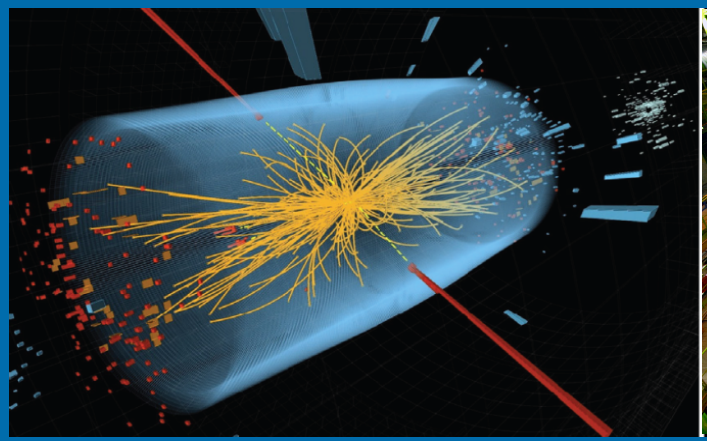
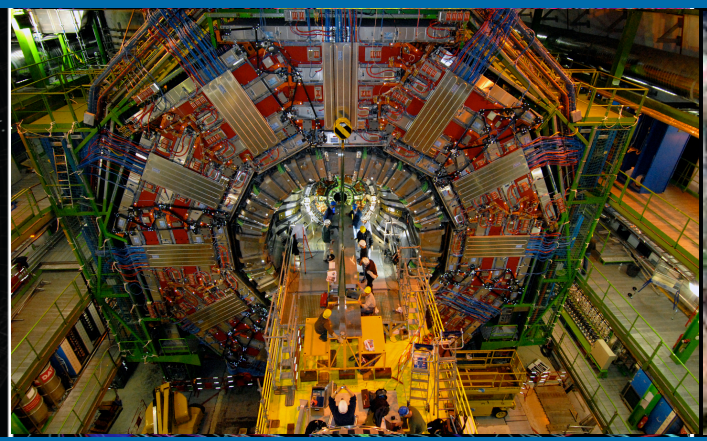
Matter and the Universe

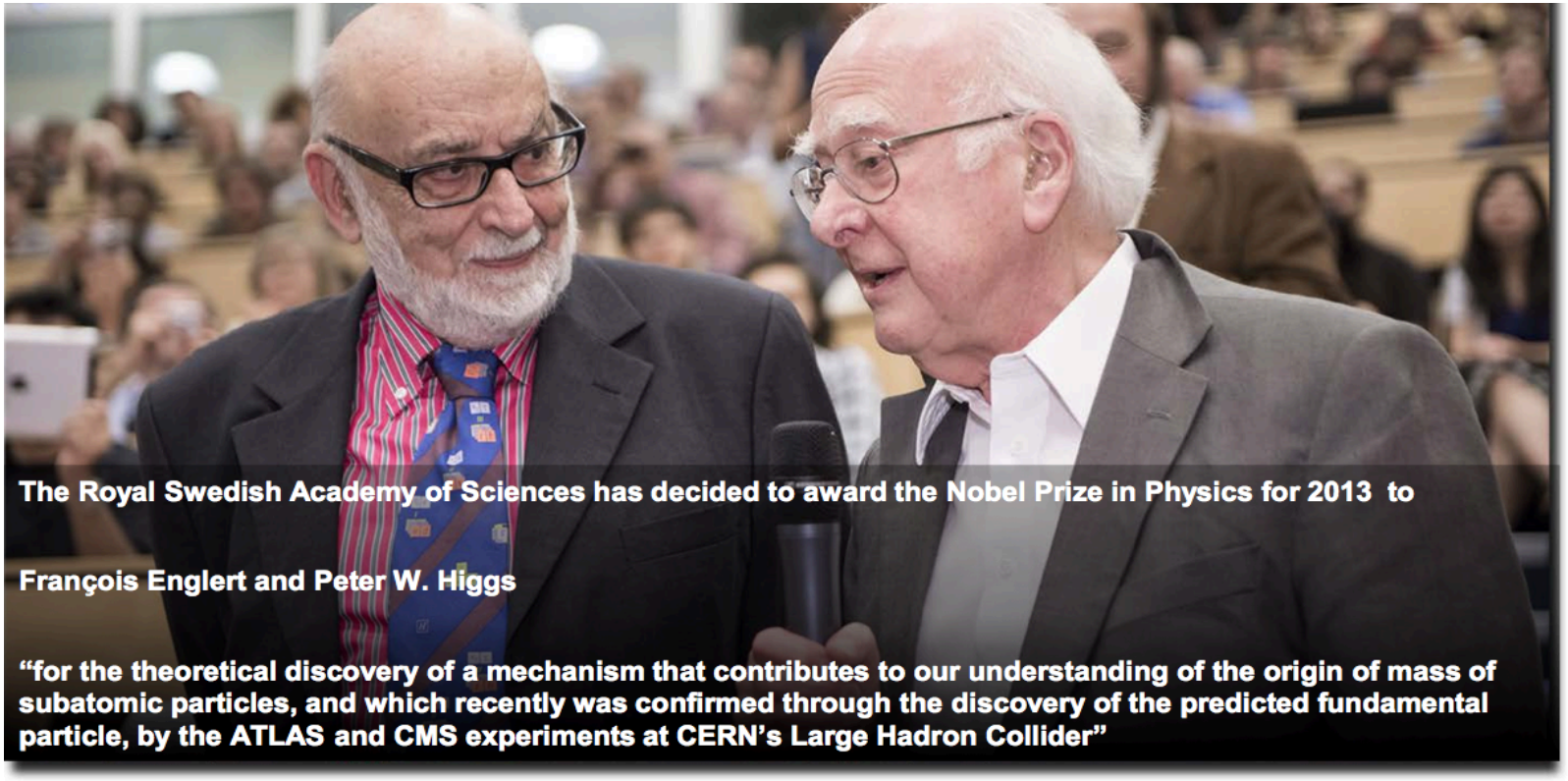
LHC – ATLAS & CMS


Isabell-A. Melzer-Pellmann – DESY

HELMHOLTZ ASSOCIATION

Helmholtz has a strong role in the Higgs discovery



Diese Hamburger halfen bei der Entdeckung des Teilchens

Etwa 150 Physiker aus der Hansestadt sind an den Experimenten mit den gewaltigen **Detektoren ATLAS und CMS** in Genf beteiligt

HAMBURG :: Die Suche nach dem Higgs-Teilchen und exotischen Partikeln ist ein Mammutprojekt: Etwa 10.000 Forscher aus aller Welt sind an den Experimenten mit dem Large Hadron Collider (LHC) beteiligt, einer 27 Kilometer langen Röhre, in der Zu[illegible] den, wie sie [illegible] heute bekannt sind – u[illegible] möglich solche, die wir bisher nicht kennen.

Den größten der vier Teilchendetektoren entlang des Beschleunigerringes nennen ATLAS und CMS. Allein CMS ist 21 Meter lang und mit einem Gewicht von 12.500 Tonnen fast doppelt so schwer wie der Eiffelturm. Zu den Forschern, die diese Geräte konstruiert haben und nun mit ihnen arbeiten, gehören auch etwa 150 Physiker

Kerstin Borras vom Desy ist seit Kurzem stellvertretende Sprecherin der CMS-Gruppe Foto: Desy

Am CERN in Genf weilte am Dienstag **Kerstin Borras**. „Hier war ein Riesenjubel", erzählte die stellvertretende Sprecherin des CMS-Experiments nach der Bekanntgabe. Sie und viele ihrer Kollegen hatten die Übertragung der Preisverkündung live verfolgt, die sich eine gute Stunde verzögert hatte. „Wir haben alle hier eine Stunde gewartet. Das war eine Superanspannung, die sich dann in einem Riesenapplaus lös-

Peter Schleper von der Uni Hamburg ist Vorsitzender des Komitees für Elementarteilchenphysik Foto: privat

Ebenfalls zur CMS-Gruppe gehört **Prof. Joachim Mnich**, Mitglied des Desy-Direktoriums. Er war bisher unter anderem am Aufbau des zentralen Spurdetektors des CMS beteiligt, mit dem Signale der durchfliegenden Teilchen gemessen werden.

Eine besondere Stellung hat **Prof. Peter Schleper** vom Institut für Experimentalphysik der Uni Hamburg. Seit 2012 ist der Forscher der Vorsitzende

Kerstin Tackmann leit[illegible] eine Nach-[illegible] zur [illegible] am DESY

schen Teilchenphysiker. Schleper ist Mitglied der CMS-Gruppe. Mit seinem Team entwickelte er einen Teil der Siliziumsensoren in dem Detektor. Diese erfassen die Bahnen der durchfliegenden Teilchen. Anhand dieser Bahnen können die Physiker am CERN auf die Energie der Teilchen schließen. Die Kombination der Energie mehrerer Teilchen wiederum gibt Auskunft über die Masse eines Teilchens (etwa des

gehören neben Schleper unter anderem die Physik-Professoren **Erika Garutti**, **Johannes Haller** und **Christian Sander**.

Erst 35 Jahre alt ist die Physikerin **Kerstin Tackmann**, und doch hat die Leiterin einer ATLAS-Nachwuchsgruppe am DESY schon einiges vorzuweisen. So [illegible] sie aus S[illegible] der Deutschen Physikalischaft (D[illegible] Teilchens bei [illegible] Dieses lässt sich nicht direkt nachweis[illegible] nationen von [illegible] fallskanäle. E[illegible] er ist der Zerfall in zwei Lichtteilchen [illegible] führte Studie[illegible] zu diesem Kanal durch und verbesse[illegible] denen sich der Zerfall berechnen lässt. Der ATLAS-Detektor wies das Higgs dann auch im Zwei-Photon-Kanal nach. Für ihre Arbeit wurde Tackmann von

CMS Deputy Spokesperson

Hertha Sponer award from German Physical Society

Helmholtz has a strong position in LHC

Strong LHC groups at DESY and KIT:

- 80 scientists (50% postdocs)
- 50 PhD students
- Undergraduates, engineers, technicians
- 6 Young Investigator Groups (YIG)

Significant management responsibilities:

Deputy Spokesperson, Publication Committee, Authorship Board, Conference Committee, Speakers Committee Advisory Board, Collaboration Board (deputy), Technical Coordinator (deputy), Physics Conveners (Top, SM, Forward Physics, Monte Carlo)

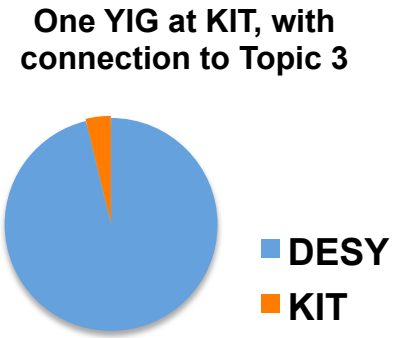
Contribution to key strategic areas in the ATLAS and CMS experiments:

- Detector upgrade
- Detector operation
- Physics analysis
- Computing

ATLAS, CMS and Theory located at the same institute

+ strong university groups in Hamburg, Karlsruhe and Berlin

→ essential synergies!



