CONTROL SYSTEM ISSUES AND PLANNING FOR eRHIC

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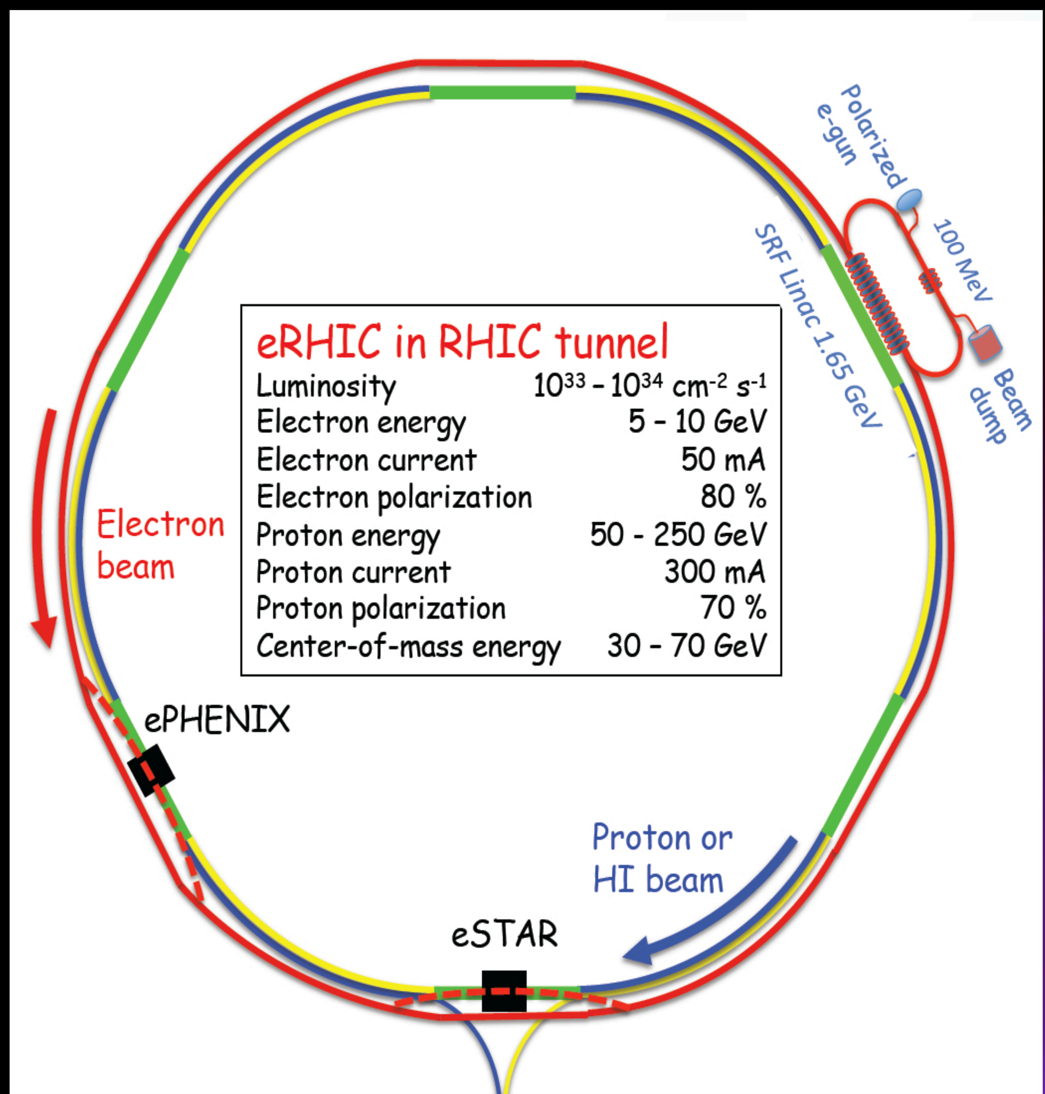
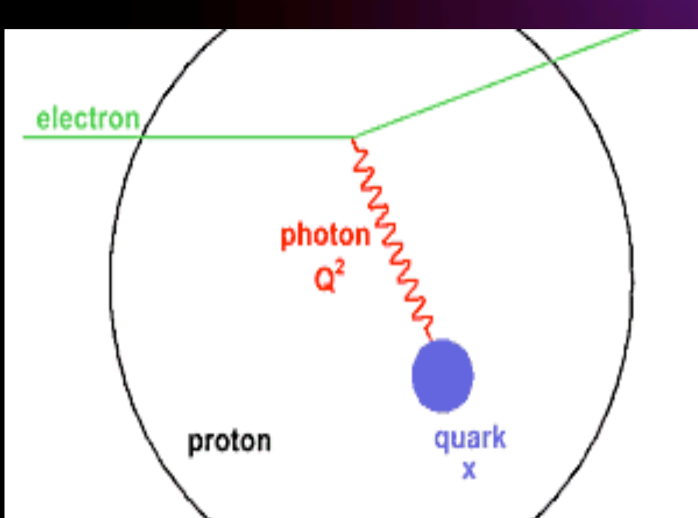


