The TOTEM, CMS PPS and LHCf Run 3 upgrades

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On behalf of the CMS, LHCf and TOTEM Collaborations

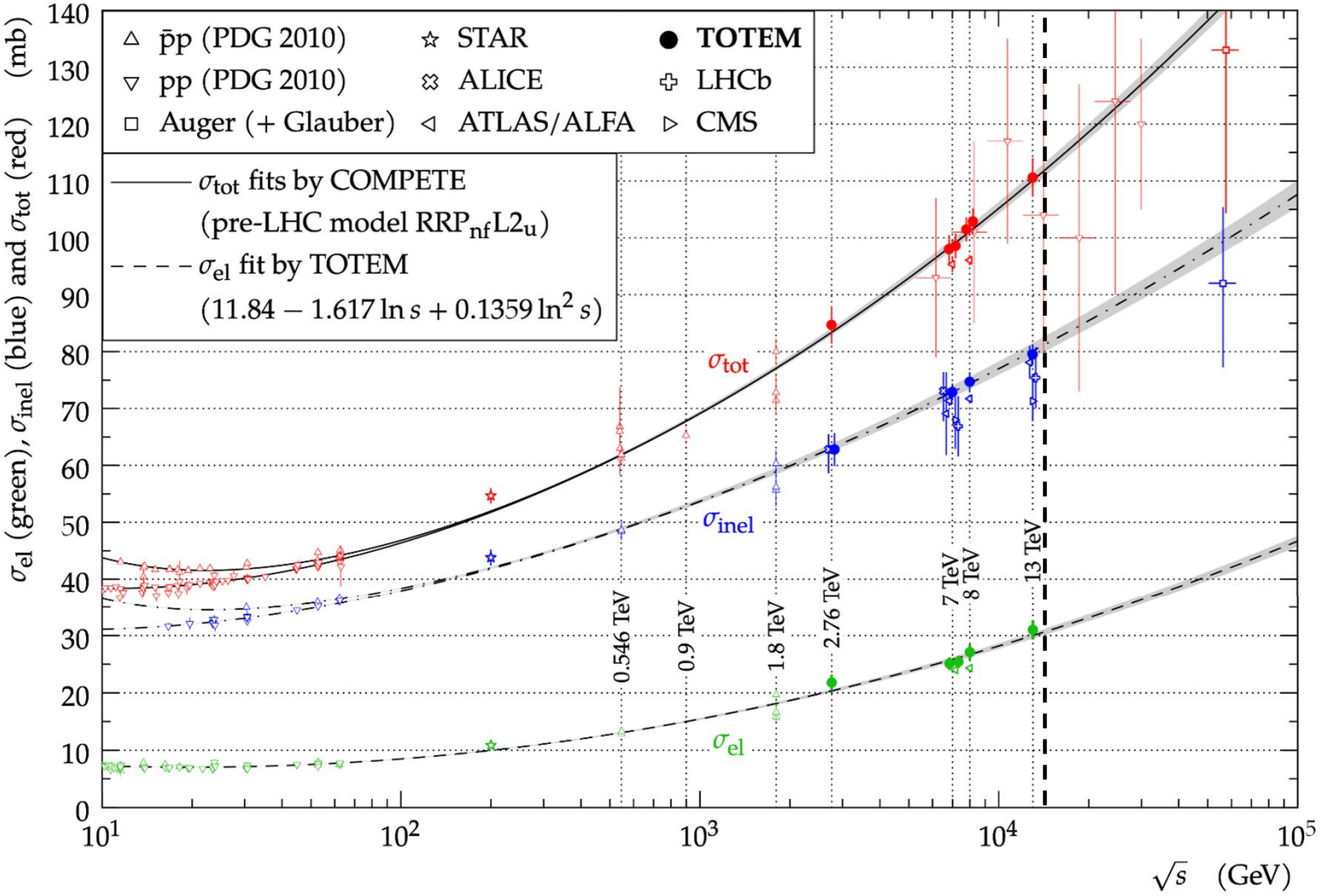
Outline

- **TOTEM:**
  - Introduction and Experimental Apparatus
  - Detector Upgrade for the nT2 telescope
  - Installation, commissioning and running scenarios
- **The Precision Proton Spectrometer of CMS:**
  - Introduction and experimental apparatus
  - Operation in Run 2 and Upgrade for Run 3
- **LHCf:**
  - The LHC Forward (LHCf) Experiment
  - Operation in 2022 and Upgrade for Run3

σ_{tot}, σ_{inel} and σ_{el} as a function of $\sqrt{s}$

TOTEM FORWARD PHYSICS EXPERIMENT FOCUSES ON THE MEASUREMENTS OF:

- The total proton proton (pp) cross section,
- The ρ parameter,
- The elastic differential pp cross section in a wide range of |t|,
- Diffractive physics with CMS



The total, elastic and inelastic cross-sections as measured at various LHC energies and below.

