Status of detector tests and signal calculation

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Signal Decomposition Meeting

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Outline

- Summary of detector tests status
- Prototype II in-beam test
- Prototype III scan and analysis (Mario)
- Prototype III in-beam test
  - LBNL
  - MSU
- Signal calculation
  - Status
  - Challenges
- What needs to be done

Test data analysis

Prototype II

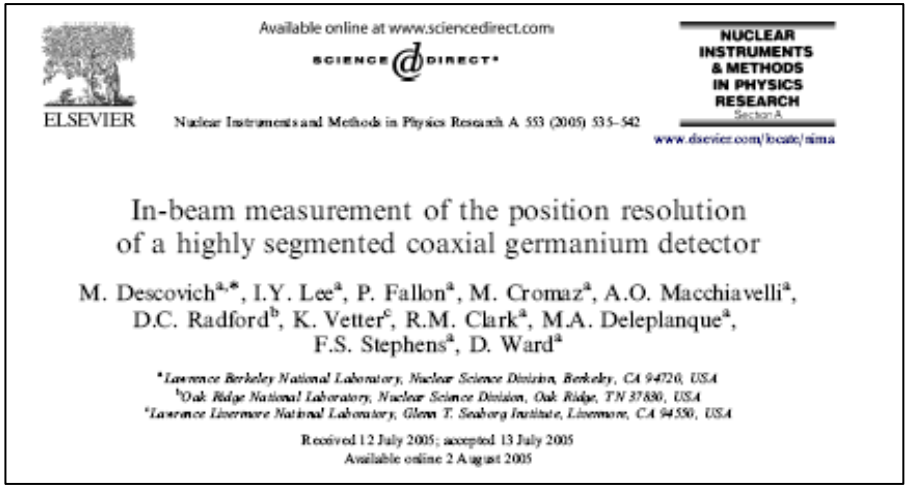
Test	Status	Position resolution (mm RMS in 3D)
Scan	completed	1.0
In-beam	completed	2.0

Prototype III

Test	Basis	Status	Position resolution (mm RMS in 3D)
Scan	old	completed	2.8
	new	completed	2.0
In-beam LBNL	old	completed	2.8
	new	to be done	
In-beam MSU	new	to be done	

Prototype II test results

- Data analysis completed
- Obtained a position resolution of 2 mm RMS in all three dimensions.
- Main contribution to the position resolution is the uncertainty associated with the signal starting time (t_0).



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In-beam measurement of the position resolution of a highly segmented coaxial germanium detector

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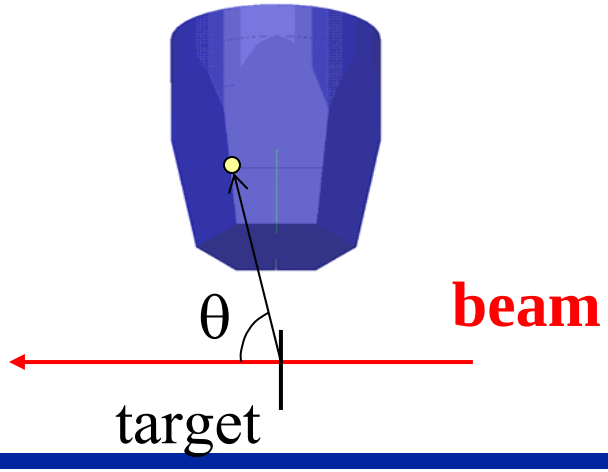
PII In-beam test

Experiment

- LBNL 88” Cyclotron (July 03)
- Prototype II detector
- $^{82}Se + ^{12}C$ @ 385 MeV
- ^{90}Zr nuclei ($\beta \sim 8.9\%$)
- 2055 keV ($10^+ \rightarrow 8^+$) in ^{90}Zr
- Detector at 4 cm and 90°
- Three 8-channels LBNL signal Digitizer modules (24 ch.)



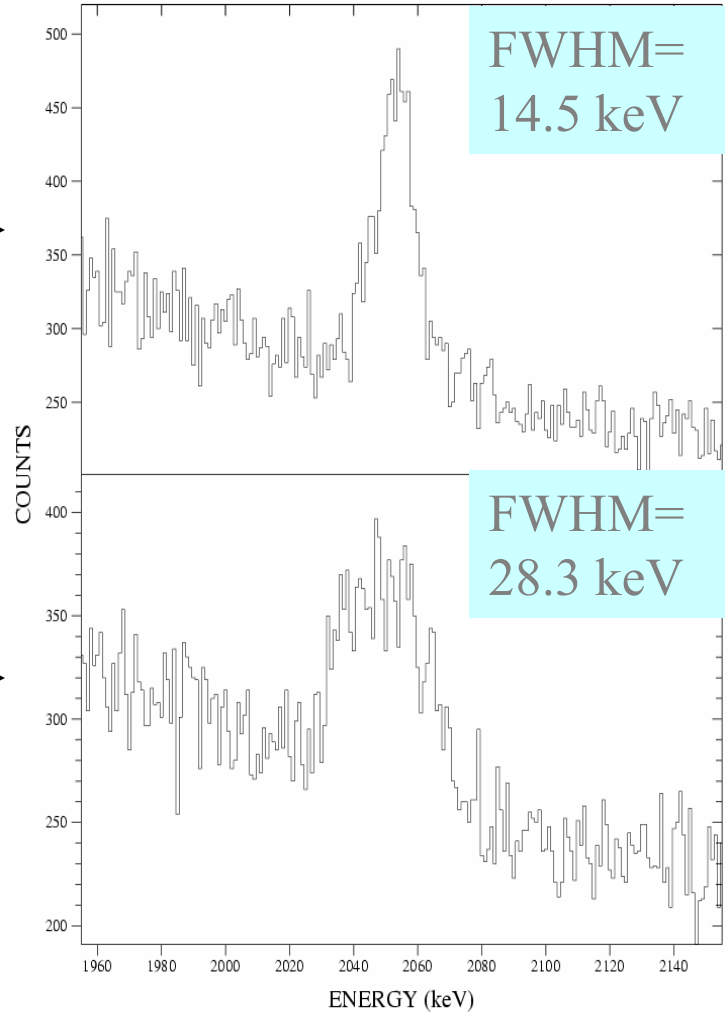
Analysis

- Event building
- Calibration : cross talk
- Signal decomposition
- Doppler correction

