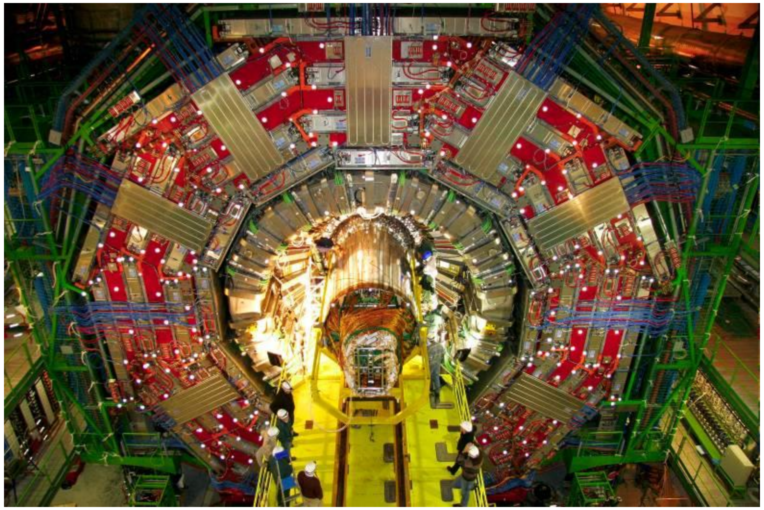
Karlsruhe Institute of Technology

CMS pixel and strip rad damage measurements
20.11.2017

Christian Barth on behalf of the CMS tracker collaboration

INSTITUT FÜR EXPERIMENTELLE KERNPHYSIK



Leakage current

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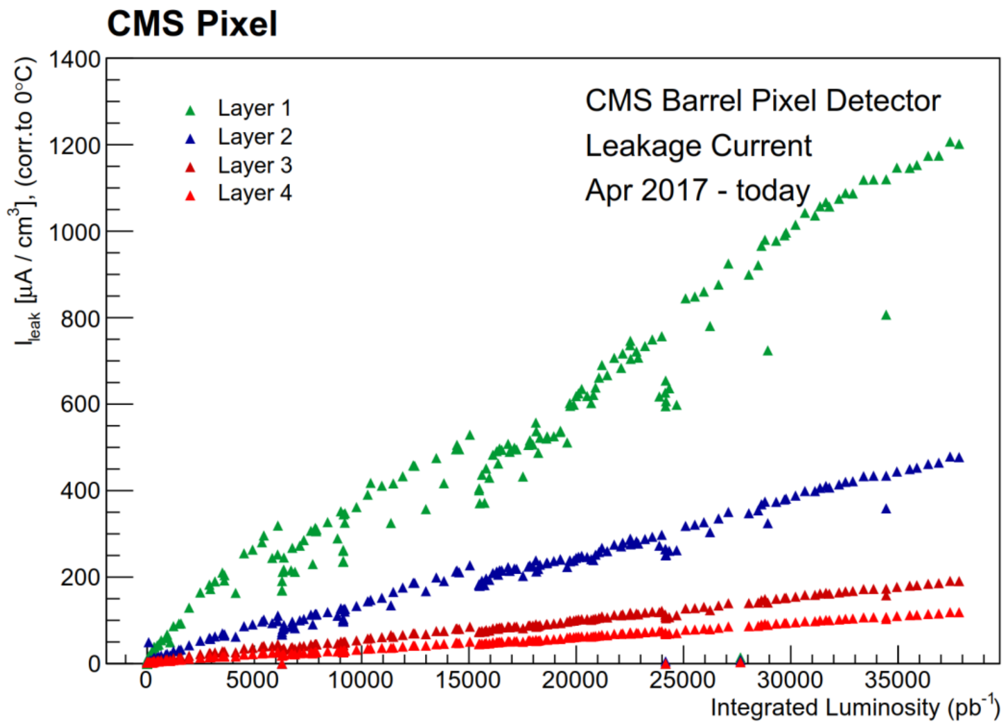
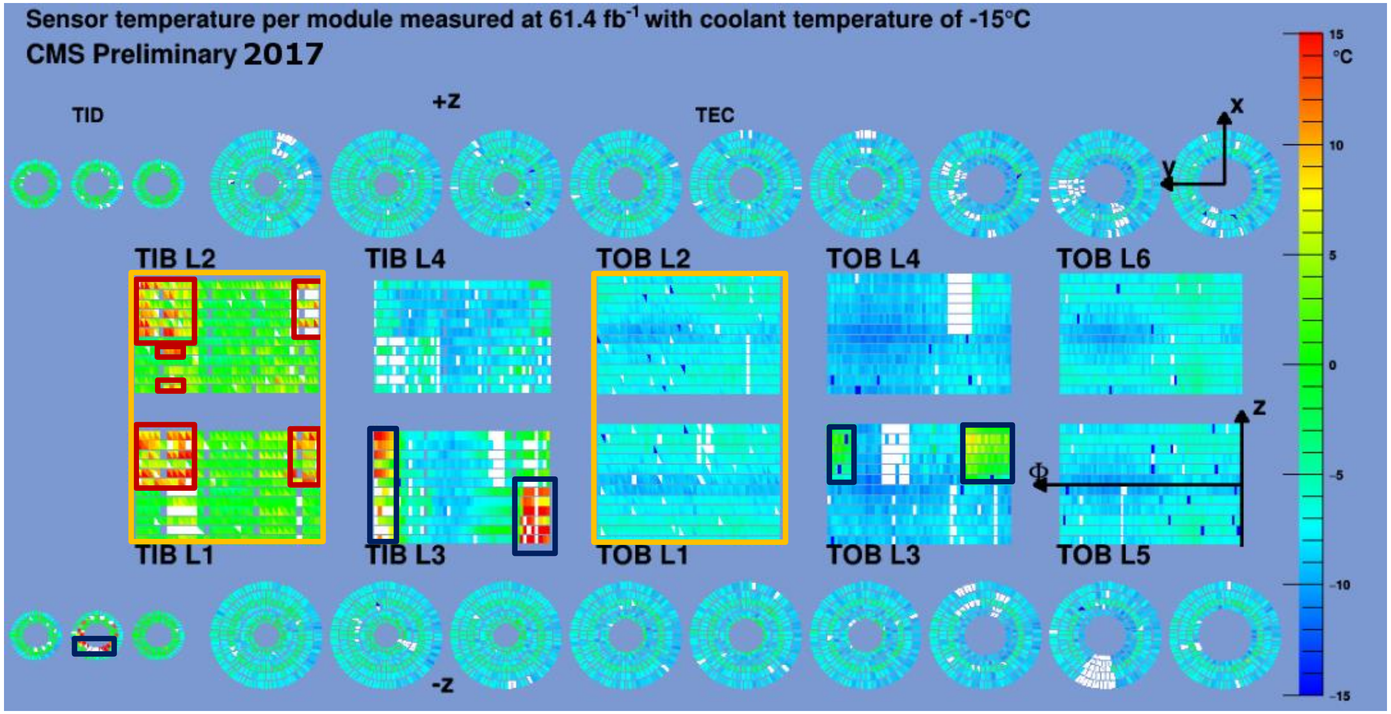
Leakage current evolution in the pixel detector



- Leakage current evolution of phase 1 pixel detector, which have been inserted beginning of the year.
- The change in slope (around 15fb^{-1}) is due to a change in operational temperature from -20°C to -22°C cooling plant set point.
- The deviations from the linear behaviour are due to thermal fluctuations (the temperature normalization is a single scale factor not appreciating actual thermal fluctuations)

