

# Tests at AØ of a stripline kicker

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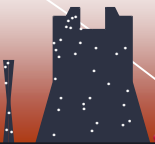


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# Outline

- Kicker
- Phase detector



# Why a fast kicker?

Main linac beam:

- One pulse: 2820 bunches, 337 nsec spacing (five pulses/second)
- length of one pulse in linac **~300** kilometers
- Cool an entire pulse in the damping rings before linac injection

Damping ring beam (TESLA TDR):

- One pulse: 2820 bunches, ~6 nsec spacing
- length of one pulse in damping ring **~6.6** kilometers
- Eject every  $n^{\text{th}}$  bunch into linac (leave adjacent bunches undisturbed)

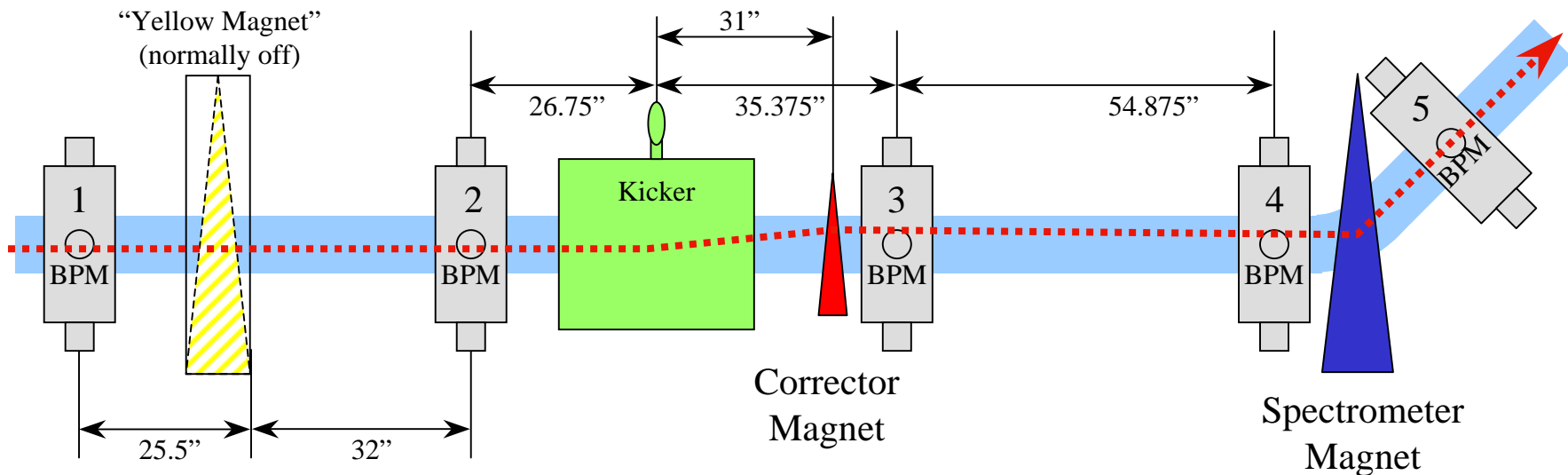
Total kick  $\sim 100\text{G}\cdot\text{m} \pm .07\%$

Kicker speed and stability are issues.

# Low energy beam tests

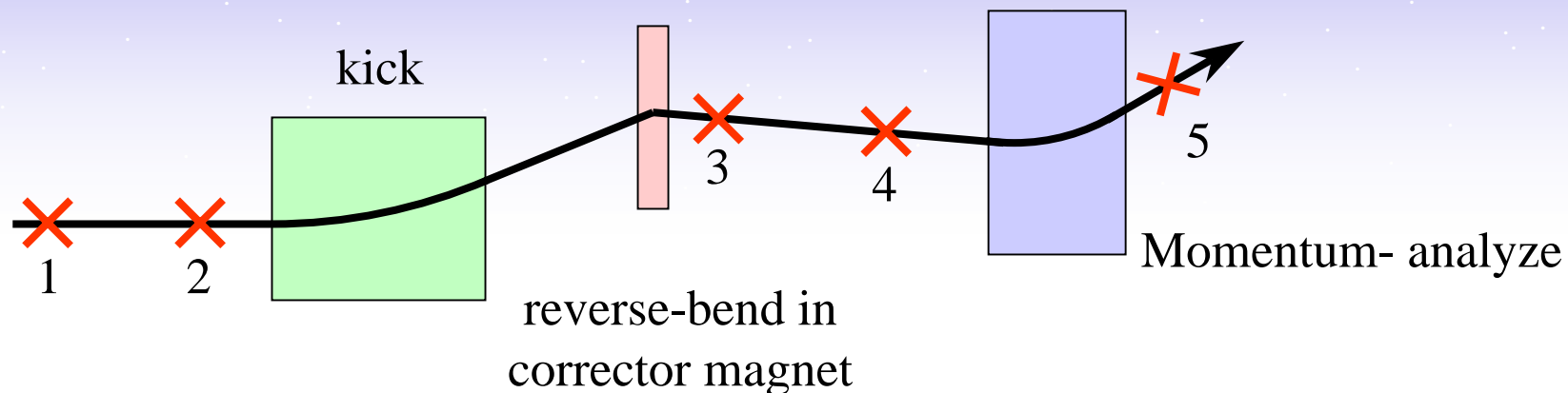
We used the 16 MeV electron beam at the AØ Photoinjector Lab for kicker tests.

Our initial goal was to learn whether or not we could do precision kicker tests with this beam.



Define  $z$  axis as passing through the electrical centers of BPMs 2 and 3

# Kick left, bend right, bend left



1. Determine the bend in the corrector from magnet current
2. Calculate kicker deflection as  $\theta_{\text{kicker}} = \theta_{34} - \theta_{\text{corrector}} - \theta_{12}$
3. Determine momentum by swimming trajectory to BPM 5 ( $x, y$ ).
4. Determine alignment constants by turning off kicker and corrector

$$\text{Kicker stability: } \delta \theta_{\text{kicker}} \sim \delta (\theta_{34} - \theta_{12})$$

