Development of a Liquid Argon Purity Monitor for ICARUS

Doktorandenseminar 10.10.01

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Overview of Purity Monitors

The e^- in Argon behaves like free $e^- \rightarrow$ its energy is not enough to ionize Ar!

But → Impurities in Ar (O_2) capture $e^- \rightarrow$ free e^- are lost!

If capture rate of the free e^- is constant

$$N(t_{drift}) = N(0)\, e^{-\frac{t_{drift}}{\tau}}$$

Where N(t) is the number of electrons

t_{drift} is the drift time

τ is the mean life-time of electrons in LAr

→ **Our Purity Monitors measure τ**

Overview of Purity Monitors

Electric Drift Field

How are e^- produced?

Homogeneous E_{field}

- Photoeffect UV→Rare Earth
- α, β Sources ionize LAr

Inhomogeneous E_{field}

- α, β, fission fragments ionize LAr (our Purity Monitor)

Overview of Purity Monitors

Homogeneous

Electric Drift Field

Inhomogeneous

How the free e$^-$ are produced

Photoeffect
UV→Rare Earth

α, β Sources
ionize LAr

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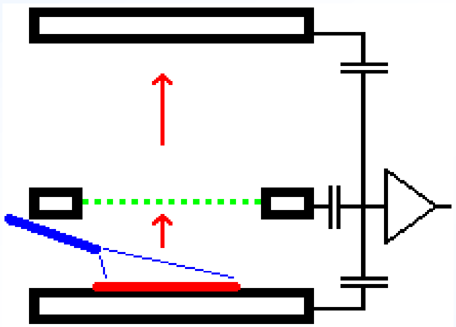
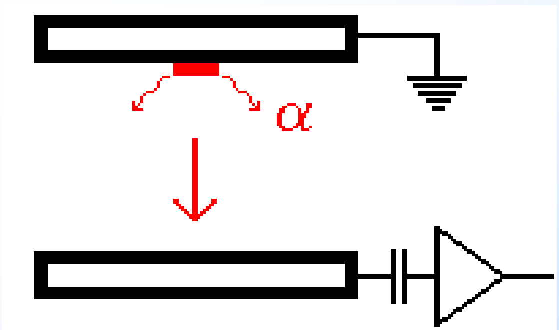
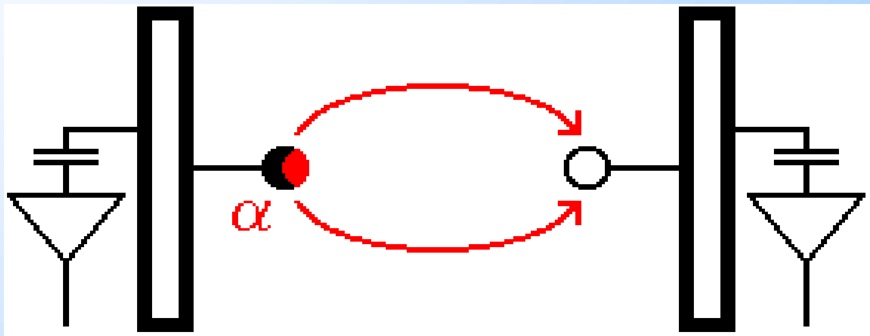
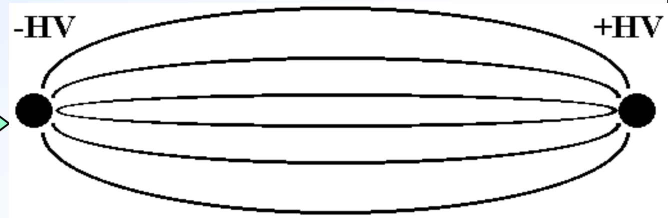






Design Study for the Purity Monitor

The Electric Field



Dipole Field generated by the 2 spherical electrodes

Calculation of the Number of Free e^-

Bethe-Bloch→ dE/dx → Ion-e^- Recombination

Calculation of Drift Velocity and Drift Times

The drift velocity is dependent on E_{field}

→ No constant Drift Times

→ e^- cloud spreads out

The Electric Dipole Field

Close to the source the E-field is well approximated by a single Coulomb field! ⇒ High field

$$|\vec{E}| = \frac{V.R}{r^2}$$

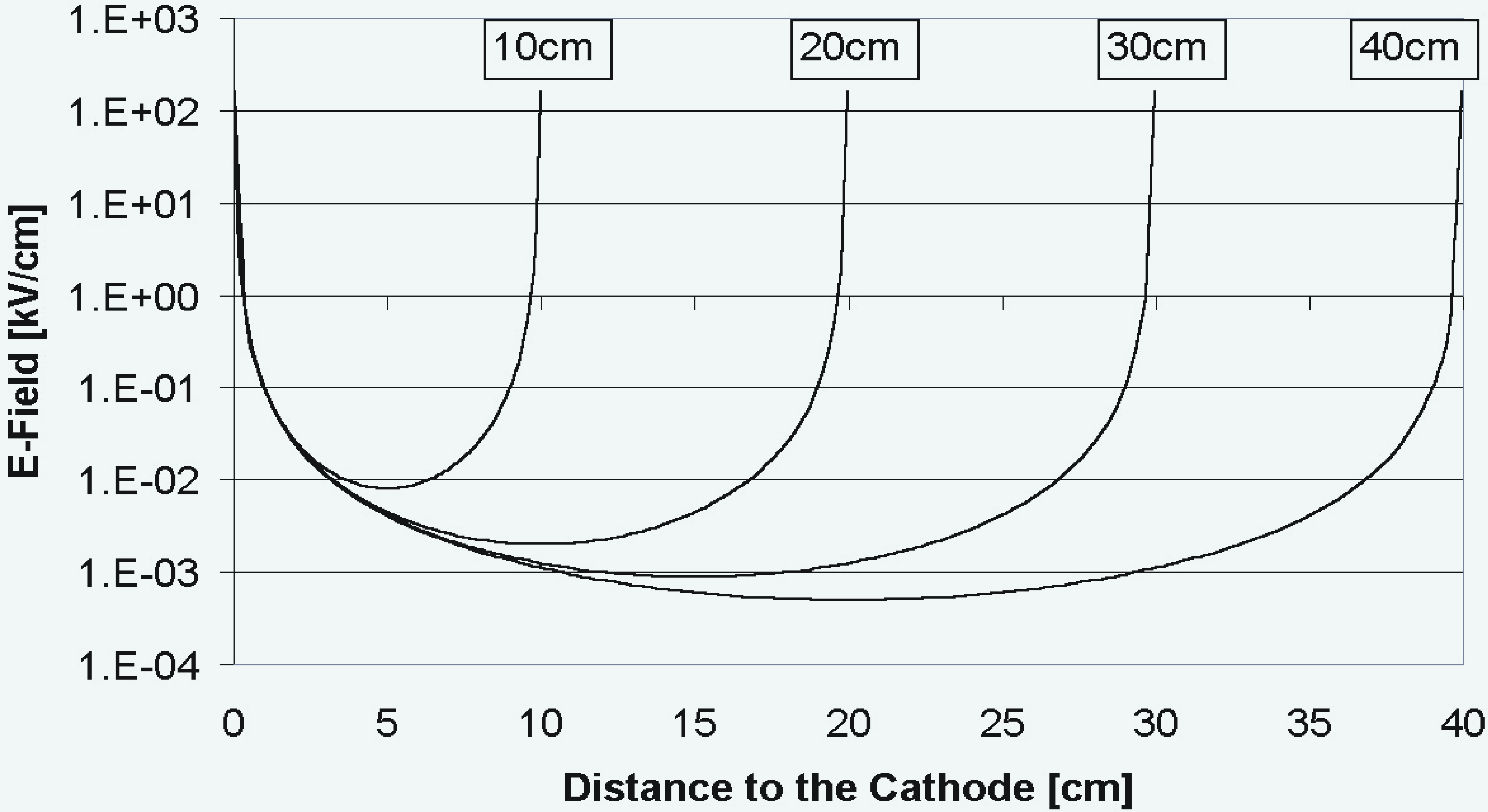
i.e: V=2kV, R=0.25mm, r=R+0.05mm

⇒E=56kV/cm

Between the two electrodes the E-field is very low!

i.e: V=±2kV, R=0.25mm, d=100mm ⇒E<5V/cm

The Electric Dipole Field



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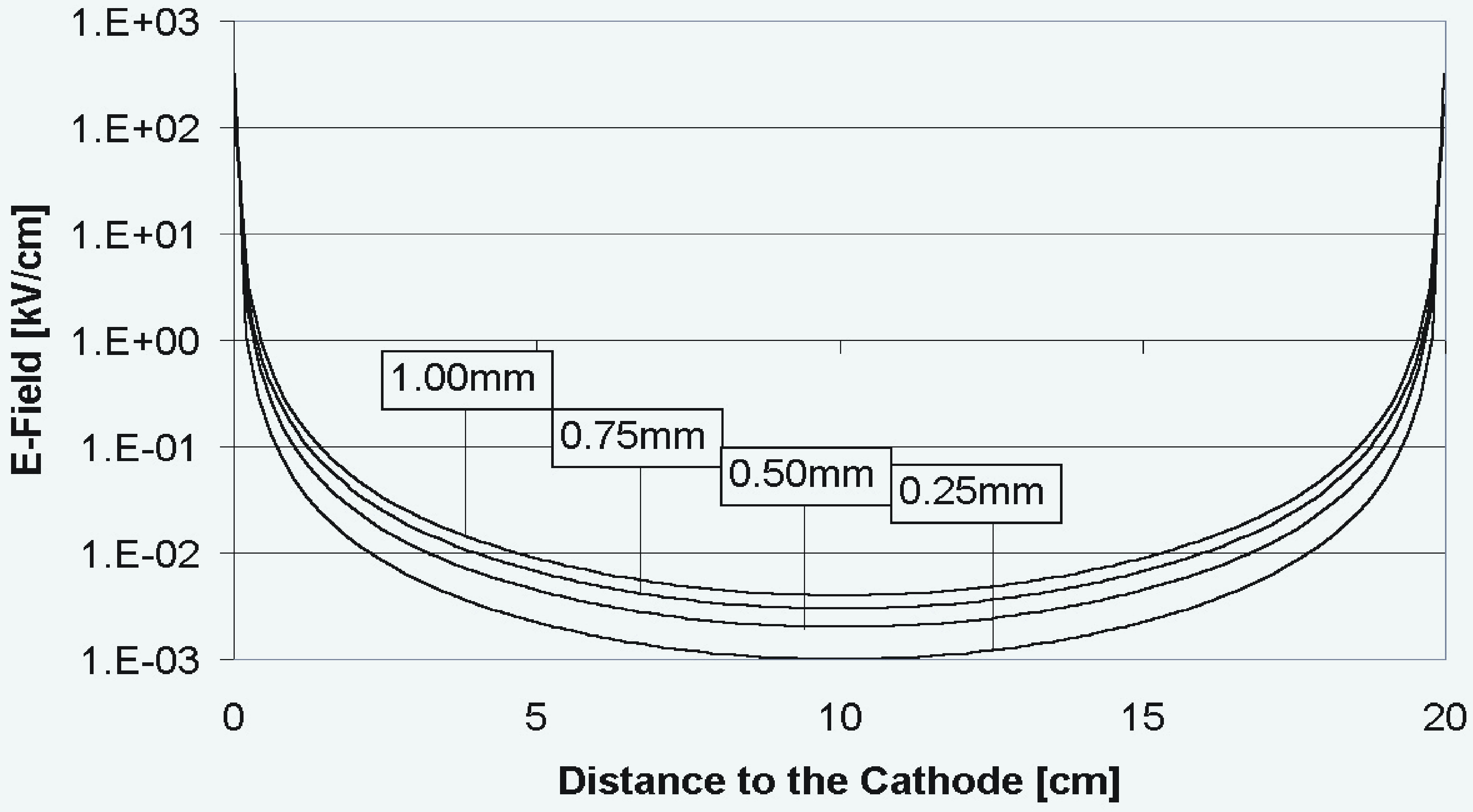
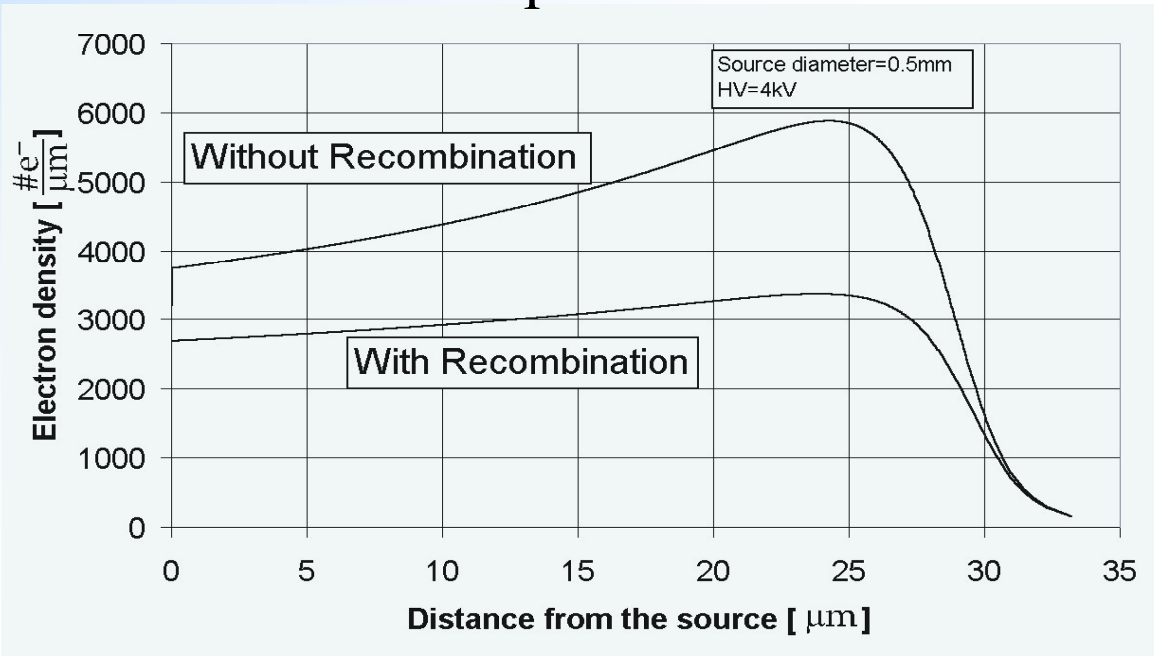


