RHIC electron lenses

Commissioning RHIC's Electron Lens

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BROOKHAVEN NATIONAL LABORATORY
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U.S. DEPARTMENT OF ENERGY

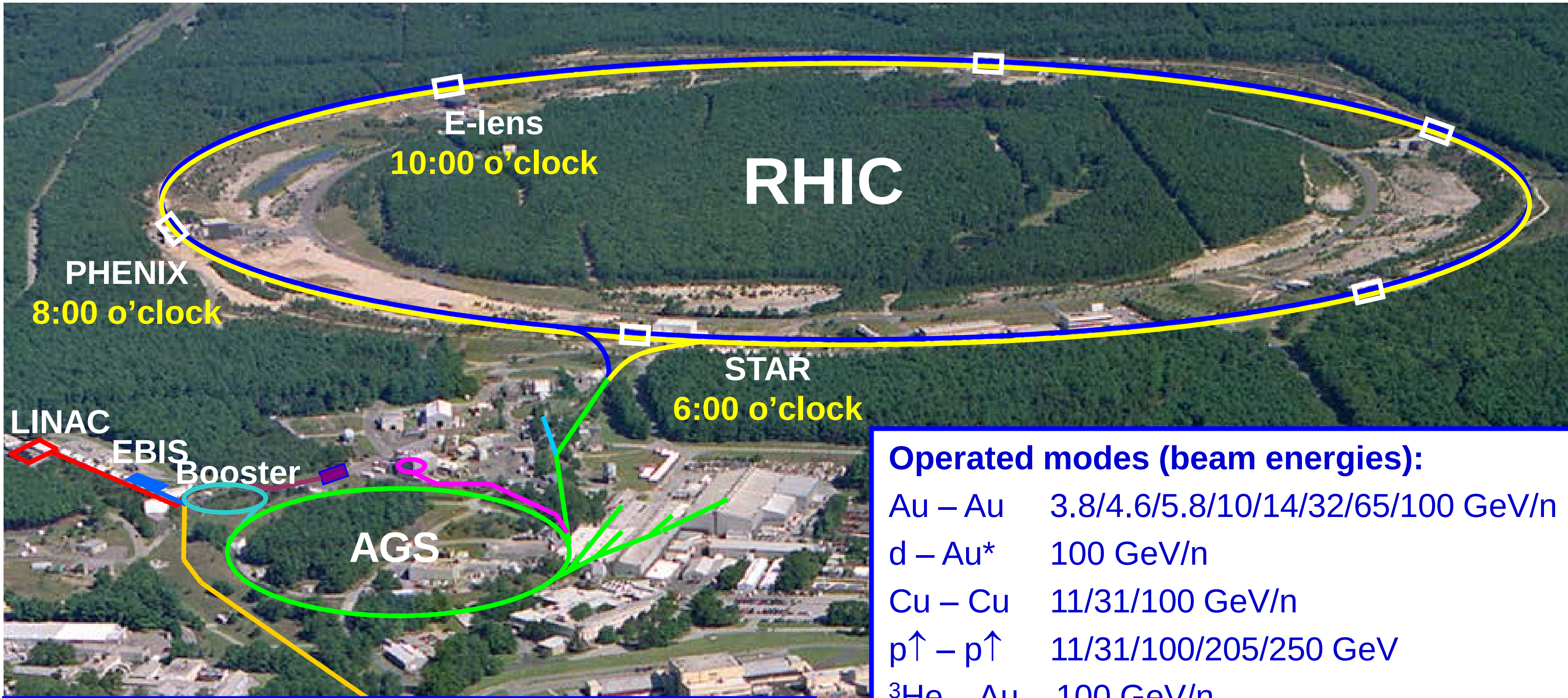
Outline

- **Introduction**

- **Hardware commissioning**
  - Super conducting magnets
  - Normal conducting magnets
  - Instrumentation

- **Electron beam commissioning**
  - Current
  - Transverse profile
  - Effect on orbit and tune
  - Emittance growth caused by electron beam

RHIC – a High Luminosity (Polarized) Hadron Collider



Operated modes (beam energies):

Au – Au	3.8/4.6/5.8/10/14/32/65/100 GeV/n
d – Au*	100 GeV/n
Cu – Cu	11/31/100 GeV/n
p↑ – p↑	11/31/100/205/250 GeV
^{3}He – Au	100 GeV/n

Planned or possible future modes:

Au – Au	2.5 GeV/n (~ SPS cm energy)
U – U	100 GeV/n
p↑ – Au*	100 GeV/n
Cu – Au*	100 GeV/n (*asymmetric rigidity)
e – p	

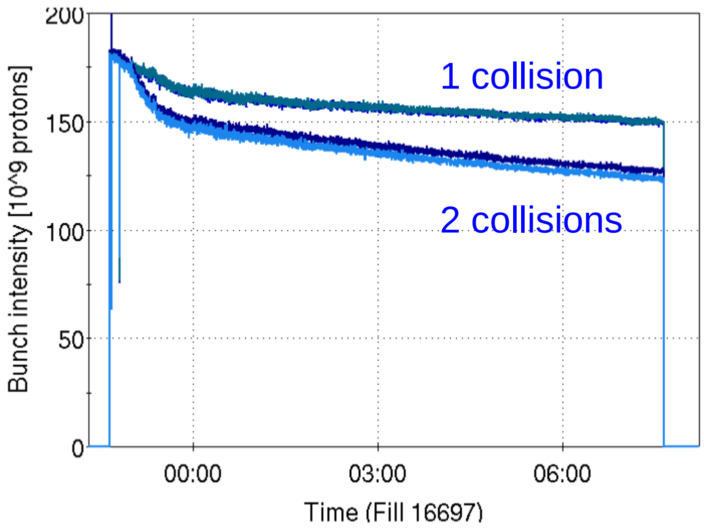
Achieved peak luminosities:

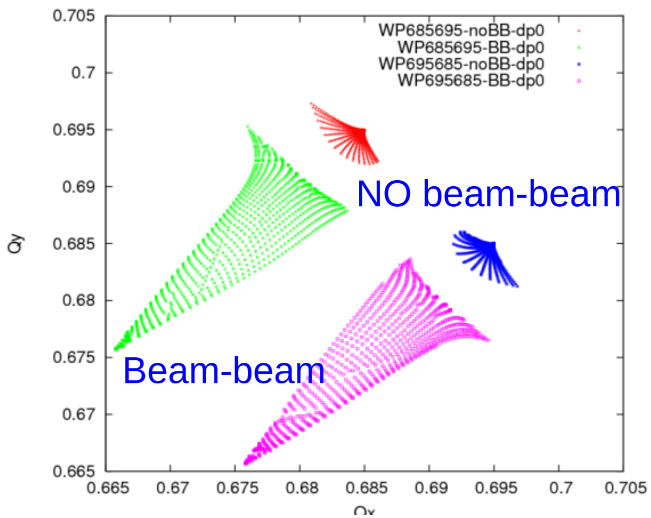
Au–Au (100 GeV/n)	195×10^{30} cm^{-2} s^{-1}
p↑–p↑ (250 GeV)	150×10^{30} cm^{-2} s^{-1}

Performance defined by

1. Luminosity L
2. Proton polarization P
3. Versatility (species, E)

Introduction -- E-lens Motivation





RHIC proton intensity threshold:

1 2013 RHIC polarized proton run:

- 2.2E11 for Blue (beam-beam)
- 2.0E11 for Yellow (longitudinal stability)

2 Beam-Beam Tracking:

If intensity >2.0 × 1011, no enough tune space for large beam-beam tune spread

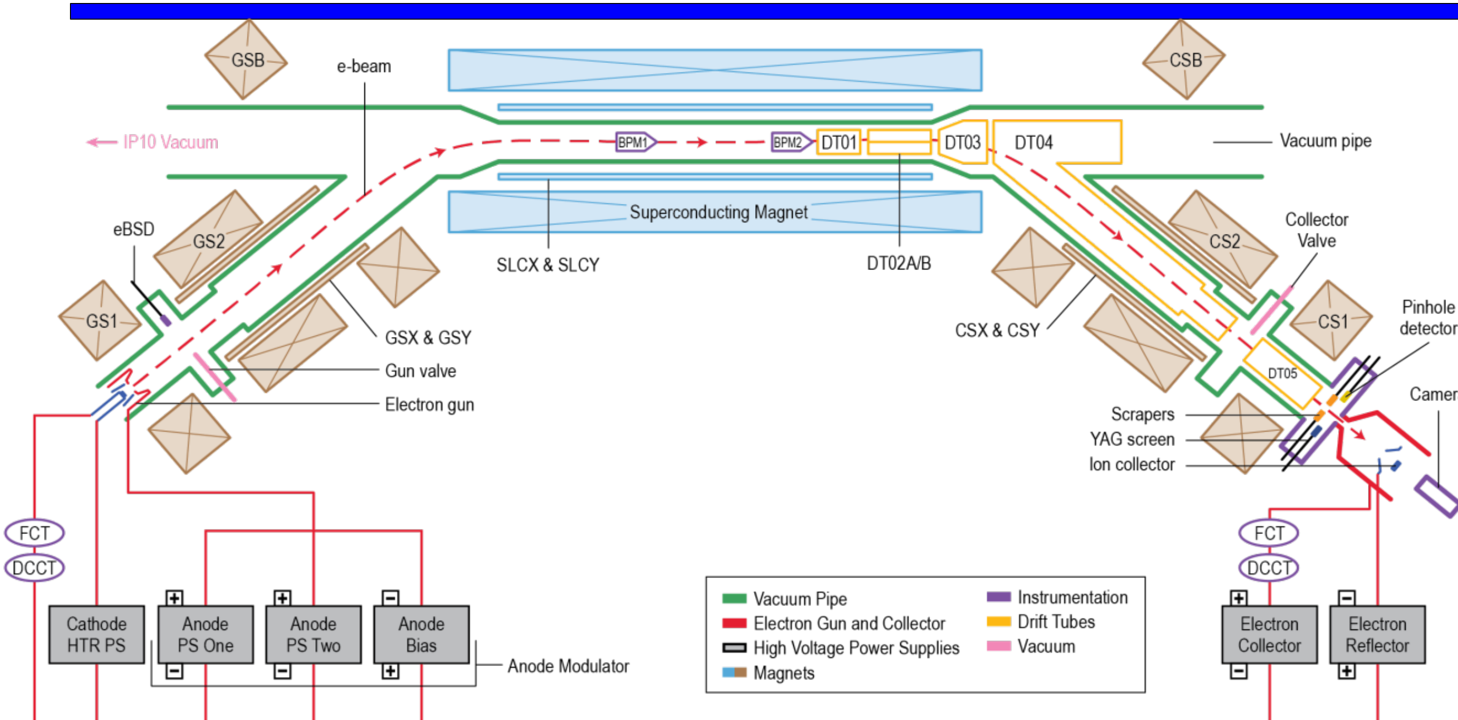
Electron lenses (e-p):

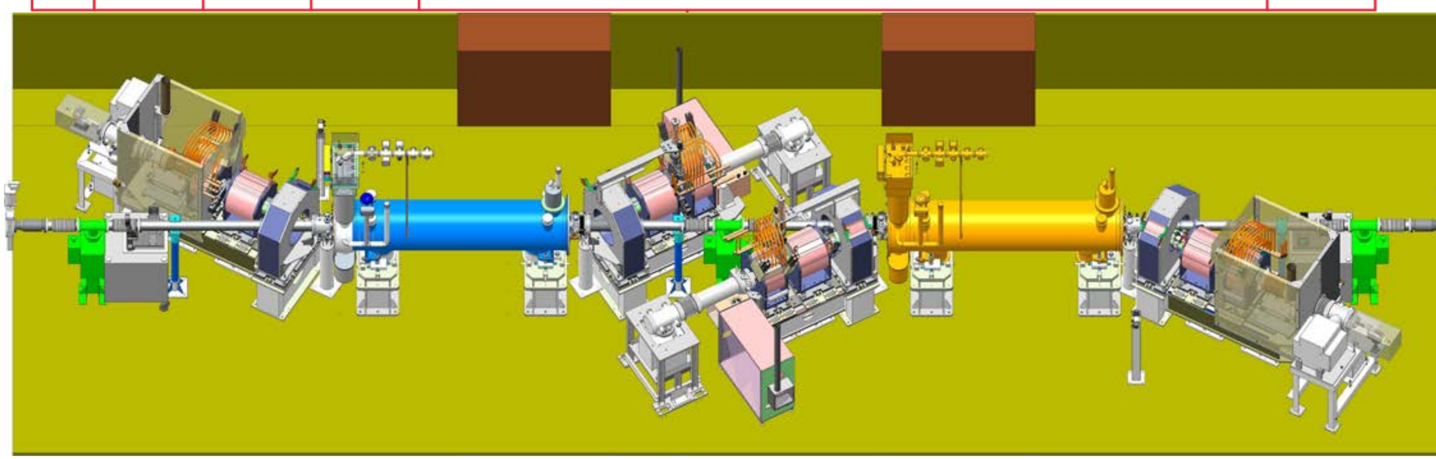
compensate for 1 of 2 beam-beam interactions (p-p), then have the capability to increase bunch intensity (Luminosity)

Coherence Instability:

