Ring Electron Scanner

ORNL:

Sasha Aleksandrov

Willem Blokland

Sarah Cousineau

BINP:

Dmitriy Malyutin

Sasha Starostenko

Outline

- **Principle**
- **Hardware**
- **Software**
- **Data**
- **Evaluation**
- **Future**
- **Summary**

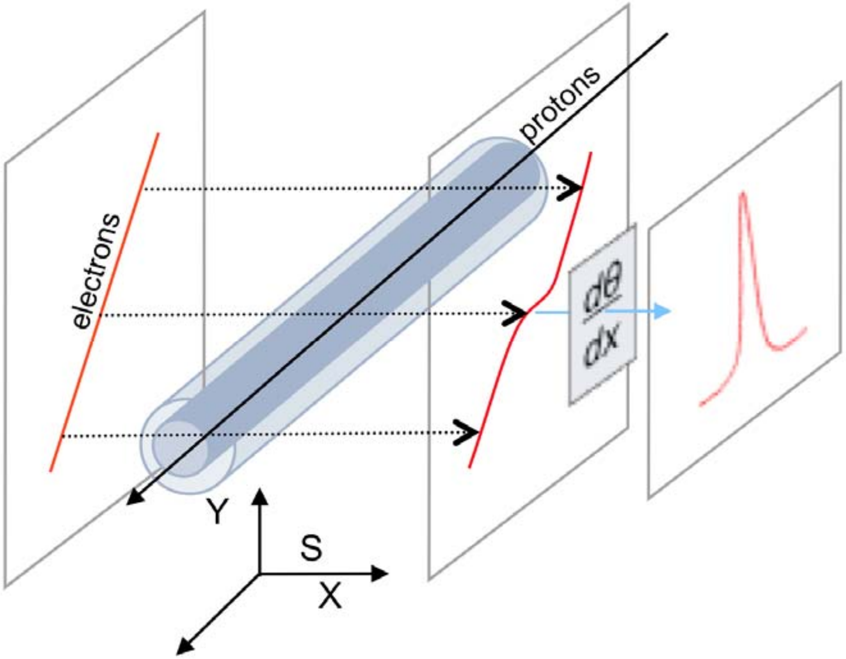
Principle

Look at the deflected projection of a tilted sheet of electrons due to the proton beam charge [1,2,3]

- **Neglect magnetic field (small displacement of projection)**
- **Assume path of electrons is straight (they are almost straight)**
- **Assume net electron energy change is zero (if symmetric).**

→ $$\frac{d\theta_0(x)}{dx} = \int_L \frac{e}{mv^2} \frac{\delta(x,y)}{\varepsilon_0} dy$$ **or, take the derivative to get the profile[3]**

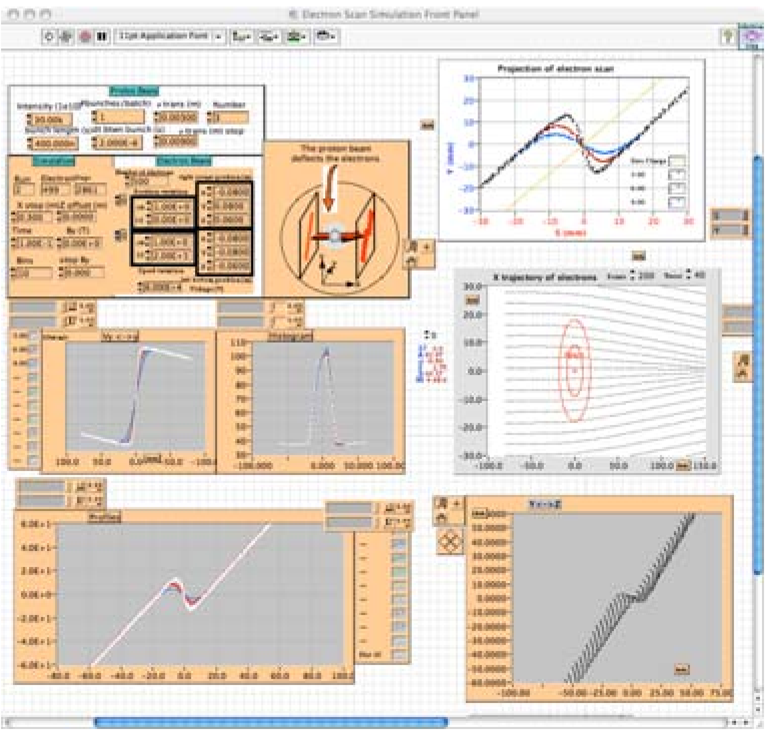
Imperfections estimated at 5-10%, .



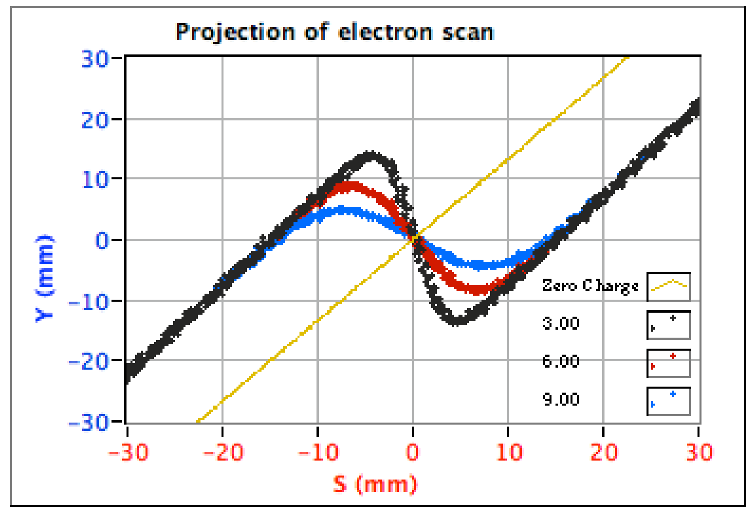
Principle

Approach:

