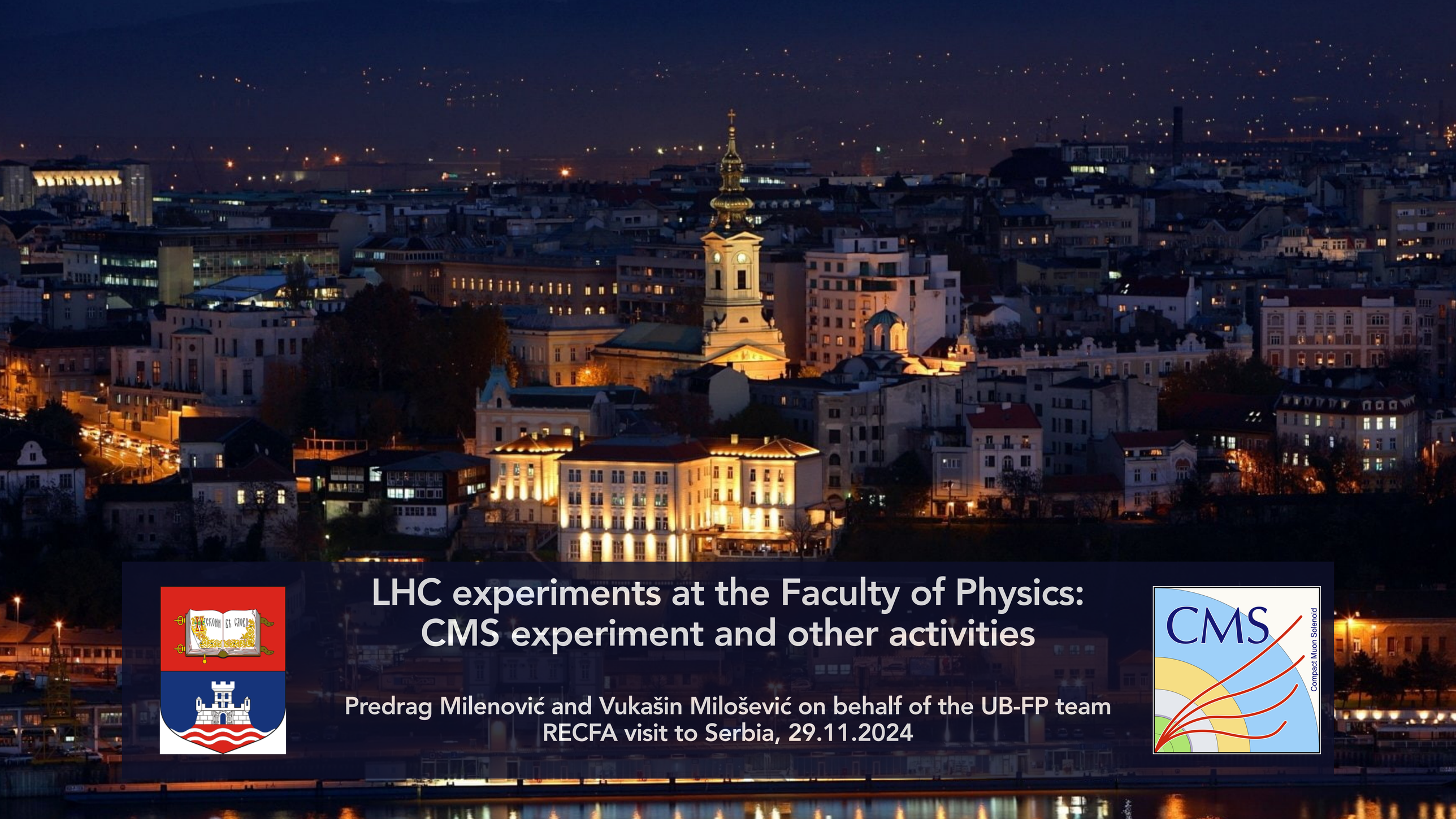

LHC experiments at the Faculty of Physics: CMS experiment and other activities

Predrag Milenović and Vukašin Milošević on behalf of the UB-FP team

RECFA visit to Serbia, 29.11.2024

A brief look into history

- **Our research team has been actively involved in the CMS experiment since 1997**

- **In-kind, hardware and engineering contribution:**
  - **Hydraulic jacks as connecting pieces for CMS magnet -** UNIOR Components, Kragujevac (2002-2003)
  - **ECAL Safety System and ECAL Relative Humidity System design**
  - **CMS Engineering and Integration Centre -** Design and 3D modelling of the CMS detector, since 2004

- **Physics and detector studies (since 1997):**
  - **Study and description of geometry for the preshower (ECAL) detector**
  - **Analyses of experimental data from test beam runs with the ECAL**
  - **Participation in preparation for the CMS data handling**

  - **Development of software packages and physics analyses of the $H \rightarrow \gamma\gamma$ decay channel**
  - **Search and analysis of events for decays of directly produced SUSY particles**

  - **Since 2010: Active physics analysis of experimental data and detector upgrade work**
    - More details in the following slides

A brief look into history

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  - Search and analysis of ev
  - Since 2010: Active physics analysis of experimental data and detector upgrade work
    - More details in the following slides

This moment was a landmark in the partnership between the Faculty of Physics and CERN!

February 26, 2014: Signed Agreement between CERN and the Faculty of Physics

The UB-FP teams

- **Faculty of Physics (FFUB):** 5 senior/junior researchers, 2 engineers, 4 PhD/master students.
- **Physics program**: SM, Higgs boson, and BSM physics
- **Detector:** Development, maintenance, operation of control systems + Mechanical 3D design for CMS detectors & services.

