US HEP Sensor Vendor Initiative

L. Spiegel, FNAL

Based on recent presentation by U. Heintz in the CMS Sensor forum and recent TCAD simulations from Ron Lipton

US Sensor Initiative

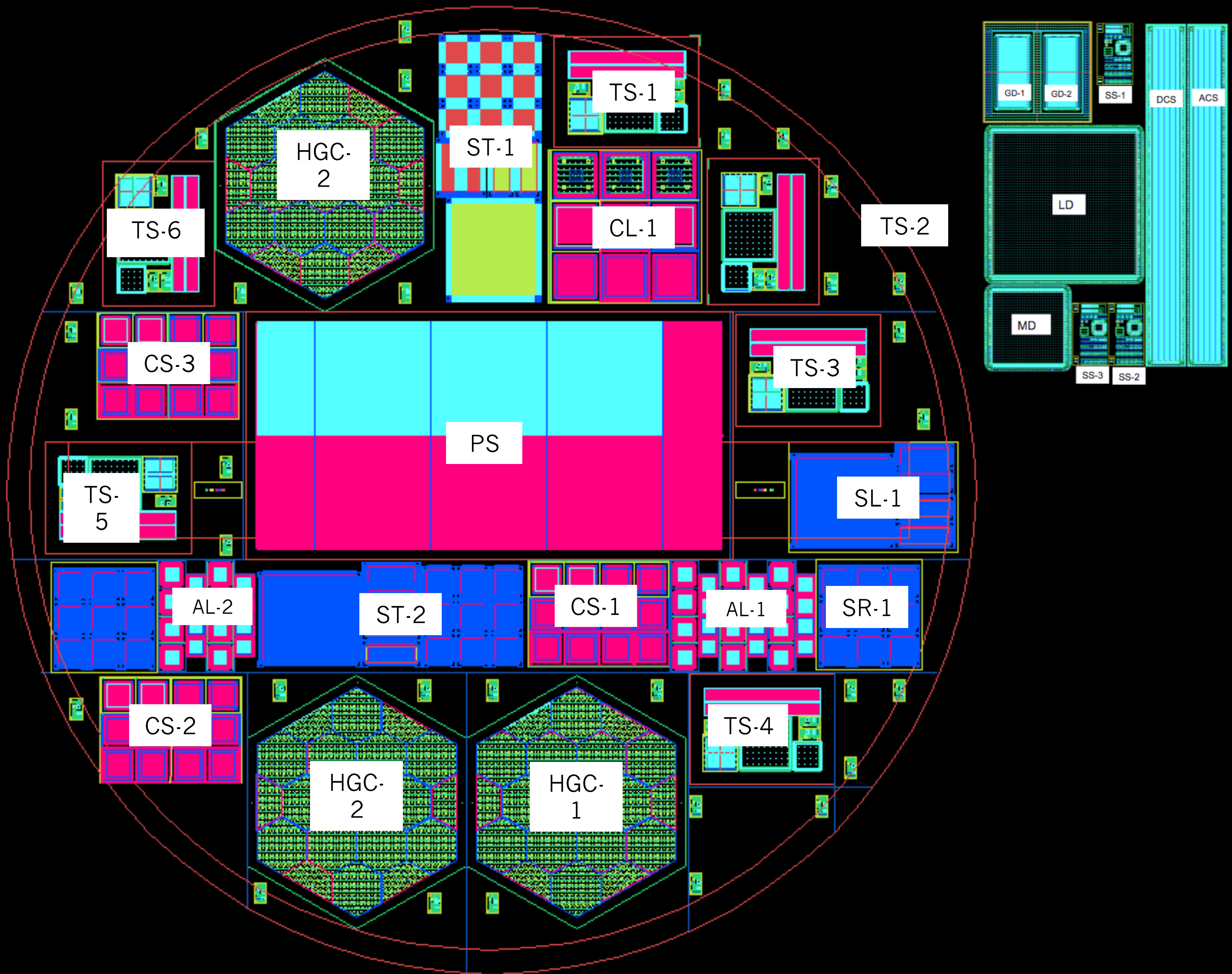
- Collaborative effort of US National labs with Tezzaron/ Novati to develop wafers for potential use in HEP experiments.
  - Developed under framework of a US DOE Small Business Innovation Research (SBIR) grant
- In the first phase Novati produced using 200 mm FZ silicon from BNL
  - Four 725 μm p-type wafers
    - 3 with p-stop + p-spray
    - 1 with p-stop only
  - Two p-type wafers thinned to 500 μm after front-side processing
    - 1 with p-stop + p-spray
    - 1 with p-stop only (broke during processing)

US CMS Outer Tracker Sensor Group

- Brown University
  - U. Heintz, M. Narain
  - Sensor Qualification
  - Process Qualification
  - Irradiation and post-irradiation characterization
    - Neutron irradiation at RI Nuclear Science Center
    - Proton irradiation at Los Alamos National Lab

- Fermilab
  - A. Canepa, R. Lipton, L. Spiegel
  - Irradiation and post-irradiation characterization
    - Proton irradiation with future facility based on FNAL Linac

- University of Rochester
  - R. Demina, S. Korjenevski
  - Sensor Qualification
  - Process Qualification



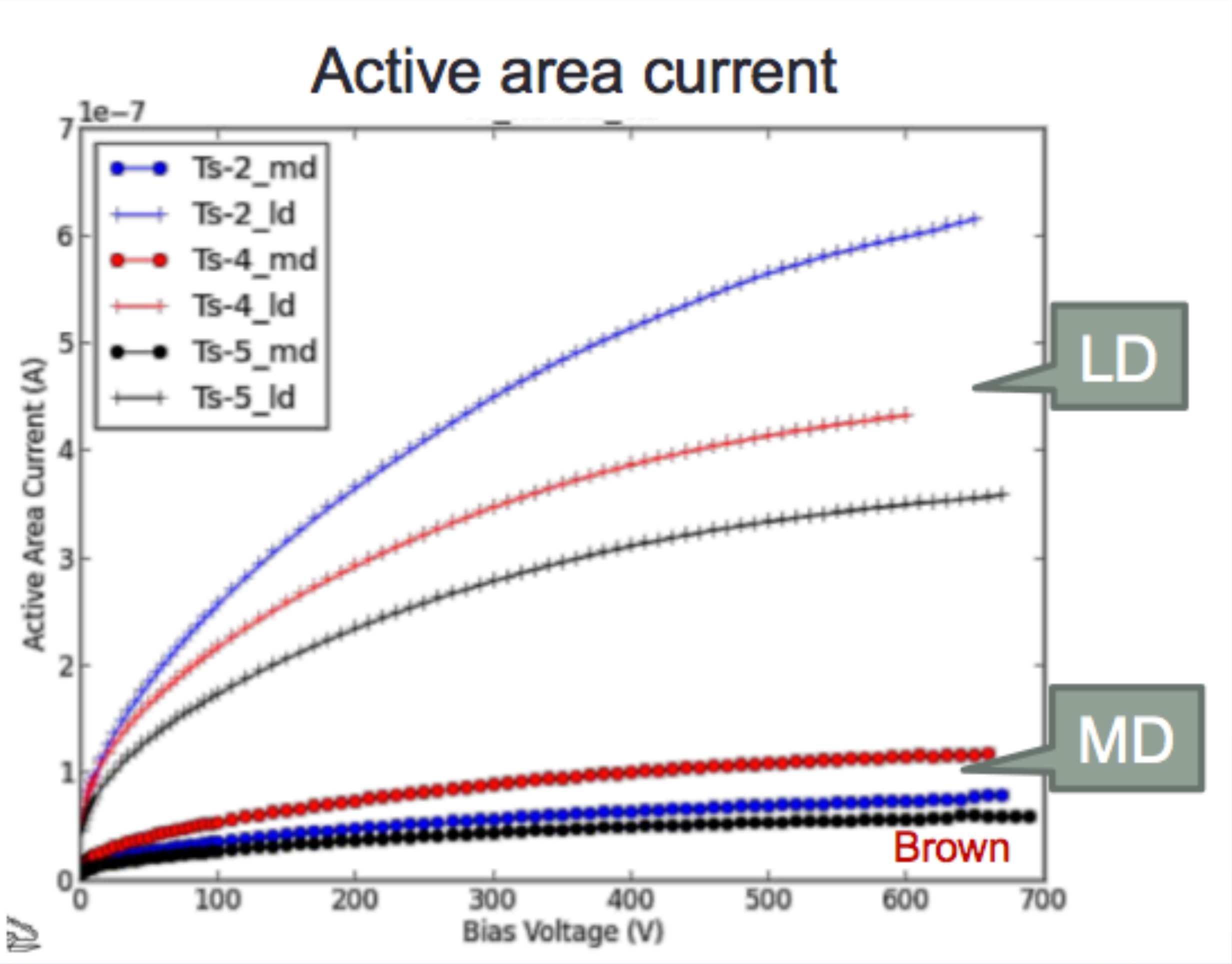
HGC-2
ST-1
TS-1
TS-6
CL-1
TS-2
CS-3
PS
TS-3
TS-5
SL-1
AL-2
ST-2
CS-1
AL-1
SR-1
CS-2
TS-4
HGC-2
HGC-1
GD-1
GD-2
SS-1
DCS
ACS
LD
MD
SS-3
SS-2

