ALPHA Project in Indiana University

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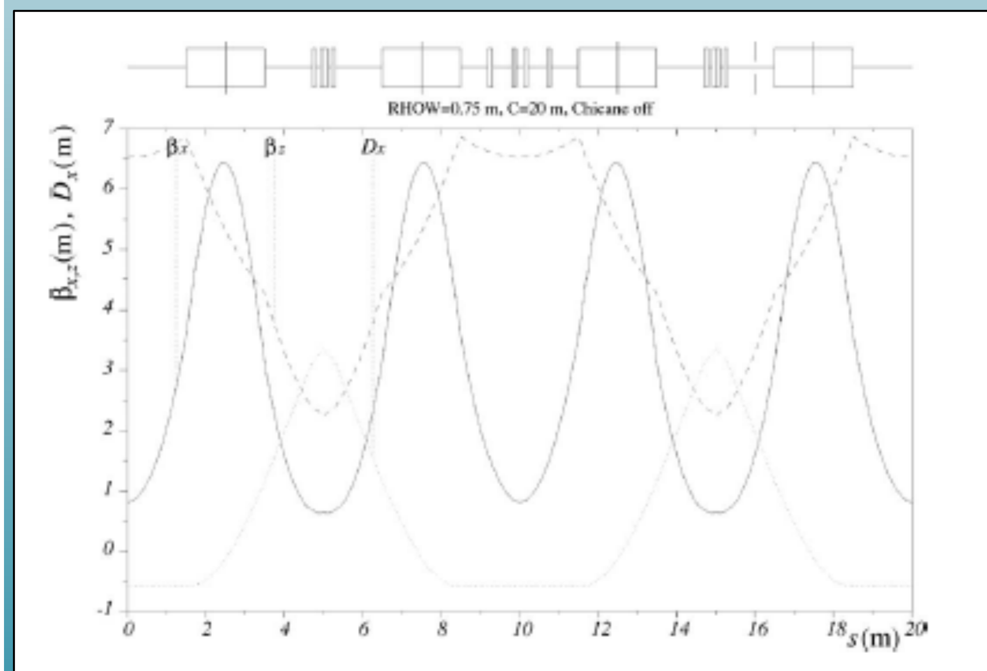
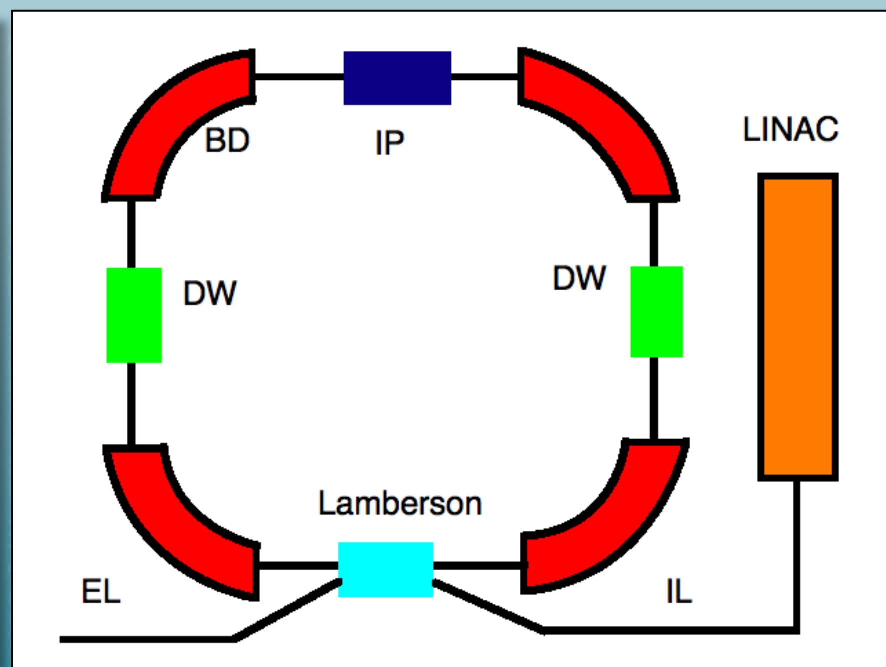
ALPHA in Indiana University

- ALPHA, Advanced eLectron-PHoton fAcility, is an electron accelerator under construction in Indiana University.
- Mission of ALPHA:

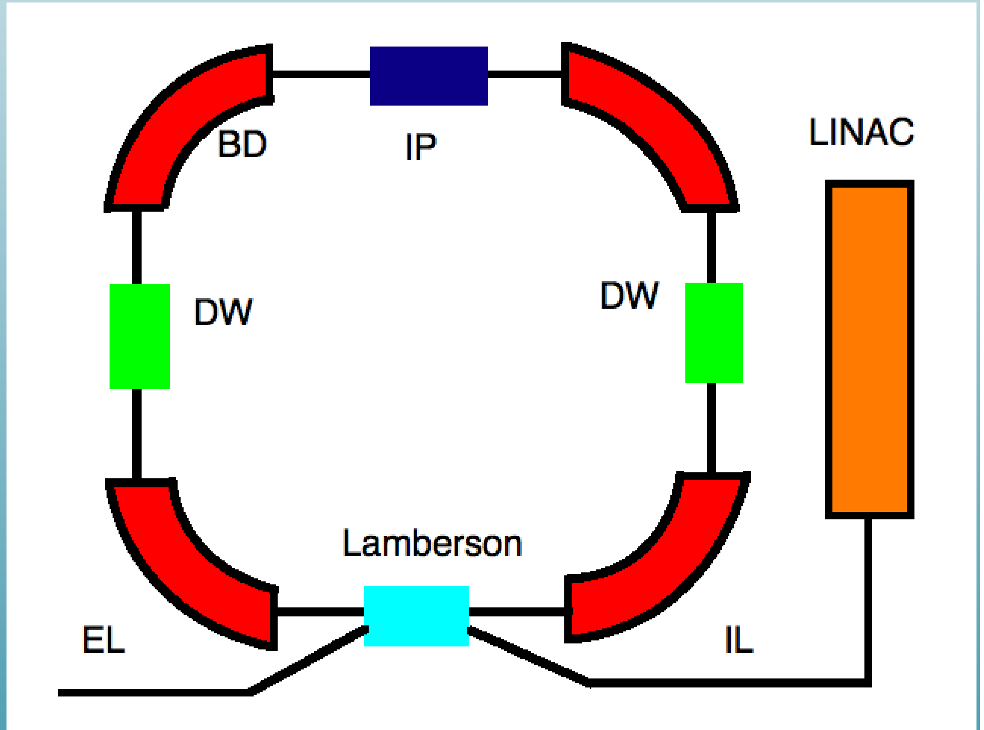
1) Provide high current electron beam for the radiation effect test (single pass mode and accumulation mode).
2) Beam dynamics study : intra-beam scattering and Touschek effect.
3) Future upgrade for Inverse Compton Scattering X-ray.





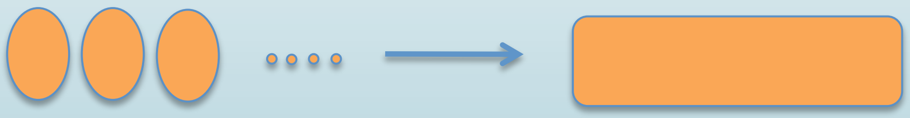
Single Pass Mode

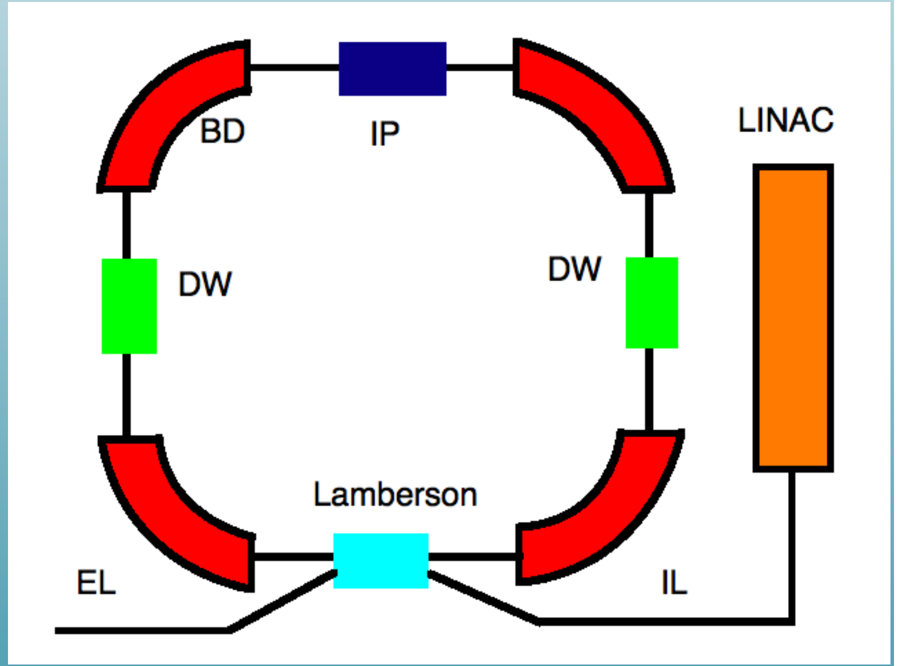
- To provide debunched beam.
- Microbunch structure from LINAC has GHz signal, which will interfere with radiation test signal.
- Momentum compaction effect: beam with different energy have different path lengths in the ring. With certain momentum spread, the microbunch will increase its length and de-bunch.



Accumulation mode

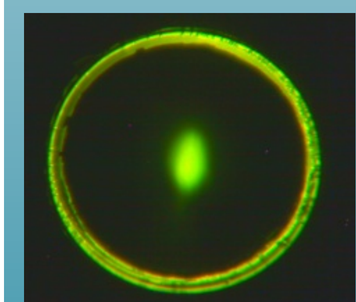
- To provide uniform and large dose radiation.
- Multi-bunch injection with pulsed magnetic kicker.
- To achieve uniform beam with 40 ns length: a h=3 Cavity or nonlinear spreading.
- Extraction kicker with fast rising time (~ 10 ns).

