Predictions on charge collection efficiency in heavily irradiated Si detectors basing on the approach of active base

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Outline

- **Motivation**
- **Background: revising of double peak E(x) distribution with active base in Si detectors irradiated up to SuperLHC fluence**
- **Simulation of E(x) and collected charge in pad and strip detectors with a consideration of active base and comparison with experimental data**
- **Impact of the study**

Conclusions

Motivation

Experiments that show **inconsistency**
between predictions and established regularities for detectors irradiated at LHC fluence (< 10^{15} cm^{-2}),
and results for the range of SuperLHC fluence (10^{15}- 10^{16} cm^{-2})

♦ At high *F* the collected charge is larger than expected

*I. Mándí*c et al., *RESMDD08, Florence, Italy, Oct 15-17, 2008;*
G. Casse, 13 RD50 Workshop, CERN, Geneva, Nov 10-12, 2008

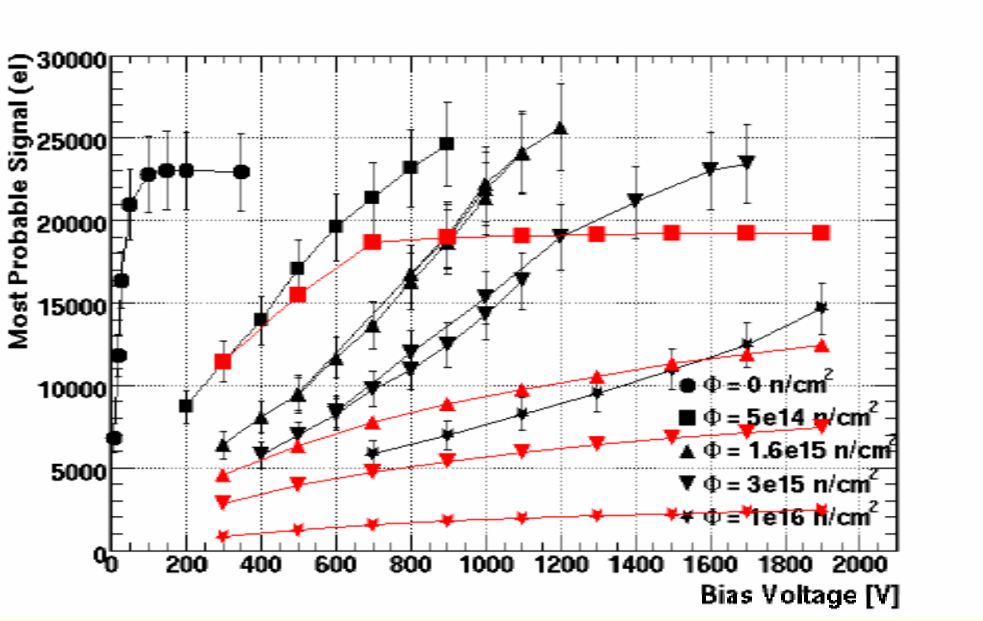
♦ deviation of trapping probability ($1/\tau$) vs. *F* from linear dependence at high *F*

