Non-invasive Beam Profile Measurements using an Electron-Beam Scanner

W. Blokland and S. Cousineau

Willem Blokland

for

the Spallation Neutron Source

Managed by UT-Battelle
for the Department of Energy

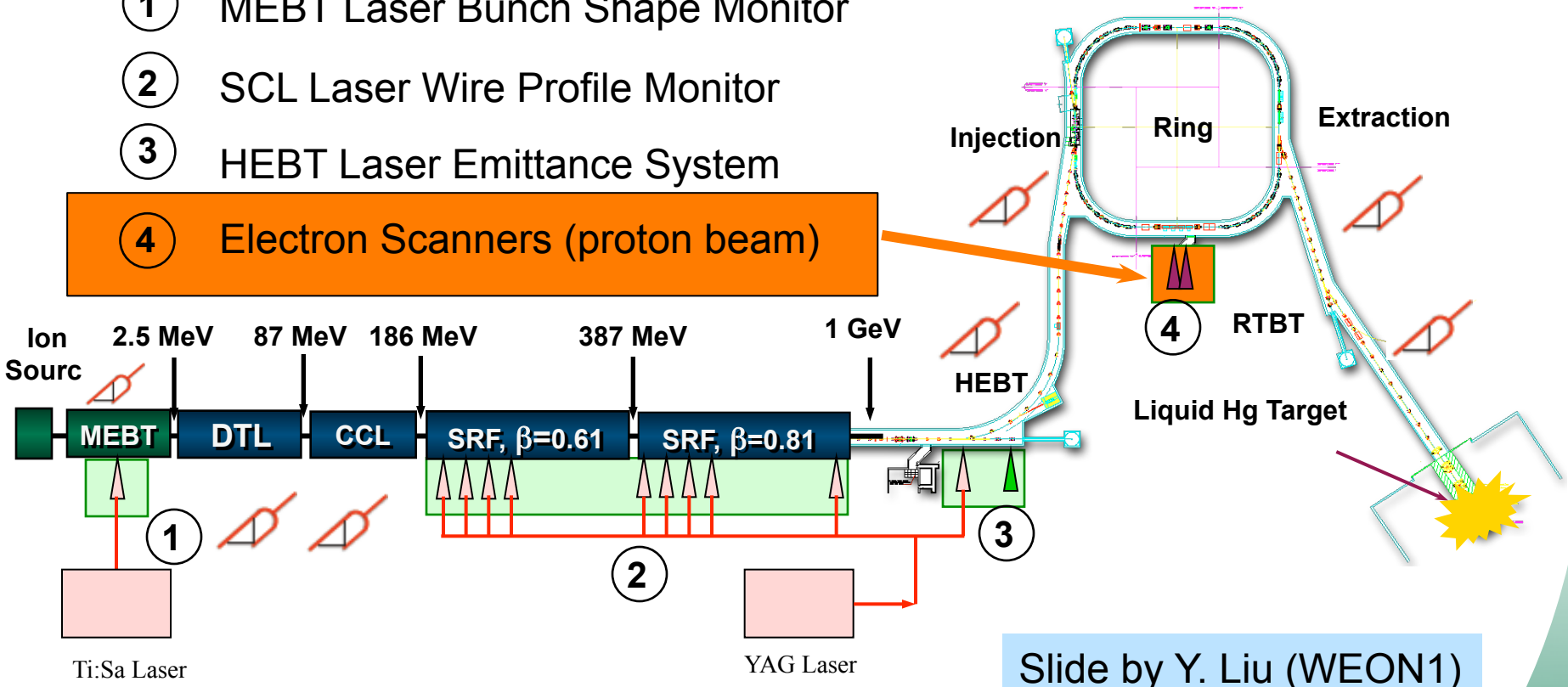
OAK RIDGE National Laboratory

Overview

- SNS Accelerator
- Electron scanner
  - Principle
  - Hardware
  - Software
- Results
  - Images
  - Analysis
  - Comparison
- Conclusion and Plans

Non-invasive Beam Profile Diagnostics at SNS

1. MEBT Laser Bunch Shape Monitor
2. SCL Laser Wire Profile Monitor
3. HEBT Laser Emittance System
4. Electron Scanners (proton beam)



Slide by Y. Liu (WEON1)

Wire Scanners

Throughout linac and transfer lines but not in super-conducting sections or in the ring

Electron Scanner Principle

Look at the deflected projection by a charged beam of a tilted sheet of electrons onto a screen

- 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

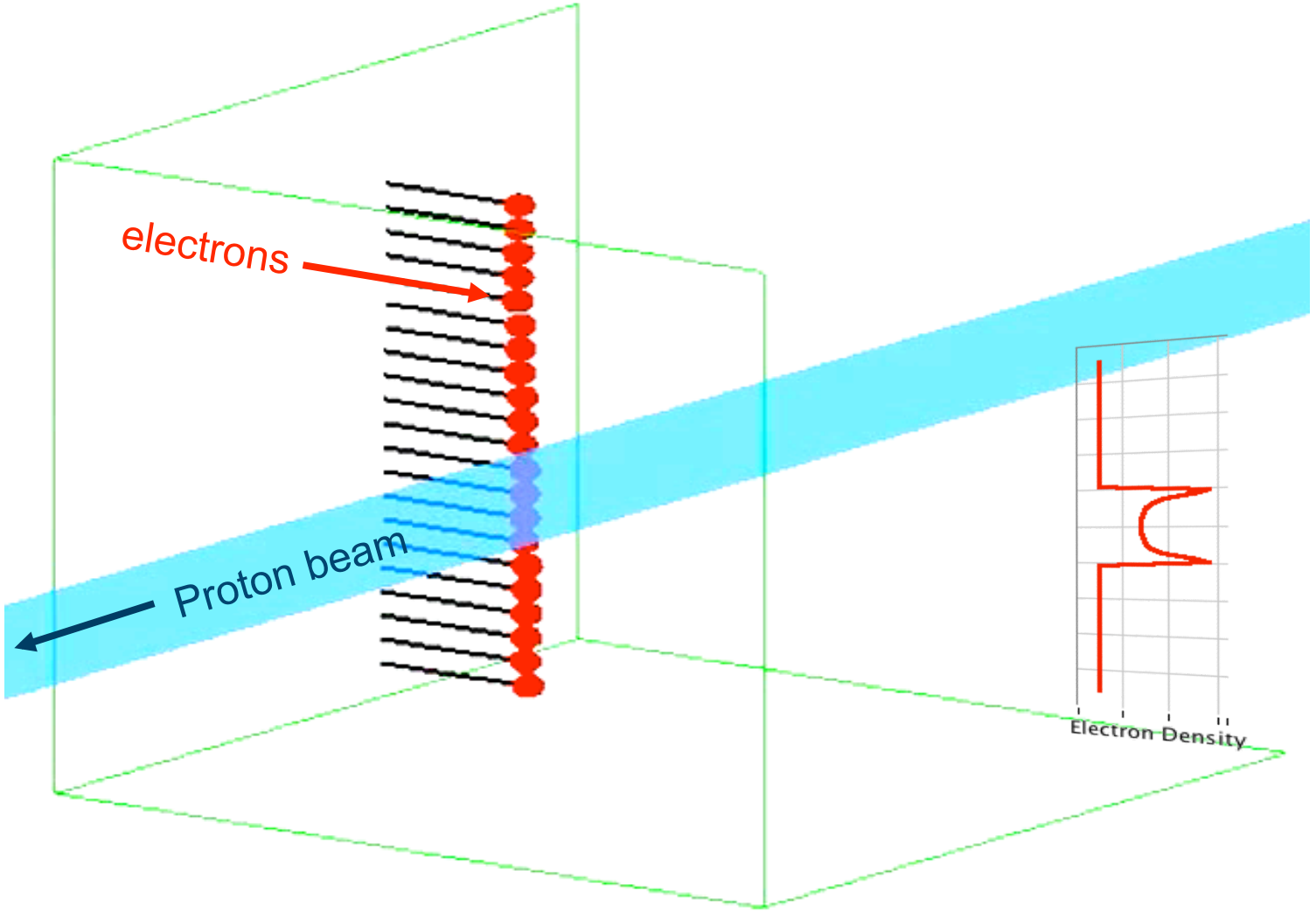
Imperfections estimated at 5-10%.

[1] Paul D. Goldan "Collisionless Sheath---An Experimental Investigation", Phys. Fluids 13, 1055 (1970), DOI:10.1063/1.1693008

[2] Tsyganov, E.; et al A., "Electron beam emittance monitor for the SSC," *Particle Accelerator Conference, 1993., Proceedings of the 1993* , vol., no., pp.2489-2491 vol.3, 17-20 May 1993