Research staff:

TL: Prof. Petar Adžić

DTL: Prof. Predrag Milenović

Dr Vukašin Milosević

Dr Marjan Ćirković

Dr Nikola Konjik

Engineering and RnD:

Nikola Rasevic, engineer

Milorad Mijic, physicist

PhD students:

Lazar Marković - PhD student

Jovan Mitić - PhD student

Luka Bulaja - PhD student

Darko Brunet - PhD student

Externally-internal collaboration:

Nebojša Smiljković - CERN LD

Dr Vladimir Loncar - CERN LD (ex IPB)

Lazar Cokic - engineer, CERN Fellow

Irena Veljajnovic - engineer, CERN Fellow

Predrag Bunčić - CERN IC

RnD collaboration:

Dr Aleksandra Radulovic, physico-chemist (IGPC)

Dr Dubravka Milovanovic, physico-chemist (IGPC)

Dr Nebojsa Begovic, physico-chemist (IGPC)

Dr Jelena Jovanovic, physico-chemist (IGPC)

Dr Saša Dujko, physicist (IPB)

Dr Danko Bošnjaković, physicist (IPB)

Research roles, responsibilities and projects

- List of projects:
  - COMETA COST Action CA22130 - Horizon Europe, 2023-2027
  - Bilateral Italy-Serbia project, RS19MO06, 2019-2021
  - VBSCAn COST Action CA16108, EU Horizon 2020, 2018-2021
  - Bilateral ETHZ - Belgrade project, 2016-2024
  - National project ON171019, MoESTD, Serbia, since 2011
  - SCOPES projects, SNF SDC, Switzerland, 2005-2015

- CERN funded positions:
  - Senior research fellowships (P. Milenovic, V. Milosevic)
  - Junior fellowships (I. Veljanovic, L. Cokic)
  - Multiple summer student positions

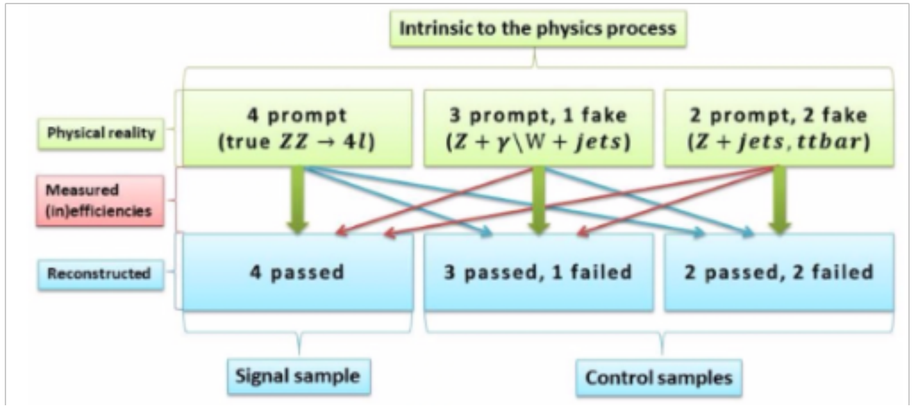
- CMS and LHC-wide coordination roles:
  - **LHC Higgs WG Steering Committee** (2021 - 2023)
  - **Effective Field Theory interpretations** (2020 – 2023)
  - **LHCHWG Higgs properties (WG2) group** (2019 - 2021)
  - **Higgs Future sub-group** (2017 - 2019)
  - **LHCHWG Higgs cross sections sub-group** (2016 - 2019)
  - **Higgs ZZ sub-group** (2015 - 2017 and 2023 - 2025)
  - **Higgs Trigger contact** (2018-2021)
  - **L1T DQM contact** (2021-2023)

- Academic and teaching roles:
  - Various undergraduate and graduate courses in HEP and scientific computing
  - Serbian teacher's programme@CERN

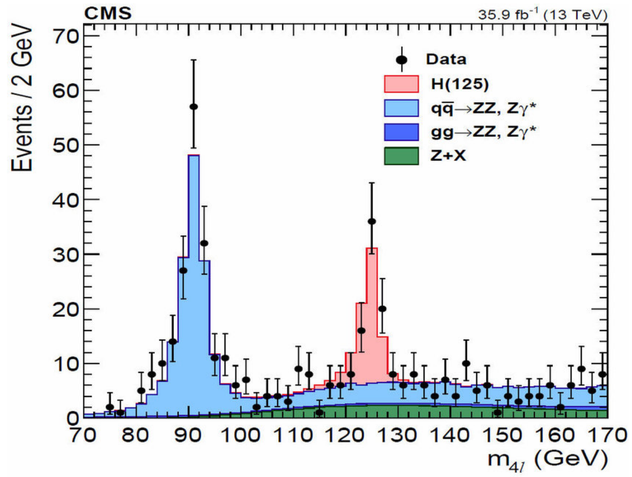
- List of conferences and workshops co-organised by group members:
  - Probing space-time properties at HEP experiment (Belgrade - 29th May 2023)
  - 11th LHC Physics (LHCP) conference (Belgrade - 22-26th May 2023)
  - CERN Danube School on Instrumentation (in PNP) - Novi Sad (8-13th Sep 2014)
  - Trans-European School of High Energy Physics 2021, Petnica (13-20th Jul 2012)
  - CERN IPPOG Physics Masterclass in Serbia - more than 10 years and across 5 cities!

Physics highlights: The road from Higgs discovery to the Run 2 with HZZ and beyond

- **Team members were key persons in the analyses that led to the observation of the 125 GeV Higgs boson and measurement of its properties in its decay to four leptons**
  - Development of a matrix element method and the public software tool **MEKD** for characterisation of the spin and parity of the newly discovered boson **(improvement in sensitivity to exotic states by up to 15%)**
  - **Strong activities in analyses focusing on anomalous HZZ interactions and fiducial and differential cross section measurements since the early days of Run 1**