Calculation of the Number of Free Electrons

Source: $Pb^{210} \rightarrow$ 3.72MeV α-particle

Energy deposition of α-particle in LAr



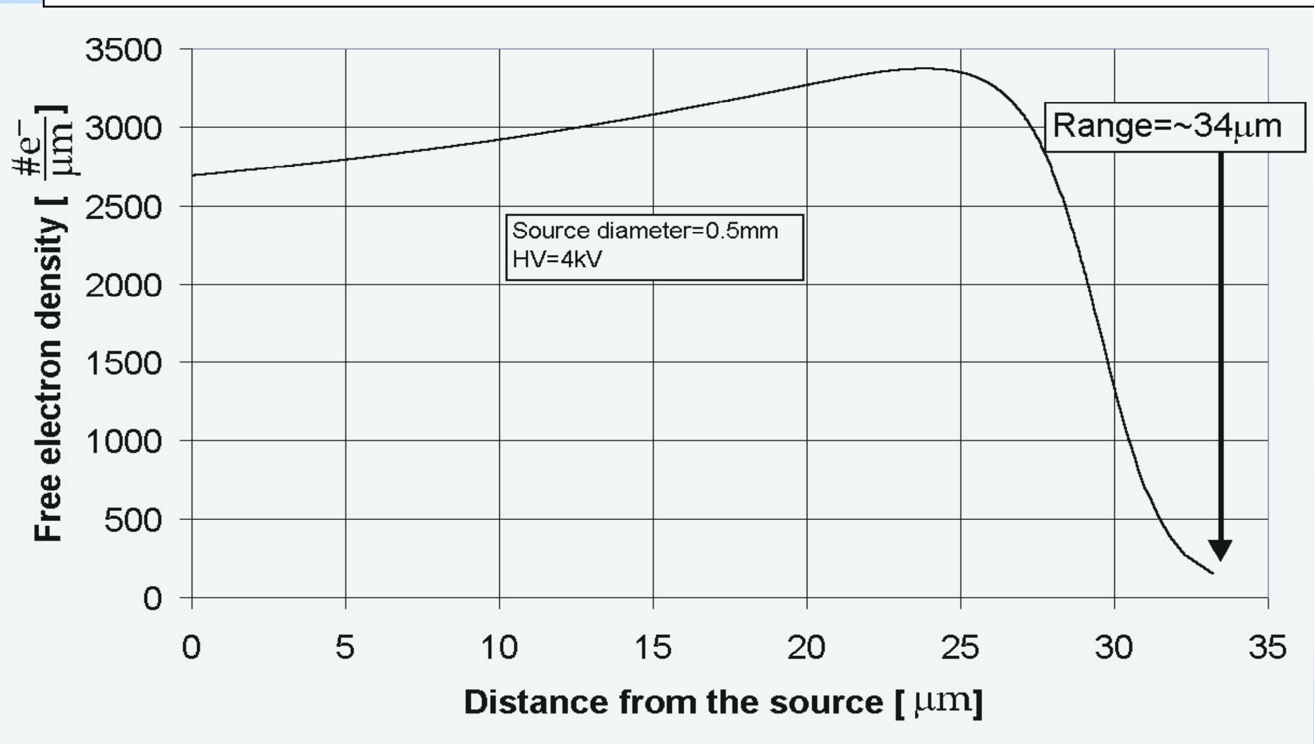
A lot of e⁻-ion pairs will recombine due to the electrostatic attraction.

Recombination Models

The α-particles ionize the LAr and produce e⁻-ion pairs.

Energy deposition of α-particle in LAr (Bethe-Bloch)

$$\frac{dE}{dx} = 0.1535.\rho.\frac{Z}{A}.\frac{z^2}{\beta^2}.\left[2\ln\left(2.511000\frac{\gamma^4\beta^2}{I_0}\right) - 2.\beta^2\right]$$



The α-particles produce a very large ionization density (700 times MIP)

→ Small dimension of the electron cloud

→ Bigger Recombination effect!

Recombination Models

Birks Model

Semi-empirical formula for the recombination at a given E-field. It takes into account the ionization density of the particle

$$\frac{dN}{dx} = \frac{\frac{dE}{dx} \cdot \frac{1}{w}}{1 + k_1\left(\left|\vec{E}\right|\right) \frac{dE}{dx} \cdot \frac{1}{\rho}}$$

w=23.6eV is the mean energy needed to produce an e^--ion pair

k_1 is E-field dependent

Box Model

The e^--ion pairs are considered as isolated and, at the beginning, the distribution is uniform in a box of certain dimensions

$$\frac{N}{N_0} = \frac{\left|\vec{E}\right|}{C} \ln\left(1 + \frac{C}{\left|\vec{E}\right|}\right)$$

N, N_0 are the number of electrons with and without recombination

C depends on source and medium

Calibration of Models

Find C on Box Model, given k_1(500V/cm)

Integrate the Birks formula with the known k_1(500V/cm) and in a homogeneous E-field (500V/cm)

N

Integrate the Bethe-Bloch

N_0

Calculate N/N_0

Find k_1 on Birks Model, given C

Integrate the Birks formula with a k_1, with the Box model, find the corespondent E-field

$$\frac{dN}{dx} = \frac{\frac{dE}{dx} \cdot \frac{1}{w}}{1 + k_1\left(\left|\vec{E}\right|\right) \frac{dE}{dx} \cdot \frac{1}{\rho}}$$

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Recombination Models: Birks Model

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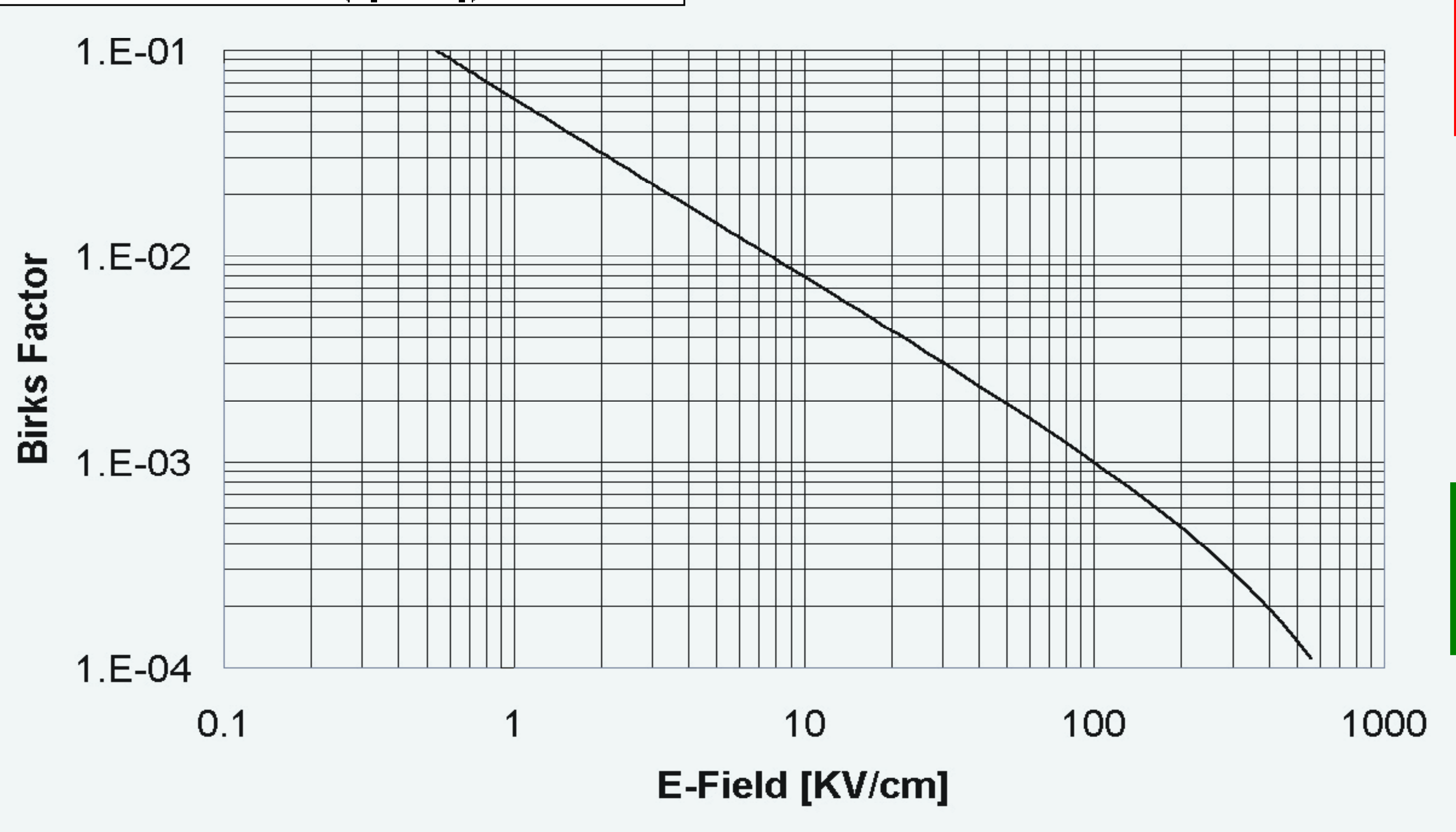

k_1 is known for LAr at 500V/cm

Calibration

k_1 is found with the Box Model

Recombination Models: Box Model

$$\frac{N}{N_0} = \frac{|\vec{E}|}{C} \ln\left(1 + \frac{C}{|\vec{E}|}\right)$$

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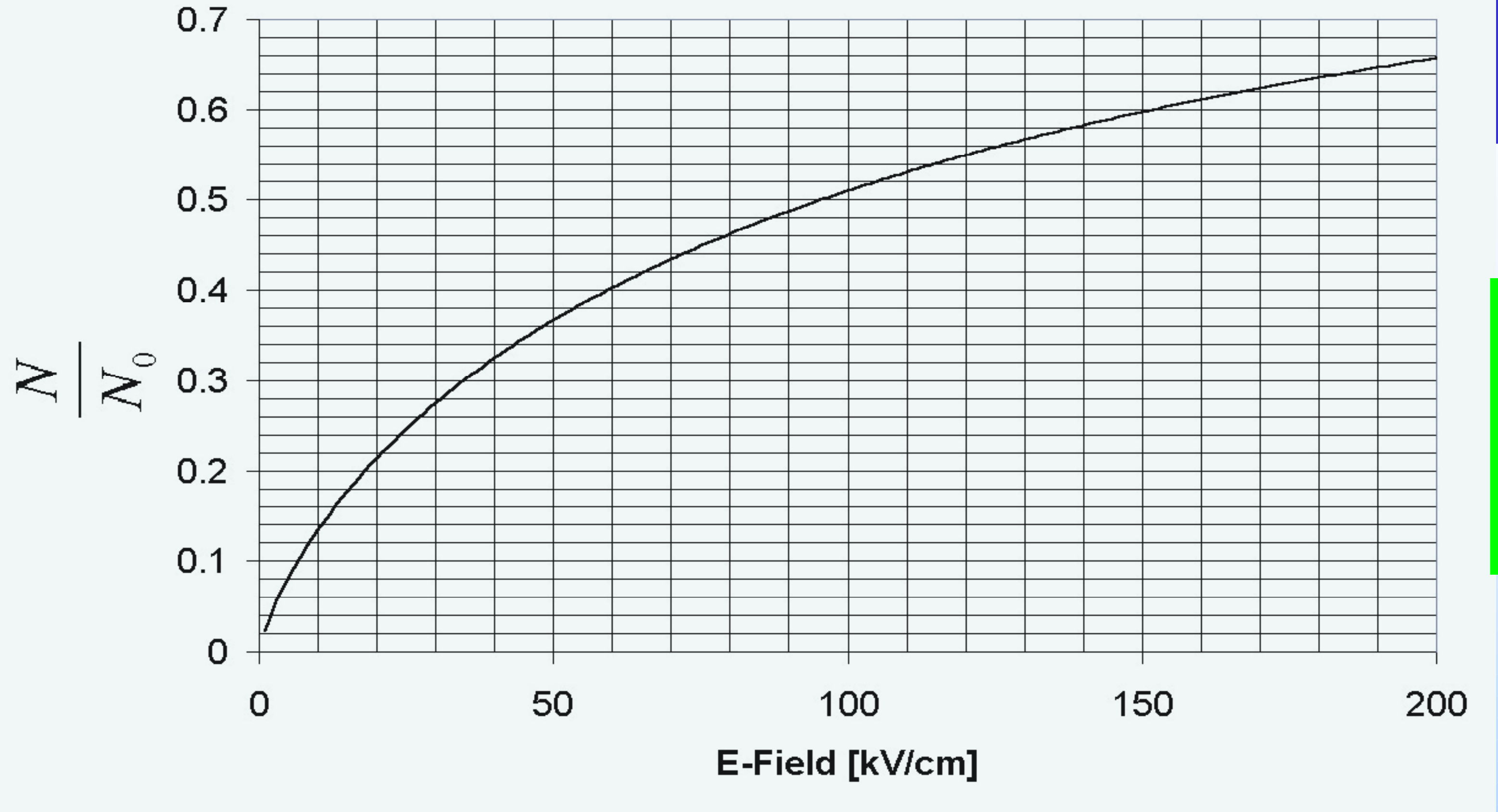
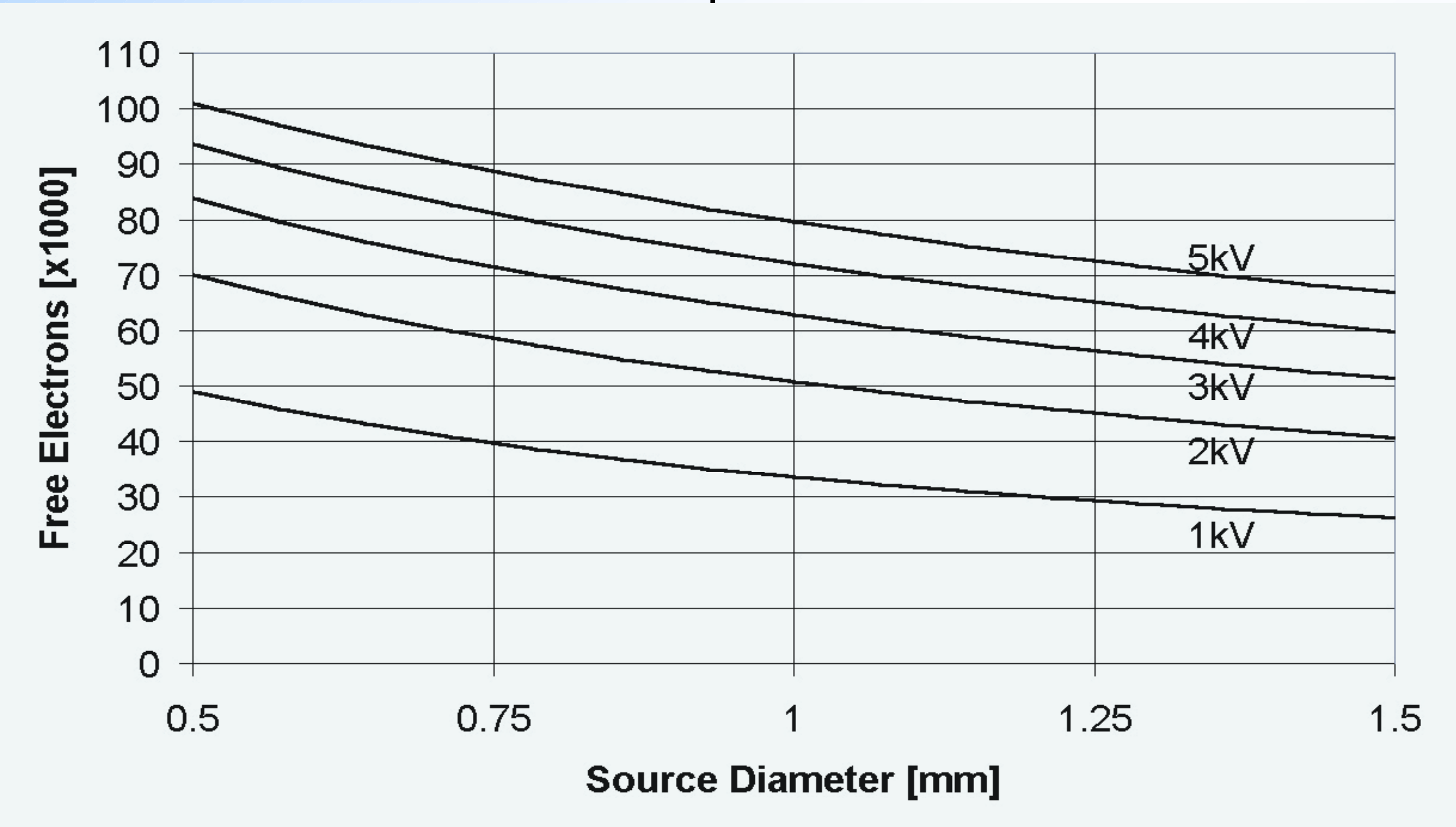


