A New High-Speed, Single Photon Imaging CCD for the Optical

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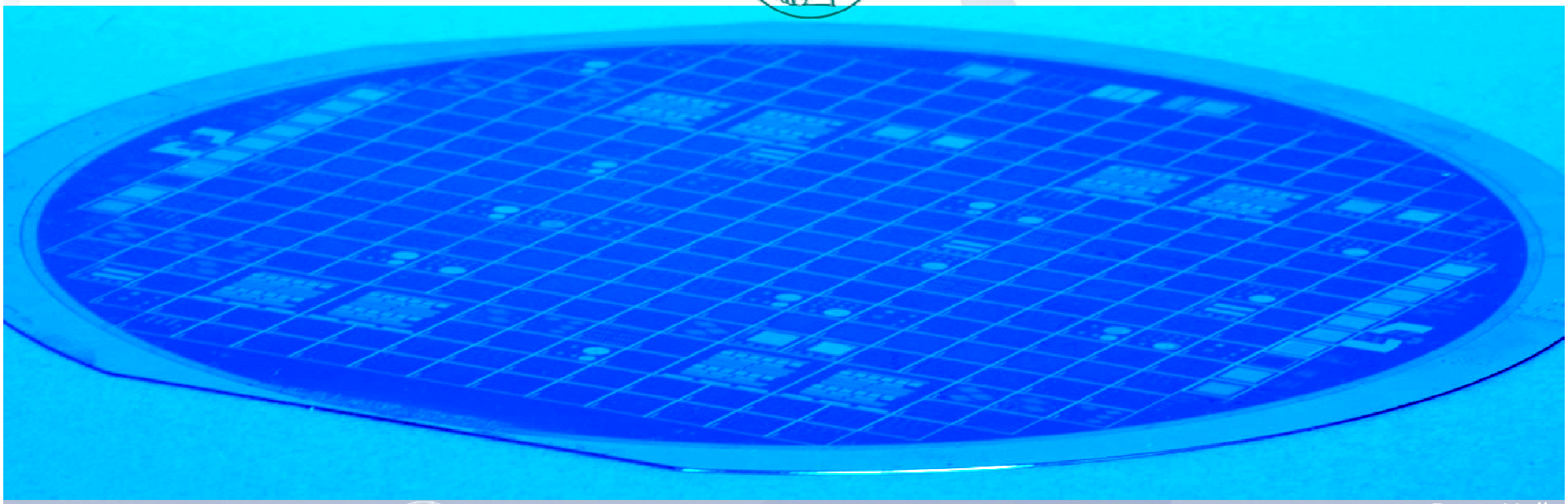


Outline

- Introduction:
  - Motivation
  - Principle of a Single Photon Imaging CCD
- Approach / Components
  - New low noise pnCCD
  - Entrance window for optical light
  - Back illuminated avalanche diodes
  - Avalanche readout test circuit
- Project Status, Summary and Outlook

Motivations

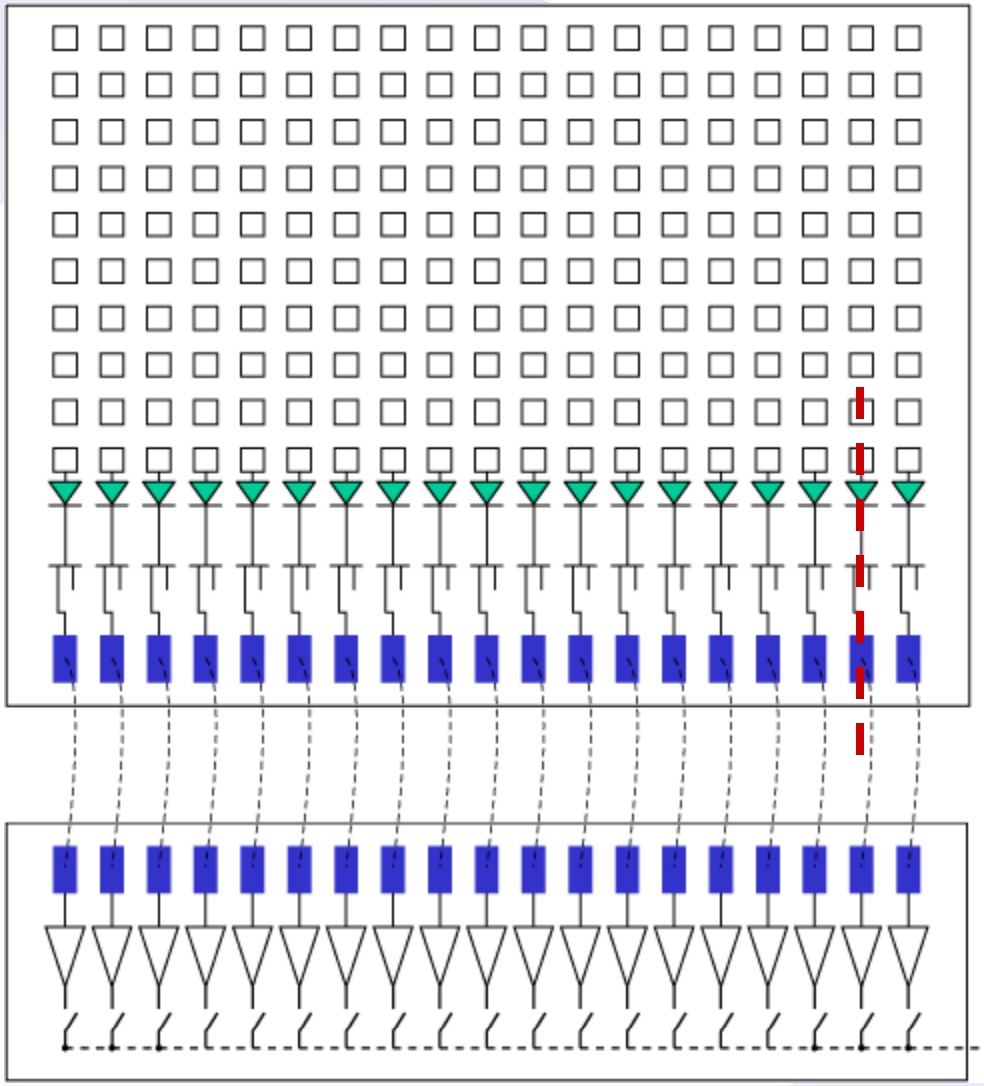
Applications:

- High Time Resolution Astrophysics (HTRA)
  (Funding from OPTICON JRA3)
- General Low Light Level Imaging

Performance:

- Superior to Existing Devices (L3CCDs and EMCCDs)
- Higher Frame Rate (up to 2,000 Frames per Second)
- Better Photon Detection Efficiency (up to 80 %)
- Better Linearity by Photon Counting

Introduction: Avalanche CCD Principle



CCD image and
frame store area

(256+256) × 256 pixels

Avalanche amplifiers

MOSFET amplifiers

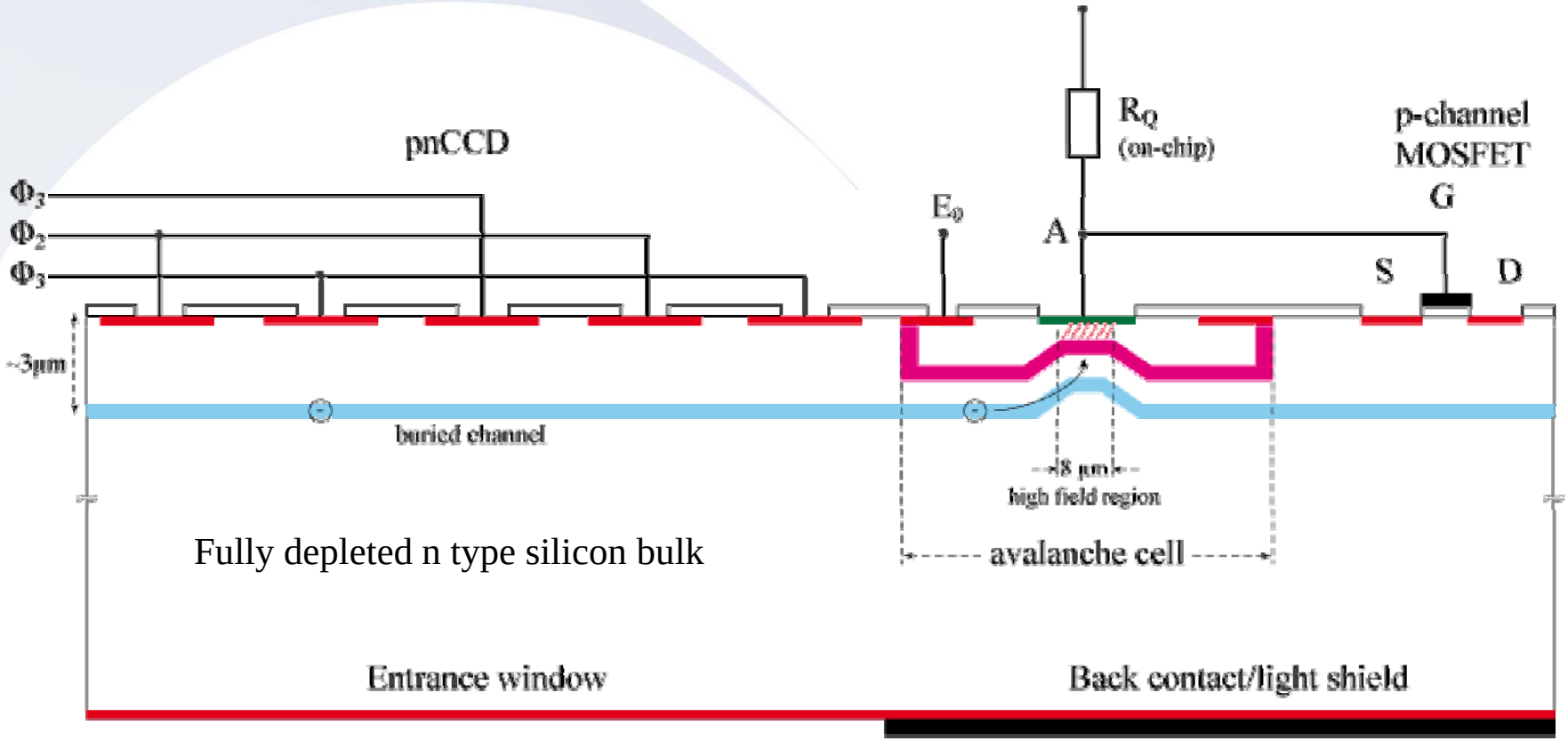
channel parallel readout
~ 1µs/line → ~250 µs / frame

Bondwires

Multiplexing ASIC
Amplifier (CAMEX)

