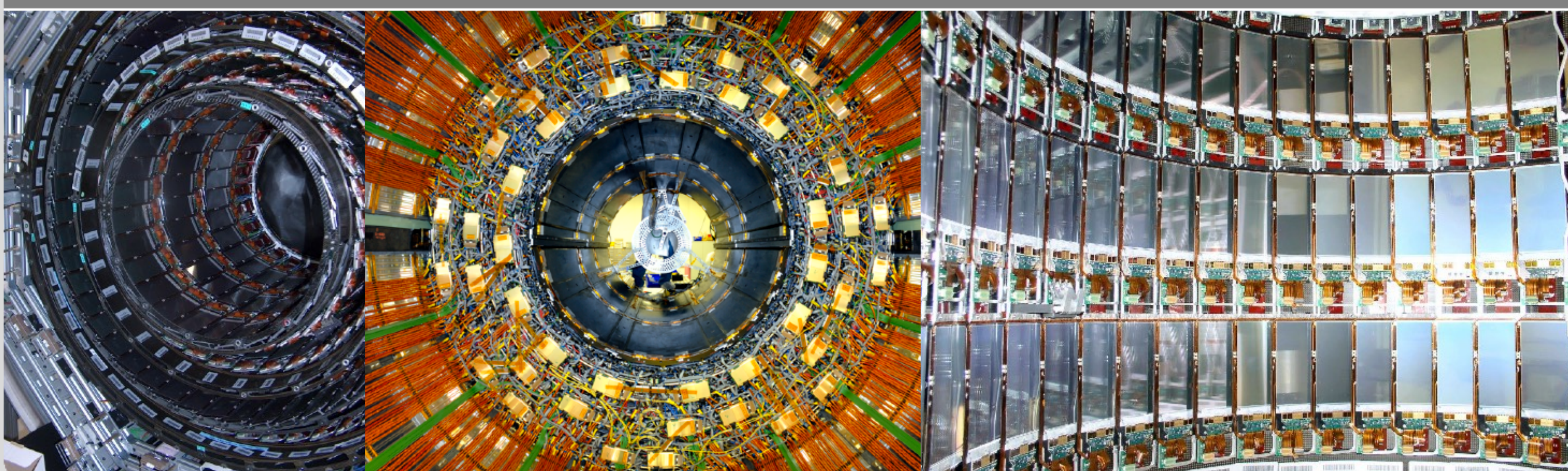
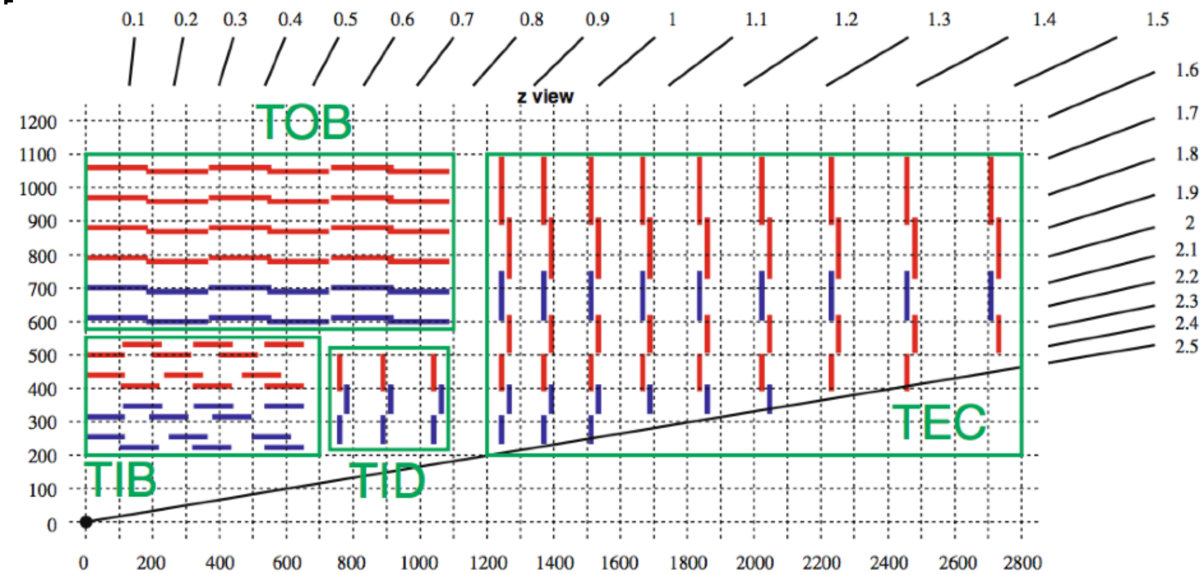
Operational experience on the CMS silicon strip detector

Ivan Shvetsov on behalf of the CMS collaboration

Institut für Experimentelle Teilchenphysik Karlsruhe Institut für Technologie

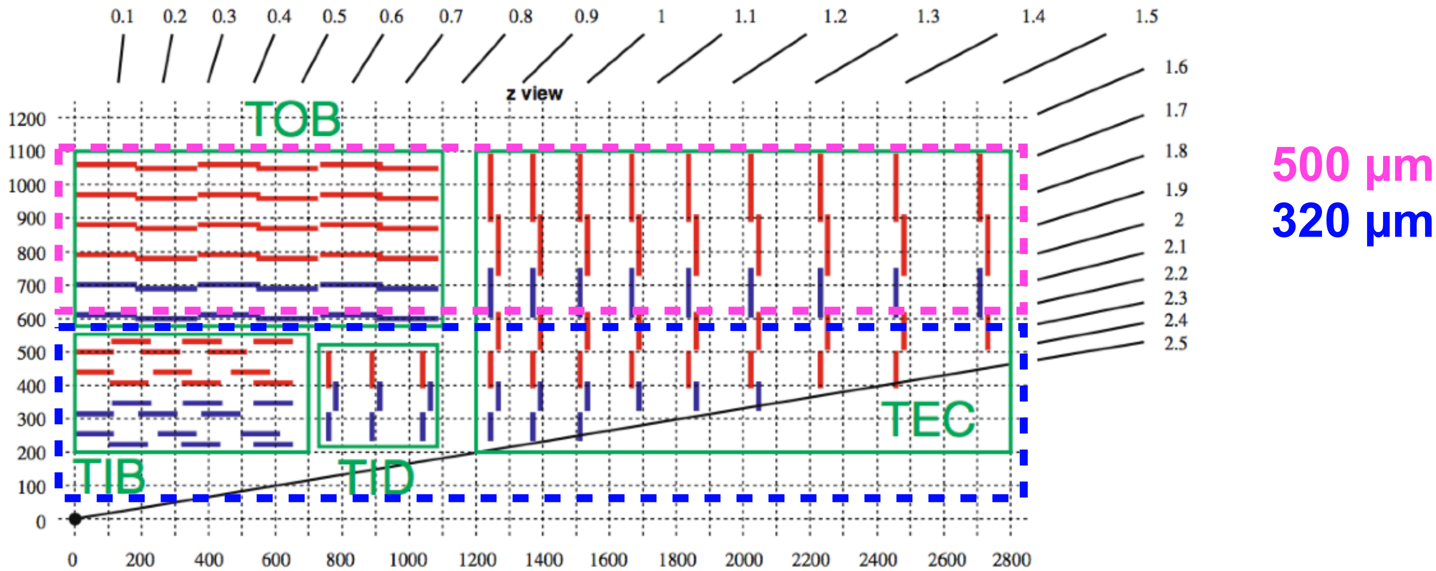


CMS Strip Tracker



- 9.3 million strips, 198 m^2 active silicon area, 15148 modules
- 5 m long, 2.5 m diameter
- 10 layers in the barrel region, 4 inner barrel layers (TIB) and 6 outer barrel layers (TOB)
- 3 inner disks (TID) and 9 endcap disks (TEC)

CMS Strip Tracker



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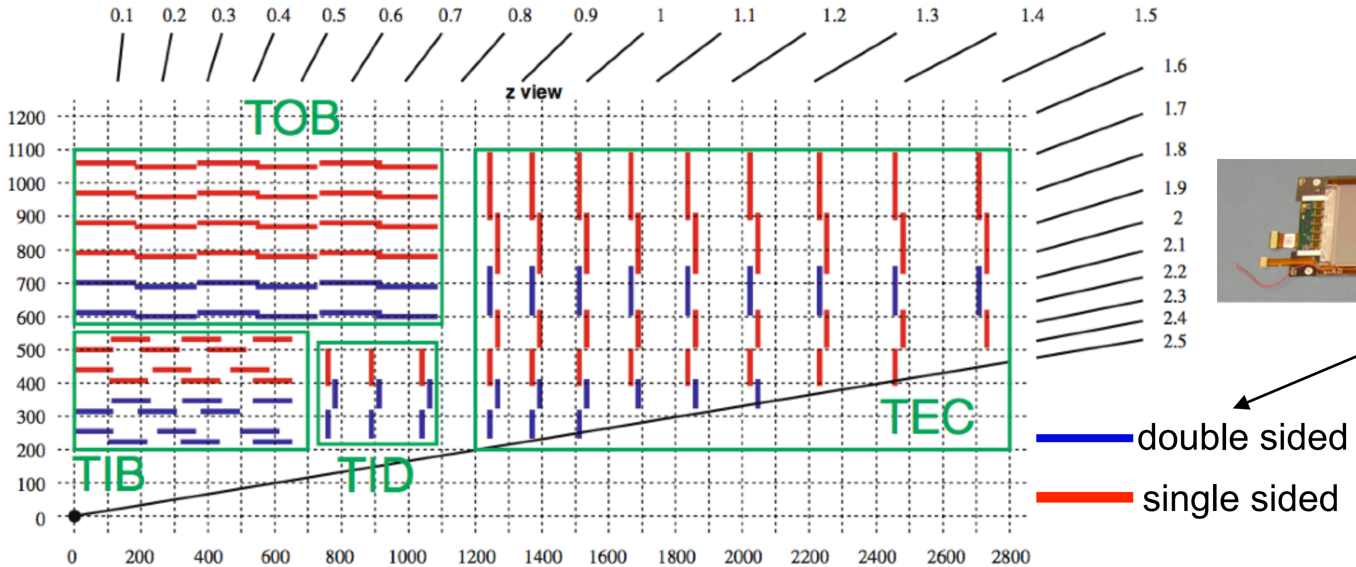
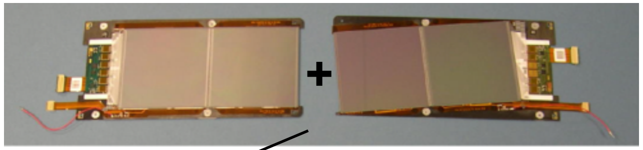
- 5 m long, 2.5 m diameter
- 10 layers in the barrel region, 4 inner barrel layers (TIB) and 6 outer barrel layers (TOB)
- 3 inner disks (TID) and 9 endcap disks (TEC)
- 320 µm Si in inner layers (TIB, TID, TEC ring 1-4)
- 500 µm Si in outer layers (TOB, TEC ring 5-7)

CMS Strip Tracker



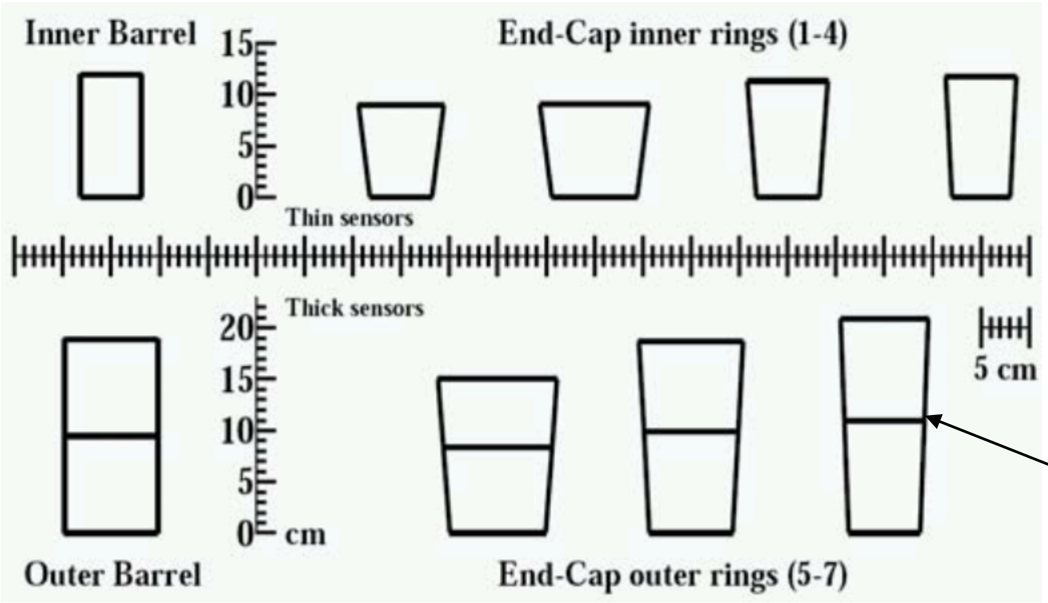


- 9.3 million strips, 198 m^2 active silicon area, 15148 modules
- 5 m long, 2.5 m diameter
- 10 layers in the barrel region, 4 inner barrel layers (TIB) and 6 outer barrel layers (TOB)
- 3 inner disks (TID) and 9 endcap disks (TEC)
- Stereo modules (2 modules with stereo angle of 100 mrad) in 4 layers (3 rings) in barrel (endcap)

