



Radiation Damage Effects to the CMS Silicon Tracker

Seth Zenz (Princeton) and Christian Barth (KIT)
On behalf of the CMS Tracker Collaboration

21st RD50 Workshop
Session on Radiation Damage in LHC detectors
November 14, 2012



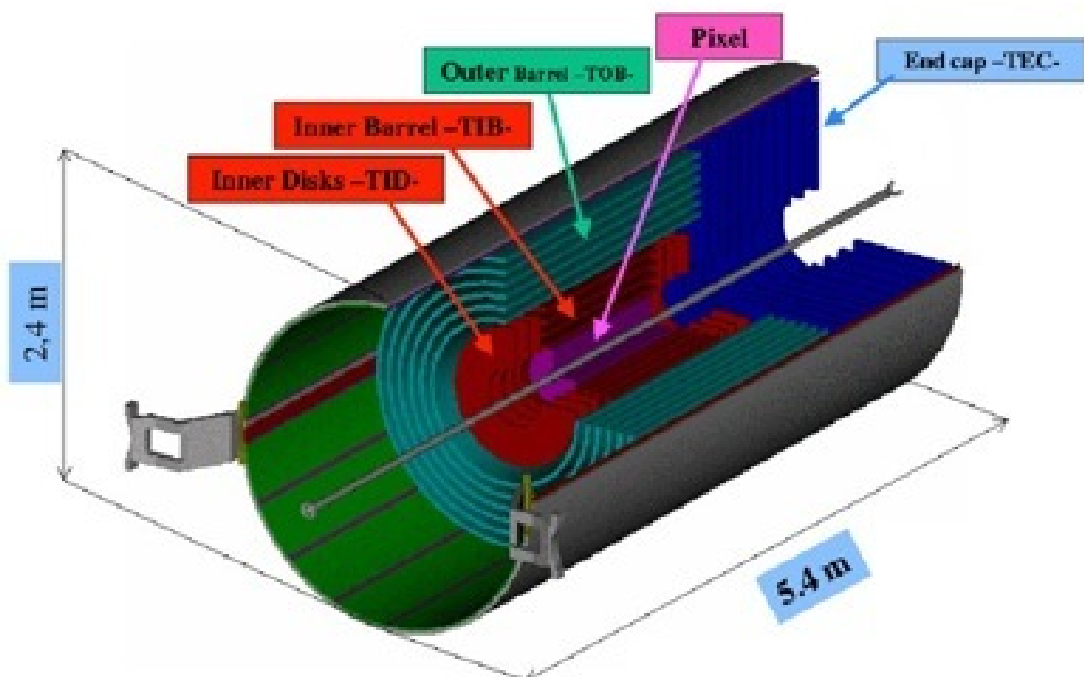
Overview



- The CMS Tracker
- Leakage Current
 - Measurements for pixels and strips
 - Model agreement
 - Work-in-progress
- Depletion Voltage
 - Pixels: Hit efficiency scan results
 - Strips: Signal scan results
 - Planned improvements and ongoing checks
- Conclusions

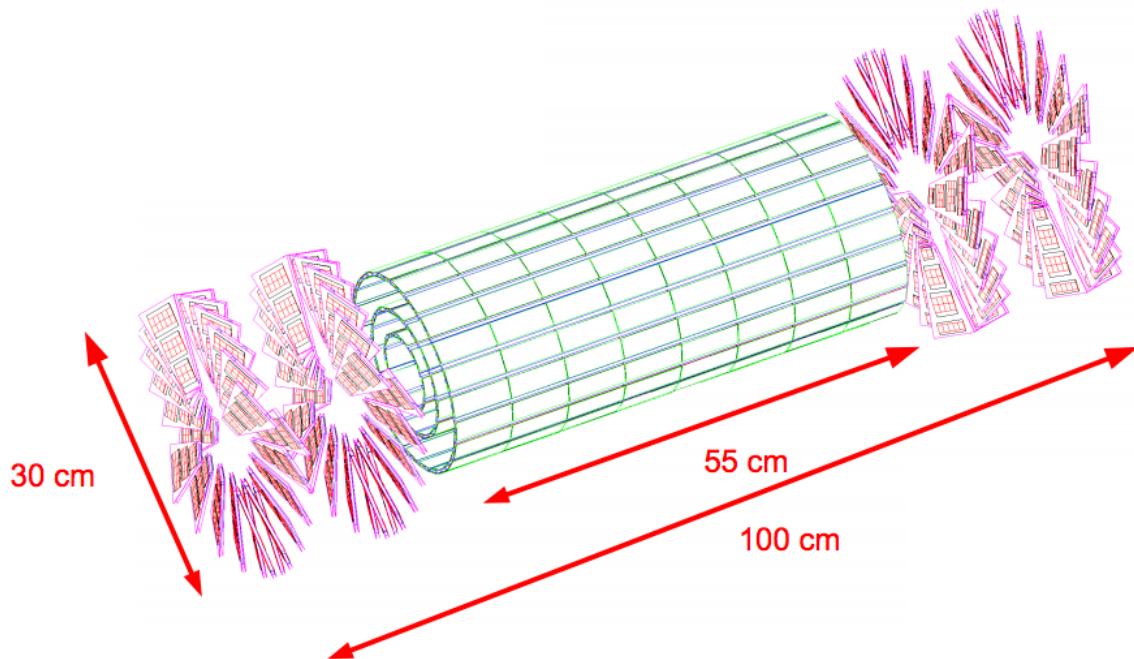
Strips

- 200 m² active silicon sensor area (p-in-n)
- ~6000 sensors with 300 μm thickness
- ~20000 sensors with 500 μm thickness
- Bias voltage: 300V



Pixels

- 1.06 m² (n-in-n, oxygenated)
- 66M pixels, 285 μm thick
- Bias Voltage
 - Barrel: 150V
 - Endcap: 300V



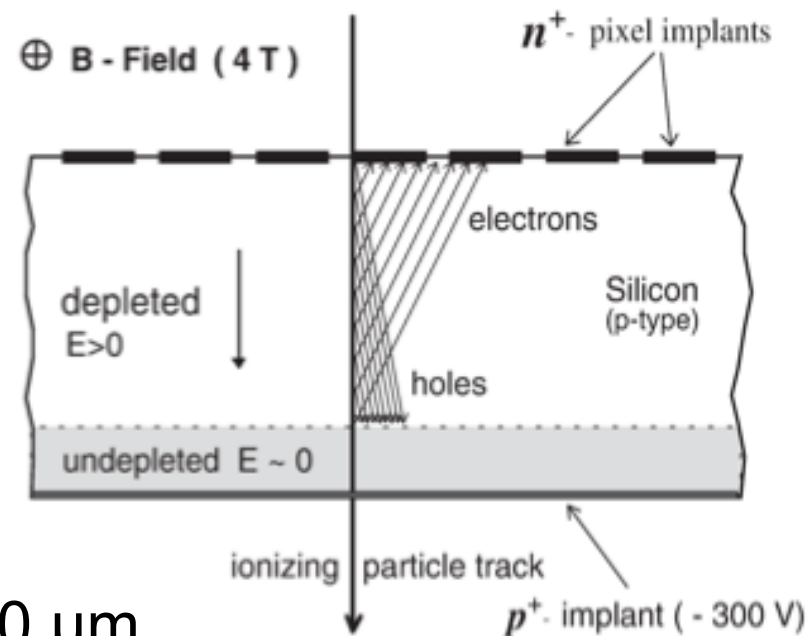
BPIX (barrel)

- 3 layers
 - $r = 4.3, 7.2, 10.8$ cm
- 48M pixels, 0.78 m^2

FPIX (forward)

- 2 disks / endcap
 - $z = 34.5, 46.5$ cm
 - $6 \text{ cm} < r < 15 \text{ cm}$
- 18M pixels, 0.28 m^2

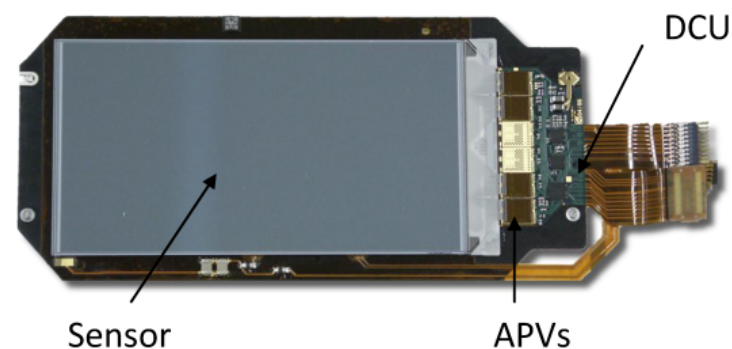
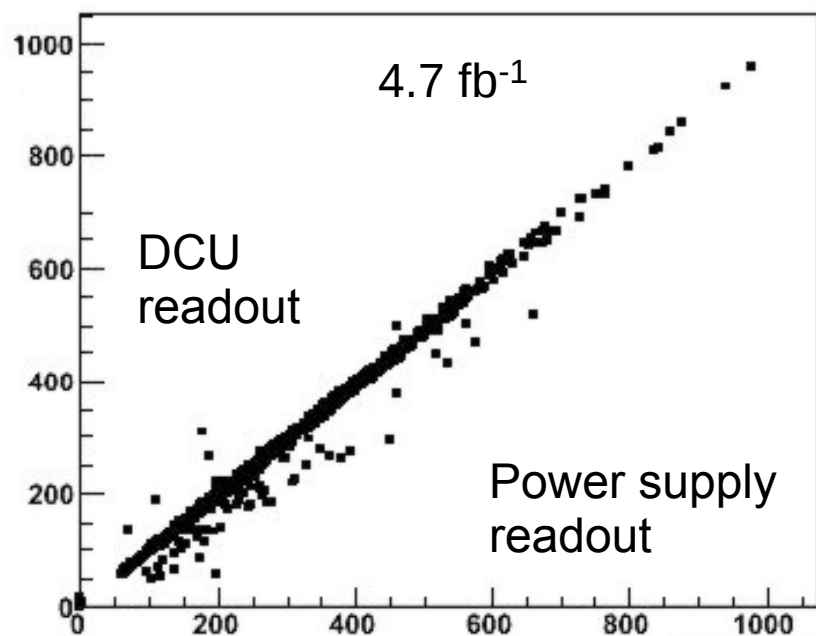
Each pixel $100 \mu\text{m} \times 150 \mu\text{m}$





Leakage Current Measurements

- Pixels: power supply only
 - Smallest unit of HV measurement: 1 Ladder = 4 Modules = 4x16 Read-Out Chips (ROCs) → 0.81 cm x 0.81 cm
 - Full length of pixel barrel along z
- Strips: Detector Control Unit (DCU)



The detector control unit is an ASIC sitting on each of the tracker modules, with the ability to measure the temperature at different positions of the module as well as the leakage current and LV voltages applied.

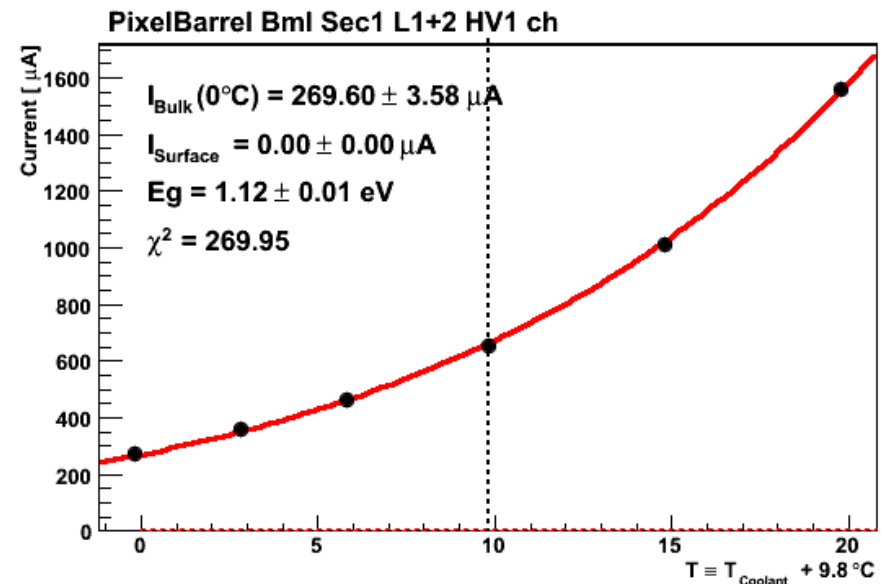
- Following the guidelines of the *Inter-Experiment Working Group on Radiation Damage in Silicon Detectors* . . .

