Beam Profile Monitor for Linear Collider

KEK-Tohoku-Hawaii collaboration

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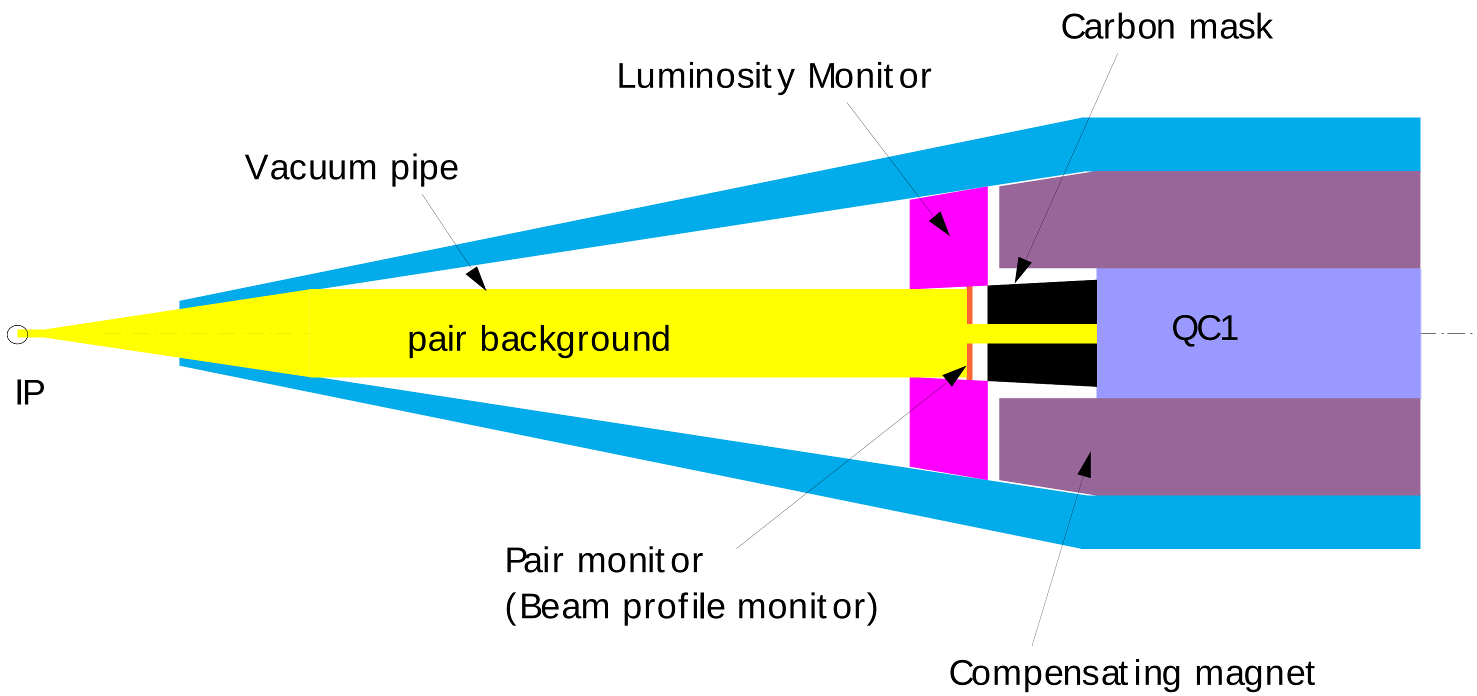
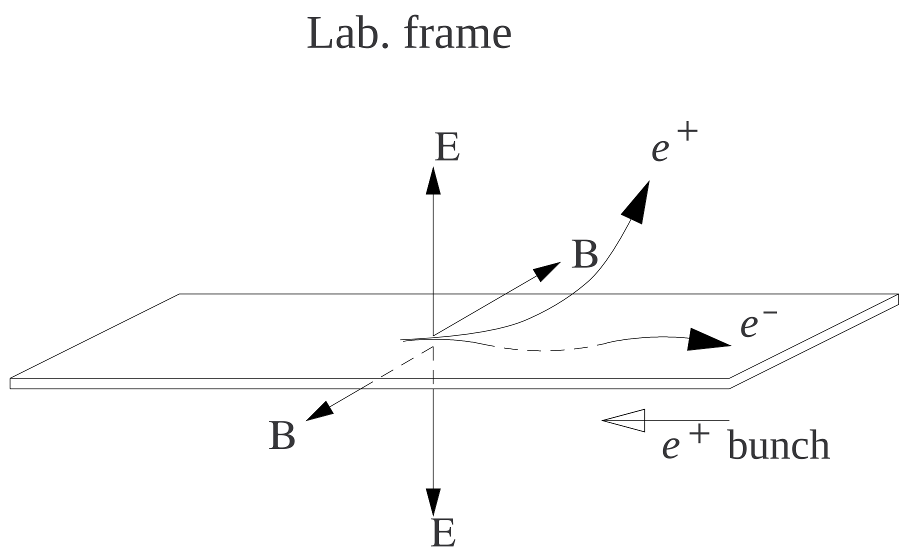
Interaction Region



