3D Silicon & Radiation Hardness

Outline:

- Why is 3D Silicon Rad Hard (at high fluences)??
- Discussion
- Results
- Conclusions and future plans

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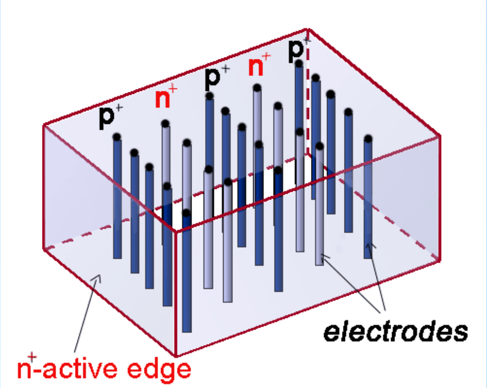
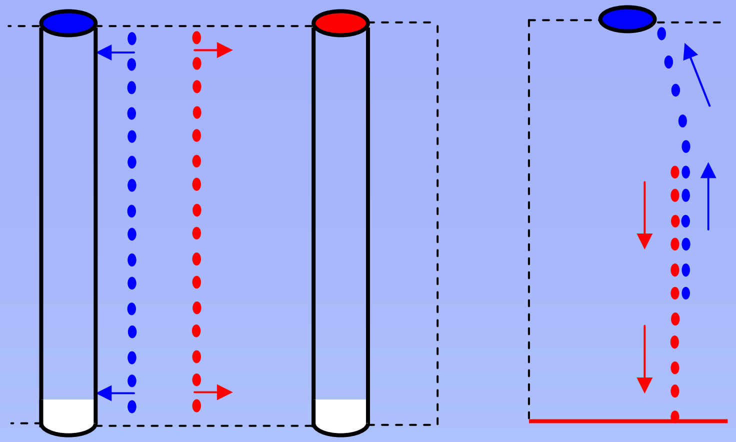


OBVIOUS ANSWER is ‘yes because 3D has’:



- ❖ Short collection distance (50 μm)
- ❖High average e-field with moderate V_{bias}
- ❖Parallel charge collection
- ❖Always use full substrate thickness (MIP ~80 e^{-}/μm)

- ❖Drawback: higher Capacitance (measured 200 fF/121μm/electrode)

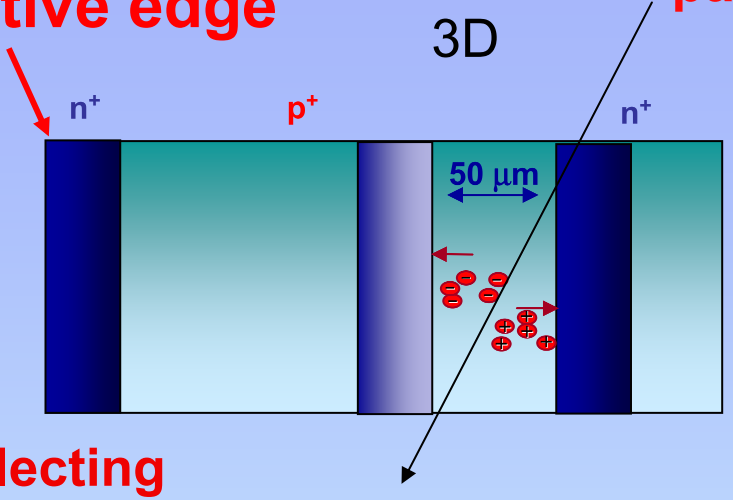
Could thin [O] rich planar Silicon devices be competitive?