Transverse bunch by bunch damper
Larger beam size and beta*

Introduction -- E-lens Layout

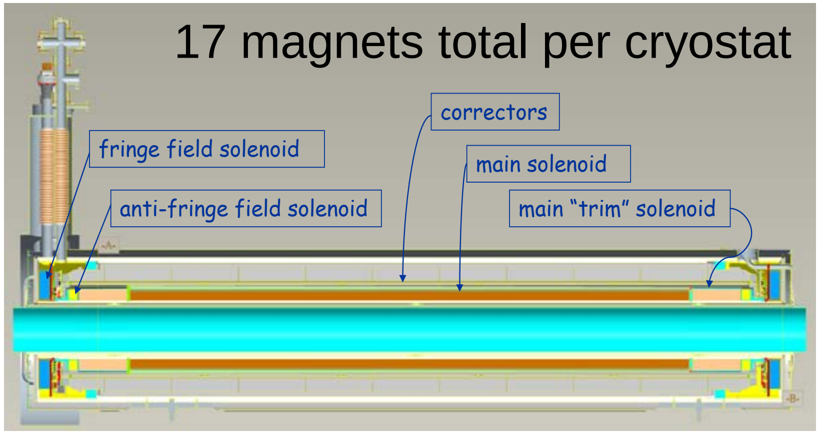


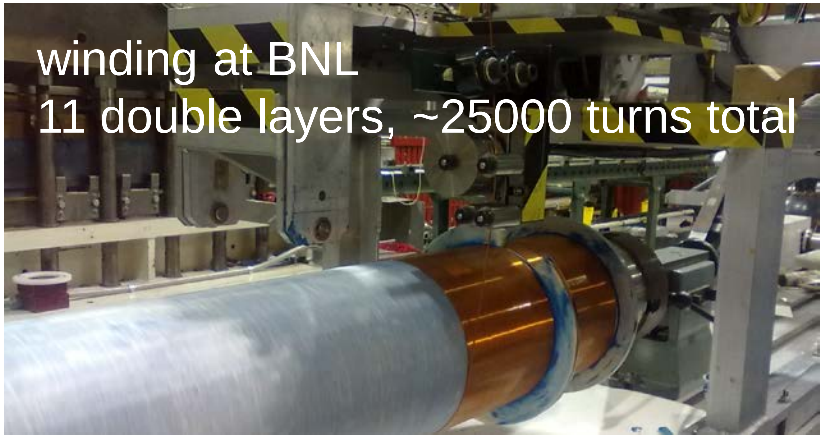


1. Warm Magnets
2. Cold Magnets
3. E-gun & Collector
4. Instrumentations
5. Vacuum
6. HV power supplies
7. Drift tube

Hardware - Superconducting Magnets Field

Main solenoid field provides transverse electron beam profile to match p-beam

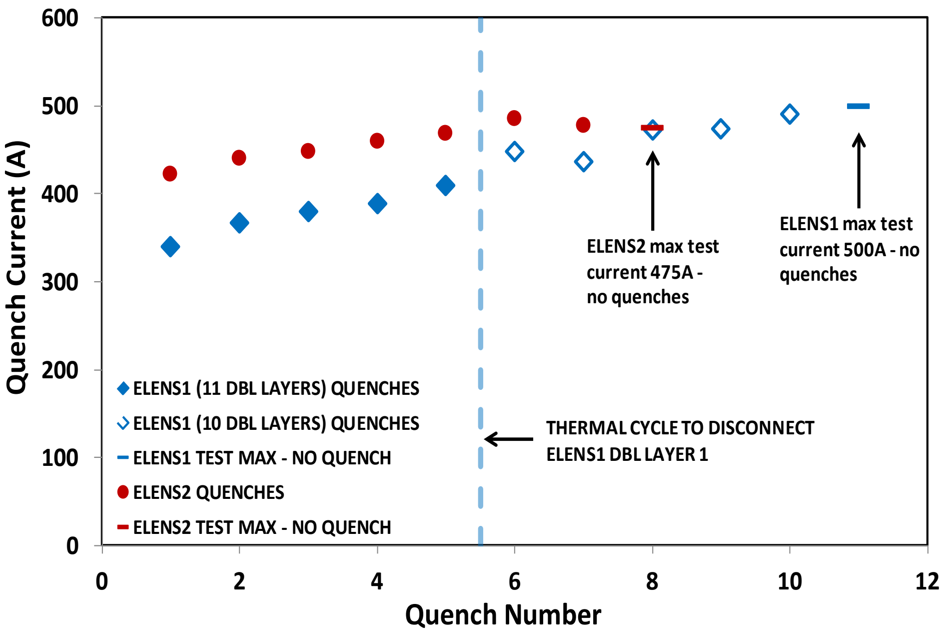




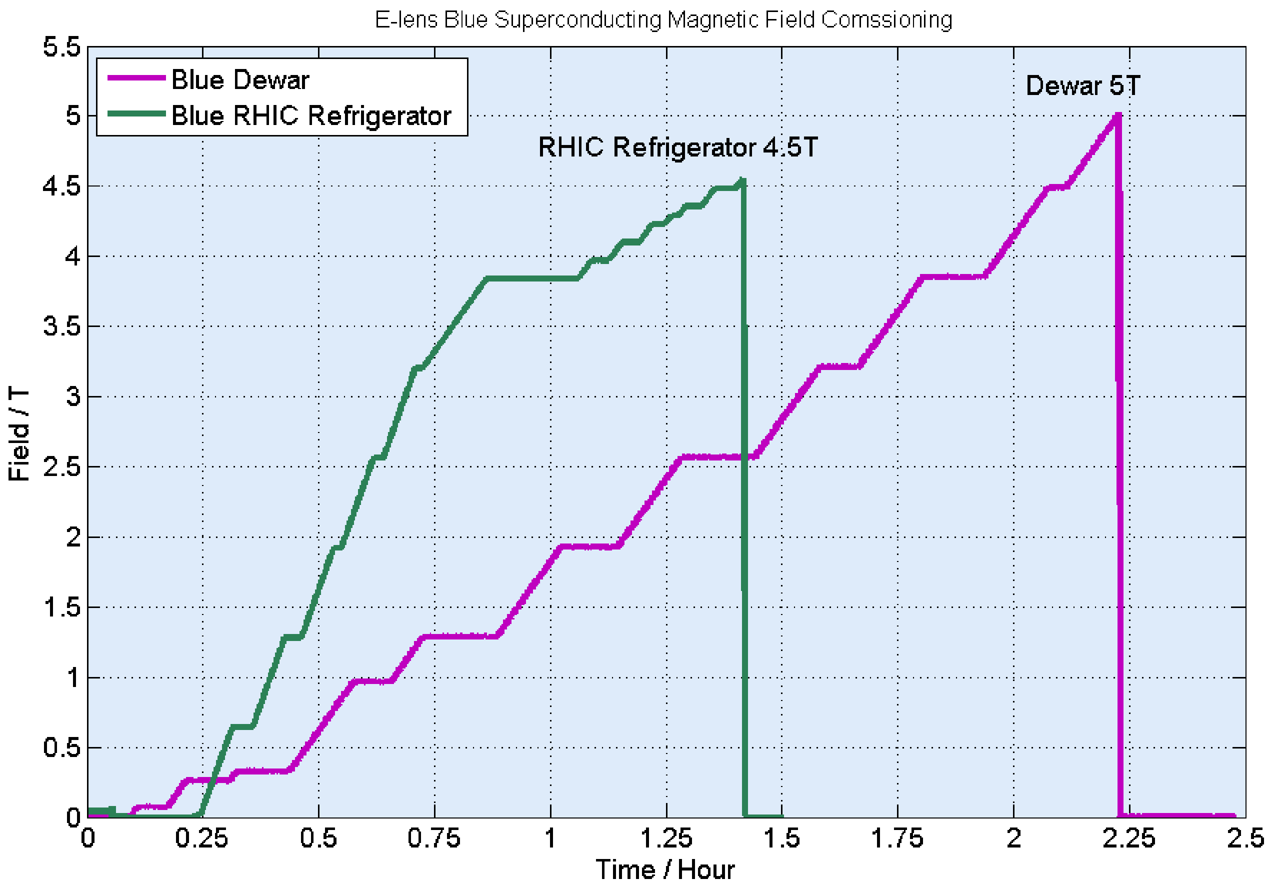
J. Muratore et. al, MT-23 (2013).

Vertical test:

1. Yellow solenoid: 475 A (10% more), no quench
2. Blue solenoid: 500 A (10% more), no quench



Hardware - Blue Field



1. Blue Solenoid 5T with Dewar, 4.5 T with RHIC refrigerator;
2. Critical temperature reached with high heater load;
3. Can get higher field with lower temperature;
4. It is thermally induced , not because of mechanical instability or conductor.

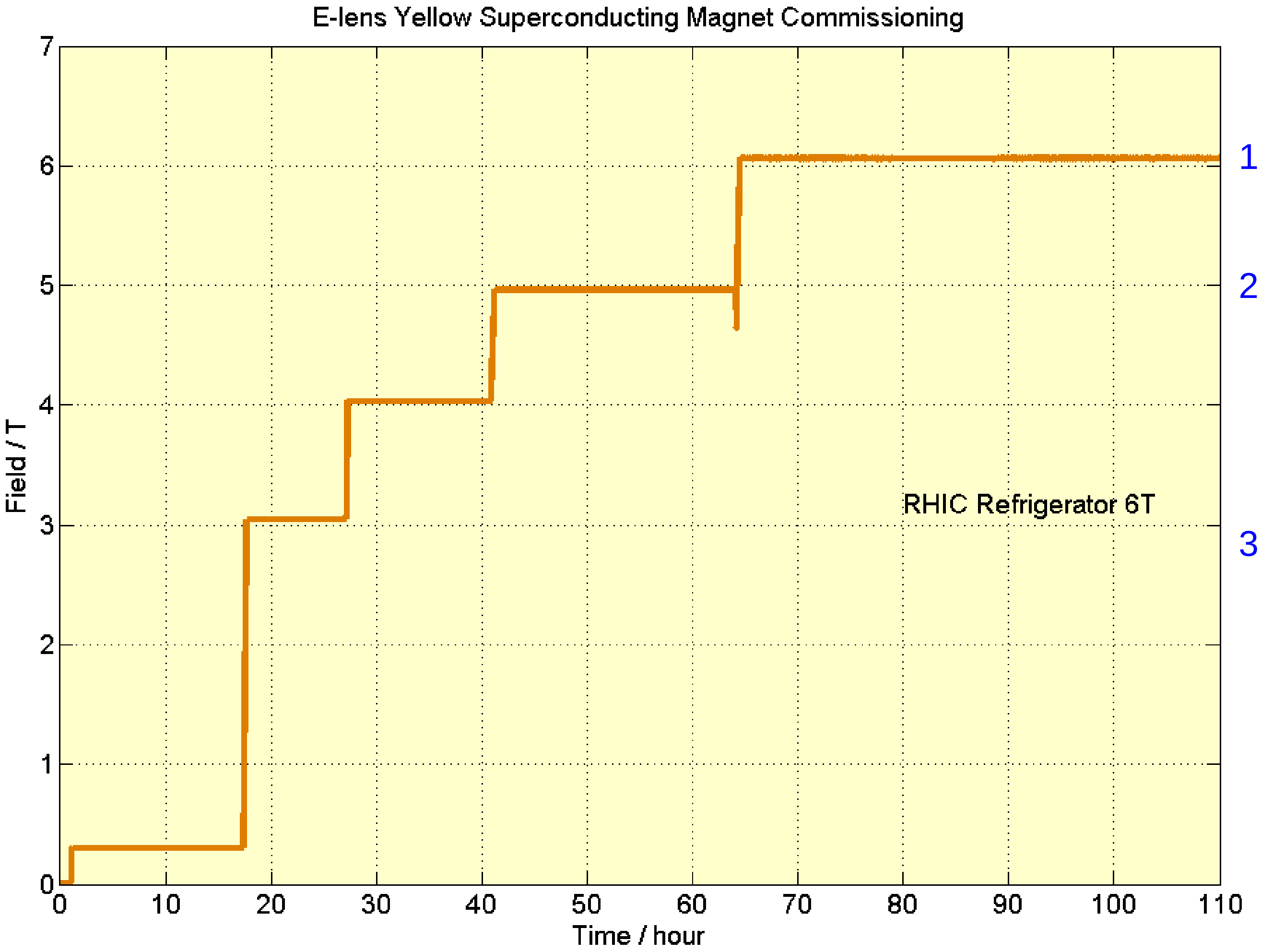
SOLUTION

1.Operate at lower temperatures

2.Add insulating vacuum on the cryostat warm bore;

3.Add FermiLab piston cold compressor (**3.8K**)

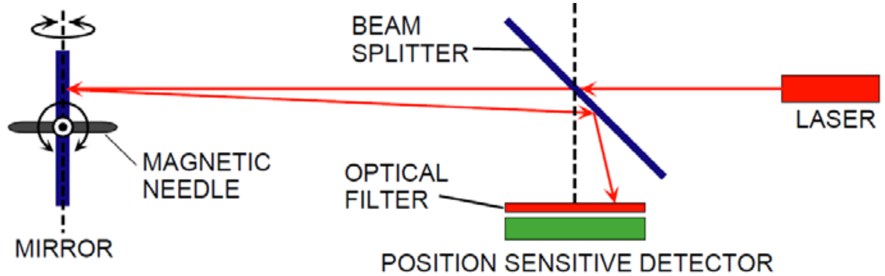
Hardware - Yellow Field



1. Yellow Solenoid **6T** with RHIC refrigerator;
2. Yellow solenoid is the second solenoid; it has better performance than the first solenoid which is the blue one.
3. Ramp up with 0.2A/s to 5T, ramp up with 0.1A/s from 5T to 6T

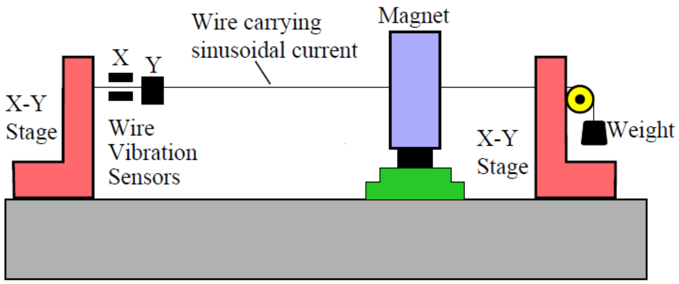
Hardware - Field Straightness Measurement