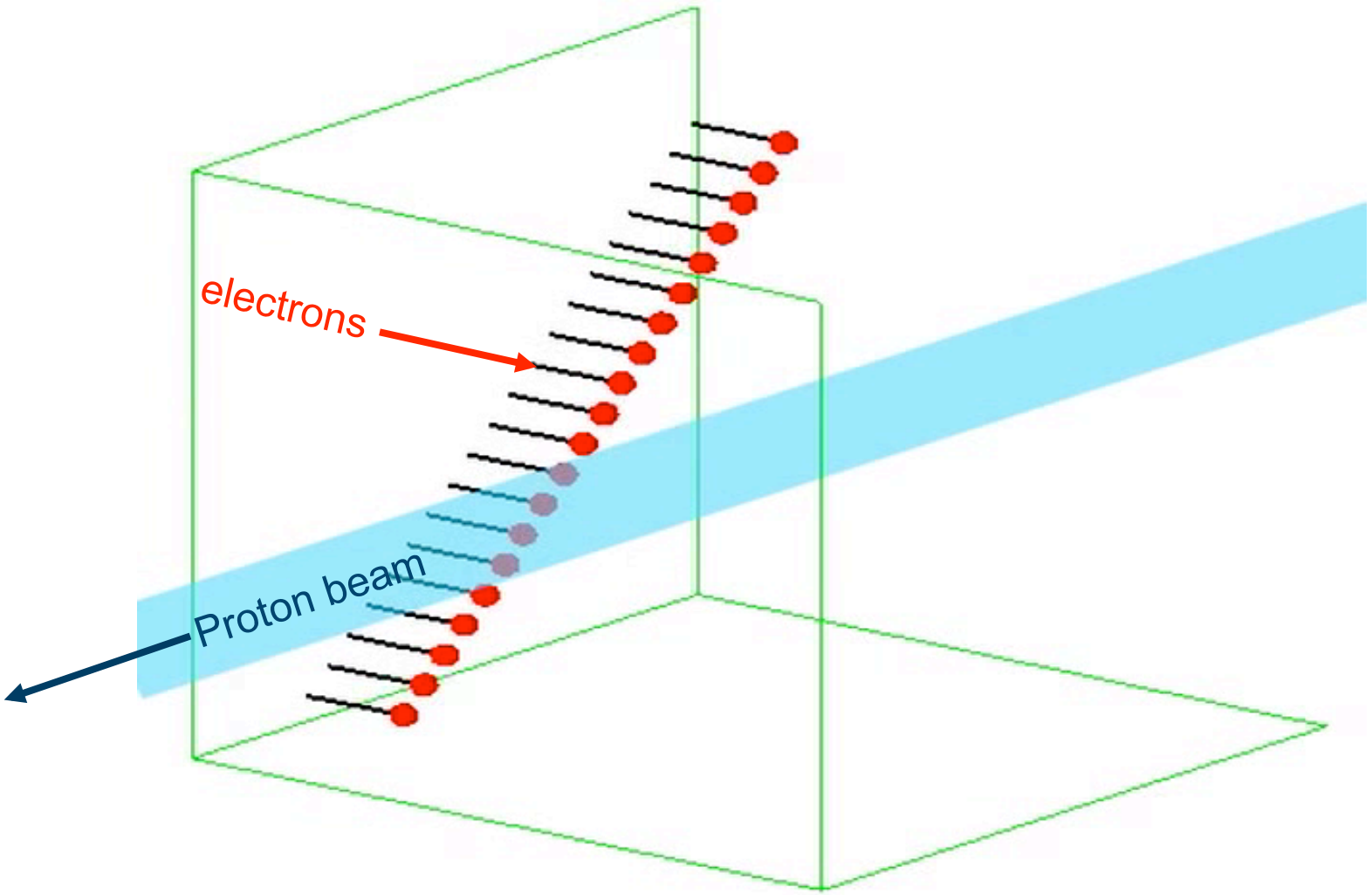
[3] Aleksandrov, et al "Feasibility Study of Using an Electron Beam for Profile Measurements in the SNS Accumulator Ring," Particle Accelerator Conference, 2005. PAC 2005. Proceedings of the , vol., no., pp. 2586-2588, 16-20 May 2005

Simulation of electron paths



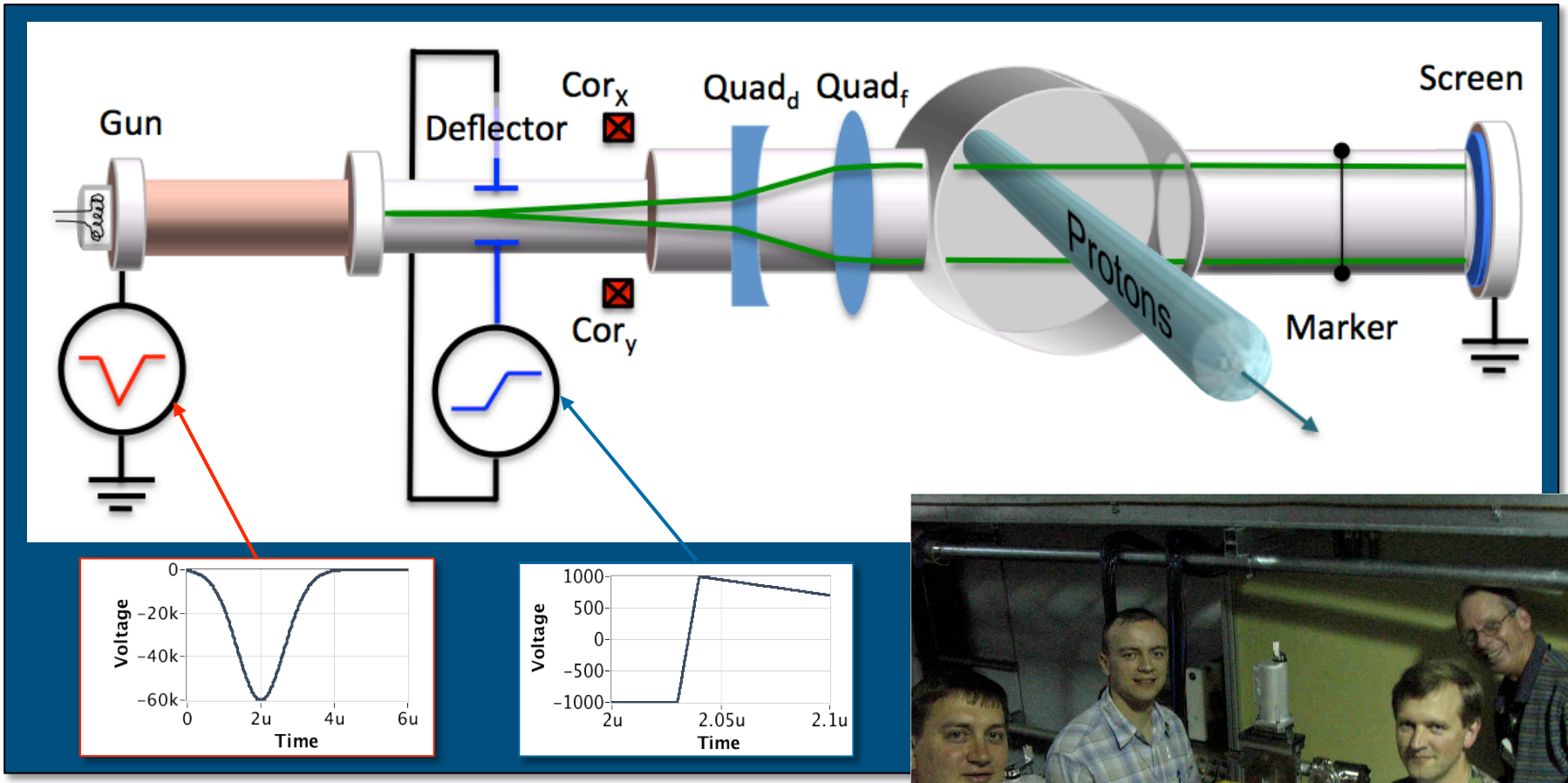
Deflection of electrons by proton beam

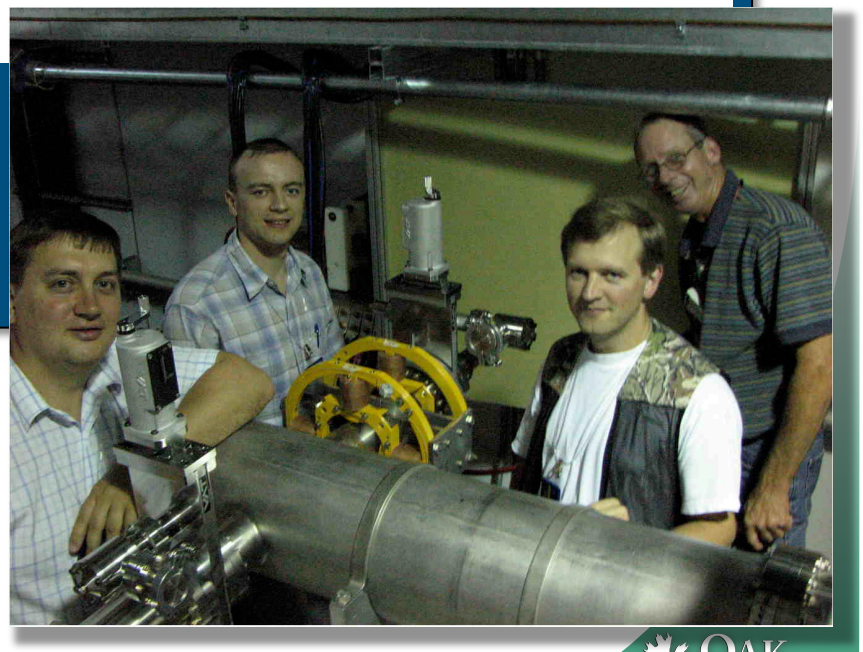
Simulation of electron paths



Deflection of electrons by proton beam

Electron Scanner Layout

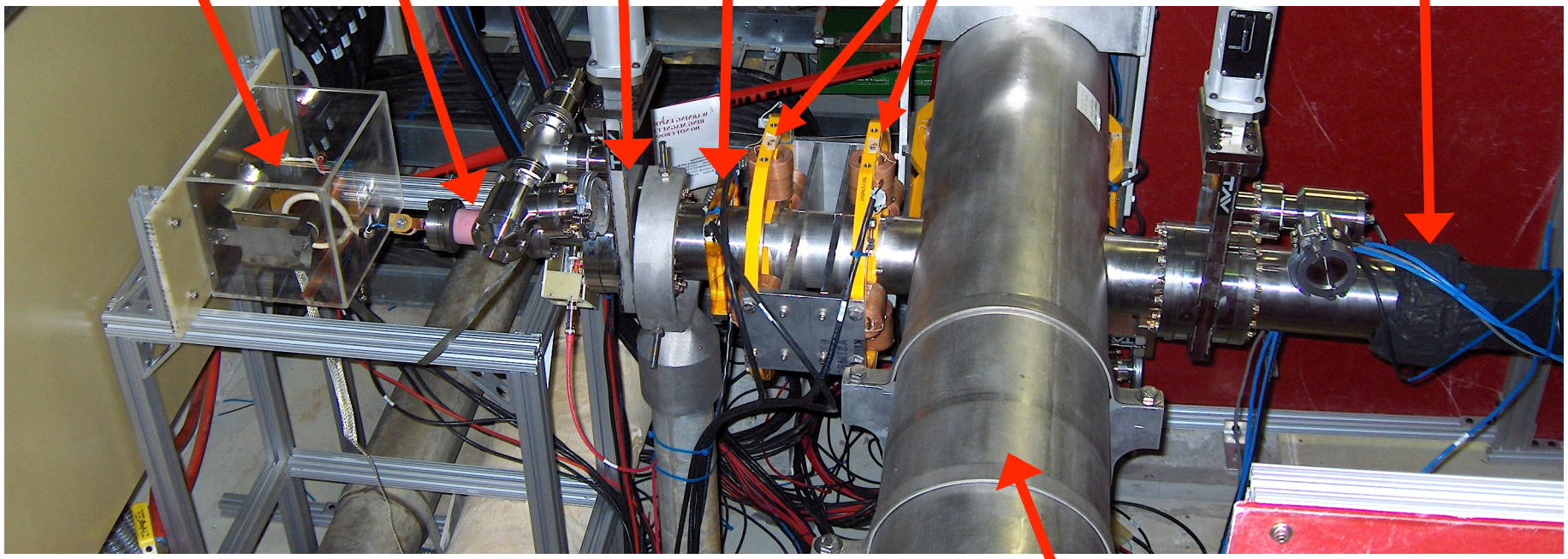




Electron Scanner hardware by Budker Institute of Nuclear Physics: Dmitriy Malyutin, Sasha Starostenko, Sasha Tsyganov