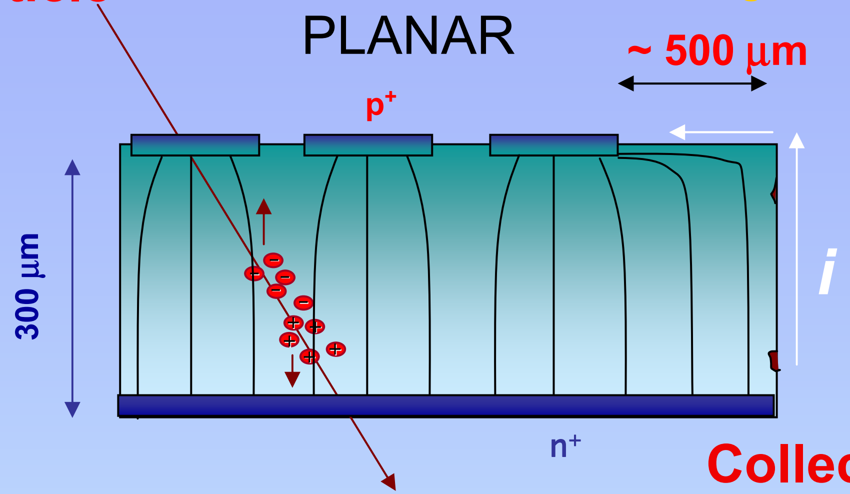
3D VERSUS PLANAR

microcracks,
chips induce surface
leakage current

Active edge

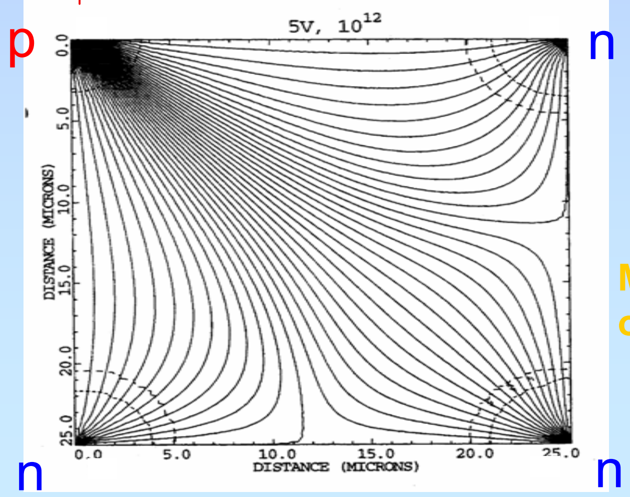
particle





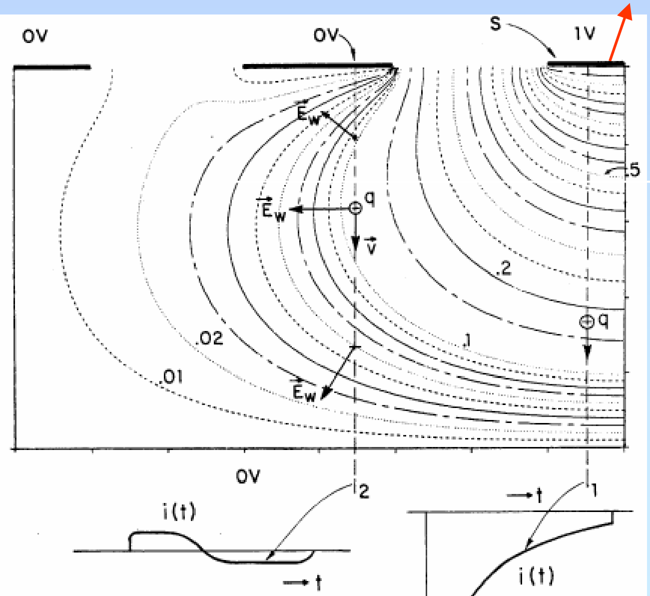
Collecting electrode

Collecting electrode



MEDICI simulation of a 3D structure

Drift lines parallel to the surface

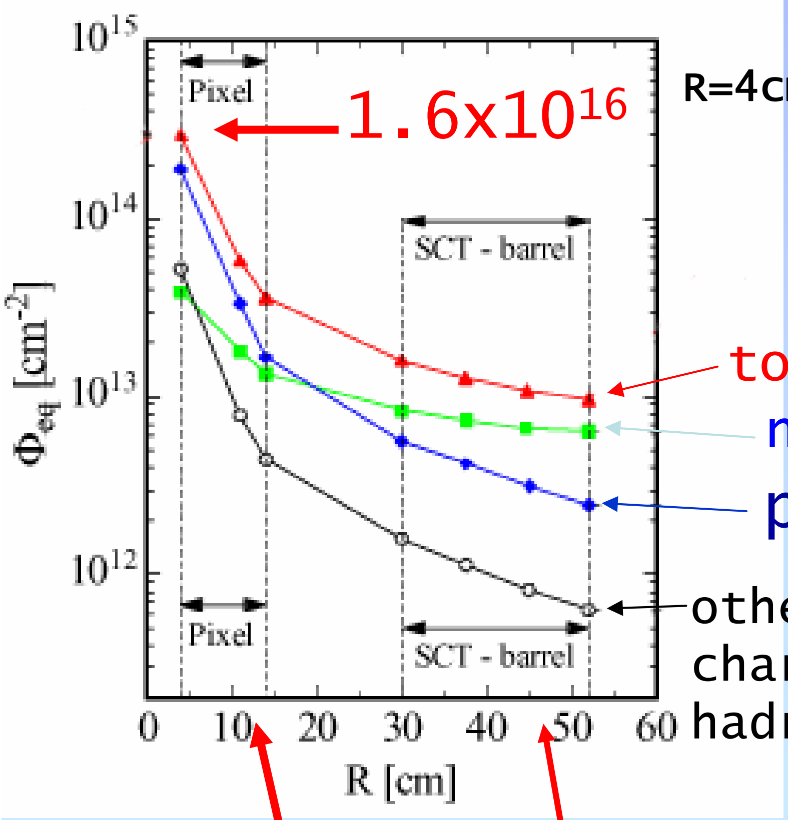


From H Spieler/LBL, data from Radeka/ BNL

RADIATION DAMAGE IN HIGH ENERGY PHYSICS EXPERIMENTS: Multiple particle environment

