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Multi level RTS in proton irradiated CMOS image sensors manufactured in deep submicron technology*

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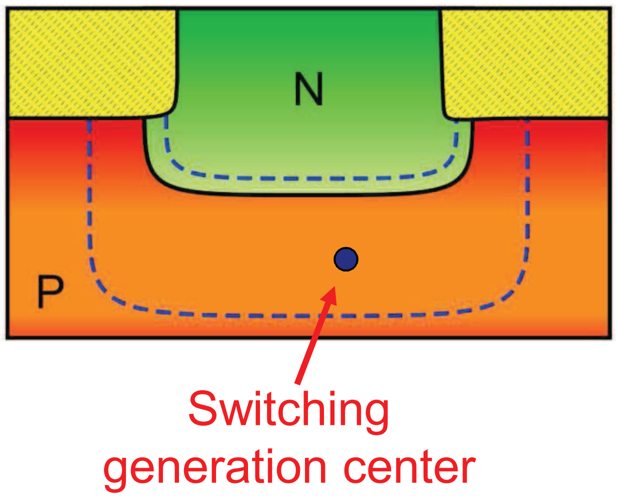
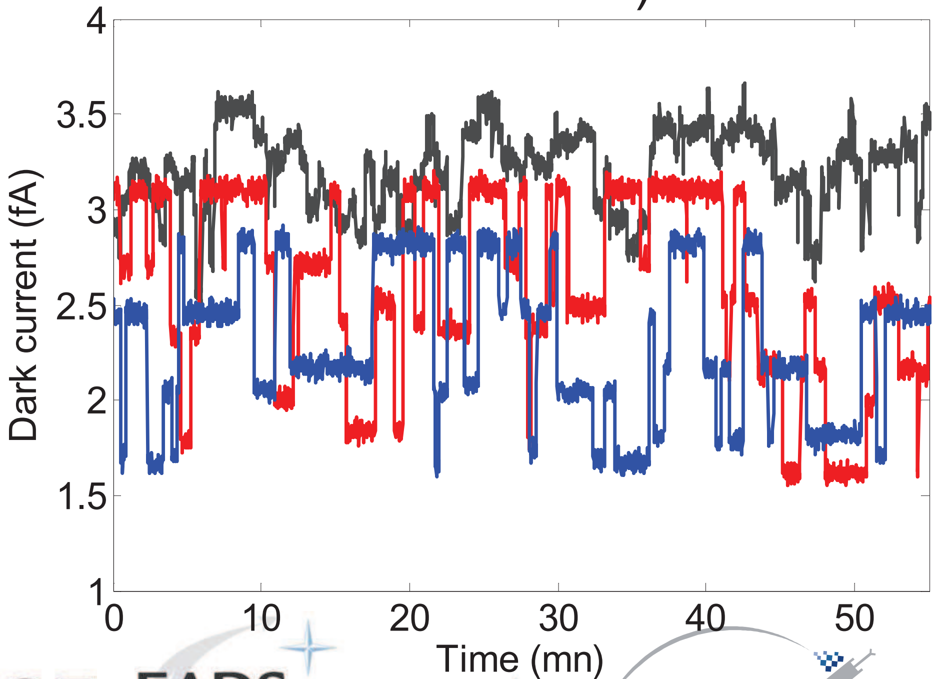
What is NIEL induced RTS? (1)

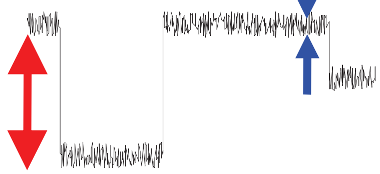
- What is NIEL induced Random Telegraph Signal?
  - Dark current random discrete fluctuation (low frequency)
- What do we know about NIEL induced RTS?
  - Induced by displacement damages only (not ionizing radiation)
  - Due to switching generation centers in the depletion region
  - Temperature activated (amplitudes and time constants)





What is NIEL induced RTS? (2)

- Why is RTS a problem for Image sensors?
  - Source of very intense dark current noise
  - Can be 100 times larger than dark current shot noise
  - Critical for low light level applications
- RTS remaining mysteries :
  - RTS amplitudes
    - much larger than what can generate one single generation center?
    - Electric field enhancement?
  - What is the responsible defect?
  - Can RTS distributions be predicted?



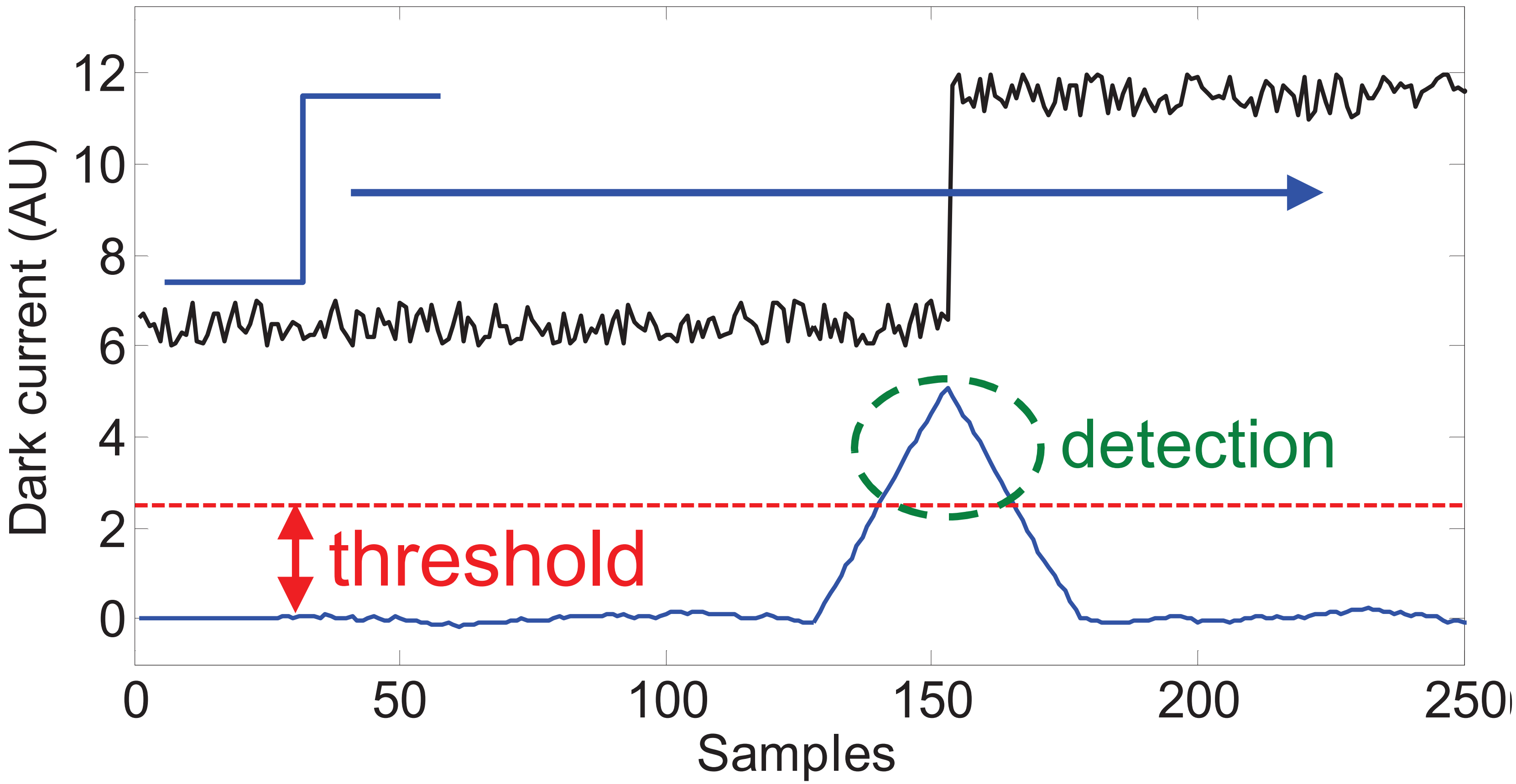
- Studying RTS requires
  - The use of a dedicated detection technique
  - Able to extract RTS parameters
  - The automated scan of an entire array

