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# Overview of the NSLS-II RF System

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presented by Ernst Wehreter

- ◆ 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 emittance	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 $\mu\text{m}$	< 1 $\mu\text{m}$
Top-off Injection Current stability ( $\Delta t > 2$ min.)	< 1%	< 0.1%
Momentum Compaction	0.00037	0.00037

# NSLS II Design Approach

- Large circumference of 780m (soft bends) for low natural emittance,  $\epsilon_0 = 2 \text{ nm}$  (144kW beam power)
- 54 m of 1.8 T damping wigglers in zero dispersion straights to further reduce emittance to 0.5nm. (> 500kW of beam power!)

$$\frac{\epsilon_w}{\epsilon_0} = \frac{1+f}{1 + \frac{L_w}{4\pi\rho_0} \left(\frac{\rho_0}{\rho_w}\right)^2} \quad \frac{\delta_w}{\delta_0} = \sqrt{\frac{1 + \frac{L_w}{2\pi\rho_0} \frac{4}{3\pi} \left(\frac{\rho_0}{\rho_w}\right)^3}{1 + \frac{L_w}{4\pi\rho_0} \left(\frac{\rho_0}{\rho_w}\right)^2}}$$

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

# NSLS-II RF VOLTAGE, POWER REQUIREMENTS

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	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
<b>TOTAL</b>		<b>529</b>		<b>1003</b>
<b>Available RF Power</b>		<b>540</b>		<b>1080</b>

# Design Concept/Design Goal

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## 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

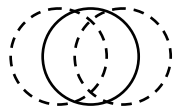
Weiming Guo et al, PAC 2007

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

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

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

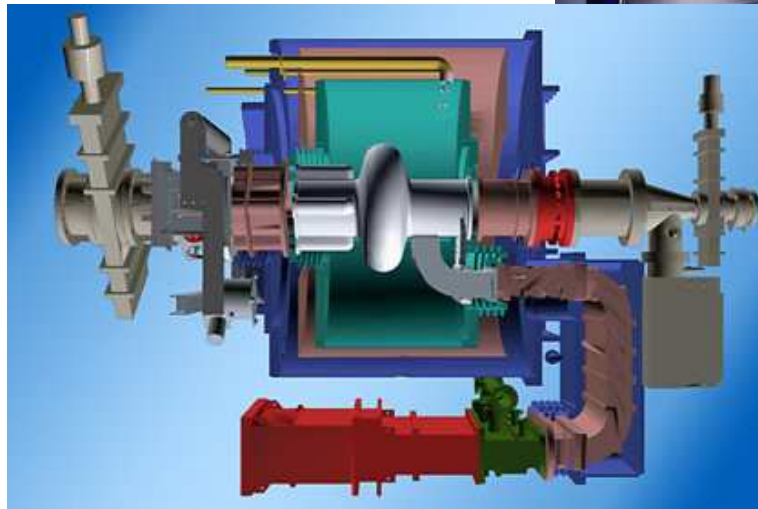
$$y = y_0 + \eta_y \langle \delta \rangle$$



	$\Delta\phi$ (°)	$d\delta$ (x10 <sup>-4</sup> )
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

