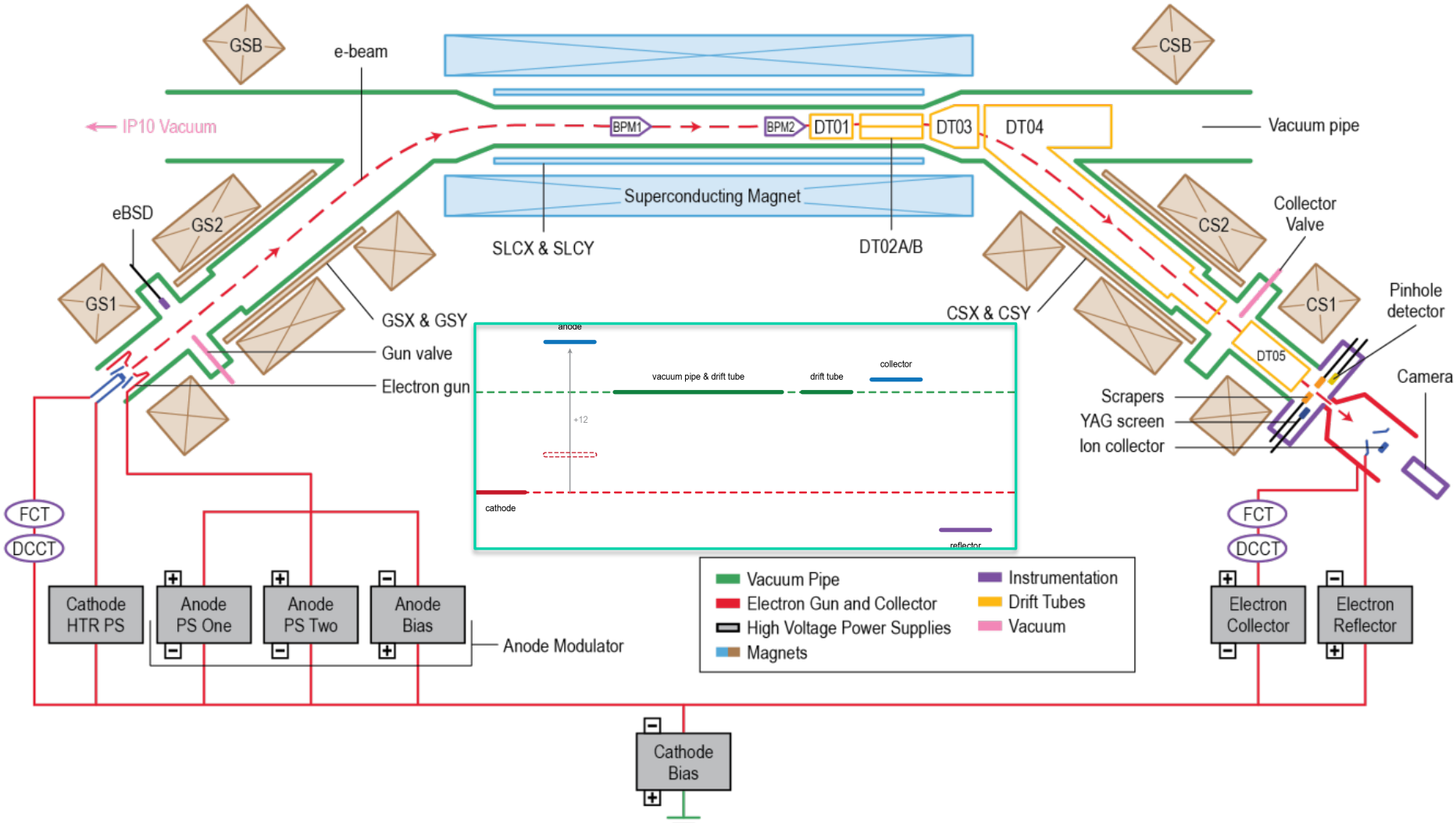
# E-lens commissioning, plans for shutdown and next run