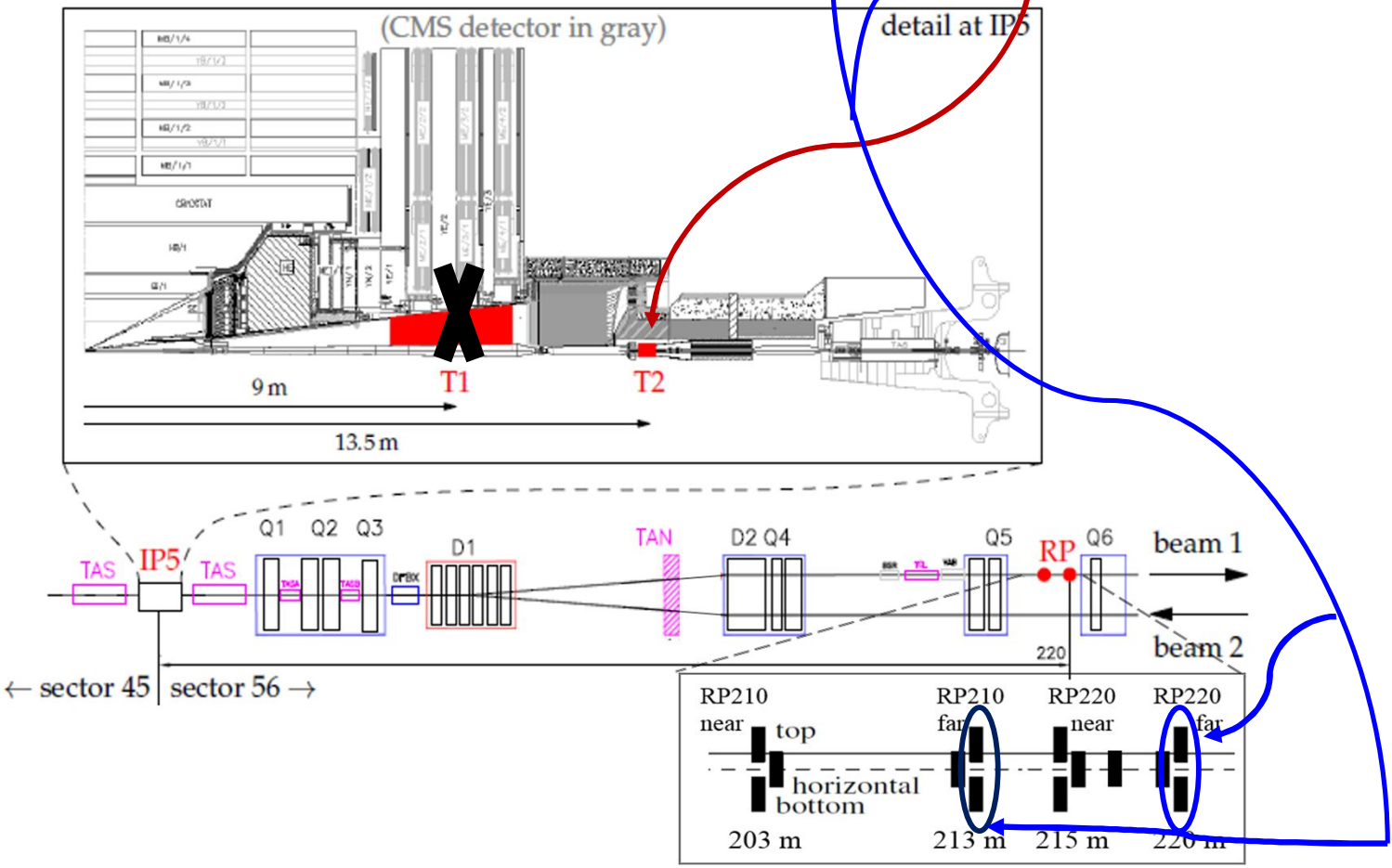
TOTEM discovery (see tomorrow's talk on Odderon exchange from elastic scattering in pp and p$\bar{p}$ with TOTEM and D0 by C. Royon)

σ_{tot} measurement at $\sqrt{s}$ = 13.6 TeV

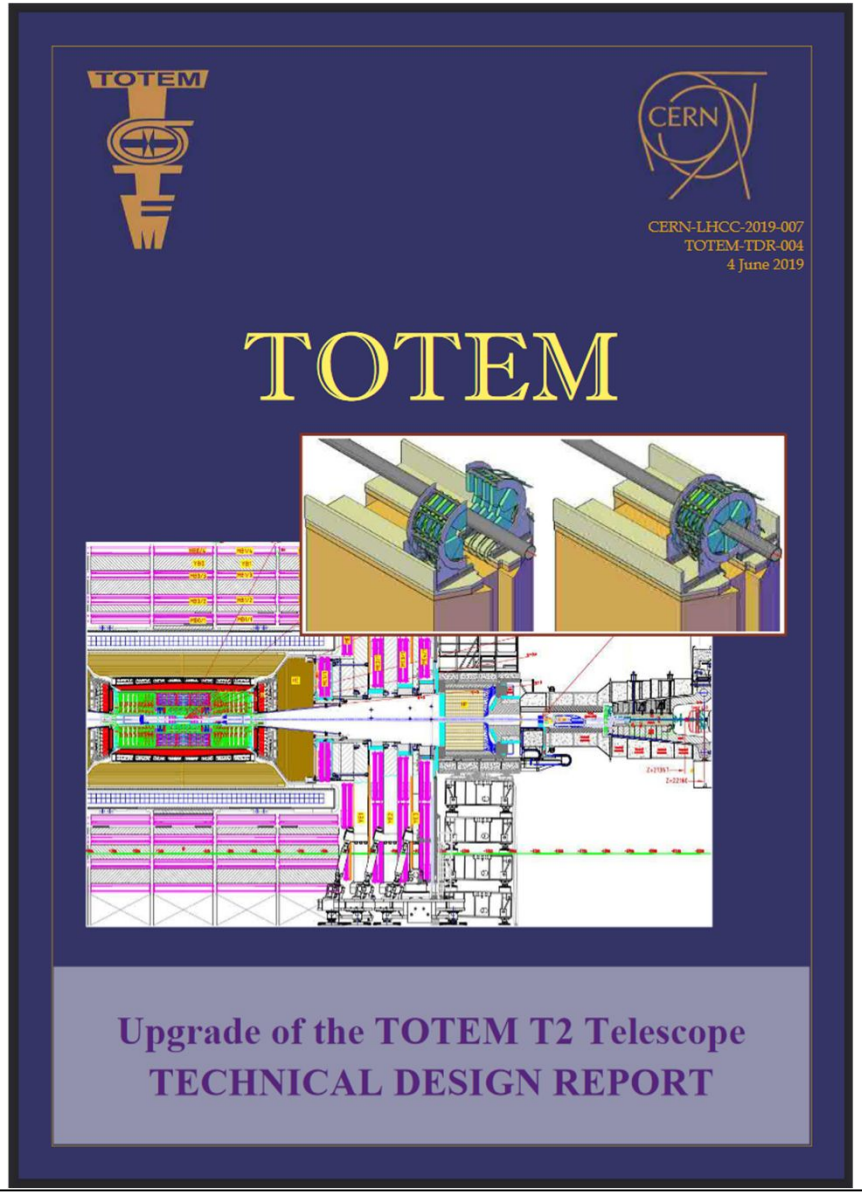
Luminosity independent method:

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

- Dedicated special β^* = 90 m run in November 2022
- Old T2 not compatible with the LHC vacuum pipe installed in LS2 (for CMS HGCAL)

