Highlights from the ATLAS Experiment

Andreas Hoecker (CERN), CERN – Ukraine 2024, Kyiv, Ukraine, May 28th, 2024

ATLAS EXPERIMENT

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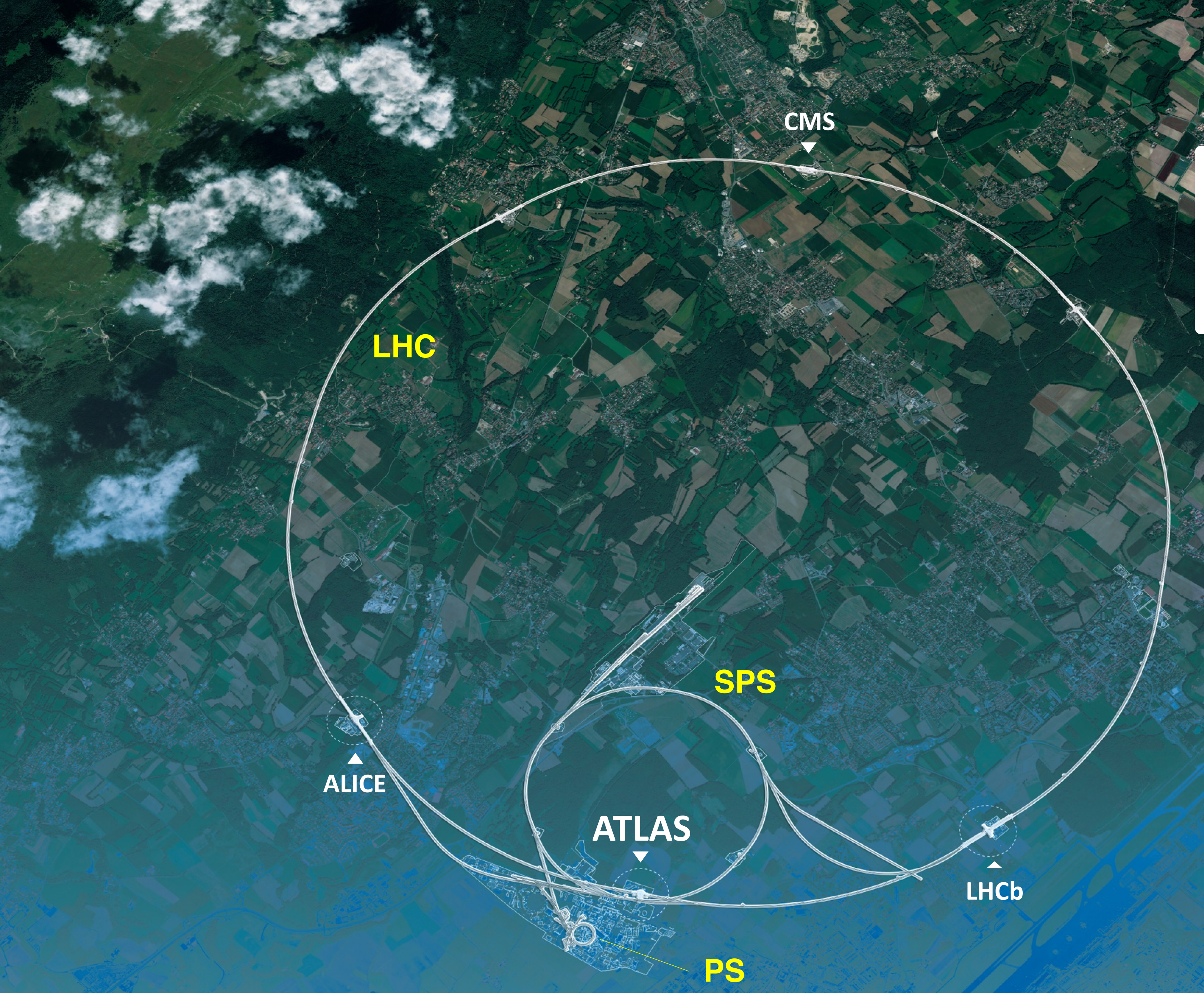
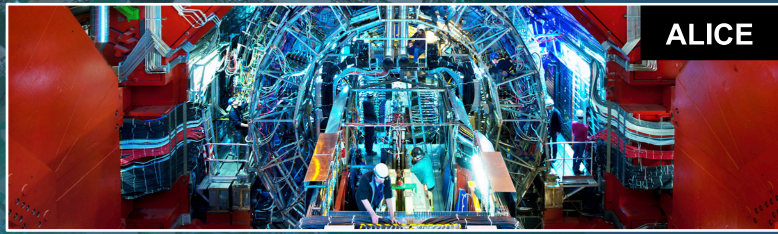
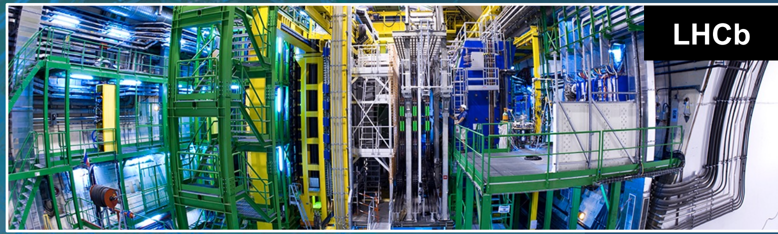
ATLAS EXPERIMENT

Outline

- Detector and collaboration
- Run-3 operation
- Physics highlights
- Phase-II upgrades

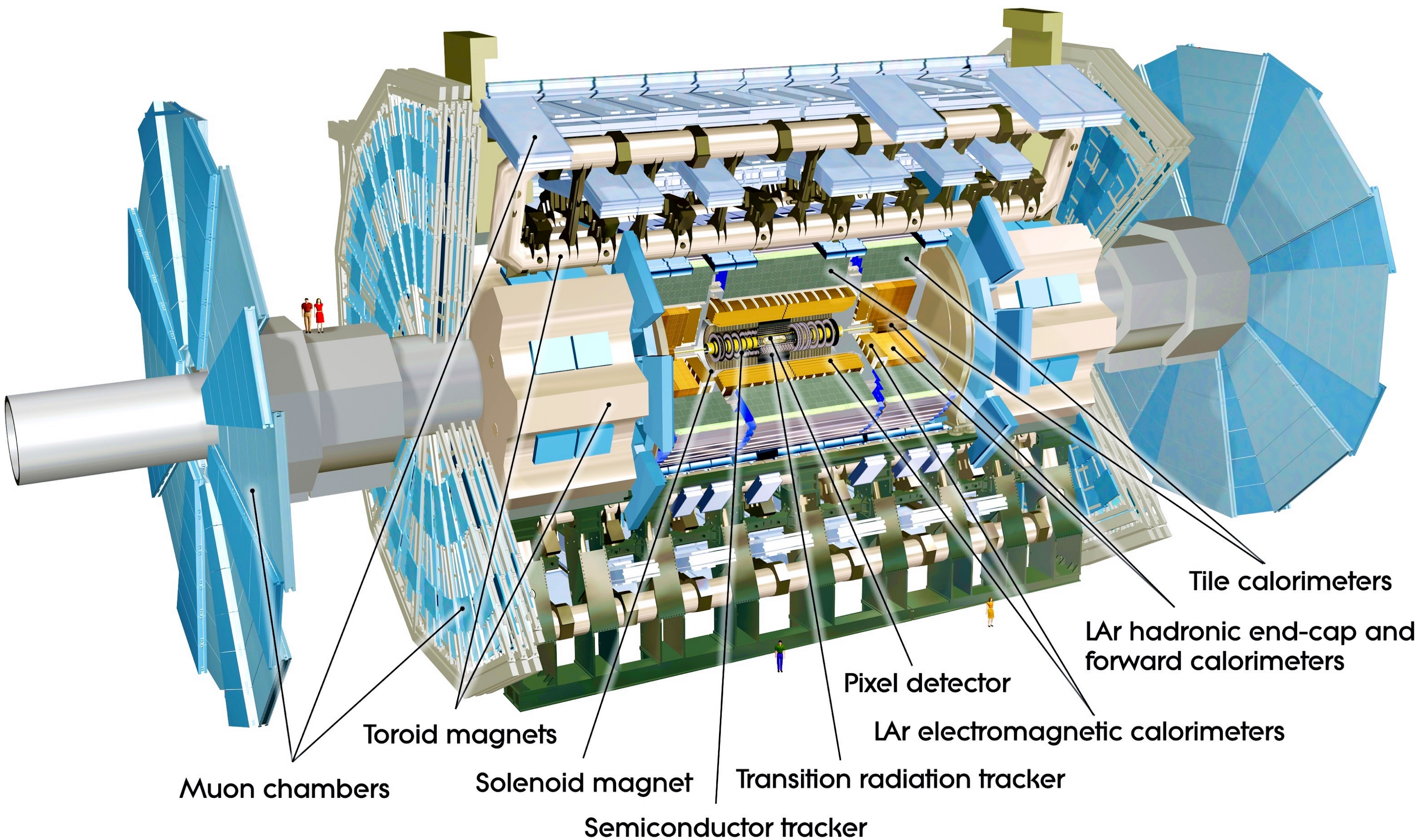


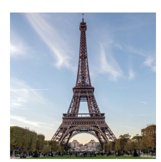




LHC — areal view

The ATLAS Detector



25 m diameter, 44 m long, 7000 tons weight ~ 

High resolution silicon **detectors**:

- 100 Mio. channels (50 μm x 250 μm)
- 6 Mio. channels (80 μm x 12 cm)

spatial resolution ~15 μm (in azimuthal direction)

Axial field provided by **solenoid** (2 T) in central region (momentum measurement)

Energy measurement down to 1º to the beam line with a **calorimeter system**

Independent **muon spectrometer** (superconducting toroidal magnet system)

Ultra-fast custom electronics and high-performance computers filter the collisions: only 1 out of 20,000 collisions is kept

The ATLAS Collaboration

ATLAS Collaboration (status: 24 March 2024)

- 185 Institutions (253 institutes) from 42 countries + 15 Technical Associate Institutes
- 2917 Scientific authors (among which 1969 contribute to M&O share)
- 1187 Physics PhD students
- 1323 Engineers or technicians
- 86 Engineering students
- 5993 Active members

ATLAS opeators in the control room

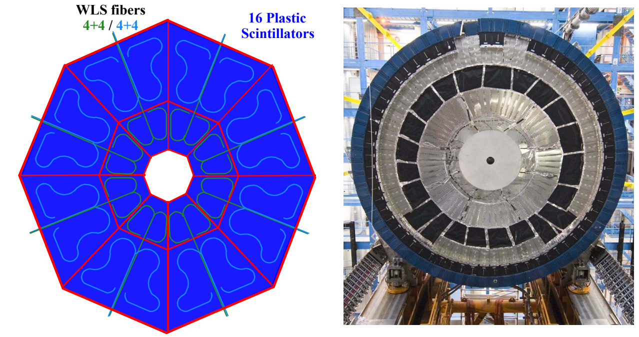
a Chaux-de-Fonds, Switzerland in 2022

While ATLAS has no direct involvement from Ukrainian institutes, Ukrainian scientists and engineers have and are crucially contributing to the ATLAS construction, operation, trigger, software & computing, physics and performance analysis, and to the upgrades of our experiment

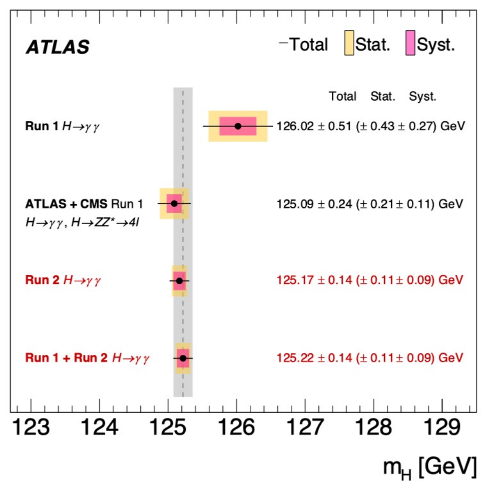
Ukraine in ATLAS

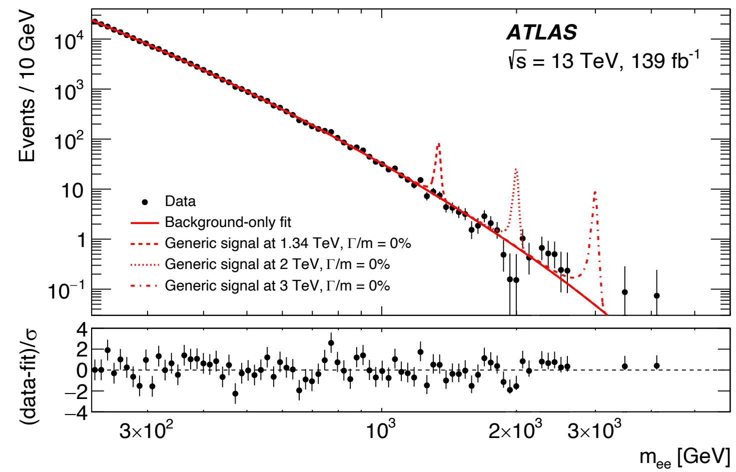
Strong & diverse contributions of Ukrainian scientists to ATLAS

- Over 40 (currently 21) Ukrainian scientists contributed to ATLAS
- Plastic scintillators for the Run 1 MBTS were produced by the Institute of Scintillation Materials, Kharkiv
- ATLAS control room and on-call expert shifts, system run coordinators
- ATLAS Trigger: software, electron/photon, overall menu coordination
- ATLAS distributed computing, MC production, fast simulation
- Electron-photon and jet reconstruction, calibration, performance, and leadership
- Broad set of analyses in most areas of ATLAS physics programme: Higgs, SM, BSM, Flavour, Heavy ion
- Phase-I & II Upgrades: IBL, NSW, LAr (incl. leadership), ITk, HGTD, test beams

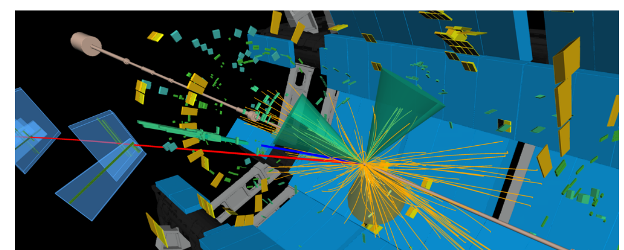


ATLAS MBTS counters during Run 1

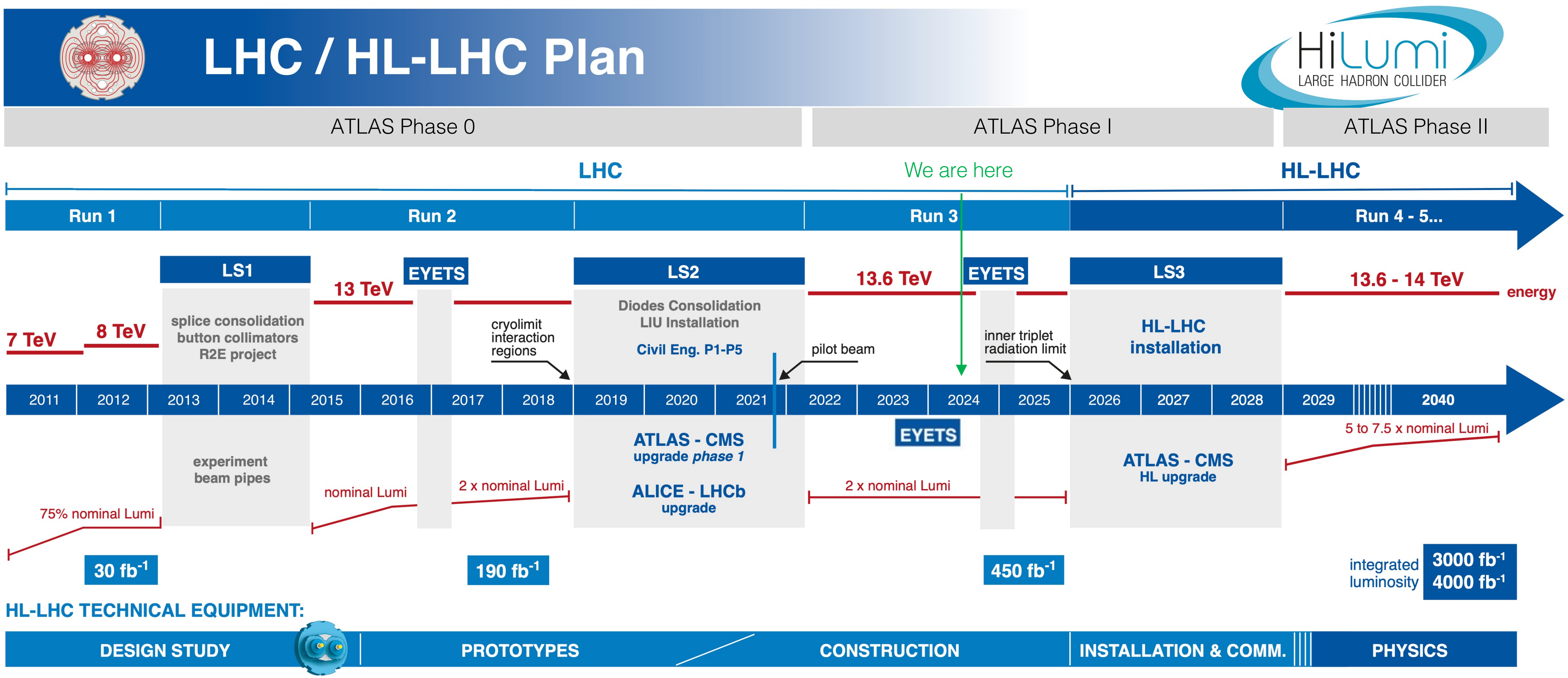




Observation of top production in proton–lead collisions



LHC Schedule, Run 3 well advanced, LS3 approaching fast



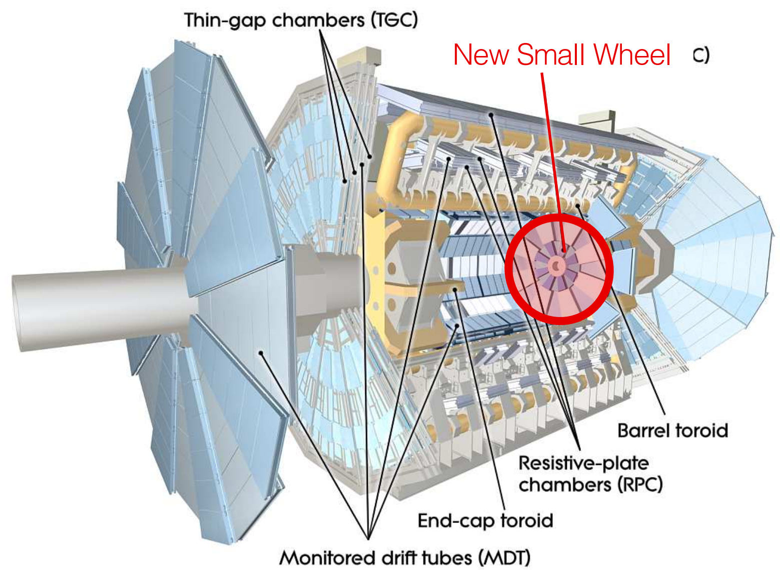
ATLAS EXPERIMENT

July 12, 2021, lowering the
NSW-A into the ATLAS cavern

Phase-I upgrade during Long Shutdown 2 (LS2, 2019–2021)

Mainly dedicated to upgrade of ATLAS’ **trigger system**

- Muon New Small Wheel to improve forward muon trigger
- Digital Liquid-Argon (LAr) calorimeter trigger with finer cell granularity
- New “Feature-extraction” boards to exploit improved calorimeter and muon information



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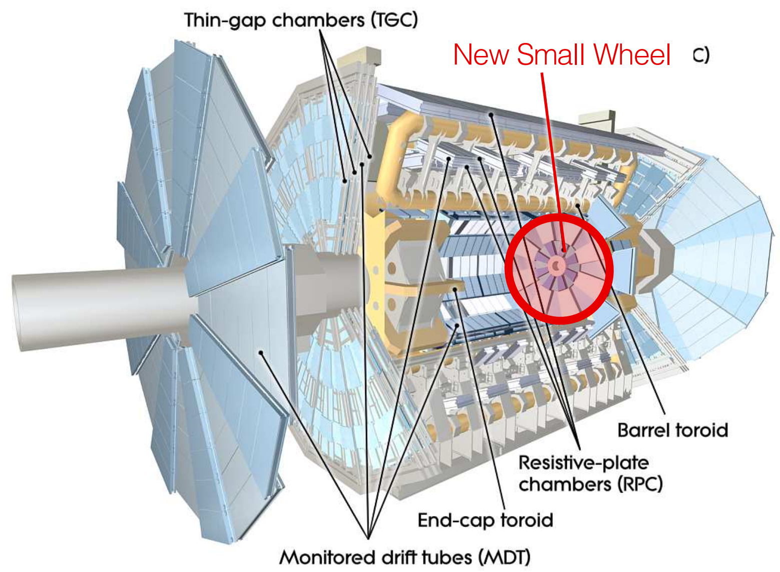
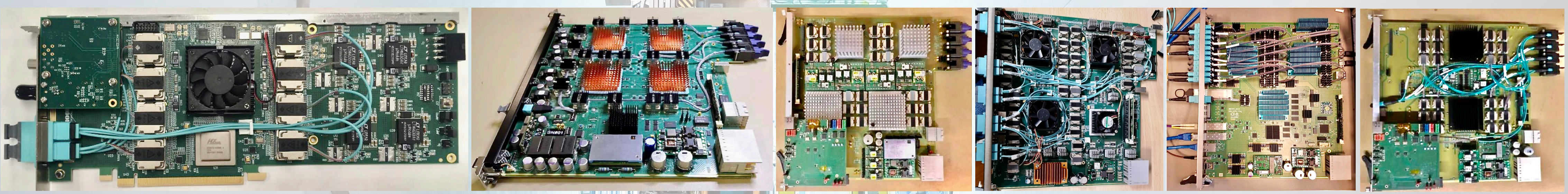


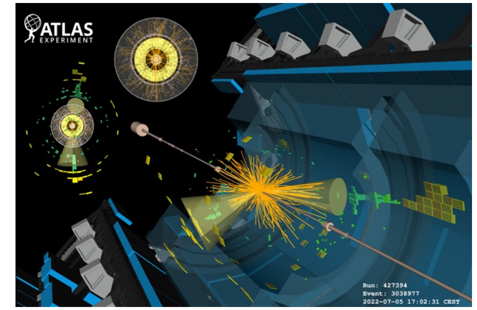


FELIX eFEX jFEX gFEX MUCTPI L1Topo

Extremely successful LHC runs between 2010 and 2018

Extremely successful LHC runs between 2010 and 2018, and continuing …

Run 3 (2022–2025) at new record collision energy of 13.6 TeV has begun



First 13.6 TeV collisions on 5 July 2022

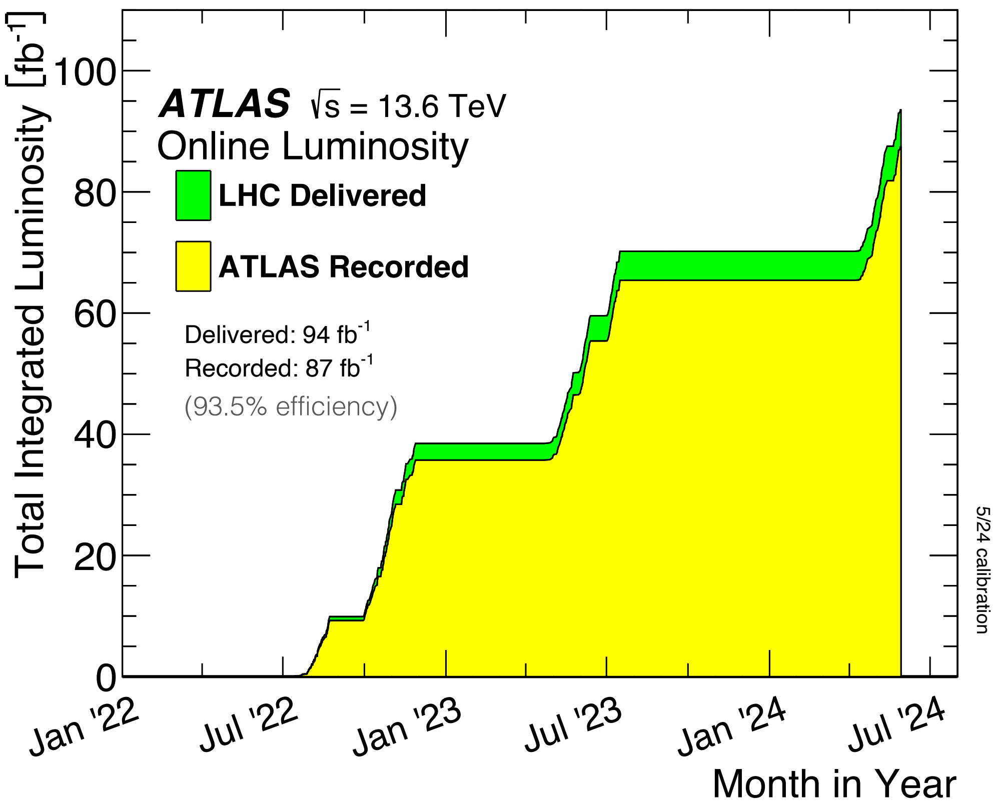
Extremely successful LHC runs between 2010 and 2018, and continuing ...