Temperature map in the strip detector



Closed (leaky) cooling loops

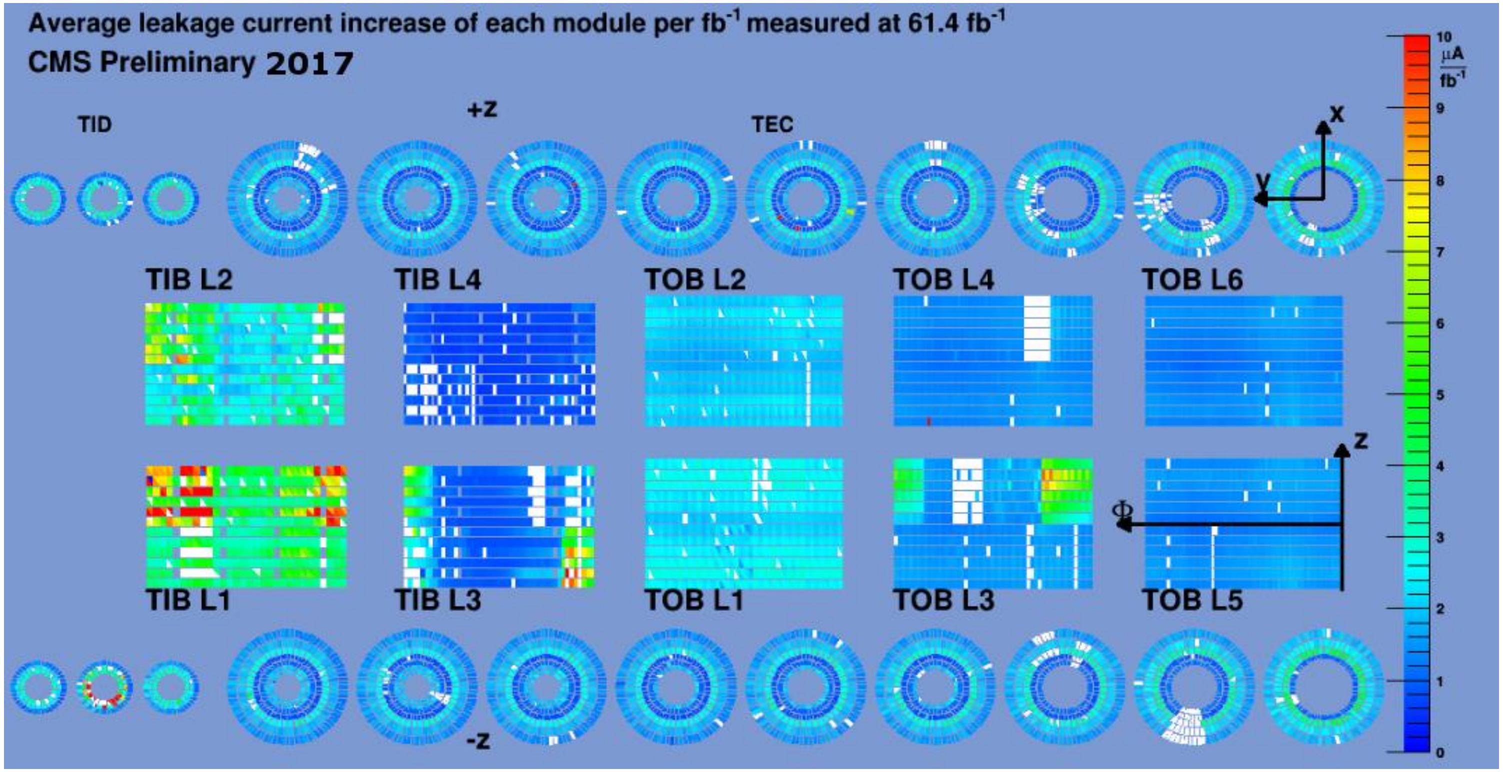
Degraded cooling contacts

Double sensor stereo modules

On top of that ring: 1,2 & 5 of the disk and end cap region use stereo modules

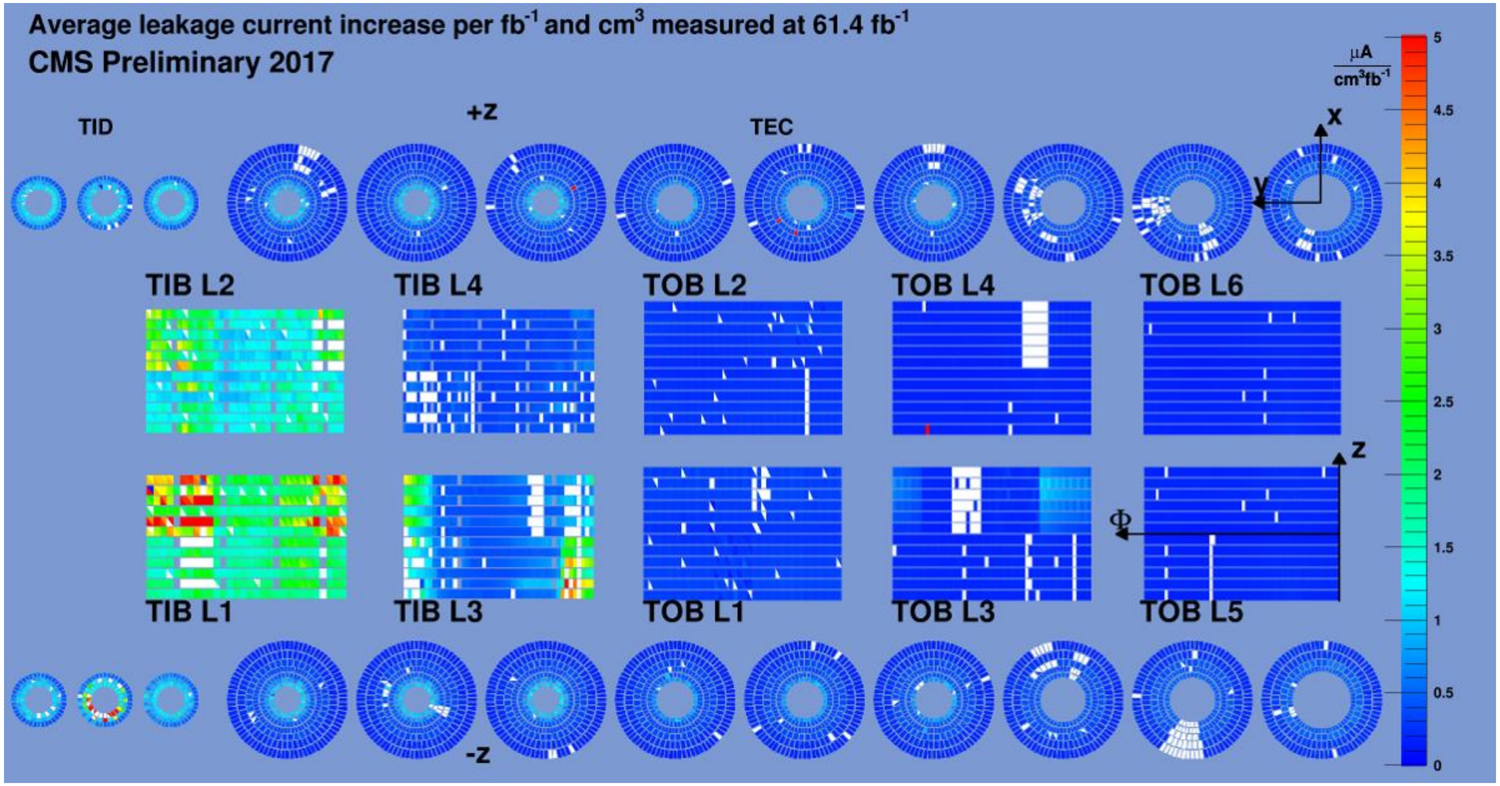
- In order to understand leakage current evolutions in the silicon strip detector one has to appreciate the different temperature regions

Leakage current distribution in strip tracker



- On top of the striking correlation with temperature also the different sensor volumes and fluence levels play a role here

Leakage current distribution volume corrected



- The active silicon sensor volume corrected leakage current is dominated by the temperatures plus some fluence dependencies.