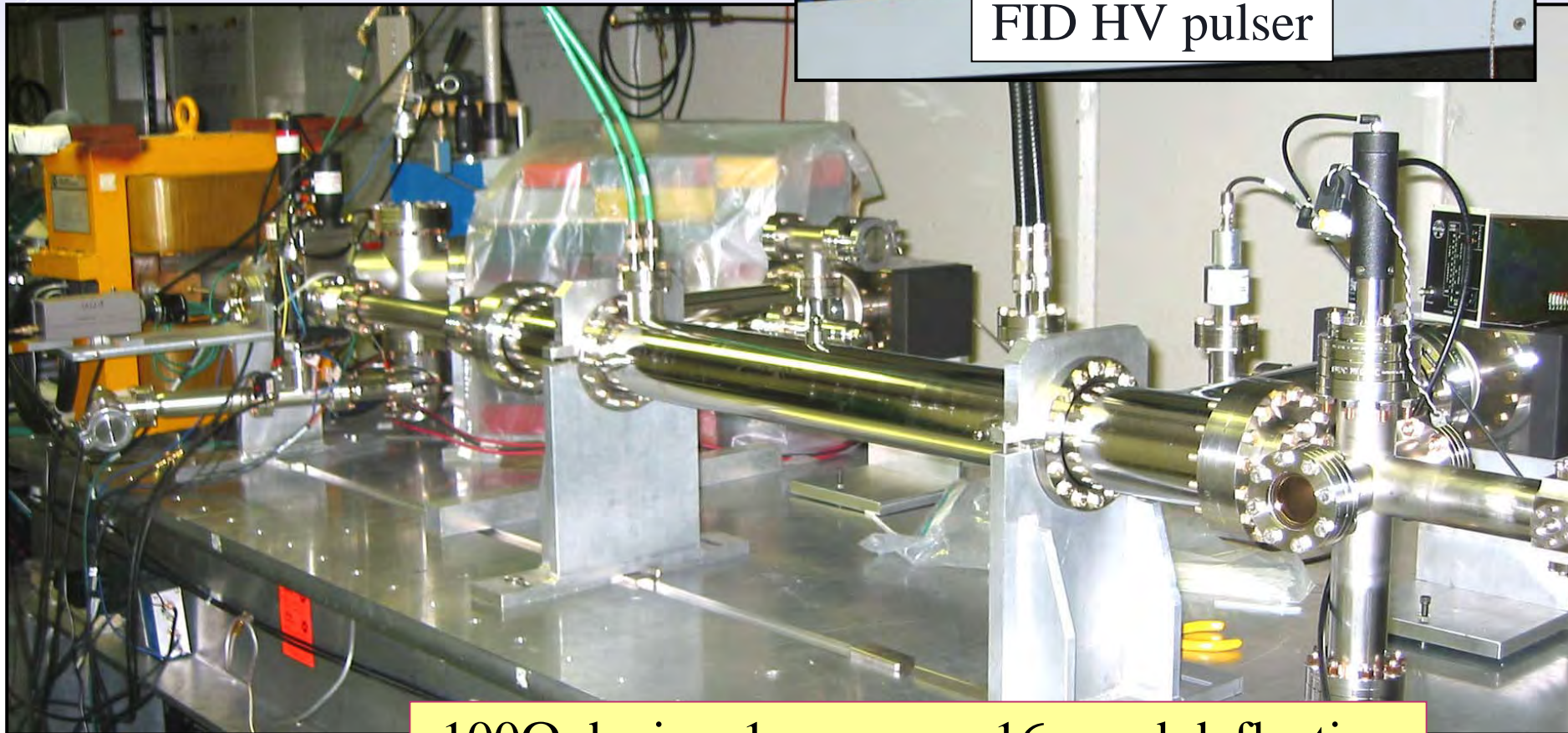
# Final assembly of the kicker



# Kicker installed at AØ

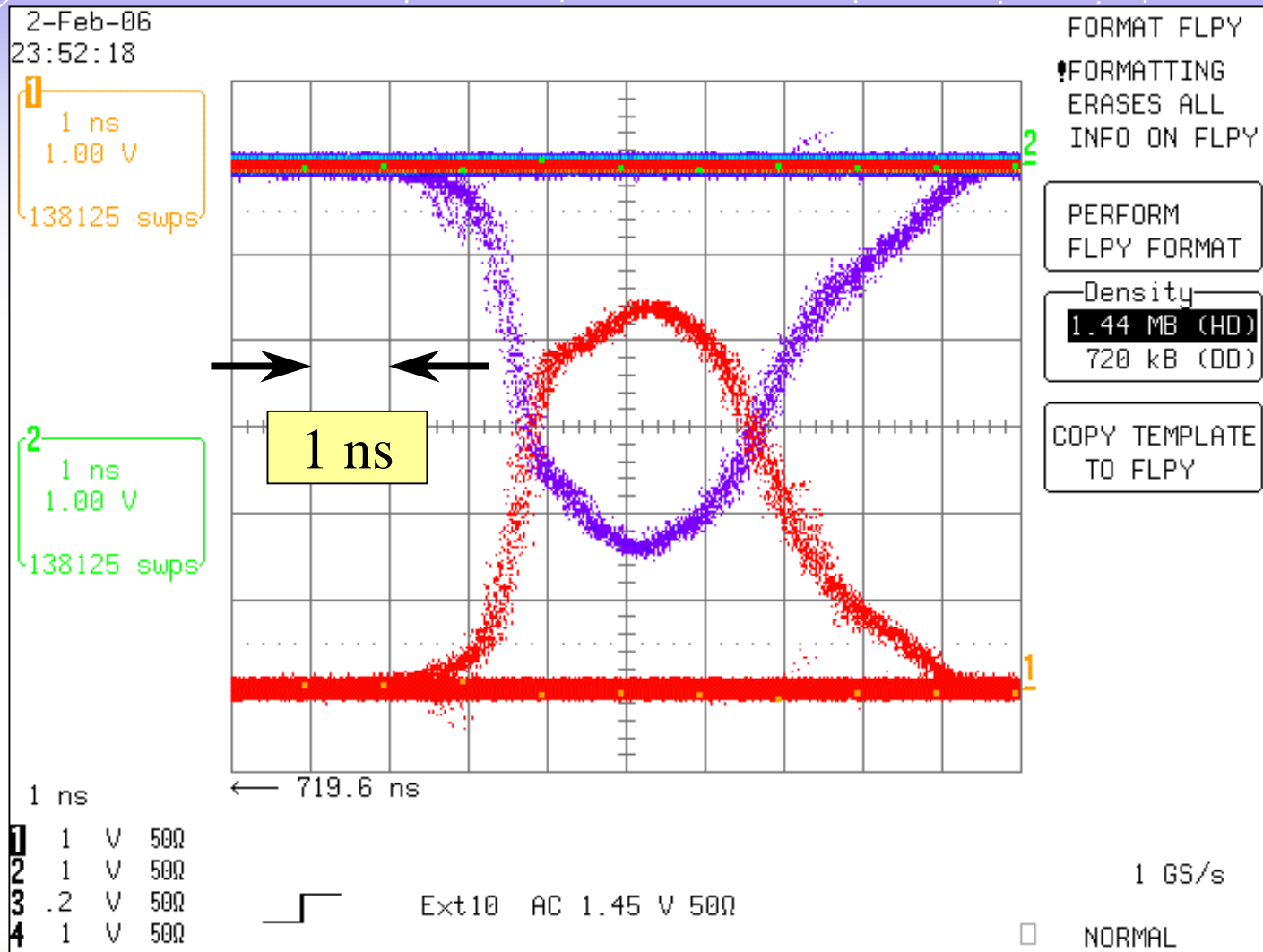


FID HV pulser



100Ω device, 1 cm gap, ~16 mrad deflection

# FID HV: $\pm 1$ kV, few ns length

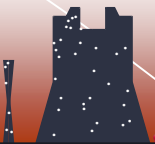
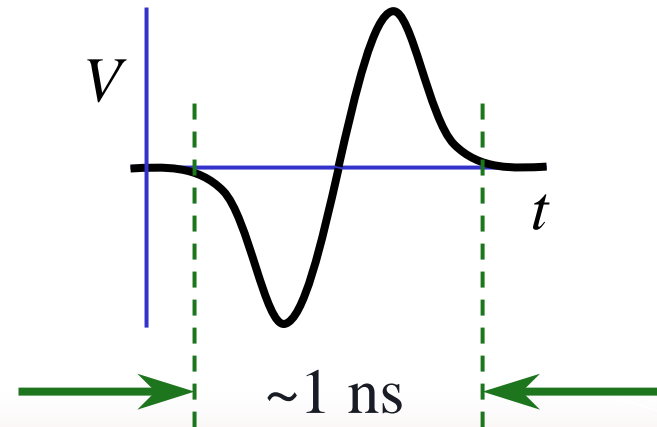


# Phase detector: precision measurement of bunch arrival time

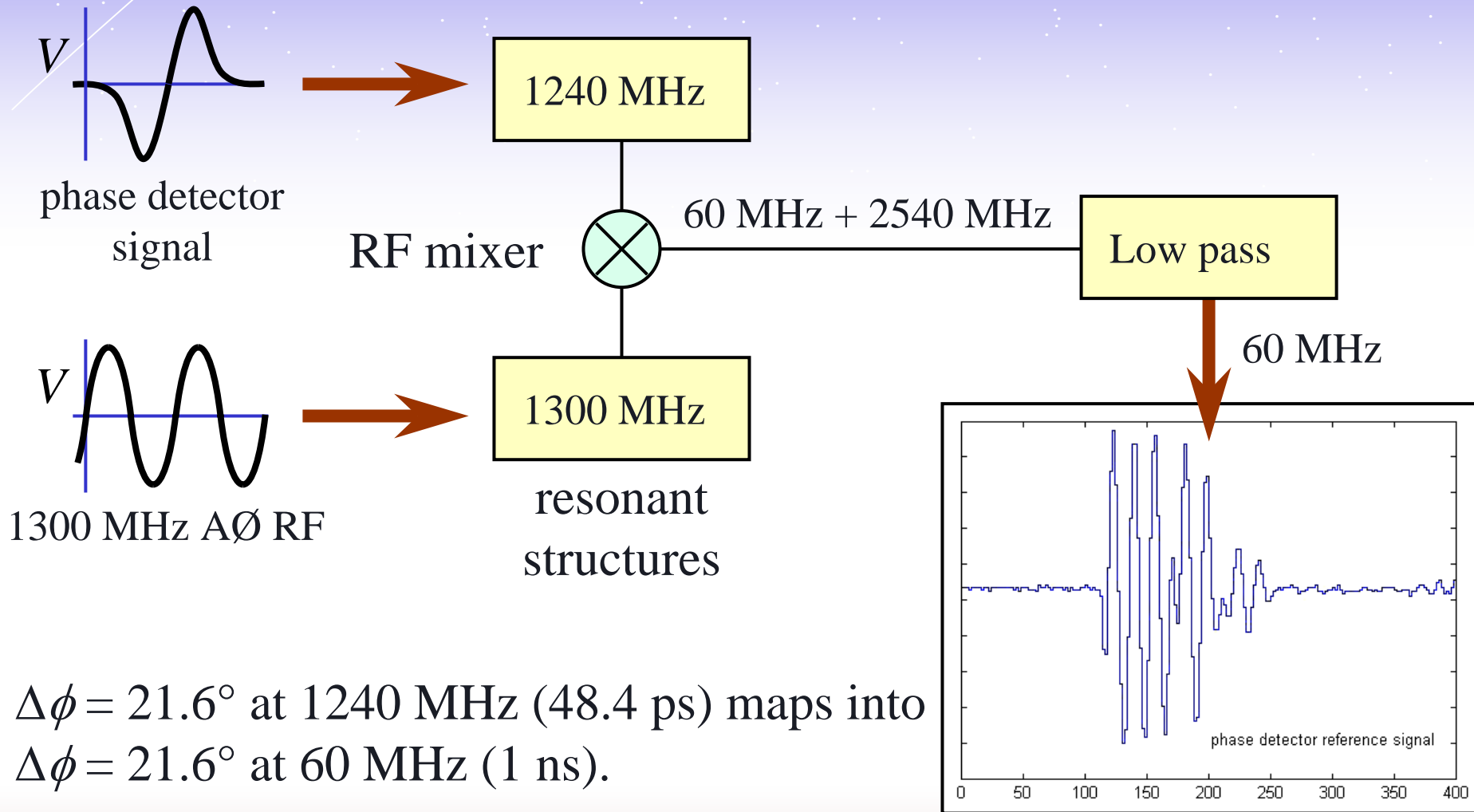


The device produces a very short bipolar signal when a bunch passes through it.

Dispersion in a coaxial cable broadens the signal to a full width of  $\sim 1$  ns.



# Phase detector signal path



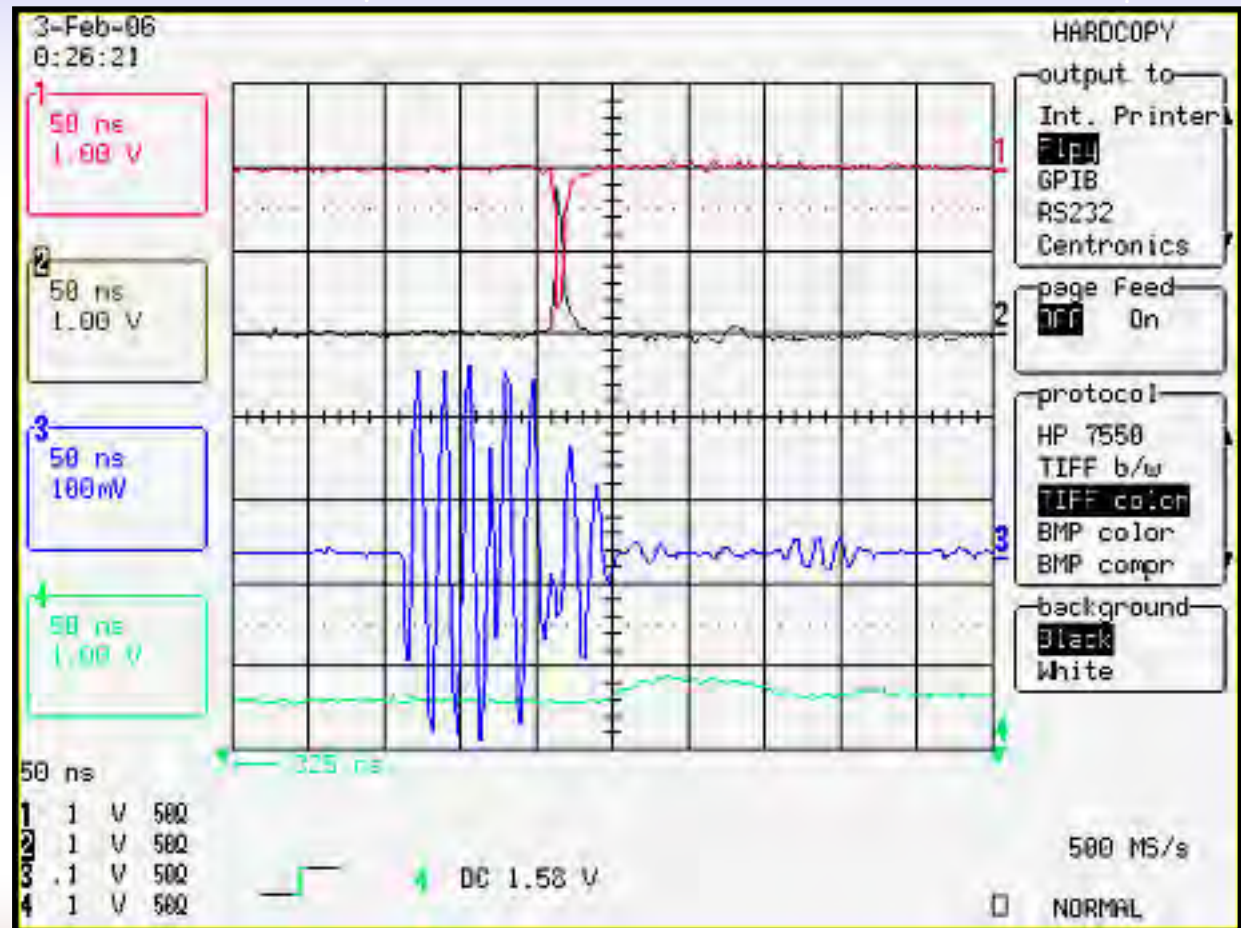
# DAQ uses an oscilloscope as a transient digitizer

BPM information read by DAQ, written directly to event data record.