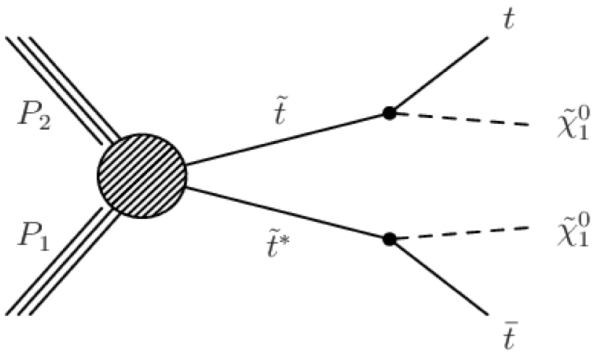
LHC Physics Highlights

First differential Higgs cross section measurement

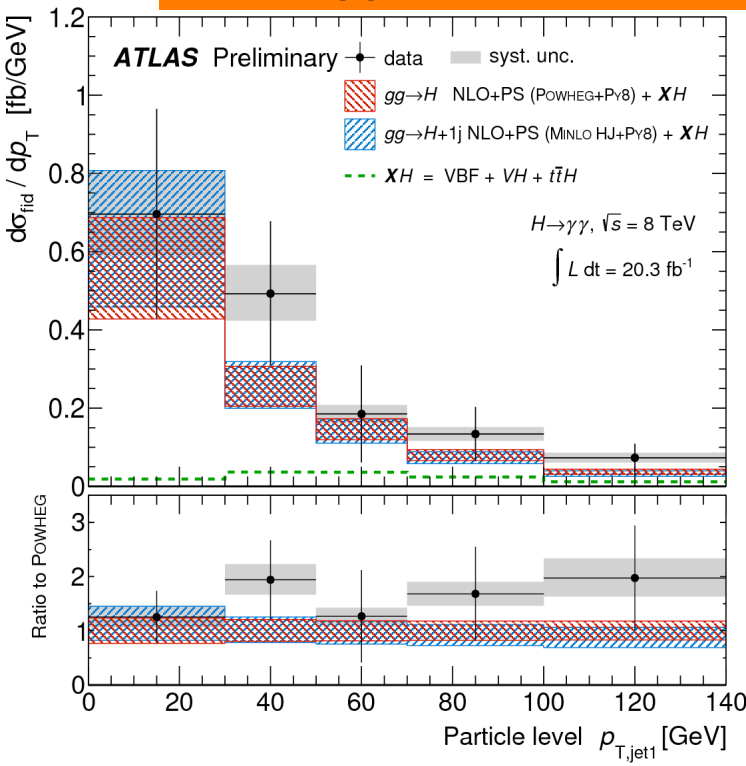
→ Better understanding the kinematics of Higgs production and decay

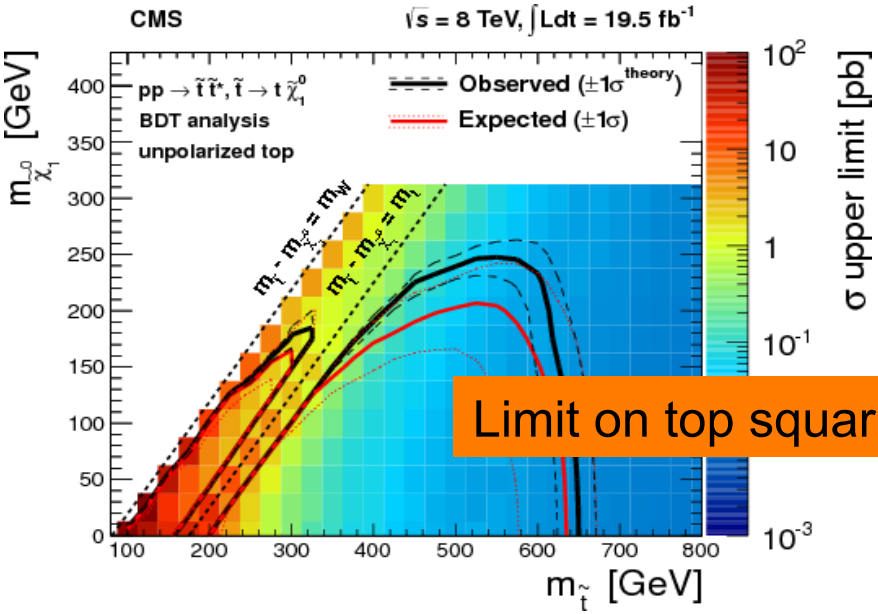
Large radiative corrections to Higgs mass not yet understood

→ Possible explanation: Cancelling due to additional new particles in loop diagrams, e.g. SUSY partner of top



Diff. Higgs cross section vs p_T^{jet}



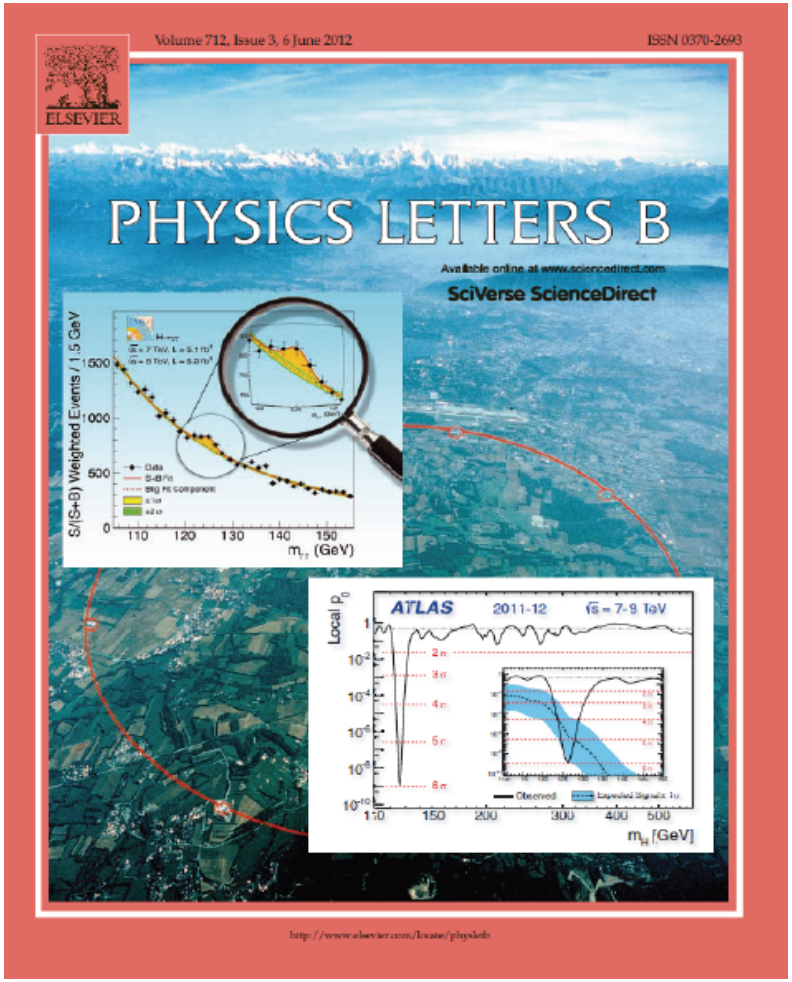


Limit on top squarks

LHC Research at the Forefront of Particle Physics

ALTAS and CMS published up to now ~400 papers, about 20% with direct contribution of Helmholtz groups

Physics area	ATLAS	CMS
Higgs analyses	5	14
Standard Model physics	15	13
Top quark measurements	3	11
Searches for new physics	13	6
Phenomenology papers	14	9

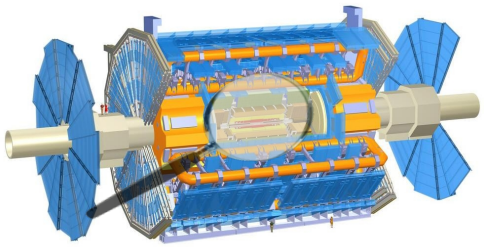


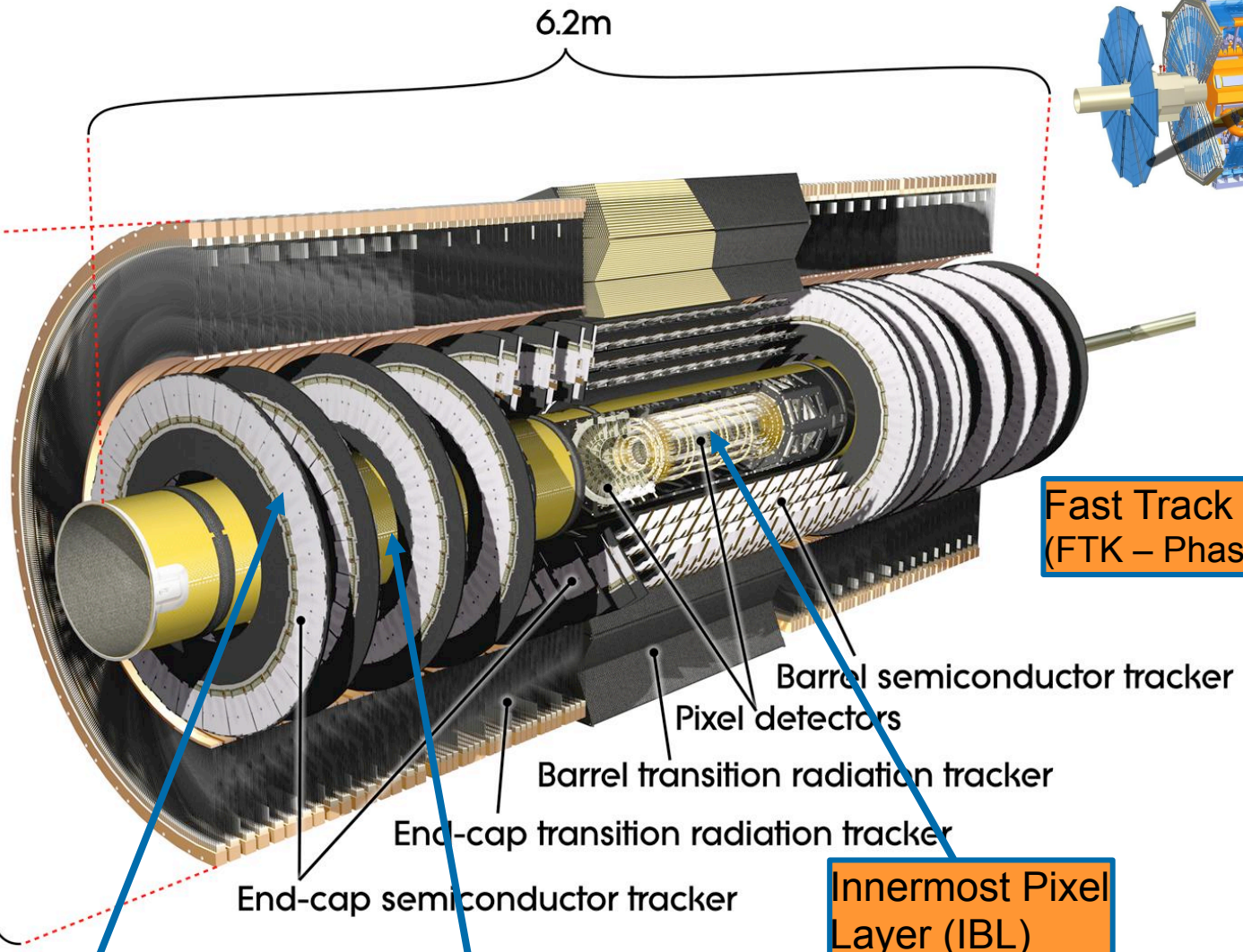
→ **Continue to fully exploit LHC physics potential**

→ **Preparation of 13 TeV analyses**

Contributions to ATLAS Components

Generic:
- Trigger
- eγ performance
- Jet calibration





~200 m

ALFA
(very forward detector)

Fast Track Trigger
(FTK – Phase 1 Upgrade)

Innermost Pixel Layer (IBL)

Silicon Tracker
(SCT – operation)

ITK Strip
(Phase 2 Upgrade)

