Results on GaAs radiation hardness

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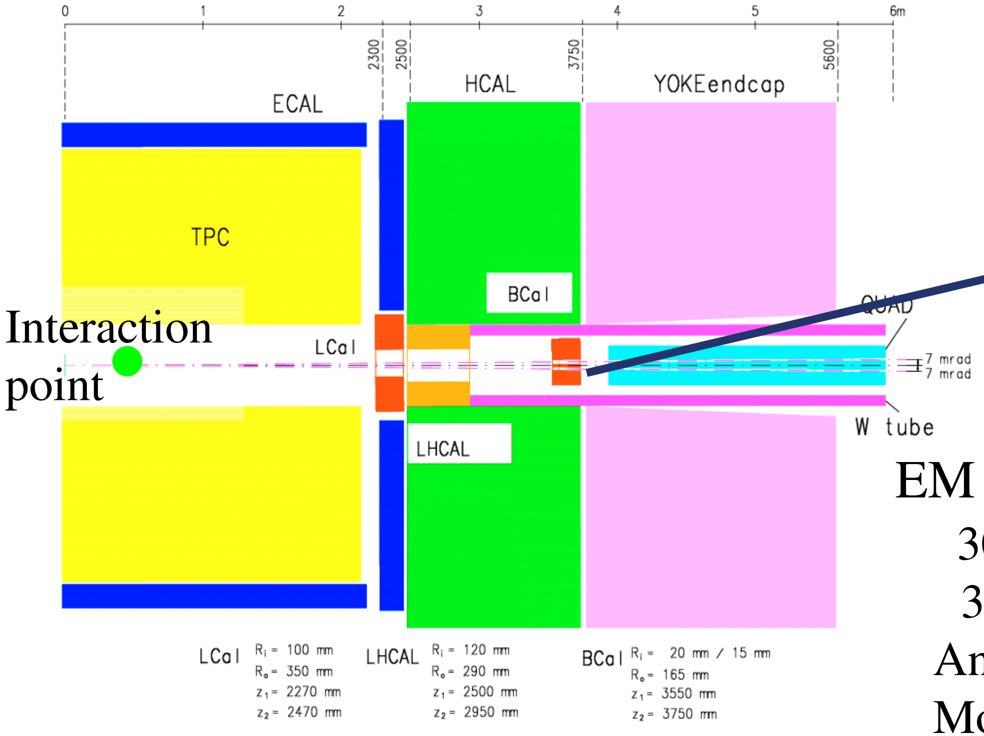
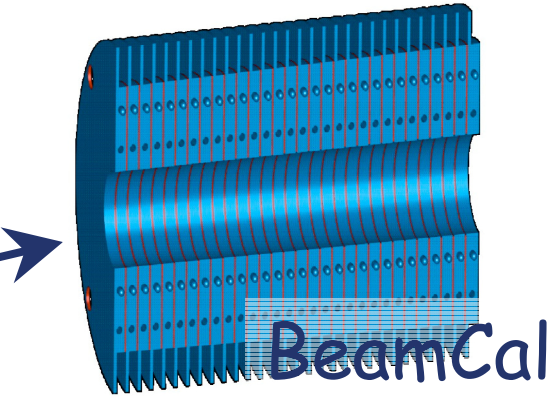
FCAL collaboration meeting
CERN, 2009

Very Forward Region of the ILC Detector





EM calorimeter with sandwich structure:

30 layers of 1 X_0

3.5mm W and 0.3mm sensor

Angular coverage from 5 mrad to 45 mrad

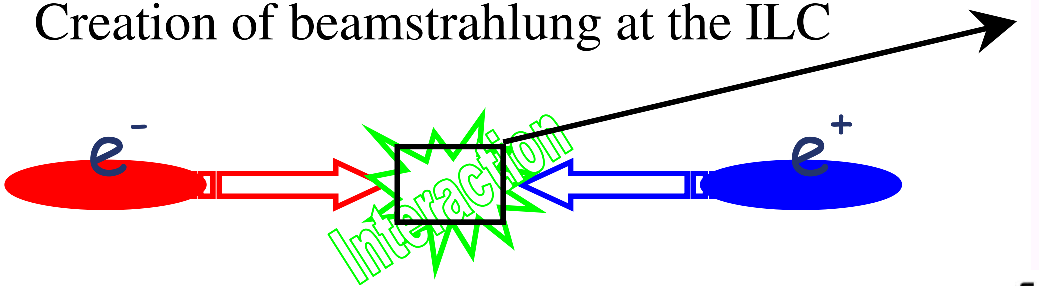
Moliére radius $R_M \approx$ 1cm

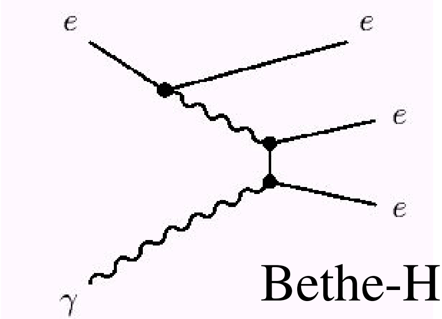
Segmentation between 0.5 and 0.8 x R_M

- The purpose of the instrumentation of the very forward region is:
  - Hermeticity: increase the coverage to polar angles > 5mrad
  - Fast beam diagnostics

The Challenges for BeamCal

Creation of beamstrahlung at the ILC





Bethe-Heitler process

e+e- pairs from beamstrahlung are deflected into the BeamCal

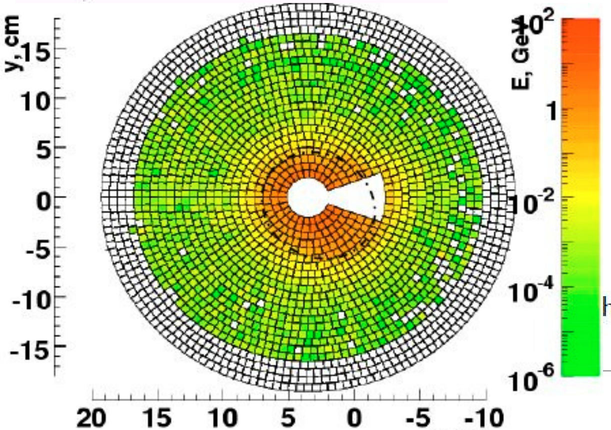
15000 e^+e^- per BX => $E_{dep} \approx$ few TeV

<u>< 1 MGy per year</u> strongly dependent on the beam and magnetic field configuration

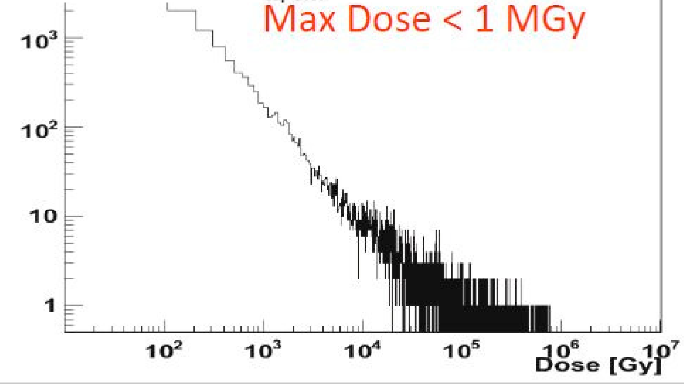
=> radiation hard sensors

Detect the signature of single high energetic particles on top of the background.

