RD50
from Experiment perspective

Frank Hartmann – THANKS FOR ALLOWING ME TO TALK HERE
Well, we couldn’t have done without RD50
What did we – THE EXPERIMENTS – get?

• Forum to discuss all
  • Reasonable and crazy ideas
• Recipes
  • What to build
  • How to operate
• Tools
A Forum – a common goal

• Always difficult to understand which R&D effort is RD50 and what is experiment
  • I consider this perfect. It means we are sharing information on successes and failures

• I am unable to decide what is most efficient
  • The sessions with talks
  • The evening get-togethers
  • The coffee breaks
  • Lab visits

Well Ok, I can:
It’s the coffee breaks plus the common goal!
I always enjoyed the clear and frank chats
• For LHC
  • Oxygen is good – Carbon is bad
  • p-in-n is OK for Tracker
  • n-in-n is OK for Vertex (oxygenated n-bulk)

• For HL-LHC
  • Oxygen is good – Carbon is also good at some places
  • n-in-p is great
    • optimise thickness
  • 3D is better
  • Precise timing is possible

• A WISE MAN SAID:
  For p-in-n sensors, the donor removal component of the Hamburg model cannot be described by a simple process $V + P \rightarrow VP$ only. There is something more behind that and we still do not exactly understand what it is.

• RD50 ALSO CLEARLY TOLD US:
  But, while new materials seem to be more radiation tolerant, a complete evaluation of each material must be conducted separately for neutron, proton and mixed irradiation. The correct radiation mixtures at different radii in the experiment should be checked.
RD50 and Hamburg Model said p-in-n is OK for E14

Seems you are right

~270m² proves it
The CMS Tracker

- 200 m²
- Strips and pixel detectors
- Operating > 1 decade
The ATLAS Tracker

- 60 m²
- Strips and pixel detectors
- Operating > 1 decade
LHCb until LS2

Detector has accumulated fluence of approximately $7 \times 10^{14}$ $1\text{MeV n}_{\text{eq}}/\text{cm}^2$

Strips
n-in-n plus some n-in-p
And RD50 followed-up if all is true

19th RD50 workshop, November 2011 at CERN, especially in the session on **radiation damage observed in HEP experiments**

→ Inter-experiment radiation damage working group
Radiation Damage and Annealing exists

Inter-experiment radiation damage working group

• The Hamburg Model rocks
  • Good recipe when to increase bias voltages
  • Parametric description of operation parameters (signal, trapping, current) as a function of fluence and temperature.
Then we learned, we should use ‘**ELECTRON READOUT**’

![Graph](image)

**Strip sensors:**
max. cumulated fluence for LHC and HL-LHC

**Pixel sensors:**
max. cumulated fluence for LHC and HL-LHC

**FZ Silicon Strip and Pixel Sensors**

- n-in-n (FZ), 285µm, 600V, 23 GeV p
- p-in-n (FZ), 300µm, 500V, 23GeV p
- p-in-n (FZ), 300µm, 500V, neutrons

References:
1. p/n-FZ, 300µm, (-35°C, 25ns), strip [Casse 2008]
2. n/n-FZ, 285µm, (-40°C, 40ns), pixel [Rohe et al. 2005]

Note: Measured partly under different conditions! Lines to guide the eye - no modeling!

**CAVEAT, PROBABLY NOT ENOUGH FOR INNERMOST SENSORS**

From RD50 (M. Moll)
And, LHCB is ahead

- New VEO with n-in-p pixels
- Exchanged in LS2
Let’s increase to 1000 m²

**L1-Trigger**
- Tracks in L1-Trigger at 40 MHz
- Particle Flow selection
- 750 kHz L1 output
- 40 MHz data scouting

**DAQ & High-Level Trigger**
- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output

**Barrel Calorimeters**
- ECAL crystal granularity readout at 40 MHz with precise timing for $\eta > 30$ GeV
- ECAL and HCAL new Back-End boards

