Development of a Single Ion Detector for Radiation Track Structure Studies

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Outline

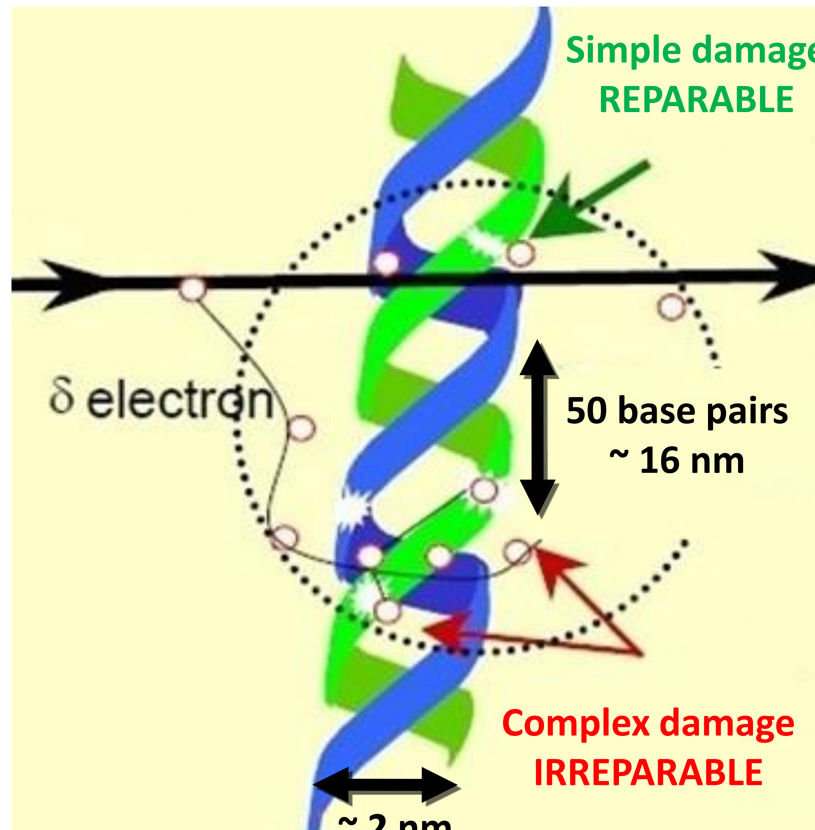
- Purpose
- Detector Working Principle
- First Prototype Characterization
- New Prototype: Thick GEMs From The CERN PCB Workshop
- Measurements With a Microbeam
- Efficiency vs Cathode Resistivity
- Summary & Outlook

Purpose

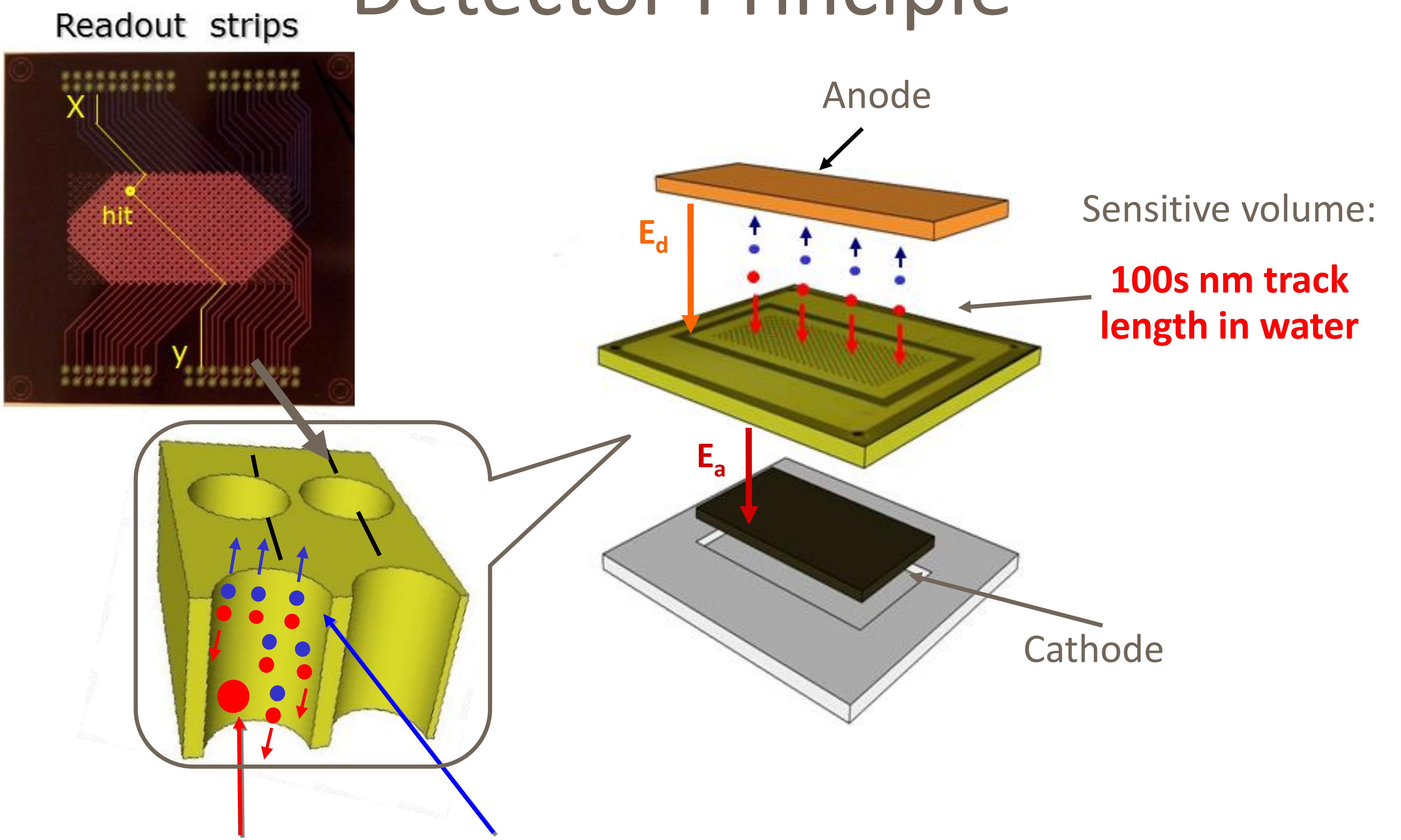
Development of a device for characterization of radiation track structure to study radiation biological effectiveness

Radiation track structure: spatial distribution of energy transfer points in radiation-matter interaction

- Local clustering of energy transfer points, in particular ionizations, is important for the production of initial biological damage
- MC simulations show large ionization clusters induced, in particular, by high LET radiation, which can create complex DNA damages
- Ideal detector should provide information on spatial distribution of ionization events with single ionization resolution



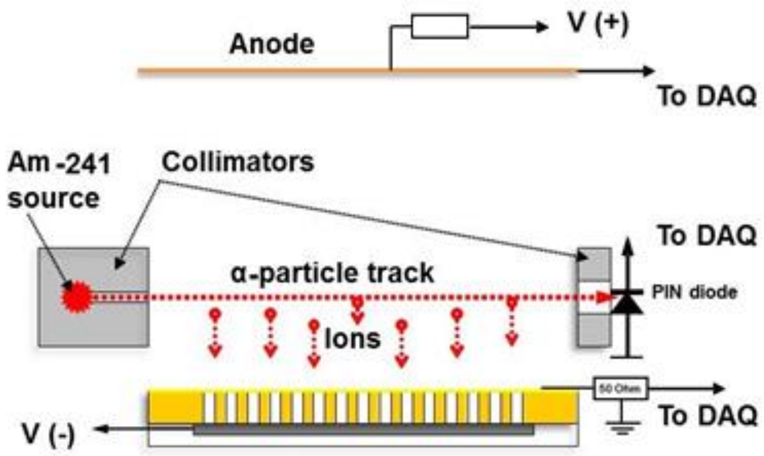
Detector Principle



Primary ion producing ion-impact ionization

Secondary electron avalanche moving towards PCB top surface

First Prototype Characterization



Source:

- Am-241 alphas 2 mm beam

Working gas:

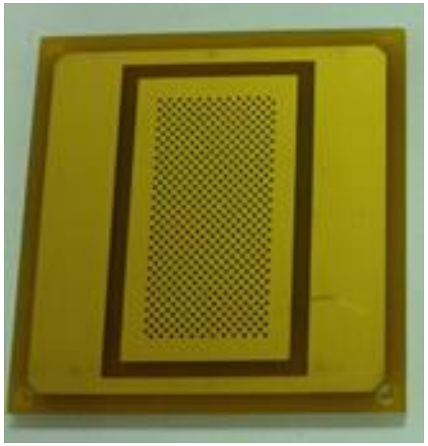
- propane

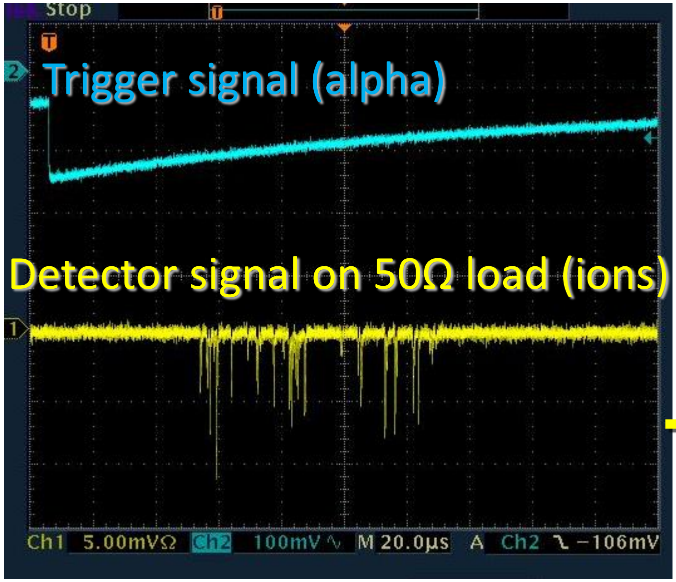
PCB:

- 3.3 mm G10 board with common top electrode
- Holes 0.8 mm, pitch 2 mm

Cathodes:

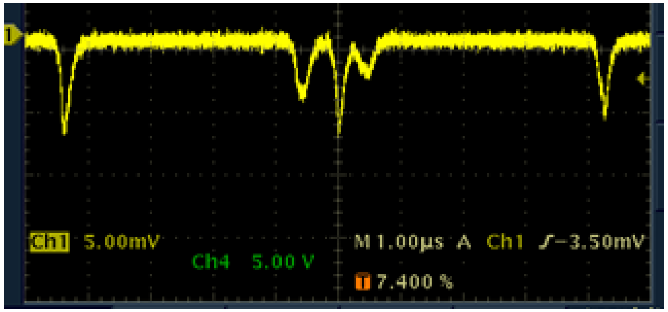
- Float glass
- Schott glass



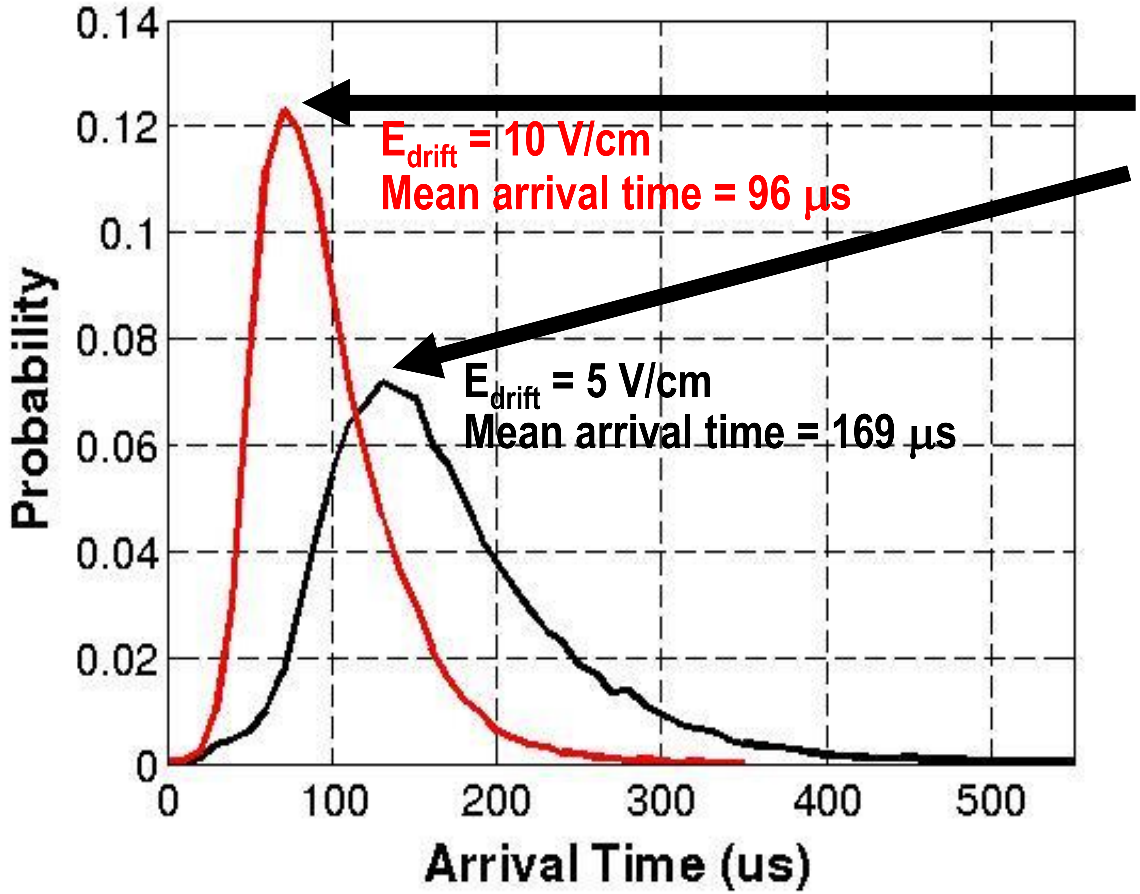


P = 3 mbar
HV = -800 V
E_d = 10 V/cm

Pulse of 5 mV and 500 ns
High gain



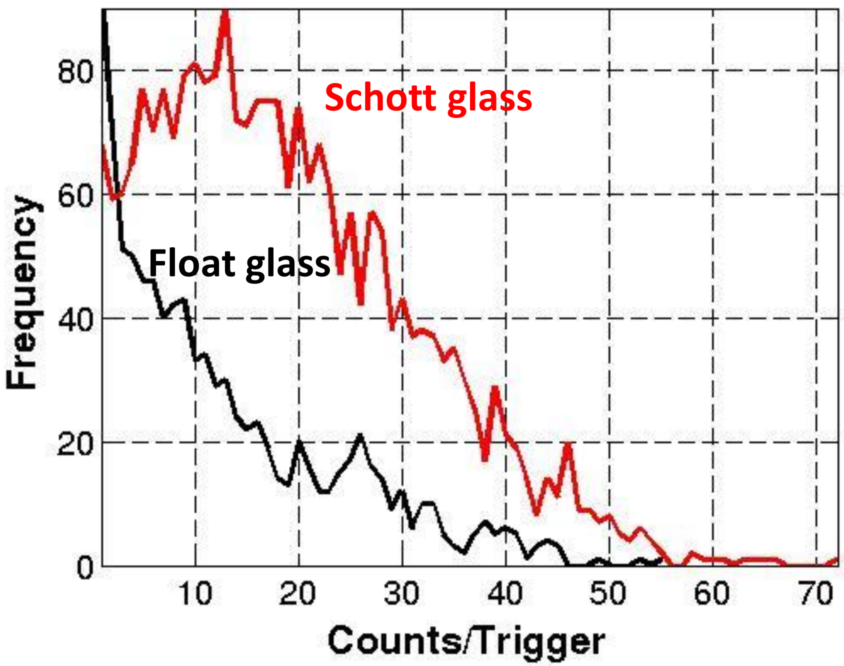
Ion Arrival Time



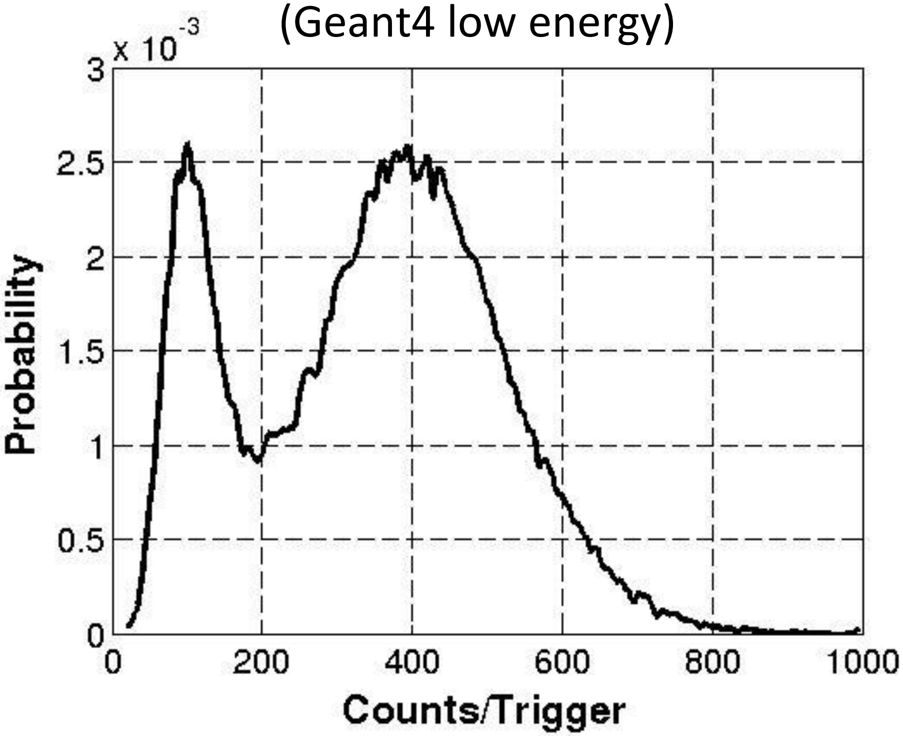
Peak shift confirms the signal comes from the track.

Ion Detection Efficiency

Measured distribution



Simulated distribution
(Geant4 low energy)

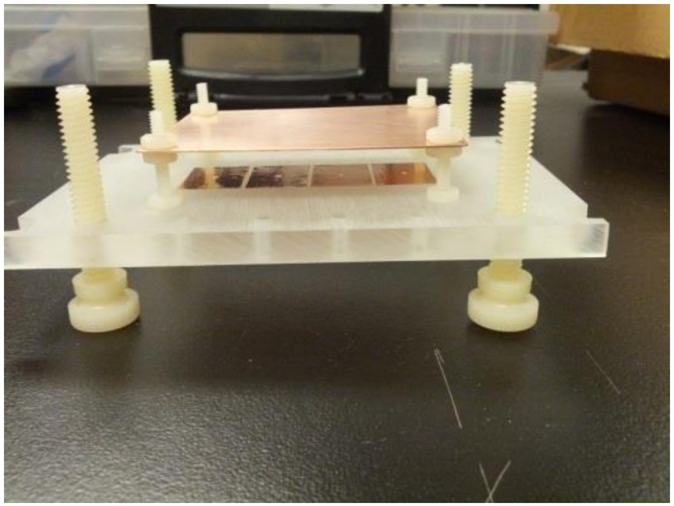


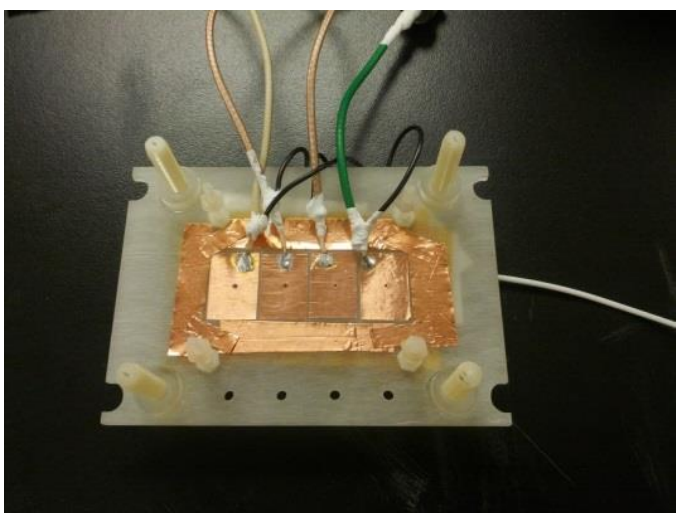
Compared to simulation, very low ion detection efficiency of the order of a few %