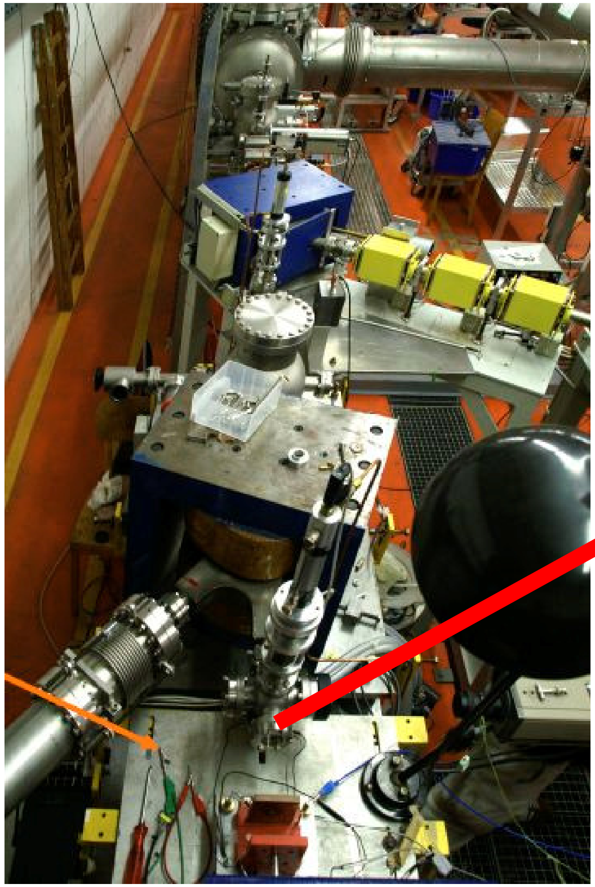
=> high dynamic range/linearity



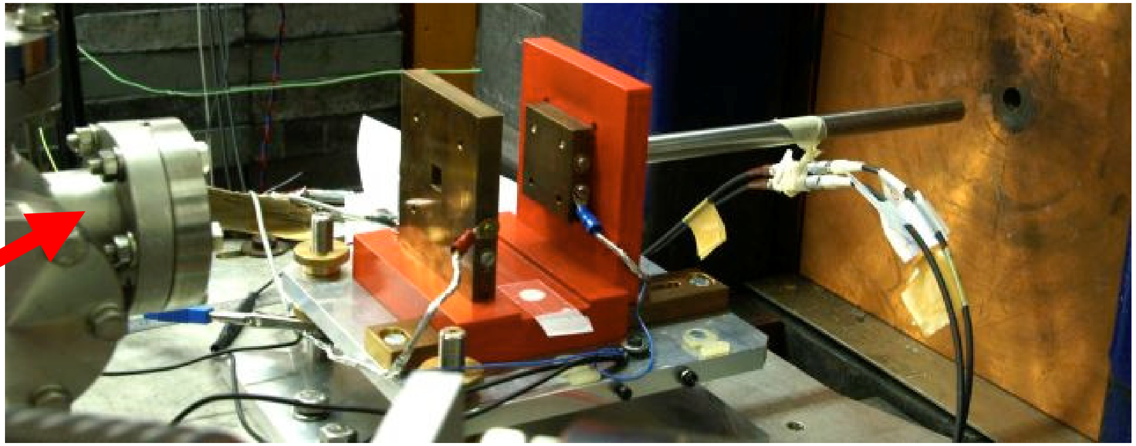
Max Dose < 1 MGy



Irradiation facility



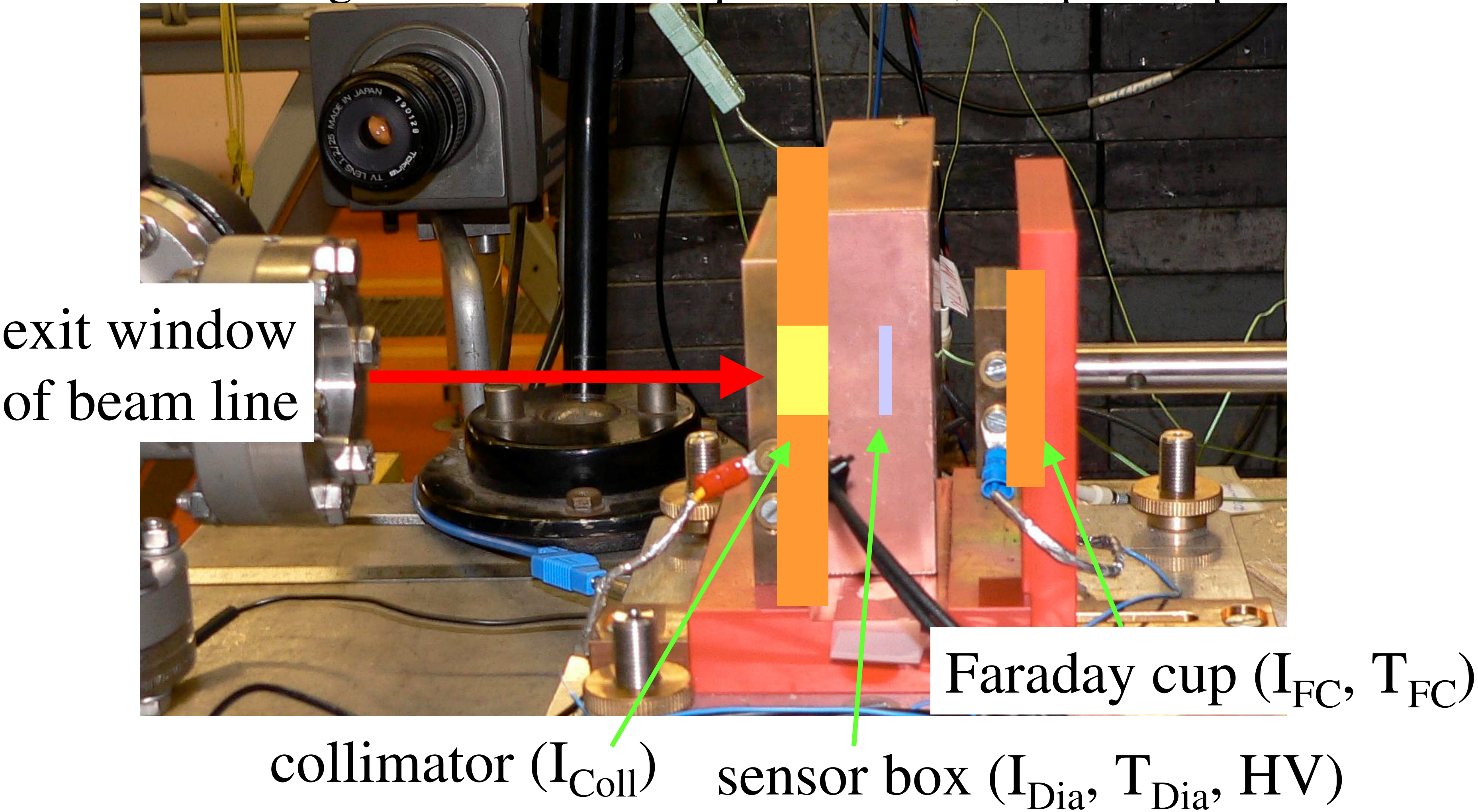
Superconducting DArmstadt LINear ACcelerator
Technical University of Darmstadt



