Electron-beam scanner experience at ORNL

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DITANET

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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
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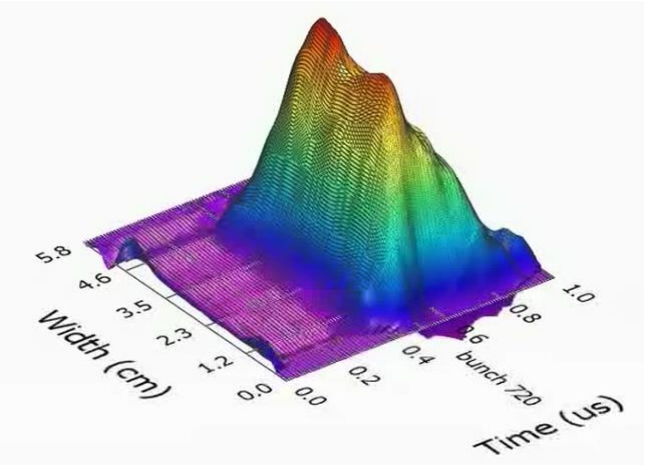
Outline

- Introduction to the accelerator of the Spallation Neutron Source (SNS)
- Electron-beam Scanner
  - Method
  - Hardware
  - Data Analysis
  - Results
  - Challenges
  - Ring Beam Study



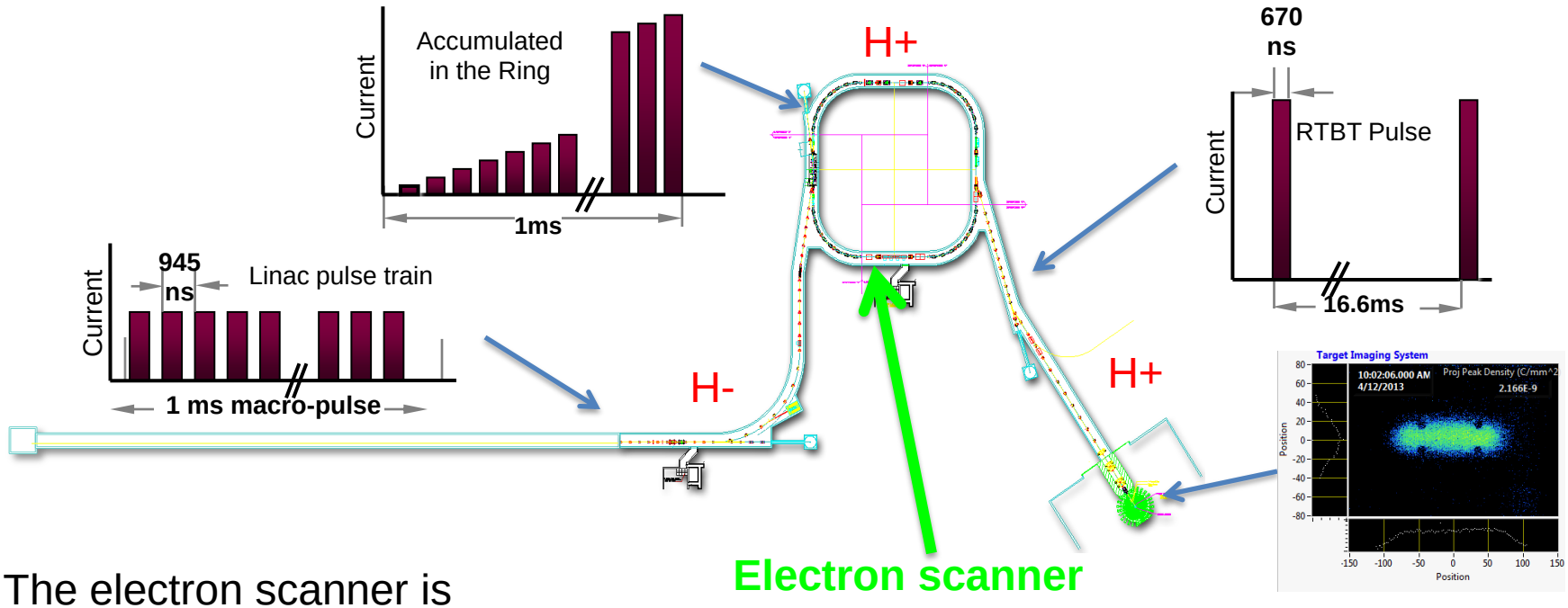
Horizontal profile of turn 720 at ~11uC

Introduction

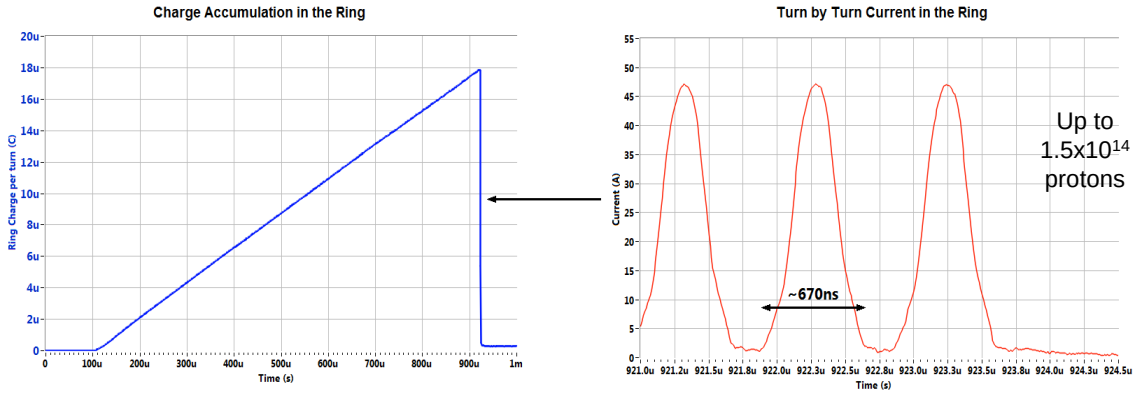
Spallation Neutron Source at Oak Ridge National Laboratory:

- $1.4B facility using a 1 GeV proton up to 1.4MW of beam on mercury target to generate pulsed neutrons (1.5×10^{14} protons per pulse)
- Built by a collaboration of five national laboratories
- Neutron scattering to study materials

Spallation Neutron Source Accelerator

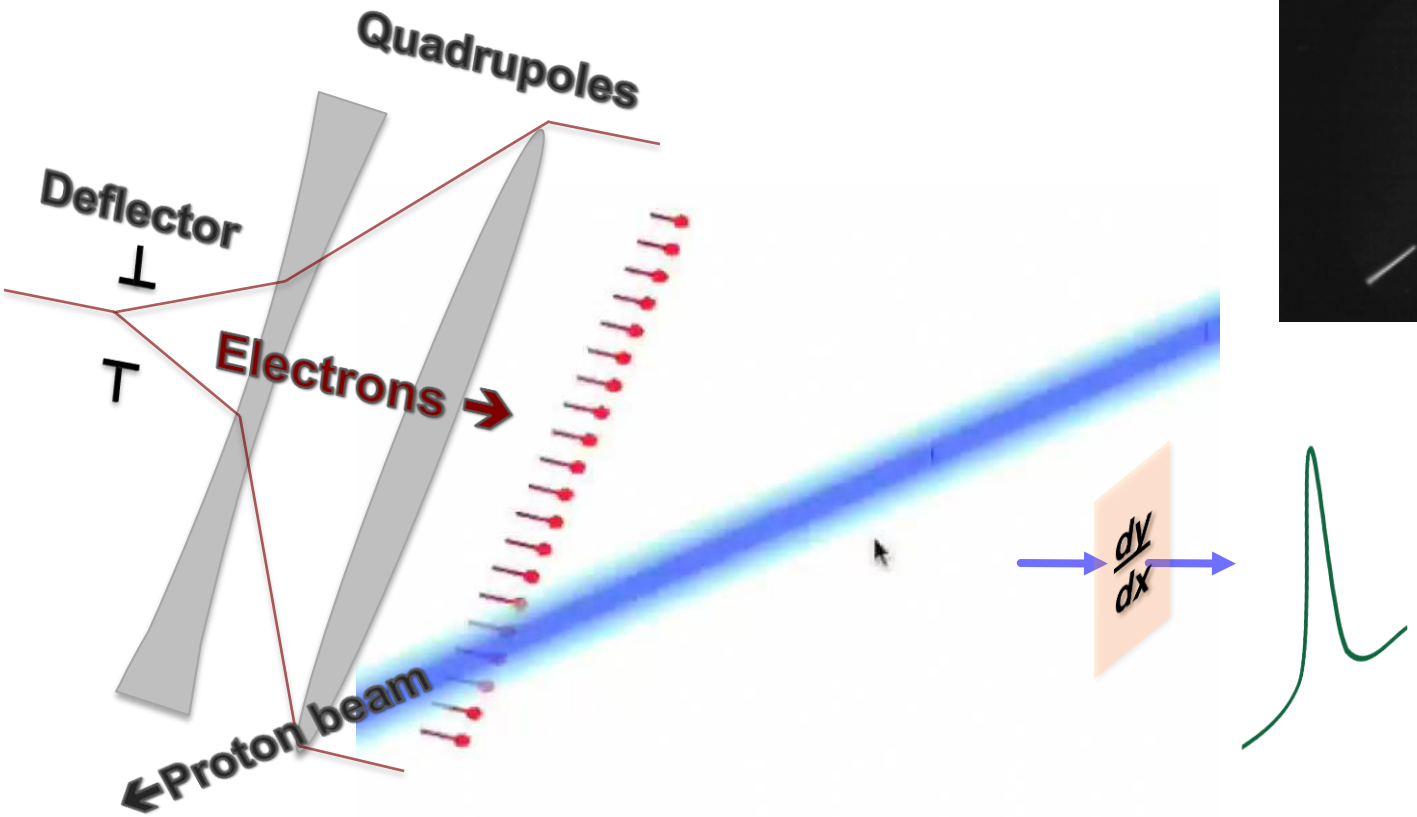


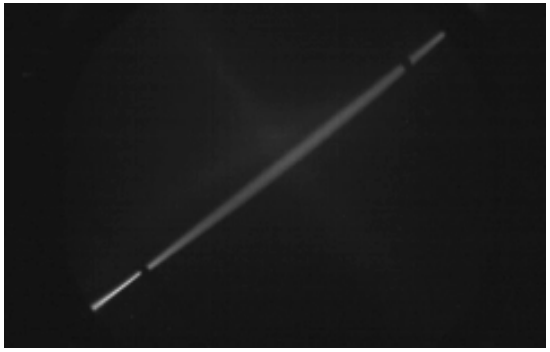
The electron scanner is the only transverse measurement in the ring. Downstream are wire scanners and one harp in the RTBT, and the target imaging system.