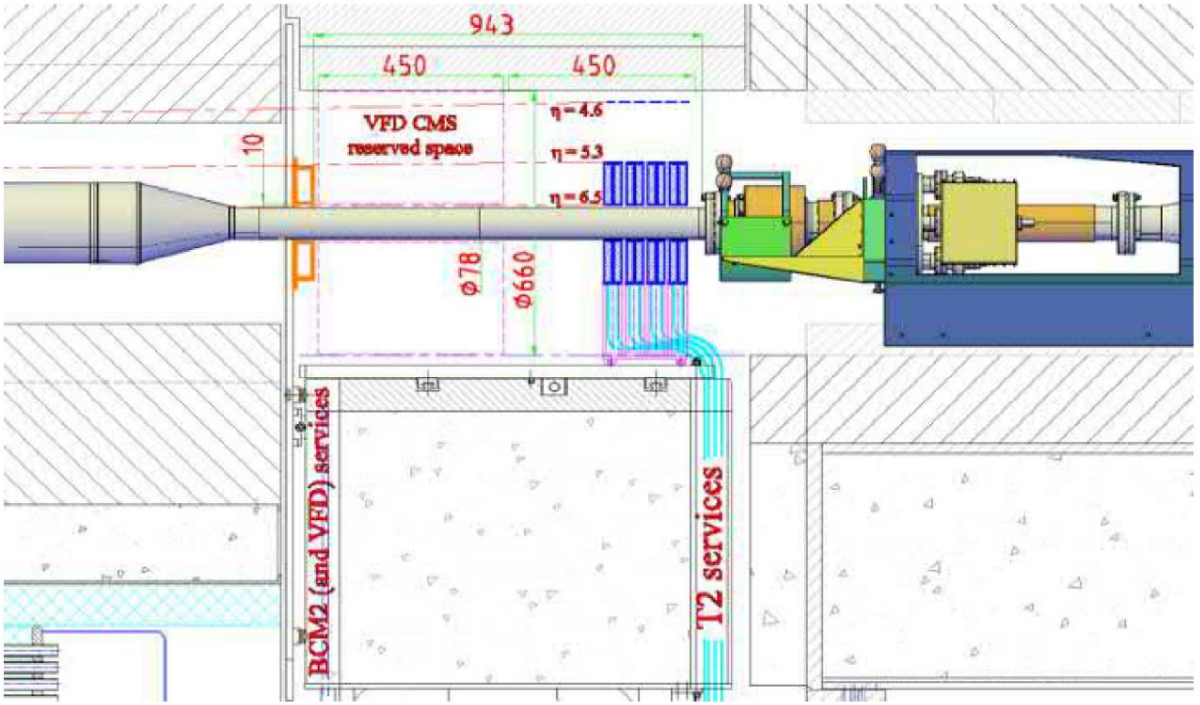


nT2 Telescope for Run 3



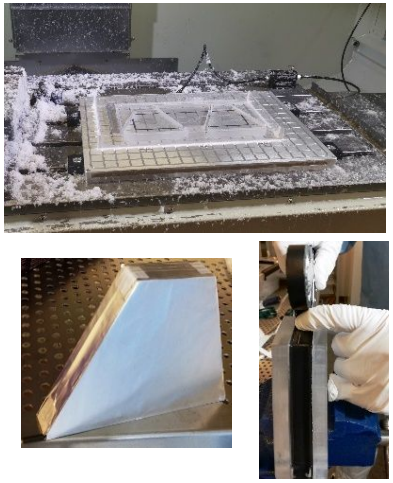
A new **plastic scintillitaion based** detector for the TOTEM experiment is designed to measure the rate of inelastic proton-proton events in low luminosity special runs dedicated to the measurement of the total cross section at the highest LHC energy.

With a **pseudorapidity coverage of 5.3 < |η| < 6.5**, the new T2 will **detect more than 90 % of the inelastic events** at a center-of-mass energy of 13.6 TeV and thus allow a precise inelastic rate and total cross section measurement.



nT2 Installation, Commissioning and Running Scenarios

Process developed at HIP: mechanical workshop & clean rooms



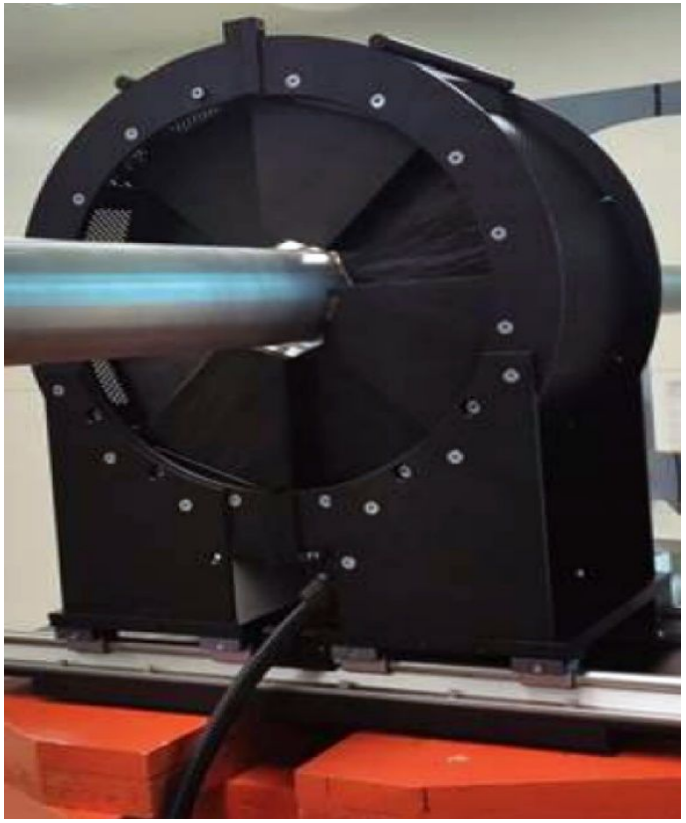
Final Tile structure and assembling

- 2022 → Commissioning 1st quarter in May at SPS
- 2022 → Commissioning 2nd, 3rd and 4rh quarters
- **2022 → pp collisions (End of the year special run)**
- 2022 → AA collisions with CMS?

The Finnish Contribution to TOTEM experiment is very wide from the coordination of the physics program to the R&D of the different types of detectors currently in use, as for instance the production and operation of the T2 telescope and now with its upgrade.

Currently the production of 80 tiles is ongoing at the Helsinki Institute of Physics. They will be used to equip four quarters, which will form the two telescopes.

Set of tiles for the first pilot quarter



Frame mockup of the nT2 frame and beam pipe

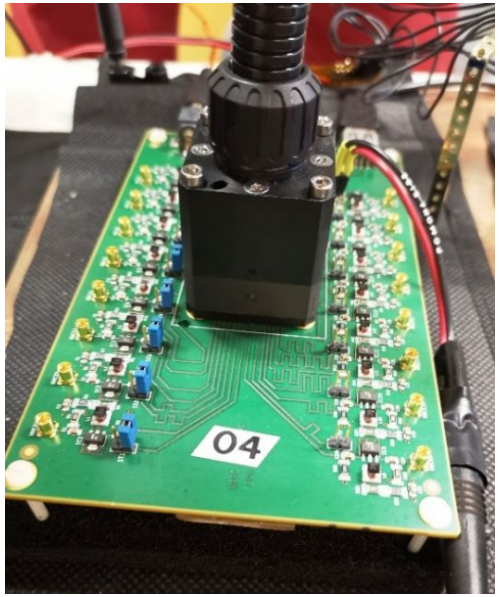
nT2 tiles test beam at the SPS/PS in 2021

Six different type of tiles assembled for a test beam

A pilot test was carried out at the SPS and PS to map the response of different types of tiles.

