Xray Beam Size Monitor (xBSM)

Bunch-by-bunch measurements of beam profile for fast emittance determination

- Image individual bunches spaced by 4ns.
- Transverse resolution < 10~15μm beam size
- Non-destructive measurement.
- Flexible operation.
- Start simple, allow various upgrade paths.

This talk will emphasize current work on detectors. See John Flanagan's talk for recent results from optics studies.

Basic Plan

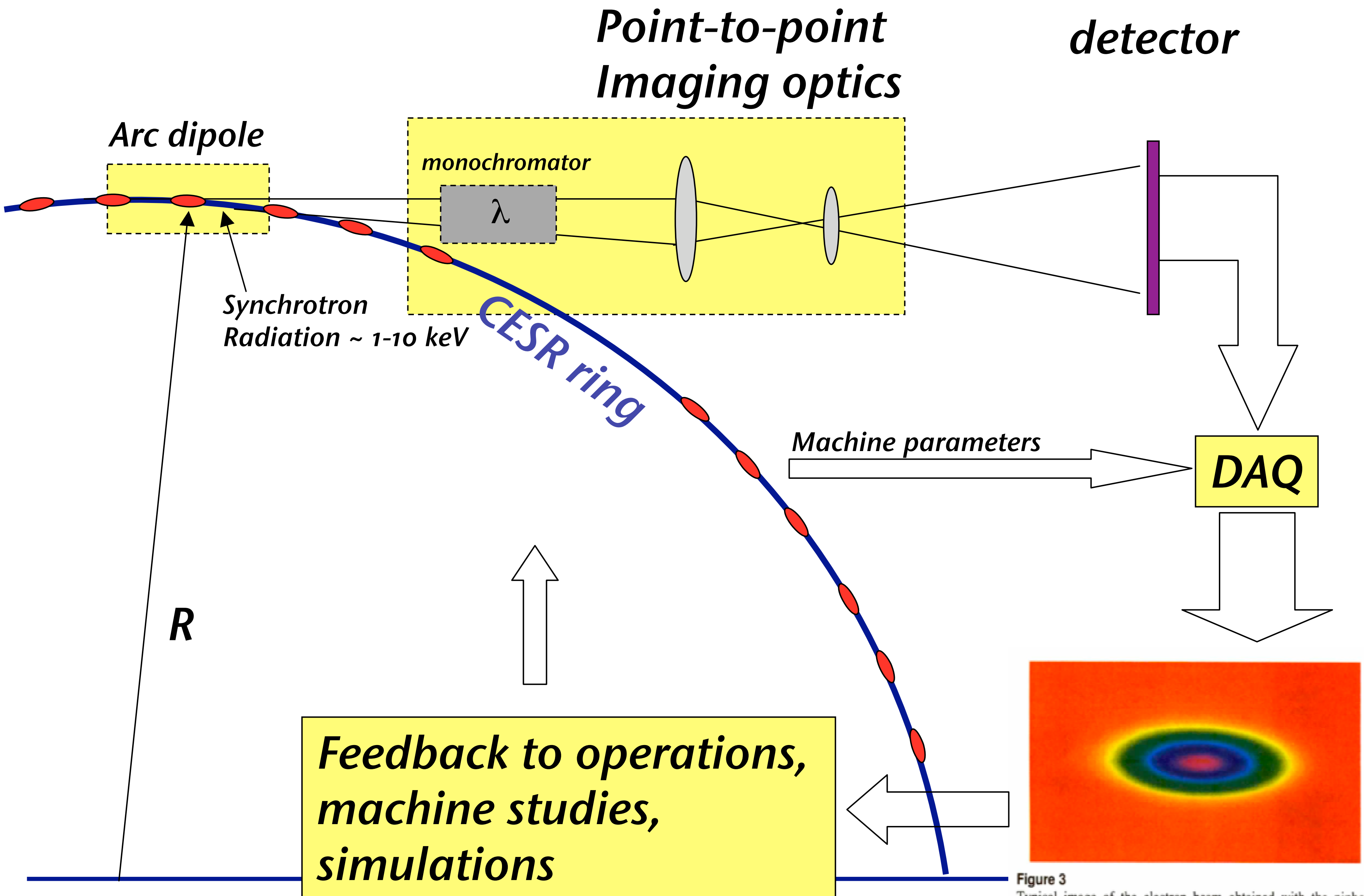
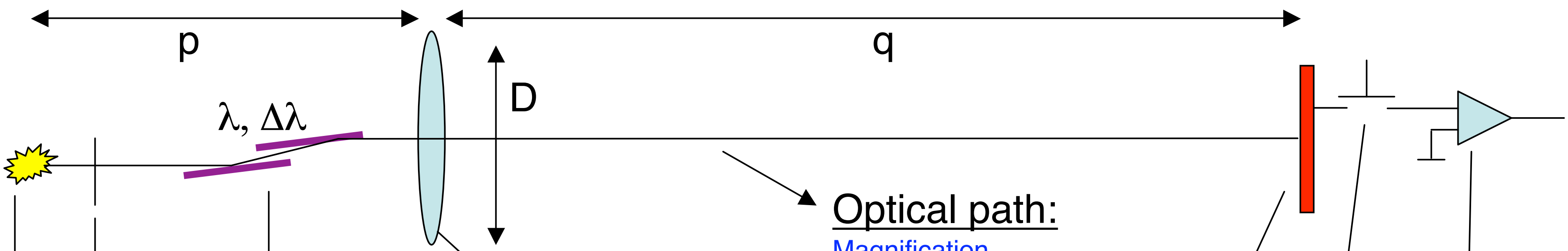


Figure 3
Typical image of the electron beam obtained with the pinhole camera.

