# Wrap-up : CBC3 X-ray Irradiation

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# Wrap-up : CBC3 X-ray Irradiation

Latest irradiation : May 2017

- Received one week of beam time with X-ray machine in May of 2017, time was used to :
  - check dosimetry for different distances of the tube from the sample
    - using a calibrated PIN diode provided by ESE [ 1 nA increase in dark current equivalent to 1.373 kRad/h ]
  - confirm that leakage is more prominent in regions of the chip with non-enclosed NMOS (stub logic)
    - Irradiated 2 chips, with stub logic exposed/shielded, at -19° and a high dose rate
  - repeat dose rate scan ( at a bias of 1.25 V ) at an elevated temperature [@ 5°C ]
    - 0.1 kGy/hr , 5 kGy/h , 10 kGy/h , 20 kGy/h

Explored Parameter Space CBC3 TID
March - April 2017

| | 20 kGy/h | 10 kGy/h | 2 kGy/h | 5 kGy/h | 0.5 kGy/h |
|---|---|---|---|---|---|
| 20° | 03/2017 | | | | |
| 0° | | | | 04/2017 | |
| -5 | 03/2017 | | 03/2017 | 04/2017 | 03/2017** |
| -20° | 04/2017 | 04/2017 | | 04/2017 | 04/2017 |

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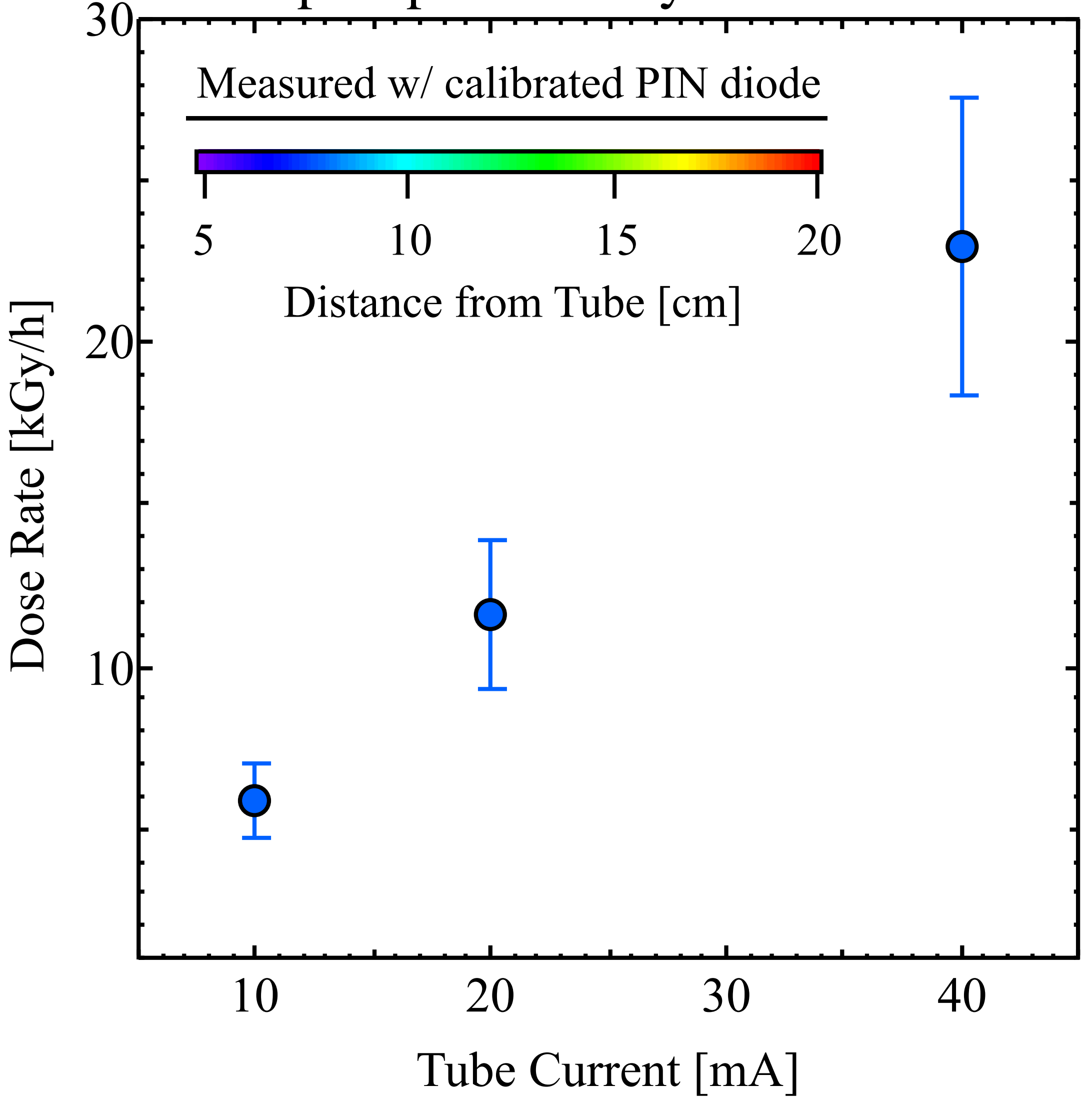
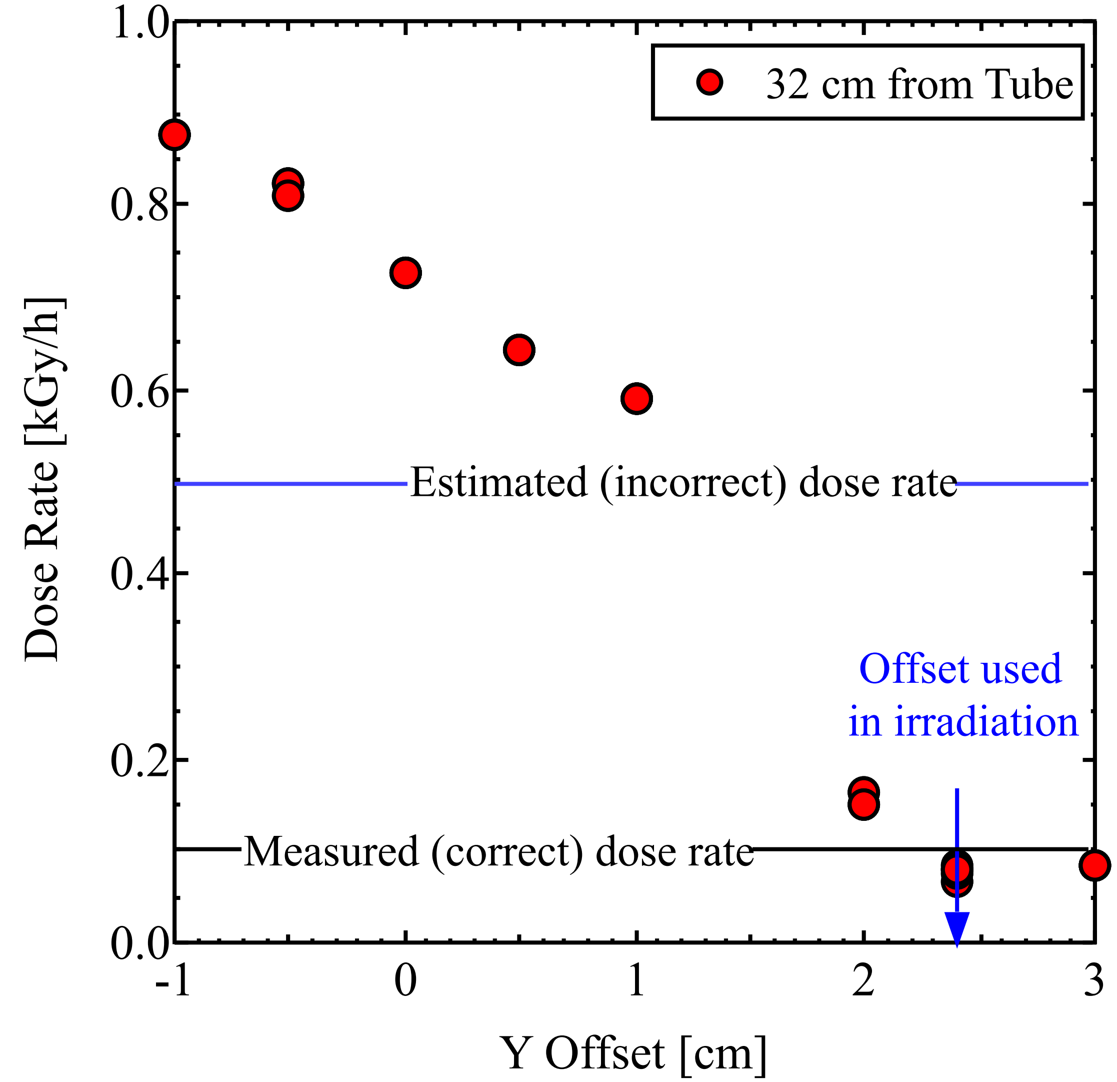
## Measured dose rate at different distances from the CERN X-ray source