Possible causes:

- Long cathode recharge time
- Low ion-impact ionization probability

Thickness of The Dielectric Plate

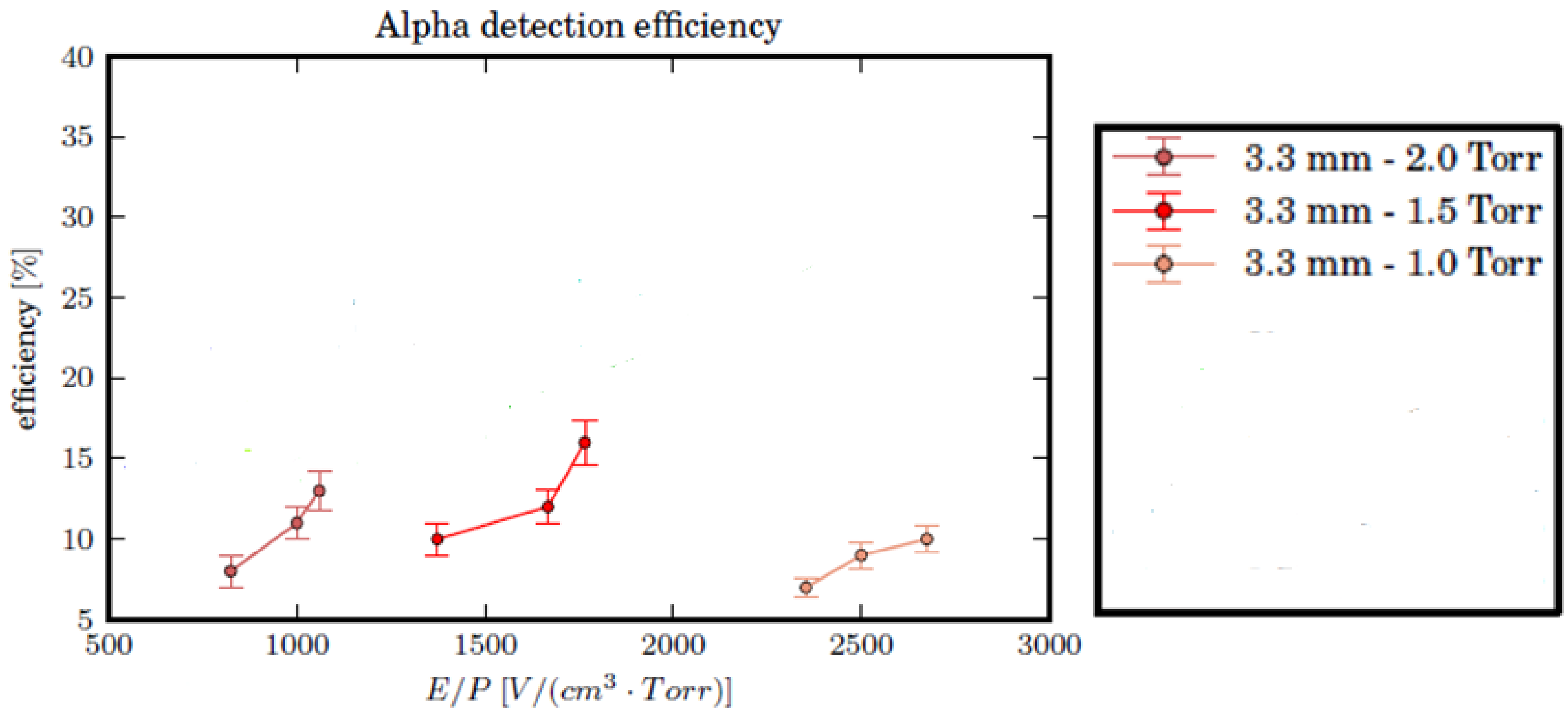




- Three simple versions made of acrylic plates with different thicknesses: 3.3 mm, 6.5 mm, 8.7 mm
- Four holes of 1.5 mm diameter and 10 mm pitch
- Float glass cathode
- Evaluation of alpha detection efficieny vs thickness with an Am-241 source collimated to 3 mm

Alpha Detection Efficiency

Efficiency: % of primaries producing at least one ionization in one of the holes



Alpha Detection Efficiency

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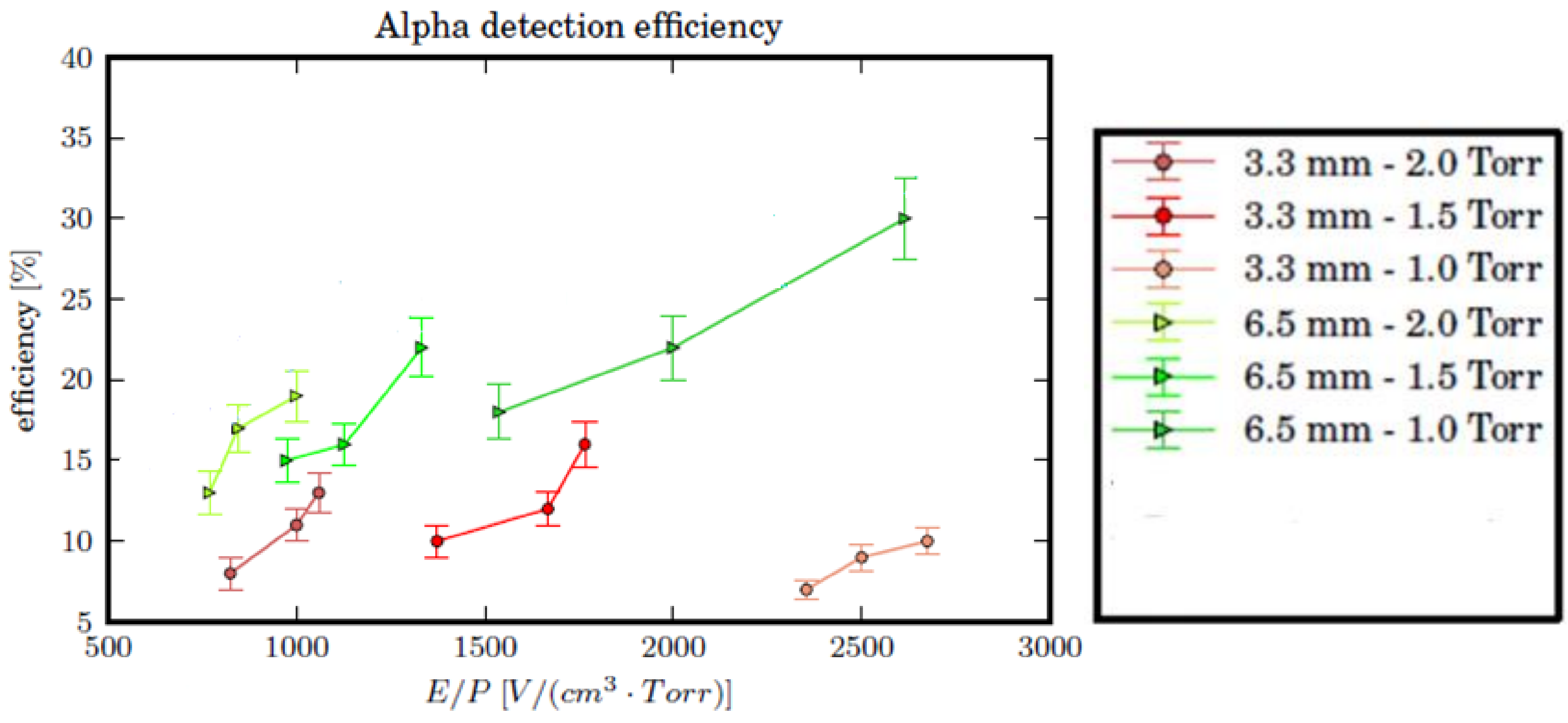