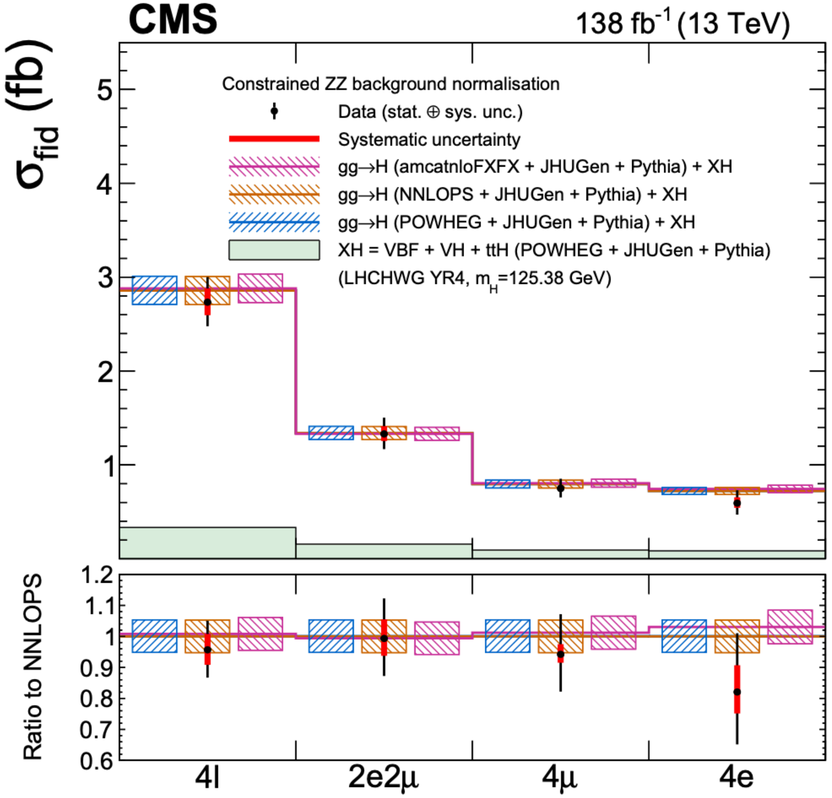


- **Crucial role in development of reducible background estimation methods for 4l processes**
  - Inclusion of extrapolation factors which take into account leptons with overlapping isolation cones
    - Phys. Lett. B 763 (2016) 280)
  - Reduced uncertainties by taking into account the sensitivity of fake rate measurements to background composition
    - CMS-PAS-HIG-16-033, JHEP 11 (2017) 047 and EPJ. C 81 (2021) 488



Physics highlights: Down the road with HZZ

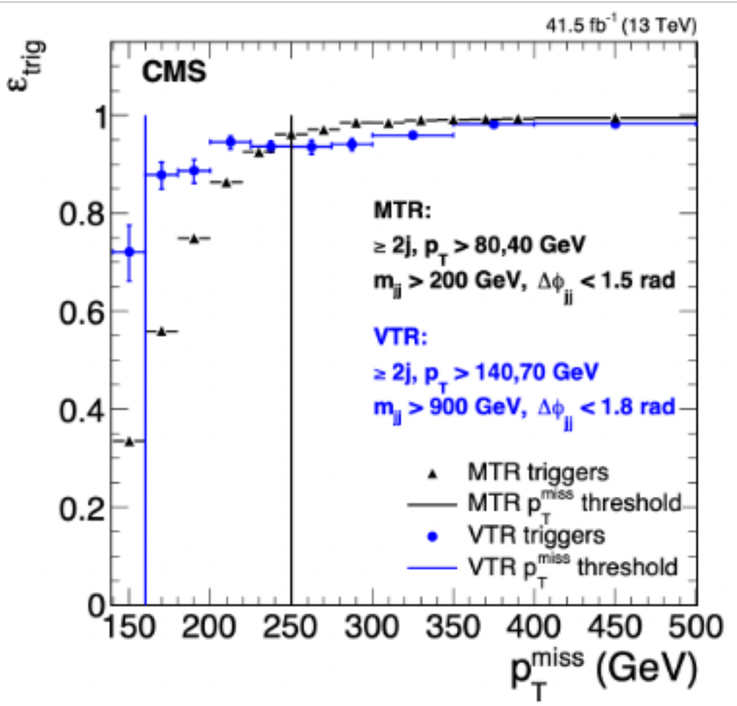
- **Run 2 legacy H4l paper comprehensive characterisation of the H → ZZ → 4*l* using fiducial cross section measurements:**
  - 1D measurement - production and jet observables
  - 2D measurements - phase space regions of interest for theorists
  - Interpretations - kb, kc and kλ
    - **Published in - JHEP 08 (2023) 040**



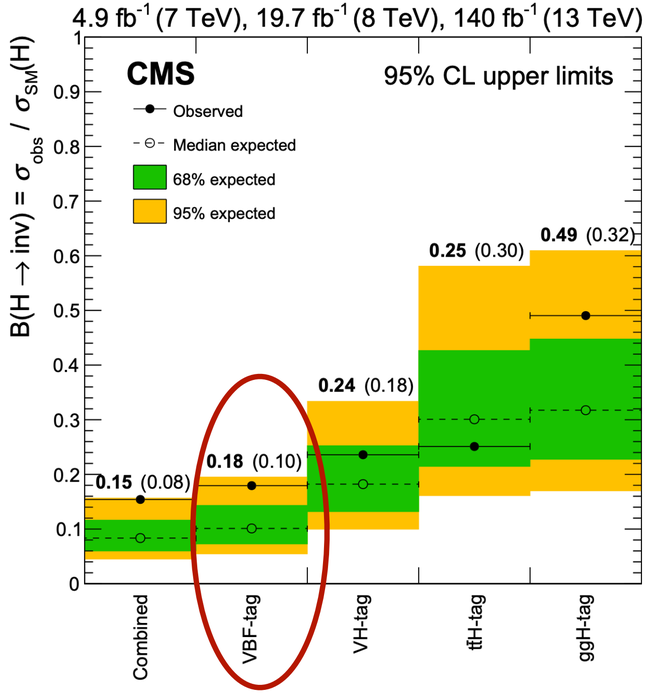
- **Ongoing work:**
  - **Partial Higgs decay width parameterisation and Higgs self coupling:**
    - H→4l at truth level for the full and fiducial phase space - parameterisation of quadratic terms
  - **Constraining Higgs boson triple self coupling using H→4l using the off-shell Higgs production:**
    - Exploit the quantum corrections from BSM $\mathbf{O_6}$ operator and constraining the Wilson coefficient $\mathbf{C_6}$
  - **High mass spin-0 resonance search in X→ZZ→2l2q and 2l2v channels**

Physics highlights: H->inv and HHH

- **Leading the search for the invisibly decaying Higgs boson:**
  - Analysis specific HLT paths focusing on the VBF H topology (2017/18 eras)
  - **Legacy Run 2 measurement:** Phys. Rev. D 105 (2022)
    - Placed 95% CL upper limit on **B(H → inv.)** at **0.18 (0.10)** obs. (exp.)
  - **Combination of H → inv. analyses:** Eur. Phys. J. C 83 (2023) 933
    - Crucial contribution to the analysis and combination efforts
    - 95% CL upper limit on **B(H → inv.)** at **0.15 (0.08)** obs. (exp.)