Modules

320 µm

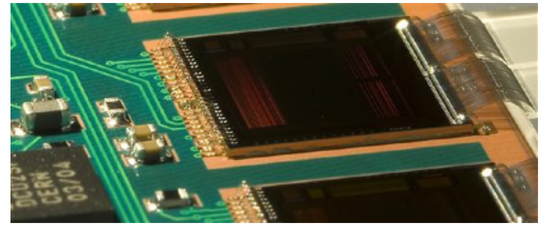
500 µm



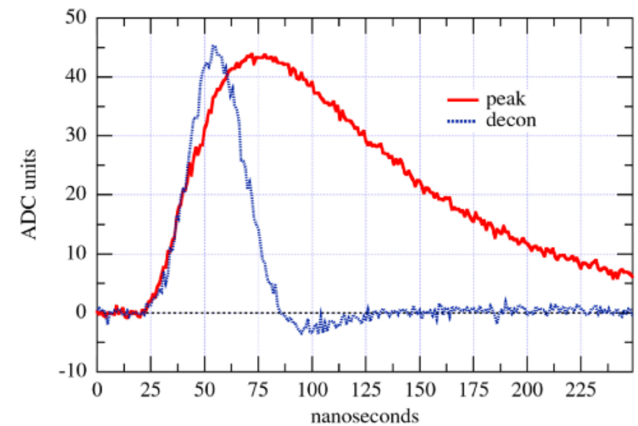
daisy chained

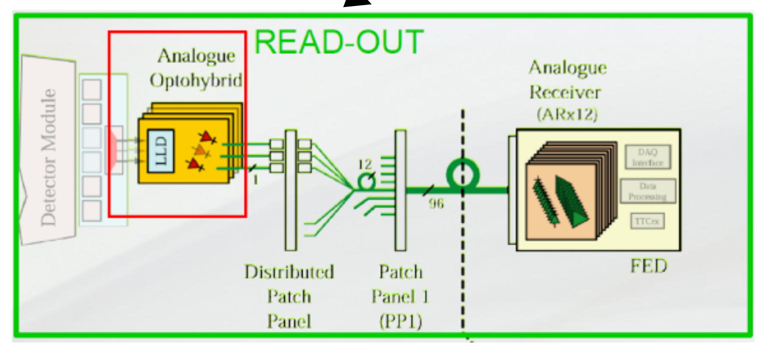
- Longer strips in outer layers/ring due to lower occupancies
- Longer strips → thicker sensor to keep high signal to noise

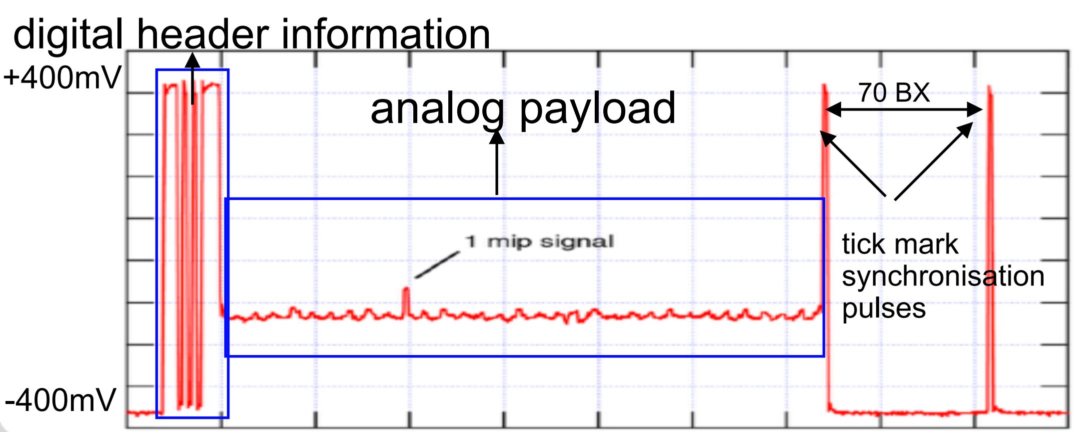
Tracker Analog readout



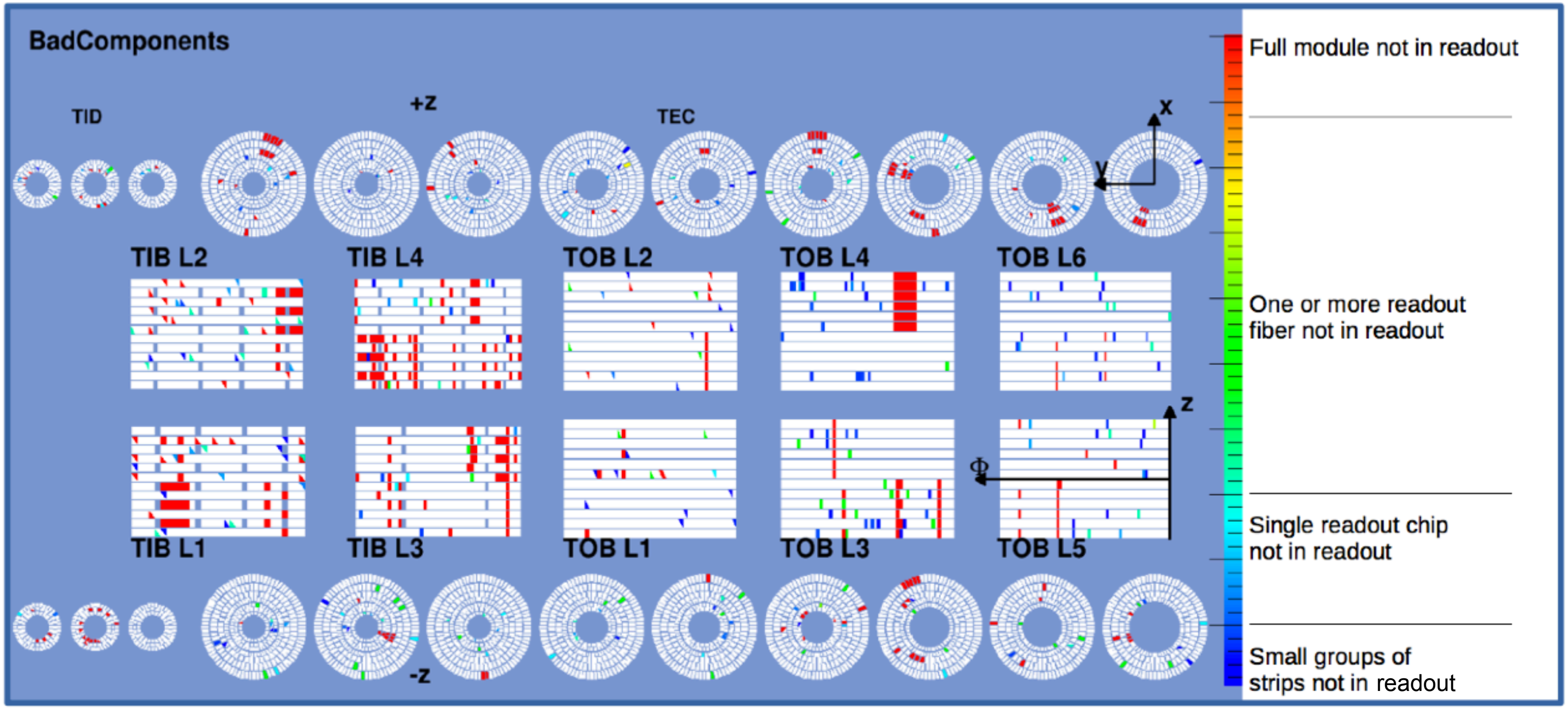
- Tracker read out is analog (signal height information)
- APV25 chip can be readout in 2 modes:
  - peak mode (single sample from shaper)
  - deconvolution mode (3 sample weighted average, shorter pulse)
- Signal from APV25 is converted to optical on the analog-opto-Hybrid (AOH):
  - linear laser drivers
  - edge emitting photodiodes
- Laser driver has four gain stages: equalise readout gain and compensate the radiation





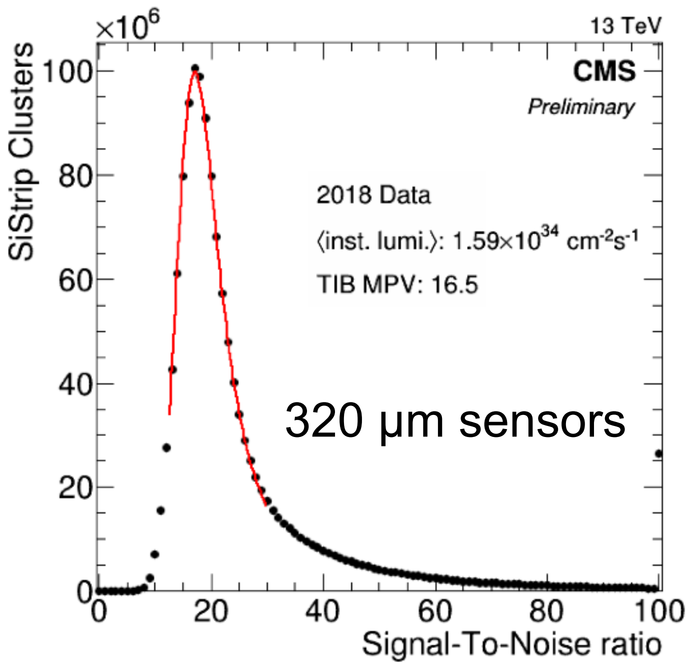


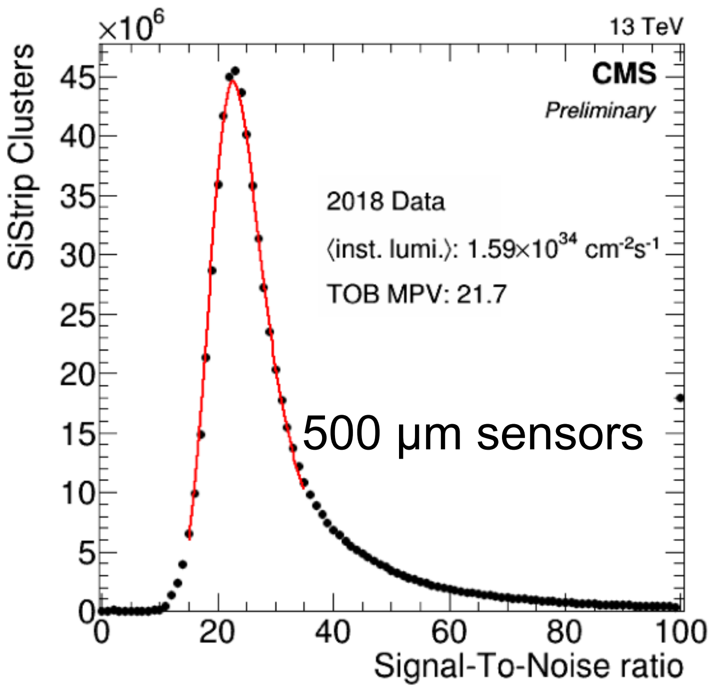
Detector status in LHC Run 2



- Fraction of active channels 96.5%
- stable during run 2
- Components excluded from data-taking: 3 control rings, power groups, individually switched off modules