Output

Introduction: Avalanche CCD Schematic Cross Section



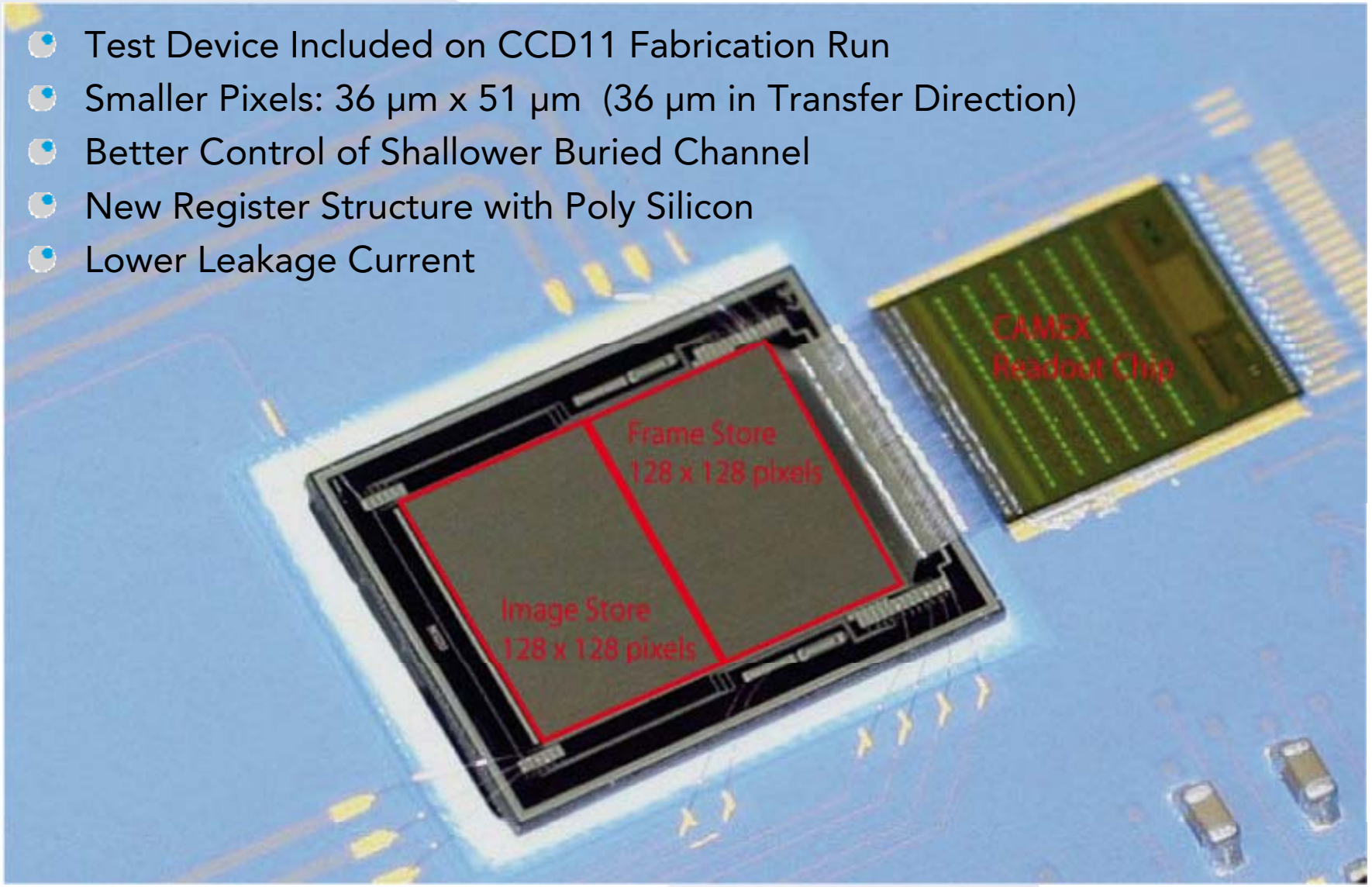
Approach to a New Device: Ingredients

- CCD Region
  - Entrance window well established – can be adapted
  - Low Noise pnCCD, new register topology – to minimize dark rate
  - Similar design **successfully tested** (experimental device on CCD11)
  - Advanced design in current fabrication (CCD14 for SCLS)
  - Additional structures to suppress optical crosstalk (designed, AVA-ET)