- Current is corrected to 0 °C

- $E_g = 1.21 \text{ eV}$

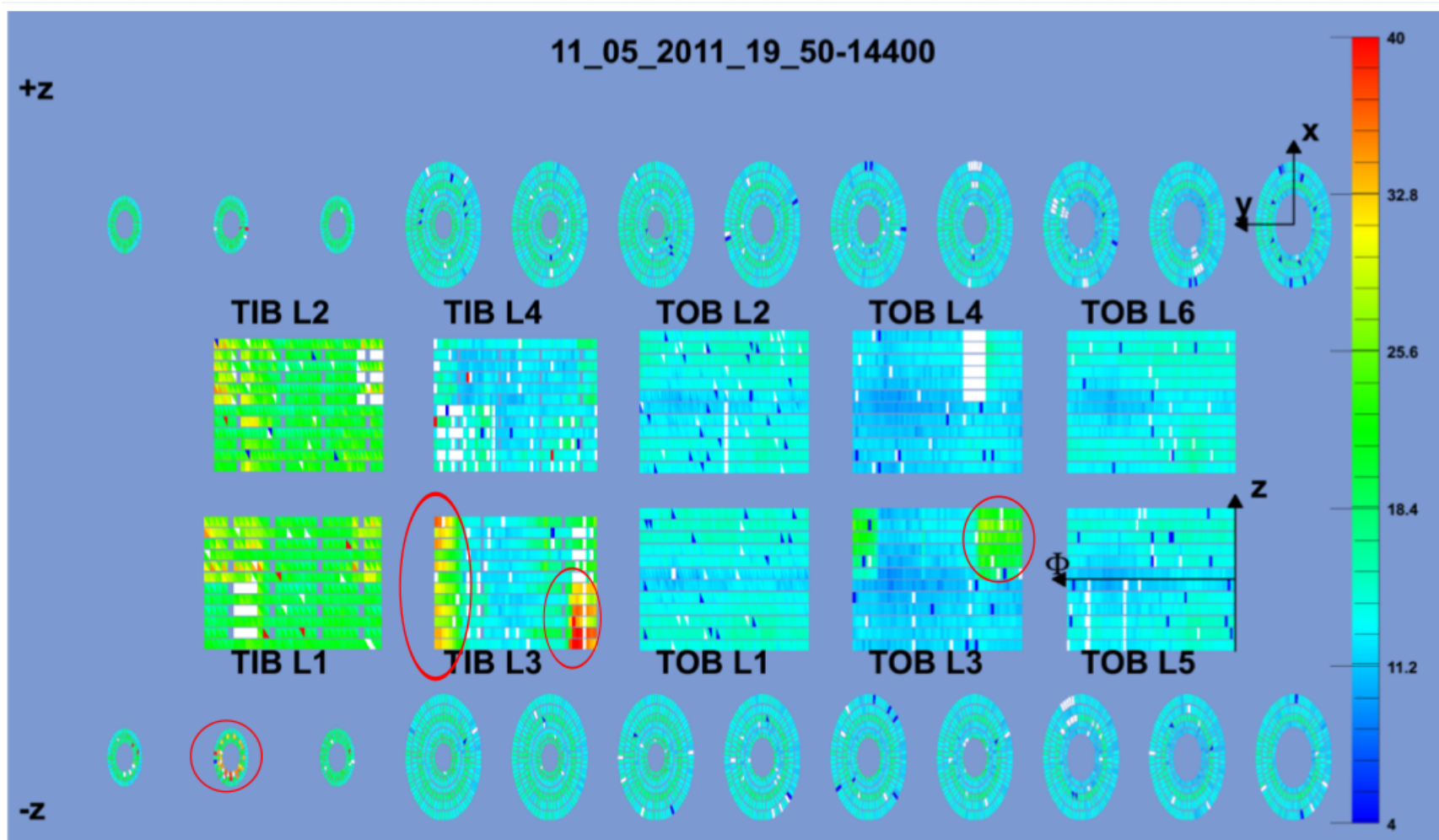
$$I(T_{ref}) = I(T) \left(\frac{T_{ref}}{T} \right)^2 \exp \left(-\frac{E_g}{2k_B} \left[\frac{1}{T_{ref}} - \frac{1}{T} \right] \right)$$

- Current is measured in $\mu\text{A}/\text{cm}^3$, normalized to the volume of active silicon

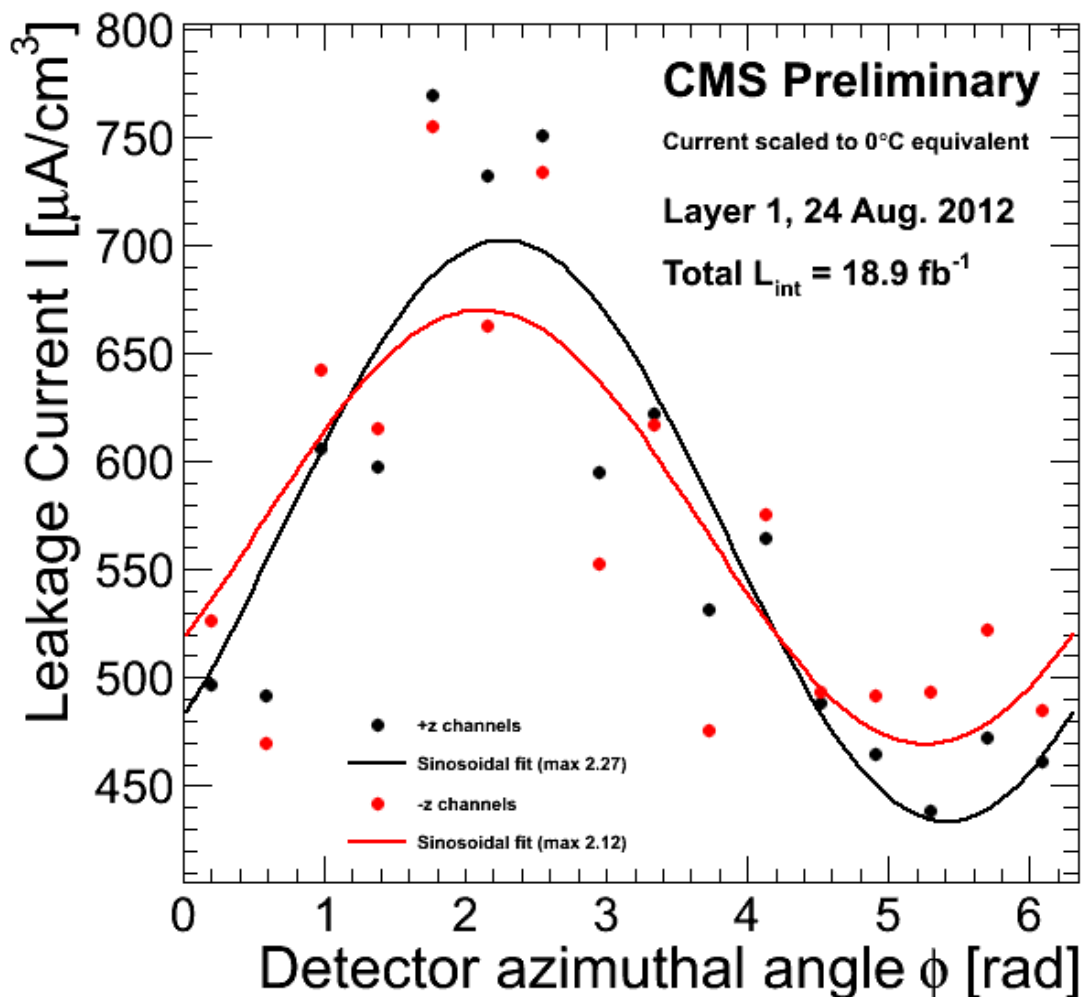


Temperatures

- Pixels: 17 °C (?) in 2011, 10 °C in 2012
- Strips: temperature varies, **some regions have no direct cooling**



Pixels: Azimuthal Dependence



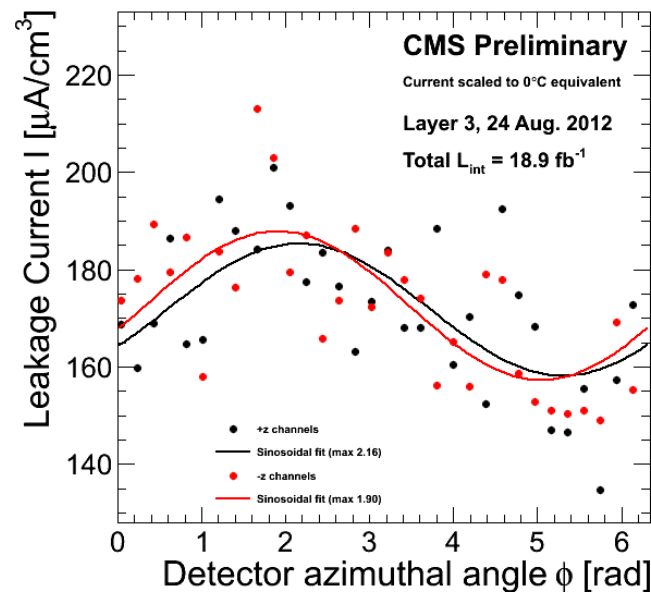
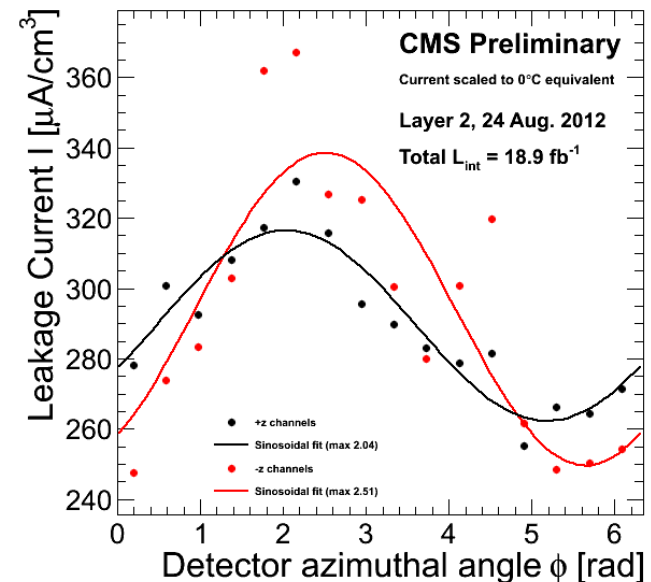
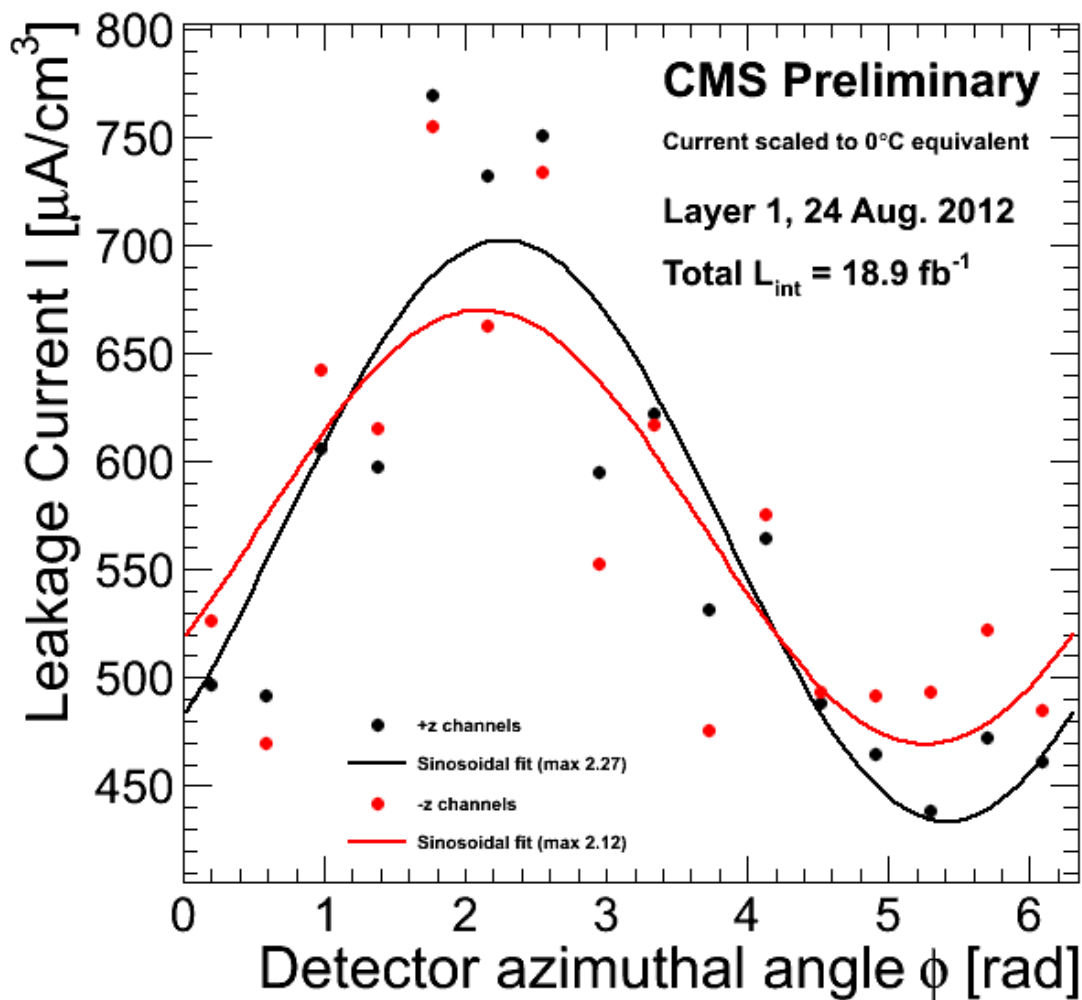
- LHC Beam Spot is not at center of Pixel Detector!
- W.r.t pixel, LHC beam spot $(x,y) = (-2.4\text{mm}, 3.9\text{mm}) \rightarrow \phi \sim 2.12$
- 30% effect on potential Layer 1 lifetime!
- Geometric issues also impact data rates \rightarrow where readout issues emerge

