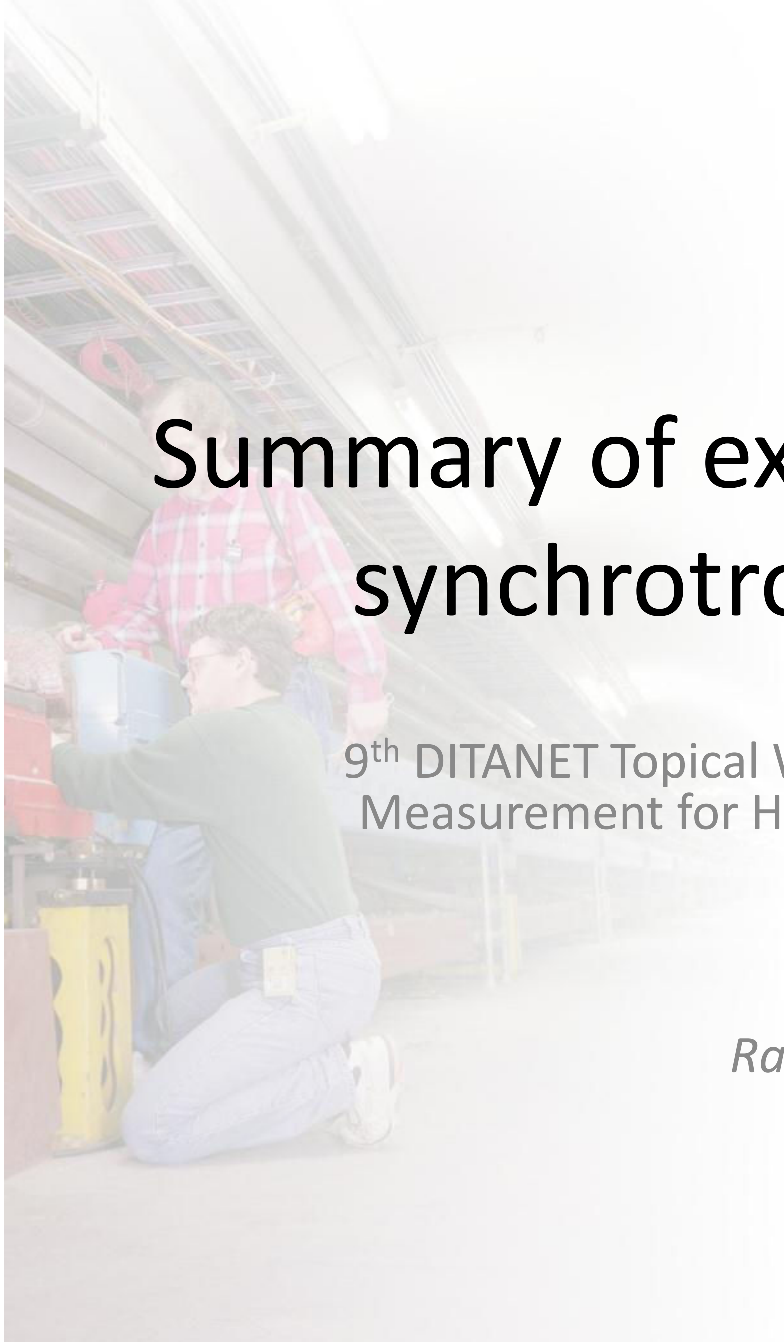


Summary of experience with Tevatron synchrotron light diagnostics

9th DITANET Topical Workshop on Non-Invasive Beam Size Measurement for High Brightness Proton and Heavy Ion Accelerators

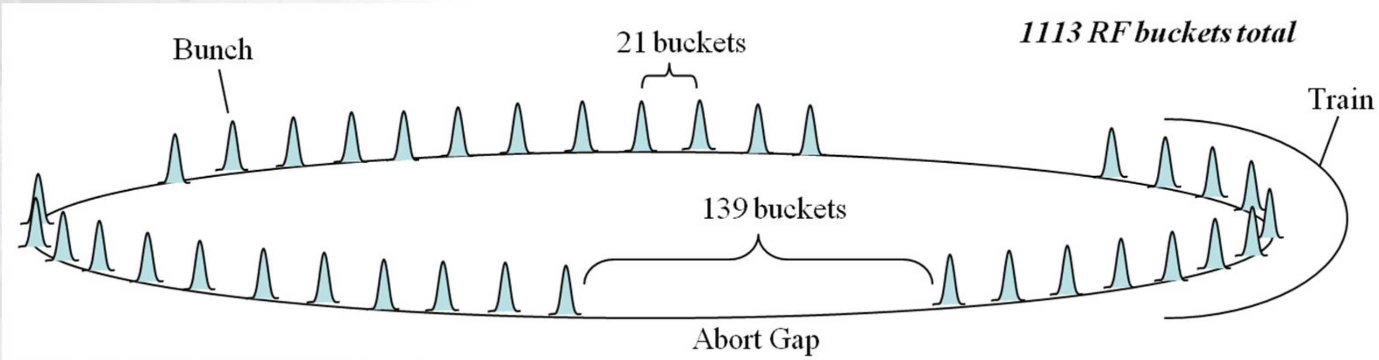
15-18 April 2013

Randy Thurman-Keup

Fermilab

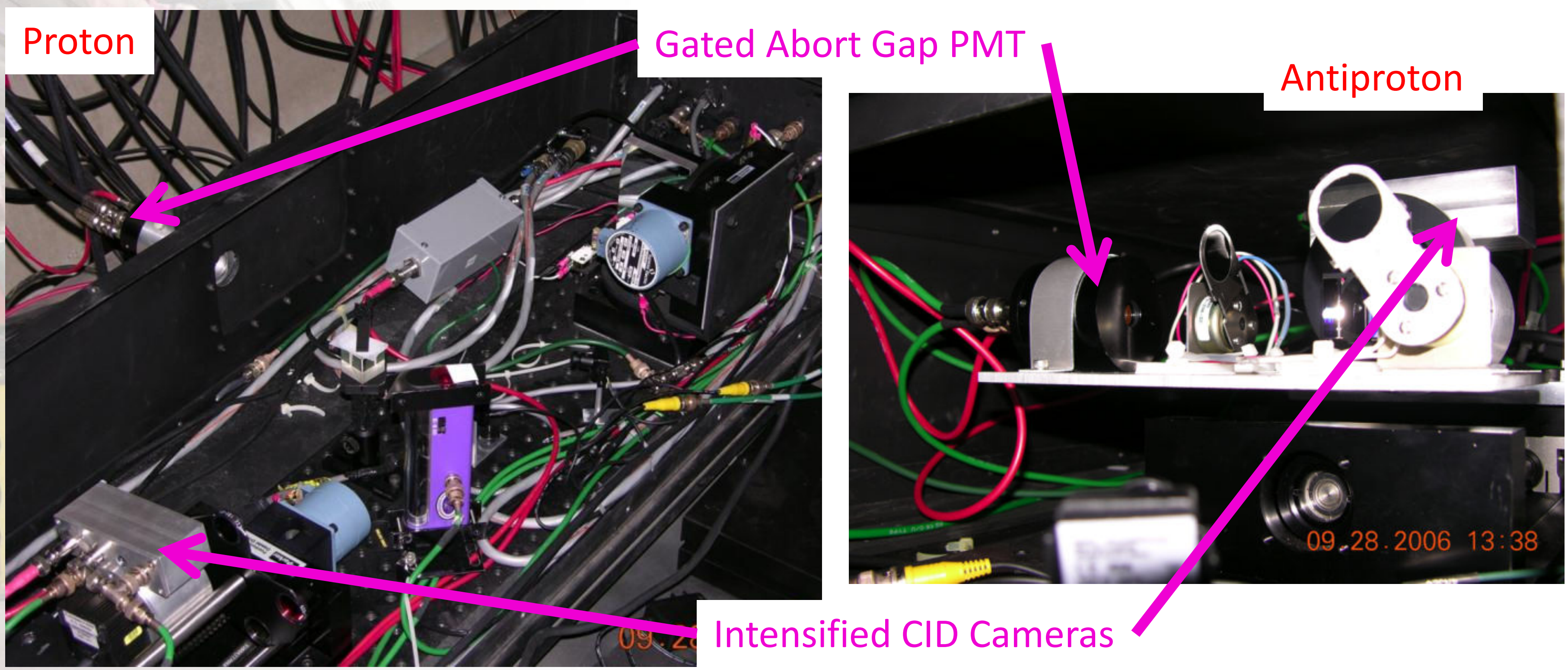
Tevatron 1985(?)-2011

- Collided 980 GeV protons and antiprotons in the same beampipe
- Proton intensity was ~1 x 10^{13} (300 x 10^{9}/bunch)
- Antiproton intensity was typically ~2 x 10^{12} (50-100 x 10^{9} / bunch at start of store)
- Beams were arranged in 3 sections of 12 bunches
- Bunch longitudinal sigma was 2-3 ns

