Silicon Microstrip Detectors
and
the Lazarus Effect

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Workshop on rad-hard semiconductor devices
CERN, 28-30 November, 2001

- The DELPHI/LHCb/RD39/COMPASS testbeam
- Cluster shapes and depletion depth
- Temperature dependence – and other dependences
- Artificial "forward bias"
- Conclusions

Test beam - August 1998

Collaboration between these people:

B.M. Barnett, P. Bartalini, W.H. Bell, K. Borer,
T. Bowcock, J. Buytaert, L. Casagrande, P. Chochula,
P. Collins, C. Da Viá, H. Dijkstra, O. Dormond, A. Esposito,
R. Frei, V. Granata, S. Janos, I. Konorov, C. Lourenço,
T.O. Niinikoski, S. Pagano, V.G. Palmieri, C. Parkes,
S. Paul, K. Pretzl, T. Ruf, G. Ruggiero, S. Saladino,
L. Schmitt, K. Smith, P. Sonderegger, I. Stavitski,
D. Steele, F. Vitobello

from these experiments:

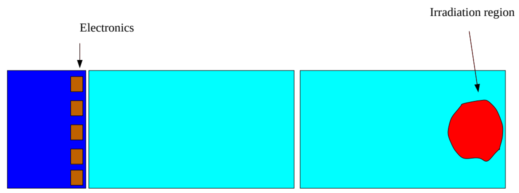
- DELPHI - provided detectors
- LHCb - interest in high radiation environments
- RD39 - cryogenics
- COMPASS - running test beam

Aim of testbeam:

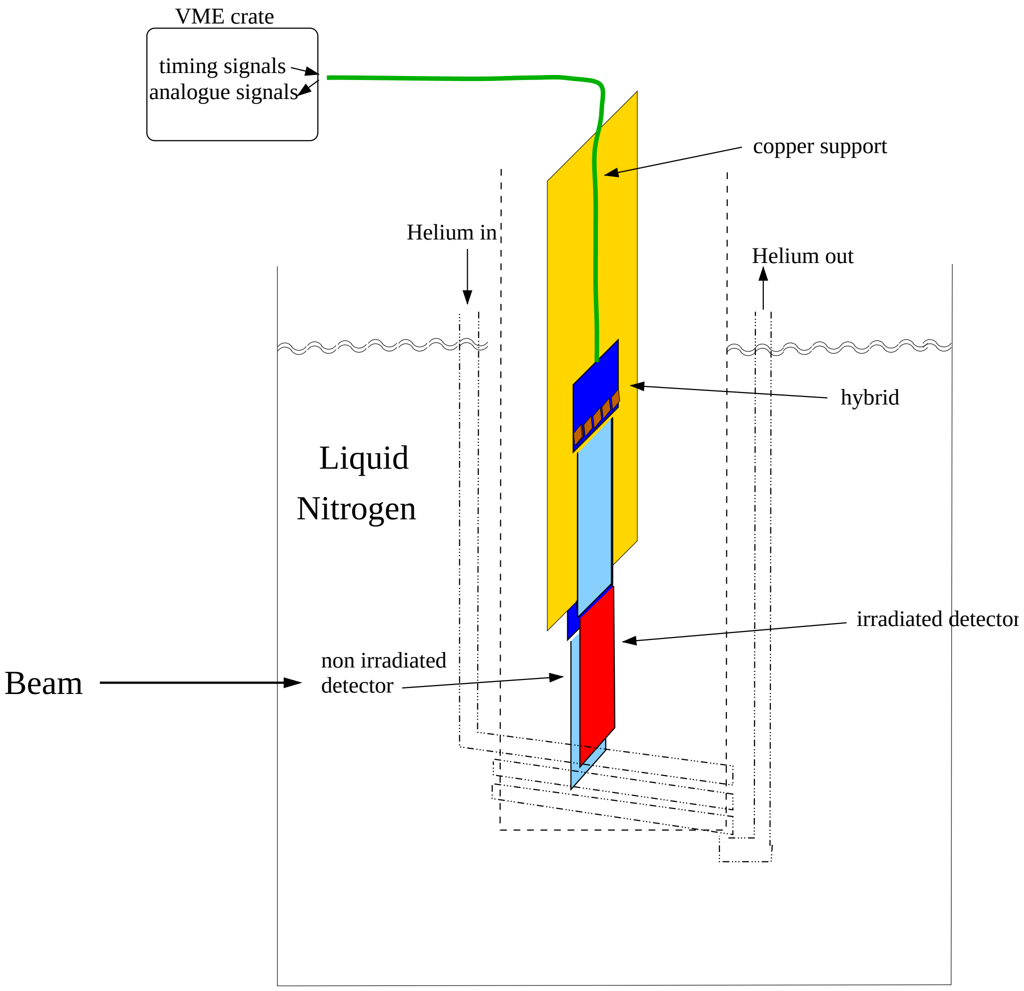
Irradiate a full, realistic detector module, to $4 \times 10^{14} p/cm^2$ and operate at cryogenic temperatures, in order to investigate the Lazarus Effect.

Recipe

- Take a long detector and remove mechanical supports
- Irradiate the tip to preserve the rad-soft electronics