Characteristics (500 μm wafer)

Parameter	**MD**	**LD**
Depletion voltage V_{dep}	351 V	341 V
Capacitance C	6 pF	23 pF
Thickness d	449 μm	450 μm
Effective doping concentration $_{Neff}$	$2.3 \times 10^{12}/cm^3$	$2.2 \times 10^{12}/cm^3$
Resistivity ρ	5.7 kΩcm	6.5 kΩcm

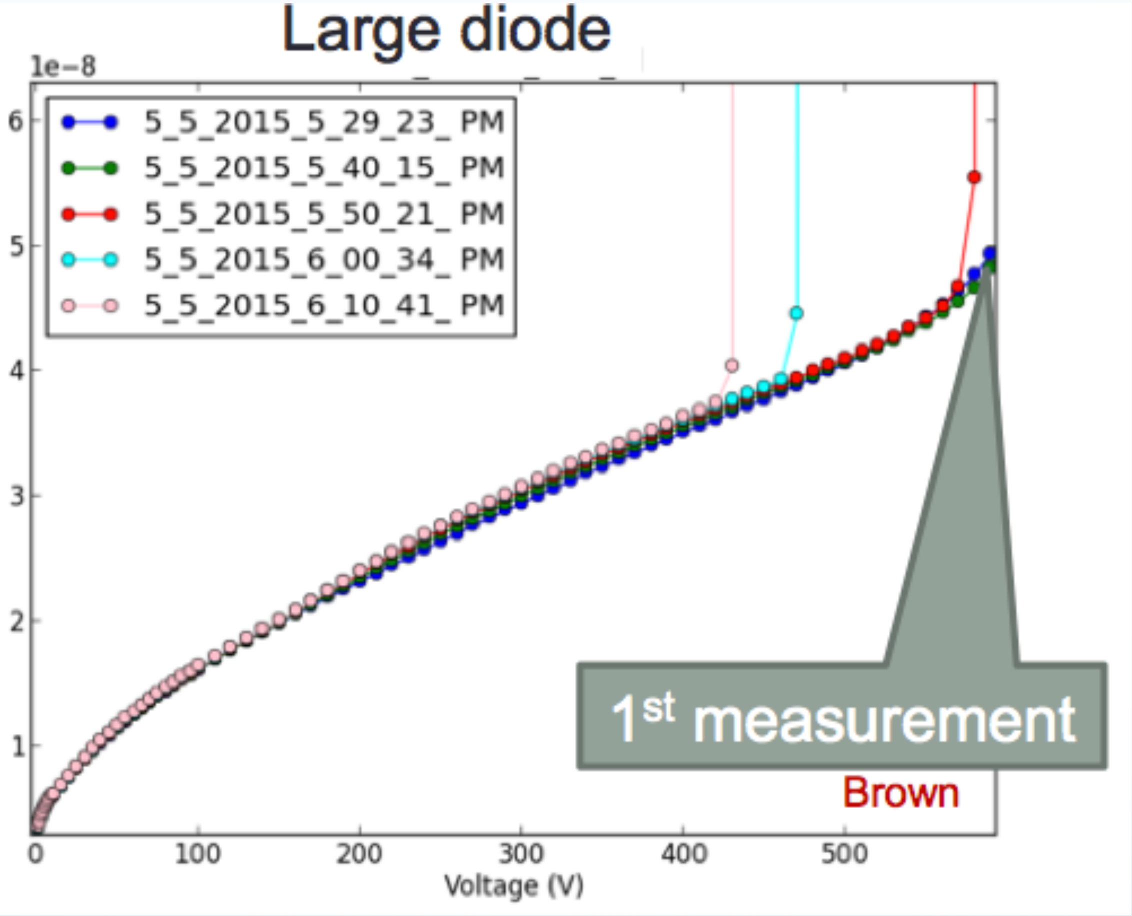
The oxide thickness is ≈1μm

Test results



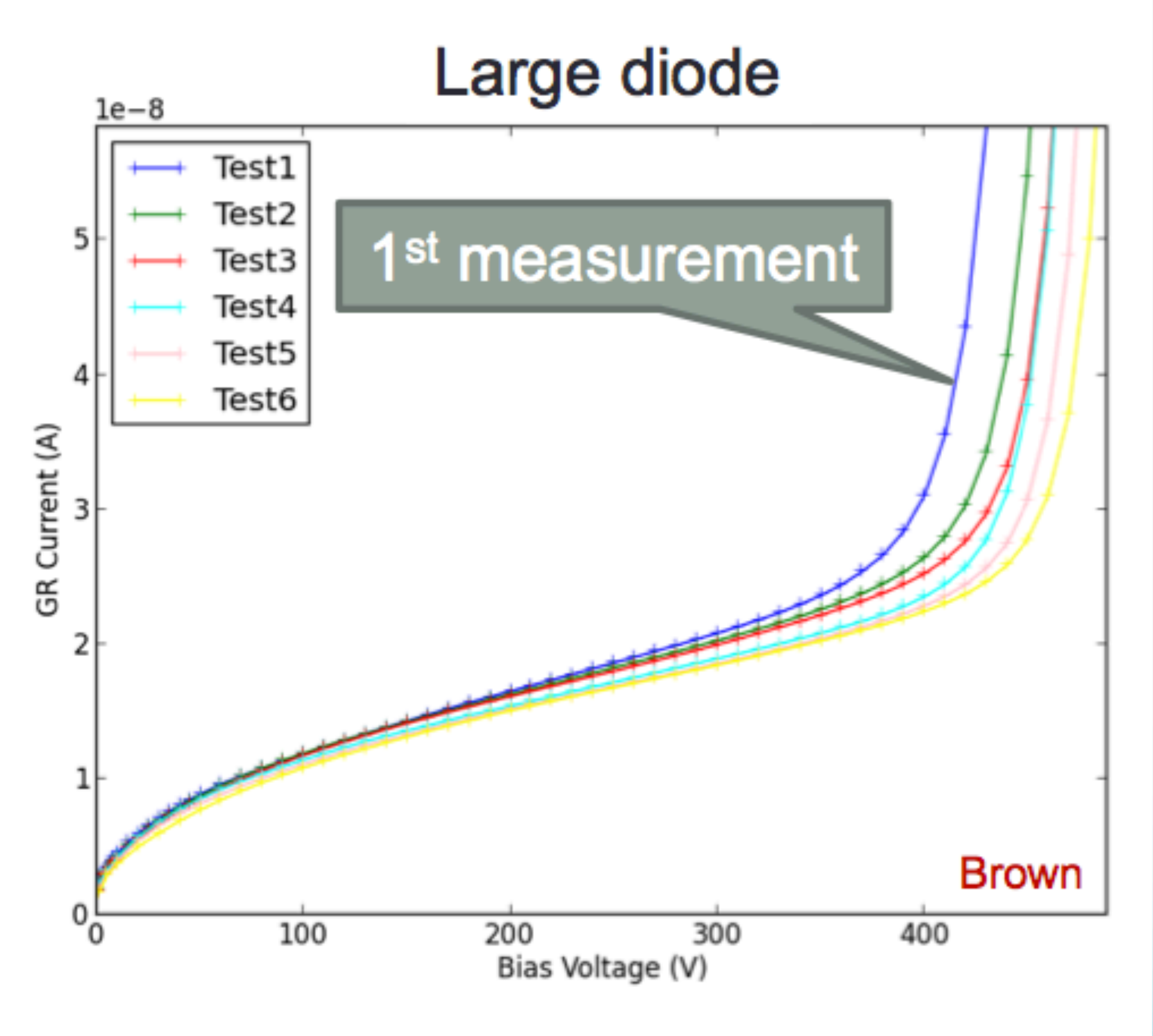
IV measurements from Brown University. Similar results observed at FNAL and Rochester.

Worsening GR breakdown for p-stop + p-spray



Guard Ring current (A)

More stable breakdown for p-stop only



Guard Ring current (A)

Guard ring breakdown phenomenon