**Xiaofeng Gu**

2014 RHIC Retreat
14 August 2014

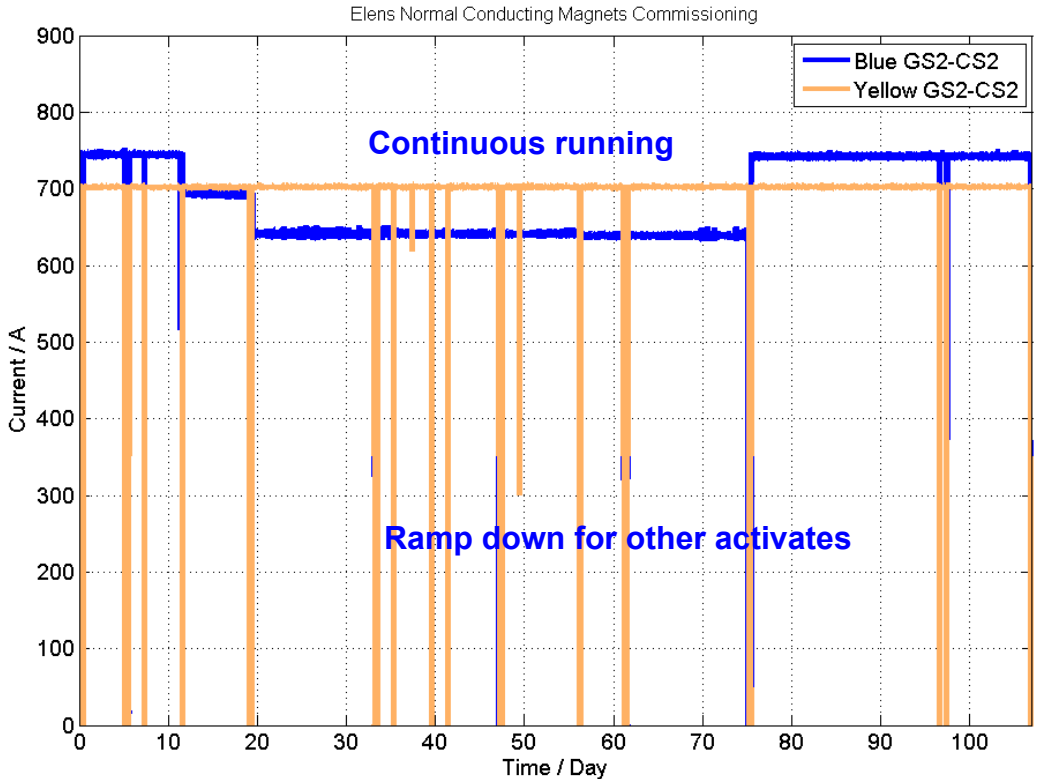
# Introduction -- E-lens Layout

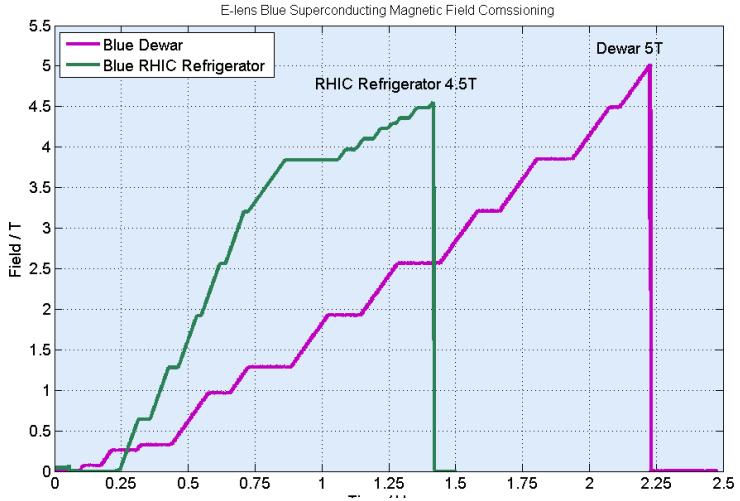


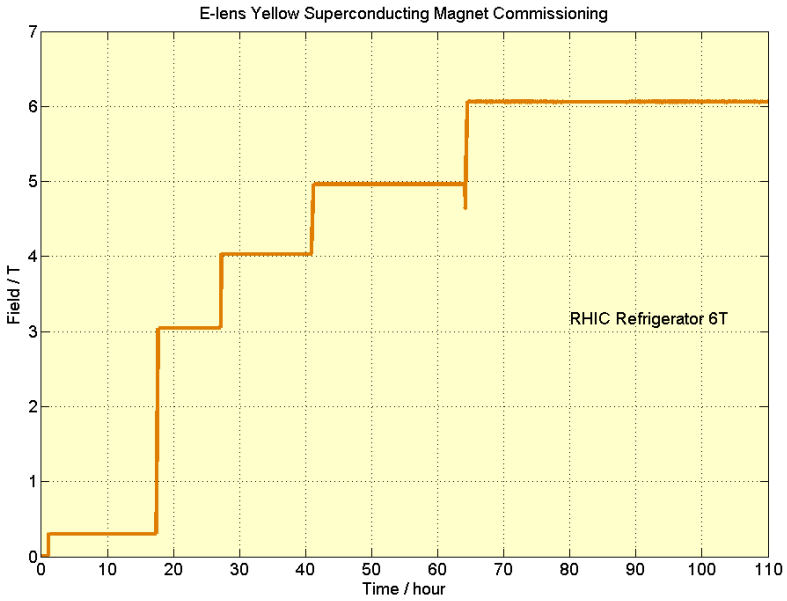

1. Warm Magnets 2. Cold Magnets 3. E-gun & Collector 4. Instrumentations 5. Vacuum 6. HV power supplies 7. Drift tube

# Hardware - Magnets

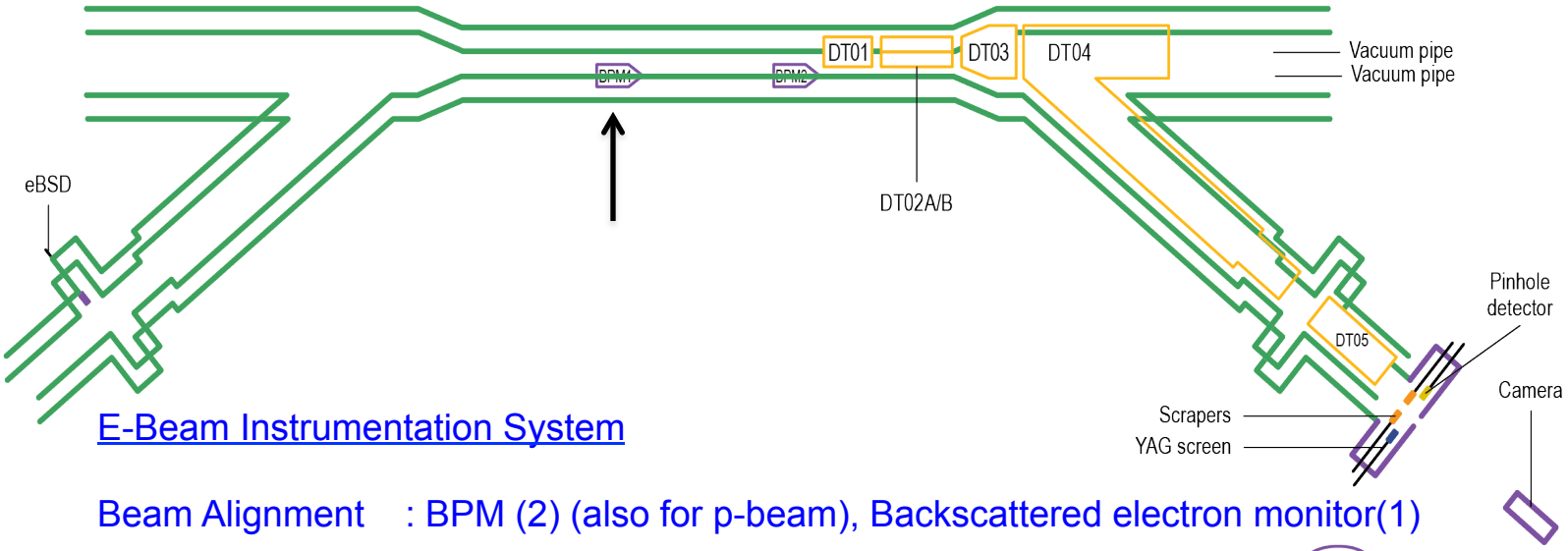
1. Blue Solenoid 5T with Dewar, 4.5 T with RHIC refrigerator;
2. Yellow Solenoid 6T.
3. Warm magnets run well, except Yellow GS2 four hours repair.