What is eRHIC?

- **RHIC = Relativistic Heavy Ion Collider: Discovered the Quark-Gluon Plasma (QGP) & its Perfect Liquid property**
- **eRHIC = Puts an Electron accelerator into RHIC**
- **Will collide e^- with ions, polarized p, and polarized helions (He^3)**
- **Will continue to study the QGP, the properties of gluons and the strong force, and detailed spin structure of the proton**

eRHIC: An Ultra-High-Resolution Electron Femtoscope

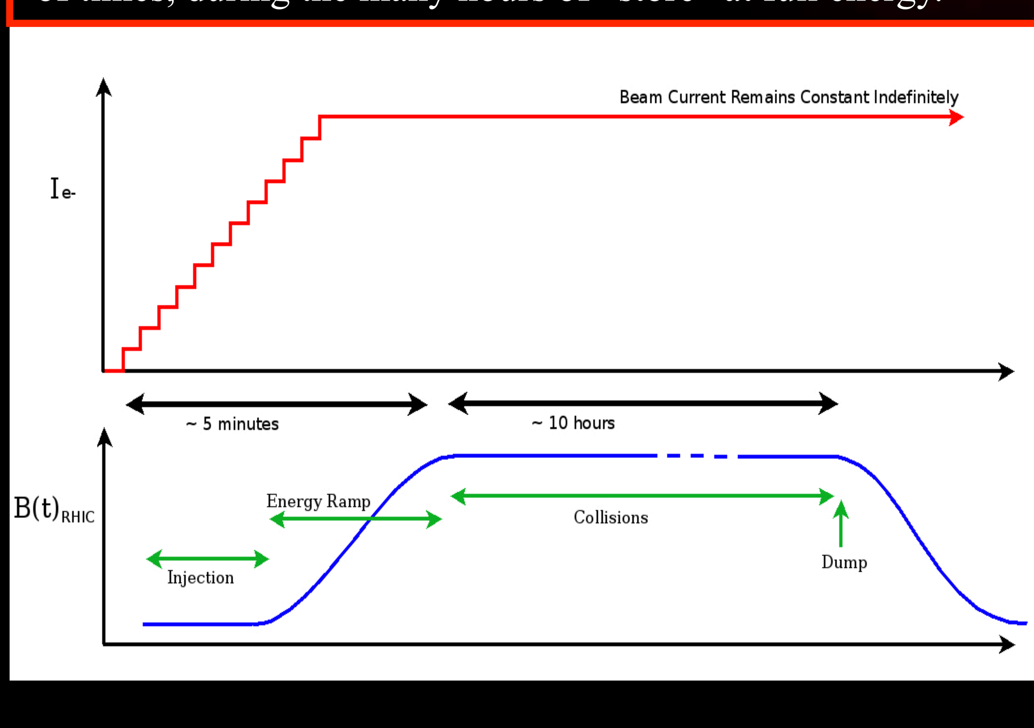


Richard Feynman: "Scattering protons on protons is like colliding Swiss watches to find out how they are built"

eRHIC Operation

Top: Each electron bunch sees an ion/proton collision once. Each bunch is accelerated up to full energy, is at 10 GeV for one turn, then is decelerated back through the Energy Recovery Linac and dumped. Beam current at 10 GeV remains constant indefinitely.

