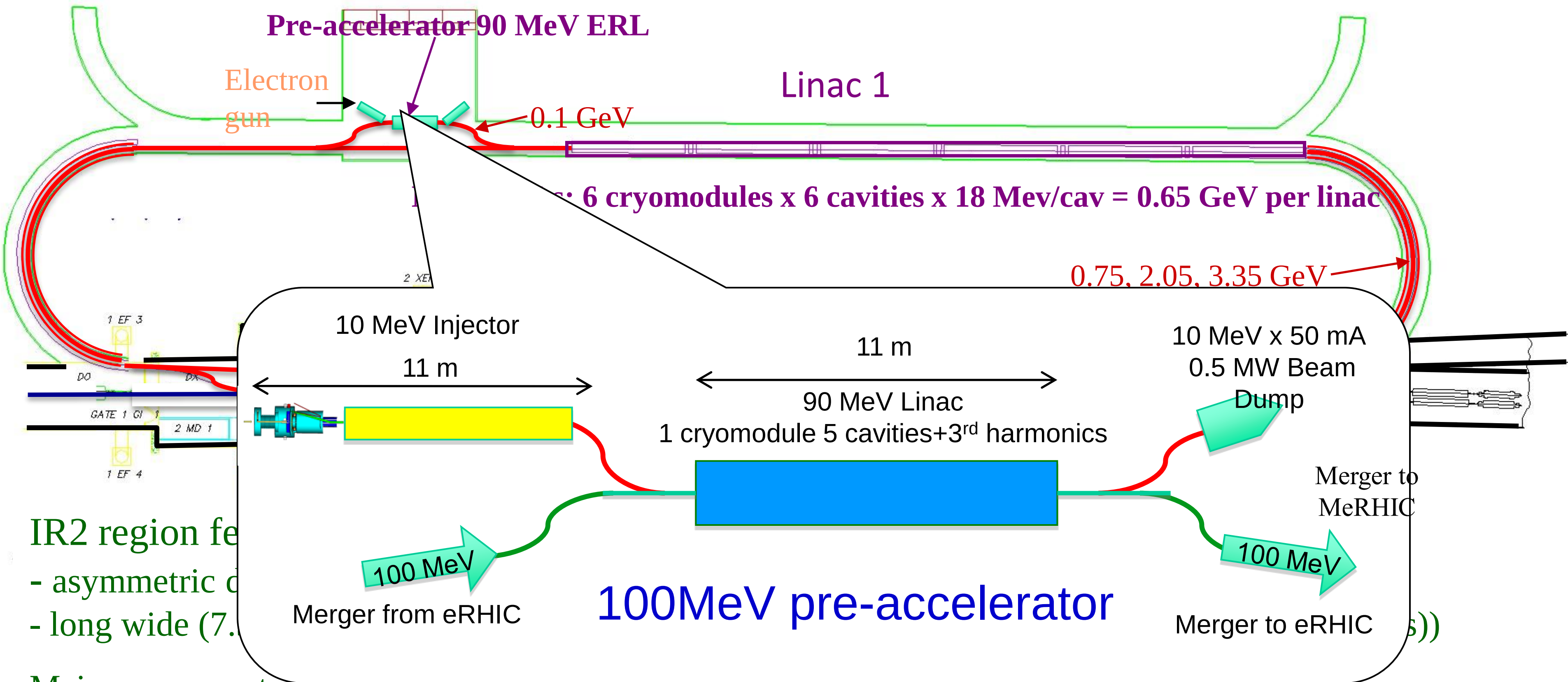
Engineering Challenges and Solutions for MeRHIC

Andrew Burrill for the MeRHIC Team

Key Components

- Photoinjector Design
- Photocathodes & Drive Laser
- Linac Cavities
  - 703.75 MHz 5 cell cavities
  - 3rd Harmonic Cavities
  - HOM absorbers
- Cryomodule Design
- Magnet Design
- Vacuum System
- RF systems
- Cryogenic System
- Tunnel Installation

MeRHIC: General layout



IR2 region fe
- asymmetric d
- long wide (7. ... s))

Main components:

