BNL Energy Recovery Linac Instrumentation

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Outline

Introduction

Purpose, layout, machine parameters

Instrumentation performance requirements

Staged approach towards recovering energy, each requires different set of instrumentation.

1. Gun, straight injection transport to SCRF cavity, to low power dump.

    Subsystem test and commissioning at low power.

2. Replace straight injection with more complex zigzag transport.
3. Close ERL loop and demonstrate energy recovery, high power capability.

Sub-system descriptions

Position Monitors

Current Monitors

Profile Monitors

Emittance measurements

Loss Monitors

Schedule & future plans

Summary

Introduction

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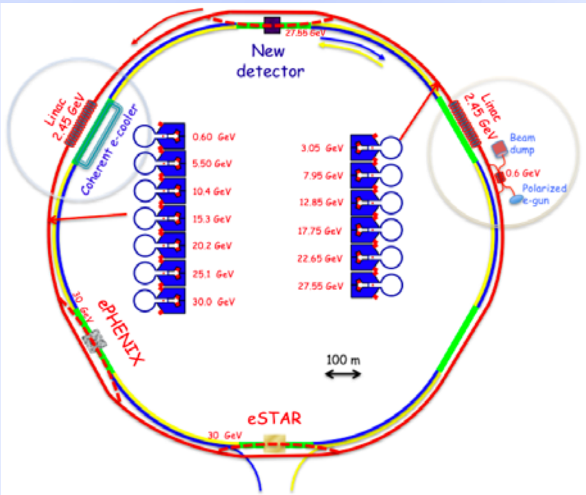
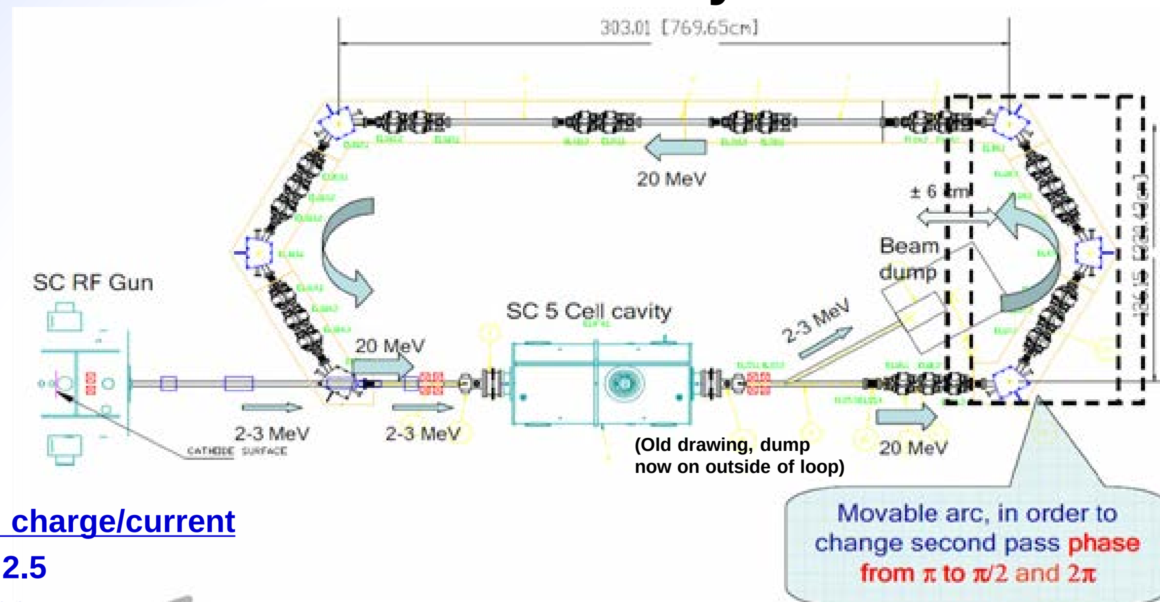
The R&D ERL facility serves a test bed for the envisioned electron-hadron collider, eRHIC (200GeV, 3.8km).



