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Silizium Labor Bonn

Technology Overview or Challenges of Future High Energy Particle Detection

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Overview

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- Introduction
- Challenges of radiation and timing requirements by example
- Possible solutions

Introduction

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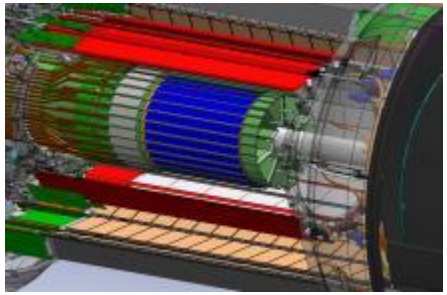
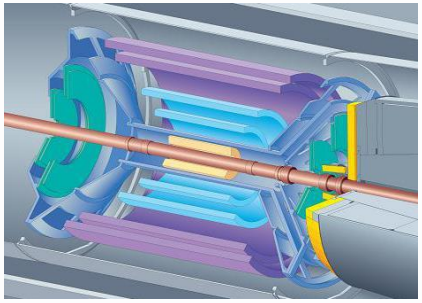
STAR

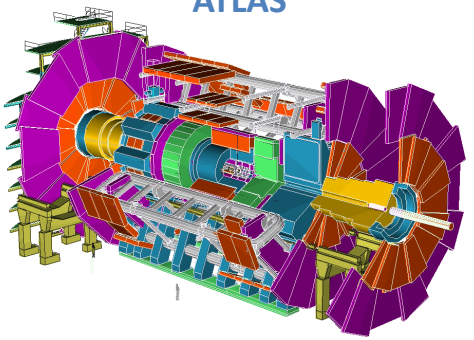


ALICE-LHC



ILC

ATLAS

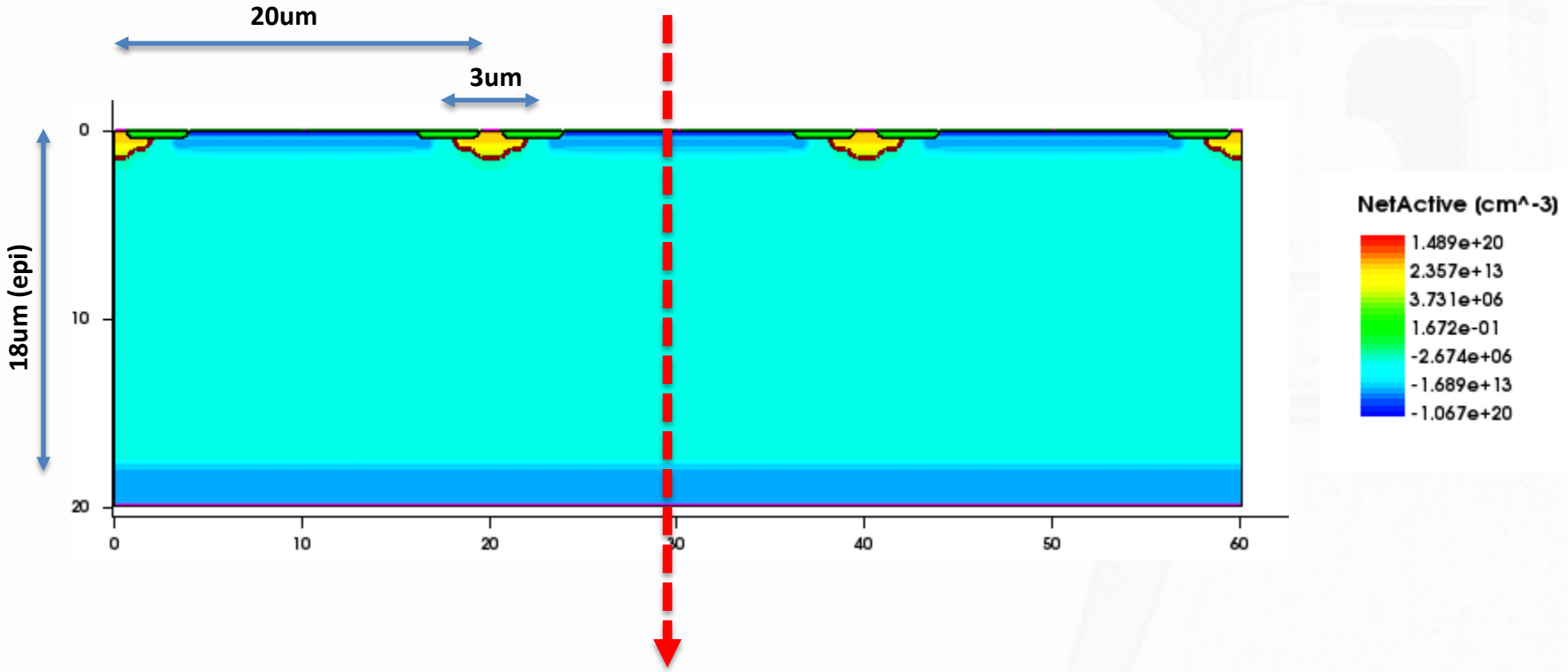


Requirements for inner pixel layers

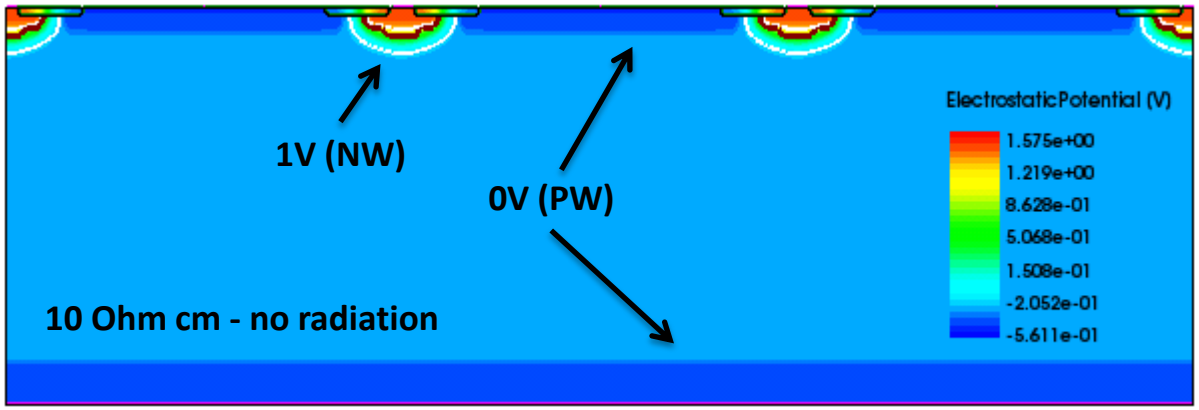
	STAR	ALICE-LHC	ILC	ATLAS-LHC	ATLAS-HL-LHC
Timing [ns]	200 000	20 000	350	**25**	**25**
Particle Rate [kHz/mm^2]	100	10	250	1000	10000
Fluence [n_{eq}/cm^2]	> 10^{11}	> 10^{13}	10^{12}	**2x10^{15}**	**2x10^{16}**
Ion. Dose [Mrad]	> 0.3	0.7	0.4	**80**	**>500**

Monolithic CMOS ?

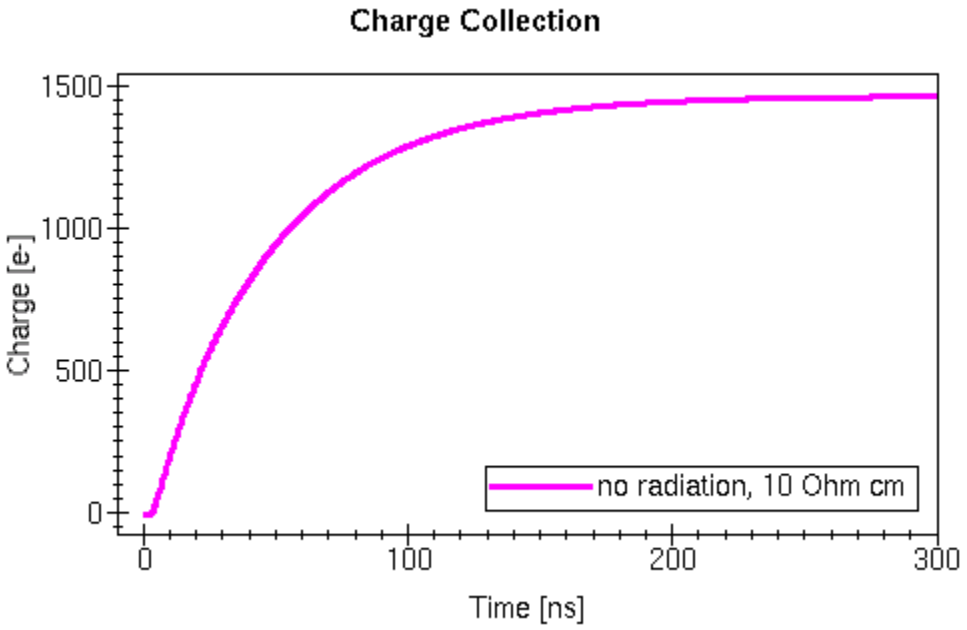
Example case



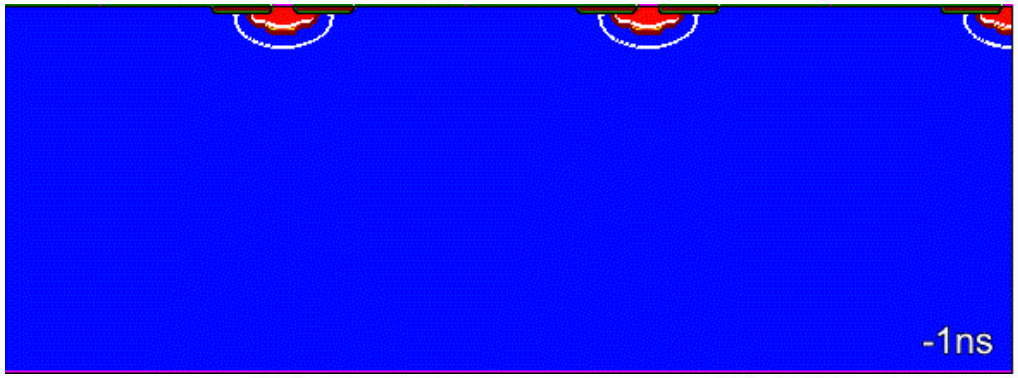
No radiation



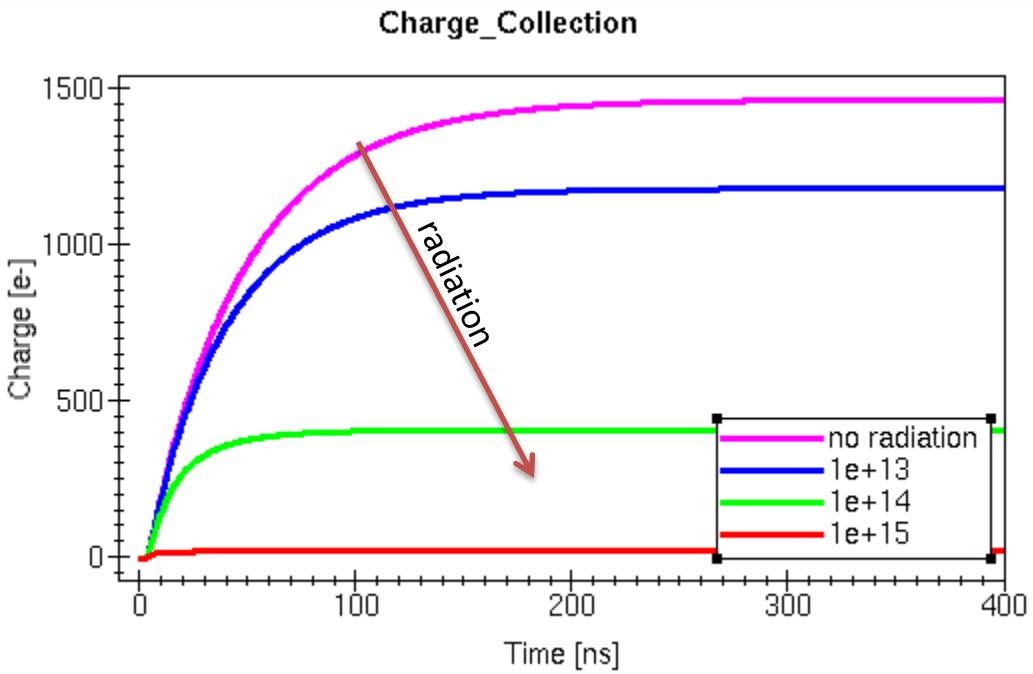
Substrate:10 Ohm cm
NW: 1V
PW: 0V



Electron Concentration

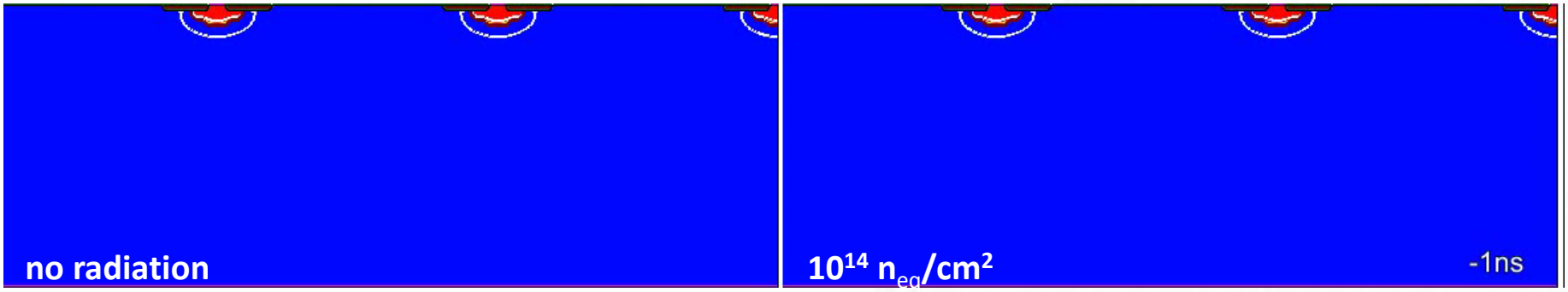


radiation effects (neutrons -> traps)