Irradiation up to several MGy using the injector line of the S-DALINAC:
8.5 and 10MeV electrons, beam currents from 2 to 100 nA
corresponding to doserates about 10 to 600 kGy/h

Methodology. Irradiation

- Irradiation under bias voltage
- Monitoring of beam and sample currents, sample temperature



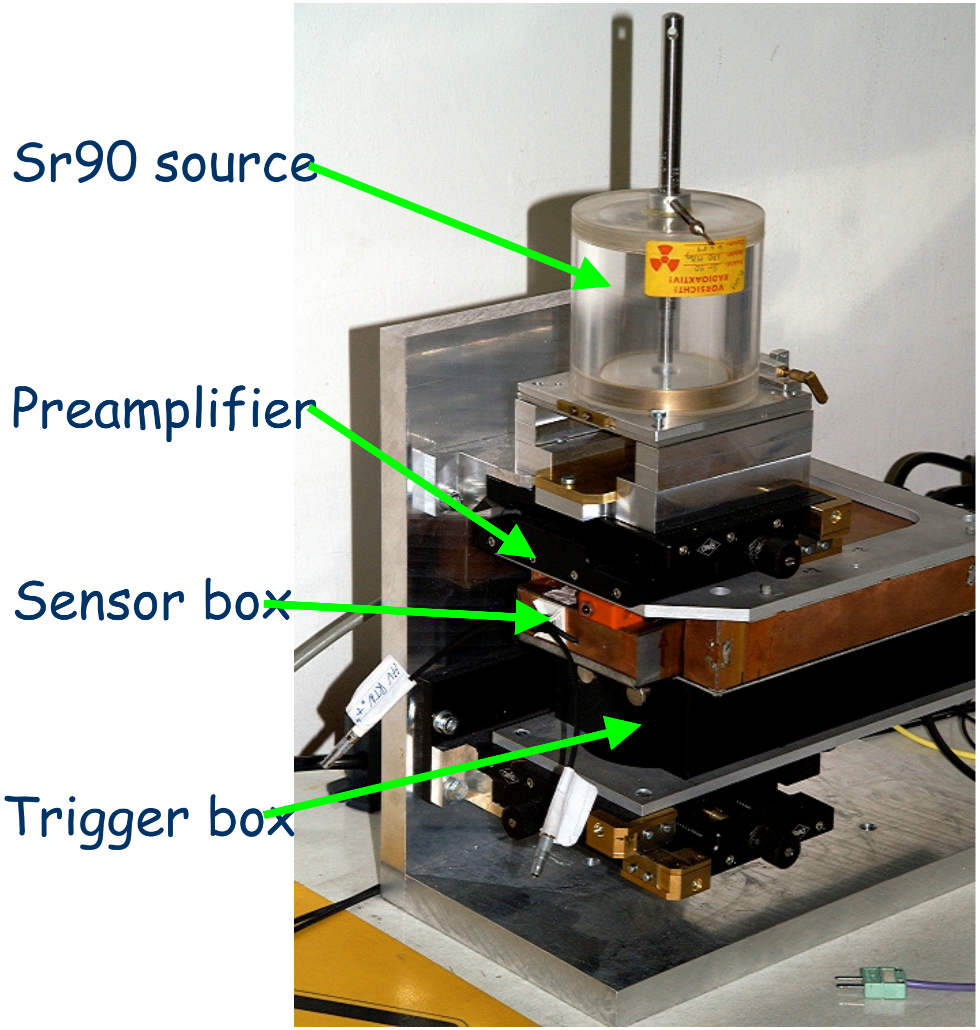
exit window of beam line

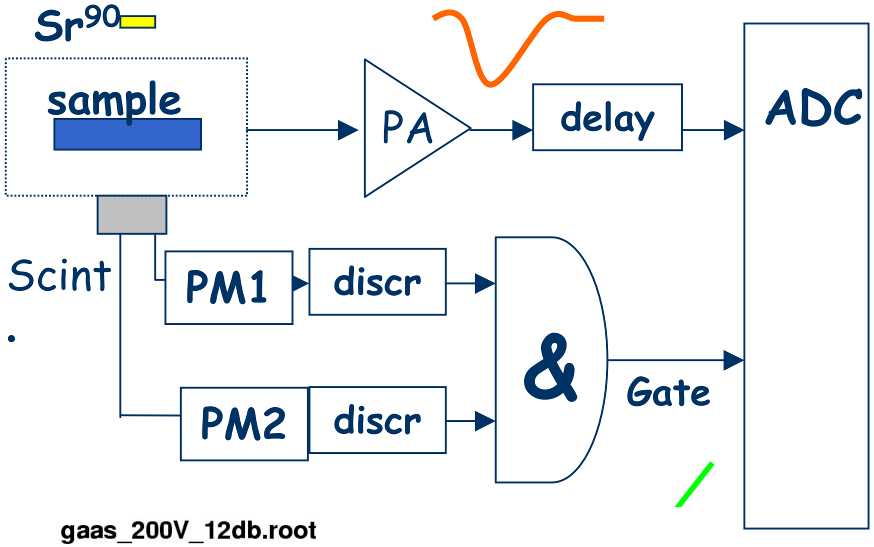
Faraday cup (I_{FC}, T_{FC})