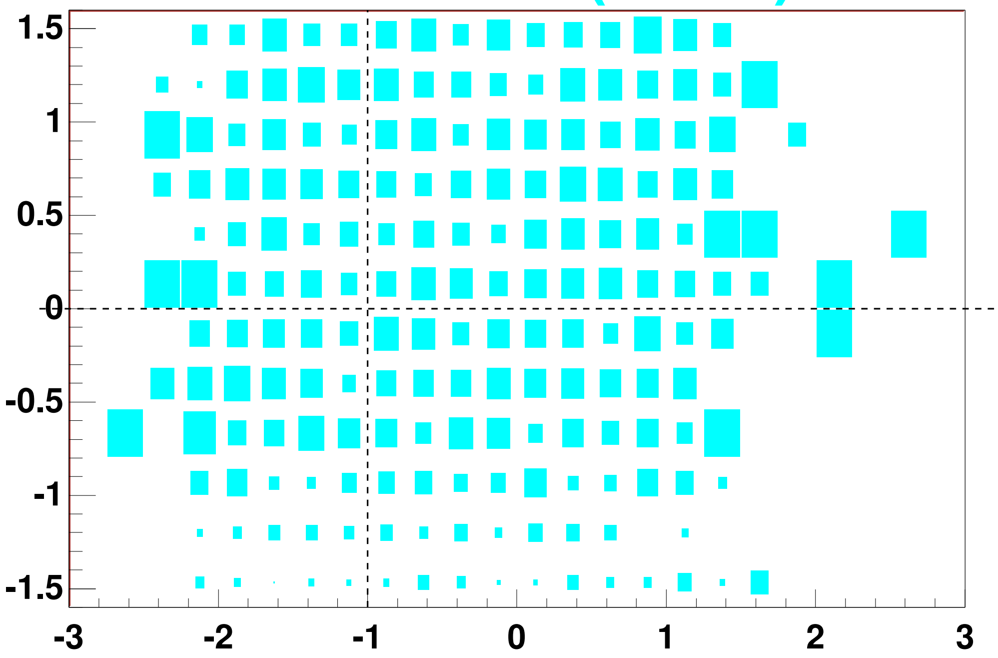


- Install in cryostat in testbeam

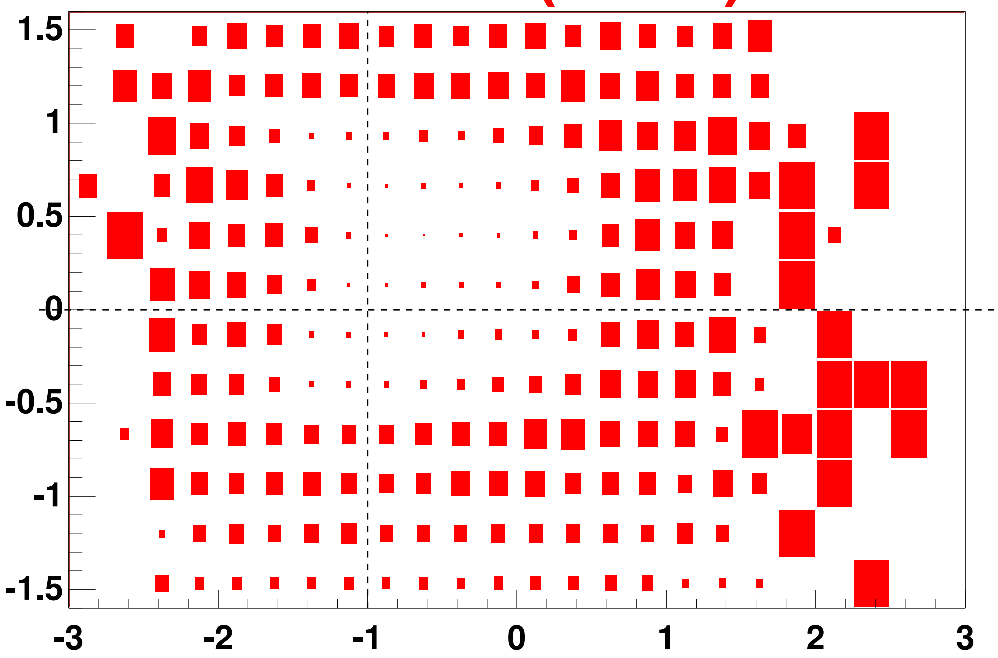


Raw Data - Lazarus Lives!

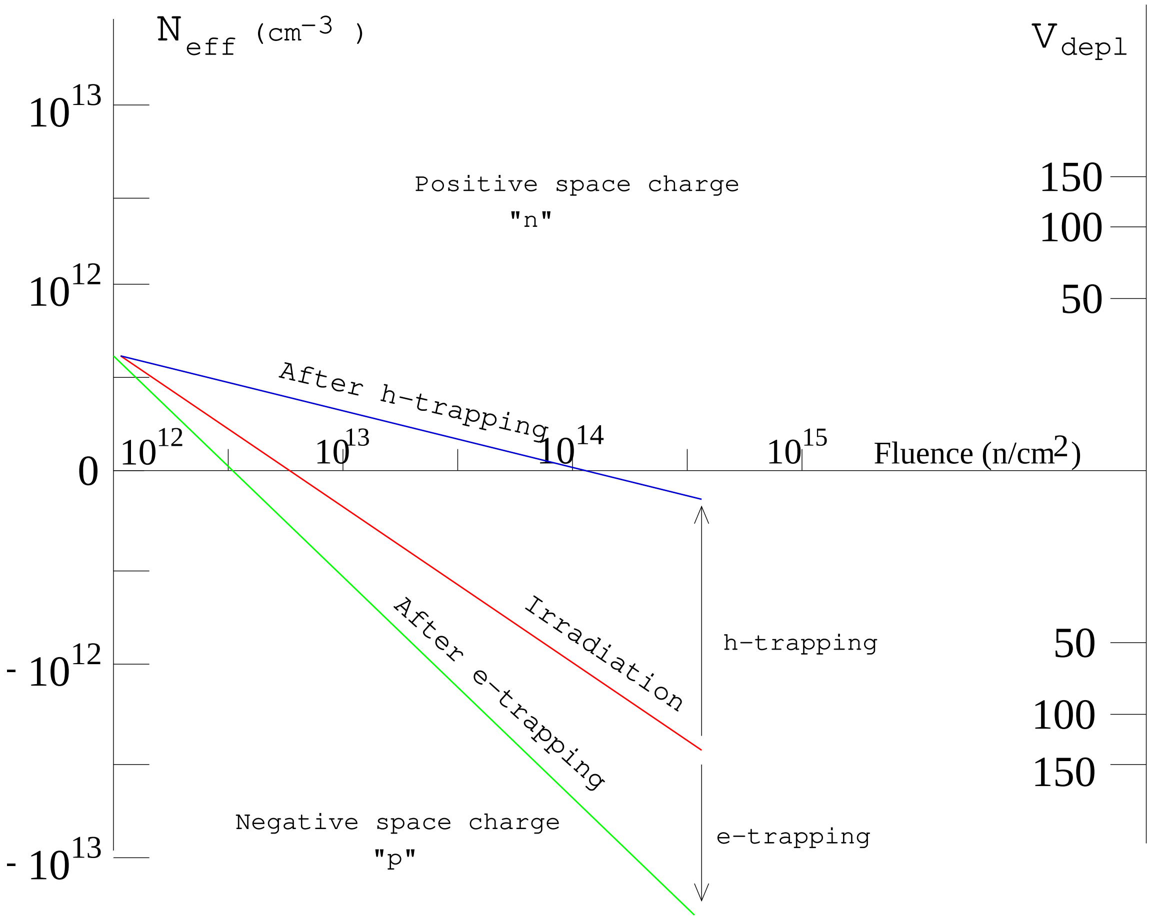
COLD (110K)



HOT (130K)



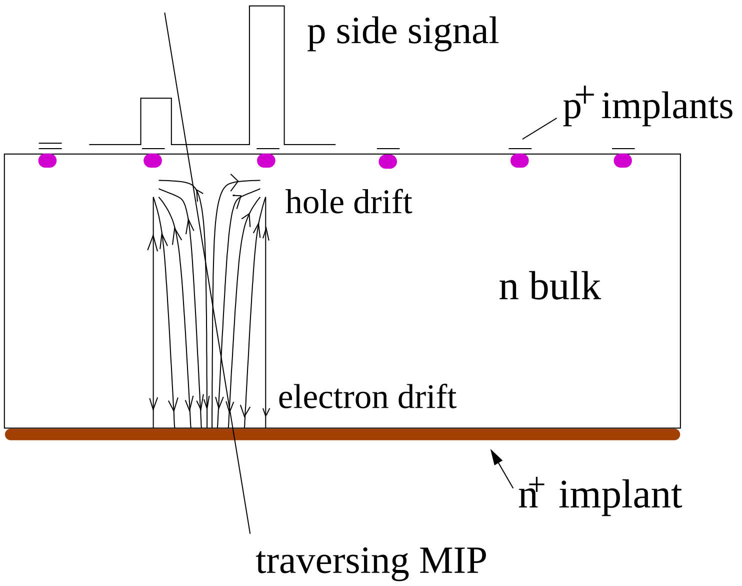
Some theory can explain the variations in Charge Collection Efficiency