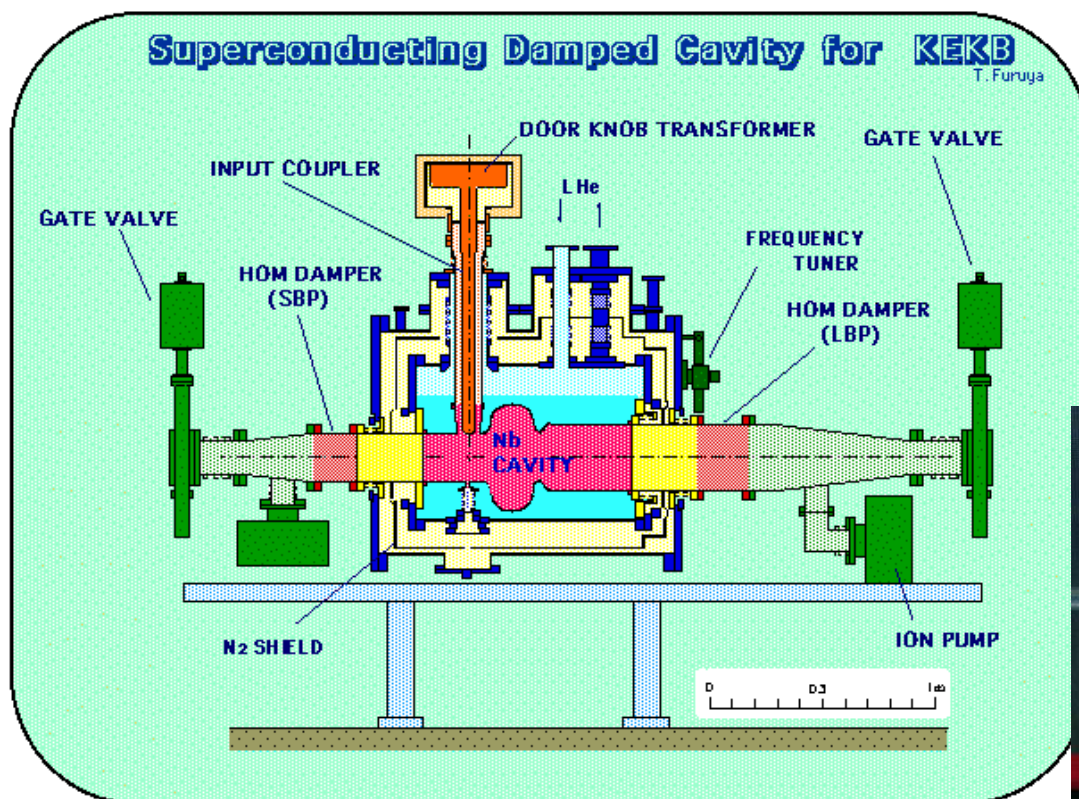
# CESR-B Cavity chosen for Baseline



**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)**

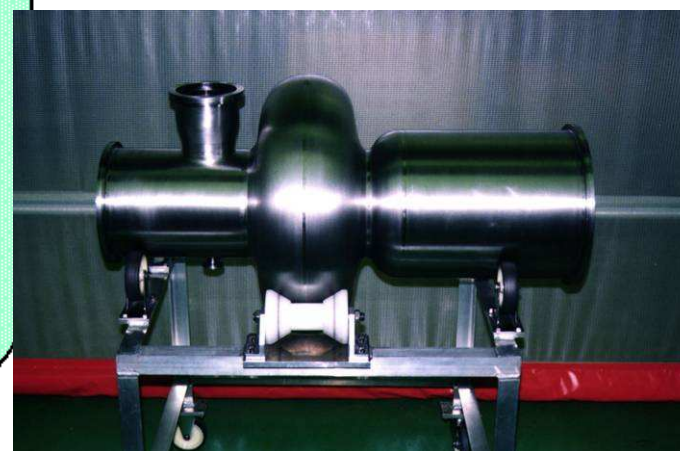
<b>Frequency</b>	<b>500 MHz</b>
<b>Beam energy gain/cav</b>	<b>&gt;2.4 MV</b>
<b>Eacc</b>	<b>&gt;8 MV/m</b>
<b>Unloaded Q</b>	<b>&gt;7·10<sup>8</sup></b>
<b>Standby (static) losses</b>	<b>&lt;30 W</b>
<b>Dynamic + static losses</b>	<b>&lt;120W</b>
<b>Operating Temperature</b>	<b>4.5 K</b>
<b>Max. beam power/cavity</b>	<b>&lt;250 kW</b>

# 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

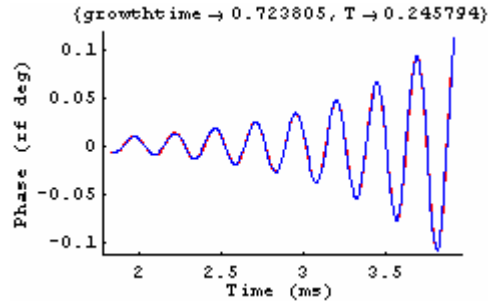


# Landau Cavity

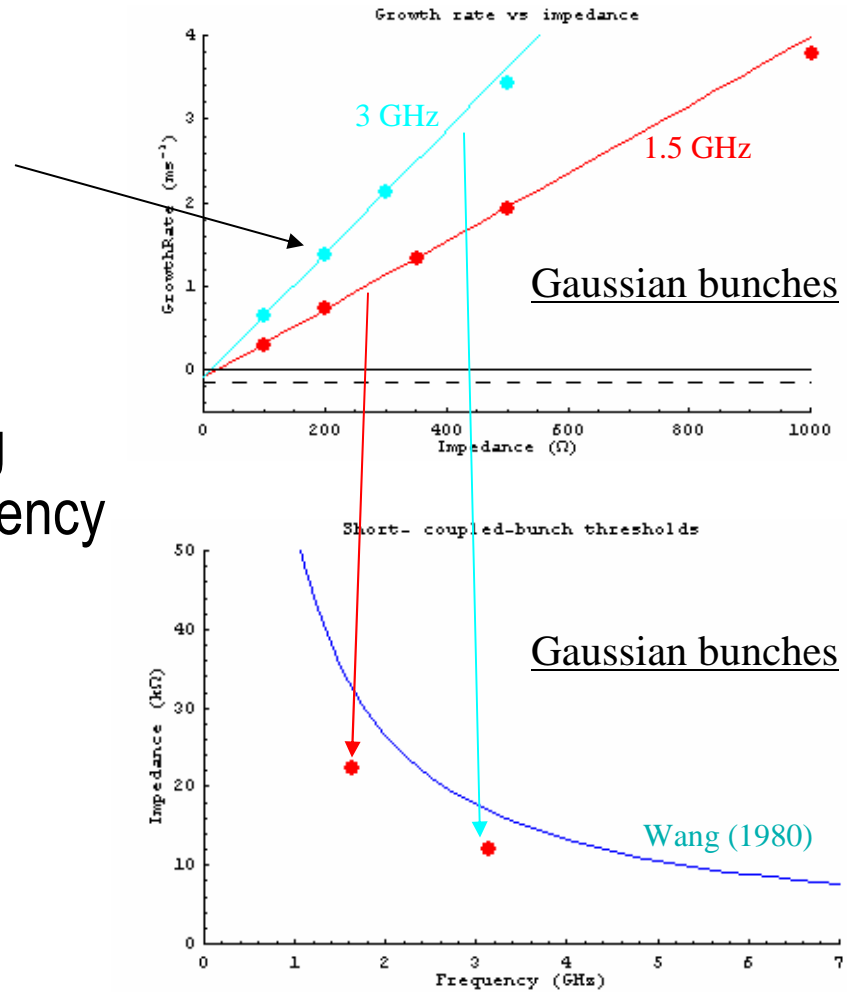
- **Super3HC cavity developed by SLS/ELETTRA/CEA-Saclay-CERN collaboration meets baseline requirements, 2<sup>nd</sup> cavity for fully built out system**
  - Longitudinal HOM impedance (7k-ohm) marginal for bare lattice, short bunches
  - Pursuing contacts with SLS/ELETTRA/CEA/SOLEIL/CERN
  - ACCEL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