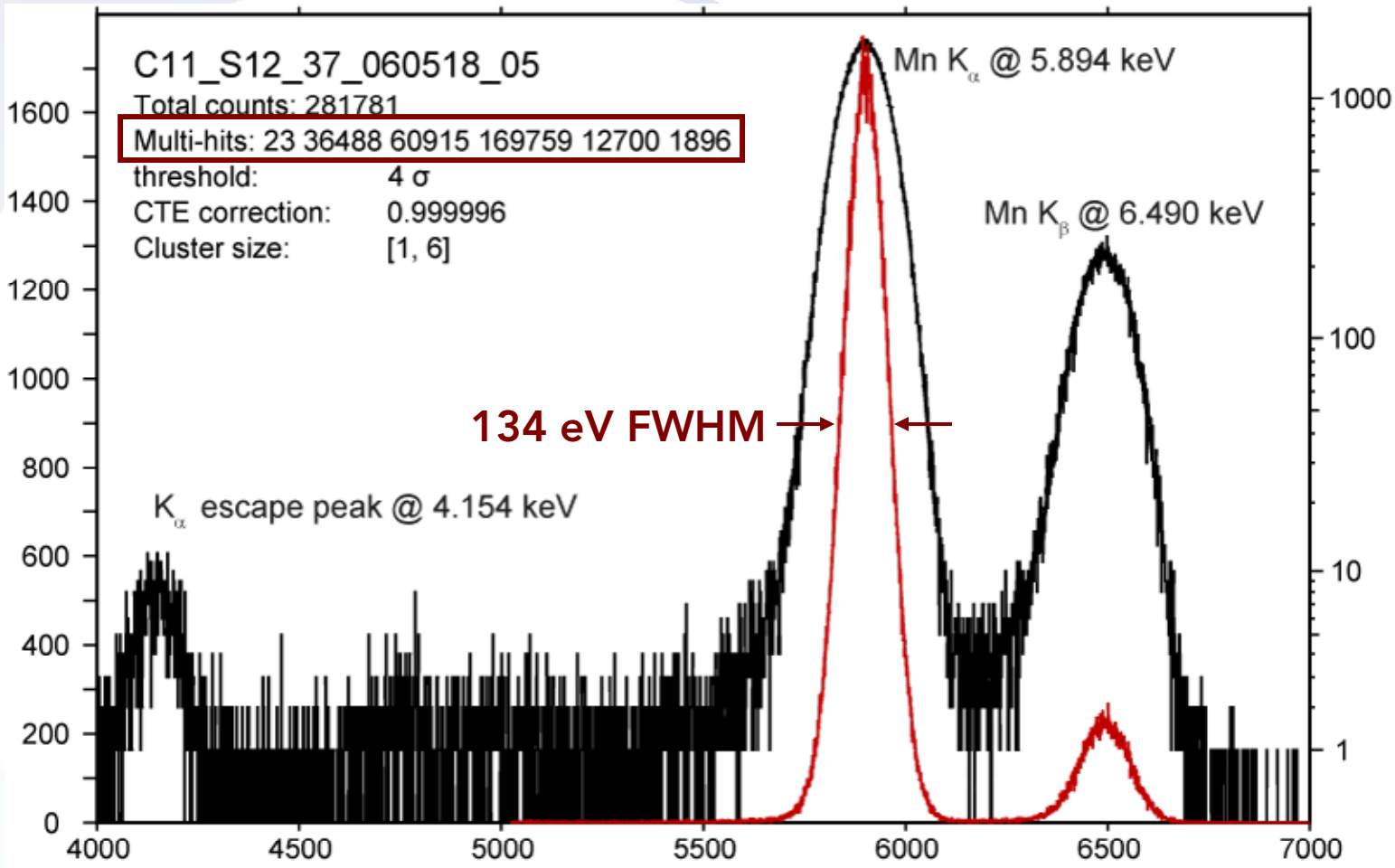
- Avalanche Readout
  - Avalanche diode, feasibility **tested successfully** (AVA-QT)
  - n-Channel MOS-FET Readout **tested successfully** (AVA-QT)
  - Compatibility to CCD (designed for AVA-ET)

Novel Low Noise pnCCD: Overview

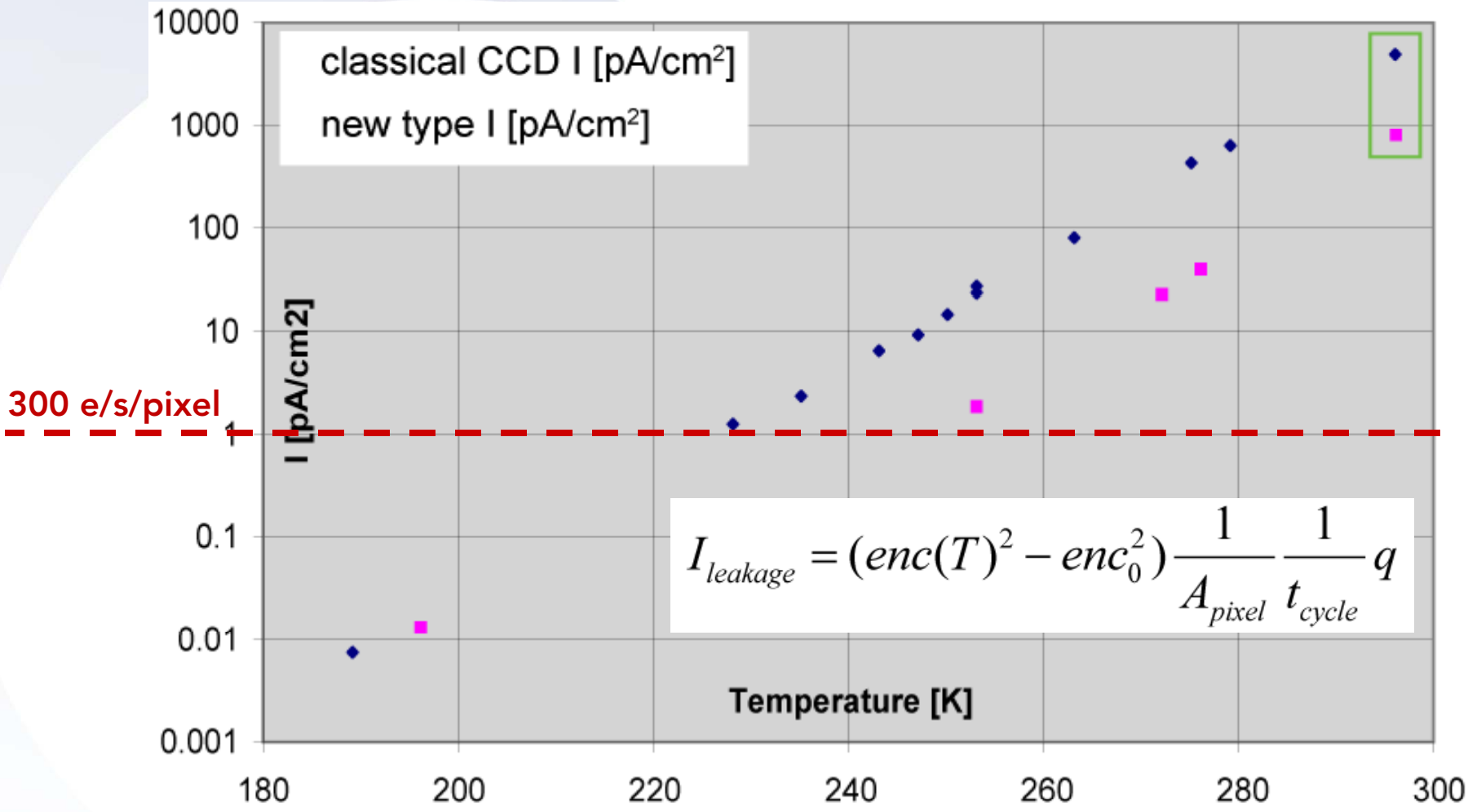
- Test Device Included on CCD11 Fabrication Run
- Smaller Pixels: 36 µm x 51 µm (36 µm in Transfer Direction)
- Better Control of Shallower Buried Channel
- New Register Structure with Poly Silicon
- Lower Leakage Current