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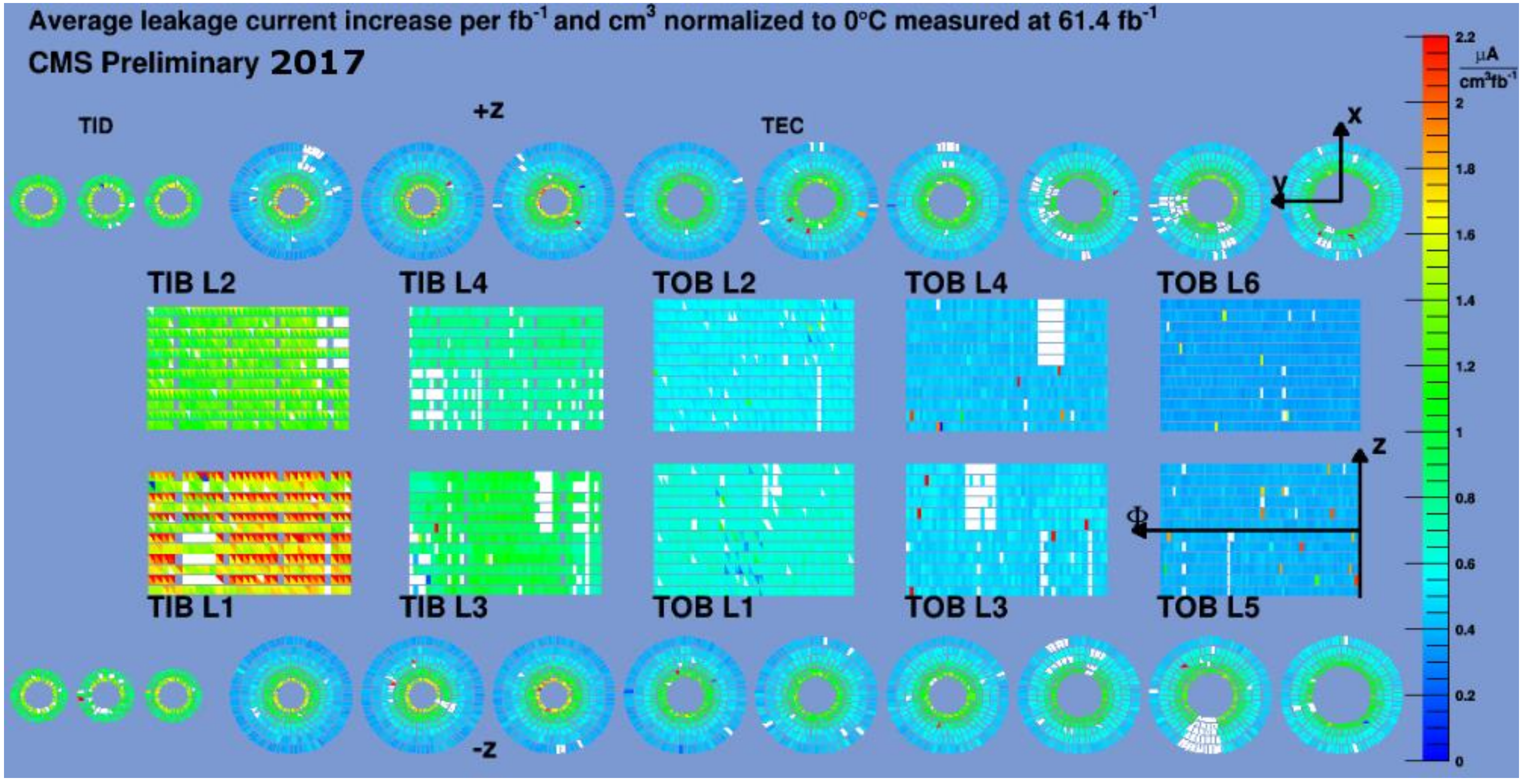
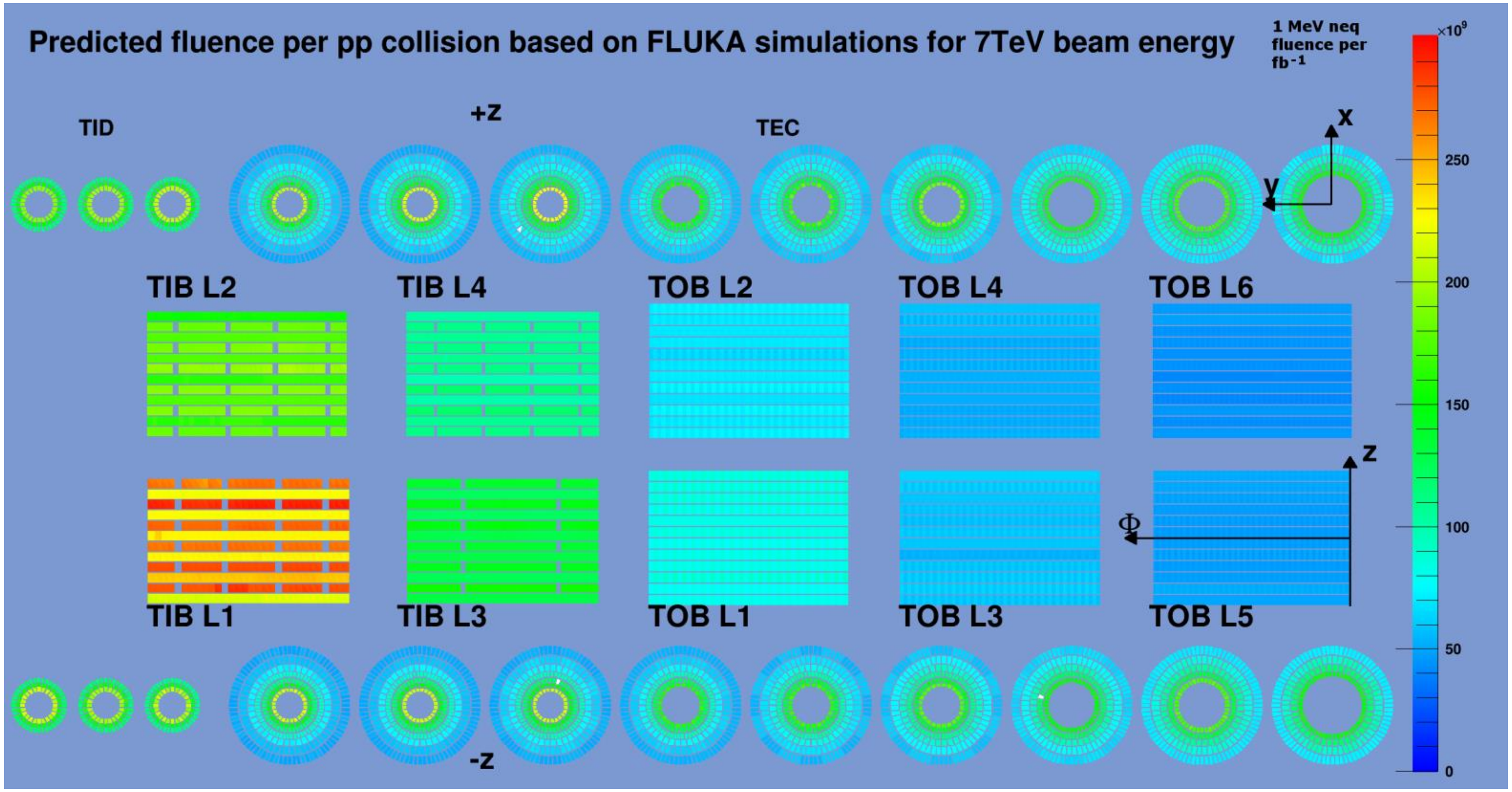
Leakage current distribution normalized to volume and temperature



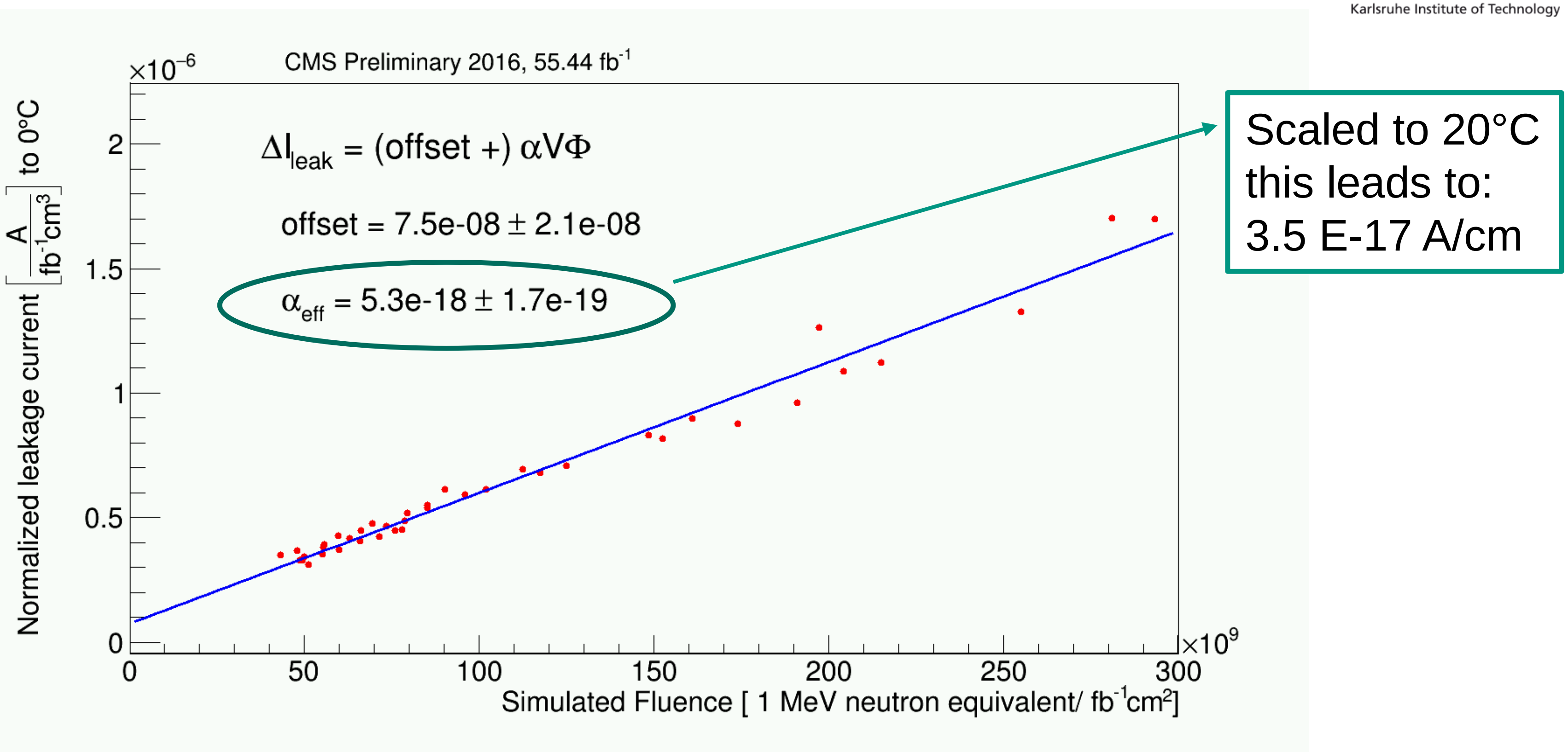
- When normalizing the leakage current to temperature and unity volume, the radial fluence dependency dominates the picture.
- On top of that, fluence increases in the outer TEC wheels is visbible, due to neutrons backscattered from the calorimeters.