The bunches in the SNS Accumulator are ~670 ns long!

Electron-beam Scanner Method





Multiple scans

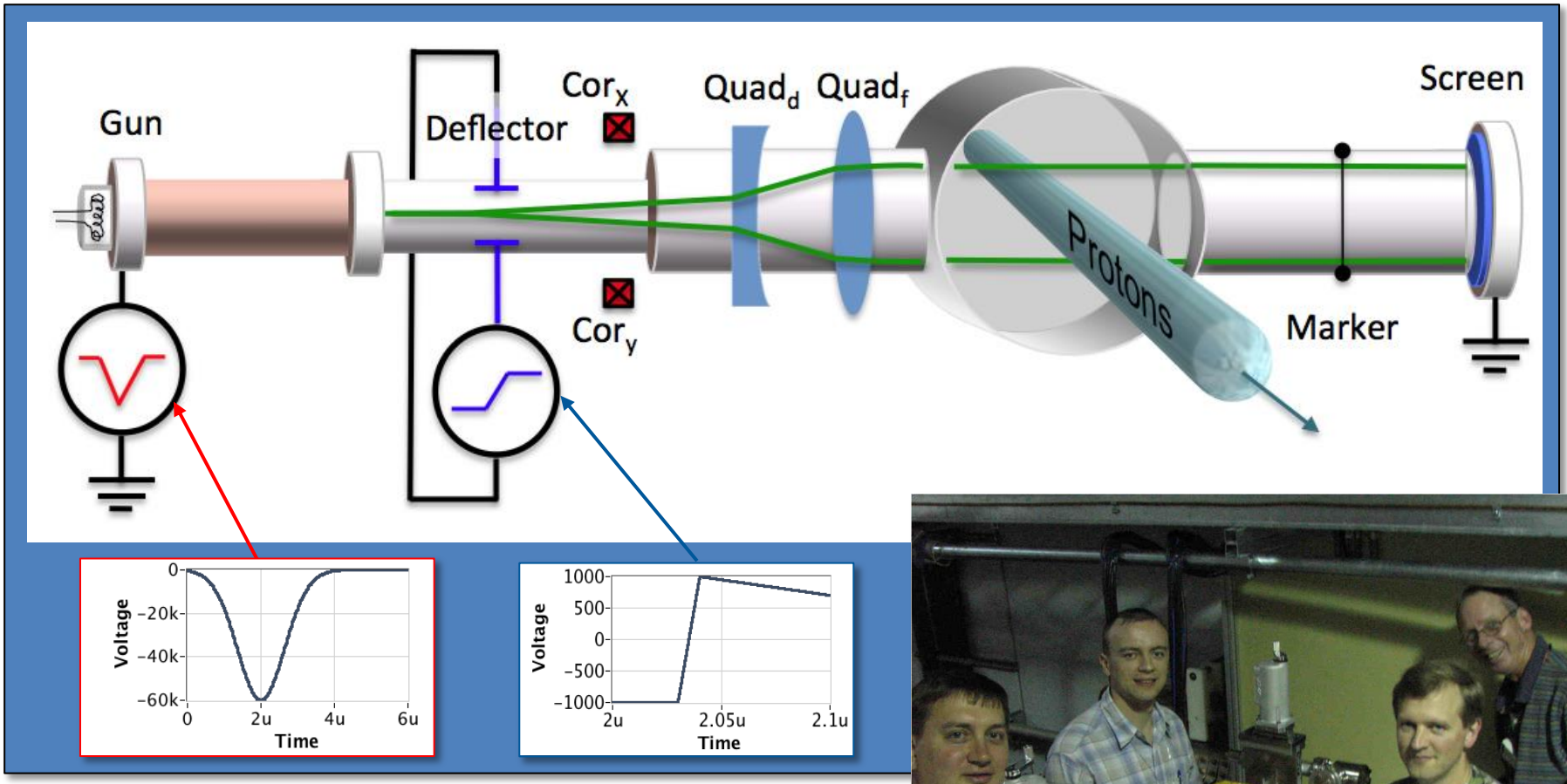
Look at the deflected projection of a tilted sheet of electrons:

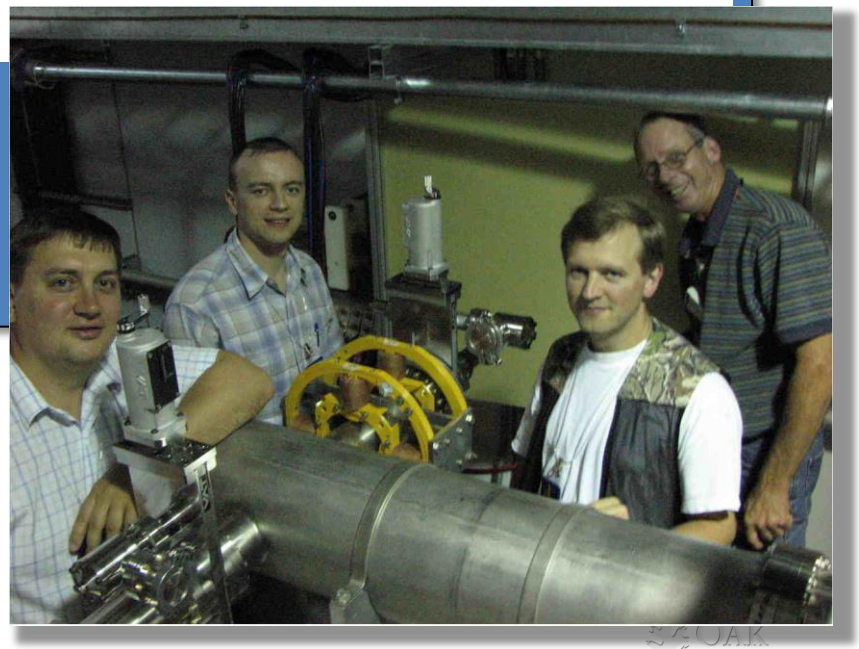
- Neglect magnetic field (small displacement of projection)
- Assume path of electrons is straight (they are almost straight)
- Assume net electron energy change is zero (if symmetric)

→ $$\frac{d\theta_0(x)}{dx} = \int_L \frac{e}{mv^2} \frac{\delta(x,y)}{\varepsilon_0} dy$$

AKA: take the derivative to get the profile

Scanner Layout

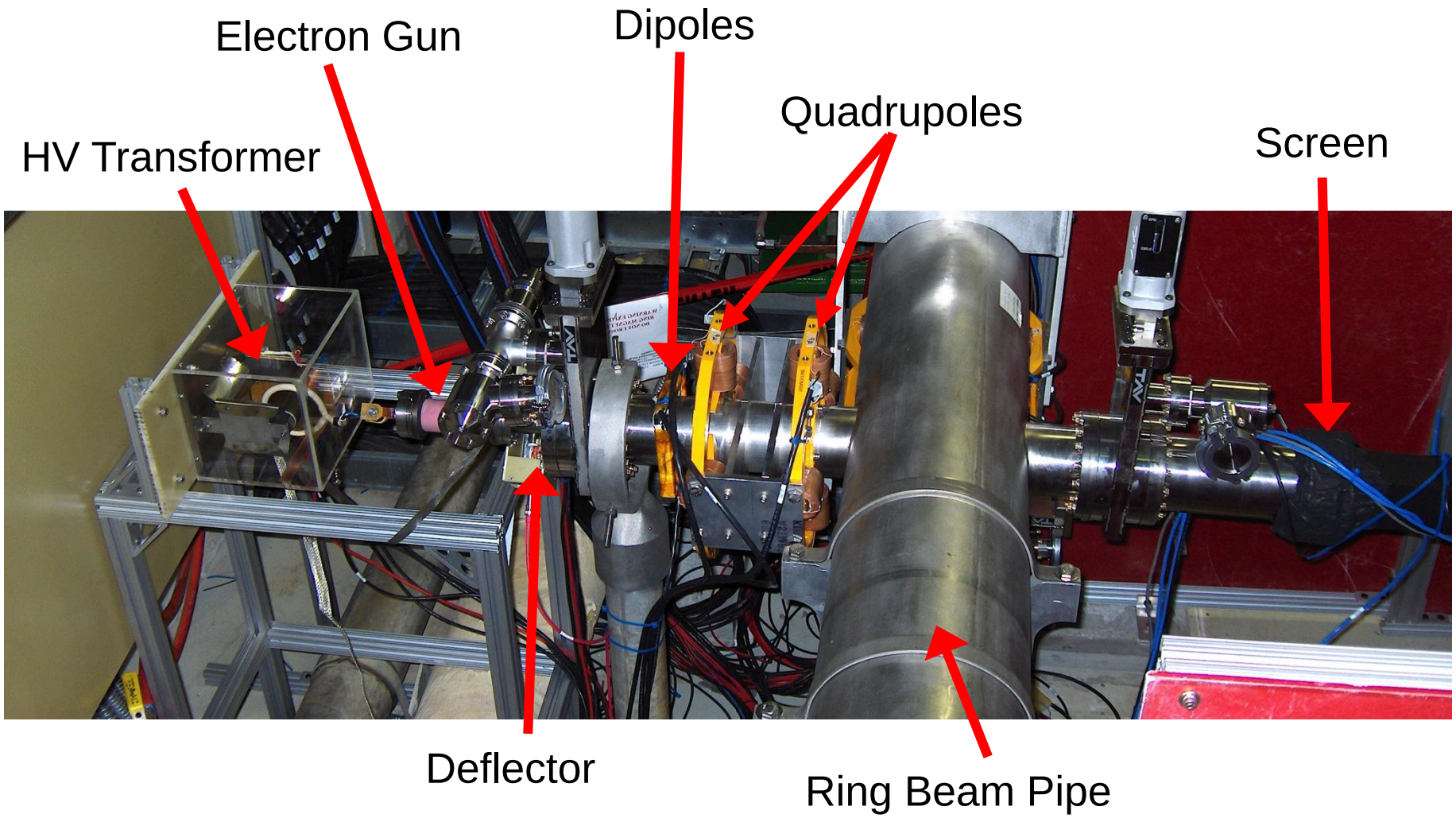




Electron Scanner hardware by Budker Institute of Nuclear Physics: Dmitriy Malyutin, Sasha Starostenko, Sasha Tsyganov