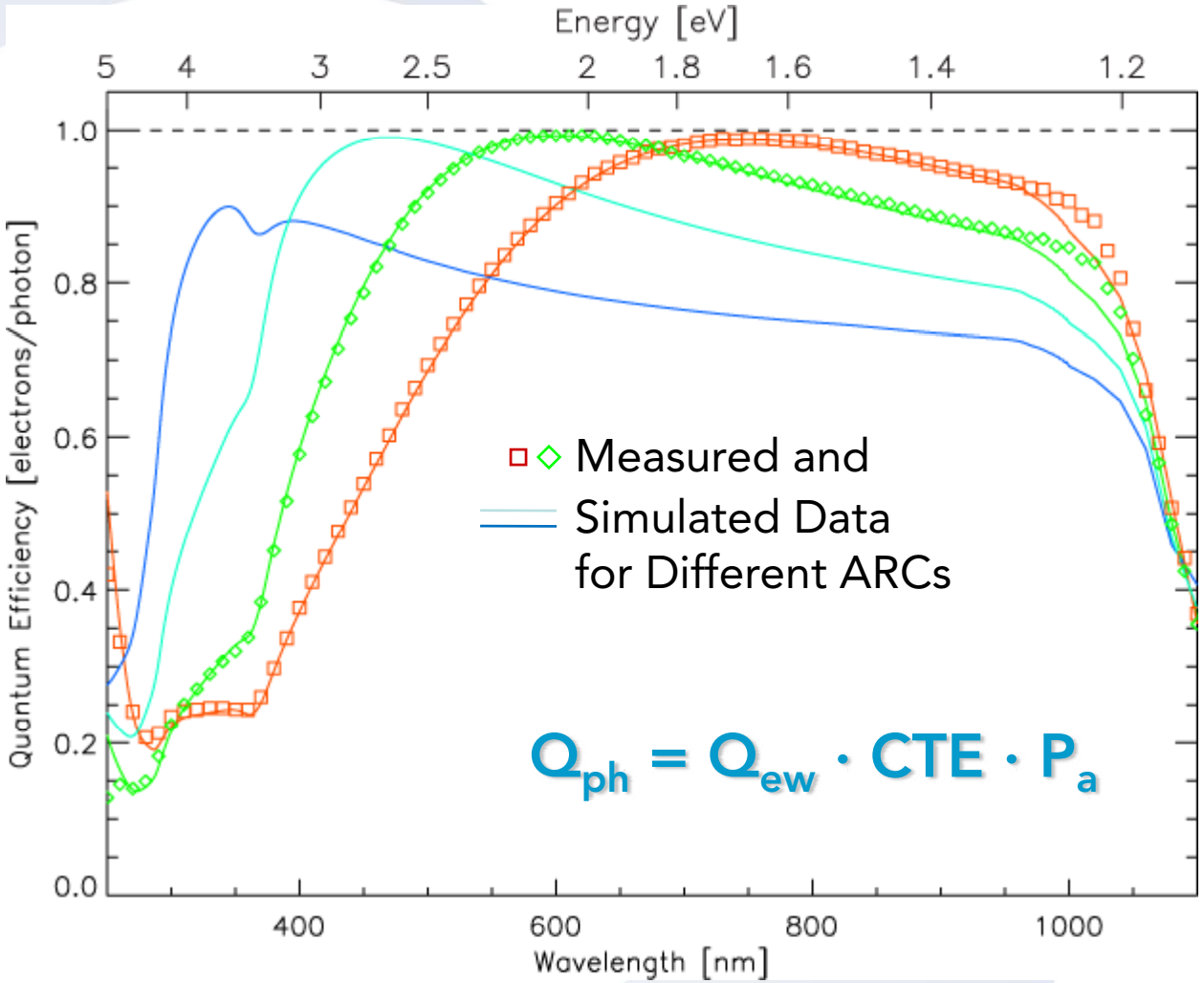
Novel pnCCD: ^{55}Fe X-Ray Spectrum



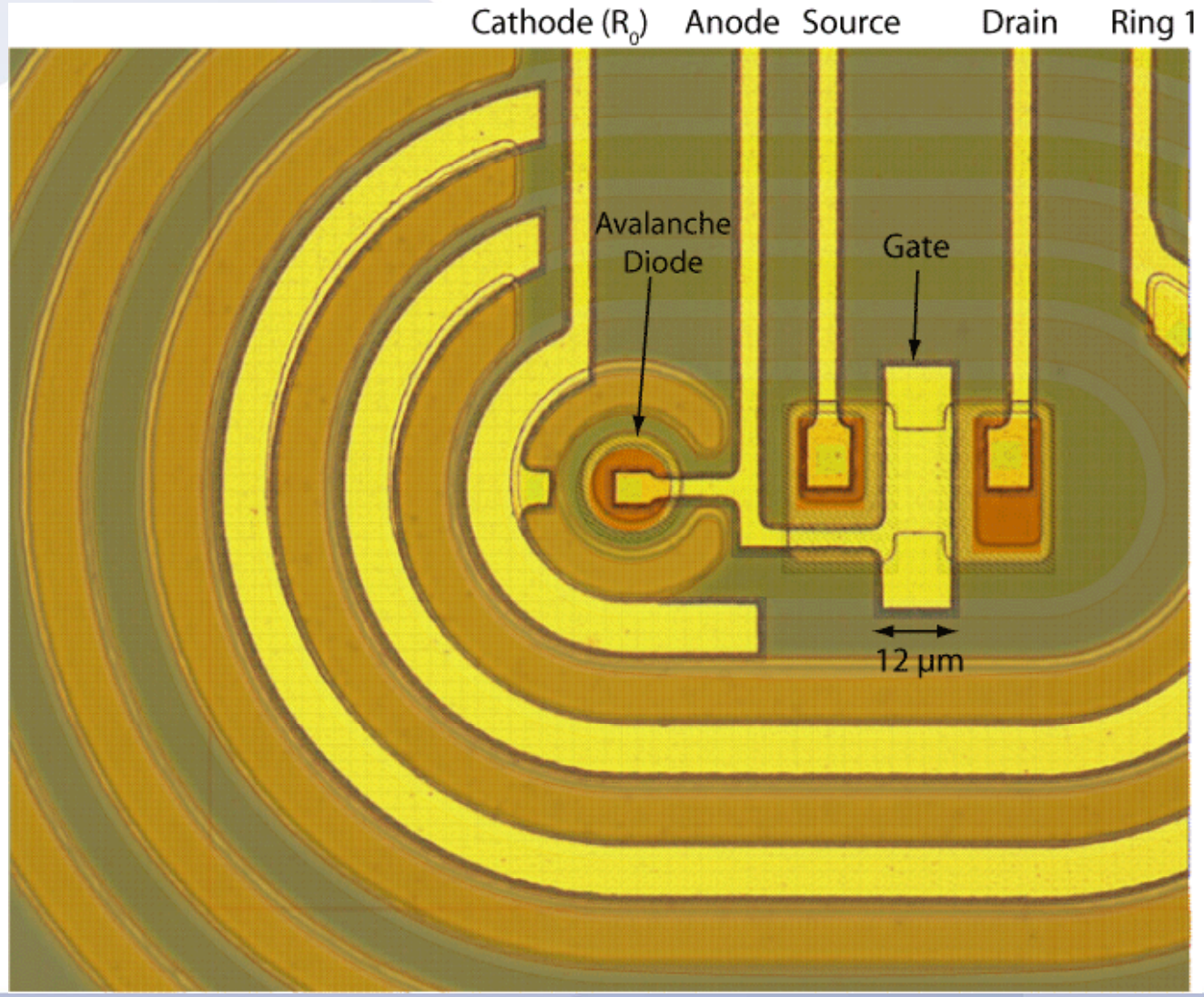
