Electron momentum distributions in metals using the Angular Correlation of positron Annihilation Radiation (ACAR)

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Supervisors:
Prof. C. D. Beling
Department of Physics, HKU

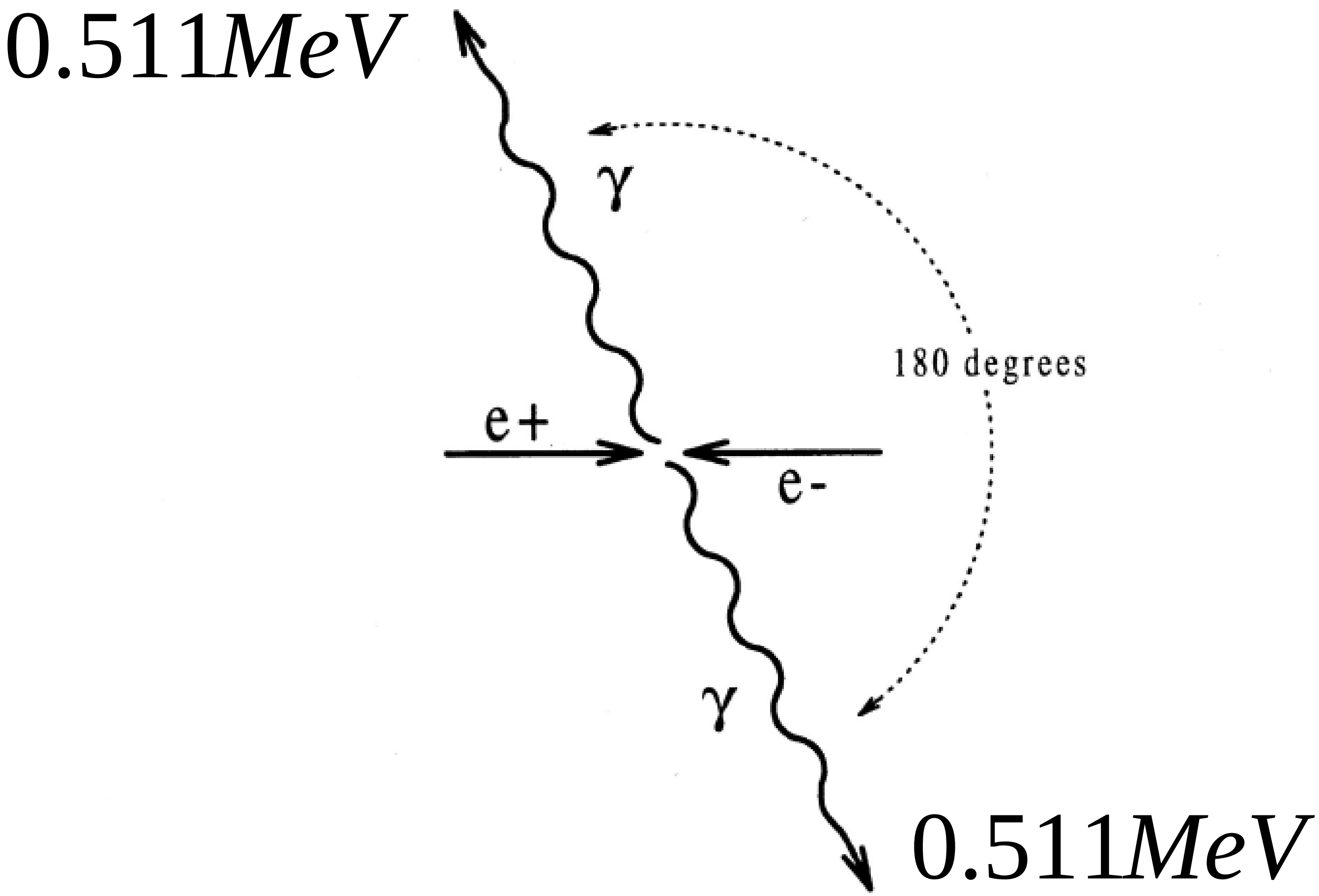
Prof. S. Fung
Department of Physics, HKU

Presenter:
Leung Wai Yan
2007132498

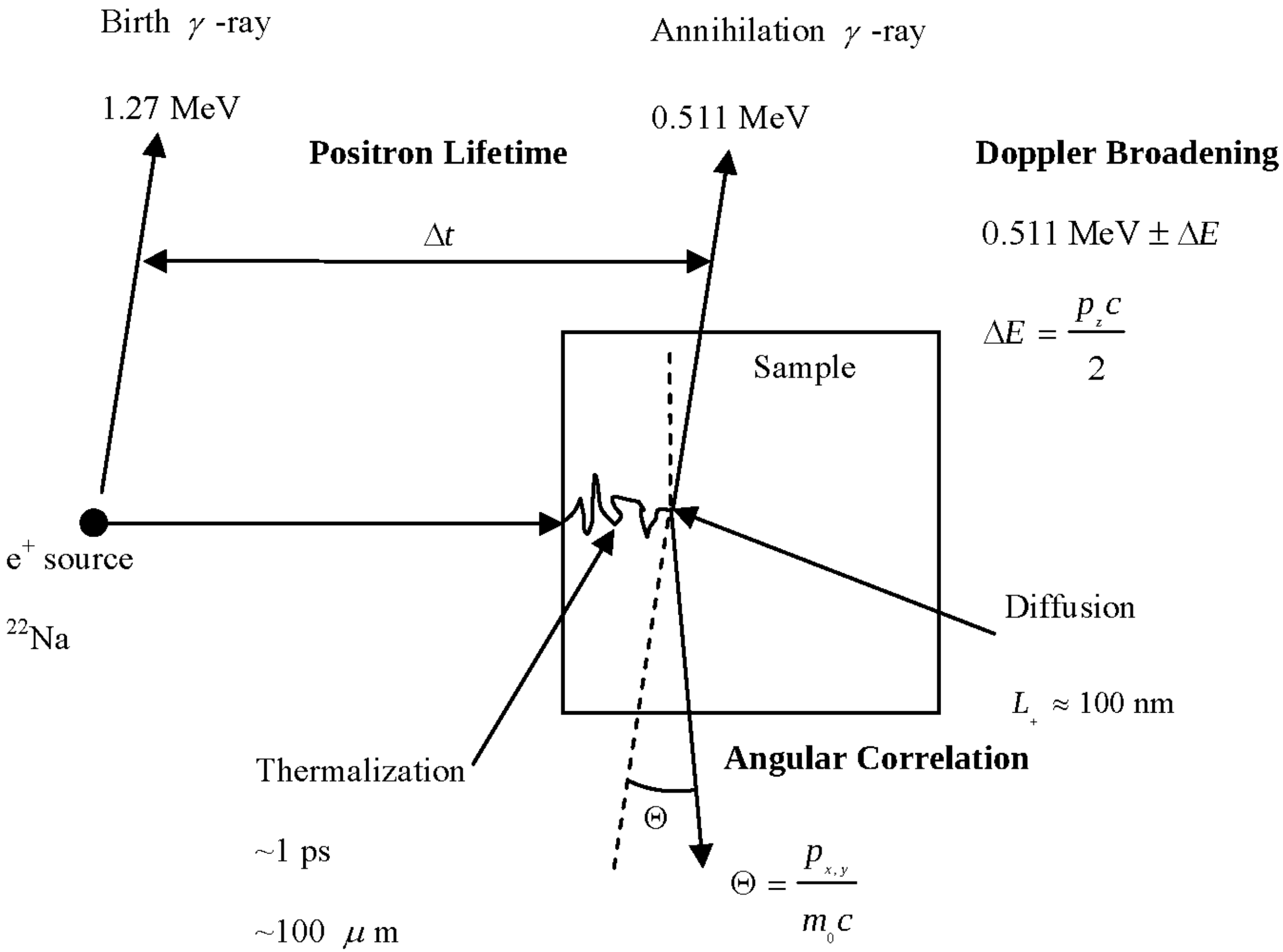
Positrons - Antimatter of electrons

- Mass: 0.511MeV
- Charge: +1
- Spin: ½
- Antimatter of electrons
- Theorized by Paul. A.M. Dirac
- Discovered by Carl D. Anderson

Electron–positron annihilation

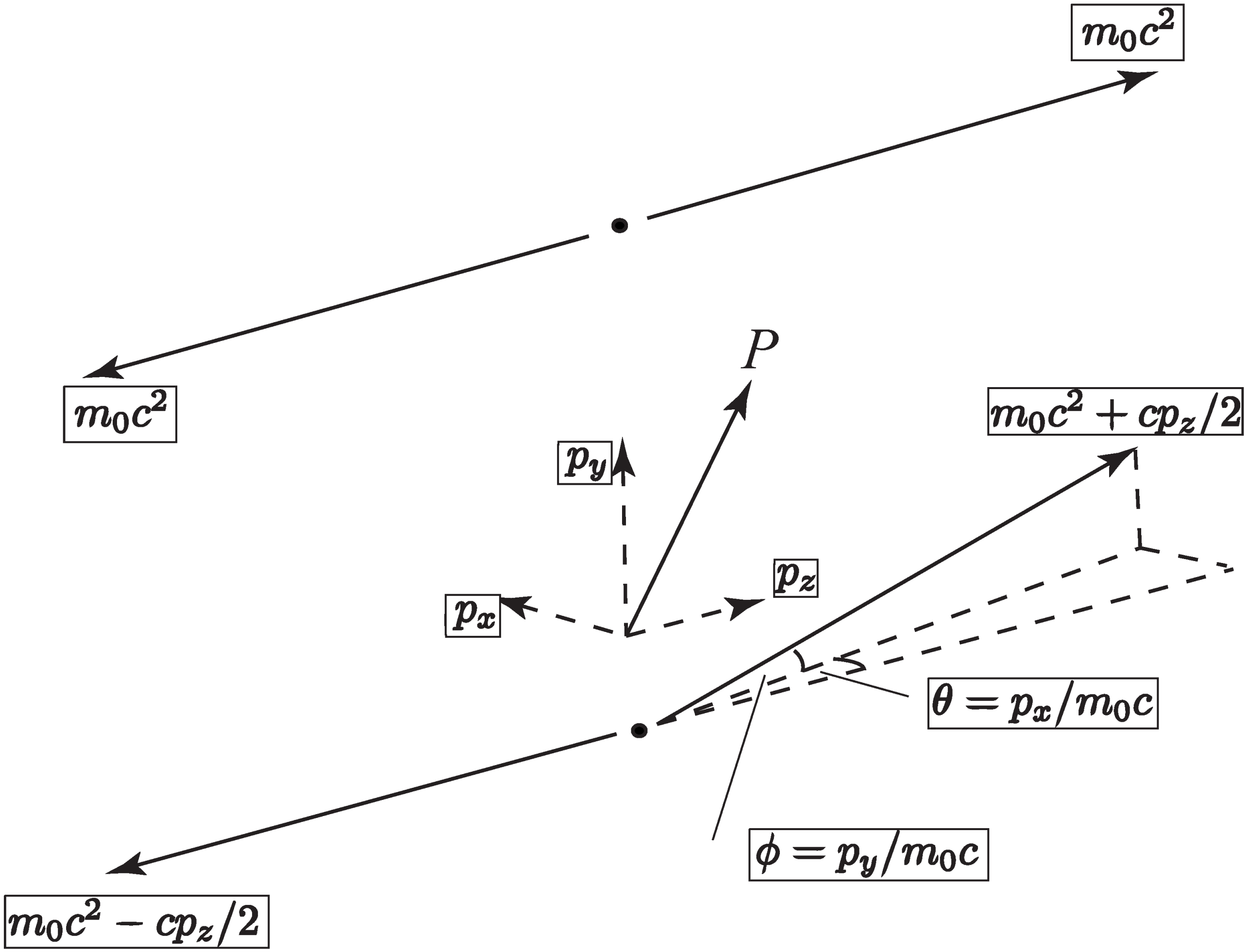


Early positron research



(Sources: 2)

