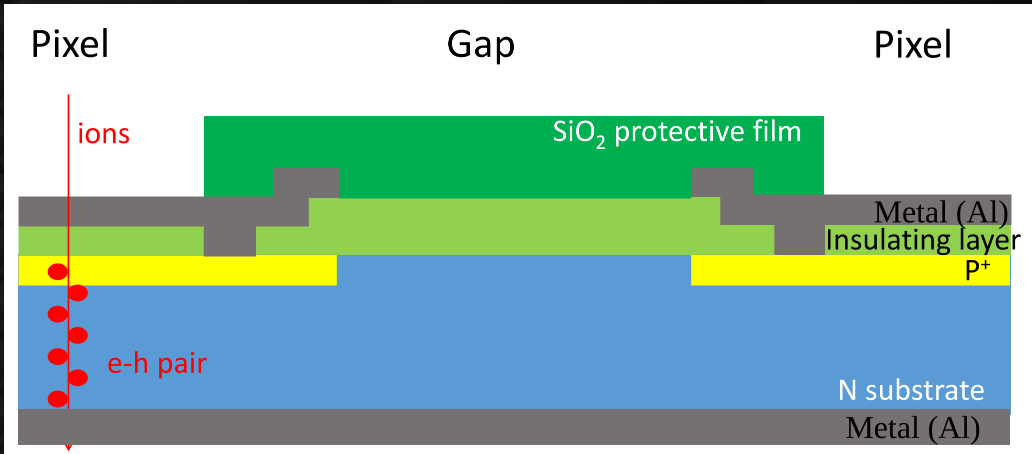
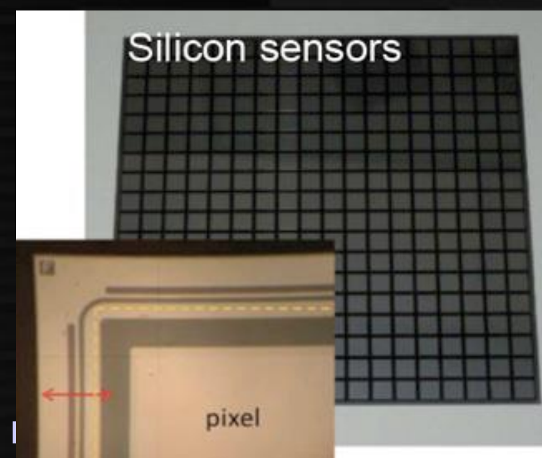
Silicon sensor study & some consideration

Taikan Suehara, Hiroki Sumida
(Kyushu University, Japan)

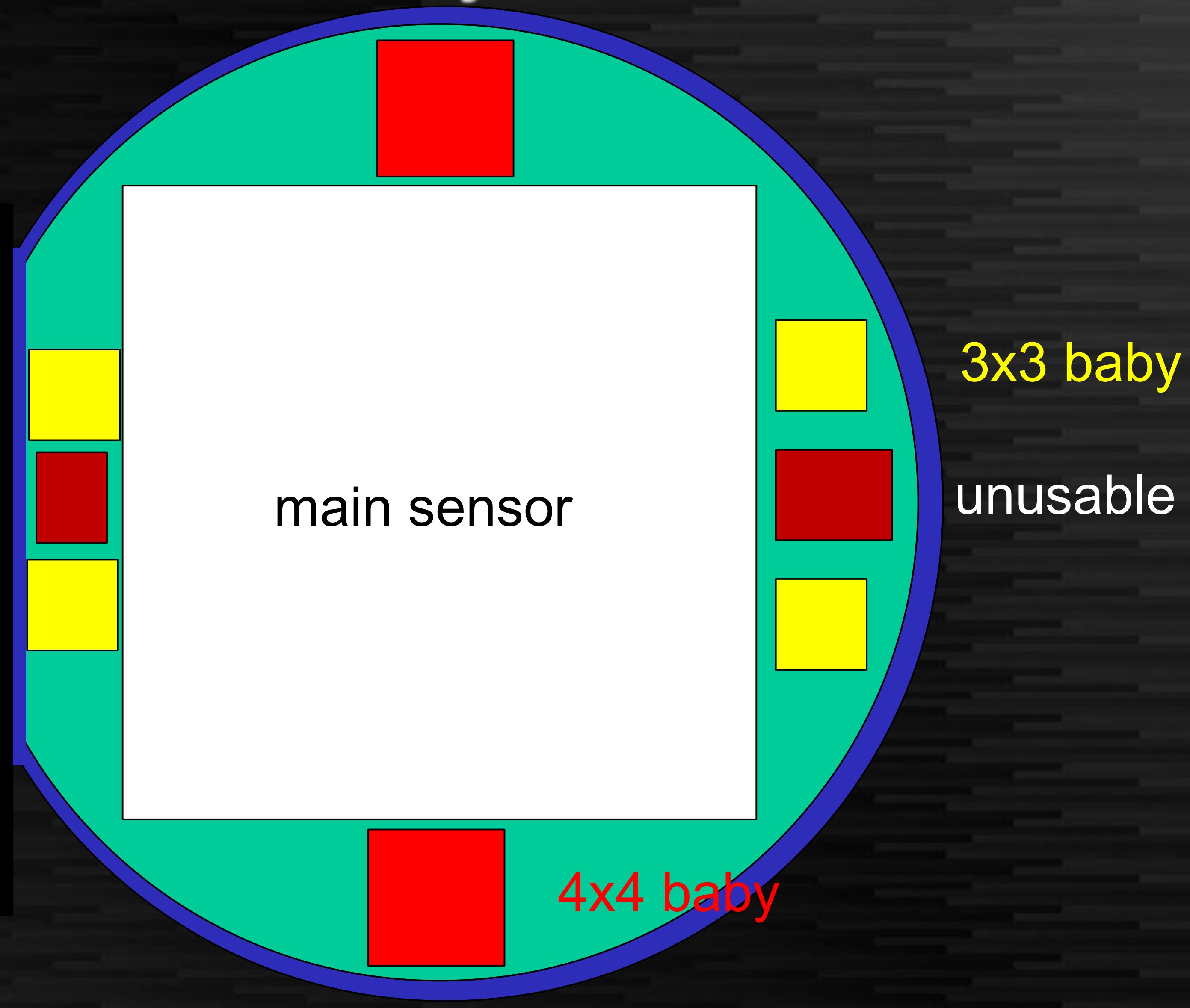
Sensor of ILD SiECAL tech. proto.

- High-resistivity silicon pads
  - Made by Hamamatsu photonics
  - 1 sensor per a 6-inch wafer
  - 16 x 16 pixels, 5.5 x 5.5 mm size (2nd gen.)
  - 320 μm thickness
  - Full depletion voltage: < 120 V
    - Resistivity not public: ~ 10 kohm cm
  - one guard ring (GR) at the edge of sensors





