The TOTEM nT2 detector: architecture, operation and performance

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OUTLINE:

- Physics case
- Experiment overview
- The nT2 detector
- Operations
- Preliminary results

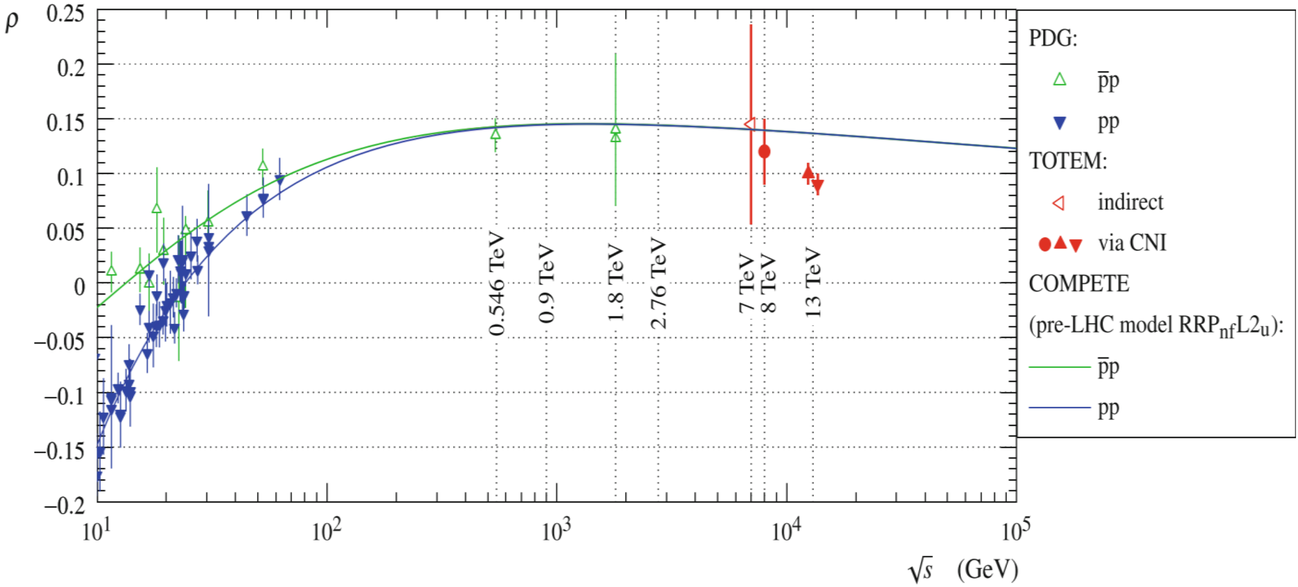
TOTEM measurements

elastic observation only (through Optical theorem)

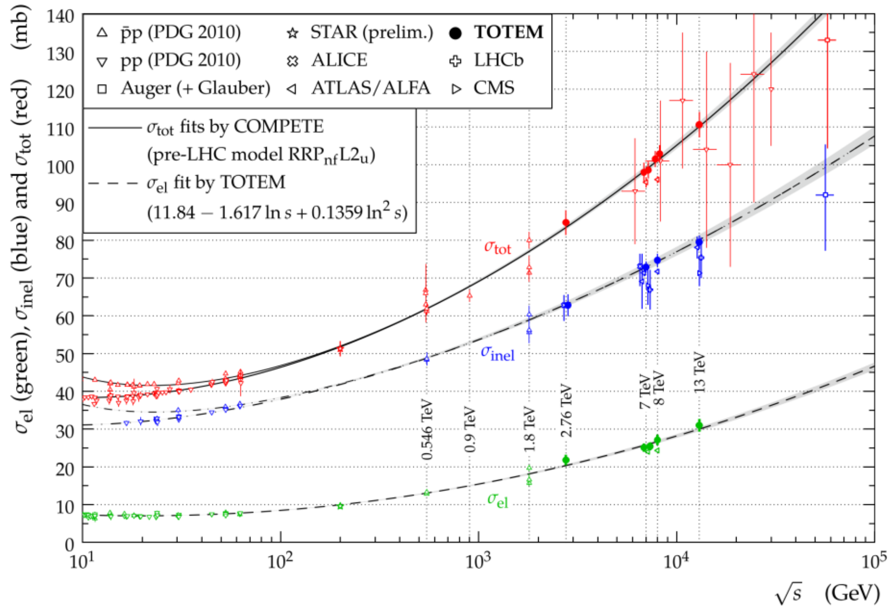
$$\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2}\frac{dN_{el}/dt|_{t=0}}{N_{el}+N_{inel}}$$

$$\rho = \frac{\text{Re A(s,t=0)}}{\text{Im A(s,t=0)}}$$

Direct measurement of ρ is also made by a precise measure of the dN_{el}/dt in the Coulomb-Nuclear Interference (CNI) region.



TOTEM data on total cross section and ρ, collected at different pp energies @LHC, lead to first evidence of the Odderon (*Eur.Phys.J.C* **79** (2019) 9, 785), C-odd counterpart of the Pomeron. Combing TOTEM and D0 (Fermilab, $p\overline{p}$) the discovery was claimed (*Phys.Rev.Lett.* 127 (2021) 6, 062003).



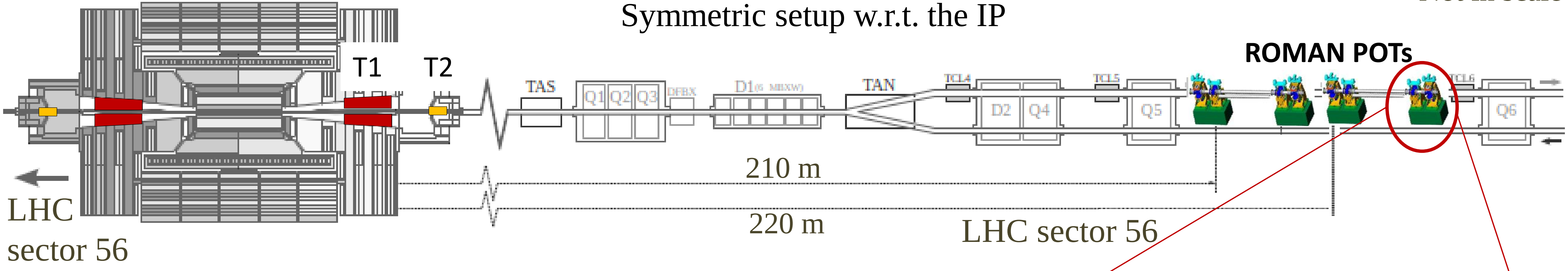
Data in the energy range 2.76-13 TeV have been collected and results published. While the analysis of data collected at 900GeV is ongoing, the LHC approved a new set of measurements @ 13.6 TeV.

