ATLAS Trieste/Udine Activities toward HL-LHC

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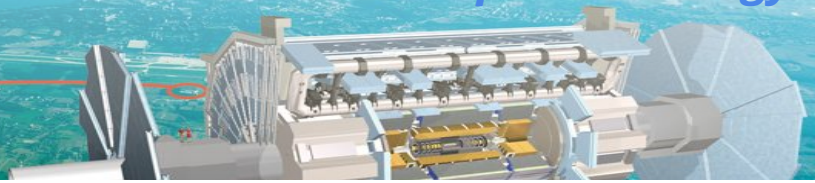
(INFN Sezione di Trieste, Gruppo Collegato di Udine, University of Udine, ICTP Trieste)

Powering tomorrow's discoveries: INFN Trieste in the European Strategy

20th November 2024



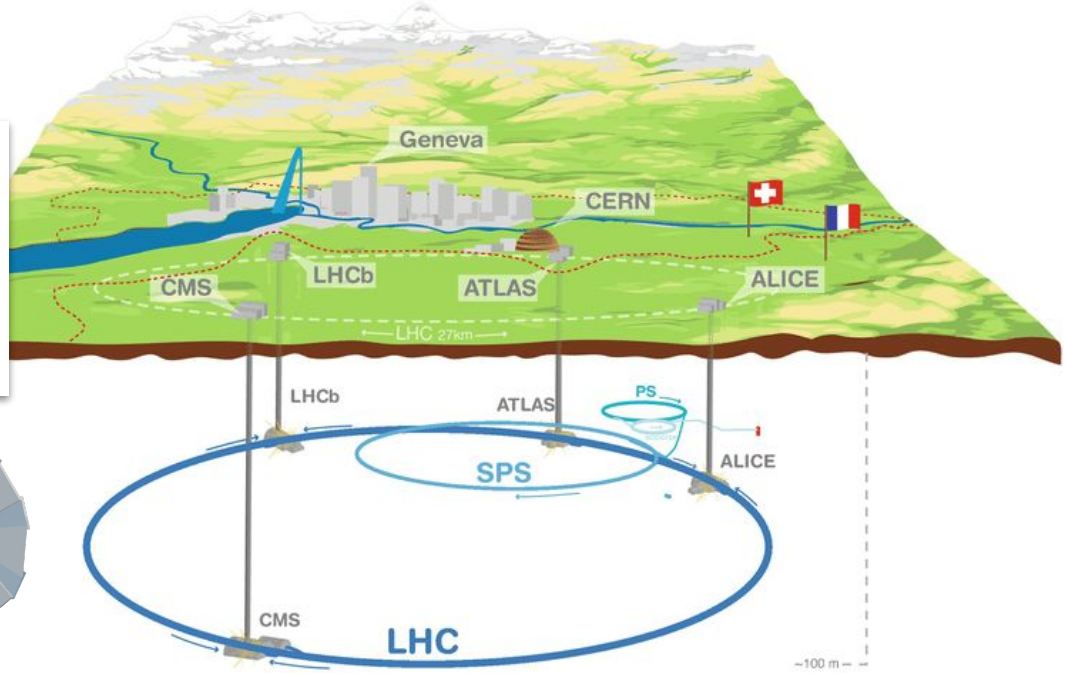
LHC & ATLAS

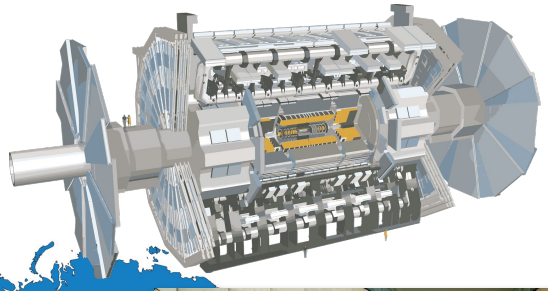
Large Hadron Collider (LHC):

27 km - *pp* - CERN, Geneva (CH)

