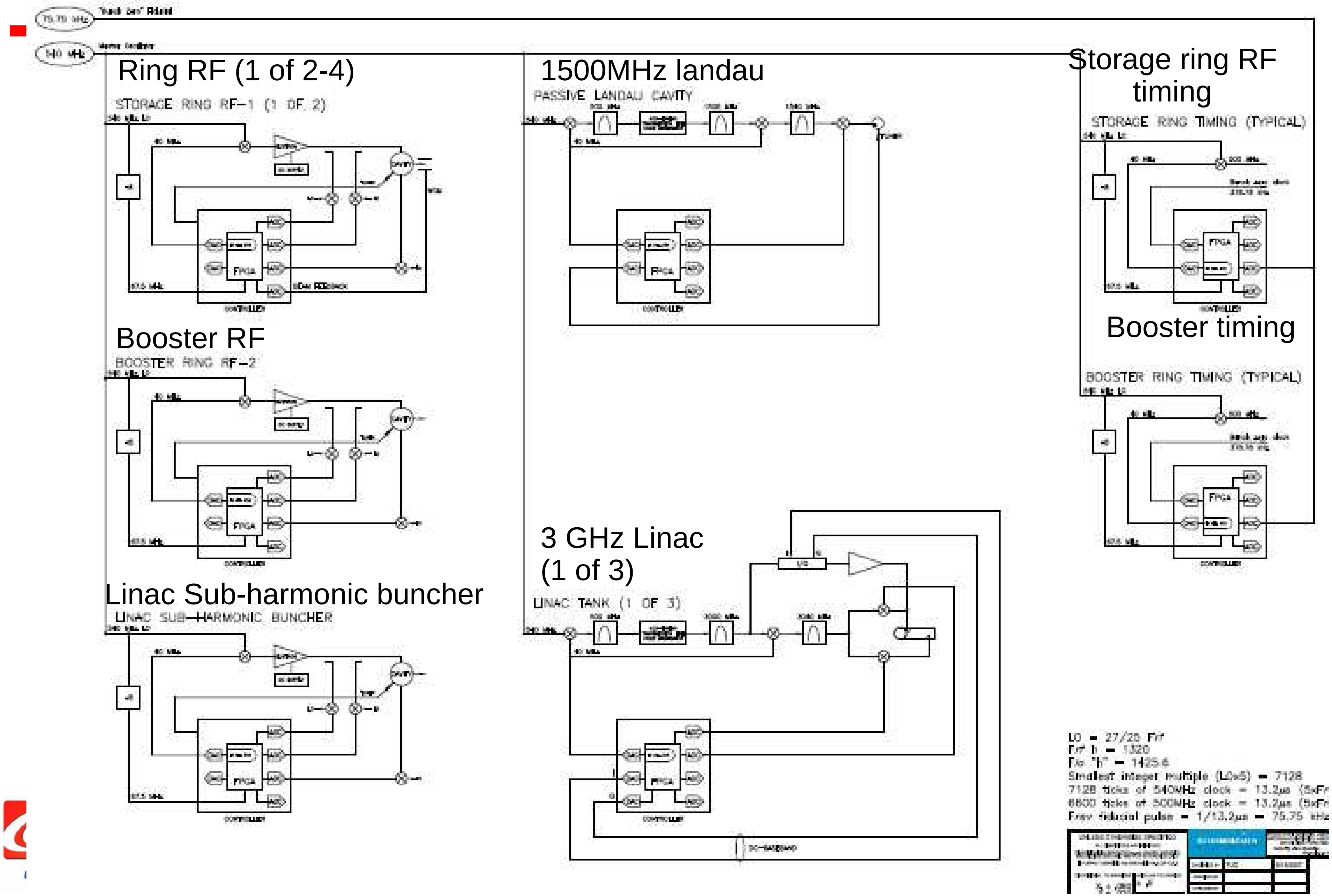


Creation of LO frequencies for down-conversion of 1500, 3000MHz

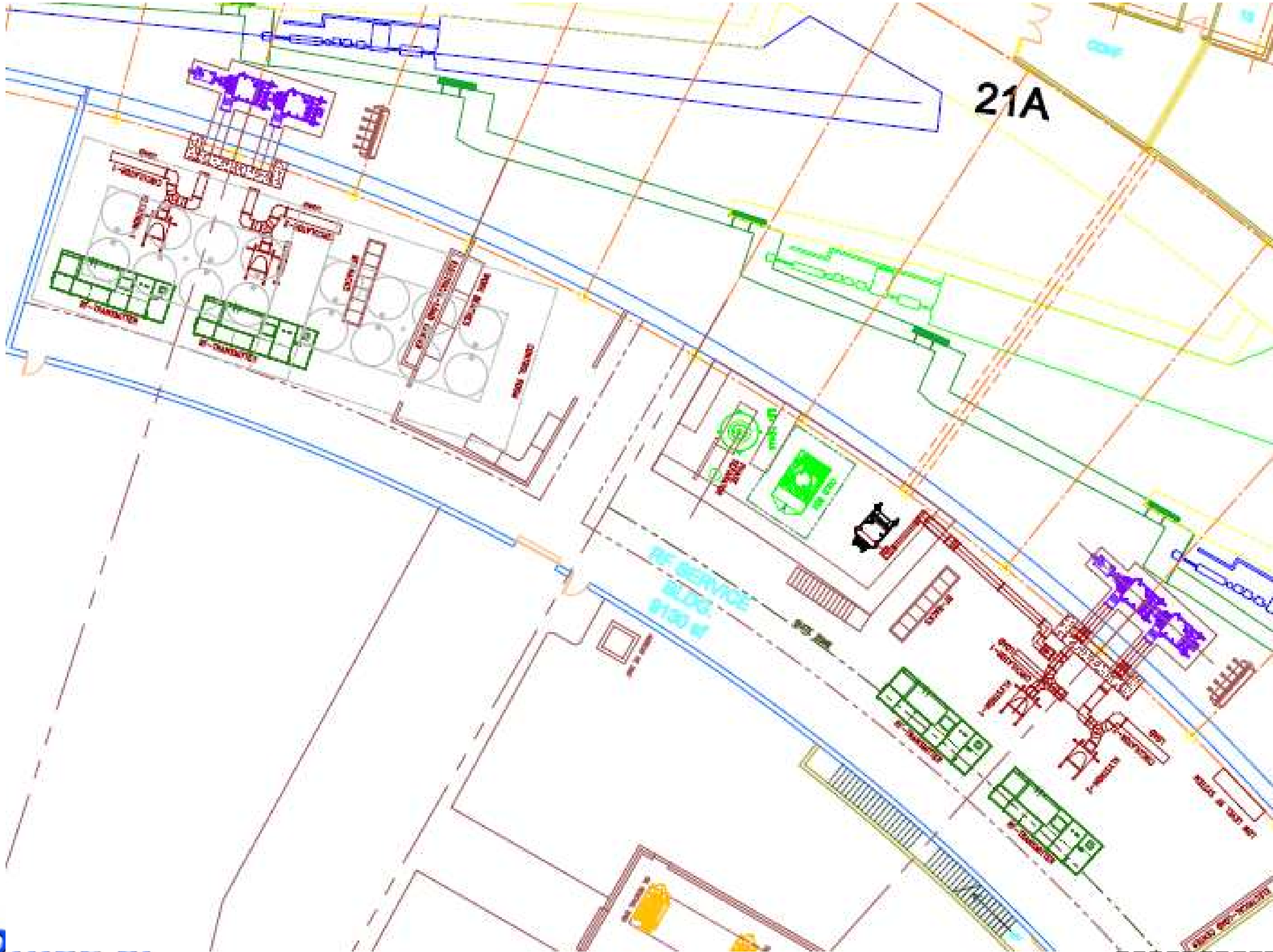


Non-linear transmission line is a lower noise comb generator (as compared to SRD)
http://www.picosecond.com/product/category.asp?pd_id=22

