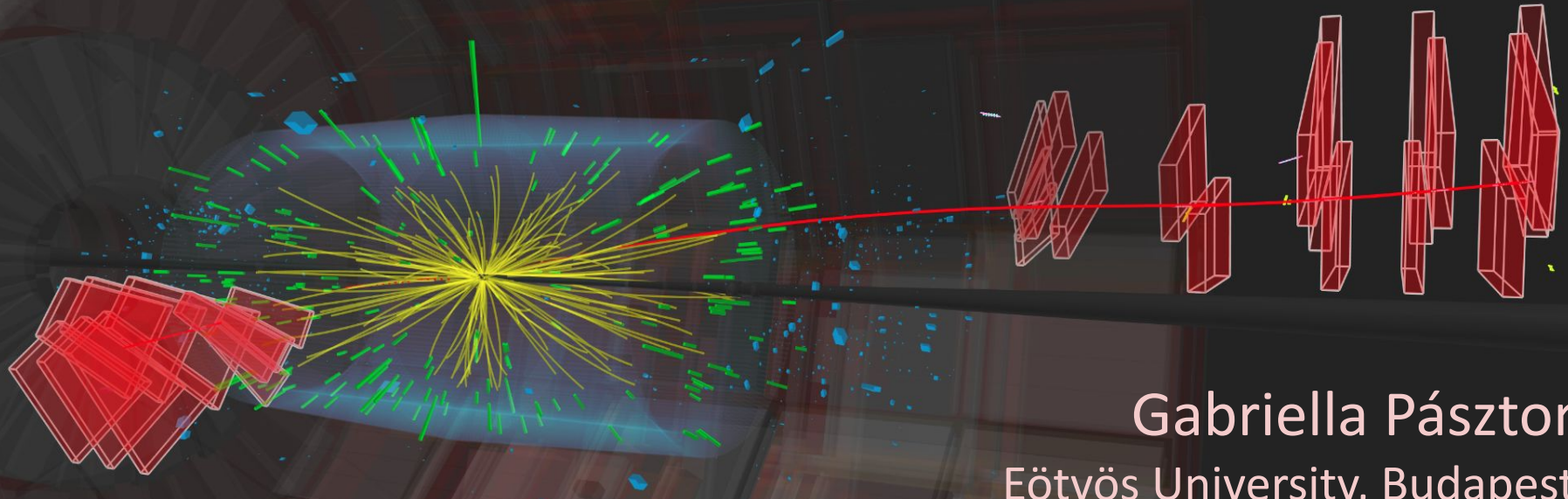
CMS in Hungary



Gabriella Pásztor
Eötvös University, Budapest

Thanks to N. Béni & J. Molnár (ATOMKI, Budapest),
M. Csanád & G. Veres (Eötvös Uni, Budapest),
B. Ujvári (Uni of Debrecen),
F. Siklér & V. Veszprémi (Wigner RCP, Budapest)

RECFA visit in Budapest, 23 September 2022

Participation

50 participants from 5 institutes (11 females)

22% female of all participants (CMS average: 21%)

- 2 M&O physicists (18%)
- 2 PhD students (non author) (18%)
- 6 undergrad (55%)
- 1 engineer software (9%)

26 authors (52% of all participants)

- 17 M&O (65%) (2 females)

  8% female of all authors (CMS average: 20%)
- 3 emeritus (12%)
- 6 PhD student (23%)

24 non-authors (48% of all participants)

- 2 physicist
- 1 emeritus
- 4 PhD student (2 females)
- 10 undergrad (6 females)
- 3 engineer
- 2 engineer software (1 female)
- 1 engineer electronics
- 1 technician

6 foreigners (2 of them authors)

Members / authors per institute

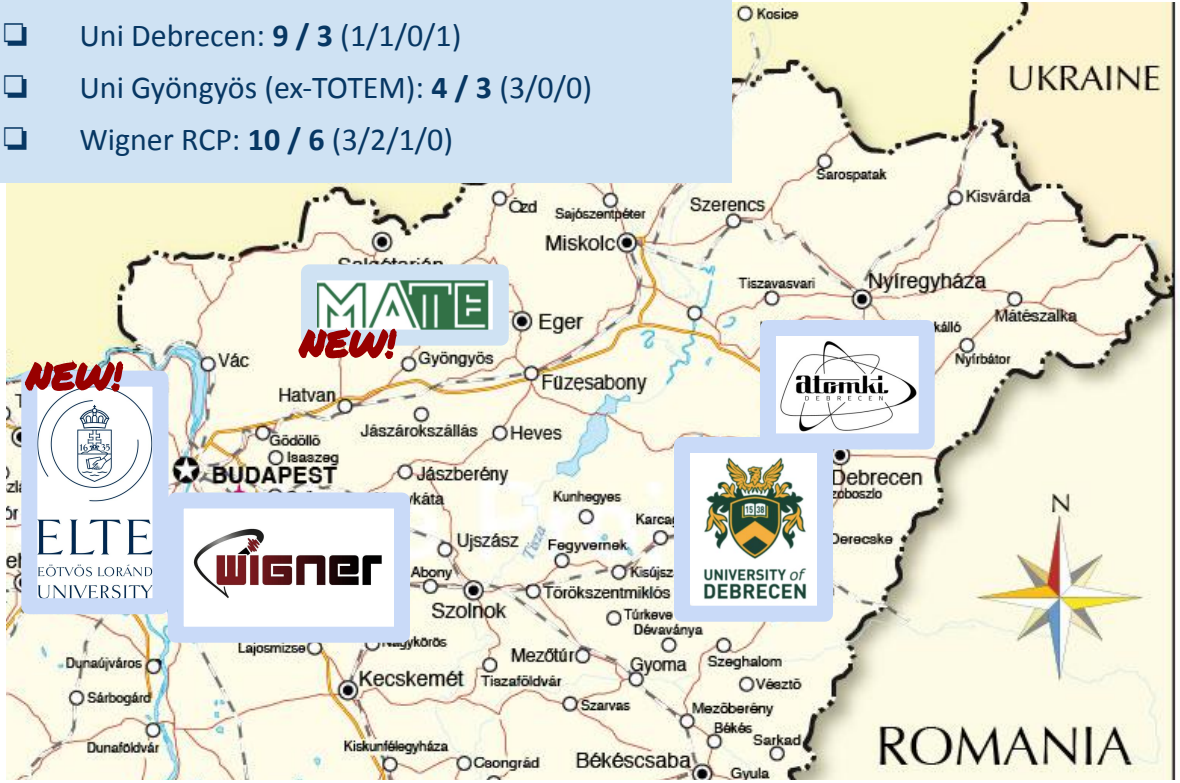
(author profile:

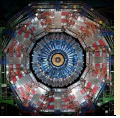
M&O physicist / emeritus / PhD student / engineer)

- ATOMKI: **7 / 5** (4/1/0/0)
- ELTE (since 2015): **20 / 9** (4/0/5/0)
- Uni Debrecen: **9 / 3** (1/1/0/1)
- Uni Gyöngyös (ex-TOTEM): **4 / 3** (3/0/0)
- Wigner RCP: **10 / 6** (3/2/1/0)

Institutes with different team profiles from “pure science with minimal engineering support” (e.g. ELTE) to “mostly technical” (ATOMKI, Uni Debrecen)

Based on CMS member database (extracted 21 Sep 2022)





Funding

Research / higher education institutions

- Mostly salaries
- Internal grants for research excellence or infrastructure / hardware development (e.g. ATOMKI Institutional Scientific Research Fund, ELTE Faculty of Science Excellence Grant, Wigner RCP Outstanding Research Group, Uni Debrecen …)
  - Amounts vary from almost negligible to 30-40 kCHF/year depending on institute and year

Hungarian Academy of Sciences

- Momentum “Lendület” Program to attract and keep outstanding researchers in Hungary and establish new research directions in a research / higher education institution (Hungarian version of ERC)
  - Financed the founding of the ELTE CMS group
- Bolyai Research Scholarship for individuals (extra salary)

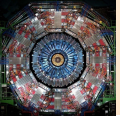
Bilateral grants

- E.g. SNSF SCOPES (ETHZ-Wigner for QCD studies)

National funding agency (NKFIH/NRDIO)

- 10 M&O A / year (2-3 per institute): ~100 kCHF/year
  - **Fixed number since joining CERN**
- Core Cost (incl. Common Fund and subsystem contributions) for Phase-2 upgrade: 1081 kCHF distributed over 10 years
- Thematic “OTKA” research grants for teams lead by established (K) or young (FK) researchers
  - **Limited budget** (30 kEUR/year) for travel, equipment, M&O B, …
  - Often consortial applications to build on synergies (e.g. ELTE + Wigner on Electroweak & BSM Physics + Phase-2 upgrade of Tracker & BRIL)
  - Typically 2-3 at a given time to cover the varied research areas in CMS (EW&BSM, QCD, heavy ions)
- Thematic Excellence Program (TKP) for research / higher education institutions
  - ELTE Astro- and Particle Physics Program
- New National Excellence Programme (ÚNKP) for individuals (extra stipend)
- Summer internships, travel grants, etc.

