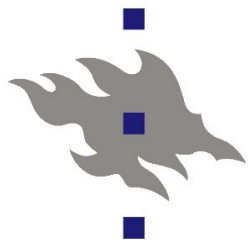


CMS programme overview, computing and forward physics projects



UNIVERSITY OF HELSINKI



K. Österberg,
CMS programme director,
Helsinki Institute of Physics,
University of Helsinki

HIP SAB 25.8.2026

Statistics:

- 95-100 publications / year
- External funding: 1 EU (ERC), 3 Academy projects (fellow + infrastructure + research)
- Personnel (25.8.2026): 6+2 staff, 4 senior scientists, 8 post-docs, 2 technician, 16 PhD students, 2 emerita & 3 MSc students (~ 40+ in total)



Current HIP CMS programme

CMS
**Kenneth
Österberg**

CMS Experiment
Mikko Voutilainen

CMS Upgrade
Erik Brücken

Tier-2 Operations
Tomas Lindén

CMS Forward
Kenneth Österberg

Coordinating Finnish participation in CMS & TOTEM experiments @ LHC

four separate projects
(programme leader budget: ~100 k€/year)

**CMS physics analysis, operation,
offline work & tools**
(budget: ~340 k€/year)

→

for details see
talk by Mikko

**CMS detector upgrades.
detector R&D + applications**
(budget: ~320 k€/year)

→

for details see
talk by Erik

LHC computing
(budget: ~110 k€/year)

→

more later
in this talk

**CMS forward (& TOTEM): physics
analysis, software, detector upgrades
& operation** (budget: ~120 k€/year)

→

more later
in this talk

New FCC project in CMS programme?

With finalization of European Particle Physics Strategy Update & organisation of the FCC week in Helsinki June 2026 $\Rightarrow$ create structure & direction of future Finnish engagement in FCC

Proposal: create dedicated FCC studies project to build structure & define direction

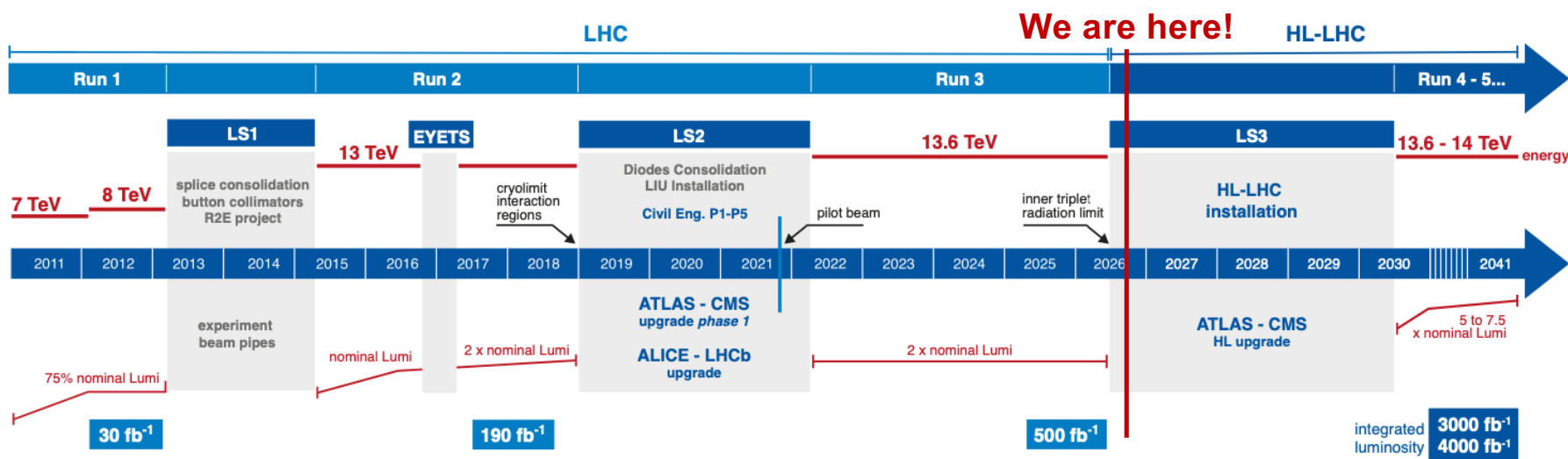
see talk by Henning Kirschenmann (national FCC contact)

Why in the CMS programme?
Most of the contributors are in the CMS programme

SABs feedback?



Main news (since last SAB)



LHC run 3 ended & long shutdown 3 (LS3) started $\Rightarrow$ focus on HL-HC preparation & detector construction + analysis of full Run 3 (& 2) data set ~ 300 (+ 140) fb⁻¹.

New positions of responsibility in CMS:

- ☐ T. Lampén, End-to-End optimization convener (L2)
- ☐ S. Laurila, Trigger officer
- ☐ N. Norjoharuddeen, Jets & Missing Energy (JetMET) convener (L2)
- ☐ N. Toikka, JetMET Algorithms & Reconstruction (JMAR) convener (L3)
- ☐ K. Österberg, Proton Precision Spectrometer (PPS) Institution board chair & resources manager

Tier-2 operations project

Statistics:

- currently: 1.2 staff and 0.1 PhD student

HIP CMS Tier-2 project

*CSC = Finnish Center for
Scientific Computing*

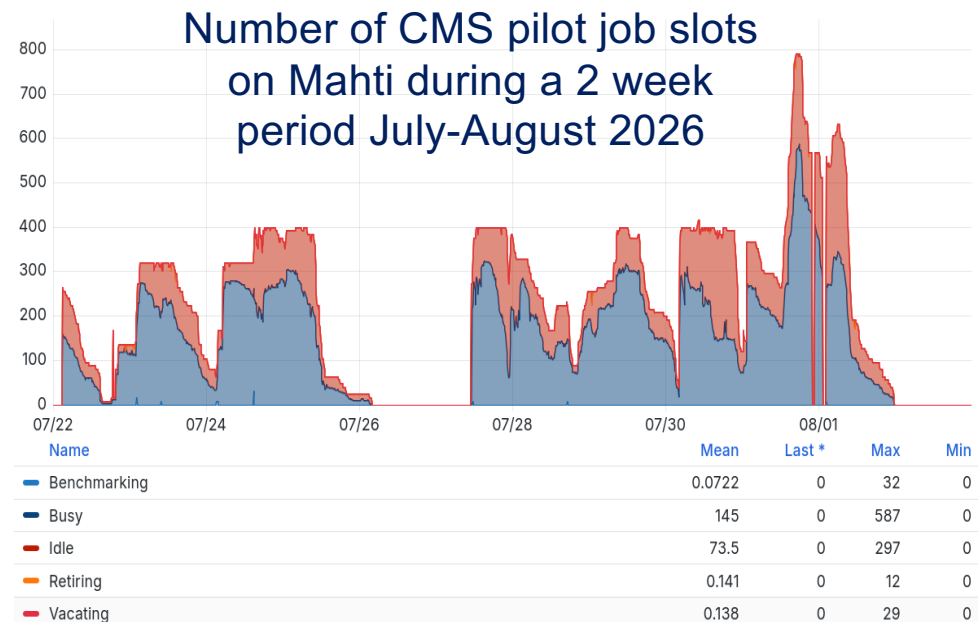
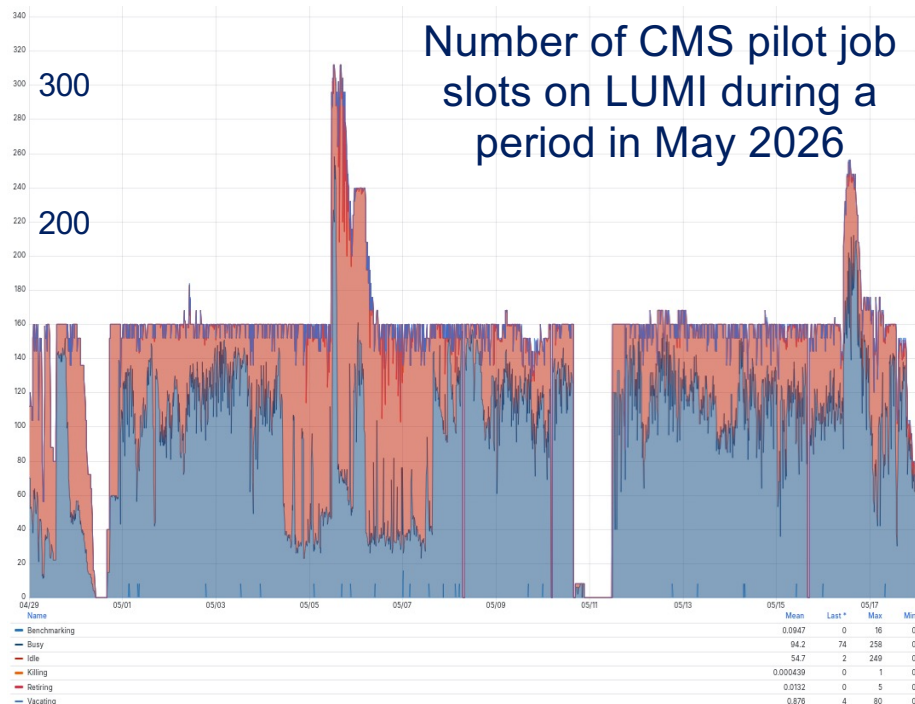
HIP CMS Tier-2 project

- ❑ Supports the LHC Run 3 Finnish computing needs.
- ❑ Prepares for the HL-LHC computing developments and requirements.
- ❑ Provides a Tier-2 site for **CMS** and for the **HIP CMS-group**
 - **CPU**: 40 kHS23 2026 pledge
 - **alcione-cms** 1024 cores (2013, recycled) in Kumpula, Helsinki
 - **snowarc** $\leq$ 280 cores, Mahti HPC (2020) at CSC, Kajaani
→ Mahti to be discontinued at end of August 2026
 - **arc2lumi** $\leq$ 160 cores, LUMI HPC (2022) at CSC, Kajaani
 - **skoll-cms** (prev. kale-cms) being installed 600 cores (2015) in Viikki, Helsinki
 - **Disk**: 3.4 PB 2026 pledge at CSC, Kajaani
- ❑ Coordinates Finnish **ALICE computing** as part of the **NDGF dTier-1**
 - **CPU**: 15.584 kHS23 2026 pledge at CSC, Kajaani, **alice-tron**, cPouta, CSC grant
 - **Disk**: 2.13 PB 2026 pledge at CSC, Kajaani

webpage: <https://www.hip.fi/research/cms-programme/tier-2-operations/>

HPC computing

- ❑ **CMS computing requirements:** software distributed with CVMFS requiring performant disk as cache & job scratch + job interface to HTCondor pool (ARC).
- ❑ CSC HPCs lack CVMFS & disk $\Rightarrow$ developed **fapptainer** for user level CVMFS
- ❑ **CMS usage of Mahti & LUMI HPCs:** ARC CEs **snowarc & arc2lumi**. Jobs submitted from ARC Computing Elements (CEs) with SSH using robot accounts. ATLAS & CMS production jobs run on Mahti & LUMI and report to NDGF.
- ❑ Remaining issues: fapptainer requires more memory than standard CVMFS, resource usage not reported correctly, ATLAS data transfer slows down ARC CE, memory & cache limited lowering usage & efficiency $\Rightarrow$ plan to study core dependent fapptainer settings.



HPC computing

- ❑ CSC **new national HPC, Roihu** replaces Mahti & Puhti HPCs.

Taken into general use at end of June 2026.

486 CPU (186k cores) & 132 GPU nodes.

RAM: ≥ 2 GB/core, fits minimum CMS requirement.

Disk (flash): 6.0 PB scratch + 0.5 PB home & project applications.

Disaggregate storage: 307.2 TB NVMe over Fabrics as job scratch.

≥ 960 GB NVMe storage for CVMFS cache & temporary use.

API = Application

Programming Interface

NVMe = non-volatile

memory express

- ❑ **CMS implementation:** plan to install CVMFS in August/September 2026.

Available job scratch disk should be performant enough for CMS.

CSC demands FirecREST API for job submission requiring specific software development of ARC-FirecREST integration.

- ❑ Mahti (Puhti) will be (was) discontinued at the end of August (July) 2026, parts of Puhti will be recycled to UH, possibly also parts of Mahti.

- ❑ **UH HPC procurement aborted due to AI data centre related price rise!**

HIP Tier-2 performance & Run 4 preparations

HIP Tier-2 CMS site readiness

2020	2021	2022	2023	2024	2025	2026 (→ 19.8)
0.847	0.655	0.910	0.838	0.924	0.920	0.848

Readiness reduction 2026 mainly due to dependence on 1 CPU cluster for production ⇒ should be improved when skoll-cms available.

HIP Tier-2 CMS CPU efficiency, HS23 wall & CPU hours

	2023	2024	2025	2026 (→ 19.8)
CPU efficiency %	53	67	74	60
MHS23 wall / CPU h	7.1 / 3.7	9.2 / 6.2	14.6 / 11.5	13.7 / 8.4

Run4 preparations:

- ❑ HIP plans to participate in next HL-LHC Data Challenge in 2027.
- ❑ Making use of CSC (and UH) HPC resources required for Run 4.
- ❑ Funding for Run 4 disk storage has been granted (expected ~480 k€).
Price rise due to AI centre boom will make procurement difficult.
- ❑ The Run 3 disk storage might be needed to be used if prices don't fall?