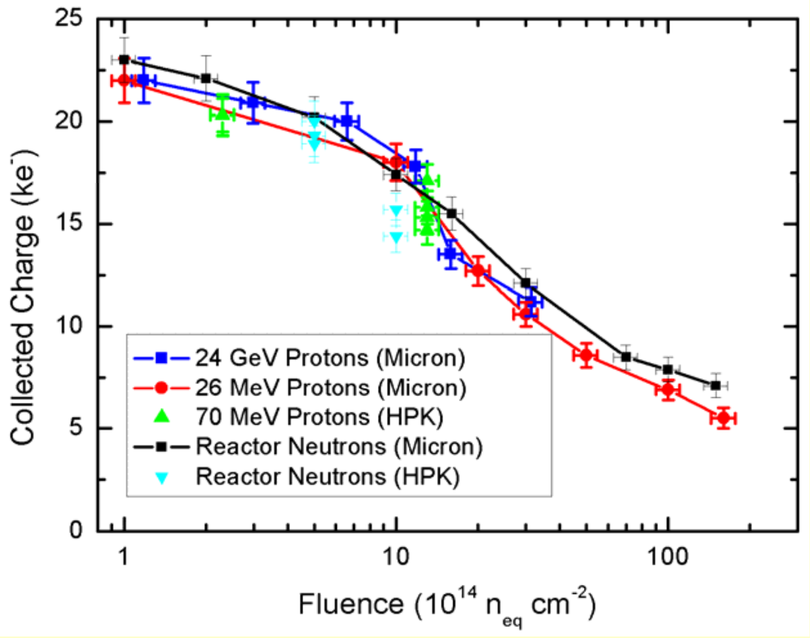
E. Verbitskaya et al.,, 14 RD50 Workshop, Freiburg, June 3-5, 2009