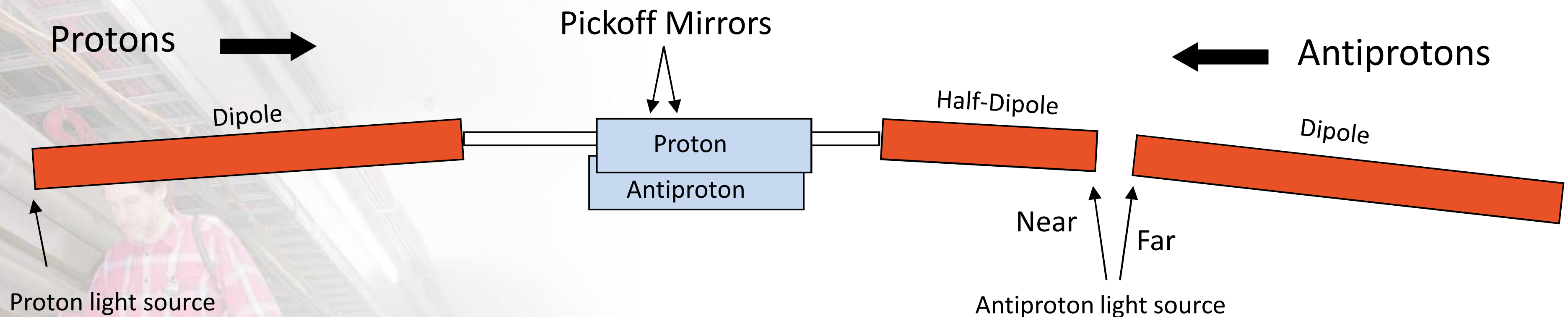


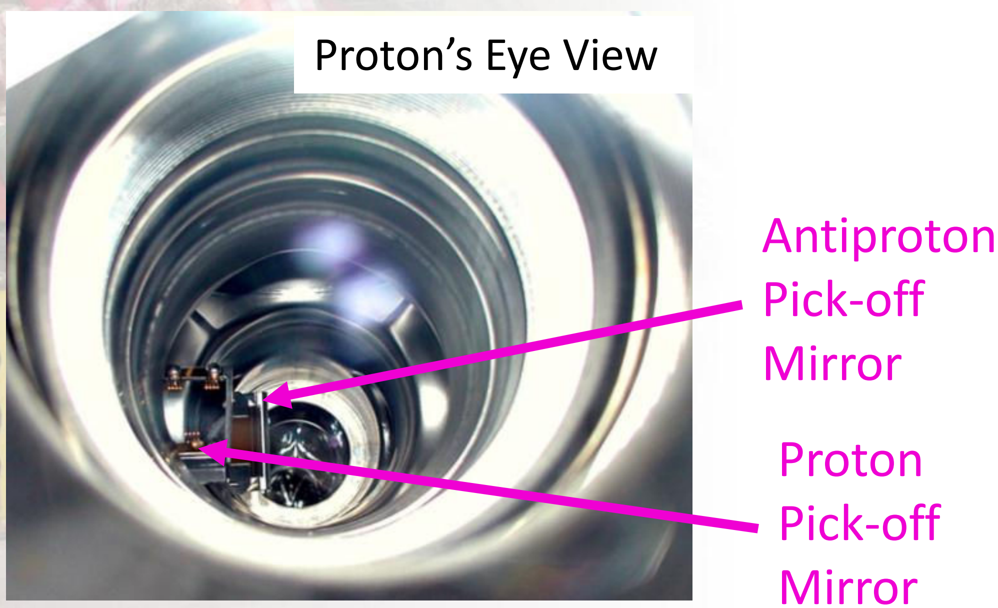
Synchrotron Radiation Monitors

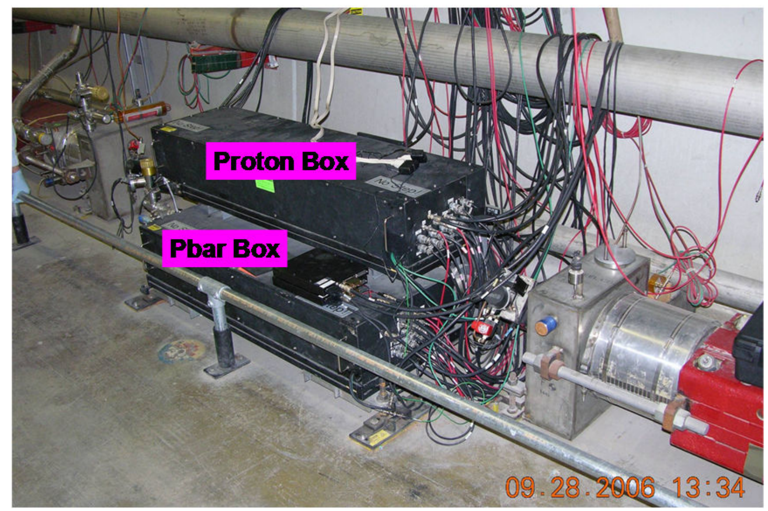
- Original creation by Alan Hahn and Pat Hurh early 1990's
- 2 profile monitors: one for protons, one for antiprotons
- 2 abort gap beam intensity monitors



Synchrotron Radiation Devices

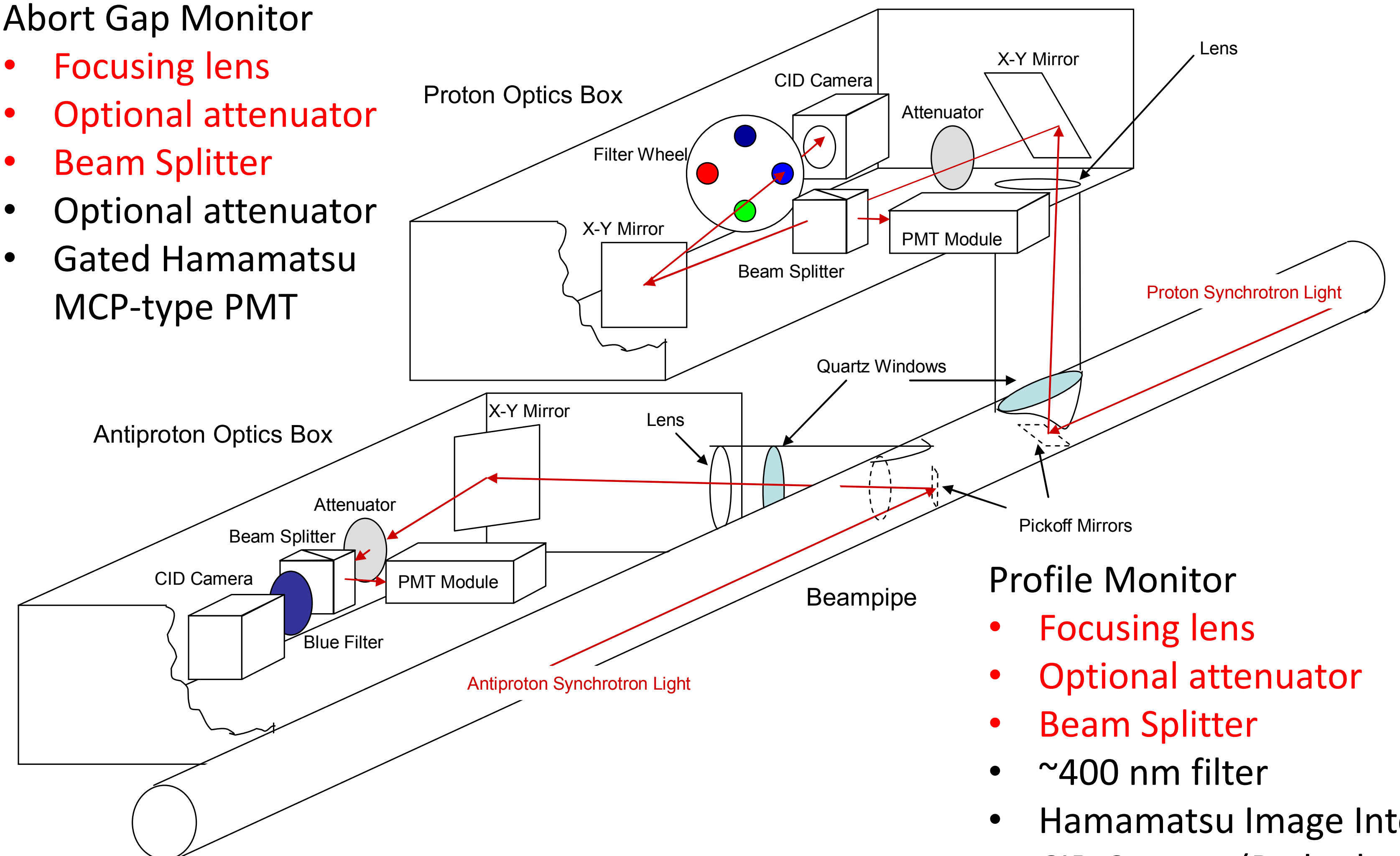






Synchrotron Radiation Devices

Abort Gap Monitor
- Focusing lens
- Optional attenuator
- Beam Splitter
- Optional attenuator
- Gated Hamamatsu MCP-type PMT



Profile Monitor
- Focusing lens
- Optional attenuator
- Beam Splitter
- ~400 nm filter
- Hamamatsu Image Intensifier
- CID Camera (Rad tolerant)

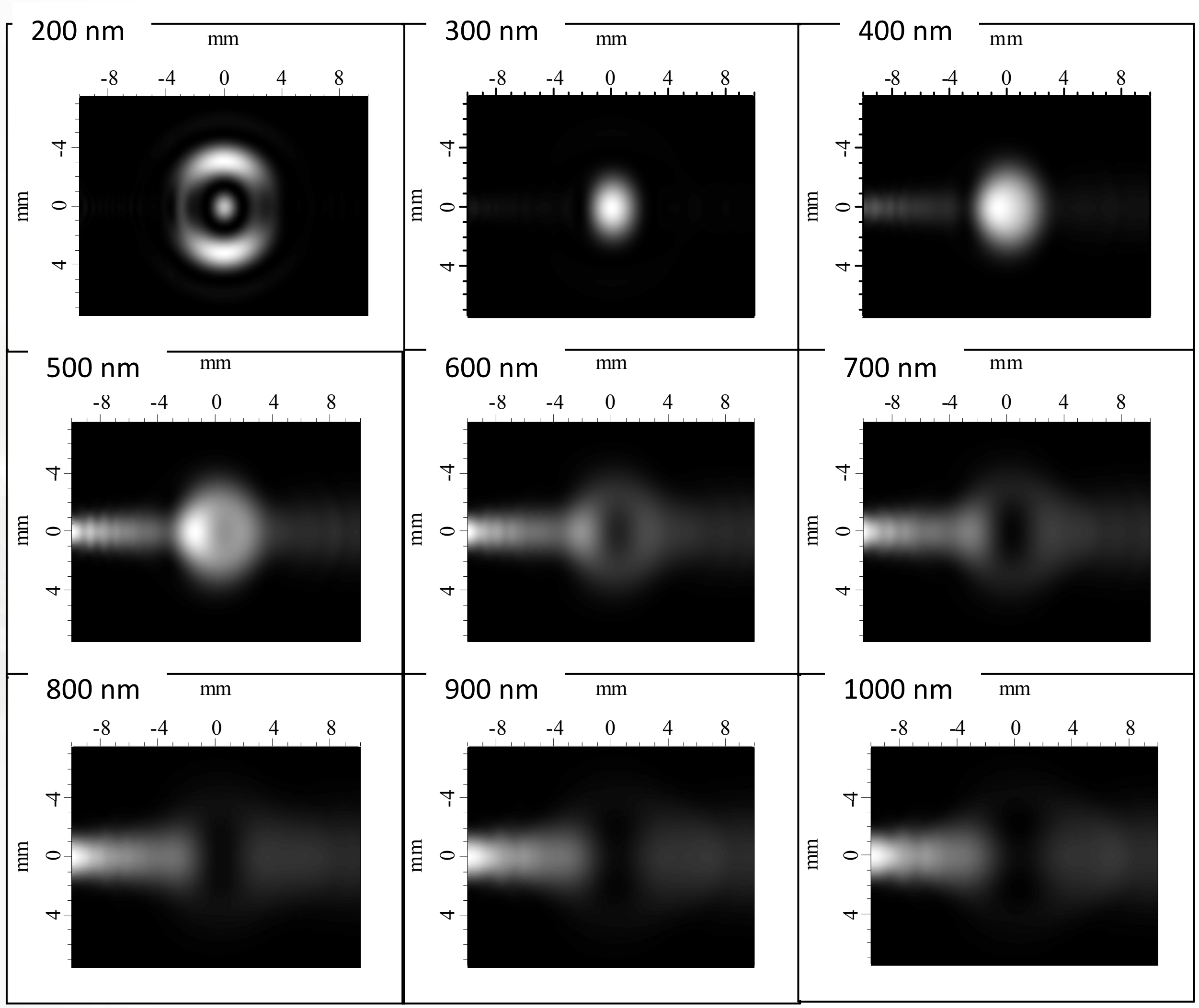
Fermilab DITANET

Antiproton Light

Synchrotron Radiation Workshop (SRW) used extensively to understand various effects