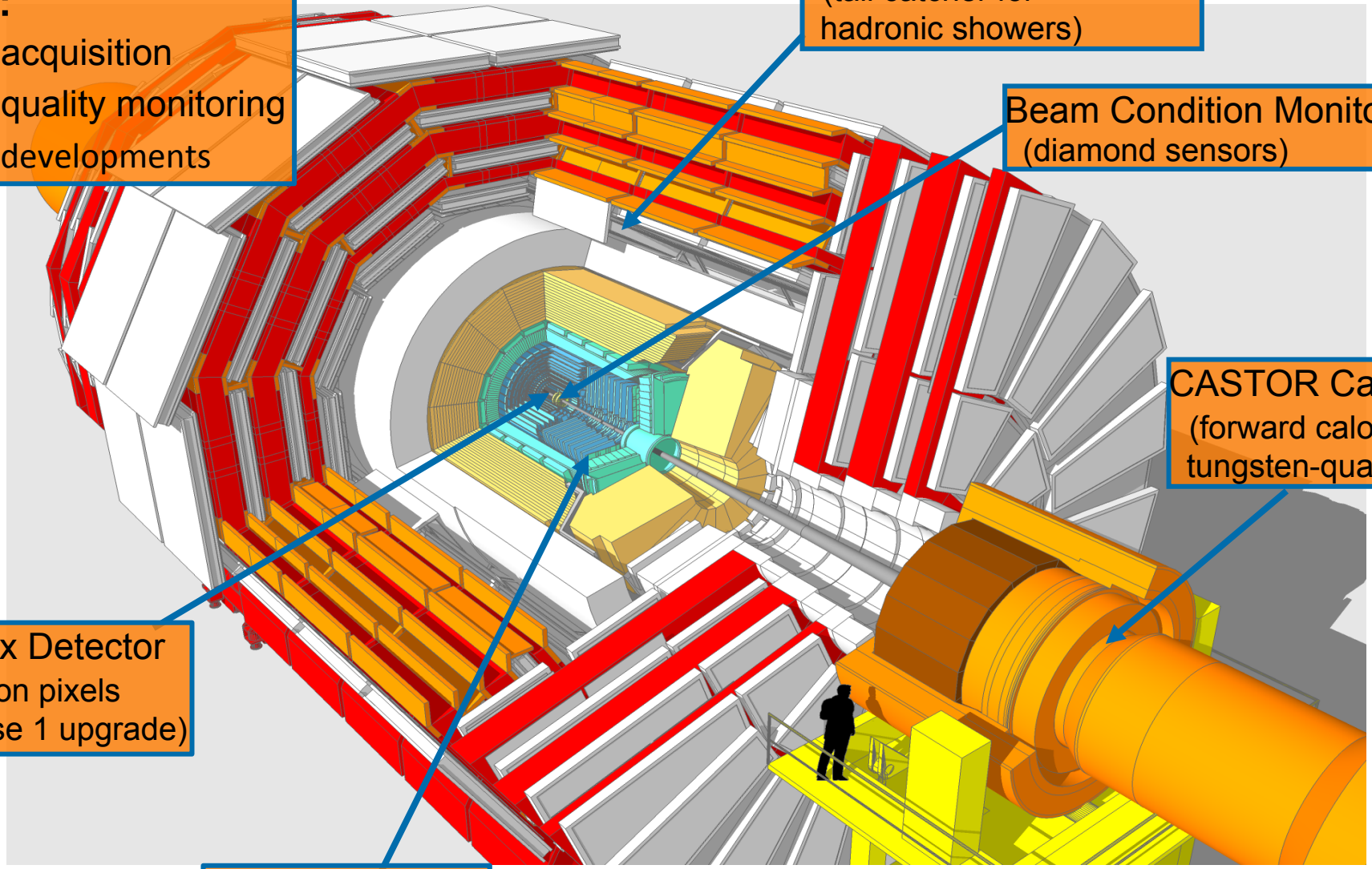
Contributions to CMS Components

Generic:
- Data acquisition
- Data quality monitoring
- µTCA developments

HCAL Outer Calorimeter
(tail catcher for hadronic showers)

Beam Condition Monitors
(diamond sensors)

CASTOR Calorimeter
(forward calorimeter tungsten-quartz plates)



Vertex Detector
(Silicon pixels Phase 1 upgrade)

Tracker Endcap
(Silicon strips Phase 2 upgrade)

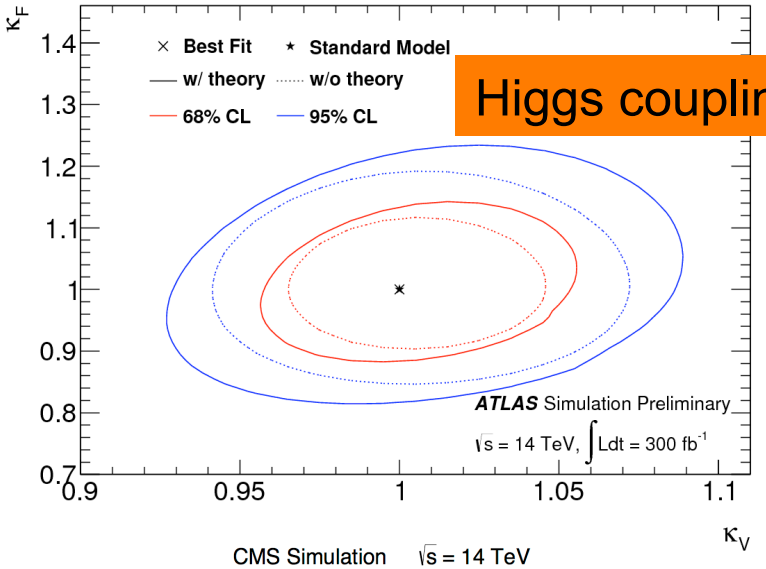
LHC Research Topics 2015-2019

Keep leading role in many physics areas exploiting higher energy and luminosity:

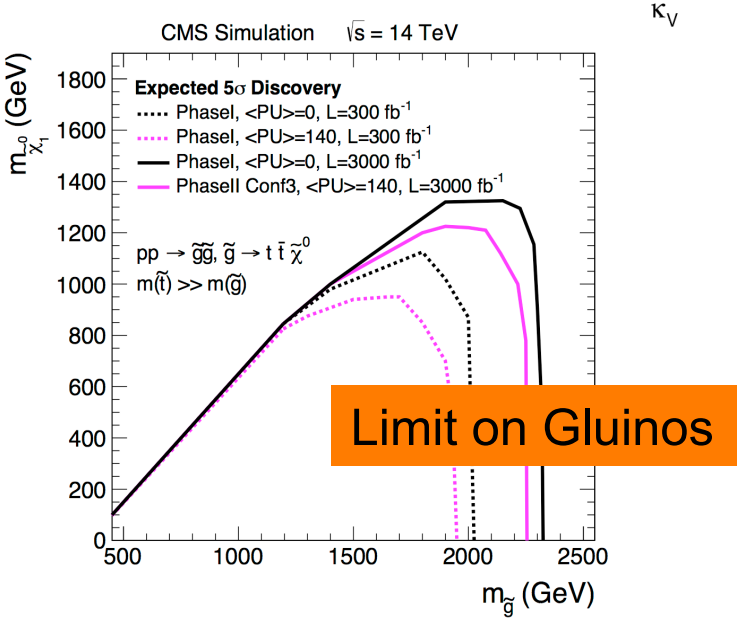
- **Higgs** precision measurements
  - Couplings
  - Properties
  - Higgs physics as probe for new physics

  → Understanding the origin of mass
- Extend **searches** for new particles
  - Supersymmetry

  → Finding and understanding Dark Matter
- Use strength in **Standard Model precision measurements, including top,** as key to high sensitivity searches

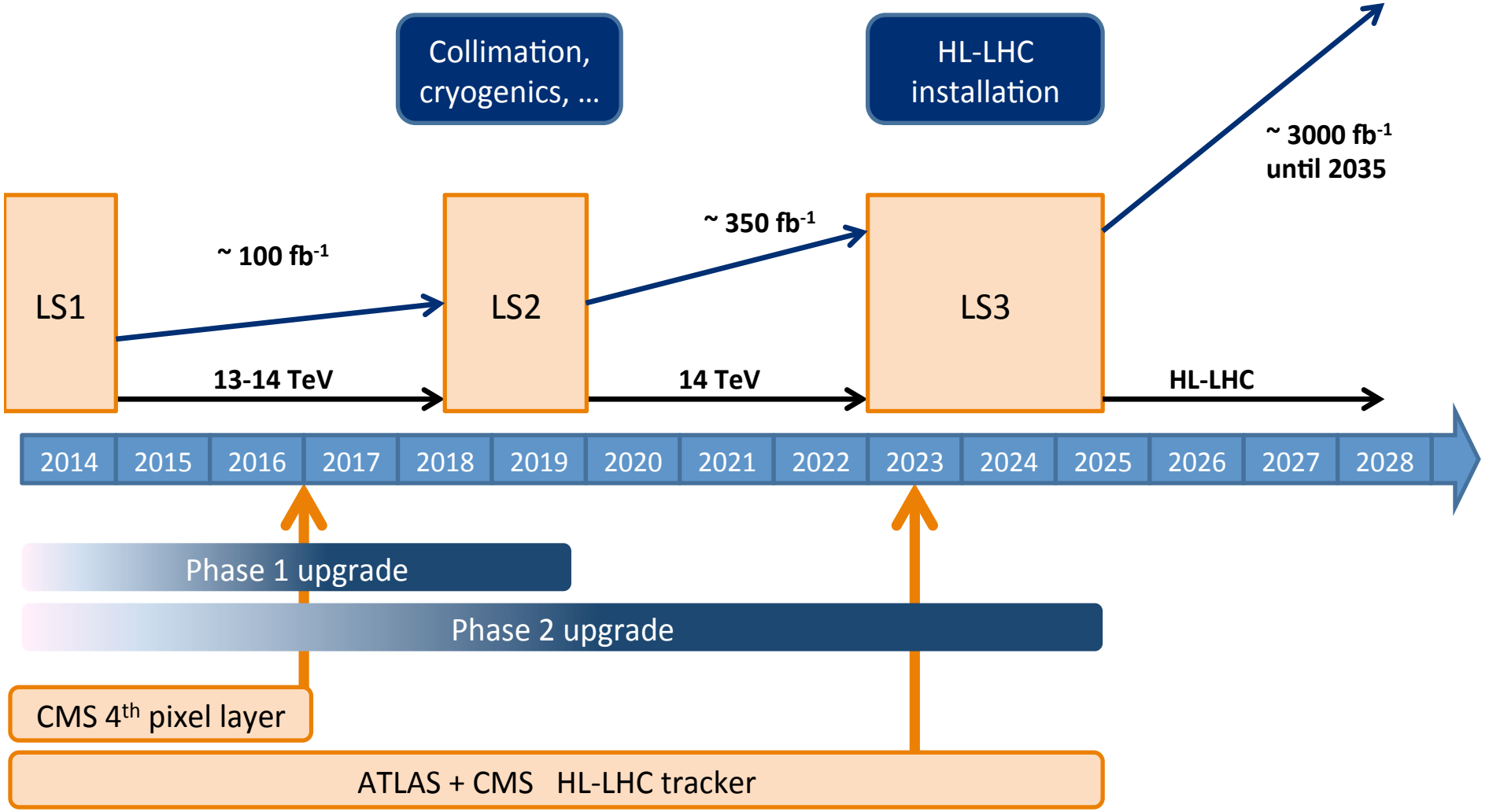


Higgs couplings



Limit on Gluinos

LHC Schedule – the Big Picture



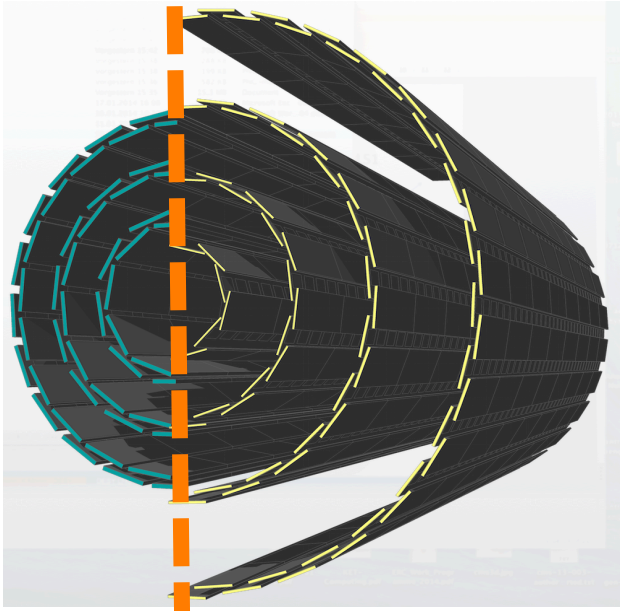
In preparation for Phase 2 upgrade:

Generic R&D on new silicon based detectors (link to **Matter and Technology**)

Phase 1 LHC Detector Improvements

CMS: 4th layer of pixel detector

- DESY to build outer layer in collaboration with German universities
- DESY's tasks:
  - Produce ~50% of the modules
  - Assemble the complete 4th layer