Expected 1 Mev neq particle fluence per fb^{-1}



- Obtained via linear interpolation based on a FLUKA simulation for 14 TeV center of mass energy, scored to 1 MeV neq according to the NIEL hypothesis.

Averaged leakage current vs expected fluence



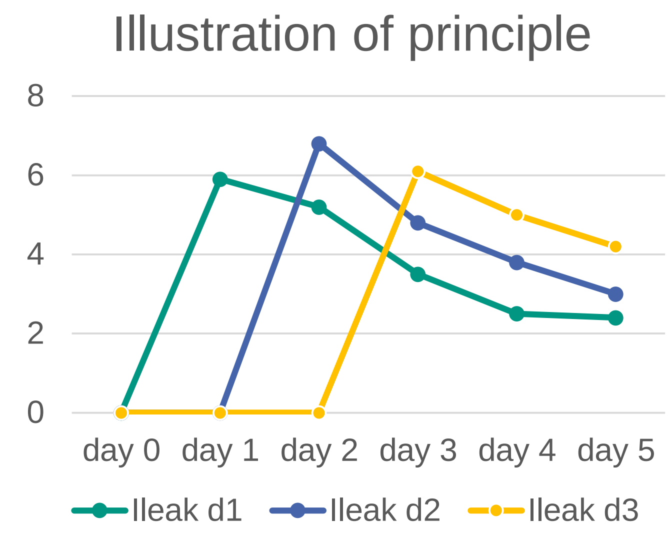
- The leakage current in the barrel region averaged for a given bin in r gives approximately a linear dependency with the expected 1MeV neq fluence for the respective areas (derived from FLUKA simulations)
- The slope is an averaged effective alpha containing the full annealing history

Getting more sophisticated

Full irradiation history

Full temperature history

Leakage current model
- alpha parameter
- FLUKA fluence predictions
- sensor position + geometry
- thermal contacts



Compute the full annealing scenario for the fluence induced leakage current at each day. Superimpose afterwards to obtain the full simulated leakage current history.

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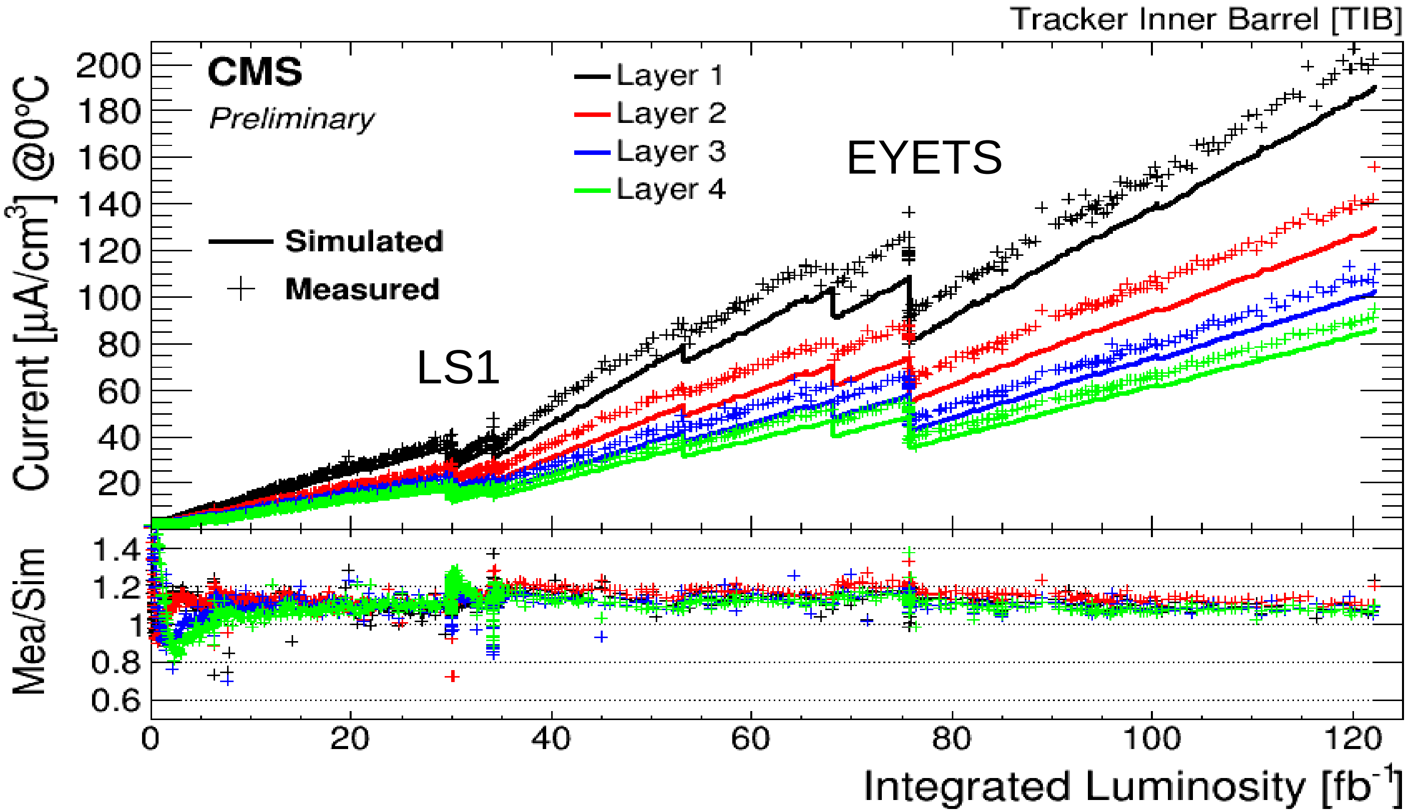
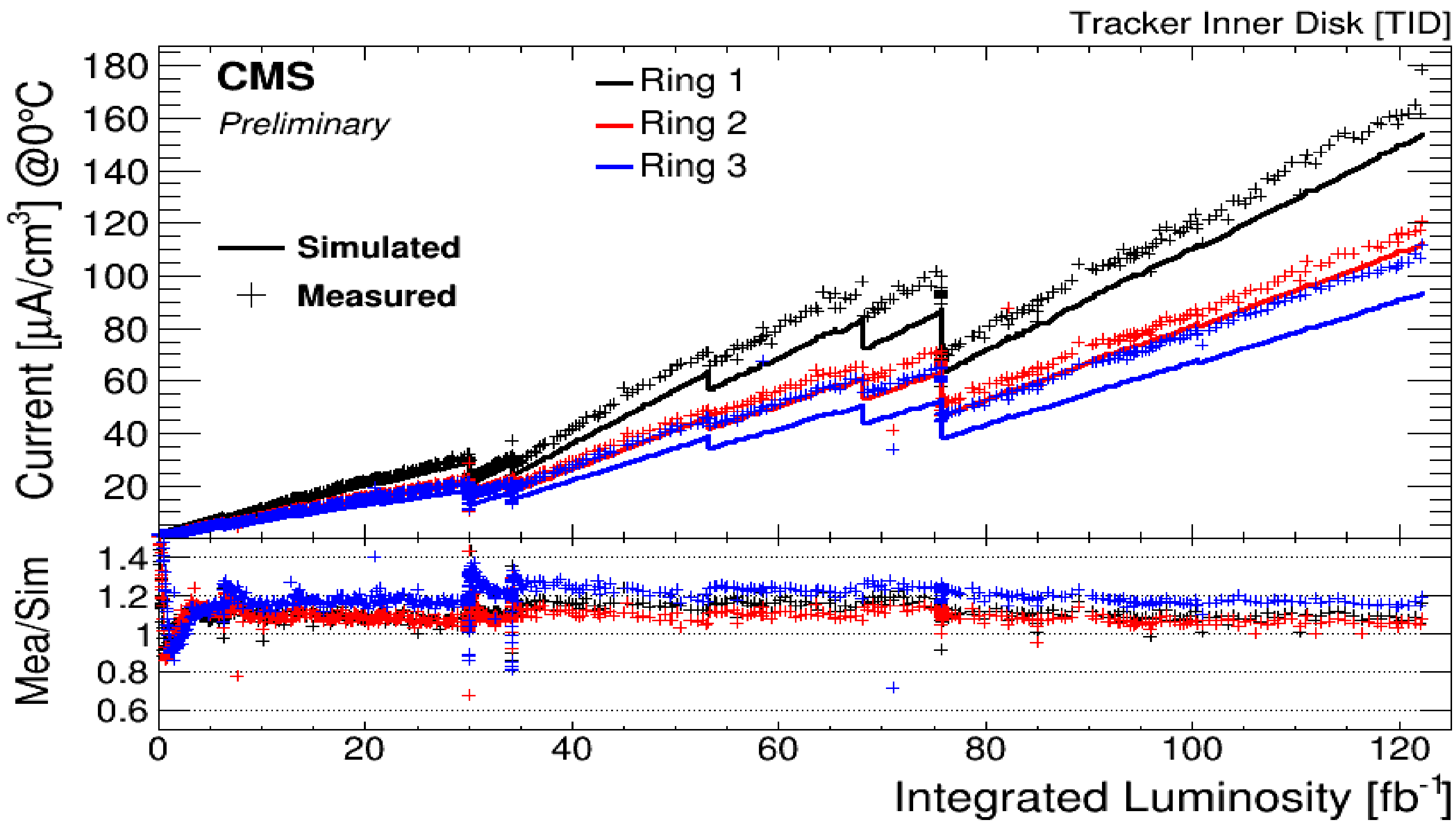
Strip inner barrel leakage current simulation and measurements