Key Features of CesrTA xBSM

- High speed (4ns), low resolution (10um). One dimension okay.
  - Choose tradeoffs to achieve this particular mix of performance characteristics
- Crucial Problem: Low photon flux per bunch passing
  - Ultimate statistical limitation
  - Dominates usual optical resolution issues
- Short time available limits fundamental development
  - Use commercial/existing solutions where possible
- 2 GeV beam energy $\rightarrow$ xray energy is low, 2-4 keV
  - All vacuum system.
  - Early testing is difficult: vacuum windows eat flux
  - Results presented here are all from 5.3 GeV running

Features that affect performance



Optical path:
Magnification
Backgrounds/baffles

Optical elements:
Type, number
Diffraction
Chromaticity
Transparency/Reflectivity
Thermal power

Detector:
Pixel size
capacitance
Absorption length
Carrier mobility / drift velocity
Overglass, metallization, dead layer
Radiation hardness

Monochromator:
Surface quality
- intrinsic flatness
- thermal distortions

Choice of λ
Bandwidth Δλ/λ
Reflectivity
Thermal power

Gate:
Charge injection
Bandwidth

Vacuum window:
Absorption, spectral hardening, thermal power
Uniformity

Source:
Dipole, undulator;
Diffraction from source of limited angular divergence
Bunch current, critical energy, etc

Readout:
Noise figure
Bandwidth

Color coding:
- Photon yield & spectrum: dN/dE
- Resolution - Point Spread Function
- Distortions
- Speed
- Other

Parameters for CESRTA xray Beam Size Monitor

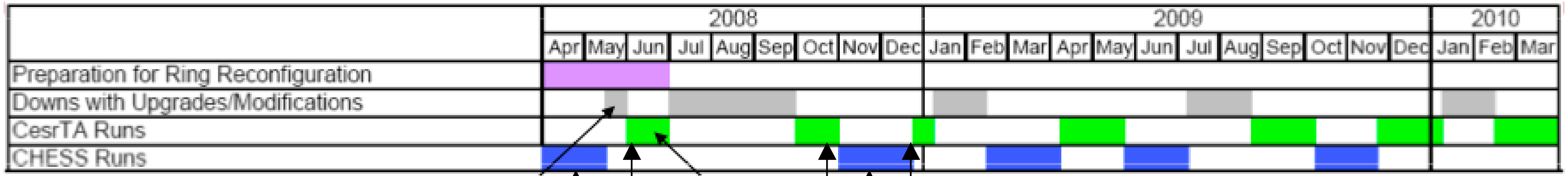
Beam and Radiation Parameters

Parameter	Value	Units
Beam energy	2.0	GeV
Bunch current	1.0	mA
Bunch Charge	1.6×10^{10}	
Vertical size (σ_y)	$10 \sim 15$	μm
Lorentz γ	3914	
Dipole bend radius	31.654	m
Critical energy	0.564	keV
Critical wavelength	2.2	nm
Photon energy	2.0	keV

Optical System Parameters

Parameter	Value	Units
Source to lens distance	4.0	m
Lens to detector distance	12.0	m
Height of synch rad fan at lens	0.63	mm
Image magnification factor, M	3.0	
Detector Pixel Size	25	μm
Lens diameter	1.02	mm
Number of Fresnel zones	140	
Focal length	3.0	m
Transparency	0.18	
Multilayer mirror bandwidth	0.010	
Multilayer reflectivity	0.36	
Overall transmission factor	0.023	
Energy transmitted, per bunch	1.04	MeV
Ionization charge in detector	39.9	fC
Resolution: detector pixellation	2.4	μm
diffraction at source	1.3	μm
chromatic aberration	0.5	μm
Fresnel zone plate PSF	0.3	μm
Total resolution	2.8	μm
Number of photons on detector	521	

Our present status & near-term plans



1. Commission new electronics, evaluate detector response

2. Low energy running. Study optics - slits, simple coded aperture. High energy running: probe detector “features”

3. New (almost) windowless vacuum line (e^+). Install Fresnel Zone Plate, new detectors. Aim for “real” measurements.

4. Detailed studies. Systematics.

Later:

- e- side
- More sophisticated coded aperture
- Upgrades as needed

Detector studies

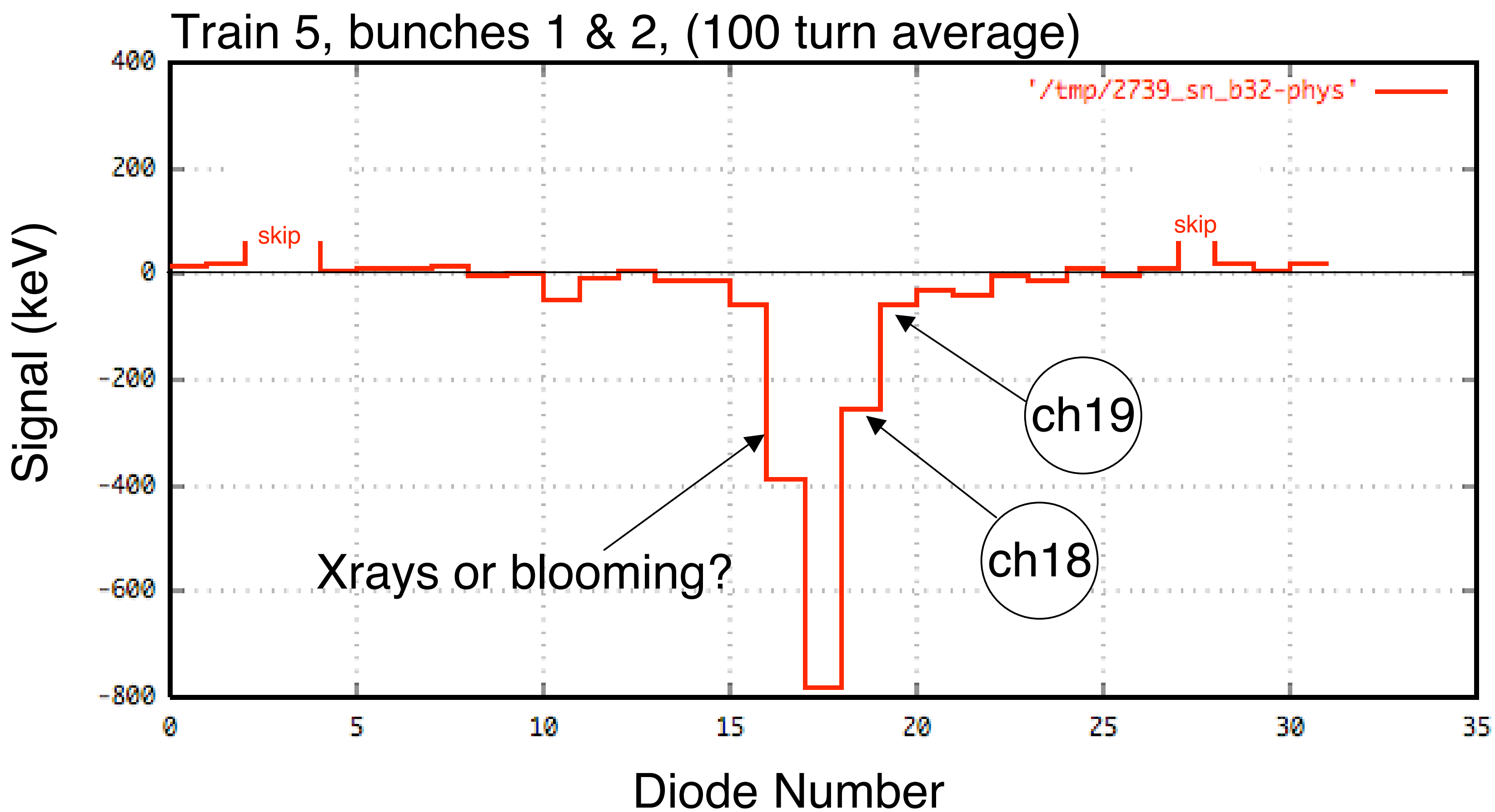
- What follows is a brief review of the features we have discovered in our detectors.

- At this point there are more questions than answers…

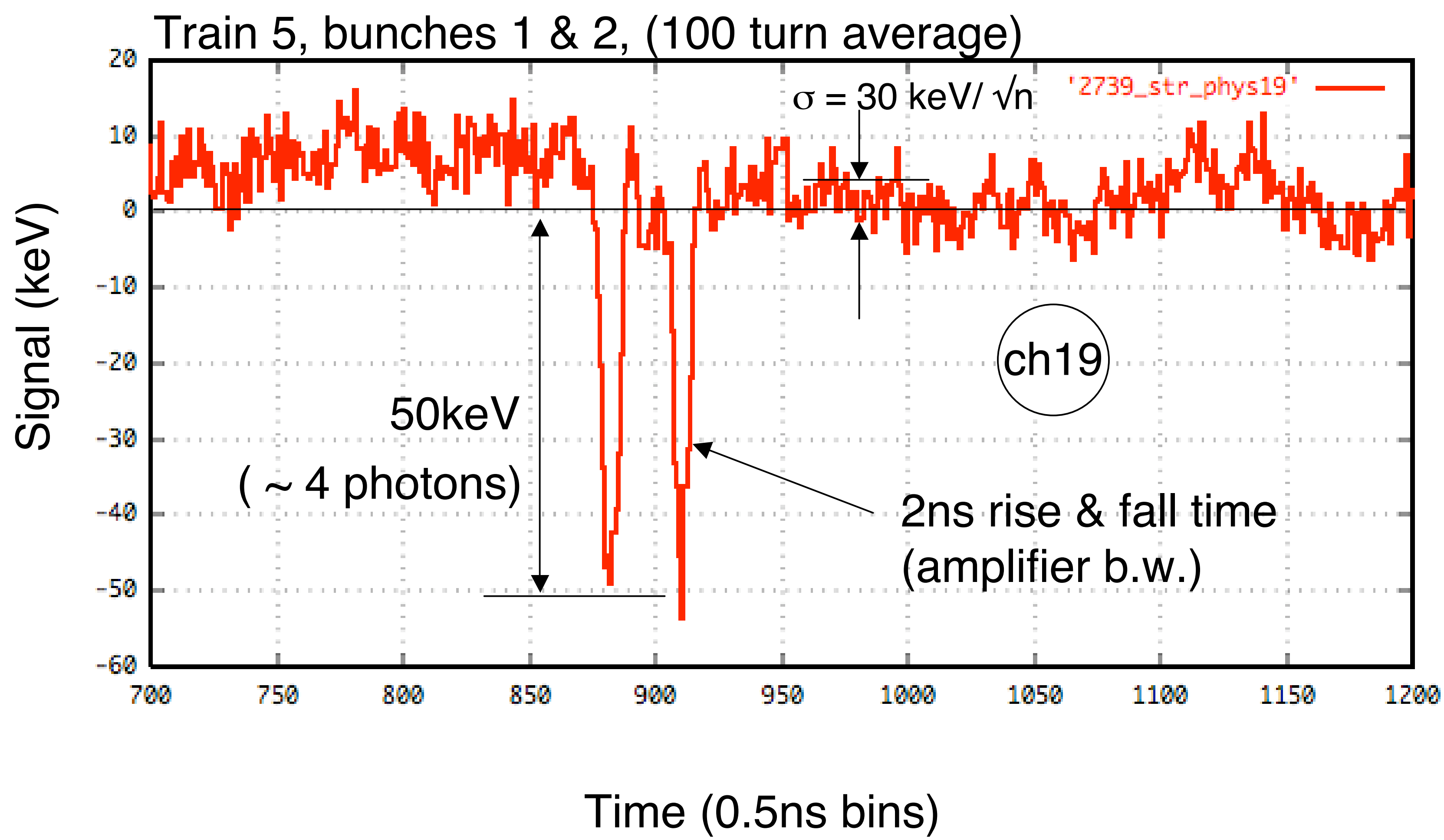
- Note: throughout these slides, the conditions are:
  - Bunch currents between 0.1 - 1.0 mA
  - Beam energy 5.3 GeV, typical photon energy ~ 15keV
  - No lenses, pinholes, coded apertures etc.
  - Narrow collimator just in front of detector (slit ~ 25um???)
  - 100 turn averages -- enhanced S/N
  - Signal sampling 0.5ns interval
  - Reverse bias on detector between 5V and 20V (enough??)