TOTEM experimental setup: proton tagging

TOTEM layout (Run2)
Symmetric setup w.r.t. the IP

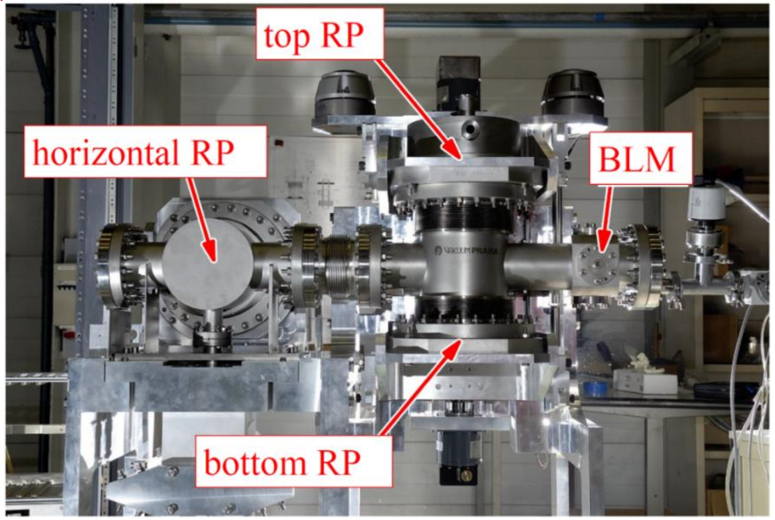
Not in scale

CMS detector



Proton scattered in the elastic collisions are detected by the tracker detectors, hosted in Roman Pot (RP) stations:

- Vacuum vessel entering the beam pipe, can be equipped with many types of detectors. For TOTEM silicon strips are used.
- Hosted detectors brought to few mm from the beam in a secondary vacuum.
- Scattered protons with very-low |t| can be detected
- Standard units composed of 3 RPs (2 verticals, 1 horizontal). Distribution of protons on the detector depends on the LHC optics. The TOTEM data needs an ad hoc optics, characterized by a very high value of β* (from 90 m up to 6 km!) and parallel to point focusing in the vertical plane.

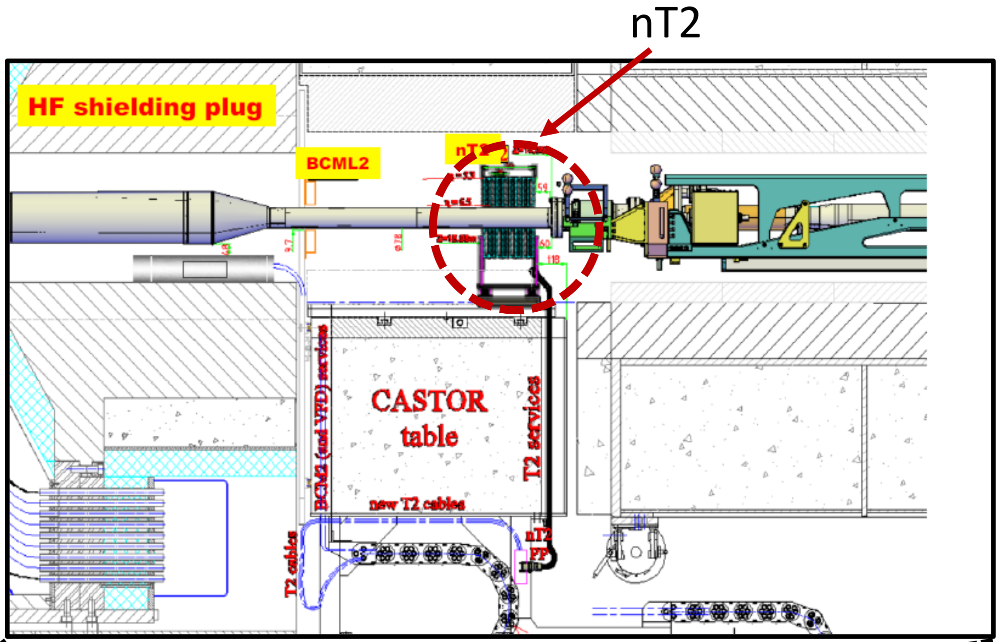


RP unit

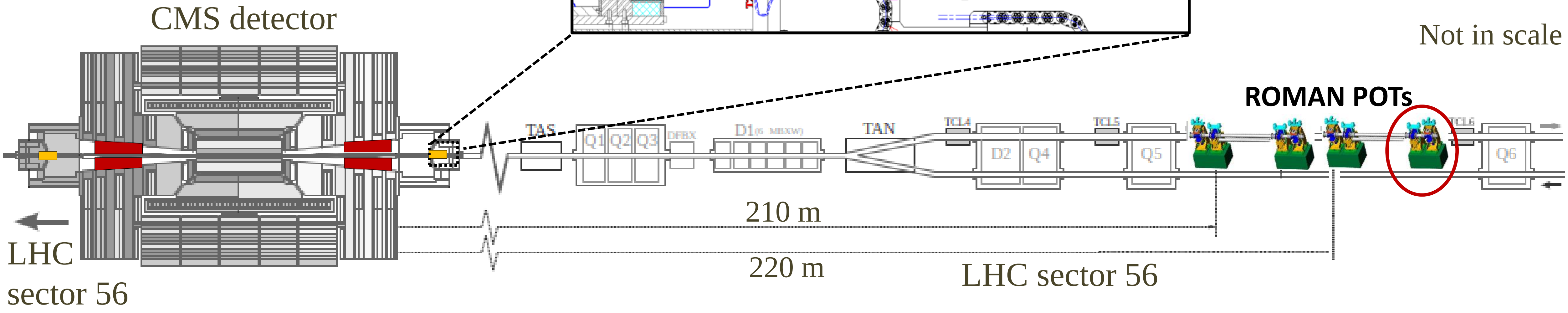
TOTEM experimental setup: inelastic tagging

Inelastic events are detected by inelastic detector, placed in the CMS region and covering the forward eta region.