Alpha Detection Efficiency

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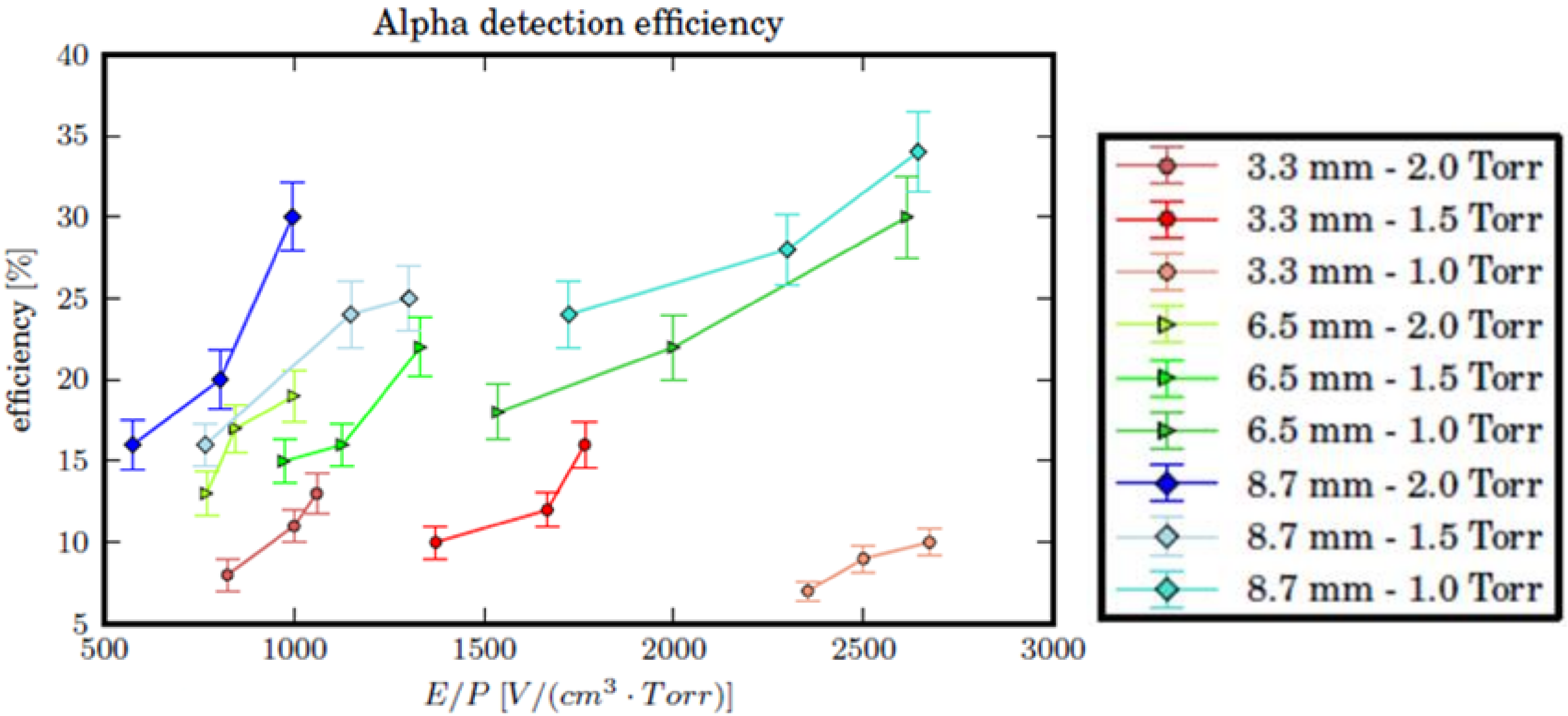
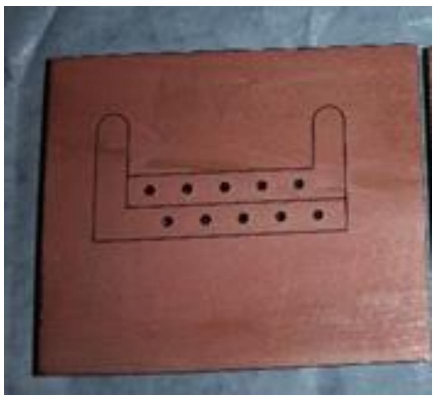