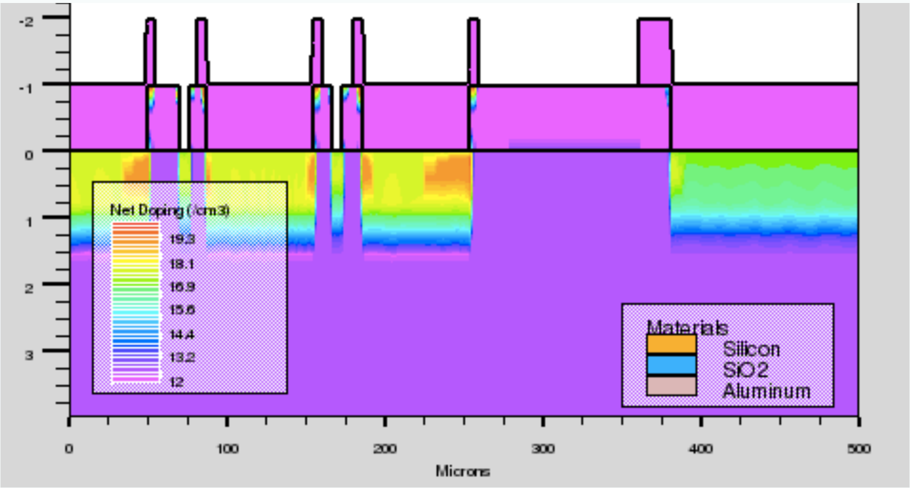
- Possible causes
  - Mixing p-spray and p-stop isolation?
  - Use of p-stops between guard rings?
  - Too high doping concentration for p-stop material?
  - Lack of significant metal "overhang"?
- Ron Lipton (FNAL) has made a number of TCAD simulations to try to understand the phenomenon.
  - Next few slides
  - Additional studies from Julie Segal (SLAC)
- Several guard ring structures will be tried in the next Novati submission.

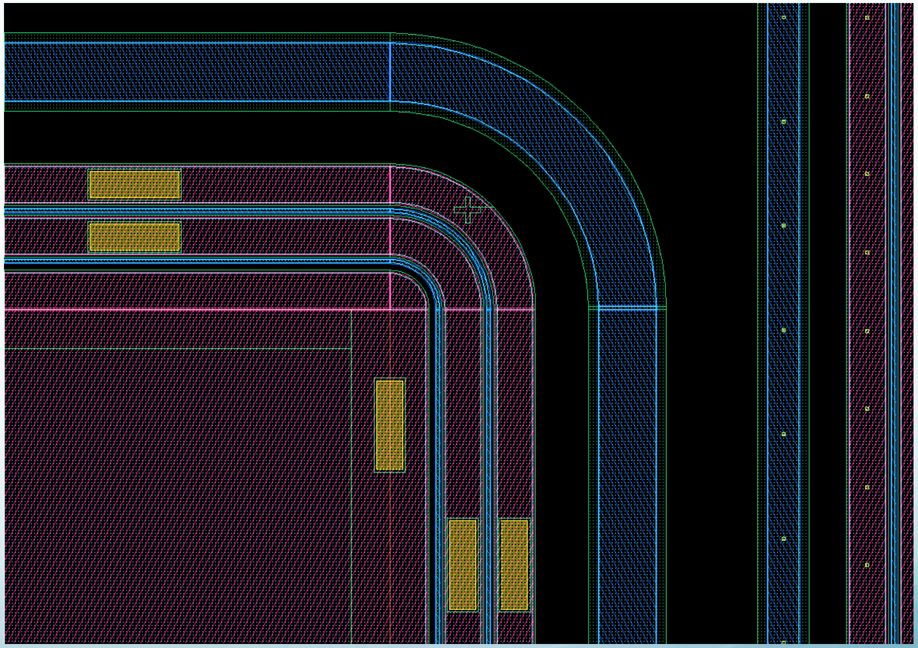
Two ring structure

TCAD studies done for 2-ring structure with the inner ring grounded. Both p-stop+p-spray and p-stop only variations explored.