CMS pixel detector

ATLAS: additional innermost layer (IBL)

- DESY's contributions:
  - Test beam campaigns
  - Responsibility for the optical fibres for signal transport
  - Fast Track Trigger

Going beyond 300 fb^{-1} → High-Luminosity-LHC

Significant gain in physics reach with 3000 fb^{-1}:

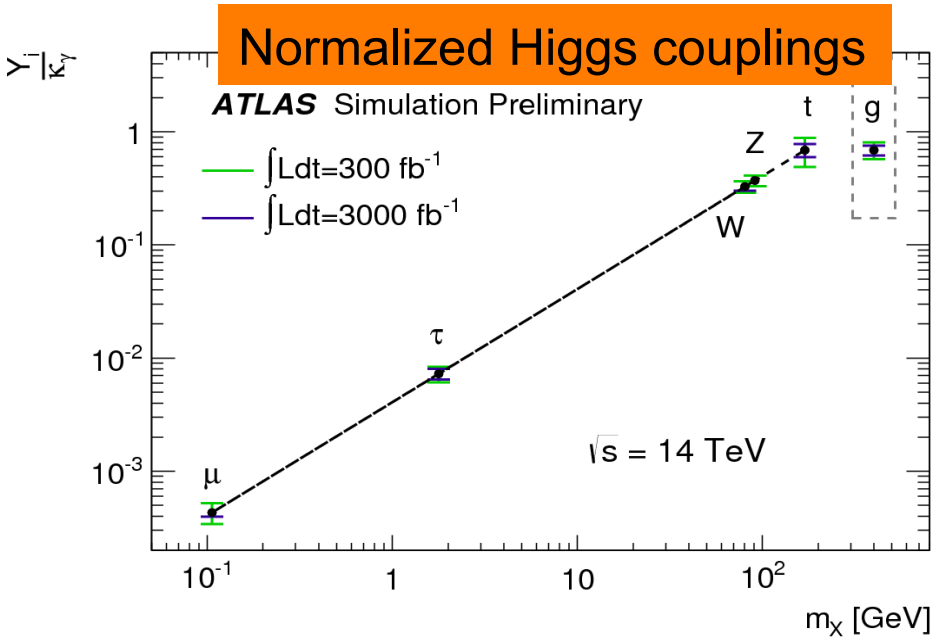
- Couplings of the Higgs boson can be measured at the 5% level (based on theoretical assumptions)
- First glimpse of Higgs self-coupling
- Search reach in channels with low cross section significantly increased

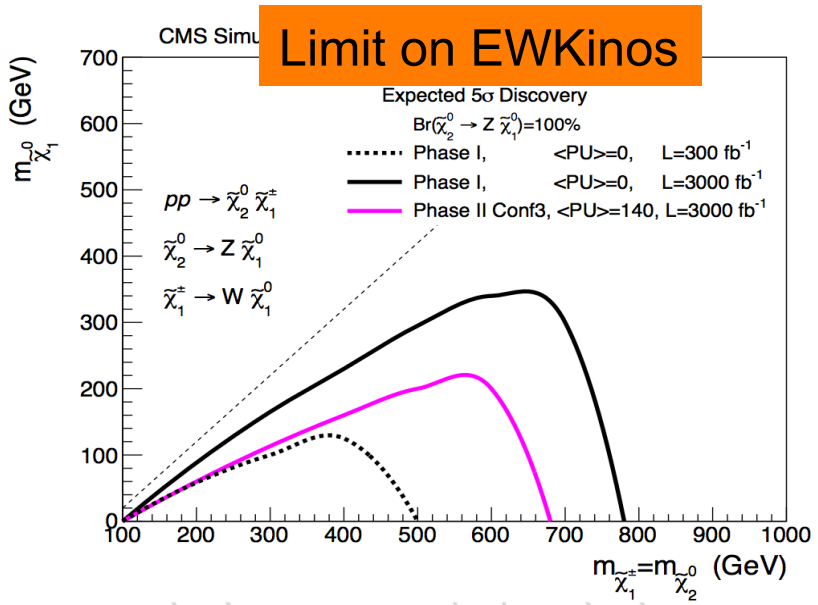
→ Testing naturalness

Problem: Current tracking detectors only designed for Phase 1 luminosity (300-500 fb^{-1})

→ Will reach end of their lifetime by 2022

→ Need to be replaced by **improved tracking detectors**





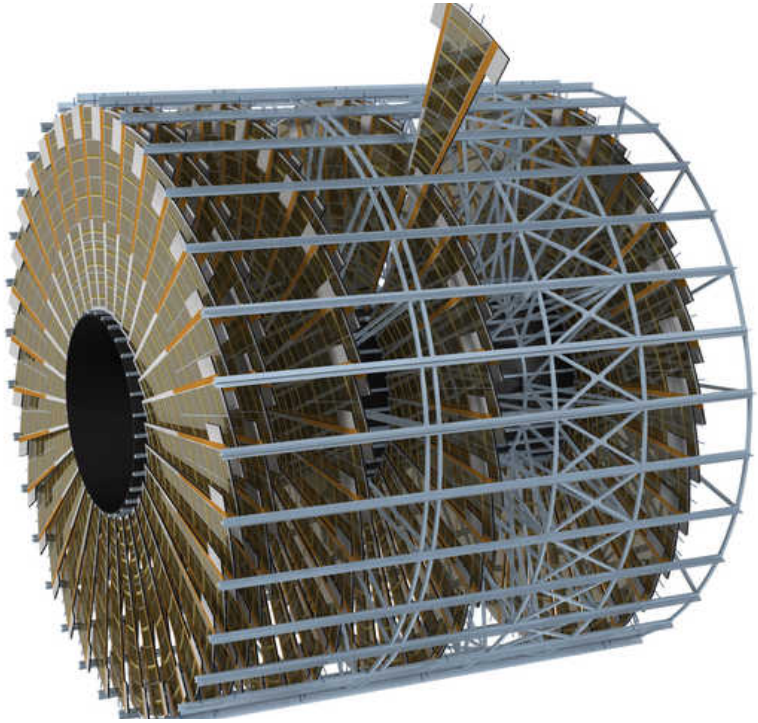
Phase 2 Upgrade Program: Improved Tracking Detectors

DESY was accepted at the LHC without significant hardware contributions!

→ **For the Phase 2 tracker upgrade we must fulfil our role as a national lab**

Contributions from DESY:

- Strong **R&D** for new silicon based trackers
- Building of one **endcap** detector for each of the two experiments in collaboration with German universities
- Provide the infrastructure for the **final assembly**



→ **Capital investment (Helmholtz) needed for detector construction: proposal in preparation for 23.8 M€** (assembly hall to be financed by DESY)

Helmholtz @ LHC – Summary and Conclusion

Highest priority tasks for 2015-2019:

- Tracker and pixel detector upgrades → large capital investment
- Physics analysis → shaping the future of the LHC physics program
- Detector operation

The **Tier-1** and **Tier-2** centers and the National Analysis Facility (**NAF**) are key to the scientific success at the LHC!

- **Maintain and develop our leading role in the LHC experiments**
- **In our role as a national laboratory we work with and provide support to the German universities!**

Thank you for your attention!

Additional information follows…

Leaders of Young Investigator Groups

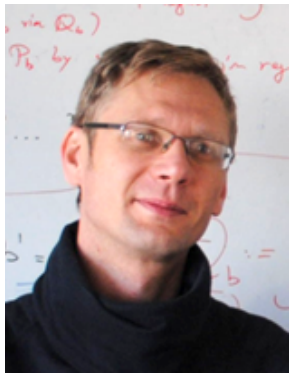
2014 María Aldaya Martín
CMS top physics

2012 Yvonne Peters
ATLAS top physics

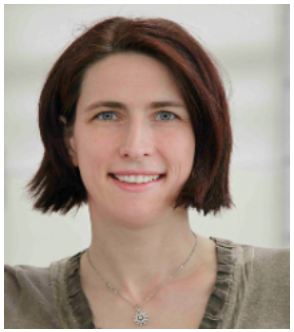
2011 Kerstin Tackmann
ATLAS Higgs

2011 Ralf Ulrich
CMS Forward physics
and Pièrre Auger

2009 Alexei Rasperezza
CMS Higgs



2009 I. Melzer-Pellmann
CMS SUSY



List of PhD Theses completed: ATLAS 13

July 2013	Clemens Lange	A novel approach to precision measurements of the top quark-antiquark pair production cross section with the ATLAS experiment
April 2013	Valentina Ferrara	Extraction of the top quark mass from the total top quark pair production cross section in the single lepton channel
December 2012	Martin Wildt	Search for new physics in diphoton and missing transverse energy final states using the ATLAS detector at the LHC
July 2012	Dörthe Kennedy	Search for Supersymmetry in Tau Final States at ATLAS and Constraints on New Physics Using Electroweak Precision Data
May 2012	Mikhail Karnevskiy	Measurement of the Z Boson Production with the ATLAS Experiment at the LHC
March 2012	Sebastian Johnert	Measurement of the W → Tau Nu Cross Section in Proton-Proton Collisions at ATLAS and the Development of the HepMCAnalysis Tool
March 2012	Michael Böhler	Exclusive Search for Supersymmetry with Same-Flavour Di-Lepton Final States with the ATLAS Detector
September 2011	Martin Goebel	Tests of the Electroweak Standard Model and Measurement of the Weak Mixing Angle with the ATLAS Detector
May 2011	Gordon Fischer	Determination of the tau-lepton reconstruction and identification efficiency using Z -> tautau events in first data at ATLAS
March 2011	Björn Gosdzik	Identification of Hadronic Tau Decays and Observation Potential of CP-Violating Effects in SUSY at ATLAS
May 2010	Sascha Mehlhase	Development of a Data-Driven Algorithm to Determine the W+Jets Background in ttbar Events in ATLAS
April 2010	Sami Kama	Automatic Monte-Carlo Tuning for Minimum Bias Events at the LHC
October 2009	Mark Terwort	Study of GMSB Models with Photon Final States Using the ATLAS Detector

ATLAS PhD Theses ongoing: 20

List of PhD Theses completed: CMS 12

Cipriano, Pedro	Forward-Central Jet Correlations in pp Collisions at CMS	PhD	28.1.14
Schettler, Hannes	The Event-Mixing Technique for Modeling the tt Background in a Search for Supersymmetry in the Di-Lepton Channel	PhD	20.8.13
Bethani, Agni	Neutral Higgs boson searches in the H−>ττ−>μμ decay channel	PhD	19.6.13
Novgorodova, Olga	Characterisation and Application of Radiation Hard Sensors for LHC and ILC	PhD	28.3.13
Behrenhoff, Wolf	Measurement of differential tt cross sections in the dilepton decay channels with the CMS detector at 7 TeV centre-of-mass energy	PhD	14.9.12
Stein, Matthias	Search for SUSY in Same-Sign Di-Lepton Events with the CMS Detector	PhD	21.6.12
Hauk, Johannes	Measurement of Associated Z0-Boson and b-Jet Production in Proton-Proton Collisions with the CMS Experiment	PhD	30.5.12
Sen, Niladri	Measurement of the Energy Flow at Large Pseudorapidities for $\sqrt{s}$ = 0.9 TeV and $\sqrt{s}$ = 7 TeV at the Large Hadron Collider using the Compact Muon Solenoid	PhD	24.10.11
Marienfeld, Markus	Measurement of the Top Quark Pair Production Cross Section in the Muon-Electron Decay Channel in Proton-Proton Collisions at $\sqrt{s}$ = 7 TeV with the CMS Experiment	PhD	7.11.11
Dammann, Dirk	Production Cross Section Measurement of Top–Antitop Pairs in the Dimuon Decay Channel at $\sqrt{s}$ = 7TeV with the CMS Experiment	PhD	27.4.11
Flossdorf, Alexander	Higher Order QCD Radiation in Top Pair Production with the CMS Detector	PhD	31.8.09
Rosemann, Christoph	Measurement of Top Quark Properties from Pair Production and Decay with the CMS Detector	PhD	1.11.08