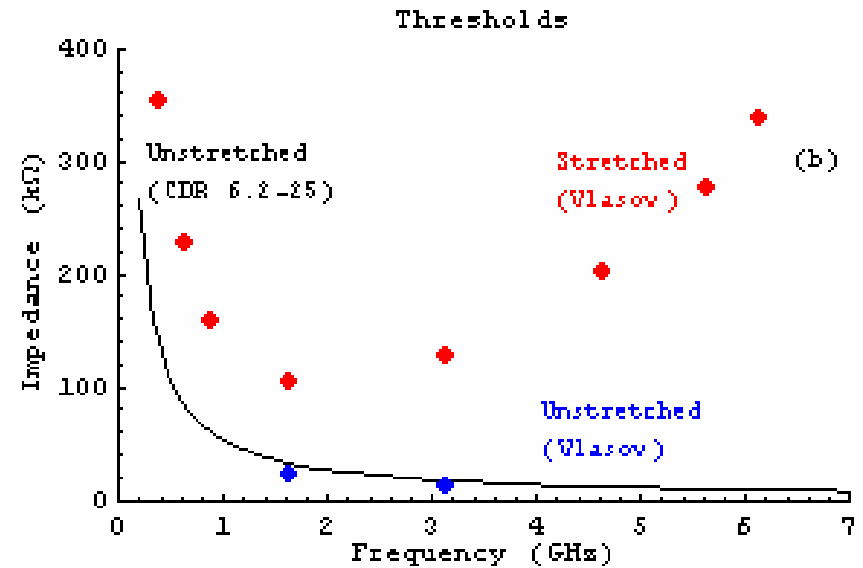
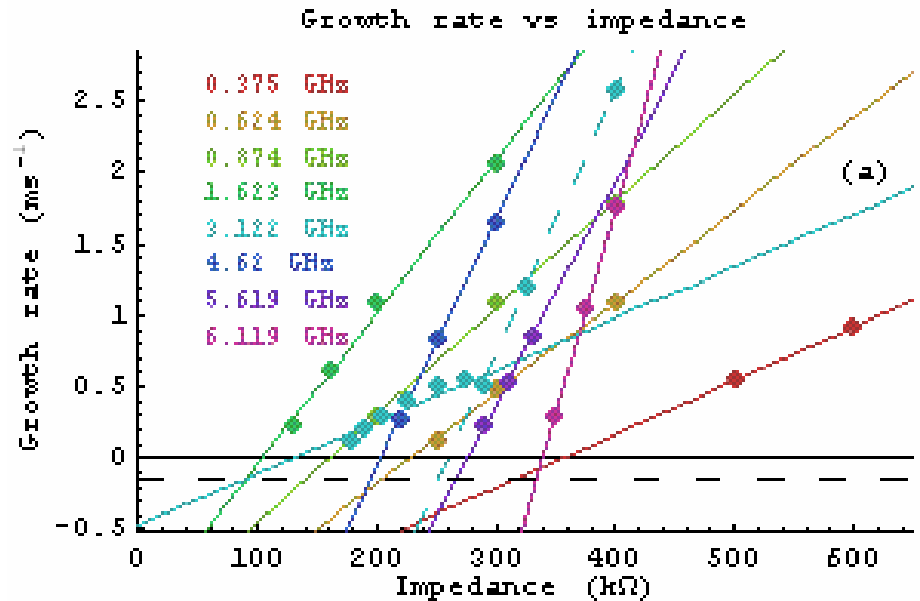
N. Towne



- 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
- Short bunch operation must still be analyzed
- Thresholds increase to comfortable margins with stretched bunches.

