GaAs:Cr for HEP – radiation tests

IHEP, Protvino
NCPHEP, Minsk
SIPT, Tomsk
ICBP, Puschino

Our predecessors

- RD-20, CERN Si, GaAs
- RD-48, CERN Si, GaAs
- A. Vorobiev, IHEP GaAs, Si
- P. Sellin e al, 1995 GaAs

neutrons, 1 MeV, fluence up to $1{\cdot}10^{14}$ n/cm^{-2}

A. Vorobiev, IHEP, 2002

GaAs cooling, temperature dependence

FNAL, D0 report, 2002

Silicon detectors from ELMA, ST, Ham., ...

and many others

Doping GaAs by Chromium –
the 5-year practice of a new technology in Tomsk

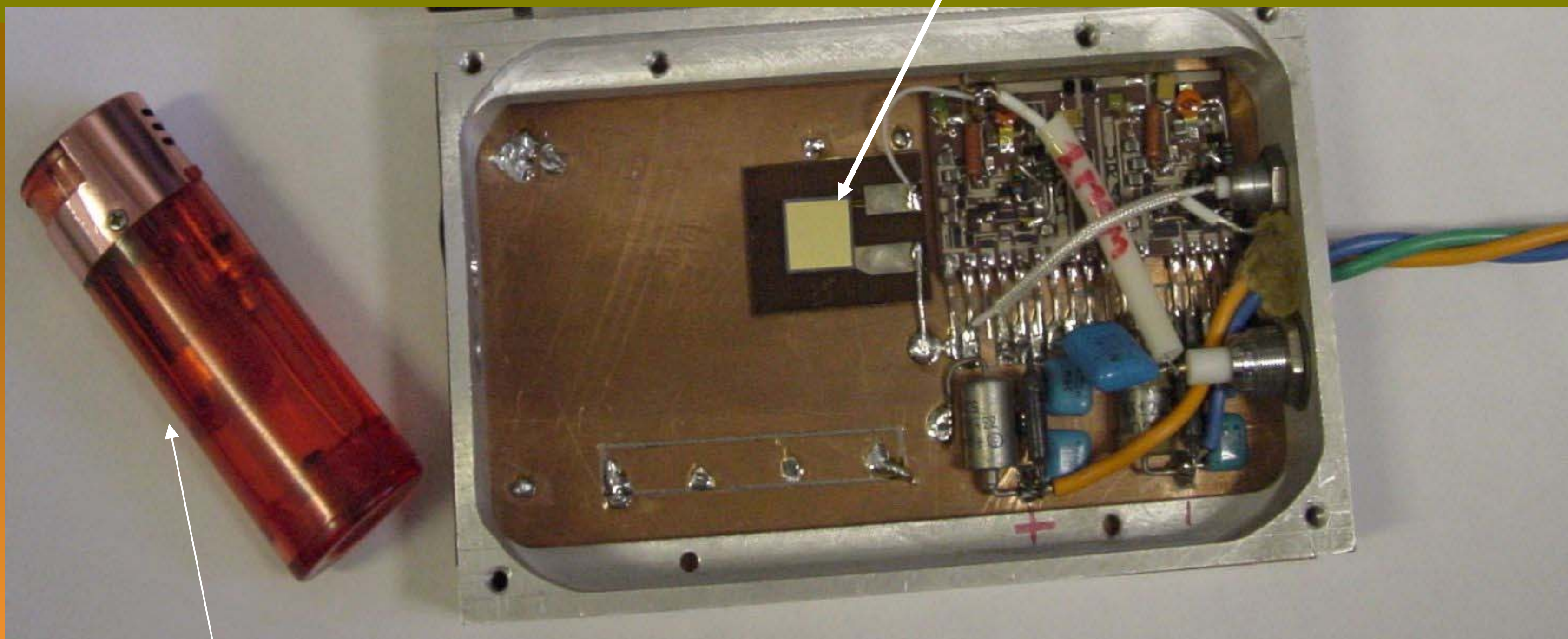
structure type	Si	GaAs
p-i-n	YES	YES
π-ν-n	NO	YES

- Resistive Si structures have not been obtained so far.
- World studies of GaAs irradiation tolerance related mainly to GaAs structures of the previous generation.

A new unique production technology of GaAs:Cr (doped by Chromium) belongs to Tomsk.

As was earlier shown by estimates and by the first measurements (Protvino, RAL), GaAs:Cr radiation hardness can be higher than that of Si by a factor of 10 or larger.

GaAs pad 1cm·1cm



Cigarette lighter

General view. The detector is shielded by 5μm gold cover.