Main & baby sensors

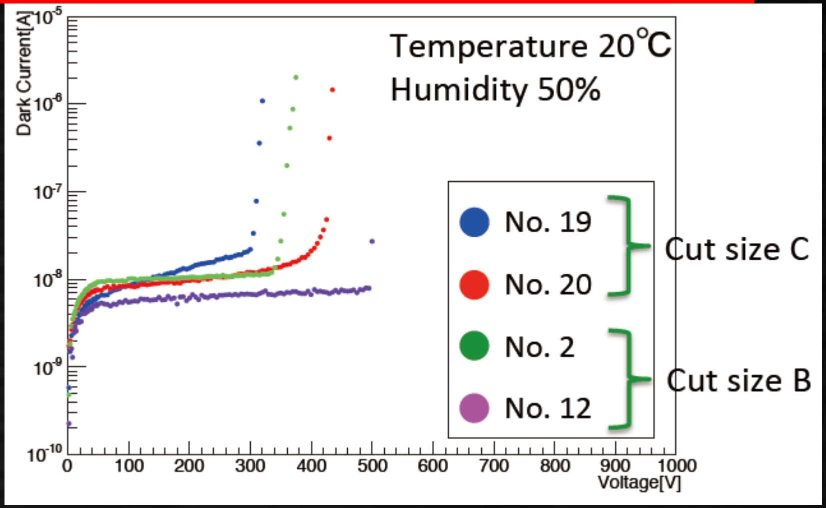


Baby sensors are useful to study basic characteristics of sensors

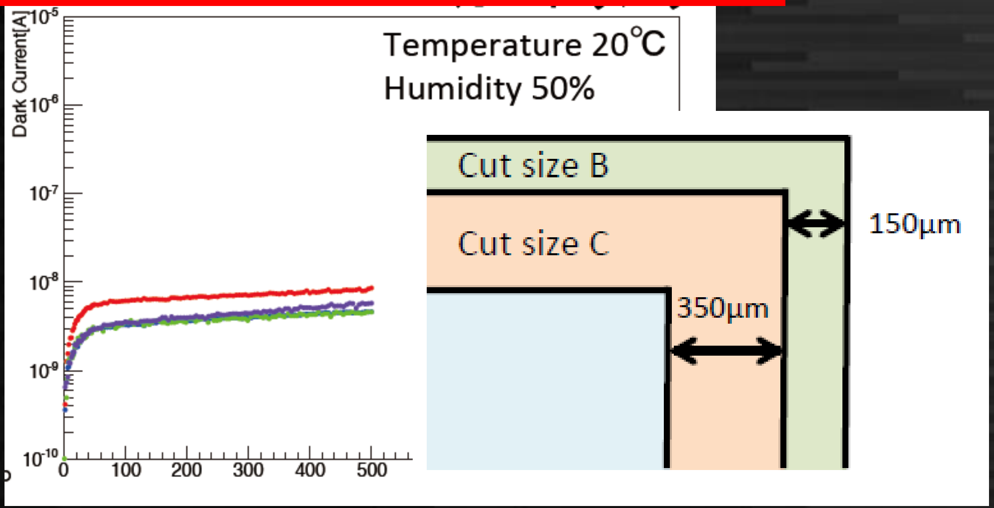
Guard ring studies (reminder)

Guard ring causes square event – try no guard ring design

No guard ring – I/V meas.



One guard ring – I/V meas.



- No critical change in I/V characteristics and breakdown V
- Square events suppressed in 0 GR with laser study

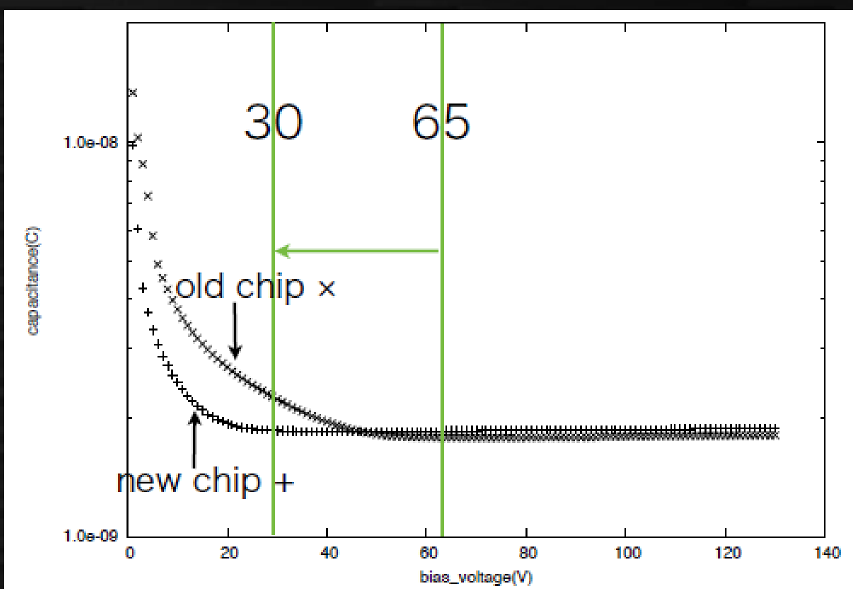
→ 0 GR preferred, to be tested in testbeam & radiation damage

New (higher) resistivity

Two batches of Hamamatsu sensors

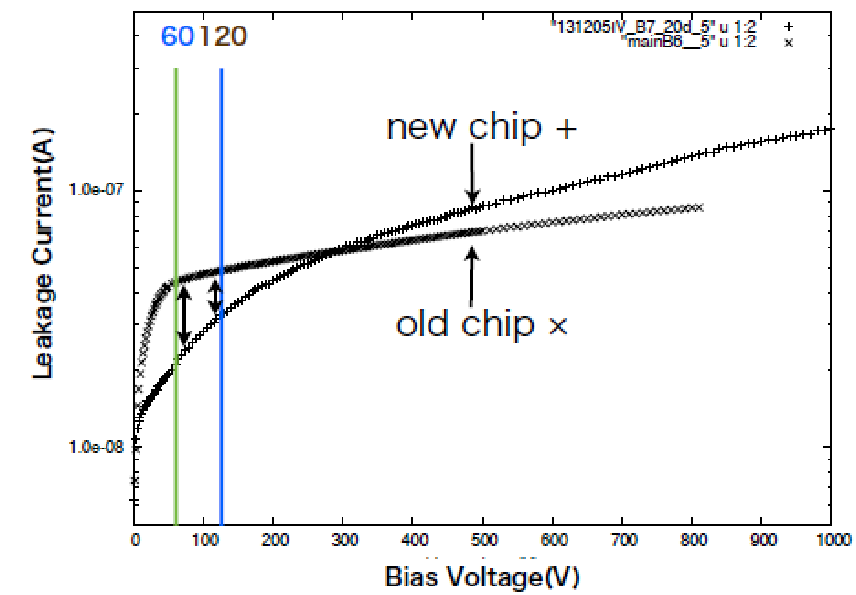
pixel size : 5.5 x 5.5 mm	same	pixel size : 5.5 x 5.5 mm
thickness : 320 μm	same	thickness : 320 μm
number of pixels : 256	same	number of pixels : 256
guard ring : 1	different	guard ring : 0
resistivity : unknown	→ higher as Hamamatsu said	resistivity : unknown

Currently only higher resistivity is available from Hamamatsu



C-V curve: saturation V differs

The leakage current at 120 V is 31nA (old : 48nA),
at 60 V is 21nA.



This value is twice lower than old prototype.

