Novel Stripixel Detectors on High Resistivity p-type Magnetic Czochralski Silicon for Experiments at Super LHC

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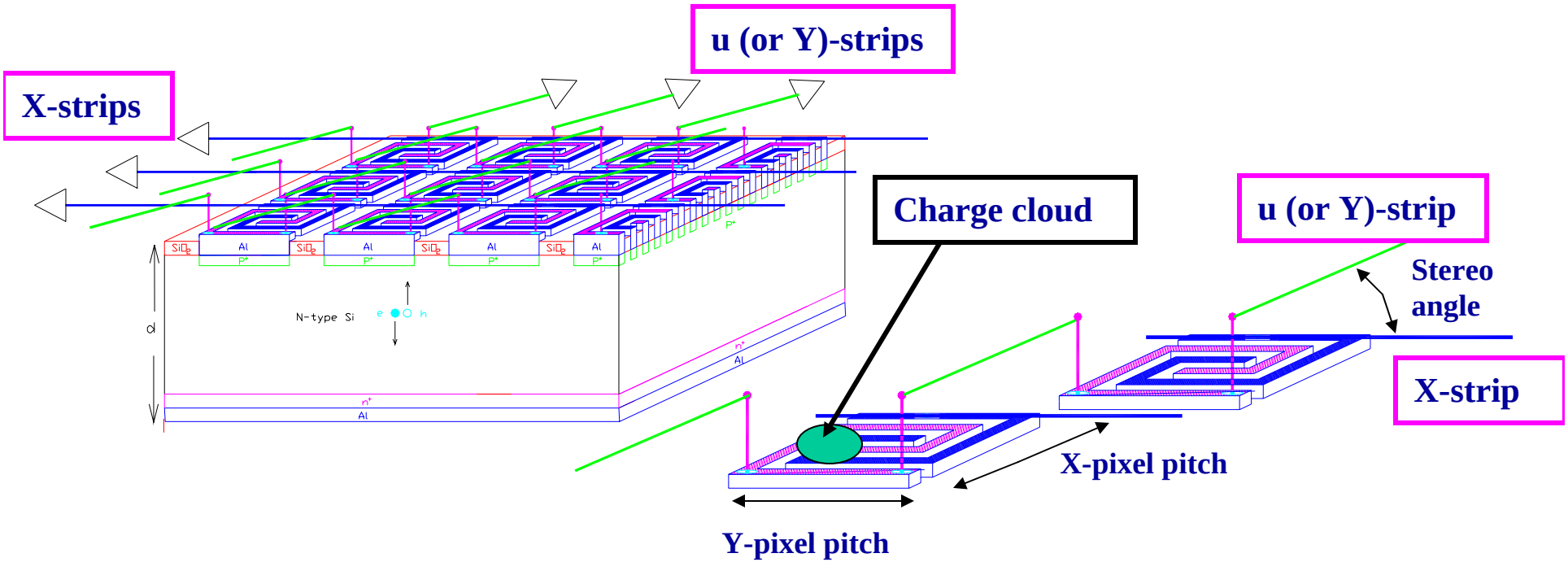
OUTLINE

- **Introduction**
- **Detector Design Considerations**
  - **Detector Layout**
  - **Detector Material**
  - **Detector Simulations**
- **Detector Design**
- **Detector Fabrication Plan**
- **Summary**

Introduction

o **Schematics of the novel stripixel detectors developed at BNL** **(Z. Li, Nucl. Instr. & Meth. A 518, Vol. 3, (2004) pp738-753)**

2d position sensitivity
One-sided process
Stereo angle between u (or X) and Y strips
X and Y pixels interleaved for charge sharing



Detector Design Considerations

US ATLAS Upgrade

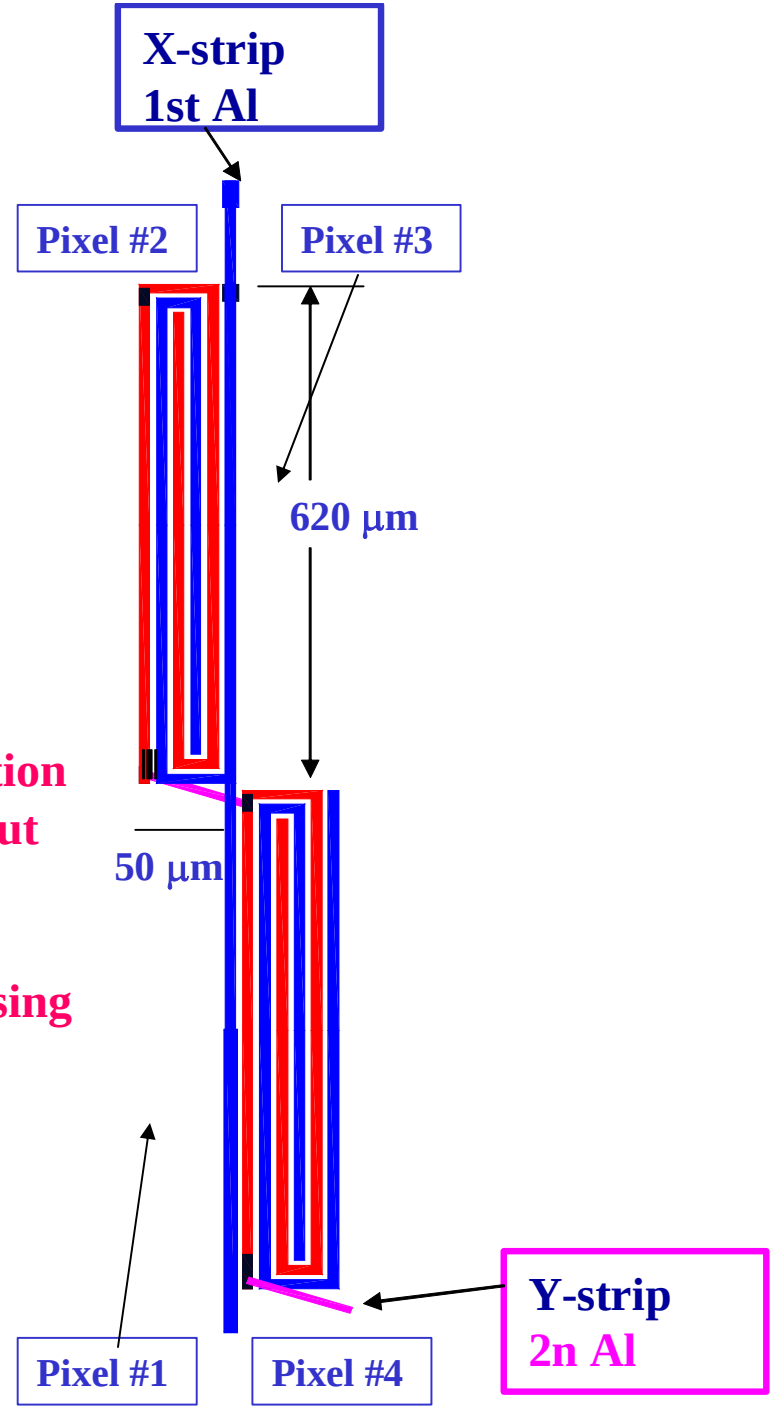
- For LHC Upgrade (Supper LHC), due to high luminosity, tracking detectors should have short strips, more radiation hardness and low cost

- Stripixel detectors with short strips is a good fit

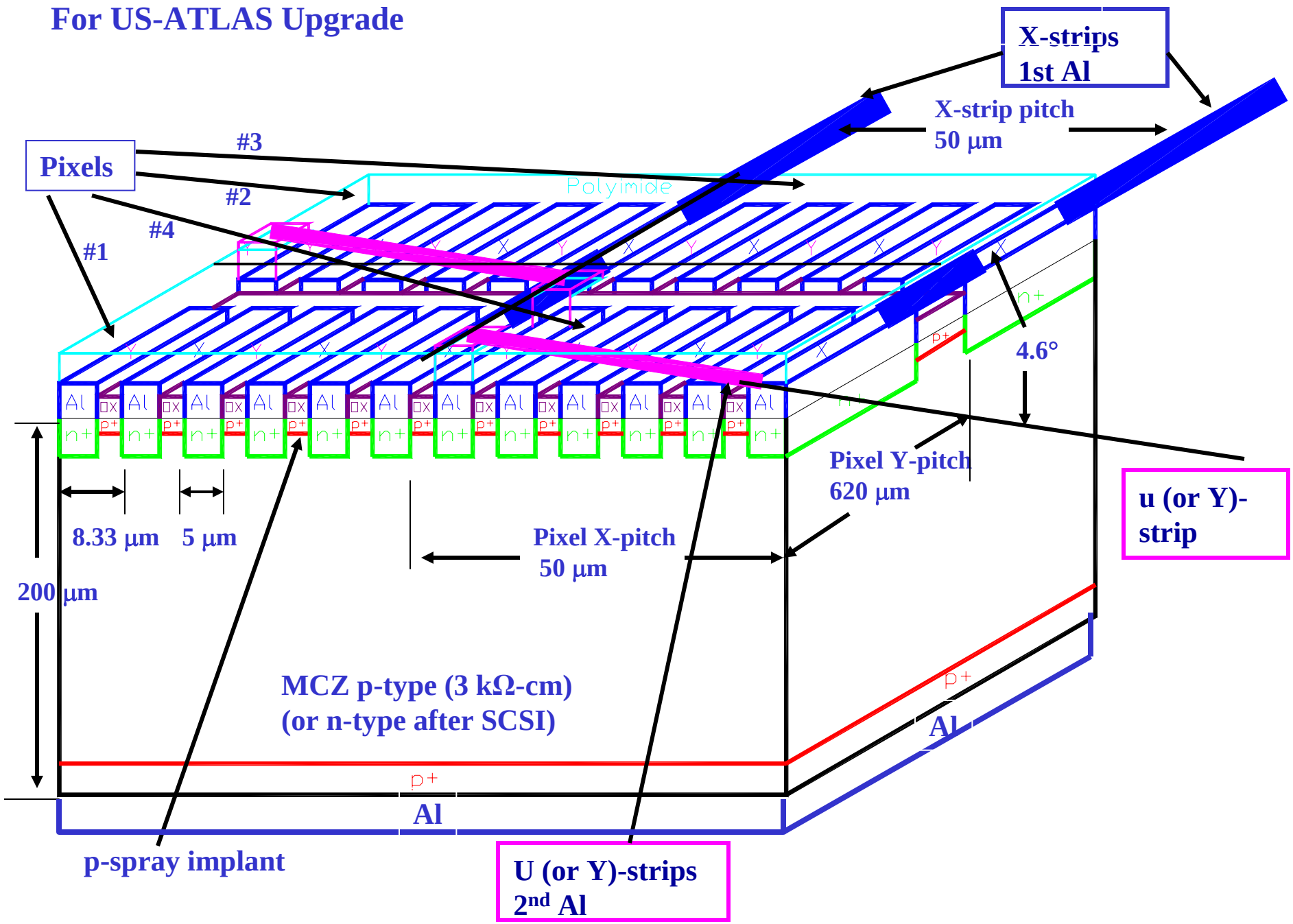
- In the inter-medium region of SLHC, expected radiation fluence of charged particles for strip detectors is about 2.0×10^{15} n_{eq} (1 MeV neutron equivalent)/cm^2.

- MCZ p-type Si is intrinsic radiation hard and processing is simple

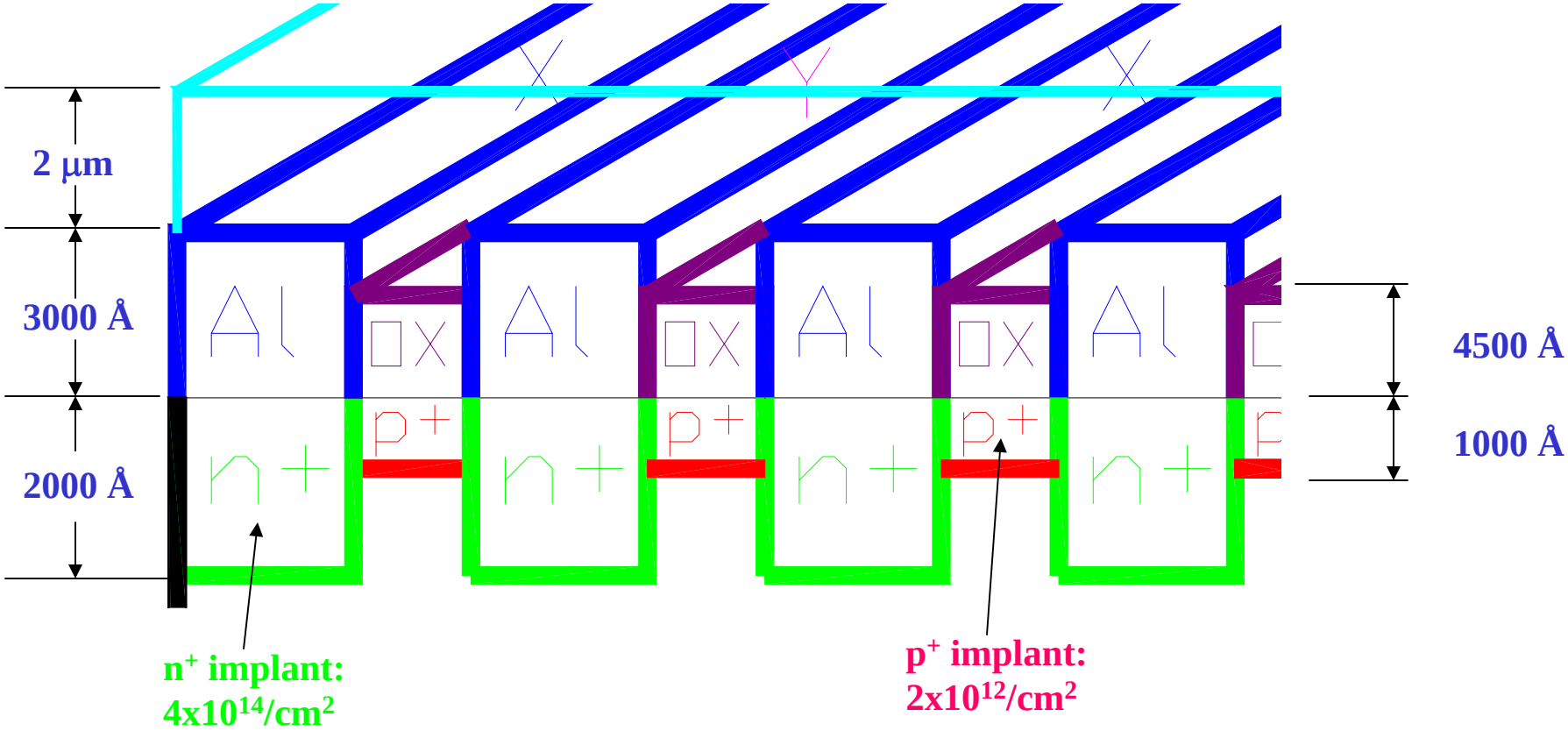
Pixel pitches: 620 μm (X) and 50 μm (Y)
Strip pitches: 50 μm (u) and 50 μm (Y)
Stereo angle between u and Y strips: 4.6 º
MCZ p-type, detector thickness 200 μm



Novel n on p and n on n 2d-sensitive Si Stripixel detectors on MCZ wafers For US-ATLAS Upgrade