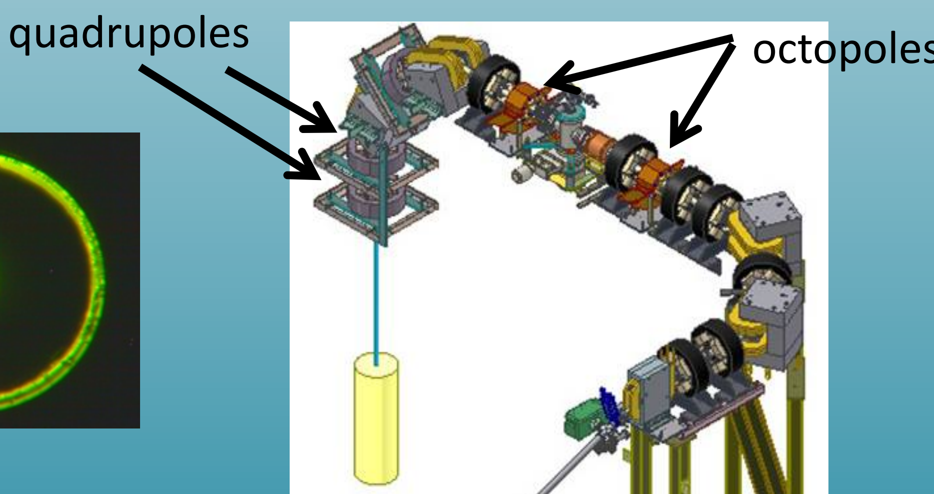


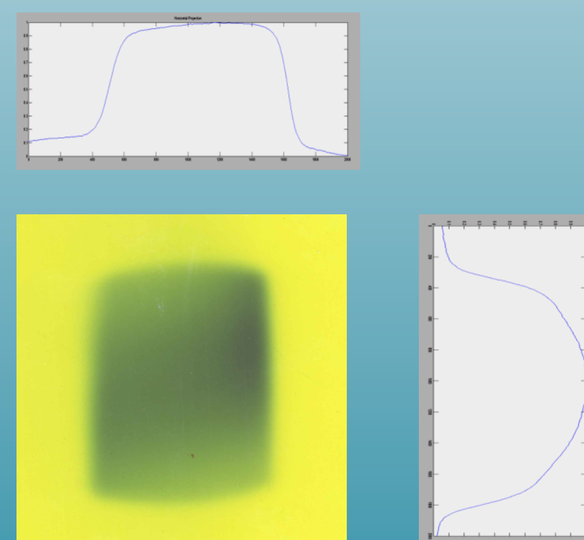


Current Status (by April 2011)

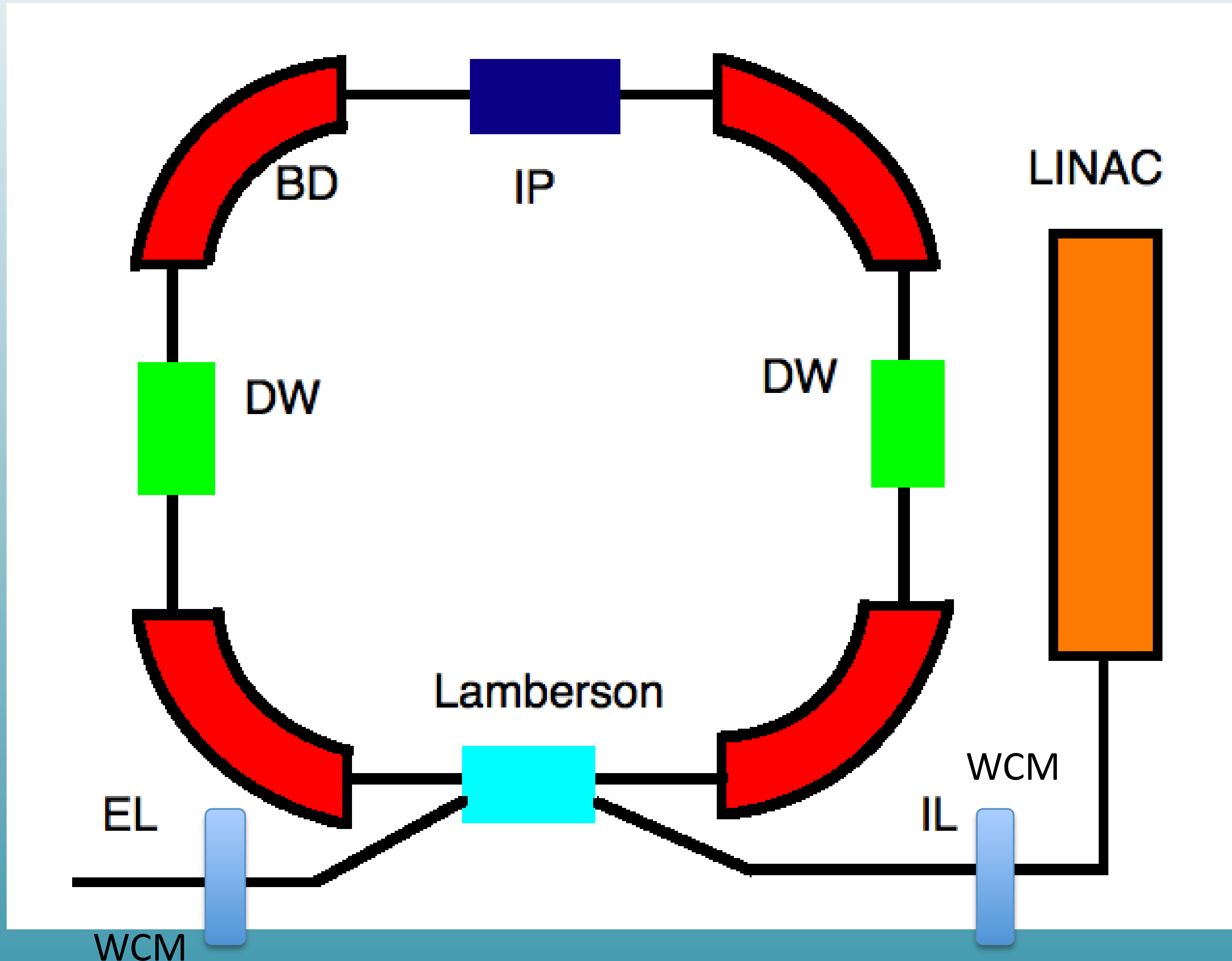
- The construction of injection line, extraction line and most of the synchrotron has been finished.
- The single pass mode has been commissioned successfully.
- The debunching effect and non-linear beam spreading has been demonstrated.
- The instrumentation for the accumulation mode, including RF cavity, Beam Position Monitor, Fast extraction kicker, magnetic kicker, damping wigglers, etc. are in preparation and will be installed soon.



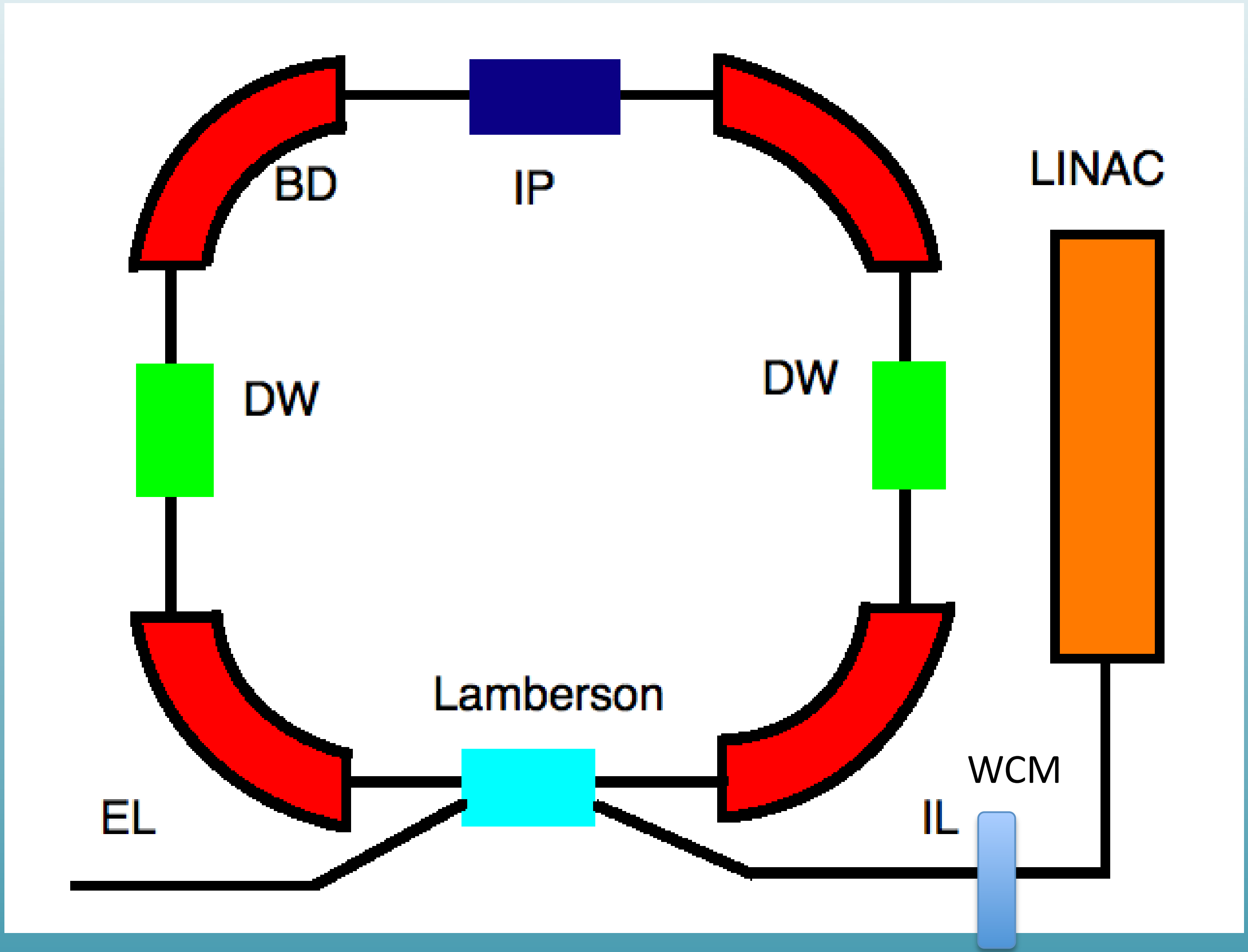




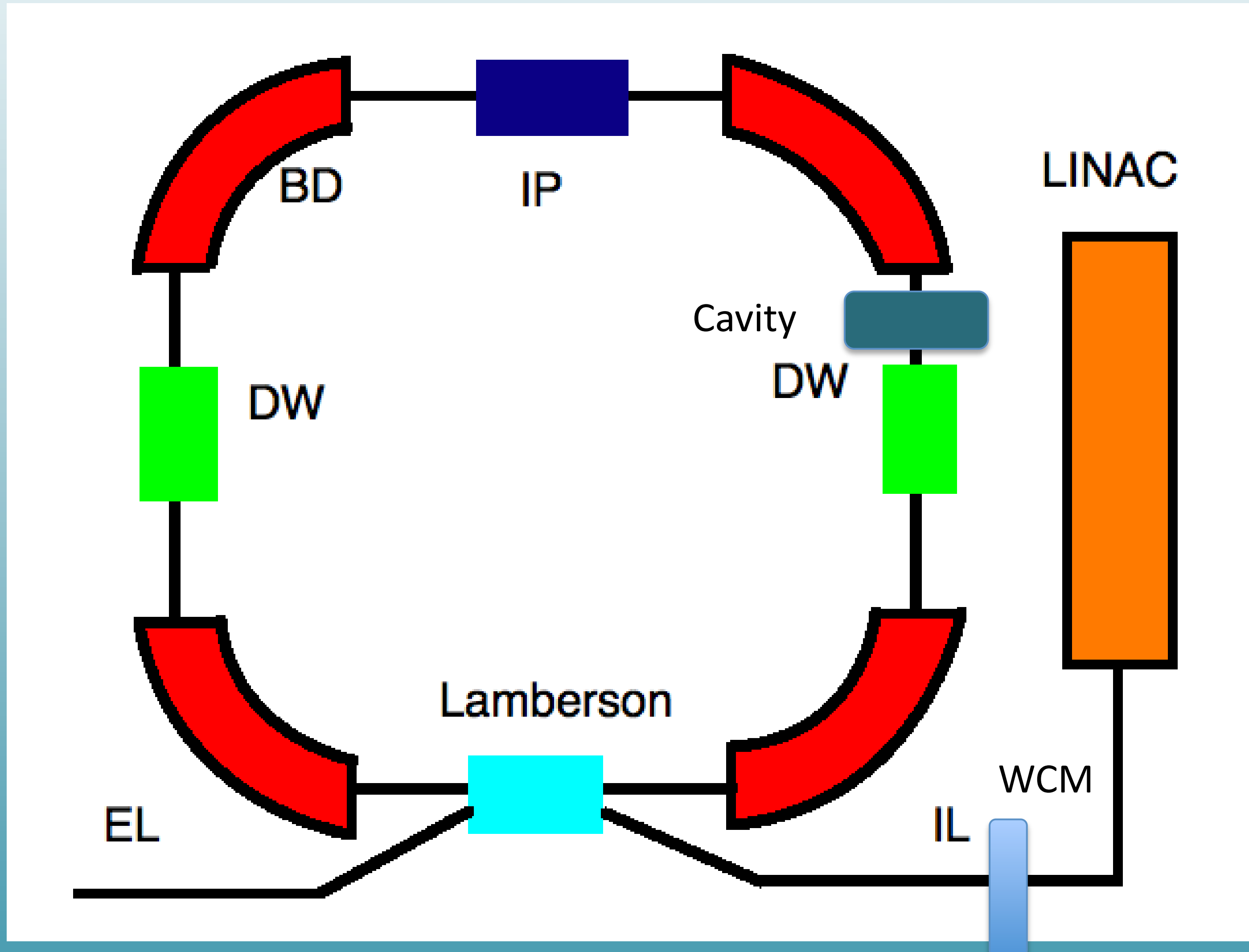
Verify the debunching effect.