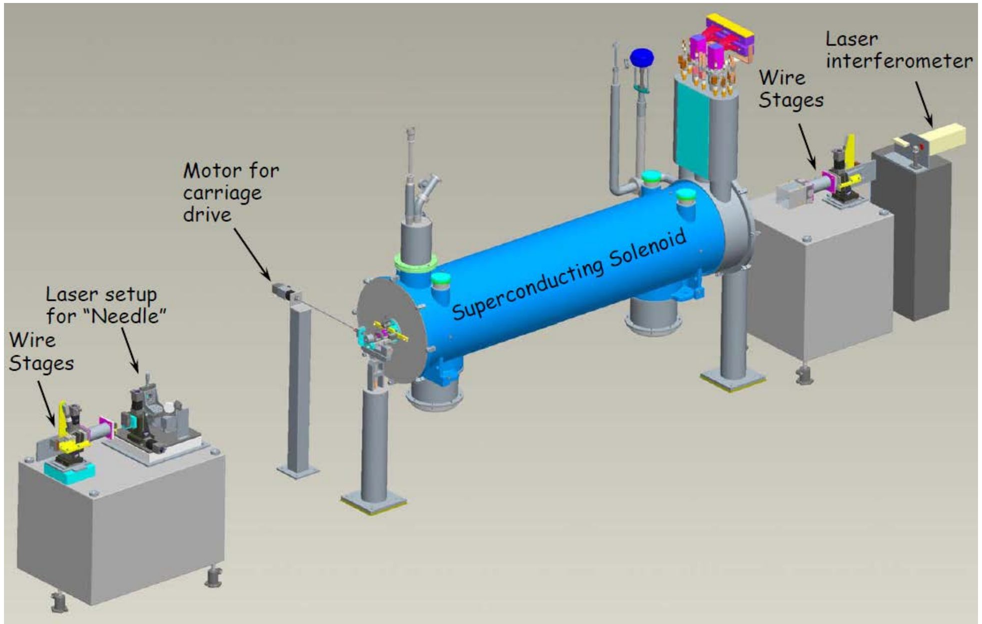
Needle & mirror



(Based on *C. Crawford et al., FNAL and BINP, Proc. PAC'99, p. 3321-3*)

Vibrating Wire

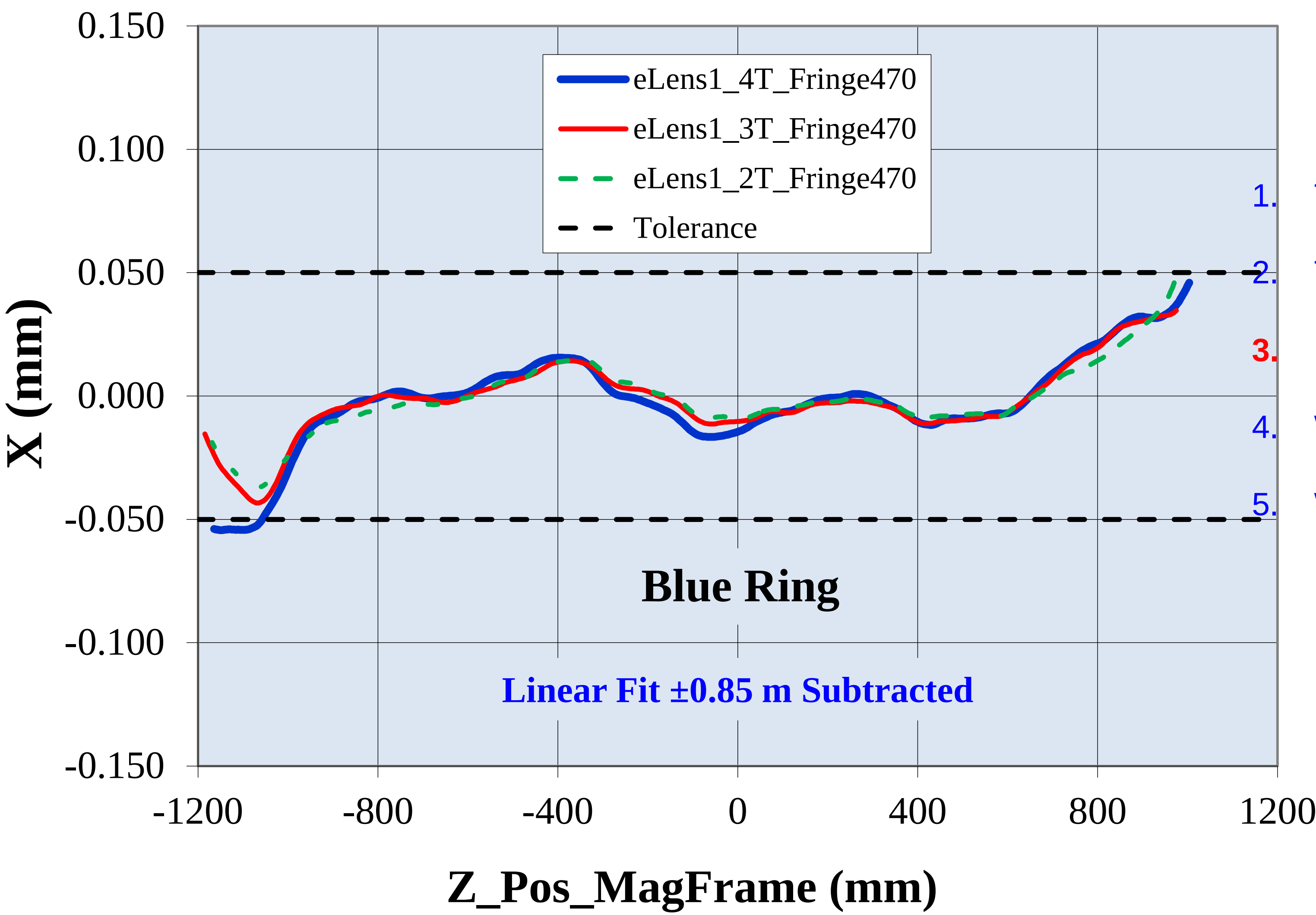




1. Needle & mirror: straightness
2. Vibrating wire: straightness, multi-poles
3. Use needle & mirror because of **NSLS-II**, space and risks from vibrating wire:

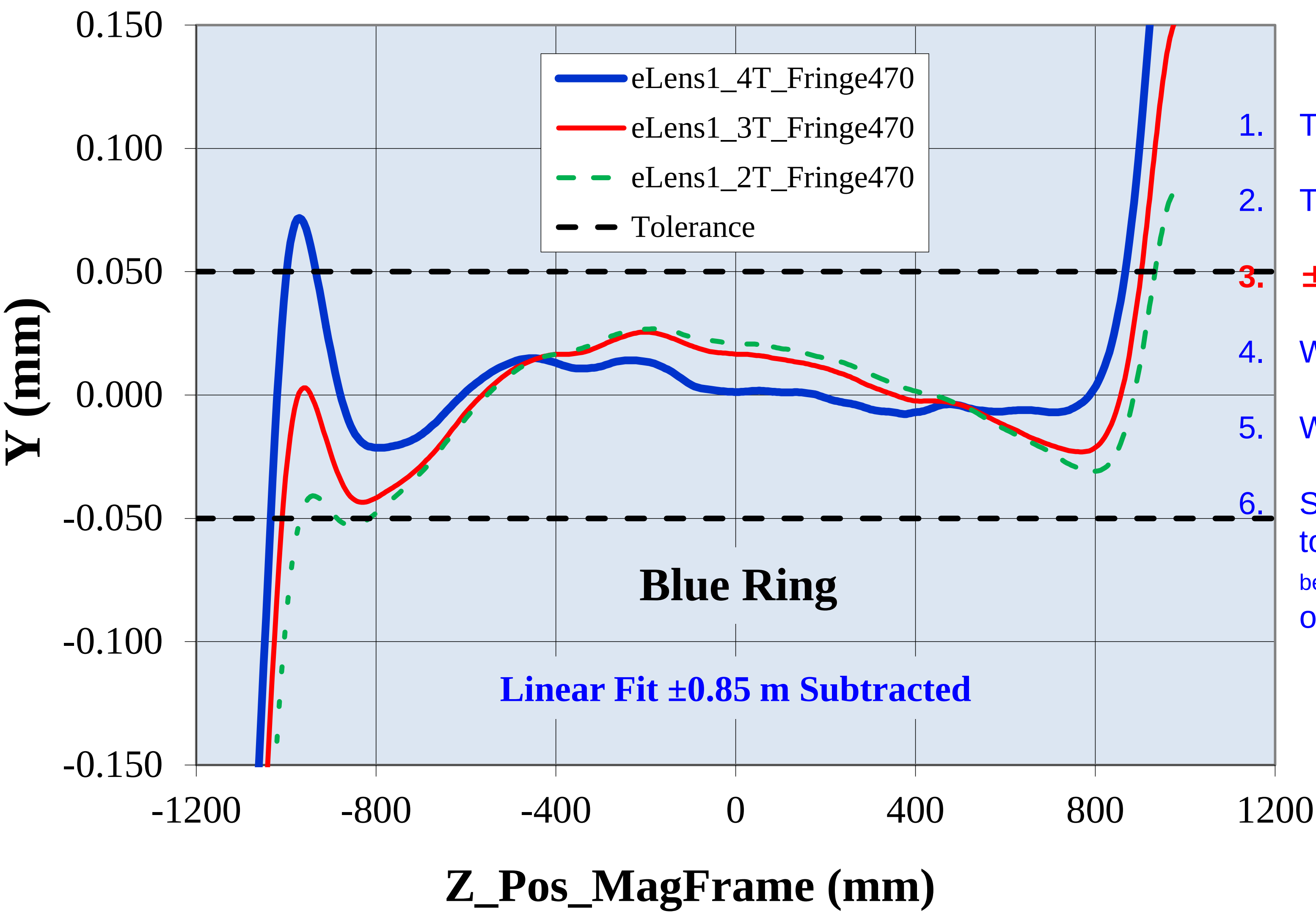
- Effect of large sag (~300 microns) of ~5 m long wire;
– Separate offset/tilt/sag from a local bending of field lines;
– Large fringe field outside the solenoid.

Hardware - Blue horizontal



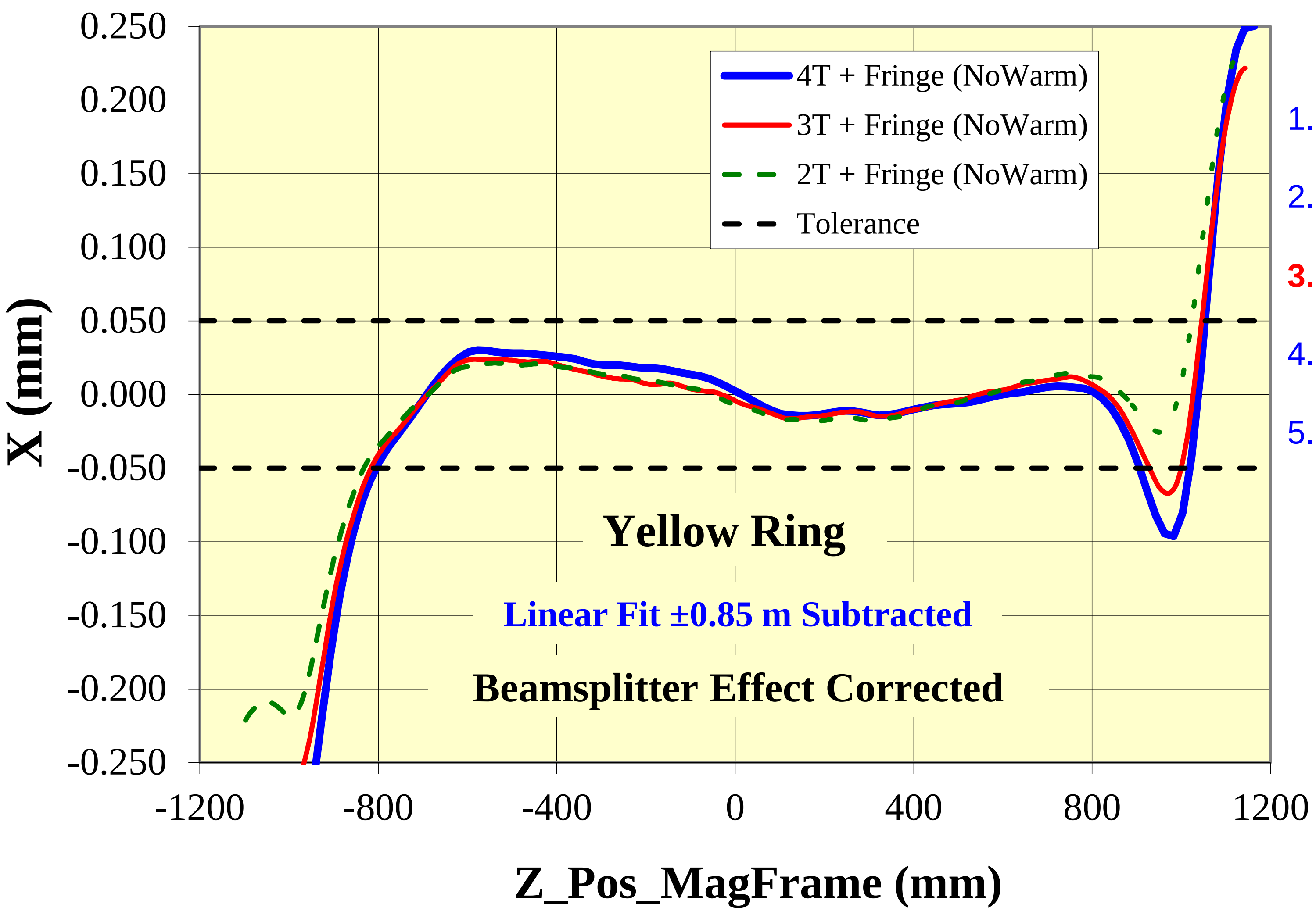
1. Tolerance = ± 50um
2. Three different fields
3. **±1000** mm good field
4. Without correction
5. With warm magnets