- Check dosimetry for different distances of the tube from the sample
  - using a calibrated PIN diode provided by ESE-MIC [ 1 nA increase in dark current equivalent to 1.373 kRad/h ]

Results consistent with X-ray calibration report provided by ESE-MIC




Lowest dose rate used in tests actually 1/5th of that we calculated (reversed the sign of the offset!)



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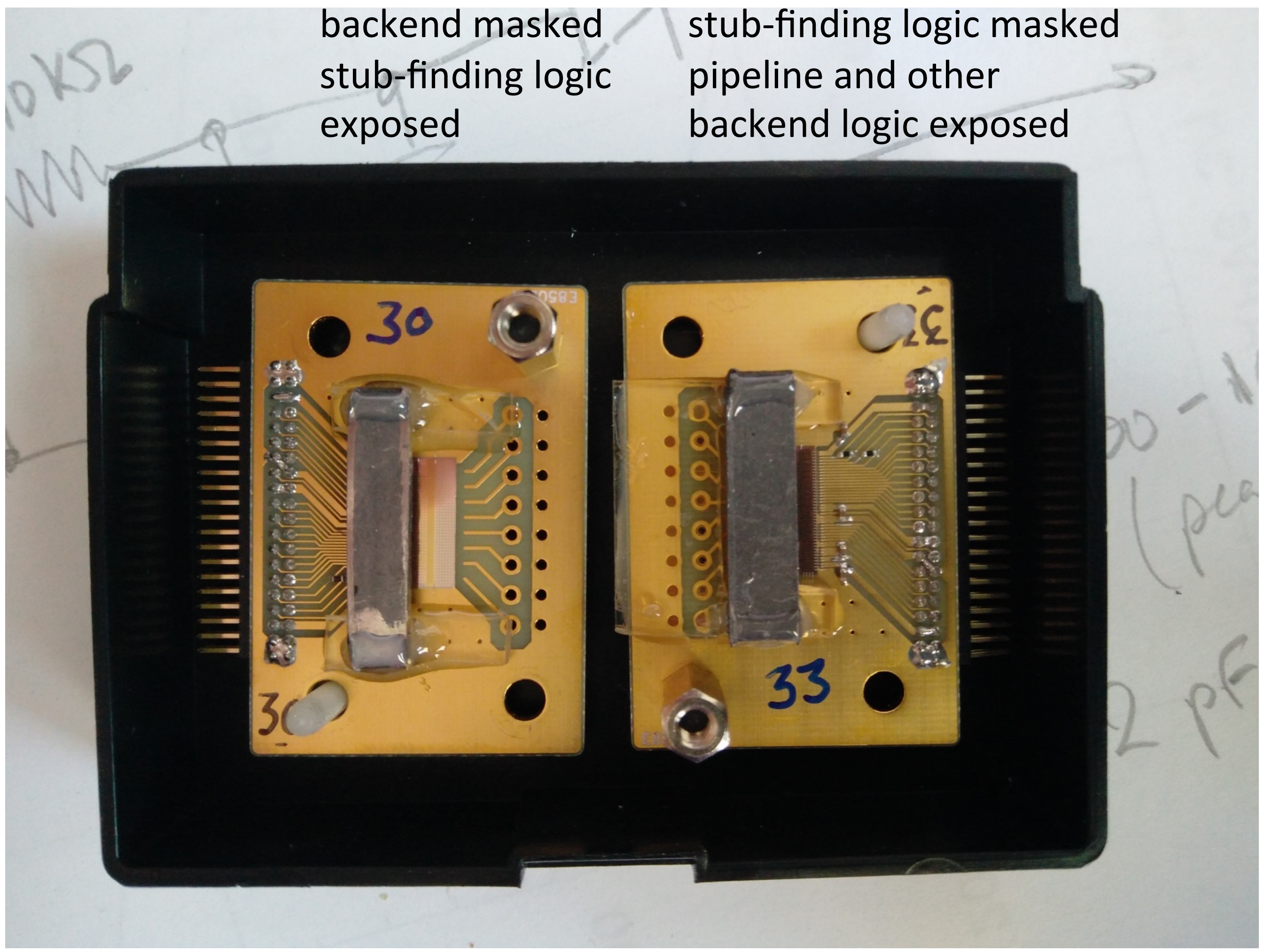
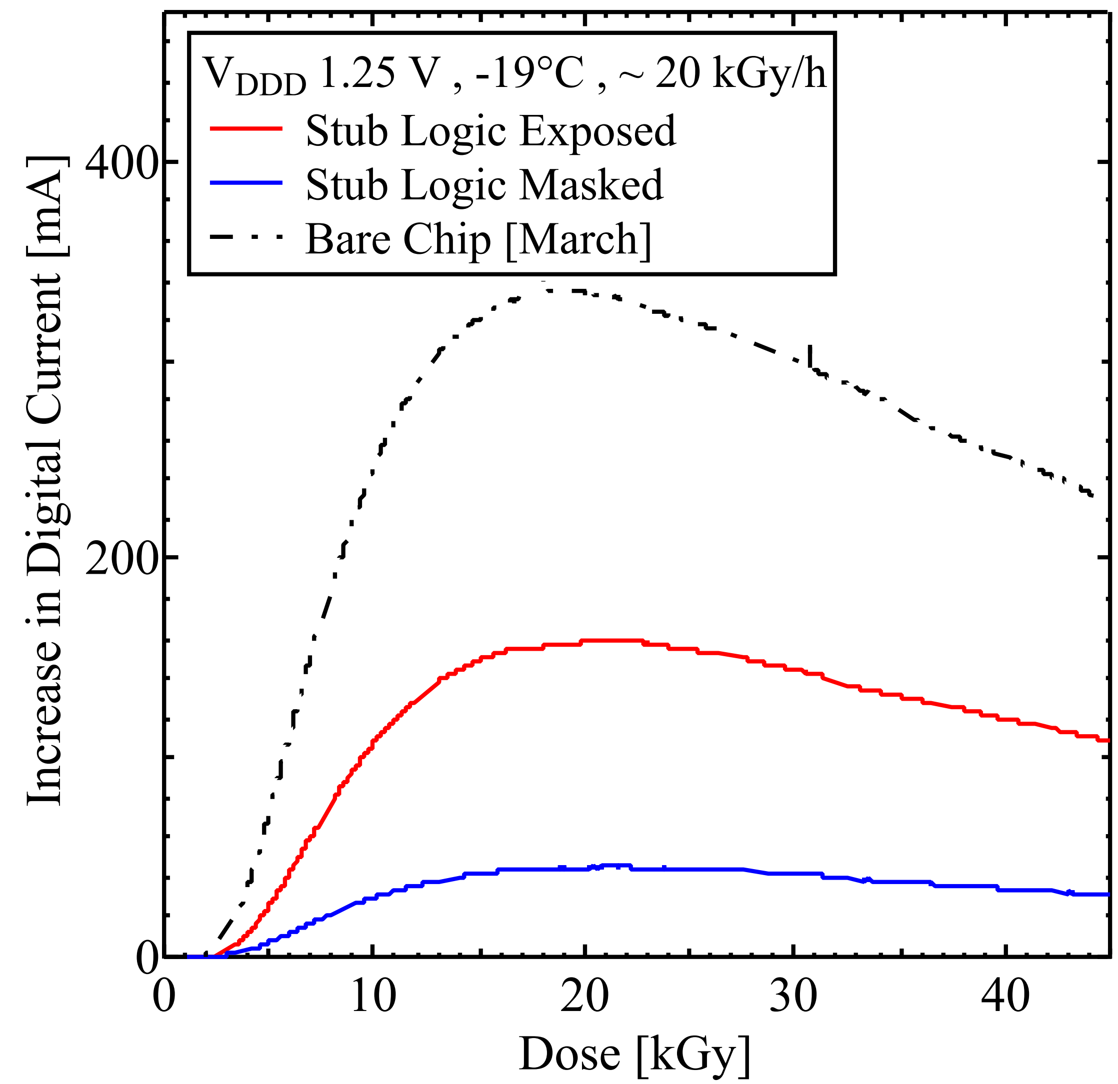
## Isolate source of leakage in the CBC3

