

RECFA Visit to Germany, Berlin, April 1–2, 2022 **ATLAS and CMS – Today and Tomorrow**

Ulrich Husemann, Institute of Experimental Particle Physics, Karlsruhe Institute of Technology On behalf of the German ATLAS and CMS Institutes



KIT – The Research University in the Helmholtz Association









Outline









RECFA Visit to Germany: ATLAS/CMS





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CMS and ATLAS

Based on 2014 J. Phys.: Conf. Ser. 513 (2014) 022032





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HC 27 km -----



German ATLAS/CMS Institutions







3 universities (Aachen (3 institutes) Hamburg, Karlsruhe)

- ~120 doctoral researchers

Federal Ministry of Education & Research (ErUM-Pro, ErUM-Data, FIS)

Deutsche Forschungsgemeinschaft, European Research Council

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Major Responsibilities

| Responsibility | EXPERIMENT |
|-----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Detector Operations & Upgrades | Silicon Pixel and Strip Tracker Muon MDT Chambers & New Small Wheel LAr Calorimeter & Electronics Forward Detectors L1 Trigger |
| Calibration & Analysis Tools | b-Tagging, W/H/t-Tagging Identification of e/γ/μ/τ Jets & Missing Transverse Momentum Data Quality, Beam Background, Alignment Monte Carlo Generators |
| Computing | Tier-1 and Tier-2 Centers Core Support |

Responsibilities typically follow contributions to building the experiment









Silicon Pixel and Strip Tracker Muon DT and GEM Chambers & Electronics HCAL/HO, CASTOR L1 Trigger & HLT **Beam Radiation & Luminosity**

Tracking, b-Tagging, Vertexing Identification of $e/\gamma/\mu/\tau$ Jets & Missing Transverse Momentum Alignment, Luminosity Monte Carlo Generators, Machine Learning

Tier-1 and Tier-2 Centers

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Computing

- Strong German involvement in ATLAS/CMS computing (see M. Dührssen-Debling's presentations):
 - GridKa the German Tier-1 center (Karlsruhe)
 - **Tier-2 centers** in Aachen, Freiburg, Göttingen, Hamburg (DESY+University), Munich (Max Planck Institute, LMU), Wuppertal, Zeuthen
 - Very reliable operation, all pledges to Worldwide LHC Computing Grid (WLCG) fulfilled \rightarrow operating model requires significant update for HL-LHC











Upgrades for LHC Run 2

- Example: upgrades of the silicon pixel detectors



Bonn, Dortmund, Göttingen, MPP, Siegen, Wuppertal















High-Level Management Positions **PATLAS**

ATLAS:

- Spokesperson: K. Jakobs (Freiburg, 2017–2021)
- Physics coordinator: K. Mönig (DESY, 2019–2020)

CMS:

- Deputy spokesperson: K. Borras (DESY/Aachen, 2014–2016)
- Upgrade coordinator: F. Hartmann (Karlsruhe, since 2018)
- Collaboration Board chair: M. Kasemann (DESY, 2017–2019)



Deputy spokesperson: B. Heinemann (DESY/Freiburg, 2013–2017)



Coordination Positions

A Anhang

Leitungsfunktionen von FSP-Mitgliedern in der ATLAS-Kollaboration

Deutsche Physiker hatten im Verlauf der aktuellen Förderperiode wichtige Aufgaben innerhalb der ATLAS Kollaboration übernommen, die im Folgenden zusammenfassend dargestellt sind.

| Ilhoraroifondo | Laitungefunktionen |
|----------------|--------------------|
| obergrenenue | Leitungalunktionen |

