Radiation Tests on IHP's SiGe Technologies for the Front-End Detector Readout in the S-LHC

M. Ullán,

S. Díez, F. Campabadal, G. Pellegrini, M. Lozano

CNM (CSIC), Barcelona

Centro Nacional de Microelectrónica CSIC

CSIC

Framework

Increased luminosity at S-LHC → 2 main challenges on Electronics:

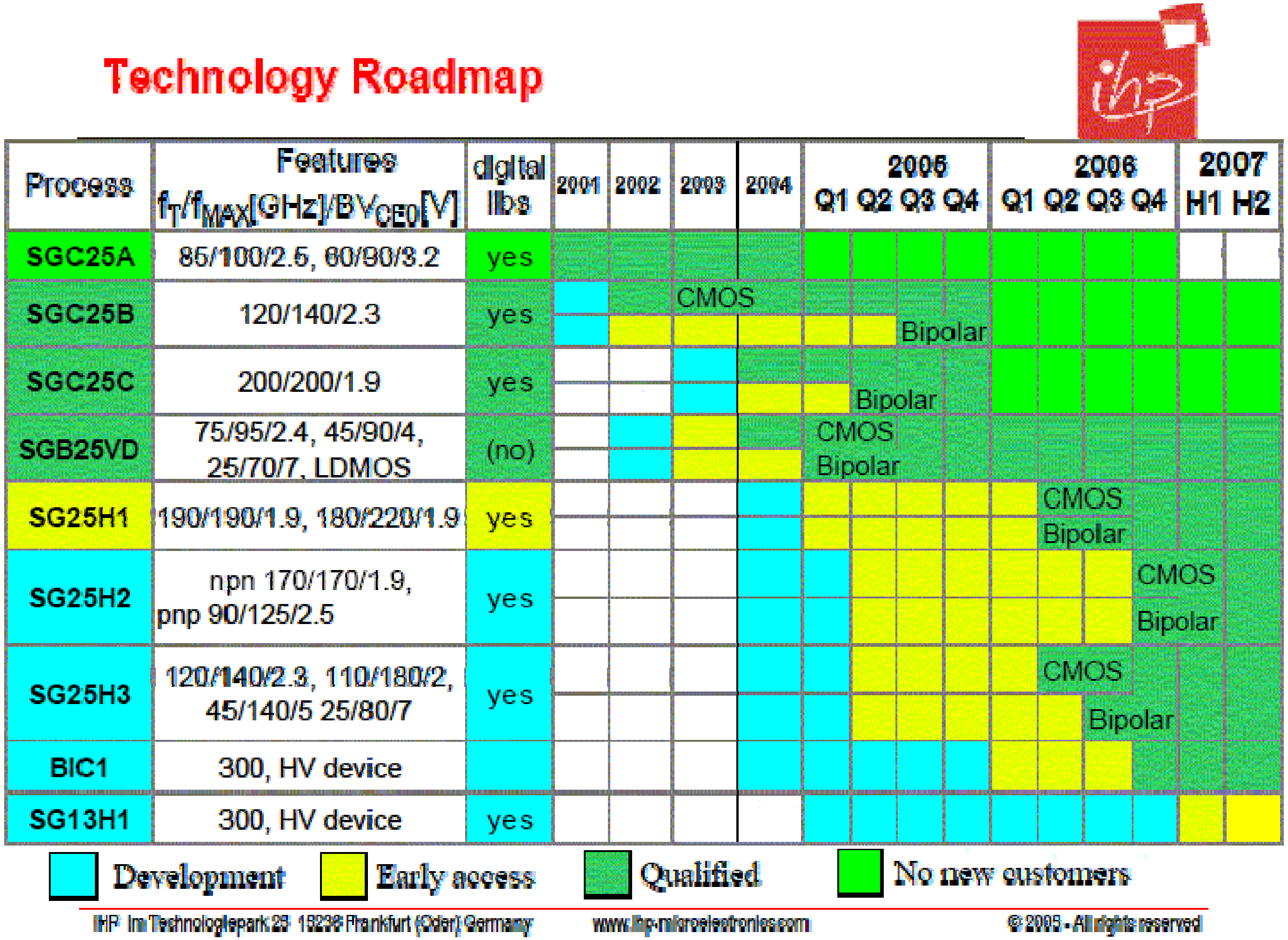
- Instantaneous ⇒ High occupancy ⇒ pile up
  - Higher segmentation → More channels → Power, Services
  - Increased shaping time → Speed, Power
- Integrated ⇒ Radiation Degradation
  - Charge Collection Efficiency ↓ → Signal ↓ → Gain, Power
  - Gain degradation → Current ↑ → Power
  - Noise degradation → S/N ↓ → Noise, Power
- Need to find a proper technology that deals with these challenges
  - High speed, high gain **with**
  - Low power consumption
  - Radiation degradation
  - Cost, availability (prototyping, long term production)

General Aims

- Evaluation of SiGe BiCMOS technologies for the readout of the upgraded ATLAS ID
  - Evaluate radiation hardness
  - Prove power saving with speed and gain
- Proposal of one SiGe BiCMOS technology for the IC-FE design
- Design of a prototype Front End IC.

IHP’s SiGe Technologies

Low cost →
Main →
200 GHz
Alternative →
0.13 µm →

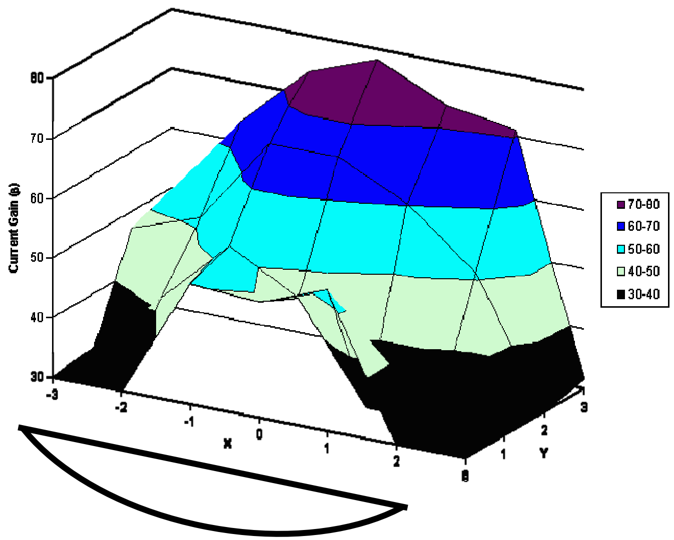


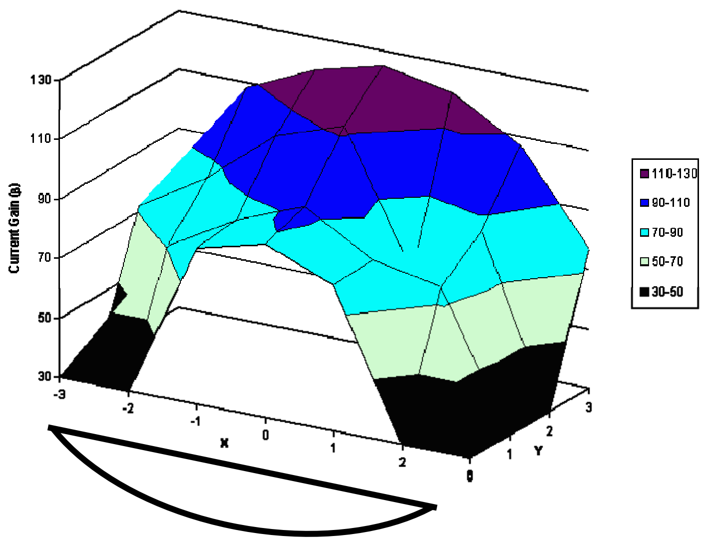
Experiments

- 2 general experiments:
- Exp 1: “first approximation”
  - 2 technologies
  - Gamma irradiations up to 10 and 50 Mrads(Si)
  - Neutron irradiations
- Exp 2: Final total dose results
  - 3 technologies
  - Gamma irradiations up to 10 and 50 Mrads(Si)