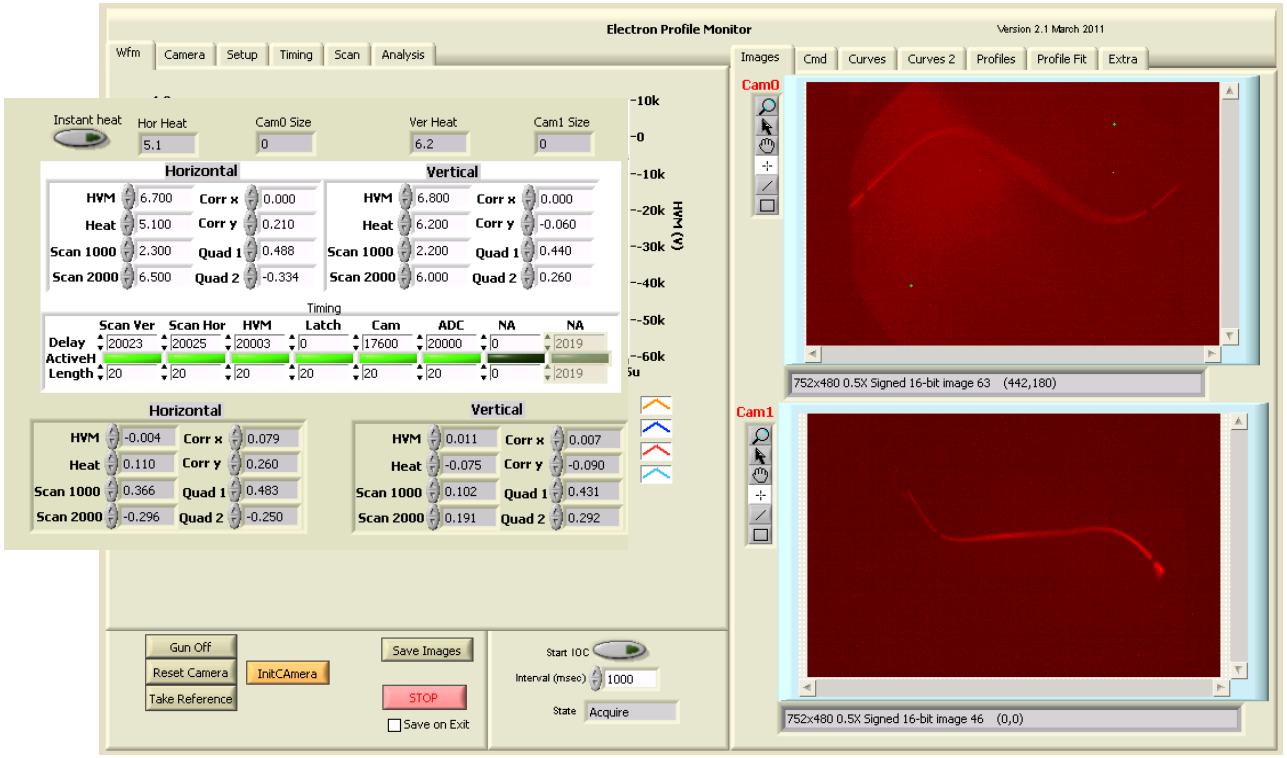
Joint design by BINP and SNS.

Scanner Hardware



Electron-beam scanner hardware (now covered with a magnetic shield)

Software



Main application

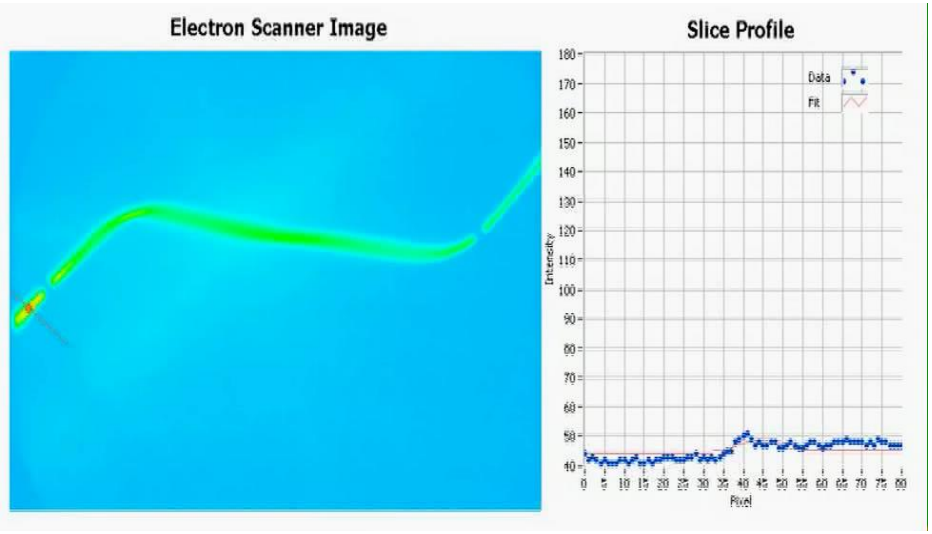
- Main application for control of hardware, acquire waveforms and images, analyze images, and interface to EPICS control system
- Wirescanner equivalent profile program
- Simulation program of electron path through proton beam
- Offline analysis program

Analysis

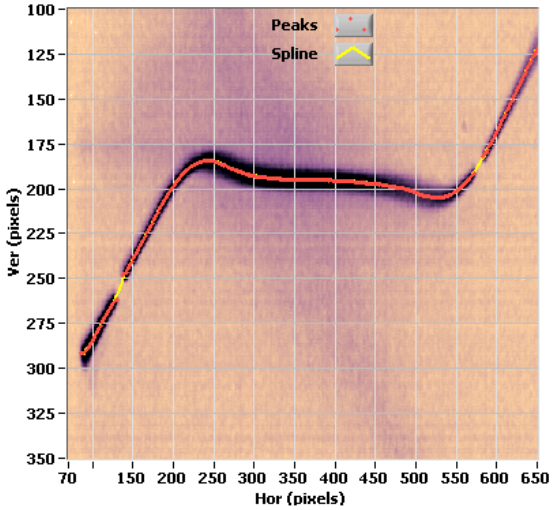
Analysis steps:

1. Find the curve (x,y) points
   - Method A
     - Find peak per column
   - Method B
     - Find peak per column
     - Fit polynomial (odd order)
     - Slice perpendicular through polynomial to find better peaks

2. Fit a spline to these points to reduce noise



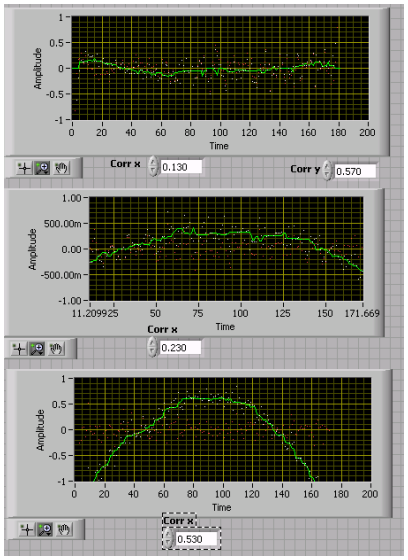
Taking slices of the curve



Fitting a spline to the curve points

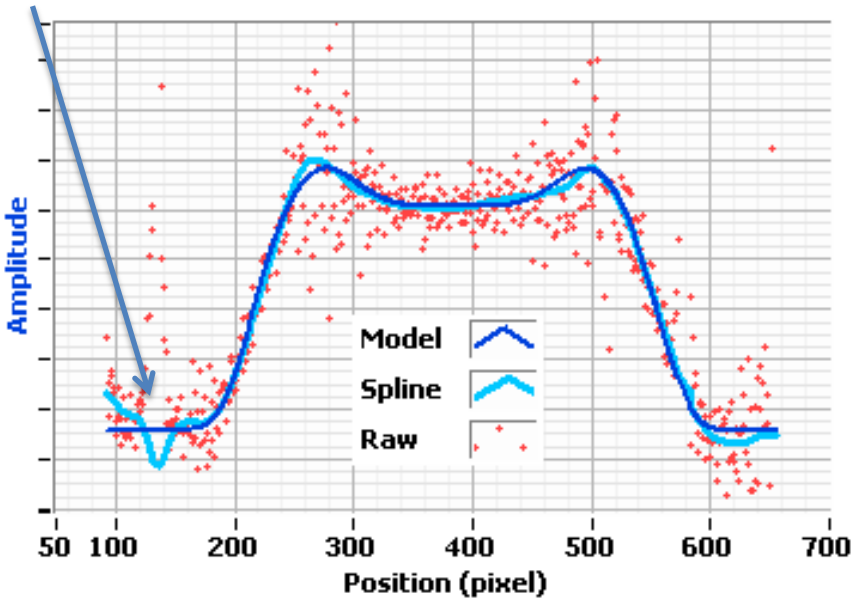
Analysis

3. Take the derivative of spline points to obtain profile
4. Optional: Fit a model-based function to profile to remove imperfections but assumes a certain profile



Deviation from a straight line as a function of corrector setting (aka path through quads).

Discontinuity from marker



Derived proton beam profiles

Model-based Analysis

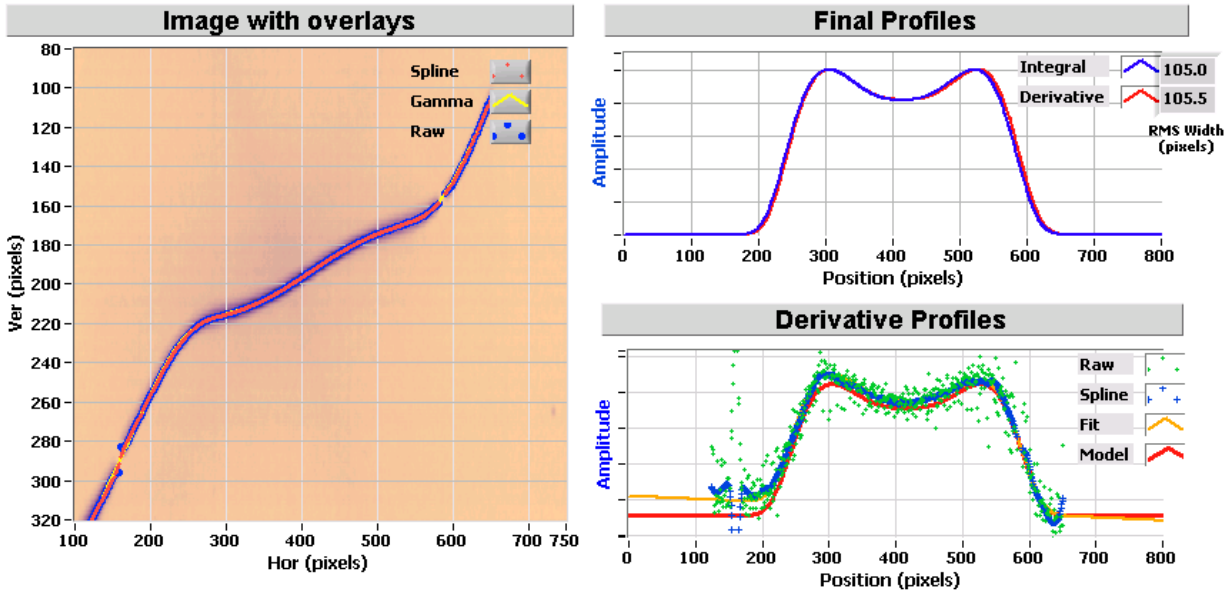
$$\int \left(a \cdot e^{-0.5\left(\frac{x-\mu}{\sigma}\right)^n} + sl \cdot x + o\right) dx =$$

$$a \cdot \frac{2^{\frac{1}{n}}}{n} \cdot sign\,(x-\mu) \cdot \text{Gamma}\left[\frac{1}{n}, 0.5\left(\frac{x-\mu}{\sigma}\right)^n\right] +$$

$$o \cdot x + \frac{sl}{2} \cdot x^2 - sl \cdot \mu \cdot x + c$$

- Fit a function, e.g. based on (double) super-gaussian profile, directly to projected curve to increase stability and fitting speed (no intermediate derivative)