C for LAr and Pb^{210} α-particle=239.9

The Box model gives the recombination in a homogeneous E-field.

Calculation of the Number of Free Electrons

Source: $Pb^{210} \rightarrow$ 3.72MeV α-particle in LAr



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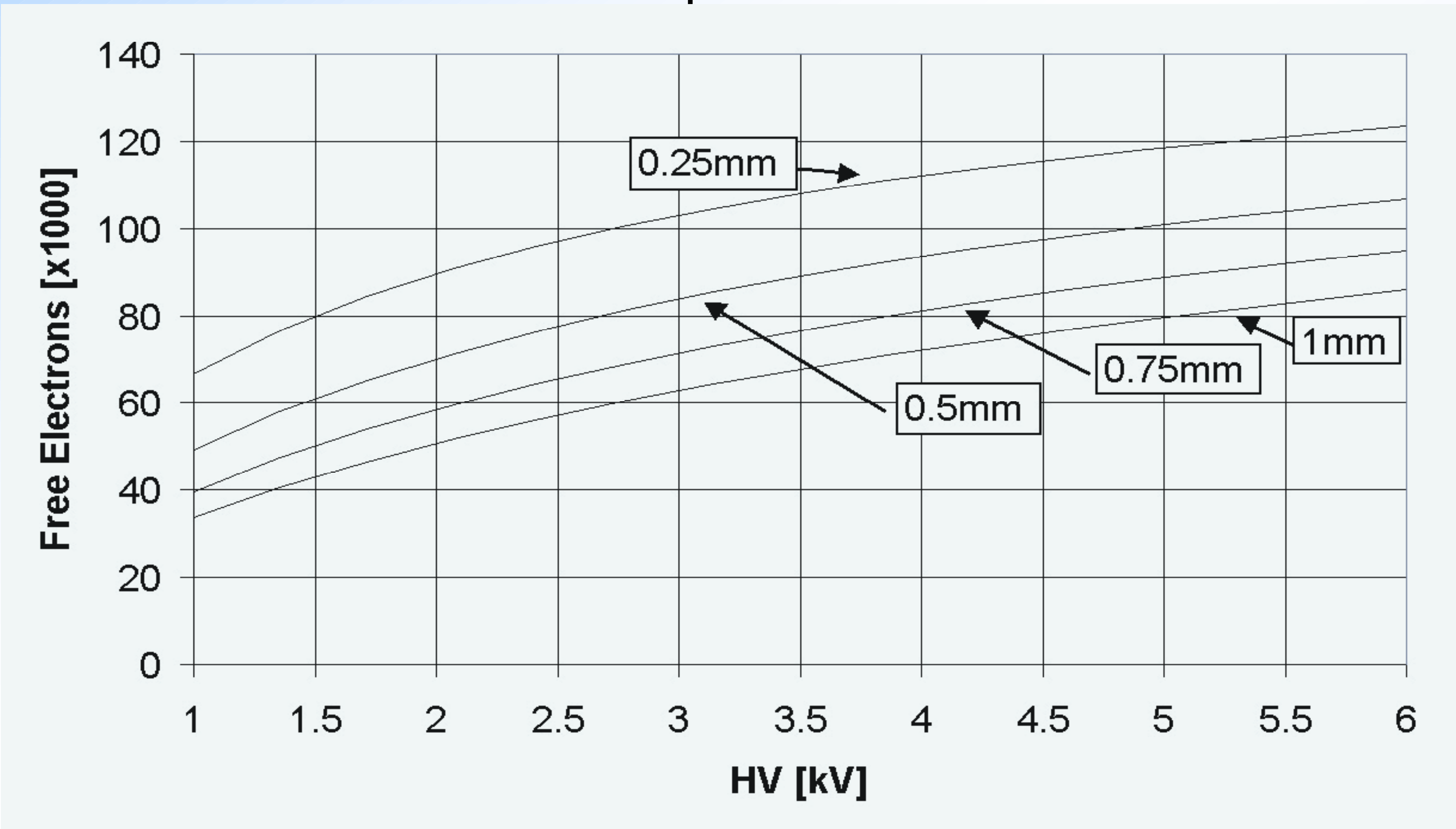
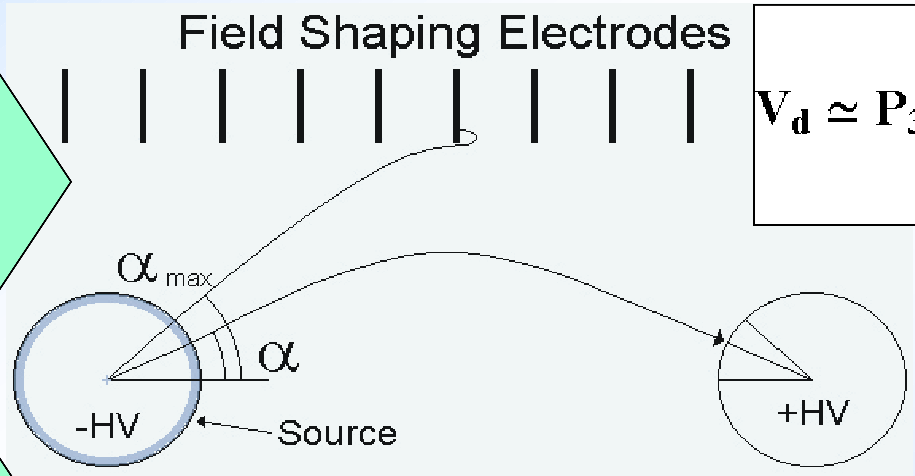


Calculation of Drift Velocity and Drift Times

- The e^- are tracked along the E-field lines with a computer program.
- The drift time should be comparable to the mean life-time for a precise life-time measurement.

$t_{drift}(HV,d,l,\alpha)$



$$V_d \simeq P_3 \cdot \left|\vec{E}\right| \ln\left(1 + \frac{P_4}{\left|\vec{E}\right|}\right) + P_5 \cdot \left(\left|\vec{E}\right|\right)^{P_6}$$

e^-- cloud diffusion

$$\delta_{diff} = \sqrt{2\,D.t}$$

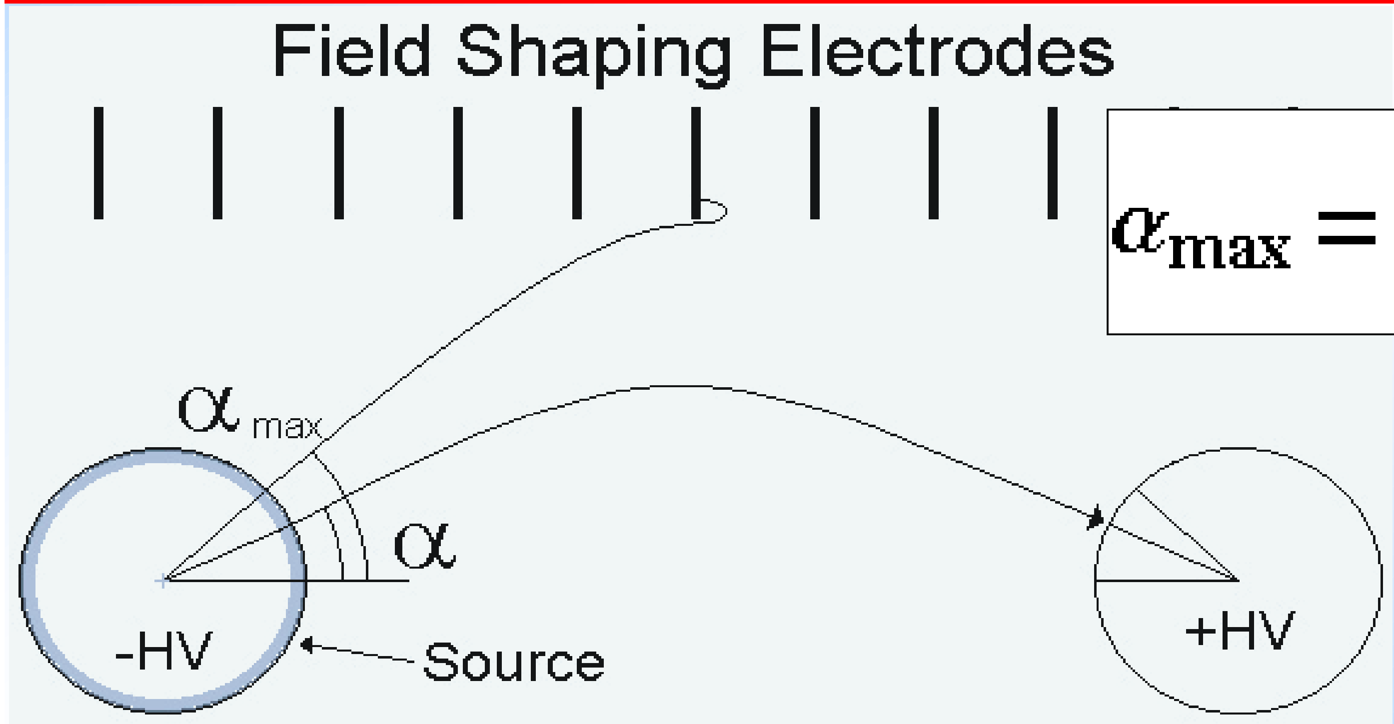
Where $D \cong 5\,cm^2/s$

$$\alpha_{max} = 31.4\,° \cdot \frac{D_{Chamber}}{l}$$

Calculation of Drift Velocity and Drift Times

The different drift times are given by the starting angle (α)