Earlier results on the collected charge

I. Mándíc et al., *RESMDD08, Florence, Italy, Oct 15-17, 2008*

G. Casse, 13 RD50 Workshop, CERN, Geneva, Nov 10-12, 2008



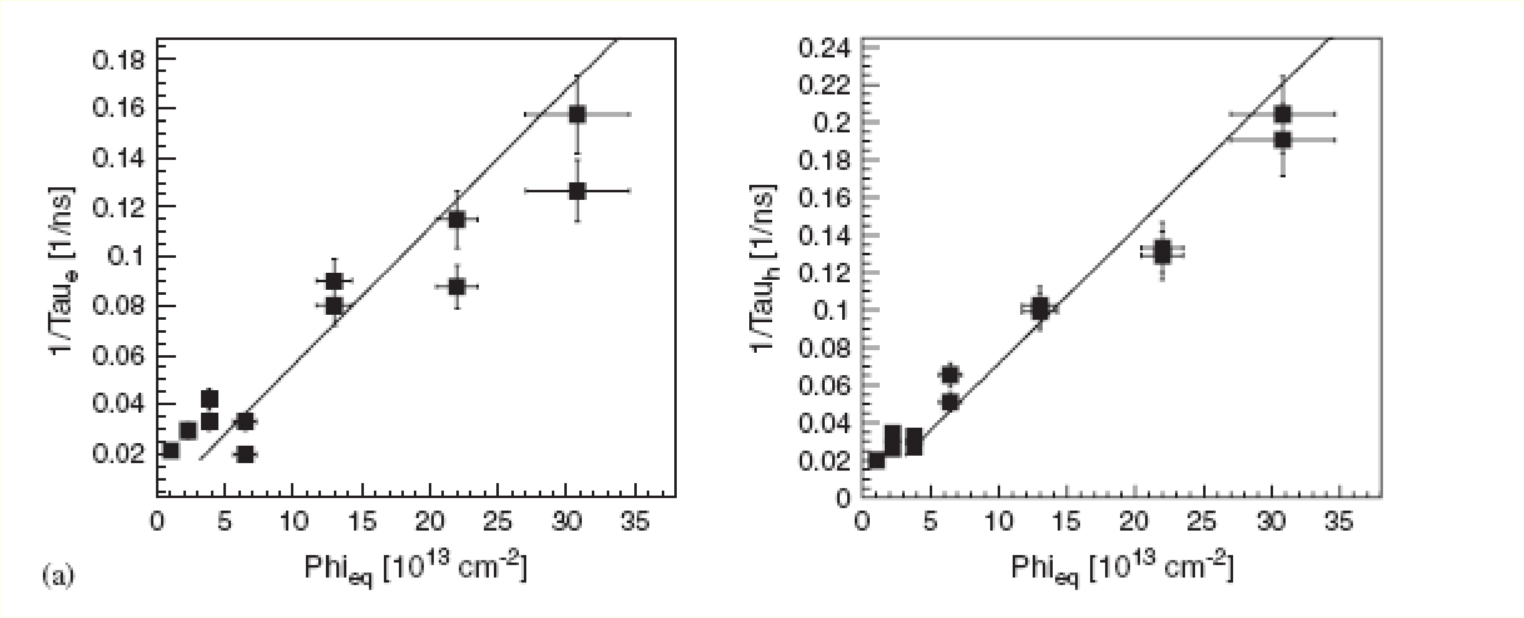


Black – experiment, red - simulations

Collected charge is higher than simulated

E. Verbitskaya et al.,, 14 RD50 Workshop, Freiburg, June 3-5, 2009

Earlier results on the trapping probability



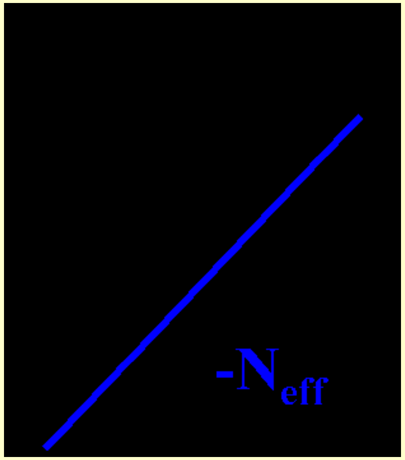
A. Bates and M.Moll, NIM A 555 (2005) 113–124

Deviation from linear dependence and a slight tendency to saturation at high *F* – underestimation?

Standard model of linear electric field distribution in irradiated Si detectors - Single Peak (SP) E(x)

N_{eff} = const, $E(x)$ – linear,
V_{fd} derived from C-V curves

Valid for $F \sim 10^{13}$-10^{14} cm^{-2}

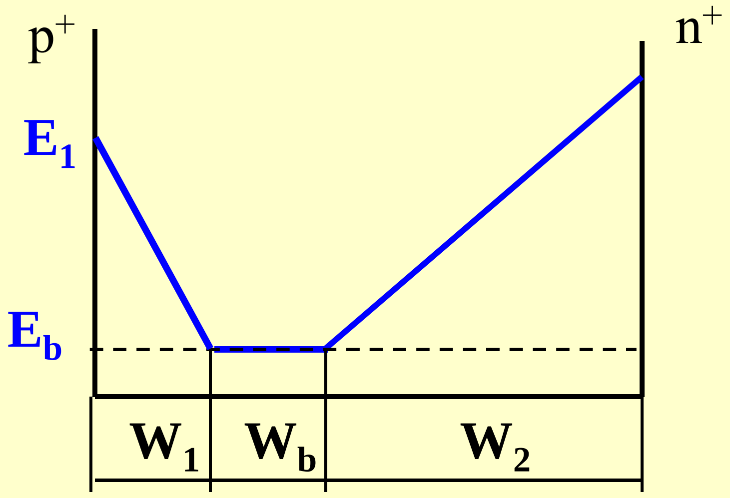


n-type Si
beyond SCSI
-N_{eff}

E. Verbitskaya et al.,, 14 RD50 Workshop, Freiburg, June 3-5, 2009

Advanced model: Double Peak (DP) E(x) distribution in heavily irradiated Si detectors

E. Verbitskaya et al., NIM A 557 (2006) 528-539, and NIM A 583 (2007) 77-86



- Three regions of heavily irradiated detector structure are considered
- **Reverse current flow creates potential difference and electric field E_b in the neutral base – base becomes active! w → d, $CCE_g \to 1$**
- **Free carriers generated by detected particles can drift in the entire detector bulk**

Active base is a key factor for charge collection

Tools for study

Task: **revising of operation of the detectors with active base; receiving the quantitative data on the influence of E_b on Q_c**

Simulation programs:

- Trapping program: E(x) **profile with a consideration of carrier trapping to midgap energy levels:** **DD** $E_V + 0.48$ eV; **DA** $E_C - 0.52$ eV; *simulation is based on* Shockley-Read-Hall statistics

- ***CCE program: collected charge Q vs. V and F in pad detectors, and strip detectors with a consideration on weighting electric field; trapping is considered via $\tau(F)$***