| Karl Jakobs | Freiburg | Spokesperson | Untergruppen Higgs-Physik | Untergruppen Higgs-Physik: | | |
|---------------------------------|---------------------|------------------------------------|---------------------------------------|---------------------------------|-----------------------------------------|--|
| Klaus Monig Korstin Lantzsch | DESY Bonn | Physics Coordinator | Sarah Heim | DESY | HComb (HSG7) | |
| Reistin Lanzsch | DOIIII | Run Coordination | Duc Bao Ta | Mainz | HLep/Htautau (HSG4) | |
| Mitarbeit in wichtigen ATLAS | Komitees. | | Judith Katzy | DESY | HTop (HSG8) | |
| Mitabelt in Wentigen ATEAO | Tomilees. | | Jason Veatch | Göttingen | Di-Higgs (HDBS) | |
| Krisztian Peters | DESY | Publication Committee | Intergruppen Ton-Physik | | | |
| Heiko Lacker | HU Berlin | Authorship Committee | Androa Knuo | Froiburg | Top Proportion | |
| James Ferrando | DESY | Speakers Committee | Sebastian Mercelmever | HILBorlin | Top Reconstruction | |
| Ludovica Aperio Bella | DESY | CB Chair Advisory Group | Begina Moles-Valls | Bonn | Single Top | |
| Monica Dunford | Heidelberg | Project Management Office | Johannes Erdmann | Dortmund | Top Properties | |
| Stefan Bichter | DESY | Early Career Scientist Board | Yichen Li | DESY | Top Reconstruction | |
| Sophio Pataraia | Mainz | Statistics Committee | Geoffrey Gilles | Wuppertal | Single Top | |
| Stefan Schmitt | DESY | Statistics Committee | | | | |
| | | Untergruppen Supersymmetrie: | | | | |
| Leitung von ATLAS-Arbeitsgr | uppen: | | Rosa Simoniello | Mainz | 3rd Generation Squarks | |
| Elizaveta Shabalina | Göttingen | Top WG | Untergruppen Exotika: | | | |
| Wolfgang Wagner | Wuppertal | Top WG | Katharina Pahr | DECV | | |
| Monica Dunford | Heidelberg | Standard Model WG | Rathanna Benr Patrick Riock | DES I MPP München | HQT Subgroup | |
| Federico Meloni | DESY | Supersymmetry WG | Dominik Duda | MPP München | DBL Subgroup | |
| Frank Siegert | Dresden | Physics Modelling WG | Bonnink Bada | WITT WIGHONON | | |
| Simone Amoroso | DESY | Physics Modelling WG | Unteraruppen Physics Mod | Untergruppen Physics Modelling: | | |
| Kersten Koonoko | DES I Freiburg | Higgs WG Higgs WG | | | - · · · · · · · · · · · · · · · · · · · | |
| Mishal Japus | Cättingen | Tau Derformence WC | Spyridon Argyropoulos | Freiburg | Generator Infrastructure and Tools | |
| Christian Grefe | Bonn | Tau-Penormance WG | Eweinia Lobodziniska | DEST | Generator initiastructure and tools | |
| Christopher Pollard | DESY | Elayour T ng WG | ergruppen Per jance | | | |
| Sascha Meblhase | | Outreach prdinator | | | | |
| | | Outreach | Brendlinge | DESY | Photon ID and Efficiencies | |
| Untergruppen Standardmode | ell: | | C Rivernyk | BOIII | Electron ID and Efficiencies | |
| | | Electronic Division | Ste Richter | | Electron ID and Efficiencies | |
| Joany Manjarres | Dh | Electrowee Physics | itrevski | LM ünchen | e/y-Reconstruction and Software | |
| | | | Roge ranjo cia | DE | e/γ -Reconstruction and Software | |
| | | | Heber rres | P .en | e/ γ Isolation and Fake Forum | |
| Leitungsfunktionen im Detekt | orbenneb: | | Markus | un . | Flavor Tag.: Algorithms, Performance | |
| - | | | Geottrey Gilles | Wuppertal | Flavor Iag.: Algorithms, Performance | |
| Institute Board Chairs: | | | Jeanette Lorenz | I MI I München | MET | |
| Gregor Herten | Freiburg | Muon Detector IB Chair (ab 4/2021) | Xingguo Li | DESY | Jet/Etmiss JetInSitu | |
| Wolfgang Wagner | Wuppertal | Inner Detector IB Chair | Jason Veatch | Göttingen | Jet Substructure / Jet Tagging | |
| | | | Johannes Junggeburth | MPP München | Muon Efficiency | |
| Muon Detector: | | | Davide Cieri | MPP München | Muon Efficiency | |
| William Leight | DESY | Muon Software Coordinator | Javier Jimenez Pena | MPP München | ID Alginment | |
| Stephanie Zimmermann | Freiburg | NSW Project Leader | | | | |
| Inner Detector: | | | | | | |
| Marcello Bindi | Göttingen | Pixel Project Leader | Datenmanagement und Comp | Datenmanagement und Computing: | | |
| Goetz Gaycken | DESY | Software Coordinator | David Cauth | DECV | | |
| Christian Grete | Bonn | IRI Software | Bodney Walker | LMU München | Commissioning Coordinator | |
| Forward Detectors: | | | Priscilla Pani Dominic Hirschbuehl | DESY | Production/Analysis Coordinator | |
| Marko Milovanovic | DESY | ARP Technical Coordinator | David South | DESY | MC Production Coordinator | |
| TDAQ: | | | Thomas Beermann | Wuppertal | Monitoring/Analysis Coordinator | |
| | DECV | | Alexander Mann | | Software Physics Validation | |
| Karolos Potamianos | DESY | FTK IM Coordinator | Goetz Gaycken | DESY | Software Reconstruction | |
| H -C. Schultz-Coulon | DES 1 Heidelberg | L 1Calo Project Leader | Oleg Kuprash | Freiburg | Trigger Software EDM Coordinator | |
| Silvia Franchino | Heidelberg | L 1Calo Bun Coordinator | David Hohn | Freiburg | HammerCloud Coordinator | |
| Julio de Souza | Mainz | L1Calo Test Facilities Coordinator | | | | |
| Rosa Simoniello | Mainz | L1 Topo Algorithm Commissioning | | | | |
| Katharina Bierwagen | Mainz | L1 Topo Algorithm Commissioning | | | | |
| Jonathan Burr | DESY | MET Signature | | | | |
| Ren-Jie wang | Mainz | MET Signature | | | | |
| Data Preparation: | | | | | n se iia | |
| Valorio Long | Fraiburg | Luminosity ID | — C | | | |
| valerie Laliy | repuly | | | | | |

