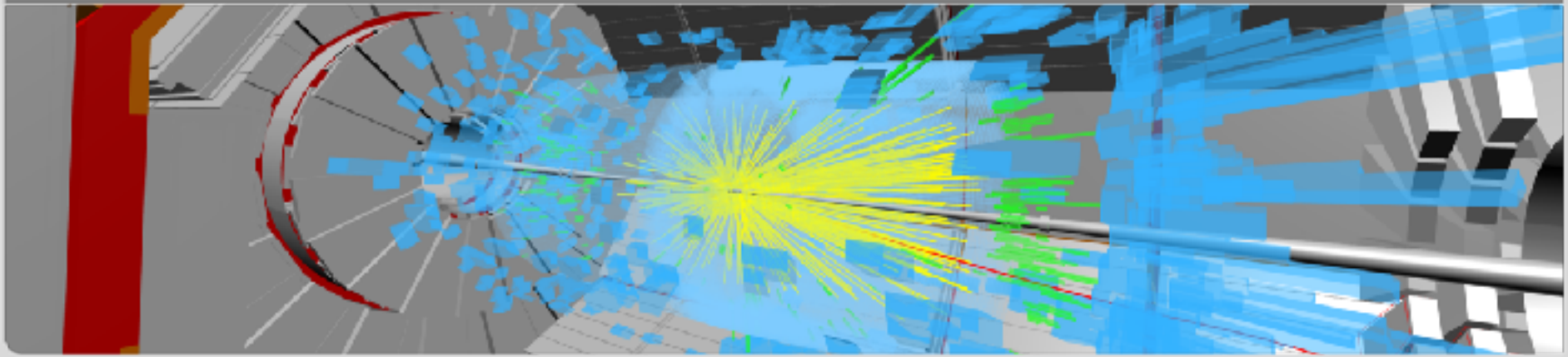
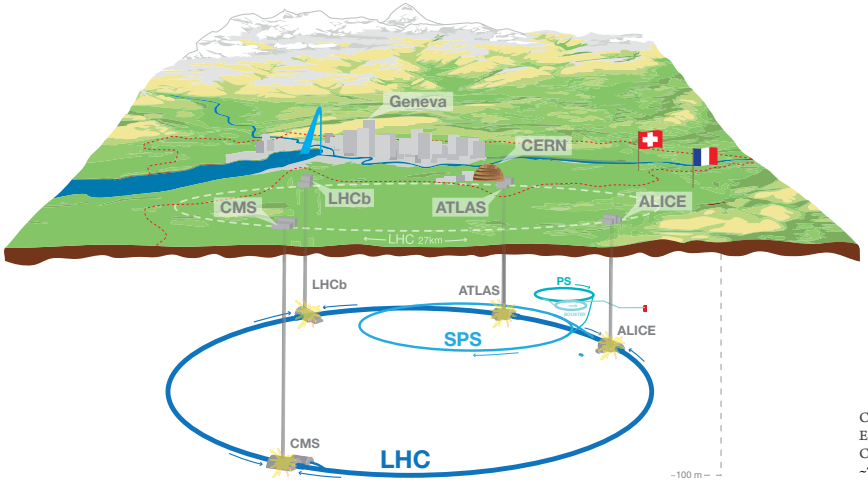
KIT@CMS: From Detector R&D to Physics Results