Our photomasks and productions

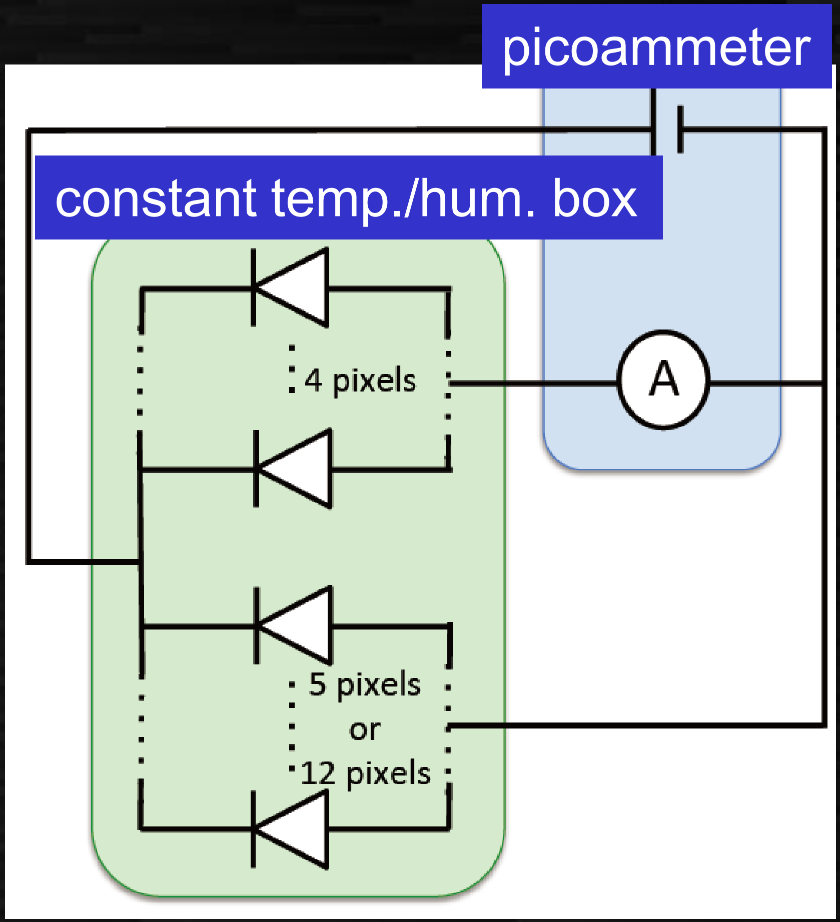
Photomask	Mask A	Mask B
Main sensor	1 GR, 5.5mm,16x16	0 GR, 5.5mm, 16x16
Baby sensor	Solid electrode, 0/1/2/4 GR	Meshed electrode, 0/1 GR

(Photomask costs 20-30 k$, sensor 1-2 k$)

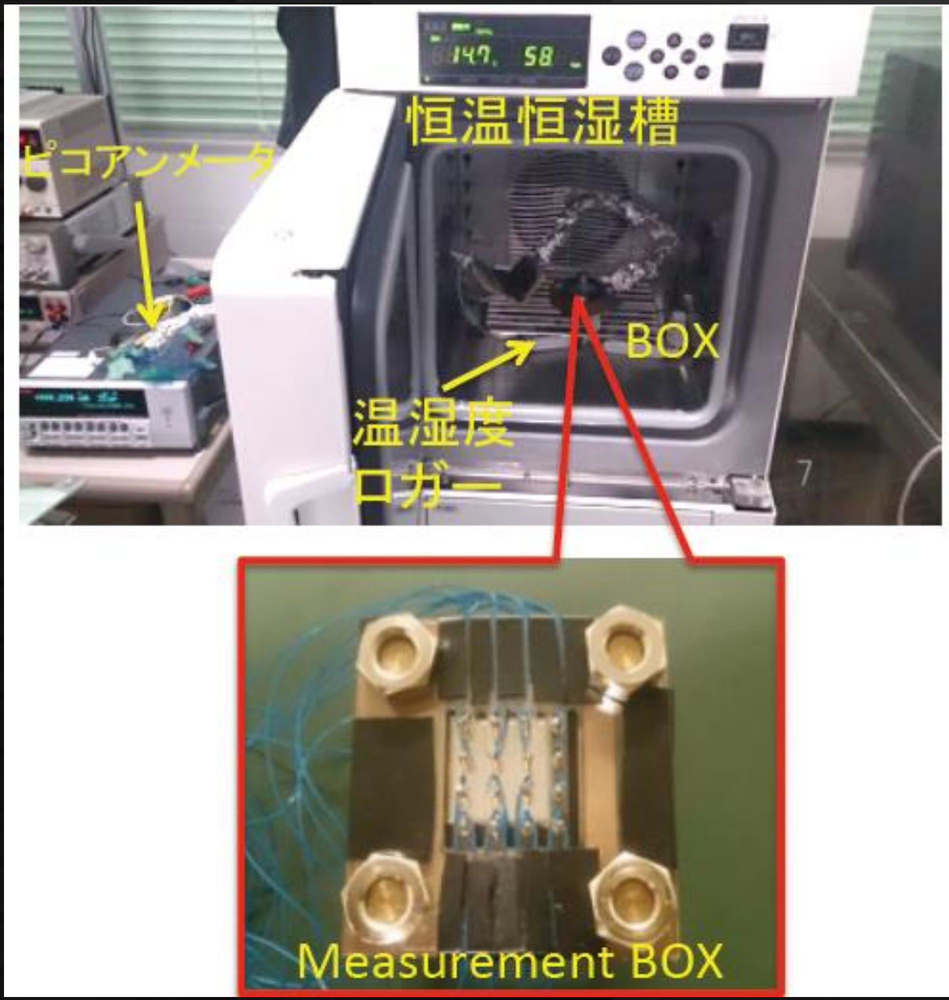
Production	2011	2013	2015A	2015B
Mask	A	B	A	A
(GR of main)	1 GR	0 GR	1 GR	1 GR
(baby)	solid	meshed	solid	solid
Thickness	320 μm	320 μm	320 μm	500 μm
Resistivity	lower	higher	higher	higher
# sensor	~16?	~16?	5	5

Newly arrived!