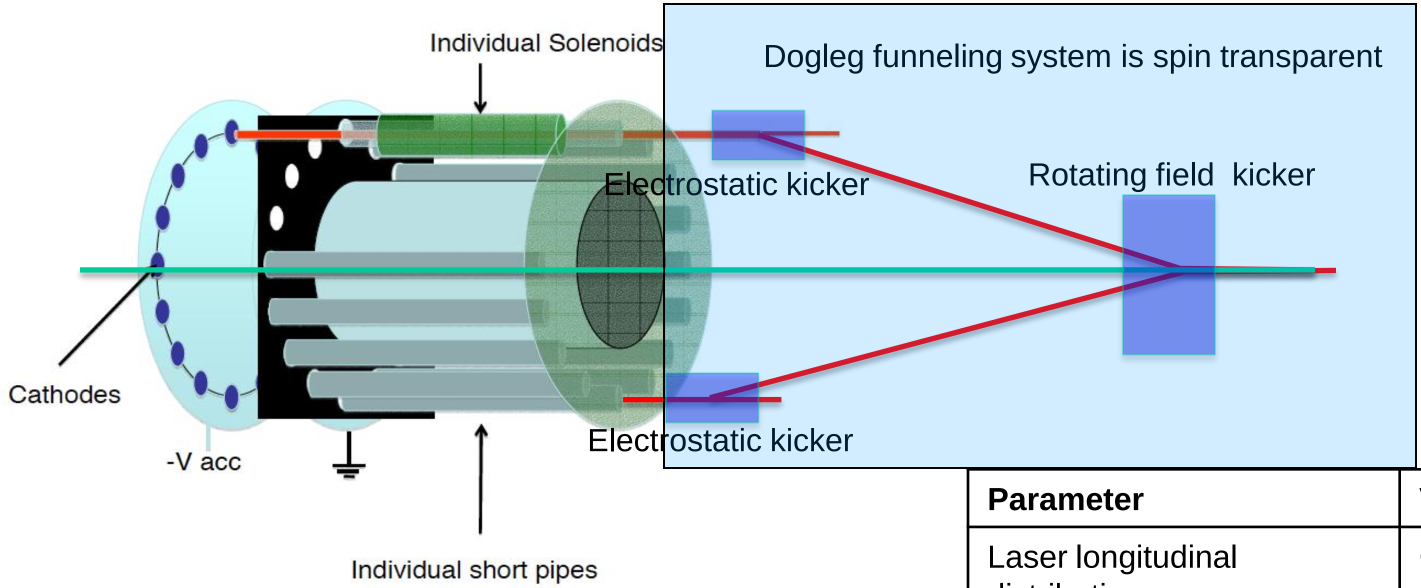
-100 MeV injector on the basis of polarized electron gun (50 mA) and pre-accelerator ERL.

-Two main ERLs (one of them in the RHIC tunnel) with maximum 0.65 GeV energy gain per linac.

-Recirculation passes are going outside of the existing tunnel: warm magnets, acceptable synchrotron radiation power.

Gatling Gun*)

*) the Gatling gun is the first **successful** machine gun, invented by Dr. Richard Jordan Gatling.



~ 50 mA from injector is needed.
State of the art electron polarized source is 1 mA.

The multi cathode to reduce load on a single cathode can be used

Parameter	Value
Laser longitudinal distribution	Gaussian
Bunch length at cathode	0.5nS [FWHM]
Laser transverse distribution	Uniform
Laser spot diameter	8mm
Bunch charge	5nC
Accelerating voltage	200kV
Cathode-anode gap	3cm
Integrated solenoid field	2.1kG-cm

Laser

Presently no Commercial Laser to meet the need

LDRD for laser development 2W/mA (780 nm, 0.1% QE)

- Three possible approaches:
  - Fiber oscillator → Fiber amplifier→ 2ħω to 780 nm
  - Ti:S Oscillator → Ti:S amplifier 780 nm
  - Diode oscillator → Power amplifier 780 nm
- All three approaches will be evaluated
- Best selected, built & test to drive up to 2 mA

Expected Results

- Laser to drive one cathode of the multi cathode gun
- Laser system scalable to deliver full EIC electron beam

