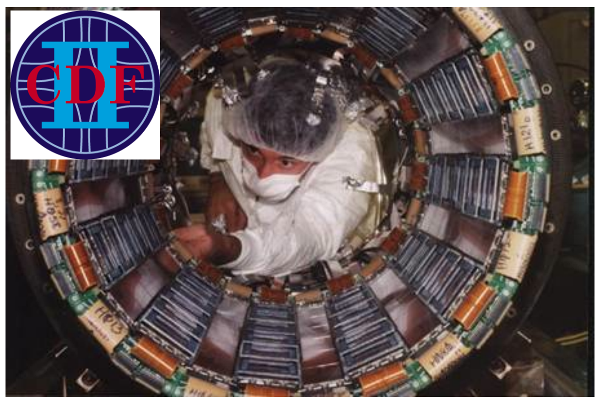
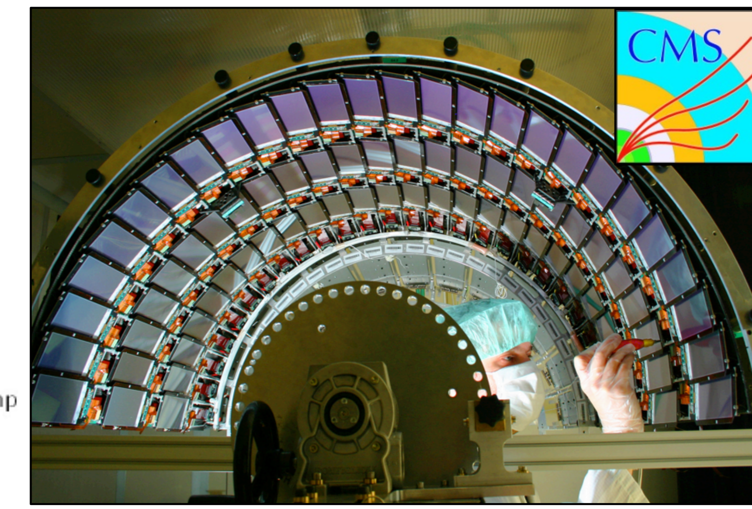
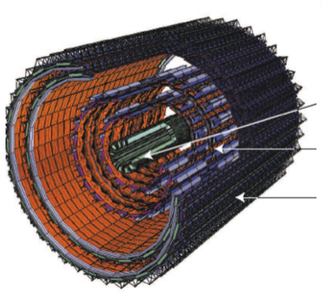
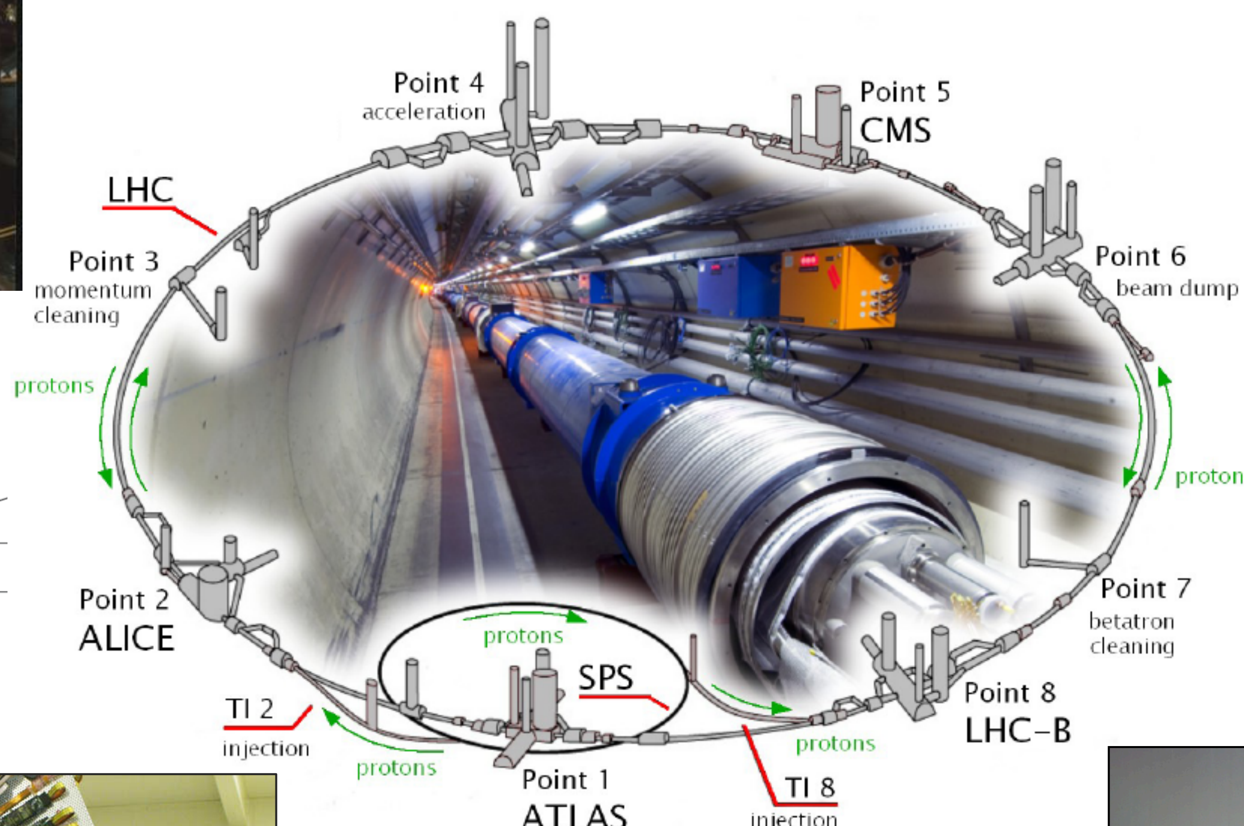
Second Inter-Experiment Workshop on Radiation Damage in Silicon Detectors