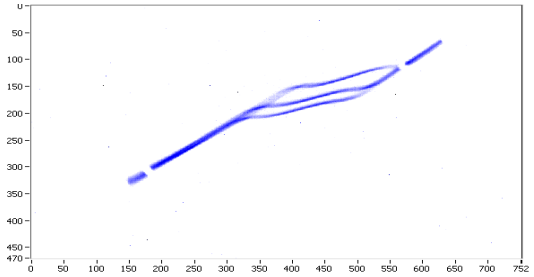
- Same stability as derivative method
- Too slow (up to 1-20 s versus 1-3 s)



Analysis process

Verification of electron-beam scanner

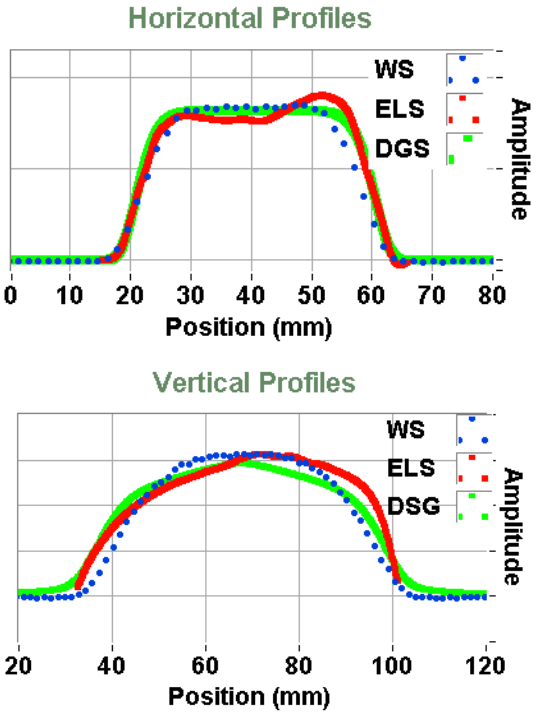
- Bumping the center of the beam and comparing BPM measurements with ES profile movements -> <15%
- Width measurements compared ES profiles with RTBT wire scanners to -> ~3-12%



