Summary Talk
11th June 2010
Paula Collins (CERN)
Thank you to the organisers for bringing us to this stunning location with its panoramic views.

Too much for my camera lens to take in – luckily as we heard this conference has a lot of experts in stitching techniques…

Thanks also for the nice gifts including this mysterious object

(what is it for? certainly not needed here!)
At Loch Lomond we have had a fantastic atmosphere and excellent talks and discussions!

52 talks, (~5 of them summary talks, 8 posters and a whisky tasting)

Great contributions from young researchers and even Lazarus effect. Contributions from companies highly appreciated

I will not do justice… Many apologies in advance
Number of acronyms is going up (Moore’s law?)

- mambo III
- fd-soi
- digimaps
- dnw maps
- vipix
- nxyter/cbm-sts-xyter/cbm-trd-xyter
- mimosis
- topix
- pxl
- victr
- slid
- depfet
- dhp/dcd
- tsv/feol/beol
- bpw/bnw
- hizpad
- ihp
- xpad
- intpix
- pixscan
- lucid
- flash
- lpd
- dssc
- lcls
- exfel
- agipd
- scss
- aid
- sdd
- ssd
- eudet
- velo
- malt
- feh
- sei
- spp
- sid
- mimosa
- plume
- serwiete
- timepix
- medipix
- velopix
- clicpix
- soipix
- spd
- elettra
- tbm
- roc1
- fec
- doh
- pAOH
- tec
- tob
- tid
- tib
- fed
Until recently, CMS was a big contributor

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New kid on the block: ATLAS

FEI4_P1
FEC4_P1
FETC4_P1
FE_T4_C4_P1
FE_T4_C4_AE
FE_T4_C4_DS
FE_T4_C4_DC
FEC4_P2
FEC4_P3
FETC4_A

mambo III
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dhp/ded

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scss
aid
sdd

ssd
eudet
velo
malt
feh
sei
spc
sid
mimosa
plume
serwiete
timepix
medipix
velopix
clicpix
Comparison with previous conferences - landscape

Cumbria, 2003
Beautiful landscape and typical rain

Loch Lomond, 2010
Beautiful landscape
Who ordered the weather?
Comparison with previous conferences - luxury

Basto Island, Finland
1992

Loch Lomond, Scotland, 2010

“Choose from indulgent en-suite facilities with private saunas or our contemporary styled rooms with smart technology and massaging showers. Select a view towards the conservation village of Luss or a room overlooking the Loch with full height windows that open onto spacious balconies, ideal for enjoying breakfast at sunrise or evening aperitifs at sunset”

Let us know by mail to BRENNER@VXCERN before Friday 15.5.1992 if you are interested. Because of limited space a maximum of 30 persons can attend this workshop.

Everybody is welcome to suggest topics for the meeting and prepare a talk. A big paper screen and colour pens will be available for explanations.

We remind you of the primitive circumstances on the island and kindly ask you to bring your own sleeping bag.
Comparison with previous conferences - transportation

Michigan, 2000

Basto Island, 1992

Ein Gedi, 1995

At this conference, you have to go by foot!
Comparison with previous conferences – lakes and volcanos

Ein Gedi swimming, muddy but warm

Loch Lomond swimming, clean…

Hawaii 2003

Iceland’s Eyjafjallajokull volcano, 2010 came very close to wrecking the entire conference!

and very cold!
Comparison with previous conferences:

**Food**

- **Basto Island:** cooked by the participants
- **Perugia 2006**
- **Loch Lomond:** gourmet indian and local cuisine!

Unfortunately, when the sun came out so did the midges – and this photo of Rosario’s hand tells the truth: Italian food is still the best!
When is she going to start the summary talk?

beats me...
Alan Homna “We know what a module looks like”
Still, the variety seen this week is impressive!
Special honour to give this summary talk: The first conference when LHC is firmly on the map!