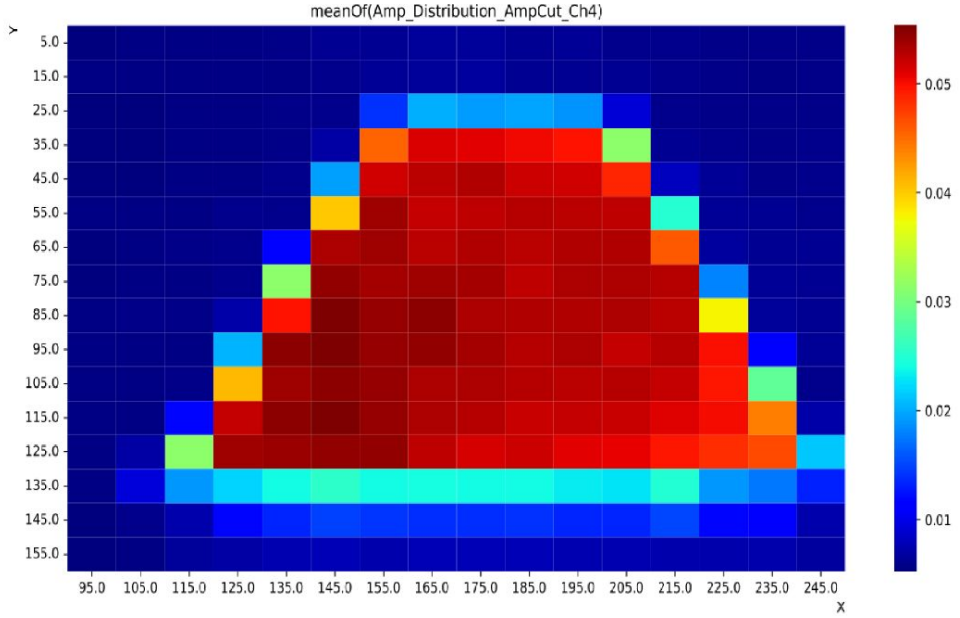
A tomography of the Mean Amplitude response for pions obtained for the tile chosen for the full production **showed good uniformity** of the light yield, the signal to noise ratio and the rise time.

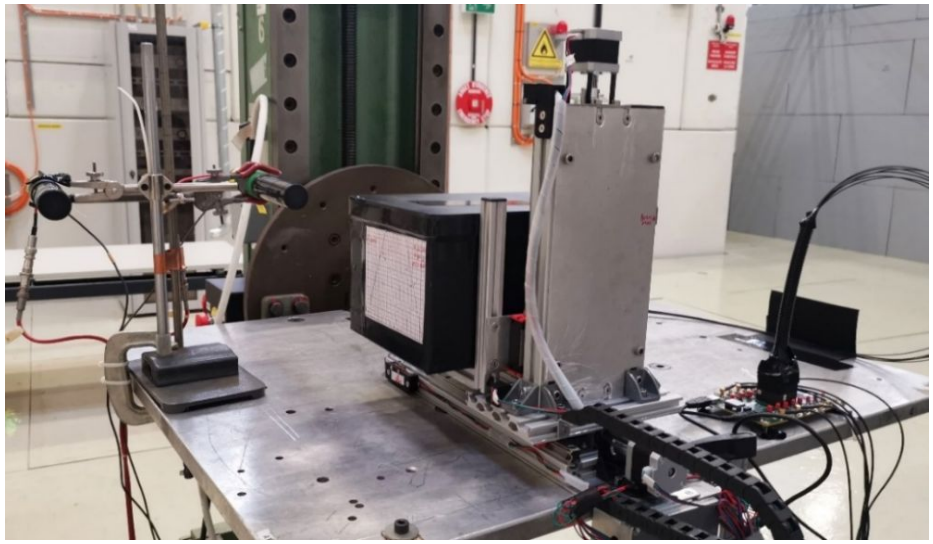
The photosensor used for the measurements was a Hamamatsu MPPC matrix array of 4 x 4 pixels.



Test bench card for the photosensor

Mean Amplitude tomography of **Final Prototype**





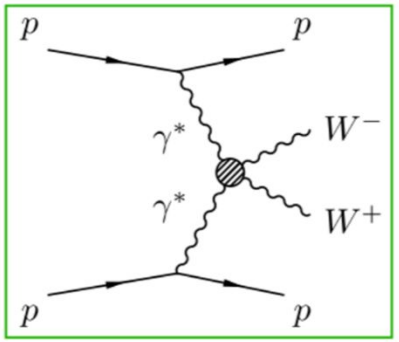
Test setup at the PS – T9 line

The Precision Proton Spectrometer of CMS

Main target of the CT-PPS physics program is the study of Central Exclusive Production (CEP) processes:

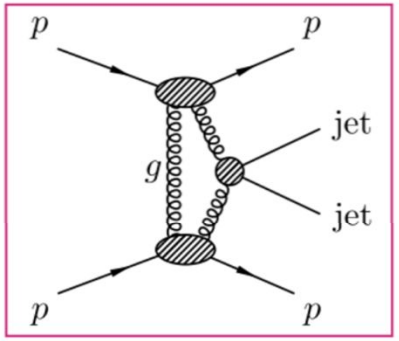
- interacting protons remain intact and get detected in the roman pots; main reconstructed kinematic variable is their fractional momentum loss, $\xi \equiv (|\boldsymbol{p}_f| - |\boldsymbol{p}_i|)/|\boldsymbol{p}_i|$
- energy lost by protons goes into exclusive final state reconstructed by CMS