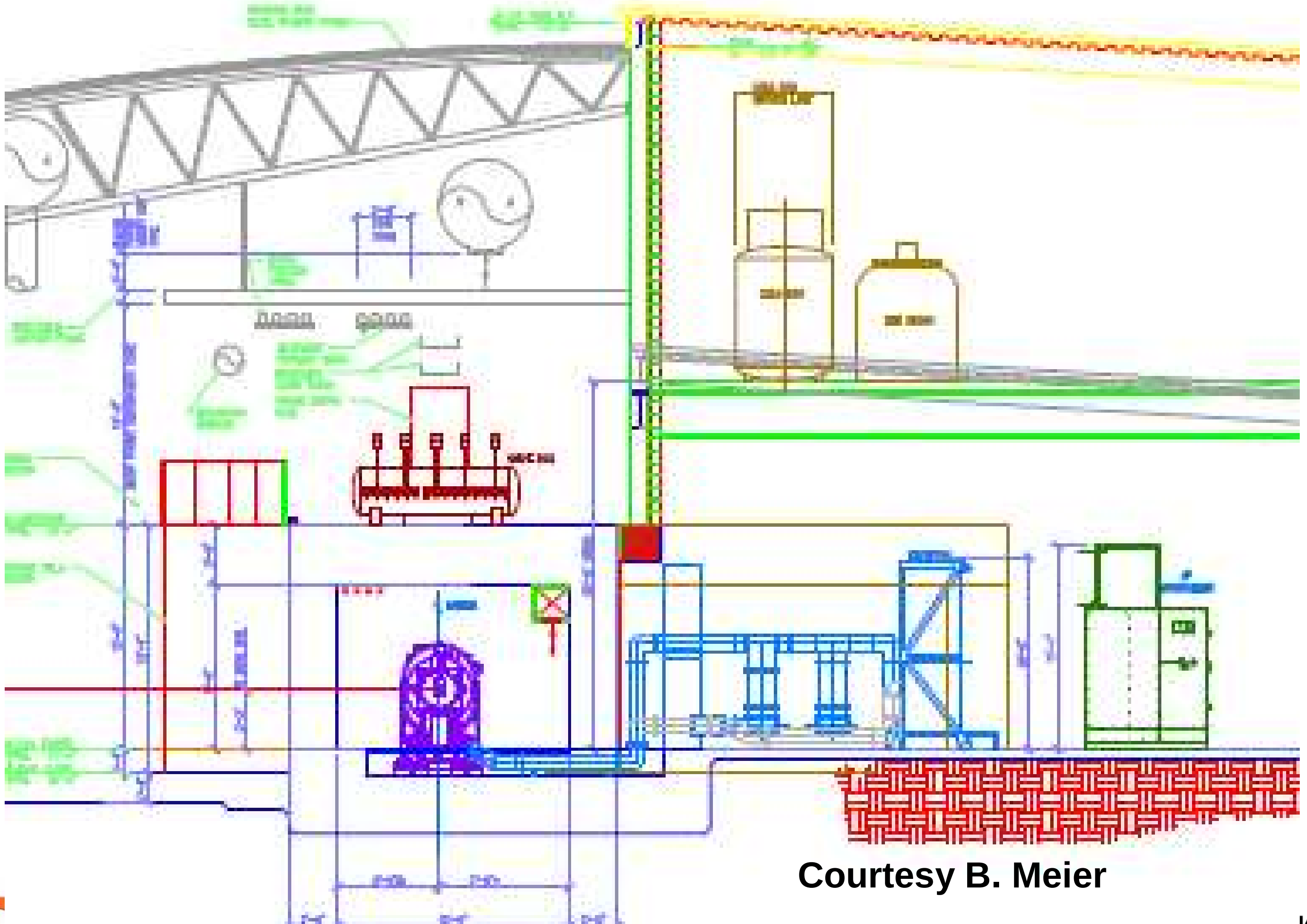
Overall LLRF system schematic



Storage ring RF Building layout



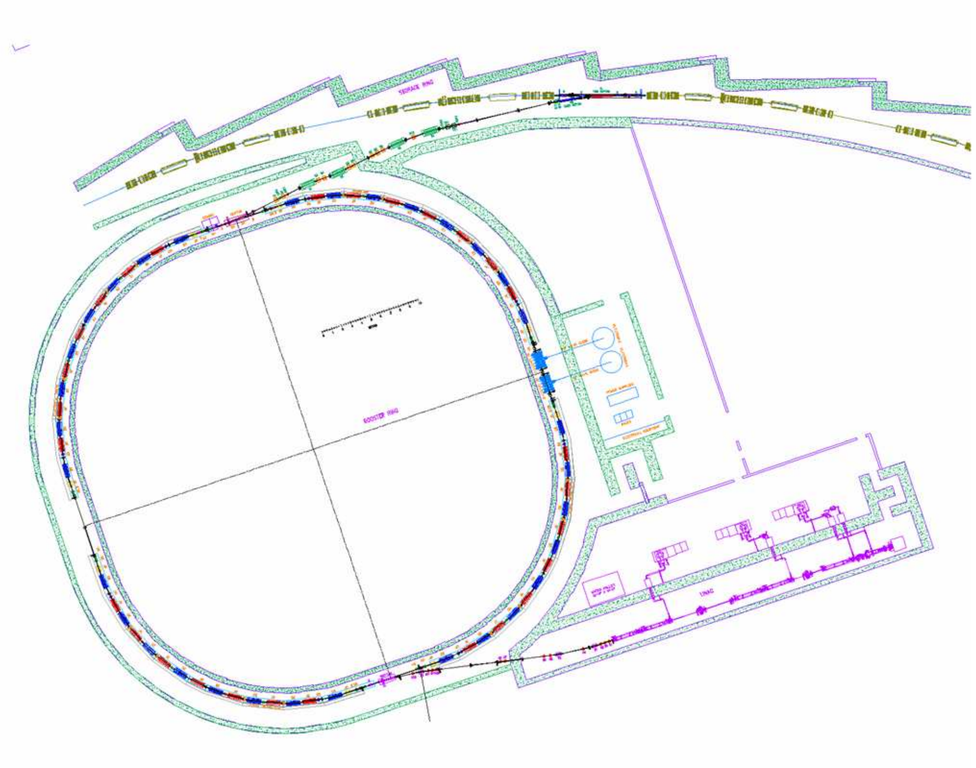
RF/Cryo Building cross section



Courtesy B. Meier

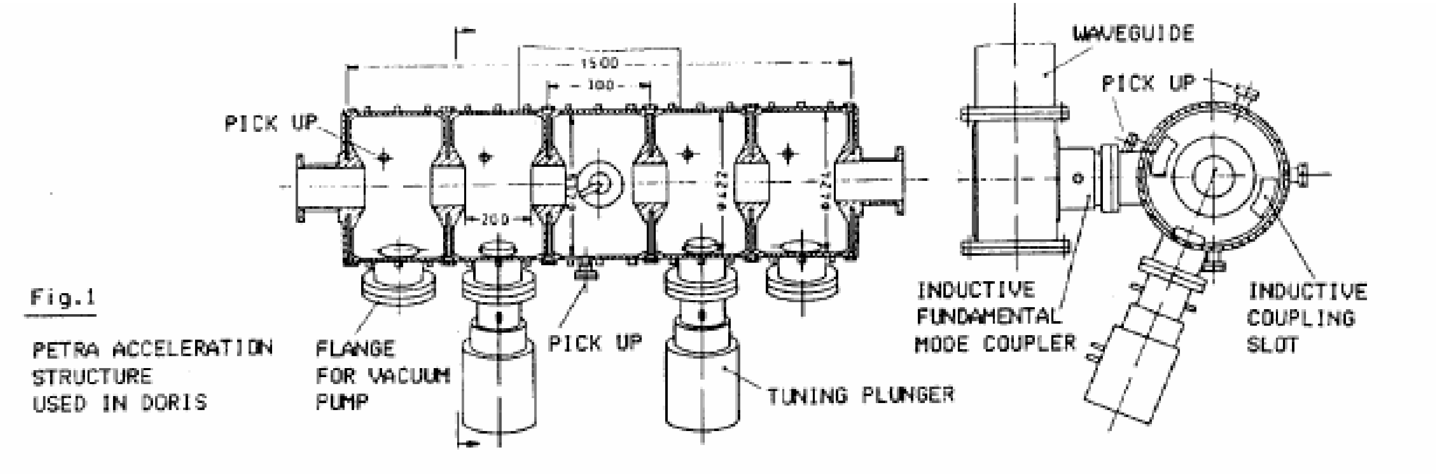
Booster RF

- Booster energy: 200MeV → 3 GeV
- RF frequency: 500 MHz
- Repetition rate: 1 Hz
- Beam current: 28 mA (15 nC circulating charge)
- Energy loss per turn: 625 keV
- Energy acceptance: 0.7% at 3 GeV → 1.2 MV booster RF voltage
- Momentum compaction: 0.0072
- Synchrotron frequency: 20 kHz
- PETRA-type 5 cell RF cavity
- RF voltage ramp



Booster Ring RF Requirements

- Energy loss per turn to 625keV/turn :
- RF voltage 1.2MV : 50kW cavity power
- Beam current = 28 mA → Beam power 18 kW



- Single IOT/cavity power is marginal for compact booster
- Decision to use 2 “Petra” type cavities and (1) 80 kW IOT
- OR 1 “Petra” type cavity and (1) 100 kW

Solid state amplifier: R&D program proposed with SLS

Summary

- Superconducting cavities are an economic choice to provide 3.3 (5) MV rf voltage and 1 (2) MW of beam power.
- CESR-B cavity is adopted for the baseline design, KEK-B cavity is an option for cost reasons and for higher power capability.
- For the Landau cavity two options are pursued: i) Super3HC of ELETTRA/SLS, ii) 2-cell cavity with beam pipe HOM absorbers.
- Longitudinal coupled bunch stability has still to be analyzed for unstretched bunches
- For the booster rf transmitter solid state and IOT are possible options. Solid state technology has operational advantages.