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LEReC Instrumentation Design & Construction

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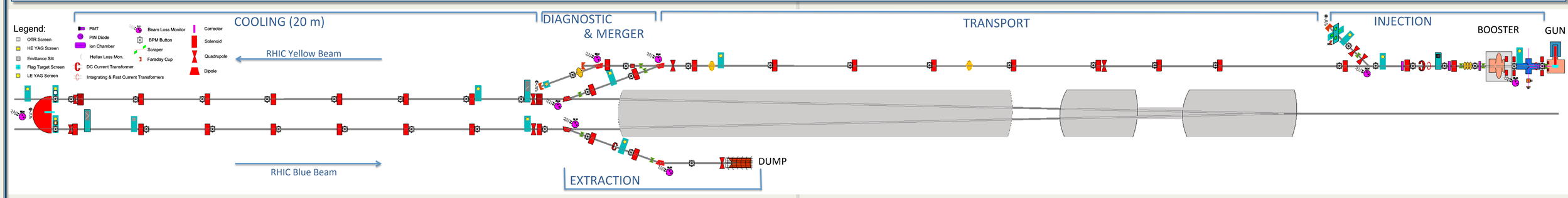
RHIC will be run at low ion beam center-of-mass energies of 7.7 – 20 GeV/nucleon, much lower than the typical operations at 100 GeV/nucleon. The primary motivation is to explore the existence and location of the critical point on the QCD phase diagram. An electron accelerator is being constructed to provide Low Energy RHIC electron Cooling (LEReC) [1] to cool both the blue & yellow RHIC ion beams by co-propagating a 10 – 50 mA electron beam of 1.6 – 2.6 MeV. This cooling facility will include a 400 keV DC gun, SRF booster cavity and a beam transport with multiple phase adjusting RF cavities to bring the beam to one ring to allow electron-ion co-propagation for ~21 m, then through a 180° U-turn electron transport so that the same electron beam can similarly cool the other counter-rotating ion beam, and finally to a beam dump. The injector commissioning is planned to start in early 2017 and full LEReC commissioning planned to start in early 2018. The instrumentation systems that will be described include current transformers, BPMs, profile monitors, multi-slit and single slit scanning emittance stations, time-of-flight and magnetic energy measurements, and beam halo & loss monitors.



Electron Beam Instrumentation

Parameter	Total	Inj	Tr	Mg	Dia	Col	Ex
Profile	**13**	3	1	1	1	6	1
Charge	**4**	2			1		1
Current	**4**	3					2
Position	**41**	8	9	2	2	17	3
Halo	**1**	1					
Emittance	**3**	1				2	
Δp/p	**2**			1		1	
Energy	**1**					1	
Long. Φ	**1**				1		
Beam Loss	**15**	4	3	1		5	2

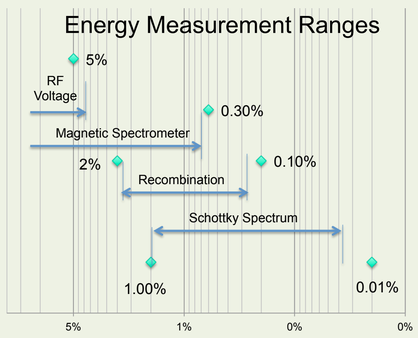
Electron Beam Parameters (Cooling Section

Parameter	Value
Beam Energy	1.6 – 2.6 MeV
Bunch Charge (γ_{ion} = 4.1 – 6.2)	100 – 200 pC
Macrobunch Charge (@ 30 – 24 bunches)	3 – 4.8 nC
Average Beam Current	30 – 50 mA
Bunch / Macrobunch Rep. Rates	704 / 9.1 MHz
Bunch Length	80 – 120 ps
Max. Allowable Energy Spread (Δp/p)	5×10^{-4}
Beam Transvers Size (cooling section)	σ = 3.84 mm
Normalized emittance	2.5 μm

Energy Matching

For successful cooling, beam energies require 10^{-4} accuracy. Electron beam energy will be set to an increasing accruacy in the following way.

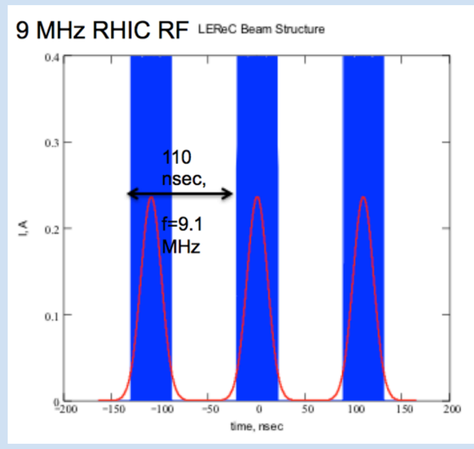
1. set to a 5% accuracy by setting the V_{RF} to an accurate value
2. Set to 0.3% accuracy by adjusting V_{RF} based on the magnetic spectrometer measurements
3. Set to 0.1% accuracy by adjusting $\Phi_{V\text{-}RF}$ based on recombination rates
4. Set to 0.01% accuracy by Schottky Spectrum measurements



Beam Pulse Structure

The electron beam has a nested pulse structure [1], where 80 ps bunches at 704 MHz are grouped in macro bunches and positioned to overlap with the 9.1 MHz RHIC ion beam.