ATLAS Φ_{eq}

>85% charged
Hadrons for pixels



R=4cm

$1.6\text{x}10^{16}$

total

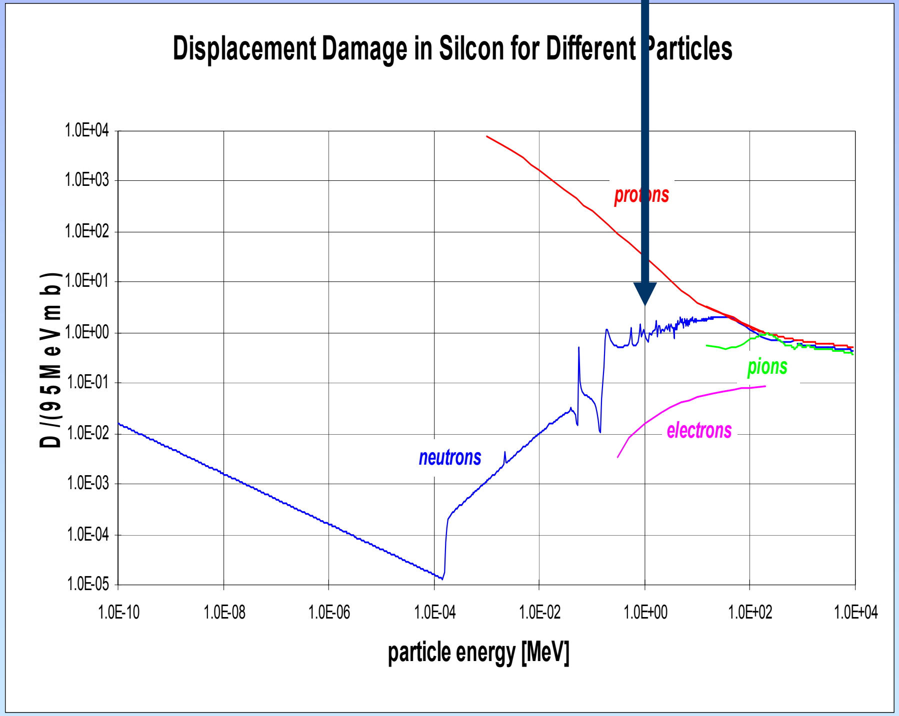
n

p

other
charged
hadrons

~$5\text{x}10^{15}$ ~$5\text{x}10^{14}$

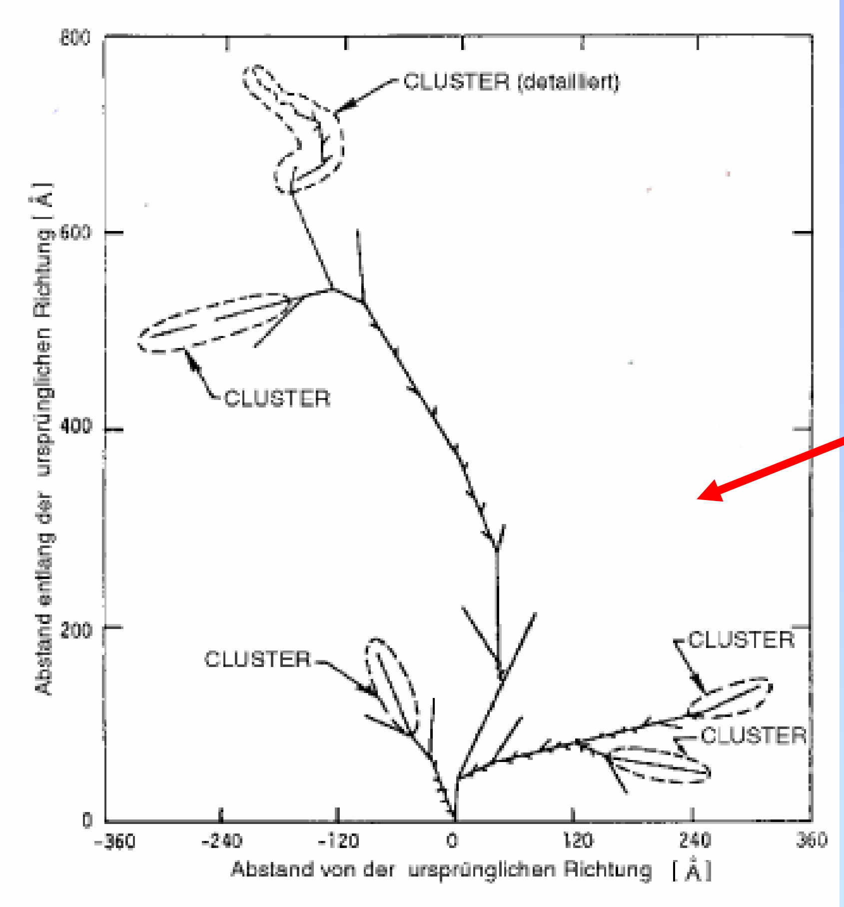
1MeV neutron eq



NIEL compilation due to G. Lindstrom,

NIEL IS VIOLATED between n and p when high [O] in Si

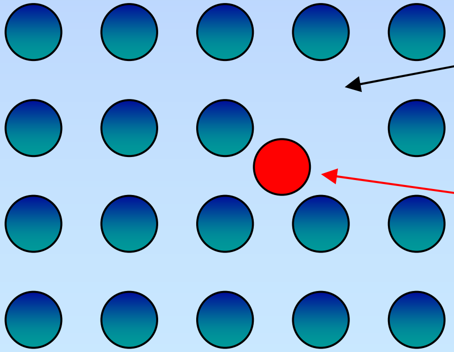
RADIATION INDUCED BULK DAMAGE in Si



Van Lint 1980

Primary Knock on Atom

Displacement threshold in Si:
Frenkel pair E~25eV
Defect cluster E~5keV



Vacancy

Interstitial

AT $1x10^{15}$ n/cm^2 :

Studies mainly from
RD48/ROSE Collaboration

STANDARD 300µm n-type SILICON at 10^{15} n/cm^2
10 years of operation at $L=10^{34}$ cm^{-2}s^{-1} at R=4 cm

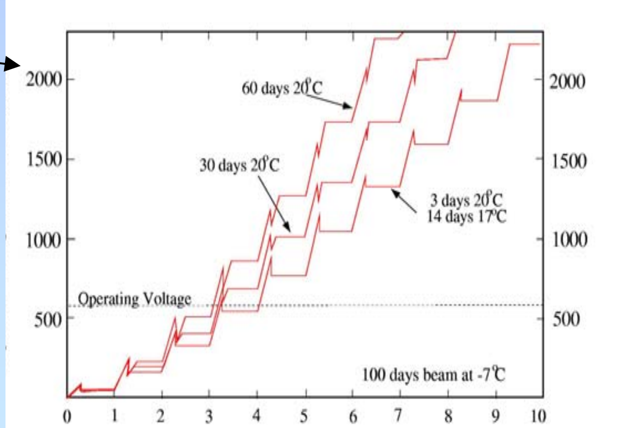
EFFECTIVE DRIFT LENGTH
Due to charge trapping **~150µm e^- ~50µm h**

- Signal formation
- Charge sharing
- Speed

SPACE CHARGE
TYPE INVERSION **-ve N_{eff} (10^{13}/cm^{3}) ~ V_{FD} (5000V)~Φ**
depletion from n-contact (e-field)

- Double junction
- Charge diffusion

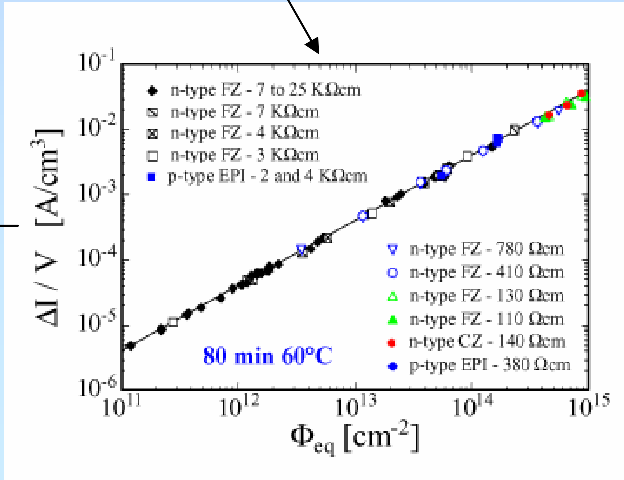
REVERSE ANNEALING **INCREASE OF -ve N_{eff} temp. dep**



Time [y]

- Maintenance

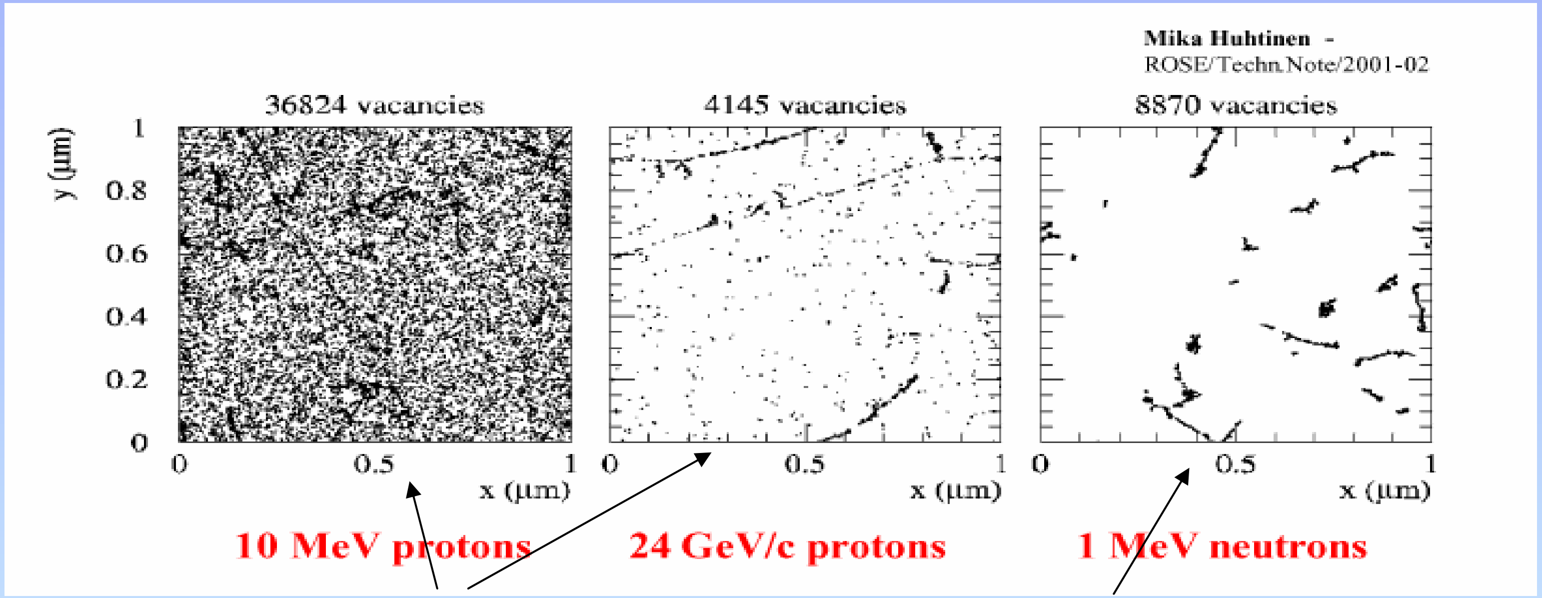
LEACKAGE CURRENT **prop to Φ (I/V ~$5x10^{-17}$ Φ)**