Measurement system updated

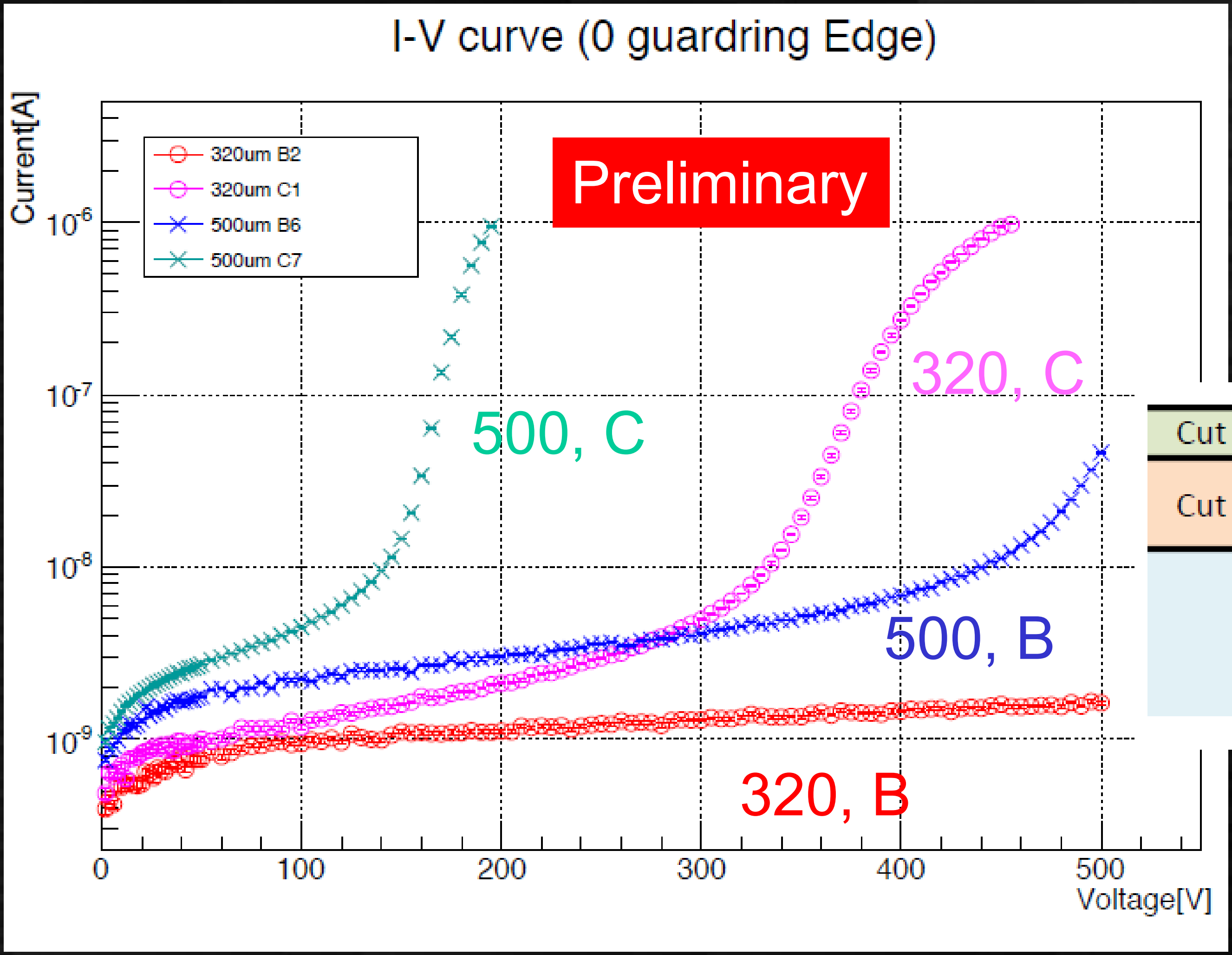


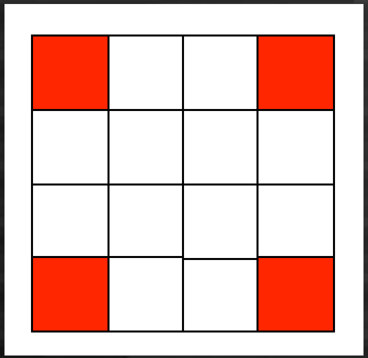
20 degree C, 50% humidity

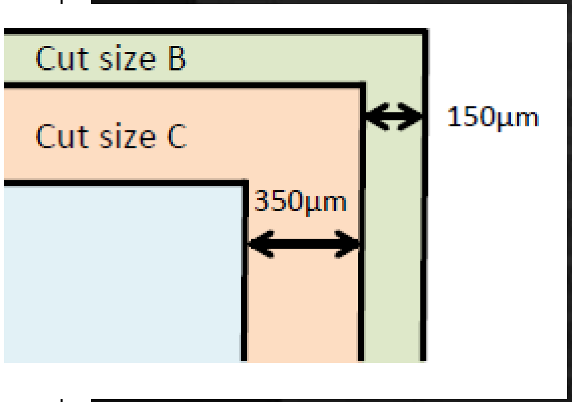


Leakage current from part of sensor can be measured

I/V curve at the edge pixels

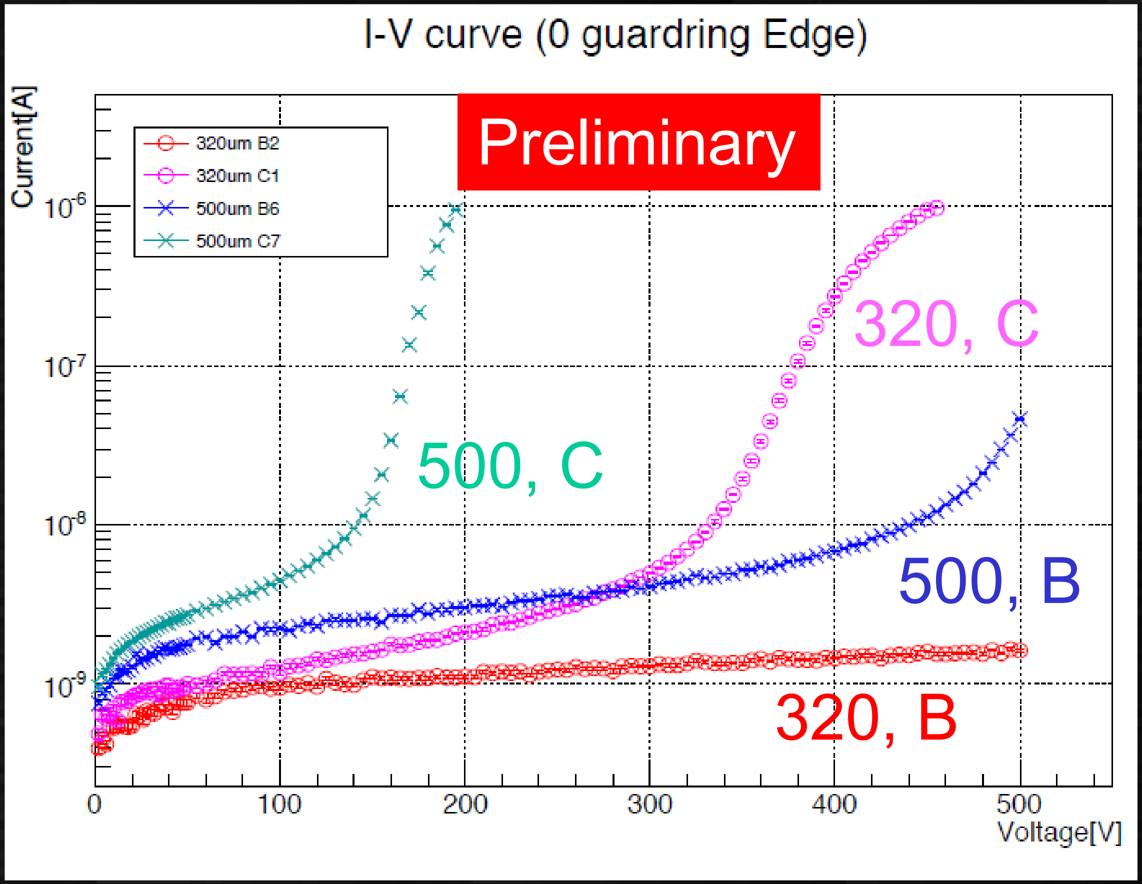




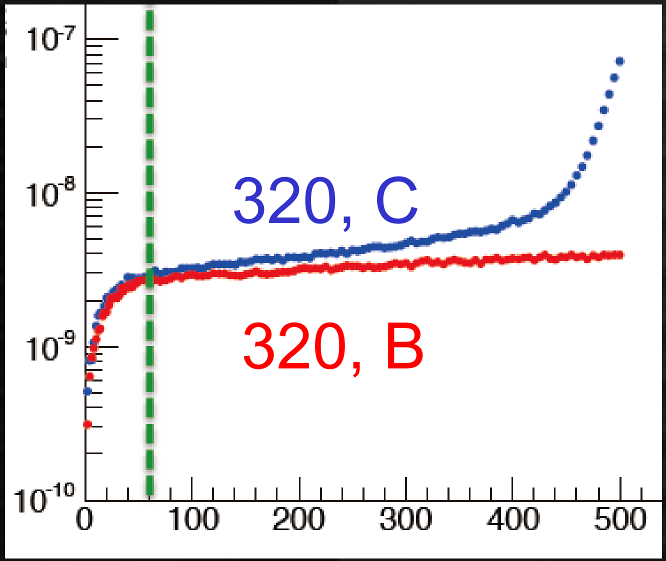