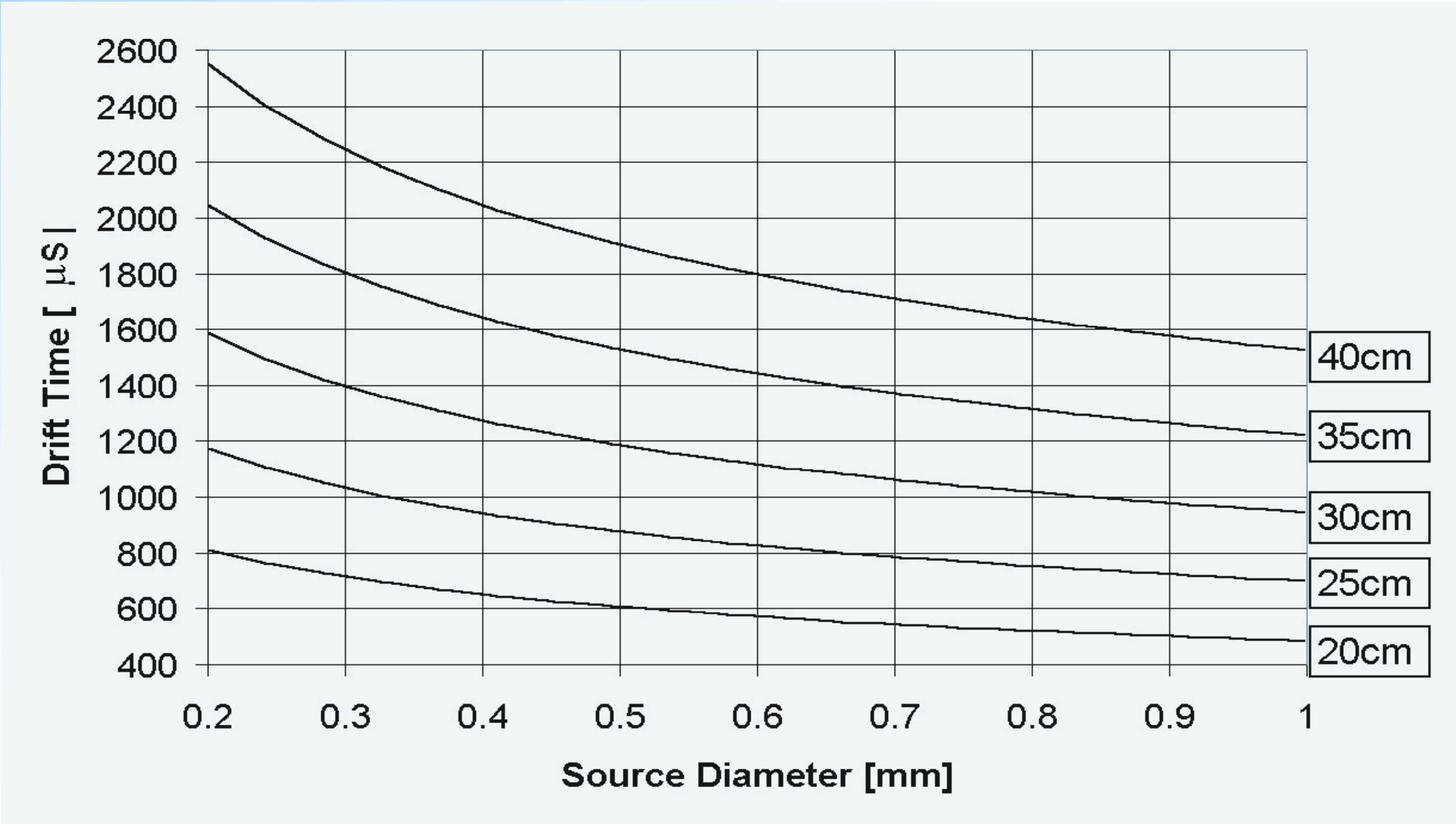
→The diameter of the Field Shaping Electrodes gives a limit on possible drift times



$$\alpha_{max} = 31.4° \cdot \frac{D_{Chamber}}{l}$$

Empirical formula

Calculation of Drift Velocity and Drift Times



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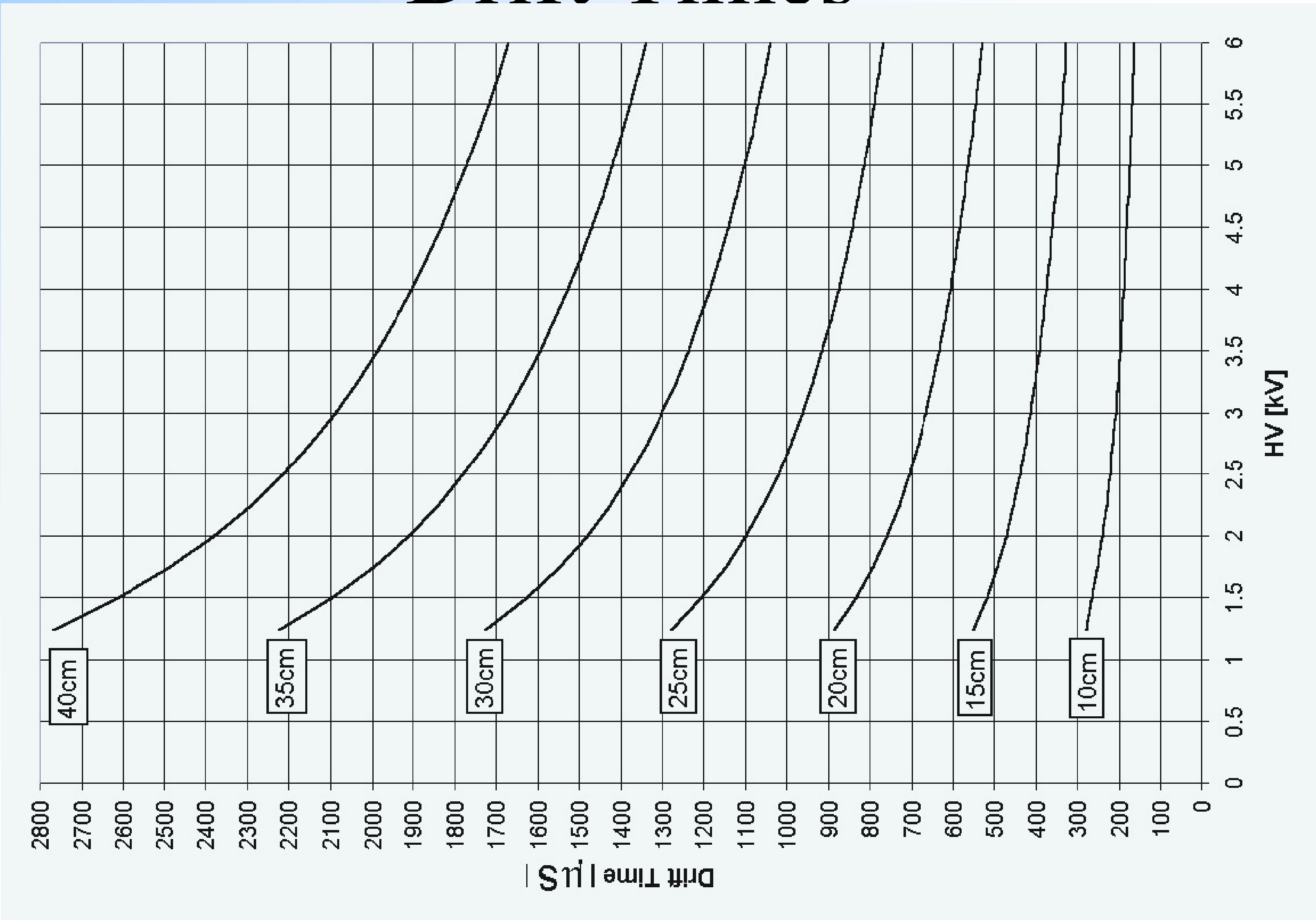

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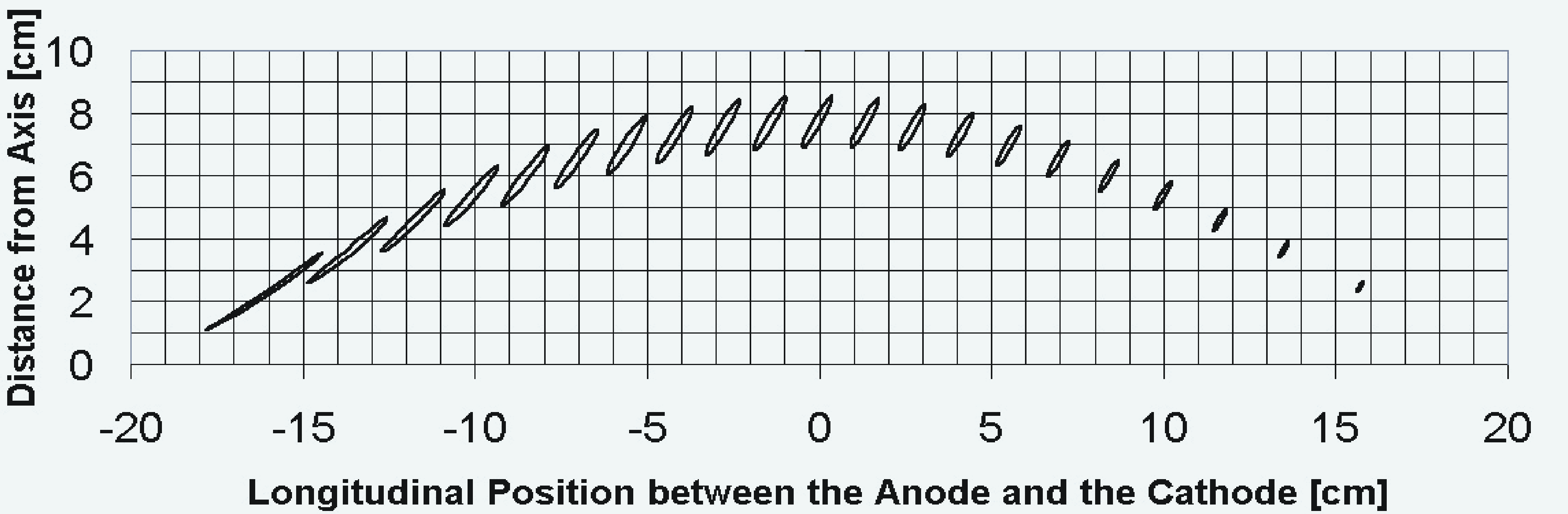
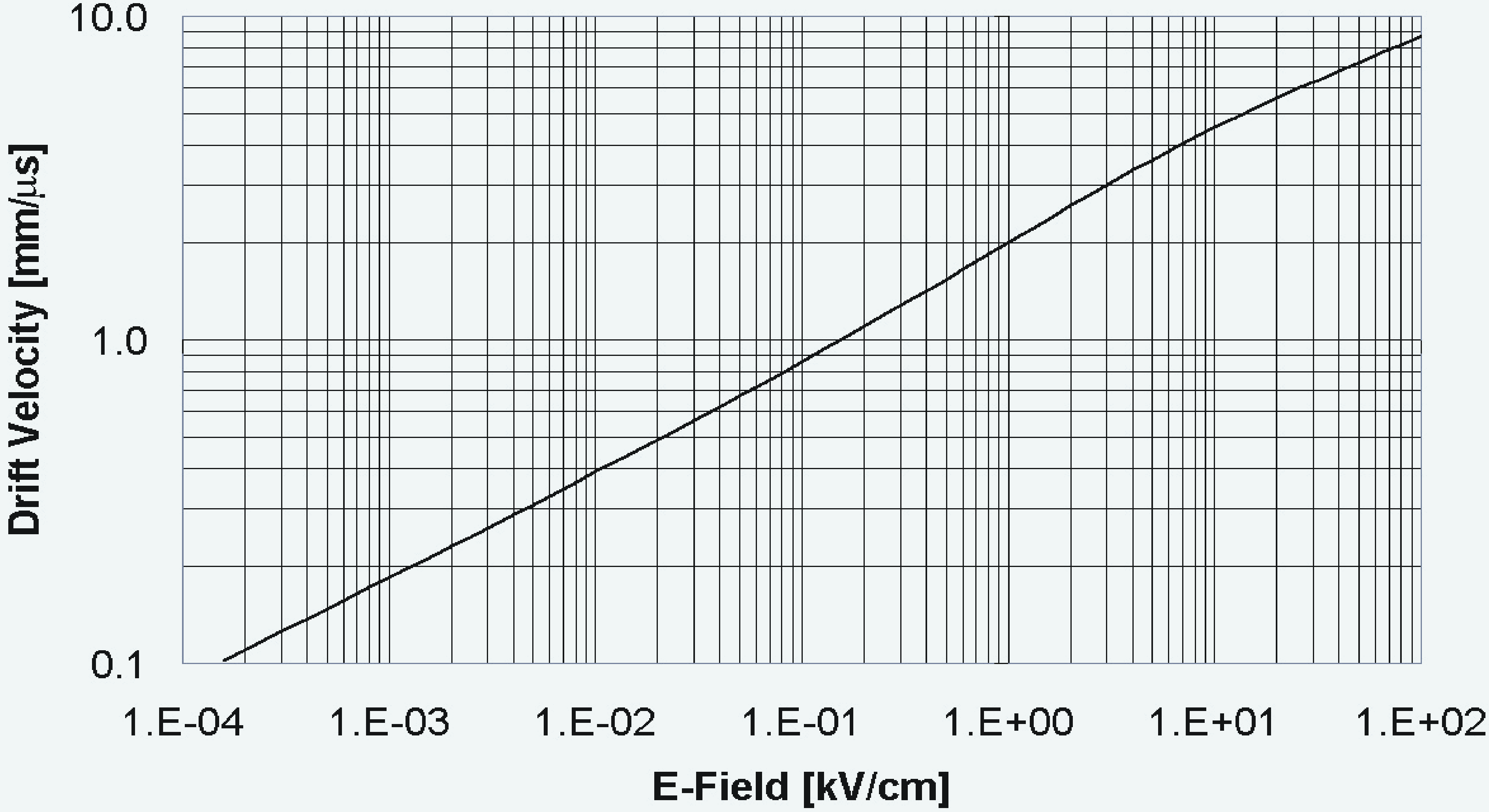


"Stroboscopic" view of an e^- cloud moving in a dipole field. The contour is 1σ of the (almost) Gaussian e^- distribution. Time intervals of 100 μs are shown.