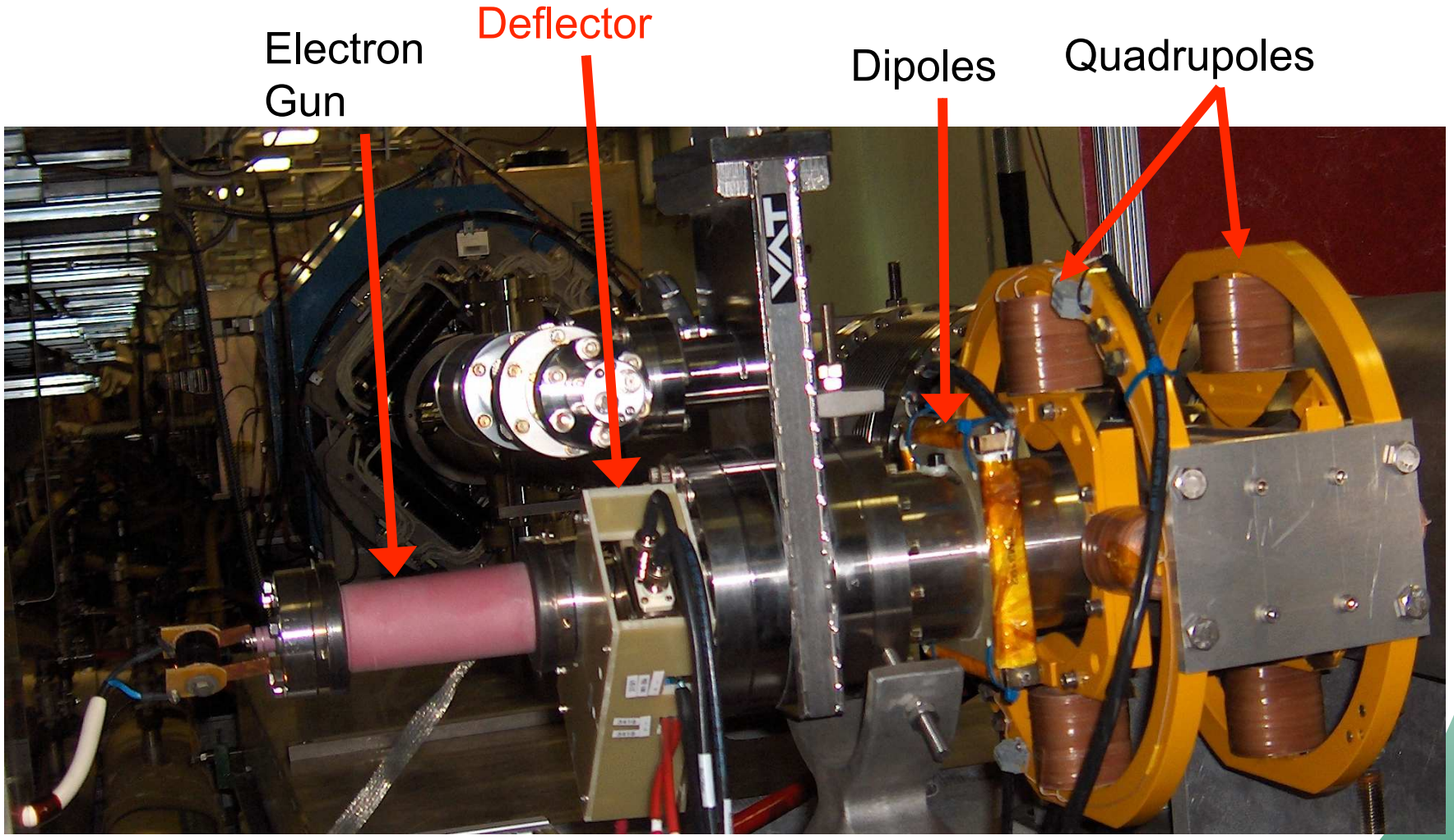
Joint design by BINP and SNS.

Hardware: Electron Scanner



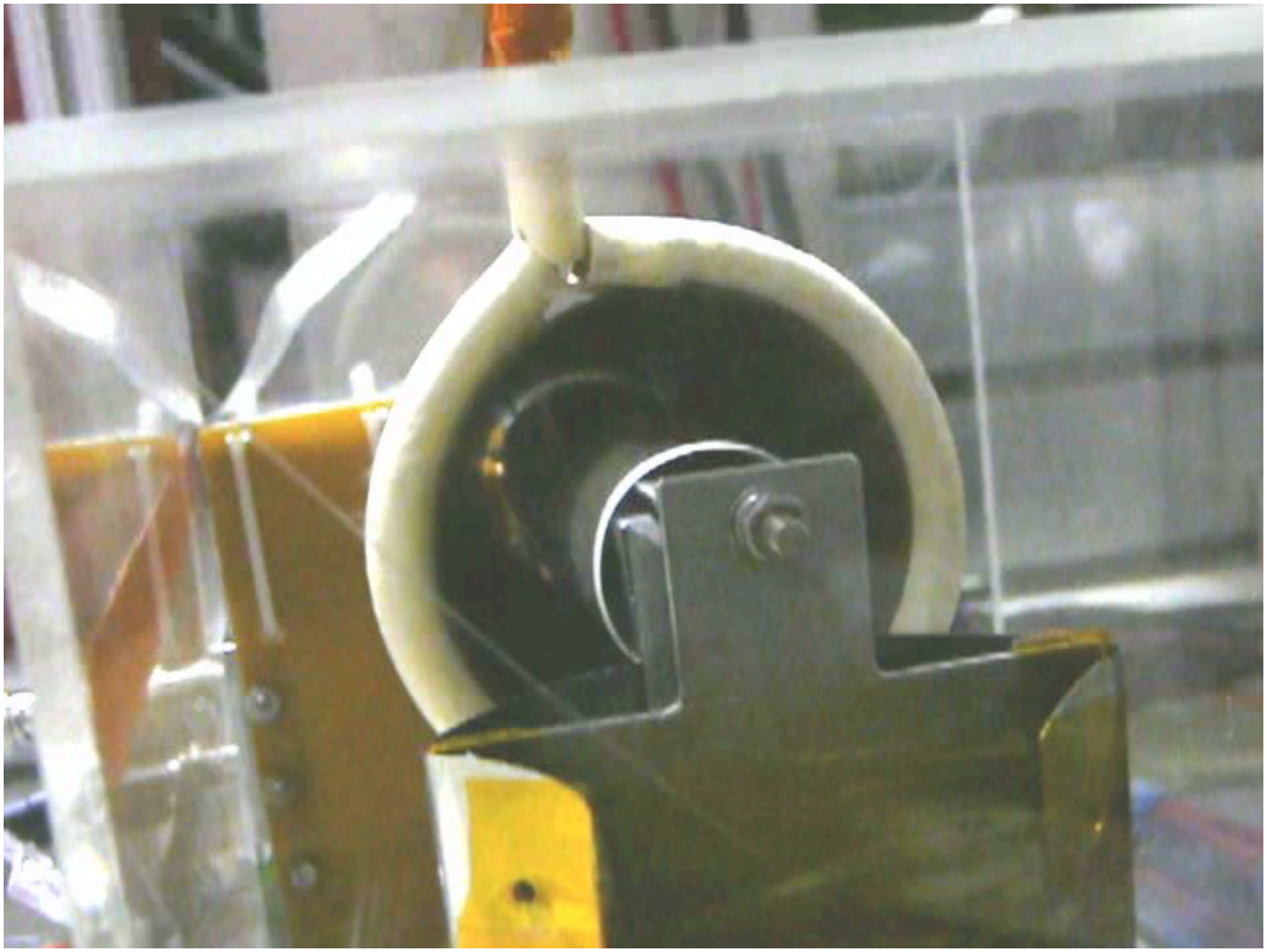
Electron scanner now covered with magnetic shield

Hardware: Electron Scanner



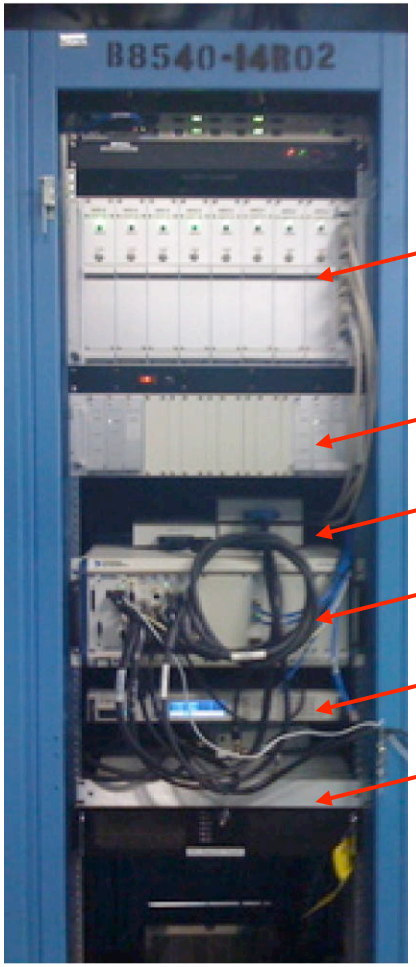
Electron Scanner parts

Hardware: Transformer



Arcing of HV Transformer

Hardware: Service Building Electronics



Magnet power supplies

HV power supplies

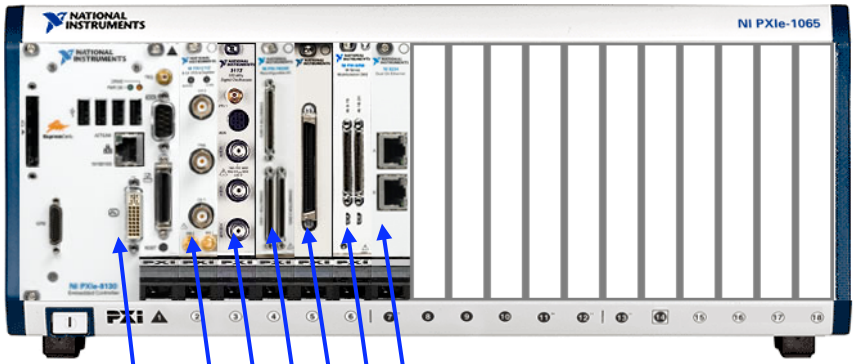
Breakout boxes

PXI: Acquisition and Control

Camera power supply

Trigger breakout

PXI crate with ADCs and DACs



GigE Vision

PS ADC readbacks

PS DAC settings

Delay generator (upgraded)