Sergio Grancagnolo

Yichen Li

HU Berlin

DESY

Non-Collision Background

Reprocessing Coordinator





• Level 2

Mitglieder der deutschen CMS-Gruppen arbeiten an vielen Stellen und sehr sichtbar im Management der CMS-Kollaboration. Im Berichtszeitraum waren dies unter anderem folgende Positionen:

· CMS-Management

- Deutscher Vertreter im CMS Management Board: J. Haller (Stellvertreter: A. Schmidt)
- Deutsche Vertreter im CMS Finance Board: J. Haller, I. Melzer-Pellmann
- Mitglied der Spokesperson Advisory Group: K. Klein
- Communications Office: F. Blekman
- o Diversity Office: I. Melzer-Pellmann
- Engagement Office: M. Kasemann

· Collaboration Board und zugeordnete Ausschüsse Regional Representative: J. Haller

- o Mitglied im Collaboration Board Chair Advisory Committee: J. Haller
- Vorsitz des Conference Committees: A. Meyer
- Vorsitz des Authorship Committees: K. Hoepfner
- Vorsitz des Career Committees: K. Borras
- Vorsitz des Standard Model Physics (SMP) PAG Publication C
- o Vorsitz des SUSY PAG Publication Committees: I. Melzer-Pel

Subsystem Institution Boards und Ausschüsse

- o Vorsitz des Muon DT Institution Boards: K. Hoepfner
- Vorsitz des BRIL Institution Boards: W. Lohmann

• Vorsitz des Tracker Editorial Boards: K. Klein

- Computing
 - o Deutscher Vertreter im CMS Computing Resource Board: G. Quast
 - Mitglied des CMS Computing Resource Boards: M. Giffels
 - o CMS-Vertreter im GridKA Technical Advisory Board: M. Giffels
 - o Koordinator der deutschen CMS-Computing-Aktivitäten: M. Giffels

LHC Cross Section Working Group

- o Mitglied im LHC Higgs Working Group Steering Committee: R. Wolf
- CMS-Vertreterin in der LHC Top Working Group: M. Aldaya
- o CMS-Vertreter für den Bereich "Higgs" in der LHC Cross Section Working Group: A. Gottmann

• Level 1

- CMS Upgrade Coordinator: F. Hartmann
- CMS Physics Performance (PPD) convener: A. B. Meyer
- Tracker Project Manager: E. Butz

up convener: S. Wuchterl nce/Validation/Commissioning subgroup conveners: J. van der Linden, S. Mondal Manager in der PdmV group: S. Kaveh

• Strategy for Trigger Evaluation and Monitoring (STEAM) group convener: L. Benato

- sible: S. Ghosh
- oordinator: A. Sharma
- ible: A. Sharma

• B tagging and vertexing (BTV) POG convener: S. Mitra • Beyond Two Generations (B2G) PAG convener: A. Hinzmann

 Electron/Gamma (EGM) POG convener: S. Mukherjee Generator (GEN) group convener: A. Grohsjean