These images are SRW simulations of illumination at the antiproton pickoff mirror

Antiproton source is two edges, hence the interference structure at 200 nm



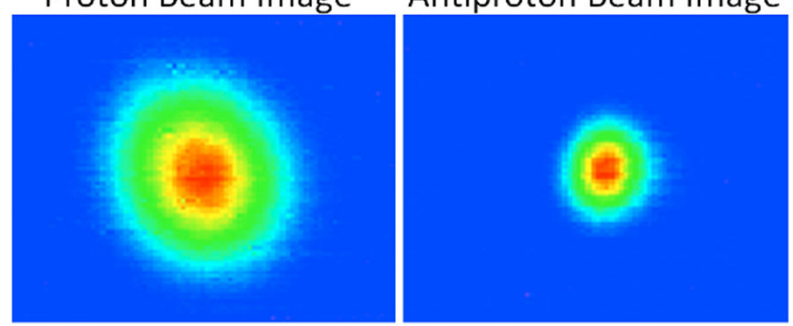
Profile Measurement, aka Synclite

After object…	Object Efficiency	# of photons / bunch / 25 nm	
		Protons	Antiprotons
Magnet Edge	—	750,000	750,000
Pickoff Mirror	90%	675,000	675,000
Vacuum Window	90%	608,000	608,000
Lens	93%	565,000	565,000
x-y Mirror	90%	509,000	509,000
Beam Splitter	44%	224,000	224,000
x-y Mirror (proton only)	90%	202,000	—
Wavelength Filter	10 nm 40% / 40 nm 160%	81,000	358,000
Photocathode	14%	11,000 p.e.	50,000 p.e.

Proton Object Distance = 769 cm
Proton Image Distance = 187 cm
Proton Optical Magnification = 0.24

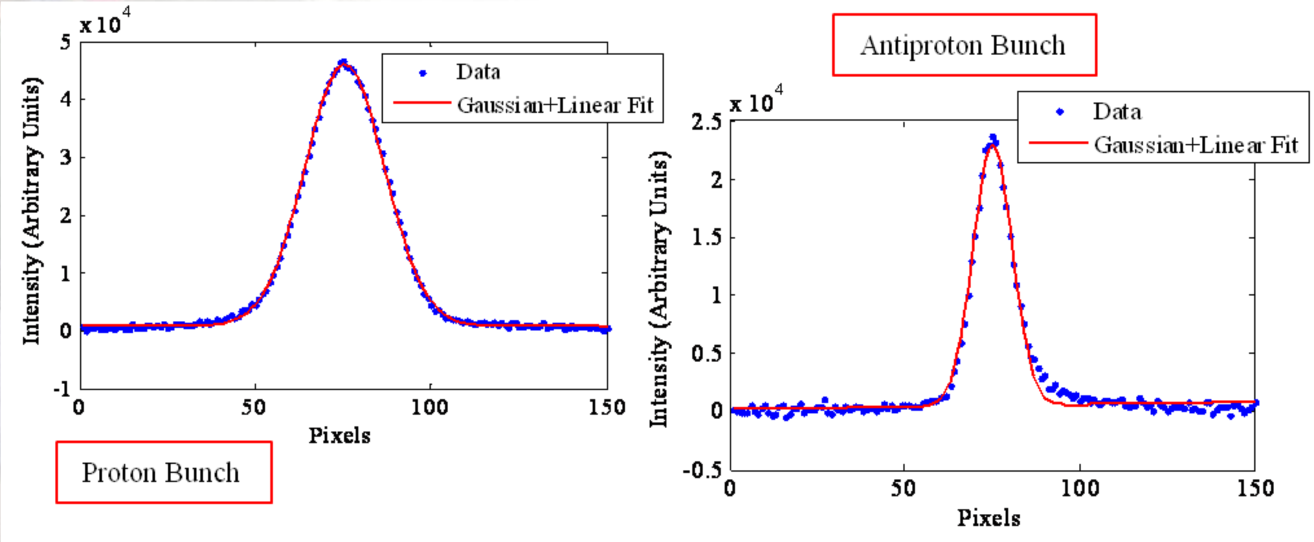
Antiproton ½ Dipole Object Distance = 503 cm
Antiproton Full Dipole Object Distance = 544 cm
Antiproton Image Distance = 85 cm
Antiproton Optical Magnification = 0.17

Proton Beam Image | Antiproton Beam Image



Acquisition

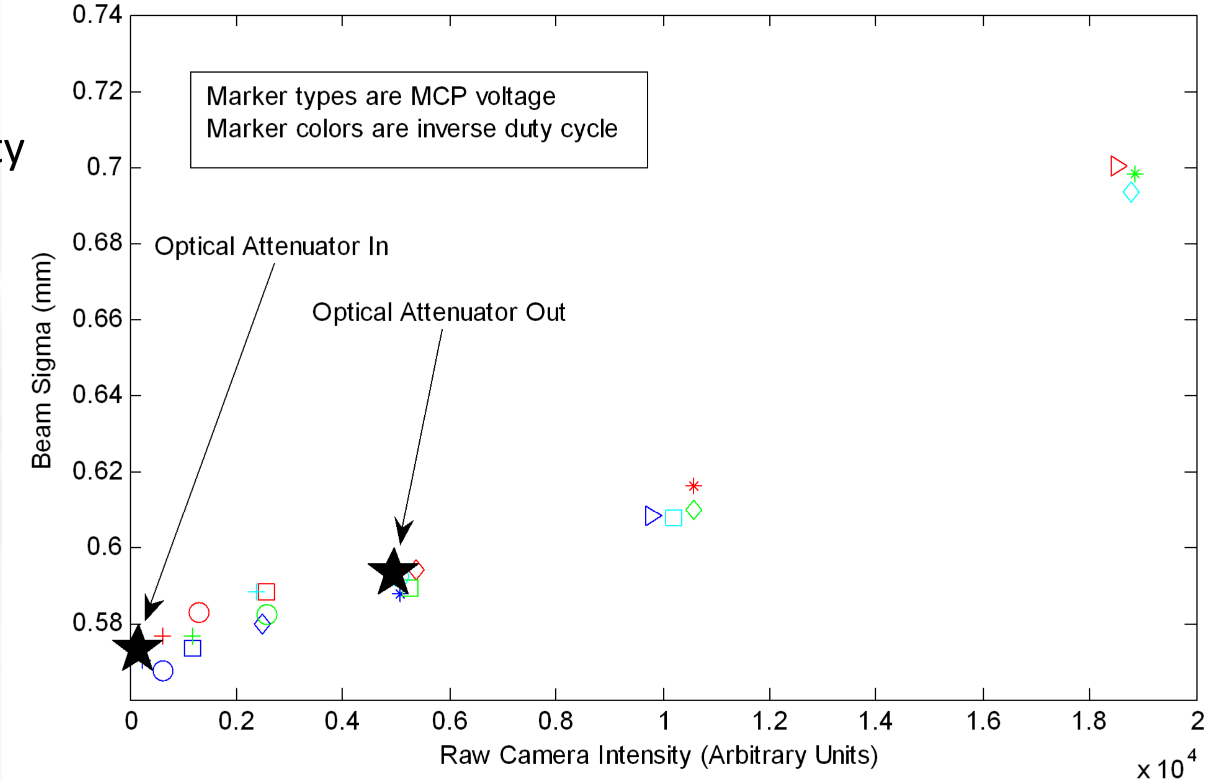
- Camera image acquired through LabVIEW program
  - Image consisted of a variable number of turns to optimize image intensity bunch-by-bunch
- Dark current image subtracted
- Line-by-line linear background subtracted from image
- Horizontal and Vertical Profiles fit with gaussian plus linear background
- Emittance evaluated from beam size plus lattice parameters plus dp/p



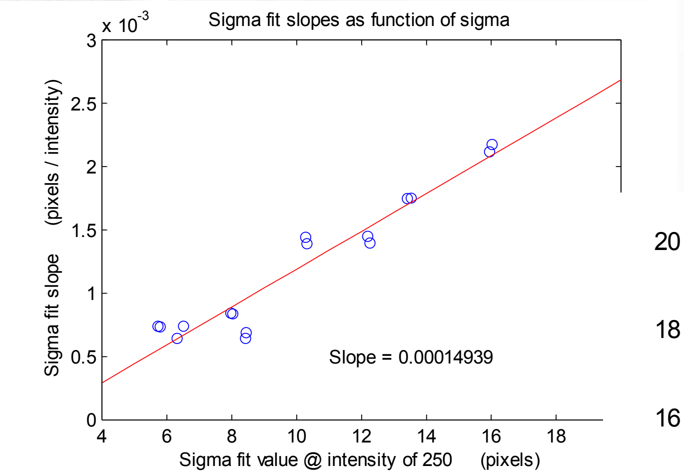
Intensity Effects on Measured Size

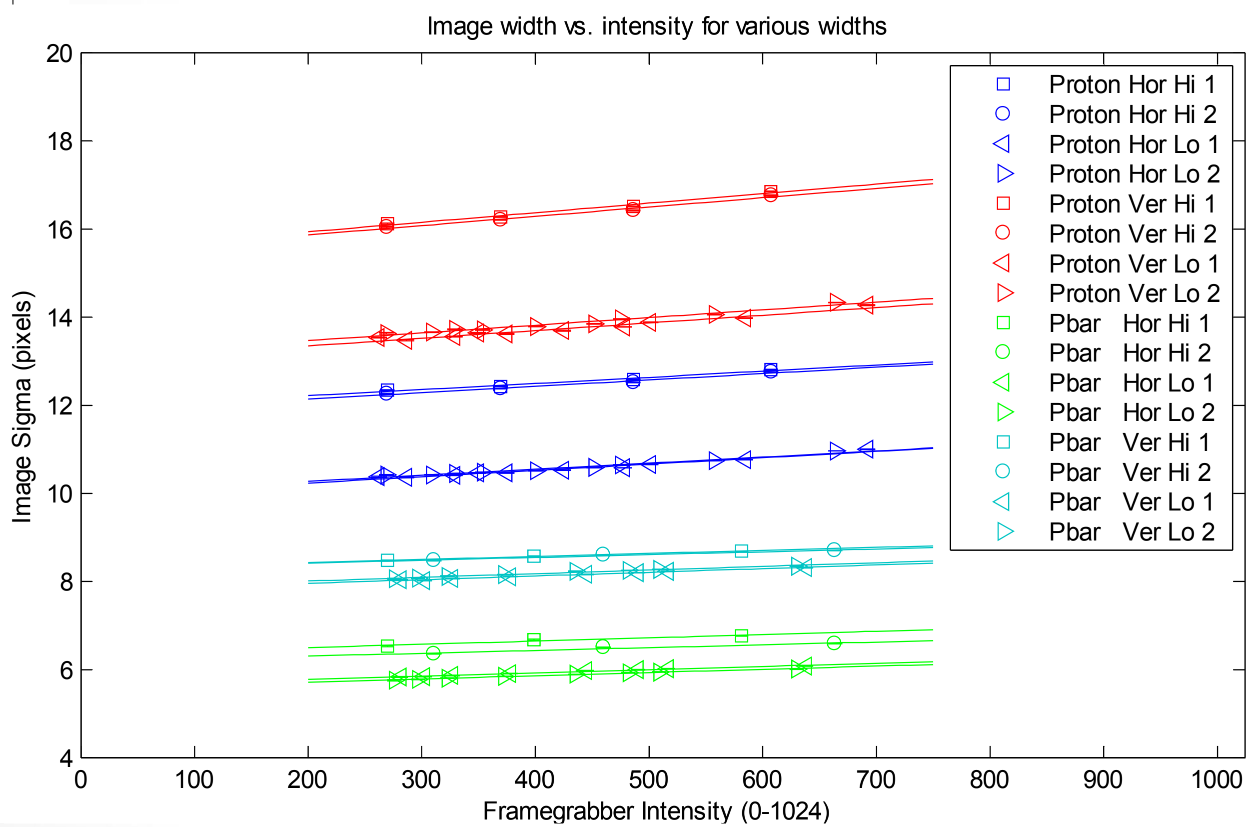
4 sources of intensity variation in the system
Intensifier gain
Intensifier gating duty cycle
Intensifier gating voltage
Synchrotron radiation intensity