Talk outline

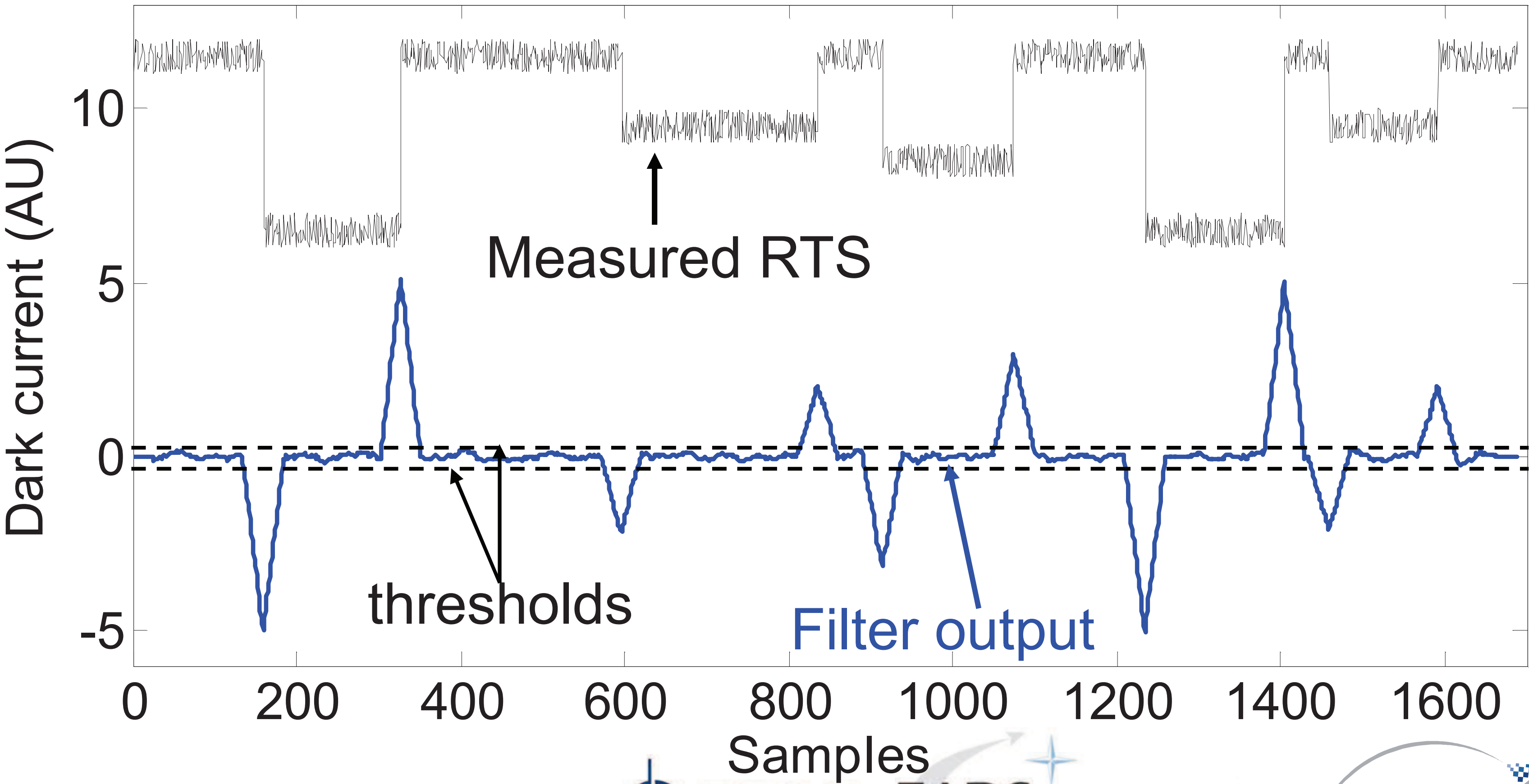
- Proposed RTS detection method
  - Detection principle
  - Parameter extraction principle
  - Illustration
- Proposed technique first results
  - Experimental details
  - RTS amplitude distribution
  - Photodiode bias effects on RTS
- Conclusions and perspectives

Proposed method principle (1)

- Detection principle :
  - Based on a classical edge detection technique
  - Convolution of a digital step shaped filter and the signal