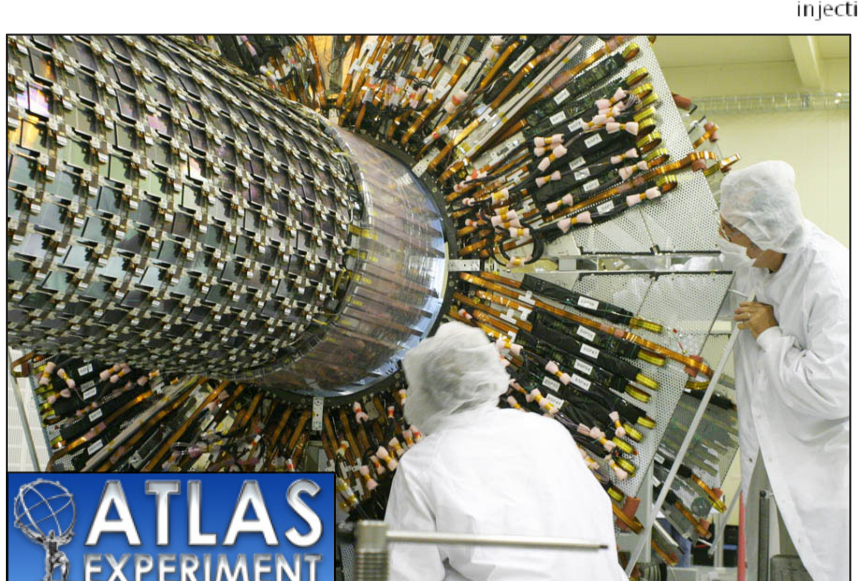
Primer for discussion on common issues









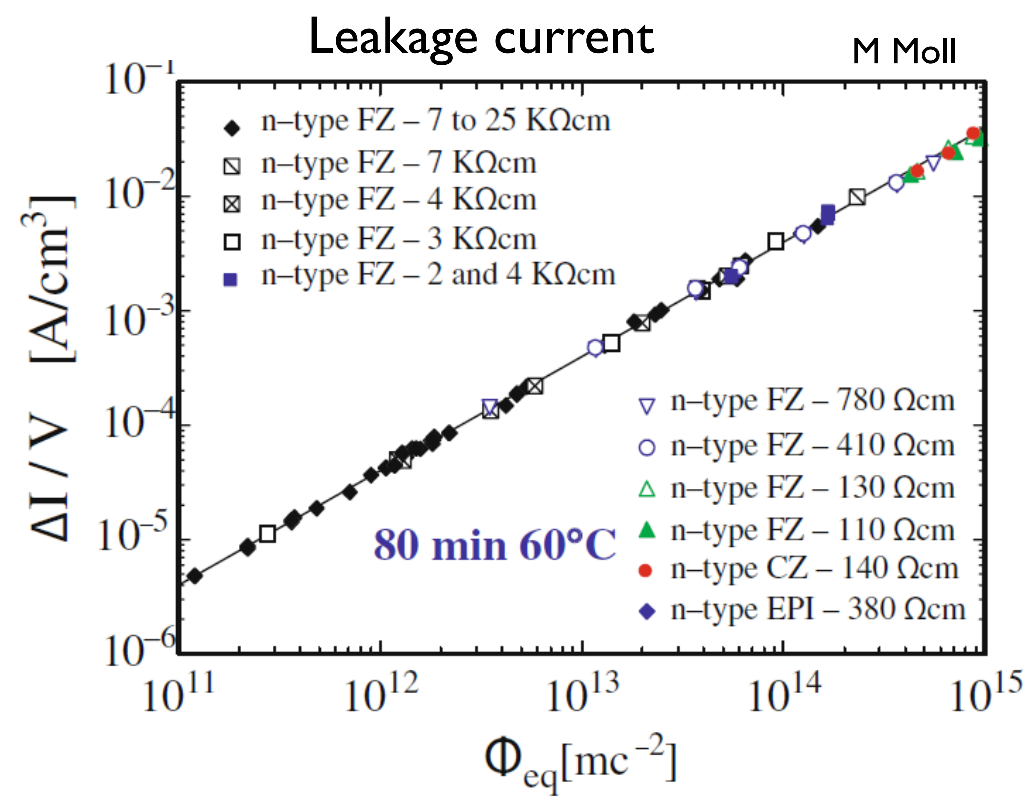


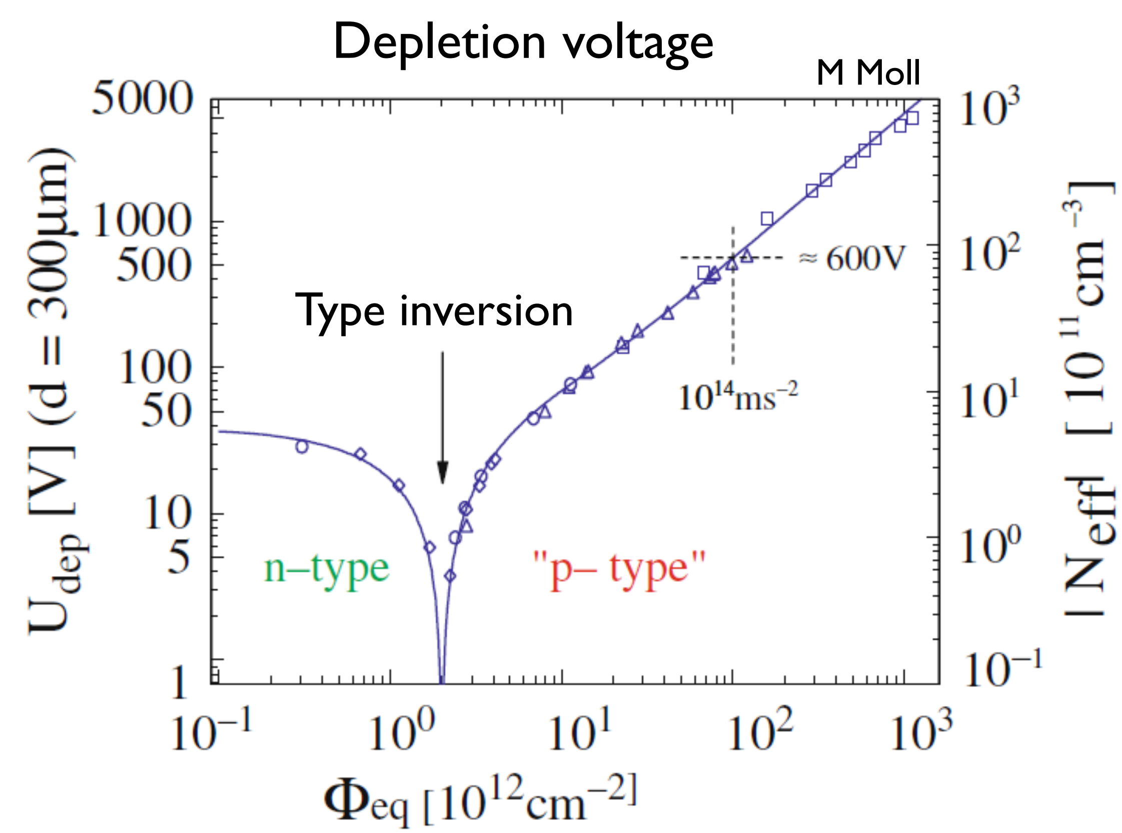
Stephen Gibson
CERN
on behalf of
Inter-Experiment Working Group

Common issues

Outline

- Effective band gap
- Fluences and leakage current
- Topics for discussion
- Future organization





Common framework

- At our first October 2011 workshop we agreed on common framework for simpler comparisons:

1. 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:

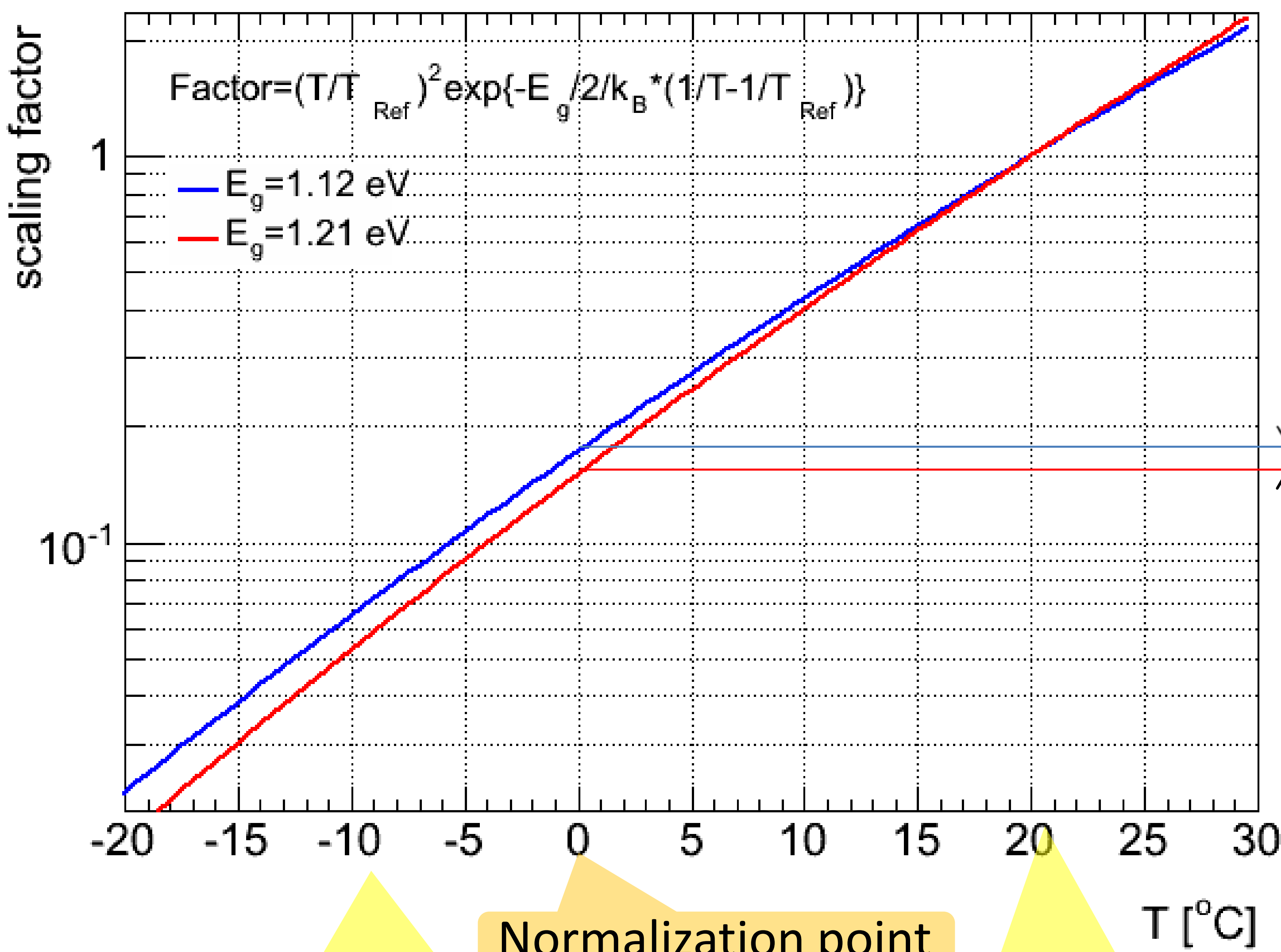
$$I(T_{\rm REF}) = I(T)\left(\frac{T_{\rm REF}}{T}\right)^2 . \exp\left[-\frac{E_g}{2k_{\rm B}}\left(\frac{1}{T_{\rm REF}} - \frac{1}{T}\right)\right]$$

Dedicated discussion today

Effective silicon band gap E_g =1.21 eV following RD50-2001-01 recommendation

3. Normalize current to the volume of silicon [cm^3] rather than per module.
4. Standard units: $\frac{\mu A}{fb^{-1} cm^3}$

Temperature scaling



14 % difference at 0°C with T_{ref} = 20°C.

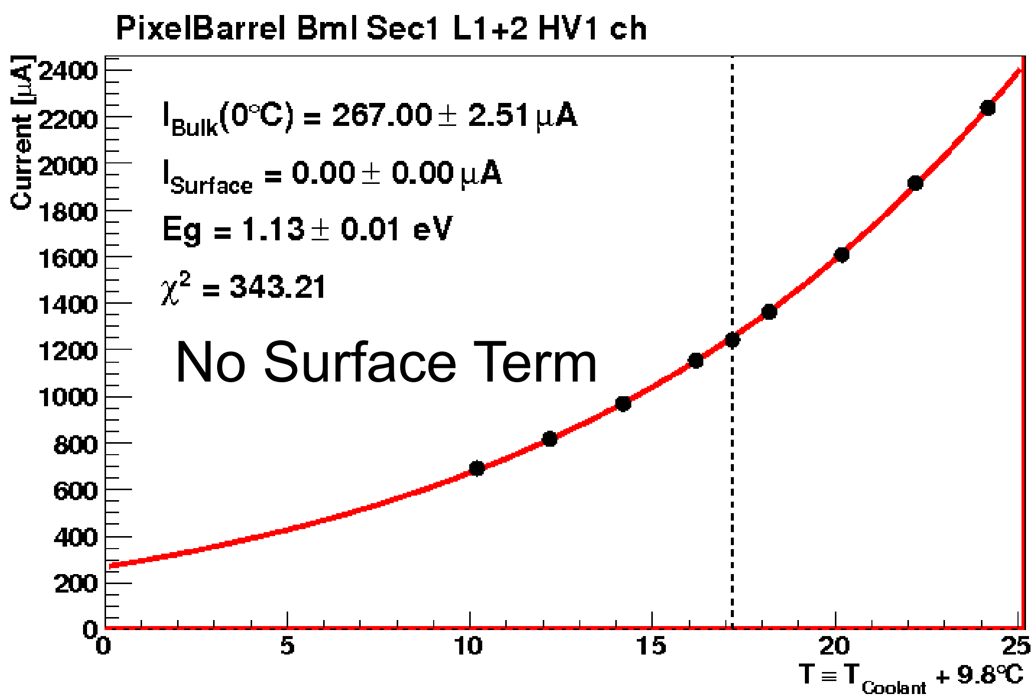
Normalization point

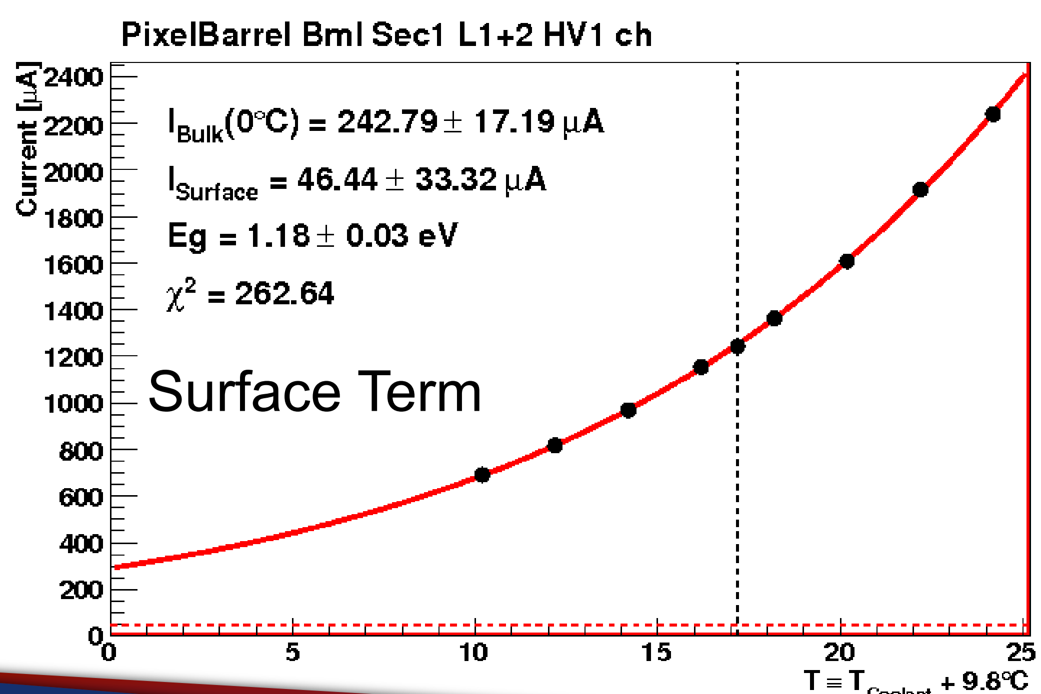
Harper model is based on experiments at -10°C ~ -8°C.