Collected data: 10’s of inverse nb per expt

Gersabeck

A. Rossi

piaquadio

Paula Collins - Summary Talk
Vertex 2010

Venturi
CMS Double $b$-jet candidate (A. Venturi)

L = 6.2 mm (L/S = 43)
M = 2.9 GeV
pt = 25.7 GeV

L = 8.6 mm (L/S = 55)
M = 3.1 GeV
pt = 17.2 GeV

jet pt = 43.7 GeV

jet pt = 40.3 GeV
Incredible work on calibration, monitoring, and data quality

ATLAS pixels achieved thresholds of 3500 with 40 e\textsuperscript{-} uniformity and 160 e\textsuperscript{-} for pixel noise
Great tot resolution
99.9\% of clusters reconstructed in correct beam crossing

Calibrations performed online with physics quality data
Using resonances
Tracking efficiencies, cluster associations
Pixel by pixel ADC to Charge Calibrations
25 DAQs to set, many reoptimised in situ,
Management pressure, timing
Noise 100-200 e, thresholds 2500 e
98% working (98.8 and 96.4)

Similar campaign for strips: concentration on gain, timing, and up time
Amazing complementarity with cosmic data taking results
ALICE has online feedback and quasi offline (just after end of run)
Clear all detectors going in this direction, interesting to see how far
ALICE fast-OR trigger tuning (unique trigger input)
  • Makes use of internal pulser:
    • every single pixel can be addressed
    • pulse is sent to: none, one or more pixels (within 12%, i.e. maximum occupancy) to check noise and efficiency in all conditions
  • Tuning possible by 4 (out of 42) 8-bit DAC in each chip + global chip threshold
  • Automatic procedure can go in parallel on all 1200 chips, time required (with optimization) ~4 h (manual procedure: 10×)

Sdd time
Zero calibration
Calibration, Data Quality - LHCb

Similar procedure to previous experiments:
pedestal monitoring and database storage
time tuning at ~1ns level per 32 channel li

Online cluster map distributions

T. Bowcock

M. Needham
More dq – dedicated streams

Express streams for physics quality monitoring
CMS run Spy channels for NZS at rates of ~ Hz
Eliminate separate calibration runs?

Captures full raw-data frame

- Provides complete non-zero suppressed data including error bits, etc.
- Read at low rate (max 0.3 Hz)

It is very important that we detector lovers take the opportunity now to sort out the problems, before they come back to haunt us! Push for calibration runs, NZS data taking etc.
Things going wrong… Thanks for sharing!!

- ALICE: blockages in mixed phase cooling system C4F10
  - Mixture of filters, some accessible, some not
  - Results in 85% (max 92% efficient system)
  - Trimming necessary on pixel power (85% on preamps)
  - Analysis performed on a one-year old filter.
  - Results and conclusions: “In the used filters several exogenous fragments were located clogging the filter. There were several fragments containing different composition elements. In addition to elements from the Stainless steel, the following traces of elements were found: O, Al, K, C, Sn, Cu, P, Ca, Cu, Na, Cl and Zn.”
- Alice sdd hv or fee problems
- SSD electrical problems, humidity problems in sintef sensors
- ATLAS pixels: small leaks in cooling system,
  - TX failures (VCSEL boards)
  - “Optical communication between fe and ode must always be subject to very stringent QA”
- ATLAS barrel cooling: decision to run at higher temperature
- LHCb:
  - Low power VCSELS
  - Failing voltage regulators
  - Oscillating LV power
  - cooling blockage (fixed)
  - Not centered around beamspot (open 300 um)
- CMS pixels
  - HV and LV connection problems: all repaired
  - Optical links sensitivity to temperature: all repaired
  - Wirebond problem, dead modules
- CDF:
  - Cooling liquid -> corrosive: partially fixed
  - Optical interface boards suffer radiation damage
  - Some noisy sensors (MICRON)
- TOTEM: Silicon touching foil due to engineering change (fixed)
Is there such a thing as a “Canonical Efficiency” for a HEP silicon detector?