T1 and T2, after having successfully sustained a radiation damage 10 times above the design requirements, have been dismounted.



Previous inelastic detector T2 was replaced by a new inelastic telescope (nT2) based on scintillators readout by SiPMs.

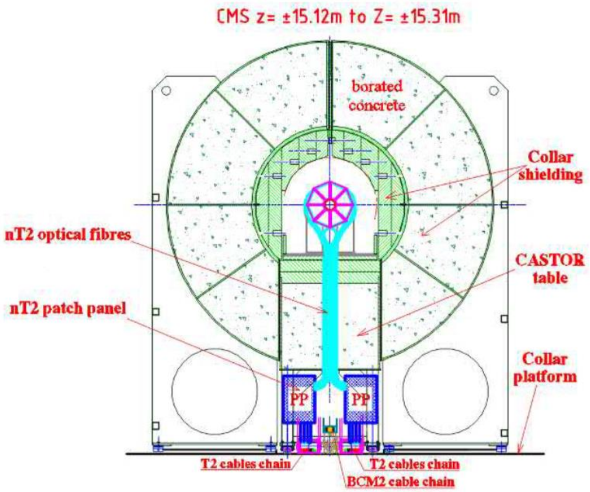


Symmetric setup w.r.t. the IP

nT2 constraint & concept

To cope with project budget, requirements and R&D schedule, scintillators+SiPM were selected as the detection technology for the nT2.

- The run was schedule to happen just after an LHC Technical Stop (TS), after a period of LHC running at maximum luminosity.
- The radiation during standard LHC fill in the nT2 region was known to damage the sensors, so the installation of the detector must be done during the TS, lasting few days.
- The location of the installation (inside the forward CMS shield), was expected to be highly radioactive during the TS



Installation of the detector to be accomplished in minutes, then no more access.

Commissioning of the detector and FE electronics in ~48h, with limited access to the electronics (even if placed outside the shields).

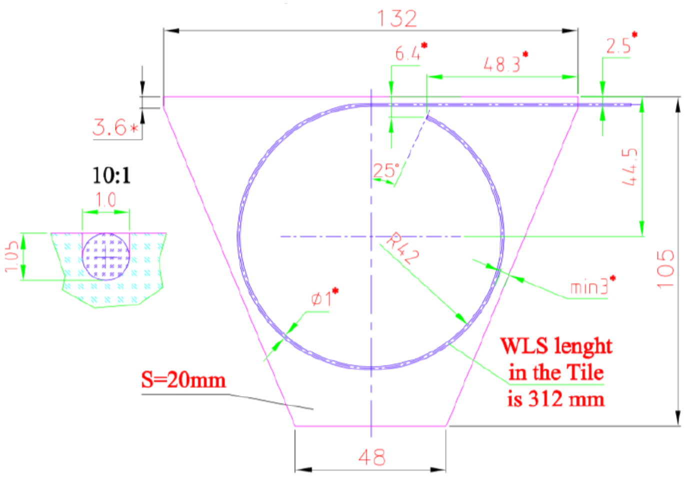
One and only one occasion (of few hours) to collect data with LHC special optics.

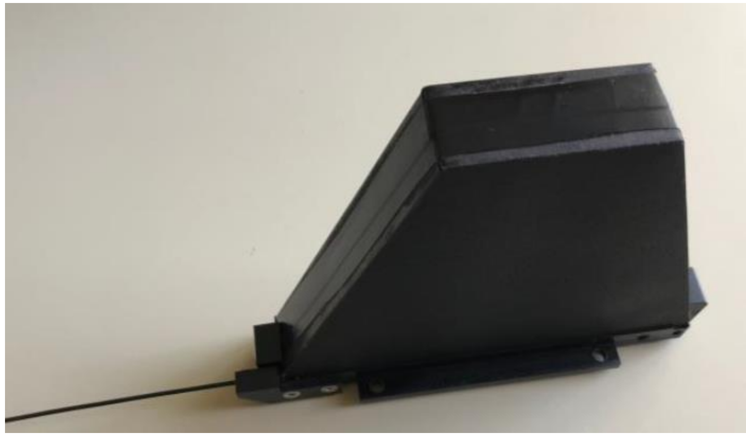
Detector to be operated inside the CMS DAQ and control framework.

Almost no space for errors!

Scintillators & SiPM

Design based on trapezoidal shape scintillators (EJ-204, 2cm thick)

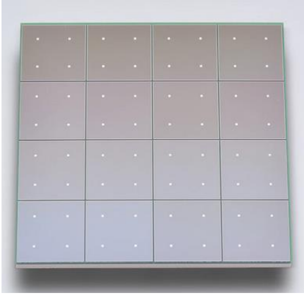




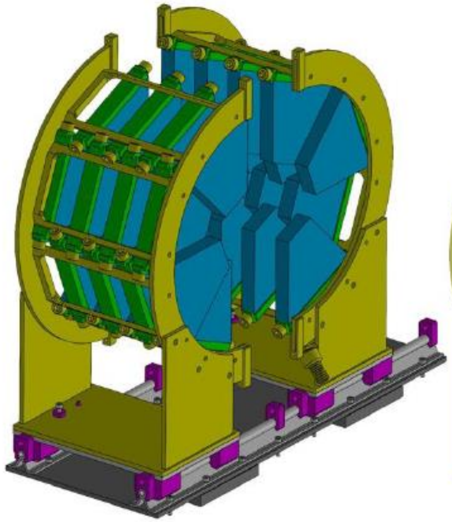
- Individual wrapping of each tile
- Internal WLS fiber spliced at the output of the tile
- Glue-free connection with a 2m long clear fiber, to reduce light attenuation

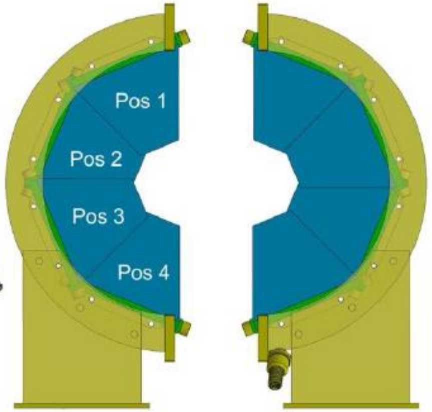
→ Both tiles and external fibers can be independently and quickly replaced in case of failure (a feature which resulted decisive)