Hamburg/Dortmund model is given with T_{ref}= 21°C

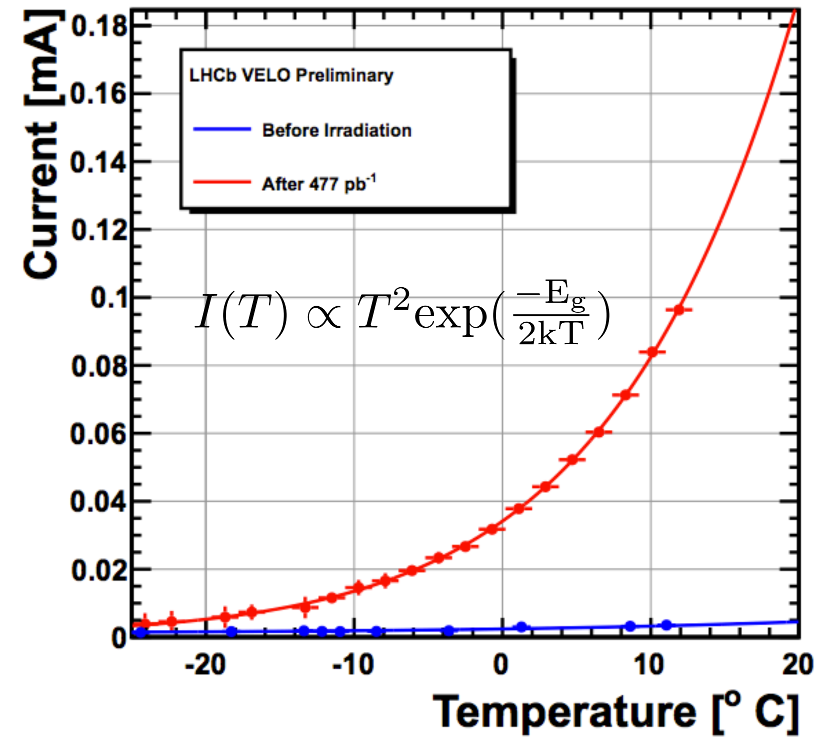
Effective band gap

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





Bulk Bulk before after



Preliminary	"effective band gap E_g"
100V 480 pb^{-1}	1.12 +- 0.06 eV
150V 480 pb^{-1}	1.11 +- 0.07 eV
150V 821 pb^{-1}	1.10 +- 0.04 eV
150V 1204 pb^{-1}	1.14 +- 0.04 eV

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

Effective band gap

1988

Radiation damage studies in Japan, Europe and US.
Among others, two papers already published in 1988:

Radiation Damage in Silicon Microstrip Detectors,
T. Ohsugi, ... T. Kondo, … K. Yamamoto .., Nucl. Instr. Meth. A265(1988)105

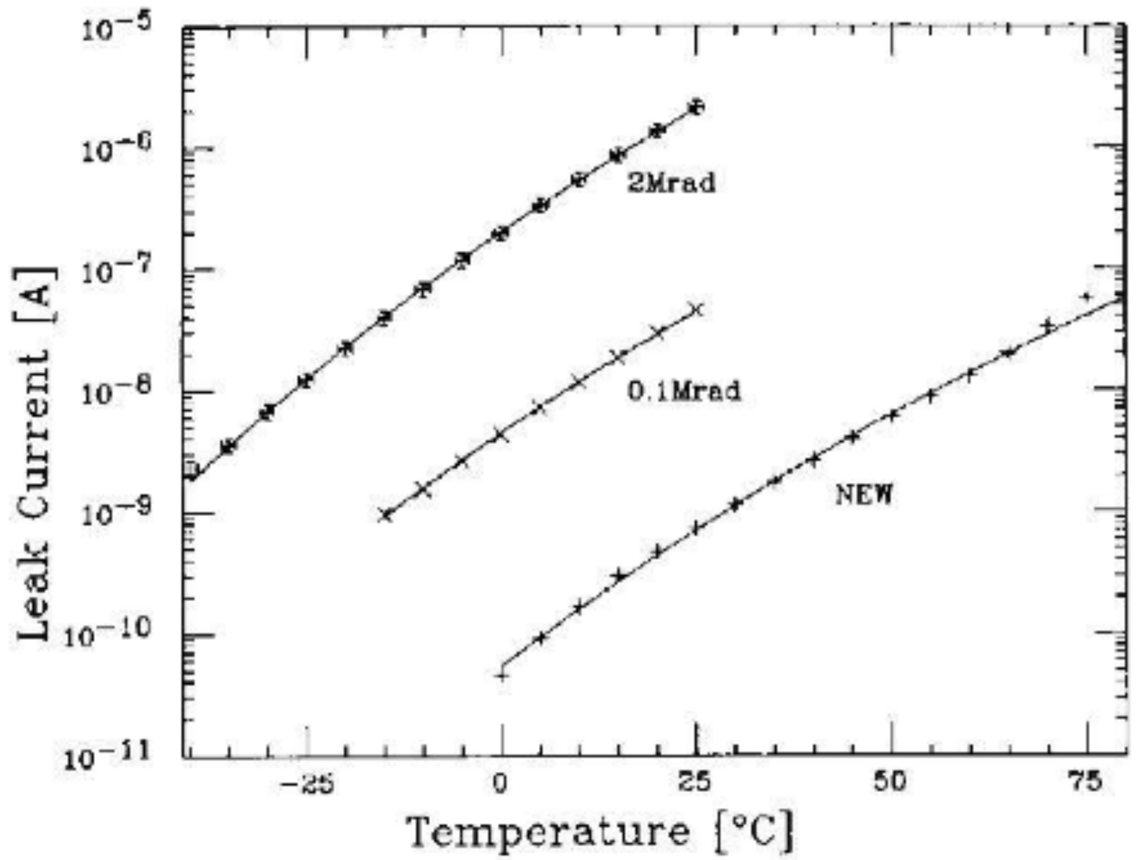


Fig. 5. Temperature dependence of the leakage current. The solid lines are the best fits using the formula given in the text.

They got a T dependence of bulk leakage current as

$$J_g(T) \propto T^2 \exp\left(-\frac{E_{ef}}{2k_B T}\right)$$

$$E_{ef} = 1.20\,\mathrm{eV}$$

23 years later !

