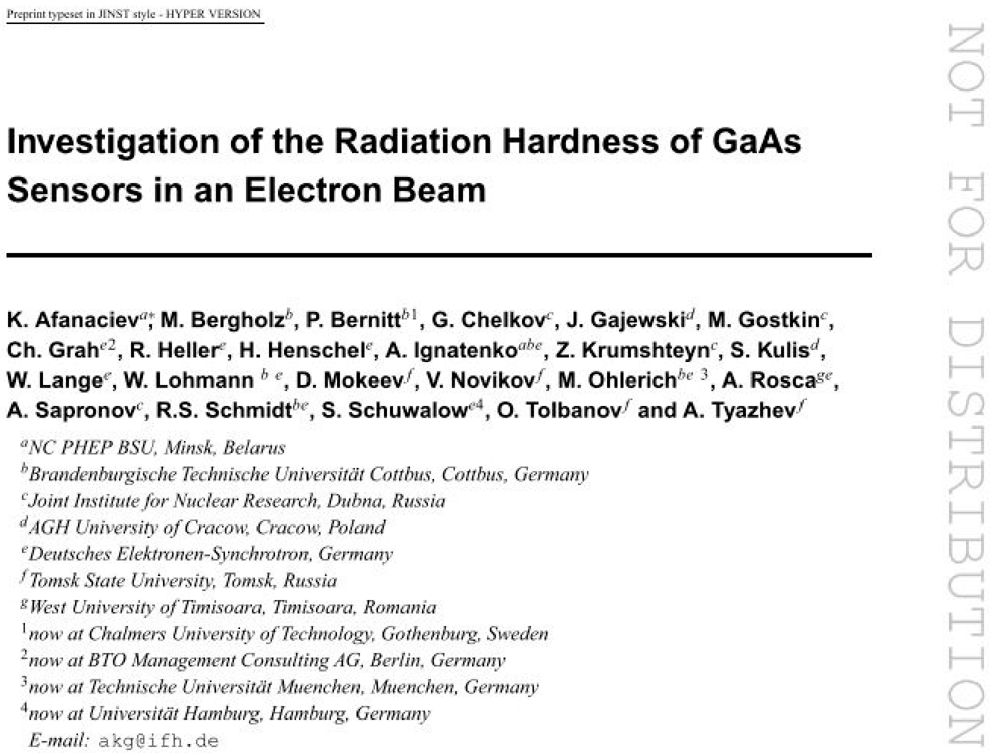
Summary of GaAs detectors properties

K. Afanaciev

FCAL collaboration meeting
CERN, 2012

GaAs paper



Investigation of the Radiation Hardness of GaAs Sensors in an Electron Beam

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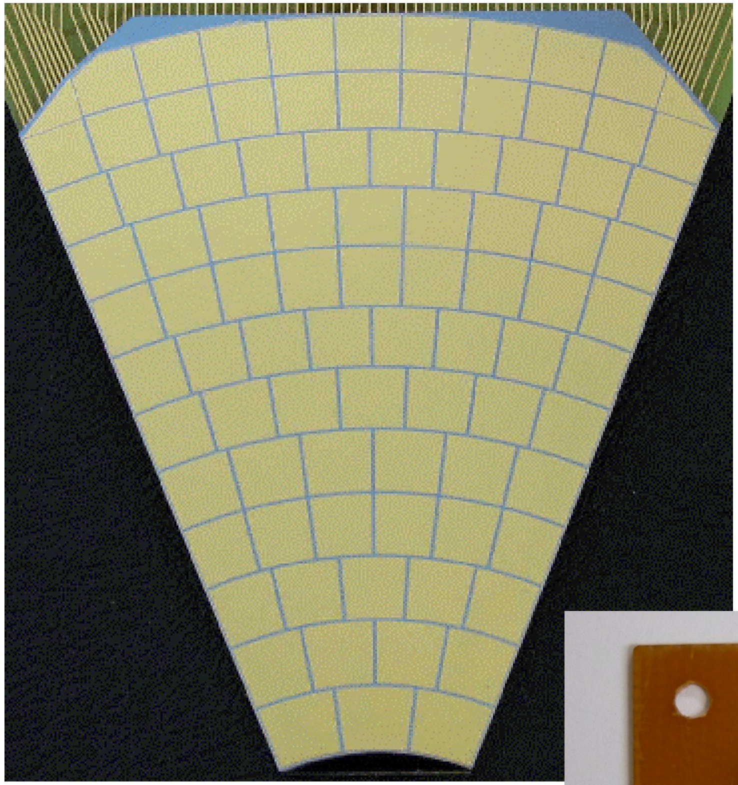
The paper is accepted for publication in JINST