Detector processing parameters

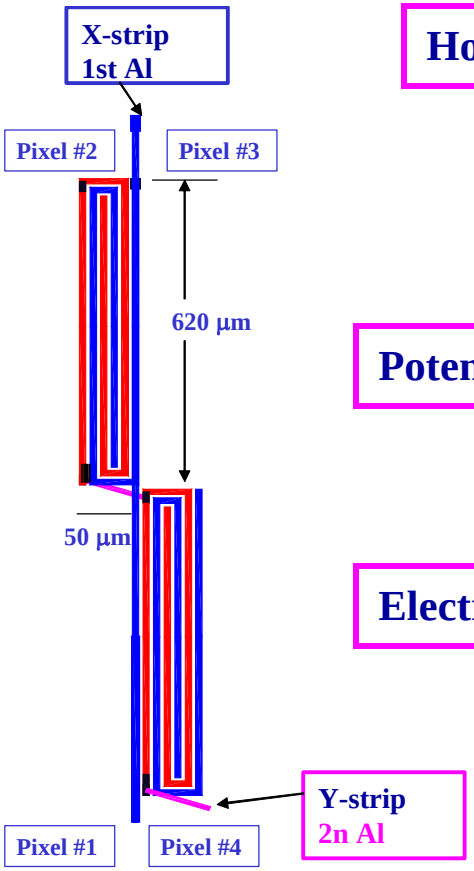


Detector Materials

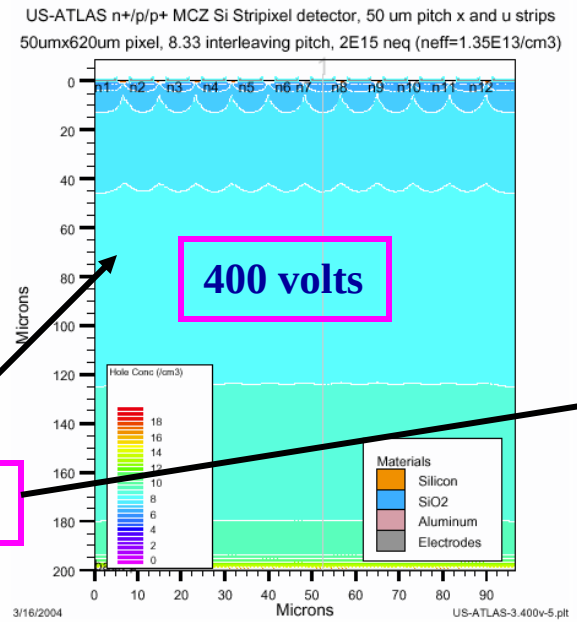
- **Magnetic Czochralski (MCZ) Si used for its intrinsic radiation hardness to charged particles (about a factor of 5 better than control float zone Si, and a factor of 2 better than oxygenated float zone Si [Z. Li et al., TNS Vol. 51, No.4, Aug. 2004, pp1901-1908])**
- **p-type Si used for the following advantages:**
  - **No SCSI**
  - **One-sided process (much simpler than n on n)**
  - **More radiation hardness in terms of higher CCE than n-type Si [G. Casse et al., Performances of miniature microstrip detectors made on oxygen enriched p-type substrates after very high proton irradiation, presented at Vienna Conference, 2004, submitted to NIM A]**

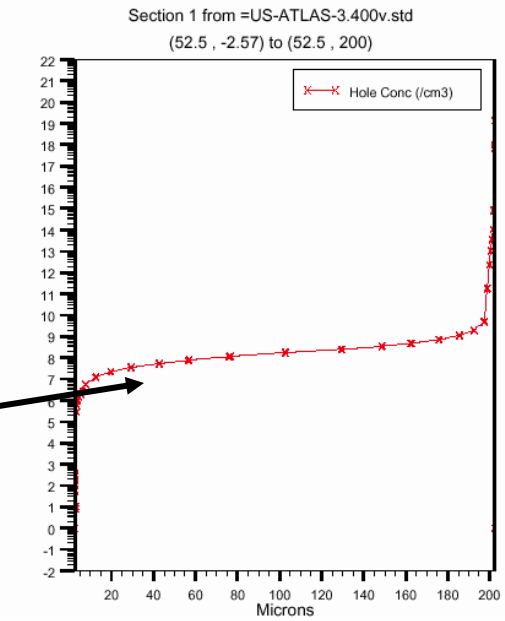
Detector Simulations

Electric simulation on the Novel n on p and n on n 2d-sensitive Si Stripixel detectors on MCZ wafers For US-ATLAS Upgrade After $2x10^{15}$ n_{eq}/cm^2 radiation

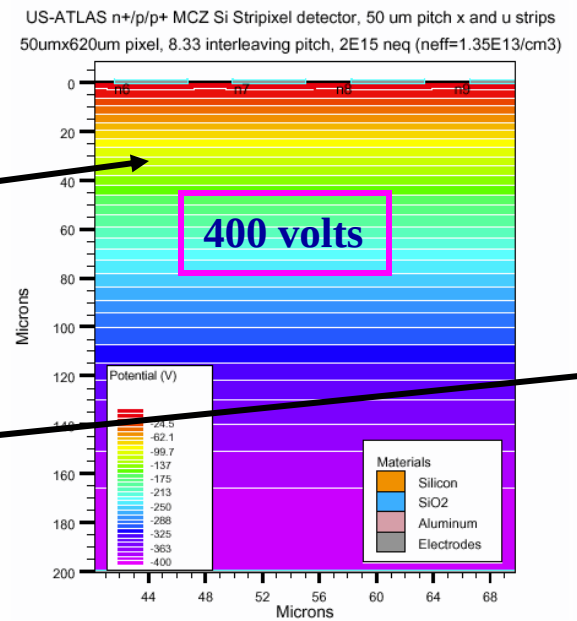


Hole concentration

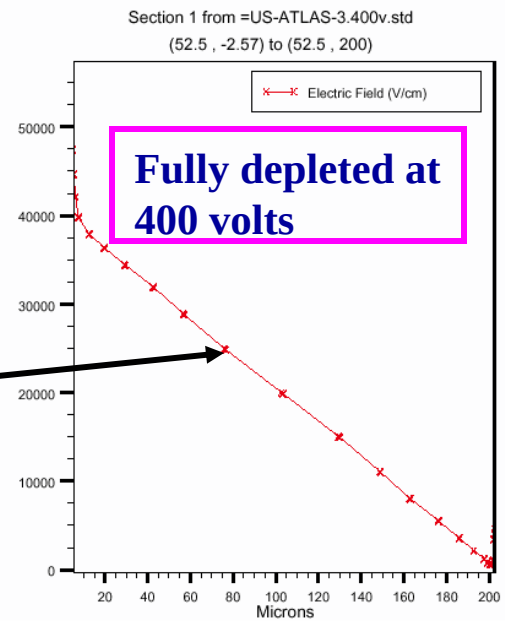




Potential profile

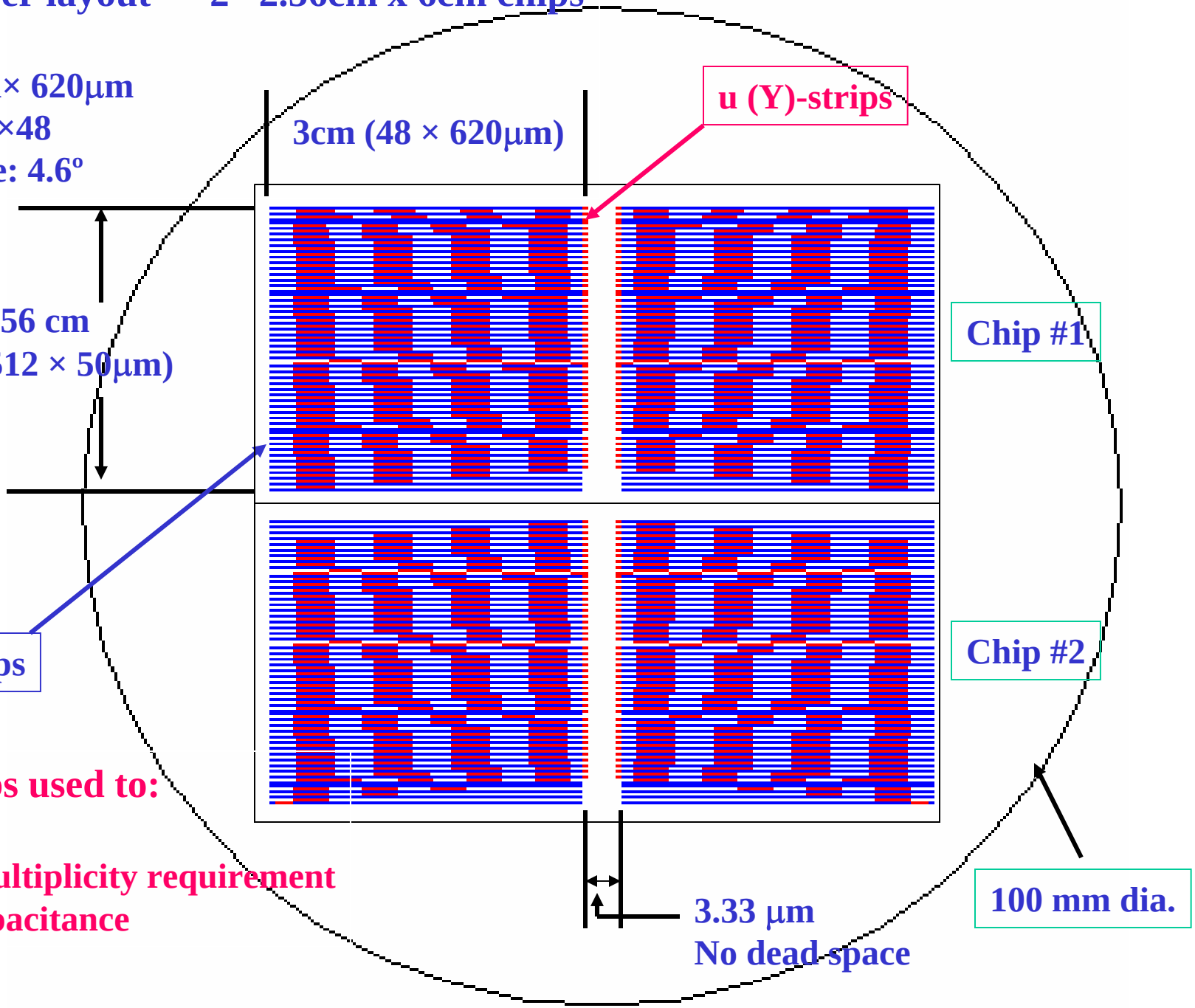


Electric field



Whole wafer layout --- 2 2.56cm x 6cm chips

Pixel: 50μm× 620μm
Array: 512 ×48
Stereo angle: 4.6º

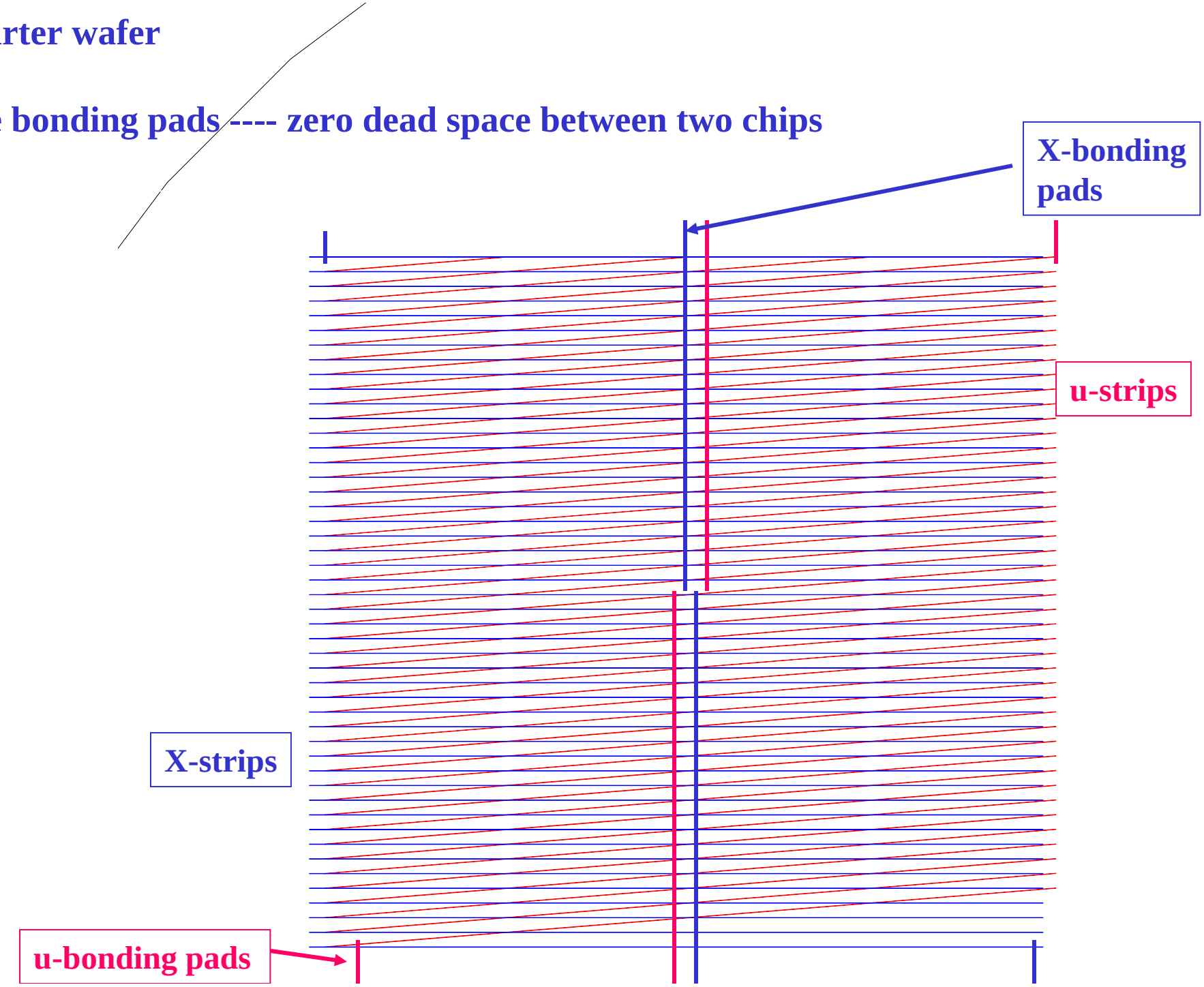


Short strips used to:

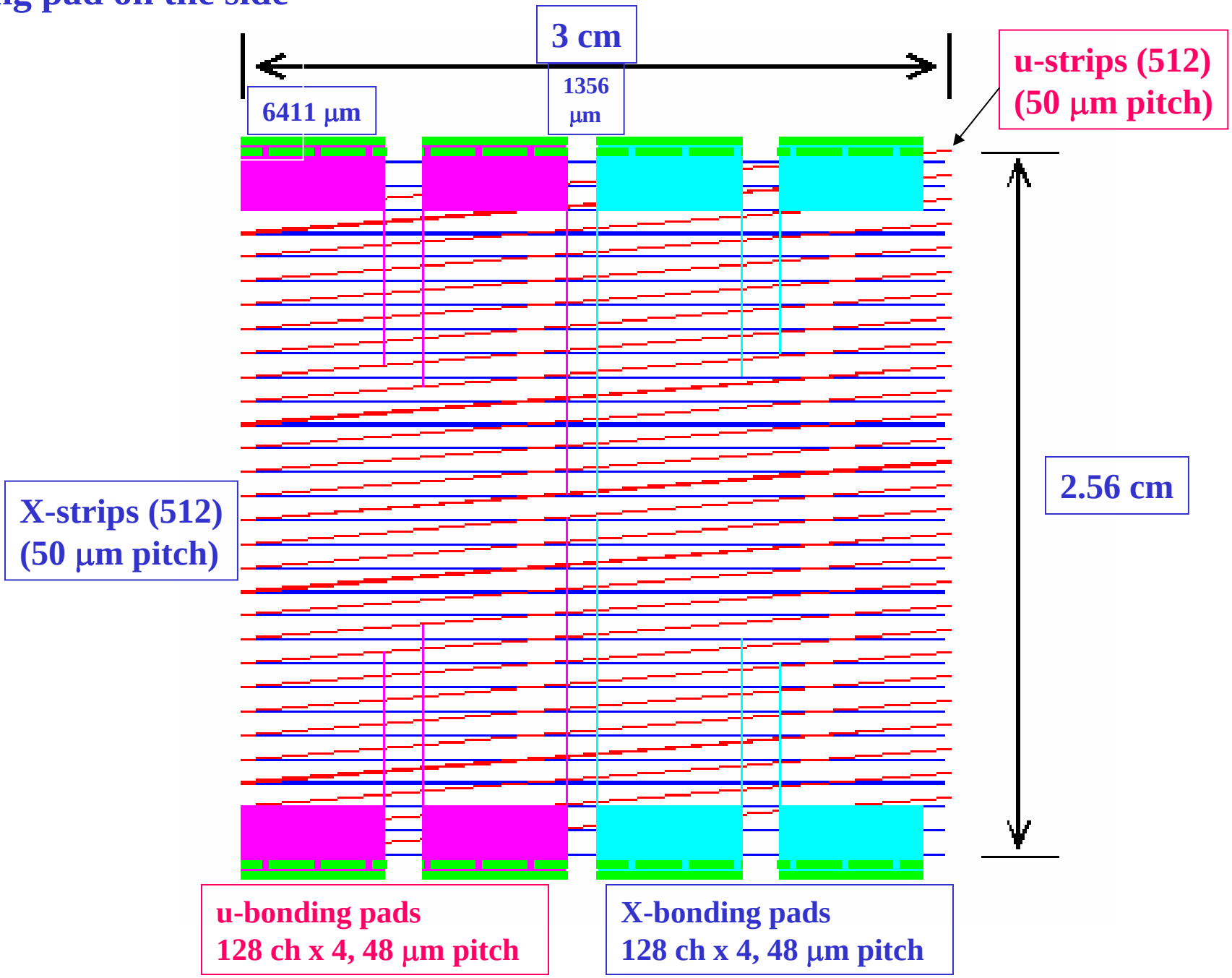
Meet the multiplicity requirement
Low the capacitance