PII in-beam results

Doppler corrected for position of 1st interaction

Doppler corrected for center of segment



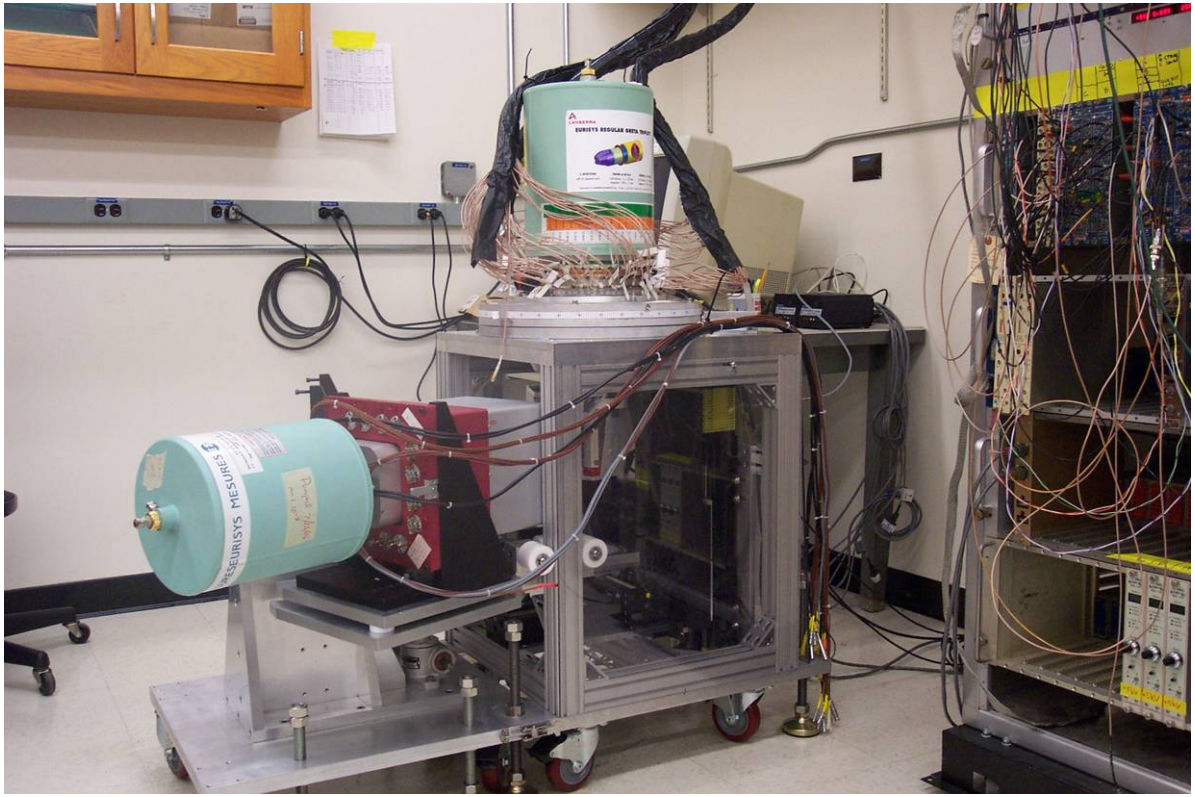
According to simulations, FWHM 14.5 keV ➔ σ_x = 2.0 mm (rms)

PII test vs. simulation

Factors				Δ E FWHM (keV)	Δ r RMS (mm)
Noise (keV)	Threshold (keV)	Working segments	T_0		
0	0	All	perfect	7.6	0.6
5	0	All	perfect	8.1	0.7
13	0	All	perfect	8.9	0.9
13	50	All	perfect	9.3	0.9
13	50	No 5th, 6th layers	perfect	9.9	1.1
13	50	No 5th, 6th layers	Leading edge	14.9	2.0

Coincidence scans setup

Position sensitivity : Measure pulse shape of a single interaction using a prompt coincidence requirement between GRETINA prototype III and Clover(s)