1) **Build an electron gun (75kV)**
2) **Shoot a tilted line of electrons through the proton beam**
3) **Use a fluorescent screen and video camera to get the projected curve**

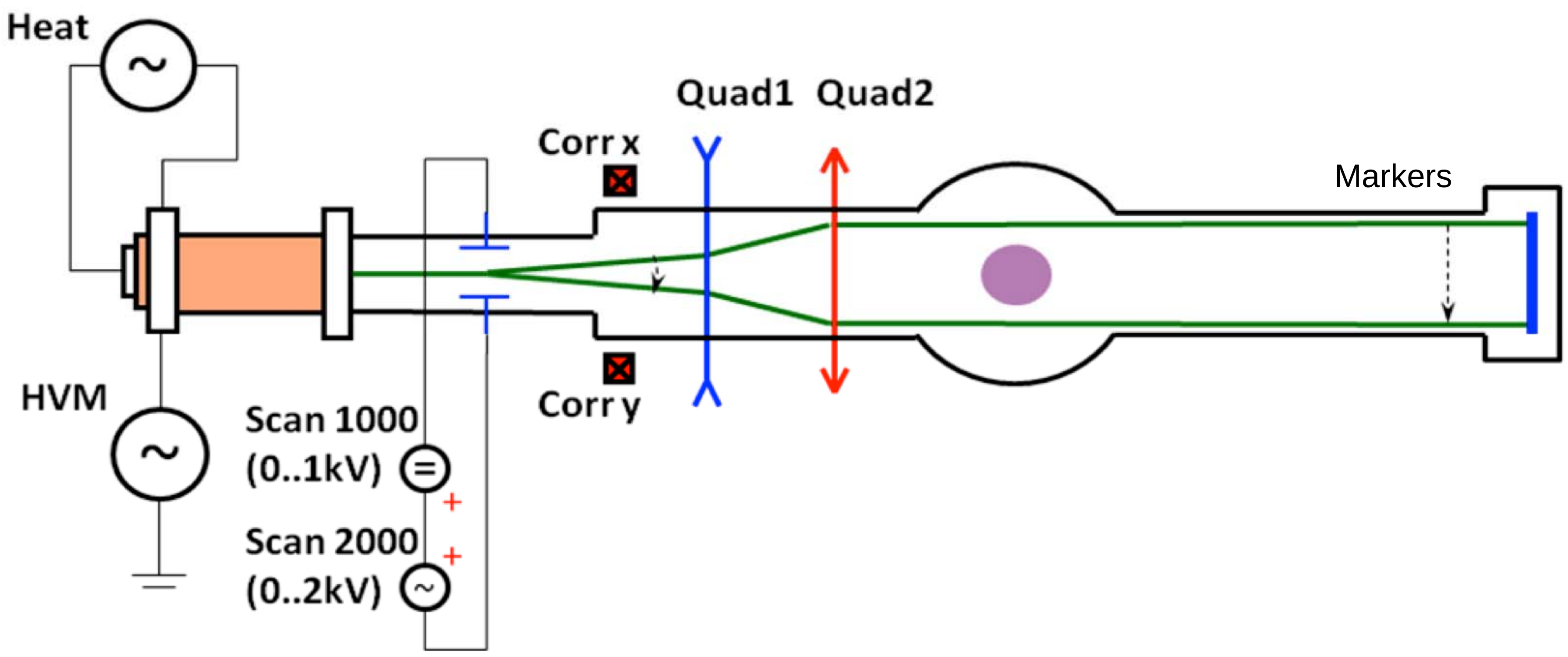


LabVIEW Simulation



Projection of electrons (LabVIEW simulation)

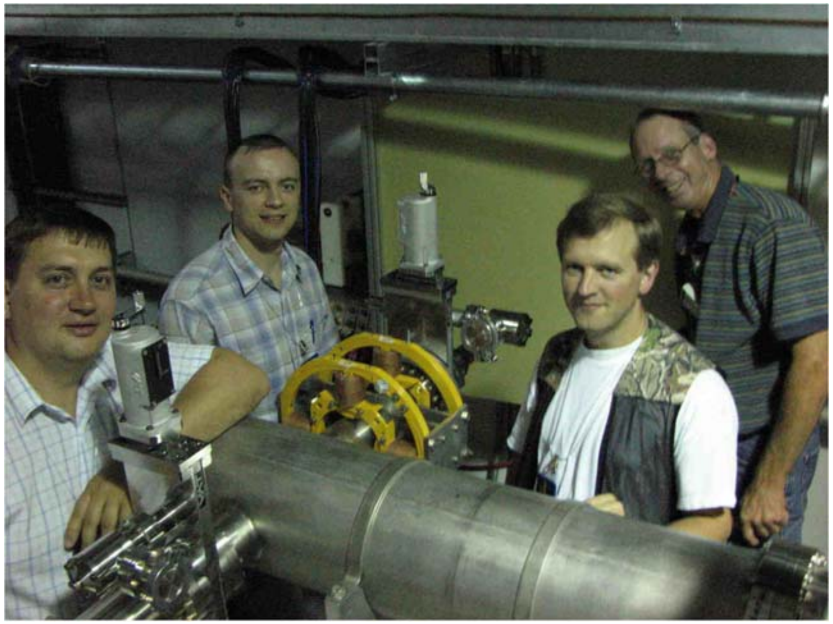
Hardware: Electron Scanner



Electron scanner diagram

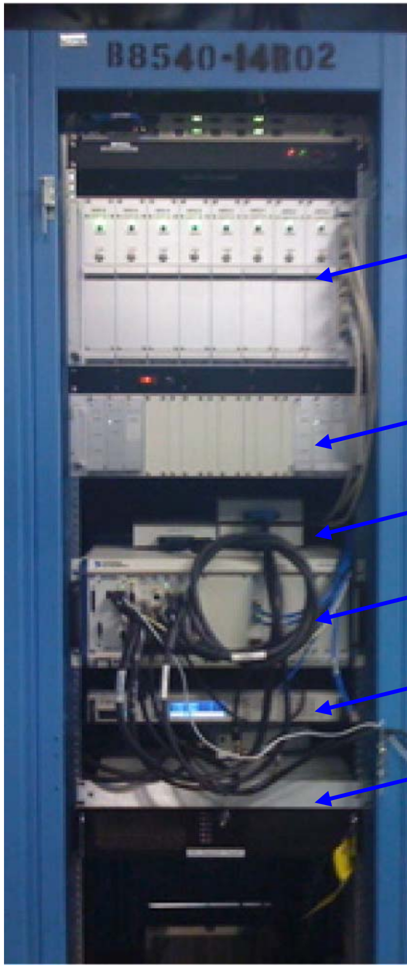
Electron Scanner made by Budker Institute of Nuclear Physics:
Dmitriy Malyutin, Sasha Starostenko, Sasha Tsyganov
Vacuum vessel by SNS.