Angular Correlation of Annihilation Radiation



Angular Correlation of Annihilation Radiation

$$\alpha = \frac{\sqrt{p^2 - p_z^2}}{m_0 c} \quad (2.7)$$

For small angles,

$$\theta = \frac{p_z}{m_0 c} \quad (2.8)$$

$$\phi = \frac{p_y}{m_0 c} \quad (2.9)$$

Fermi Gas Model

Energy level of a fermi gas

$$E = \frac{\hbar^2 k^2}{2m}$$

Fermi-energy and Fermi-momentum

$$E_F = \frac{\hbar^2 \pi^2}{2m} \left(\frac{3n}{\pi} \right)^{\frac{2}{3}} \qquad E_F = \frac{\hbar^2 k_F^2}{2m} \qquad p_F = \hbar k_F$$

Distribution in the magnitude of momentum

$$\begin{aligned} N(p) &= p^2 \quad \text{for} \quad p^2 < p_F^2 \\ &= 0 \quad \text{for} \quad p^2 > p_F^2 \end{aligned}$$

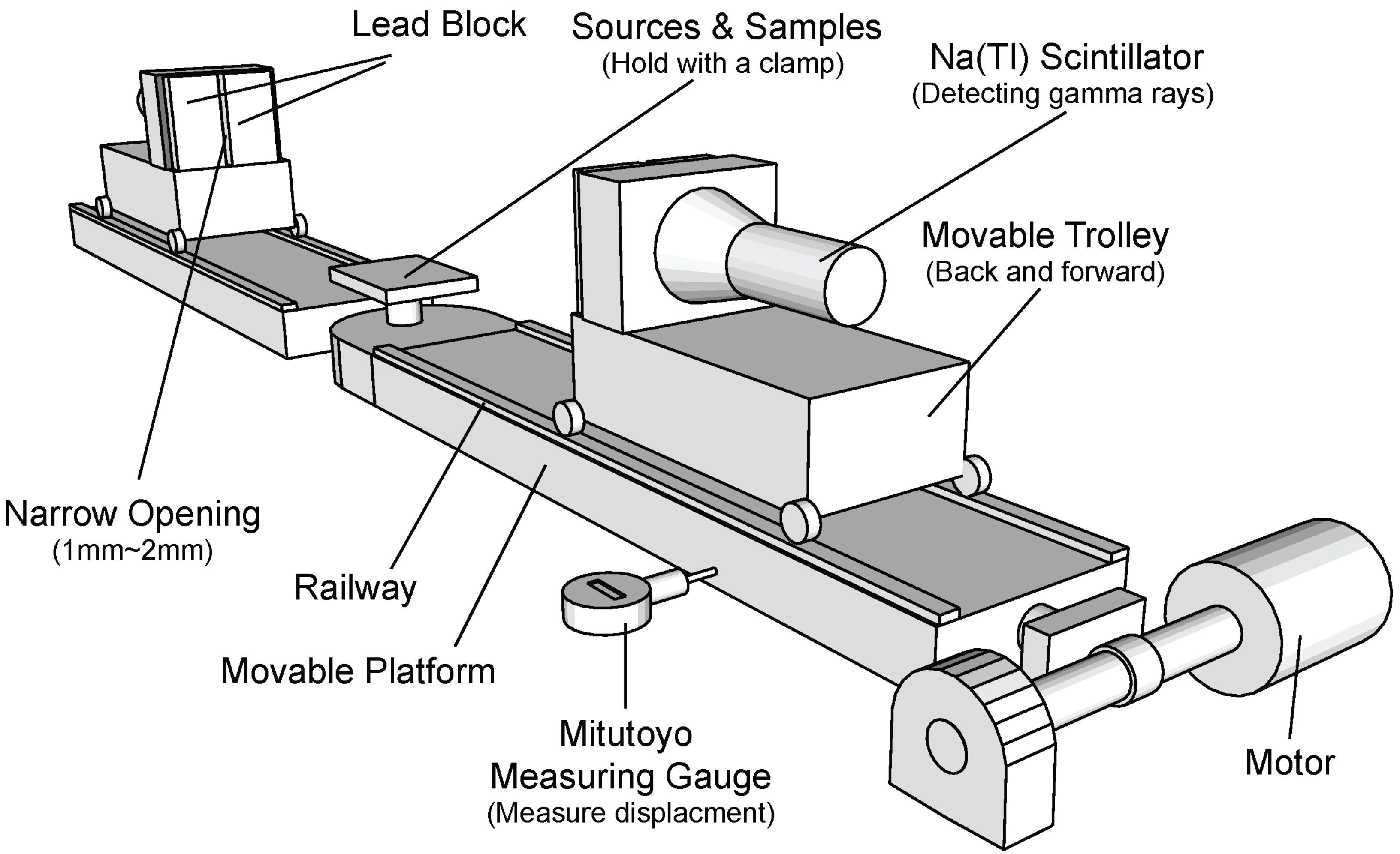
Distribution in the x component of momentum

$$\begin{aligned} N_x(p_x) &= (p_F^2 - p_z^2) \quad \text{for} \quad p^2 < p_F^2 \\ &= 0 \quad \text{for} \quad p^2 > p_F^2 \end{aligned}$$