Calculation of Drift Velocity and Drift Times



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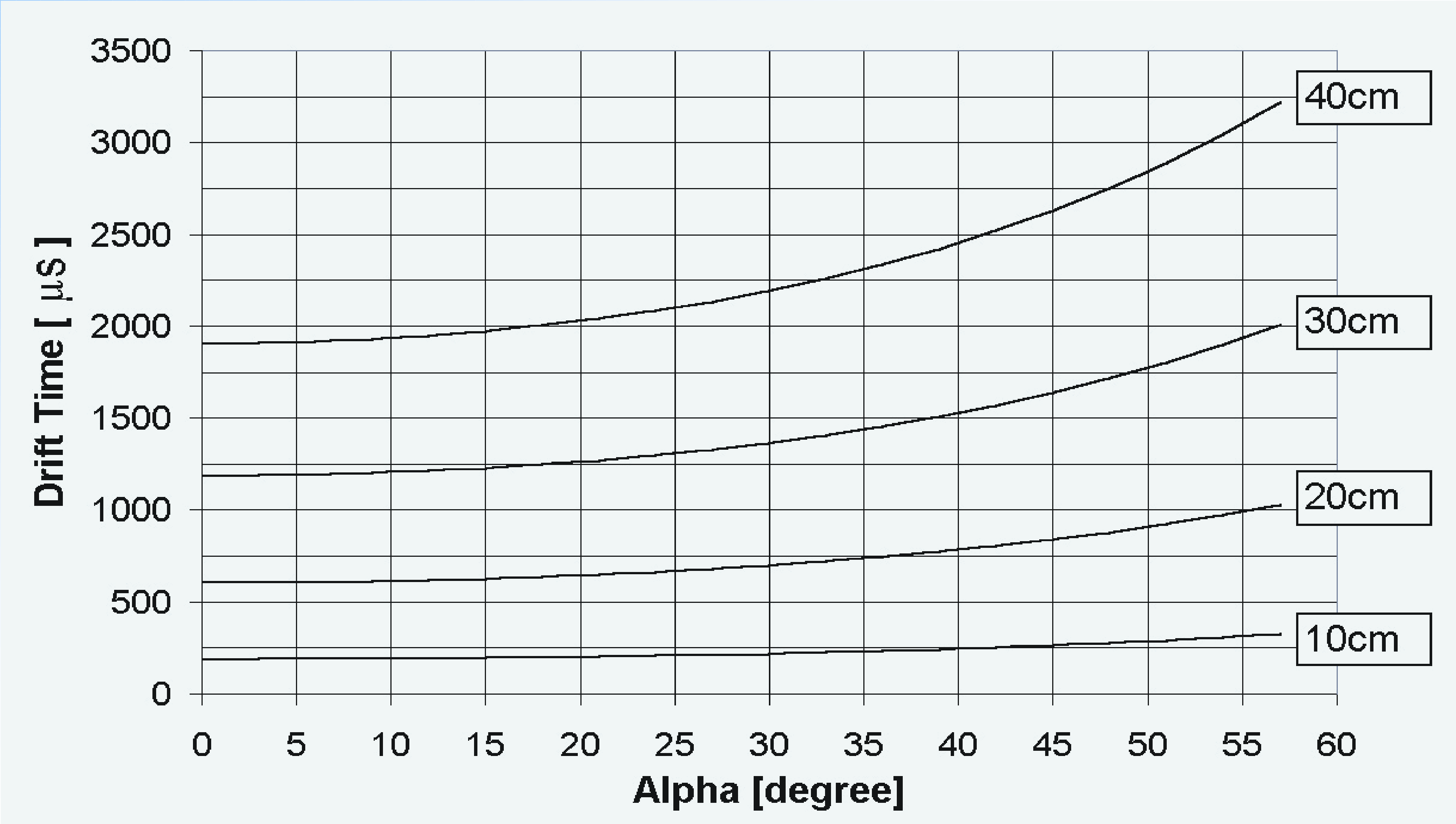

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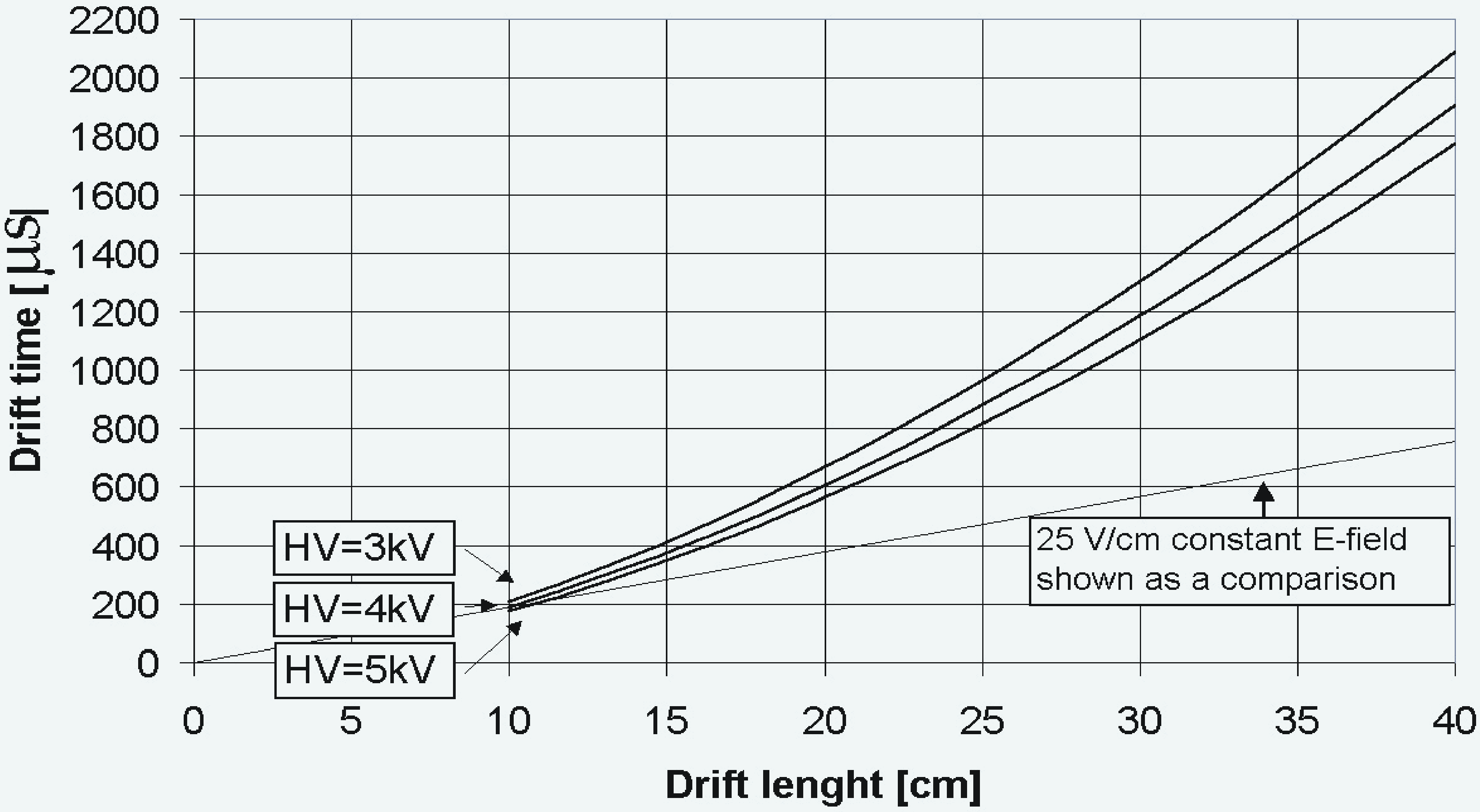


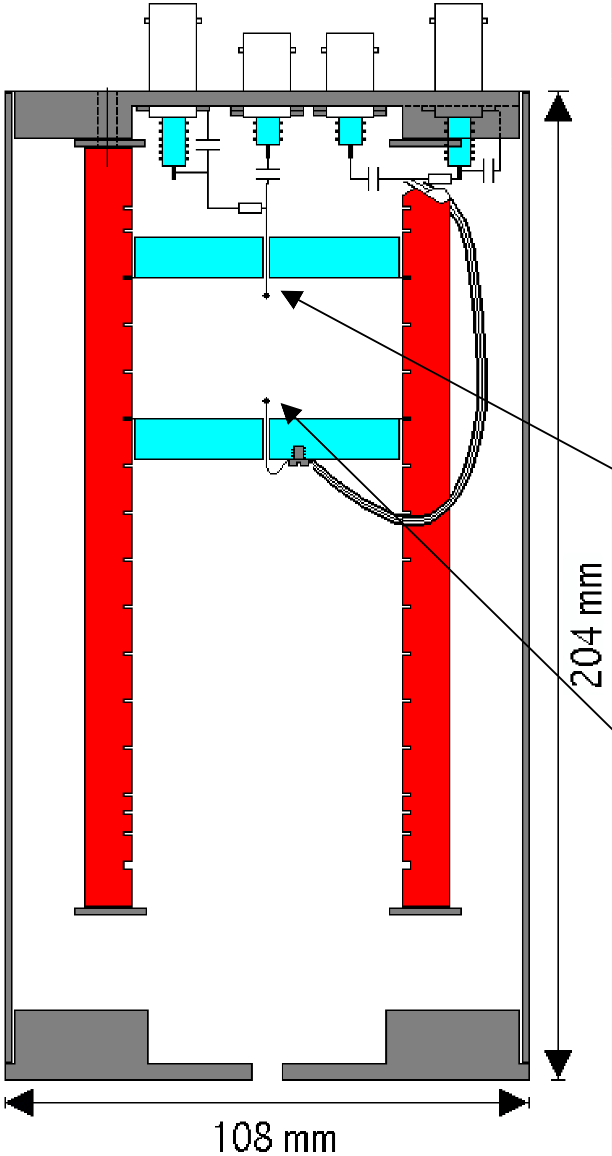
Experimental Setup

Purity Monitor Mechanics → Materials for high purity, vacuum and cryogenic temperature

Electronics and DAQ → 10k e^- preamp and filters to have best S/N. DAQ card @20Ms/s

Cryogenic Vessel → High purity LAr (CuO filter). Materials for purity, vacuum and cryogenic temperature