ERL Layout

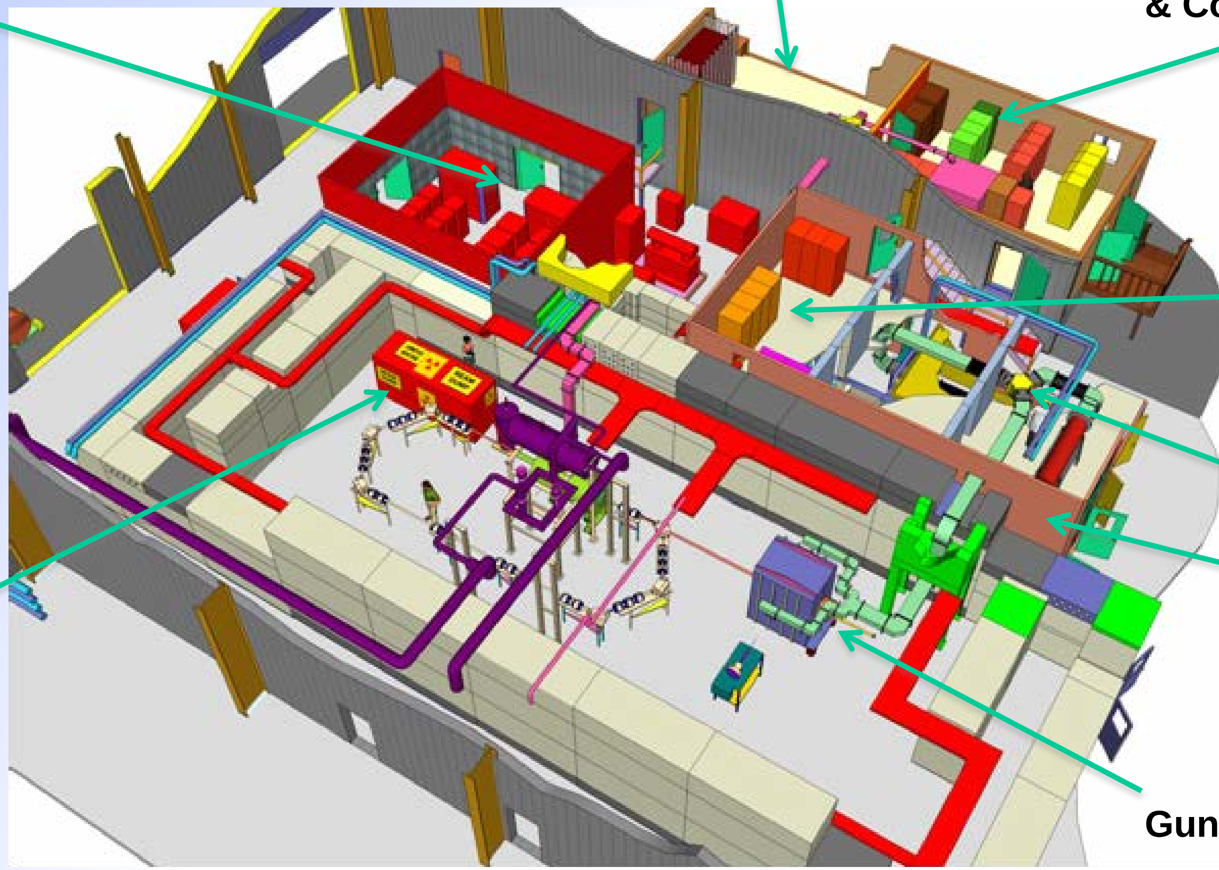


Parameters for the R&D ERL

Mode:	High charge/current
Injection energy, MeV	2.5 / 2.5
Maximum beam energy, MeV	20 / 20
Average beam current, A, up to	0.05 / 0.5
Bunch rep-rate, MHz	9.4 / 704
Charge per bunch, nC	5 / 0.7
Bunch length rms ps	31 / 18
Normalized emittance, mm*mrad	<10 / ~2

ERL is presently under construction

ERL Facility Layout



Instrumentation Performance Requirements
(Low Energy Injection Transport / Dump)

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Parameter	Expected Value/Range	Accuracy	Resolution	Comments
Beam Loss (localized)	0.5 μA (trip level) / 0 - 25 μA (range)	**20%**	**5 nA**	BLM trip level is 0.5 μA
		Beam Position		
Transverse, 1st-time tuning	Full aperture, Bunch rep. rate 1 Hz	**500 μm**	**50 μm**	Flags could be used to bring the beam through
Transverse, Regular tuning and Operations	Aperture: ±1.5 cm, ≥10 Hz	**200 μm**	**50 μm**	Ability to operate with bunch trains. Refresh rate not lower than 1 Hz.
		Beam Profile		
Beam emittance	2 – 10 μm, norm	**30%**	**0.1 μm, norm**	Pepper pot in the injection line. Projected emittance will be larger than the slice emittance.
Transverse Beam Profile	Size (rms): 2.0-5.0 mm.	**5% (LP)**	**20 μm (LP)**	Required in the low power (LP) only. In the high power regime (HP), position will be sufficient.
		Current/Charge per bunch		
Current (Tuning)	0 - 1 μA	**5%**	**0.5 nA**	Ring BLM tuning will require dumping 50 nA locally.
Current (Ops.)	0 – 500 mA	**1%**	**0.1% at I=500 mA / 0.25 μA at I=0 mA**	
Bunch charge	(0.05) 0.1 – 5 nC, 1 Hz -10 MHz	**5%**	**0.1% (at 5 nC)**	1% will be sufficient for ERL.

Instrumentation Performance Requirements (High Energy Ring)

Parameter	Expected Value / Range	Accuracy	Resolution	Comments
Beam Loss (localized)	50 nA (trip level) / 0-2500 nA (range)	20%	0.5 nA	Higher resolution for higher power. BLM trip level is 50 nA.
Beam Position				
Transverse, 1st-time tuning	Full aperture, Bunch rep. rate 1 Hz	500 μm	50 μm	Flags could be used to bring the beam around.
Transverse, Regular Operations/Tuning	Aperture: ±1.5 cm, ≥10 Hz, two beams	100 μm	20 μm	Ideally, position of accel./decel. beams simultaneously. Ability to operate with bunch trains. Refresh rate not lower than 1 Hz. **Ability to improve accy. by averaging**.
Beam Profile				
Beam emittance	2 – 10 μm, norm	30%	0.1 μm, norm	ε=2 μm is nominal. Quad/Sol. scan. See next line.
Transverse Beam Profile	Size (rms): 0.1-5.0 mm. (Aprt. ±1.0 cm)	10% (LP)	5 μm (LP)	High resolution is required for quad scan and beam matching in the low power (LP) mode. In the high power regime (HP), lower accy./res. can be sufficient. Not easy.
Current/Charge per bunch				
Current (Ops.)	0 – 500 mA	1%	0.1% at I=500 mA / 0.25 μA at I=0 mA	Lower range needed for tuning.
Tot. Current Loss	< 1 μA (expected)	1%	0.25 μA	Requires nulling feedback, nulling cur. in both DCCTs
Bunch charge	(0.05?) 0.1 – 5 nC, 1 Hz – 10 MHz	5%	0.1% (at 5 nC)	1% will be sufficient for ERL.

Note: All in-vacuum diagnostics designed & processed for Class 100 particulate free, & UHV bake-out.