Hardware: Tunnel



Electron scanner Ring Tunnel Pictures

Hardware: Rack



Magnet power supplies

HV power supplies

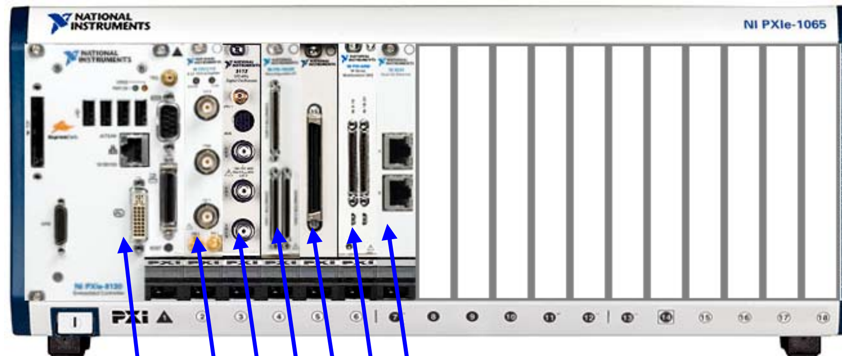
Breakout boxes

PXI: Acquisition and Control

Camera power supplies

Trigger breakout

Electron scanner Ring Service Building



GigE Vision

PS ADC readbacks

PS DAC settings

Delay generator

HV digitizer

Deflector digitizer

CPU

PXI crate with ADCs and DACs

Software

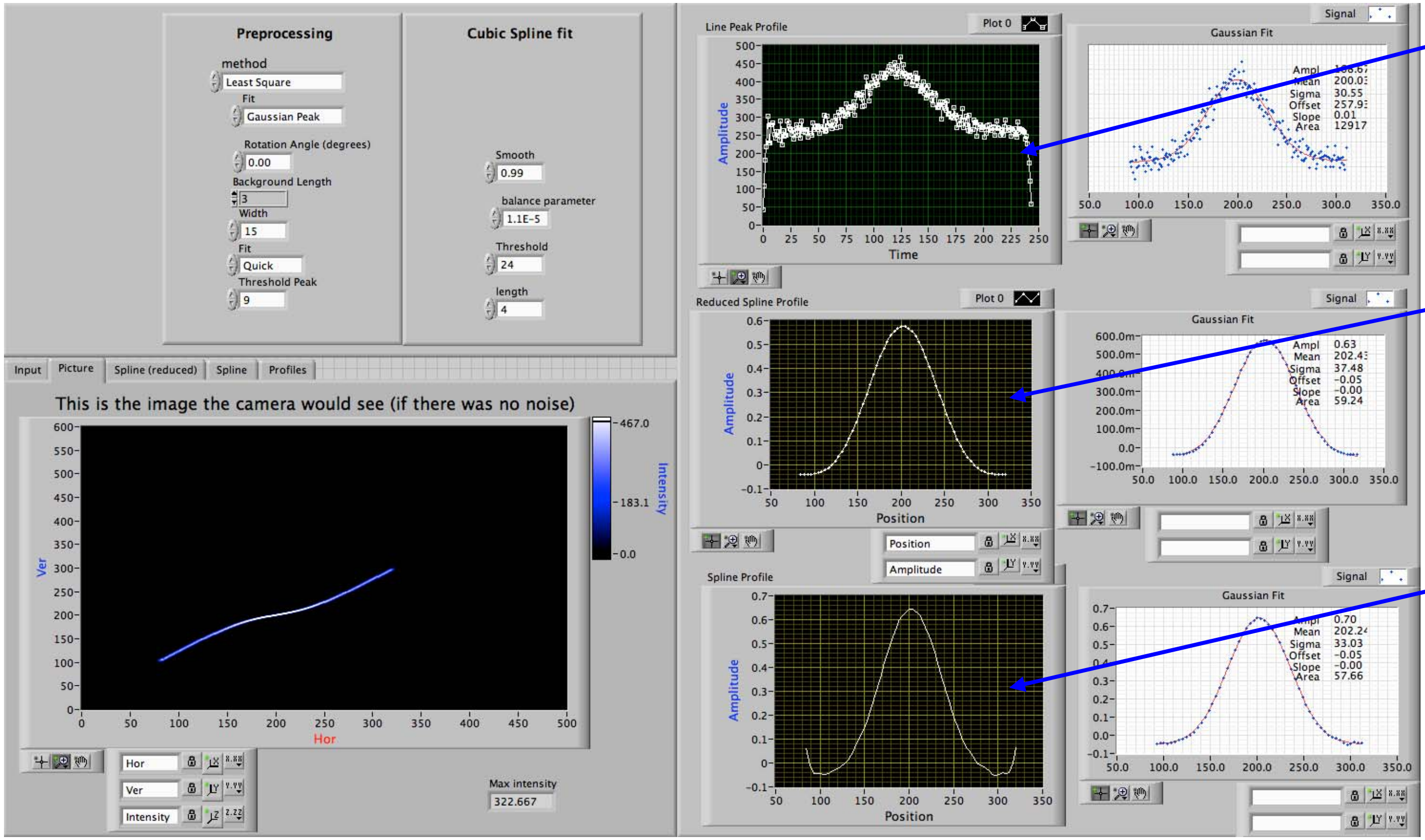
1) Simulation software
    - Simulate electrons through proton beam to create profiles
    - Test analysis software with simulated profiles
2) Electron scanner Hardware Control
    - Quadrupoles
    - Correctors
    - Deflector
    - Heating
    - Accelerating voltage
3) Image Acquisition and Analysis:
    - Image acquisition and control
    - Image analysis
    - EPICS interface
    - Image calibration
4) Scan Software
    - Controls timing and retrieves profiles from main program to:
        - Create 3D plot of bunches
        - Wire Scanner equivalent profile