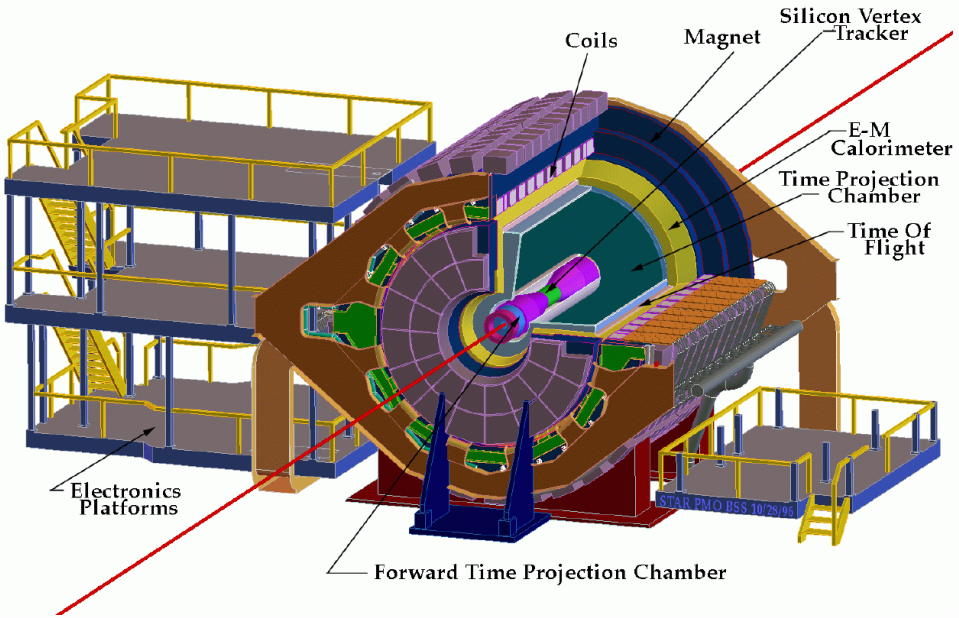


Substrate:10 Ohm cm
NW: 1V
PW: 0V

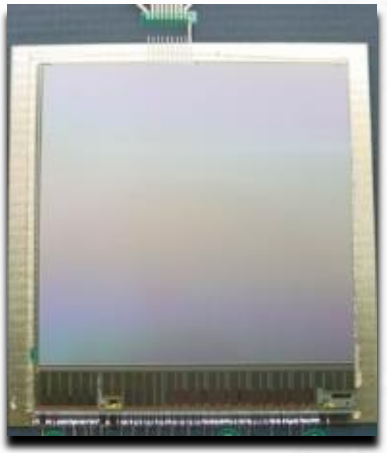
Electron Concentration



STAR Experiment



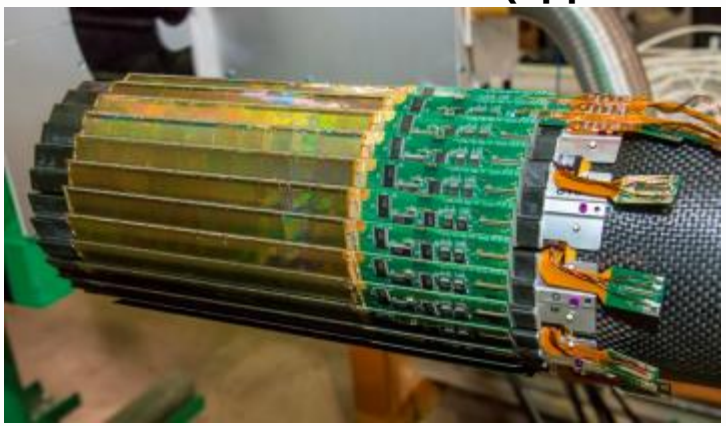
Ultimate



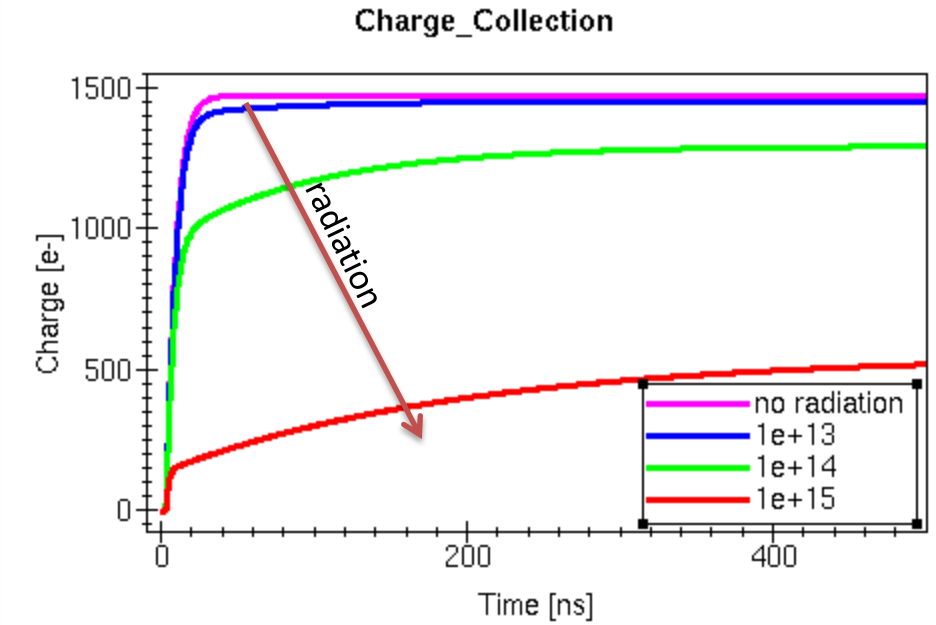
Reticle size (2x2 cm²)
Pixel pitch 20.7 µm
Array size: 928 x 960
Integration time: 185.6 µs
In pixel CDS
Sensors thinned to 50 µm
High Res Si option

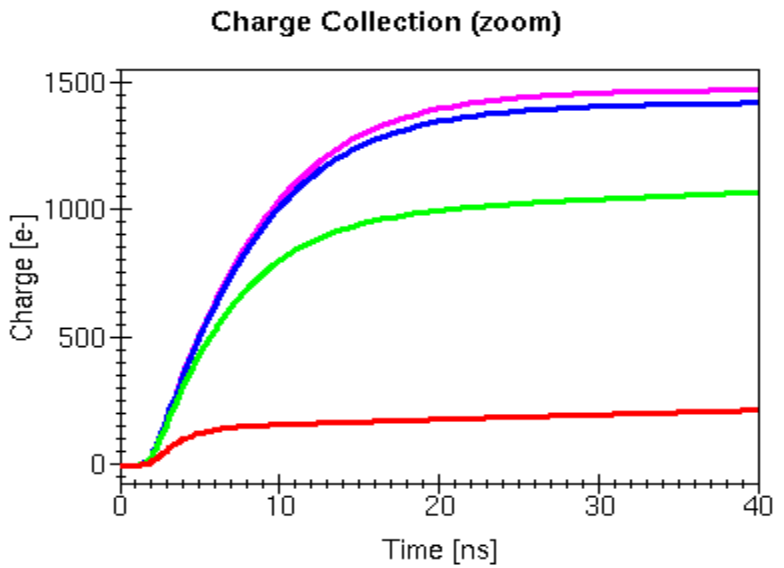
Technology: AMS 0.35u

Ladders with 10 MAPS sensors (approx. 2×2 cm each)