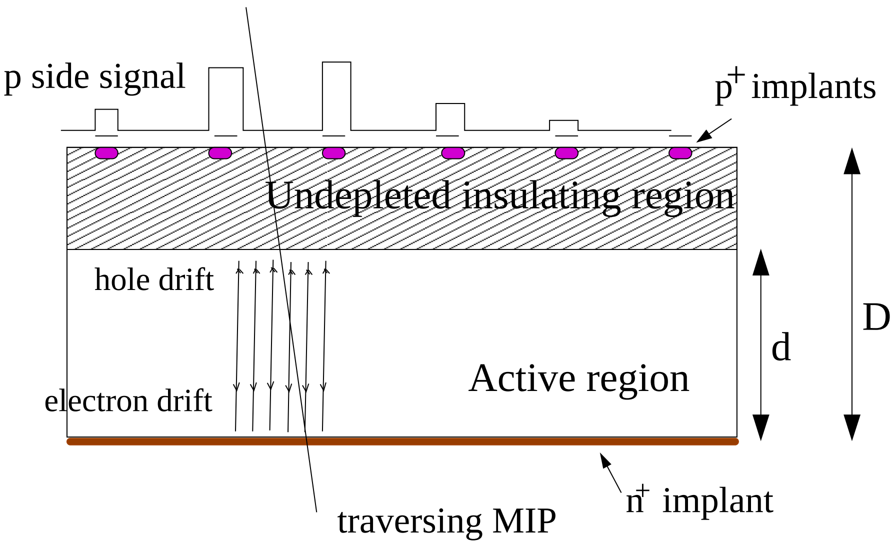


- **At warmer temperatures at 90V we are not fully depleted**
- **At colder tempeartures the same voltage is sufficient to fully deplete the detector**

But.. the efficiency falls off faster on the p side than the n side! And the resolution deteriorates on the p side but not on the n side! → there is a second effect

Based on a publication of Alex Chilingarov (NIM A 395 (1997) 29-34)

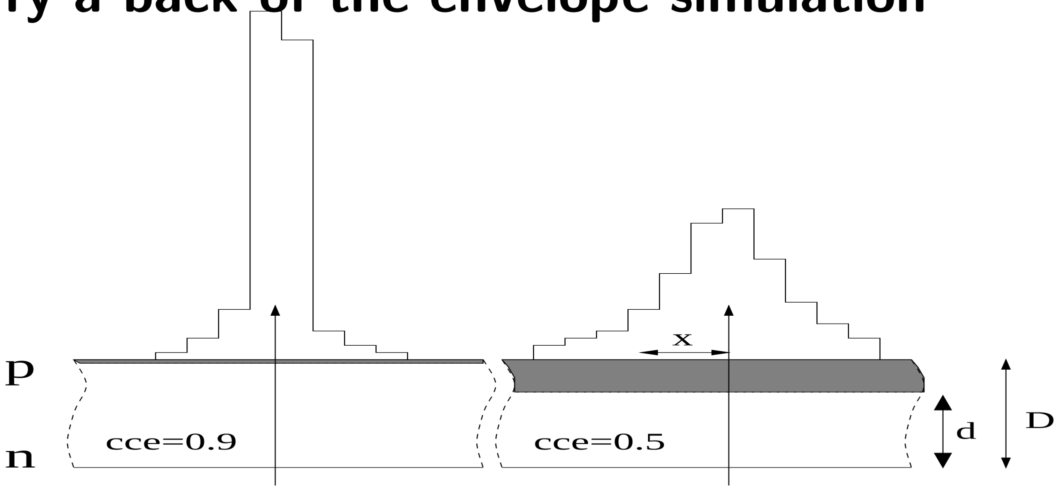




The Double Disaster of underdepletion: detector:

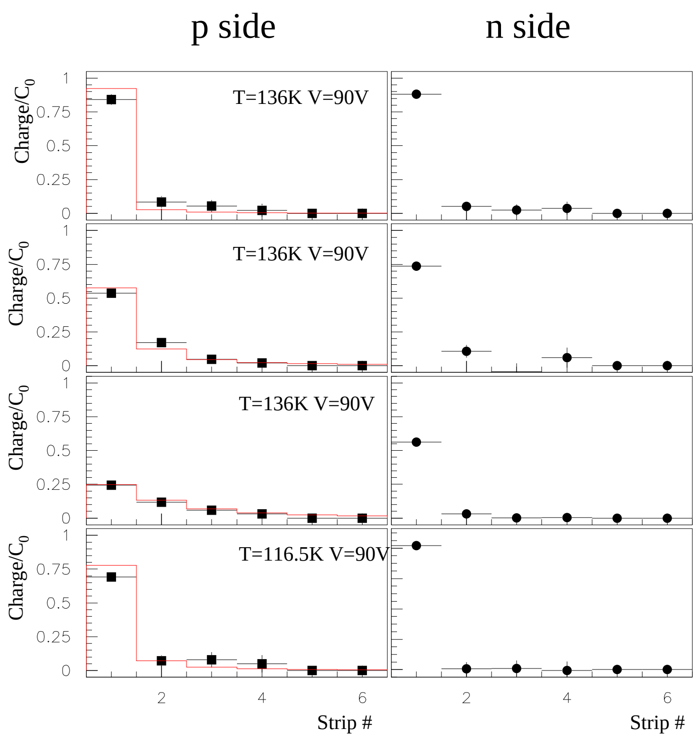
- **Charge collection efficiency drops on both sides ($\propto d^2/D^2$)**
- **Clusters spread on the p side, leading to loss of efficiency and resolution**

How to quantify the effect?
Try a back of the envelope simulation



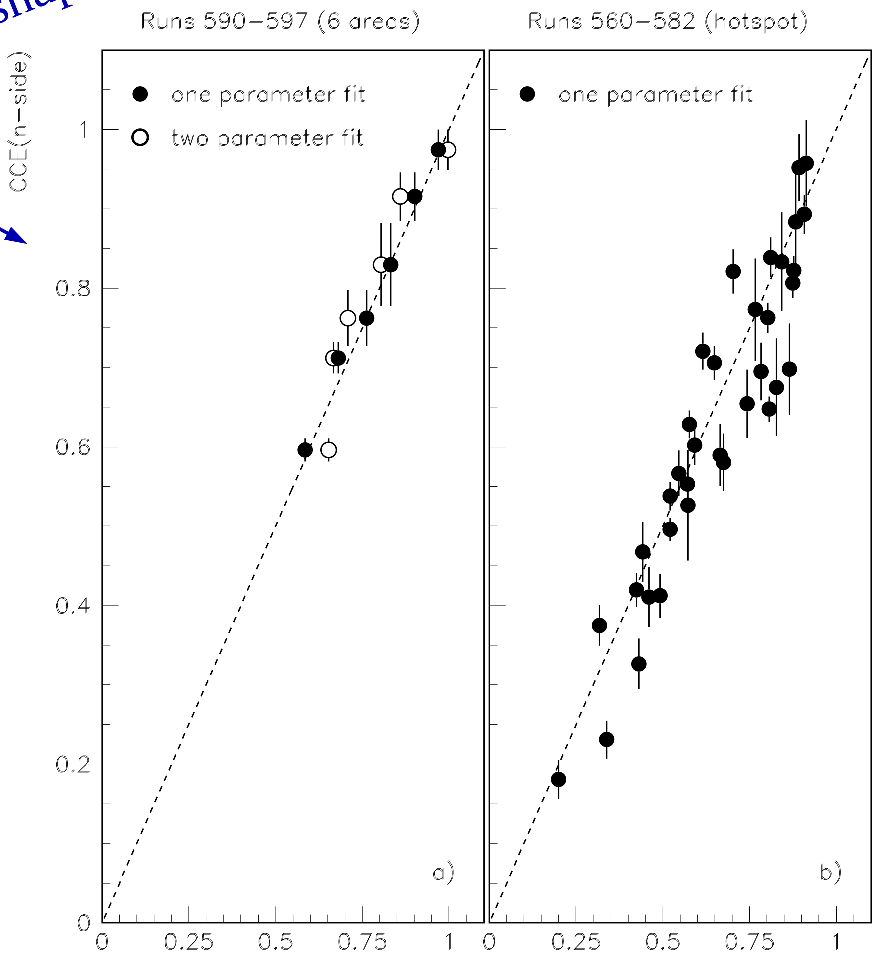
$$f_{\mathrm{CCE}} = \frac{\frac{1}{x^2+(D-d)^2}}{\sum_{\mathrm{strips}} \frac{1}{x^2+(D-d)^2}} \tag{1}$$