- Noise
- Thermal runaway

NEUTRON PROTON PUZZLE

PROTONS → POINT DEFECTS



V+O = VO

EFFICIENT TRAPS!

V_2+0 = V_2O

CONTRIBUTES TO N_{EFF}

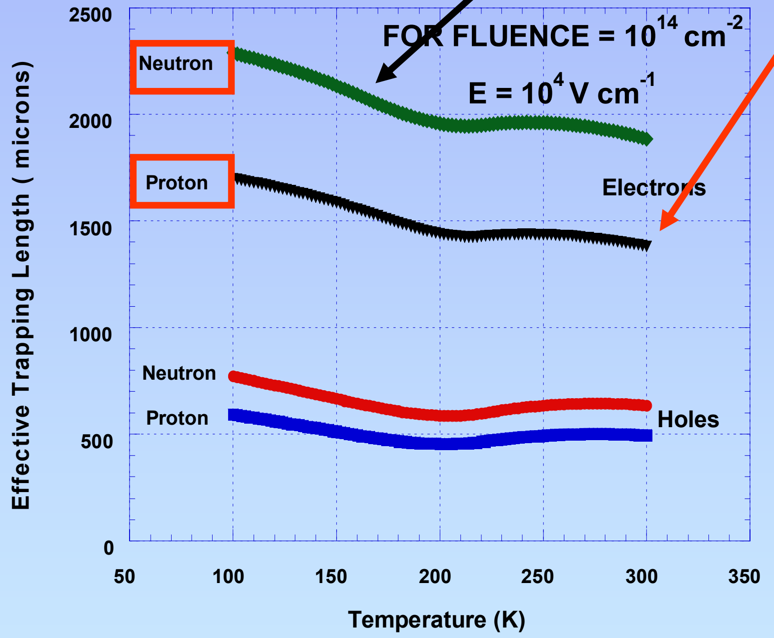
Signal can degrade because of:

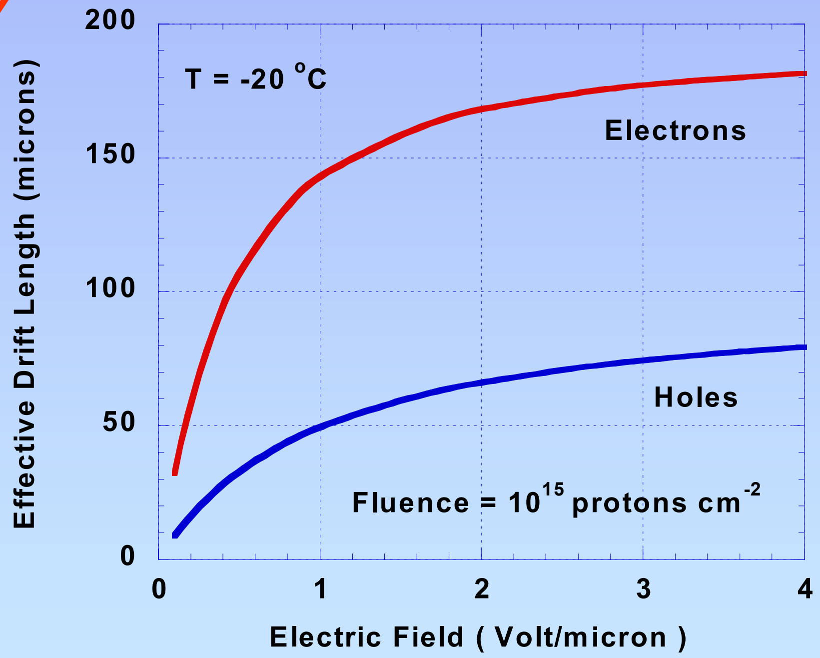
reduced depleted volume
trapping

EXAMPLE OF NIEL VIOLATION

Effective trapping time τ_t for e and h measured by Kramberger differs between neutron and proton irradiation