Horizontal orbit bumps

Width	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%

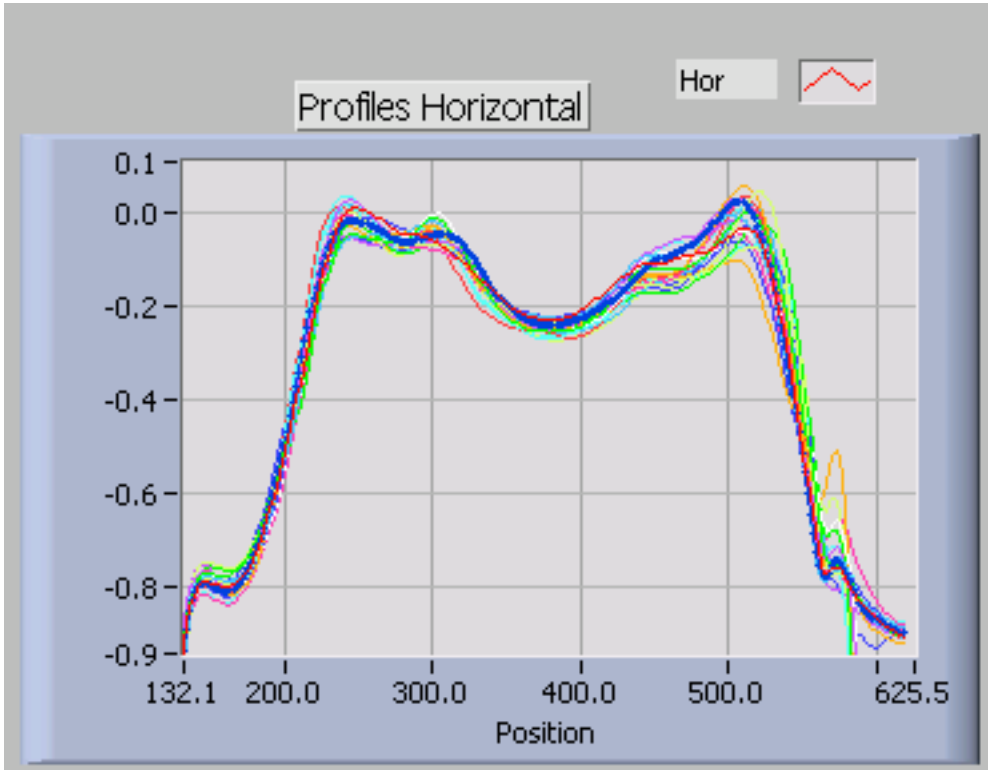
Comparisons by S. Cousineau



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

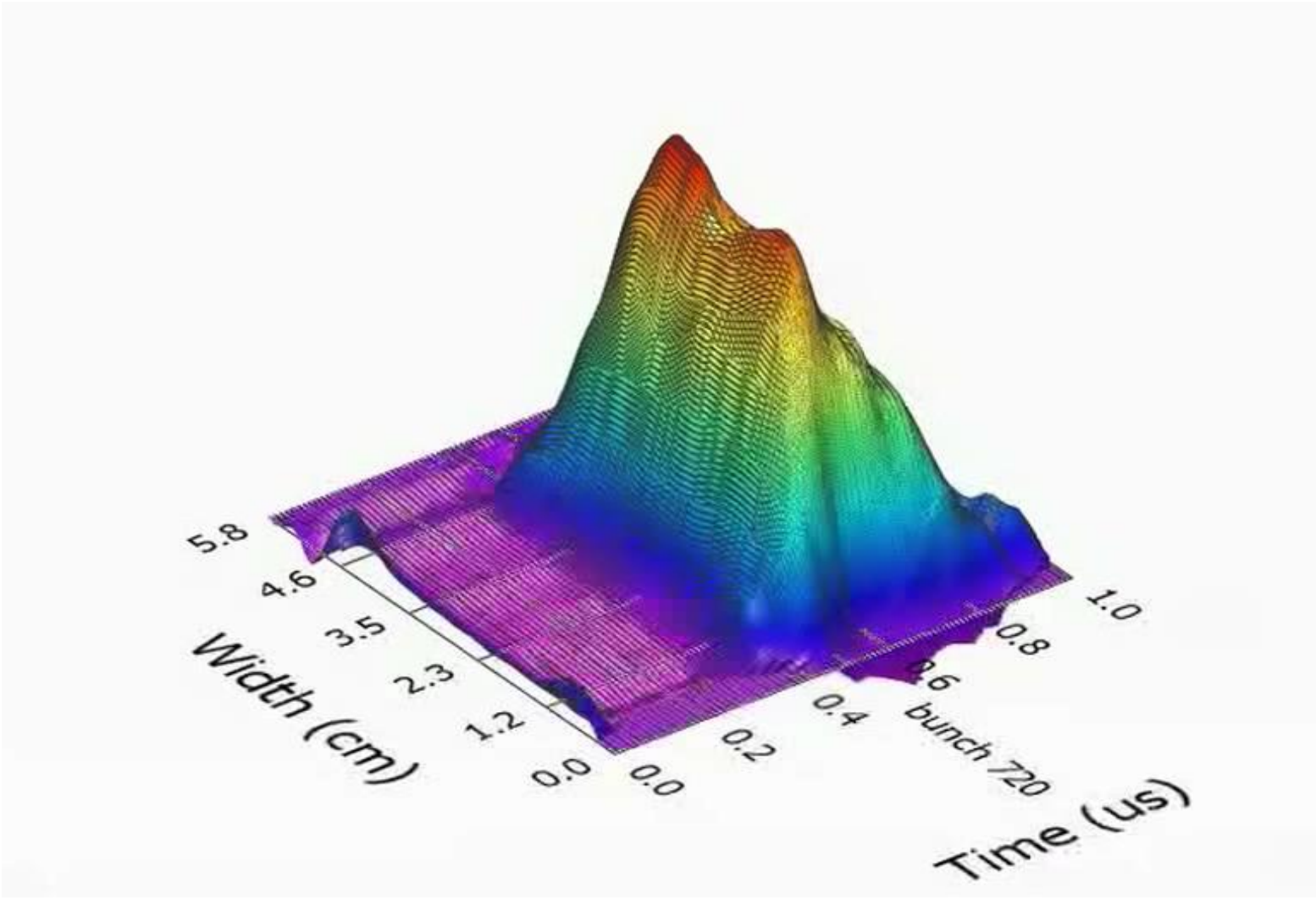
Verification of electron-beam scanner

- 20 consecutive measurements



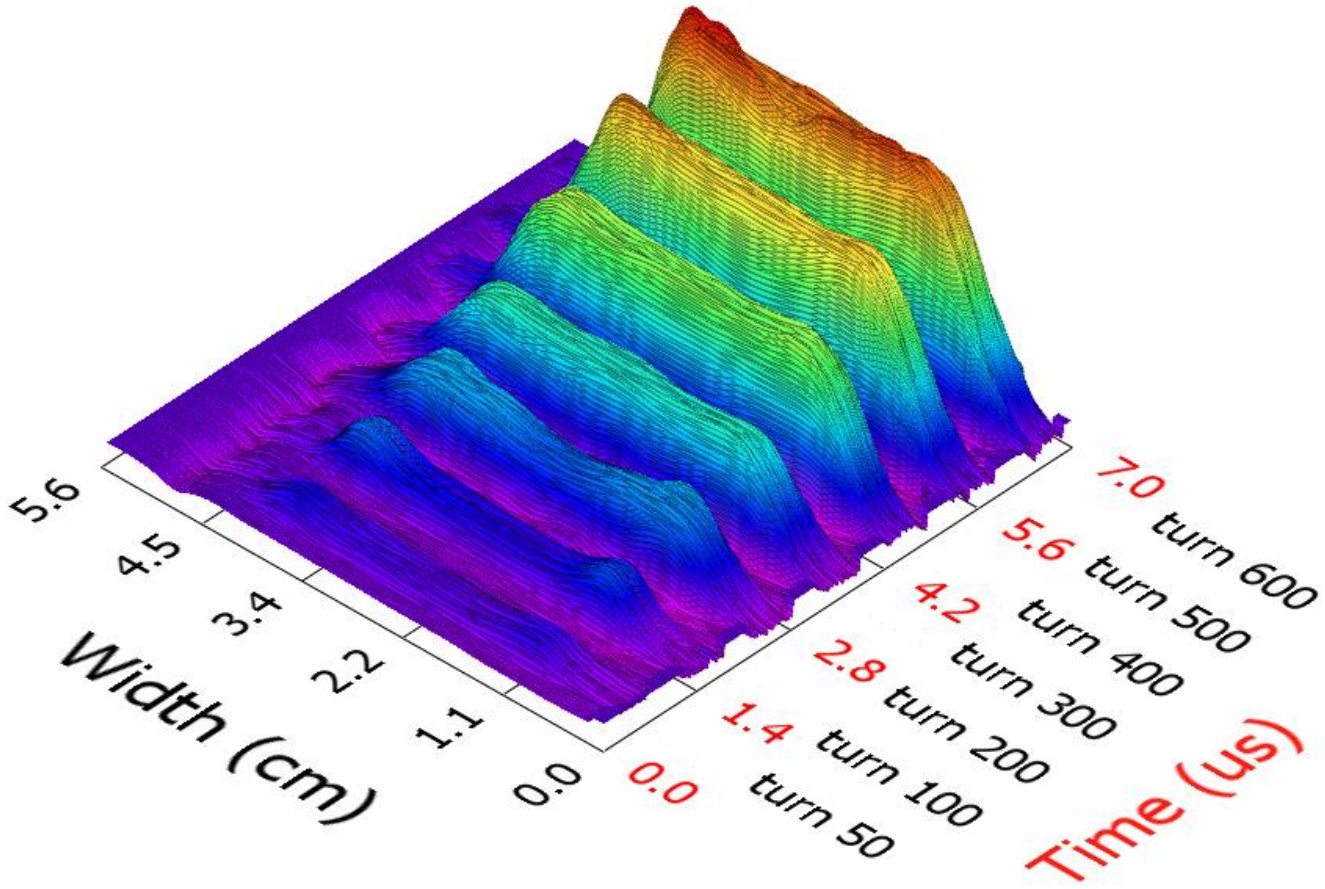
Bunch 400, horizontal profiles in middle of bunch

High intensity profile



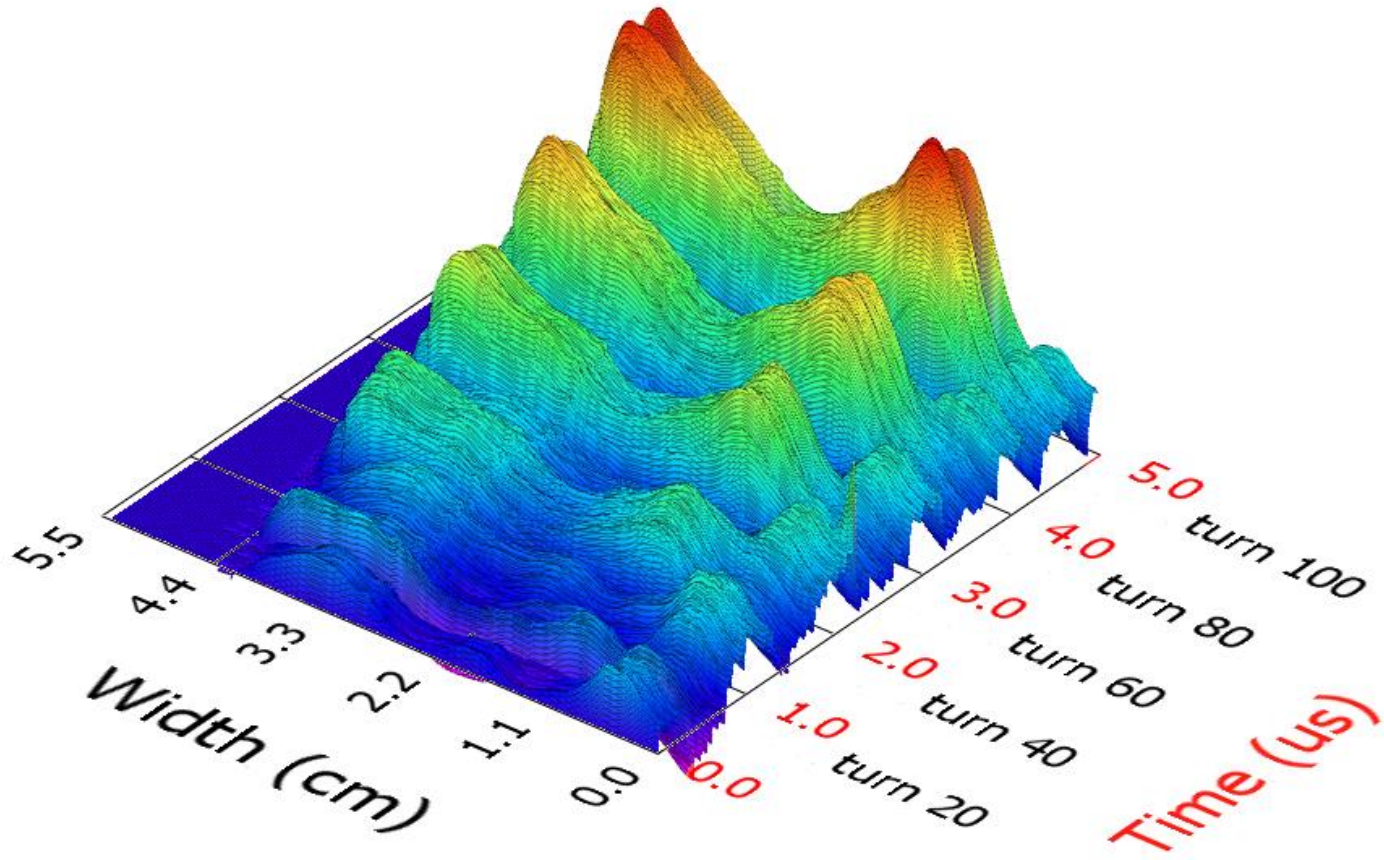
3D plot of horizontal profile of turn 720 at ~11uC

High intensity profiles



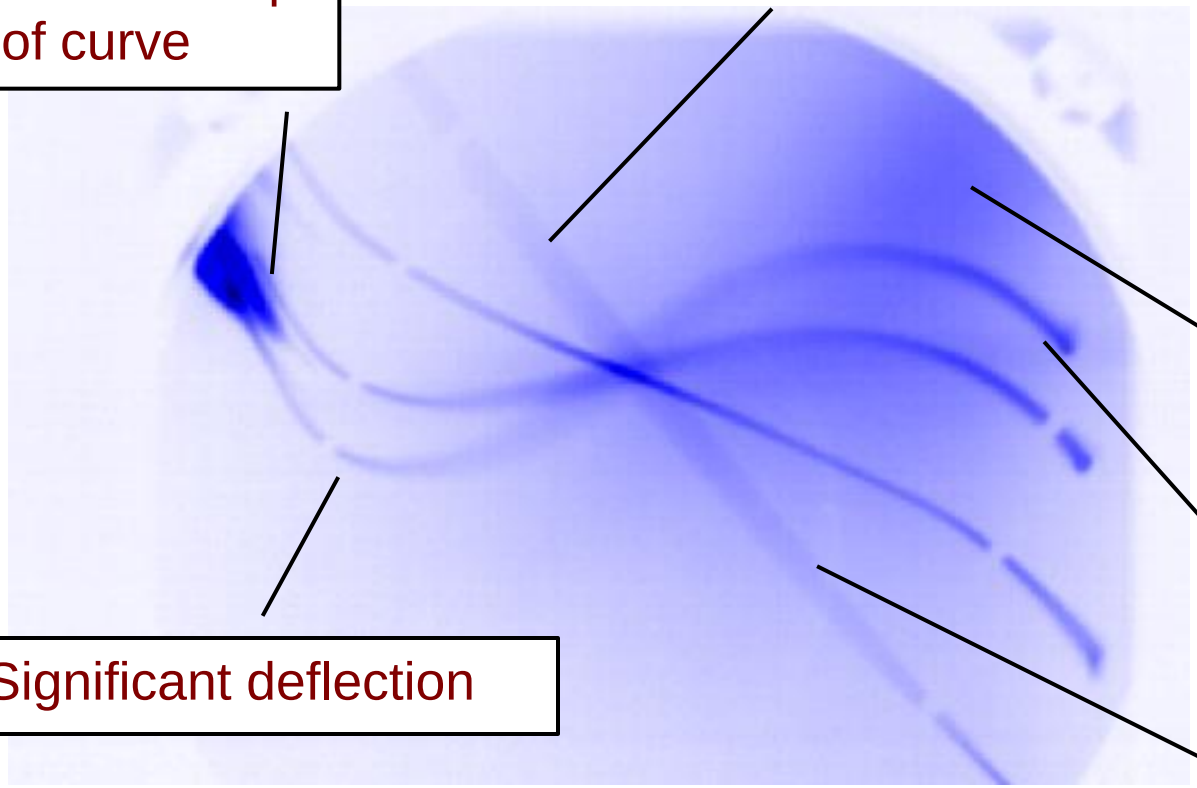
Horizontal Profiles (spline derivative)

