Low Dose-rate Irradiation of RD53A Chip//Update

Students Instrumentation Meeting

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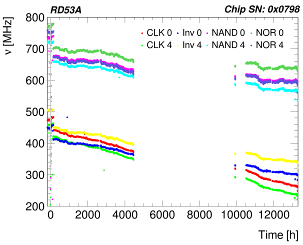
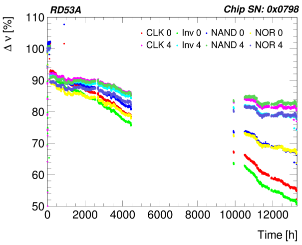
Aleksandra Dimitrievska, Maurice Garcia-Sciveres,
Timon Heim, Simone Pagan Griso

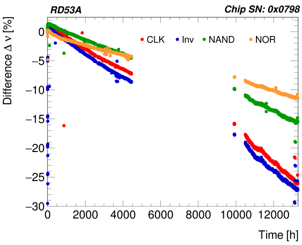
Lawrence Berkeley National Laboratory

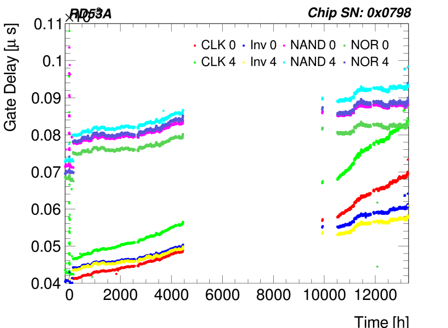
SLIPPER: SLow Irradiation of Phase-II PixEl Readout

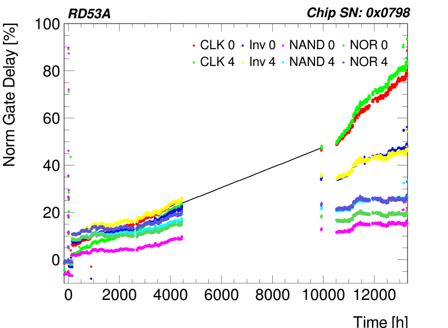
- 335 Mrad total, dose rate: 25 krad/h











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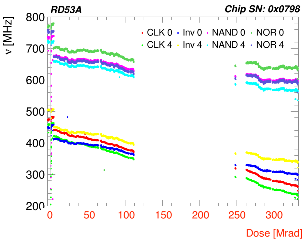
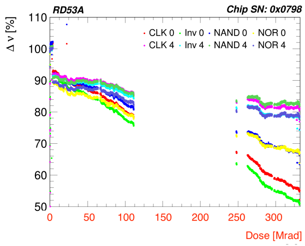
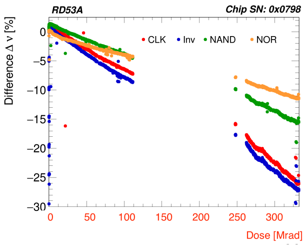
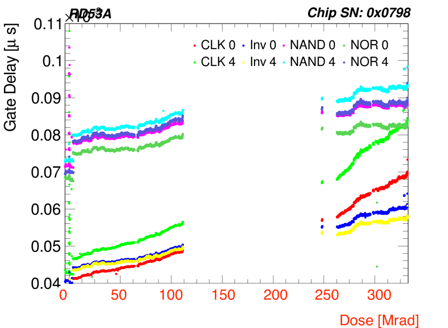
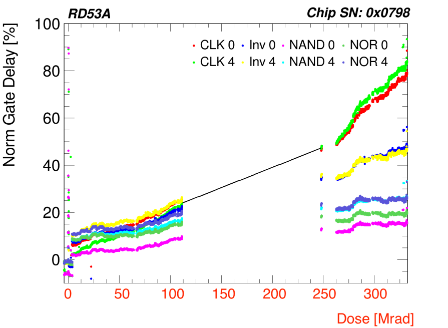