Quarter wafer

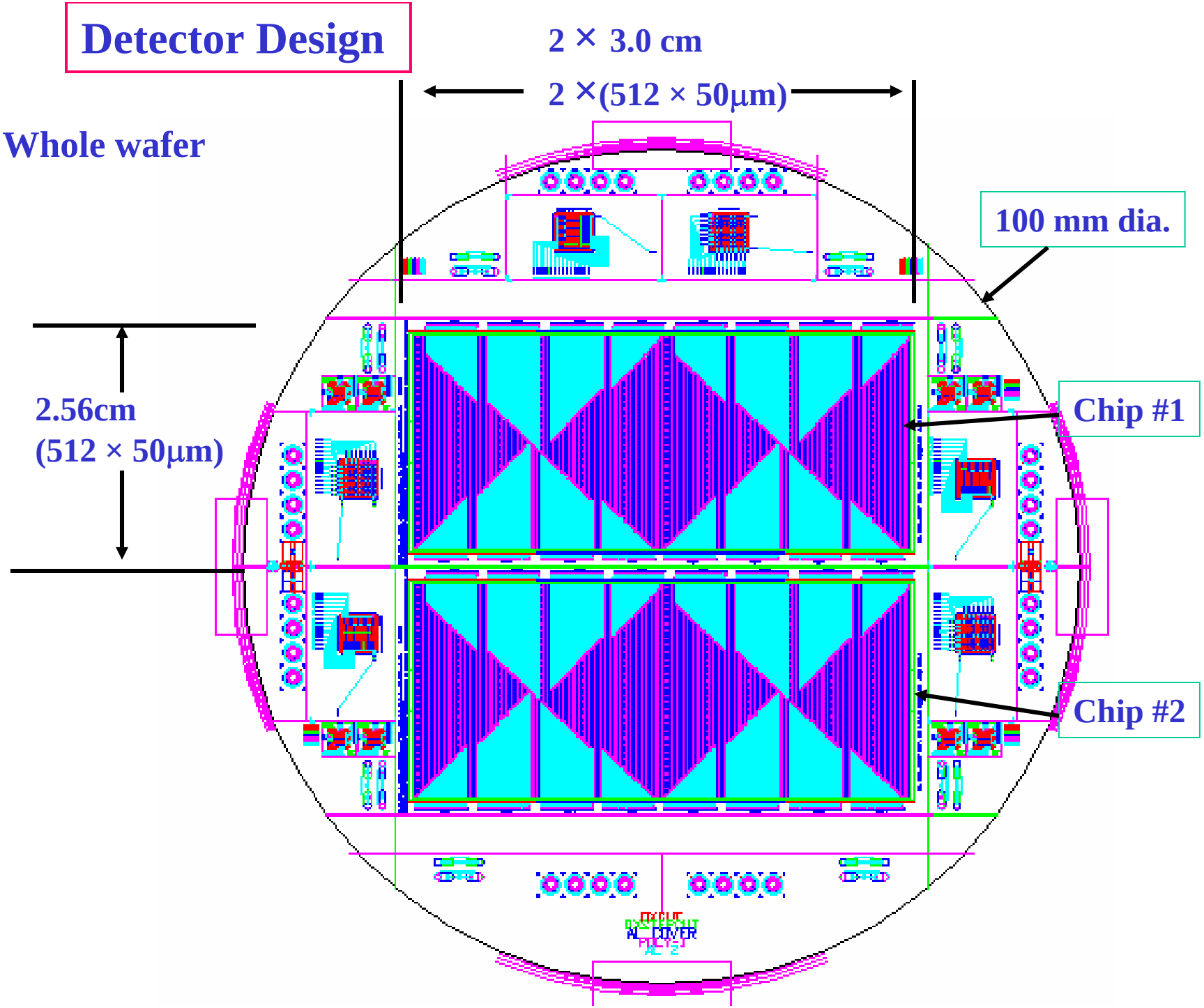
Side bonding pads ---- zero dead space between two chips



Bonding pad on the side

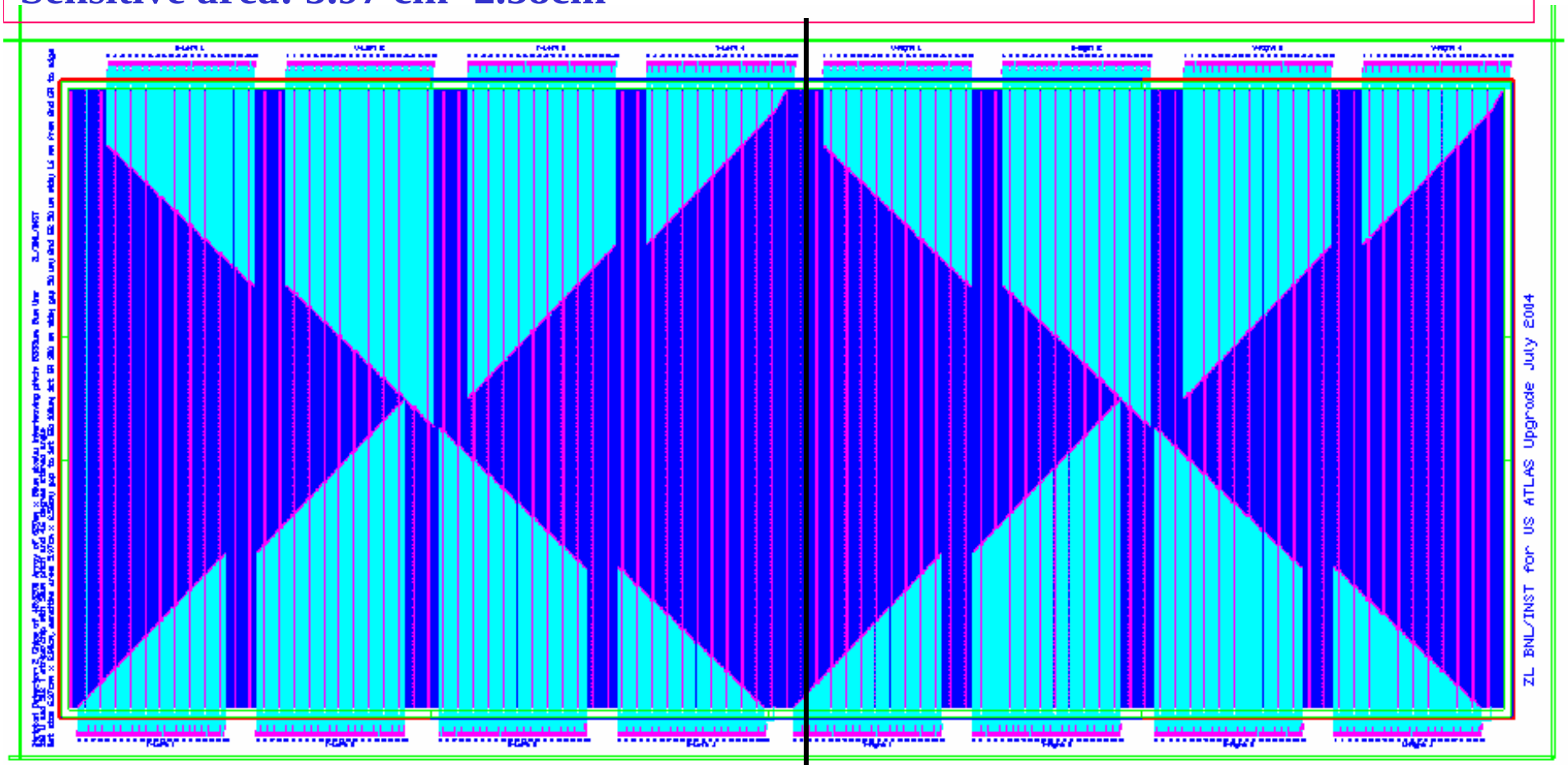


Detector Design



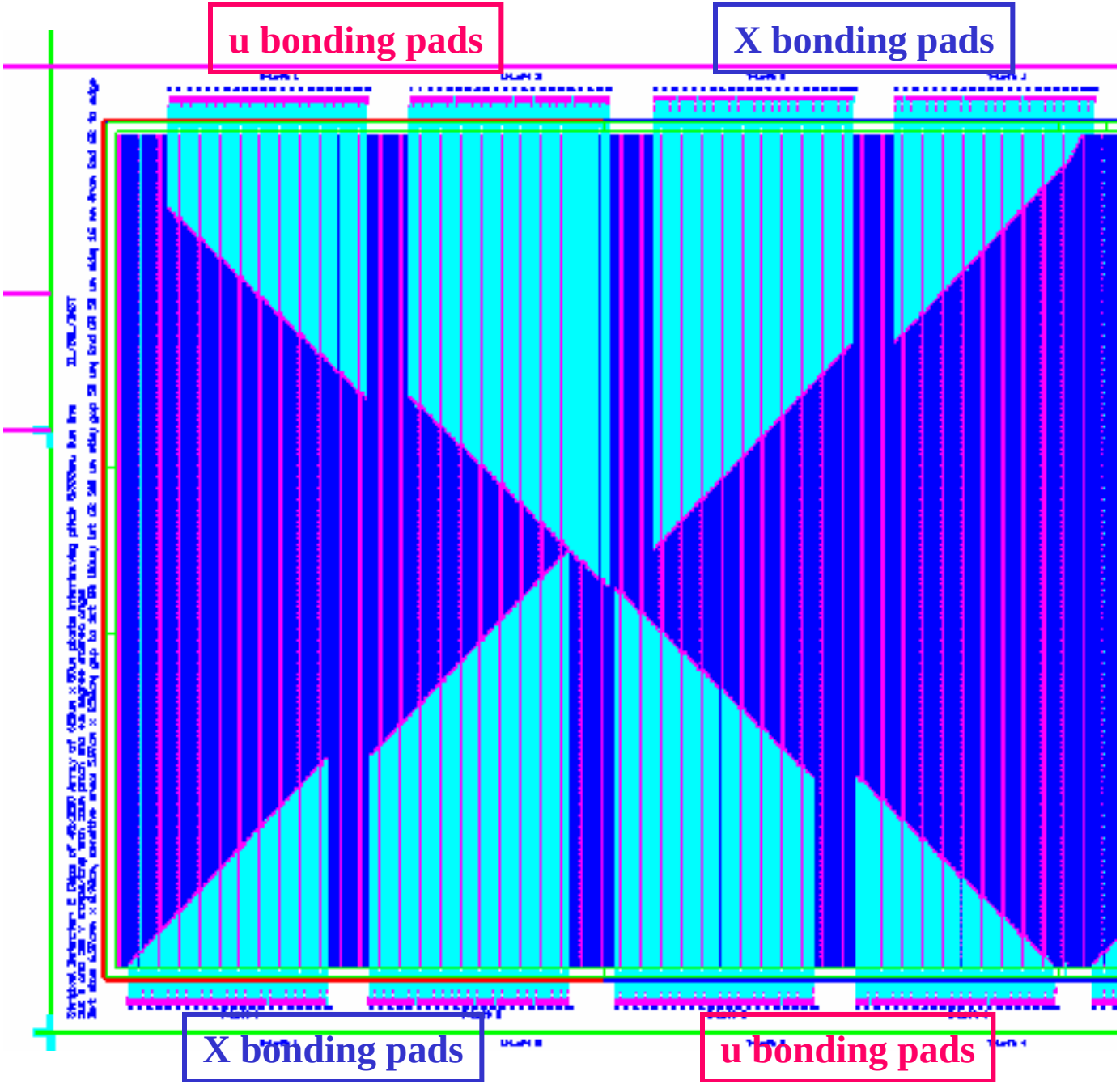
Detector Chip (half wafer)

US ATLAS Stripixel Detector: 2 halves of 48×512 array of 620 μm×50 μm pixels
Interleaving pitch: 8.33 μm, 5 μm line width
512 u and 512 X strips/half with 50 μm pitch and 4.6 stereo angle
Detector size: 6.37 cm×2.98 cm
Sensitive area: 5.97 cm×2.58cm

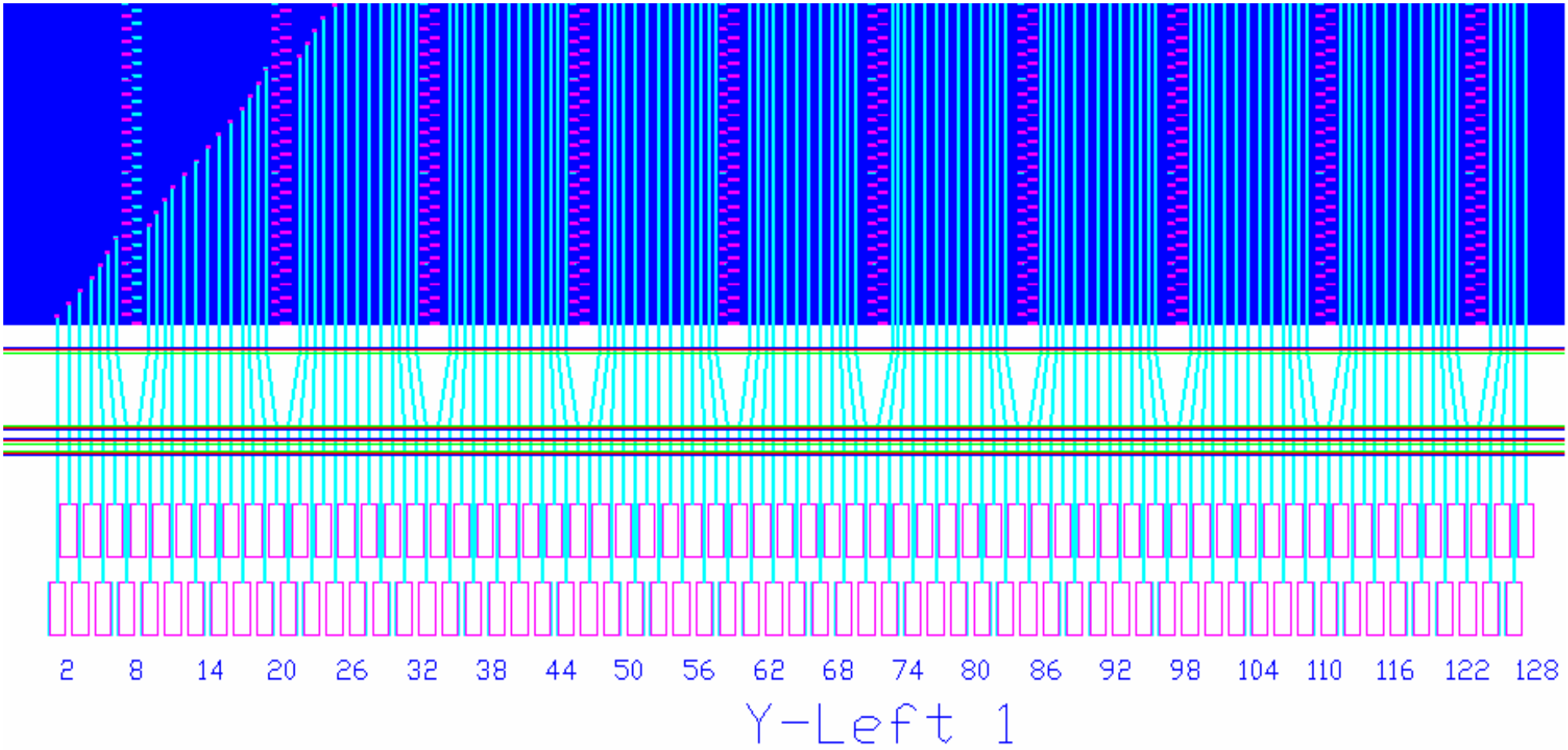


Left half | **Right half**

Quarter wafer (half of detector chip)