It took 3 years and 3 revisions

It summarizes results from Testbeams 2007 and 2008

Detectors

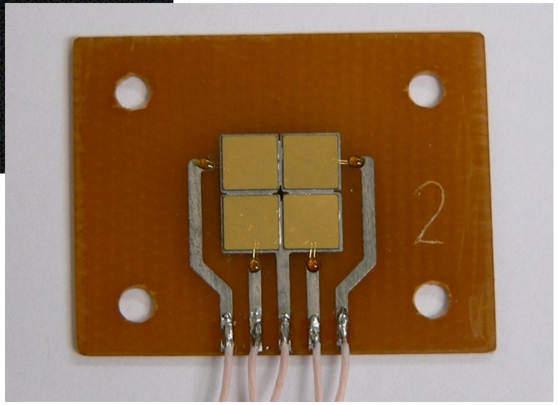
Developed and produced in Tomsk, supplied by Dubna



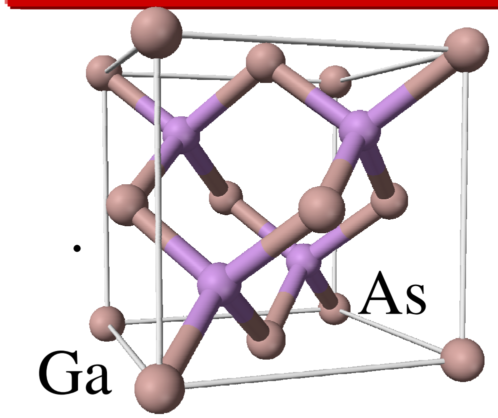
~ 6.5 cm heigth, ~ 6 cm base
500 µm thickness

30 nm V + 1 µm Au metallisation

Segmentation defined by metallisation



GaAs Detector Material



Gallium arsenide (GaAs)

Compound semiconductor, direct bandgap
Two sublattices of face centered cubic lattice
(zinc-blende type)

GaAs grown by Liquid Encapsulated Czochralski (LEC).
doped by Te or Sn (shallow donor) to fill EL2+ trapping centers.
Compensated by Cr (deep acceptor) to high-ohmic intrinsic type material.
Compensation by thermal diffusion

$$N_{cr} > N_{d} > N_{def}$$

	GaAs
Density	5.32 g/cm^3
• Pair creation E	4.3 eV/pair
• Band gap	1.42 eV
• Electron mobility	8500 cm^2/Vs
Hole mobility	400 cm^2/Vs
• Dielectric const.	12.9
• Radiation length	2.3 cm
Ave. E_{dep}/100 µm (by 10 MeV e^-)	70 keV
Ave. pairs/100 µm	16000
• MPV E_{dep} (MIP)	56 keV

Described in “GaAs as a material for particle detectors”
DOI:10.1016/S0168-9002(02)01455-9

Should really check these numbers once more

Charge transport

Due to the nature of material doping the signal charge is transported by electrons (low hole mobility and lifetime - due to compensation)

This means maximum CCE is ~ 50%
Still the average collected charge for MIP is ~ 7500 e (9200 e for Si)

This also means that material can't be used for example for γ-spectrometry as the signal size depends on on the interaction depth

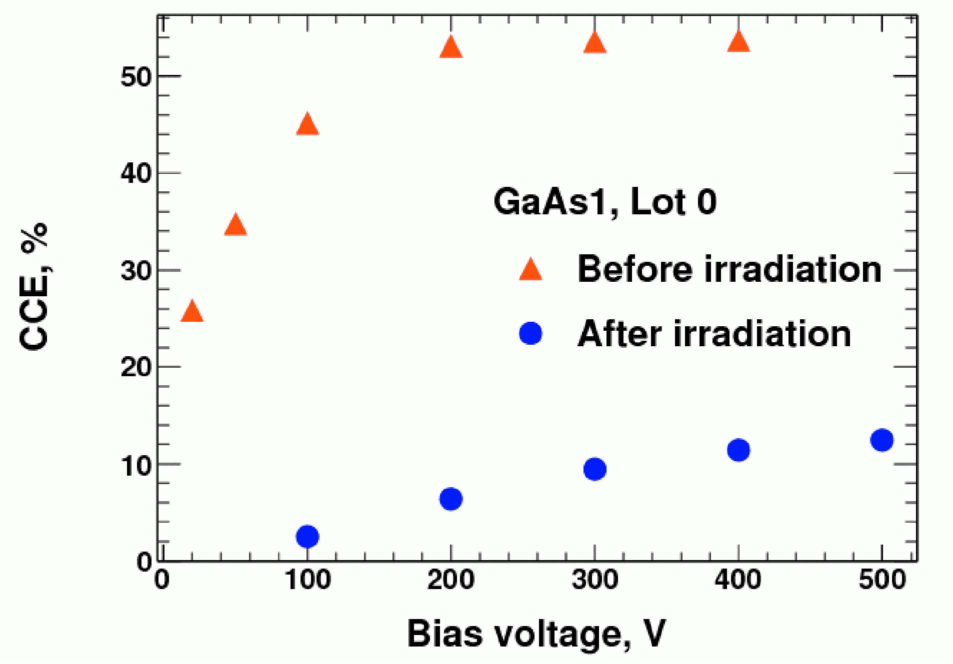
This was checked with α-source measurements.

