FDC Status

Simon Taylor
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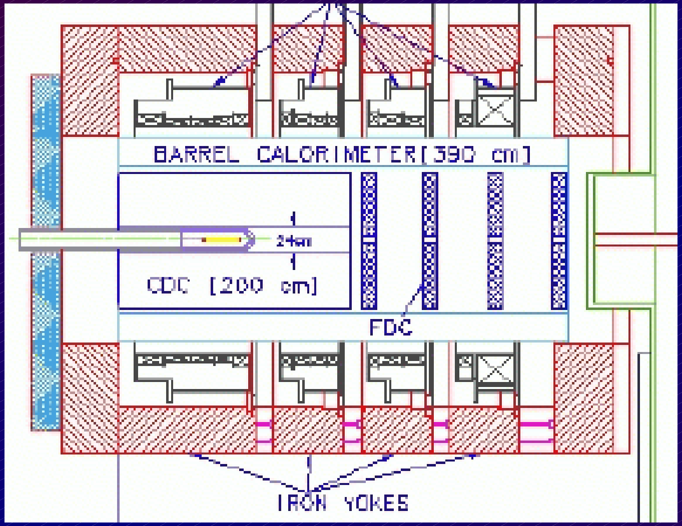
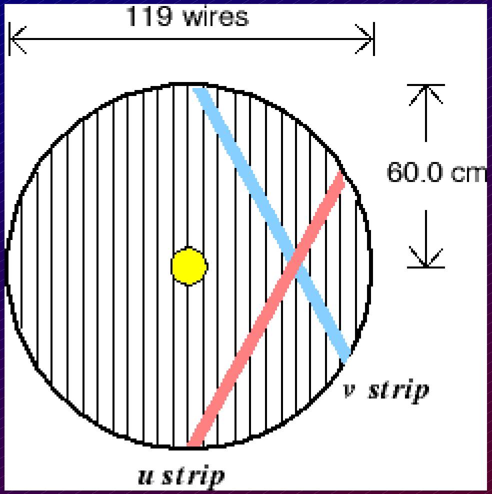
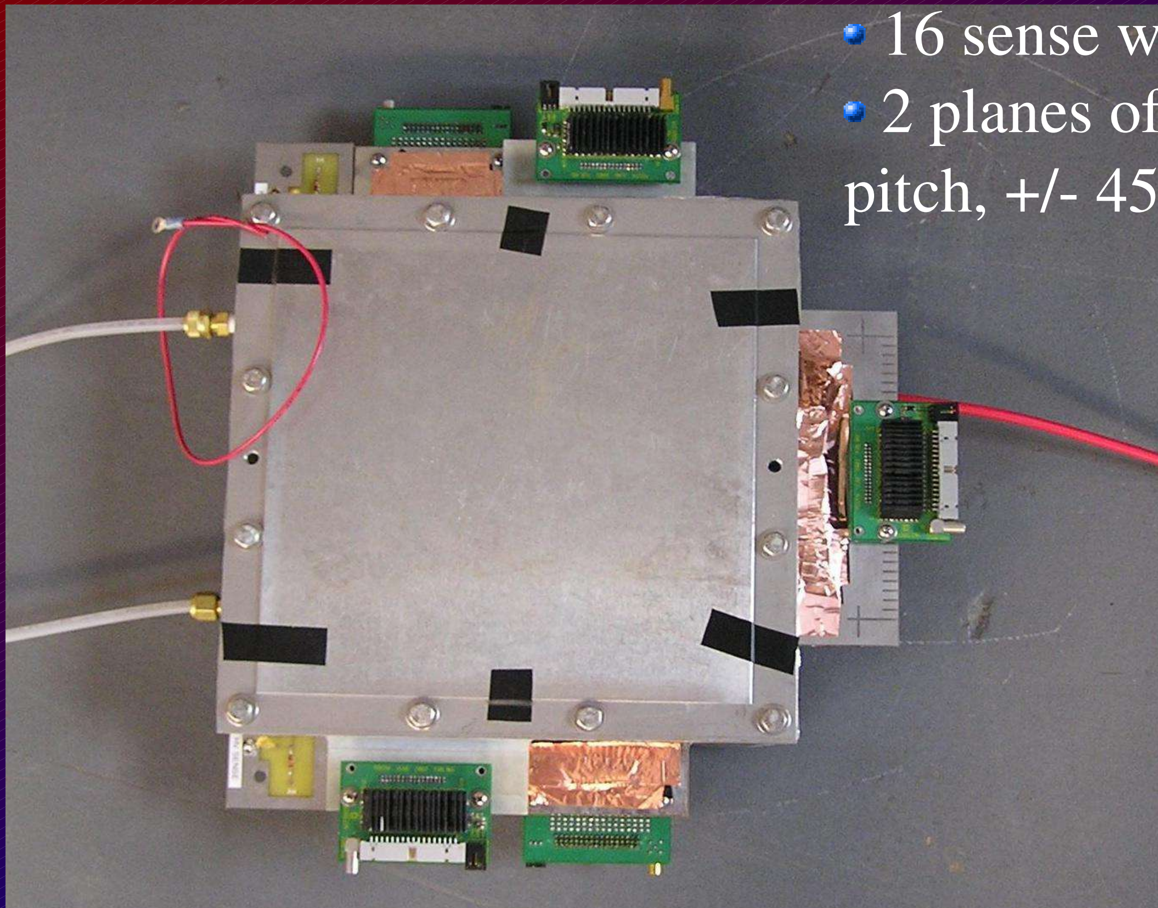


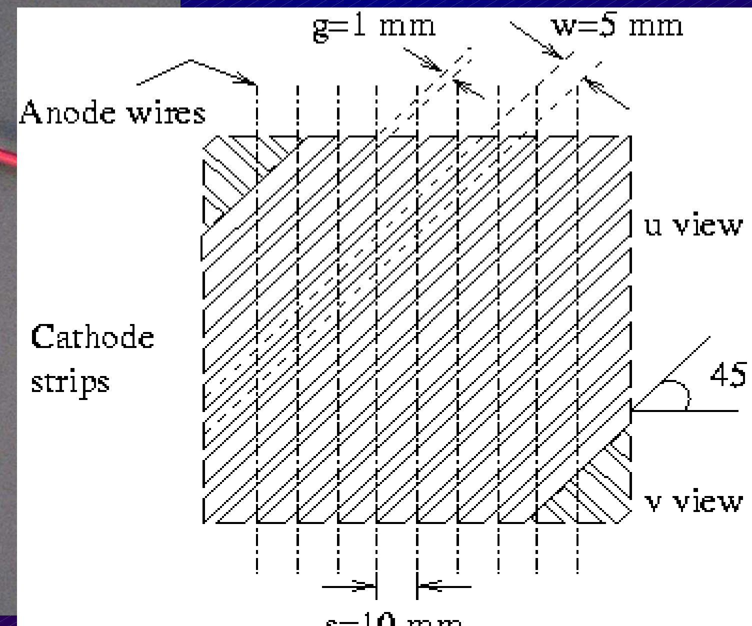


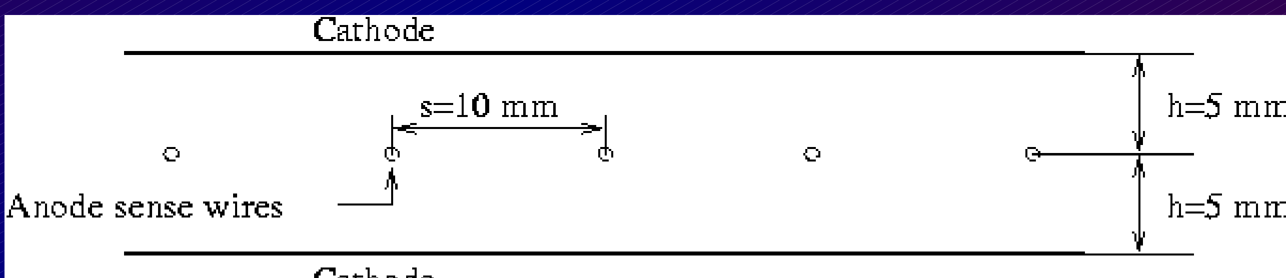
GlueX Electronics Meeting, April 6-7, 2006.