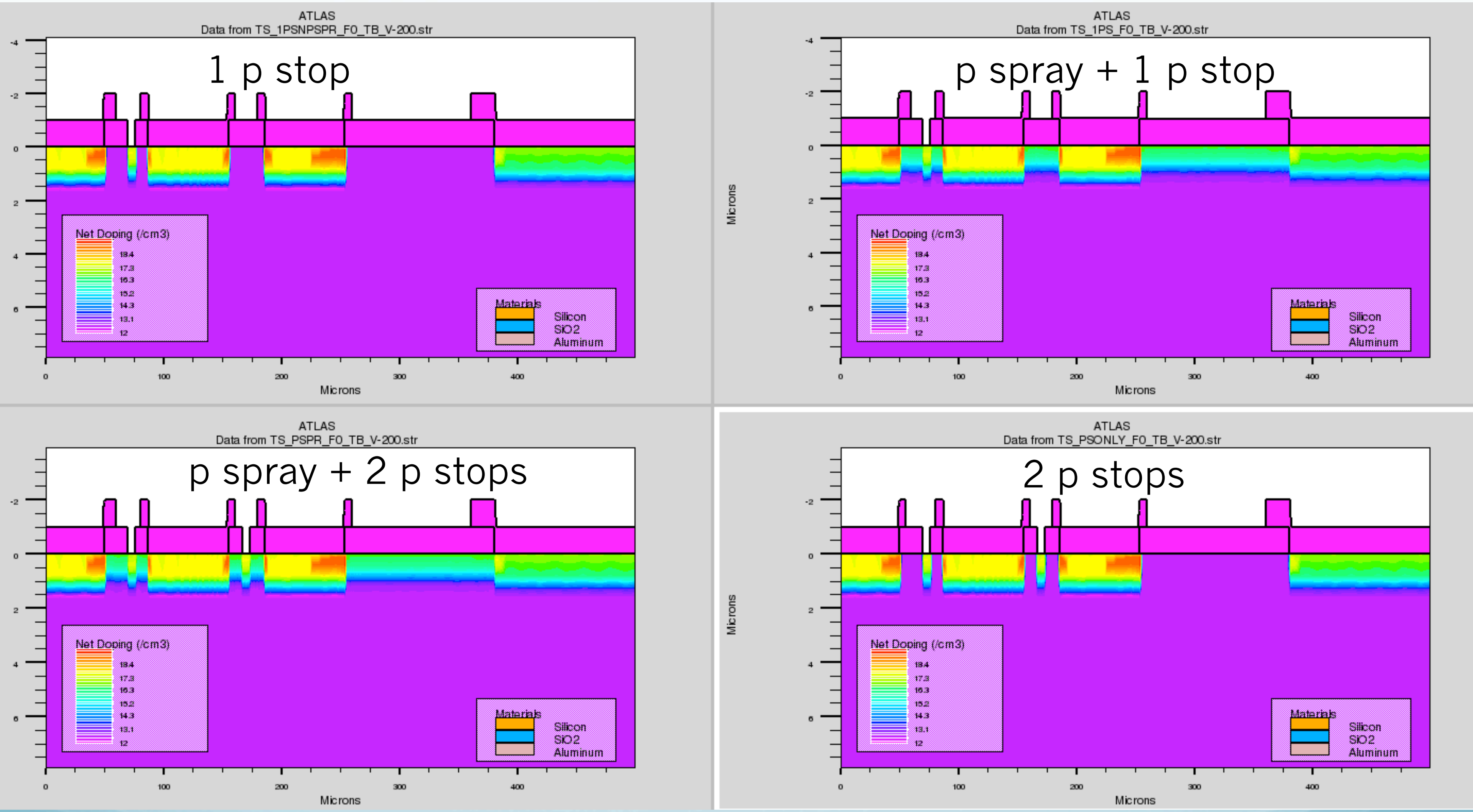
SIMS measurements compared with Silvaco results.

The measured p-stop implant density is high (about 1E18).

