

Prototype Performance and Design of the ATLAS Pixel Sensor

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Contents:

- Introduction*
- Sensor Concept*
- Performance*

Ⓜ before and after irradiation

- Conclusion*

Pixel 2000 – June 2000, Genova, Italy



F. Hüggling - University of Dortmund

Participating Institutes

Canada

- *University of Toronto*

Czech Republic

- *Academy of Sciences - Institute of Physics of Prague, Charles University of Prague, Czech Technical University of Prague*

France

- *CPPM, Marseille*

Germany

- *Bonn University, Dortmund University, Siegen University, Bergische University - Wuppertal, MPI Munich (R&D only)*

Italy

- *INFN and University of Genova, INFN and University of Milano, INFN and University of Udine*

Netherlands

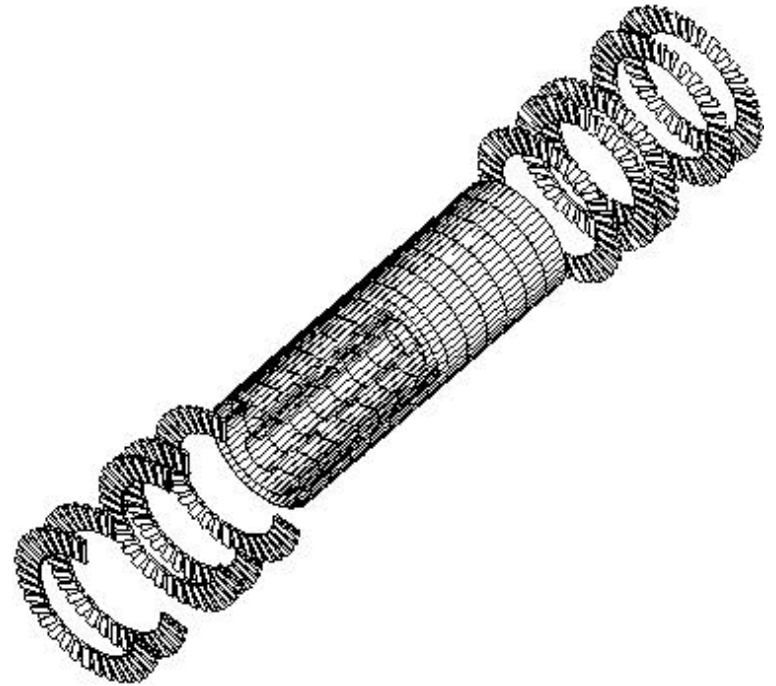
- *NIKHEF - Amsterdam*

USA

- *University of New York - Albany, LBL and University of California - Berkeley, University of California - Irvine, University of New Mexico - Albuquerque, University of Oklahoma, University of California - Santa Cruz, University of Wisconsin - Madison*

Requirements

- *pixel size $50\mu\text{m} \times 400\mu\text{m}$*
 - $50\mu\text{m}$ pitch*
 - $12\mu\text{m}$ diameter bump connection*
- *total active area 2.3m^2 (2228 modules)*
 - high yield*
 - testability*
- *10 years operation*
 - fault tolerance*
- *harsh radiation environment*
 - up to 10^{15}cm^{-2} (1 MeV neutron eq.)*
 - radiation hard technology and design*



Development Strategy

Design Studies

- *performed within ATLAS*
- *Prototype Sensors concerning*
 - *isolation technique*
 - *design of the pixel cell*

Studies of Silicon

- *performed within ROSE*
- *Various Si Impurities concerning*
 - *damage parameters*
 - *fabrication process*

Radiation Tolerant Sensors

Sensor Concept

- *50*400 μm^2 pixel size*
- *n on n pixel*
- *moderated p-spray isolation*
- *3 sensor tiles per wafer*
- *various test and monitor structures*

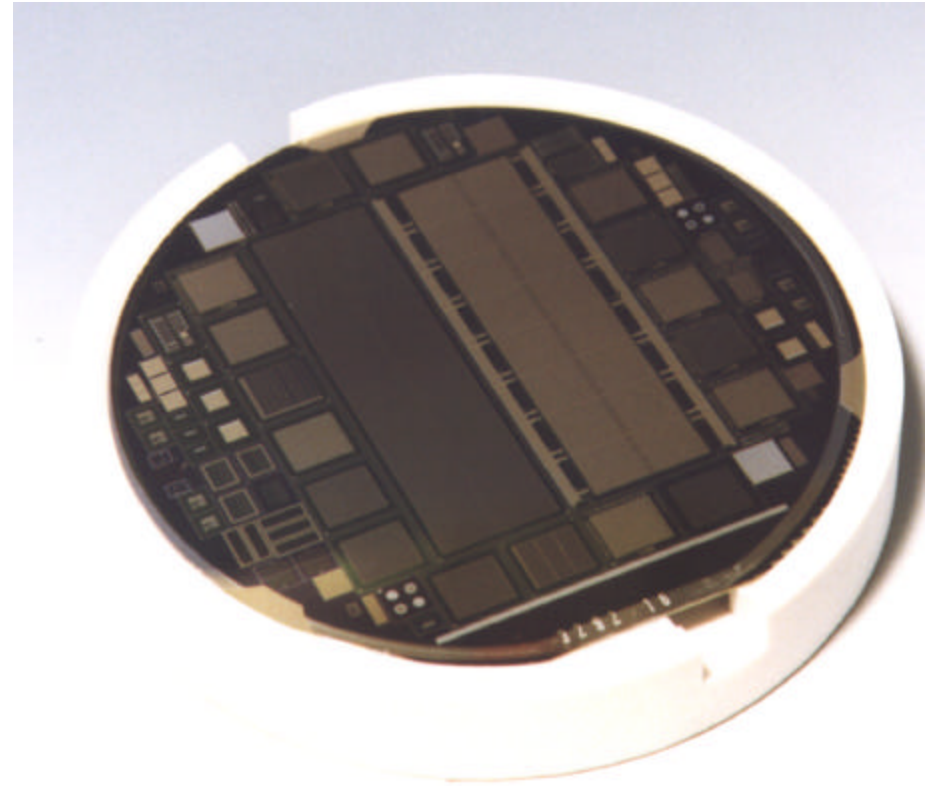
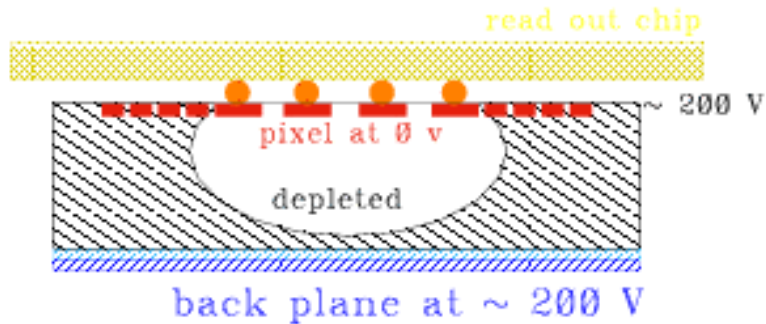


