Development of New 3d Si Detectors at BNL and CNM*

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Introduction

- **For SLHC, one of the main issue is the radiation hardness for inner most detectors**

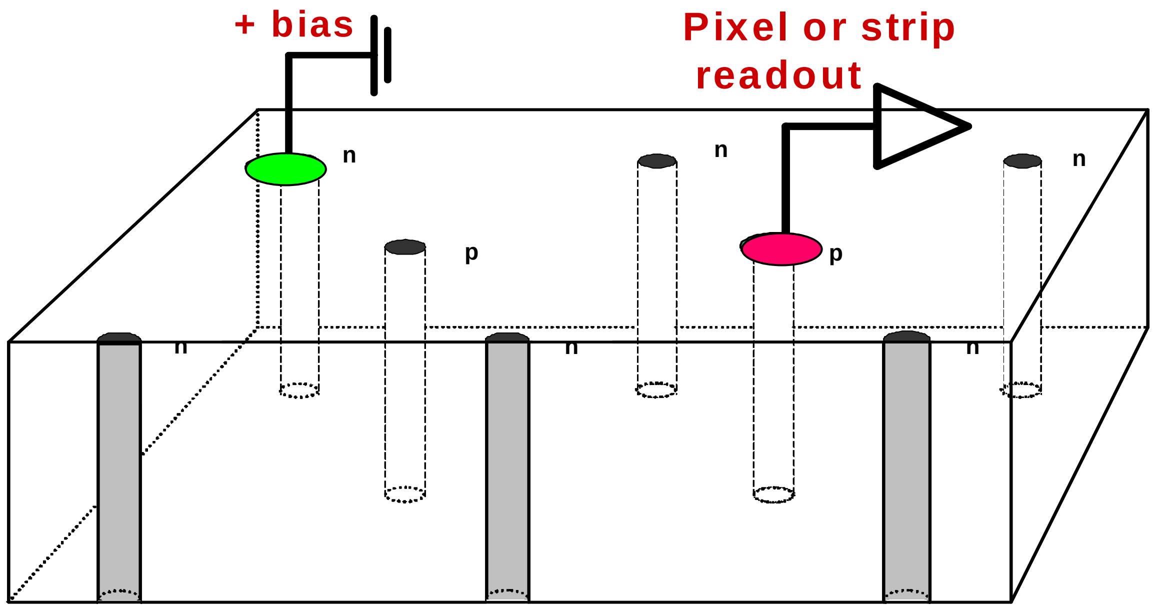
- **At fluence of 10^{16} n_{eq}/cm^2, the limiting factor for CCE is trapping of charges by radiation induced trap levels:**
  - **Average trapping time:** τ_{tr}**= (5x10^{-7}cm^2/s $\times$ 10^{16} $n_{eq}/cm^2)^{-1}$= 0.2 ns**
    (H.W. Kraner et al, NIM A326 (1993) 350-356)
  - **Charge collection distance:** $d_{cce} \leq V_s \times \tau_{tr}$ **= 20 μm!**

- **For planar detectors of >100 μm thickness, most volume is dead space even if fully depleted!**

- **3d detectors decouples the detector thickness (*d*) and depletion depth (*W*) (i.e. the pitch (*P*) of p and n electrodes)**

Standard 3d Si detectors

Schematics of a 3d detector (3d in terms of processing)



- *3d processing*
- *2-sided process*
- *Read out only p or n electrodes*

Sherwood I. Parker et al., UH 511-959-00

Comparisons between planar and 3d pixel detectors

Planar

- **Easy processing (planar or 2d technology)**
- **Low leakage current**
- **Good electric field profile**
- **Not radiation hard at SLHC fluences**
  - **High full depletion voltages (thousands of volts)**
  - **Less sensitive volume: $d_{cce} << W \leq d$ (small CCE)**

3d

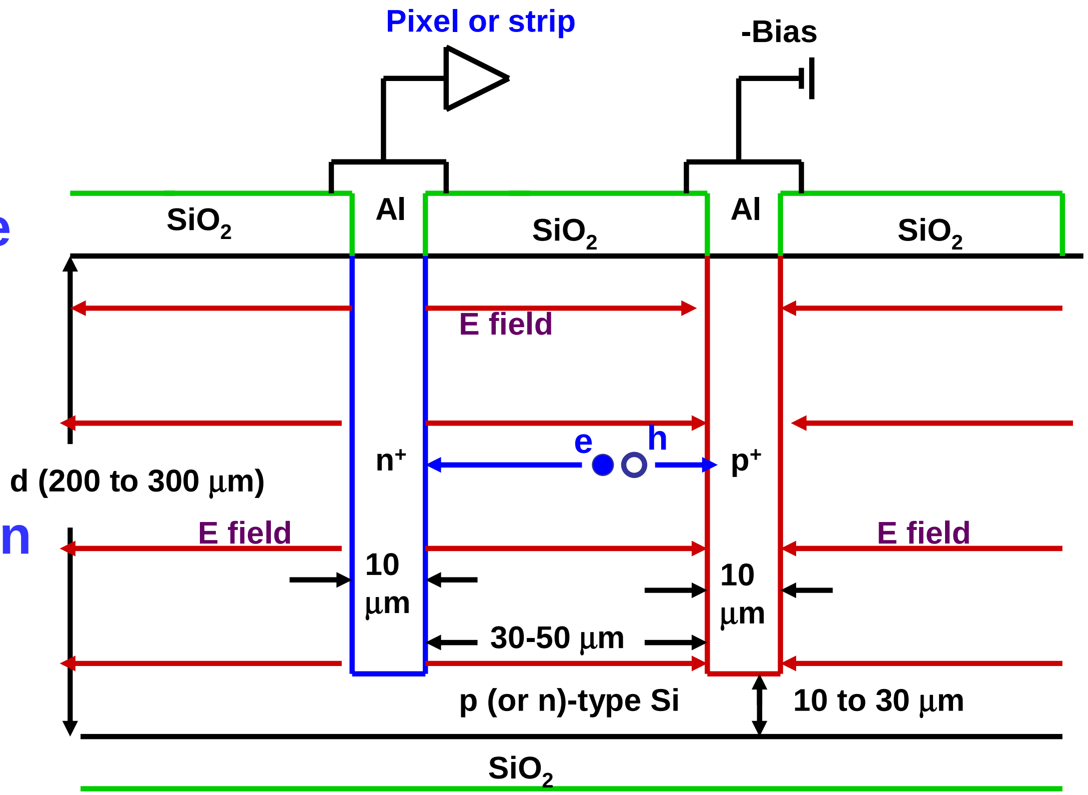
- **Radiation hard for SLHC fluences**
  - **small full depletion voltages (10-100 volts)**
  - **Depletion and charge drift distance independent on thickness *d***
  - **Whole volume sensitive: $d_{cce} \sim P = W$ (large CCE)**
- **Complicated processing (3d technology)**
- **High leakage current**
- **Abnormal electric field profile (low field regions)**