Kinematic configuration of pair background

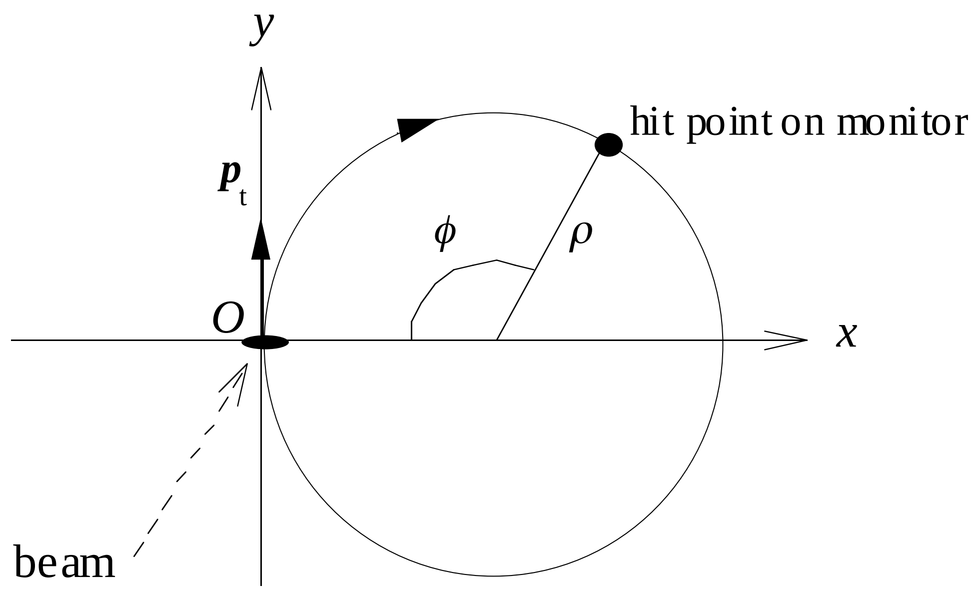


Pair background

- $|E| = |B|$: No force from the co-moving bunch.
- E, B ~ 4×10^7 gauss → r = 170μm (σ_z ~ 80μm)
- For an incoming e^+ bunch,
  - e^- oscillates around the beam plane.
  - e^+ acquires a large pt kick vertically.
- Round beam: no ϕ dependence

  ϕ dependence → information on σ_y / σ_x

Motion in the solenoid field



ρ (cm) = pt(MeV)/3B(Tesla)

ϕ (rad) = 3B(Tesla)L(cm)/pz(MeV)

(L: distance from IP, B: solenoid field)

Hit location

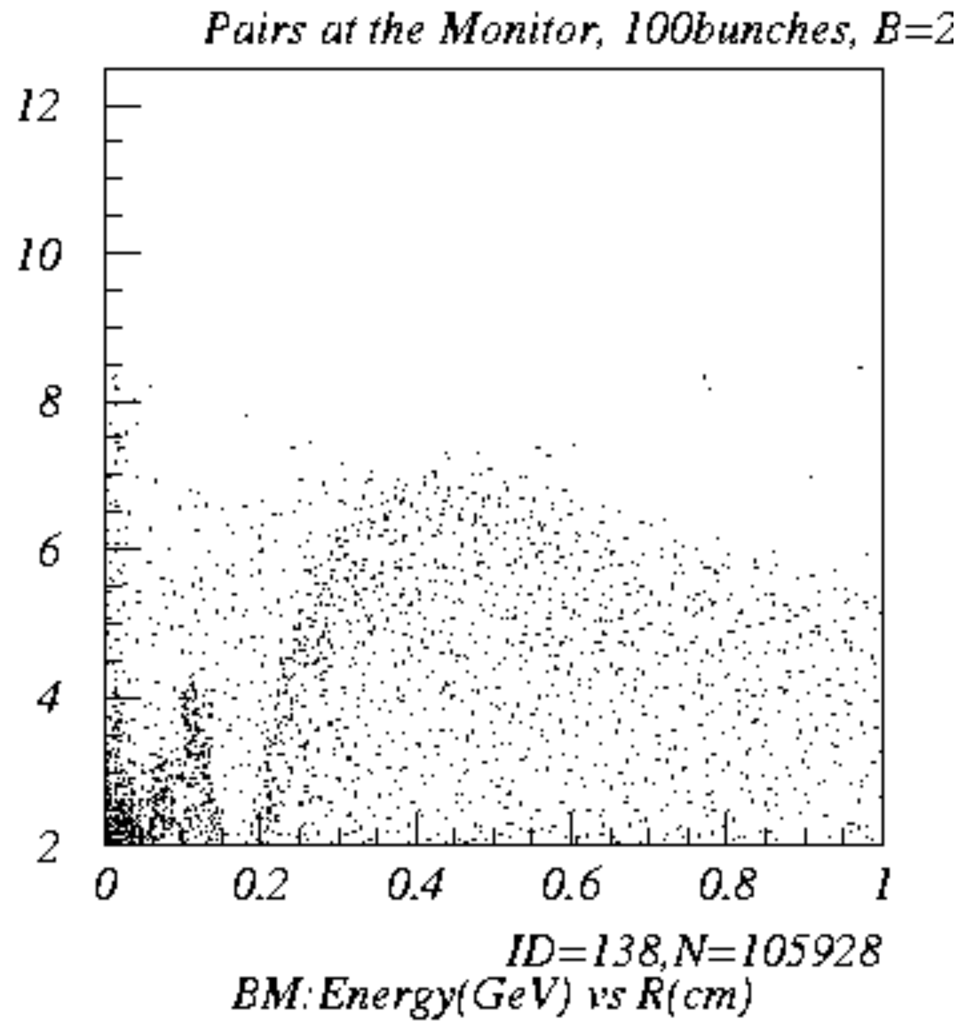
- ρ measures pt , ϕ measures p_z.
- For E_{beam} = 250 GeV, $N_{bunch} = 10^{10}$

  And $\sigma_{x/y/z}$ = 260nm/3nm/80μm,

  $pt_{max} \sim$ 20MeV $\rightarrow$ $\rho \sim$ 3.3cm
- For L = 176cm and pz = 300MeV, $\phi \sim \pi$.
- Look at ϕ pattern at $r \sim 2\rho \sim$ 6cm.

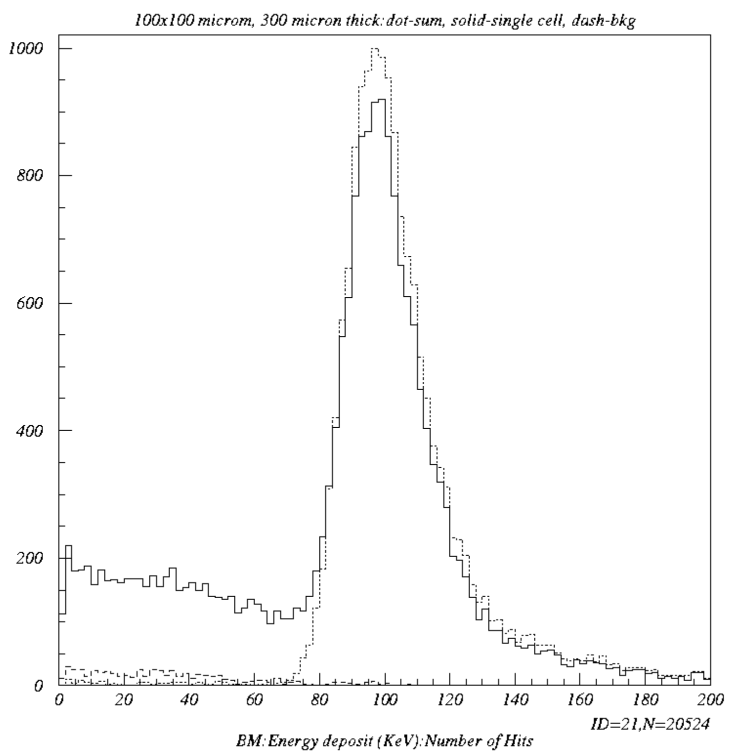
GEANT simulation (by Tauchi)