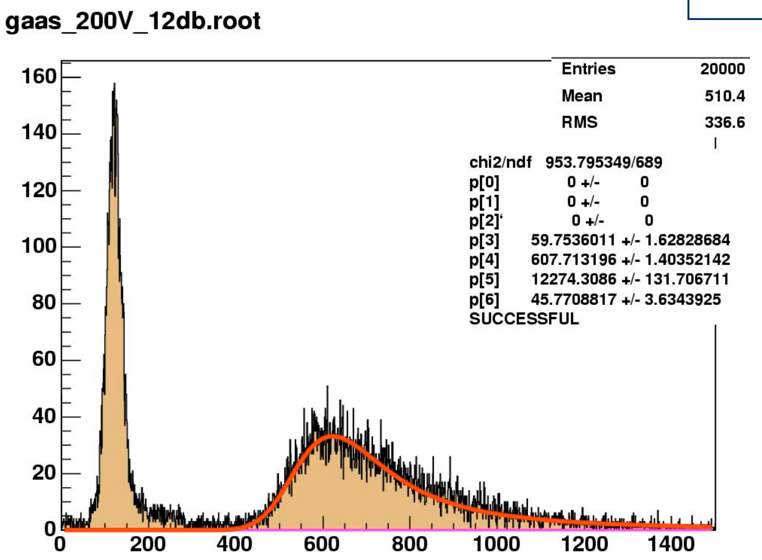
collimator (I_{Coll})

sensor box (I_{Dia}, T_{Dia}, HV)

Methodology. CCD Setup

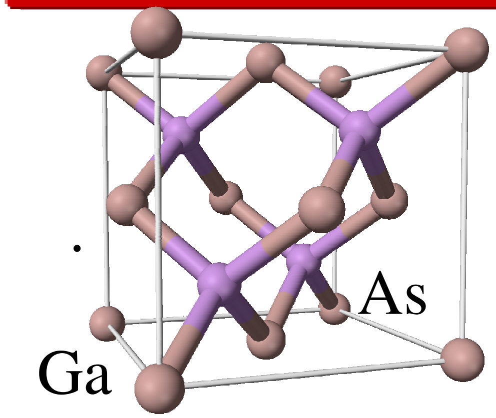






typical spectrum of GaAs sensor

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 material.
Compensation is temperature controlled

Semi-insulating - no p-n junction

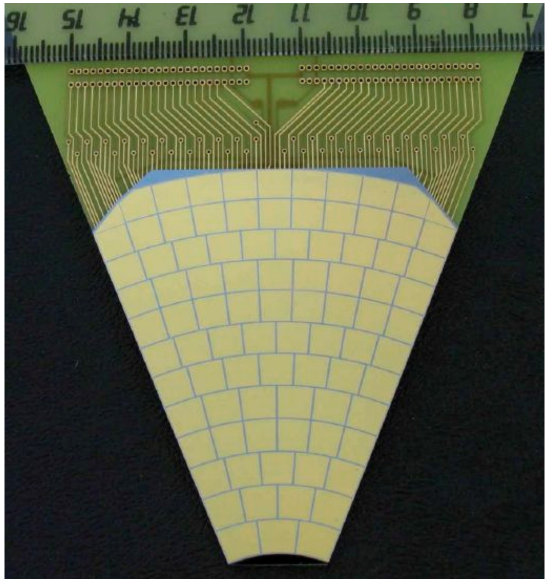
Signal charge transport mainly by electrons

Structure provided by metallisation (similar to diamond)

	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.	12.85
● Radiation length	2.3 cm
Ave. E_{dep}/100 µm (by 10 MeV e^-)	69.7 keV
Ave. pairs/100 µm	13000
Structure	p-n or insul.

GaAs Samples

Supplied by FCAL group at JINR
Developed and produced in Tomsk

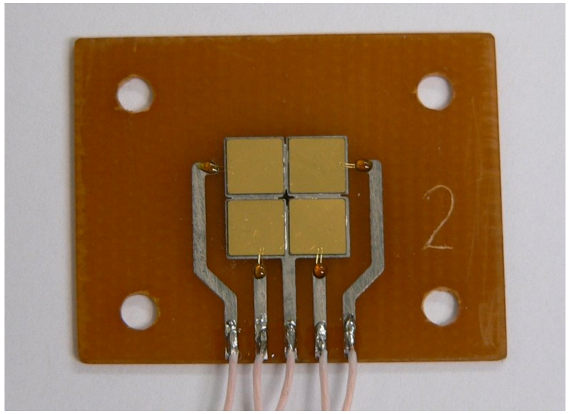


Testbeam 2007

Two pads of 2 sector samples irradiated by 10 MeV e^-

500 µm thick detector is divided into 87 5x5 mm pads and mounted on a 0.5mm PCB with fanout