# Hardware - Instrumentation




E-Beam Instrumentation System

Beam Alignment : BPM (2) (also for p-beam), Backscattered electron monitor(1)

FCT
DCCT

E-beam Current : BCT (4), e-beam Loss (drift tubes)

FCT
DCCT

E-beam Profile : YAG Screen (1), Pin-hole detector (1)

Ion Current : Ion collector (1)

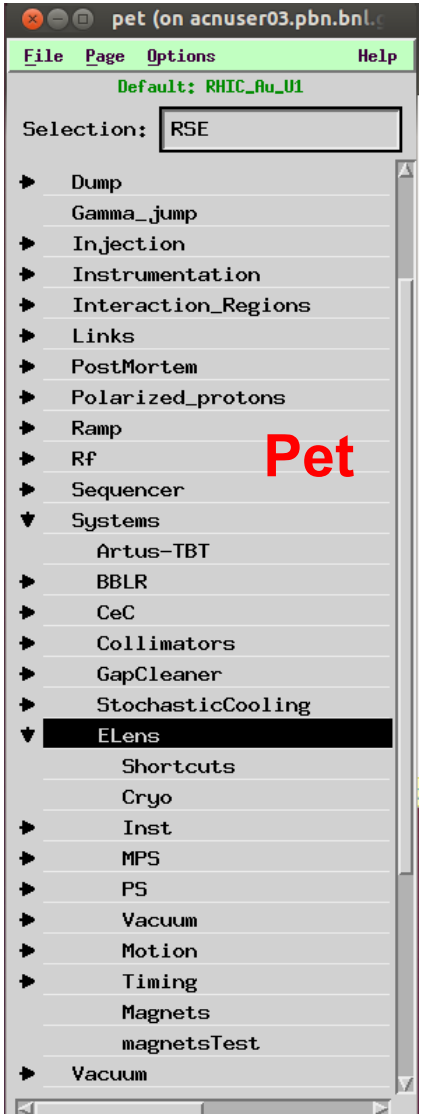
Collector Temperature: RTD (8)

Drift tubes (5 for each e-lens)

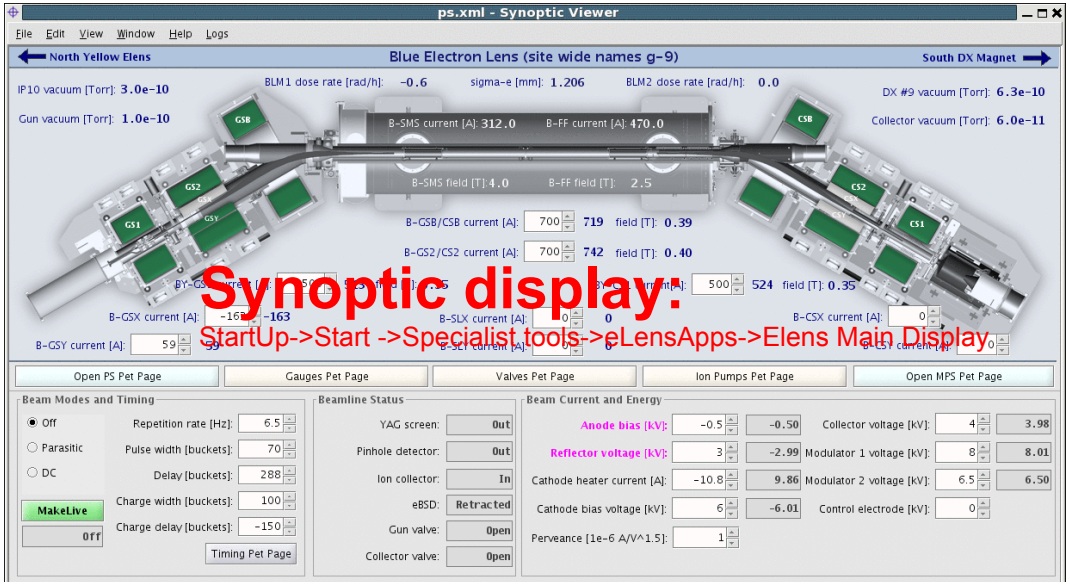
Anode Voltage Measurement

| E-Lens CT Scope MUX Channel Assignments | | | |
|---|---|---|---|
| Ch1 | Ch2 | Ch3 | Ch4 |
| Drift Tube 04-1/HF<br>R50 | REL Anode Voltage<br>Hi-Z | BPM2's (4)<br>R50 | eBSD PMT signal<br>Hi-Z |
| eBSD W-Block<br>Hi-Z | eBSD W-Foil<br>Hi-Z | Cathode FCT<br>Hi-Z | Collector FCT<br>Hi-Z |
| Cathode Voltage<br>Hi-Z | ABS Anode Voltage<br>Hi-Z | Cathode DCCT<br>Hi-Z | Collector DCCT<br>Hi-Z |
| Drift Tube 04-1/LF<br>R50 | Beam Loss (Shunt)<br>Hi-Z | Anode Current FCT<br>Hi-Z | Gun FCT<br>Hi-Z |

# Software – Control and application




1. Power supplies (PS): all warm magnets, HV, cathode heater, modulator
2. Timing: e-beam mode control, instrumentation timing control
3. MPS: machine protection system
4. Instrumentation: all instrumentation parameters and motion control
5. Magnets: cold magnet
6. Vacuum: gun, collector and IP vacuum



# Electron Beam

| *Hardware* | | | | |
|---|---|---|---|---|
| Vacuum system closed | 12/31/13 | 12/31/13 | 12/31/13 | 12/31/13 |
| Bake-out completed | 01/20/14 | 01/20/14 | 01/20/14 | 01/20/14 |
| GS1s operational | 02/19/14 | 02/19/14 | 02/19/14 | 02/19/14 |
| GS2-CS2 operational | 02/19/14 | 02/19/14 | 02/19/14 | 02/19/14 |
| CS3s operational | 02/19/14 | 02/19/14 | 02/19/14 | 02/19/14 |
| GSX-GSY-CSX-CSY operational | 02/19/14 | 02/19/14 | 02/19/14 | 02/19/14 |
| Gun conditioned | 02/19/14 | 02/19/14 | 02/19/14 | 02/19/14 |
| Drift tubes conditioned | 02/19/14 | | 02/19/14 | |
| Collector conditioned | 02/19/14 | 02/19/14 | 02/19/14 | 02/19/14 |
| SC solenoid 3T + FF 470 A | 02/26/14 | 03/05/14 | 02/26/14 | 03/05/14 |
| SC solenoid 3T + FF 470 A | 02/26/14 | 03/11/14 | 02/26/14 | 03/11/14 |
| Operational recovery for SC solenoid and FF | 02/28/14 | 04/02/14 | 02/28/14 | 04/02/14 |
| Turn on all warm solenoids during operations | 03/05/14 | 02/27/14 | 03/05/14 | 02/27/14 |
| Turn on all warm dipoles during operatoin | 03/05/14 | 03/01/14 | 03/05/14 | 03/01/14 |
| Establish operational recovery for warm solenoids | 03/05/14 | 04/10/14 | 03/05/14 | 04/10/14 |
| Established RHIC ops with all magnets always on | 03/06/14 | 03/12/14 | 03/06/14 | 03/12/14 |
| Long superconducting dipole correctors operational (4 | 03/26/14 | 03/19/14 | 03/26/14 | 03/19/14 |
| SC solenoid 4T + FF 470 A | 06/28/14 | 05/16/14 | 06/28/14 | 05/16/14 |
| SC solenoid 5T + FF 470 A | 06/28/14 | | 06/28/14 | 05/28/14 |
| SC solenoid 6T + FF 470 A | 06/28/14 | | 06/28/14 | 05/28/14 |