Stage 1, Gun to 5 Cell

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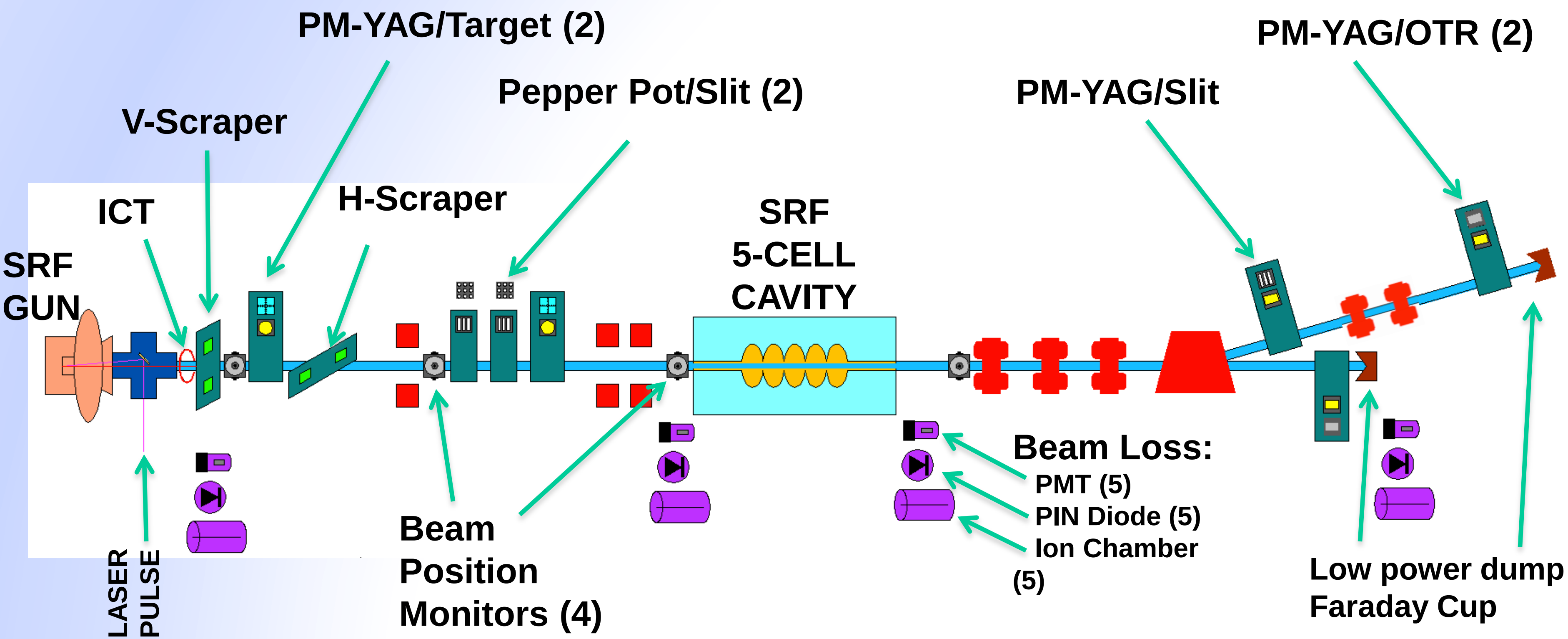
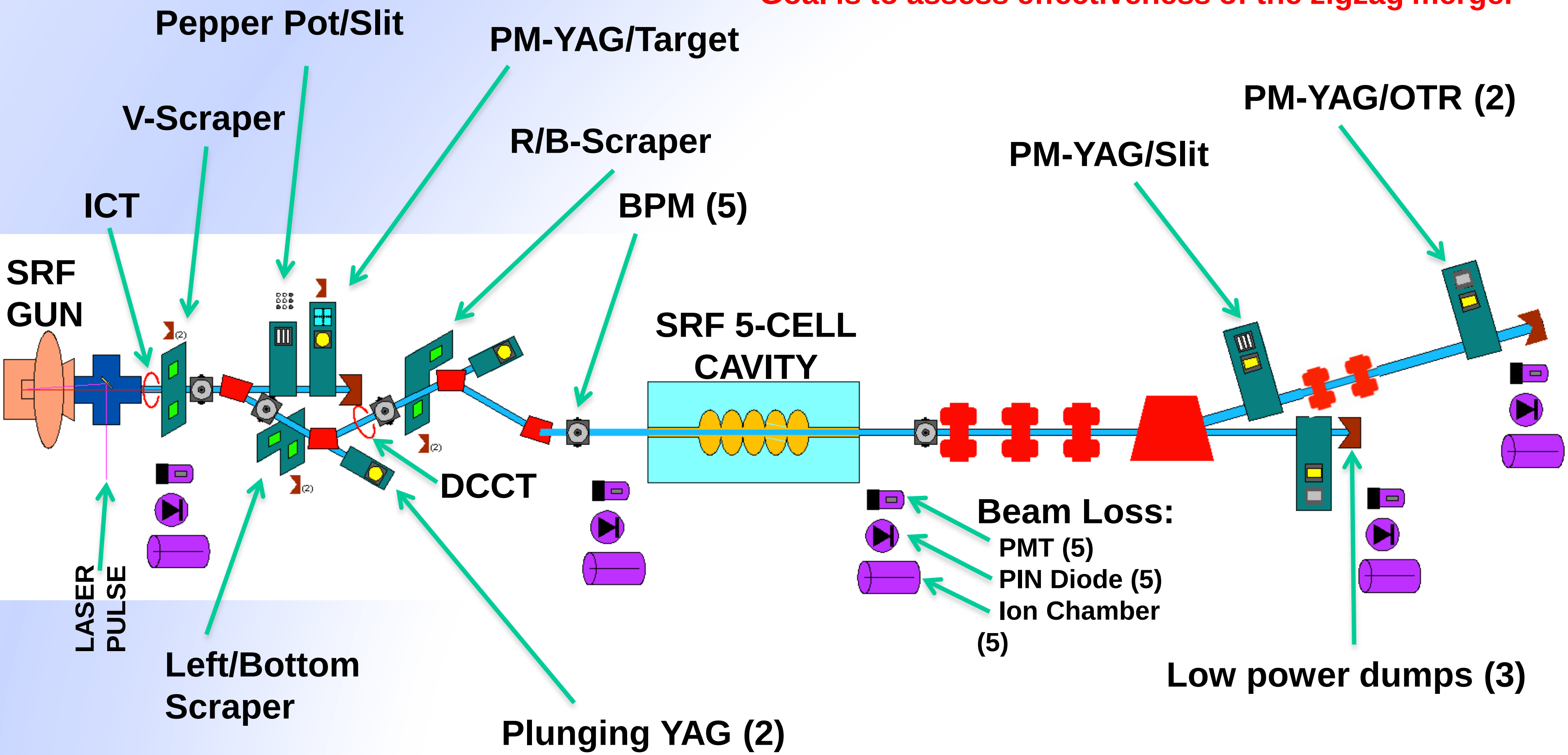
Gun, Linac, & subsystem test and commissioning at low power (<10W) with straight injection. Goals are to characterize gun & test critical beam components.