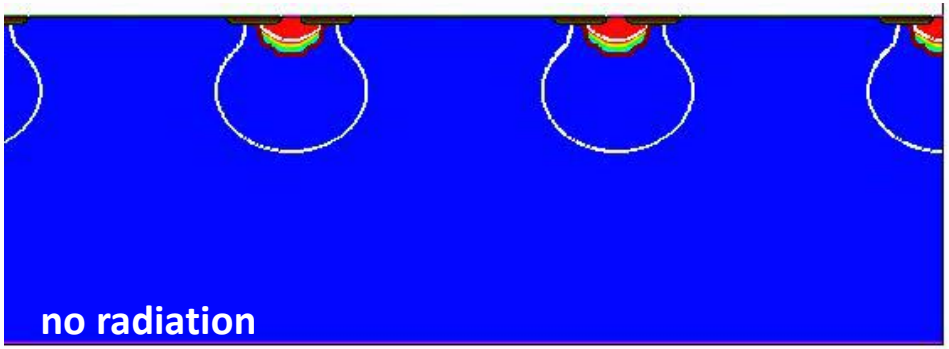
change substrate to 2k Ohm cm

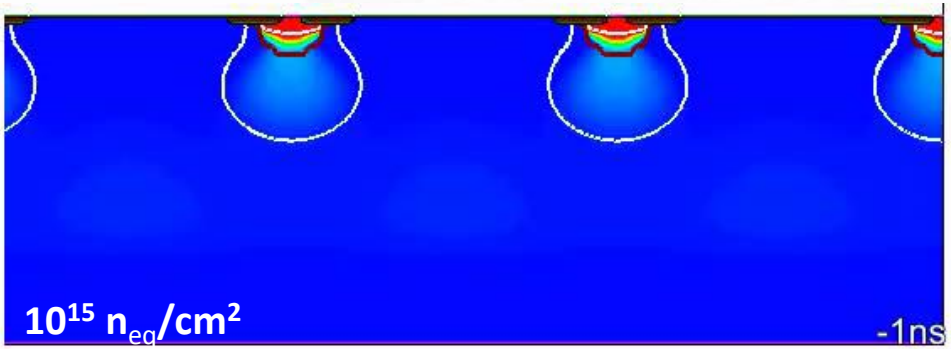




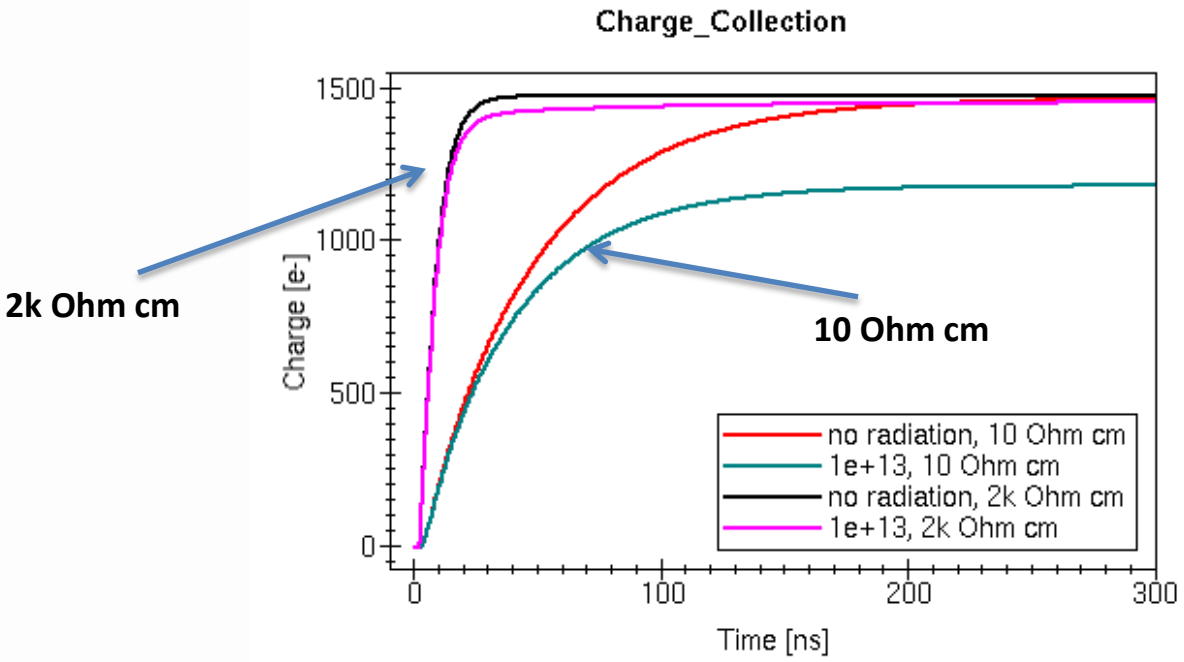
NW: 1V
PW: 0V
Substrate:2k Ohm cm

Electron Concentration



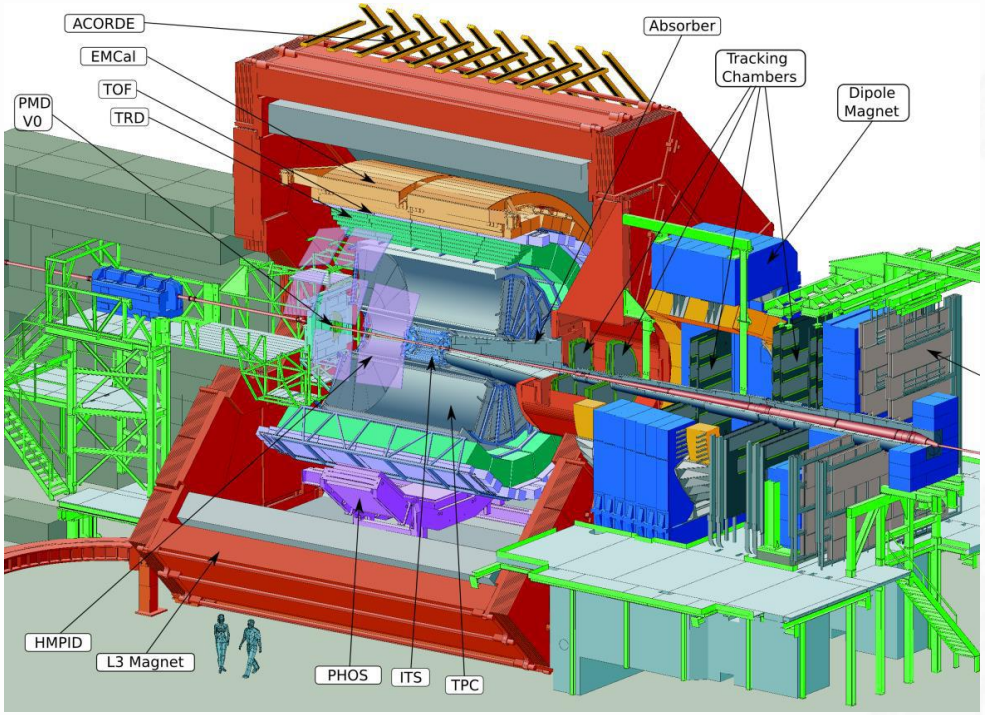


Substrate resistivity influence



NW: 1V
PW: 0V

ALICE Experiment



To be ready by 2018

Integrations time: <30us
Substrate: hi-res epi

Technology: TowerJazz 0.18um CIS

Potential difference influence

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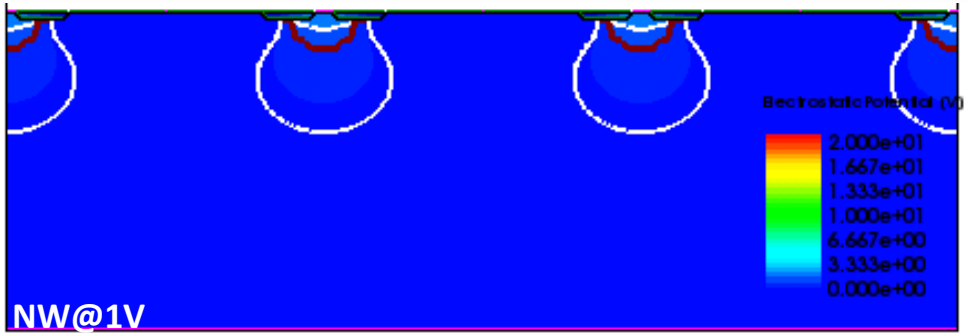
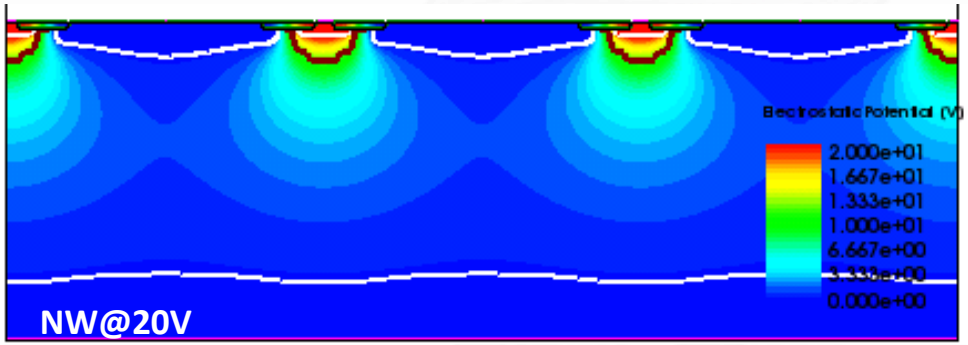
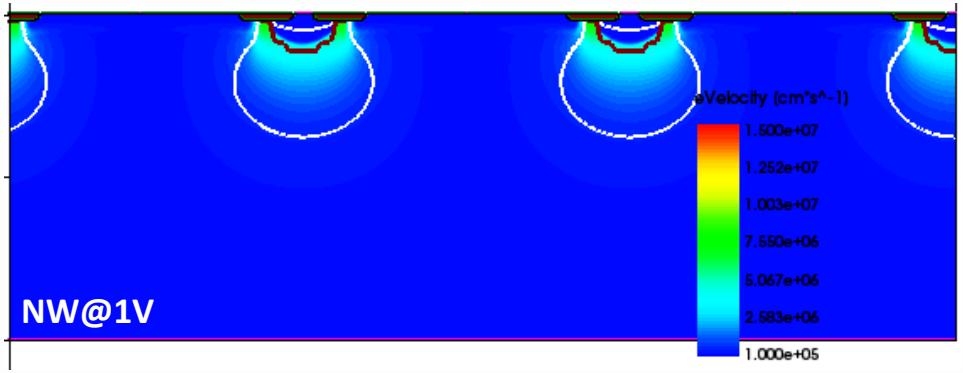
Electrostatic potential