New 3d Structures

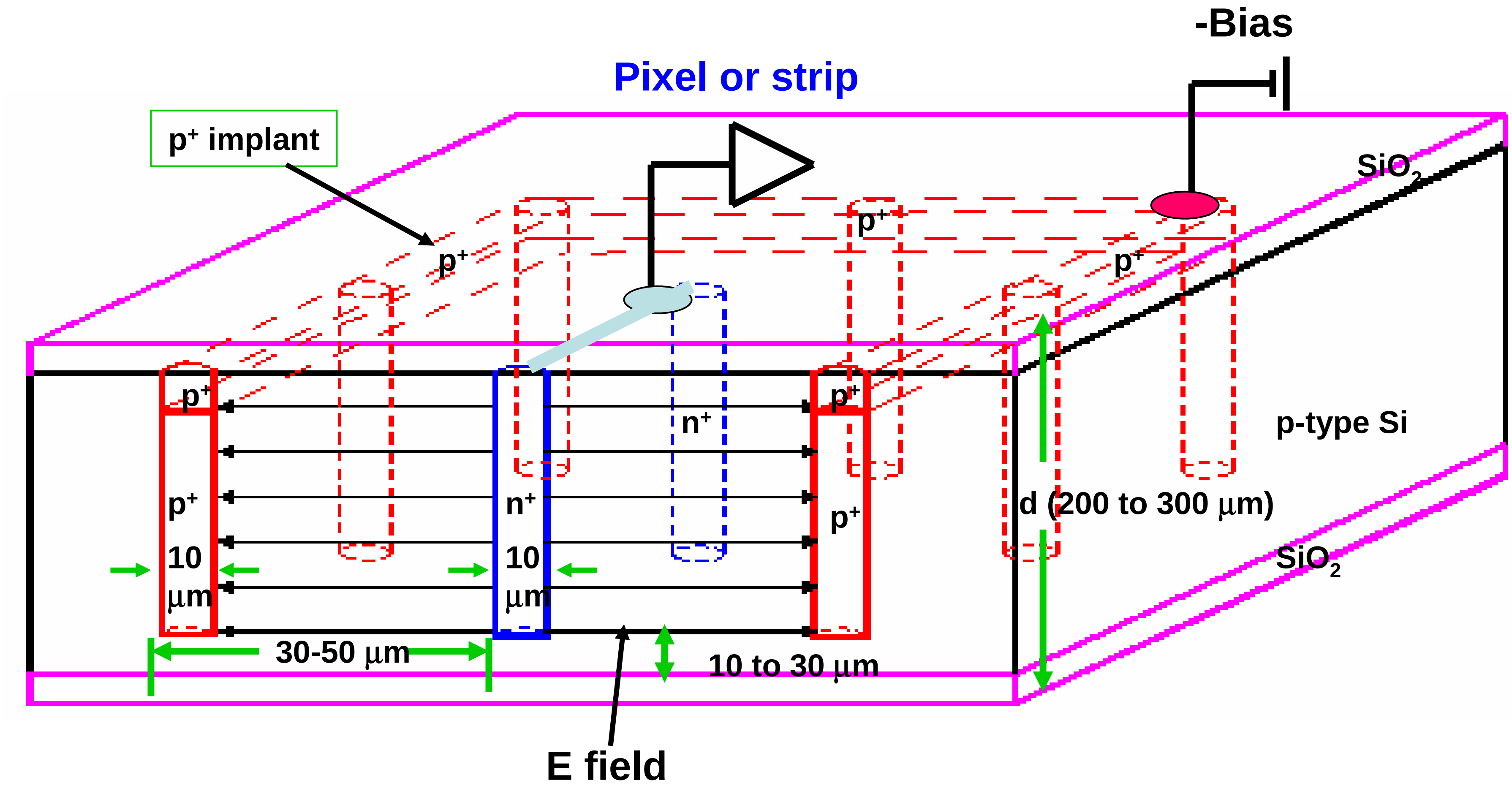
- **Planar + 3d (we call it P+3d) processing technology**
- **Dual-column or 1-column etching and doping possible**
- **True single sided processing (no processing at all on the back side, different from ITC's 3DSTC detectors)**
- **Pixel, strip, and 2d stripixel configurations possible depending on electrode connections**
- **No support wafer**

Dual-column P+3d detector

- Both type of electrodes through holes etched into Si (p^+ and n^+)
- Each type of electrode columns in a pixel cell are connected by planar implantation of the same type
- No back side processing – easier than the standard 3d technology
- Good electric field distribution
- Small depletion voltage
- significant improvement on CCE at SLHC fluence as compared to planar detectors