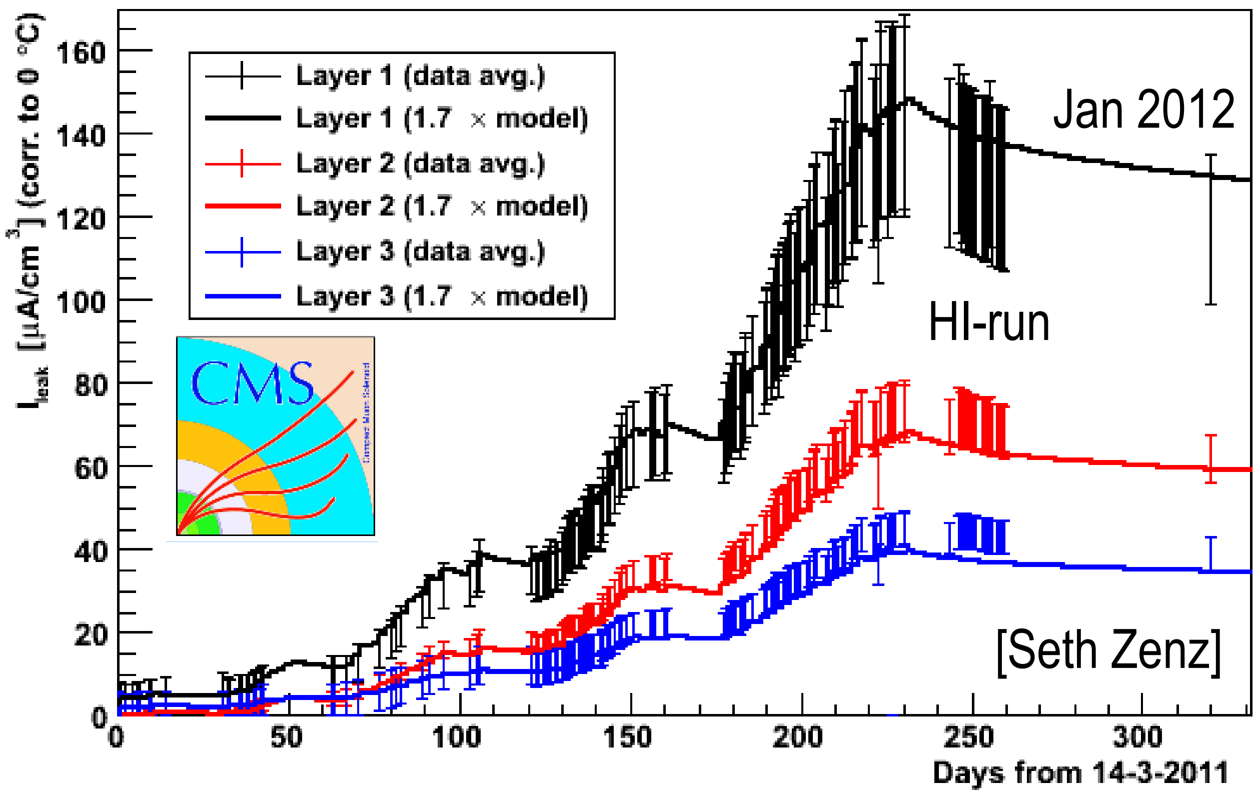
2011

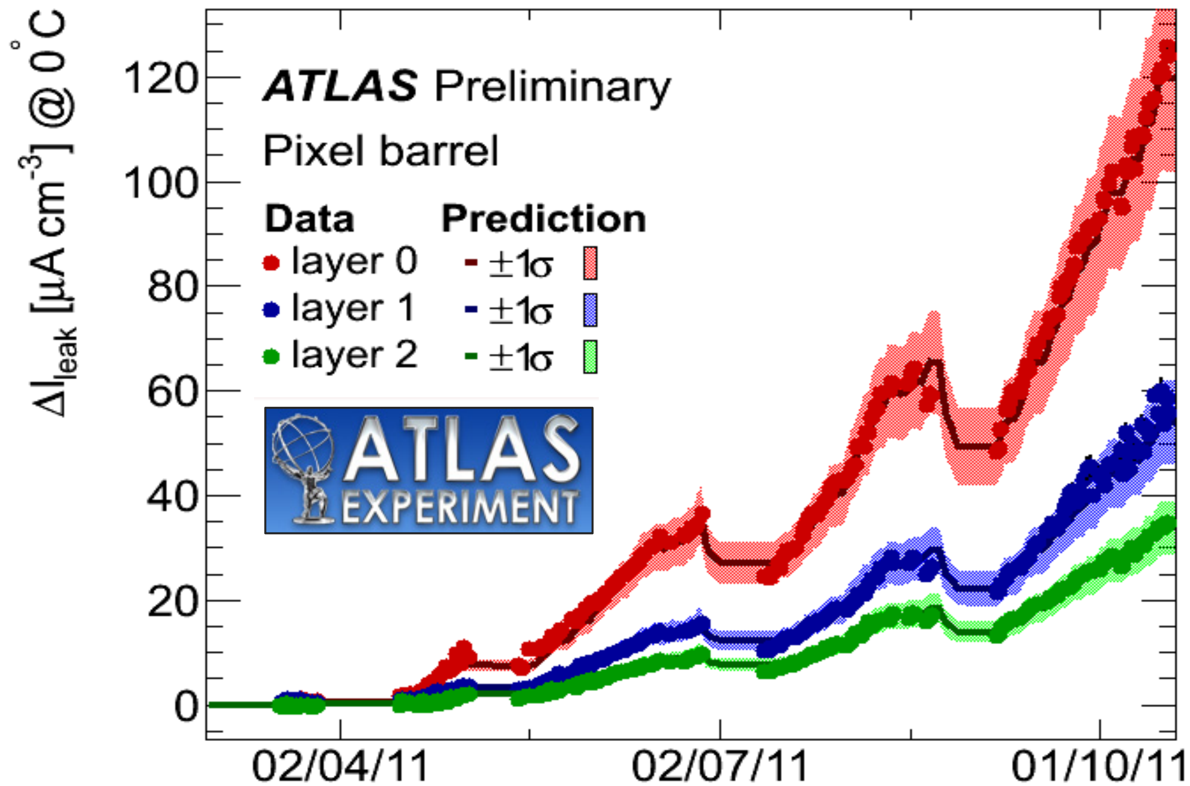
A. Chilingarov proposed

$$E_{ef} = 1.206\,\mathrm{eV}$$

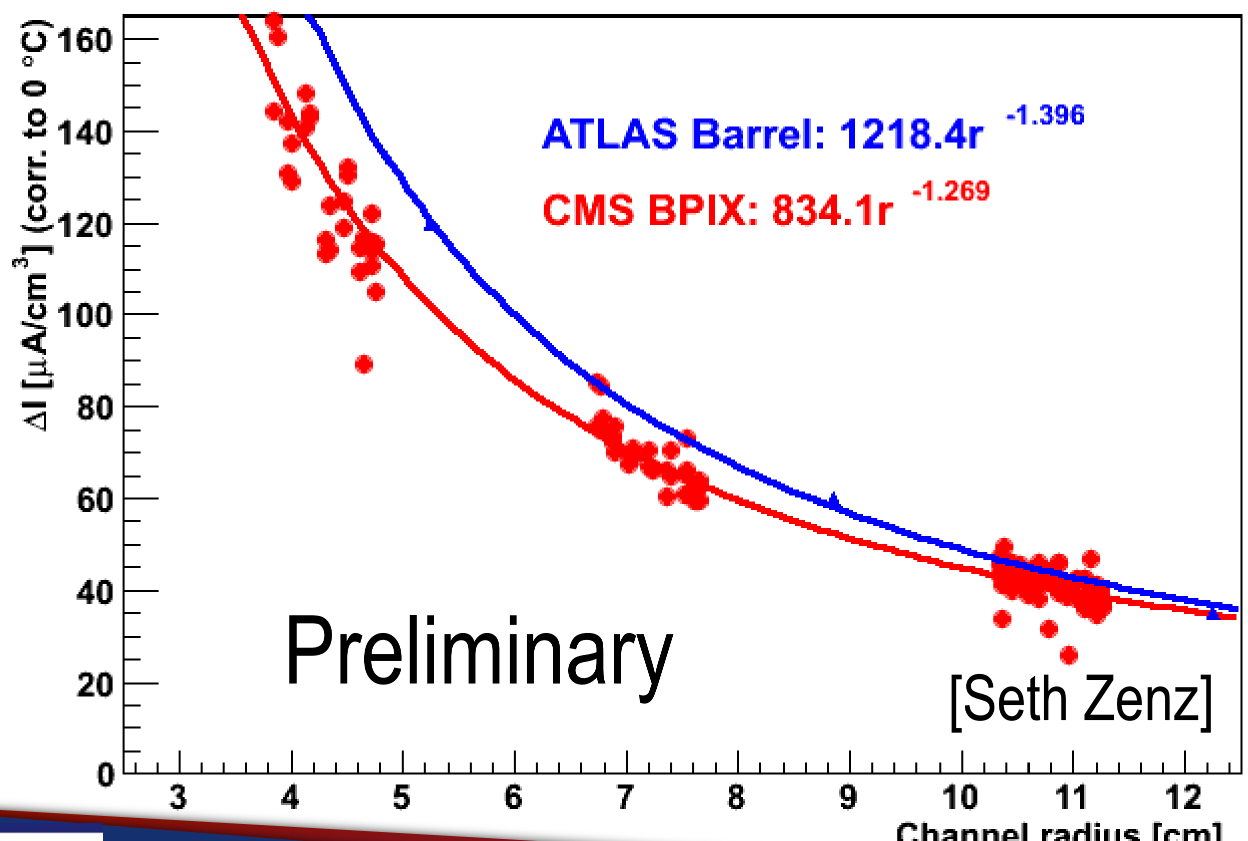
at RD50 Workshop, Liverpool, May 2011

Leakage current





L0 +15%, L1, L2 + 30%



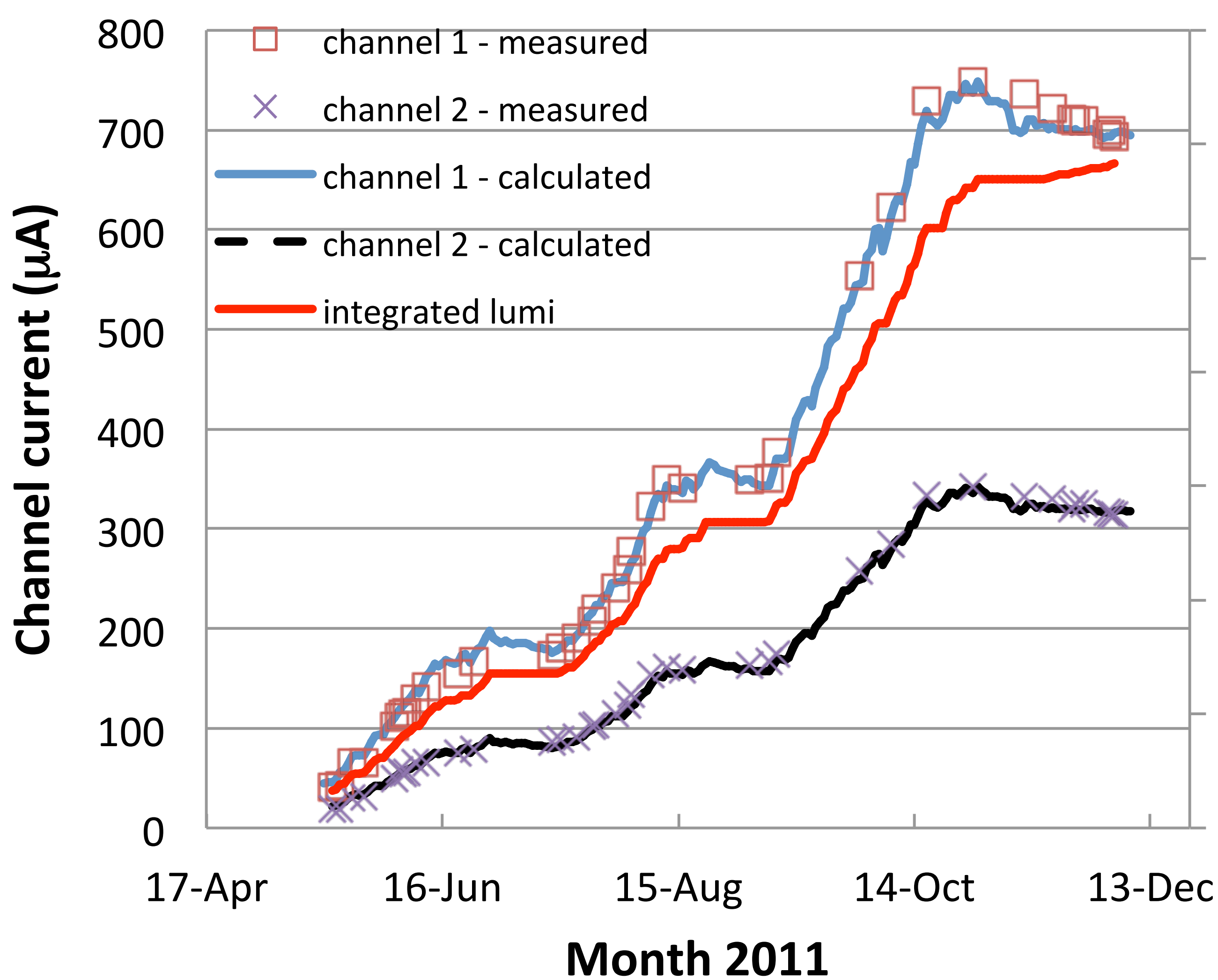
Pixel barrel	radial position (cm)	1 MeV neq (x 10^8 cm^{-2})	Dose (Gy)
1	5.09	21.50	1.06
2	8.89	8.91	0.44
3	12.29	5.57	0.27

FLUKA 1MeV neq fluence in ATLAS

SCT barrel	radial position (cm)	1 MeV neq (x 10^8 cm^{-2})	Dose (Gy)
1	29.9	1.66	0.069
2	37.1	1.30	0.049
3	44.3	1.07	0.036
4	51.4	0.90	0.027