- **Ongoing work on Higgs Boson Self-Interactions (ggH in 6b final state):**
  - **Problem:** Correctly assigning pairs of b-jets to the corresponding Higgs bosons.
    - **Symmetry Preserving Attention Network (SPANet) used for S/B discrimination**
    - **Transformer-encoder** structure:
      - Leverages attention mechanism and symmetry of the jet system
  - Overall improvements from SPANet are around **32% in jet pairing** and **20% in signal discrimination** when compared to the baseline methods



CMS ECAL Control and Safety system

- **ECAL Safety System (since 2002):**
  - Developed by Belgrade & ETH Zurich in 2002-2010, maintained and operated in 2010-2025, ongoing upgrade for 2029.
  - **Siemens-based system**, full hardware redundancy, **endorsed by CERN/CMS**.
  - **Follows/leads** standardised approaches **across sub-detectors** in multiple areas (sensors, interfaces, integration).

- **DCS SCADA System and operation:**
  - **Based on WinCC OA,** in line with CERN recommendations
  - Providing experts for the on-call services 24h/7d (during LHC Run 1 - Run 3).

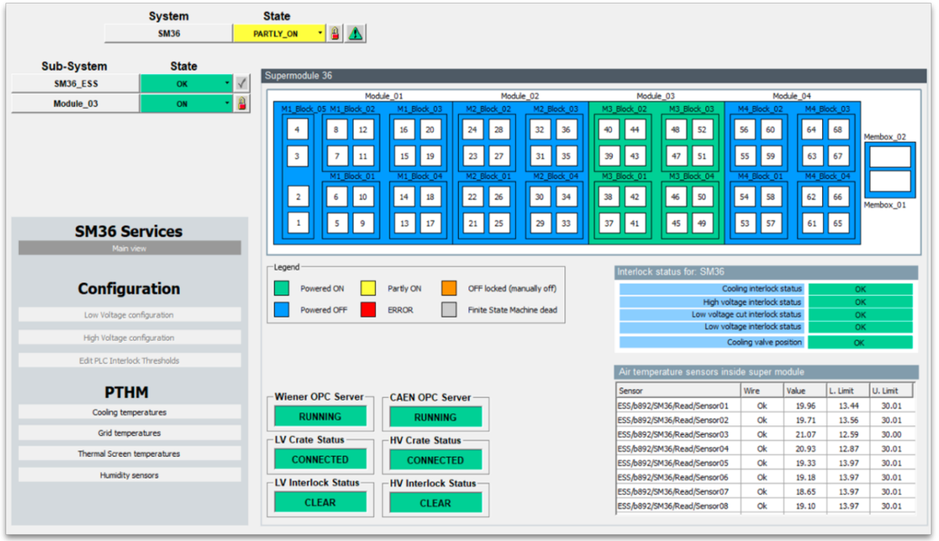
- **Towards ECAL Barrel Phase-2 upgrade:**
  - DCS/EBSS will provide support for ECAL upgrade in multiple areas.
  - Significant contribution to the system developments and coordination of the CMS ECAL integration activities at P5.
  - Several papers published in high-impact international journals and presented at international conferences. Contributed to ECAL TDRs.

- **Institutional support / responsibility:**
  - Contribution to CMS ECAL Upgrade in system hardware of 100 kCHF.
  - Planed institutional responsibility for the future CMS ECAL DCS/EBSS for period 2026 - 2040 (being discussed with CMS and FA), with aim to develop and maintain expertise relevant for future large-scale projects.

ECAL Barrel Safety System (Phase-2 prototype)

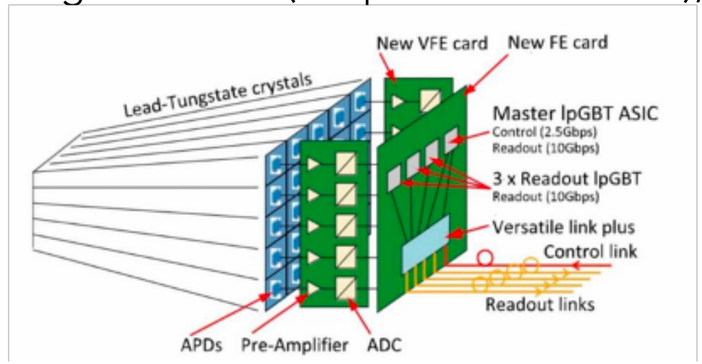
ECAL Safety System (Run 1 & Run 2)

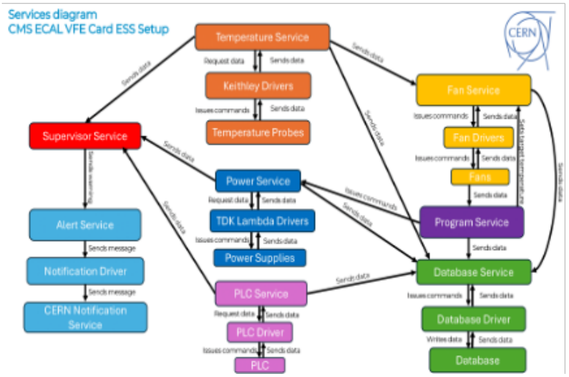
ECAL Barrel DCS Supervisor (Phase-2 prototype)