$L_{eff} = \tau_t \times v_{drift}$



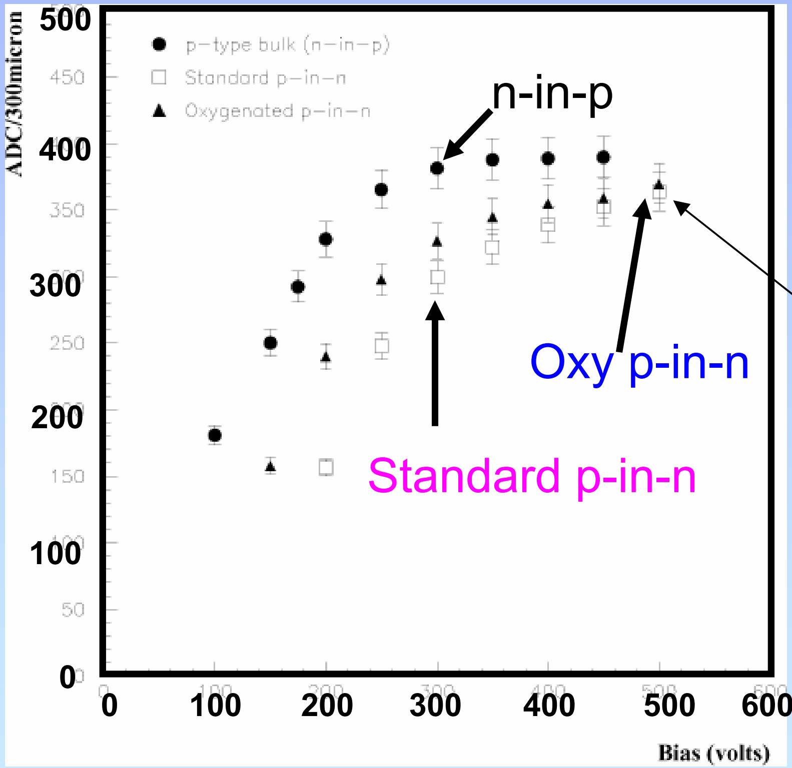


- Collect electrons
- Beware protons!
- Work at v_{drift} saturated

Trapping times from Kramberger et al. NIMA 481 (2002) 100
Simulations CDV and S.Watts NIM A 501(2003) 138 (Vertex 2001)

CONSIDERATION ON CCE and SIGNAL

25ns electronics
$3x10^{14}$ n/cm^{2}
T=-17^{0}C



Casse' et al. NIMA 487 (2002) 465-470

2 REGIMES:

1- LOW FLUENCE- DEPLETION VOLUME DOMINATES
Neutrons= bad
Protons =good
Oxygen helps

2- HIGH FLUENCE –TRAPPING DOMINATES
Neutrons = bad
Protons = worse!
Oxygen does not help

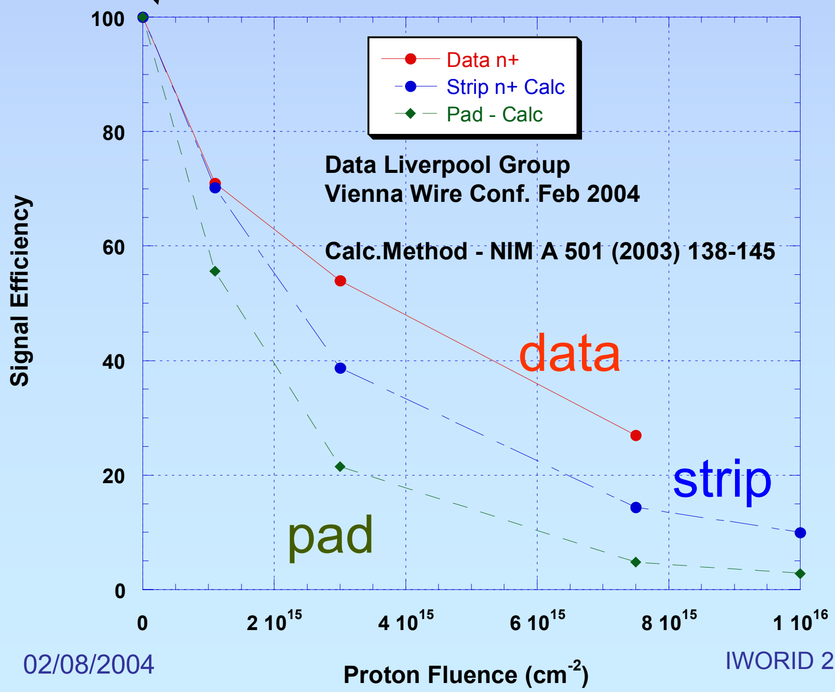
THE SIGNAL IS DIRECTLY PROPORTIONAL TO L_{eff}

$$S = \int_0^d q e^{-\frac{x}{L_{eff}}} W(x)dx = qL_{eff}\left(1-e^{-\frac{d}{L_{eff}}}\right)K$$

Positive!
The signal flattens at high ϕ

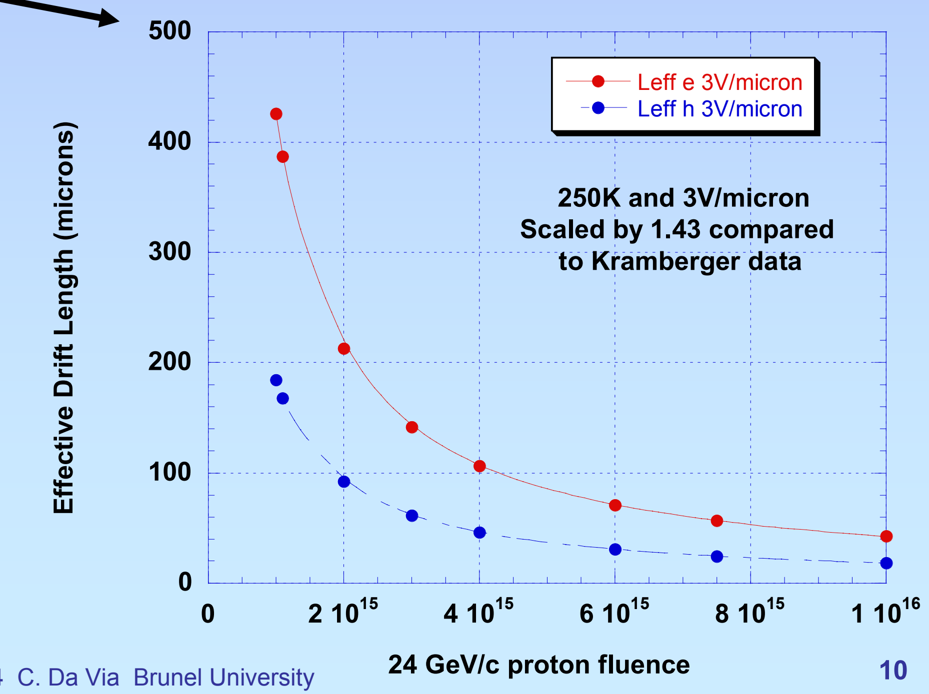
$$\boxed{S} \propto \boxed{L_{eff}} = v_{drift} \times \tau_{trap} \propto \frac{1}{N_{traps}} \propto \boxed{\frac{1}{\Phi}}$$

Should then planar detectors be thinner? →



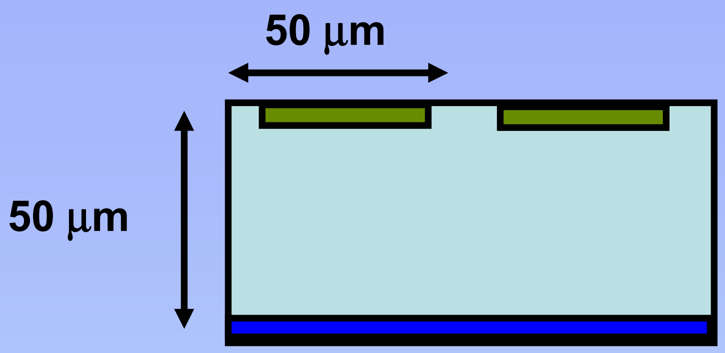
Data Liverpool Group
Vienna Wire Conf. Feb 2004