Can also see impact of staggered geometry



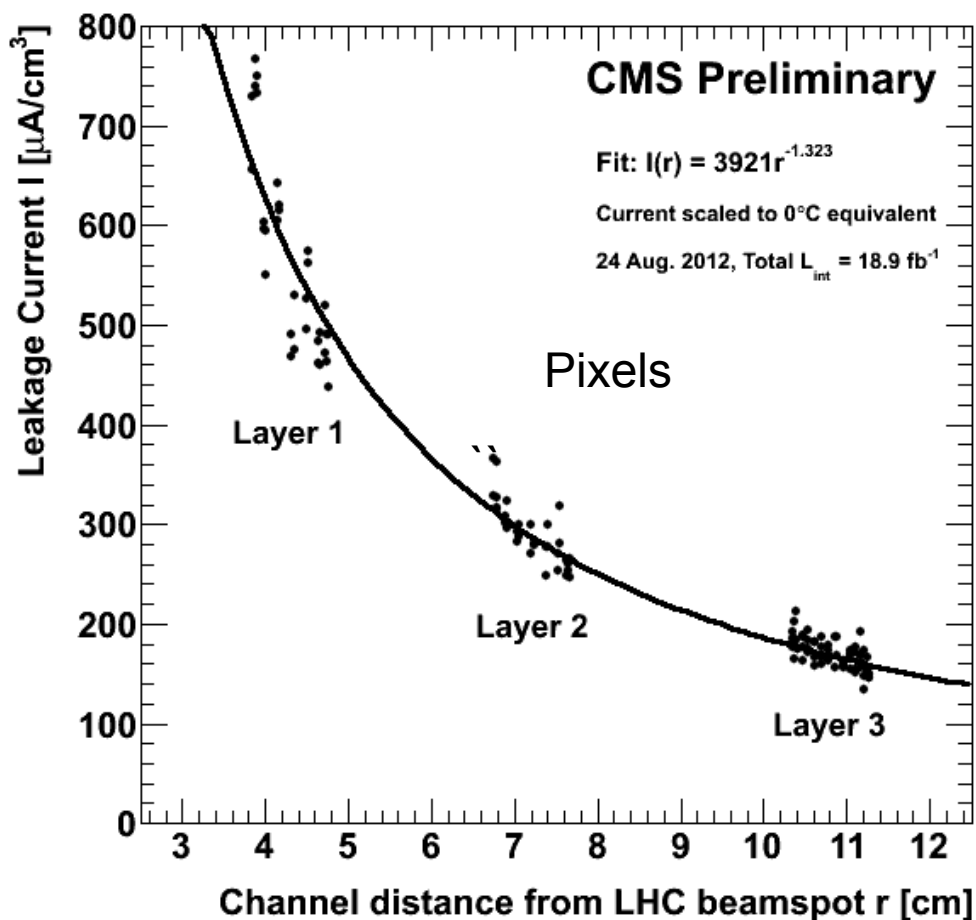


Pixels: Azimuthal Dependence

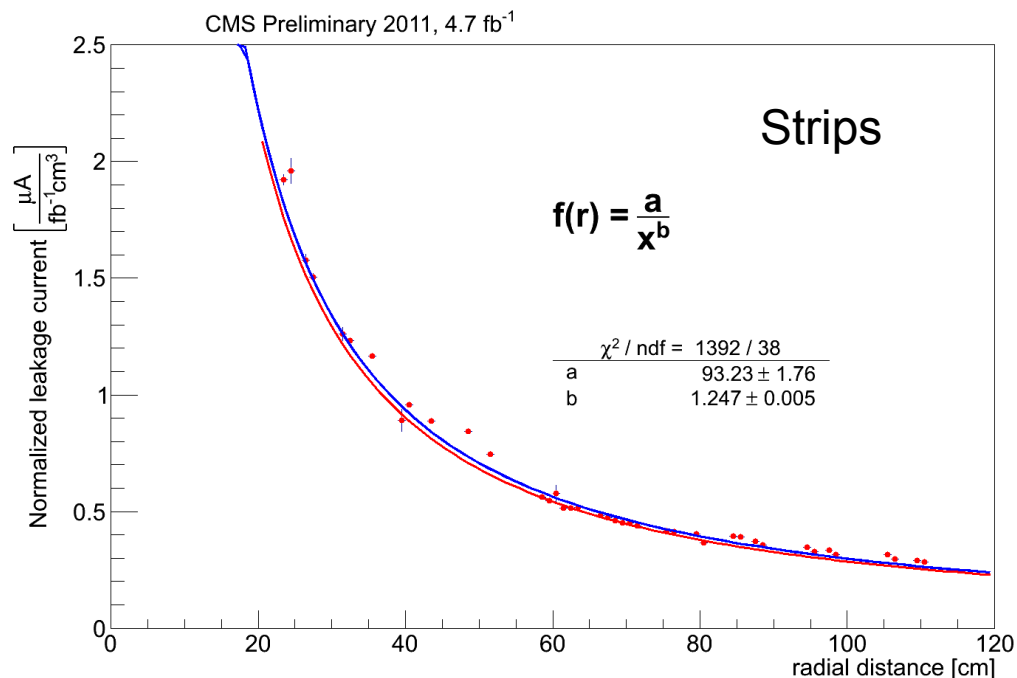


Current vs. Radius

- Pixels: beam spot offset gives us measurements in many radii
- Independent leakage current fits give good agreement in radial dependence