HIP CMS Tier-2 summary & challenges

*RHEL = Red Hat
Enterprise Linux*

- ❑ Tier-2 disk storage system performs well despite being almost full.
- ❑ Funding for a new Run 4 disk storage system granted but acquisition might be difficult with the recent price level & availability due to AI centre boom.
- ❑ Tier-2 CPU cluster (alcyone-cms) reliable but its' old (x86 64-v2) hardware not supported by RHEL 10. skoll-cms (x86 64-v3) should improve things once available.
- ❑ fapptainer has enabled usage of LUMI and Mahti HPCs but HPCs provide for time-being only complementary CPU.
- ❑ UH HPC procurement aborted, remedy recycle CSC HPC nodes taken out of use.
- ❑ Computing environment complex, takes long time to learn for newcomers.
- ❑ Software and tools change & new services add complexity.
- ❑ Enabling Roihu for CMS usage important, but will require further work.
- ❑ Nordic e-Infrastructure Collaboration (NeIC) re-organization. Only Nordic Data Grid Facility (NDGF) stays in NeIC. New NeIC MOU signed. NDGF to be re-reviewed.
- ❑ *Support from UH & CSC for HPC local storage essential for enabling CMS usage.*
- ❑ *Usage of UH & CSC HPC resources required to be able to retire oldest CPU resources and to be able to prepare for HL-LHC.*

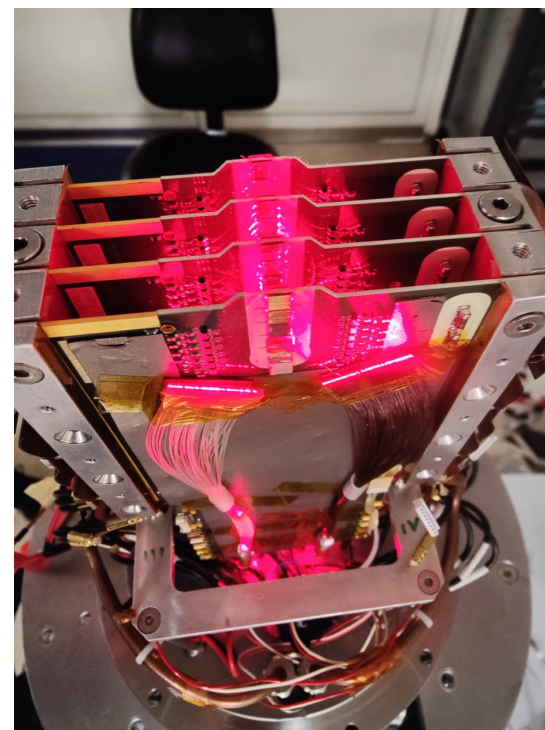
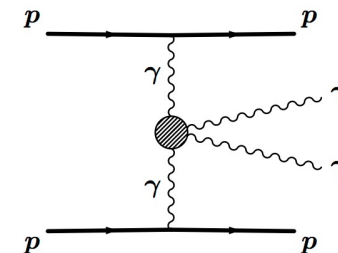
CMS Forward physics project

Statistics:

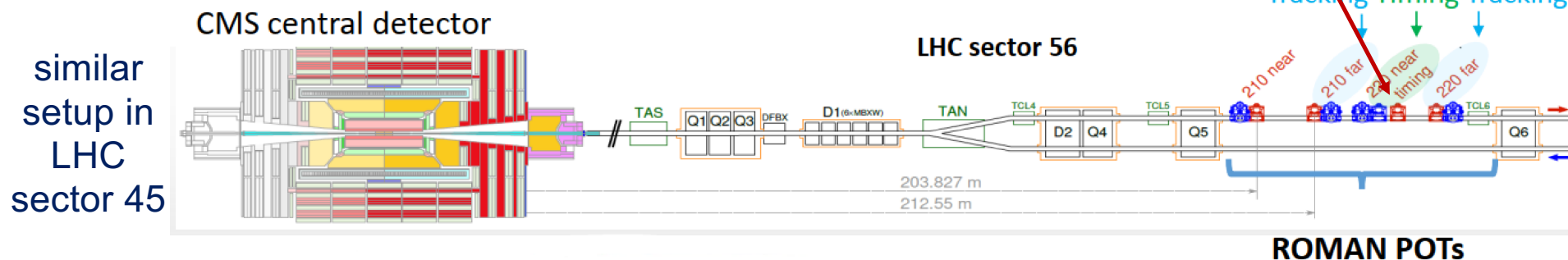
- 3-4 publications / year
- currently: 1+1 staff, 1 post-doc, 3 PhD students, 1 MSc student

CMS Forward & TOTEM physics Central exclusive processes

- CMS Precision Proton Spectrometer (PPS)
 - ❑ high mass central exclusive processes & BSM searches
continuous high luminosity data taking as part of CMS
 - ❑ horizontal Roman Pots (RPs) with proton tracking detectors: 3D Si pixels detectors
 - ❑ horizontal RPs with proton Time-of-flight (TOF) detectors: double-layered diamond sensors
- TOTEM forward physics experiment @ LHC
 - ❑ total pp cross-section, elastic pp scattering, low mass exclusive & diffractive processes
special high β^* optics runs, vertical RPs
 - ❑ T2 telescope for inelastic event counting
 - ❑ vertical RPs for measurement of elastic & diffractive protons using Si strip detectors



PPS timing detector module tested before insertion



Helsinki PPS & TOTEM contributions 2025-26

PPS TOF detector related activities:

- ❑ PPS TOF detector refurbishment & LHC operation (F. Garcia, A. Milieva & F. Musonov)
- ❑ Diamond polarization & radiation hardness studies (F. Garcia & M-M. Rantanen)
- ❑ HL-LHC PPS TOF detector component tests in lab & test beams (F. Garcia)

PPS data validation & physics related activities

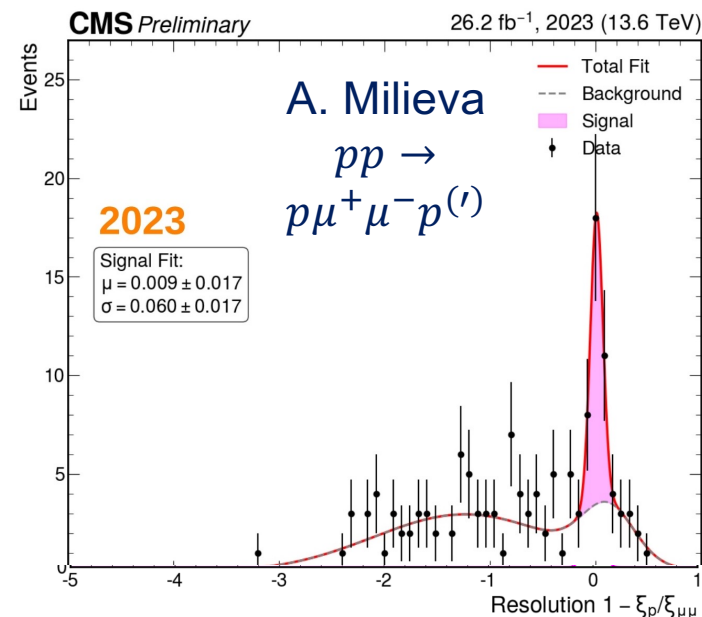
(A. Milieva, A. Kokko, F. Musonov, S. Lehti & KÖ):

- ❑ Validation of PPS calibrations 2023-24
- ❑ Initial central exclusive dilepton analysis