Bottom: Each ion/proton bunch goes into collisions millions of times, during the many hours of "store" at full energy.



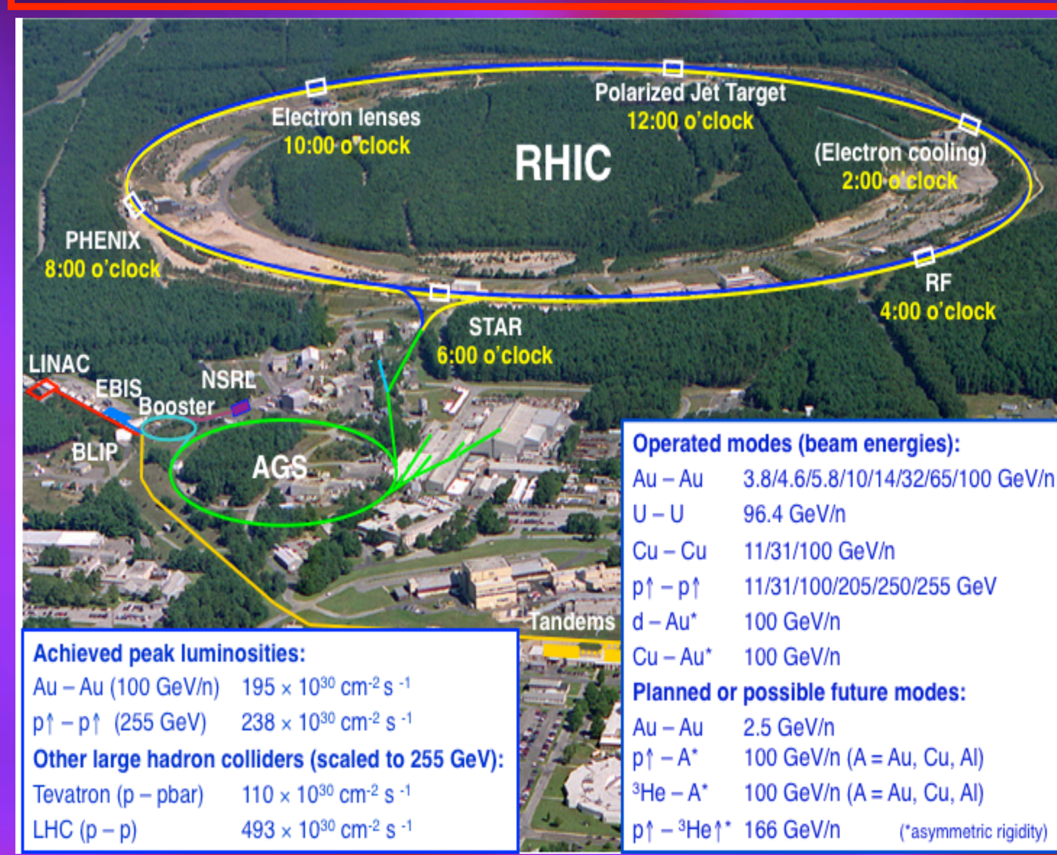
RHIC Controls: A Distributed Object Model Architecture