A sample "image": shadow of nearby slit

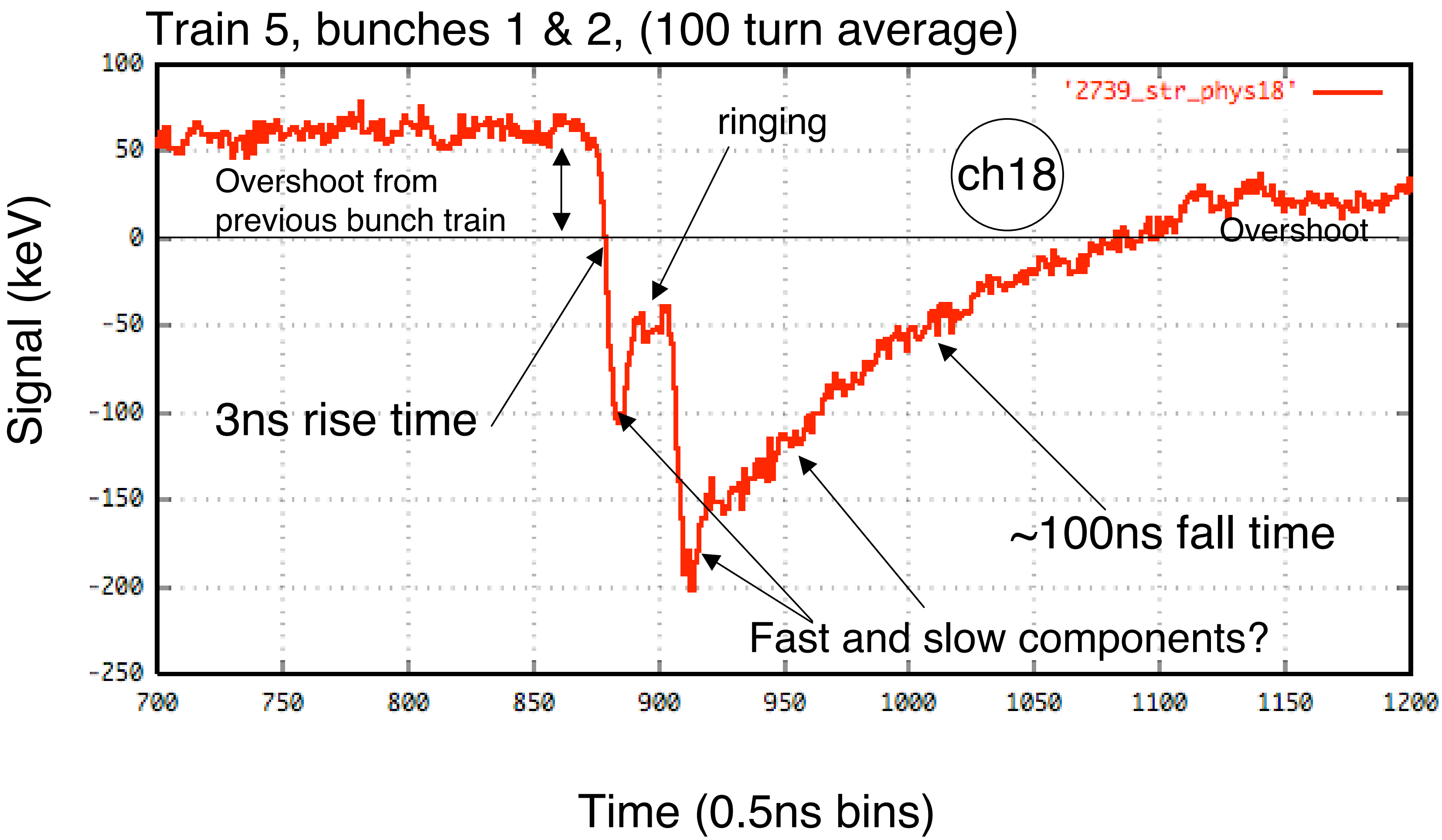
Conditions: ~0.5mA/bunch, very tight collimation in front of detector to try to illuminate a single pixel (approximately)



This is what we thought it would always be like:



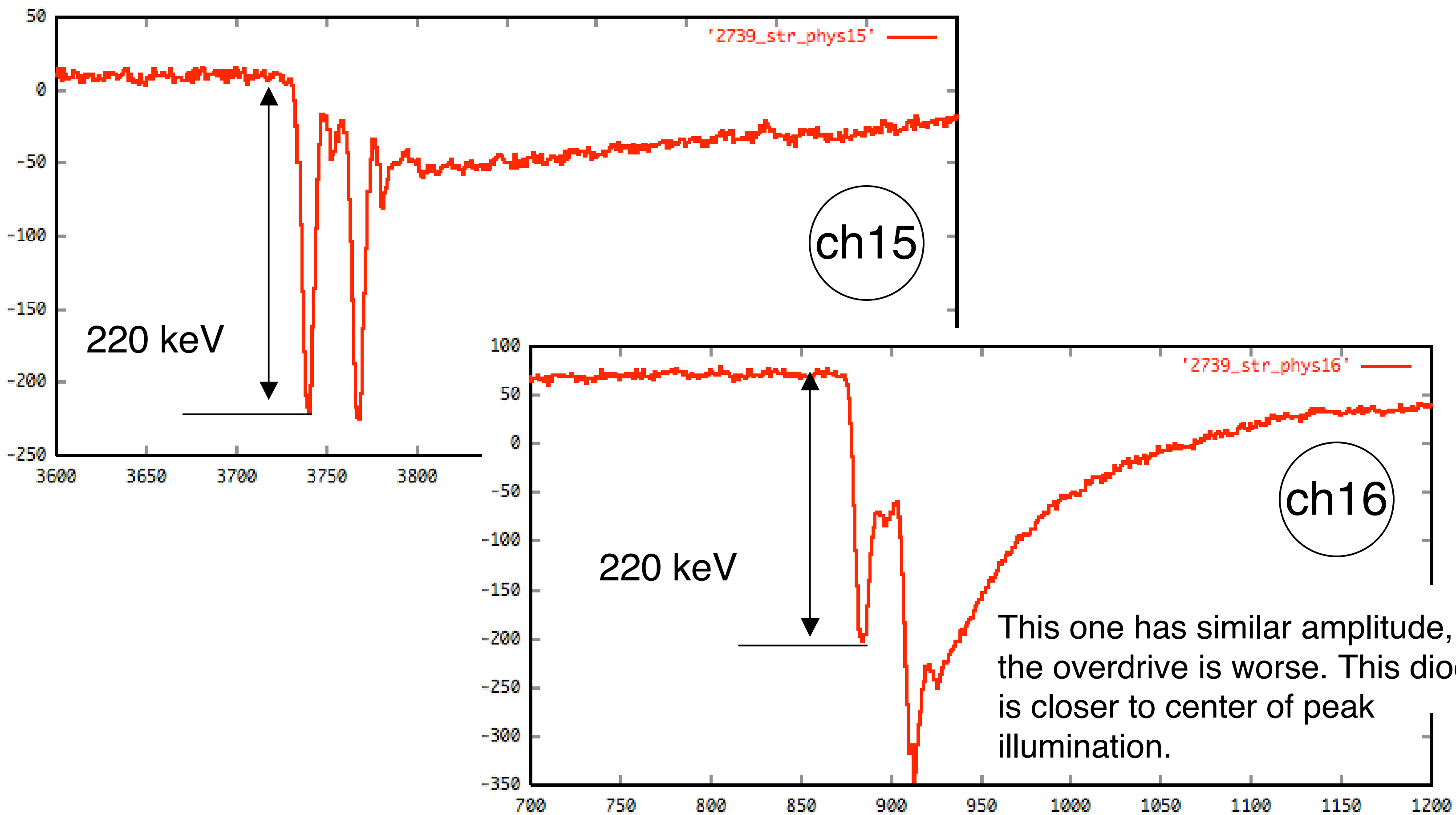
But it ain't. Heavy signal causes problems:



Comment: signal size is well within range of electronics. ADC maxes out at 1000 keV; preamp linear to 3000keV. The problems shown here are in the detector response.

Transition from "okay" to "overdriven"

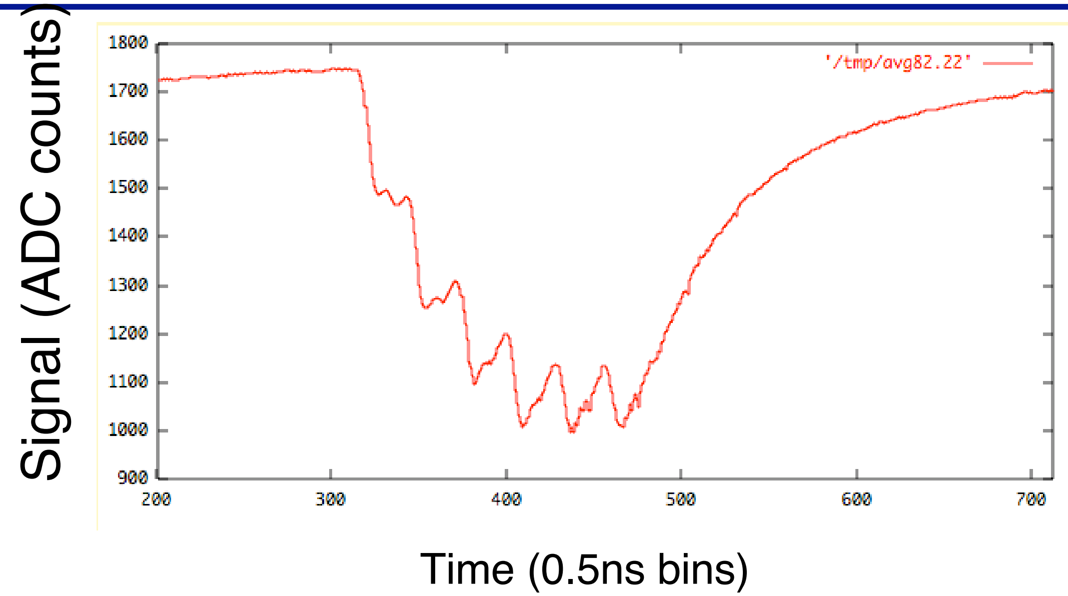
In this trace, for intermediate signal amplitude, the fast component is still dominant but the slow one is evident as a broad, low tail.