FDC prototype



- 16 sense wires with 10 mm pitch
- 2 planes of 32 cathode strips with 5 mm pitch, +/- 45° with respect to the wires



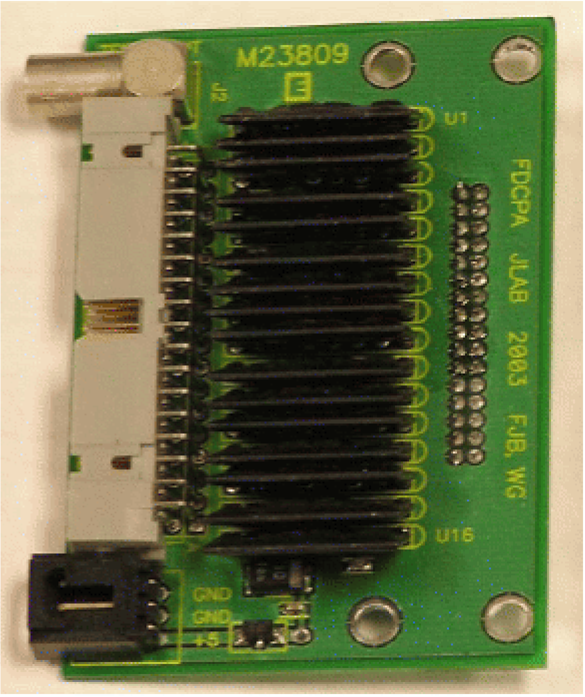


Goal: measure space point with <150 µm resolution in each coordinate

Standard configuration in literature: no field wires...

FDC Pre-amp boards

HALL B SIP PREAMPS

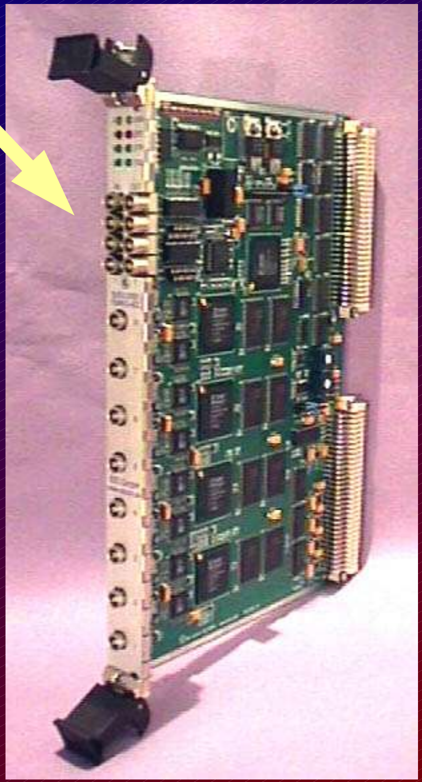


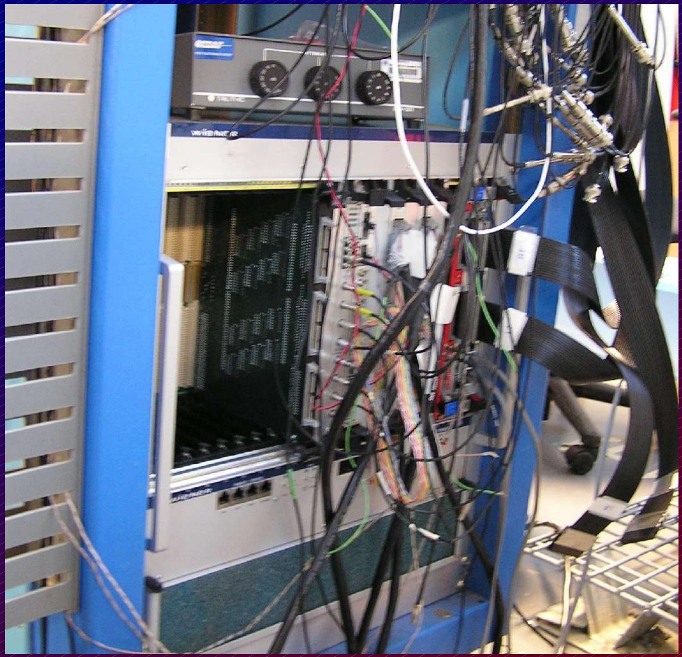
- **Preamplifier properties:**
  - *Gain 2.25 mV/µA*
  - *fast rise and fall time (3–4 ns)*
  - *wide frequency bandwidth*
  - *wide dynamic range*
  - *low noise*
  - *low power dissipation (65 mW)*
- **SIP performance will be used as a benchmark for performance comparisons.**

Presently cathode and anode amplifier boards are identical except for cathode polarity inversion.

FDC daq

- Readout hardware completely in VME
  - Cathode signals integrated using CAEN V792 (charge-integrating) ADCs
  - FDC anode wire timing signals and test stand chamber signals digitized using F1 TDC modules
  - 7 cathode signals + 1 anode wire read out with Struck SIS3300 FADC
    - 8 channels @105 MHz per channel
    - (1 MHz - 105 MHz configurable)
    - 2 banks x 128K samples/channel memory
    - 0 ↔ -1 V input range





Cathode Charge Distribution

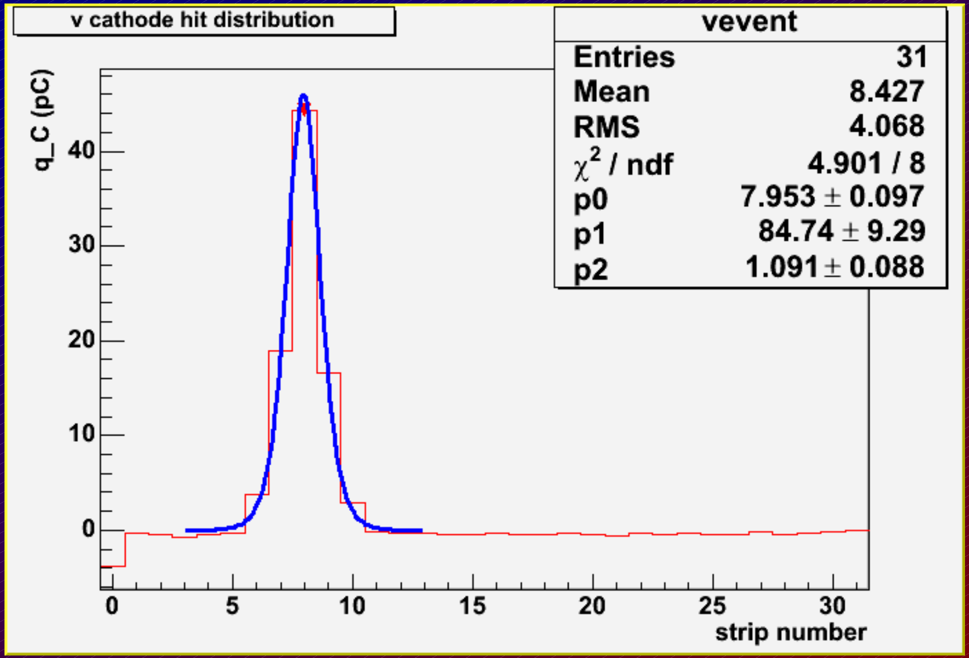
- Semi-empirical formula due to Gatti, et al./Mathieson & Gordon:

$$\frac{\rho(\lambda)}{q_a} = k_1 \left(\frac{1 - \tanh^2(k_2\lambda)}{1 + k_3 \tanh^2(k_2\lambda)} \right),$$

k_1, k_2, k_3 are empirical constants
λ = normalized coordinate in cathode plane

- Prototype geometry: **$k_3 \to 0$, $k_1 \to k_2/4$, $k_2 \approx 1$**

$$\frac{\rho(\lambda)}{q_a} = \frac{k_2}{4}\left(1 - \tanh^2(k_2\lambda)\right)$$



Newton-Raphson method I

Goal: Given distribution of charge over several adjacent strips, find the centroid position.