HV digitizer

Deflector digitizer

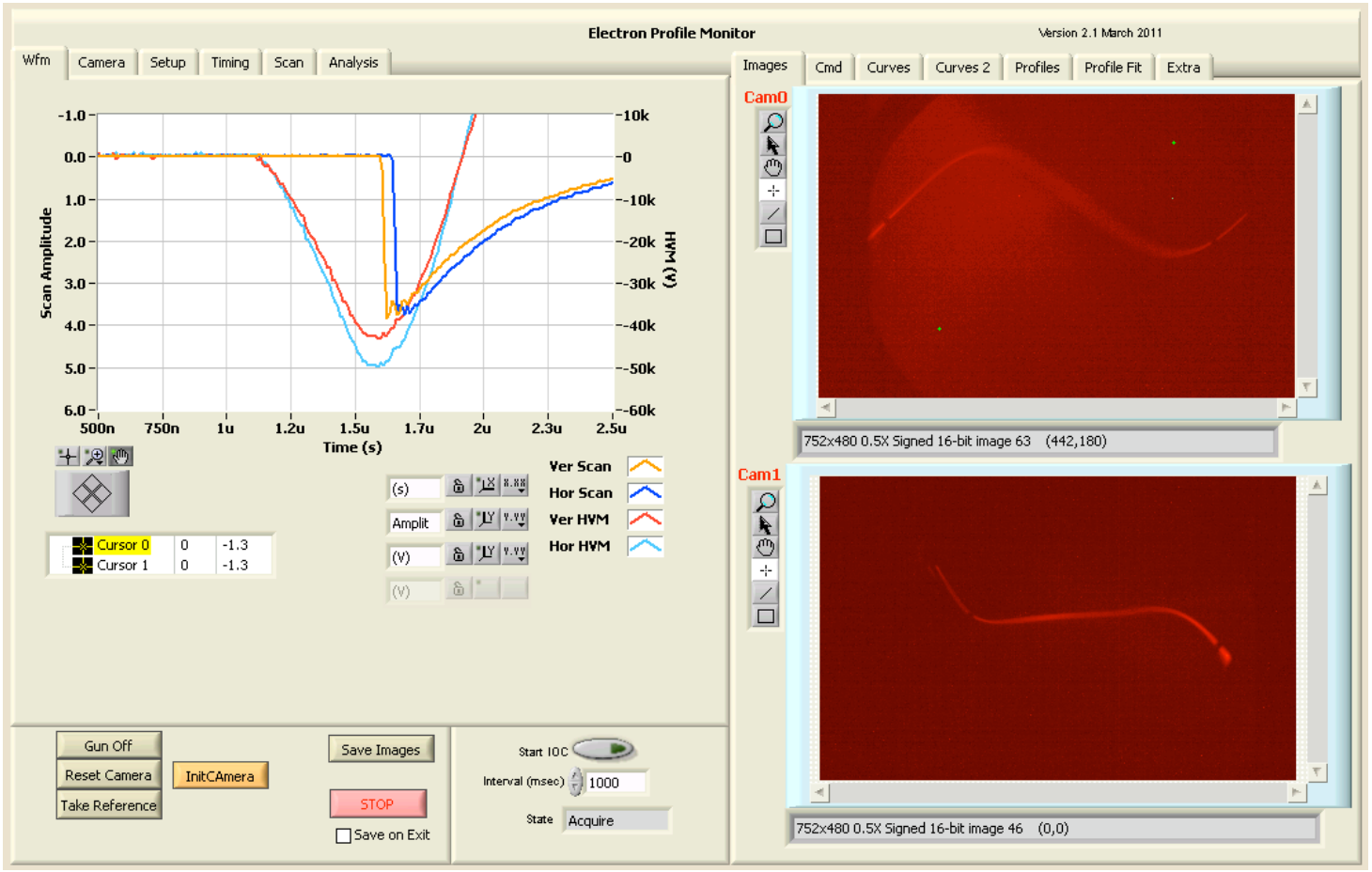
CPU

Electron scanner Rack in the Service Building

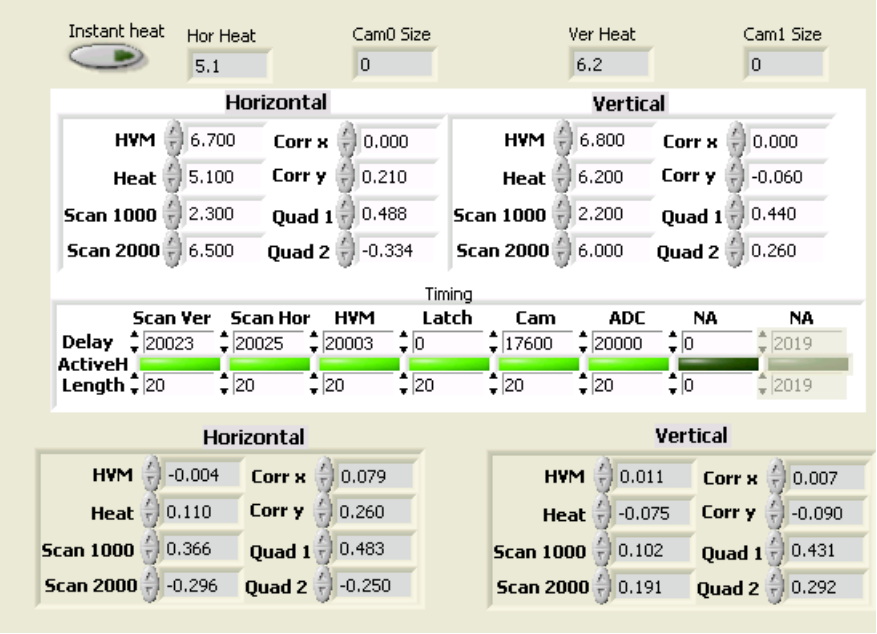
Software

LabVIEW Application

- Control, acquire, and calculate the profiles
- Interface to EPICS



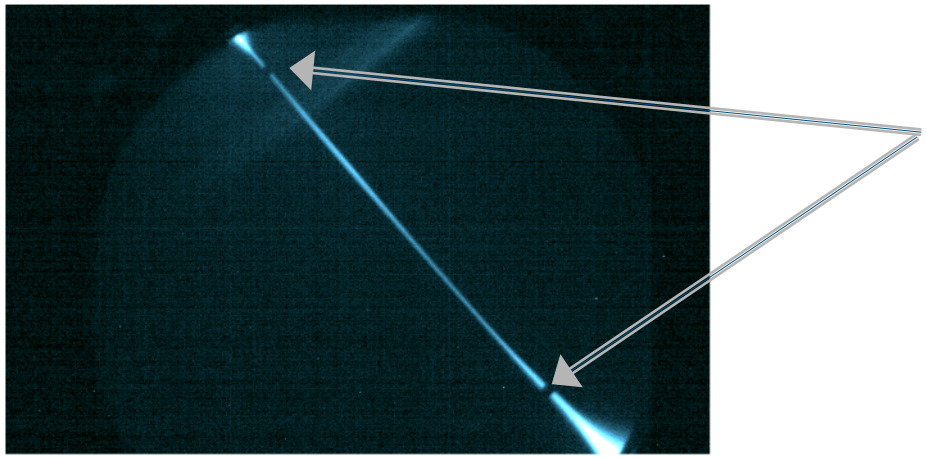
Software



Control of accelerating voltages, cathode current, deflector voltages, magnets and timing.

Sequencer to support scanning through multiple bunches and adjustments while scanning

Images



No proton beam, vertical profile

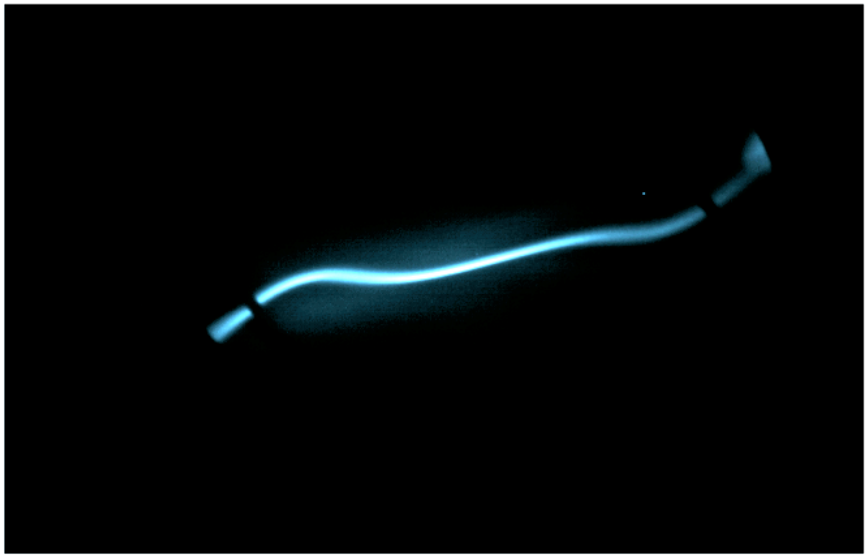


Image of horizontal curve

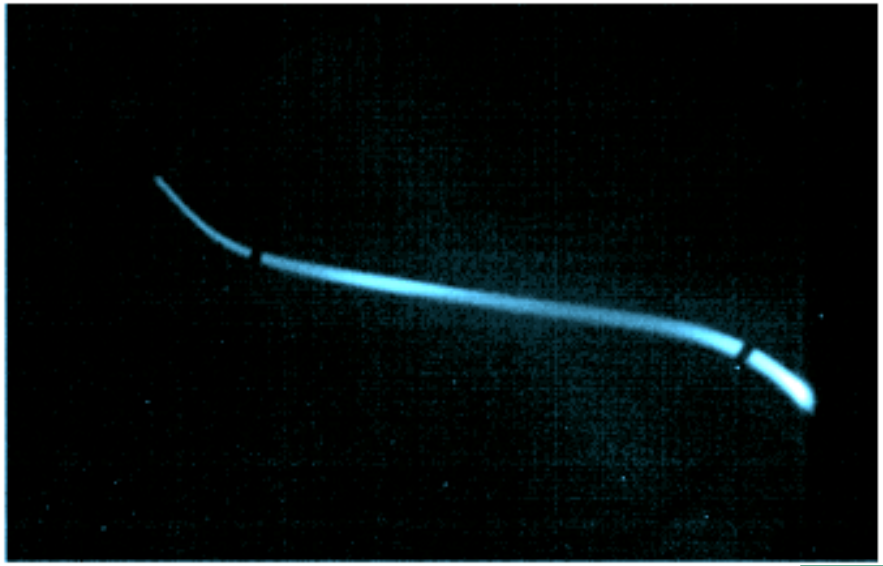
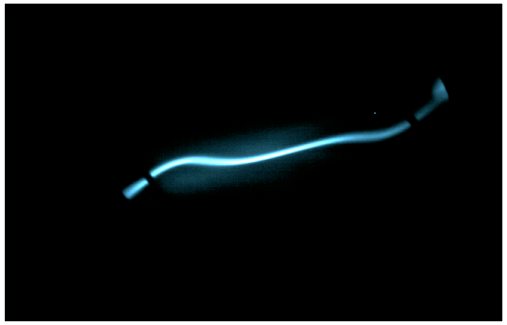