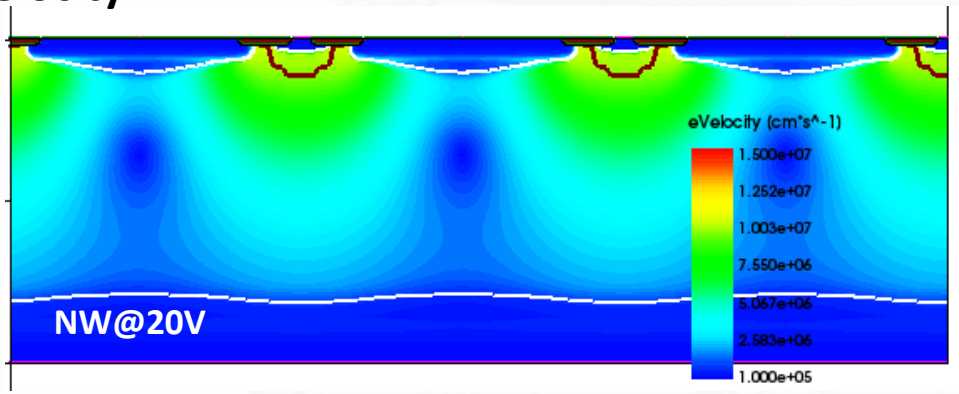




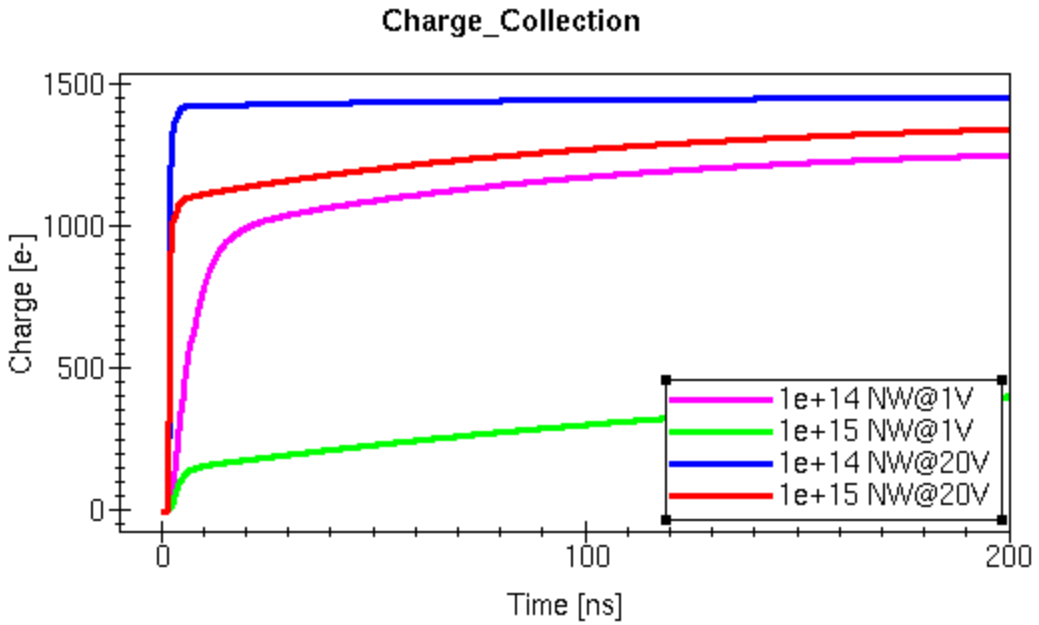
PW: 0V
Substrate:2k Ohm cm

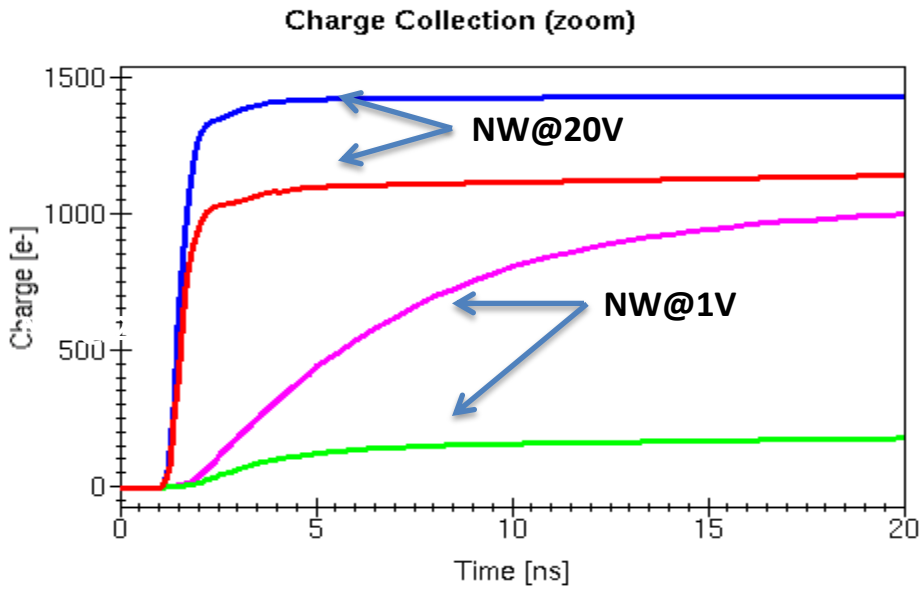
Electron Velocity





2k Ohm cm and potential difference

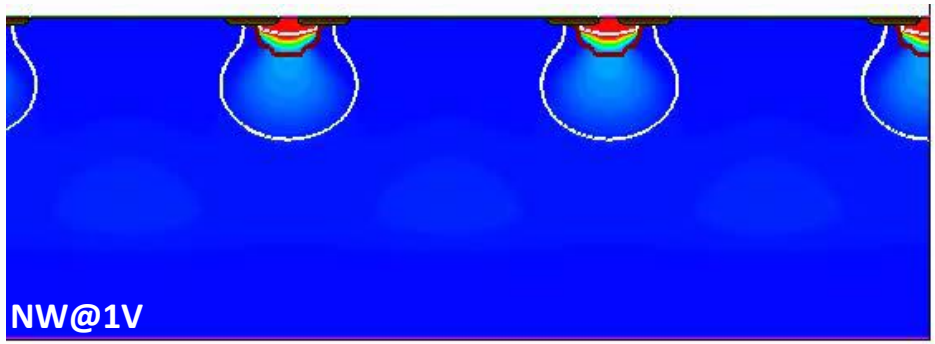


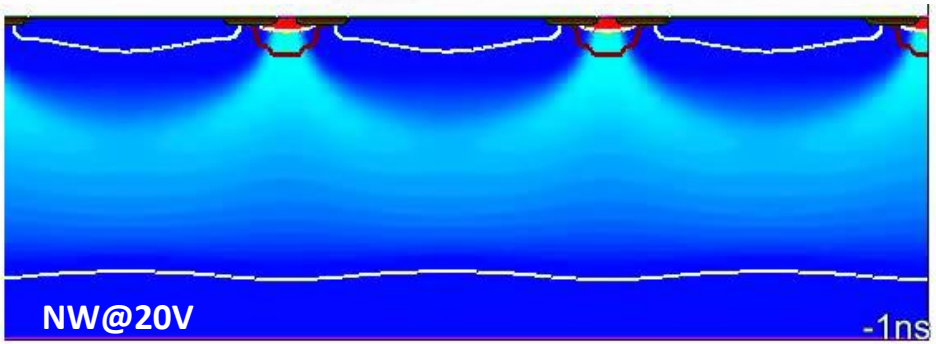


PW: 0V

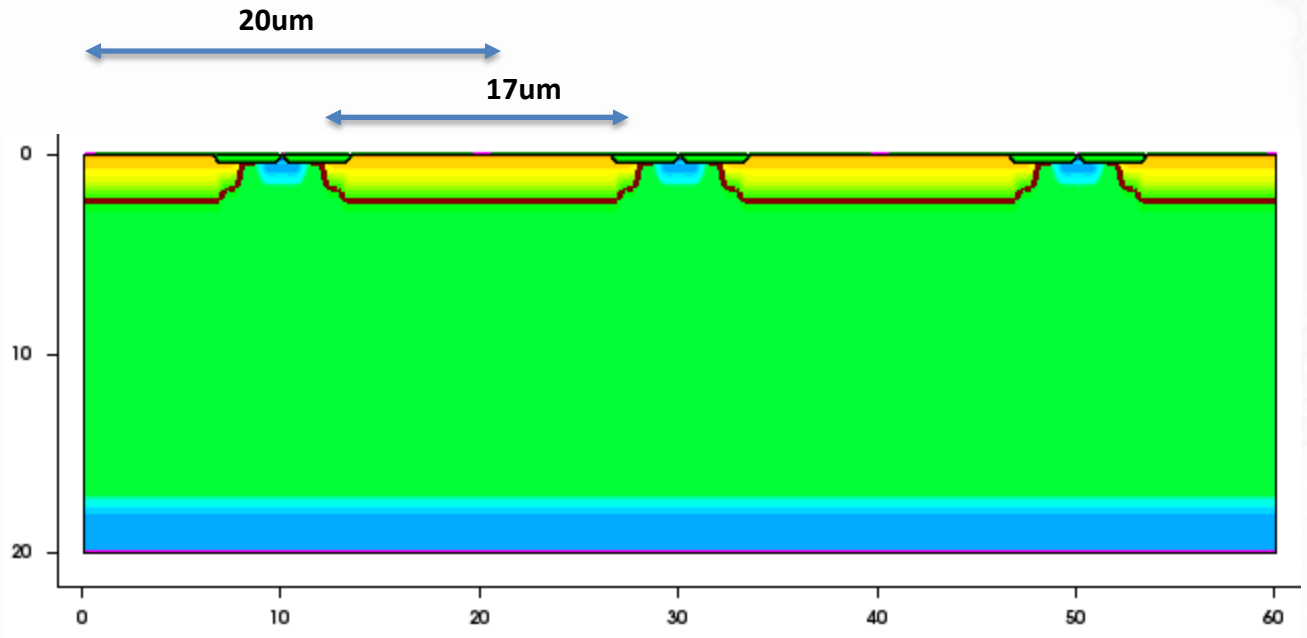
Substrate:2k Ohm cm

Electron Concentration (10^{15} n_{eq}/cm^2)





Influence of fill factor



Fill Factor influence at 10^{15} n_{eq}/cm^2

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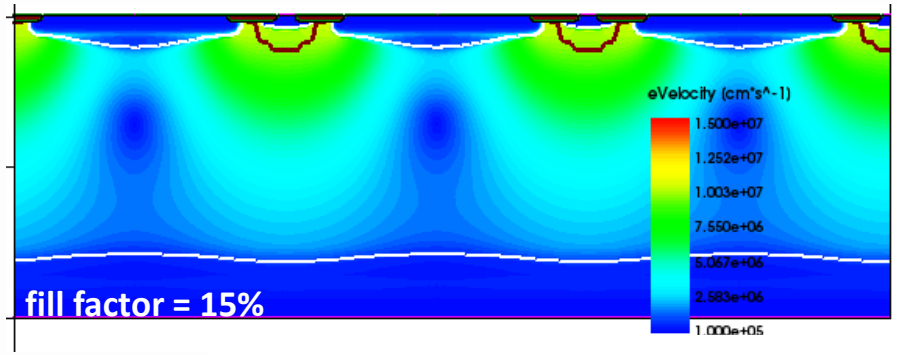
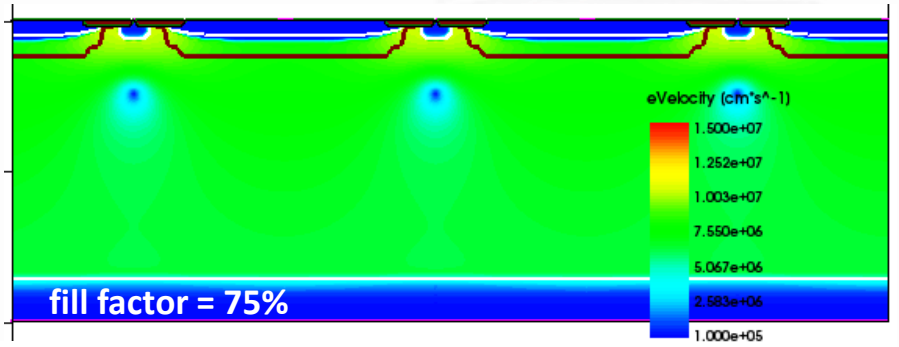
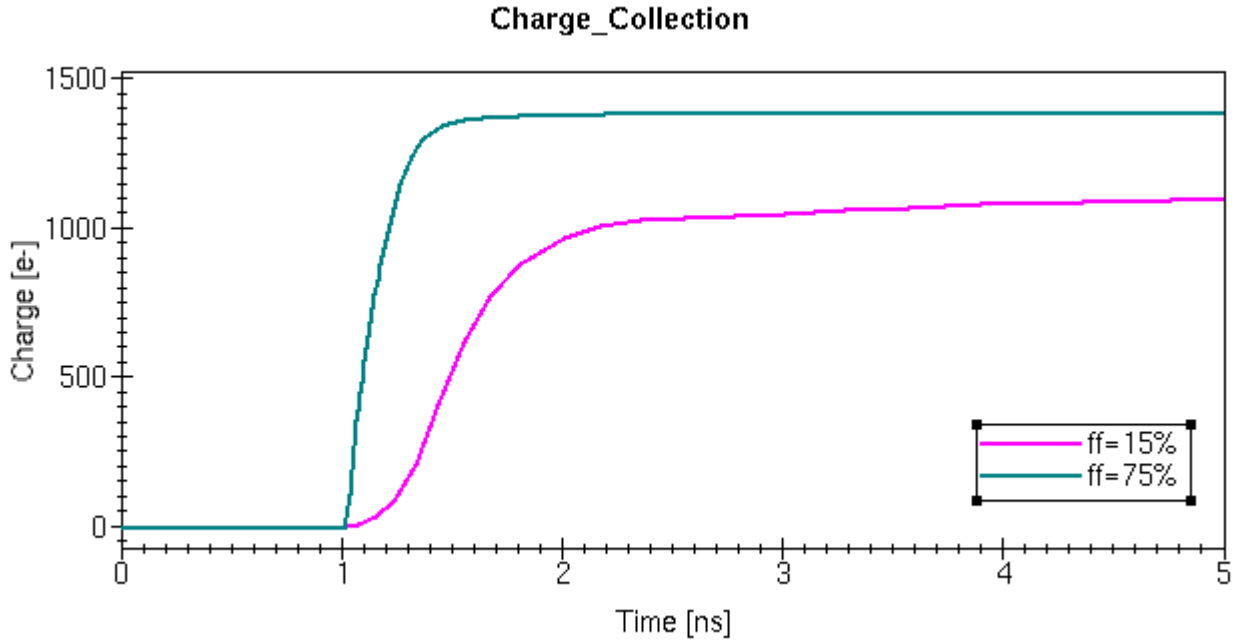
Electron Velocity

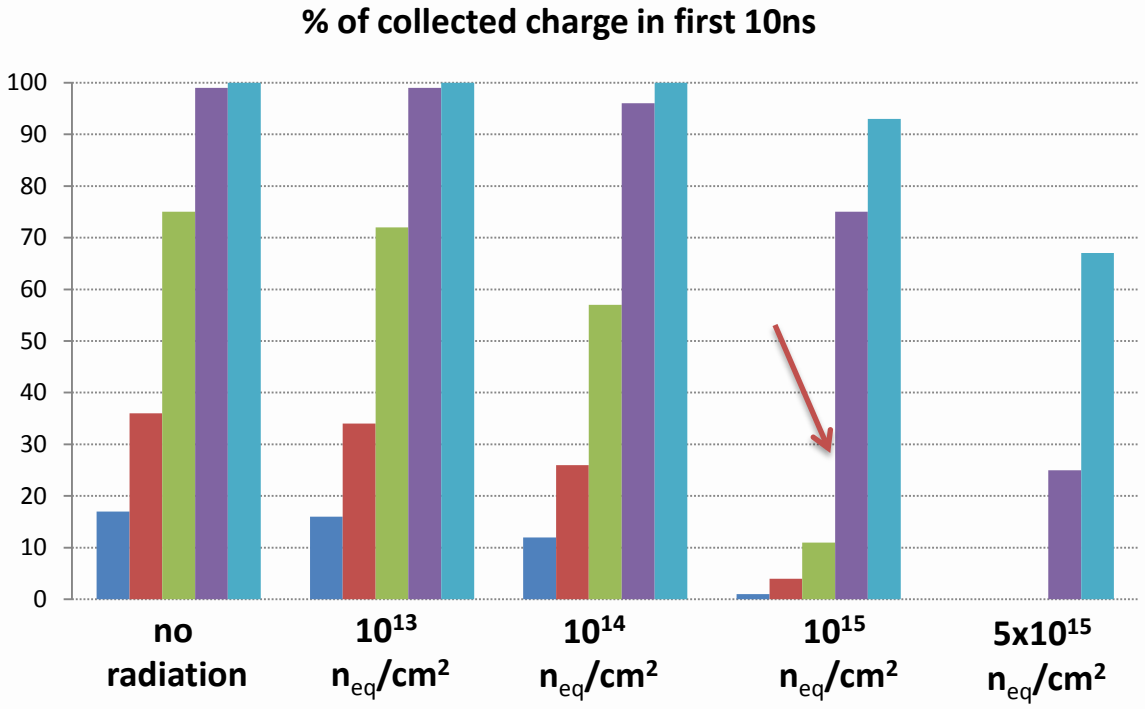






NW: 20V
PW: 0V
Substrate:2k Ohm cm
Dose: 10^{15} n_{eq}/cm^2

Summary



	substrate resistivity [Ohm cm]	Bias [V]	Fill Factor [%]
	10	1	15
	10	20	15
	2k	1	15
	2k	20	15
	2k	20	75

