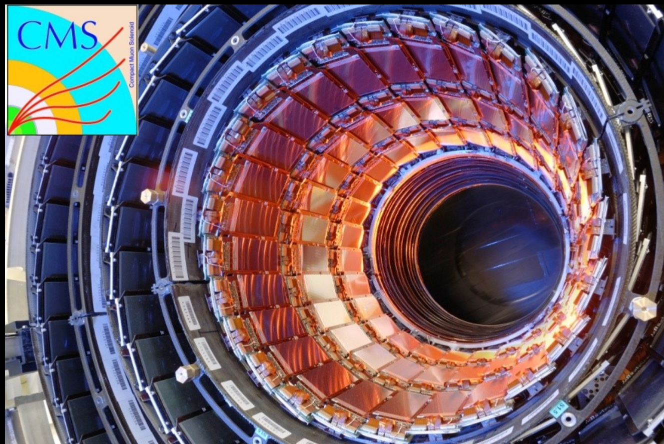
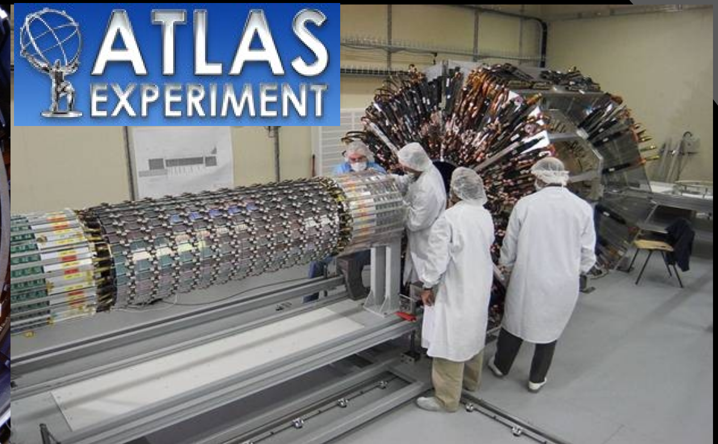
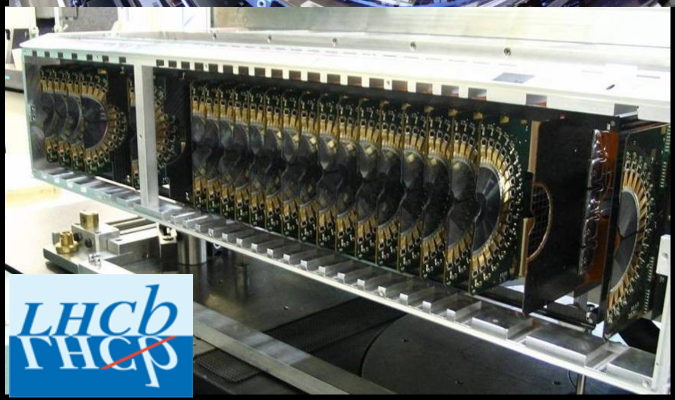




Karlsruhe Institute of Technology



Frank Hartmann
Frank.Hartmann@CERN.CH
23.06.2011

EVOLUTION OF SILICON PARAMETERS DUE TO IRRADIATION AT THE LHC

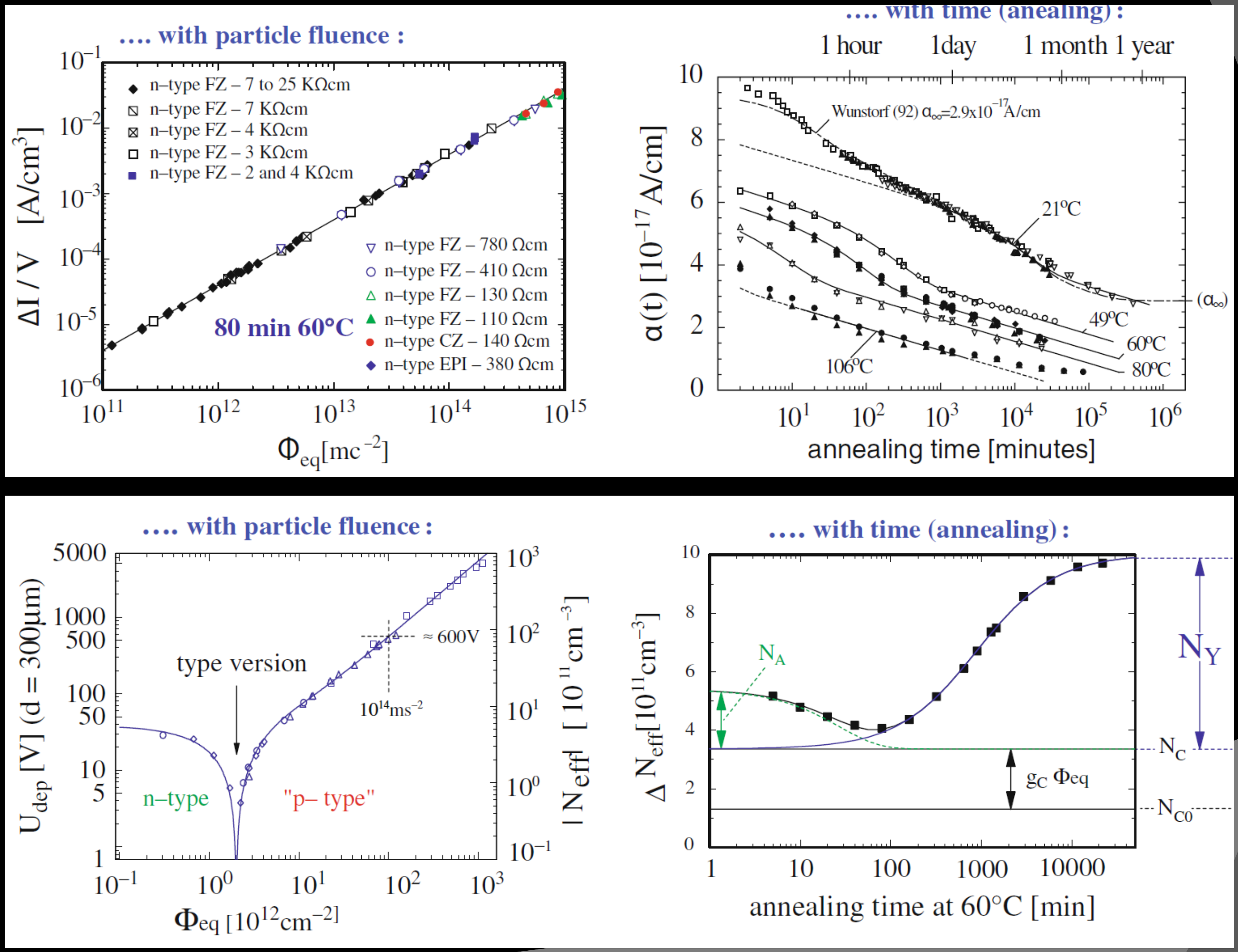
Content & Disclaimer

- Different Strategies
- Leakage currents
- Comparison with expectation
- Depletion Voltage

- Effects are showing up, monitoring efforts and comparison efforts started
  - More integrated lumi will decrease errors
    - current results are first glimpse

- Everybody is following the same goal but with slightly different strategies

What happens in a nutshell



From M. Moll and R. Wunstorf and others

Test strategies

ATLAS

- Pixel
  - Currents:
    - Some high res. current measurement boards (10nA)
    - Single pixel res. 0.125 nA
  - Vdep:
    - Single pixel cross talk vs. voltage;
      - TS, now more often
      - non-beam
    - Monitor depletion depth – threshold -no scan
- SCT
    - In-situ radmon sensors
      - Dose & Fluence
    - Efficiency and depletion depth vs. voltage;
      - non-beam

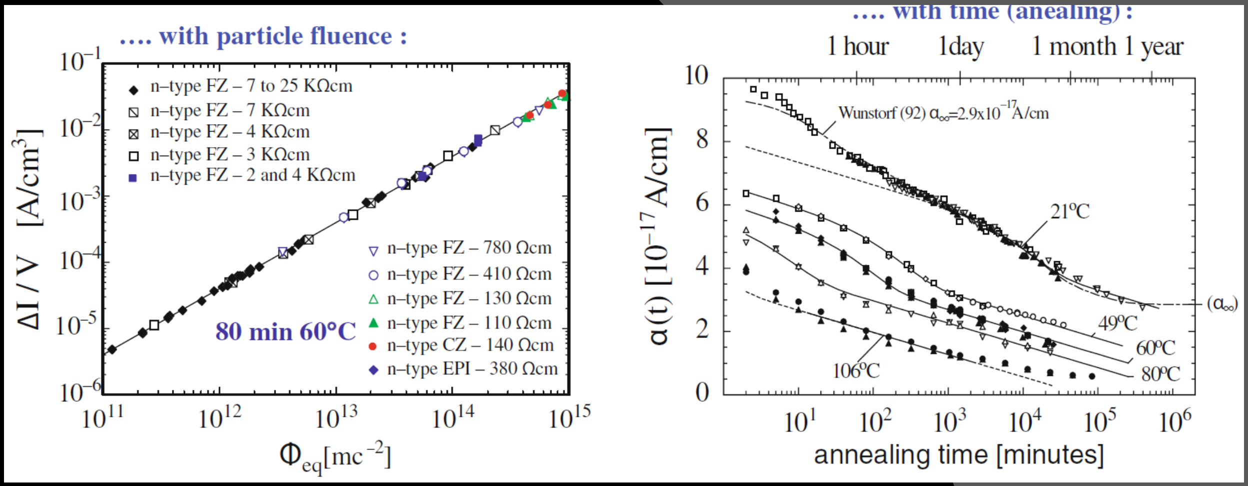
CMS

- Pixel
  - Vdep:
    - Small # of channels (1%) Signal vs. bias
      - Several times per year
      - Stable Beam
- SST:
  - Currents:
    - Some high res HV boards
    - Current per sensor via DCU
  - Vdep:
    - Noise vs. bias scans (IV)
      - 4/y
      - non-beam
    - Full signal vs. bias scan (IV)
      - 2/y
      - Stable beam
    - Small (1%) Signal vs. bias scan
      - (monthly; just started)
      - Stable Beam

LHCB

- VELO
  - Current:
    - IV scan
      - Weekly
      - Non-beam
  - Vdep:
    - Noise vs. bias
      - Monthly
      - Non-beam
    - Signal vs. bias – layer scanning
      - Few times per year
      - Stable beam

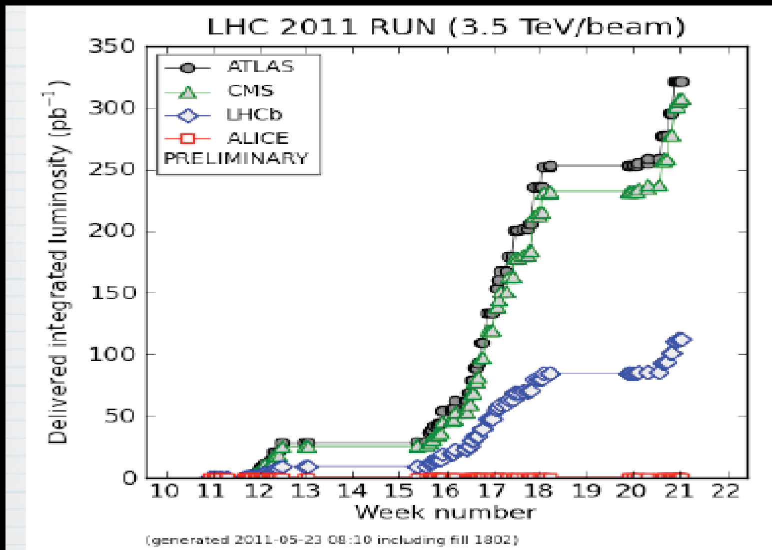
More or less continuous archiving of currents and temperature

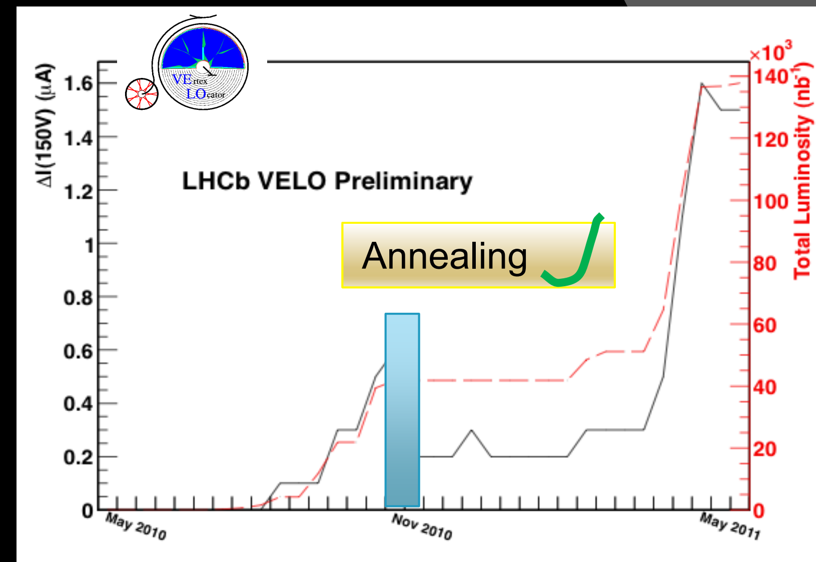


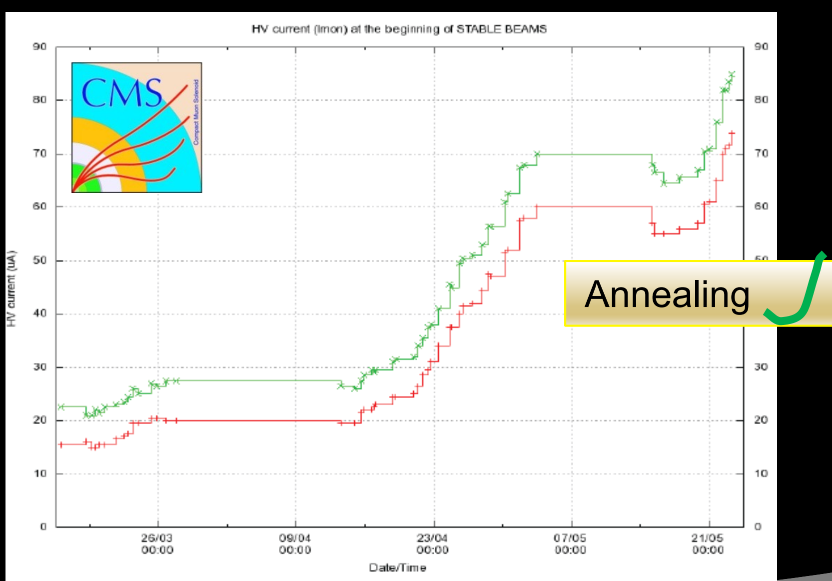
Does it increases?
Alpha?
Annealing?
Comparison with simulation?