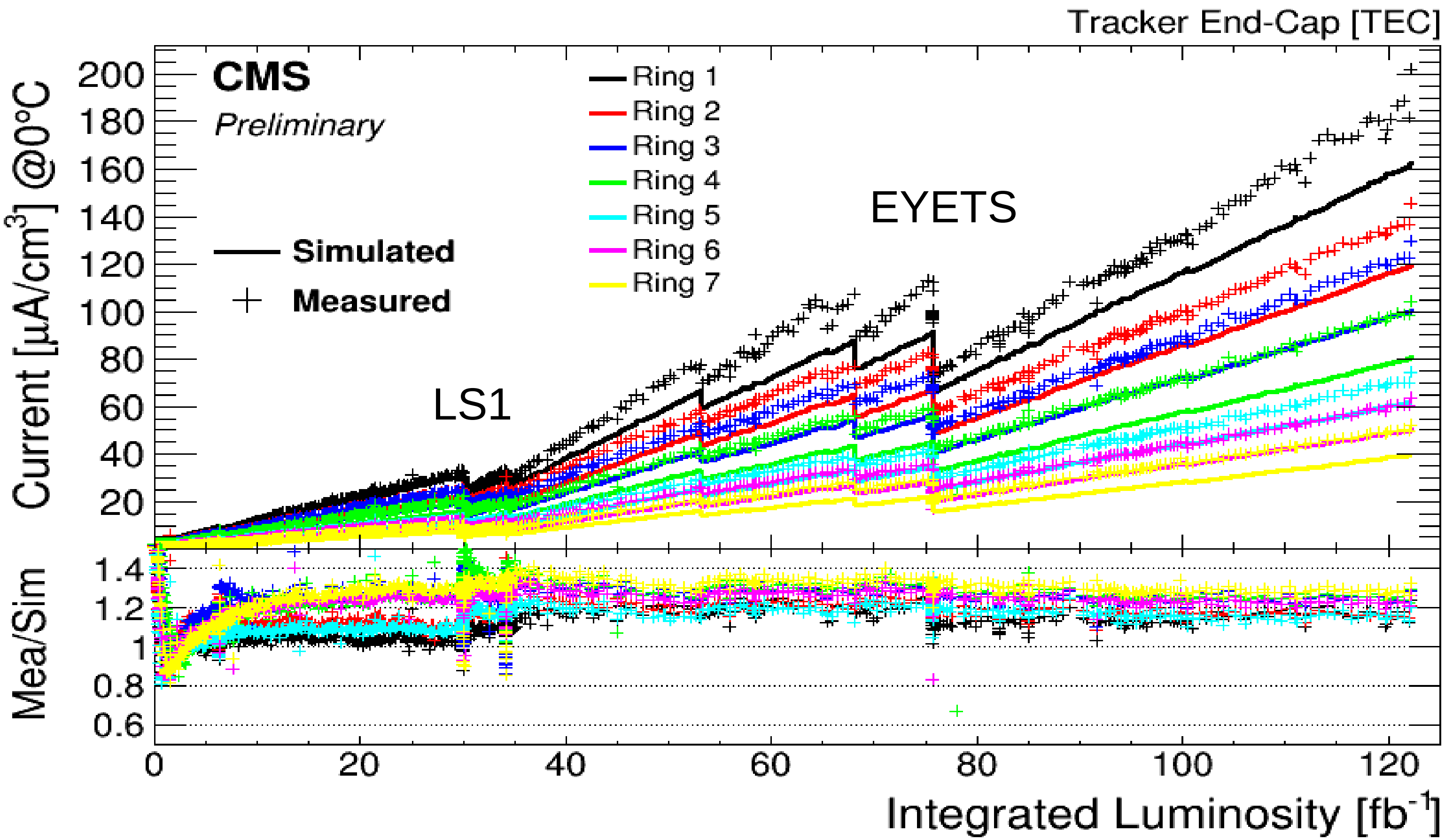
- The method sketched in the previous slide was used to compare a simulated current with the actual measurements.
- We observe a nice agreement throughout the years.

Simulated and measured leakage current in the inner disk region



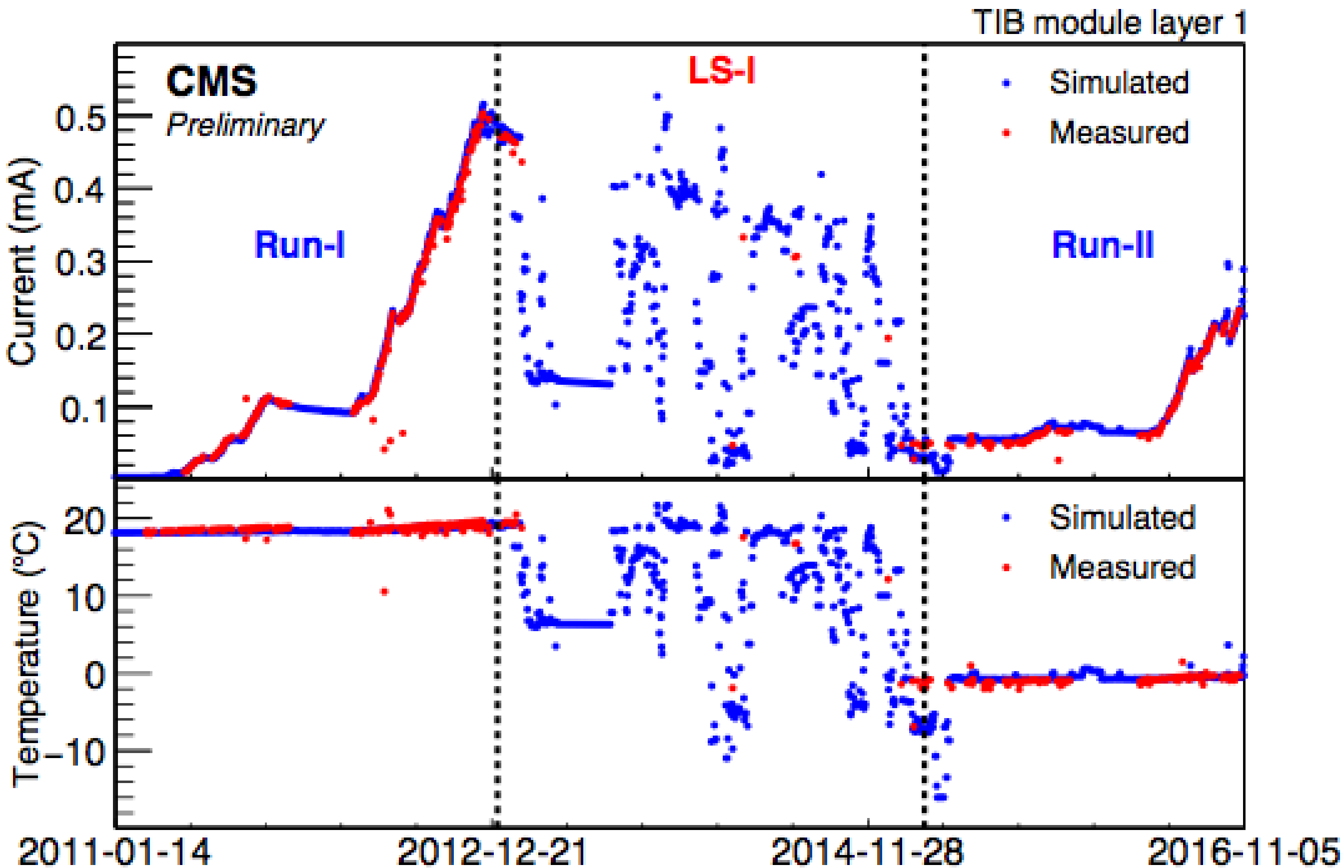
- We observe similar agreements also for the disk regions (perpendicular to the beam).