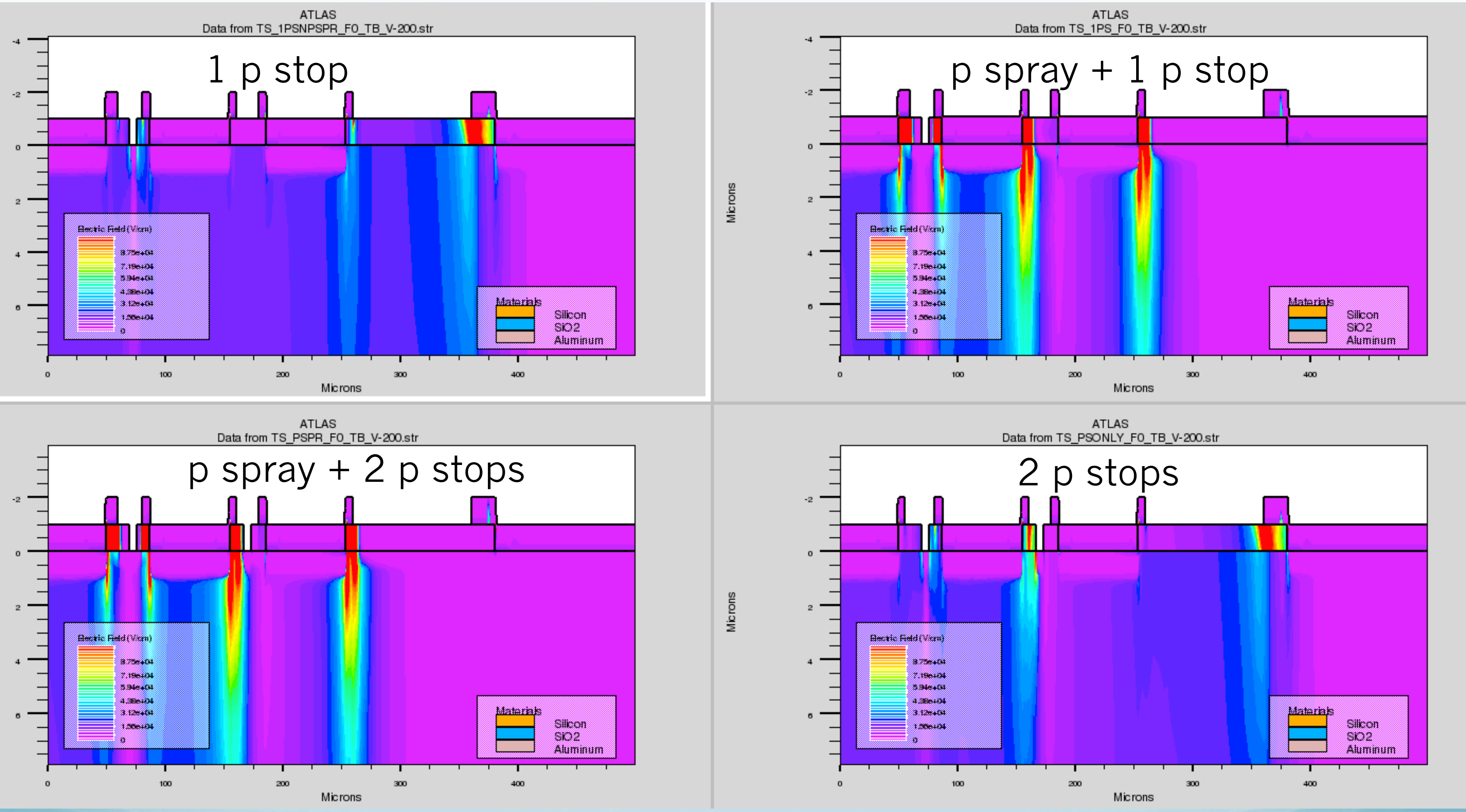




Variants studied

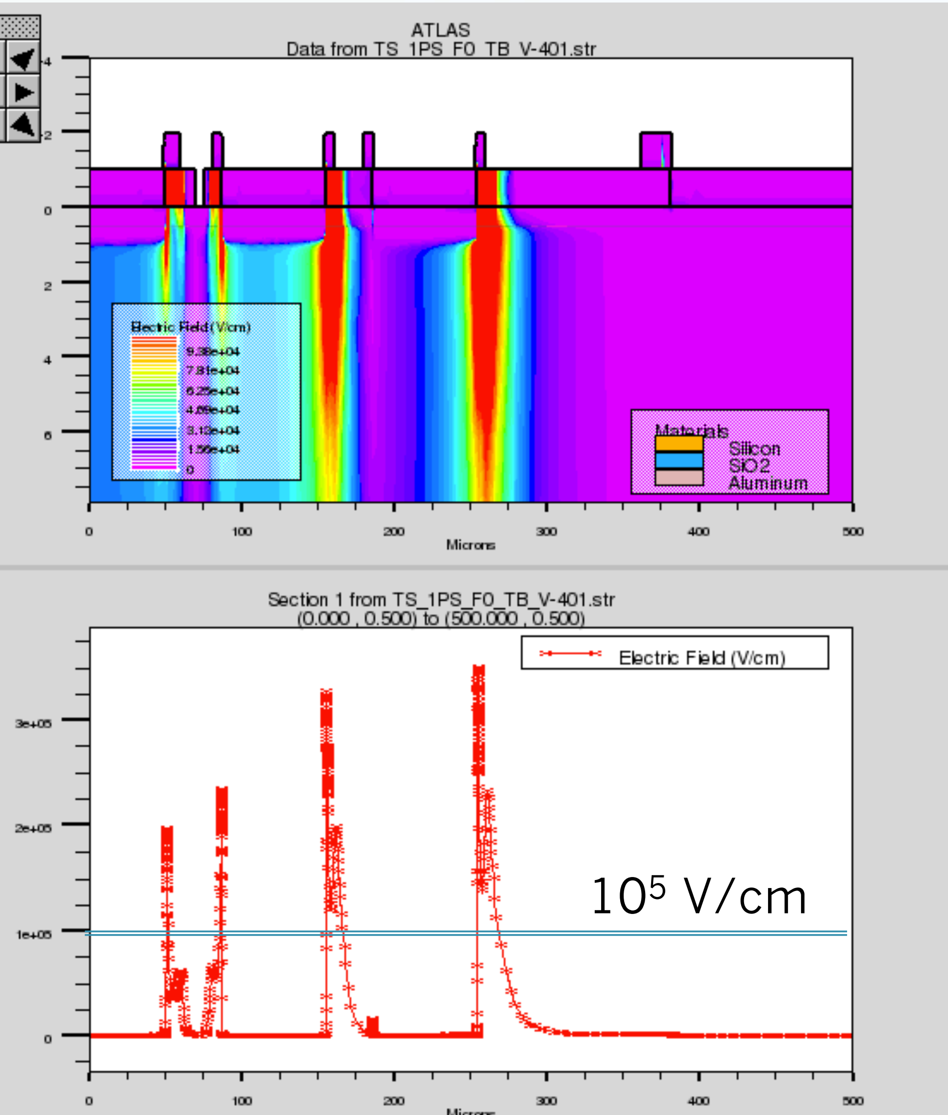


Electric fields

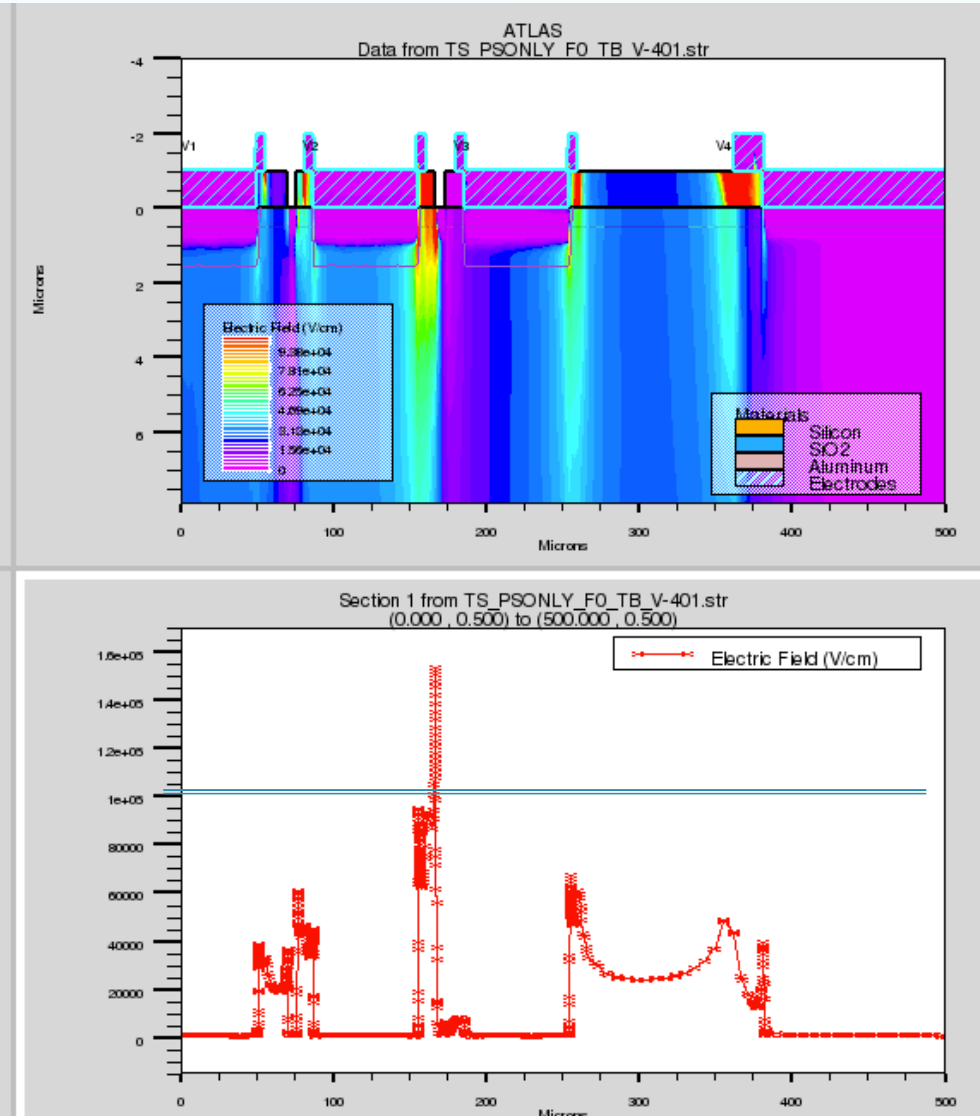


Effect of p-spray