ATLAS pixels 97.2% working
ATLAS strips 99.0% ON

Cms pixels 98% working
Cms strips 98.1 (96.3/98.3/99.1/98.8)

ALICE SSD 92.5% working (99% in good modules)
ALICE SSD 90% channels working
ALICE pixel 85-92% working

LHCb silicon 99.2% (700k channels)
LHCb TT 99.8%
LHCb ST 99.2%

CDF (after 9 years) 90% (but started out much lower)
Silicon doing all the things it is supposed to do – and lots more besides!

Expected from parameterization: $-0.042$ K$^{-1}$
Point correction is small: $\sim 0.1$ $\mu$m/K
...but nice it can be observed
Silicon is even behaving as a bubble chamber

- The barrel works as a bubble chamber, the particles fly parallel to the silicon.
- The background events leave (centimeters!) long charge deposits.
- We see production of secondaries in the silicon volume.

H. Snoek

Detailed analysis shows
Rate proportional to number of protons

Excellent pattern recognition and tracking can identify the lousy hit association in these events and cut them out with the "pixel template" fitter

The rate is estimated around 0.5 Hz/bunch/beam/10^{10} protons

At a rate of 11kHz of physics events at 10^{11} protons per bunch an overlap with a background events is expected at a rate of about 1%.
Silicon for Triggering is coming online

See talks from this morning
Martin van Beuzekom
Richard Brenner
Mark Pesaresi
LHC – the ultimate beam test?

LHCb showed high statistics studies on modules

Alice – able to tune pixel corners and recover 6% efficiency
Resolution: More complicated story...

Atlas applying corrections of 30-60 um
Studies of data pulls show effective resolution of 7+7 um

CMS quote resolution of 12 um (for 100 um pitch) using overlaps

LHCb show worse than expected eta distribution for perpendicular tracks (but excellent performance for angled tracks)
Impact Parameter resolutions

The gold standard performance plot for a vertex detector

Interpretation of these plots not easy! With a VERY big grain of salt you can compare the highlighted numbers

For the time being no management approved result from ATLAS and CMS

Will be extremely interesting to see how these plots evolve

Many thanks to Andrea and Rosario for enlightening discussions!

Who ordered this?
Primary vertex resolutions

Similar technique followed by all experiments
Puzzles from past conferences

1. LHCb party puzzle
   - What is the prize?
   - How will LHCB align for each fill & with non-uniform irradiation?

2. Who knows how to readout short-strips (~10mm) or macro-pixels?
   - Another prize?

M. Tyndel, 2005
Puzzles for this conference

1. Fast electronics, fine pitch, perpendicular tracks
   Is there an anomaly? LHCb and ATLAS data
   maybe point that way?

   MAPS, ultimate

   [Graphs showing resolution vs. pitch, efficiency vs. threshold, and resolution vs. strip pitch]

   Could become an issue especially after irradiation
   When tricks and helping hands like inclinations and lorentz angles become less effective...

2. ageing w/o radiation?

   [Graphs showing some ladders in L2 and L4 had a recent efficiency drop (9 out of 172)
   -Layers became under-depleted as they aged.
   -All 9 had their bias increased with no increases in noise.]
System Issues and Material Budget
Beginning to be well understood

Atlas calibrate
By using
Reconstructed
Kaons; momentum
Scale correct down to
~0.04% so confidence
Coping with beams and operational issues

Push configuration issues as much as possible out of stable beam period
Fast HV ramp after stable beams declared
New for this conference: VELO Closing around LHC beams (S. Redford)
Daring to go up close

TOTEM have approached
Within 4.5 sigma of the beam

Edgeless technology shows very
Impressive efficiency and is able to hold
>500 V post irradiation

P on n technology means that high
Bias voltages are needed

J. Kaspar
Another beautiful image from the conference

LHC beam gas interactions measured in LHCb for 450 GeV run, for magnet up and magnet down, beam1-gas and beam2-gas superposed

Maybe not as beautiful as the loch? but has a scottish feel to it!
2.4M vertices in plot, ~20k from material interactions, ≥3 tracks per vertex
CDF running then, now, and in the future