All intensity effects can be parameterized with image intensity



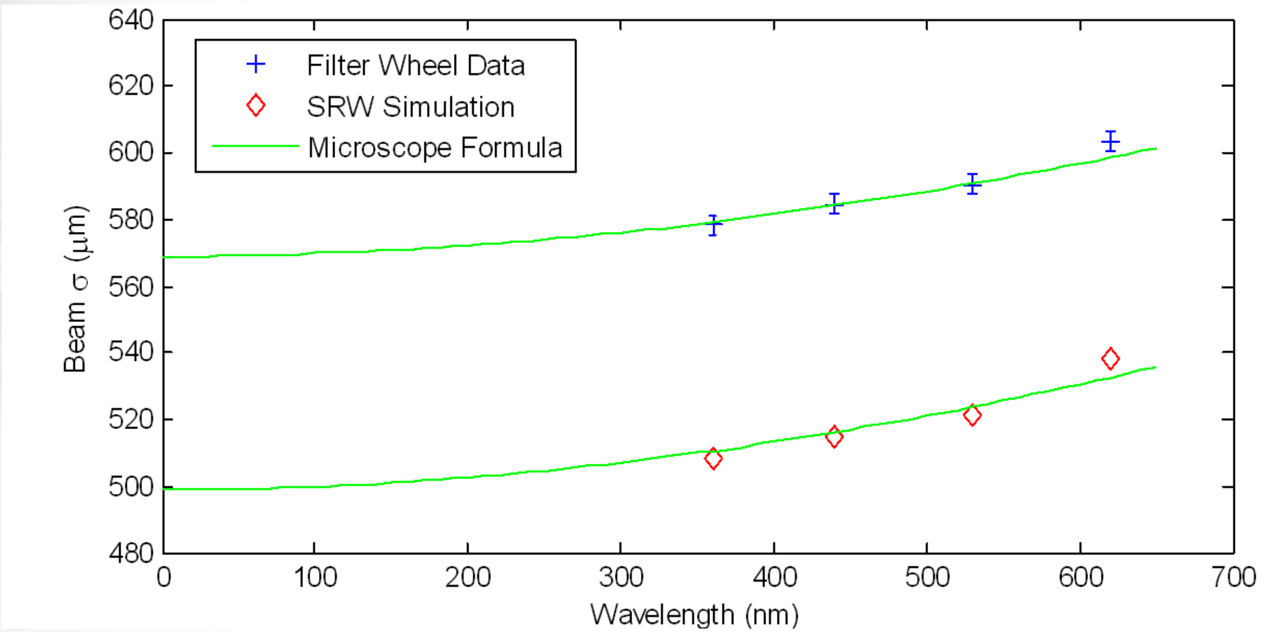
Intensity Effects on Measured Size





Diffraction

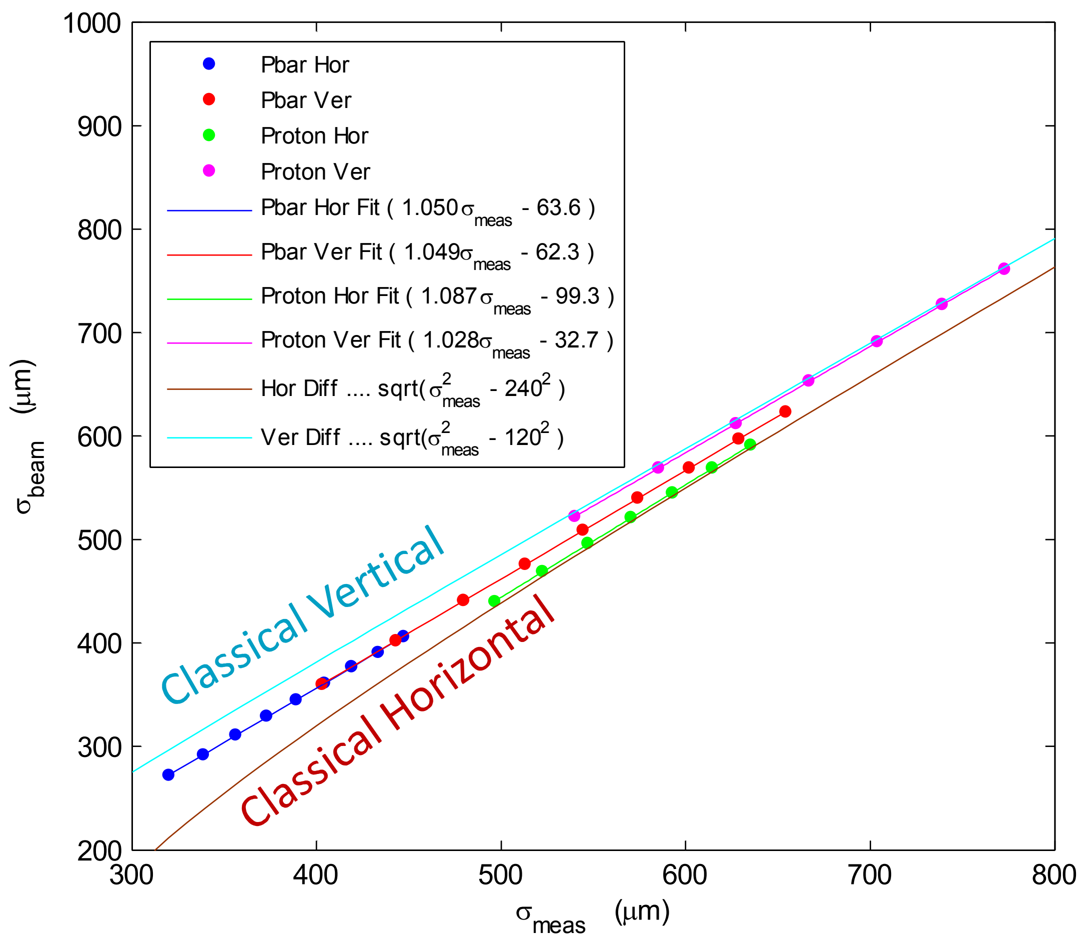
- Classical diffraction $r_{airy} = 0.61\frac{\lambda}{NA}$
- Plot is measured sigma vs. wavelength
  - Data points are taken with 10 nm bandwidth filters
  - Red points are SRW simulation



Diffraction

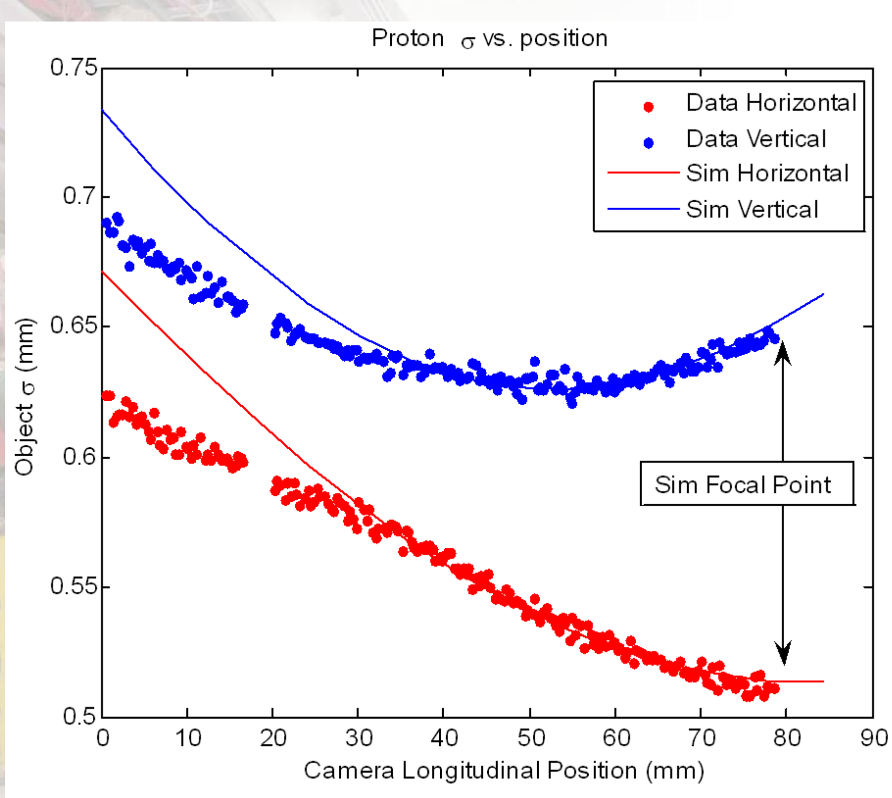
SRW simulation of diffraction as a function of sigma

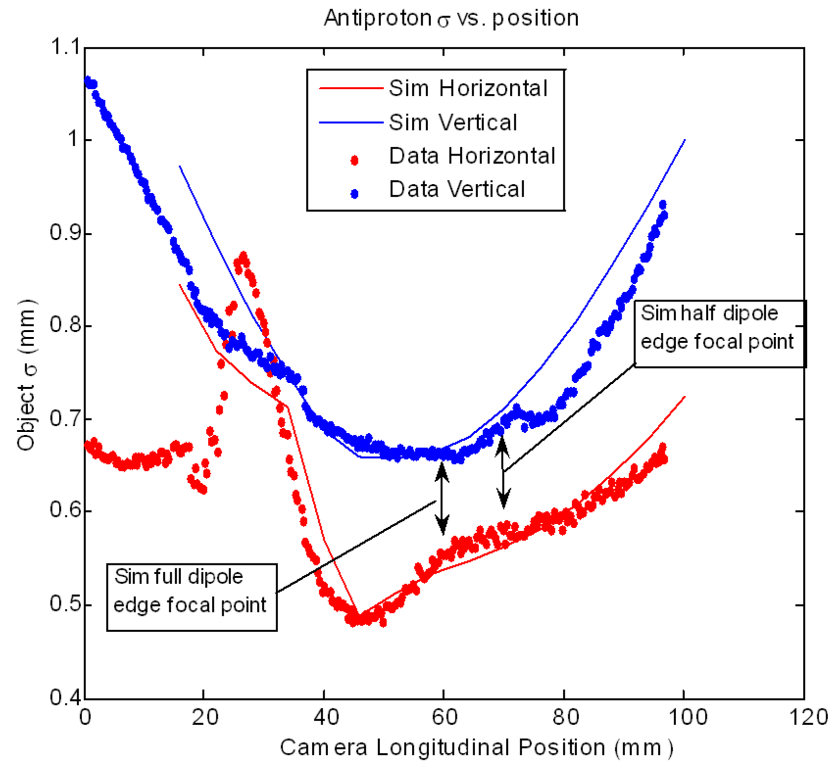
Proton simulations agree with classical but antiproton does not
- Diffraction varies across image
- Presumably due to multiple source points and/or body light