RHIC Systems

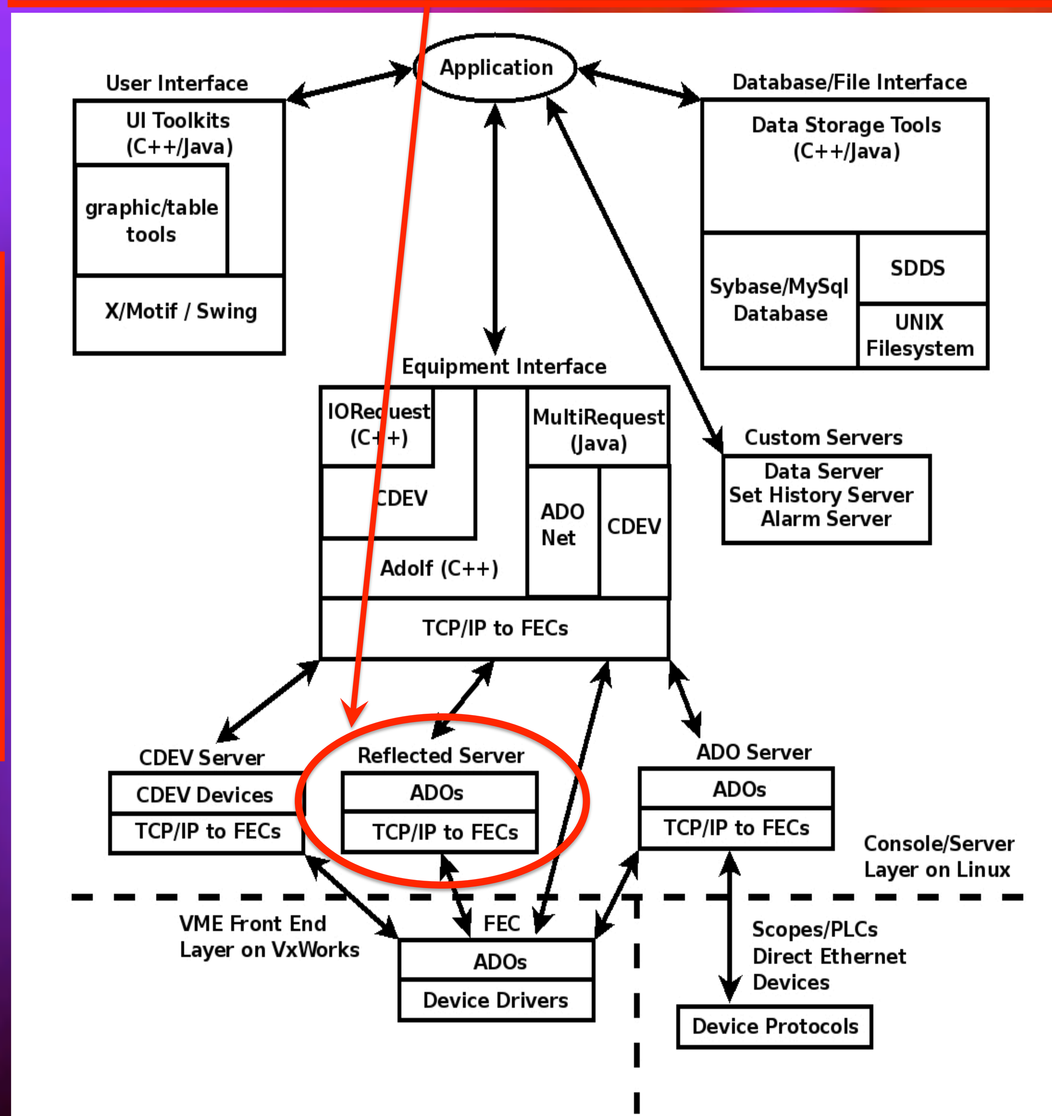
- 1740 superconducting magnets
- 396 Dipoles, 492 Quadrupoles, 72 Trim Quadrupoles, 288 Sextupoles, 492 Correctors
- Each ring is 2.5 miles in circumference
- 25 kw Helium refrigerator
- Operates at 4.5 K°

Controls Systems

- >4000 control and data acquisition modules
- 58 miles of fiber optic cable (controls communication)
- > 420 front end systems
- > 1100 waveform & function generators
- 70 networked buildings, 450 miles of fiber (general communication)
- 8550 switch ports, managed packet routing system



Below: RHIC Controls System Software Architecture
Each front end consists of a server that contains specific accelerator device objects (ADOs), written in C++. One important innovation to the middleware layer is the development of Reflective servers, or what is basically a specialized proxy server to an ADO.