- Hypothesis was that leakage is caused by the large number of linear NMOS transistors used in the logic of the CBC3
    - 2 chips irradiated ( different masks ) at -19°C and 20 kGy/h

**chip 30**
backend masked
stub-finding logic exposed

**chip 33**
stub-finding logic masked
pipeline and other backend logic exposed




- Results consistent with hypothesis!

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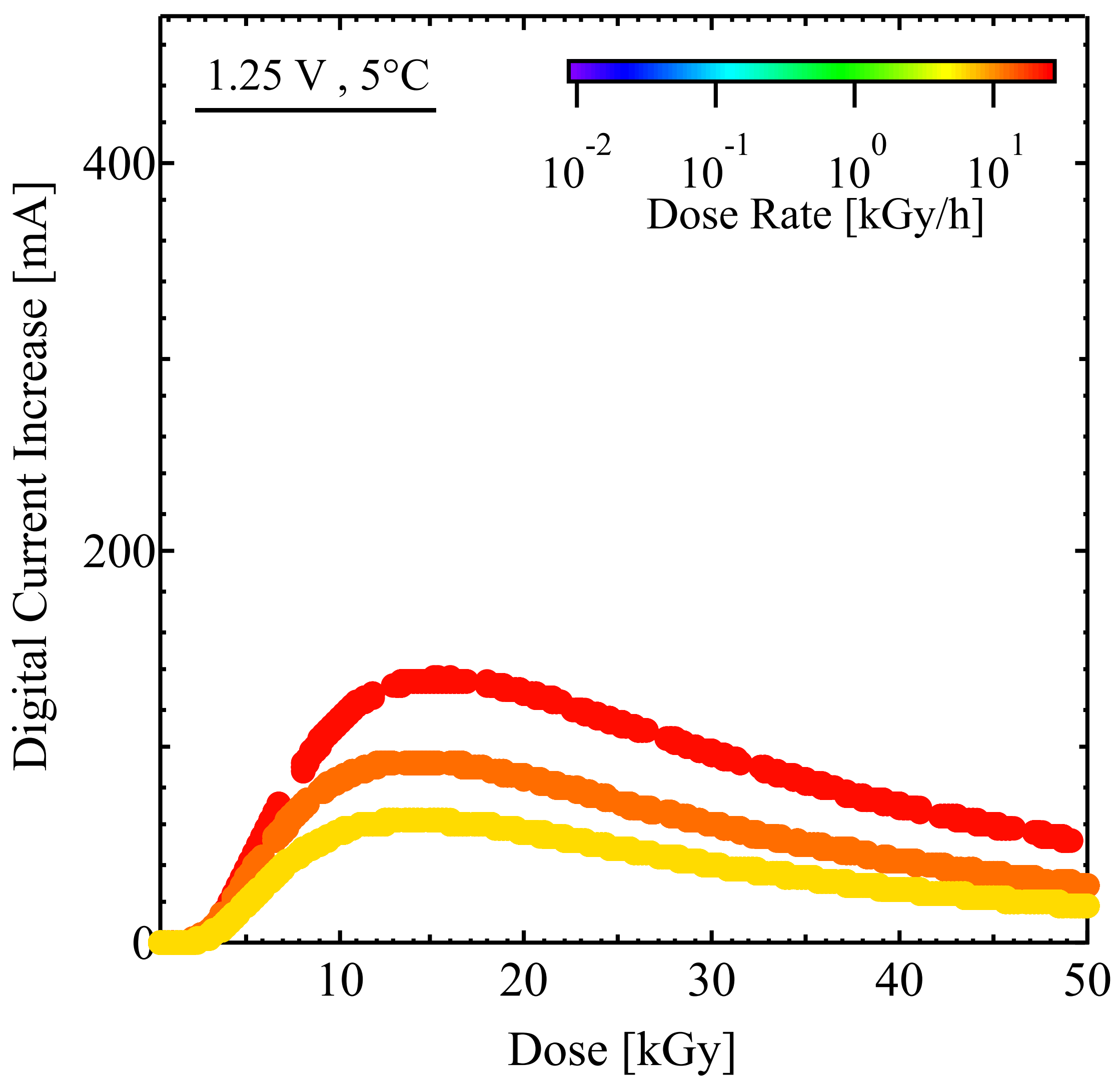
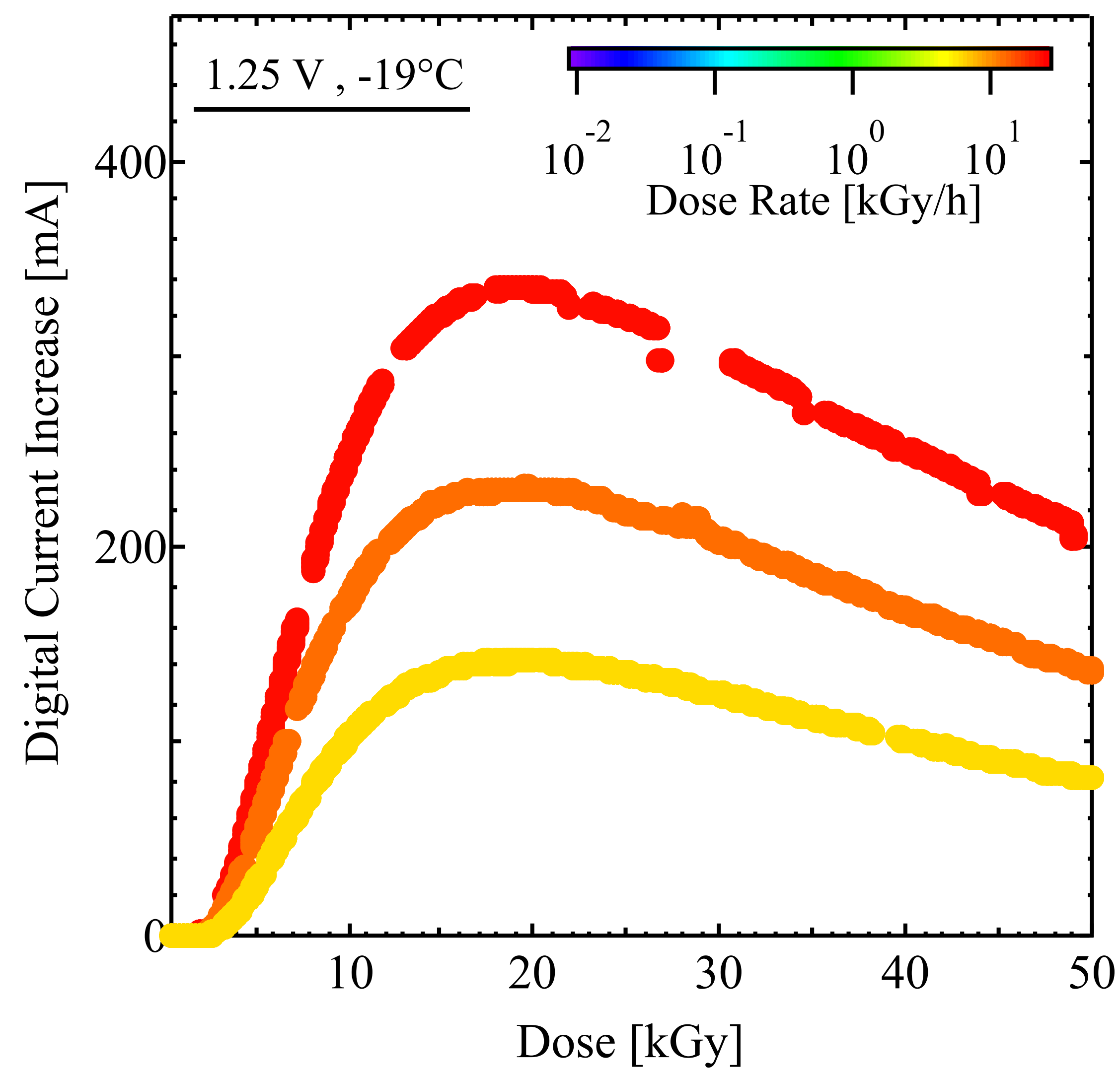
## Dose rate scan at +5°C and 1.25 V

- Explored parameter space extended by repeating the dose rate scan performed over Easter at a higher temperature
  - 4 chips irradiated at +5°C

