TREND IN HEP DETECTOR R&D

Junji Haba
KEK Detector Technology Project
These days there are so many regular Detector conferences, workshops...

- **General topics only**
  - International Workshop On New Photon Detectors (PD07)
  - 1st Workshop On Photon Detection For High Energy, Medical And Space Applications
  - 5th International Conference On New Developments In Photodetection (NDIP08)
- **Calorimetry**
  - 12th International Conference On Calorimetry In High Energy Physics (CALOR 06)
- **Gaseous**
  - 3rd Symposium On Large TPCs For Low Energy Rare Event Detection
  - Micro-Pattern Gas Detectors (RD51) Workshop
  - International Conference on Micro Pattern Gaseous Detectors (MPGD 20XX)
- **Vertex/Pixel/3D**
  - VERTEX 2006: 15th International Workshop On Vertex Detectors
  - Vertex 2007: 16th International Workshop On Vertex Detectors
  - 6th International Symposium On The Development And Applications Of Semiconductor Tracking Detectors (STD6 Hiroshima)
  - 8th International Conference On Large Scale Applications And Radiation Hardness Of Semiconductor Detectors (RD 07)
  - 6th International Conference On Radiation Effects On Semiconductor Materials, Detectors And Devices
  - PIXEL 2008: International Workshop On Semiconductor Pixel Detectors For Particles And Imaging
Too hard to review this active field in only 20min.

- Previous talk successfully gave experimentalist a clear image of
- String theory

This talk
For theorist to learn how to cook the strings with modern detectors
For a comprehensive view, attend new series of IUPAP conference Technology and Instrumentation in Particle Physics Chicago, June 2011
What to measure with detectors?

- Two Lorentz four vectors, $x_\mu$ and $p_\mu$
  
  (theorists know well) or

  $(t, x)$ and $(E, p)$:

  **time, position, energy and momentum**

- That’s it?

  $Q$ (charge) and **mass** (particle species) necessary for Particle identification. To be skipped today.
Position

100 μm

Opera First ντ

4 parent

γ1

8 daughter

2

5

3

6

Nuclear emulsion is still the best detector for precision.
1968: Georges Charpak revolutionizes detection

In the 1960s, detection in particle physics mainly involved examining millions of photographs from bubble chambers or spark chambers. This was slow, labour intensive and not suitable for studies into rare phenomena.

However, the revolution in transistor amplifiers was to trigger new ideas. While a camera can detect a spark, a detector wire connected to an amplifier can detect a much smaller effect. In 1968, Georges Charpak developed the 'multiwire proportional chamber', a gas-filled box with a large number of parallel detector wires, each connected to individual amplifiers. Linked to a computer, it could achieve a counting rate a thousand times better than existing detectors. The invention revolutionized particle detection, which passed from the manual to the electronic era.

(CERN archive)
Detectors @High luminosity

More and more particles occupy the elements

- Higher rate, high occupancy
  - 1D easily saturated $\rightarrow$ 2D
    - Wire chamber $\rightarrow$ Wireless MPGD
    - Silicon strip $\rightarrow$ pixel
    - To distribute hits in 2D elements

ALICE TPC Web page
Wireless chambers, MPGD

\[ V_{\text{GEM}} = -467 \text{ V} \ (\text{Gain} \sim 100) \]
\[ V_{\text{DRIFT}} = -2000 \text{ V} \]
\[ \text{Ar-CO}_2 \ (70-30) \]

F. Sauli TIPP09
Very fine but small

Timepix derived from Medipix-2
256 × 256 pixel of size 55 × 55 μm²

Each pixel can be set to:
• Hit counting
• TOT = integrated charge
• Time between hit and shutter end

Larger

• The base material is only 457 mm wide
• Get larger width by splicing GEMs
• 2 mm wide kapton overlay on GEM edges
• Pressed and heated up to 240 °C

Spherical

J. Kaminski
Large area MicroMegas successfully applied in the T2K TPC
Silicon detectors also go 2D

Strip $\rightarrow$ Pixel

Photo from Stapnes, Nature 448
Tiny pixel modules, huge # of channels

<table>
<thead>
<tr>
<th></th>
<th>ALICE</th>
<th>ATLAS</th>
<th>CMS</th>
<th>LHCB</th>
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<tr>
<td><strong>Pixel</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td># channels</td>
<td>9.8M</td>
<td>80M</td>
<td>66M</td>
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<tr>
<td># modules</td>
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<td><strong>Strips</strong></td>
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<td></td>
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<tr>
<td># channels</td>
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<td>3.2m</td>
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<tr>
<td># modules</td>
<td>1698</td>
<td>4088</td>
<td>15148</td>
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</table>
Impact parameter resolution

- Belle
- Alice
- ATLAS
- ILD
- LHCb
LHC detectors are miracles but ... 

A bit heavy !?
Reconstructed secondary vertices due to hadronic interactions in minimum-bias events in the first layer of the Pixel detector (sensitive to interaction length $\lambda \to$ complementary to $\gamma$ conversion studies)

- Vertex mass veto applied against $\gamma \rightarrow ee$, $K^0_S$ and $\Lambda$
- Vertex $(R, Z)$ resolution $\sim 250 \mu$m ($R < 10$ cm) to $\sim 1$ mm
The thinner, the more beautiful!

- Monolithic detectors
  - Sensors and readout chip fabricated on single wafer
  - MAPS, DEPFET, Deep N-Well, SOI, CAP...