Most grants cover 3-5 years: continuity / availability of funding is an issue, especially for R&D projects (Phase-2 upgrade)



BSc / MSc / PhD degrees awarded since 2014

Based on institute of supervisor(s), degrees always given by a university
(includes a few undergrad degrees at BME with "external" supervisor)

Based on best effort basis using private communications from supervisors (omissions possible)
- **TOTEM not included**

Bachelor (31)

- 25 @ ELTE (mostly physics analysis, 2 detector study)
- 2 @ Wigner RCP (detector study)
- 4 @ Uni Debrecen (electrical engineering)

Master (12)

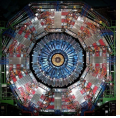
- 7 @ ELTE (mostly physics analysis, 1 detector study)
- 1 @ ELTE / Wigner RCP (physics analysis)
- 4 @ Wigner RCP (2 physics analysis, 2 detector study)

PhD (6) – physics analysis content compulsory

- 1 @ ELTE
- 2 @ ELTE / Wigner RCP
- 1 @ Uni Debrecen / Wigner RCP
- 2 @ ATOMKI

PhD students typically start with same supervisor already at BSc/MSc level, so frequently by the time of getting the degree they work 5-9 years in the group

Frequently they complete the PhD degree after more than the official 4 years (requirement: 2 published papers, at least 1 must be physics analysis)

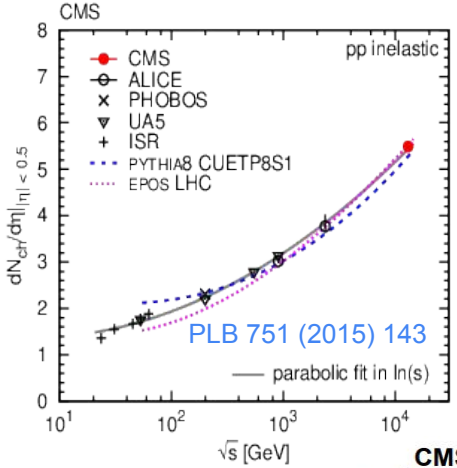


Scientific research

From abundant events (inelastic scattering) to extremely rare phenomena (double parton scattering, vector boson scattering, BSM physics)

- Strong interaction: hadronisation, correlations, exclusive processes
- Double parton scattering
- Heavy ion collisions: quantum correlations, femtoscopy, light-by-light scattering
- Electroweak physics: diboson production, vector boson scattering, anomalous couplings
- Beyond the Standard Model: supersymmetry, axion-like particles and more

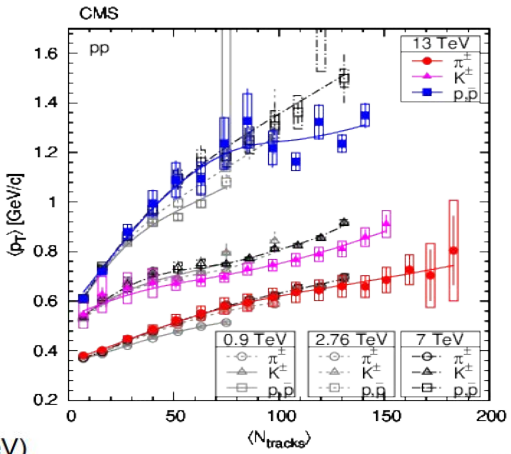
Study of strong interaction

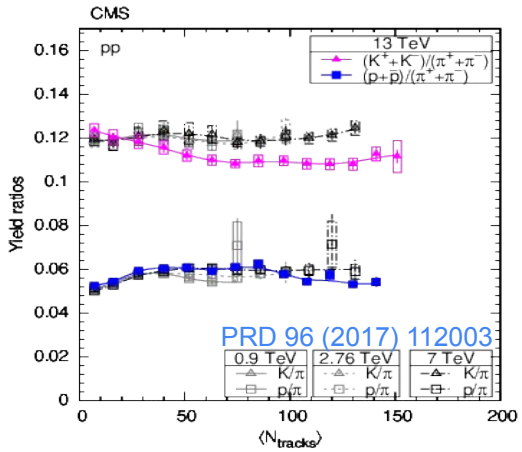


PLB 751 (2015) 143

Charged particle yield vs. collision energy:
1st paper at 13 TeV
(no magnet)

Multiplicity dependence of charged hadron production, scaling

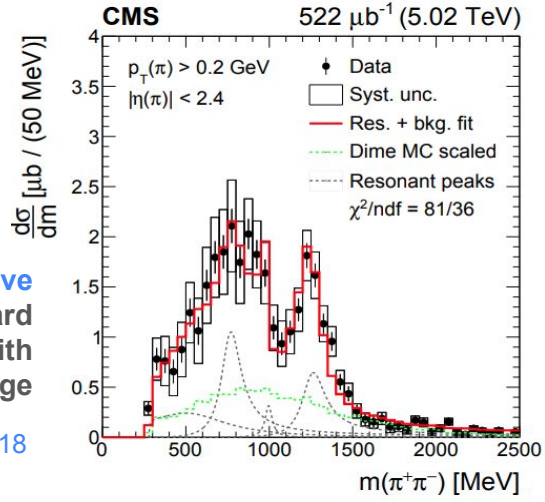




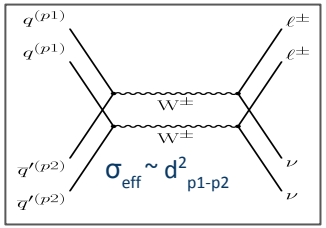
PRD 96 (2017) 112003

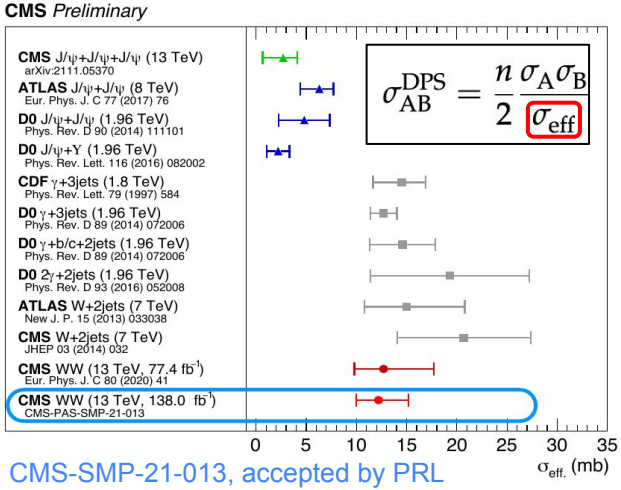
Central exclusive production, forward physics with pomeron exchange

EPJ C 80 (2020) 718



1st observation of same-sign WW production via double parton scattering, effective cross-section, proton structure