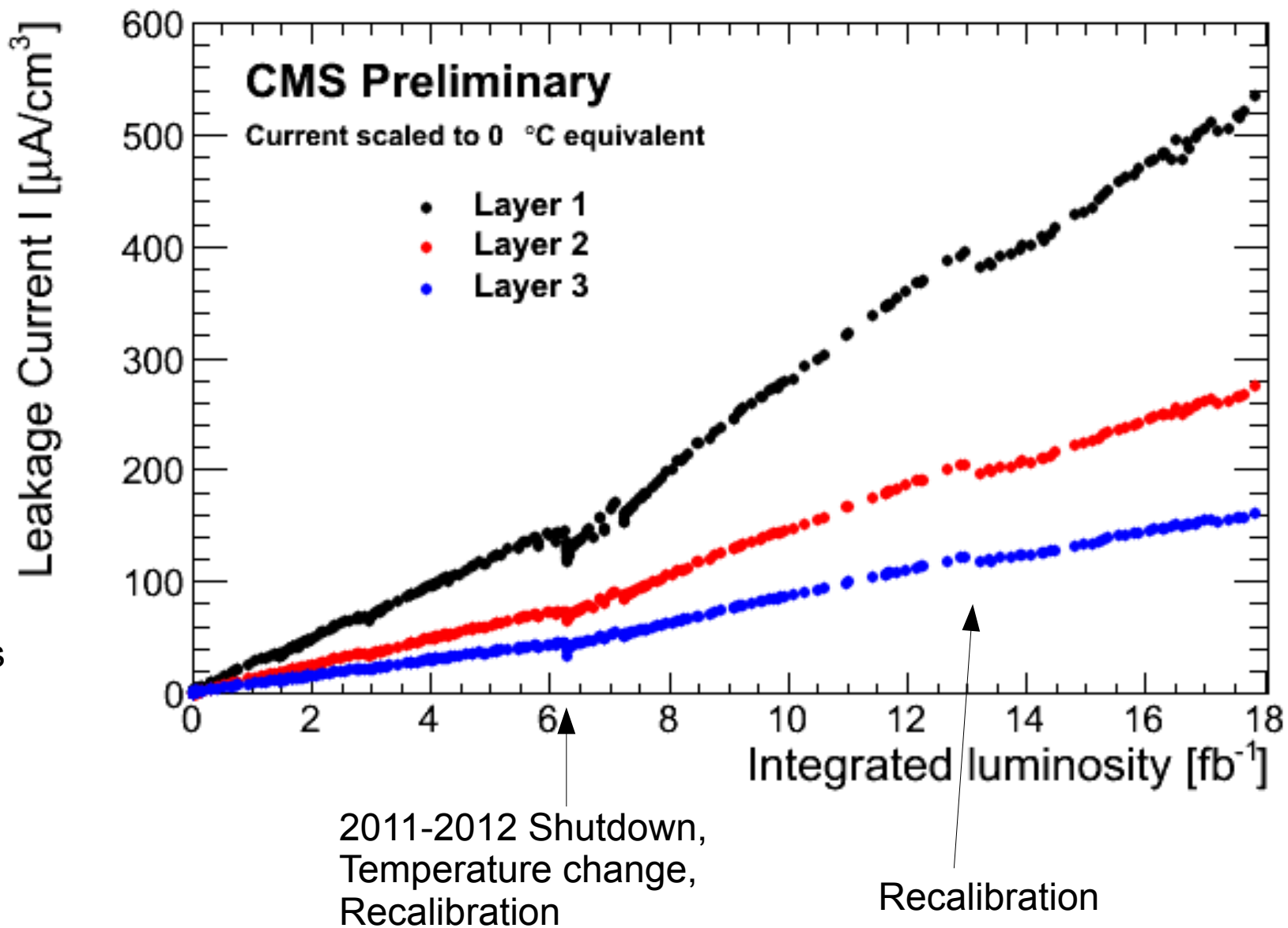


- Pixels: $r^{-1.32}$
- Strips: $r^{-1.25}$



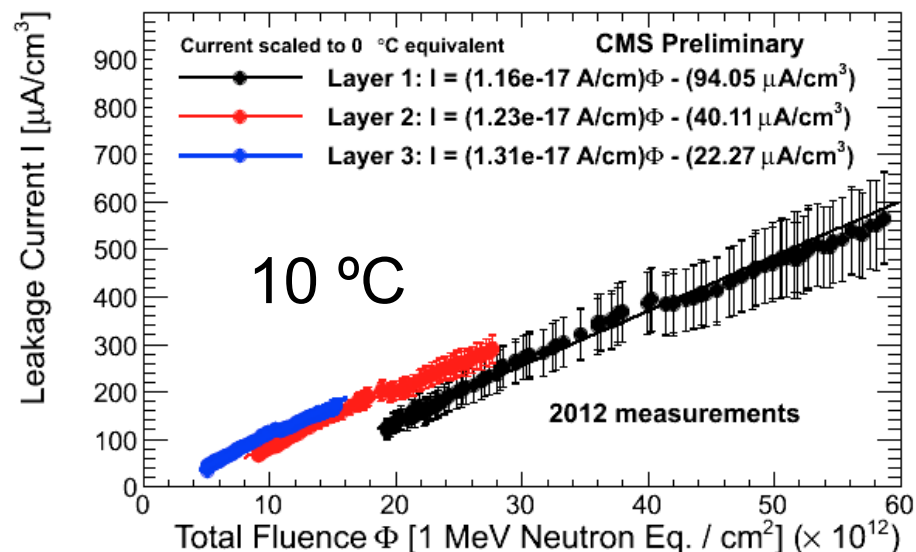
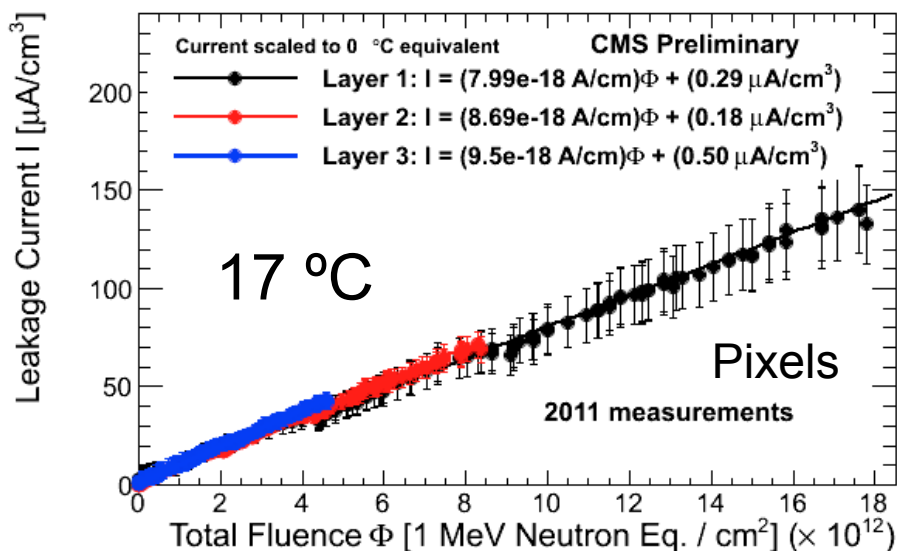
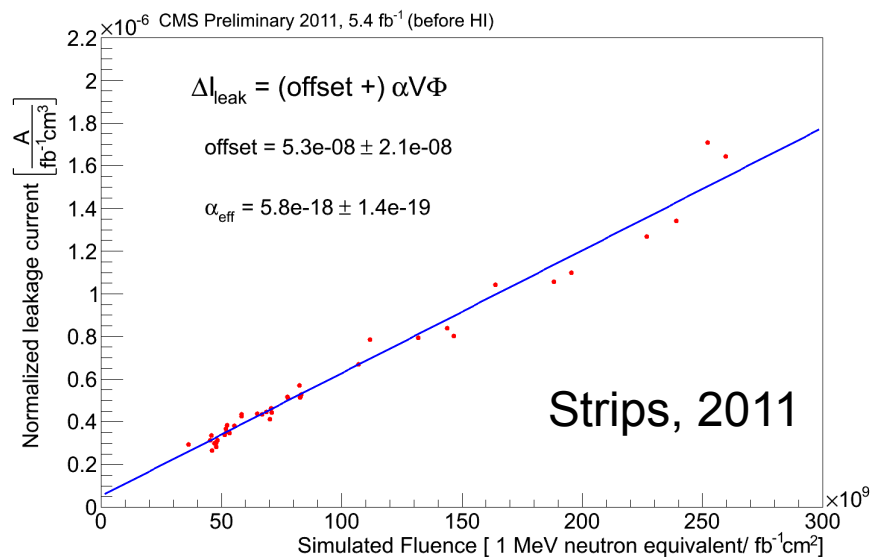


Pixels: Current vs. Time

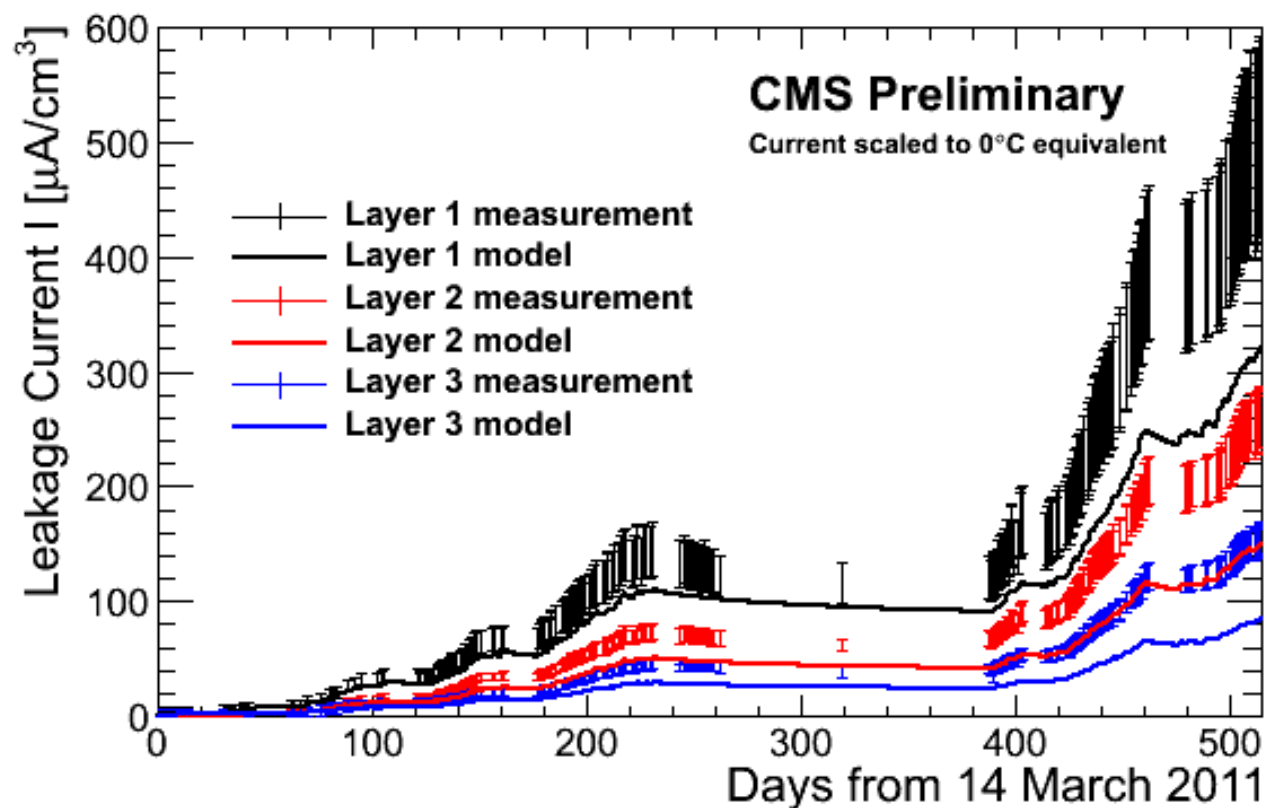


Current vs. Fluence

- $I_{\text{leak}} / \text{Vol.} = \alpha \Phi$
- Literature: $\alpha(21^\circ\text{C}) \sim 4\text{e-}17 \text{ A/cm}$
 $\rightarrow \alpha(0^\circ\text{C}) \sim 6\text{e-}18 \text{ A/cm}$
- 2011 Measurements:
 - Pixels: $\sim 9\text{e-}18 \text{ A/cm}$
 - Strips: $\sim 6\text{e-}18 \text{ A/cm}$

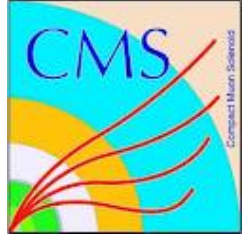


- Using day-by-day annealing parameterization and temperature information over 2011-2012...
... we see the same tension as in the simple fit of α

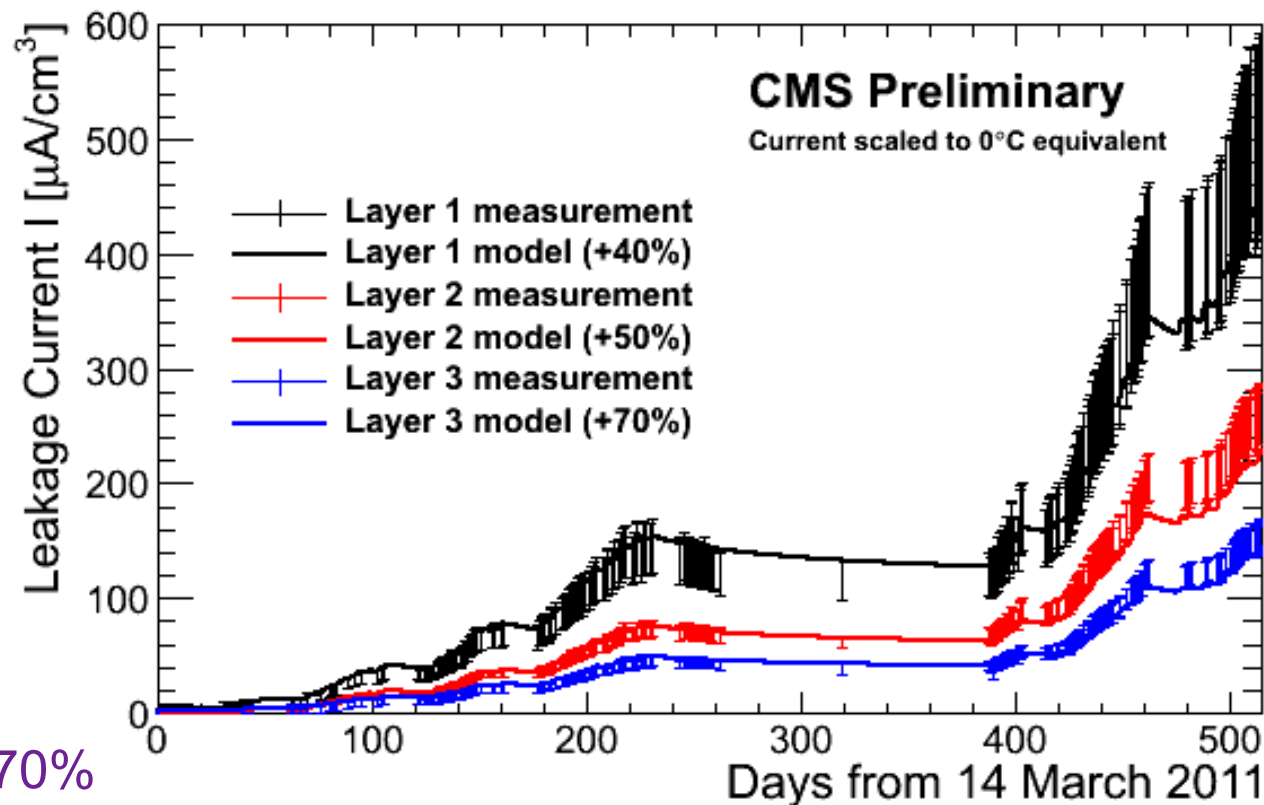




Pixels: Current vs. Time (2)



- Using day-by-day annealing parameterization and temperature information over 2011-2012...
... we see the same tension as in the simple fit of α



Good agreement when predictions scaled up by 40-70%



Pixels: Model Work-in-Progress



- Temperature measurement updates
 - Revision of 2011 pixel temp: $\sim 17\text{ }^{\circ}\text{C} \rightarrow \sim 20\text{ }^{\circ}\text{C}$
 - Impact on both data temperature extrapolation and modeled current evolution: **removes most of the need for scaling 2011 leakage current data**
 - **Unrevised for 2012 ($\sim 10\text{ }^{\circ}\text{C}$): disagreement persists**
 - To-do: assign and propagate reasonable temperature uncertainties
- Temperature variation within fills
 - Leakage current measurements from start-of-fill are used to ensure consistent configuration conditions
 - Start-of-fill temperature is several degrees higher in Layer 1, due to increased digital current
 - To-do: account for this in temperature extrapolation
 - Smaller impact on L2, L3