Purity Monitor Mechanics



Stainless Steel

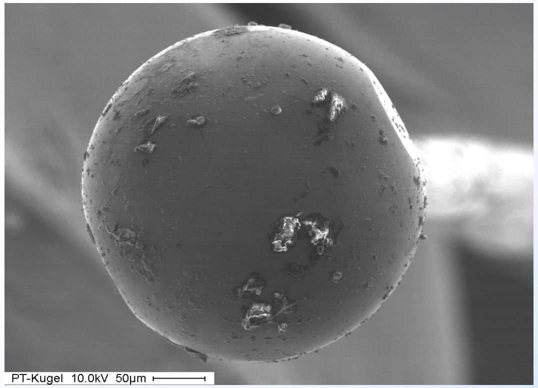
Polyethylene

Macor

Materials for high purity, vacuum and cryogenic temperature

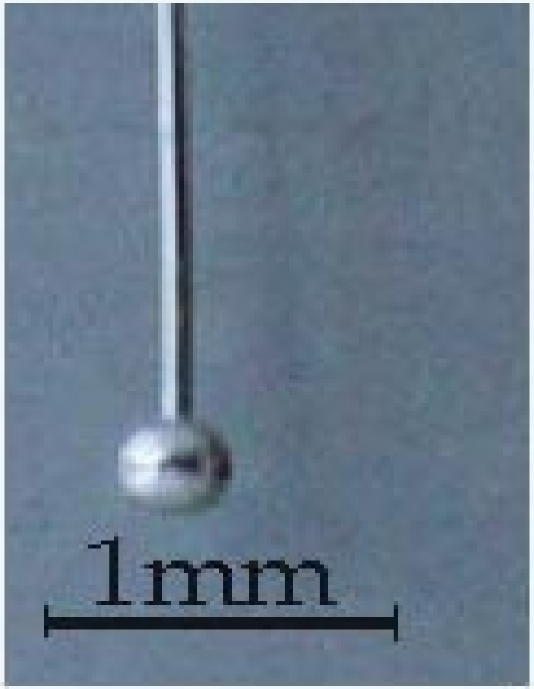
Spherical anode

Pb^{210} spherical source



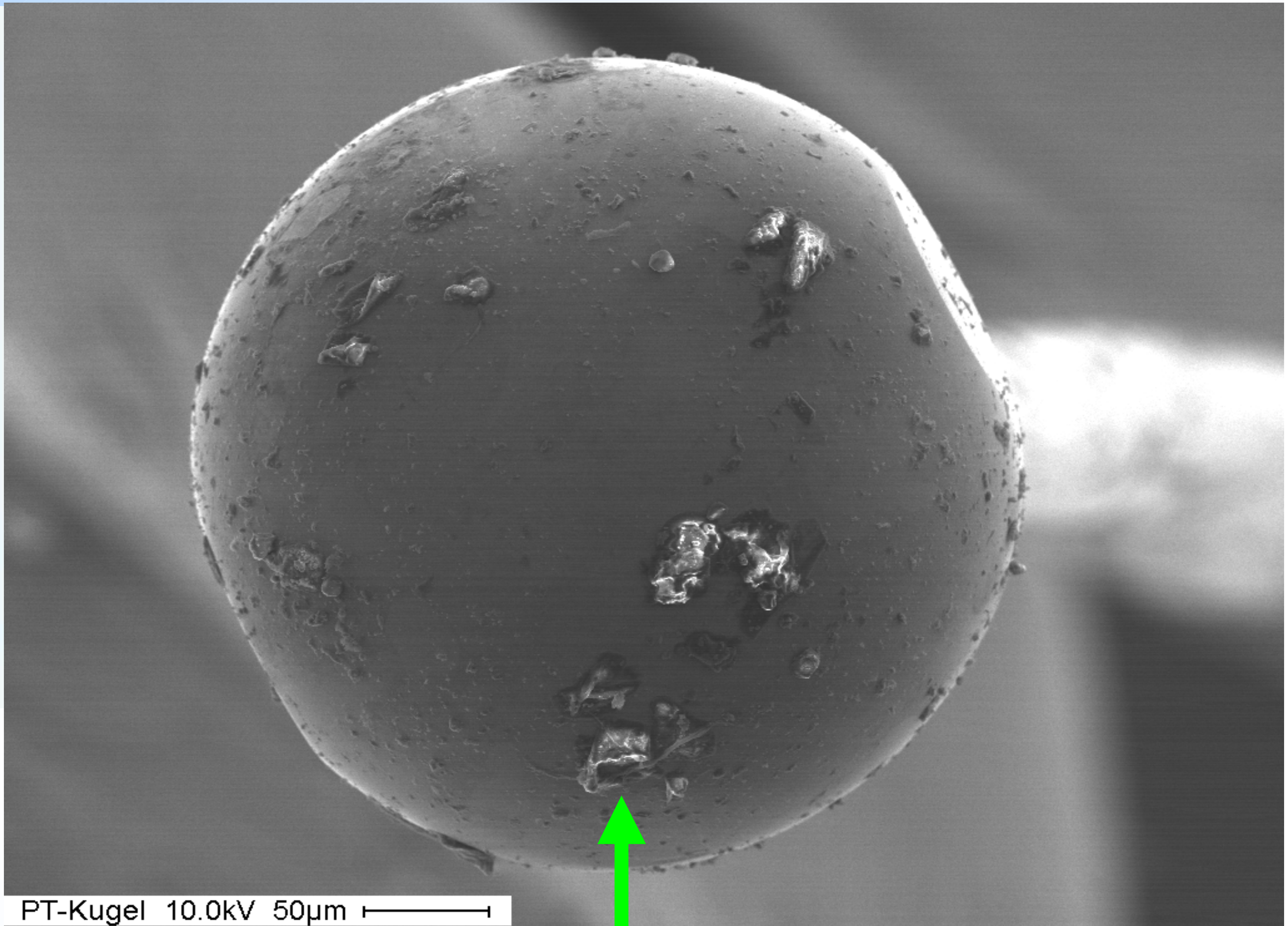
Built by our group

Spherical Anode



A Pt-wire is melted in a flame

⇒spherical by superficial tension



Plastic particle coming from a plastic envelope

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Spherical Pb^{210} α-Source

A Pt-wire is melted in a flame

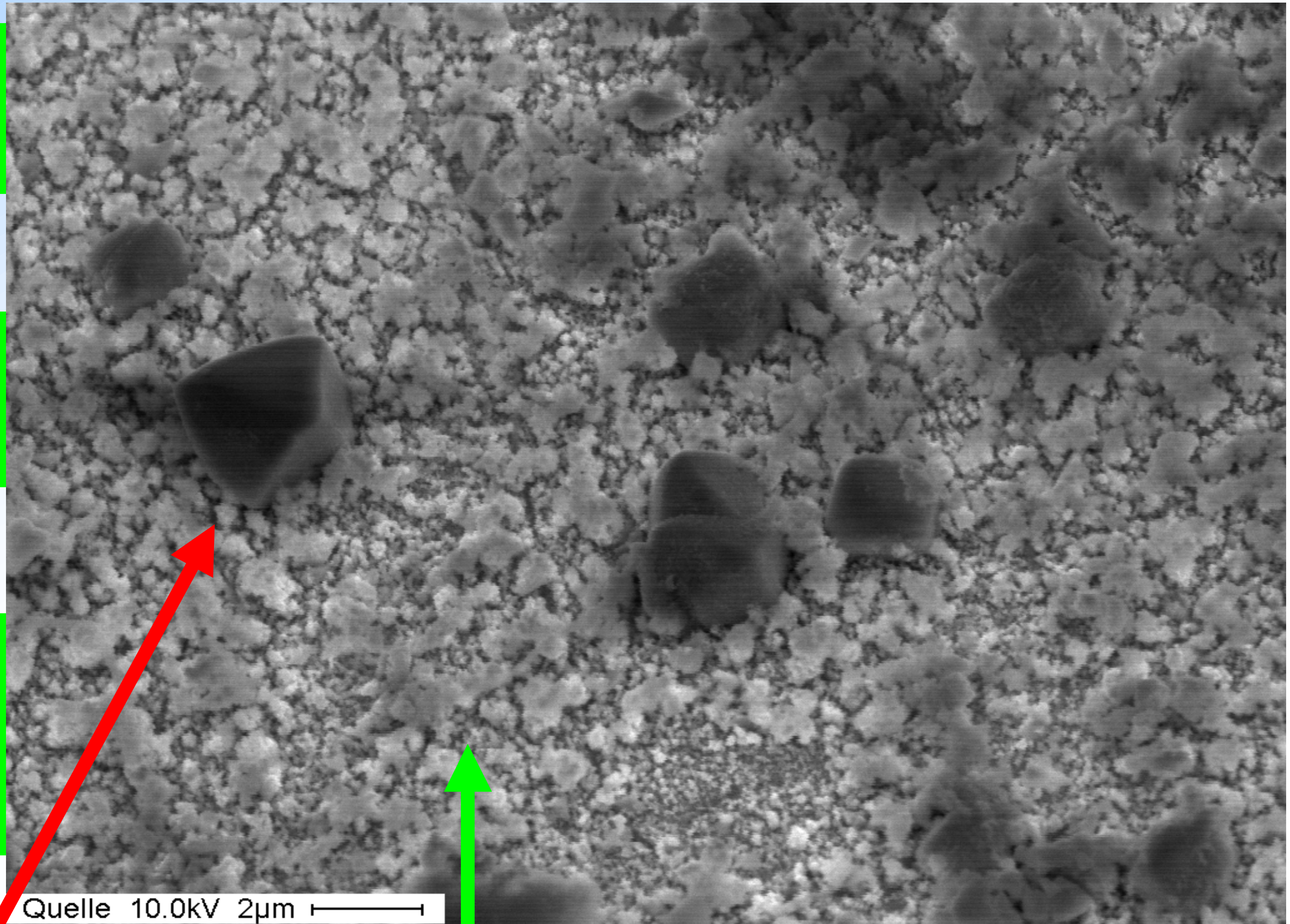
⇒ The source is deposited by an electro-chemical procedure

Spherical Pb^{210} α-Source

$1.2Mol\ HNO_3\ Pb^{210}$ solution ~20kBq

The solution is dried out

Dissolved in 1Mol Acetic acid and 1Mol NH_4-acetate



Unknown crystals

Pb crystals grown at the Pt surface

Spherical Pb^{210} α-Source

Isotope	Life-time	Modes of Decay	Particle Energy [Mev]	Particle Intensities
$_{82}Pb^{210}$	21y	β	0.015	0.81
			0.061	0.19
		α	3.72	1.7E-8
		γ	~0.047	With β

Isotope	Life-time	Modes of Decay	Particle Energy [Mev]	Particle Intensities
$_{80}Hg^{206}$	8m	β^-	0.935	1.00
		γ	0.305	With β^-

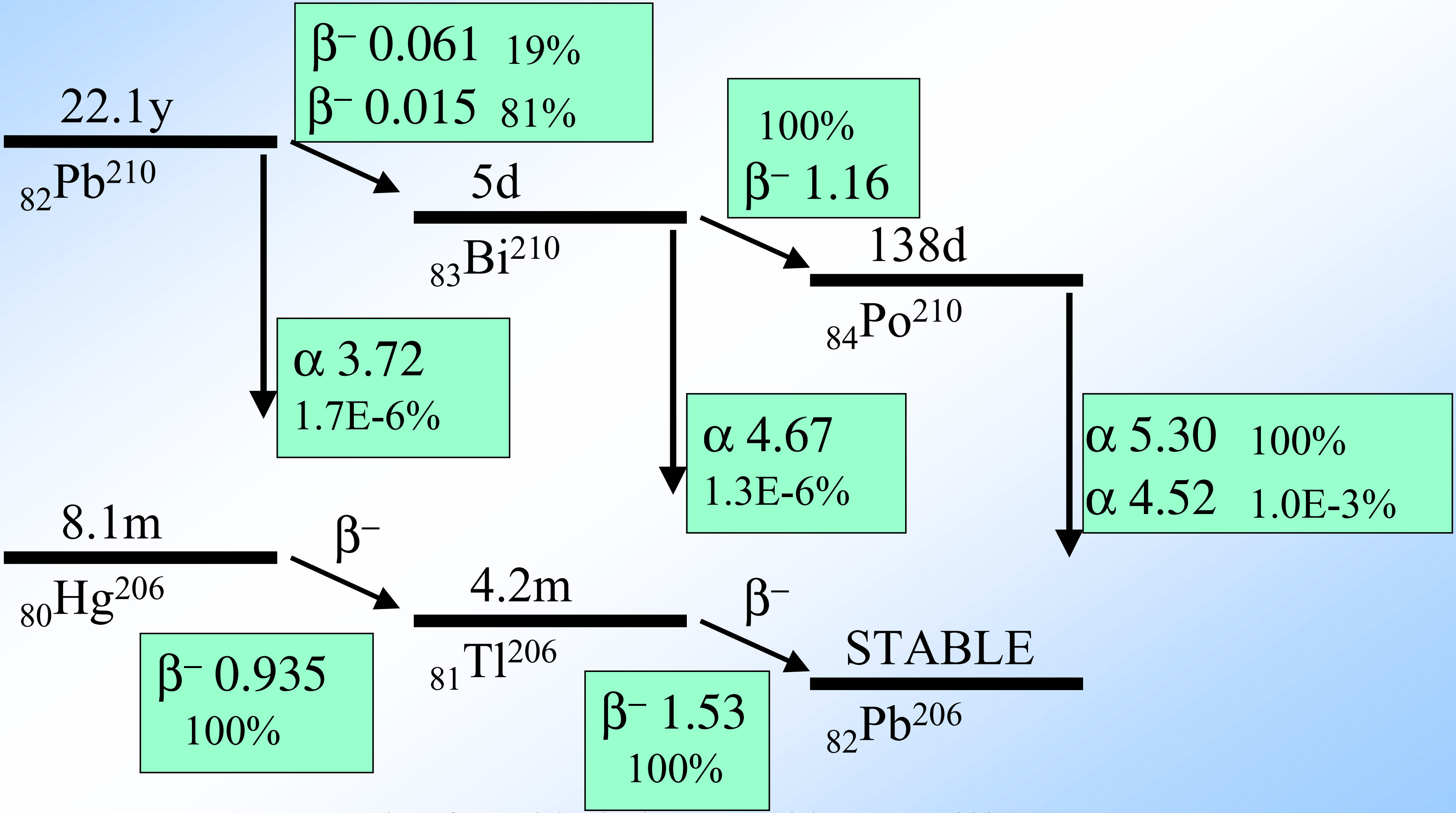
Isotope	Life-time	Modes of Decay	Particle Energy [Mev]	Particle Intensities
$_{81}Tl^{206}$	4m	β^-	~1.530	1.00
		γ	1.163	6.2E-4

Spherical Pb^{210} α-Source

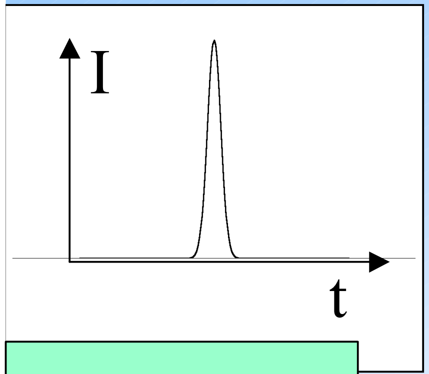
Isotope	Life-time	Modes of Decay	Particle Energy [Mev]	Particle Intensities
$_{83}Bi^{210}$	5d	β^-	1.16	1.00
		α	~4.67	1.3E-6
		γ	~0.3	With α

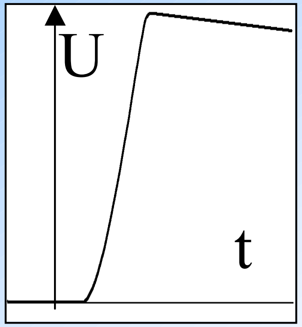
Isotope	Life-time	Modes of Decay	Particle Energy [Mev]	Particle Intensities
$_{84}Po^{210}$	138d	α	5.30	1.00
		α	4.52	1E-5
		γ	0.80	1.6E-6

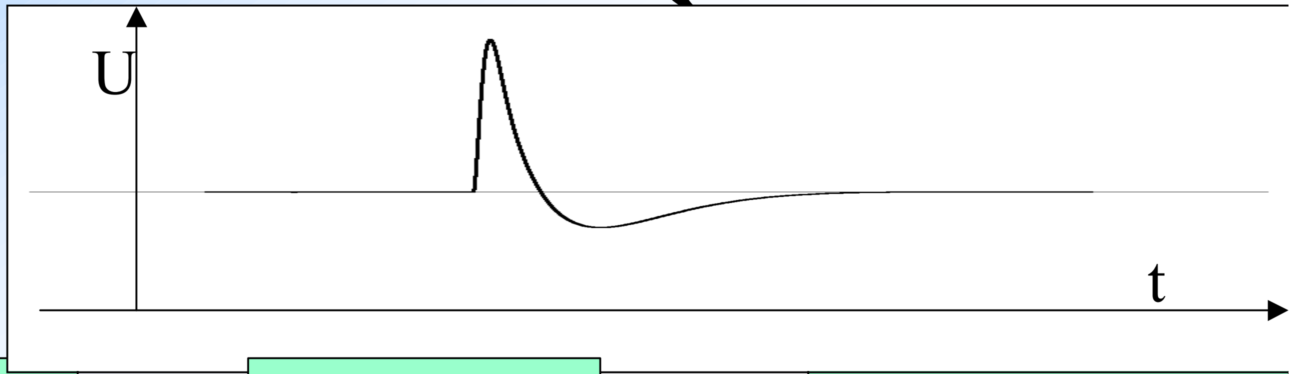
Spherical Pb^{210} α-Source



Electronics and DAQ

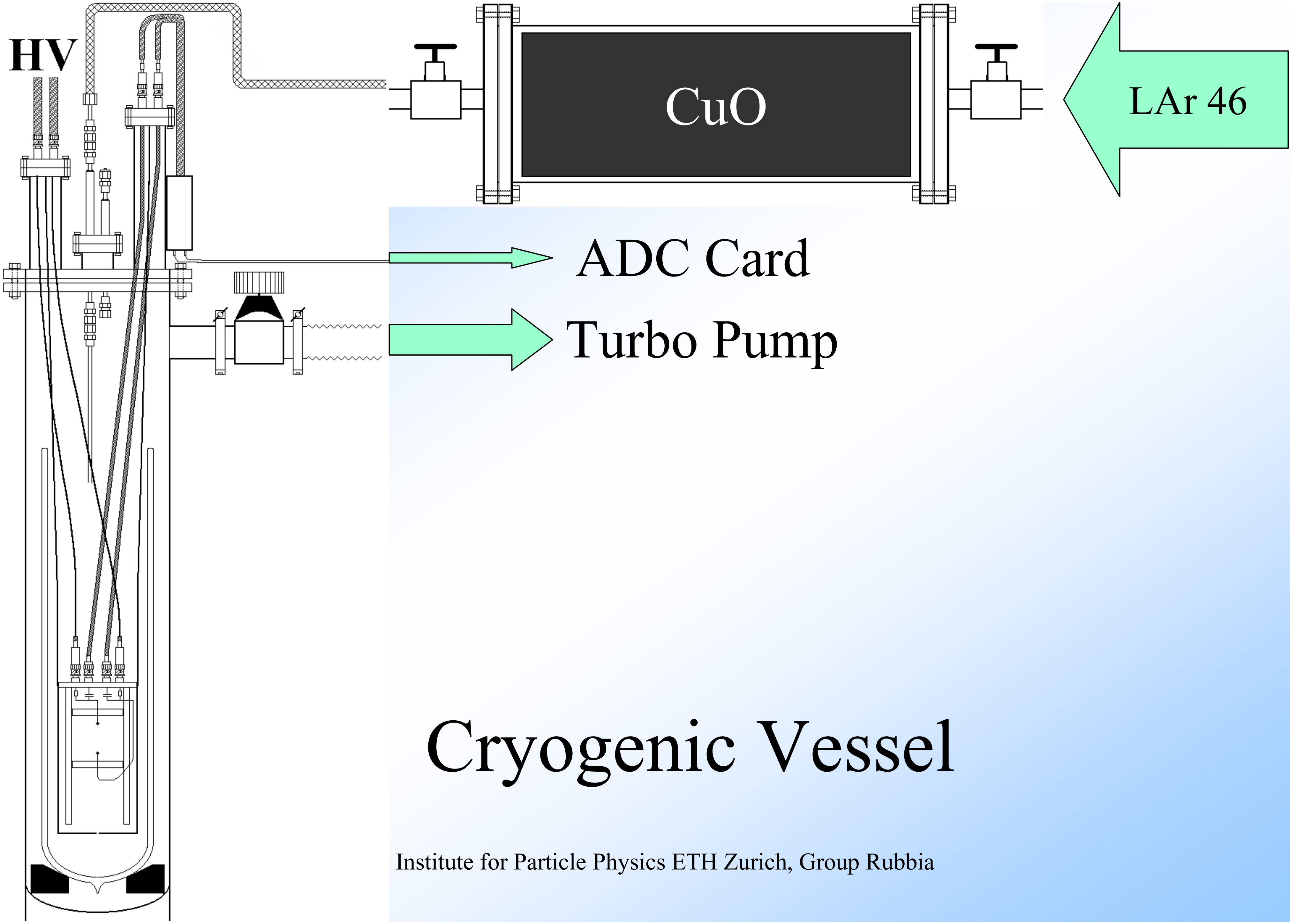






Charge to Voltage Preamp → Filter to optimize S/N → Offset and Amplifier → DAQ Computer Card