Exp 1: Samples

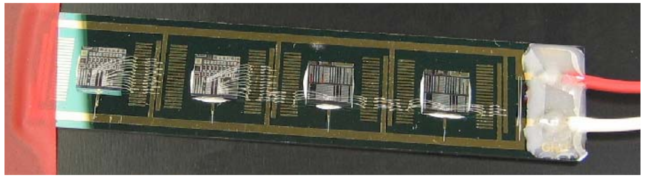
- 2 Test chip wafer pieces with ~20 chips
- 2 Technologies:
  - ➢ SGC25C (bip. module equivalent to SG25H1)
  - ➢ SG25H3 (Alternative technology)
- Edge effects: Solved in next samples





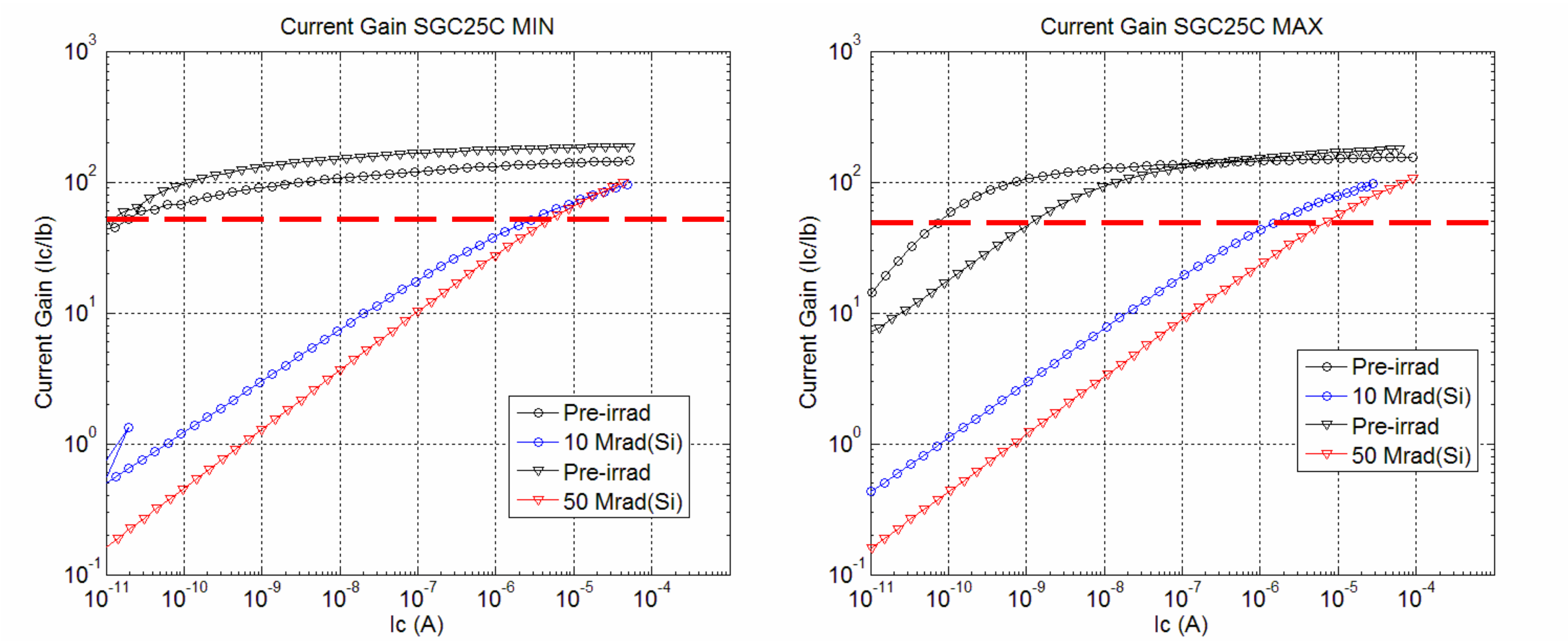
Irradiation Setup

- 4 chips per board, 2 of each technology
- 2 different transistor sizes:
  - ➢ 0.21 x 0.84 μm^2
  - ➢ 0.42 x 0.84 μm^2
- Biased
- Pb(2 mm) – Al(2 mm) shielding box
- NAYADE: “Water Well” Co60 source at Madrid (CIEMAT) ~300 rad(Si)/s up to 10 Mrad(Si)



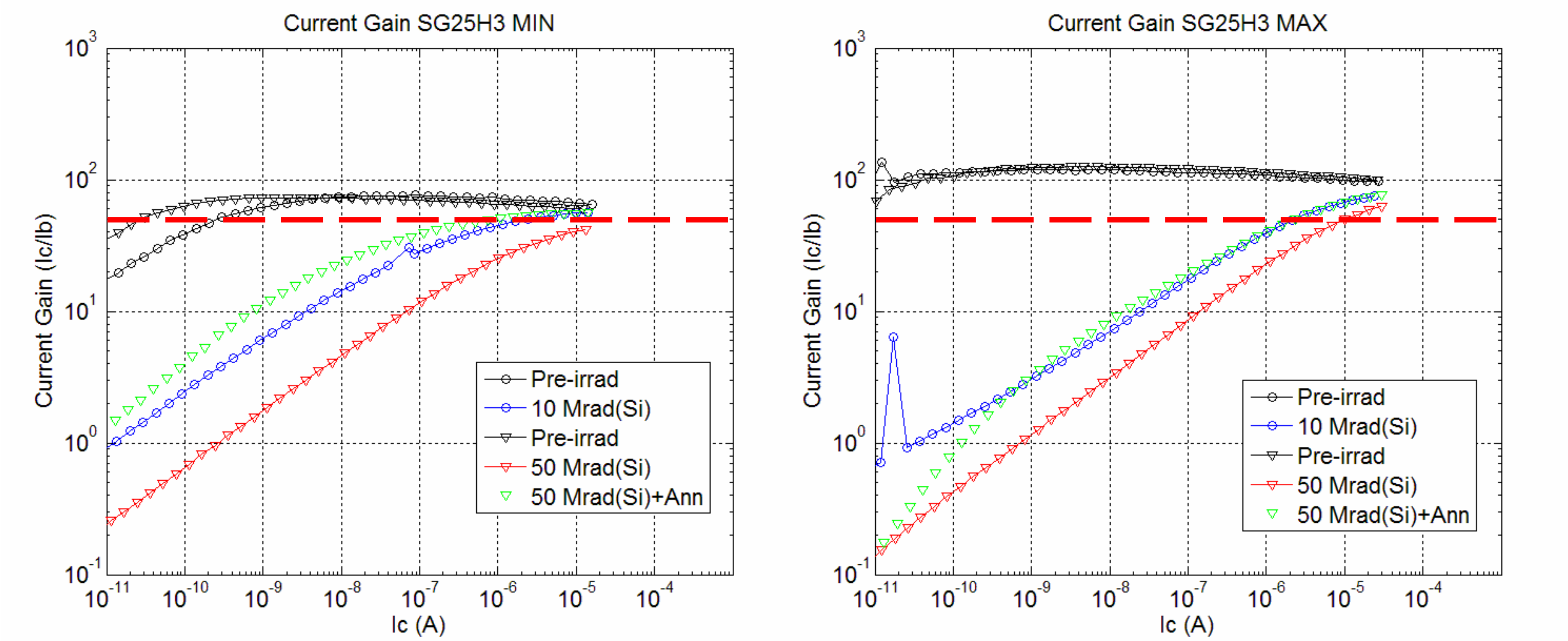
IHP's SGC25C Technology

- Bip. tr. equivalent to SG25H1 technology (f_T = 200 GHz)
- No Annealing !