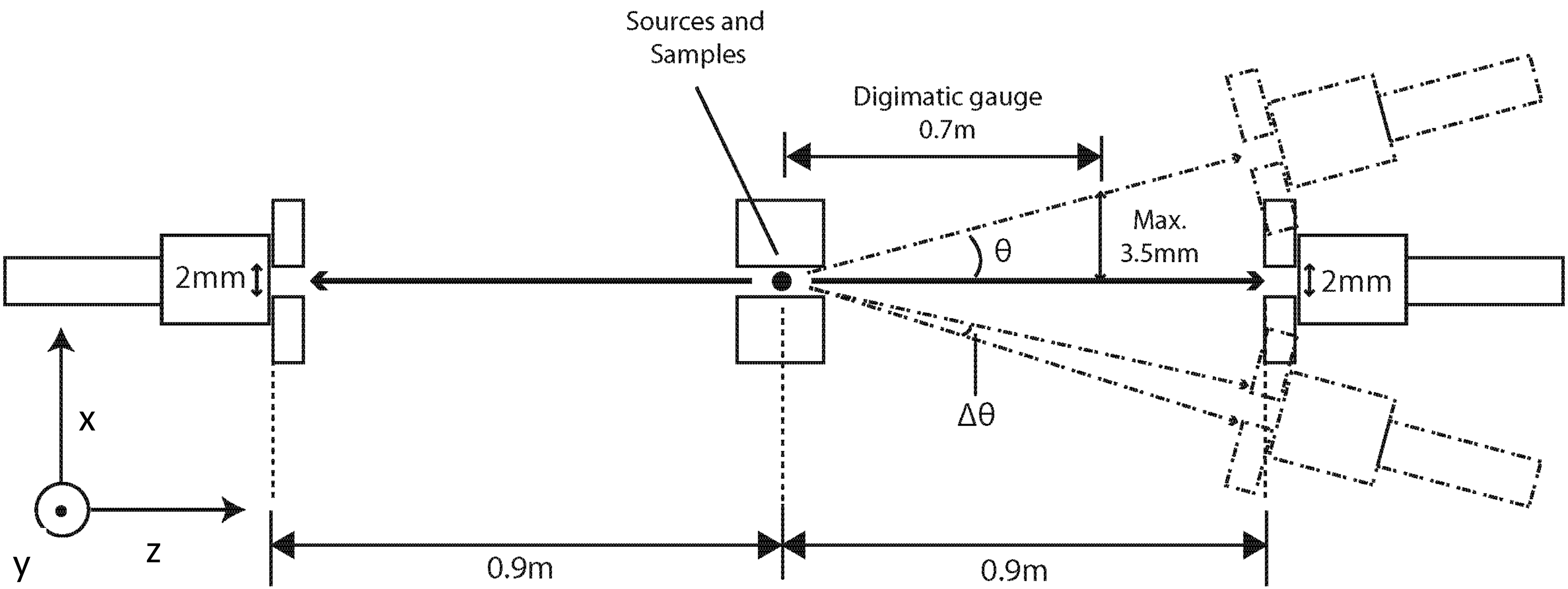
Chapeter 2

ACAR EXPERIMENT

1D ACAR Spectrometer



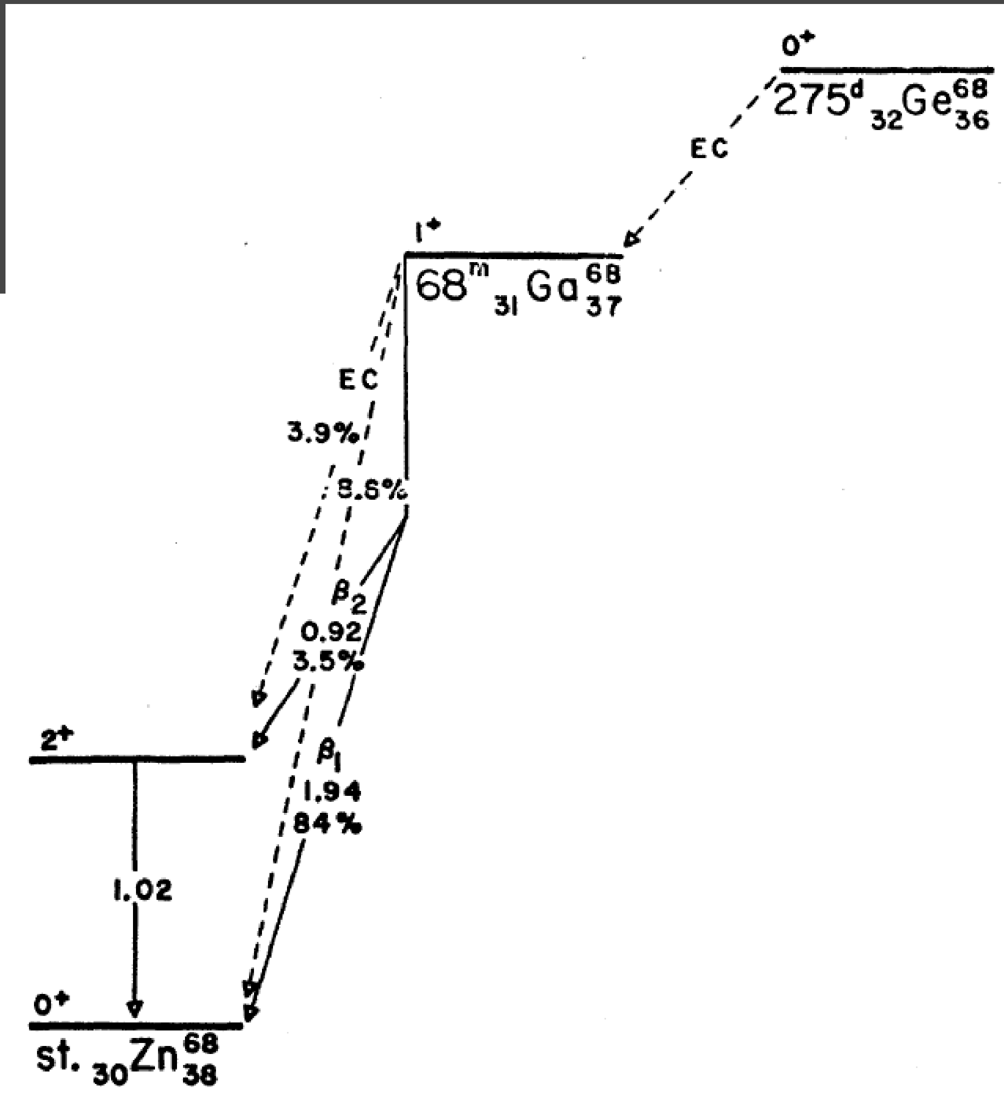
Schematic Diagram



Positron Sources

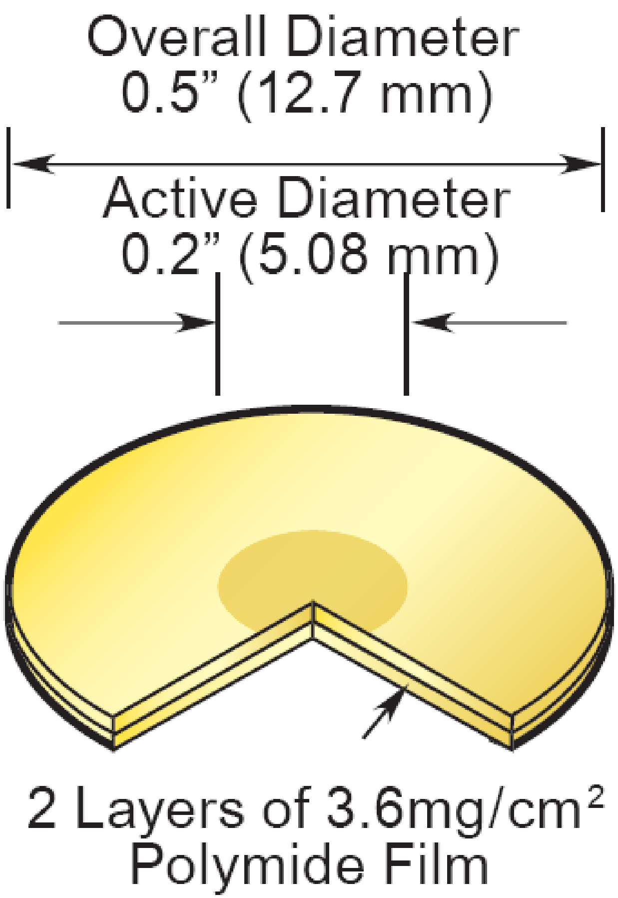
- Germanium - 68
- Half life: 275 days
- All decay into Gallium - 68 first

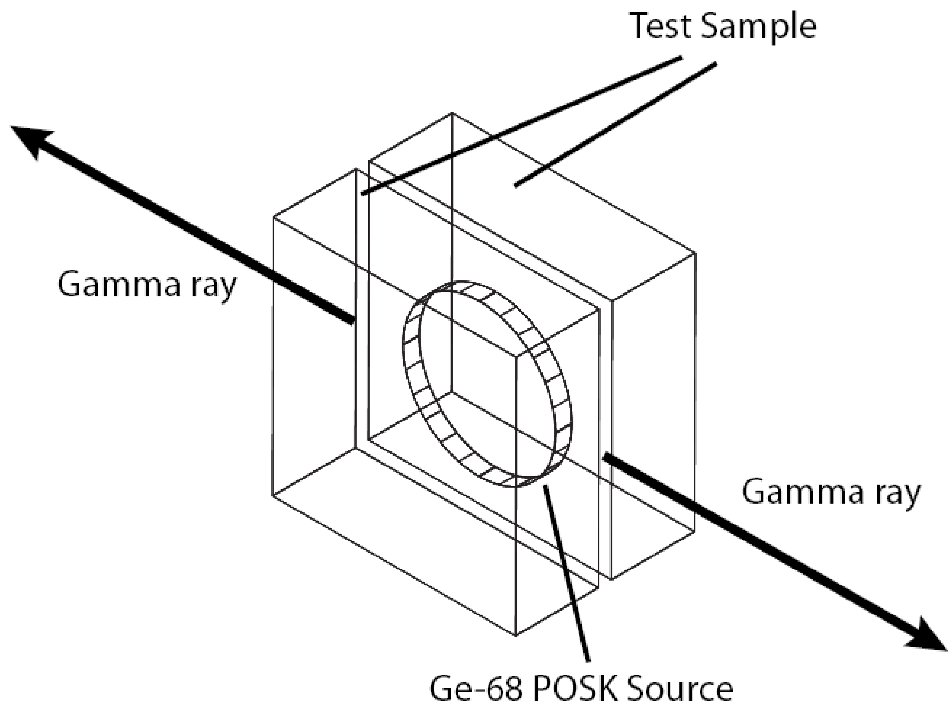
Decay into.. By...	Stable Zinc-68	Excited Zinc-68 $+1.02\text{keV}\ \gamma - ray$
Positron emission	84%	3.5%
Electron capture	9.8%	3.9%