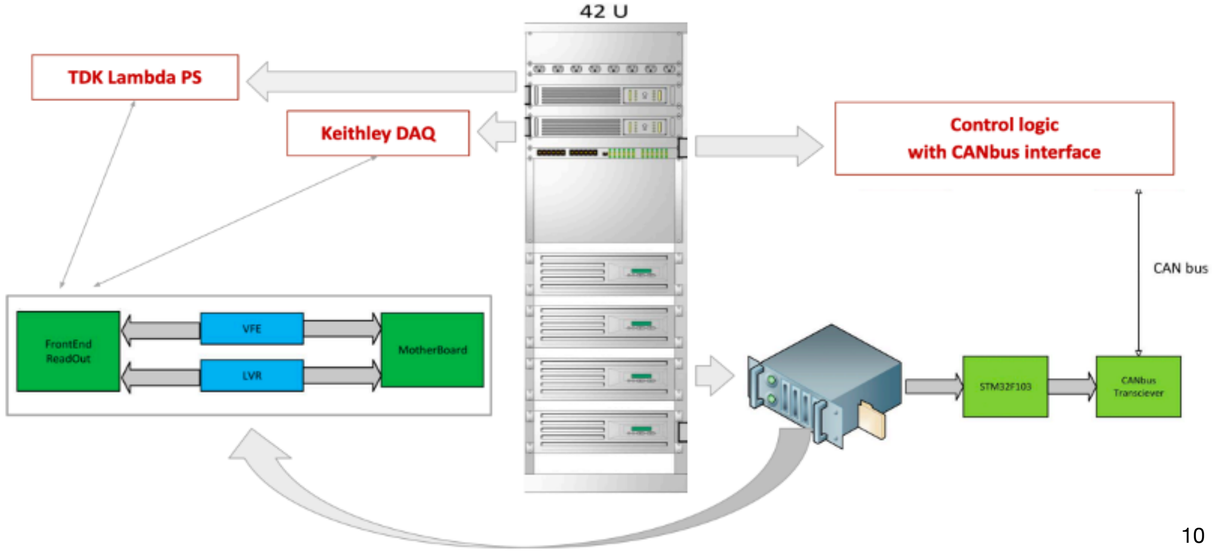


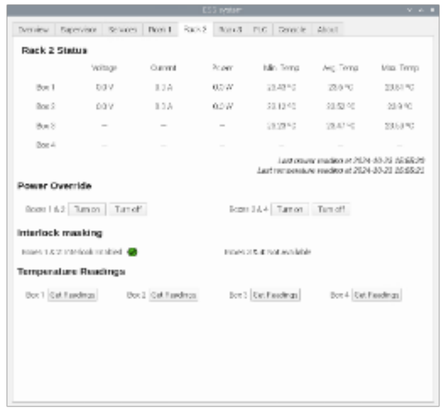
CMS ECAL Upgrade - systematic testing/screening of readout electronics

- To accommodate higher trigger rates (750 MHz), full detector readout at 40 MHz, and improve timing resolution (30 ps for E ≥ 50 GeV), the **entire** on-detector and off-detector CMS ECAL electronics **will be replaced!**
- **Extracting an EB module** for repair **is not foreseen** for the operation period of ~20 years, thus we aim at excellent reliability targeting <0.5% of failing channels at end-of-life.
- This will be achieved by systematic testing/screening with dedicated systems for the **Environmental Stress Screening (ESS)**.
  - Designed and built as a highly modular, configurable, scalable and safe system by **Faculty of Physics Belgrade in cooperation with ETH Zurich**.
  - Capable of performing the full testing/screening program for about 750 ECAL readout electronics boards simultaneously (within period of about 5 days).



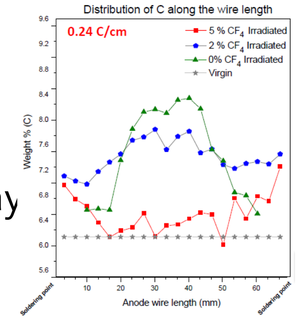


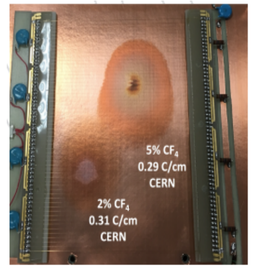




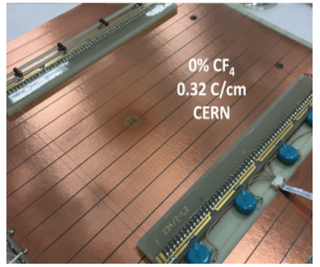
Detector RnD - Muon Chambers

- **Physics program and participating teams:**
  - **Participating teams:** Institute of General and Physical Chemistry, Faculty of Physics Belgrade, Institute of Physics in Belgrade.
  - **Program:** Study the **ageing effects in the muon chambers** in a systematic way and develop the **tools for modelling their performance** in order to efficiently **search for the eco-friendly gas mixtures**.



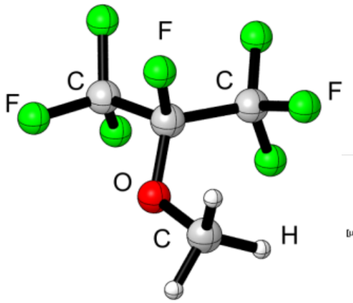


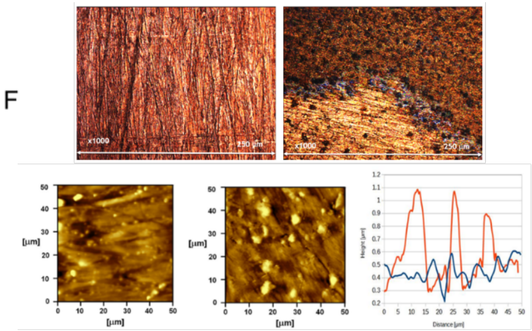
Cathode panel



Anode wire panels

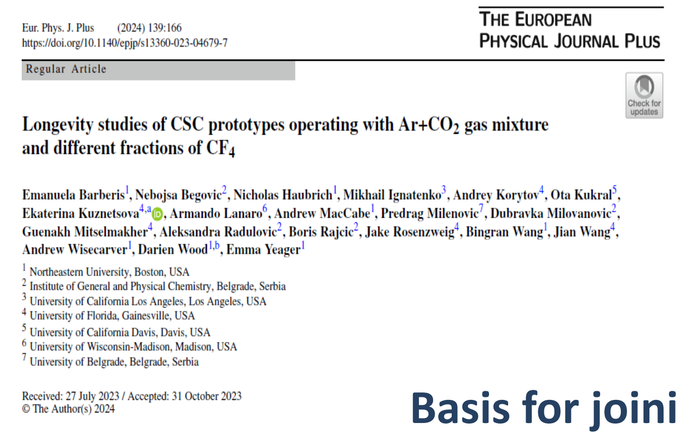
- **Study the ageing effects of the Cathode Strip Chambers (IGPC):**
  - As well as search for the eco-friendly gas mixtures for the Phase-2 upgrade.
  - **Established the procedures** for characterization, analysis, sampling, handling, measurements of the deposits on the electrode of the muon gas chambers, to be used for the studies of future muon gaseous detractors.