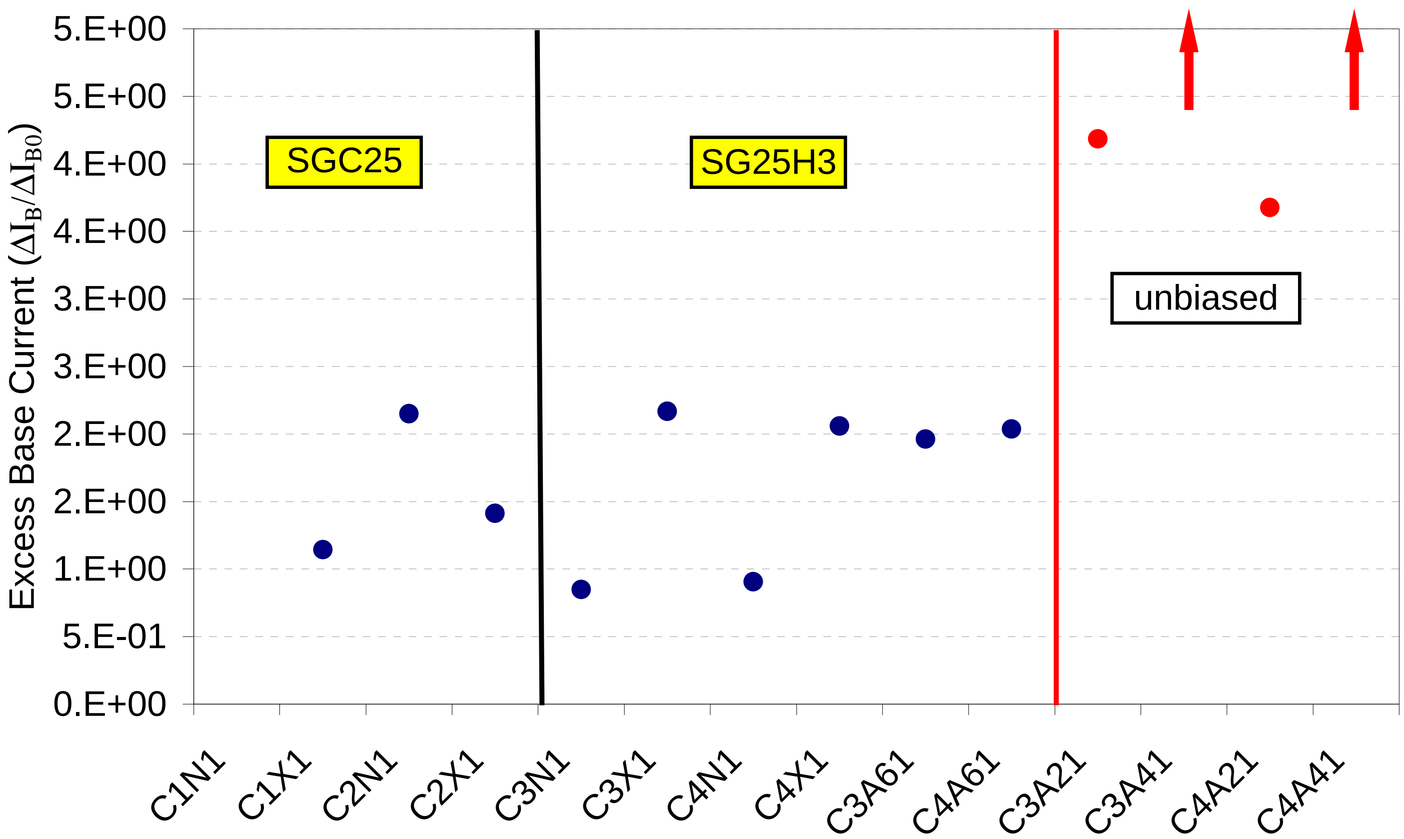
IHP's SG25H3 Technology

- f_T = 120 GHz, Higher breakdown voltages
- Annealing after 50 Mrads: 48 hours, very good recovery
- Very low gains before irrad (edge wafer transistors)



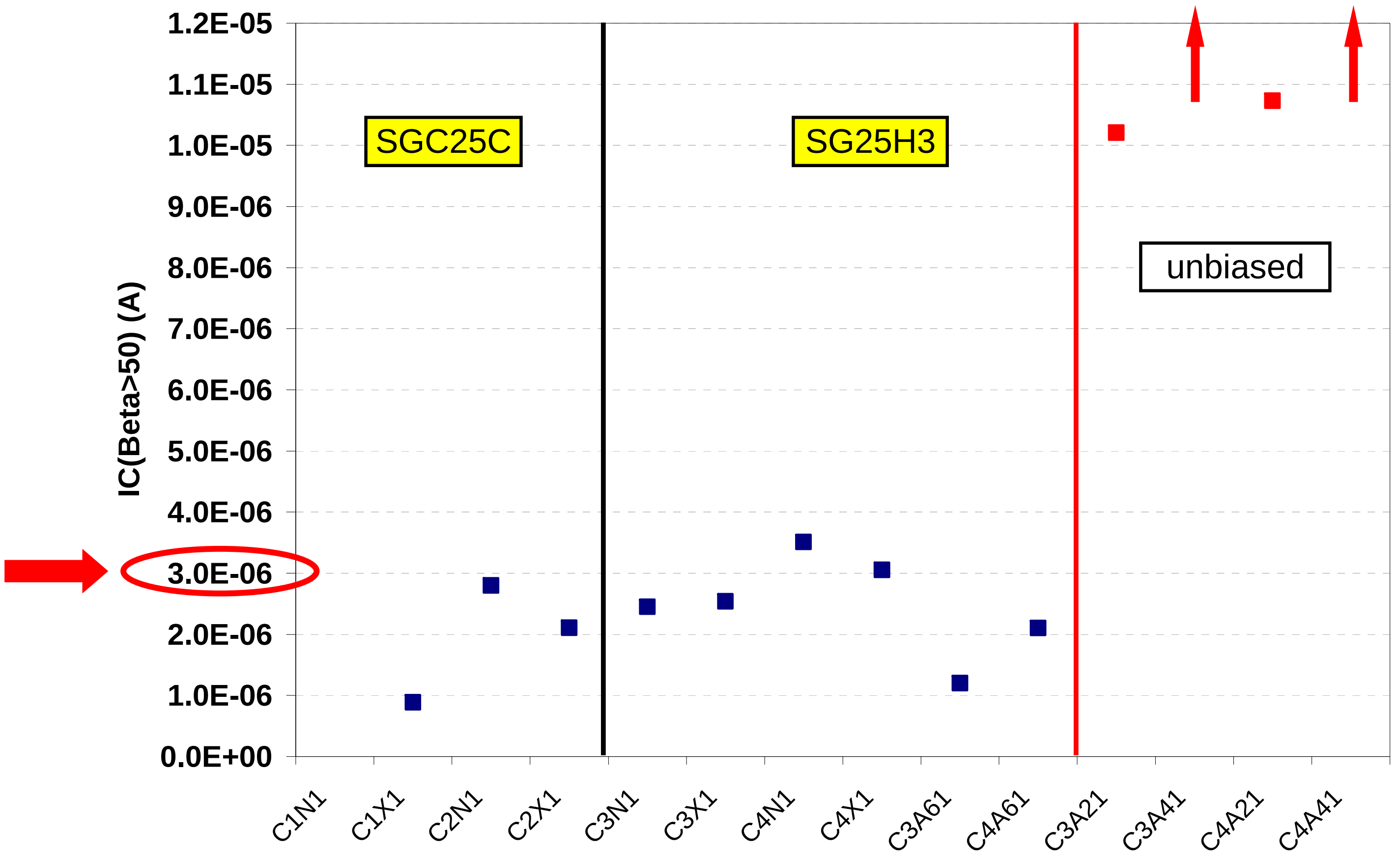
Results Exp 1

- Excess Base Current @ 0.7 V [10 Mrad(Si)]