Testbeam 2008

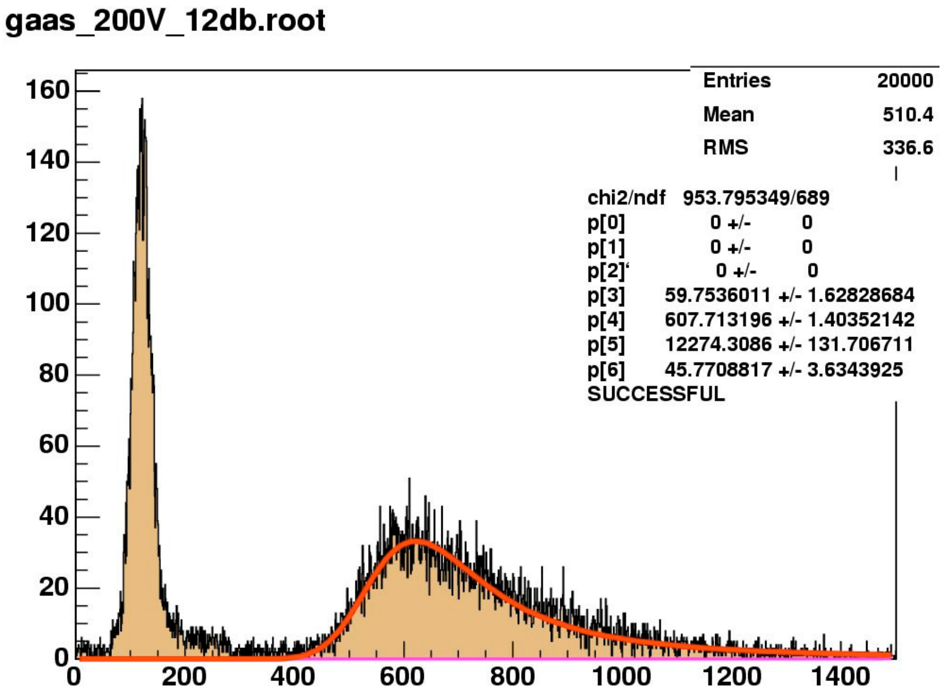


6 samples irradiated by 8.5 MeV e^-

Thicknesses 160 – 200 µm

Metallisation is V (30 nm) + Au (1 µm)

GaAs. Signal



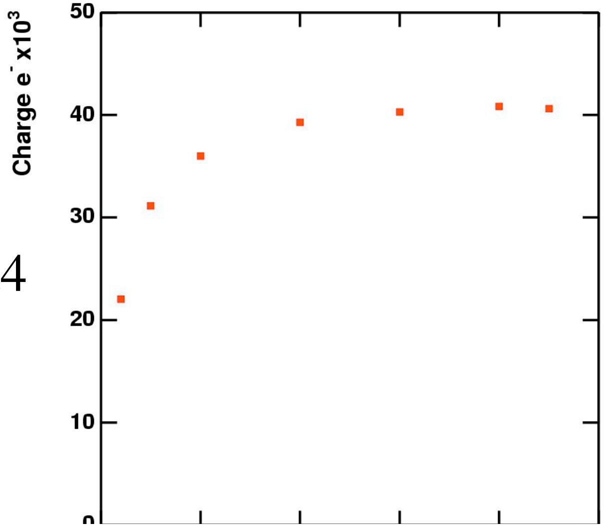
Clear separation of peaks from Sr^{90} source

