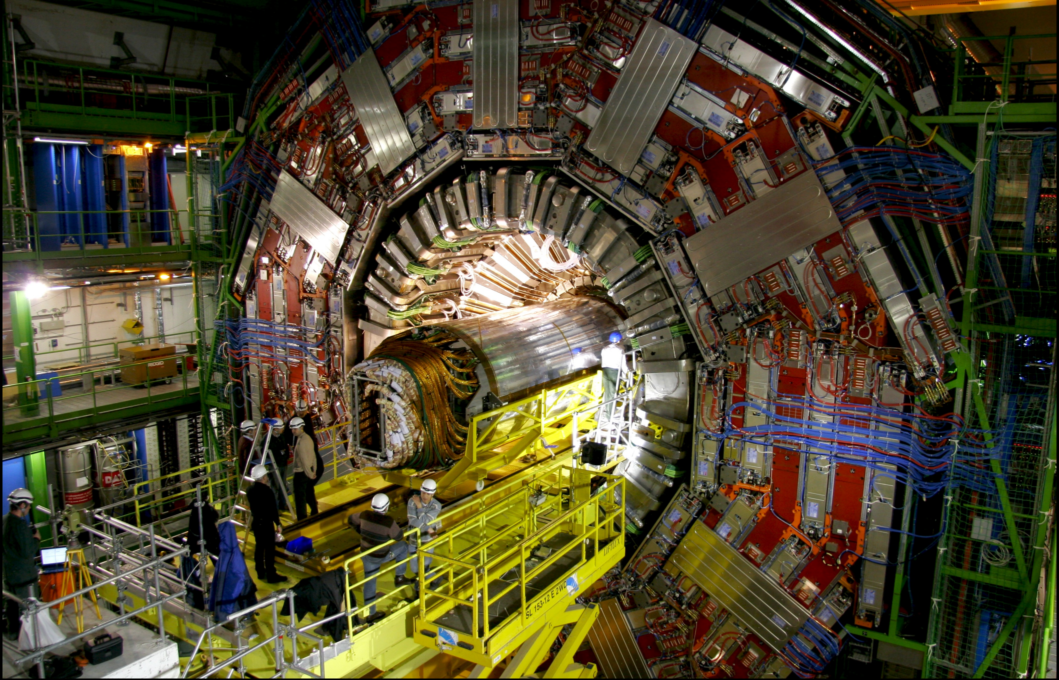
SPRACE

São Paulo Research and Analysis Center

São Paulo CMS group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Physics Analysis

Physics Beyond the Standard Model and Heavy Ion Collisions

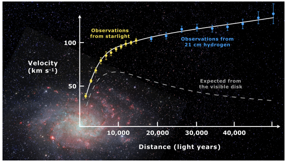
Physics Beyond the Standard Model

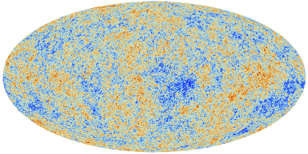
Gravitational effect on all cosmological scales

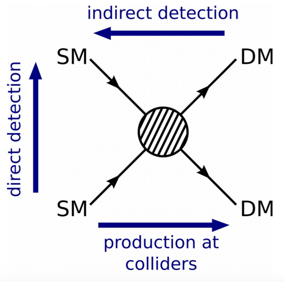
"Missing Mass" $\overset{?}{\Longrightarrow}$ Elementary Particle

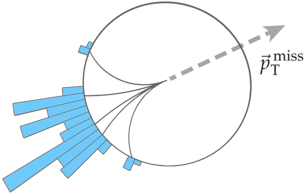
Search for nongravitational effects:

- Direct detection
  - Scattering between DM particle and nuclei
- Indirect detection
  - Annihilation of DM pair
- Production at colliders
  - Complementary search







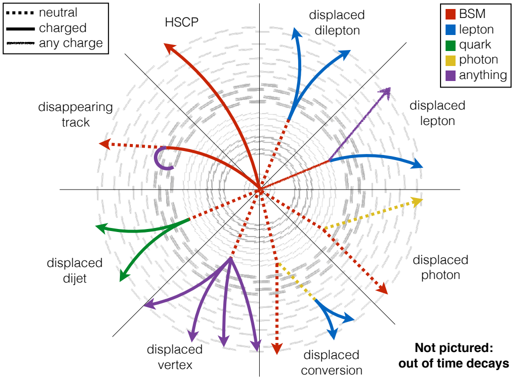


LHC initial approach

Search for p_T^{miss} + prompt SM particles.

Long-lived Particles (LLPs)

Recent push towards nonprompt signatures:
Weaker constraints, richer phenomenology

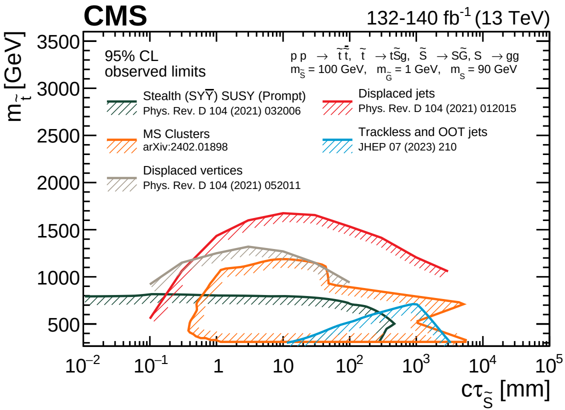


SPRACE searches for DM (Run 3):