Conclusions

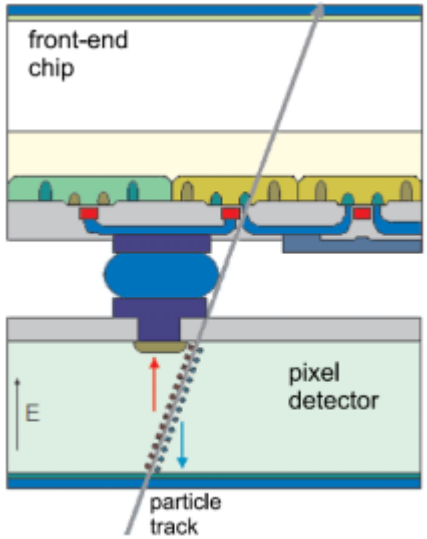
Need to be fast with charge collection

Drift in electrical field

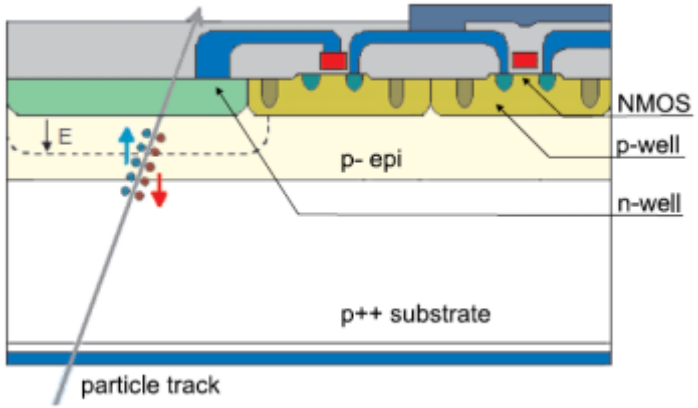
New type of sensors

Mind the leakage

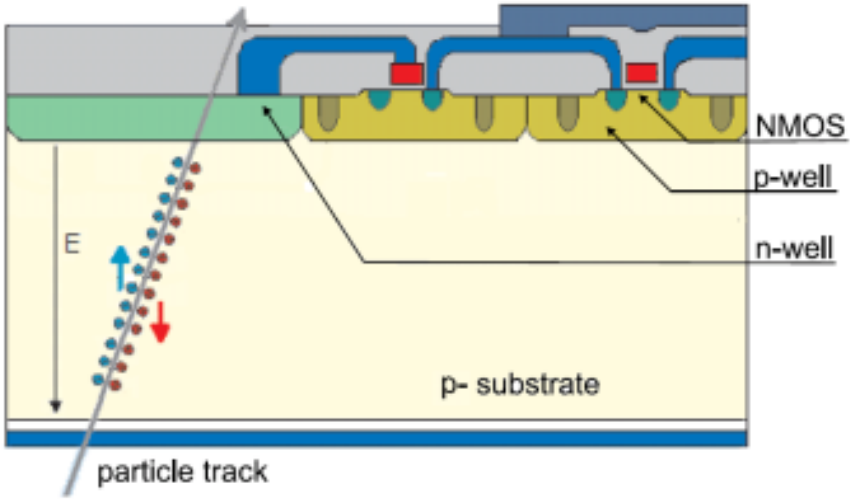
Hybrid Pixel Detectors



Monolithic Pixels



Depleted Monolithic Pixels



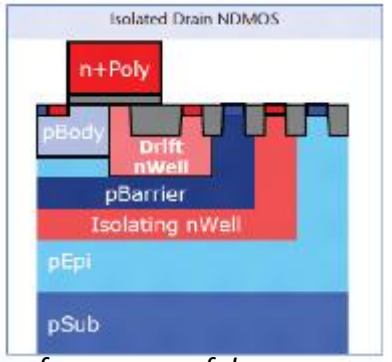
Enabling technologies

"High" Resistive Wafers

8" hi/mid resistivity silicon wafers that will be qualified by the foundry.
What is the influence of CMOS processing? (thermal donors …)

Sensor/Implants (<3nm gate)

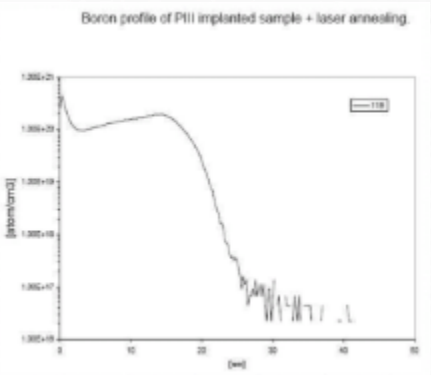
Radiation hard process with as many wells as possible.
High voltage tolerant. Foundry accepts some process/DRC changes!



from: www.xfab.com

Low Temperature Backside Process

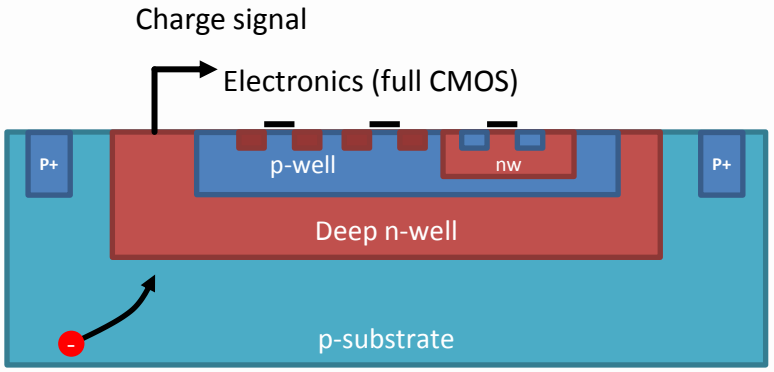
To achieve backside contact after CMOS processing.
Laser activation?

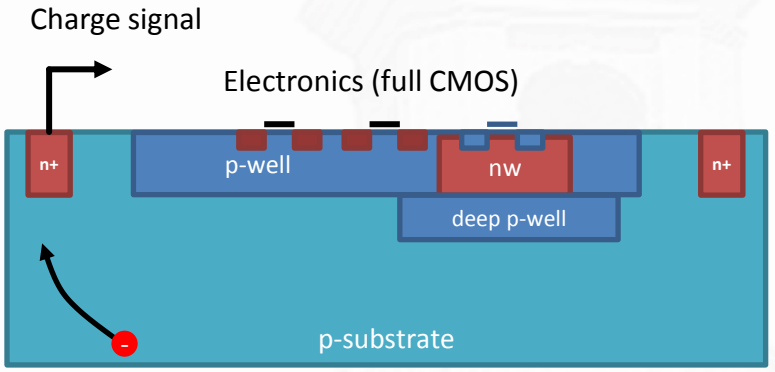


from: ion-beam-services.com

Technological support

Bulk process options (simple options, n-on-p)





Electronics **inside** charge collection well

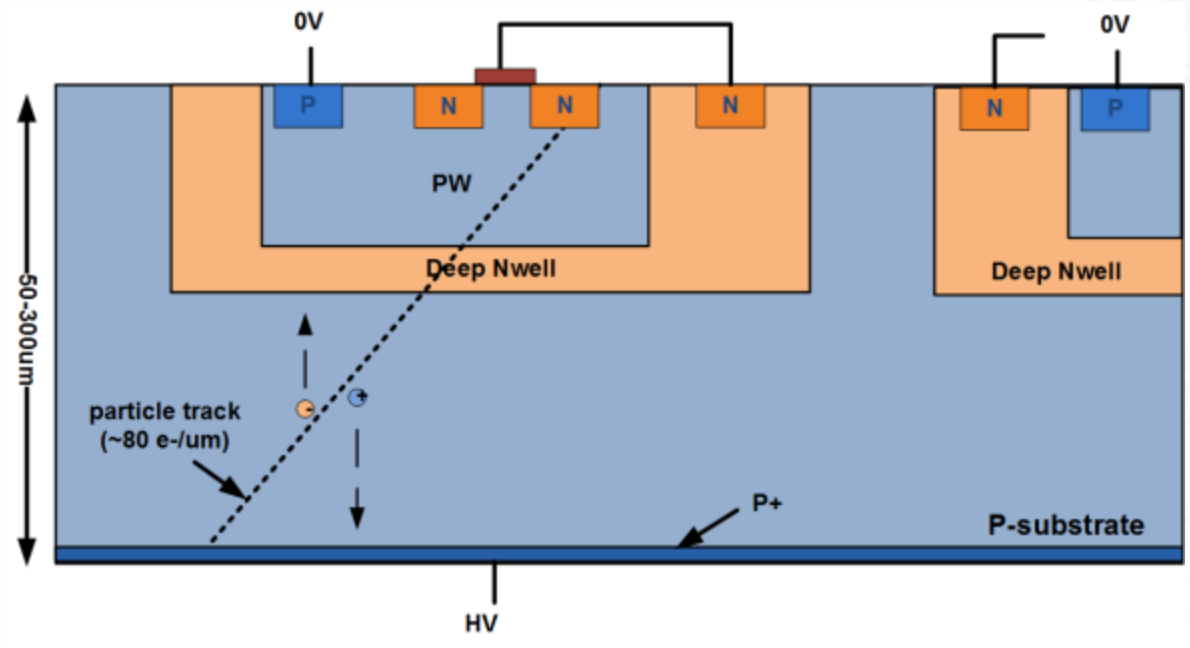
- Collection node with **large fill factor** → rad. hard
- Large sensor capacitance (DNW/PW junction!) → x-talk, noise & speed (power) penalties
- Full CMOS with isolation between NW and DNW

Electronics **outside** charge collection well

- Very **small sensor capacitance** → low power
- Potentially less rad. hard (longer drift lengths)
- Full CMOS with additional deep-p implant

larger capacitance makes it more difficult for the readout

Simple device cross-section



high signal (full depletion possible)

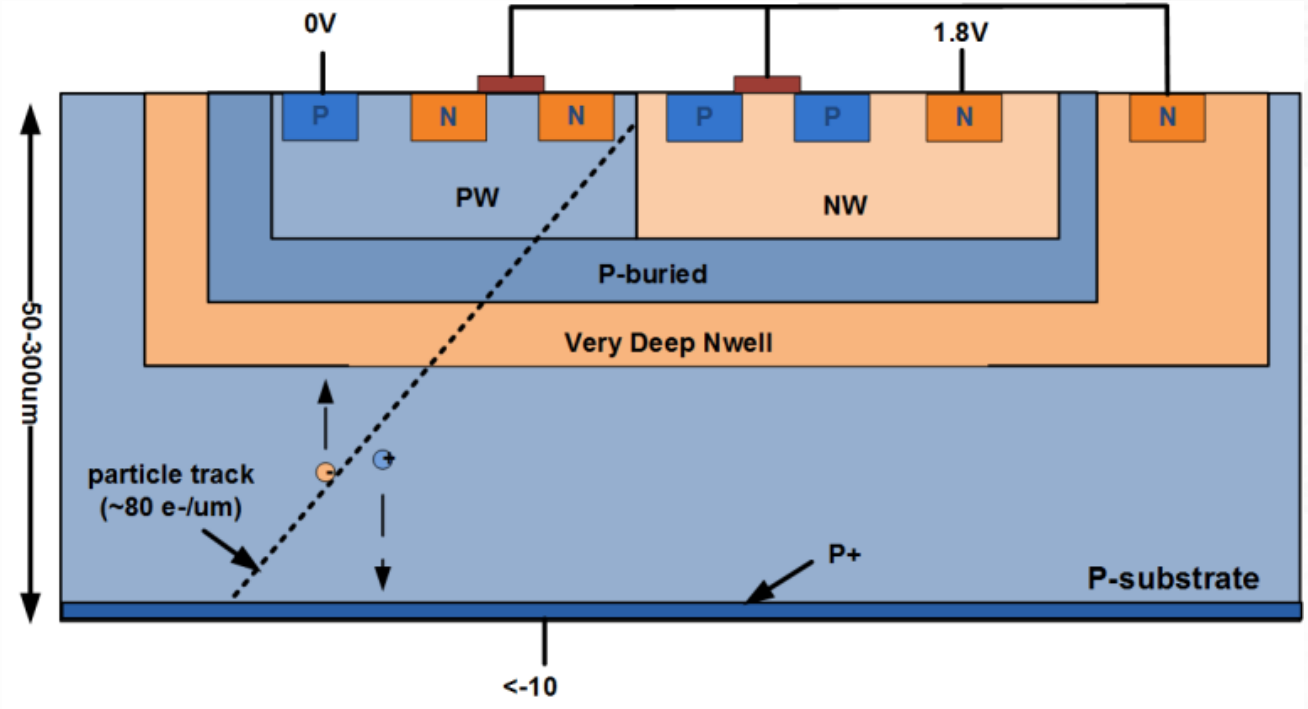
fast (collection by drift)