- **Quantum-chemical calculations for gaseous detectors (IGPC, IPB):**
  - Design of new molecules on the basis of the **quantum chemical calculation**, considering evolution of molecules in plasma-ionized states.
  - **Predictive analysis** and pre-selection of novel eco-friendly gases.

- **Modelling of Resistive Plate Chambers performance (IPB):**
  - Microscopic 3D Monte Carlo model for **modelling RPC performance characteristics**
  - Obtained cross sections for electron scattering, as well as electron transport and streamer dynamics in environmentally friendly (and ultra-low GWP) gases
  - **Good prediction of detector performance** in environ.-friendly RPC gas mixtures.



Eur. Phys. J. Plus (2024) 139:166
https://doi.org/10.1140/epjp/s13360-023-04679-7

THE EUROPEAN PHYSICAL JOURNAL PLUS

Regular Article

Check for updates

Longevity studies of CSC prototypes operating with Ar+CO_2 gas mixture and different fractions of CF_4

Emanuela Barberis[1], Nebojsa Begovic[2], Nicholas Haubrich[1], Mikhail Ignatenko[3], Andrey Korytov[4], Ota Kukral[5], Ekaterina Kuznetsova[4,a], Armando Lanaro[6], Andrew MacCabe[1], Predrag Milenovic[7], Dubravka Milovanovic[2], Guenakh Mitselmakher[4], Aleksandra Radulovic[2], Boris Rajcic[2], Jake Rosenzweig[4], Bingran Wang[1], Jian Wang[4], Andrew Wisecarver[1], Darien Wood[1,b], Emma Yeager[1]

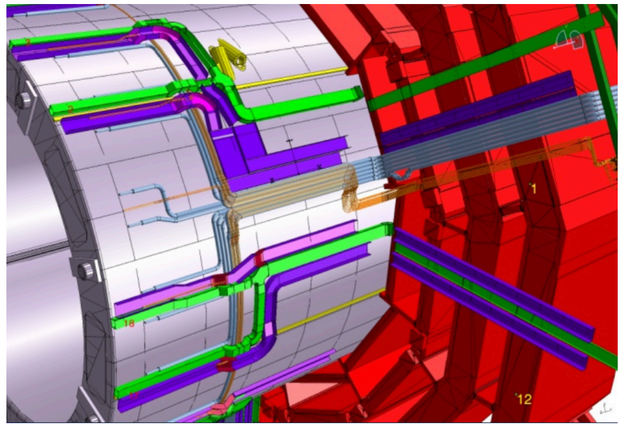
[1] Northeastern University, Boston, USA
[2] Institute of General and Physical Chemistry, Belgrade, Serbia
[3] University of California Los Angeles, Los Angeles, USA
[4] University of Florida, Gainesville, USA
[5] University of California Davis, Davis, USA
[6] University of Wisconsin-Madison, Madison, USA
[7] University of Belgrade, Belgrade, Serbia

Received: 27 July 2023 / Accepted: 31 October 2023

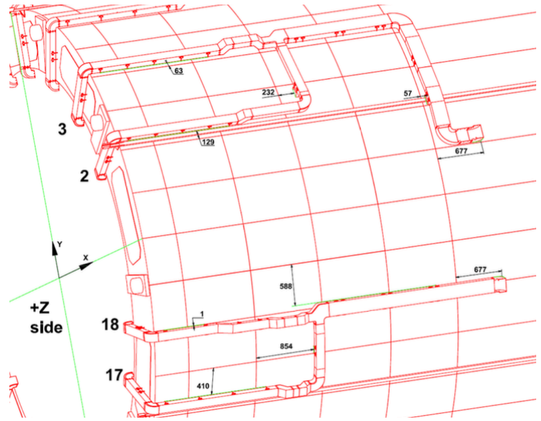
Basis for joining DRD1 Collaboration in 2024!

CMS engineering and integration center

3D models

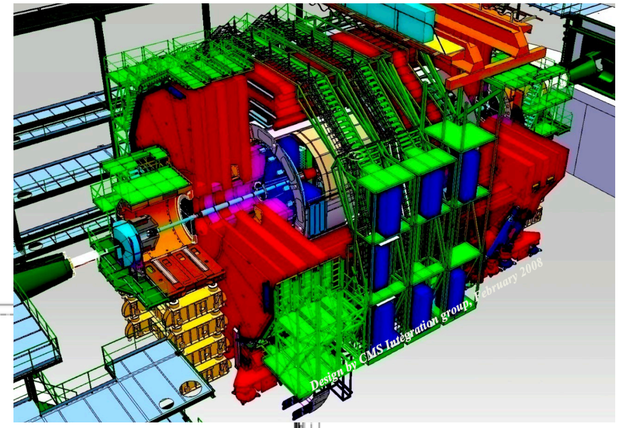


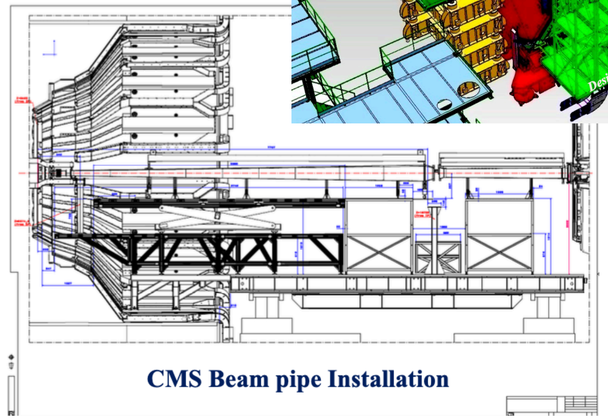
Installation drawings



- **Activities dating from 2003!**
- **Transformation of the 3D envelopes** into the **real 3D models** of the systems converting models from EUCLID to Autodesk sft
- Present day: **reverse engineering** to provide "Built models" as a base for **coming upgrade projects**