Results Exp 1

- Bias Current for beta > 50 after 10 Mrad(Si)



Exp 2: Samples

- 3 Test chip wafer **center** pieces with > 20 chips
- 3 Technologies:
  - ➢ SG25H1 ("Wafer D")
  - ➢ SG25H3 ("Wafer I")
  - ➢ SGC25VD ("Wafer V")

Exp 2: Samples

WAFER V (SGB25VD)

$\beta_{target} = 190$

	Complete	R.o.I.
Beta	173.31	190.79
Sigma	22.72	7.6157

Vbe = 0.7 V

TRANSISTOR	Y3
IHP name	S461c
description	50Ghz
L	0.5
W	1
A	0.5

	-3	-2	-1	0	1	2	3
8	147	183	204	196	189	189	194
7	142	187	193	189	185	194	189
6	144	184	199	187	192	187	190
5		180	199	186	197		182
4	134	170	196	197	200	196	178
3	128	155	178	187		183	170
2		139	164	174		167	143
1		135	146	153	148	146	
0			144	133	140		

- (white) → GOOD TRANSISTOR
- (orange) → LOW GAIN AT LOW BIAS
- (yellow) → TRANSISTOR WITHOUT PLAIN GAIN
- (red) → NO TRANSISTOR OR DEAD
- (green) → REGION OF INTEREST

Exp 2: Samples

WAFER V (SGB25VD)

$\beta_{target} = 190$

Vbe = 0.7 V

	Complete	R.o.I.
Beta	174.07	190.96
Sigma	23.6	9.2217

TRANSISTOR	Z2
IHP name	S462b
description	80Ghz
L	0.5
W	1
A	0.5

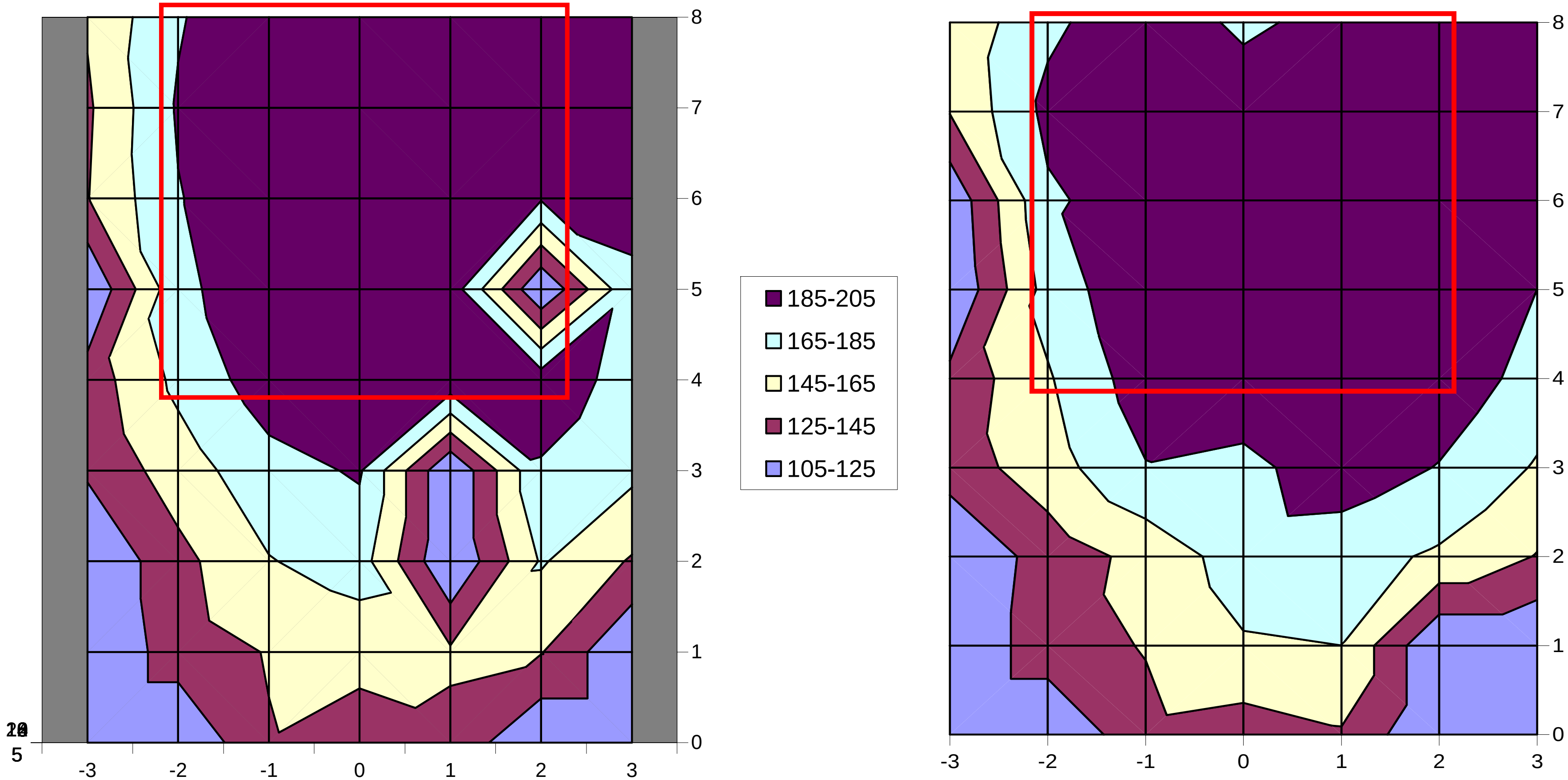
	-3	-2	-1	0	1	2	3
8	149	181	198	181	192	194	189
7	146	190	197	197	190	188	189
6	109	182	195	194	187	201	187
5		173	202	188	196	195	185
4	130	163	196	201	194	199	177
3	134	156	184	179	197	184	163
2		134	151	175	173	162	144
1		137	146	163	165		
0			140	135	143		

- White → GOOD TRANSISTOR
- Orange → LOW GAIN AT LOW BIAS
- Yellow → TRANSISTOR WITHOUT PLAIN GAIN
- Red → NO TRANSISTOR OR DEAD
- Blue → PRE-STRESSED TRANSISTOR WITH BVEBO MEASUREMENTS
- Green → REGION OF INTEREST

Exp 2: Samples

- No edge effect in the area of interest

S461c (Y3) **S462b (Z2)**



Exp 2: Samples

WAFER D (SG25H1)

Complete wafer

Beta 246.73
Sigma 25.8

Vbe = 0.7 V

TRANSISTOR	N
IHP name	552a
description	min
L	0.21
W	0.84
A	0.18

	0	1
10	212	246
9	233	258
8	257	272
7	253	282
6	272	277
5	264	265
4	245	272
3	230	264
2	189	240
1	211	258
0	207	221

→ GOOD TRANSISTOR
→ LOW GAIN AT LOW BIAS
→ NO TRANSISTOR OR DEAD
→ EDGE EFFECT

$\beta_{target} = 200$

Exp 2: Samples

WAFER I (SG25H3)