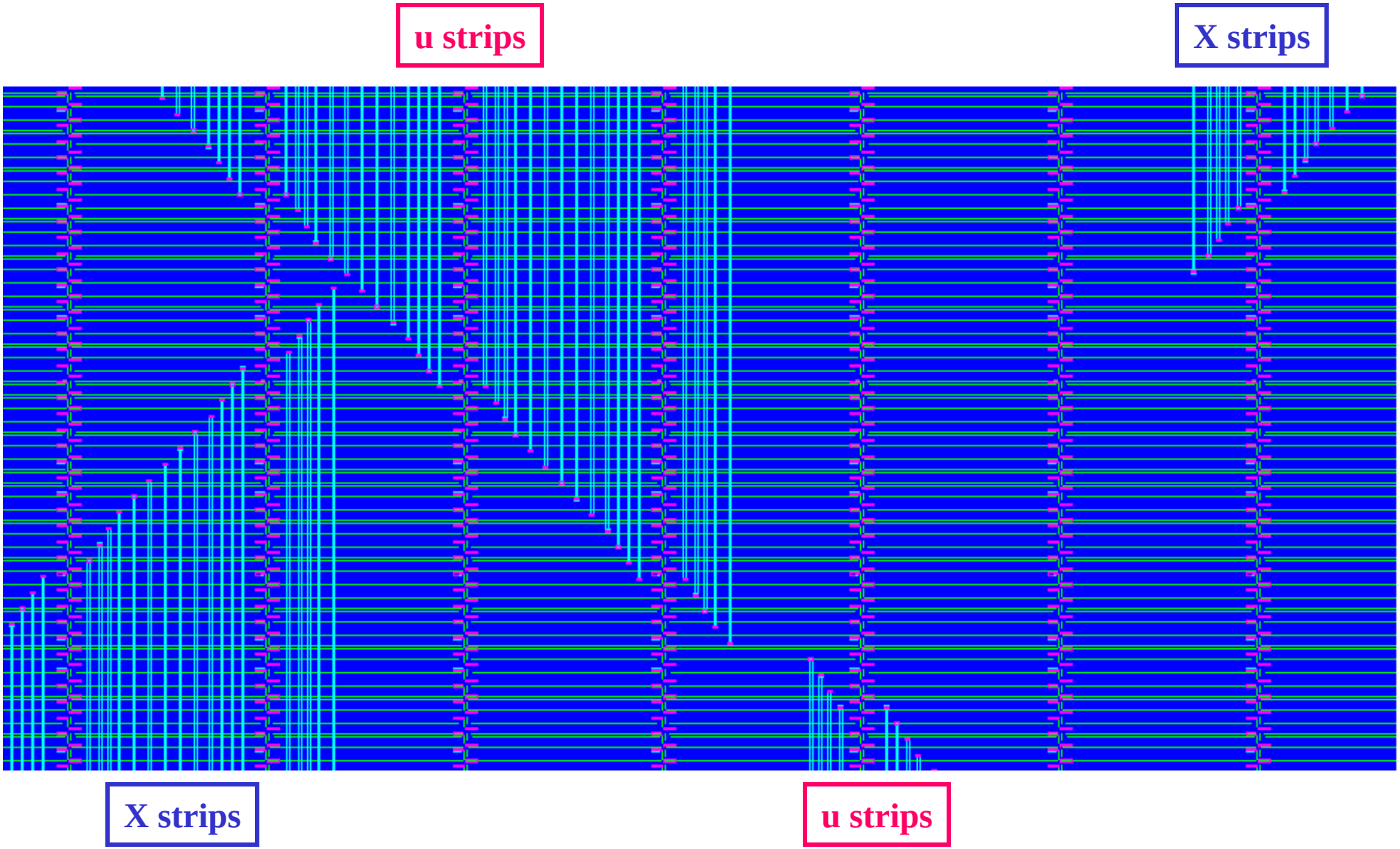


Bonding pads

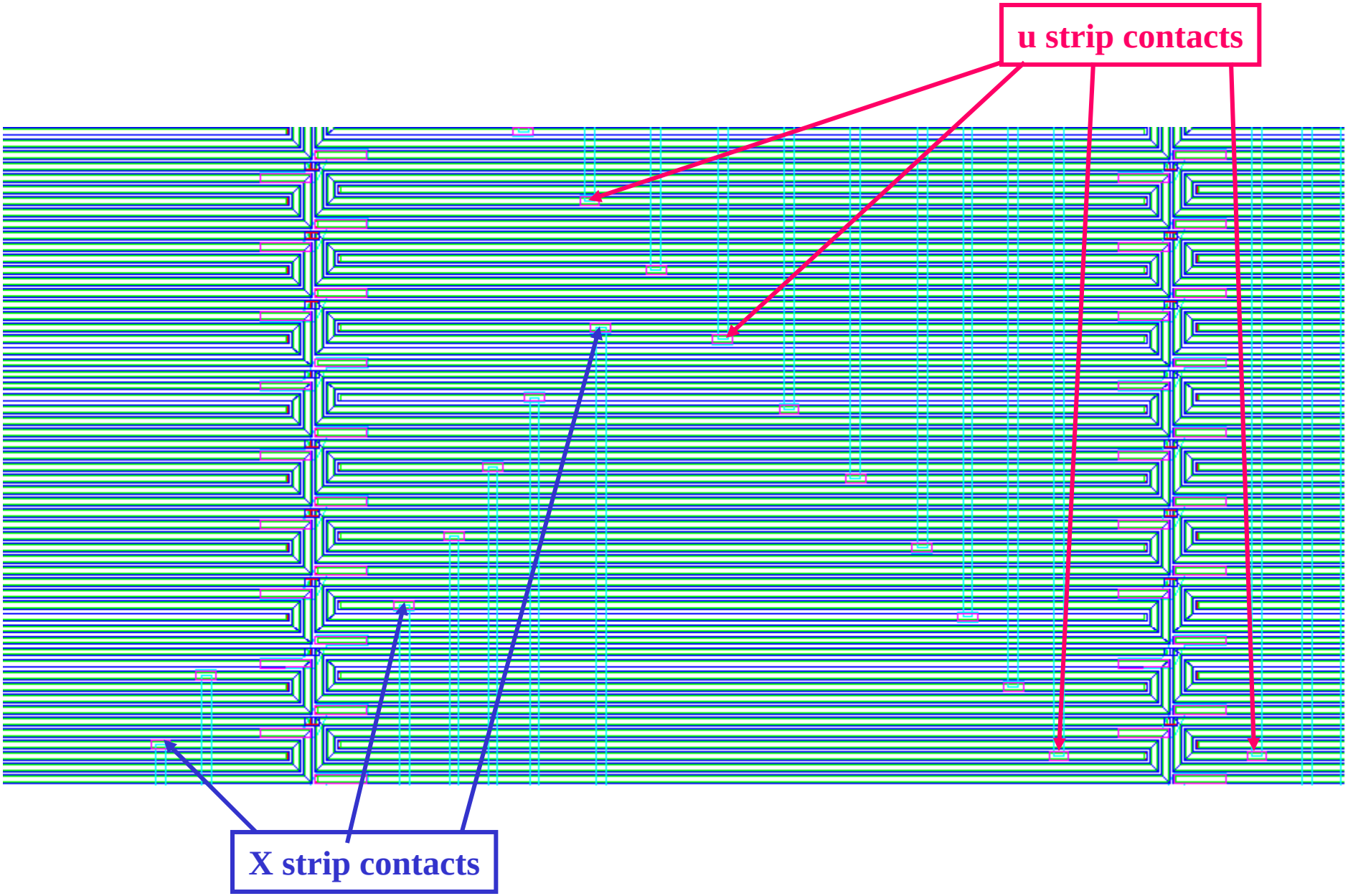


128 channels, 48 μm pitch

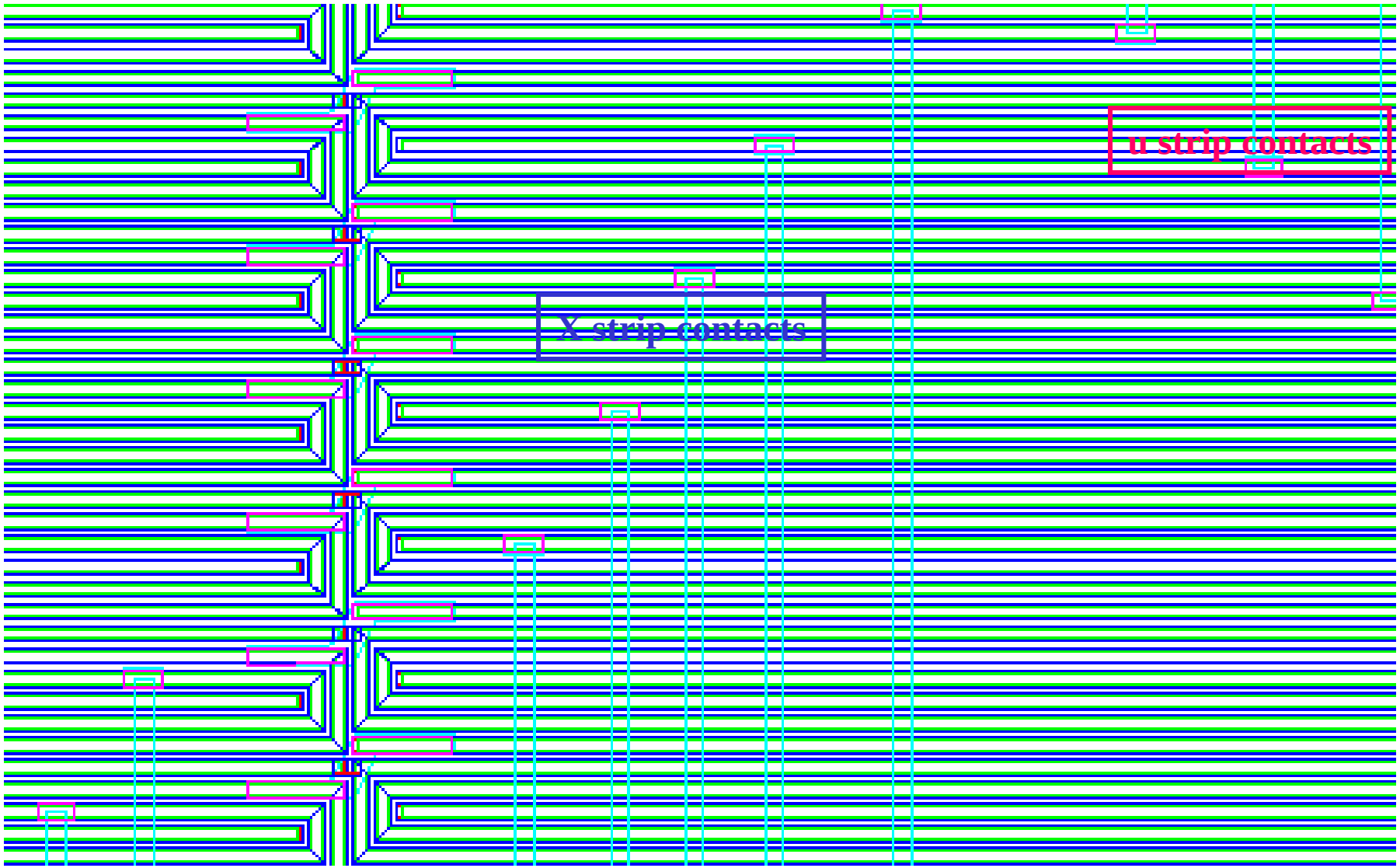
Strip routing to the sides



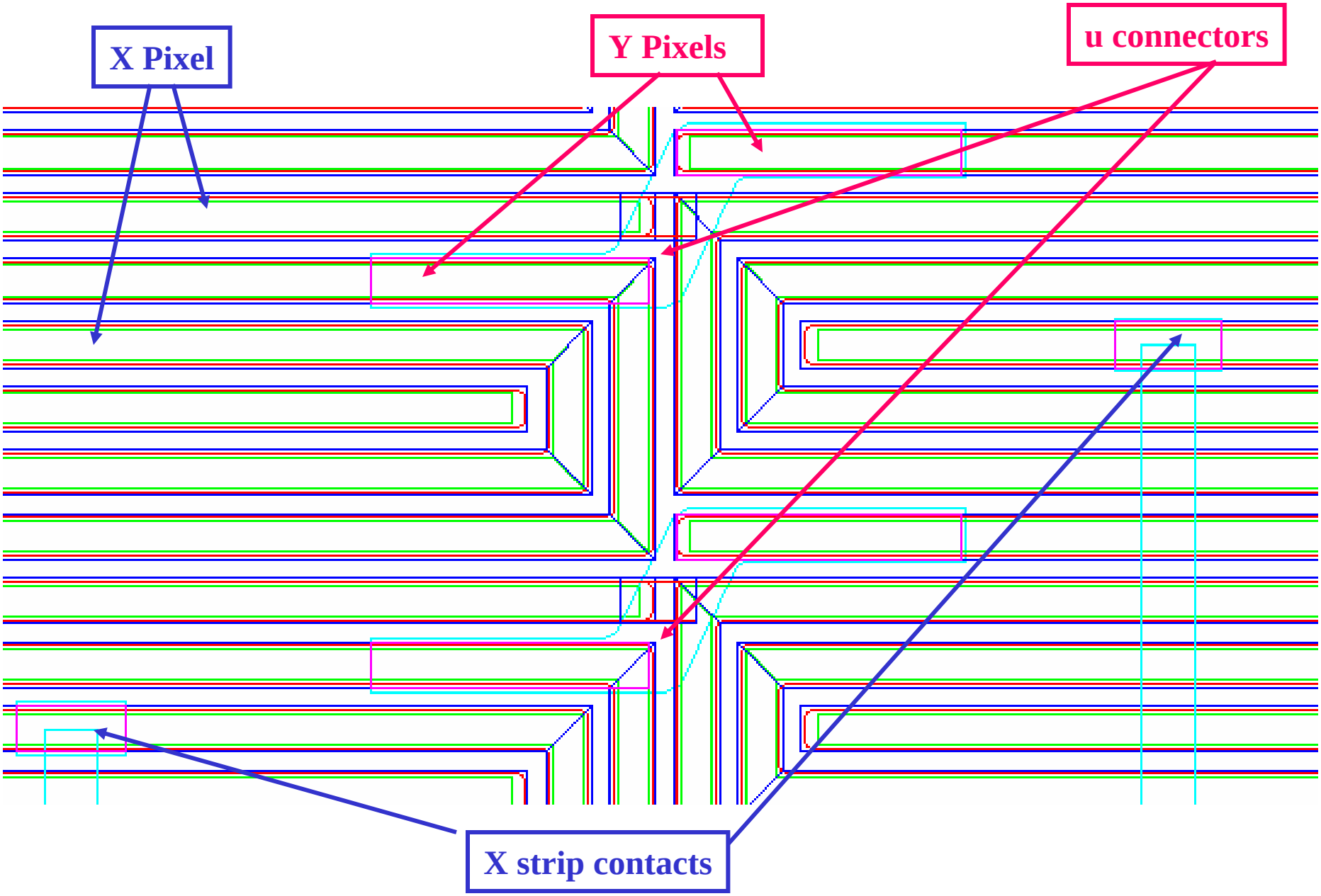
Contact vias for strips between 1st and 2nd Al layers