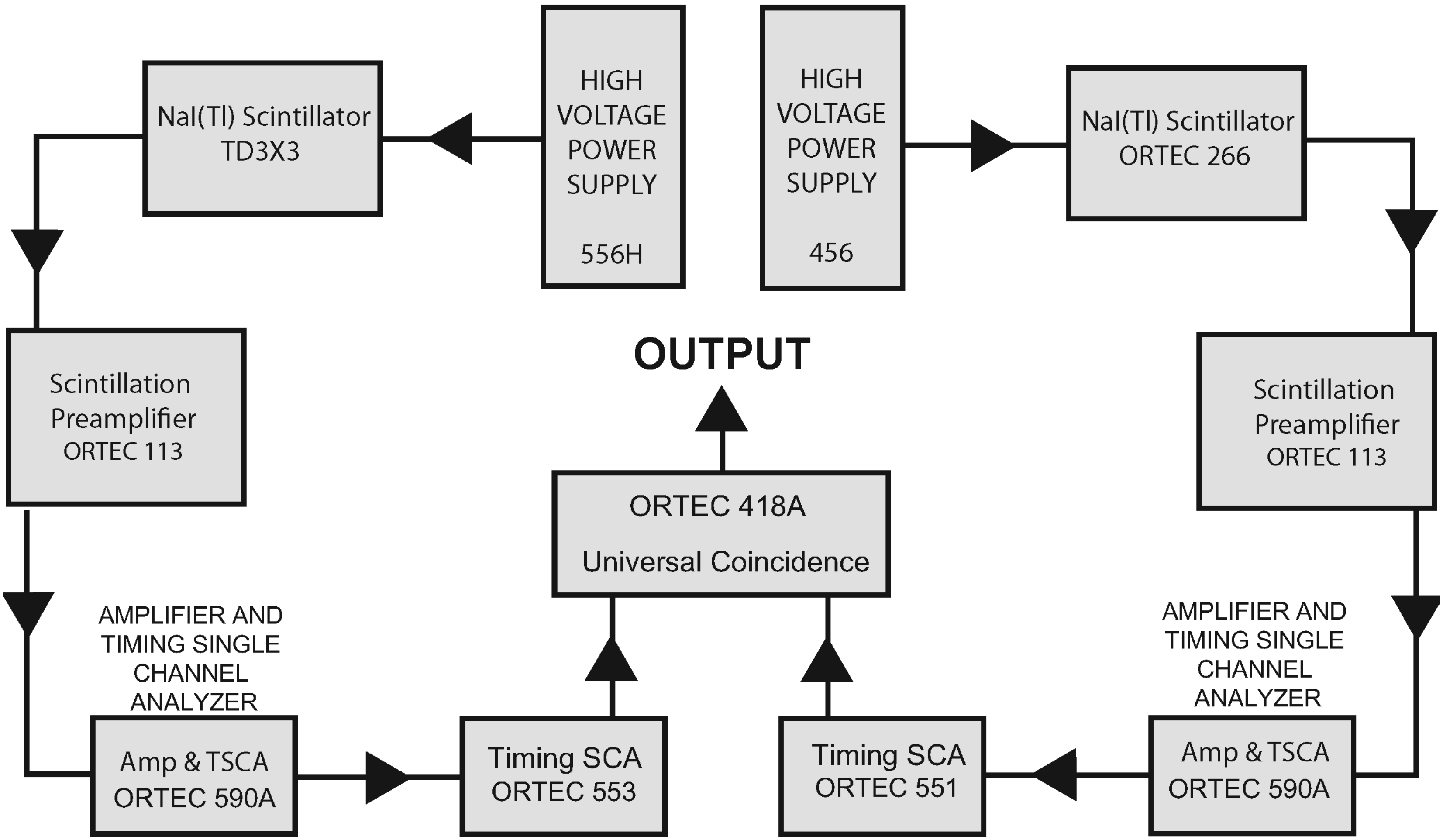
Germanium Decay Diagram

Germanium-68 Source

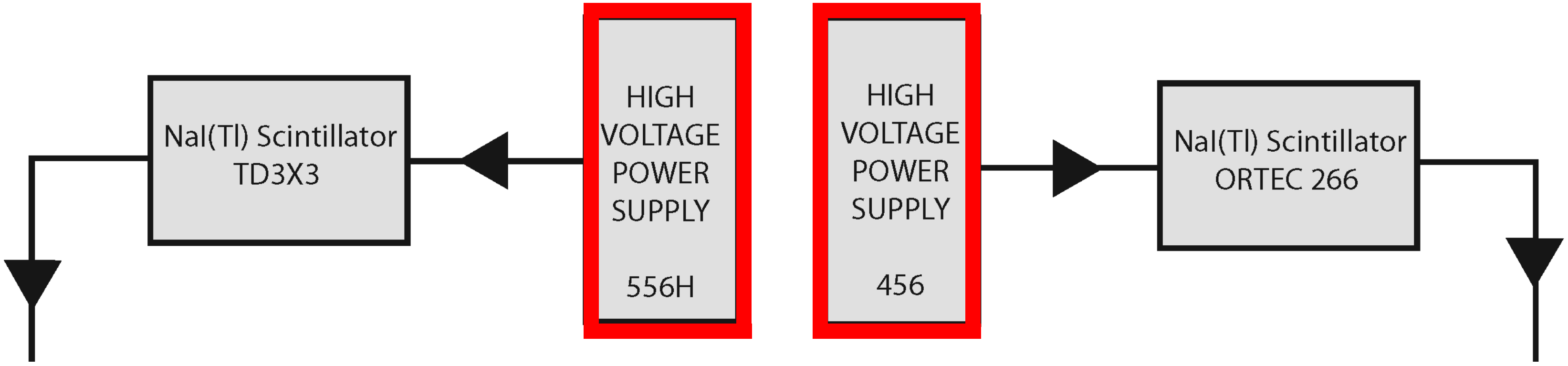




Gamma-Gamma coincidence electronic setup

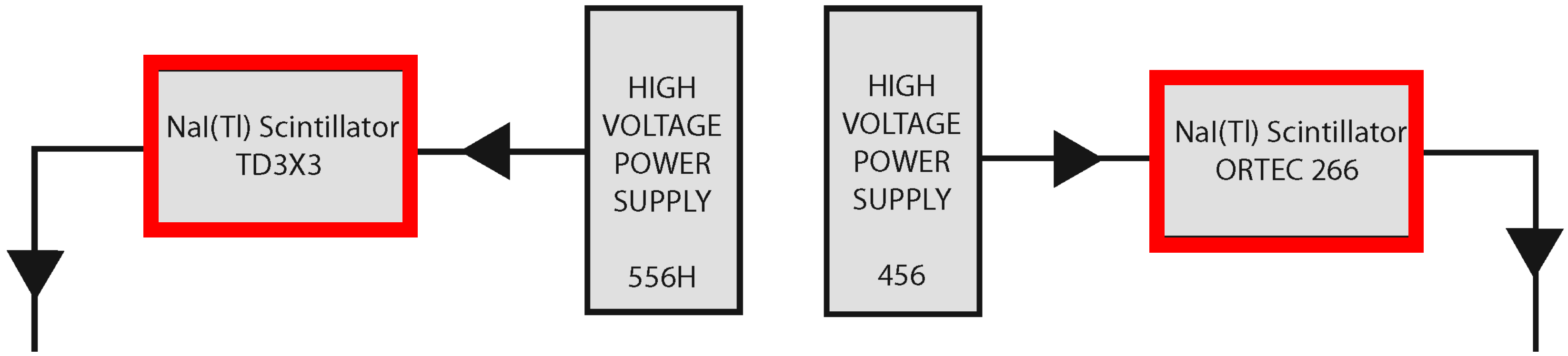


High-Voltage power supply



- Provide enough power for the operation of the photomultiplier tube in the NaI Scintillation detectors
- Left Detector Model : Ortec 556H (0.6V)
- Right Detector Model : Ortec 456 (0.6V)

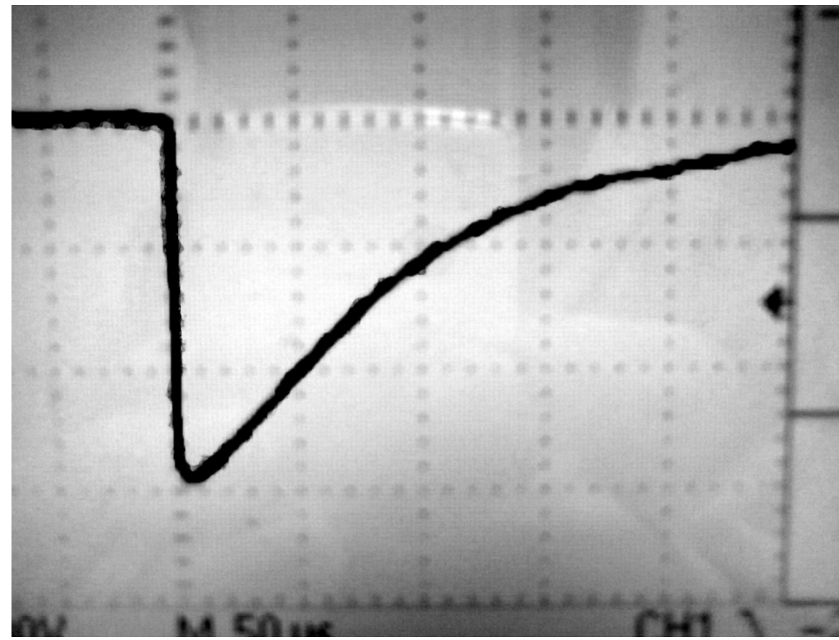
NaI(TI) Scintillation Detector



- The Scintillation Detector detects the gamma ray and releases photo electrons to a photomultiplier tube.
- The photomultiplier tube increases the number of photoelectrons to make a current pulse.

Scintillation Preamplifier

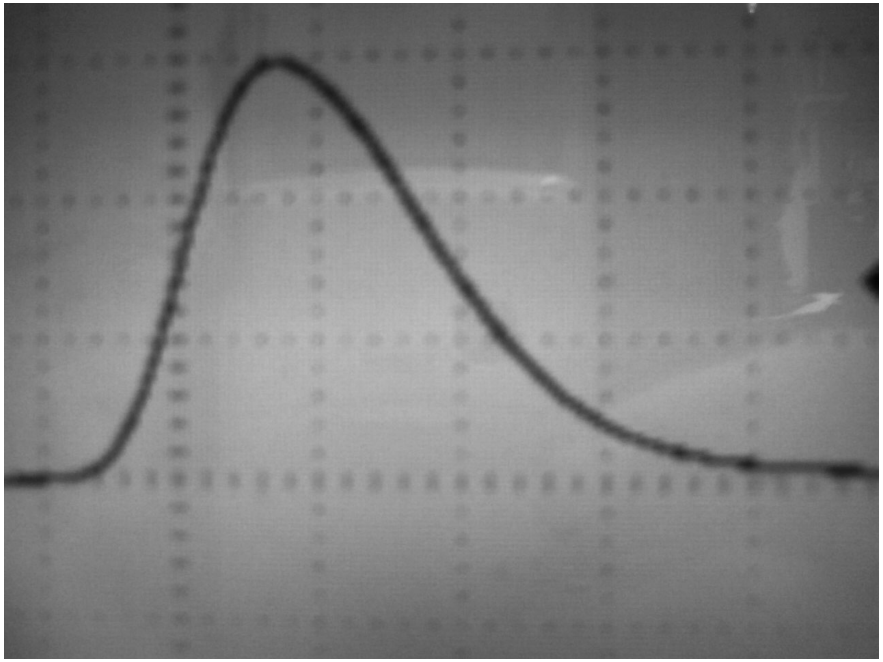
- Model: Ortec 113
- Extract the signal from the scintillation detectors
- Change the charges from the PM Tube to produce a voltage pulse



Signal Shape

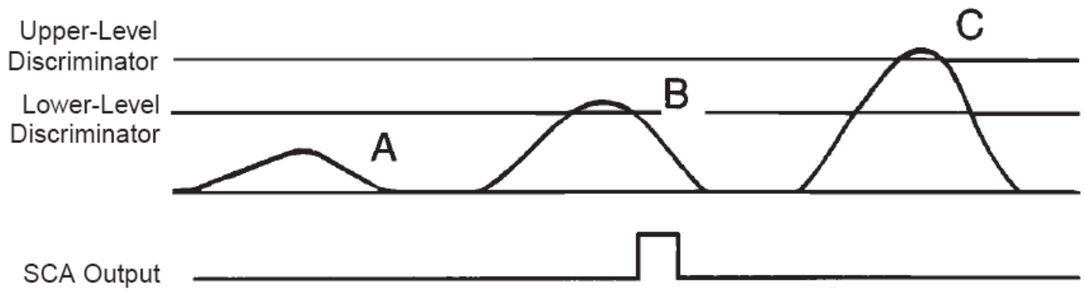
Amplifier

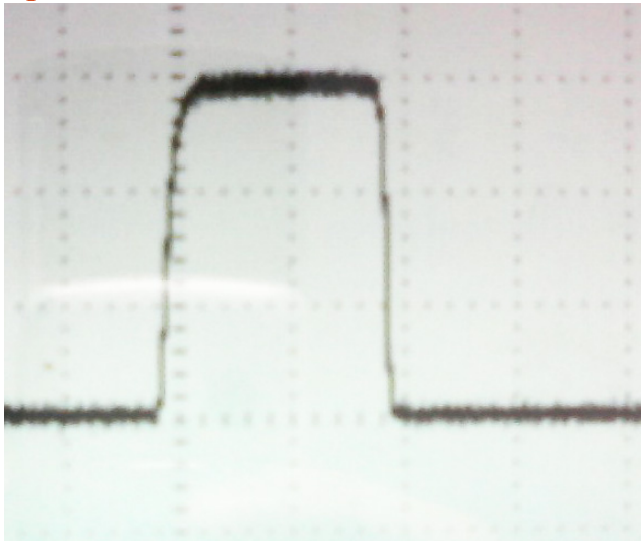
- Model: Ortec 590A
- Low-noise shaping amplifier (active-filter shaping on the incoming signal)
- Unipolar semi-Gaussian pulse shape



Timing Single-Channel Analyzer

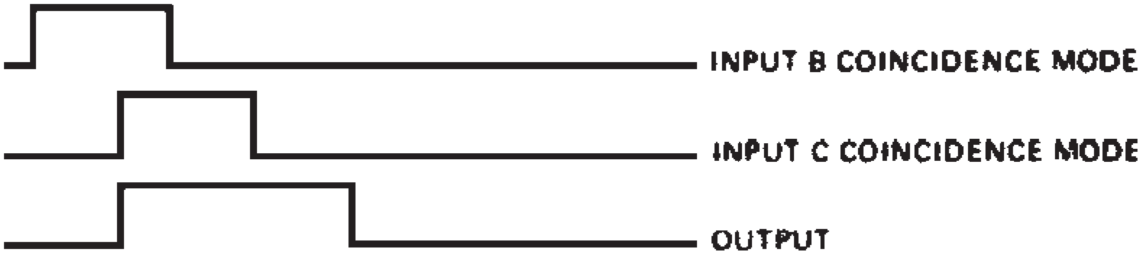
- Model: Ortec 551
- Select specific range of pulses
- Logic pulses will be generated only if the peak of the input signals falls within the range