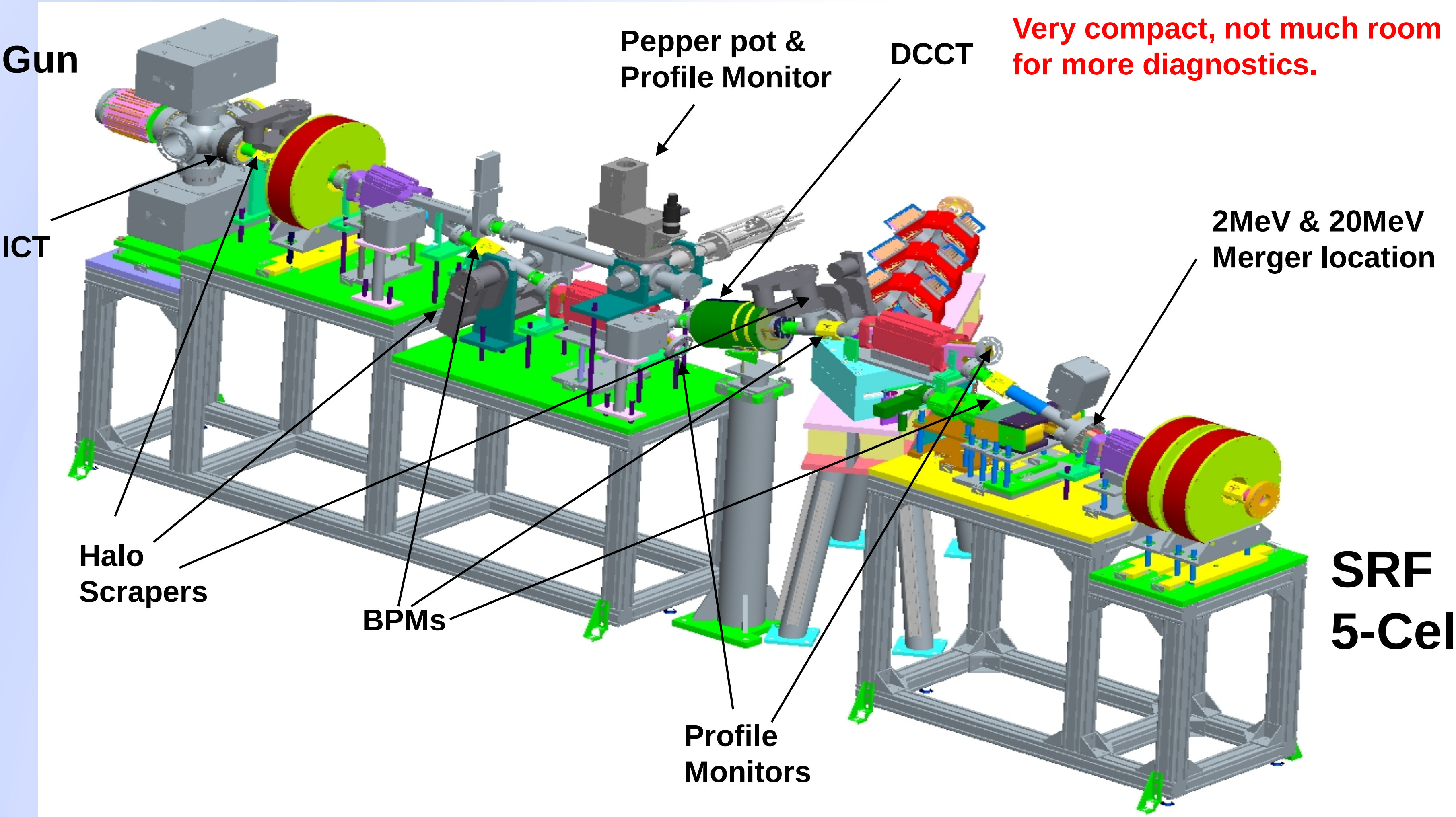


Stage 2, Gun to Zig-Zag to 5-Cell

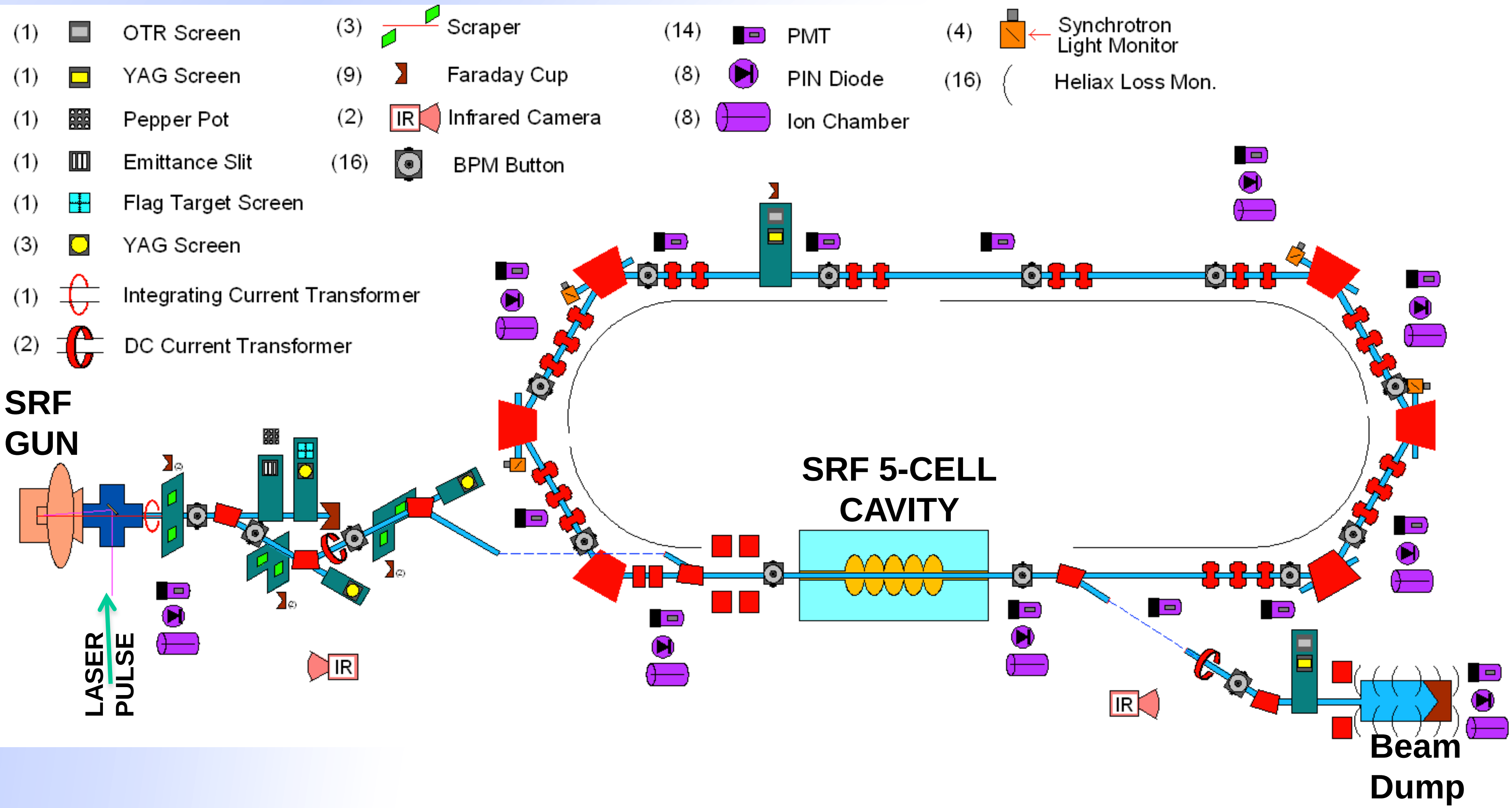
Goal is to assess effectiveness of the zigzag merger