- ☐ Disappearing tracks
  - New charged particle → DM + low-momentum, undetected pion.
    Phys. Lett. B 806 (2020) 135502
- ☐ Displaced vertices
  - New neutral particle → DM + pair of charged particles.
    Phys. Rev. D 104, 052011 (2021)

Dark Sector Searches with CMS

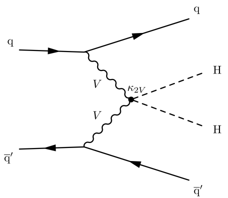
- Evolution of the searches for dark matter
  - Dark matter $\rightarrow$ *dark sector*.
- Reinterpretation of Run 2 results underway
  - Target: Physics Reports
- Contributions from SPRACE
  - Leading the section on common experimental challenges
  - Reinterpretation of the Run 2 result in dedicated to (stealth) SUSY models



Machine Learning: Twin Higgs Production (HH→4b via VBF)

- **Non-resonant:**
  - Sensitivity to κ_{2V}
  - Small cross-section

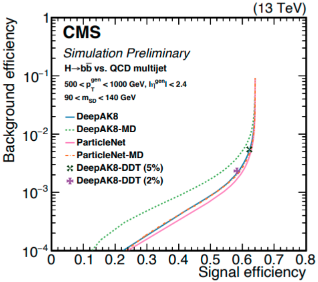
- **Decay mode:**
  - Biggest Branching Ratio
  - Challenge Background (QCD, $t\bar{t}$)



The **size of boost** of the di-Higgs system depends on the **deviations of** κ_{2V} from the SM.

ParticleNet

- Boosted topology induces **unclear correlations** between mass, substructure and flavour.
- Novel ML approach can **identify Mass Decorrelated Signal.**
- Jets are treat as an **unordered set of particles** using a **permutation invariant GNN architecture.**



Heavy Ion Physics

Femtoscopic Correlations

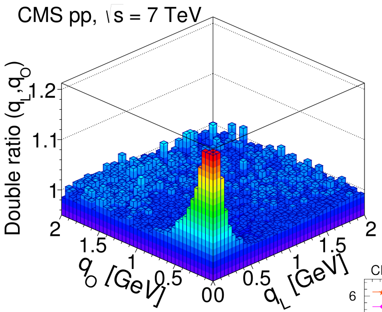
Important tool to access

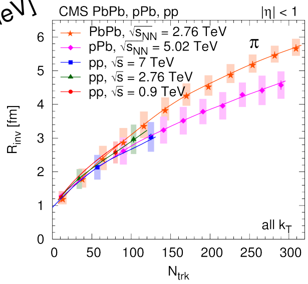
- Size and shape
  - Emitting region in hadronic collisions
- Final state interactions
  - Residual hadron-hadron interaction

SPRACE contributions

- Studies in pp, pPb, and PbPb collisions
  - Using non-identified hadrons and identified pions and kaons
  - Characterization of particle emitting regions in 1D. 2D , 3D

Phys. Rev. C 97, 064912 (2018)

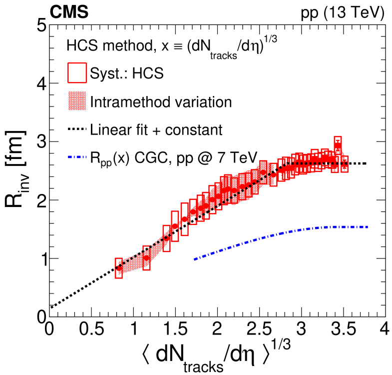


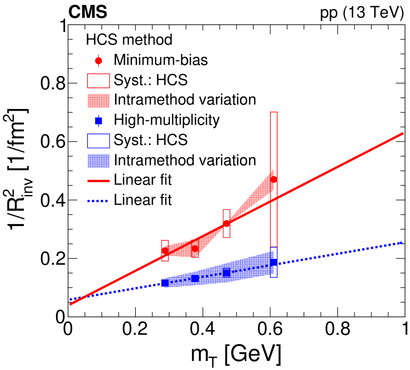


Femtoscopy in Small Colliding Systems

Wide range in charged particle multiplicity in pp (Ongoing: neutral s-hadrons in pPb)

- From very small and up to very high multiplicity ($2 < N_{\text{charged}} < 250$ particles)
- Understanding collective phenomena in pp: similarities with peripheral and in central AA



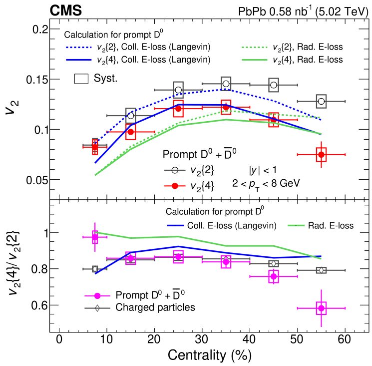


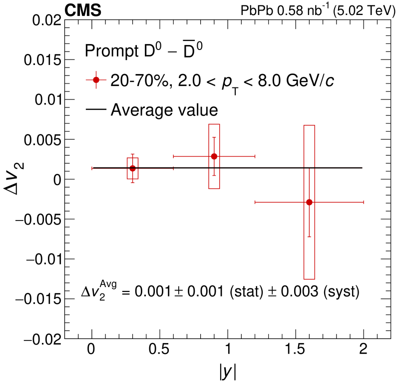
JHEP 03, 014 (2020)