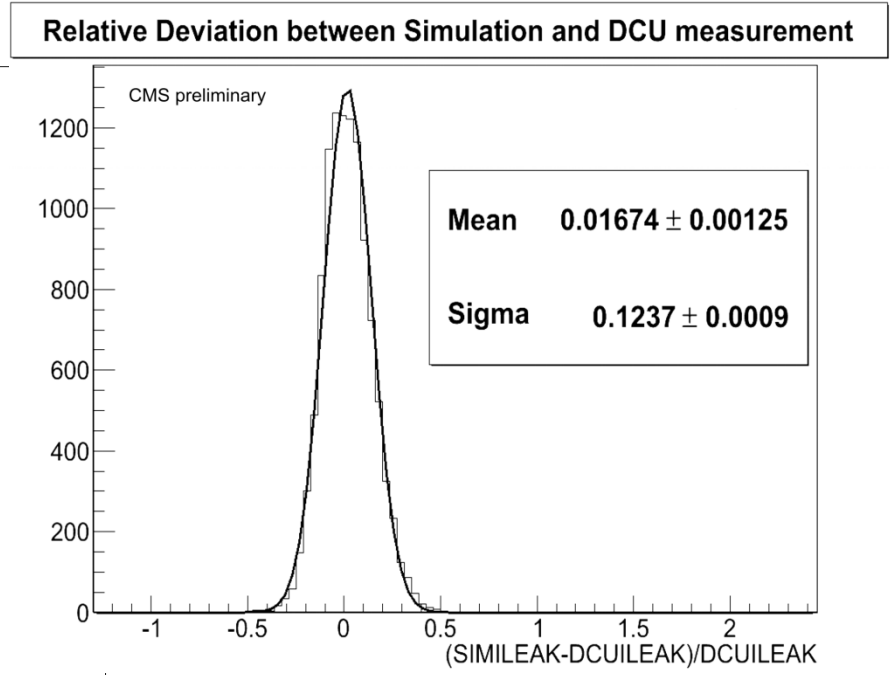
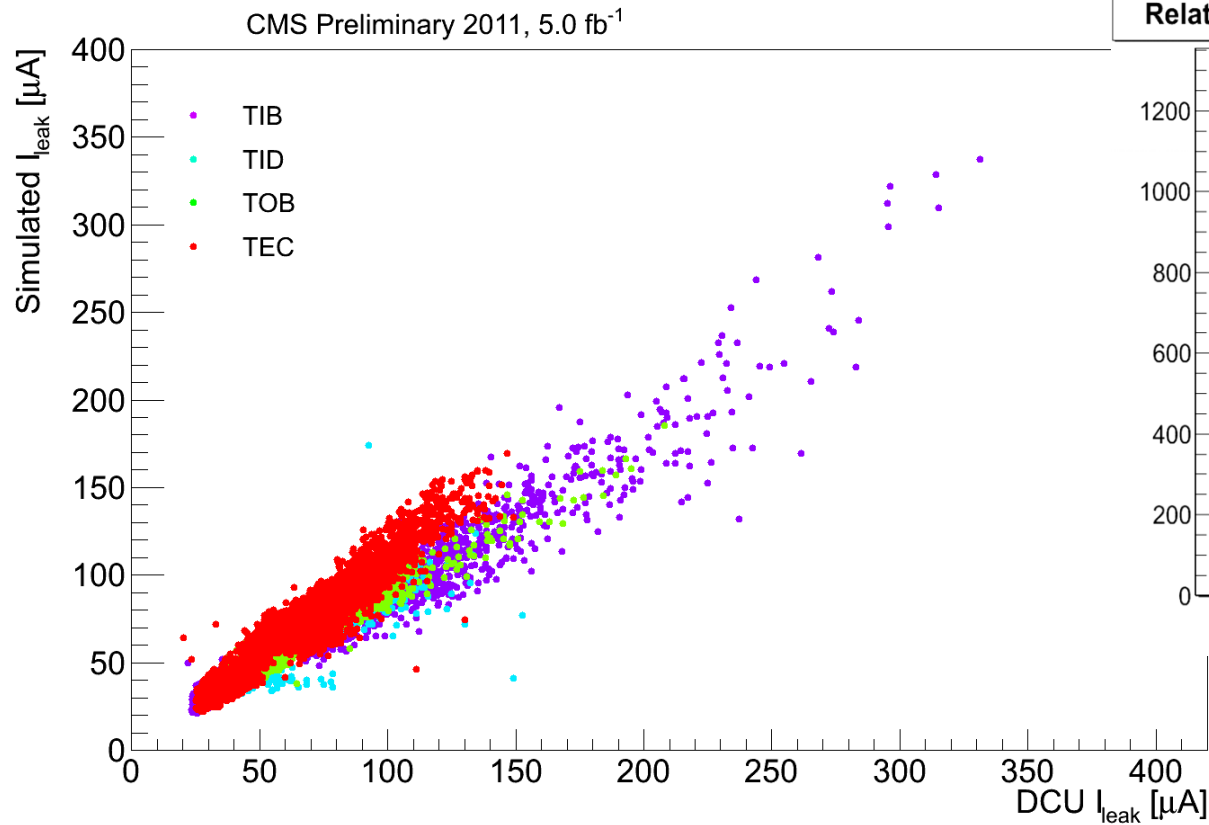
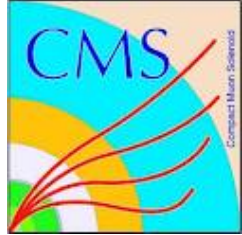
Pixels: Fluence Work-in-Progress



- Fluence inconsistencies being investigated
 - Normalization disagrees with ATLAS by $\sim 20\%$
 - Radial dependence ($\sim r^{-1.5}$) disagrees with that of charged particle count and leakage current ($\sim r^{-1.3}$)
- Solutions investigated
 - ~~FLUKA~~ grid size
 - Recent update: radial grid size 2.5 cm \rightarrow 1 mm
 - No significant change in power law fit
 - ATLAS/CMS magnetic field difference:
 - ATLAS B field studies: 2T \rightarrow 4T gives $\sim 10\%$ effect at $r = 4.3$ cm, increasing with radius (I. Dawson)
 - ~~Treatment of kaons~~
 - Same as pions, consistent with ATLAS
 - MC generator input: to be investigated



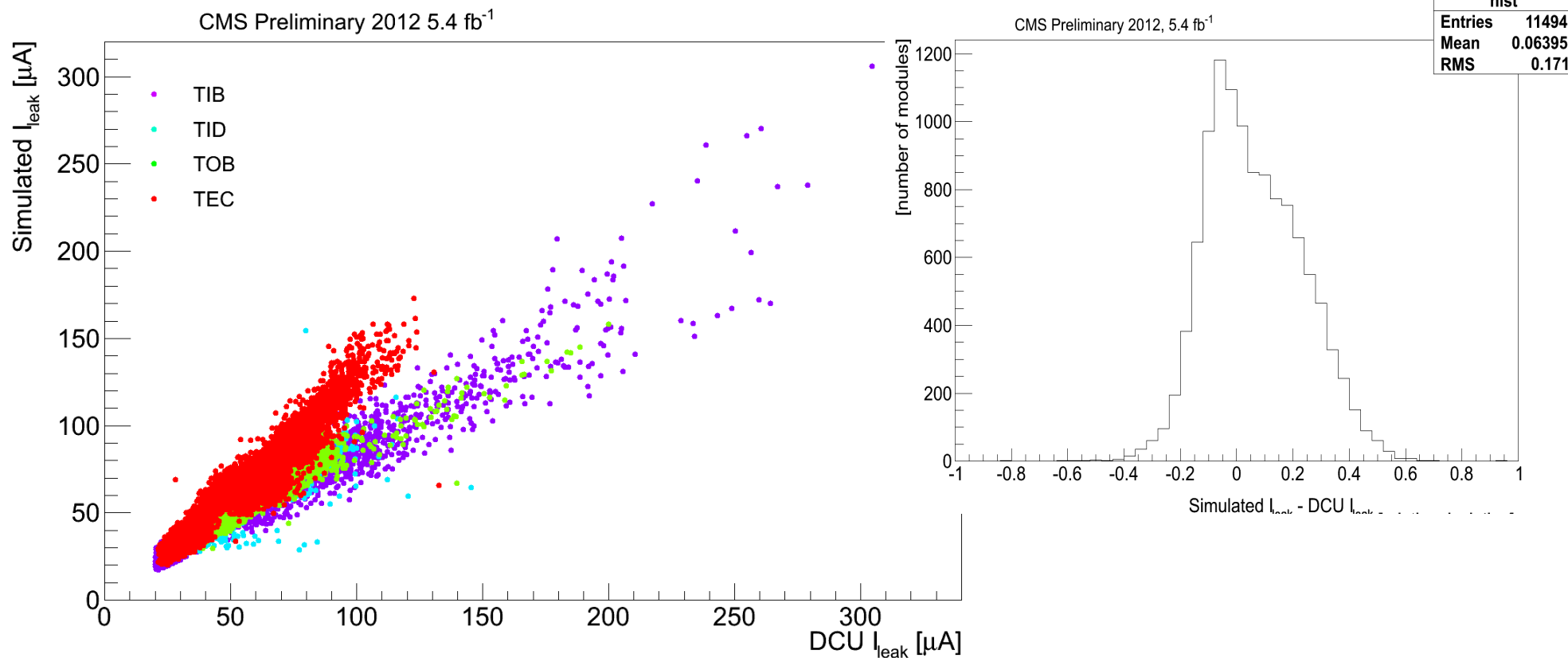
Strips: Model Agreement (5.0 fb⁻¹)



- Average strips measurements agree with model within 5-20%, varying over time and detector region



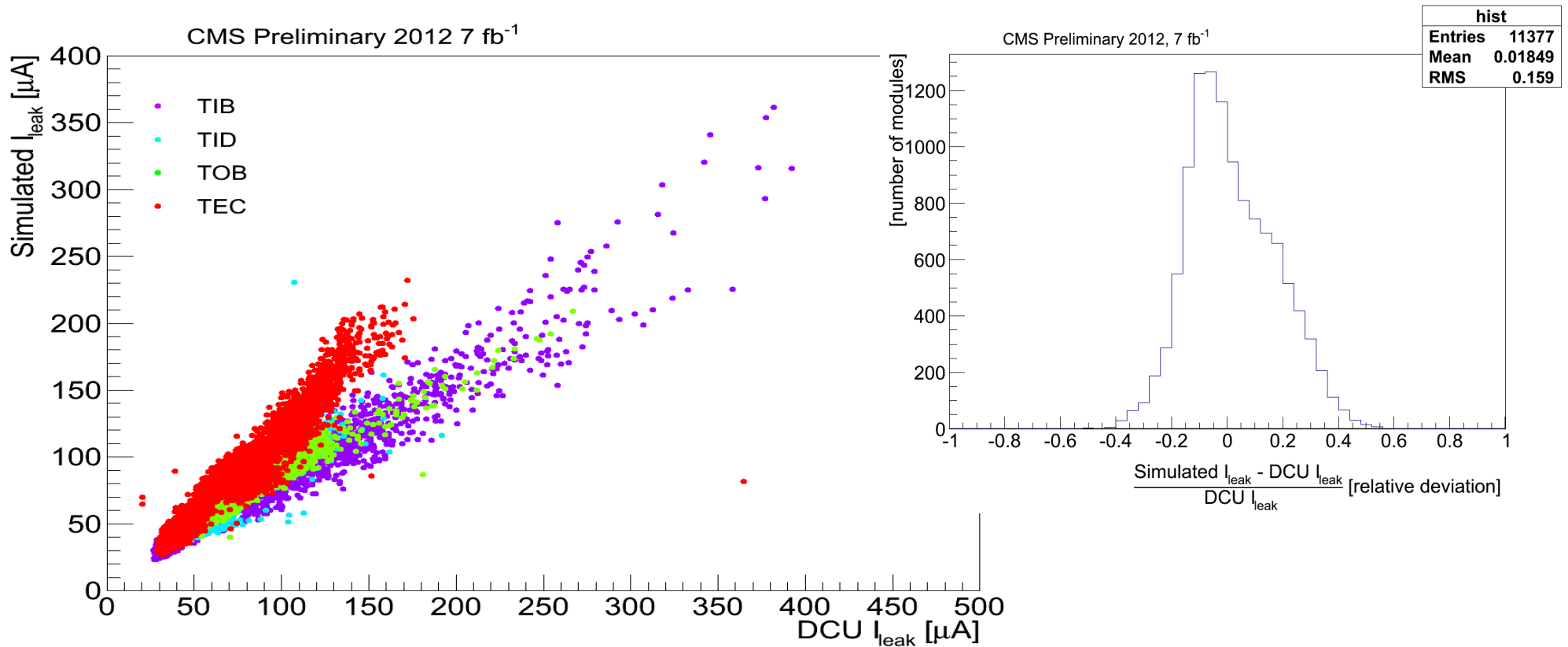
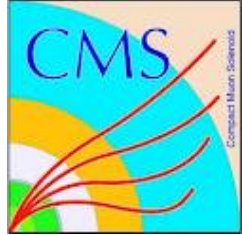
Strips: Model Agreement (5.4 fb⁻¹)