Stage 2, Gun to Zig-Zag to 5-Cell



Stage 3, Energy Recovery Linac

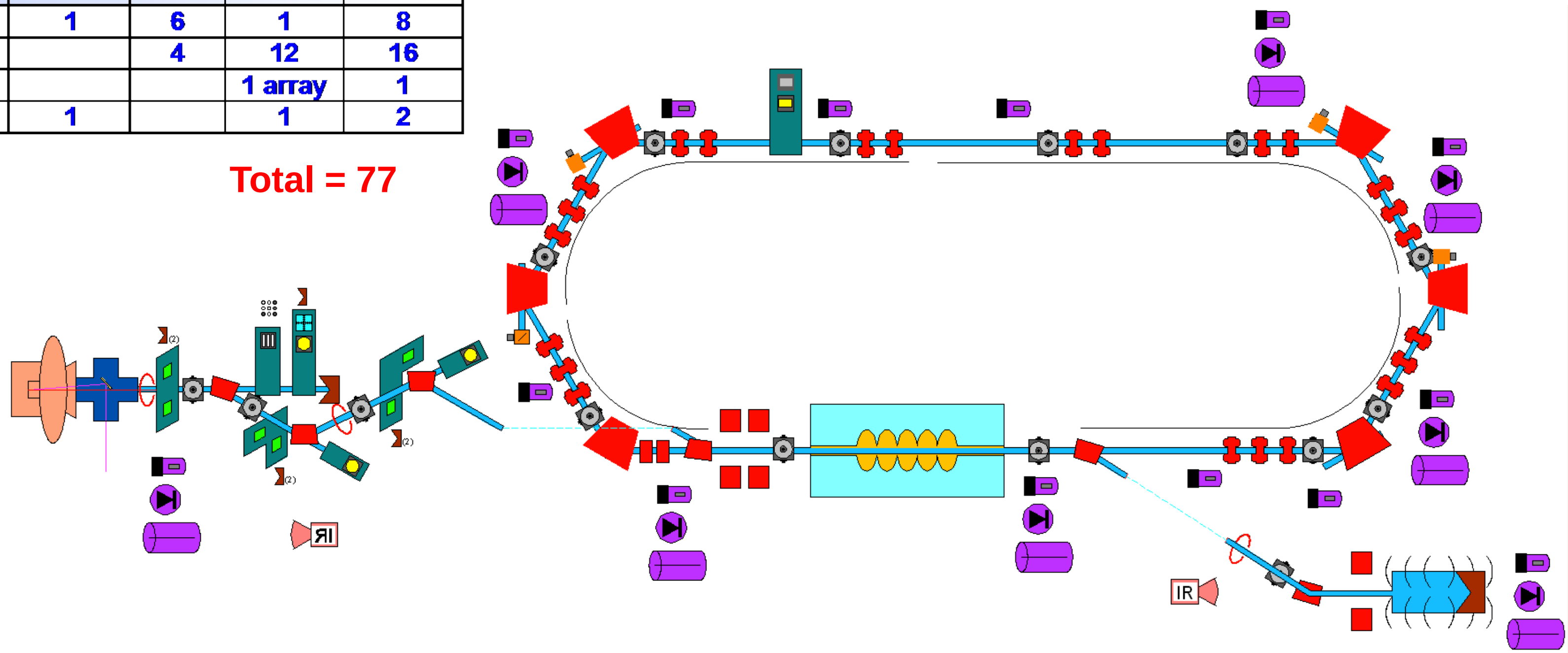


Stage 3, Energy Recovery Linac

Quantities & Location Table

	Gun/Inj	Loop	Dump	Total
BPM	4	11	1	16
DCCT	1		1	2
FCT	1			1
Flag	3	1	1	5
Pepper Pot	1			1
Wire		1		1
Scraper	6			6
Synch Light		4		4
PMT BLM	2	11	1	14
Pin Diode BLM	1	6	1	8
Heliax BLM		4	12	16
Thermocouples			1 array	1
Thermal Camera	1		1	2

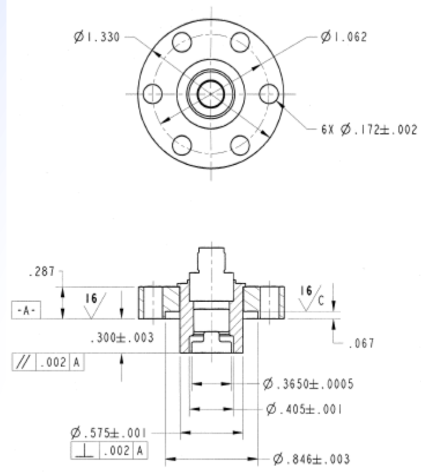
Total = 77

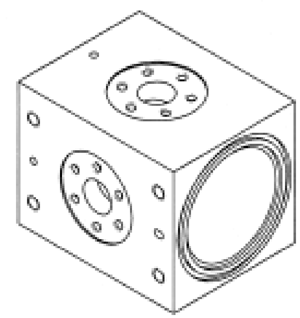


Beam Position Monitors – Pick-ups

Dual plane button pick-ups
16 locations (5 at 2MeV, 11 at 20MeV)
Times Microwave SK-59044

- 10mm diameter molybdenum button's
- SMA Connector
- 1- 4pF, 5% matching
- 150C bake-out





BPM Button Stainless Steel cube
2.5" X 3.25"

Beam Position Monitors – Electronics

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Libera Single Pass Electronics

Advertised features:

- High accuracy
- Low drift
- Built-in custom configurable FPGA processor
- GB Ethernet
- Beam inhibit capability
- Beam positions measured: average orbit, 0.1-100mA, and single bunch, 0.1-5nC.

BPM sum signals can be calibrated with high-resolution DCCT system.

Our requirements are:

Position: 100-500 micron accuracy, 20-50 micron resolution

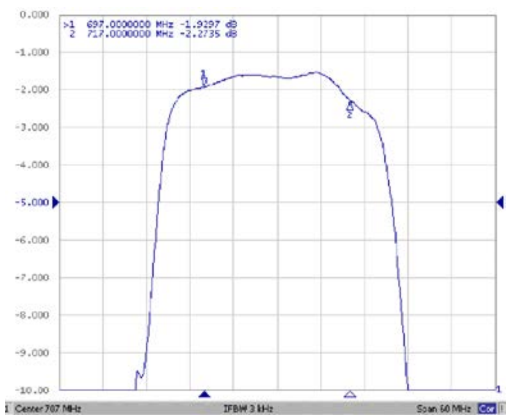
Worked closely with I-Tech on development & simulations, optimistic application will work.