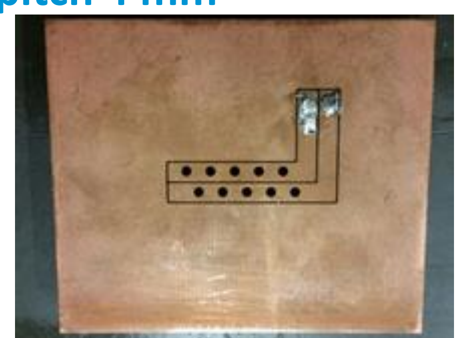
The New Prototype

Thick GEMs from the CERN PCB workshop : FR4 1 cm thick

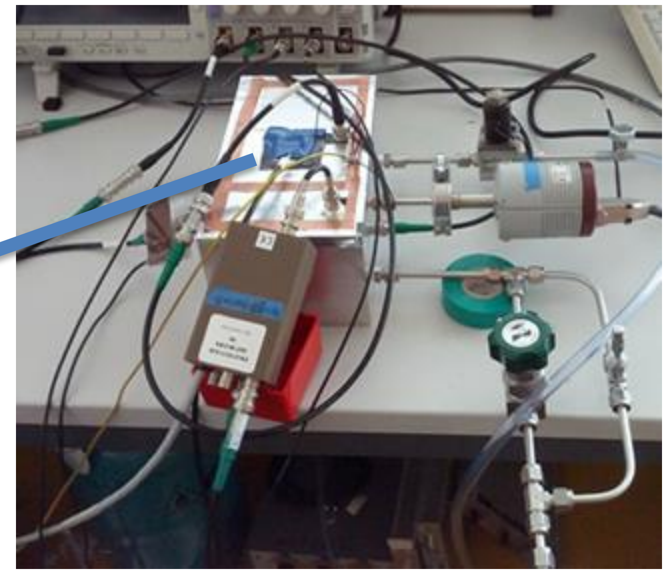
Design 1: 1.5 mm holes, pitch 6 mm



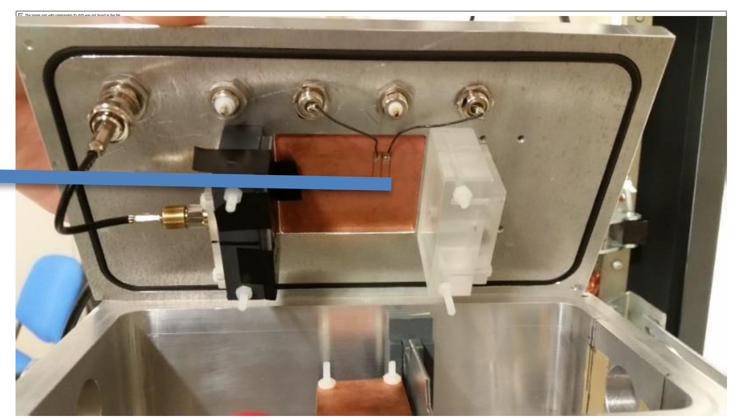
Design 2: 1.5 mm holes, pitch 4 mm



Compact low pressure chamber and gas system

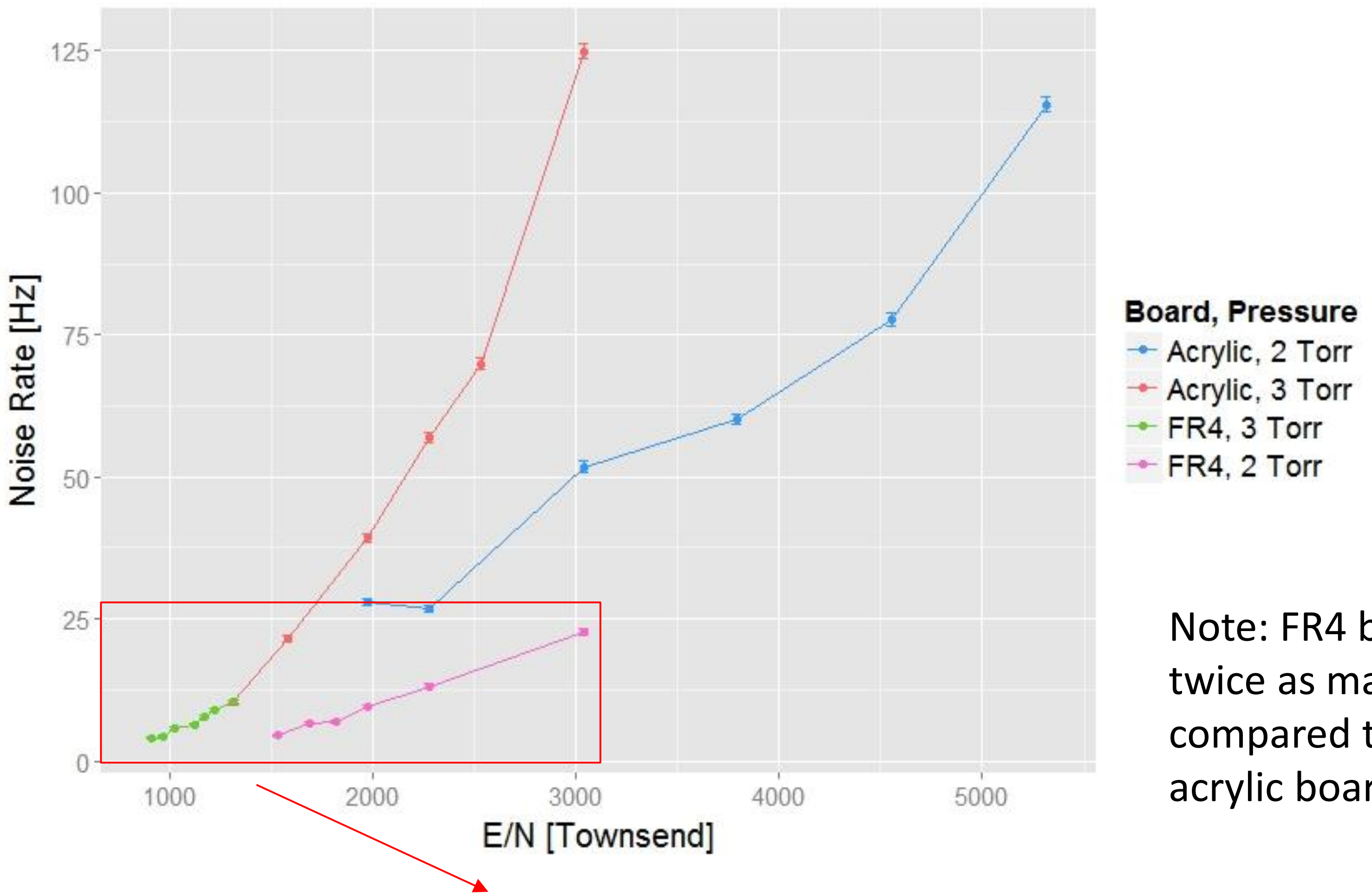


Resistive cathode outside the low pressure volume



THGEM embedded in the chamber lid

Dark Rate: acrylic vs FR4 boards

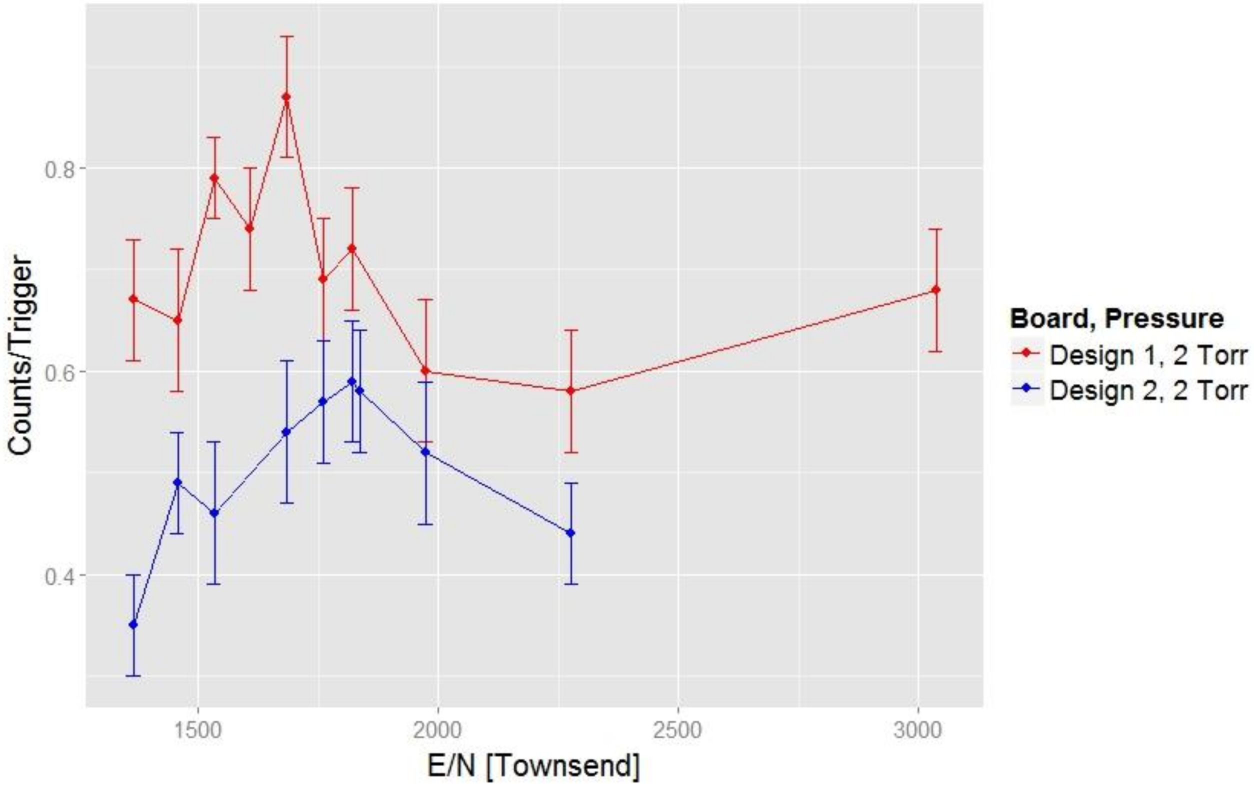


Note: FR4 boards have twice as many holes compared to previous acrylic boards

Reduction of noise with FR4 CERN boards due to better manufacturing technique and, possibly, properties of dielectric material

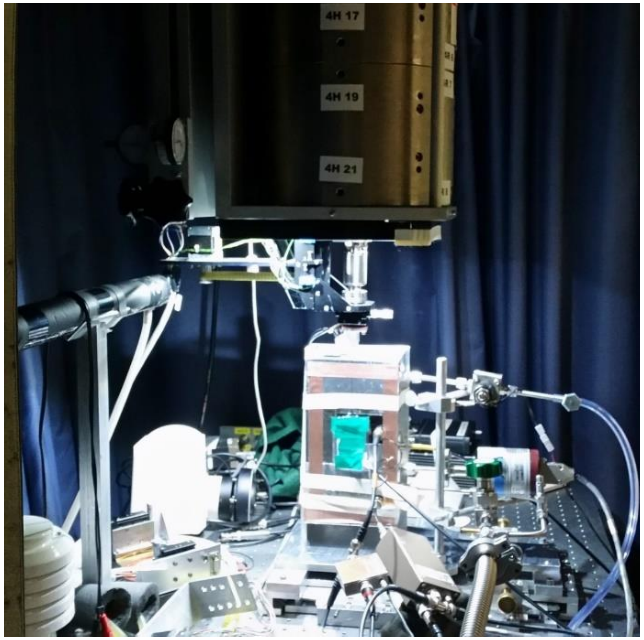
Design 1 (6 mm pitch) vs Design 2 (4 mm pitch)

Mean counts/trigger: mean number of detected ions per primary particle



	Expected counts/trigger at 2 Torr	Expected counts/trigger at 2 Torr (with dead time)
Design 1	10	1.0
Design 2	16	1.5

Measurements at the PTB microbeam



Primaries:

- Protons: 10 MeV
- Alphas: 8 MeV, 20 MeV
- Beam size: ~5 um at the vacuum window
- Primary rate: 6Hz

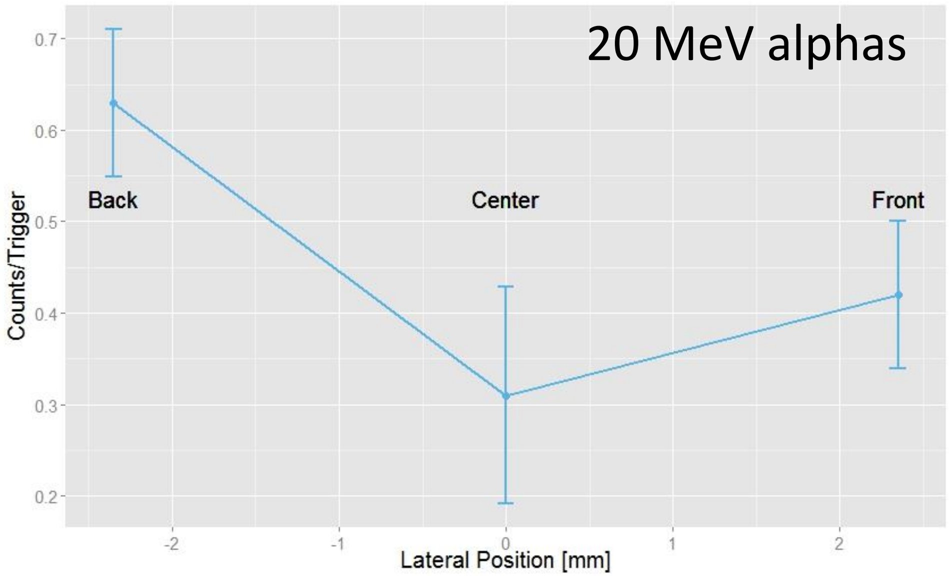
Detector:

- Design 1 board and Schott glass

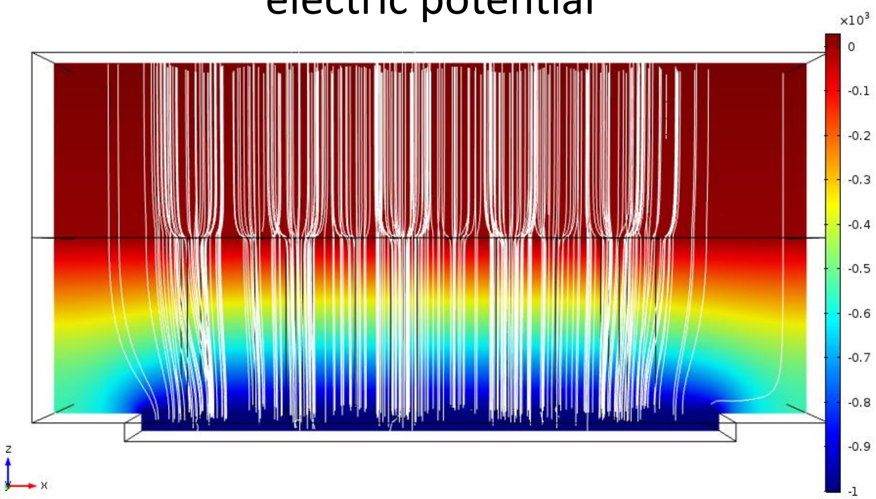
Increasing LET (↑)

	Measured c/t	Expected c/t	Expected c/t with dead time	Ion detection efficiency
Alpha 10 MeV	0.7±0.1	5.3	0.7	13%
Alpha 20 MeV	0.3±0.1	1.1	0.2	27%
Proton 10 MeV	0.06±0.1	0.13	0.02	46%