Contact vias for strips between 1st and 2nd Al layers

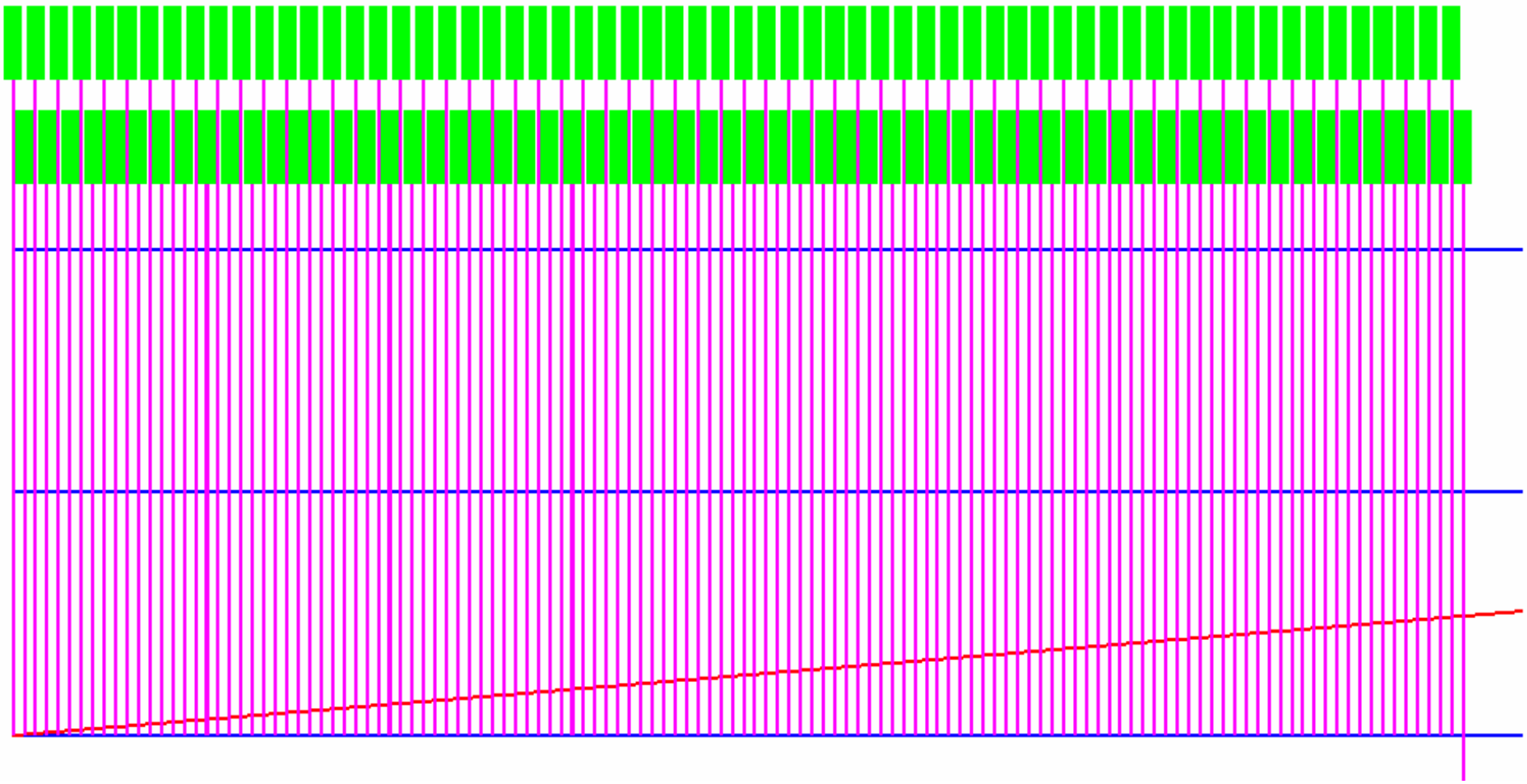


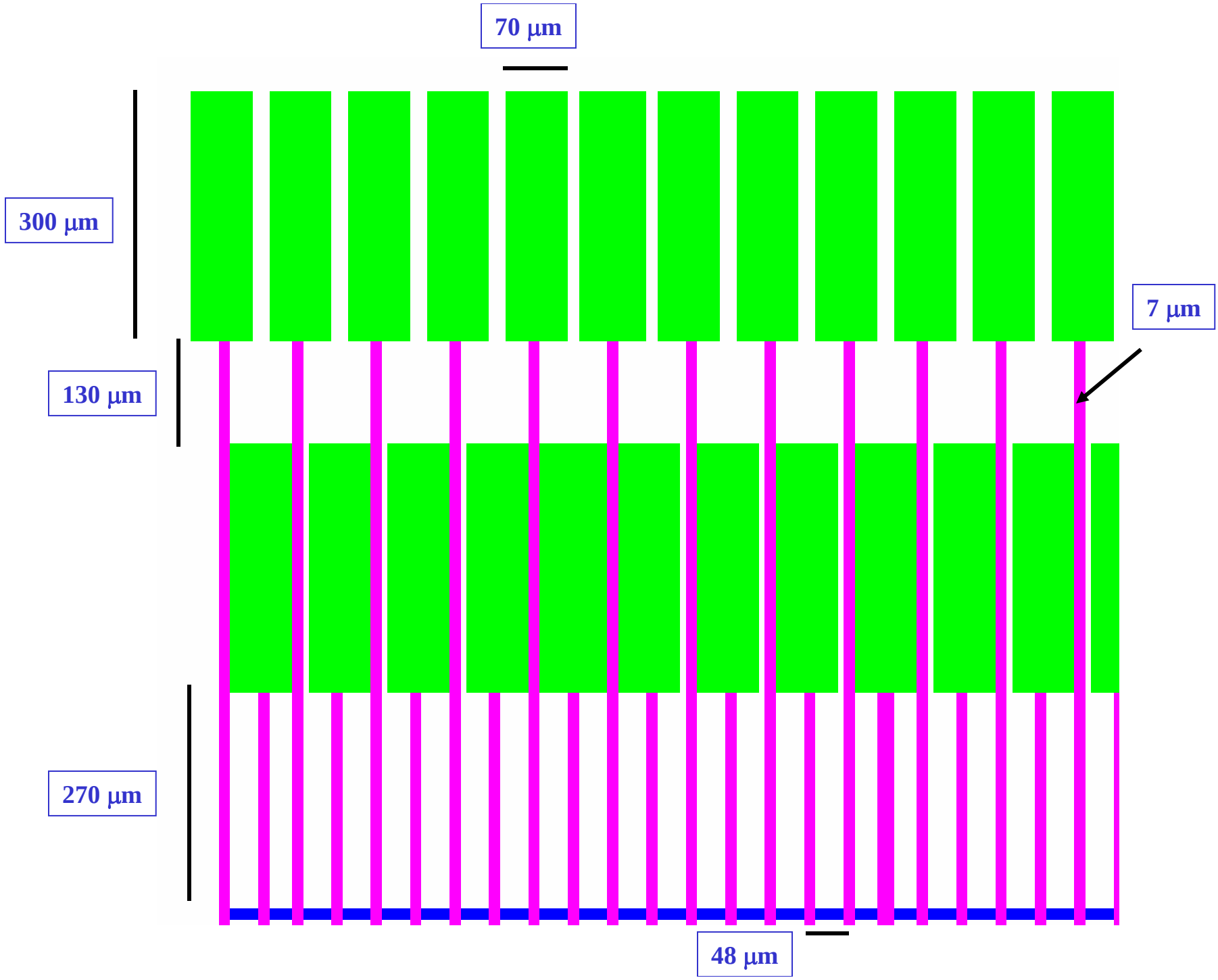
Connections between the Y pixels for the formation of u-strips



Bonding pads

Bonding pads, 70x300 μm^2
128 ch, 48 μm pitch




70 μm
300 μm
7 μm
130 μm
270 μm
48 μm

Detector Fabrication plan

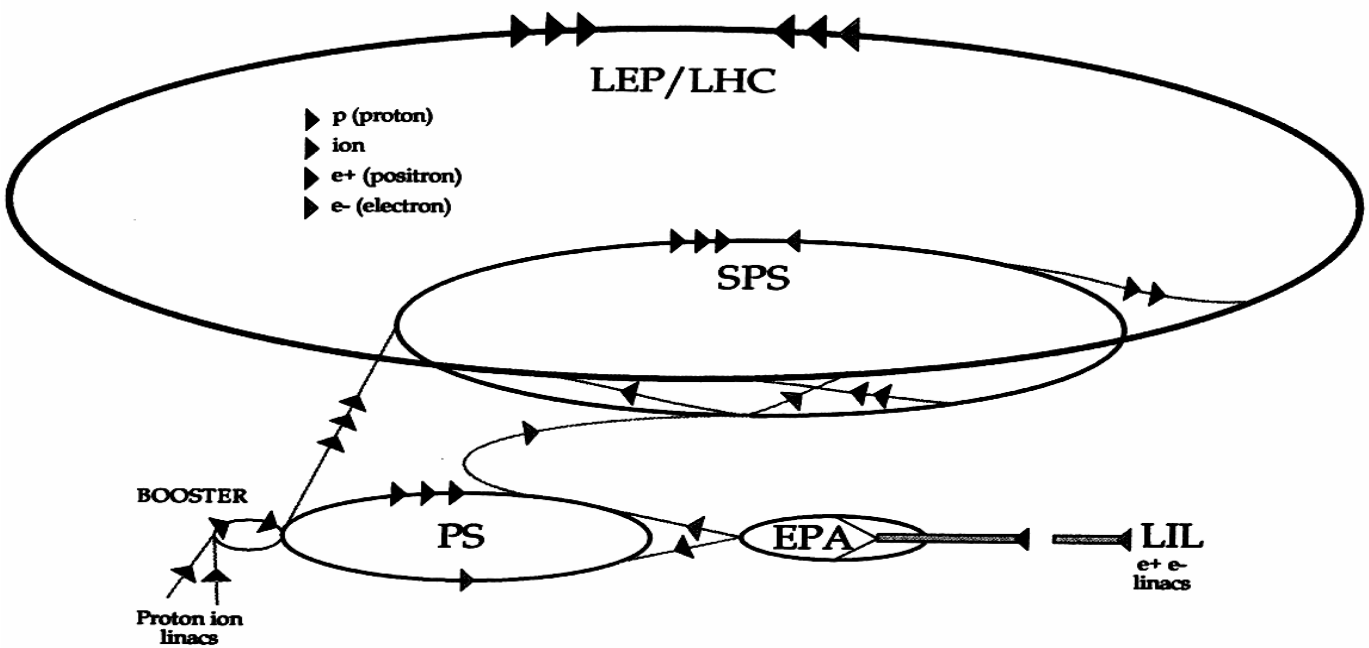
- **Mask set for the first prototype batch has been ordered**
- **A pre-check batch on n-type MCZ wafers has started in November, 2004 (completion by 1/05)**
- **The first prototype batch on p-type MCZ wafers will start in 1/05**
- **Testing of the first prototype detectors before and after proton radiation:**
  - **IV, CV**
  - **TCT**
  - **CCE's**

Summary

- **Novel Si stripixel detectors has been proposed for US-ATLAS Upgrade**
  - **2d position sensitivity**
  - **One-sided process**
  - **Short strips to low the capacitance and met multiplicity requirement**
- **P-type MCZ Si wafers will be used**
  - **Intrinsically radiation hard due to nature high [O]**
  - **No SCSI**
  - **One-sided processing**
  - **Possible higher CCE than n-type Si**
  - **Partial depletion mode possible**
- **Simulations show normal electric properties**
- **Processing of prototype detectors is now underway**

High Energy Physics experiments

- The Large Hadron Collider (**LHC**) at CERN (Geneva, Switzerland)



  - EPA: Electron Proton Accelerator
  - PS: Proton Synchrotron
  - SPS: Super Proton Synchrotron
  - LEP: Large Electron Positron

High Energy Physics experiments at LHC

- ATLAS:

  A Toroidal Lhc Apparatus

- CMS:

  Compact Muon Solenoid

- ALICE:

  A Large Ion Collider Experiment

- LHC-B:

  Beauty experiment

p+/n-/n+ Cz-Si Detectors Processed on p-type Boron Doped Substrates with Thermal Donor Induced Space Charge Sign Inversion

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In Framework of CERN RD50 Collaboration

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OUTLINE

- Cz-Si detector processing issues
- Thermal Donors (TD) in oxygen rich silicon
- TCT results
- Proton irradiation
- Conclusions

Processing of Cz-Si Detectors

•Basically no difference from standard Fz-Si detector process, except…

•High O content leads to Thermal Donor (TD) formation at temperatures 400^0C – 600^0C.

•TD formation can be enhanced if H is present.

•Typical process steps at 400^0C – 600^0C

- Aluminum sintering
(e.g. 30min @ 450^0C)
- Passivation insulators over metals
PECVD (Plasma Enhanced CVD)
Si3N4 @3000C, which contains H2