Important factors:

700MHz Custom SAW BPF (ERL bunch frequencies 9.4, 351, 703MHz)
117MHz Sampling Frequency
1024 – 8kB buffer length (max 70us of data/trigger)
Max trigger rate 200Hz

Need to measure both energy beam positions at common locations near the cavity.

Low and high energy bunches are separated by loop transit time.
Considering fast switches, or fast digitizers.



I-Tech Libera 700 MHz SAW BPF Response

Integrating Current Transformer

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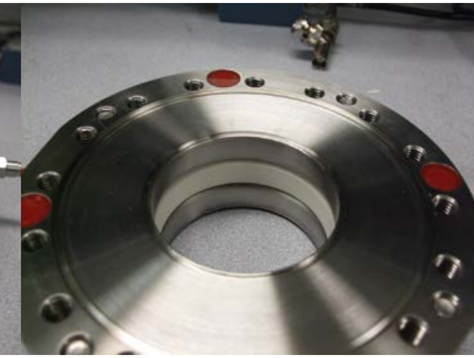
Located just downstream of the gun

Bergoz **ICT-CF6-60.4-070-05:1-H-UHV-THERMOE**

Integrating type, In-flange CT

- For bunches bunches & bunch trains
- Bergoz IHR electronics
- Noise <1pC beam charge
- Calibrated



Mechanical details:

60.4mm ID

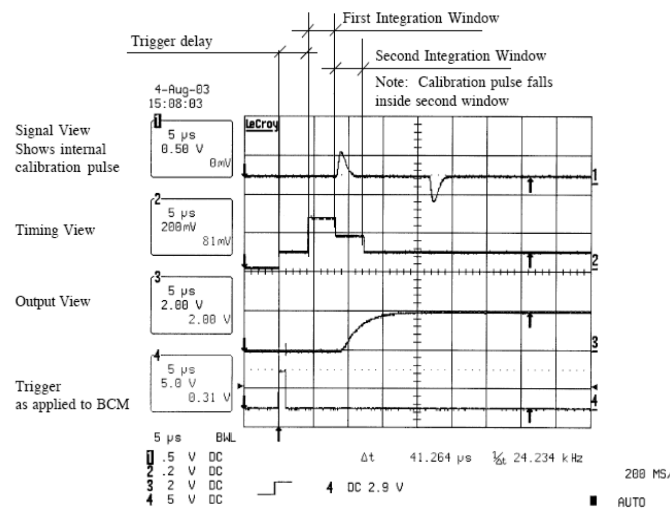
40mm axial length

Rad-Hard option

Bakeable to 180C, plan 48h at 150C

- Separate bake-out zone
- Internal TC, type-E

Signal processing timing diagram:
Gate width <0.1us up to >7us

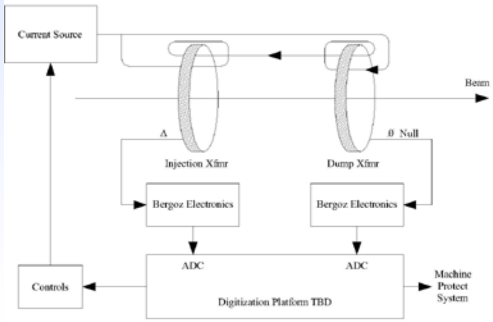


ERL requirements for bunch charge at 0.1-5nC:

- 5% accuracy
- 1% resolution (at 5nC)

DC Current Transformers

Provides
- High precision current measurement
  sub-uA resolution
- Differential Current
  Using Null Winding to extend DR
- kHz bandwidth
- Machine protection

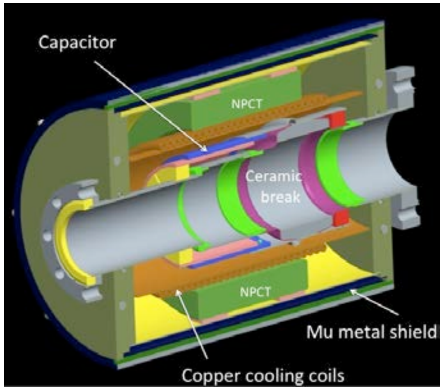


Bergoz NPCT system

The toroids installed in the injector and dump lines are connected via a current loop that threads both toroids (the 10 turns calibration windings of the DCCT's are convenient and well suited to this purpose), and that is driven by a stable low-noise current source. The current of this source is regulated to minimize the output of the dump toroid. The output of the injection toroid is then the differential current measurement.

Bergoz model # NPCT-S-115 New Parametric Current Transformer
115mm ID
Very high resolution (<0.5uA/sqrt(Hz))
Radiation resistant sensor option

BNL designed DCCT enclosure



Cut-away assembly

Beam Profile Monitor

<u>5 Profile Monitor Stations (Low power only)</u>

Radiabeam will provide entire assembly as per BNL specification.

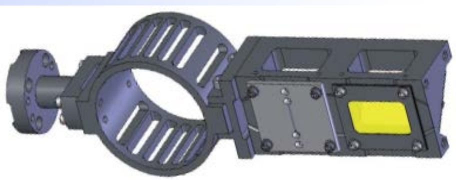
<u>Plunging head detail:</u>

Impedance match + two diagnostics positions

Low Energy PM

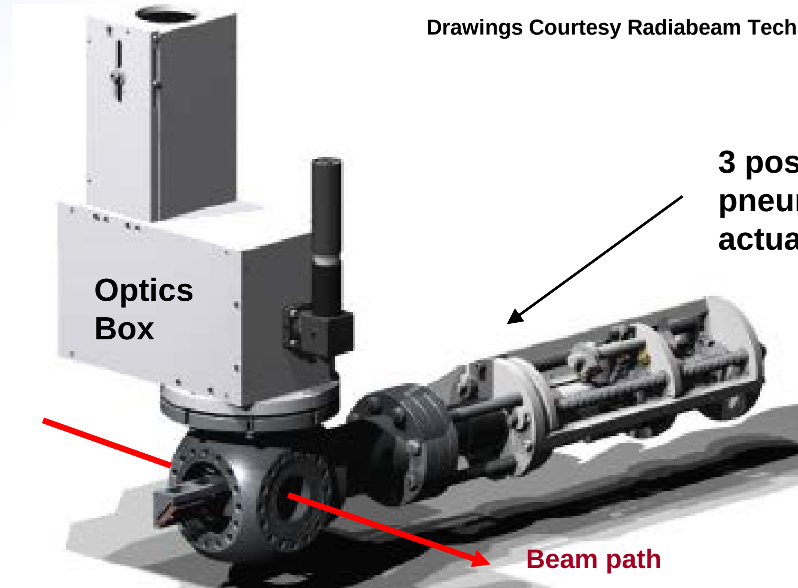
Cal Tgt & YAG

High Energy PM



500u slit or OTR YAG

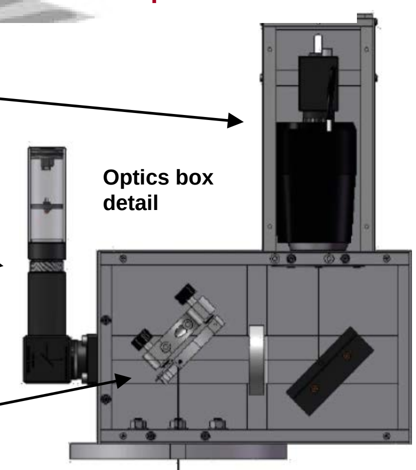
Drawings Courtesy Radiabeam Technologies