- Energy vs radius



GEANT simulation of pulseheight
(by Tauchi)

0.3mm thick, 0.1x0.1mm^2 pixel

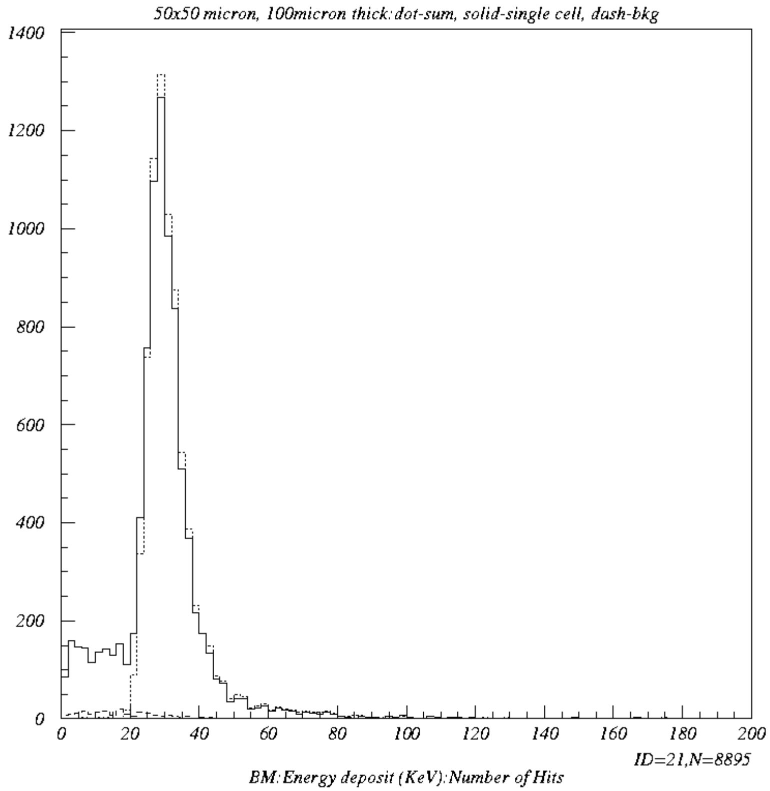


Solid line: per pixel.
Dashed line: per cluster.

70keV cut eliminates
X-ray background
(EGS simulation needed)

GEANT simulation of pulseheight
(by Tauchi)

0.1mm thick, 0.05x0.05mm^2 pixel



Solid line: per pixel.
Dashed line: per cluster.

Signal pulseheight → 1/3.
Less cell sharing.

Requirements for pair monitor

- Detect e^+/e^- of a few 100 MeV.
- High rate : ~30hits/mm^2/train.
- ~50kRad dose/yr (not bad).
- Identify bunch in a train (at least front, middle, back, or hopefuly each bunch).
- Threshold (~70keV for 0.3mm) to reject x-rays.
- Real time information on σ_y / σ_x

Selection of detector type

- Rate is too high for a Si strip detector.
- CCD has difficulty rejecting X-rays.

  (also no bunch identification by time)

→ active pixel sensor

Pixel detector configuration:

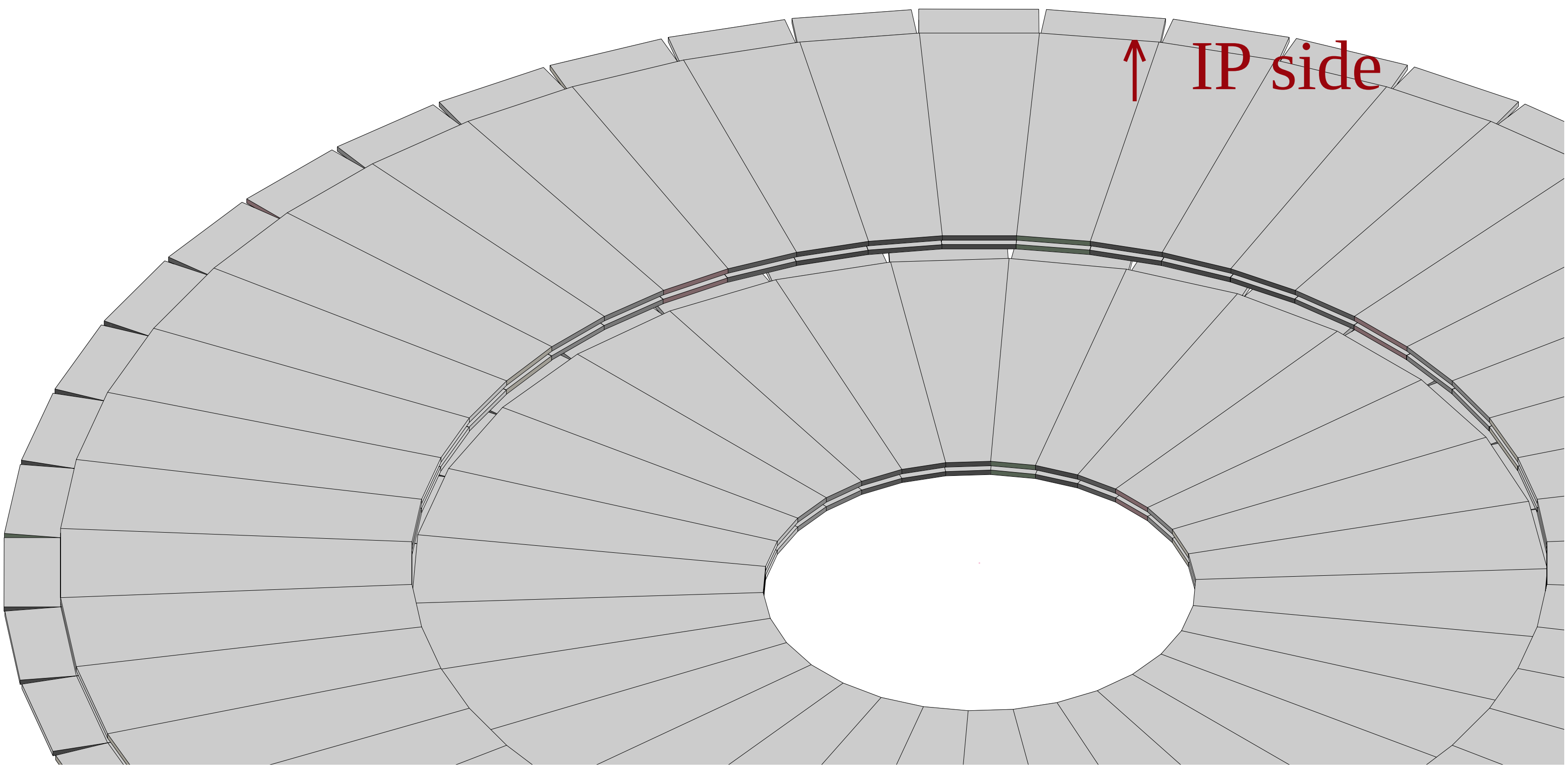
0.1×0.1 mm^2 ~ 0.05×0.05mm^2 pixel

0.1 ~ 0.3 mm thick

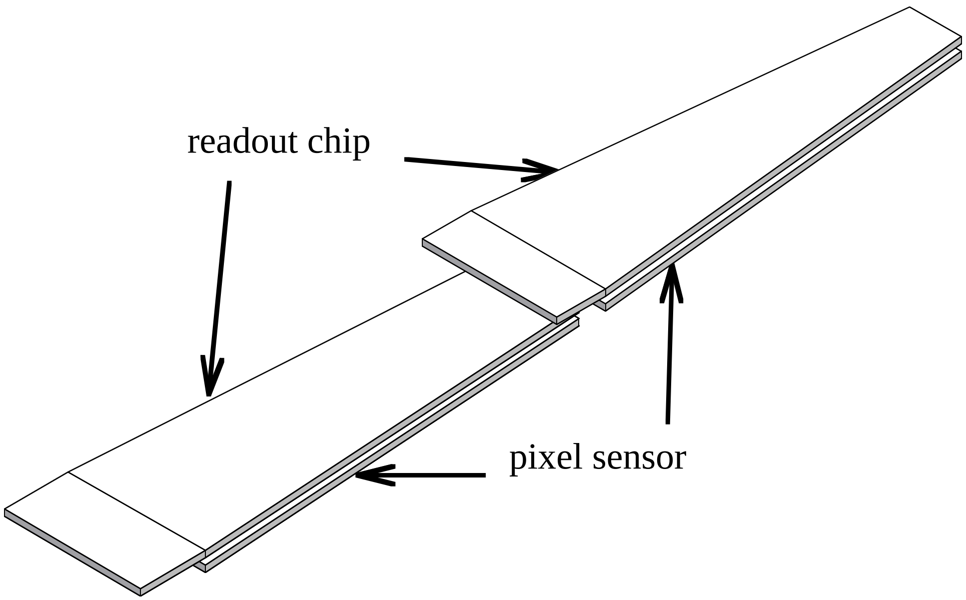
gating, or TDC for bunch identification.

Pixel beam profile monitor arrangement (one disk)

2 rings.   R ~ 8cm

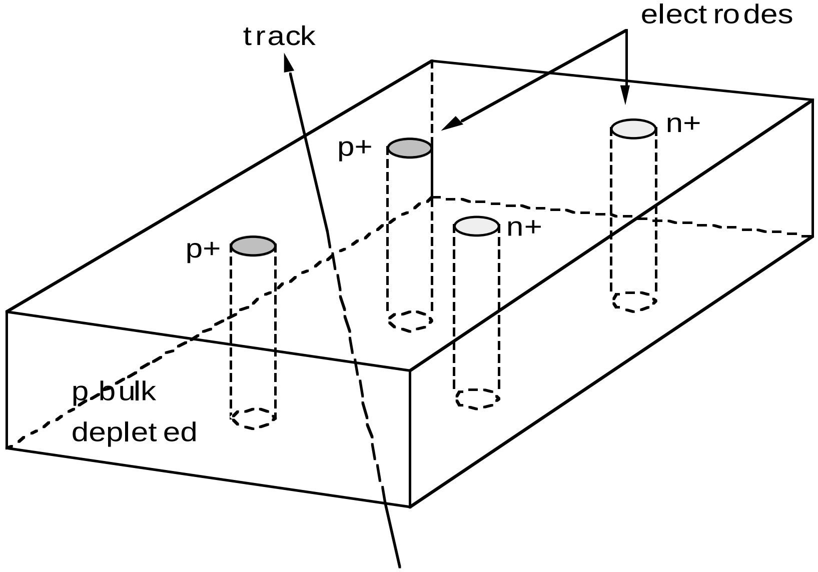


One stave



↓ IP side

3D pixel sensor



- Pole electrodes transverse to the sensor plane.
- Drift field parallel to the sensor plane.

3D pixel sensor

Merits

- Fast: signal pulse 1/10 of typical pixel sensor.
- $V_{depletion}$~ 5V (low!). Radhard.
- Flexible geometry (e.g. trapisoid).
- Active all the way to the edge (no guard rings).