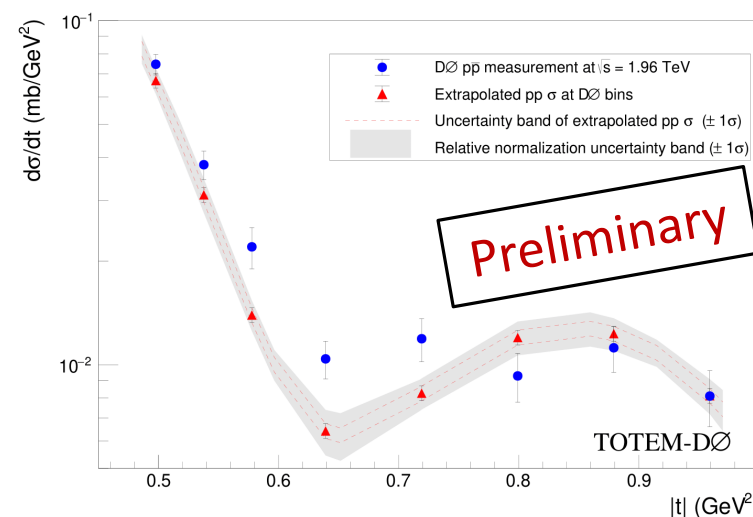
TOTEM physics related activities:

- ❑ physics analysis & publication coordination (KÖ)
- ❑ updated comparison of elastic pp & $p\bar{p}$ cross section for observation of odderon (KÖ)
- ❑ elastic & inelastic analysis for total cross section measurement @ $\sqrt{s} = 13.6$ TeV (F. Oljemark)
- ❑ glueball candidate studies (L. Negri & KÖ)

PPS calibrations validations for 2023



Elastic pp & $p\bar{p}$ cross section comparison



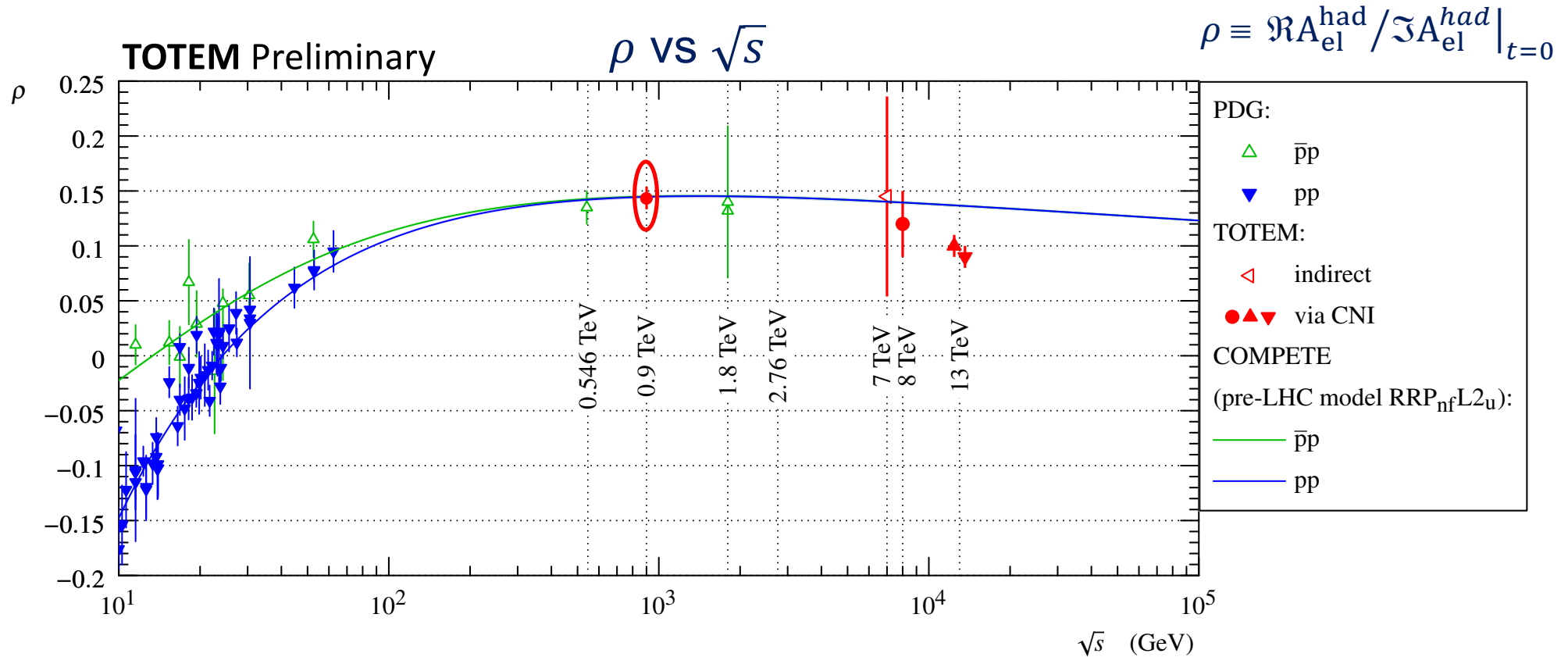
Observation of odderon exchange

Physics highlight

pp total cross section & ρ parameter measurement at $\sqrt{s} = 900$ GeV

$$\sigma_{tot} = 68.7 \pm 1.3 \text{ mb}$$

$$\rho = 0.143 \pm 0.010$$

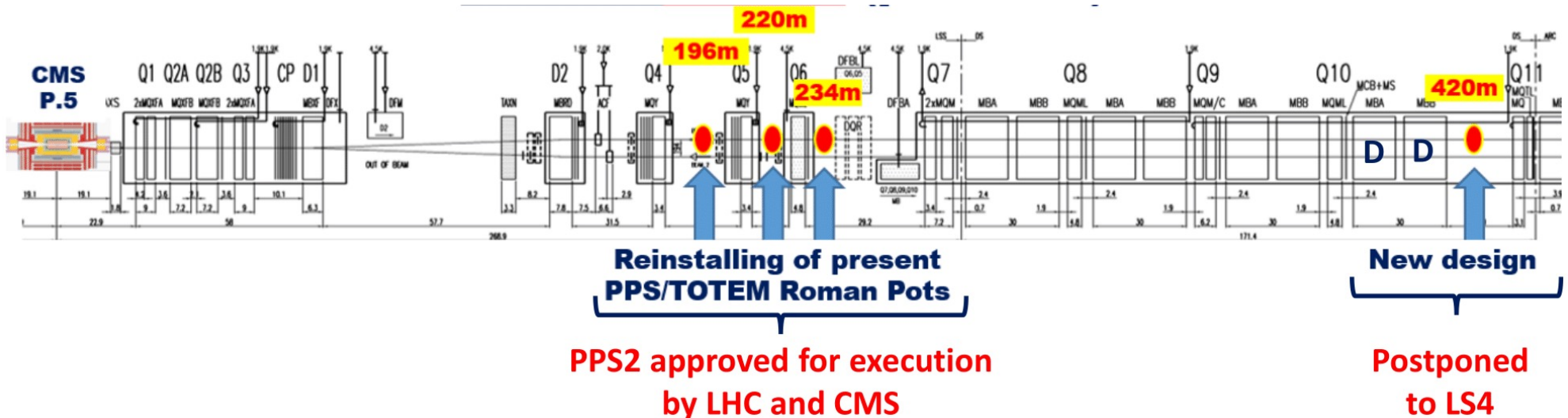


ρ in pp at $\sqrt{s} = 900$ GeV compatible with ρ in $p\bar{p}$ at $\sqrt{s} = 546$ GeV,
however neither of them compatible with ρ in pp at $\sqrt{s} = 13$ TeV $\rightarrow$