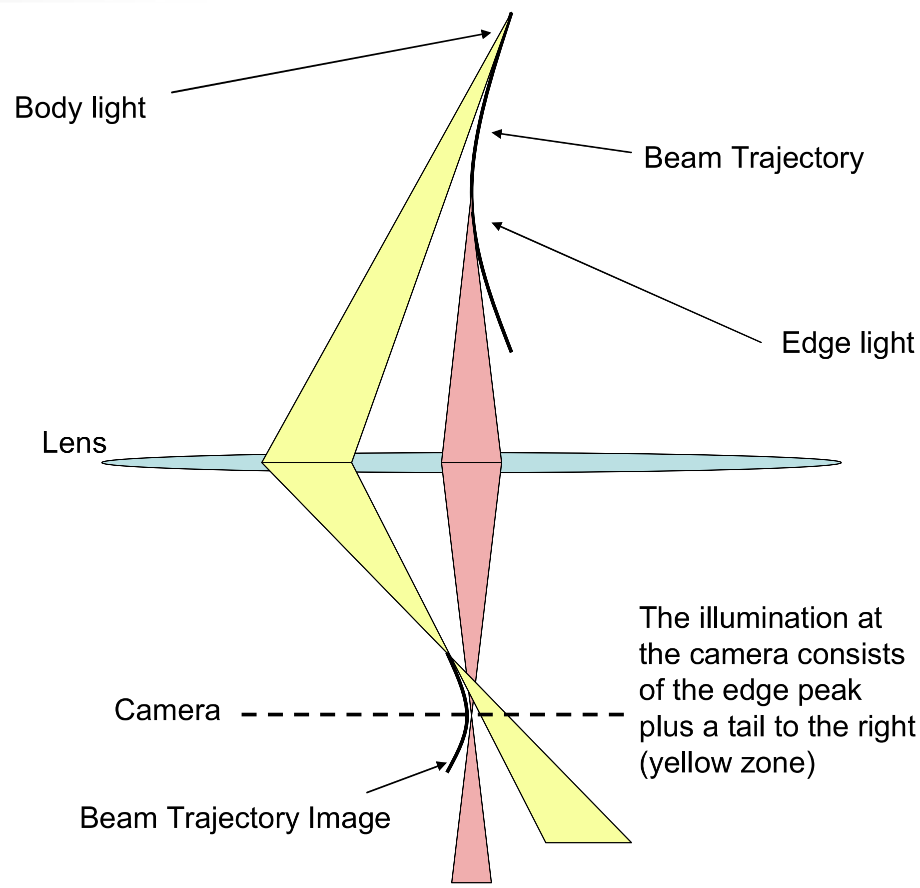
Camera Focus

Because synchrotron radiation is not a point source, focusing is a more complicated issue
Particularly in the antiproton case with 2 magnet edges