Cut size B is preferred; 500 μm is OK with cut size B

Compared with lower R sensor

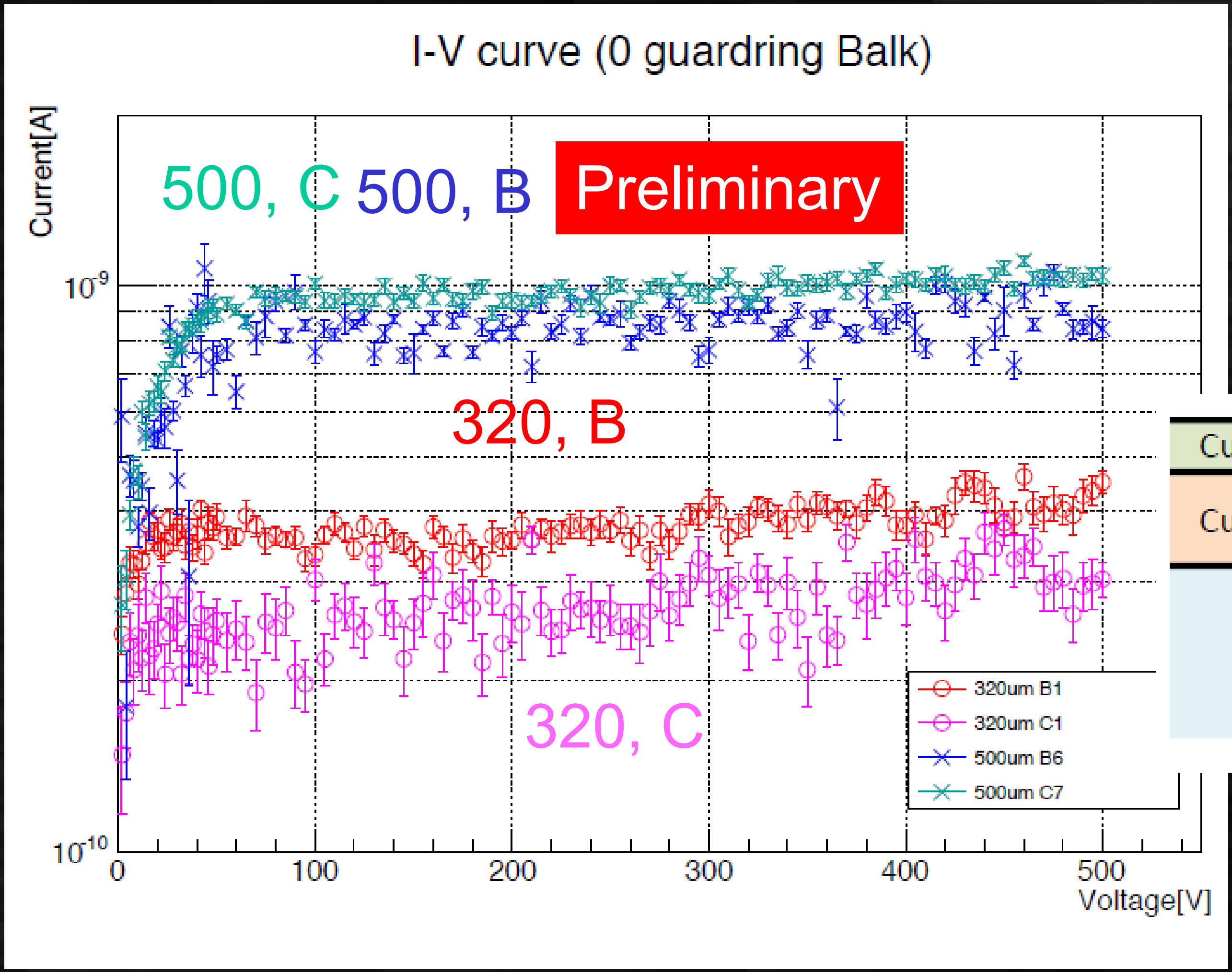


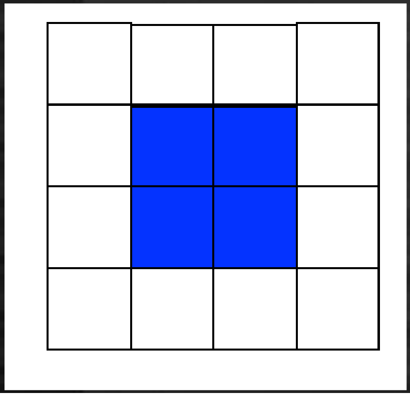
Old sensor
with lower resistivity

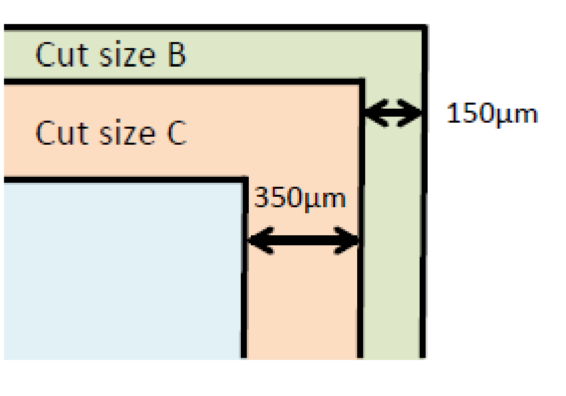


Slightly lower leakage current seen in new sensor
(breakdown voltage lower, but this has sample dependence)