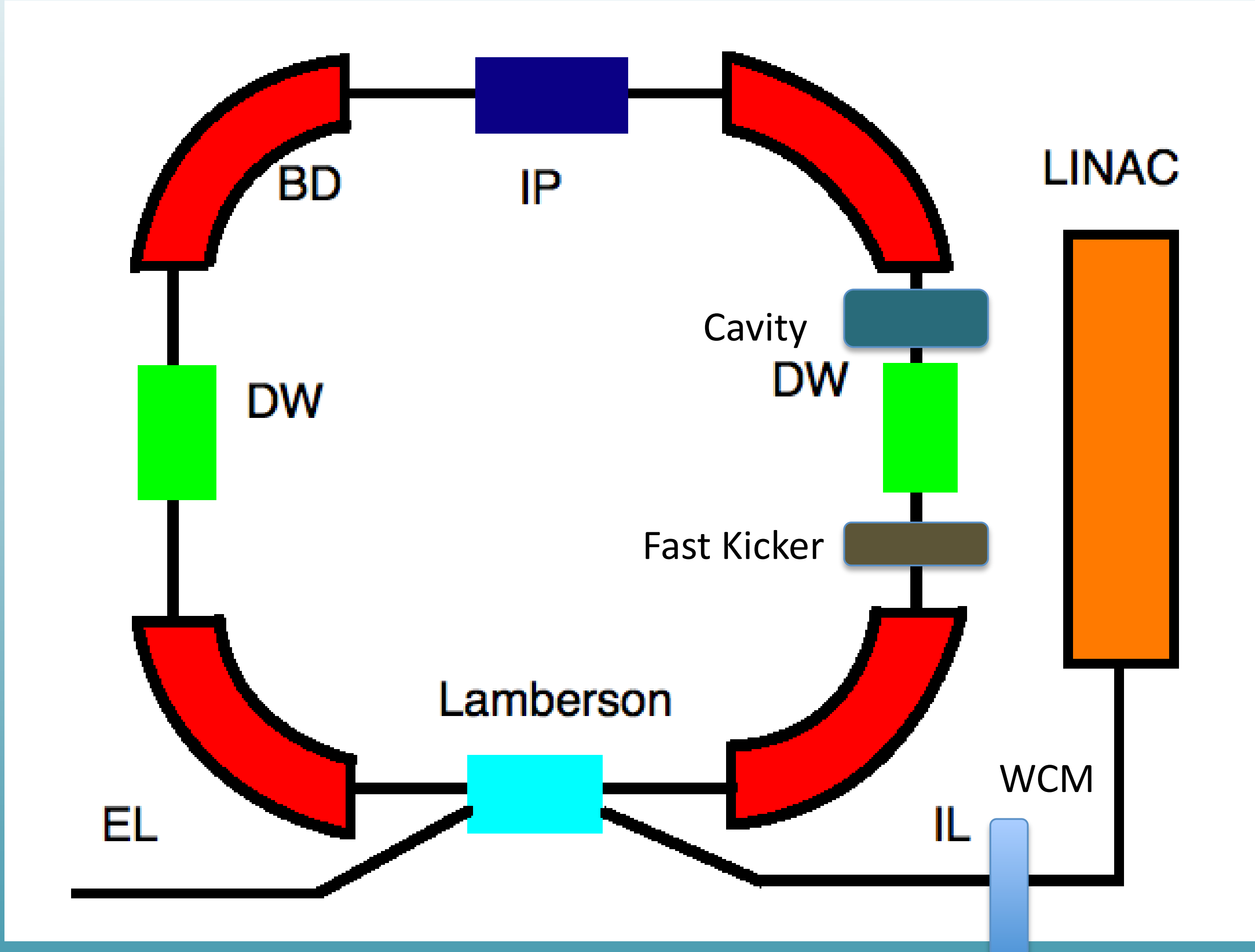
LINAC Beam Longitudinal phase space measurement.



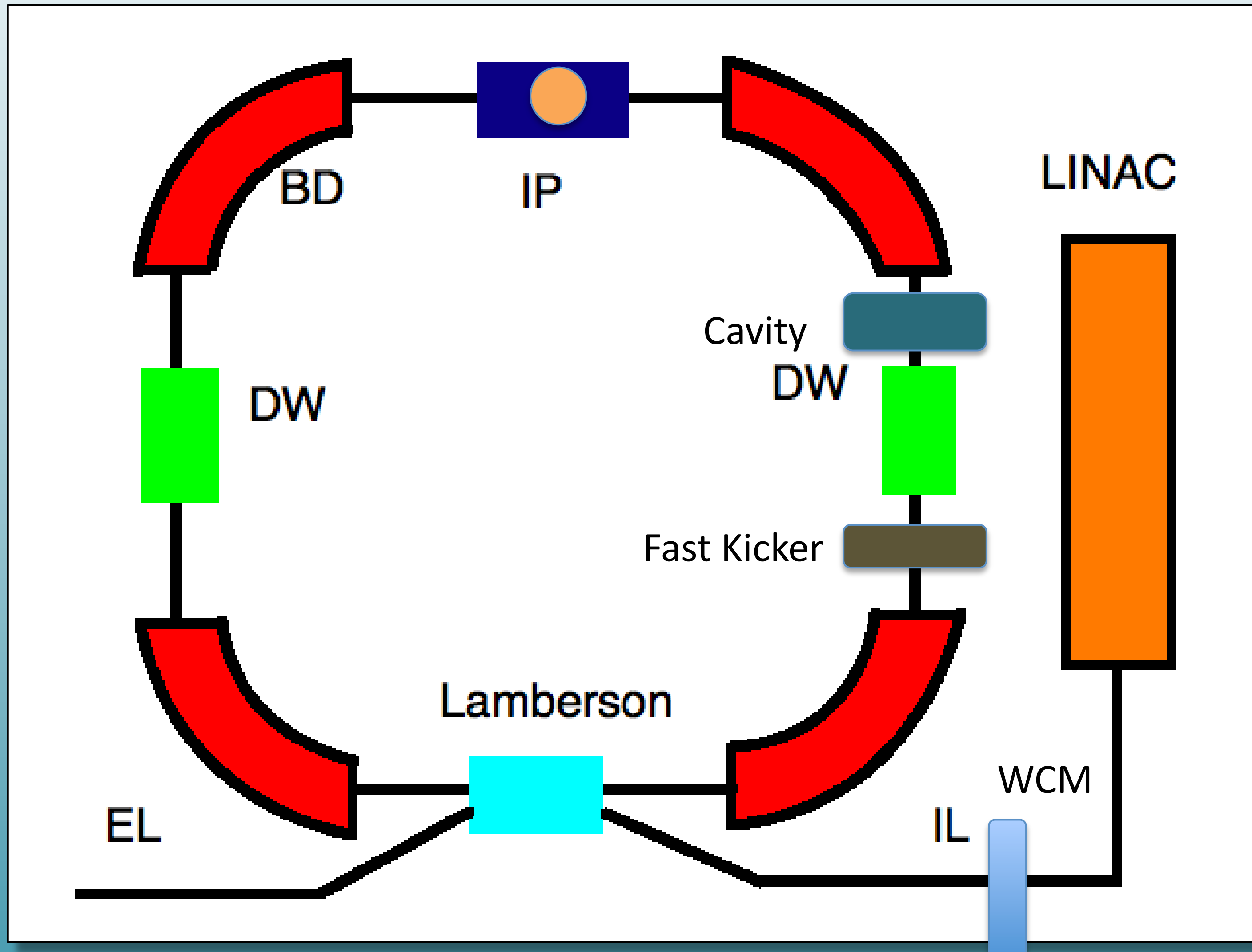
Development of 15 MHz Ferrite loaded Cavity



Development of a fast extraction kicker

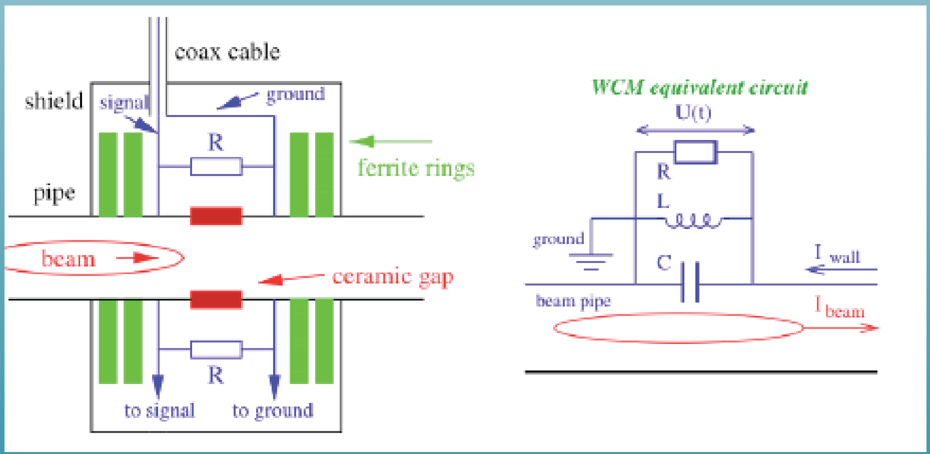


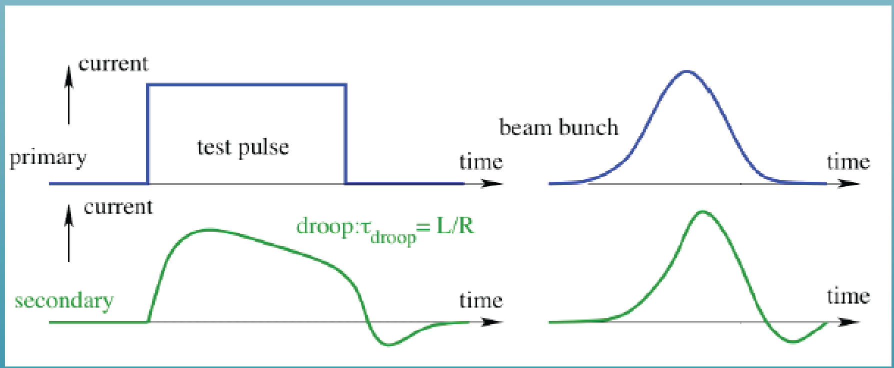
Emittance estimation in accumulation mode