See also:

TUCOCA03: Machine Protection Issues for eRHIC
THPPC024: Operating System Upgrades at RHIC
TUPPC034: Experience Improving the Performance of Reading and Displaying Very Large Datasets
MOPPC157: Application of Transparent Proxy Servers in Control Systems
MOPPC158: Application of Modern Programming Techniques in Existing Control System Software
TUPPC132: Accelerator Control Data Visualization with Google Map
TUPPC131: Synoptic Displays and Rapid Visual Application Development
THPPC023: Integration of Windows Binaries in the UNIX-based RHIC Control System Environment
MOPPC039: Hardware Interface Independent Serial Communication (IISC)
MOPPC076: Quantitative Fault Tree Analysis of the BNL Relativistic Heavy Ion Collider (RHIC) Beam Permit System Elements
MOPPC075: A Monte Carlo Simulation Approach to the Reliability Modeling of the Beam Permit System of Relativistic Heavy Ion Collider (RHIC) at BNL
FRCOBAB05: Distributed Feedback Loop Implementation in the RHIC Low Level RF Platform

Evolution of RHIC Controls: Focus of changes over past 11 years

System	2002	2013
Data (Bytes) Written/Run	1.1 TB	24.6 TB
Total Data Stored (1998 - date)	1.8 TB	109 TB
Lines of Computer Code	1,345,870	3,763,060
# of C++ applications	207	354
# of C++ Servers	71	252
# of Java applications	12	135
# of Java Servers	0	22
# of Front end systems	160	424
# of legacy controllers	50	3
# control point settings (operational)	220,000	497,830
# control point measurements (operational)	160,000	623,878
# All control points in system	~500,000	1,367,504
# of named server entries	21,500	54,797
# of system servers (machines)	<20	111

Better Monitoring and Diagnostic Tools

- Alarm system upgrade
- Expanded system monitoring
- Automated system diagnostics

More Data, Better Analysis Tools

- More complete data logging
- Database driven archives of machine settings
- Saved history of all changes in settings
- Electronic logbooks
- Improved tools for generic viewing and analysis
- Custom tools – StoreAnalysis, FDAView

Modernization

- Injectors upgraded to RHIC style controls
- Hardware upgrades throughout system
- Embedded real time architecture (LLRF+)
- Injector modeling integration with Controls
- Modern network architecture & new router

Cyber Security

- Keeping pace with new requirements
- Maintaining secure remote access
- Homegrown Screen Lock for authentication in control rooms

Increased Automation

- Improved sequencing software
- Lots and lots of sequences!
- More feedback and feed-forward systems

Feedback systems have revolutionized RHIC operations and have been critical towards reaching record luminosities and performance. Tune, Coupling, & Orbit feedback have decreased initial setup time for RHIC, from 5 weeks to 3 weeks, and decreased time for mode changes from a few days to one shift. 10 Hz feedback significantly stabilized the beams during collisions.

Below: 3 D, bunched beam stochastic cooling in action. Luminosity decrease is almost purely burn-off from collisions.