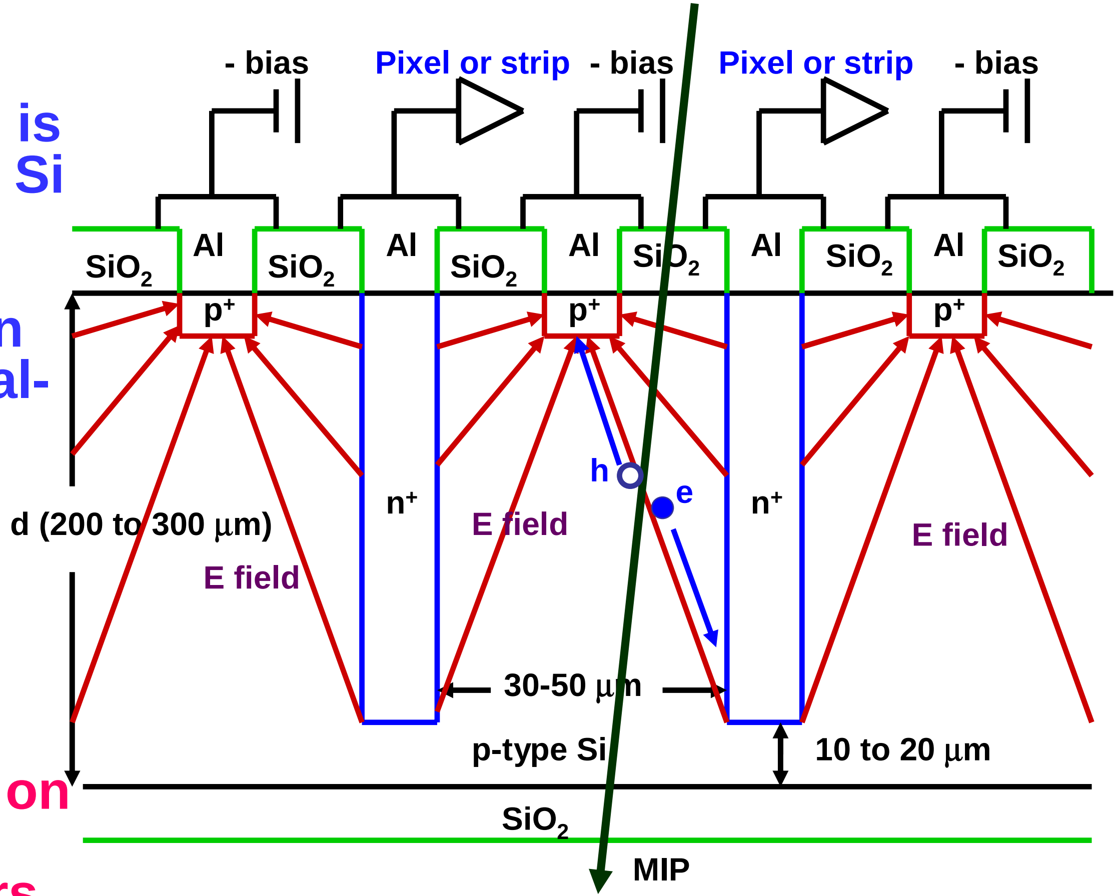


Schematic of ½ of a single Cell

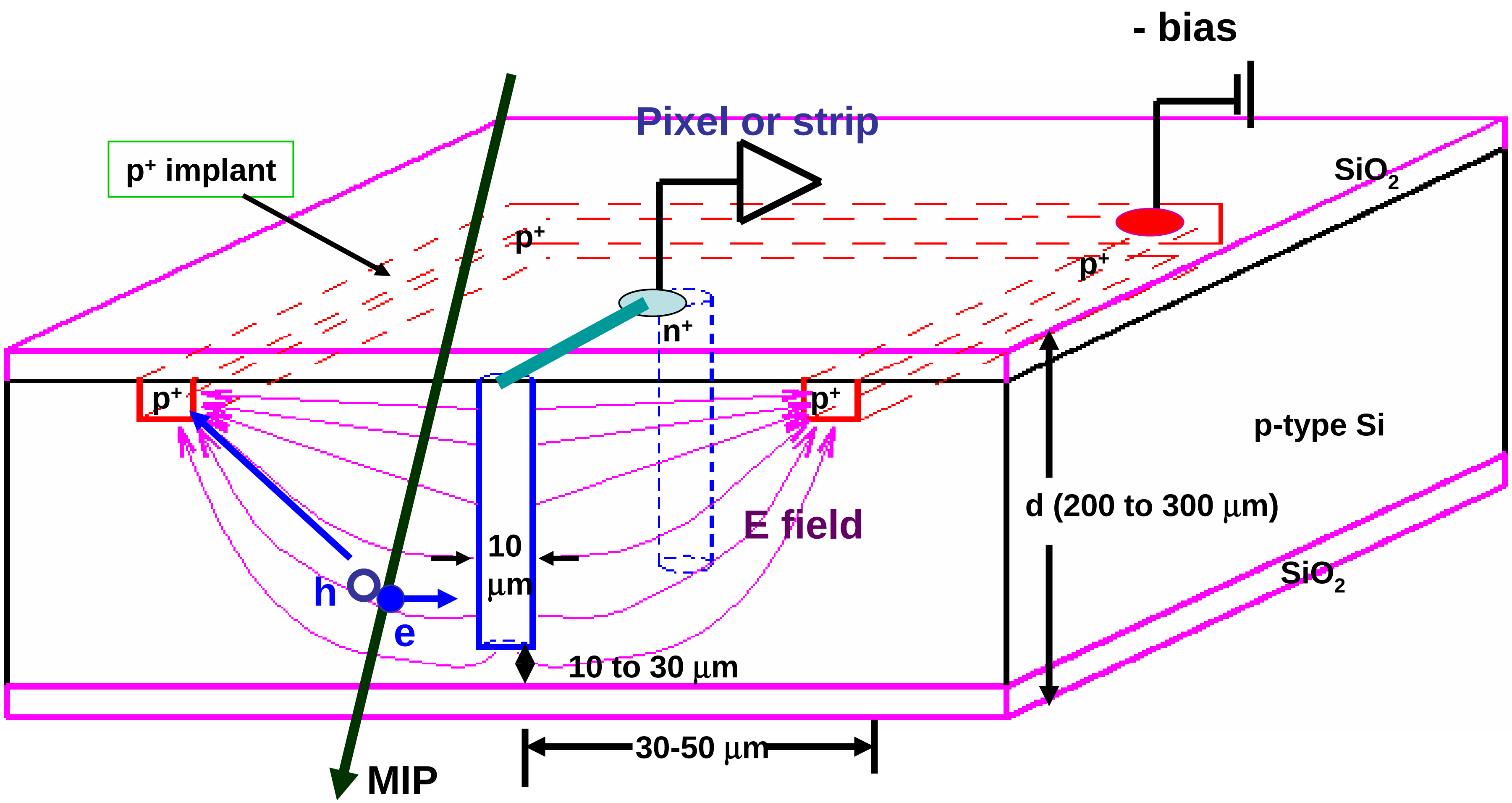


1-column P+3d detector

- One type of electrodes is planar implanted (p^+ here)
- The other type of electrodes is formed by holes etched into Si (n^+ here)
- Much easier processing than standard 3d technology (dual-column etching and doping, back side treatment, wafer bonding, etc.)
- Small depletion voltage
- No significant improvement on CCE at SLHC fluence as compared to planar detectors



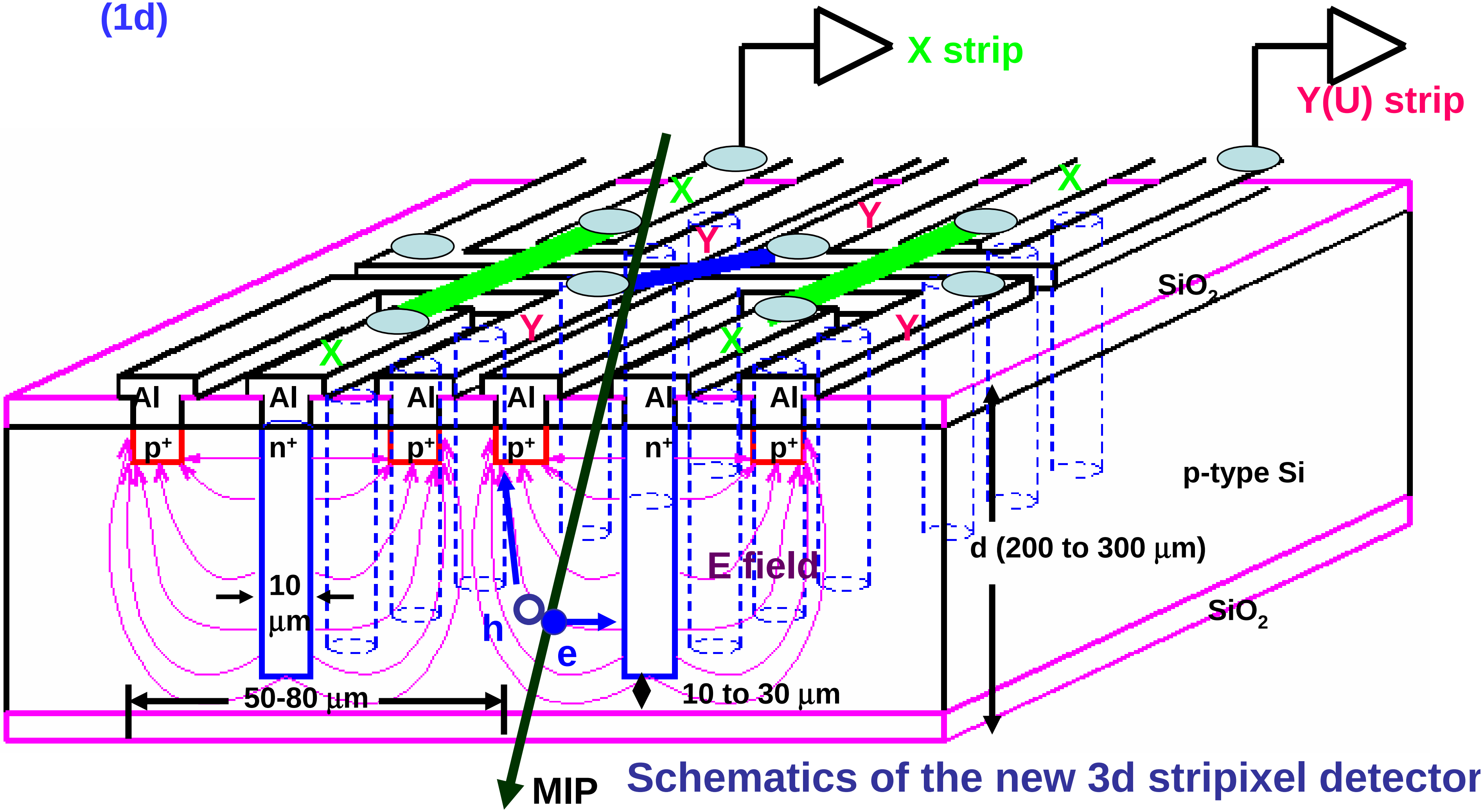
Schematic of ½ of a single Cell



- p^+ here comes naturally from the isolation ring

The two types of the P+3d detectors can be connected to form a 2d stripixel detector: 3d stripixel detector

- Electrons automatically go to the n+ electrodes (X-strip), and holes go to the p+ electrode (Y-strip)--- 1-sided 2d position sensitive detector (2d)
- No charge loss and much less capacitance as compared to the standard stripixel detector
- Can serve as a detector between pixel (true 2d) and single-sided strip (1d)



Schematics of the new 3d stripixel detector

- **Single-column processing is much easier than 2-column**
  - **Half of the work of hole etching and doping**
  - **Not many processing labs can do doping of both types (UH and Glasgow)**

- **P-type substrates a natural choice:**
  - **No inversion or double junctions to worry about upon radiation**
  - **The area under oxide is naturally inverted, providing a depletion region**

- **Our new P+3d detectors can be processed just like planar detectors after the first few steps of column etching and doping**

- **BNL and CNM are now collaborating to produce 1-column P+3d detectors, n^+ columns etched and doped (no column filling)**

- **First prototype detectors will be ready in a few months**

System Aspects

- For pixel detectors, the size of the bump-bonding pads is an issue: >10 μm.