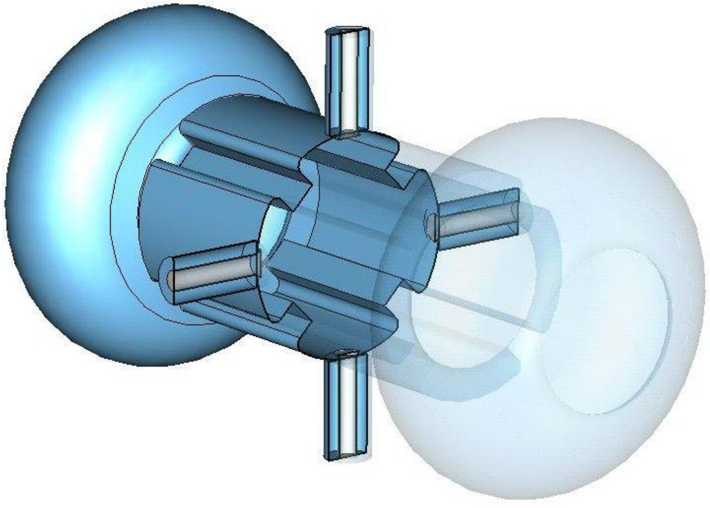
2 LDRD's for the new injector and laser have been approved

Linac Cavities

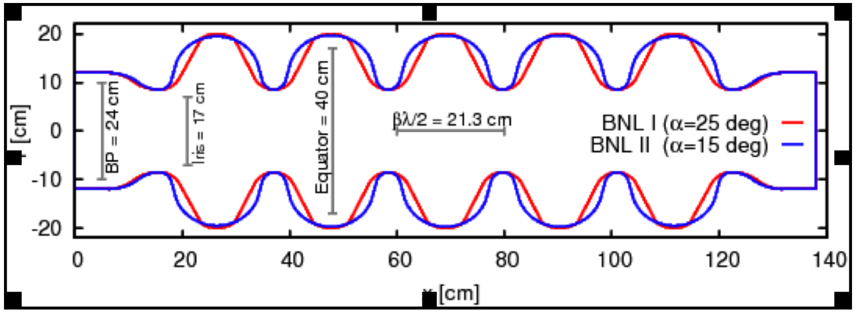
- We have a large number of SRF cavities in MeRHIC:
  - Main linac – 72 elliptic 5-cell cavities at 703.75 MHz and 2 second harmonic cavities (1.4075 GHz)
  - Pre-accelerator linac – 5 703.75 MHz elliptic 5-cell cavities and one 3rd harmonic cavity.
  - Injector linac – Seven 112 MHz quarter wave cavities and one 336 MHz single-cell cavity.
  - Energy loss compensator cavity – a single 703.75 elliptical two-cell cavity.
- We are in a strong position in high-current ERL cavities, but-
- there is a lot of R&D and engineering to be done. We are carrying out an aggressive R&D program.

Linac Cavities

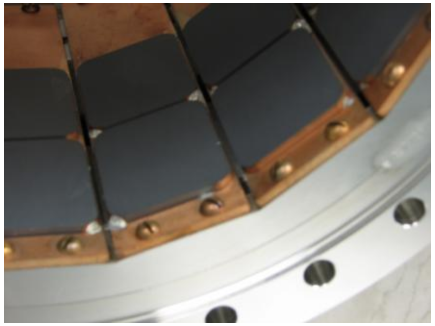
- Development of next generation:
- Reduce Hpeak by 18% to 4.7 mT/MV/m
- Increase Epeak 19% to 2.34
- Increase R/Q 7% to 465Ω
- Reduce stiffness by a factor of 2.
- Apply new ideas in HOM damping:
  - Reduce evanescent fundamental in beam tubes
  - Increase real-estate gradient