Final state generated via $\gamma\gamma$ fusion or gluon exchange



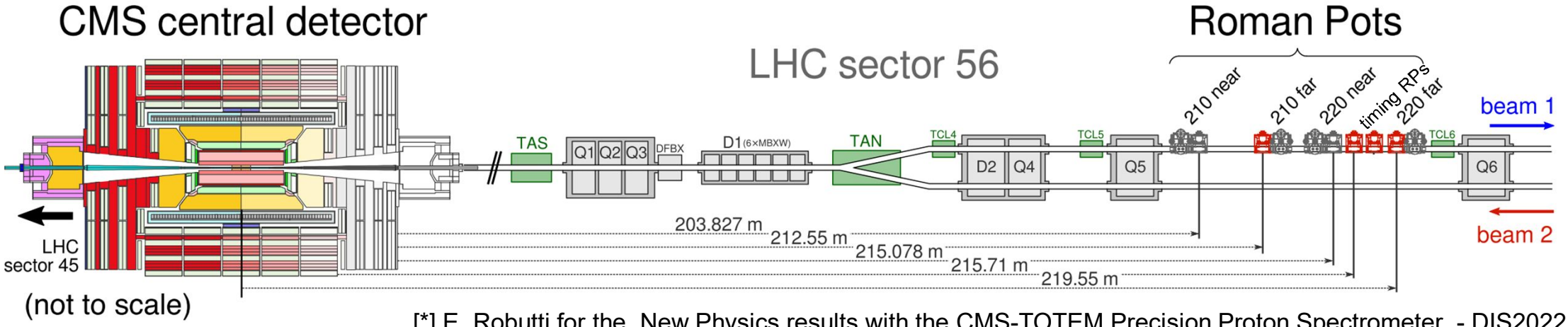
Wide range of physics measurements accessible:

- rare SM processes ⟹ anomalous gauge couplings, BSM contributions;
- direct search for new resonances, including invisible states;
- diffractive physics;
- jet characterisation (dominant gluon component)



[*] E. Robutti for the New Physics results with the CMS-TOTEM Precision Proton Spectrometer - DIS2022

The Precision Proton Spectrometer of CMS



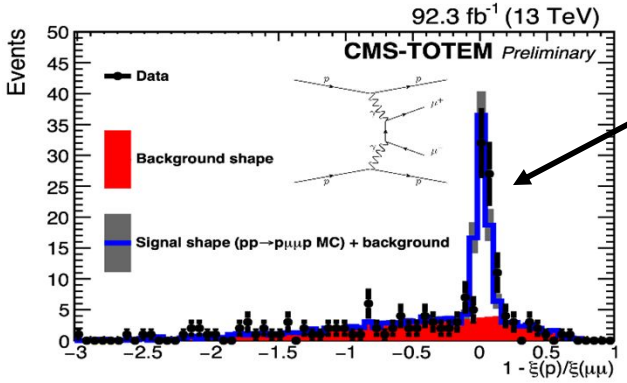
[*] E. Robutti for the New Physics results with the CMS-TOTEM Precision Proton Spectrometer - DIS2022

- CT-PPS was a joint CMS-TOTEM project for a Precision Proton Spectrometer→ Since 2018 is a CMS subdetector
- Detectors are located in horizontal Roman pots along the LHC beam pipe at ± 210 m and ± 220 m from the interaction point

  during Run 3 (2023-25) / Run 2 (2016-18)+2022 two tracking stations and **two**/one timing station
- Detects intact protons surviving from the IP and driven by magnets within the beam pipe → Detector approach the beam at few millimetres
- Designed to operate continuously at standard LHC running conditions (**for Run2 PPS collected data up to an integrated luminosity of 100 fb^{-1}**)

Recent (CT-)PPS Results:

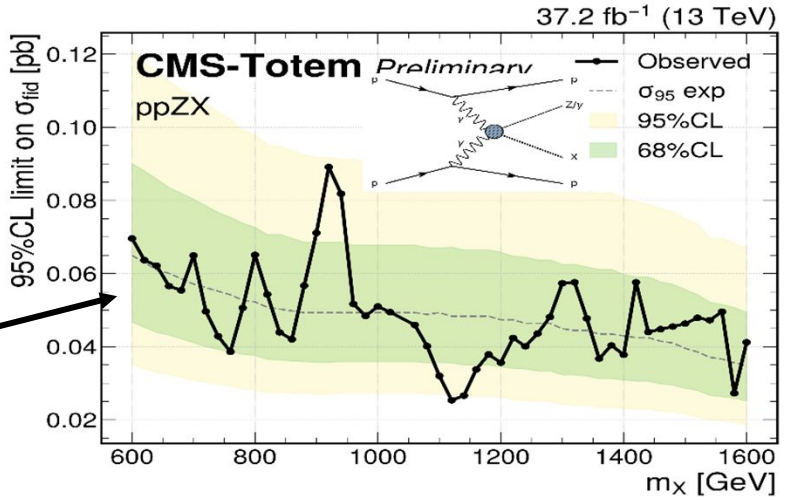
CMS-PAS-PRO-21-001



Proton reconstruction

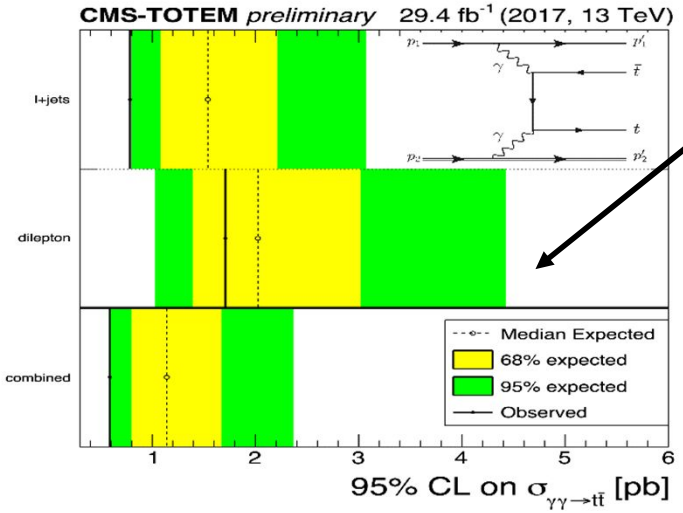
Search for Z + X

CMS-PAS-EXO-19-009



see talk by Saranya Samik Ghosh

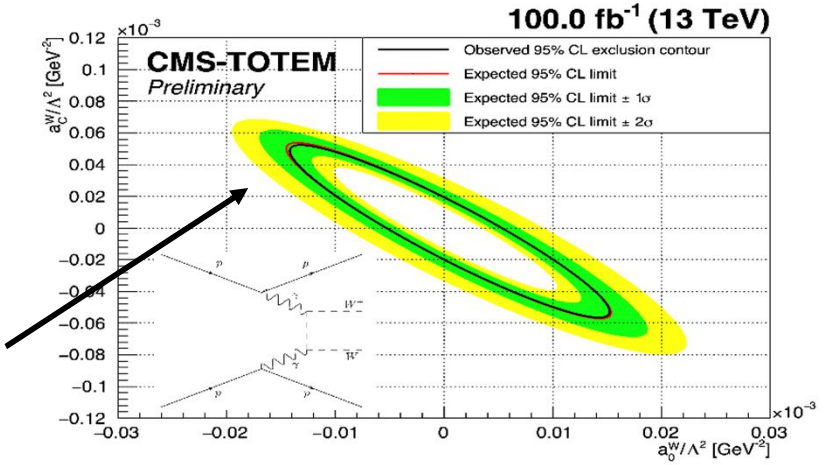
CMS-PAS-TOP-21-007



Search for exclusive $t\bar{t}$ production

see talk by Enrique Palencia Cortezon

CMS-PAS-SMP-21-014



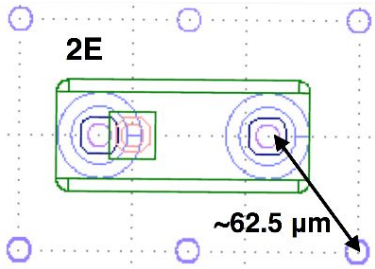
Search for exclusive WW & ZZ production

see talks by Andrew Michael Levin, Jing Peng, and Ankita Mehta.