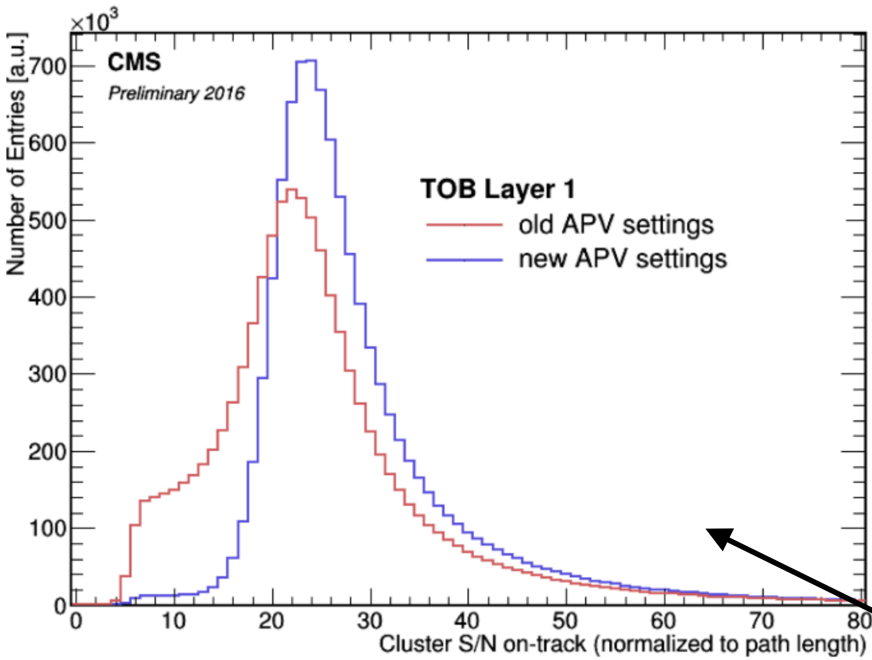
Signal to noise performance

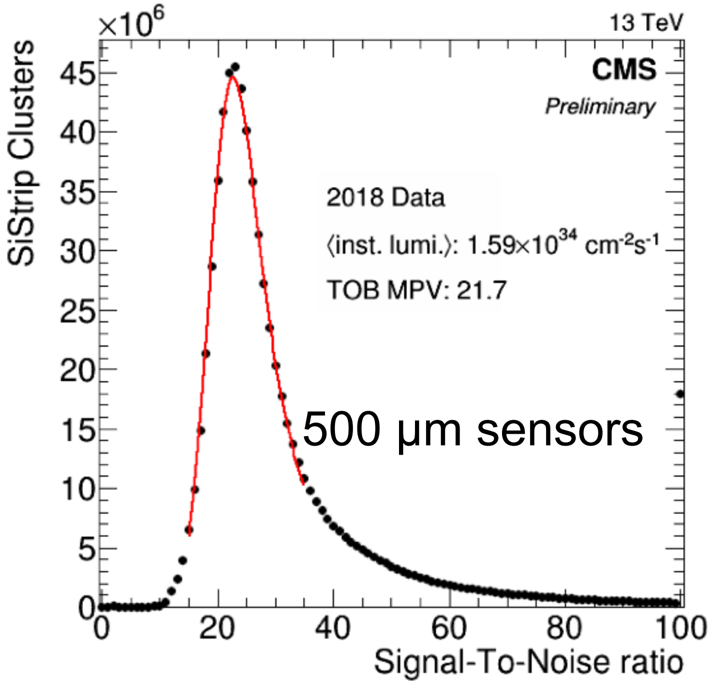




- high signal to noise

Signal to noise performance

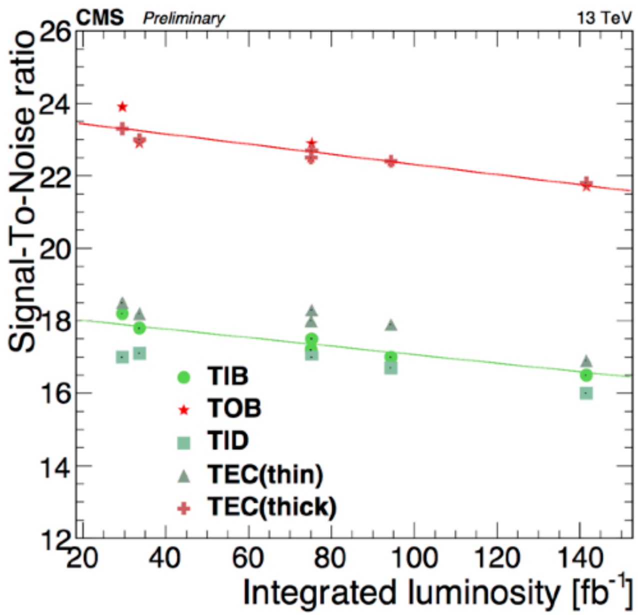




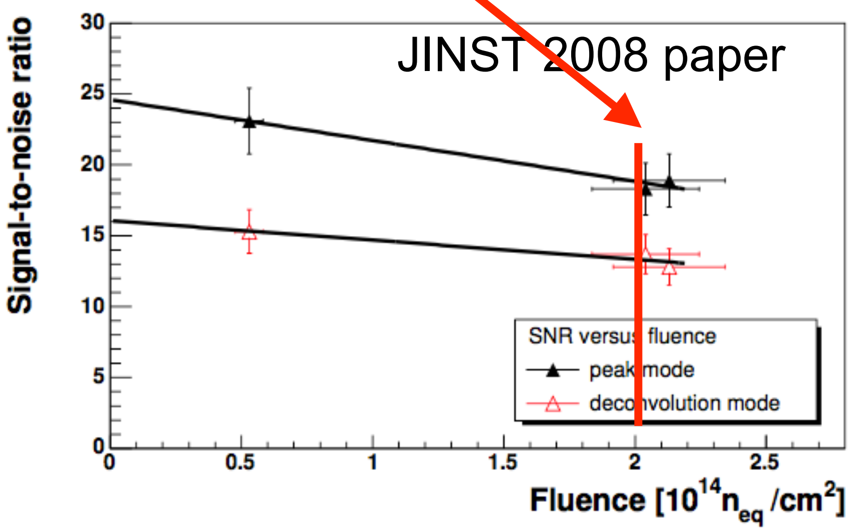
- high signal to noise
- no sign of saturation effects in the preamplifier as observed in 2015/16

Signal to noise performance

- no sign of systematic decreasing with collected luminosity
- Signal to noise will not be an issue at the end of life (~ 500 fb^{-1})

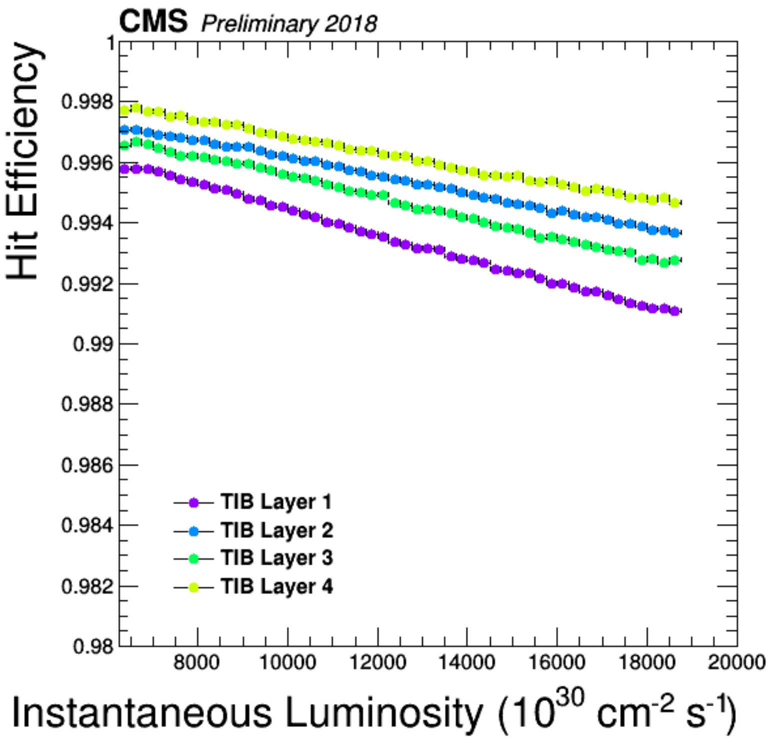


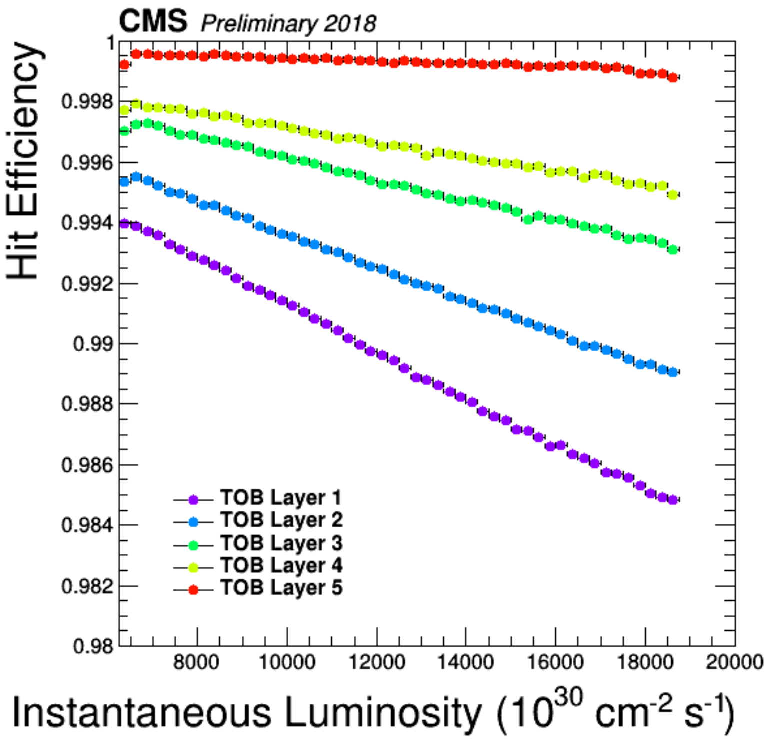
max expected damage to TIB L1 after 500 fb^{-1}



Hit efficiency

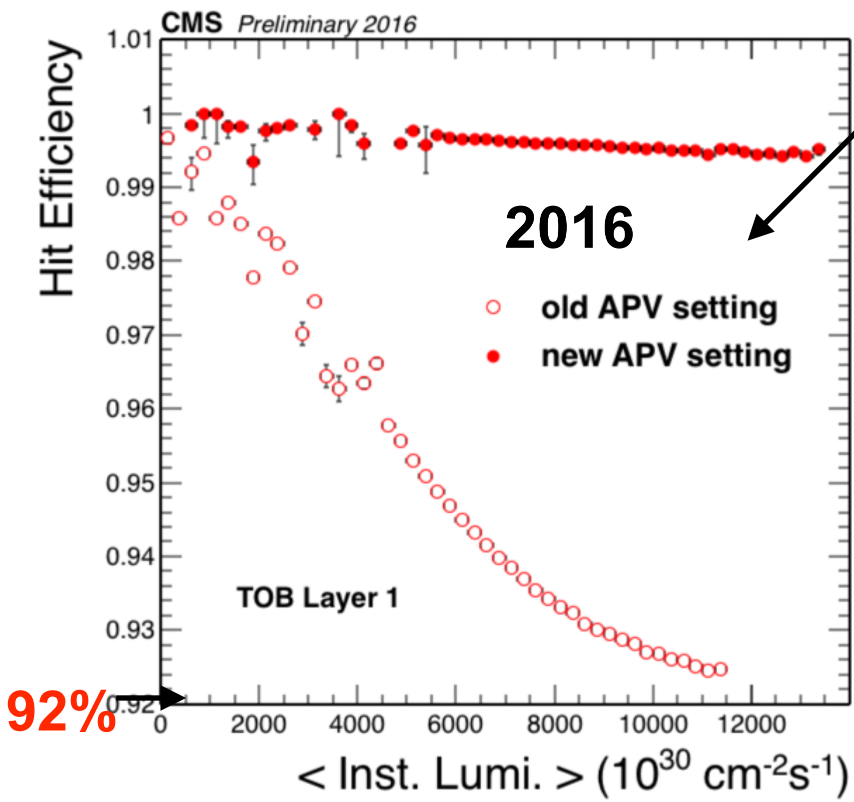
- Hit efficiency > 98 % at instantaneous luminosity of 1.9e34
- Linear as a function of instantaneous luminosity

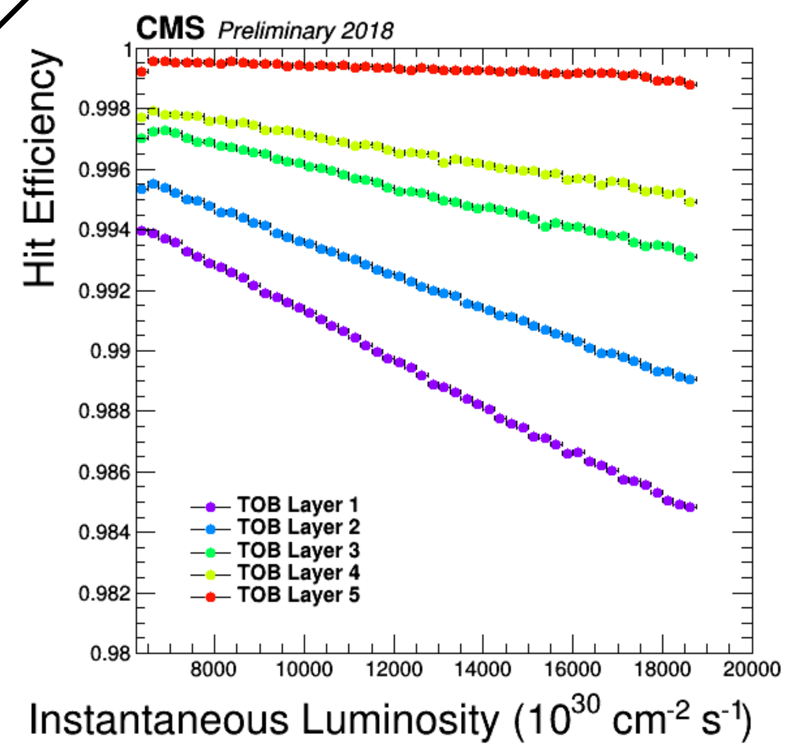




Hit efficiency

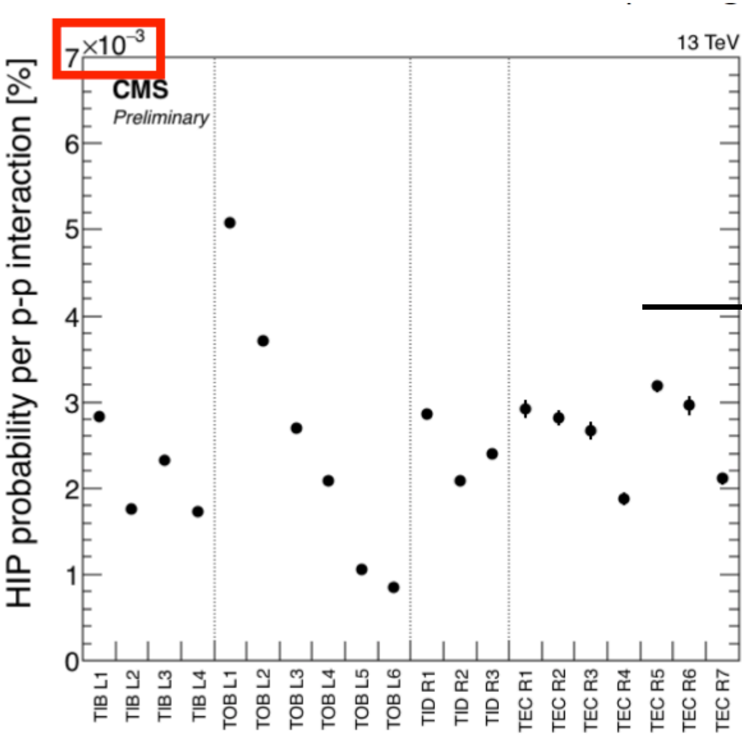
- Hit efficiency > 98 % at instantaneous luminosity of 1.9e34
- Linear as a function of instantaneous luminosity
- No indication of new saturation effects in the preamplifier