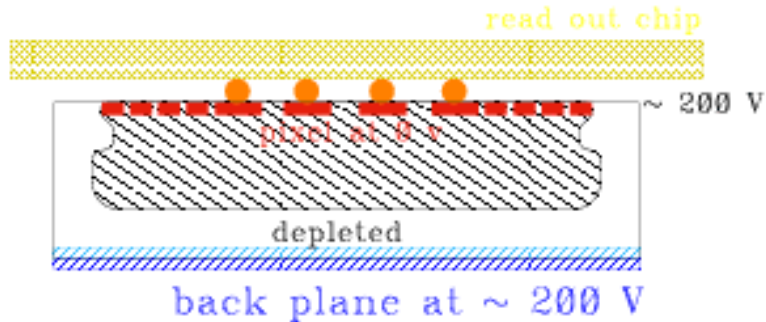
Photo of Prototype 1 Wafer

Sensor Concept

before irradiation: *p-on-n*

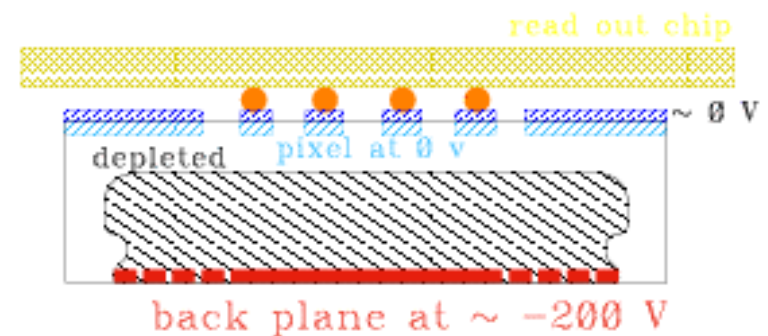
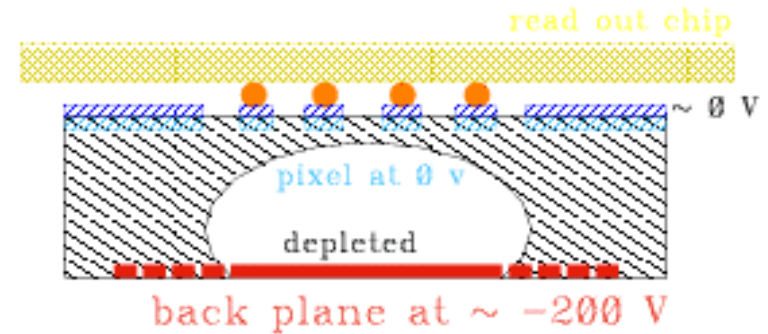


after irradiation:



- *have to be operated (almost) fully depleted*
- *potential drop on the read out side*
- *only single sided processing necessary*

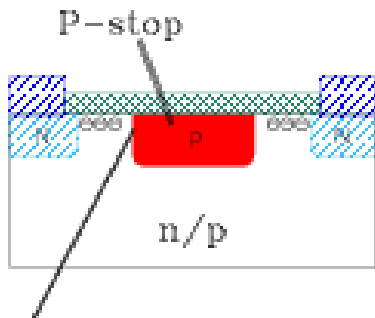
n-on-n



- *can be operated partially depleted*
- *potential drop on the back side*
- *double sided processing needed*

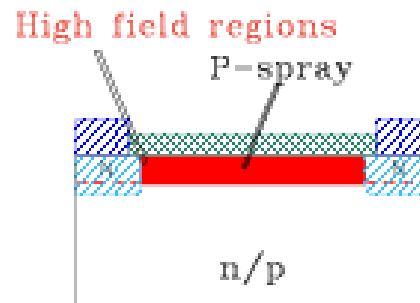
Isolation Techniques

p-stop



High field regions

p-spray



before irr. : *low E-field*

high E-field

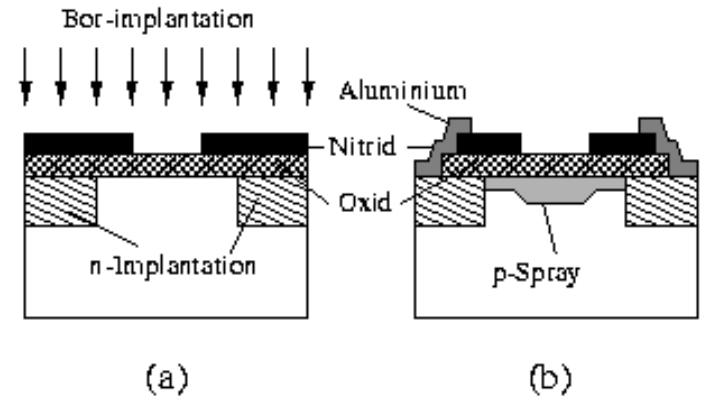
low E-field

after irr. : *high E-field*

low E-field

low E-field

moderated p-spray



Quality Assurance

Quality test plan for sensor production:

- *I-V characteristics on every sensor before bonding, depletion on every wafer*
- *process parameters on special test structures (e.g. p-spray dose)*
- *both at vendor and at institutes for better control*
- *see talk by J. Klaiber-Lodewigs*

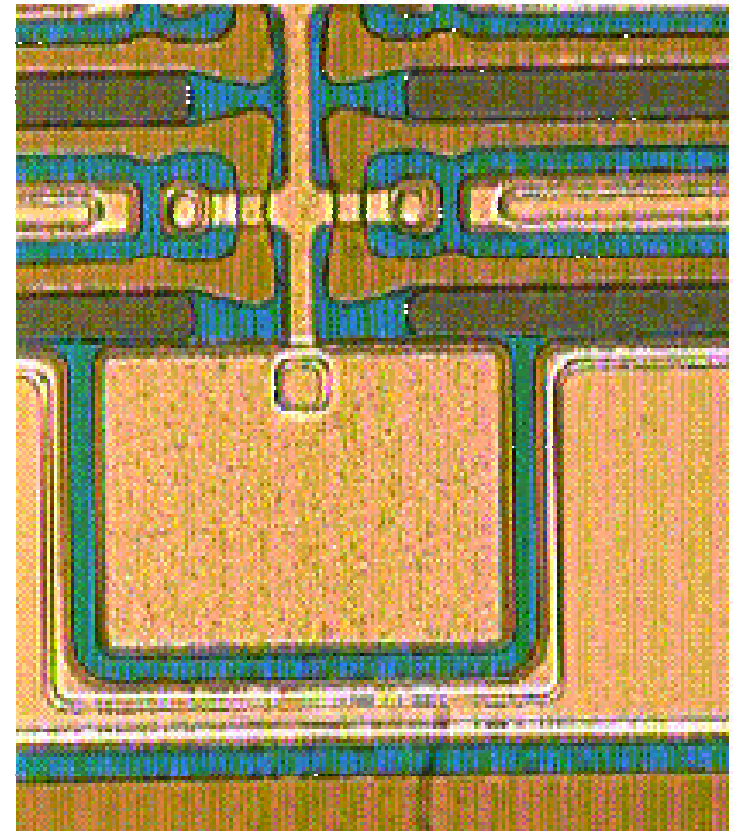
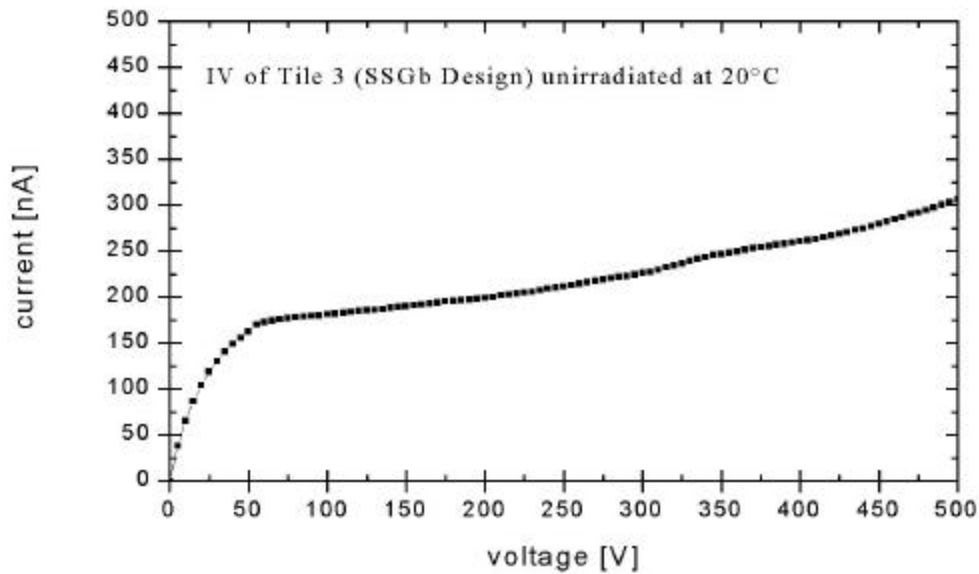