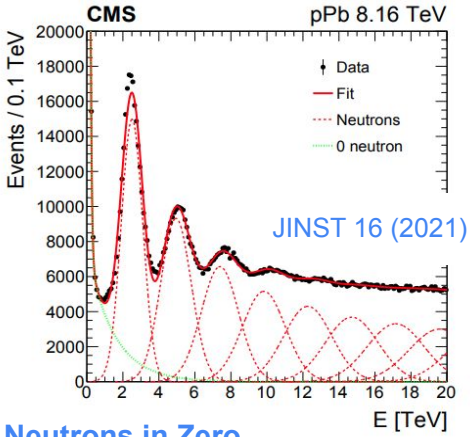


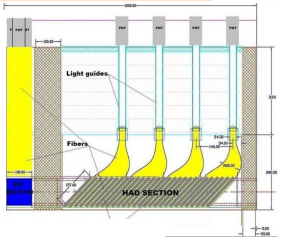


CMS-SMP-21-013, accepted by PRL

Forward detectors

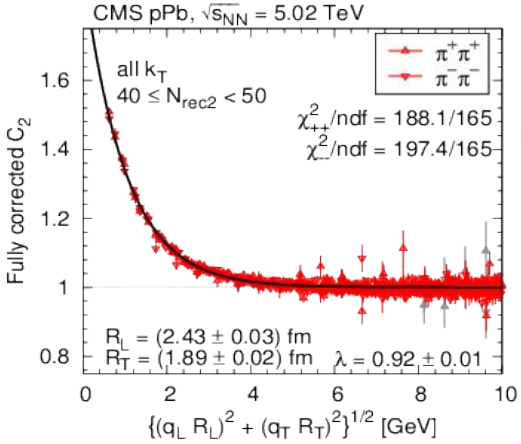
Particle correlations

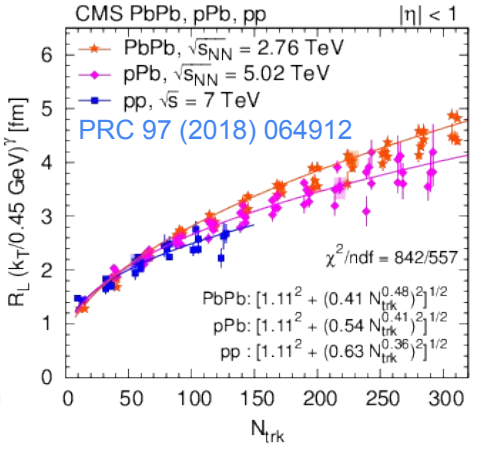




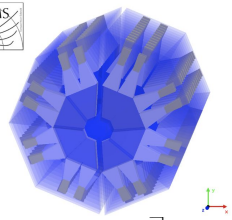
JINST 16 (2021) 05, P05008

antum correlation of identified hadrons, shape of particle emitting source



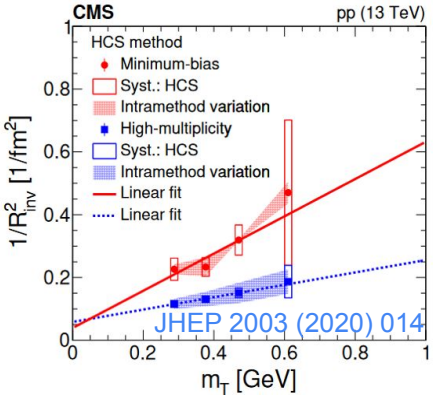


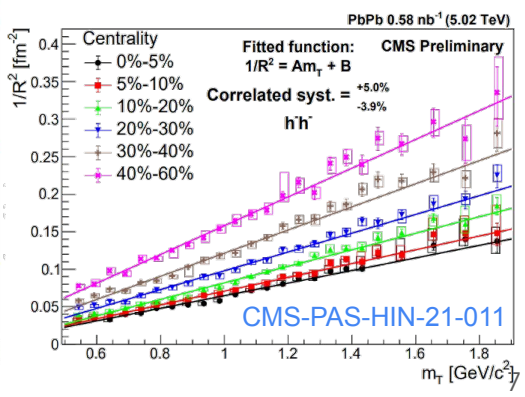
Neutrons in Zero Degree Calorimeter, event centrality in pPb and PbB



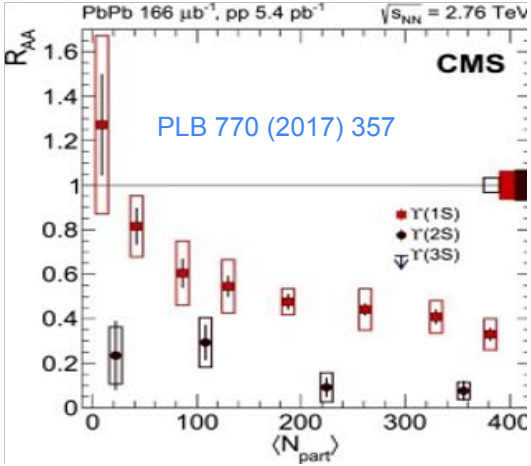
Very forward particle production, pseudorapidity dependence of the forward energy flow With CASTOR

Bose-Einstein two-particle momentum correlation, Lévy-type source distribution parameters: size, non-Gaussian, non-Cauchy shape in PbPb





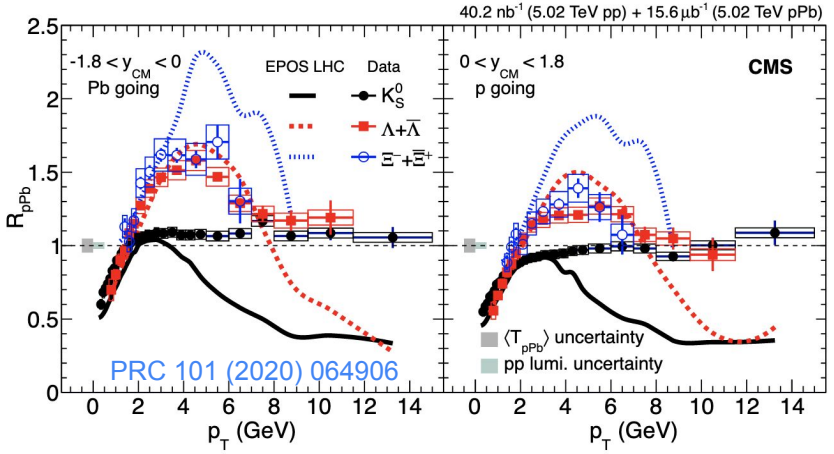
More heavy ion physics



PLB 770 (2017) 357

Suppression of Υ (nS), sequential melting of quarkonium states

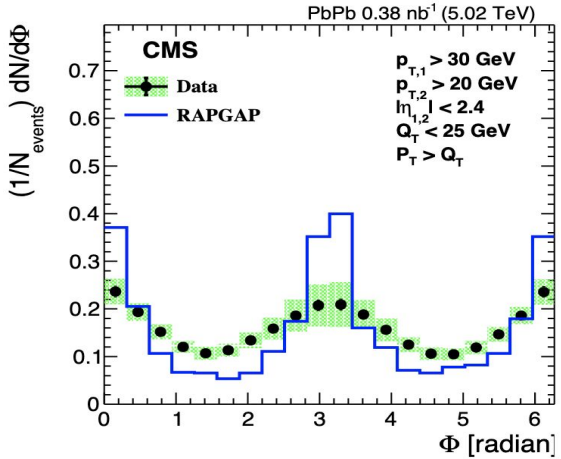
Strange hadron production, nuclear modification factor, asymmetry vs pPb rapidity, enhancement by strangeness

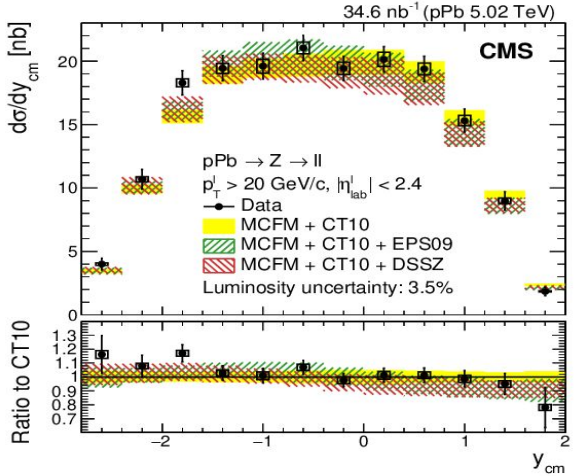


PRC 101 (2020) 064906

Exclusive dijet angular correlations in photon-lead collisions, largely overestimated by popular model

CMS-HIN-18-011
Submitted to PRL



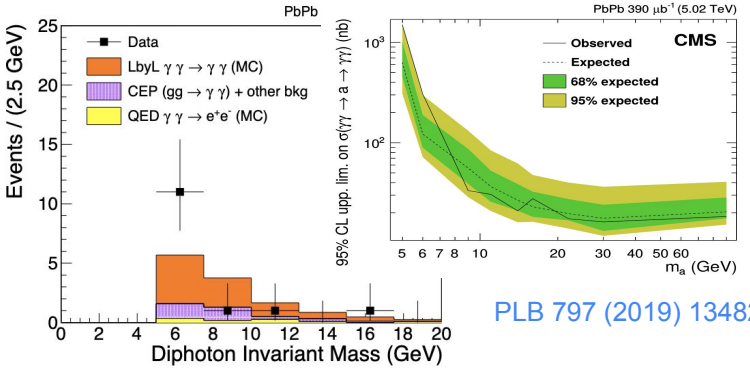


Z boson production, modification of PDFs in cold nuclear matter (pPb vs pp)