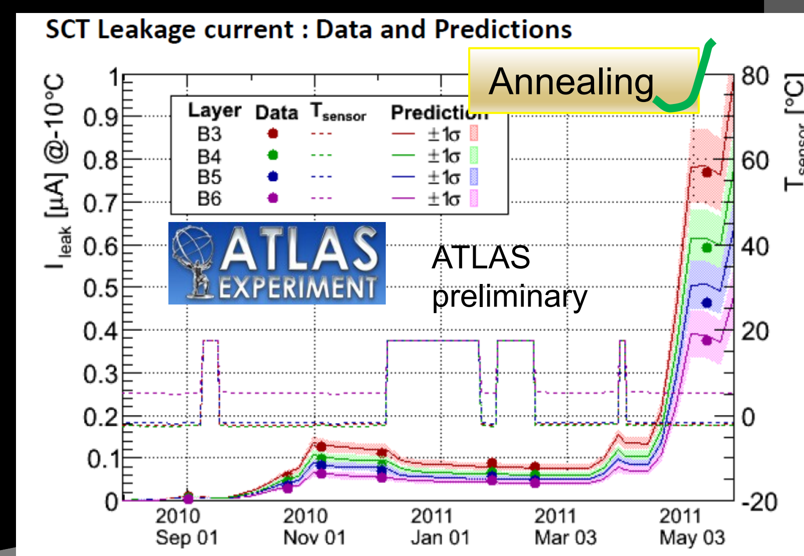
Leakage Currents

Evolution of Sensor Currents



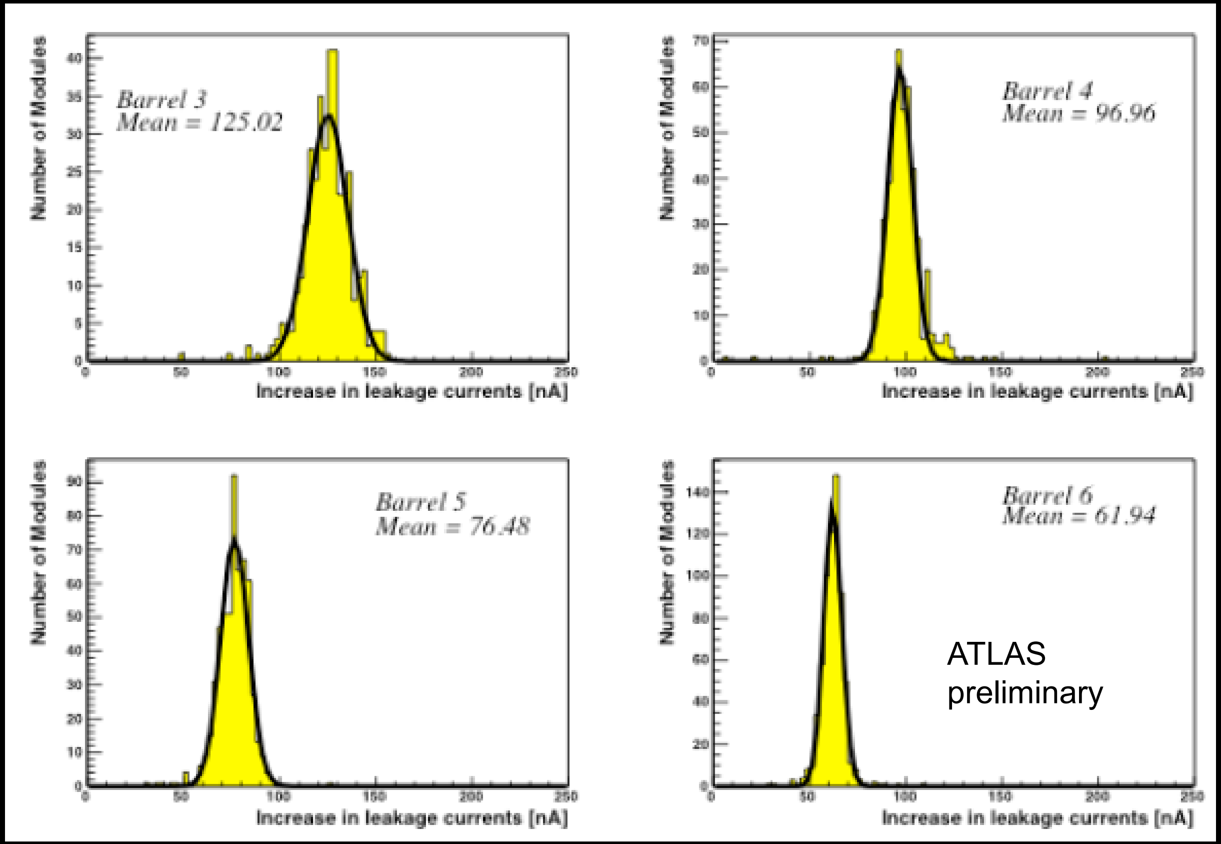






Yes, current changes and at least it qualitatively follow the delivered luminosity

ATLAS SCT the end of pp 2010



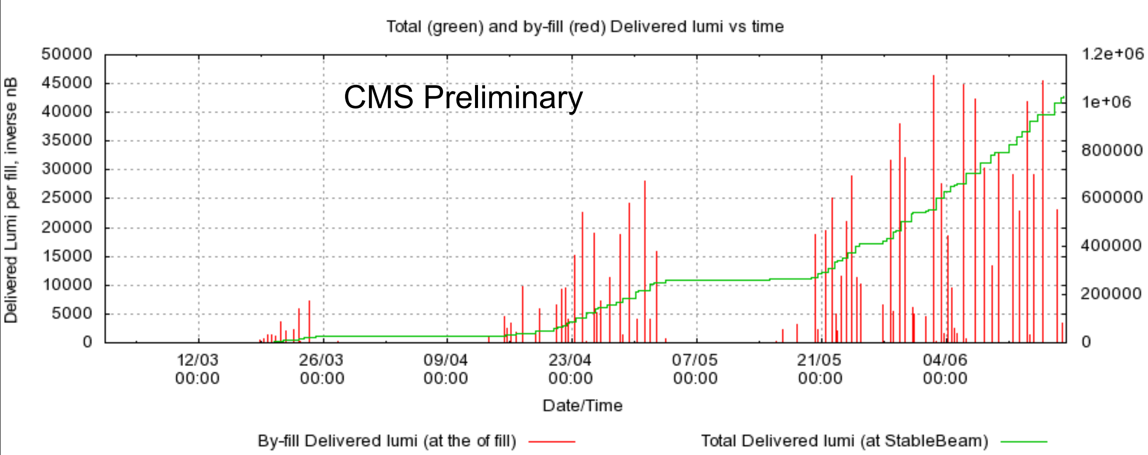
Histograms showing increases in SCT barrel module leakage currents (normalized to -10C) from

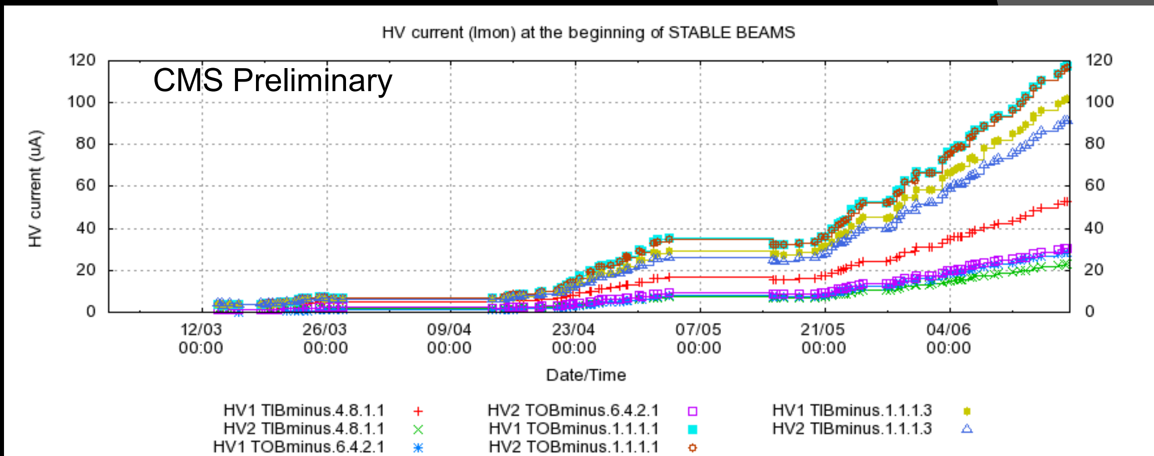
Begin of operation to end 2010.

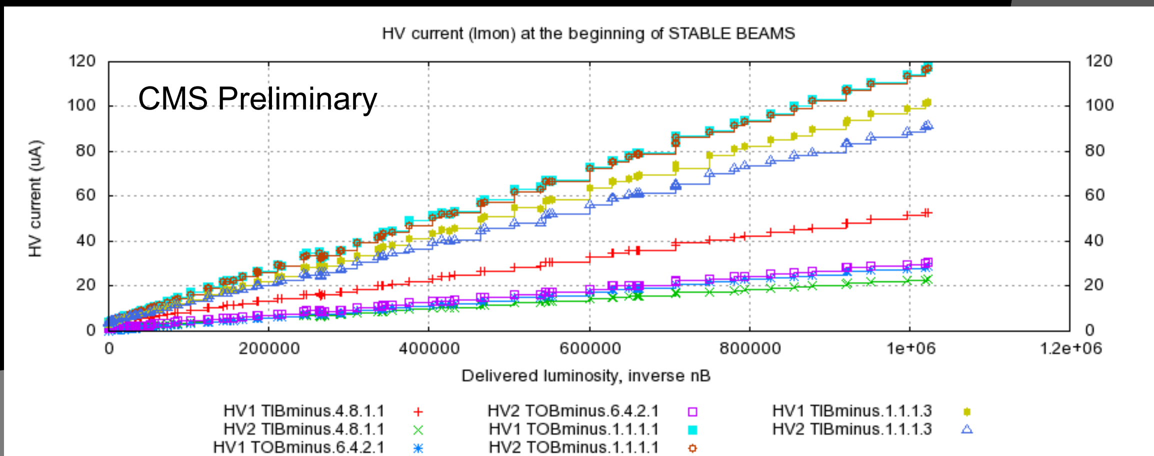
- Very impressive current resolution (10nA), much better than CMS or LHCb
- At that time CMS SST only quoted: "in the noise"

DB query

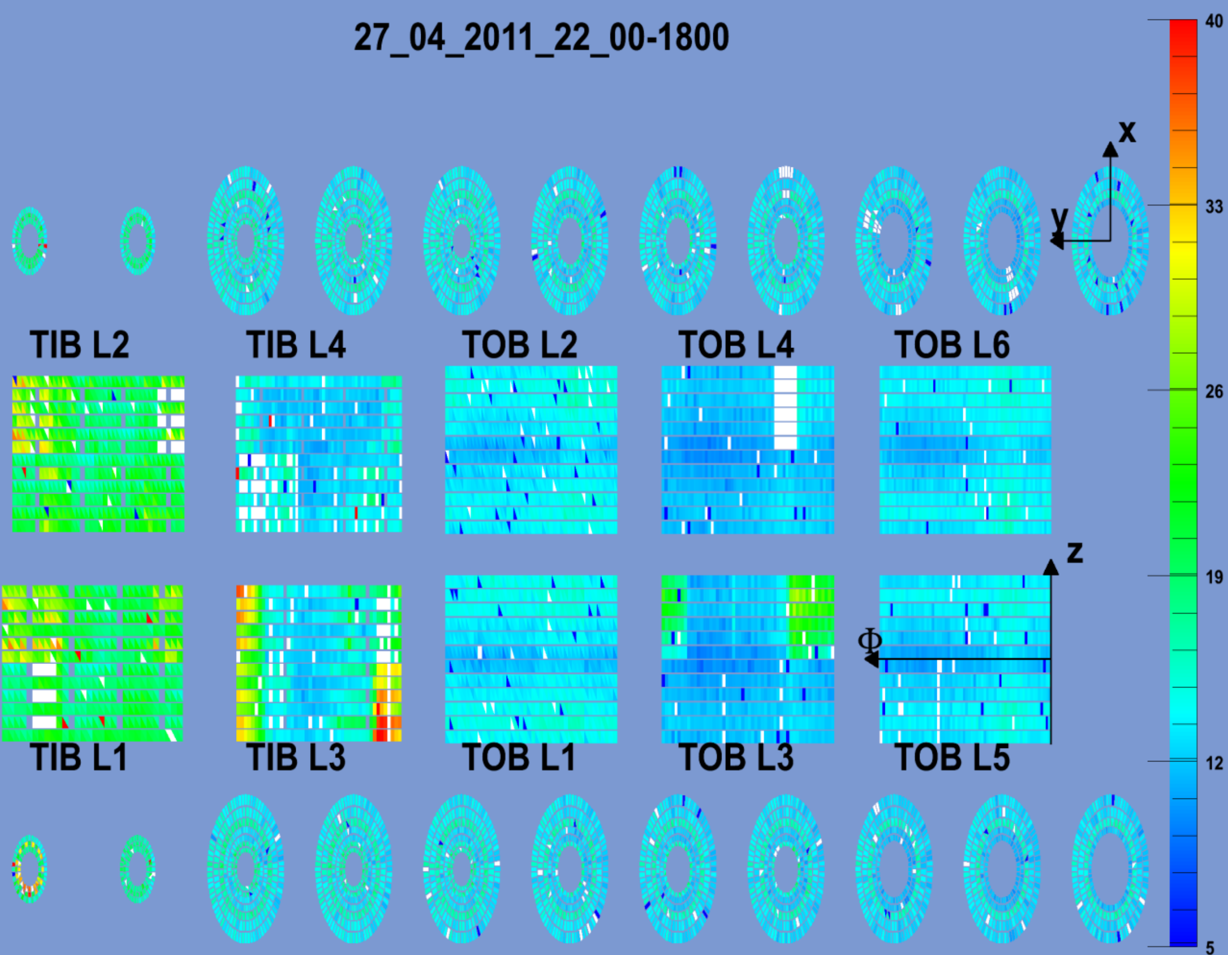
- WEB-based online tool
  - No dedicated measurement
  - Standard DB query
- Power supply I value, begin of each fill (10min)
  - Different layers – different ϕ
  - Different # of modules
  - Different T
    - ➔ different curves
- ➔ Offline analysis
  - Normalize volume & T
  - Normalize to slope [$\mu A / 1 fb^{-1} / cm^3$]