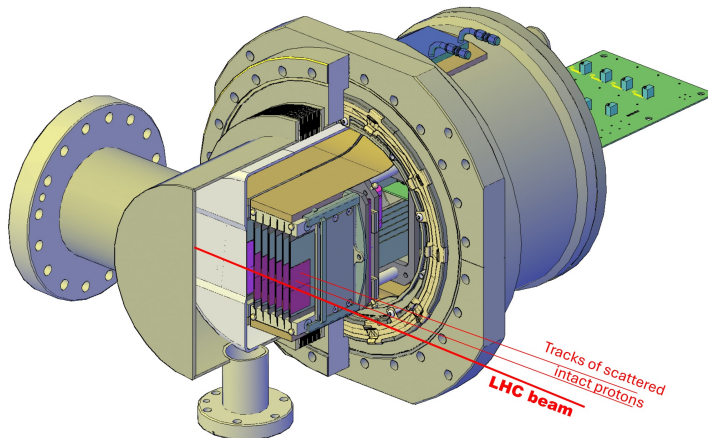
if changes due to odderon effects then these seem to grow with energy

HL-LHC CMS Proton Precision Spectrometer (PPS2)

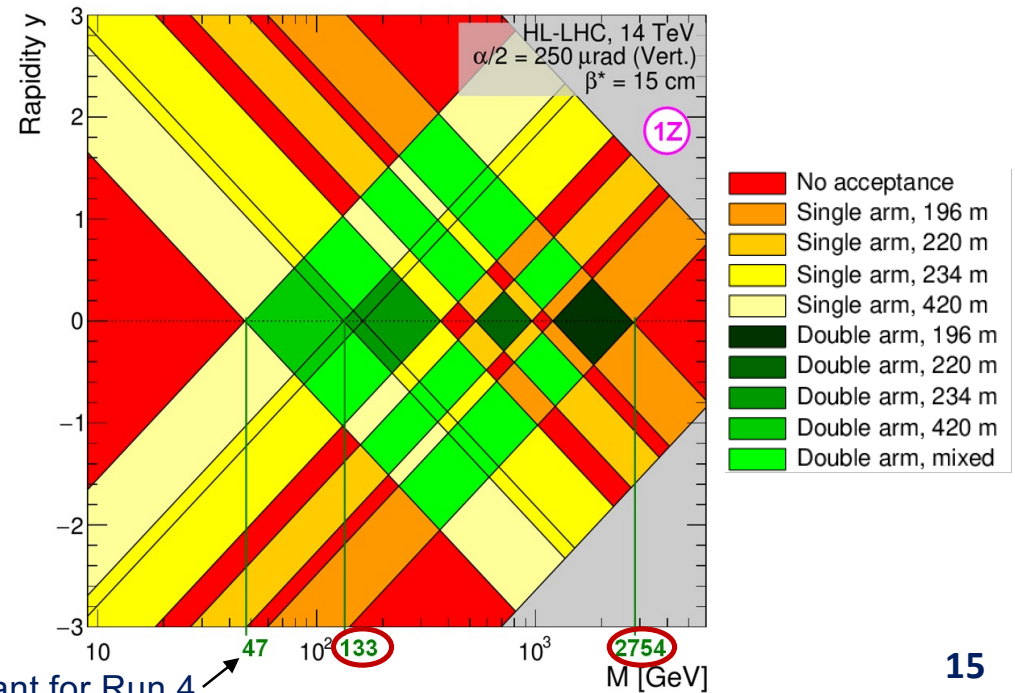
- ❑ Completely refurbished PPS detector to measure forward protons at HL-LHC



- ❑ RPs with proton tracking (3D Si pixel) & Time-of-flight (LGAD) detectors
- ❑ Similar sensors + readout as CMS Tracker (3D Si pixel) & MTD-ETL (LGAD)
- ❑ Only forward proton detector @ HL-LHC



Mass & rapidity acceptance example

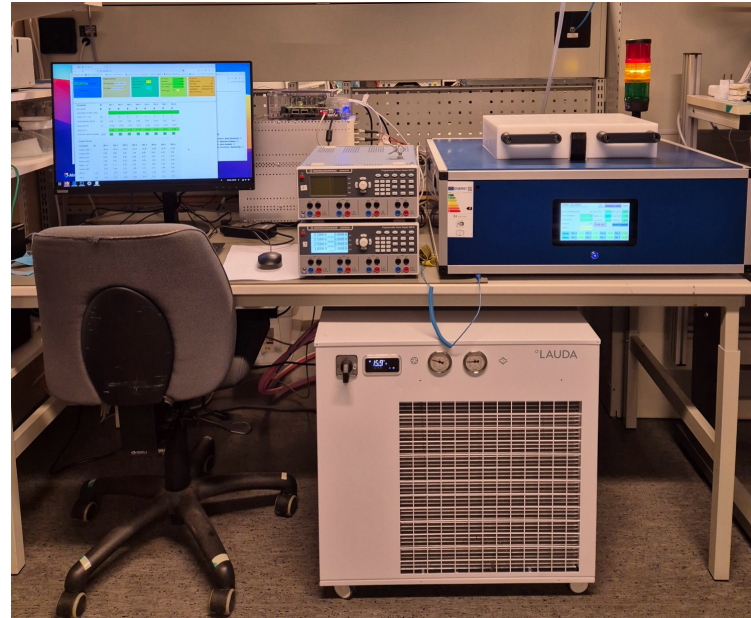


Finnish PPS2 contributions

- ❑ Large synergy with Finnish CMS Tracker & MTD-ETL contributions
- ❑ Costs included in granted Research Council of Finland HL-LHC roadmap project

Tracking detectors (E. Brücken, T. Hildén):

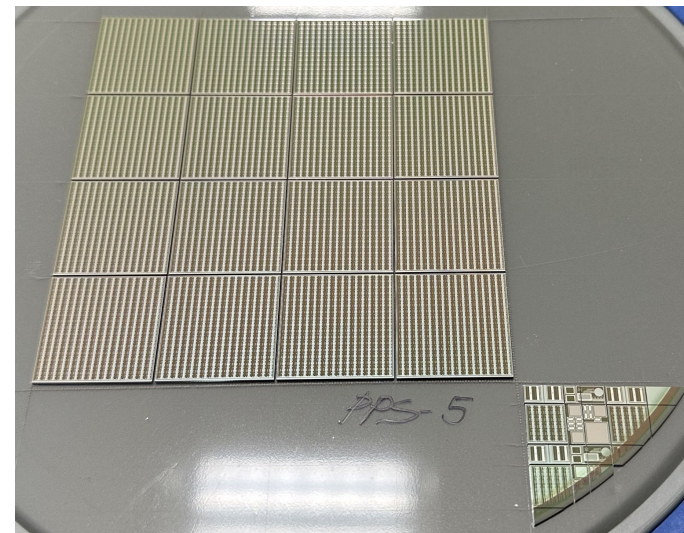
- ❑ 3D Si pixel with customized PPS2 geometry readout with CROCv2 chip
- ❑ Assembly & quality control of pixel modules 2028-29 using existing CMS Tracker setups modified for the PPS2 requirements in close collaboration with PPS INFN groups.