5°C Dose rate scan




-19°C Dose rate scan

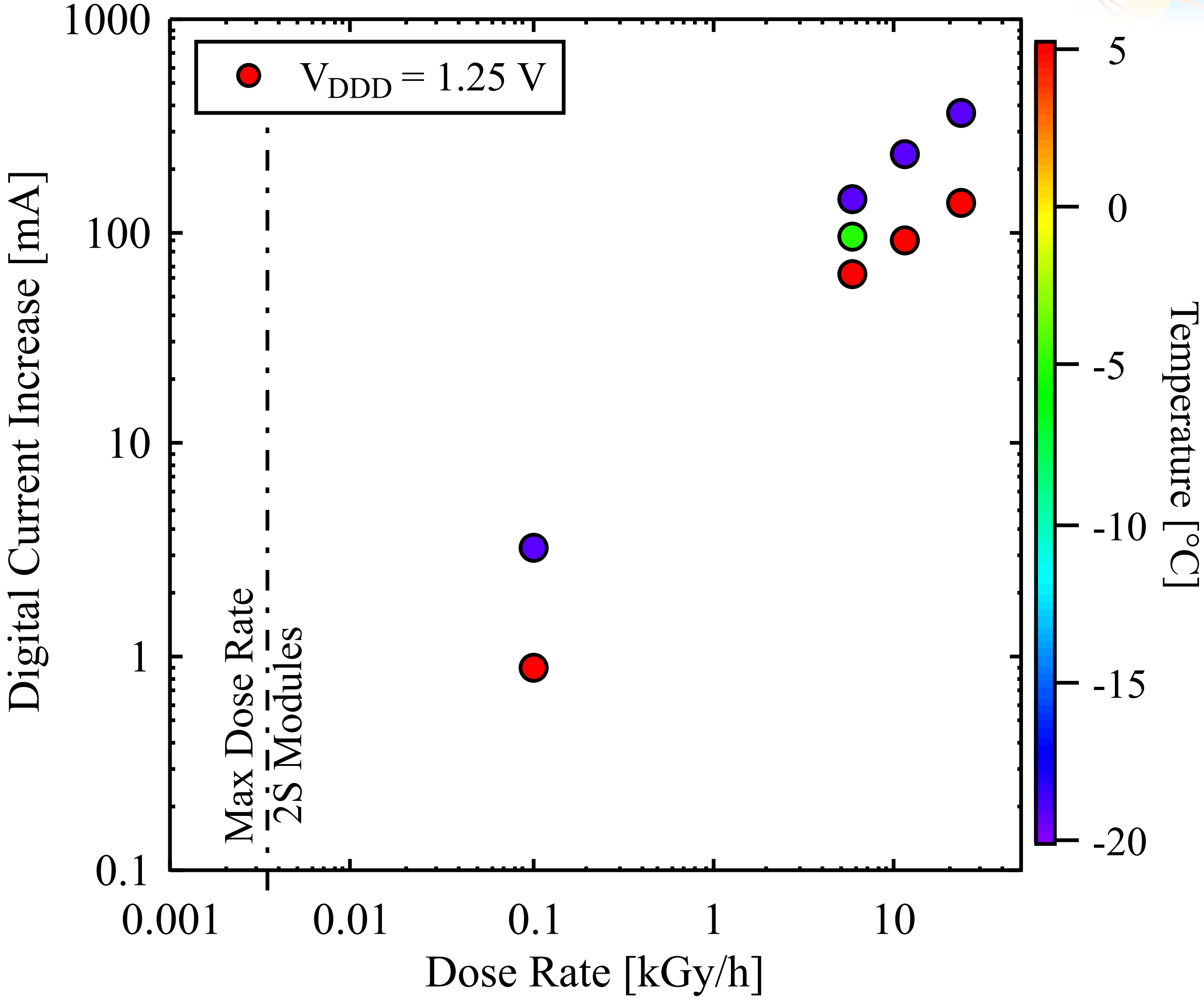



- Dose rate dependance and temperature dependance as expected

# Wrap-up : CBC3 X-ray Irradiation

Summary of CBC3 irradiation @ 1.25 V using CERN X-ray facility

- Measured (maximum) increase in current consumption on the power rail supplying $V_{DDD}$ to the CBC3 during exposure to X-rays at :
  - maximum expected CBC3 bias
  - 4 dose rates at two temperatures
  - 3 temperatures at fixed dose rate



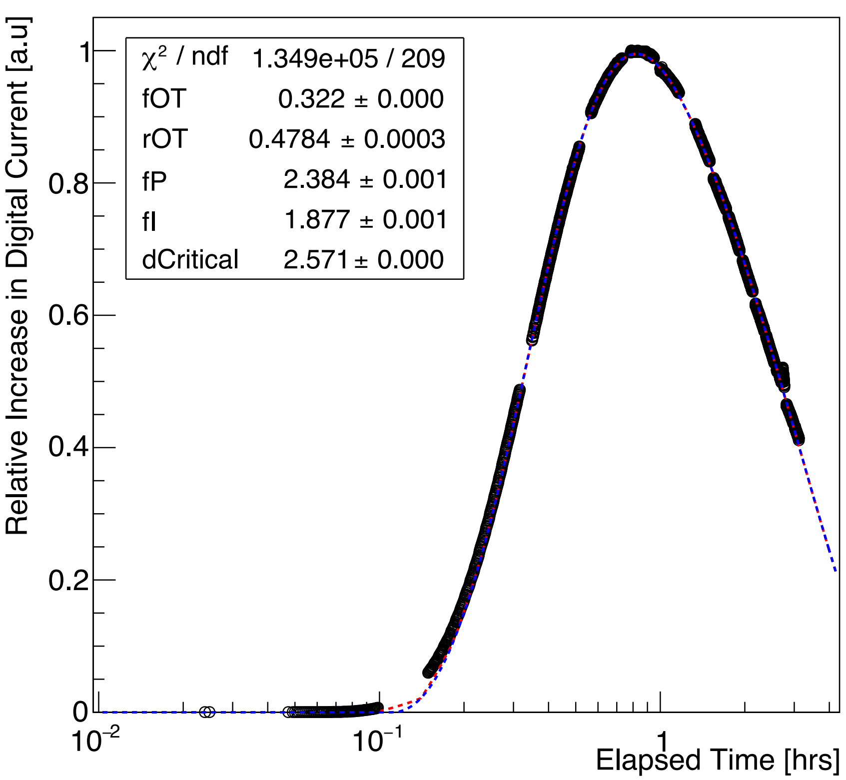

- Enough information collected to place a (conservative) upper limit on the expected magnitude of the current increase in a 2S module under HL-LHC operating conditions.
  - accomplished by fitting a mathematical model to the measured increase in current
  - model based on known radiation damage effects in CMOS (build up of fixed positive charge in the STI + creation of interface traps along the Si-SiO2 interface )
    - extension of ATLAS FeI4 damage model

# Wrap-up : CBC3 X-ray Irradiation

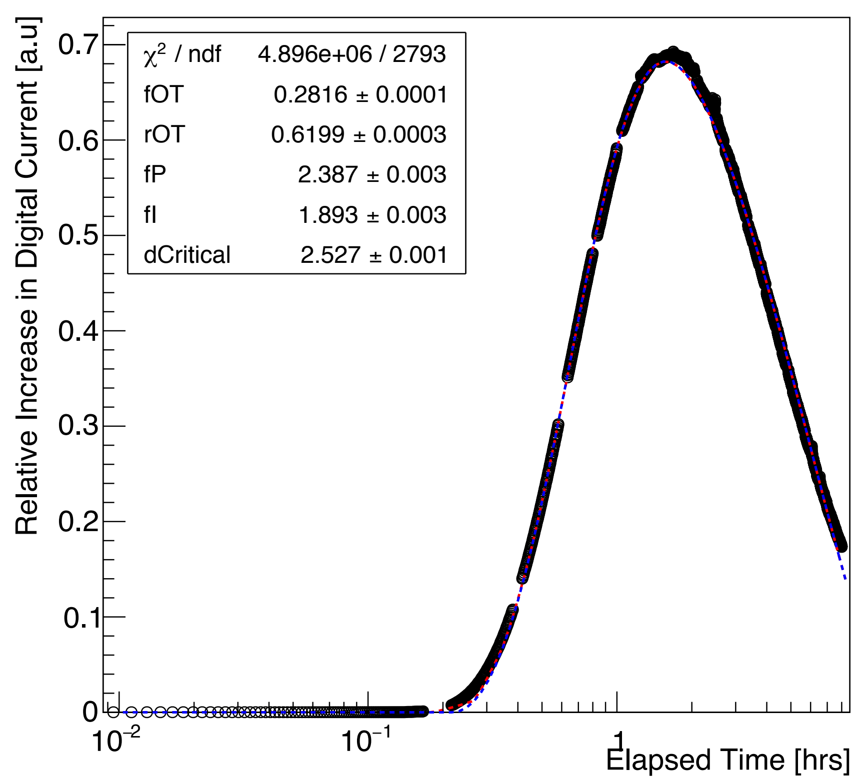
## Results of fit to individual chips ( -19°C )