Described in detail in "GaAs resistor structures for X-ray imaging detectors"
DOI 10.1016/S0168-9002(02)00951-8

Detector structure

Semi-insulating material => **NO** p-n junction => No $V_{\text{full deplition}}$
=> Resistive behavior (similar to diamond)
$\Omega \sim 10^9$ ohm cm => Typical resistance ~ 0.3 GΩ (5x5x0.5 mm pad)

No $V_{\text{full deplition}}$ but there is a saturation of CCE

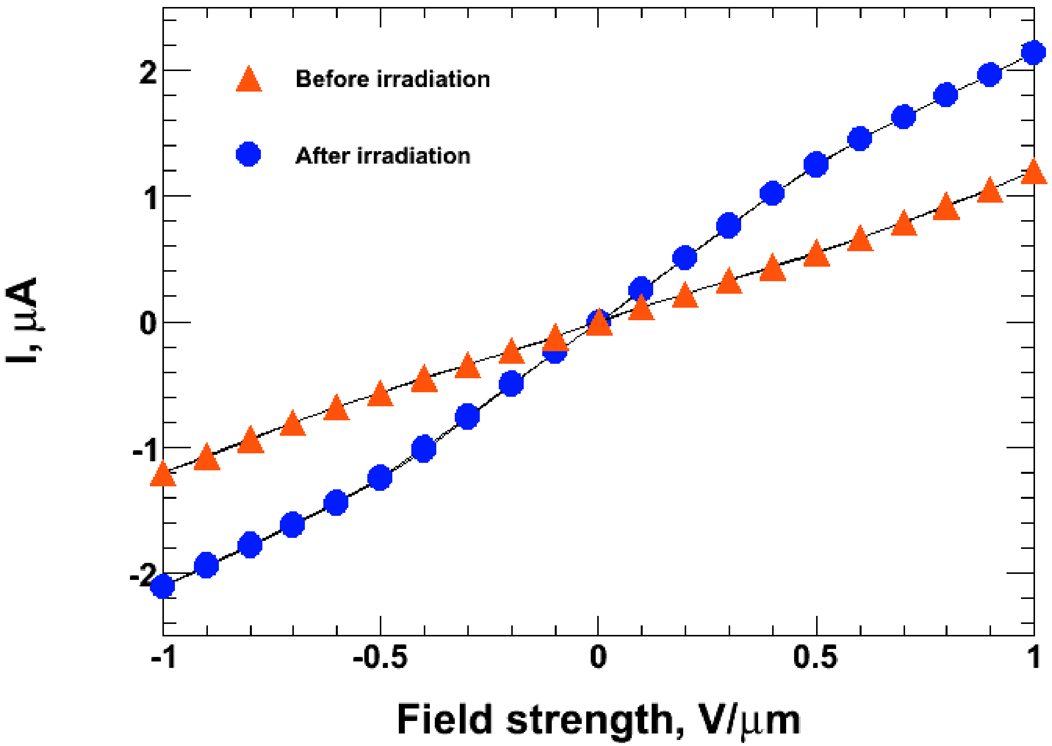


CCE saturates @ 0.2-0.4 V/um

For irradiated samples $V_{\text{saturated}}$ is higher

If we go for GaAs sensors this should be investigated systematically

I-V characteristics

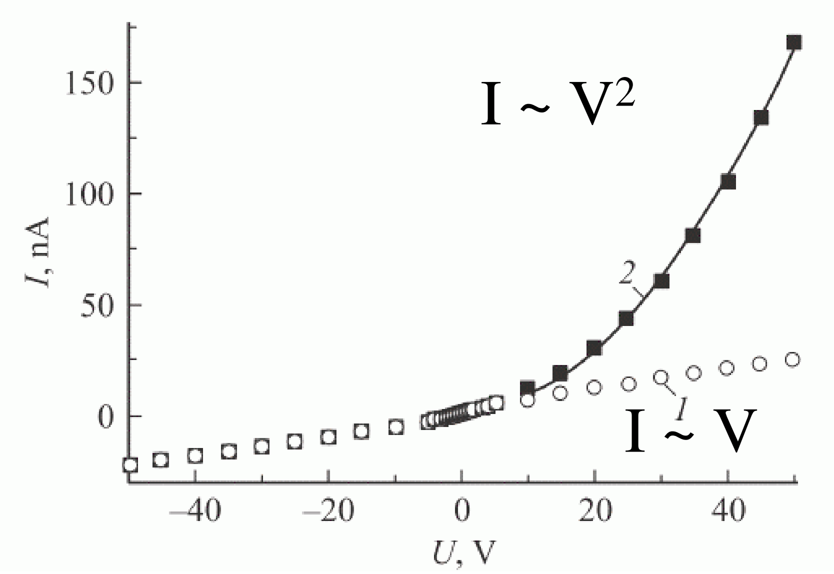


Ohmic behavior
Typical currents ~ 1μA
(same 5x5x0.5mm pad)