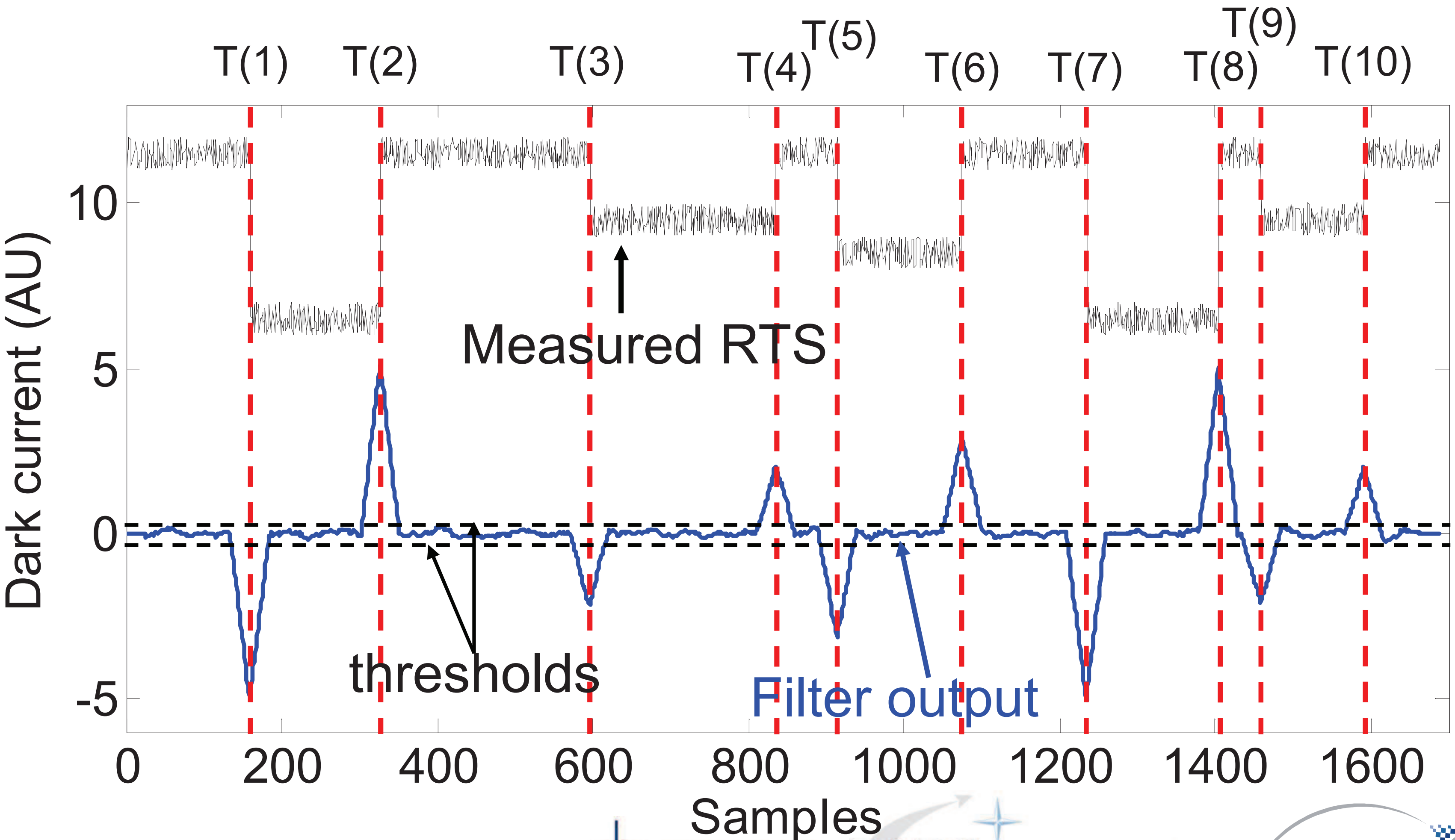


Proposed method principle (2)



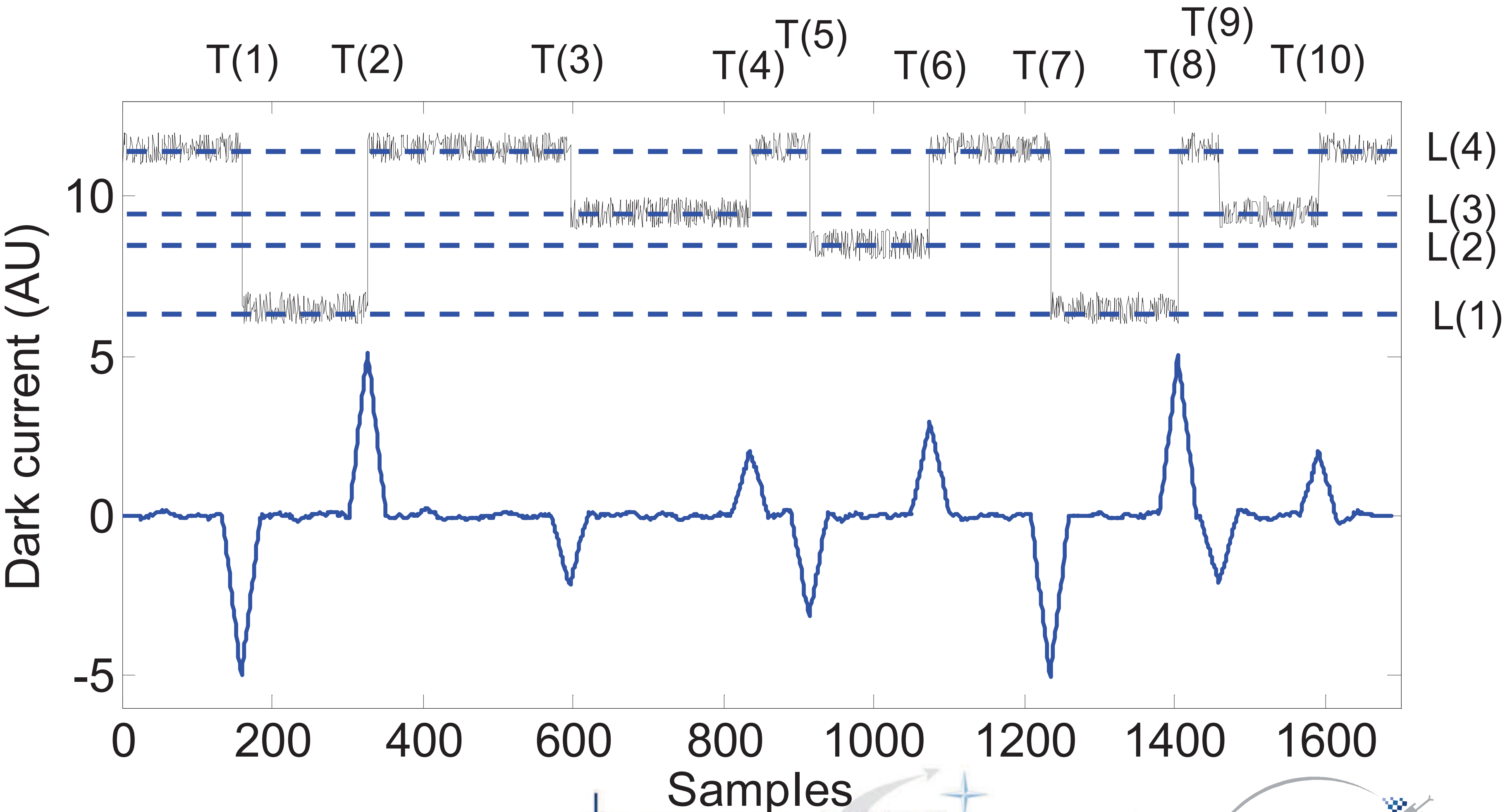
Proposed method principle (2)