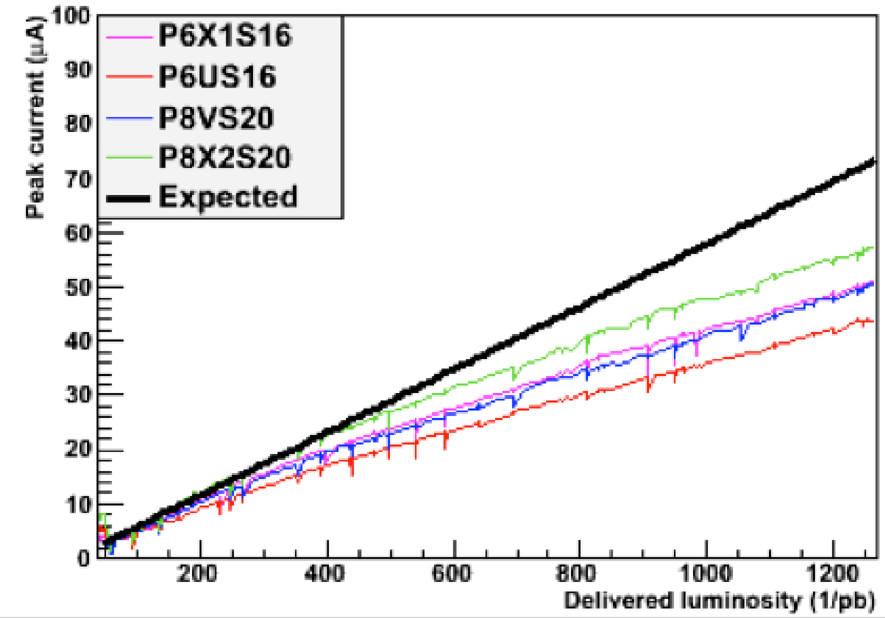
Leakage current

Preshower

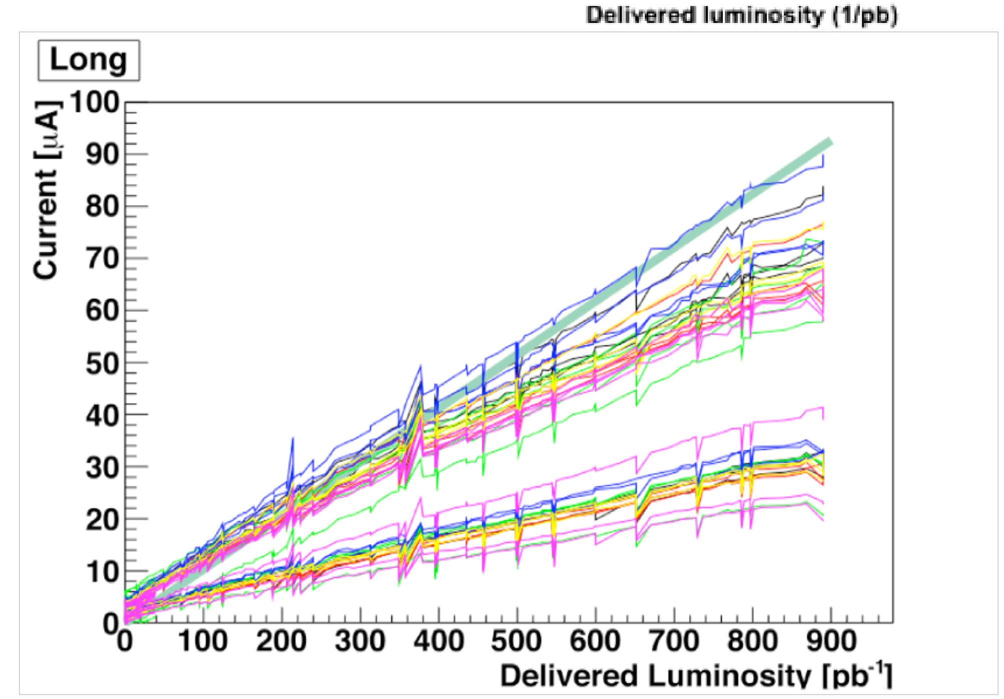


Good agreement, after scaling (data 13% lower than prediction) radii ~40 to 120 cm,

TT:



IT:



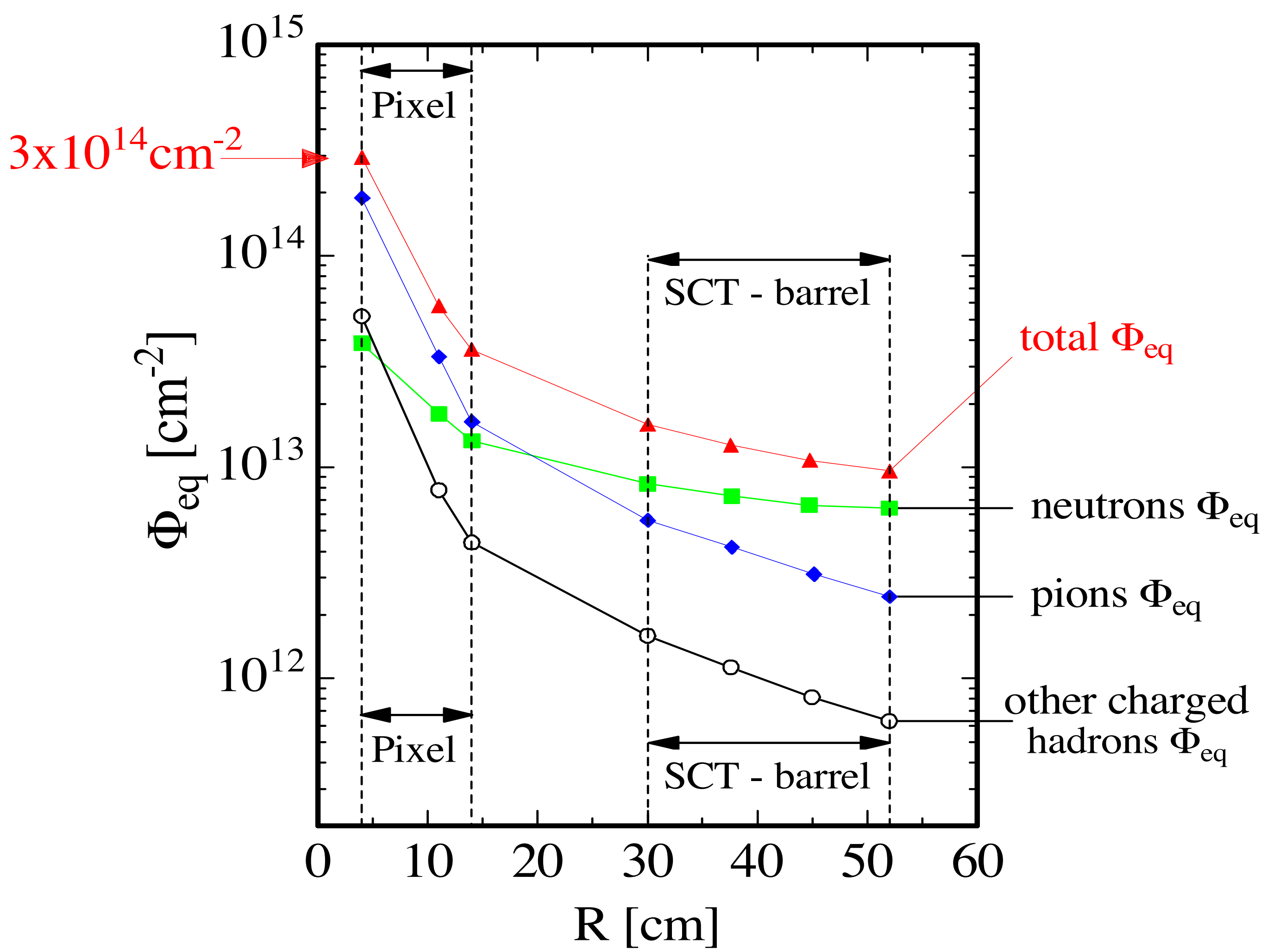
- Improvements to simulations on-going

Leakage current

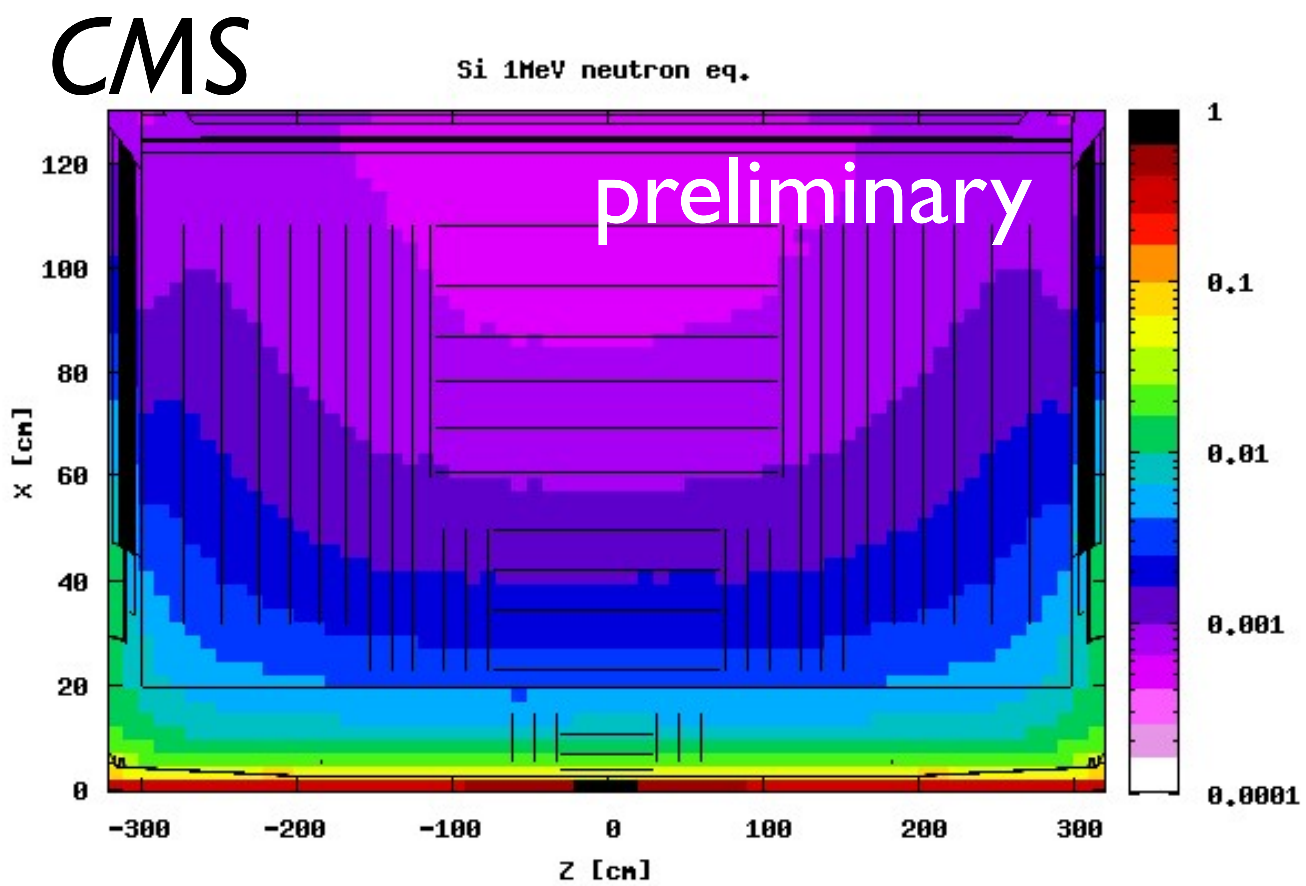
- In general the agreement between model and data is remarkably good; *"within a factor of 2 is already amazing"*, Marko Mikuz, at last week's 7th "Trento" workshop.
- Agreement between model and data is better at the larger radii of the strip detectors in ATLAS and CMS, where the fluence is neutron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

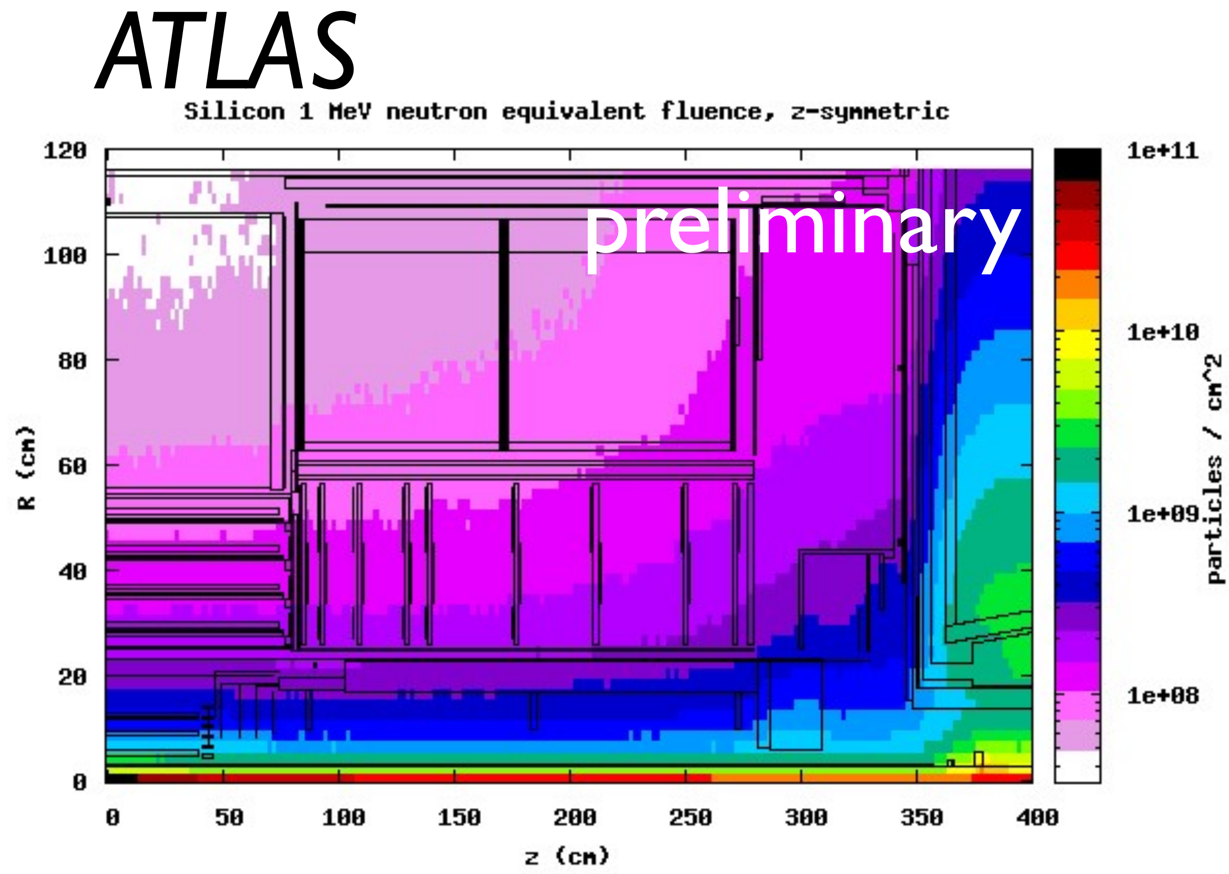
For discussion:

- *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?*



FLUKA fluence comparison

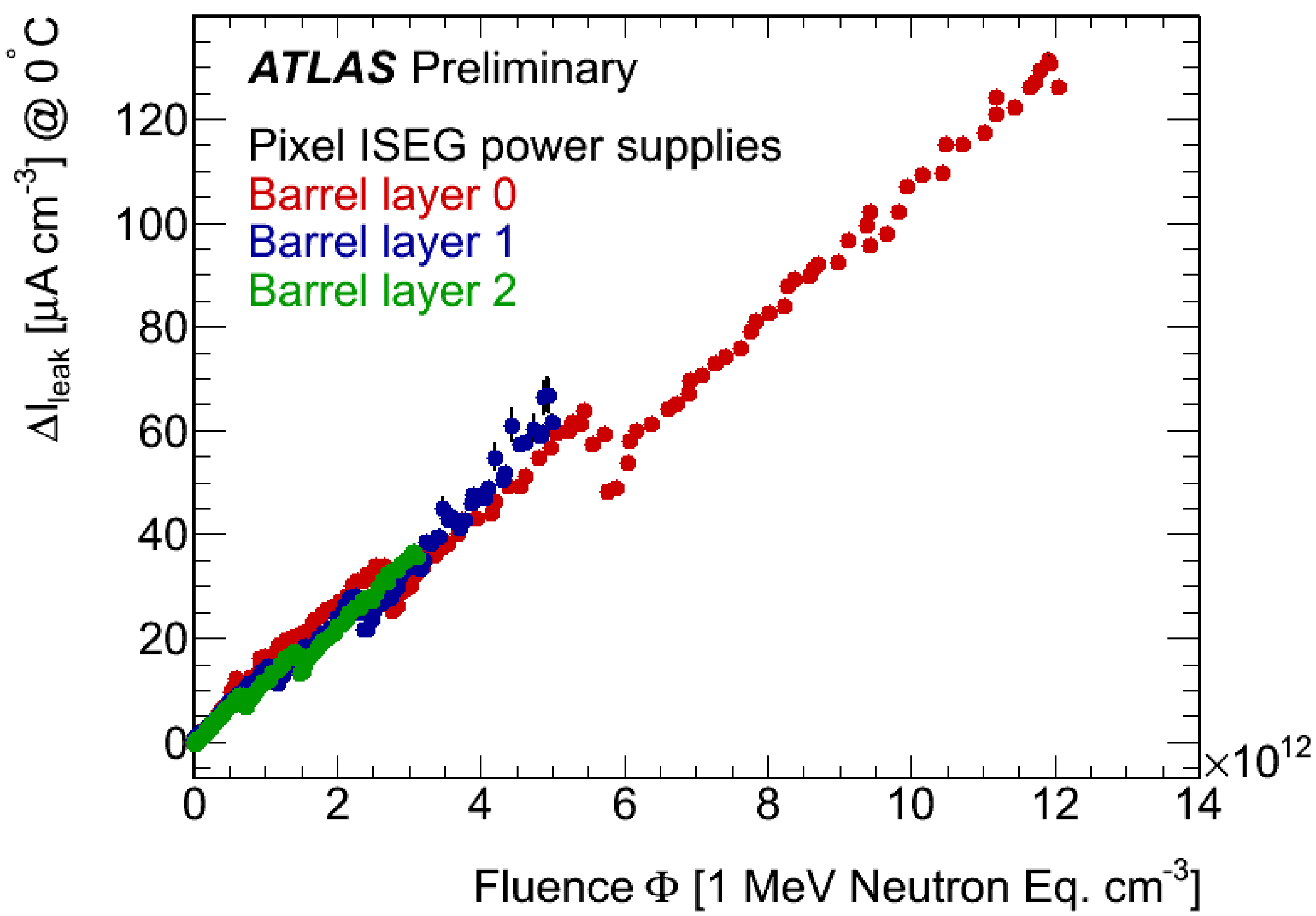


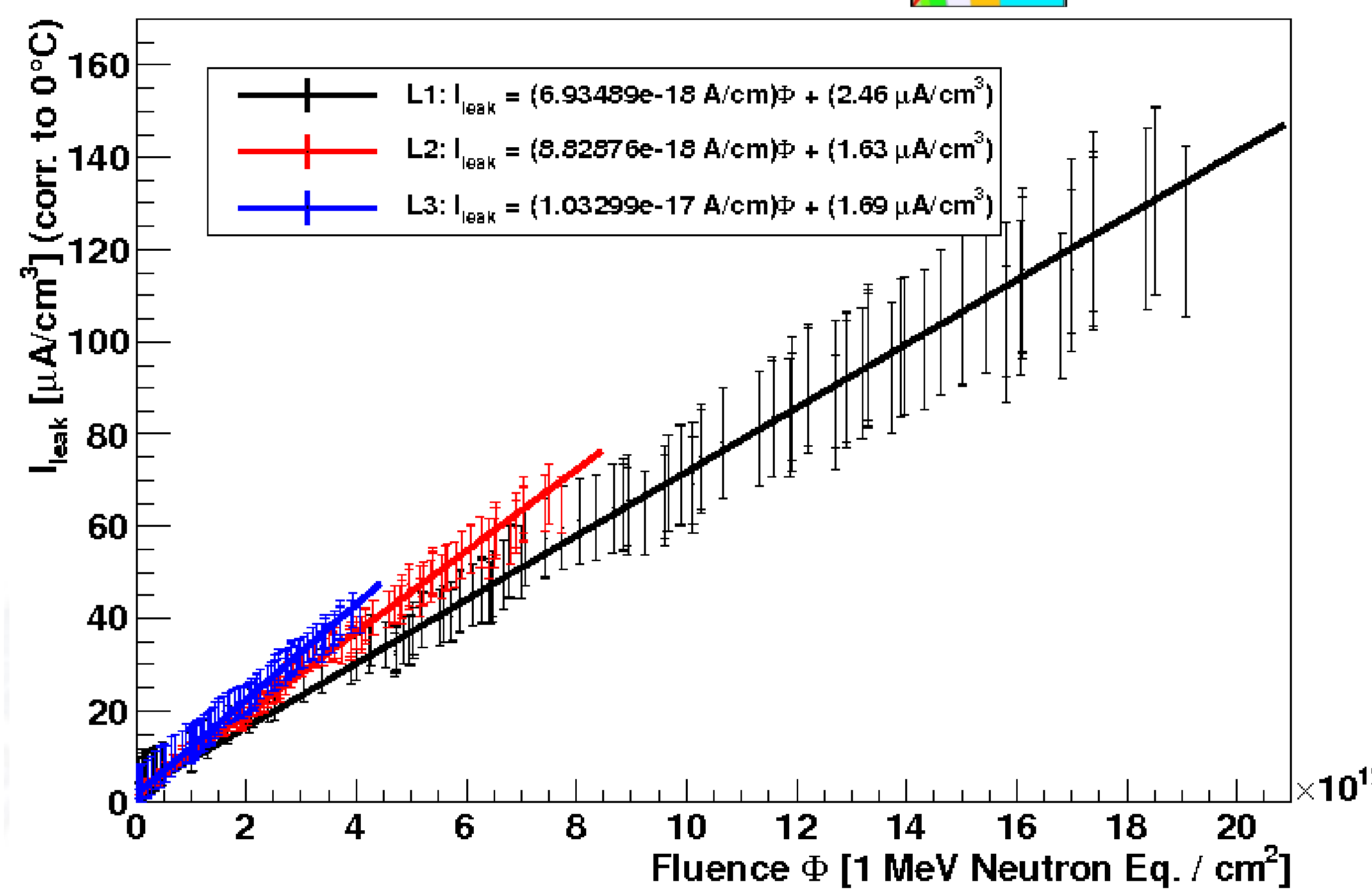


Earlier work toward checking FLUKA models between experiments:

- Radial dependence at different Z slices being 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).
- Aim for a more detailed comparison of 7 TeV fluence predictions?