# 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:

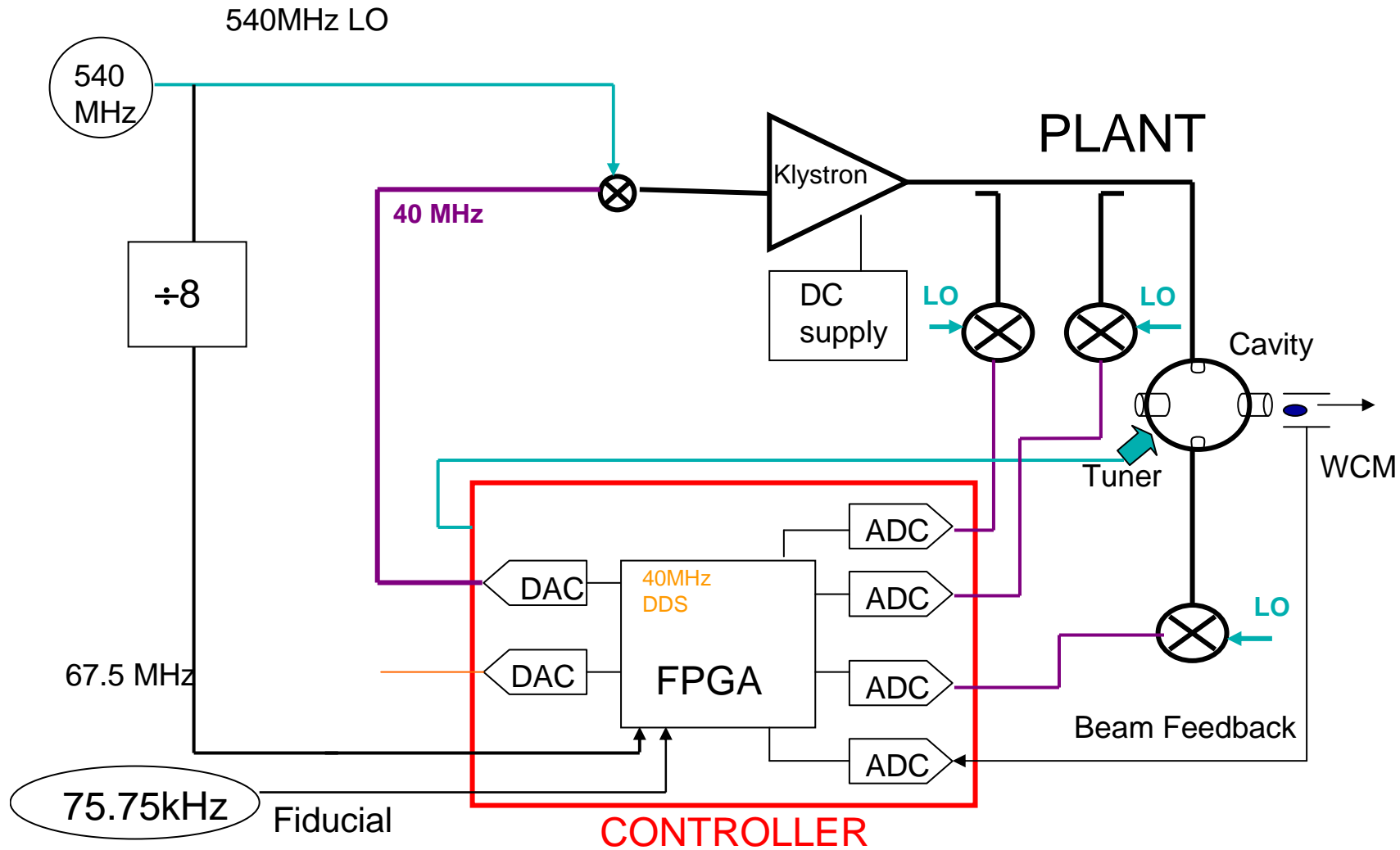
- RF phase variation vs. beam voltage (constant mod. Anode voltage) 12 degrees/%
- RF power vs. beam voltage 0.2dB/%