Drawbacks:

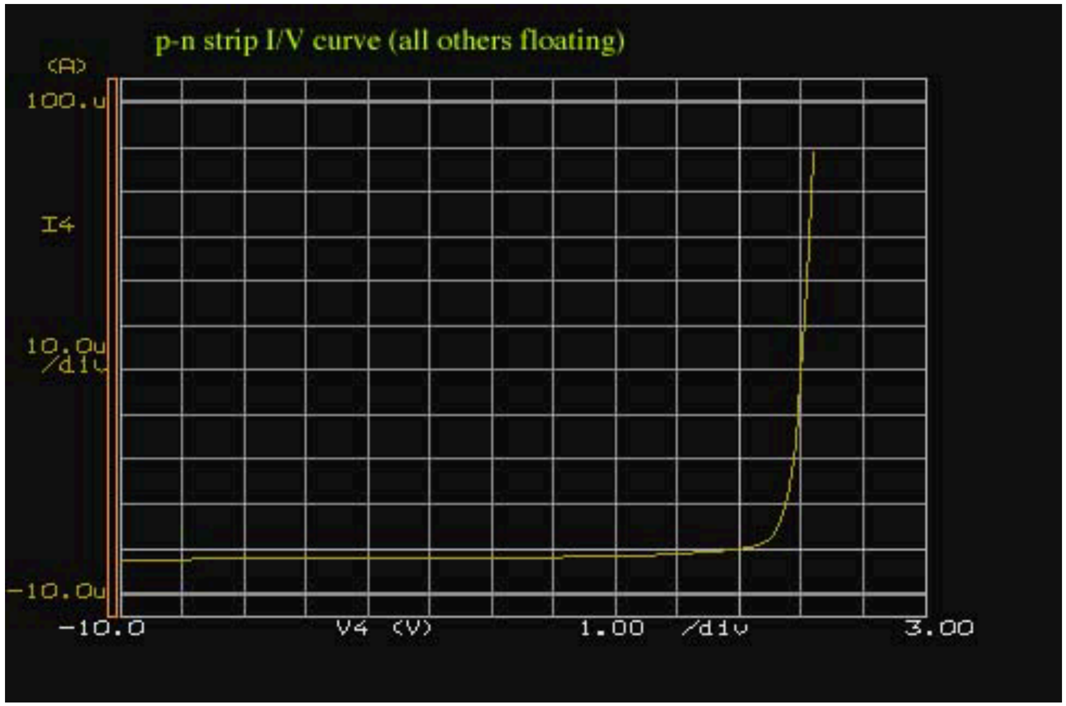
- Requires a special etcher.
- Technology not fully established.

3D sensor tests

prototype

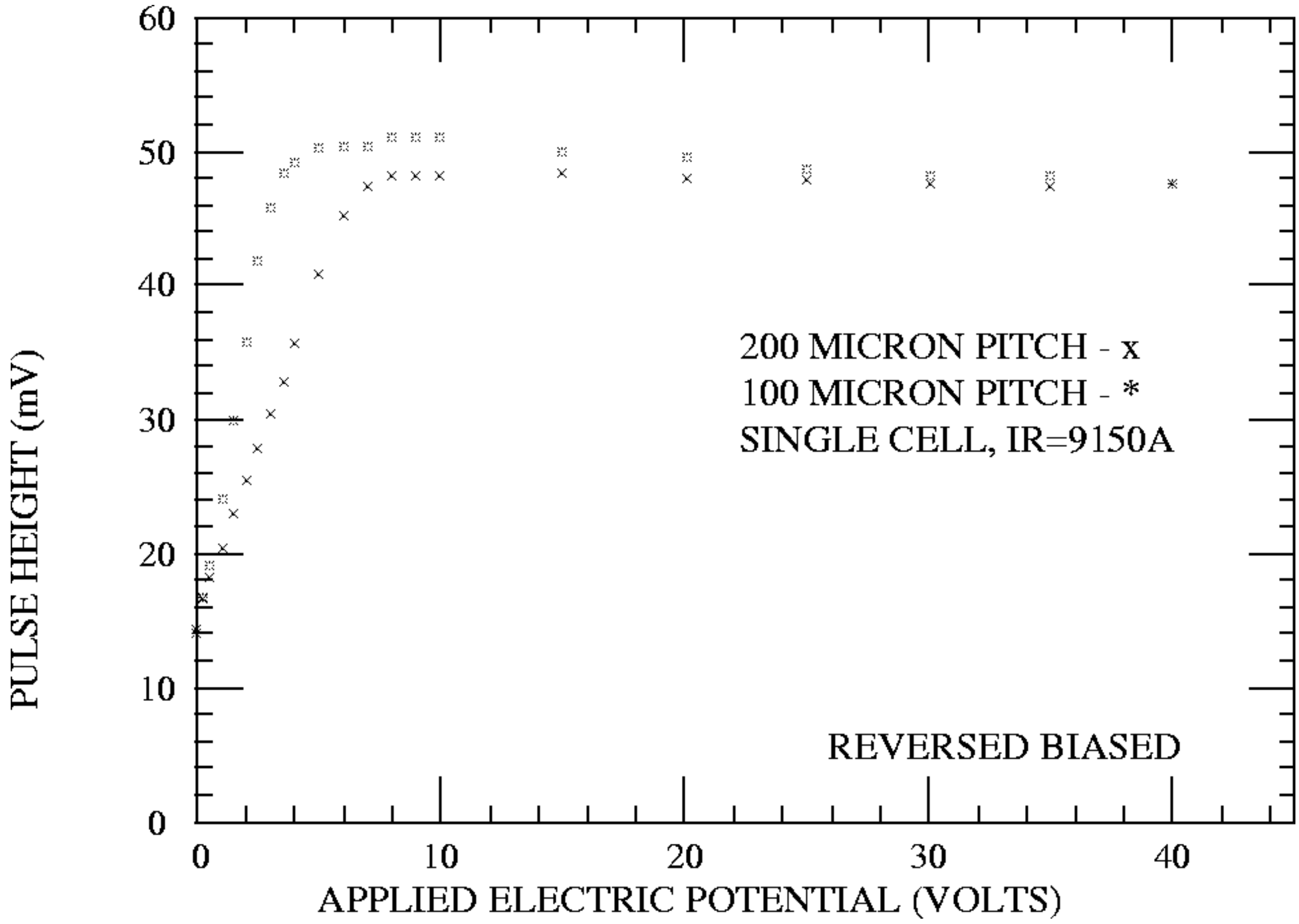
- 120μm thick wafer
- Electrode diameter 20μm
- Pitch : 100μm and 200μm (2 versions)
- 14 by 28 array

100μm pitch version



- PN junction between n and p electrodes

IR laser test



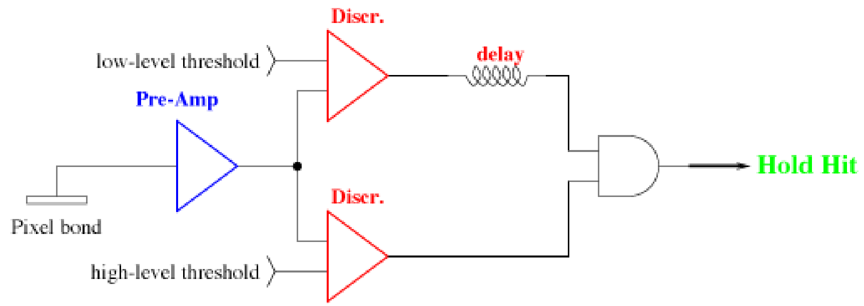
Thickness

- Thick: easier to eliminate X-rays.
- Thin: easier to fabricate 3D electrodes.
- Thin: less cell sharings.