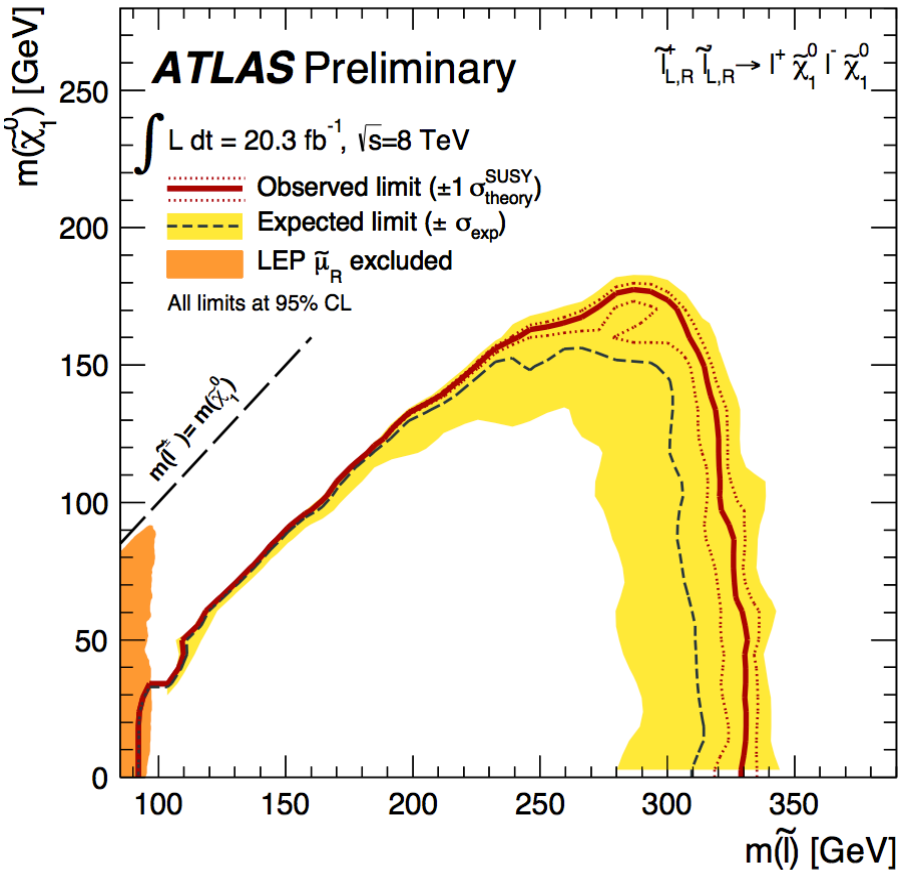
CMS PhD Theses ongoing: 28

LHC groups – detector and analysis related work

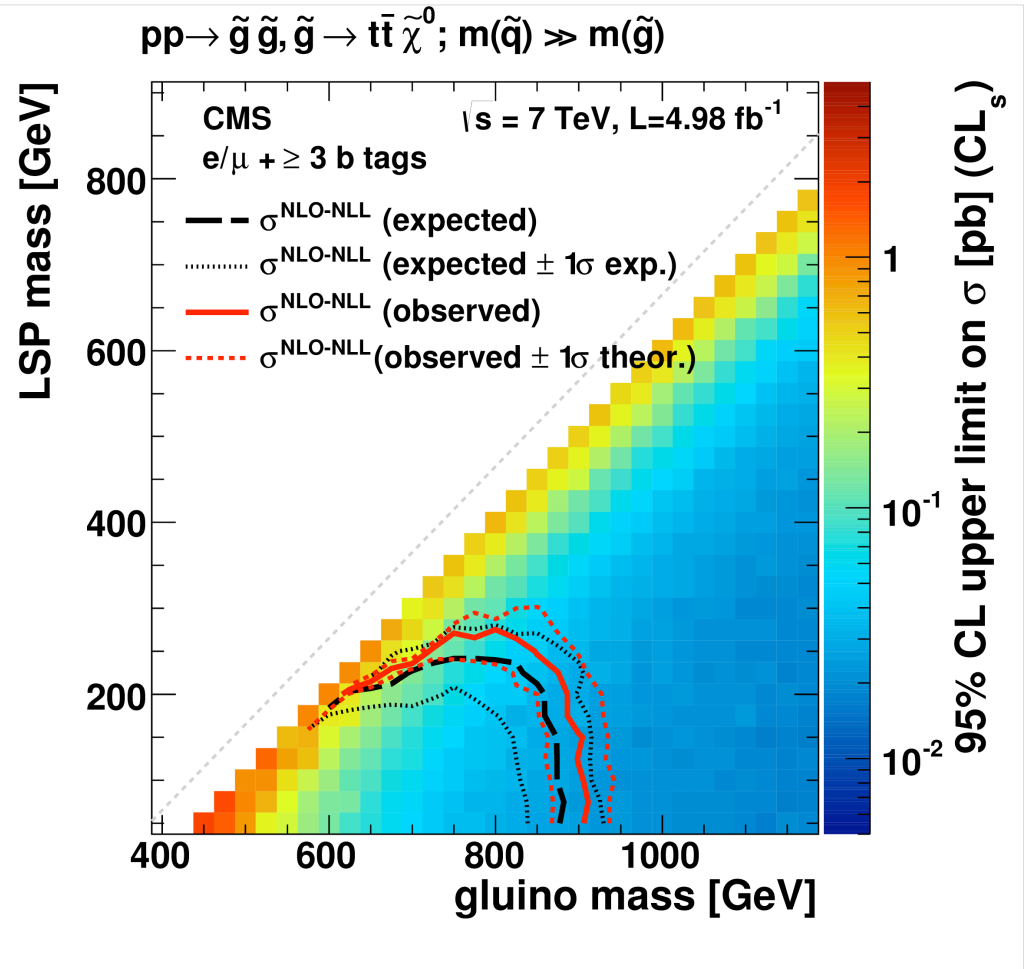
The long list of key responsibilities and significant contributions shows the impact of the groups at the LHC:

- Data and analysis related work:
    - MC generator interfaces, conditions database, e-gamma reconstruction, Tracker alignment, Data Quality monitoring, Remote Operations Centres, b-tagging for Higgs, lepton trigger for top
- Detectors and operations related work:
    - SCT operations, ALFA, IBL, CASTOR, BCM1F, BCM4LHC, DAQ, µTCA

Helmholtz Contributions to SUSY Searches



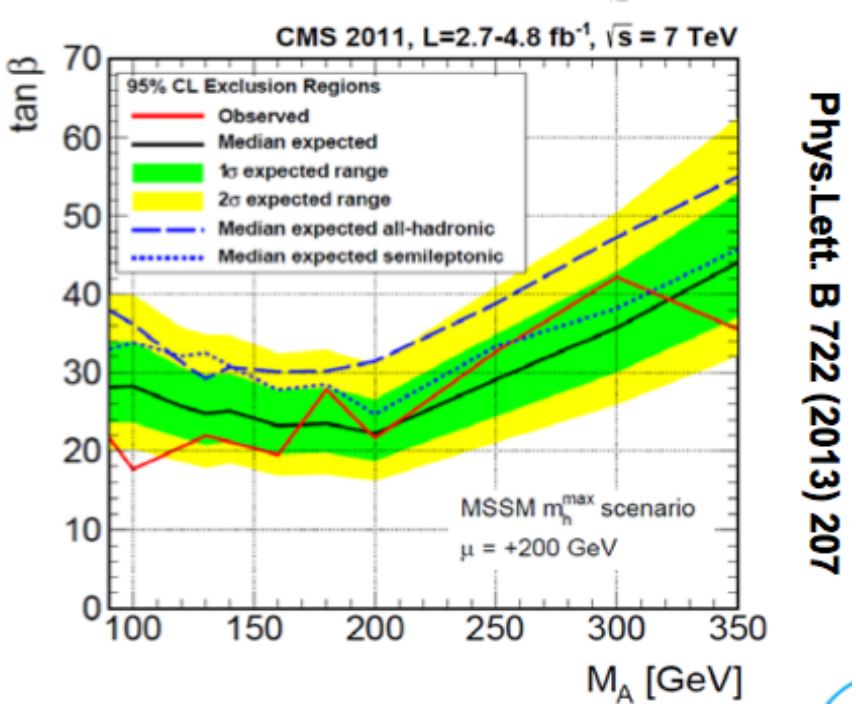
Limit on slepton mass



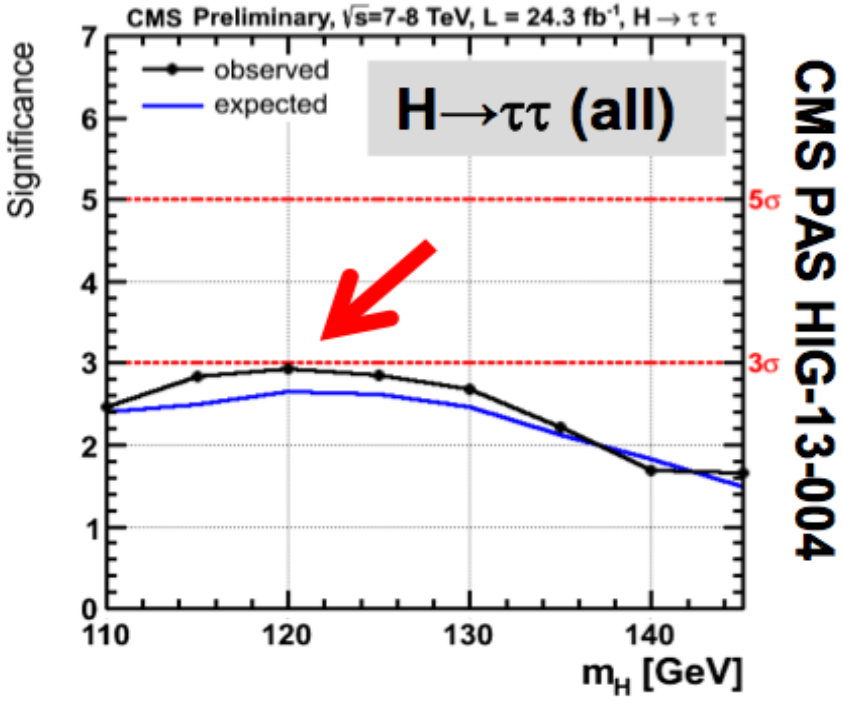
First limit on gluino mass decaying to 3rd generation squarks

PRD 87, 052006 (2013)

Helmholtz Contributions to MSSM Higgs and H→ττ



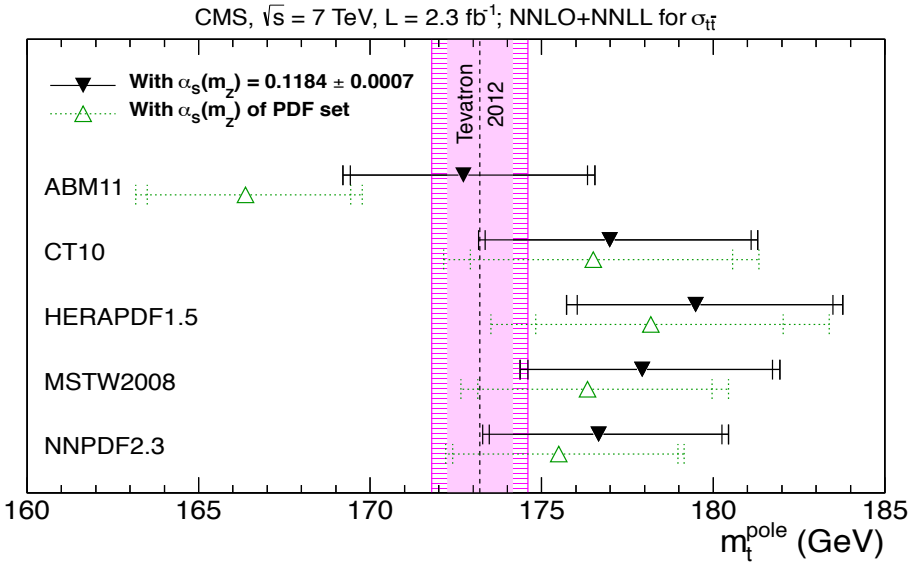
MSSM 7 TeV H->bb analysis:
World-best sensitivity in this channel