- Average strips measurements agree with model within 5-20%, varying over time and detector region



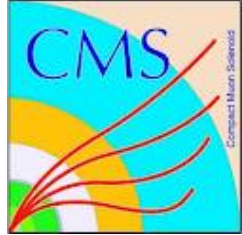
Strips: Model Agreement (7.0 fb⁻¹)



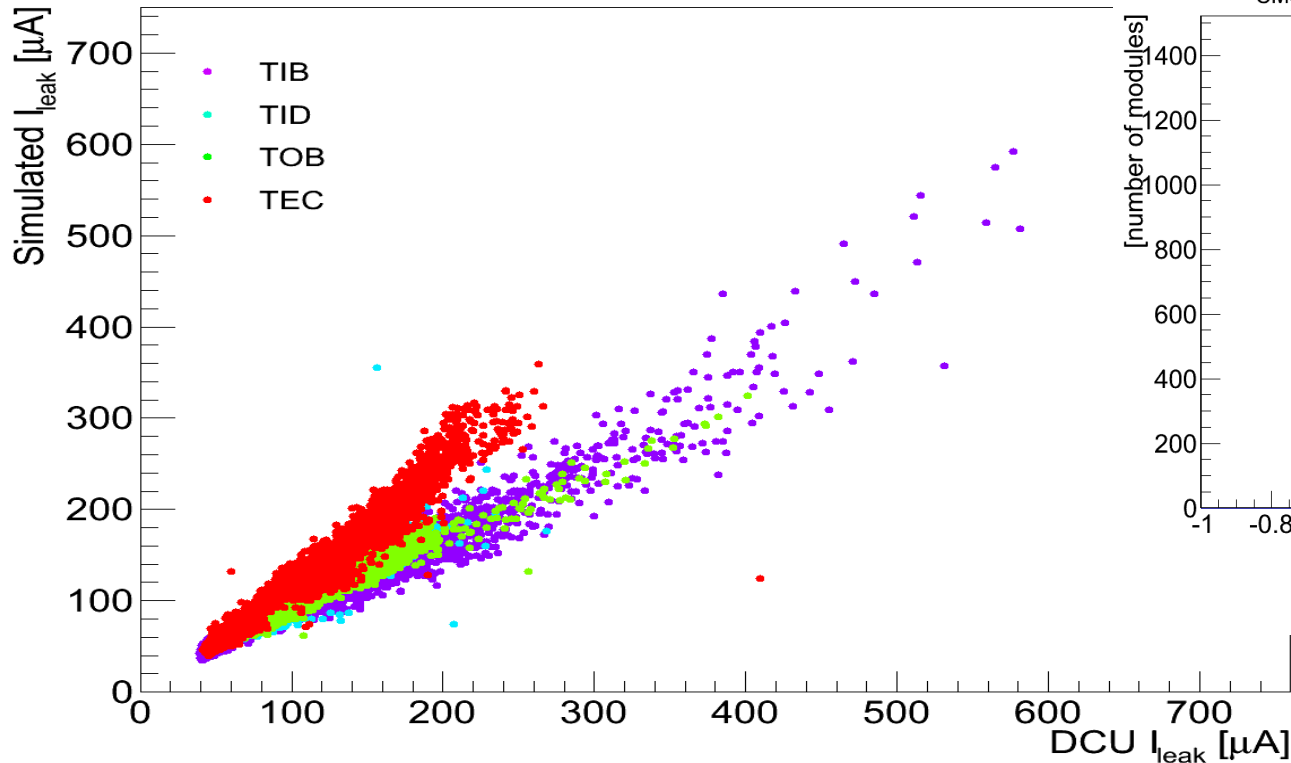
- Average strips measurements agree with model within 5-20%, varying over time and detector region



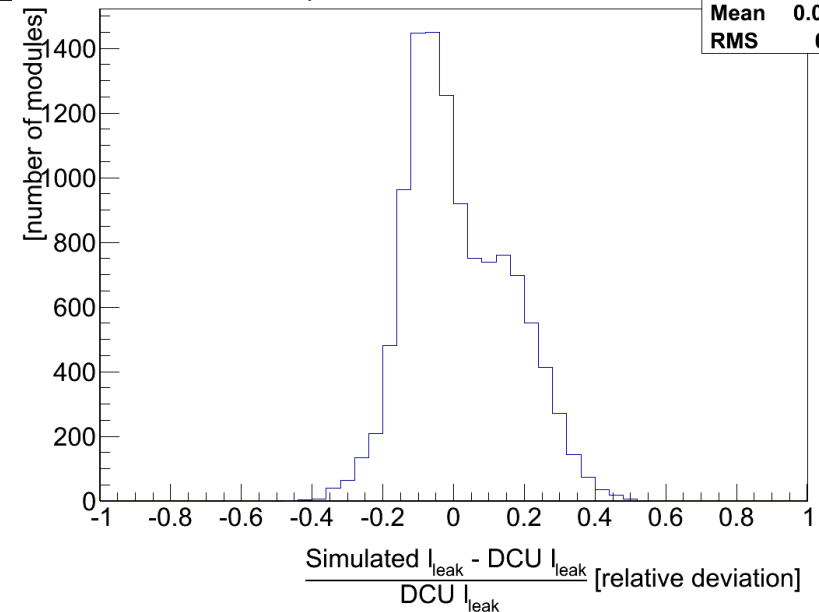
Strips: Model Agreement (10 fb^{-1})



CMS Preliminary 2012 10 fb^{-1}

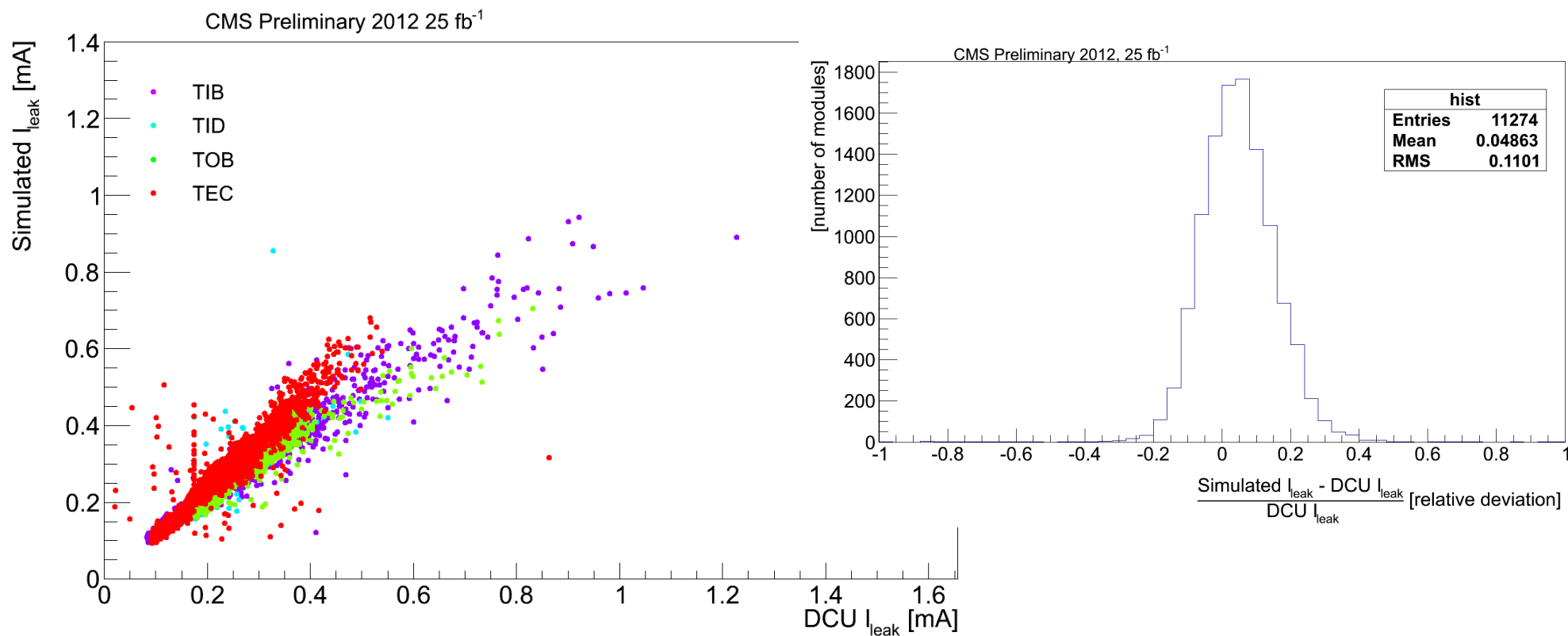


CMS Preliminary 2012, 10 fb^{-1}



- Average strips measurements agree with model within 5-20%, varying over time and detector region

Strips: Model Agreement (25 fb⁻¹)



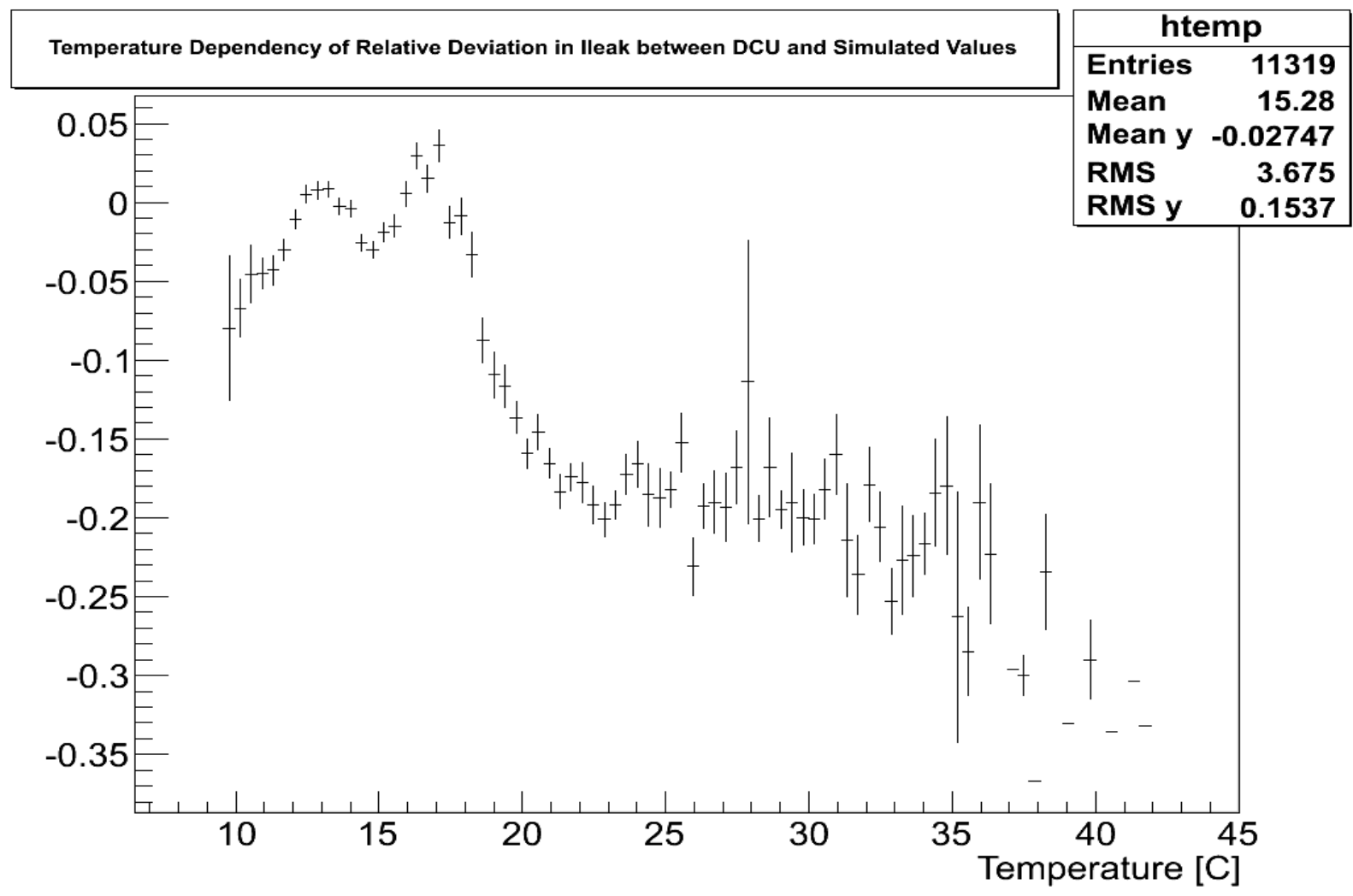
- Average strips measurements agree with model within 5-20%, varying over time and detector region