- Transition time index extraction



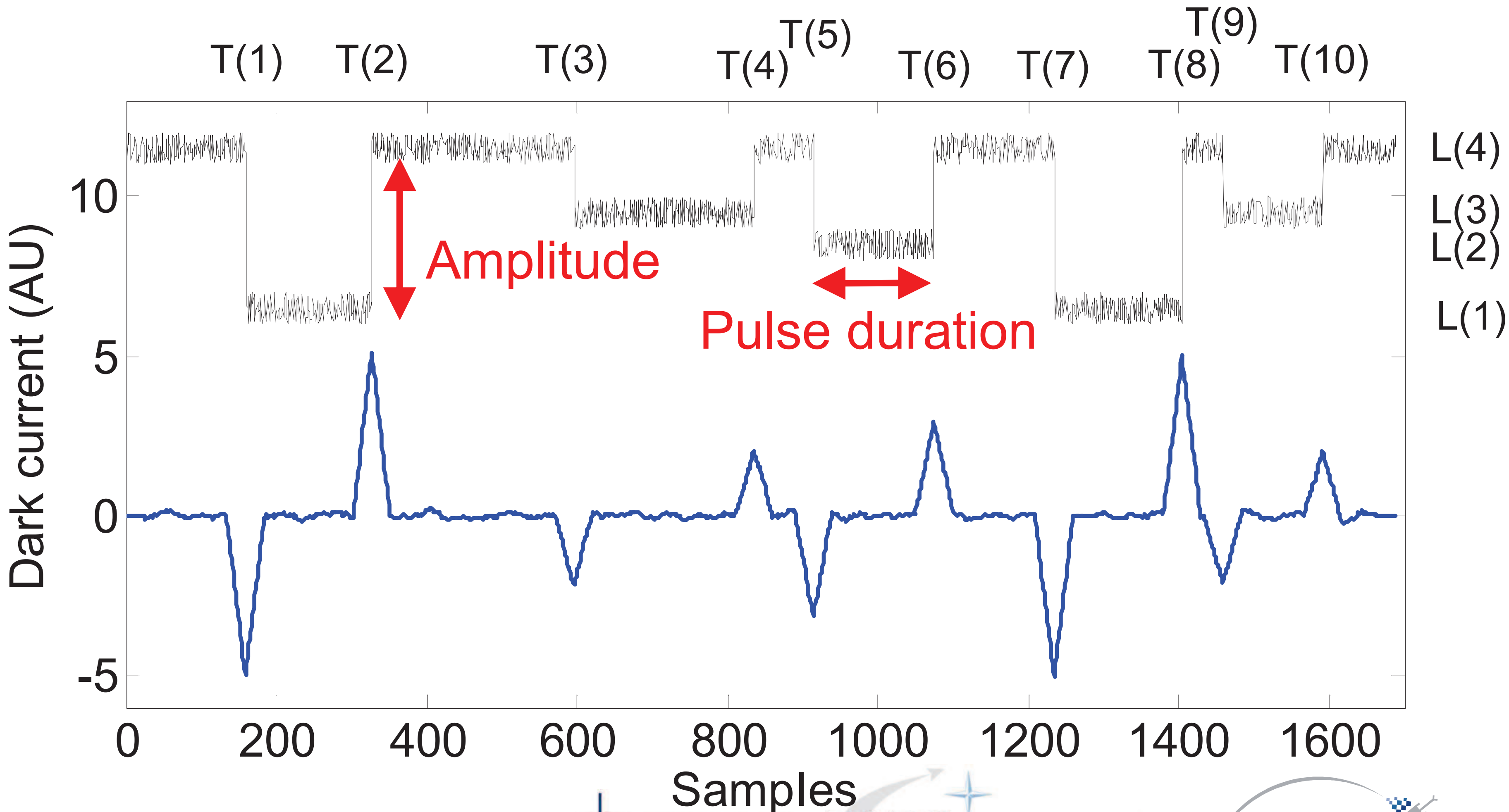
Proposed method principle (2)

- Transition time index extraction
- Level value extraction



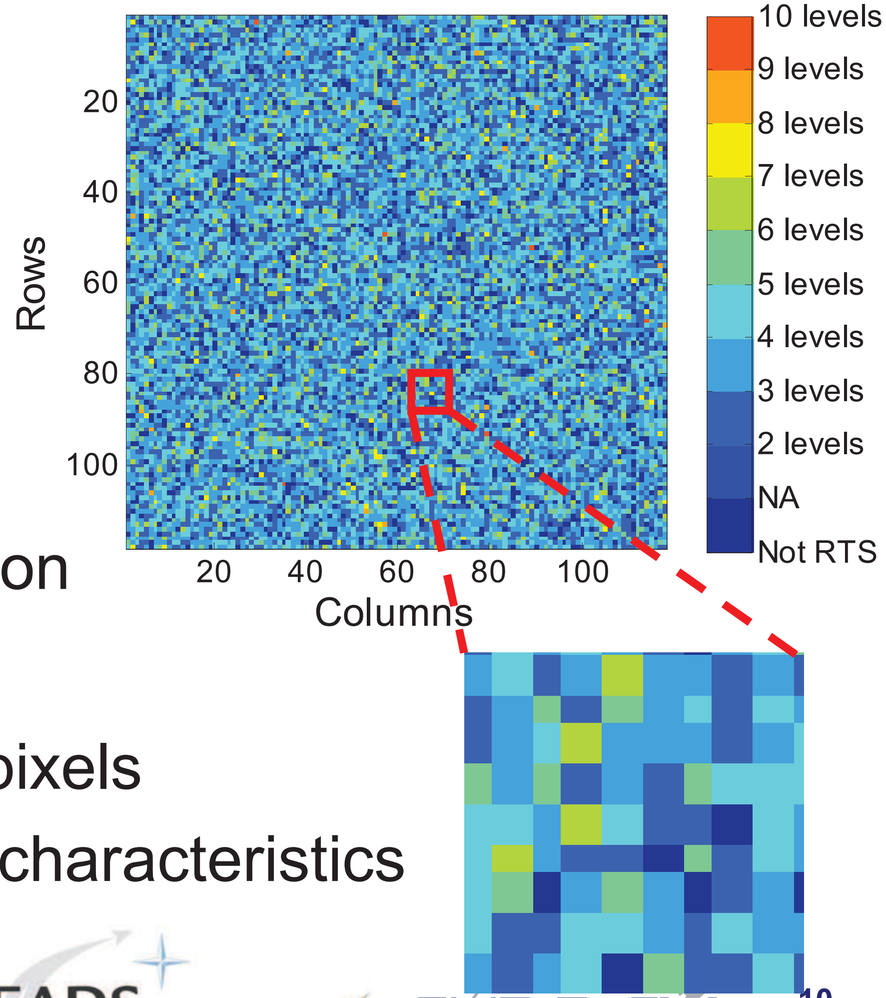
Proposed method principle (2)