Current increases after
irradiation
~ 2x after 1.5 MGy

There is a nonlinear
part near 0V

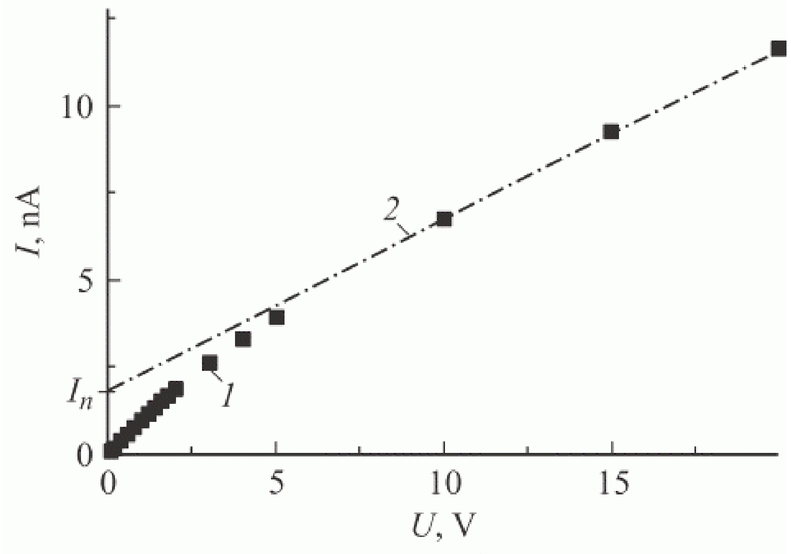
Schottky contacts



$I \sim V^2$

$I \sim V$

1. V-Au contacts (schottky)
2. AuGe (ohmic) and V-Au

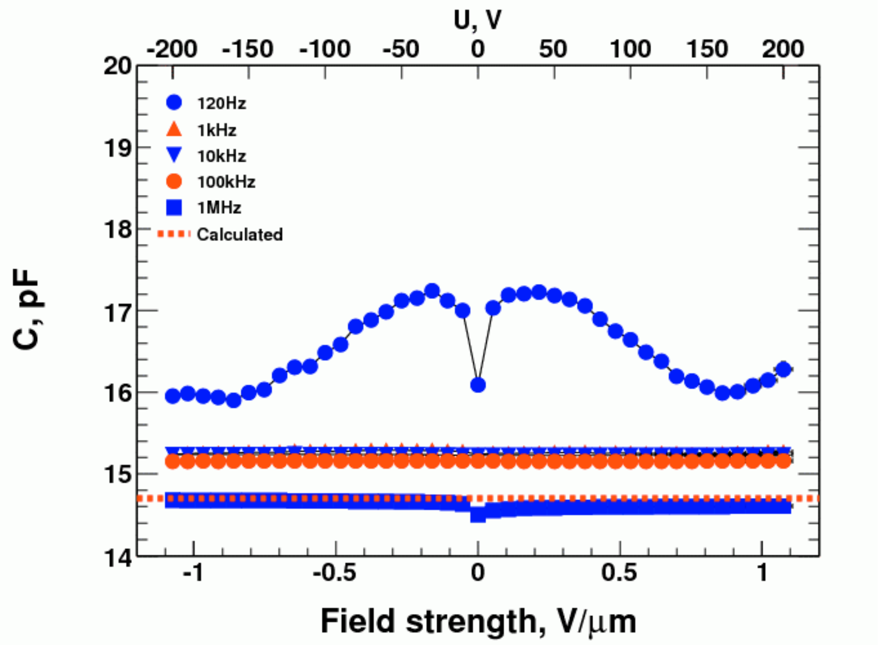


The schottky barrier ~ 0.8 V