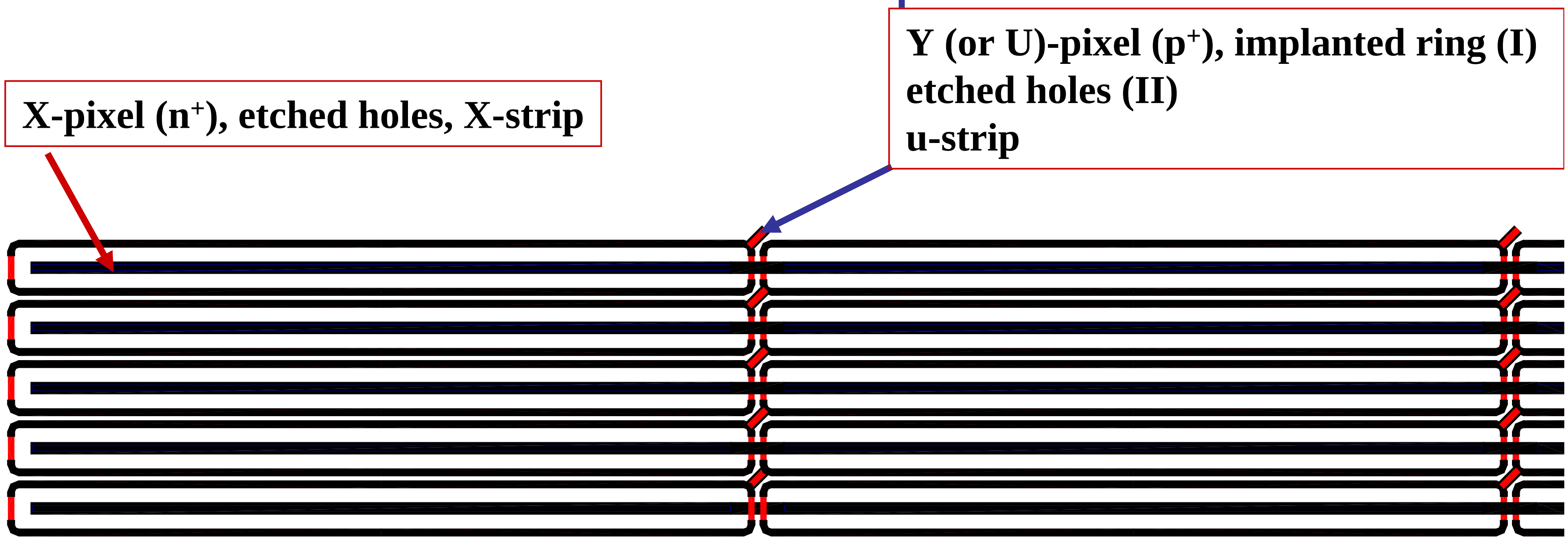
- Options to chose from for different regions:

Region	25-50 cm	15-25 cm	7-15 cm
Radiation level	10^{14} -10^{15} n^{eq}/cm^2	~ 10^{15} n^{eq}/cm^2	~ 10^{16} n^{eq}/cm^2
Occupancy requirement	80 μm × 2-3 cm	50 μm × 400 μm	50 μm × 300 μm
Detector type	Short strip and 2d stripixel	Pixel	Pixel
Radiation hardness requirement	Short strip and 2d stripixel	Pixel	3d pixel or replacing every 2 years
Overall detector type	Short strip and 2d stripixel	Pixel	3d pixel or replacing every 2 years

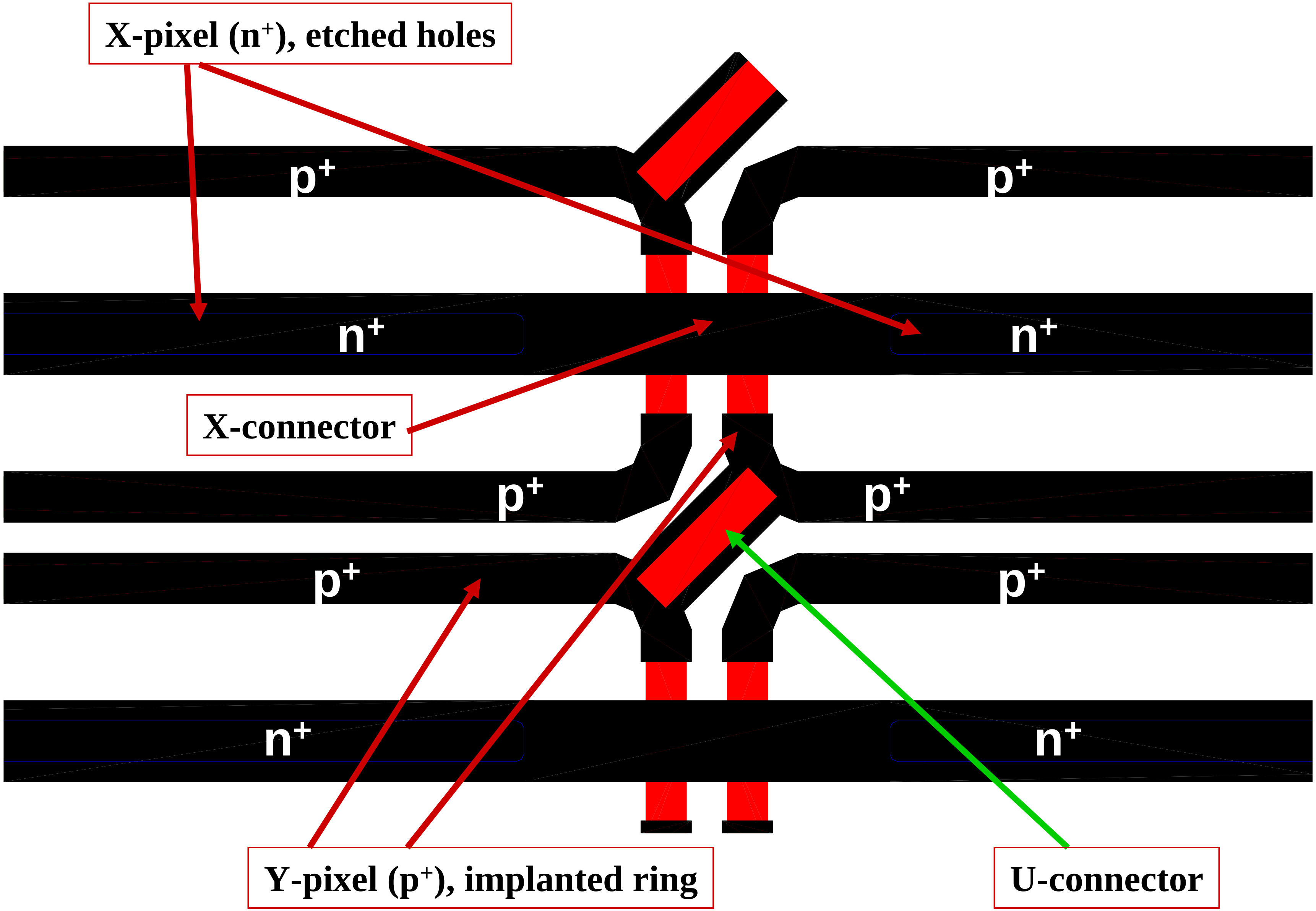
Processing of Single Column 3d Stripixel Detectors