• HGCAL System Validation group convener: K. Krueger

• Machine Learning group convener: G. Kasieczka

• TEDD Coordinator im Tracker Upgrade: A. Mussgiller

• HGCAL Scintillators and SiPM Tileboards group convener: F. Sefkow

• Jets und Missing ET (JetMET) POG convener: H. Kirschenmann

DT Run Coordinator: A. Sharma

• FastSim group convener: S. Bein

• Tracker DPG convener: P. Connor

Dynamic Resource Provisioning: C. Wissing

-Hadronic subgroup convener: S. Ghosh Higgs Extended subgroup convener: R. Ma**nkel**

rations & Technical Field Manager: I. Shvetsov

- HIG PAG Higgs to bb subgroup convener: L. Mastrolorenzo
- HIG PAG Higgs to tt subgroup convener: A. Raspiareza
- Monte Carlo (MC) request manager: A. Pozdnyakov, N. Johmari Zulaiha
- MC Physics Comparisons and Generator Tunes group convener: A. Bermudez Martinez
- MC validation convener: A. Grohsjean
- Outer Tracker Hybrids working group convener: K. Klein
- o Outer Tracker Sensors working group convener: A. Dierlamm
- Outer Tracker System Tests working group convener: A. Dierlamm
- Inner Tracker Sensor working group convener: G. Steinbrück
- Outer Tracker Module and Mechanics working group convener: A. Mussgiller
- SMP PAG Hadronic subgroup convener: K. Rabbertz
- Strip Local Reconstruction group convener: R. Walsh
- Tau POG ID subgroup convener: A. Cardini
- TOP PAG ttX subgroup convener: O. Behnke
- Machine learning production subgroup: M. Rieger
- Tracker Alignment group convener: S. Consuegra Rodriguez
- TRK POG Tracking@HLT subgroup convener: K. Pena
- Upgrade Physics study group (UPSG) SMP subgroup convener: A. B. Meyer

many more coordination positions on all levels

ees: K. Wichmann



ErUM-FSP LHC Office

Public Relations & Outreach Promotion of Young Talent Technology/Knowledge Transfer for BMBF-funded contributions to ALICE, ATLAS, CMS, LHCb ("LHC ErUM FSPs")

(see U. Bilow's presentation)









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LHC Run 2 Dataset



Very successful data taking

Thanks to the accelerator and detector teams

140 fb⁻¹ per experiment "good for physics" (only 5% of projected full LHC dataset size)



Significant German involvement in detector, trigger, and object performance groups and MC simulation

- Focus related to experiment responsibilities and physics interests
 - Excellent starting point for doctoral researchers









Physics Harvest

COLLISION PAPERS

Image credit: ATLAS

...and >850 doctoral theses on ATLAS and CMS defended in Germany.







Image credit: CMS

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Physics Harvest

Higgs boson: completely new window to the universe and its open questions \rightarrow from discovery to exploration of the Higgs sector







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Focus of German Groups

Percentage of Institutes Contributing to Physics Topics







Similar physics interests in ATLAS/CMS:

- Covering (almost) full LHC collider physics landscape
- Main focus: top, Higgs, exotics

Many innovative **applications of** machine learning to physics analysis

Close connections to strong German particle phenomenology community see M. Mühlleitner's presentation)









Single Top + Gauge Boson Production Stream

tqγ: Fiducial Cross Section





tZq: Differential Cross Section





Result:

 $\sigma_{tq\gamma} \times \mathcal{B}(t \rightarrow \ell \nu b) = 580 \pm 19 \text{ (stat.)} \pm 63 \text{ (syst.) fb}$

\rightarrow **observation** with 9.1 standard deviations (6.7 s.d. expected)



Ulrich Husemann, KIT

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Limits on H—cc in VH Production



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ATLAS EXPERIMENT

Ratio $|\kappa_c/\kappa_b|$ smaller than ratio of bottom to charm quark masses \rightarrow Higgs coupling to charm quarks smaller than to bottom quarks

Di-Higgs Production: Examples

Bonn, DESY, Göttingen

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Searches: Dark Matter & MUSiC

2HDM with Dirac DM & Pseudoscalar Mediator

Model-Unspecific Search for New Physics

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Searches: Long-Lived Particles

From Picoseconds to Years

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Trigger/DAQ Upgrades for Run 3

- Upgrade of ATLAS LAr calorimeter readout electronics and trigger:
 - **10-fold increase** in granularity
 - More selective level-1 trigger
- German contributions to calorimeter trigger electronics boards:
 - jFEX (Jet Feature Extractor)
 - TREX (Tile Rear Extension)
 - L1Topo (Level-1 Topological Trigger)
- CMS: improved high-level trigger performance using **GPUs**