CMS Silicon Temperatures

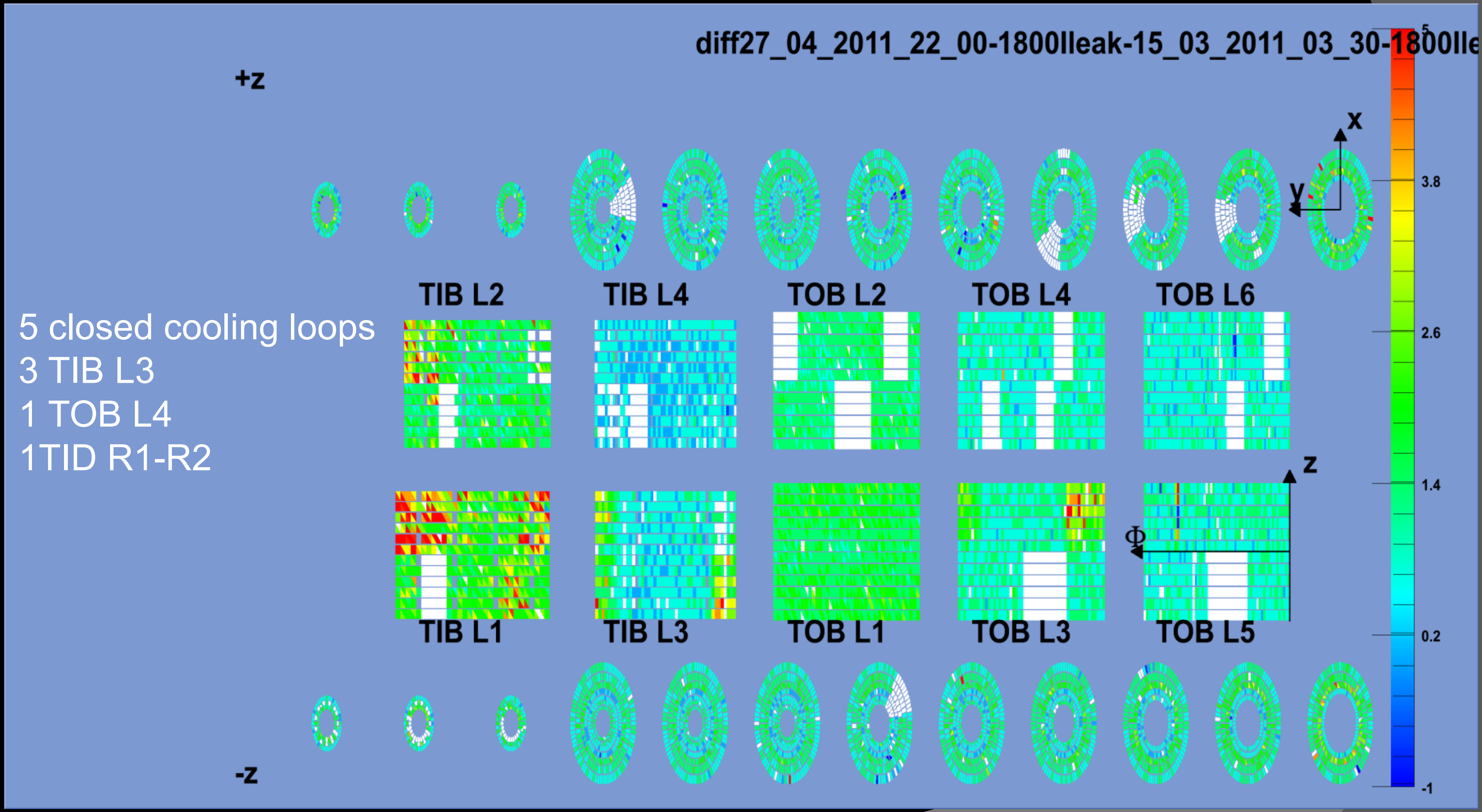


5 closed cooling loops
3 TIB L3
1 TOB L4
1TID R1-R2

DCU measurements of individual modules

Ileak difference

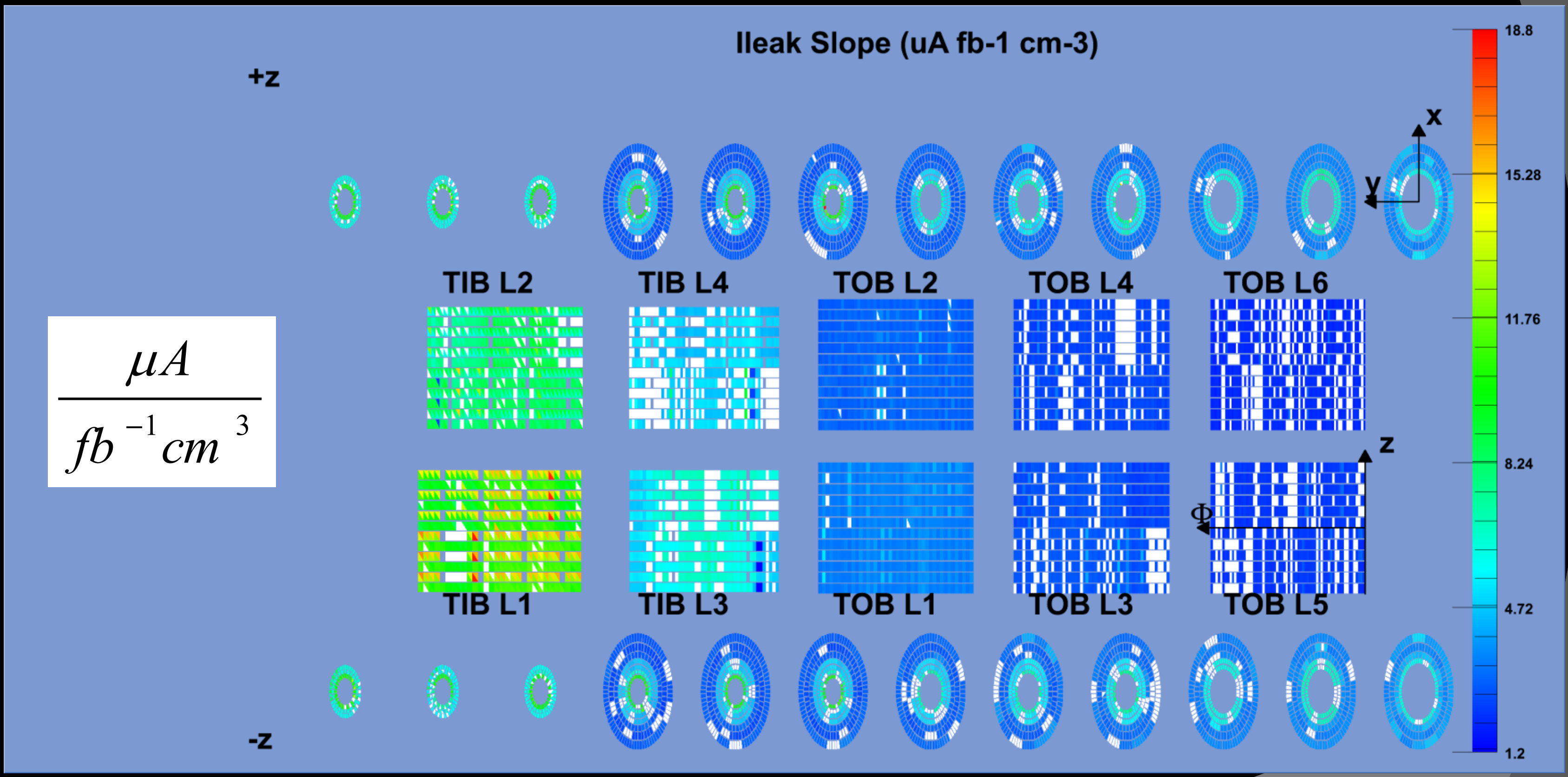
27/04/2011 and 15/03/2011



Hot regions see higher current - not a real surprise

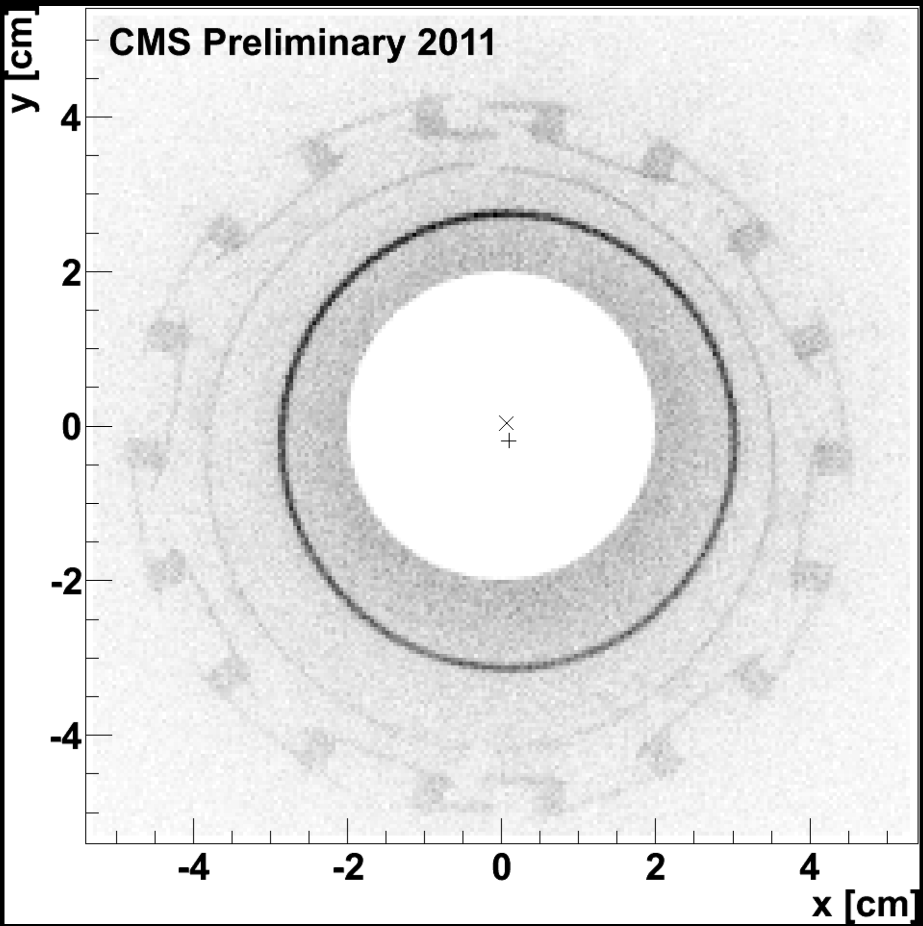
Leakage current slopes normalized

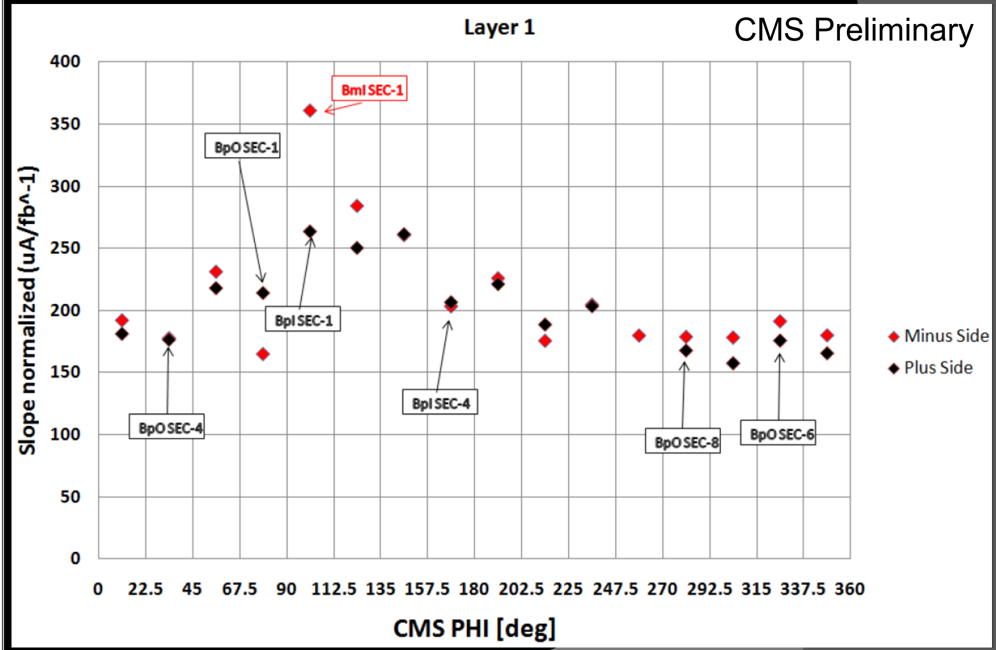
$$\frac{\mu A}{fb^{-1}cm^{3}}$$



Radial dependence! ✓

Where is the beam?

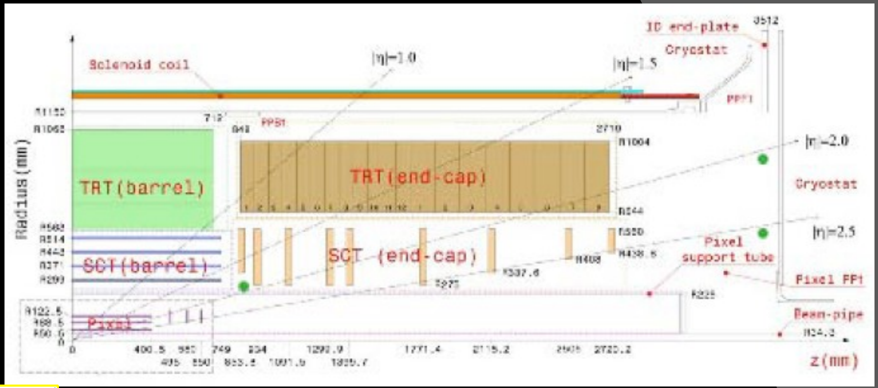




A try to compare results with simulation

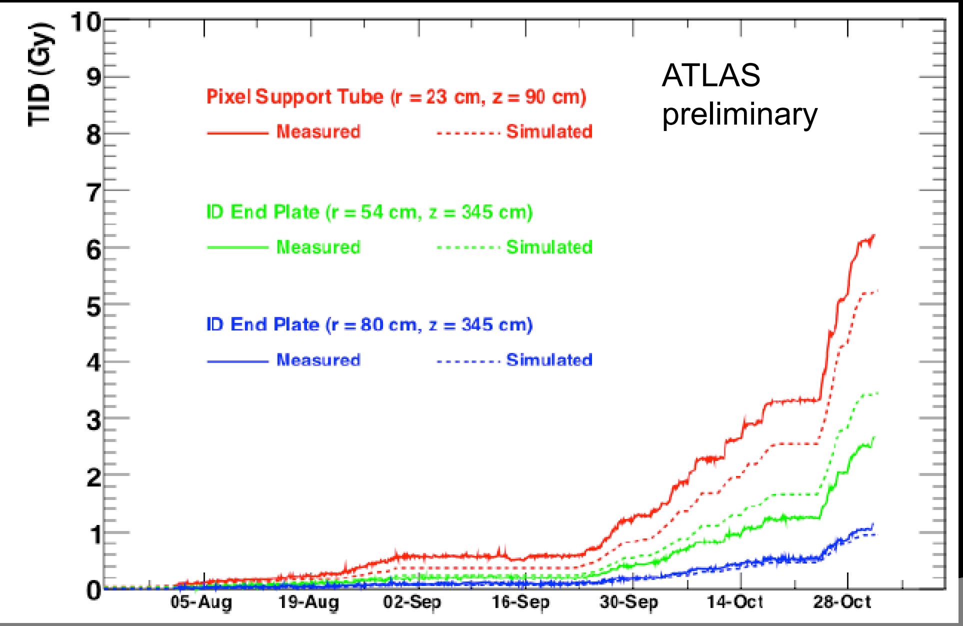
ATLAS current data vs. simulation

- **Dedicated** RADmon sensors readout via DCS
  1. Radiation sensitive p-MOS transistors (RADFETs).
  2. Calibrated diodes