Flow with D^0 Mesons and Charged Particles

Input on heavy quark interactions with Quark-Gluon Plasma (QGP)

Search for effects of the strong electromagnetic fields expected to be created in the PbPb

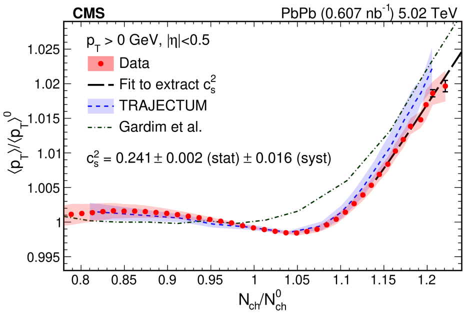


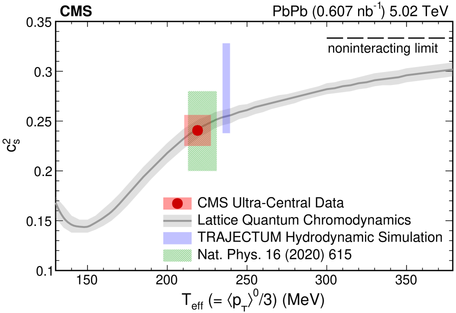


Phys. Rev. Lett. 120, 092301 (2018) Phys. Lett. B 816, 136253 (2021) Phys. Rev. Lett. 129, 022001 (2022)

Speed of Sound in the Hot QCD Matter

- Directly accessing the Equation of State of hot QCD matter
  - Measuring the speed of sound vs. temperature
- Head-on PbPb collisions: Good agreement with Lattice QCD at $\mu_B = 0$





arXiv:2401.06896 (Submitted to RPP)

Instrumentation

Development and Implementation of OpenIPMC

SPRACE

IPMC Role in the CMS Electronics

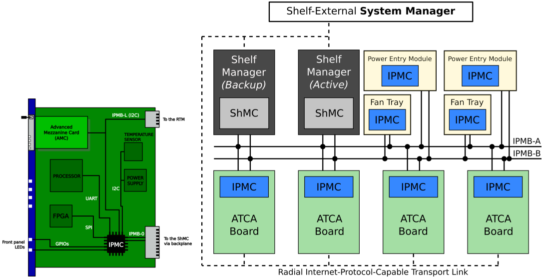
- Intelligent Platform Management Interface **(IPMI)**
  - A standard on the management of computing hardware infrastructure (Intel, HP, NEC, Dell)
  - All servers, computers, laptops, and embedded electronics follow the standard
- Advanced Telecommunication Computing Infrastructure **(ATCA)**
  - A standard for highly-reliable, high-performance modular processors

The ATLAS and CMS experiments use ATCA electronics

All ATCA boards are required to have an IPMI controller (IPMC)

- Function of the **IPMC** board in the ATCA electronics
  - Monitoring of the health of the board: temperature, current, voltage, and error messages
  - Management of the device state: power on/off, reset, insertion/extraction from the shelf, emergency shutoff (high temperature, etc.)
  - Integration with other shelf components: inform presence, state and capabilities, management interface to the shelf orchestrator (shelf manager)

An ATCA shelf at the CMS experiment

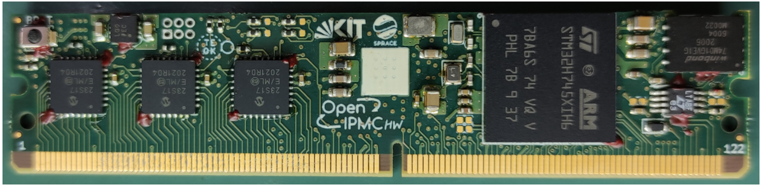


ATCA board sketch, shelf IPMI schematic

From Proprietary to an Open Source Alternatives (OpenIPMC)

- First IPMC for HEP was developed at LAPP Annecy, France
  - Microcontrollers available at the time did not allow to design a simple and low cost solution
  - LAPP IPMC project was terminated and CERN was in need of an IPMC
- CERN negotiate with nVent Company
  - Closed source, Non-Disclosure Agreements, legal risks involved in NDA
  - Researchers were excluded from development: slow support cycle

Availability of new microcontrollers: SPRACE develop the OpenIPMC



SPRACE OpenIPMC

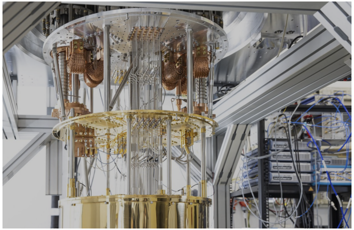
- **Project lead by SPRACE**
  - Collaborators KIT, Boston University, Imperial College London, CERN
- OpenIPMC is a module which is inserted in a slot in the main ATCA board
- Core of the device is a STMicroelectronics STM32H755XIH6 MCU
  - Runs services inside a real-time open-source operating system (Amazon FreeRTOS)
  - Follows the JEDEC MO-244 form factor, used for DDR3 memory modules
- Free and open-source hardware and firmware
  - Mezzanine (OpenIPMC-HW), firmware (OpenIPMC-FW), and software (OpenIPMC-SW)
  - Each stakeholder can be developed on top of the design and apply customizations
  - Important for student contributions, long-term support, use in new projects