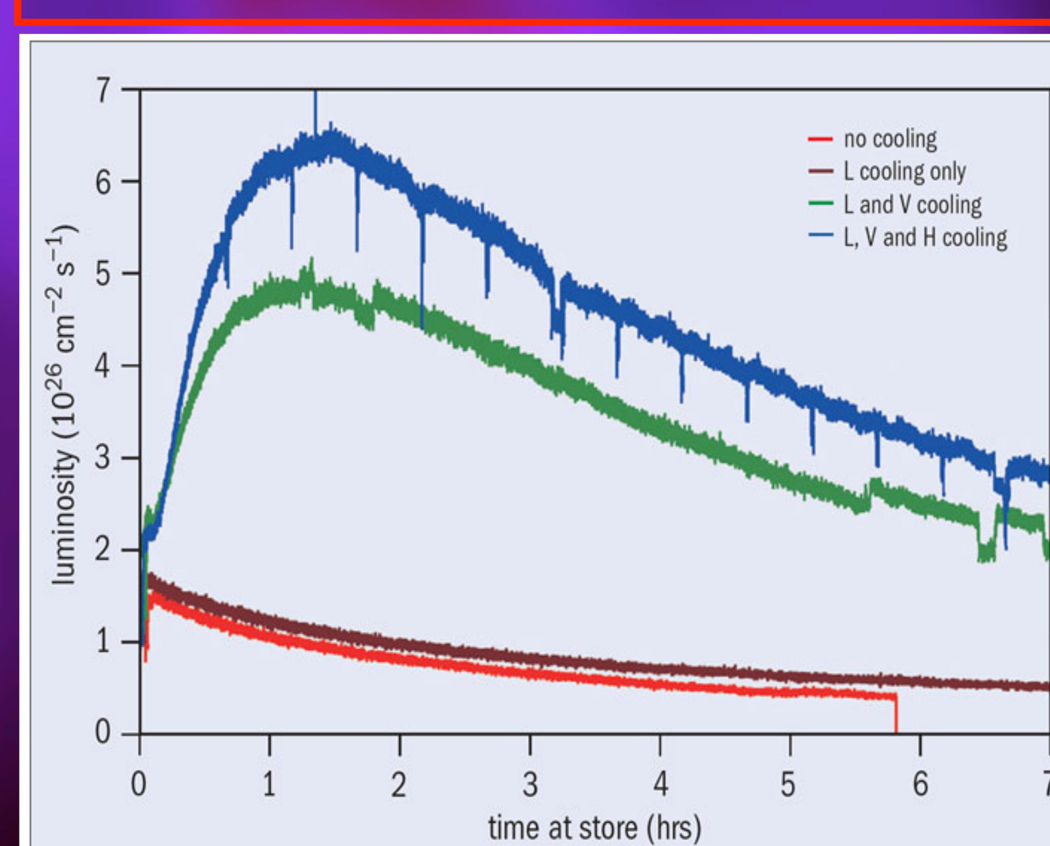


Fig. 2. Luminosity (collision rate) for stores without cooling; with longitudinal cooling only; with longitudinal and vertical cooling; and with cooling in all planes.

eRHIC Planning & Issues

eRHIC Planning

- eRHIC is mostly an idea, at the moment
- 2013 to 2021 = finish RHIC physics program
- 2022 to 2024 = transition to eRHIC (construction)

Front Ends

- ~300 new VME systems
- ~80 miles new cable
- ~10 miles new fiber optic cable
- up to 2850 new power supplies
- 10,000 coil temp. monitors, 720 water flow monitors
- 3 beam dumps, with new machine protection system

Instrumentation

- up to 2100 BPMs with 730 synch. Rad. cameras
- up to 200 imaging camera systems
- up to 2400 loss monitors
- many motion controllers
- significant number of Internet enabled devices