Hardware - Blue vertical



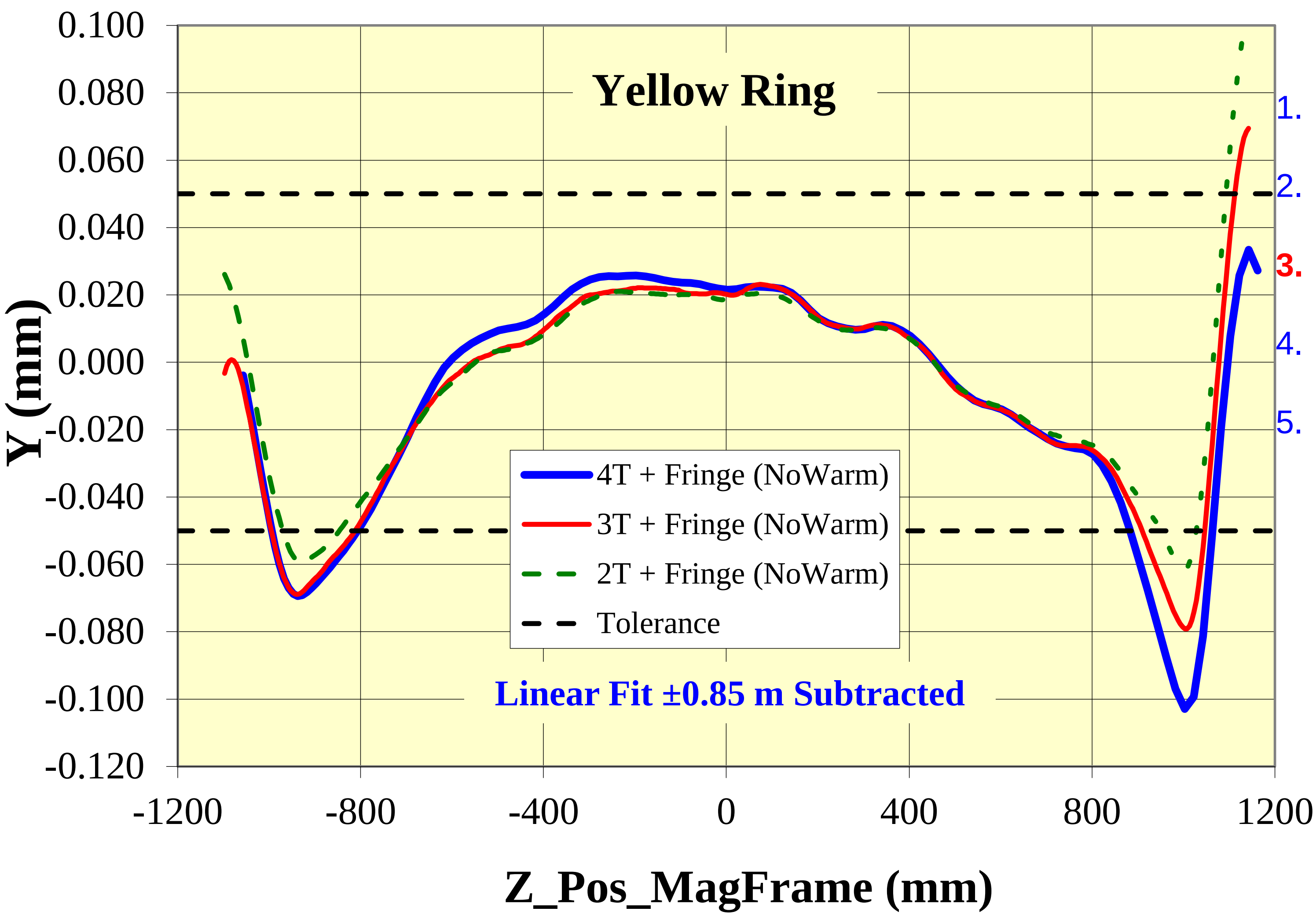
1. Tolerance = ± 50um
2. Three different fields
3. **±800** mm good field
4. Without correction
5. With warm magnets
6. Straightness tolerances (±15% rms beam size) for sufficient overlap

Hardware - Yellow horizontal



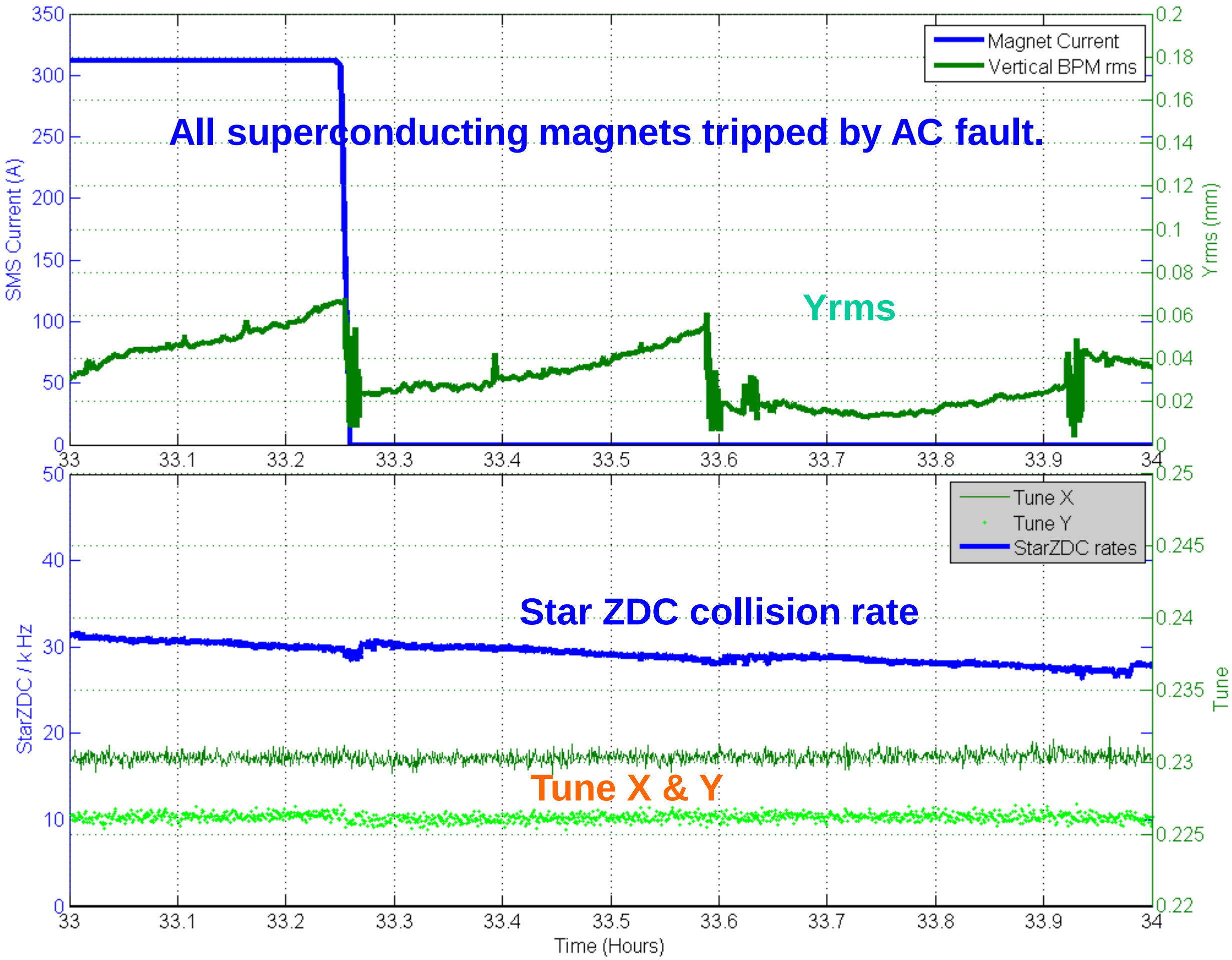
1. Tolerance = ± 50um
2. Three different fields
3. **±800** mm good field
4. Without correction
5. NO warm magnets

Hardware - Yellow vertical



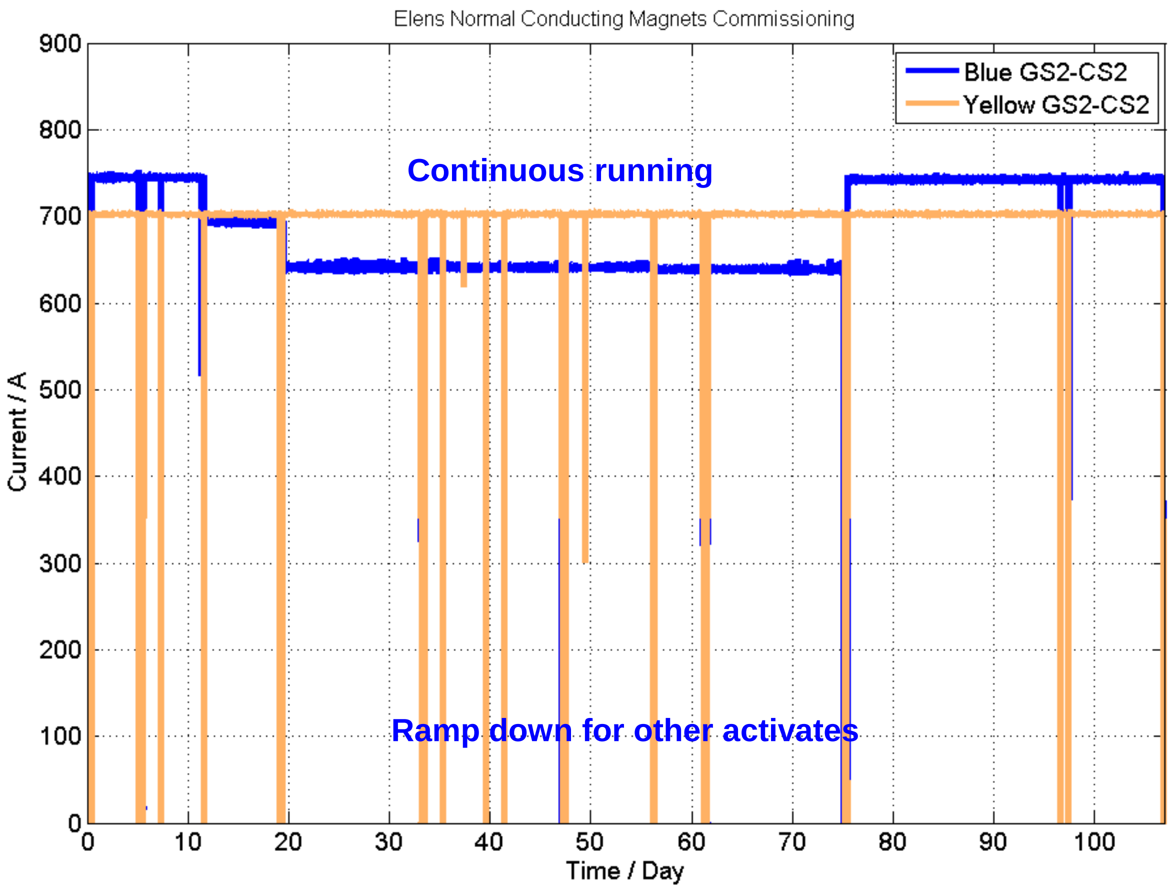
1. Tolerance = ± 50um
2. Three different fields
3. **±800** mm good field
4. Without correction
5. NO warm magnets