Simulations of $Q_c(F)$ are made for 1 MeV neutron irradiation - SCSI is evident, E(x): ~ SCR at n^+ contact (W_2) + active base

$\beta_e = 3.7 \cdot 10^{-16}$ ns
$\beta_h = 5.7 \cdot 10^{-16}$ ns
G. Kramberger,
NIM A 583 (2007) 49-57
$g_c = 0.02$ cm^{-1}
V = 900 V
T = 263K

Comparison with experimental data of G. Casse;
***V* = 900 V**

Considerations

***Q* ~ *CCE*$_g$ · *CCE*$_{tr}$**

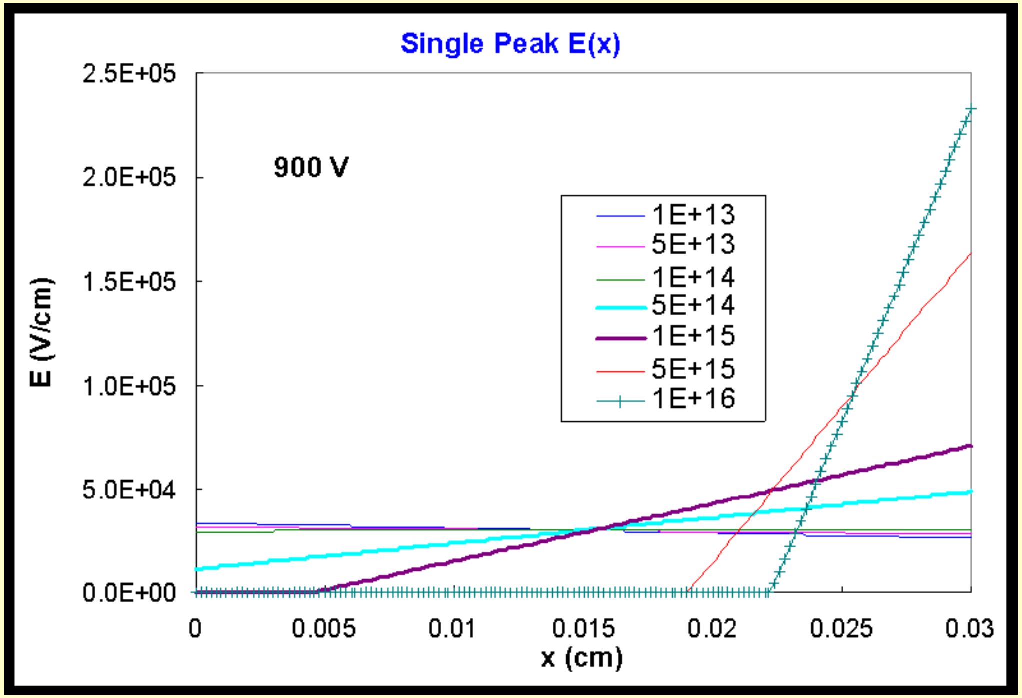
***CCE*$_g$ ~ *w/d* - geometrical component**

***CCE*$_{tr}$- - trapping related component**

- In case of active base w → d and $CCE_g \rightarrow 1$
- Maximum Q_c is expected at uniform E: w ≡ d
- In case of uniform E and without trapping
  $Q_c = Q_{max}$ = 23 keV at any F

SP E(x)

Neutron irradiation, pads p-on-n, MCZ n-type Si, ρ ≈ 2 k, d = 300 μm



At F > 10^{15} cm^{-2} E at n^+ contact becomes ≥10^5 V/cm – close to breakdown! Questionable!