One parameter (depletion depth) predicts perfectly the cluster shape and the amount of charge collected



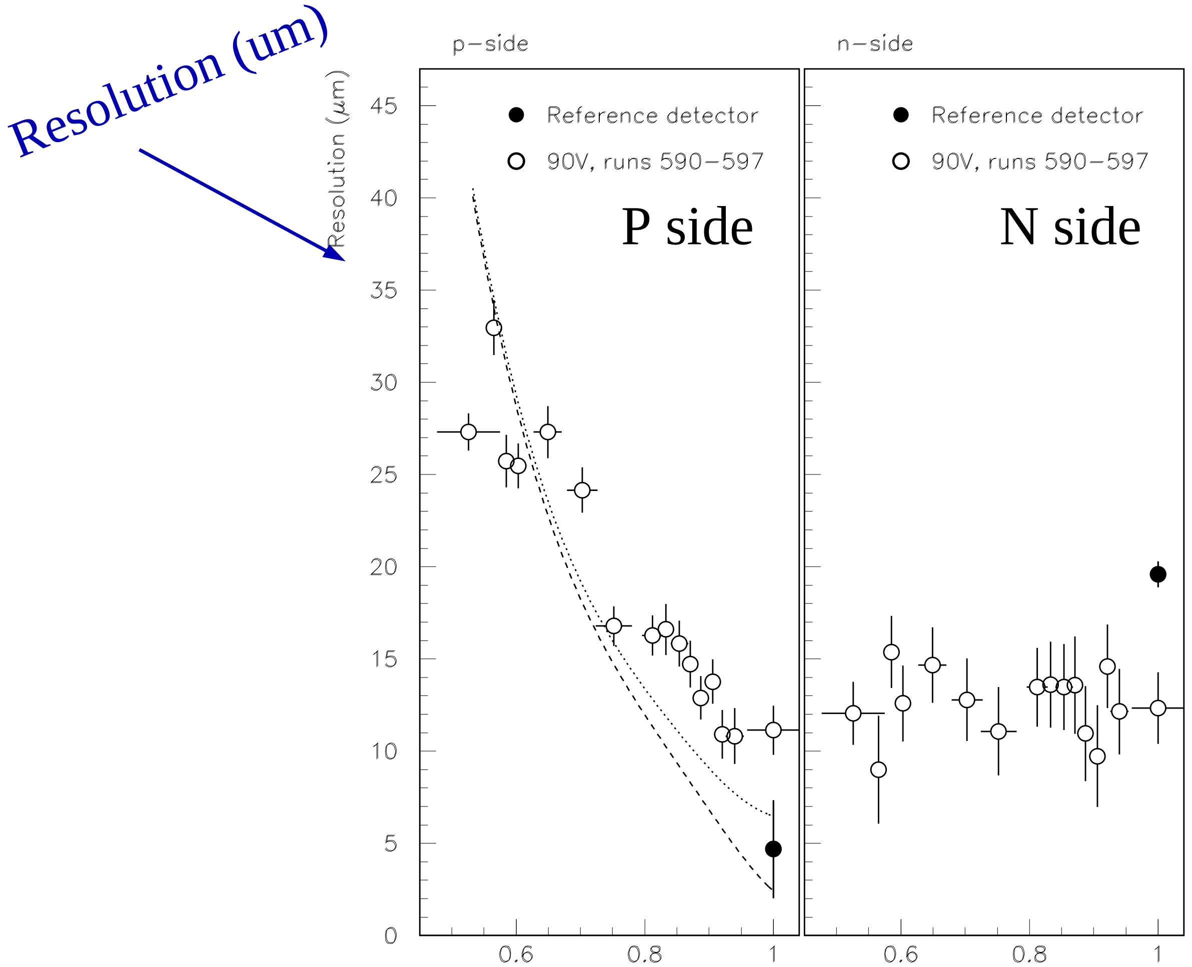
Perfect Agreement between n and p side at all ranges of underdepletion

CCE predicted from
p side cluster shape



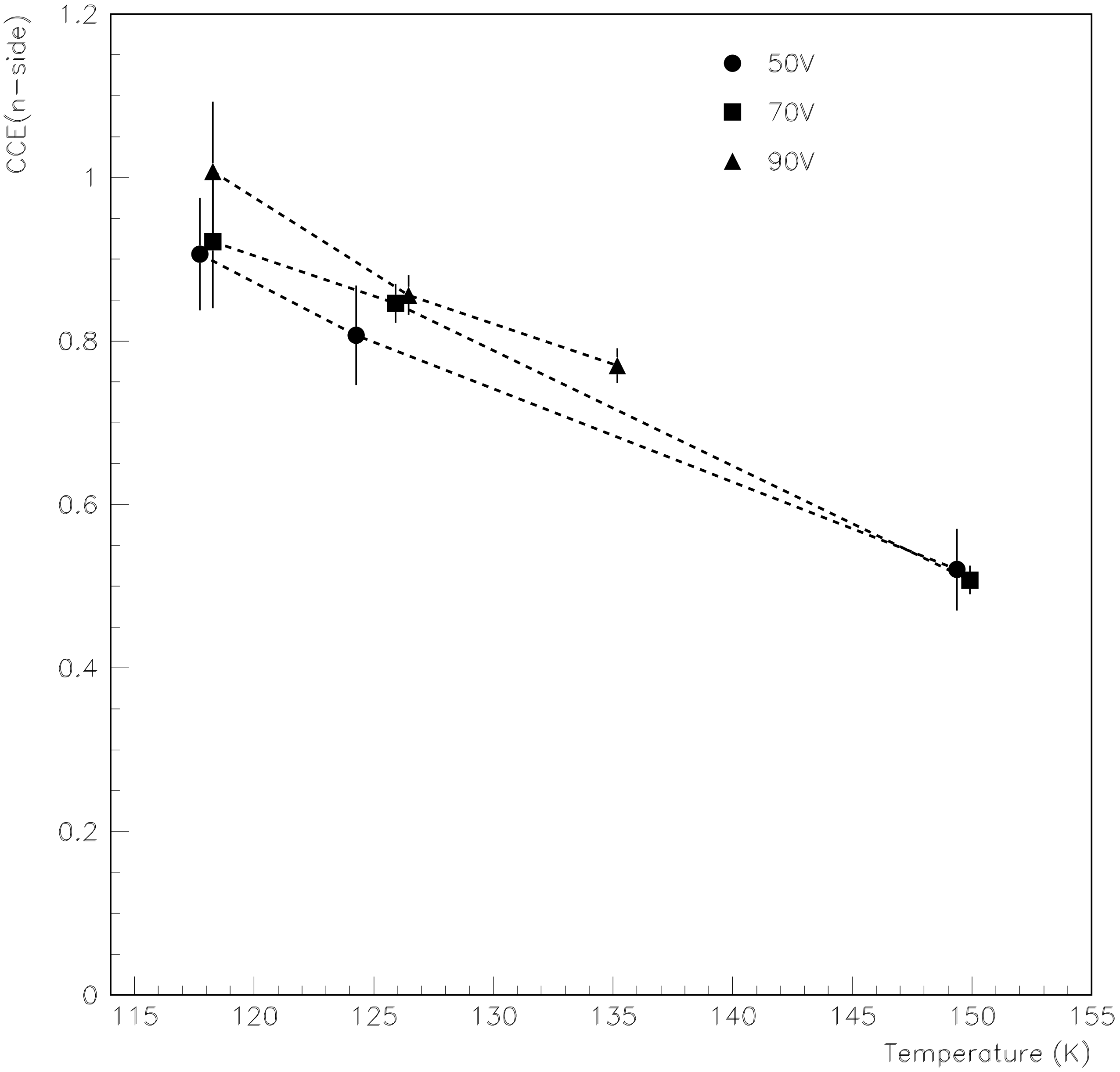
CCE measured on n-side
(= CCE measured on p side)