S13361-6050 MPPC from Hamamatsu selected as light sensor



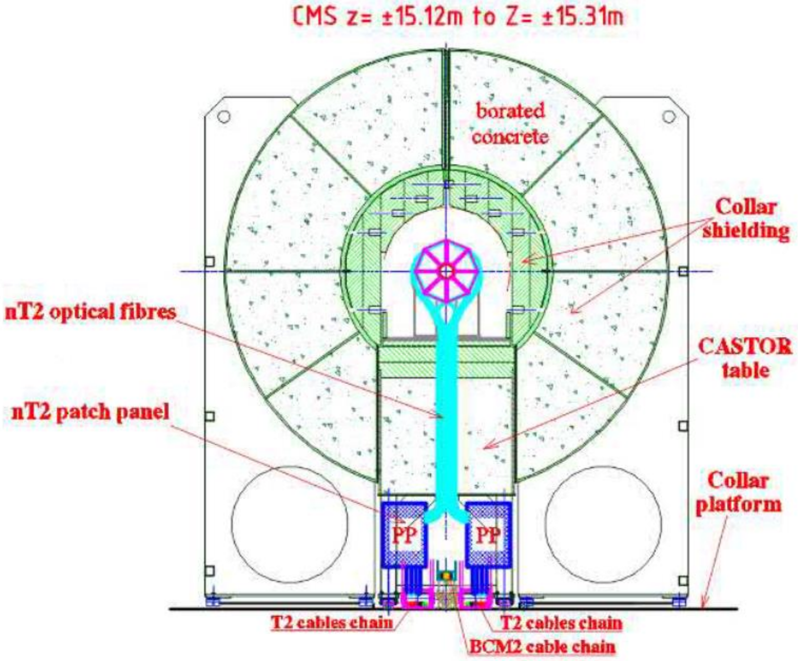
The near-beam detecor





This design allows to avoid any active component inside the shield.

The mechanical rails and the support for the electronics placed below the shield, have been installed during the winter shutdown.

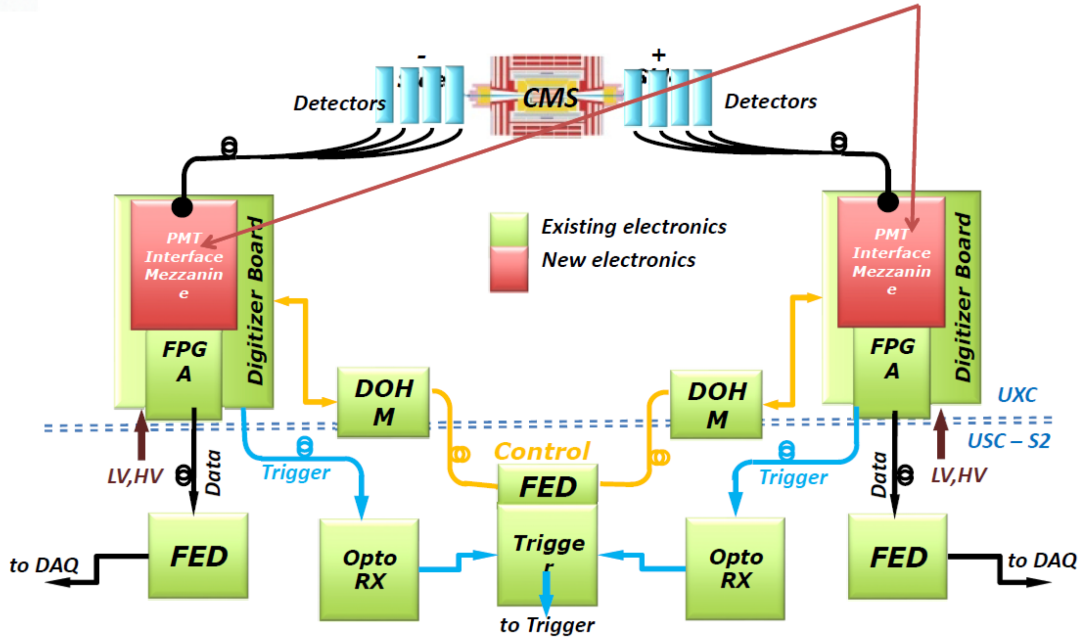


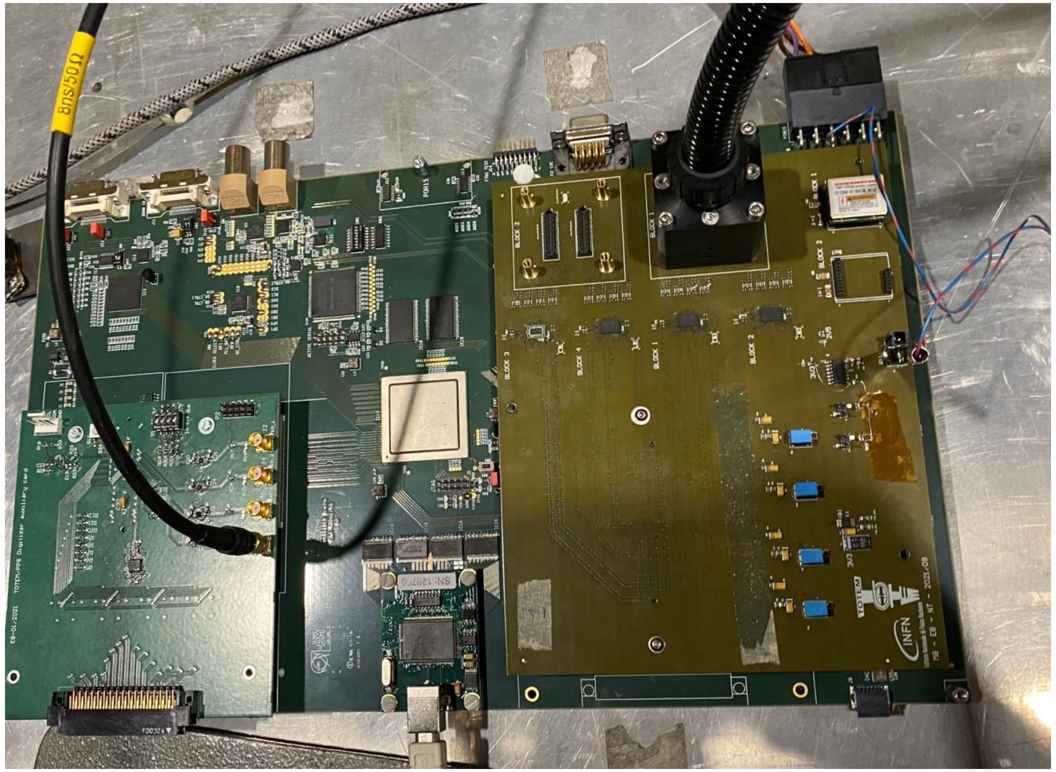
Like the previous T2 detector the detector is divided, on each arm, in two «quarters», closing around the beam pipe. On each quarter:

- 4 detection layer
- Each layer made by 4 tiles, with partial overlap

Each particle will traverse at least 4 aligned tiles, providing a good level of redundancy for particle rejection and noise suppression

Electronics



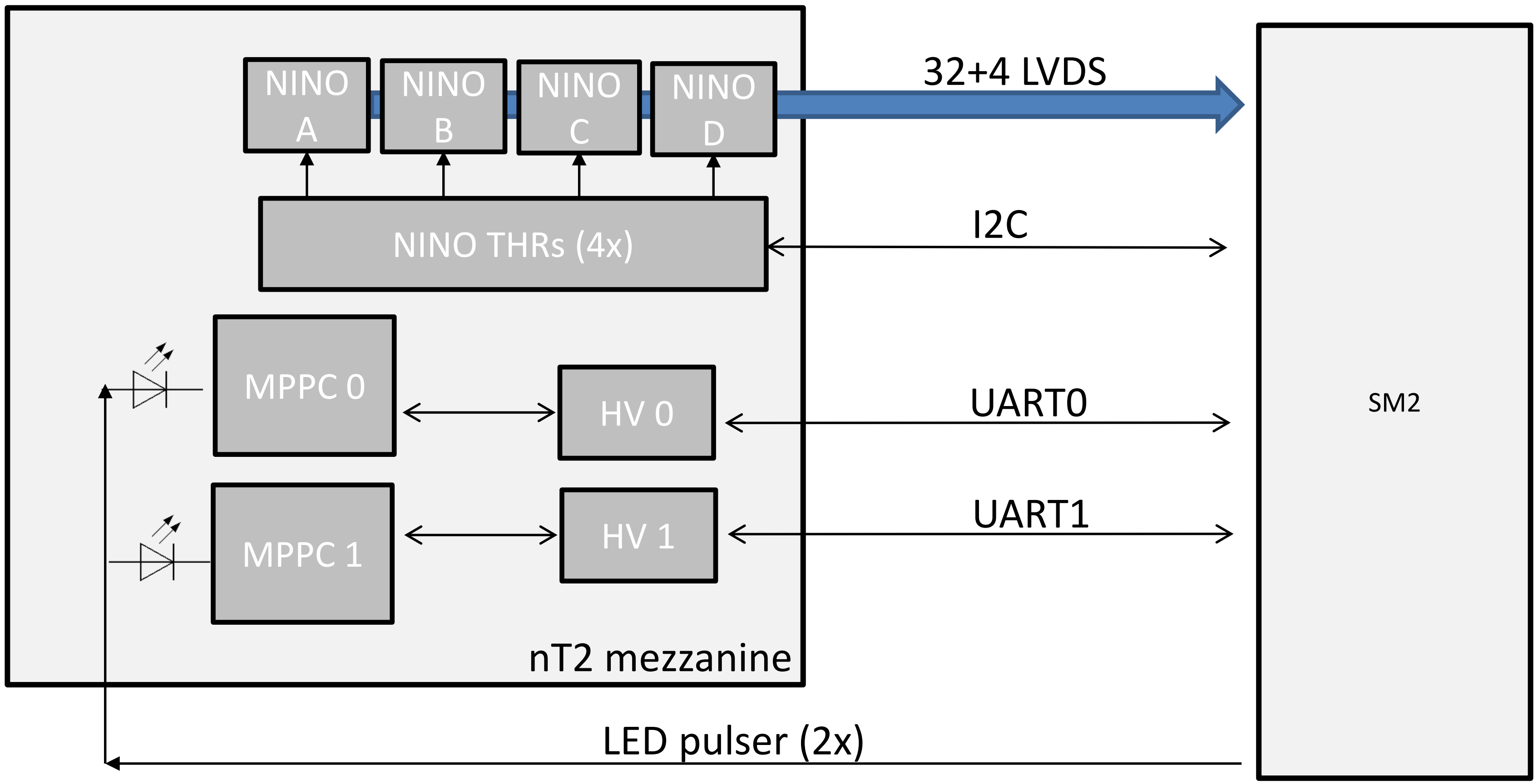


In the last years, the TOTEM readout has been integrated in the CMS framework.
This was made in the framework of the joint CMS-TOTEM project CT-PPS (now only PPS).

Electronics from the timing system of the PPS detector have been readapted to fit the requirements of the nT2 and branched (with non negligible effort) the previous T2 services and infrastructure.

By using the CMS-TOTEM general purpose digitizer board, we developed an interface mezzanine.

nT2 Mezzanine and firmware



The integration of the nT2 with the CMS control and readout system rely on the firmware loaded in the SmartFusion2 SoC FPGA on the Digitizer board:

- Event building
- Data buffering
- TDC feature, adding a coarse timestamp to the leading and trailing edges of the signal (6 ns bin), used in the offline analysis