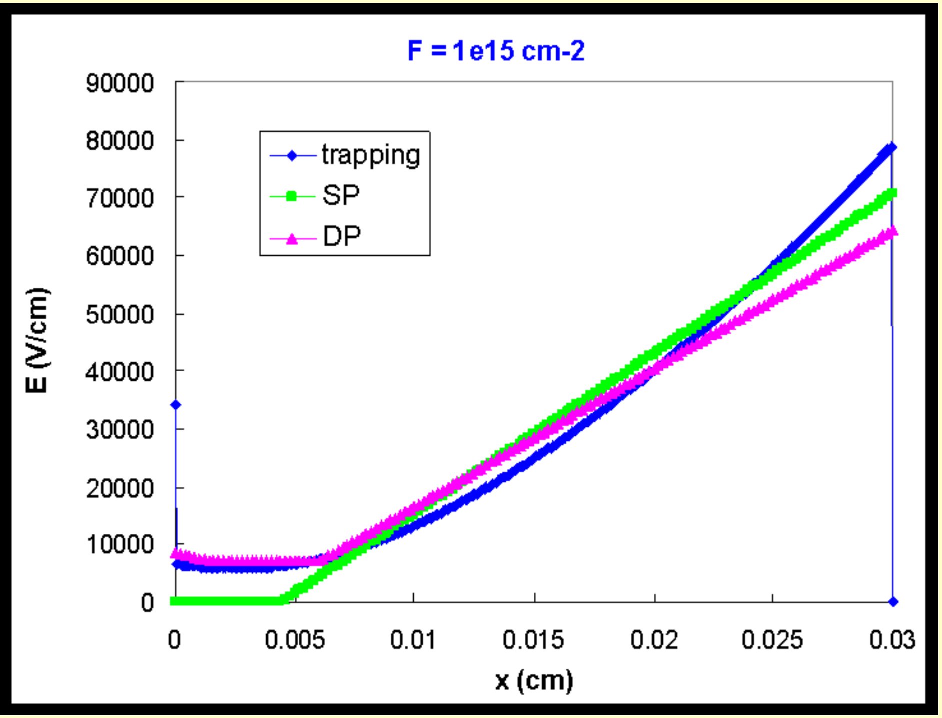
Data of I. Mándíc are similar - simulated E may reach 10^5 V/cm

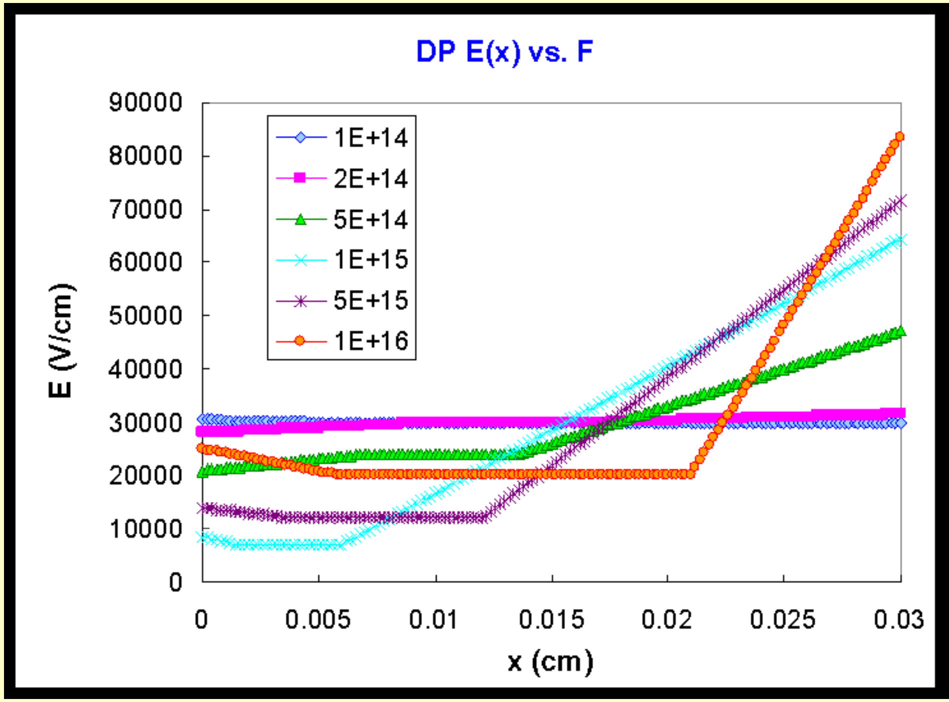
BUT detectors well operate up to V ~ 2 kV!