Cell size

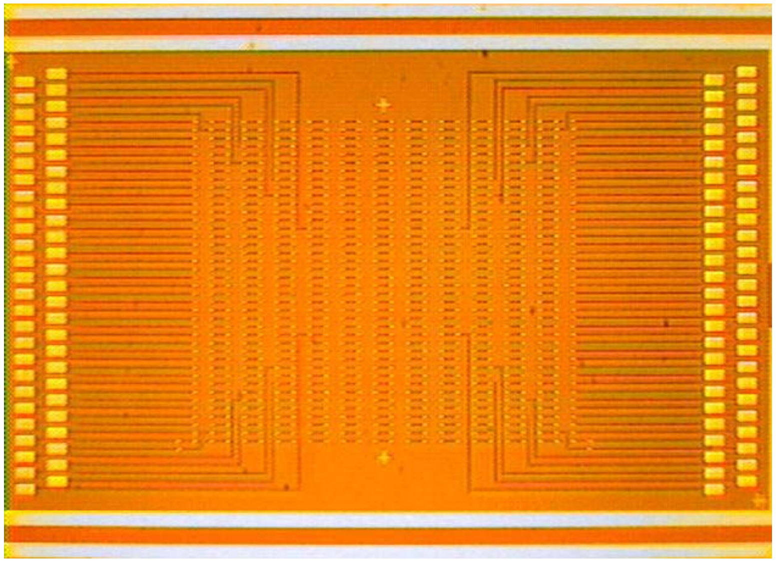
- Large: easier for readout electronics.
- Large: less cell sharings.
- Large: less dead reagion due to electrodes
- Small: takes higher rate.
- Small: less multiple hits.

Possible timing circuit (very preliminary)

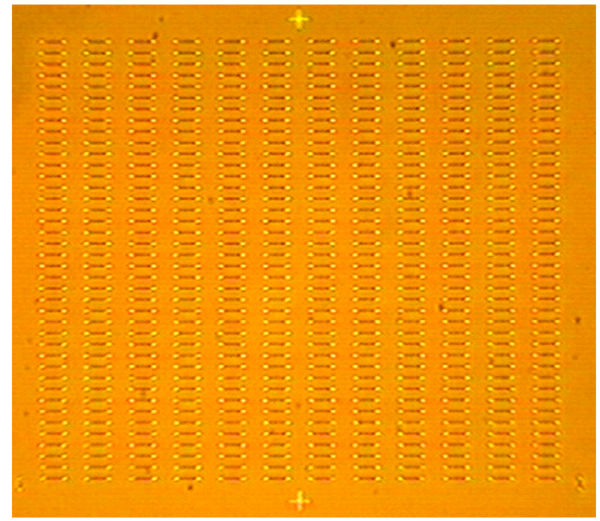


- Low threshold defines timing, and high threshold defines hit.
- TDC value stored in each pixel (8bits)
- Readout time ~ 3.5 ms

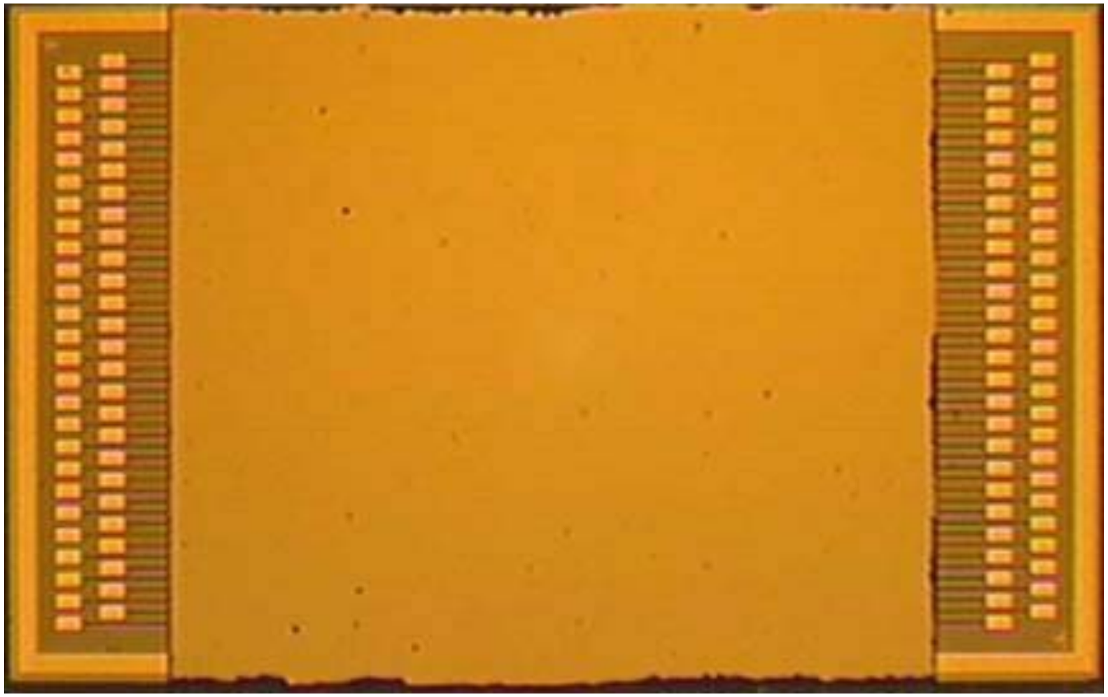
Thin die bump bonding



dummy sensor (patterned side)



- Dummy Si sensors and dummy readout chips fabricated at SNF (former CIS) at Stanford.
- 5 pairs: both back-thinned to 100μm thick (lap and polish).
- 4 pairs: 300μm-thick each.
- 24x40 array, 100x200μm^2 pitch.