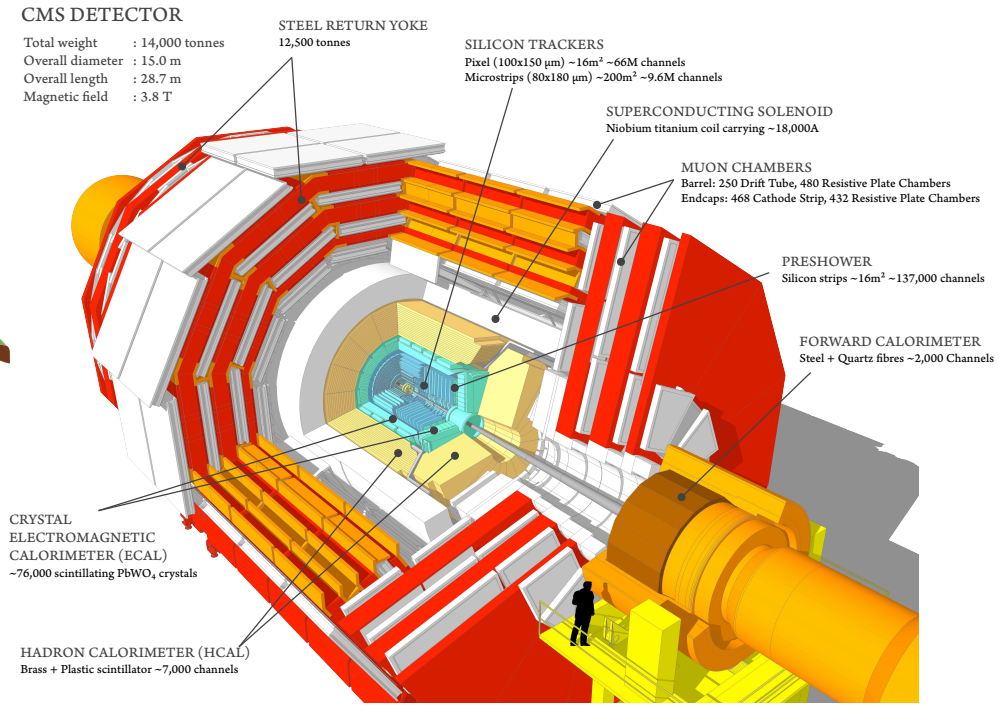
SJTU-KIT Collaborative Research Workshop “Particles and the Universe”
Karlsruhe, September 6–8, 2017

Ulrich Husemann, Institute of Experimental Particle Physics, Karlsruhe Institute of Technology



The LHC and the CMS Experiment





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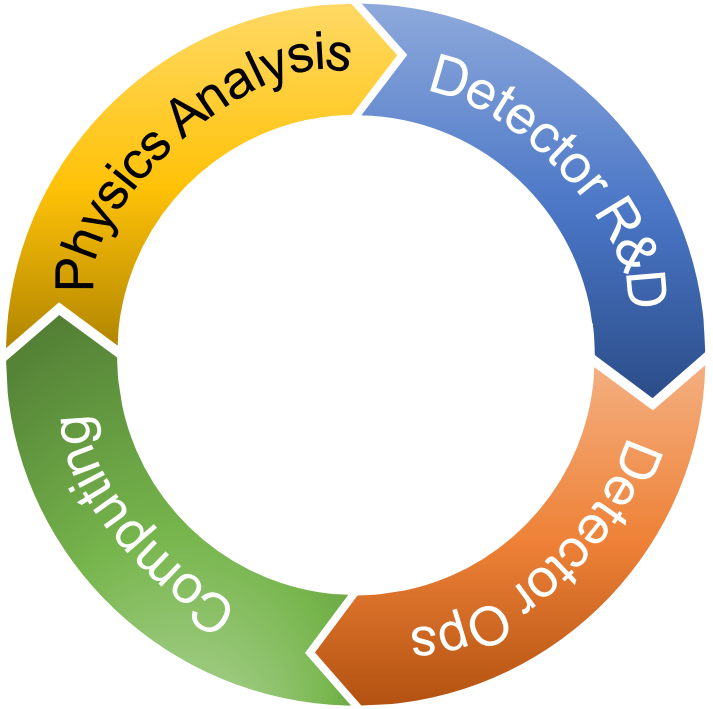
Overview

- KIT contributions to **full life cycle** of CMS experiment at the CERN LHC:
  - Detector research and development (R&D)
  - Detector operation
  - Algorithms and Grid computing
  - Physics analysis