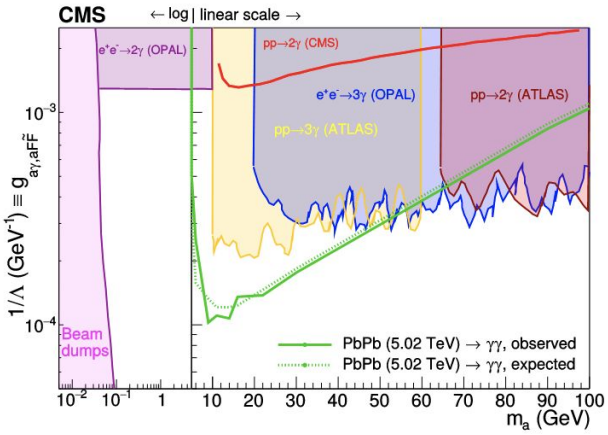
PLB 759 (2016) 36

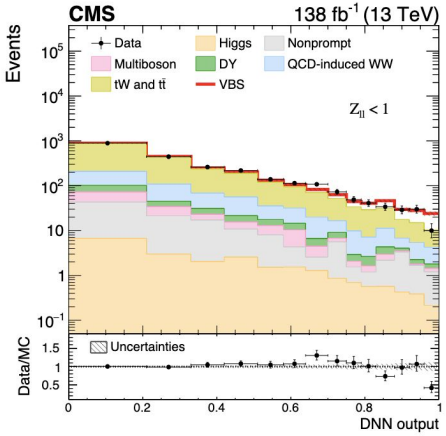
Electroweak and new physics

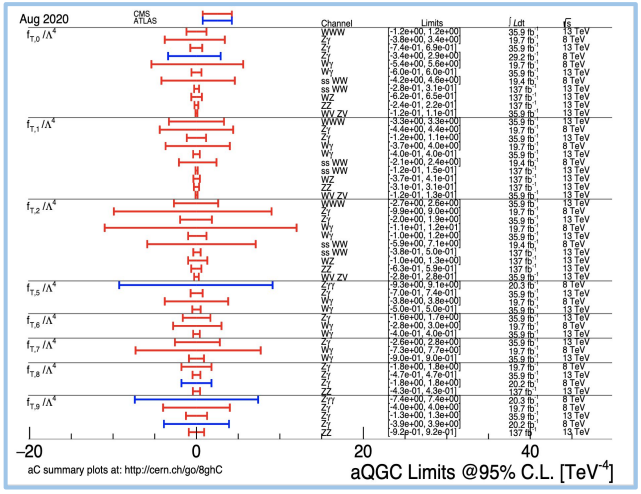
Light-by-light scattering, search for axion-like particles

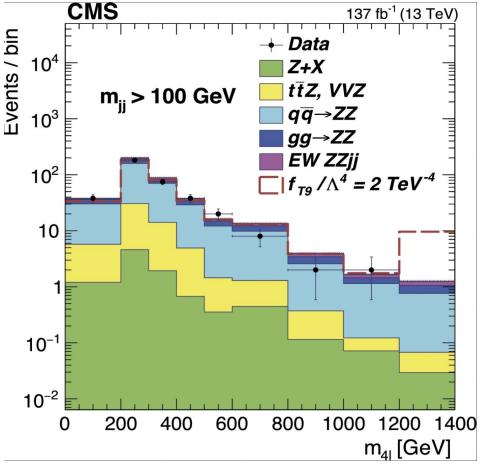


PLB 797 (2019) 134826









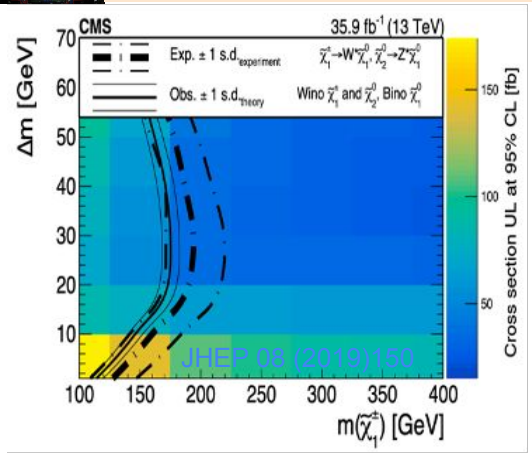
Observation of electroweak W+W− pair production in association with two jets

CMS-SMP-21-001, submitted to PLB

Evidence for electroweak production of four charged leptons and two jets, constraints on anomalous couplings

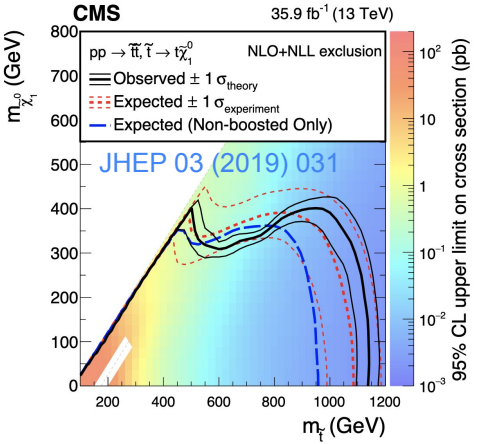
PLB 812 (2021) 135992

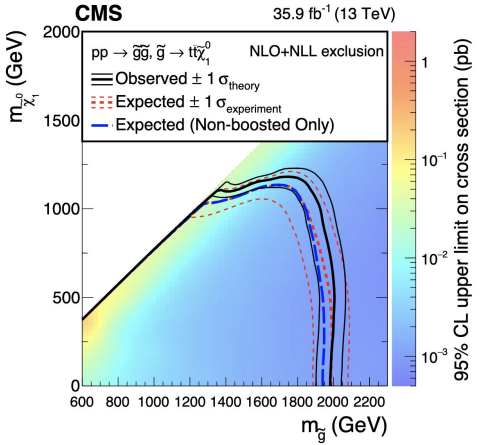
Search for supersymmetric particles

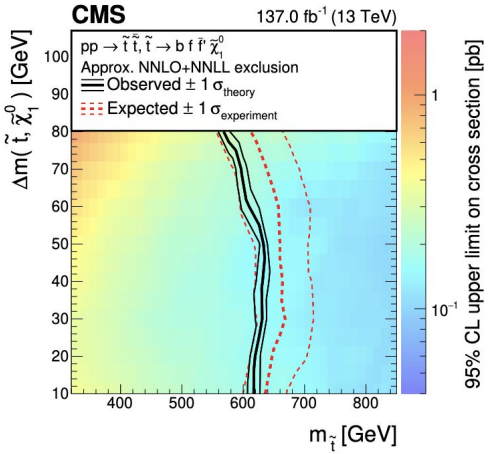


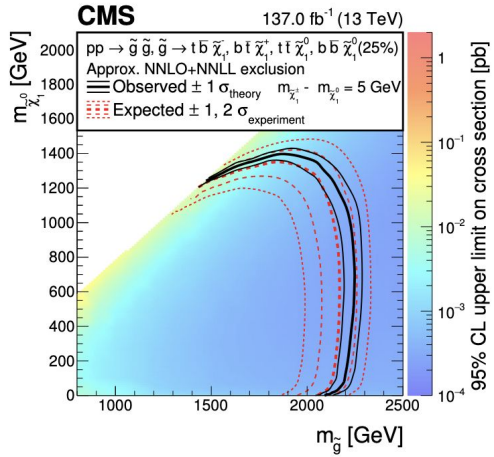
Inclusive search for supersymmetry using razor variables and boosted objects in 0ℓ & 1ℓ final states

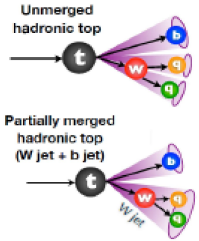
Supersymmetry with **compressed mass spectrum** in vector boson fusion topology in 0ℓ & 1ℓ final states







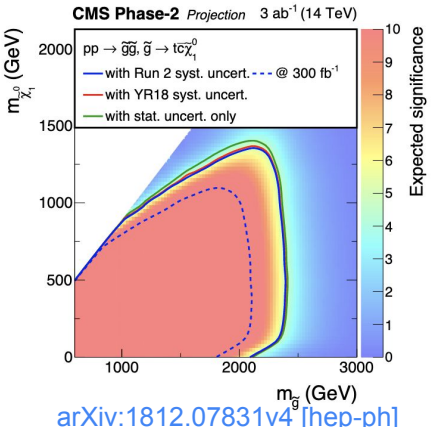




Search for **top production** in fully-hadronic final states, including compressed spectra with four-body decay

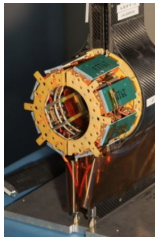
PRD 104 (2021) 052001

HL-LHC projection



arXiv:1812.07831v4 [hep-ph]

CMS operations



ELTE

Beam Radiation Instrumentation and Luminosity (BRIL) system

- Operation, calibration, performance
- Project management
- Precision luminosity

ELTE

High-Level Trigger

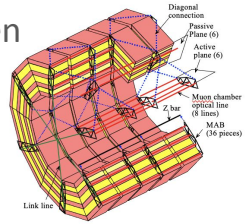
- Development, operation, performance
- e/γ & Jet/MET triggers
- Luminosity calibration
- Standard Model physics