E. Verbitskaya et al.,, 14 RD50 Workshop, Freiburg, June 3-5, 2009

DP E(x)

Pads, V = 900 V





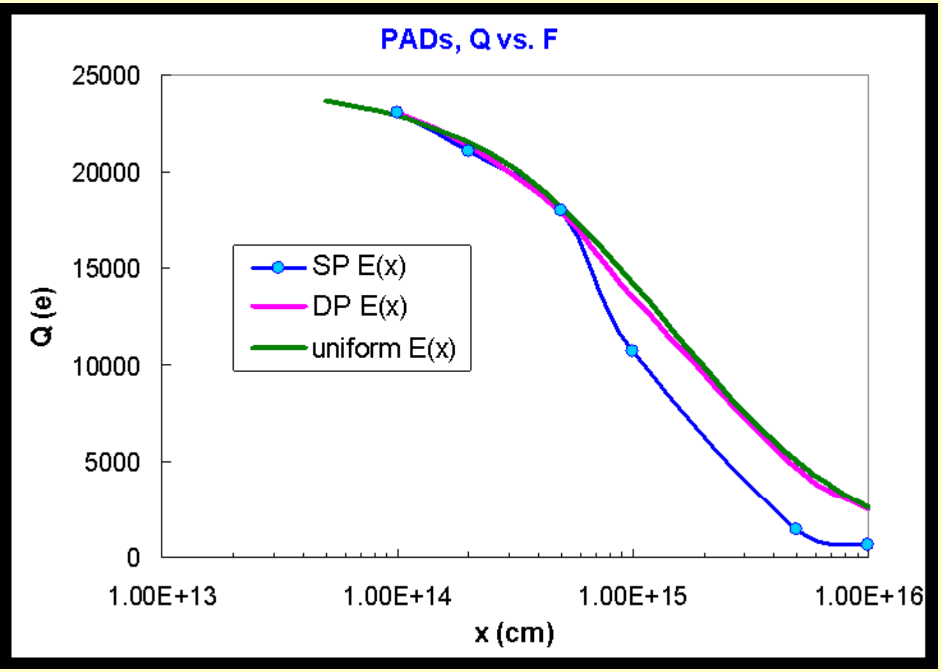
Trapping model:

$k = N_{DA}/N_{DD} = 1.35$

E. Verbitskaya et al., *NIM A 583 (2007) 77-86*

- **Electric field profile is asymmetric as it is for neutron irradiation**
- **E is below 10^5 V/cm**

Collected charge for SP, DP and uniform E(x) in pad p^+-n detectors



The collected charge is similar in detectors with DP and uniform E(x) – related to the saturation of drift velocity at E ~ kV/cm