$\pm$ FID pulses digitized after leaving the kicker and passing through soft cables.

Phase detector signal mixed with 1.3 GHz RF, then digitized.

500 MHz scope data read, then written to event record.



# Data

Two data-taking periods:

August 2005

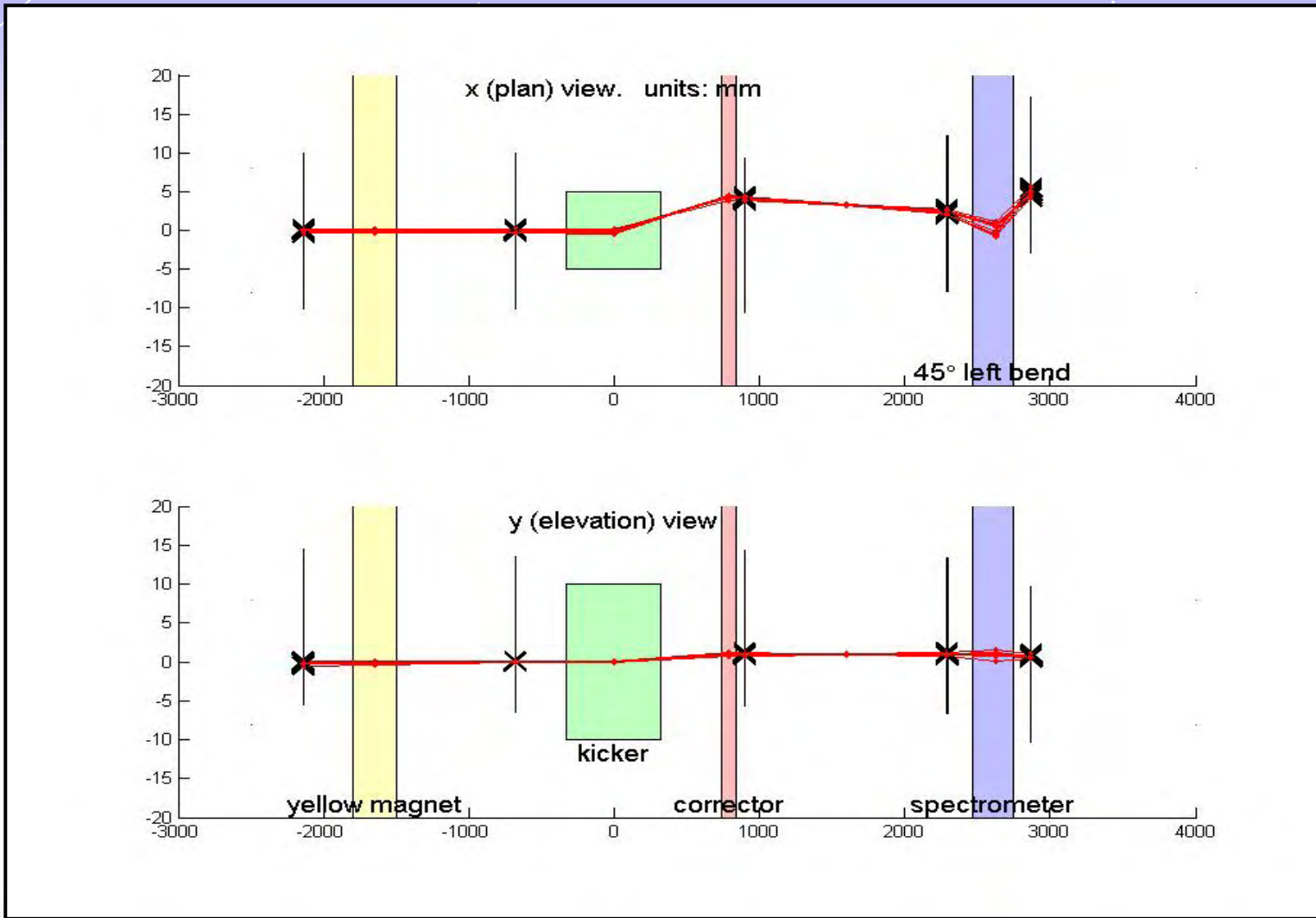
- commission the portion of the beamline holding the kicker
- develop DAQ system
- write data for use in analysis code development

February 2006

- map corrector magnet current vs. deflection
- map kicker impulse vs. FID trigger time
- write data for kicker stability analysis and Monte Carlo studies

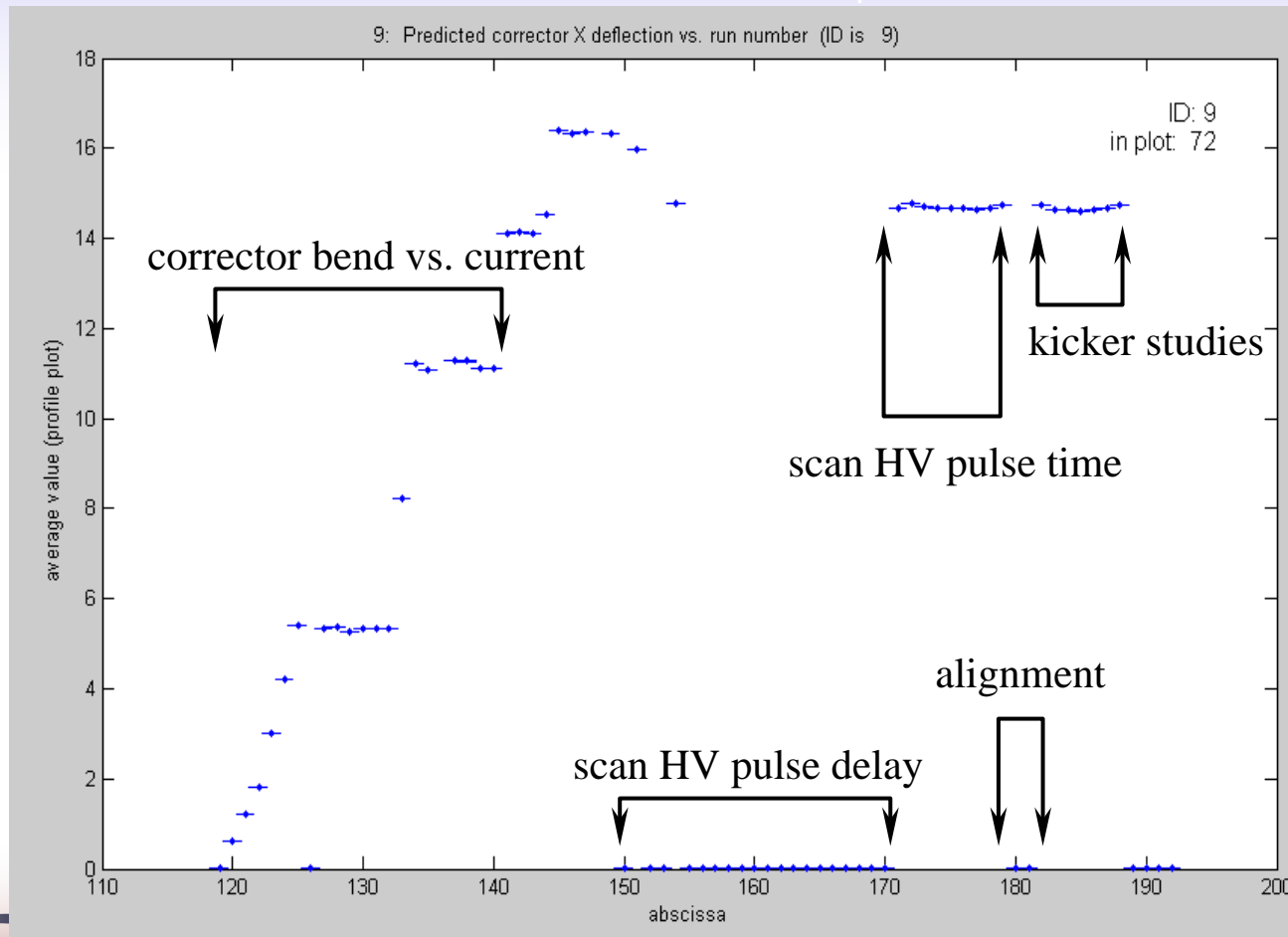


# Event display, 10 pulses



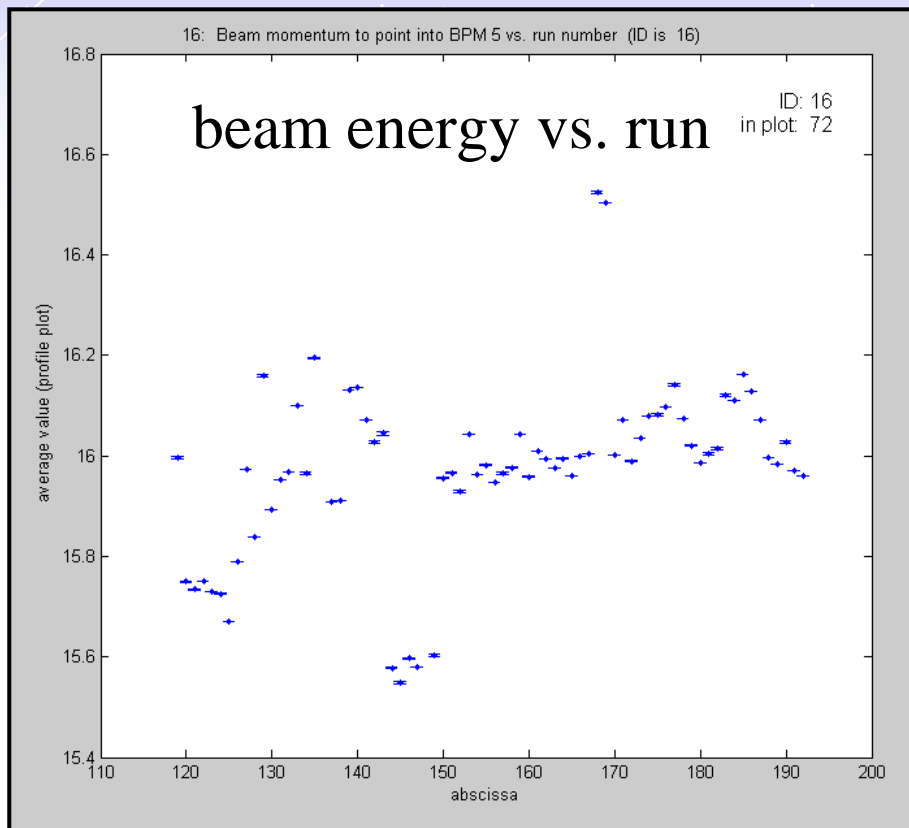
# 2006 runs

Predicted corrector deflection is a useful flag of what we might have been doing in a given run.