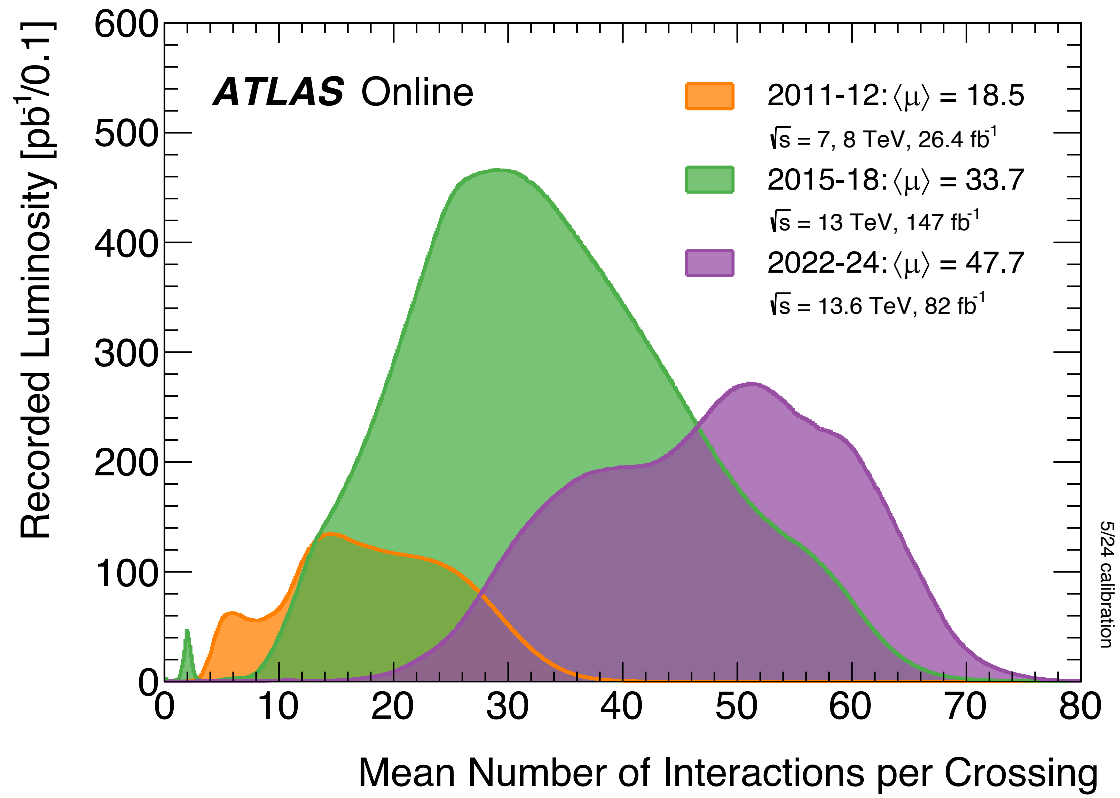
2024 physics data taking has resumed

Proton–proton data taking in Run 3

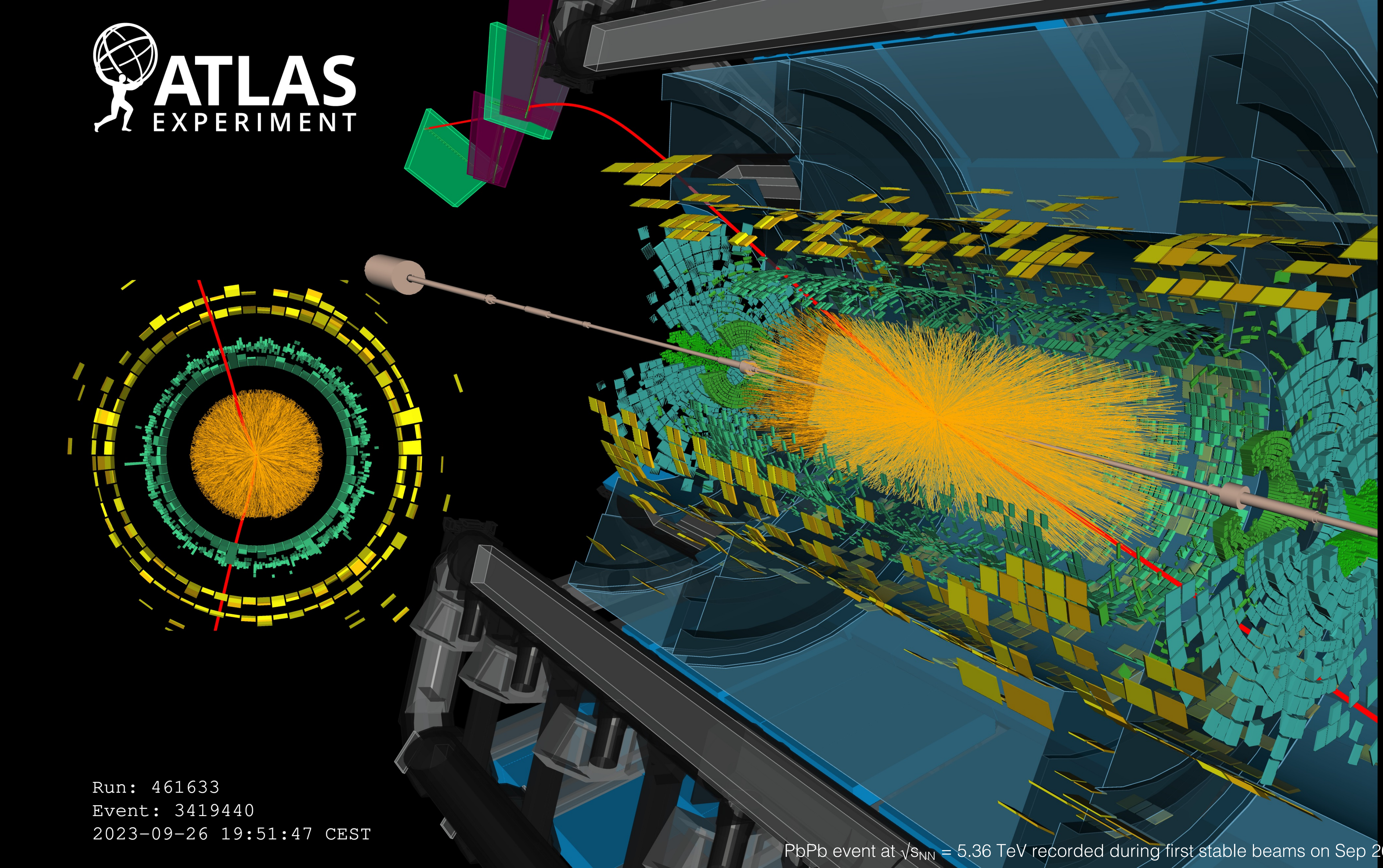
Accelerator problems during 2022 & 2023, less integrated luminosity than anticipated. Good startup in 2024

2024: 23.3 fb^{-1} delivered and 22.0 fb^{-1} recorded (94.2%). Higher pileup than in previous years and during Run 2





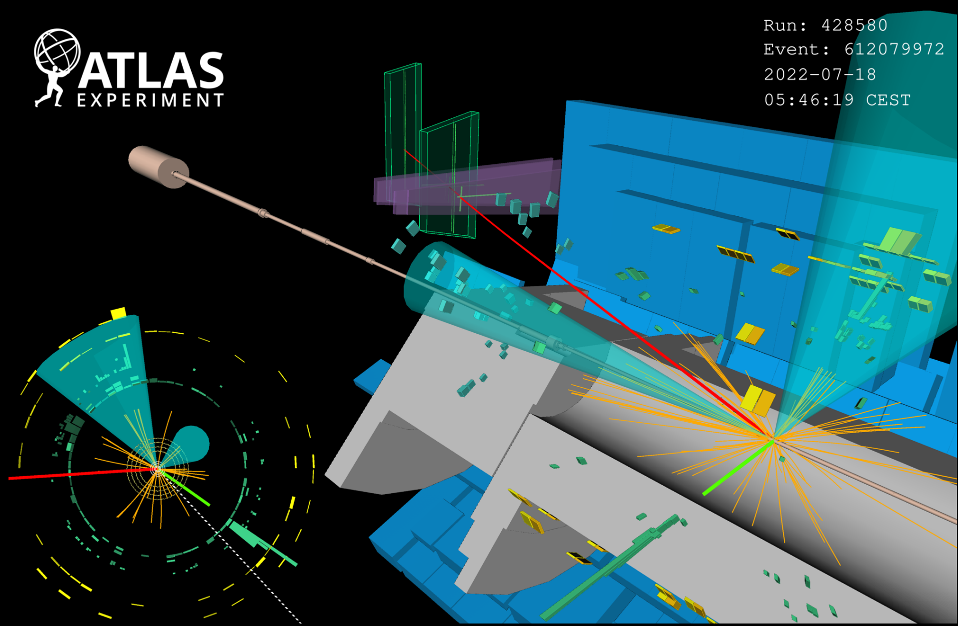
Successful Pb–Pb run in 2023: almost doubled integrated luminosity of Run 2

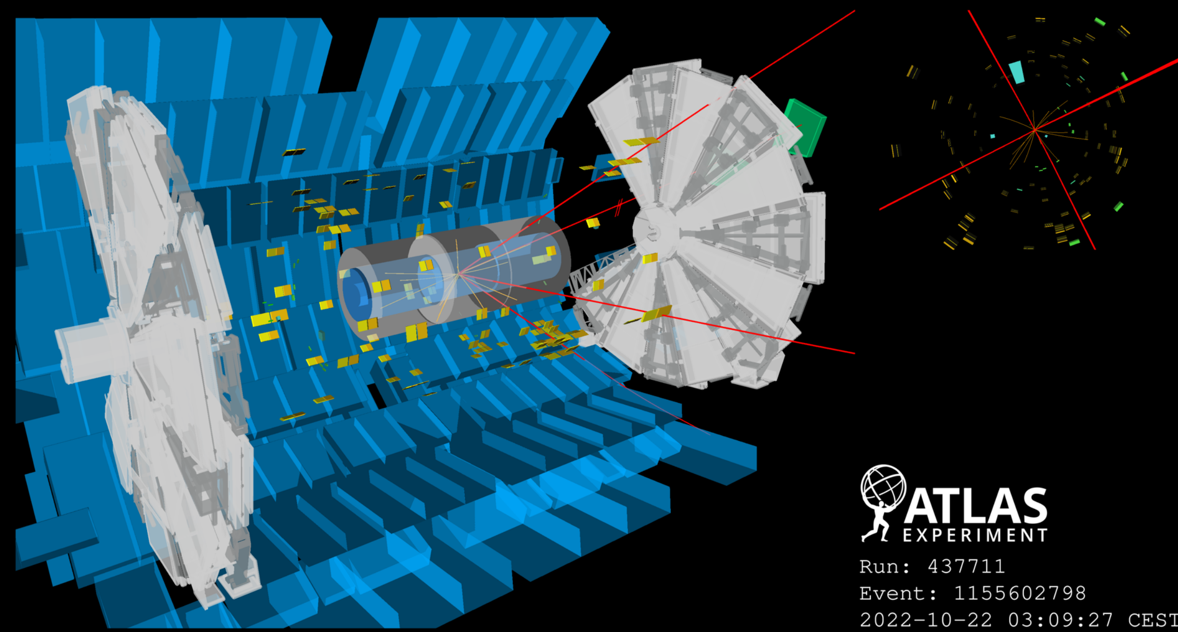


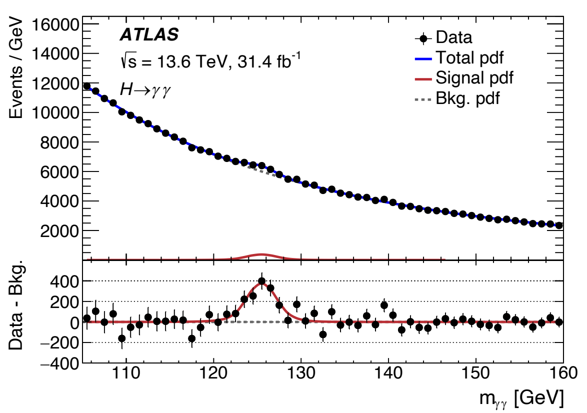
PbPb event at $\sqrt{s_{NN}}$ = 5.36 TeV recorded during first stable beams on Sep 26 [link]

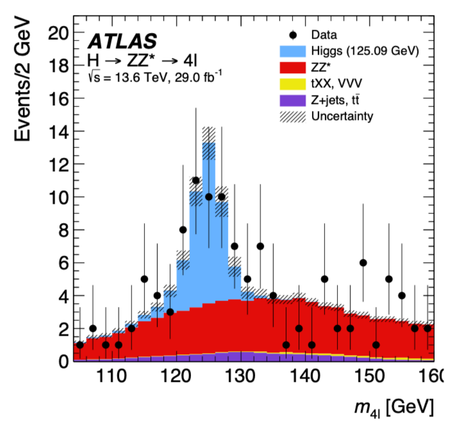
Run-3 data analysis

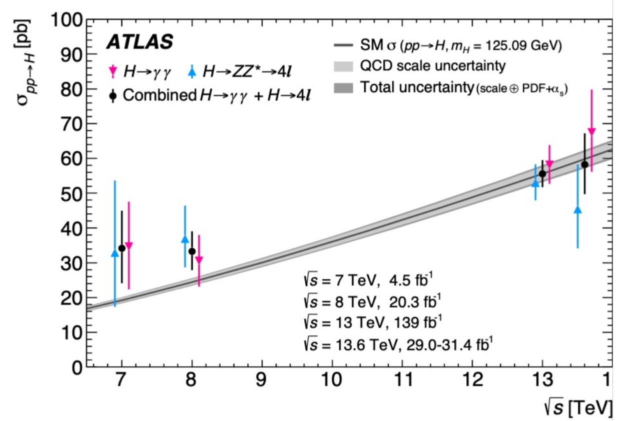
Excellent detector and reconstruction performance, 9 papers, 2 CONF notes, 7 PUB notes released on Run 3

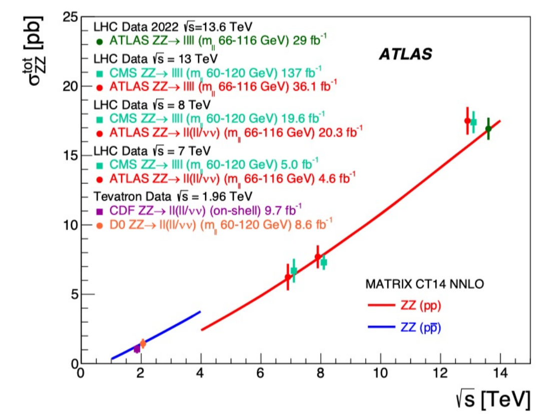












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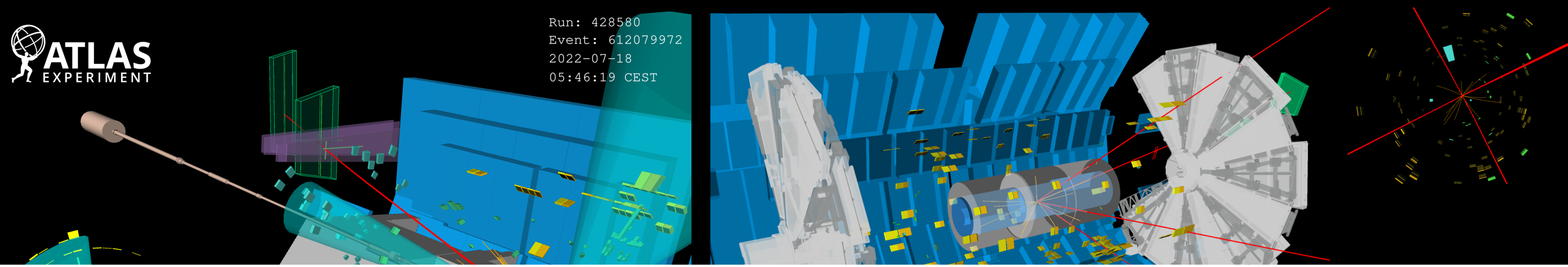
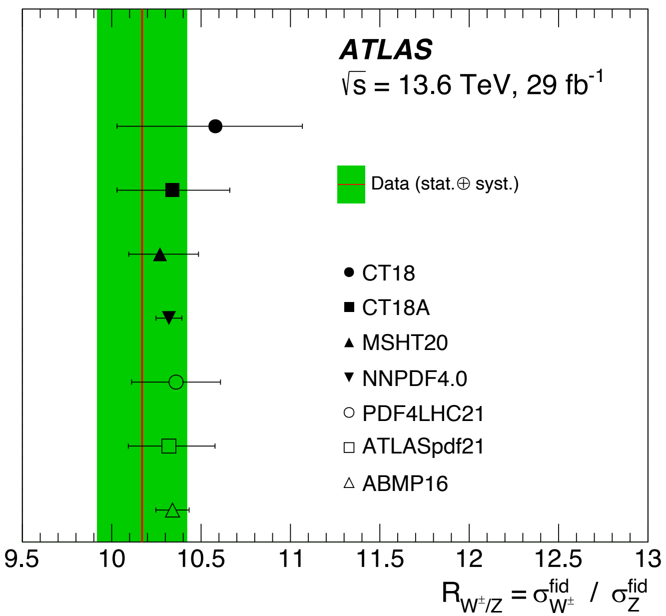
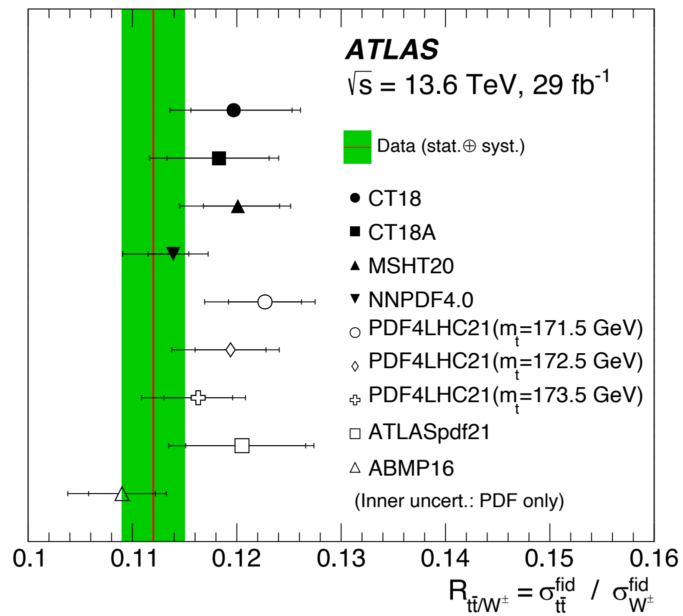
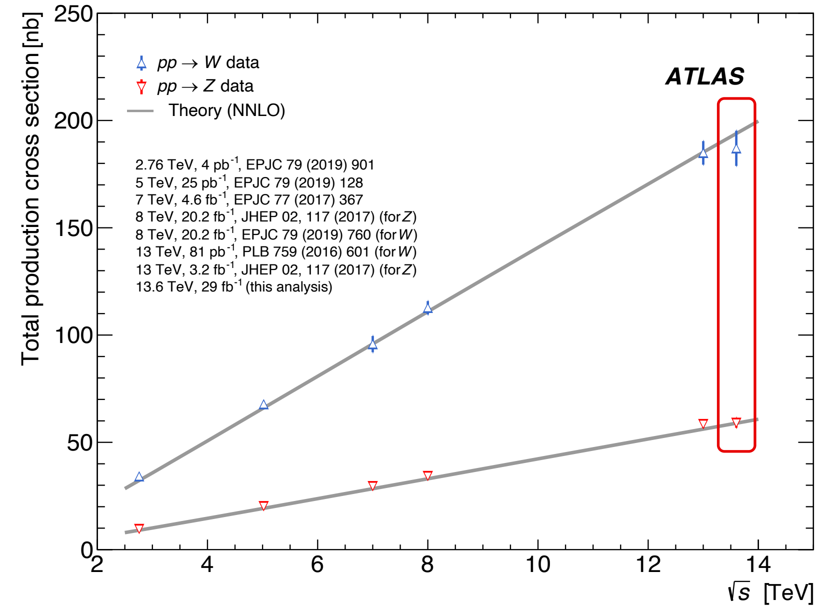


Weak boson production at 13.6 TeV: total, fiducial cross sections and ratios

arXiv:2403.12902







Run-2 data analysis

ATLAS continues to complete its Run-2 physics analysis programme: 340 full Run-2 papers (1287 papers total)

Series of topical Physics Reports synthesizing Run-2 achievements

Electroweak, QCD and flavour physics studies with ATLAS data from Run 2 of the LHC
arXiv:2404.06829

Climbing to the Top of the ATLAS 13 TeV data
arXiv:2404.10674

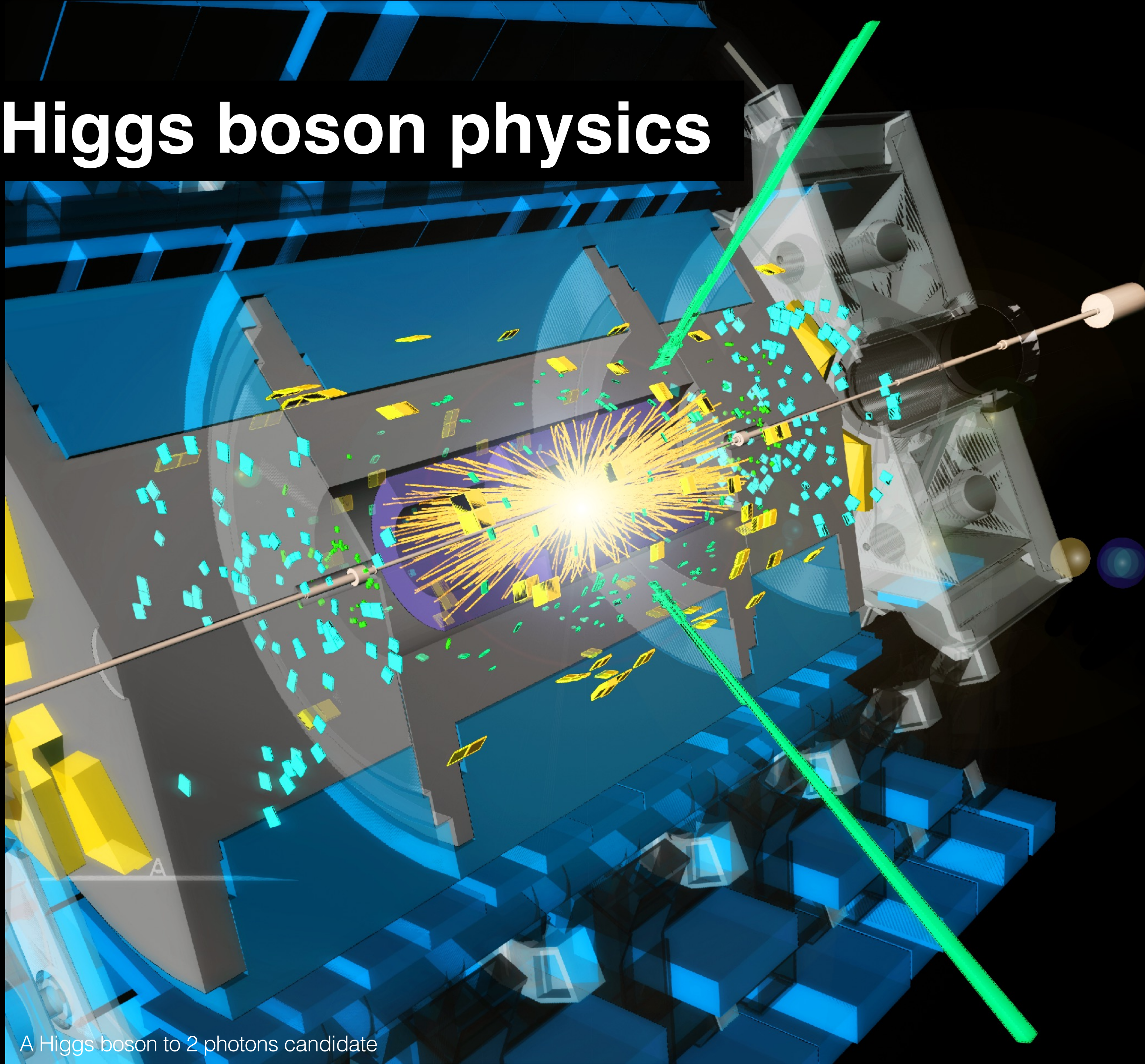
Characterising the Higgs boson with ATLAS data from Run 2 of the LHC
arXiv:2404.05498

ATLAS searches for additional scalars and exotic Higgs boson decays with the LHC Run 2 dataset
arXiv:2405.04914

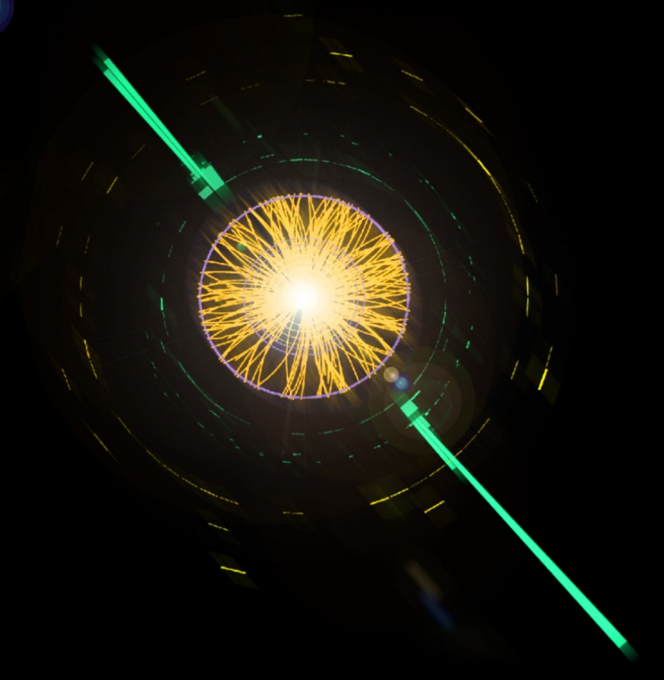
The quest to discover supersymmetry at the ATLAS experiment
arXiv:2403.02455

Exploration at the high-energy frontier … investigating the exotic jungle beyond the Standard Model
arXiv:2403.09292