I/V curve at the center pixels

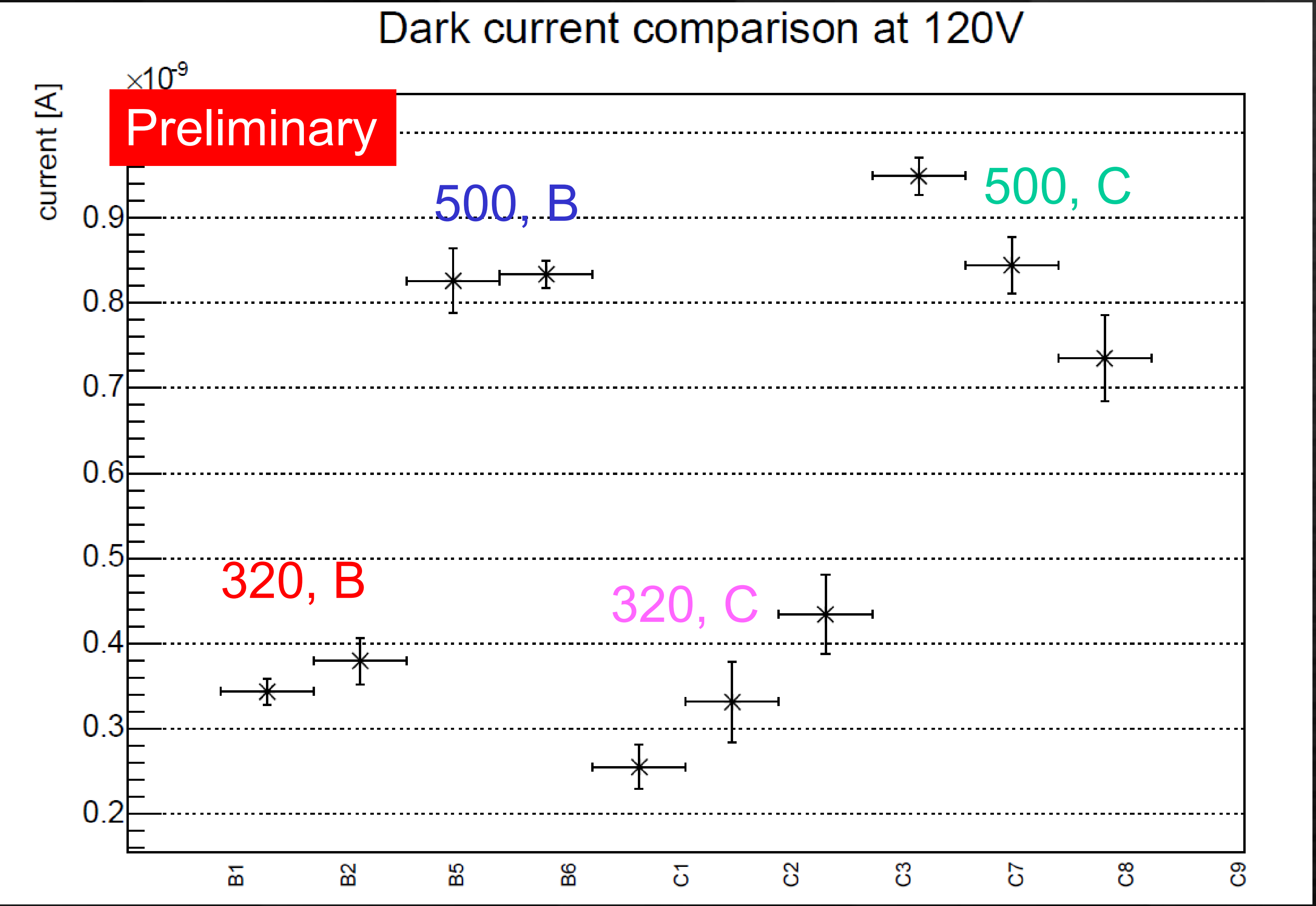






500 μm have ~3 times higher current, no difference on B/C

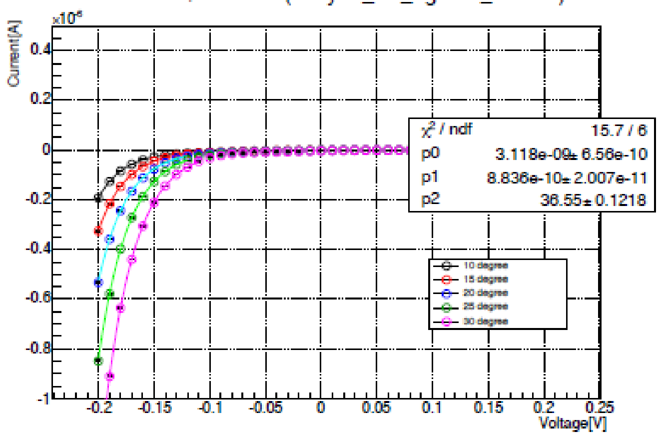
Statistics

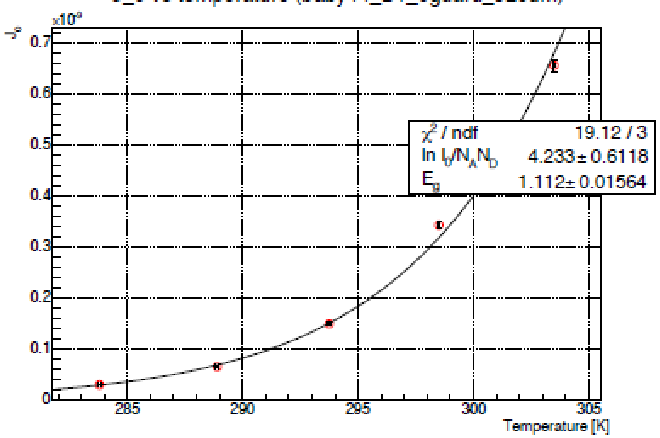


Dark current comparison at 120V
current [A]
×10⁻⁹
Preliminary
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
500, B
500, C
320, B
320, C
B1
B2
B5
B6
C1
C2
C3
C7
C8
C9

Low voltage positive bias

- How to calculate





✓ Measure I-V curves at several temperature

✓ Applied voltage is from -0.2 to 0.2 V

✓ Fit each data with the following equation, then derive J_0

$$J = \frac{I_0}{N_A N_D} T^3 e^{-E_g/kT} \left(e^{\alpha q V/kT} - 1\right)$$

$= J_0$

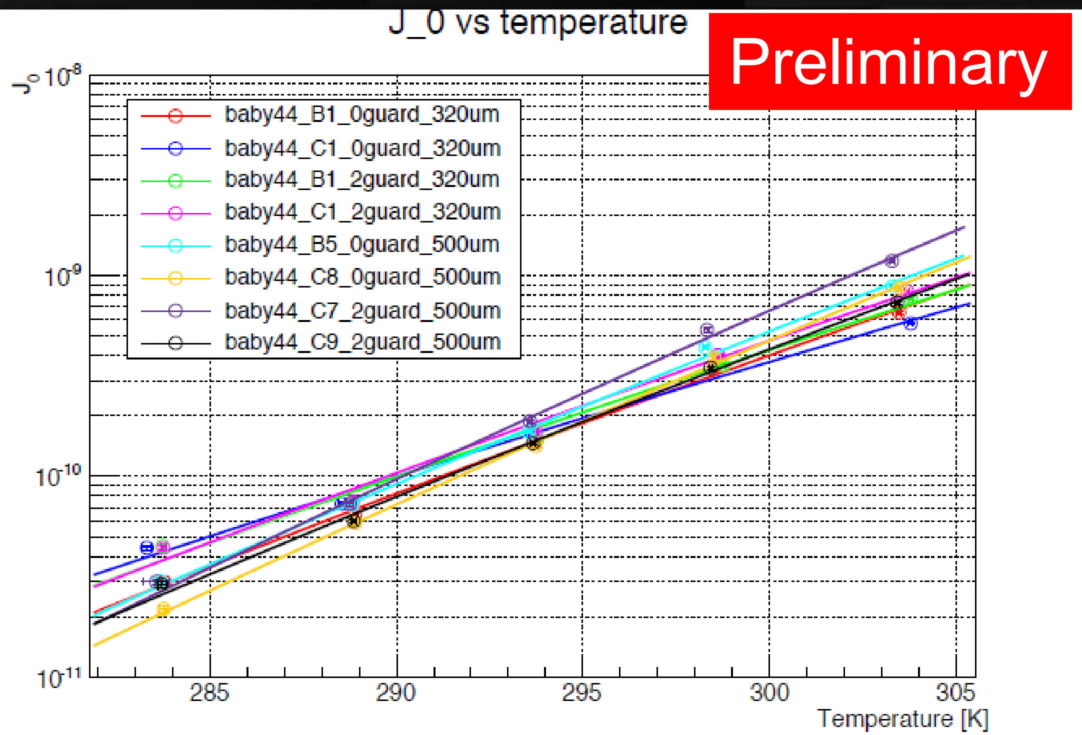
$N_{A(D)}$: Accepter (Doner) concentration
I_0 : Constant
T : Absolute temperature
E_g : Gap energy
α : A parameter to show the difference from ideal value
q : Elementary charge
V : Bias voltage