“leaving no ladder behind”

using almost every opportunity for diagnostic and repair work
Radiation Damage: are we ageing gracefully?
New kid on the block: charge multiplication
G. Casse, J. Lange, G. Kramberger…

- Charge multiplication gives more signal!
- Applies also to leakage current: difficult to optimise!
- 2nd peak in edge tct clearly linked to avalanche multiplication of electrons close to strips
- Good news but
  - watch out for common mode behaviour (CNM)
  - watch out for resolution
- Dependence on detector thickness very encouraging: thin is good, thinner is better
- Overall optimisation depends on initial contribution of different noise factors
- Edge TCT measurements spectacular proof that charge multiplication is happening
- can measure relative contribution of primary and secondary charge and show the turn on at sufficiently high voltage
- confirms connection between Ileak and CCE
- Annealing very surprising behaviour
New results on NIEL scaling violations with diamond irradiations
Point the way to new irradiation campaigns with relevant neutron energies
(few x 100 MeV)

New material: spectacular results!
New US vendor (Element II-VI)
On the second iteration got a 2.2.5 mm thick wafer which showed results equivalent to the best ever achieved with previous vendor (previous vendor delivered many pieces with CCD<250)
Much excitement!
Evaluated several wafers: most recent 2-2.5 mm thick
Fantastic charge collection distances!
And even a Lazarus effect:

Reworked module
3d sensors and pixel sensors

Learning the design rules
Take a pixel array
Add horizontal vias
Etch trenches… add some color…
Hey presto! The vertex tartan...
Many, many, many, many, many, many, many, many possibilities shown at this conference…

After DRIE
After polyfilling

A. Kok, C. Fleta

many gorgeous results from sintef (drie process 3d sensors) and cnm (ICP etching) worked hard on etching aspect ratios, stress in wafer, voids during wafer bonding etc. huge improvements and good 2E testbeam results for CMS
Pixel detectors for the new generation photon sources

- Completely new science
- Fast science – 100 fs
- Single shot science
- 2700 bunches in 600 us, repeated 10 times per second
- Big coverage pixel detectors
- “no noise”
- Big dynamic range
- No material budget requirement
- Currently 3 solutions on the table:
  - Parallel gains per pixel
  - non linear response (engineered DepFet)
  - 3 switched gains

Output voltage as function of charge

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Vertex 2010
Low dose x ray tomography

- Hybrid pixels for X ray imaging
- Single photon counting with threshold
  - Low doses possible
  - Crystallography also accessible
- 7x8 cm tiled xpad chips
- Images achieved with very low doses
- 2 ms readout and up to $10^6$ photons/s
- Next step: small pixel with big threshold range
- Latest version xpad3.1

- Big step forward: simultaneous PET/CT scan
- Combine PET with xpad
- Color images

XPAD2 Hybrid Pixel Detector
330 x 330 $\mu$m$^2$ pixels

X-Ray source

Images achieved with very low doses

Patrick Pangaud

09/09/09
Paula Collins - Summary Talk
Vertex 2010

courtesy: A. Butler, MARS Biomedical Imaging Ltd.
High Z solutions Masterclass

- **Challenges**
  - homogeneity
  - leakage current, resistivity, trapping
  - pixellation, bump bonding

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**GaAs (Cr)**

- 300µm, ohmic contacts (Au)

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**X-ray absorption / interaction**

- Silicon (500um)
- Ge / GaAs (500um)
- CdTe (500um)
Medipix and progeny

R. Plackett

SPS beam line

Medipix dosimetry

Medipix 3 images

Crystal beam channelling

Photon detection

Medipix electron microscopy

Medipix 3 clustering
Mrs Roentgen, eat your heart out!
MAMBO III – Showcasing SOI and a glimpse of 3D

- Separate substrate and cmos circuitry
- reminded us of the painstaking work in getting chip working
  - issues of matching
- T-Micro 3D integration process
- Negotiate detector specific demands to the oksi process to reduce cross talk

dummy contacts to provide enough coverage for yield
detector and electronics the same

Farah Khalid
And also something completely different

neutron detection for radiation portal monitors
screening of scrap metal prior to melting
control of nuclear sites

John McMillan
From HEP to Medicine and back again
The road to 3d

adaptive gain integrating pixel detector
3d technologies
See Ray Yarema’s talk!