Low intensity profiles



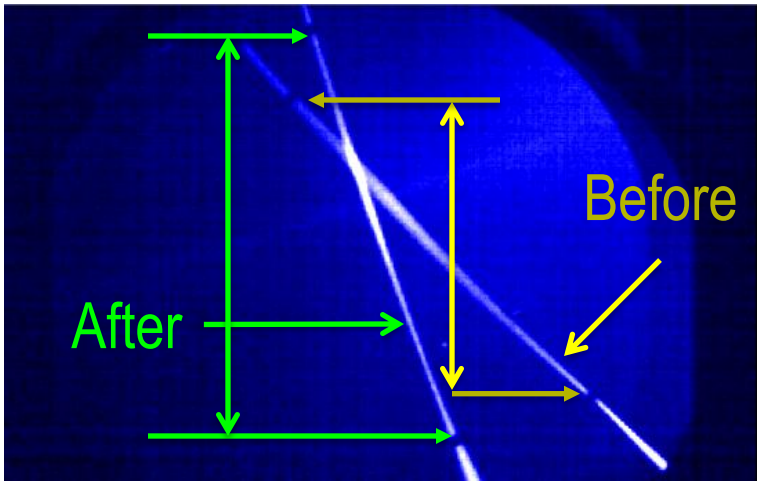
Vertical Profiles (spline derivative)

Challenges with prototype

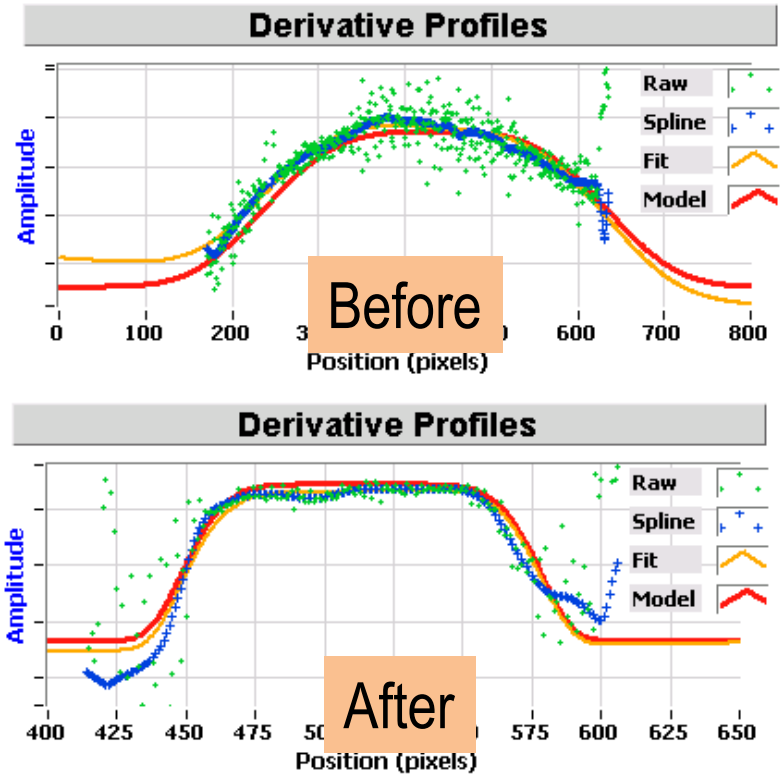


Superimposed vertical scans through a bunch of ~19µC beam

Deflector Rotation



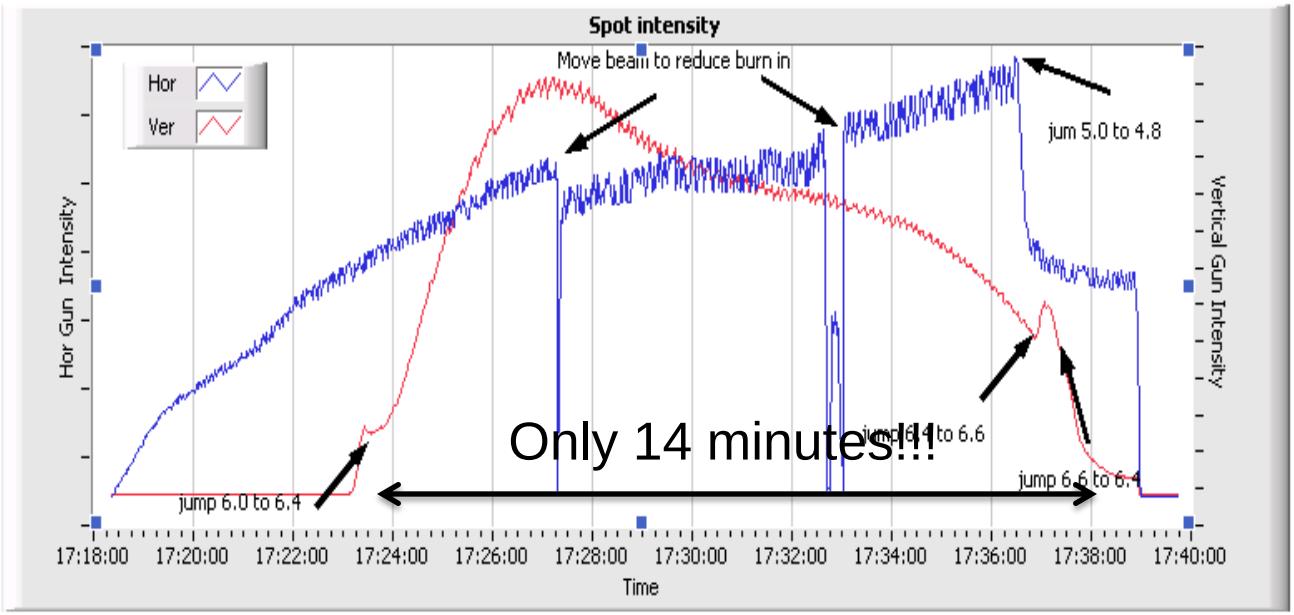
Projection without beam before and after the rotation



Increasing the scan range resulted in a more complete profile

The range of vertical profile scanner is not wide enough -> rotating the deflector from 45 degrees to almost 70 degrees adds almost 30% to range (but we loose resolution)

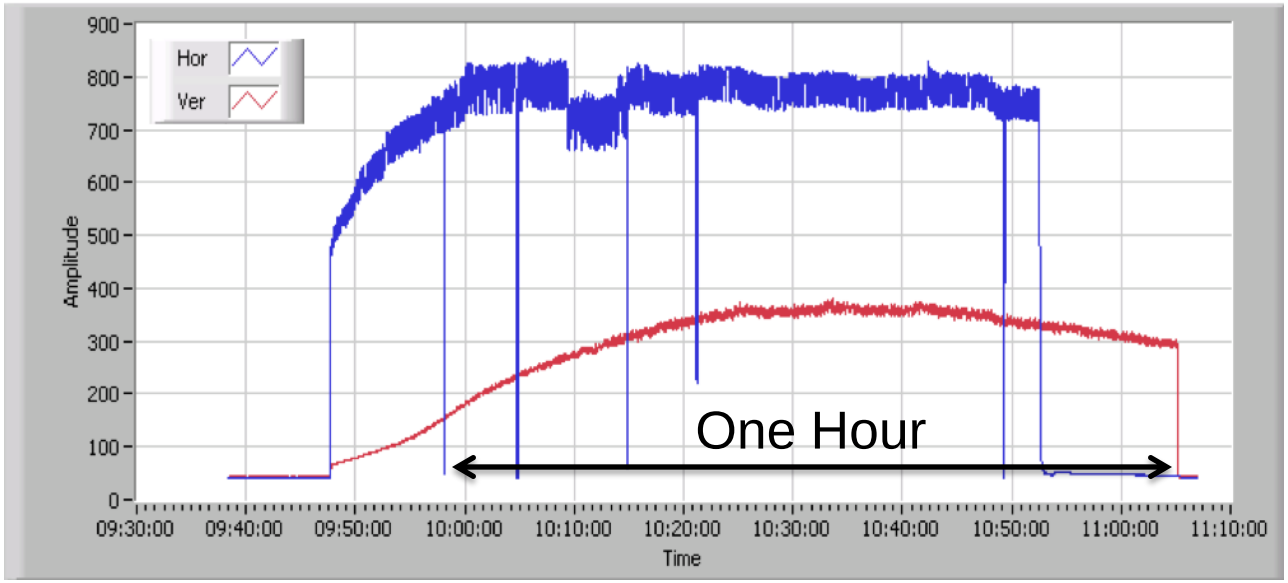
Cathode Poisoning



Intensity of image on the screen

After rotation, the vertical cathode (focused beam, deflector off) delivered very short lived and low intensity current -> cathode poisoned?!