Novel pnCCD: Leakage Current Comparison



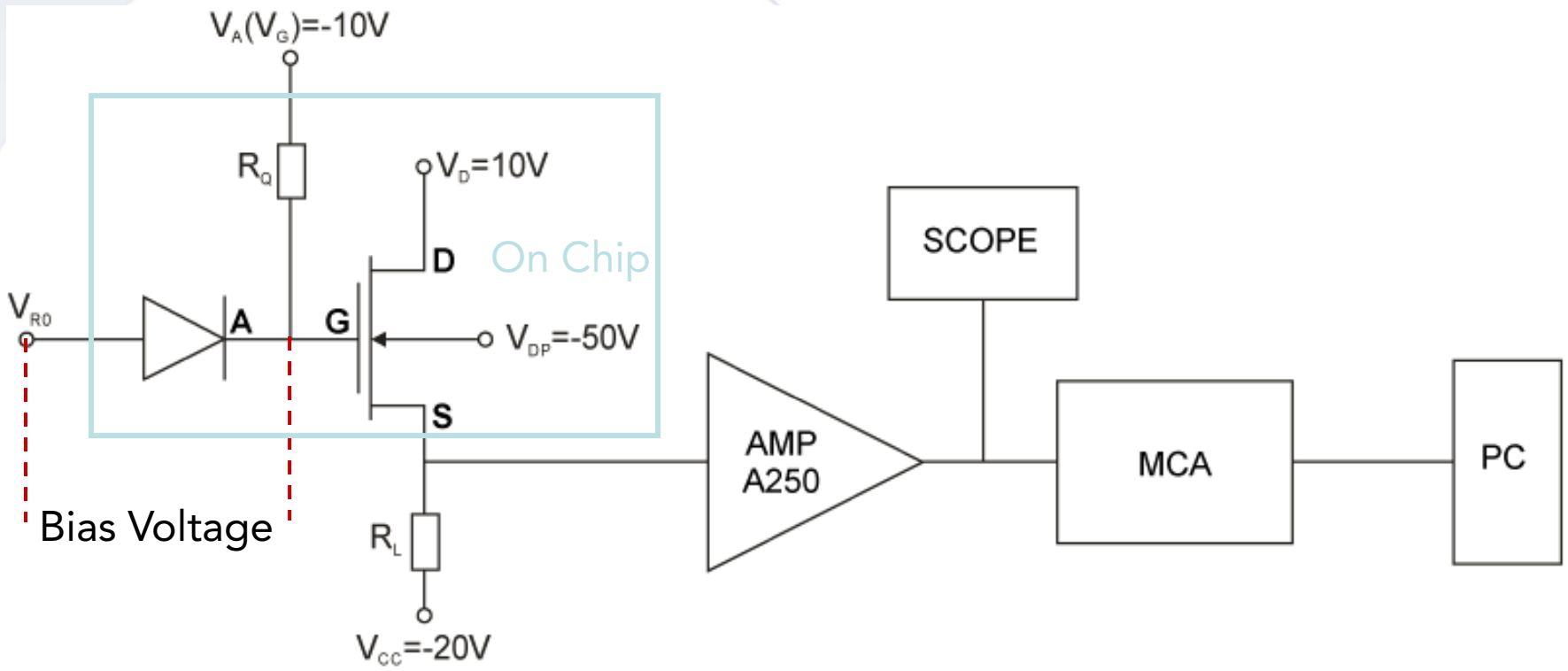
Entrance Window of Back Illuminated Devices