Higgs boson physics



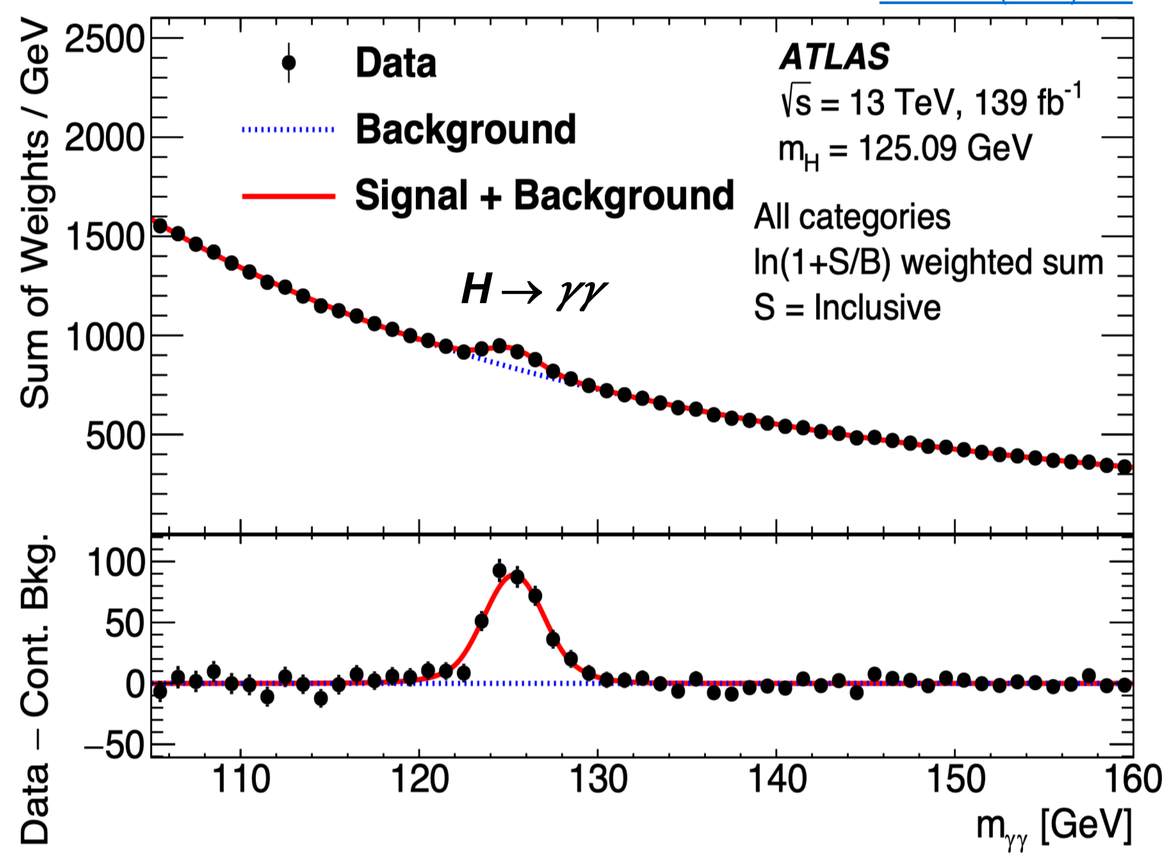
A Higgs boson to 2 photons candidate



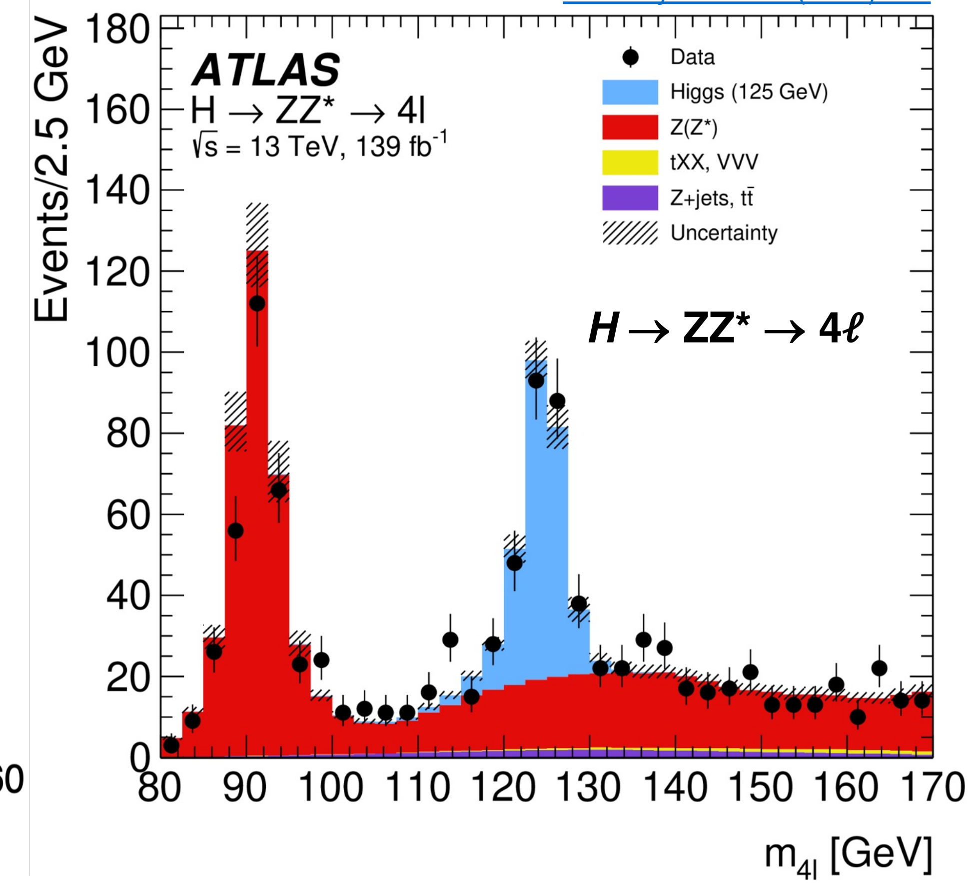
The Higgs boson — At 10

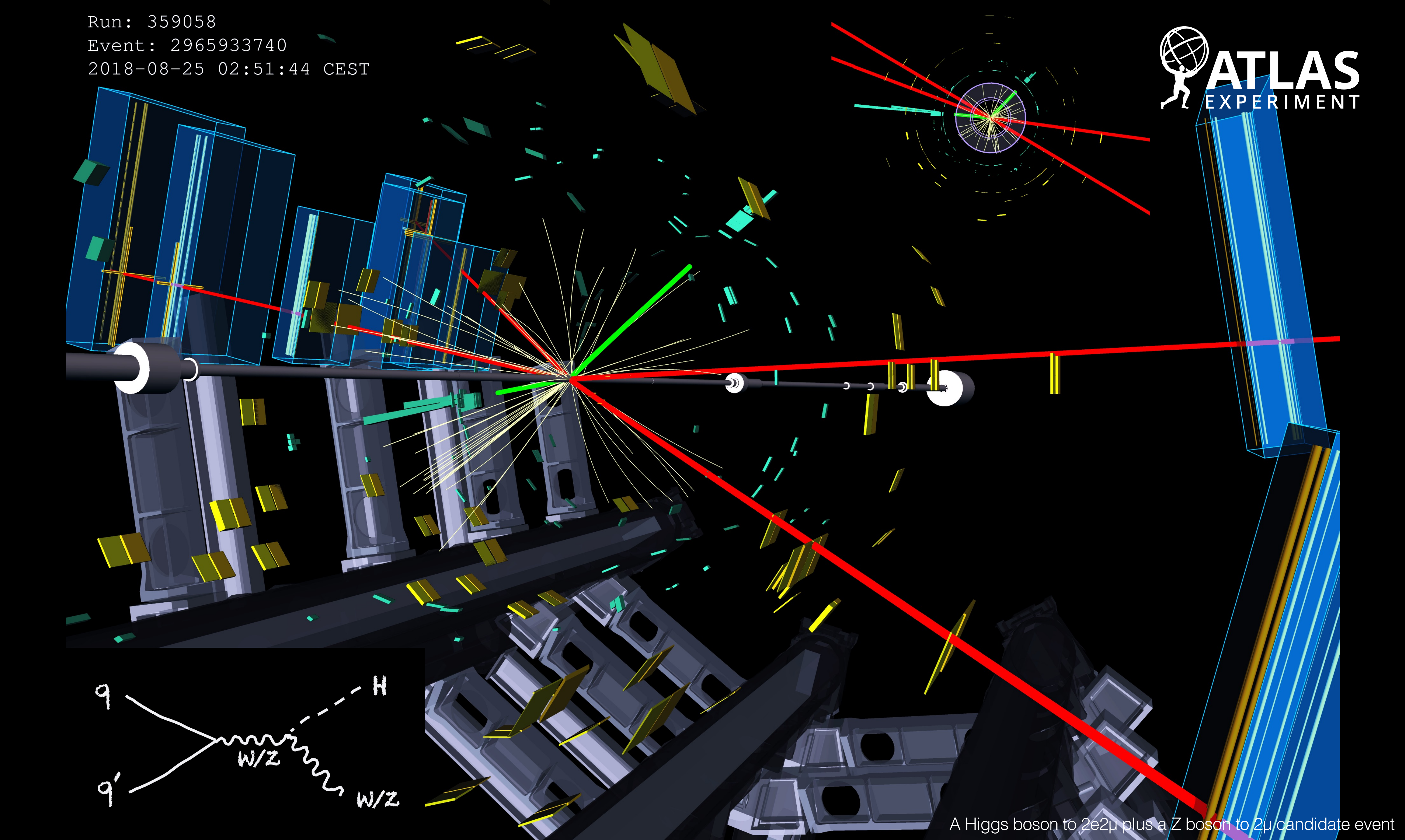
2020

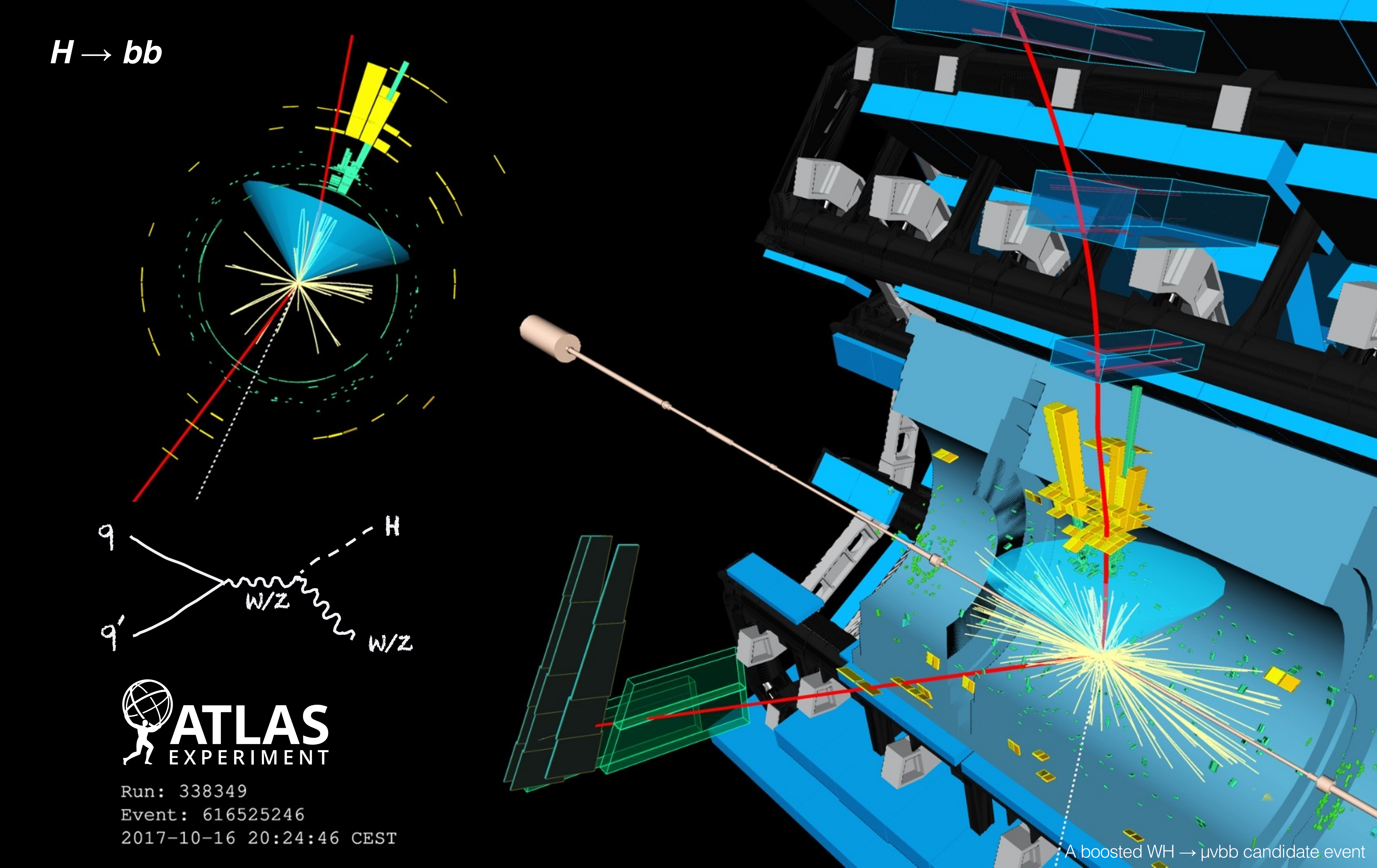
JHEP 07 (2023) 088



Eur. Phys. J. C 80 (2020) 942




Run: 359058
Event: 2965933740
2018-08-25 02:51:44 CEST
ATLAS
EXPERIMENT
q
q'
H
W/Z
W/Z
A Higgs boson to 2e2μ plus a Z boson to 2μ candidate event

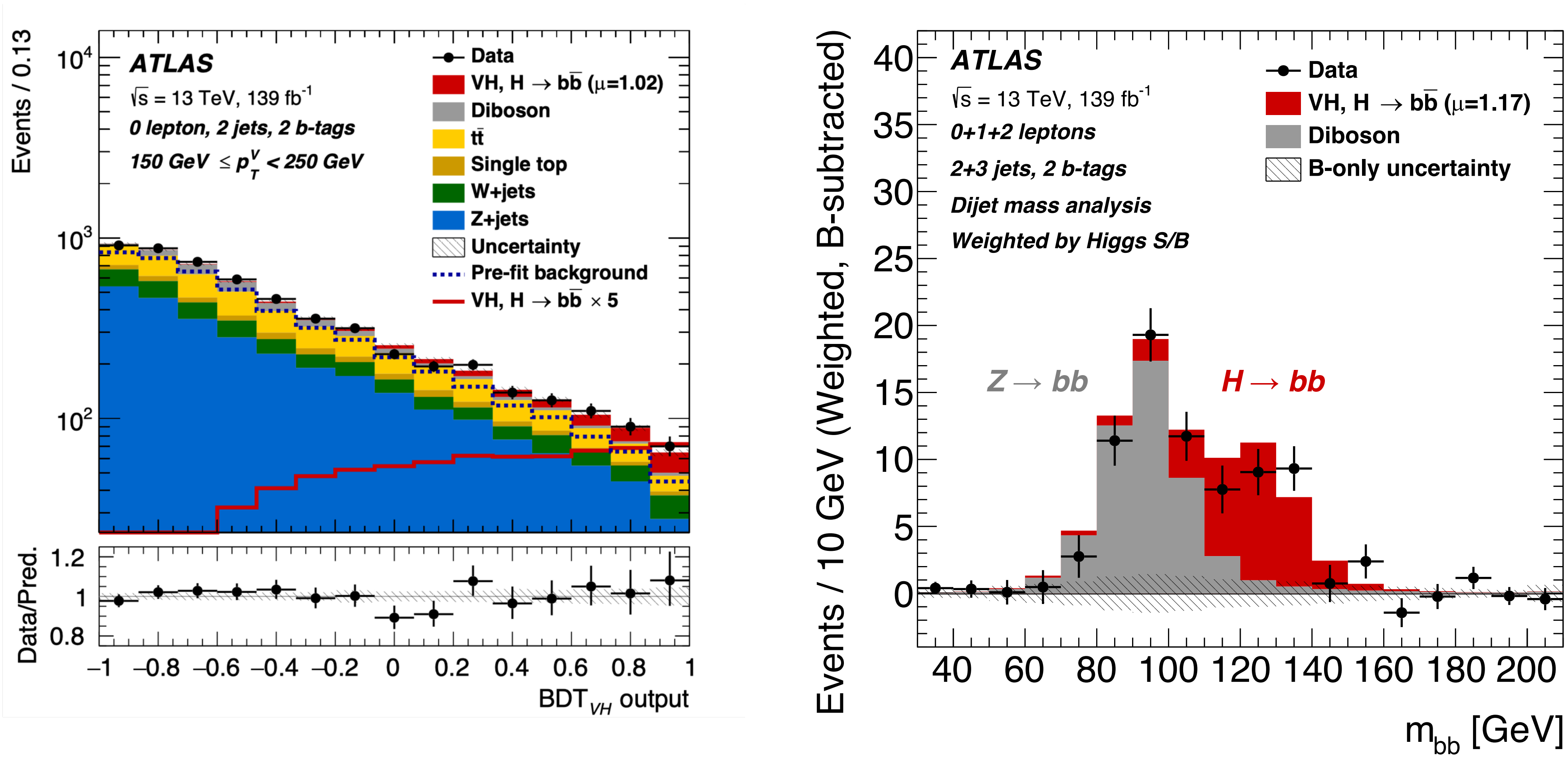


H → bb
q
q'
W/Z
W/Z
H
ATLAS
EXPERIMENT
Run: 338349
Event: 616525246
2017-10-16 20:24:46 CEST
A boosted WH → μνbb candidate event

$H \rightarrow bb$

Measurement of H → bb via associated production pp → W/Z + H and leptonic W/Z decays

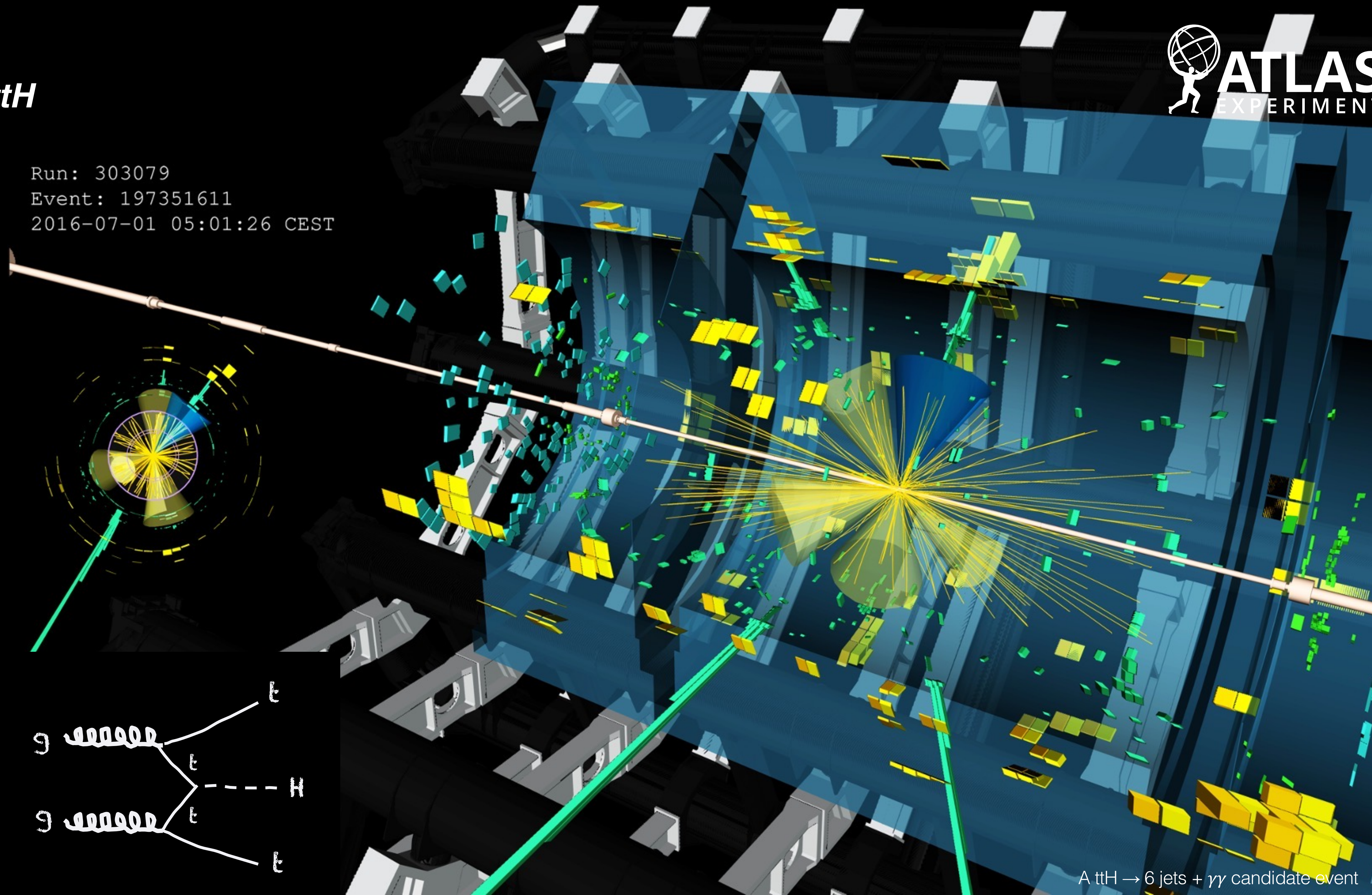
Highly complex analyses requiring excellent control of background processes and signal purification with machine learning



Event: 616525246
2017-10-16 20:24:46 CEST

A boosted WH → μνbb candidate event

ttH

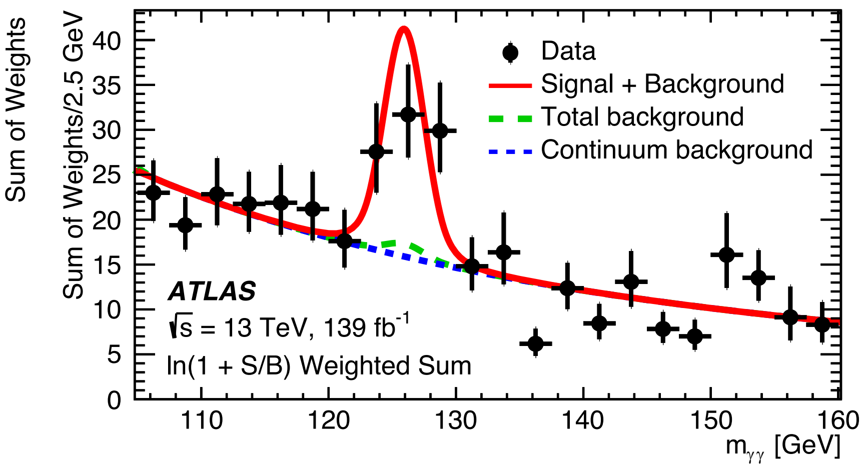


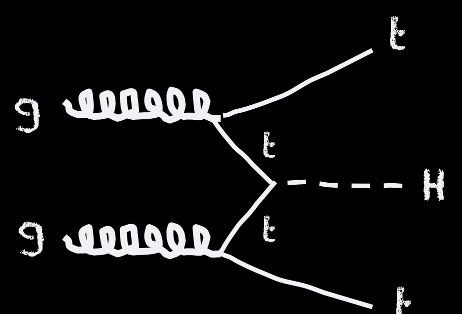
A ttH → 6 jets + $\gamma\gamma$ candidate event