Production of the SPRACE OpenIPMC Boards

- Versions 1.0 e 1.1 already produced in four manufacturing runs
  - Successful in-house assembly at SPRACE and KIT laboratories
  - Successful assembly by a company in Campinas for SPRACE
  - Successful assembly by an US company for Boston University
- A batch of version 1.2 boards are being produced in Brazil
  - Expected 82 boards, 55 to be used in development for CMS
  - PCB production: Circuibras, Araucária, PR (starts soon)
  - Still selecting the contractor for board assembly
- The CMS experiment will need approximately **1,100 IPMC** for its back-end boards
  - OpenIPMC can be an important Brazilian contribution to CMS and other experiments
  - Approximate dates for mass production for CMS is mid 2025 – 2026
  - This is a relatively large production run: requires planning and financial support

SPRACE OpenIPMC: Employed all over LHC and Beyond

- Serenity and Apollo ATCA boards for **ATLAS and CMS** (Tracker, HGCAL, ...)
- ATCA controller boards for the **Quantum Computers** at KIT
- Read-out boards for **TRISTAN**, new detector system of **KATRIN** experiment (ν_e mass)
- OpenIPMC is a flexible device suitable for many other applications



We were approached by interested companies dealing in space hardware (nanosatellites), embedded electronics for defense, and a Canadian conglomerate also related to the defense.

Computing

BR-SP-SPRACE Tier 2 and the WLCG

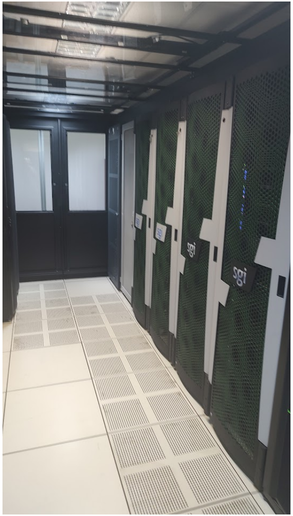
Computing Resources

Processing Servers

- 138 worker nodes
  - 2784 physical cores
  - 3620 condor batch slots, HT on
  - at least 2.5 GB of RAM per Batch slots
  - 1/10 GBits NIC

Storage Servers

- 3.83 PB
- dCache Distributed File System
  - 1 Storage Element
  - 14 disk Pool Servers
    - 10/40 Gbits NIC
    - 965 hard disks (2–20 TB)



General Servers

- Headnodes and Auxiliary Servers
  - CE: HTCondor-CE gatekeeper and HTCondor job scheduler
  - Shared Filesystems: NFS, CVMFS
  - Proxy Servers: 2 frontier squids
  - Support services: Grafana, Prometheus, VM servers, DNS server, etc

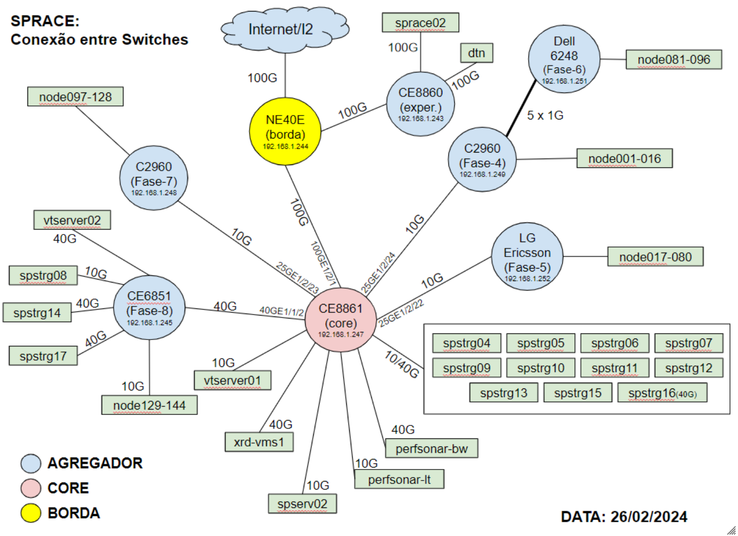
Network Infrastructure

- Cluster internal connections
  - Worker nodes: 1/10 Gbps (to TOR switches)
  - 10 Gbps links between TOR and core switch
  - NFS, CVMFS, Frontier, VM servers (Hypervisors), storage servers: 10/40 Gbps

Metropolitan Area Network

- SPRACE to REDNESP provider
  - 100 Gbps
  - Links fully dedicated, independent from the university commodity network

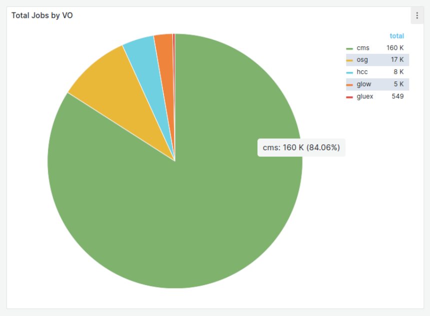
Network Infrastructure



Perfomance of BR-SP-SPRACE

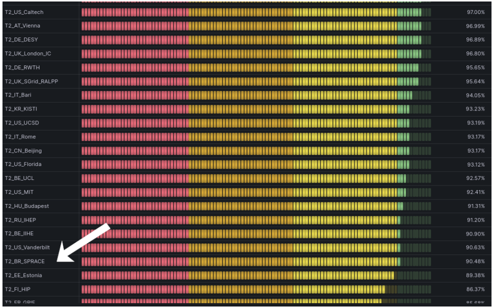
Jobs Executed Last Year

- ☐ 160,000 CMS jobs executed (84.60 %)
- ☐ 31,000 OSG jobs from OSG (15.4%)