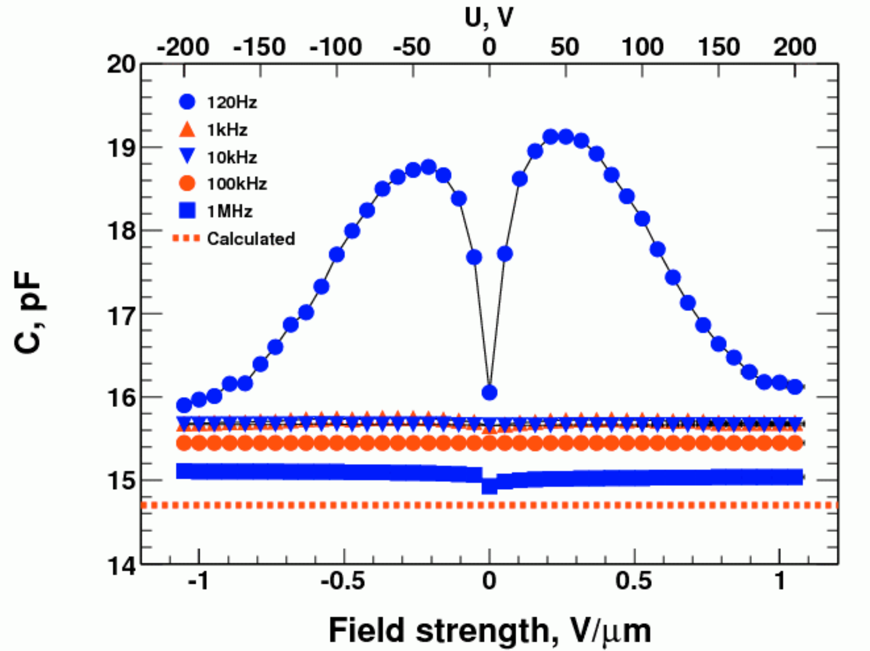
The field depth ~ 0.5 μm

Г.И. Айзенштат, М.А. Лелеков, В.А. Новиков, Л.С. Окаевич, О.П. Толбанов
“Токоперенос в детекторах на основе арсенида галлия, компенсированного хромом”
“Измерение высоты барьера на границе металл - полуизолирующий арсенид галлия”
Физика и техника полупроводников, 2007.