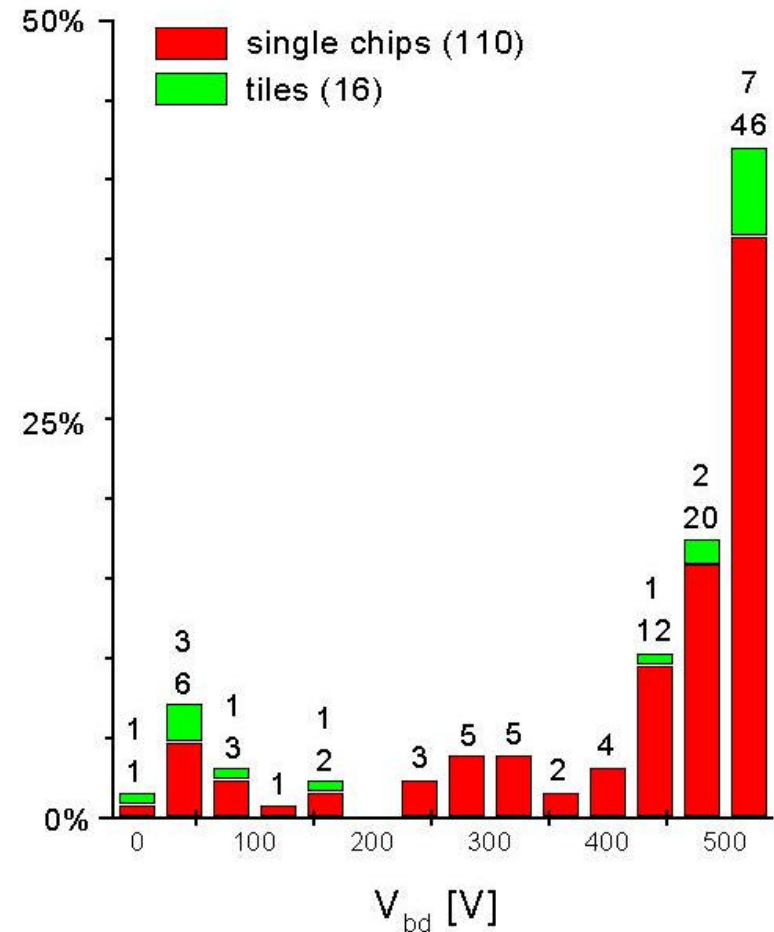
photo of bias grid structure

Performance

leakage current before irradiation



Breakdown voltages
on 280μm wafers



Test Beam Studies

- *Single Chip detectors bump bonded to FE electronics*
- *tested designs in CERN SPS Testbeam*

p-stop Design: Tile 1

*p-spray Design: Tile 2,
SSGb, SNGb*

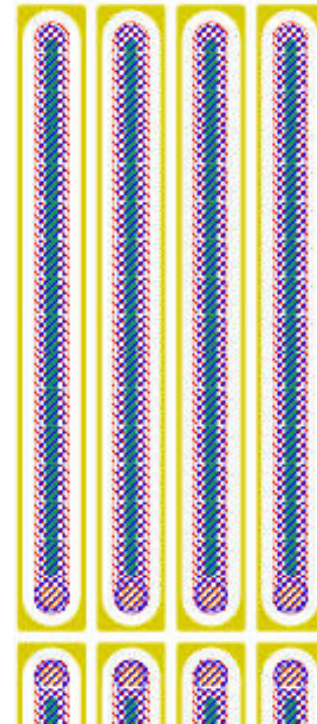
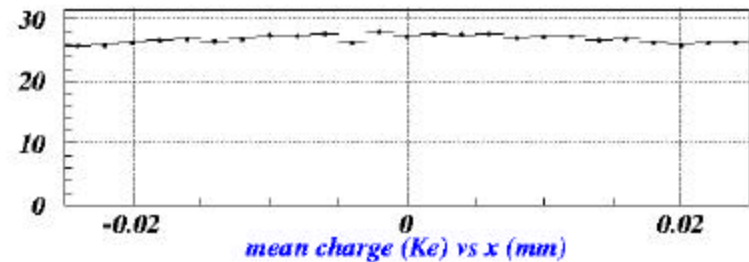
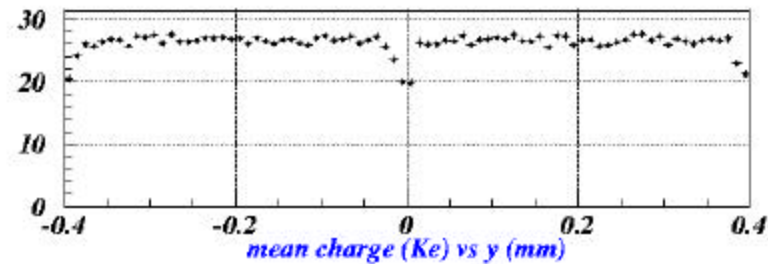
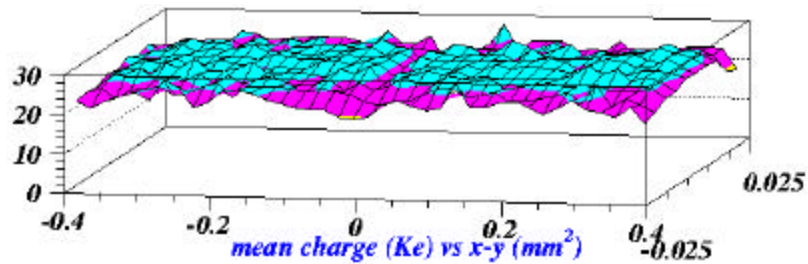
- *radiation tests with **p** and **p** (sensors only)*