Availability

- ☐ 90.48% during last year
- ☐ Great team work & datacenter consistency



Data Challenge 2024 (DC24)

Goals

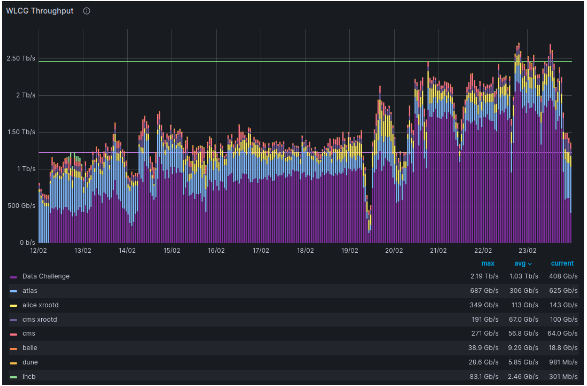
- ☐ Be prepared for HL-LHC
- ☐ Stress the current Infrastructure

Overall Performance

- ☐ 2.19 Tbps flowing between all participants
- ☐ 1.03 Tbps (avg): 12-23 February 2024.

Performance

- ☐ 63.92 Gbps from SPRACE to FNAL
- ☐ No disruption in production during the tests.

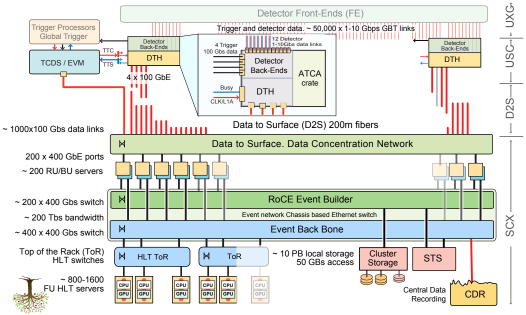


Next Generation Triggers for CMS

Natural **evolution** of the Phase I HLT

- ☐ 750 kHz input from Level-1 Trigger.
- ☐ GPU-equipped computer farm.
- ☐ Tradeoff between algorithms' reconstruction speed and accuracy.
  - Dedicated online calibrations.
- ☐ Output rate of 7.5 kHz to tape.
  - Full raw detector data (51 GB/s).

. . . to go beyond that, we need a **revolution**.



Proposal for CMS Phase II DAQ and HLT

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

The Real-time Reconstruction Revolution – R^3

Overcome the two main limitations of the HLT:

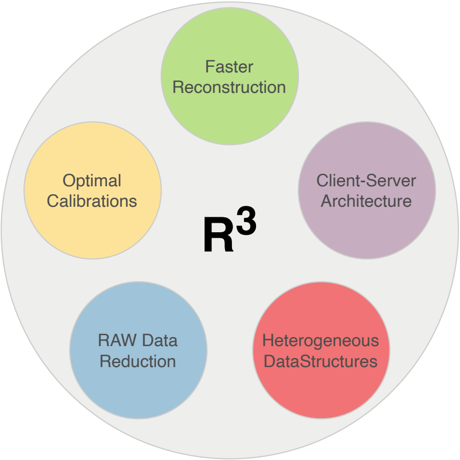
- Quality of the online reconstruction is limited by the processing capacity of the HLT farm
- Output rate limited by storage and processing capacity of offline infrastructure.

What if we could...

- have offline-like quality calibrations and reconstruction at the HLT?
- store all events in a summary, ntuple-like format?

The goal of the R3 project is to address these limitations through a comprehensive work program, consisting of five synergic tasks.

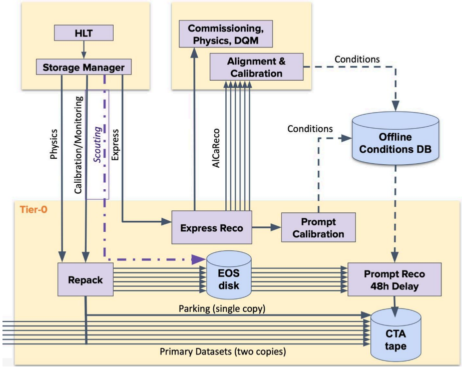
- ☐ Heterogeneous-ready & fast algorithms.
- ☐ Distributed client–server processing for HLT within CMS software.
    - Offload to remote accelerators.
- ☐ Optimised data structures for heterogeneous architecture.
- ☐ Approaches for RAW data size reduction.
    - Lossless/lossy data compression.
    - Replacing raw with locally reco'ed data.
- ☐ Solutions for optimal HLT calibrations: **task lead by SPRACE**.



The five tasks of R^3

R^3 Optimal Calibrations for HLT

- Design accelerated calibration workflows to achieve at HLT the same accuracy as the offline reconstruction.
  - Optimise the subdetectors' calibration process beyond the Prompt Calibration Loop.
  - Introduce data buffering online.
  - Exploit predictive AI techniques.
- Synergy with Run-3 operations.
  - Deploy a prototype of the HLT Scouting workflow (last year of Run-3).
  - Rethink the hardware and software infrastructure for the calibration workflow.