With important implications for the resolution



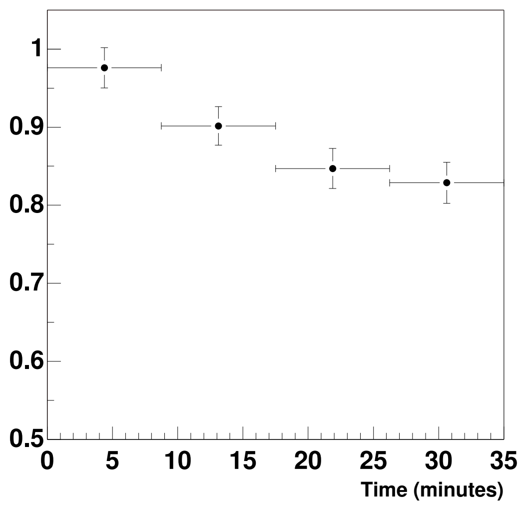
CCE measured on n-side
(= CCE measured on p side)

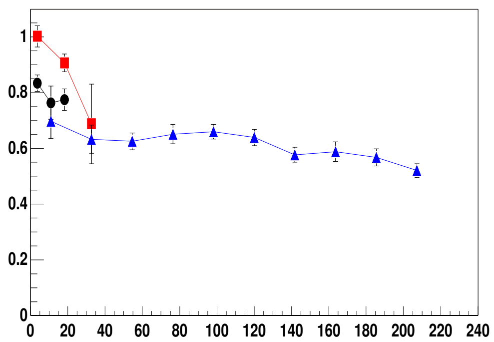
How can we control the amount of underdepletion?
$\rightarrow$ Change the temperature!



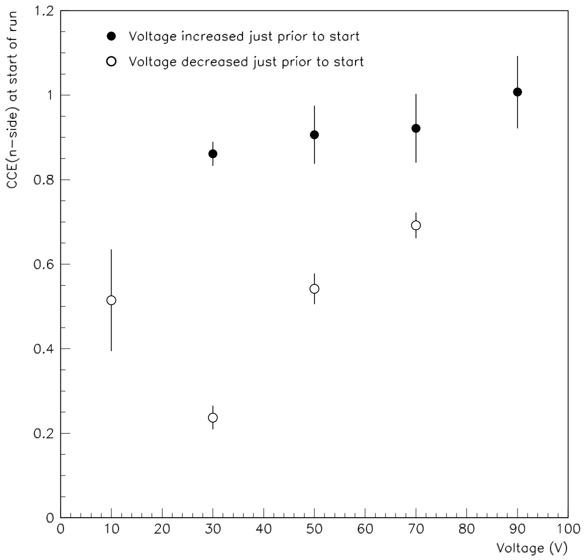
A more detailed analysis showed that other effects are equally important:

CCE shows a time dependence:

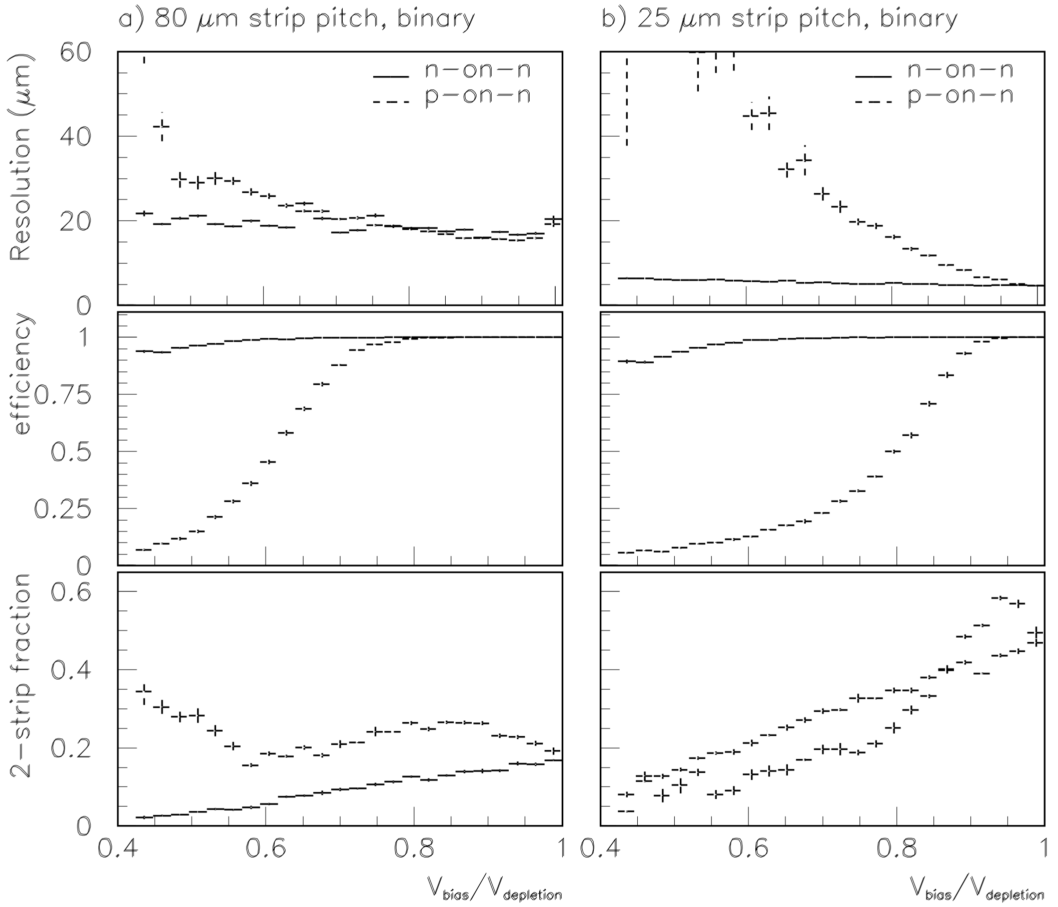




And a dependence on starting conditions:

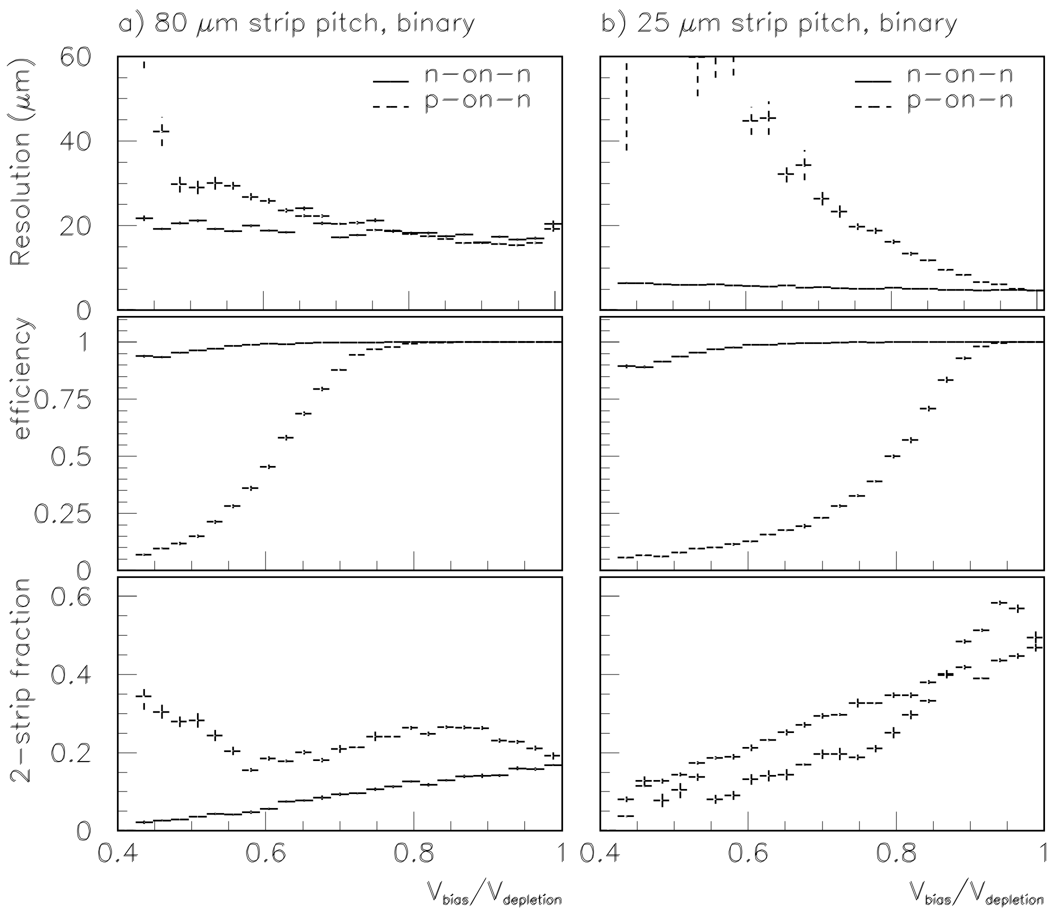


The same model predicted behaviour for wide pitch/fine pitch detectors:

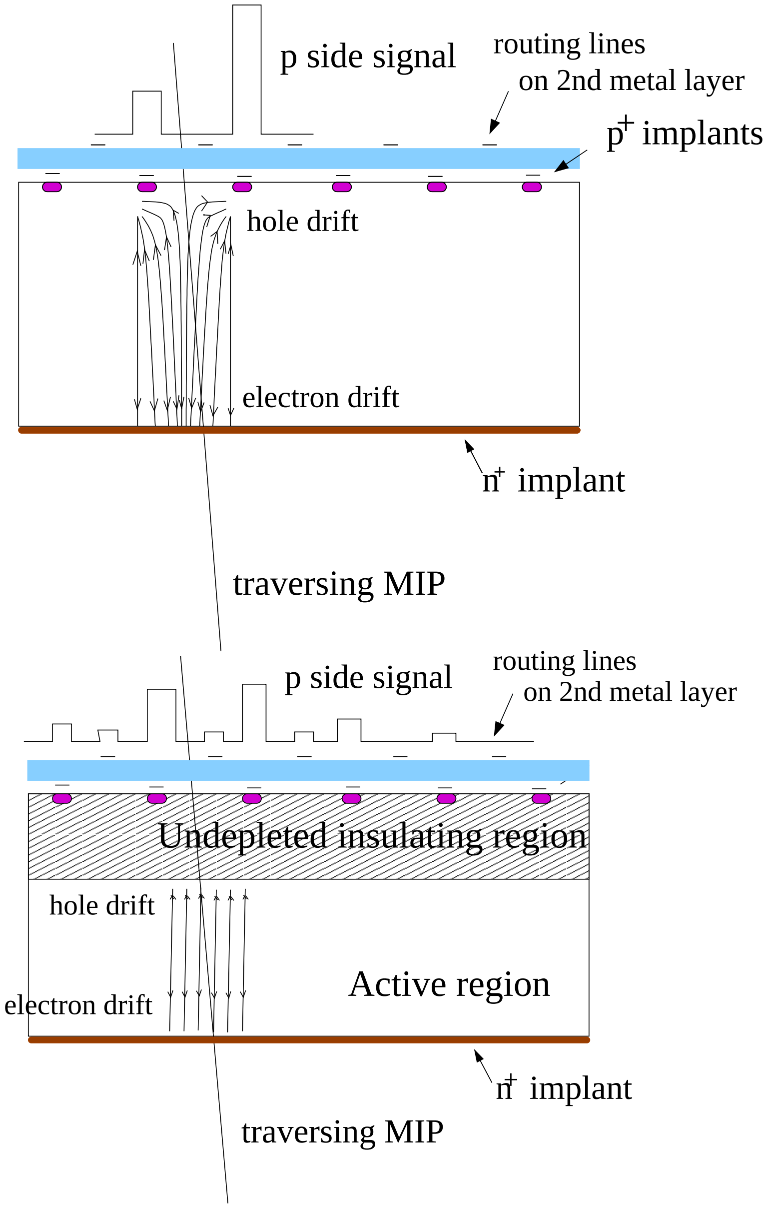


In agreement with:

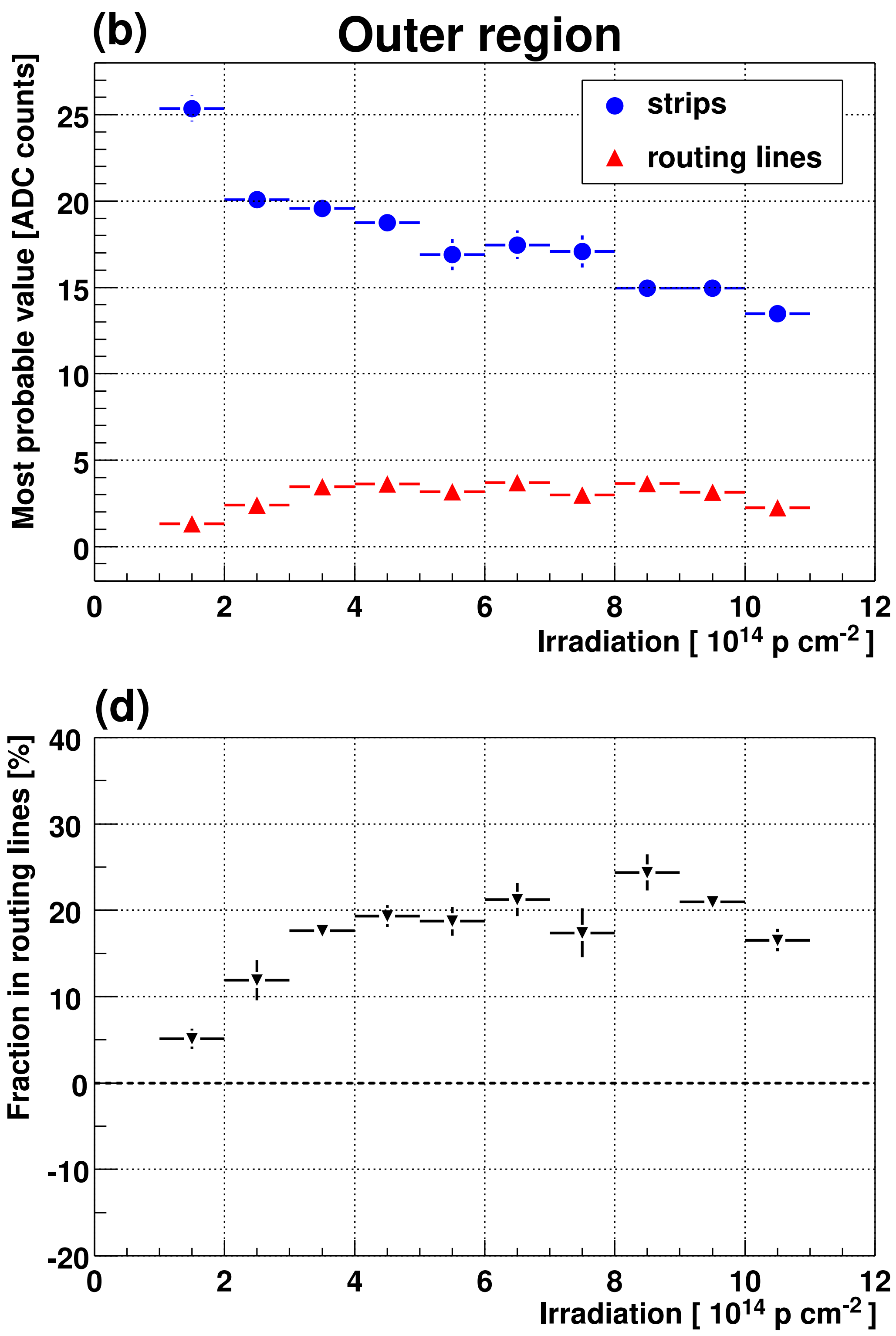
P.P.Allport *et. al.* NIMA 450 (2000) 297–306
LHCb TDR 5 CERN/LHCC 2001–011



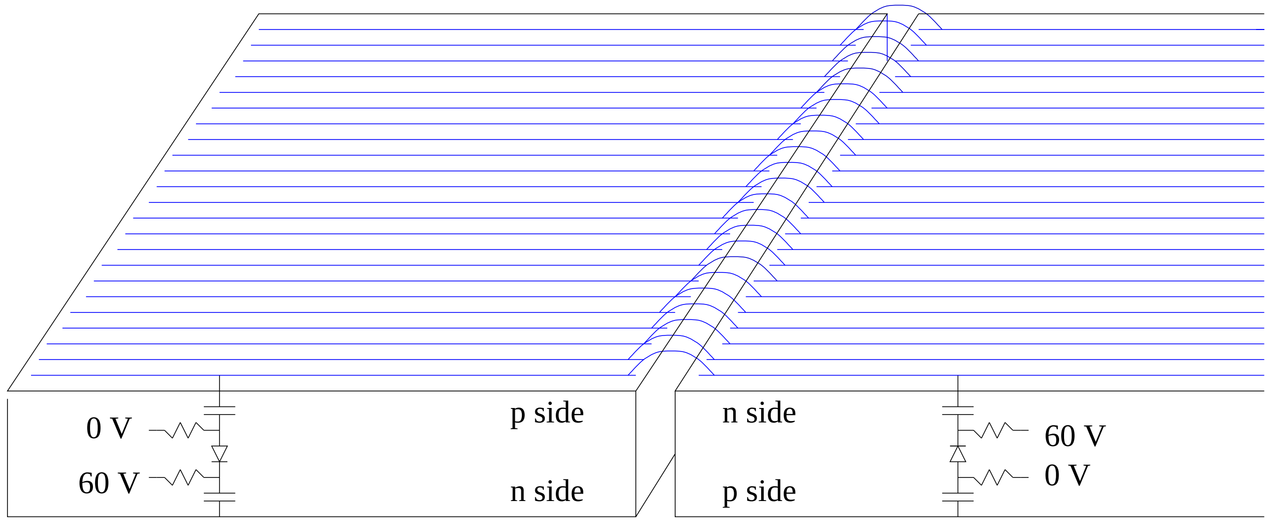
The same model explains charge pickup in second metal layer:

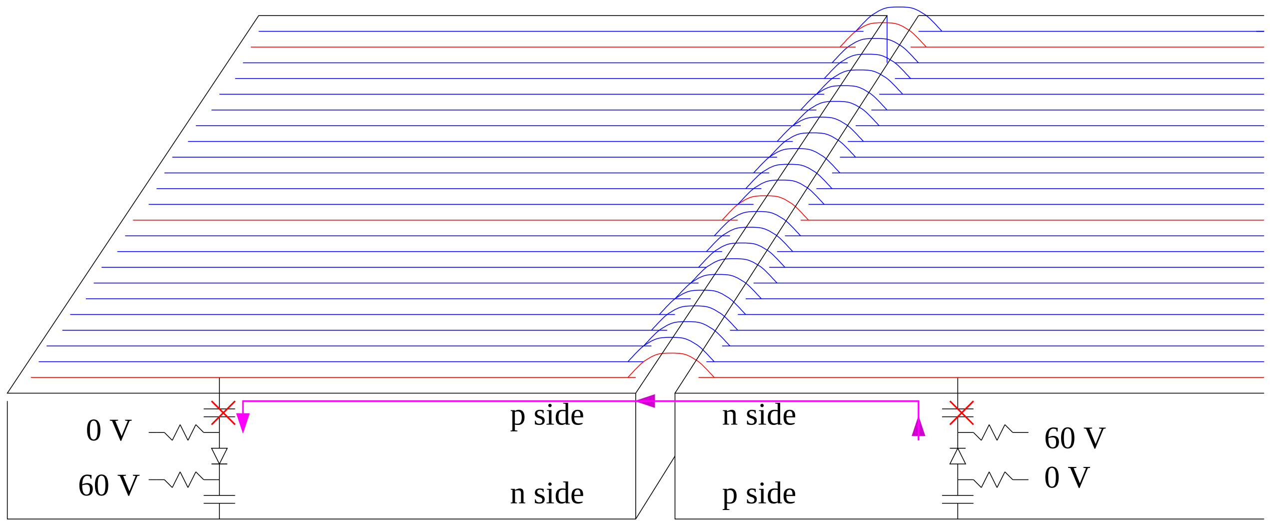


As seen in LHCb testbeam results:

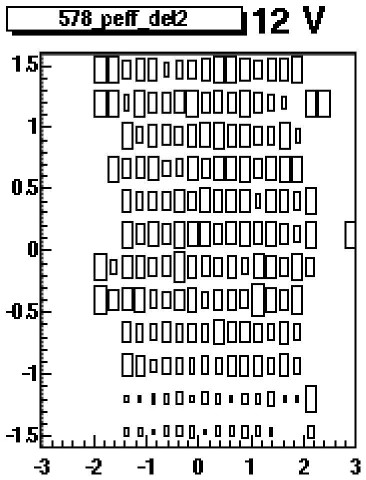


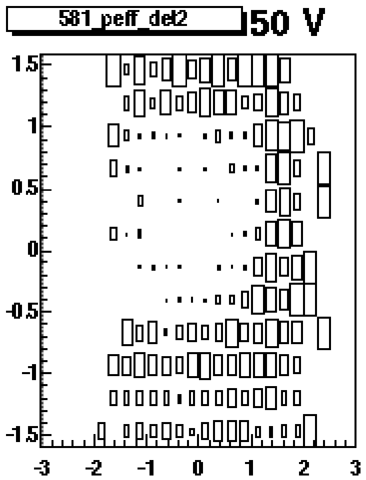
Can we get rid of the time dependence using artificial charge injection?