Thermal Donor generation

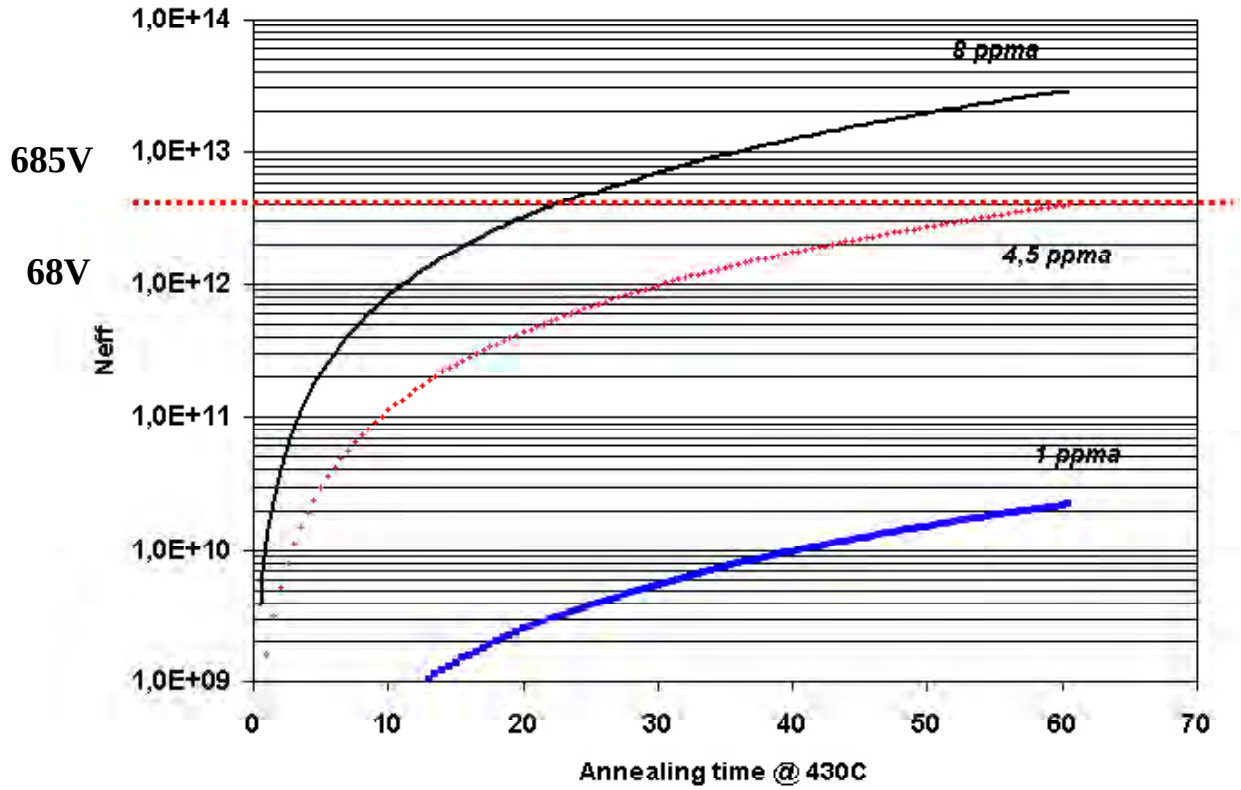
$$N_{TD} = \left(\frac{a}{b}\right) C_{io}^{\chi} \frac{1}{|N_d - N_A|^2} \left\{1 - e^{-bD_i C_{io} t}\right\}$$

$$D_i = 0{,}13\, e^{-\frac{E_A}{kT}}$$

χ = 2,45

E_A=2,53eV

W. Wijaranakula, Appl. Phys. Lett. 59 (13) 1608 (1991).

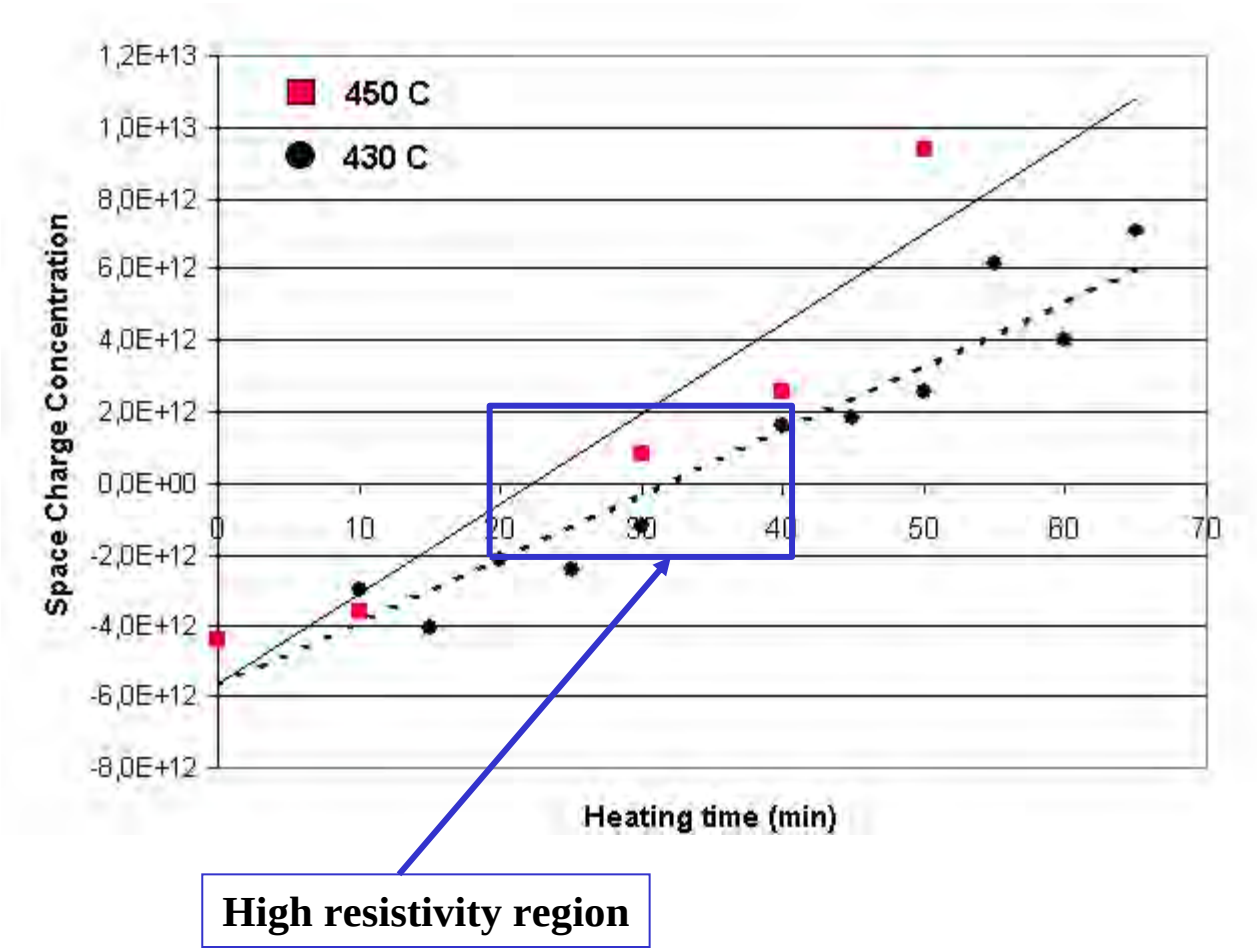


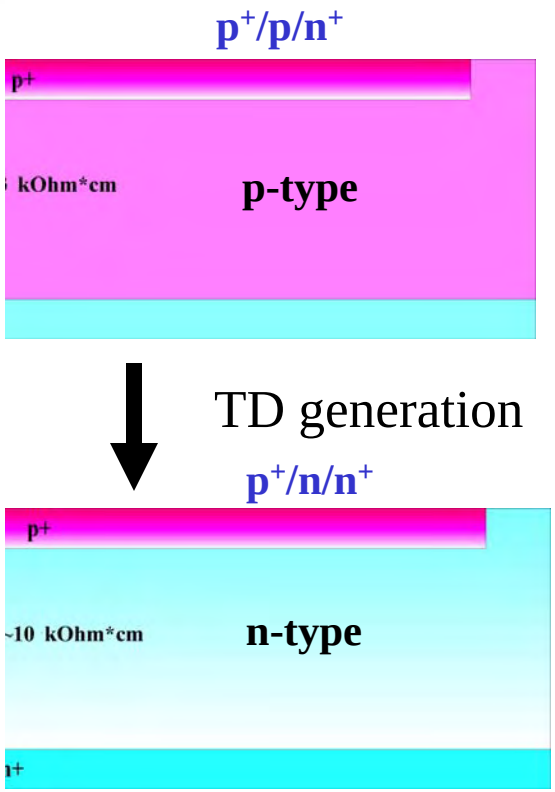
Cz-Si,
$O_i \approx 8*10^{17}$ cm^{-3}

MCz-Si,
$O_i \approx 4*10^{17}$ cm^{-3}

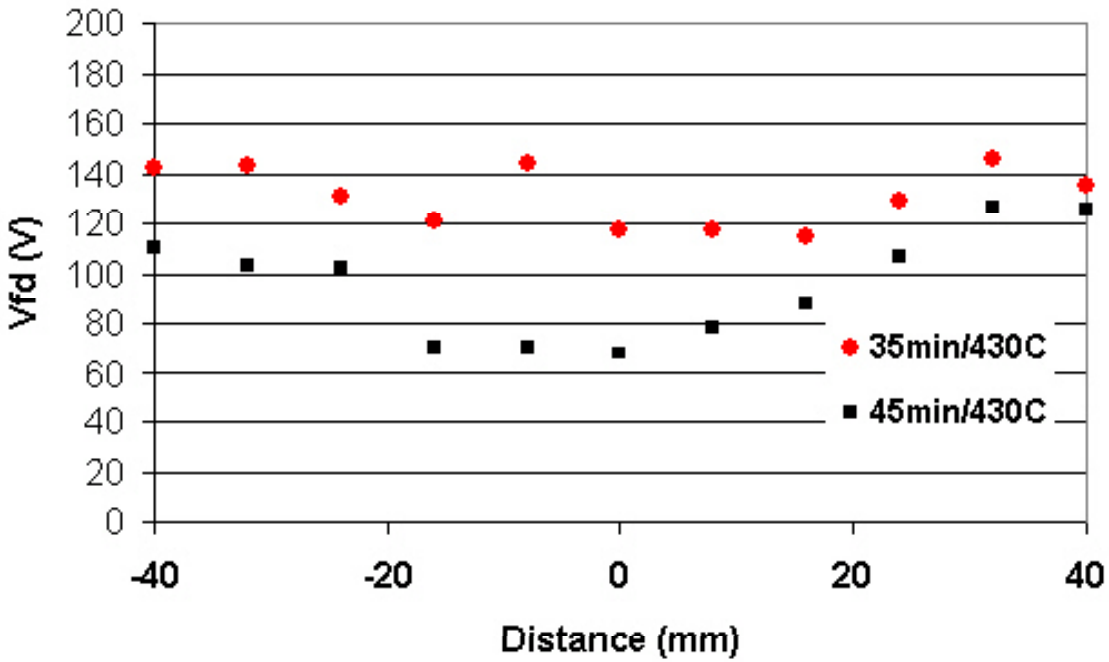
Oxygenated Fz-Si,
$O_i \approx 1*10^{17}$ cm^{-3}

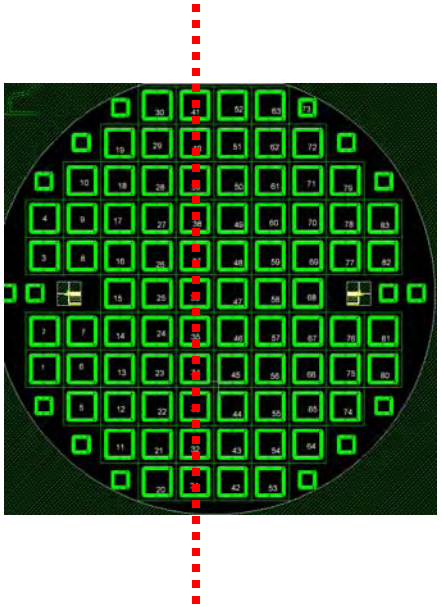
Thermal Donor generation (experimental results)





Thermal Donor generation (Homogeneity)





•We have not observed enhanced TD generation when the passivation was made by PECVD (Plasma Enhanced CVD) Si_3N_4 @300^{0}C, which contains H_2 10-30%.

See talk by Esa Tuovinen at 3rd RD50 Workshop

http://rd50.web.cern.ch/RD50/3rd-workshop/

MCZ-P33, p-type, $p^+/p/n^+$ detector, 307 μm, 430 ºC, 35 min (TDG) laser (red) front