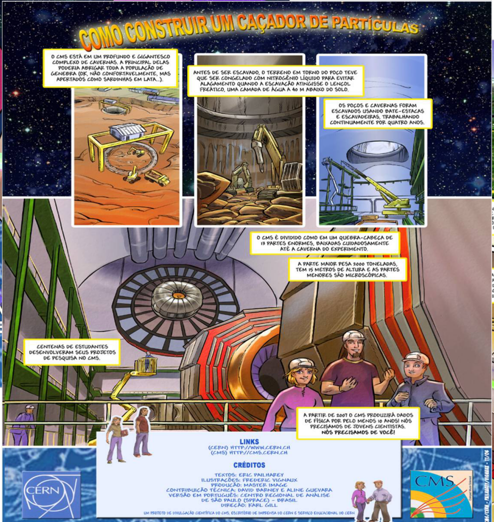
The Prompt Calibration Loop today

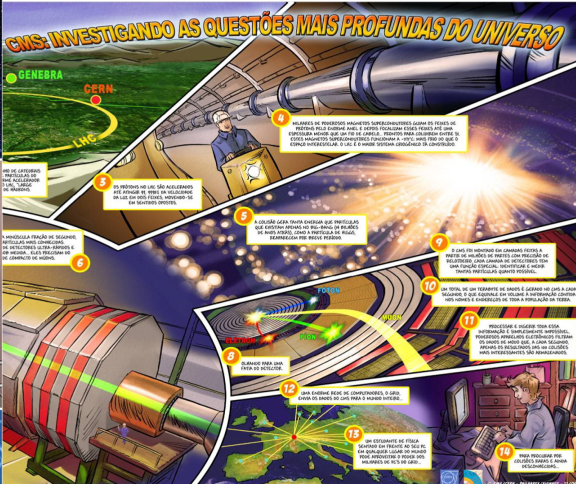
Outreach

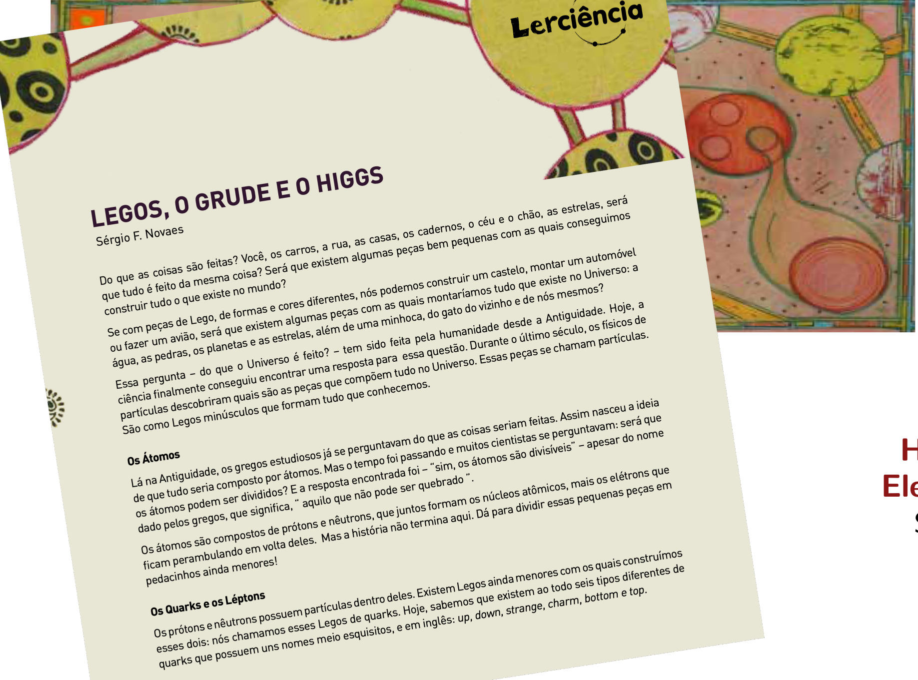
MasterClass, A Chart in Every School, SPRACE Game, The Particle

Comics: The CMS detector

(in Portuguese)






Lerciência

LEGOS, O GRUDE E O HIGGS

Sérgio F. Novaes

Do que as coisas são feitas? Você, os carros, a rua, as casas, os cadernos, o céu e o chão, as estrelas, será que tudo é feito da mesma coisa? Será que existem algumas peças bem pequenas com as quais conseguimos construir tudo o que existe no mundo?

Se com peças de Lego, de formas e cores diferentes, nós podemos construir um castelo, montar um automóvel ou fazer um avião, será que existem algumas peças com as quais montaríamos tudo que existe no Universo: a água, as pedras, os planetas e as estrelas, além de uma minhoca, do gato do vizinho e de nós mesmos?

Essa pergunta – do que o Universo é feito? – tem sido feita pela humanidade desde a Antiguidade. Hoje, a ciência finalmente conseguiu encontrar uma resposta para essa questão. Durante o último século, os físicos de partículas descobriram quais são as peças que compõem tudo no Universo. Essas peças se chamam partículas. São como Legos minúsculos que formam tudo que conhecemos.

Os Átomos

Lá na Antiguidade, os gregos estudiosos já se perguntavam do que as coisas seriam feitas. Assim nasceu a ideia de que tudo seria composto por átomos. Mas o tempo foi passando e muitos cientistas se perguntavam: será que os átomos podem ser divididos? E a resposta encontrada foi – "sim, os átomos são divisíveis" – apesar do nome dado pelos gregos, que significa, " aquilo que não pode ser quebrado ".