- improve spatial resolution
- deal with an increasing counting rate
- decrease pixel size without adding material
- huge number of variations and stacking possibilities
- use for electrical signals but also cooling, interposers..

chartered 130 nm tech
tezatron 3d technology
wafers stacked face to face with cucu thermo compression bonding
Super contacts formed and wafers thinned (pangaud)
3d consortium  G. Traversi

- High resistivity pixels:
  - larger signal available from detector
  - more advantageous trade-off between S/N and dissipated power
- Bump bonding can have significant mass and represent a high $X_0$ for fine pitch assemblies or high density interconnections
- In the next MPW run, development of a 3D front-end chip (32x128, 50um pitch) to be vertically integrated with fully depleted detectors through some more (bump bonding) or less (direct bonding) standard technique

- less PMOS in the sensor layer $\rightarrow$ improved collection efficiency
- more room for both analog and digital power and signal routing

Fine pitch (50um) bump bonding (IZM, Munich), with a 2D FE chip in progress, with a 3D FE chip in the future

Other technologies (Direct Bonding by Ziptronix) will be investigated in the future
SOI pix – many developments pick out two here –

More can sometimes be less!
ATLAS Chartered-Tezzaron MPW run

3-D benefits:
- Pixel size reduction
- Functionalities splitting
- Technologies mixing

FEI4_P1 design: IBM 130nm, 8 metals

FEC4_P1 circuit: 2D Chartered, 8 metals
FETC4_P1 circuits: 3D first prototype
FEC4_P2 circuit: 2D Chartered, 8 metals
FEC4_P3 circuit: 2D Chartered, 8 metals
FETC4_A design: Second/last 3D design
  - Chartered (5 metal levels) + Tezzaron
  - Pixel size: 50µm x 125µm
  - Complete functionalities will be implanted on analogue and digital Tiers.
MPI 3D R&D Program

- Build demonstrator using ATLAS pixel chip (FE-I2/3) and thin pixel sensors made by MPI (complete wafers with FEI2, FEI3 chips available!)
- Use interconnection technology allowing postprocessing
- Interconnection with SLID and ICV technology by Fraunhofer IZM
- Demonstration of postprocessing of standard ASICs with via last

R&D Issues:
- Technology: compatible with sensors, ASICs?
- Interconnection quality: e.g. capacitance
- Yield & Costs.
- Production in industry.
- Material (copper layer).
Future directions

Reading the manual

Experimental approach
Complete spectrum of upgrade proposals (probably to be viewed on a log scale)

- **Today**
  - NA62 GigaTracker Project
- **Tomorrow**
  - STAR
  - Belle II
  - ATLAS IBL
  - LHCb upgrade
  - CMS Phase I Pixel upgrade
- **Next week**
  - CBM, Panda
- **After that**
  - SLHC related upgrades
  - CLIC related detectors

“Ultimate goal remains a massless, cheap, infinite granularity, 100% hermetic and efficient, infinite bandwidth, long lifetime detector”

(Muenstermann, after Garcia-Sciveres)

Progress on these projects not necessarily inversely proportional to timescale…
LHCb upgrade (~2015)

- LHCb upgrade plans do not require SLHC luminosity
- (but we would quite like LHC to deliver nominal running during the next 4-5 years)
- Challenges are radiation hardness (=thermal management), data rates, and vacuum operation
- ASIC development well underway with Medipix/Timepix collaboration
NA62 Gigatracker (~2012)

Pixel detectors with time resolution thrown in

- Many requirements in common with LHCb
  - Enormous data-rates
  - Low material
  - Operation in vacuum
  - Radiation hardness (more relaxed)
  - Timestamping (More severe: ~100 ps)
- Have developed and tested two (2!) ASICs
  - constant fraction discriminator + on-pixel TDC
  - Time-Over-Threshold circuit followed by shared TDC
- The cooling is very cool!!

chip demonstrating fantastic (non) timewalk behaviour, and full r/o chain demonstrated
MAPS based vertex detector at STAR ~2013

“Most critical and difficult part of HFT upgrade!”