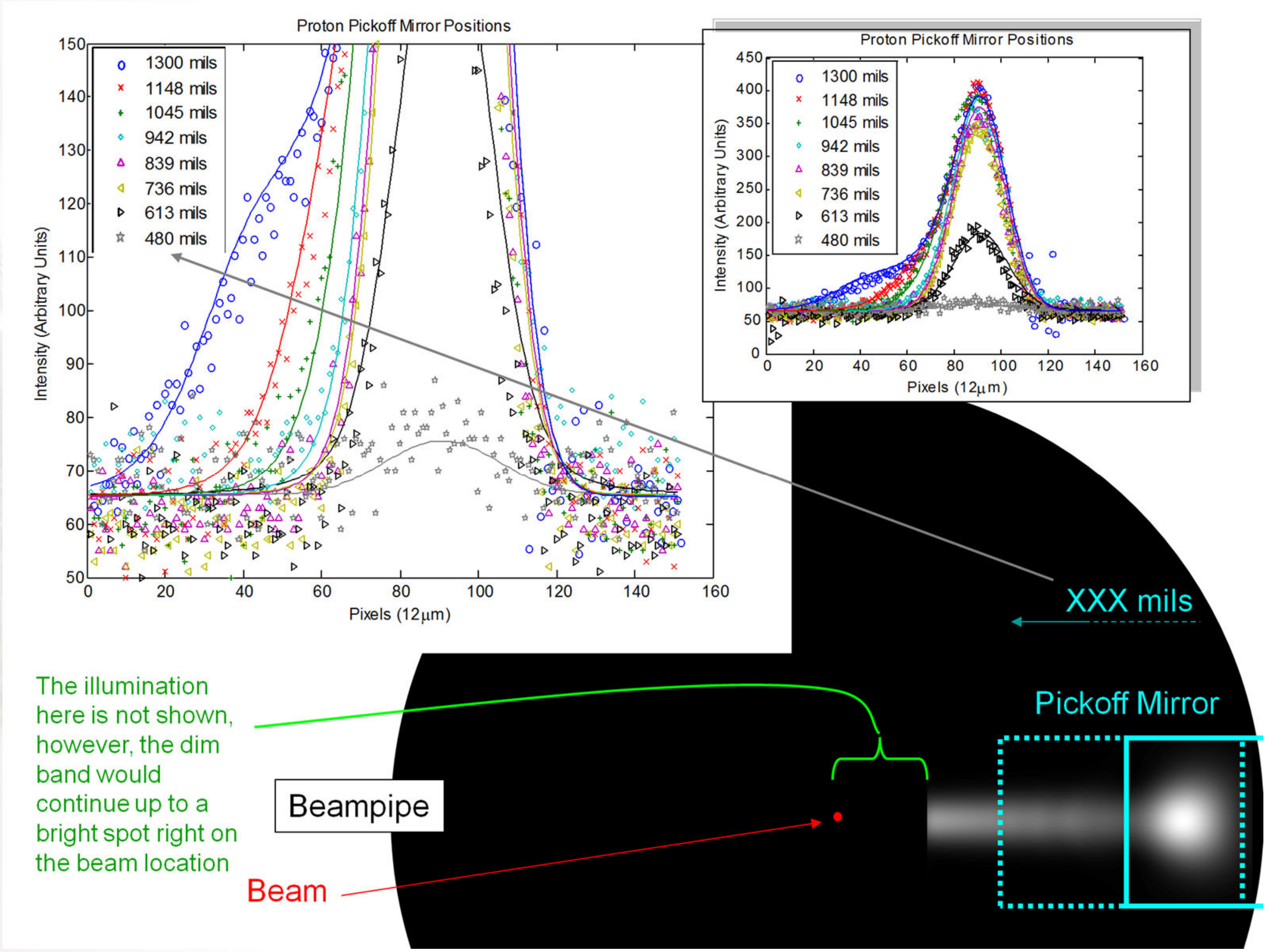


Impact of Extended Source

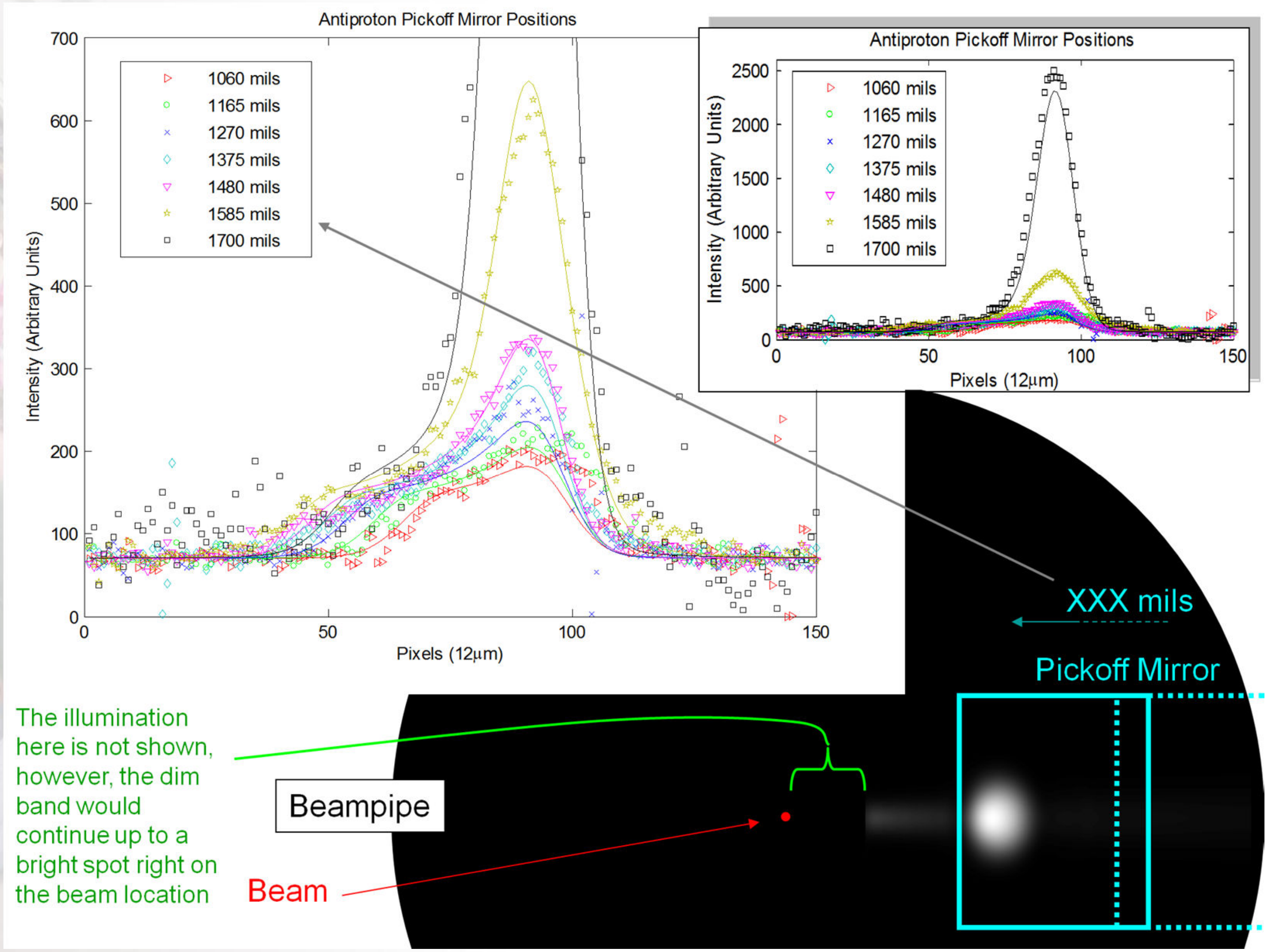


Proton Mirror Study

Moved the pickoff mirror which selected differing contributions of light



Antiproton Mirror Study

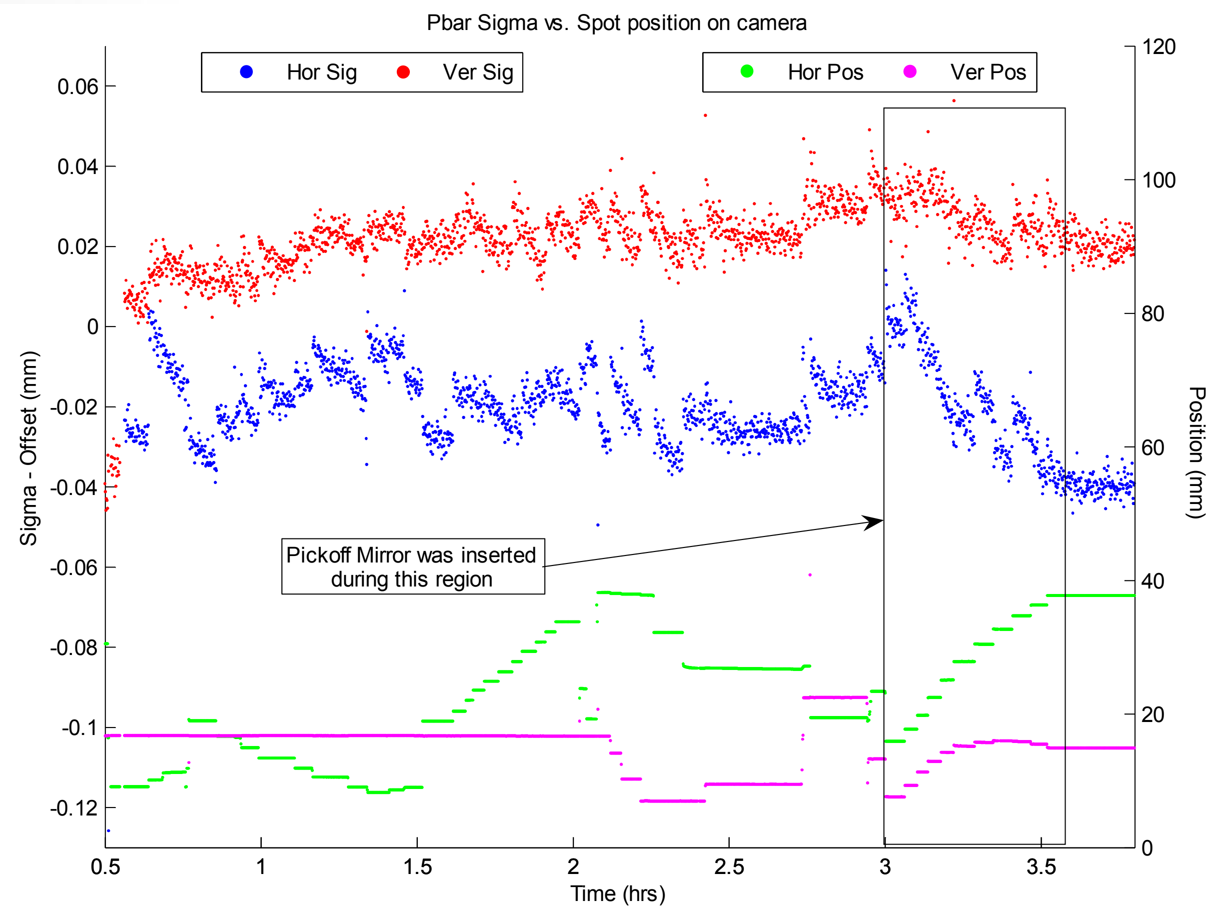


Resolution vs. Position on Intensifier

Variation of measured sigma as a function of position on the intensified camera

RMS is < 10 μm

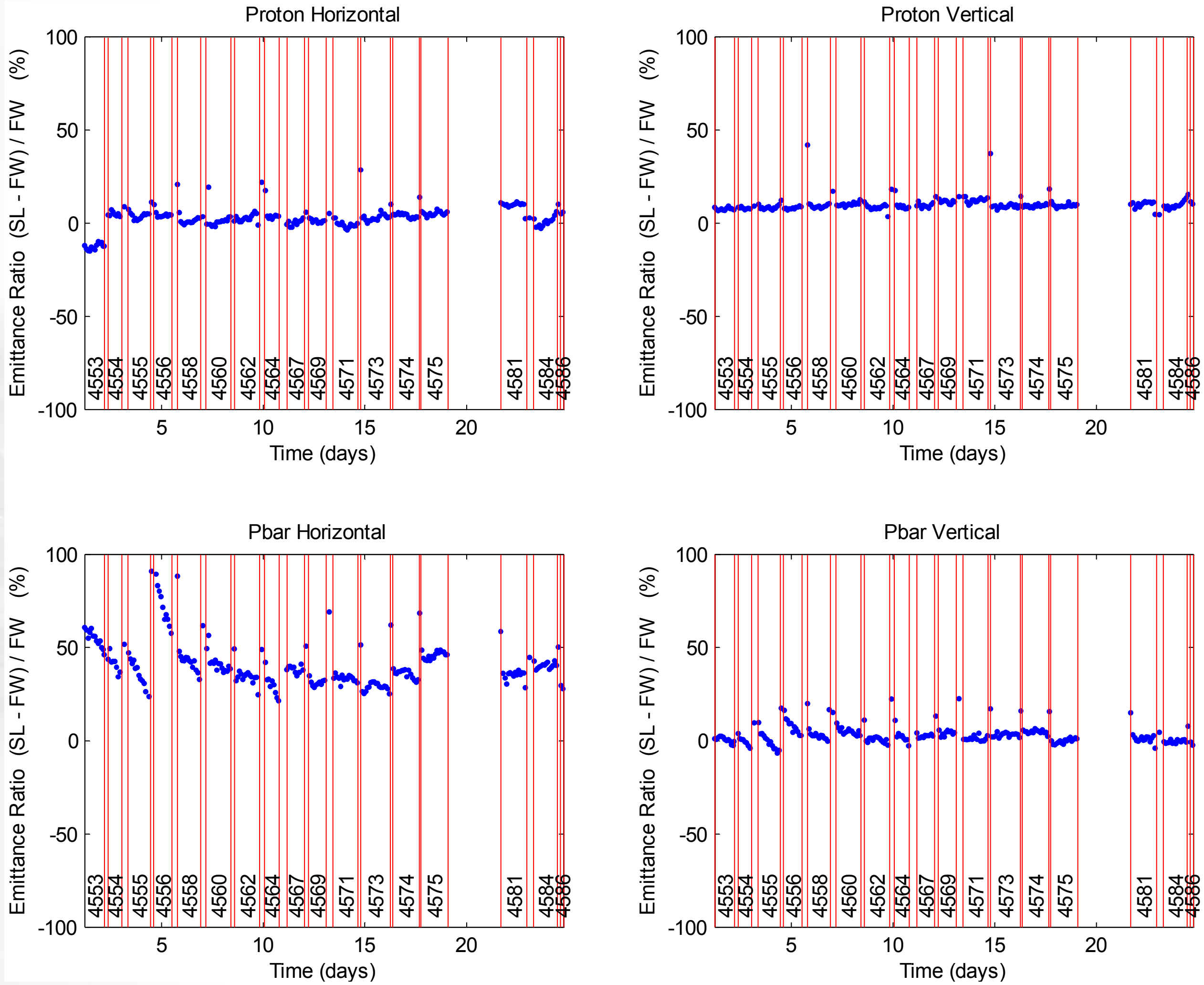
Saw signal degradation towards end of Tevatron



Synclite vs. Flying Wire

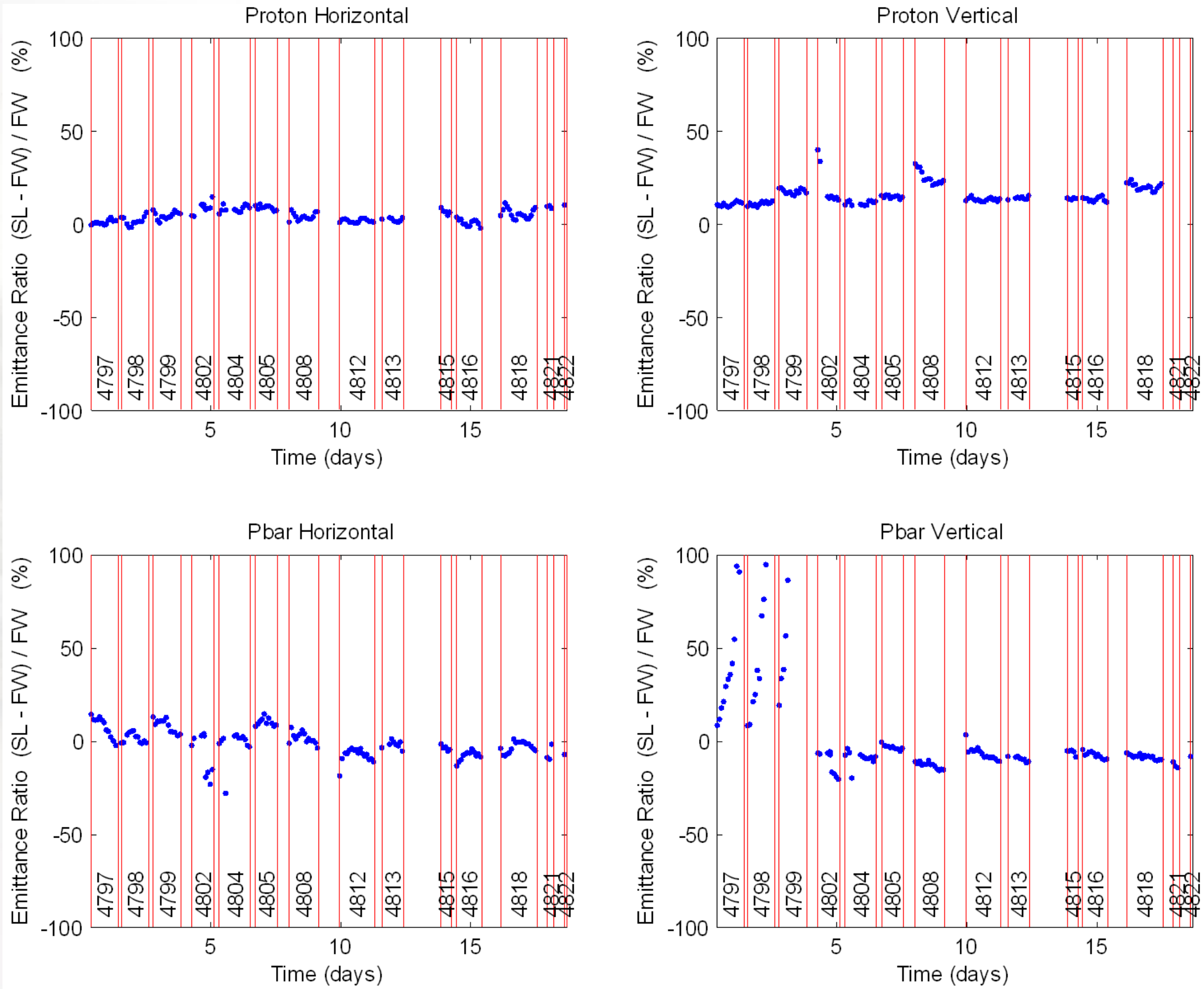
Overall resolution term obtained by flattening the comparison within store (red lines)