TEPX pixel module test setup in Helsinki det lab

Time-of-flight detectors (F. Garcia):

- ❑ Trench isolated (TI-)LGADs with customized PPS2 geometry readout with ETROC2 (MTD-ETL design)
- ❑ Component & prototype R&D, module production, characterisation & integration into RPs in close collaboration with LIP (Lissabon) & CBPF (Rio de Janeiro) groups.



First full sized TI-LGADs with PPS2 geometry

Planned PPS2 activities in/by Helsinki

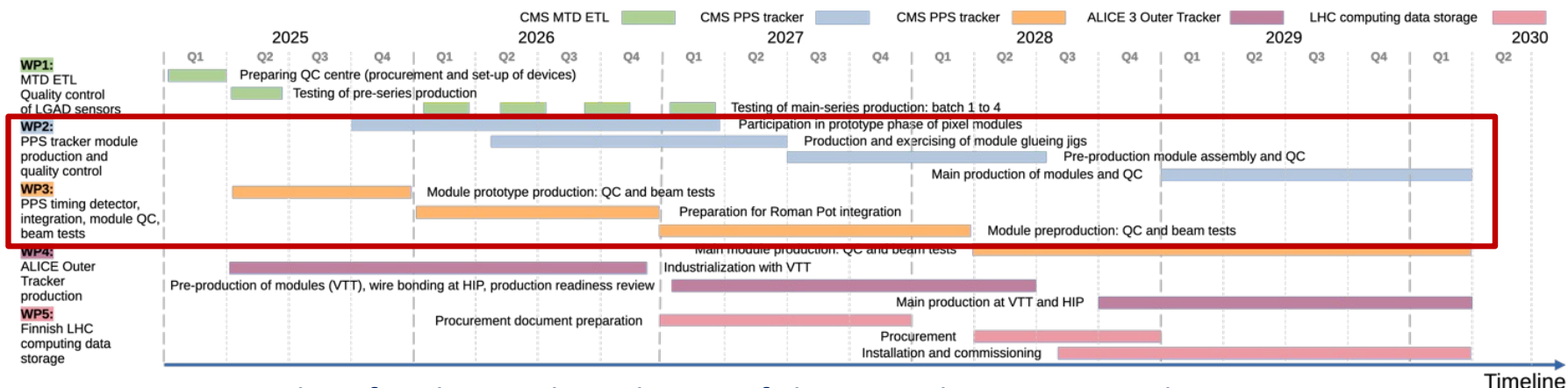
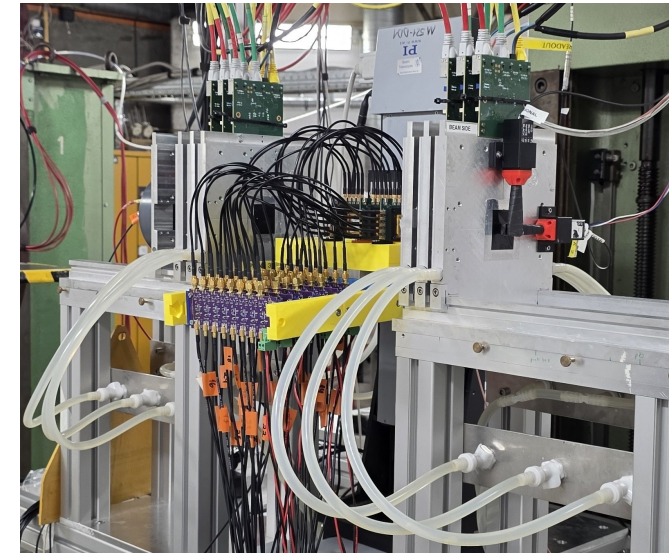
PPS2 pixel tracking detectors: model assembly and extensive Quality Control (QC):

- ❑ Assembly and QC test of about 110 modules at HIP (about 50% of required modules).
- ❑ Hire engineer for module assembly (including gluing) & QC for a year in 2028-29.
- ❑ Radiation studies & preproduction module testing 2027-28.

LGAD tests @particle beams 2026

PPS2 LGAD timing detectors: component & prototype tests in lab & particle beams, module production, characterisation & particle beams, integration into RPs

- ❑ 2026-27: Extensive tests of PPS2 type LGADs, LGAD carrier boards, wire bonded ETROCs & preproduction TOF modules both in lab & at particle beams.
- ❑ 2027: Module preproduction & qualification.
- ❑ 2028-29: Module production & QC.
- ❑ 2029: Module integration in to Roman Pots @CERN.



PPS data validation & physics contributions 2026-28

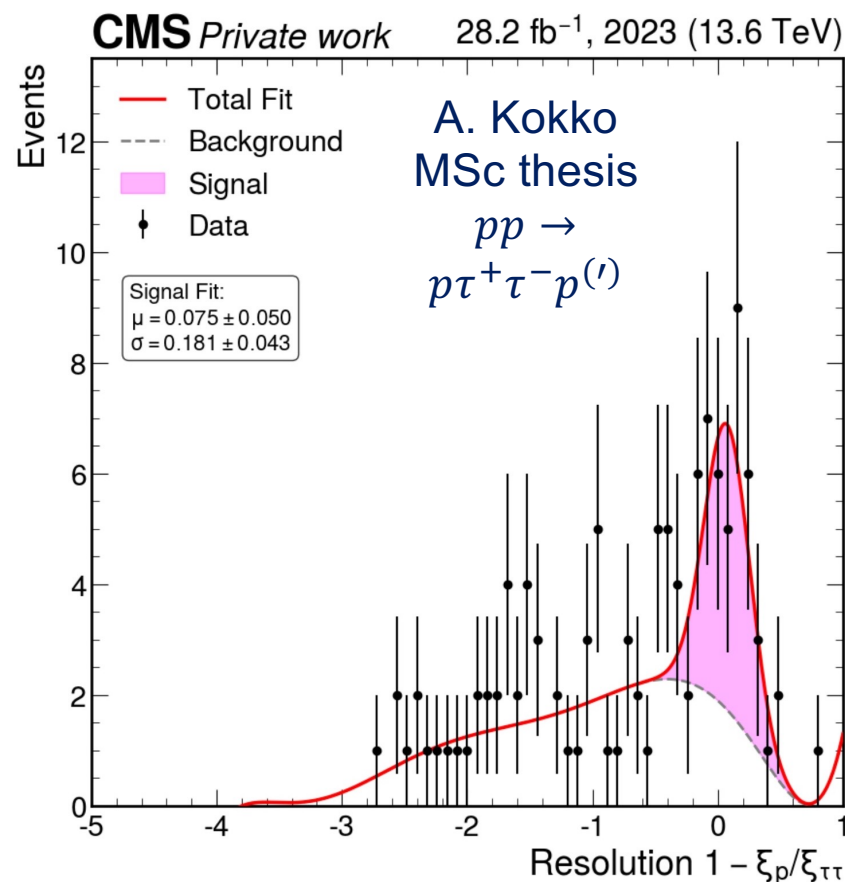
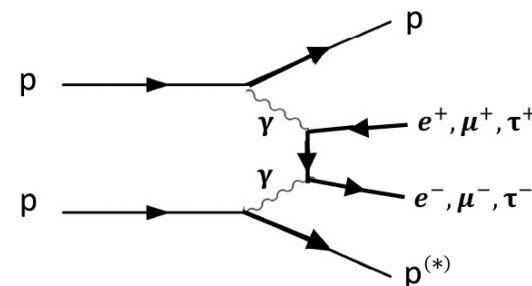
PPS data validation in LHC Run 3 (2022-26)