Charge Collection

Tile 1 Design: n^+ pixel and p -stop isolation

Threshold 2 Ke

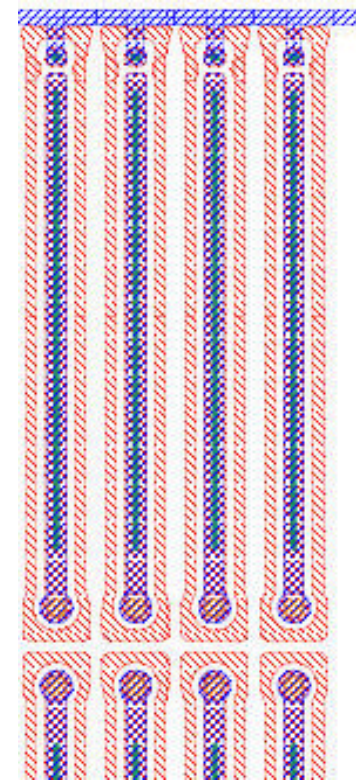
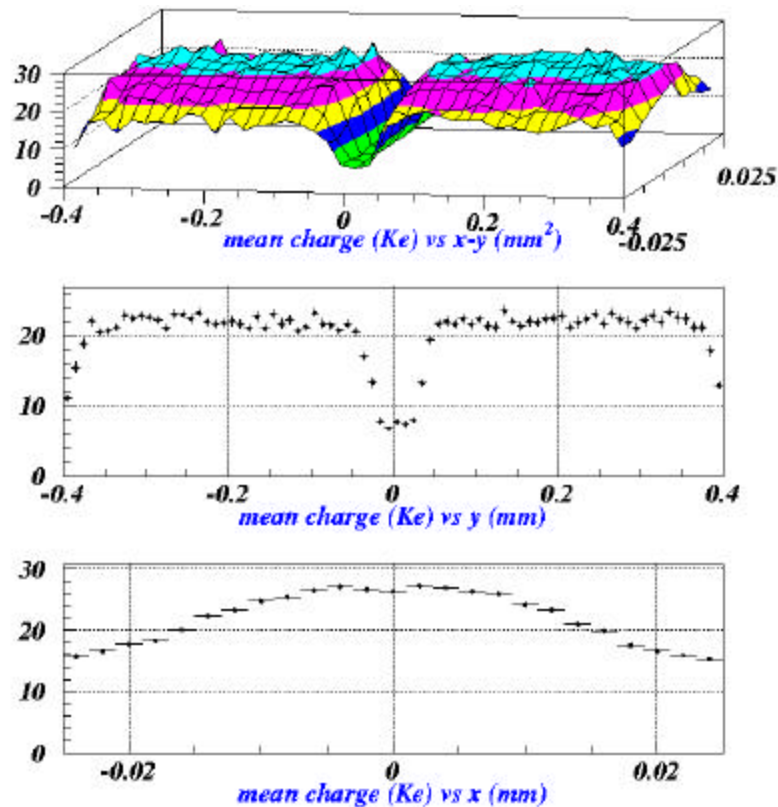