## E-beam commissioning

| *Electron beam* | | | | |
|---|---|---|---|---|
| ASSRC checklist done | 02/26/14 | 02/26/14 | 02/26/14 | 02/26/14 |
| MPS verified | 02/26/14 | 02/19/14 | 02/26/14 | 02/19/14 |
| sinle pulse, low current | 03/05/14 | 03/01/14 | 03/07/14 | 03/05/14 |
| ~100 Hz, low current | 03/07/14 | 03/06/14 | 03/07/14 | 03/06/14 |
| BPM operational | 03/15/14 | | 03/15/14 | 04/01/14 |
| 78 kHz, low current | 03/22/14 | 03/14/14 | 03/22/14 | 03/11/14 |
| 78 kHz, timed into abort gap | 03/22/14 | 03/14/14 | 03/22/14 | 03/18/14 |
| 78 kHz, full current (1 A) | 03/22/14 | 03/18/14 | 03/22/14 | 03/18/14 |
| Profile measured with YAG screen | 03/22/14 | 04/16/14 | 03/22/14 | 04/16/14 |
| ~~Profile measured with pinhole detector~~ | 03/22/14 | 05/07/14 | 03/22/14 | 05/28/14 |
| Drift tubes tested operationally | 03/29/14 | | 03/29/14 | |
| DC beam, low current | 03/29/14 | 03/11/14 | 03/29/14 | 03/11/14 |
| DC beam, full current (1 A) | 03/29/14 | 04/21/14 | 03/29/14 | 04/21/14 |
| Ion extraction operational | 03/29/14 | | 03/29/14 | |
| 78 kHz, low current in operational store | 04/12/14 | 03/19/14 | 04/12/14 | 03/19/14 |
| 78 kHz, full current (1 A) in operational in store | 04/15/14 | 04/21/14 | 04/15/14 | 04/21/14 |

1. Electron beam propagated with several configurations: 1.5T (470A fringe), 3T (250A and 470A fringe), 4T (470A fringe);

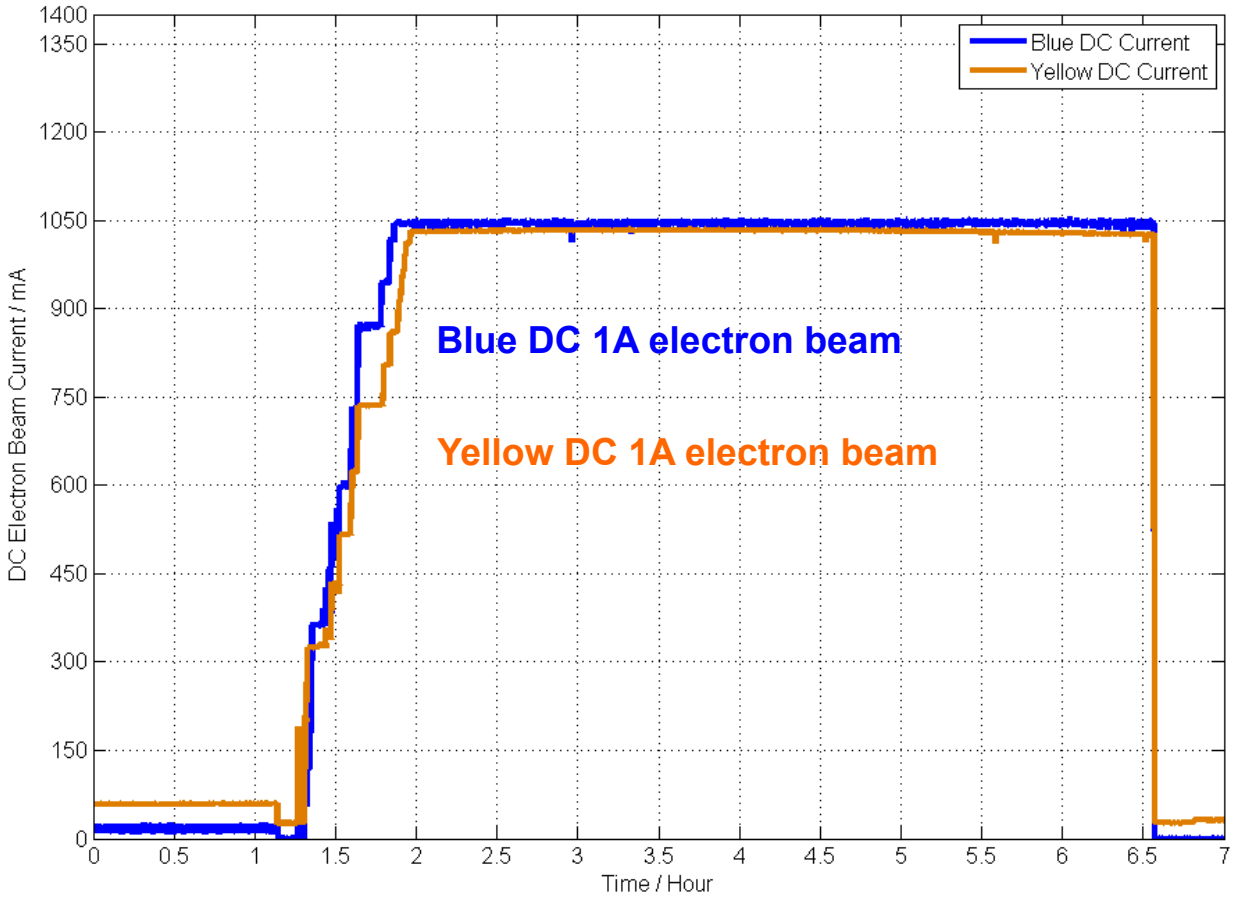
2. Provide electron beam for all APEX sections: elens commissioning (some times, only limited mode available), beam-beam instability with low field, asymmetric beam-beam, beam-beam driven Non-linear resonance;