- Modified damage model used to fit current increase for all chips irradiated at -19°C
  - can see that already with the individual fits that parameters related to the production of interface traps are not dependant on dose rate ( consistent across all chips )

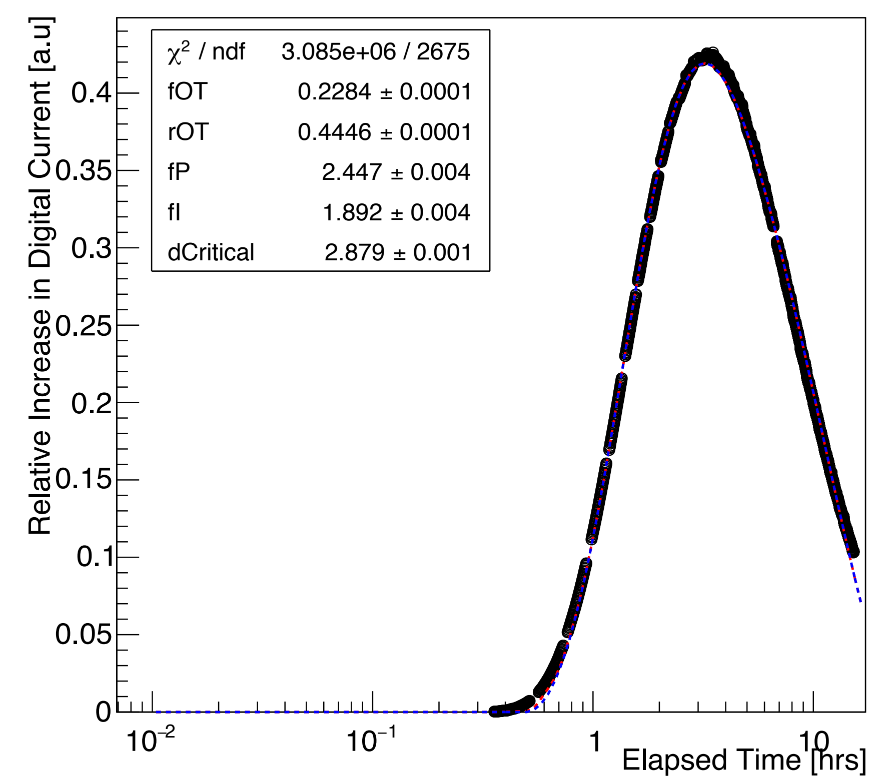
Chip7 : 23.000 kGy/hr




Chip8 : 11.600 kGy/hr




Chip4 : 5.800 kGy/hr

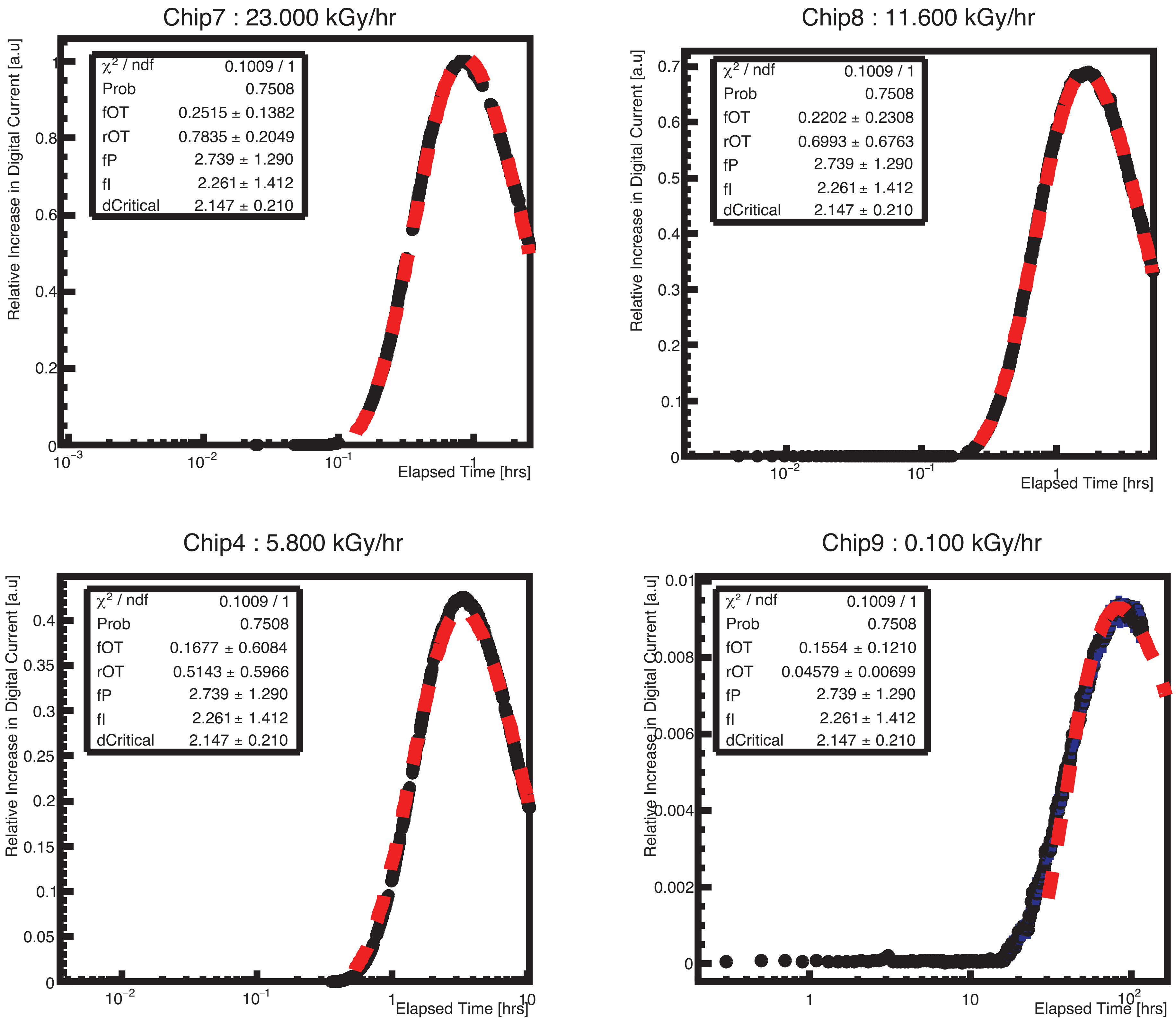



- Next step is to try and fit all chips simultaneously, keeping parameters related to interface trap production fixed.