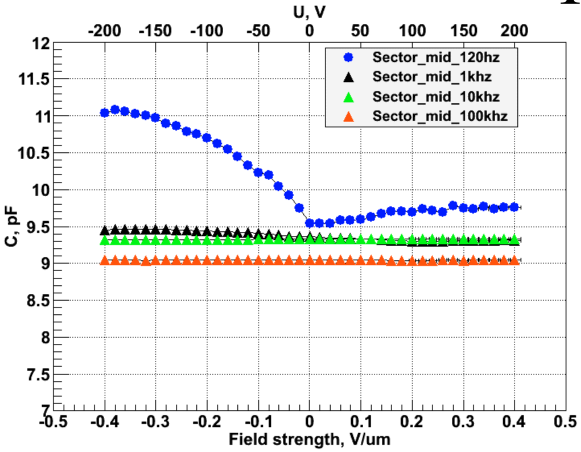
C-V characteristics



Unirradiated

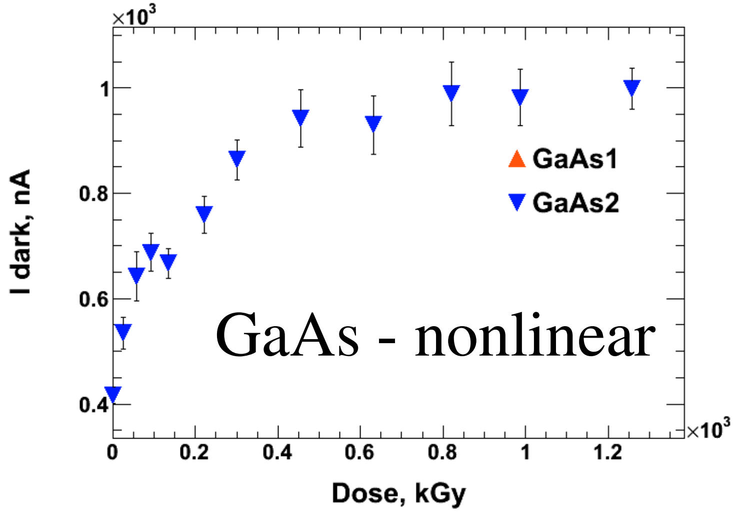


Irradiated to 800 kGy

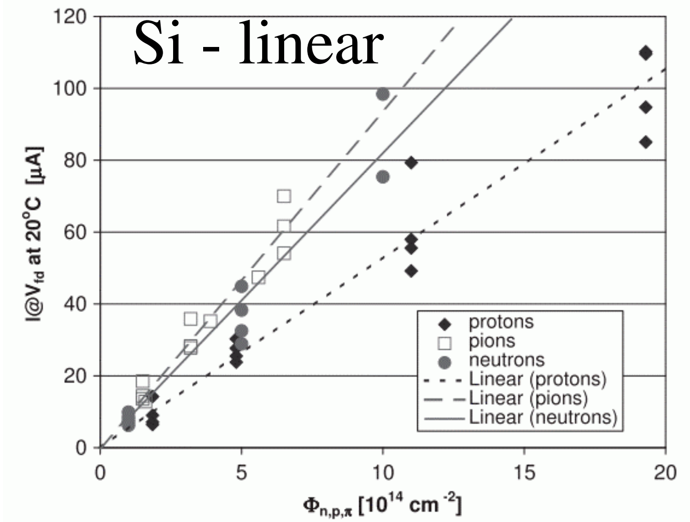


Sector unirradiated

Radiation effects

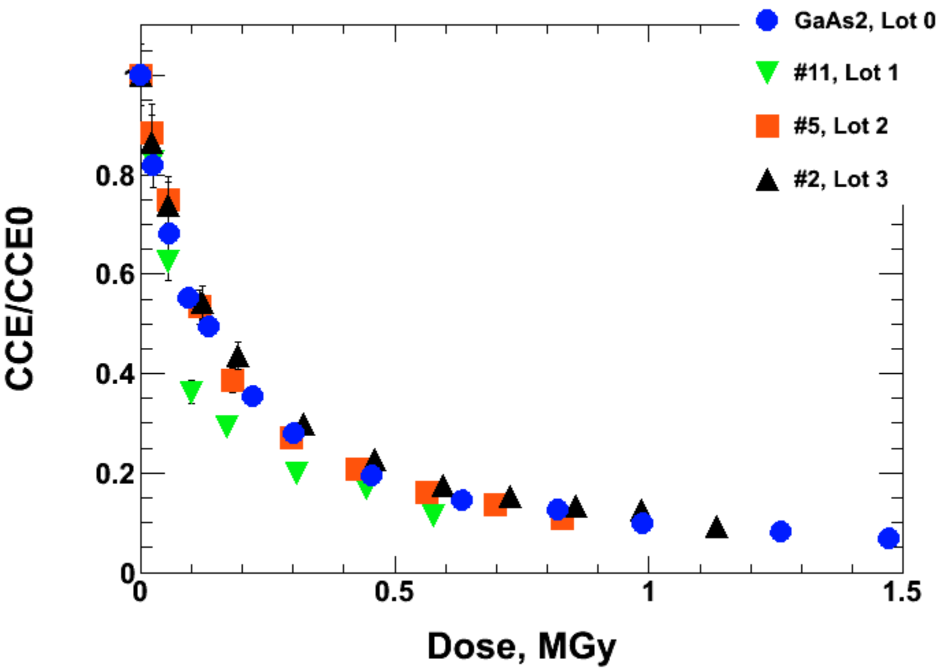


GaAs - nonlinear



Si - linear

Leakage current vs dose (fluence)