ATOMKI & Uni Debrecen

Muon system

- Operations, run coordination
- Temperature and humidity monitoring
- Alignment of 250 drift tubes (DT) using 10k LEDs and 600 video cameras (construction, operation, maintenance)

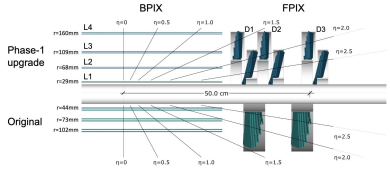
(see talk by B. Ujvári)

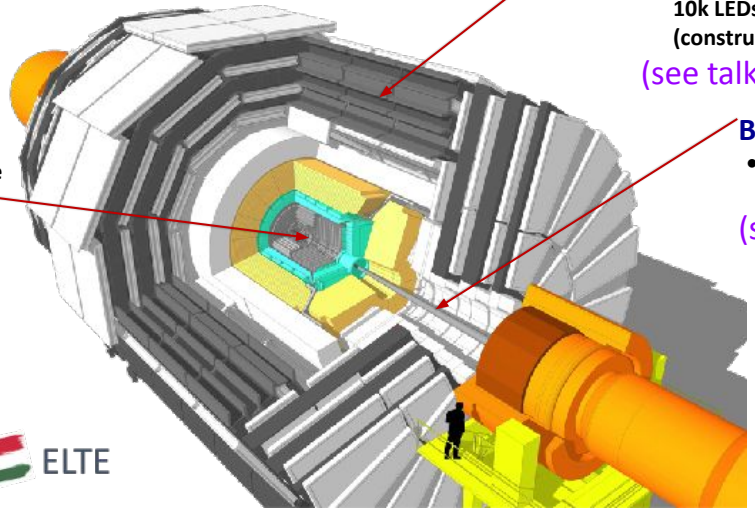


Wigner FK

Tracker

- Phase-1 pixel supply tube design, construction
- Pixel detector operation, calibration, performance
- Project management
- Online beamspot measurement



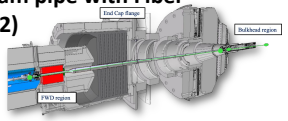


ATOMKI

Beam pipe

- Temperature monitoring of beam pipe with Fiber Optical Sensors (installed in LS2)

(see talk by B. Ujvári)

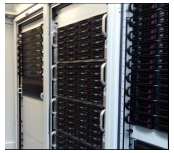


Wigner FK

Computing Tier-2

- Operation, maintenance

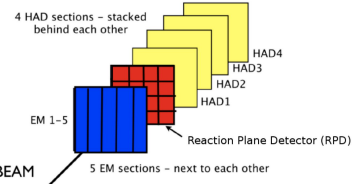
(see talk by G. Bíró)

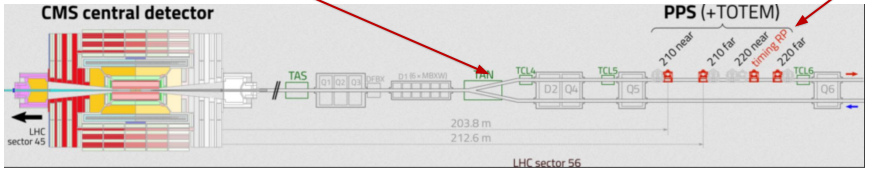


ELTE

Zero Degree Calorimeter (ZDC)

- Installation before ion runs
- Operation, calibration, performance

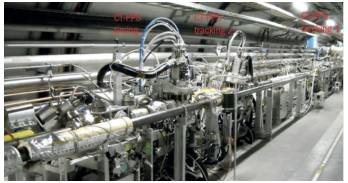




Precision Proton Spectrometer (PPS)

- LHC optics determination

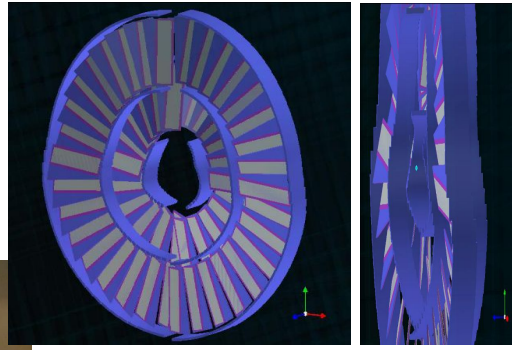
(see talk by T. Csörgő)

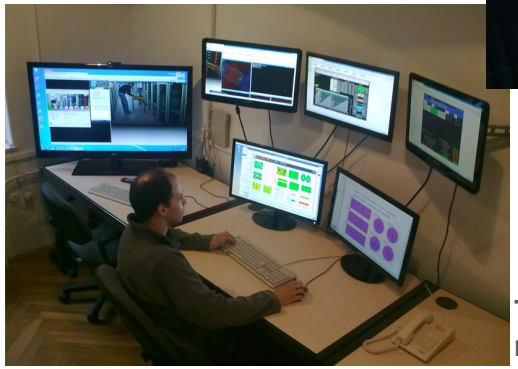


Uni Gyöngyös

Phase-1 Tracker

- **Construction of Phase-1 Barrel Pixel (BPix) supply tube** providing LV & HV, read out (optohybrids), slow control and timing, module programming, in collaboration with Aachen, PSI, Uni Zürich
  - Control and read-out electronics by Wigner & CERNTech
- Phase-1 pixel geometry: BPix validation, **FPix full description**
- Local reconstruction
- Online Data Quality Monitoring
- Calibration Database
- Pixel performance
- Project management

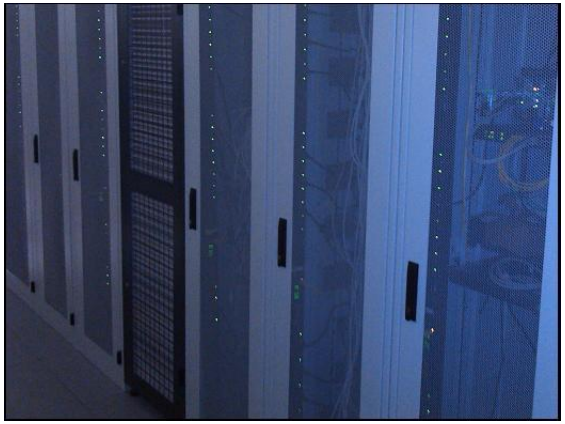




Tracker Offline remote shifts

T2_HU_Budapest grid site (~70% CMS)

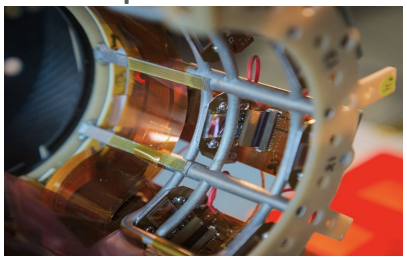
- Central CMS tasks
- **Tracker (Pixel Offline) performance**
- **Monte Carlo production**
- QCD and SUSY analyses



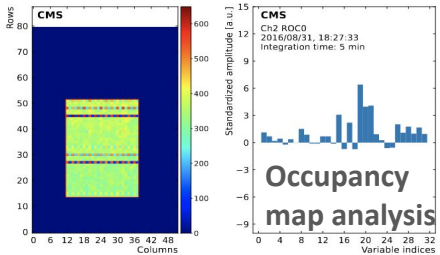
Luminometry

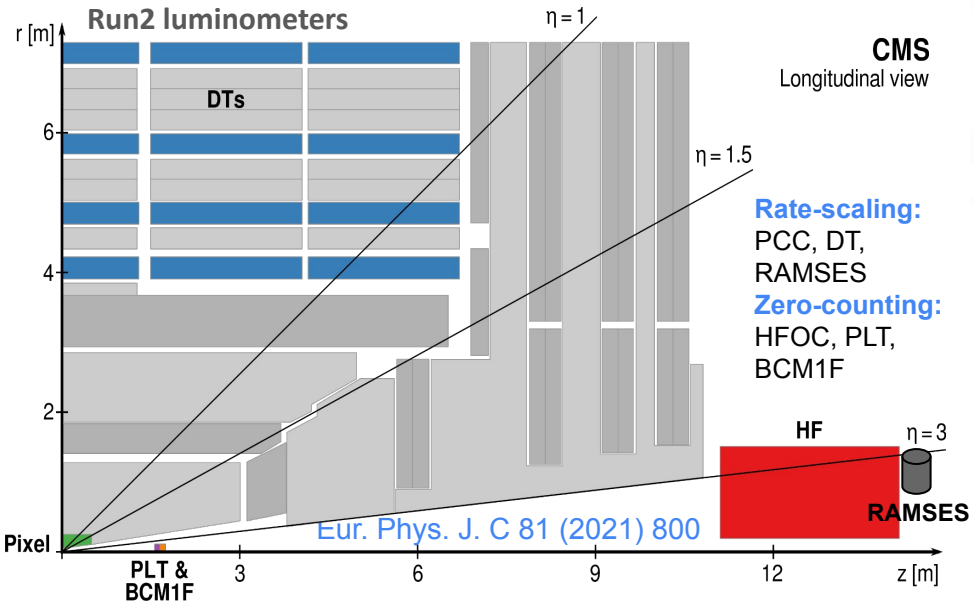
- BRIL project coordination, participation in operations
- **Pixel Luminosity Telescope** (PLT): unsupervised machine learning based data quality monitoring
- Run 2 pp and PbPb luminosity calibration
- Van-der-Meer scan program planning
- Beam-related systematics: beam-beam interactions, transverse factorisation of bunch proton density, LHC transverse orbit position length scale