Higgs decaying into tau pairs
measures leptonic couplings

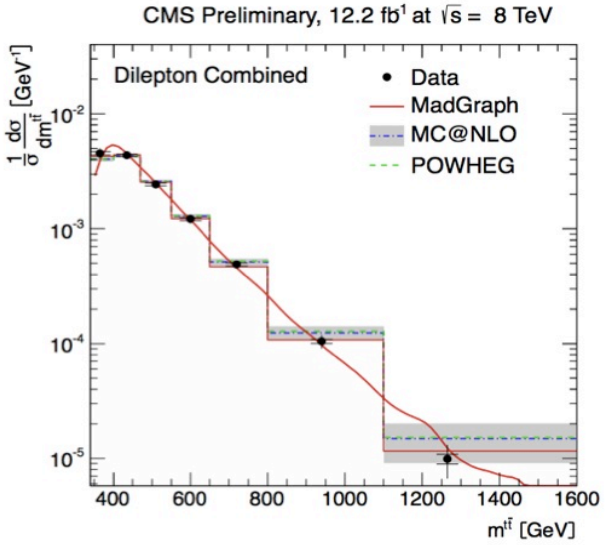
Helmholtz Contributions to Top Physics

Top Quarks: unique means to challenge the SM and the key for BSM physics



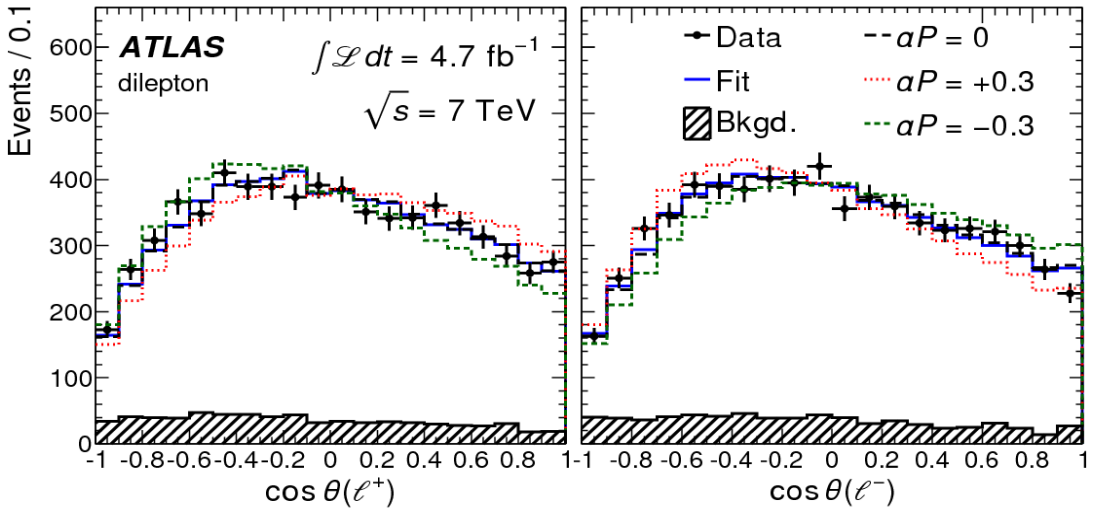
PLB 728 (2013) 496

Determination of top-quark pole mass from top-quark-pair cross sections



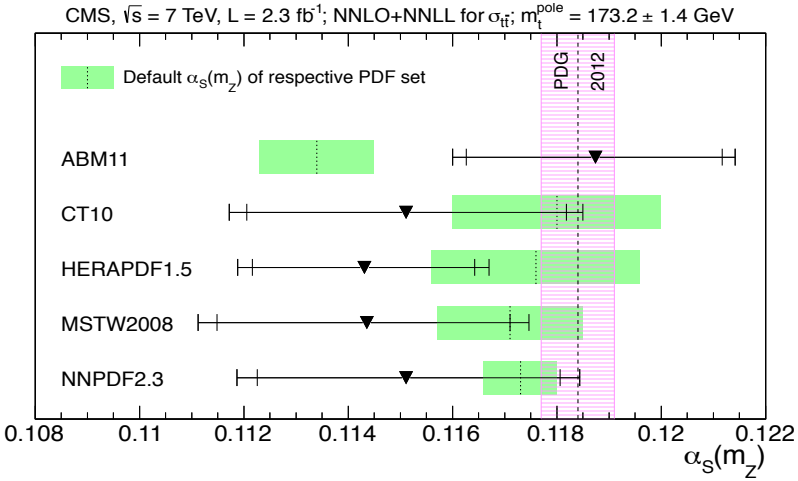
EPJ C73 (2013) 2339, CMS-PAS TOP-12-028

Differential top-quark-pair cross section



PRL 111 (2013) 232002

Top quark polarization in top-quark-pair events consistent with SM

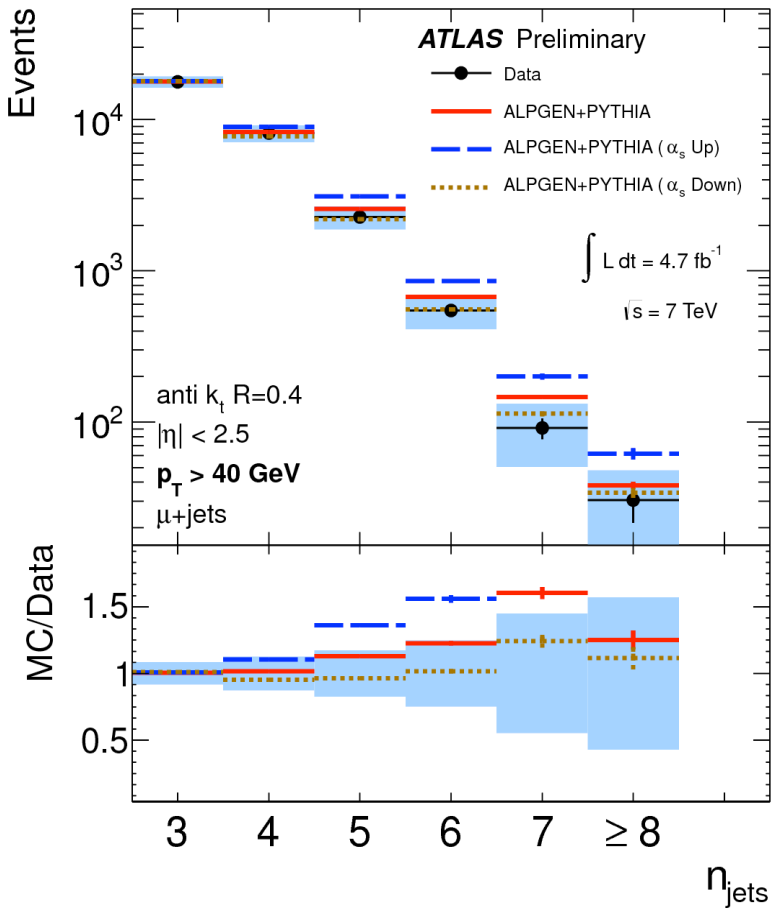


PLB 728 (2013) 496

First determination of α_S from top-quark-pair cross sections

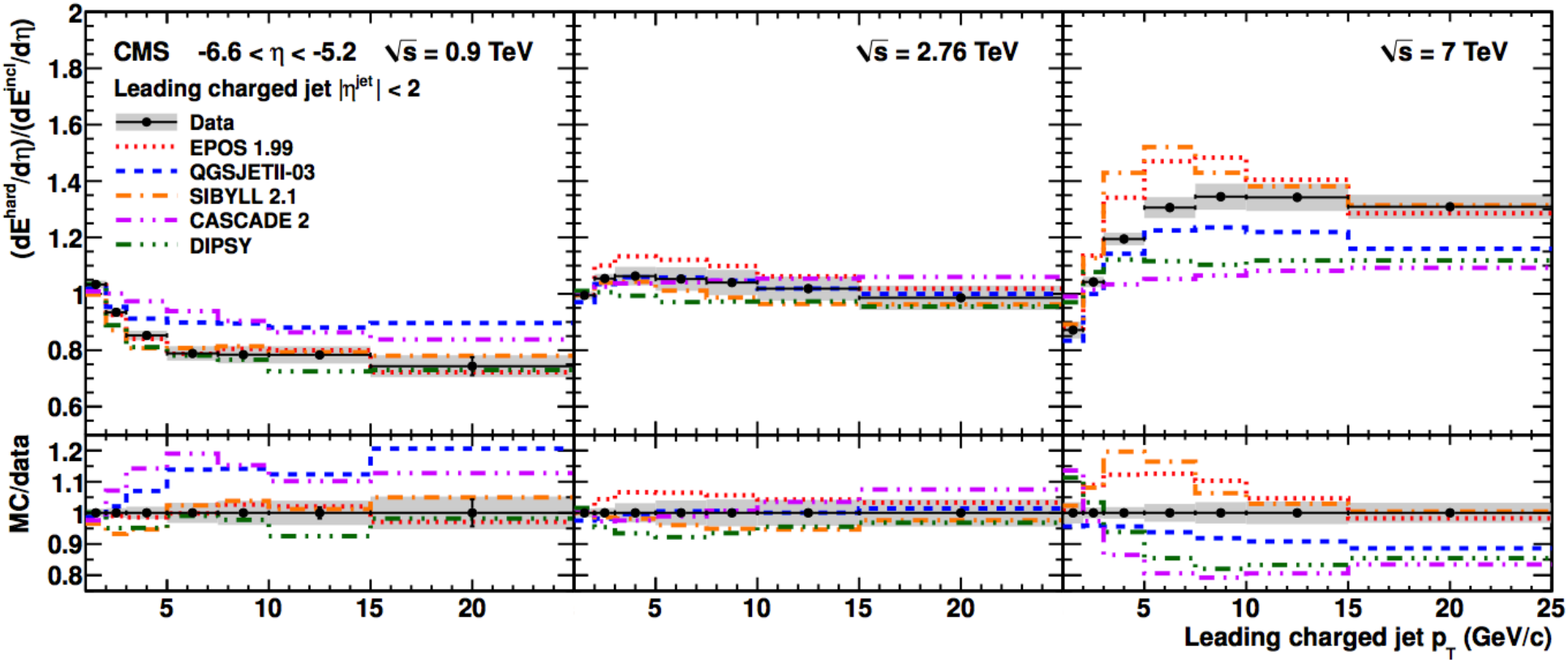
New YIG in Top Quark research: Maria Aldaya, in cooperation with UHH & KIT

Helmholtz Contributions to Top Physics



Jet multiplicity in top-anti-top final states

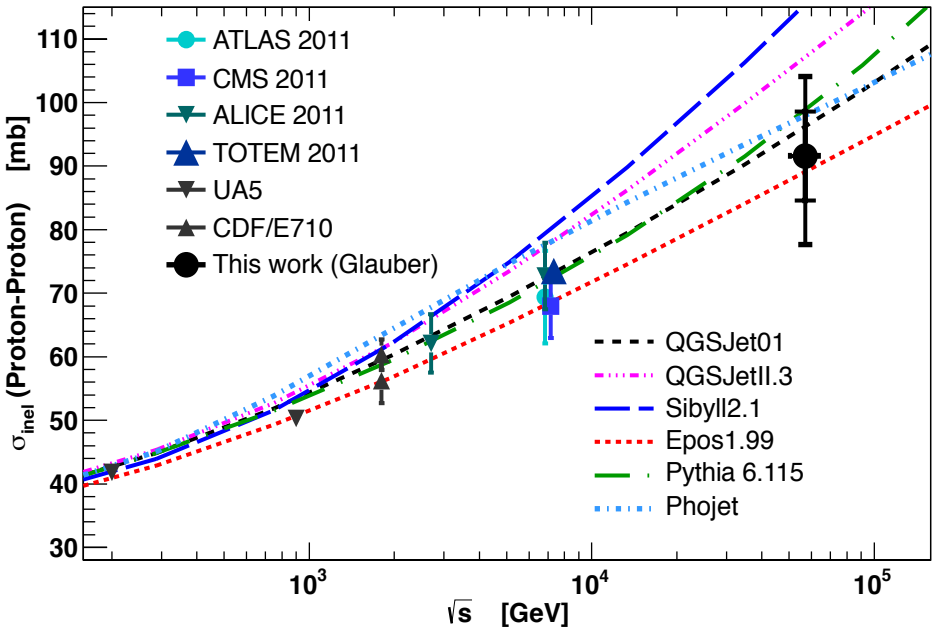
Helmholtz Contributions to Forward Physics