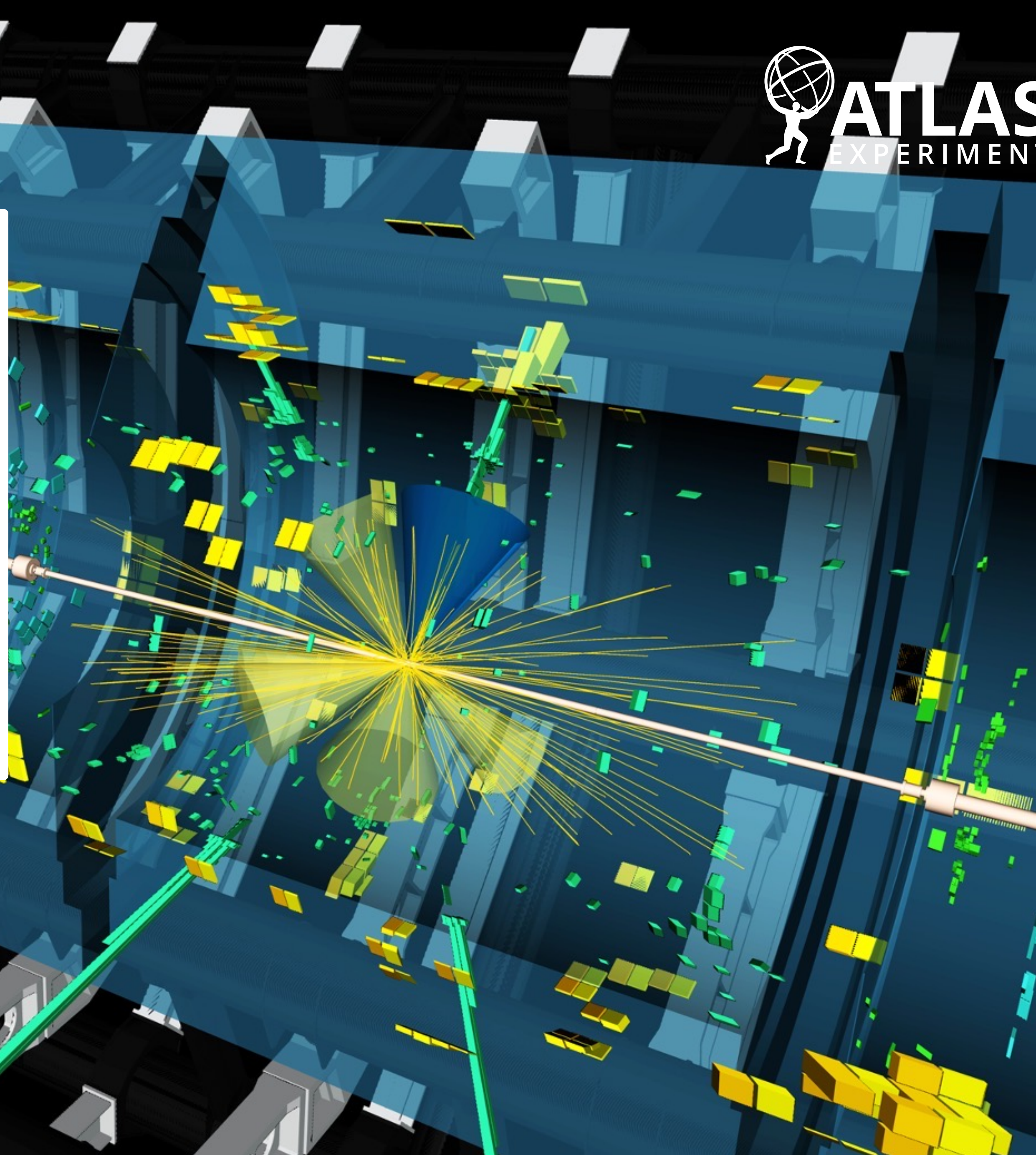
ttH

ttH production features rich events,
H → $\gamma\gamma$ channel most powerful

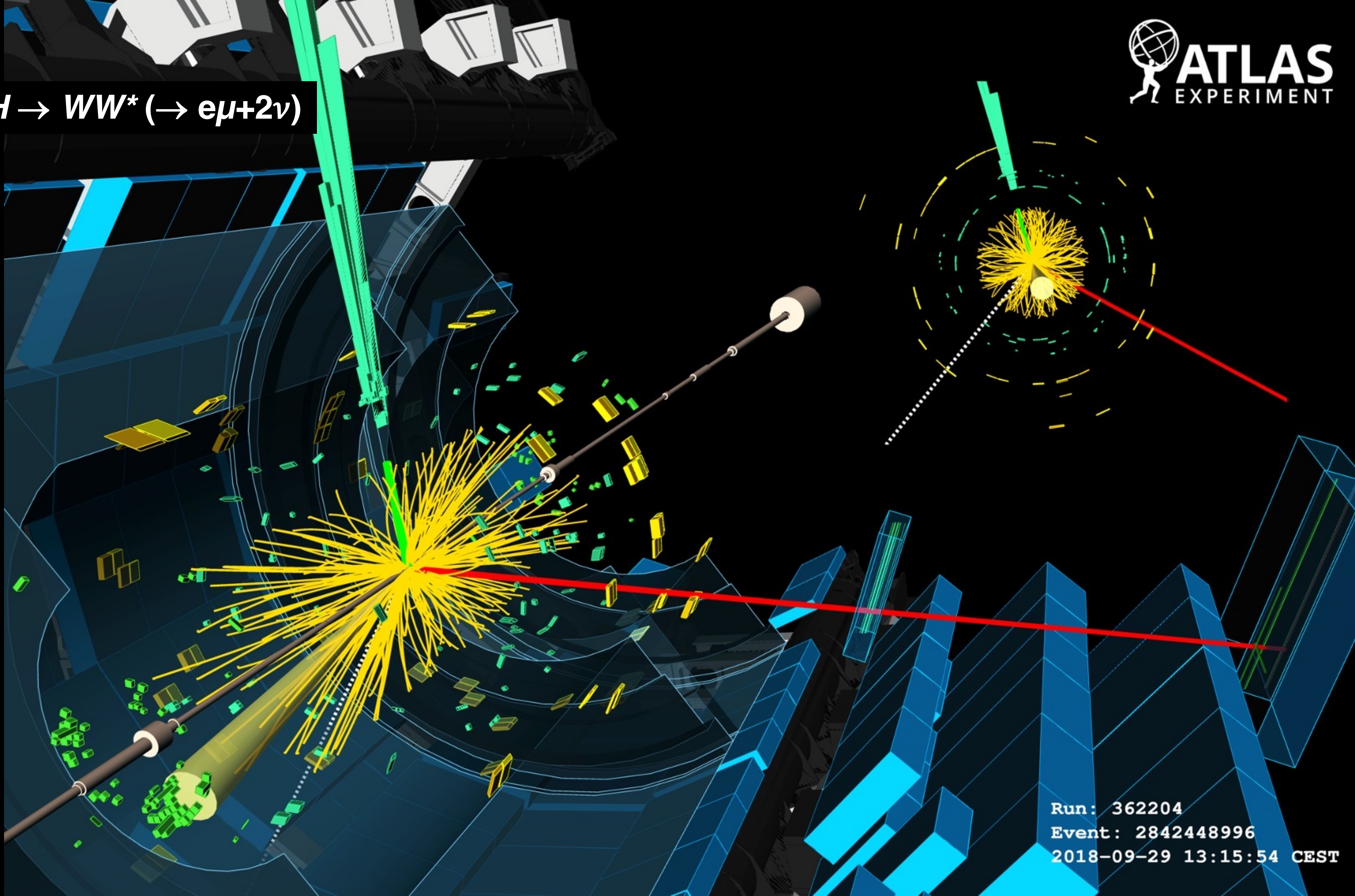
arXiv:2004.04545

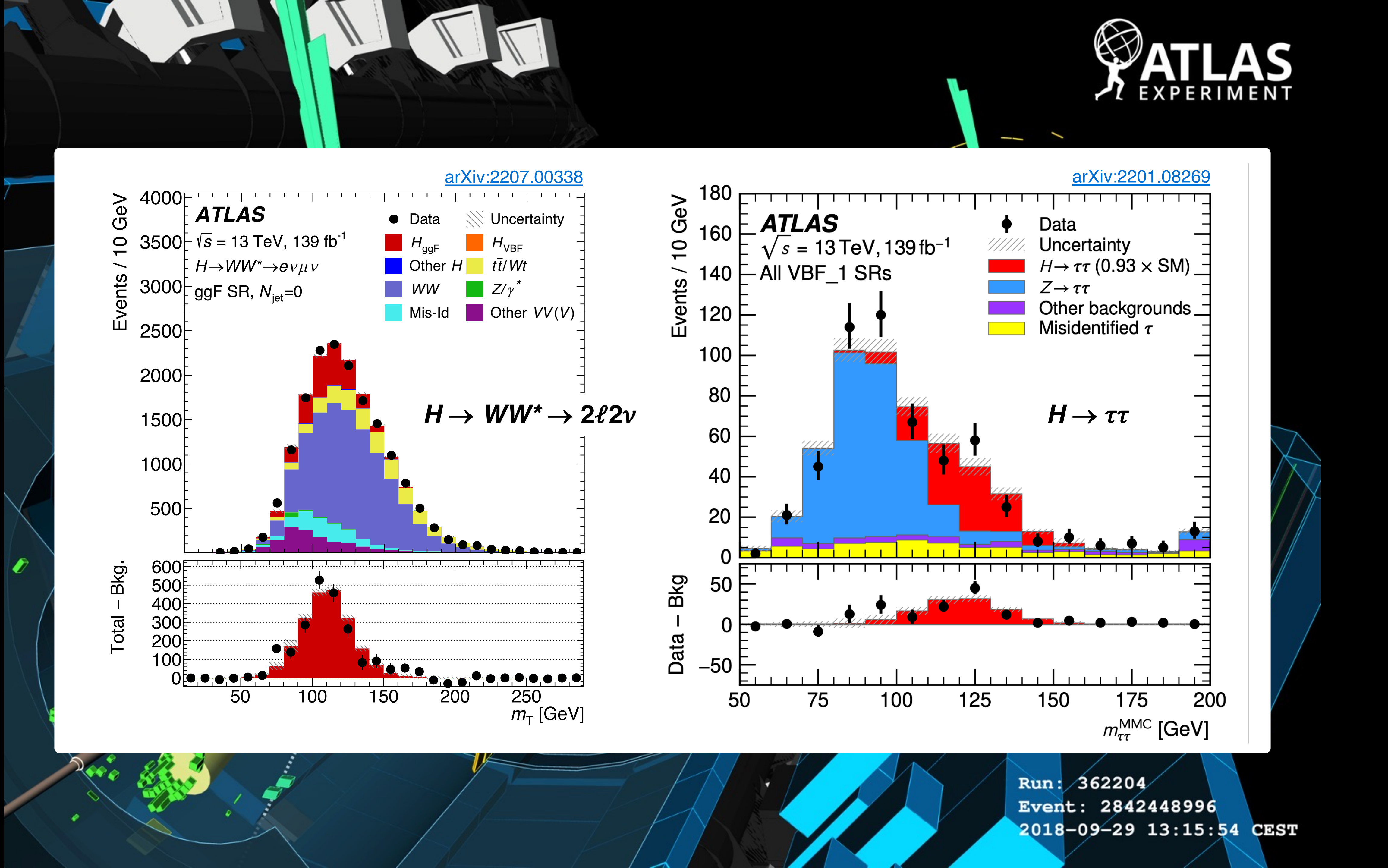






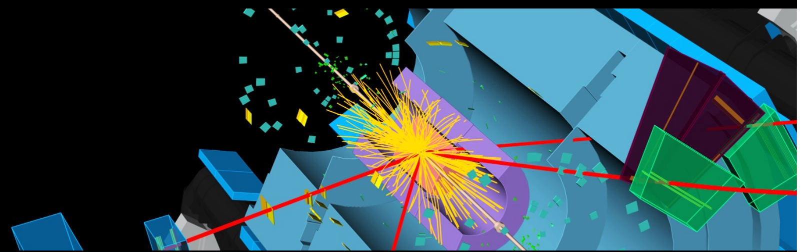
A ttH → 6 jets + $\gamma\gamma$ candidate event


$H \rightarrow WW^* (\rightarrow e\mu+2\nu)$
ATLAS
EXPERIMENT
Run: 362204
Event: 2842448996
2018-09-29 13:15:54 CEST

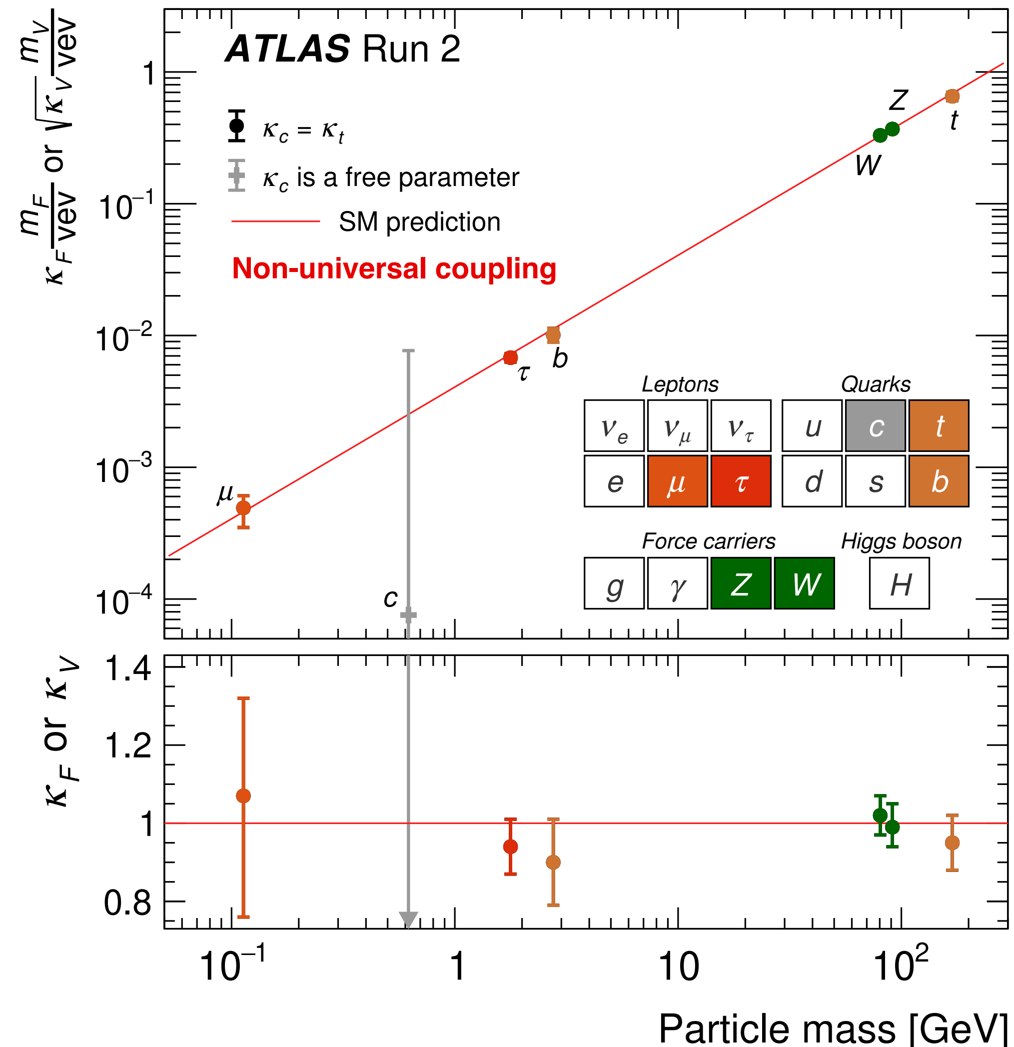


arXiv:2207.00338
ATLAS
√s = 13 TeV, 139 fb-1
H→WW*→eνμν
ggF SR, Njet=0
Data
Uncertainty
HggF
HVBF
Other H
tt̄/Wt
WW
Z/γ*
Mis-Id
Other VV(V)
Events / 10 GeV
Total – Bkg.
mT [GeV]
H → WW* → 2ℓ2ν
arXiv:2201.08269
ATLAS
√s = 13 TeV, 139 fb-1
All VBF_1 SRs
Data
Uncertainty
H→ττ (0.93 × SM)
Z→ττ
Other backgrounds
Misidentified τ
Events / 10 GeV
Data – Bkg
mττMMC [GeV]
H → ττ
Run: 362204
Event: 2842448996
2018-09-29 13:15:54 CEST

The Higgs mechanism is real !



Measurements by ATLAS and CMS have confirmed the non-universal, mass-dependent coupling strengths of the Higgs boson to the SM particles



Nature 607, 52 (2022)

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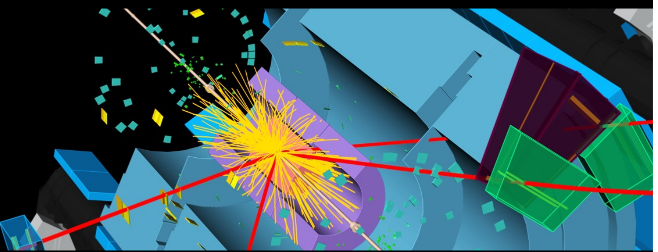

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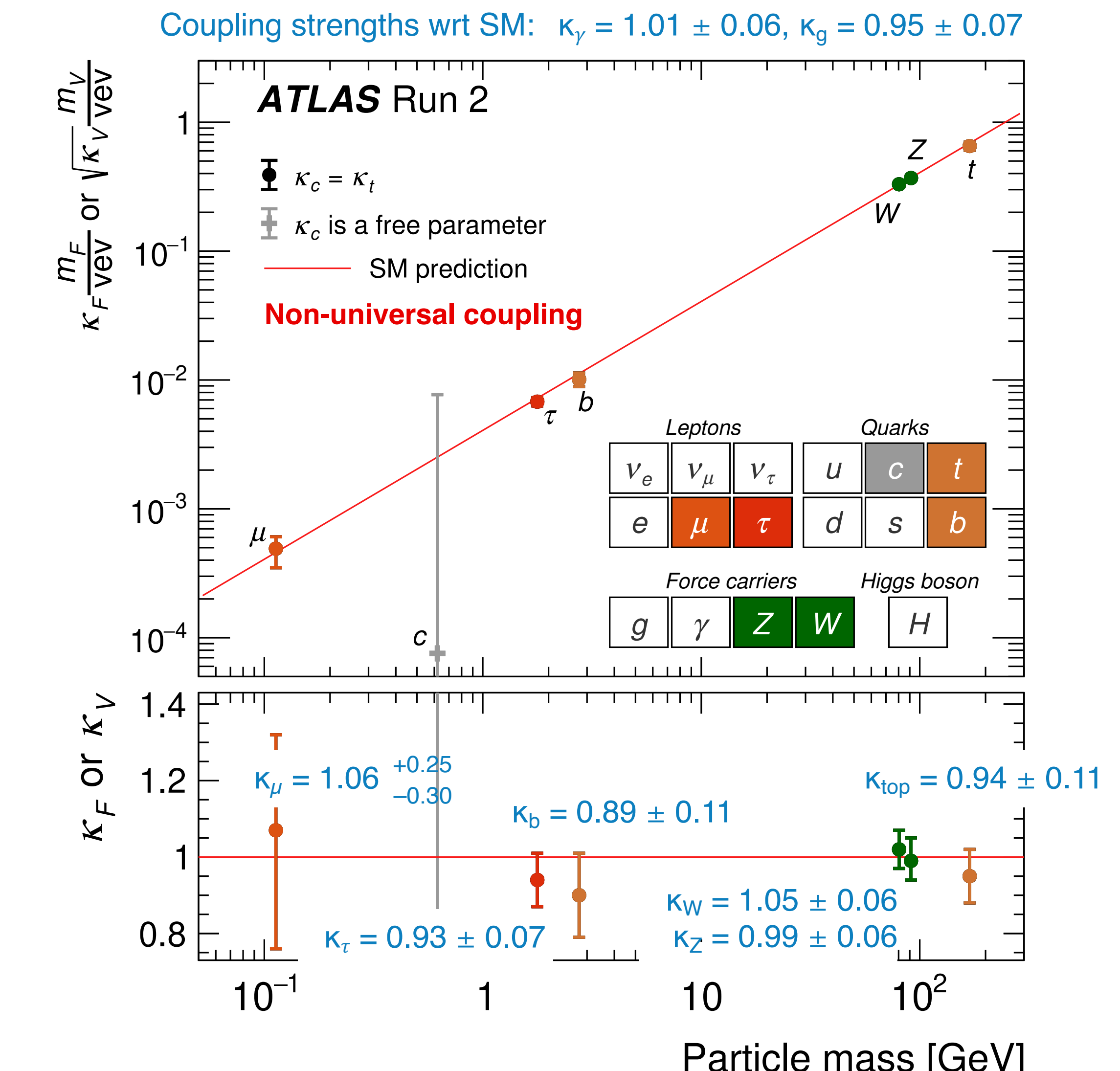

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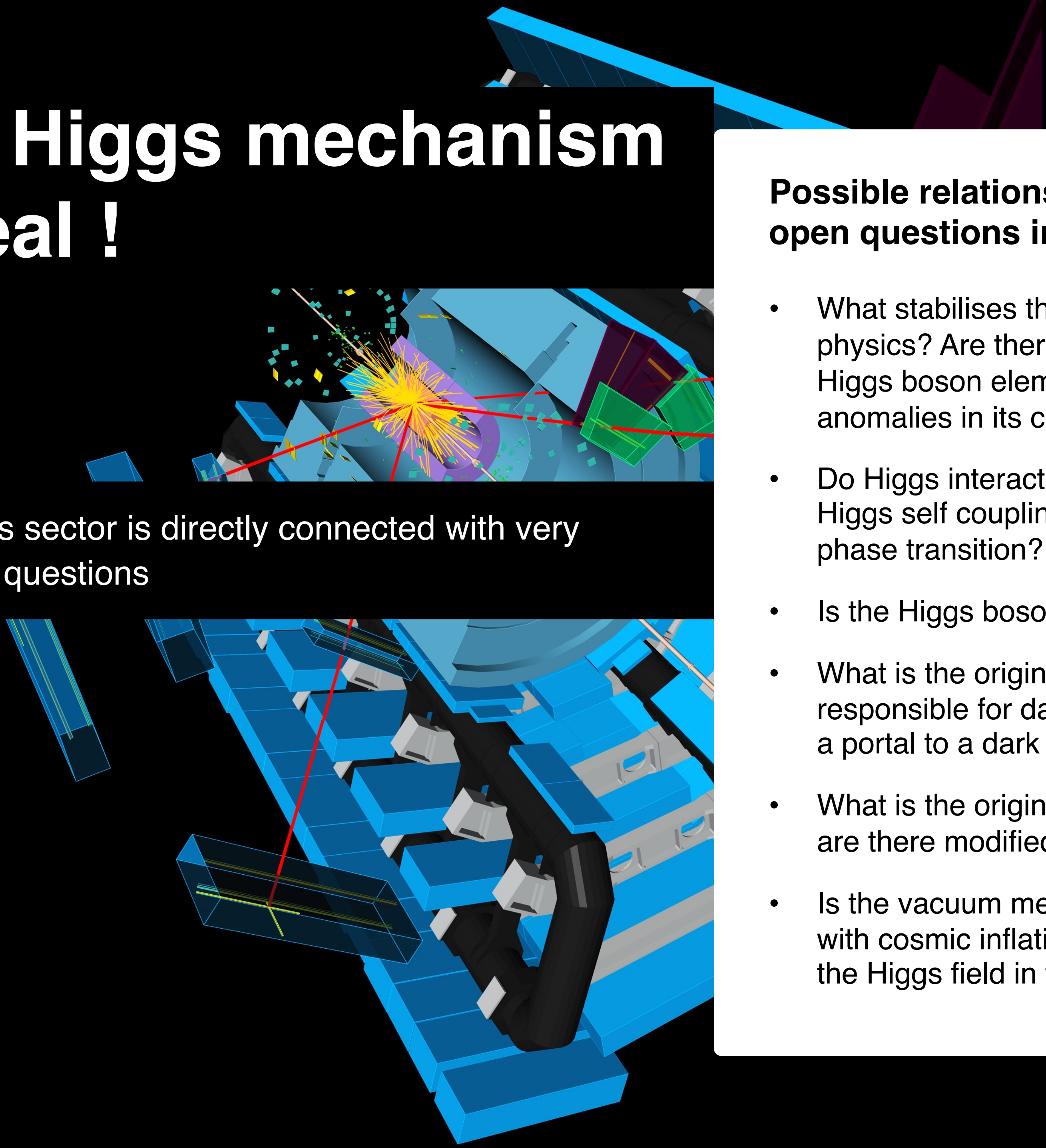


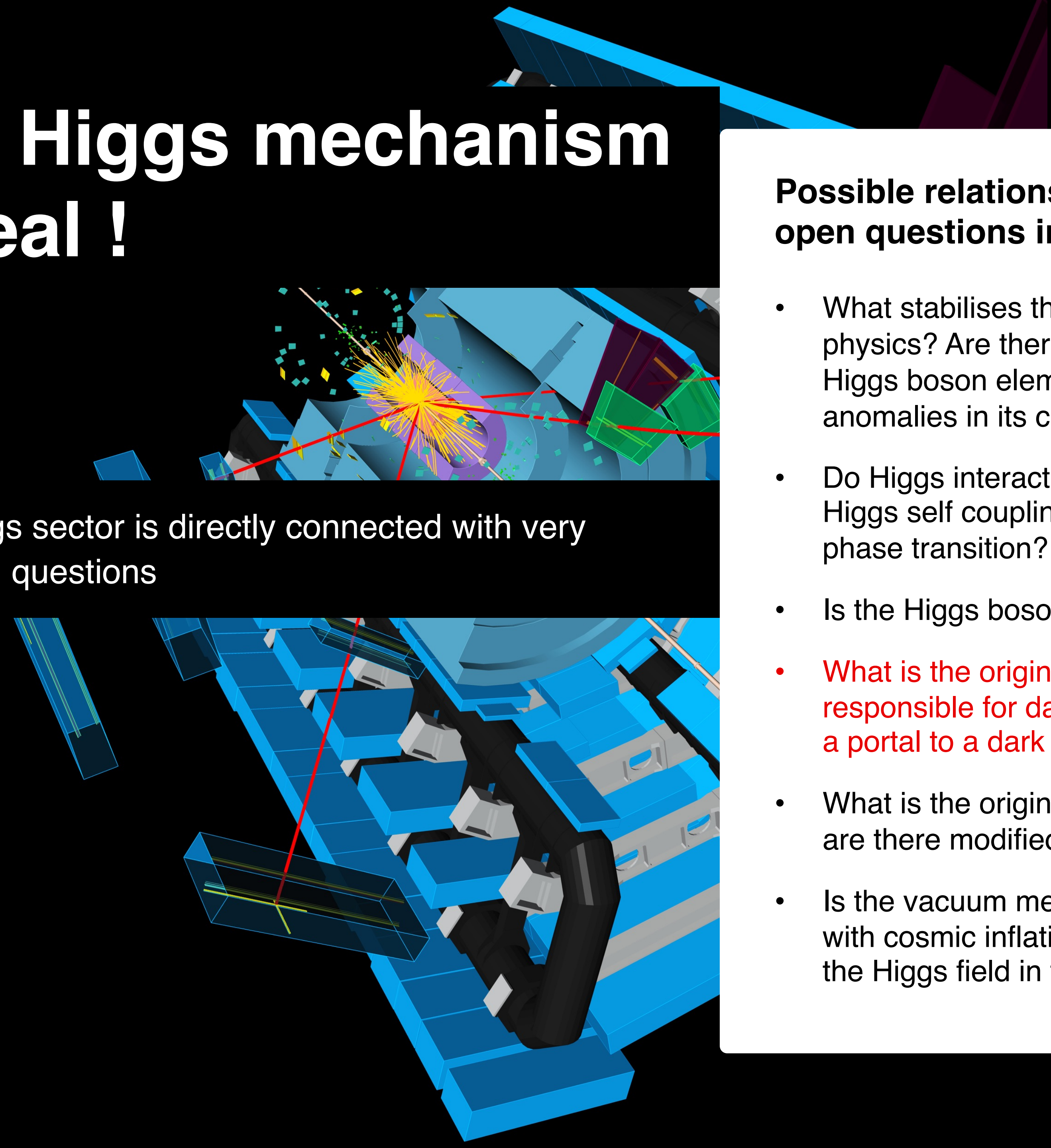
The Higgs sector is directly connected with very profound questions

Possible relations between the Higgs boson and open questions in particle physics and cosmology

- What stabilises the Higgs mass versus high-scale new physics? Are there new TeV-scale symmetries? Is the Higgs boson elementary or composite (eg, are there anomalies in its coupling to the W or Z)?
- Do Higgs interactions violate CP? Is there an anomalous Higgs self coupling to allow for a first order electroweak phase transition?
- Is the Higgs boson unique?
- What is the origin of dark matter, is the Higgs mechanism responsible for dark matter? Can the Higgs boson provide a portal to a dark sector?
- What is the origin of the vast range of Yukawa couplings, are there modified interactions, lepton-flavour violation?
- Is the vacuum metastable? Is the Higgs field connected with cosmic inflation? What counteracts the large VEV of the Higgs field in the universe?

Salam, Wang, Zanderighi: Nature 607, 41 (2022)

The Higgs mechanism is real !



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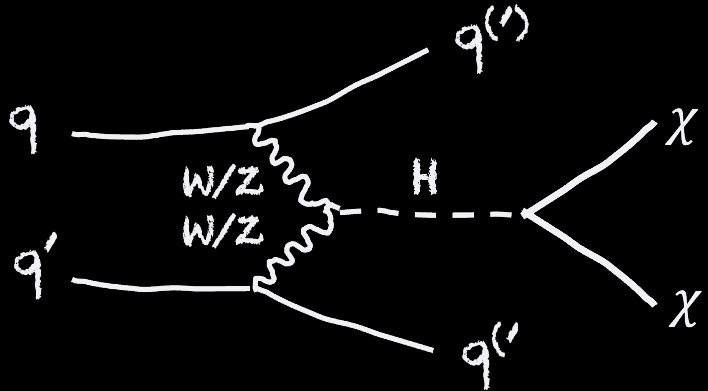
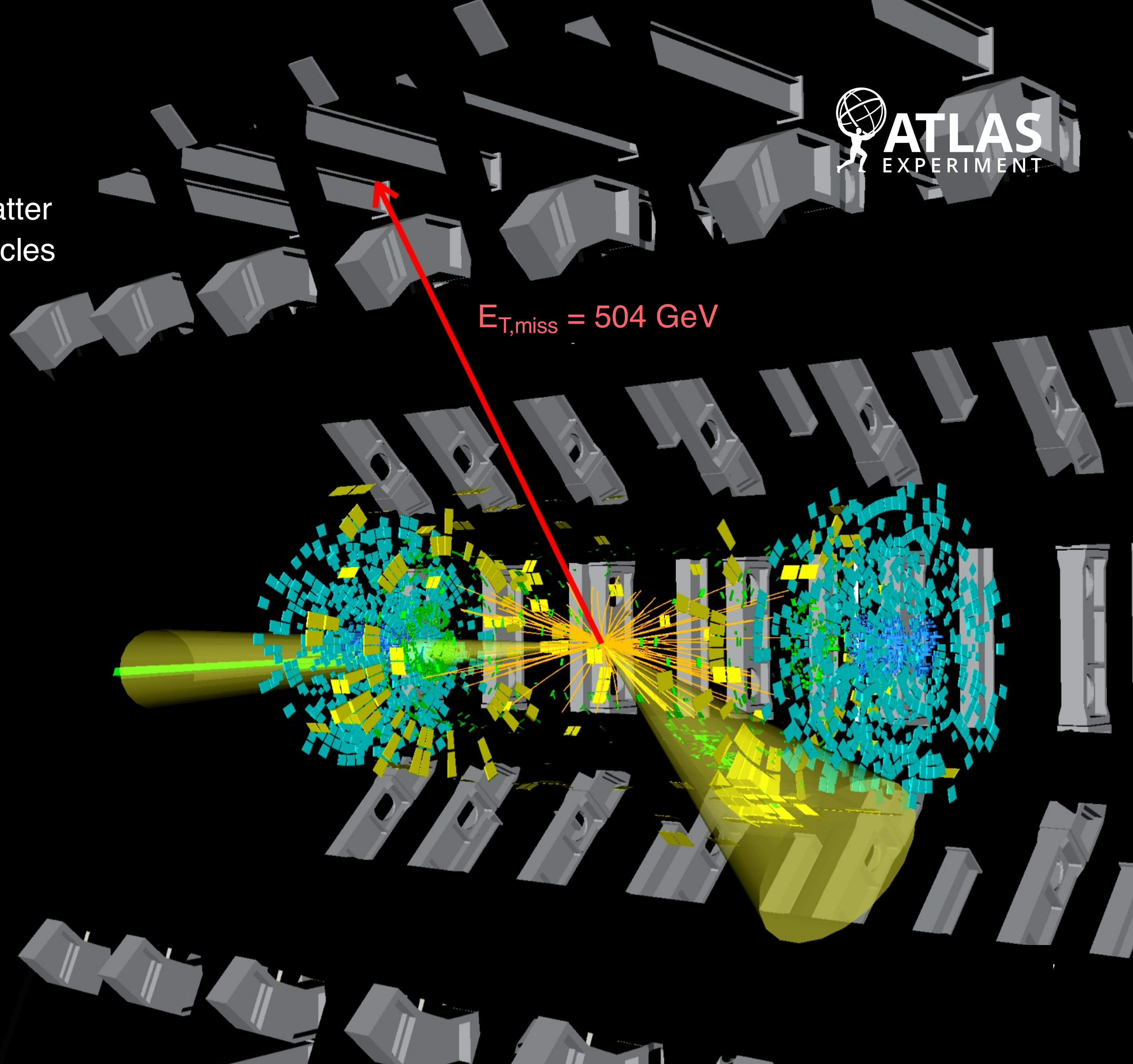
Salam, Wang, Zanderighi: Nature 607, 41 (2022)

Dark matter

The Higgs boson may couple to dark matter and "invisibly" decay to dark matter particles (if kinematically allowed)