Image of vertical curve

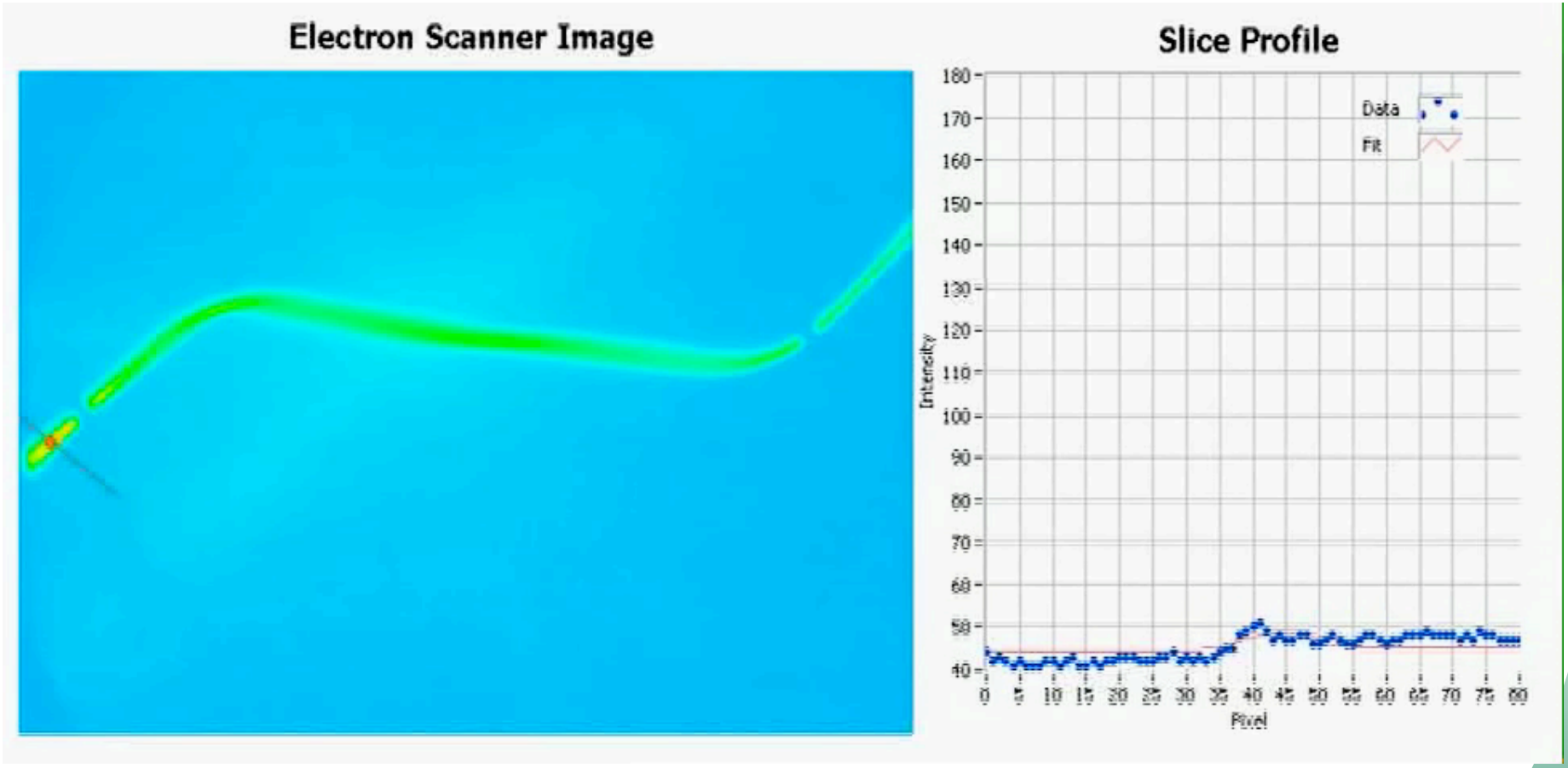
Analysis



Find peak in each column

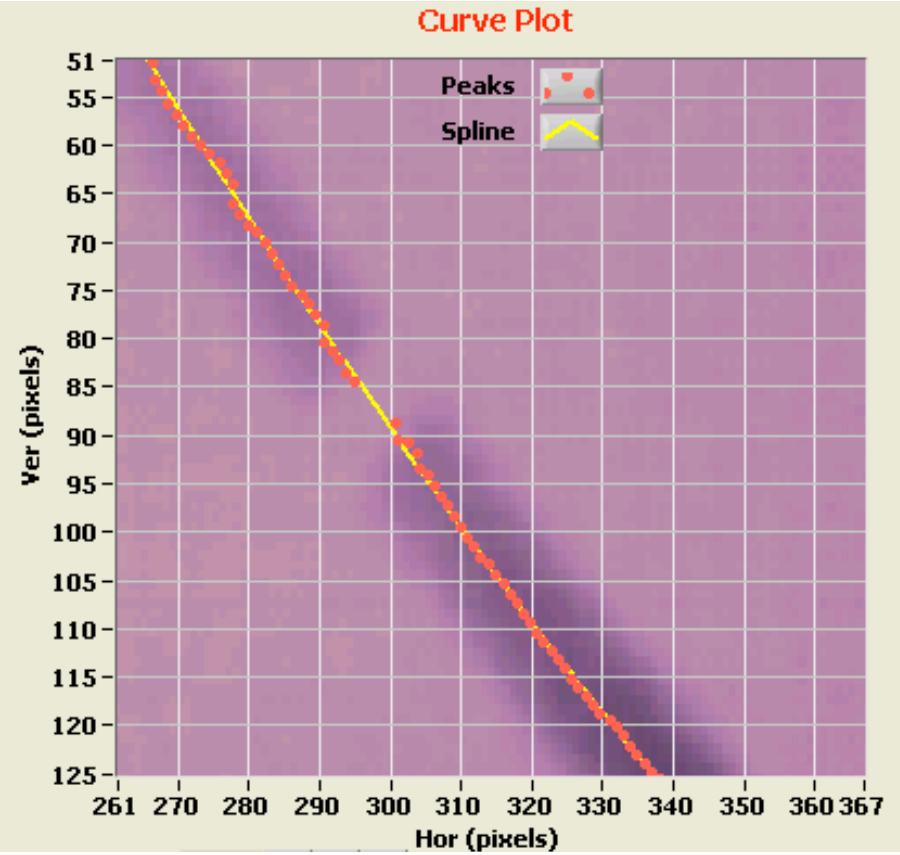
- Find the curve (x,y) points
- Fit a spline to these points
- Take the derivative of this spline -> profile
- Fit a model-based function to profile to remove imperfections
- Correct width to assumed angle of deflectors (20% smaller for horizontal, 20% larger for vertical)