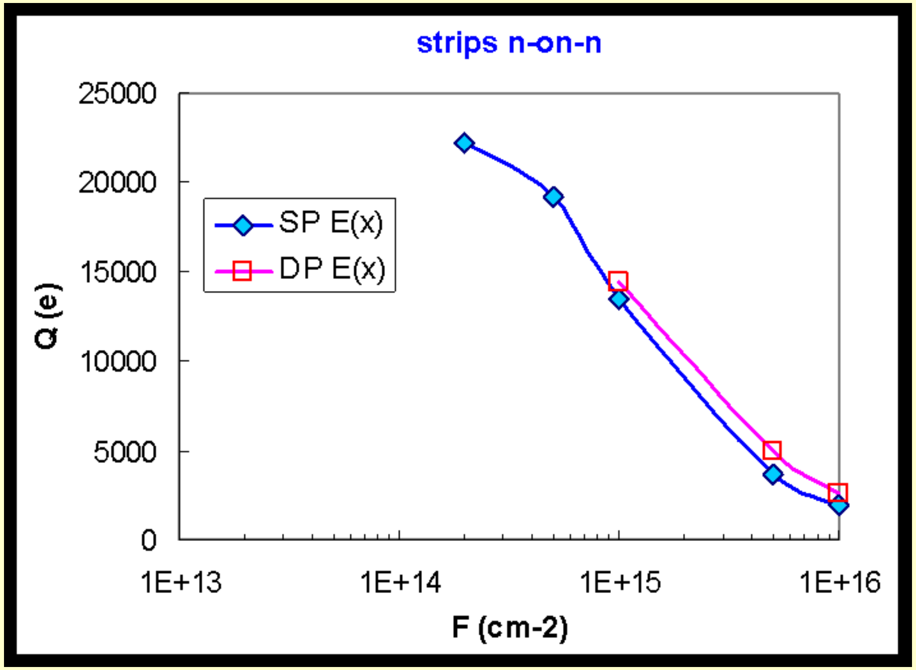
***E_b*:** 1-20 kV/cm
at F_{eq} $5 \cdot 10^{14}$-$1 \cdot 10^{16}$ cm^{-2}

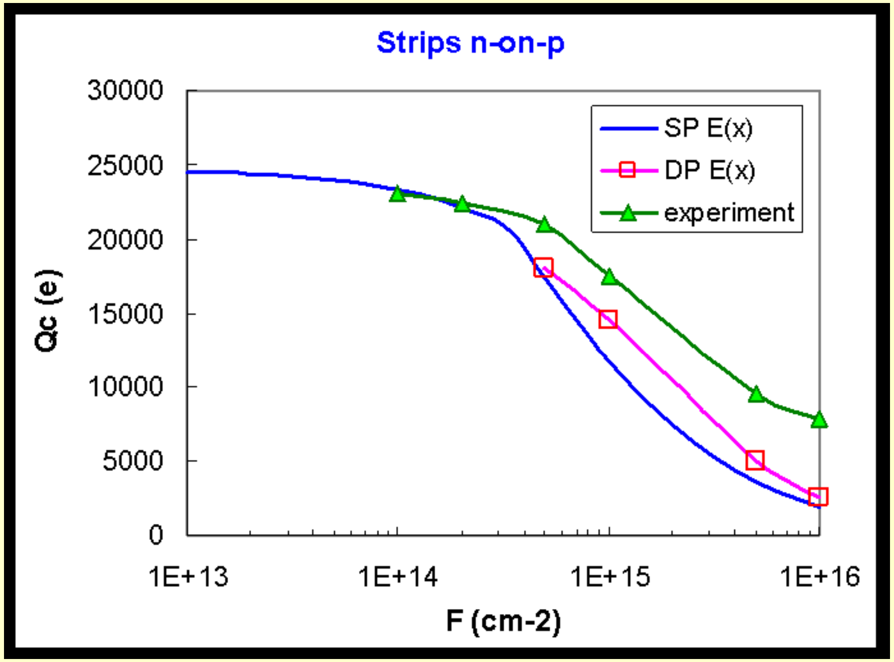
$$E_b = \rho \cdot I \rightarrow \sim F$$

$\rho = \rho_i$ – in neutral bulk only,
active base is modulated by current,
$\rho = 5 \cdot 10^4$ Ohm·cm