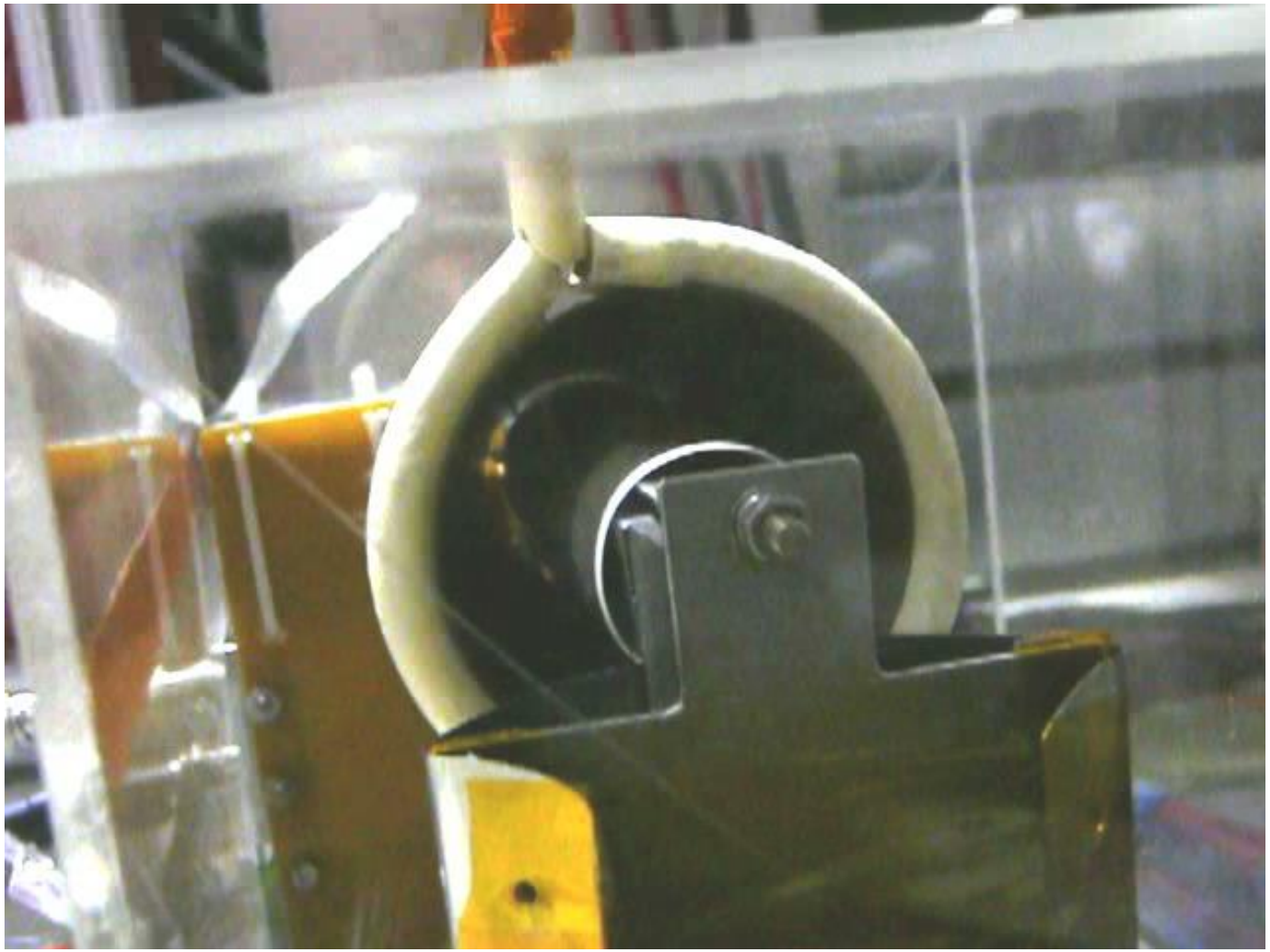
Cathode poisoning



Intensity of image on the screen

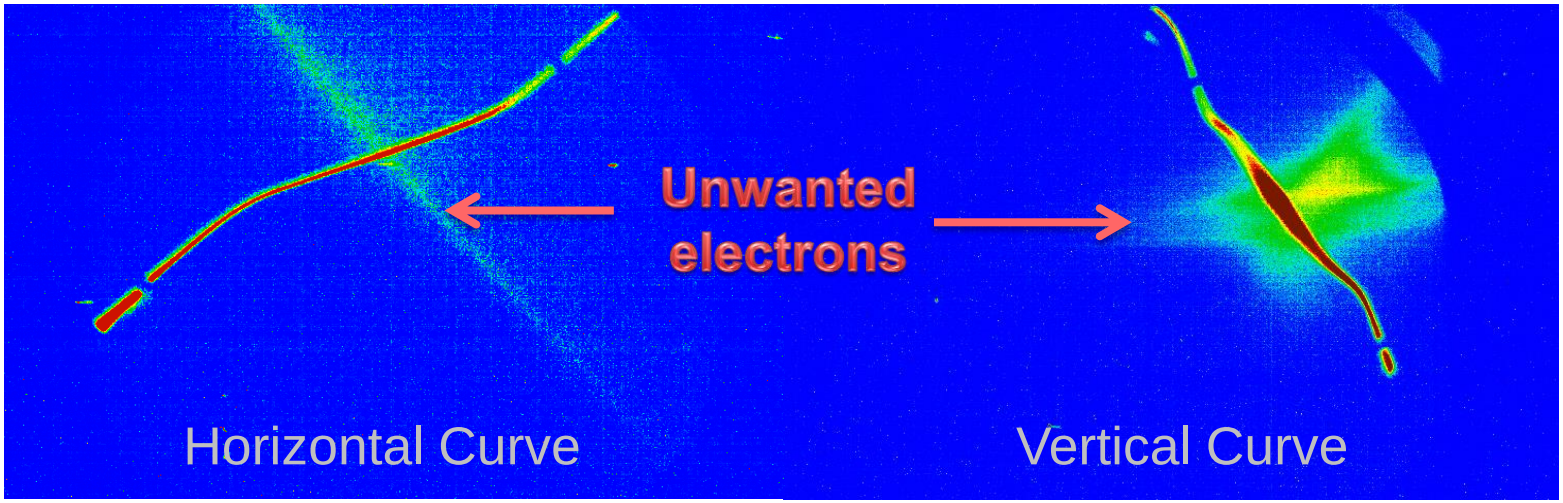
- Cure cathode (Lanthanum Hexaboride: LaB6) poisoning by overheating
- Must also turn HV Off
- Repeated procedure several times to recover and even improve performance

High VoltageTransformer



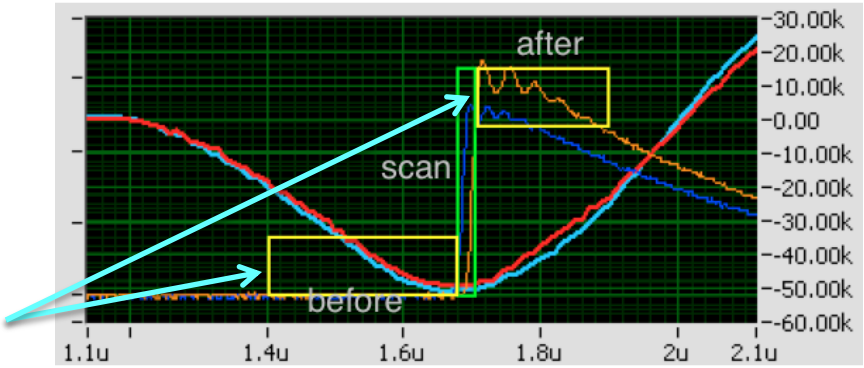
Arcing of HV Transformer

Blobs and more



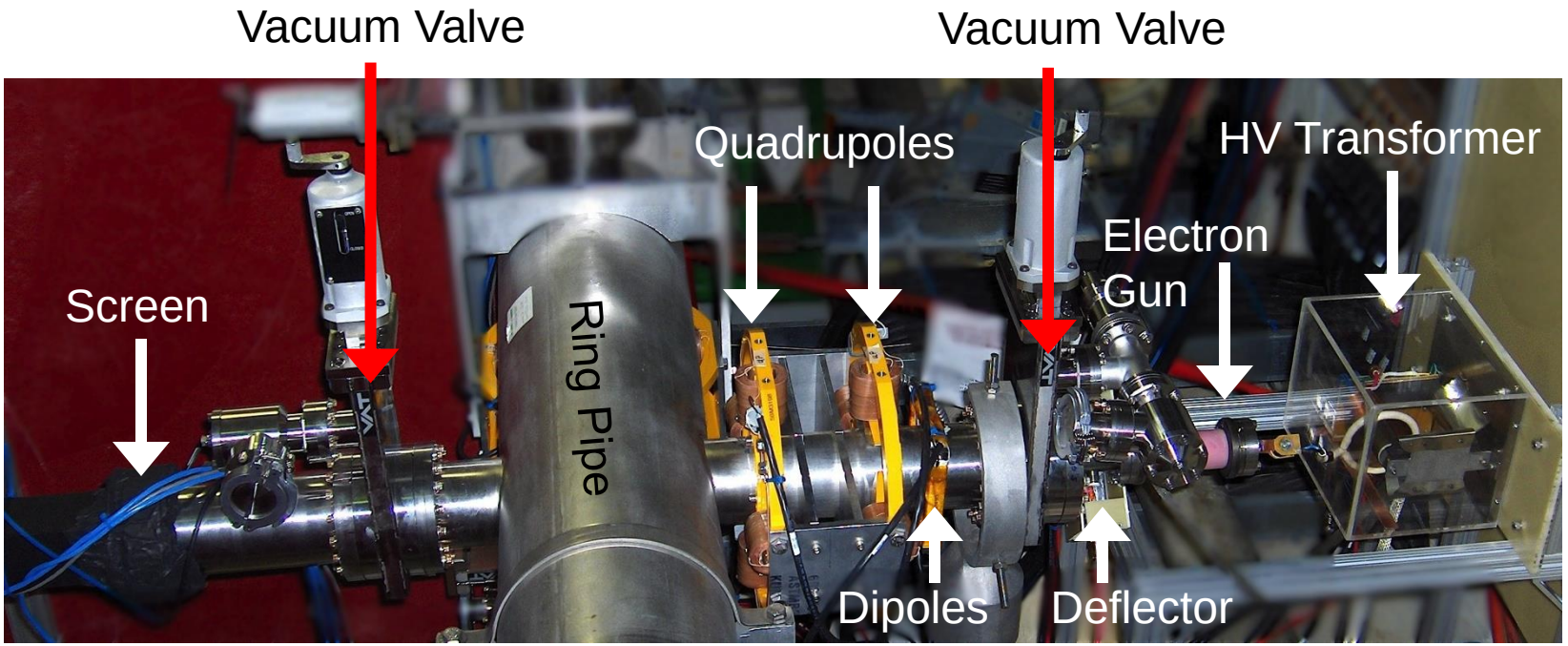
Unwanted electrons interfere with the analysis

- Unwanted electrons illuminate the screen and impede the analysis
- These electrons are thought to originate from before and after the deflector scan