L1Topo Board Installation at CERN (Mainz)

Dresden, Heidelberg, Mainz

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New Muon Chambers for Run 3

Micromegas (ATLAS) and GEM (CMS)

ATLAS New Small Wheel Installation

Freiburg, Mainz, LMU, MPP, Würzburg

reduce/replace greenhouse gases in gaseous detectors

https://atlas.cerr

Getting Ready for Data Taking

CMS Experiment at the LHC, CERN Data recorded: 2021-Oct-19 13:01:24.690432 GMT Run / Event / LS: 345881 / 17244 / 734

Pilot beam in October 2021: Beam splashes and 900-GeV collisions Significant German contributions to beam monitoring Until March 2022: detector closing, magnet ramps, long cosmic runs

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Longer Term LHC Schedule

You are here.

Shutdown/Technical stop Protons physics Ions Commissioning with beam Hardware commissioning/magnet training

Ihc-commissioning.web.cern.ch

\rightarrow delayed by **three years** w.r.t. planning from 2015.

+ upgrades to on-detector and off-detector electronics, trigger, data acquisition

+ contributions to MIP Timing Detector and **High-Granularity Calorimeter**

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Phase-2 Upgrades: Funding

- German community secured funding for ATLAS/CMS phase-2 upgrades from additional funding lines
 - **BMBF Research Infrastructures** ("FIS"): initially 90 MEUR (ATLAS/CMS = 60/30)
 - **Cost increase** due to delays (e.g. unexpected additional R&D, COVID-19) \rightarrow increased to **103.8 MEUR** in 2021
 - Helmholtz Large-scale Investments: 16.7 MEUR
 - CORE contributions to detectors: **52 MCHF** (BMBF, Helmholtz, Max Planck; ATLAS/CMS = 31/21) \rightarrow to be updated after Engineering Design Reviews
 - Recent schedule changes will most likely require additional funding

ATLAS

Pixel Trackers

Module Assembly

Bonn, Dortmund (TU&FH), Göttingen, MPP, Siegen, Wuppertal

Hamburg

Upgraded phase-2 pixel trackers: larger geometric acceptance, higher granularity, improved radiation hardness

Strong German involvement:

- RD53 readout chip
- Sensor design
- Module assembly
- **Tests & quality** assurance

Strip Trackers

Building one endcap each for ATLAS/CMS in Germany

- Phase-2 strip tracker upgrades: higher granularity, improved radiation hardness, input for Level-1 track trigger (CMS)
- Strong German involvement:
 - Sensors
 - Hybrids
 - Development/production of mechanical structures
 - Module assembly, tests & quality assurance
 - Integration into larger structures at DESY

Berlin, Dortmund, DESY, Freiburg

Aachen, DESY, Karlsruhe

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Muon Detectors & Fast Timing

Aachen

- ATLAS/CMS muon drift tube detectors: robust operation at highest particle rates
- German contributions:
 - Chamber production
 - Frontend electronics
 - Testing

ATLAS HGTD (high-granularity timing detector): LGAD modules for picosecond timing

Giessen, Mainz

Ulrich Husemann, KIT

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Calorimeters

- ATLAS: improved high-rate capability and trigger selectivity
 - LAr Calorimeter: signal processors and radiation-hard low-voltage power supplies
 - **Tile Calorimeter** off-detector readout electronics: TileCal PreProcessor
- CMS HGCAL

(high-granularity calorimeter):

- Highly segmented replacement for endcap calorimeter, precision timing
- **Synergies** with CALICE, e.g. module assembly & testing (CALICE technology also used for DUNE Near Detector)

ATCA carrier + 4 CPMs

HL-LHC Computing Challenges

- Compute resources required for HL-LHC most probably not covered by purchases on "sustained" budget → new model for resource provisioning being discussed
- R&D and prototyping in Germany (see M. Dührssen-Debling's presentation):
 - Common developments with neighboring science communities (astroparticle physics, hadrons and nuclei)
 - Example: heterogeneous resources at highperformance computing centers

Annual CPU

Summary & Outlook

Close connections to German particle phenomenology (see M. Mühlleitner's presentation)

additional funding for HL-LHC upgrades

- German groups: strong contributions to all aspects of ATLAS and CMS operations, calibration, computing, physics, upgrades, management
- Very stable funding support for ATLAS/CMS by three funding agencies,
- Looking forward to bright future at the HL-LHC with continued support

Thank You.

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 G. Quast, M. Schumacher, G. Steinbrück.