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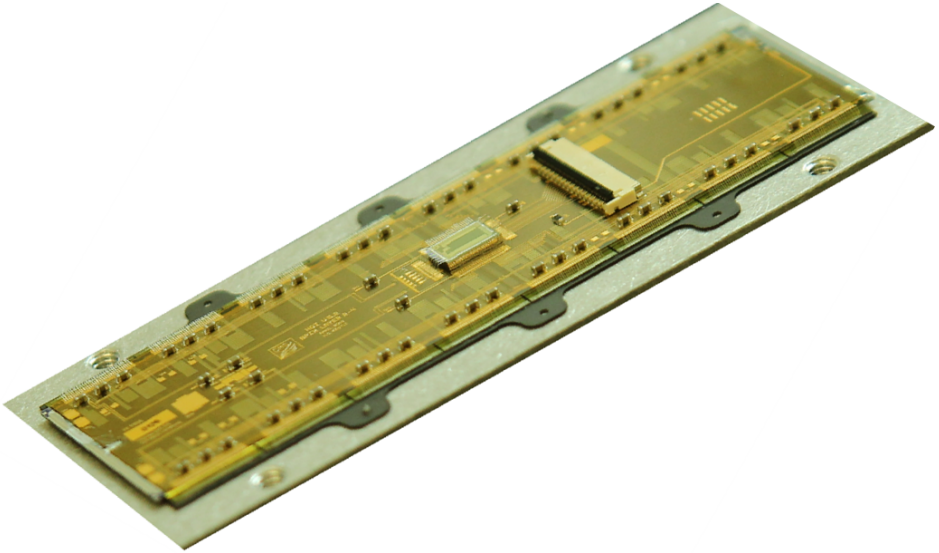

Preparing for the Future

DETECTOR R&D

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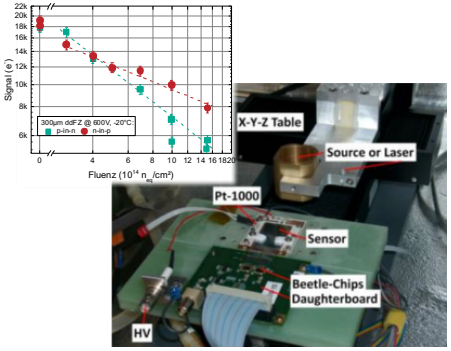
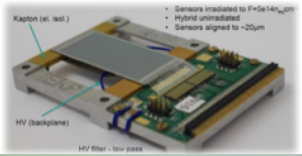
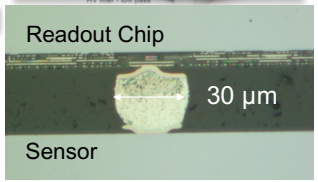
Silicon Detector R&D



