Primer for discussion



Discussion...

Outline

- Inter Experiment Working group
- What have we learnt? Where next?
 - Fluence and leakage current
 - Temperature effects: surface / bulk current and effective band gap
 - Effective Depletion Voltage

Future





Working group history

Radiation Damage Inter-Experiment Working Group

Set up in 2011 to focus on recent measurements and modelling of radiation damage in silicon detectors, particularly first results at the LHC.

- History: the working group was initiated following conversations at RDII in July, starting with informal meetings of silicon experts from ATLAS, LHCb CMS, RD50.
 - We held our first Inter-Experiment Workshop on Radiation Damage in Silicon Detectors, 4 October 2011, which aimed to trigger further collaboration:
 - <u>https://indico.cern.ch/conferenceDisplay.py?confld=156565</u>
 - Fruitful discussion led to several inter-experiment agreements which enabled a common approach for the special session in the 19th RD50 workshop:
 - <u>https://indico.cern.ch/conferenceOtherViews.py?confld=148833</u>
 - Second Inter-Experiment Workshop on Radiation Damage in Silicon Detectors:
 - <u>https://indico.cern.ch/conferenceDisplay.py?confld=178194</u>

Further collaborators are welcome - please join us!

- Meetings are announced via e-group mailing list: rad-damage-iewg.
- Join the e-group to access the sharepoint: <u>https://cern.ch/rad-damage-iewg/</u>



- Radiation damage is clearly visible in the 2011 5fb⁻¹data:
 - Leakage currents rise with the fluence profile and anneal with temperature and model describe the data well qualitatively, with the expected shape:
 - Best agreement is for high radii detectors (ATLAS / CMS strips)
 - Some scaling up of the model is required for certain low radii detectors for the model(s) to describe the data – why?



Leakage current at higher radii



annealing of heavy ion run



- Midpoint: mean over entire layer
- Errors bars: RMS deviation
- Model comparison: See talk by C. Barth, this session
- Model uses
 z = 0, mean r

Good agreement i ^{23 November 2011} with no scaling of Dortmund model. (Harper predicts 10% lower with uncertainties)



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Discussion

In A/cm³1 (corr to 0°C

Leakage current at higher radii



Good agreement, after scaling (data 13% lower than prediction) radii ~40 to 120 cm,



 Improvements to simulations on-going (annealing to be included)



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Leakage current

- In general the agreement between model and data is remarkably good; "within a factor of 2 is already amazing", Marko Mikuz, at recent 7th "Trento" workshop.
- Agreement between model and data is better at the larger radii of the strip detectors in ATLAS and CMS, where the fluence is neutron dominated:
- For the Pixel detectors, the models needs to be scaled up by less in the inner layers than for the outer layers:

For discussion:

- Why do the experiments see this ~15% discrepancy increase in the outer Pixel radius?
- ALTAS uses Phojet, CMS uses DPMJet III
- Secondaries? Low pT Loopers? Charge fraction?





Damage from fluence distribution



Phi distributions and beam spot



Leakage current Z distributions

20

15

(cm) 10

5

10

20

30

7 TeV FLUKA fluence prediction in Pixel

preliminar

1e+10

particles /

/ cm²

l_{leak} [μΑ/cm³] (corr. to 0°C)

- Slightly larger fluences in central regions, at a given radius, reflected in leakage current distributions.
- Next steps?
 - Normalized comparisons at RZ positions between experiments.
 - Check of fluence prediction models.





FLUKA fluence comparison



Earlier work toward checking FLUKA models between experiments:

- Radial dependence at different Z slices compared for 7 TeV and 14 TeV FLUKA simulations in CMS and ATLAS.
- Initial studies show reasonable agreement at low radii, despite effects of material and different magnetic fields (low p_T loopers).
- Next step: 8 TeV simulation needed for 2012 data?



Leakage current vs fluence 2011



- Annealing steps from maintenance periods apparent in ATLAS data (-13°C, with stoppages at 20°C). Simple fit for effective alpha yields: $\alpha \sim 1.1 \text{ e-}17 \text{ A/cm}$
- Parallel annealing in CMS (17°C operation, drops to 10°C when detector is off)



2011/2012 fluence at 7 TeV / 8 TeV

- Rate of increase of current in 2012 is higher than in 2011, due to higher fluence in changing from 7 TeV to 8 TeV collisions.
 - Leakage current model includes a very preliminary interpolation of ATLAS 7 TeV and 14 TeV FLUKA simulations to 8 TeV: this underestimates the data. Ideally new 8 TeV simulations are needed.
 - Can alternatively measure the gradient between cooling stops, to determine the relative 7 TeV and 8 TeV fluence factors. Operation is at -13 C, so annealing during each operation period is frozen / negligible.





IV curves: bulk / surface current

- LHCb see two categories of sensor, dominated by bulk current or by surface current: Current(µA
- ATLAS sensors so far appear bulk current (at dominated.
- Why the increase after full depletion? OR .
 - Hint that active volume growing in guard ring region for higher bias? Surface current?
 - Which volume to take for leakage current?



Surface

14





- Correct leakage currents to a common reference temperature of T_{REF} = 0 °C Chosen to suit the range of sub-detector operating temperatures.
- 2. Use the same temperature correction:

Discussion, next slides

 $I(T_{\text{REF}}) = I(T) \left(\frac{T_{\text{REF}}}{T}\right)^2 \cdot \exp\left[-\frac{E_g}{2k_{\text{B}}} \left(\frac{1}{T_{\text{REF}}} - \frac{1}{T}\right)\right] \qquad \text{Effective silicon band gap } \mathbf{E}_g = 1.21 \text{ eV}$ following RD50-2001-01 recommendation

- 3. Normalize current to the volume of silicon [cm³] rather than per module.
- 4. Standard units: $\frac{\mu A}{fb^{-1}cm^3}$ Discussion which volume: active / guard ring?



Temperature scaling



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Discussion

Measurements of effective band gap

- Temperature dependence
 - Fitted E_a compatible with literature value (1.21 eV)
 - Only if constant term is allowed (else 1.13 eV)





1.10 +- 0.04 eV

1.14 +- 0.04 eV





0.516 ± 0.012

Measured ratio of mean of 5.16 +/- 0.012 compatible with 5.08 expected for Eg = 1.21 eV

Studies ongoing: Systematics on temperature measurement *in situ*?



Discussion

 $I(T) \propto T^2 \exp\left(\frac{f E_g}{2\pi}\right)$

150V

150V

821 pb-1

1204 pb-1



Effective depletion voltage





- Model appears to underestimate the data close to type inversion:
 - Theoretical value goes to zero, where as in reality is the measuremed value goes close to an offset before rising.
- Cross-talk method will be replaced by track-based method after type inversion.



- Open topics:
 - Second metal layer charge loss in LHCb
 - Non-conformance of results from certain sensors: e.g. CMS Preshower measurements.
 - Understanding depletion voltage evolution / annealing before type inversion.
 - LHC simulated fluences and agreement with leakage currents at low radii.
 - Understanding leakage currents in new alpha regime.
 - Effective band gap and recent measurements.
 - Common framework and future.
- **Working groups** on the following topics are being set up; please join!
 - FLUKA simulations of fluences,
 - Leakage currents and modelling
 - Depletion voltage and modelling.
 - Anomalous effects.



Thanks to all the experts