- **Charge to Voltage Preamp**: Preamp developed for ICARUS
  →Sensitivity of 0.95 mV/10ke$^-$
- **Filter to optimize S/N**: Double band-pass filter. Center frequency ~15kHz
- **Offset and Amplifier**: Low noise Op-Amp
- **DAQ Computer Card**: 20Ms/s 12bit DAC



Cryogenic Vessel

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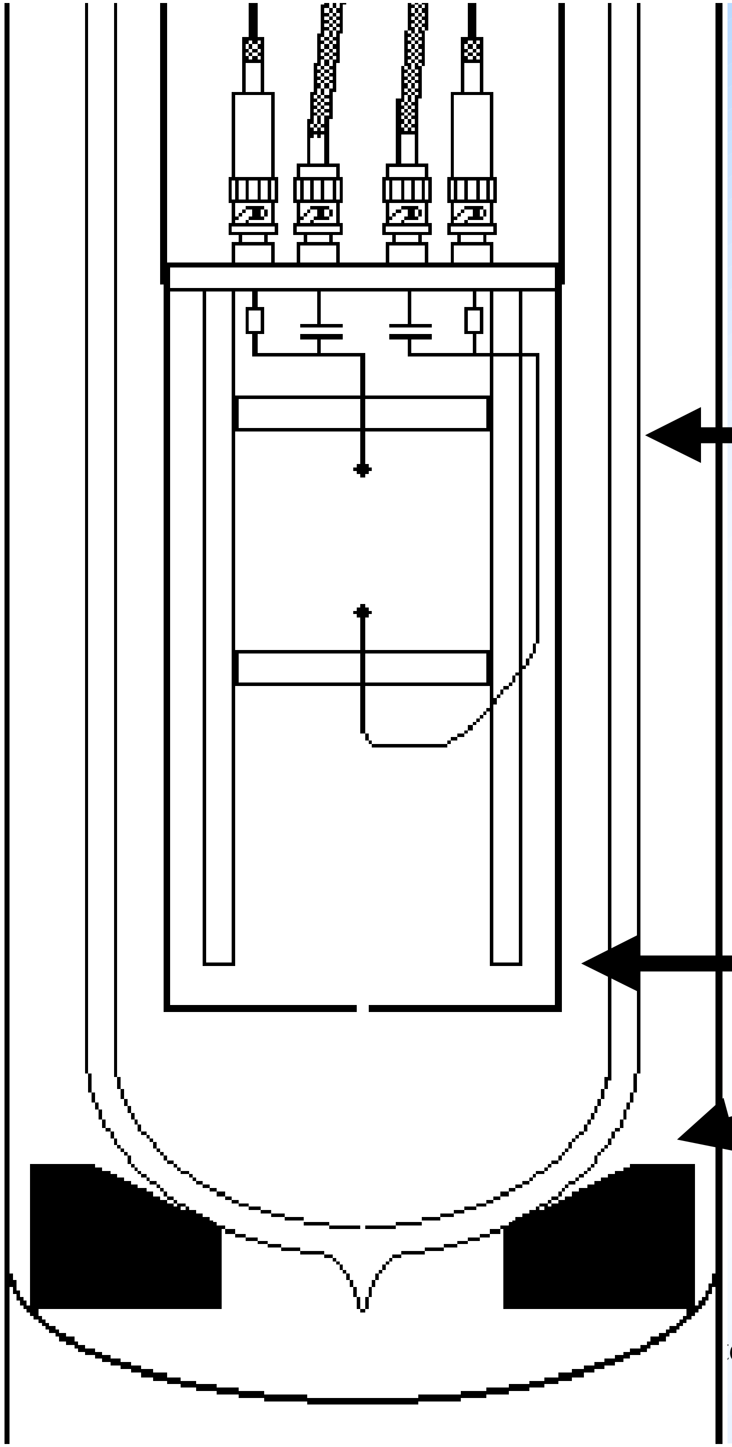
Cryogenic Vessel