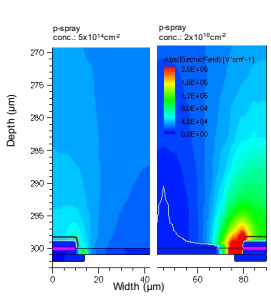
Testing



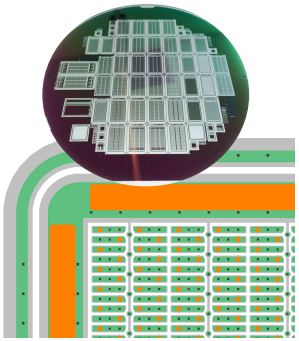


Module Assembly

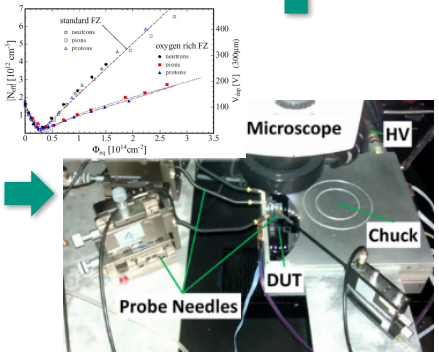
Irradiation



TCAD Simulation



Sensor Design



Characterization

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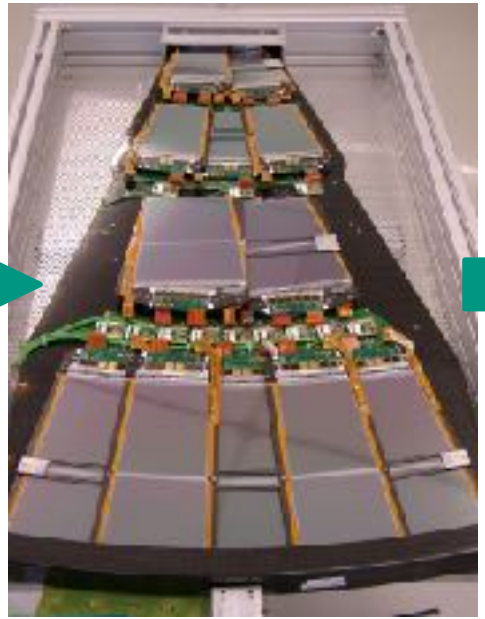
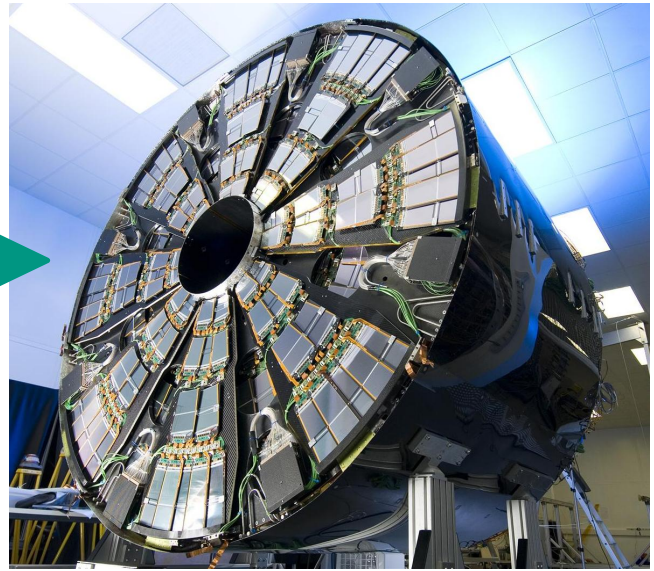
Detectors for CMS: Past

- 1/3 of the petals for the end-cap of the current CMS silicon strip tracker (installed: 2007)





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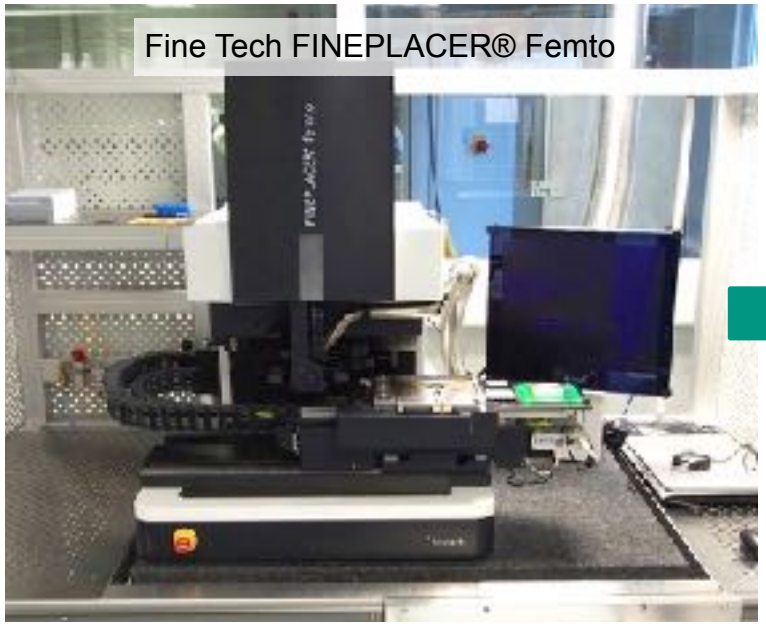
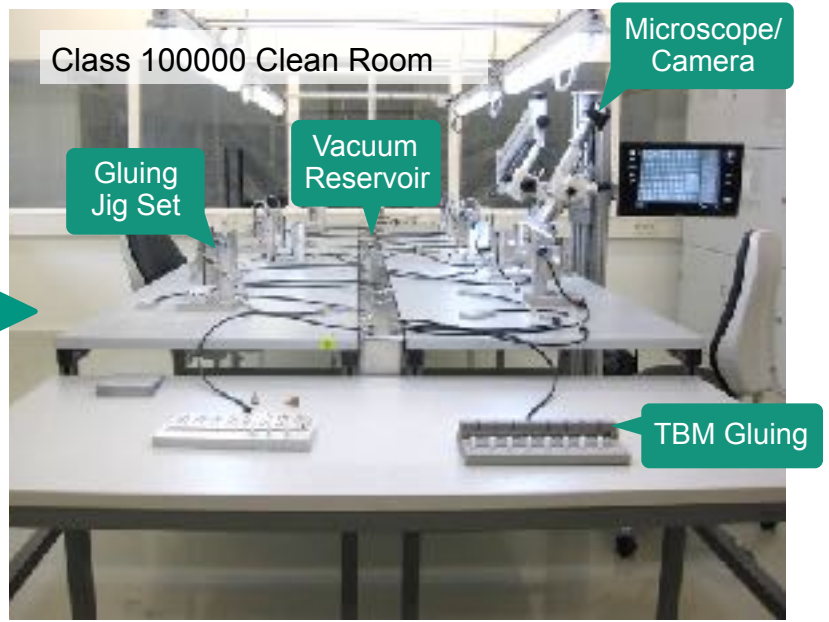
Detectors for CMS: Present