Wish to solve the following set of equations for $\vec{x} = \{q_a, K_2, x_p\}$:

$$F_i = Q_i - \frac{q_a}{4}\left[\tanh\left(K_2\left(\frac{x_p - x_i + a}{h}\right)\right) - \tanh\left(K_2\left(\frac{x_p - x_i - a}{h}\right)\right)\right] = 0, \; i = 1..3.$$

Taylor Expansion:

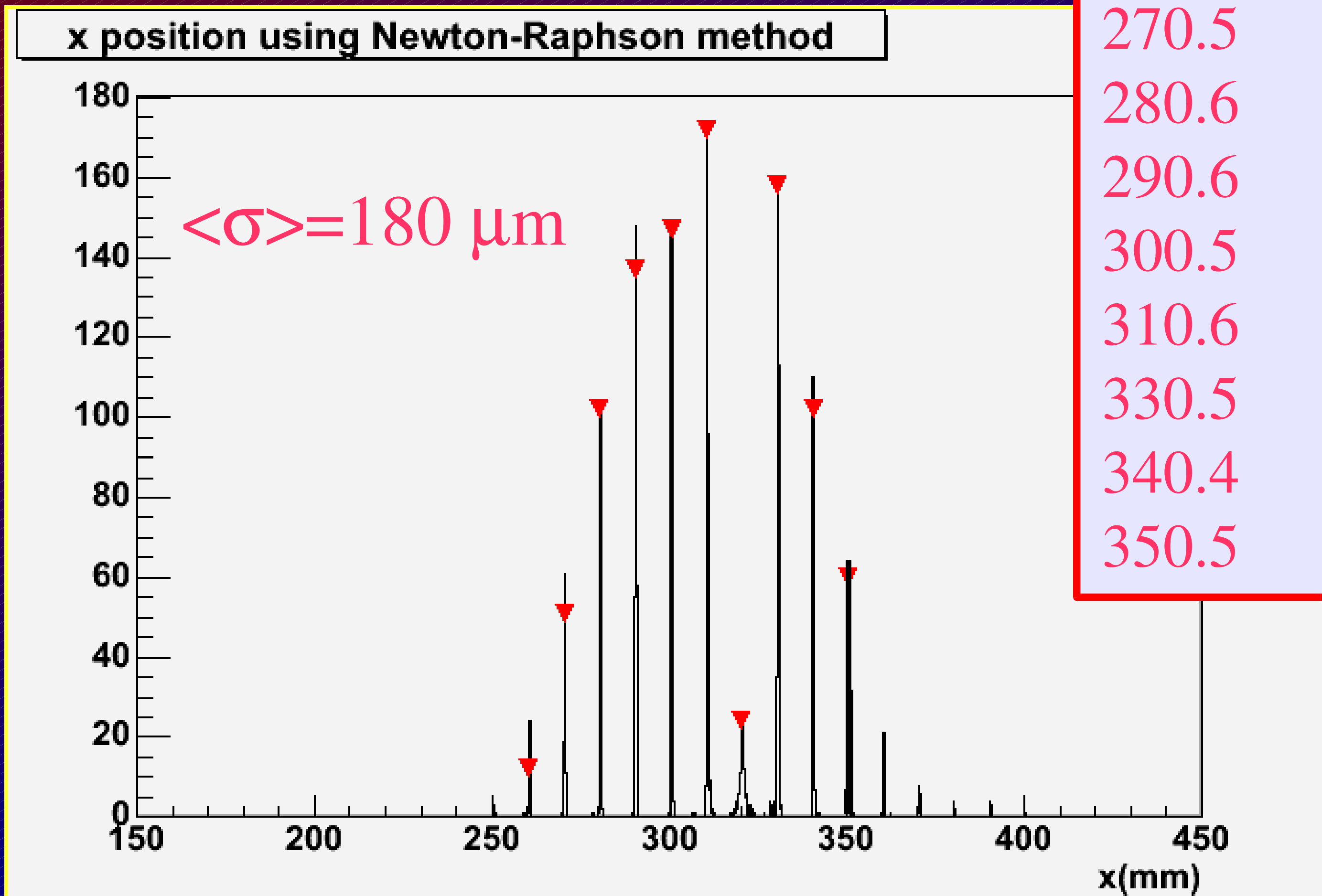
$$F_i(\vec{x} + \delta\vec{x}) = F_i(\vec{x}) + \sum_{j=1}^{3} \frac{\partial F_i}{\partial x_j}\delta x_j + \mathcal{O}(\delta\vec{x}^2).$$

Estimate for correction:

$$\delta\vec{x} = -J^{-1}\vec{F}, \qquad J_{ij} \equiv \frac{\partial F_i}{\partial x_j}.$$

Iterate until $\sum_{j=1}^{3} |\delta x_j| < \delta x_{min} = 0.0001$ or $\sum_{i=1}^{3} |F_i| < F_{min} = 0.0001.$

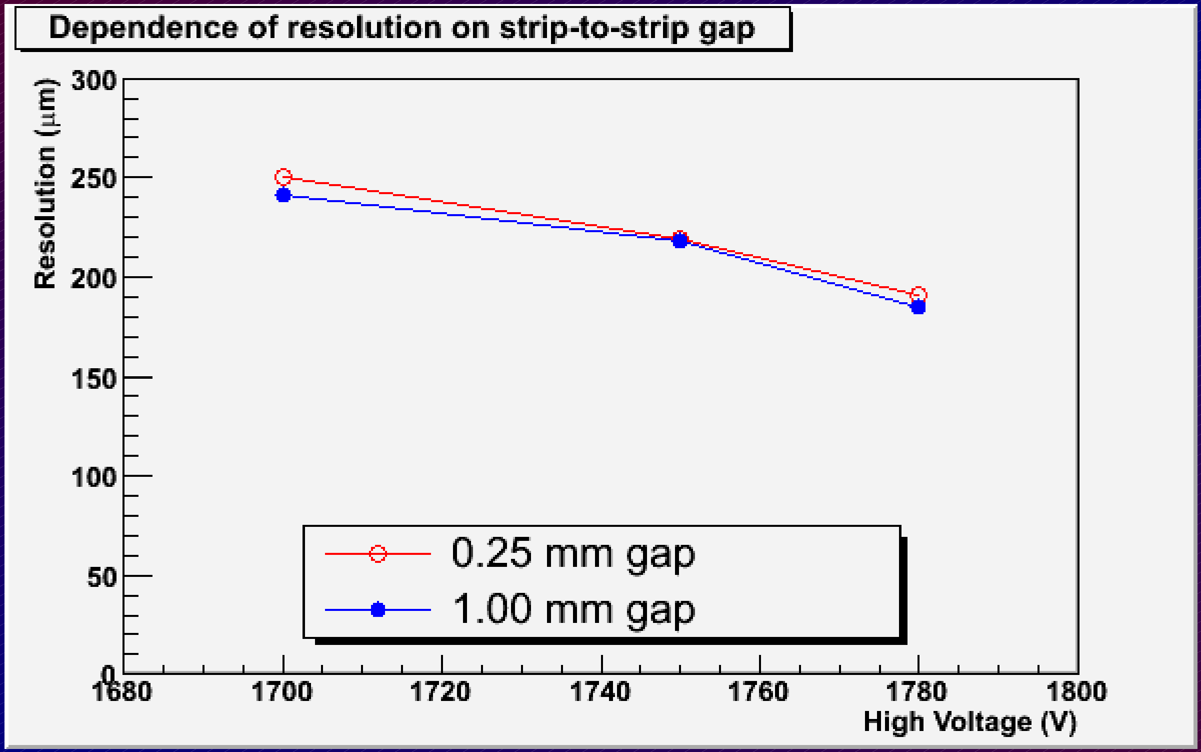
Best results at V_a=1750 V, 0.25 mm gap



x(mm)	σ(µm)
270.5	232.0
280.6	192.5
290.6	185.3
300.5	192.6
310.6	192.4
330.5	203.0
340.4	203.6
350.5	150.9