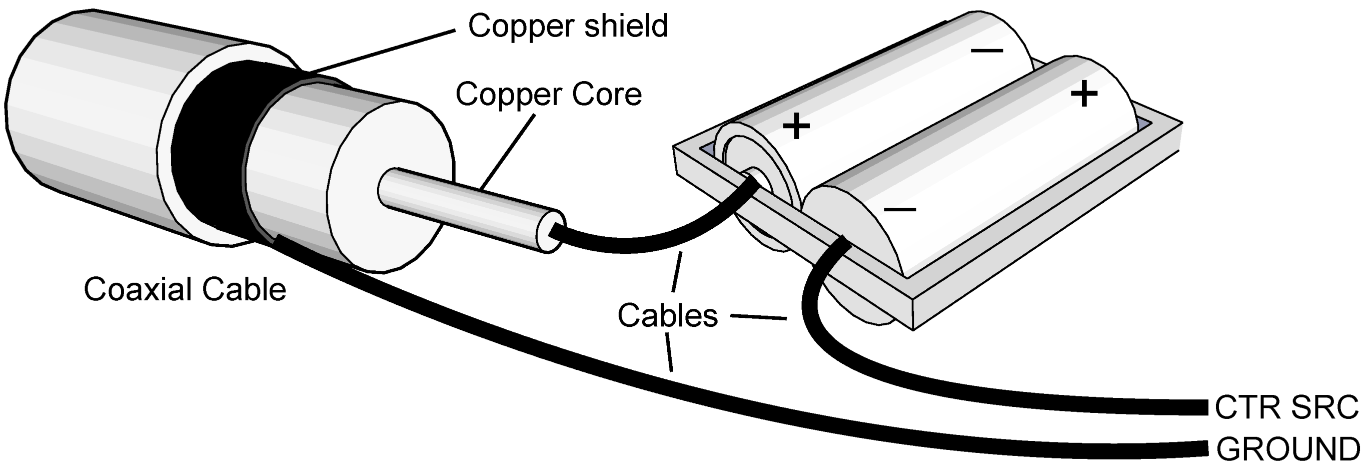
Universal Coincidence

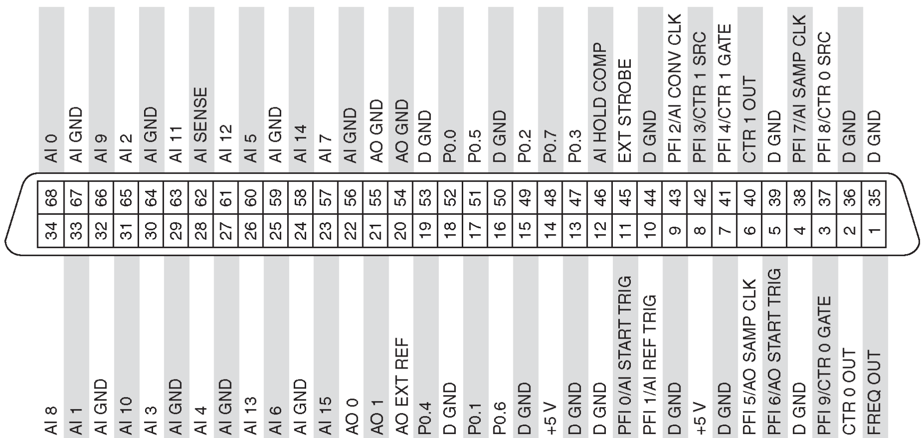
- Model: Ortec 418A
- Generate a logic pulse if a signal from one of the inputs arrived within the resolving time of a pulse from another input.



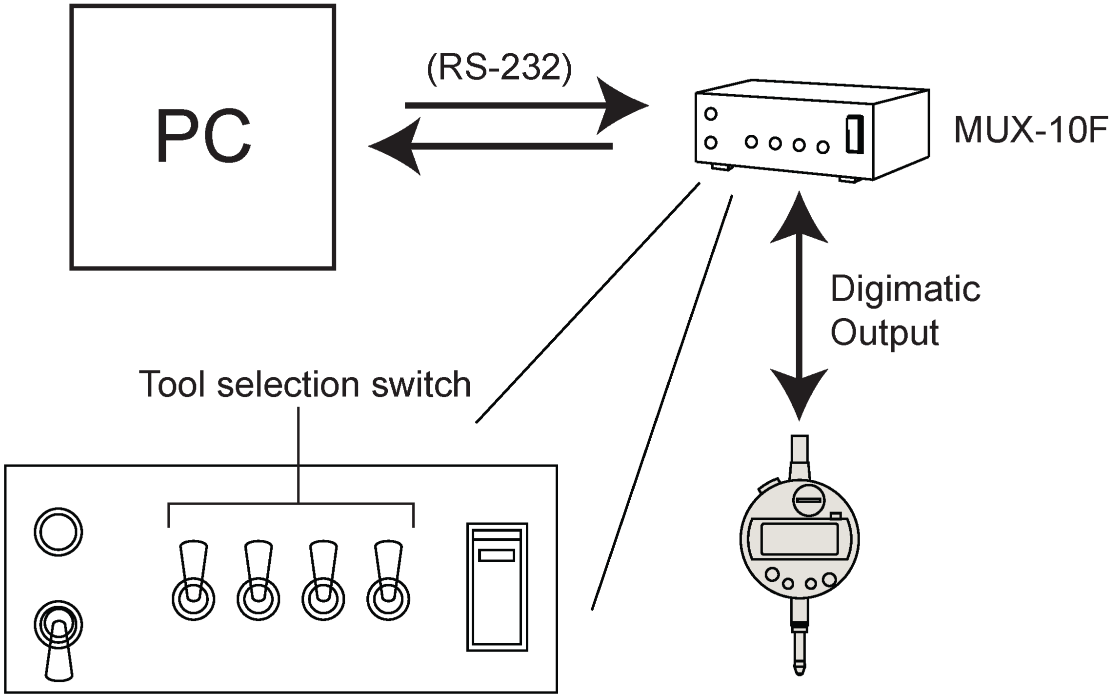
Coincidence Requirements When Switch Setting is 2.

Multifunction Data Acquisition (DAQ) Card



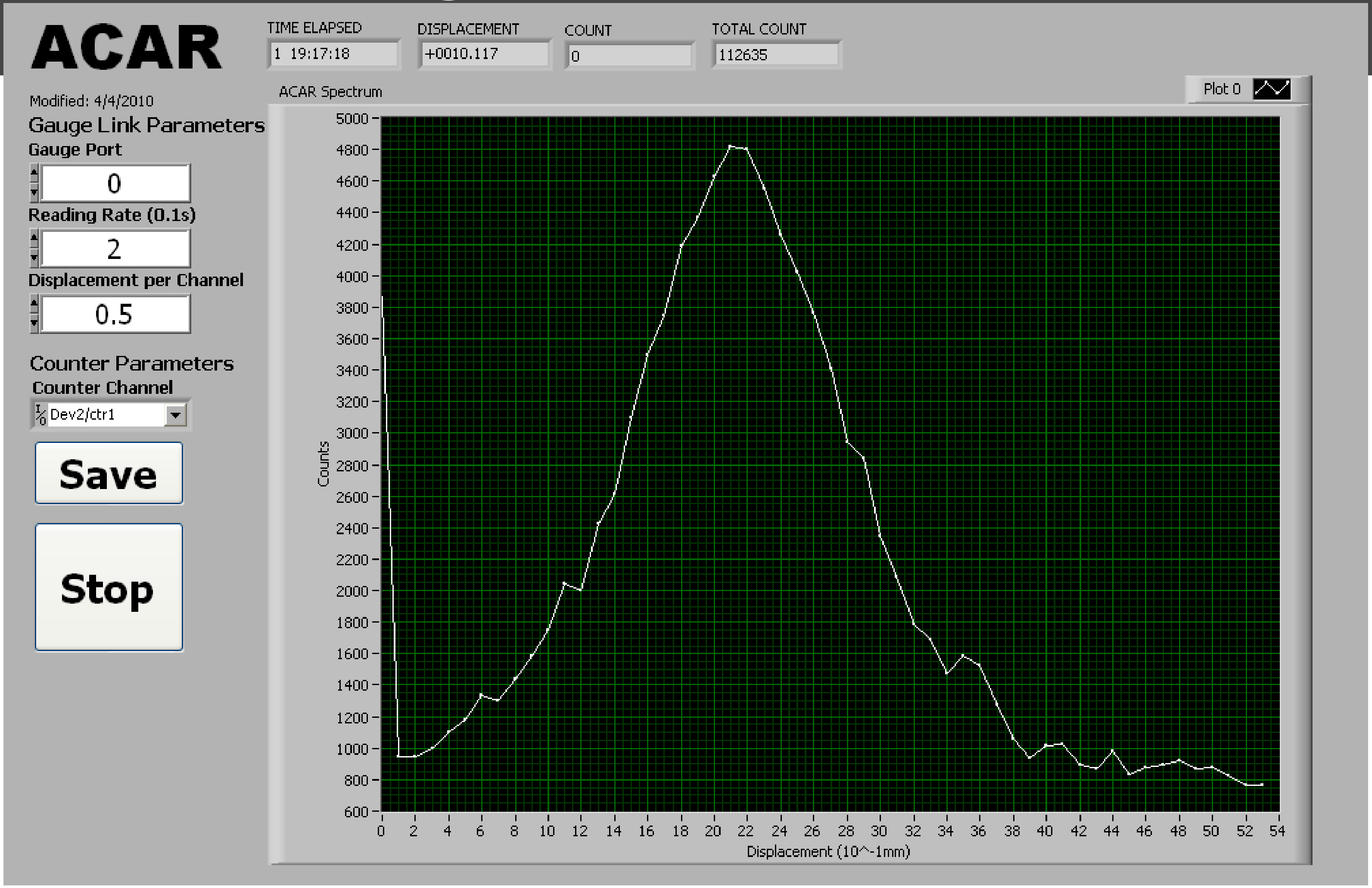


Digimatic measuring gauge



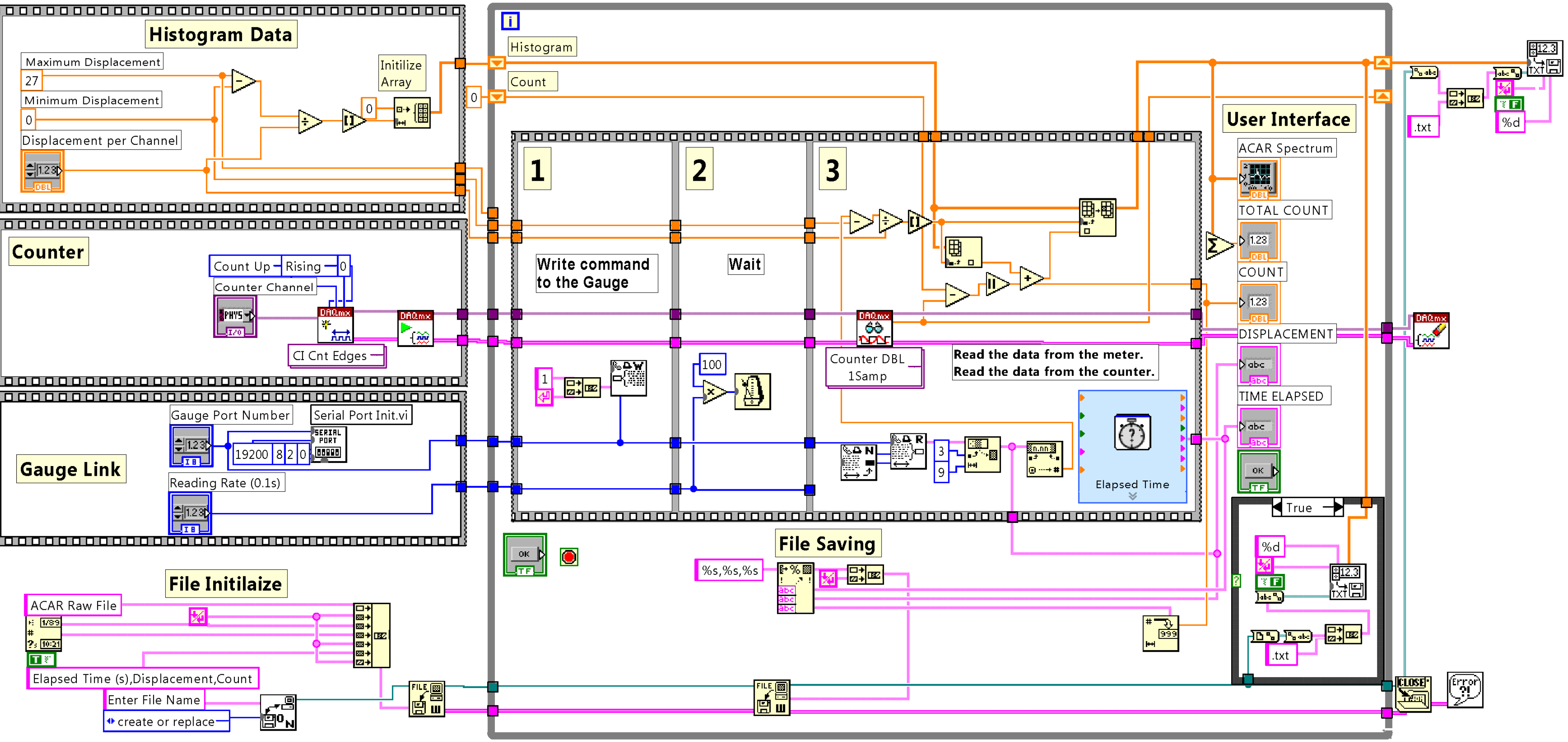
Commands (ASCII)	Transfer channels
1 (ASCII corde31) CR	1
2 (ASCII corde32) CR	2
3 (ASCII corde33) CR	3
4 (ASCII corde34) CR	4
A (ASCII corde41) CR	1, 2, 3, 4
B (ASCII corde42) CR	1, 2, 4
C (ASCII corde43) CR	1, 3, 4
D (ASCII corde44) CR	2, 3, 4
E (ASCII corde45) CR	1, 2, 3
F (ASCII corde46) CR	1, 2
G (ASCII corde47) CR	1, 3
H (ASCII corde48) CR	1, 4
I (ASCII corde49) CR	2, 3
J (ASCII corde50) CR	2, 4
K (ASCII corde51) CR	3, 4