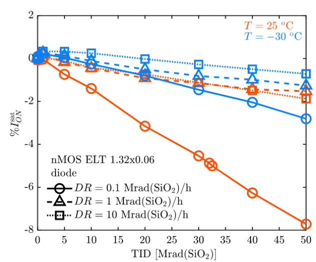


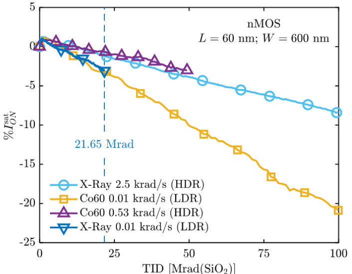


BACKUP

Radiation Damage

- Radiation damage models:
  – RD53A: only standard threshold **single transistors models** irradiated at room temperature (200 Mrad)
  – RD53B: based on newer and more extensive cold irradiation and test data (100, 200, 500 Mrad at 25C, 0C, -30C)
- However the models work only for analog part
  (large transistors where the damage is independent of the dose rate)
- For the digital part (small transistors), the dose rate has a big impact
  – all models are for high dose rate
  – no data and no simulation to predict the high total dose damage at HL-LHC
  – from single transistor measurements (F. Faccio and G. Borghello) after 10-20 Mrad the damage at low dose rate is approximately twice worse than at high dose rate

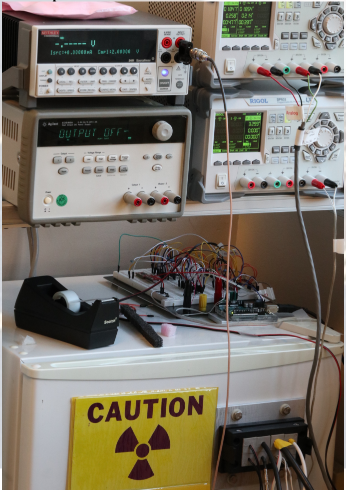


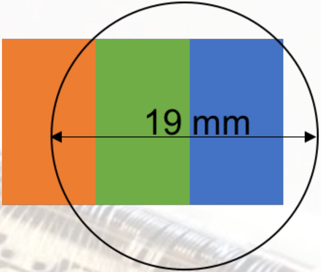


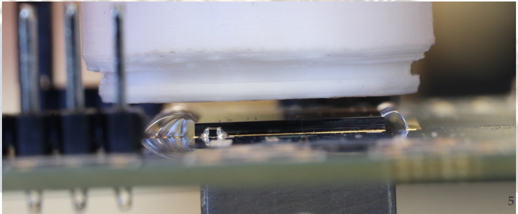
Slipper SLow Irradiation of Phase-II PixEl Readout

- Beta Kr-85 sources: 60 mCi (2.22 GBq), the dose is about 7 rad/s.
- Irradiation with one RD53A chip started on September 6, 2018
- Total dose: about 220 Mrad
- Position of the source:

on top of the linear and differential FE, synchronous FE is not receiving the full dose







Slipper SLow Irradiation of Phase-II PixEl Readout

Software

- Monitoring and data acquisition code: `https://gitlab.cern.ch/berkeleylab/slipper-monitoring-sw`
- Combines: Yarr, labRemote (control power supplies, multimeters), mysql

Testing Procedure

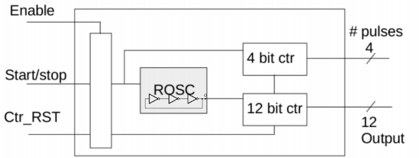
- Keep chip busy all the time (noise scans with global pulse for ring oscillators)
- Perform scans every hour (threshold, tot, MUX, ring oscillators)
- Tuning (1ke, 7 ToT at 10k e) once a day
- Monitor environmental conditions, humidity and temperature, voltage outputs from the chip every minute via Arduino
- Monitor input current of the chip
- The data is stored in database: Arduino, Chip and Log tables.

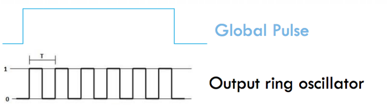
Previous Updates

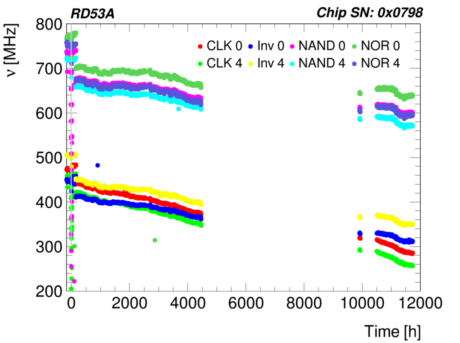
- `https://indico.cern.ch/event/774154/contributions/3238373/attachments/1766695/2869089/LowDoseRate_RD53Collaboration.pdf`
- `https://indico.cern.ch/event/790618/contributions/3329338/attachments/1801647/2938843/LowDoseRate_20190225.pdf`
- FDR of the Pixel Readout Chip `https://indico.cern.ch/event/835605/contributions/3502871/attachments/1904035/3151043/Dimitrievska_RD53APixelReadoutChip_TestResults.pdf`