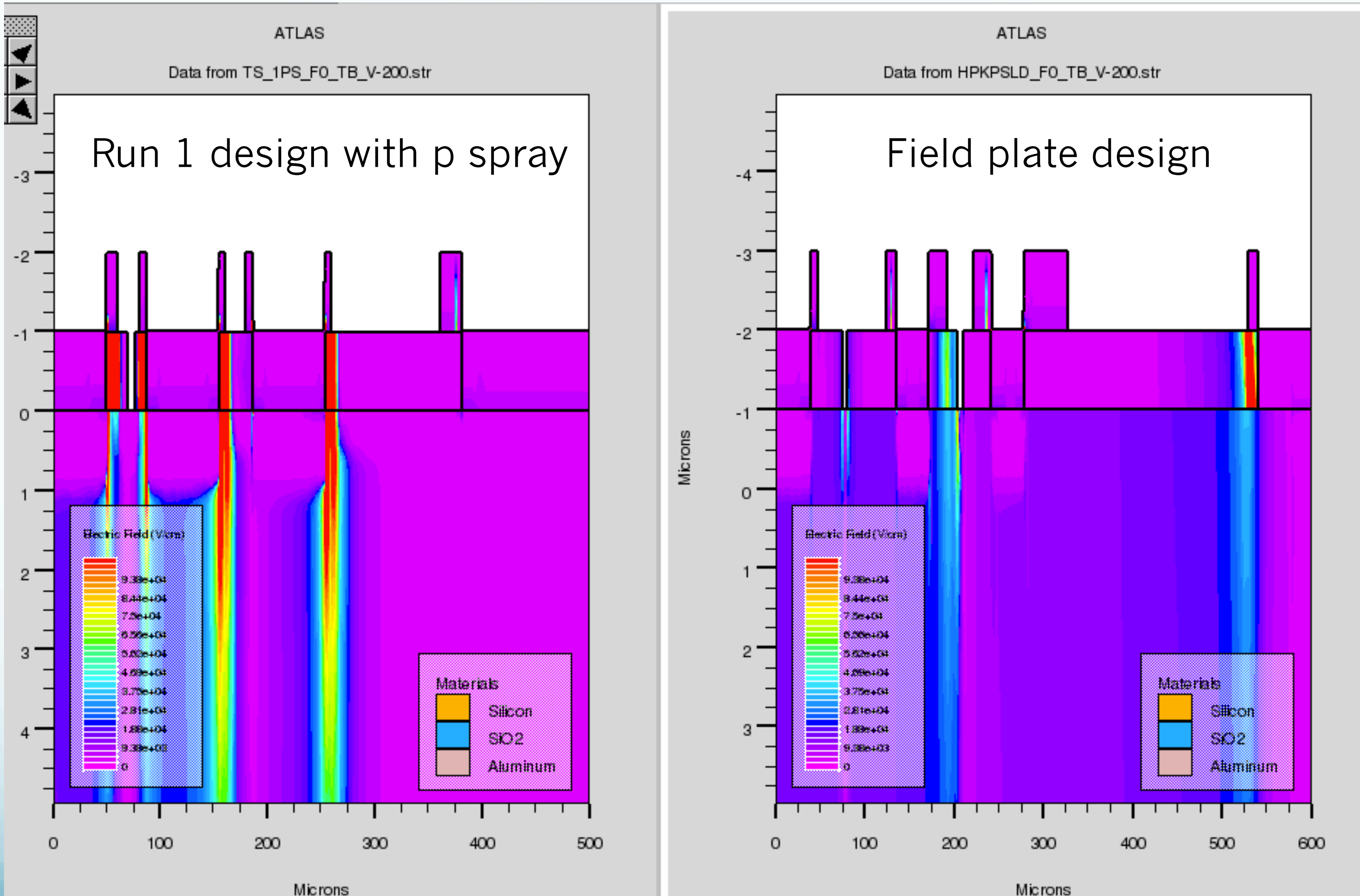
one p-stop + p-spray



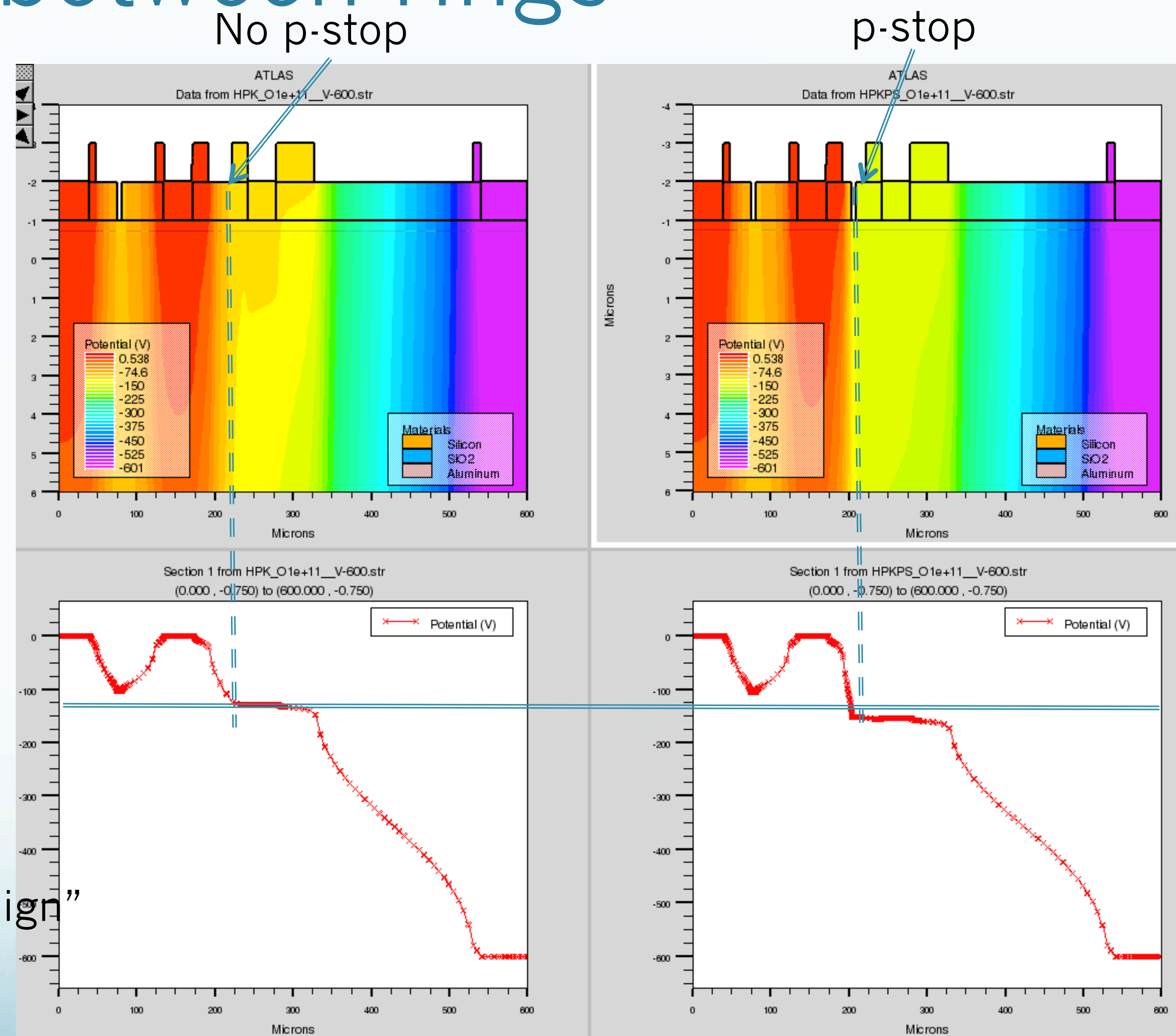
p-stops between rings No p-spray



Comparison with HPK design