-  *p-stop*
-  *contact hole*
-  *metal*
-  *n-implant*
-  *pass. hole*

Charge Collection

Tile 2 Design: n^+ pixel and p -spray isolation

Threshold 2 Ke

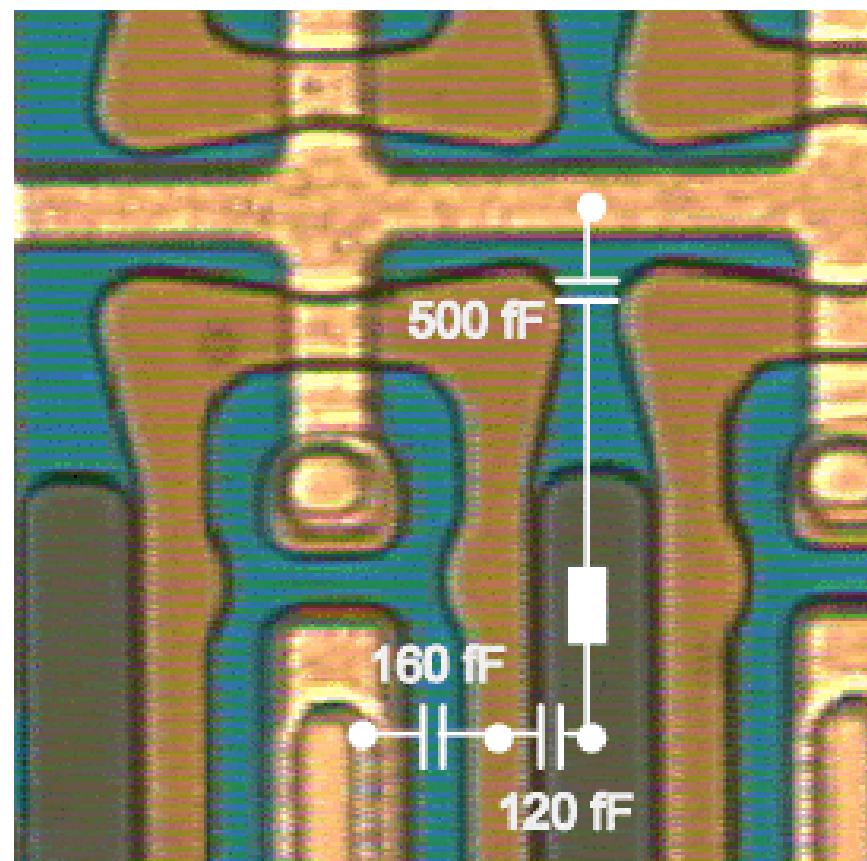


- contact hole
- metal
- n -implant
- pass. hole

Charge Collection

Explanation for bad charge CCE of Tile 2 Design

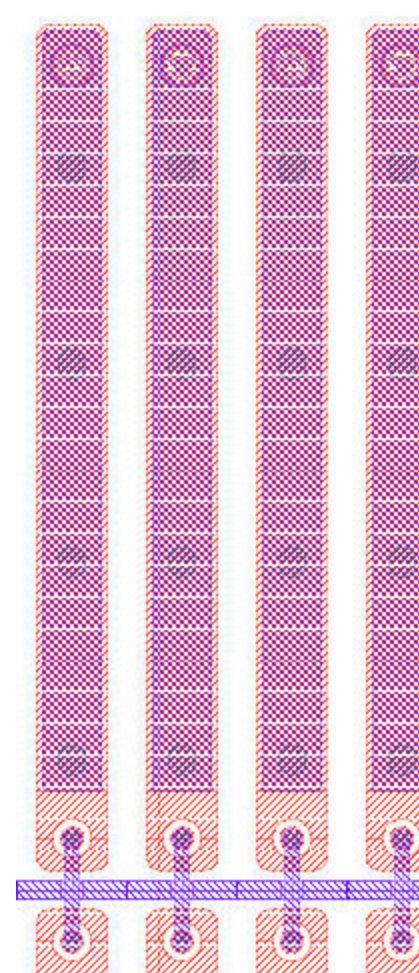
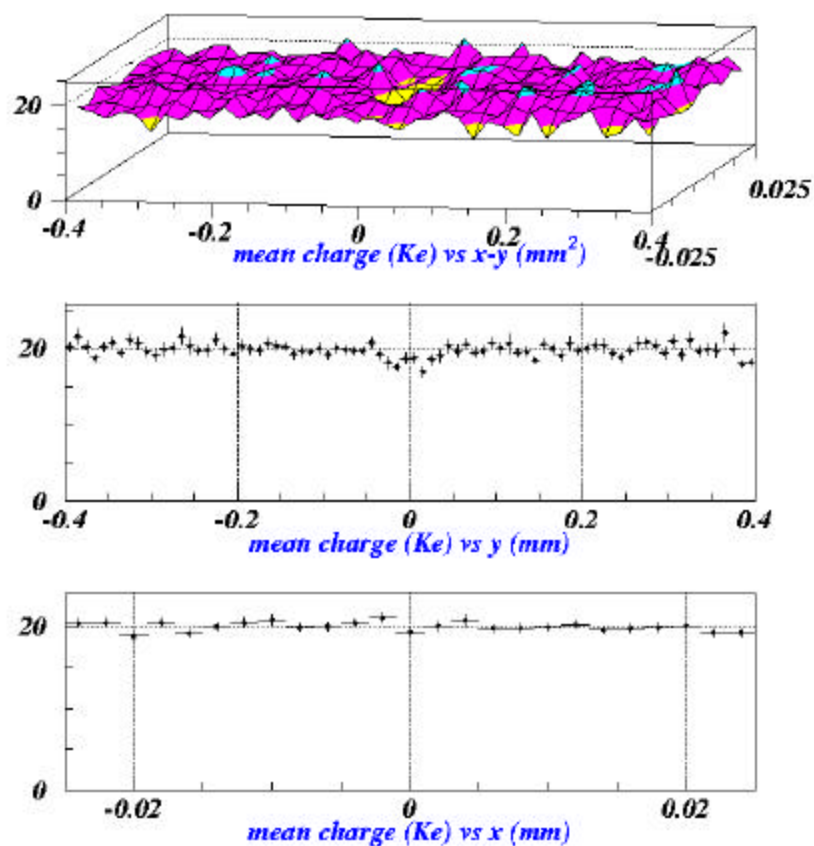
- *a modified Version of the Tile 2 design was introduced*
- *detailed 3D Simulations to understand this effect are in progress*



Charge Collection

SSGb Design: final design

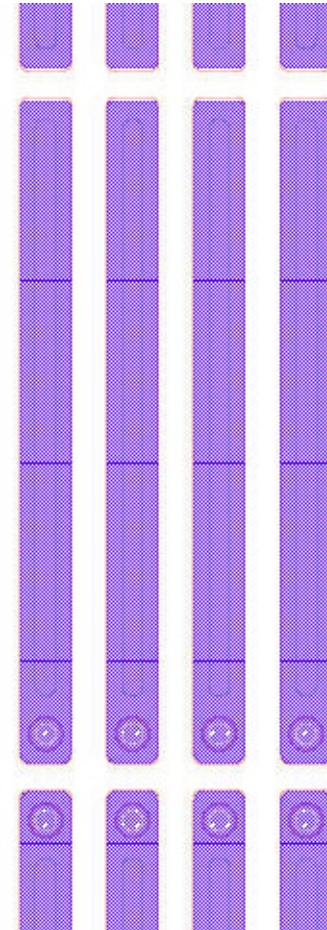
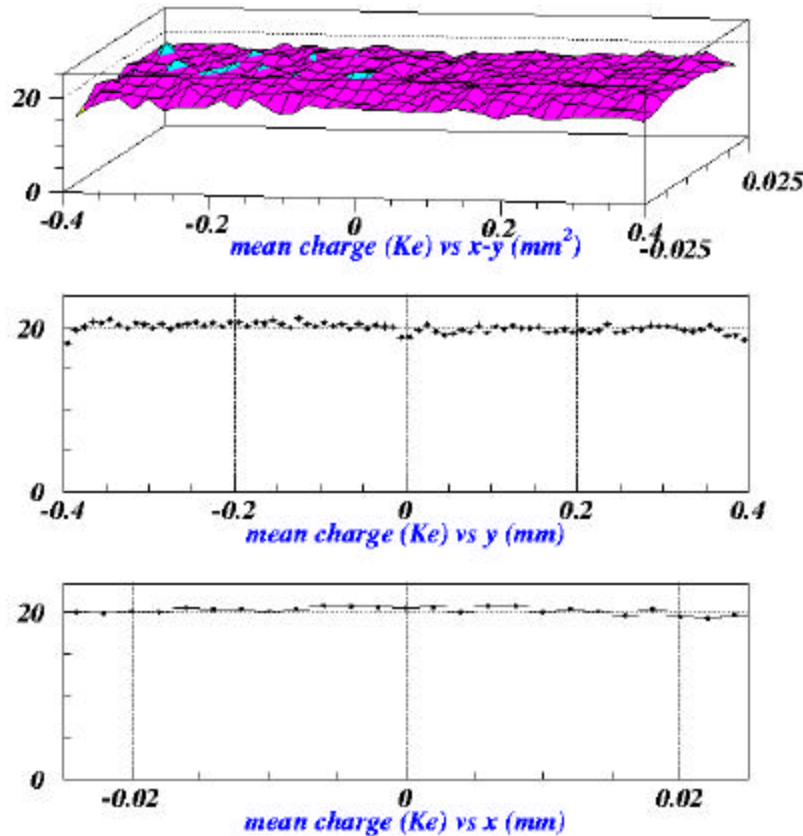
Threshold 2 Ke