CCD Camera & lens

Virtual Resolution Target

Semitransparent mirror



<u>YAG:Ce Screens:</u>

100u thick crystal, Crytur

For low intensity beams:

10's of pC at 2.5MeV, and ~1 pC at 20MeV

<u>OTR foils:</u>

Silicon wafer 250u thick, 1000Ang Al coating.

For higher energy & intensity beams:

20MeV, & > ~130pC

Transverse Emittance & Longitudinal bunch parameters

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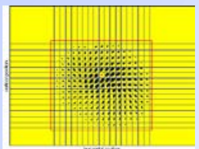
Method 1, 2MeV

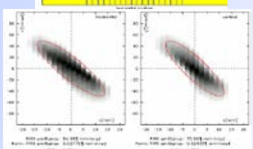
Pepper Pot & Profile Monitor

Remote control plunging masks (slits or hole pattern)

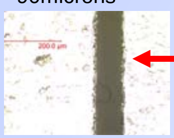
2MeV profile monitor viewer

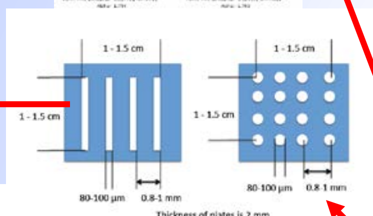
Image data from BNL EBIS





Measured slit ~90microns





Method 2

Turning on 16 degree dipole allows measurement of longitudinal electron bunch parameters:
Bunch length
Longitudinal tails

Slice emittance will be measured using off crest RF operation and slits.

Method 2, 20MeV Variables

RF phase

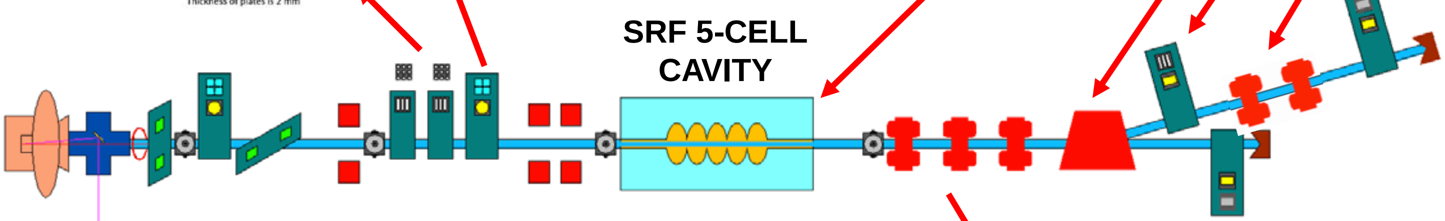
Dipole, 16^0

500u Vert slit

Doublet

Profile monitor YAG or OTR

SRF GUN



Method 3: Triplet and Profile monitor YAG or OTR

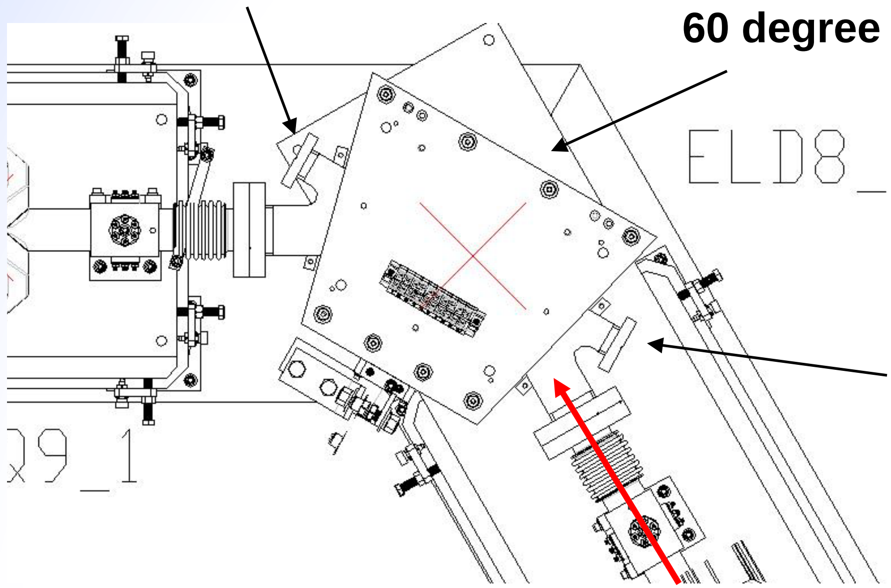
Synchrotron Light

These monitors are traditionally used to monitor the transverse & longitudinal beam profiles in the high power/current regime.

However, using these monitors can be **problematic** if the beam energy is **below 18 MeV** due to the long wavelength of the synchrotron radiation. The present plan is to have optics and CCD cameras available at the dipole chamber locations.

Synchrotron light port

60 degree Arc Dipole plan view



Alignment & Calibration port

ERL Dipole chamber

Beam direction

Halo Scrapers, Wire Scanners

Halo Scrapers

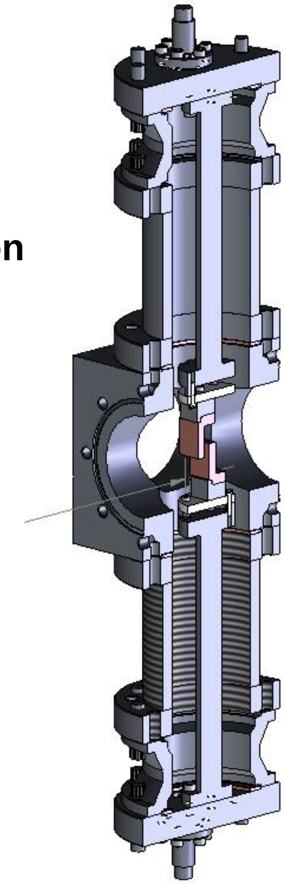
Measure beam halo distribution at upstream 2MeV transport
Need high reliability device near SCRF cavities (wire too risky)
Three sets of isolated, 2mm thick jaws, H & V, from Radiabeam
First scraper for primary collimation
Second & third located in a dispersive region for momentum collimation
Stepper motor control & position readback.