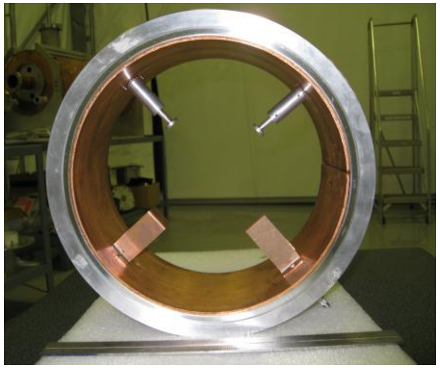


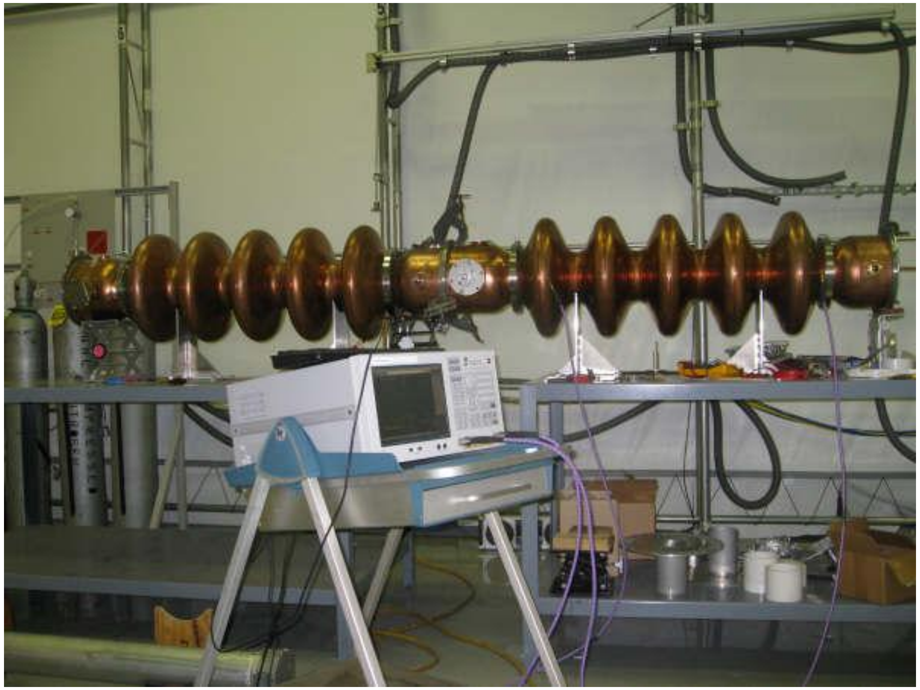
Supported by a DOE HEP grant through Stony Brook CASE



HOM Absorbers/ Dampers







In BNL I, damping is done with ferrites.
For BNL II, we are considering pick-up probes in the beam tube.
Measured Q_{HOM} of a few 1000's, Q_{FUND} about 10^8.
Expected result: Compact, simple HOM damping.

Linac Components

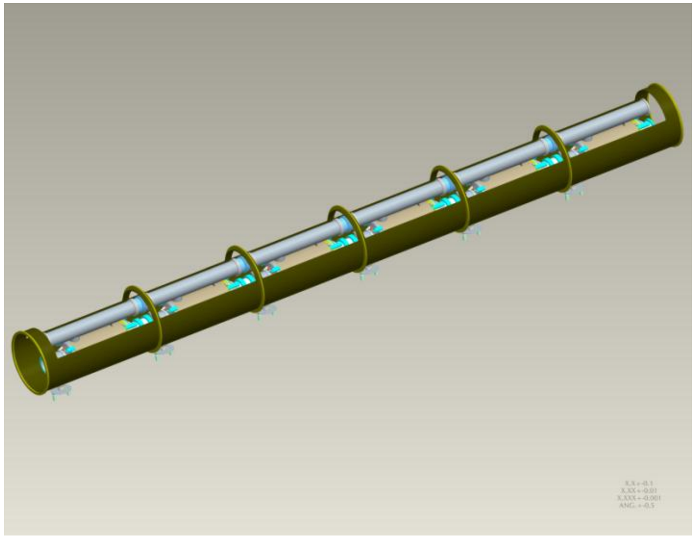
- Preliminary Engineering & Design (PED)
  - Cavity & Cryomodule – Design of six (6) SRF cavity types, their helium vessels, support systems, thermal & magnetic shielding, vacuum vessels & other components
    - Risk – Required iterative design process between scientific & engineering staff can result in increased labor cost. 4 of 6 required cavities similar to previous designs – remaining 2 will each require a new design