- yearly validation of PPS calibrations (mainly the RP alignment & the LHC optics) with central exclusive dimuon & dielectron events (sufficient to measure only 1 proton in PPS)

PPS physics analysis using LHC Run 3 data

- measurement of central exclusive dilepton pair production cross section (“standard candle”) for the same processes & the extraction of the “rapidity gap survival probability” for central exclusive processes from data.
- search for & measurement of central exclusive tau lepton pair production (requiring either both or only one proton(s) in PPS) & determination of tau lepton anomalous magnetic moment (higher mass $\Rightarrow$ better sensitivity to BSM physics).

central exclusive dilepton production



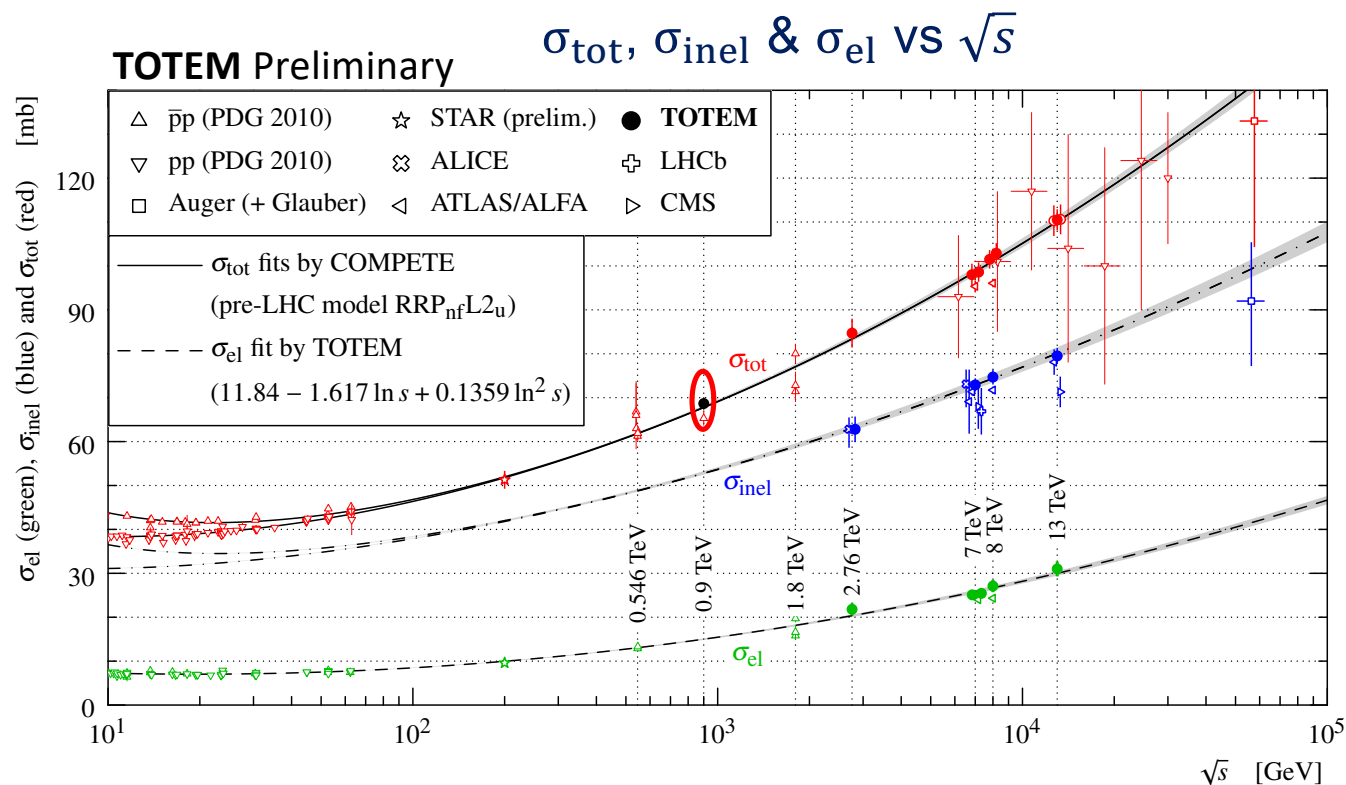
TOTEM physics contributions 2026-28

TOTEM physics programme completion (TOTEM legacy)

- ❑ after last data taking in 2023, TOTEM data analysis will still continue for a few years
- ❑ update of elastic pp & $p\bar{p}$ differential cross section comparison with D0 (2026)
- ❑ odderon characterization using σ_{tot} & ρ parameter measurements at $\sqrt{s} = 0.9$ TeV (2018 data, preliminary result shown here) & $\sqrt{s} = 13.6$ TeV (2023 data)
- ❑ study of scalar & tensor glueball candidates with CMS using CMS-TOTEM 2018 data
- ❑ preparation of TOTEM data sets & tools for data preservation on CERN Open data

HIP contributions:

- ❑ coordination of physics analysis & publication
- ❑ updated comparison of elastic pp & $p\bar{p}$
- ❑ elastic & inelastic for σ_{tot} @ $\sqrt{s} = 13.6$ TeV
- ❑ contribution to glueball candidate studies (f_0 's & f_2 's) using low mass central exclusive events



Summary:

HIP CMS programme:

- making focused and highly valuable contributions to CMS and TOTEM experiments @ LHC → currently several L1 & L2 CMS & TOTEM positions (5: P. Inkaew, T. Lampén, S. Laurila, N. Norjoharudeen & K. Österberg)
- build structure & define direction for future FCC work within new project?

HIP CMS Forward Physics project:

- actively participating in CMS PPS tracking & TOF detector HL-LHC upgrades.
- contributing to the CMS PPS data validation & physics analyses.
- actively engaged in finalizing TOTEM legacy analyses & publications.

HIP Tier2 project:

- provides essential Finnish LHC computing resources for ALICE & CMS analysis of and MC production for Run 2, Run 3 and HL-LHC data.
- usage of UH & CSC HPC resources essential for future Run 3 and HL-LHC data analysis, require support from UH & CSC for HPC local storage (CVMFS).