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

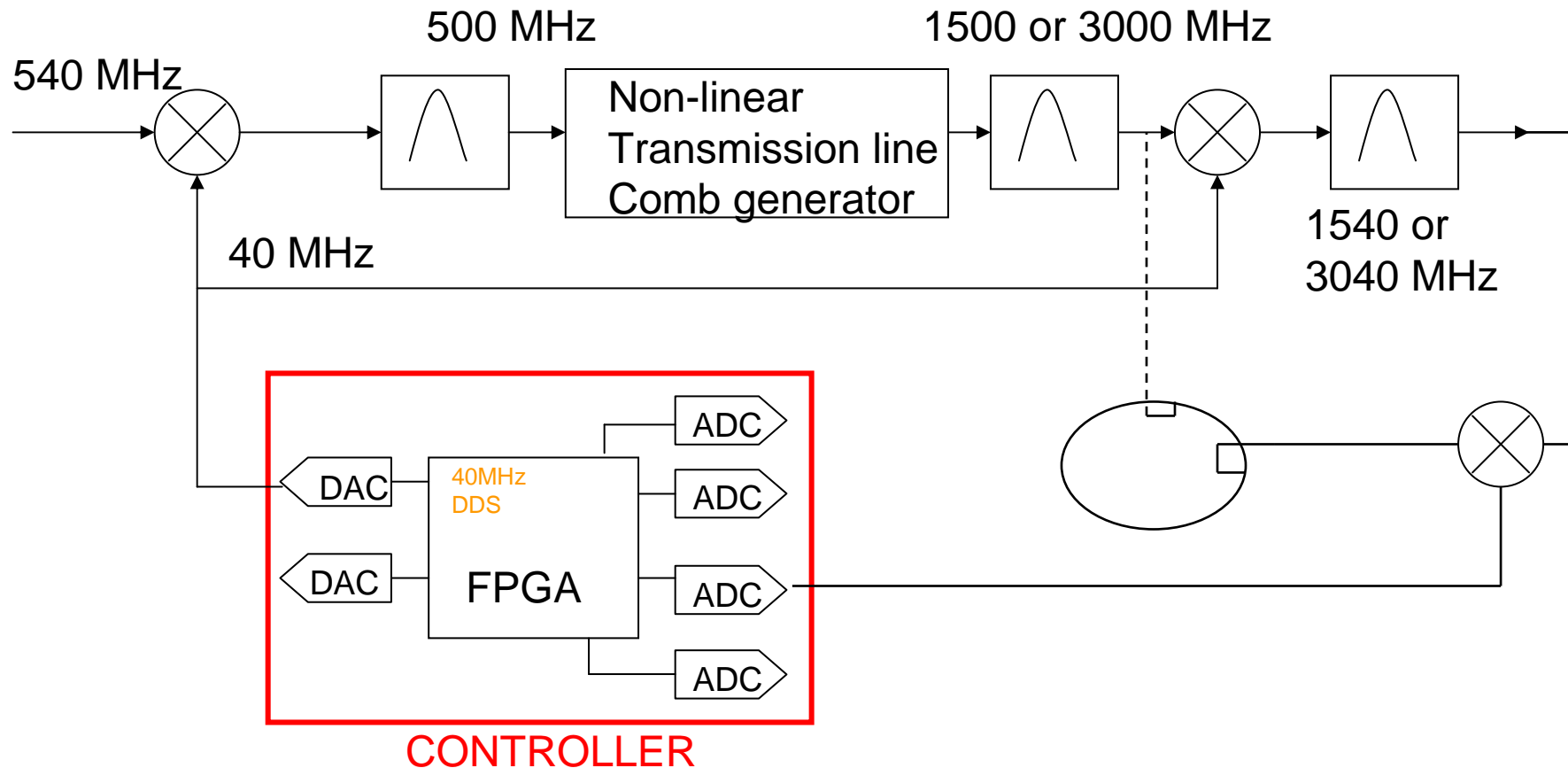
- Full range < 1% pk-pk
- 75V from 1kHz-2kHz (0.14%) = 1.7 degrees
- 15V from 2kHz-4kHz
- 3V from 4kHz-12kHz
- 50V for >12kHz