GaAs:Cr general properties

	GaAs	Si	$PbWO_4$	Pb	W
X_0, cm (rad. length)	2.30[a]	9.36	0.89	0.56	0.35
R_M, cm (Molliere radius)	2.63[c]	4.91[c]	2.2	1.60[c]	0.89(0.91[c])
λ_I, g/cm^2 (nucl. Int. length)/cm	140[a]/ 26.1	106/ 45.5	/ 22.4	194/ 17.09	185/ 9.59
ρ, g/cm^3 (density)	5.36	2.33	8.28	11.35	19.3
Z/A	Ga: 31/70 As: 33/75	14/28		82/207	74/183.8
E_c, MeV, electron critical energy[b]	18.35	40.03		7.33	8.11
dE/dx, MeV/cm per mip	7.44	3.6	13.0	~13	~23

[a] – taken as for Ge with Z=32 and A=72.6 and ρ=5.32 g/cm^3.

[b] – calculated as E_c = 610 MeV/(Z+1.24)

[c] – calculated as $R_M = X_0 \cdot 21$ MeV/E_c

GaAs vs Si

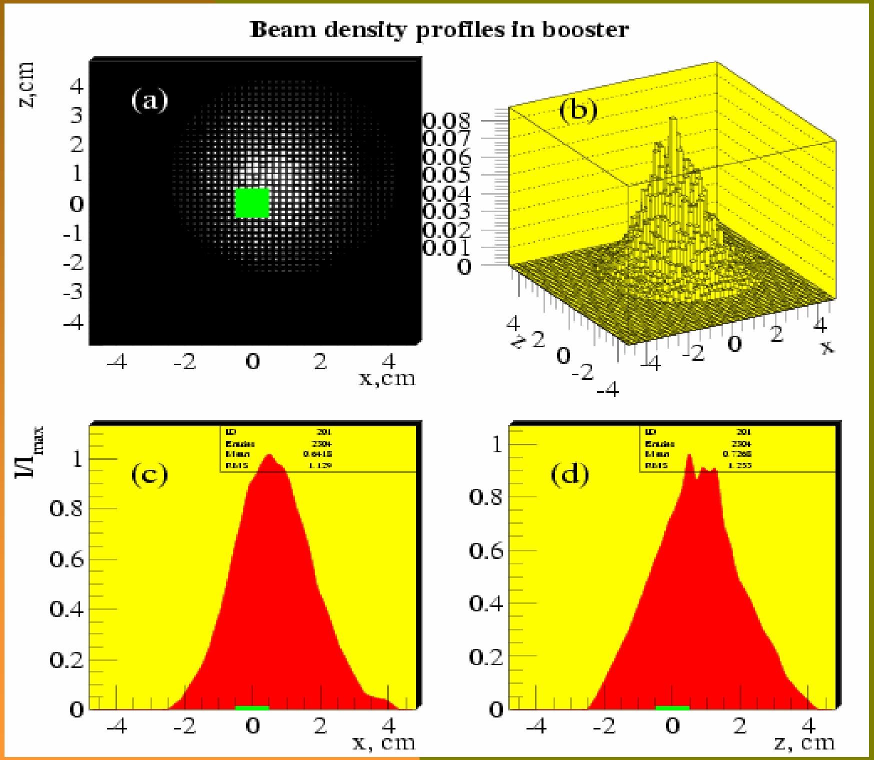
Properties (*by courtesy of O.P. Tolbanov*)	Si	GaAs:Cr
Ionization density, *dN/dx* (pair/μm)	90	177
Charge drift velocity, *cm/sec*	$3 \cdot 10^6$	$1 \cdot 10^7$
Response (amplitude of induced current per mip), μA	0.4	3
Radiation hardness in terms of *CCE*, Charge Collection Efficiency	30% at $\sim 10^{12}$ cm^{-2}	50% $\sim 10^{14}$ cm^{-2}
Leakage current	Refrigeration needed	No refrigeration

GaAs test series in Nov. 2003 – Jan. 2004

- Proton beam at IHEP booster
- Gamma source in Puschino
- Data analysis in Protvino and Tomsk

Absorbed dose – is it known accurately? -- YES

- Direct measurement with Al foils -- *Г.И. Бритвич*
- Verification with booster beam profiles – *А.С. Гуревич*



Mrad

0.4 3.5 120

Fluence, p/cm**2

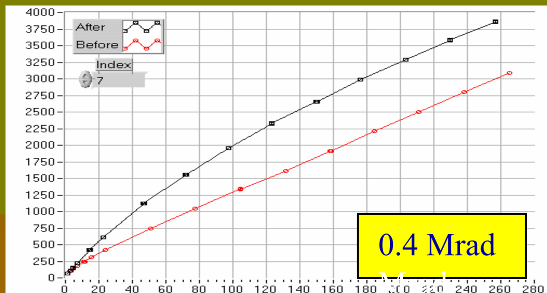
$1.7 \cdot 10^{13}$ $1.5 \cdot 10^{14}$ $5.0 \cdot 10^{15}$