- Transition time index extraction
- Level value extraction

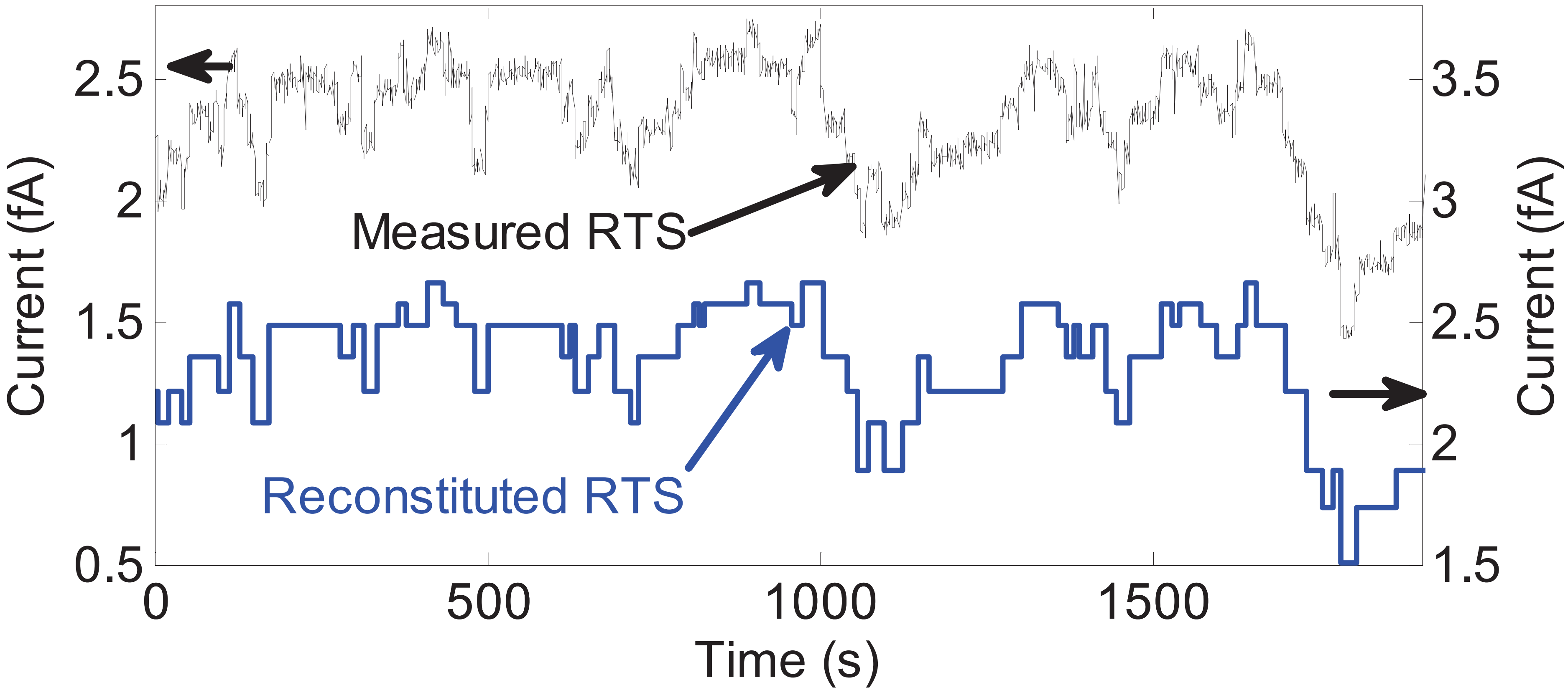


Proposed method feature

- This automated process yields:
  - Levels L(i):
    - RTS maximum amplitude
    - Inter level amplitude
    - Number of levels
  - Transition time index T(i):
    - Level time constant
    - Mean time before a transition
- Applied to a whole array
  - Automated detection of RTS pixels
  - Automated extraction of RTS characteristics