Charge Collection

SNGb Design: p -spray isolation, no bias grid

Threshold 2 Ke



Charge Collection: Summary

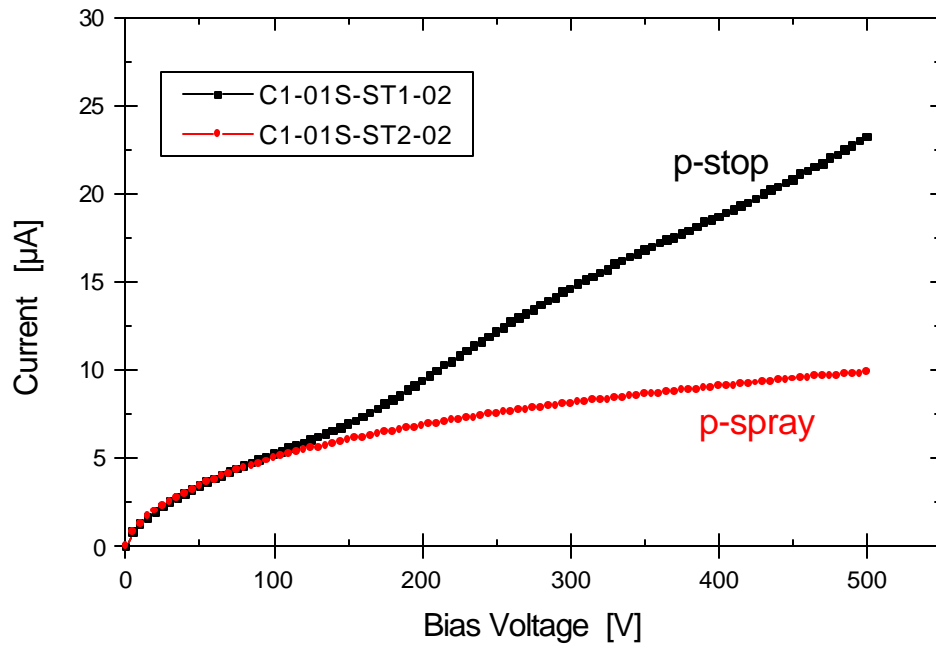
	Old Design 280 μ m			New Design 280 μ m	
	Tile 1	Tile 2	SSG	SSGb	SNGb
1 hit	72.0	82.0	71.7	81.8	84.4
2 hits	25.2	14.6	25.6	15.6	15.0
³ 3 hits	2.4	2.2	2.0	1.7	1.1
Efficiency	99.6	98.8	99.3	99.1	99.5
Losses	0.4	1.2	0.7	0.9	0.5
0 hits	0.1	0.4	0.2	0.4	0.4
Not matched	0.2	0.2	0.2	0.1	0.0
Not in Time	0.1	0.6	0.3	0.4	0.1

SSGb

- *good charge collection*
- *radiation hardness*
- *testability*

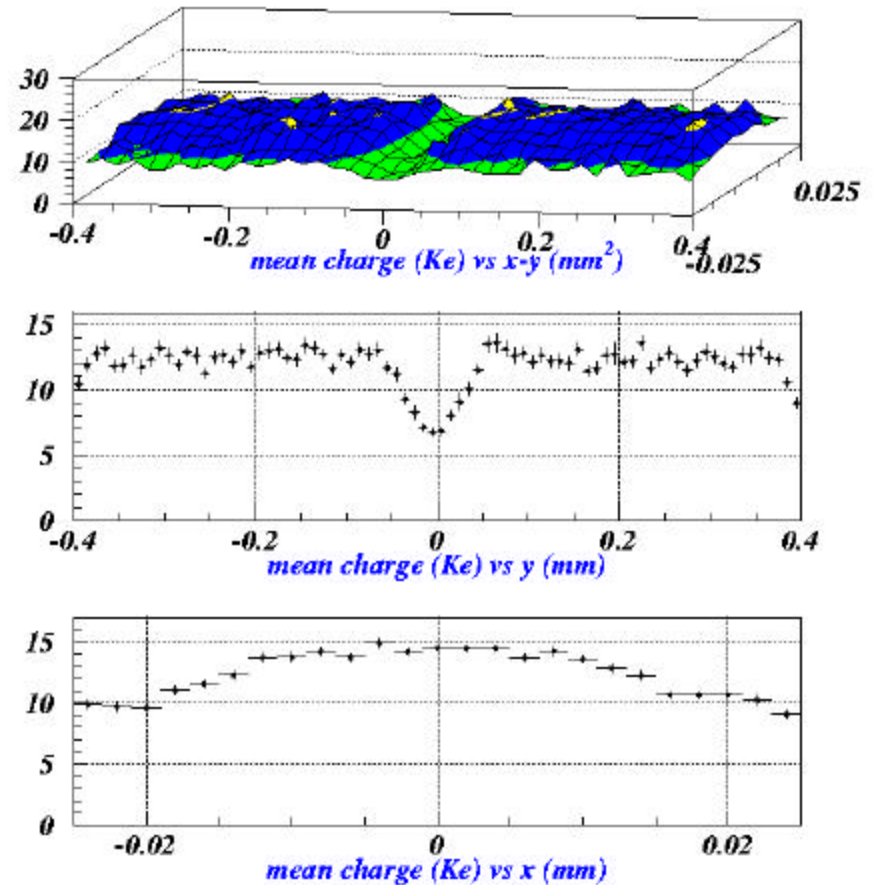
Radiation Hardness

I-V characteristics of irradiated sensors flip-chipped to FE-chip



Measured after $0.5 \cdot 10^{15} \text{ n/cm}^2$ at -18°C

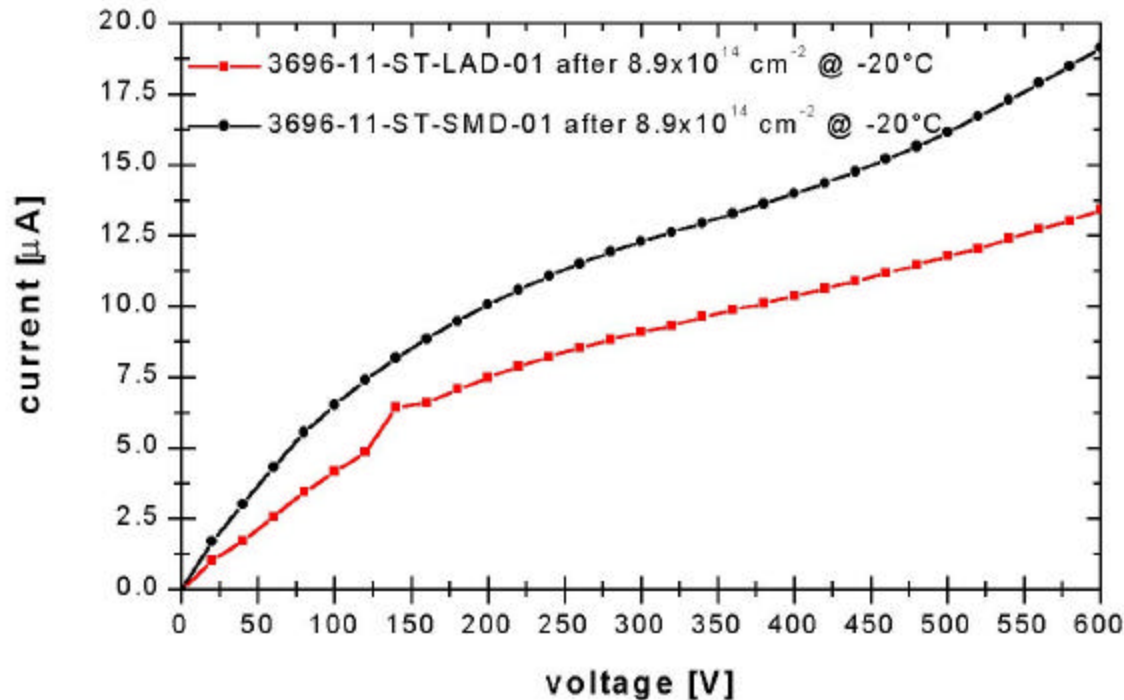
CCE of ST2 after irradiation with 10^{15} n/cm^2 at 600 V



Radiation Hardness ... oxygenated silicon

IV of prototype 2 single chips on oxygenated silicon after irradiation with $8.9 \cdot 10^{14} n_{eq} cm^{-2}$ (55MeV protons)