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

# RF System LLRF Architecture

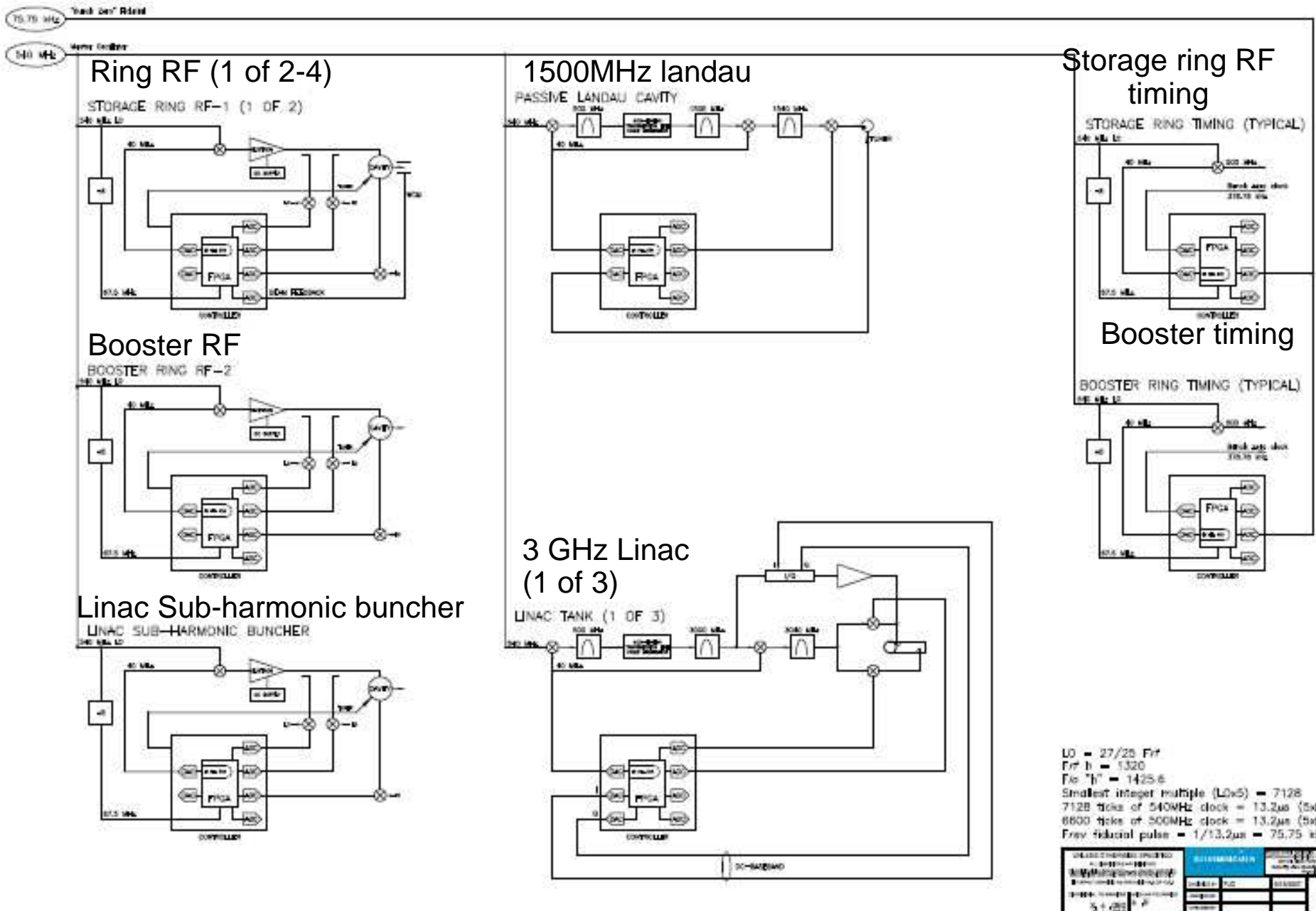


# Creation of LO frequencies for down-conversion of 1500, 3000MHz

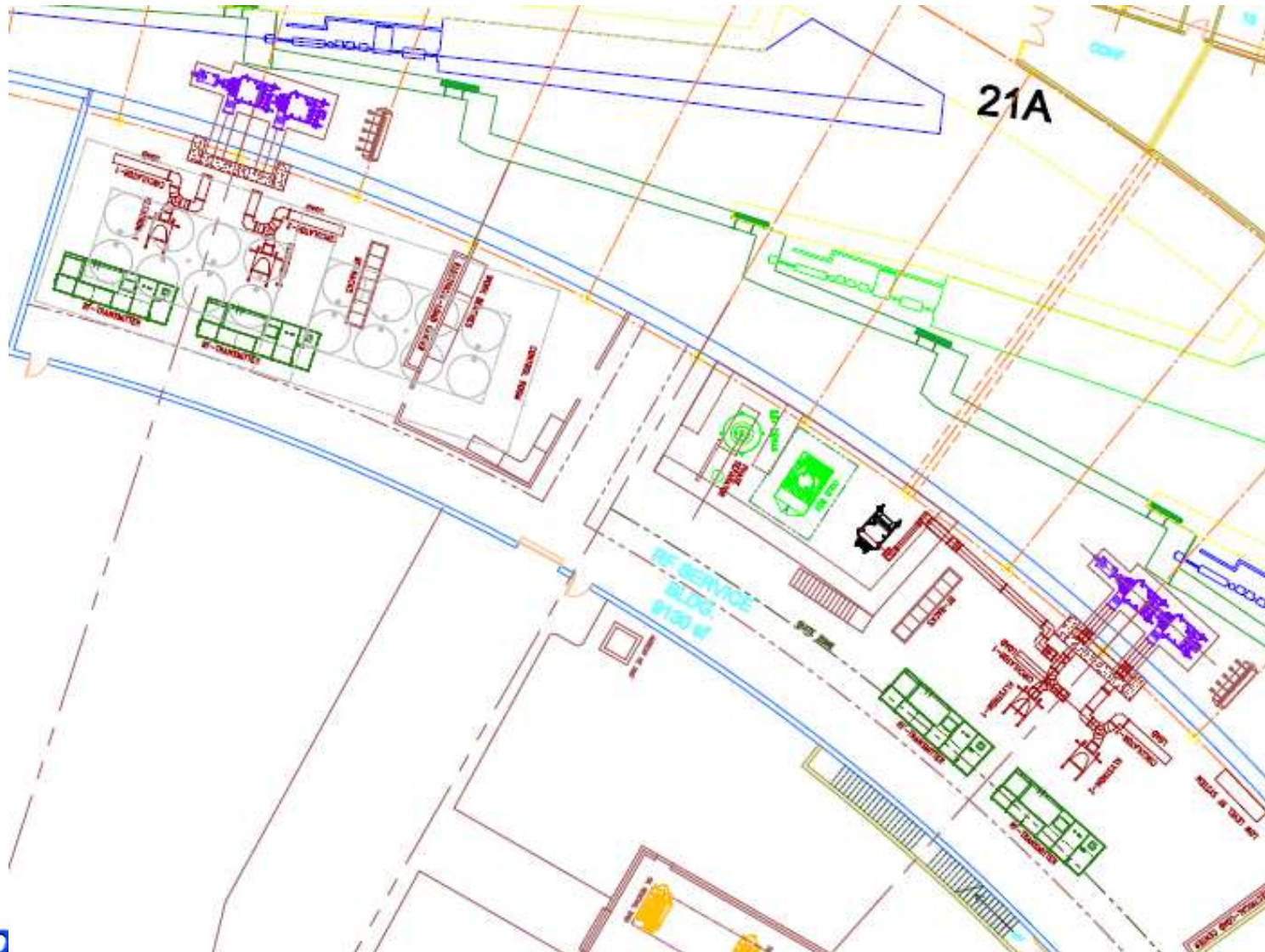


Non-linear transmission line is a lower noise comb generator (as compared to SRD)  
[http://www.picosecond.com/product/category.asp?pd\\_id=22](http://www.picosecond.com/product/category.asp?pd_id=22)