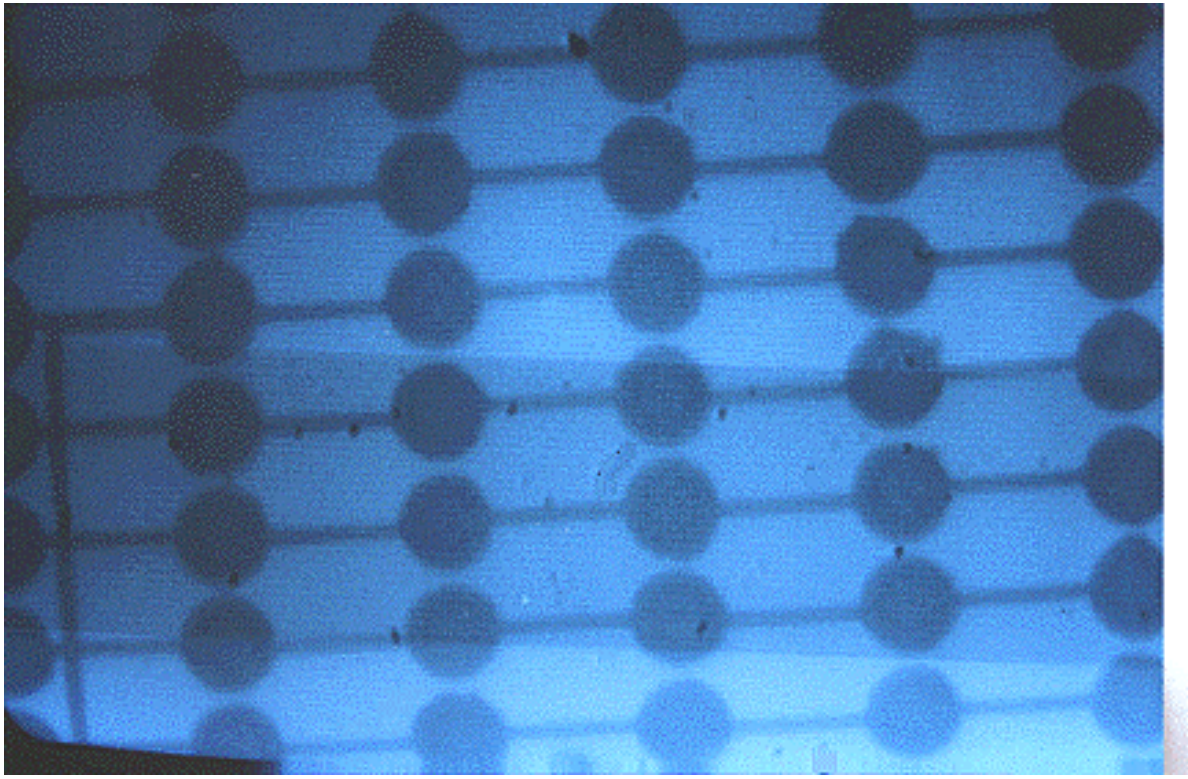


- Bump-bonded by AIT (Advanced Interconnect Technology), Hong Kong.
- Indium bumps.

IR microscope inspection of bonds

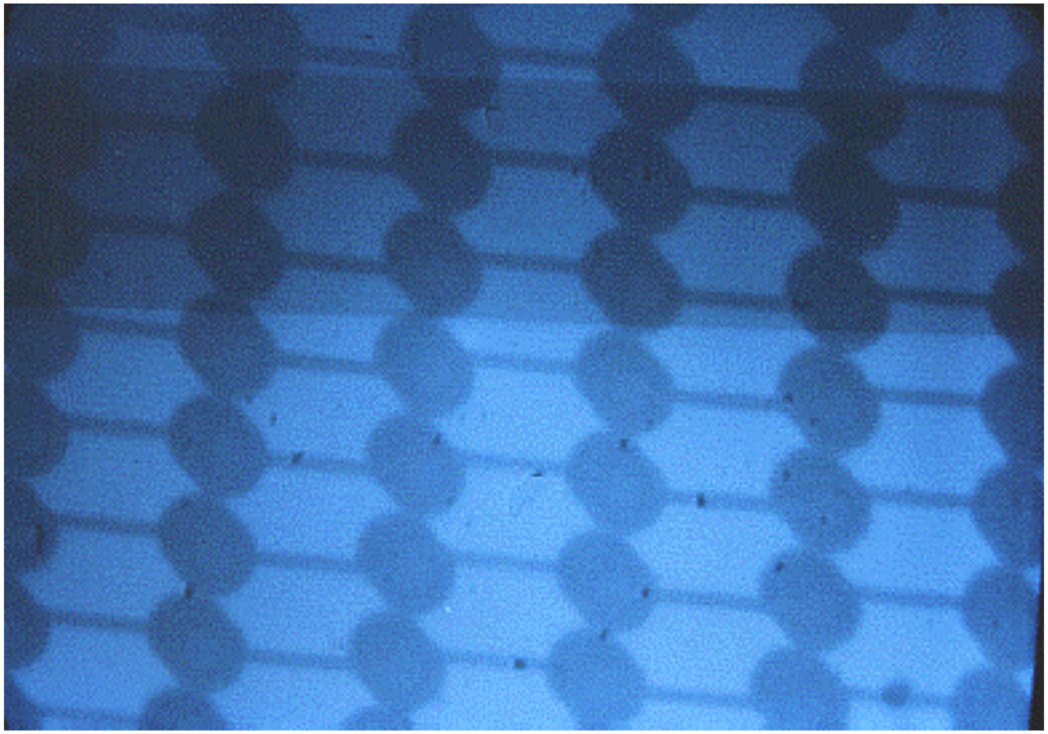
- Works as well as X-ray photos.
- Identifies misalignment, excess force, etc.
- Real-time, easy to use.