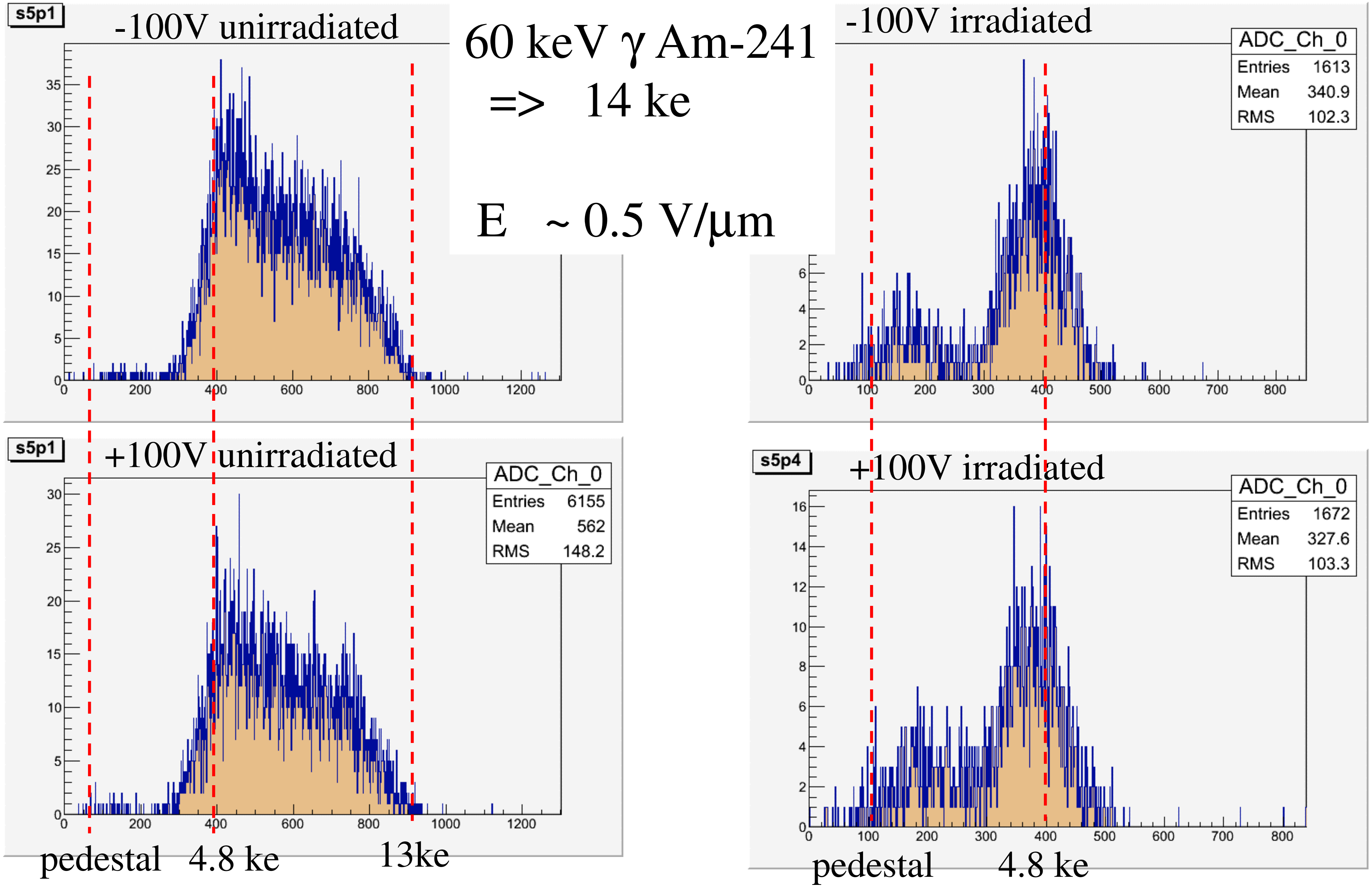


CCE vs dose - similar to diamond

~ 10 times drop after 1.5 Mgy

signal still visible < 1000 e

Alpha-source



60 keV γ Am-241

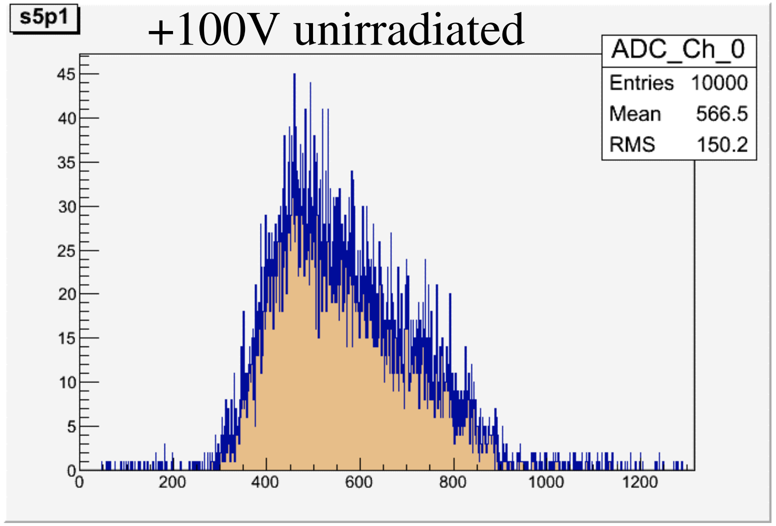
=> 14 ke

E ~ 0.5 V/µm

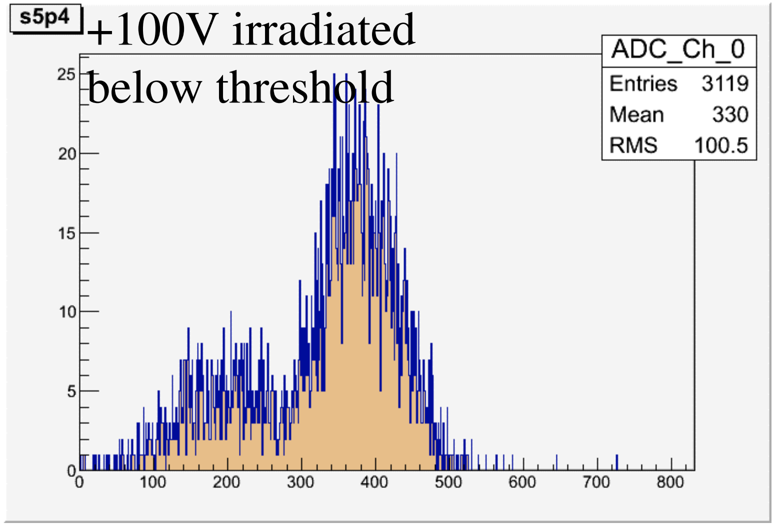
pedestal 4.8 ke 13ke

pedestal 4.8 ke

Alpha-source

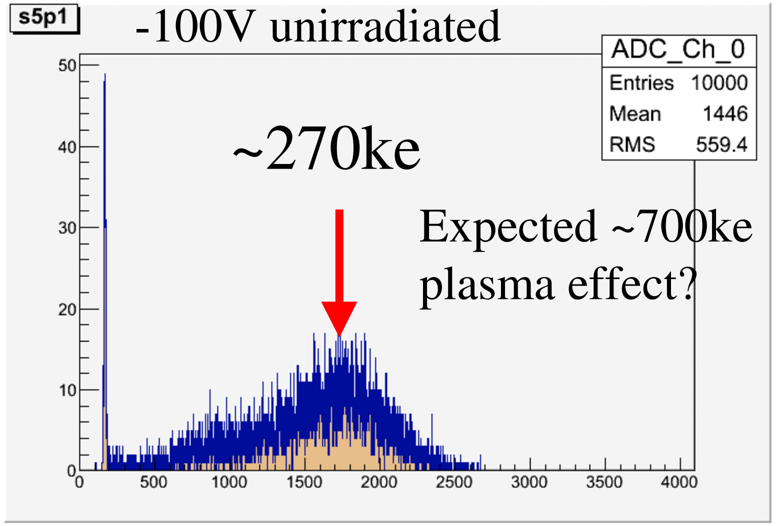


+100V unirradiated



+100V irradiated

below threshold

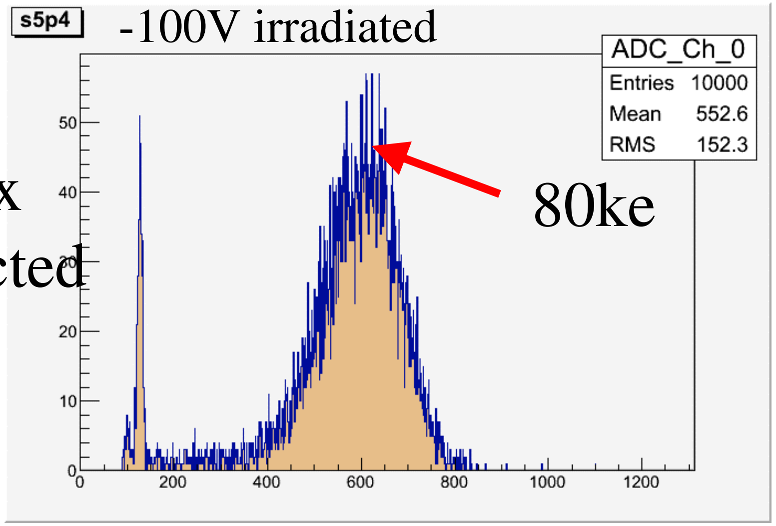


-100V unirradiated

~270ke

Expected ~700ke
plasma effect?

~ 3.5x
expected
more



-100V irradiated

80ke

+20dB => ~ 30-40x difference => electron transport - for irradiated too

Conclusions

We have collected some statistics on GaAs detectors. Is it possibe to produce some model based on that? Especially concerning radiation damage.

Some other methods of characterization to complement this data?

To do (short term)

MIP signal saturation vs voltage for irradiated samples

Refine alpha-source measurements (if needed)

Simulate E depositions for GaAs, diamond and Si
for different particles consistently