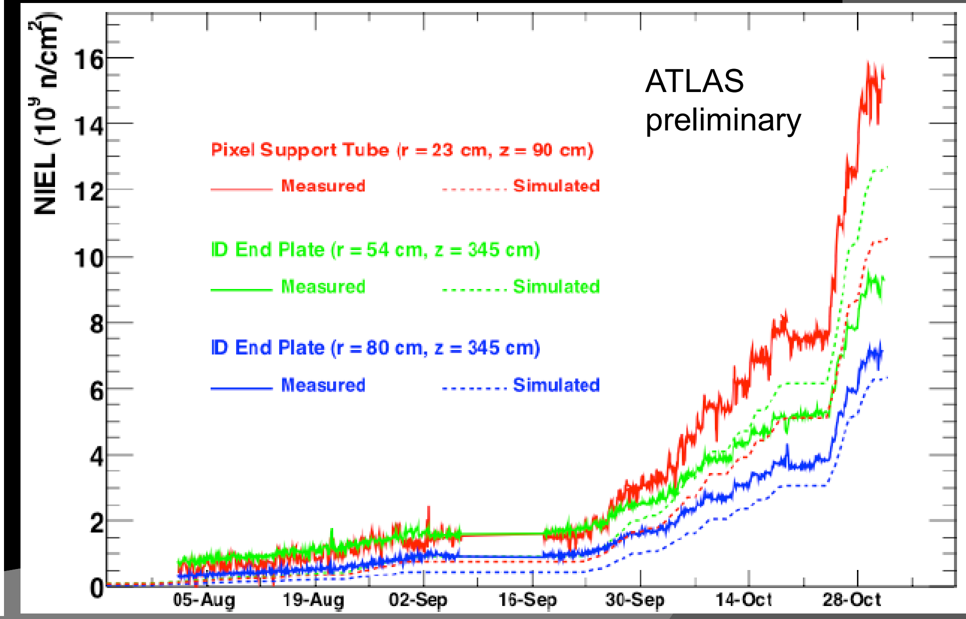


Comparison

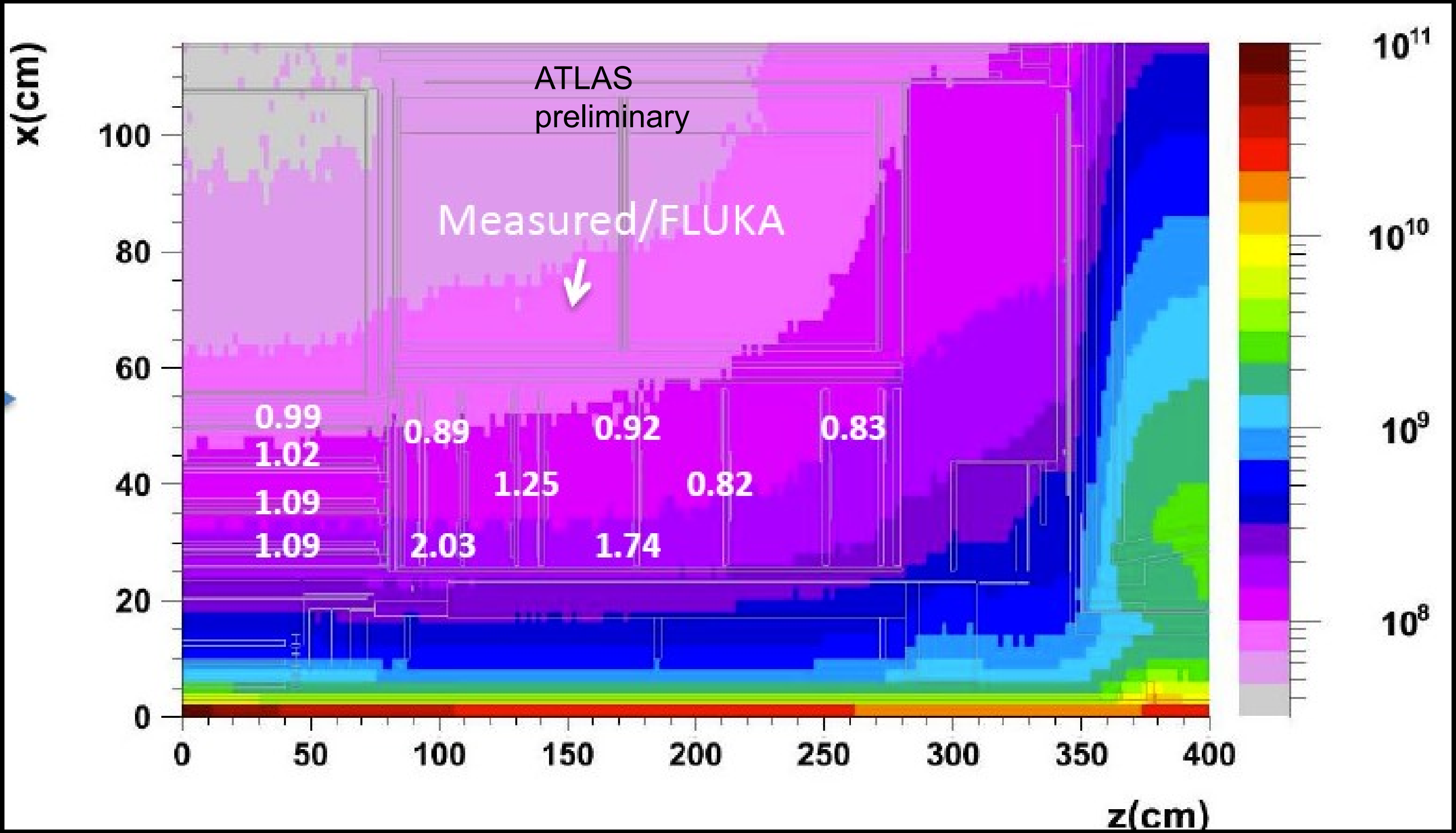
Comparison of ionising-dose measurements and simulated predictions



Comparison of NIEL (1MeV neutron equivalent) measurements and simulated predictions



ATLAS current comparison with FLUKA

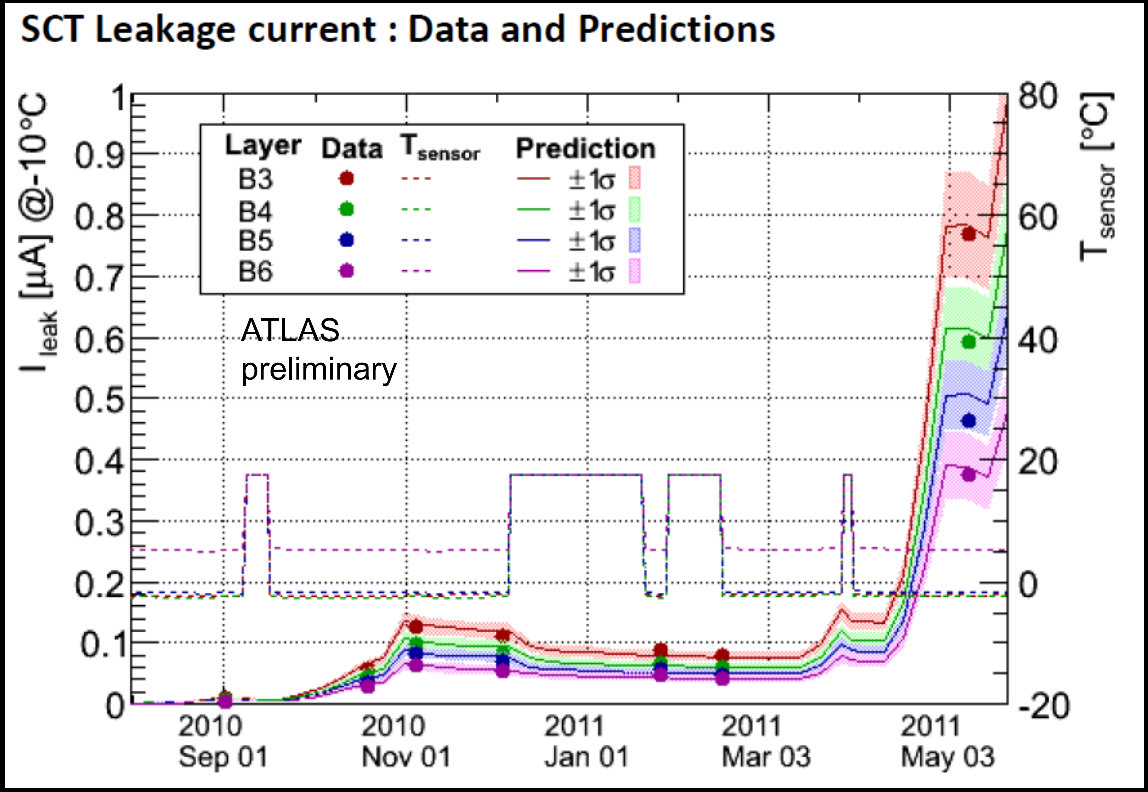


Numbers are ratio Measured/FLUKA

Comparison ✓

- Approach: normalize averaged currents for temperature and then calculate fluence in 1MeV n_equiv (with standard alpha); then compare derived fluence with FLUKA Sim
- Larger differences in the inner endcap regions

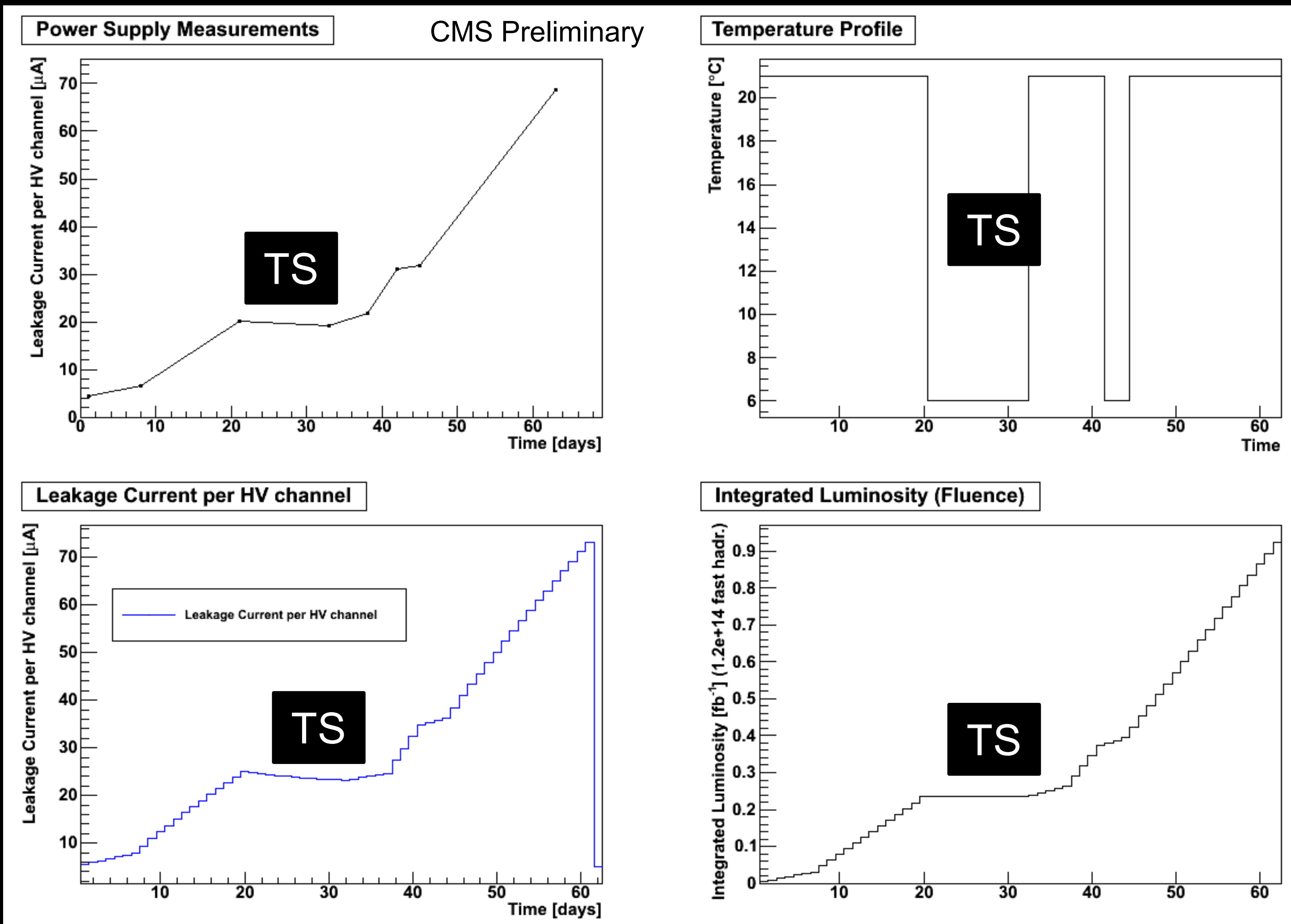
Leakage current evolution in ATLAS and comparison with model



Comparison ✓

- Prediction is based on the total 7-TeV luminosity profile and the FLUKA simulations, taking the self-annealing effects into account.
- The prediction uncertainties are mostly due to errors in the fraction of the slowest annealing component (11%) and luminosity measurement (4.5% in 2011). The uncertainty of FLUKA simulation is not included.
- Scaled to -10C

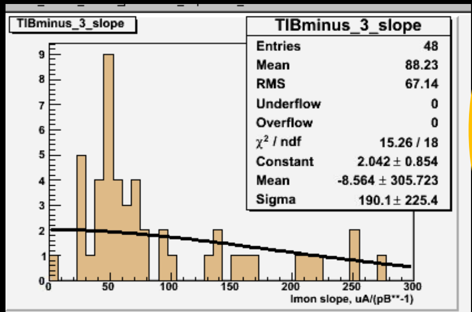
Match data with simulation in a timely fashion