# Wrap-up : CBC3 X-ray Irradiation

## Results of combined fit to CBC3 data ( -19°C )

- Modified minimization function used to simultaneously fit current increase for all chips irradiated at -19°C



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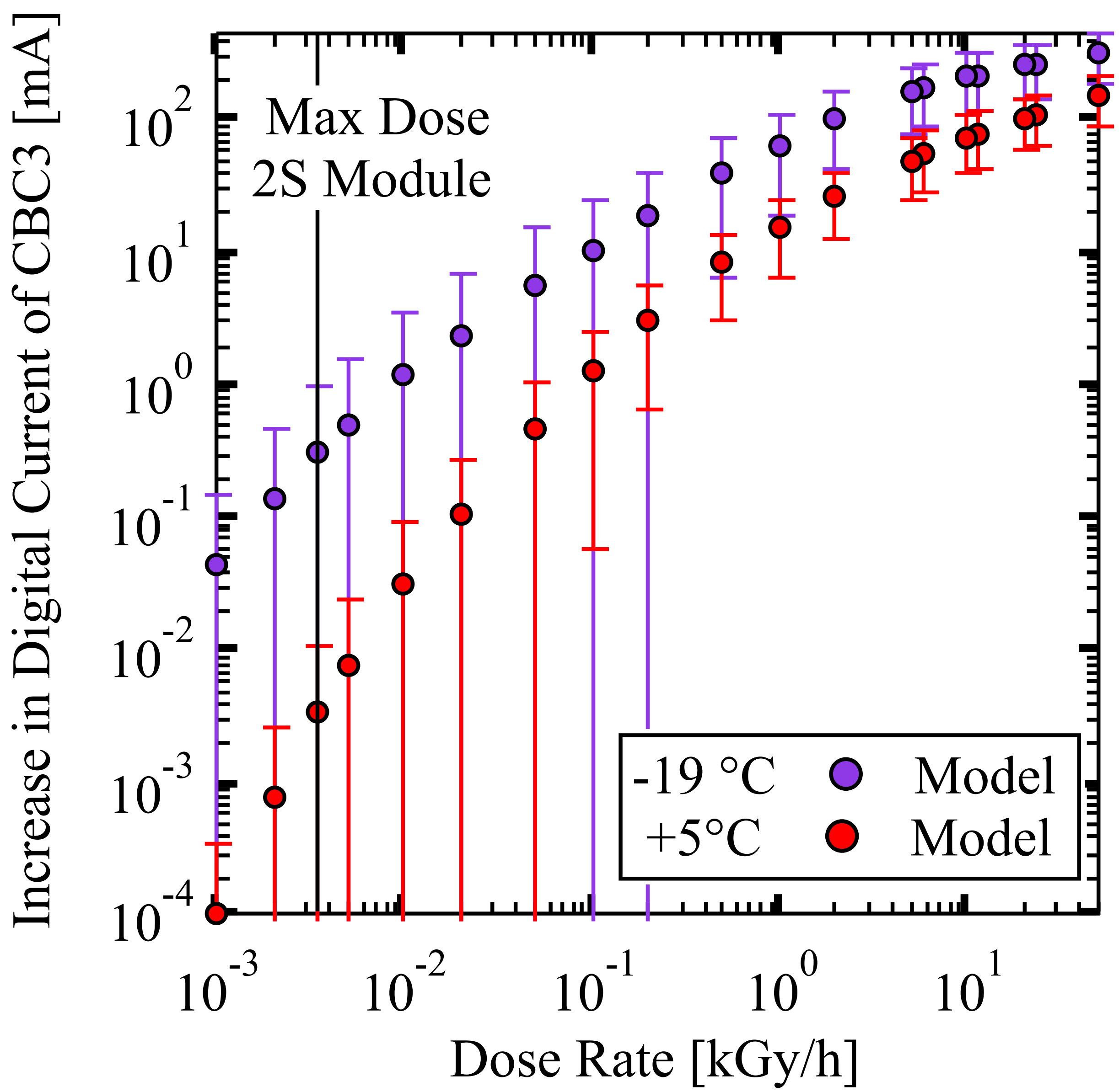
## Predicted increase in current consumption of CBC3

- Know that lowest expected temperature on the 2S modules is ~ -15°C
  - measured that the current increases with decreasing temperature
  - can use results from irradiations at -19°C and 5°C to set bounds on the expected increase per CBC for a 2S module

Predicted increase in digital current

( upper limit from fits to measurements performed at 23, 11.6 , 5.8 , 0.1 kGy/h )