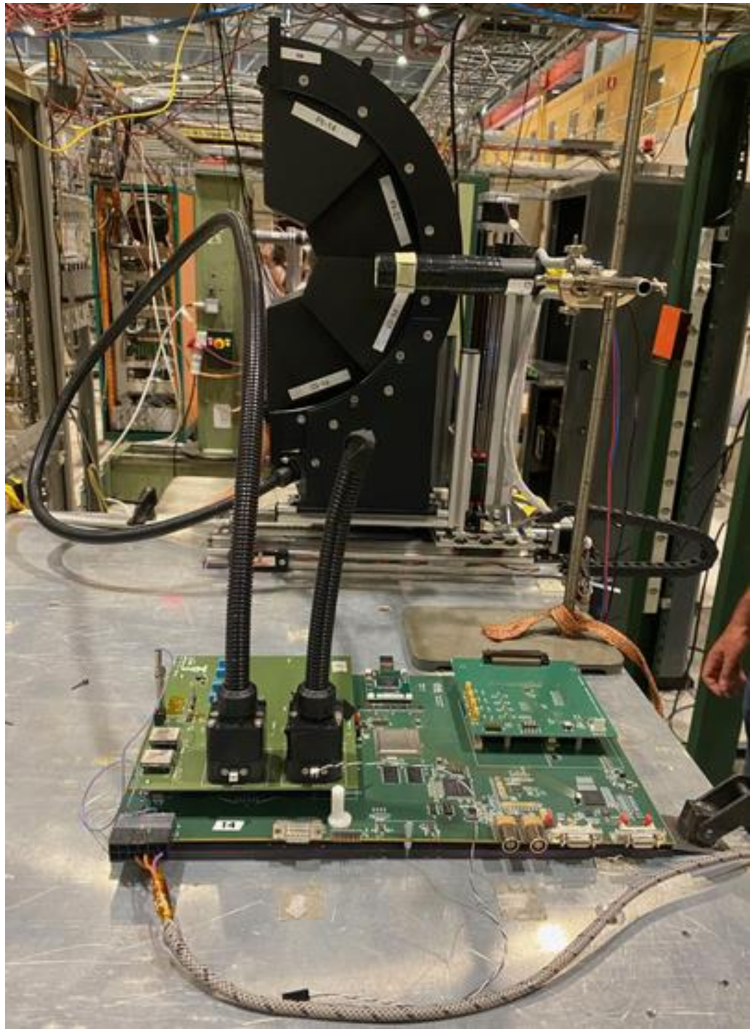
- Communication with the mezzanine components

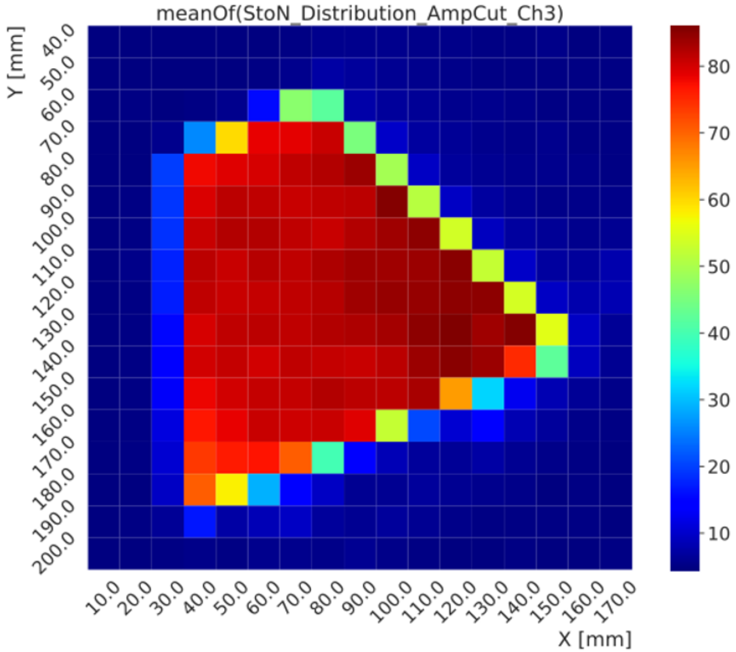
- Debugging and online monitoring
- Online efficiency monitor
- Flags to identify events with multiple leading/trailing

Control of mezzanine devices, trough UART or I2C, is handled through the ARM CORTEX M3 integrated in the SF2 SoC.

Adding flexibility and quick to change in case of need, even during the data taking uCode stored on FLASH device and rebootable through the firmware

Test beams

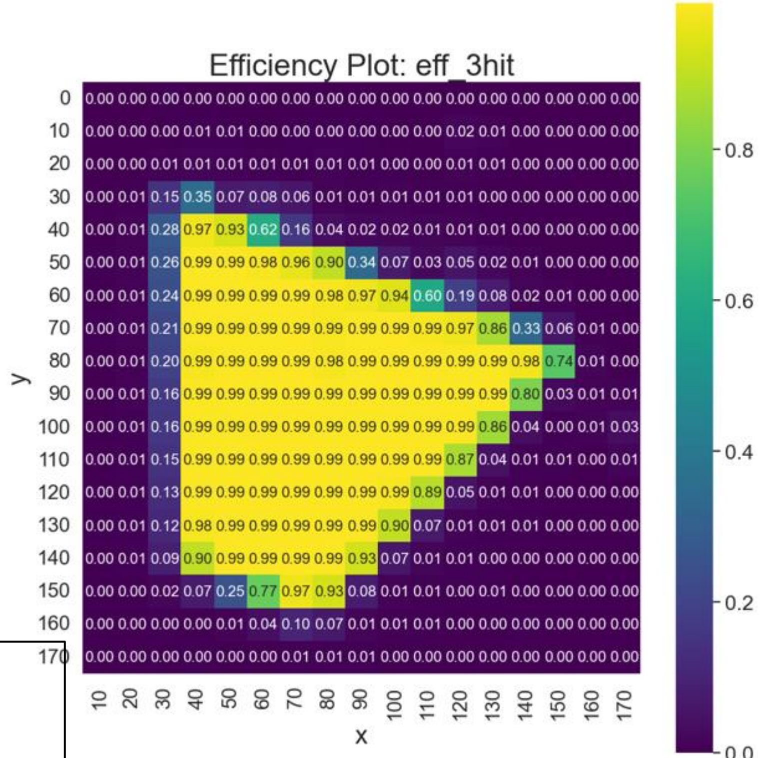




SNR scan of one of the tiles

All tiles tested in a dedicated test beam campaign to assess «wedge» efficiency

Readout with an oscilloscope after a single stage amplification of the MPPC output



Efficiency scan of a wedge (4 aligned tiles) requiring a 3/4 coincidence

The same test performed with final electronics just before the installation, showed a critical problem in some fibers, which were promptly exchanged

Installation and decommisioning

- The Electronics was mounted and tested with the shields closed the day before the sensor installation.

• Detector installation on the first arm took 8 minutes, from waking in and out.
• The second arm took 5 minutes.
• The photodetectors were plugged with the shields closed, negligible dose expected and seen.

And after ~2 weeks…

• The deinstallation phase required on both arms 2 minutes.
• The dose was minimal.
• Everything went smooth!