3. Drift tube connections issues;

4. Blue superconducting solenoid 6T field.

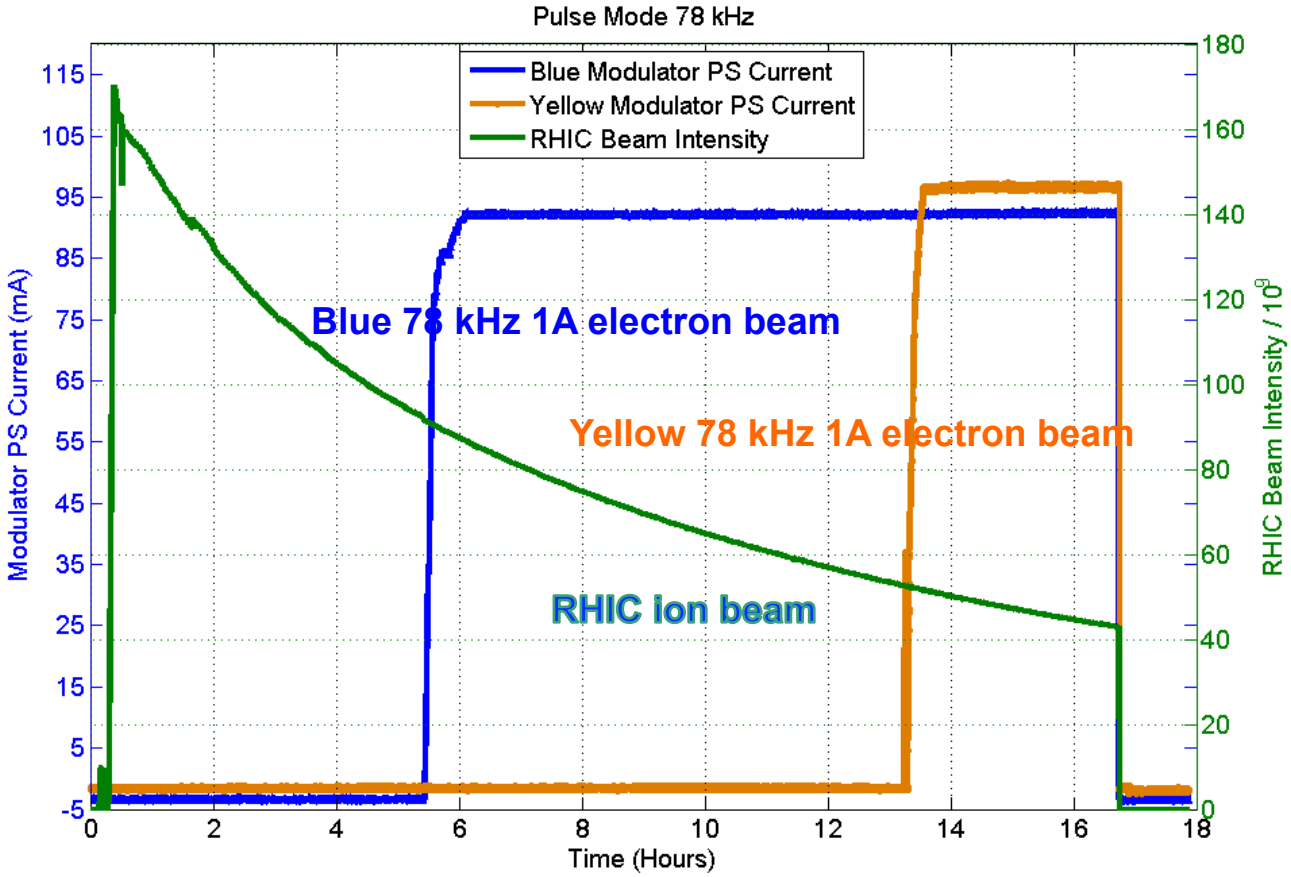
**courtesy of Peter Thieberger**

# Electron beam – DC mode



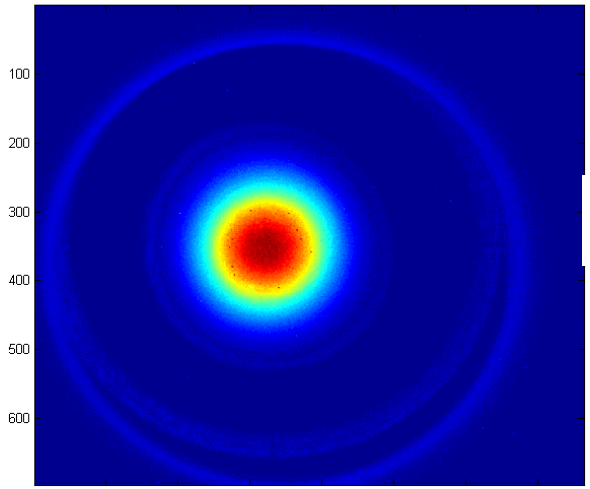

1. NO RHIC ion beam
2. Blue and Yellow were running simultaneously
3. Beam current is **1 A**
4. Blue was running for 9.5 hours during 2013 commissioning.

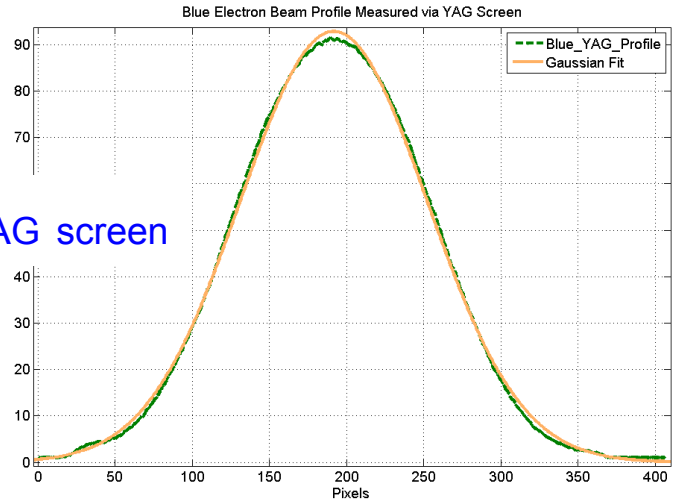
# Electron beam – Pulsed Mode




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;