Software: Image Analysis

Steps:

1) Use LabVIEW simulation to create image then analyze picture

2) Create picture, print out, take image with camera (test with noise)



1) Find peak
2) Take derivative

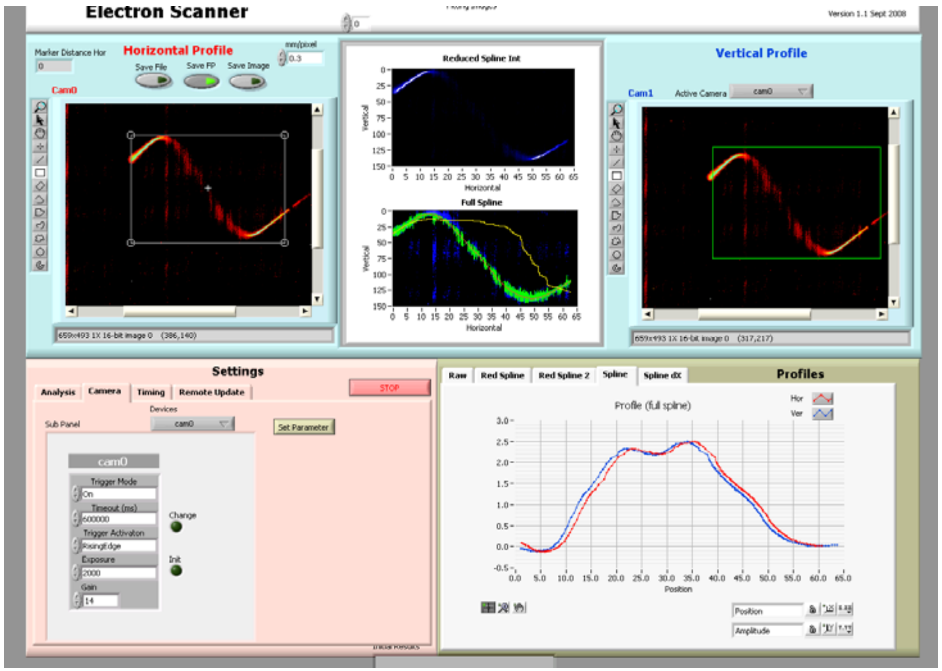
1) Find Gaussian peak per column
2) Fit Spline
3) Take derivative

1) Fit Spline
2) Take derivative

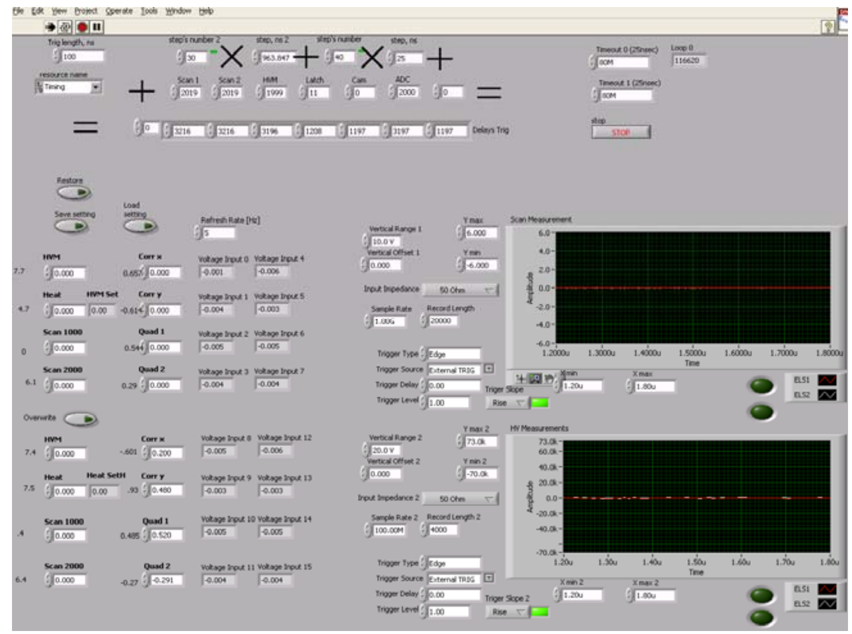
Pixels not near the curve and below threshold are removed

Test of image analysis using a simulated gaussian shaped proton beam.