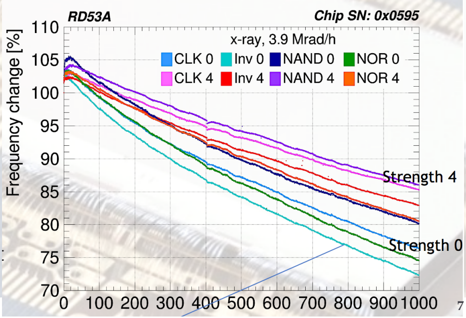
Ring oscillators

- Eight ring oscillators (bottom right corner of the chip)
- Each oscillator drives a 12-bit counter, enabled for a known amount of time set by configuration, dependence on temperature and Vddd
- Calculate the frequency ν or delay $T_D = 1/(N \cdot \nu)$ (N - number of cells)



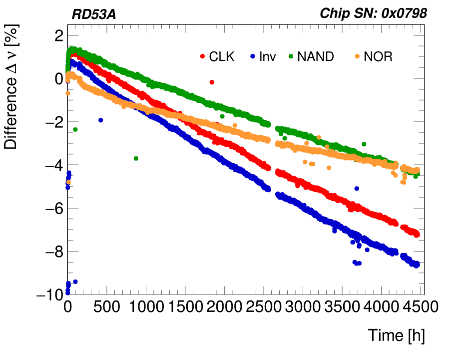


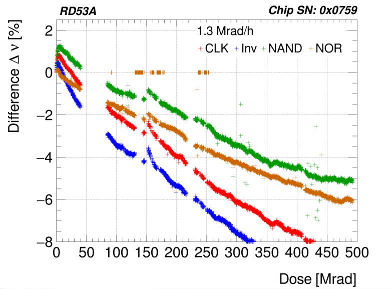


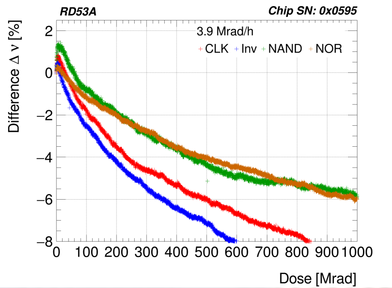


Dose Calibration

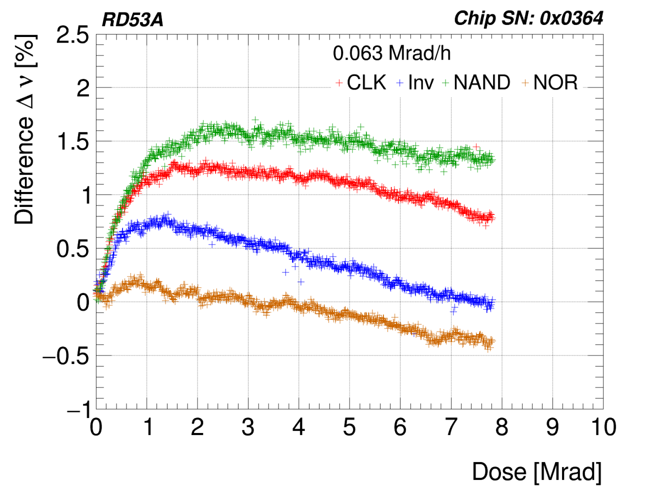
- Use Ring Oscillators as Dosimeters
- The **difference** between the gates with driving strengths 4 and 0
- Compare to X-ray irradiation results
  - Glasgow (high dose rate) 500 and 1000 Mrad
  - CERN (high dose rate) up to 80 Mrad
  - CERN (low dose rate) 8 Mrad