Ion beam bunches @ 9.1 MHz rep rate
overlapped by
704 MHz **electron macro-bunches** @ 9.1 MHz rep rate

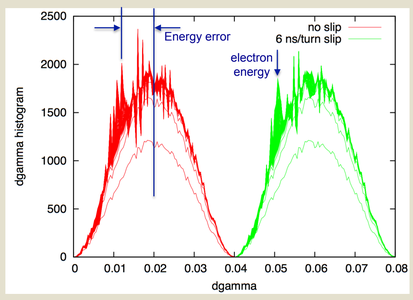


Schottky Spectrum

Analyzing the Schottky spectrum from the RHIC wall current monitor (WCM), the evidence of cooling can be seen as was done at FermiLab recycler [S. Nagaitsev, et al.]. The Schottky spectrum will be used as a probe to find the precise electron beam energy.

- Inject debunched beam into RHIC: acceptance $\Delta p/p=\pm4\times10^{-3}$
- Electron beam concentrates ions at Electron energy
- Peak forms in Schottky spectrum on Wall Current Monitor
- Adjust LEReC RF to alight energies

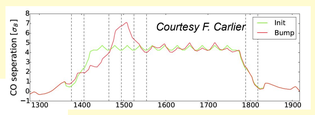
Knowing the ion energy to $<1\times10^{-4}$ and measuring the electron energy with respect to the ion energy we, know the electron energy also to $<1\times10^{-4}$

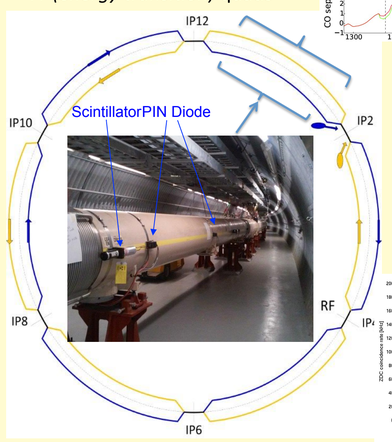


Recombination Monitor

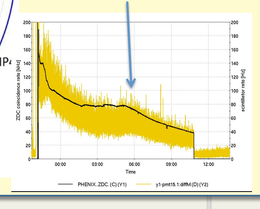
As an indicator of proper alignment of the electron and ion beams for cooling, PIN diodes attached to rate counters will be installed in one of the cold arcs of RHIC to detect radiation from lost Au^{78+} ions from recombination.

- Dispersion bump created using γT *(energy transition)* quads

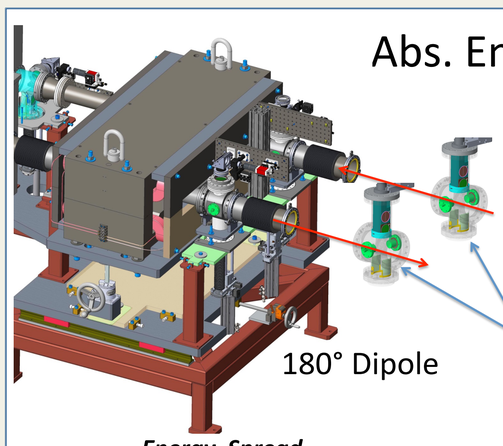




- Au^{78+} driven close to wall. & detected by loss monitors.
- Current Au-Au recombination detected pro-portional to collisions.



Abs. Energy & Energy Spread

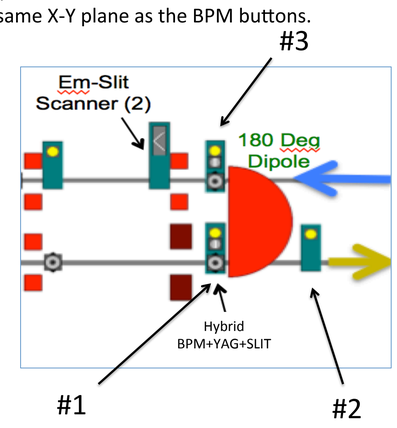


Absolute Energy Measurement

BPM accuracy requirement: 50 μm

Two BPMs will be used with the 180° dipole magnet in the cooling section as a spectrometer. For absolute calibration, a YAG screen profile monitor is inserted into the BPM chamber in the same X-Y plane as the BPM buttons.