- **Mask set has been designed and made**
- **Processing has begun, and n^+ columns have been etched and doped at CNM in Barcelona, Spain**
- **The remaining planar processing is now going on at BNL**
- **First prototype single column 3d stripixel detectors will be ready for testing in September**

Schematics for the new 3d stripixel detectors



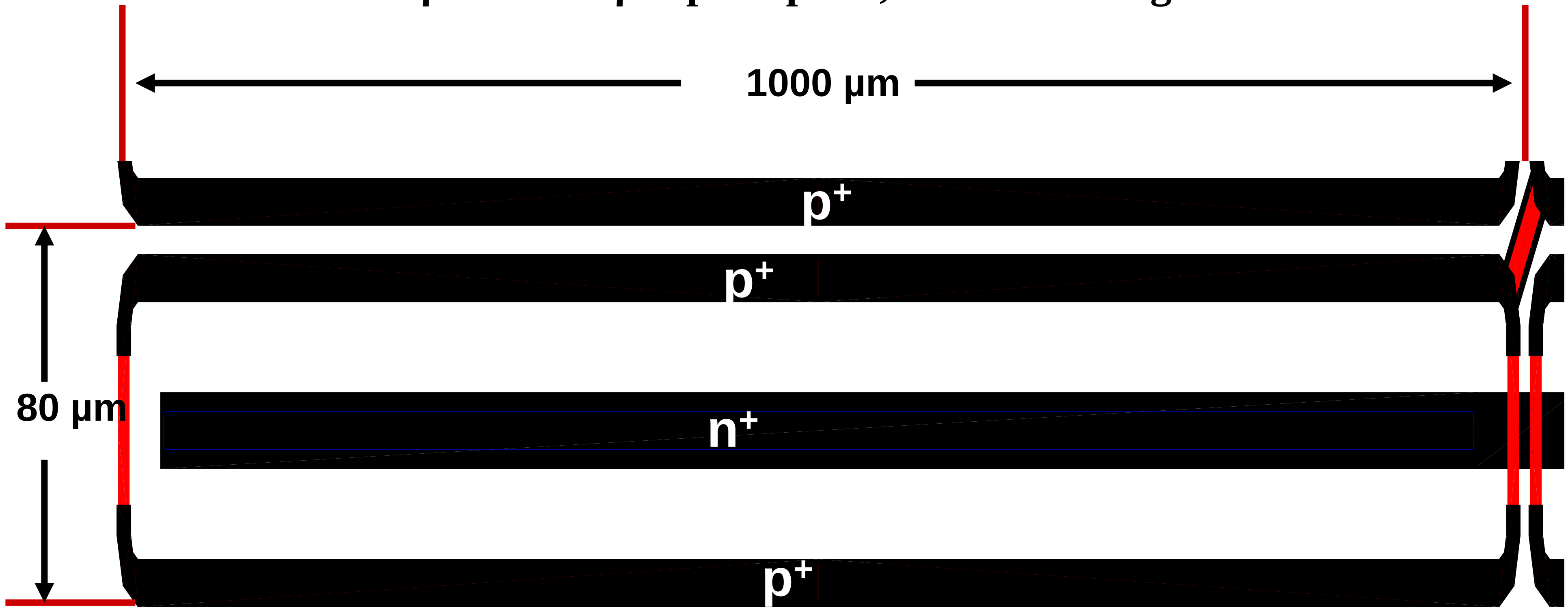
Schematics for the new 3d stripixel detectors



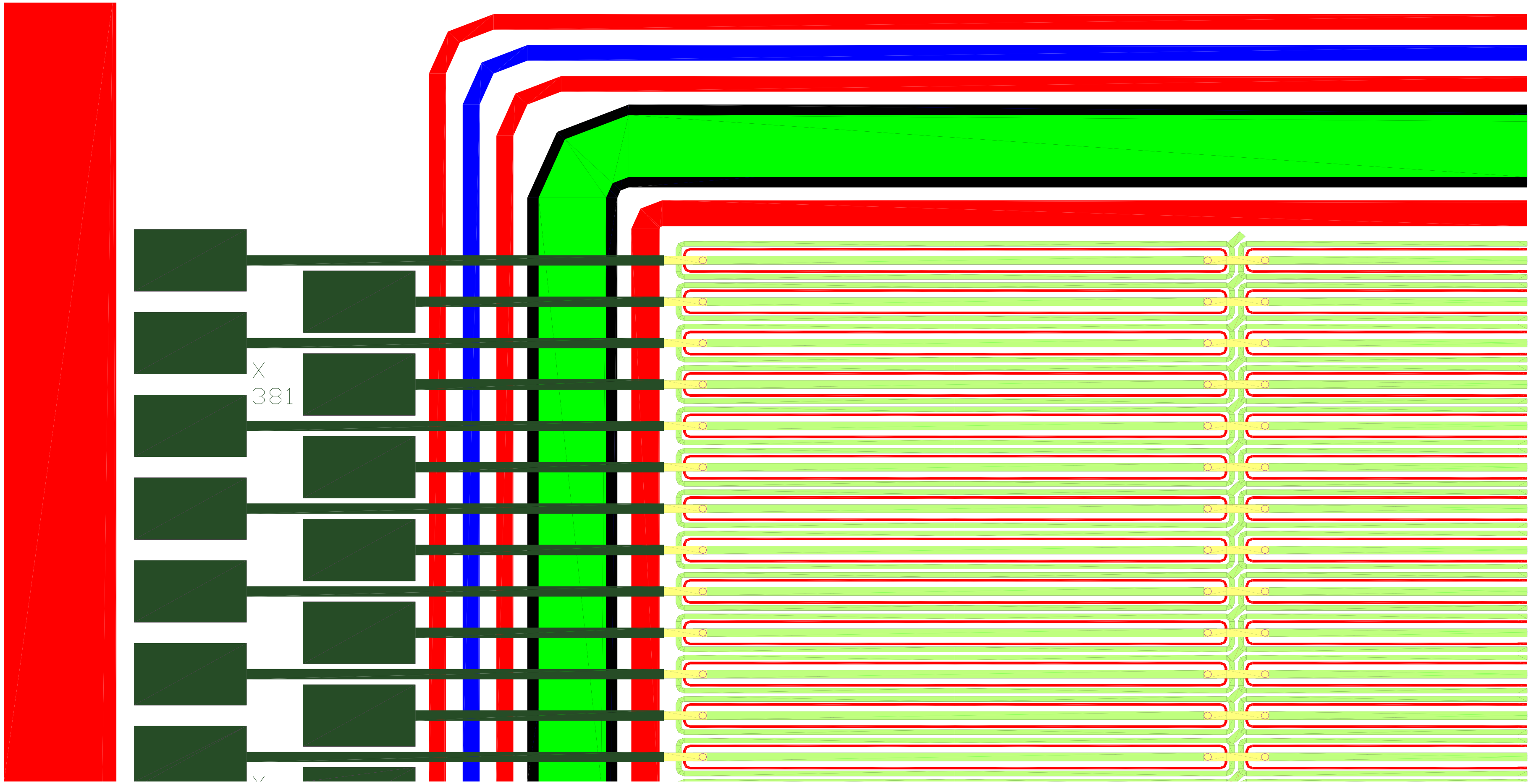
Schematics for the new 3d stripixel detectors