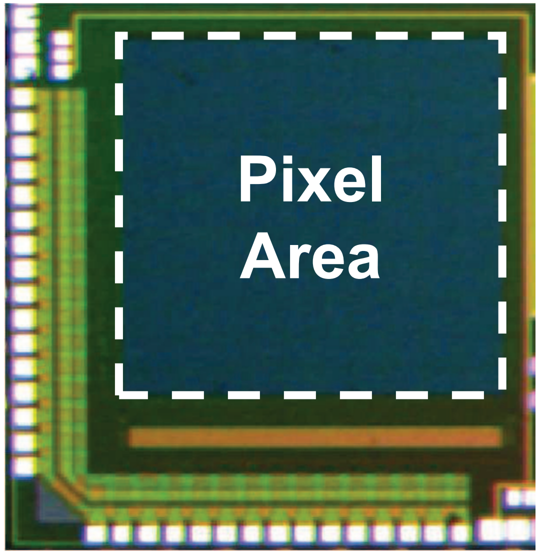
Result illustration



- All the level are recognized
- Most of the transition are detected

Experimental details

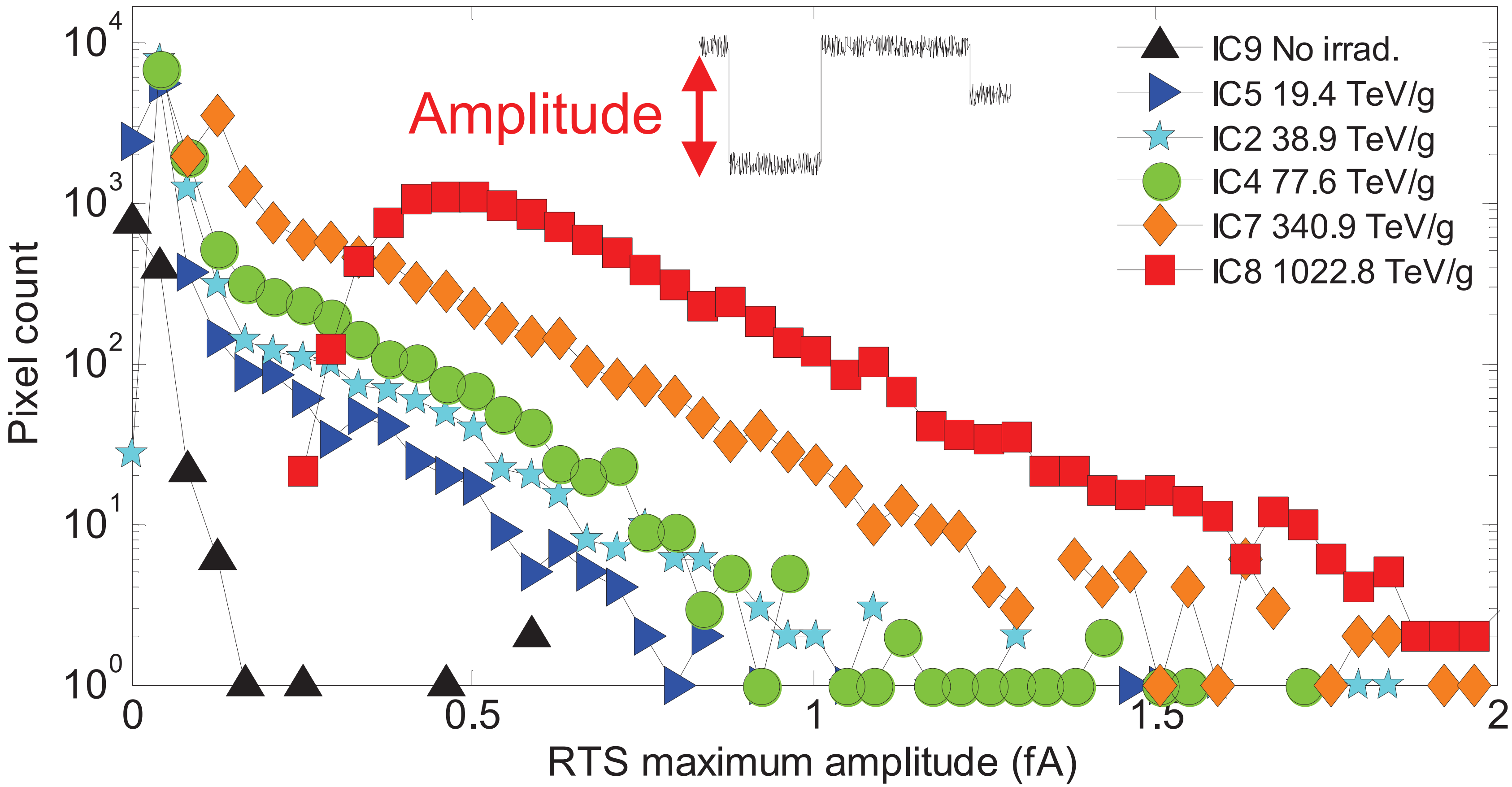
- Test device
  - Custom 128 x128 pixel array
  - Standard 3T pixel design
  - UMC CIS 0.18 µm CMOS process
  - Technology dedicated to imaging



- Proton irradiation
  - Facilities : KVI, Isotron, UCL
  - Room temperature
  - Energies : from 7.4 to 184 MeV
  - Fluences : from 5×10^{9} to 3×10^{11} H^{+}/cm^{2}
  - Displacement damage dose : from 31.6 to 1022 TeV/g

RTS amplitude distribution (1)

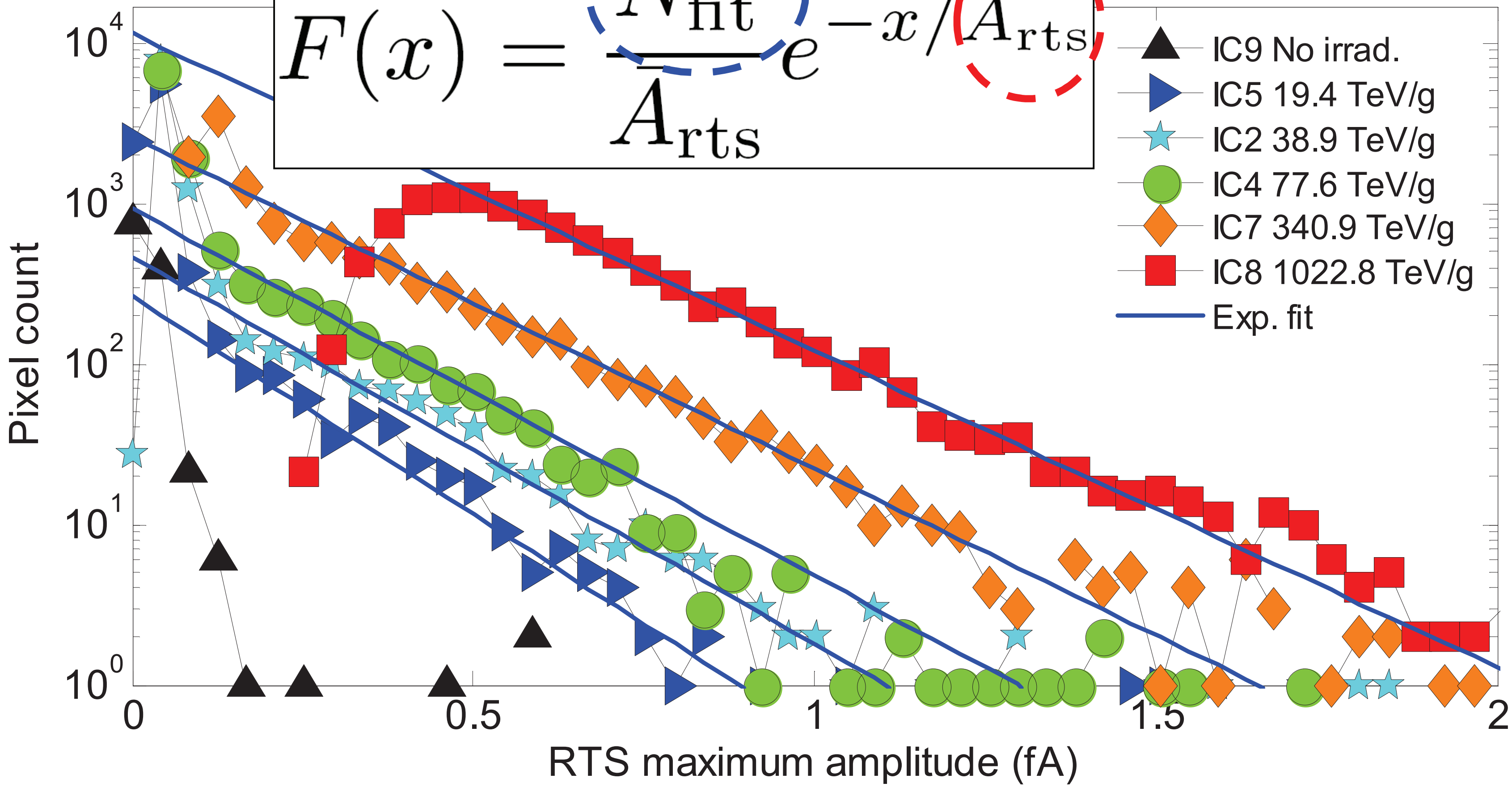
- Large amplitude RTS are exponentially distributed