E. Verbitskaya et al.,, 14 RD50 Workshop, Freiburg, June 3-5, 2009

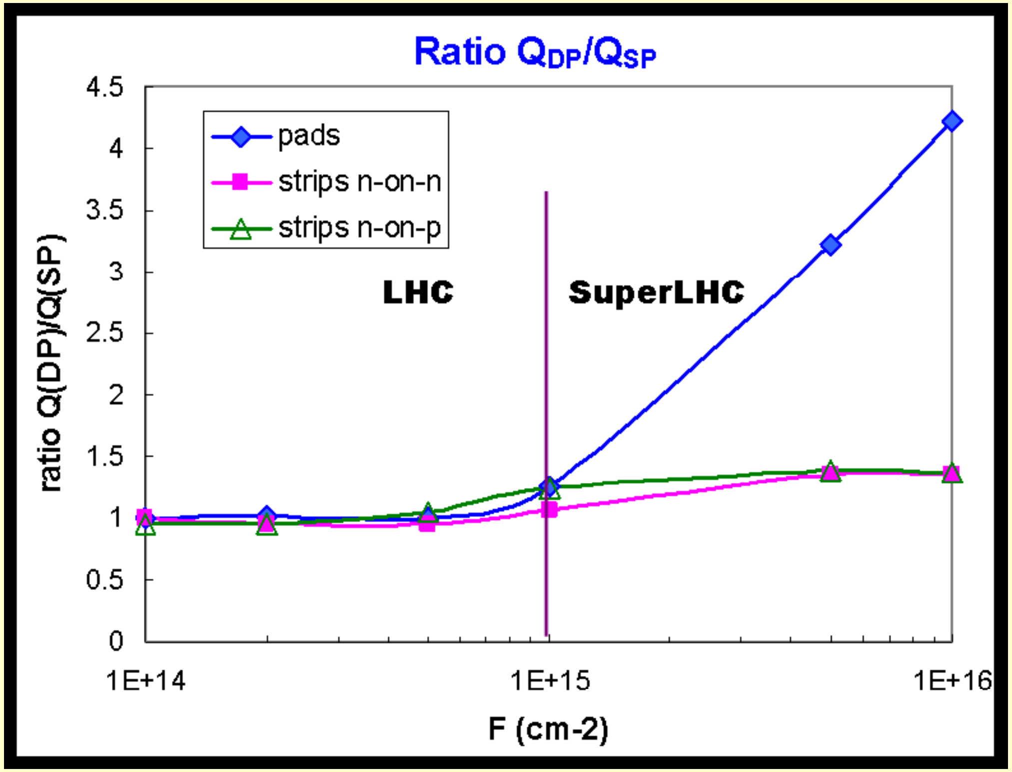
Q_c for SP and DP E(x) in strip detectors





Experimental collected charge is still larger than Q_c simulated with DP *E(x)* profile

Gain in the collected charge for DP E(x) in pad and in strip detectors



Significant increase of collected charge is predicted in the SuperLHC fluence range

Pads: 4.2

Strips: 1.35

Strips: interference with weighting field which has its maximum near the strips

E. Verbitskaya et al.,, 14 RD50 Workshop, Freiburg, June 3-5, 2009

Possible reasons of enhanced experimental Q_c

Additional factors that may lead to Q_c increase:

- underestimation of trapping time constants,
- avalanche effects,
- Poole-Frenkel effect.

At F = $1 \cdot 10^{16}$ cm^{-2} adjustment of calculated Q_c to the experimental value of 7800e (with lower β) gives calculated Q_c larger than experimental values at all $F < 1 \cdot 10^{16}$ cm^{-2}!

→ **the other factors are essential – now under study**

(Avalanche effects: V. Eremin, 14 RD40 workshop)

Impact of the study

- Operation of irradiated Si detectors with active base is revised: Enhanced current of detectors irradiated by SuperLHC fluence leads to significant increase of the electric field in the base region.

- Innermost pixel detectors are p-on-n structure and E_b is the important parameter for prompt detector operation.

- Upcoming experiments in nuclear and high energy physics (FAIR project) require low mass detectors for which double sided strip design is optimal. P+ side of these detectors will operate in the low field defined by the active base properties.

Conclusions

- Electric field in the active base is a key factor for charge collection increase in heavily irradiated Si detectors since the carrier transfer occurs in the entire detector.
- **The collected charge is insensitive to the value of this field that is related to saturation of drift velocity at E ~ kV/cm while E_b may reach 20 kV/cm.**
- **The active base leads to the increase of the collected charge in SuperLHC fluence range.**

Acknowledgments

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Thank you for attention!