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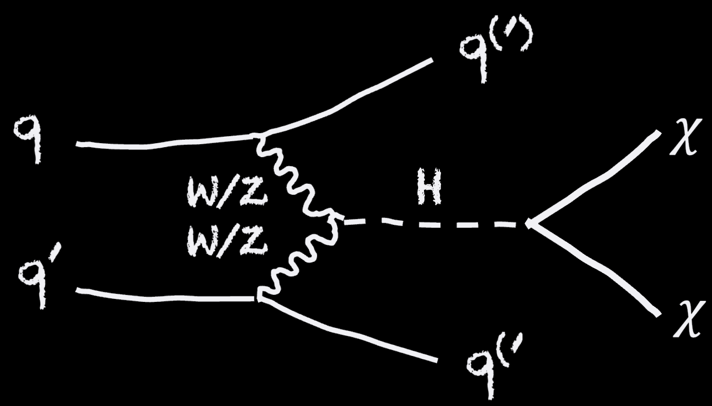
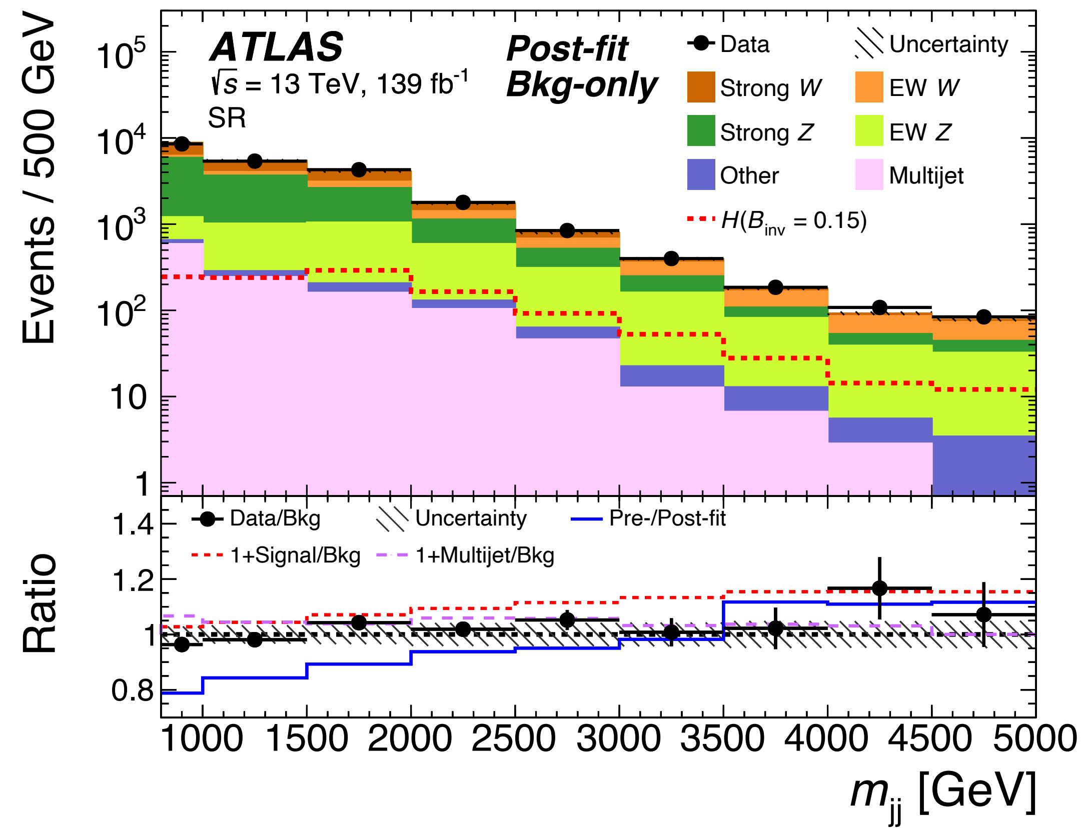


arXiv:2202.07953, arXiv:2301.10731

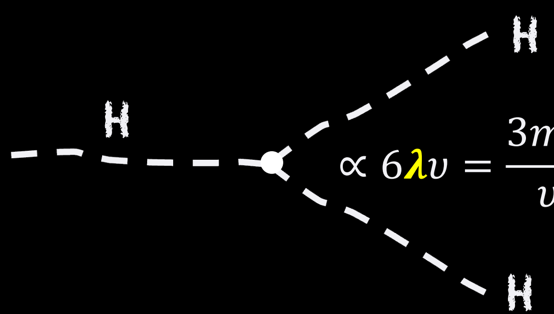


➡ BR(H → invisible) < 0.107 (0.077) at 95% CL

Higgs pair production

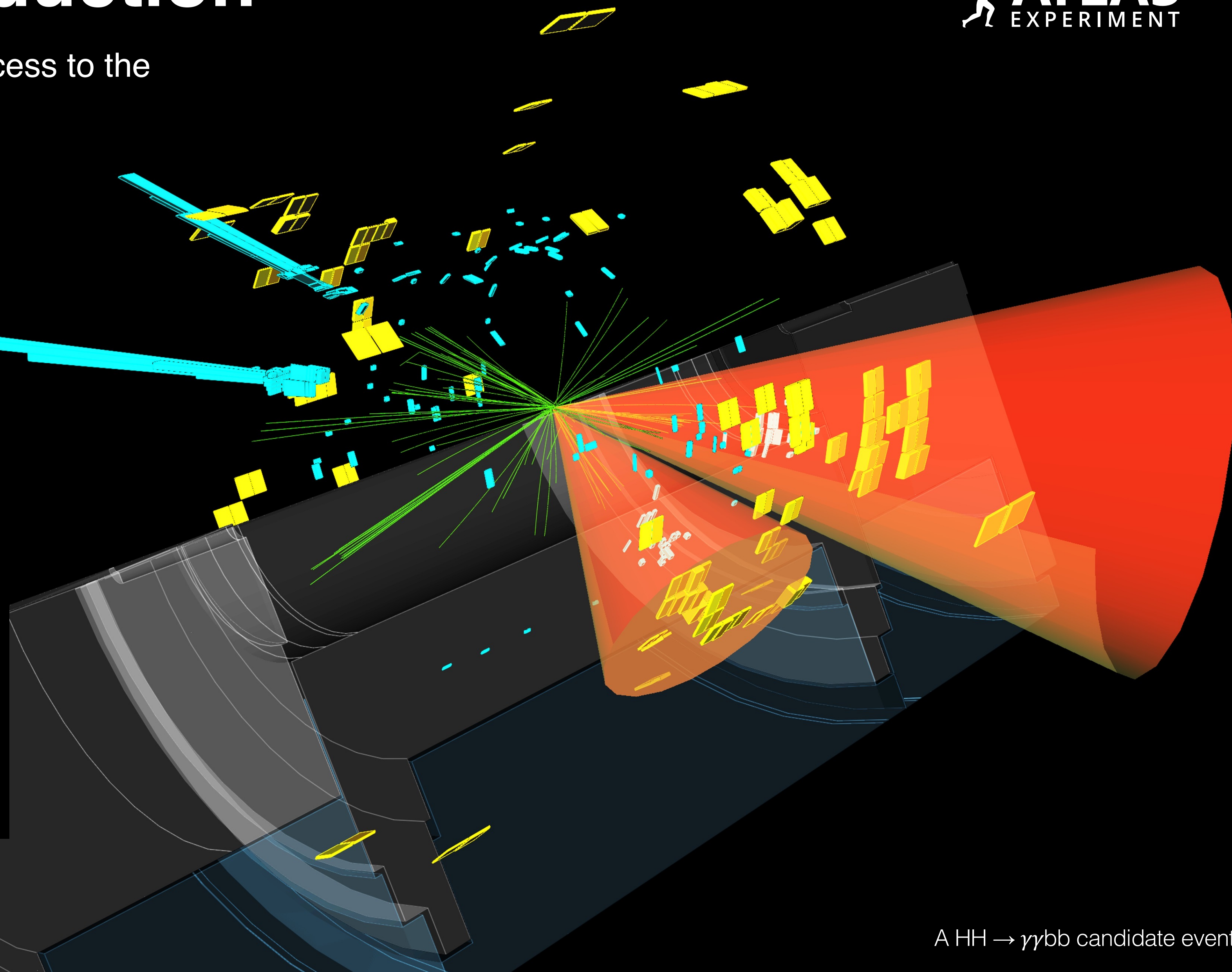
ATLAS EXPERIMENT

The holy grail of Higgs physics: access to the symmetry breaking Higgs potential



$$\propto 6\lambda v = \frac{3m_H^2}{v}$$

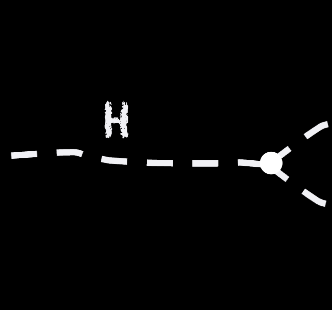
$$V(\phi) = -\mu^2|\phi|^2 + \lambda|\phi|^4$$



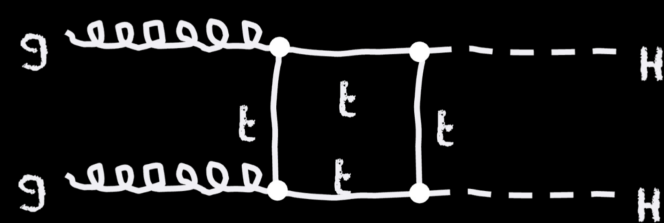
A HH → $\gamma\gamma$bb candidate event

Higgs pair production

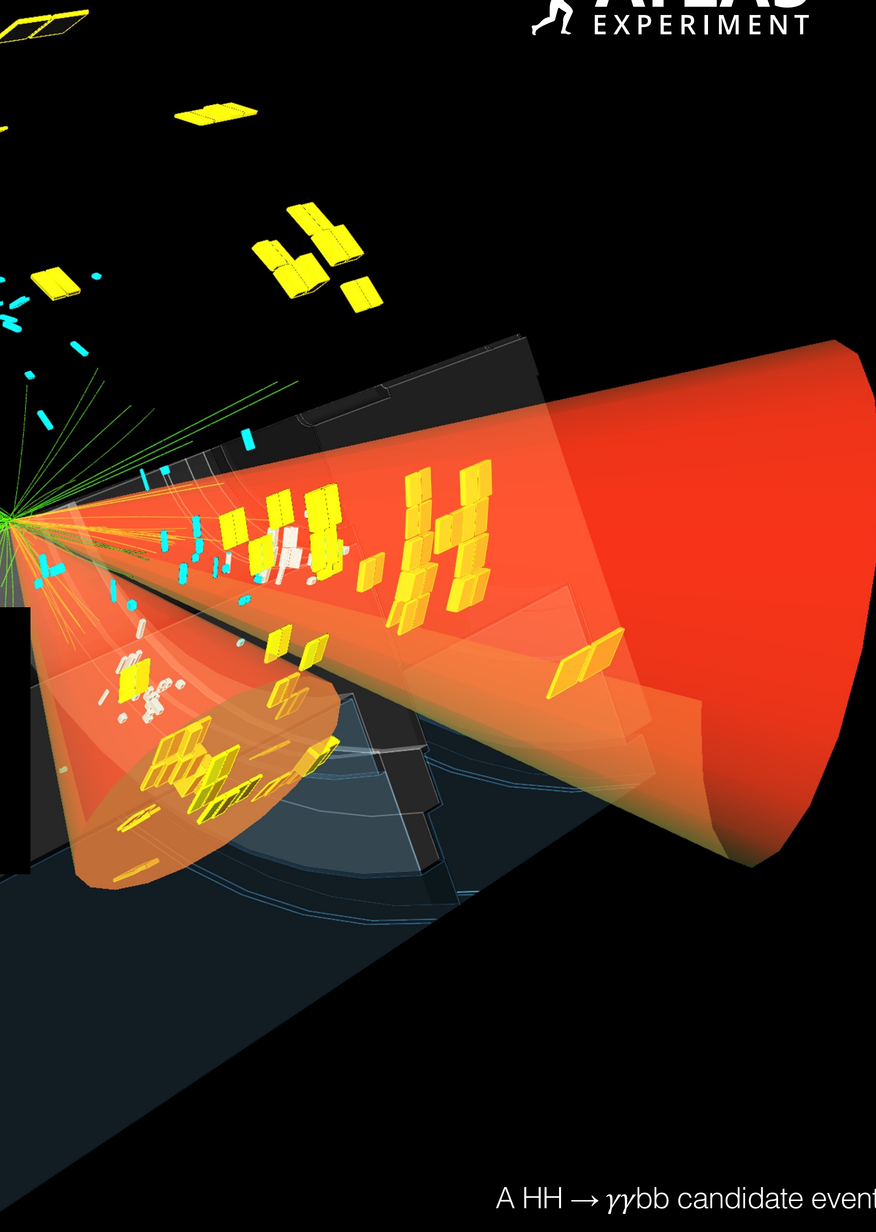
The holy grail of Higgs physics: access to the symmetry-breaking Higgs potential



$\propto 6\lambda v = \frac{3m_H^2}{v}$



$$V(\phi) = -\mu^2|\phi|^2 + \lambda|\phi|^4$$



A HH → $\gamma\gamma$bb candidate event

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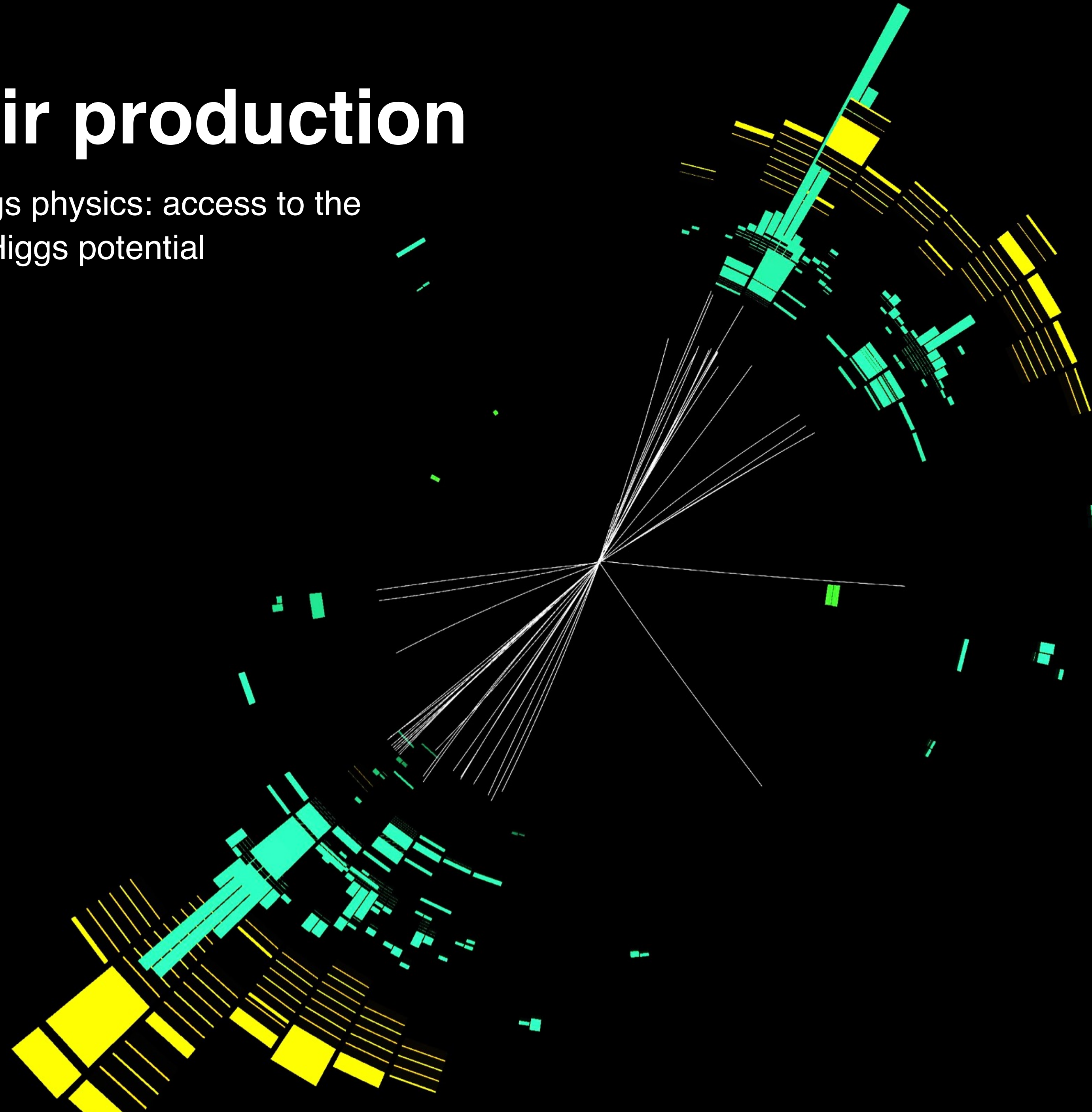
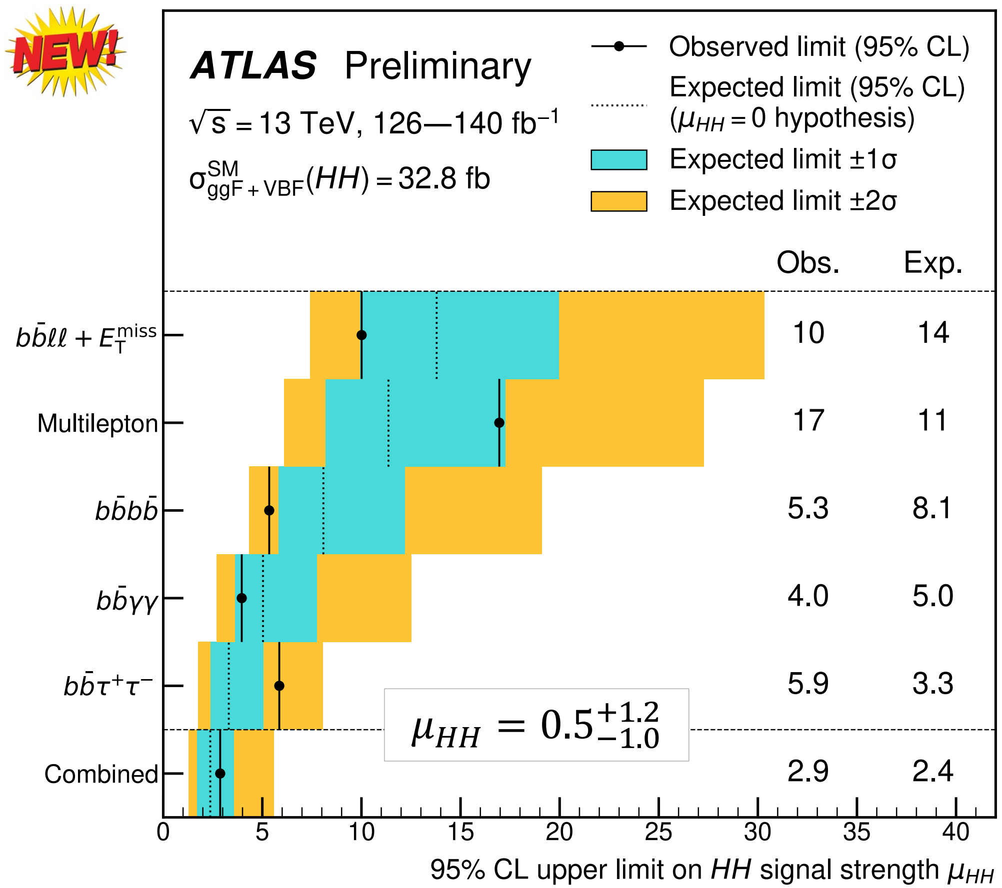


A HH → bbbb candidate event

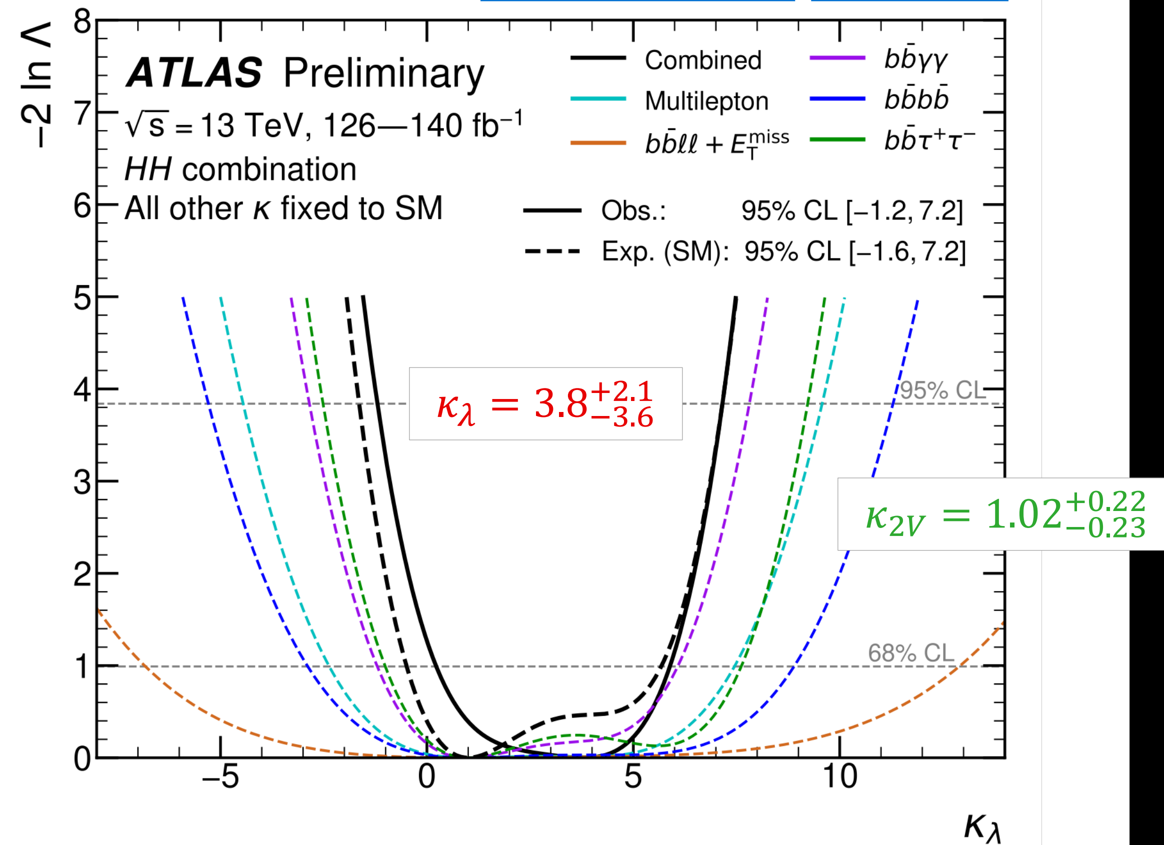
Higgs pair production

New combination of updated HH searches using full Run-2 dataset

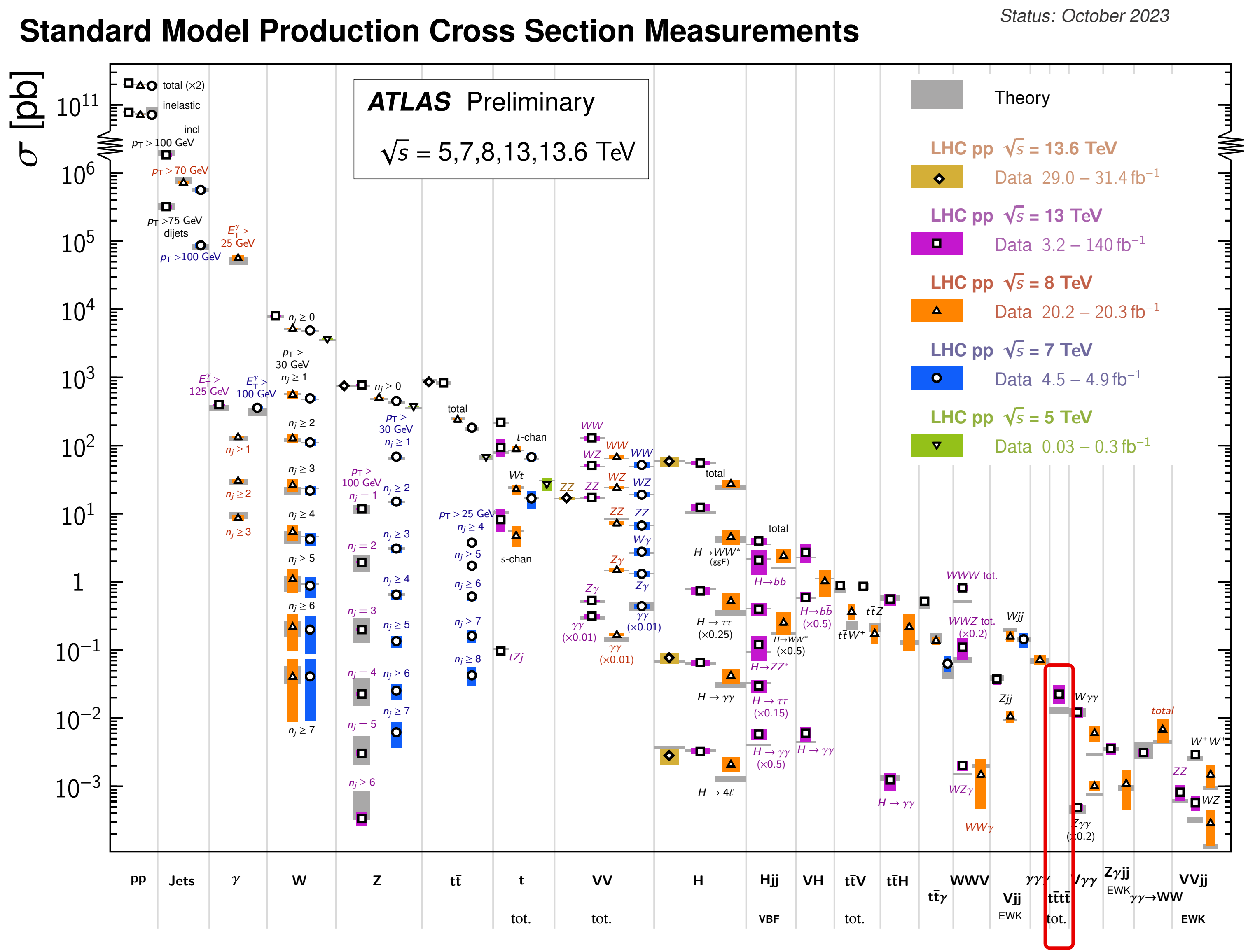


Constraint on $\kappa_\lambda = \lambda/\lambda_{SM}$ benefits also from single-Higgs coupling measurements via quantum loop corrections

ATLAS-CONF-2024-006, CERN Seminar



Of course, ATLAS physics is much more than Higgs

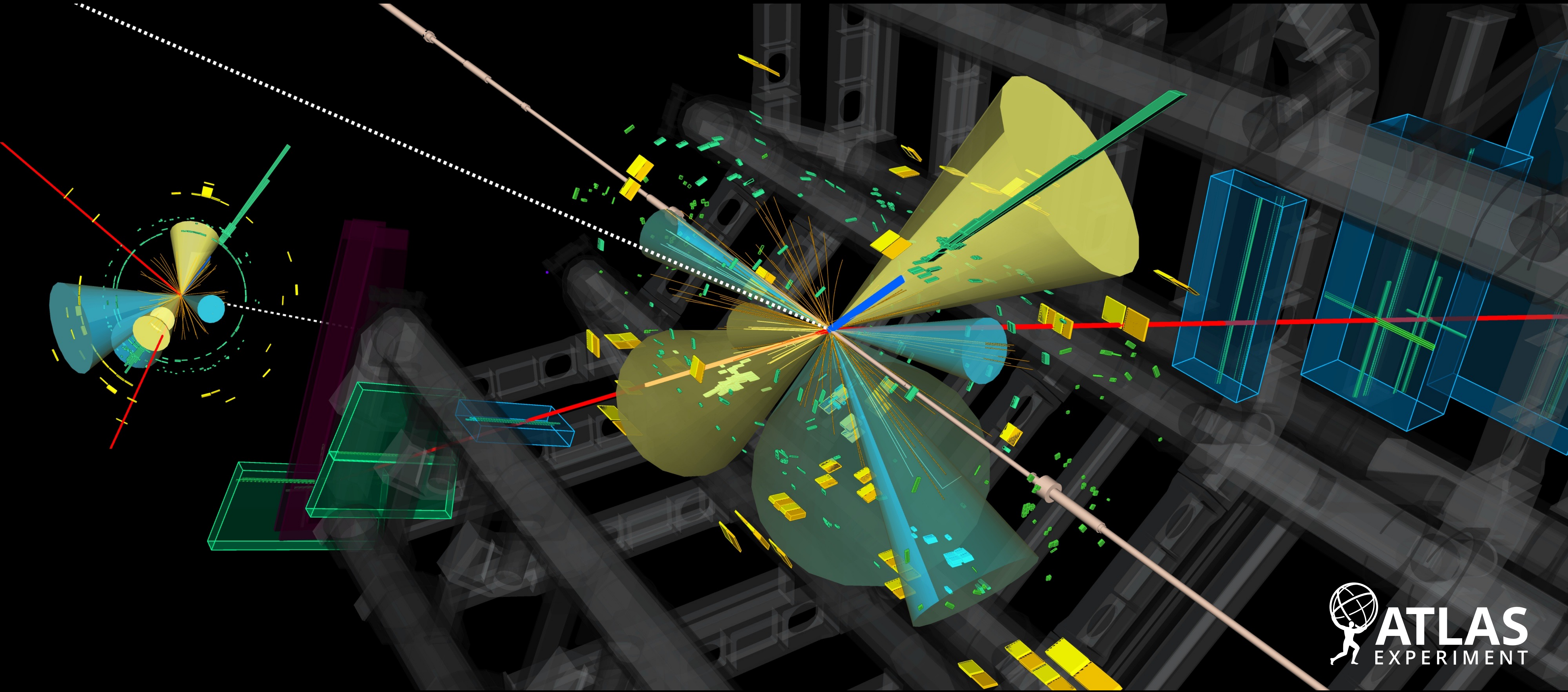


A harvest of unique measurements probing new forms of particle interactions and very rare processes, and (so far) confirming the predictive power of the Standard Model