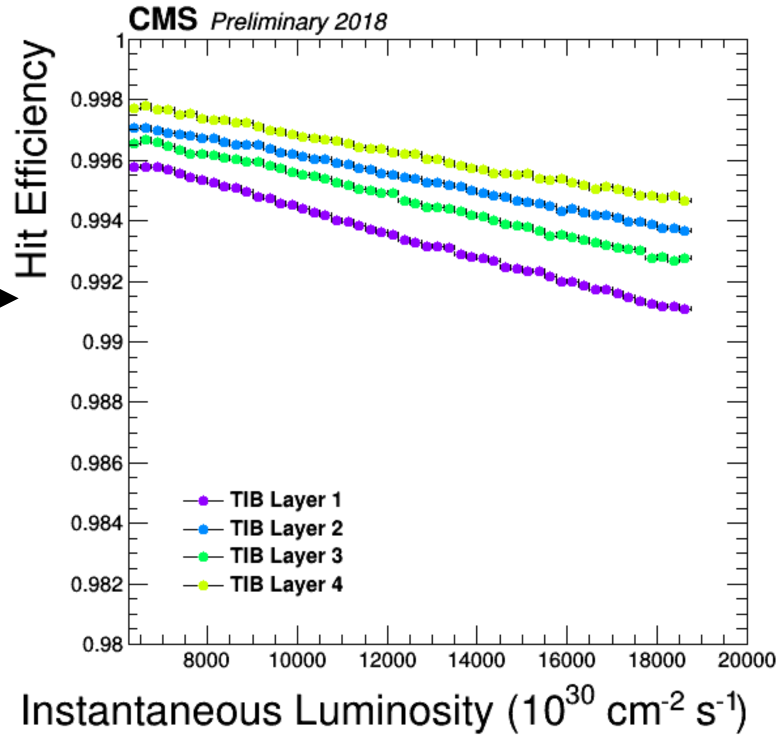




HIP probability

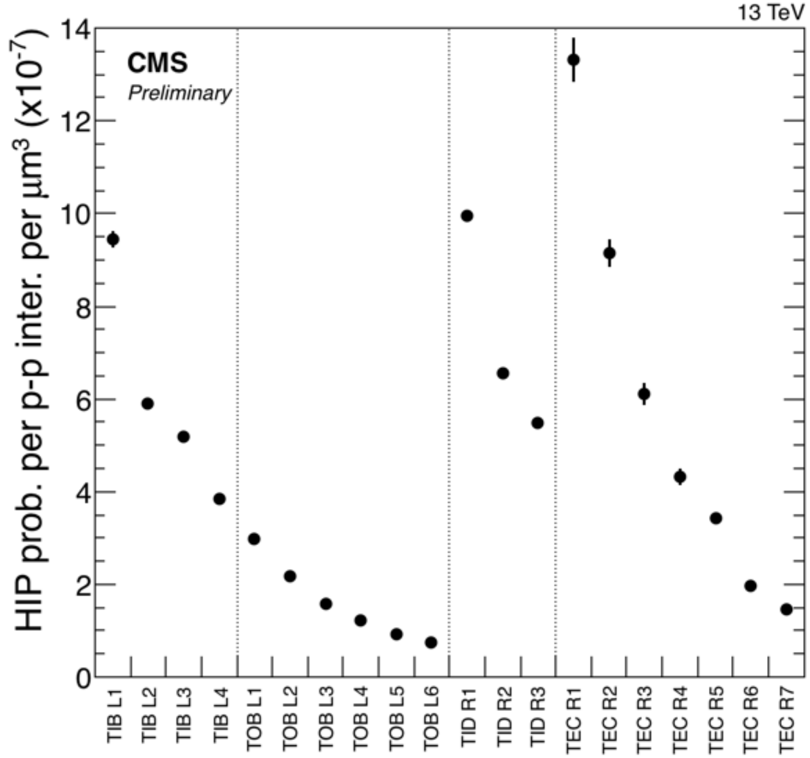
- Probability of Highly Ioning Particles (HIP) is measured per ***interaction***
- Inelastic collision of hadrons in a silicon sensor (energy deposit ~100 MIP)





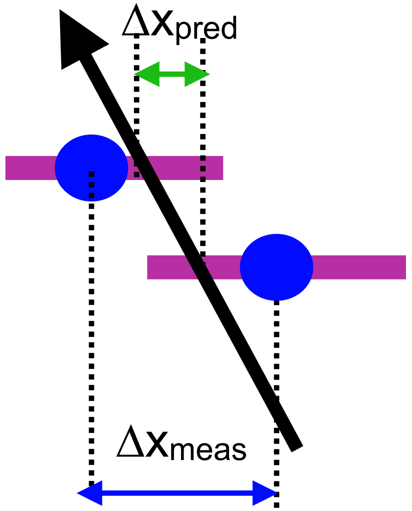
HIP probability

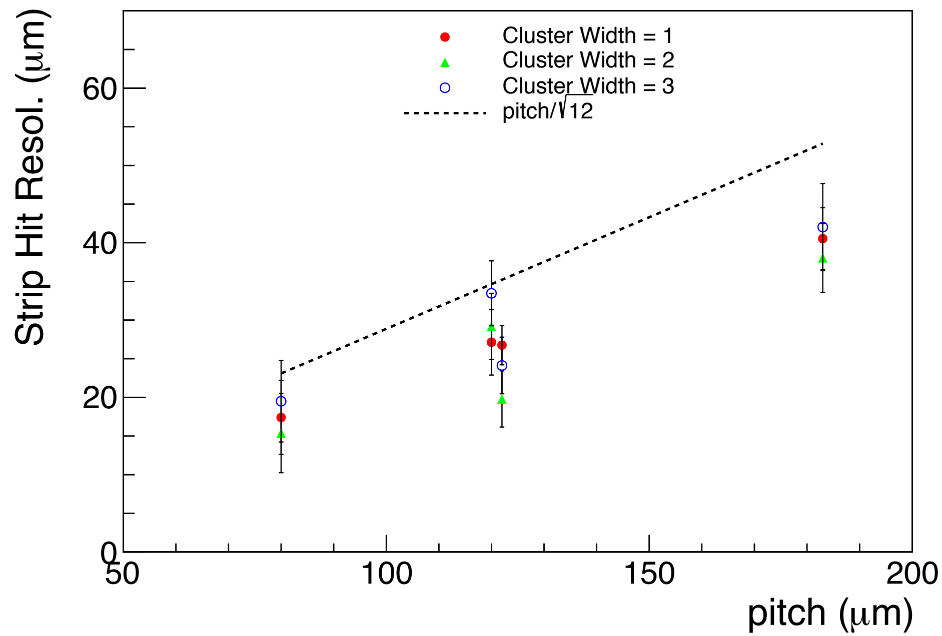
- Probability of Highly Ioning Particles (HIP) is measured per ***volume unit***
- Inelastic collision of hadrons in a silicon sensor (energy deposit ~100 MIP)
- Clear dependence on radius



Single hit resolution

- Pair method: hit resolution is computed by using hits from overlapping modules in the same layer



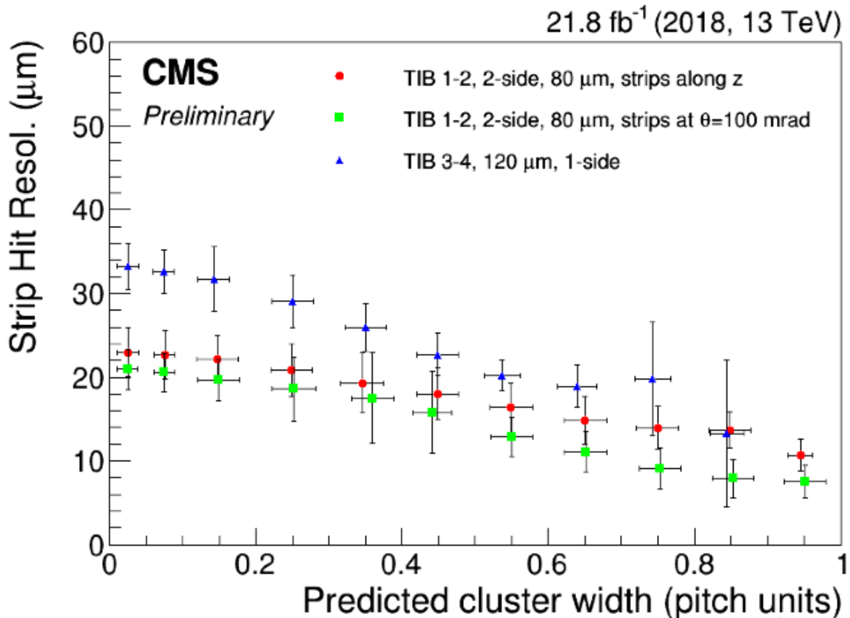


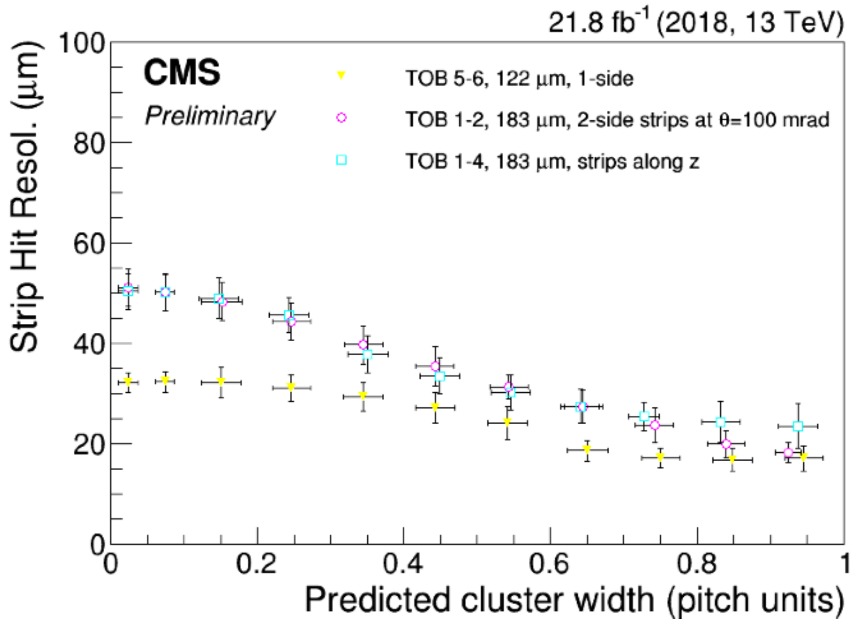
$$\sigma_{hit} = \frac{\sqrt{\sigma(_{meas-pred})^2 - \sigma^2_{meas}}}{\sqrt{2}}$$

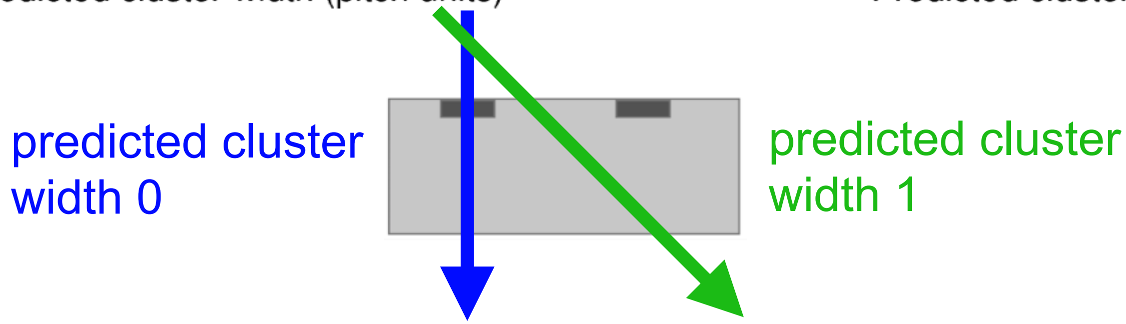
- Expected scaling with the pitch size can be seen

Hit resolution

- Resolution as function of predicted cluster width benefiting from charge sharing