- **Run 1**: √s = 7 – 8 TeV, 2010 – 2012, 30 fb^{-1}
- **Run 2**: √s = 13 TeV, 2015 – 2018, 150 fb^{-1}
- **Run 3**: √s = 13.6 TeV, 2022 – 2025, ~300 fb^{-1}

WE ARE HERE



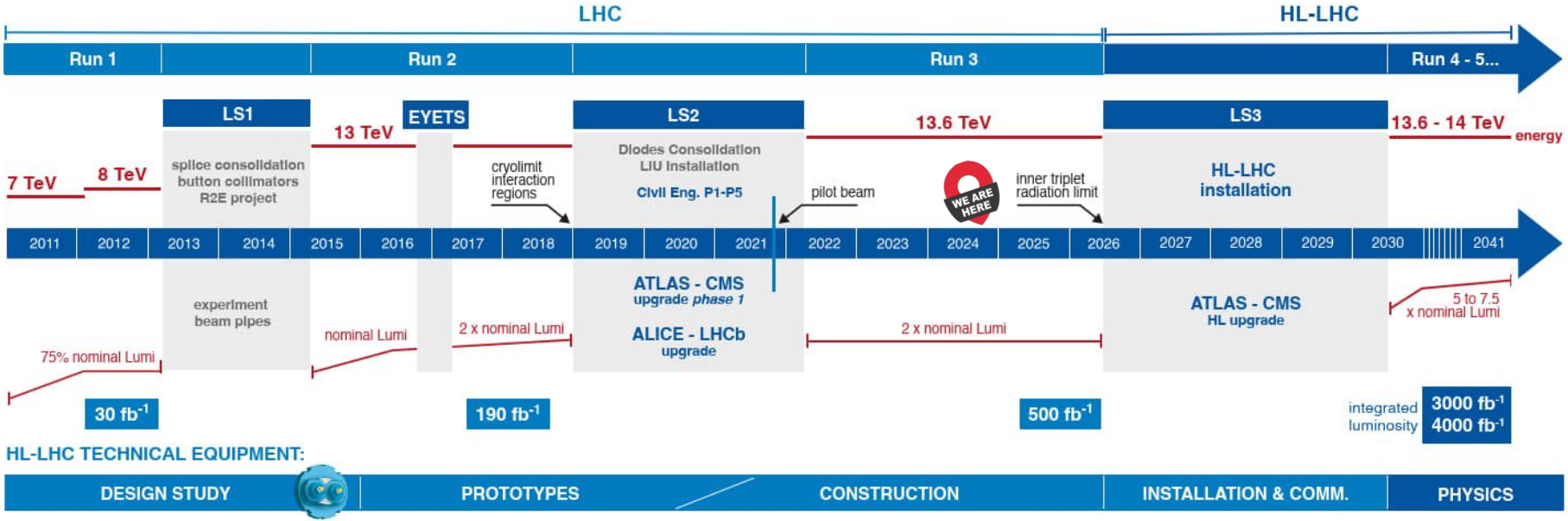


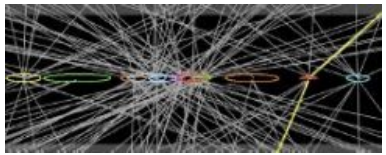
ATLAS Experiment:

- *general-purpose* particle detector @LHC
  - size: 45 x 25 x 25 m
- collaboration: ~ 6000 members, 3000 authors
  - 182 institutions, 42 countries
- > 1000 journal publications so far!