CMS programme statistics

External funding

- 2022-27: ERC CoG grant “Jet energy calibrations for HL-LHC (JEC4HL-LHC)” (M. Voutilainen)
- 2023-27: Research Council of Finland fellowship “Vector Boson Scattering in all-hadronic channel (ForVVard)” (H. Kirschenmann)
- 2023-27: WP leader in Research council of Finland project “Optimization of BNCT for cancer treatment at Helsinki University Hospital ” (E. Brücken)
- 2024-27: Research Council of Finland infrastructure funding “Upgrade of the CMS tracking detector and construction of the ALICE FoCal detector for the HL-LHC” (E. Brücken)
- 2025-29: Research council of Finland infrastructure roadmap “High-luminosity Large Hadron Collider (HL-LHC) at CERN” (includes CMS MTD-ETL & PPS, ALICE3 (first part) and HL-LHC storage system for Finnish LHC computing, K. Österberg)
- 2025-29: Research Council of Finland project “Jet Energy Calibrations for Prompt reconstruction in CMS (JEC4Prompt)” (T. Lampén, M. Voutilainen)
- 2026-xx: University of Helsinki starting grant (S. Laurila)
- Various PhD grants and doctoral pilot funding 2026-2027 (P. Inkaew, F. Musonov, M-M. Rantanen, S. Saariokari, A. Stadnitski, N. Toikka, D. Van Le)

CMS experiment project personnel & responsibilities

Personnel:

Mikko Voutilainen, prof. UH & project leader

Henning Kirschenmann, prof. LUT

Santeri Laurila, univ. researcher UH (25 %)

Kati Lassila-Perini, senior scient. (40 %)

Sami Lehti, senior scient. (80 %)

Tapio Lampén, senior scient.

Nurfikri Norjoharuddeen, post doc

Ravindra Verma, post doc

Theodoros Chatzistavrou, post doc

Mikael Myllymäki, post doc

Patin Inkaew, PhD stud.

Nico Toikka, PhD stud.

Bettina Lehtelä, PhD stud.

Nestor Mancilla Xinto, PhD stud.

Alex Stadniski, PhD stud.

Emilia Veikkola, PhD stud.

Dung Van Le, PhD stud.

Punnawich Chokeprasert, PhD stud. (90 %)

Onni Salmi, PhD stud.

Dan Näsman, MSc student

Naik Shounak, MSc student

Jorma Tuominiemi, emeritus prof.

– jet physics & JEC

– VBS, ML in HEP

– Trigger., Higgs

– data preservation & open data

– charged Higgs, JEC

– End-to-end optimization, JEC PCL

– JetMET, VBS, JEC

– V+jet, flavoured jets, JEC

– JEC PCL

– top mass, JEC

– Scouting, ML in HEP

– VBS, JEC

– V+jet, JEC

– multijets, JEC

– VBS

– top mass, JEC

– α_s , JEC

– JEC PCL

– trigger

– JEC PCL

– charged Higgs

- VBS = Vector Boson Fusion

- PCL = Prompt Calibration Loop

- ML = Machine Learning

- JetMET = Jet and Missing Transverse Energy

- JEC = Jet Energy Calibration

- JMAR = JetMET Algorithms and Reconstruction

CMS responsibilities 2026-27:

- S. Laurila, Trigger officer
- N. Norjoharuddeen, JetMET L2
- T. Lampen, End-to-End Optimisation L2
- P. Inkaew, Scouting L2
- B. Lehtelä, JME-Trigger L3
- N. Toikka, JME-JMAR L3

CMS upgrade project personnel & responsibilities

Personnel:

Erik Brücken, univ. lecturer & proj. leader

Panja Luukka (LUT), prof.

Timo Hildén, senior scient.

Aneliya Karadzhinova-Ferrer (LUT), post doc

Ahti Karjalainen (LUT), post-doc

Hussam Badran, post-doc

Antti Numminen, technician

Kaino Kantakoski, technician

Nikita Kramarenko (LUT), PhD stud.

Mika Väänänen (LUT), PhD stud.

Santeri Saariokari, PhD stud.

Mila Myllymäki, PhD stud.

– CMS Tracker & MTD-ETL, det. R&D & applications

– CMS Tracker, detector R&D & applications

– CMS Tracker & MTD-ETL, det. R&D & applications

– detector R&D & applications

– detector R&D & applications, electrical engineering

– CMS Tracker

– detector bonding & quality control

– detector quality control

– CMS MTD-ETL, detector R&D

– sensor & readout electronics, detector R&D

– Geant4 & TCAD detector simulations, CMS Tracker

– medical imaging, dosimetry

Kumpula radiation detector laboratory:

Pirkitta Koponen, technician

Raimo Turpeinen, technician

– detector bonding

– mechanics, test setup assembly

Graduations (since 08/2025)

PhD (1): Mikael Myllymäki

MSc (7): N. Annala, F. Jordanek, A. Kokko, A. Kössi, S. Moraes, K. Pakarinen, Y. Shaikh

Tier2 operations project personnel & responsibilities

Personnel:

Tomas Lindén - CMS Site Admin and Data Manager, project leader
Sami Lehti (20 %) - CMS Site Admin and Data Manager, SW development
Punnawich Chokeprasert (10 %) - CMS Site Admin and Data Manager, SW development
Center for Scientific Computing (CSC, Finland): 0.5 FTE divided over Ville Salmela and Juhani Nourteva (dCache service work bought by HIP)
CSC/Nordic Data Grid Facility (NDGF): Erik Edelmann (NDGF ALICE coordinator) → 31.12.2026
ALICE: Dong Jo Kim (HIP-University of Jyväskylä), ALICE computing
Collaborators: UH IT for Science group, University of Oslo (Ievgen Sliusar, ATLAS) and University of Bern (Gianfranco Sciaccia, ATLAS) on CSC LUMI and Mahti HPC exploration

International and national responsibilities:

- T. Lindén, Nordic LHC Computing Grid (NLCG) Steering Committee chair, WLCG Grid Deployment Board (GDB) deputy member, Finnish Computing Competence Infrastructure (FCCI) board member, coordinating LHC-computing tasks with CSC, IT for Science customer panel member

CMS Forward project personnel & responsibilities

Personnel:

Kenneth Österberg, prof. & project leader	– physics coordination, TOTEM & PPS analysis
Heimo Saarikko, emeritus prof.	
Francisco Garcia, lab. engineer (40 %)	– PPS operations, test beams, PPS2 upgrade
Fredrik Oljemark, post-doc.	– TOTEM physics analysis, PPS
Milla-Maarit Rantanen, PhD stud.	– diamond Q&A and R&D
Anna Milieva, PhD stud.	– data analysis & validation PPS
Fedir Musonov, PhD stud.	– data analysis & validation PPS
Leonardo De Negri, MSc stud.	– TOTEM glueball analysis
Kumpula radiation detector laboratory/CMS upgrade or experiment projects:	
Erik Brücken, univ. lecturer	– pixel module assembly for PPS2 upgrade
Timo Hildén, senior scientist	– pixel module assembly for PPS2 upgrade
Pirkitta Koponen, technician	– diamond quality assurance
Sami Lehti, senior scientist	– data analysis PPS

CMS & TOTEM responsibilities 2026-27:

- K. Österberg, TOTEM physics coordinator, CMS PPS Institution board chair and resources manager
- F. Garcia, CMS PPS Time-Of-Flight detector operations coordinator
L3 & CMS PPS Time-Of-Flight detector upgrade coordinator L3