- 350 modules for the upgrade of the CMS barrel pixel detector (installed: spring 2017)



Bump Bonding



Assembly

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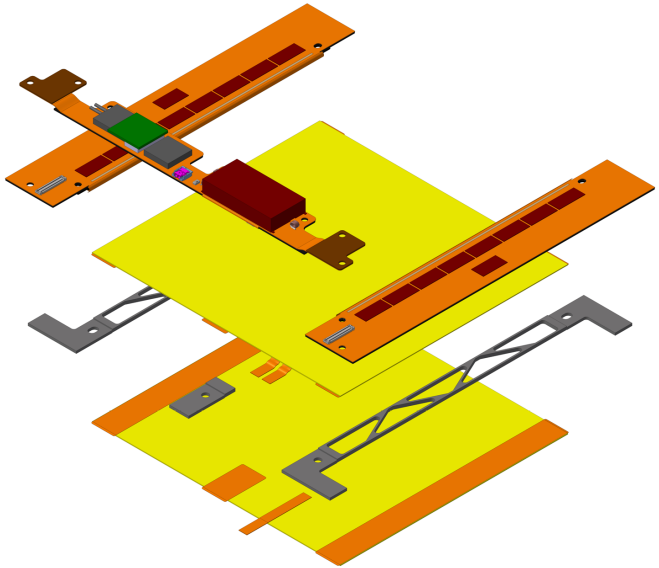
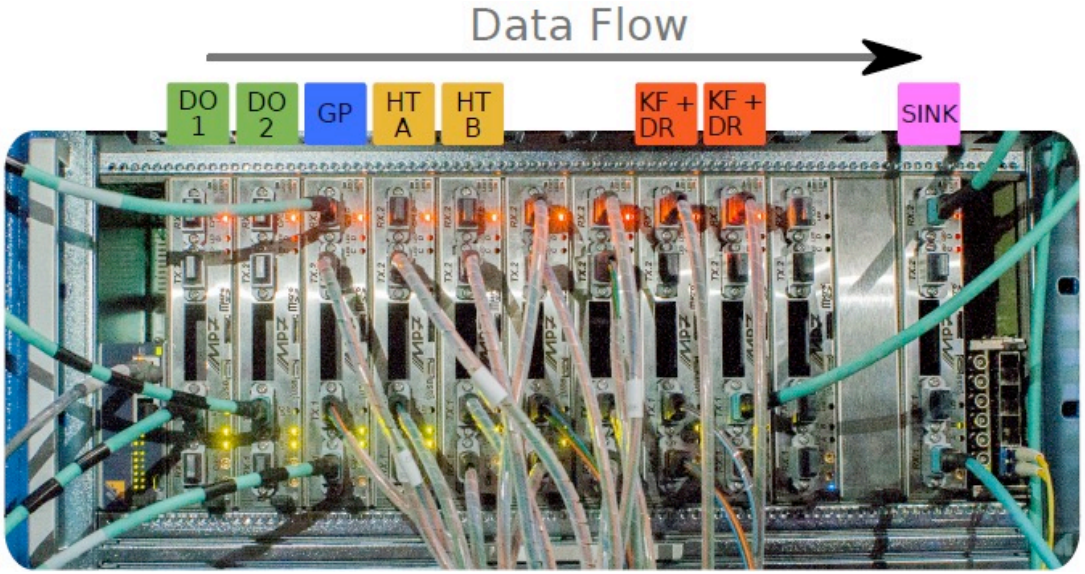
Detectors for CMS: Future