1mCi ^{137}Cs source

Vertical and slit collimators to define 90 deg scattering

500nsec overlap

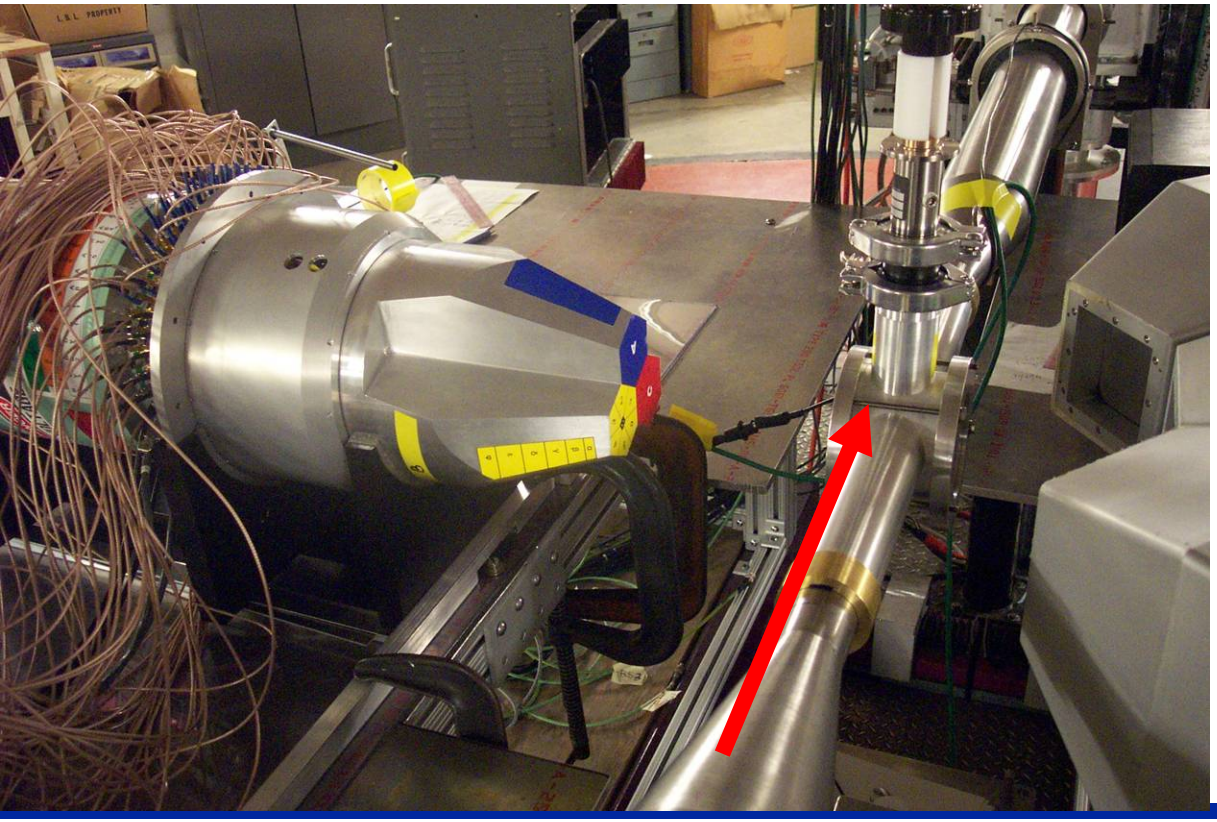
Coincidence trigger ~ 200 events/day

PIII in-beam test setup

Experimental measurement of position resolution Doppler broadening related to Δr

Goal: Maximize Doppler effect

- $^{82}Se + ^{12}C$ @ 385 MeV
- ^{90}Zr nuclei (b ~ 0.09)
- 2055 keV ($10^+ \rightarrow 8^+$) in ^{90}Zr
- Target–detector @ 5 cm
- Beam–detector @ 90^0