Wall Current Monitor

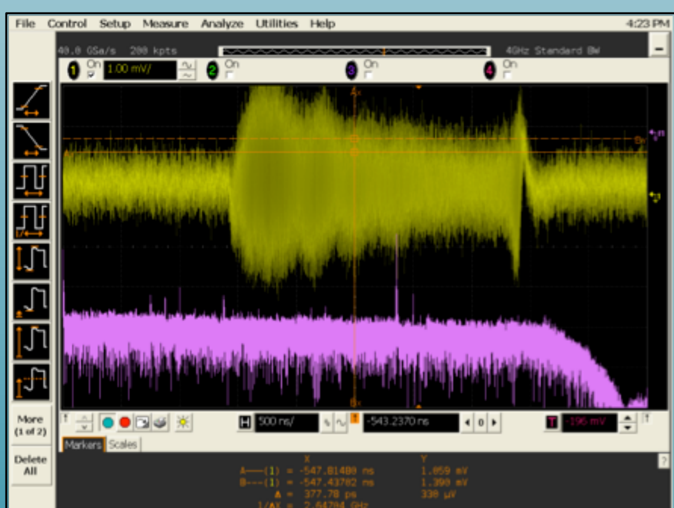
- Recycled from Cooler Injector Synchrotron (CIS) , designed and made by Fermilab.
- Effective resistance: R=V/I~2.1 ohm.
- Wide bandwidth: ~4 KHz to ~3 GHz.

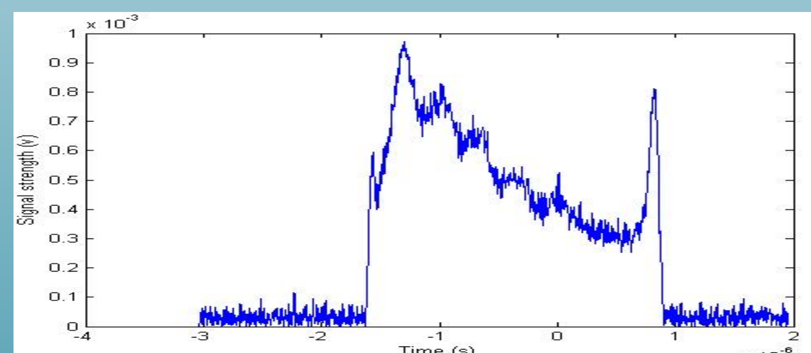




WCM Current Measurement

- To get a good WCM signal:
1) Good Helix cable and shielding, to get rid of Klystron noise
2) Low noise RF amplifier.
- Modulation-demodulation signal processing:
1) Recover the DC information from the first harmonic peak.
2) Suppress all the low frequency noise and don't worry about the frequency cut off by amplifier.
3) Applicable only when microbunch length much shorter than the bunch interval.

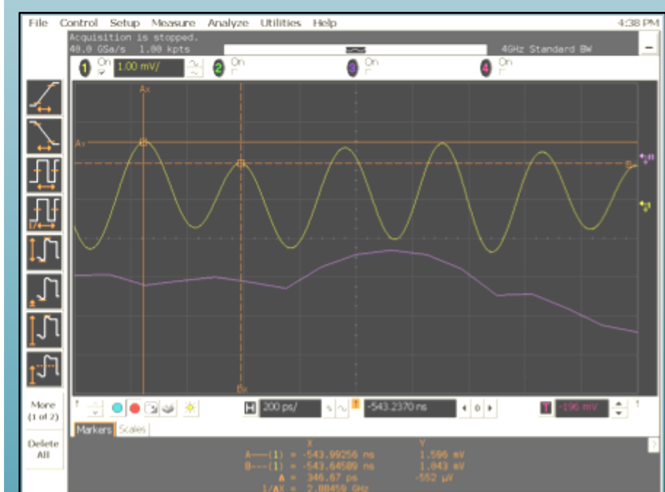


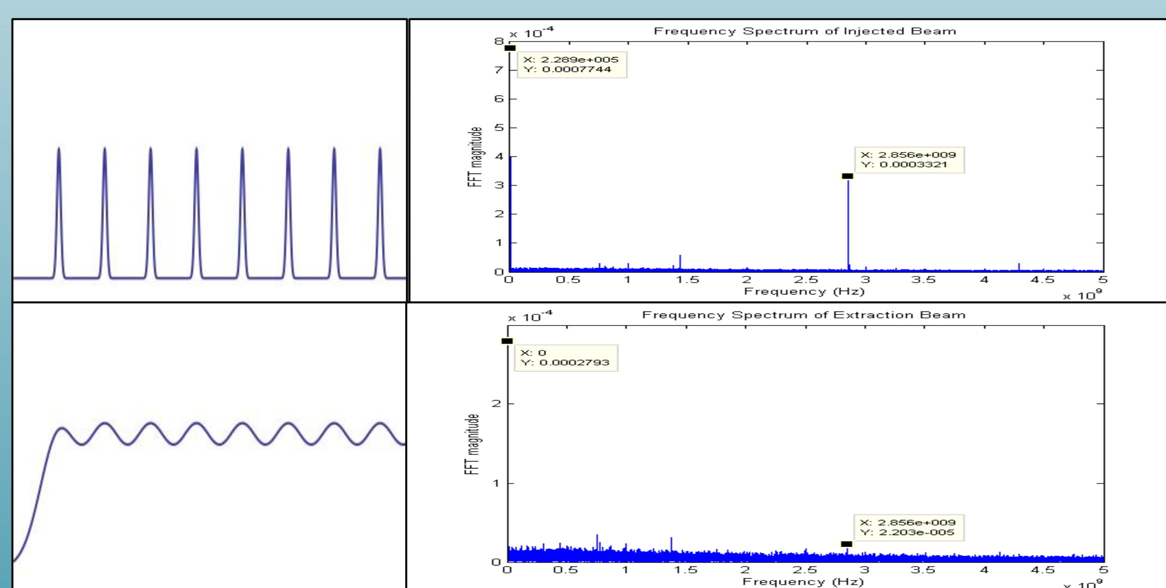


$$Q = \int V \cdot dt / R$$

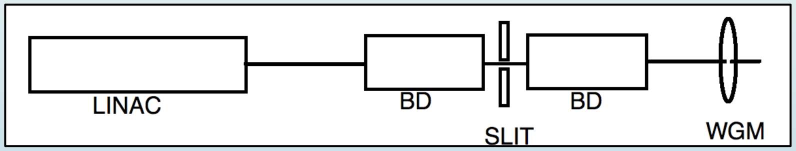
Verifying the debunching

- The microbunch period is ~ 350 ps, corresponding to the 2.856 GHz S-band LINAC. Due to the bandwidth limit of the WCM, we can't measure pico second length of the beam directly.
- We can tell the debunching effect from the reduction of the first harmonic strength, which is 2.856 GHz and in the working range of WCM. When the beam is totally debunched, the 2.856 GHz peak should disappear completely.



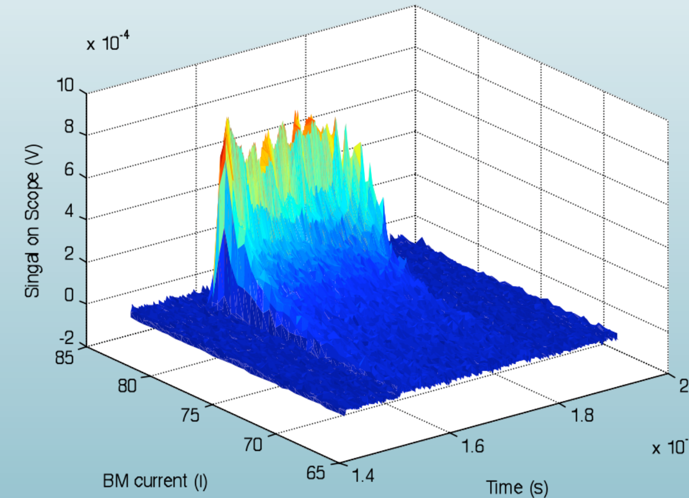


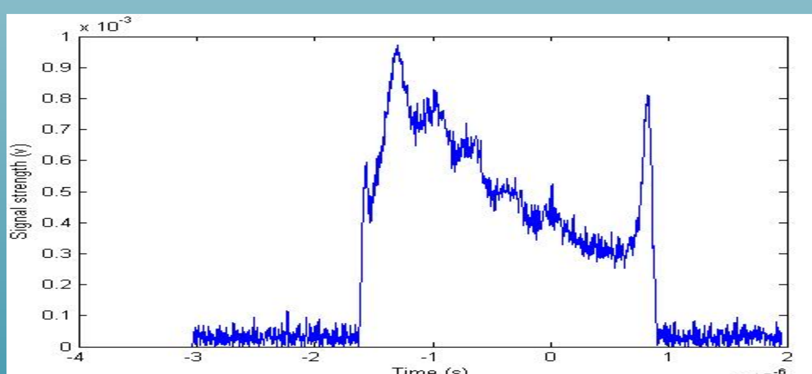
Longitudinal Phase Space Tomography of the LINAC Beam

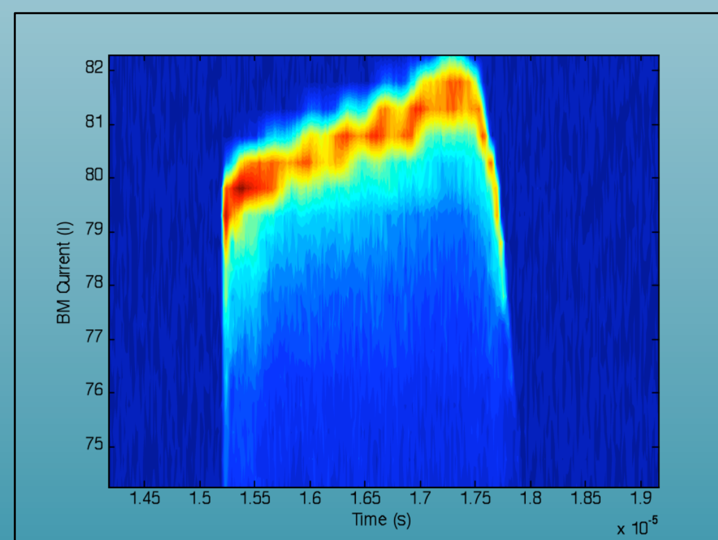


Injection Beam Line sketch

The bending dipole and slit work as an beam energy selector. By scanning the bending dipole strength, we measure the longitudinal profile of the beam with different energy. Combining each profile together, we paint out the longitudinal phase space of the LINAC beam.