(CAEN charge-integrating ADC readout, 1 anode wire/event)

Comparison between 0.25 mm and 1 mm strip-to-strip gap widths



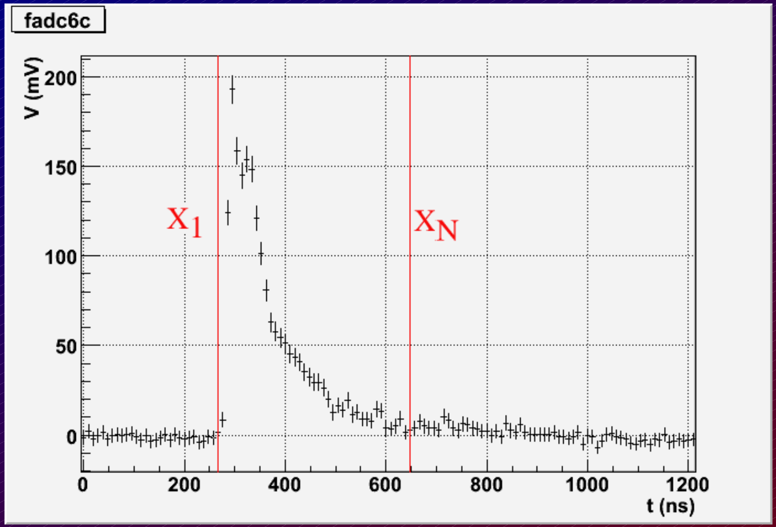
- Comparison was done with no cut on number of anode wires
- No significant difference in position resolution between two sets of measurements...

Extracting Charge from FADC data

Simple method: unweighted sum over bin contents.

$$\int_{x_1}^{x_N} f(x)dx = h\sum_{i=1}^{N} f_i,$$

where $\boldsymbol{h}$ = bin size and $\boldsymbol{f_i}$ = bin contents



- Lower bound (x_1) for integration:
  - Look for rising edge above threshold T.

$$f_2 - f_1 > \sqrt{\delta f_2^2 + \delta f_1^2}, \quad f_2 > T.$$

- Upper bound (x_N) for integration:
  - Look for first region in tail (above peak) consistent with zero.

$$f_{N-1} < \delta f_{N-1}, \quad f_N < \delta f_N$$

Extended Simpson's Rule

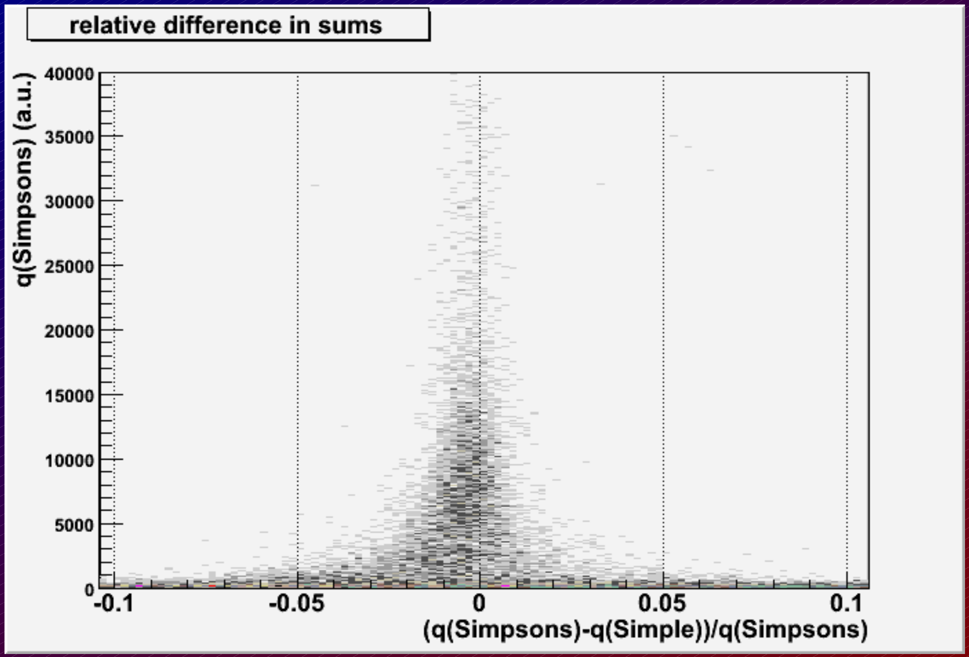
Method for integrating a function known at discrete points.

$$\int_{x_1}^{x_N} f(x)dx = h\left[\frac{1}{3}f_1 + \frac{4}{3}f_2 + \frac{2}{3}f_3 + \frac{4}{3}f_4 + \cdots + \frac{2}{3}f_{N-2} + \frac{4}{3}f_{N-1} + \frac{1}{3}f_N\right] + \mathcal{O}\left(\frac{1}{N^4}\right),$$

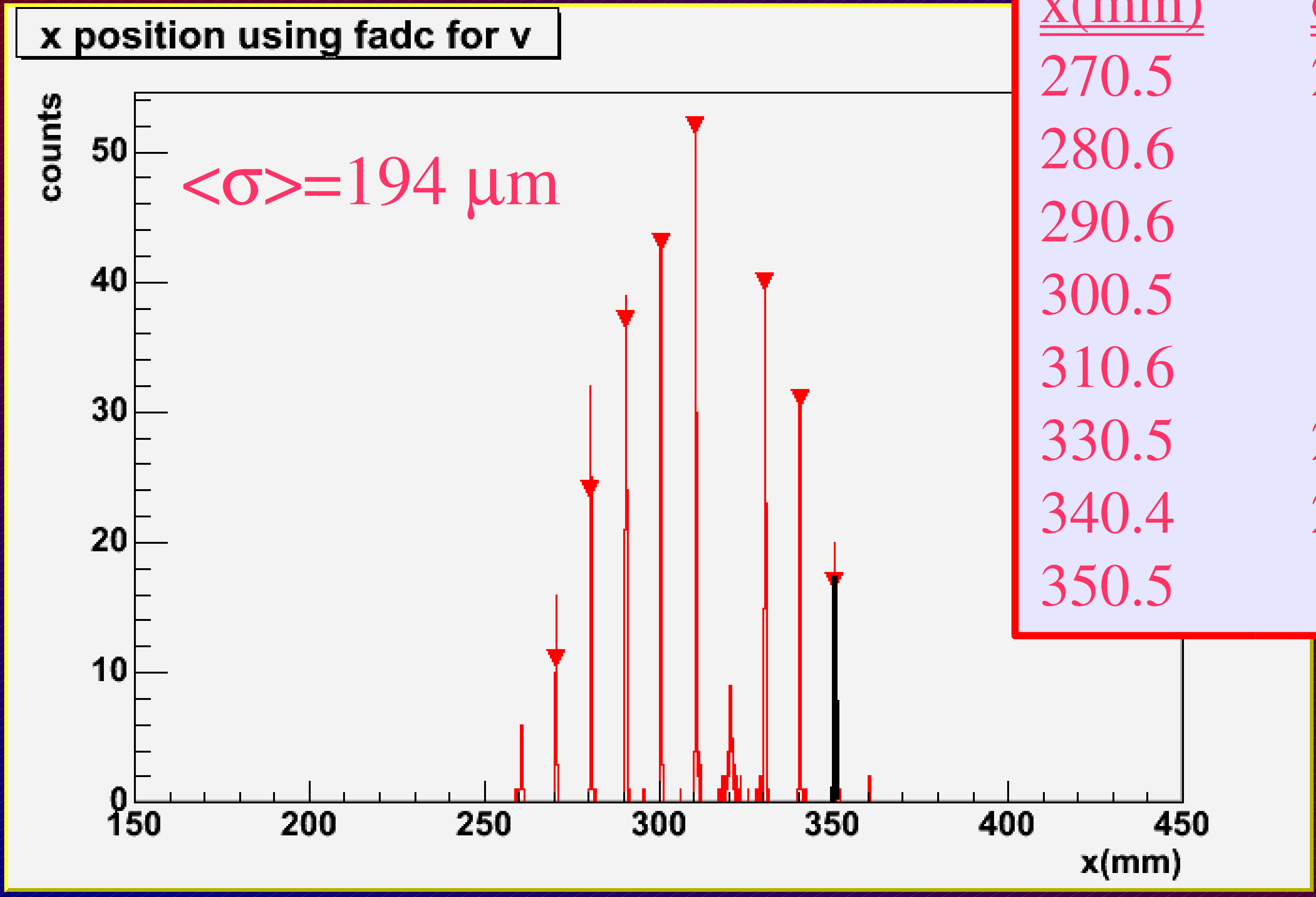
where h is the interval between points, and $f_i=f(x_i)$.