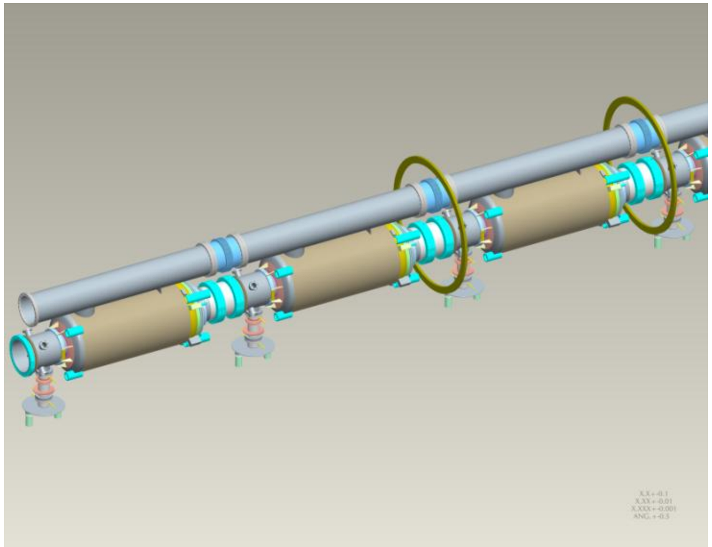
ERL 5-cell Cavity

- Construction - Procurement
  - Cryomodule Component & Cavity
  - Procurement of all SRF cryomodule components including cavities (93 units total)
  - Risk – Moderate due to price fluctuations in strategic materials (Nb, SST, Cu) and limited number of cavity vendors. Quantity/variety of cavities may require multiple vendors – depending on schedule & global demand – impacting cost.

Cryomodule Design

- Cryomodule development
  - "out-of-the-box" approach to modern cryomodules
  - Emphasis on modularity, cleanliness, maintenance





RF Systems – Main and Pre-accelerator Linacs

Main Linac and pre-accelerator:

- 77 5-cell cavities at 703.75 MHz powered individually by 15 kW power amplifiers
- 2 each 2nd harmonic cavities at 1.4 GHz powered by 250 kW power amplifiers
- 1 each 3rd harmonic cavity at 2.1 GHz powered by 15 kW power amplifier

Injector Linac:

- 7 quarter wave cavities at 112 MHz powered individually by 100 kW power amplifiers
- 1 each 3rd harmonic single cell cavity at 336 MHz powered by 15 kW amplifier

Energy loss comp cavity:

- 1 each 2-cell cavity at 703.75 MHz powered by 350 kW amplifier

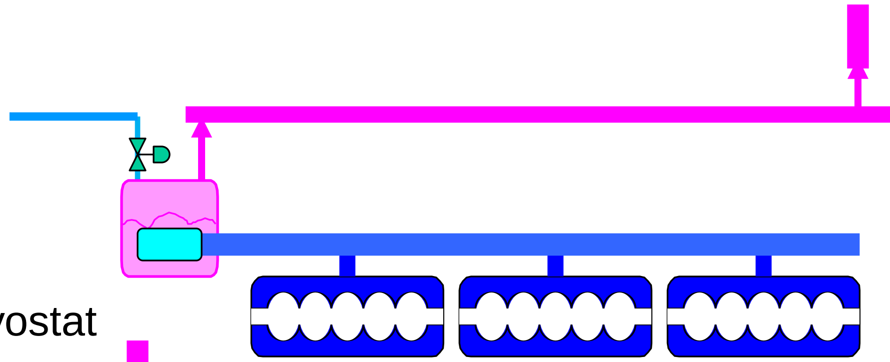
Cryogenics System

- Cavity cooling:
  - 1.9K @ cavities
  - 1.8K @ HX / cold compressor bath
  - **Quiet System:** Vibration & microphonics
  - Heat transfer: SFTC or local evaporation
- Quad cooling: 1.8K: Leads: HTS with shield flow as lead flow
  4.5K: Leads: Normal leads.
- Sub-atmospheric system type/configuration
  - Hybrid: Cold compression/ warm compression
  - 100% cold compression
- New 4.5K plant @ 2 O'clock; Existing RHIC plant (1005) for Collider
- Use existing RHIC Plant for MeRHIC & RHIC
- New plant for both RHIC and MeRHIC

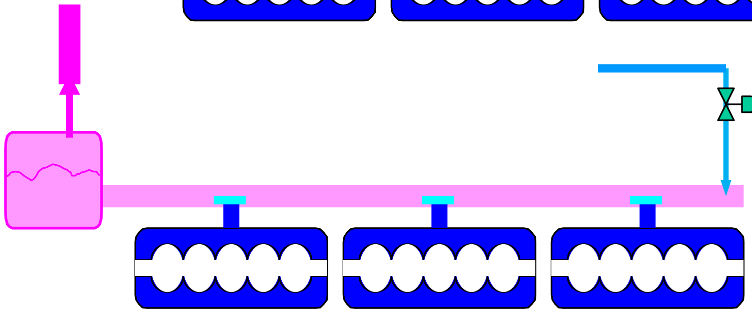
Cryogenics System

SUPERFLUID HEAT TRANSFER:

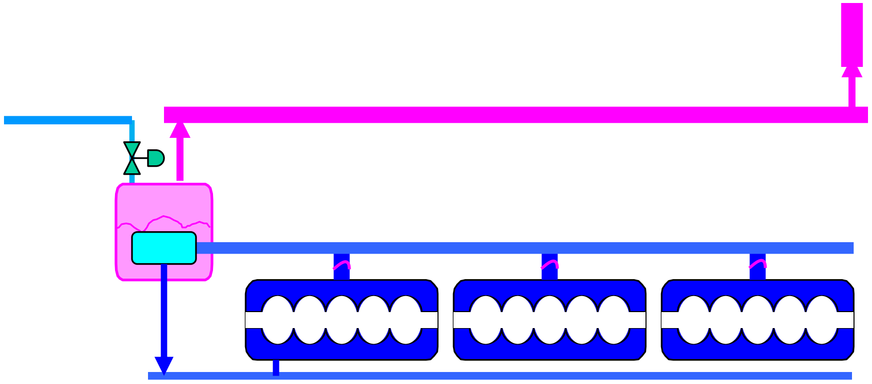
- SFT Conduction via pressurized superfluid
  - Heat exchanger every 3 cavities
  - ~ 8 inch Superfluid line
  - 8 inch 12 Torr Vapor return line outside cryostat



- 2-ϕ flow boiling (LHC) heat transfer
  from pressurized superfluid
  - Continuous heat exchanger
    / two-phase flow / vapor return