Operations

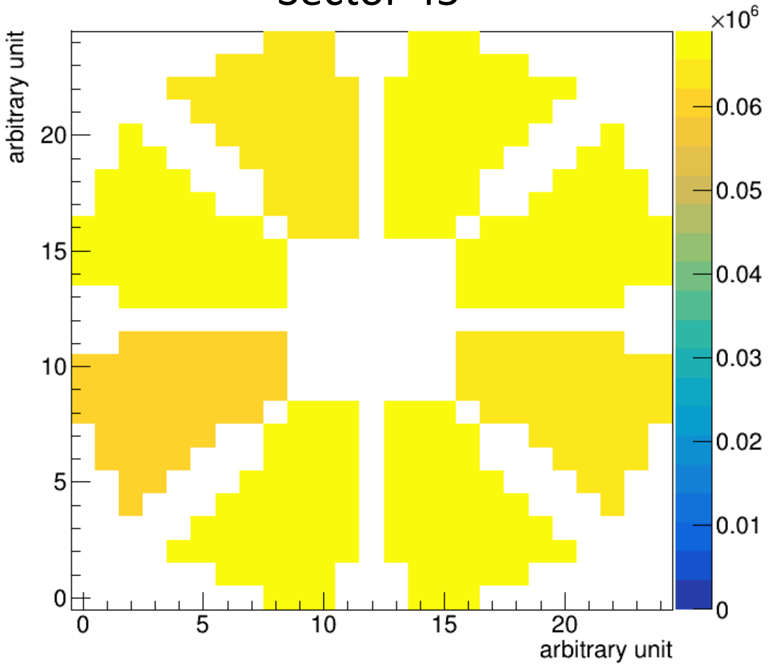
It was a very long marathon, but the running of the detector went very smooth.

- No crashes or problems from the DAQ side: al software/firmware/hardware performing at 100%, since the beginning of the operation!
- Tuning of NINO thresholds and MPPC voltages was performed online, during the commissioning runs, exploiting the FPGA onboard functionality
- The efficiencies looked as we expected from the test pre-Installation.

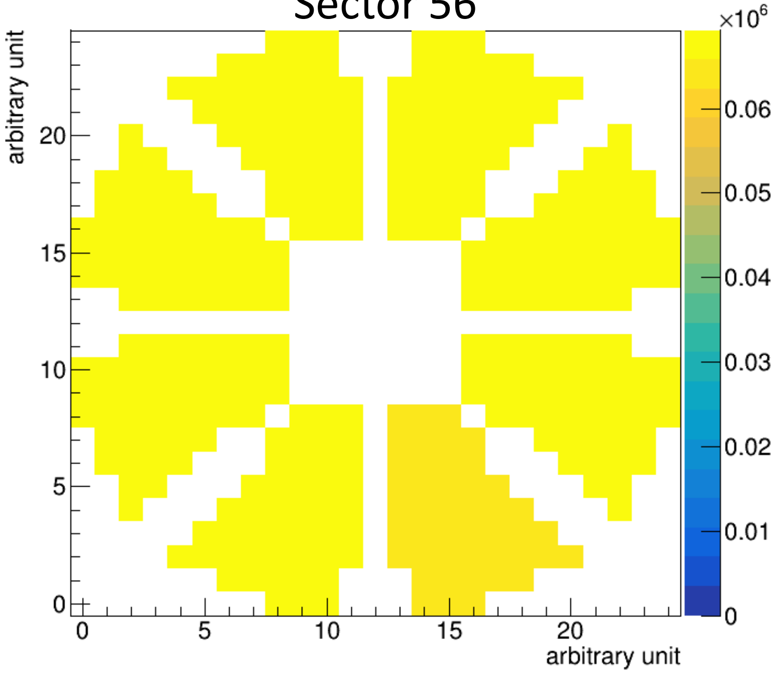
Trigger:
Full Zero Bias (3b)
Random Trigger (20khz) for calibration
Non colliding bunch (~1.7 Khz)

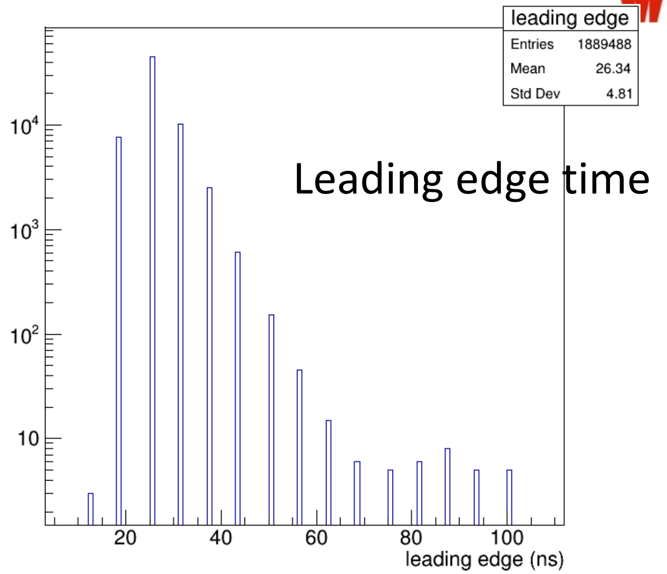
Online Data quality

Sector 45



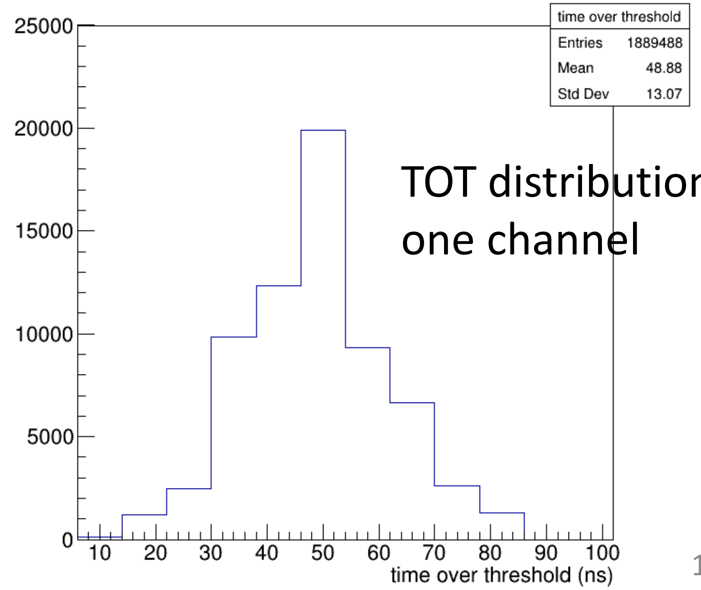
Sector 56





Leading edge time

Occupancy of the wedges requiring a 3 out of 4 coincidence.