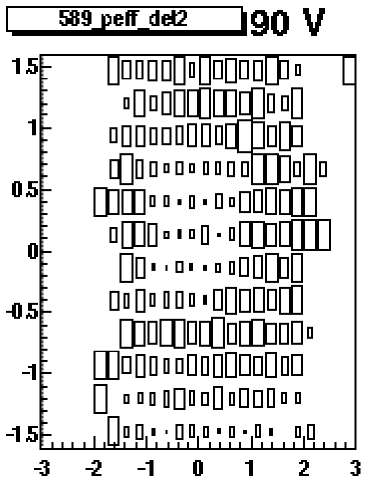




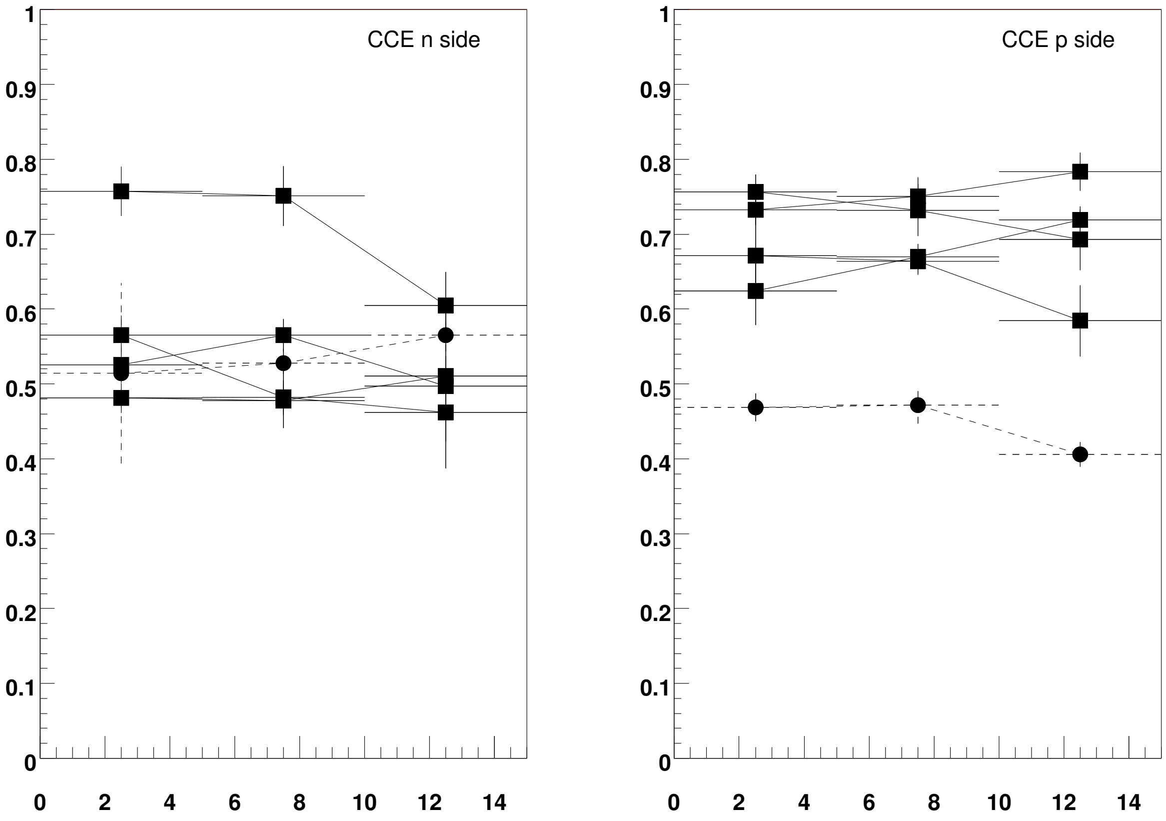
The charge comes back:





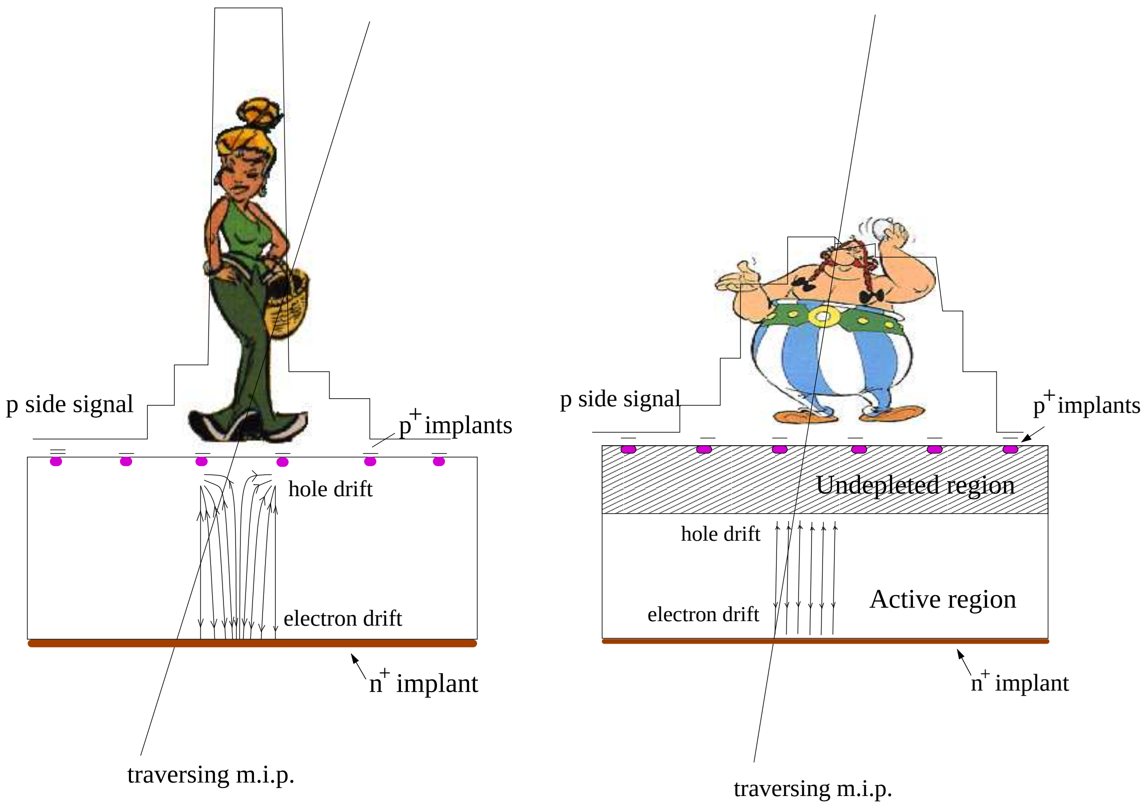


And does not immediately disappear:



Conclusions:

- The Lazarus effect works for microstrips as it works for diodes (CERN-EP/99-98, NIMA 440 (2000) 17)
- Cluster shapes give a good diagnostic tool to estimate underdepletion
- Clusters spread on the p side for underdepleted detectors!



- The CCE recovery is unstable. Charge injection might control it but R&D is needed
- LHCb decisions
  - n-on-n silicon
  - non-cryogenic operation for phase I