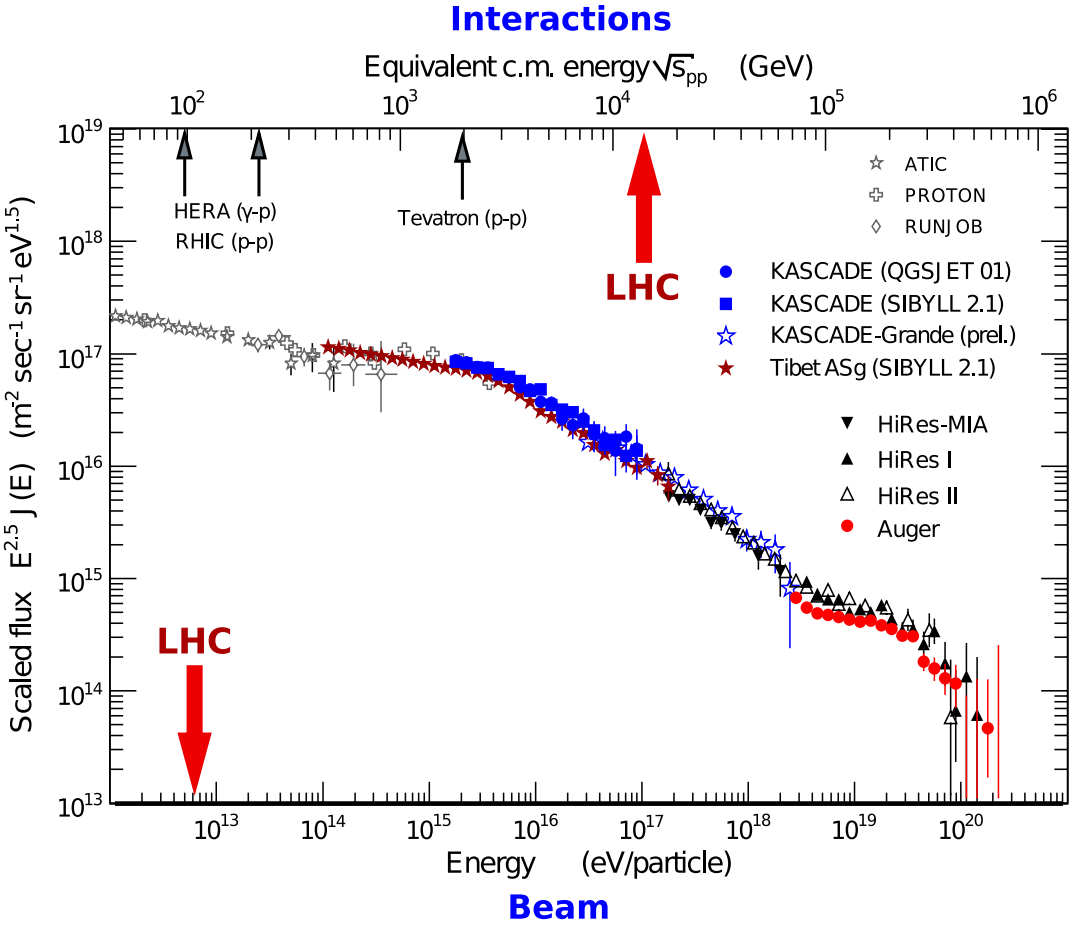
Forward energy flow including CASTOR

Testing MC models used in cosmic ray physics with LHC energies
→ Connection to Topic 3

Helmholtz Contributions to Forward Physics and Connection to Topic 3



Testing MC models used in cosmic ray physics with LHC energies
→ Connection to Topic 3



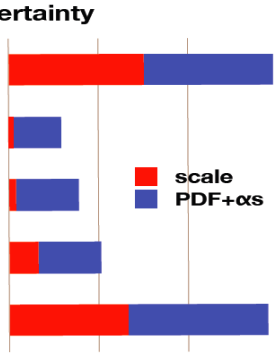
Helmholtz Contributions to Proton Structure

The HERA legacy is continued with the HERAfitter www.herafitter.org

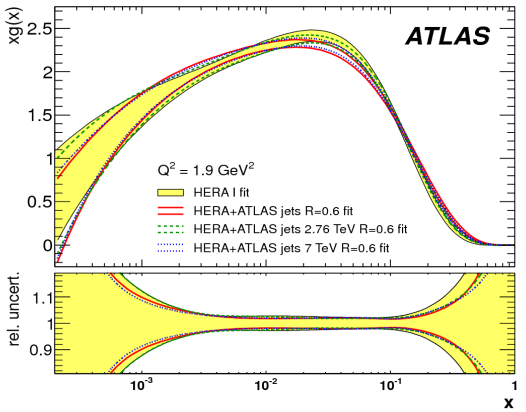
Used at the LHC to improve constraints on the proton structure

Accuracy of proton structure important for the Higgs and searches

		σ (8 TeV)	uncertainty
NNLL QCD +NLO EW	gg→H	19.5 pb	14.7%
	VBF	1.56 pb	2.9%
NNLO QCD +NLO EW	WH	0.70 pb	3.9%
	ZH	0.39 pb	5.1%
NLO QCD	ttH	0.13 pb	14.4%



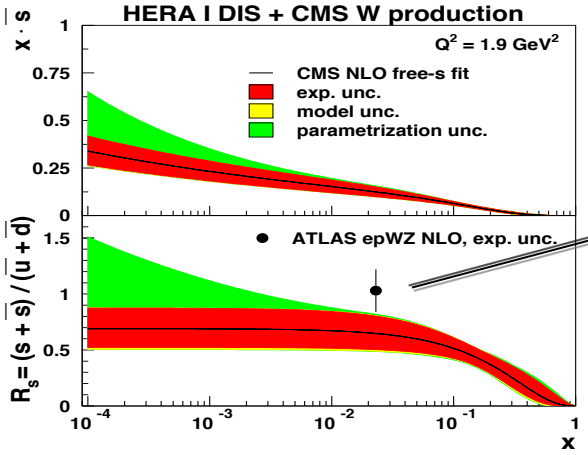
Improved gluon distributions using jet production



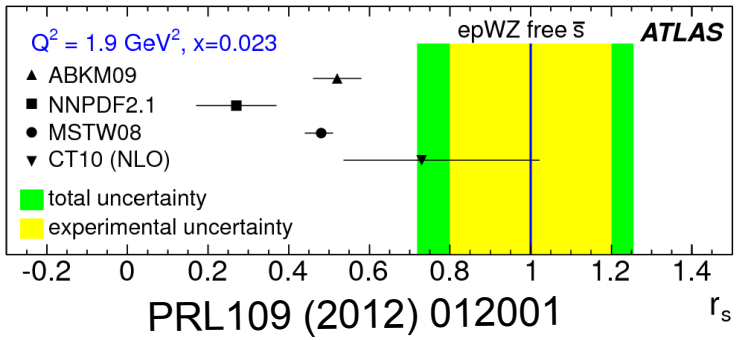
EPJC (2013) 73 2509

Determination of the strange-quark density at hadronic collider using W, Z and associated W+c production

arXiv:1312.6283



Strange-quark fraction in the proton using W -> l nu and Z -> ll



PRL109 (2012) 012001

Detector Operation Tasks in the Past

- CMS:
  - Significant fraction of the data-quality monitoring tasks, assessing the quality of new data and releasing them for physics analysis
  - Leading role in the alignment of the inner tracker exploiting Millepede, a method originally developed at DESY and the University of Hamburg during the HERA programme
- ATLAS:
  - Coordination of the prompt reconstruction of the data and the production of simulated events; also responsible for the “conditions database”
  - Responsibility for the maintenance of the interfaces of event generators to the ATLAS simulation software package

Detector Operation Tasks 2015-2019

Future:

- CMS: continuing tasks from Run 1
  - Significant fraction of the data-quality monitoring tasks, assessing the quality of new data and releasing them for physics analysis
  - Leading role in the alignment of the inner tracker exploiting Millepede, a method originally developed at DESY and the University of Hamburg during the HERA programme
  - In addition: operation of the silicon strip tracker
- ATLAS:
  - Coordination of the prompt reconstruction of the data and the production of simulated events; also responsible for the “conditions database”
  - Operation of the silicon strip tracker (SCT)

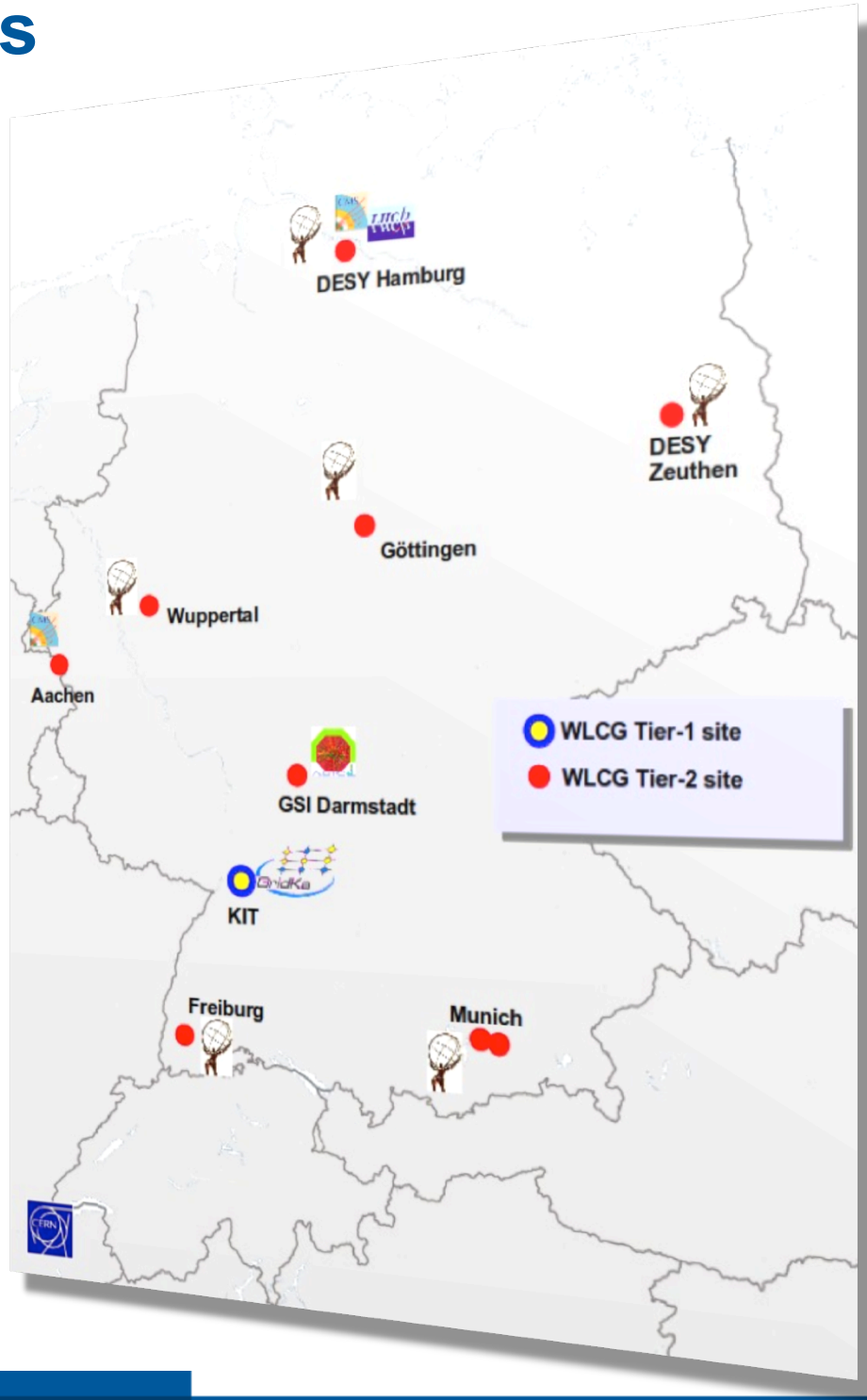
Computing for LHC Data Analysis

The Tier-1, Tier-2 centers and the National Analysis Facility (NAF) are key to the scientific success at the LHC!