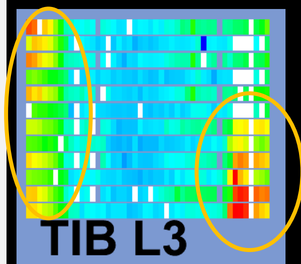


- CMS SST
  - Starting point
  - To be used for extrapolation
  - $\alpha(T,t)$

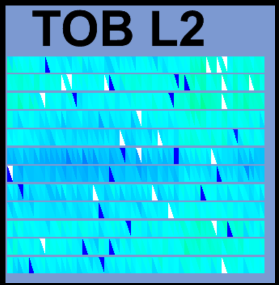
Annealing alpha ✓

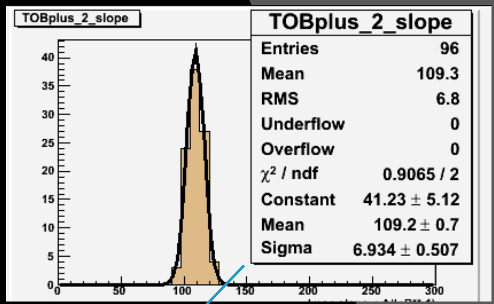
Leakage currents normalized



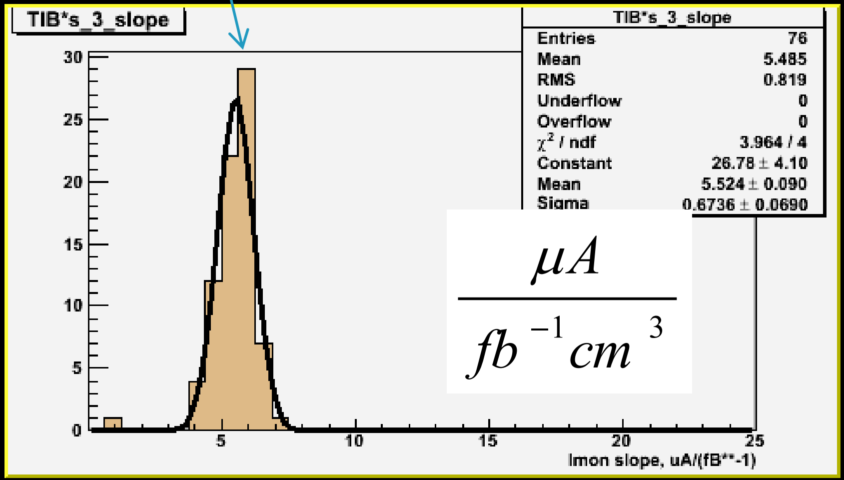


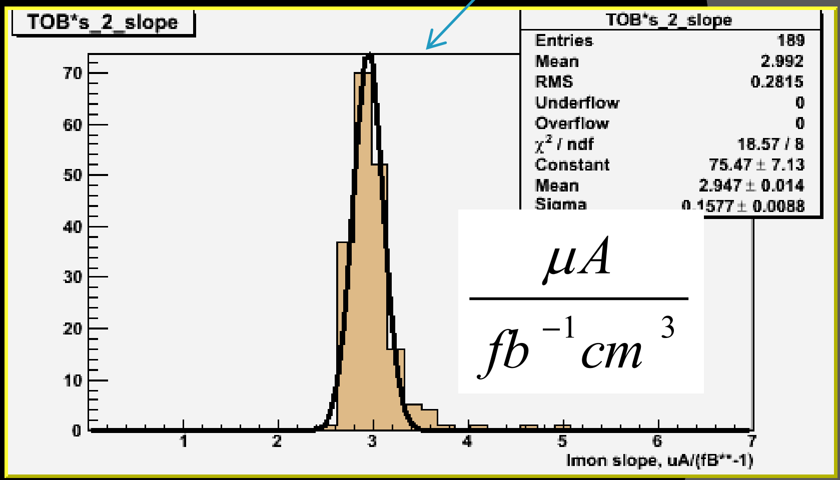
temperatures





temperatures



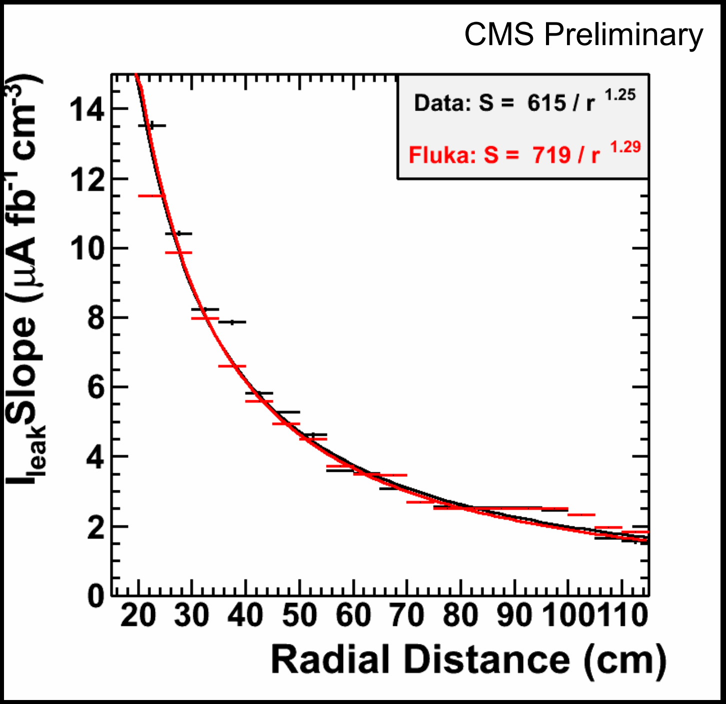


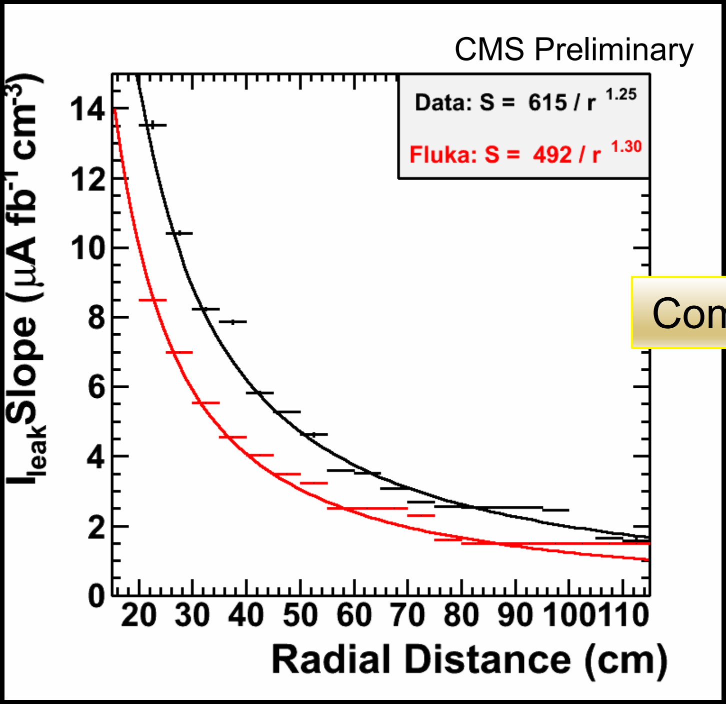
- Normalization with respect to volume and temperature
- → Radial dependence
- → Comparison with expectation

First attempt to compare with simulation

Approach: calculate current increase from simulated fluence (*alpha)
Simulation: Fluka 14TeV scored to 1MeVn_equivalent per pp collision

- There are still some uncertainties how to scale from 14TeV to 7TeV; waiting for new simulation
- With the above zero temperature we have continuous parallel annealing and alpha is not directly obvious
- Mind also that the radial dependence also changes a bit with Z (here used central region)





Comparison ✓

Assumption:

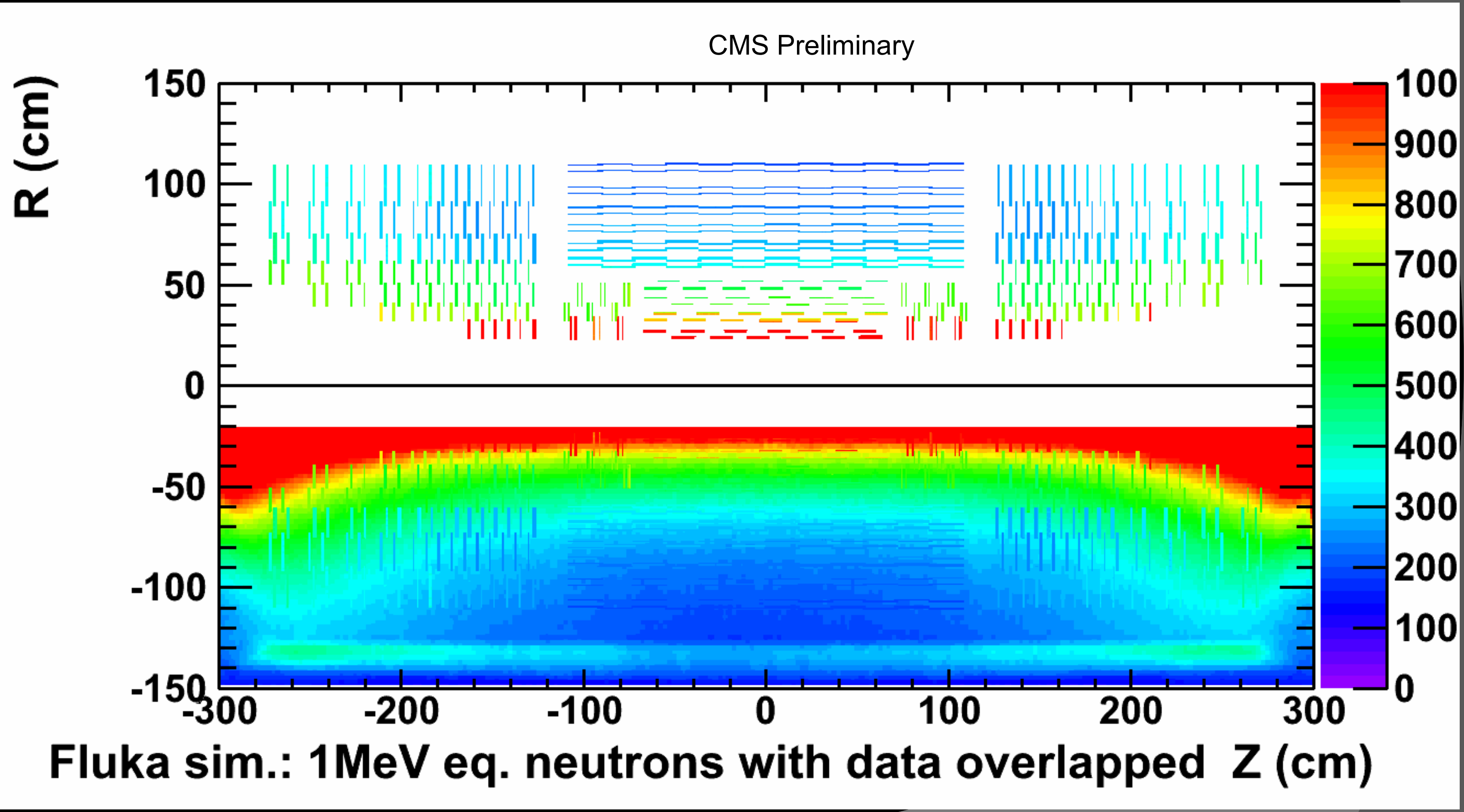
Xsec 77mb
Alpha 4.85 (20C 5d)

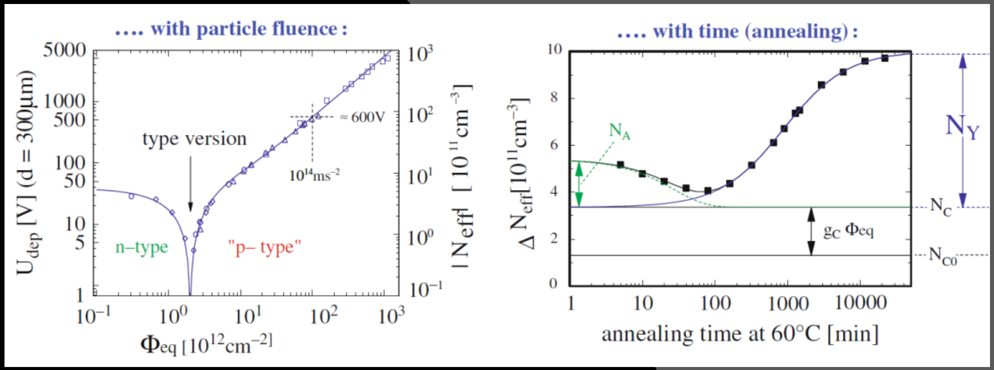
Assumption:

Xsec 77mb
Alpha 4.85 (20C 5d)
Multiplicity correction Sqrt(E) = Srqt (7/14)=0.71

Hide & Seek -- Localized comparison

Comparison ✓





Do we see already effects?

Can we tune the HH model parameters?

Depletion voltage

Signal vs. Voltage Scans during STABLE BEAM

ATLAS

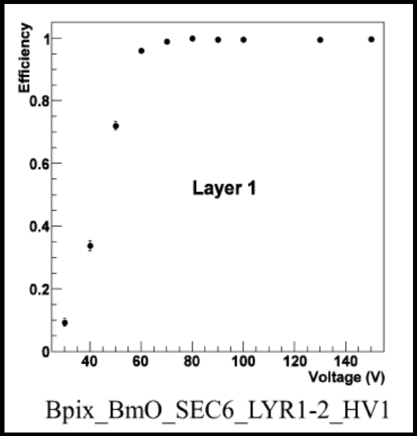
- **Pixel**
  - None
  - Non beam scans show decrease Mar → June 50V → 35V

Vdep evolution

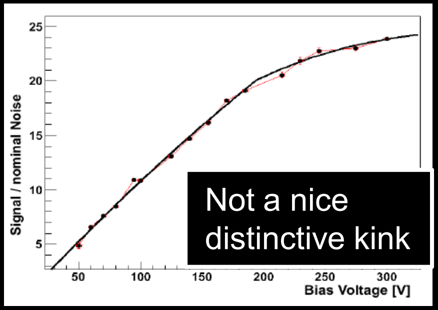
- **SCT**
  - None

CMS

- **Pixel**
  - Scan sample modules
    - All sensors from one ingot
  - Semi manual



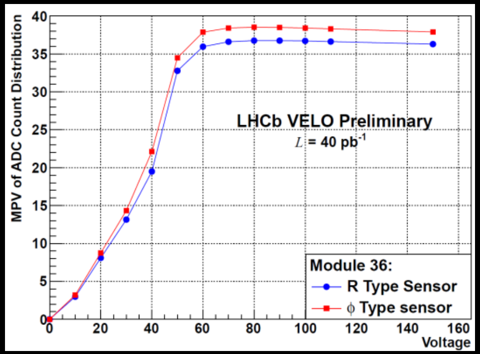
- **SST**
  - Scan full detector at once
  - Semi manual
  - Use pixel for track seeding
  - Model chip response



LHCb

Vdep evolution

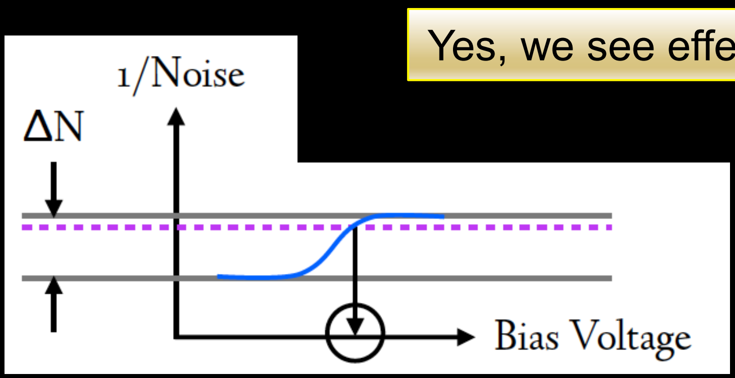
- **VELO**
  - Scan 3 double layers at once
  - Cycle through the layer combinations
  - Fully automated
    - 80% value used matching lab CV