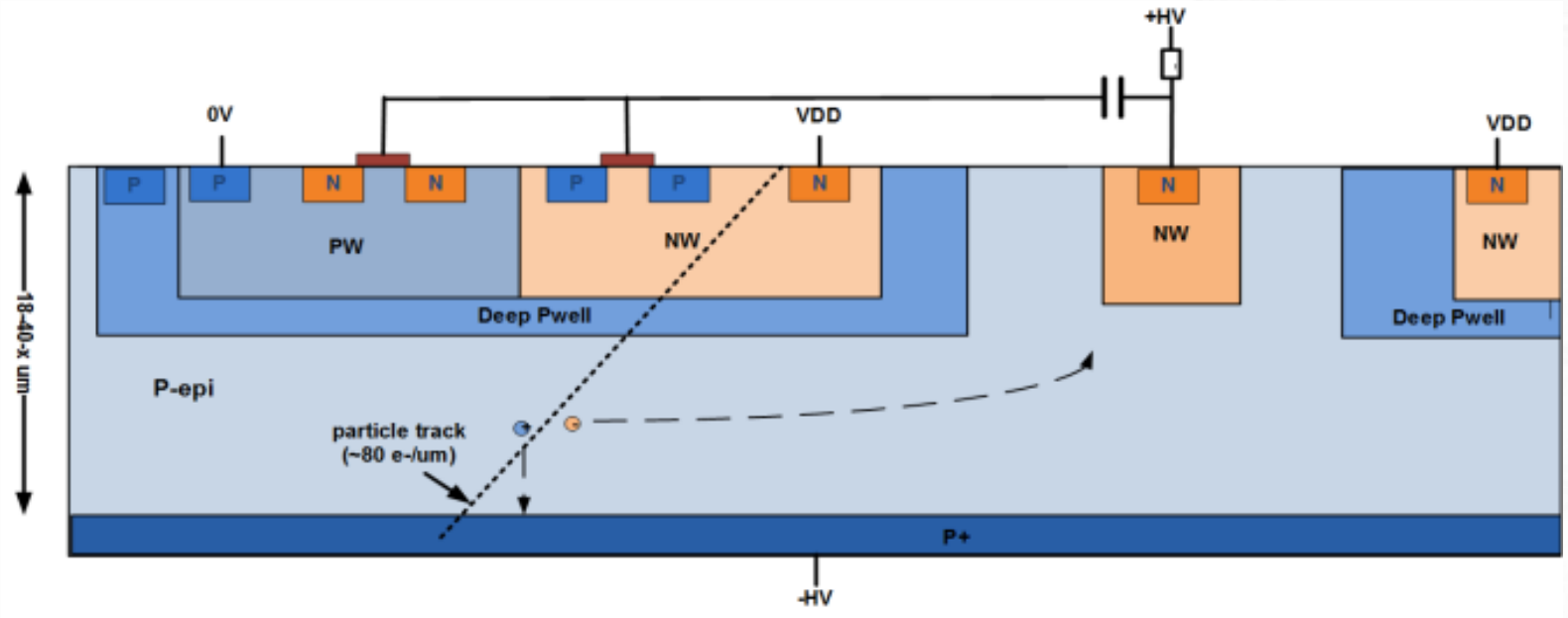
small pixels

limited PMOS in active area

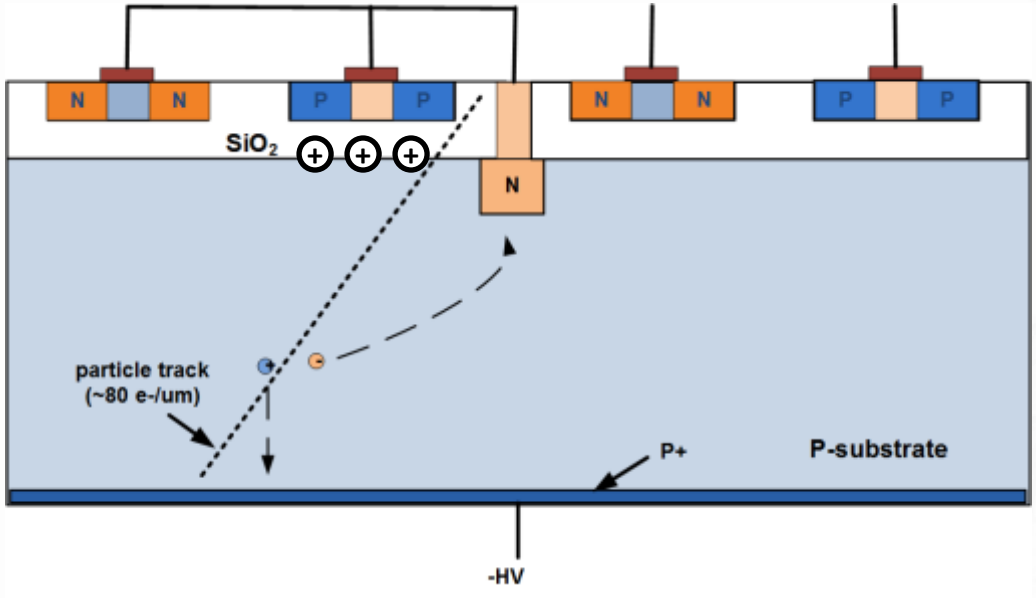
input capacitnce dominated by deep-nwell to pwell capacitance

Something better

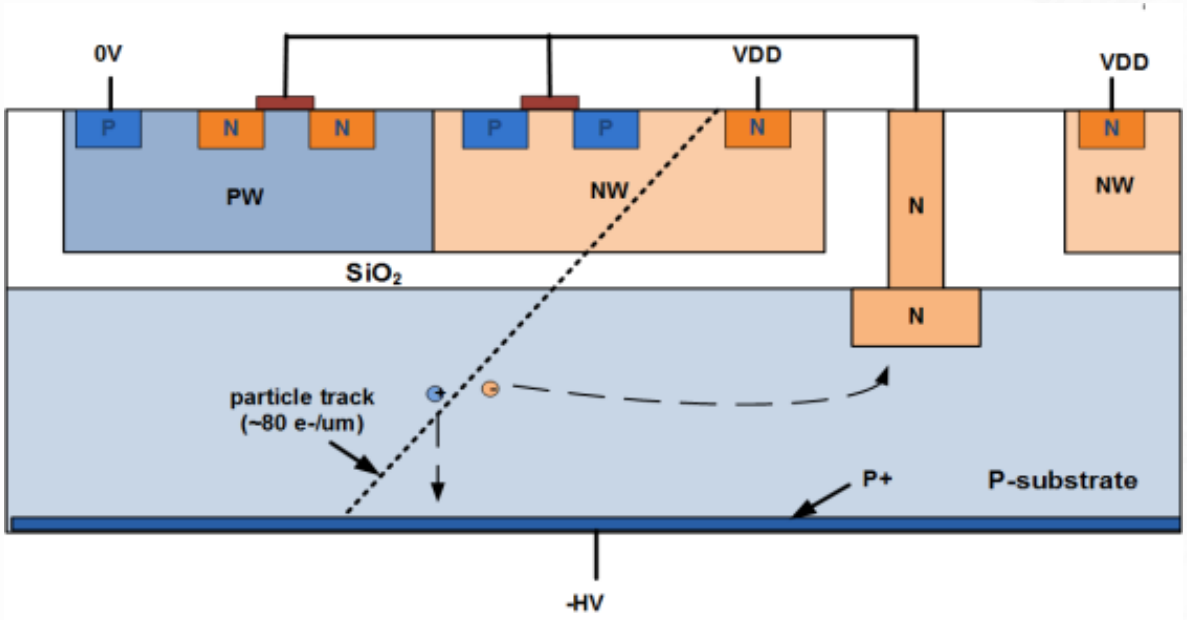



+HV
0V
VDD
VDD
P
P
N
N
P
P
N
N
N
N
PW
NW
NW
Deep Pwell
Deep Pwell
18-40-x um
P-epi
particle track
(~80 e-/um)
P+
-HV

FD-SOI



PD-SOI


0V
VDD
VDD
P
N
N
P
P
N
N
PW
NW
NW
N
N
SiO_2
particle track
(~80 e-/um)
P+
P-substrate
-HV

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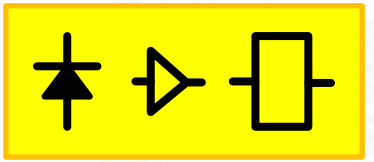
Other options?

And what about:

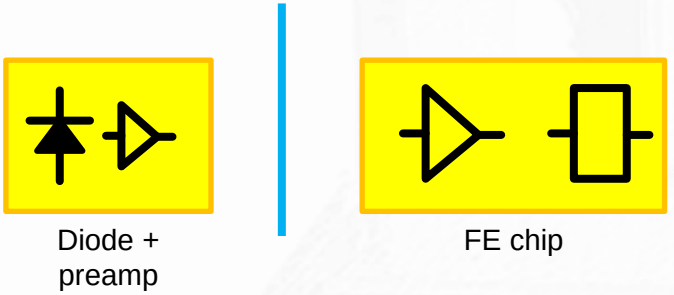
- **Oxide charging (TID) > 100 MRad**
- **How to make readout ?**

Possible scenarios for Active Sensors

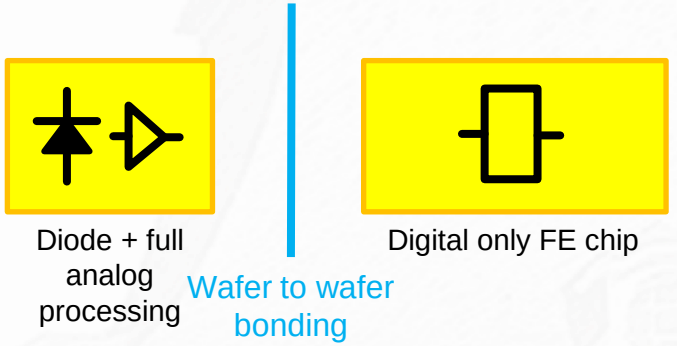
- Depleted Monolithic Active Pixel Sensor
  - HR- material (charge collection by drift) ➔ **Fully depleted** MAPS (**DMAPS**)



- Hybrid Pixels with “smart” diodes:
  - HR- or **HV-CMOS** as a sensor (8”)
  - Standard FE chip
  - CCPD (HVCMOS) on FE-I4



- CMOS Active Sensor + Digital R/O chip
  - HR- or HV-CMOS sensor + CSA (+Discriminator)
  - Dedicated **“digital only” FE chip**



Conclusion

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- Particle detection in high radiation environments based on commercial CMOS technologies looks possible
- Progress in technology and openness of industry for niche applications allows new concept to be realized
- Possible technology developments for other fields?

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Thank you

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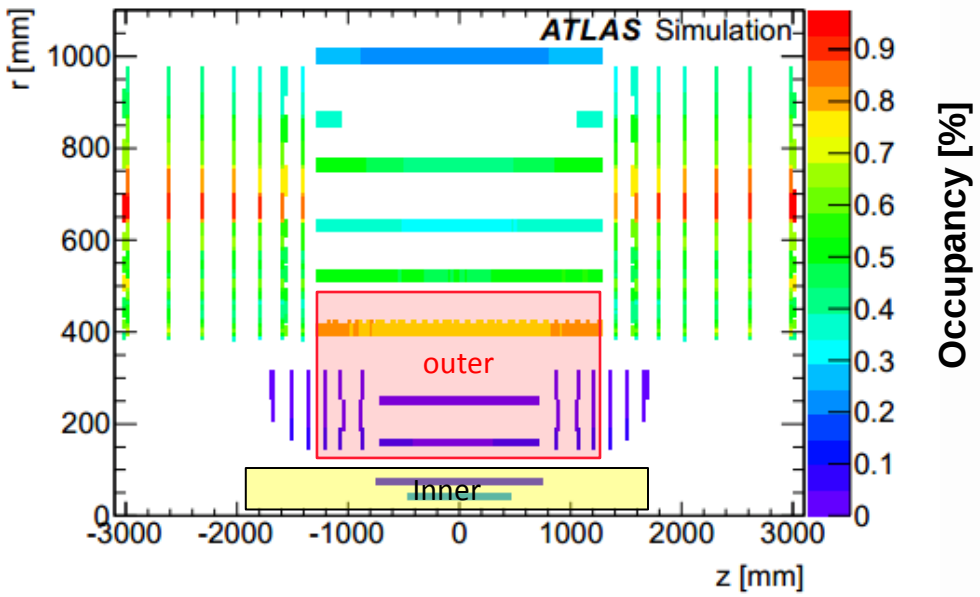
Backup

High Luminosity LHC Environment - Requirements



Detector:	Silicon area [m^2]	Channels [10^6]
Pixel barrel	5.1	445
Pixel end-cap	3.1	193
Pixel total	**8.2**	**638**
Strip barrel	122	47
Strip end-cap	71	27
Strip total	**193**	**74**