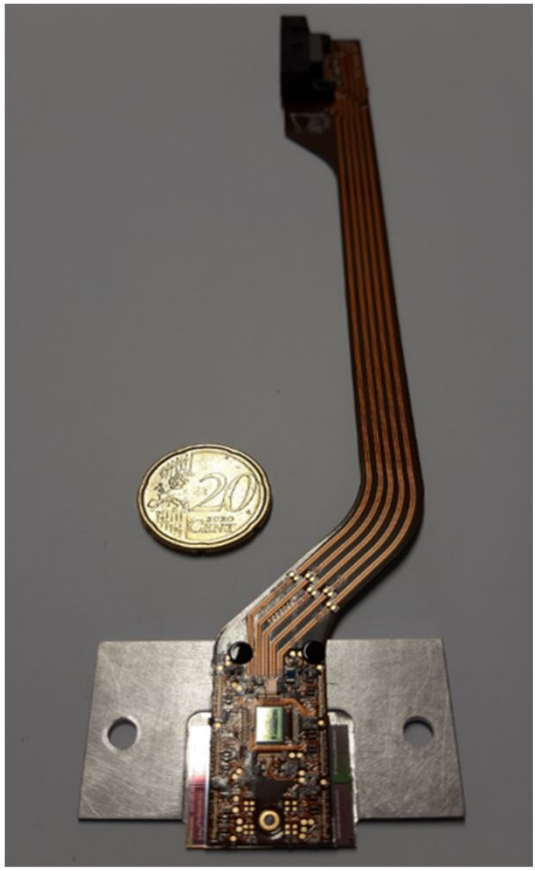
PPS - Roman pots Upgrade for tracking

New 3D Silicon Pixel detectors produced by FBK:

- Single side technology
- 2 x 2 sensor geometry
- 150 μm thick
- 2E electrode configuration



Pixel electrode configuration

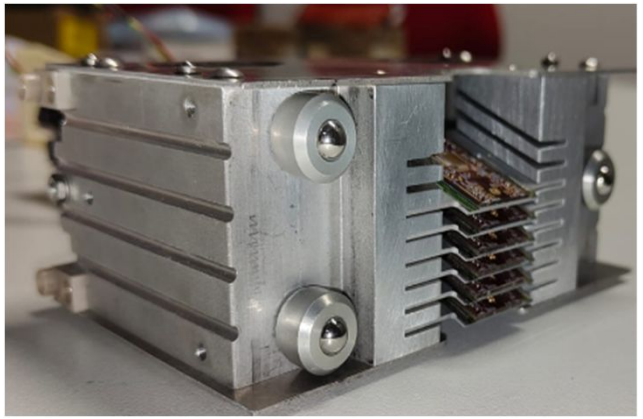


Flex cable with detector and electronics

ROC: PRO600 (same as for layer-1 of CMS pixel detector)

New flex circuit design (different look but similar to the one used in Run 2).

New detector package with internal moving system (12 positions spaced by 500 μm withstanding 50 fb^{-1} with minimal efficiency losses).

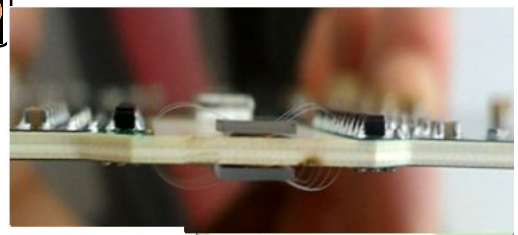


One pixel package equipped with six detector planes

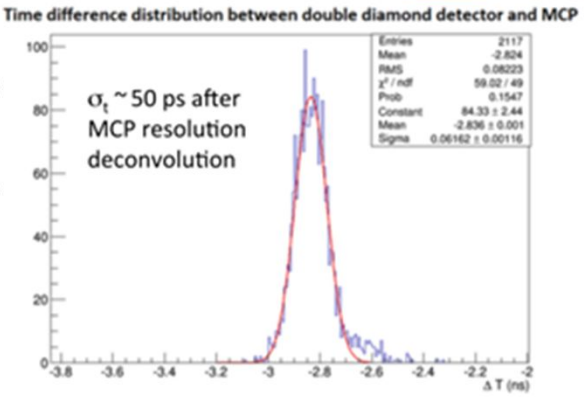
[*] A. Solano for the Precision Proton Spectrometer of CMS: performance and upgrade – ICHEP2020

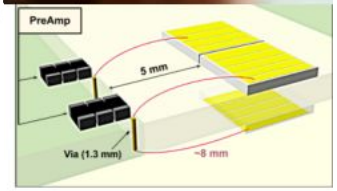
PPS - Roman pots Upgrade for timing

DD plane configuration (right)



Time resolution for a **DD plane** (bottom)





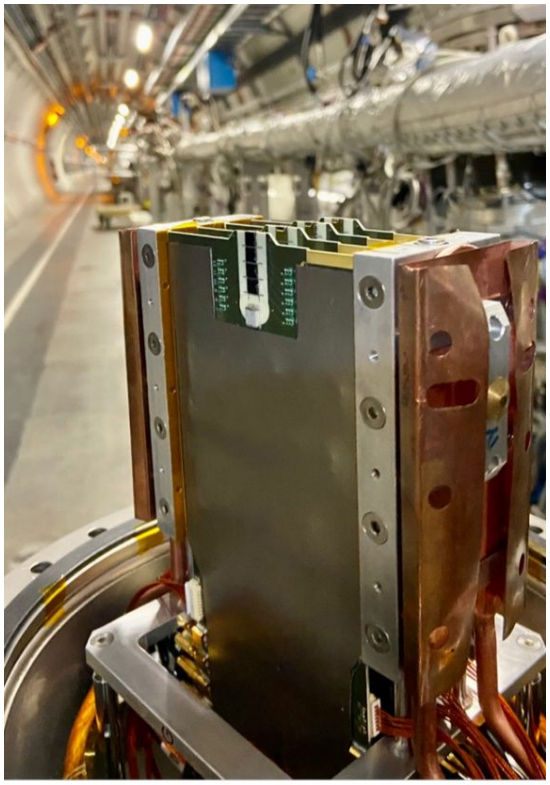
ScCVD diamond detectors:

- Four **Double Diamond (DD)** detectors per plane (4.5 mm x 4.5 mm) of 500 μm thick (detector configurations of 2 and 4 strips)
- Intrinsic radiation hardness withstanding an integrated radiation flux $5 \cdot 10^{15}$ p/cm^2
- Time resolution 50 ps per plane
- Amplification with TOTEM hybrids (remote control for low voltages)

Readout by TOTEM boards (remote control of thresholds) for NINO chips plus HPTDC (calibration)

[*] M. Beretti et al., JINST 12 (2017) P03026

RP in sector 56 at the LHC tunnel (right)



Lab test of High voltage stability under vacuum (bottom)

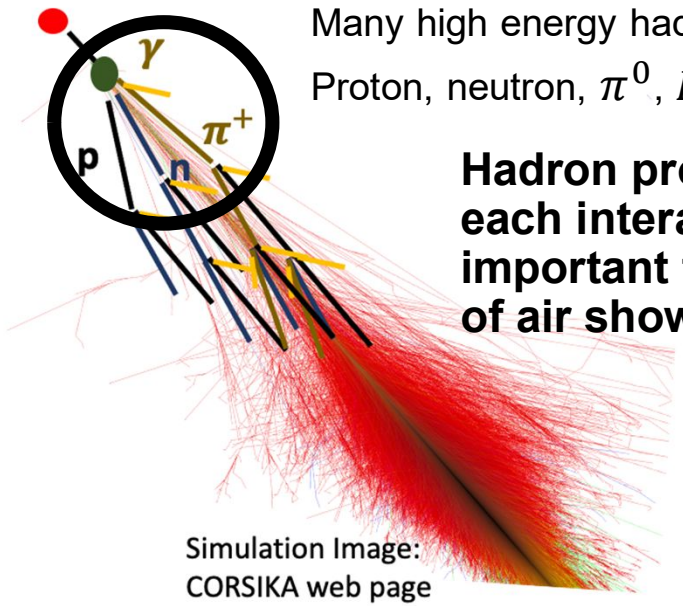
For Run 3:

- Two Roman pot already equipped with **double diamond** planes and installed at the LHC tunnel in sectors 45 and 56
- Two more additional stations to be installed during the EYETS 2022
- Ultimate resolution goal (< 30 ps) with the 8 planes on each sector

LHC forward (LHCf) experiment

To validate hadronic interaction models adopted in ultra-high energy cosmic rays

Air shower induced by ultra-high energy cosmic rays



Simulation Image:
CORSIKA web page

Many high energy hadrons are produced:
Proton, neutron, π^0, K, η

Hadron productions in each interaction are very important for simulation of air shower.

LHCf experiment

measures photons, π^0, neutrons, and η mesons in very forward regions ($|\eta| > 8.4$) at LHC.

LHCf operations

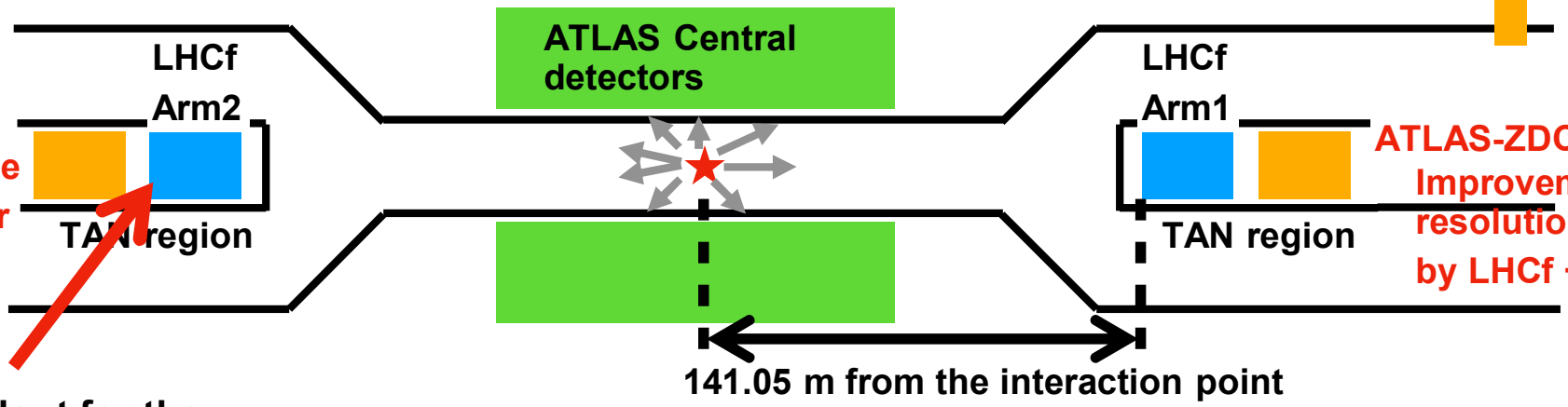
2009/2010 proton-proton, $\sqrt{s} = 0.9\text{TeV}$
2013 proton-proton, $\sqrt{s} = 2.76\text{TeV}$
2013 proton-Pb, $\sqrt{s_{NN}} = 5\text{TeV}$
2015 proton-proton, $\sqrt{s} = 13\text{TeV}$
2016 proton-Pb, $\sqrt{s_{NN}} = 8\text{TeV}$
2022 proton-proton collision (in this summer)
2024 proton-Oxygen, Oxygen-Oxygen

Operation in 2022

Proton-proton collisions
Low luminosity run

After TS1, ~2 days operation,
1 week including other low luminosity programs

ATLAS Roman pot detectors
(Under discussions)



New
ATLAS Zero Degree Calorimeter (ZDC)

ATLAS-ZDC
Improvements of energy resolution for hadrons by LHCf + ATLAS ZDC

Upgrade

New readout for the Arm2 detector

Ten times larger statistics than operation in 2015.