Analysis: Finding the curve

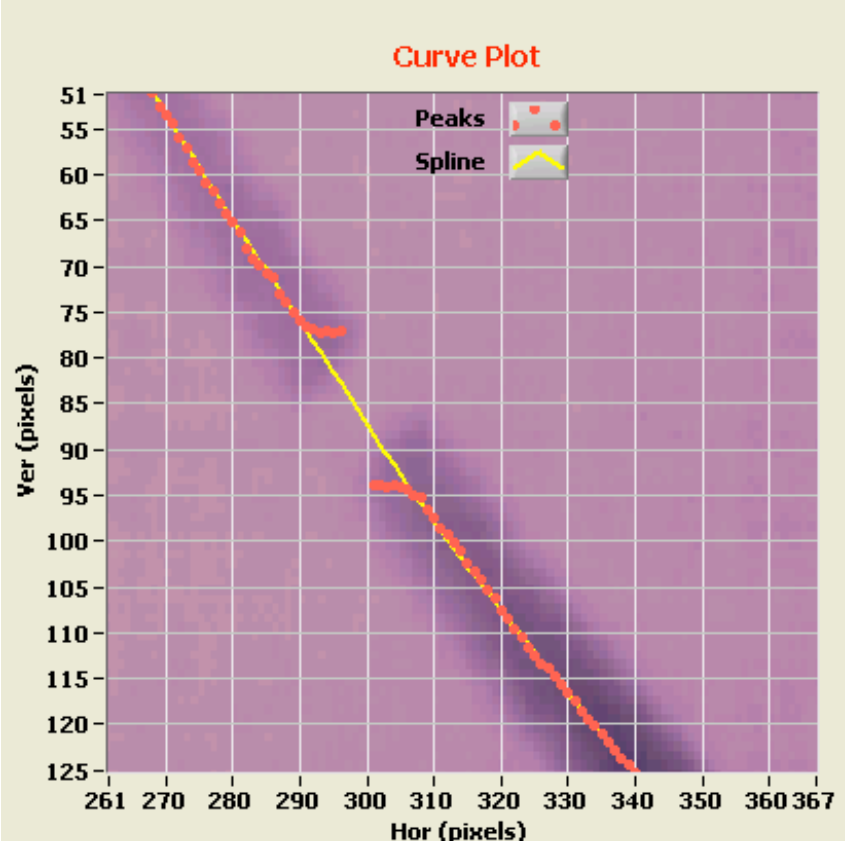


Slicing perpendicular to the curve

Analysis: Fitting a spline

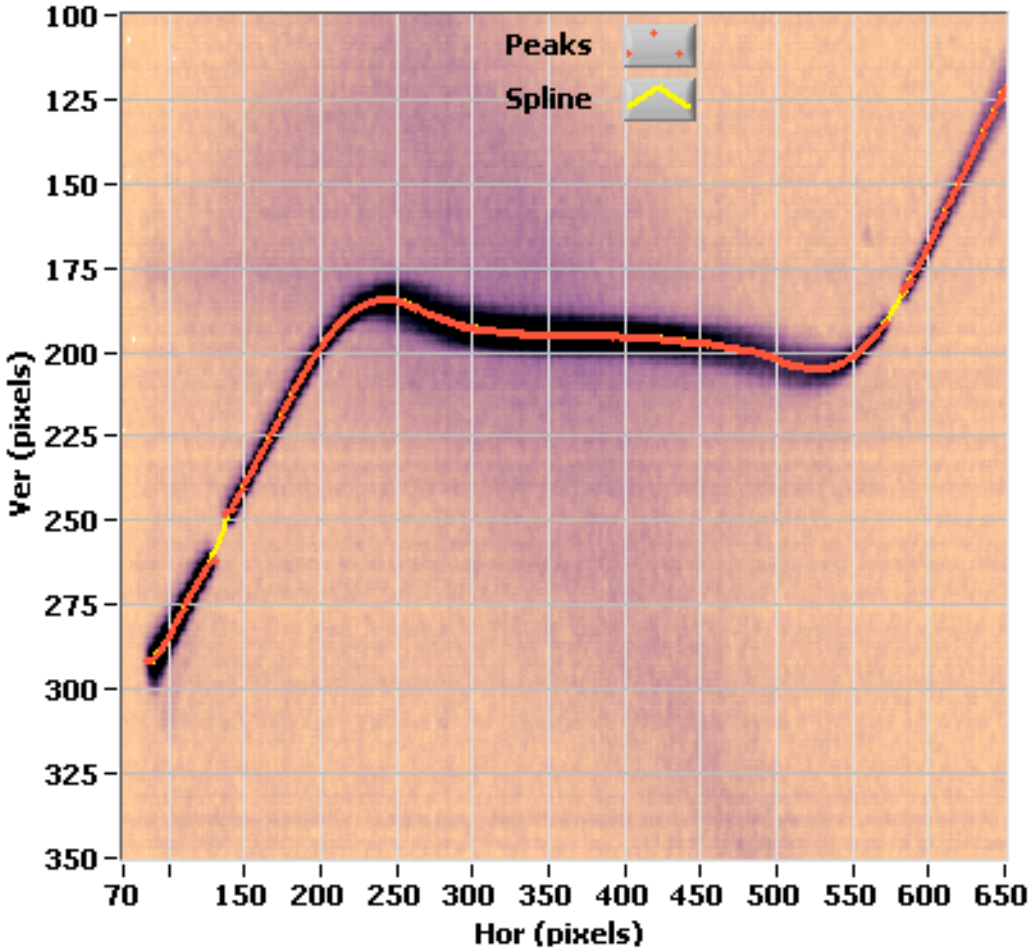


Slicing perpendicular to the curve



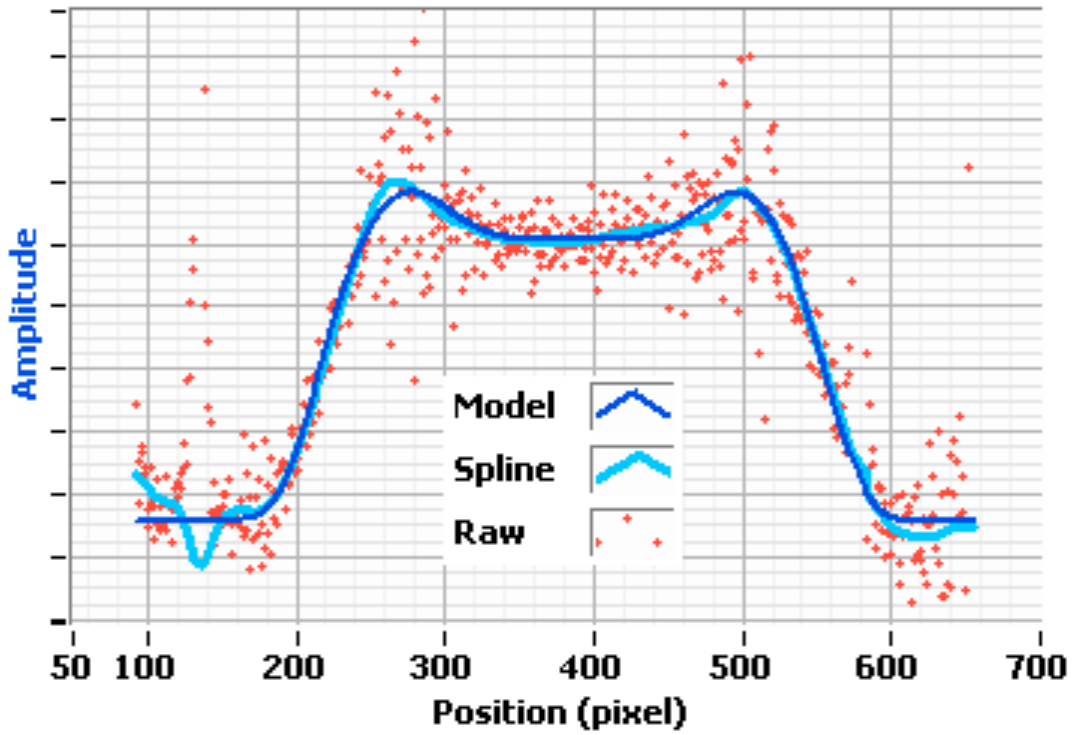
Slicing vertical to the image

Analysis: Fitting a spline



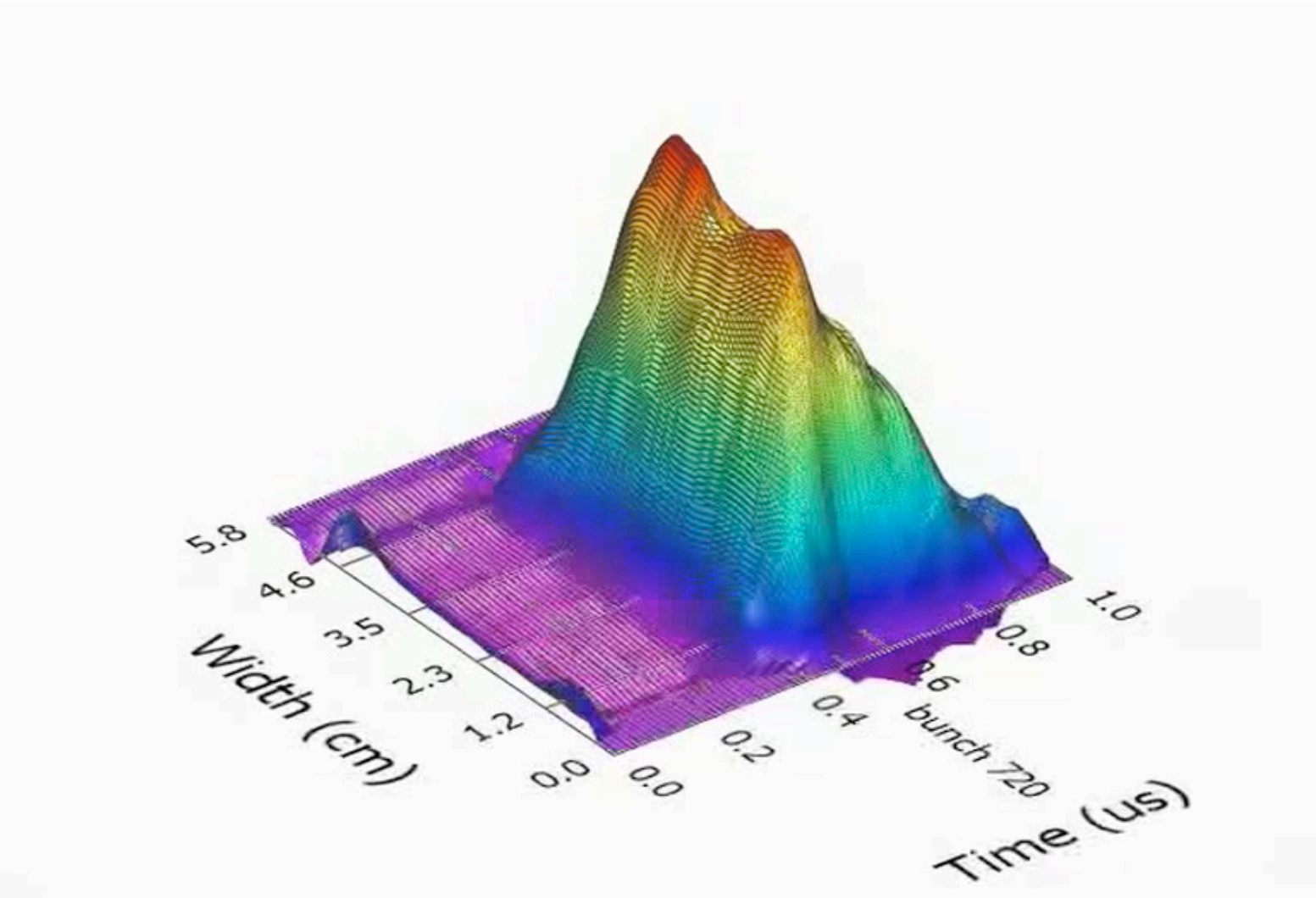
Overlay of camera image with peaks and spline fit