ATLAS Phase II Letter of Intent

Inner layer

1. **Low power**
2. **Low material**
3. Occupancy
4. Resolution

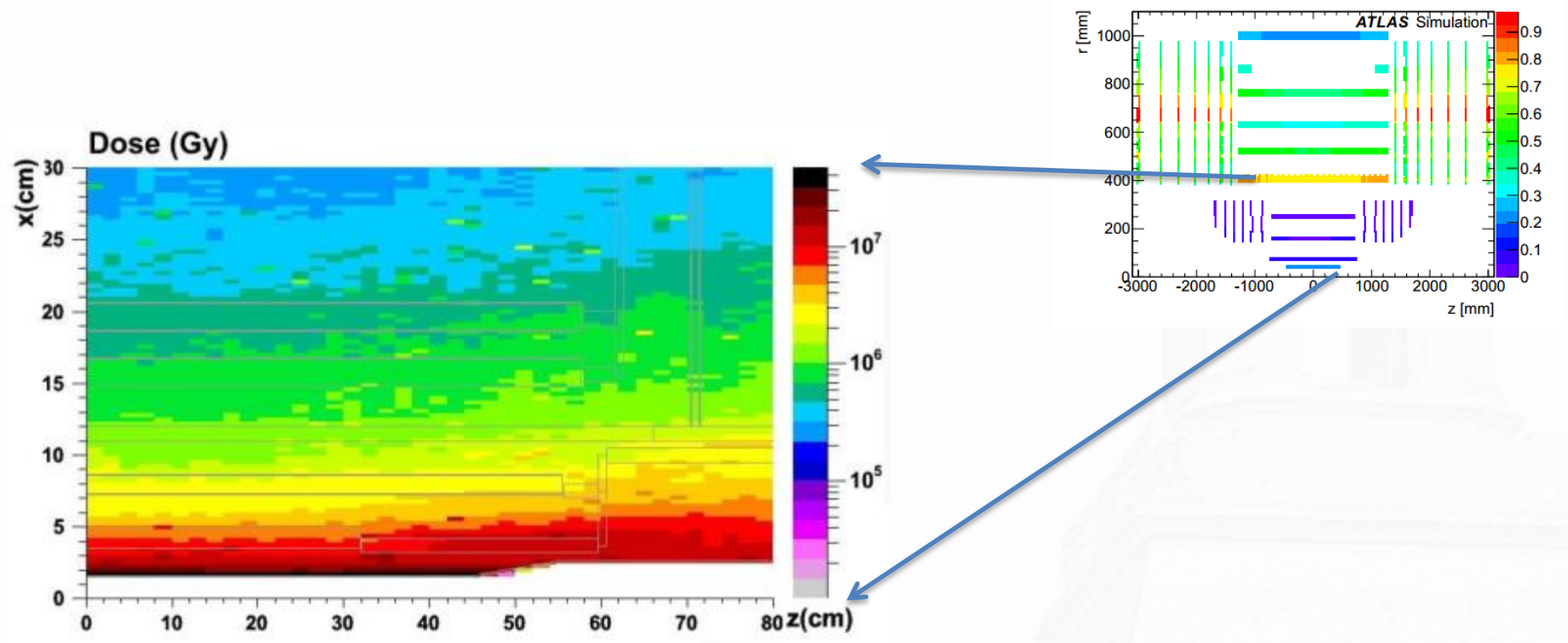
hybrid pixels (65nm? + sensor?)

Outer layer

1. **Low cost**
2. **Low power**
3. Low material
4. Resolution

low cost hybrid pixels or monolithic?

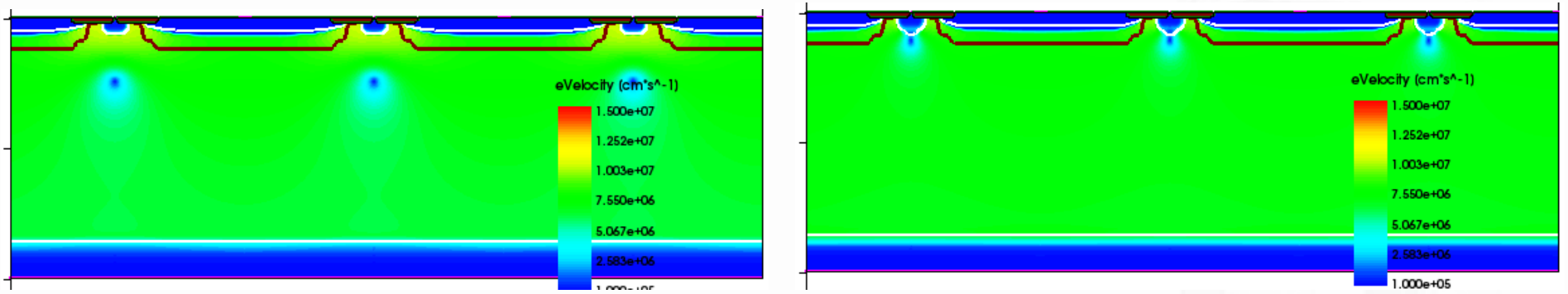
High Luminosity LHC Environment - Requirements

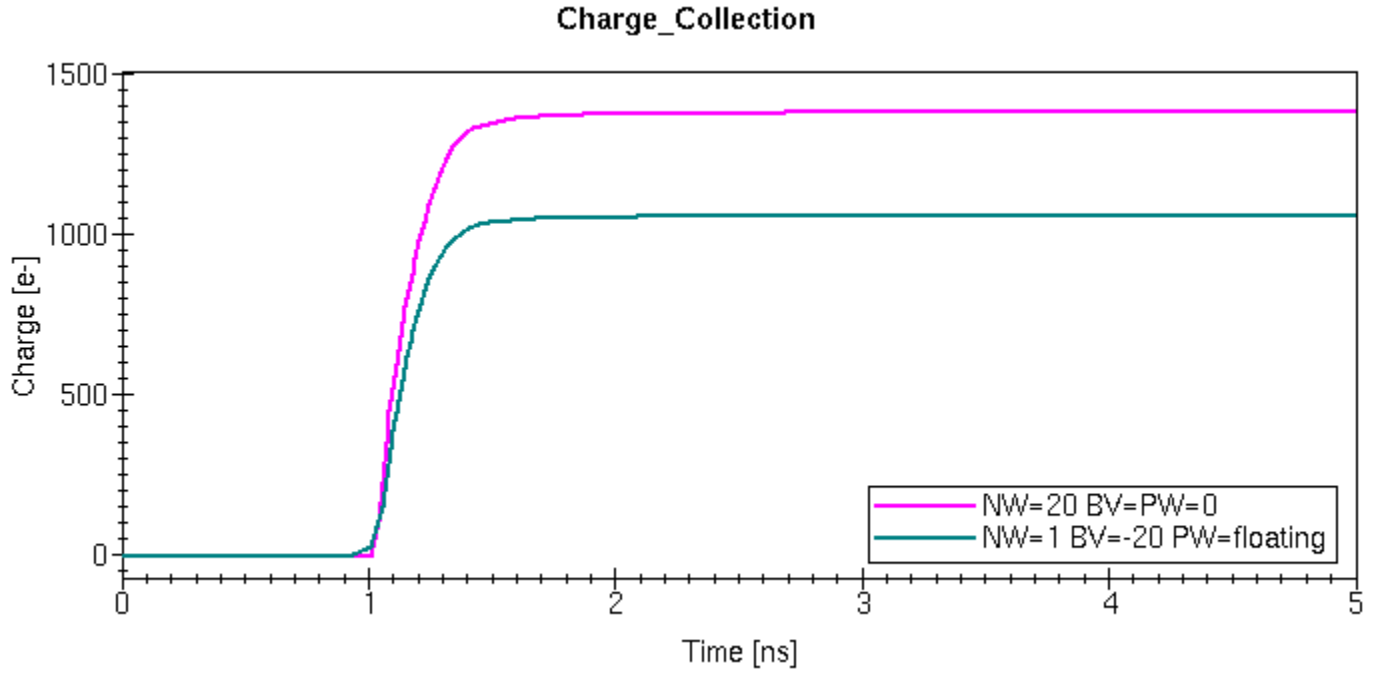


- **Radiation levels:**
  - at 5 cm : ~1500 Mrad ($2 \cdot 10^{16}$ n_{eq}/cm^2)
  - at 25cm : ~100 Mrad (10^{15} n_{eq}/cm^2)

