Bump Bonding for Pixel Detectors

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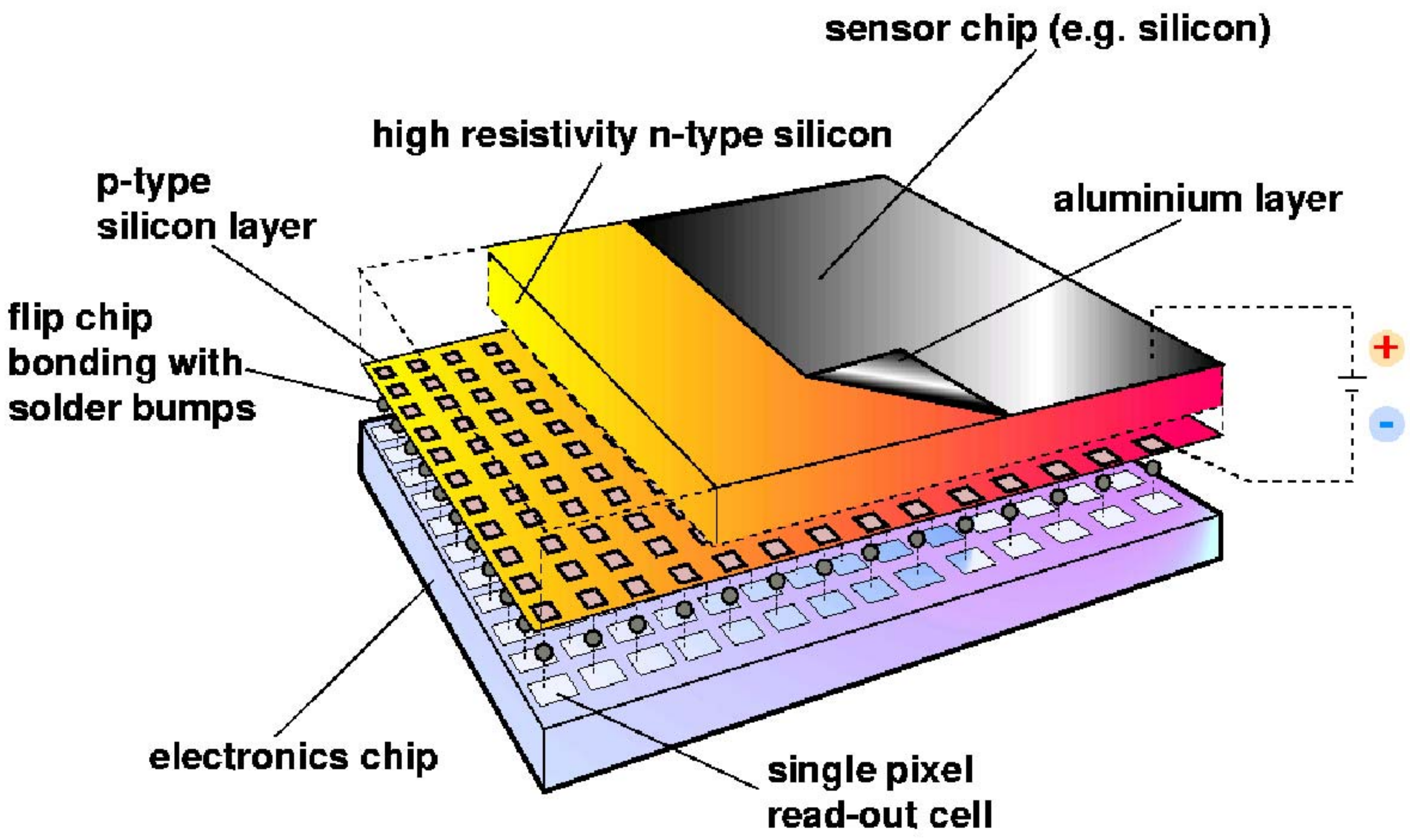
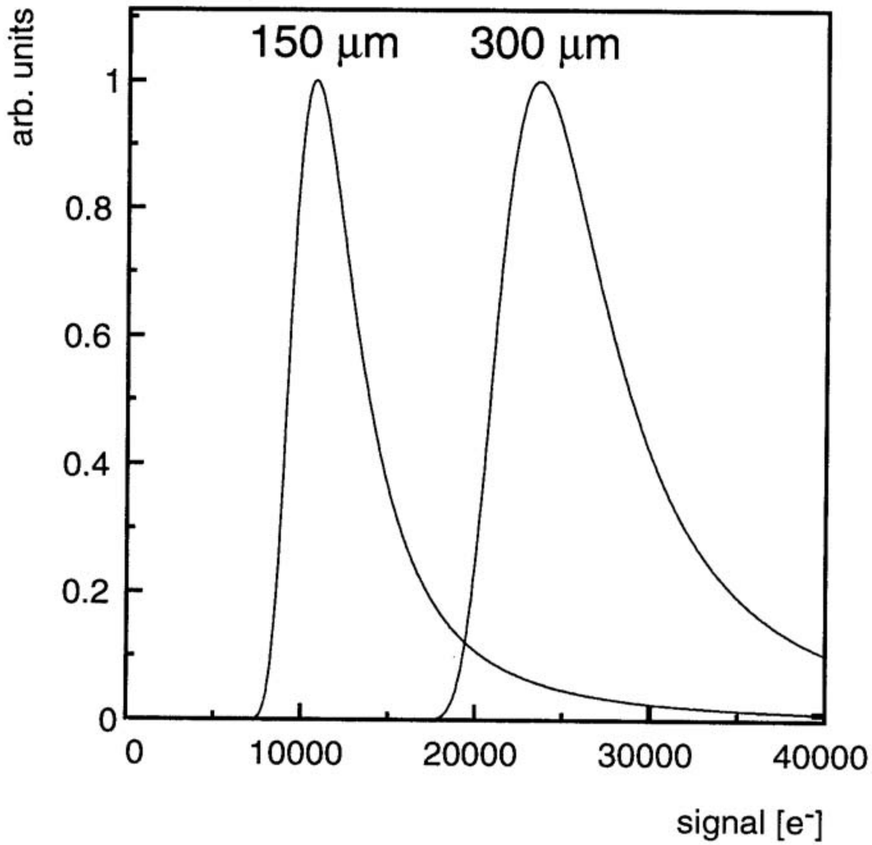
Outline