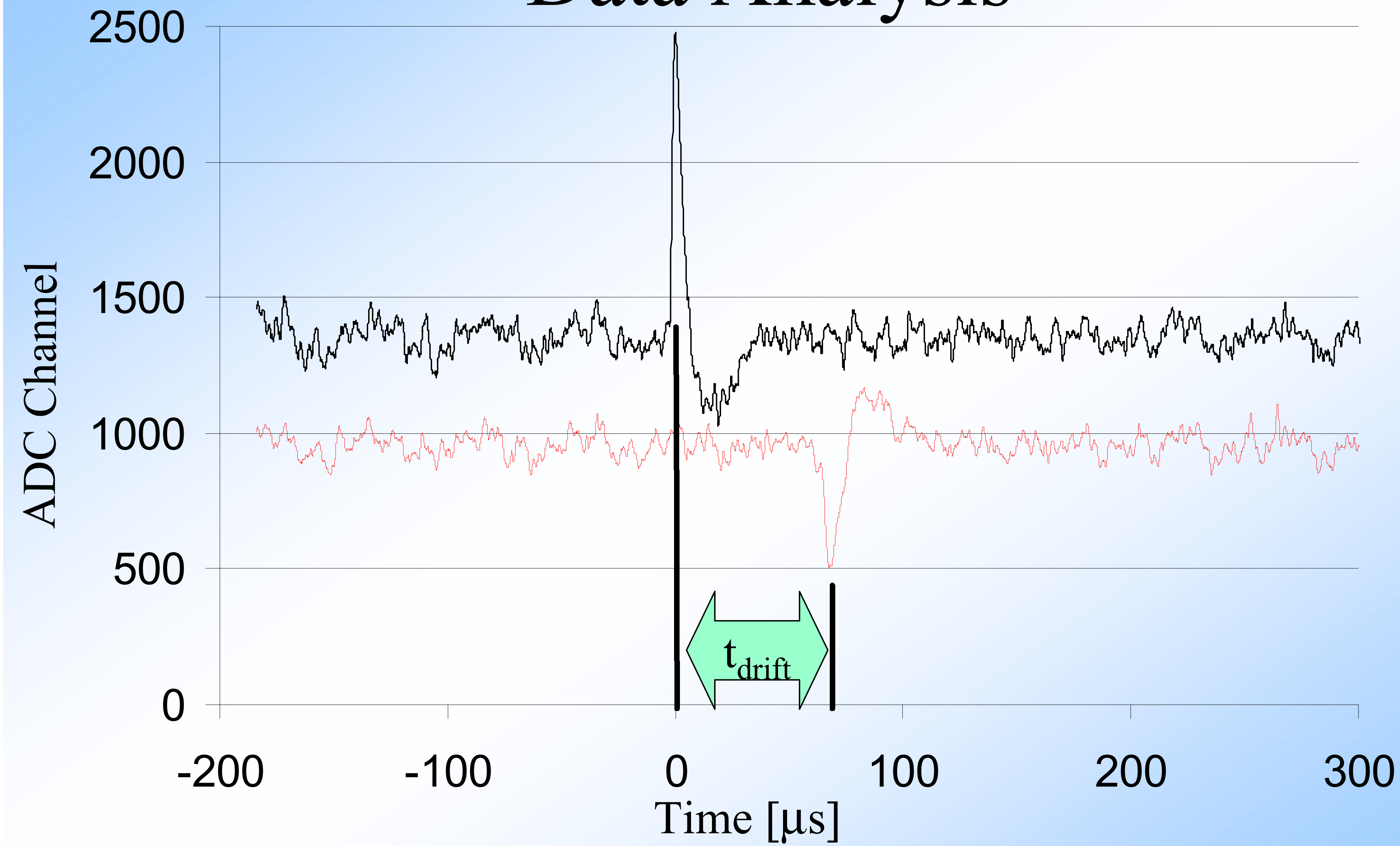


Glass Dewar

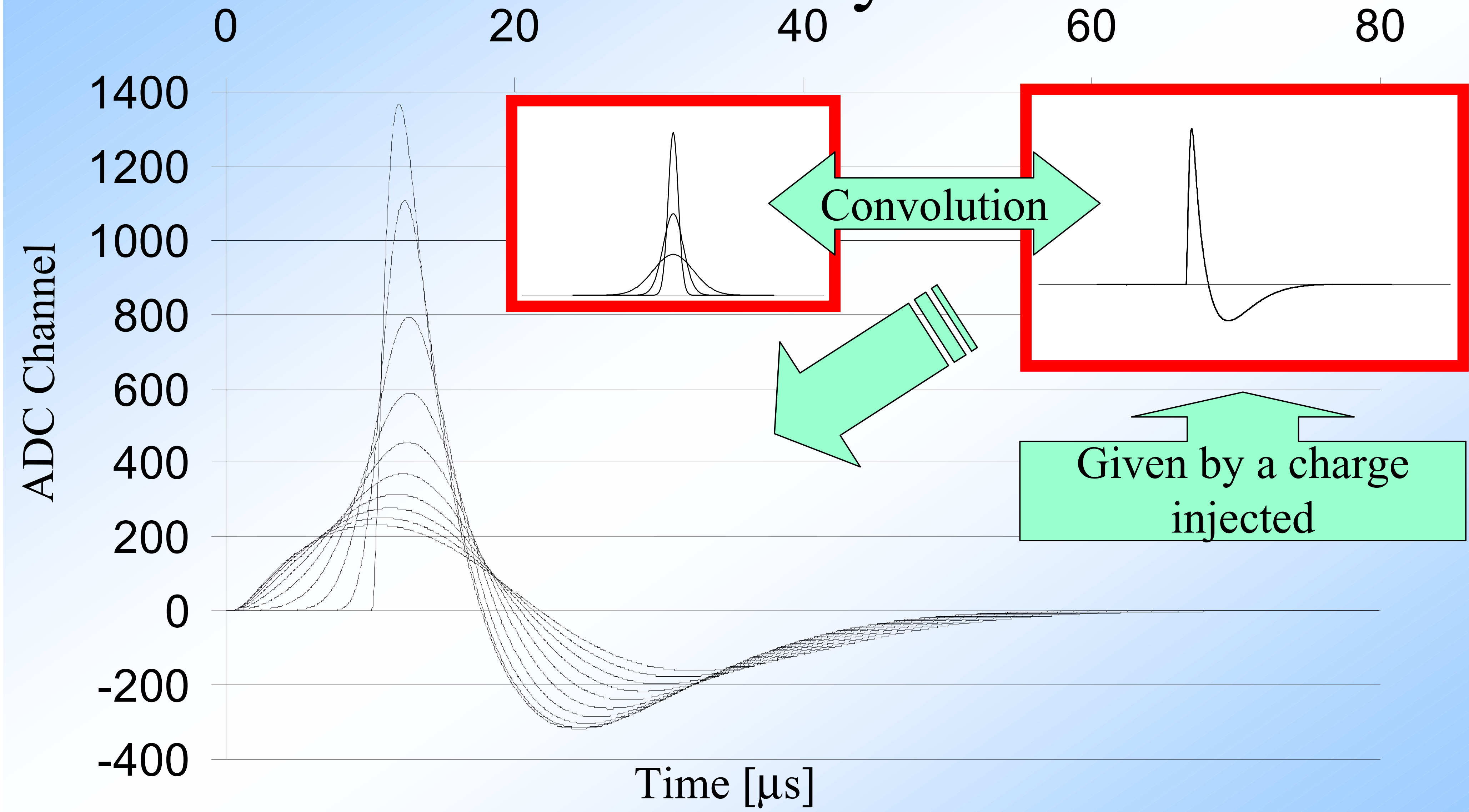
Purity Monitor

Polyethylene

Data Analysis



Data Analysis



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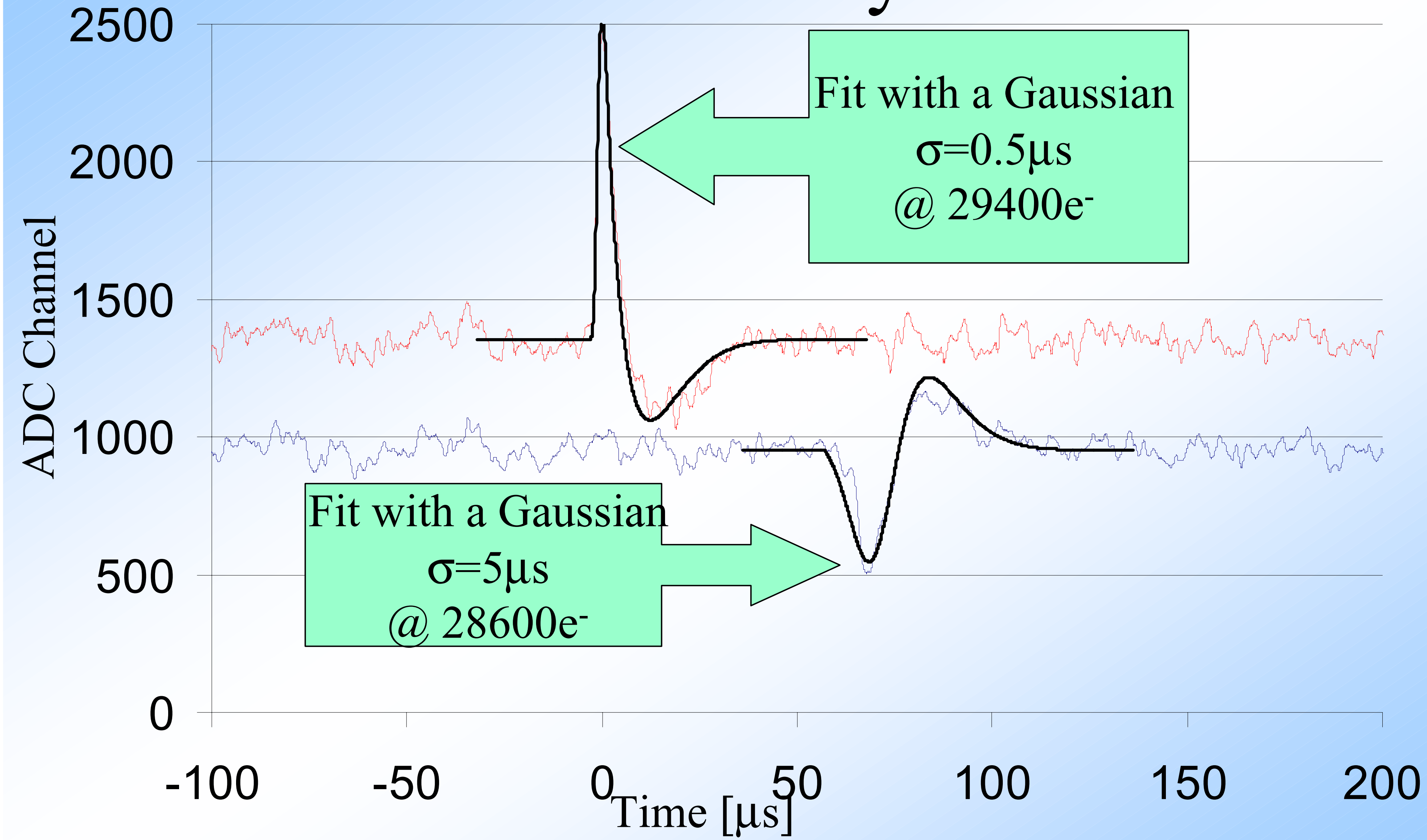

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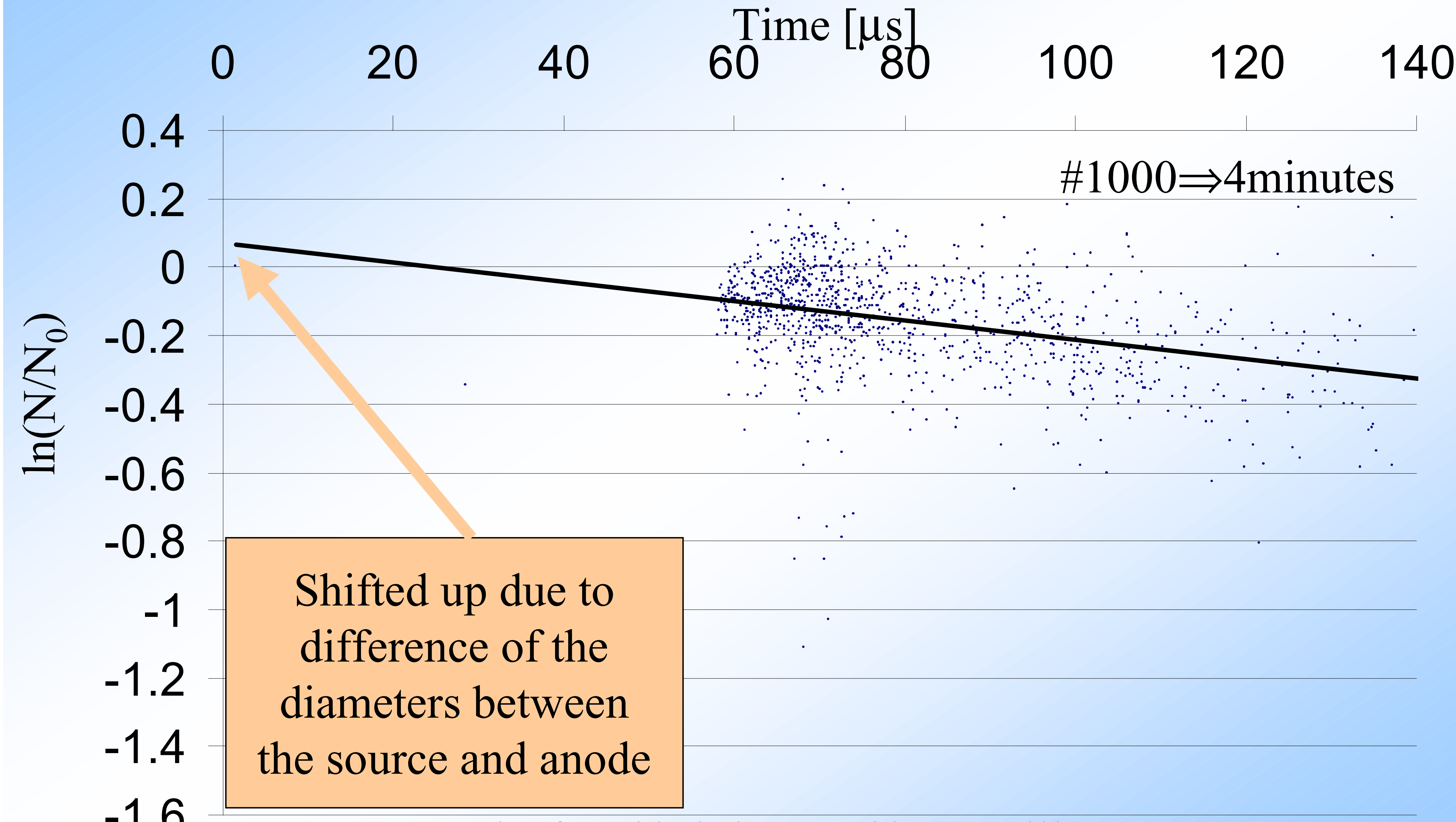

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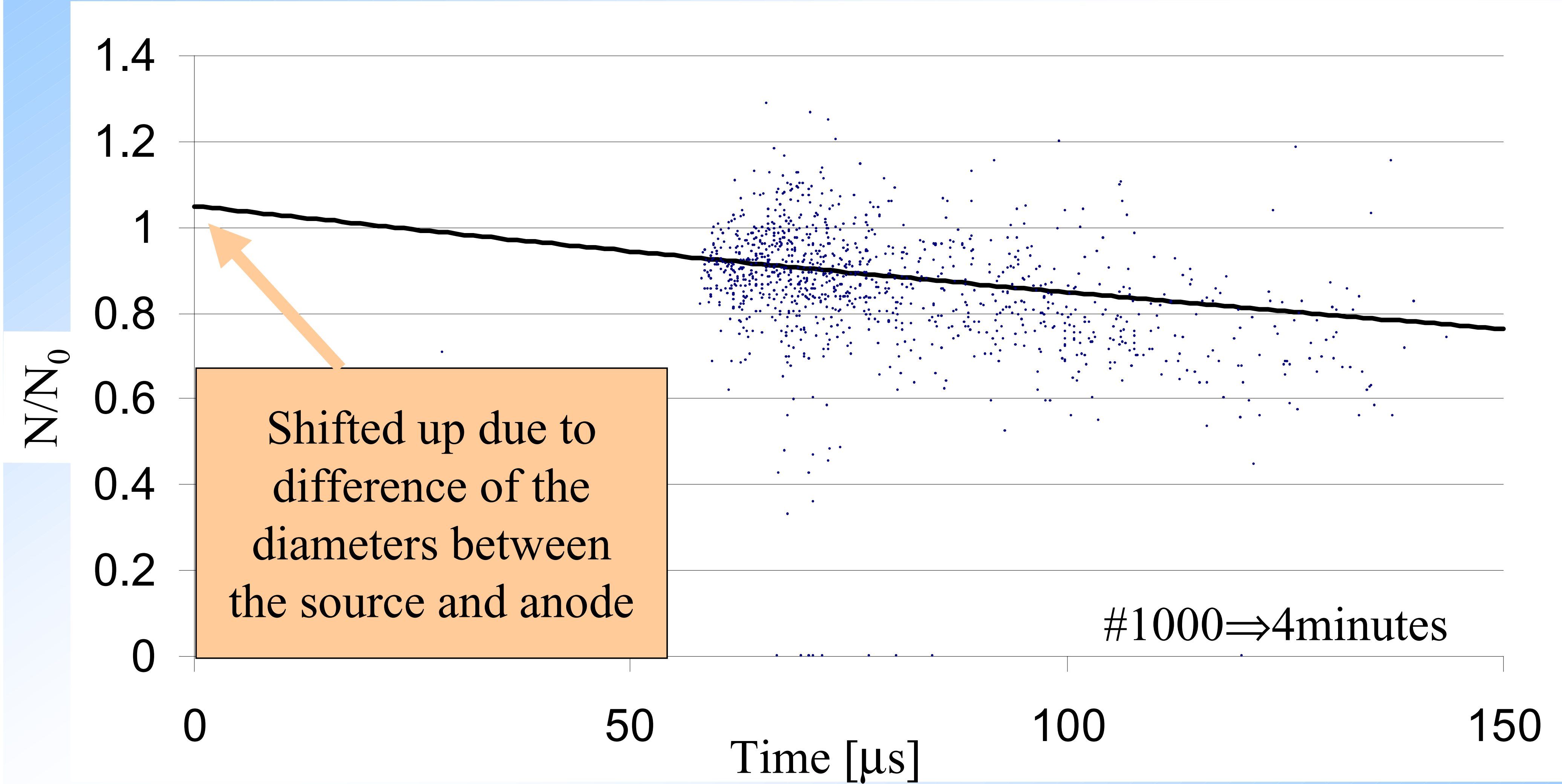

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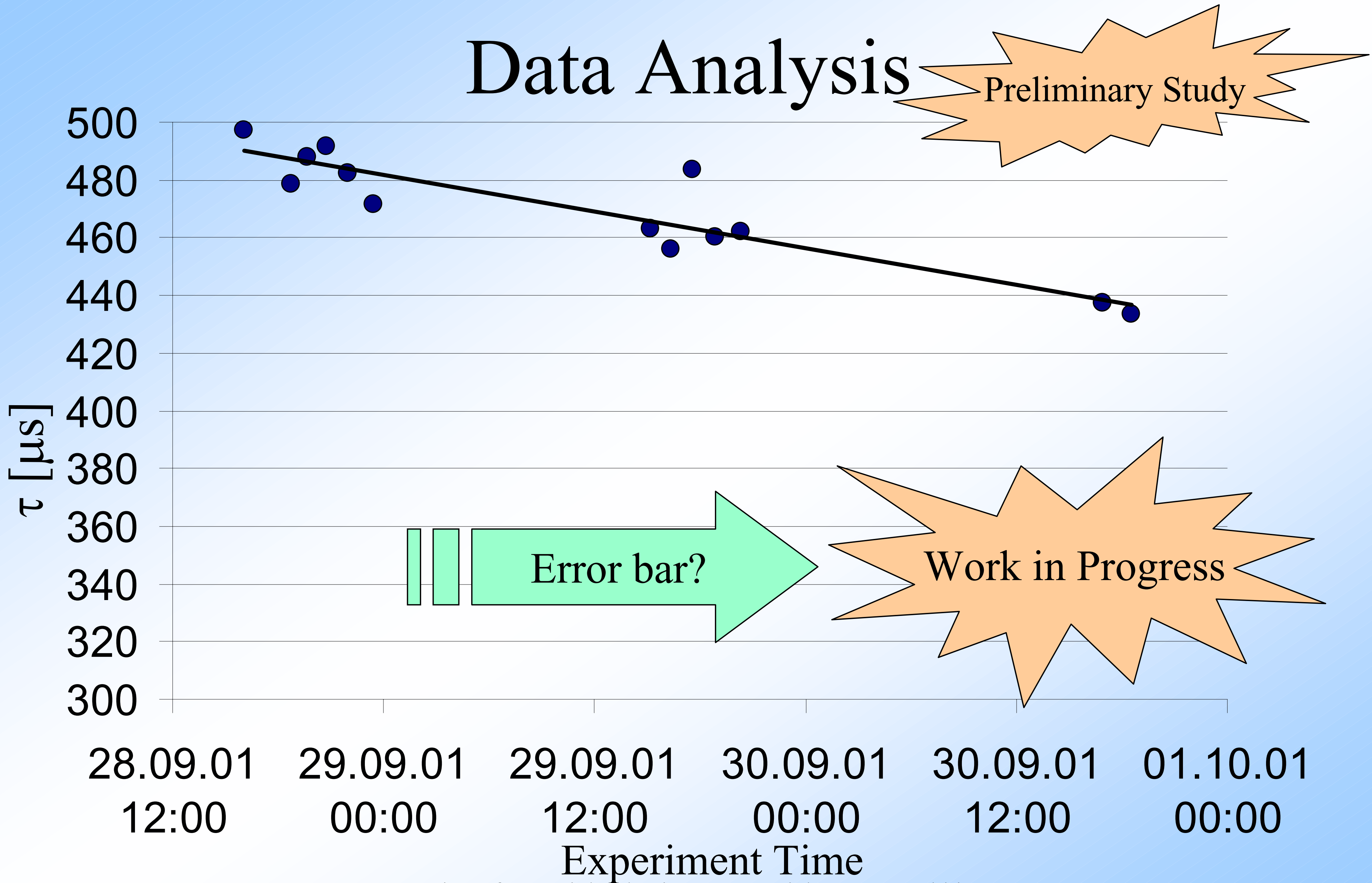

Need for a Purity Monitor

- Long Drift Length Needs Long Drift Time
  - →The LAr should be so pure that almost all electrons produced by the particle arrive at the grid.
    - →Filling and on-line operations will need the information of the LAr purity.
- Signal Correction in the Analysis
  - →The LAr is a fine grain homogeneous calorimeter, it means that the number of free e^- is proportional to the deposited energy.
    - →Off-line analysis will need precise information of the LAr purity

Purity Monitor with Spherical Source