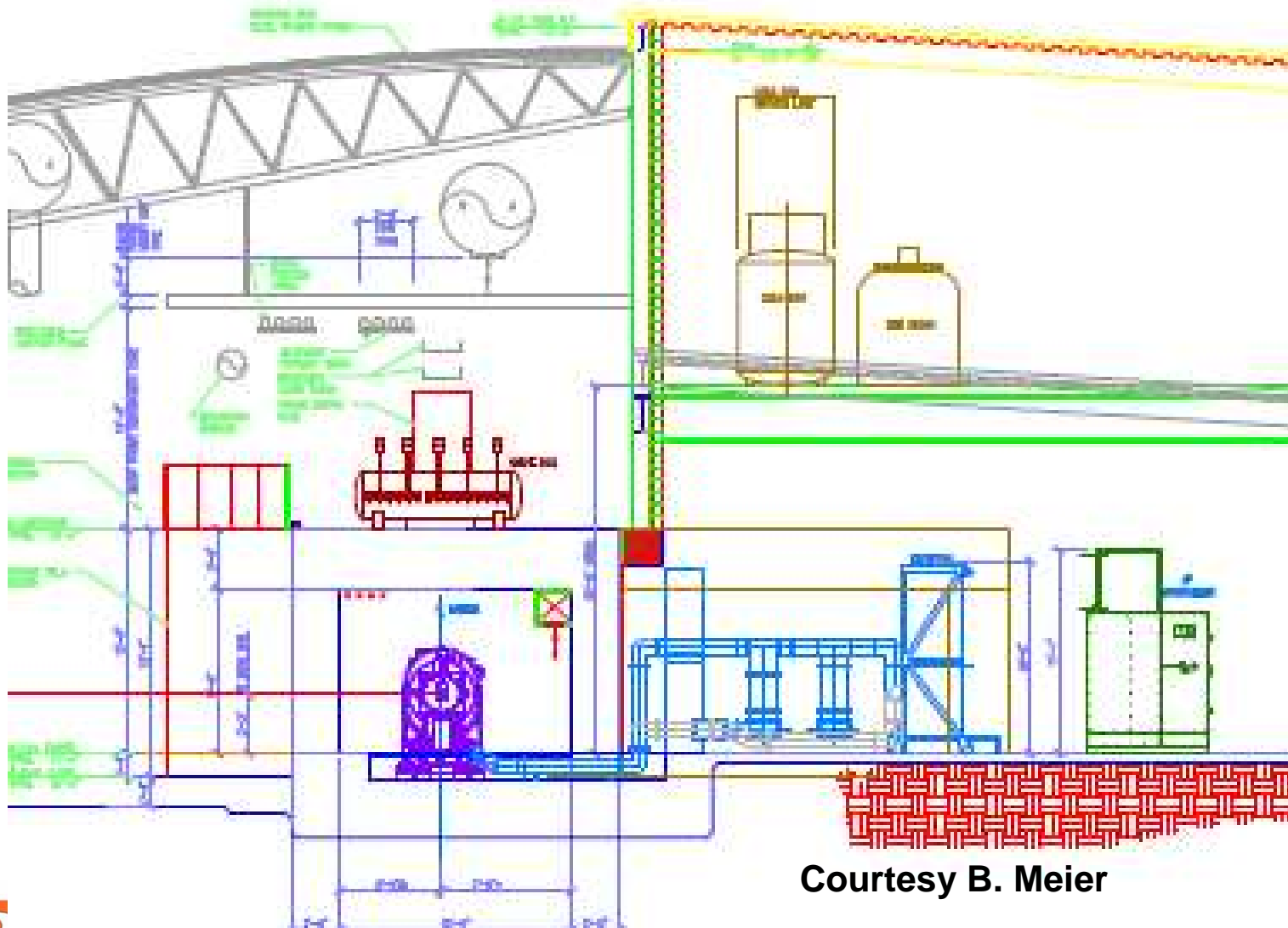
# Overall LLRF system schematic



# Storage ring RF Building layout



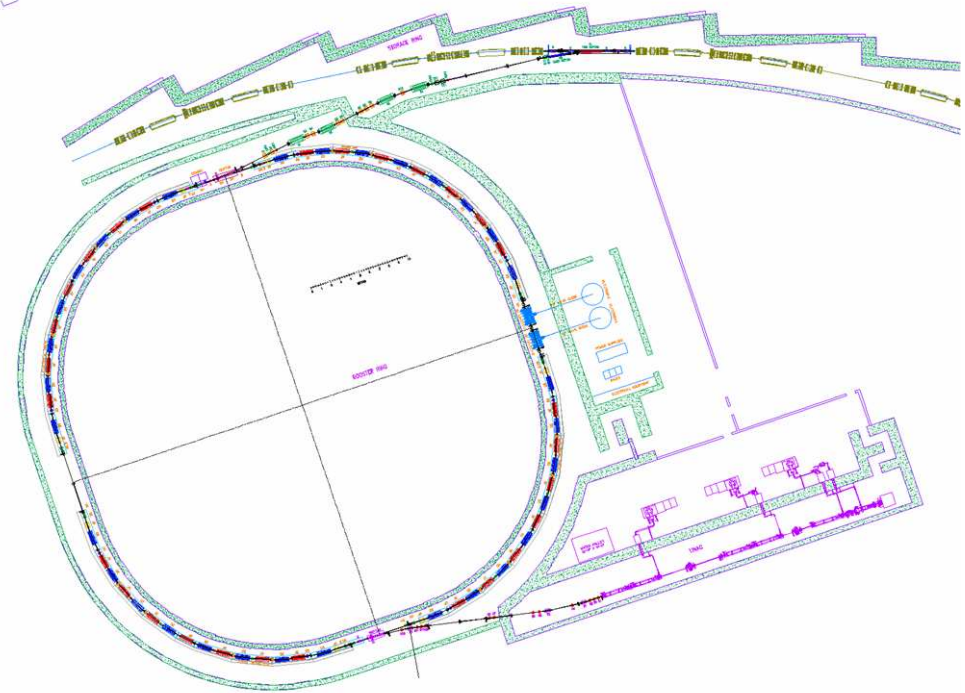
# RF/Cryo Building cross section



Courtesy B. Meier

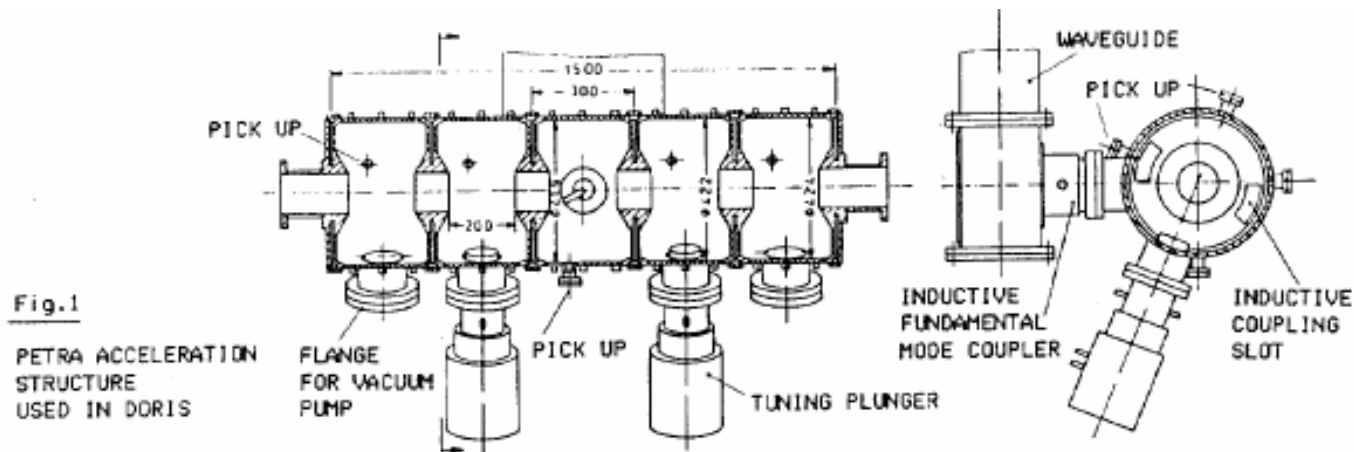
# Booster RF

- Booster energy: 200MeV  $\rightarrow$  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  $\rightarrow$  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

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- 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.