1.5kHz each crystal

Trigger on A or BC

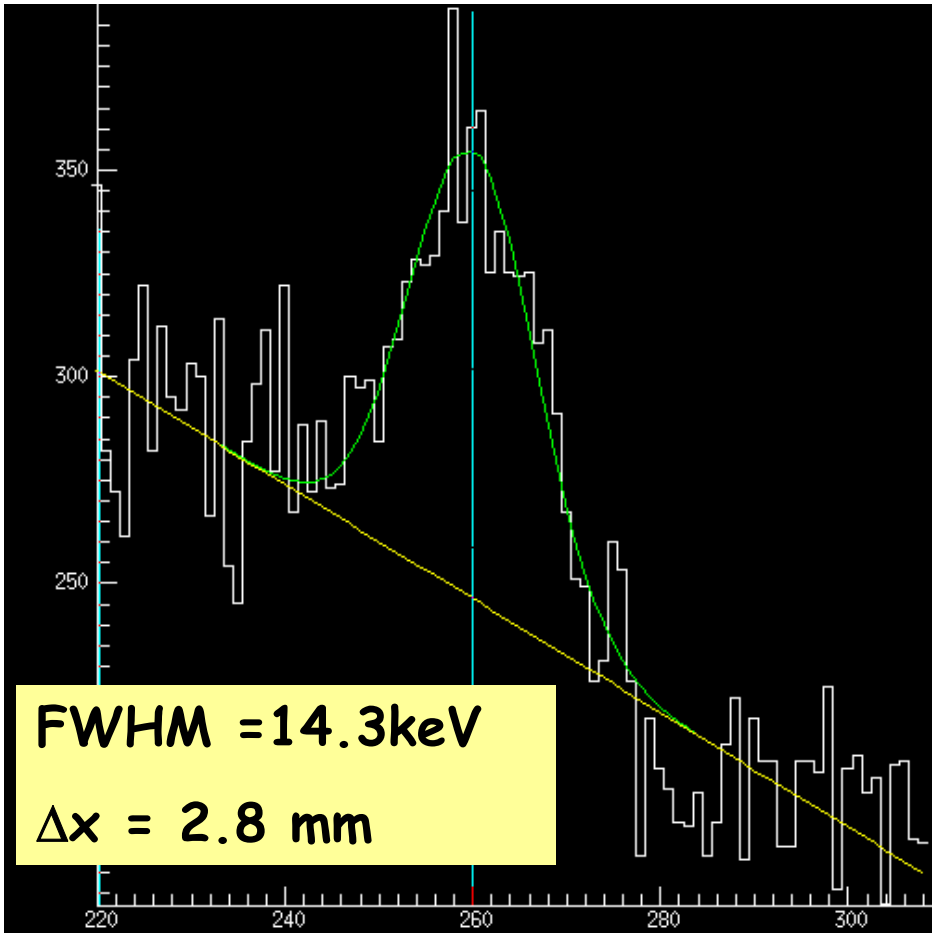
1MeV cut on total energy

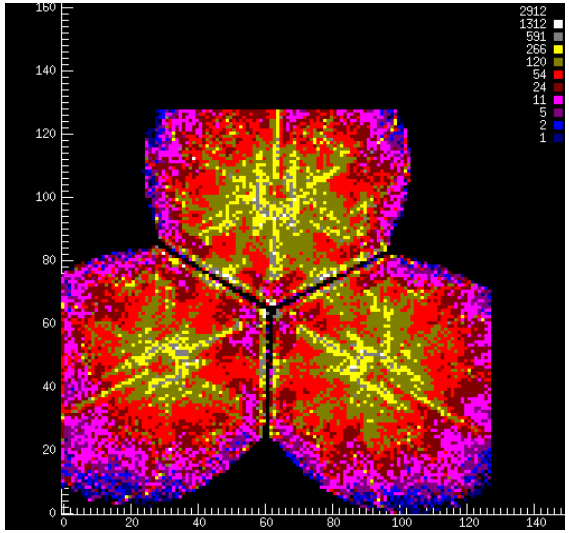
~3MBytes/sec to disk

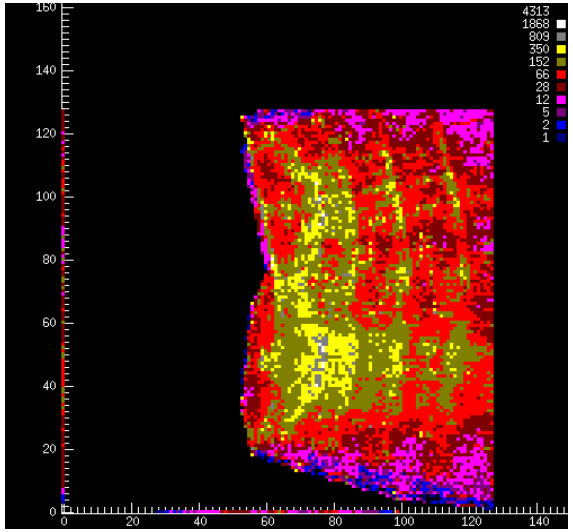
3/4 Tbyte of data

Comprehensive calibration data set

In-beam test results of PIII





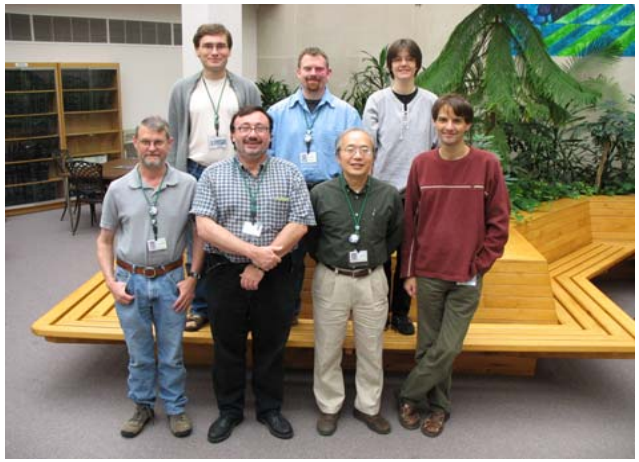


2 or 3 Crystals

In-beam test at NSCL MSU

August 26 – 29, 2006

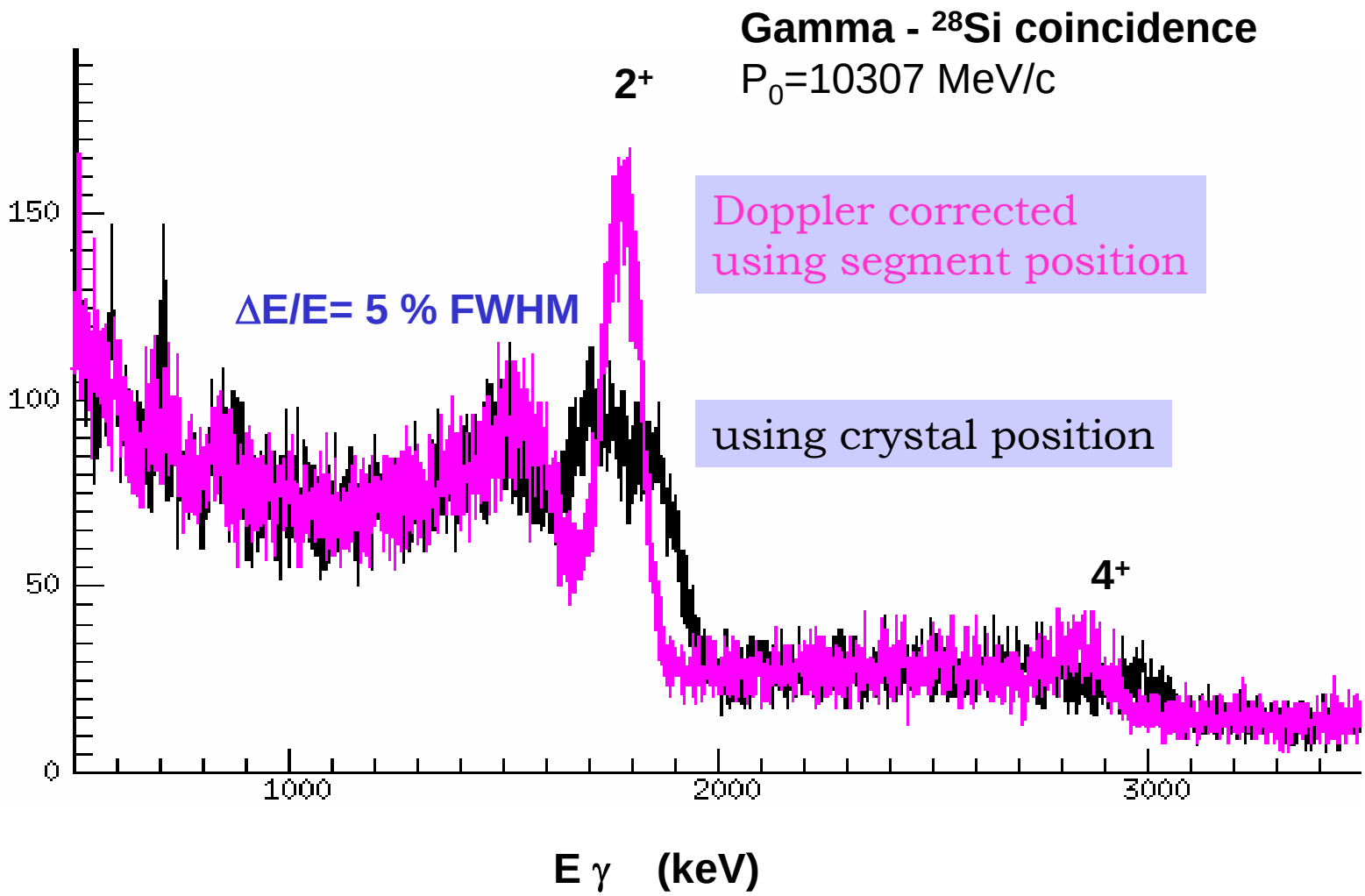
Measure position resolution at high recoil velocity
Use time stamps to correlate auxiliary detector data