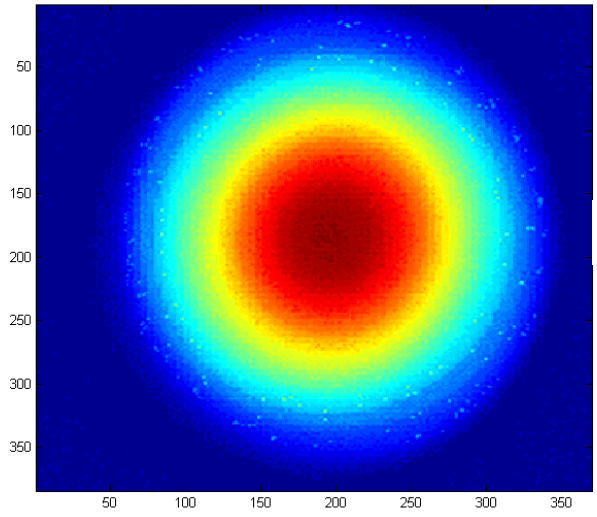
# Electron beam Blue Transverse Profile

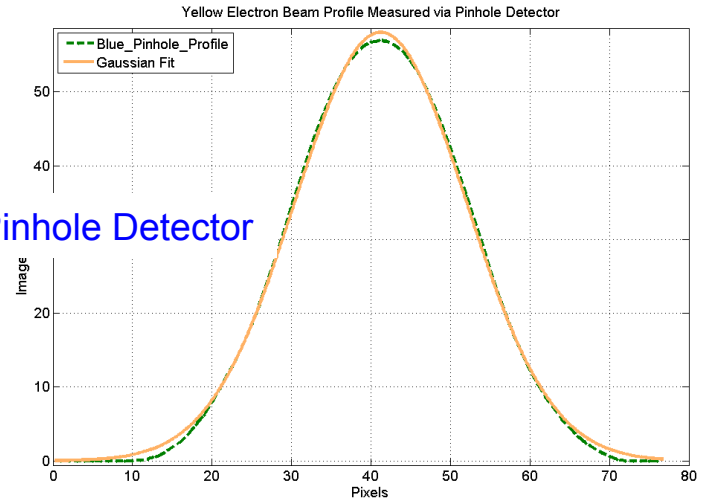





YAG screen

- Current 70 mA
- Beam profile from YAG is a Gaussian



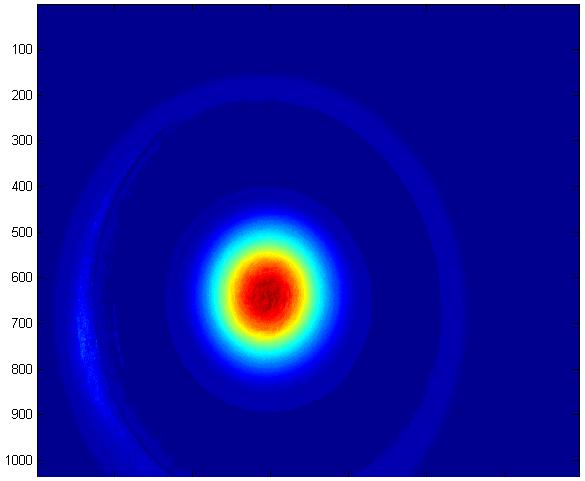


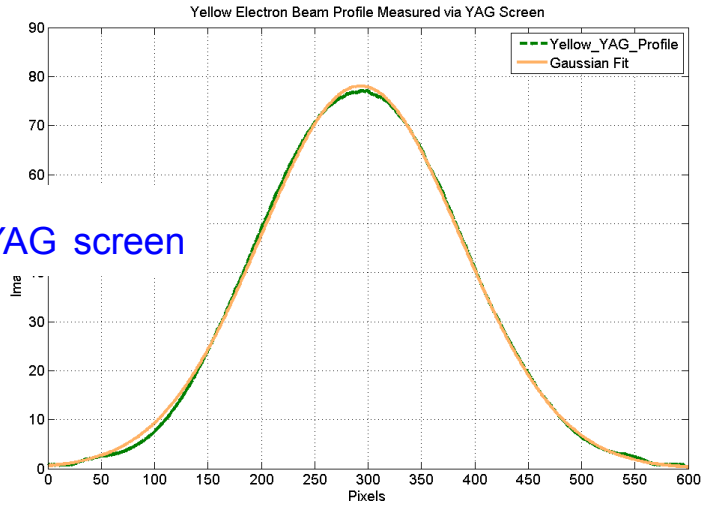

Pinhole Detector

- Profile does not change with current

- Current 1150 mA.
- Pinhole profile is Gaussian

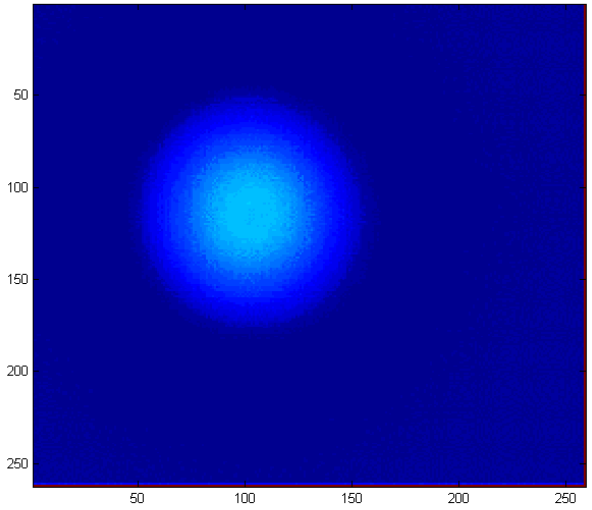
# Electron beam Yellow Transverse Profile