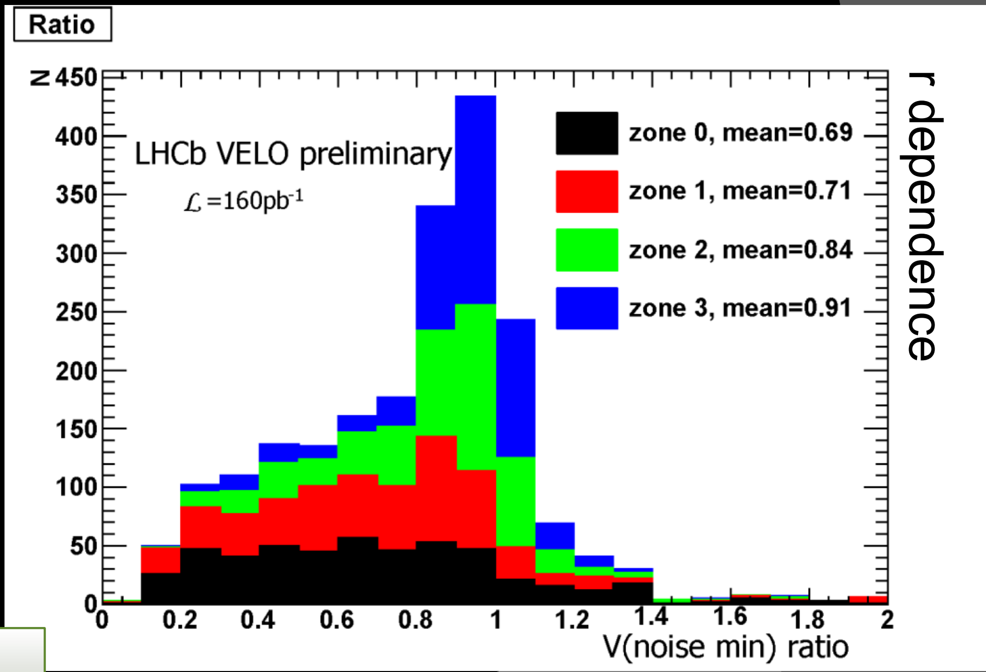
Strategy - Noise vs Voltage

Measure voltage required to get noise to reduce by a specified fraction of the total depleted/undepleted change in noise

Yes, we see effects



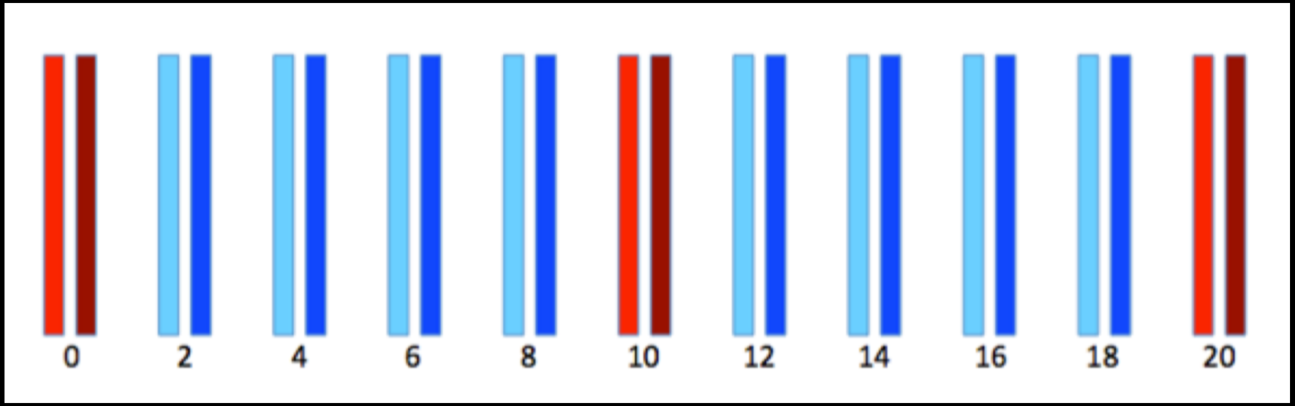
Dependence on $1/r^{1.9}$ and station (z)



Stations (z)

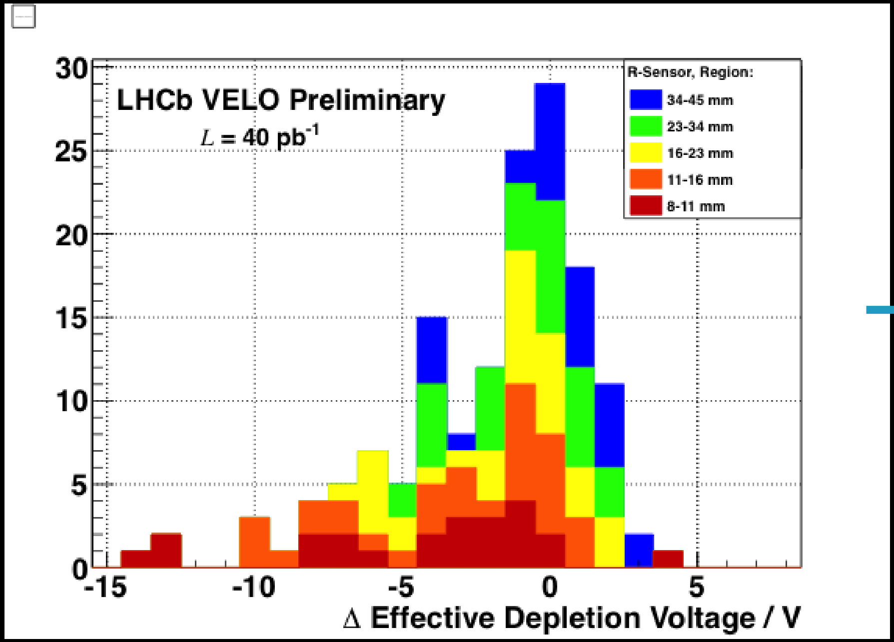
- Allows localized analysis
- n-in-n sensor
- Strategy after SCSI to be defined/tested

Strategy - Signal vs. voltage

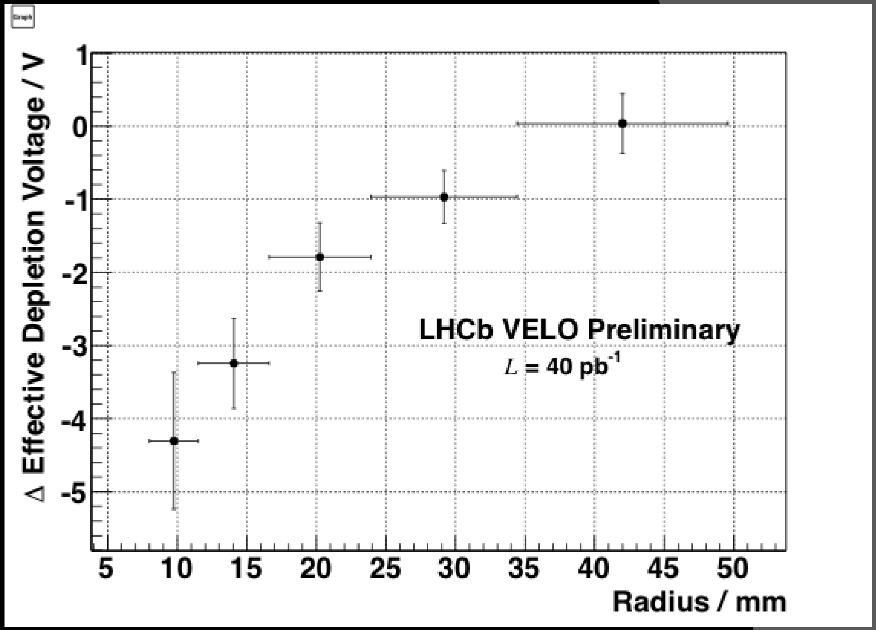


- Blue – tracking sensors – at full bias voltage
- Red – test sensors – bias voltage ramped
  - 10V steps, 0V-150V
  - Rotate through patterns, fully automatic scan procedure
- Tracks fitted through tracking sensors
  - Charge collected at intercept point on test sensors measured as function of voltage
    - Non-zero suppressed data taken so full charge recorded
  - Can study regions of sensor

Signal vs. voltage
Vdep changes clearly visible



mean



Yes, we see effects ✓

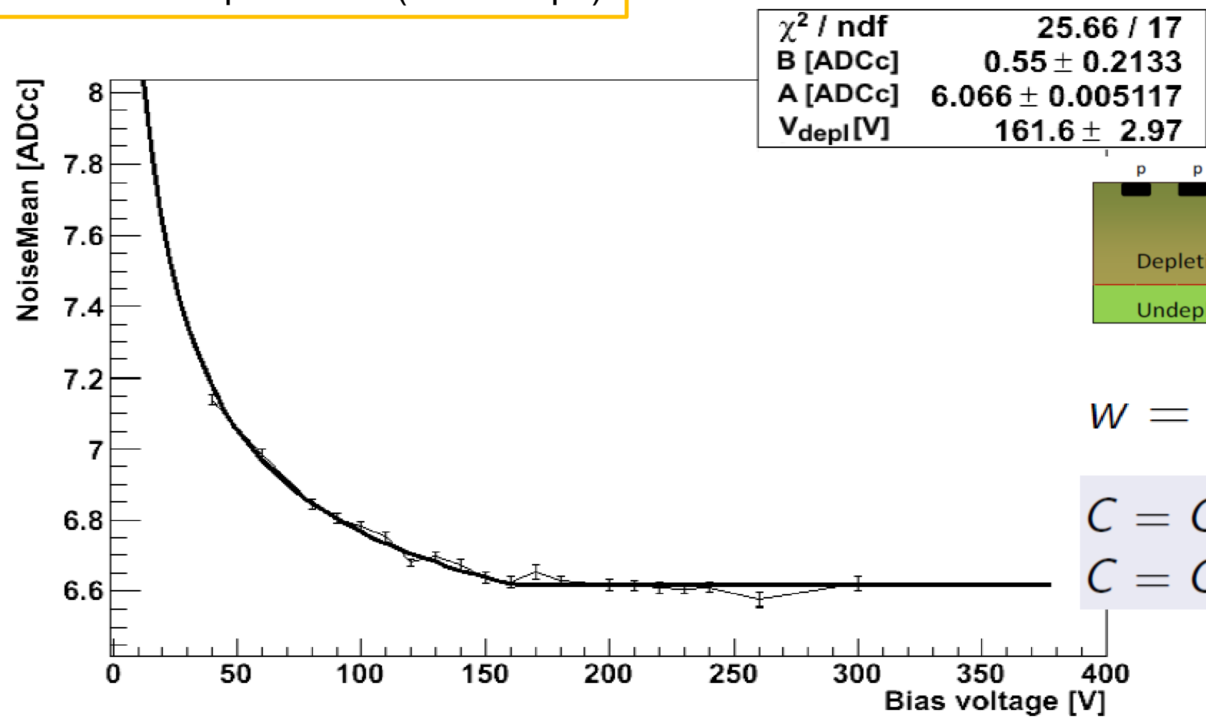
- Charge collection efficiency vs. voltage measured.
- Voltage at which CCE is 80% extracted
    - 80% chosen as gives best agreement un-irradiated with depletion (CV)
- Dependence on $1/r^{1.9}$ and station (z)

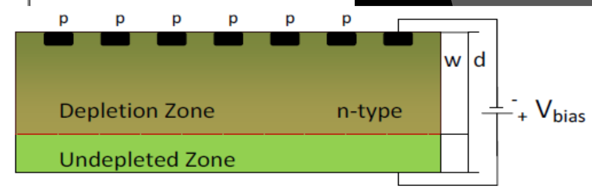
For CMS SST

More detailed example of method to determine depletion voltage

Vdepletion via Noise measurement

It was not clear from the beginning that we can use this method in n-in-p sensors (CMS strips)





$$w = \sqrt{\frac{2\epsilon_{Si} V}{q|N_{eff}|}} = d\sqrt{\frac{V}{V_{depl}}}$$

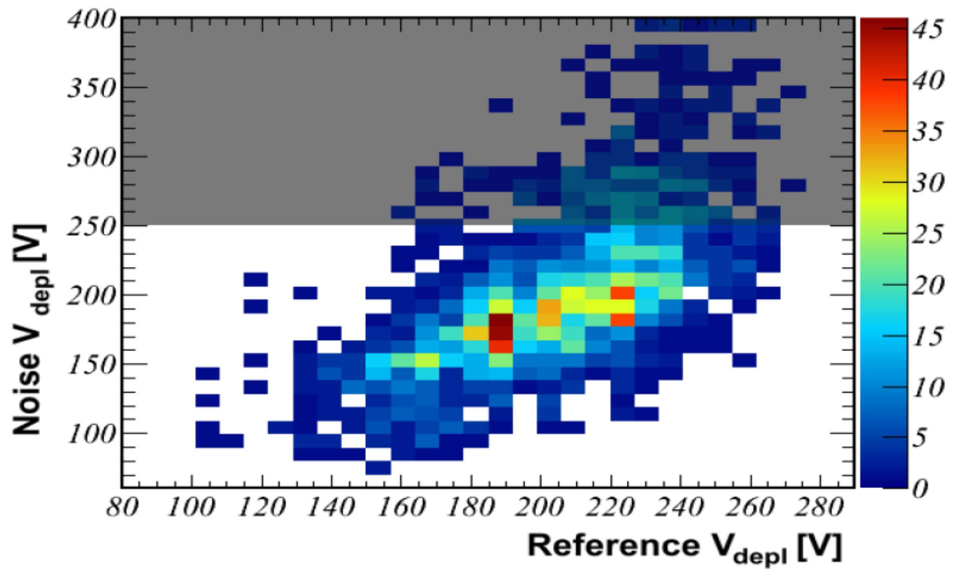
$$C = C_0\sqrt{\frac{V_{depl}}{V}} \quad for \ V < V_{depl}$$
$$C = C_0 \quad for \ V \geq V_{depl}$$

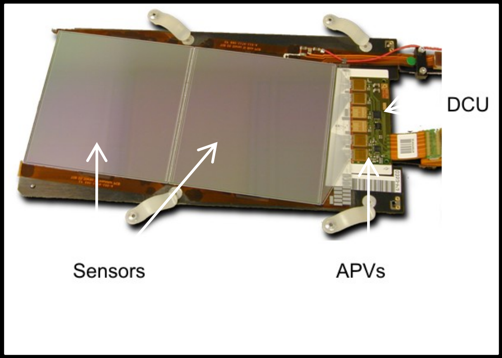
The noise is fitted with

$$n = \sqrt{(A + B \cdot \sqrt{\frac{V_{depl}}{V}})^2 + others^2} \ \ for \ V < V_{depl} \quad ; \quad n = n_0 \quad else.$$

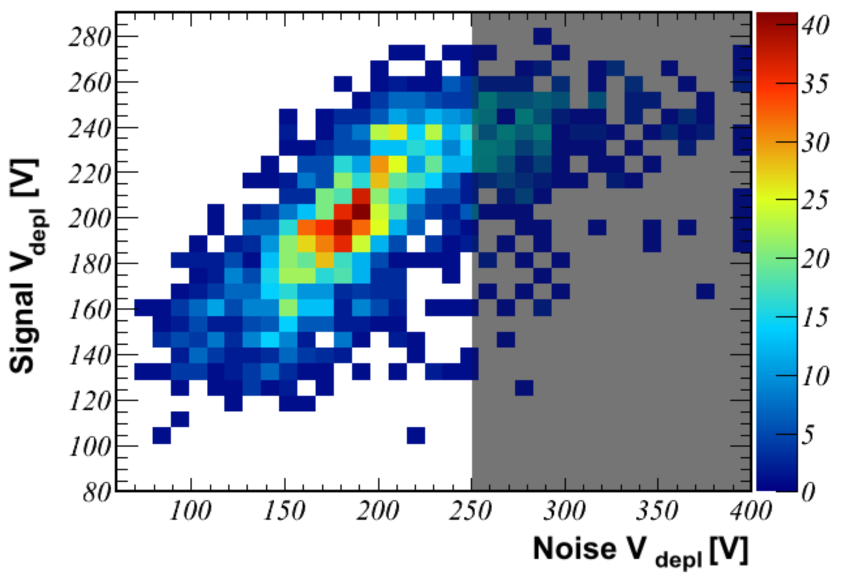
Due to the range of the measurement this leads only to reliable results up to depletion voltages of about 250V.