Comparison of 2 methods:

Simple method systematically overestimates integral relative to Simpson's method by about 0.36% on average (from FDC test data)



Position resolution using FADC data



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- Newton-Raphson method used for both views
- Result worse than previous case by about 14 μm

Summary

- Average wire position resolution using CAEN ADCs ~ 180 μm for V_a=1750 V
- No significant difference between 0.25 mm and 1.0 mm gap results
- Resolution using FADC still slightly worse than using charge-integrating ADCs

FADC Timing Algorithms

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GlueX Electronics Meeting, April 6-7, 2006.

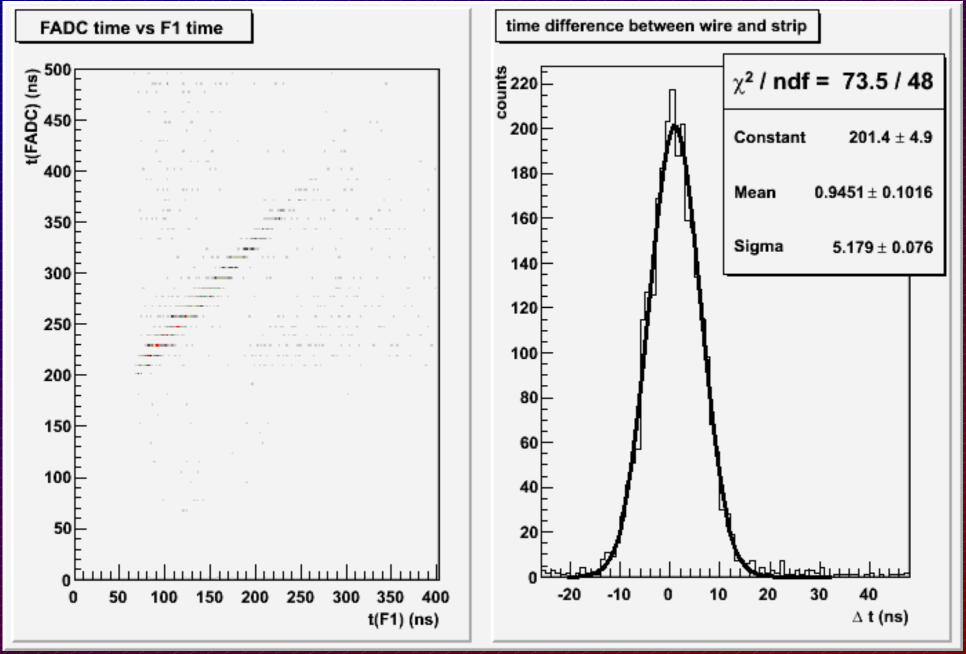
Simple timing algorithm

Method 1: Leading edge technique.

- Time at bin where data exceeds some threshold
- $\sigma_t = \Delta t / \sqrt{12}$ = 2.75 ns @ 105 MS/s, σ_t = 4.44 ns @ 65 MS/s
- Assuming drift velocity of 50 μm/ns: σ_x = 137 μm @ 105 MS/s

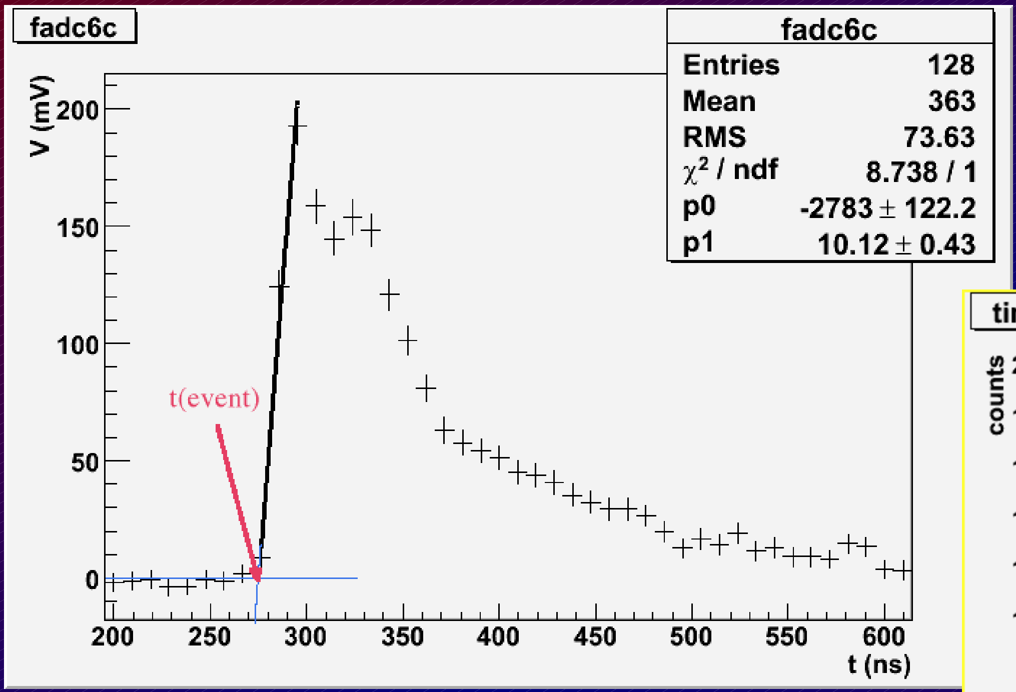
  σ_x = 222 μm @ 65 MS/s
- Measured avalanche timing using leading-edge discriminators and F1 TDCs on the anode wires
- Compared this time with the time deduced from cathode strip with largest signal.