- final design SSGb*
- measured at -20°C, unbumped sensors measured via bias-grid*



Performance

„in time“ efficiency:

non - irradiated
3000 e threshold

efficiency = 99.1%
81.8% single hits
15.6% double hits
1.7% > 2 hits
0.4% out of time

$10^{15} n_{eq} / cm^2$
3000 e threshold

efficiency = 98.4%
94.2% single hits
3.1% double hits
1.1% > 2 hits
1.2% out of time

sensors

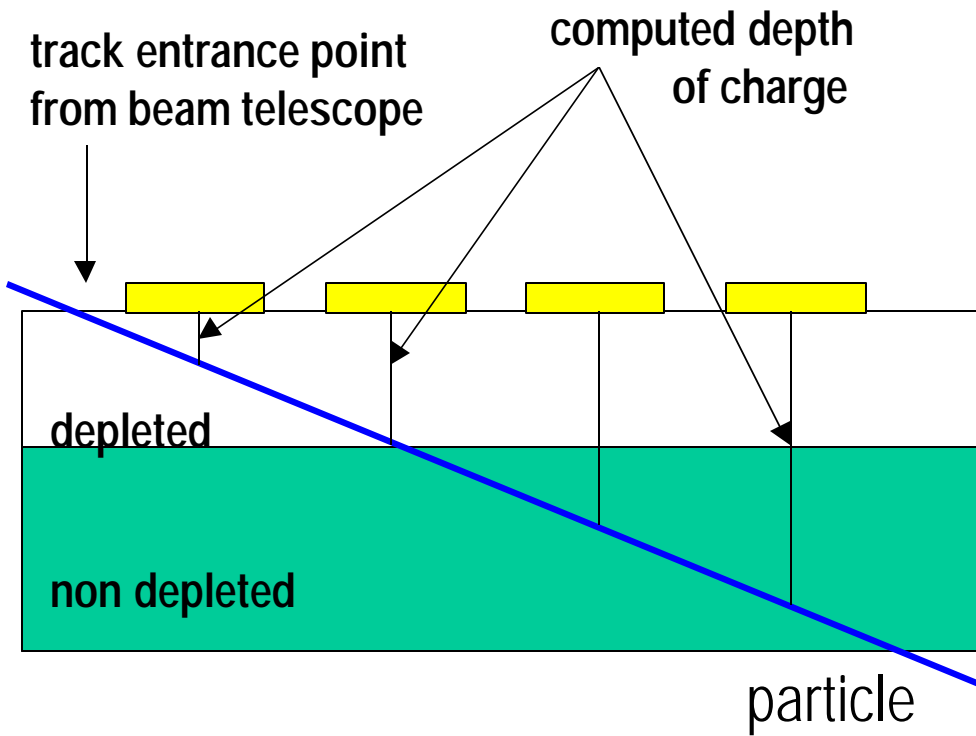
moderated p-spray

space resolution:

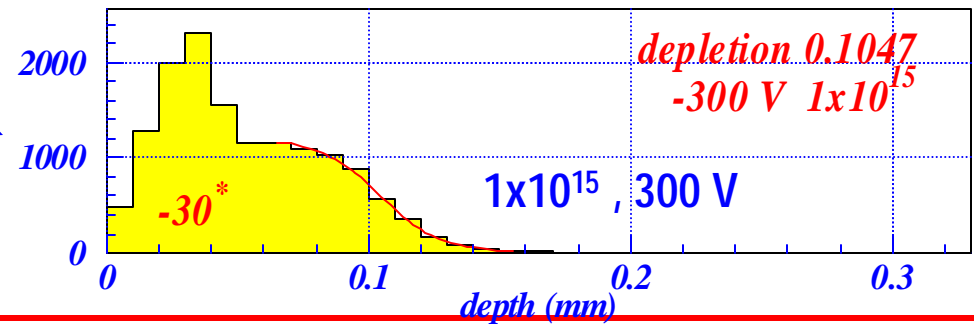
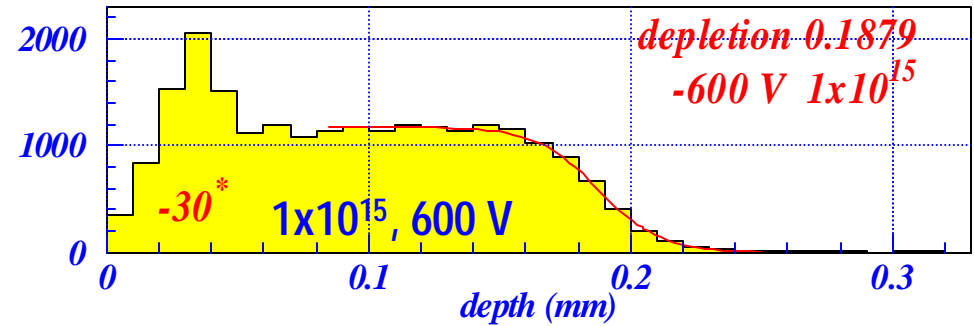
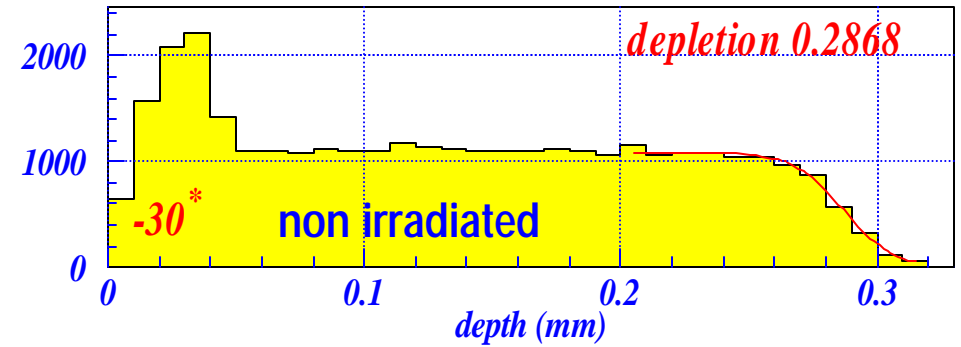
- ➔ charge sharing confined to $\pm 5 \mu m$ between adjacent pixels
- ➔ fraction of 2 pixels clusters is
~ 15% at 0° before irradiation
~ 7.5% after $10^{15} n_{eq} / cm^2$
- ➔ space resolution
 - ➔ flat top: 22 μm **⤷** 23 μm
 - ➔ double hit: 5 μm **⤷** 6 μmafter irradiation

Performance ... depletion depth

the method



after 10^{15} cm^{-2} the depletion depth is $190 \mu\text{m}$ @ 600 V , $105 \mu\text{m}$ @ 300 V