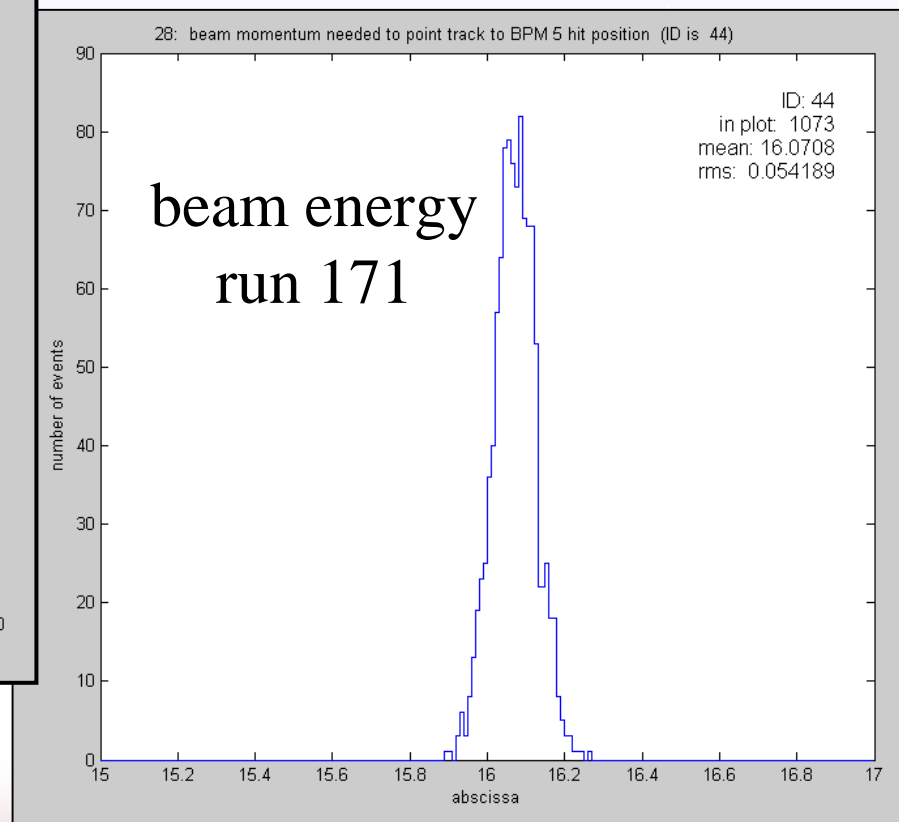


# Apparent beam energy (MeV)

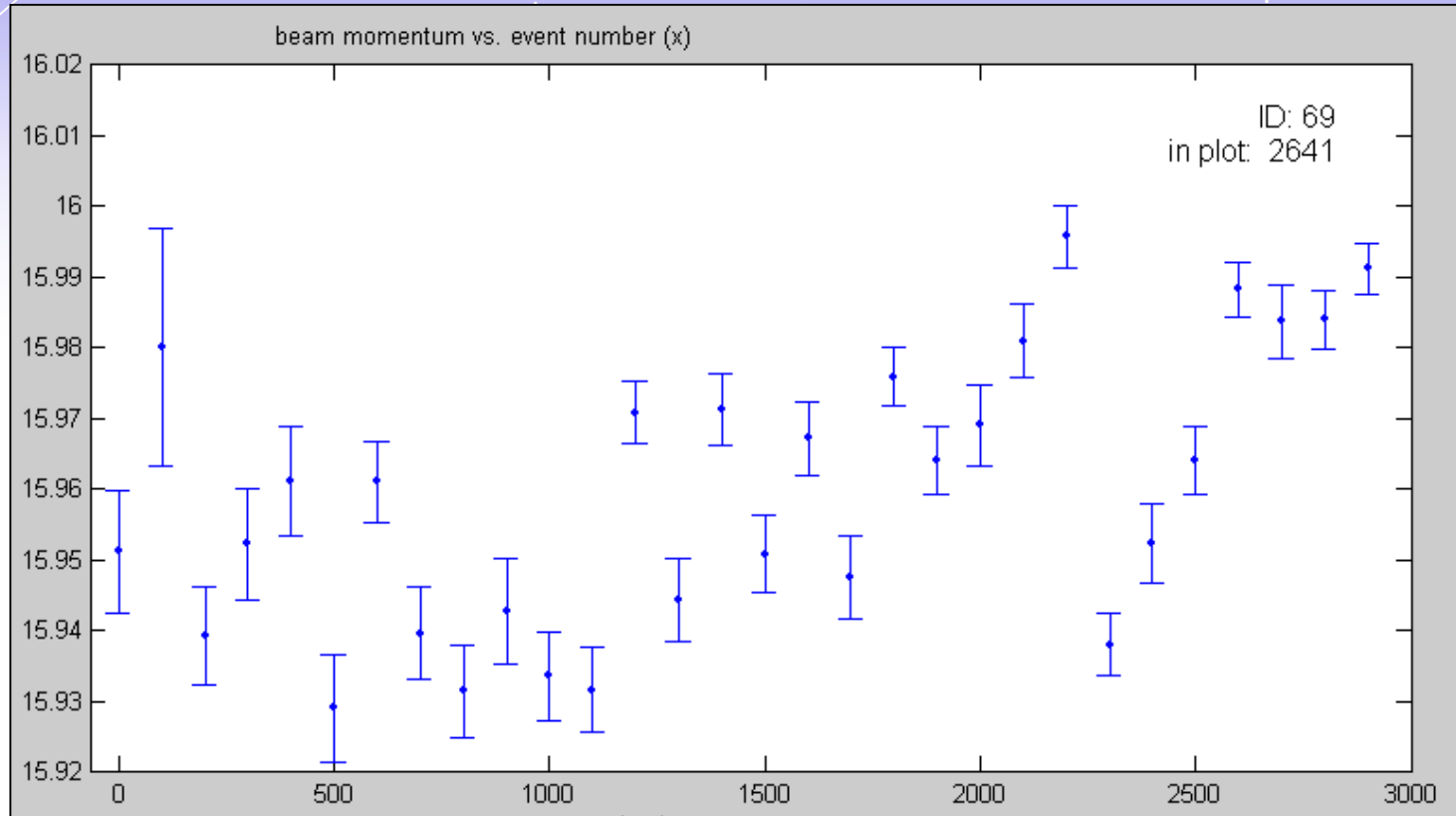
The beam energy seems to move around a little from run to run.



16 MeV, 54 keV RMS ( $\sim 0.3\%$ )



# AØ beam momentum, during one run

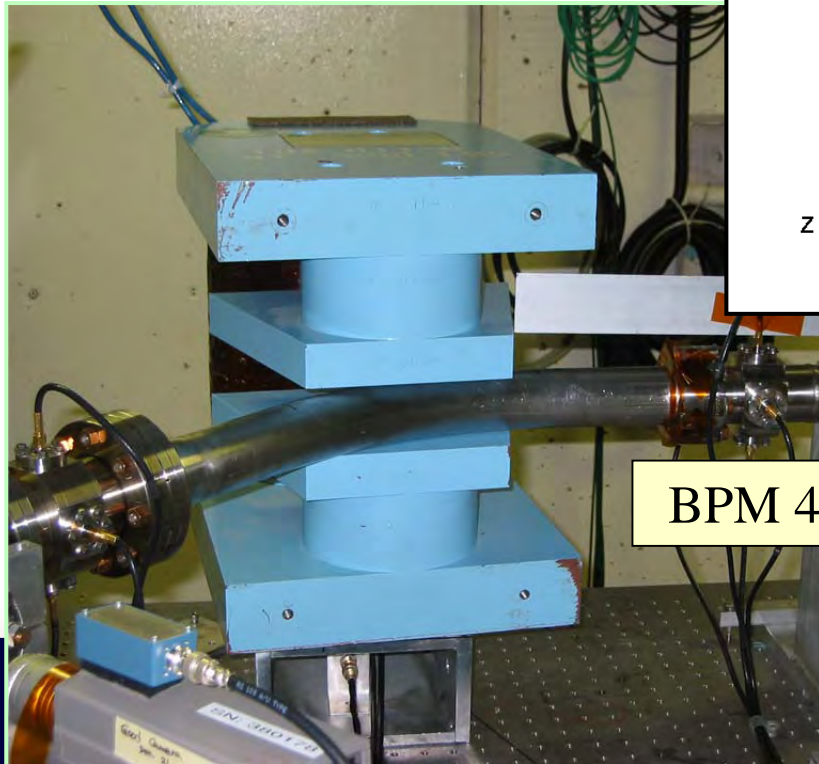


Straight-through run: average momentum per 100 events as a function of event number. It bounces around!

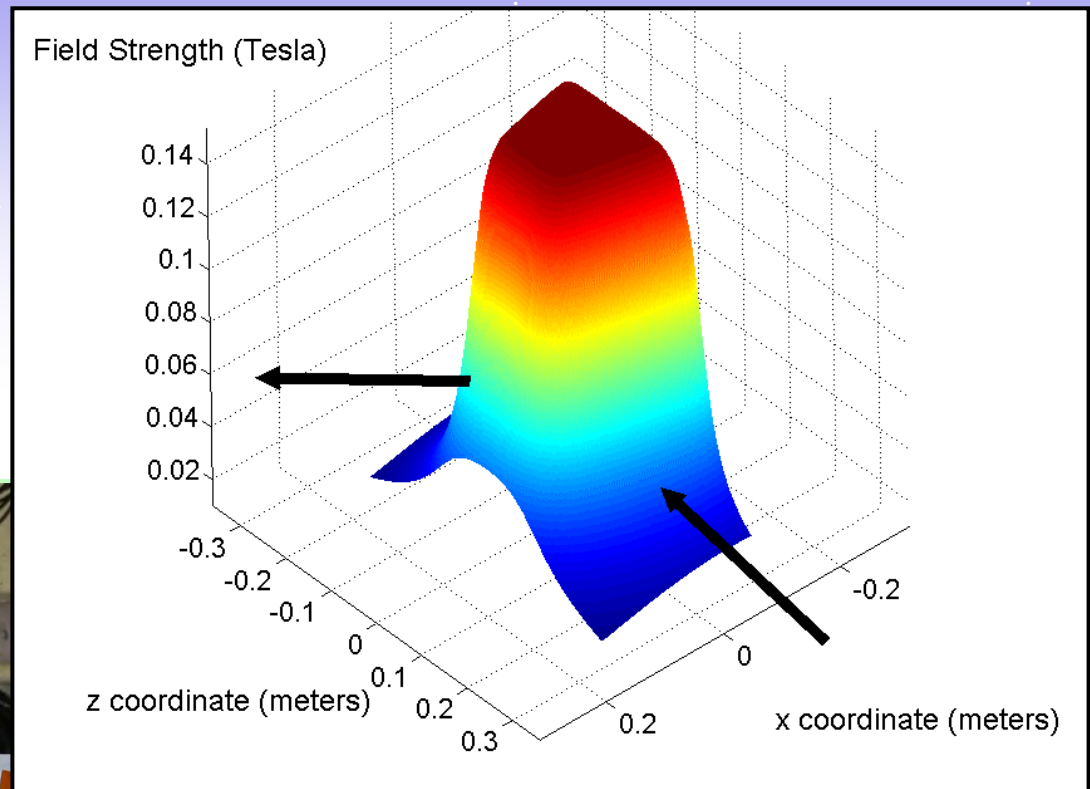


# Trapezoidal magnetic field

Could our track reconstruction be at fault?  $x$  errors could change field integral... and we also find that the overall kick is smaller than field map would suggest.