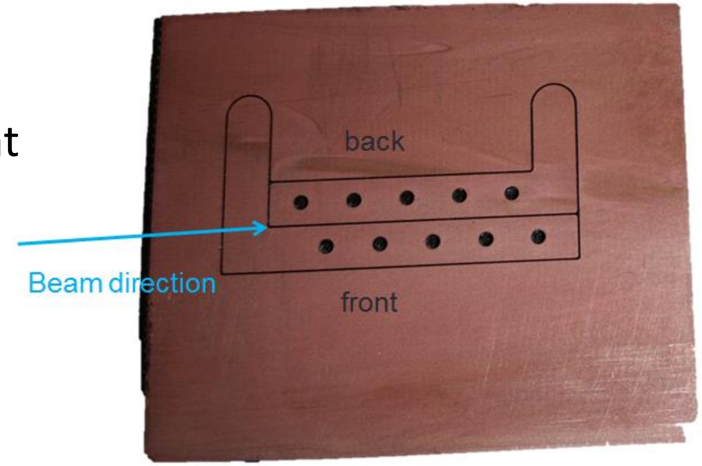
Scan of The Sensitive Area



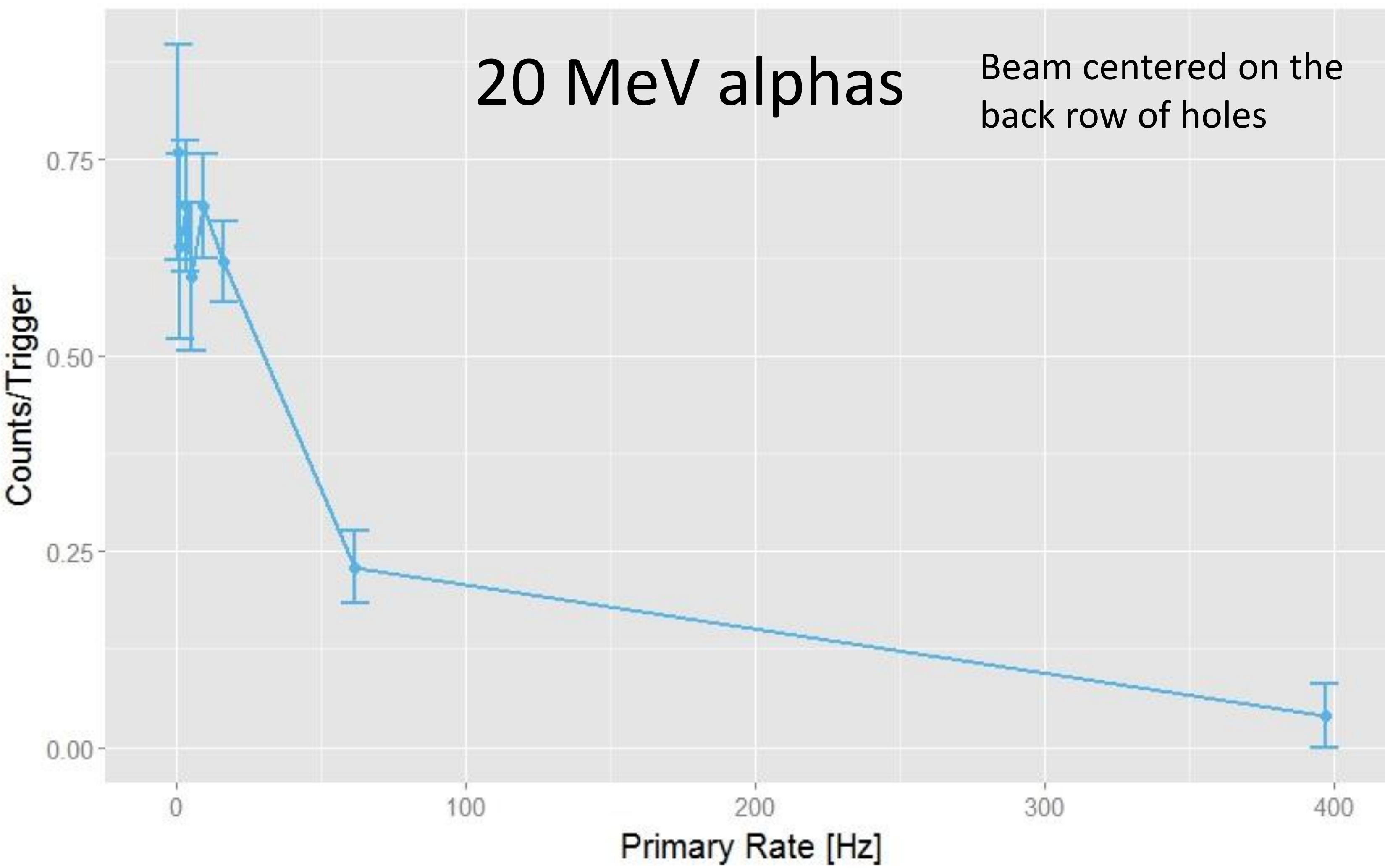
Calculated electric field lines and electric potential



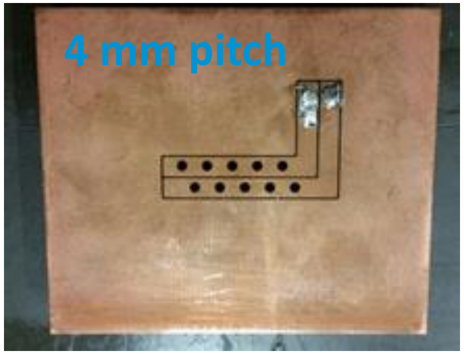
Beam: 2 mm FWHM at center of SV



Efficiency vs Primary Rate



Efficiency vs Cathode Resistivity

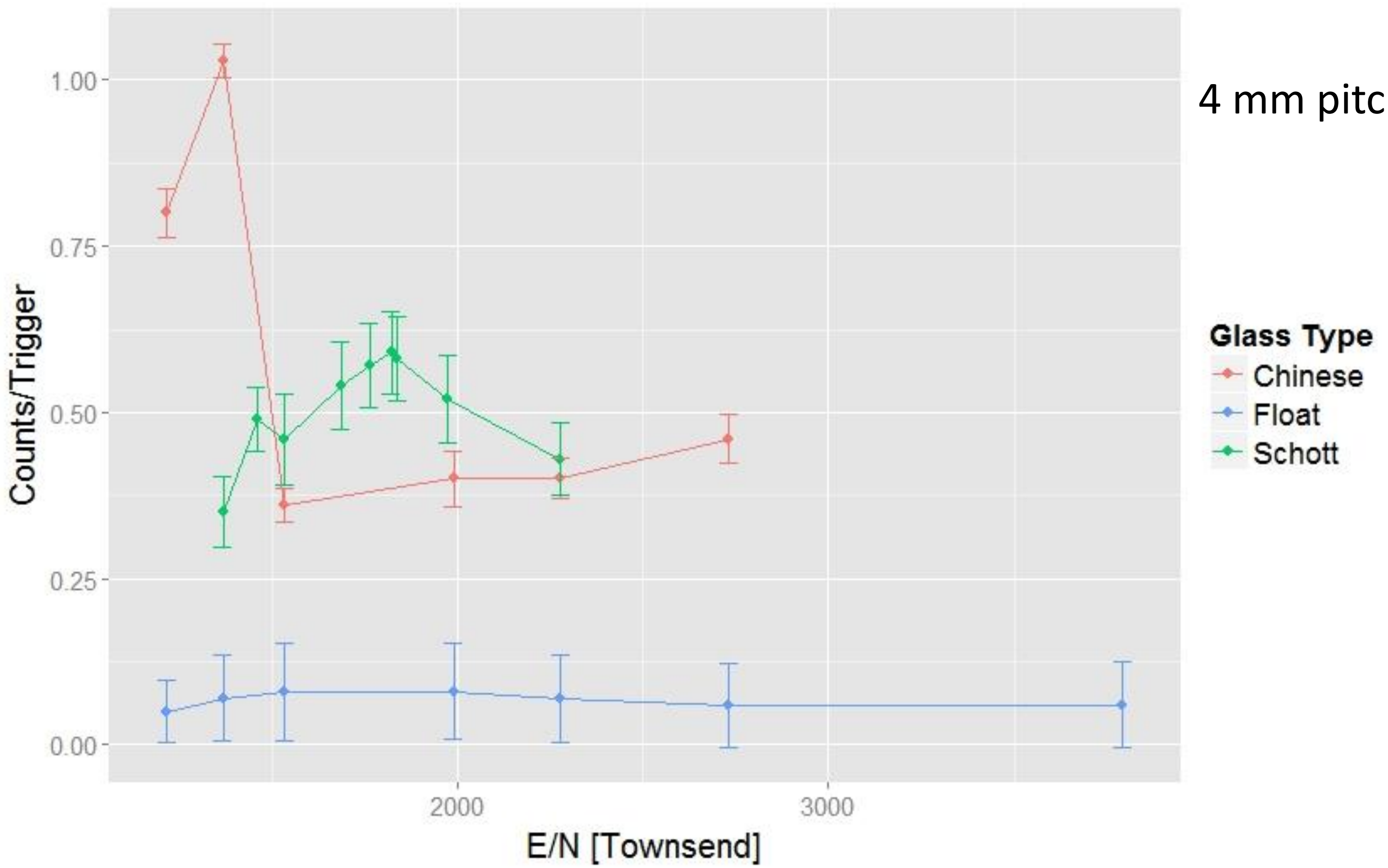


Glass type	Float	Schott	Chinese
Resistivity	10^12 Ωcm	10^11 Ωcm	10^10 Ωcm
Thickness	2 mm	3 mm	1 mm
Alpha detection efficiency	7%	42%	65%

Further Increase With Larger Pitch

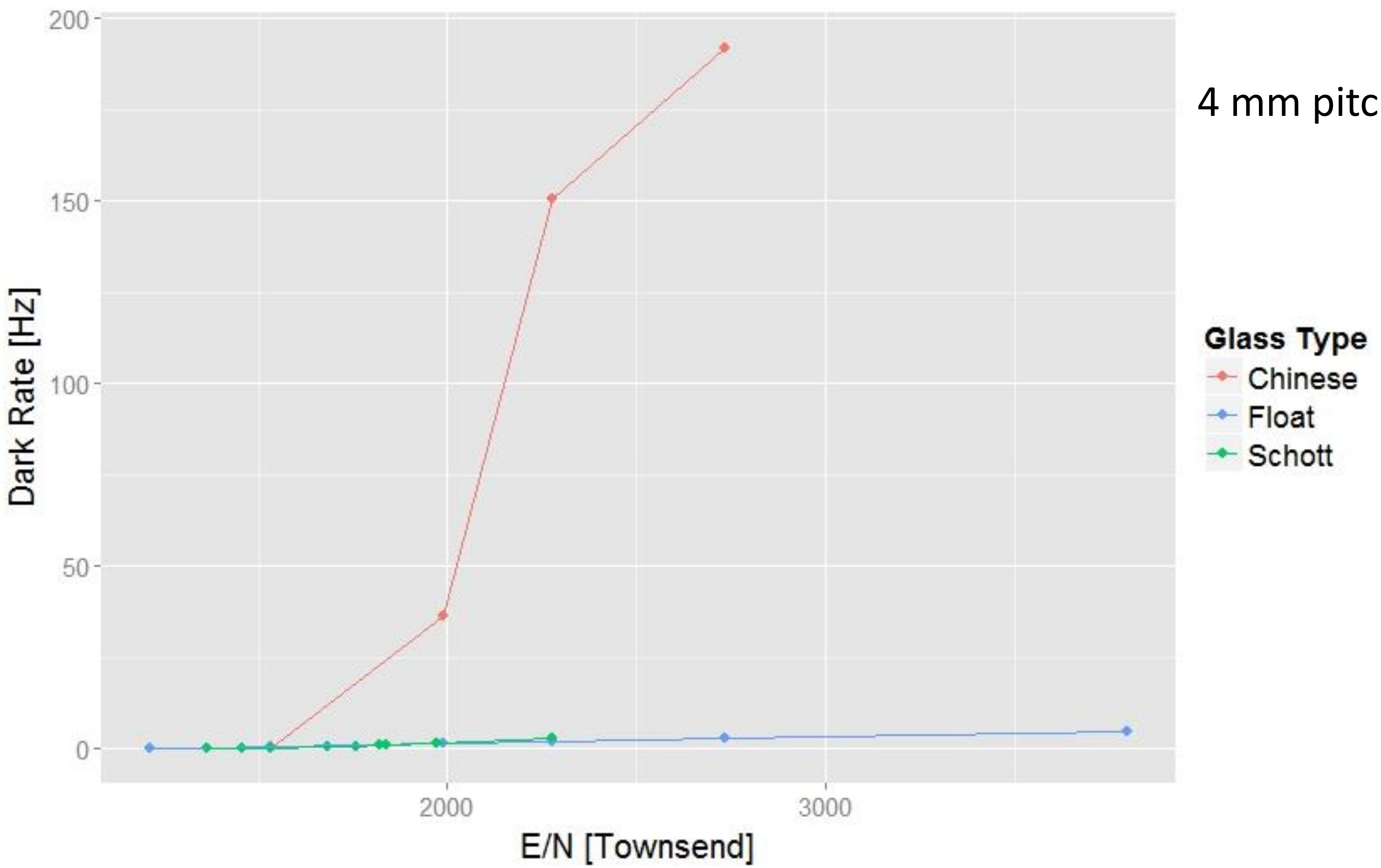
Glass type	Float	Schott	Chinese Pitch: 4 mm	Chinese Pitch: 6 mm
Resistivity	10^12 Ωcm	10^11 Ωcm	10^10 Ωcm	10^10 Ωcm
Thickness	2 mm	3 mm	1 mm	1 mm
Alpha detection efficiency	7%	42%	65%	89%