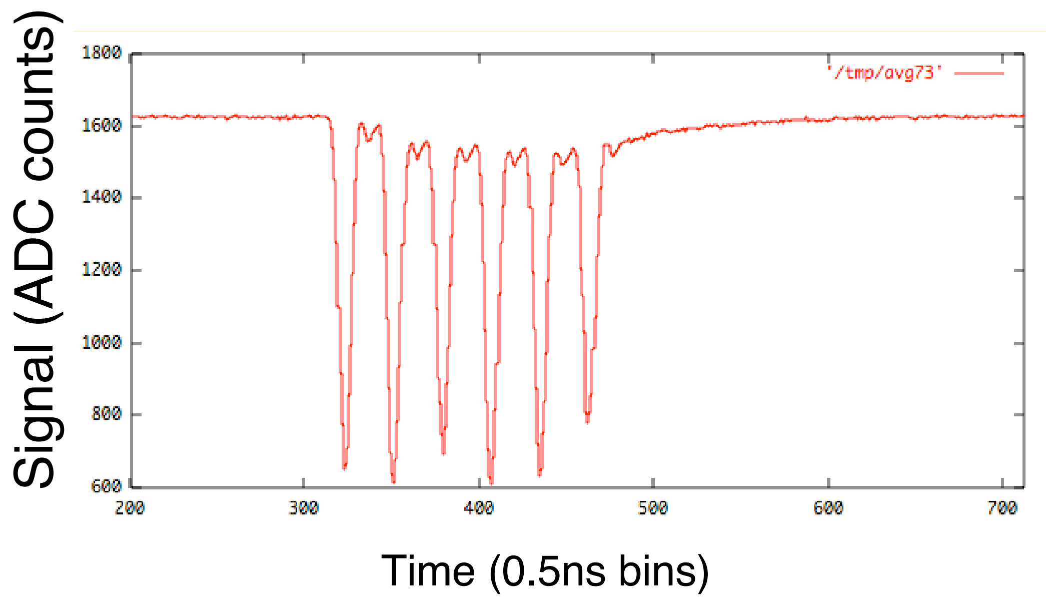
This one has similar amplitude, but the overdrive is worse. This diode is closer to center of peak illumination.

Different detectors show different responses

Hamamatsu InGaAs
512 photodiode array
25um pitch



Emcore GaAs
singleton photodiode
46um diameter

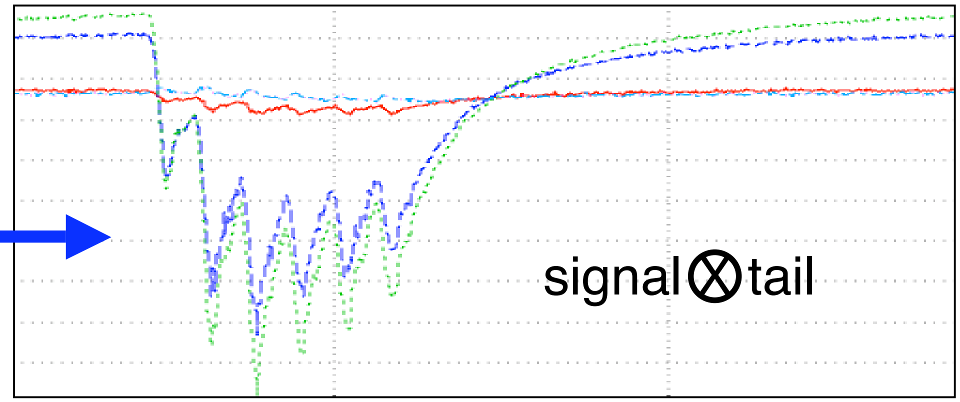


Deconvolution may recover signal

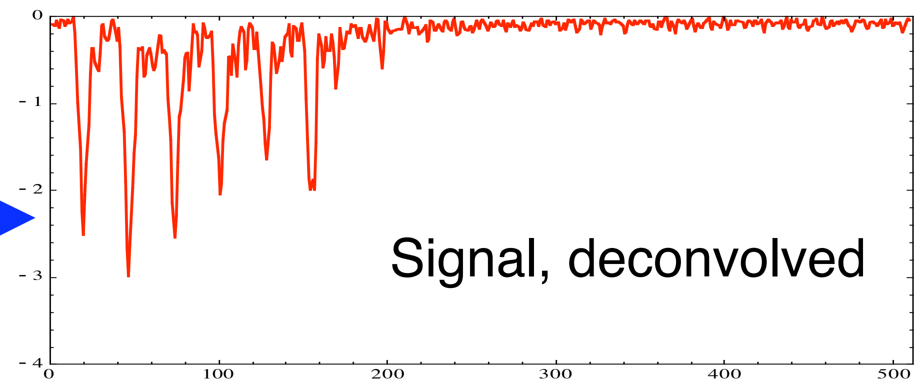
(at least in easy cases with good S/N and 14ns spacing…)

Hamamatsu InGaAs Photodiode array.

Baseline recovery issues are evident…



Underlying signals can be reconstructed by deconvolution:

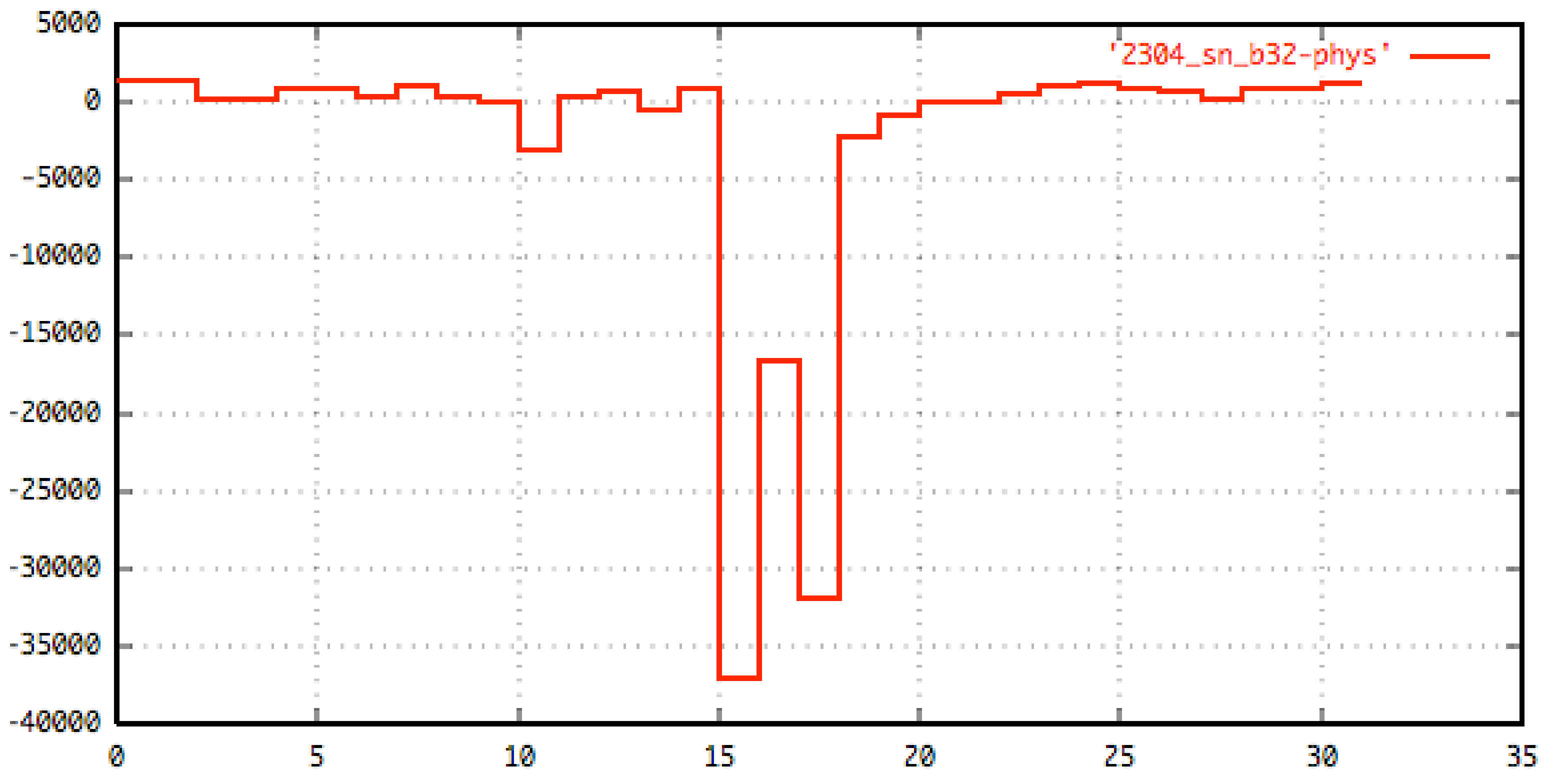


Even this isn't perfect. Remember, what we need is amplitude.

Lateral charge sharing: blooming

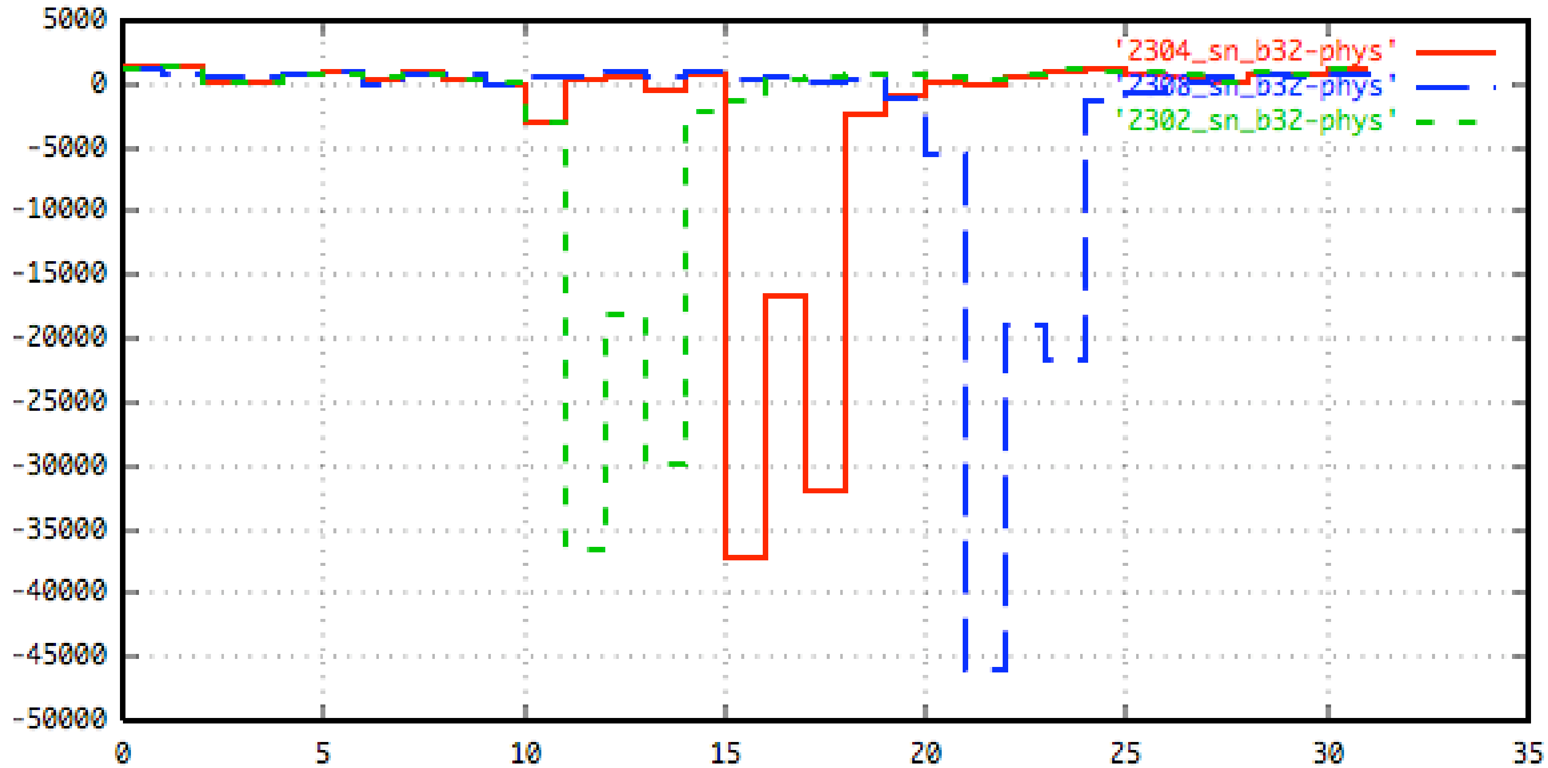
The pixels seem to be sharing charge in ways we don't understand.