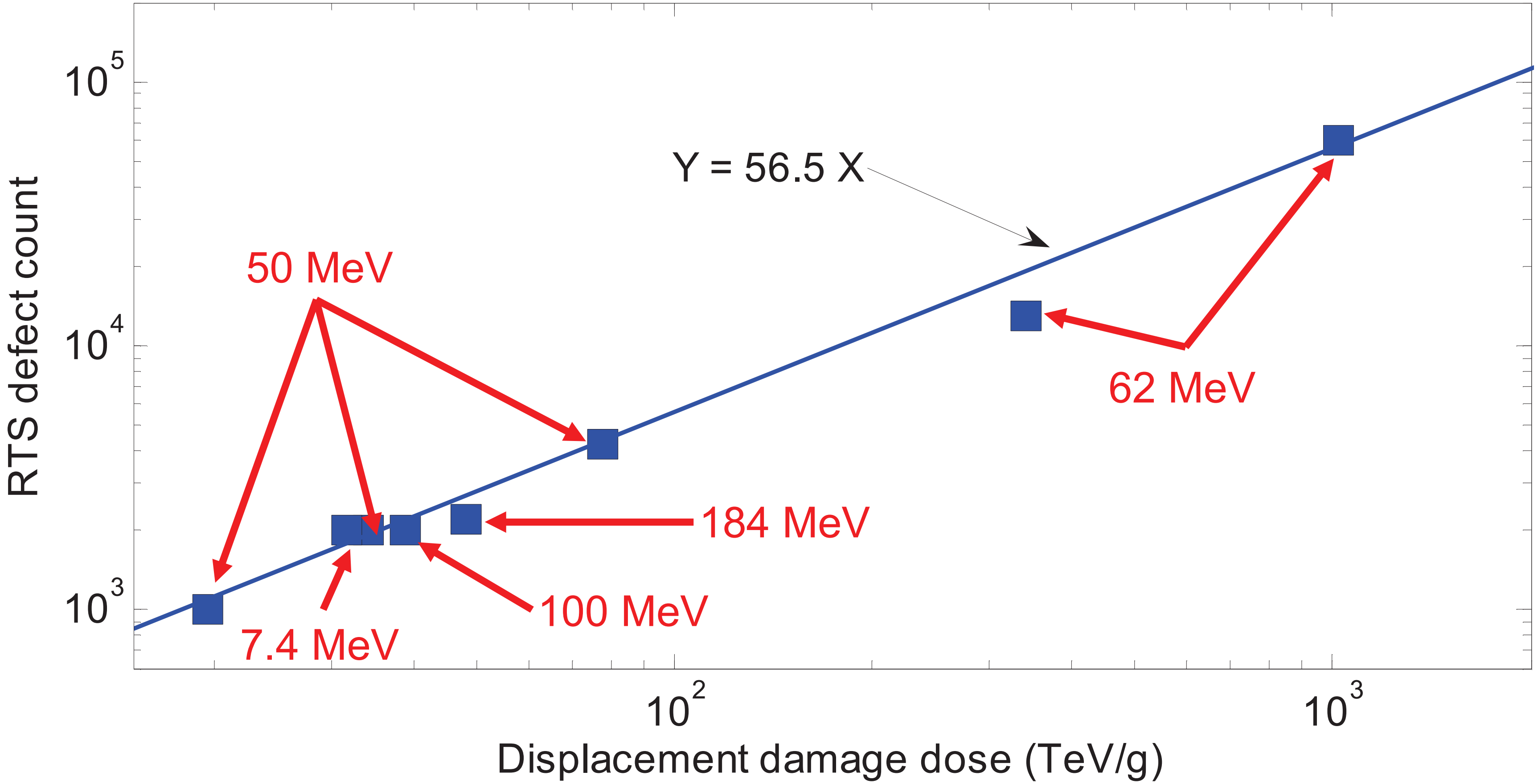
RTS amplitude distribution (2)

- No significant change in slope with irradiation
- A constant average amplitude exist: A_{RTS}=0.19 +/- 0.03 fA

$$F(x) = \frac{N_{\text{fit}}}{\bar{A}_{\text{rts}}} e^{-x/\bar{A}_{\text{rts}}}$$