Counts/Triggers



4 mm pitch

Dark Rate



4 mm pitch

Summary & Outlook

- Ionization events produced in low pressure gas can be detected with single-ion resolution
- The ion detection efficiency can be enhanced and dead time reduced by using thick GEMs (1cm) and by lowering cathode resistivity
- Efficiency needs to be further optimized to reconstruct the 3D spatial distribution of ionization tracks

Main open issues – next steps:

- Optimization of cathode resistivity
- Optimization of cathode design (e.g. resistive paste)
- Charge-up of dielectric material (e.g. use of glass GEM)

Acknowlegements

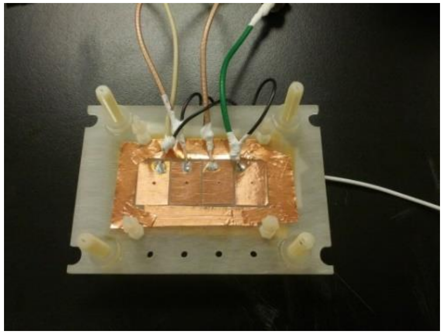
- Gas Detector Development Group at CERN for technical support and advice
- Ulrich Giesen for support of microbeam measurements at PTB

THANK YOU

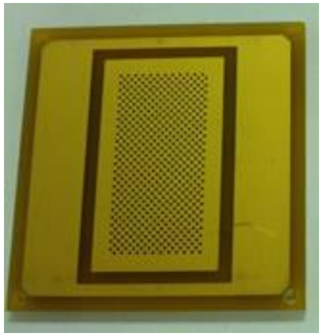
Back up slides

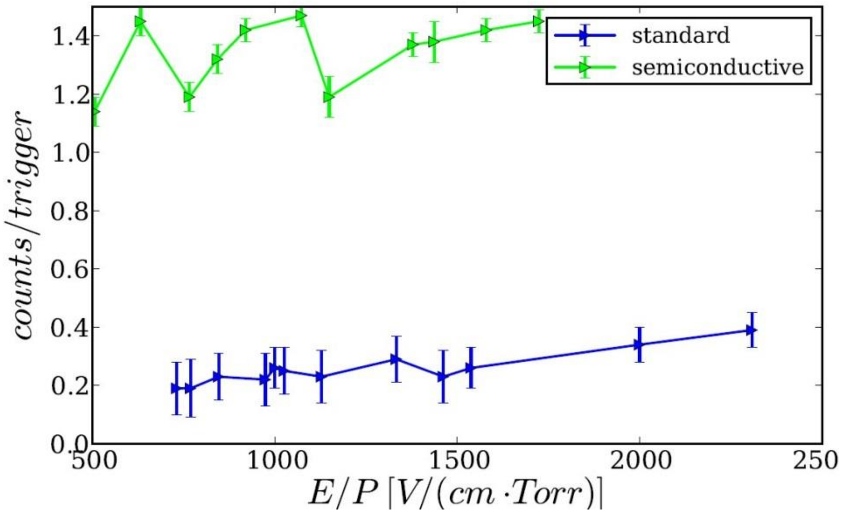
PREVIOUS MEASUREMENTS WITH DIFFERENT CATHODES

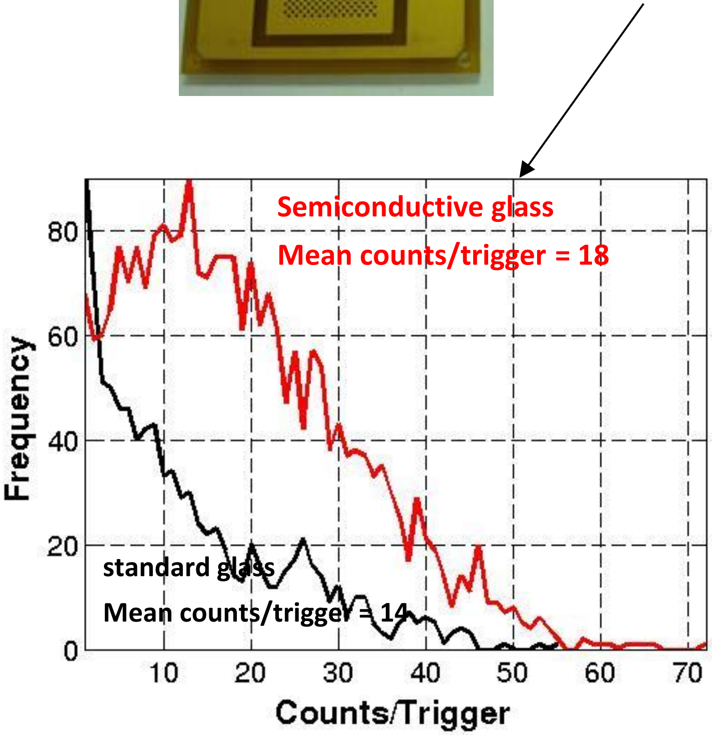
1 hole 1 mm diameter
Board 6.5 mm thickness pitch 1 cm



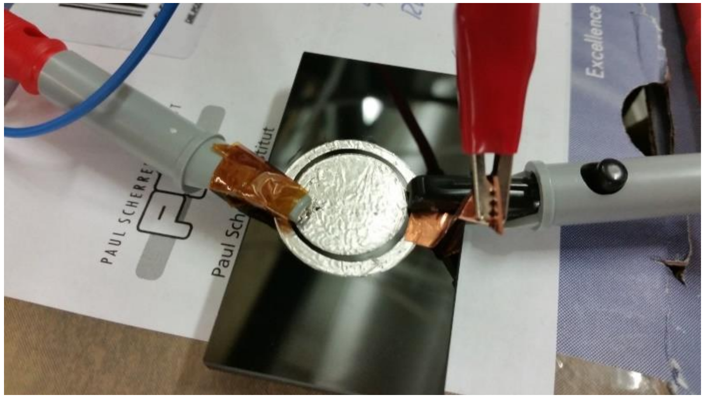
24x24 holes .8 mm diameter
Board 3.3 mm thickness pitch 0.8 mm