Hardware – Superconducting magnets



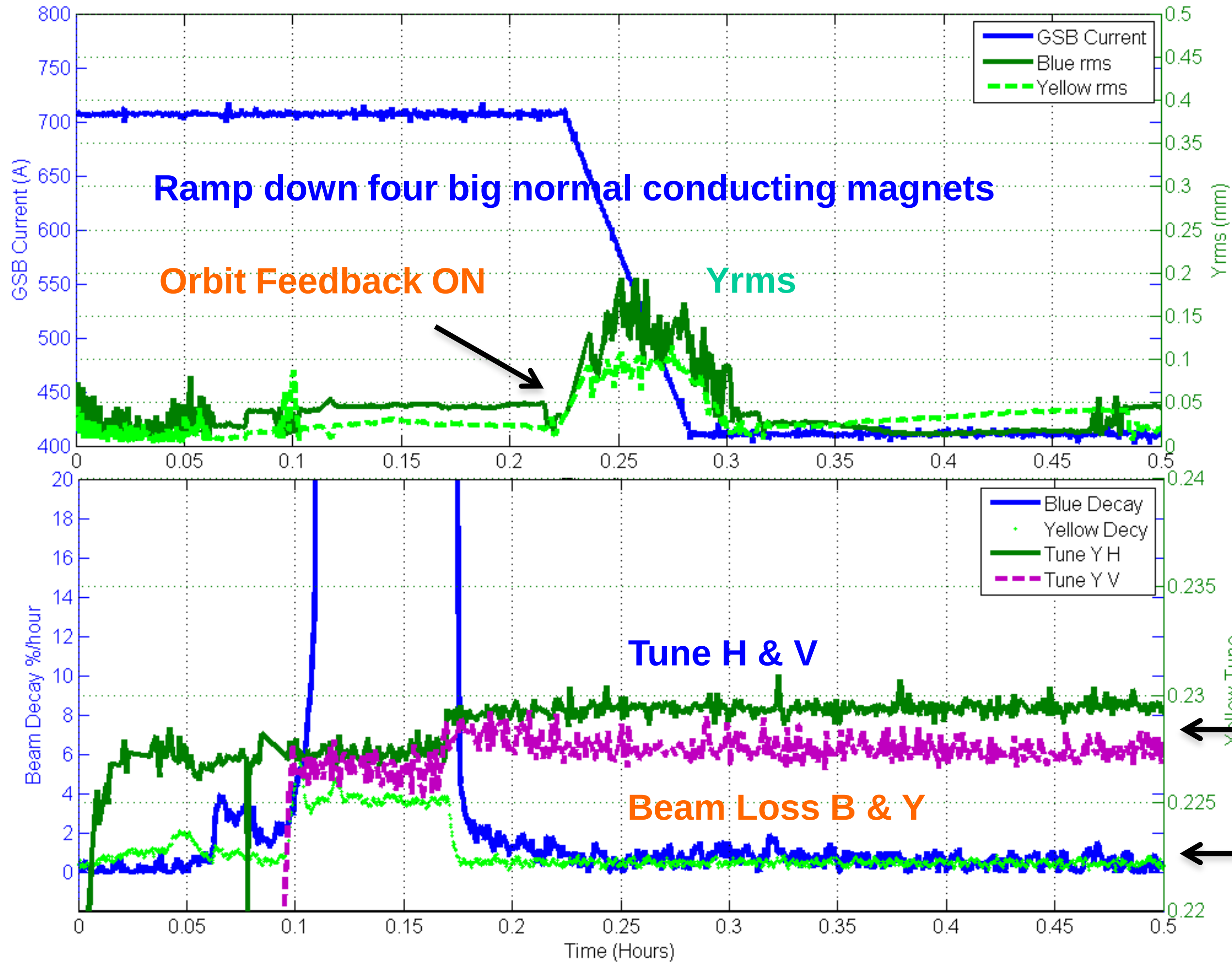
1. Superconducting magnets tripped by AC fault from 4T to 0
2. Also effected orbit rms, 3~4 times less than ramp down of normal conducting magnets
3. RHIC orbit feedback can handle it
4. No effect on tune
5. No effect on beam loss

Hardware - Normal Conducting Magnets



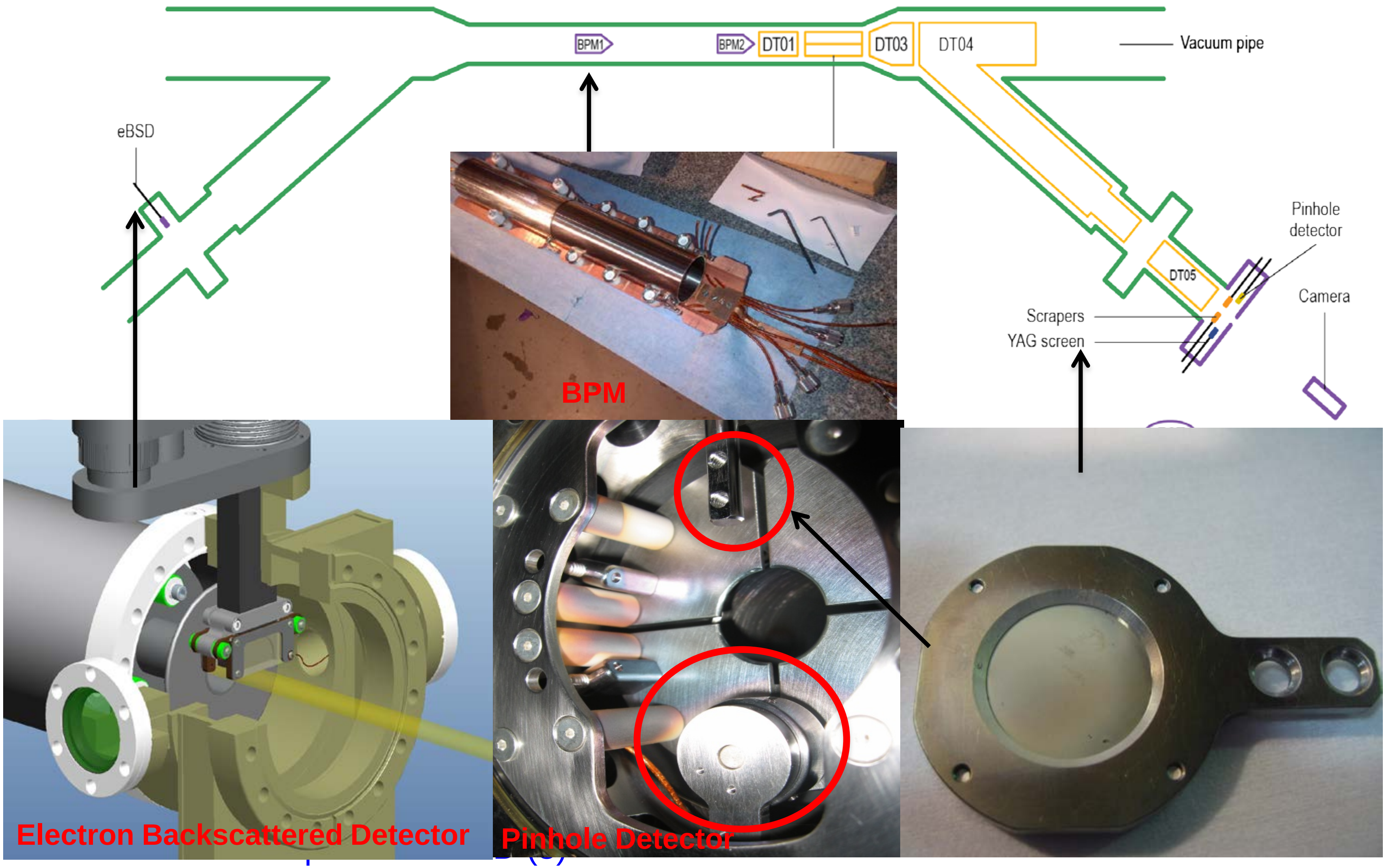
1. Totally 12 solenoids and 6 power supplies.
2. Magnetic fields as function of current were measured during 2012;
3. All magnets run very reliable from 2013;
4. Most of magnet PS run very well;
5. Only the yellow GS2-CS2 PS has a fault during 2014 RHIC run and took 4 hours to fix it.

Hardware - Normal Conducting Magnets

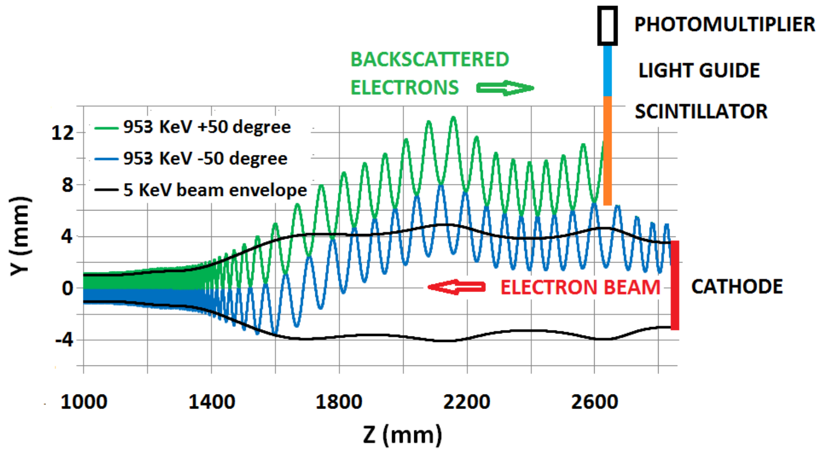


1. Ramp down four big normal conducting magnets during store
2. Affected the vertical orbit rms
3. RHIC orbit feedback can handle it
4. Orbit feedback runs routinely every 20 min. for orbit drift correction.
5. No effect on tune
6. No effect on beam loss

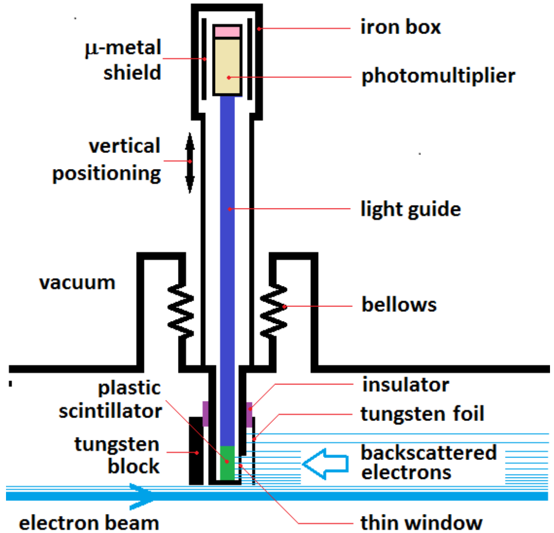
Hardware - Instrumentation

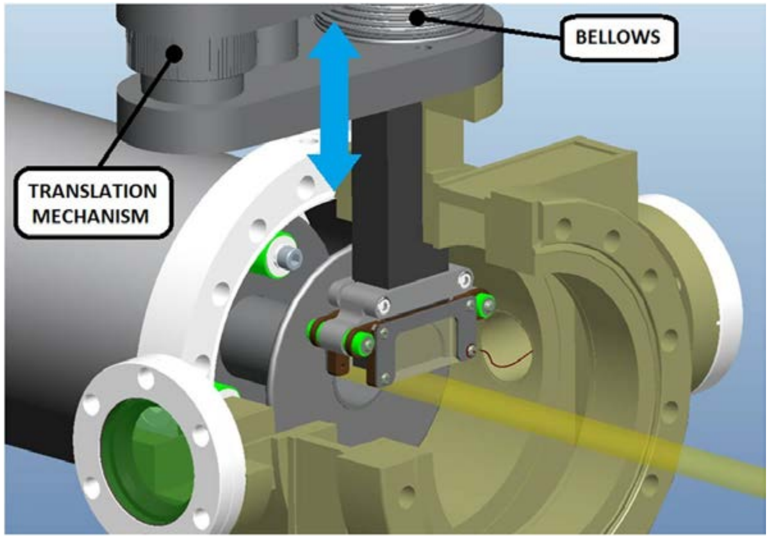


Hardware - The Electron Backscattering Detector



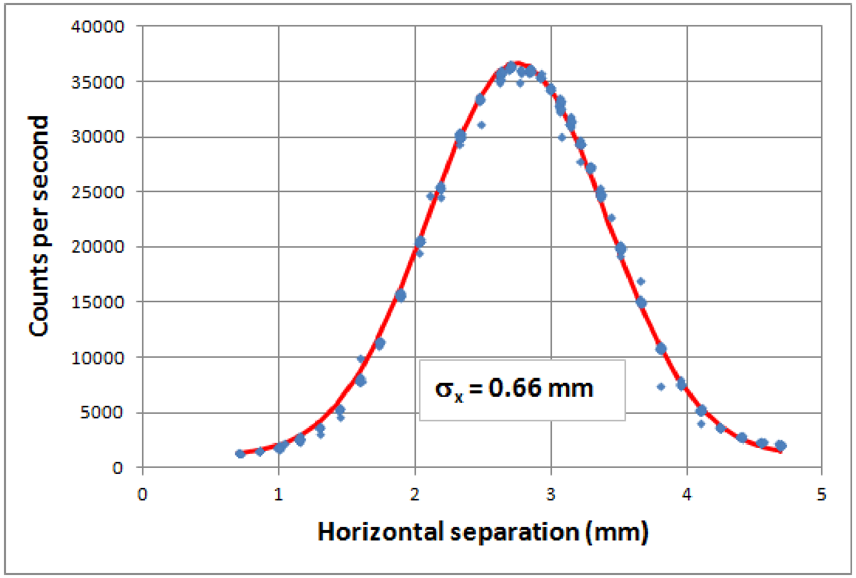
1. The backscattered electrons: scattered by collisions with the ions or proton, reach the detector located close to the gun;
2. The detector position: the centroid of the backscattered electrons moves up or down because of the bending B field.
3. Used for ion and ^{3}He during 2014 RHIC run

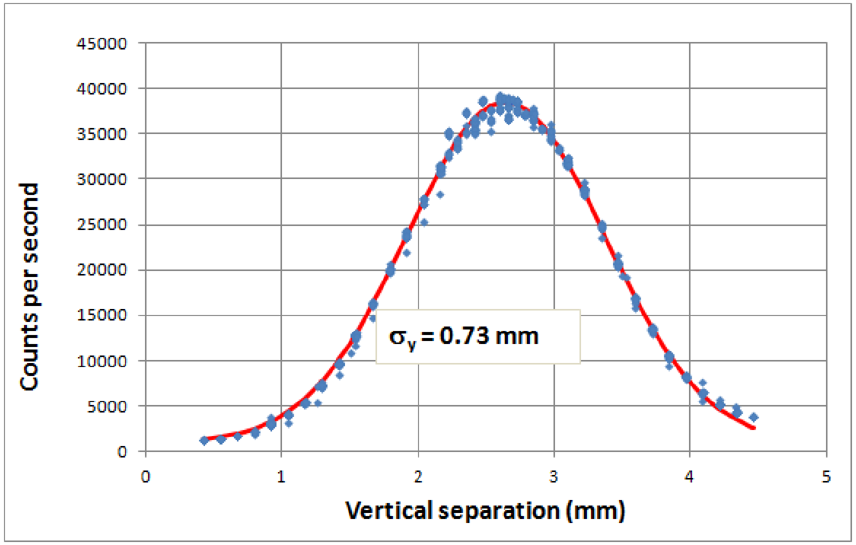




courtesy of Peter Thieberger

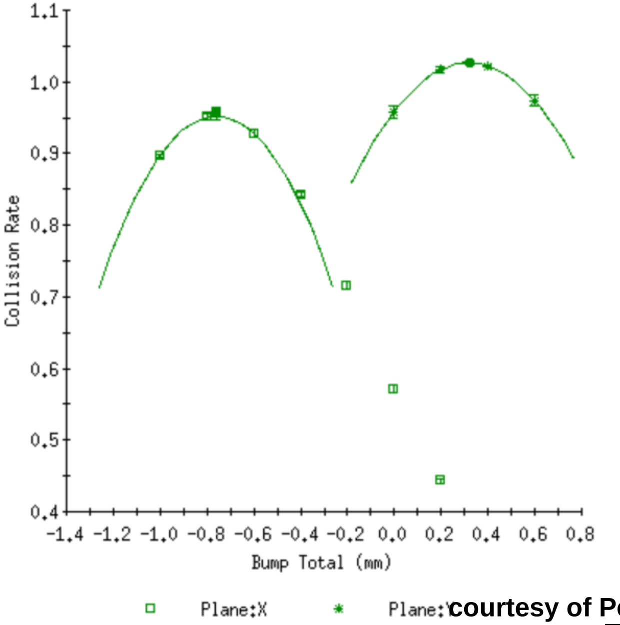
Hardware - Proof-of-principle eBSD scans





1. The program LISA (Luminosity and IR Steering Application) routinely used for optimizing luminosity for the experiments has been adapted to automatically optimize electron-ion alignment.