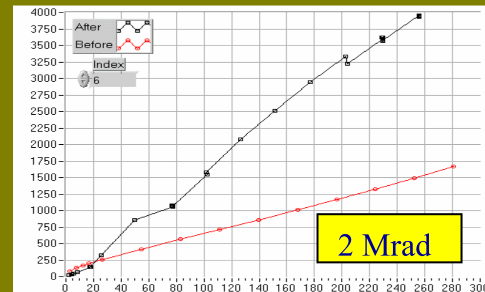
Beam density, p/bunch

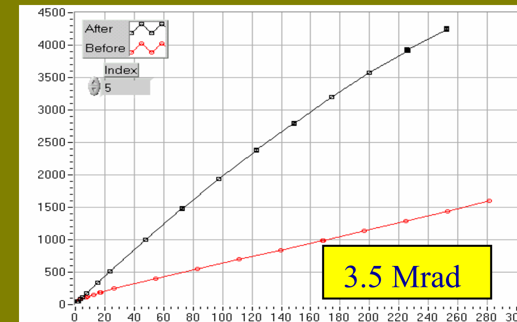
$2 \cdot 10^{11}$ $6 \cdot 10^{11}$

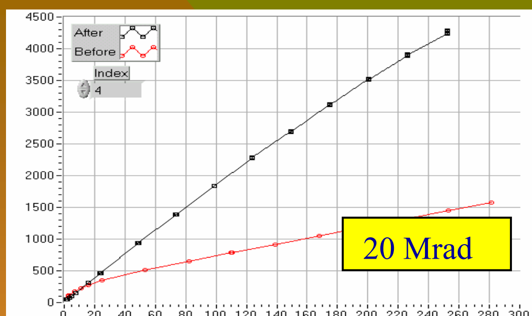
GaAs diodes NN= 1÷7
Low beam intensity I_p=2·10^{11} p/pulse