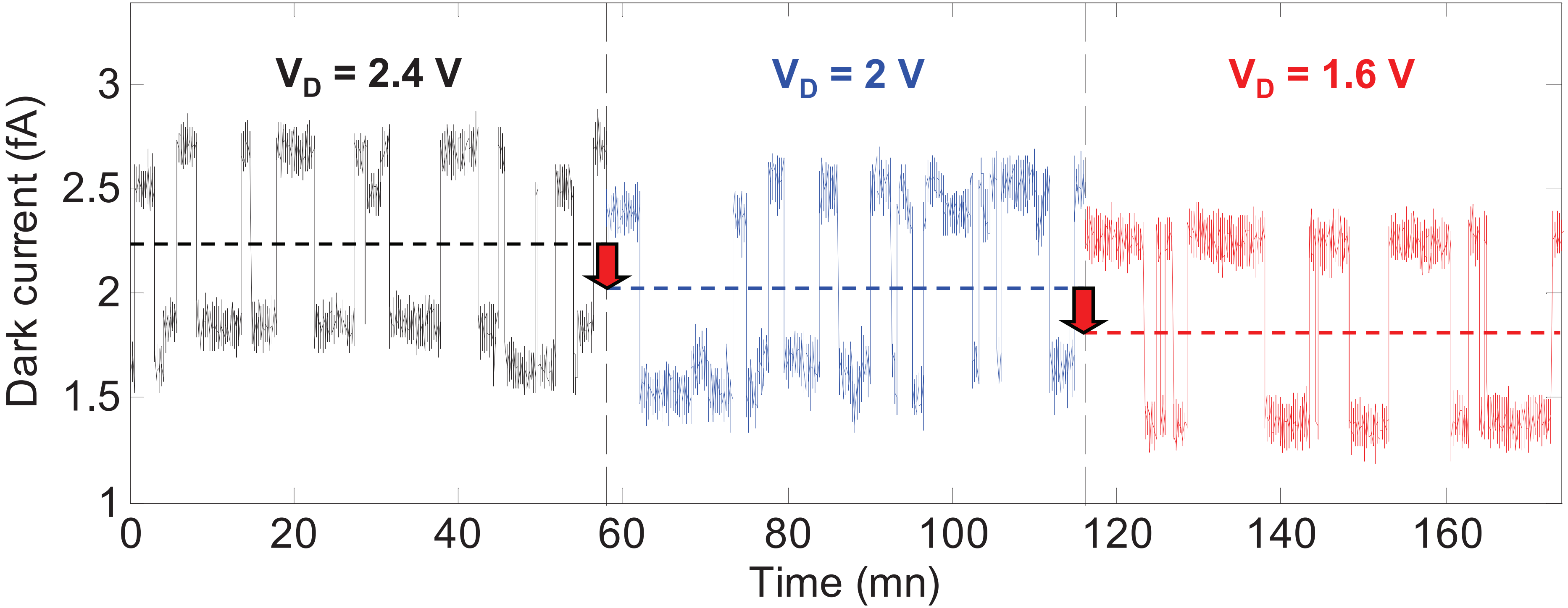
RTS defect counting



- The number RTS defects increases linearly with displacement damage dose (whatever the proton energy)

The number of RTS defects scales with total NIEL

Photodiode bias effects (1)

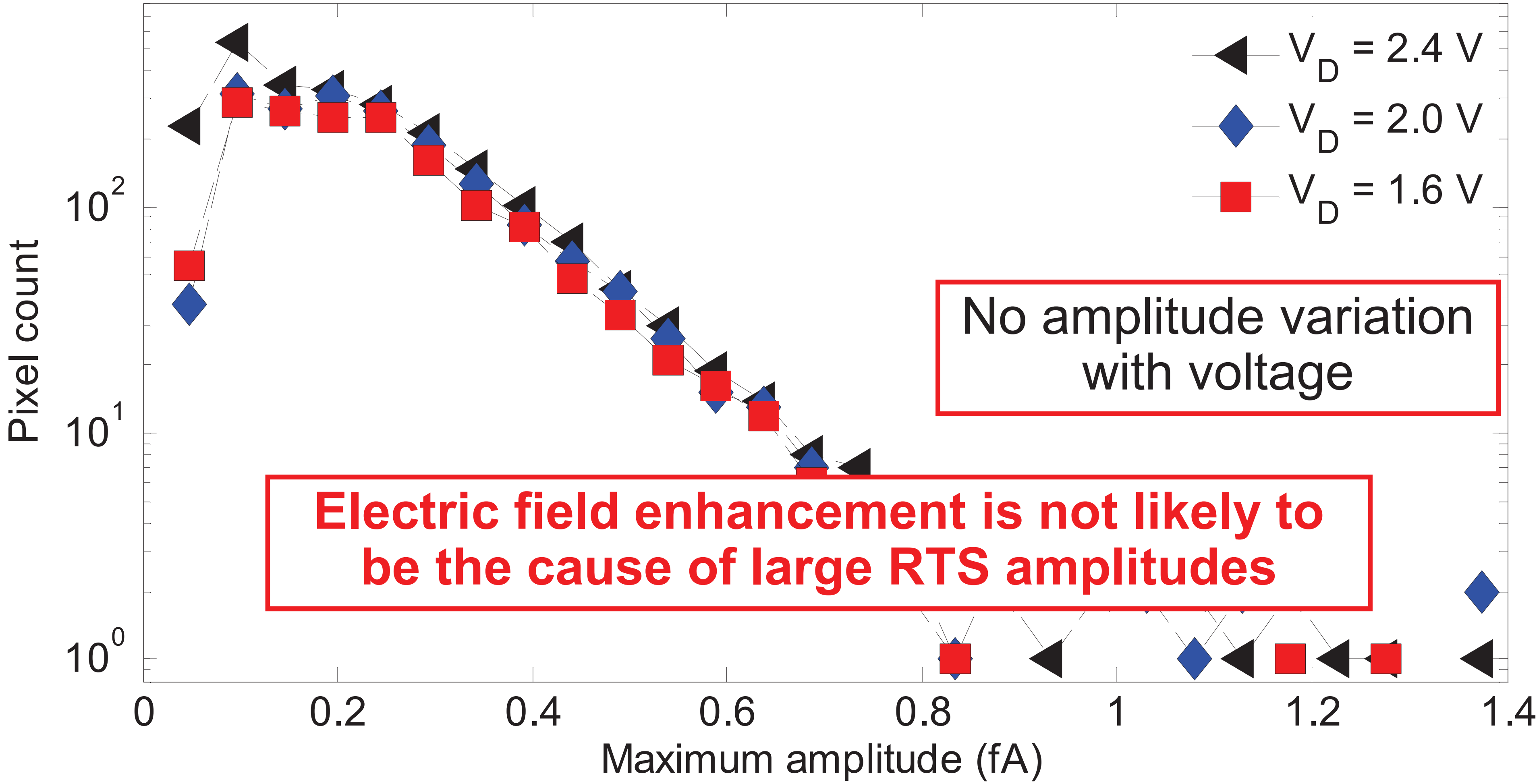


- Mean dark current decreases with voltage
  - Due to depletion width reduction
- No amplitude variation with voltage

No sign of electric field enhancement

Photodiode bias effects (2)

- The same trend is observed on the whole RTS population



Conclusions and perspectives

- We have proposed a new RTS detection method
  - Based on a classical edge detection technique
  - Able to automatically extract multi level RTS parameters
- First results indicate that:
  - Large RTS amplitudes are exponentially distributed
    - A universal mean RTS amplitude exists : ~0.19 fA
    - The number of RTS defects scales with total NIEL
    - RTS distributions can be predicted
  - Electric field enhancement can not explain RTS amplitudes
- Future work
  - Explore the alternative explanation for RTS amplitudes
    - inter center charge transfer?
  - Use of lower fluences and larger arrays to confirm these results with better statistics
  - Study of time constants (inter transition time constant)

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