Simulated and measured leakage current in the end cap region



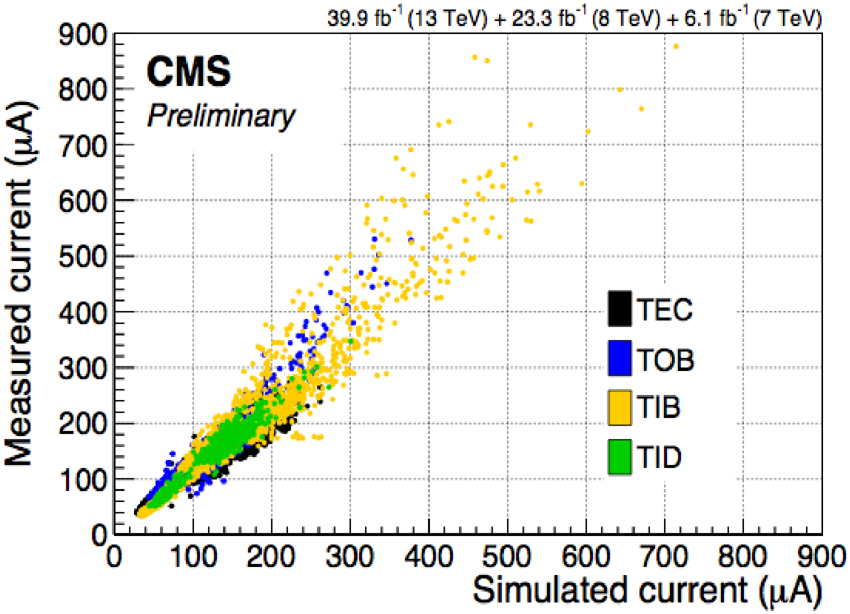
- Expected to be less accurate, since sensors are oriented perpendicular to the beam and extend over very different radii (but simulation only considers one point per module)

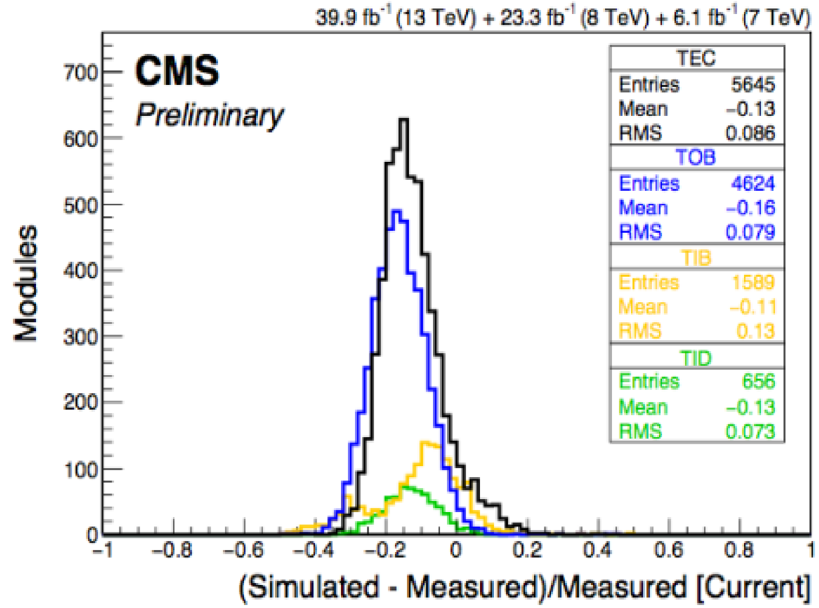
Spotlight on single modules‘ leakage current evolution in time



- Overlay of leakage current simulation with measurement for an example module.
- During LS-1 the temperature was not very stable.

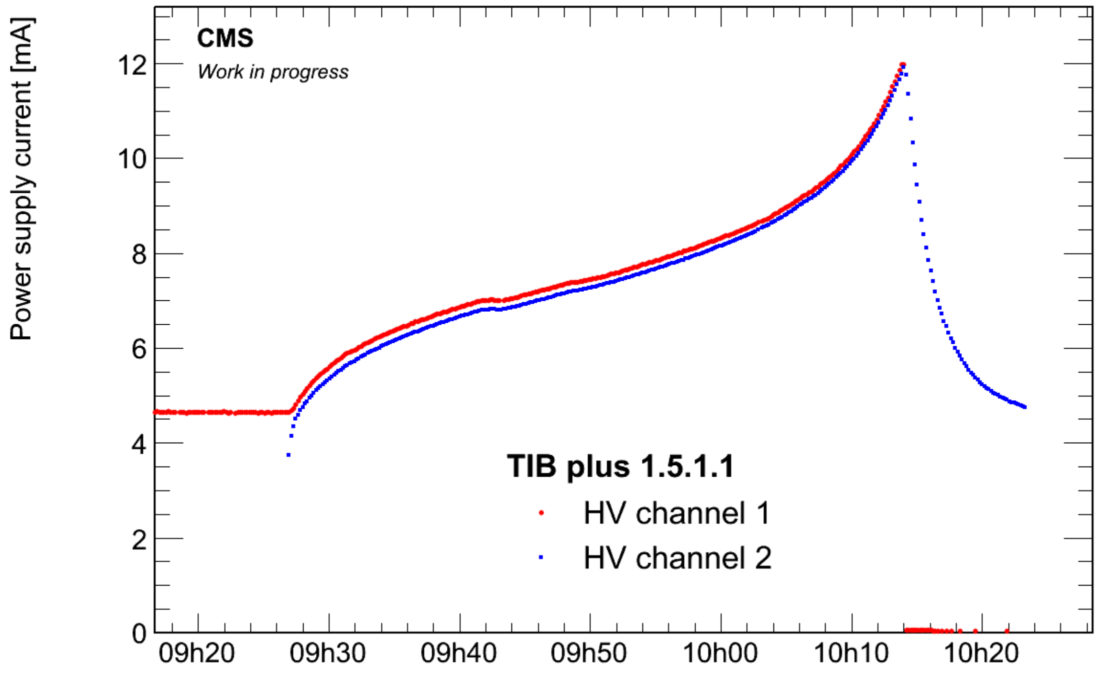
Overall agreement between leakage current simulation and measurement for a given time (@ 39.9 fb^{-1})





- Each dot in the scatter plot to the left corresponds to one module.
- The histograms on the right hand side show more or less normal distributions, except for TIB where we observe two peaks

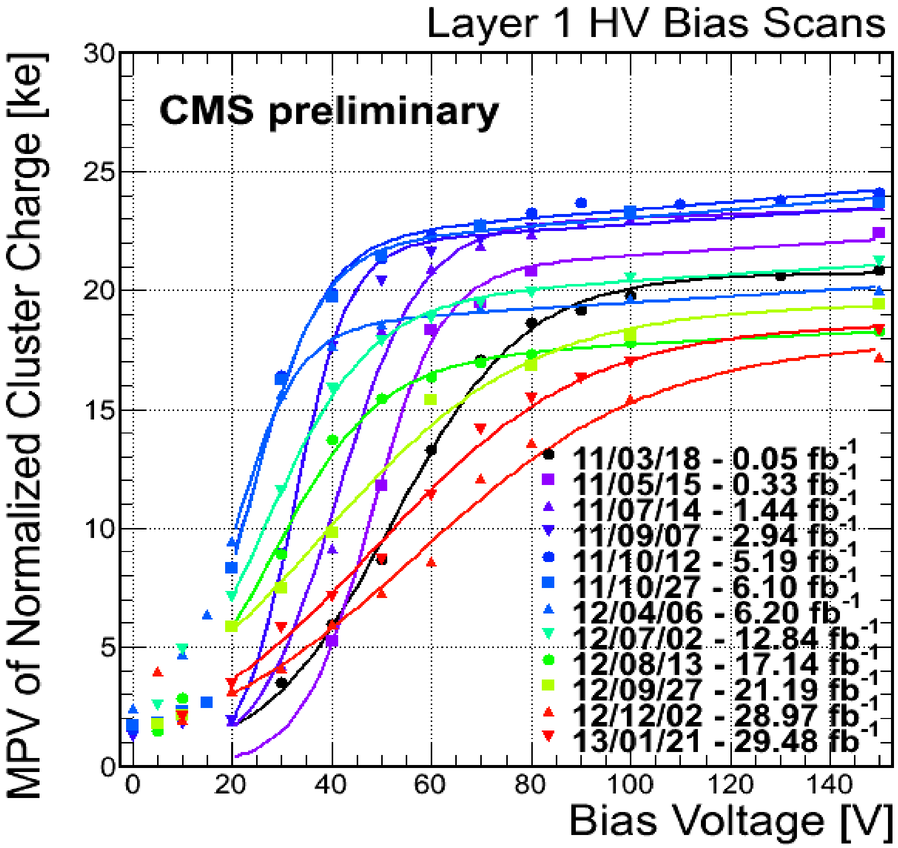
Thermal runaway



- A thermal runaway was observed for one power group (out of 2000) with a known issue of degraded cooling contact leading to high operational temperatures (~30°C).
- The combination of bad cooling contact and high radiation level led to a point where the leakage current induced temperature increase of the sensor could no longer be compensated by the cooling system, leading to a self amplifying leakage current behavior until a trip of the channel occurs.
- In order to operate the channel the bias voltage had to be lowered.
- Operational temperature will be lowered by 5°C in the coming YETS.