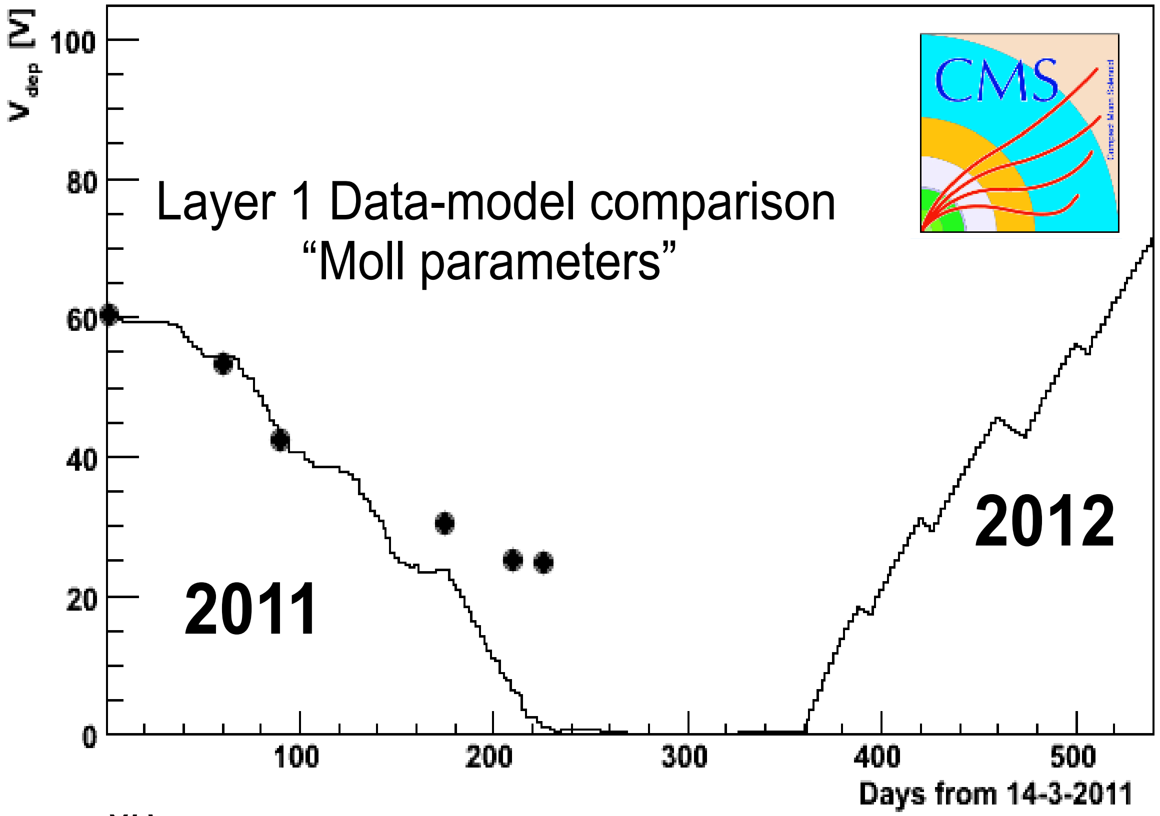
Leakage current vs fluence

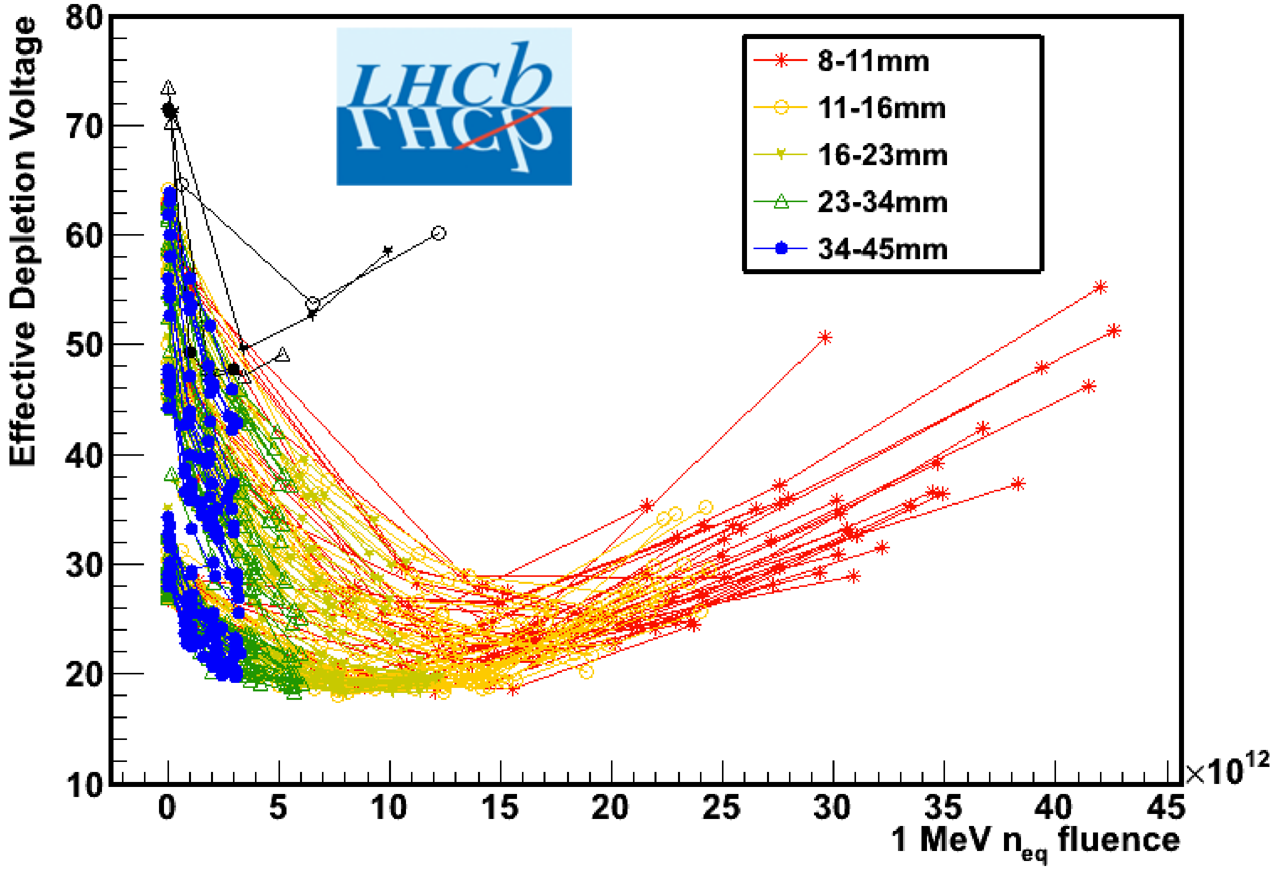


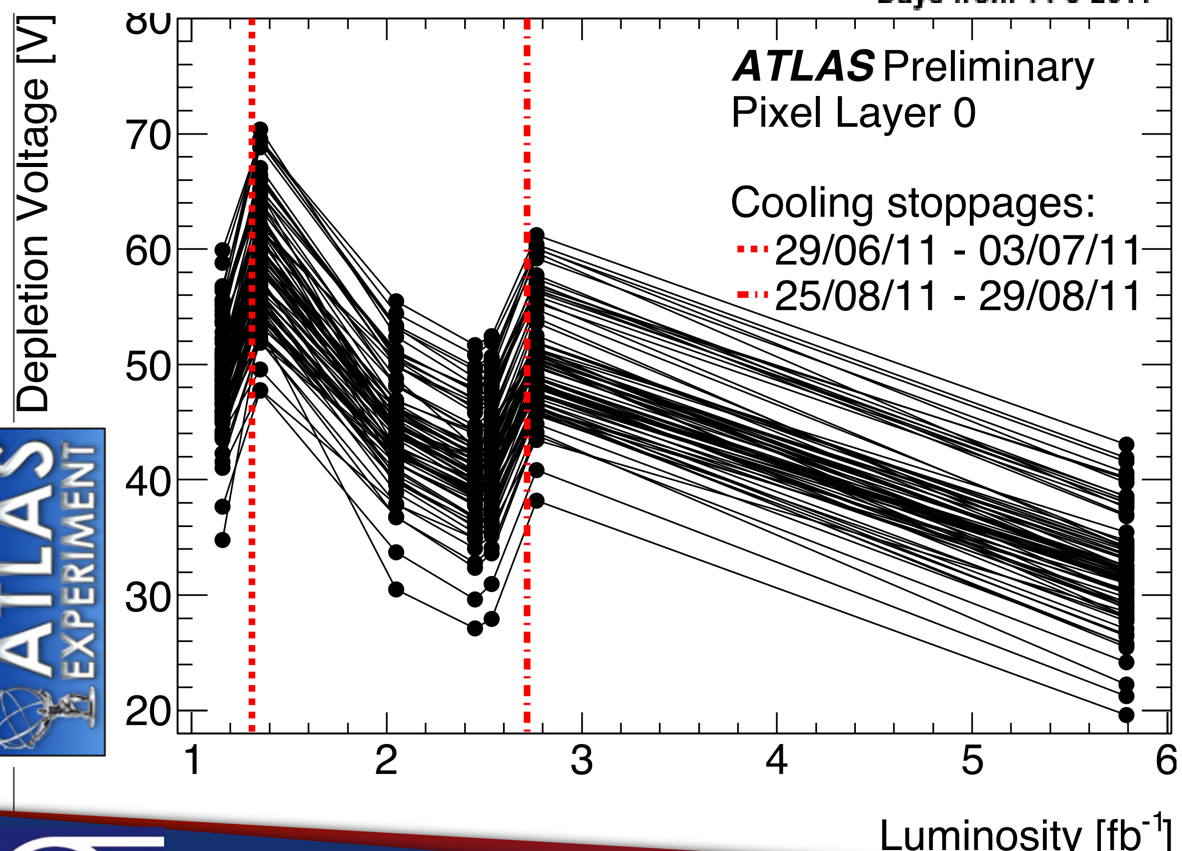


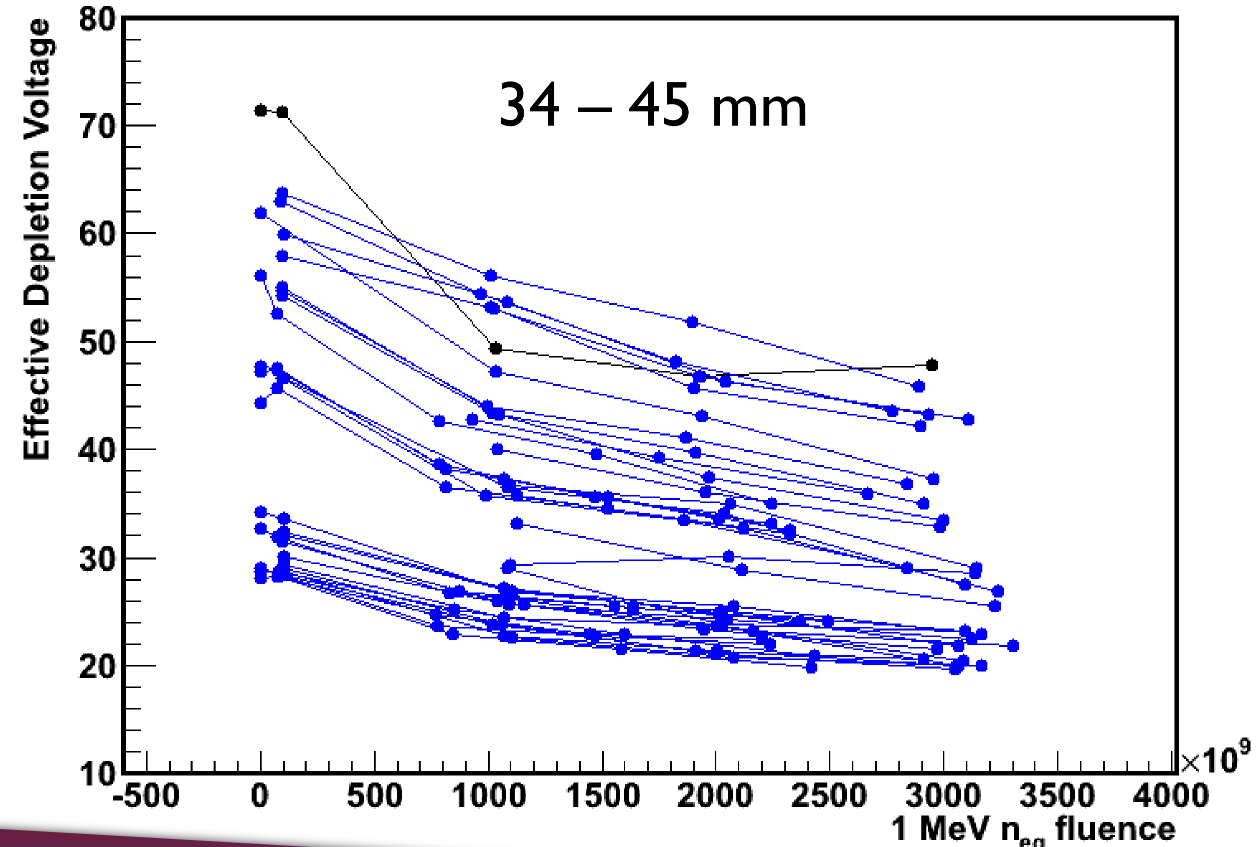
- *Annealing steps from maintenance periods apparent in ATLAS data (-13°C, with stoppages at 20°C). Simple fit for effective alpha yields:* $\alpha \sim 1.1$ e-17 A/cm
- Parallel annealing in CMS (17°C operation, drops to 10°C when detector is off)