Calc.Method - NIM A 501 (2003) 138-145

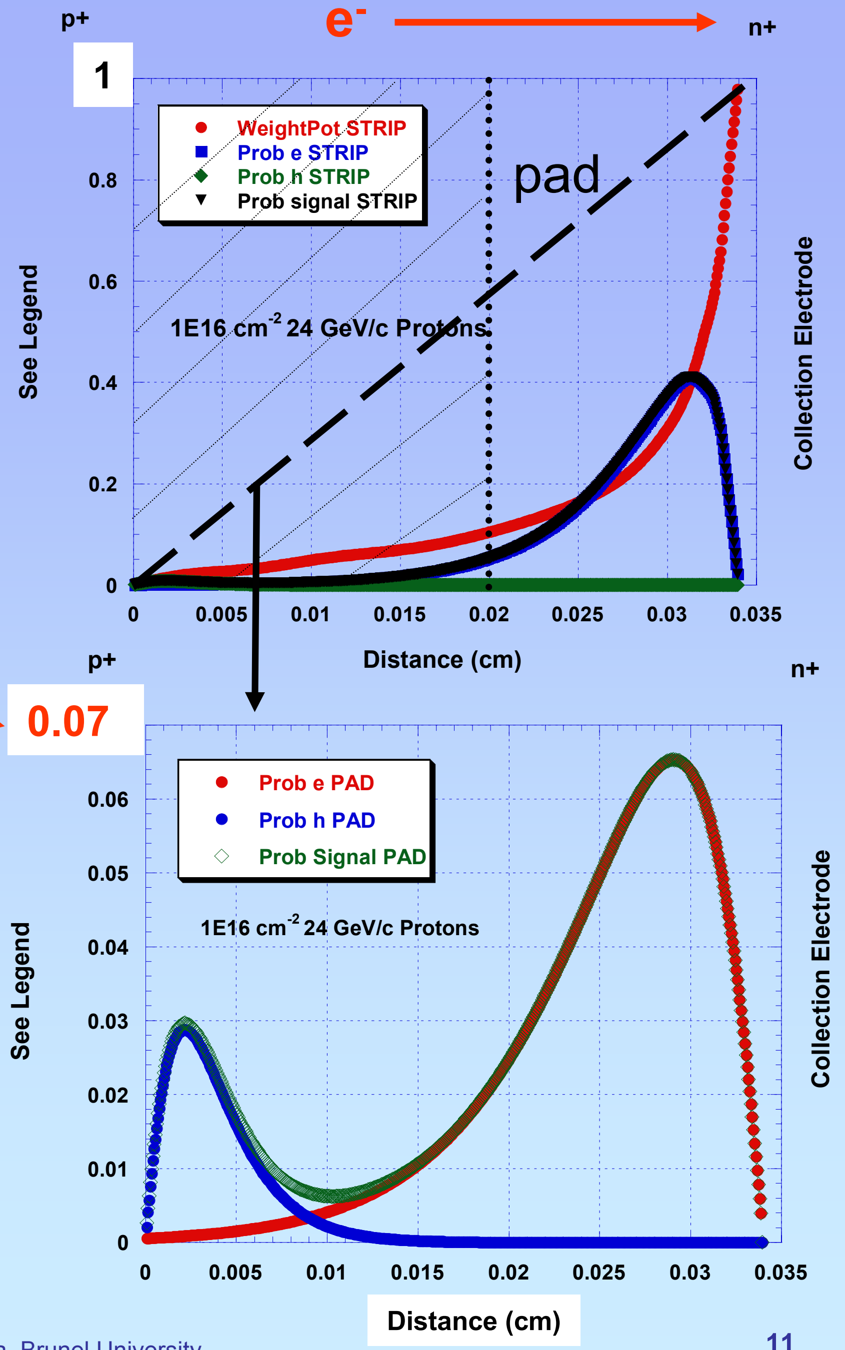


250K and 3V/micron
Scaled by 1.43 compared
to Kramberger data

ONLY IF PITCH PROP. SMALLER

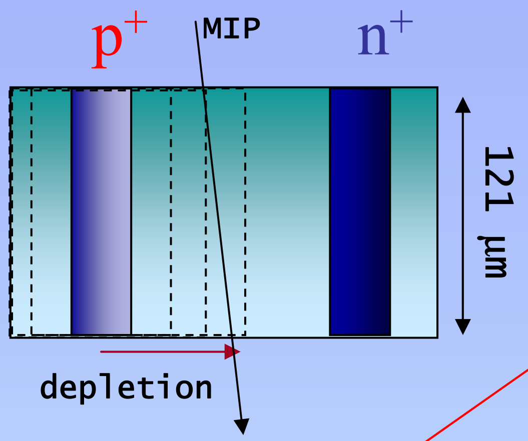


If same pitch →Thin detector = PAD!



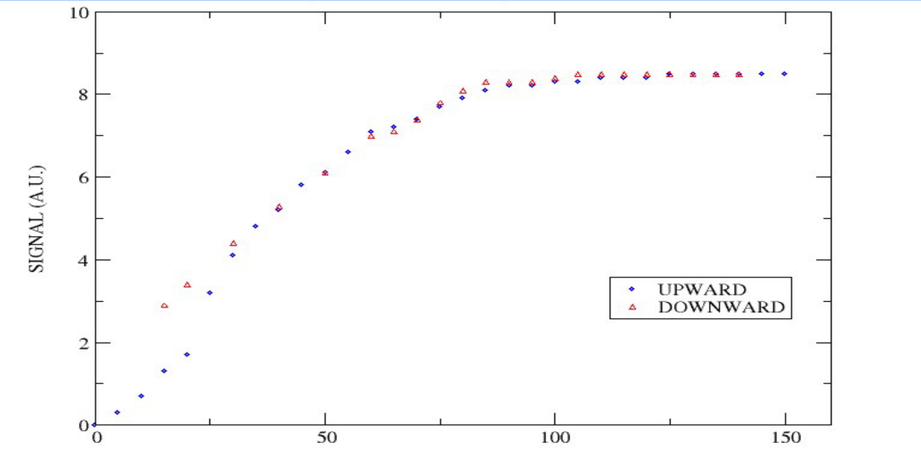
**Better to work under-depleted
With a thicker detector
to make use of the steepness
of the weighting potential (which
only depends on the electrode
width/thickness ratio)**