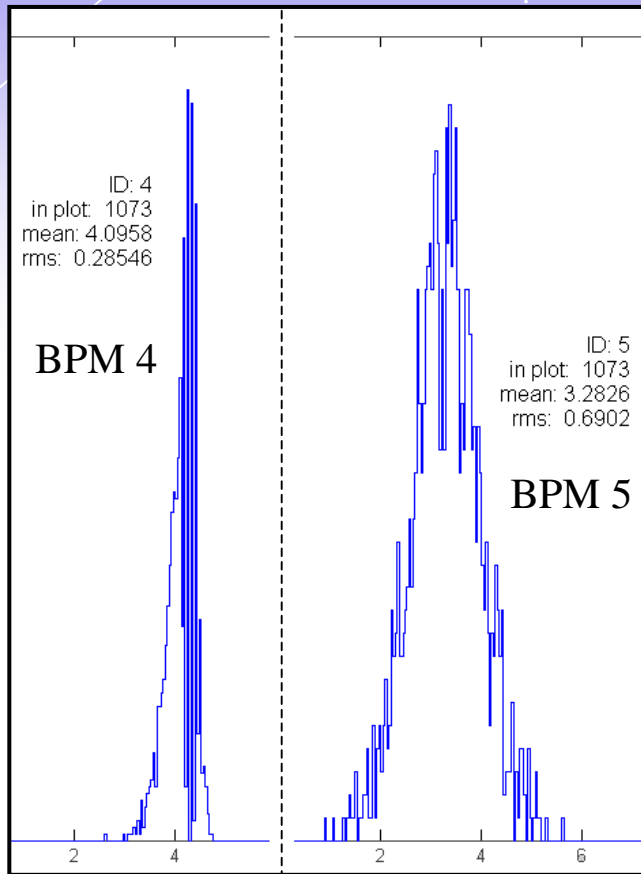
BPM 4



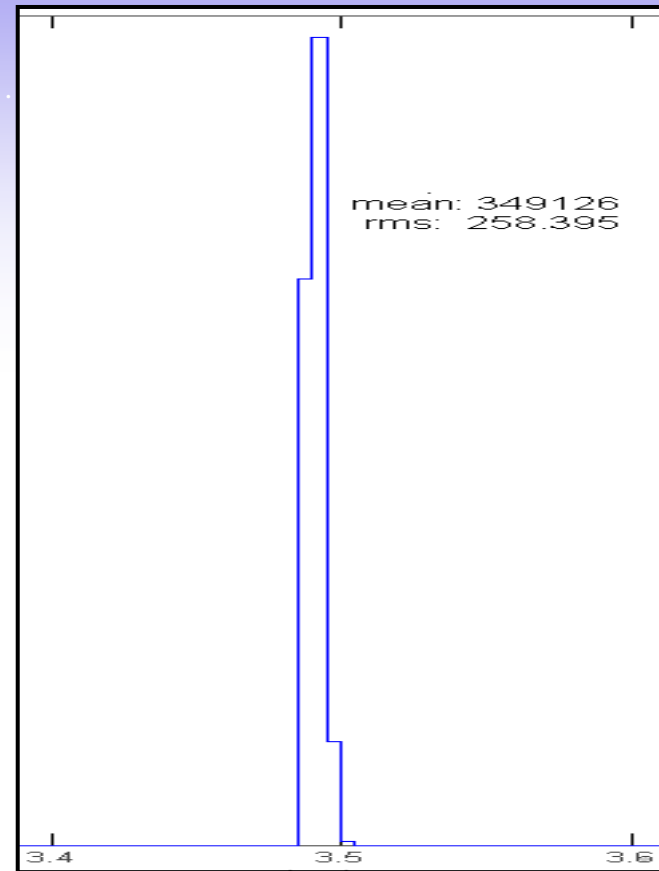
Alex Lang's smoothed field map

trapezoidal magnet (before we fixed its final position)

# We think we're doing the reconstruction properly



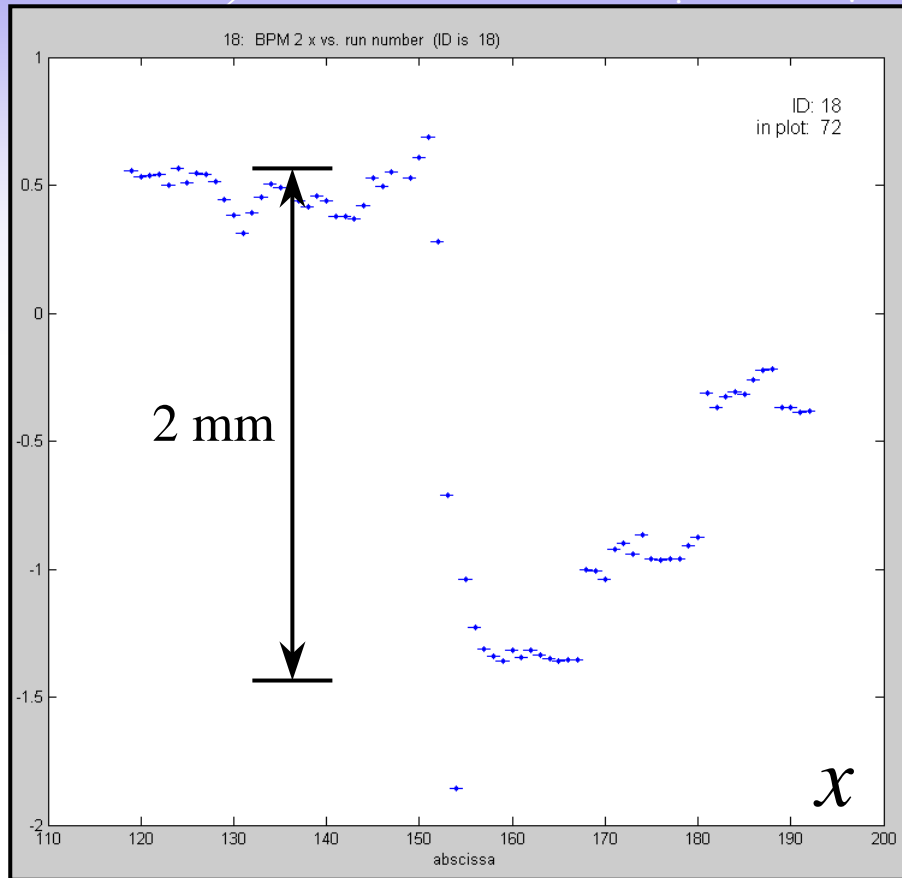
BPM 4 x profile is much narrower than BPM 5 x profile



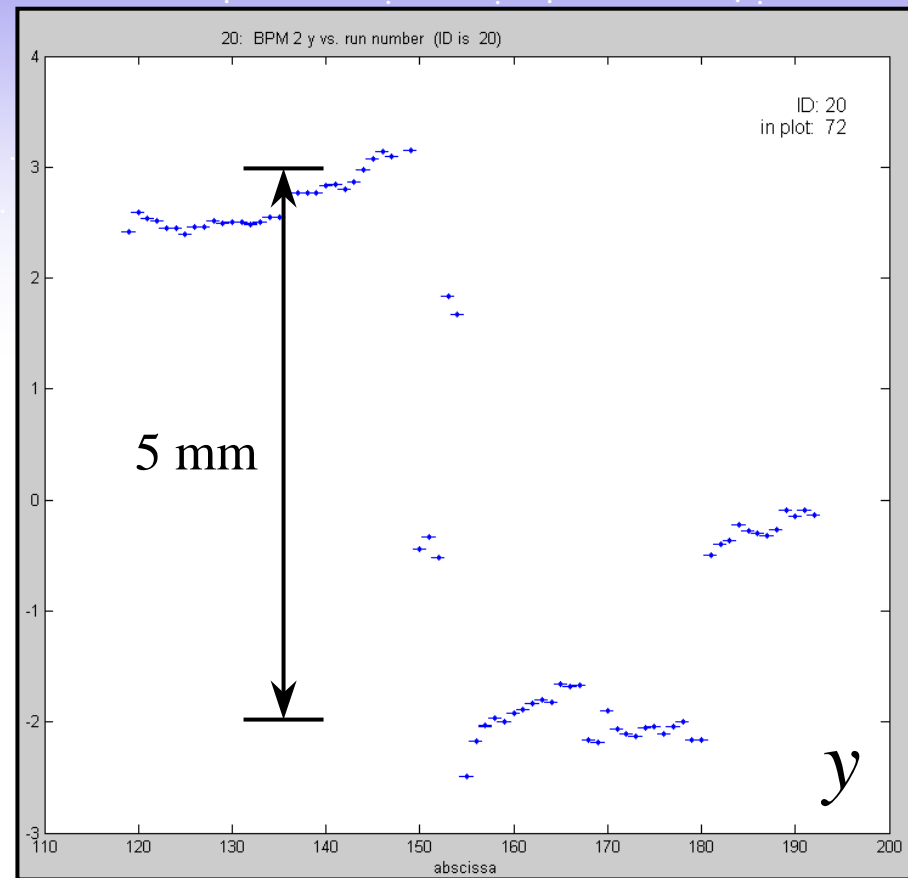
field integral over path in magnet only varies by .07%

Conclusion: 0.3% width momentum spectrum is real

# Beam average $x$ , $y$ near kicker vs. run number



Beam  $x$  centroid at BPM 2  
(near kicker)