High-Luminosity-LHC

	LHC	HL-LHC (2026)
E	7 - 13.6 TeV	14 TeV
L	2×10^{34} cm^{-2}s^{-1}	7.5×10^{34} cm^{2}s^{-1}
pile-up $< \mu >$	≈ 50	≈ 200





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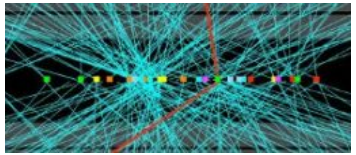

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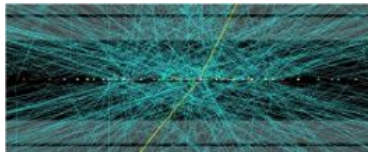
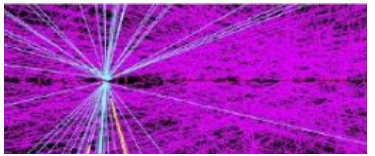


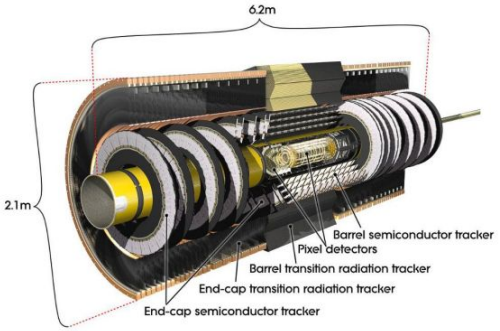
<μ>=60



<μ>~200

HL-LHC & ATLAS

- Major detector upgrade to cope with **x5-10** higher ***collision rates***, ***pile-up*** and ***radiation damage***
- Most important:
  - completely **new** all-silicon **Inner Tracker (ITk)** replacing current Inner Detector

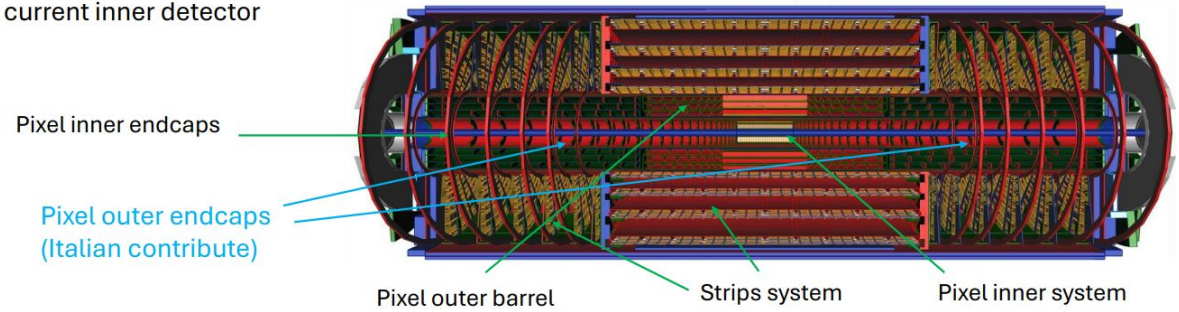


The current inner detector

From the current inner detector to ITk

- Number of pixels from 92M to 1.4G
- Number of modules from 2000 to 19400
- Silicon pixel area from 1.9 m^2 to 13 m^2
- η from 2.5 to 4

all-silicon Inner Tracker (ITk) ATL-PHYS-PUB-2021-024



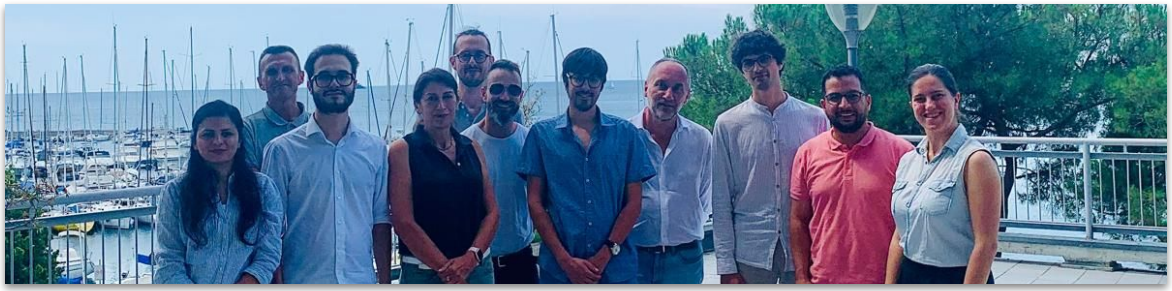
The HL-LHC physics potential:
huge dataset + improved performance will allow:

- factor of 5 gain in **Higgs couplings**
- possible evidence/observation of **double-Higgs**-boson production
- improved **precision SM** measurements
- largely improved sensitivity of BSM searches involving **rare processes** and **weakly coupled** new sectors
- …

The ATLAS Udine-ICTP Group

https://atlasud.uniud.it/

- Local group based on collaboration between:
  - **University of Udine**, **ICTP Trieste** and **INFN Trieste, Gruppo Collegato di Udine**
- **19 people** currently in the group:
  - **seniors**: 7 permanent staff + 2 RTDb + 2 post-docs
  - **students**: 6 PhD + 1 Master

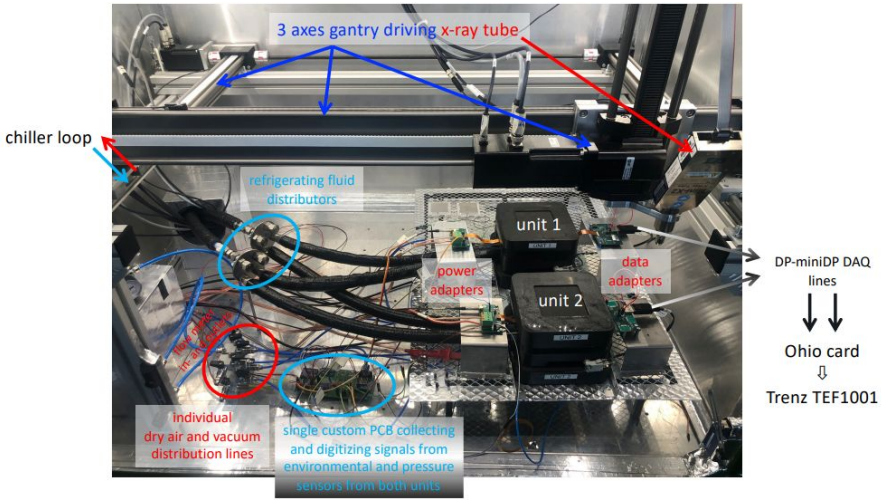


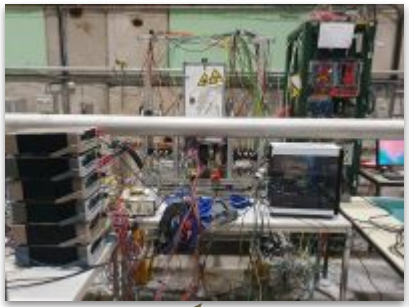
- **Group activities**:
  - **hardware**: silicon pixel detector & ITk upgrade
  - **data analysis**: top-quark, Higgs & EW physics + BSM-searches
  - **detector operations**: trigger, data-quality & distributed computing
  - **detector performance**: b-jet-tagging & electron identification

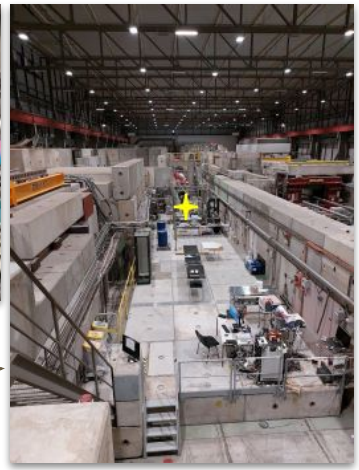
- Collaboration with **theory community** (ICTP & INFN)

ITk Pixel Activities

- Udine group involved in **ITk Pixel module testing** for HL-LHC ATLAS upgrade:
  - together with Milano, Bologna, Frascati, Lecce & Trento
  - laboratory in Uni-UD ~ready for testing ~700 Pixel modules (in 2 years) before they enter ITk
    - setup for testing both **electronics** and **sensor** in place, 2 modules in parallel, DAQ & DCS systems
    - checking electronics **integrity**, **thermal resistance**, response to **X-ray irradiation**