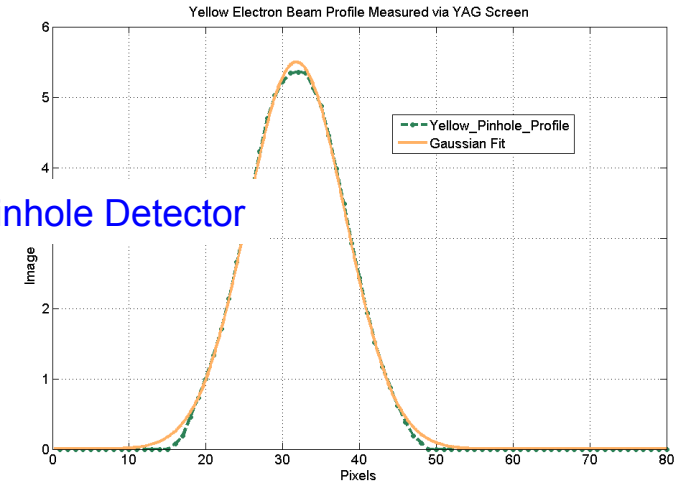





YAG screen

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

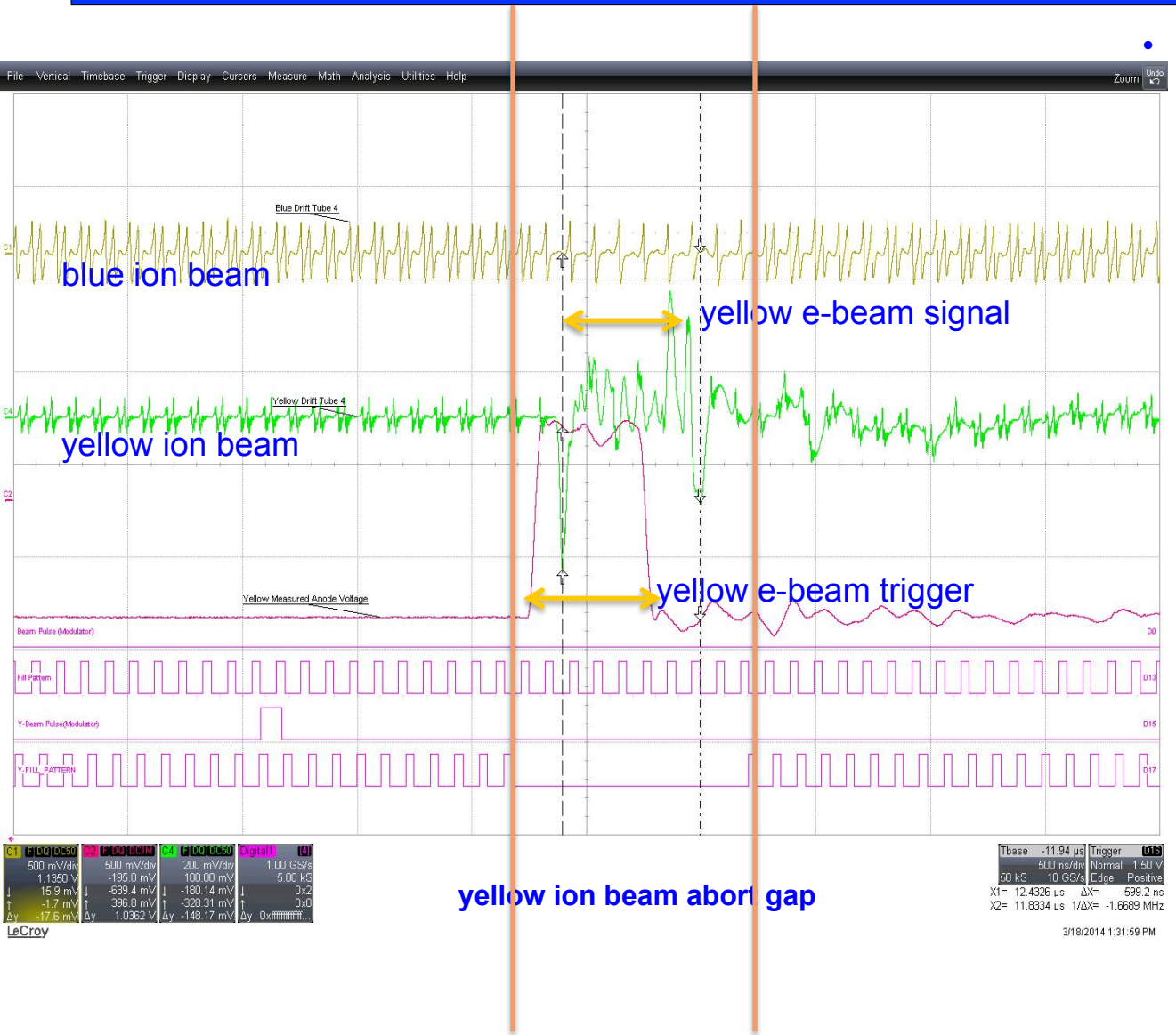





Pinhole Detector

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

# Longitudinal alignment

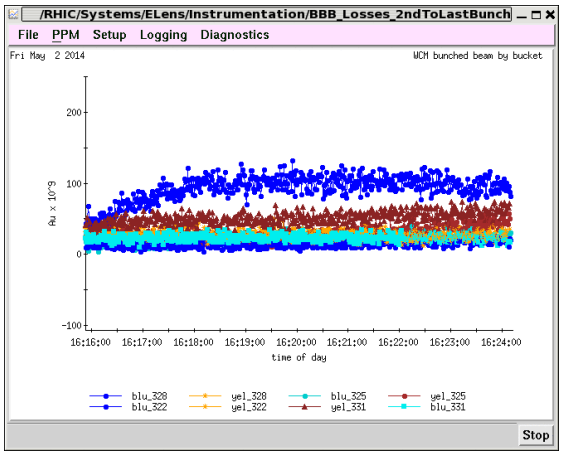



- **longitudinal** and **transverse** alignment via colliding with the last one or two bunches

**Aligned to beam abort gap** via Drift tube 4.

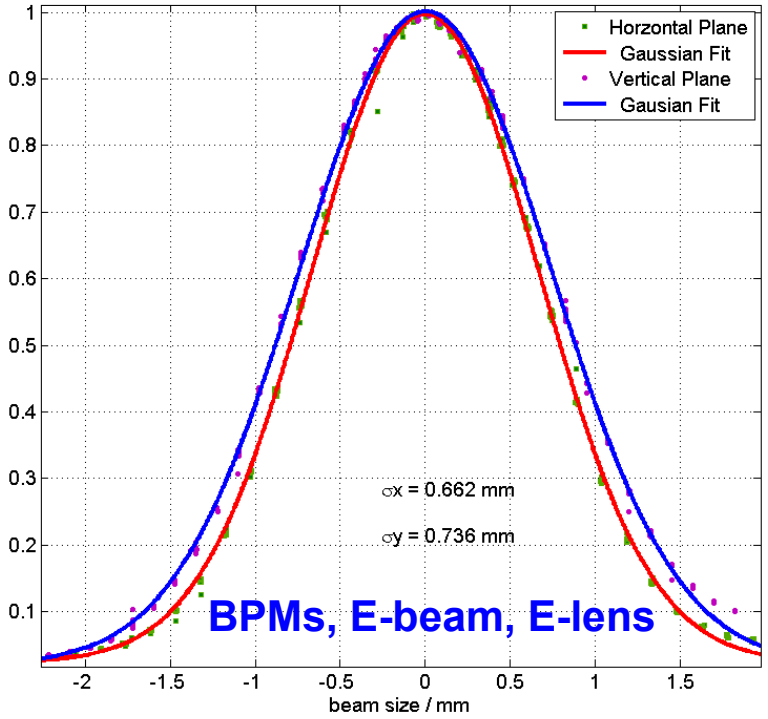
**Longitudinal alignment**: no emittance growth or loss for the unwanted bunch.

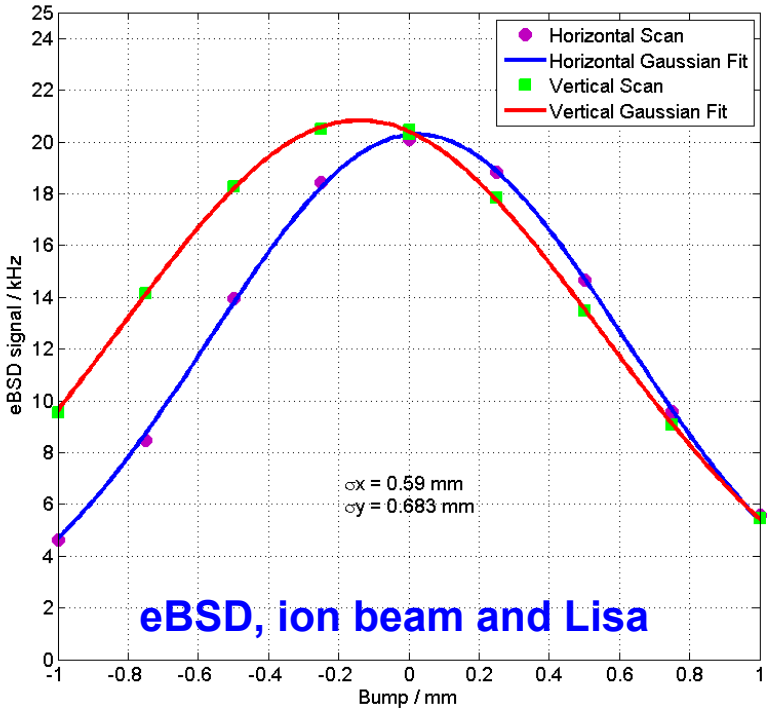
http://www.cadops.bnl.gov/cgi-bin/elog/viewMain.pl?elog=Elens_2014&shiftlog=Mon_Apr_28_2014_12:54:48_PM#20140402180729