In-beam test at NSCL MSU

- **Fragmentation reaction: ^{36}Ar + Be**
- **GRETINA 3-crystal prototype:**
  at 58° and 9 cm from target.
- **S800 selects p_0=10307 MeV/c :**
  E_0=70 MeV/A, v/c=0.368
- **Two separated ACQ systems:**
  data correlated by time stamps.
- **Total gamma –recoil coincidence event:**
  10M
- **Gamma - ^{28}Si coincidence event: 330,000**

^{28}Si gamma spectrum



Signal Calculation

- Detector geometry
- Impurity concentration
- HV

Field Calculation (FEM)

(Maxwell 3D)

- Electric field
- Weighting potentials (tabulated on a 1 mm grid)

- Detector geometry
- Drift velocity
- Neutron damage

Signal calculation

- Interaction position
- Electronics response

- Calculations are carried out for a grid of interaction points in crystals
- Pulse shape from the central and 36 outer contacts are calculated

Field and weighting potential

- **Electric field**

$$\vec{E} = \vec{\nabla} V$$

$$\nabla^2 V = \rho \qquad \rho : impurity\ \ concentrat\,ion$$

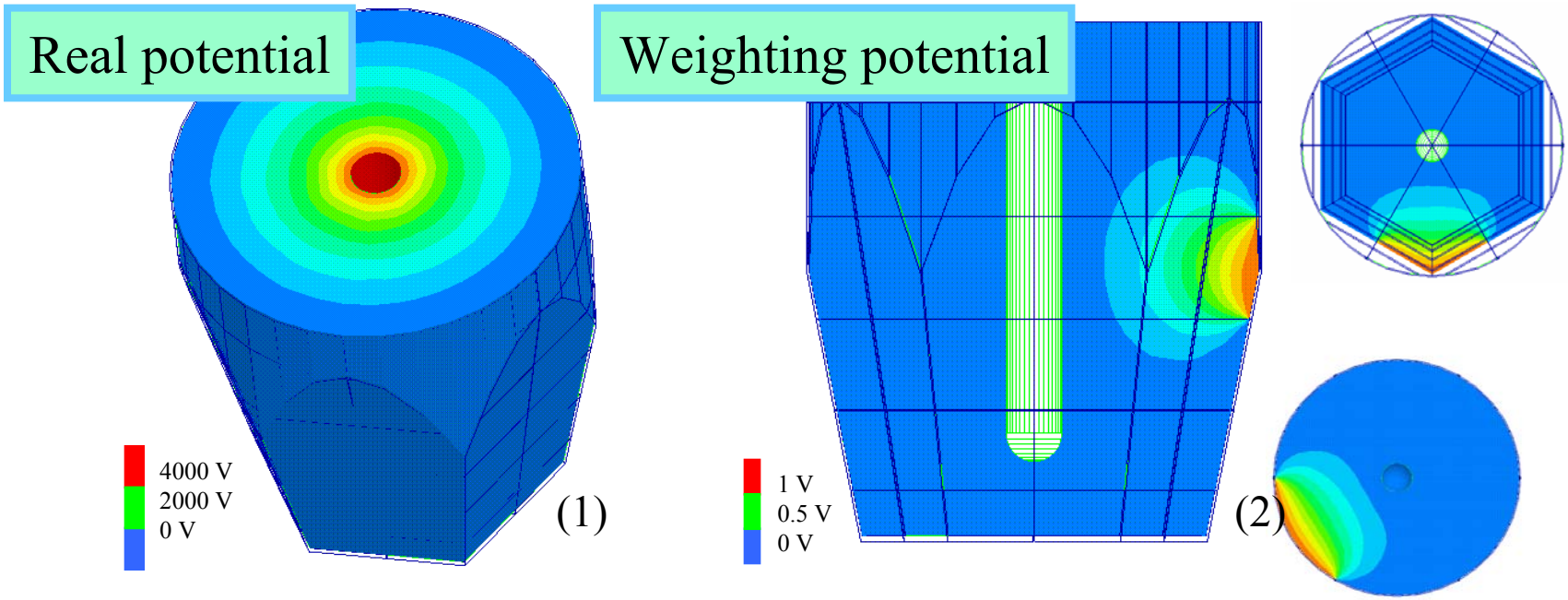
$$Boundary\ condition :\quad applied\ bias\ voltage$$

- **Weighting potential for segment *k***

$$\nabla^2 V_k = 0$$

$$Boundary\ condition :\quad 1\ V\ on\ the\ segment\ k$$
$$0\ V\ on\ all\ other\ segments$$

Maxwell 3D



- Weighting potential is calculated by applying 1 V on the segment collecting the charge and 0 V to all the others (Ramo's Theorem).
- It measures the electrostatic coupling (induced charge) between the moving charge and the sensing contact.