Depletion voltage







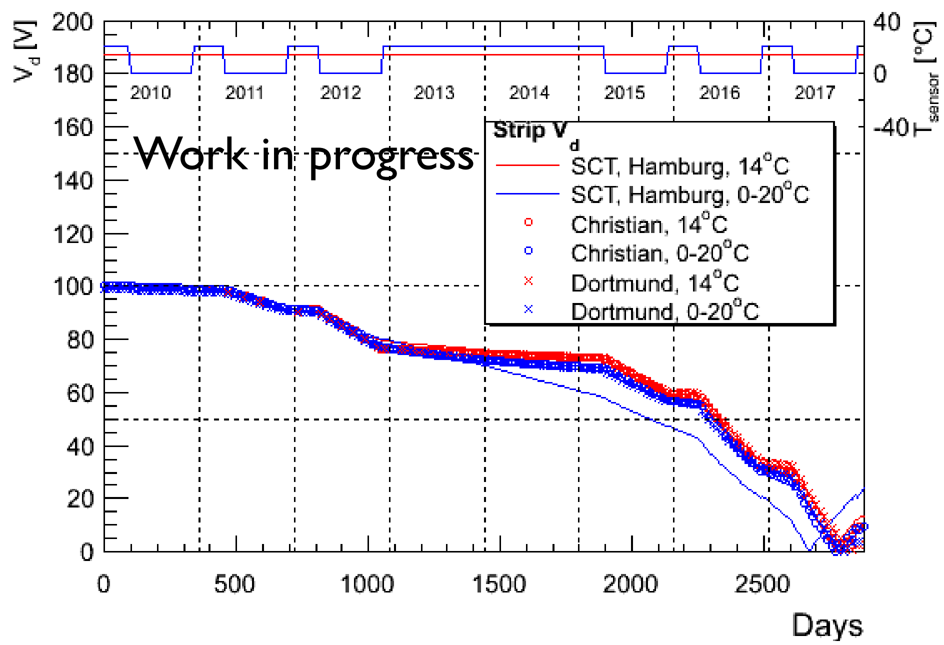


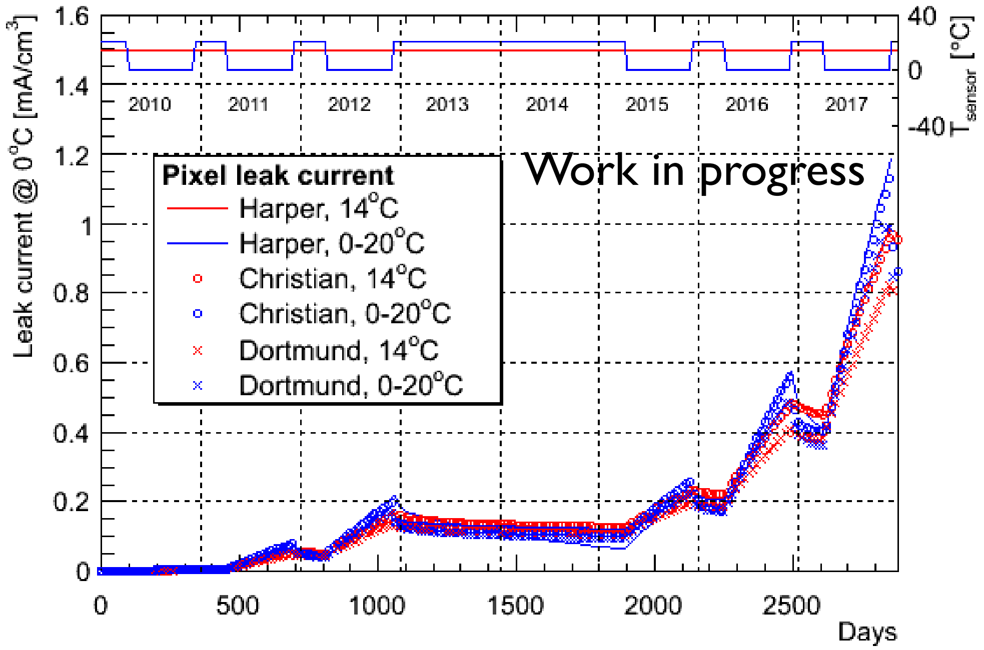
Topics for discussion

- Some of the topics:
  - Second metal layer charge loss in LHCb
  - Any non-conformance of results from certain sensors.
  - 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.

Discussion on future

- We all see the same qualitative effects: increase in leakage current, reasonable agreement with the model"
- How can we improve the comparison?
  - Check the FLUKA prediction and underlying MC:
  - Continue our efforts to check the different models:

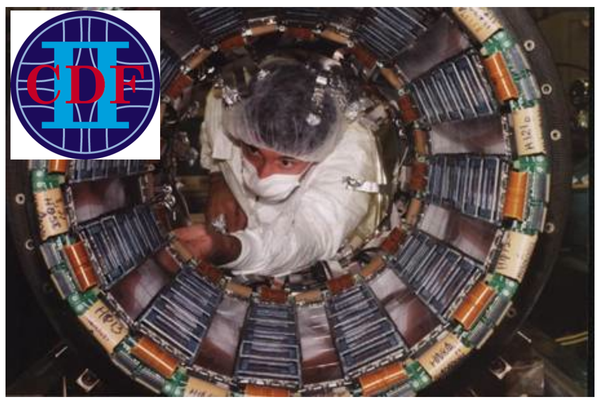


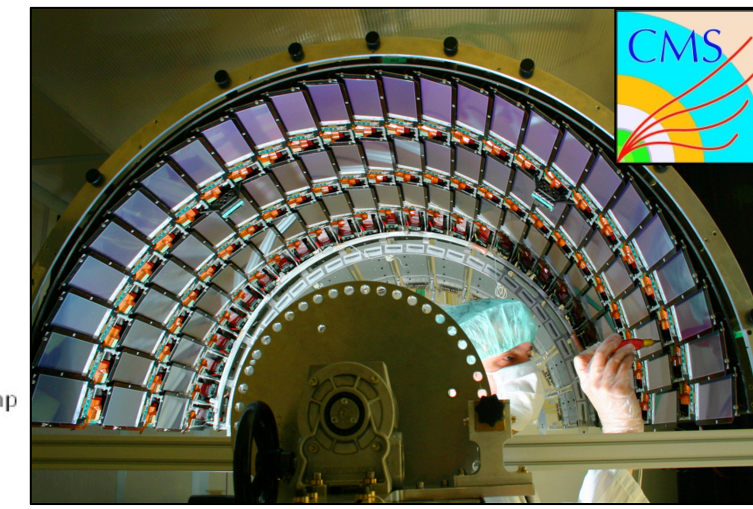


- We may consider to arrange ourselves into dedicated sub-groups around topics to go into further detail? Meeting of all sub-detector experts on each topic: e.g.
  - FLUKA simulations of fluences,
  - Leakage currents and modelling
  - Depletion voltage and modelling.
  - Anomalous effects.
  - Your topic here…

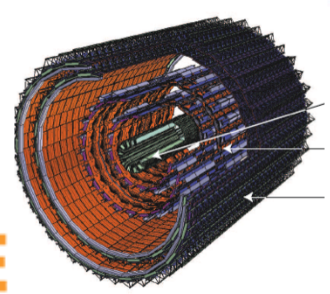
Second Inter-Experiment Workshop on Radiation Damage in Silicon Detectors

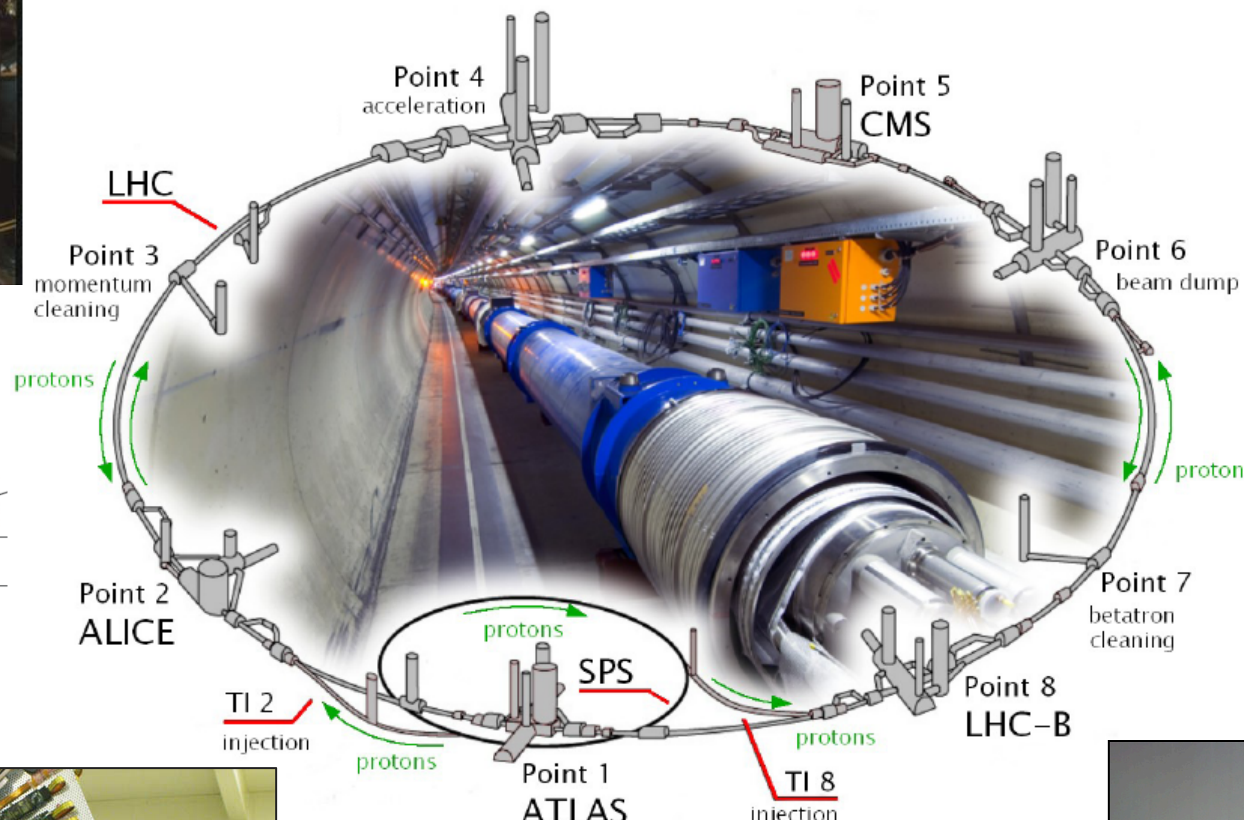
Thanks *to all the experts!*





ALICE





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