VACs before /after



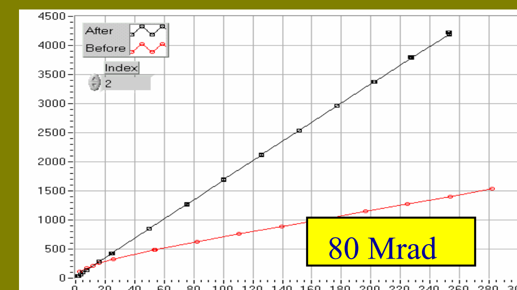


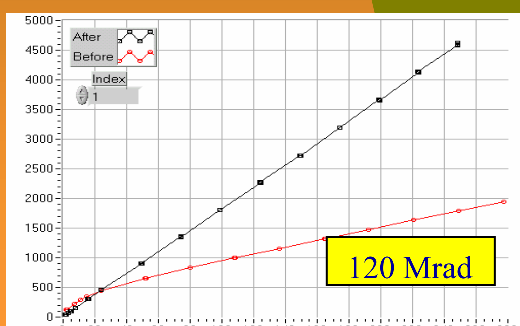




N3

40 Mrad



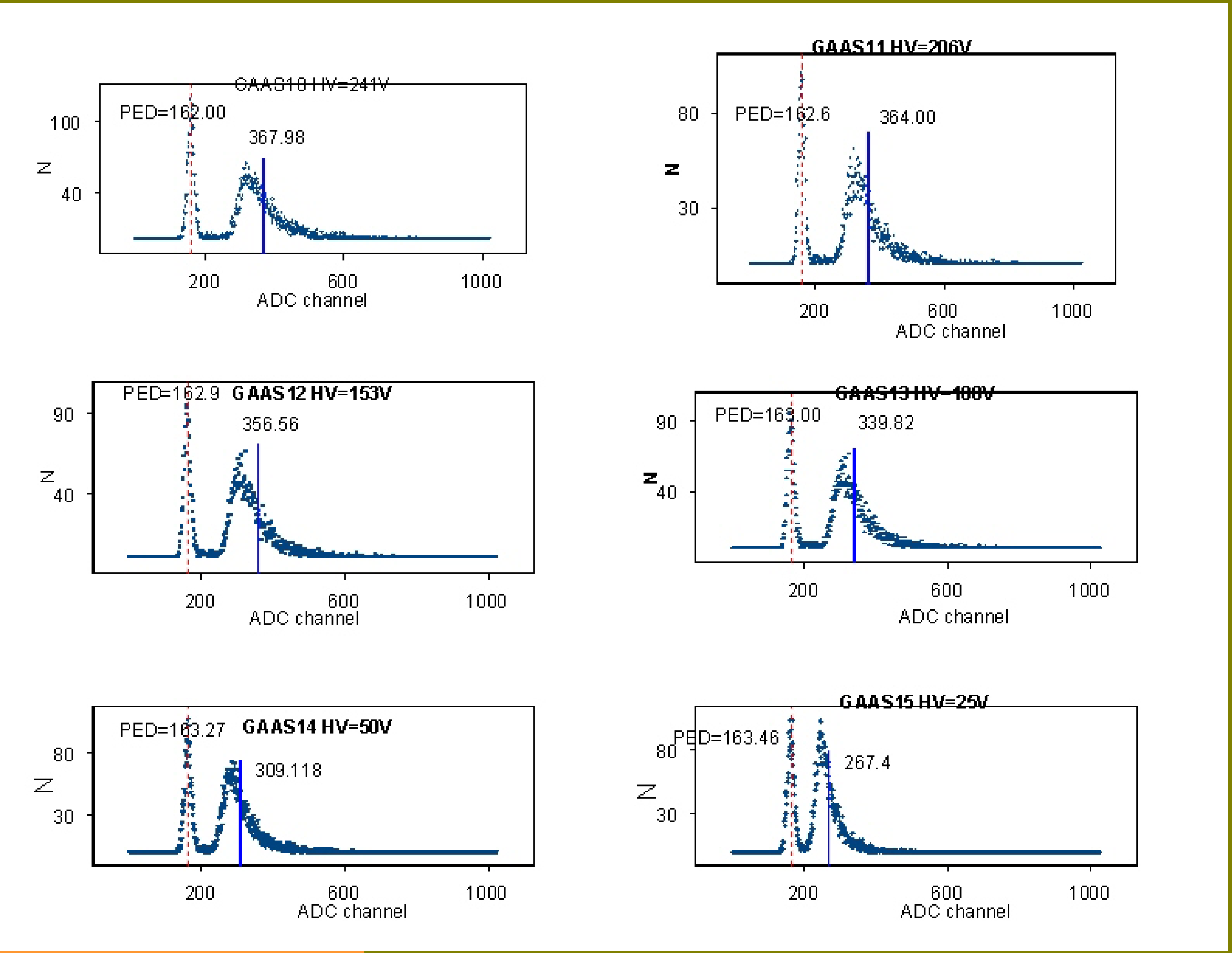


NOTE. Diode N3 was irradiated up 40 Mrad, and later it was found to be damaged mechanically due to an unknown reason.

Stand at work

A.G. Kholodenko, 14.01.2004

Это сбор заряда от напряжения, просто данные и центры тяжести сигнального и пьедестального пиков.