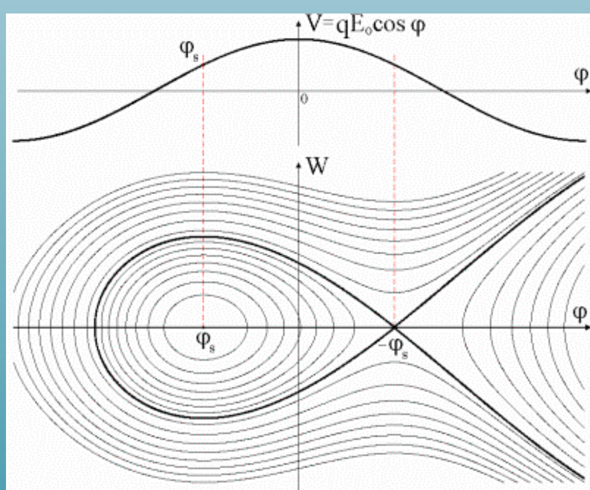


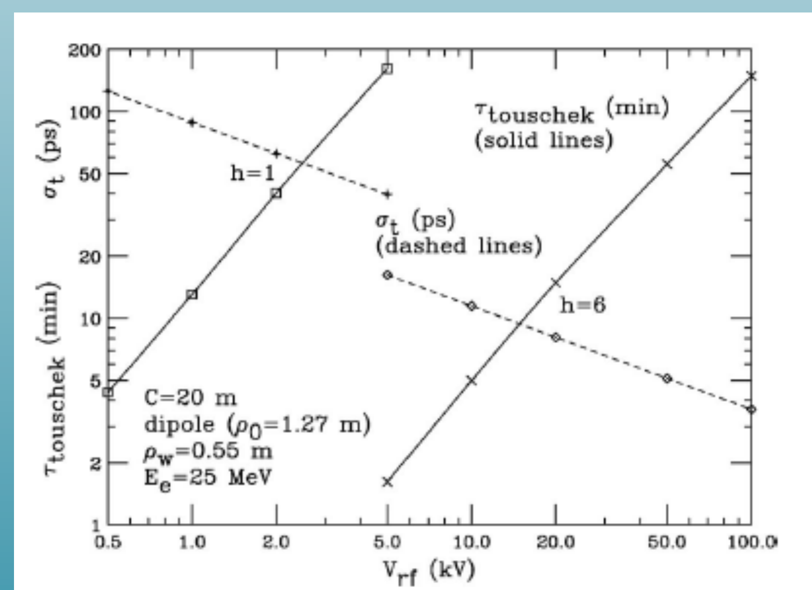
RF Cavity of ALPHA

- Cavity function: provide the longitudinal focusing to overcome Touschek effect and achieve long beam life time.
- First Harmonic: $f_0 = 15\ \text{MHz}$

$$\frac{d\phi}{dt} = \frac{h\omega_0^2\eta}{\beta^2 E}\left(\frac{\Delta E}{\omega_0}\right), \qquad \frac{d\left(\Delta E/\omega_0\right)}{dt} = \frac{1}{2\pi}eV\left(\sin\phi - \sin\phi_s\right),$$

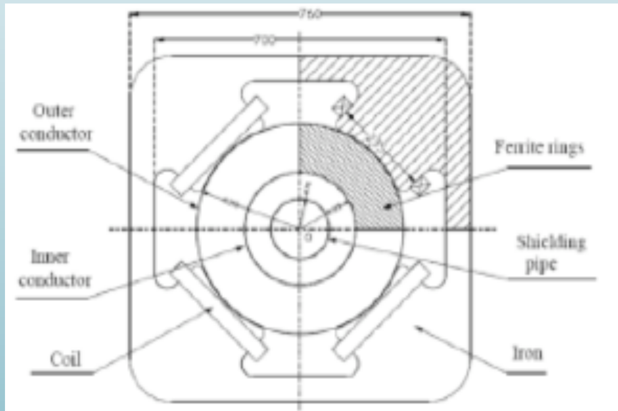
$$H = \frac{1}{2}\frac{h\eta\omega_0^2}{\beta^2 E}\left(\frac{\Delta E}{\omega_0}\right)^2 + \frac{eV}{2\pi}\left[\cos\phi - \cos\phi_s + (\phi - \phi_s)\sin\phi_s\right].$$

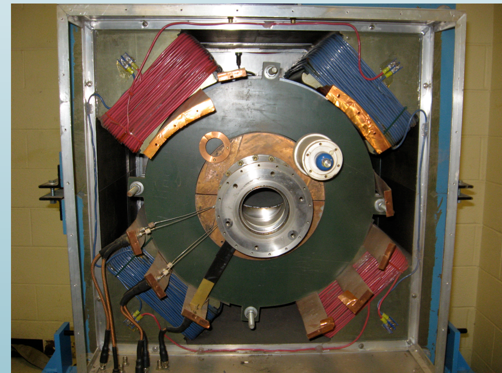


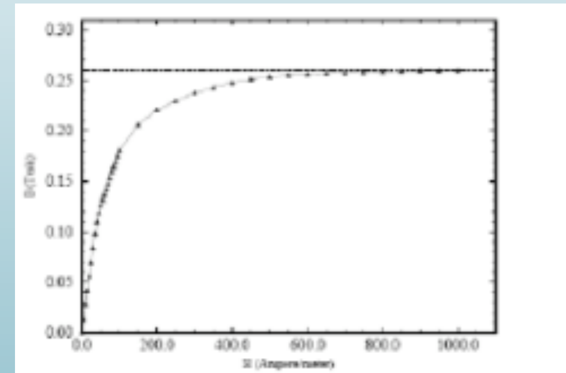


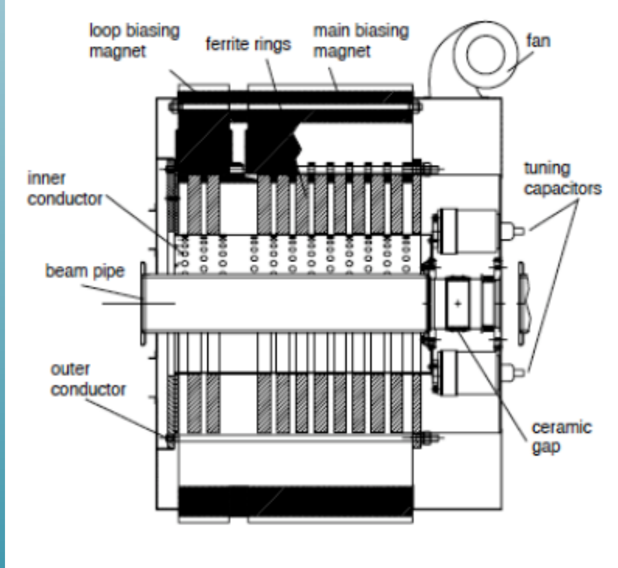
Refurbish CIS Cavity?

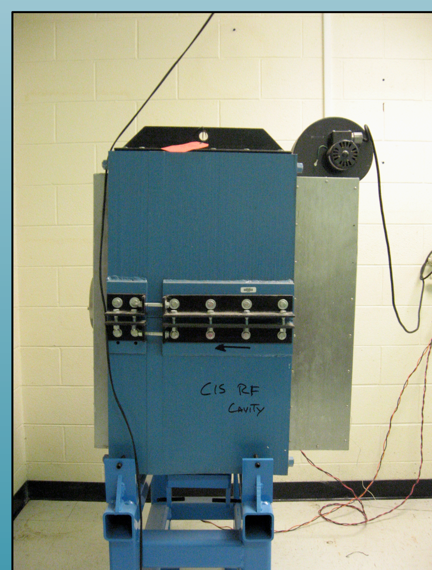
- CIS Cavity: coaxial quarter wave cavity.
- Ferrite: frequency tuning and coupling adjustment

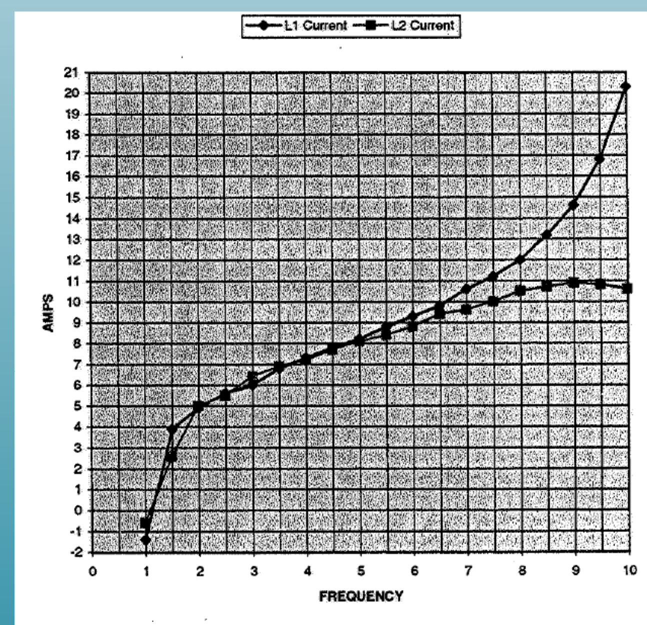






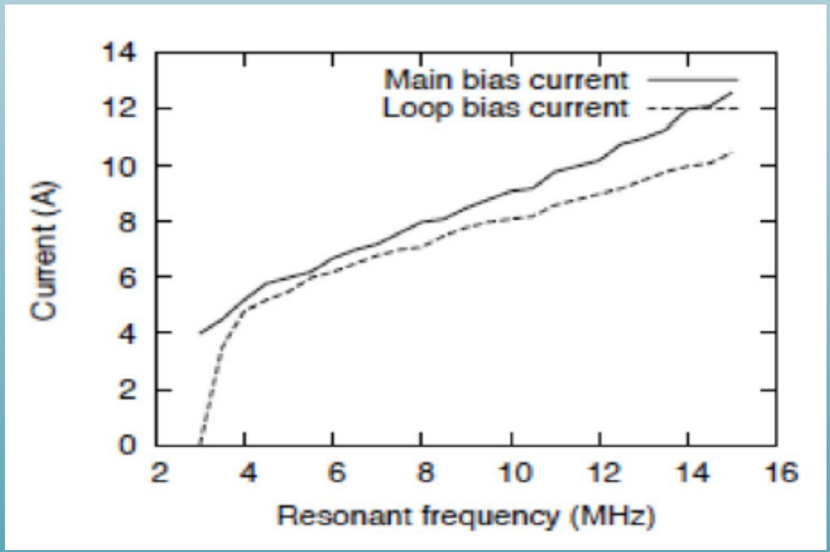


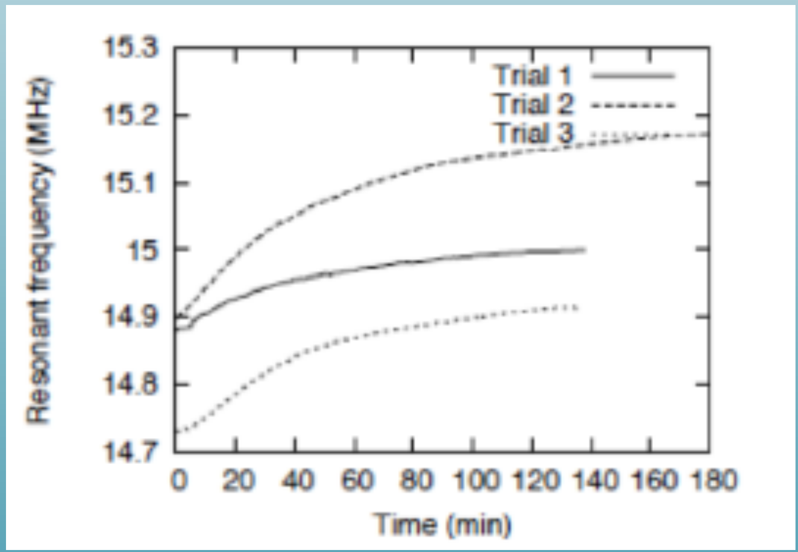




Low Power Test of CIS Cavity (1)

- Resonant frequency is tuned to 15 MHz.
- Q is measured by Network Analyzer, with both S21 (3 dB method) and S11 (Linear fitting). Both results are about 13.
- Resonant Frequency drift: magnet permeability change due to temperature rising.