Close up of PLT



arXiv:2206.08870 (physics.ins-det)

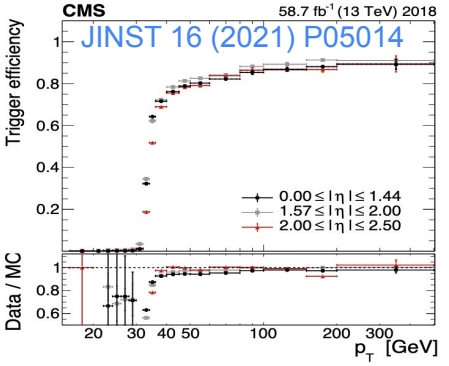




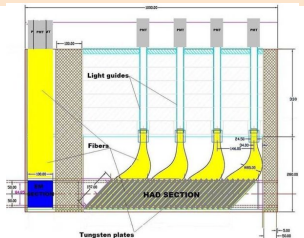
High level trigger

- Trigger operations
- HLT development (e/γ, Jet/MET)
- Standard Model Physics and Luminosity trigger coordination

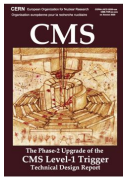
Electron trigger efficiency



+ Zero Degree Calorimeter (slide 7)



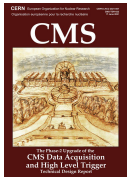
CMS Phase-2 Upgrade



Level-1 Trigger

https://cds.cern.ch/record/2714892

- Tracks in L1 Trigger at 40 MHz
- Particle Flow selection
- 750 kHz L1 output
- 40 MHz data scouting



DAQ & High-Level Trigger

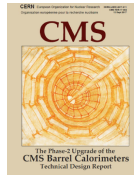
https://cds.cern.ch/record/2759072

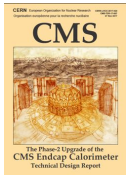
- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output

Barrel Calorimeters

https://cds.cern.ch/record/2283187

- ECAL single crystal granularity readout at 40 MHz with precise 30 ps timing for e/γ at 30 GeV
- Spike rejection
- ECAL and HCAL new Back-End boards

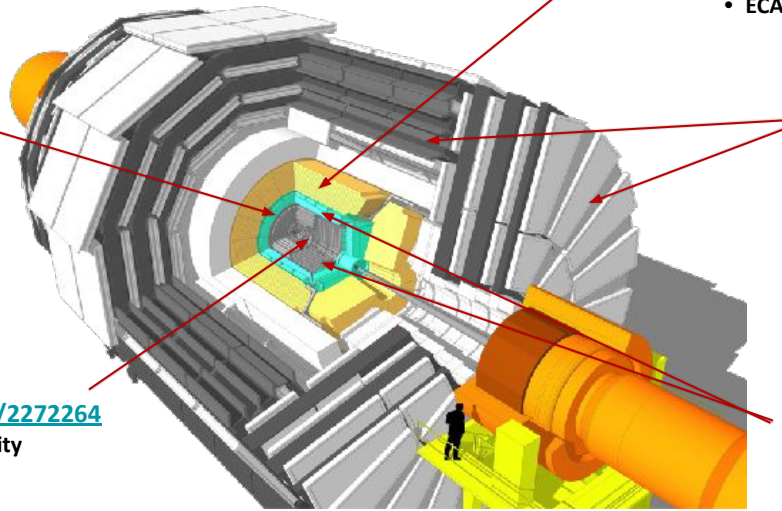




High-Granularity Calorimeter Endcap

https://cds.cern.ch/record/2293646

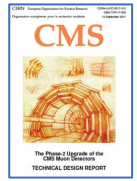
- 3D showers and precise timing
- Si, Scintillator+SiPM in Pb/Cu-W/SS



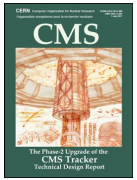
Muon systems

https://cds.cern.ch/record/2283189

- DT & CSC new FE/BE readout
- RPC BE electronics
- New GEM/RPC 1.6 < η < 2.4
- Extended coverage to η ≃ 3



ATOMKI (see talk by B. Ujvári)



Tracker https://cds.cern.ch/record/2272264

- Si-Strip and Pixels increased granularity
- Extended coverage to η ≃ 4
- Design for tracking in L1 Trigger

Wigner FK

Beam Radiation Instrumentation and Luminosity

http://cds.cern.ch/record/2759074

- Beam abort & timing
- Beam-induced background
- Bunch-by-bunch luminosity: 1% offline, 2% online
- Neutron and mixed-field radiation monitors

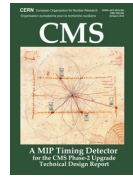
ELTE

MIP Timing Detector

https://cds.cern.ch/record/2667167

Precision timing with:

- Full coverage to η ≃ 3
- 30-50 ps time resolution for MIPs
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes



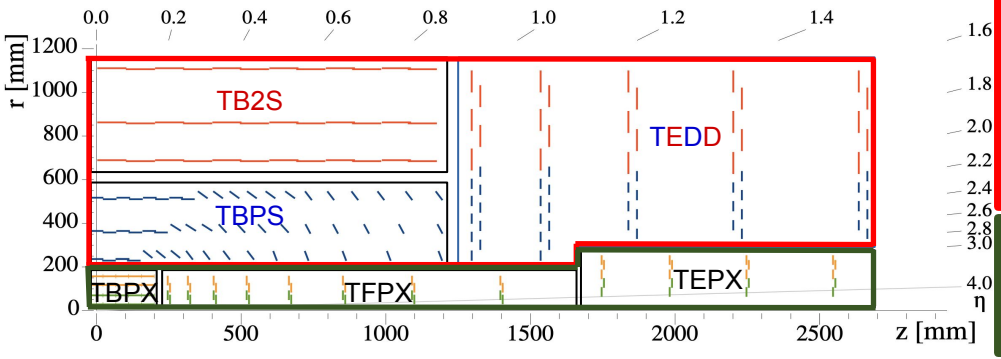
Uni Debrecen

(see talk by B. Ujvári)

SS: stainless steel, FE: front end, BE: back end, MIP: minimum ionizing particle, SiPM: Silicon Photomultiplier

Phase-2 Tracker

To fight challenging HL-LHC environment
- Finer segmentation: ~25xLHC channels
- Extended coverage
+ Real-time luminosity measurement



Outer Tracker (190 + 25 m^2)
- ~13200 modules
- 43M strips, (2,4-5) cm x (90-100) µm
- 170M macro-pixels, 1,5 mm x 100 µm
- **Input to L1 trigger @ 40 MHz**

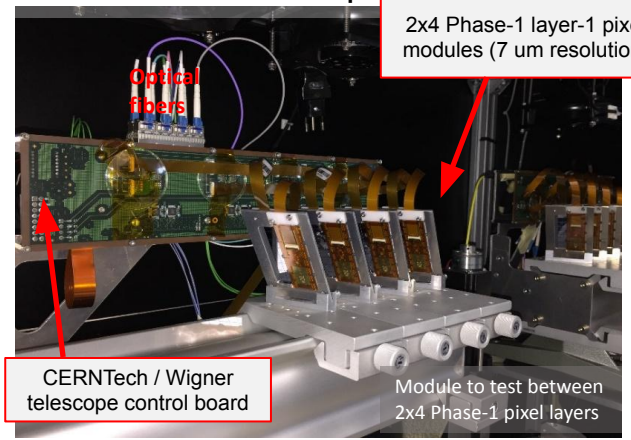
Inner Tracker (4.9 m^2)
- ~4000 modules
- ~2G pixels, 25 µm x 100 µm