V_{anode}=+1750 V
20 mV CAMAC threshold
5 mV software threshold
n_{wire}=1

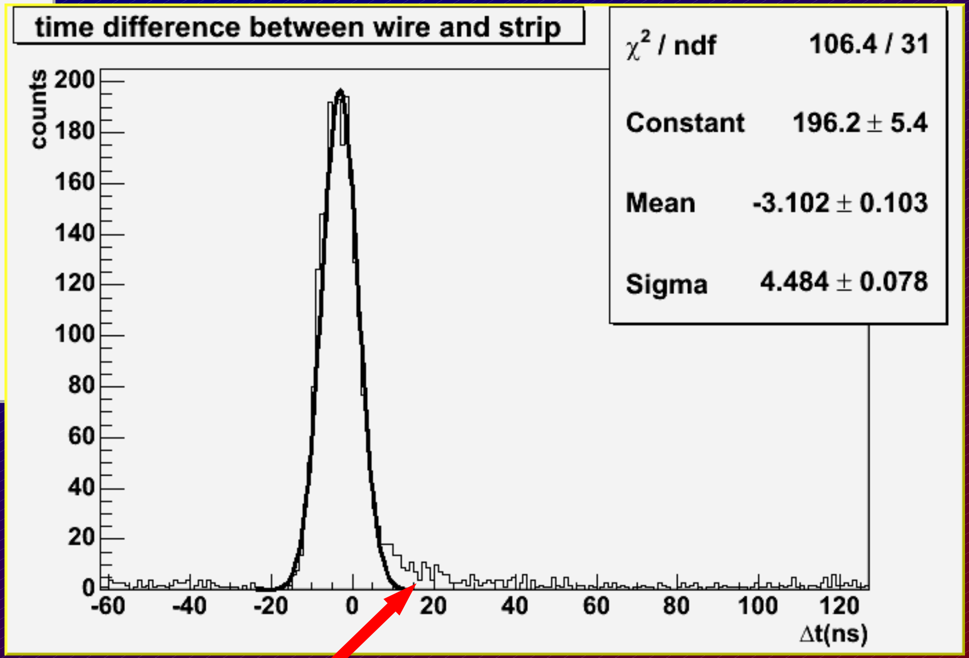


Extraction of time II

Method 2: Linear extrapolation to intersection with background



Measurably narrower than Method 1 …

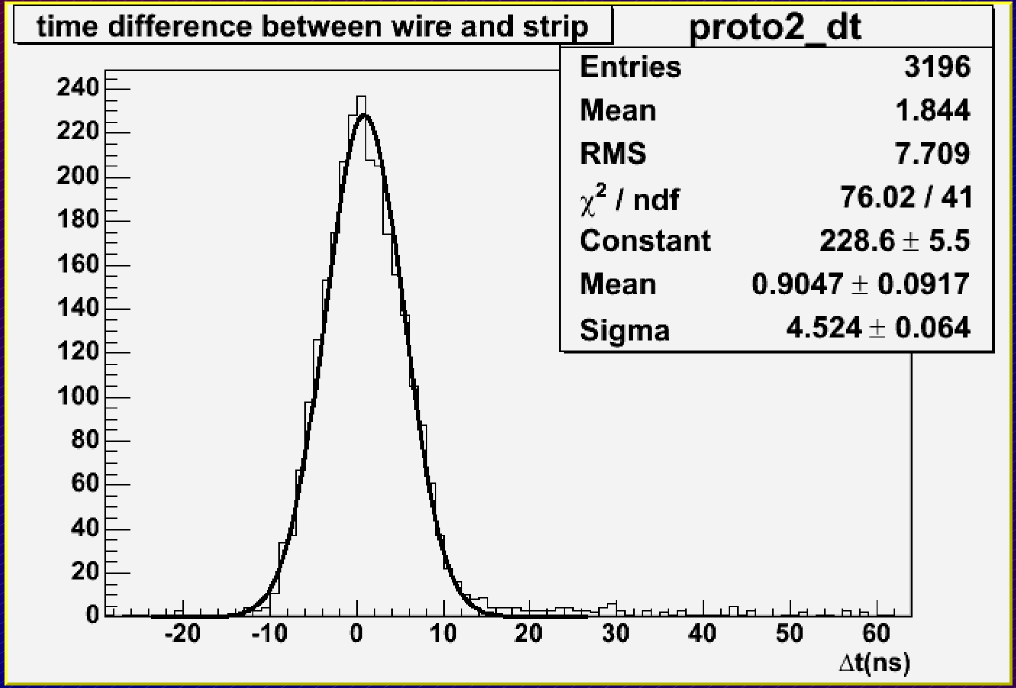


Use three samples, starting with the sample that exceeds some threshold (in this case 5 mV)

Asymmetric tail…

More on linear extrapolation method

- Choice of first sample is important – get better results starting with sample *before* sample that exceeds threshold



V_a=+1750 V,
Software threshold= 5 mV

Recall $\sigma(\Delta t)$ = 5.18 ns for one-sample method
→ 0.66 ns difference...

- Can we do better with a more realistic model for the pulse?

Model for Pulse Shape (I)

Signal induced on wire seeing avalanche:

$$i(t) = \begin{cases} -q_a \frac{C}{4\pi\varepsilon_0} \frac{1}{t+t_0} & \text{for } t \geq 0 \\ 0 & \text{for } t < 0 \end{cases}$$

(Corresponding cathode signals:)

$$i_c(\lambda, t) = \frac{q_c(\lambda)}{t + t_0} \text{ for } t \geq 0,$$

Model for preamp response function = single pole in s-space, exponential in t:

$$h(t) = \frac{-R_F}{\tau} e^{-t/\tau}.$$

where R_F is the preamp gain in mV/ μA

Convolution:

$$V(t) = \int_0^t i(t')h(t - t')dt'.$$

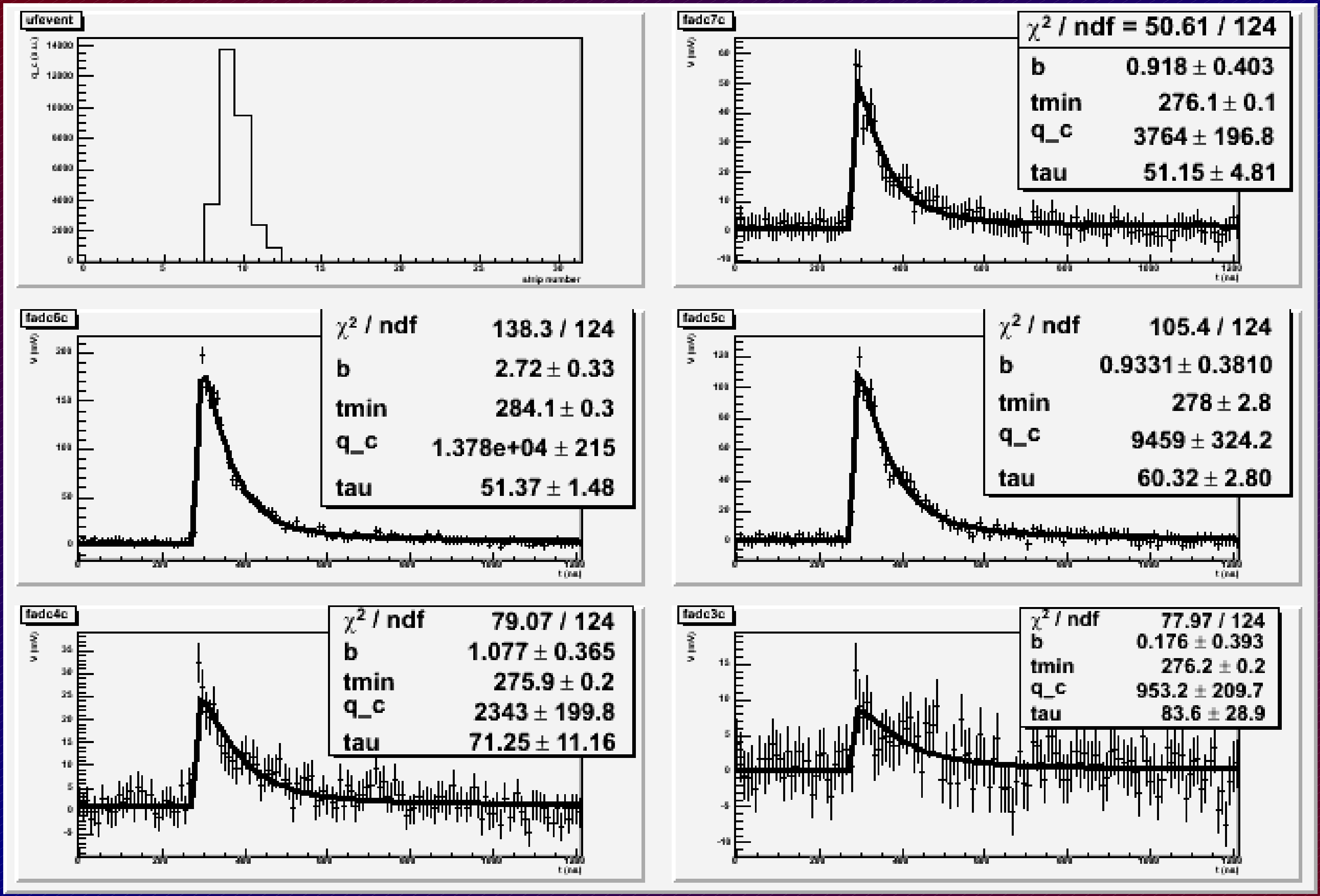
Result:

$$V(t) = \frac{q_a C R_F}{4\pi\varepsilon_0 \tau} e^{-(t+t_0)/\tau} \left[Ei\left(\frac{t + t_0}{\tau}\right) - Ei\left(\frac{t_0}{\tau}\right)\right] \text{ for } t \geq 0.$$