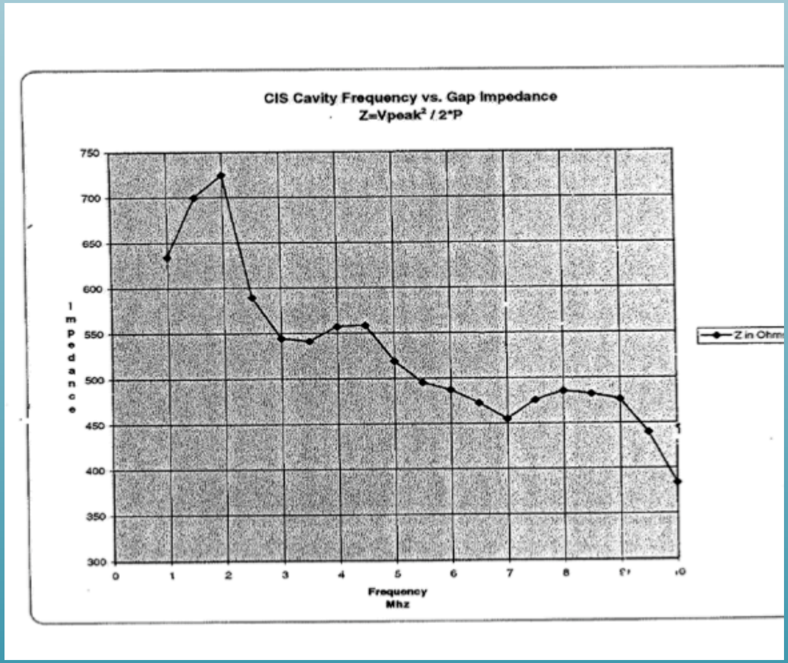


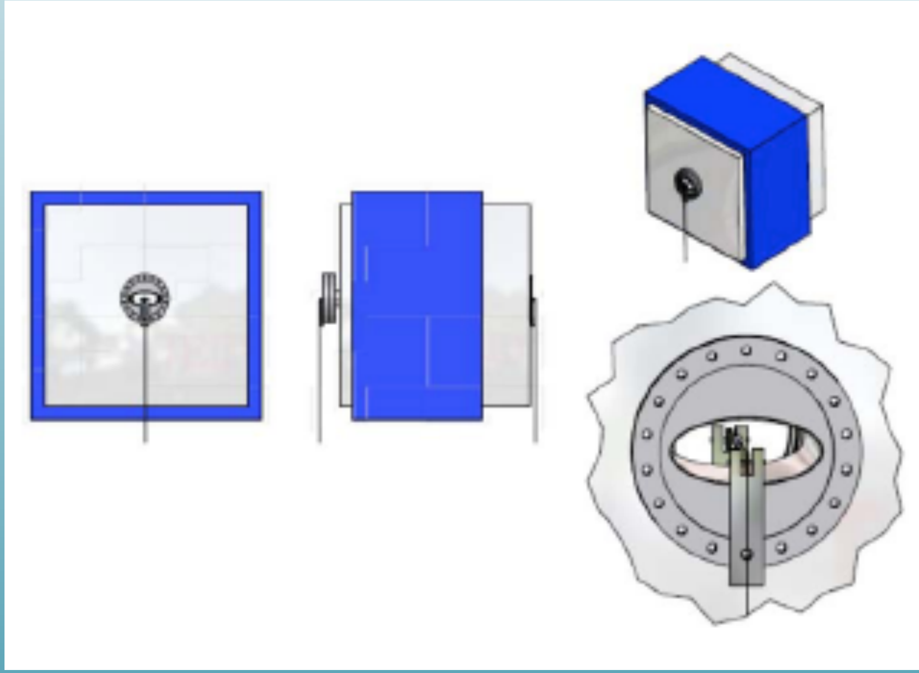


Low Power Test of CIS Cavity (2)

- Beam Pull Measurement: due to the small Q value,, the frequency shift is hard to measure, thus hard to get an accurate result. A rough estimated value from the measurement is 273 ohm +/- 50%, which is consistent with previous CIS measurement.

$$\frac{R_{sh}}{Q} = \frac{1}{F}\frac{1}{\omega_0}\left[\int_{gap}\sqrt{\frac{\Delta\omega}{\omega}}dZ\right]^2$$

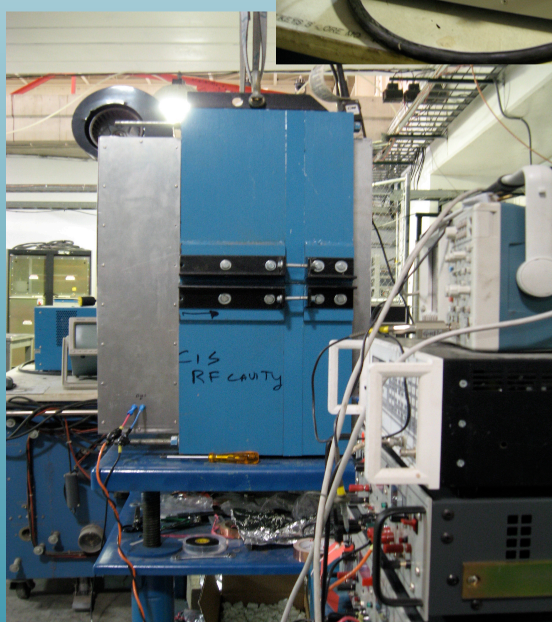


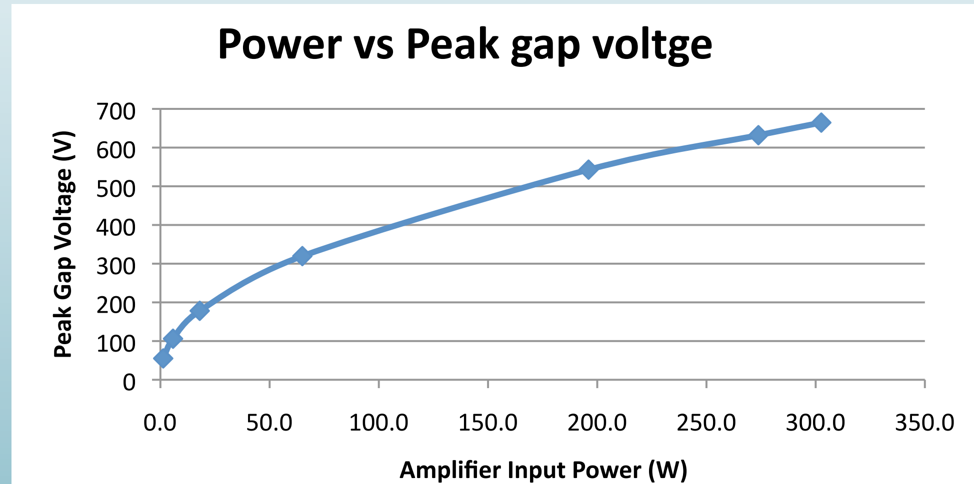


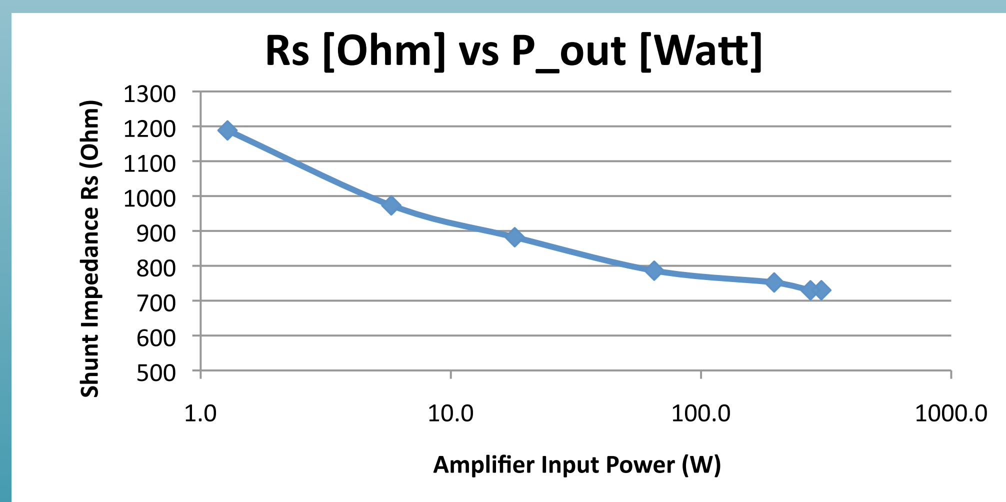
Drawn by Jack Dascow

High Power Test of CIS Cavity

- Shorten the bias quadrupole iron and remove 3 ferrites.
- High power test.

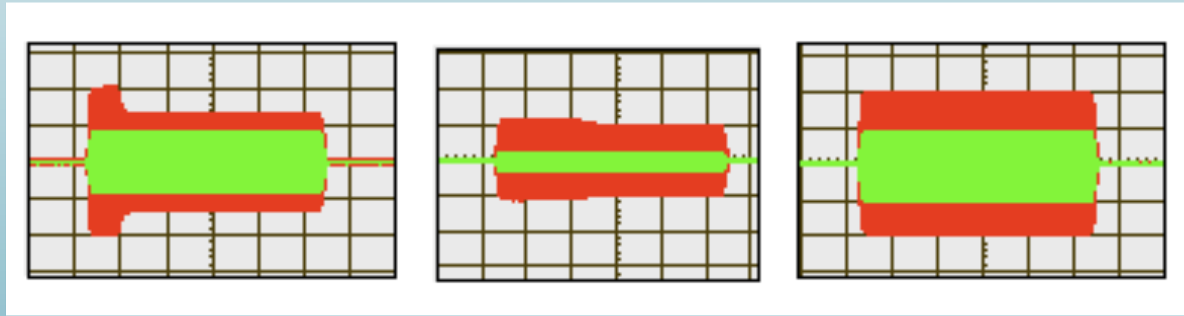






Problem with CIS Cavity

- High Loss Effect , or Q Loss Effect, is an RF power loss phenomenon: sudden voltage drop after first few milliseconds, following by a noisy amplitude. imposes the limit of the maximum magnetic flux in the cavity for it to work properly, thus the maximum peak voltage.