IR microscope inspection



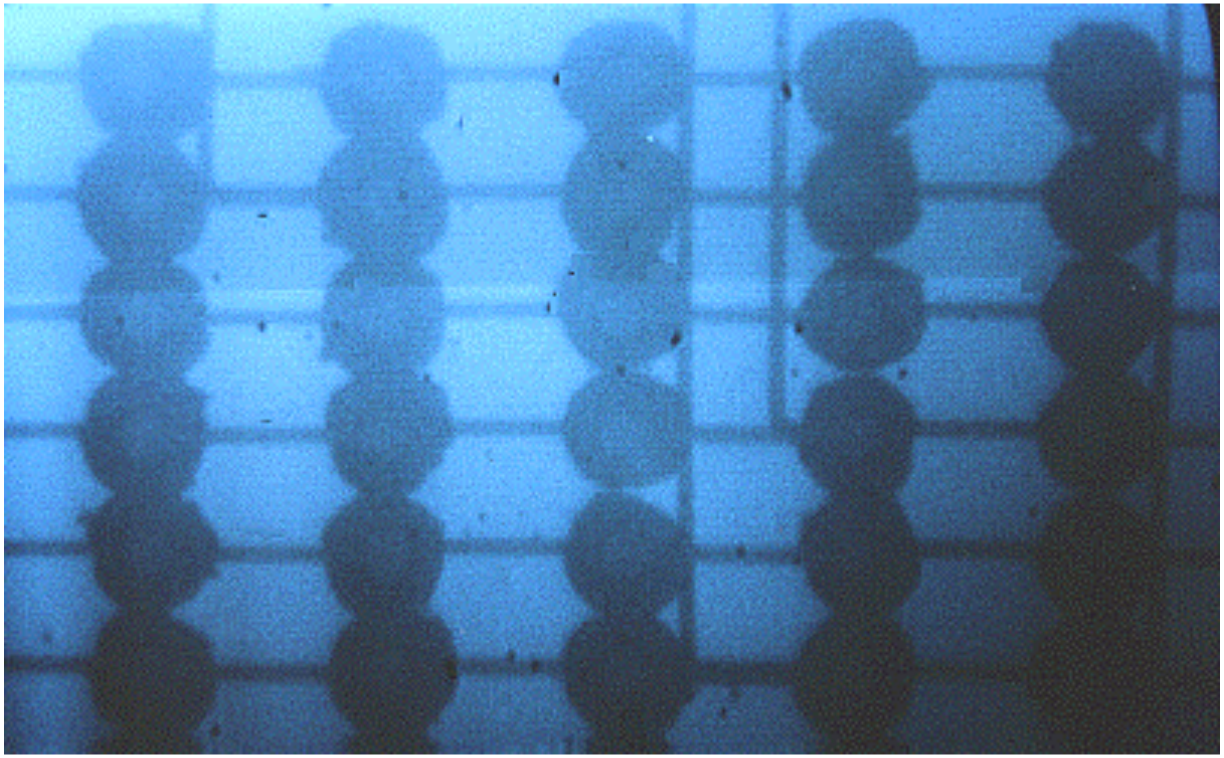
Good bonds.

IR microscope inspection



Misaligned.

IR microscope inspection



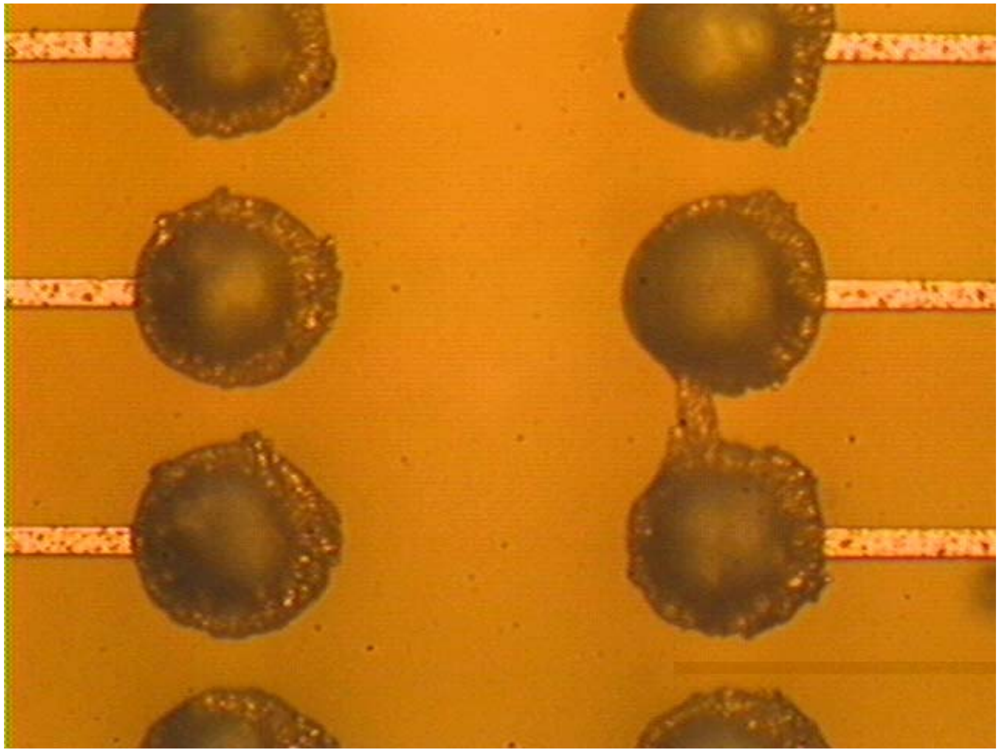
Excessive bonding force.

Electical tests of bonds by AIT

- No misconnections found.
- Shorts : ~ 2% (Run A), ~ 0.1% (Run B) per bond.
  (likely to get better after ‘practices’)
- ~ 100Ω/bond for thin dies.
- ~ 1k Ω/bond for thick dies.
  probably due to an oxidized surface layer on bump.
  (reduced to ~ 3 Ω when heated by a high current)

Optical microscope inspection

- Indium bumps before bonding (unbomded sample).
- UBM (under-bump metalization) connection seen.



(Re)organization

- HY: Hawaii → Tohoku.
- Prof. Ikada (KEK) joined to work on the readout electronics.
- Two tohoku students, one working with Prof. Ikeda, one on X-ray background simulation.

Next steps

1. Readout electronics design.
2. Submission to foundry, tests.
3. Bump-bond prototype readout electronics and a 3D sensor.
4. Fabricate and bond large readout chips and large sensors.