Analysis: Take derivative



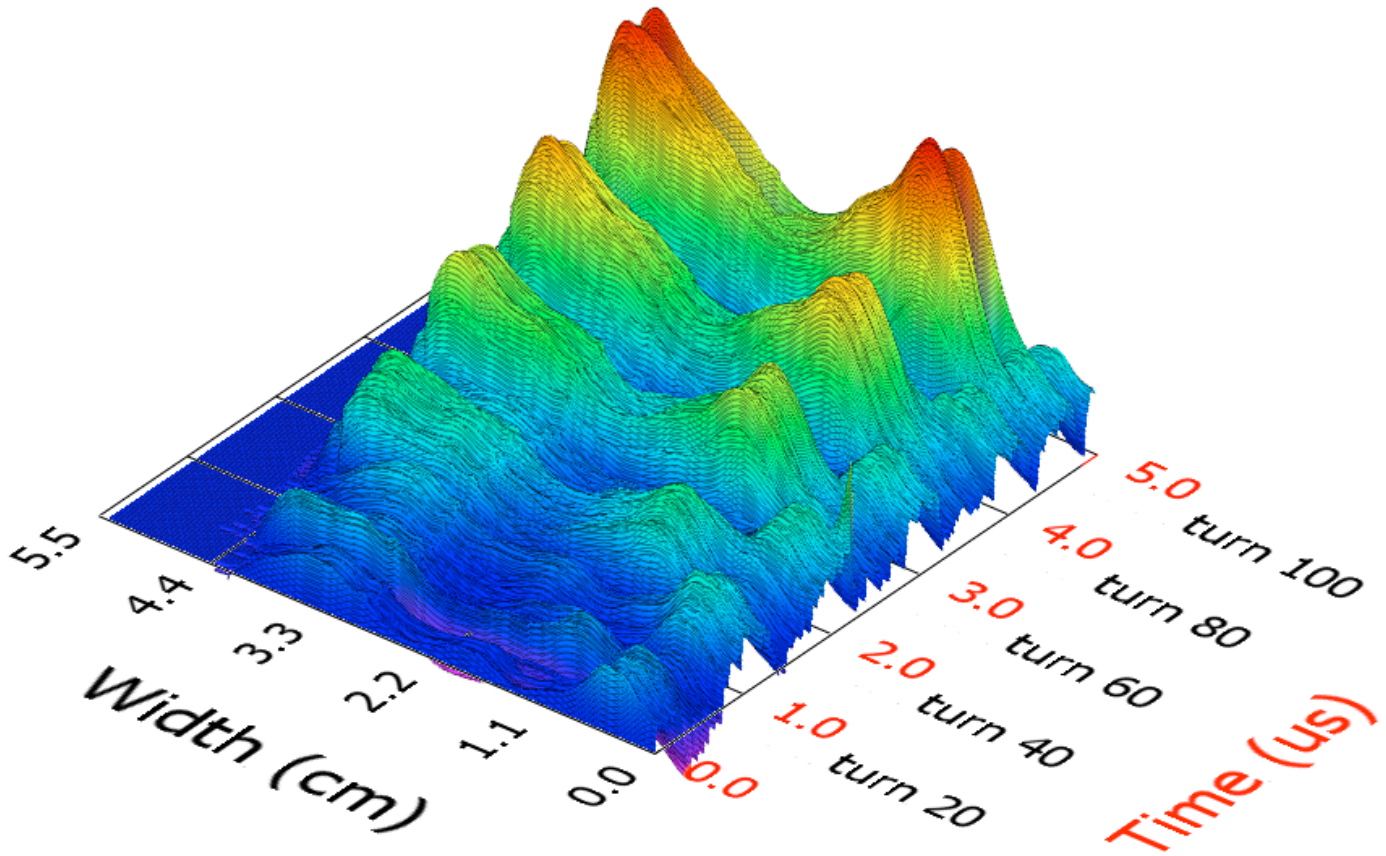
Take derivative of peaks
Take derivative of spline fitted to the peaks
Take derivative of spline fitted to the peaks and fit to model-based function

Results



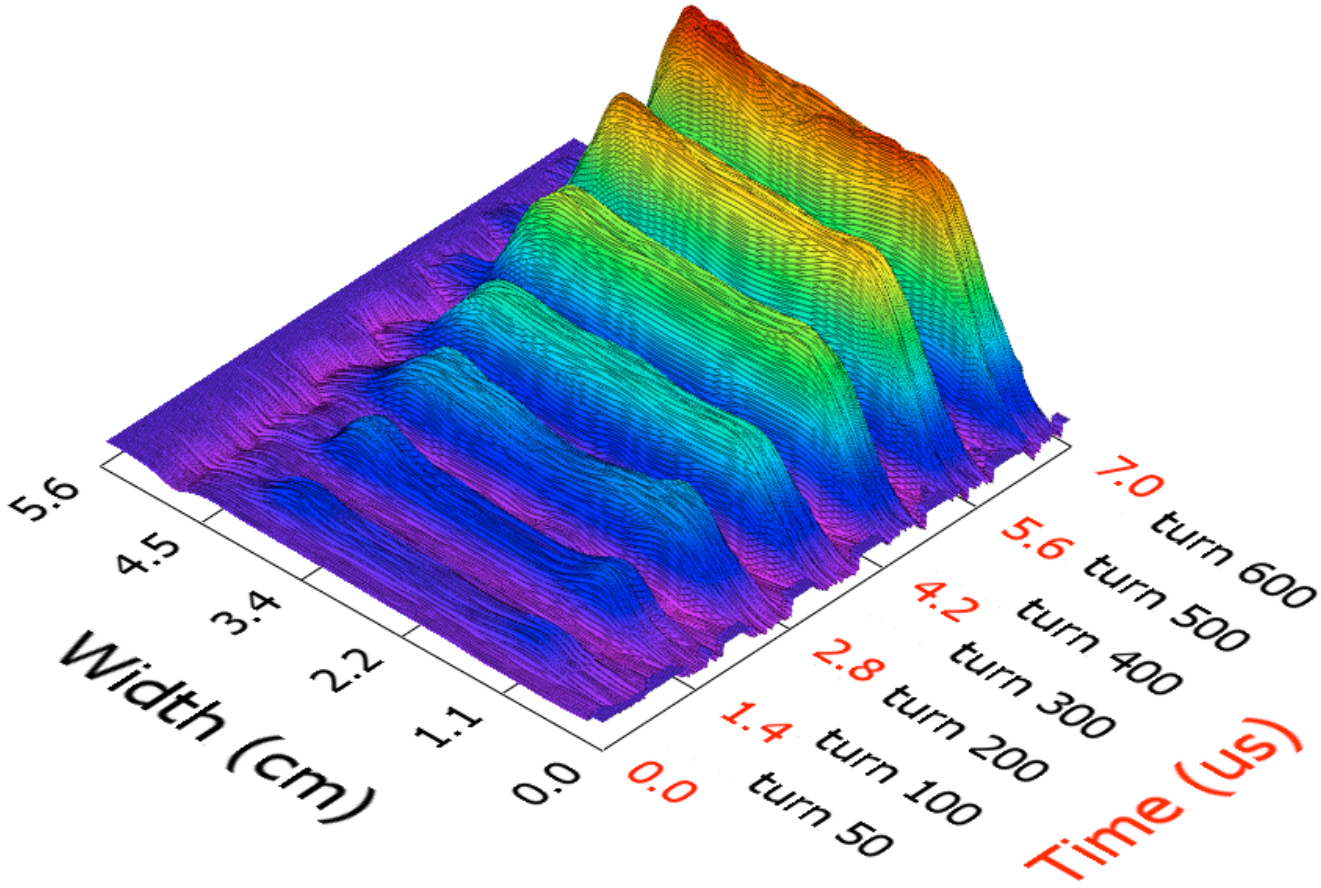
3D plot of Turn 720 at ~11uC

Data



Vertical Profiles (spline derivative)

Data

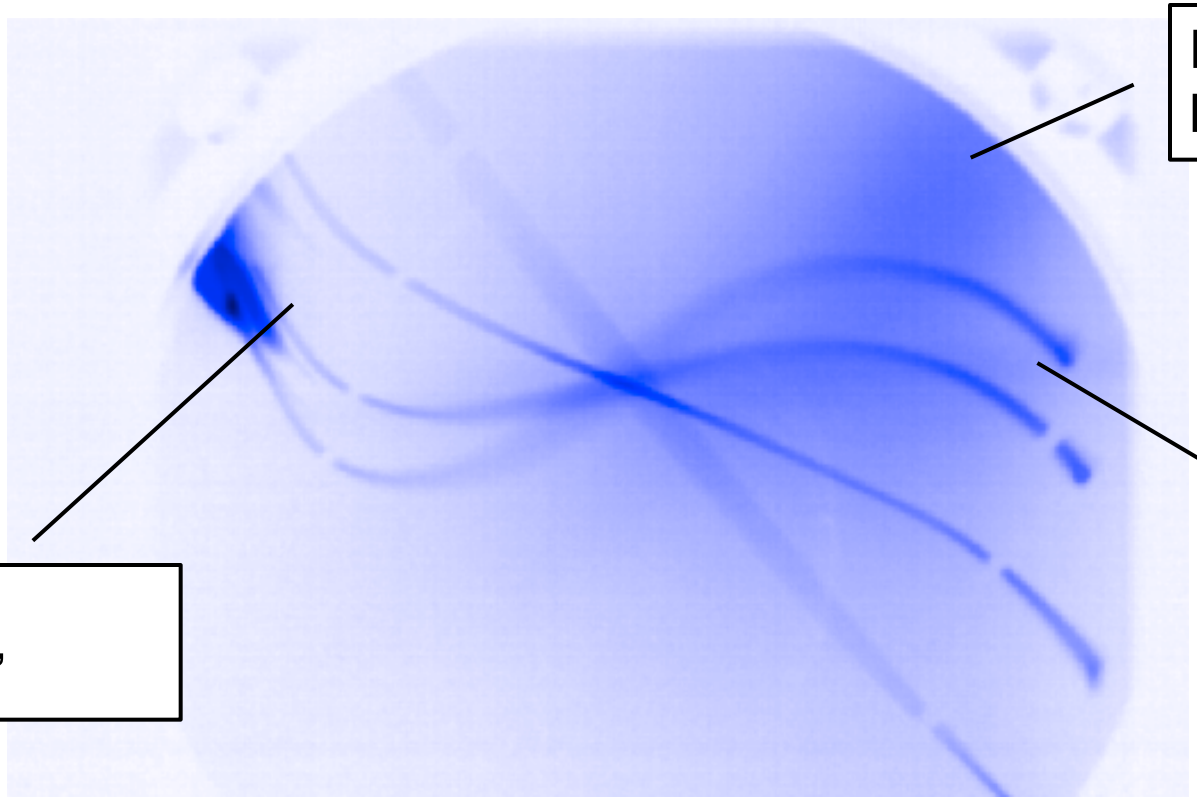


Horizontal Profiles (spline derivative)

Model-based Function

Goals:

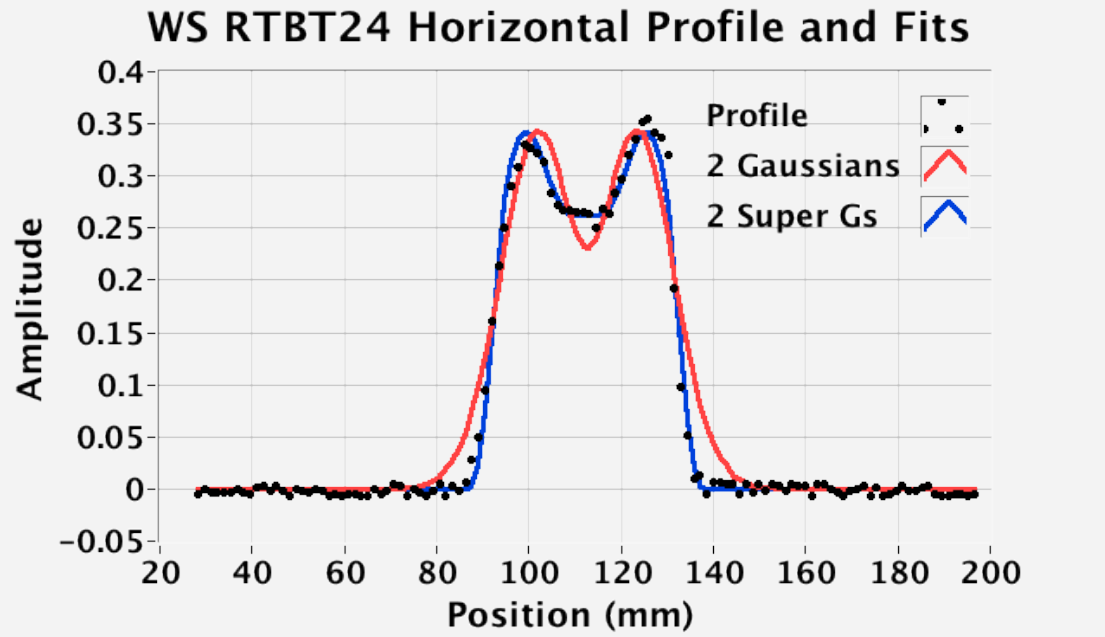
- Reduce noise
- Extrapolate the tails
- Use integral version of model to fit directly to curve



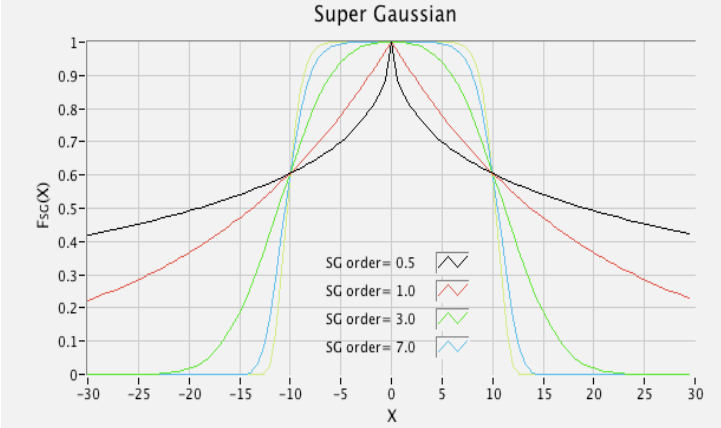
Superimposed images of ~19μC beam

Model-based function

The injection painting and space charge effects are the main contributors to the transverse profile in the ring and transfer line to target.



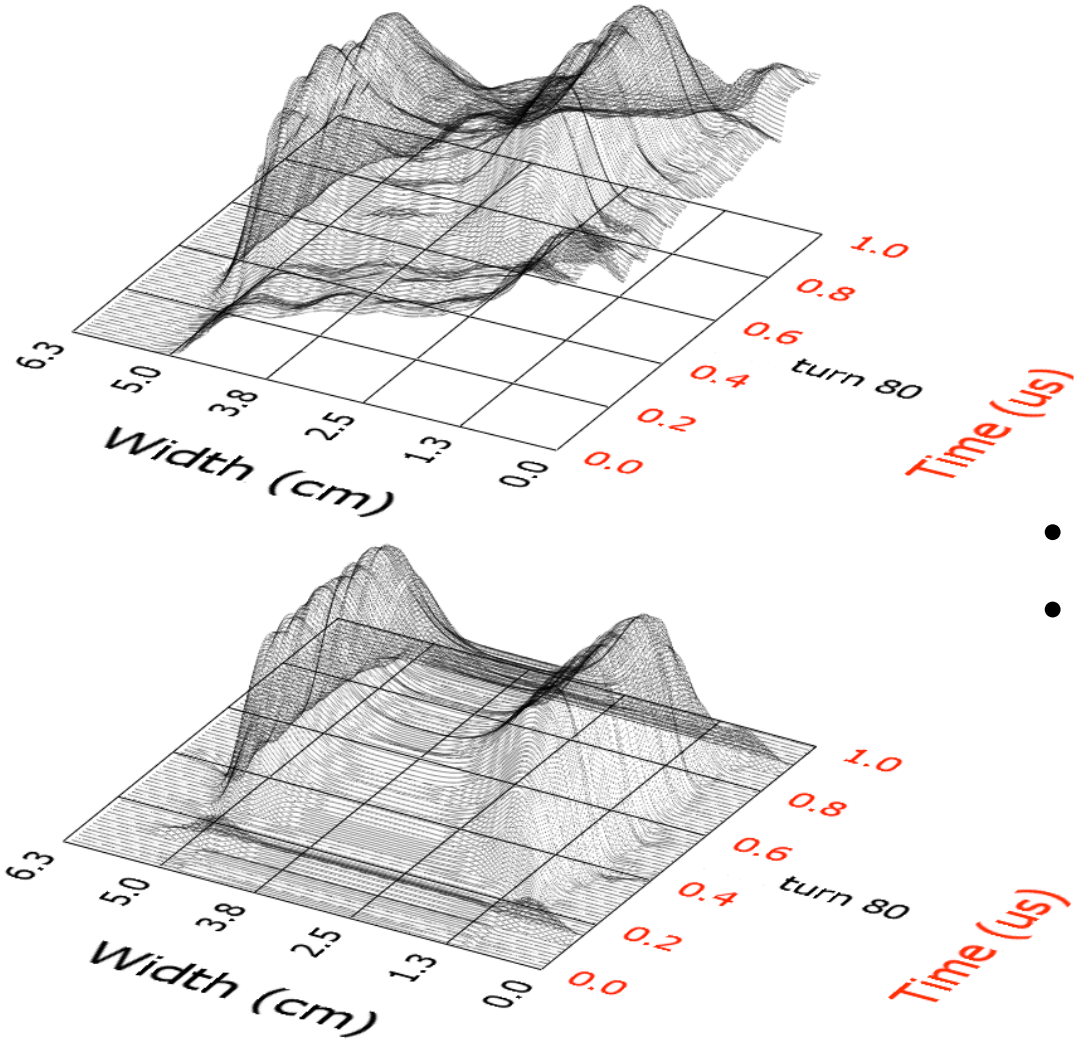
RTBT WS24 Profile: Double Super-Gaussian



Super-Gaussian

$$f_{DSG}(x) = a_1 \cdot \exp\left(-\left(\frac{|x-\mu|}{\sigma_1}\right)^{n_1}\right) + a_2 \cdot \exp\left(-\left(\frac{|x-\mu|}{\sigma_2}\right)^{n_2}\right) + sl \cdot x + o$$

Results: Model-based function

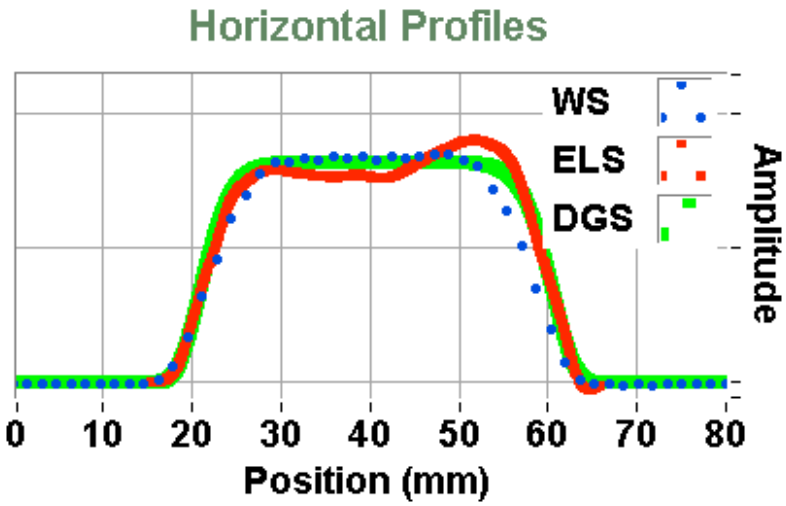


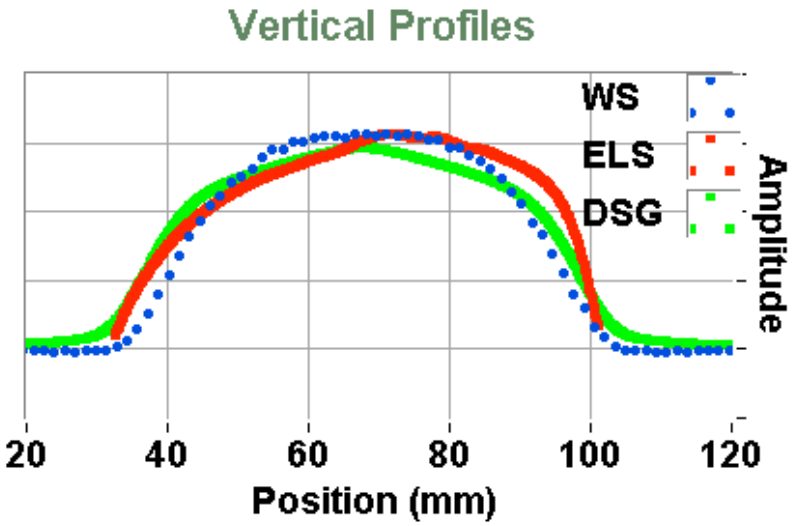
Work in progress
- Fitting speed
- Model must be right

- Take out the slope
- Extrapolate tails

Comparison

	FWHM Hor (mm)	FWHM Ver (mm)
Wire Scanner	37.6	51.5
ELS Spline	37.8	56.6
ELS Model	38.8	57.8
Difference	~3%	~12%





Previous Study:

- Bumping the center of the beam and comparing BPM measurements with ES profile movements agrees to within 20%

ES Profile from all slices of bunch and slope and baseline corrections

Conclusions and Plans

Provides non-intrusive measurement of the transverse and longitudinal profile of the proton beam almost anywhere in the accumulation cycle.

- Open chamber to measure deflector angles
  - Adjust quads if necessary
  - Tilt deflectors even more to increase aperture
- Upgrade HV transformers to 75kV
- Upgrade cameras to increase sensitivity to lower cathode heating to extinguish blobs
- Electron Scanner successful, considering tomography