Theory developments and computations are key to this progress

Observation of 4-top production

[arXiv:2303.15061, Physics briefing]



pp → tttt candidate event (very rare events, 70,000 rarer than tt, 4000 rarer than Higgs production, with spectacular signature: 4 b-jets, many leptons and jets), **observed with 6.1σ significance**

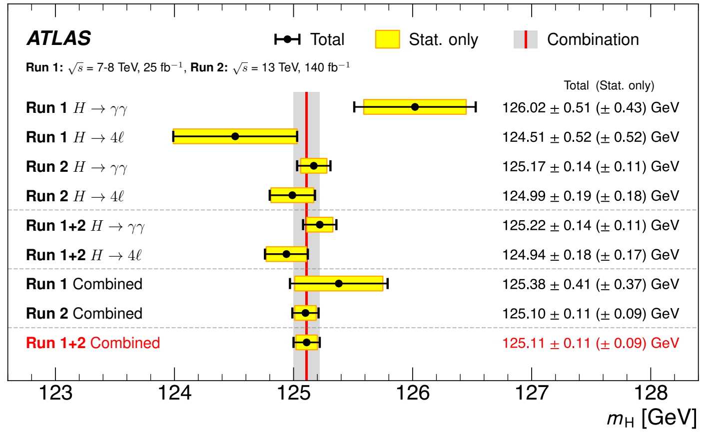
Recent high-precision results

Most precise luminosity measurement ever achieved at a hadron collider

Run 2: 140.1 ± 1.2 fb^{-1} (0.83%)

arXiv:2212.09379, Physics briefing

Most precise Higgs mass to date



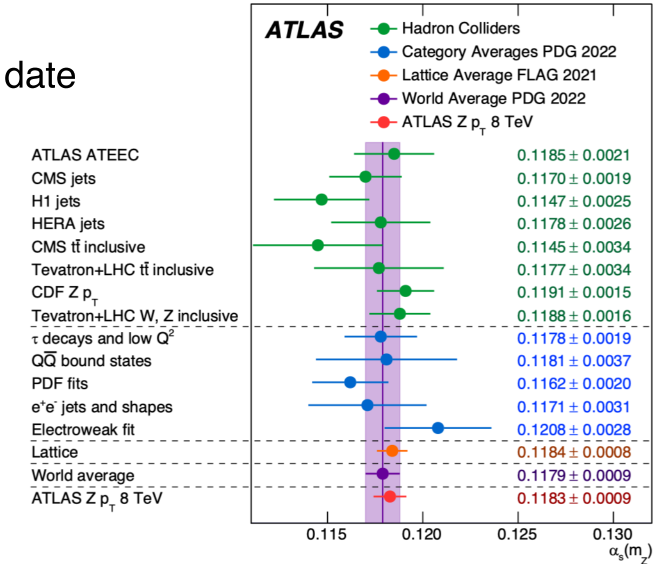
arXiv:2308.07216, arXiv:2308.04775, arXiv:2309.05471, CERN press update, Physics briefing

$\sigma(m_H)$ = 110 MeV (0.09%)

Most precise α_S measurement to date

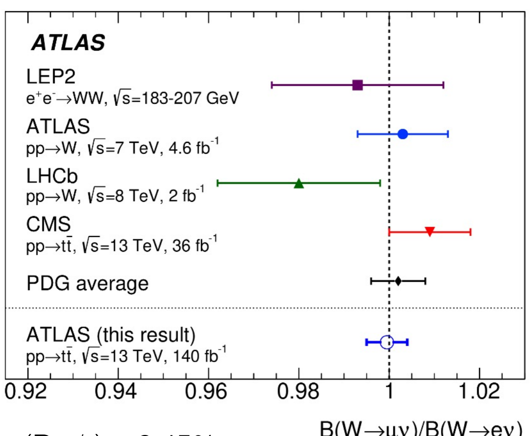
arXiv:2309.12986, CERN press update, Briefing

$\sigma(\alpha_s(mZ))$ = 0.0009



Precise test of lepton universality in W decays

arXiv:2403.02133, CERN news article

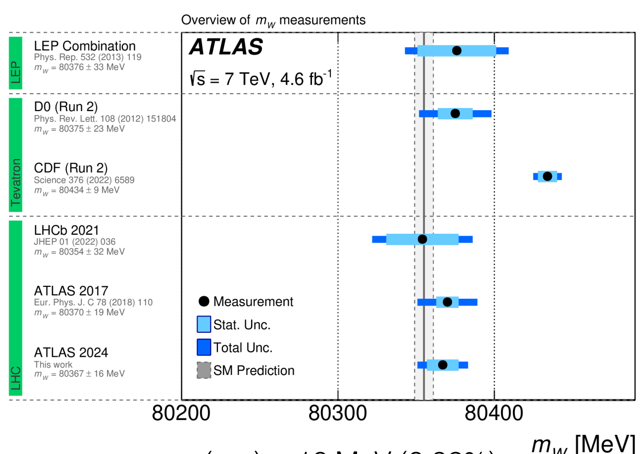


$\sigma(R_W^{\mu/e})$ = 0.45%

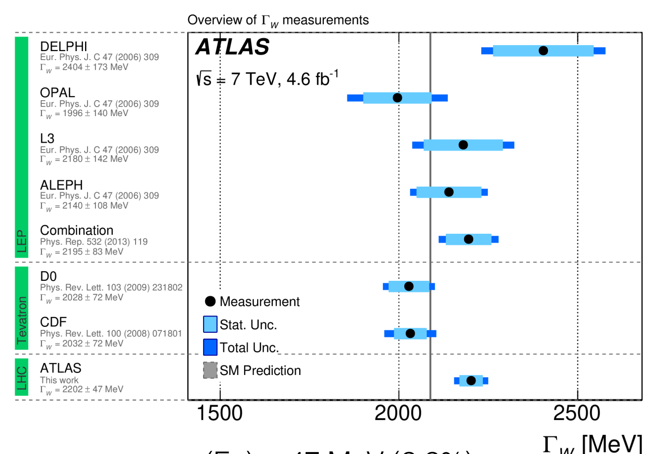
Precise measurements of W p_T, mass & width, as well as top mass (Run-1 combination with CMS)

arXiv:2403.15085, CERN news article, ATLAS briefing

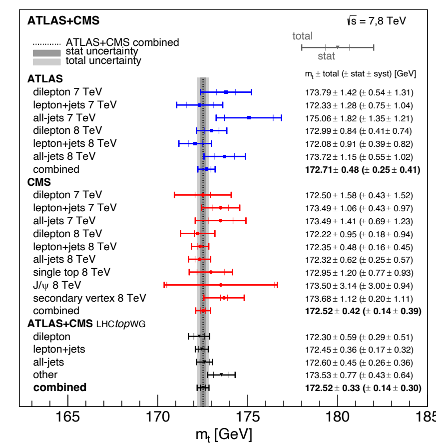
arXiv:2402.08713, Physics briefing



$\sigma(m_W)$ = 16 MeV (0.02%)



$\sigma(\Gamma_W)$ = 47 MeV (2.2%)



$\sigma(m_t)$ = 330 MeV (0.2%)

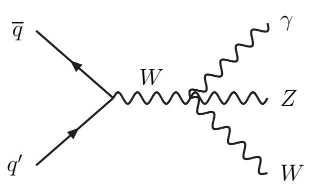
Recent SM results

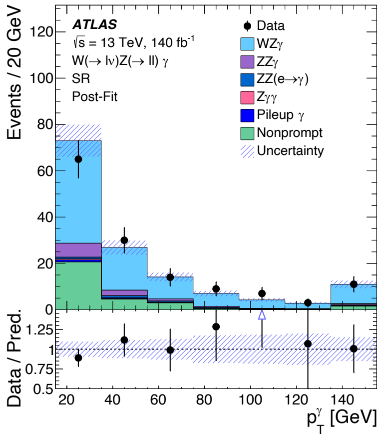
ATLAS EXPERIMENT

Several first multi-boson observations and measurements probing EW symmetry breaking

arXiv:2305.16994

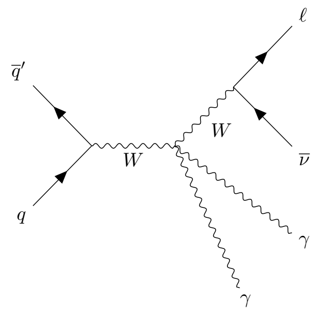
WZγ observation at 6.3σ (5.0σ exp)

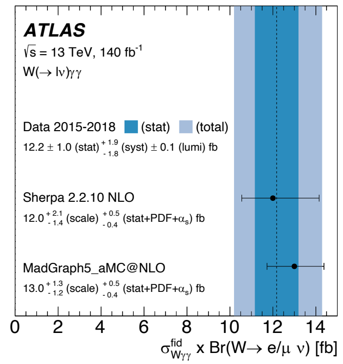




arXiv:2308.03041

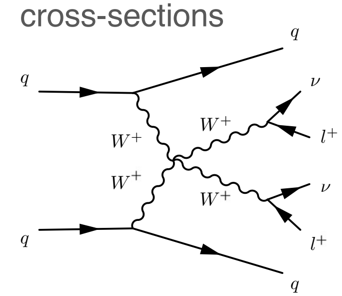
W$\gamma\gamma$ observation 5.6σ (5.6σ exp)

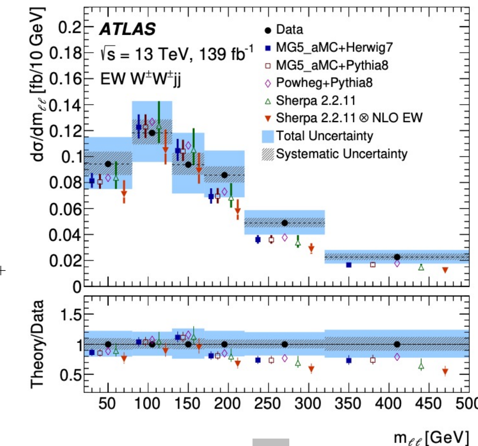




arXiv:2312.00420

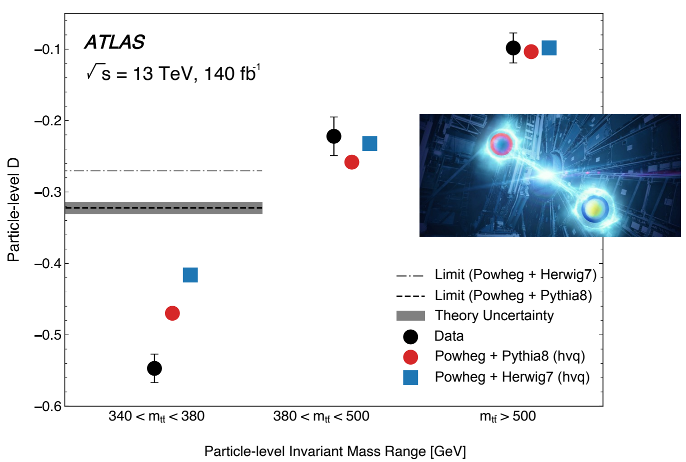
VBS W±W±qq differential cross-sections





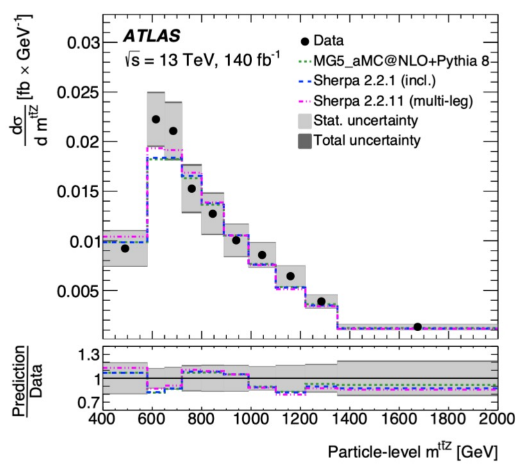
Observation of quantum entanglement in top–antitop production

arXiv:2311.07288, CERN Courier, Physics briefing

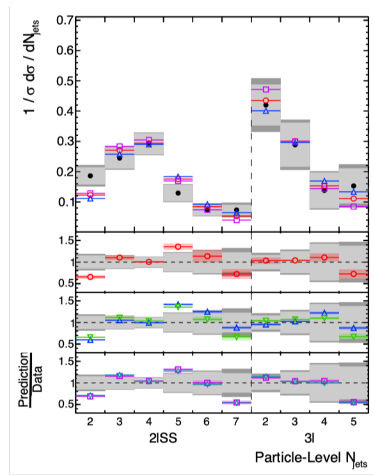


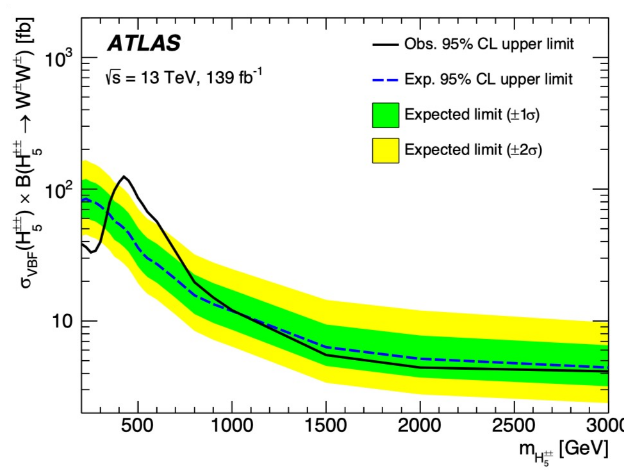
Measurements of rare tt+Z/W production

arXiv:2312.04450



arXiv:2401.05299



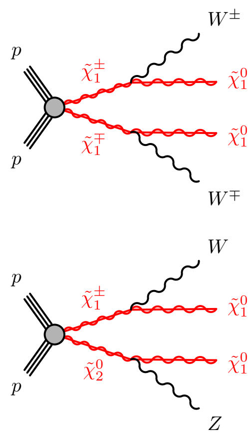


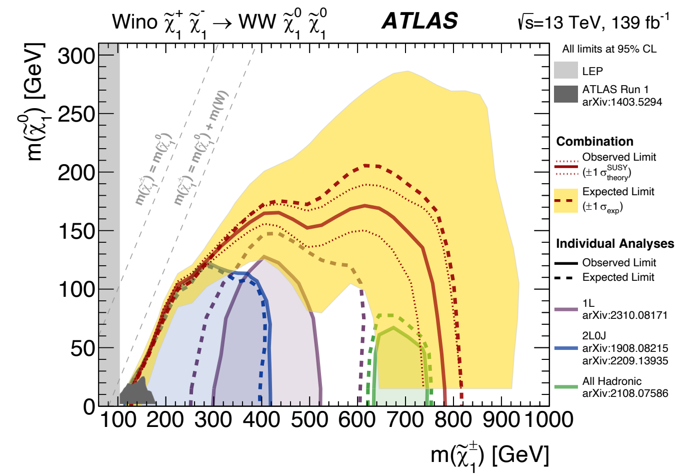
Searches for new phenomena

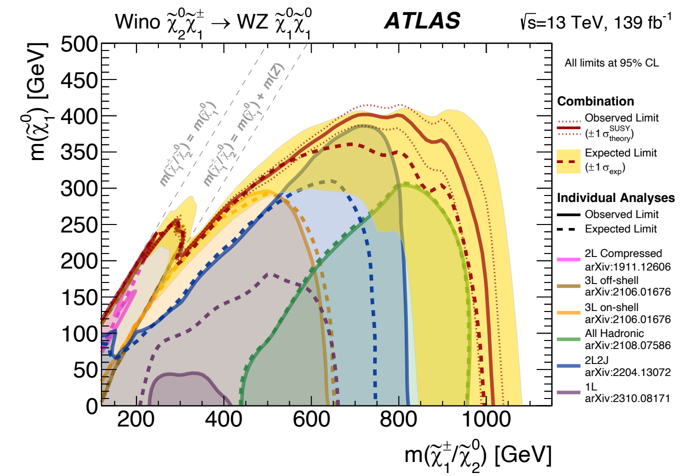
Combination of searches for electroweak supersymmetry production

arXiv:2402.08347

Comprehensive searches for electroweak SUSY, including detailed pMSSM study exploring 12k full models — substantial gain in sensitivity



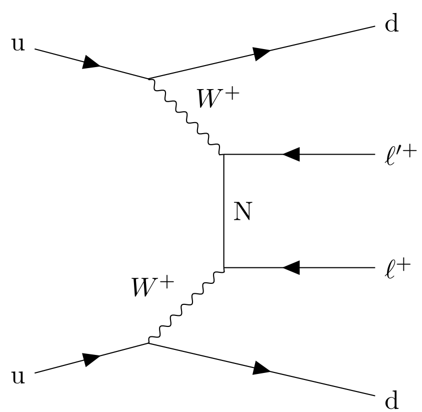


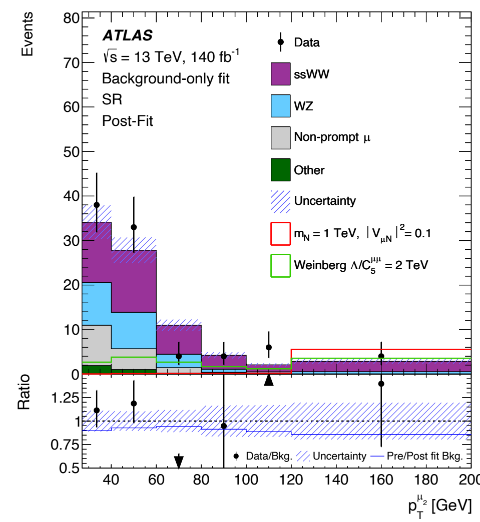


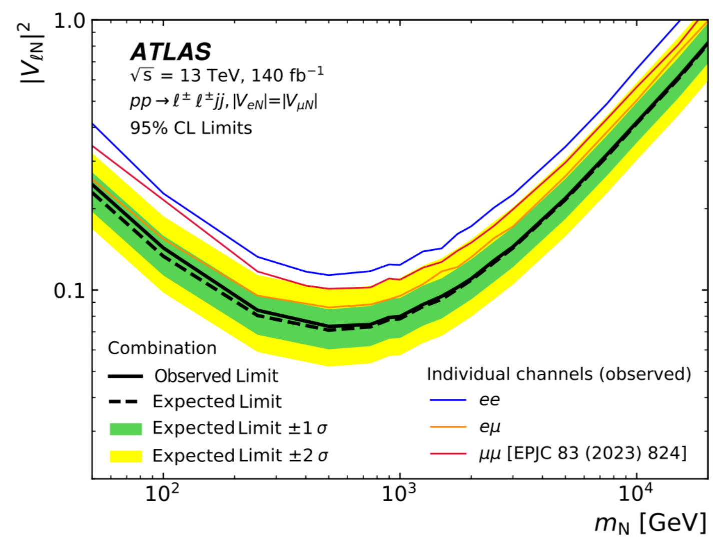
arXiv:2305.14931, arXiv:2403.15016

Search for heavy Majorana neutrinos

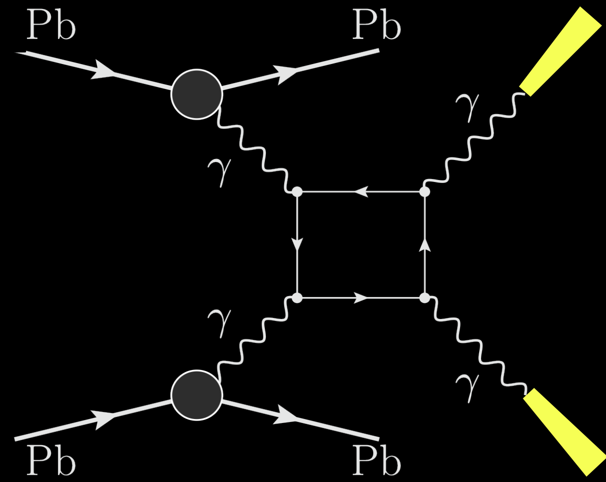
Similar signature as weak-boson scattering, but no missing energy

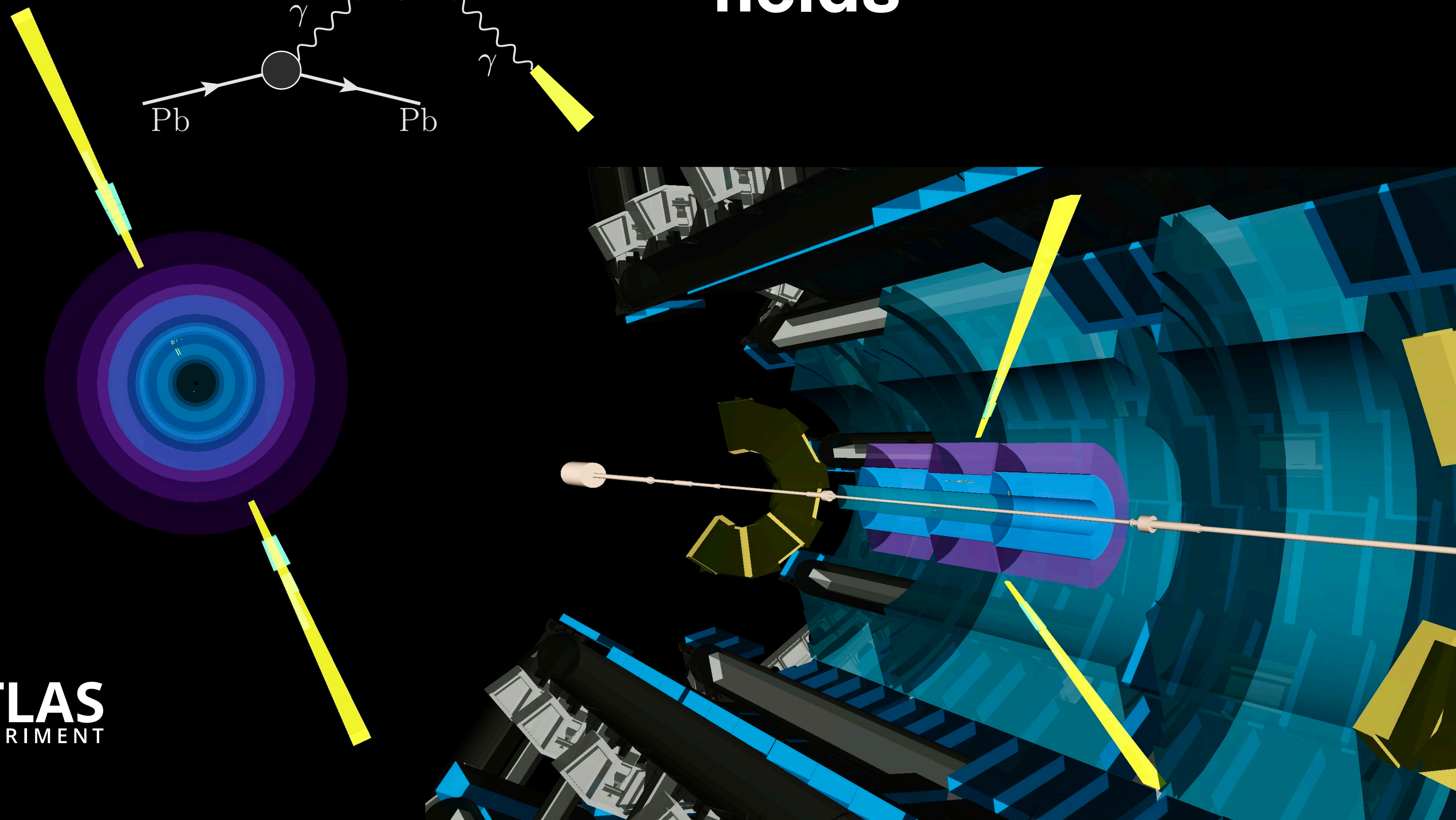






Studies of physics in extreme electromagnetic fields

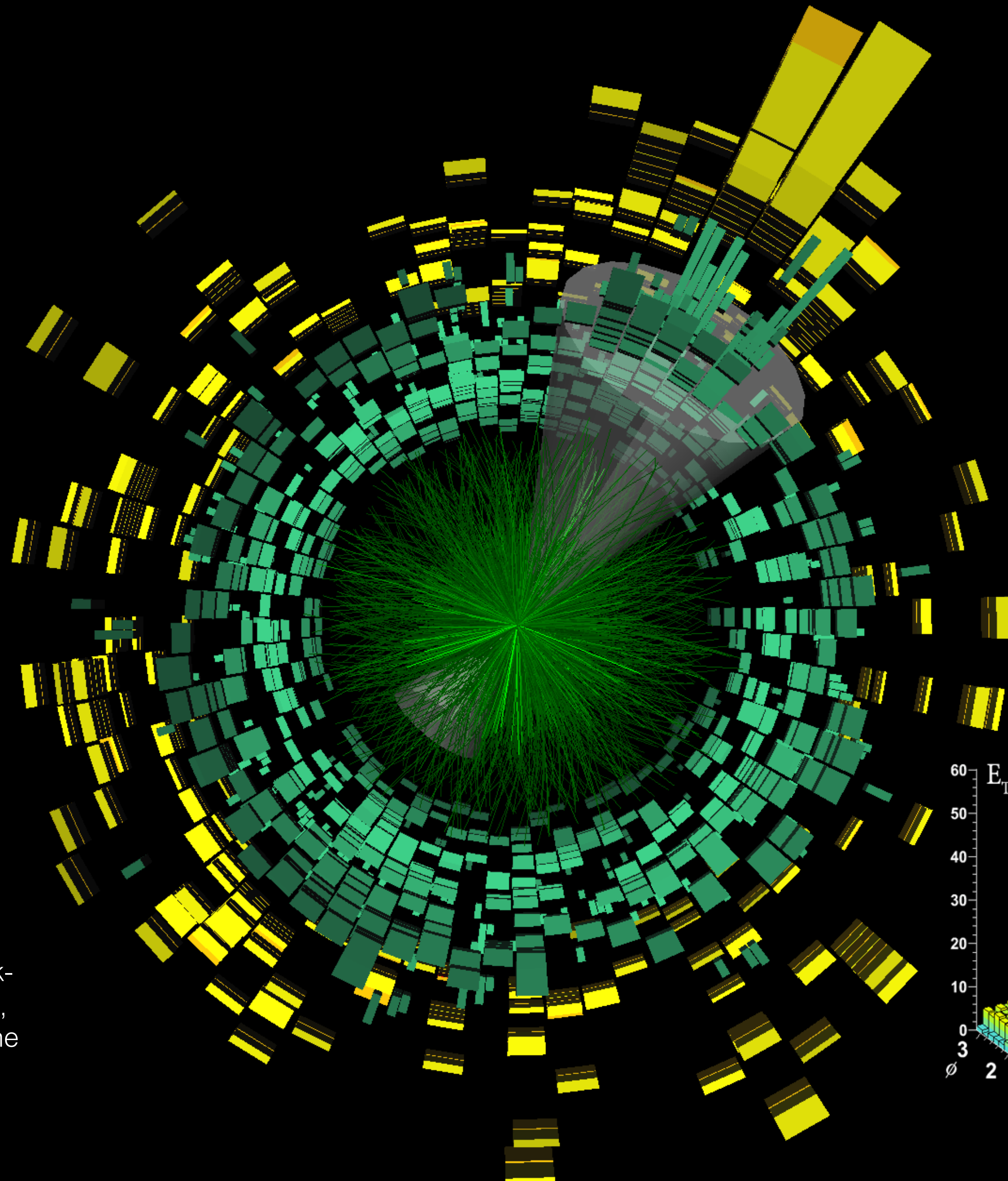


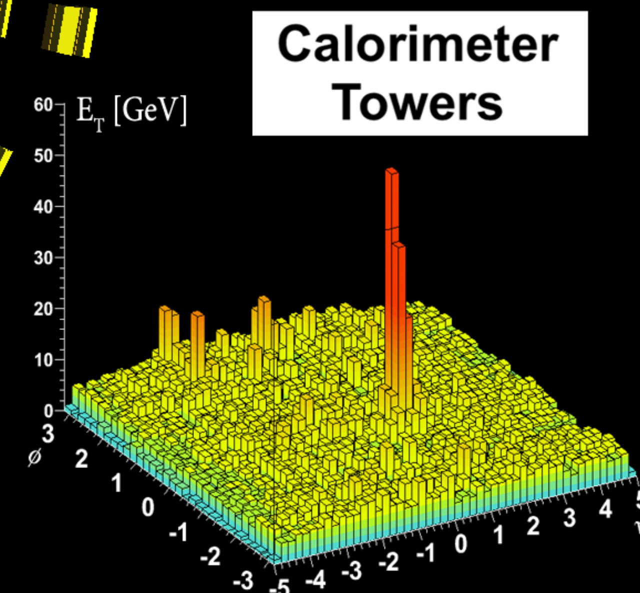


ATLAS EXPERIMENT

And a detailed mapping of the properties of the quark-gluon plasma with soft and hard probes