Software: Image and Hardware

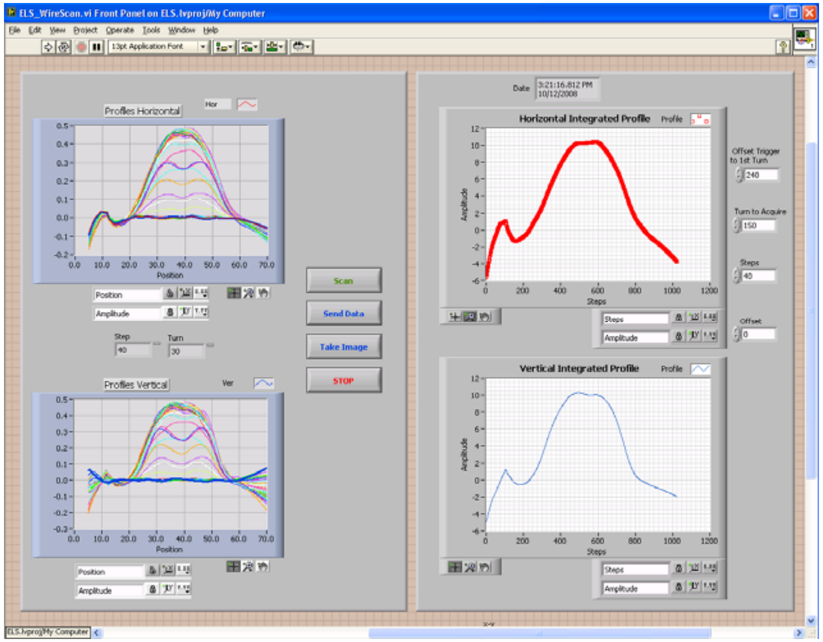


Main Program front panel

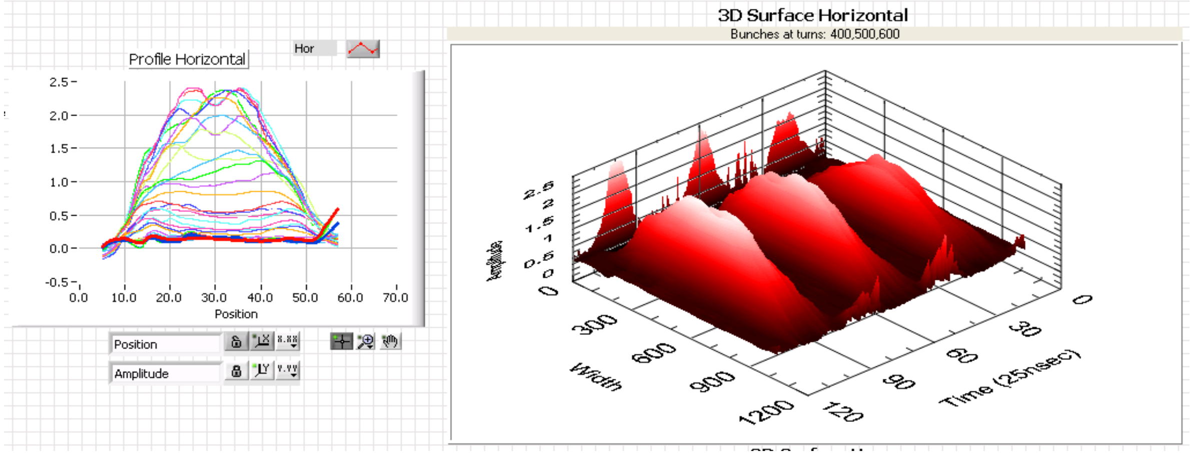


ELS Control Program front panel

Software: Software on CPU: WS & 3D



Wire Scanner emulation program



3D Bunch Display program

Data

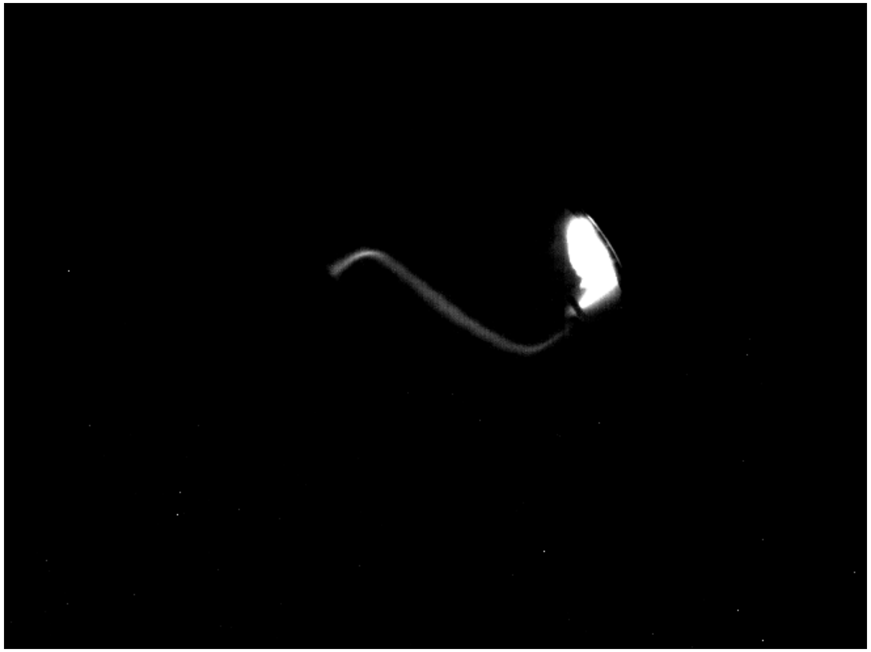