Quite homogeneous response
over different pads

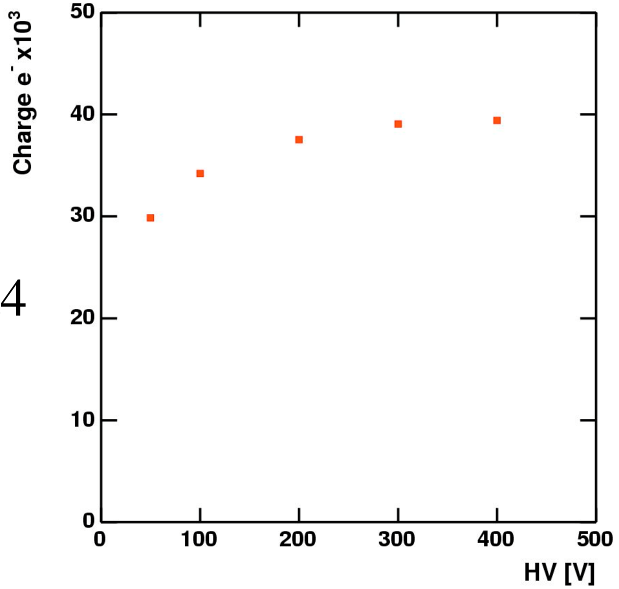
Saturation of signal @ about 200V bias

Collection efficiency ≈ 60%

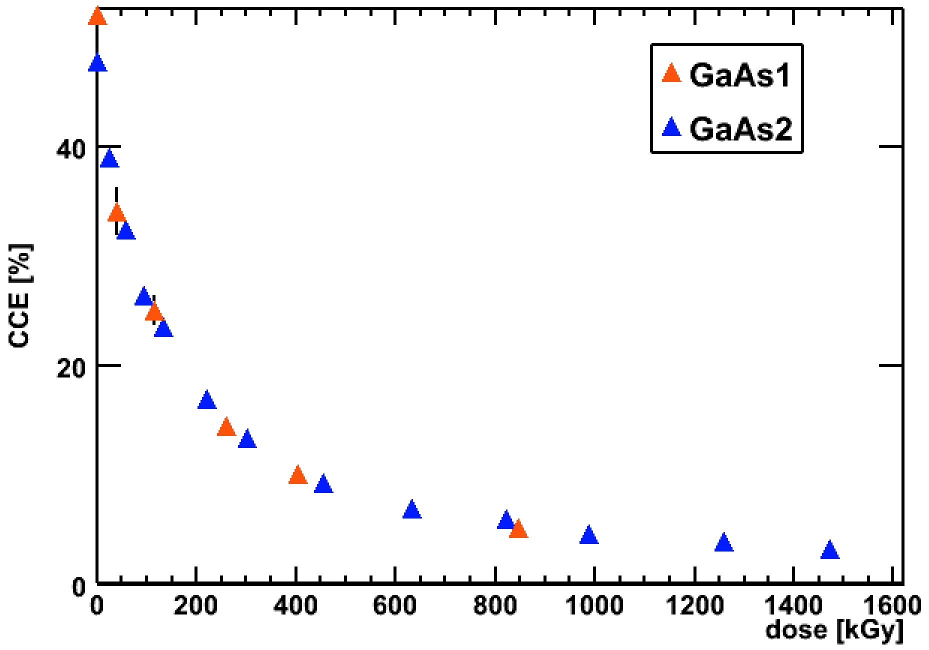
S8 pad4
ring 4

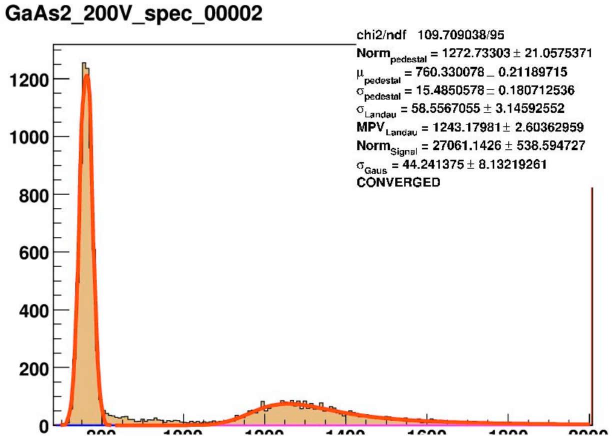


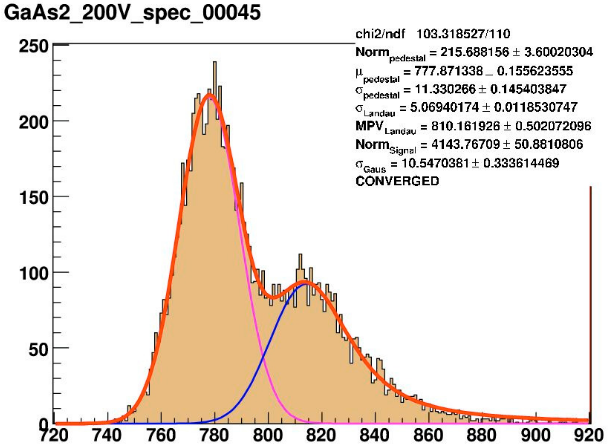
S8 pad4
ring 6



GaAs. Irradiation results



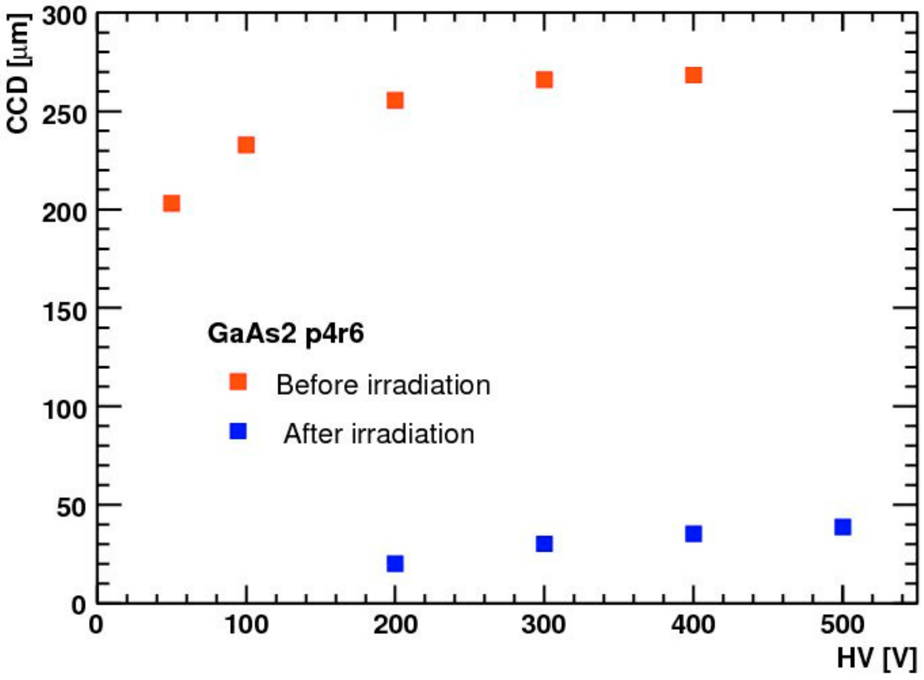


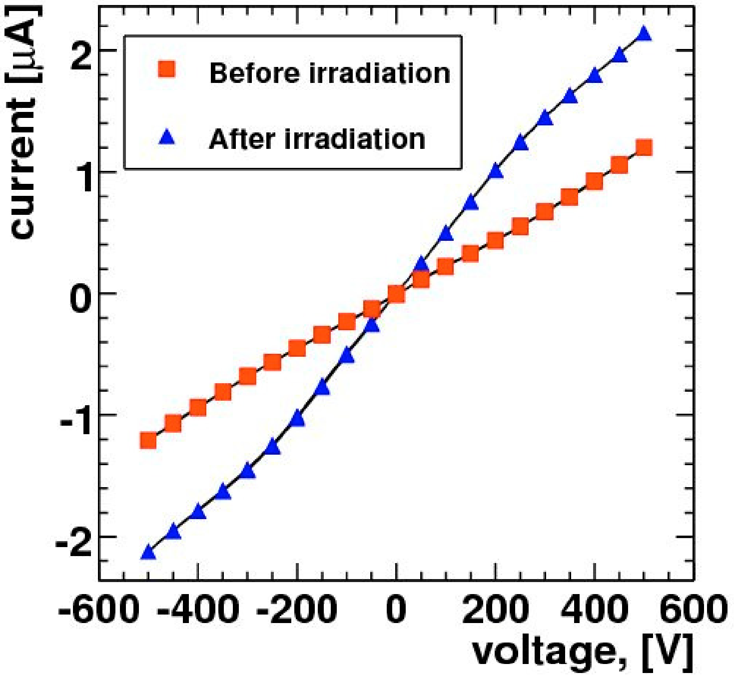


Samples 7&8, pad4, ring6 @ 200V

Results: CCE dropped to about 6% from 55% after 1.5 MGy
this corresponds to signal size of about 2000 e^-

GaAs. Irradiation results





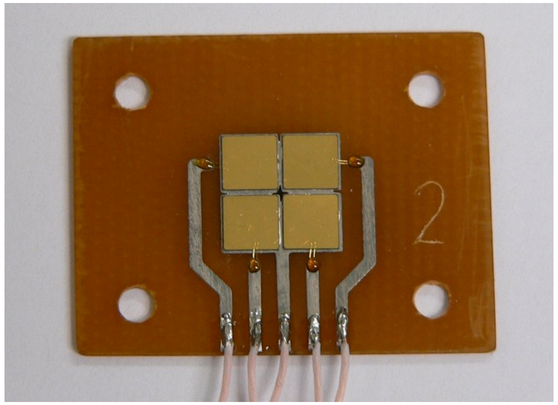
Dark current increased ≈ 2 times (from 0.4 to 1 μA @ 200V)

Signal is still visible for an absorbed dose of about 1.5 MGy

GaAs. Second testbeam

A set of GaAs samples with different doping concentrations was irradiated

Batch #	Shallow donor type	Concentration, cm^{-3}
1	Te	$(1\text{-}1.5)*10^{17}$
2	Te	$(5\text{-}6)*10^{16}$
3	Sn	$(1\text{-}3)*10^{16}$