ATLAS EXPERIMENT





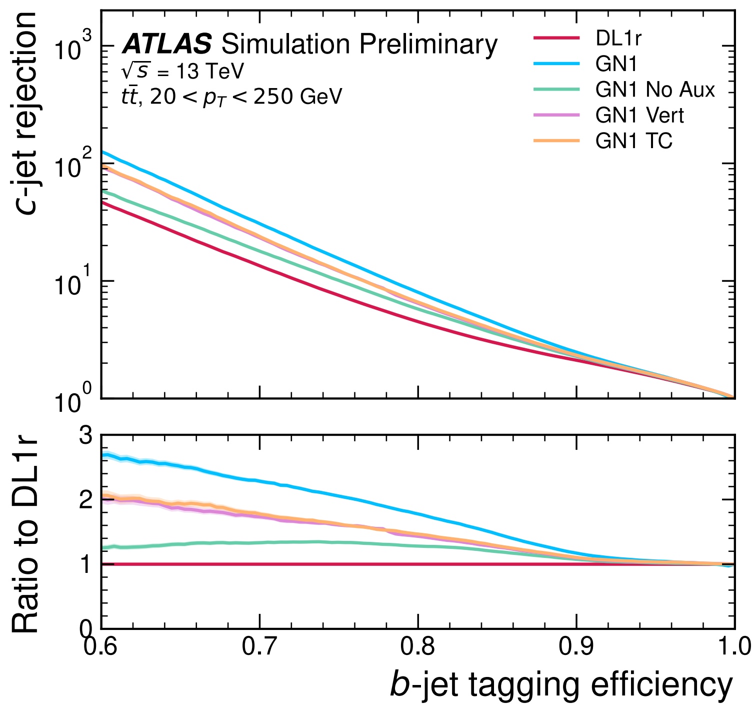
In collisions of heavy ions, the LHC creates for a very brief moment a quark-gluon plasma of up to 6 trillion degrees, almost half a million times hotter than the core of the sun

AI/ML offers opportunities for large improvements

Machine learning in likelihood fits, calibration, and classification – the Graph NN revolution

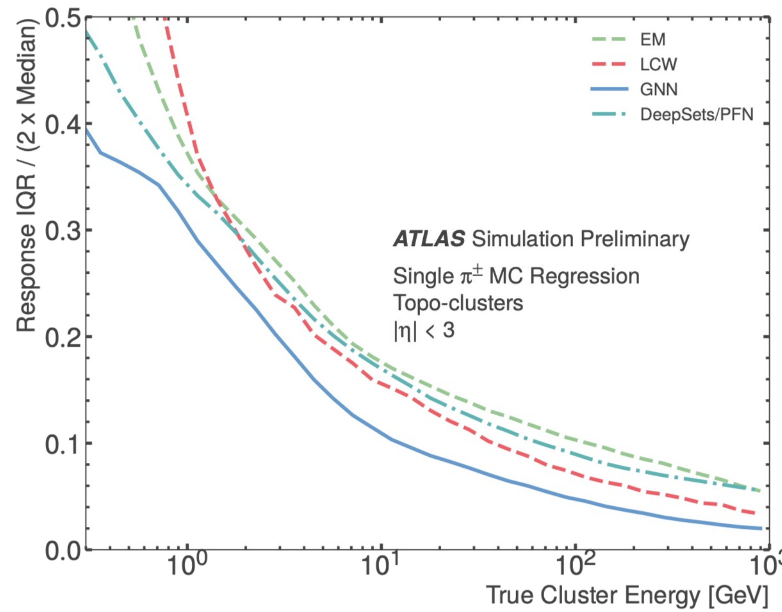
ATL-PHYS-PUB-2022-027 (2022)

The Graph NN (GNN) family in flavour tagging and tau reconstruction with astounding results



ATL-PHYS-PUB-2022-040 (2022)

Improved pion energy reconstruction (scale & resolution) using ML regression techniques



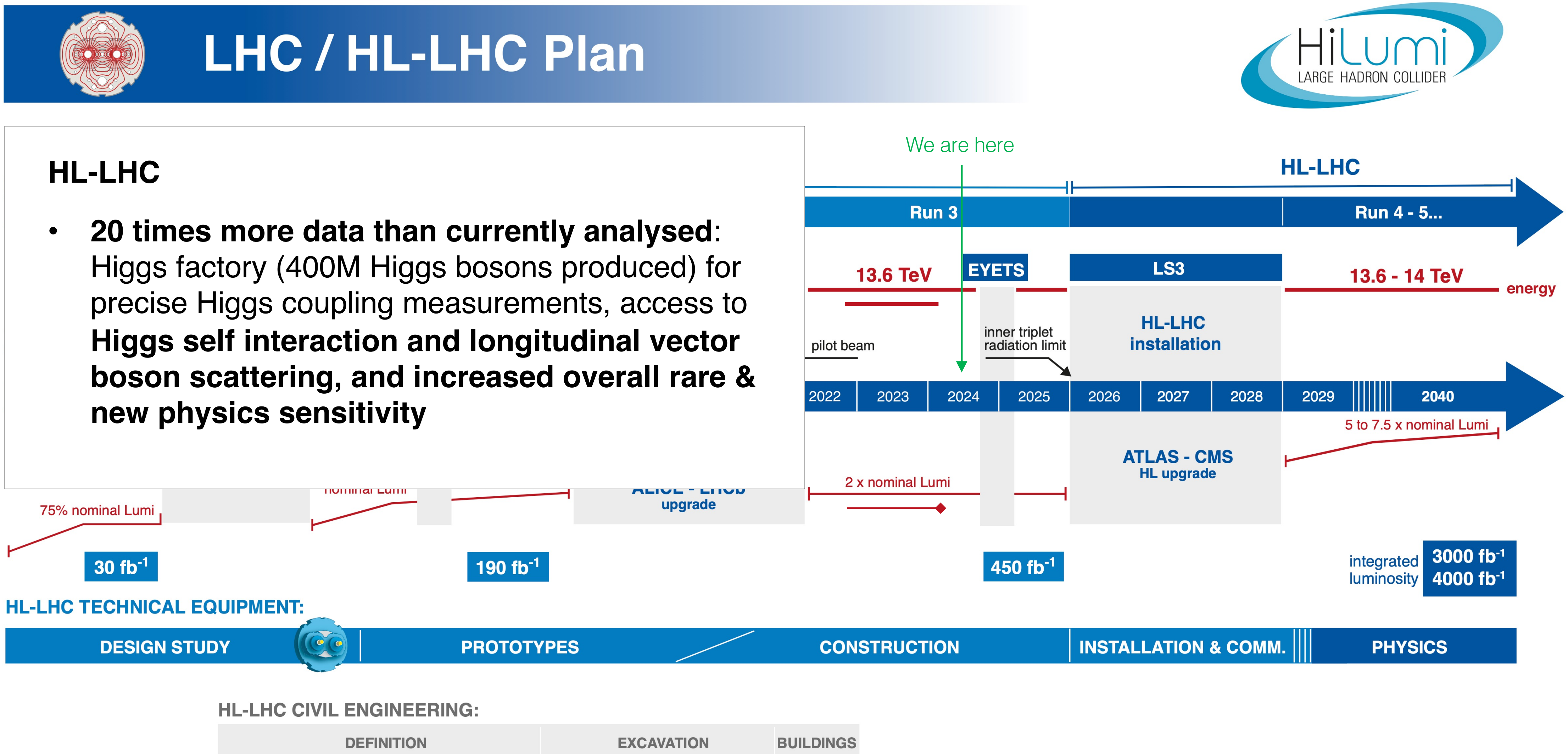
ATLAS LOVES ML/AI

Internally, we have a new version (GN2), which further outperforms GN1, and similarly for tau-lepton identification

Preparing the future — the High-Luminosity LHC

HL-LHC

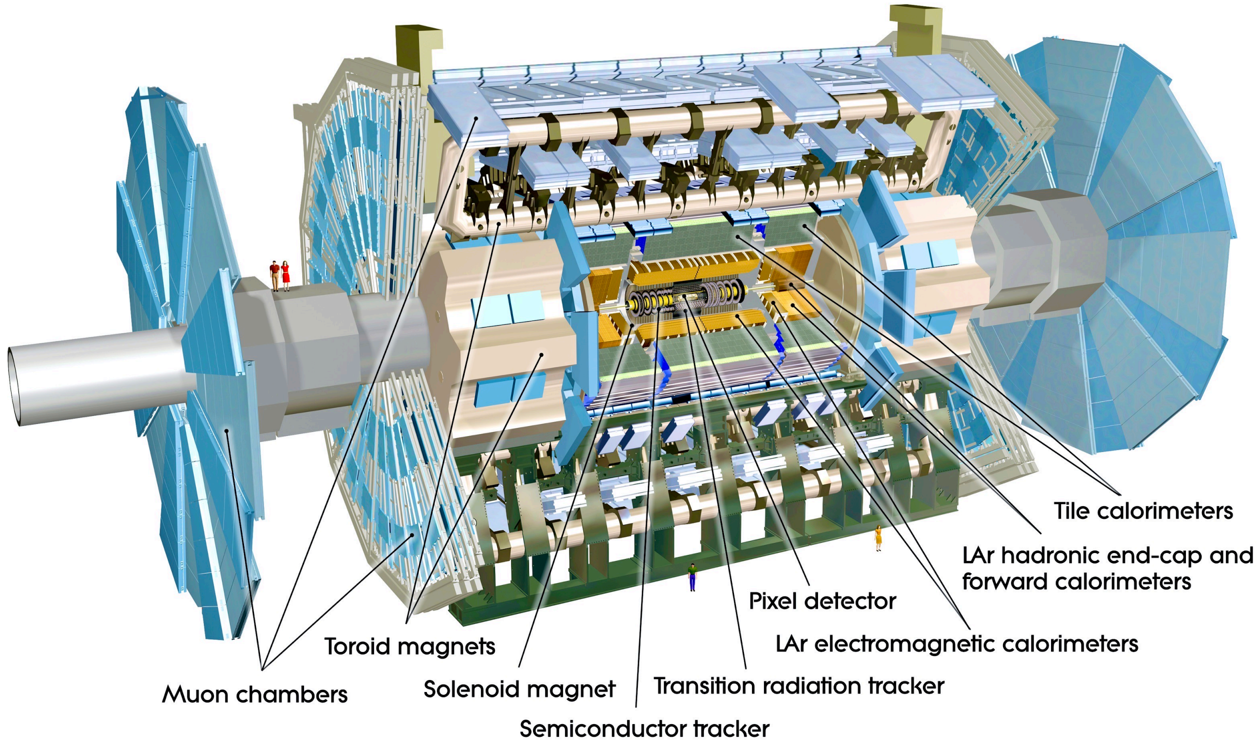
- **20 times more data than currently analysed**: Higgs factory (400M Higgs bosons produced) for precise Higgs coupling measurements, access to **Higgs self interaction and longitudinal vector boson scattering, and increased overall rare & new physics sensitivity**

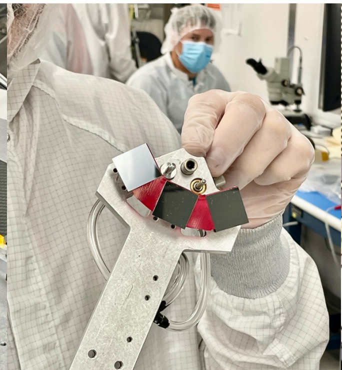


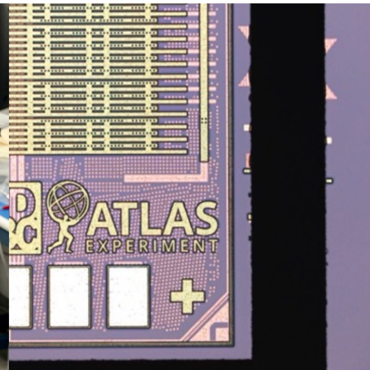
High-Luminosity LHC (HL-LHC)

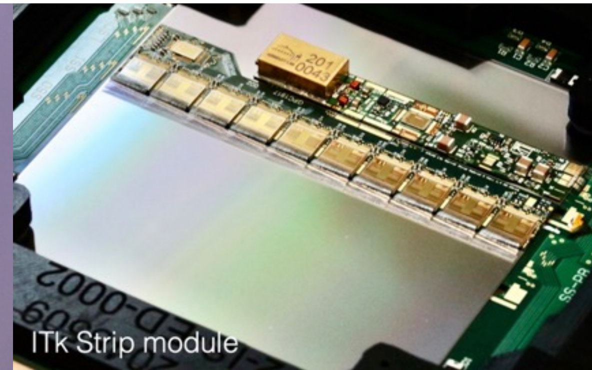
The HL-LHC's luminosity (up to 200 pileup events) requires unprecedented detector and computing technologies:

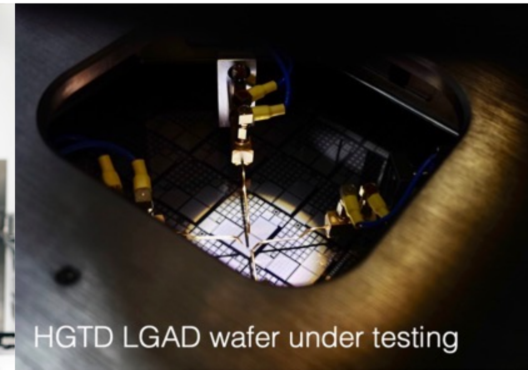
- Radiation hardness
- High detection granularity and resolution
- Precise timing detectors
- More powerful online filtering
- Machine learning & data science
- High-performance software & computing







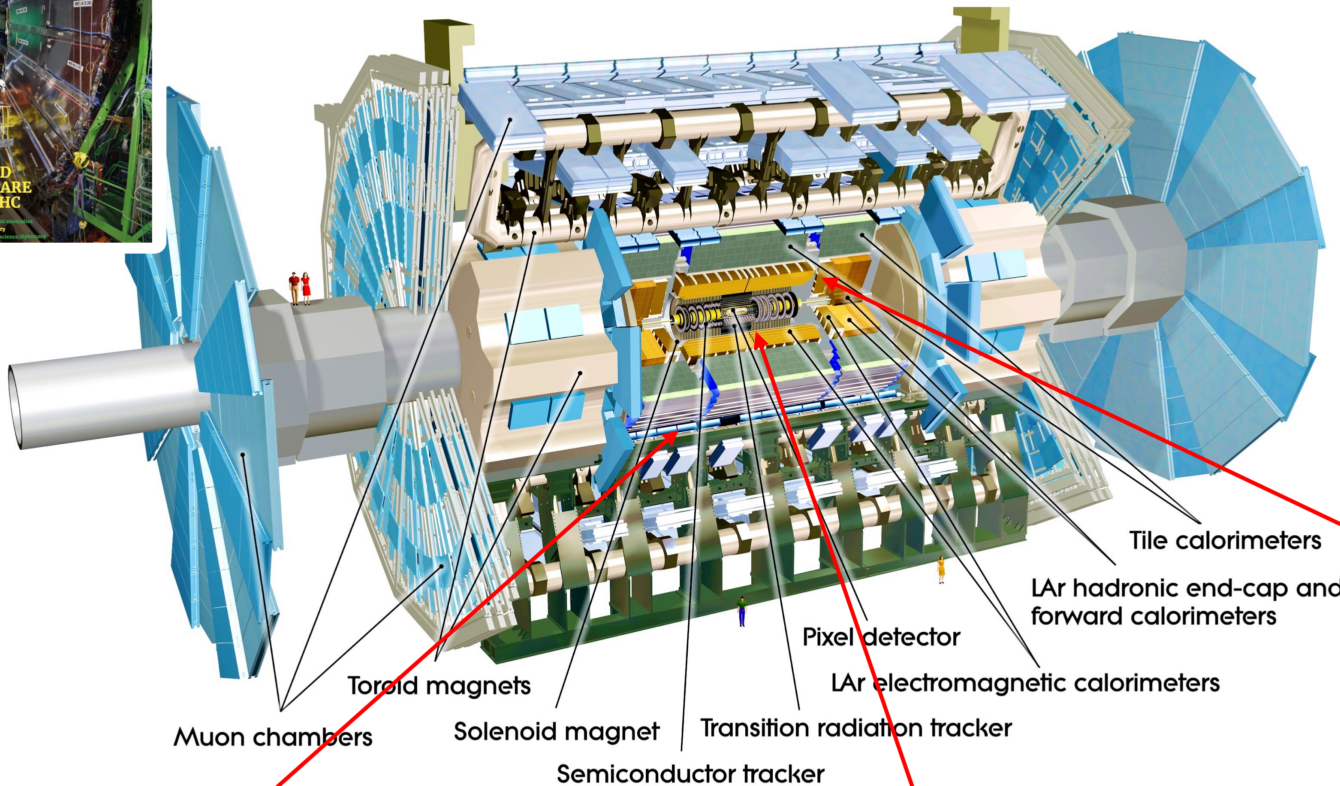




ATLAS Phase-II upgrade

Phase-II predictions
2019: 615 FTE
2020: 651 FTE
2021: 771 FTE
2022: 864 FTE
2023: 886 FTE
2024: 916 FTE

Jan/Feb 2023 CERN Courier
[link]



Upgraded Trigger and Data Acquisition system

Level-0 Trigger at 1 MHz

Improved High-Level Trigger
(150 kHz full-scan tracking)

Electronics Upgrades

LAr Calorimeter

Tile Calorimeter

Muon system

High Granularity Timing Detector (HGTD)

Forward region ($2.4 < |\eta| < 4.0$)

Low-Gain Avalanche Detectors (LGAD)
with 30 ps track resolution

New Muon Chambers

Inner barrel region with new
RPC and sMDT detectors

New Inner Tracking Detector (ITk)

All silicon, up to $|\eta| = 4$
High-granularity Pixel and Strip systems

Additional upgrades

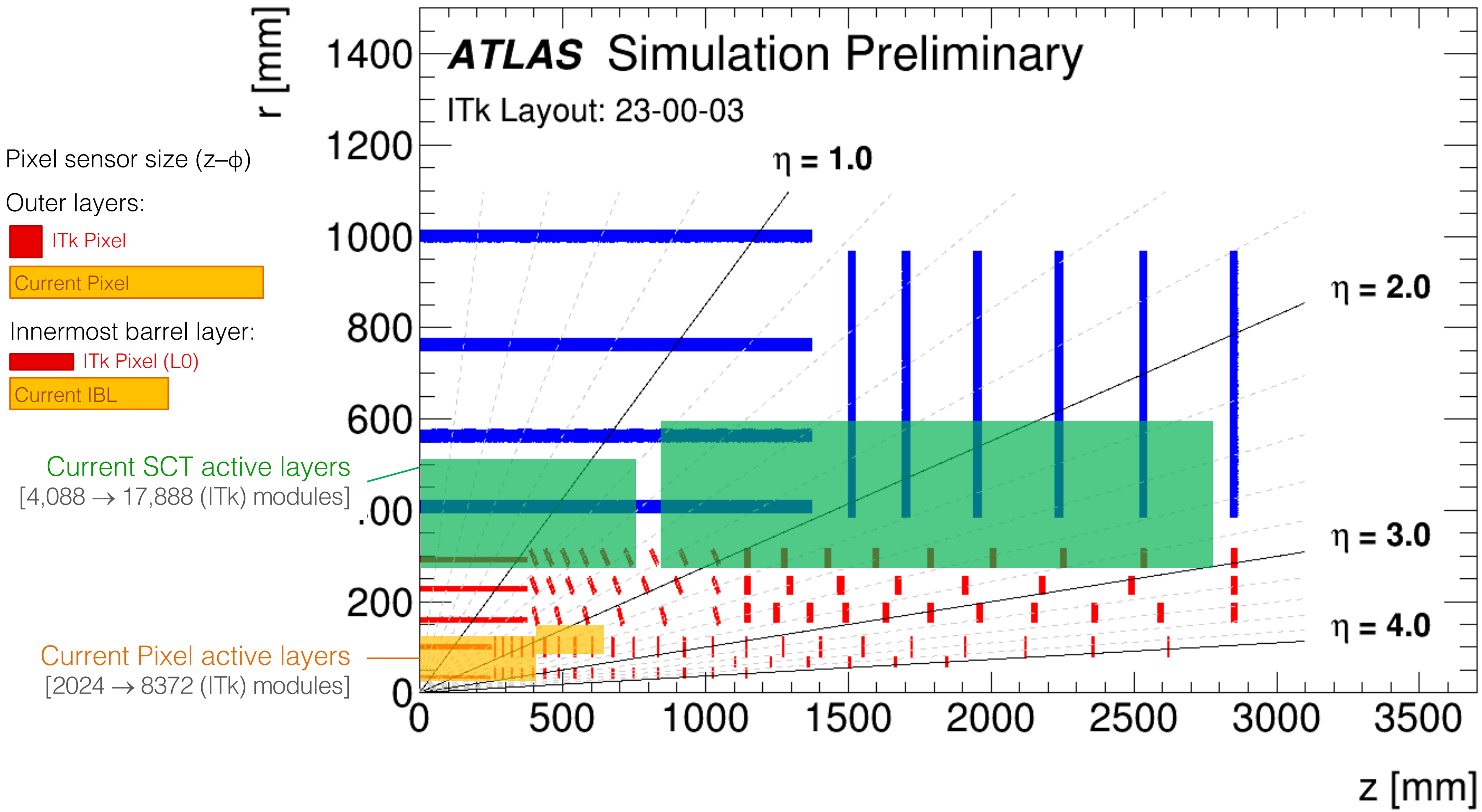
Luminosity detectors (1% precision goal)

HL-ZDC

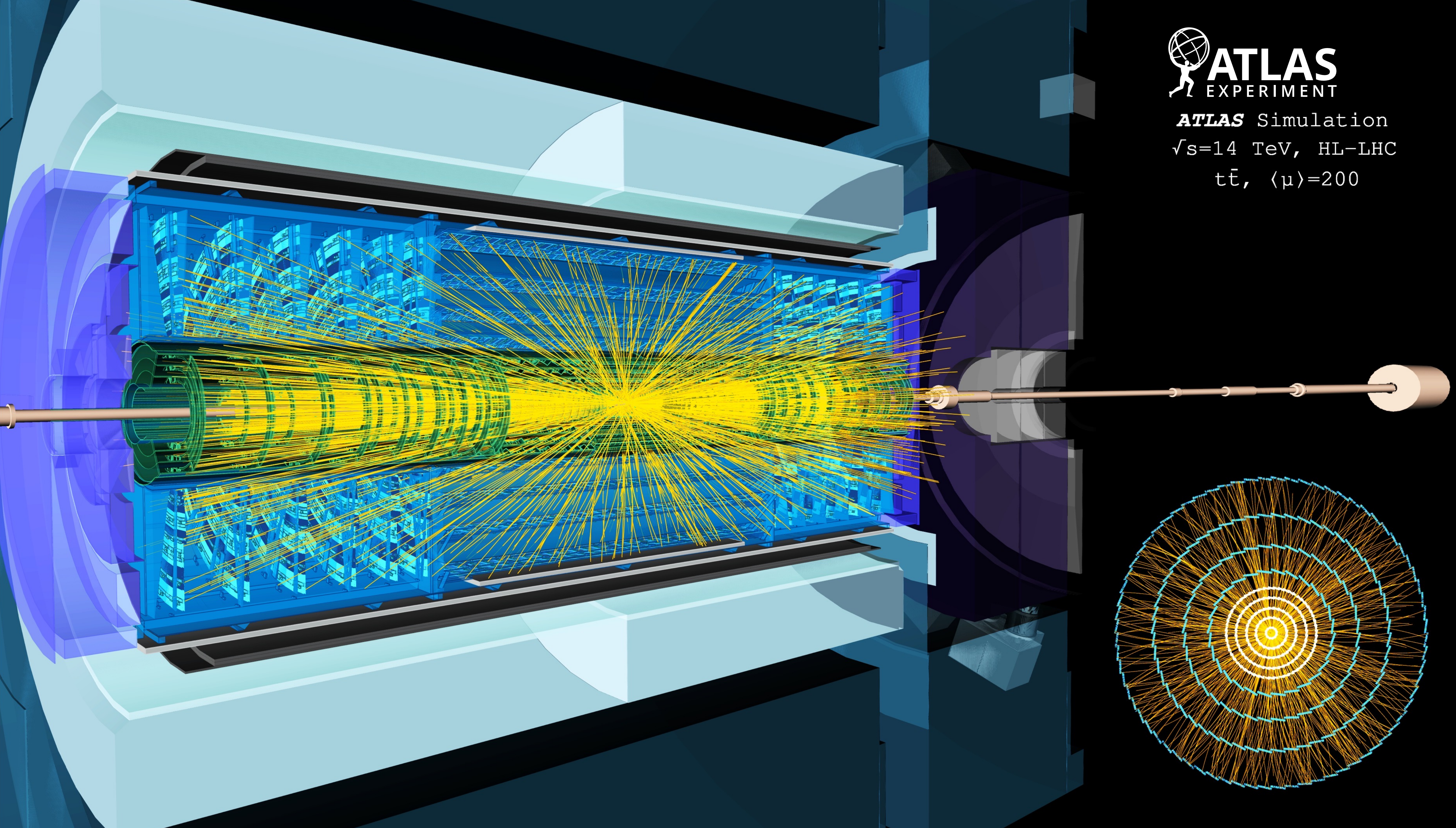
Offline software and computing

Detailed scope described in 7 TDRs approved by the CERN Research Board in 2017, 2018, 2020

ATLAS Phase-II upgrade



ITk: ~13 hits in barrel (incl. 2 hits per Strip module), minimum ~9 Pixel hits in forward region