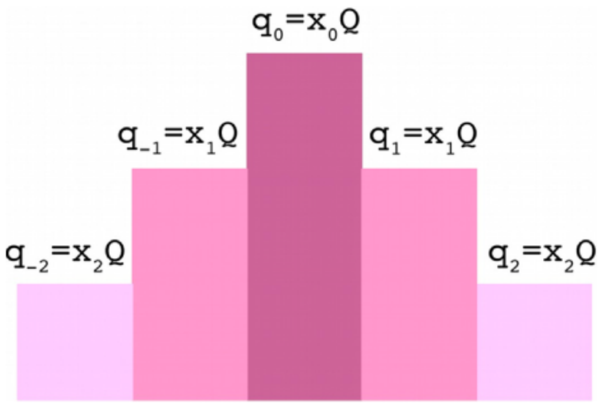




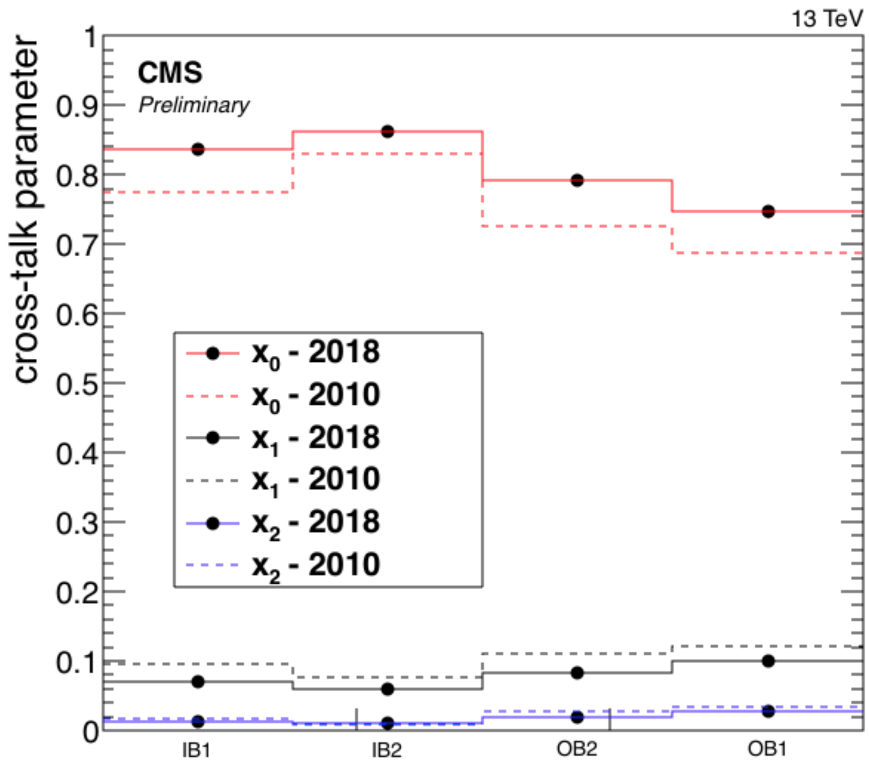


Cross talk measurement

- Effect of interstrip capacitance is measured
- Measured in cosmic run with 0T



$$x_0 + 2x_1 + 2x_2 = 1$$



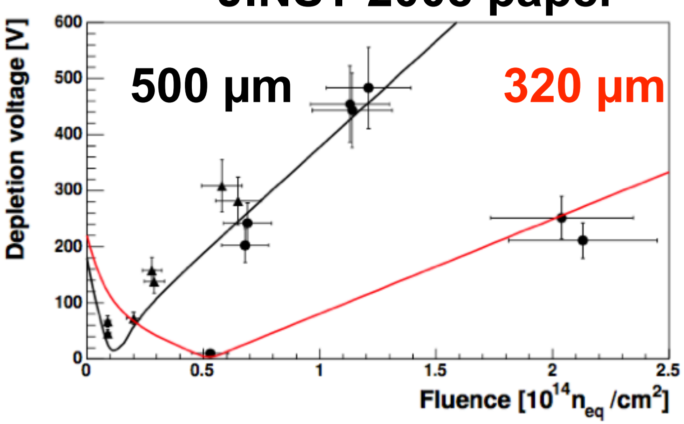
- narrower clusters than in beginning of run 1

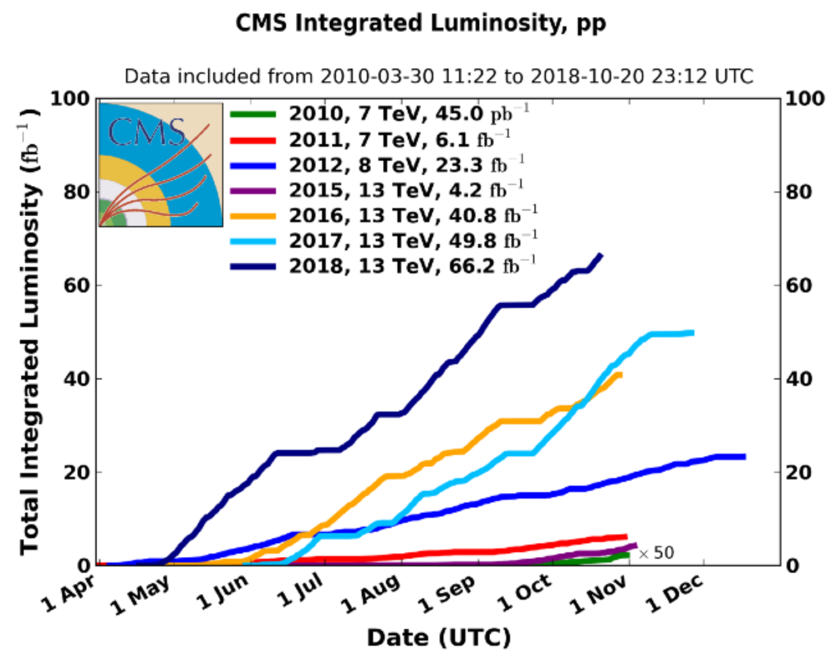
Radiation effects

Radiation effects

- About 200 fb^{-1} delivered by the end of Run 2
- Regular measurement of radiation related quantities done
- Leakage current (I_{leak}) is measured using power supply and with detector control units on the module level
- Full depletion voltage:
  - bias scan on full detector (twice per year)
  - once per month on representative power groups

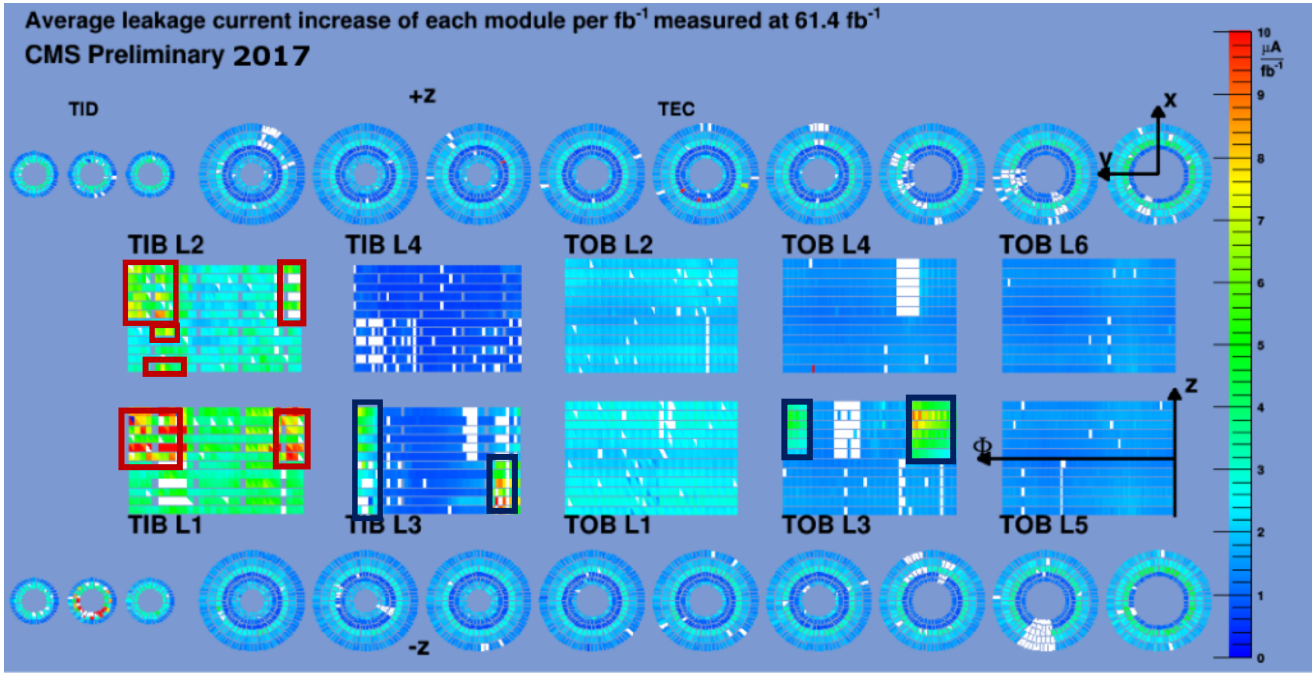
JINST 2008 paper





Leakage current

- In 2017 high voltage channels (mostly TIB L1) reached current limit
- Still in most of the cases limit could be increased
- However, there was no safety margin to stay at -15 ℃ (power supply limit 12 mA)



increase of leakage current divided by integrated luminosity

Closed (leaky) cooling loops

Degraded cooling contacts

- empty regions correspond to problem with slow local control readout

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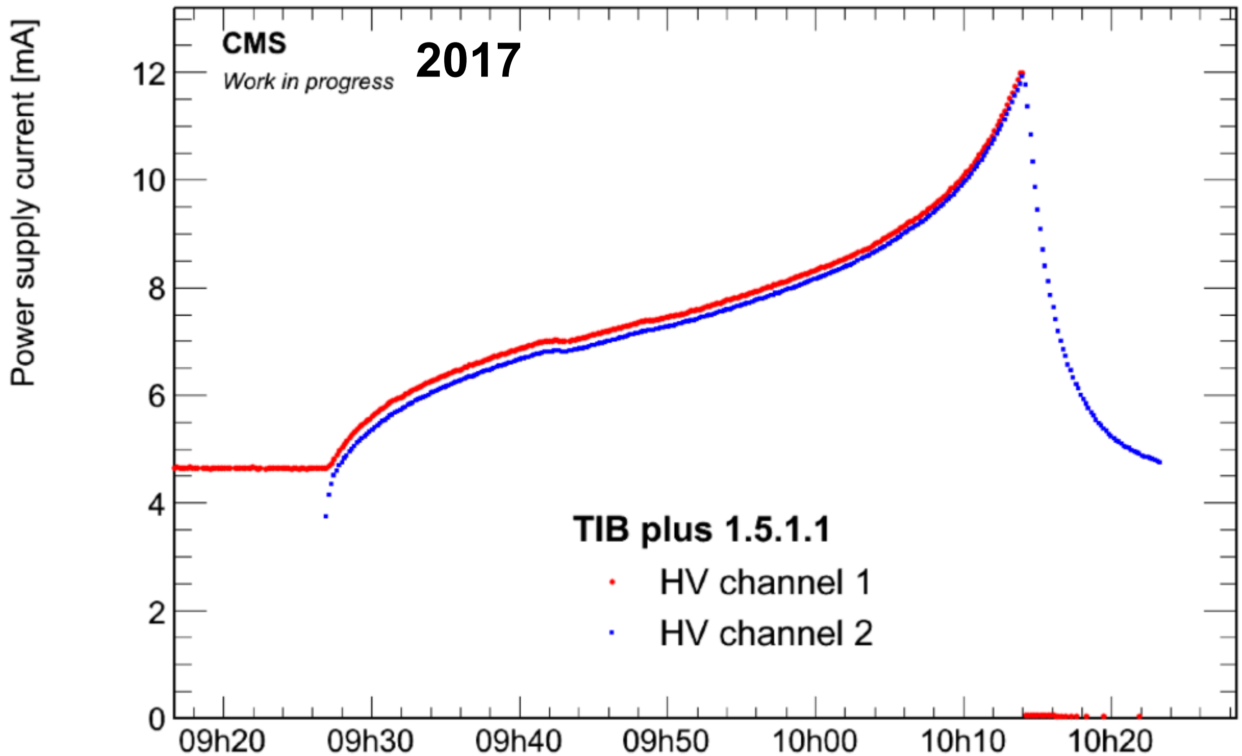
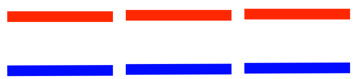
Thermal runaway

- Thermal runway was observed!
- Self heating effect reduced by switching off half of stereo modules
- Then reduced bias from 300 V to 200 V