	Complete wafer
Beta	**158.41**
Sigma	**9.1108**

$\beta_{target} = 150$

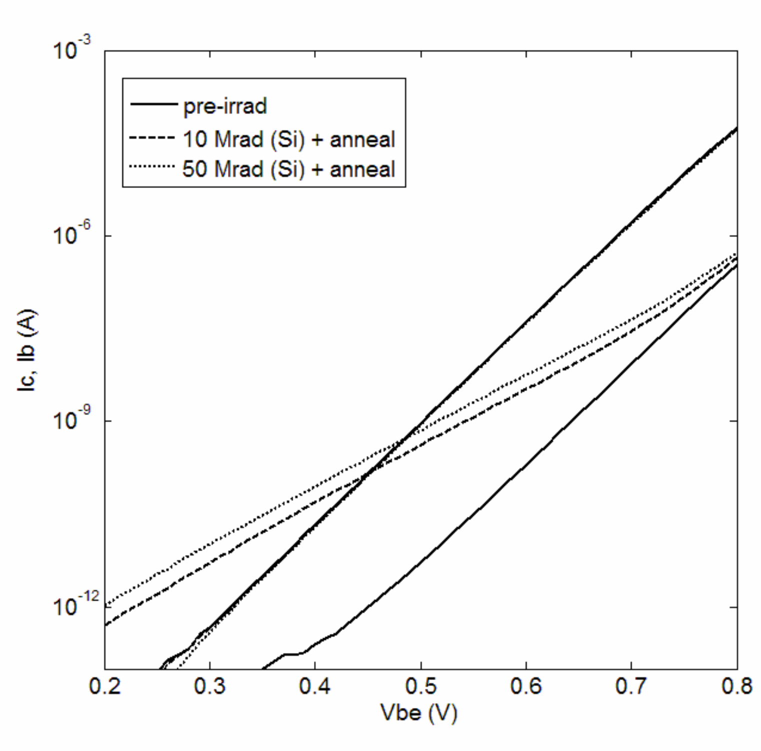
TRANSISTOR	N
IHP name	H03a
description	min
L	0.21
W	0.84
A	0.18

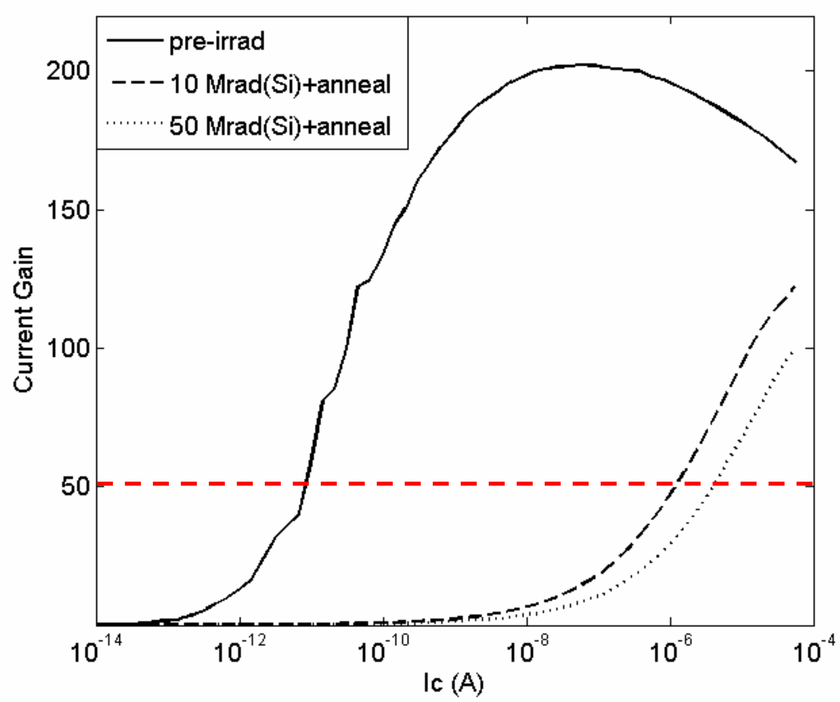
	0	1
8	141	161
7	146	158
6	152	163
5	160	170
4	163	172
3	157	168
2	159	
1	144	167
0	150	162

→ GOOD TRANSISTOR (white)
→ LOW GAIN AT LOW BIAS (orange)
→ NO TRANSISTOR OR DEAD (red)

Heavy rad damage

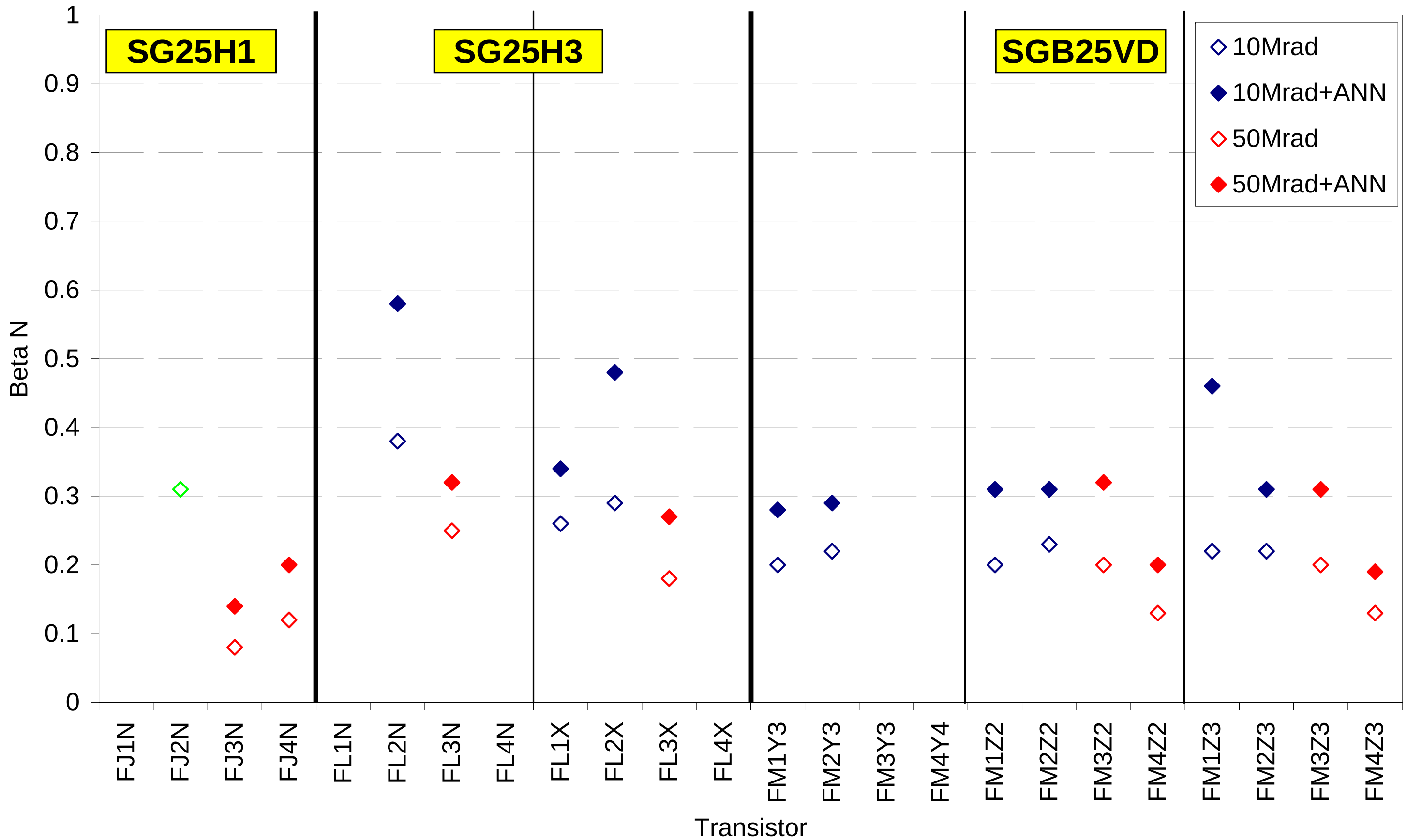
- Transistors heavily damaged but still functional
- Possible damage saturation
- Significant beneficial annealing