Trajectory and signal

- **Trajectory : for electrons and holes**

$$\vec{v} = \vec{v}(\vec{E})$$

anisotropic

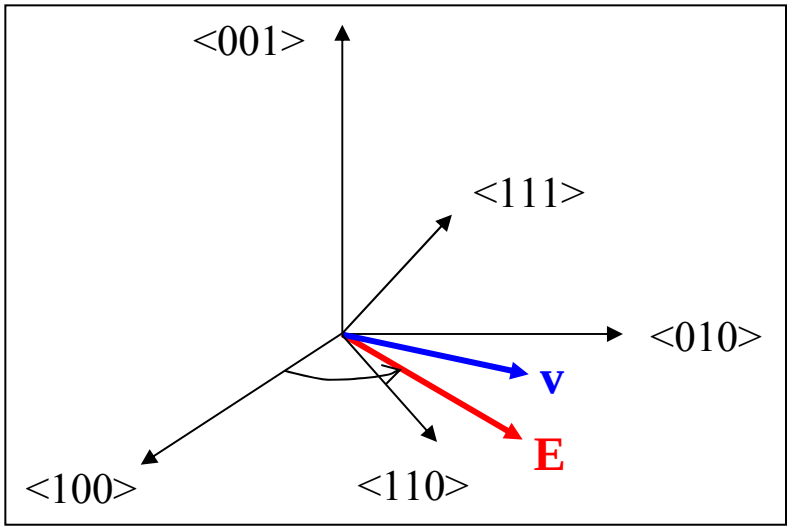
$$\vec{x}(t) = \vec{x}_0 + \int_0^t \vec{v}\, dt$$

- **Induced charge (S. Ramo, Proc. IRE 27(1939)584)**

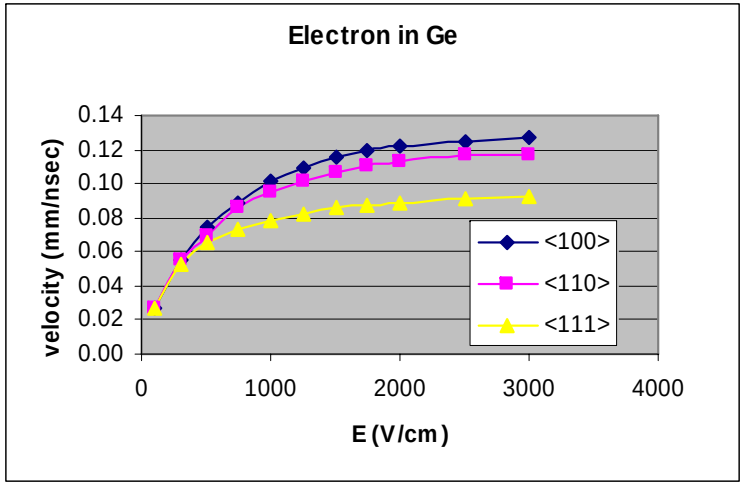
If a charge q moves from position x_1 to position x_2, then the induced charge on electrode k is

$$\Delta Q_k = q\left(V_k(\vec{x}_2) - V_k(\vec{x}_1)\right)$$

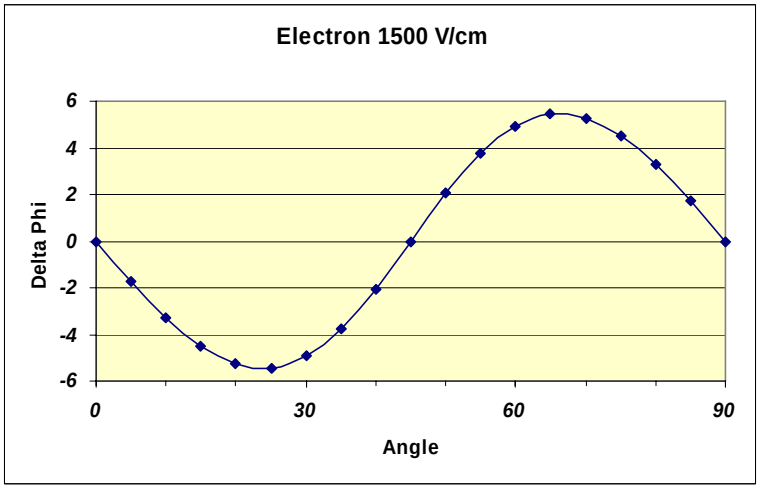
Drift velocity



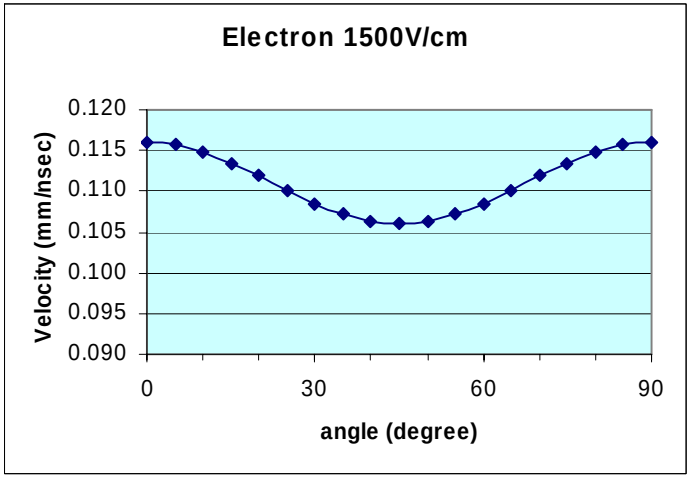
Function of E-filed



Anisotropic in direction



Anisotropic in magnitude



Effects of velocity anisotropy

- Magnitude variation ≈ 10% max.
  - → Position variation in drift direction :

    35 mm × 0.1 = 3.5 mm
- Direction deviation ≈ 6° max.
  - → Position deviation perpendicular to drift direction:

    35 mm × 5° = 3.0 mm

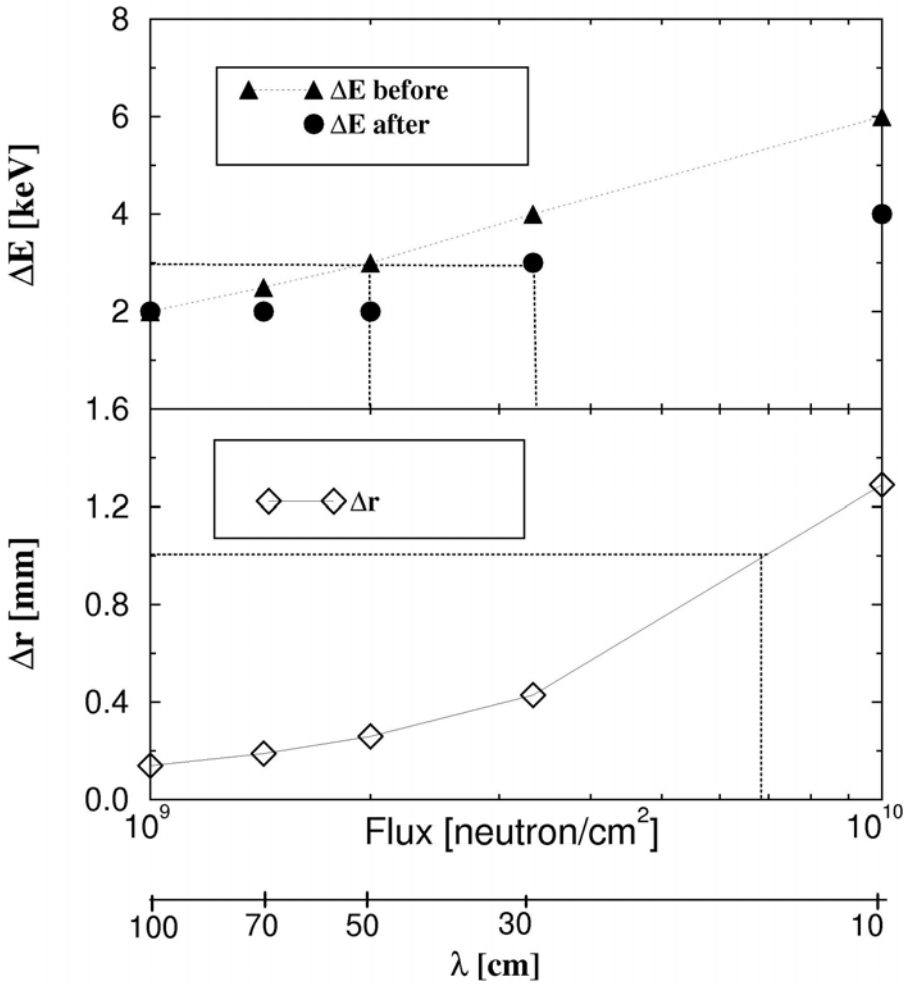
Status of drift velocity

	Velocity	Measurements	Theory/model
electron	magnitude	yes	physics
	direction	some	physics
hole	magnitude	yes	interpolation
	direction	few	empirical

Neutron Damage effects

- Degradation in E resolution occurs for λ<50 cm, before correction and for λ<30 cm, after correction.
- But only for λ<17 cm position resolution becomes worse than 1 mm.

A measurable effect of neutron damage on position resolution is never reached before annealing is required for energy resolution!



Impurity Concentration

Impurity => Space Charge =>Electric Field => Drift velocity => Pulse shape

- Impurity concentration is not constant in the crystal.