HV channel grouping double sided layer



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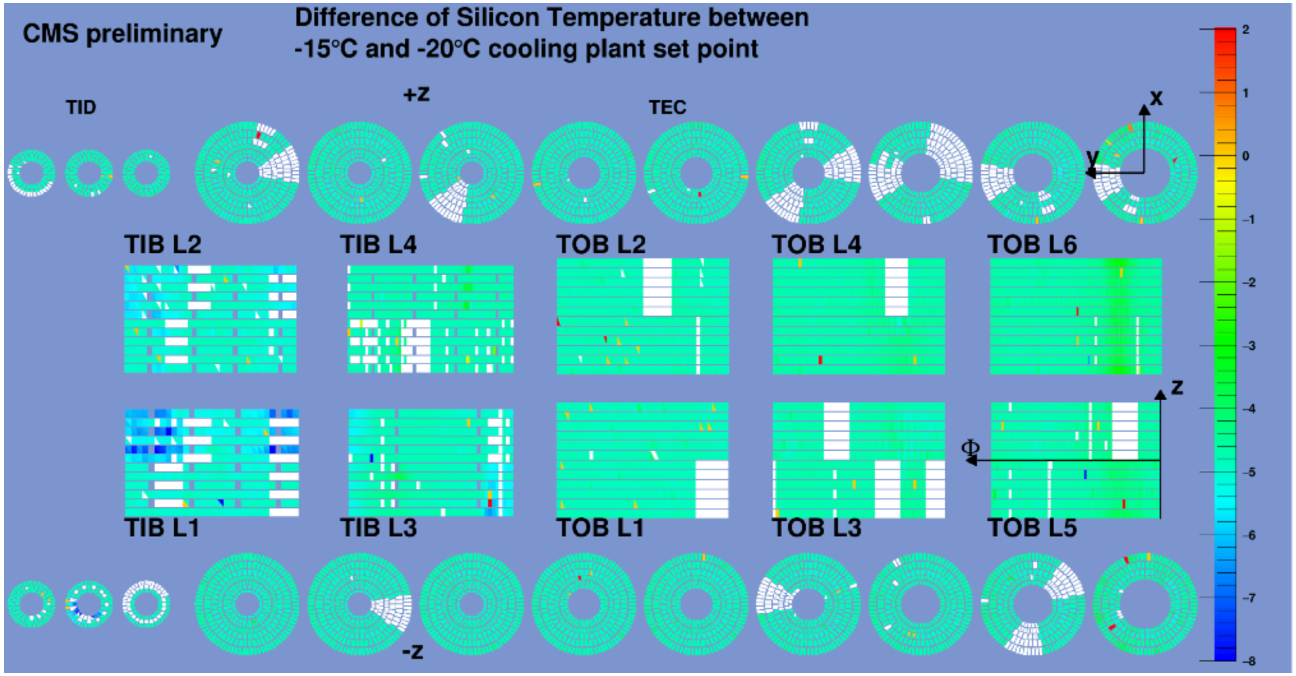
Change of operational temperature

- Operational temperature change from -15 ℃ to -20 ℃ in beginning of 2018 operation
- Leakage currents decrease substantially due to reduced self-heating (e.g in TIB L1 due to degraded cooling contact or no direct cooling e.g in TIB L3)

$$I_{leak} \sim T^2 \exp\left(\frac{-c}{T}\right)$$



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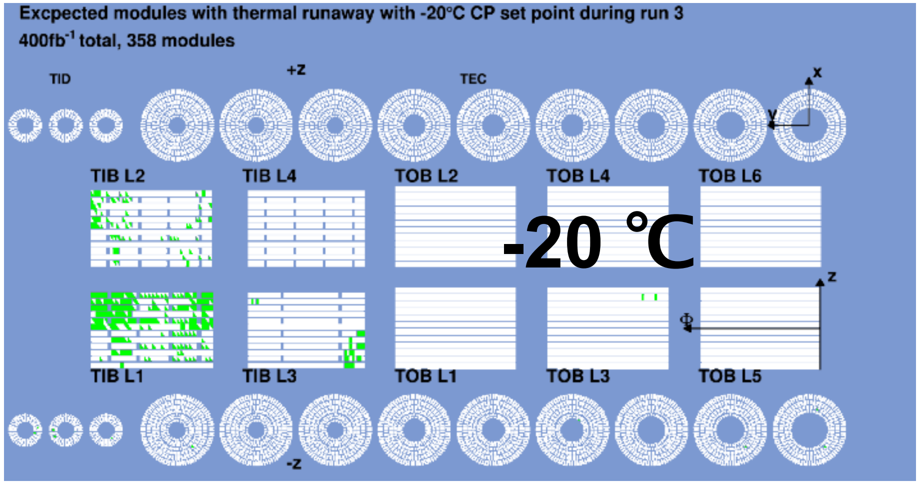
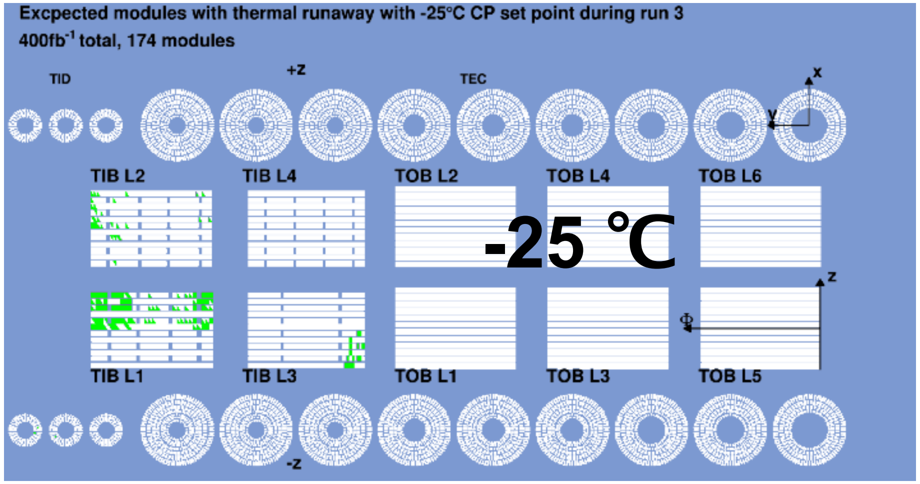
Number of expected thermal runaways

- Expected modules with thermal runaway by the end of Run 3 (400 fb^{-1})





- Number of thermal runaways is reduced by decreasing the cooling set point
- Still further handles of this would be possible:
  - it is possible to switch off individual modules (using so called HV jumpers)
  - switch off half of the stereo layer of power group
- Plan to test running at -25 ℃ during LHC Long Shutdown 2

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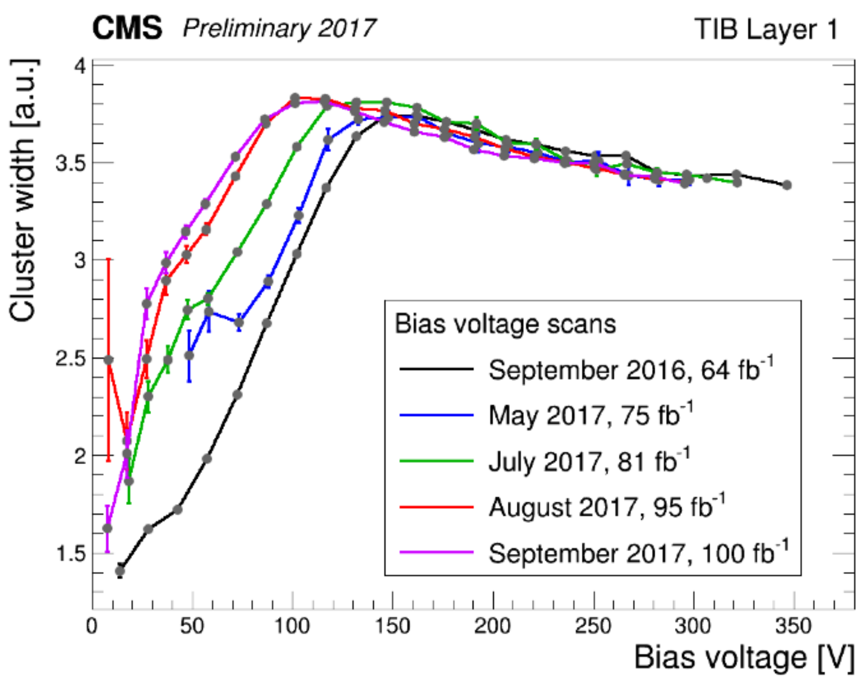
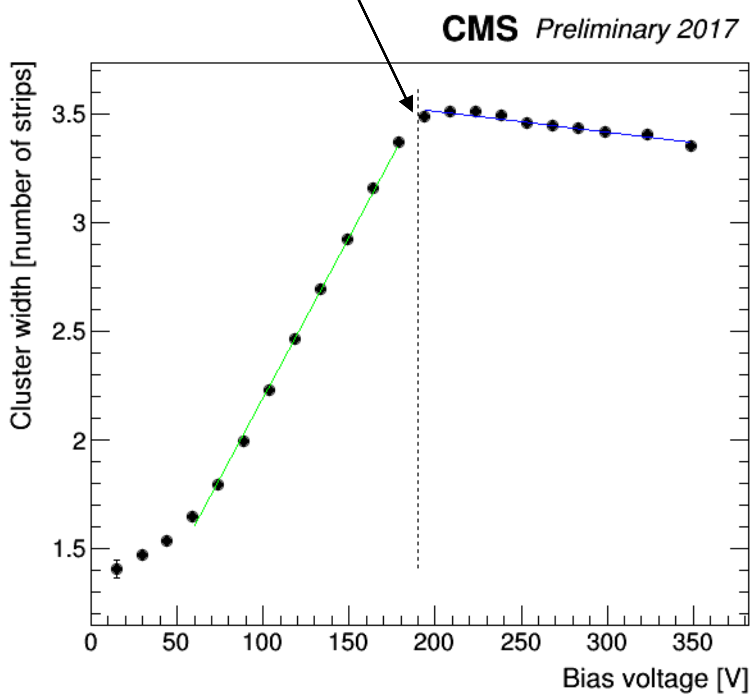
Measurement of full depletion voltage

- Illustration of the method
- Cluster width used as observable
- Method runs in difficulty close to inversion point

crossing of two lines is taken as estimation V_{fd}





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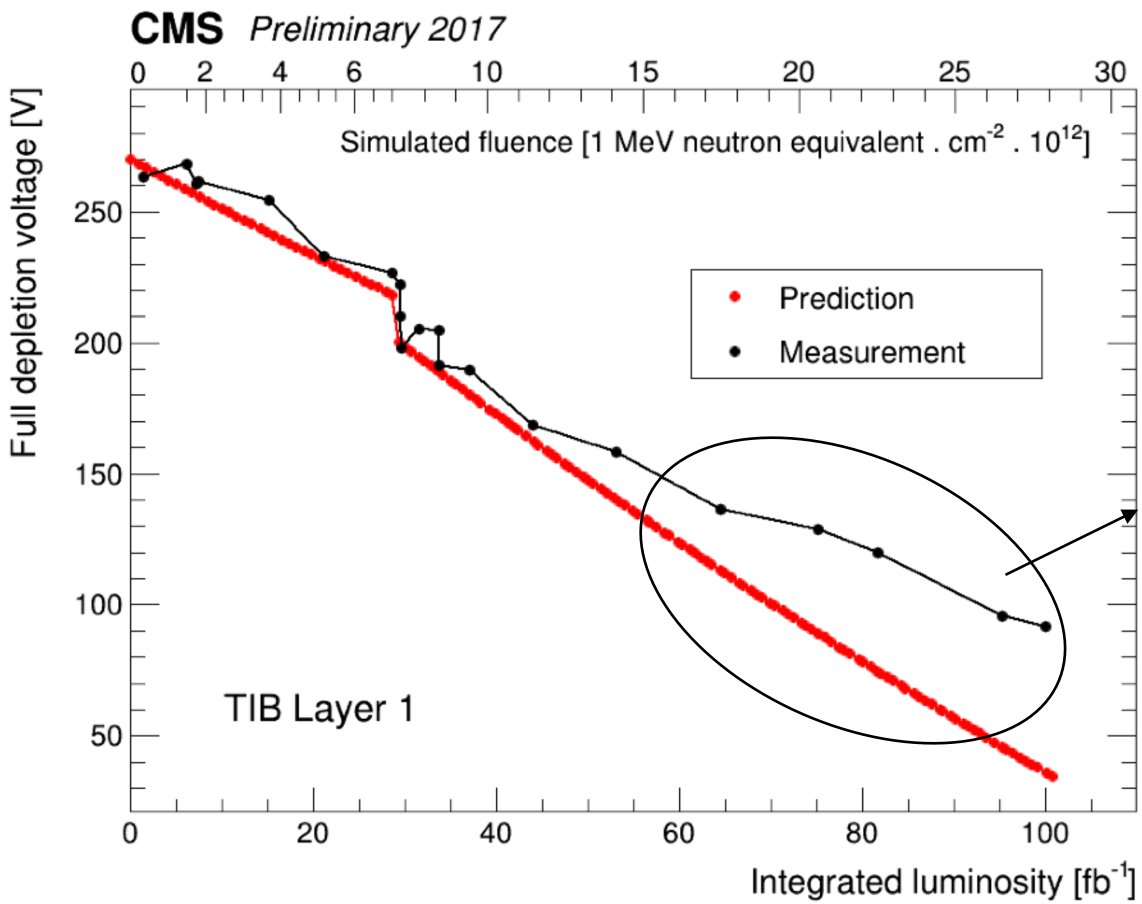
Full depletion voltage