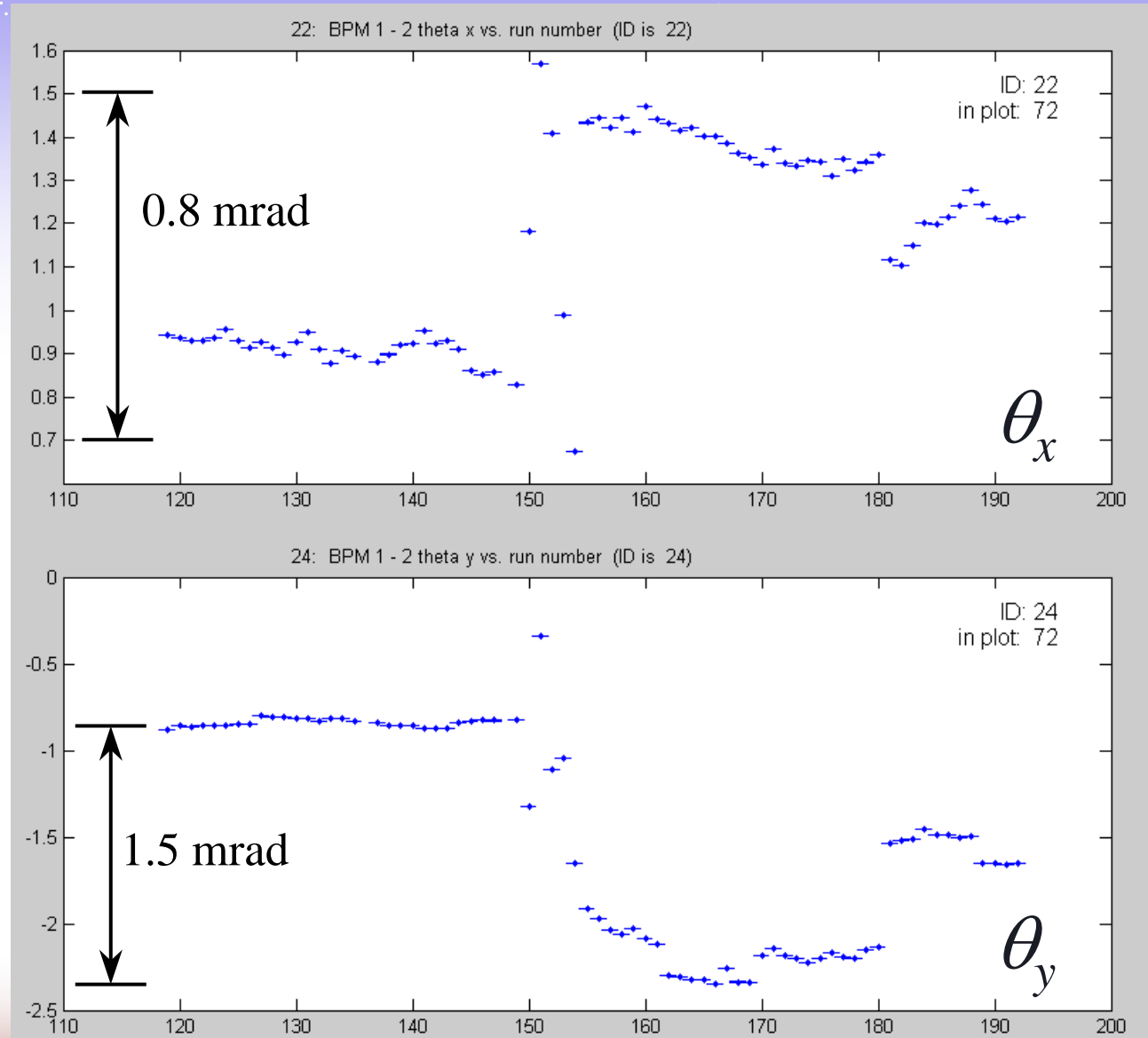
Beam  $y$  centroid at BPM 2  
(near kicker)

Short term stability is usually quite good.



# Beam angles $\theta_x$ and $\theta_y$ entering kicker vs. run

mean  $x$ ,  $y$  angle of beam as it enters the kicker (mrad) vs. run number



Again, short term stability is usually good.

# BPM resolution

Finite width of measured  $\theta_x$  and  $\theta_y$  determined by a pair of BPMs arises from several sources (pairs of BPMs are spaced by  $\sim 1400$  mm):

$$\begin{aligned}\delta\theta_{12} &= \delta\theta_{\text{BPM1 resolution}} \oplus \delta\theta_{\text{BPM2 resolution}} \oplus \delta\theta_{\text{beam natural width}} \\ &\sim \frac{\sqrt{2} \times \delta x_{\text{BPM resolution}}}{1400 \text{ mm}} \oplus \delta\theta_{\text{beam natural width}}\end{aligned}$$

Finite width of the change in angle before/after kicker:

$$\delta(\theta_{34} - \theta_{12}) \sim \frac{2\delta x_{\text{BPM resolution}}}{1400 \text{ mm}} \oplus \delta\theta_{\text{kicker imprecision}}$$

I am neglecting the effects of residual and stray magnetic fields.



# BPM resolution from straight-through run 170

Kicker and corrector are off during this run.

$$\delta\theta_{12}^x = .0692 \text{ mrad}$$

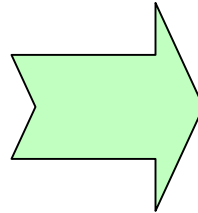
$$\delta\theta_{12}^y = .0427 \text{ mrad}$$

$$\delta\theta_{34}^x = .0739 \text{ mrad}$$

$$\delta\theta_{34}^y = .0482 \text{ mrad}$$

$$\delta(\theta_{34}^x - \theta_{12}^x) = .0784 \text{ mrad}$$

$$\delta(\theta_{34}^y - \theta_{12}^y) = .0557 \text{ mrad}$$



$$\delta x_{\text{BPM resolution}} = 54 \text{ } \mu\text{m}$$

$$\delta y_{\text{BPM resolution}} = 39 \text{ } \mu\text{m}$$

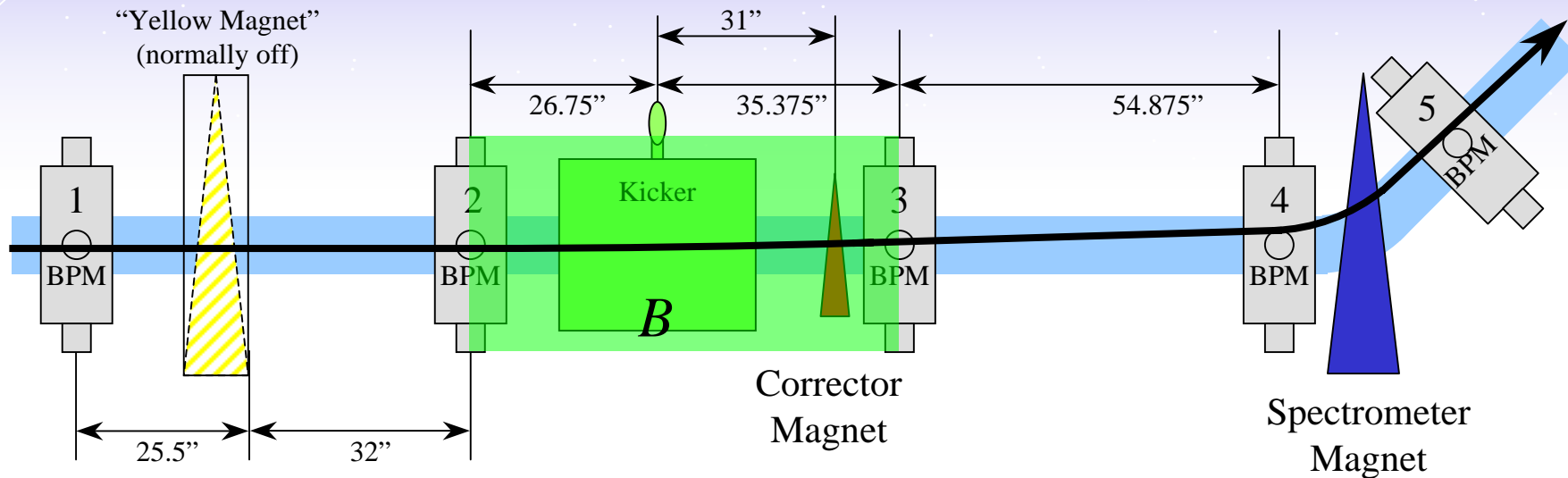
$$\delta\theta_{\text{beam natural width}}^x = 43 \text{ } \mu\text{rad}$$

$$\delta\theta_{\text{beam natural width}}^y = 16 \text{ } \mu\text{rad}$$



# Stray and residual fields' effects on BPM "resolution"

Imagine there is a 2 Gauss vertical field between BPM 2 and 3.

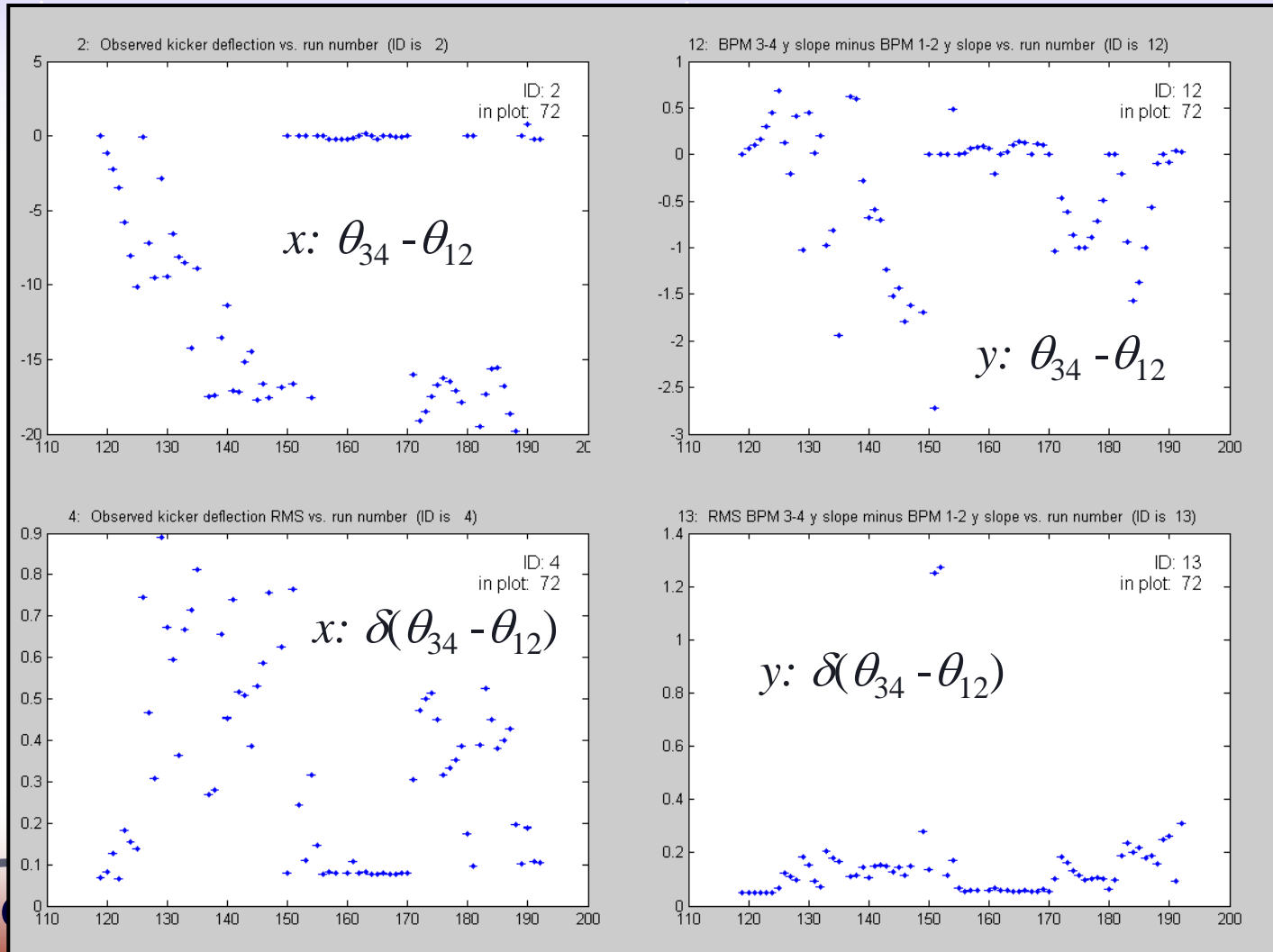


$2 \text{ Gauss} \times 1578 \text{ mm} \rightarrow 0.095 \text{ MeV}/c \rightarrow 6 \text{ mrad bend at } 16 \text{ MeV}/c.$

0.3% width energy spectrum  $\rightarrow$  .018 mrad contribution to BPM  $\theta$  error, small (but not negligible) compared to observed errors. Spectrometer fringe fields are probably significant. (We do see steering from them.)