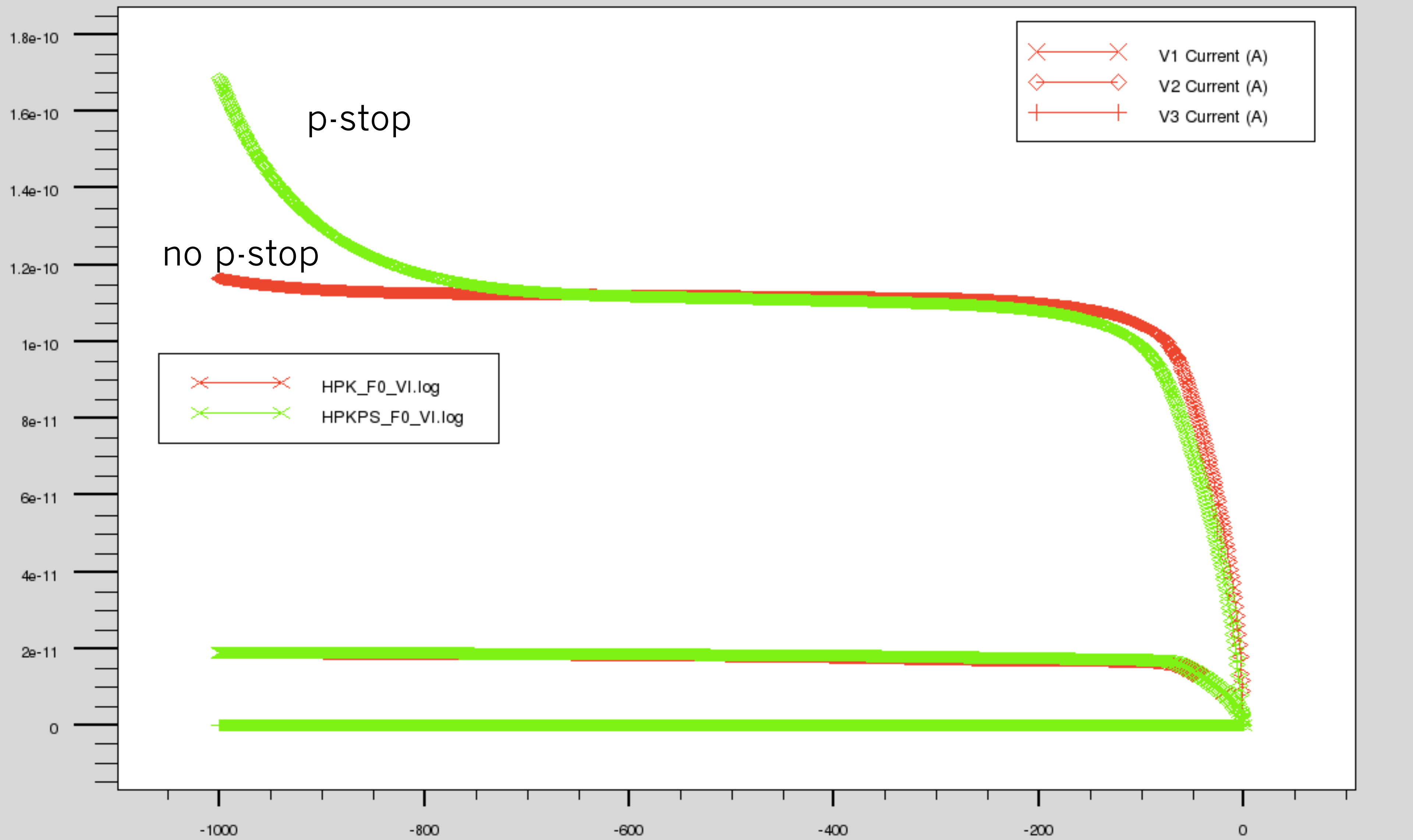
p-stops between rings



The HPK* design does not have p-stops between n-type guard rings, but does have a significant (50μm) metal overhang

*CMS "HPK Campaign"