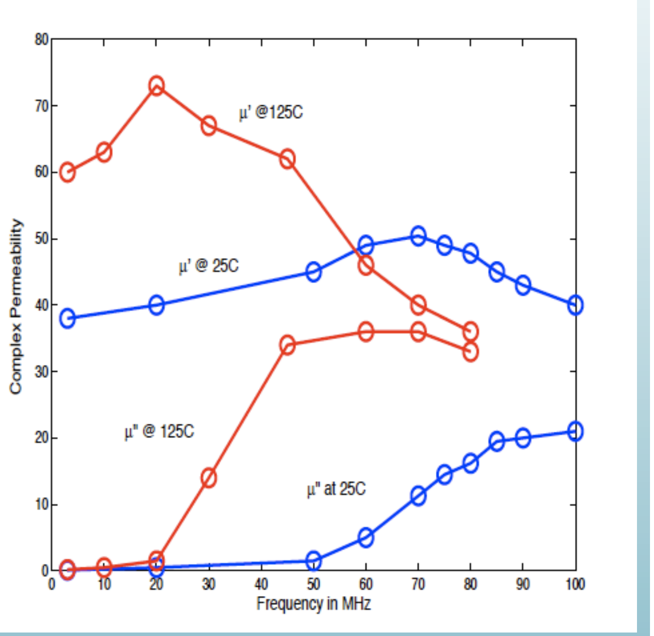
- Using the transmission line model and Superfish simulation, we have estimated that the CIS ferrite Philips 8C12 will reach its HLE thresh hold at around 1000 V.
- The frequency ramping is not needed for ALPHA.
- Large size, heavy weight, not easy to fit into ALPHA storage ring.
- Plan B: Build a new cavity with different ferrite material, more compact size and easier tuning scheme.

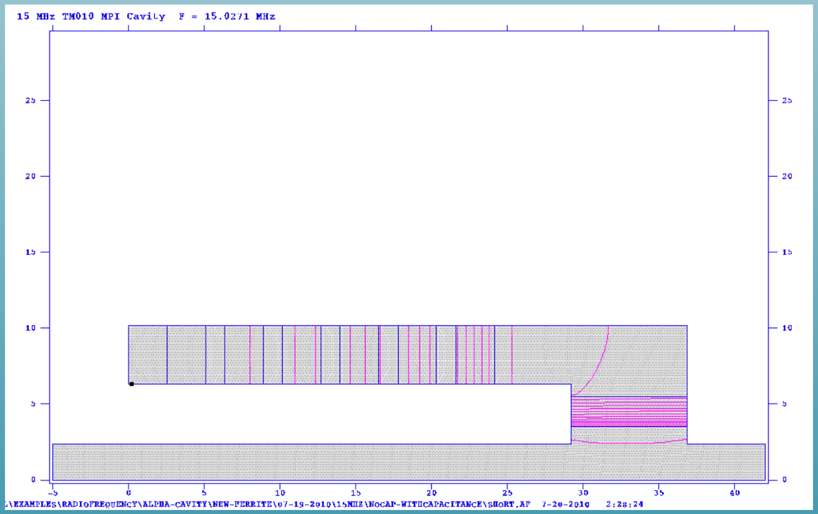
Design of the new cavity

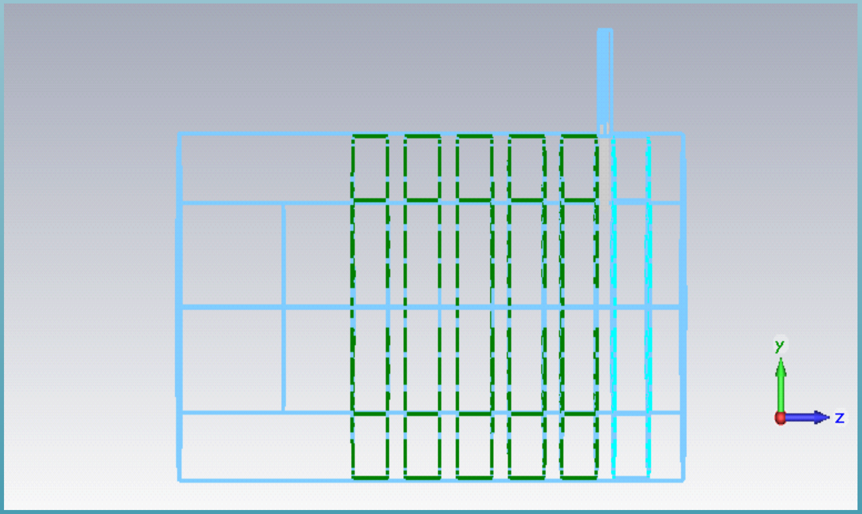
- New Ferrite Material： M4C21A

1) HLE threshold up to 3 KV.
2) More suitable permeability for 15 MHz.
3) More compact size
4) Great reduction on the heating. (Air cooling)

- New Design:
- 6~7 ferrite disks, no external bias field.
- Frequency is tuned by external capacitor.
- Coupling.

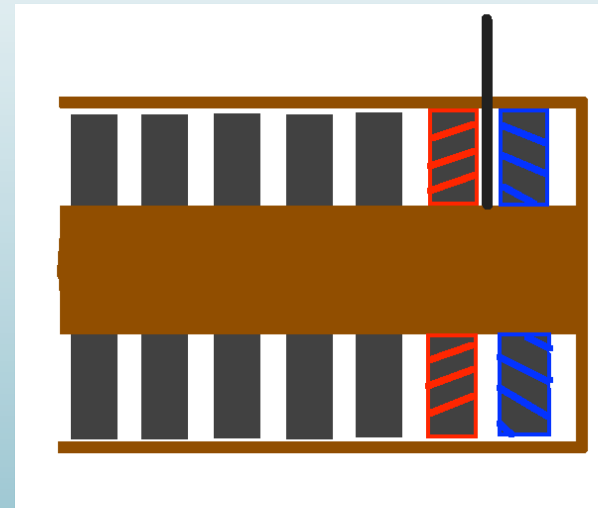


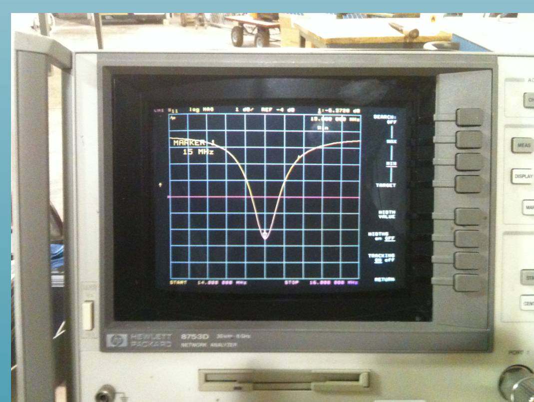


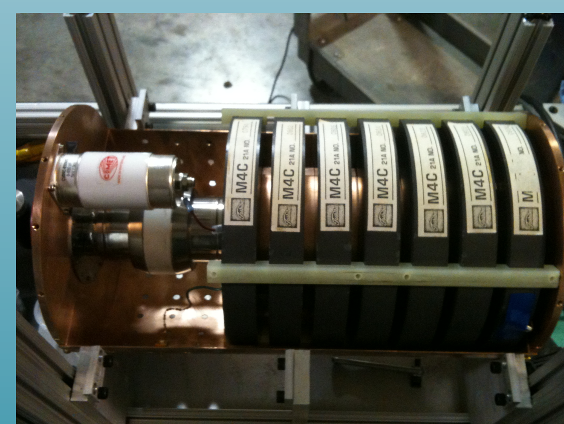


Test of new Cavity

- We have built a prototype cavity with the new design.
- By tuning the external capacitor, we have tuned the frequency to 15 MHz.
- Power transmission matching: Tee junction or ferrite tuning.
- The shunt impedance optimization is under way.