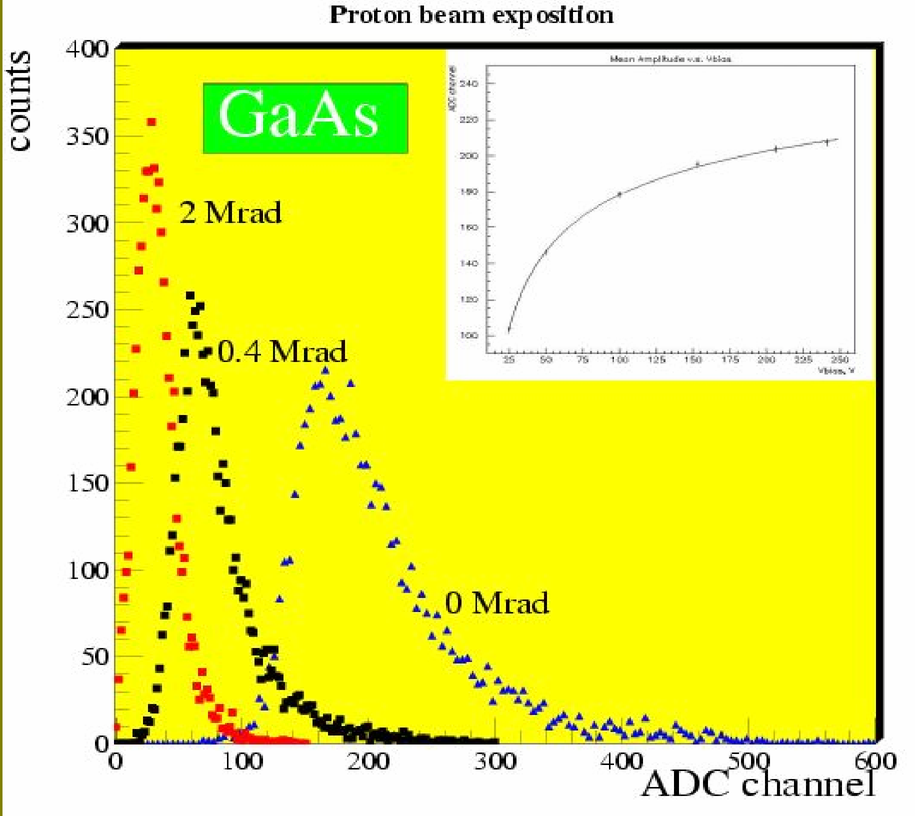


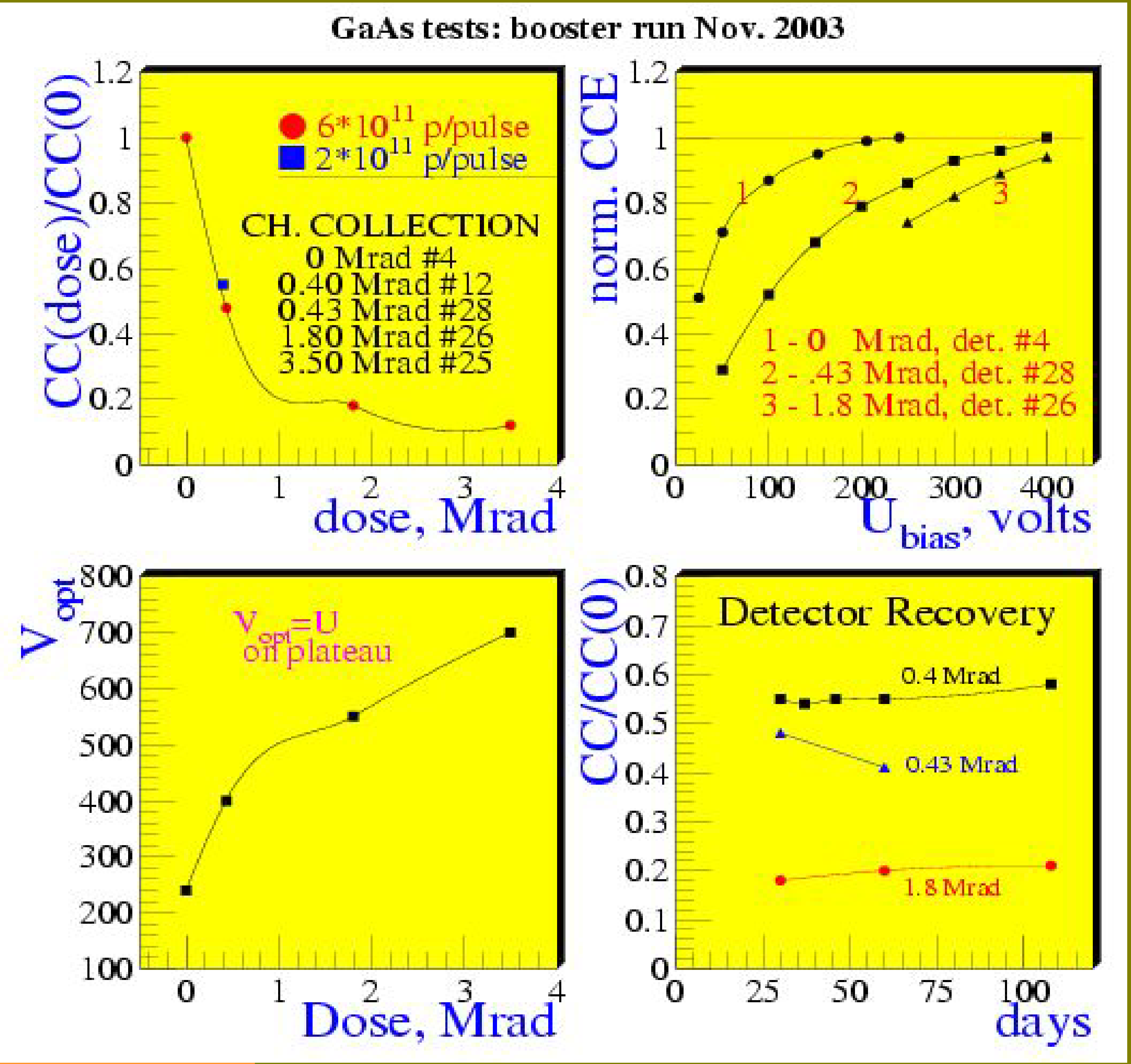
GaAs:Cr 1cm•1cm detectors

in 1.7 GeV/c proton beam (Dec. 2003)

14 GaAs detectors were exposed, and 7 of them to 'low lintensity' beam with $2{\cdot}10^{11}$ p/pulse and 7 to high-intensity beam with $6{\cdot}10^{11}$ p/pulse.