Image of horizontal curve

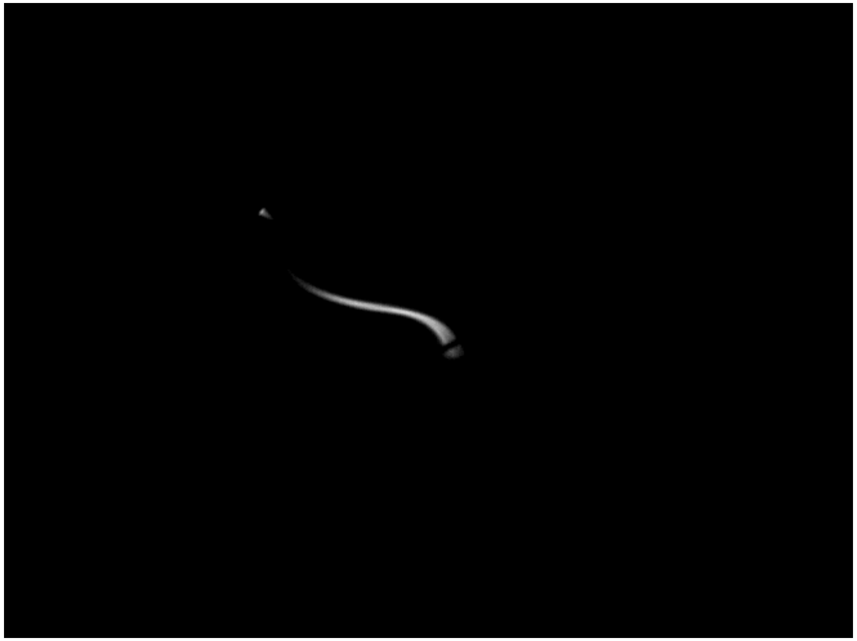
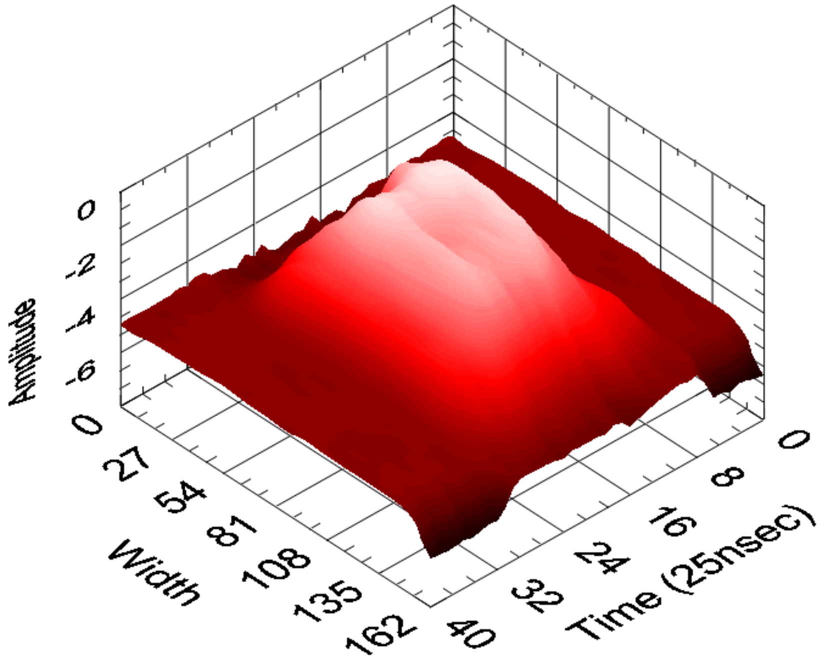
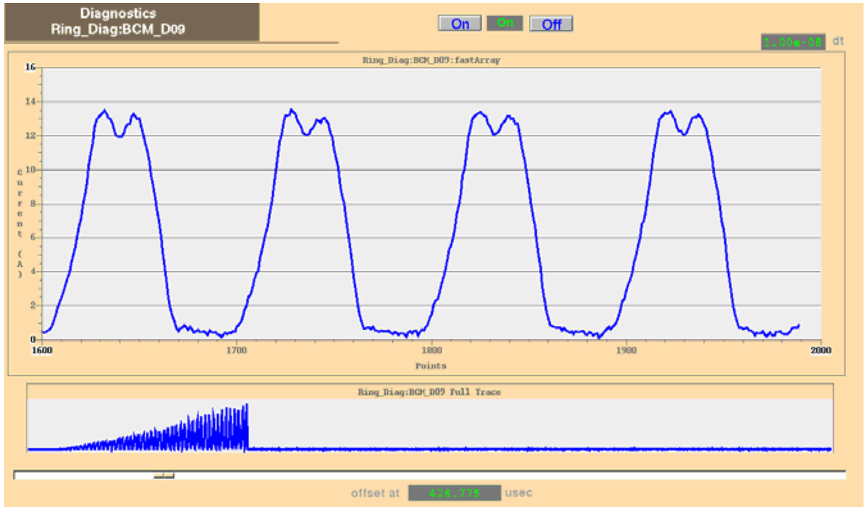


Image of vertical curve

Data

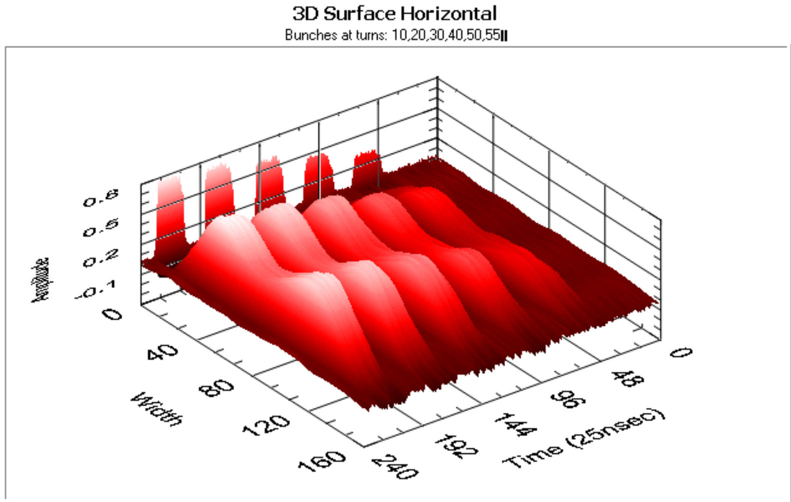


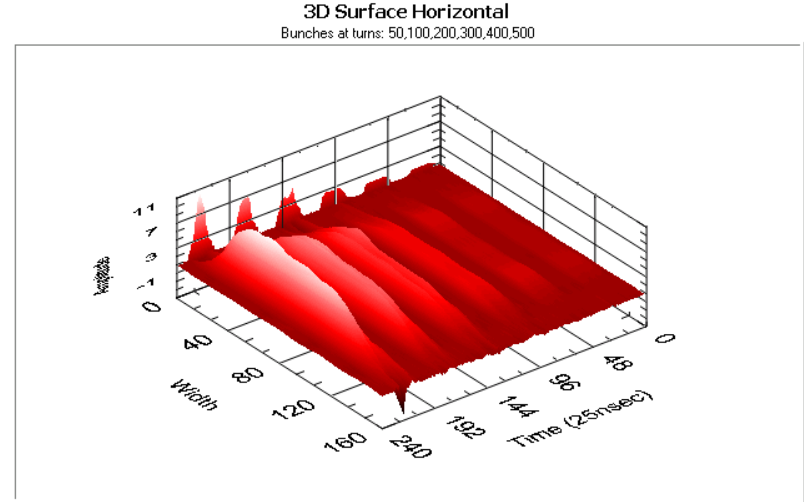
3D plot of Turn 343.