HV and defection waveforms

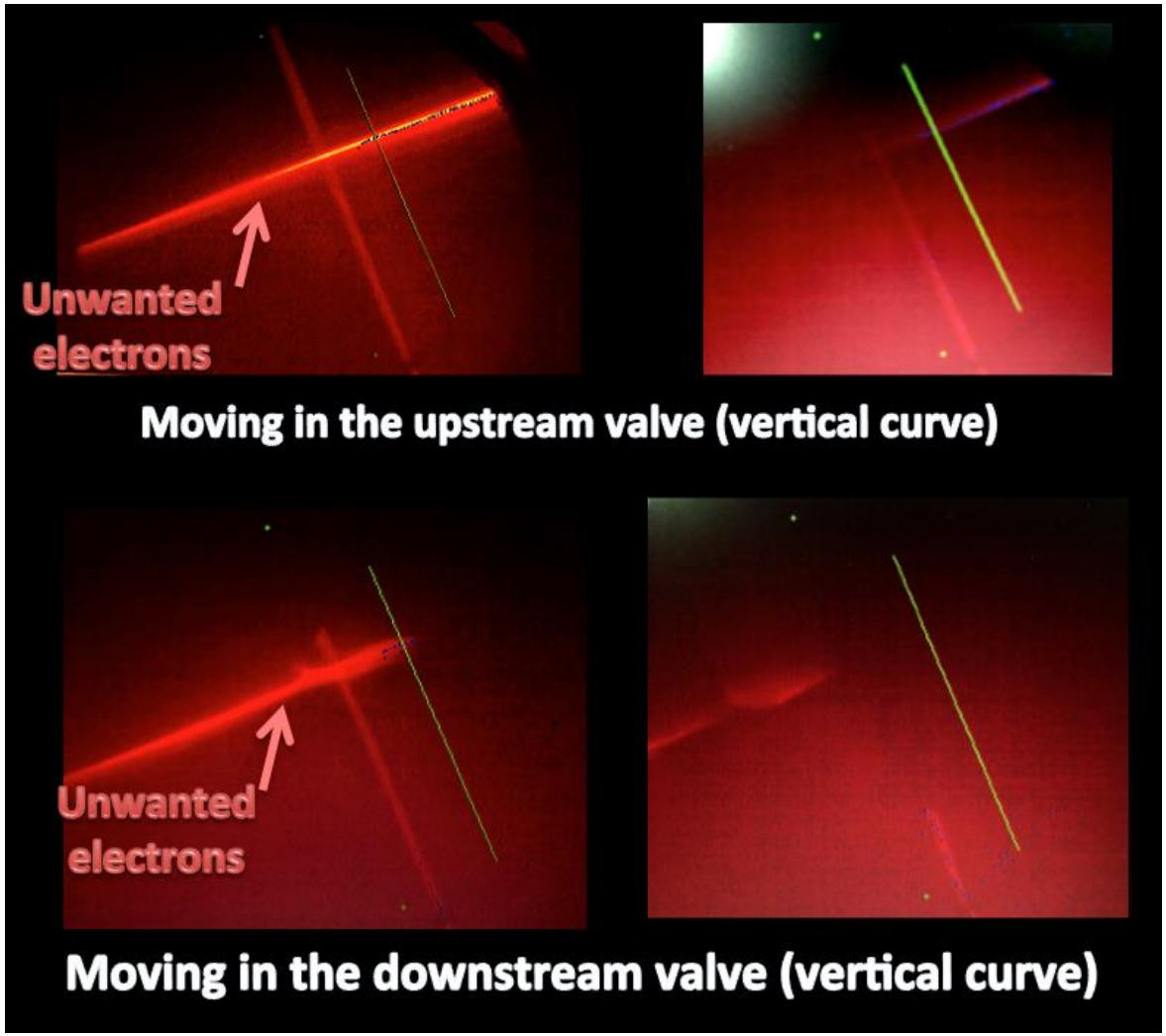
Improvising scrapers



Electron-beam scanner components

Note the manual vacuum valves!!!

Improvising scrapers



Using the vacuum valves as scrapers

- No proton beam
- Setup ES to show unwanted electrons
- Manually adjust valves

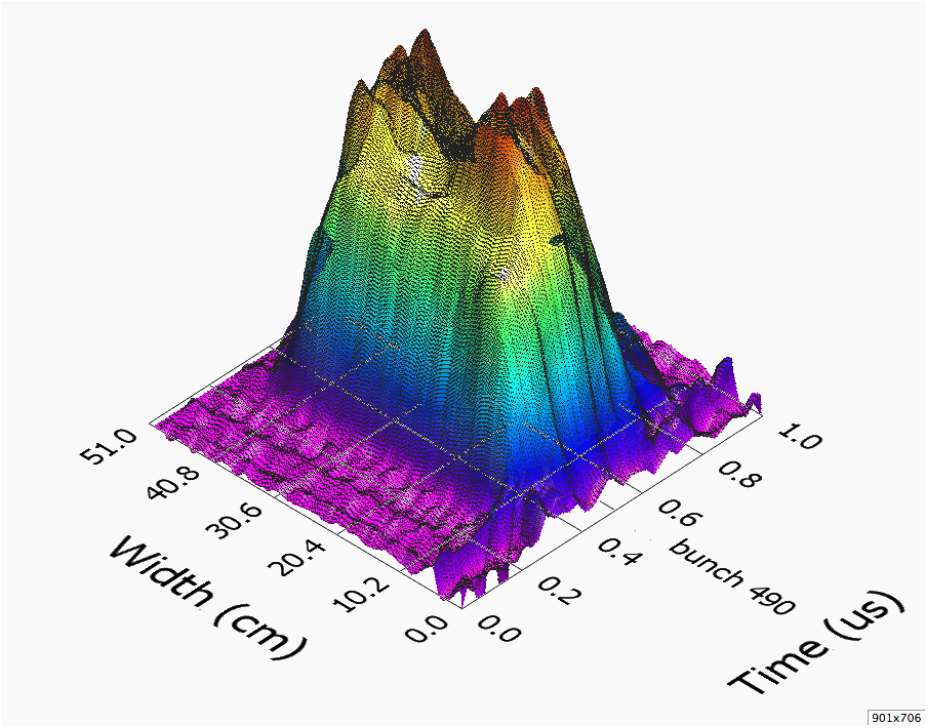
➔ able to scrape some of the unwanted electrons away

➔ Install aperture restriction (upstream of proton beam) Verify still needed after deflector update

Use In Physics Studies

E-beam scanner being used for doctoral research* into unexpected transverse beam dynamics. The main parameters appear to be injection size and ring tune.

- It is used specifically to observe the evolution of the beam during accumulation.
- It also allows an in-depth look at the beam along the longitudinal axis at a level, which was not previously possible.



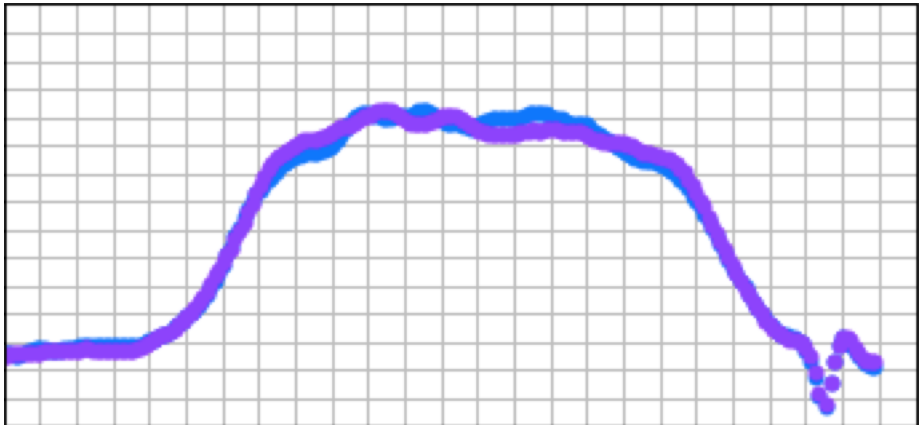
Unstable high intensity hor. profile

*Courtesy of R. Potts

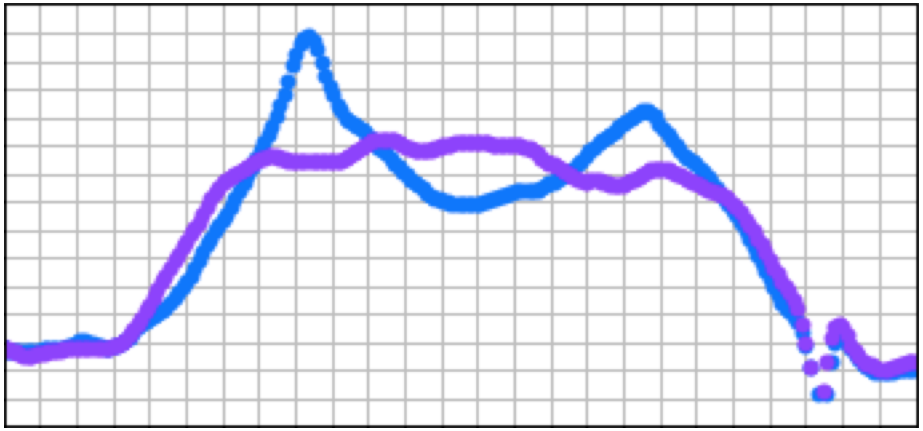
Use In Physics Studies

- Typical beam configurations demonstrate pulse-to-pulse consistency in the transverse shape.
- Using the EPM, an unstable beam configuration has been identified and is being studied.
- The EPM profiles below demonstrate the pulse-to-pulse consistency for beams at 350 turns of accumulation.

Typical Beam



Unstable Beam



Courtesy of R. Potts

Use In Physics Studies

This video demonstrates the extremes of the pulse-to-pulse variations for the unstable beam configuration:

Profile of beam

Deflected electron curve

Courtesy of R. Potts

Summary

- Electron Scanner progress:
  - Verified with wirescanner and position measurements
  - Improvements made:
    - Scan range, cathode current, cameras, analysis, magnetic shielding
  - Future plans:
    - Better cameras, deflector electronics, HV transformer, move markers, scrapers, simulation for ebeam transport
  - Studies:
    - Instabilities in ring
  - Far Future: Tomography!

Wildlife waiting to see the electron-beam scanner

REFERENCES

- [1] E. Tsyganov, et al, "Electron beam emittance monitor for the SSC", PAC1993, pp.2489-2491.
- [2] A. Aleksandrov et al, "Feasibility Study of Using an Electron Beam for Profile Measurements in the SNS Accumulator Ring", PAC 2005, pp. 2586-2588.
- [3] W. Blokland, "Non-Invasive Beam Profile Measurements Using An Electron-Beam Scanner," Proc. HB 2010, Morschach, Switzerland, p. 438-442.
- [4] W. Blokland and S. Cousineau, "A Non-Destructive Profile Monitor For High Intensity Beams," Proc. 2011 PAC, New York, NY, USA, pp. 1438-44.
- [5] W. Blokland, "Recent developments on High Intensity Beam Diagnostics at SNS," Proc. HB 2012, Beijing, China.
- [6] P.V. Logachev, D.A. Malyutin, A.A. Starostenko, "Application of a low-energy electron beam as a tool of nondestructive diagnostics of intense charged-particle beams," Instruments and Experimental Techniques, Volume 51, Number 1 (2008)

Extra: Challenges with prototype

Challenge	Hardware	Software
Magnetics stray fields	Magnetic Shields	--
Significant deflection	Upgrade HV pulser	--
Defocussing of electrons	Upgrade HV pulser	Fit perpendicular to curve with pulse of SG functions
Background intensity/ Blobs	Install scrapers, upgrade deflector electronics	Reject lower intensities & Model-based fitting
Missing tails	Rotating of deflector, move markers	Model-based fitting
Limited aperture	All new hardware	--
Electron gun poisoning	Condition gun, light-sensitive cameras	Model-based fitting
Curvature in deflection	Adjust location on screen, new transport optics, new vacuum chamber	Model-based fitting, automatic slope removal

 Done  In progress  $Keep dreaming$  Investigated