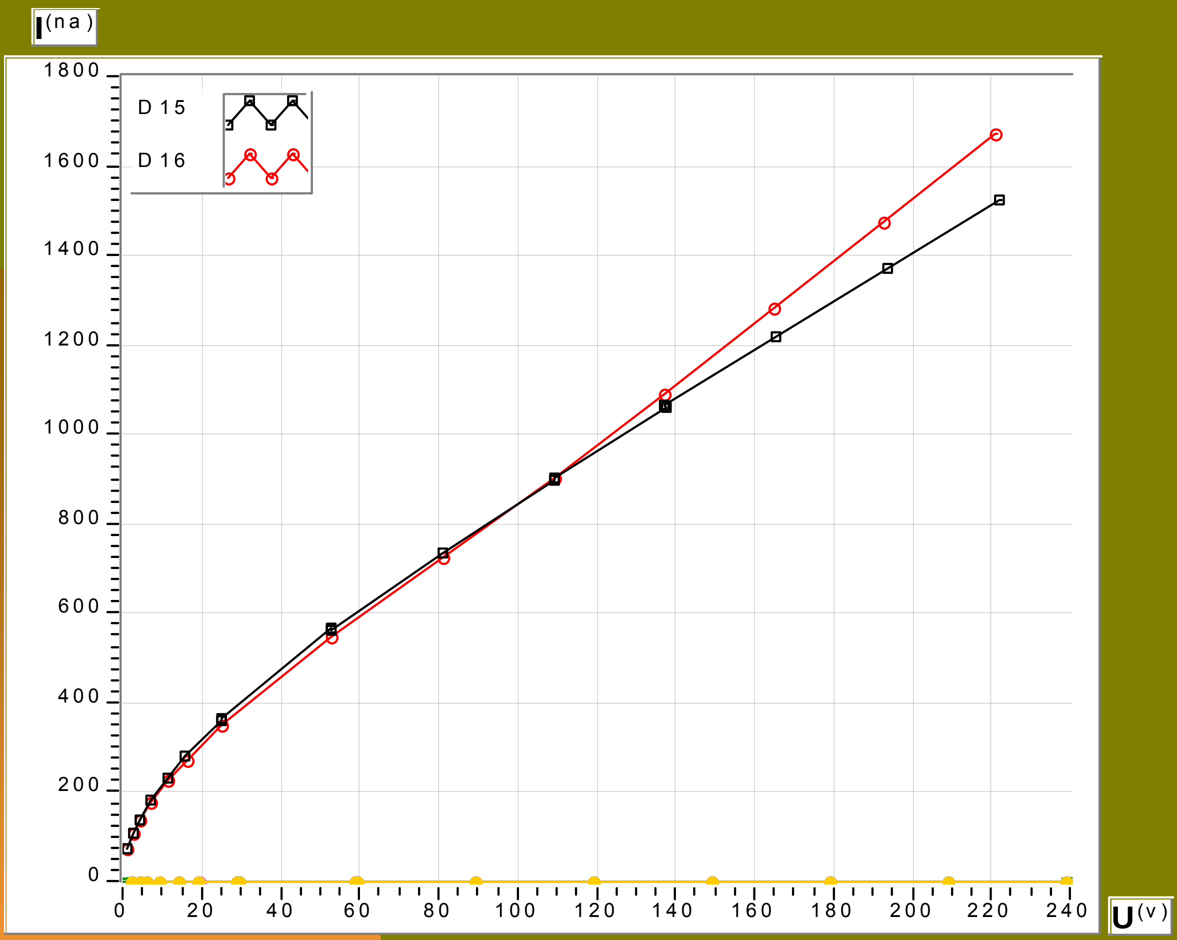
The absorbed doses were the same in both sets and they corresponded to fluences from $2{\cdot}10^{13}$ p/cm^2 to $5{\cdot}10^{15}$ p/cm^2 .





GaAs tests: booster run Nov. 2003
6*10^11 p/pulse
2*10^11 p/pulse
CH. COLLECTION
0 Mrad #4
0.40 Mrad #12
0.43 Mrad #28
1.80 Mrad #26
3.50 Mrad #25
CC(dose)/CC(0)
dose, Mrad
norm. CCE
1 - 0 Mrad, det. #4
2 - .43 Mrad, det. #28
3 - 1.8 Mrad, det. #26
U bias, volts
V opt
V opt=U on plateau
Dose, Mrad
Detector Recovery
0.4 Mrad
0.43 Mrad
1.8 Mrad
CC/CC(0)
days