Pre 2006 shutdown



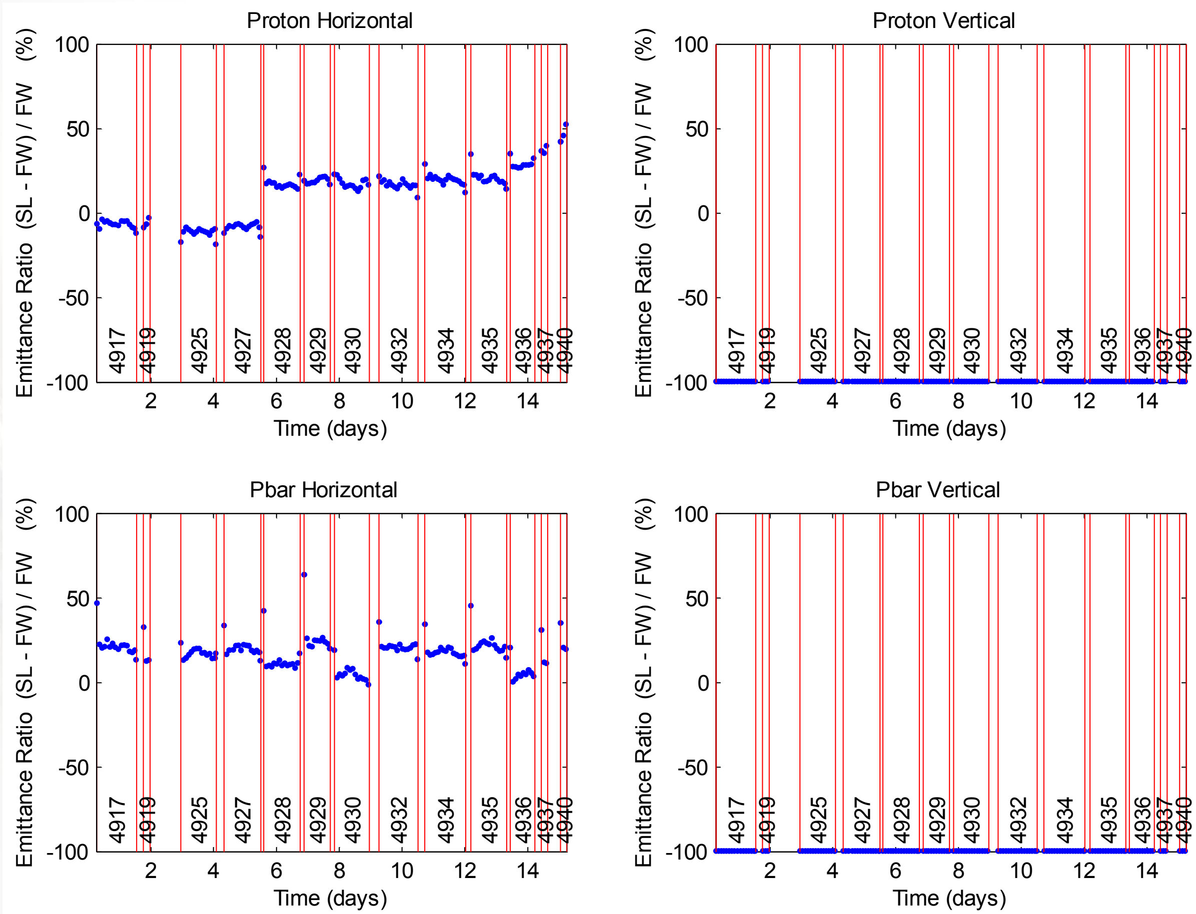
Synclite vs. Flying Wires

Post 2006 shutdown



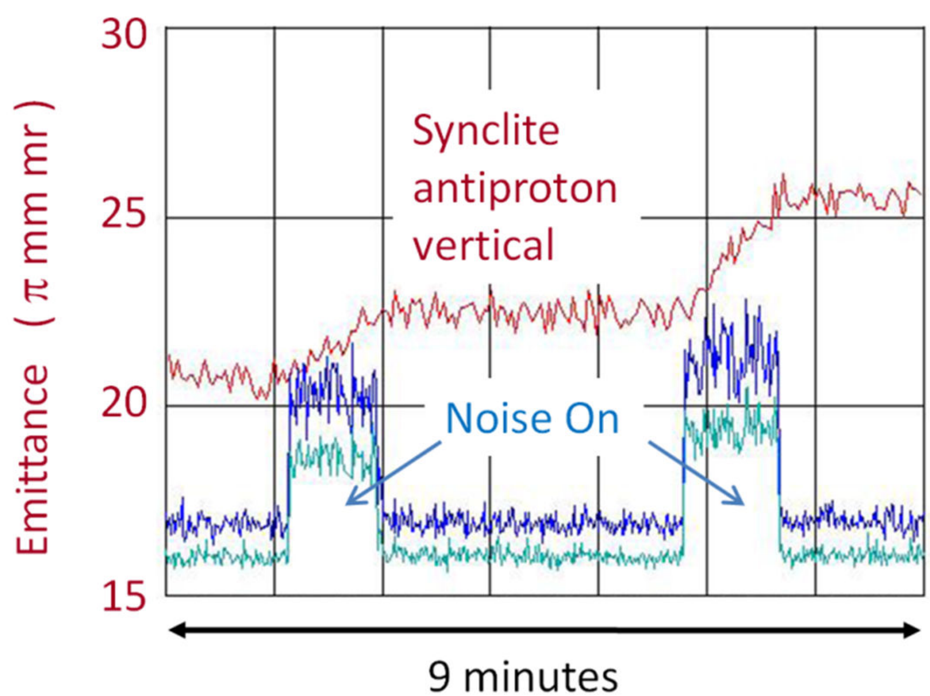
Synclite vs. Flying Wire

Variation from store to store



Synclite Use

- With the advent of electron cooling
  - Antiproton beam too bright
  - Proton beam emittance growth
  - Poor luminosity lifetime
- So… uncool the antiprotons a bit
  - Noise source kicker
  - Synclite antiproton signal as feadback



Abort Gap Monitor

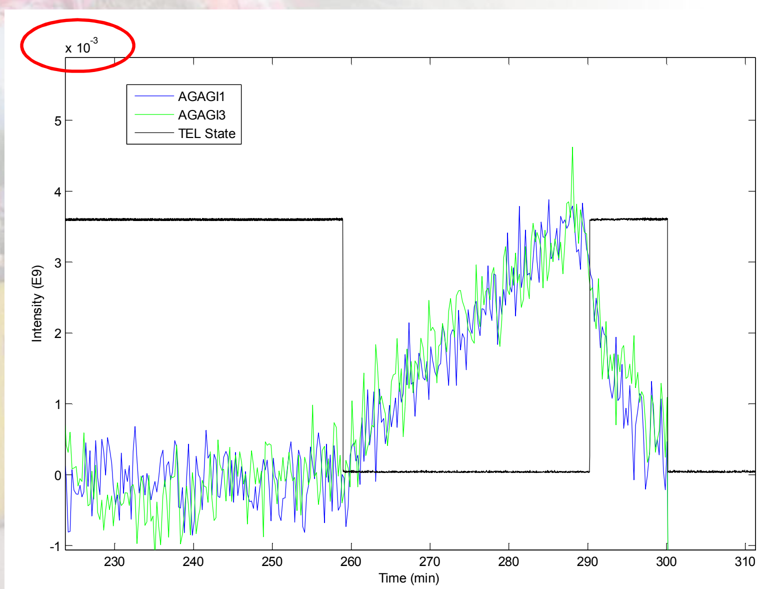
- PMT is a Hamamatsu 3-stage MCP type
- PMT charge signal is integrated for a specified duration and digitized
- Critical time was during the early part of the gap in which the abort kicker would fire
- The table below lists the number of photons or or photoelectrons after a particular optic element

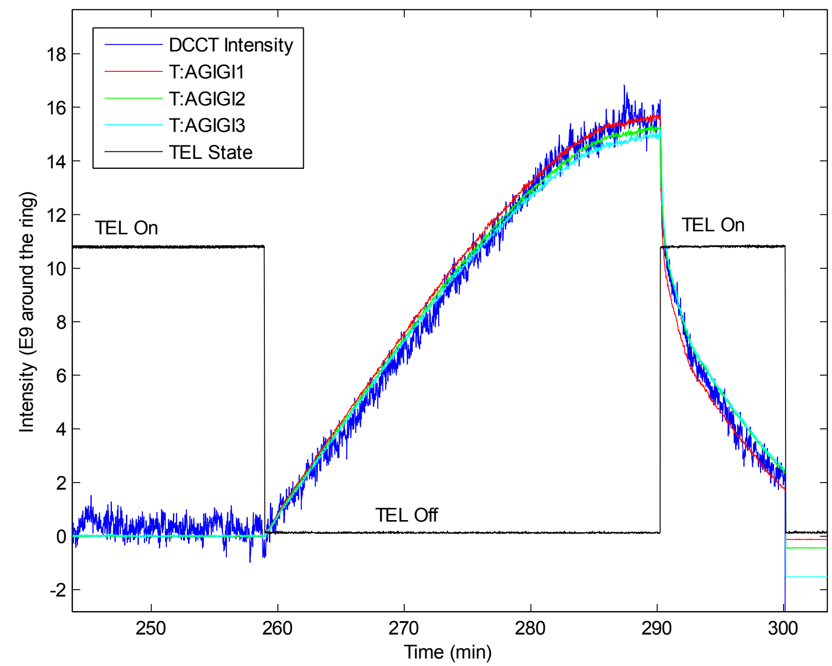
	Protons				Antiprotons			
Wavelength (nm)	**450**	**550**	**650**	**750**	**450**	**550**	**650**	**750**
# of photons / 100 nm / 10^9 particles	15,000	24,000	30,000	37,000	39,000	58,000	80,000	106,000
Optical Efficiency – Mirrors, etc…	30.0%				30.0%			
Quantum Efficiency	13.0%	8.5%	5.5%	2.0%	13.0%	8.5%	5.5%	2.0%
Duty Cycle (1 abort gap)	0.1				0.1			
# photoelectrons	191				496			