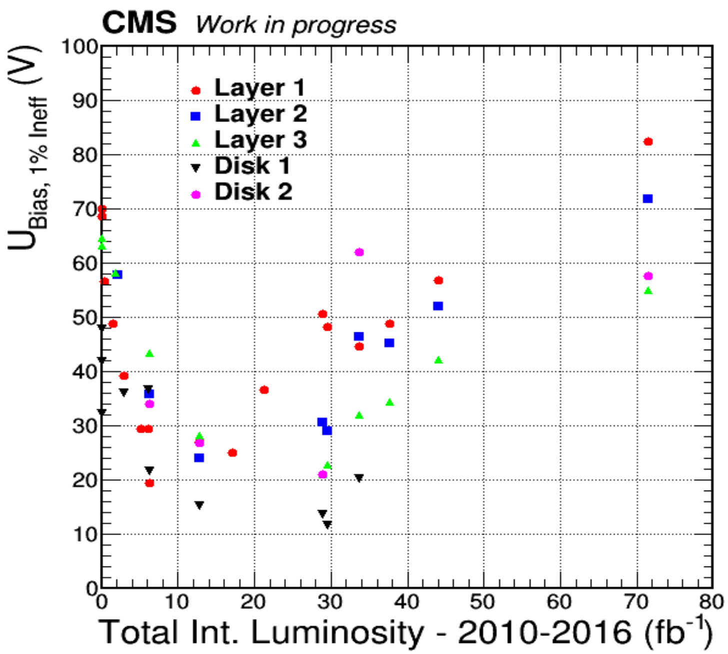
Full depletion voltage

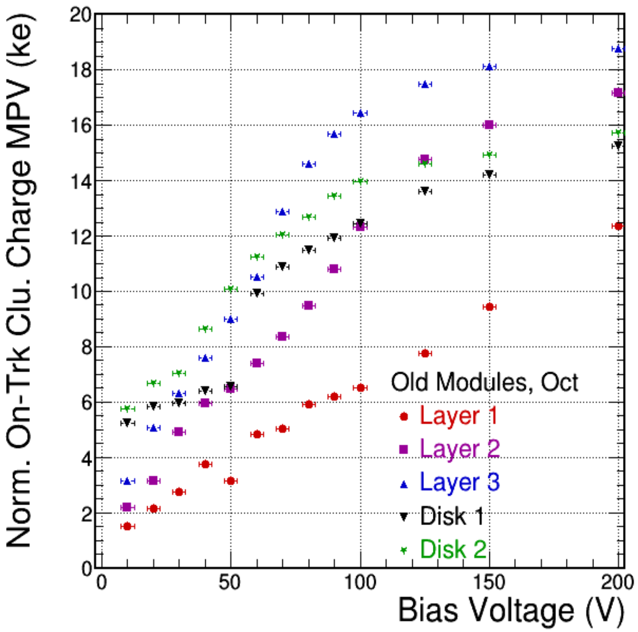
Bias voltage scans pixel



- The MPV cluster charge curves in the course of various irradiation levels are shifted towards lower voltages first, and shifter towards higher voltages afterwards (after inversion) as expected.

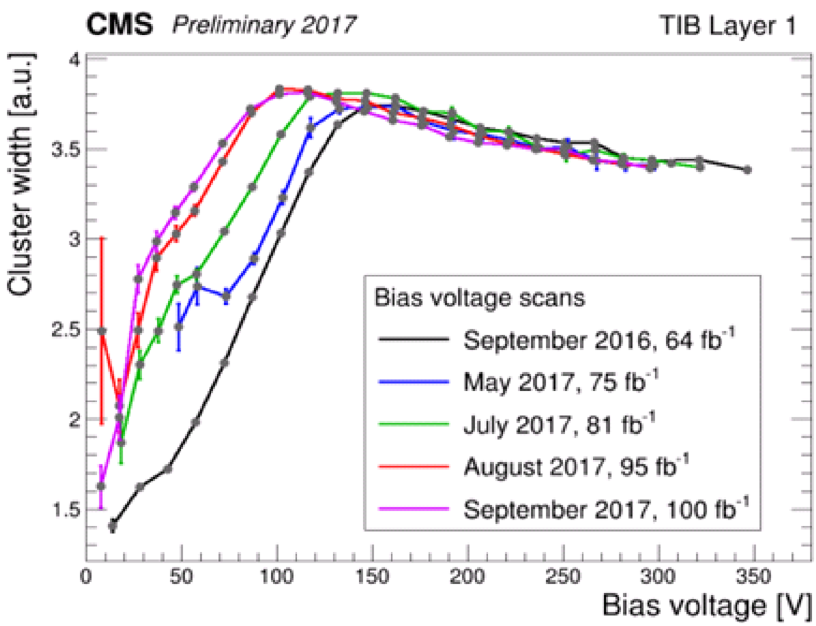
Pixel bias voltage scan evolution

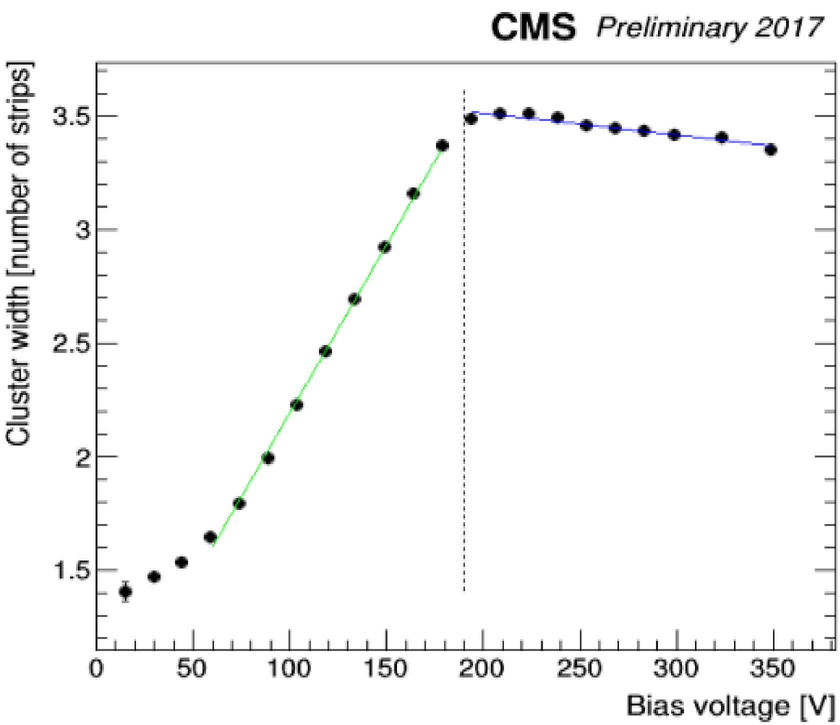




- Lefthand side plot shows evolution of the 99% hit-efficiency point. This is only losely related to full depletion voltage, the n+-in-n (DOFZ, <111>) sensors are tailored to operate also well while being underdepleted.
- We have a rich dataset of bias voltage scans, the righthand side plot shows the cluster charge MPV curves for the last bias voltage scan taken before extraction of the phase 0 detector.

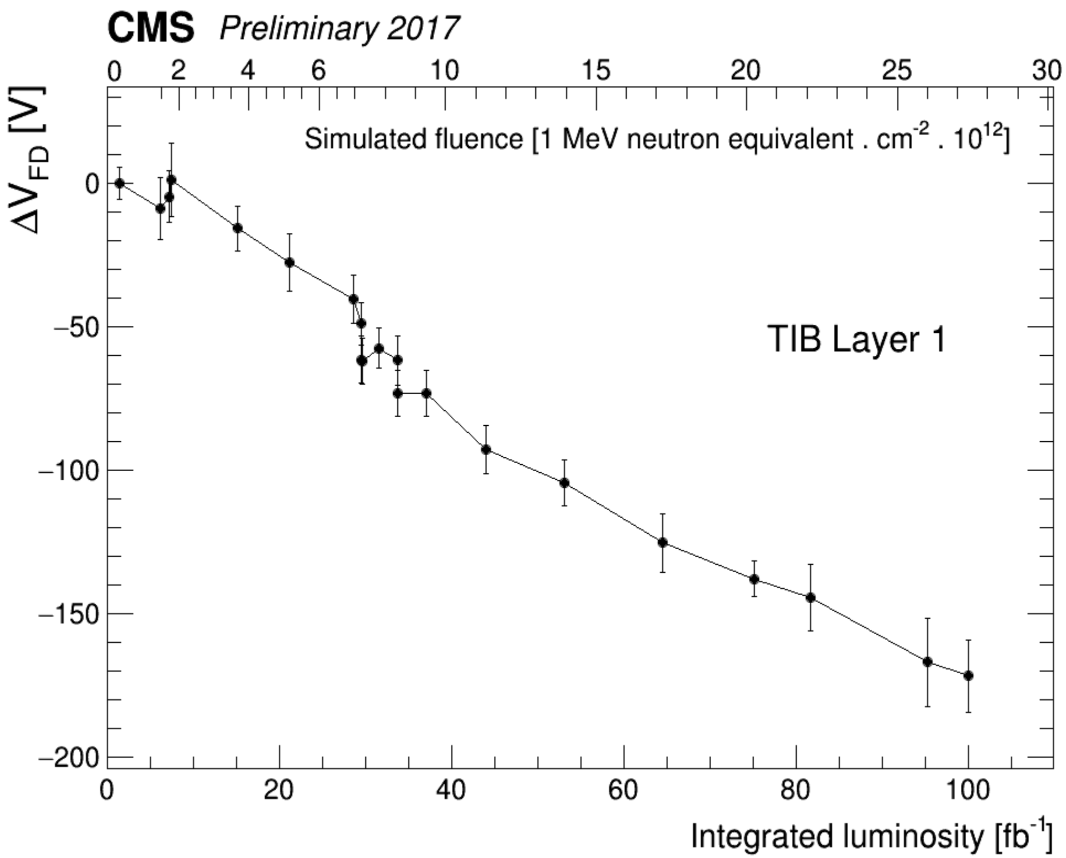
Full depletion voltage extraction for strips