Vdepletion from noise in p-in-n sensors





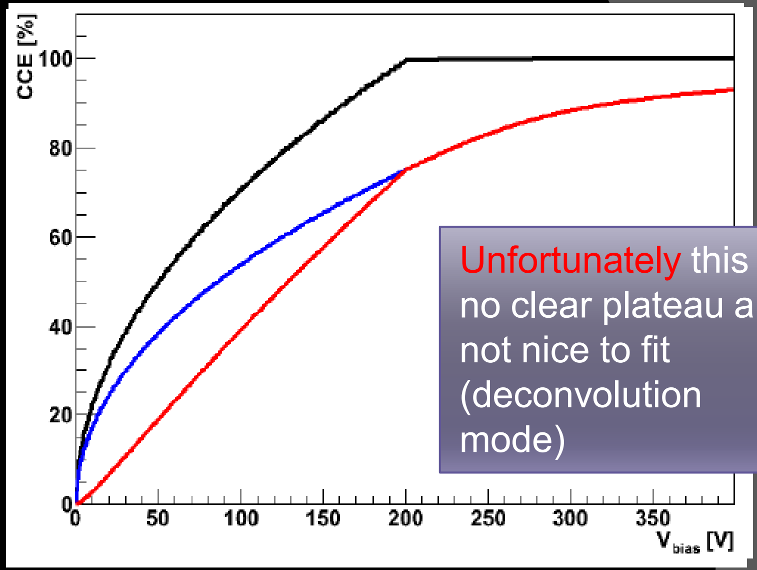
TOB



Reference measurements are from lab CV measurements on full sensor or company CV on diodes

Vdepletion in the CMS case from signal vs. voltage

- Variation of depletion width changes the amount of charge collected

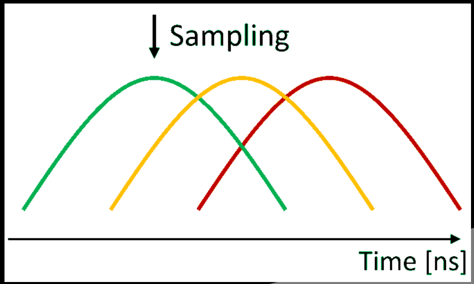


Unfortunately this is no clear plateau and not nice to fit (deconvolution mode)

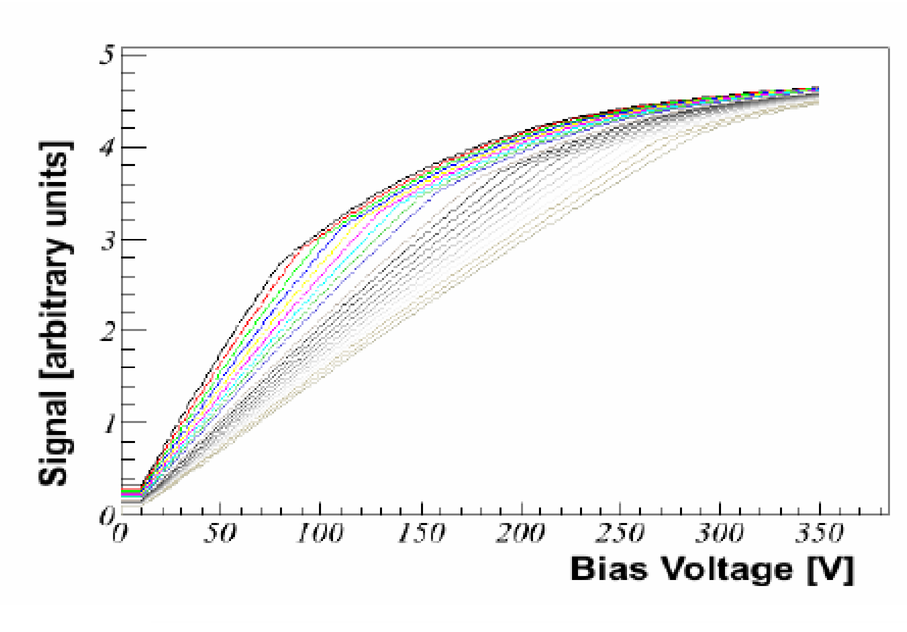
- Change of charge carrier mobility

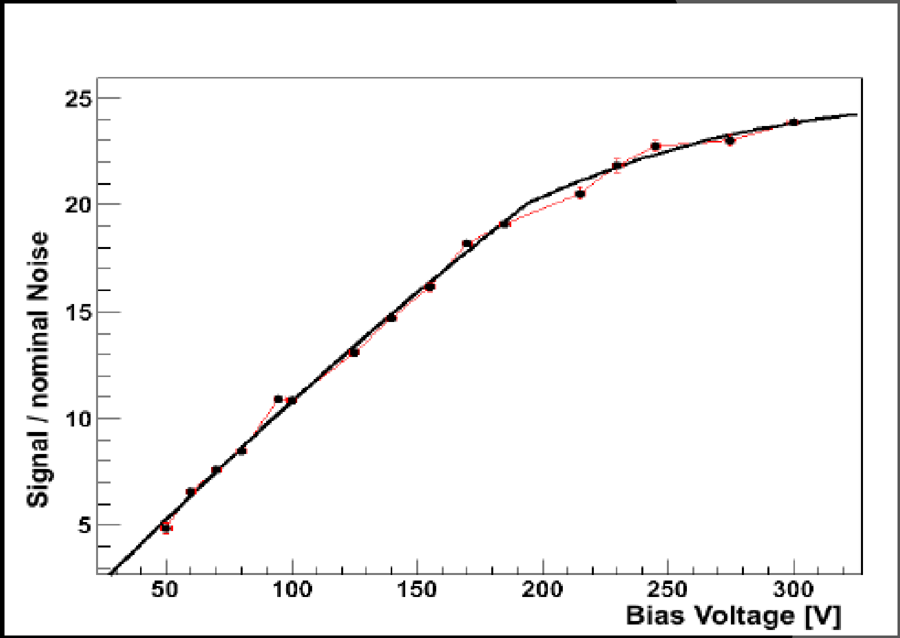
But fortunately the deconvolution mode is very sensitive to the effects

- Change in load capacitance change the signal shaping of the signal pulse thus the measured signal



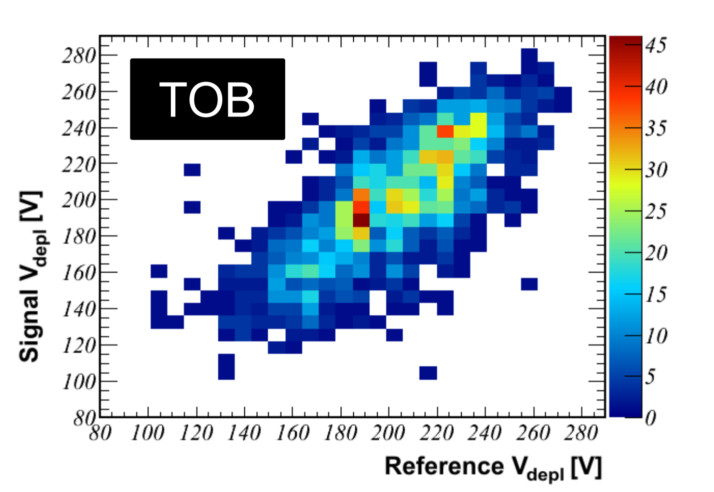
Vdepletion from signal vs. voltage

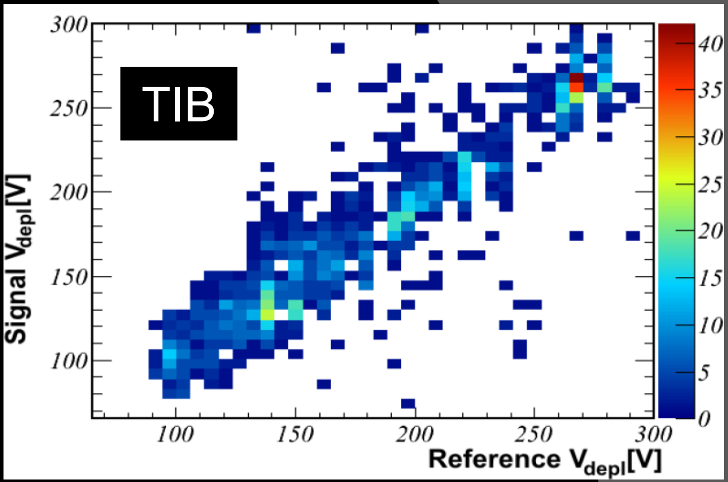


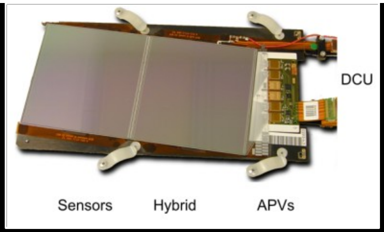


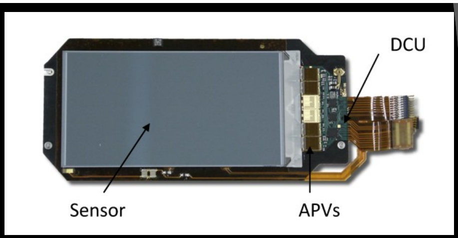
- Laudau fit per given voltage
- onTrack cluster with good Landau fits
- Fit graph with pre-modeled curve

Signal vs. voltage (during STABLE BEAM)



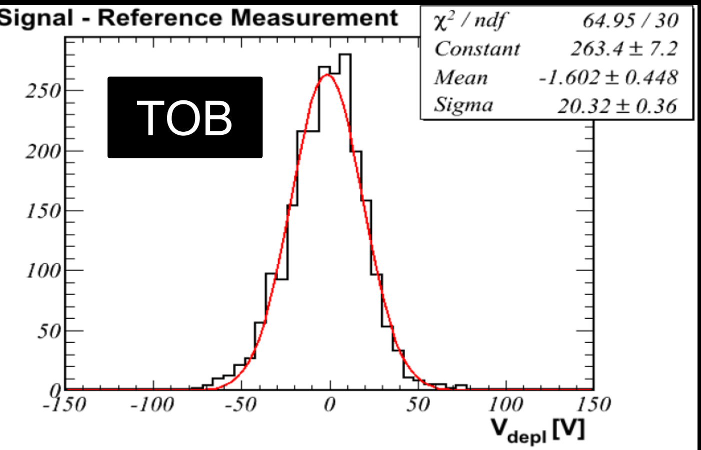


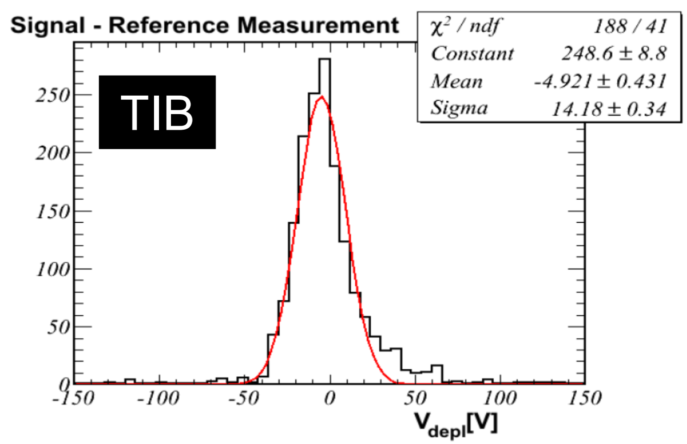




Very good agreement between the results from the signal scan and the reference measurements (especially in TIB partition with only one sensor per module)

➔ Anchor measurement for the future

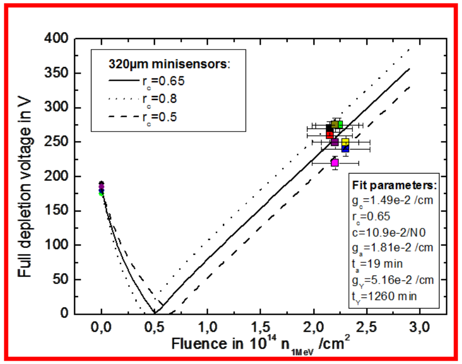


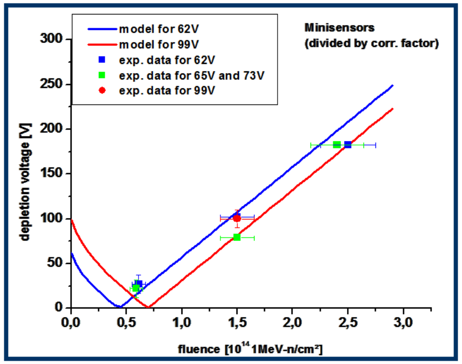


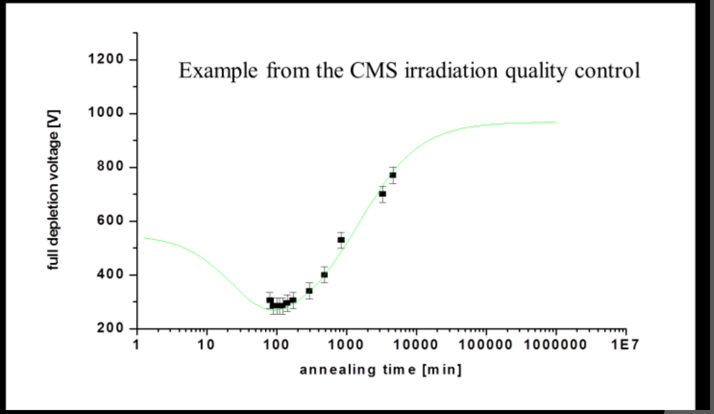
Within to the accuracy of the measurement “no” significant change in Vdep is visible so far (Feb11).