3D - RADIATION HARD TESTS
Room Temperature NON oxygenated

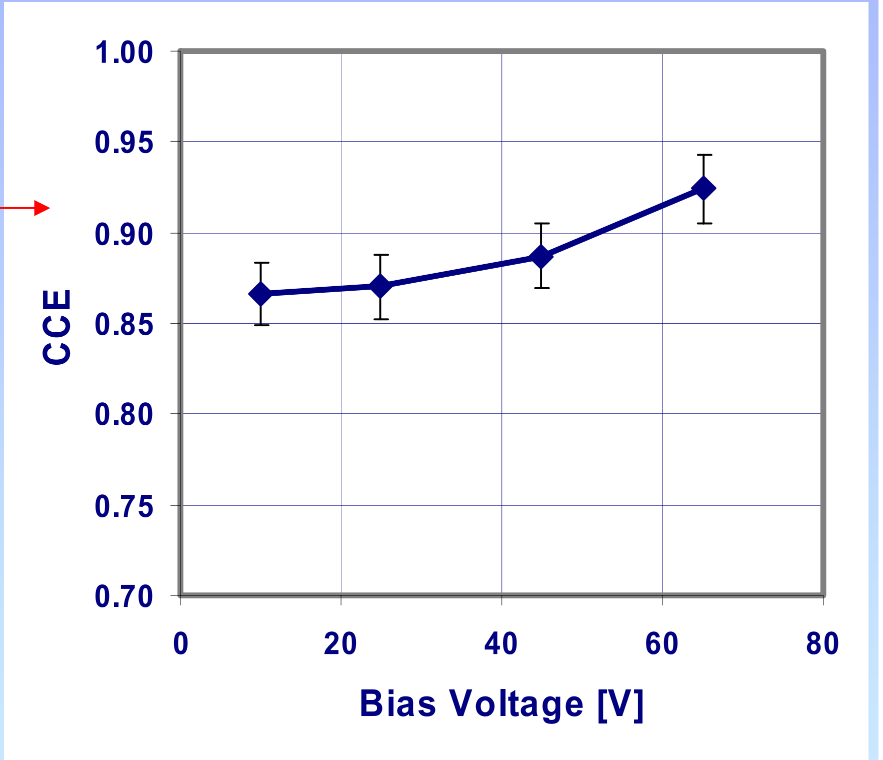


❖V_{FD}

❖CCE



105 V AFTER $2x10^{15}$ n/cm^2

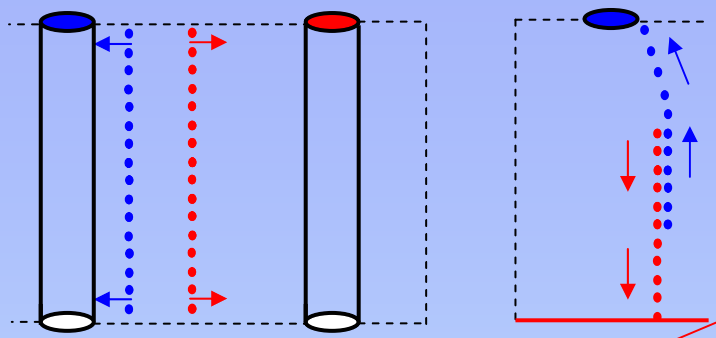


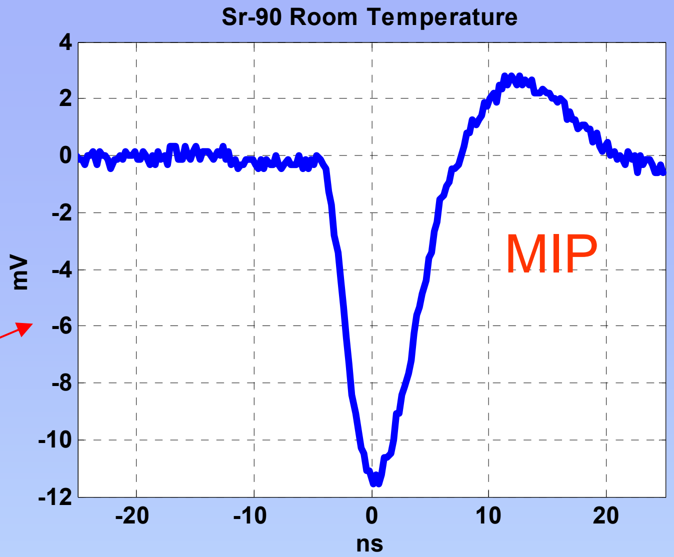
AFTER $1x10^{15}$p/cm^2 ($5x10^{14}$n/cm^2)

❖IEEE Trans on Nucl Sci 48 (2001) 1629
❖Nucl.Instrum.Meth.A509:86-91,2003

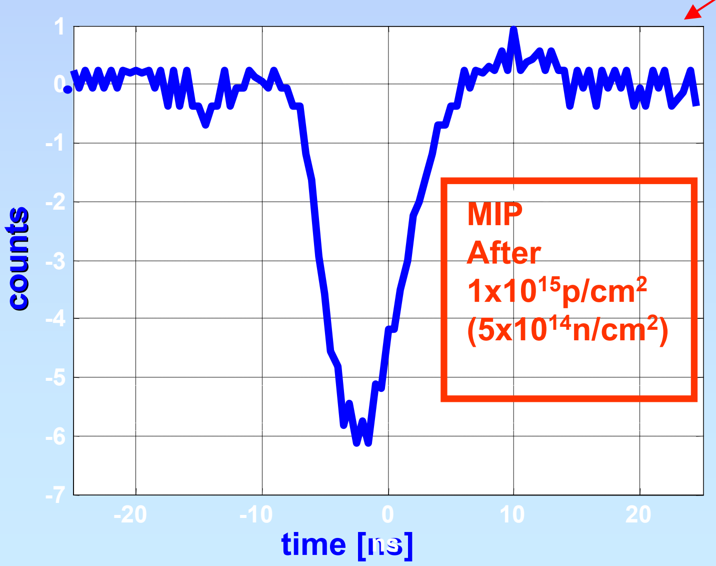
joined work Brunel, Cern, Hawaii to be published

SPEED (SLHC bx =12.5ns)