2. The eBSD output pulses are used instead of the Zero Degree Calorimeter (ZDC) coincidence signals.



courtesy of Peter Thieberger

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Hardware - Instrumentation

Anode Voltage Measurement:

- A circuit is developed to measure the voltage on the anode;
- Can be used for modulator or trigger diagnostic;

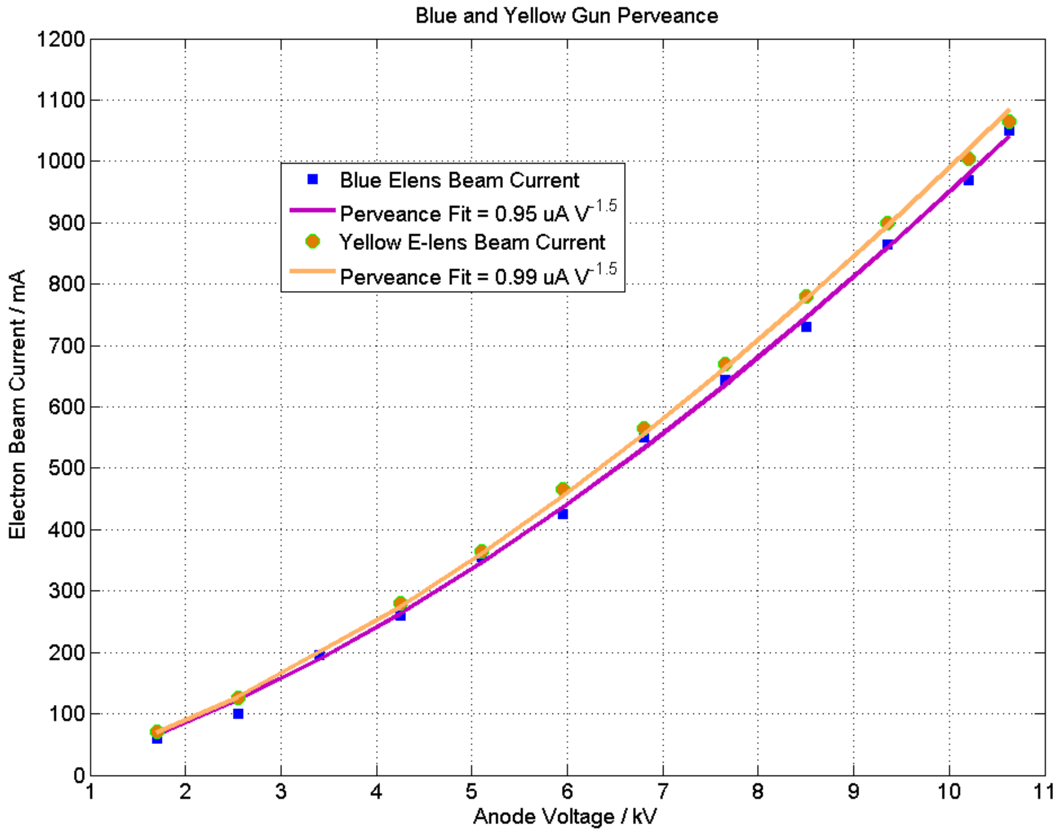
Collector Temperature Sensor (8):

- Eight temperature sensors are mounted outside of collector;
- The electron beam position (off-set or centered) inside the collector can be roughly estimated by the temperature distribution,
- Useful for DC electron beam;

Drift tubes (5 for each e-lens):

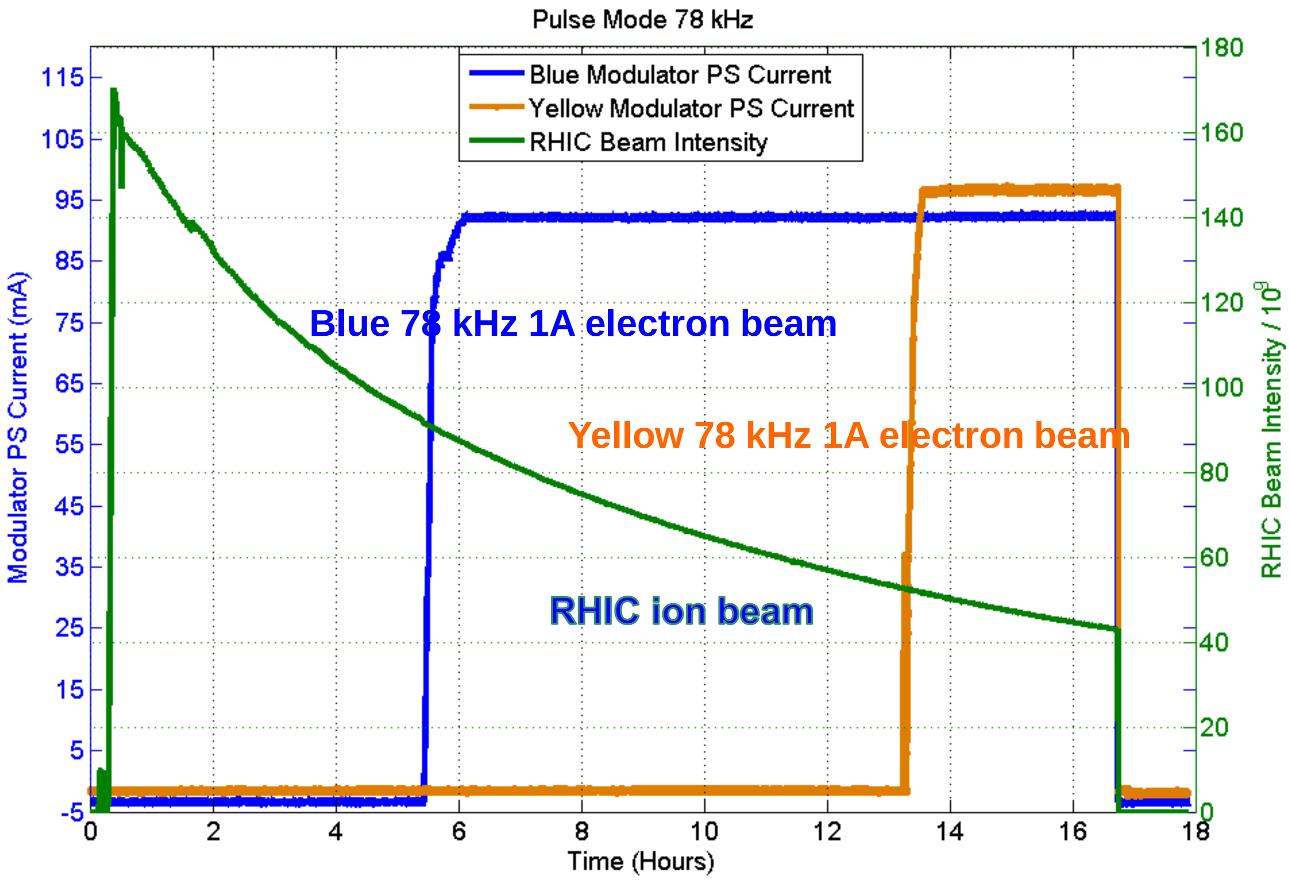
- Design for accumulated ion extraction;
- Blue drift tube 2&4 connections were broken because of vacuum baking;
- Yellow drift tube 4 has the same problem. They will be fixed during 2014 summer;
- Other drift tubes were commissioned and vacuum conditioned.

Electron beam – Current



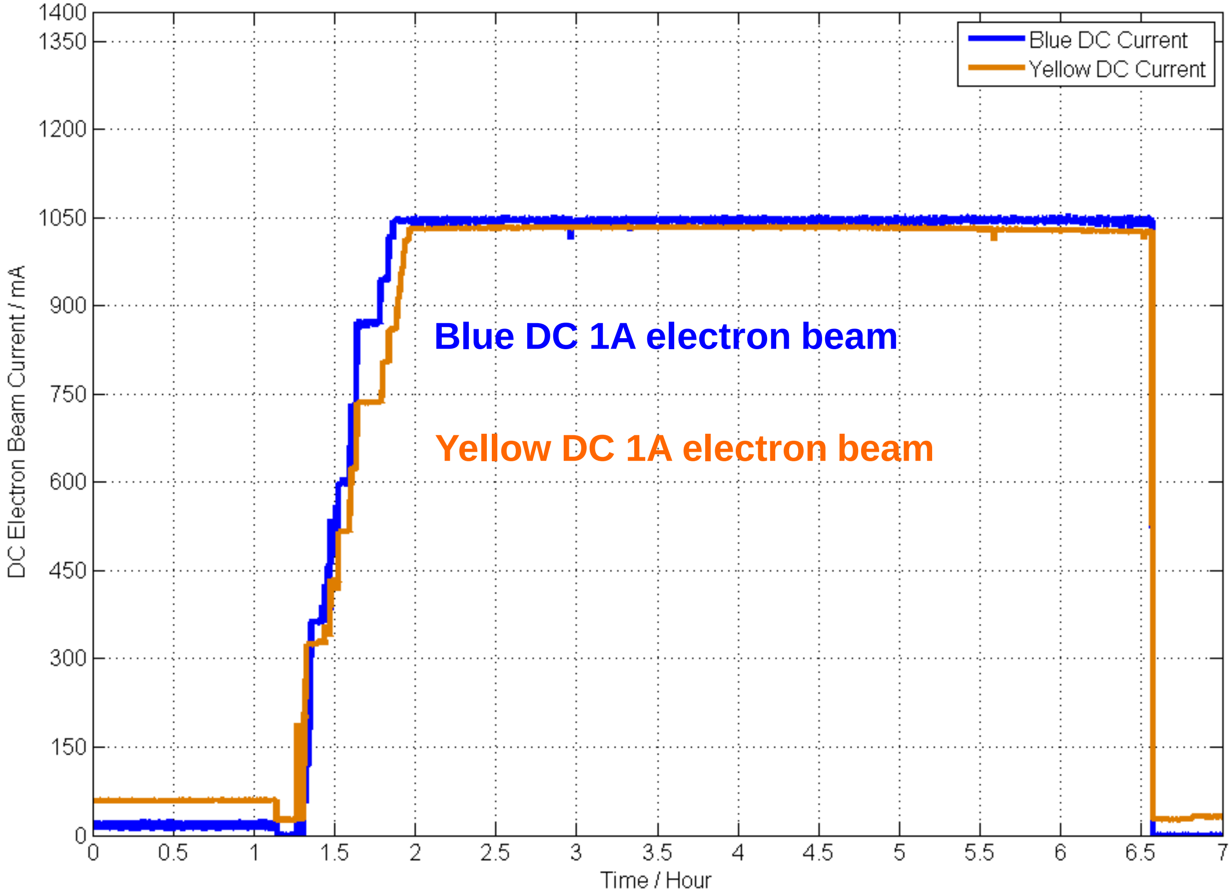
1. Electron gun perveance is measured in pulse mode
2. Blue electron gun perveance **0.95 μA $V^{-1.5}$**
3. Yellow electron gun perveance **0.99 μA $V^{-1.5}$**
4. DC beam dark current issue is understood and resolved.