- 2000 p_T modules and track trigger electronics for the HL-LHC upgrade (data-taking from 2026)





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Getting the Data On Tape

DETECTOR OPERATIONS

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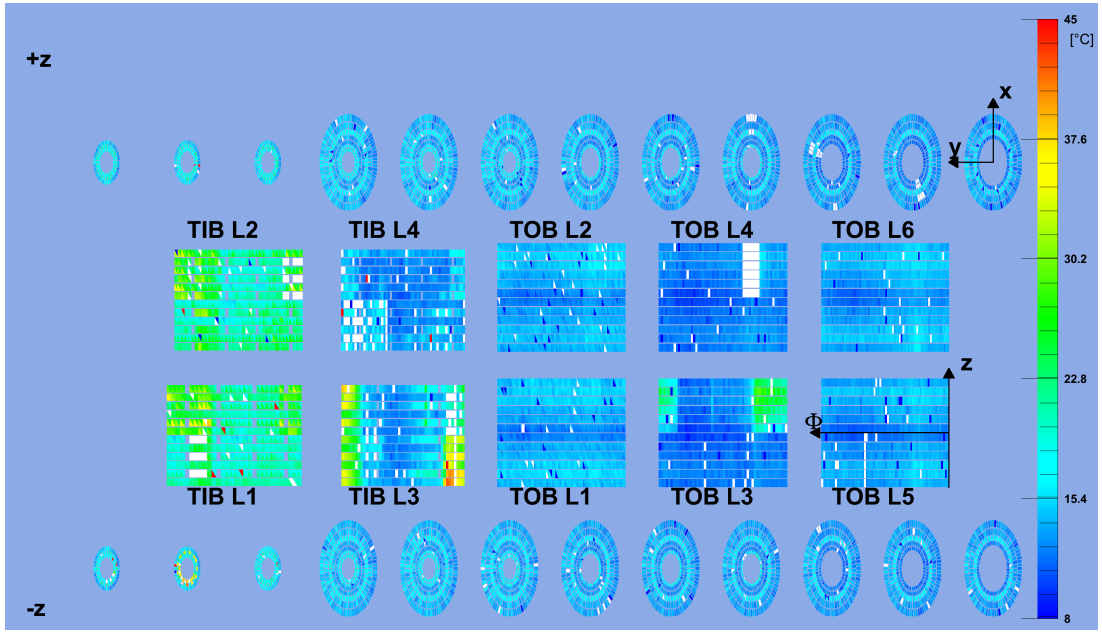
Detector Control System

- KIT responsible for development and maintenance of **Detector Control System** (“slow control”) for the CMS tracker



Tracker Temperature Map

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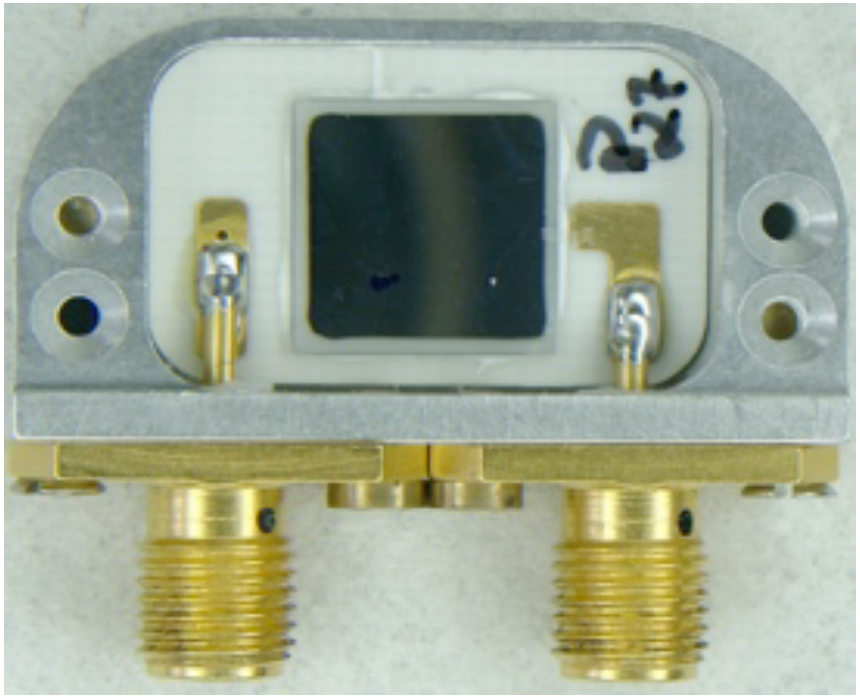
Diamond Beam Monitors