- Condition: narrowly collimated beam illuminating detector.
- Does diode #16 have unexpectedly low gain?



No. The pattern is everywhere

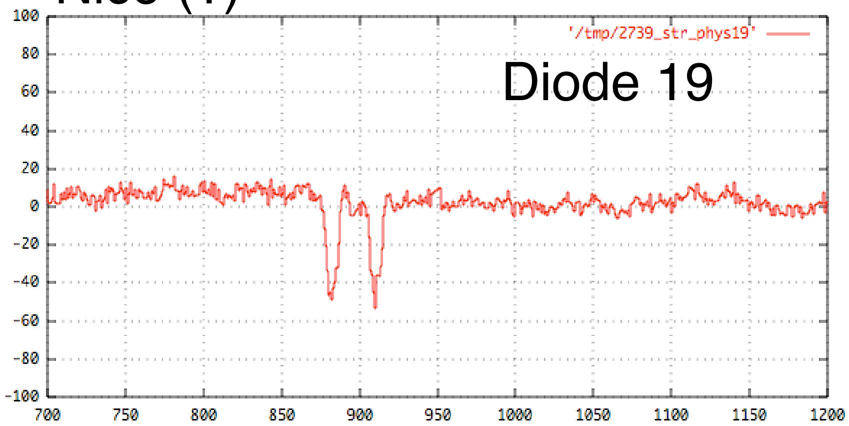
- Change the colllimator position:
- Note that this is note the beam! (DC current measurements are normal!)



- This is some weird effect associated with overdriving a pixel.

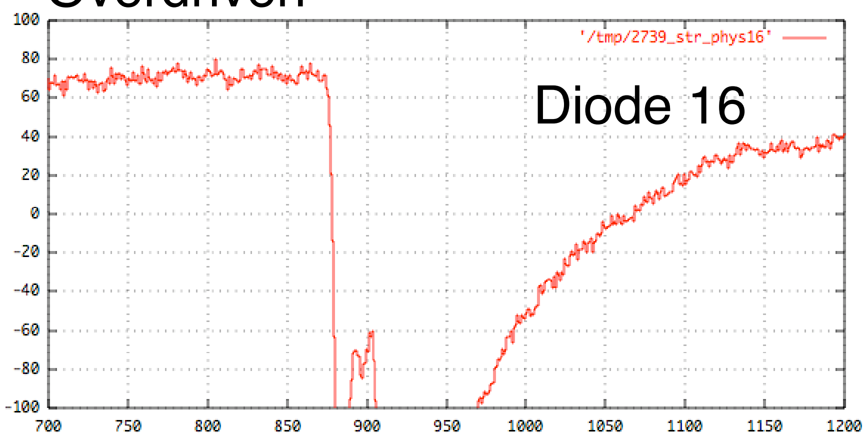
Four types of responses

Nice (?)

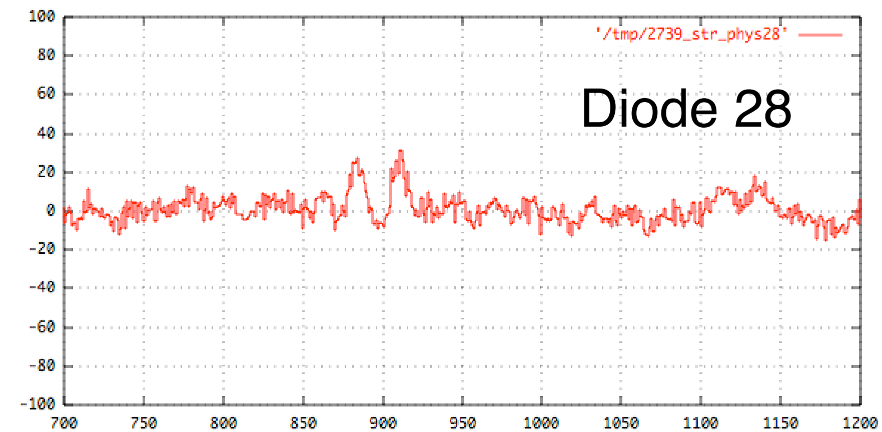


Disconnected

Overdriven



Huh????



Where to go from here

- Acquire sensors from several vendors (Hamamatsu, Kyousemi, Fermionics, Sensors Unlimited, Emcore, Perkin Elmer, Pacific Sensor…)
  - Some of these explicitly advertise “anti-blooming”
  - Larger pixel pitch (50um,…)
  - Diodes will be at least 20x longer, so greater photon acceptance (maybe less end effect?)
  - Will explore silicon
  - Bench measurements to characterize sensor properties better
  - Alternate sacrificial diodes? Higher reverse bias voltage?
- Modify front end electronics to suppress tails
  - Also, consider gating switch (if speed, charge injection okay)
  - Match gain properly to input signal, output ADC range
- New modular arrangement to allow interchangeable detectors
- Custom sensors?? (Inter pixel barriers -- like HEP detectors!)

Summary

- The detectors can be fast, but are easily overdriven
- The interpixel sharing (blooming) is especially bothersome
- Some diodes (not in illuminated area) go positive
- Single diode (Emcore) are fast and don't seem to overdrive
- All of the above seem to indicate that charge collection in the pixel array is complicated and we don't understand it.
- In 2 GeV running the *present* configuration with 500um Be vacuum window is untenable. No fast signal. Real configuration will have 50um window.
- There are still many avenues to explore -- this is just the beginning.