Os átomos são compostos de prótons e nêutrons, que juntos formam os núcleos atômicos, mais os elétrons que ficam perambulando em volta deles. Mas a história não termina aqui. Dá para dividir essas pequenas peças em pedacinhos ainda menores!

Os Quarks e os Léptons

Os prótons e nêutrons possuem partículas dentro deles. Existem Legos ainda menores com os quais construímos esses dois: nós chamamos esses Legos de quarks. Hoje, sabemos que existem ao todo seis tipos diferentes de quarks que possuem uns nomes meio esquisitos, e em inglês: up, down, strange, charm, bottom e top.

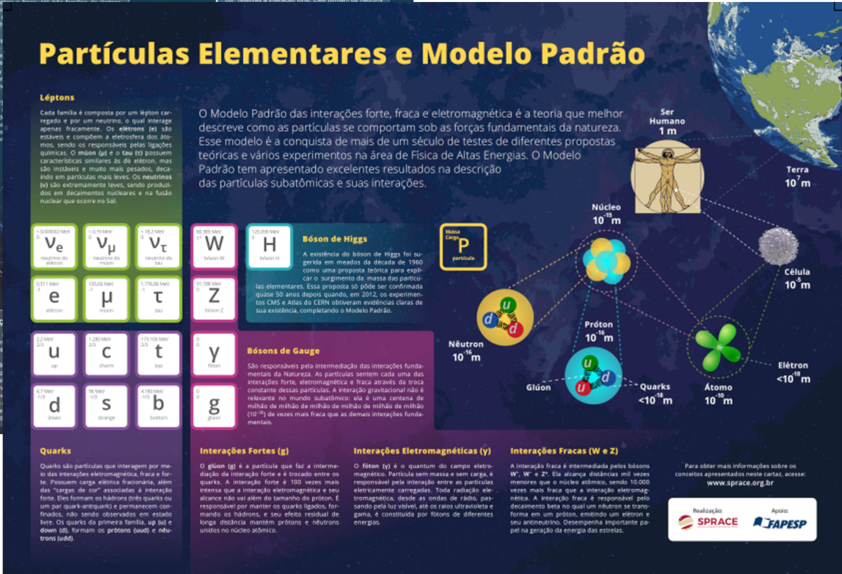
Higgs Boson for Elementary School

Sérgio F. Novaes

Alice Ruiz

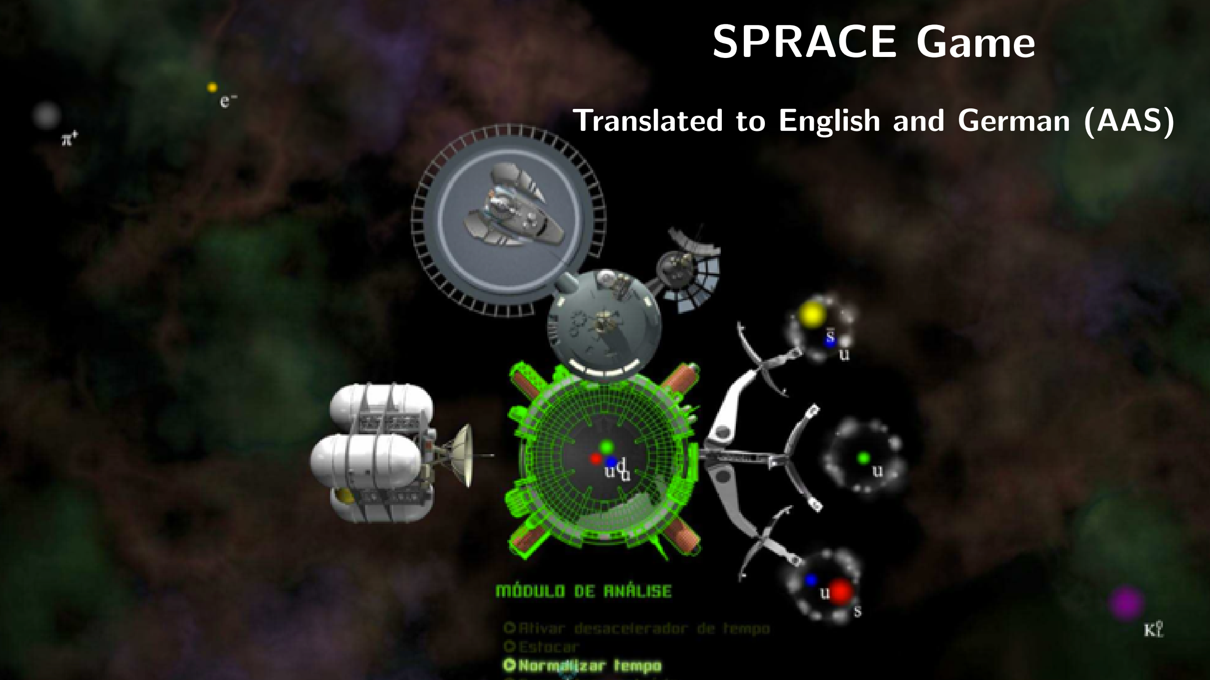
Leda Catunda

25,000 High Schools



SPRACE Game

Translated to English and German (AAS)