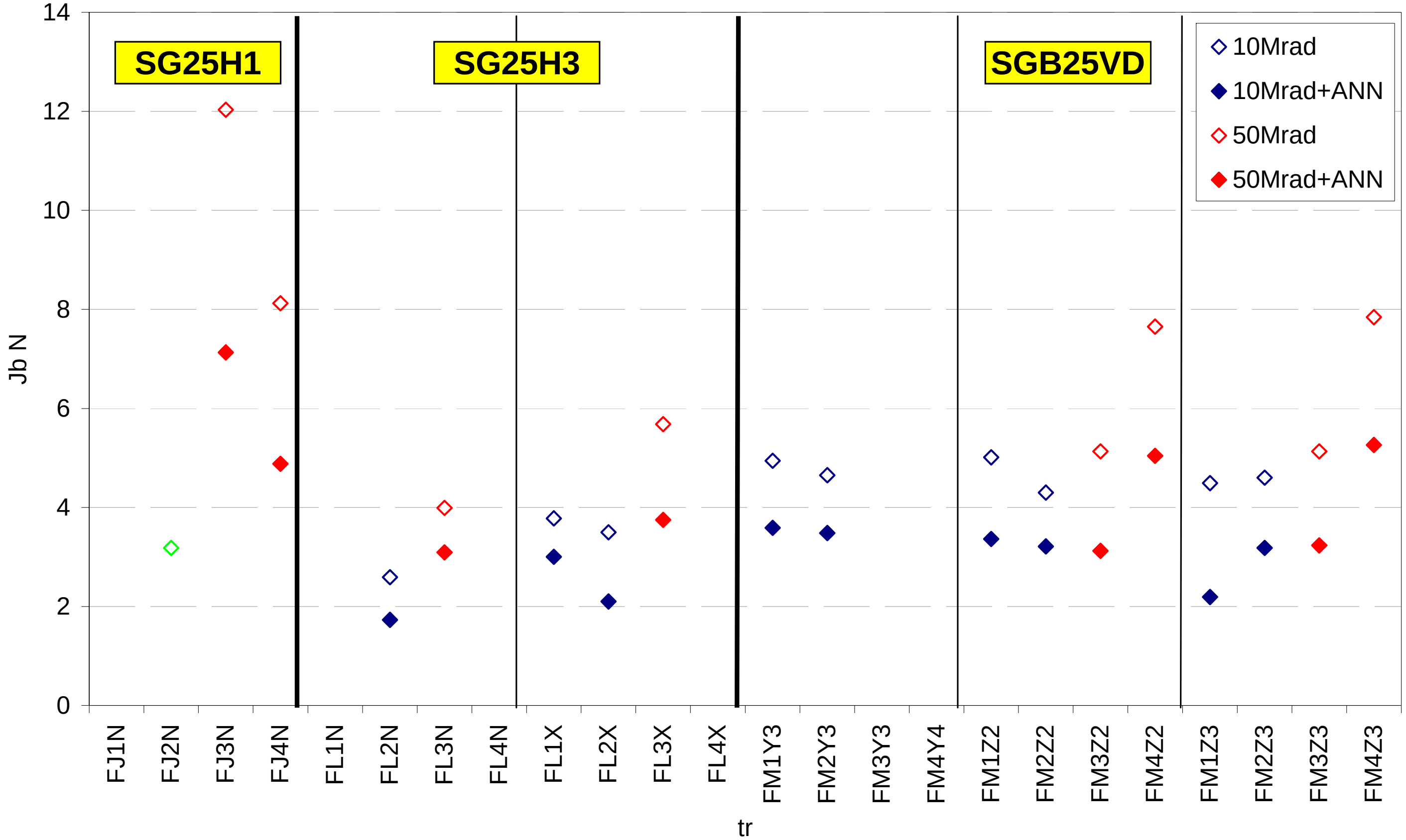
Results Exp 2

- Normalized gain β_f/β_0 @V_{BE} = 0.7 V



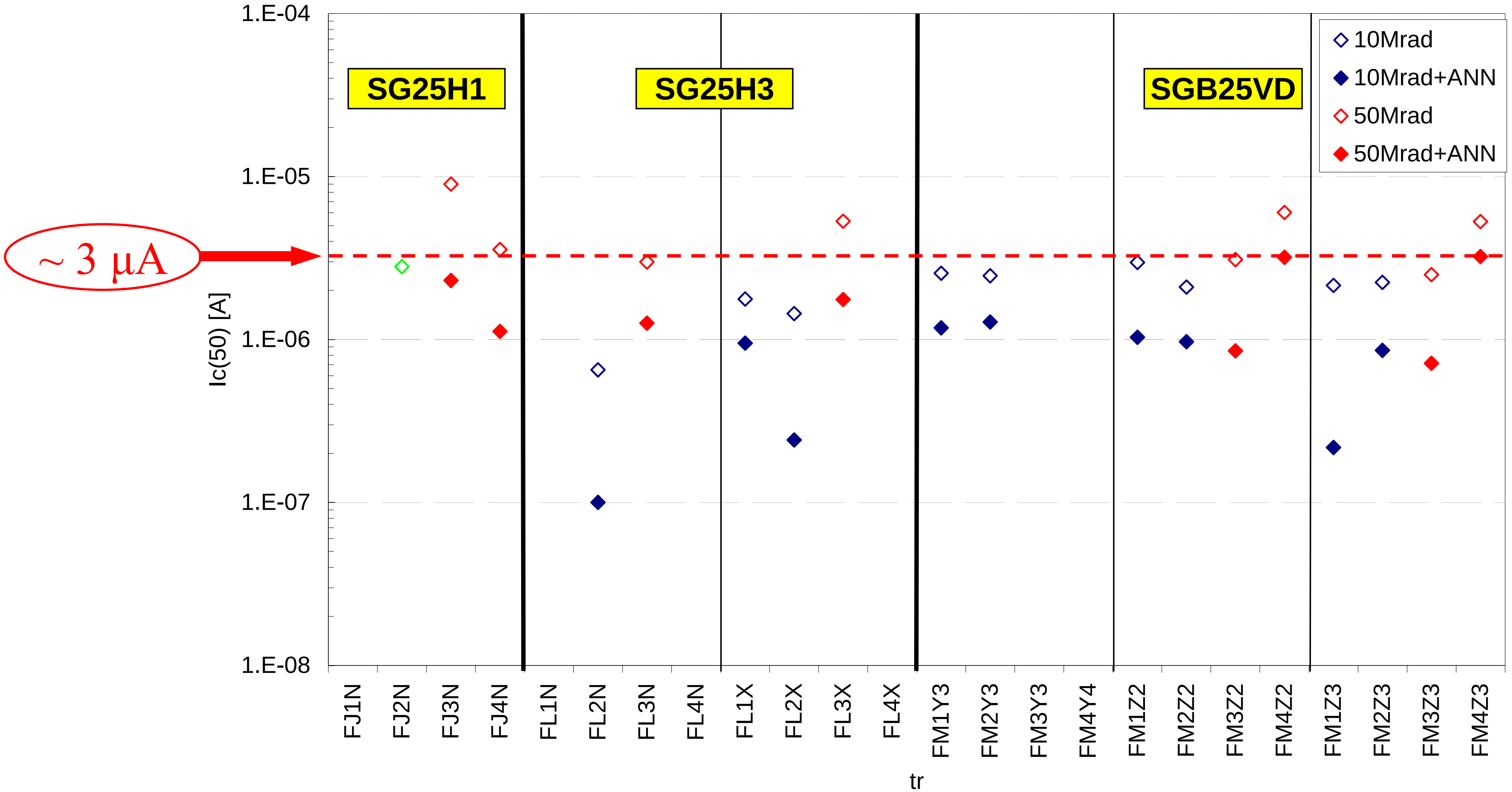
Results Exp 2

- Normalized base current density J_{Bf}/J_{B0} @V_{BE} = 0.7 V



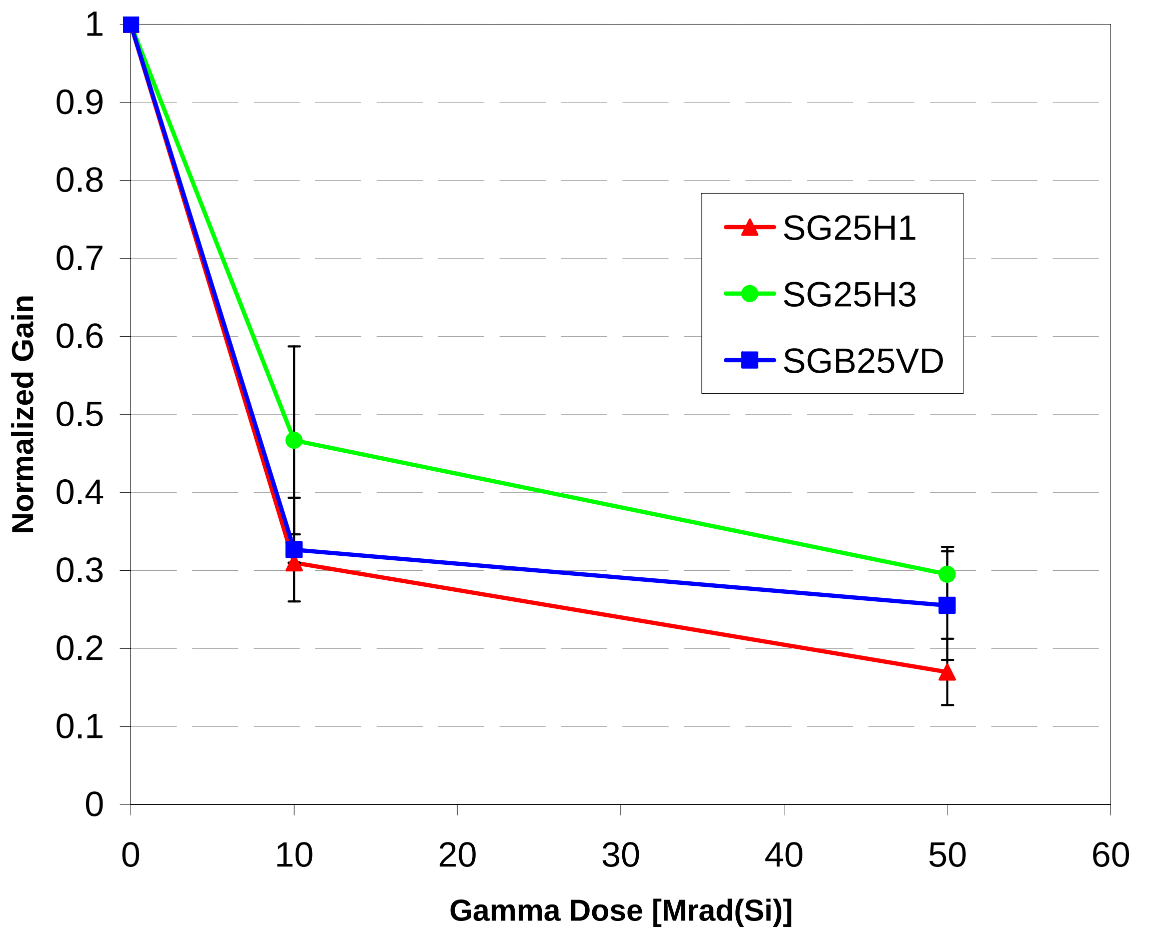
Results Exp 2

- Collector current needed for $\beta = 50$



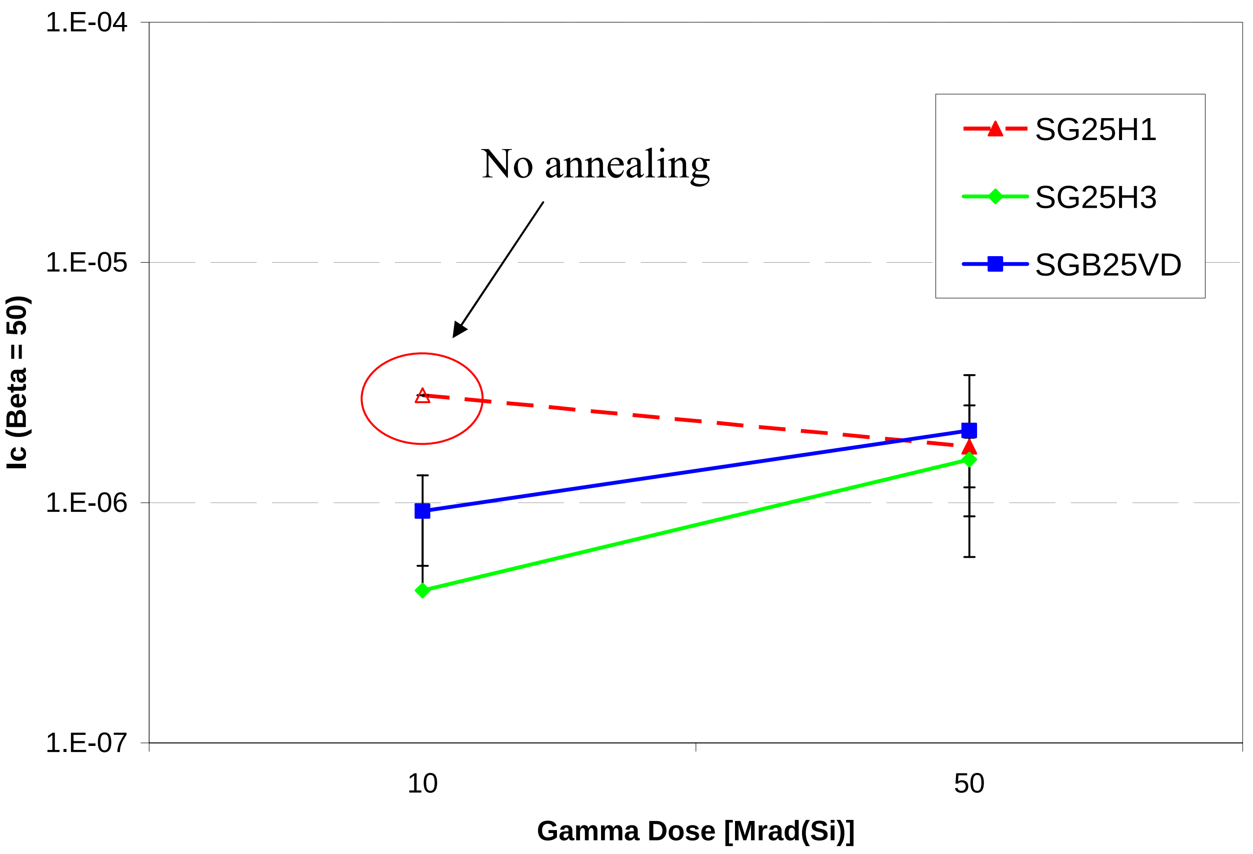
Exp 2: Tech. comparison

- Current Gain Degradation



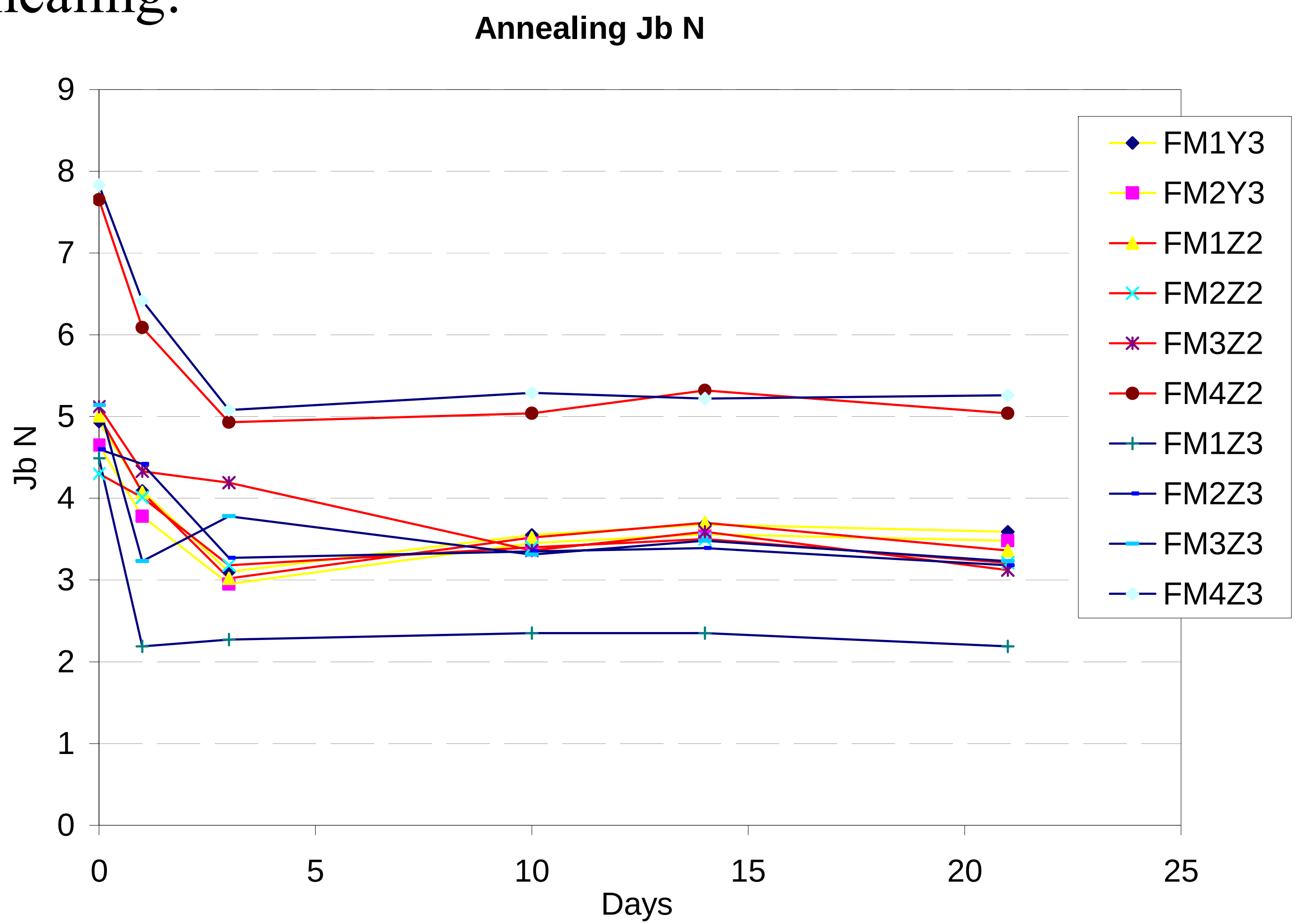
Exp 2: Tech. comparison

- Collector current for $\beta = 50$