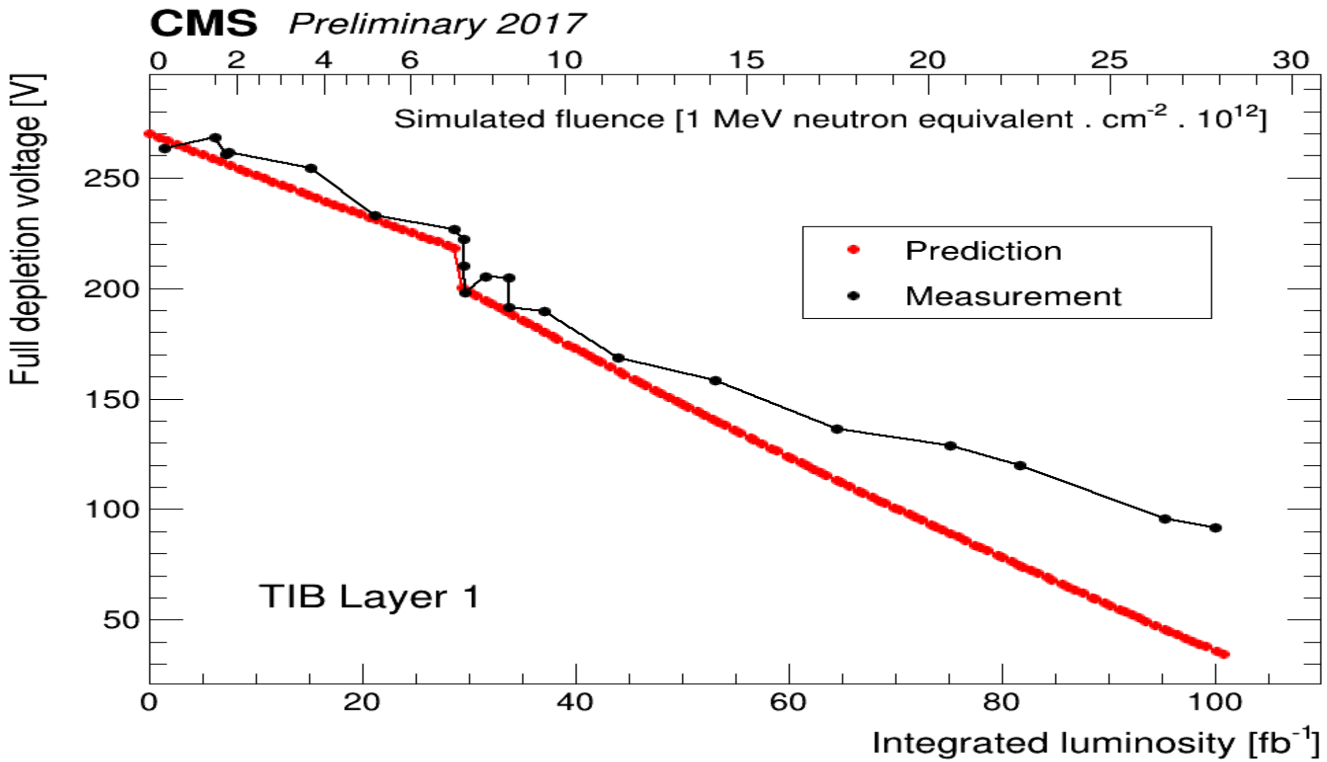
- Various different methods tested (modelling of curves, curveture minimum) to extract Vfd from bias voltage scan observables (cluster charge or cluster width).
- Best results obtained with a fitting method which applies two linear fits. The intersection is considered a good estimate of the full depletion voltage.

Evolution of full depletion voltage strips



- Relative change of full depletion voltage for 9 modules in the inner barrel region obtained by linear fitting method of cluster width vs bias voltage curves. In dependency of the integrated luminosity (lower x-axis) and fluence values (upper x-axis).

Comparing Vfd evolution with expectation



- Comparison of full depletion voltage evolution dervied by measurement and obtained via simulation for one example module (similar method as described in slide 10).
- Best agreement was found with the original parametrisation presented in Michael Moll's thesis, for the p-in-n FZ sensors <100>.

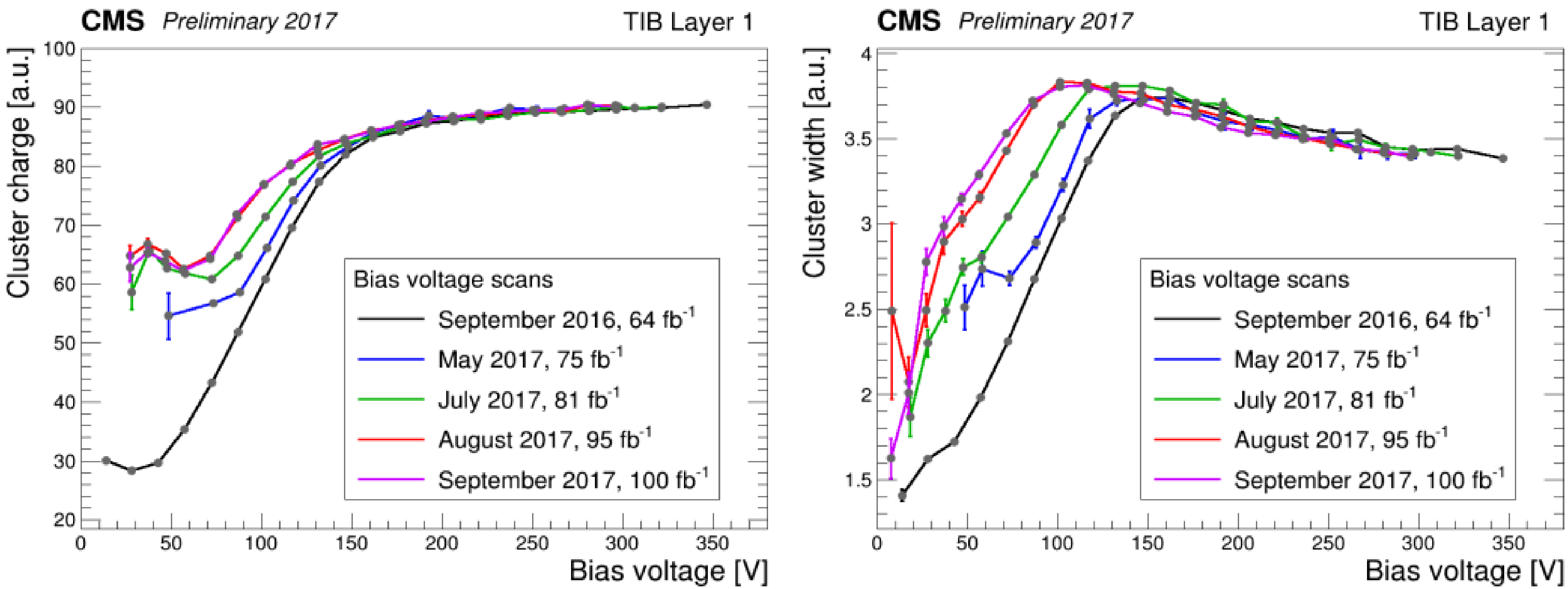
Summary

- We have still a lot to do!
  - Effort started to adopt the simulation and analysis scripts developed for the strip detector for the pixel detector.
  - Looking forward to exciting results from the pixels in the not too distant future (measurements have been recorded systematically).

- Comparisons between observables and simulations for the strip detector show a fair agreement
  - Leakage current simulations are up to about 20% off, in a very consistent manner.
  - Full depletion voltage simulations agree well in the beginning, and start to deviate when approaching inversion point.
    To be seen how this trends develops in the future.

BACKUP

Cluster charge/width as a function of bias voltage for strips



- Since beginning of 2017 a cut on the cluster charge (CCC) is applied in the reconstruction algorithms to reduce out of time pile up. The impact to the cluster charge (and cluster width) curves is clearly visible.

Leakage current simulation and measurement in the out barrel region