One example

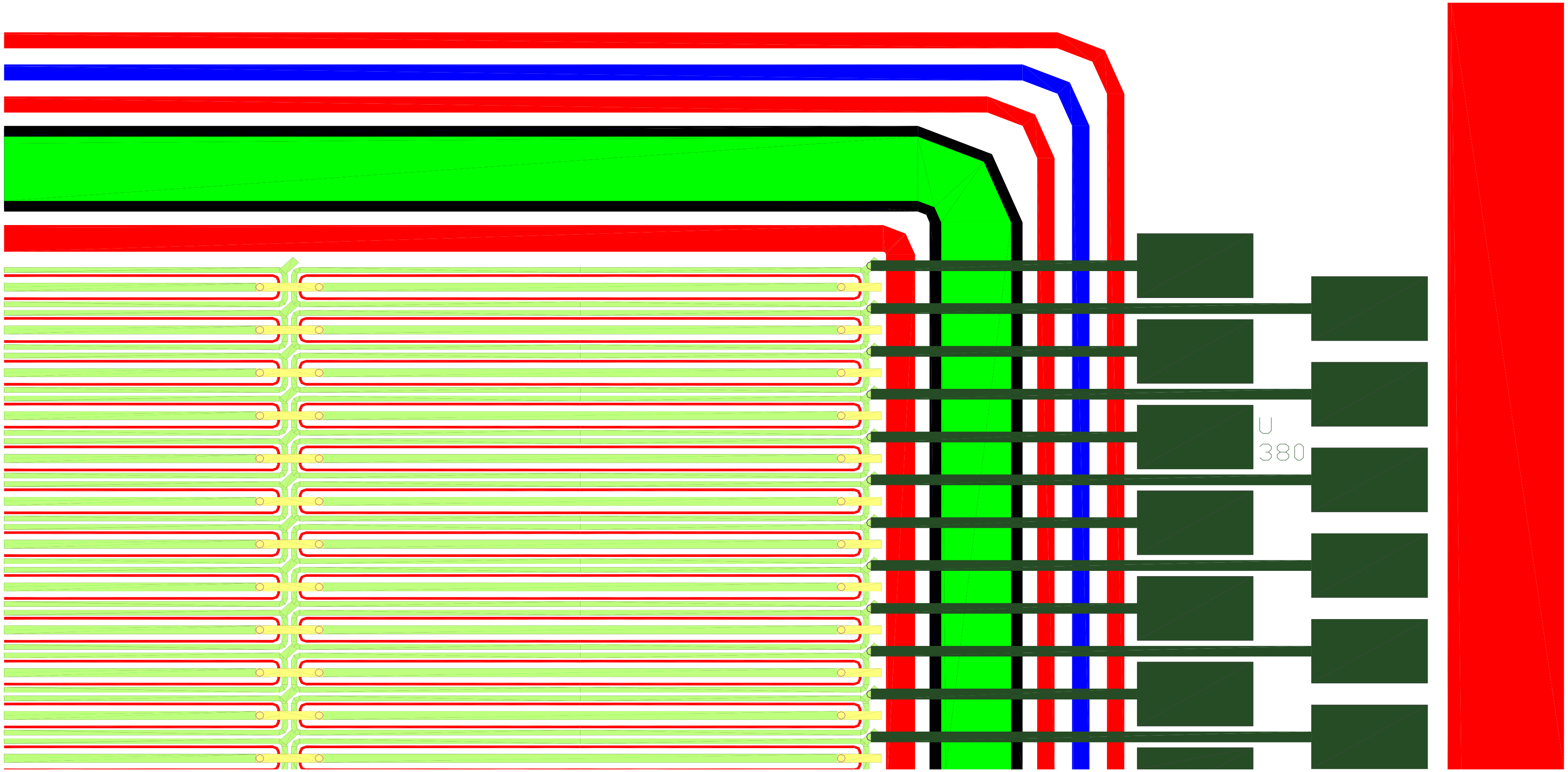
80 μm ×1000 μm pixel pitch, 4.6° stereo angle



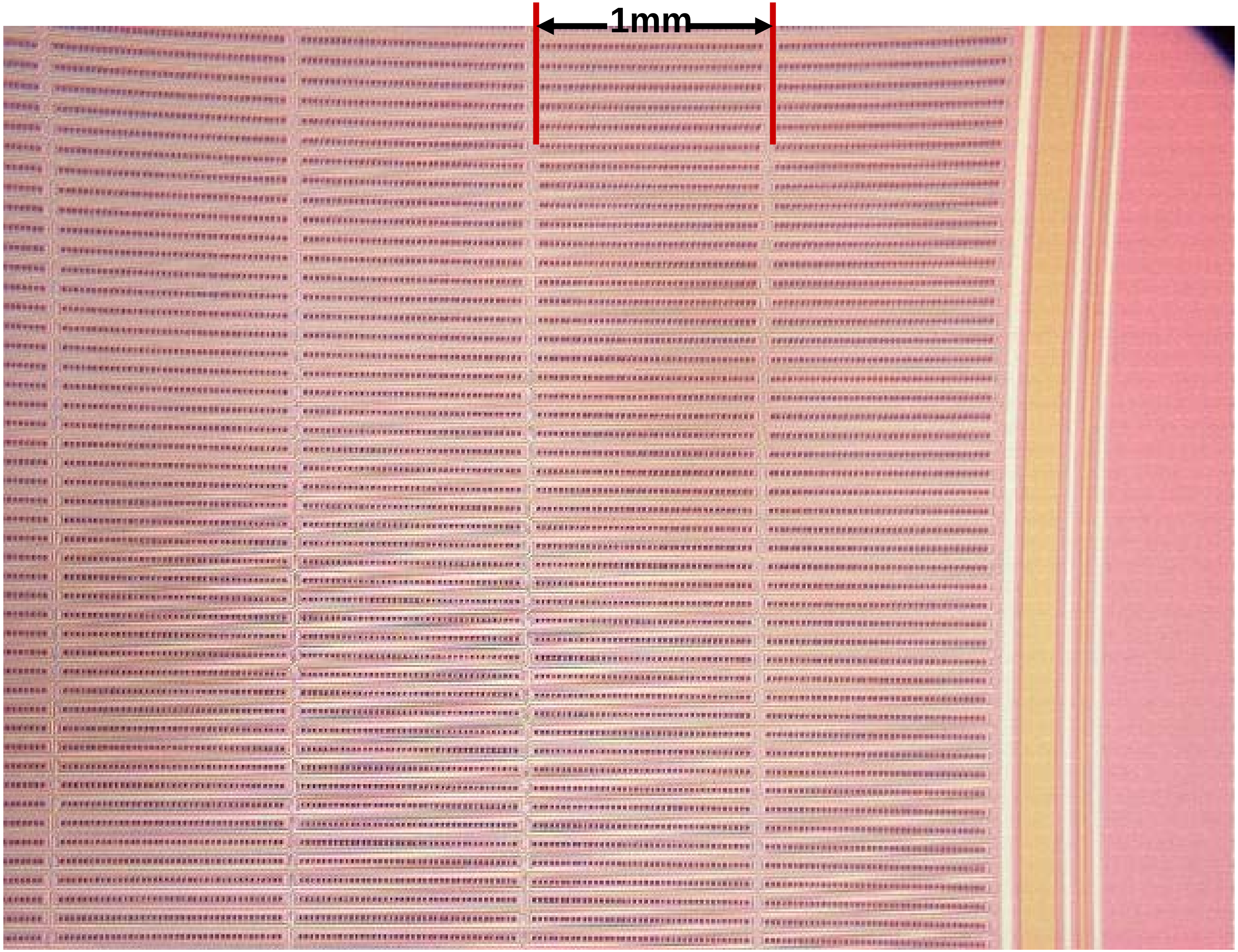
Schematics for detector design
x- strips