- Predictions are made based on the Hamburg model



measurement deviates from the prediction close inversion

Full depletion voltage

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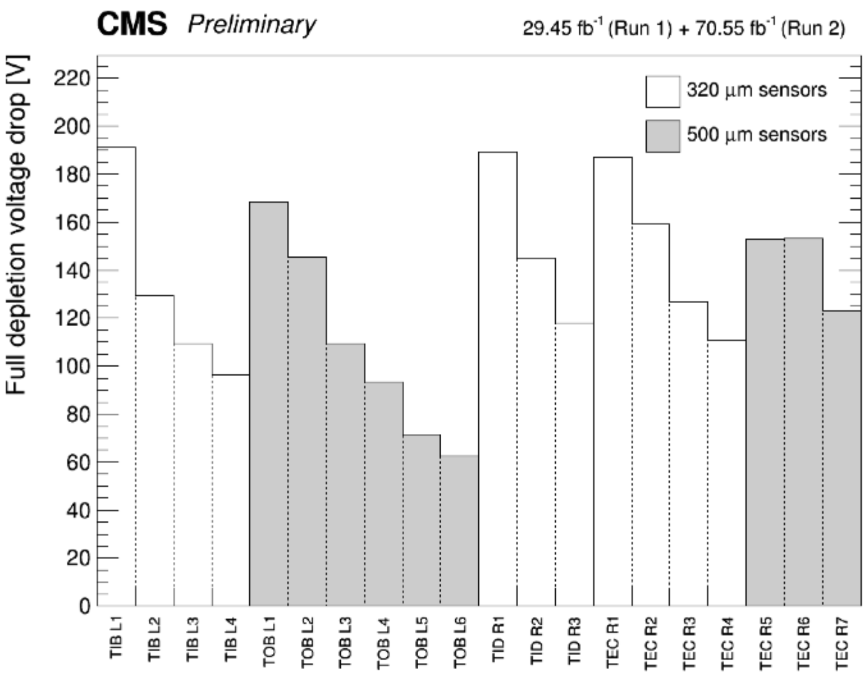
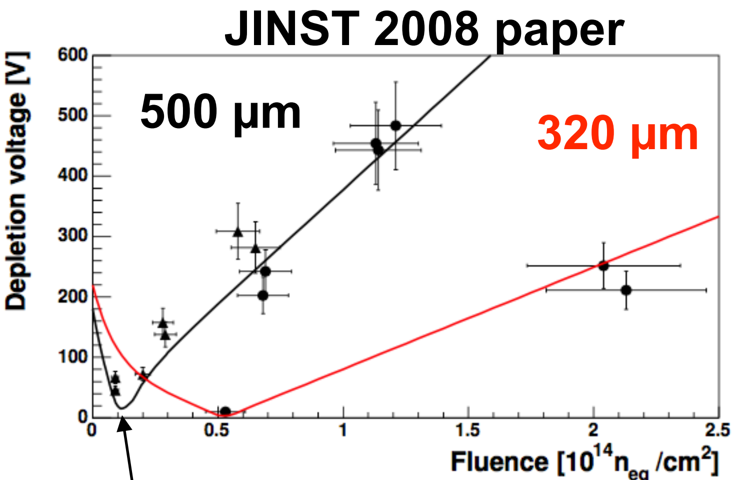
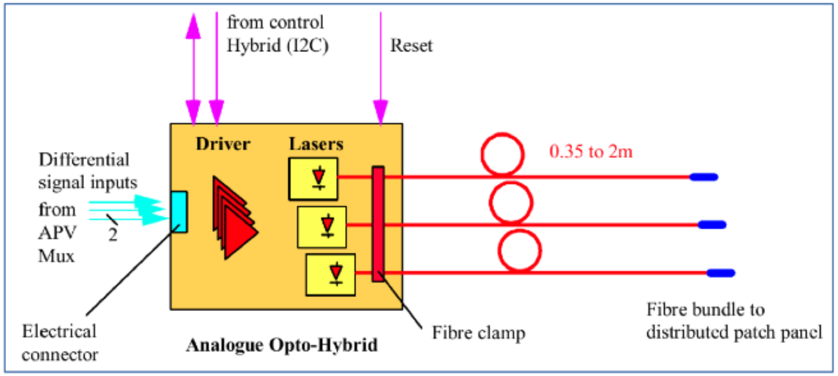
- Overall status at ~ 100 fb^{-1}
- TIB L1 below 100 V at 100 fb^{-1} ⇒ should be close to inversion at 200 fb^{-1}
- Method not very reliable to measure V_{fd} around inversion point



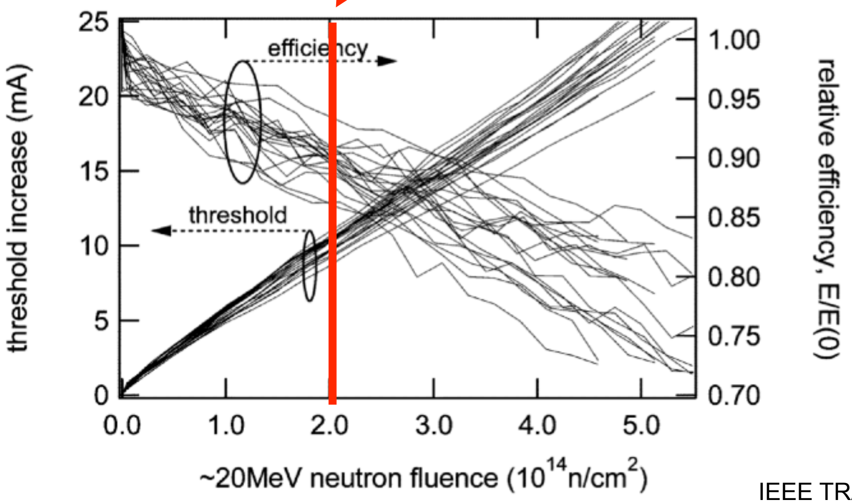


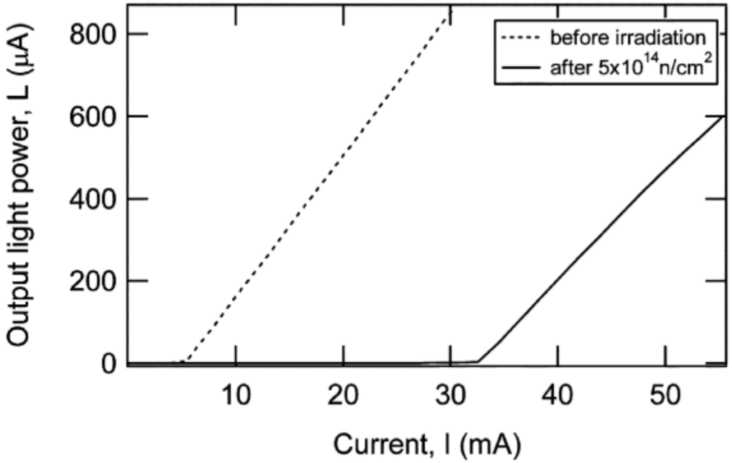
Radiation effects in the optical readout

- Laser drivers and photodiodes are aging due to irradiation causing:
  - threshold increase
  - loss of efficiency



max expected damage to TIB L1 after 500 fb^{-1}





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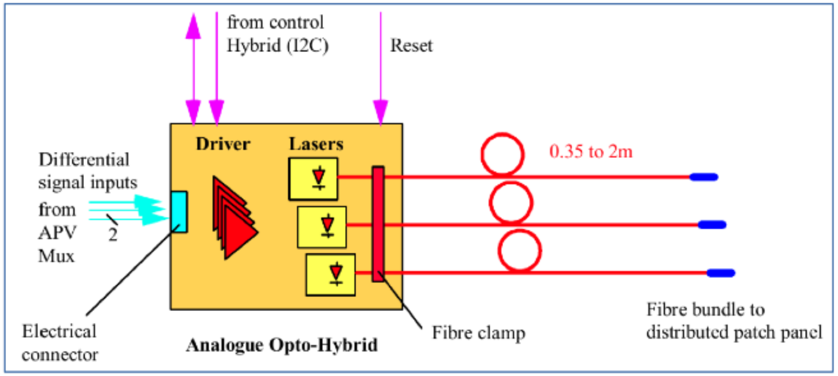
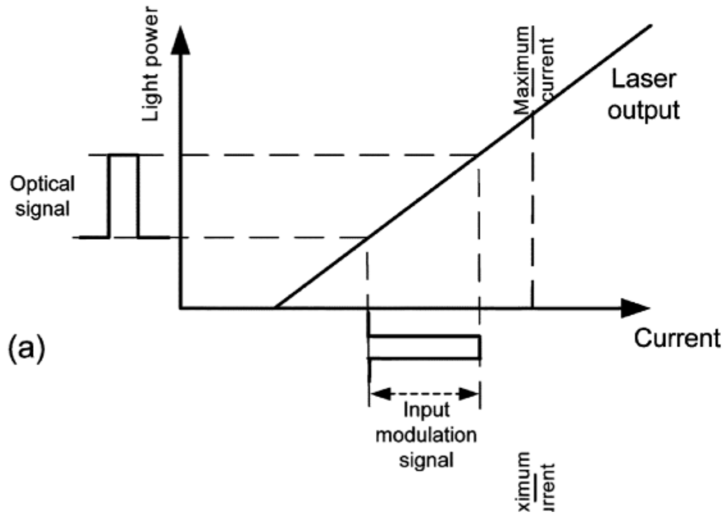


normally working laser driver



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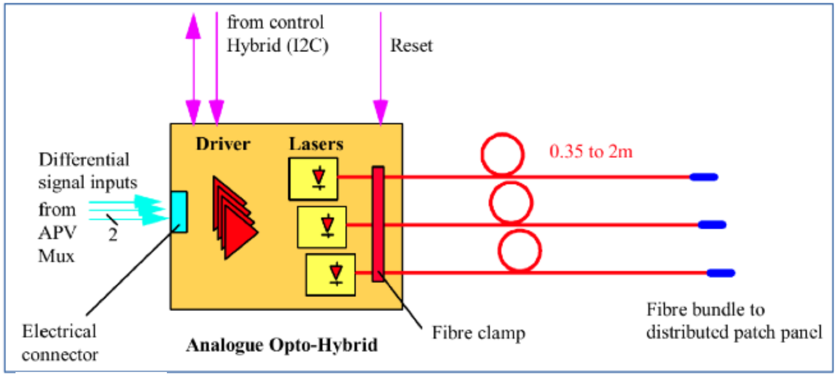
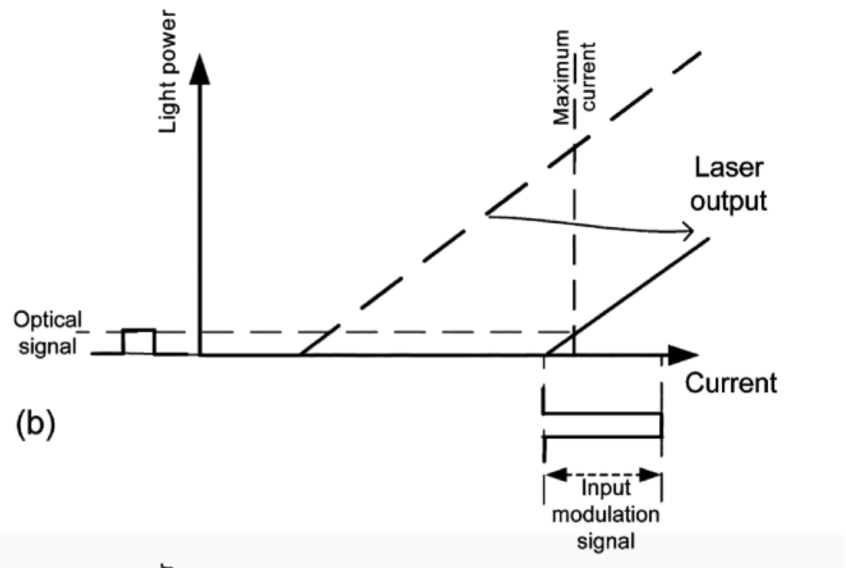


threshold increase



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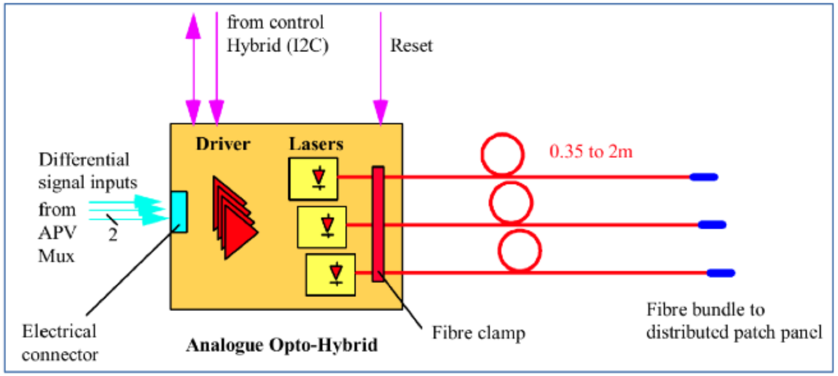
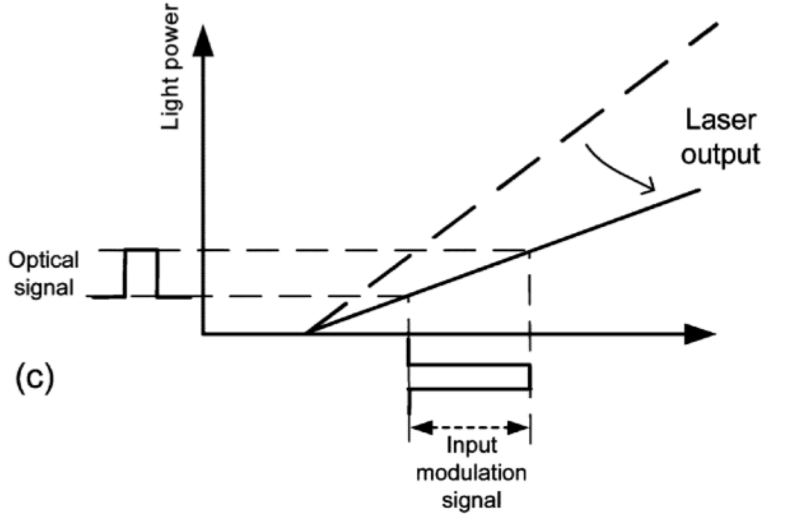