LabVIEW Program



Front Panel

LabVIEW Program



Block Diagram

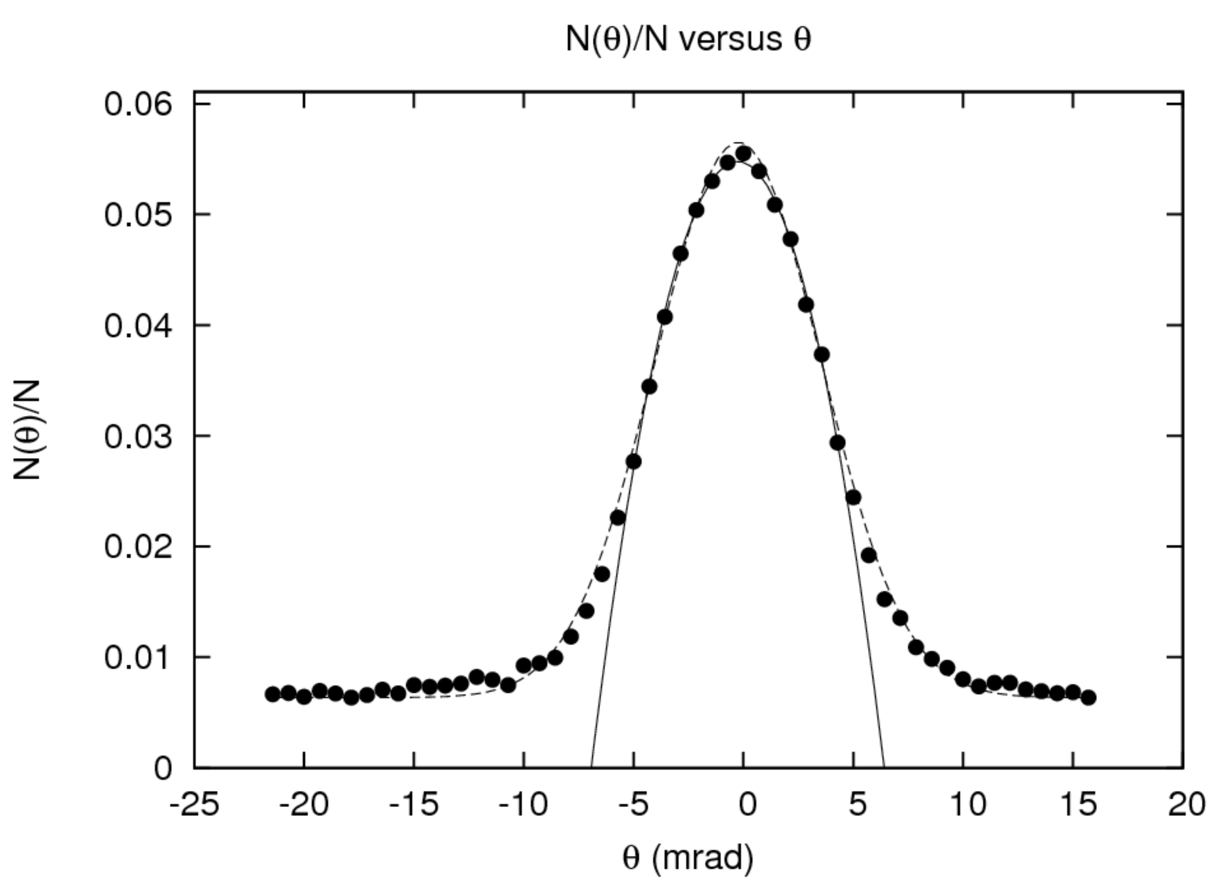
Other software

- GNU plot
  - For plotting the graph
- C++ language
  - -For customized programming