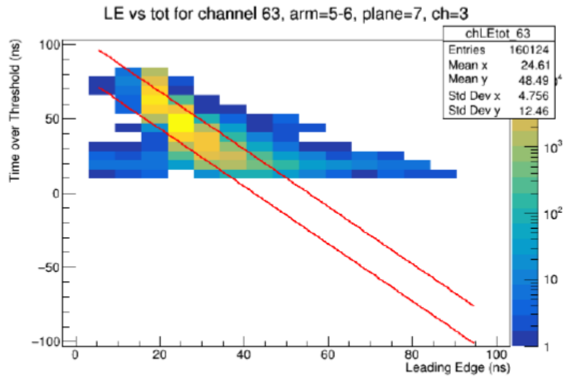
TOT distribution for one channel

The signal Time Over Threshold (TOT) is obtained by the offline substraction of the trailing and the leading time.

The DQM software performed as expected, giving all required tool to monitor the detector operation

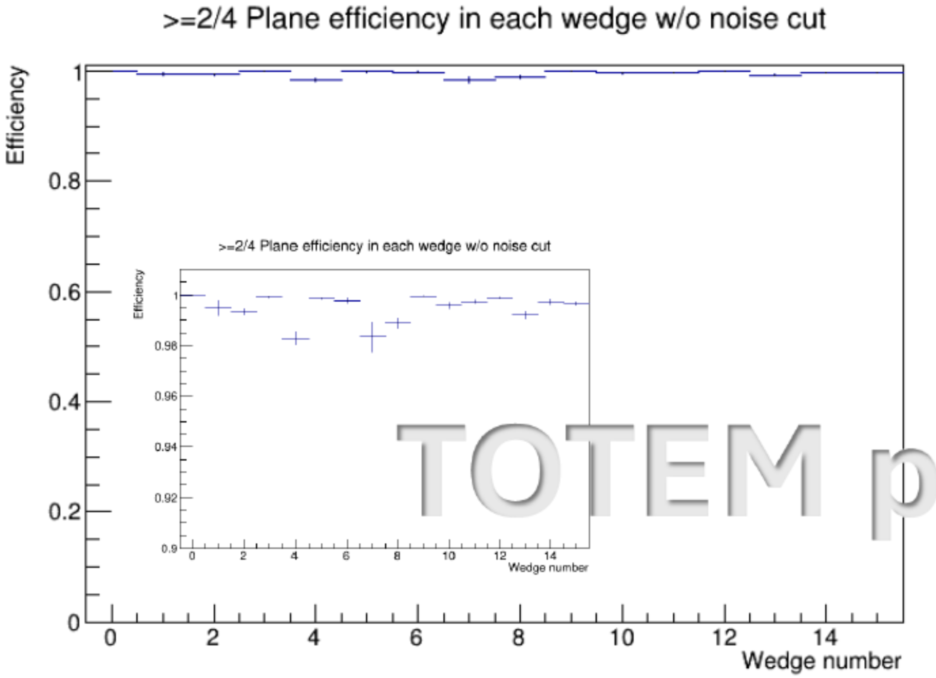
Offline analysis -preliminary

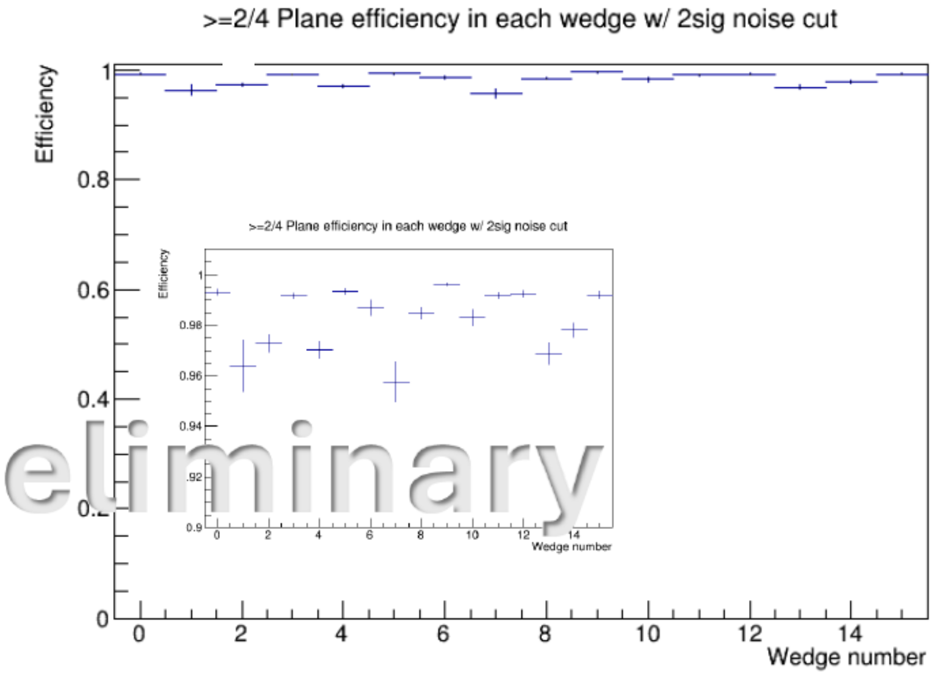
The offline background removal is based on the Leading time and TOT. The correlation, caused by the signal time walk, is clearly visible.



No background removal: median 99.7%

Background removal: median 98.6%





Conclusions

- The LHC approved a new set of measurements @ 13.6 TeV.
- The T2 inelastic detector, crucial for the measurements, after having successfully sustained a radiation damage 10 times above the design requirements, have been dismounted. A new inelastic telescope (nT2) based on scintillators readout by SiPMs, was designed.
- The detector has been operated for the special run of TOTEM. Despite the required fast installation and very short commissioning time, addressed by the detector design, all went smooth during the data taking!
- Preliminary results demonstrates that good quality data were collected, which are now used for the data analysis to complete the TOTEM physics program.