Exponential integral:

$$Ei(x) \equiv \int_{-\infty}^{x} \frac{e^z}{z} dz.$$

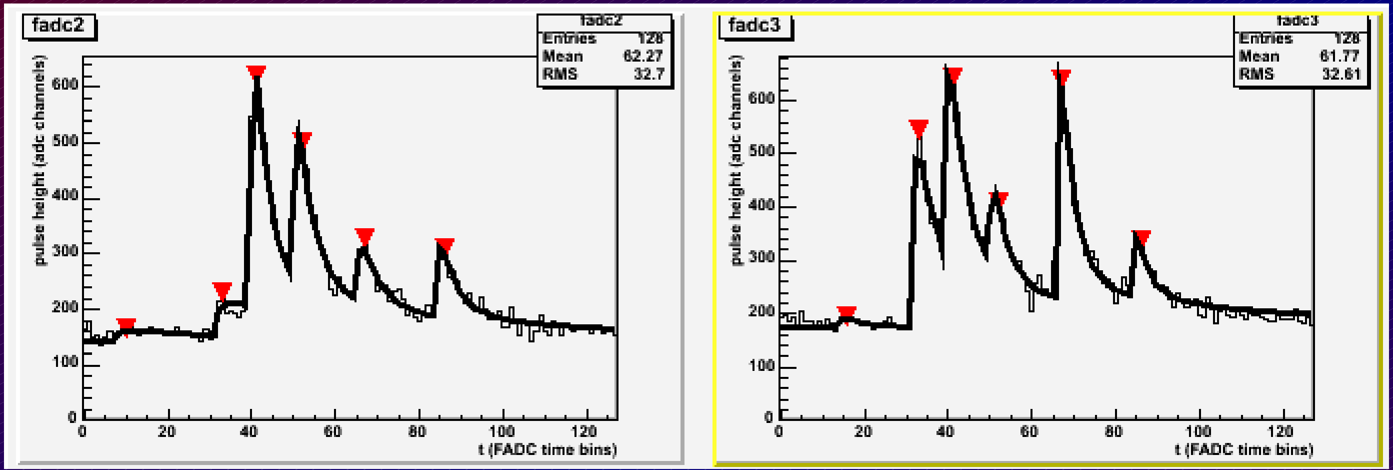
Sample Event with pulse-shape fits



Shape well-described but need to fix τ (should not vary from event to event)

Multiple Pulsing

Sample signals on cathode strips at 1770 V anode voltage:



The problem worsens (becomes more frequent) as the high voltage is increased

- Peak-finding and pulse-fitting algorithm may be able to sort out the mess, but...
- Data suggests need to add quencher to gas to prevent secondary avalanches due to emission from cathode planes

Newton-Raphson Method II

- Goal: use small number of samples with a good model for the shape of the leading edge to extract the time
- Time constant τ should not change from event to event → keep fixed.
- System of non-linear equations in 2 unknowns: **$\{t_{min}, q_C\}$**

$$F_i = V_i - |V(\lambda, t_i; t_{min}, q_c)| = 0,$$

- Taylor expansion:

$$F_i(\vec{x} + \delta\vec{x}) = F_i(\vec{x}) + \sum_j \frac{\partial F_i}{\partial x_j}\delta x_j + \mathcal{O}(\delta\vec{x}^2),$$

- Estimate for correction:

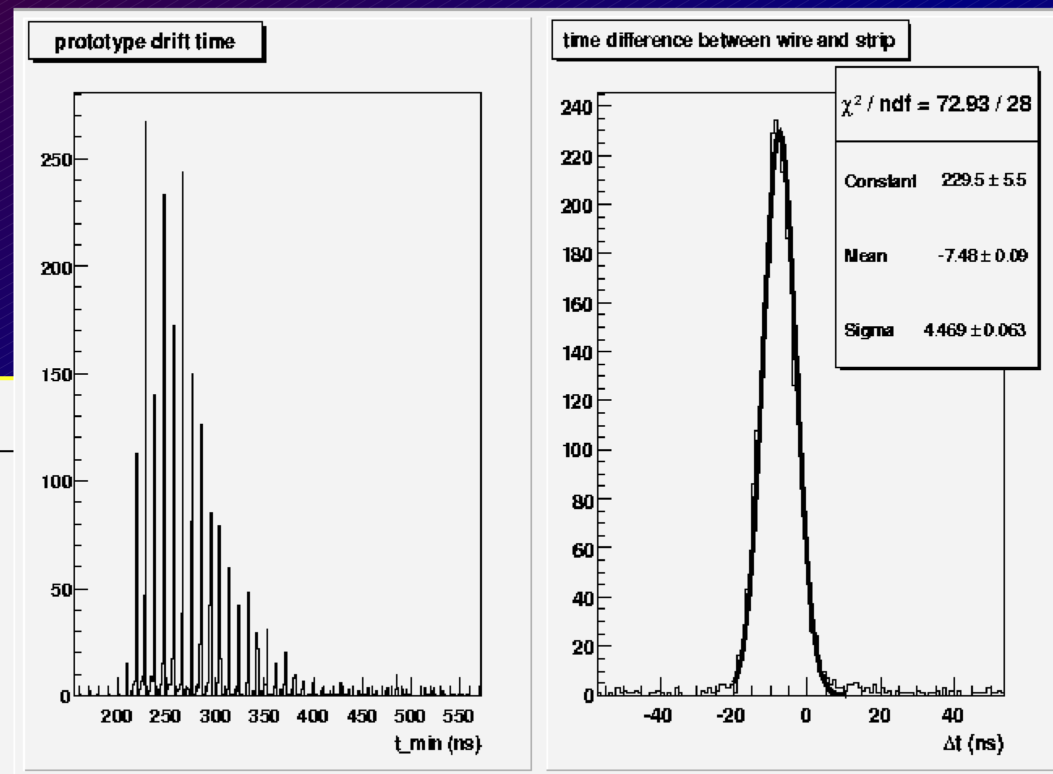
$$\delta\vec{x} = -\left(J^T J\right)^{-1} J^T \vec{F},$$
$$J_{ij} \equiv \frac{\partial F_i}{\partial x_j}.$$

- Iterate until

$$\sum_j |\delta x_j| < \delta x_{min} = 0.0001 \text{ or } \sum_i |F_i| < F_{min} = 0.0001.$$