GaAs N15 and N16 irradiated by gammas



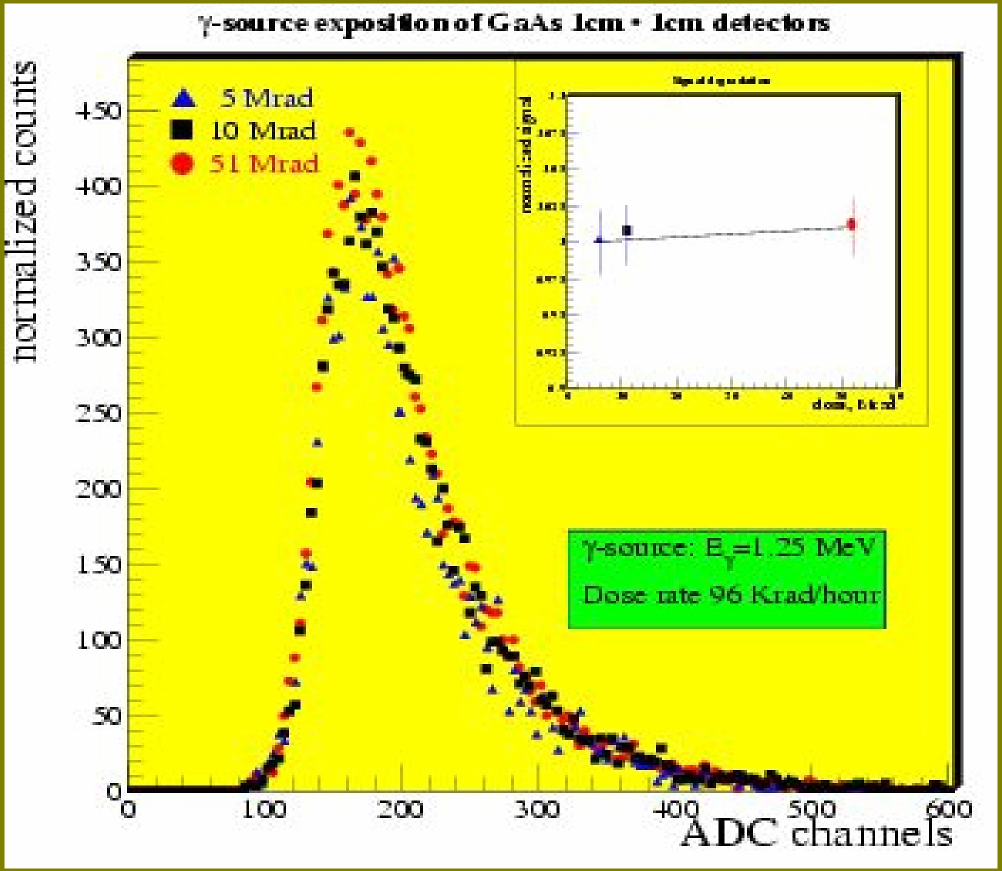
- γ source: Co_{27}^{60} , E_{γ} = 1.25 MeV
- Dose rate 96 Krad/hour
- Absorbed dose 5 Mrad

NOTE. Unfortunately, no curves obtained before irradiation

GaAs: Cr 1cm•1cm detectors

at gamma irradiation (Jan. 2004)

The detectors were exposed to γ source with the gamma energy 1.25 MeV. The absorbed doses ranged from 5 to 51 Mrad . The figures show the full tolerance of GaAs to the gamma fluxes within this load range.



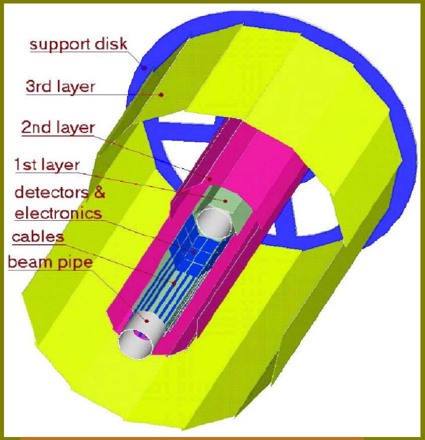
GaAs Prospects for LC particle ID

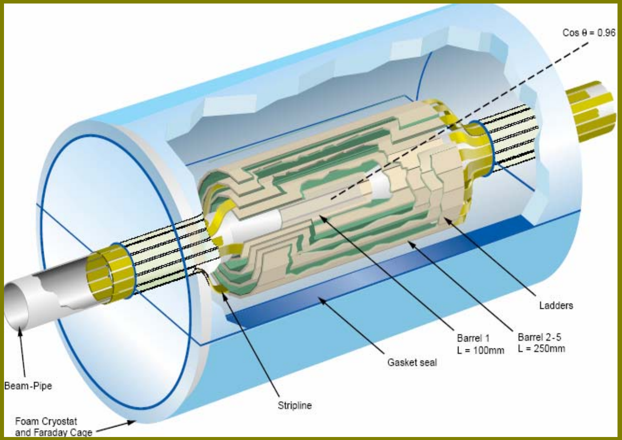
- Vertex detectors
- Forward detectors
- Forward calorimetry
- Luminosity monitors