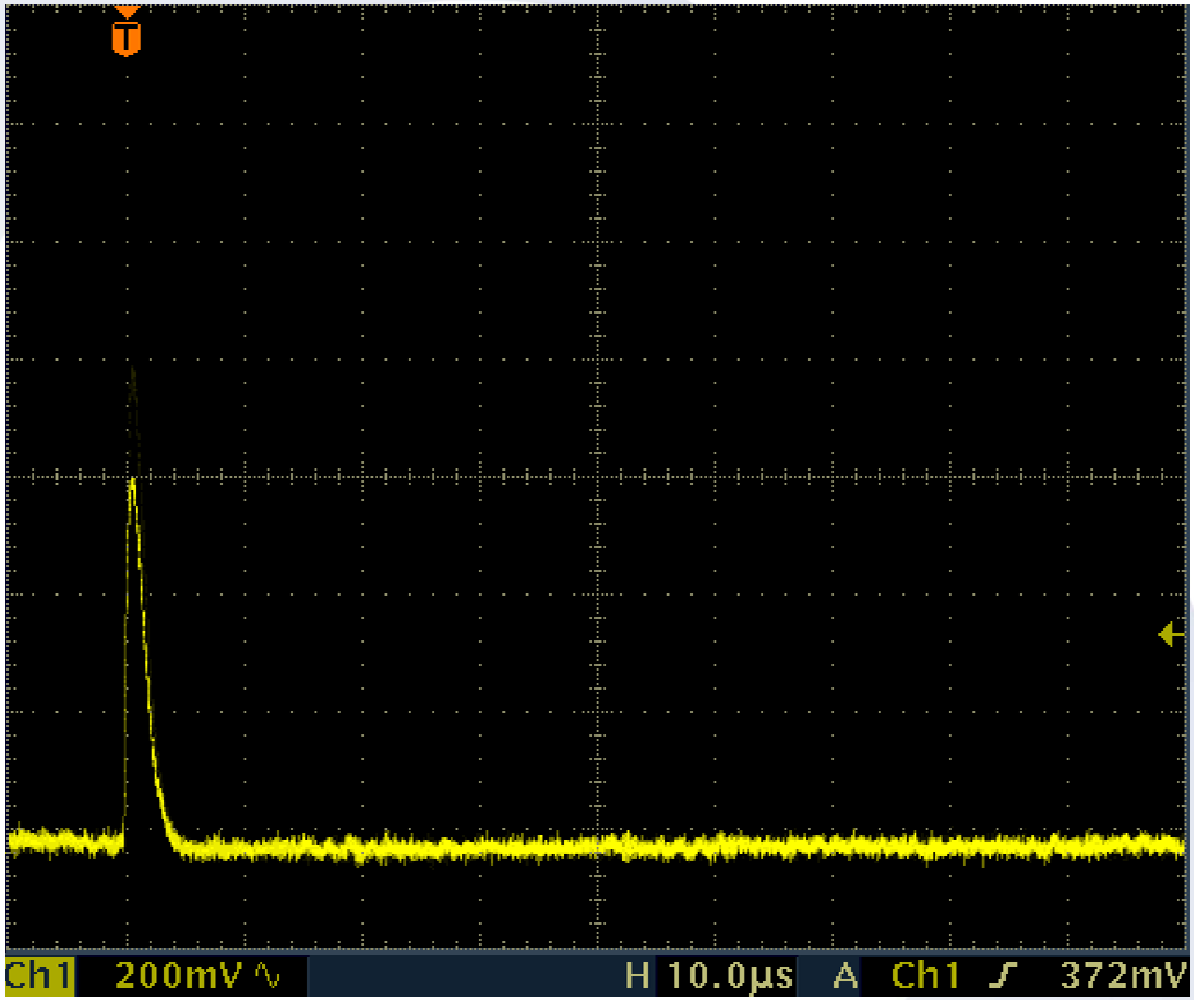
Avalanche Diode with NMOSFET Readout



Circuitry for Avalanche-NMOSFET Readout



Avalanche Diode: Single Electron Signal

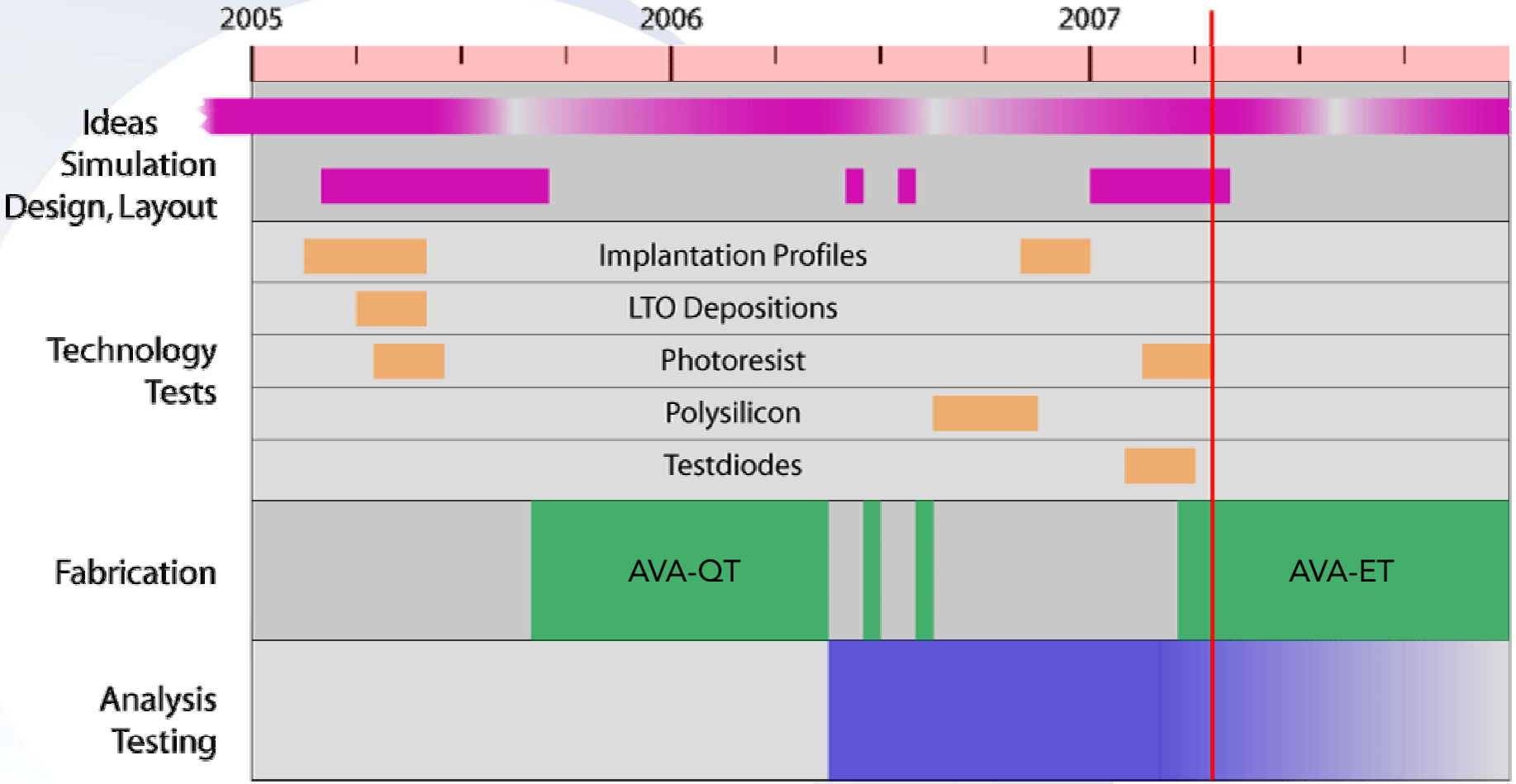


Rise Time: 400 ns

Fall Time: 2.5 µs

Multiplication ~10000

Status: Where Are We?



Further Steps (April 2007)

Fabrication related:

- Layout completion (prelim.) ..... *imminent*
- Production ..... *ongoing*
- Further, More Detailed Simulations ..... *ongoing*
- Evaluation of Inline Measurements ..... *~ 1 month*
- Finetuning of Layout and Fabrication ..... *ongoing*

Measurements

- Additional Tests of 36 µm CDD from ..... *starting May*
  different Wafer Types (Temperature Scans)
- Preparation of Independent CCD Test Setup ..... *planning phase*
- Concept for Operation (High Offset of ..... *planning phase*
  Clock-Voltages)
- Design and Fabrication of Mounting Modules ..... *end of 2007*

CCD Variants

Pixel Size 51 µm x 51 µm

264 x (256+256) Pixels

1x **Avalanche/nMOS-FET Readout**

30 Chip Units (18 x 30 mm²)

132 x (60+60) Pixels