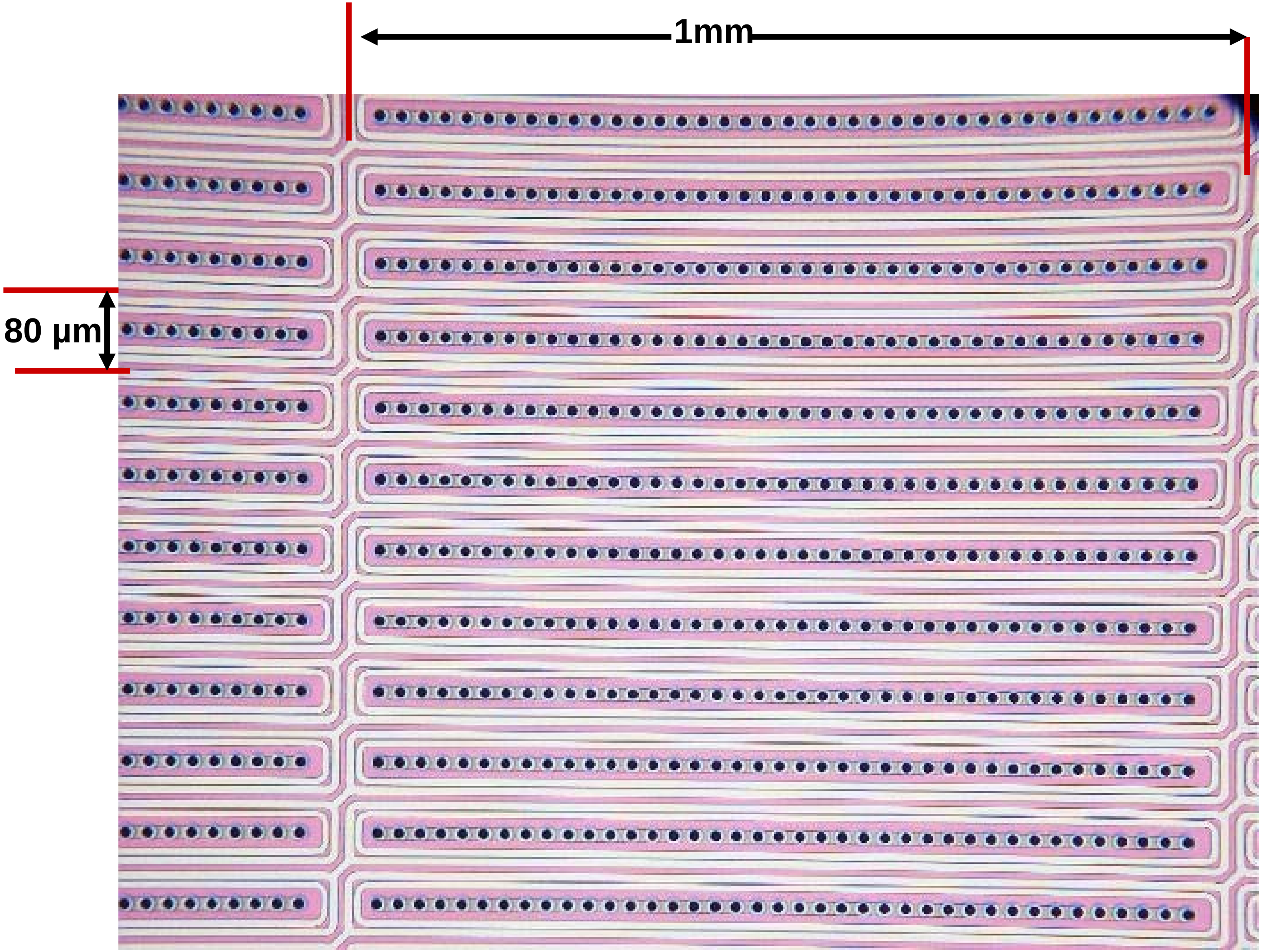


Schematics for detector design
u- strips



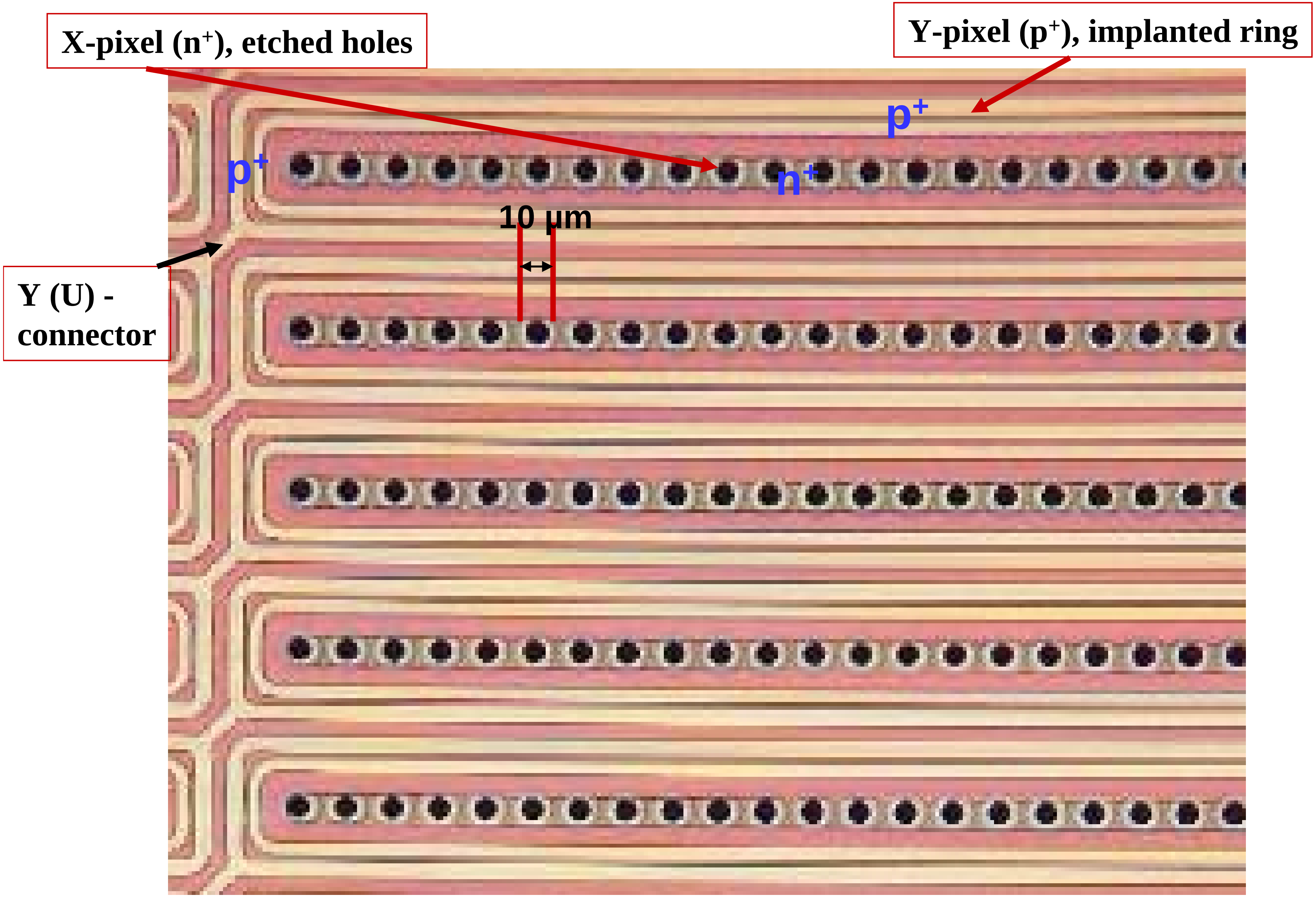
Photos of detectors in the processing





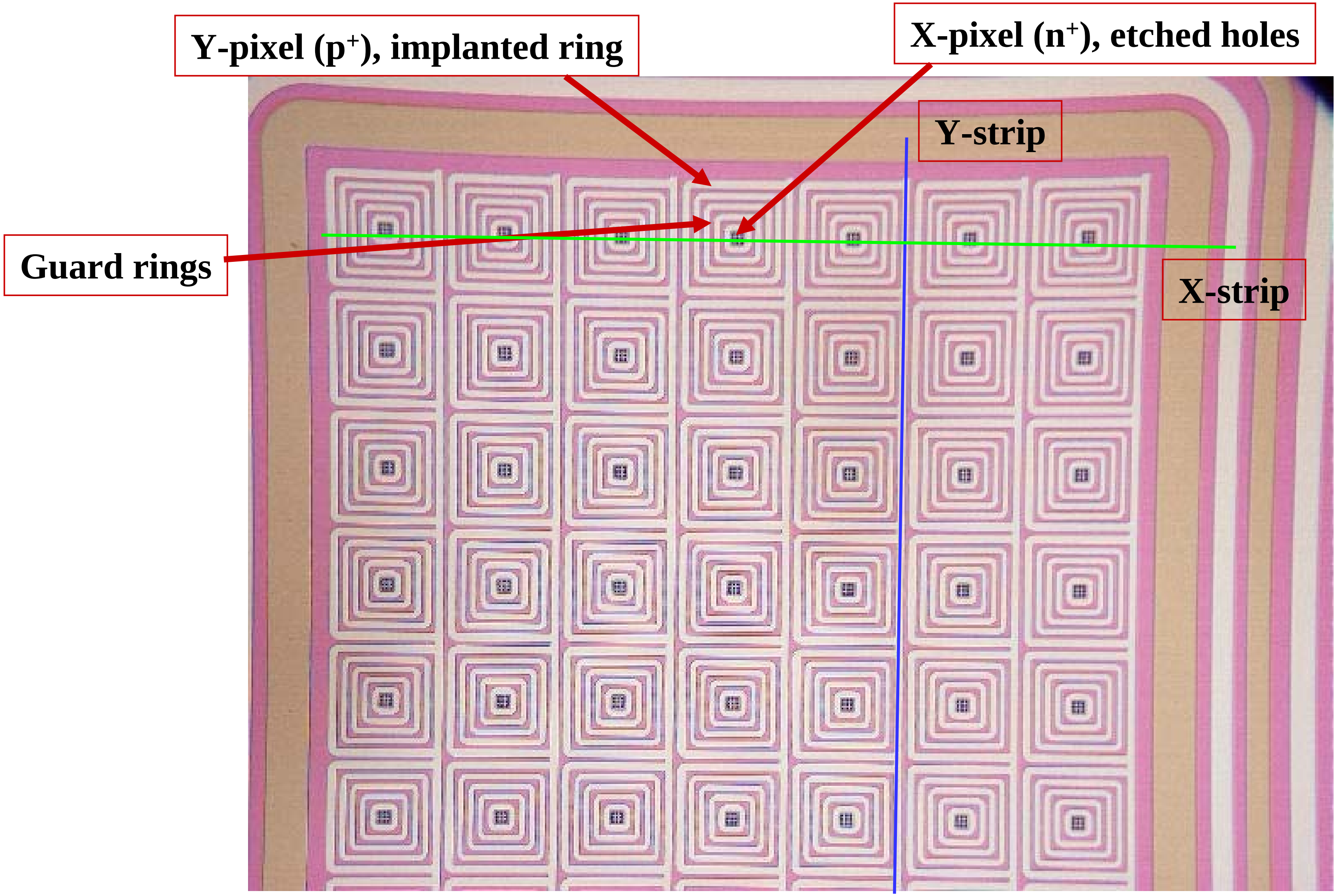
1mm
80 µm

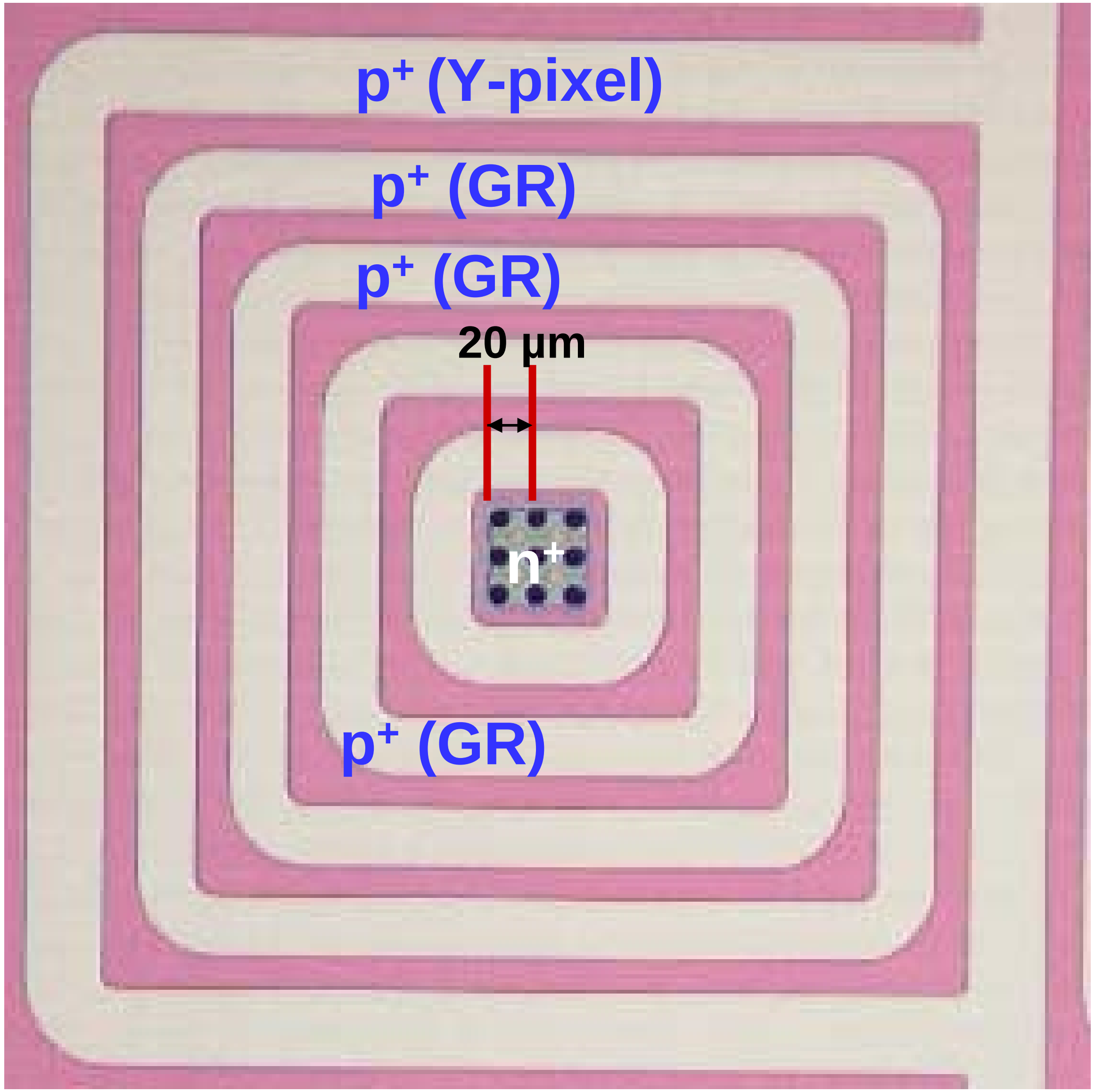
n^+ columns: 10 μm diameter, 240 μm deep (300 μm thickness)



Test Structures:

500 μm pitch, n^+ region: 50 μm x 50 μm,





p+ (Y-pixel)
p+ (GR)
p+ (GR)
20 µm
n+
p+ (GR)

Summary

- New 3d Structures have been proposed

- Design and processing of new 3d detectors have begun
  - 1-column 3d detectors
  - One-sided processing with 2d sensitivity
  - Planar and 3d technologies
  - n^+ columns have been etched and doped at CNM
  - The remaining planar processing are under way at BNL

- First prototype detectors will be available in 2 months