The German Grid infrastructure includes the Tier-1 center at KIT, the Tier-2 centers at DESY, GSI, MPI and at University sites.

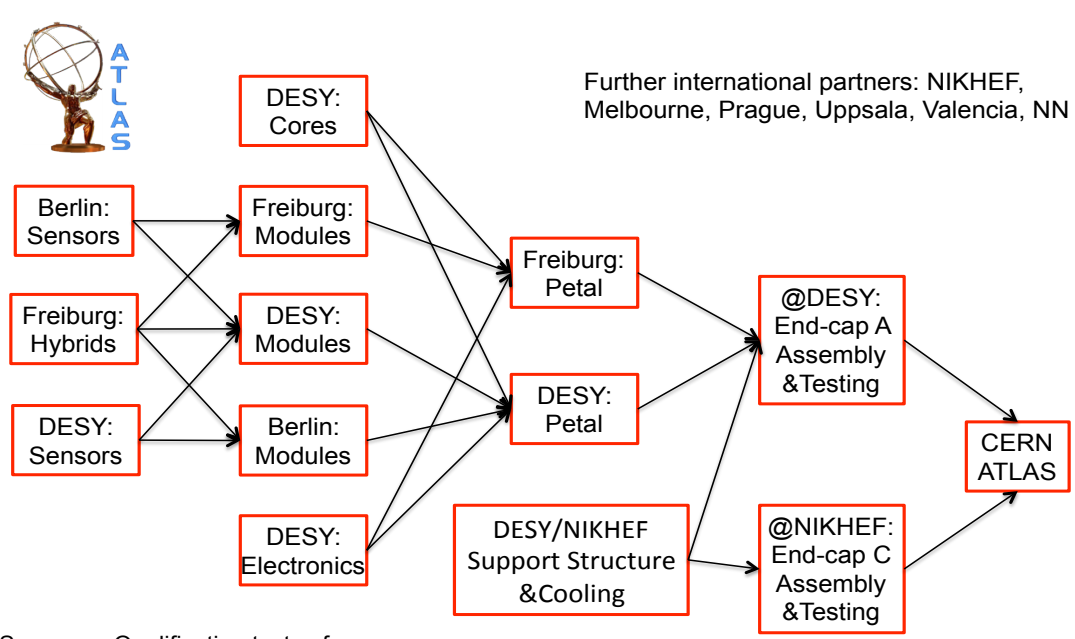
German sites rank among the most-used and most-efficient sites in the WLCG.

Sufficient funding is not secured yet for Tier-1 and Tier-2 resource replacements and upgrades.

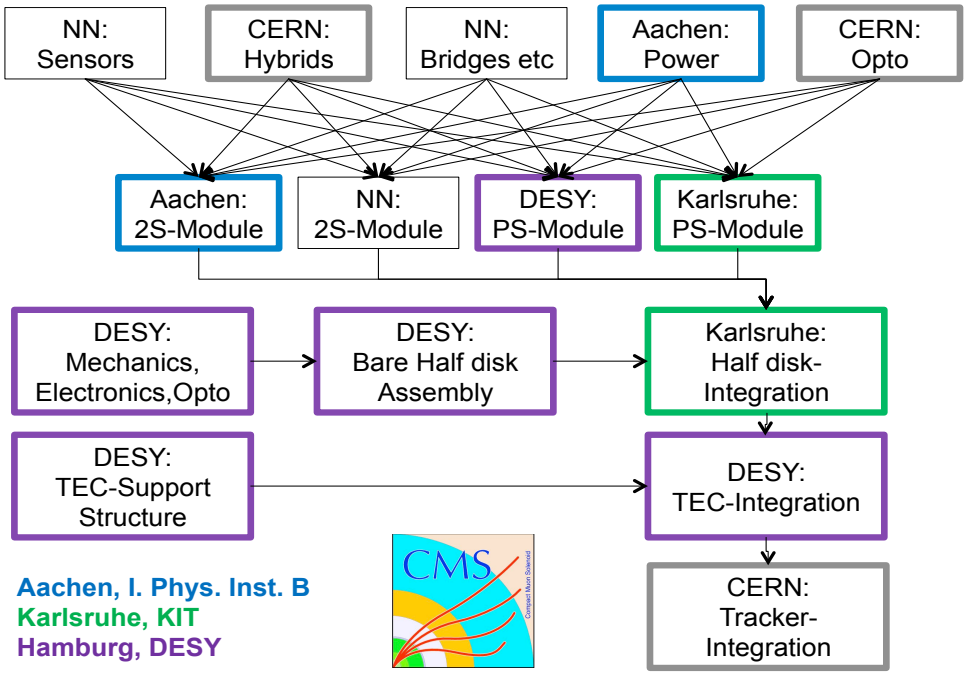


Detector upgrades for high luminosities

Detailed plans for a share of the workload within Germany in both collaborations:



Sensors = Qualification tests of sensors
Hybrids = design, construction and assembly of kapton boards with FE- electronics
Modules = placement of hybrids onto silicon sensors
Cores = construction of carbon fibre structure with cooling
Petal = assembly of full petal with modules and interface electronics



Plans already discussed with the funding agency (BMBF)

Capital Investment Proposal

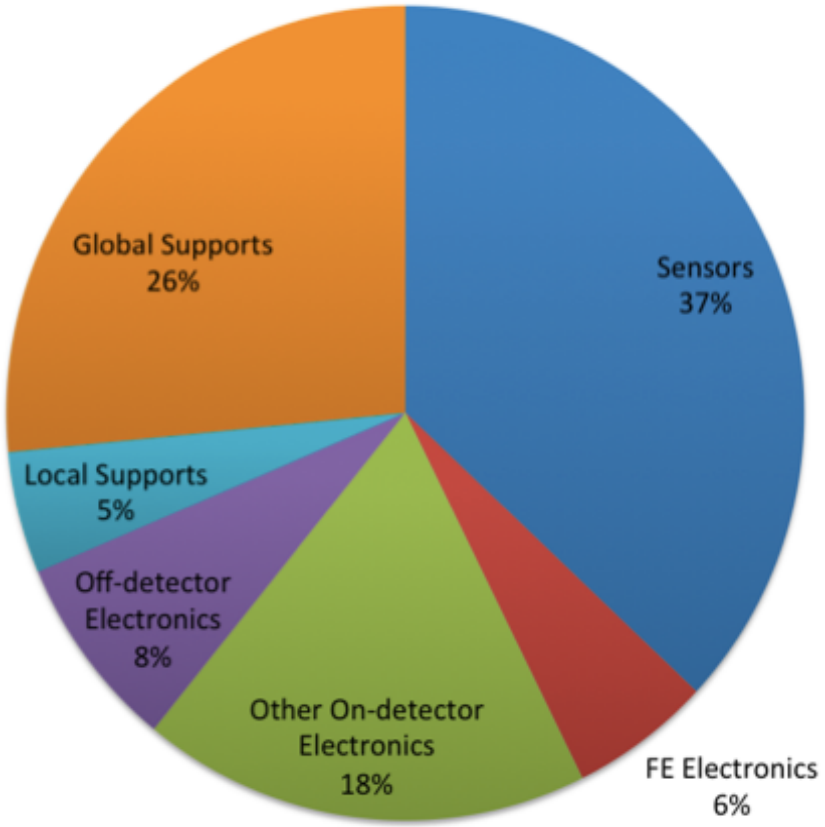
- Cost estimates based on ATLAS Phase-2 Letter of Intent and CMS RRB preparation
- Research equipment covers core contributions and prototypes
- Technical Infrastructure -> special tooling for production

Requested Funding DESY	Cost [M€]
Technical infrastructure	2
Sensors	5.5
Readout electronics	5
Mechanics	5.4
Power supplies etc.	1.1
Other items	1.2
Total	**20.0**

Costs in M€		2015	2016	2017	2018	2019ff	Total	Grant application
DESY&KIT	Technical infrastructure	2.4	4.2	2.2	0.4	0.4	9.6	2.6
	Research equipment	0.6	2.5	6.3	5.8	6	21.2	21.2
	Total	**3**	**6.7**	**8.5**	**6.2**	**6.4**	**30.8**	**23.8**

New Strip Tracker Costs (example from ATLAS LOI)

- Strip Tracker 82.5MCHF + 50% of Global ITK
  - ~90.1MCHF
  - ~75M€
- One EndCap -> ~20M€



3.7 Total Strip costs

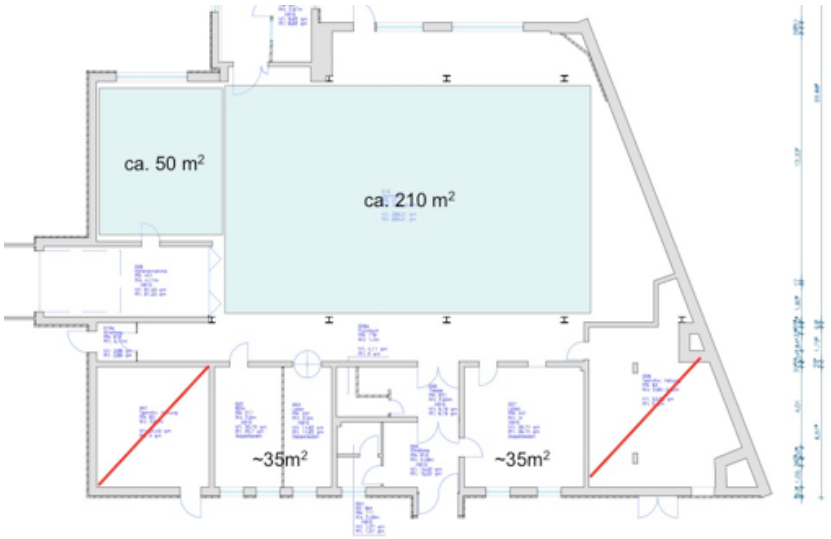
Sensors	31397
Additional module costs (including ASICs)	16478
Local Supprts	6488
On Detector Electronics (including EOS)	6939
Off Detector Electronics (Readout/PS)	4676
Global Supports	16470
Total	82448

Sum of ITK cost

Subcomponent	Cost (KCHF)
Pixel	**29600**
Strips	**82500**
Global ITK	**16200**
Sum	**128300**

Assembly Facility

- Refurbish and extend building 25c
  - Reasonable hall space for end-caps assembly
  - Extension for the required laboratory space
- Start of construction ~2015



POF2 Proposal and HGF Senate Recommendations

Strengthen the concerted efforts on detector upgrades, remote control room, training courses, and NAF!

- The program of schools and workshops organized by the Terascale is targeted to a large extend to the ongoing analysis of the LHC program.
  - It is well attended by by scientists at junior and senior level from universities and HGF laboratories involved in the LHC experiments and HEP theory.
- The resources provided by the National Analysis Facility were upgraded continuously to match the growing data samples. A large fraction of LHC results were achieved using the NAF.
- The concept of provisioning all Tier-2 datasets has been proven very successful and lead to large acceptance and usage from institutes all throughout Germany.
- The remote control rooms are routinely used for remote experiments shifts on controlling the computing infrastructure, detector components and data processing in the experiments.

POF2 Proposal and HGF Senate Recommendations

Explore solutions to participate to the LHC upgrade program!

- The detector upgrade strategies of ATLAS and CMS have emerged into sound plans and proposals to build substantial parts of the tracking detectors together with German institutes.
- A concrete proposal has been worked out to build two large tracking endcap detectors, one for the ATLAS and one for the CMS experiment.
  - Both detectors will be build in a concerted effort with several German Universities, the integration and assembly is planned to be done at DESY.
  - The funding request for the detector is being prepared and is attached to the material for this review. Submission of the request is expected this fall.
  - DESY will provide the assembly hall and lab space infrastructure.