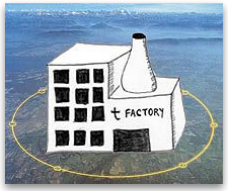




- Recently getting involved in ITk Pixel **beam tests** at CERN

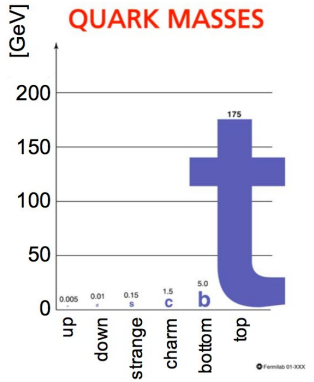
Data Analysis Activities

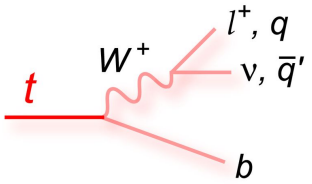
- *Group historically specialized in data-analysis in the context of **top-quark physics***

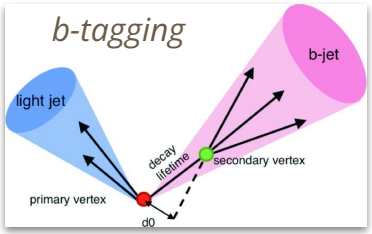


The top quark:

- heaviest known fundamental particle
- decays before hadronising
- strongest coupling with Higgs field
  ⇒ possible key role in new physics?





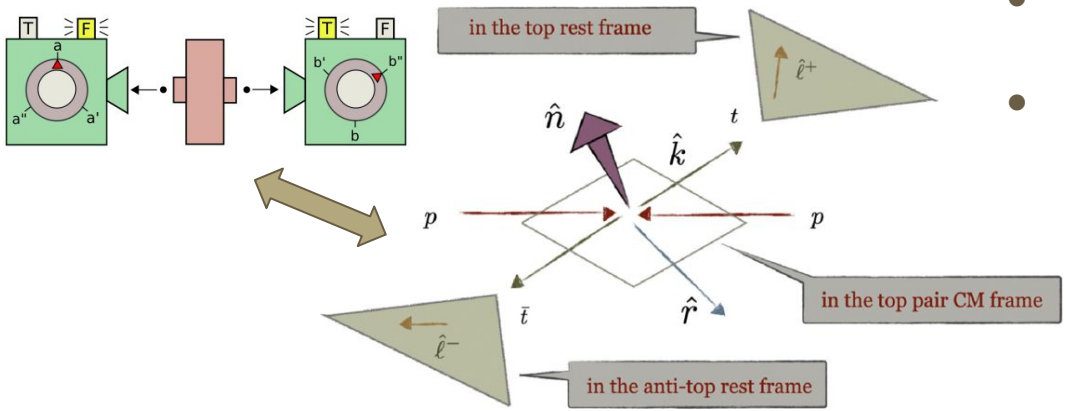


- **Recently strong group involvement in:**
  - first top-quark-pair ($t\bar{t}$) cross-section measurement in Run 3 [Phys. Lett. B 848 (2024) 138376]
  - single-top production measurement at $\sqrt{s}$ = 5 TeV [Phys. Lett. B 854 (2024) 138726]
  - search for heavy Higgs boson decaying to $t\bar{t}$ [JHEP 08 (2024) 013]
  - search for high-mass $t\bar{t}$ resonances [ongoing]
  - measurement of $t\bar{t}+Z$ with $Z \rightarrow \nu\nu$ decay [ongoing]
  - measurement of b-quark forward-backward asymmetry in Z-b vertex [ongoing]
  - quantum information in $t\bar{t}$ events [ongoing]
  - search for dark-sector jets [starting]

Focus topic: Quantum entanglement in top-quark pairs

- $t\bar{t}$ pairs predicted (*and verified*) to have **correlated spins**:
  - t and $\bar{t}$ spins accessed via decay-product angular *distributions*
  - allow to study **quantum mechanics effects**:
    - quantum **entanglement**: "*spin correlations beyond classical*"
    - **Bell's inequality** violation: "*exclusion of hidden-variable effects*"