# Transverse Alignment

- BPMs in both lenses to bring e- and A- beam in proximity (transverse electron beam position for blue and yellow, electron beam angle steering for yellow)
- backscattered electron detector to maximize overlap
  P. Thieberger, BIW12, IBIC2014
- BPMs and electron beam; BPMs and ion; **eBSD and ion beam**; eBSD and electron beam.



# Documentation and Training

RHIC Electron Lenses and Their Operation: An Introduction

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1. The document about e-lens operation (2014 retreat website, next to this presentation, still open for modification).

2. Trained a operator for e-lens operation during run and the day of run.

- Give an introduction to e-lens;
- Can run all modes: continuous, parasitic and DC;
- Start to familiar with the Beam profile measurement via Yag and pinhole;
- Measured e-gun perveance;
- Run parasitic mode as a gap cleaner independently.

# E-lens hardware failures

- Blue BPM2, horizontal plane, no signal: BPM2 can not work very well.
- Drift tubes: Blue DT02A and DT02B connection, Yellow DT02A and DT02 power supplies and bias tee: clearing electrode for electron cloud, and ion accumulation extraction;
- Collector PS induced voltage on cathode: Blue YAG screen was damaged, will be replaced;
- Blue eBSD inserted and damaged by e-beam without protection: replaced;
- Blue modulator 240mA: HV breakthrough between cathode and anode?
- Blue and yellow Modulator 24 V power supplies: replaced and will move them out of tunnel;
- Yellow GS2/CS2 power supply: Fixed;
- 05/24/2014 yellow DC beam trigger failure: always ON, high ion beam loss during injection.

# Vacuum spike, E-cloud and Others

These are the several cases where an electron lens had a detrimental effect on the beam :

18068 (03/18/14) vacuum spike, increased loss rate, emittance increase (reduce ramp rate for current);

18135 (03/28/14) high pressure, loss rate increasing slightly, no effect on emittance (set limit for vacuum);

18170 (04/04/14) no pressure increase, increase in Yellow and decrease in Blue loss rate, emittance increase in both rings;

18193 (04/10/14) pressure increase, increase in Blue loss rate, emittance increase in both rings (reduce limit from 5E-8 Torr to **1E-8Torr, increase parasitic mode current slowly**);

18338 (05/21/14 12:41) during APEX, drift tube induced vacuum spike, large emittance increase;

(05/21/14 ~ twenty minutes ) during APEX, drift tube were ON, beam loss during injection or ramp?

18349 (05/23/14 11:28) yellow vacuum spike with -3kV cathode bias, emittance increase;

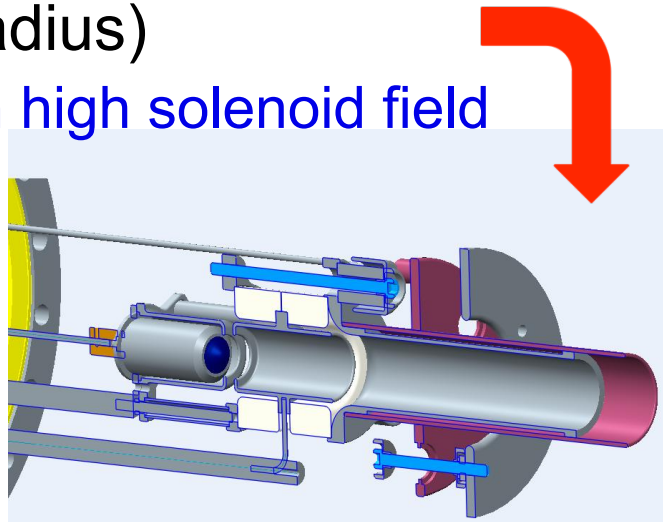
(05/28/14 20:06~21:10) drift tube voltage were forgot to turn OFF, vacuum spike during ramp. MPS for drift tube was OFF (**enable MPS to trip off drift tube PS**);

One mystery: beam loss when e-lens superconducting magnets on

# 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

# Shut down plan

1 Repair the blue bad BPM cable/feed through;
2 check the cleaning electrode for both e-lens;
3 Repair drift tube cable/feed through for both blue and yellow.(why exactly the drift tubes got shorted to ground after bakeout and if necessary to change the design of tubes/connections slightly to prevent it from ever happening again in a future)
4 Replace the three bad blue temperature sensors (done);
5 Check yellow cathode size and blue gun;
6 Measure magnetic field at YAG as function of CS1 and CS2 current;
7 Increase pumping speed in IR10, possibly clearing electrode;
8 Protective baffle for the eBSD;
9 Transverse damper in both beam;
10 e-beam current monitor from the first drift tube;
11 increase **bake-out temperature, cleaning vacuum chamber & drift tube**;
12 new gun with r = 7.5 mm;
13 collector modification for larger e-beam;
14 calibrate warm solenoid current read-back;
15 Train SC magnets to 6T;
16 Documentation of e-lens;
17 Picture in tunnel with every one involved;
18 e-beam current feed back;
19 Power supplies precision / instability;
20 Real DC beam (timing;
21 Yellow synoptic display.
22 Yellow reflector PS trip off issue.
23 Blue YAG screen
24 Modulator PS 25 auto steer application

**courtesy of Peter Thieberger**

# Summary:

1. Most e-lens hardware and software are functional except one blue BPM strip-line and drift tube system;

2. Propagated e-beam with several configurations. E-beam current and transverse profile are met the requirement;

3. Longitudinal and transverse alignment with RHIC beam;

4. Provide e-beam for APEX for several topics;

5. 1E-8 Torr (5E-9 Torr) vacuum criteria was found to prevent e-cloud developing, maybe also useful for other projects with e-beam;

6. Need to pay attention to clean vacuum pipe and elements for electron machine (vacuum spike and MPS).

courtesy of Peter Thieberger

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