BPM Calibrated by Profile Monitor ("HYBRID")



Energy Spread

An energy spread measurement is required with a resolution of better than 10% of the maximum Δp/p of 5×10^{-4}.

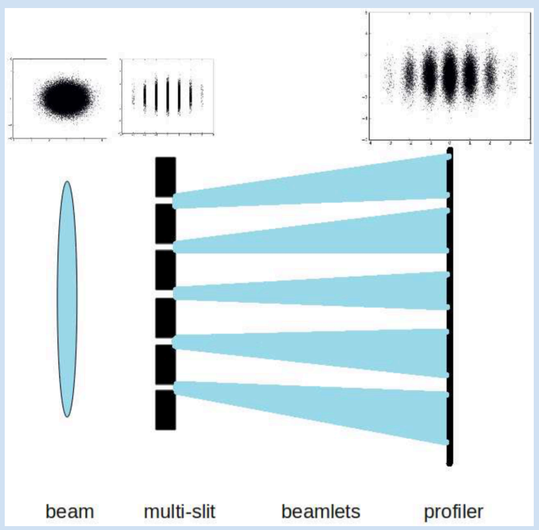
1) Insert slit in #1 ,turn off 180° Dipole, energize high field solenoid
2) Take Profile on #2
3) Energize 180° Dipole & take image on #3
4) Compare images from #2 - #3 in horizontal

Emittance (Injection)

Multi-Slit – Injection Section:

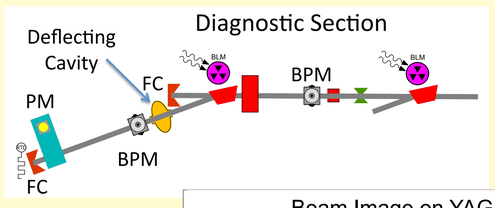
- Automated Analysis,
- 0.5 μm res. (norm Emit < 2.5 μm)
- Low Power Operations Only (1 macrobunch / sec)
- Tungsten Slit mask,

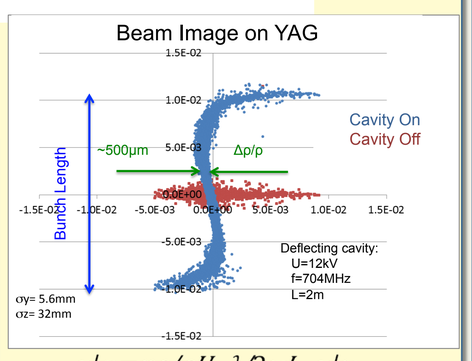
Mask 1.5mm thick…
10 x 150 μm slits @ 1.35mm



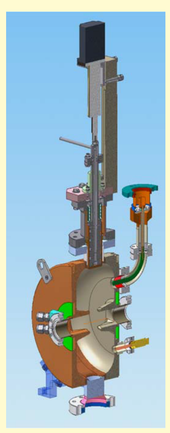
Longitudinal Phase Space

Comprised of a 704-MHz deflecting cavity located just after a 20° dipole and upstream of the mirrorless PM. The Δp/p of the macrobunch is displayed on the PM as the dipole expresses the Δp/p as horizontal $\Delta\sigma_x$ and the deflecting cavity tilts the beam to express the beam's longitudinal axis onto the vertical axis. This gives an image of Δρ/ρ vs time (or length – z).





$$\sigma_z = pc/eU \cdot \lambda/2\pi L \cdot \sigma_y$$



704 MHz Transverse Mode Deflecting Cavity

Charge & Current

All digitized by Zynq ADC @ 250 MS/s

Faraday Cups
- (3) one for each dump
- (2) end flanges
- (4) Halo Mon's

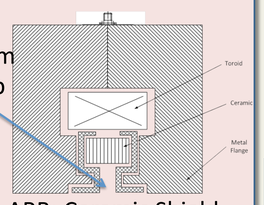
Integrating Current Xrmf's
- ICT-CF6-60.4
- Shielded ceramic

Fast Current Xfmr's for MPS
- FCT-CF6.75"-96.0-UHV-ARB
- 5.0 V/A Sensitivity
- Tuned to 704MHz with Q=**5**
- ARB option: 3-mm Slit shield

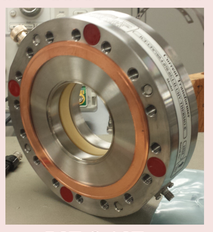
DCCT (NPCT) Differential Inj-Extr
- NPCT-S-115
- Shielded Ceramic
- 1Hz Average – Slow beam loss