**Muon systems**
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta = 3$

**Tracker**
- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta = 3.8$

**MIP Timing Detector**
- Precision timing with:
  - Barrel layer: Crystals + SIPMs
  - Endcap layer: Low Gain Avalanche Diodes

**Beam Radiation Instr. and Luminosity**
- Beam abort & timing
- Beam-induced background
- Bunch-by-bunch luminosity: 1% offline, 2% online
- Neutron and mixed-field radiation

**Calorimeter Endcap**
- 3D showers and precise timing
- Si, Scint+SIPM in Pb/W-S5

**Axial field provided by solenoid (2 T) in the central region (momentum measurement)**

**High-resolution silicon detectors**
- 700 Mio. channels (50 $\mu$m x 250 $\mu$m)
- 6 Mio. channels (80 $\mu$m x 12 cm)

**Spatial resolution ~15 $\mu$m (in azimuthal direction)**

**Precise energy measurement down to 1$\sigma$ to the beamline with a calorimeter system**

**Independent muon spectrometer (superconducting toroidal magnet system)**

**Ultra-fast custom electronics and high-performance computers filter the collisions: only 1 out of 30,000 collisions is kept**

**Ok, now we need**
- $X \cdot E_{16}$
- And precision timing
ATLAS Phase II

End-cap petal loading with 9 modules per side

Strips & Pixel
All n-in-p

Barrel stave loaded with 14 modules per side
CMS Phase II

- Outer Tracker modules in final configuration – n-in-p
- Pixel Tracker module – n-in-p
- High Granularity Calorimeter – n-in-p (8 in.)
Evolution of 3D implementation

- Double or single type?
- Double or single sided?
- Full 3D-pass-through?
- Thin or thick?

First RD50 workshop
Silicon 3D radiation sensors: general characteristics; irradiation test results
Sherwood Parker and Christopher Kenney (LBL Berkeley, USA)

Deep reactive-ion etching (DRIE)

© ATLAS APPRECIATES - L0 AS FIRST USE-CASE
Fig. 2.27 The final HL-LHC 3D sensor layout with $25 \times 100 \mu m^2$ pixel cells – 1E-scheme
Then there was head scratching

Then we had daring ideas ‘to use’ the amplification

Then we re-invented reach-through diodes – optimised them – and called them LGADs

And all of the sudden CARBON IS GOOD
Let’s put LGADs at work

ATLAS and CMS will equip their endcaps with LGADs to associate a timestamp to their tracks – 4D
LHCb – LS4

• Precision **timing** is key

... and do not forget **spatial** precision

➔ We need an upgrade on LGADs
From Abe Seiden, Hartmut Sadrozinski and Nicolo Cartiglia pioneers on LGADs:

I'm wondering if we can do both measurements (space and time) in one object, a silicon detector with very good timing resolution.

We thought it was a dumb question...but over lunch, we jotted down some numbers.

... The main question is understanding the gain in silicon sensors

Watch out – people from different experiments working together... -- Thanks for the framework – and the BLUR
In summary, I present THE ZOO

Anybody up for a bet?

LGAD

DJ-LGAD

inverse LGAD \((p-in-p)\)

inverse LGAD \((n-in-n)\)

RSD

Monolith

or the new DC-RSD (DC-LGAD)
Tools, spearheaded, improved, standardized, distributed by RD50
- ANYHOW, THEY CHANGED OUR UNDERSTANDING SIGNIFICANTLY

• TCT – front, back, edge and then TPA-TCT
• TSC, DLTS
• IV, CV
• Alibava
• Many more …

• Custom simulation tools
• Radiation defect models, Hamburg Model
THANK YOU RD50

• IT WAS FUN

• TOGETHER RD50 AND EXPERIMENTS
  • WE REALISED MARVELLOUS DETECTORS

• MORE TO COME BASED ON ALL THE GOOD WORK OF RD50