✓ Plot J_0 on the J_0-T graph

$$J_0 = \frac{I_0}{N_A N_D} T^3 e^{-E_g/kT}$$

✓ Fit with right equation and derive E_g

Low voltage – band gap energy



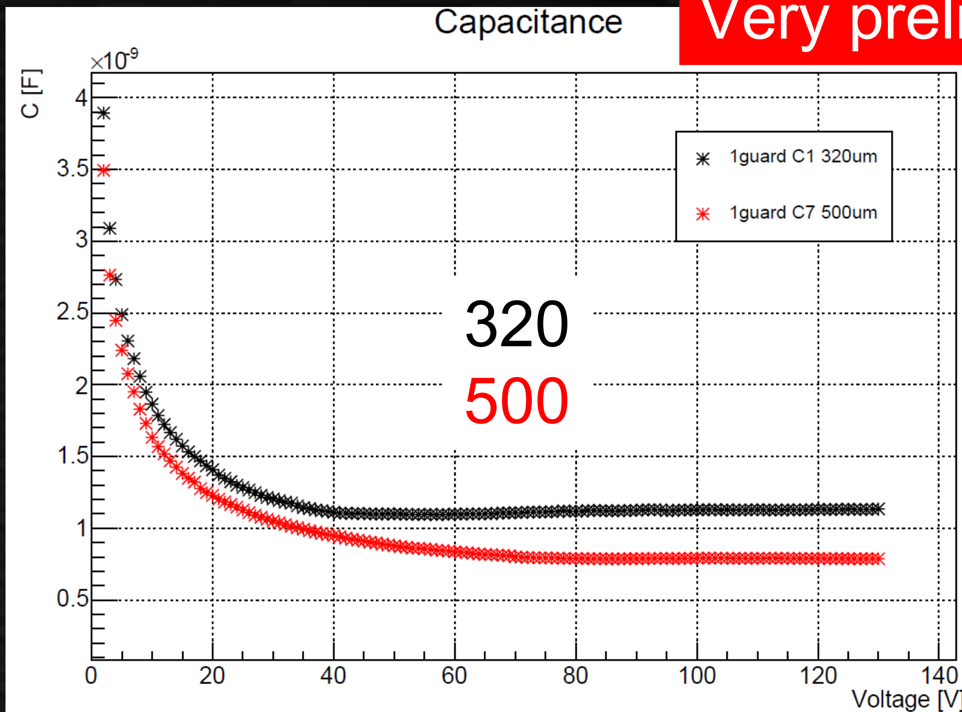
Imaginary gap energy

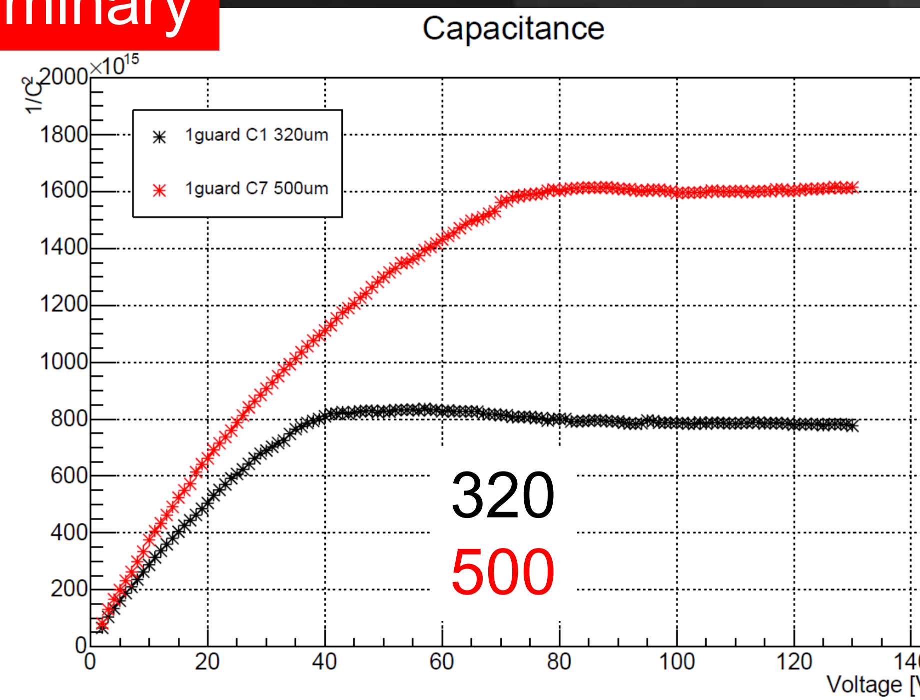
	E [eV/ 4 pixels]
B1 0guard	1.112 ± 0.012
C1 0guard	0.906 ± 0.013
B1 2guard	1.012 ± 0.013
C1 2guard	1.061 ± 0.014
B5 0guard	1.236 ± 0.020
C8 0guard	1.333 ± 0.016
C7 2guard	1.371 ± 0.019
C9 2guard	1.192 ± 0.013

- Significant difference between thickness or cut size of sensor cannot be seen
- If a precision of the measurement is improved, these difference might be able to be seen

C/V measurement (main chip)

Very preliminary





Full depletion: ~ 40 V in 320 μm, ~ 80 V in 500 μm
Some doubt in the absolute value: still need to be checked

Appendix: Consideration of hexagonal sensor

Calculation in 6-inch wafer

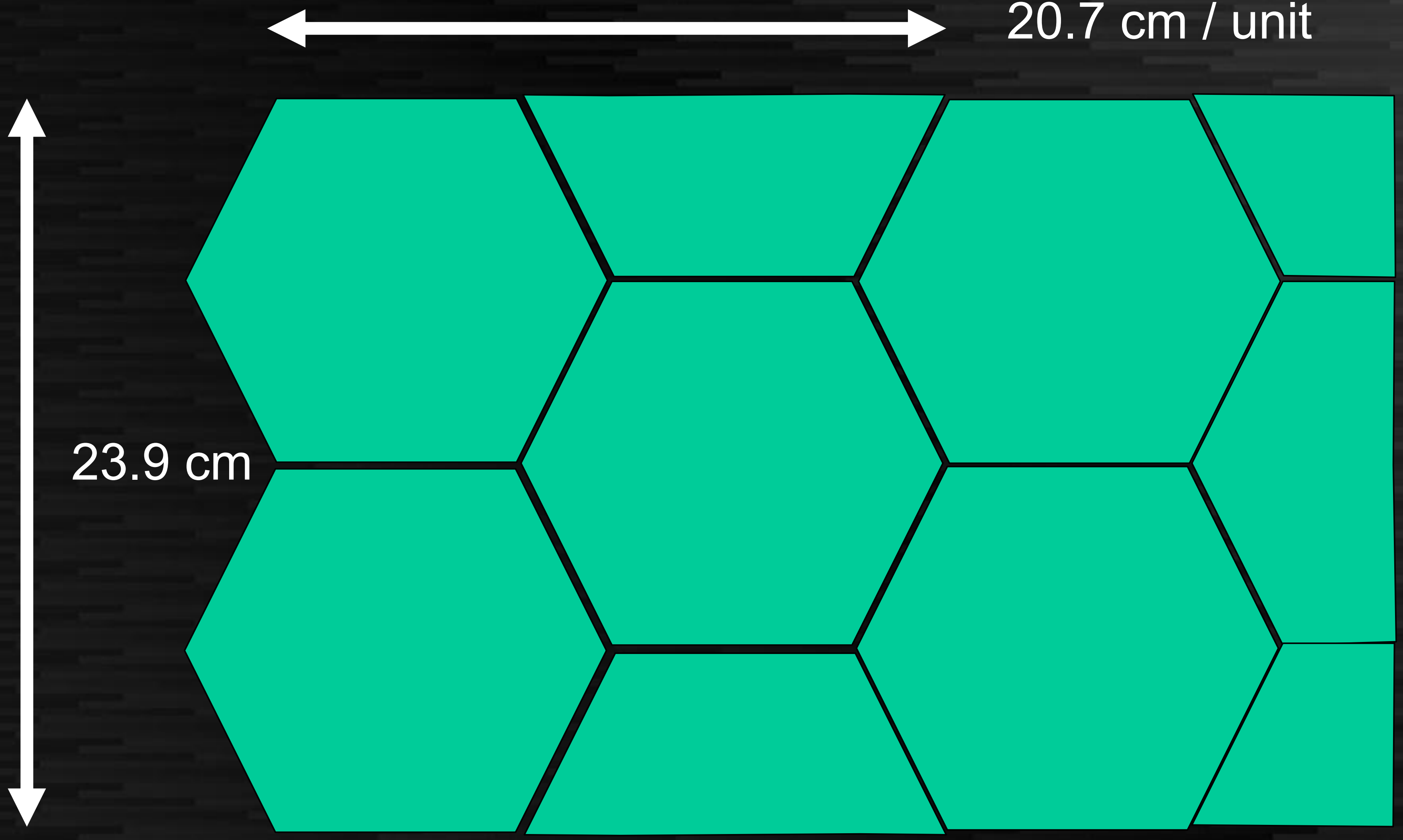
Square
Max. 9.8x9.8 cm^2
Area = 96.04 cm^2

Hexagon
Max. 6.9 cm each edge
Area = 123.69 cm^2
(28.8% larger than square)

28.8% more area per wafer → 22.4% less wafers needed

Integration (A)