Strips: Model Agreement vs. Temperature



- Largest disagreements for high-temperature modules





Depletion Voltage Measurements



Depletion Voltage Measurements



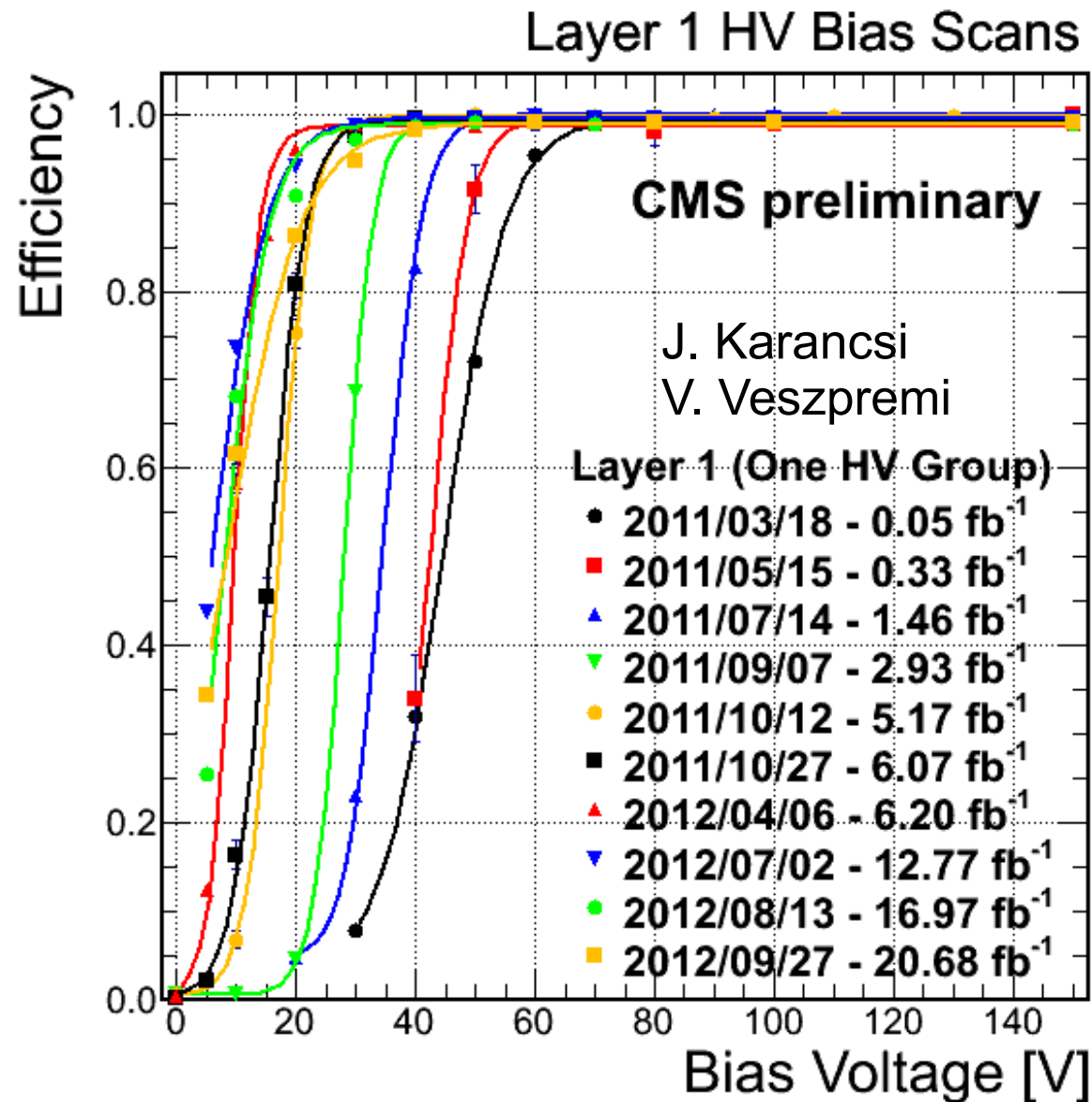
- Two methods for Strips:
 - Noise Scan (interfill periods)
 - Signal Scan (during operation)
 - Monthly for 5 power groups, twice annually for entire detector
 - Fit cluster charge vs. voltage
- Pixels:
 - Hit efficiency vs. voltage (during operation)
 - Work in progress: cluster charge vs. voltage



Pixels: Bias Voltage Scan



- Vary voltage during LHC running
 - Use small area of detector or non-physics datataking
- Measure efficiency for hits on track
- Treat 99% hit efficiency point as “full depletion voltage” – **this no longer makes sense after type inversion**