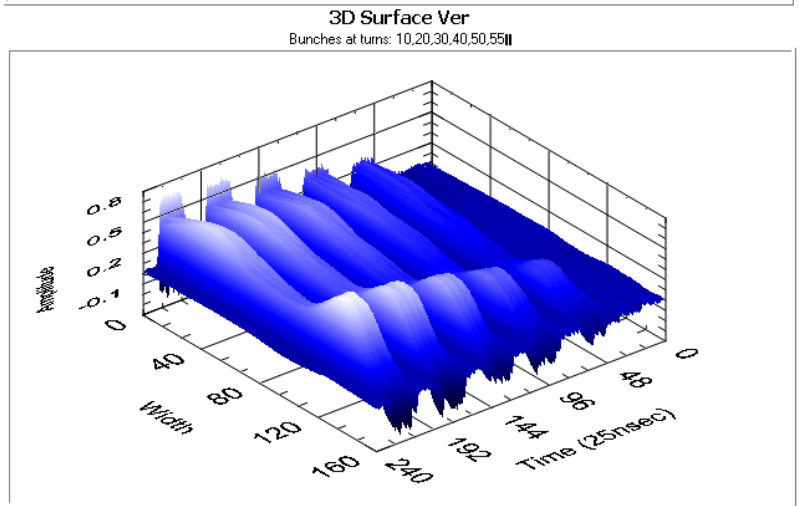


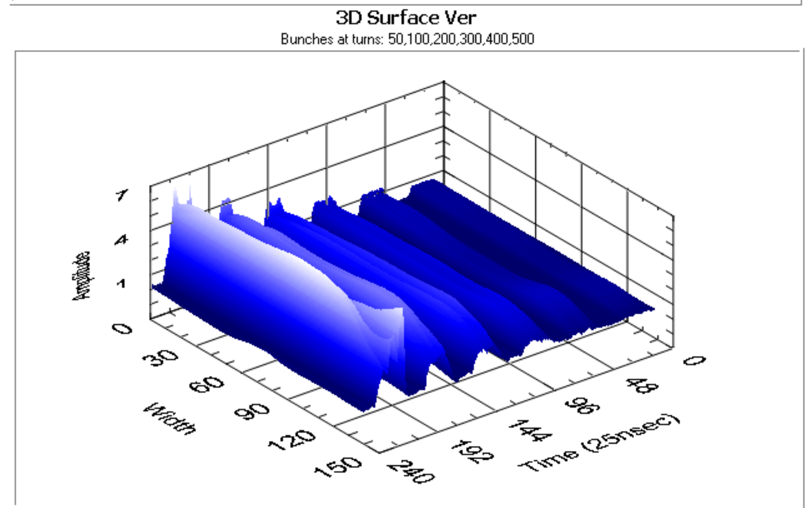
Ring BCM around Turn 343.

Data





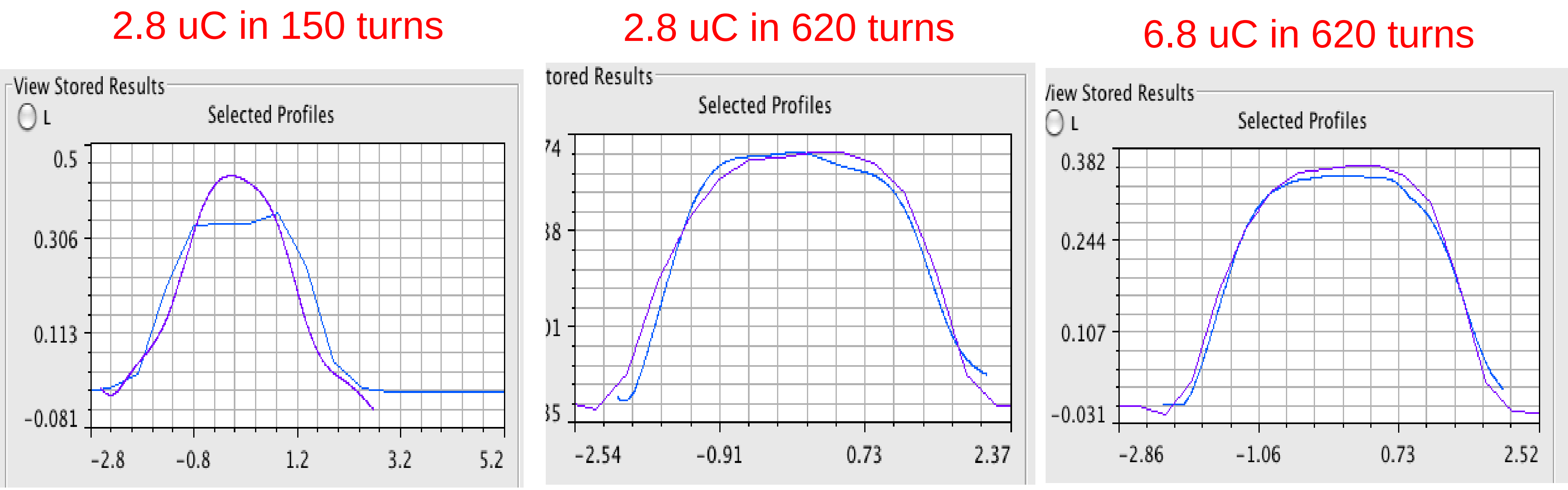




3D plot of turns 10,20,30,50, and 55.

3D plot of turns 50,100,200,300,400, and 500.