P-type

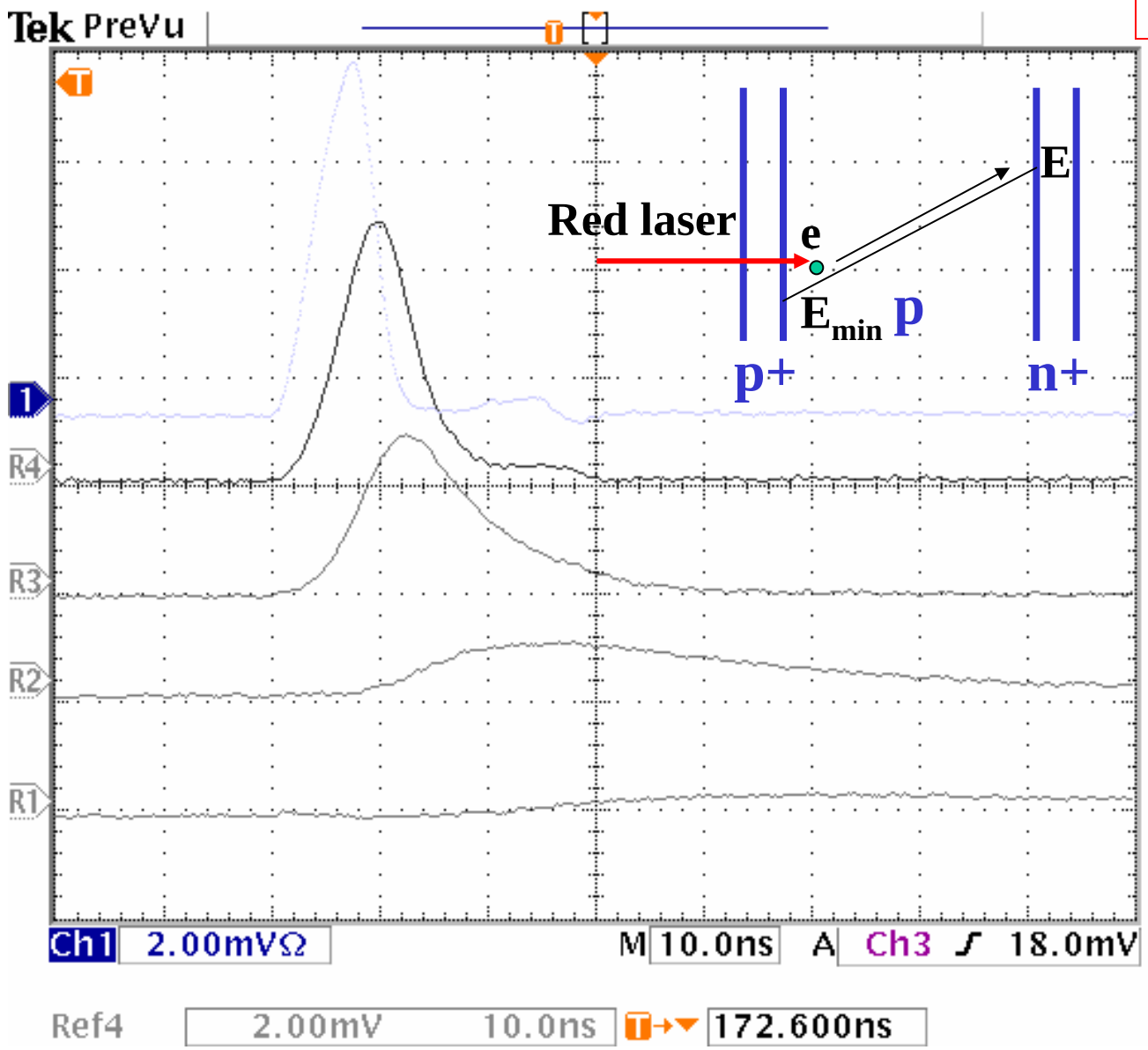
170 V

150 V

140 V

120 V

100 V



30 Mar 2004
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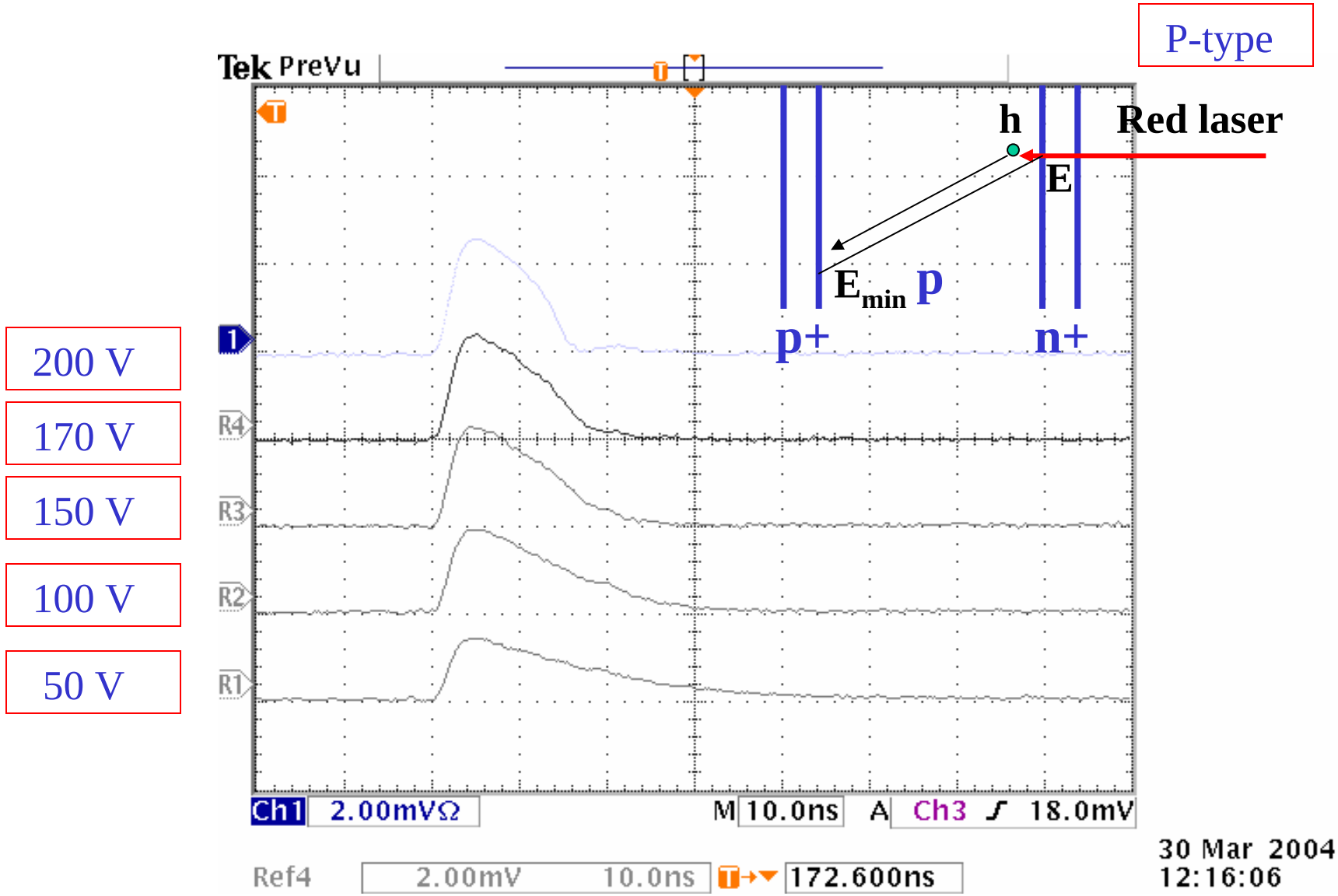
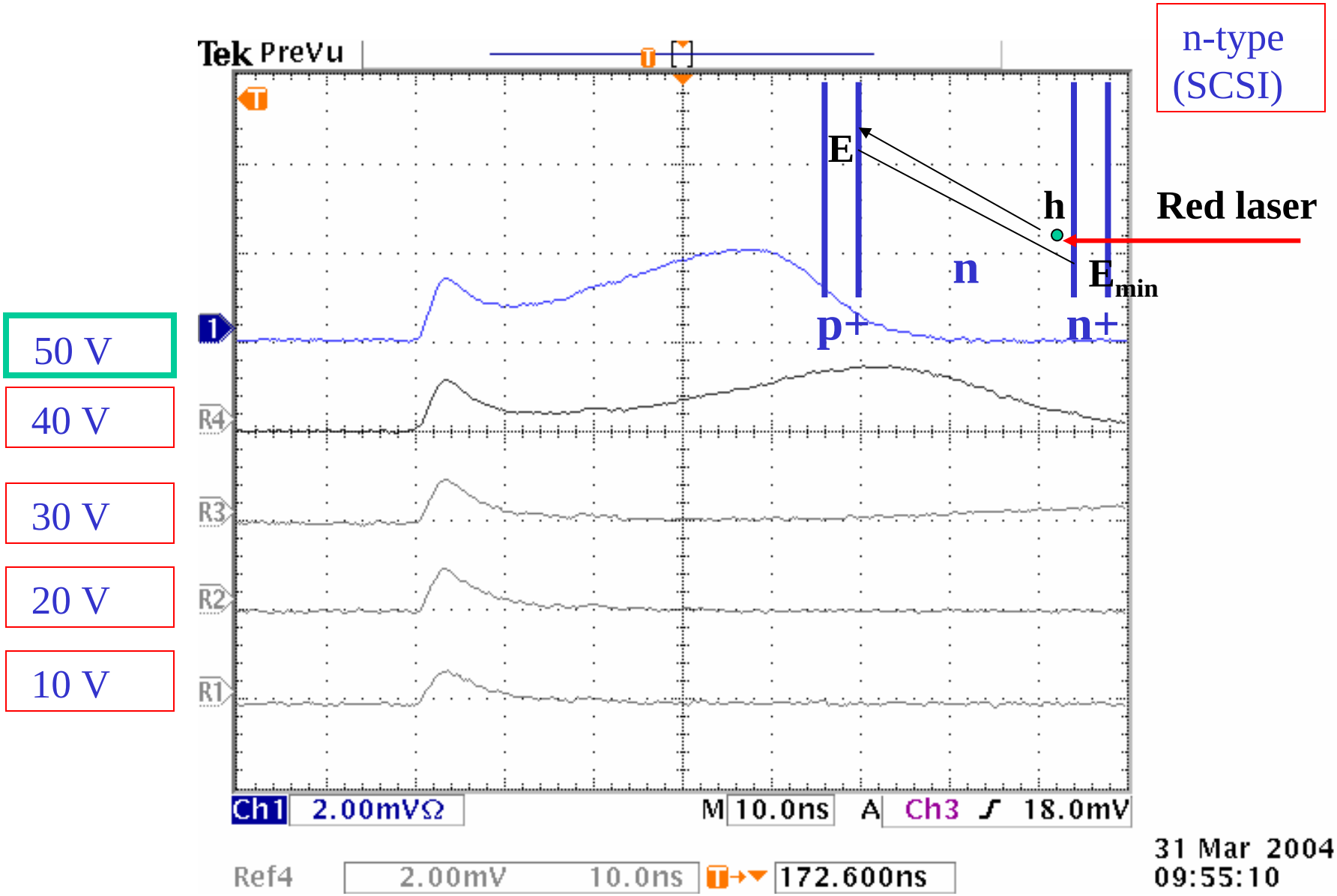
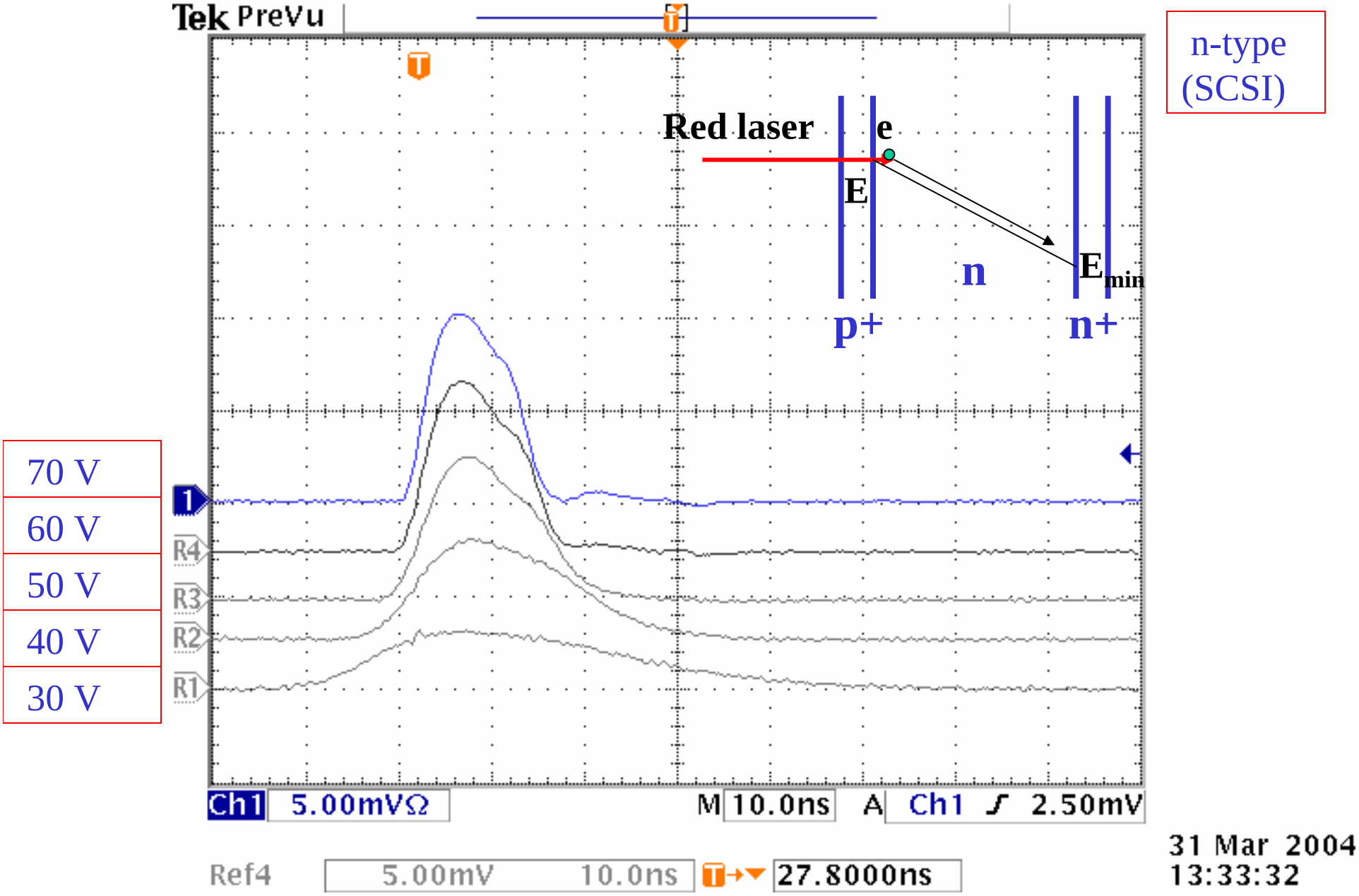
MCZ-P33, p-type, $p^+/p/n^+$ detector, 307 μm, 430 ºC, 35 min (TDG) laser (red) back



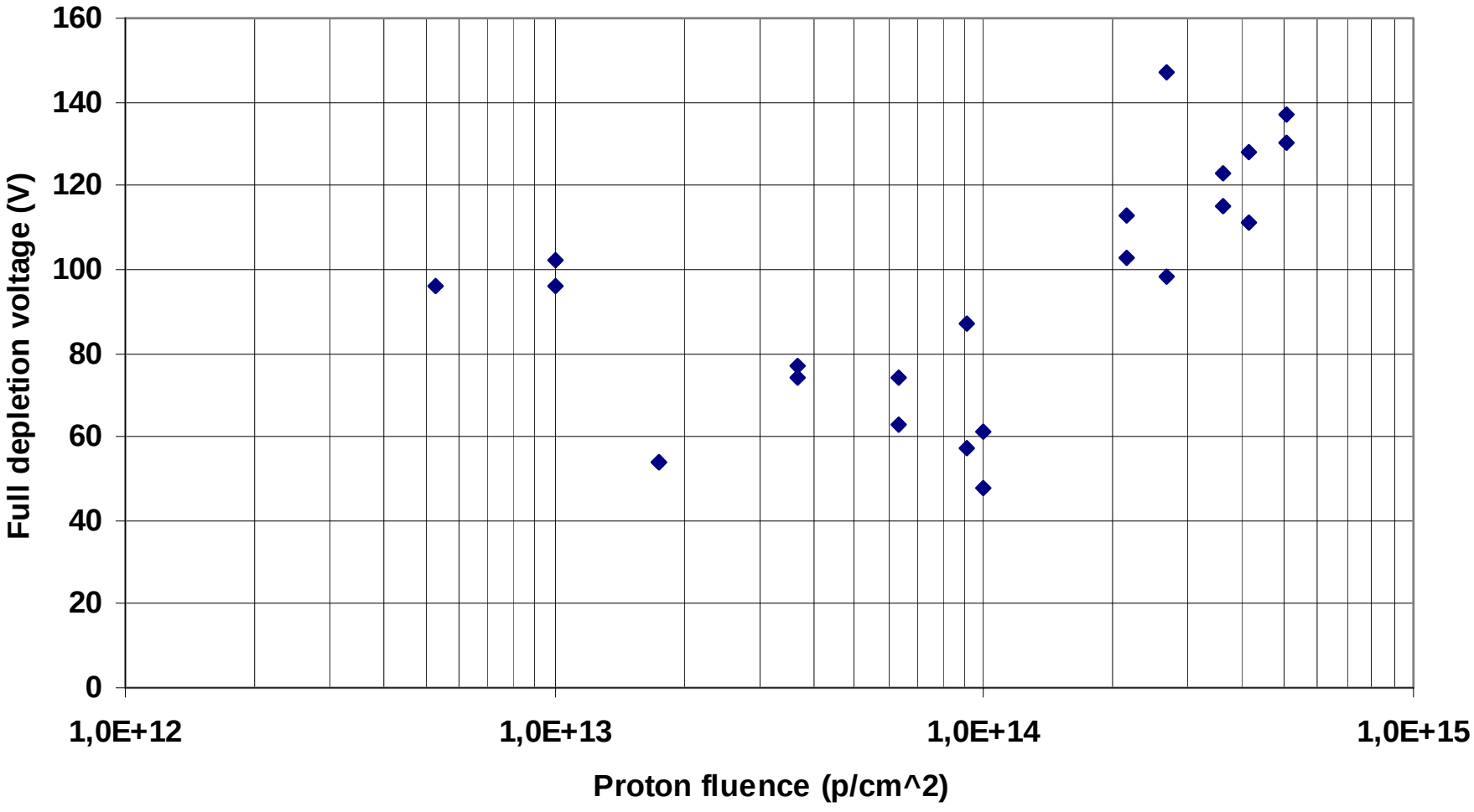
MCZ-P37, p-type inverted to n, $p^+/n/n^+$ detector, 307 μm
430 °C, 75 min (TDG), laser (red) back



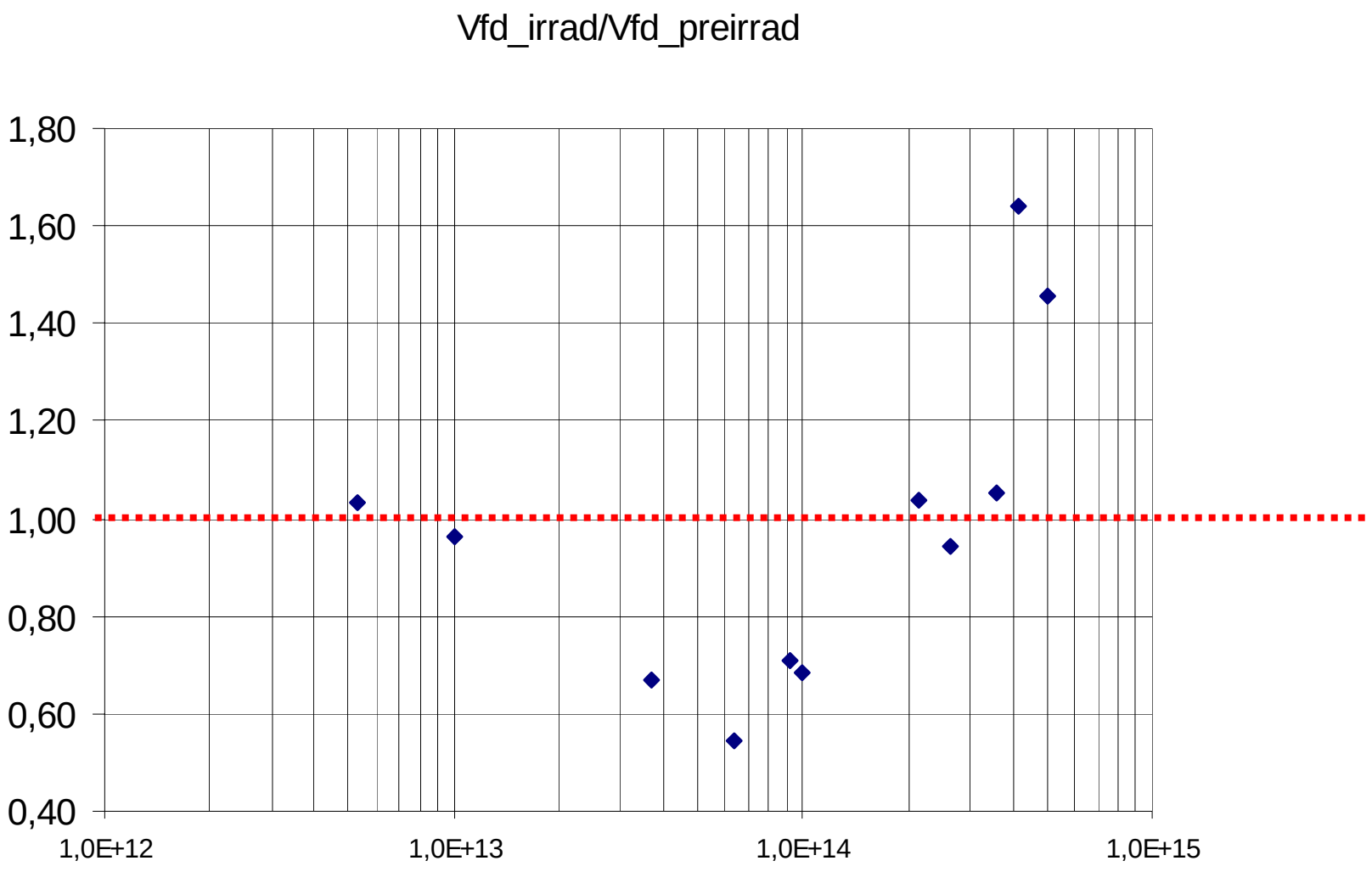
MCZ-P37, p-type inverted to n, $p^+/n/n^+$ detector, 307 μm
430 °C, 75 min (TDG), laser (red) front