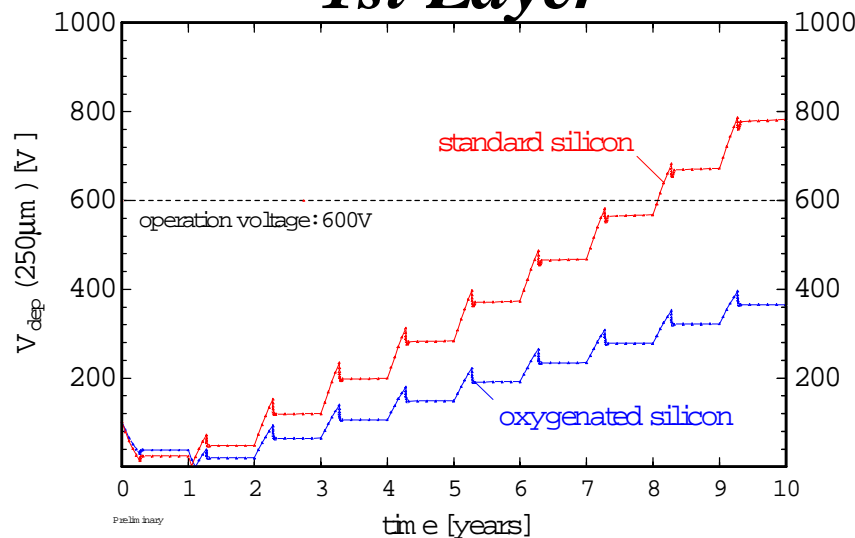


performance ... prediction

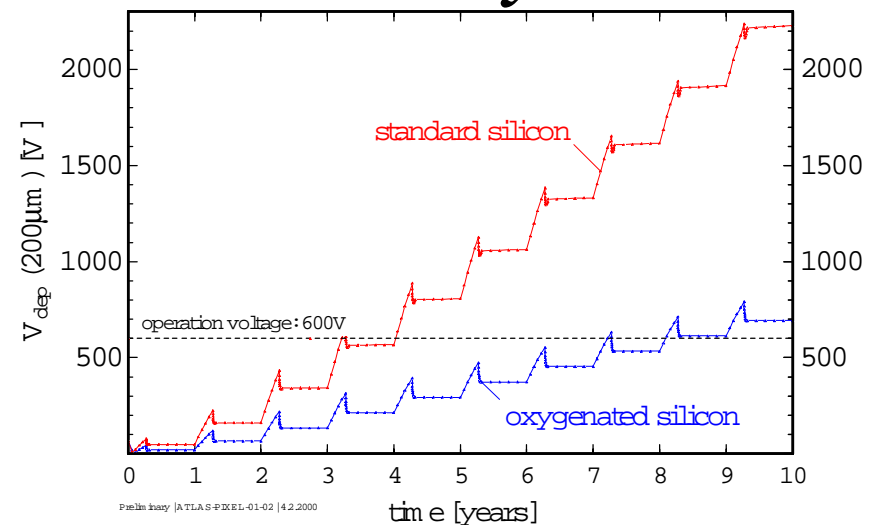
prediction calculation of V_{depl} with oxygenated silicon

- 1st-layer: $\phi_{eq} = 6.6 \cdot 10^{14} \text{ cm}^{-2}$ in 10 years
- B-layer: $\phi_{eq} = 3.5 \cdot 10^{14} \text{ cm}^{-2}$ per year at full luminosity
- for B-layer > 85% charged hadrons, for 1st-layer 70% charged hadrons
- standard scenario: 100 days beam per year, 14 days warm-up @ 17°C, 3 days @ 20°C

1st Layer



B-layer



next step ... production wafer

3 tiles per wafer

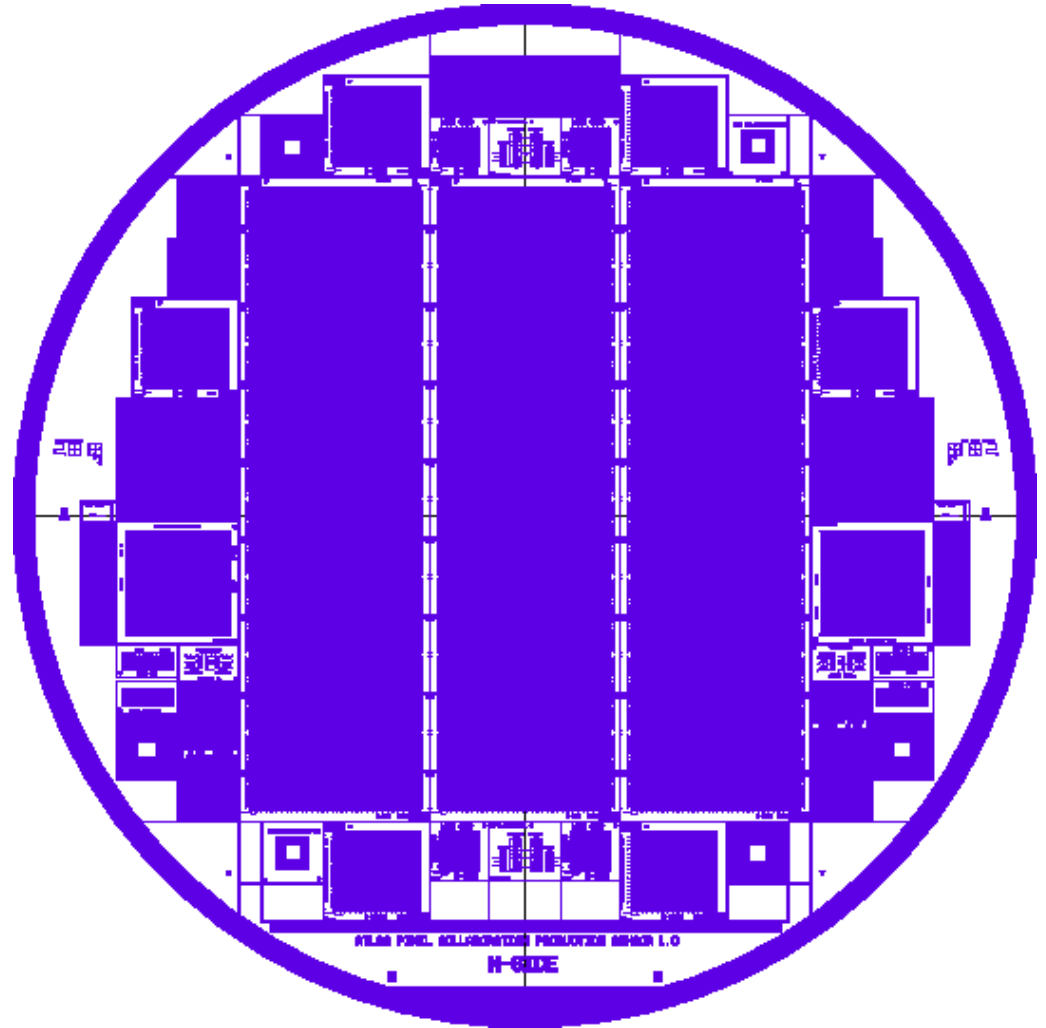
- *SSG, 20 μm gap*

6 single chips

- *tile like design*

Test-&monitor structures

- *6 diodes (2 designs)*
- *4 mini-chips*
- *further structures for process monitoring*



Conclusions

Pixel Design

Ready

Radiation Hardness

Ensured

FDR and PRR

Passed

Tender for Production

now

Start of Production

July/August 2000