Profile Shape Benchmark with Harp



Harp and projected ELS profiles.

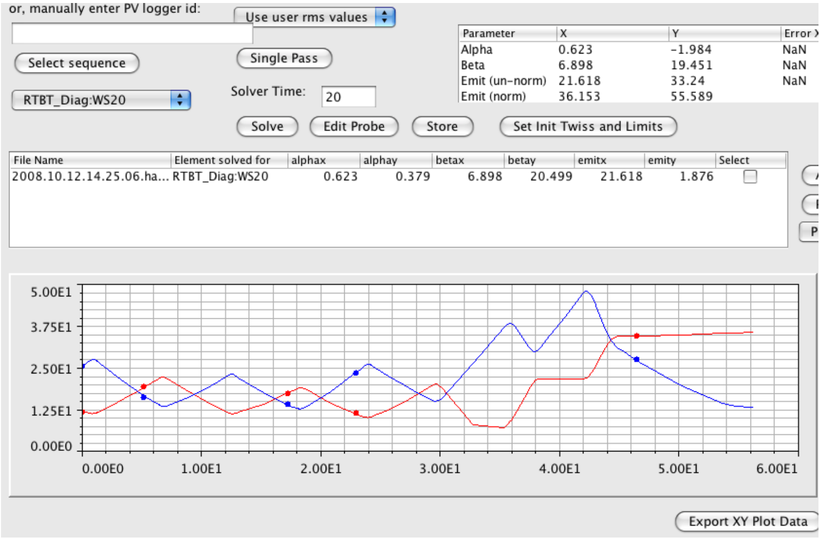
- **ELS delivered integrated profiles over the 700ns pulse width for comparison with Harp. Compared ELS profile shape with Harp shape by normalizing by profile rms + area.**
- **For 620 turn accumulation, profile shape in good agreement for both intensities.**
- **For 150 turn accumulation, agreement is not as good but Harp data had very few points and suspicious profile shape.**

Profile Size/Scale Issues

We predicted the beam size at the ELS by fitting the emittance in the RTBT and using the design beta function at the ELS location.

The result was different than measurement. Beta would have to be 2.5 times greater than design in order to resolve the discrepancy.

This is a mystery, but one we can probably solve.

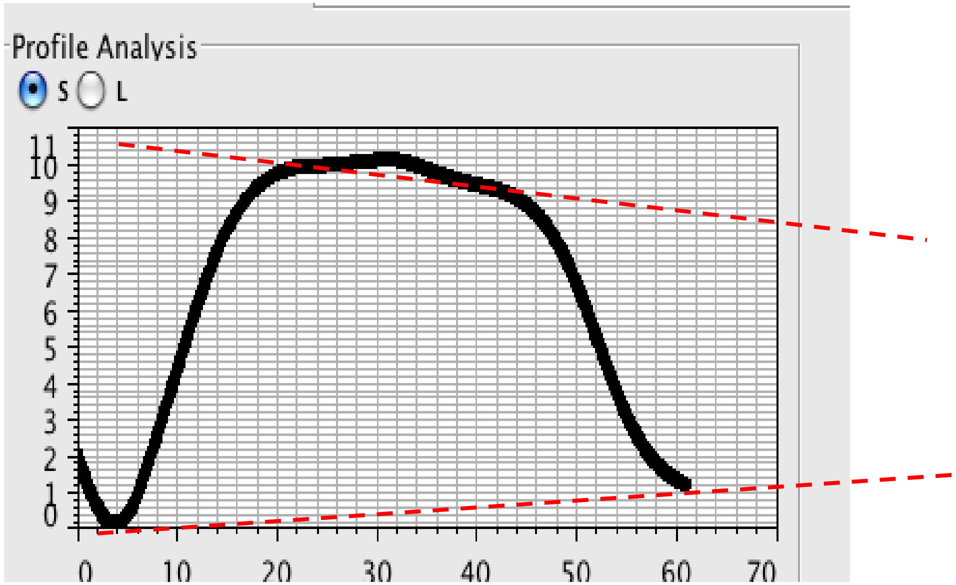


RTBT Wizard

State	Predicted X	Measured X
6.8 uC, 620 turns	9 mm	14 mm
2.8 uC, 150 turns	6 mm	11 mm

Difference is ~ 1.6 (sqrt(2)).

Tilt at low intensity



Tilted Profiles.

Profile tilt is an issue, especially at lower intensity where profile amp is small.

At higher intensities, the effect is small compared to the profile amplitude.

This is probably due to stray magnetic fields in the order of a few gauss. Magnetic shielding is being installed. Software and fine tuning can already partially correct the tilt.

Conclusions

- **Can deliver a profile for a 20 ns slice of beam anywhere in accumulation and anywhere along the bunch width.**
- **Can be operated completely parasitically during production.**
- **Profiles delivered look physical and quality (beam tilt, pulse to pulse jitter) is improving rapidly.**
- **The profiles the ELS is delivering look reasonable and physical, and the device has uniquely attractive features compared to traditional harp and wire scans.**

- **The profile shape are very sensitive to precise setting of the device hardware (quads and correctors).**
- **In it's current state, aperture is too small for large beams, and profiles not available for very low (< 2uC) or very high (> 9uC) intensities.**

This is a great success for a new device.

Once minor issues are addressed, there will be a strong case for upgrading to a full tomography device.

Future

Short term plans:

- **Jitter reduction**
  - Switch to a 1nsec jitter timing card
  - Increase speed of LabVIEW FPGA to 120 Mhz
  - Synchronize to Ring RF
- **Magnetic shielding**
  - Should get rid of tilt
  - Will make tune-up quicker
- **Increased light sensitive cameras**
  - Increases low charge range of electron scanner (lower accelerating voltage gives less visibility)
  - Will make adjustment of the electron scanner easier (electrons visible under more conditions)

Long term plans:

- **Larger aperture**
  - Handle more beam sizes in the ring
- **Simplify hardware**
  - Replace some custom hardware with off-the-shelf hardware
- **Tomography**