- Introduction
- Applications in High Energy Physics
- Applications to X-ray Imaging
- Common Requirements
- Specific Requirements
- Accessible Companies and Technologies
- Comparison of Technologies
- Remaining Challenges for LHC
- Beyond LHC

Hybrid Pixel Detector

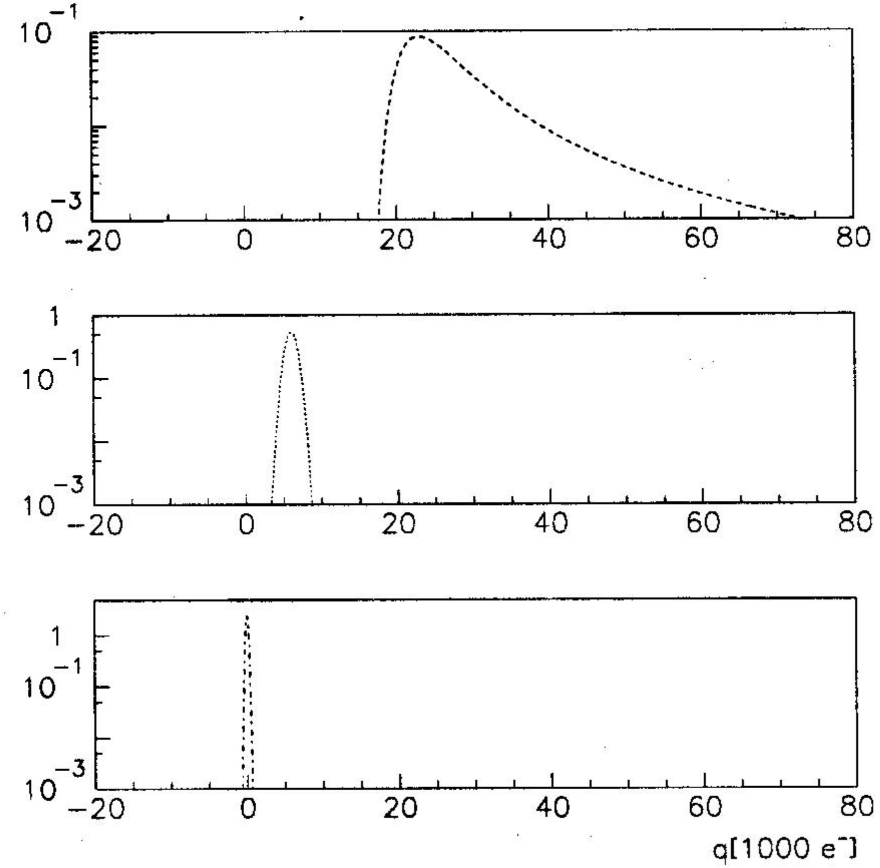


Landau distribution in Si detector

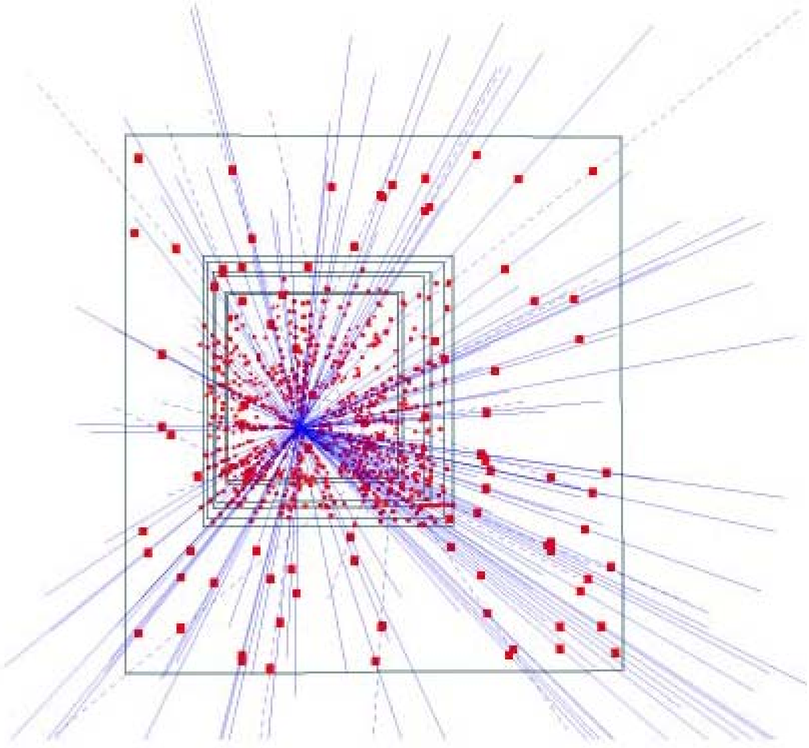


Because of charge sharing threshold normally set around 1/3rd Landau peak

Signal, Threshold, Noise



CERN Experiment WA97 (1995)



5 x 5 cm^2 area
7 detector planes
Pixel dimensions 75 x 500 μm^2
Trigger precision 1 μsec
1 kHz trigger rate

NB. Dead area ~3% in total over 7 x 5 x 5 cm^2

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Alice pixel detector

- 2 barrel layers
- p^+ on n detectors
- pixel dimensions 50 μm x 425 μm
- chip contains 256 x 32 pixels
- 1 x 5 chips/module
- ~ 240 modules
- ~ 2 million channels in total

see talk of Petra Riedler

Atlas pixel detector

- 3 barrel layers and 3 disk layers
- n^+ on n detectors with p spray isolation
- pixel dimensions 50 μm x 400 μm
- chip contains 160 x 18 pixels
- 2 x 8 chips/module
- ~ 1 500 modules
- ~ 100 million channels in total