Chapeter 3

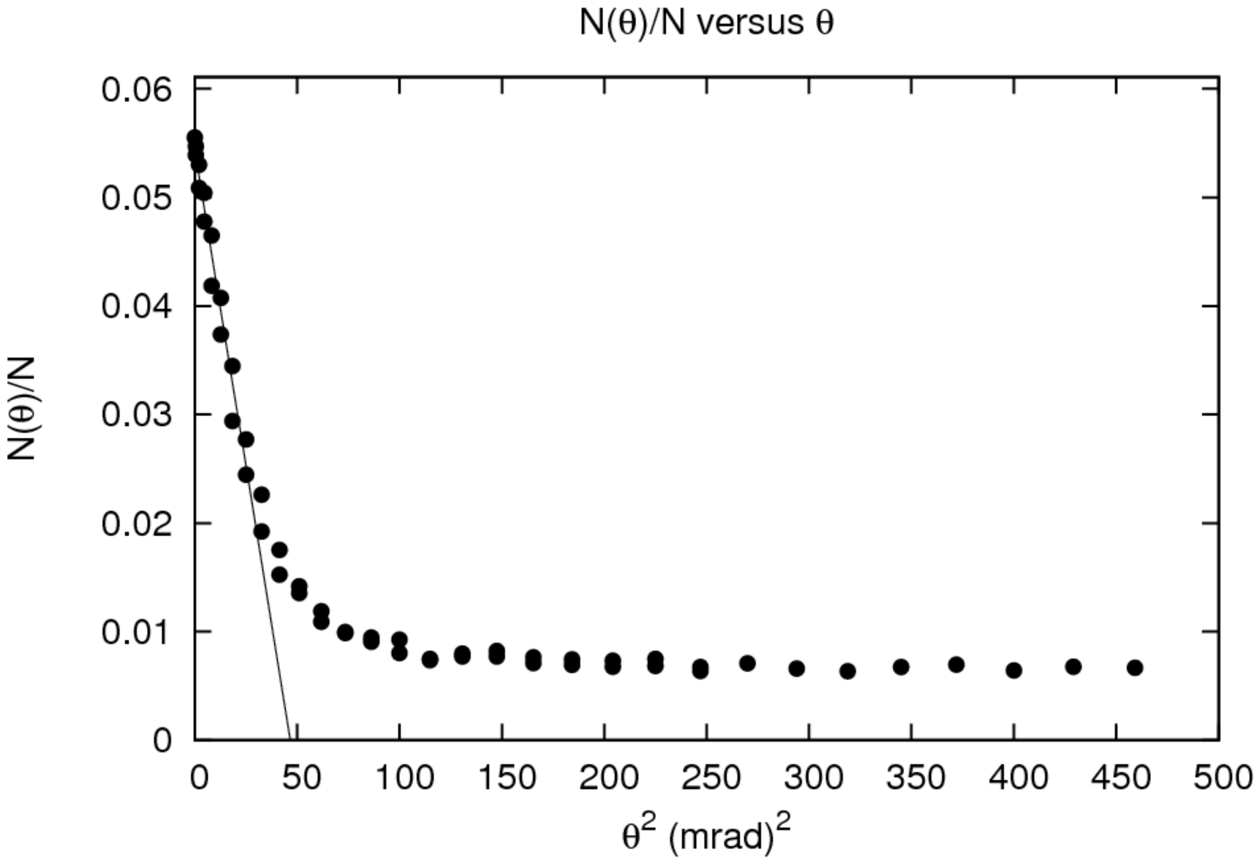
RESULT AND DATA ANALYSIS

Aluminium



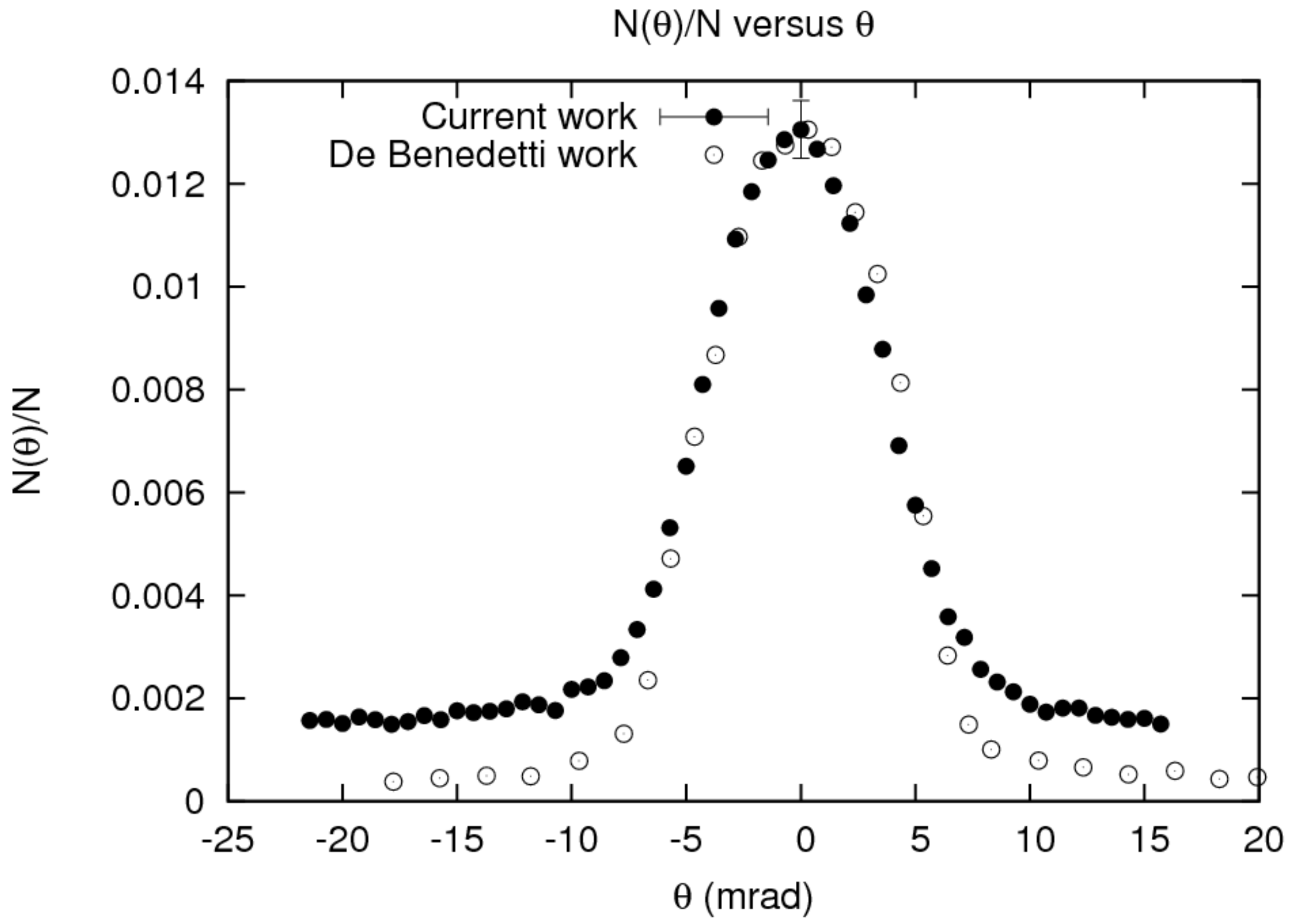
$$\theta_{max} = \frac{6.413 + 6.930}{2} = 6.672mrad$$

Aluminium



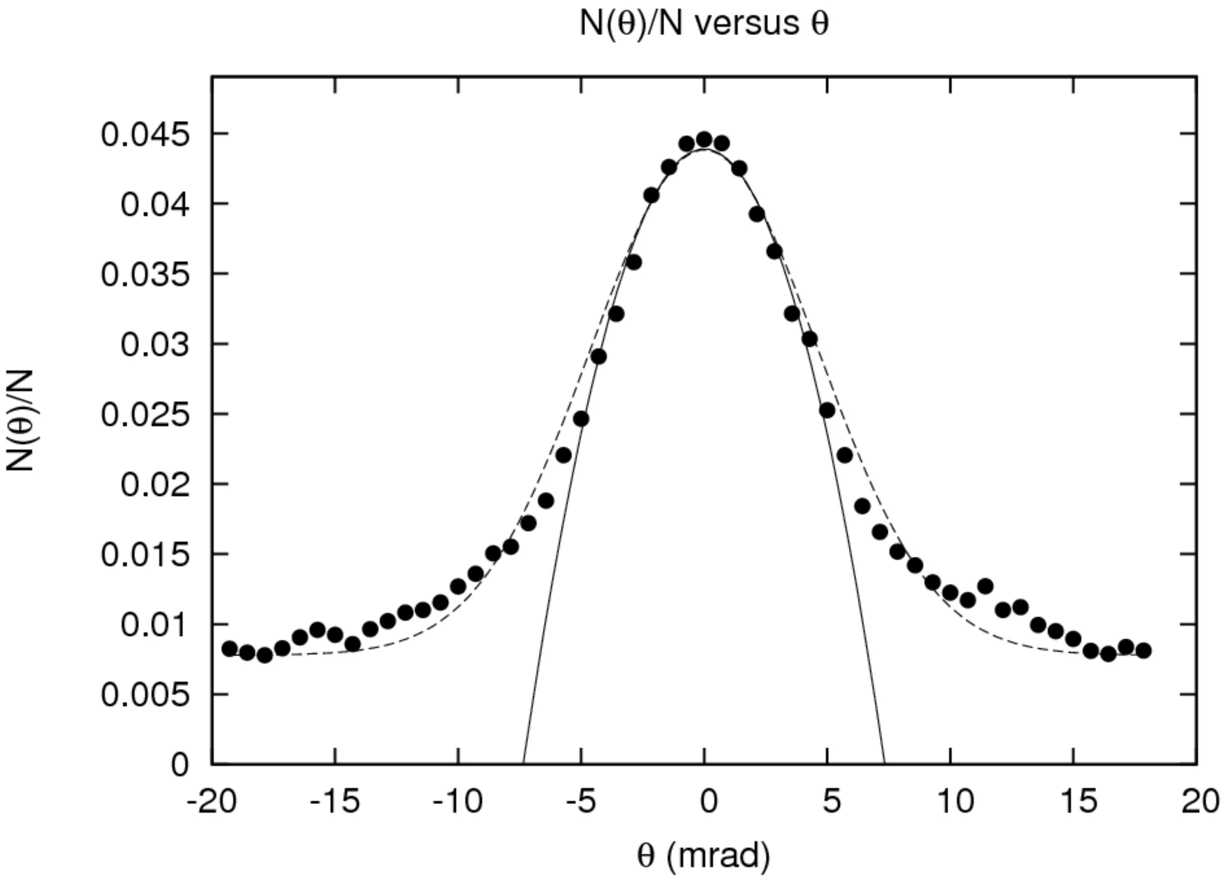
$$\theta_{max} = \sqrt{0.0544081/0.00116694} = 6.83mrad$$

Aluminium



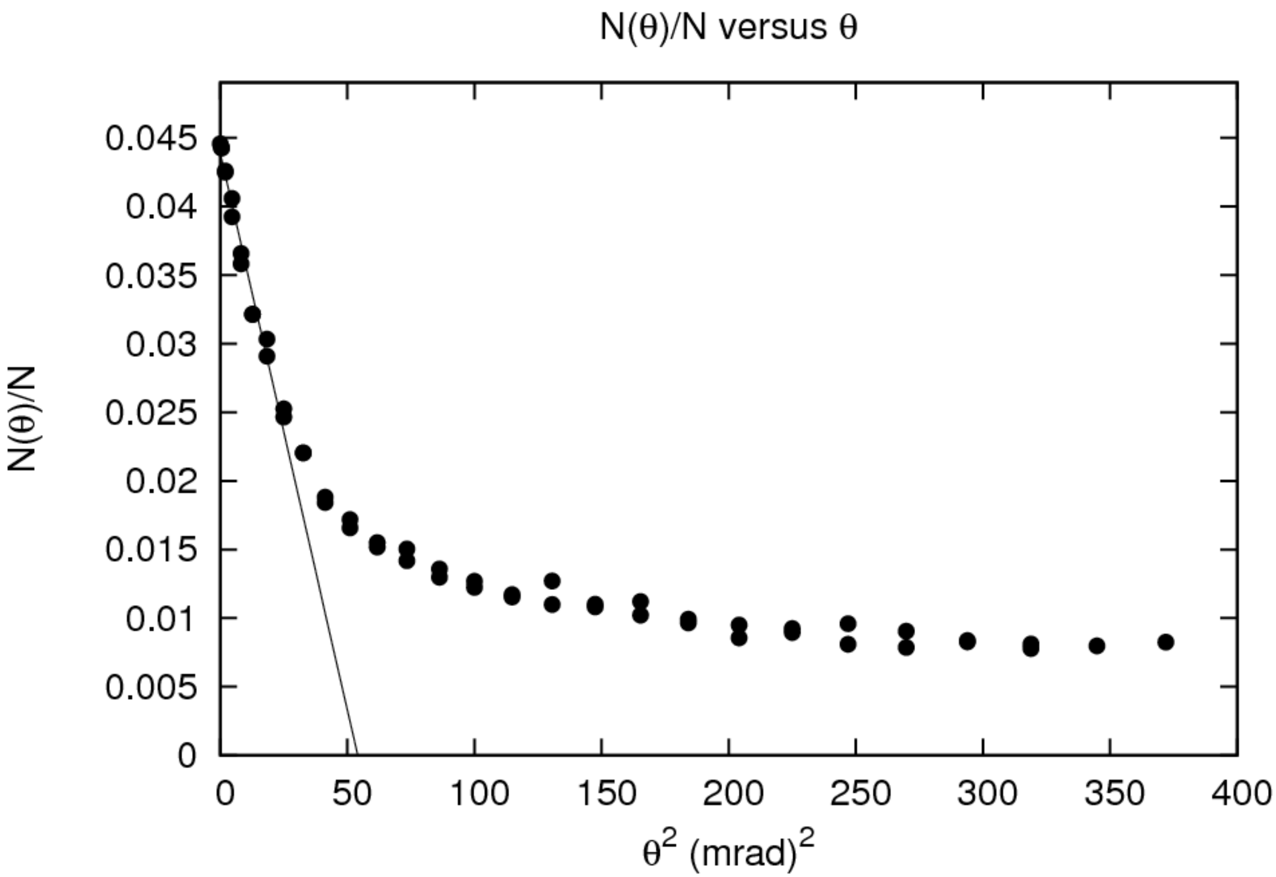
N(θ)/N versus θ
Current work
De Benedetti work
N(θ)/N
θ (mrad)
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
-25
-20
-15
-10
-5
0
5
10
15
20