16 Years of International MasterClass: Hands on Particle Phycis

- **Almost 2,500 students**
- **330+ teachers**
- **80+ High School (public & private)**

Traditional MasterClass

- ☐ Beginners Group (2-day event)
  - 1st day: introductory talks & demos
  - 2nd day: Event display exerc. & games
- ☐ Advanced Group (1-day event)
  - Event display exerc. & demos
  - Virtual visits to the CMS detector

MasterClass for Women and Girls

- ☐ Two-day event
  - 3 discussion panel with (women) scientists
  - Conversation moderated by psychologists
  - Introductory talks (teachers and students)
  - Event display exerc. & demos
  - VC with CERN moderators
  - SPRACE game & visit to datacenter

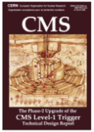
Impact of the MasterClass at SPRACE was investigated by 3 M.Sc. Dissertations.



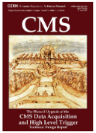



Budget

The CMS Phase II Upgrade

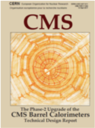


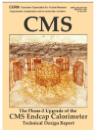
L1-Trigger
https://cds.cern.ch/record/2714892
- Tracks in L1-Trigger at 40 MHz
- Particle Flow selection
- 750 kHz L1 output
- 40 MHz data scouting



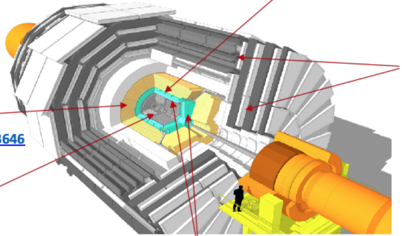
DAQ & High-Level Trigger
https://cds.cern.ch/record/2759072
- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output

Barrel Calorimeters
https://cds.cern.ch/record/2283187
- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards

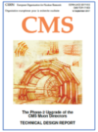


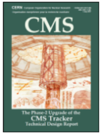


Calorimeter Endcap
https://cds.cern.ch/record/2293646
- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

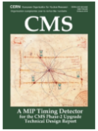


Muon systems
https://cds.cern.ch/record/2283189
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \simeq 3$





Tracker
https://cds.cern.ch/record/2272264
- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta \simeq 3.8$

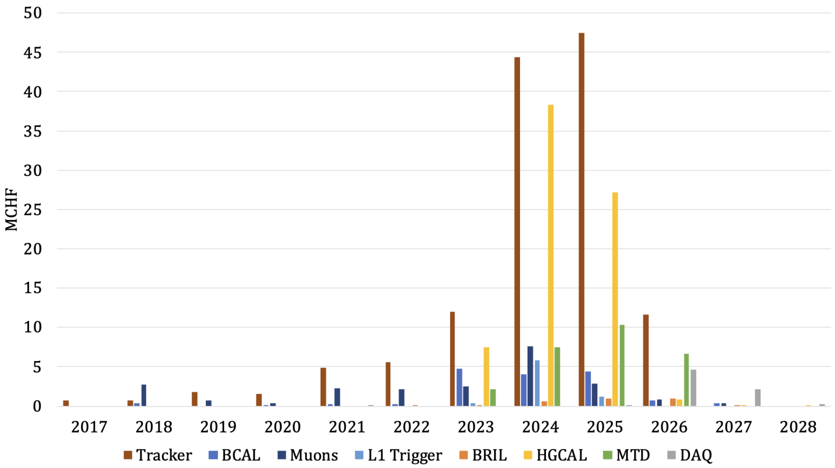


MIP Timing Detector
https://cds.cern.ch/record/2667167

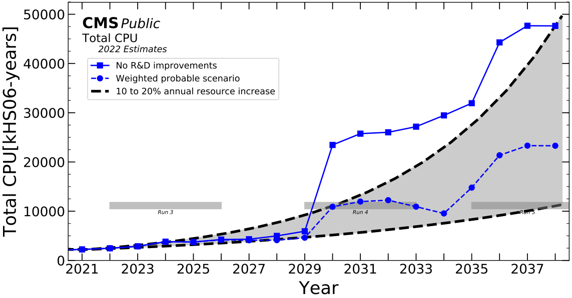
Precision timing with:
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

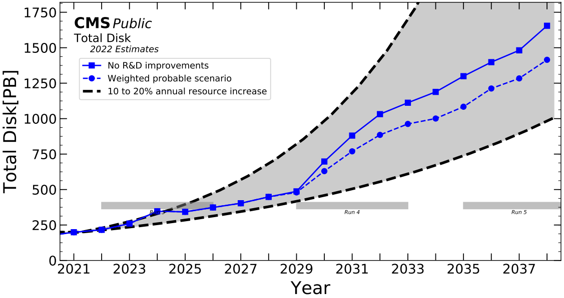
Beam Radiation Instr. and Luminosity
http://cds.cern.ch/record/2759074
- Beam abort & timing
- Beam-induced background
- Bunch-by-bunch luminosity: 1% offline, 2% online
- Neutron and mixed-field radiation monitors

Phase II Upgrade Projects Spending Profile (March 2024)



CMS CPU and Disk Space Resources Required into the HL-LHC Era





2025–2035: CMS will need 3.5 times more computer power and 4.0 times more disk space.

https://twiki.cern.ch/twiki/bin/view/CMSPublic/CMSOfflineComputingResults