Electron beam – Pulsed Mode



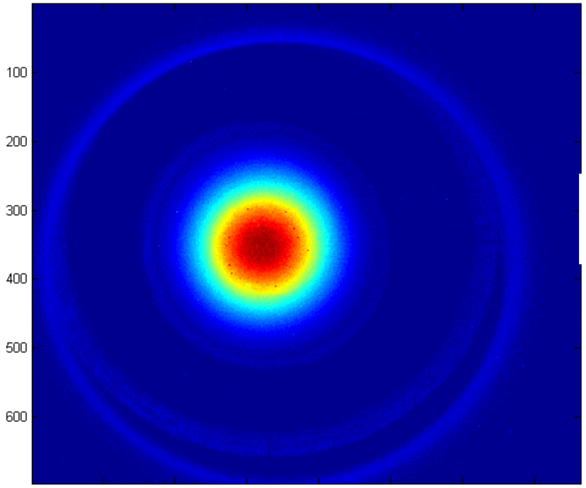
1. Modulator current indicates 78 kHz is running.
2. Blue and Yellow were running **78 kHz pulse** mode with 1A **simultaneously** within RHIC beam abort gap;
3. Parasitic to RHIC beam provides more commissioning time;
4. Blue e-lens 78 kHz was running for 14 hours during 2013;

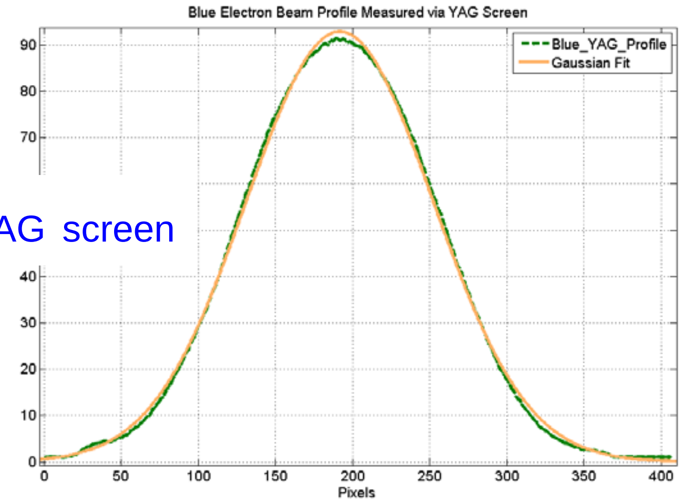
Electron beam – DC mode



1. NO RHIC ion beam
2. Blue and Yellow were running simultaneously
3. Beam current is **1 A**
4. Blue was running for 9.5 hours during 2013 commissioning.

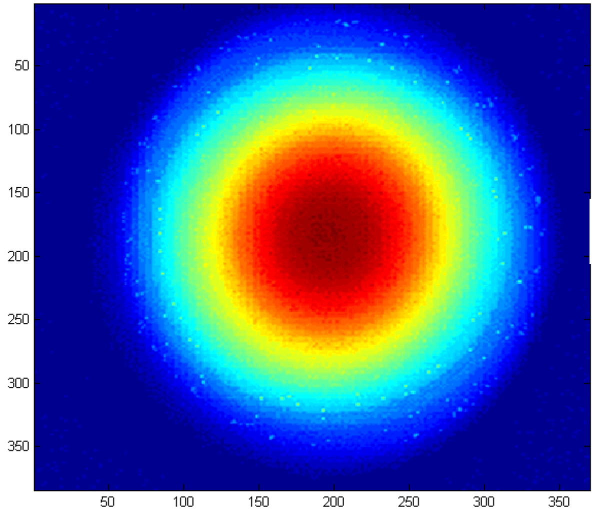
Electron beam Blue Transverse Profile

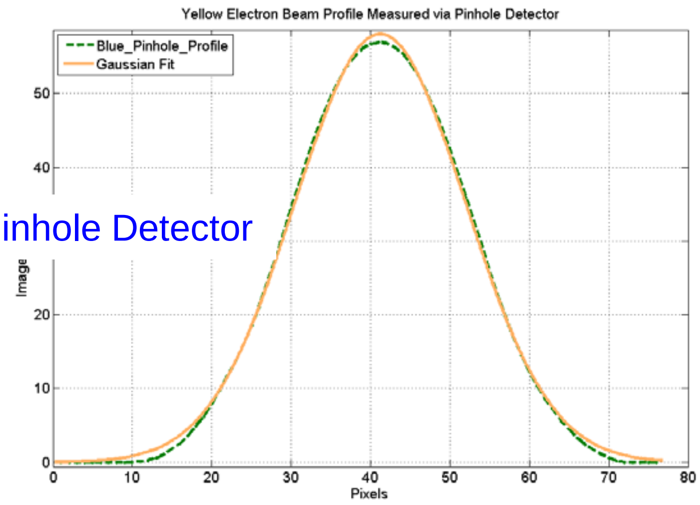




YAG screen

- Current 70 mA
- Beam profile from YAG is a Gaussian
- Profile does not change with current

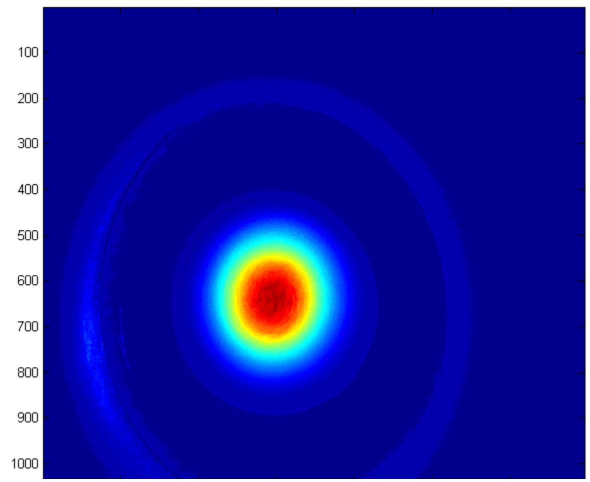


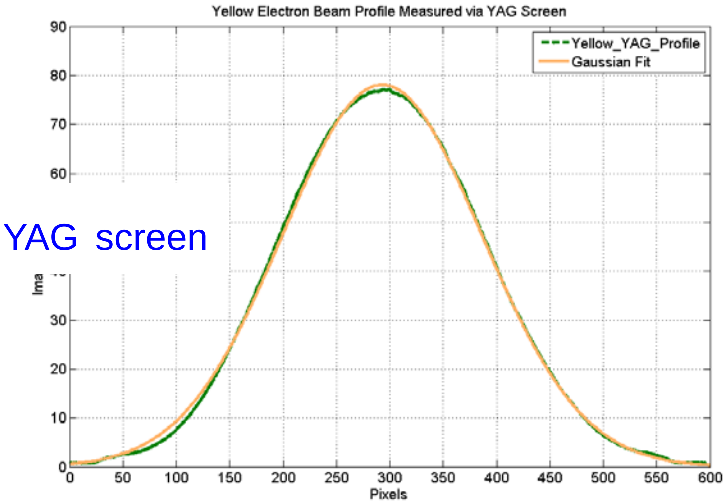


Pinhole Detector

- Current 1150 mA.
- Pinhole profile is Gaussian

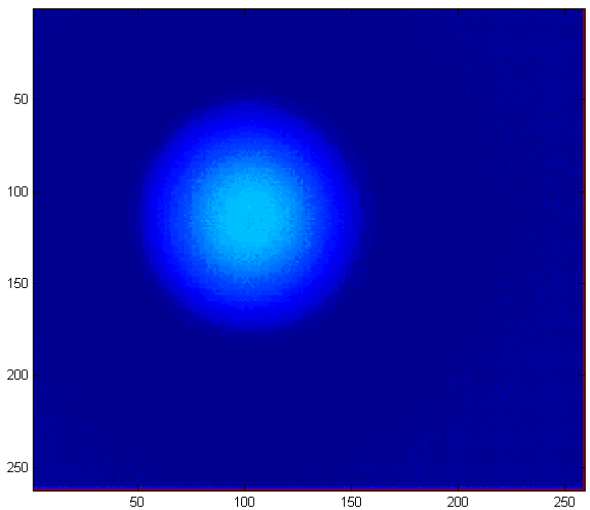
Electron beam Yellow Transverse Profile

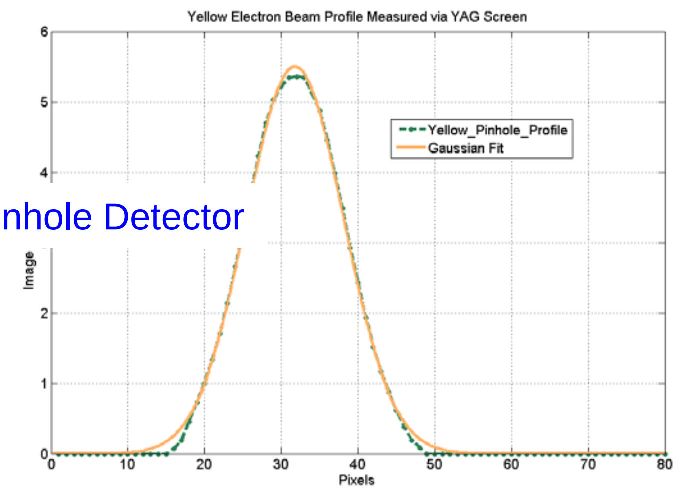




YAG screen

1. Current 100 mA
2. Beam profile from YAG is a Gaussian

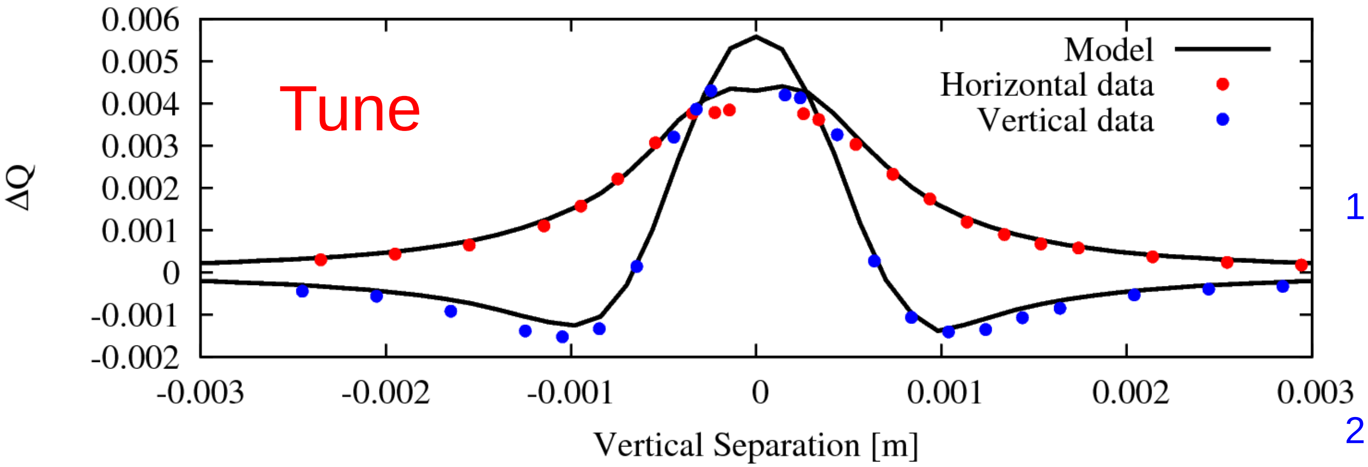


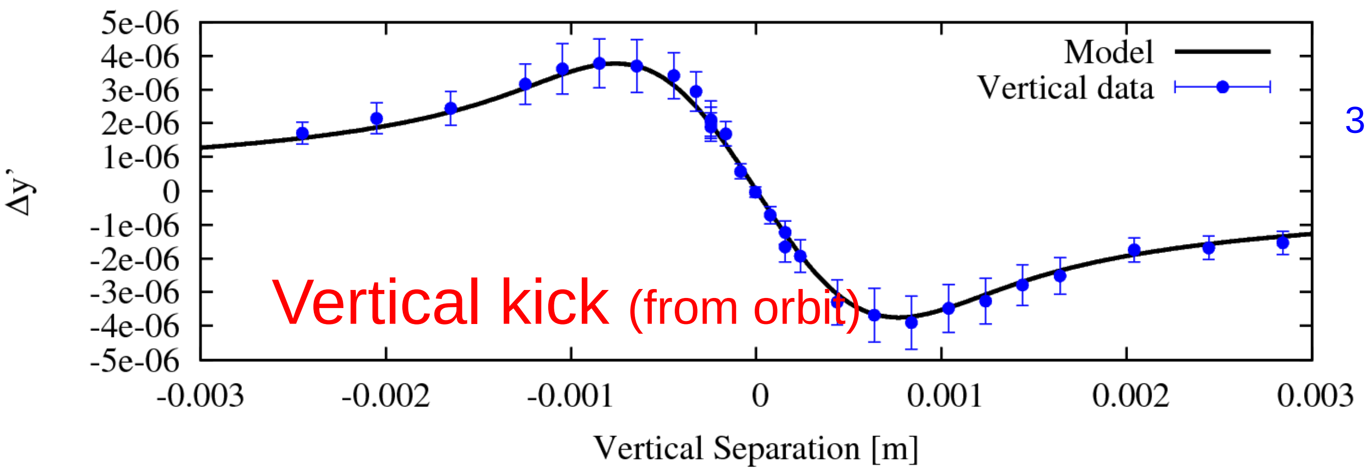


Pinhole Detector

3. Current 100 mA.
4. Pinhole profile is Gaussian with a flat top
5. Maybe caused by fewer data points
6. Center depression ok in simulations