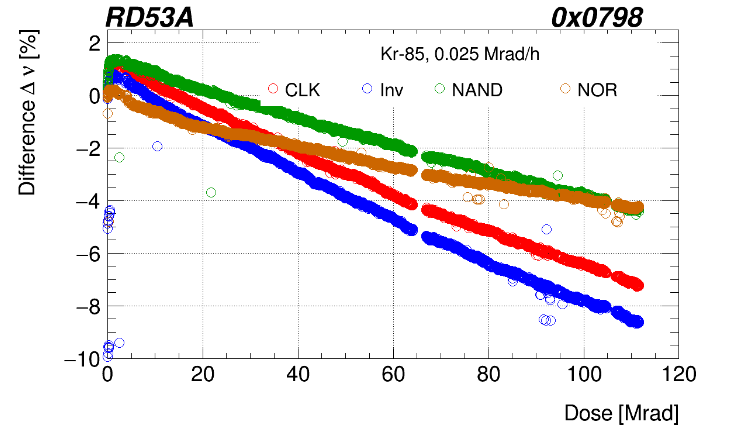


- Extract the values when the lines are crossing 0:
  when the irradiation effects are the same for the gates with driving strengths 4 and 0
  (when lines don't cross, linear fit after the peak and extract value when y=0)

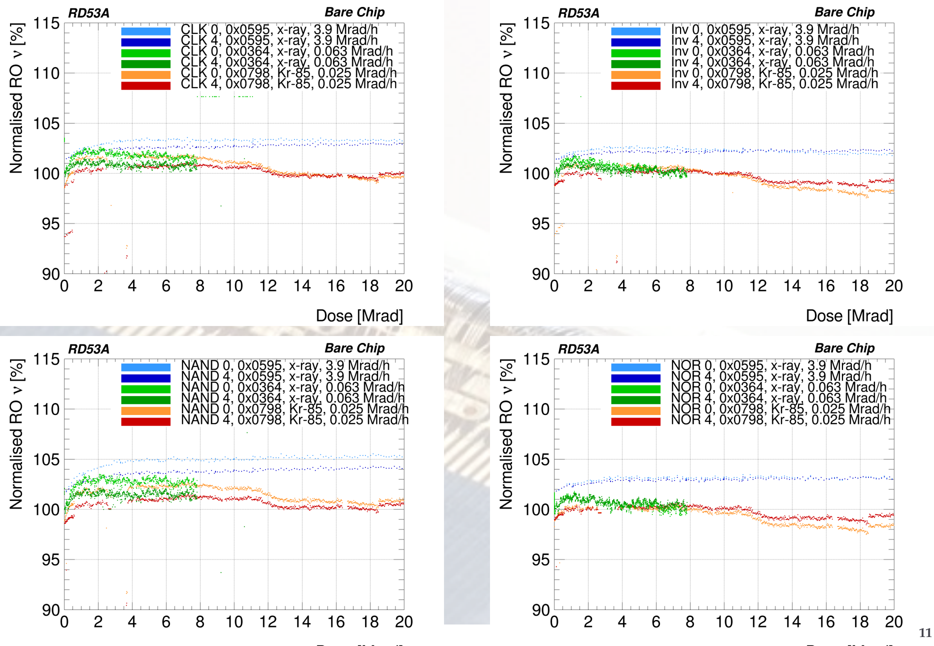


Estimation of the dose rate for Kr-85 source from x-ray irradiations

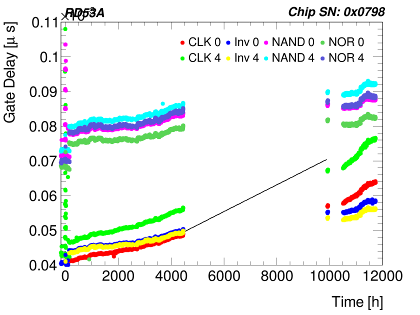
- Kr85 estimated dose rate is: 0.025 Mrad/h
  (back on the envelope calculation from the activity and opening window)
- Change due to activity of the source: 0.75 % per month
- Kr-85 dose rate estimation from the 0.063 Mrad/h x-ray irradiation:
  0.030 Mrad/h (Clock), 0.021 Mrad/h (Inverter),
  0.031 Mrad/h (NAND), 0.048 Mrad/h (NOR)