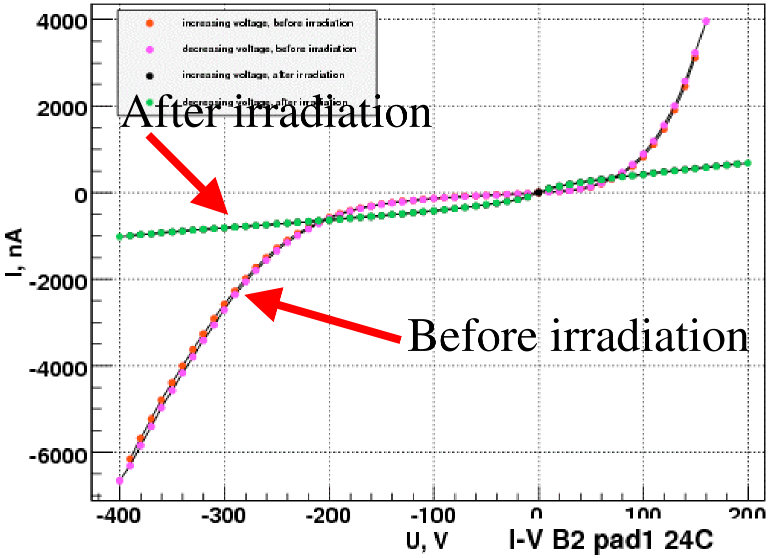


Thicknesses 150 – 200 μm

Metallization:
V (30 nm) + Au (1 μm) from both sides

GaAs. Second testbeam. I-V

I-V B11 pad4 23C

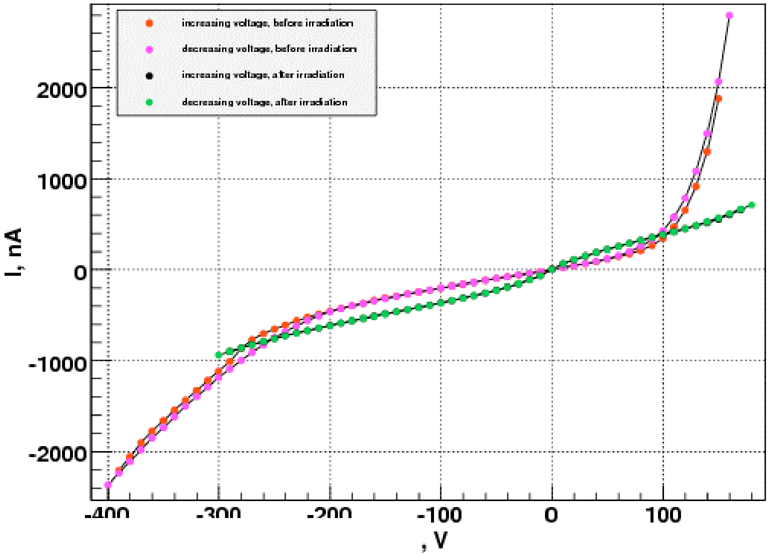


After irradiation

Before irradiation

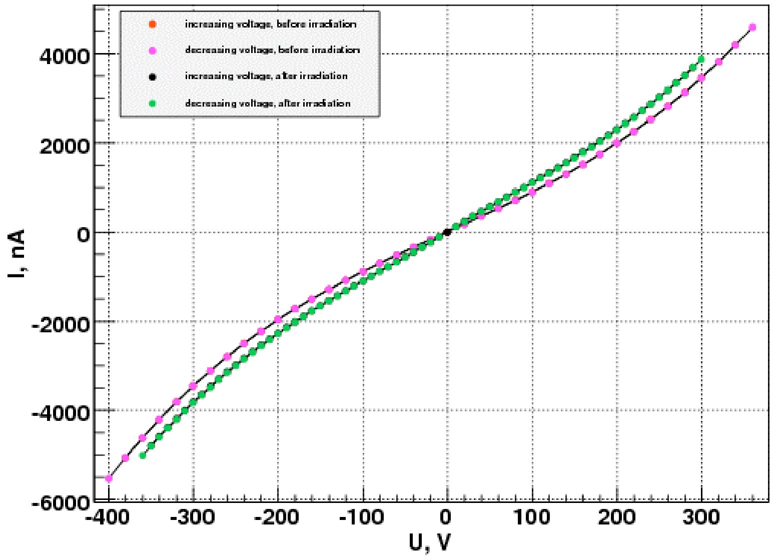
Batch#1

I-V B7 pad2 23C



Batch#2

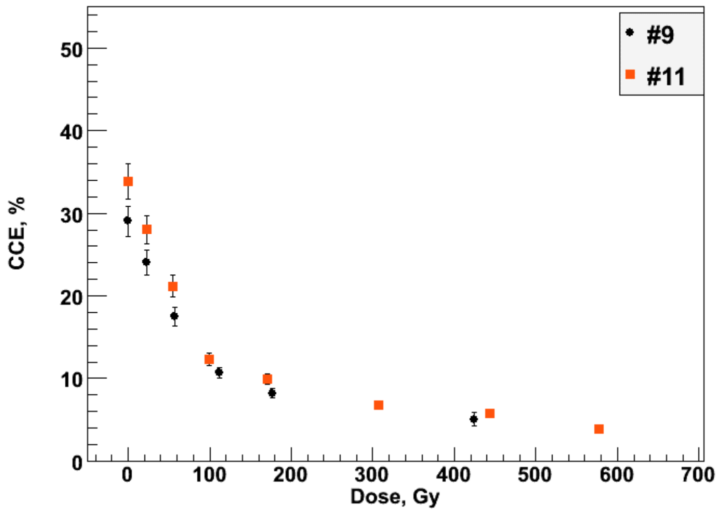
I-V B2 pad1 24C



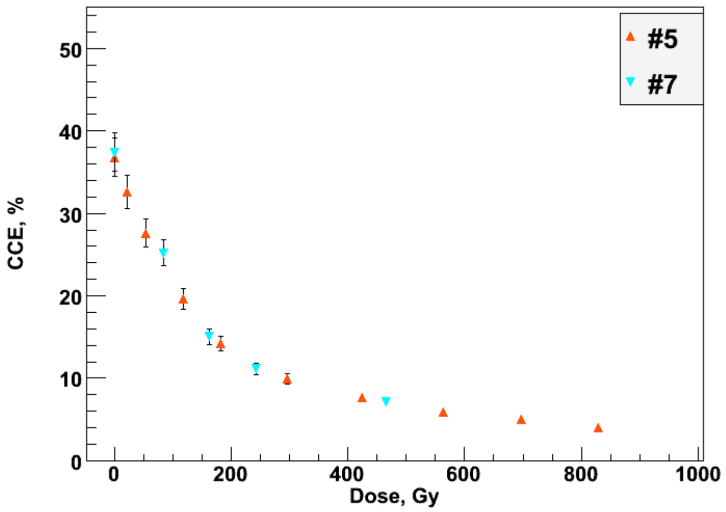
Batch#3

GaAs. Second testbeam. Irradiation results
CCE measurements

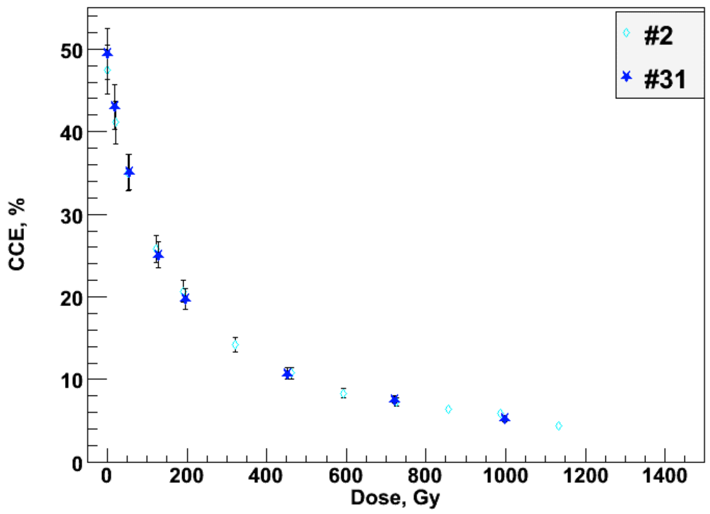
GaAs:Cr CCE vs dose, batch #1



GaAs:Cr CCE vs dose, batch #2



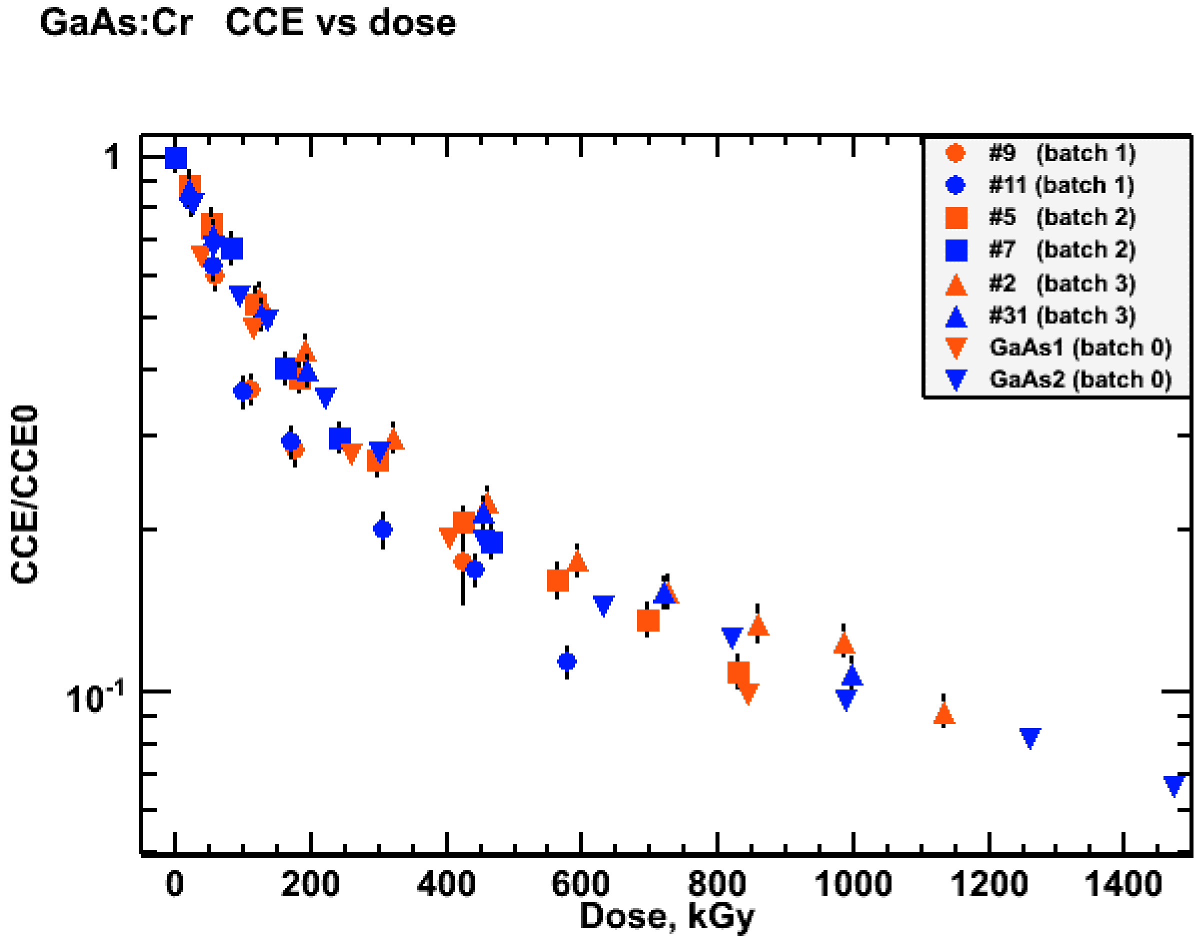
GaAs:Cr CCE vs dose, batch #3



1% CCE <-> 260 e^-

GaAs. Radiation hardness.

A set of GaAs samples with different doping concentrations was irradiated



Batch 0 and batch 3
are very similar

Difference in thickness

=> 500um vs 200 um

=> larger C and noise
lower signal size

Conclusion

For Electromagnetic irradiation
Semi-insulating GaAs operational up to 1.5 MGy

Samples with lower dopant concentration show better results

Samples with Sn shallow donor dopant show better results
(but low statistics)

Material from batch 3 (2008 testbeam) and batch 0 (2007 testbeam)
show very similar behavior both in I-V and radiation hardness

A beta-version of a report on the results is avaliable at
www.ifh.de/~akg/gaas_final/
you are welcome to comment

Future work

A new testbeam is being planned

New GaAs samples are being commisioned by JINR FCAL group
We are going to test samples with different donor types and acceptor diffusion parameters.

#samples	Shallow donor type	Concentration, cm^{-3}	T diffusion
2	Te	$(2\text{-}5)*10^{16}$	T1
2	Te	$(2\text{-}5)*10^{16}$	T2 > T1
2	Sn	$(2\text{-}5)*10^{16}$	T1
2	Sn	$(2\text{-}5)*10^{16}$	T2

Thank you for your attention

Backup slides

Irradiation facility