CHROMIE testbeam telescope

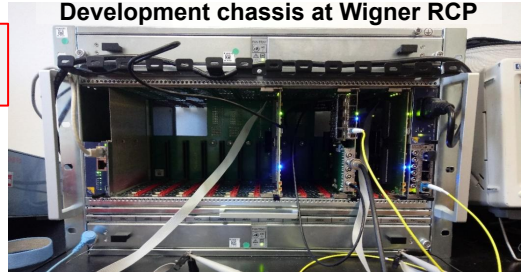
- To perform extensive system-level testing before production (radiation tolerance, speed, resolution), e.g. at CERN SPS
- Front-end control board (powering, control, read out) & CMSSW reconstruction software developed at Wigner FK
- Production jointly with CERNTech

TTC-FC7: New FPGA-based µTCA back-end electronics system and firmware development ongoing for timing, trigger and control for system tests

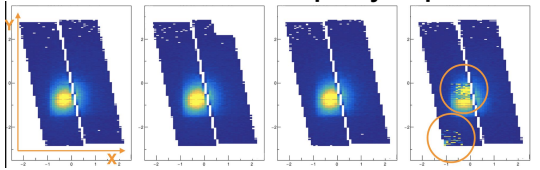
CHROMIE testbeam telescope



Development chassis at Wigner RCP

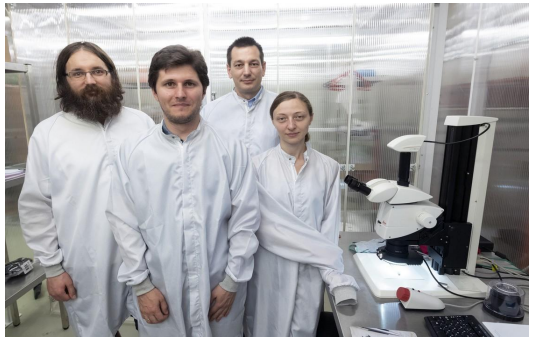


Test result: sensor occupancy maps



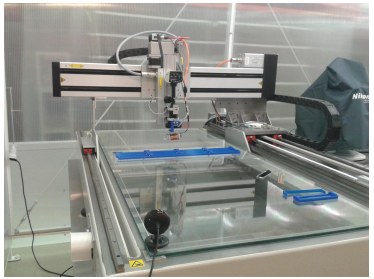
Optical tests of Phase-2 Outer Tracker FE hybrid electronics

- Assembly of more than 13.2 k OT modules in ~3 years
- No access after installation: high reliability for 10 years under extreme conditions (high radiation, low T…)
- Thorough component testing before module assembly to check production quality, component alignment, etc.
- ~55k hybrid circuits to be inspected from Feb 2023 at Wigner RCP (~20k) and CERN
  - 2 technicians to be hired from mid-2023
  - Collaboration with CERNTech (engineering) and FFT Kft (maintenance of clean room)

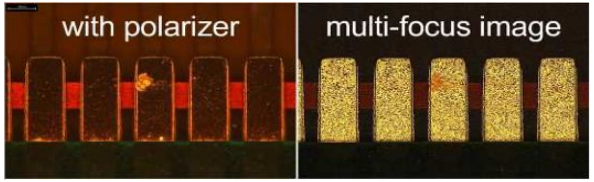


Infrastructure and equipment

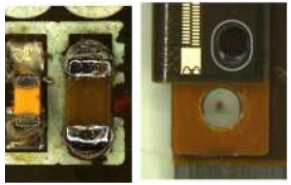
- 15 m^2 ESD-safe laminar clean room with 3 air filtering stages (cleanliness > ISO7) with active ventilation, humidity and temperature monitoring and control
- Leica M205C stereomicroscope with motorized vertical stage
- 2 Nikon SMZ800N stereo-microscopes
- Large area optical scanner (60 cm x 90 cm) with ~5 µm resolution

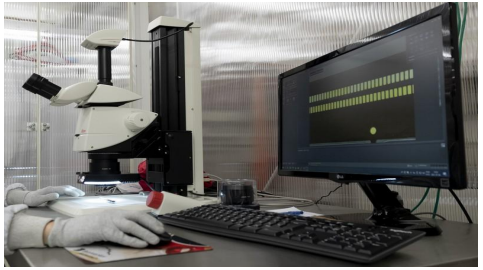


100µm wide pads for wire-bonding (to inspect: cleanliness, color, damages)



Soldering & alignment to be checked





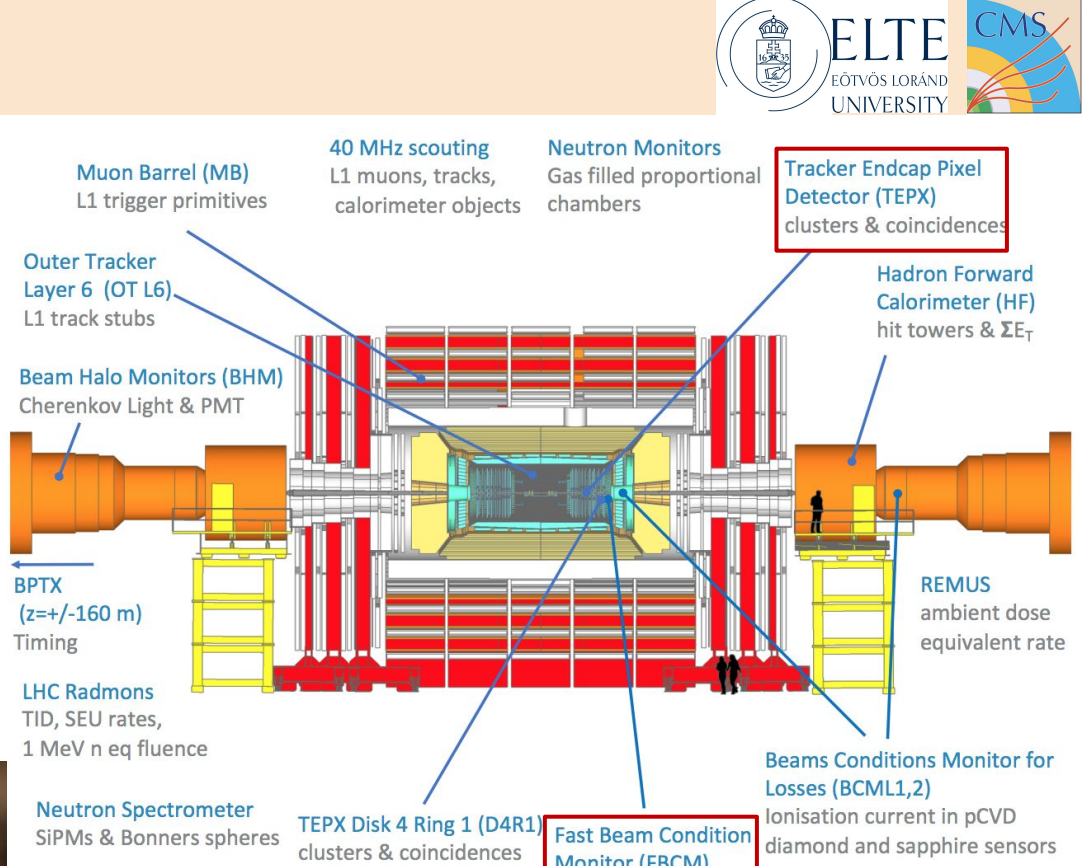
BRIL upgrade

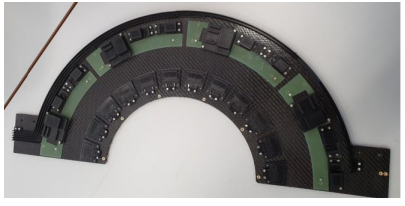
Challenge: 1% luminosity precision at pileup 200

TDR approved in 2021
Preparation of Engineering Design
MoU and responsibilities under discussion

- Coordination
- Fast Beam Conditions Monitor (stand-alone luminometer based on Si-pad sensors and fast readout with sub-BX time resolution) design optimisation
- Tracker Endcap Pixel Detector real-time cluster and coincidence counting
  - Simulation studies
  - RD53 readout test system in small electronics lab at ELTE

Readout test system Front End & Back End





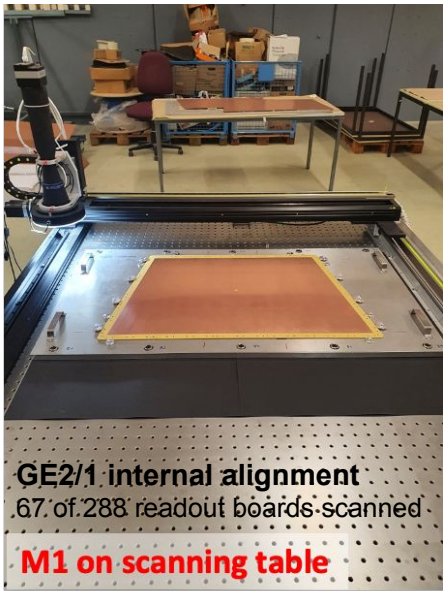
FBCM mechanical mock-up

Muon system upgrade MIP Timing Detector

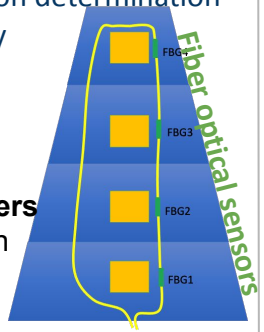
(see talk by B. Ujvári on detector R&D and research infrastructure in Debrecen)