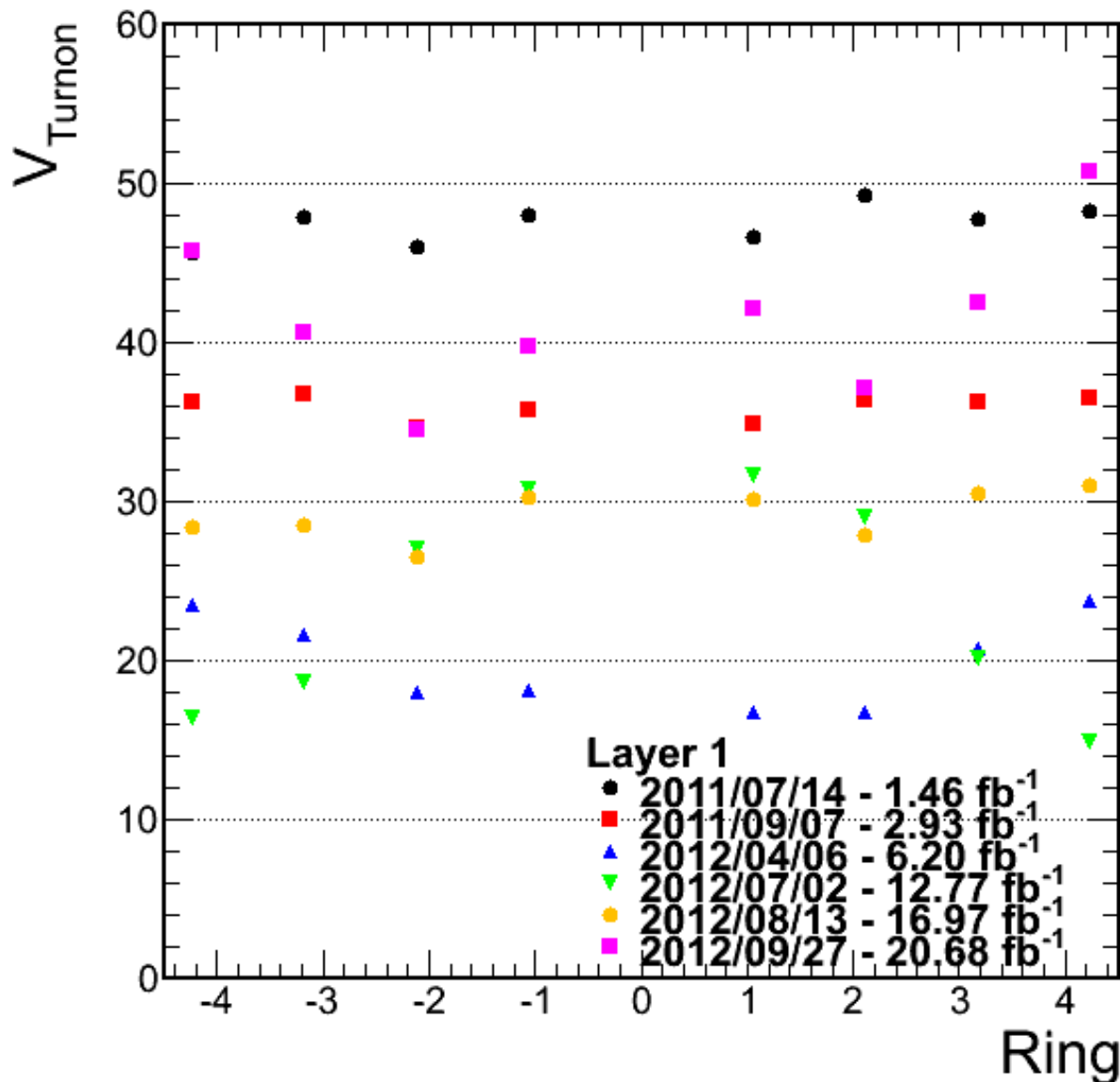




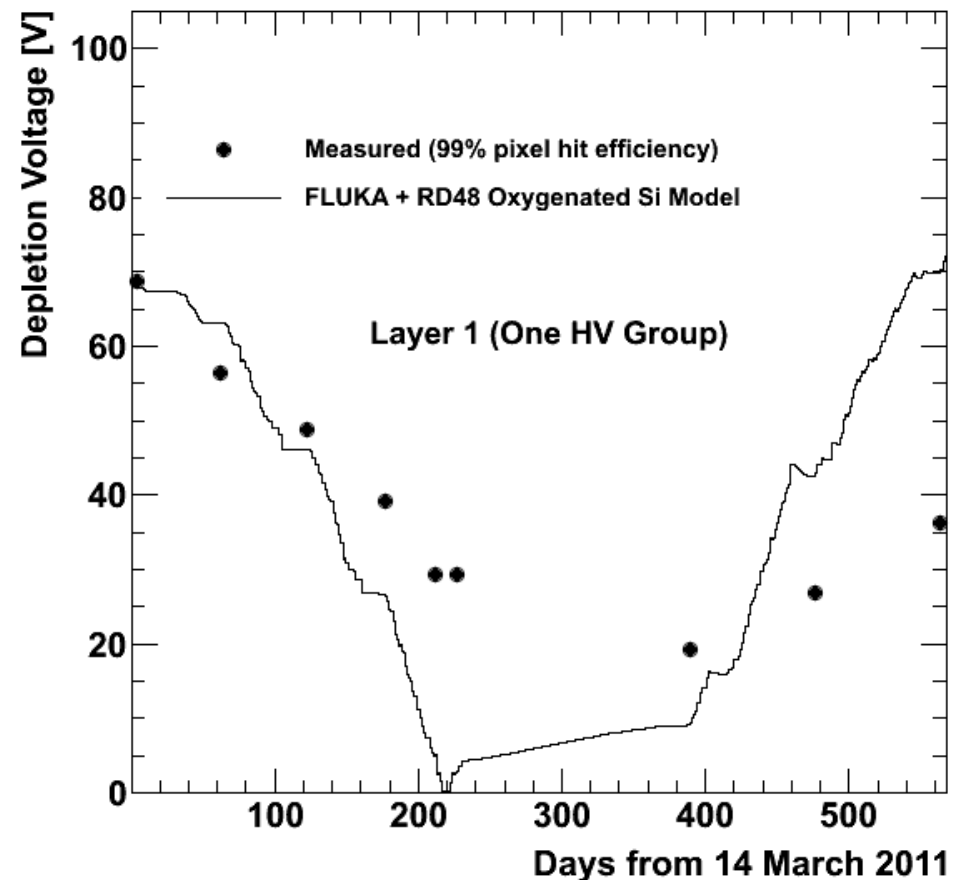
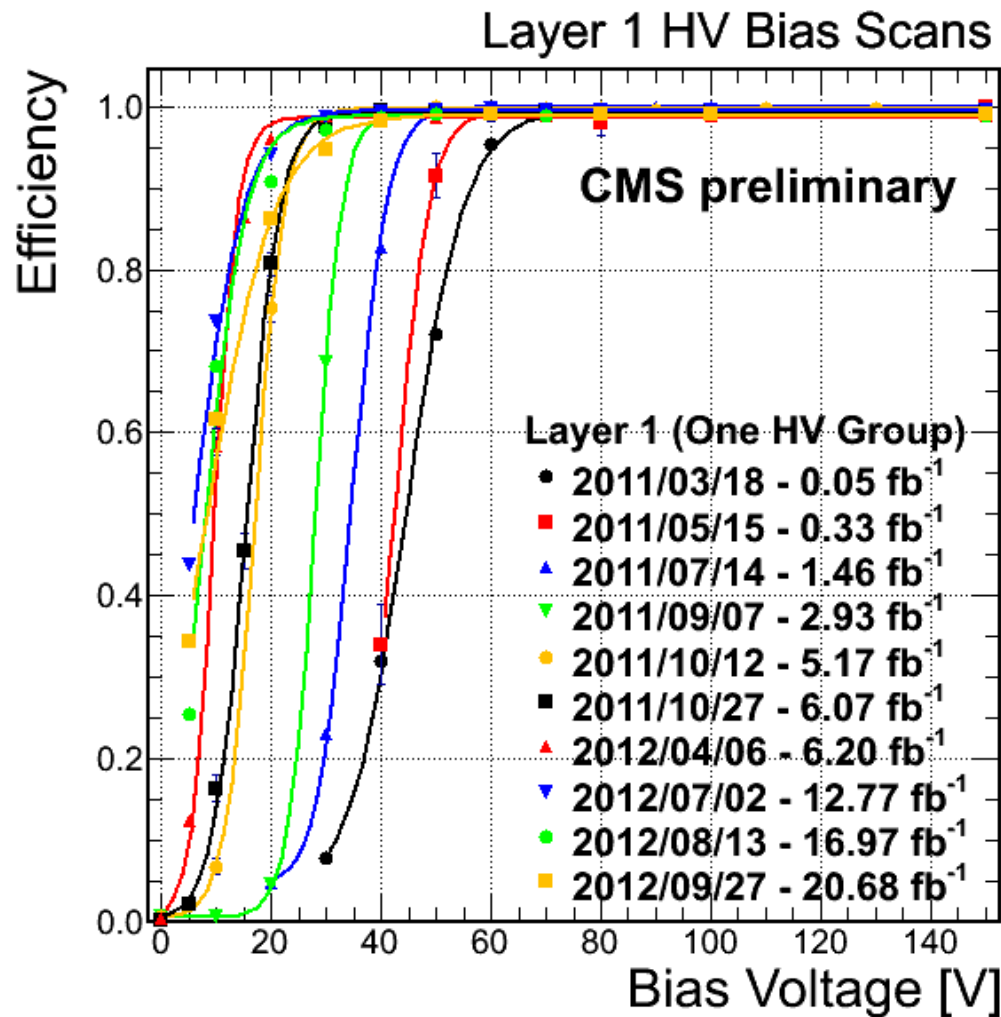
Pixels: Depletion Voltage vs. Z



- 99% point plotted over a series of scans, as a function of module z position
- Type inversion seen, first in central modules, then in outer ones



- Improvement to model: use RD48 oxygenated Si model (instead of parameters from strips)



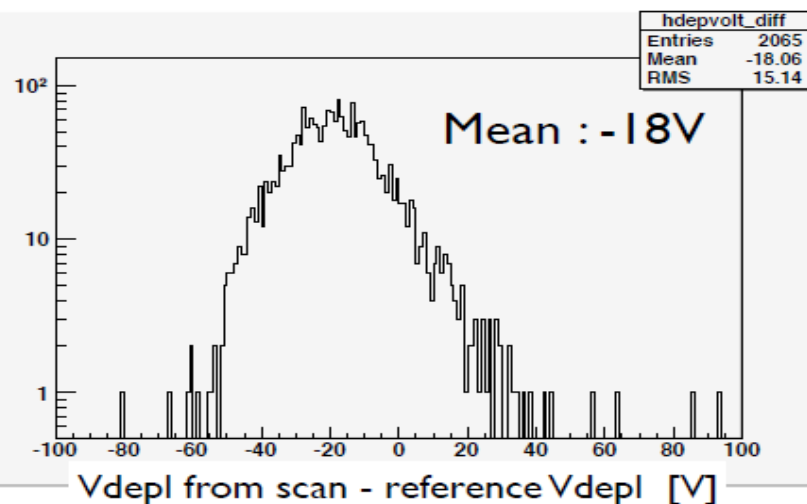
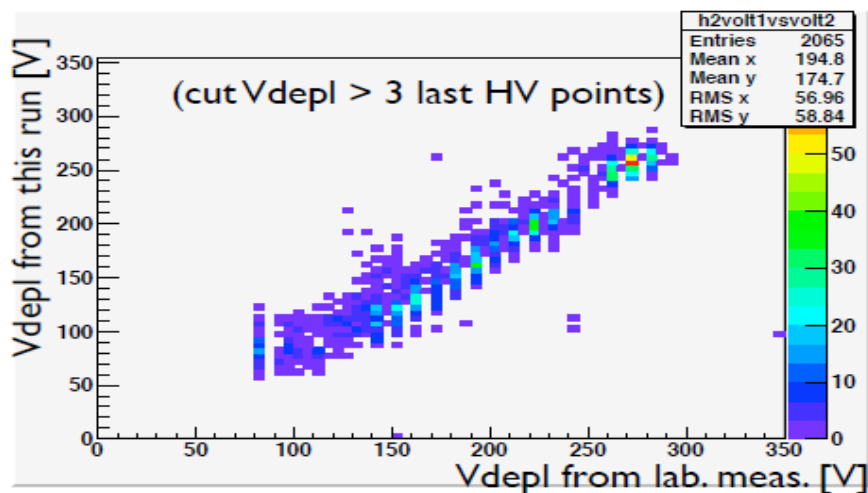
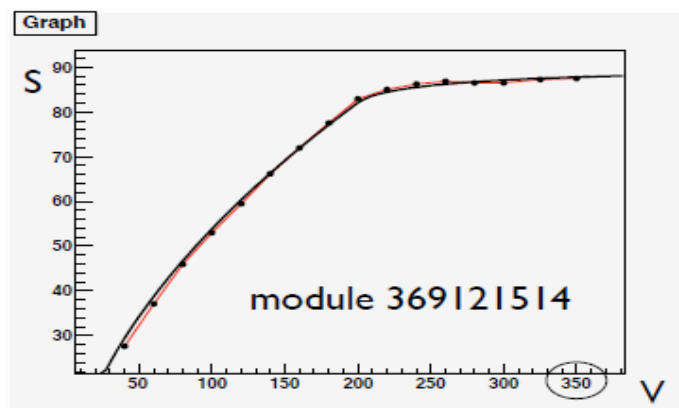


Strips: V_{dep} in 2011



march 2011

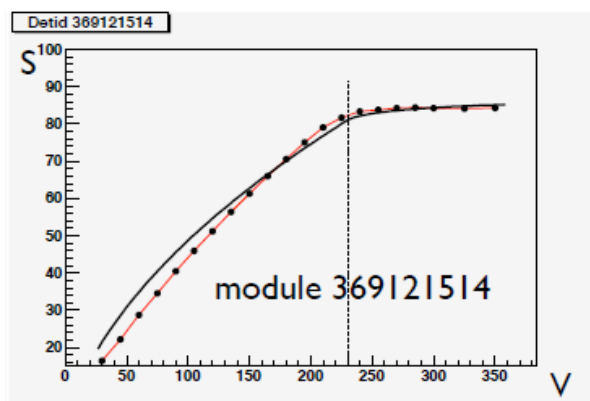
more steps toward
higher HV and higher
statistics



Strips: V_{dep} in 2012

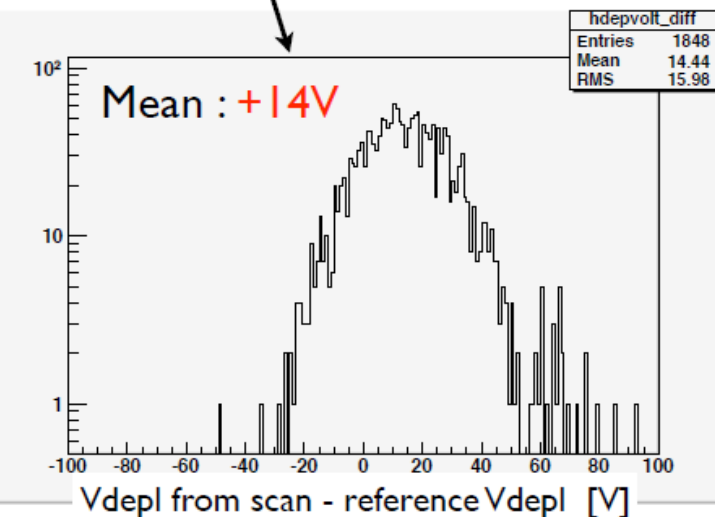
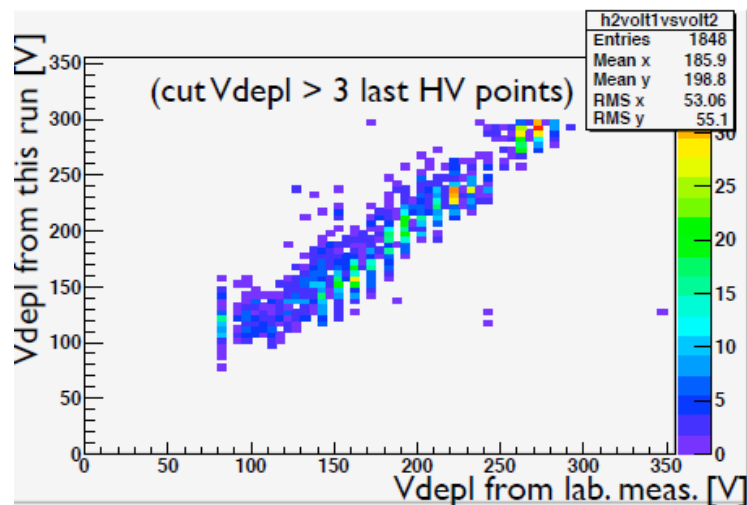
- Contrary to expectation, depletion voltage seems to increase...

april 2012



- ▶ Less good fits (slope of first part of the curve)
- ▶ Higher V_{depl} (while expect it to decrease)

Model prediction for 10fb-1 in TIB is in the order of -20V





Depletion Voltage Work-in-Progress



- Pixels: switch to MPV of cluster charge
- Strips: investigations into 2011-2012 increase ingoing
 - ~~Hysteresis from ramping direction and rate~~
 - ~~Increase in leakage current → drop in effective bias voltage~~
 - Effect exists, but too small
 - ~~Timing shifts~~
 - Modeling optimized to improve fits, but offset remains



Conclusions



- Models give reasonable agreement with measurements
- Ongoing work on improvements
 - Pixel leakage current models
 - Temperature measurements
 - Monte Carlo generator input
 - Depletion voltage measurements
- Major lesson from 2011-12 experience, looking toward upgrades: no big surprises
- During upcoming shutdown, we will have full lab access to pixel detector: are there special measurements we should make?