- **Organization, planning and control of the installation of the CMS detector**
  - Proposal to convert different CAD files in to the CATIA system
  - DMU, fitting and kinematic simulation modules, automatic transfer of the survey data are used in planning and control of different sequences of installation.
  - **Engineering:**
    - **Process to design & reinstall the new CMS Central beam pipe**, starting from conceptual design, using the stored data and proven procedure from the first installation.
    - **Data base and functional files organisation**



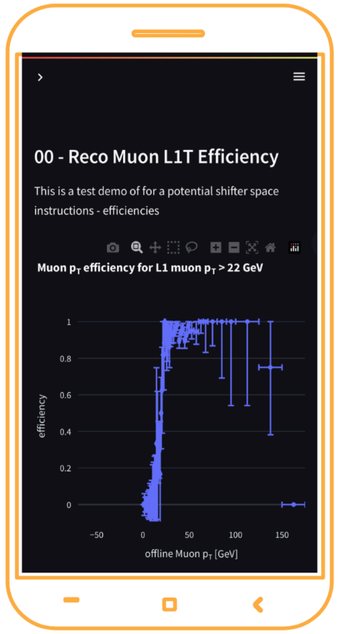


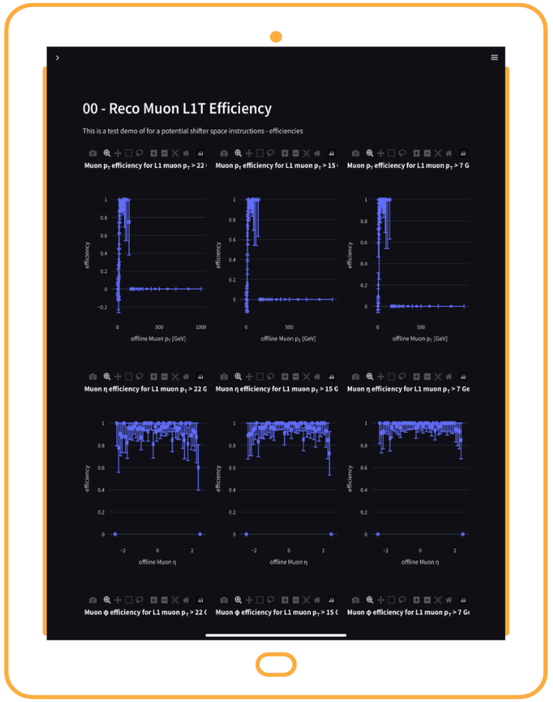
Advanced monitoring for CMS L1 trigger

Monitoring app can be tested here
(N.B. A CMS account is required to access the page)

- **A complete overhaul of the CMS L1T Data Quality Monitoring approach for Run 3 and beyond:**
  - A new and dedicated Level-1 Trigger monitoring application based on plotly/streamlit solutions
    - **Plotly:** an interactive, open-source, and browser-based graphing library for Python
    - **Streamlit:** a dashboard solution that turns data scripts into shareable web apps without much complexity

  - The application is **re-deployed in ~10 min** after a change has been pushed to deployment
    - A much **simpler workflow** from a training perspective, offers **transferable skills** for students/experts involved in projects!
    - **Accessibility through all devices** (laptop, tablet, smarthphone) with CERN SSO protection

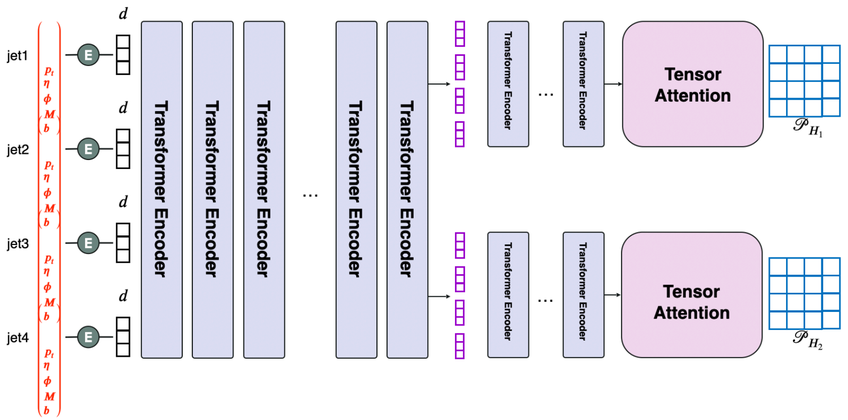


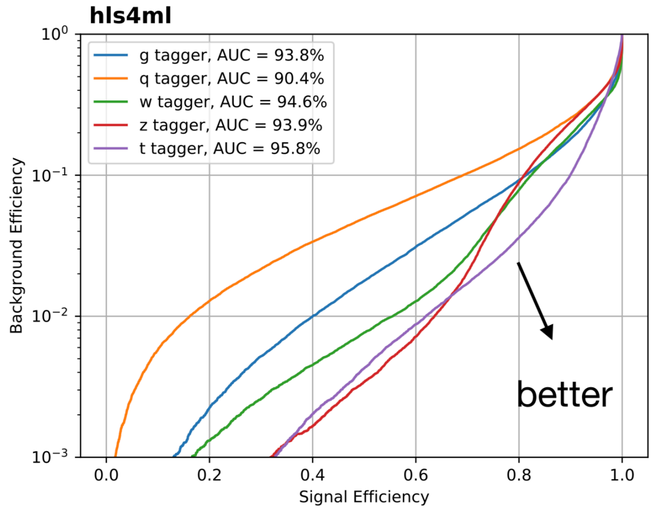


Advanced computing technologies at HEP

R&D in application of ML-based algorithms @ HEP:

- Development of tools for **ML on-demand service** and tools for optimisation of the **ML training on large scale distributed heterogeneous computing resources**.
- Development for algorithms for **particle identification**, for **event classification**, and for solving combinatorial problem: clustering algorithms of HGCAL, CNNs/DNNs for FPGA @ L1, transformer-encoder networks for multi-b-jets final states.