BTeV pixel detector

- 31 station 10 cm x 10 cm
- n^+ on n detectors with p-stop or p-spray
- pixel dimensions 50 μm x 400 μm
- chip contains 128 x 22 pixels (tentative)
- 1 x (4 to 8) chips/module
- ~ 30 million channels in total

CMS pixel detector

- 3 barrel layers and 2 disk layers
- n^+ on n detectors with dual concentric broken p-stop rings
- pixel dimensions 150 μm x 150 μm
- chip contains 52 x 53 pixels
- 2 x 8 chips/module
- ~ 752 modules
- ~ 33 million channels in total in barrel

see talks of Alan Honma and Christian Brönnimann

LHCb RICH readout

- Chip/detector assembly inside Hybrid Photon Detector (under vacuum)
- single photo-electron detection required (5000 e-)
- p^+ on n detectors
- pixel dimensions 500 μm x 500 μm
- chip contains 32 x 32 super-pixels (each super pixel contains 8 sub pixels)
- ~ 1000 tubes needed
- ~ 1 million channels in total

See talk by Thierry Gys

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Synchrotron Applications

- **PILATUS (SLS)**
  - 44 x 78 pixels, 217μm pitch
  - 2 x 8 chip ladders

    see talk by Christian Brönniman
- **ALADIN (RAL)**
  - 64 x 64 pixels, 150μm pitch
  - 1 x 7 chip ladders
- **XPAD (Marseilles)**
  - 24 x 25 pixels, 330μm pitch
  - 2 x 5 chip ladders

Medical Imaging Applications

- **Integrating systems**
  - **Nova R&D Mary chip**
    - **192 x 384 pixels, 50μm pitch**
  - **AJAT DIC100**
    - **Xx x yy pixels, 100μm pitch**

- **Photon counting systems**
  - **MPEC2.3 (Bonn) 32 x 32 pixels, 200μm pitch**
  - **Medipix2 256 x 256 pixels, 55μm pitch**

Common Requirements

- Pitch ~ 50μm
- Chips > 1 cm^2
- 1 000 – 100 000 bumps/chip
- Large area coverage -> multi-chip ladders (5-16 chips per ladder)
- Dead area between ladders should be limited
- Deep sub-micron CMOS (8” wafers)

Application Specific Requirements

- **HEP**

  Low mass assembly

  Thin Si detectors and (post bumping thinned CMOS)

  Pitch limited by material budget – going < 50μm makes no sense in present systems

- **For Photo Multiplier Tube Encapsulation**

  Vacuum compatible technology

  High temperature cycling

- **X-ray imaging**

  High ρ (exotic!) material

Accessible Companies and Technologies

Company	Technology	Experiment
AMS	In (cold)	Atlas/Alice
IZM	SnPb (eutectic)	Altas
MCNC	SbPb (eutectic)	BTeV
PSI	In (reflow)	CMS
VTT	SnPb (eutectic) SnPb (high Pb)	Alice/NA60 LHCb RICH

Comparison of Used Technologies

Technology	Pull Strength (g/bump)	Max Temp (^{o}C)
In (cold)	0.1	100
In (reflow)	0.2-0.3	250
SnPb (eutectic)	1	230
SnPb (reflow)	??	380

Typical defect and causes

- Missing corners – poor co-planarity during alignment / reflow
- Low pull strength – poor UBM adhesion / poor wetting (in reflow processes)
- Local shorts between pixels – too much compression / movement during reflow
- High detector leakage currents – incomplete field layer etching / poor dicing

Remaining challenges for the LHC

- Selection and burn-in of KGD
- Total quantities (~ 40 000 installed placements needed!)
- QA during production and feedback to suppliers
- Lifetime testing of bumps
- Handling of large numbers of extremely thin and (sometimes) fragile components
- Rework

A controversial question:

Will bump bonding problems sign the death warrant for hybrid pixel detectors in HEP ?

Depends on how we do for LHC….

Cost

Ultimately, hybrid pixels provide unbeaten pattern recognition.

Beyond LHC1

- Solutions for single chip tiling
- Thinner assemblies
- Inter-layer interconnect
- True vertex finding…

- X-ray imaging community may become a large user too (depends on developments..)