From the manufacturer (z-variation) → V_{op} = 5000 V

Crystal A: $\rho = (0.45 - 1.5) \times 10^{10}$ a/cm^3 → V_{fd} = 2500 V

Crystal B: $\rho = (0.76 - 1.2) \times 10^{10}$ a/cm^3 → V_{fd} = 2000 V

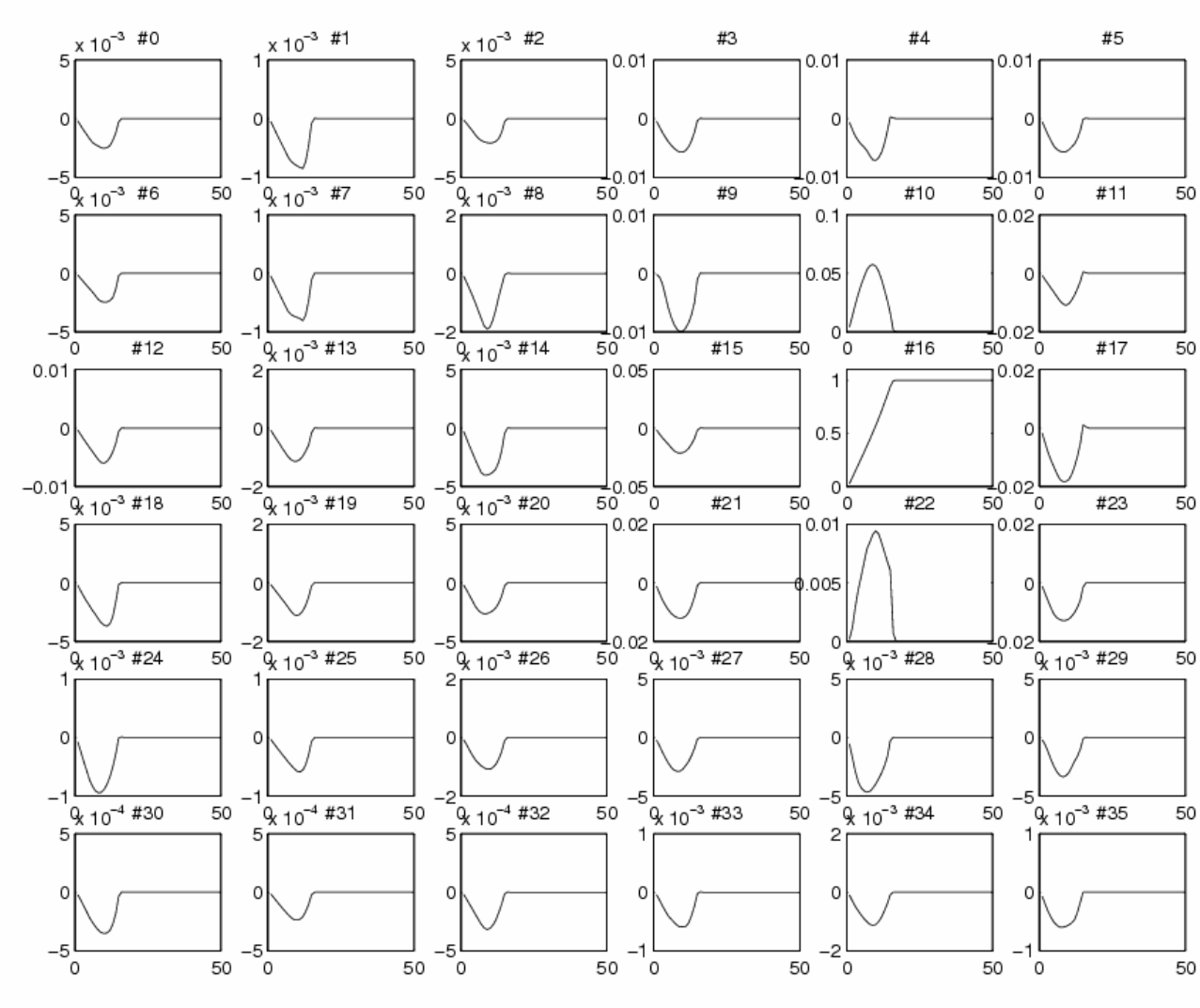
Crystal C: $\rho = (0.83 - 1.8) \times 10^{10}$ a/cm^3 → V_{fd} = 3750 V

- Studied concentration from $\rho = 0$ to $\rho = 1.4 \times 10^{10}$ a/cm^3.
- Position sensitivity has been calculated.
- The capability of reconstructing the interaction position is not affected, if the impurity concentration is known with accuracy of:

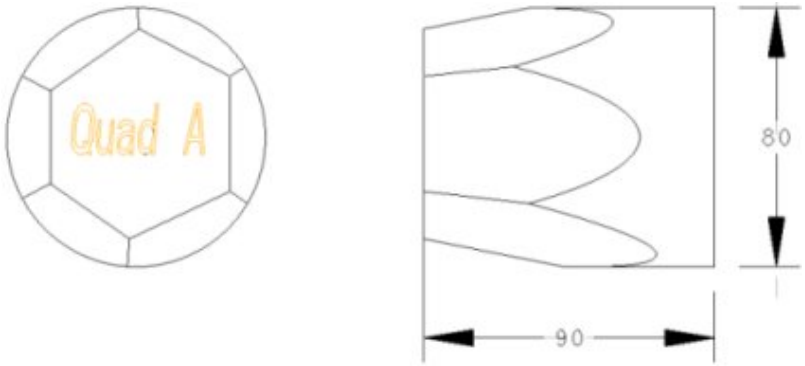
$\Delta\rho$ = 0.75 x 10^{10} atoms/cm^3 => 1 mm

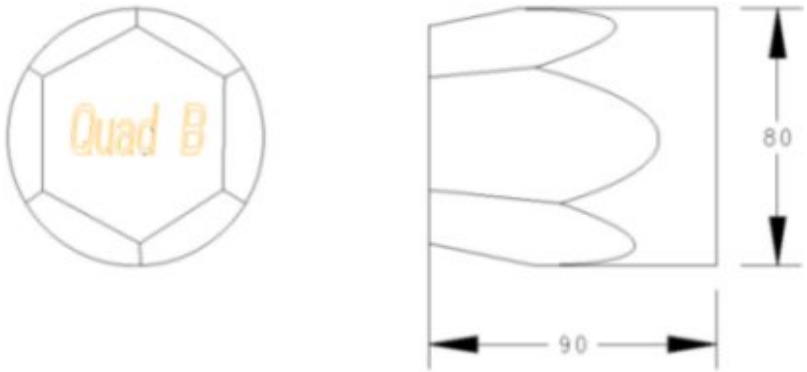
Example of calculated signal

Prototype III (x,y,z) = (-9, 20, 30)



Quad Crystal Shapes





Crystal A	
Corner angle	**Taper angle**
124.84	9.70
117.71	9.64
117.45	9.33
115.18	9.86
119.98	9.70
124.84	9.59

Volume = 376,302 μl

Crystal B	
Corner angle	**Taper angle**
118.29	9.72
121.46	9.64
119.41	9.86
123.51	10.15
118.94	10.15
118.39	9.34

Volume = 392,040 μl

Challenges of signal calculation

- **Improve model of drift velocity**
  - **needs model and/or measurements for holes**
  - **maximum error 3 mm**
- **Knowledge of impurity concentration**
  - **1 mm error ~ 0.75×10^{10} atom/ml**
- **Neutron damage**
  - **1 mm error ~ 5 keV resolution**
- **Understand charge collection at segment lines and end of crystal**
- **Determine electronics response**
- **Match time of experimental signal with time of base signal (t_0)**

What needs to be done

- **Analyze PIII in-beam data – new basis**
- **Understand hole drift velocity**
- **Include direction anisotropy in signal calculation**
- **Understand charge collection at segment lines and end of crystal**
- **Determine response of electronics**
- **More coincidence scan measurements**
- **Match time of experimental signal with time of base signal (t_0)**
- **Calculate signals for quad crystals**