Copper



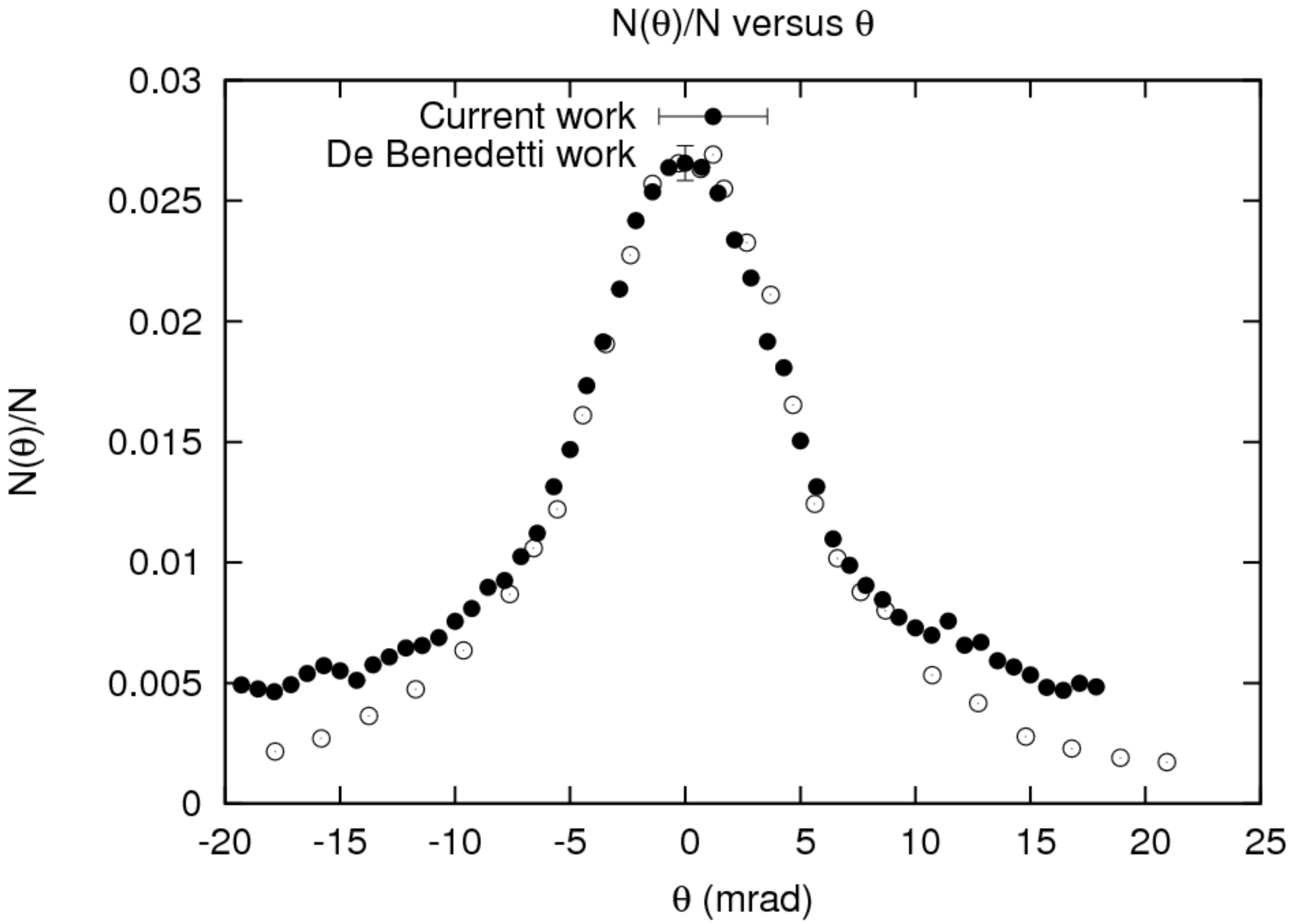
$$\theta_{max} = \frac{7.348 + 7.354}{2} = 7.351mrad$$

Copper

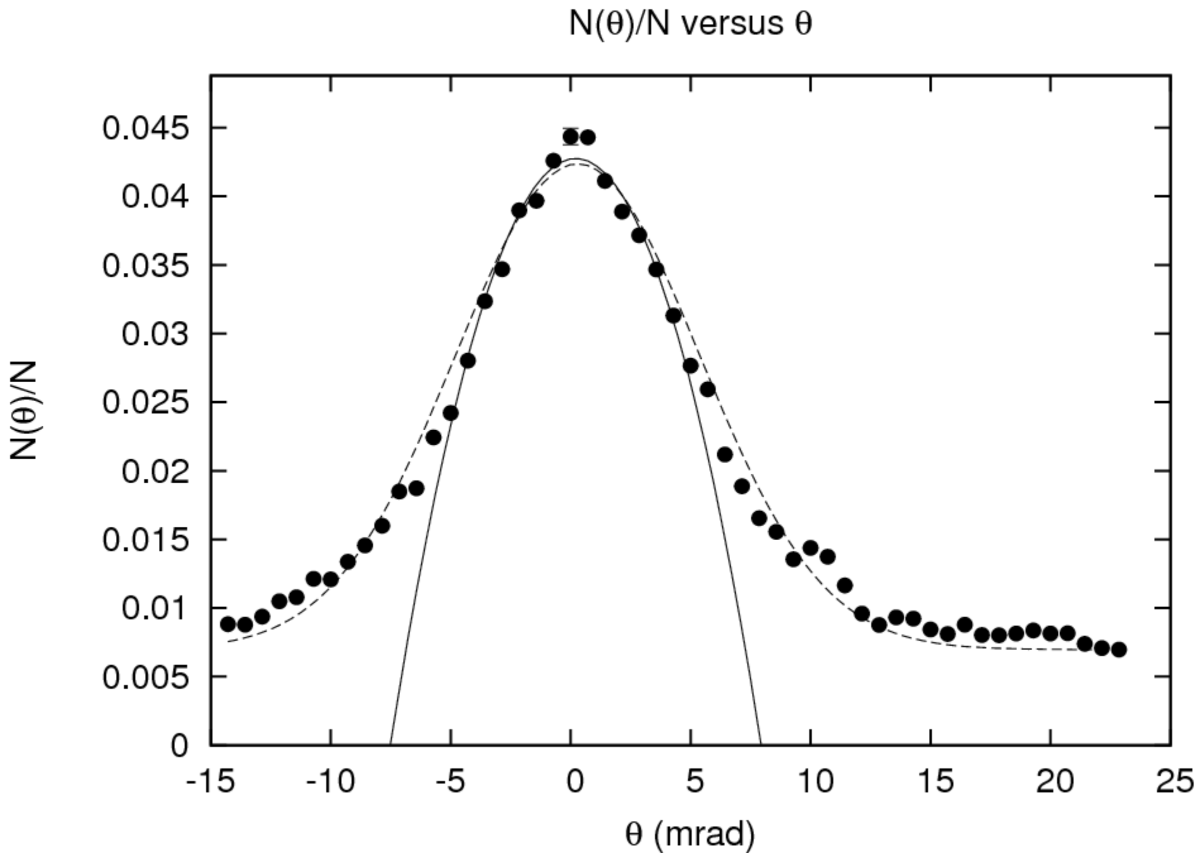


$$\theta_{max} = \sqrt{0.0438954/0.000811792} = 7.353 mrad$$

Copper

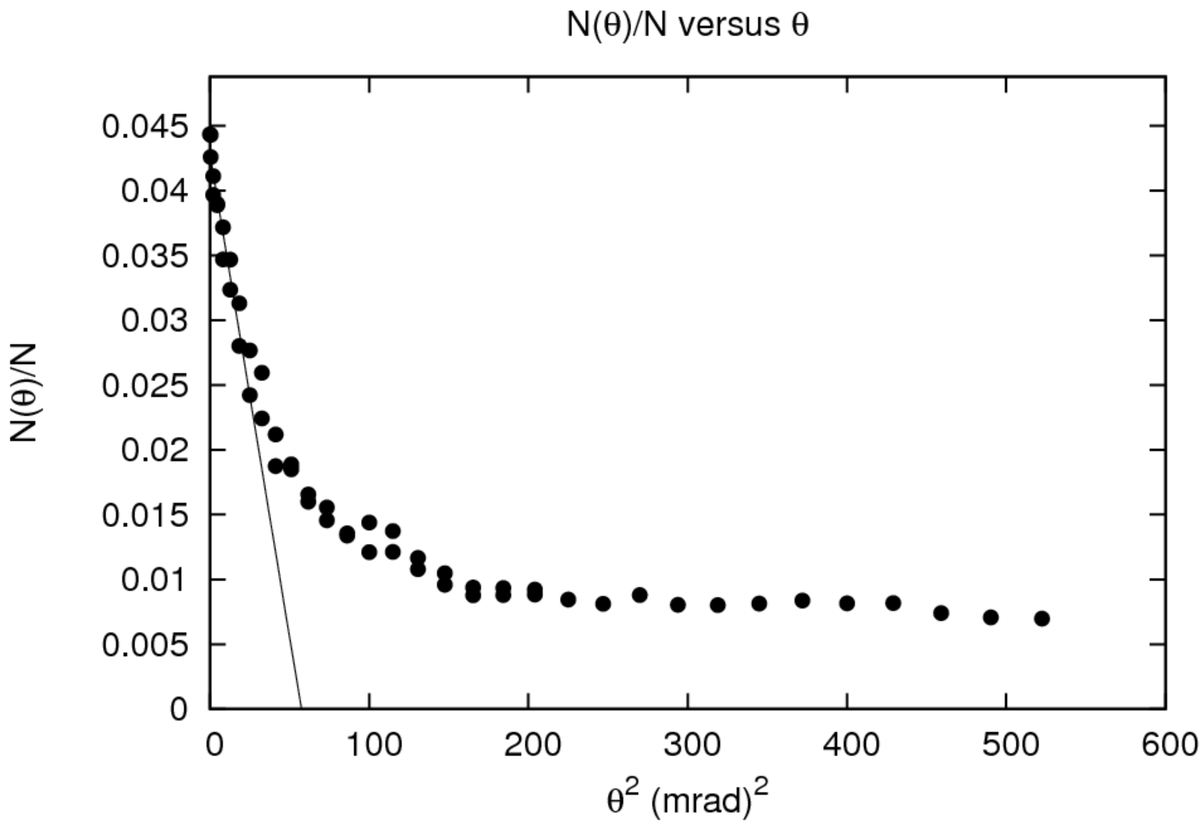

N(θ)/N versus θ
Current work
De Benedetti work
N(θ)/N
θ (mrad)
0.03
0.025
0.02
0.015
0.01
0.005
0
-20
-15
-10
-5
0
5
10
15
20
25

Stainless steel



$$\theta_{max} = \frac{7.943 + 7.5204}{2} = 7.732 mrad$$

Stainless steel



$$\theta_{max} = \sqrt{0.042874/0.000746015} = 7.581 mrad$$

Comparison with Fermi gas model

Aluminium

	Fermi-gas model	Experimental value	Percentage difference
Maximum angular deviation θ_{max}	6.75mrad	6.83mrad	1.19%
Fermi momentumP_F	1.846×10^{-24}	1.867×10^{-24}	1.14%
Fermi wave numberk_F	1.750×10^{10}	1.770×10^{10}	1.14%
Fermi energyE_F	$12.324eV$	$11.94eV$	3.12%

Copper

	Fermi-gas model	Experimental value	Percentage difference
Maximum angular deviation θ_{max}	5.23mrad	7.353mrad	1.19%
Fermi momentumP_F	1.429×10^{-24}	2.0094×10^{-24}	40.6%
Fermi wave numberk_F	1.356×10^{10}	1.961×10^{10}	44.6%
Fermi energyE_F	$7eV$	$13.835eV$	97.6%

Stainless steel

	Fermi-gas model	Experimental value	Percentage difference
Maximum angular deviation θ_{max}	6.59mrad	7.581mrad	15%
Fermi momentumP_F	1.800×10^{-24}	2.072×10^{-24}	15.1%
Fermi wave numberk_F	1.707×10^{10}	1.965×10^{10}	15%%
Fermi energyE_F	$11.1eV$	$14.706eV$	32.4%

Comparison with Fermi gas model

- DeBenedetti suggested that there are three types of metals that can be classified according to the ACAR results
- Group A: Li, Na, Be, Mg, Al. Ge, Sn, and Bi
  - Distributions that ended at a sharp break
  - the distribution curve have an inverted parabola at the center
  - Have a long flat tail to large angle

Comparison with Fermi gas model

- Group B: Ca, Ba, Zn, Cd, and Pb
  - Also have a central parabola but the tail is comparatively larger than group A
- Group C: Cu, Ag, Au, Fe, Co, Ni, Rh, Pd, Pt and W
  - Do not follow this distribution and show a "bell-shaped angular distribution"

Chapeter 4

DISCUSSION

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