DCCT with current bypass shield

3-mm Gap

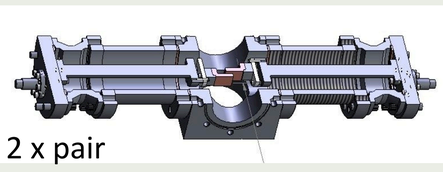


ARB: Ceramic Shield



FCT & ICT

Halo Monitor (Quad)



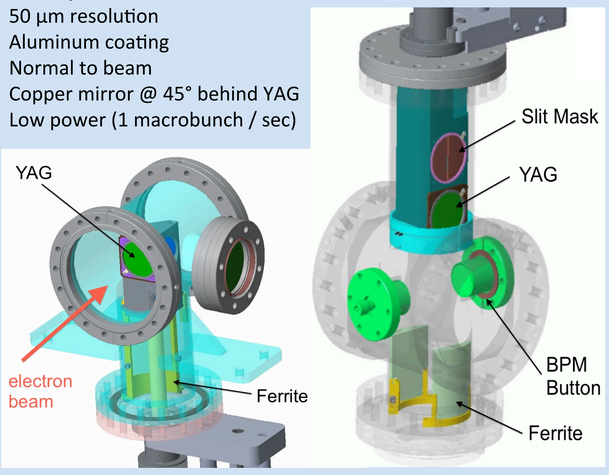
2 x pair

2 pairs of stepper controlled copper jaws with current measurement from the blades with loss signals from downstream BLMs.

Profile Monitor & Hybrid PM+BPM

PM Key Parameters:
- Cylindrical Vacuum Chamber
- 45 mm screen aperture
- YAG crystal 0.1 X 50 mm
- 50 μm resolution
- Aluminum coating
- Normal to beam
- Copper mirror @ 45° behind YAG
- Low power (1 macrobunch / sec)

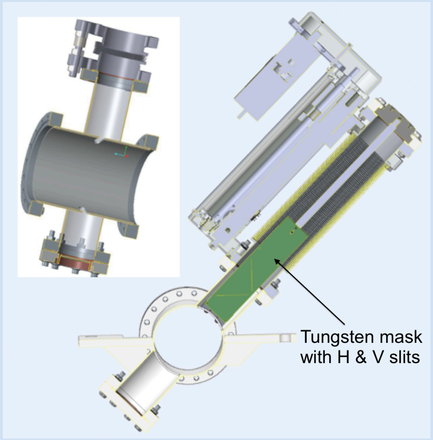
Hybrid PM Functions:
- Absolute Enrgy
- Beam Profile
- Energy Spread



Emittance (Cooling)

One in each cooling section, a tungsten single-slit mask is scanned through the beam upstream of a profile monitor that takes images once per second.

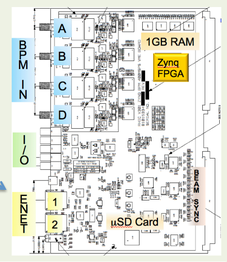
- 0.5 mm/s scan over 30 mm beam spot (1 min)
- 2 mm thick tungsten mask
- 1Hz images
- Step Drive
- H+V Slits
- Low impedance chamber



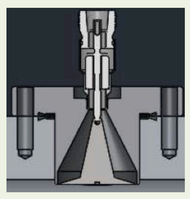
Beam Position

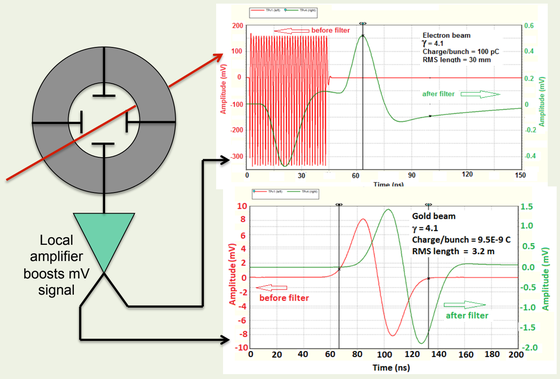
- 41 Button BPMs (28, 15, 9 mm)
- 16 Libera Single Pass
- 25 + 17 V301 BPM modules (BNL)
  - Ions + Electrons in Cooling (2x17)
  - Position Alarm
  - Time of Flight Energy

V301 Module



Libera Single Pass





Beam Loss

PMT BLM electronics developed at JLAB for the 12GeV upgrade will be used for the PMT detectors.
- R11558 side-on PMT
- For MPS & Diagnostics
- 16-bit DAC for LIN & LOG signals
- Response < 1μs
- FPGA based & VME interface
- For pulsed beam & CW

Ion Chamber RHIC style loss monitors.
- 113cc glass tubes
- 0.95 atm of Ar
- Ni electrodes,
- +1400V biased.
- Signals processed by VME electronics developed for RHIC.