Display of a simulated ttbar event with μ = 200 (1600 tracks) in the ATLAS ITk

Phase-II Upgrade

ATLAS EXPERIMENT

Progress with ITk large-scale structures

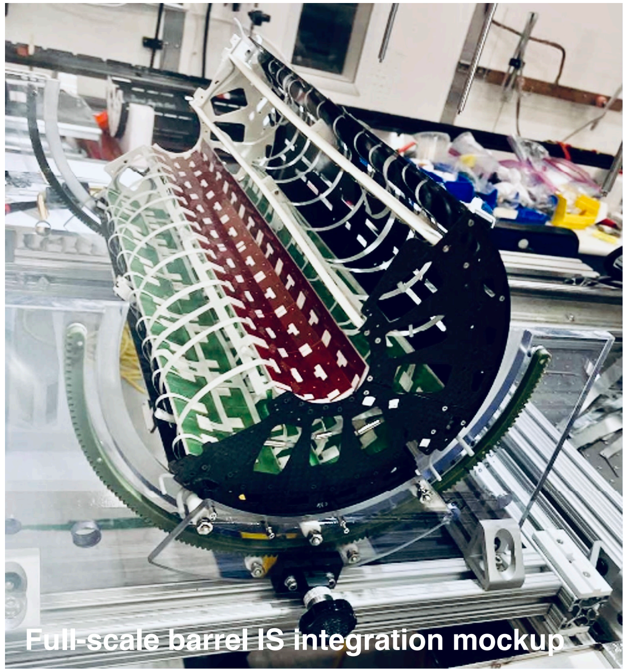
Outer ITk cylinder at LBL on 5 Dec 2023

Strip L3 structure and mounting brackets at Oxford U on 9 Nov 2023

Phase-II Upgrade

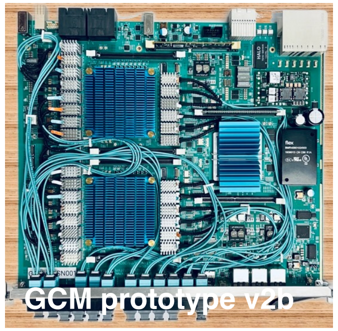
ATLAS EXPERIMENT

SR1 ITk surface assembly cleanroom at CERN



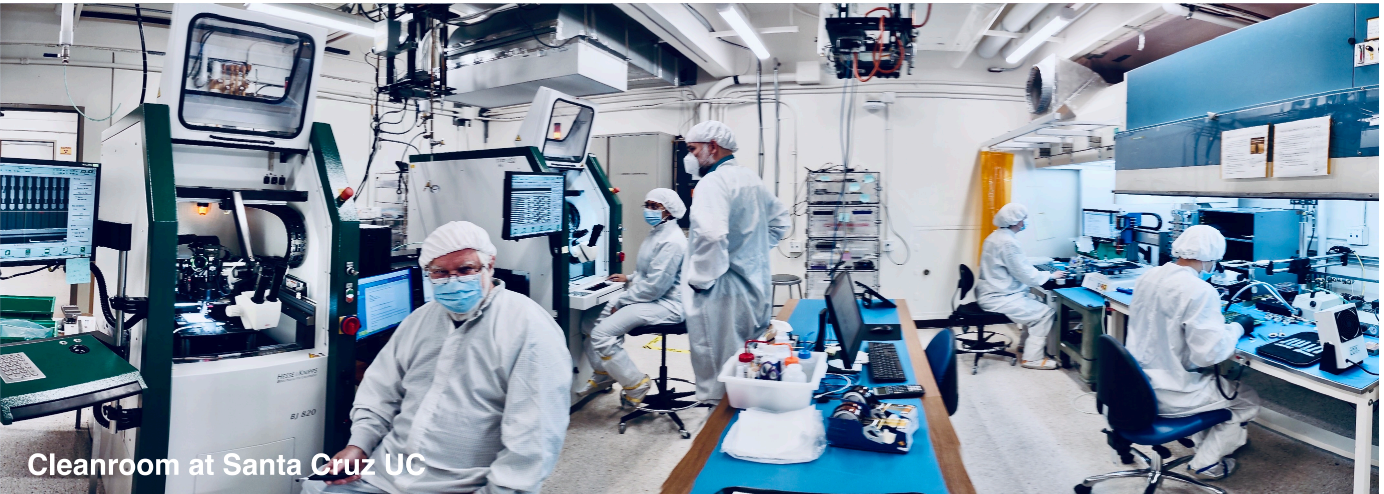
Full-scale barrel IS integration mockup

sMDT chambers at CERN (BB5)



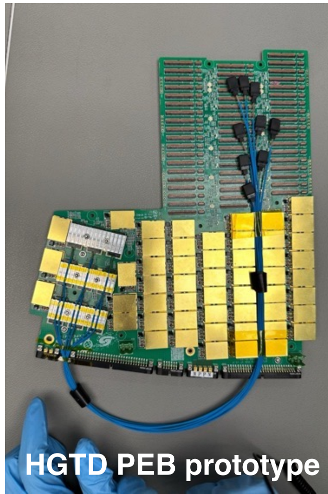
GCM prototype v2b

LAr ALFEv2 ASIC



Cleanroom at Santa Cruz UC

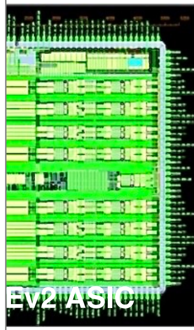
ALTIROC-3 beamtest at DESY



HGTD PEB prototype

Phase-II Upgrade

SR1 ITk su



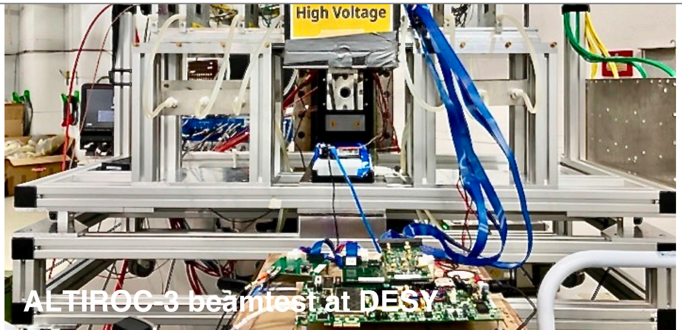
Ev2 ASIC

Huge technical progress across all systems. Design phase completed. Many components in series production (eg, ASIC production for ITk close to finished, Pixel hybridization production started, module production in starting blocks)

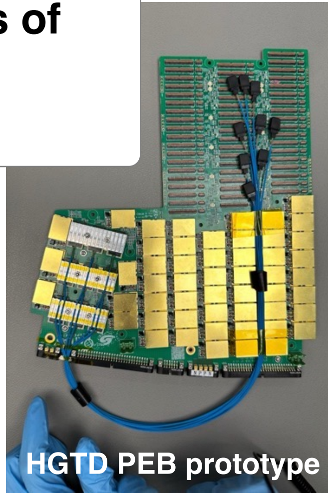
Main technical issue is ITk Strip sensor fracturing under thermal stress, intense follow-up, mitigations being tested

Phase-II upgrade mobilises increasing resources, all institutes are fully engaged — this is of highest priority for ATLAS

Cleanroom at Santa Cruz UC



ALTIROC-3 beamtest at DESY



HGTD PEB prototype

Conclusions

Conclusions

ATLAS has its hands full with exciting present and long-term prospects

Run-3 status

- Physics data taking ongoing, good LHC and ATLAS performance so far this year
- Phase-I Level-1 trigger upgrades in operation and achieving required rate reduction

The Phase-II upgrade for the HL-LHC is our key to the future

- Large-scale upgrades required to withstand HL-LHC conditions
- Design completed, series production has started for many components, remaining technical challenges being addressed

Sustained rich physics production

- Continued high-pace paper output, **results from Run-2 data have been transformative for particle physics**
- Unique measurement and discovery opportunities at Run 2+3 and High-Luminosity LHC

Thank you for organising this important symposium in Kyiv in the framework of the CERN-70 celebration

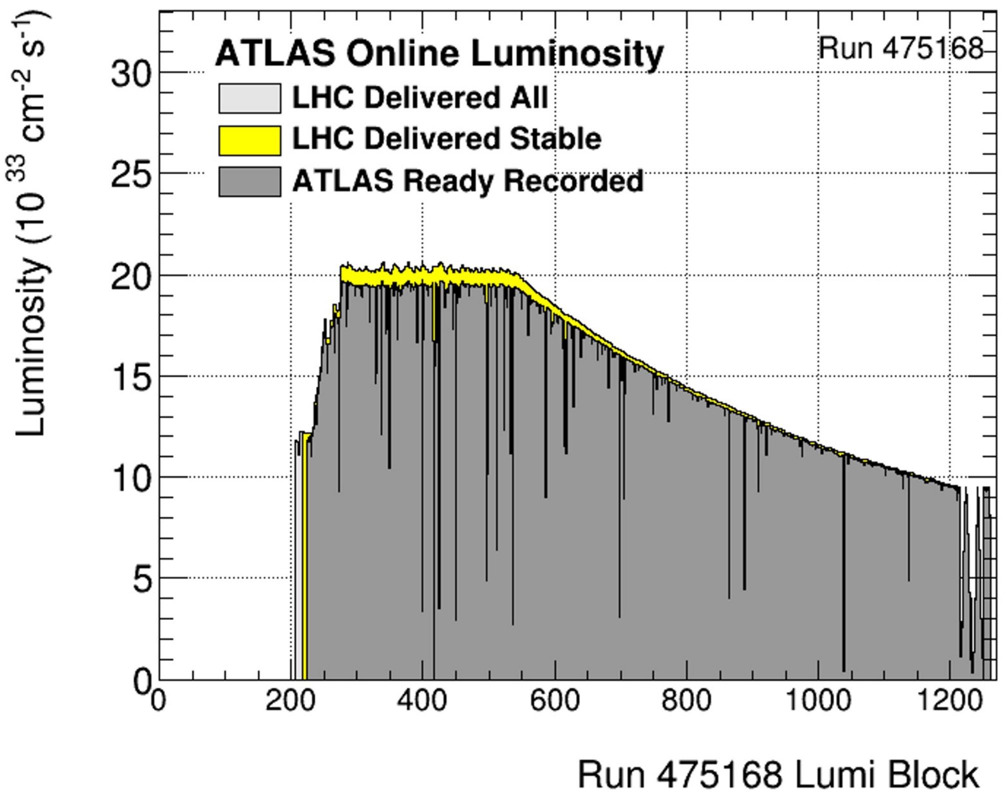
YEARS / ANS CERN
1954-2024

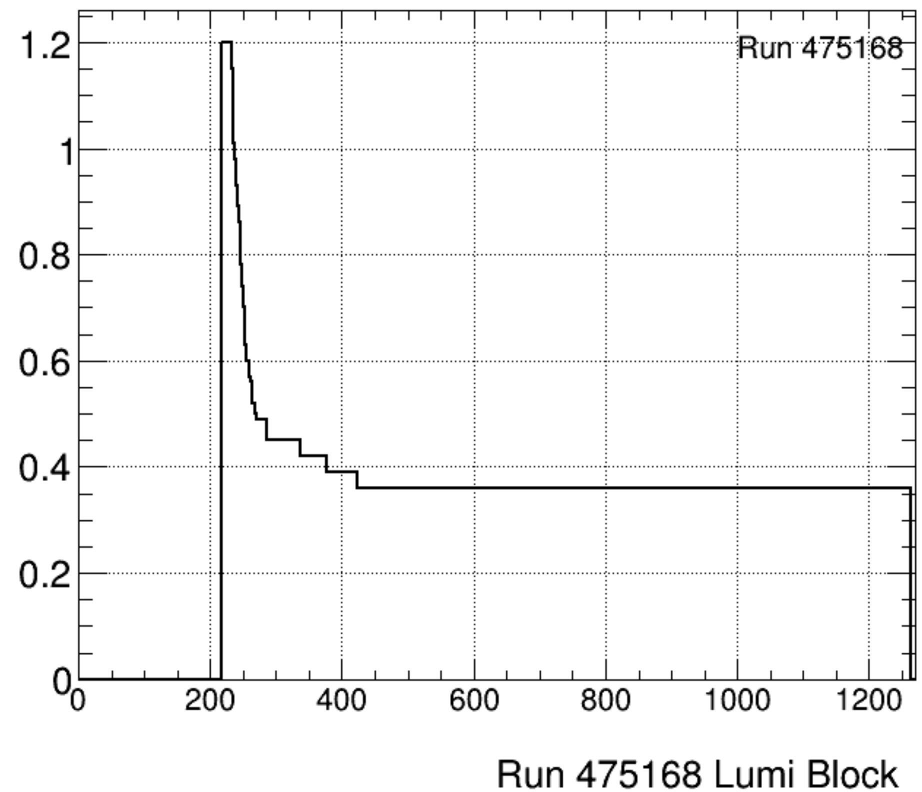
Additional slides

Proton–proton data taking in Run 3

A typical proton fill over 14 hours stable beams

ß* optical levelling achieves constant luminosity until beam intensity is too low





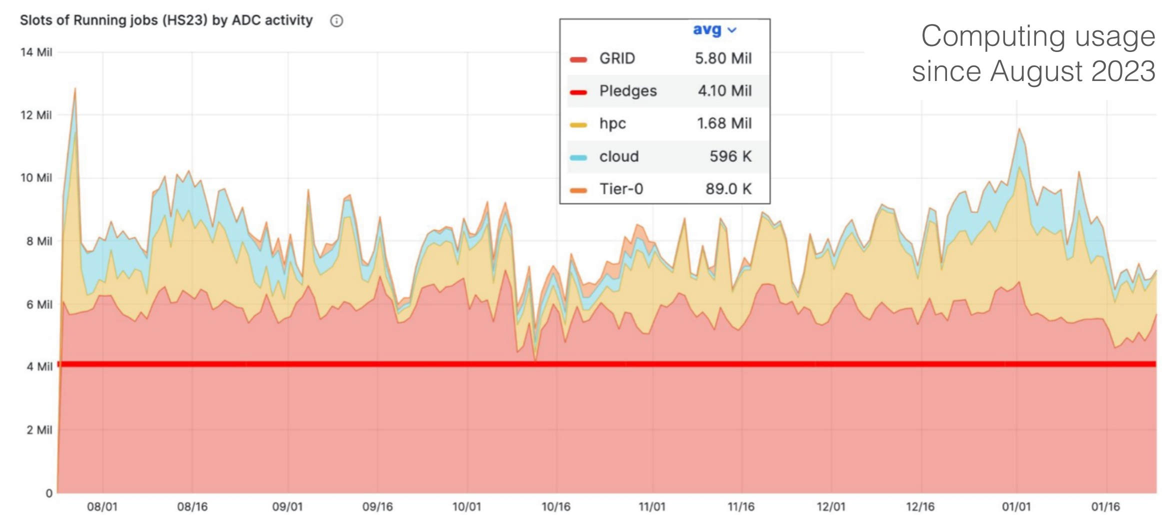
Computing

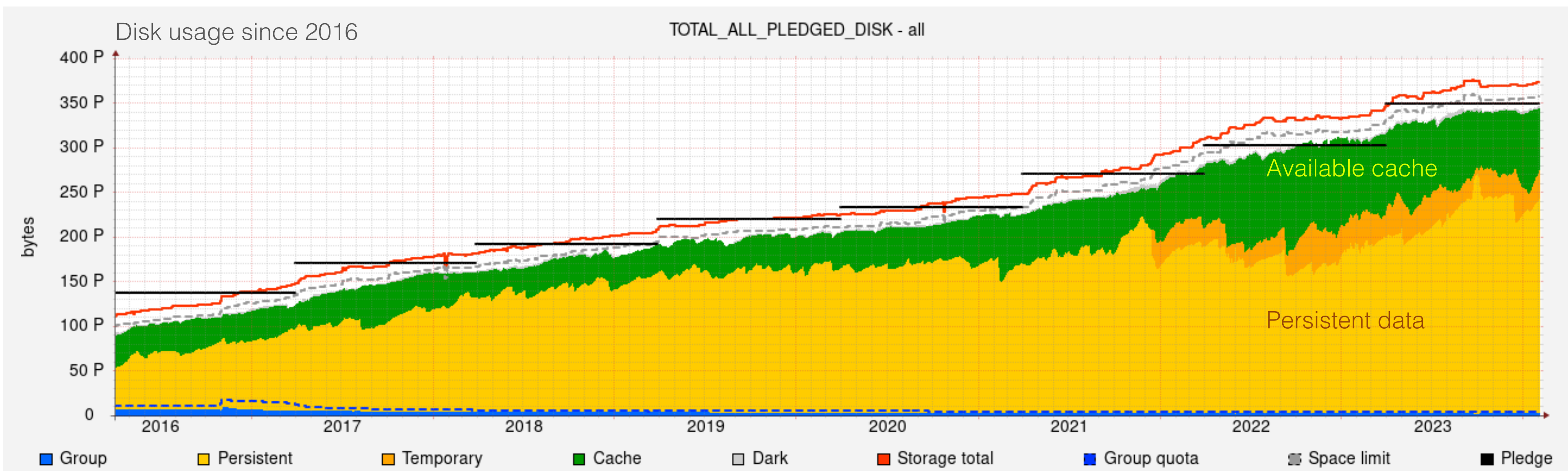
Smooth distributed computing operations

- Tier-0 cluster always fully exploited by prompt and grid processing, no significant backlog during 2023
- WLCG sites incl. HPCs continue to over-deliver

Disk space availability good

- Regular deletion campaigns necessary



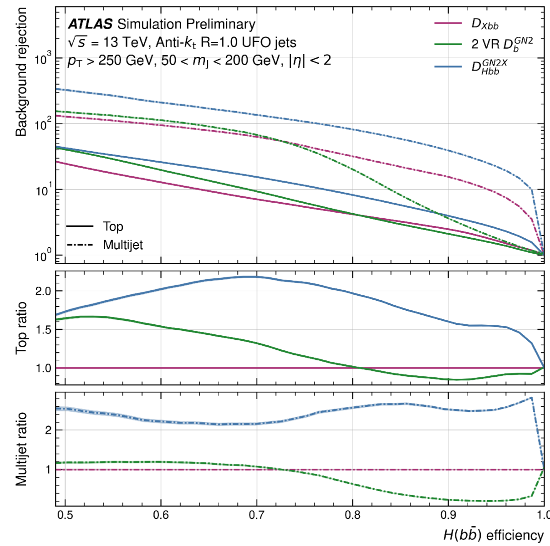


GPU developments in ATLAS

Graphics processing unit (GPU) accelerator hardware receives a worldwide boost due to AI applications. This offers opportunities for ATLAS in particular for the HL-LHC

Current usage: extensive use in ML training for physics performance (e.g. GNN for jet flavour tagging) and analysis analysis (classification and regression)

Ongoing developments: active R&D toward Run 4 with multiple demonstrators in the areas of core software infrastructure (integration in Athena framework), fast detector simulation, HLT tracking and calorimetry, offline reconstruction (traccc, topoclustering)



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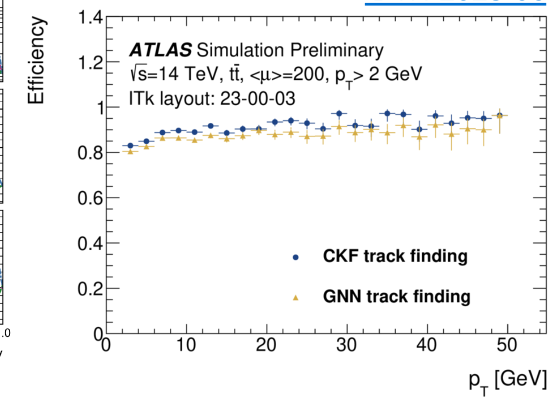


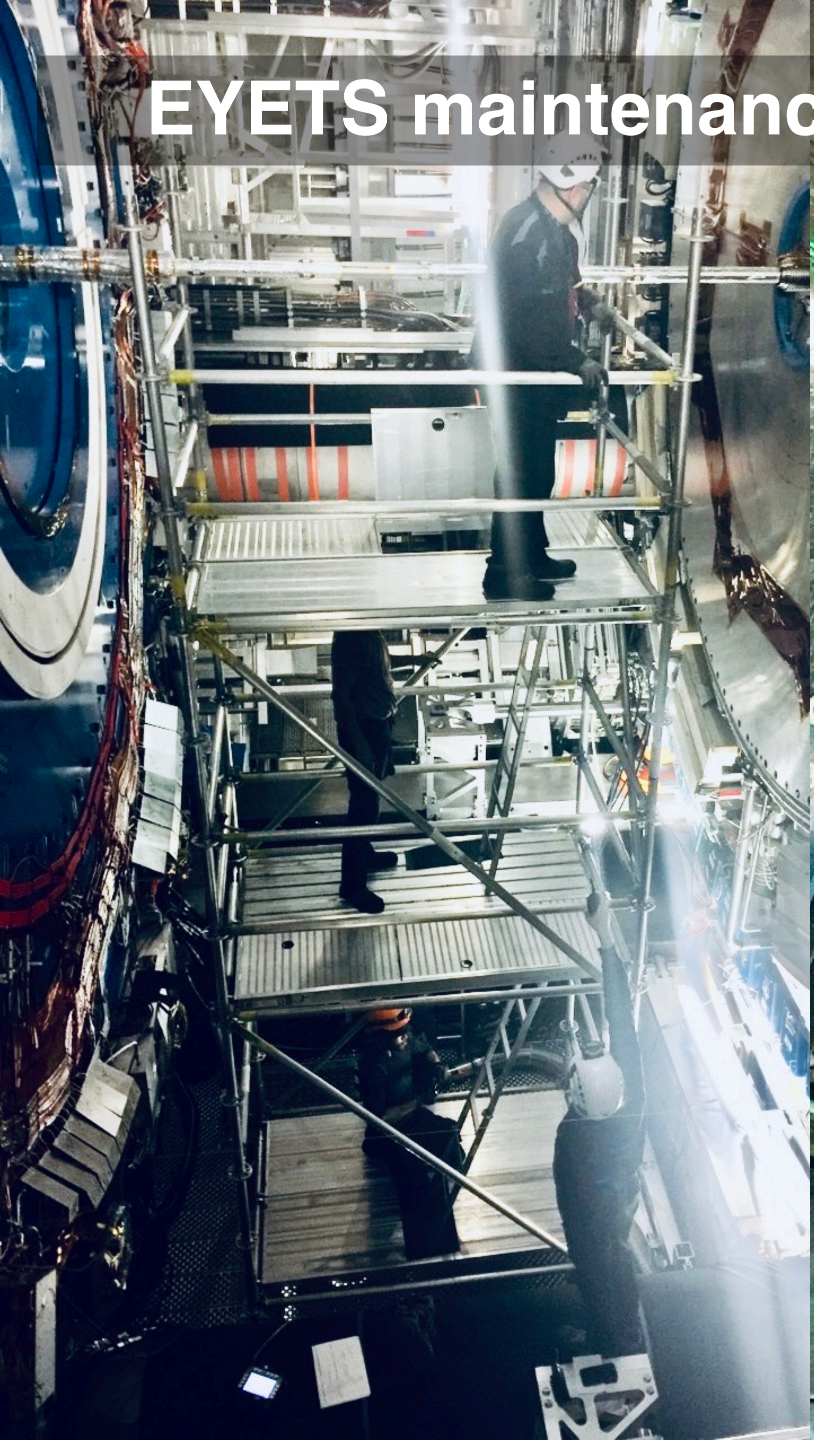
Category	Algorithms	CPU	CUDA	SYCL	Futhark
Clusterization	CCL	✅	✅	✅	✅
	Measurement creation	✅	✅	✅	✅
Seeding	Spacepoint formation	✅	✅	✅	⚪
	Spacepoint binning	✅	✅	✅	⚪
	Seed finding	✅	✅	✅	⚪
	Track param estimation	✅	✅	✅	⚪
Track finding	Combinatorial KF	✅	✅	🟡	⚪
Track fitting	KF	✅	✅	✅	⚪

✅: exists, 🟡: work started, ⚪: work not started yet

News article on ATLAS–Intel case study

EYETS maintenance work

ATLAS EXPERIMENT



EYETS maintenance work

Among the principal EYETS (19 weeks beam-to-beam) **interventions performed**:

- **Cryogenics & vacuum**: shield refrigerator dryer regeneration & installation of additional dryer, LAr endcap C diffusion pump repair, CERN cryogenics group improved safety systems and controls, all magnets now up
- **TRT**: installation of by-pass pipe to reduce pressure on leaking FE cooling loops
- **Tile**: front-end electronics cooling leak repairs, all modules up (very recently may have experienced new leak)
- **Muons**: RPC inlet consolidation and repair, replacement of 19 TGC chambers on Big Wheel C, NSW refurbishment of ICS* and replacement of accessible VTRx* on rim crates, DAQ fixes (GBTX issues)
- **Service caverns**: replacement of cooling hoses and heat exchangers (3 water leaks in 2023)
- **Advance LS3 work**, eg, on CO_2 cooling equipment (transfer lines, mezzanine, control cabinets), MDT service rearrangements

*ICS = Intermediate Conversion Stage (power converter), VTRx = Versatile Link Tranceivers (optical link interfaces), L1DDC = Level-1 Data Driver Card

Recent Phase-II project highlights

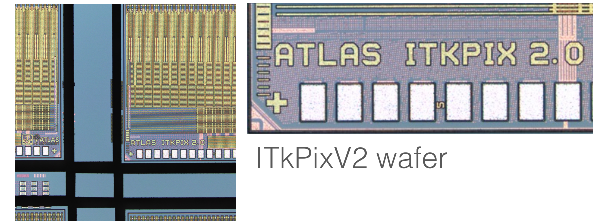
Huge progress on all projects transiting towards production, crucial reviews passed, but few critical technical challenges still to overcome

ASIC design almost complete for all projects

- Pixel readout ASICs (ITkPixV2) fully functional, in production
- RPC readout ASIC: tests provided good results for all options, in production
- HGTD readout ASIC (ALTIROC3) tests well, FDR passed
- LAr front-end ASICs: Preamp/Shaper (ALFEv2) and ADC (COLUTAv4) pre-production chips available and being tested

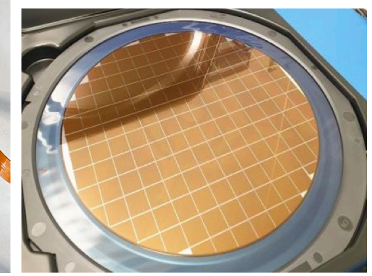
ITk

- Qualification of the four Pixel hybridisation vendors ongoing (two completed)
- Barrel Strip cold noise mostly understood & mitigated
- **Strip sensor fracturing after gluing modules on staves under intense follow up (TF)**
- Progress on procurement of critical items, concerns for services have been addressed (carbon foam, Pixel & Strip data cables, Pixel PP1 connectors, …)
- Production of ITk common structures proceeds well
- **No remaining contingency for ITk in current schedule: priority to solve technical problems, scenarios to speed up production being developed** [24 (20) scenarios studied for Pixel (Strips)]



ITkPixV2 wafer


ITk Pixel PP1 connector prototypes


ALTIROC3 diced wafer


ITk Pixel quad modules

Recent Phase-II project highlights

LAr Calorimeter

- Loss of contingency due to delay in front-end board (FEB2) FDR driven by completion of power down-conversion circuit
- Low contingency for off-detector signal processing board (LASP) driven by the availability of first prototype, gains expected by injecting more effort and by fast-track PCB fabrication by the vendor

Tile Calorimeter

- Good overall progress (Main Board production, burn-in test, LVPS pre-production, calib. system design, etc), comfortable float

Timing Detector — HGTD

- Good recent progress, no delays
- Development of complex Peripheral Electronics Boards (PEB) and hybridisation remain areas of attention (initial results with pre-production sensors and ALTIROC3 chip are positive but more work is needed for imminent hybridisation FDR)

First 2 of most complex HGTD PEB prototypes produced and under test

Muon

- Good overall progress, RPC trigger & readout electronics and power system have little float, close follow-up by management

TDAQ

- Good overall progress, negative float due to insufficient effort in NSW trigger processor, new effort found, need to consolidate