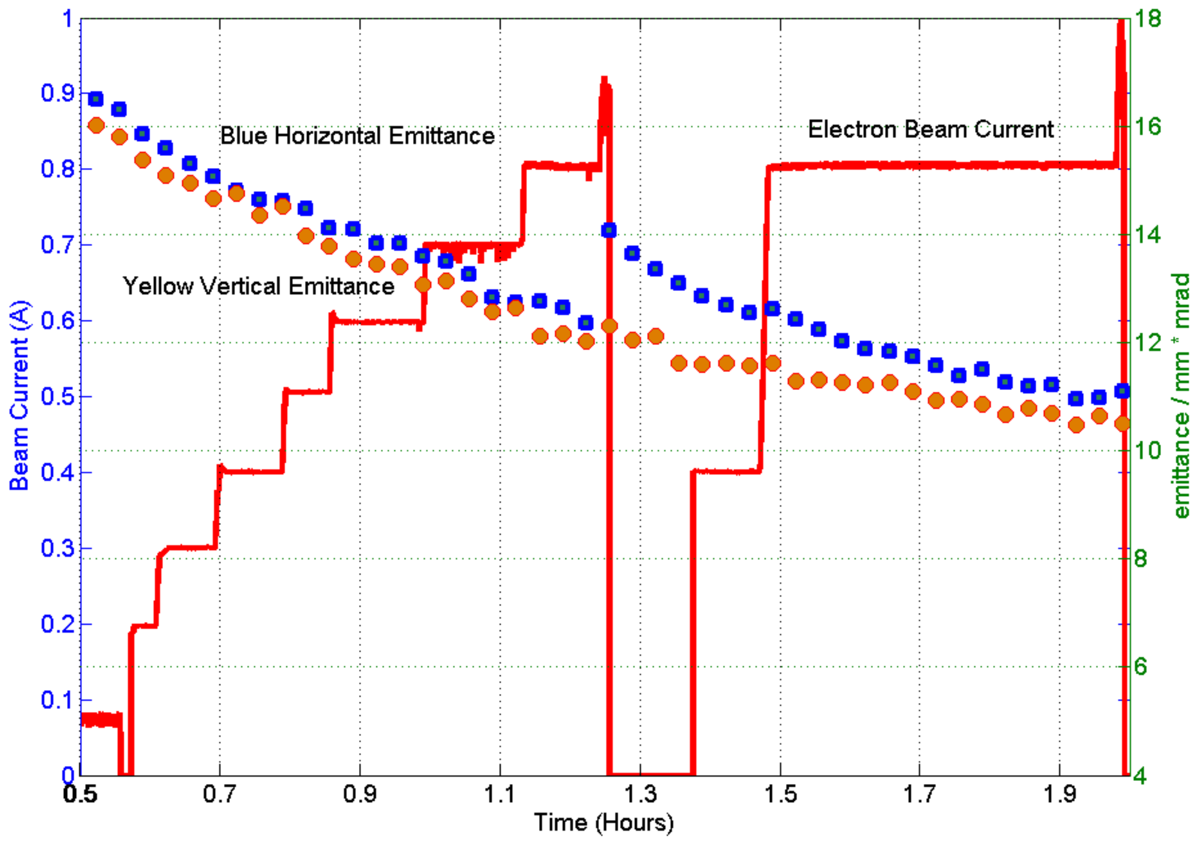
Electron beam – Orbit and Tune





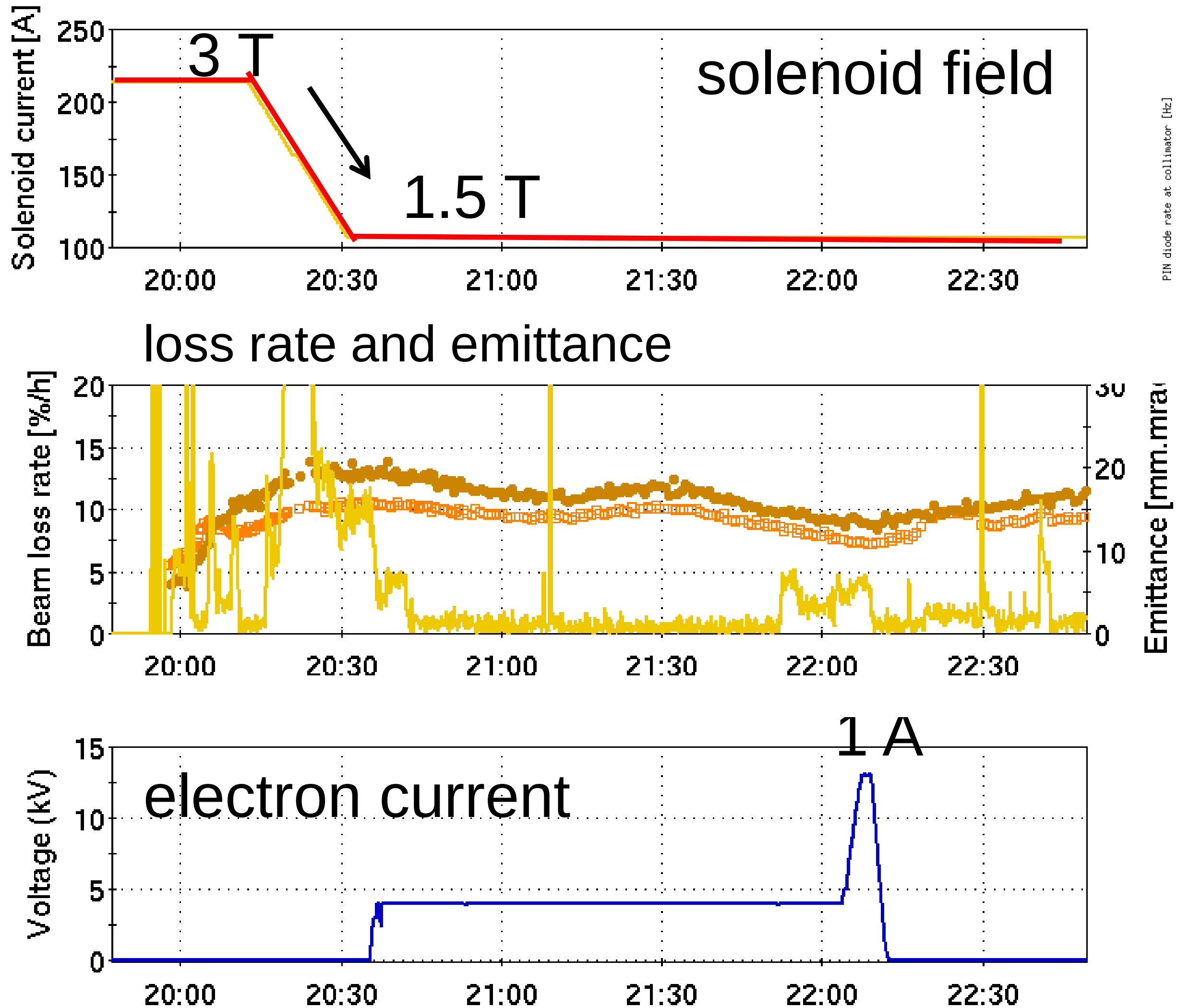
1. The first electron and ion beam alignment by moving electron beam;
2. Yellow ion beam at store
3. Vertical kick strength agree with model

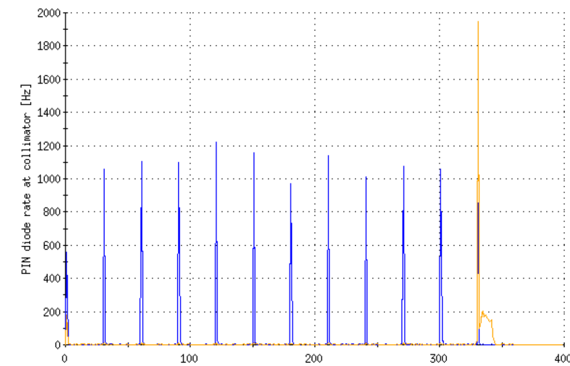
Electron beam – Emittance Growth



1. Blue DC mode with ion beam;
2. Emittance decreasing because of cooling;
3. Increasing electron beam current (red);
4. **No additional emittance growth;**
5. Vacuum spike caused emittance growth;
6. With stochastic cooling ;
7. With rebucketing;
8. 1 hour = cooling or IBS growth time.

Electron Beam – Beam-beam driven instabilities





1. Last bunch only
2. Field from 3T to 1T;
3. Beam is stable;
4. Will re-do it again.

courtesy of S. White

RHIC electron lenses - Preparation for 2015

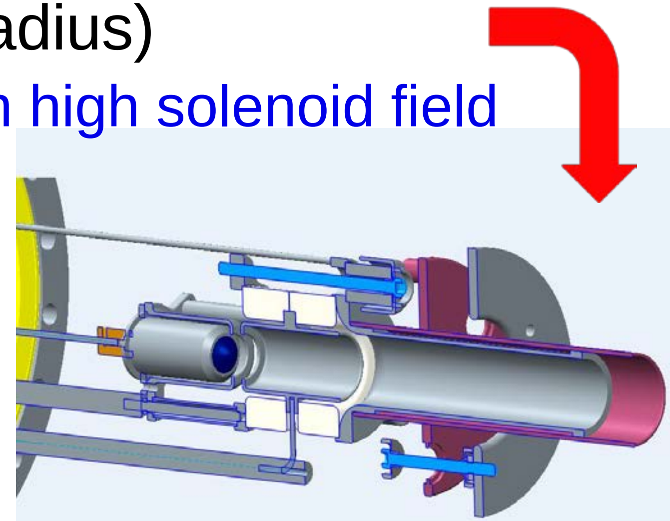
2015 – First proton run with electron lenses => compensation

•Larger cathodes (7.5 vs. 4.1 mm radius)

=> allows for matched beam size with high solenoid field

=> raises instability threshold

=> easier alignment



•Transverse damper

=> raises instability threshold

•New lattice, based on ATS optics (S. Fartoukh, CERN)

=> phase advance kp between p-p and p-e interactions

=> small nonlinear chromaticity

=> no depolarization

Summary

1) A minimum main solenoid field of 5 T with the completed magnet.

2) A maximum deviation of the main solenoid field lines from a straight line of ±50 um without correction at a main field of 4 T, and over a range of at least ±800 mm)

3) All instrumentation are commissioned. eBSD was used for beam-beam alignment;

4) A Gaussian transverse beam profile as verified by the two installed profile monitors (YAG screen and pin hole detector)

5) Both blue and yellow e-lens provided the electron beam for beam-beam studies for several times.

THANK YOU!

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CONTRIBUTORS:
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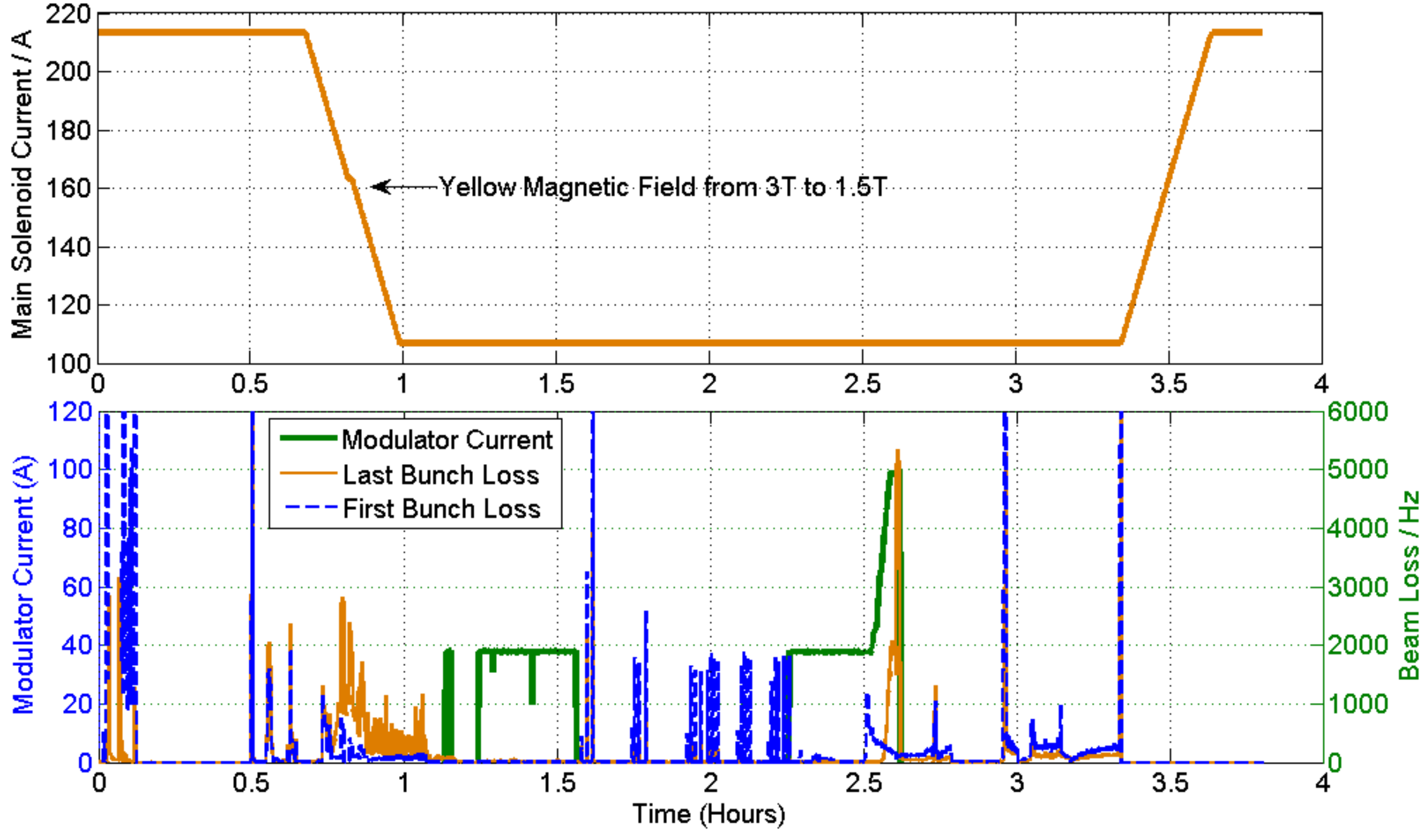

Main Solenoid Current / A
Yellow Magnetic Field from 3T to 1.5T
Modulator Current (A)
Beam Loss / Hz
Modulator Current
Last Bunch Loss
First Bunch Loss
Time (Hours)