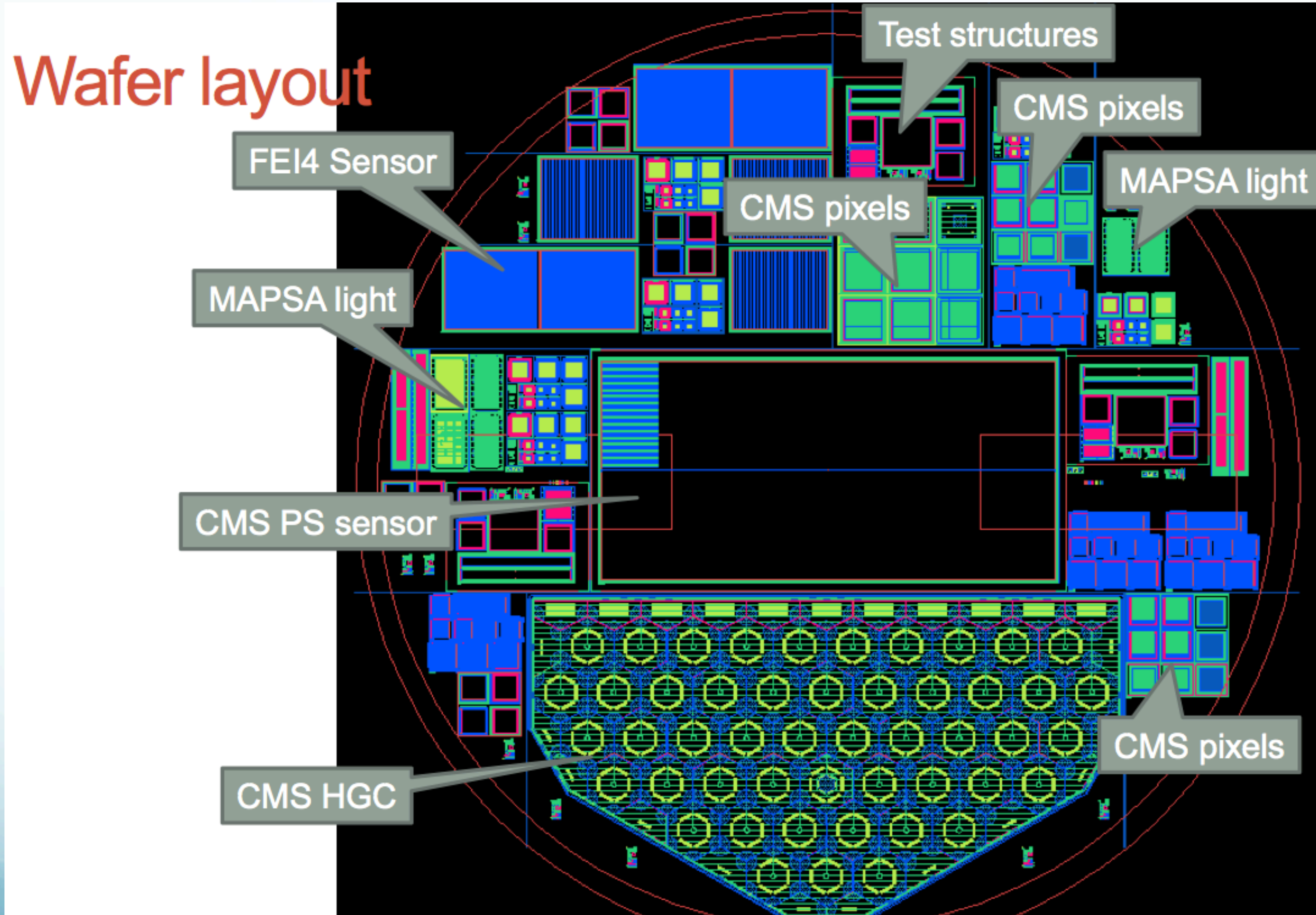
Leakage current dependence



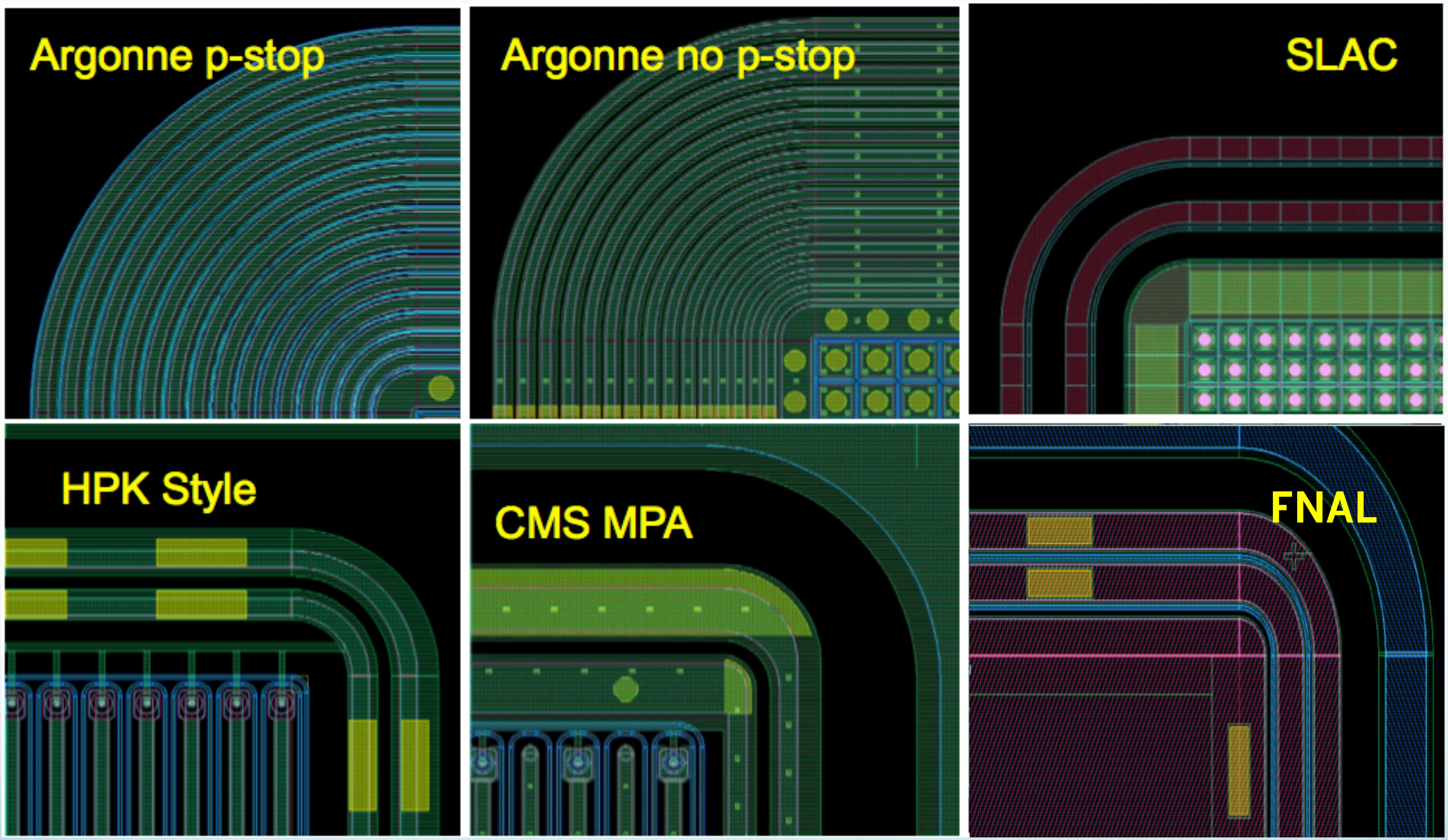
Changes for the second Novati submission

- New materials
  - 2 FZ wafers thinned to 500 microns
  - 4 SOI wafers with 200 μm FZ thickness
- CMS MaPSA strip and lite structures
- Several guard ring variations
- No p-spray!
- Two p-stop doping variants
  - 1E17 and 1E16

Second Novati submission layout



Guard ring designs for second submission



Summary

- Expect another 6 wafers from Tezzaron/Novati by the end of January.
- The main goal is to produce thin sensors.
- Some modifications to the design and processing; in particular a number of guard ring options.
- Tezzaron/Novati will apply for a two-year phase 2 SBIR grant with the idea of producing prototype sensors.
  - For both the CMS Tracker and HGC

Backup

Second submission specs

Icemos Technology Ltd **Product Specification** **1000.435601** Issue Date 17 July 2015 00:01:02

Part Number	FERM SiSi 001 200mm, Customer Part: FERM SiSi 001 200m	Customer	Fermilab

Category		Parameter	Specification	Measurement Method
OverallWafer	1.0	Diameter	200.00 +/- 0.50 mm	
	2.0	Notch Direction	{110} +/- 1 degree	Wafer Vendor
	3.0	Notch or Flat	Notched	Wafer Vendor
	4.0	Secondary Flat Orientation	none	
	5.0	Secondary Flat Length	none	Wafer Vendor
	6.0	Overall Thickness	725.00 +/- 12.00 µm	ADE, 100%
	7.0	Total Thickness Variation (TTV)	<5.00um	ADE 100% to ASTM F534
	8.0	Bow	<80.00µm	ADE to ASTM F534, 20%
	9.0	Warp	<80.00µm	ADE to ASTM F657, 20%
	10.0	Edge Chips	0	Bright Light, 100% (note 2)
	11.0	Edge Exclusion	5mm	
HandleSilicon	12.0	Handle Growth Method	CZ	Wafer Vendor
	13.0	Handle Orientation	{100} +/- 1 degree	Wafer Vendor
	14.0	Handle Thickness	525.00 +/- 10.00 µm	ADE, 100%
	15.0	Handle Doping Type	N	Wafer Vendor
	16.0	Handle Dopant	Any	Wafer Vendor
	17.0	Handle Resistivity	<0.1 Ohm-cm	Wafer Vendor
	18.0	Backside Finish	Polished	Wafer Vendor
BuriedOxide	19.0	Oxide Type	NONE	
DeviceSilicon	20.0	Device Growth Method	FZ	Wafer Vendor
	21.0	Device Orientation	{100} +/- 1 degree	Wafer Vendor
	22.0	Nominal Thickness	200.00 +/- 2.00 µm	Filmetrics, 100% 9-Pt (note3)
	23.0	Distance to device silicon edge from wafer edge	<= 2mm	Typical by Process
	24.0	Device Doping Type	N	Wafer Vendor
	25.0	Device Dopant	Phosphorous	Wafer Vendor
	26.0	Device Resistivity	>5000 Ohm-cm	Wafer Vendor
	27.0	Voids	none	Wafer Vendor
	28.0	Scratches	0	Bright Light, 100% (note 2)
	29.0	Haze	none	Bright Light, 100% (note 2)

SIMS measurements (Evans)

n implant (phosphorus) | p-stop implant (boron) | p-spray implant (boron)