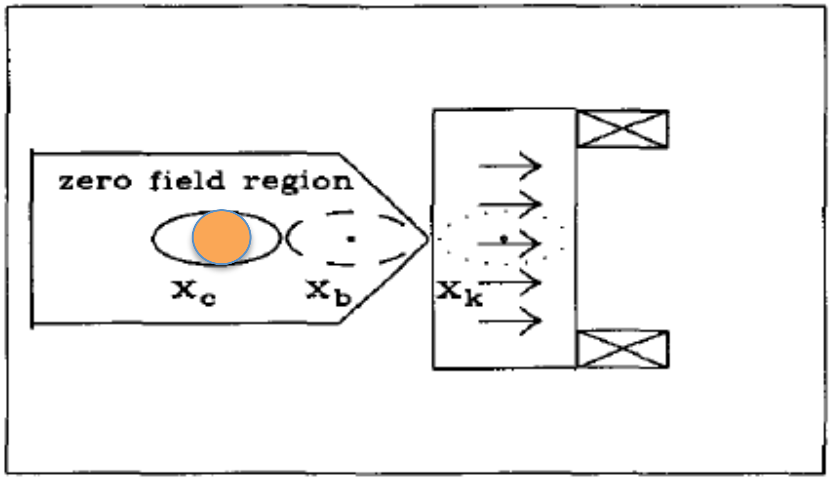


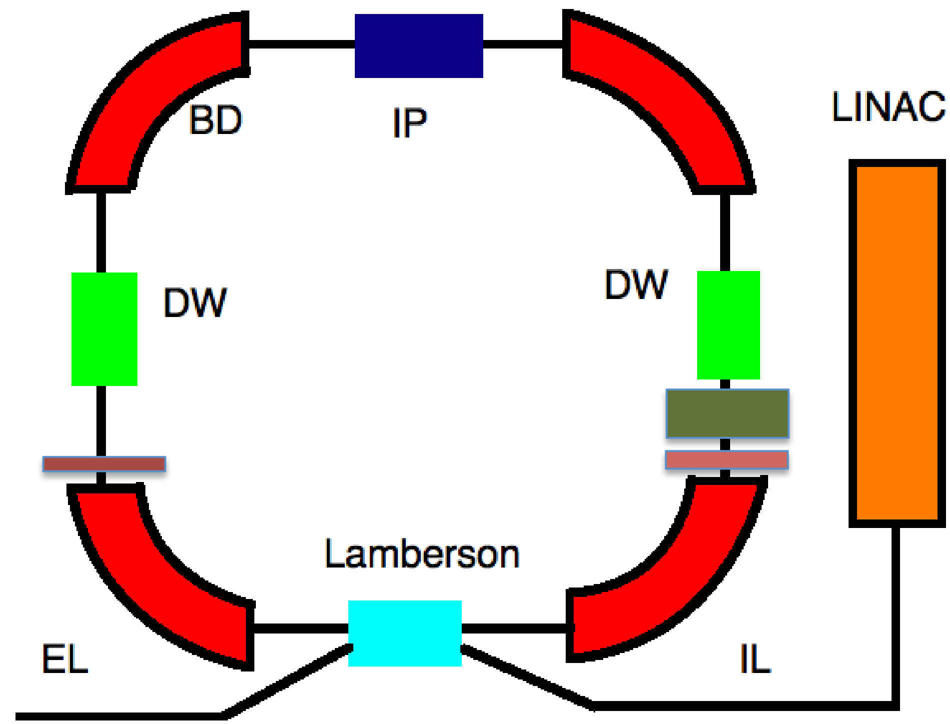




Taken by Alfonse Pham

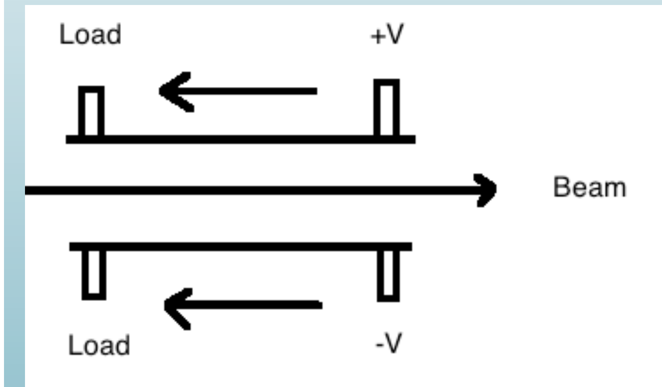
Extraction Scheme

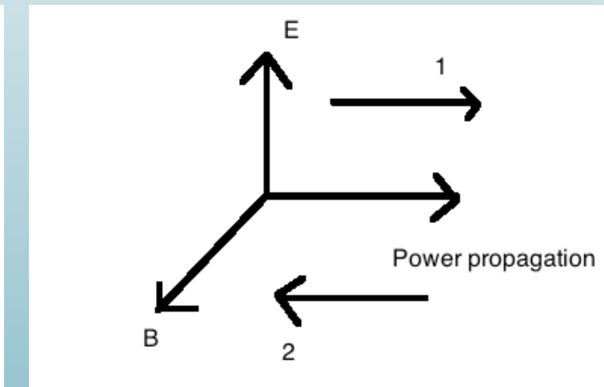


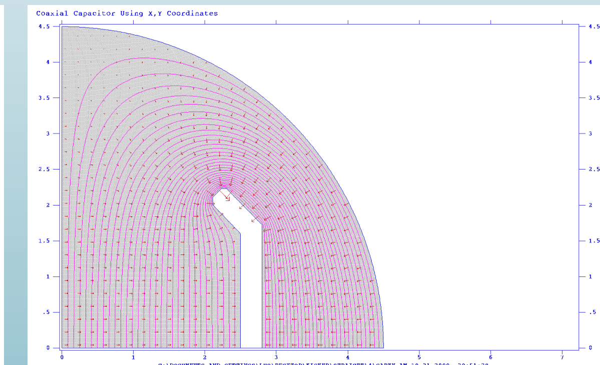


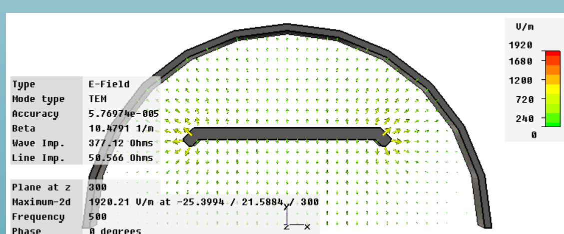
Fast Stripline Kicker

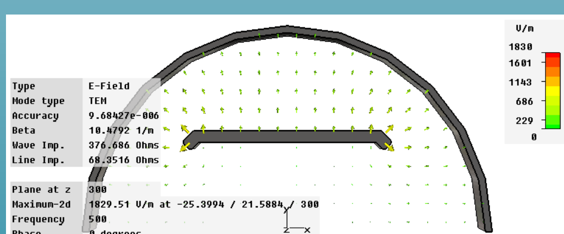
- The requirements of high voltage (at least 80 KV) and fast rise time (with in 10 ns) lead us to the traveling wave stripline kicker.
- Kicker Design: filed uniformity; transmission line impedance matching.

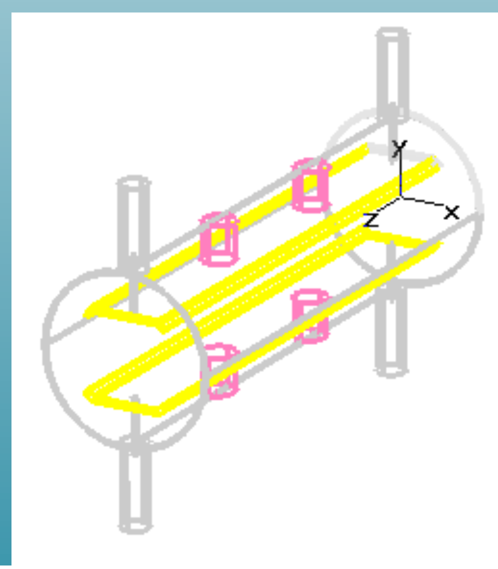


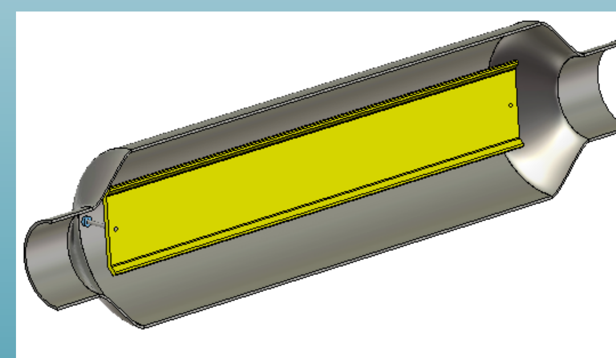












Appreciate the help of Stefano, Derun and John in LBNL on the kicker design.

Evaluation of Emittance (1)

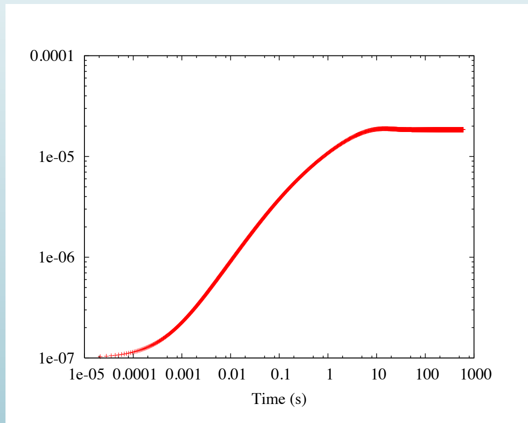
- In the accumulation mode, the beam will store in the synchrotron before the extraction. Under different damping and growing mechanisms, the beam emittance will evolve into an equilibrium state.
- Synchrotron radiation, quantum fluctuation, gas scattering, intra-beam scattering and linear coupling.

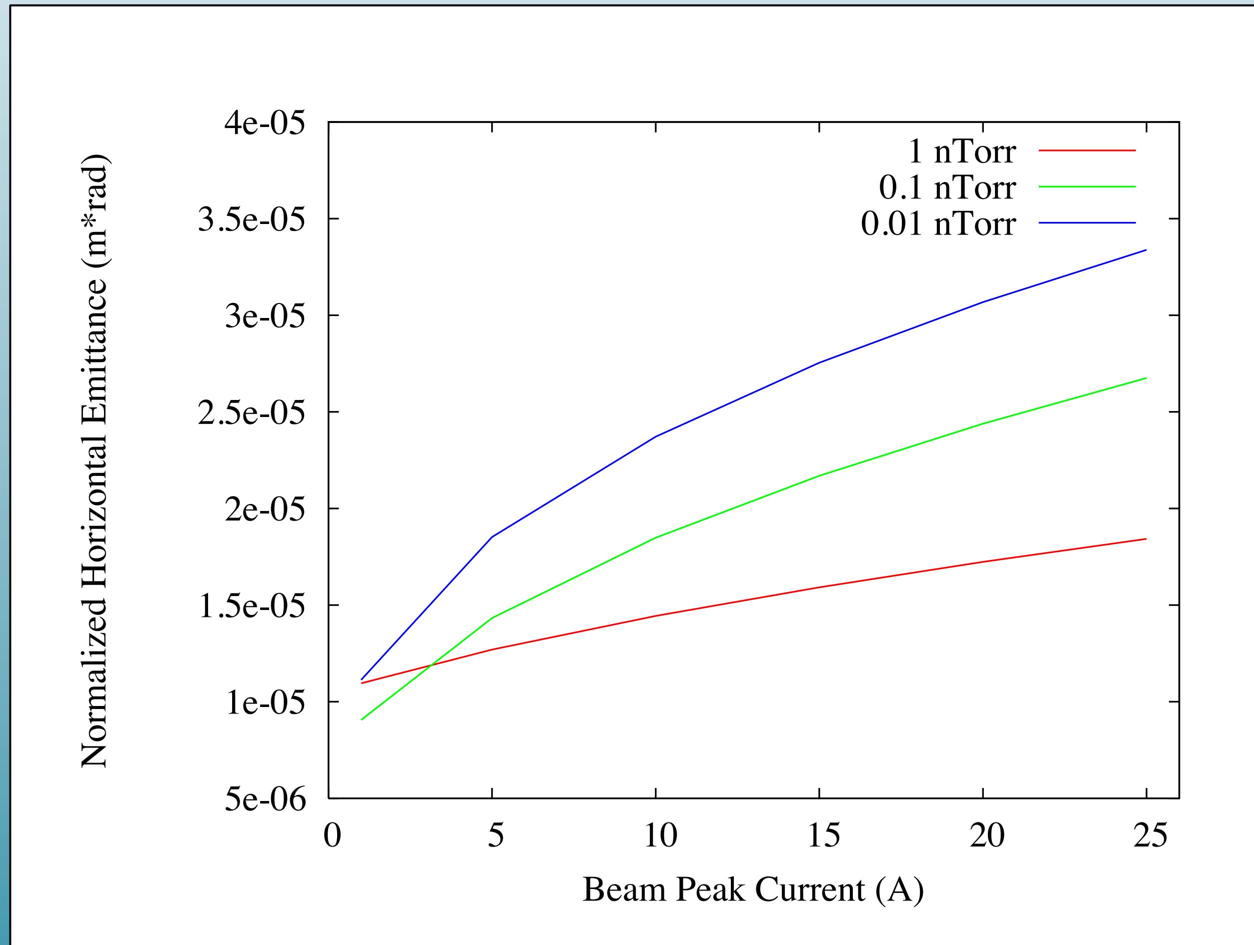
$$\frac{1}{\tau} = \frac{1}{\tau_{syn}} + \frac{1}{\tau_{qf}} + \frac{1}{\tau_{gs}} + \frac{1}{\tau_{ibs}}$$

$$\frac{d\varepsilon_{x(z)}}{dt} = \varepsilon_{x(z)} \times \frac{1}{\tau_{x(z)}} \qquad \frac{d\delta}{dt} = \delta \times \frac{1}{\tau_{\delta}}$$

- Calculation scheme: time evolution tracking.
- Ignore all the single loss scattering process, like Touschek effect, gas scattering loss. Focus on the emittance diffusion caused by multiple coulomb scattering.

Evaluation of Emittance (2)





- This scheme can estimate both relaxation time and beam size.
- For 25 A, 50 MeV beam, the equilibrium beam emittance is within the machince acceptance.

Future Plan

- Commission the accumulation mode with Varian Medical LINAC, demonstrate the storing the accumulating ability of ALPHA.
- Install and commission the upgraded LINAC, which provides beam with smaller energy spread, shorter pulse length and larger current. Test and optimize the radiation performance of ALPHA.
- Beam physics study: Intrabeam scattering, Touschek effect and beam control by Gradient Damping Wiggler.

Thank you!