3x **with(out) Avalanche Mulitplication**

with(out) Crosstalk Reduction

2.25 Chip Units (9 x 9 mm²)

132 x 60 Pixels

4x **Layout Variations**

1.5 Chip Units (9 x 6 mm²)

Pixel Size 75 µm x 71 µm

128 x (60+60) Pixels

2x **Avalanche/NMOS-FET Readout**

Crosstalk Reduction

4 Chip Units (12 x 12 mm²)

128 x 40 Pixels

2x **Layout Variations**

1.5 Chip Units (9 x 6 mm²)

54 Chips Units (of 360) + Test Structures

Summary and Outlook

We Can Do It!

- All Key Components Successfully Tested!
  - Proof-of-Principle of Back Illuminated Avalanche Structure *Tested and Testing*
  - Low Leakage Current pnCCD *Measured*
  - High Q.E. Back Illuminated Entrance Window *Measured and Modeled*
  - High Speed Readout up to 2,000 Frames per Second *Tested*

We Will Do It!

- Production of CCDs with Further Improved Leakage Current *Started*
- Prototype Production with Double Sided Processing *Starting*
  - Will Include CCD with Avalanche Readout
  - Shall Show Overall Feasibility
  - Answers on Gain, Avalanche Probability, Optical Crosstalk
- Dedicated Prodocution as Follow-Up to AVA-ET *Wanted!*