- 2.5 cm and 8 cm radius
- 8 um hit resolution
- 0.37% X/X0
- 0.2 ms readout time
- 8 hour detector swap over time
  - Similar to an NHL line change?
- Very low mass features include
  - featherweight mechanics
  - air cooling system

Vacuum chuck for probe testing 50 μm thick MAPS

- Silicon power: 100 raised to 170 mW/cm² (~ power of sunlight)
- 350 W total in the low mass region (Si + drivers)
Belle II SVD upgrade
Aim: super high luminosity -> $10^{10}$ BB per year

- Current SVD cannot sustain lumi increase
  - hammamatsu restarted dssd line
  - micron home designed sensors
- have to put the chip on the sensor because of cap load – readout sensors individually
- use apv25, thinned to 100 um
- can use timing information to remove off-time background hits
- total reduction of 100 in occupancy
- origami modules

SVD-II Layout (2014-)

4 layers of double-sided strip sensors
Double-layer of DEPFET pixels
Trapezoidal sensor with test structures

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Vertex 2010
CBM + PANDA @ FAIR

“Accelerator for everything from antiprotons to Uranium”

- Major tracking challenges ahead for completely new detectors
- Extensive prototyping and simulation
- Close collaboration with MAPS groups (dedicated developments)
- Beautiful results from demonstrator projects in testbeams
CMS and ATLAS phase 1 upgrades

Expectation of ~100 p.u. events…

- CMS: going for the kill on material budget (= i.p. resolution) and track seeding (adding a pixel layer)
  - current 3 layers 17 kg
  - future 4 layers 6.5 kg
- How do they do it???
  - Move to CO2 cooling
  - Use of Airex and Carbon Fibre
  - chip away at everything else!
- New databuffer circuit tester
  - Elegant R&D tool
  - Verilog model and random data generator implemented in fpga
  - Can directly test sustainable rates
Reminder of conditions at CLIC and ILC

Design very critical on the belief that the pixels can be *very* small, and that differences of 5, 4, and 3 micron resolution can be made to count

A long way to go!!

<table>
<thead>
<tr>
<th>CLIC:</th>
<th>1 train = 312 bunches, 0.5 ns apart</th>
<th>trains at 50 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILC:</td>
<td>1 train = 2820 bunches, 308 ns apart</td>
<td>trains at 5 Hz</td>
</tr>
</tbody>
</table>

\[
\begin{array}{|c|c|}
\hline
\sigma_{\text{point}} & 3 \mu m \\
\hline
\sigma_{IP} & 6.5 + \frac{16.7}{p_t} \mu m \\
\hline
\sigma_{\text{point}} & 5 \mu m \\
\hline
\sigma_{IP} & 9.2 + \frac{18.6}{p_t} \mu m \\
\hline
\end{array}
\]
1998

“Major advances in radiation hardness with oxygenated silicon detectors and deep submicron chips (just in time!).”

“Hope was expressed by Steve Watts that b=0 silicon could be engineered, where b is the coefficient of reverse annealing.”

2010

LHC data!
Huge diversification of pixel applications
Charge Multiplication

Next Year

Avalanche of progress in *real* real steps in 3d processing
“hep should be ready to embrace the via revolution and the benefits it will bring”
ultra rad hard progress
Performance plots at ultra fine level
Some quotes from the conference:

- Lars: Chris seems to be pushing the wrong button

- Karl: “easier to shift the cms pixel detector than the monte carlo”

- Marco: “On to the flavour physics lecture”

- “not necessarily technically feasible”

- “Every detector developer should be forced to take an image with his teeth”
Huge thanks to the organising committee

Special mention for the paparazzo