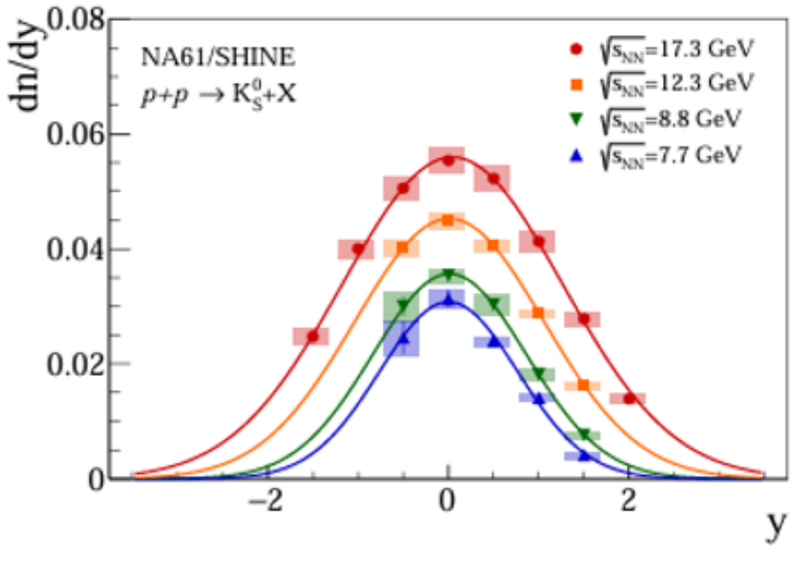


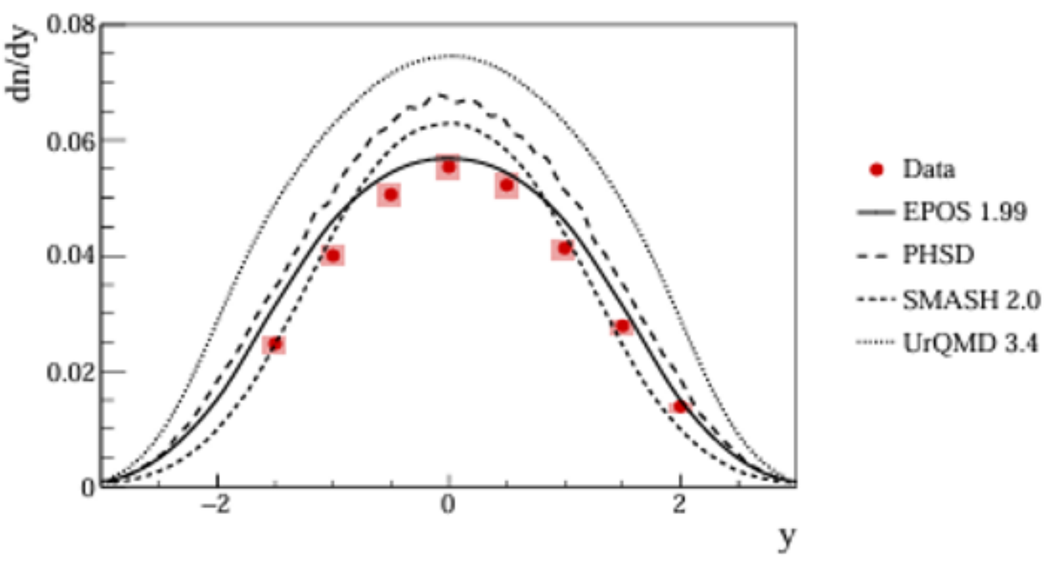
Application of advanced technologies @ HEP:

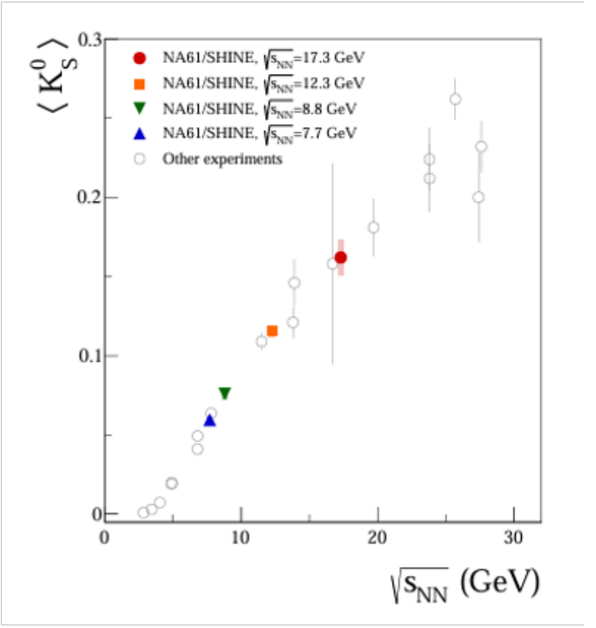
- **Next-generation acceleration**: Exploring possibilities with intelligent compute accelerators (AI, HPCs, vector DBs)
  - Cooperation with CERN & private companies.
- **Quantum technologies initiative**: Exploring application/advantages of quantum algorithms in LHC data analysis
  - Through cooperation with other groups at CERN, MIT, Vienna, Belgrade

FFUB and NA61/SHINE

- **Analysis: strange particle production in p+p and Ar+Sc interactions (K^0_S, Λ and Λ̄)**
  - Crucial contributions to two publications: **EPJ C 84 (2024) 8, 820** and **EPJ C 82 (2022) 1, 96**







- **Callibration: T**ime **O**f **F**light detectors in several interactions: *p+p*, Be+Be, Ar+Sc, Xe+La, *p*+Pb, Pb+Pb and several beam energies: 13, 20, 31, 40, 80 and 158 GeV/*c*.
  - Significant contribution leading to several publications:
    - **EPJ C 84 (2024) 4, 416, EPJ C 81 (2021) 1, 73 and EPJ C 77 (2017) 10, 671**

Main challenges from the FFUB point of view

- **It is challenging to retain young Serbian scientists within the country and the field, making it difficult to sustain expertise in domestic research groups**

- **The Faculty of Physics faces significant challenges in this area:**
  - It is not recognised by the state as a research institution, unlike dedicated institutes, while teaching positions remain very limited
  - Difficult to attract foreign researchers - no mechanism for permanent employment
- **Student situation: Extremely difficult to fulfil the PhD requirement of 2 published papers in 3-4 years**
  - Where at least 1 has to be on the physics analysis
- **Recognition of individual contribution to the large collaboration for grants, career advancement, excellence awards, etc.**

Thank you for your time!

Backup