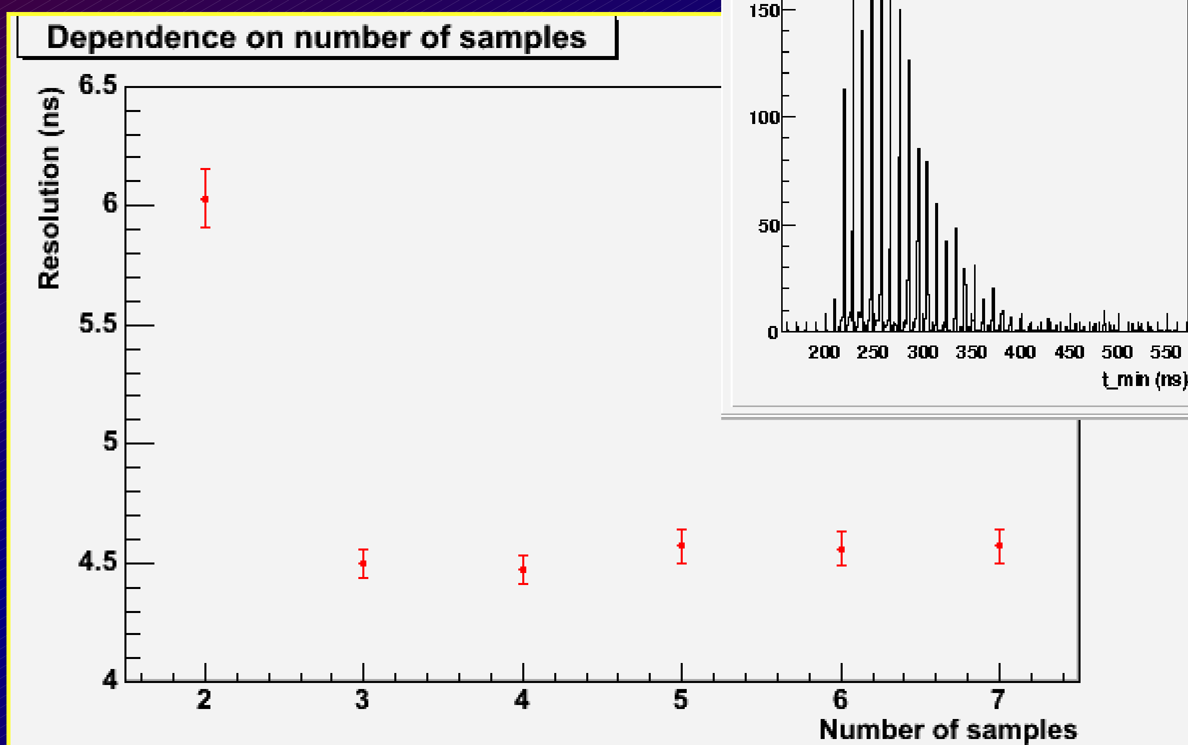
Results for pulse shape model I

For N(Samples)=4: $\sigma\ (\Delta t) = 4.47$ ns



V_a =+1750 V,

Software threshold = 5 mV



The N=4 result is the same as for the linear extrapolation method...

Improved Model for Pulse Shape

- Revised transfer function:

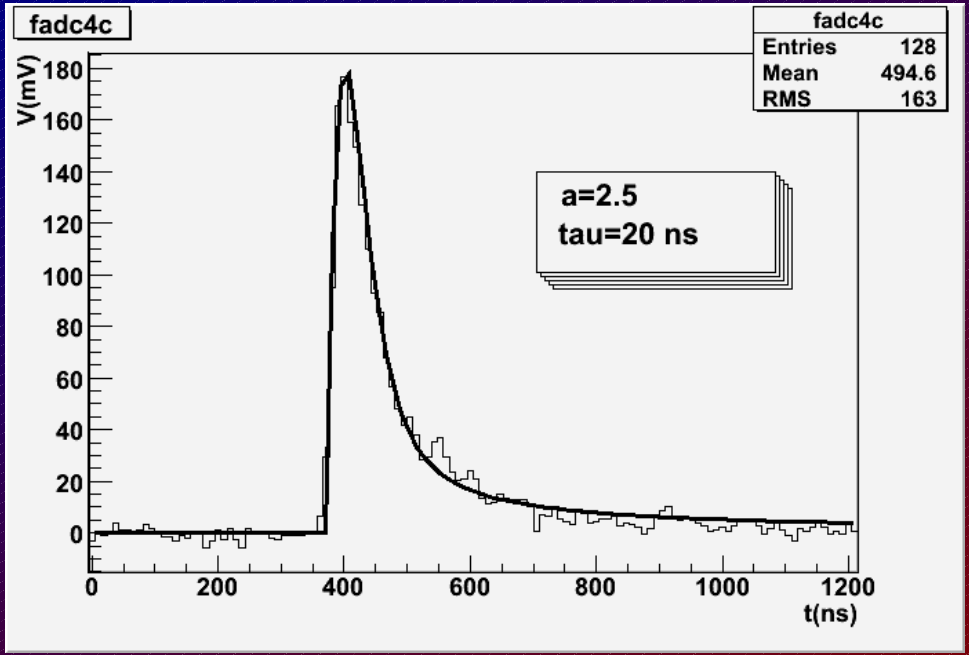
$$h(t) = -\frac{R_F}{\tau} e^{-t/\tau} \left(1 + a\frac{t}{\tau}\right)$$

a=0 corresponds to previous model

- Result of convolution:

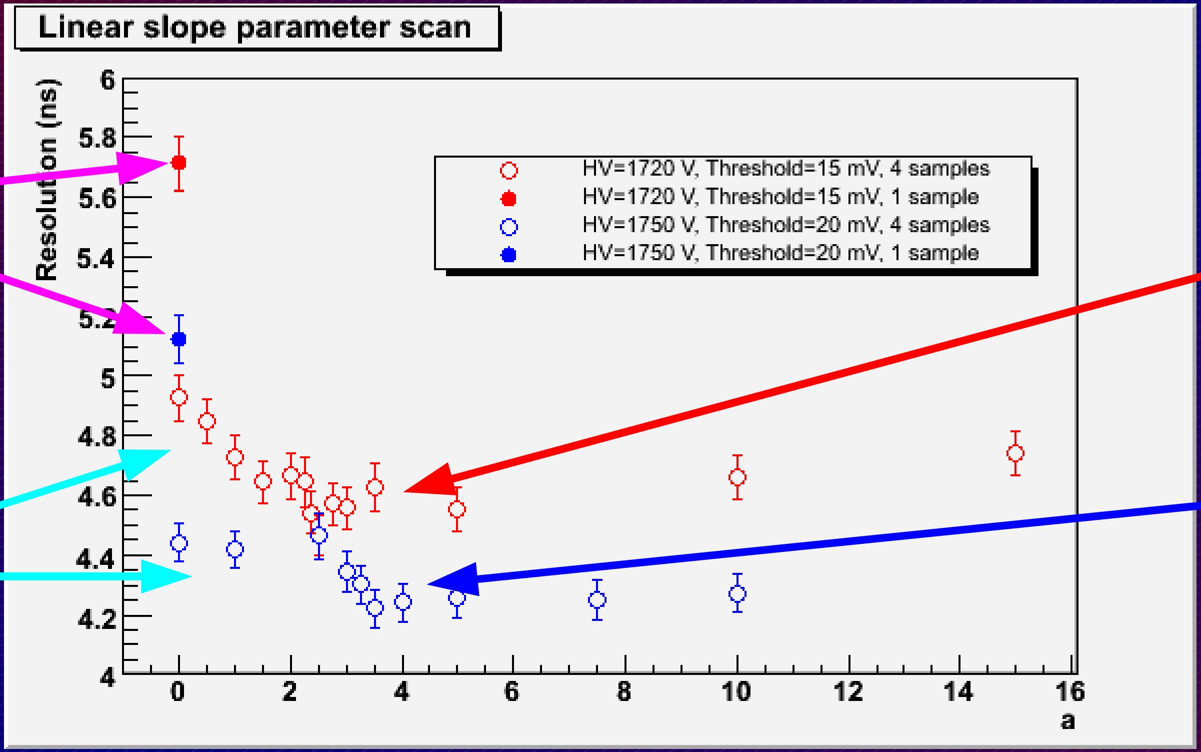
$$V(t) = -\frac{qR_F}{\tau} \left[e^{-(t+t_0)/\tau} \left(Ei\left(\frac{t+t_0}{\tau}\right) - Ei\left(\frac{t_0}{\tau}\right)\right) \left(1 + a\frac{t+t_0}{\tau}\right) - a\left(1 - e^{-t/\tau}\right)\right]$$

Sample cathode pulse, V_a=+1720 V



Results for Pulse Shape Model II

One sample method



Four sample method

$\sigma_{min} = 4.47$ ns

$\sigma_{min} = 4.22$ ns

- Effect of tuning *a* larger for smaller V_a
- For V_a=1750, ~250 ps improvement relative to a=0

  → ~1 ns improvement relative to one-sample method.

Summary

- Simple one sample method gives worst timing results – more samples in leading edge needed
- Linear extrapolation and pulse shape model I give equivalent results for V_a=1750 V
- Best results obtained for pulse shape model II after tuning the *a* parameter.