Other Controls

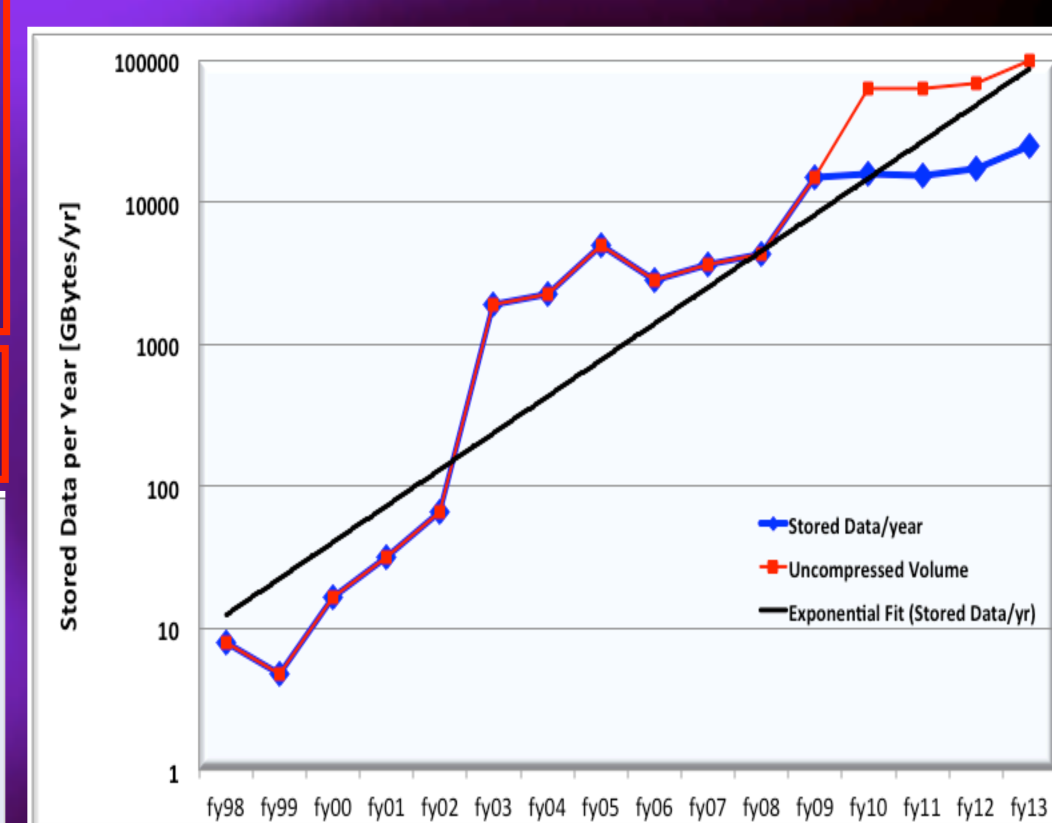
- All ERL cavity PA controlled through embedded real time processors with FPGAs
- Coherent electron cooling controls

Interesting Problems

- BPMs will need to measure the positions of multiple beams in a single beam pipe
- How do we correct the orbits of these beams
- Machine protection system will have to dump the beams while keeping the beam currents balanced in the ERLs
- Scale and Complexity of eRHIC systems:
  - an Internet of things (possibly 1000's of things)
  - Hundreds of camera systems & thousands of BPMs = data bandwidth requirements?
- Custom interfaces: Support the Open Hardware Repository

Projections based on growth from 2002 to 2013

- Front ends increase from 425 to 1000
- # of control points increase from 1.4 to > 3 million
- # lines of code increase from 3.76 to 10 million
- # system servers increase from 111 to ~500
- maximum bandwidth from 20 GB/sec to > 1 TB/sec?
- amount of data written per run: 100 GB to ~ 2 PB?



Above: Amount of data stored per year over the past 15 years has increased exponentially. The data stored/year in 2002 was a little over 1 TB, while in 2013 it was over 100 TB. Logged Data compression began in 2010, reducing the data written to disk by a factor of 4. Come 2024 we may be storing 2 PT/year!

Background Image:

Elliptic and triangular flow in event-by-event (3+1)D viscous hydrodynamics
Bjoern Schenke, Sangyong Jeon, Charles Gale
Phys.Rev.Lett.106:042301,2011
http://arxiv.org/abs/1009.3244