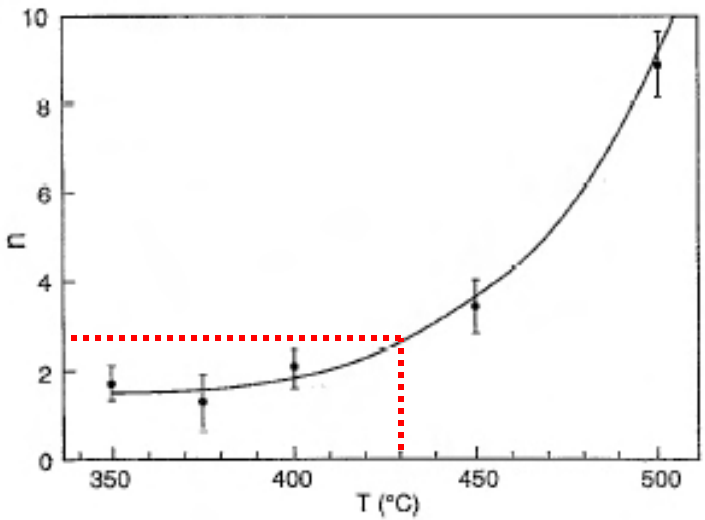
24 GeV/c irradiation



24 GeV/c irradiation



TD formation and O_i exponential dependence ?



It is commonly accepted that the TD generation ∝ O^4

W. Kaiser, Phys. Rev. 105, (1957) 1751.
W. Kaiser et al., Phys. Rev. 112, (1958) 1546.

There is agreement between Wiranajakula's equation only if TD generation ∝ O^*2,45*

C. A. Londos et al., Appl. Phys. Lett. 62 (13) (1993) 1525.

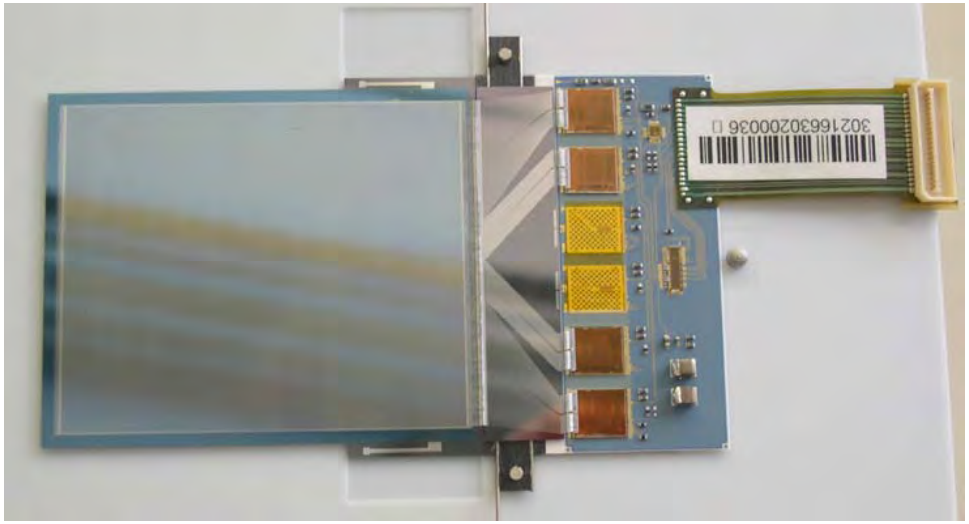
Conclusions

•High O content $p^+/n^-/n^+$ detectors can be processed with p-type boron doped Cz-Si wafers by inverting p $\rightarrow$ n with TD's

•It is low temperature, low cost process >> feasible solution for large scale experiments

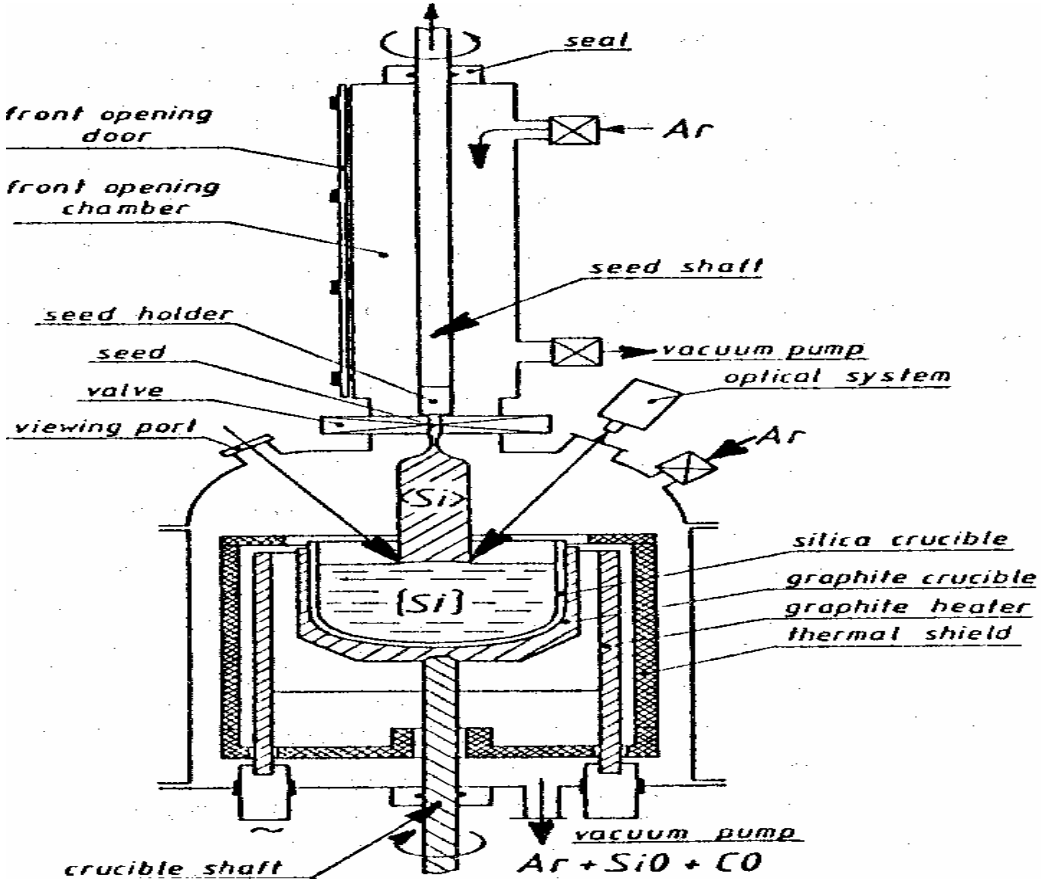
•Resistivity range is very wide in p $\rightarrow$ n TD-process 500Ωcm < σ < ~10 kΩcm

• TD generation provides a easy, low temperature technology to make high resistivity (>10 kΩcm) p-type and n-type MCZ Si and Si detectors



Silicon Crystal Growth

CZ Crystal Growth

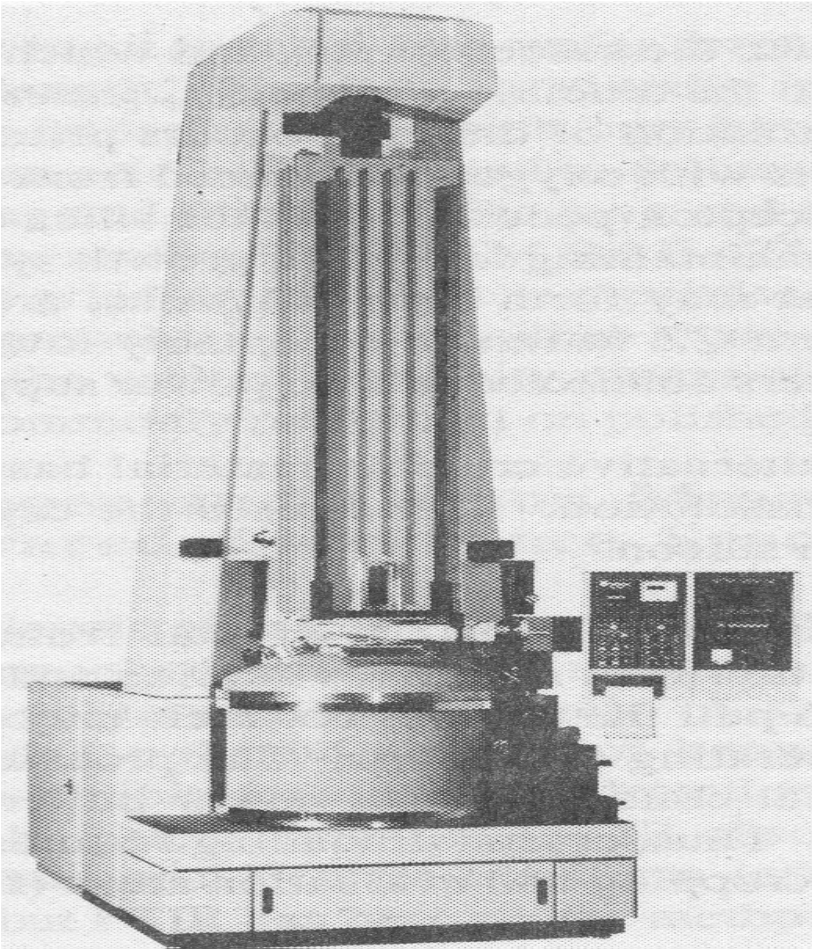


Schematic drawing of CZ puller

Ref.[2]

Silicon Crystal Growth

CZ Crystal Growth



Modern computer controlled CZ puller

Ref.[2]

CZ Crystal Growth

- *Incorporation of impurities:*

  Doping the impurity of choice (P, B, As, Sb)

- *Factors influence the ingot properties:*

  - *Temperature fluctuation:*
    - *dimensional nonuniformities*
    - *resistivity variations*

  - *Pull-rate:*
    - *dislocation density*

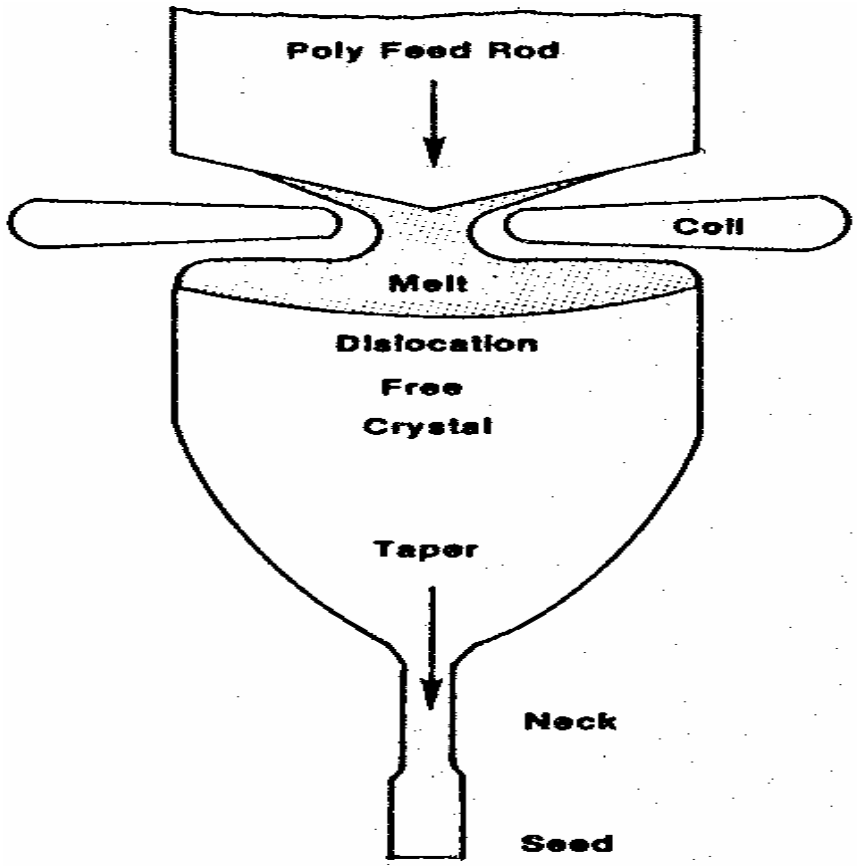
  - *Rotation:*
    - *doping concentration*

FZ Crystal Growth

- A molten zone is passed through a poly-Si rod of approximately the same dimensions as the final ingot.
- A needle-eye coil provides RF power to the rod to establish the molten zone.
- A neck is formed to obtain dislocation-free crystal region.
- A taper is then induced to allow crystal formation at the desired diameter.
- The Si does not come into contact with any substance other than ambient gas in the growth chamber.

Silicon Crystal Growth

FZ Crystal Growth



Schematic of the FZ process

Ref.[2]

Summary

- FZ crystal growth:

  higher inherent purity

  low oxygen (~10^{15}-10^{16} cm^{-3})

  high resistivity (1 to 10kΩ-cm possible),

  good for HEP detectors

  severe microscopic resistivity variations

  costly

- CZ crystal growth

  larger diameter

  less expensive

  good resistivity uniformity

  low resistivity range

  higher impurity concentration

  high oxygen concentration (~10^{17} cm^{-3})

Silicon Crystal Growth

Summary

Comparison of selected properties of CZ & FZ crystals:

Properties	**CZ crystal**	**FZ crystal**
Resistivity (P doping) n-type (Ω-cm)	1-50	1-20k
Resistivity (B doping) p-type (Ω-cm)	0.5-50	up to 20k
Resistivity gradient (four-point probe) (%)	5-10	20
Minority carrier lifetime(μs)	30-300	50-500 ms's for det grade
Oxygen (cm^{-3})	10^{16}-10^{17}	10^{15}-10^{16}
Carbon (cm^{-3})	10^{16}	10^{15}-10^{16}
Heavy-metal impurities (cm^{-3})	$\leq 10^{19}$	$\leq 10^{21}$

MCZ Si wafers

A magnetic field can be applied in the crystal growth system in order to damp the oscillations in the melt. The applied field creates an electric current distribution and an induced magnetic field in the electrically conducting melt. This produces a Lorentz force that influences the flow and reduces the amplitude of the melt fluctuations