# $\theta_{34} - \theta_{12}$ and $\delta(\theta_{34} - \theta_{12})$ vs. run number

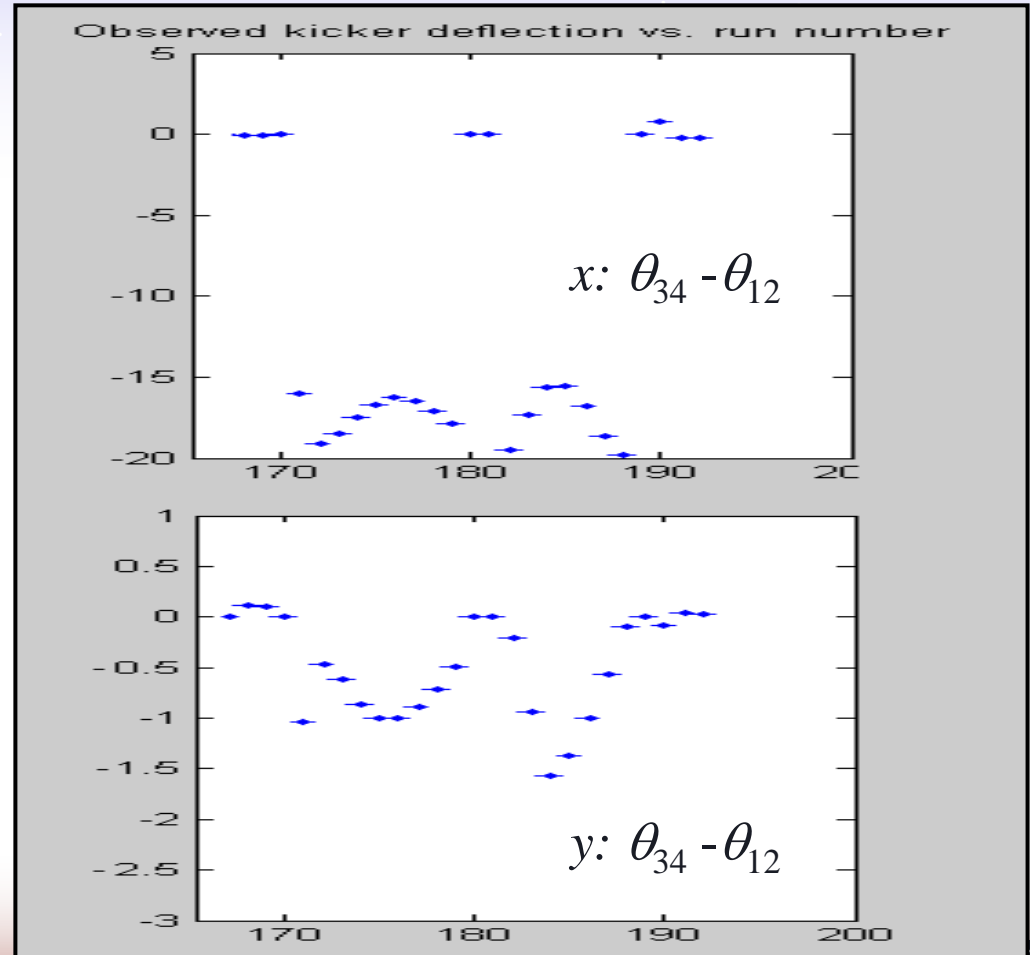
Note that  $\delta$  for  $x$  increases substantially when kicking. Also note the small  $y$  kick.



# Correlated effects in $x$ and $y$ vs. run number

Note that larger  $x$  kick does not induce a larger  $y$  kick. (Effect is opposite in sign.), Also,  $x$ - $y$  dependence is nonlinear: it's probably not a rotation of the kicker.

Curious. Something to do with the corrector field??



# Conclusions regarding kicker stability

Maximum kick:  $\sim 19.8$  mrad

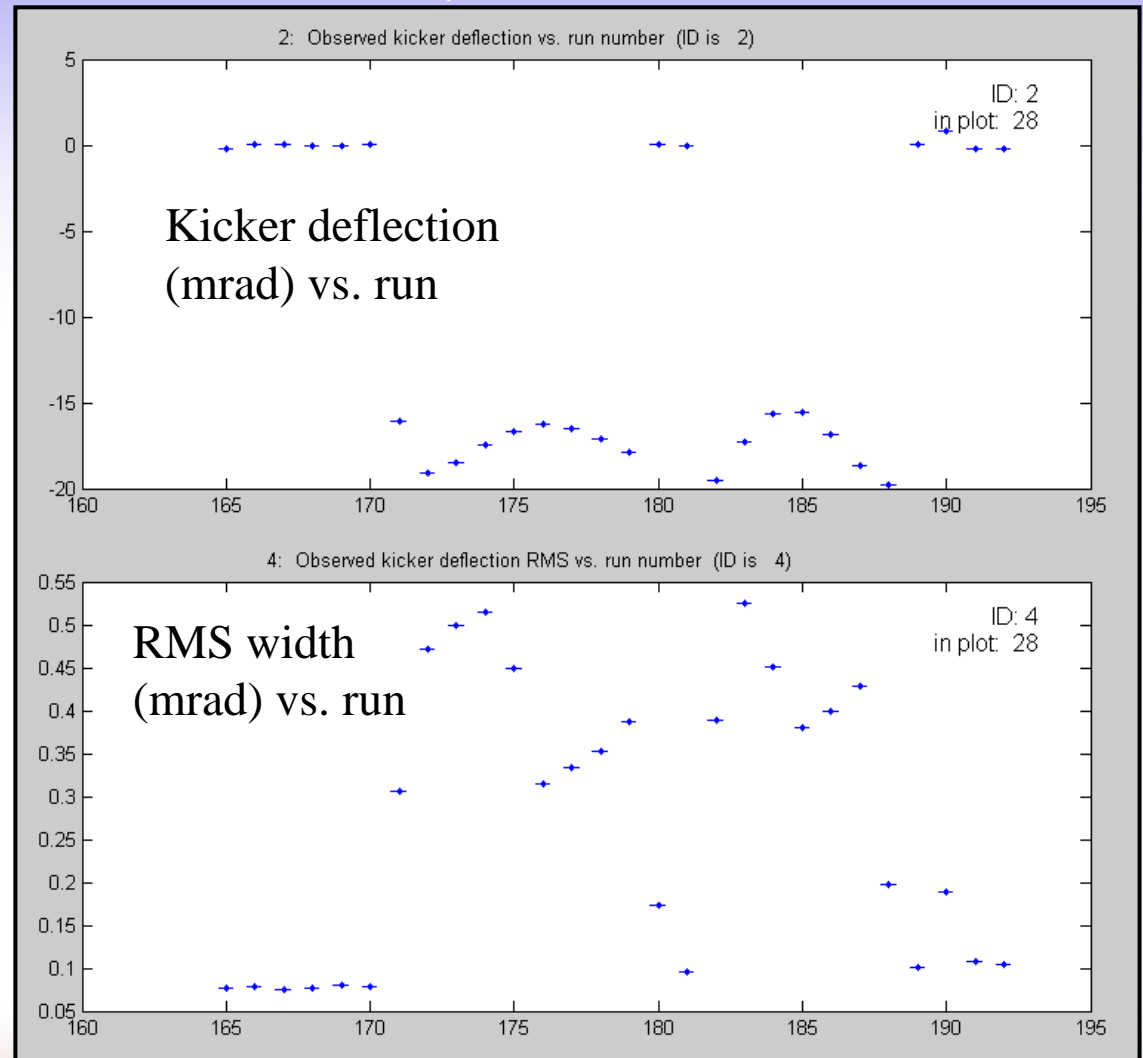
Kicker off: RMS  $\sim 0.1$  mrad

Kicker on: RMS  $\sim 0.4$  mrad

We find the kicker is stable to  
 $\sim 2.0\%$  ( $0.4 / 19.8$ )

Our measurement uncertainty  
is  $\sim 0.5\%$  ( $0.1 / 19.8$ )

ILC spec for a single kicker  
module (there will be 64) is  
 $\sim 0.5\%$ .



# Limitations in the AØ configuration we used

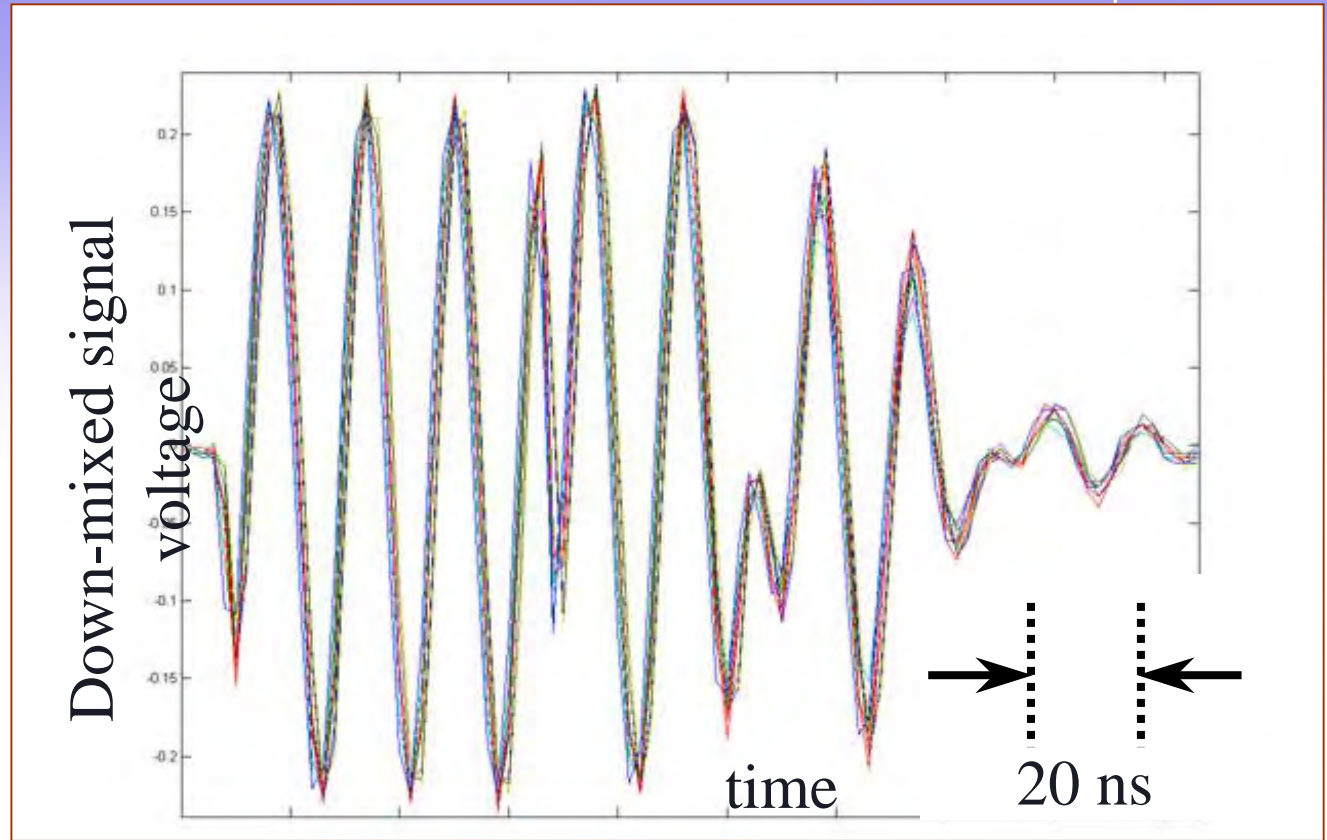
We would like to understand fine details in the data.