Spin correlations ⊆ Entanglement ⊆ Bell's inequality violation

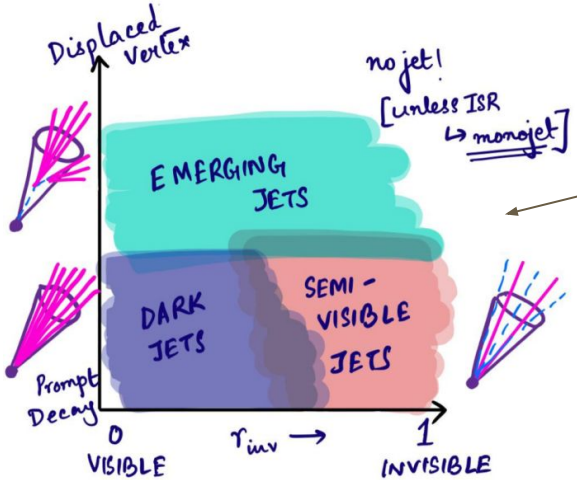


- **Entanglement** in $t\bar{t}$ recently observed by ATLAS and CMS
- **Bell's inequality violation** test more ***challenging***:
  - selection of **high-invariant mass $t\bar{t}$** system → *low statistics, difficult $t\bar{t}$ reconstruction from final state particles…*

Collaboration with M. Fabbrichesi, R. Floreanini & E. Gabrielli

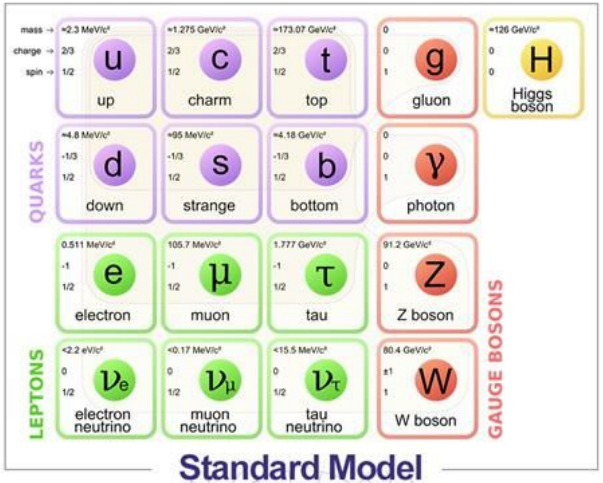
Focus topic: Search for dark jets

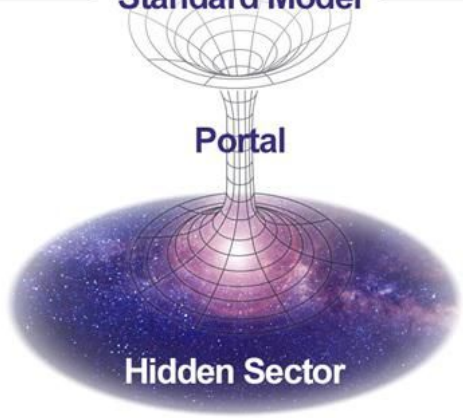
- Intriguing hypothesis for **Dark Matter** nature:
  - not single new particle but entire "Hidden" or "Dark" Sector
- Interaction between **Dark Sector** and Standard Model provided by a ***portal*** (e.g. the Higgs boson):
  - LHC could produce *dark* particles via this *portal*
  - if dark particles strongly coupled (e.g. via ***dark QCD***)
    ⇒ ***dark jet*** production!