** estimates for 10years of operations*

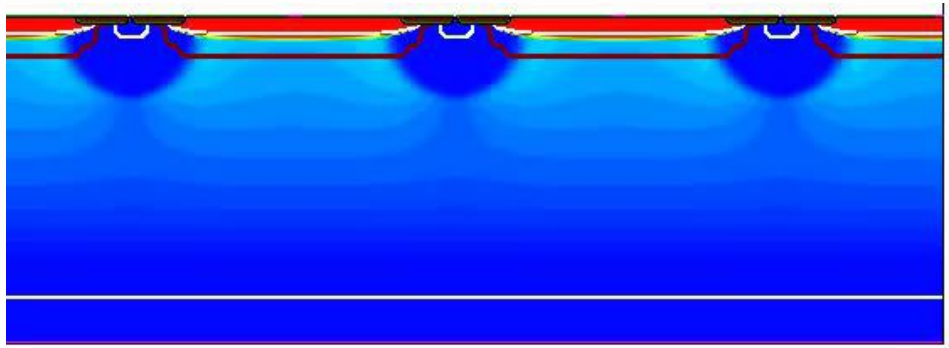
different bias possibilities

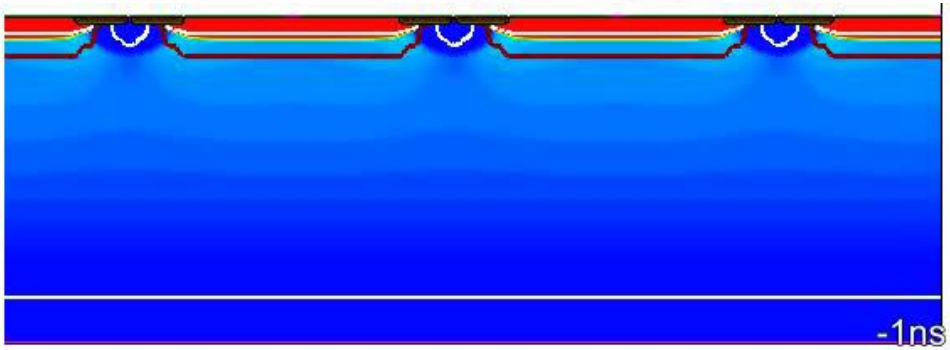


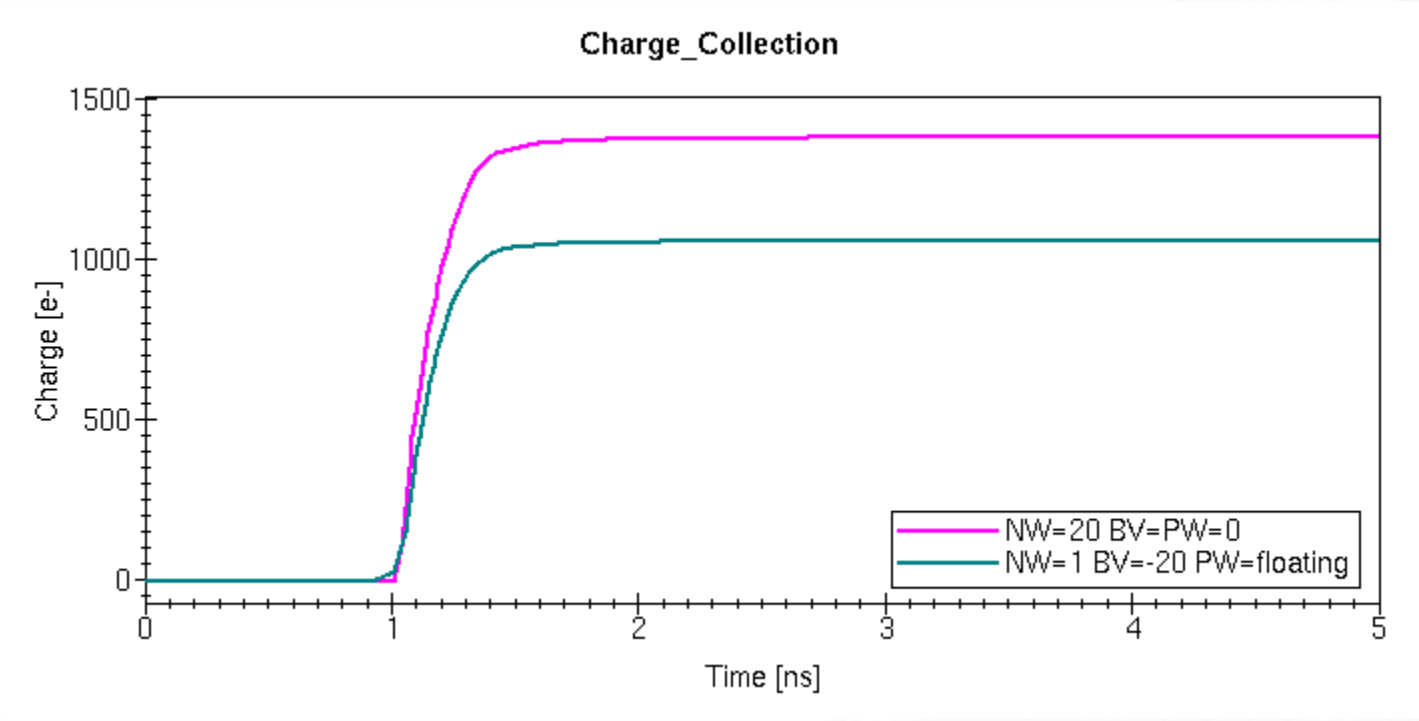


Substrate:2k Ohm cm
Dose: 10^{15} nq/cm^2

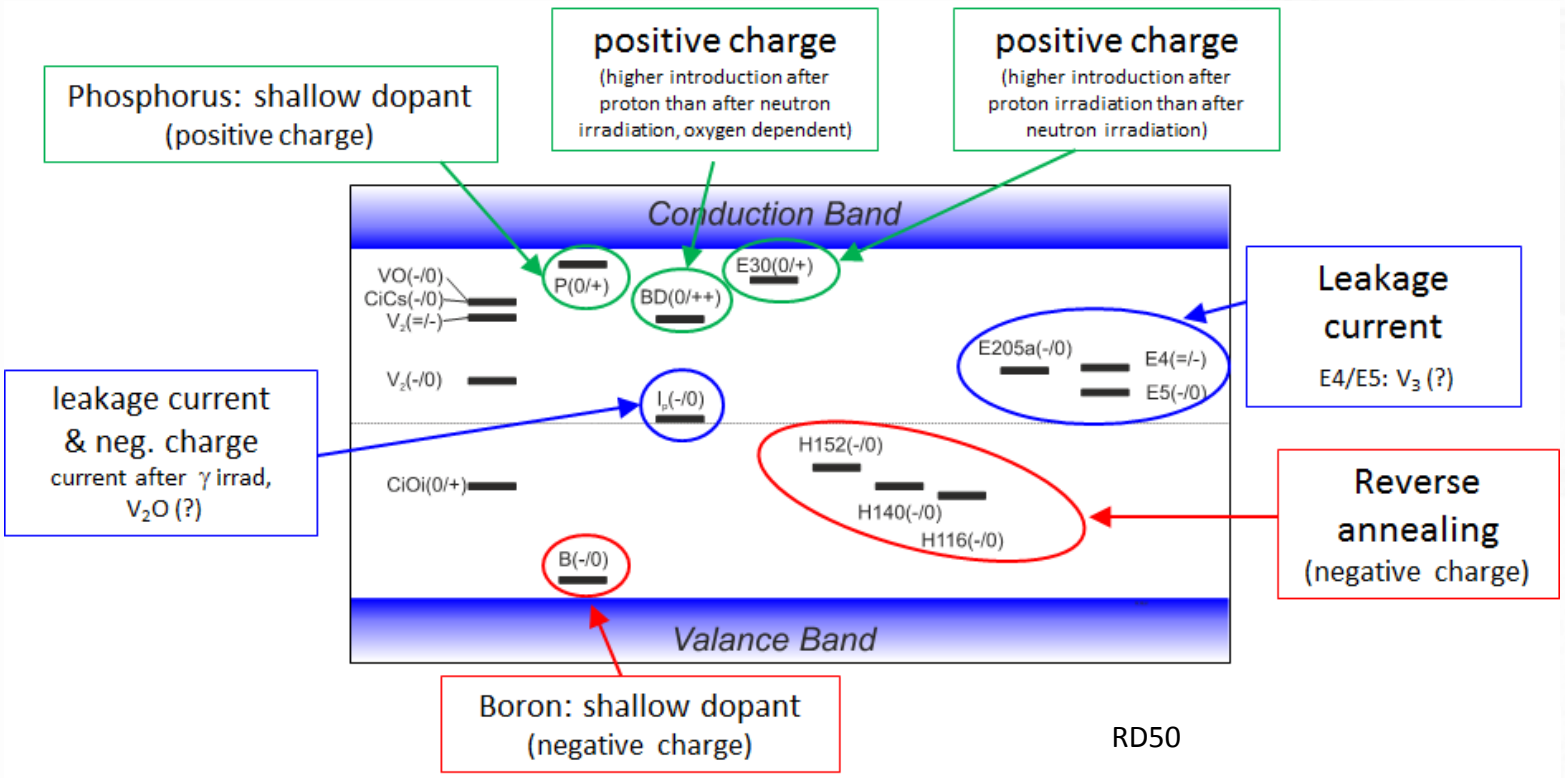
Bias @ 10^{15} nq/cm^2







Trapping in irradiated silicon



1.00E+15	15	0	1	1	0	0	0	1E-06	1241.62	227.55	1469.16	106.64	4.18E-14	17.35	0.01	98.60	17.11
1.00E+15	15	0	1	0	0	-20	-20	5E-07	1360.34	130.08	1490.40	56.61	4.18E-14	36.14	0.01	100.03	36.15
1.00E+15	15	0	20	1	0	0	0	1E-06	1351.49	132.66	1484.01	57.69	4.269E-13	35.38	0.13	99.60	35.24
1.00E+15	15	0	40	1	0	0	0	5E-07	1378.30	97.67	1475.68	44.44	9.299E-13	45.18	0.28	99.04	44.75
1.00E+15	15	1.00E+13	1	1	0	0	0	5E-07	1026.66	157.87	1184.48	88.95	1.251E-13	20.72	0.04	79.50	16.48
1.00E+15	15	1.00E+13	20	1	0	0	0	5E-07	1208.26	102.25	1310.23	52.22	9.147E-13	38.50	0.28	87.93	33.86
1.00E+15	15	1.00E+14	1	1	0	0	0	5E-07	393.27	18.50	411.50	42.30	8.636E-13	43.13	0.26	27.62	11.91
1.00E+15	15	1.00E+14	20	1	0	0	0	5E-07	642.39	18.57	659.30	31.08	5.39E-12	58.41	1.65	44.25	25.88
1.00E+15	15	1.00E+15	1	1	0	0	0	1E-06	27.33	0.86	25.67	32.20	8.227E-12	75.04	2.52	1.72	1.29
1.00E+15	15	1.00E+15	40	1	0	0	0	5E-07	128.15	3.92	108.69	24.67	7.632E-11	81.89	23.38	7.29	6.62
1.00E+15	15	1.00E+15	20	1	0	0	0	5E-07	82.89	2.55	70.28	27.22	4.944E-11	79.80	15.15	4.72	4.17
1.00E+15	75	0	1	1	0	0	0	1E-06	1269.25	119.10	1388.30	54.55	1.495E-13	45.55	0.05	93.17	42.44
1.00E+15	75	0	20	1	0	0	0	1E-06	1337.16	58.29	1395.05	30.40	1.314E-12	64.79	0.40	93.63	60.66
1.00E+15	75	1.00E+14	20	1	0	0	0	5E-07	960.46	13.68	968.51	16.74	1.834E-11	81.71	5.62	65.00	53.27
1.00E+15	75	1.00E+15	20	1	0	0	0	5E-08	464.18	0.97	412.80	2.43	1.709E-10	96.57	52.35	27.70	29.98
1.00E+15	75	1.00E+15	40	1	0	0	0	5E-08	561.96	1.30	485.93	1.85	2.524E-10	97.18	77.32	32.61	36.48
1.00E+15	75	1.00E+15	60	1	0	0	0	5E-08	598.37	1.87	503.90	1.65	3.145E-10	97.32	96.34	33.82	38.89
6.50E+12	15	0	1	1	0	0	0	5E-07	1465.19	12.50	1477.60	15.09	2.966E-13	75.55	0.09	99.17	74.93
6.50E+12	15	0	20	1	0	0	0	5E-07	1480.91	0.15	1480.19	0.99	2.832E-12	100.00	0.87	99.34	99.37
6.50E+12	15	1.00E+13	1	1	0	0	0	5E-07	1445.68	12.45	1457.75	16.34	1.22E-12	74.42	0.37	97.84	72.82
6.50E+12	15	1.00E+13	20	1	0	0	0	5E-07	1481.31	0.46	1479.04	0.98	8.905E-12	99.81	2.73	99.26	99.17
6.50E+12	15	1.00E+14	1	1	0	0	0	5E-07	1286.23	11.18	1294.55	89.45	9.303E-12	65.58	2.85	86.88	57.04
6.50E+12	15	1.00E+14	20	1	0	0	0	5E-07	1464.11	3.26	1447.94	1.07	6.344E-11	98.13	19.44	97.18	96.00
6.50E+12	15	1.00E+15	1	1	0	0	0	5E-07	519.17	4.61	500.21	303.67	7.691E-11	32.17	23.56	33.57	11.06
6.50E+12	15	1.00E+15	1	0	0	-20	-20	5E-07	1253.75	18.17	1248.35	93.03	7.691E-11	82.91	23.56	83.78	70.12
6.50E+12	15	1.00E+15	20	1	0	0	0	5E-07	1397.80	30.35	1246.22	52.31	5.938E-10	83.79	181.93	83.64	75.20
6.50E+12	15	1.00E+15	30	1	0	0	0	5E-07	1399.85	32.45	1238.48	32.68	6.326E-10	86.94	193.83	83.12	77.92
6.50E+12	15	1.00E+15	40	1	0	0	0	5E-07	1408.28	33.29	1242.66	19.70	6.492E-10	88.77	198.90	83.40	79.96
6.50E+12	15	1.00E+16	20	1	0	0	0	5E-08	188.61	17.22	-820.87	36.54	3.351E-09	67.25	1026.69	-55.09	6.97
6.50E+12	15	1.00E+16	40	1	0	0	0	5E-08	459.50	27.41	-1115.43	32.22	5.23E-09	75.19	1602.35	-74.86	20.53
6.50E+12	15	1.00E+16	1	0	0	-20	-20	5E-08	217.25	22.82	100.38	39.25	4.56E-10	51.75	139.69	6.74	8.10
6.50E+12	15	1.00E+16	1	0	0	-40	-40	5E-08	730.38	56.85	647.53	33.04	4.56E-10	72.24	139.69	43.46	37.83
6.50E+12	15	1.00E+16	80	1	0	0	0	5E-08	699.16	34.16	######	29.33	6.458E-09	78.70	1978.41	-83.56	33.51
6.50E+12	15	5.00E+15	40	1	0	0	0	5E-08	811.23	16.57	-112.73	24.60	3.07E-09	82.93	940.53	-7.57	43.46
6.50E+12	15	5.00E+15	20	1	0	0	0	5E-08	515.57	12.44	-191.14	29.95	2.347E-09	78.03	719.15	-12.83	25.77
6.50E+12	15	5.00E+15	1	1	0	0	0	5E-08	14.25	1.44	-70.28	40.28	2.806E-10	56.18	85.98	-4.72	0.43
6.50E+12	75	1.00E+15	20	1	0	0	0	5E-07	1509.71	35.03	1335.52	0.35	6.829E-10	96.72	209.22	89.63	93.48
6.50E+12	75	1.00E+15	30	1	0	0	0	5E-07	1358.96	35.13	1183.65	0.32	6.869E-10	97.00	210.45	79.44	83.90
6.50E+12	75	1.00E+15	1	0	0	-30	0	2E-07	1113.53	13.38	1016.69	0.29	3.598E-10	96.42	110.23	68.23	71.50
6.50E+12	75	1.00E+15	1	0	0	-20	-20	5E-07	1162.04	34.05	1085.86	0.40	3.598E-10	93.49	110.23	72.88	71.59
6.50E+12	75	1.00E+15	1	1	0	0	0	5E-08	932.16	2.39	826.00	6.47	3.543E-10	91.89	108.55	55.44	57.30
6.50E+12	75	1.00E+16	20	1	0	0	0	5E-08	945.42	36.88	######	3.88	6.636E-09	91.62	2033.18	-70.53	54.15
6.50E+12	75	1.00E+16	40	1	0	0	0	5E-08	1016.27	37.59	######	1.08	6.852E-09	92.60	2099.30	-70.16	58.97
6.50E+12	75	1.00E+16	1	0	0	-40	-40	5E-08	1020.34	37.91	494.70	12.25	1.839E-09	89.33	563.56	33.20	61.76
6.50E+12	75	1.00E+16	1	0	0	-20	-20	5E-08	998.15	38.32	472.90	14.30	1.839E-09	88.63	563.56	31.74	59.98
6.50E+12	75	1.00E+16	60	1	0	0	0	5E-08	1014.24	37.45	######	0.78	6.875E-09	92.97	2106.17	-70.77	59.05
6.50E+12	75	5.00E+15	40	1	0	0	0	5E-08	1048.56	18.59	15.85	0.45	3.431E-09	95.33	1051.29	1.06	64.91
6.50E+12	75	5.00E+15	20	1	0	0	0	5E-08	1090.29	19.21	68.72	0.61	3.397E-09	94.60	1040.77	4.61	67.14
6.50E+12	75	5.00E+15	60	1	0	0	0	5E-08	1072.57	18.85	35.53	0.41	3.446E-09	95.72	1055.90	2.38	66.73
6.50E+12	30	1.00E+15	30	1	0	0	0	5E-07	1437.59	34.14	1268.06	1.43	6.648E-10	91.75	203.67	85.10	84.35
6.50E+12	50	1.00E+15	30	1	0	0	0	5E-07	1441.09	35.18	1266.43	0.50	6.849E-10	94.66	209.83	85.00	87.12