TESLA

GaAs for TESLA tracking

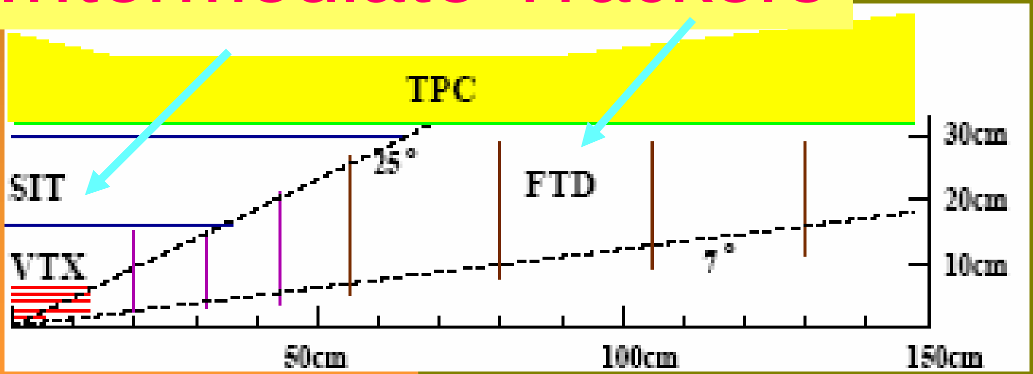
VTX





- Vertex Detector
- Intermediate Tracking System

Intermediate Trackers



GaAs:Cr for ECAL

LAT = Low Angle Tagger

TDR: 63 planes of W (2.6mm) and silicon (0.5mm)

GaAs alternative: a few front planes with GaAs diodes.

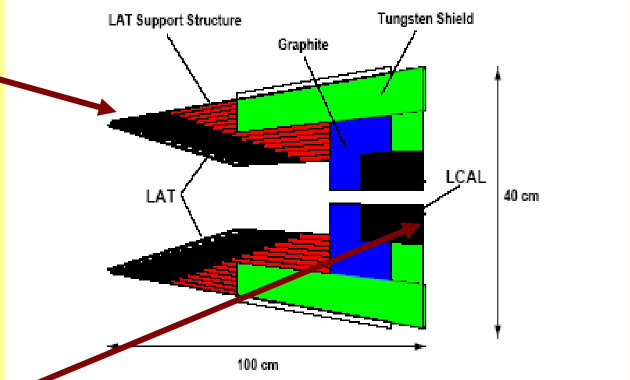
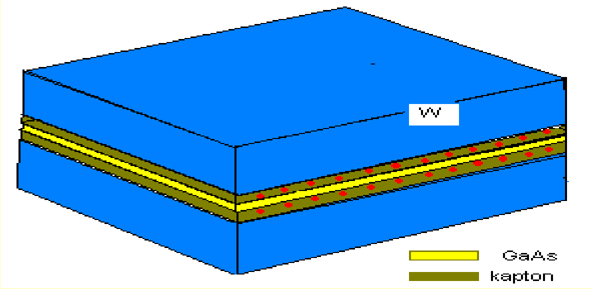


Figure 3.5.1: *Design of the forward angle calorimeters. The sampling calorimeters (LAT and LCAL, shown in black) are integrated into the tungsten shield of the mask.*

LCAL=LumiCAL

TDR: LAT-like W+Si design

GaAs alternative: full GaAs replacement of silicon



Conclusion

О.П. Толбанов говорит:

Вывод 3: В GaAs вдвое выше плотность ионизации, втрое выше быстродействие и в 5 раз выше амплитуда импульсов наведённого тока.

Вывод 4: GaAs в сравнении с Si имеет радиационную стойкость более, чем на 2 порядка выше.

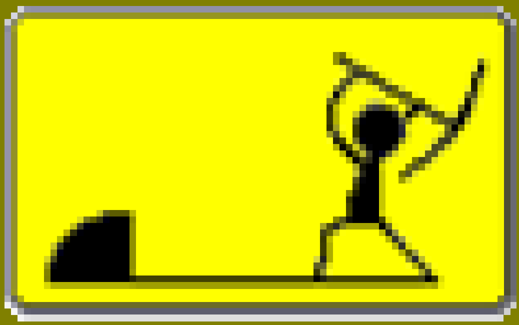
GaAs detectors provide:

- Stronger signal:
- Higher radiation hardness:
- Tolerant leakage currents (no refrigeration)
- New high-tech opportunities in HEP instrumentation
- Applied science and interdisciplinary studies

YET...

We continue to work…

It would be nice:



- to **continue studies** in hadron beams up to a final conclusive step regarding GaAs vs Silicon.
- to irradiate in **neutron** beams.
- to involve **interested parties**.
- to get **a support**.