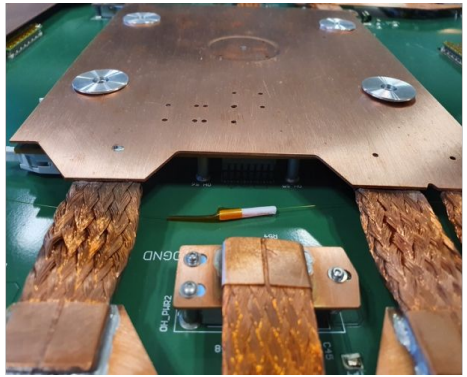
New Gas Electron Multiplier chambers to extend muon coverage to |η|≈3: GE1/1 (LS2), GE2/1 (EYETSs 2023, 2024), ME0 (LS3)

- Internal alignment of readout boards using precision scanning table constructed at CERN
- Photometric measurements for initial position determination
- Temperature monitoring with independently operated Fiber Optical Sensor (FOS) system



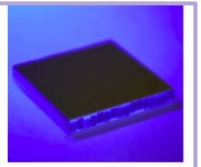
Temperature monitoring of GE2/1 chambers
Test installation of FOS on first chamber





4D reconstruction of tracks & vertices with 30-50 ps time resolution to limit PU effects

BTL: LYSO bars + SiPM readout:
- TK / ECAL interface: |η| < 1.45
- Inner radius: 1148 mm (40 mm thick)
- Length: ±2.6 m along z
- Surface ~38 m^2; 332k channels
- Fluence at 4 ab^{-1}: $2x10^{14}$ n_{eq}/cm^2



Barrel Timing Layer (BTL)

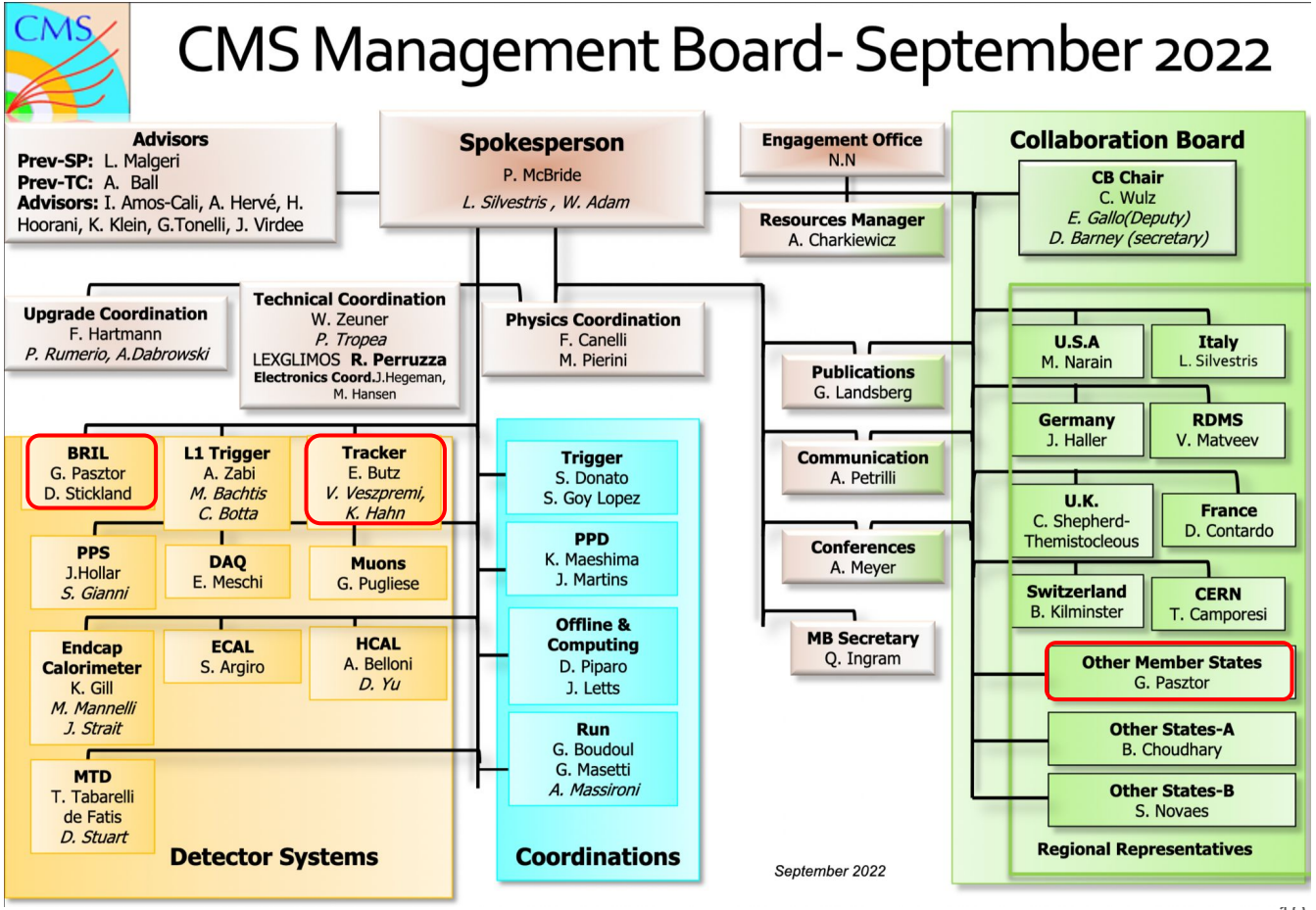
- SiPM testing at -40 C: I-V scan and ingle photon spectrum (breakdown voltage, gain curve, photon detection efficiency)
  - 10 k flex circuits with arrays of 16 SiPMs
  - From PCB design to measurement and data analysis at Uni Debrecen
- BTL module testing with Cs-137 source before integration with read out electronics
  - Spectrum measurement to test glueing quality, presence of shortcuts…
  - 32 channel / module, 160M samples per sec

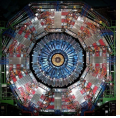
Roles in the collaboration

Currently also Hungarian members in
- Heavy Ion (HIN) Physics Publication Board
- Standard Model Physics (SMP) and Detector Performance (DP) Publication Board
- Diversity Office

Few years ago
- Chair of Young Scientist Committee

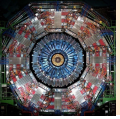
Various leadership roles in
- Standard Model (QCD, Forward and low-x) Physics Analysis Group
- Heavy Ion Physics Analysis Group
- Electron/photon Physics Object Group
- Luminosity Physics Object Group
- Trigger Coordination
- Calibration & Alignment Group
- Tracker Project
- BRIL Project
- HIN, SMP&DP Publication Boards
- Management Board Advisor Group



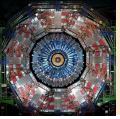


Summary

- CMS has the largest high energy physics team in Hungary
  - Two new institutes since last RECFA visit: ELTE (2015), Uni Gyöngyös (2019, from TOTEM)
  - Diverse and successful physics, detector operation and upgrade projects
  - Well-integrated to the international collaboration
    - Leading various detector projects and physics groups
    - Receiving CMS Awards (e.g. in Muon Project 2021, in PPS 2019)
- Concerns
  - Further strengthen collaboration between Hungarian institutes, especially links between universities (with a steady stream of students) and research institutes (with more technical and engineering resources)
  - Lack of dedicated R&D funding for hardware development, phase-2 upgrade participation
  - (In)stability / limited availability of research funding makes consolidation of new projects and sustainable growth difficult
  - Heavy administration and slow obligatory public procurement
  - Young Hungarians leave the country and / or the field and also difficult to attract foreign scientists
  - Challenging to fulfil PhD requirement of 2 published papers (at least 1 on physics analysis) in 4 years
  - Recognition of individual contribution to the large collaboration for grants, career advancement



Extra



ATOMKI Detector Development Infrastructure

Detector Laboratory including instrumentation for Fiber Optical Sensor R&D (based on Fiber Bragg Grating technology)

- Dark environment, optical bench, laser light source, optical interrogator, test generators, fast transient recorders, IT infrastructure
- Possible industrial applications

In-house accelerator facility (for neutron production), Co-60 gamma irradiation technology

- Able to provide relevant types of ionizing radiation with appropriate intensity and energy for radiation hardness tests for experimental HEP and space research