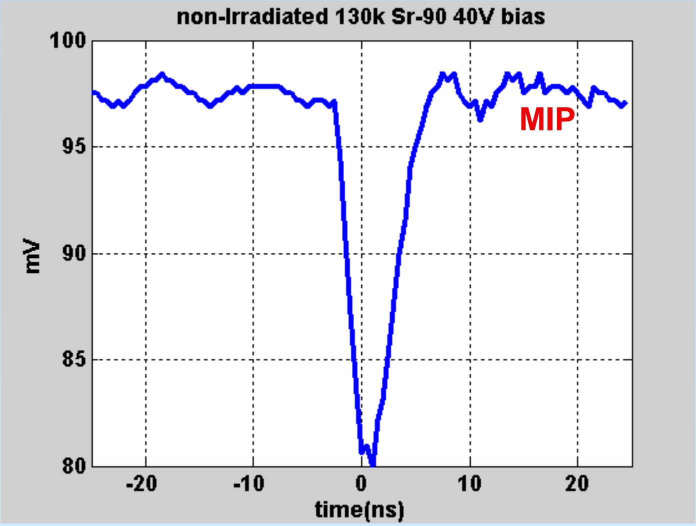




3.5 ns at 300K before and after ϕ



1.5 ns at 130K



*Fast Electronics CERN MIC : P. Jarron et al. NIM A 377 (1996) 435

In Conclusion:

- 3D wins compared with equal electrode spaced Si if pitch is not smaller despite larger 3D capacitance (thin substrate → higher C in planar devices as well)
- S/N better for 3D because one can use all the charge deposited in the substrate

A lot to do!

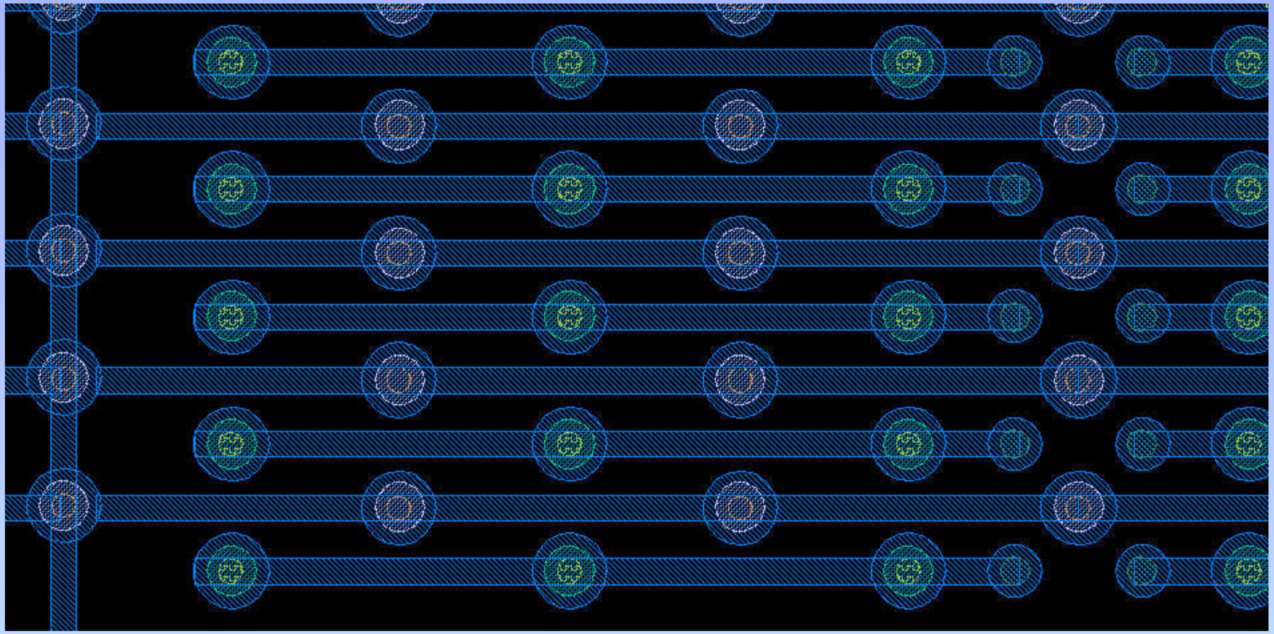
- At high fluences charged hadrons are lethal for trapping
- Oxygen does not help when trapping is dominating
- Signal depends on L_{eff} and on $1/\Phi$

Very inspiring article by Kramberger et al. NIM A 511 (2003)82

Forthcoming 3D tests:

- ❖ATLAS pixel compatible (radiation limit)
- ❖TOTEM 3 x 4 cm^2 (pure 3D, planar with 3D edges)
- ❖Speed measurement with 0.13 µm CMOS
- ❖Radiation tests for active edge (planar/3D)

Atlas Upgrade Pixel Cell Design

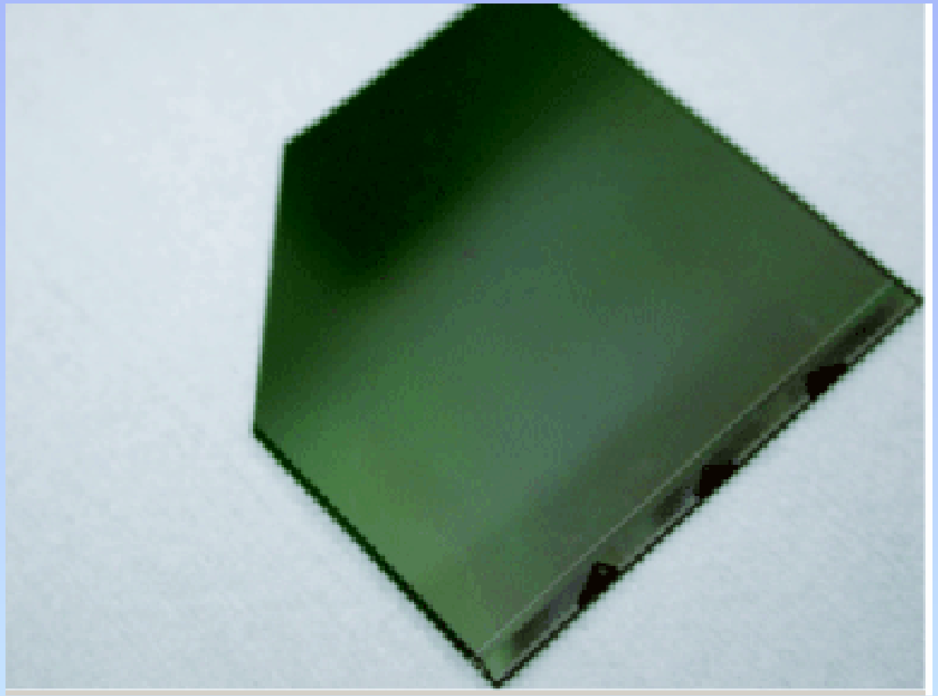


- 3 Collection and 3 Field electrodes per Cell

- Depletion Distance Under 75 μm

- Electrode Area 6 % of Cell
(improved etching may reduce this)

3D – TOTEM



- Full size active edge sensor 3 x 4 cm^2
- Forthcoming tests at X5 and SPS