History and Future - comment

- CMS did extensive radiation studies during construction to establish the “respective CMS” HH parameters
  - These are used in our comparison and future extrapolation







- Let’s see how much we can constrain the model and corresponding future extrapolation? Useful for upgrade?!?!
- How can 10 LHC years in 10 minutes be compared with 10 LHC year in 10 years?

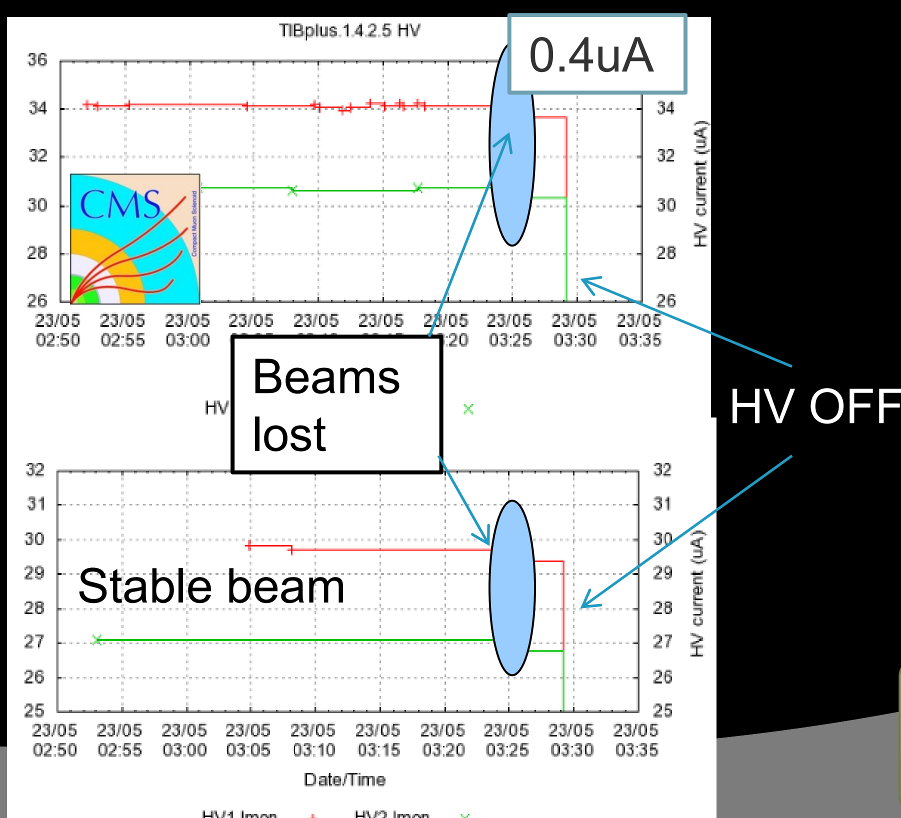
Comments and Conclusion

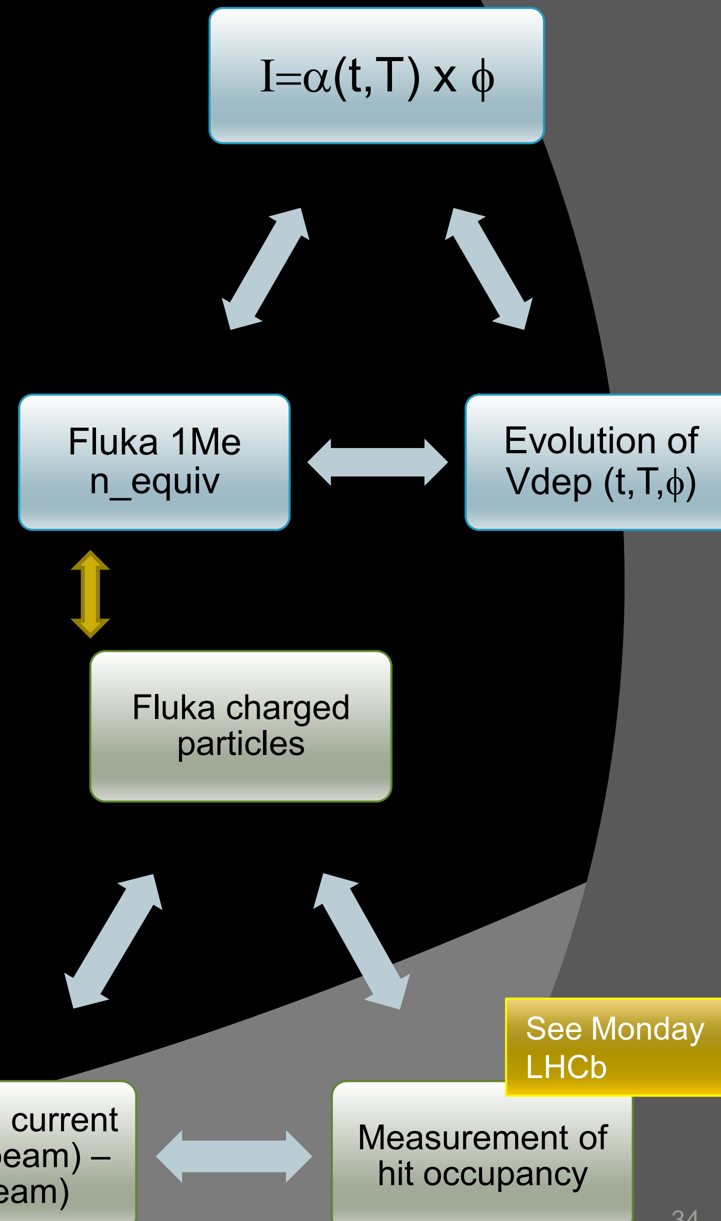
Some ideas about tuning

FLUKA – HH parameters – alpha – luminosity – fluence - occupancy

- Matching of all the above allow us more precise extrapolation into the future
  - Life time (depletion voltage)
  - Determination of best maintenance scenario/environment
  - Upgrade strategies
- Can we over-constrain the models and re-tune HH or FLUKA?

With high resolution PS
Back-on-the envelope match in a factor of 2





Conclusion

The effects of radiation on the silicon sensor is clearly visible in the first 1fb $^{-1}$

- Current ~ integrated luminosity
  - Normalization for temperature and volume is necessary to allow comparison
  - First comparison of data to simulation looks ok
  - Uncertainties in
    - CMS: Still waiting for 7Tev Fluka SIM
    - FLUKA, multiplicity, scaling and alpha - especially in the annealing term

- Effects on Vdepletion are still tiny or not observable or not evaluated yet
  - Methods to determine Vdepletion are established
    - Number of scans will remain small – cut into data taking
    - Comparison and HH parameter tuning for Vdep is not yet possible

- Projections are underway to
  - estimate lifetime or define environment during technical stops or shutdowns
  - support the upgrade planning

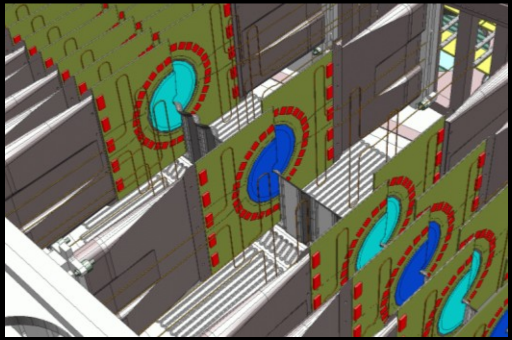
Big thanks to ATLAS and LHCb to allow me to show and compare strategies & results

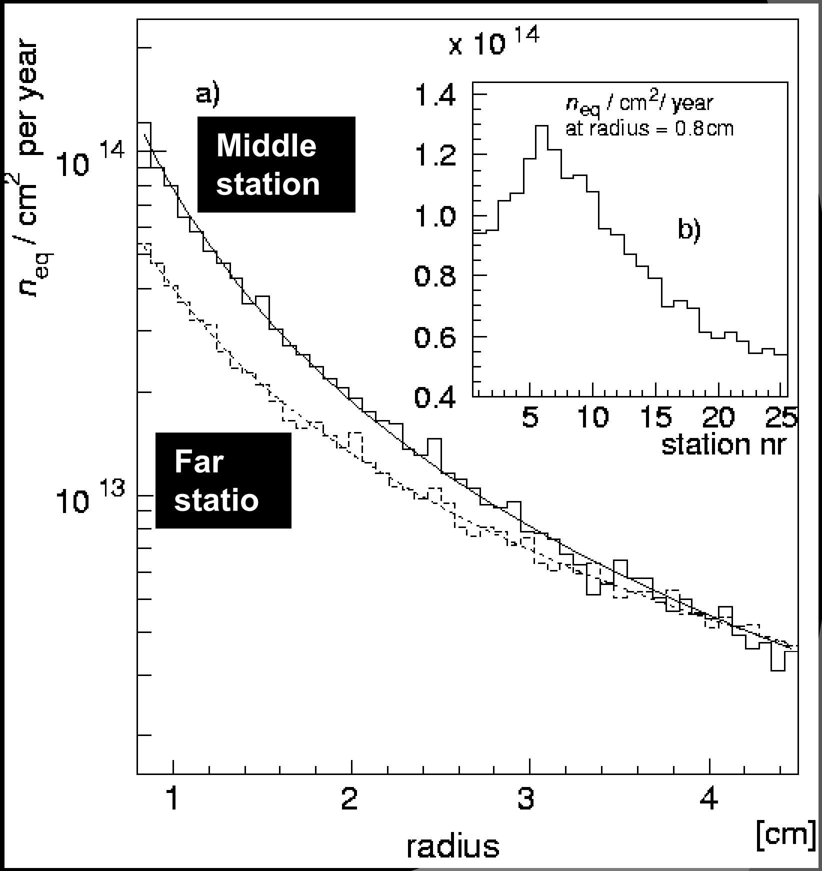
Backup

And now to LHCb - VELO

TDR Prediction

- First Strip only 8mm from LHC beam
  - Outer strip 40mm
- Maximum Fluence predicted at 14TeV
  - 1.3×10^{14} 1MeV $n_{eq}/cm^2/2\ fb^{-1}$
- Strongly non-uniform
  - dependence on $1/r^{1.9}$ and station (z)

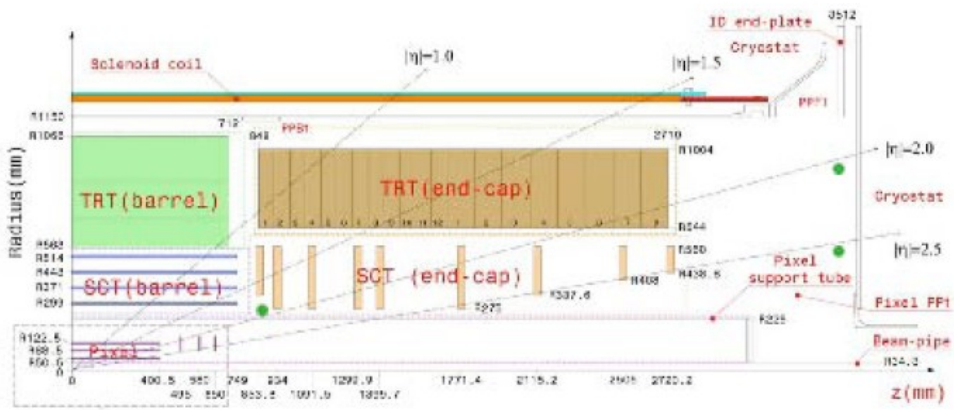




Tips of VELO sensors expected to type invert in next months of LHC running

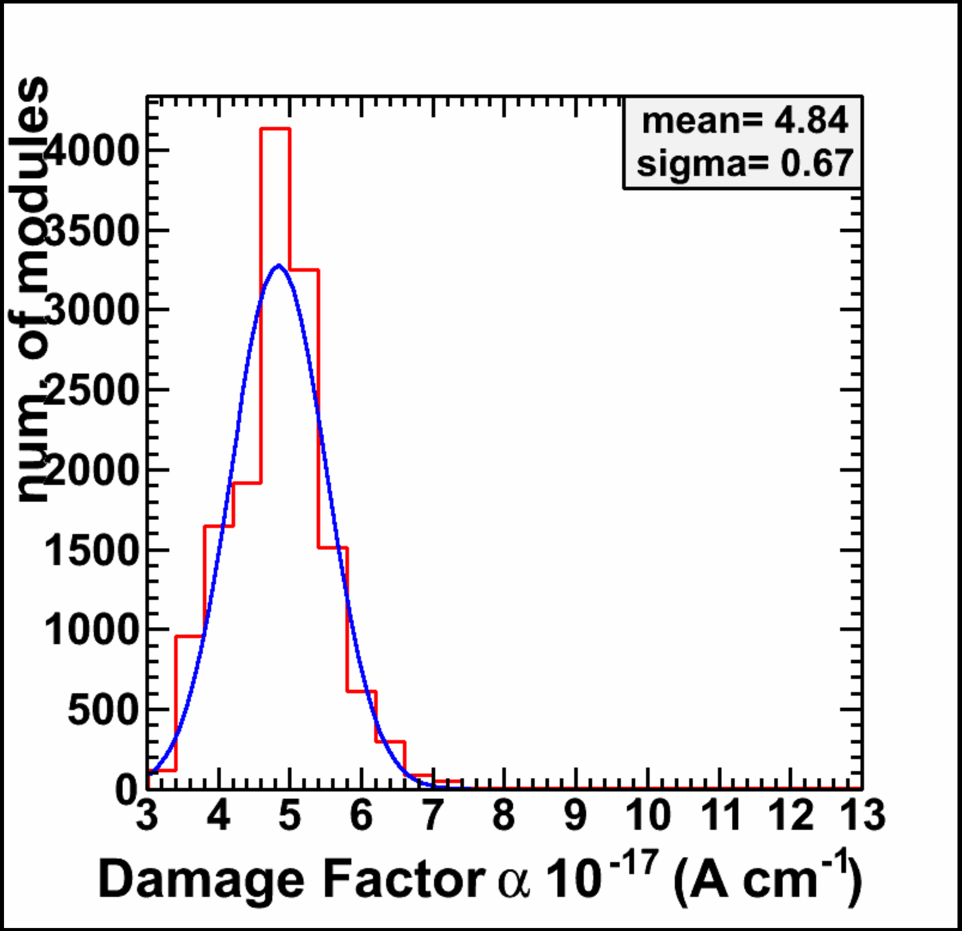
Fluence and dose measurements in the ATLAS inner detector (SCT + RadMon) and comparison with radiation background simulations.

http://cdsweb.cern.ch/record/1322208



Schematic diagram showing a quarter-section of the ATLAS inner detector. The SCT comprises four barrel layers and nine disks per end-cap. Each disk contains either one, two or three rings of modules. Average values of leakage currents are obtained from each barrel layer and disk ring.
Also indicated by green dots are the locations of the RadMons used in the current analysis, which are attached to the Pixel support tube and ID end-plates

Deriving alpha from data to fluka



Fitting data to Sim
Derive linear factor from FLUKA to data and vice versa.