Wire scanners (don't need until later)

Not yet designed.
Planned for high energy (20MeV) in ERL loop far from SRF cavities.
Considering the vibrating wire technique.

Signal Acquisition

Goal is 1e-6 (ambitious at low energy)
Monitor losses downstream (PMT BLM)
Differential current measurements
Profile Monitor screen with hole
Other methods at 2MeV?



Halo Scraper

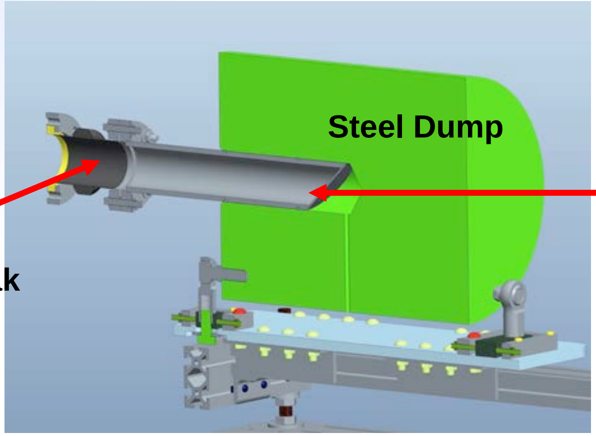
Low Power Dump

Low Power Dump / Faraday Cup

Simple low cost BNL design, <10W (0.5uA at 20MeV)

Located at the end of stub transport

Ceramic break, isolated beam stop



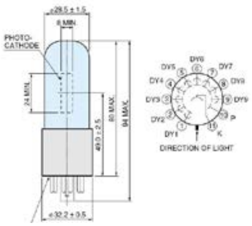
Ceramic break
~2 inch ID

Wedged steel beam stop
Electrically isolated

Loss Monitors

Beam Loss Monitors (3 types)

Machine Protection for 1MW beam



Courtesy K. Jordan

Primary Detector

PMT's (JLAB-CEBAF) (Hamamatsu R11558)

Fast (<10us)

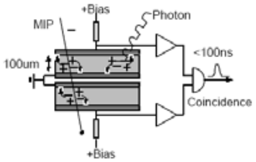
50dB DR (5nA – 100uA from tube)

Limited coverage

Pin Diode Bergoz BLMs

MIP sensitive, ignores x-rays, small area coverage, rate limited to ~10MHz.

Bergoz BLM



Ion Chambers (RHIC BLM's & long cables), (ELBE, etc..)

Full coverage

Calibrated (R/hr)

Less sensitive, useful at areas where we expect high levels

Infrared Camera (FLIR A310)

Check for beam pipe heating, or losses other detectors can't see.
Remote image display & storage, Ethernet communication.

Schedule & Future Plans

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Schedule

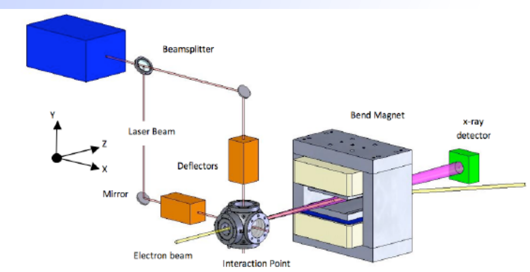
First electron beams in Stage 1 (Gun to 5-cell) when gun is ready, presently under construction.
After Stage 1 studies are complete, install zig-zag injection.
After zig-zag commissioned, close the ERL loop.

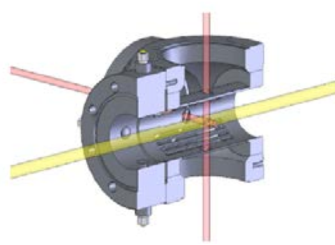
Future Instrumentation

Streak Camera:
Measure longitudinal bunch characteristics using synchrotron light or optical transition radiation.
Hamamatsu Universal Streak Camera C5680 system with temporal resolution of 2ps is under consideration.

Laser Wire Profile Monitor: (presently no way to directly measure high power beam profiles)
A combination of a "laser wire" with a Compton photon counter can be used to measure all three dimensions of electron bunches in the high power regime. We are evaluating a possibility of using a commercial CO2 laser, or laser pulses of either IR or green light produced by the gun driver laser as a byproduct. Correlating the laser pulses with electron bunches we will be able to measure the longitudinal beam profile.

Laser Wire Scanner conceptual design figures below courtesy of Radiabeam Technologies, effort presently in early stage Small Business Innovation Research (SBIR) proposal.





Summary

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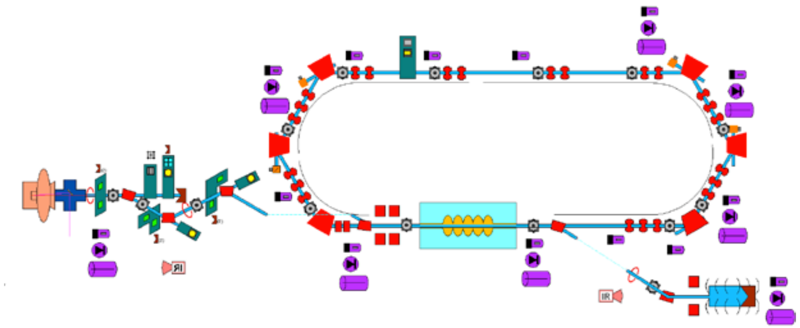
- A high power (~500mA) ERL is needed to upgrade RHIC to eRHIC.
- Beam commissioning of the BNL R&D ERL systems will begin soon.
- There is a 3 tiered staged approach to characterize and test all of the subsystems, achieve energy recovery, and meet performance requirements.
- The early instrumentation measurements include:

Position	Current
Profile	Loss
Emittance	Halo
Bunch length	Longitudinal tails



- There are plans to add more exotic and expensive instrumentation beyond what is initially planned.

Acknowledgments

BNL C-AD

R&D Energy Recovery Linac Group

Instrumentation Systems Group

Controls & Vacuum Group

V. Litvinenko, E. Pozdeyev, K. Jordan, P. Cameron, G. Mahler, D. Weiss, S. Trabocchi

Radiabeam Technologies – A. Murokh, M. Ruelas

Thank you for your attention!