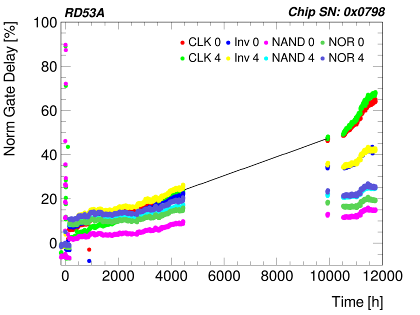


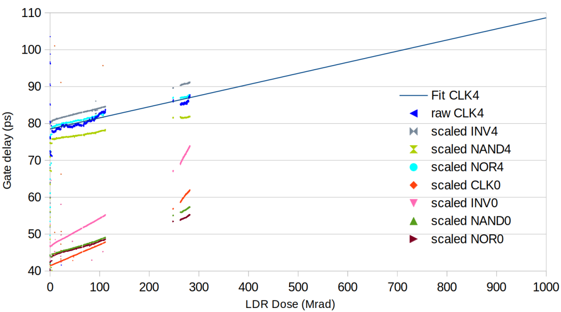
Comparing high and low dose rate



Comparing high and low dose rate - extrapolating the value of the delay







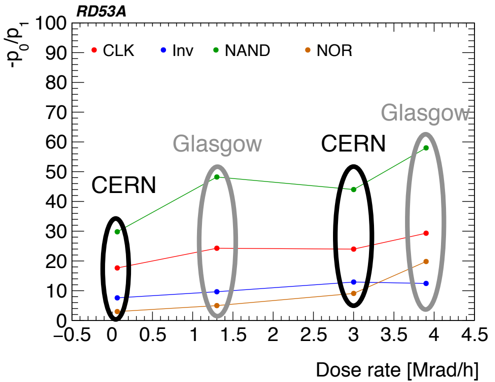
Comparing high and low dose rate - extrapolating the value of the delay

	500 Mrad			
	% Delay degradation			
	Glasgow HDR (experimental data)	ETH HDR FIT (radiation up to 100Mrad, fit to 500Mrad)	ETH LDR FIT (radiation up to 50Mrad, fit to 500Mrad)	500Mrad model tt 0C 1.2V NVT
Dose rate	4Mrad/h	751 krad/h	100 krad/h	9Mrad/h
Temperature	- 15°C	- 10°C	- 10°C	0°C
VDDD	1.2V	1.2V	1.2V	1.2V
CLKN_D0	16%	32%	69%	133%
CLKN_D4	9%	12%	25%	96%
INV_D0	20%	39%	88%	133%
INV_D4	11%	15%	33%	92%
NAND4_D0	13%	24%	46%	138%
NAND4_D4	8%	11%	21%	77%
NOR4_D0	17%	27%	58%	133%
NOR4_D4	12%	16%	30%	68%

	1000 Mrad			500 Mrad model
	% Delay degradation			
	Glasgow HDR (experimental data)	ETH HDR FIT (radiation up to 100Mrad, fit to 1Grad)	ETH LDR FIT (radiation up to 50Mrad, fit to 1Grad)	500Mrad model tt 0C 1.2V NVT
Dose rate	4Mrad/h	751krad/h	100krad/h	9Mrad/h
Temperature	- 15°C	- 10°C	- 10°C	0°C
VDDD	1.2V	1.2V	1.2V	1.2V
CLKN_D0	32%	67%	141%	133%
CLKN_D4	18%	25%	51%	96%
INV_D0	39%	80%	177%	133%
INV_D4	21%	32%	66%	92%
NAND4_D0	27%	52%	97%	138%
NAND4_D4	18%	24%	44%	77%
NOR4_D0	36%	57%	118%	133%
NOR4_D4	26%	34%	61%	68%

High Dose Rate vs Low Dose Rate

- Plenty of data to analyze!
- Low dose rate irradiations with Co-60 from CMS side in Zagreb (3 chips at 0 C and 3 chips at 10 C)
- High and low dose rate irradiations at ETH (CMS) with x-rays



- Discussing with Dima (Glasgow) when their new x-ray tube arrives
- Plan to have different dose rates, ideally 2 chips with same dose rate
  – dose rate 3 Mrad/h, 1 Mrad/h, 0.5 Mrad/h, 0.1 Mrad/h, 0.025 Mrad/h
  – small total dose