Project financed by PNRR sub-call, ICSC, Spoke 2

- **Different possible signatures**:
  - extensive and coherent search programme essential
  - possibly with **machine-learning** techniques to distinguish standard jets from dark-jets and classify/tag them (*similarly to b-tagging!*)





Conclusions

- ATLAS Udine-ICTP group involved in **HL-LHC detector upgrade**

- **Physics analysis**:
  - plan to focus on a number of different areas where the group can use its expertise

- **Operation and performance**:
  - main current activities (Trigger and b-tagging) expected to play a key role for HL-LHC phase

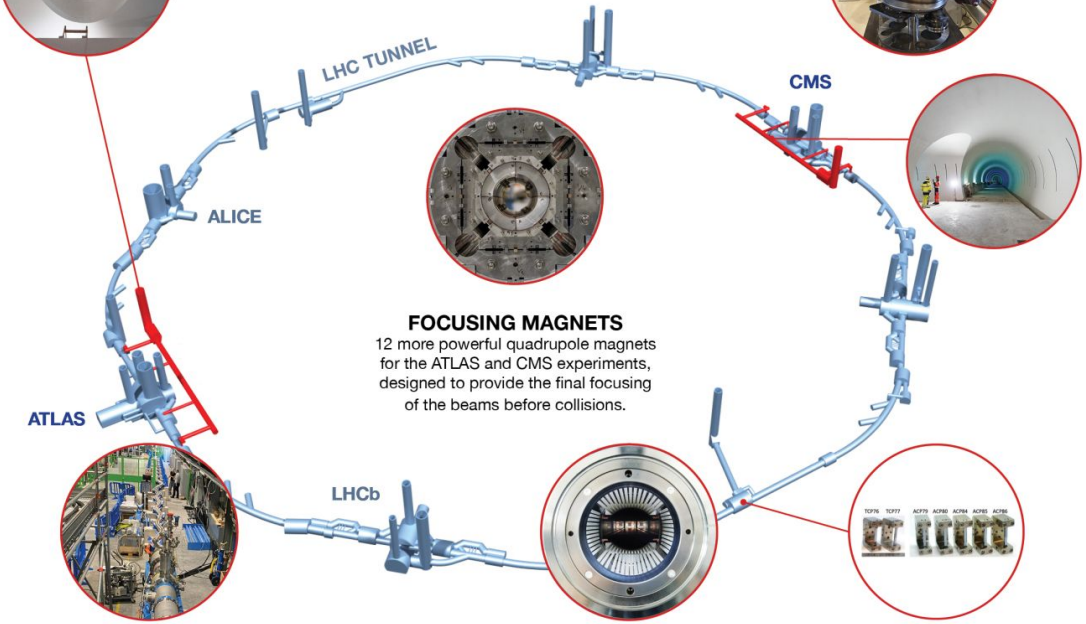
- **In addition, the group plans to contribute to:**
  - **computing**:
    - x10 data means more **disk space** and **computing power** and/or **more efficient usage** of them
      → planning ***stronger interaction*** with **local computing farm** team & National **INFN-cloud** resources
  - **analysis tools and techniques**:
    - more data and more sophisticated analyses ⇒ essential to develop and adopt:
      machine-learning *techniques, modern* ***data-processing tools****, refined/new* ***statistical analysis*** *techniques*

Backup

NEW TECHNOLOGIES FOR THE HIGH-LUMINOSITY LHC

CIVIL ENGINEERING
2 new 300-metre service tunnels and 2 shafts near ATLAS and CMS.

"CRAB" CAVITIES
16 superconducting "crab" cavities for the ATLAS and CMS experiments to tilt the beams before collisions.



FOCUSING MAGNETS
12 more powerful quadrupole magnets for the ATLAS and CMS experiments, designed to provide the final focusing of the beams before collisions.

SUPERCONDUCTING LINKS
Electrical transmission lines based on a high-temperature superconductor to carry the very high DC currents to the magnets from the powering systems installed in the new service tunnels near ATLAS and CMS.

COLLIMATORS
15 to 20 additional collimators and replacement of 60 collimators with improved performance to reinforce machine protection.

CRYSTAL COLLIMATORS
New crystal collimators in the IR7 cleaning insertion to improve cleaning efficiency during operation with ion beams.

CERN February 2024

https://indico.cern.ch/event/1291157/contributions/5890119/attachments/2897159/5083915/HL-LHC-Status_and_prospects.pdf