- What is the origin of the vertical kick?
- Are residual fields the source of some of the effects we see?
- Can we explain the system's resolution from first principles? (BPM resolution, etc.)
- Are our alignment constants stable? (They seem to move around more than is reasonable.)

Could we do considerably better with higher resolution BPMs?

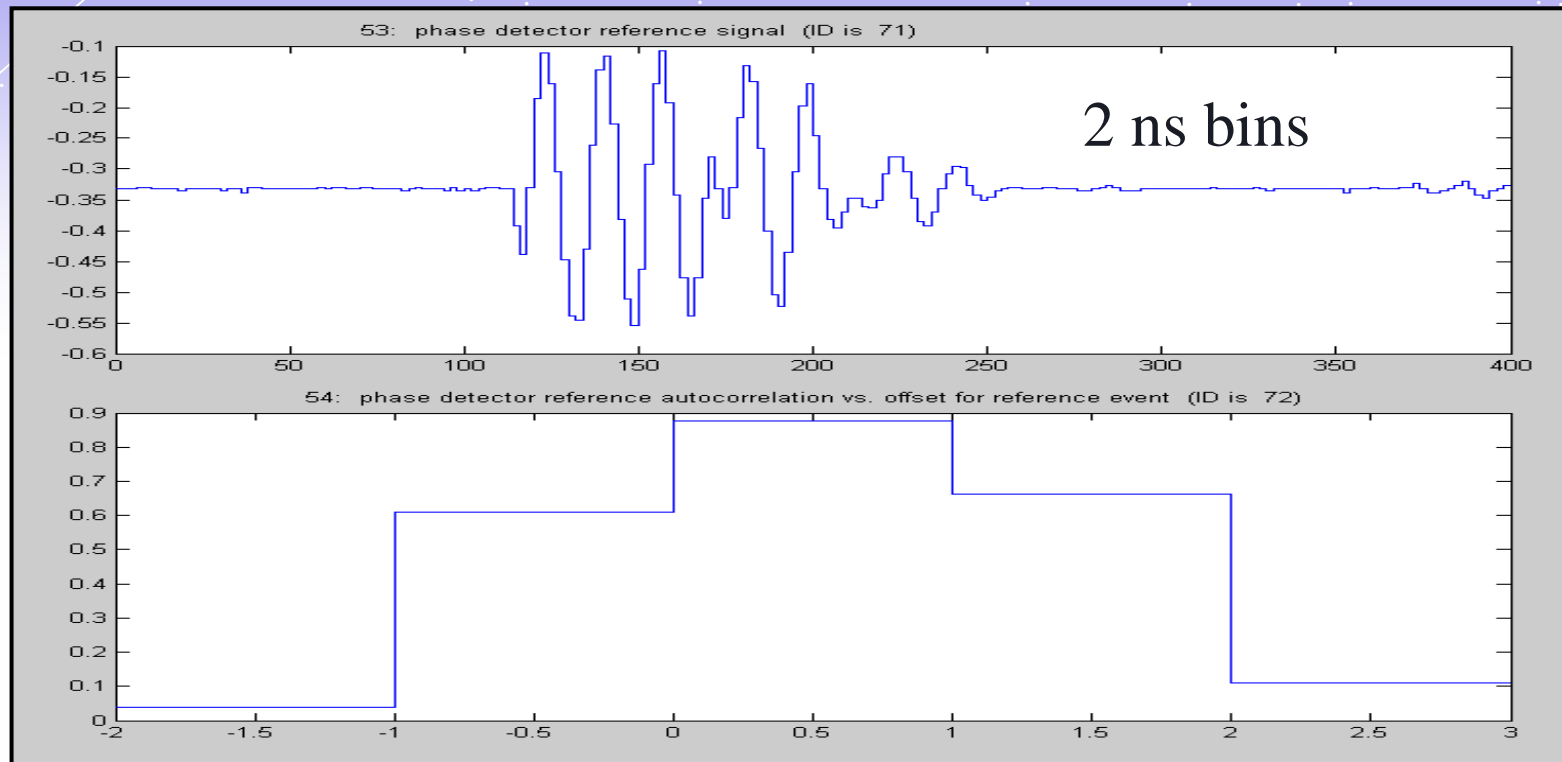


# Phase detector AØ data



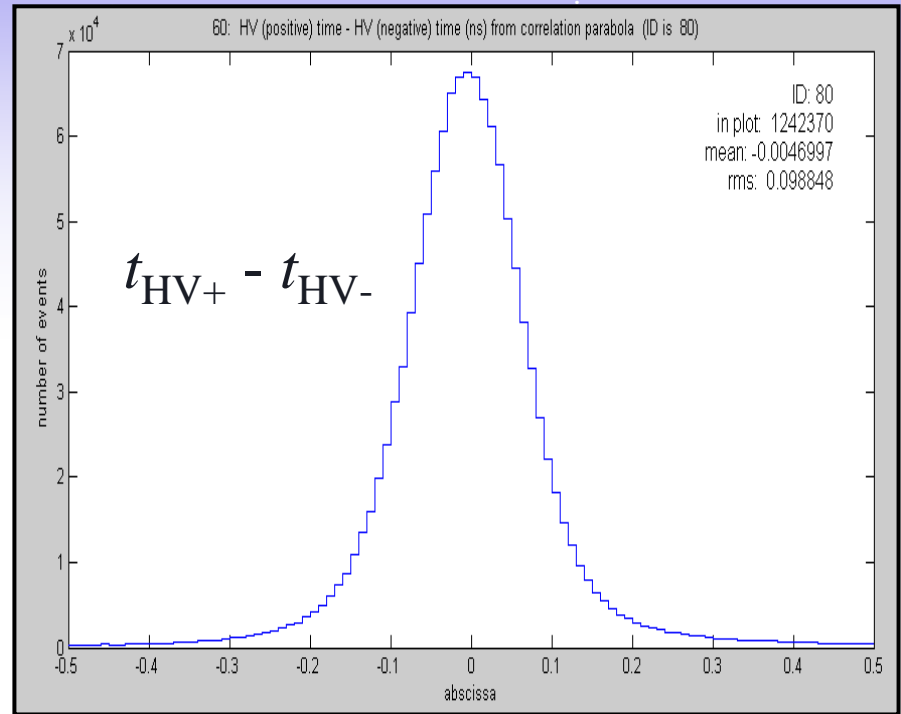
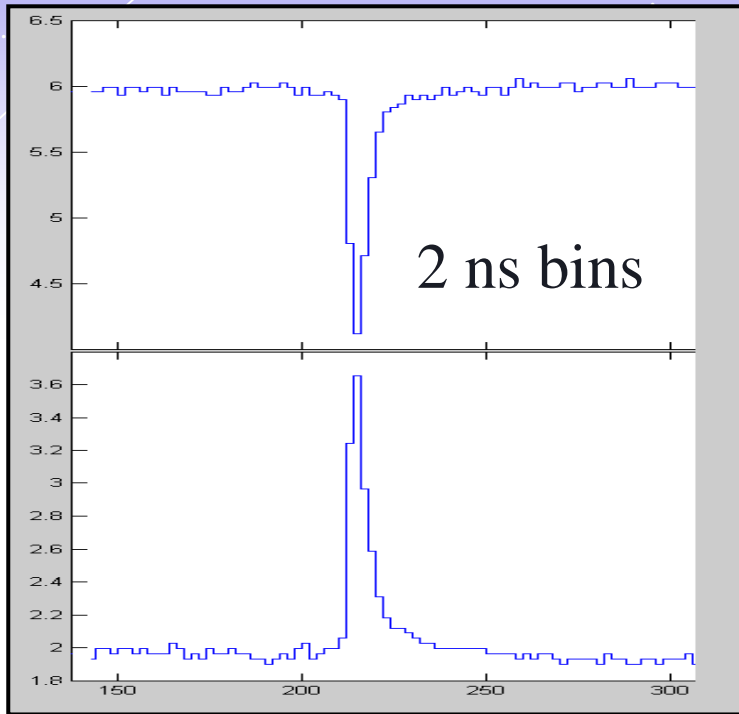
We can determine the relative start times for each of the displayed signals with a precision of  $\sim 9$  ps. That corresponds to a bunch timing accuracy of  $\sim 0.4$  ps. (Note that ILC IP phase detectors should have  $\sim 0.1$  ps accuracy.)

# Phase detector algorithm



Shift the phase detector signal in time, looking for where it best aligns with a reference signal. The offset required to obtain best alignment gives the time delay.

# FID HV pulser data



The same technique also works with the HV pulses, giving time accuracies of  $\sim 60$  ps.

# Low beam energy and lack of redundant measurements...

...made things messy sometimes.

Fringe fields from the spectrometer magnet steered the beam in spite of installation of lots of shielding.

Fringe fields from other “normally off” magnets also steered the beam.



We learned a lot about using AØ this way

BPM resolution was about 50  $\mu\text{m}$ .

Coupling between  $p$  and  $x, y$  made ballistic alignment complicated.

Trapezoidal-pole spectrometer magnet without an accurate field map complicated the momentum analysis of the AØ beam.

Timing information from phase detector was excellent, and we'd like a second one to understand that system's precision.

Full Monte Carlo of beam line before installation would have helped us avoid a few silly things (goofs in shape of curved pipe through spectrometer, etc.). Alex Lang's new MC is very helpful.



# Rough conclusions

Precision momentum and beam trajectory measurements are tricky at this energy with this geometry.

Timing measurements are easily done at AØ.

This could be a nice drop-in test facility for various devices, but more thought and sophistication in future layouts will be helpful.

FID pulser is probably not sufficiently stable for ILC purposes, but we would like to spend more time with our analysis.