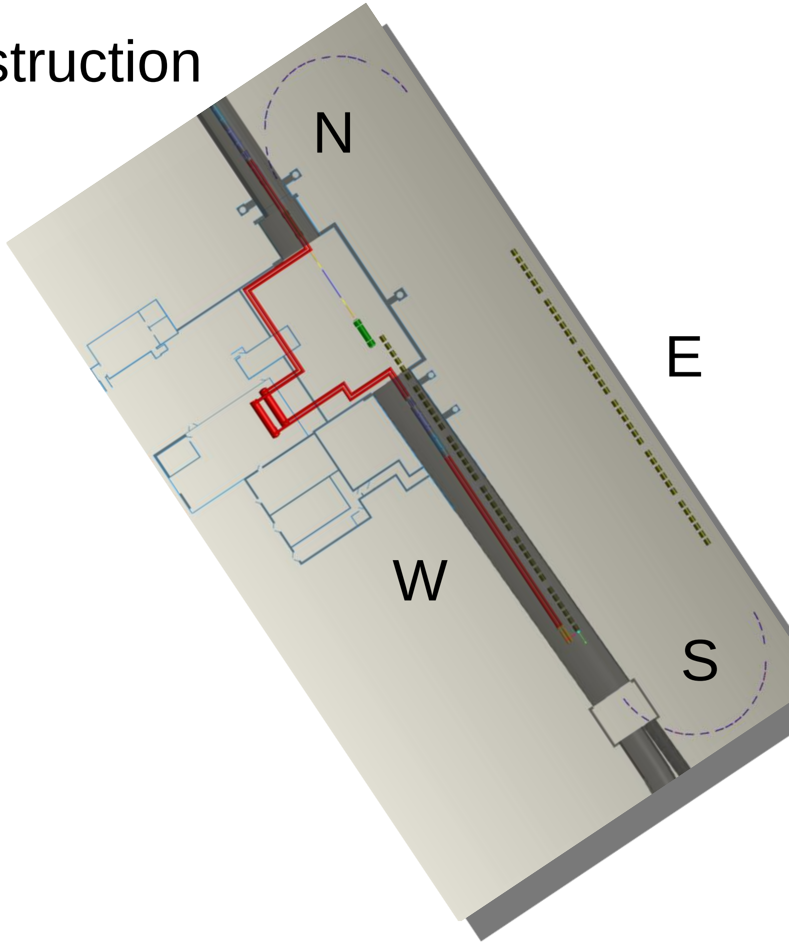


- Saturation Line
  central vapor recondensing unit per 6 cavities



Tunnel Installation

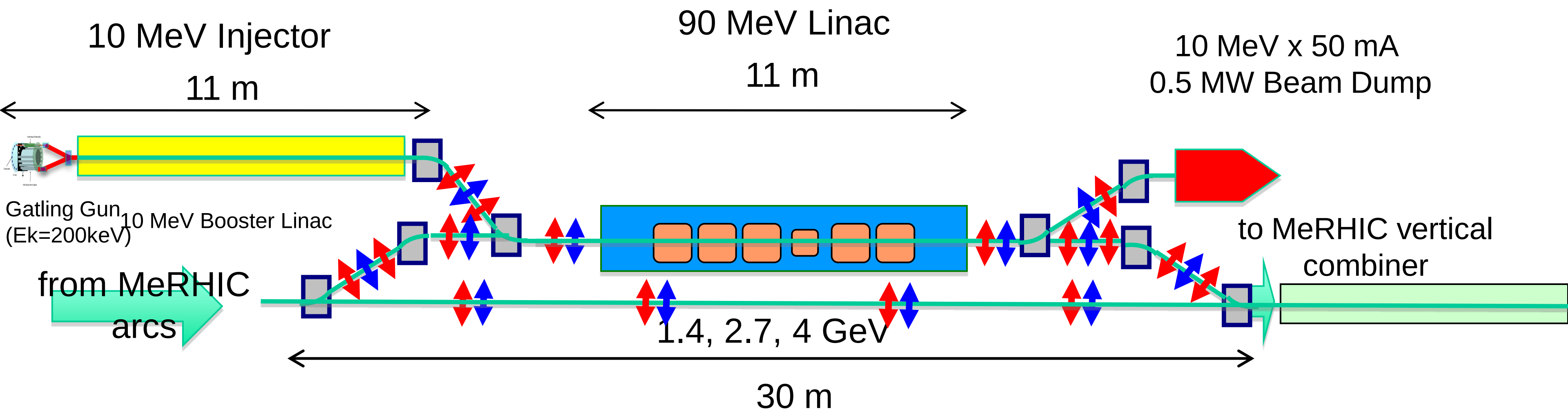
- Only Four year construction project CD-3 to CD-4
- Critical Items must be ordered during CD-1 and CD-2
- RHIC Operations Schedule During Construction
- New Tunnel tied in 2 years after CD-3
- Temporary Shielding at Tunnel Tie-in
  - Existing 20 Ton Crane!
- Long Lead Items will drive schedule



Conclusions

- Key Technical challenges have been identified
- Technical and cost reviews are underway to identify items of concern
- An early jump on the planning will allow for a successful project to be carried out
- SRF infrastructure is growing at BNL to handle the anticipated cavity workload
- C-AD department and BNL site have a wealth of experience in large scale construction projects
  - RHIC
  - NSLS
  - NSLS-II
  - Collaboration on other programs, SNS, LHC etc.

100 MeV Pre Accelerator ERL



<u>Injector Parameters</u>
Polarized Gun (200kV)
Cathode GaAs,
Laser 780nm
Emax= 10 MeV
Iavr =50 mA,
Q per bunch =5nC

<u>Pre-accelerator ERL:</u>
One pass
Energy gain 90 MeV
Einj & Eextr=10 MeV
Emax =100 MeV

<u>eBeam parameters :</u>
E=100 MeV
Iavr=50 mA
Ipeak=500 A
Reprate = 9.8 MHz
Emittance =70 mm-mrad
Banchlength = 3 mm
dE/E = 1E-3

Linac Components

- **Cavity Processing & String Assembly - PED**
  - Process & String Assembly Tooling - Design fixtures & tooling required to clean, bake, polish, rinse, cold-test cavities and assemble cavity/helium vessel assemblies into hermetic string. (Class 100 Cleanroom).
    - Risk is estimated as moderate based on past experience.

- **Construction - Procurement**
  - SRF Processing/String/Installation Tooling Procurement
    - Procurement of cavity tooling required to process all 6 types of cavities (93 units total).
    - Risk – Low based on recent experience. Fairly low-tech components.

  - **Cavity Processing**
    - Costs of all processing steps – cleaning, baking, polishing, rinsing, etc. through to and including string assembly.
    - Risk – Moderate level of risk, since multiple vendors may be required (including BNL facility) to achieve needed throughput.