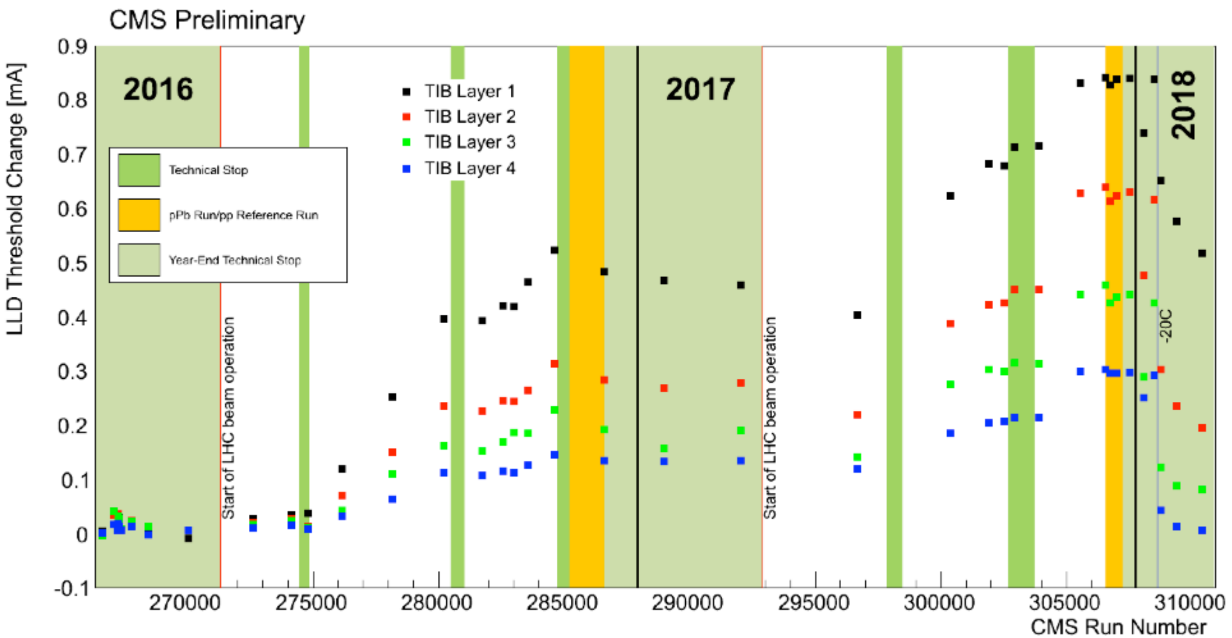
loss of efficiency



AOH performance with irradiation

- Absolute threshold increase in mA
- Average threshold current at the time of reference runs around 3 mA
- Maximum allowable threshold current 22.5 mA
- Increase during high luminosity periods
- Decrease after changing coolant temperature from -15 ℃ to -20 ℃
- Clear dependence on radius

Inner Barrel



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Summary and outlook

- CMS Strips tracker performing well at the end of Run 2 after 10 years of operation
- No major degradation of detector components in the last years
- Signal to noise, hit efficiency and hit resolution are very good
- Operation temperature changed from -15 ℃ to -20 ℃ at the beginning of 2018 which helped to decrease leakage current which was important in uncooled regions and regions with degraded cooling
- Radiation effects are visible in all parts of the detector
  - Monitoring various effects (leakage current, full depletion voltage)
  - TIB L1 should be close to inversion point
  - Uncooled regions and regions with degraded cooling could still benefit from annealing period during LS2 and possibly from changing coolant temperature to -25 ℃)
- Detector will be kept cold as much as possible during LS2 (120 days detector will stay warm due to services unavailable, pixel extraction)

BACKUP SLIDES

Sensors types

Module type	Pitch [μm]	Strip length [mm]	S/N Peak mode	S/N Dec. mode
IB1	80	116.9	25.8 ± 1.3	18.3 ± 0.5
IB2	120	116.9	29.5 ± 1.4	20.3 ± 0.6
OB1	122	183.2	36	25
OB2	183	183.2	38	27
W1TEC	81–112	85.2	33.1 ± 0.7	21.9 ± 0.6
W2	113–143	88.2	31.7 ± 0.5	20.7 ± 0.4
W3	123–158	110.7	29.2 ± 0.6	20.0 ± 0.4
W4	113–139	115.2	28.6 ± 0.5	19.2 ± 0.3
W5	126–156	144.4	42.2 ± 1.1	24.1 ± 1.1
W6	163–205	181.0	37.8 ± 0.6	23.0 ± 0.4
W7	140–172	201.8	35.5 ± 1.0	20.3 ± 1.1

What should we expect for Run 3?

- Simulations are done based
  - temperature measurements per module
  - particle flux simulations with FLUKA

$$I(\Phi, t, T) = I_0 + \alpha(t, T)\Phi V$$

$$\alpha(t, T) = \alpha_0(T) + \alpha_I \exp\left(\frac{-t}{\tau_I(T)}\right) - \beta \ln \frac{t}{t_0}$$

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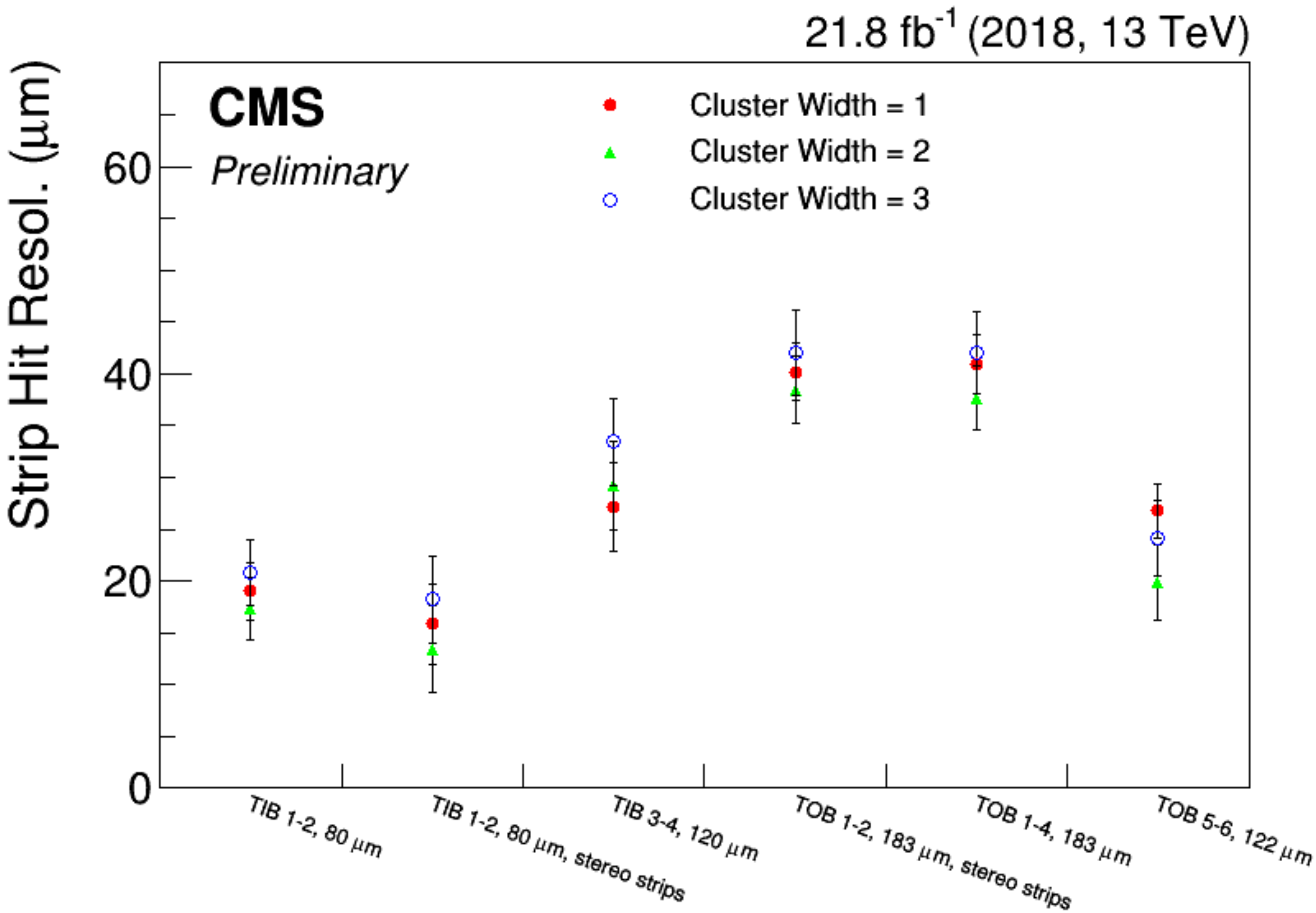
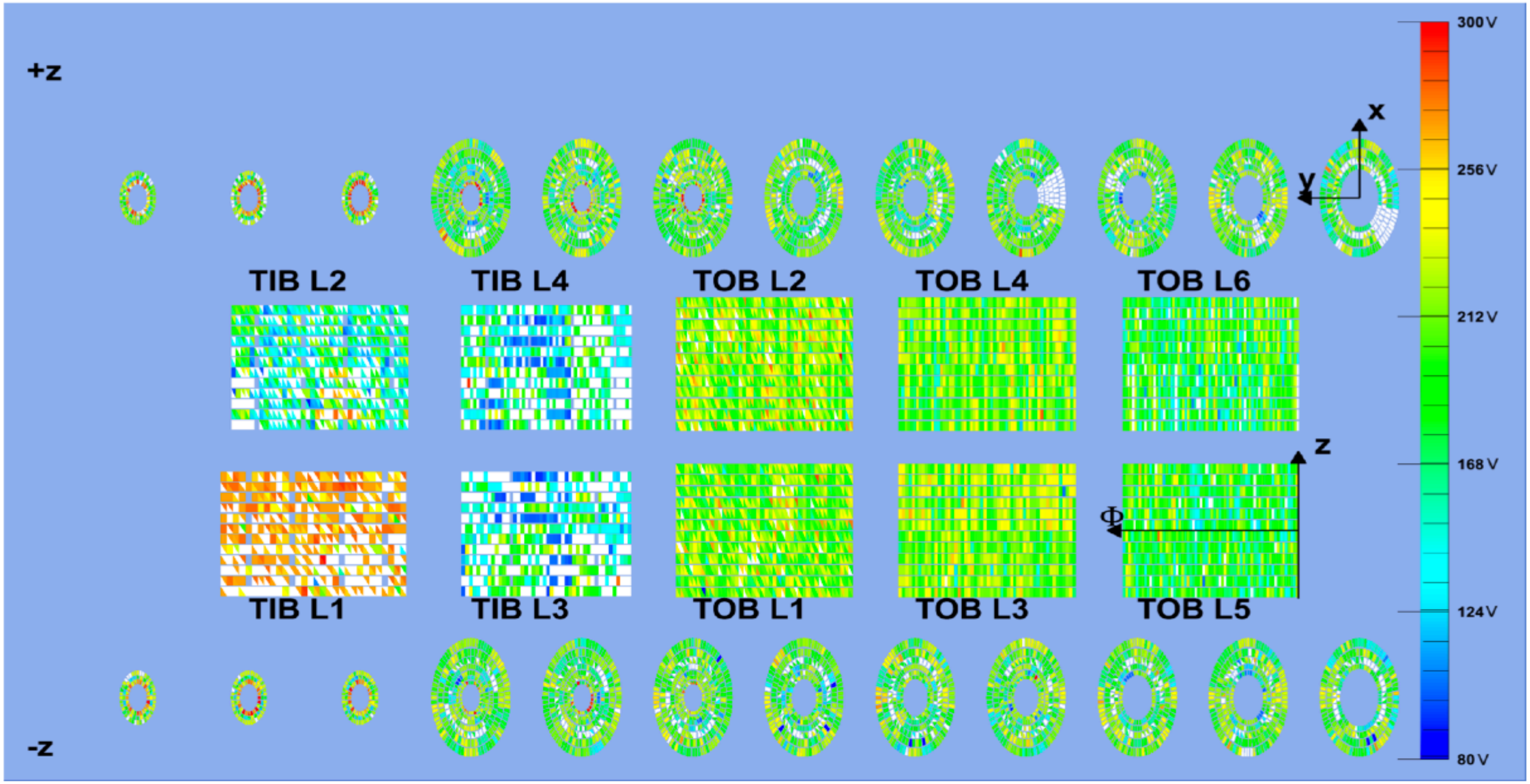

21.8 fb^{-1} (2018, 13 TeV)
CMS
Preliminary
Cluster Width = 1
Cluster Width = 2
Cluster Width = 3
Strip Hit Resol. (μm)
0
20
40
60
TIB 1-2, 80 μm
TIB 1-2, 80 μm, stereo strips
TIB 3-4, 120 μm
TOB 1-2, 183 μm, stereo strips
TOB 1-4, 183 μm
TOB 5-6, 122 μm

Intial Vfd

- Christian Barth thesis



JINST 2008 paper