$$\Delta I_{+5^\circ} < \Delta I_{expected} < \Delta I_{-19^\circ}$$

$$0.01 \text{ mA} < \Delta I_{expected} < 0.99 \text{ mA}$$

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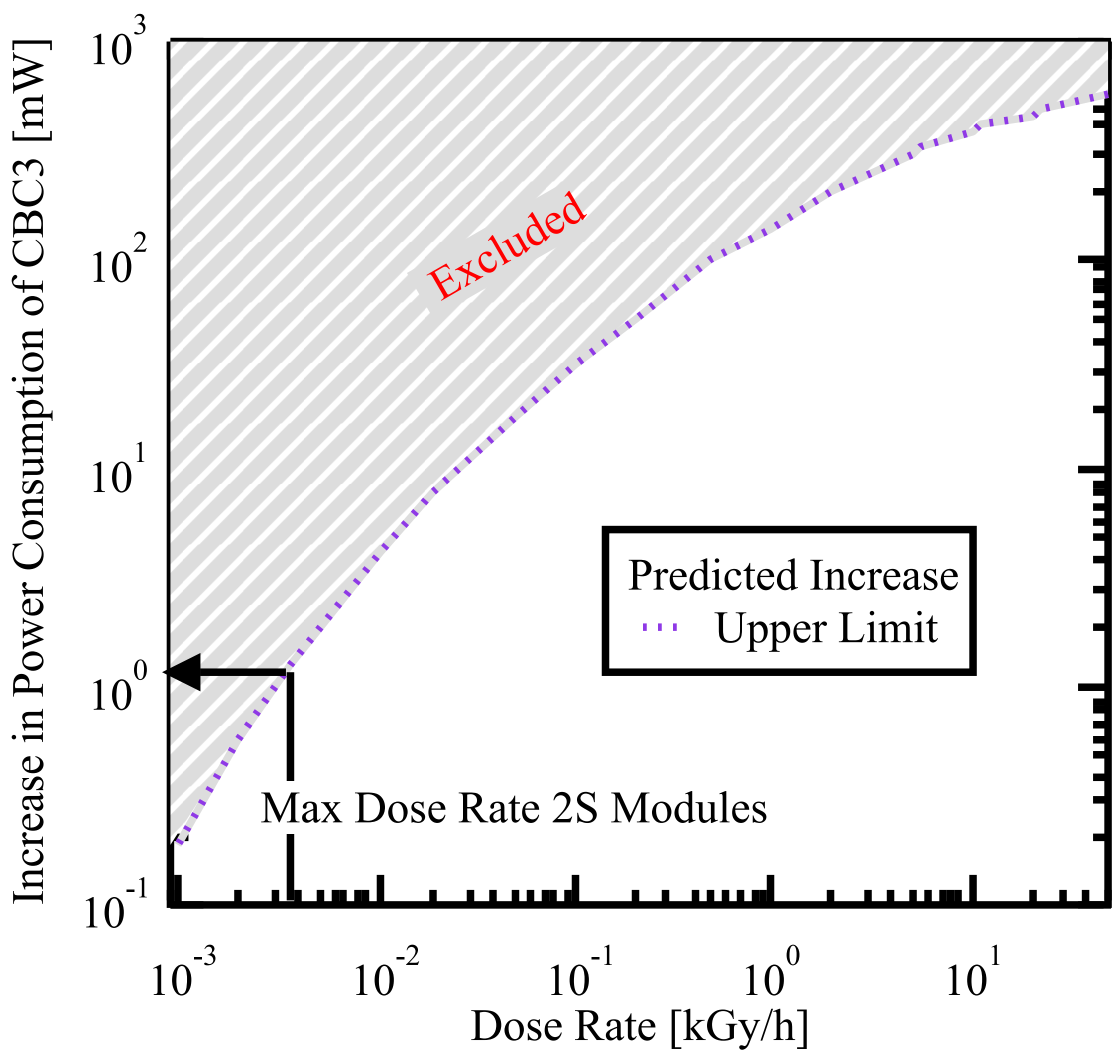
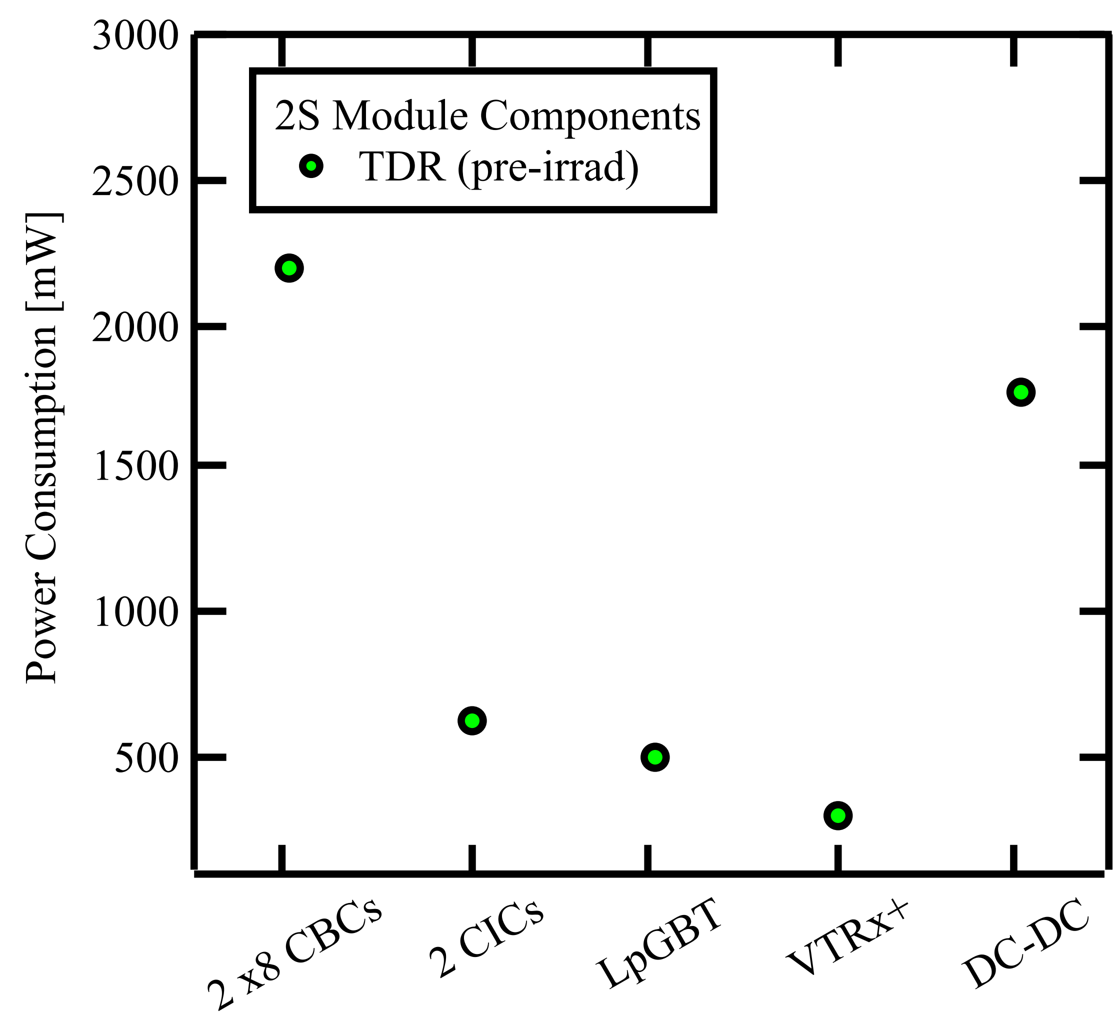
## Impact on power consumption of 2S Modules

- Want to understand the effect the expected current increase due to damage from ionizing radiation will have on the power consumption of a single 2S module
  - max. expected current increase in CBCs would increase power consumption of a 2S module by ***approximately 20 mW*** ( x16 CBCs per 2S module )
    - corresponds to a ***0.4 % increase in power consumption per module***
      - 0.5 % increase if DC-DC converter is not considered

Prediction from model




Pre-irrad estimate from TDR



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## Conclusions and Future Work

- Qualification of CBC3 (TID) for HL-LHC levels completed in first half of 2017
  - confident that current increase measured in accelerated conditions using the CERN X-ray irradiation facility represents a worst-case scenario
  - expected increase on power consumption of a single 2S module due to leakage in CBC3 expected to be < 1%
- Radiation damage model used to perform extrapolation available on gitlab
- Preparing CMS note with details of irradiation
  - (preliminary) draft available soon.

# Back-up Slides

# CBC3 X-ray Irradiation :

## Fitting increase in current/CBC3

- Want to achieve the best possible fit for 4 curves with very different amplitudes
  - default function to minimize would be the sum of the Chi2 for the 4 curves

$$g = \sum_i \chi_i^2 \qquad \chi_i^2 = \sum_j \frac{(y_j - f(x_j))^2}{\sigma_j^2}$$

  - error (on the measured current) is the same for all 4 data sets, so can see that the value of g would be dominated by the curves with large amplitudes
  - expect the minimizing algorithm to be pretty insensitive to what is going on with the curve at the lowest dose rate.
  - So instead chose to minimize the sum of the residuals of the individual curves

$$G = \sum_i R_i \qquad R_i = \sum_j \frac{|y_j - f(x_j)|}{y_j}$$

  - effectively a normalization.