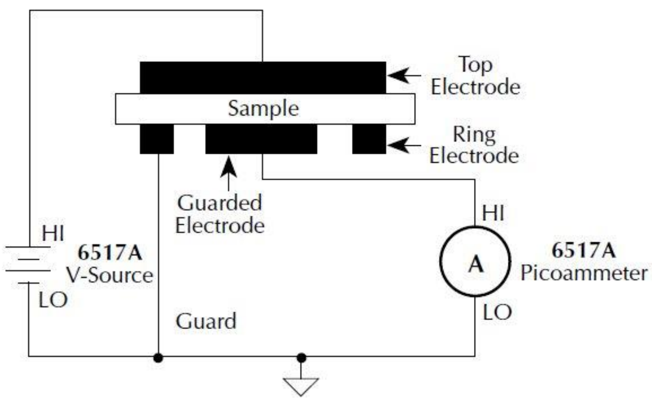




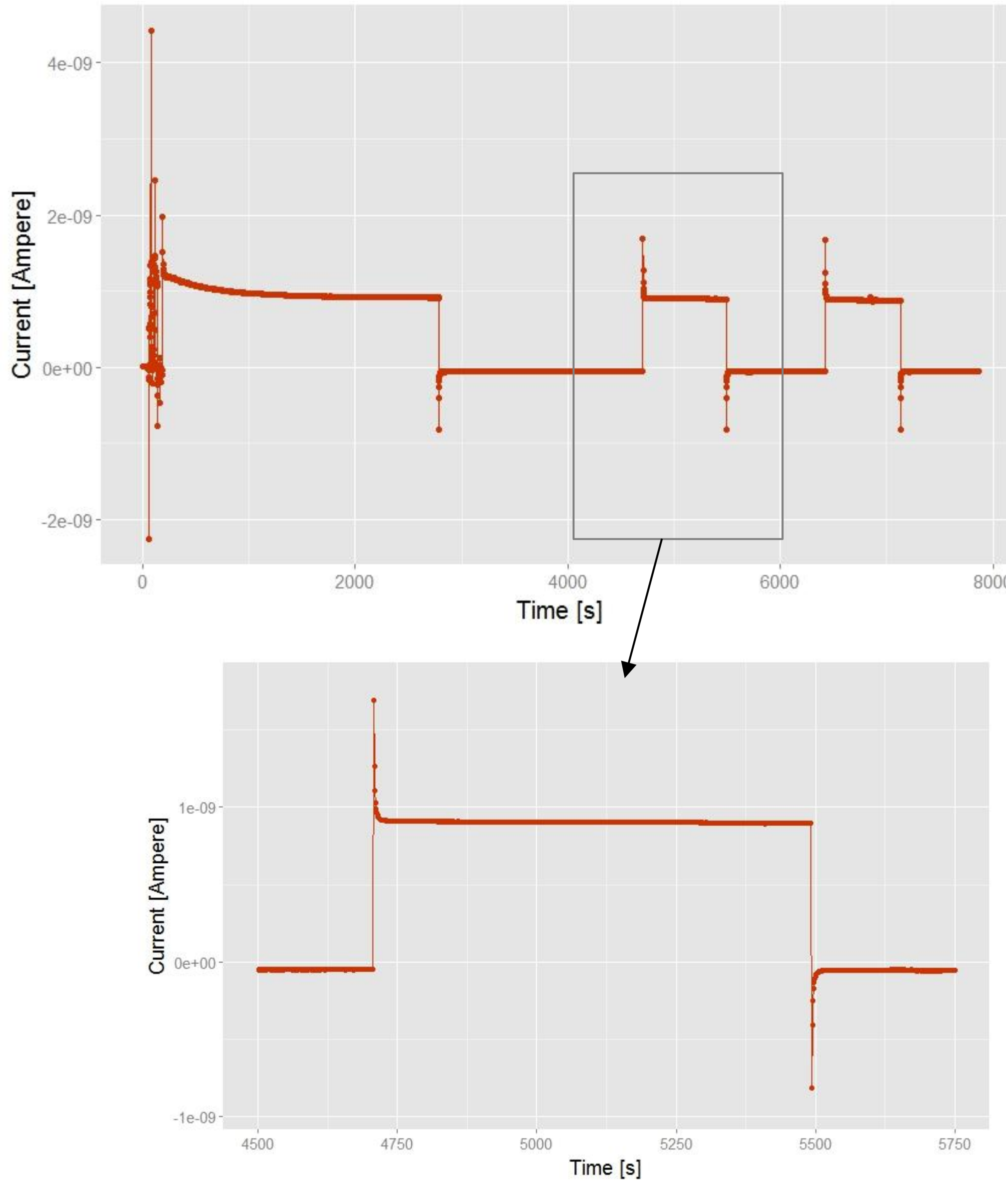


CATHODE RESISTIVITY MEASUREMENTS

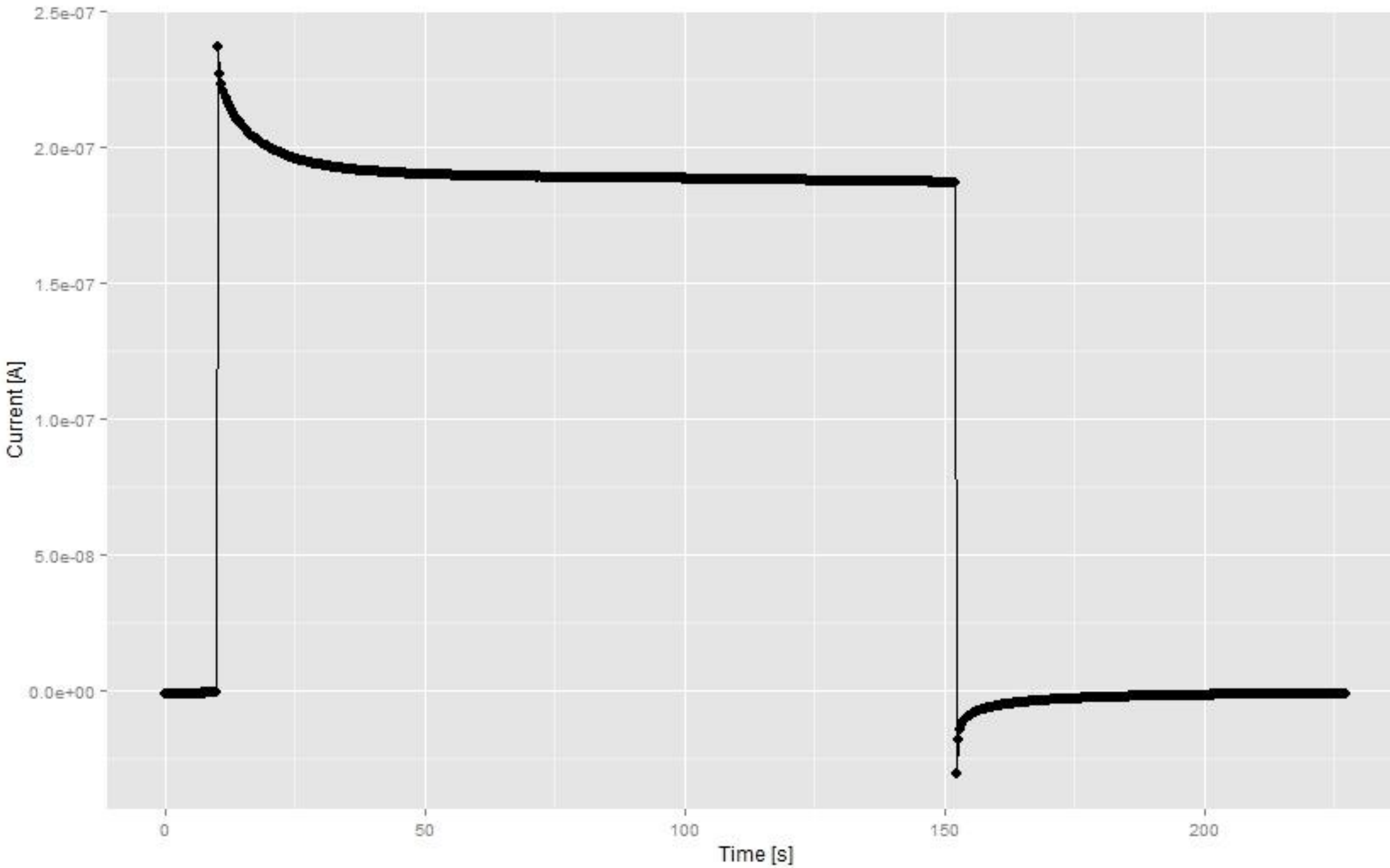




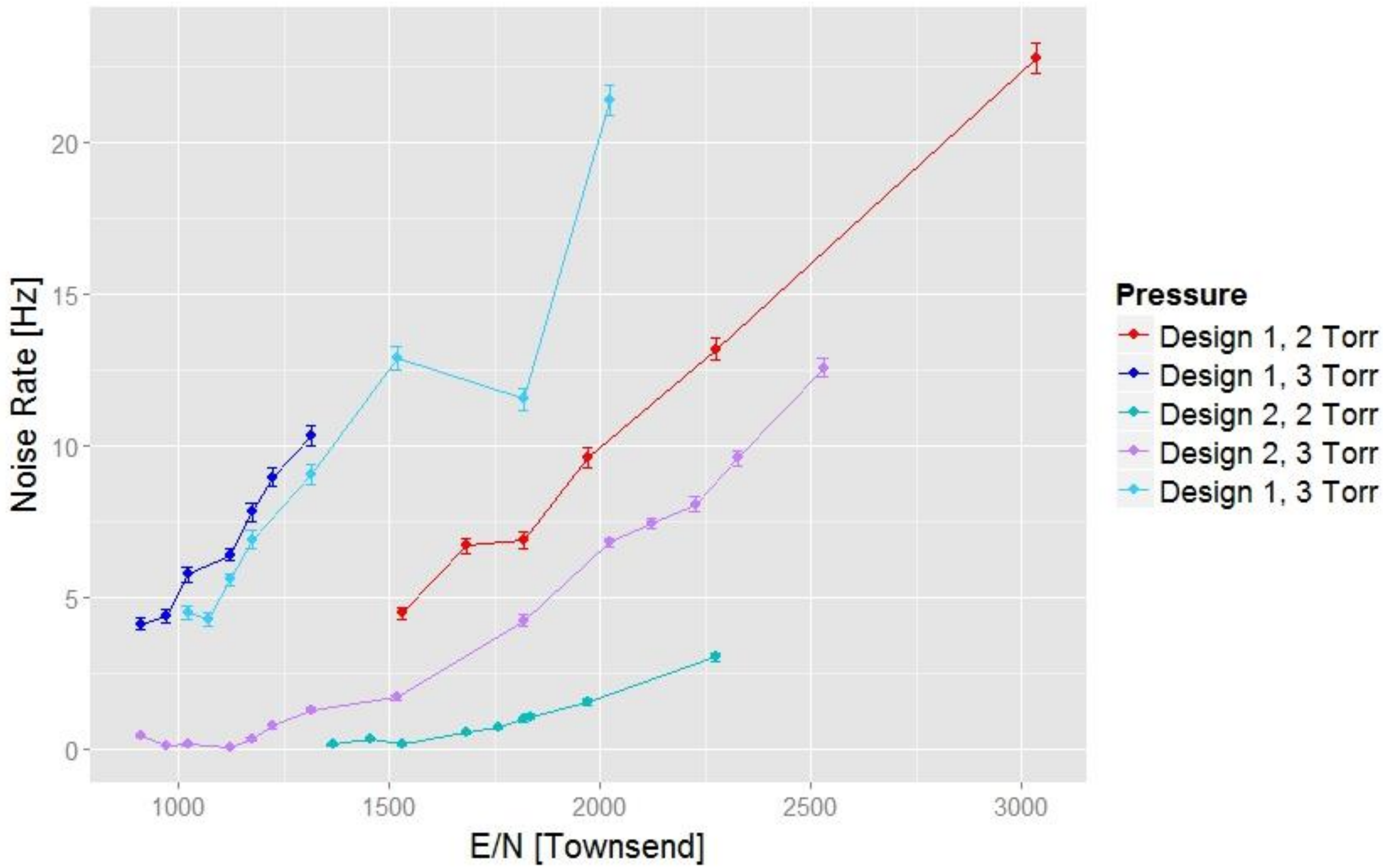
(at 50 Volts)	A= 279.7 mm^2
$\rho(10^{12})$ [Ωcm]	0.53 ± 0.2



Chinese Glass



Dark Rate



Noise Rate [Hz]
20
15
10
5
0
1000
1500
2000
2500
3000
E/N [Townsend]
Pressure
Design 1, 2 Torr
Design 1, 3 Torr
Design 2, 2 Torr
Design 2, 3 Torr
Design 1, 3 Torr