- No bumps, high pixel density, thinnest electronics

From PVA TePla web
Highly Pixelated Transparent Devices for Future Vertex Detectors

Marc Winter (IPHC-Strasbourg)

(on behalf of the MIMOSA, PLUME, HP-2 & AIDA collaborations)

▷ more information on IPHC Website: http://www.iphc.cnrs.fr/-CMOS-ILC-.html

CONTENTS

- Introductory Remarks:
  ▷ the trend for very light pixelated systems ▷ ILC driven R&D

- CMOS pixel sensors:
  ▷ high-resistivity epitaxy ▷ applications ▷ advent of vertical integration

- Other thin pixel technologies currently under development:
  ▷ DEPFET ▷ CCD based: FPCCD & ISIS for ILC ▷ CMOS pixels: APSEL, Chronopix

- Summary – Conclusions
Need more and more functions

Vertical Integration comes next

- Moore’s law (“Livingstone plot” in microelectronics) will be slowed down in 10 years only with “2D” technology

- Physical limitation in finer pitch

ULSI can’t stay in 2D brane in future!
Multi Project Wafer (MPW) to share chip area and enormous cost

- 3DIC collaboration
- SOI collaboration
The tougher, the better

- Radiation tolerance is the most serious issue in
  - (HL-)LHC
  - (Super-)B-factory.
Or another type of 3D device
Momentum measurement

ATLAS Preliminary Cosmic '08

Belle

CMS
Advanced Superconducting Magnets

New conductor development for higher current density
(⇒ higher magnetic field)

$\text{Nb}_3\text{Sn}$, $\text{Nb}_3\text{Al}$...

Dual solenoid (w/o yoke)
Popular in MRI system.
Energy measurement:

ILC "requirement"

Mass Resolution: Requirements for separation

- Width of gauge bosons sets a natural scale for the required resolution

<table>
<thead>
<tr>
<th>Jet E res.</th>
<th>W/Z sep</th>
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<tbody>
<tr>
<td>perfect</td>
<td>3.1 $\sigma$</td>
</tr>
<tr>
<td>2%</td>
<td>2.9 $\sigma$</td>
</tr>
<tr>
<td>3%</td>
<td>2.6 $\sigma$</td>
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<tr>
<td>4%</td>
<td>2.3 $\sigma$</td>
</tr>
<tr>
<td>5%</td>
<td>2.0 $\sigma$</td>
</tr>
<tr>
<td>10%</td>
<td>1.1 $\sigma$</td>
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</table>

W/Z separation = $(m_Z - m_W)/\sigma_m$
Jet energy resolution

Jet Energy Resolution $\sigma/E_{\text{jet}}$ (%) vs. Jet Energy (GeV)

- ALEPH measured
- CDF measured
- H1 measured
- ATLAS simulation
- ILC goal
- DREAM measured
- PFA simulation

Partons are reconstructed as Jets

$Z^*$

$H$

$q$

$b$

$Z$

$q$

$b$
Ideas for better calorimetry

PFA (Particle Flow Algorithm)

- Pushing the idea further: Identify neutral and charged hadrons in the calorimeter directly
- Requires extremely high granularity in the calorimeters

Dual Readout (not adopted in ILC)

- Number of counts (arb. units)

F. Simon, KEK seminar

Richard Wigmans*
(Texas Tech University)
High granularity allows for particles separation and PFA application

- Explosion of the channel count!
  - ILD: ~100 M channels in ECAL, ~10 M channels in the HCAL
  - Compare to LHC: CMS ECAL: 76 k channels, ATLAS HCAL: ~10 k channels

About a factor of 1000 more channels: A totally different calorimeter technology!

CALICE, talk given by Imad Laktineh in this conference
**Time**

- Relevant scale in HEP experiment
  \[ t \sim \frac{L(m)}{c} \sim o(nsec) \]
- Traditional technique
  - Scintillator + Photo Multiplier Tube \( \sim o(100\ psec) \)
- Breakthrough with a spark discharge in gas
  - Pestov counter \( \rightarrow \) ALICE MRPC \( \sim 50\ psec \)

![Diagram of cathode pickup electrodes and anode pickup electrode](image_url)

**Rigidity (GeV/c)**

![Graph showing rigidity vs. momentum](image_url)

- Fast spark
- Multiplication measurement

**ALICE Performance**
- \( p+p \) at \( \sqrt{s} = 900\ GeV \) (2009 data)
- TOF
- 150k channels!
- \( \sigma \approx 90\ ps \)
Faster photon detections

- Micro channel plate (MCP) PMT
- Hybrid Photon Detector (HPD)
- Channel ~400 μm
- Photocathode
- Corrected for the jitter of light source

Inami, TIPP09

TOF with Cherenkov counter
Npe ~ 180

6.2 ps

Best for single particle

Inami, TIPP09
Further precision?

- Streak camera
- EO modulation (Pockels effect)

Applicable for beam pulse
Not for single particle

Subpico second world

HPK Catalog C6138

Not for single particle
“Spin off” is another important key word for the HEP labs to survive...

The most successful example From PSI, Pilatus Xray pixel
A very short look of the recent Detector R&D is given for theorists. Detector R&D is a very active field (even beyond) HEP. We are about to reach the sub-micro-meter, sub-pico-second world. 1D → 2D transitions is going in several places. Next step; thin and highly integrated sensors with 3D technology. Energy measurement (calorimetry) seems the hottest now. Measurement at low energy with ultra high sensitivity has not been covered → new chapter in PDG. R&D activity in HEP can not and should not be independent of the applications in the other sectors (industrial, medical….)