LHCf detectors

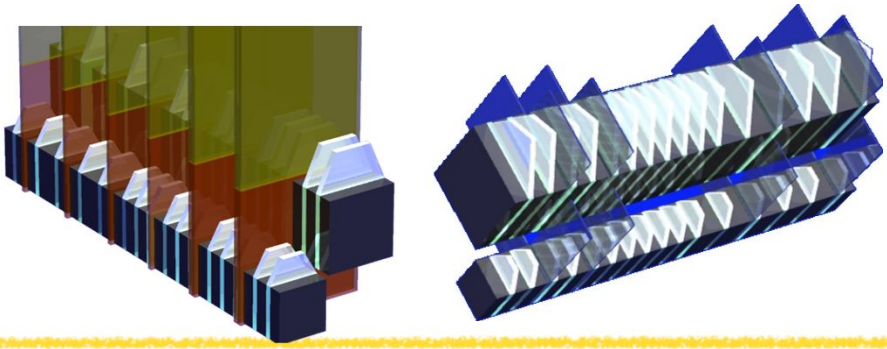
Sampling calorimeter with position sensitive layers

Energy and position resolution

Energy : < 5% (photons), 40% (hadrons)

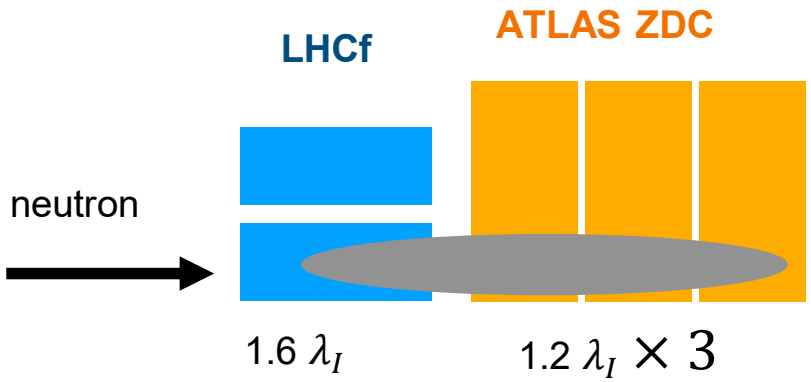
Position: <200 μm (photons)
300-100 μm (hadrons)

LHCf-Arm2 detector **LHCf-Arm1 detector**



Upgrades for RUN3

Common Operation with ATLAS ZDC



Leaked particles from hadronic showers are detected by ATLAS-ZDC.

Energy resolution for neutrons is improved to ~20% from 40%.

Upgrades to increase statistics of π^0 and η

Upgrade of silicon readout of the Arm2 detector

New electronics using GbEthernet protocol
100 Mbps -> ~1 Gbps

Trigger logic

<u>Optimization of trigger scheme:</u>
New trigger modes for high energy hadrons and photons

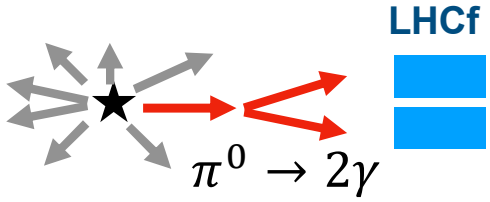
Introduce prescale to trigger

=> ~ten times larger statistics for π^0 and η

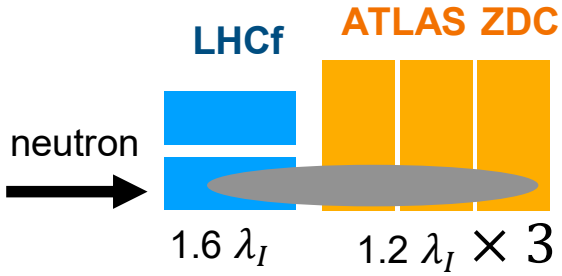
Physics targets

Precise measurements of π^0, η

Ten times higher statistics are expected.
Much smaller statistical errors than 2015.



Improvements of measurements of neutron production cross-section

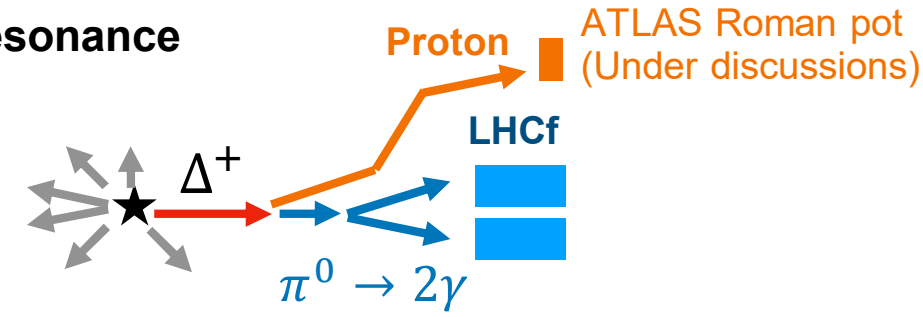


Particles leaked from the LHCf detector are detected by ATLAS-ZDC.

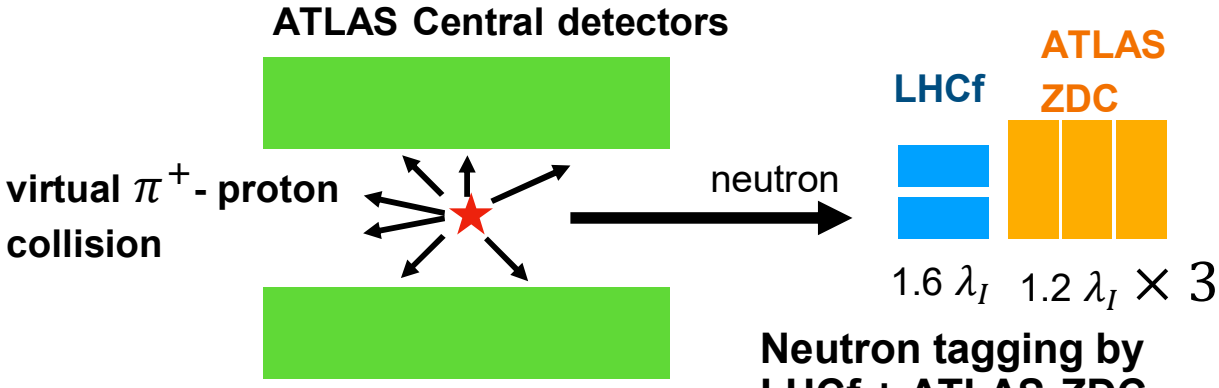
Energy resolution : $40\% \rightarrow 20\%$

ATLAS-LHCf common data-taking

Δ resonance



One-pion exchange



Neutron tagging by LHCf + ATLAS ZDC

Summary

- The scintillator based nT2 telescope of TOTEM will be installed for the total cross section measurements at 13.6 TeV during special run (Nov. 2022)

- The CMS Precision Proton Spectrometer has been upgraded for tracking and timing for continuous operations in standard LHC running conditions during Run 3

- Improved LHCf measurements of neutron production cross-section together with ATLAS ZDC as well as measurements of π^0 and η with increased statistics

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