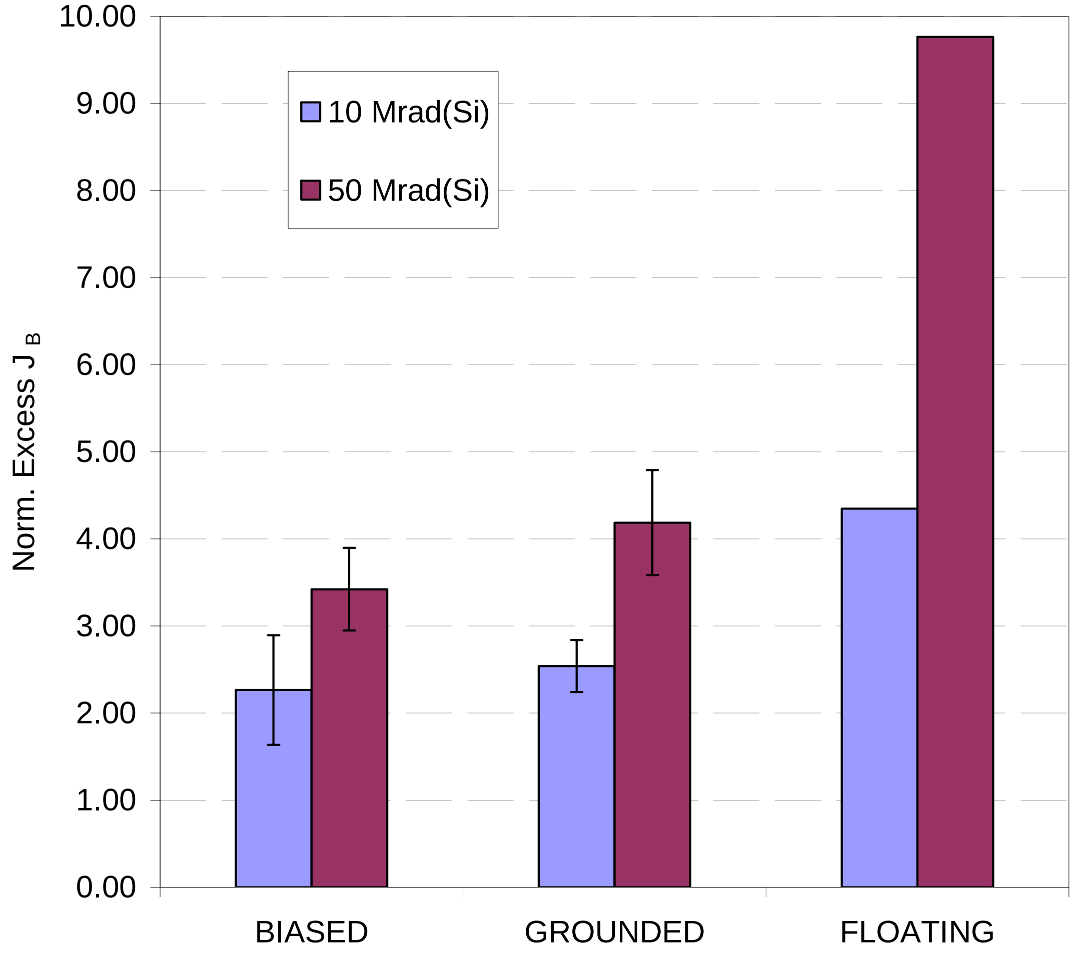
Other results

- Annealing:



Other results

- Biasing:



Conclusions

- Evaluation of three different IHP's SiGe BiCMOS technologies
- Results indicate that IHP's technologies would remain functional after S-LHC life span
- Not large differences in degradation among technologies, although one can see:
  - Higher damages in SG25H1 technology,
  - lower damages in SG25H3 technology
- Annealing behavior studied, saturation is observed.
- It has been proven that device irradiations with floating terminals produce an over-damage on the devices. Small damage differences between biasing or grounding the devices during irradiations.

Future work

- 100 Mrads(Si) total dose
- LDRE – damage vs. dose mapping
- Measure more devices/components of technologies
- More statistics needed for a finer data analysis
- Study emitter geometry influence
- Specific TEST CHIP for irradiations is being designed
- Investigate damage under n and p irradiation
- Temperature influence

☞ Compare with other SiGe technologies → Choose → DESIGN FE CHIP