Abort Gap Monitor Calibration

Calibration of the abort gap monitor via

- Baseline-subtracted DCCT signal
- Tevatron Electron Lens (abort gap cleaner)

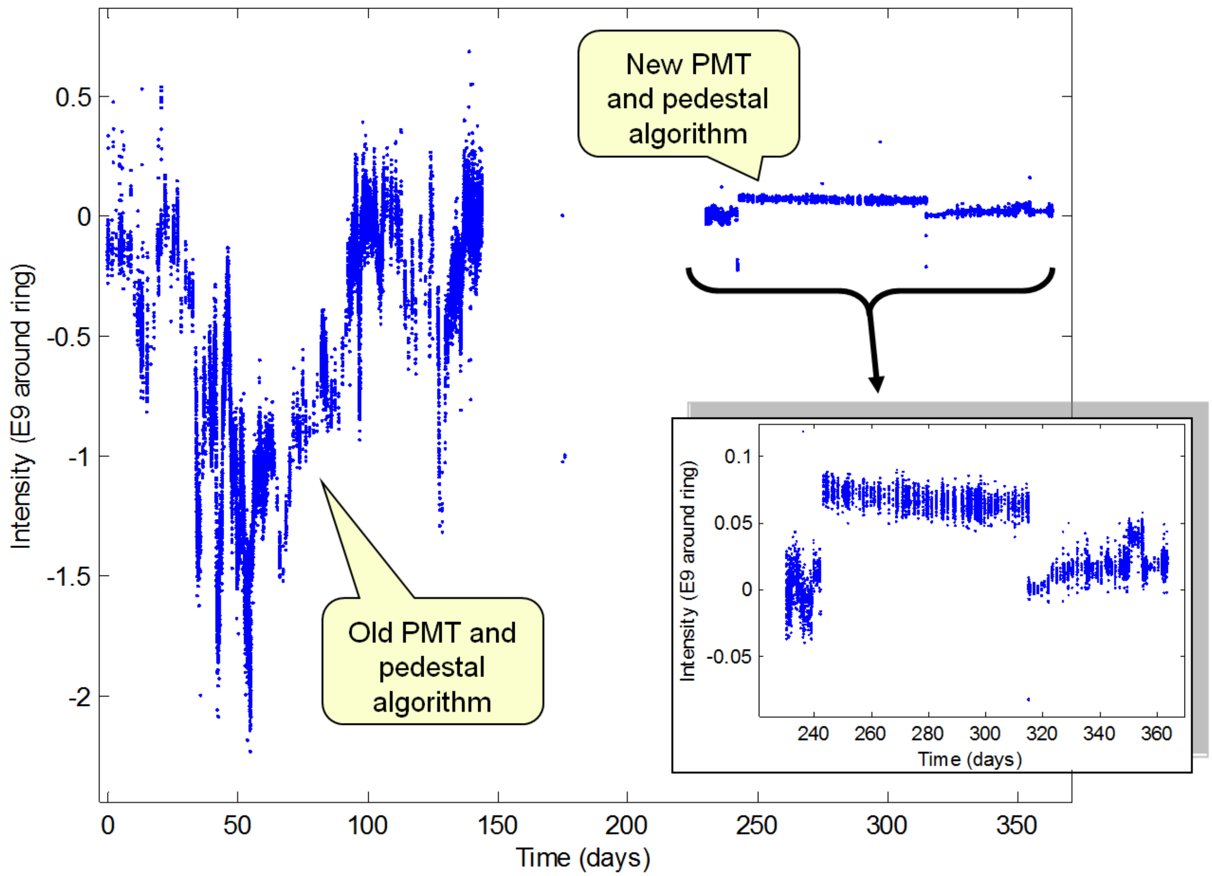




Pedestal Algorithm

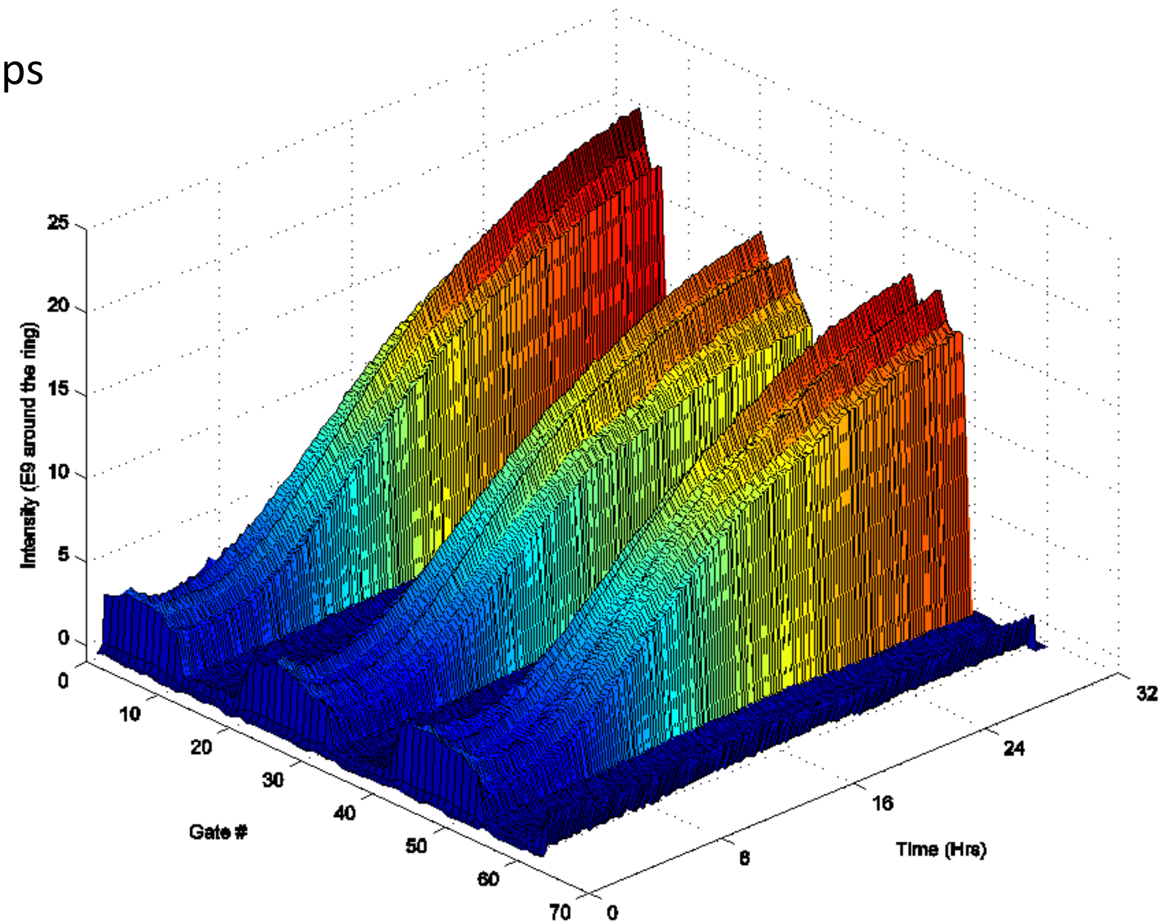
Pedestals have two components

- A beam-off pedestal
- A beam-on non-gated pedestal
    - Tracks changes over time



Beam Growth Between Bunches

Tevatron Electron Lens
keeps the level low in the gaps

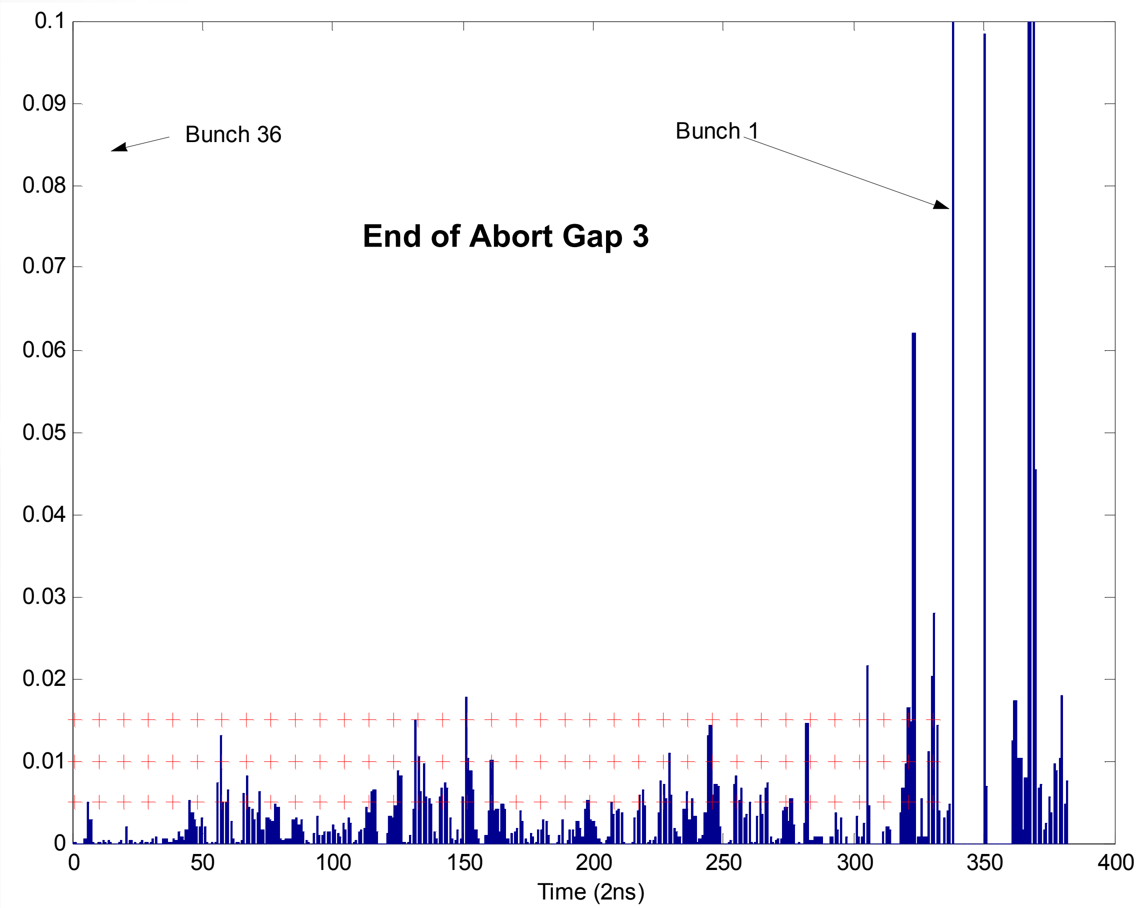


Bunched Beam From Main Injector

Measurements in photon counting mode

Bunch 36 is 2 microsecs to the left of this plot

The red crosses show my best guess at the location of the center of the buckets.



Conclusions

- Synclite
  - Worked well
  - Should have had a uniform illumination calibration source (actually did, but not very uniform)
  - Should have measured the optical resolution
    - Planned to but didn't finish it