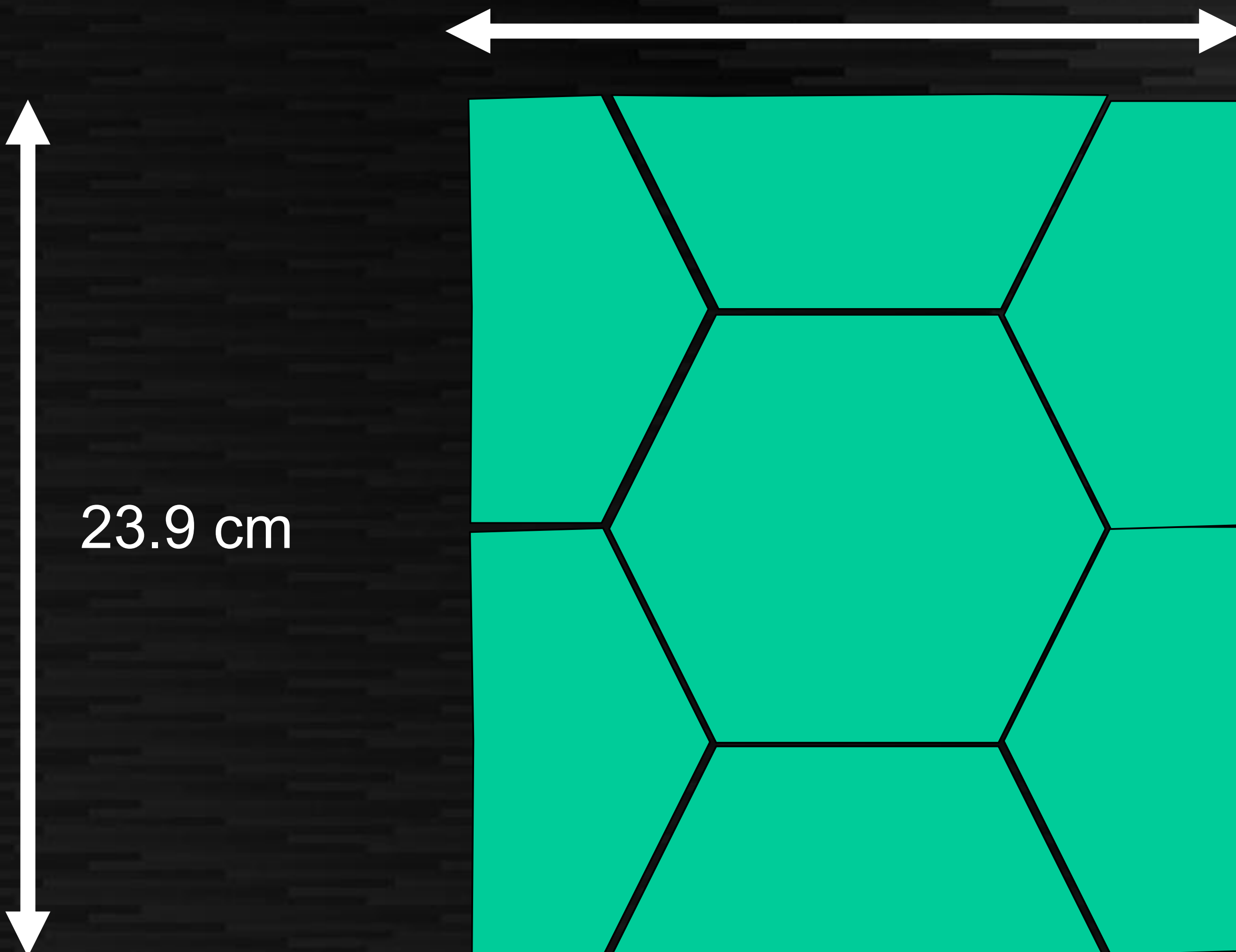
assuming 6.9 cm side length



3 masks: middle, upper/lower, edge(center + upper/lower)

Integration (B)

assuming 6.9 cm side length



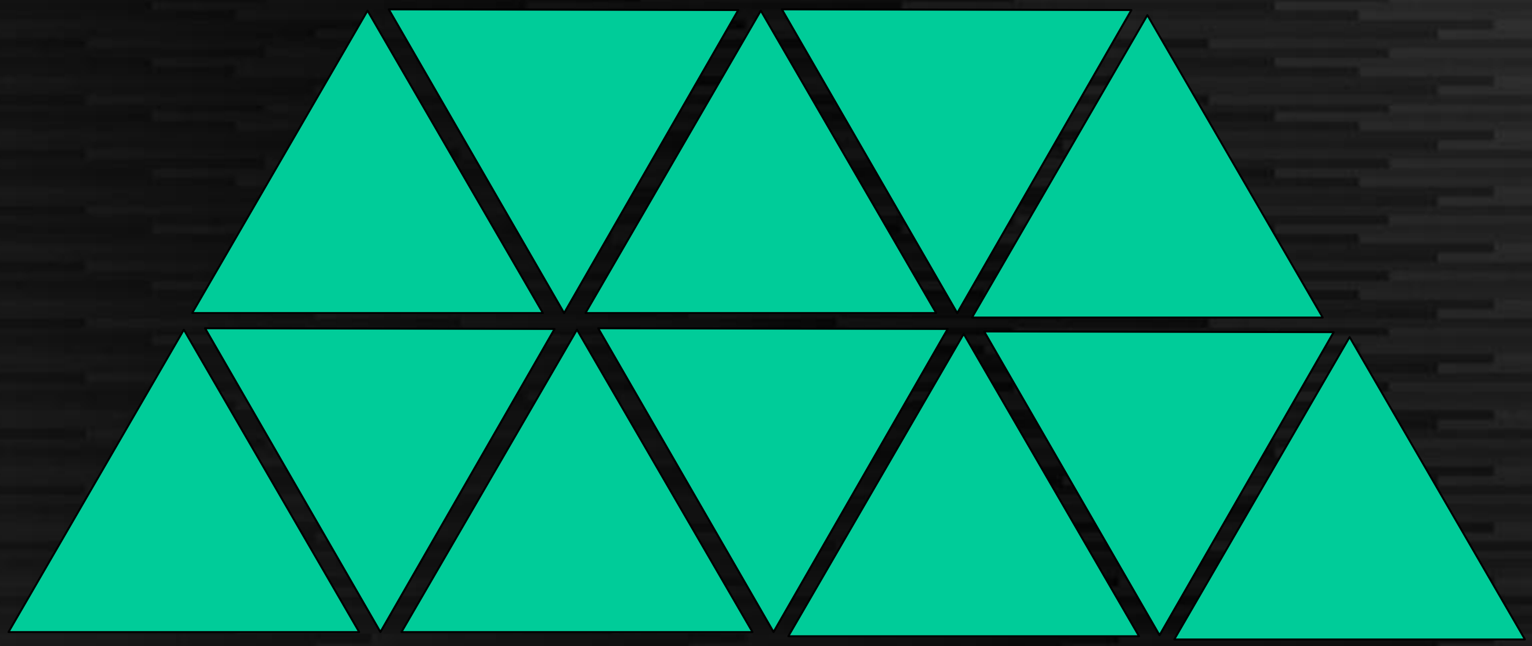
CMS HGCAL design

more cutting in center, but simpler end region

3 masks: middle, upper/lower, left/right

Pixels

- Triangular pixels



Good symmetry, but steep angle of pixels

Issues to identify

- In hexagonal sensors we need several types of wafers. This may create additional cost. (seems negligible, but should check)
- Jigzag-shaped PCB is needed in integration (A). Interconnection may be inclined.
- The length of long-slab is slightly different layer by layer. May need tens of patterns at the end. (Common in square, but seems more difficult)
- Number of edge is not uniform throughout slabs, need small adjustment of pixel size.
- Non-square pixels need investigation of both simulation (PFA) and basic characteristics.

Summary for all

- New sensor Preliminary
  - 500 μm wafer seems feasible for ILD SiECAL, cut size B is preferred
- Hexagonal sensor
  - 22% reduction of the cost is not negligible, need to establish realistic design and compare with square sensor