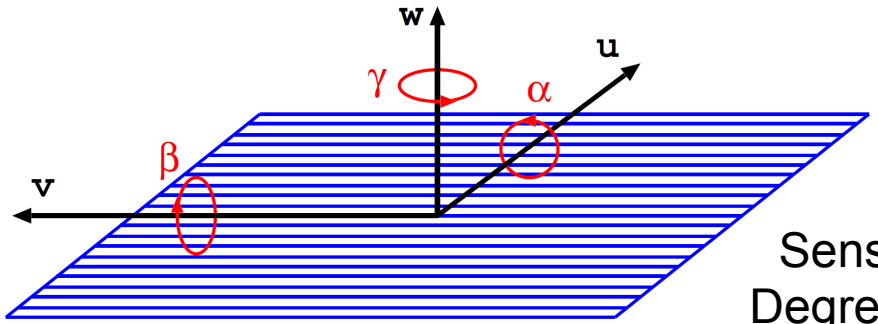


- Safety system: protect against **beam incidents** endangering CMS
- Technology: single-crystalline and poly-crystalline **diamond sensors**
- Production: chemical vapor deposition (CVD)

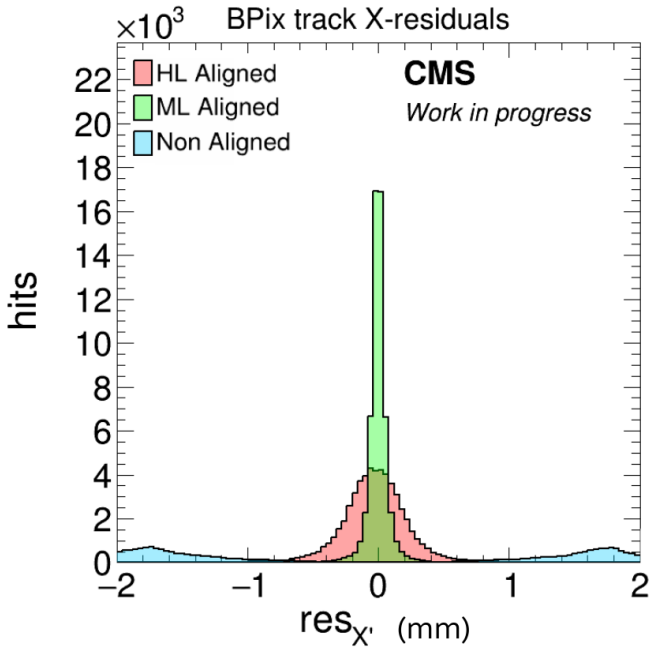
CVD Diamond Sensor

Tracker Alignment

- **Positions of sensors** in CMS tracker must be known within **O(10–20 µm)**, much better than mechanical precision and survey data
- Solution: **precision alignment** using **tracks** from cosmic rays and pp collision



Sensor Degrees of Freedom



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Processing the Data

ALGORITHMS AND GRID COMPUTING

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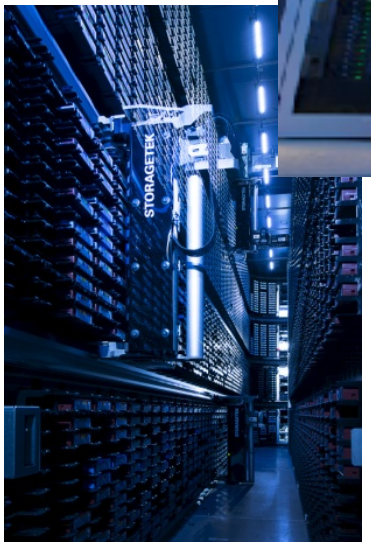
GridKa: The German Tier-1 Center

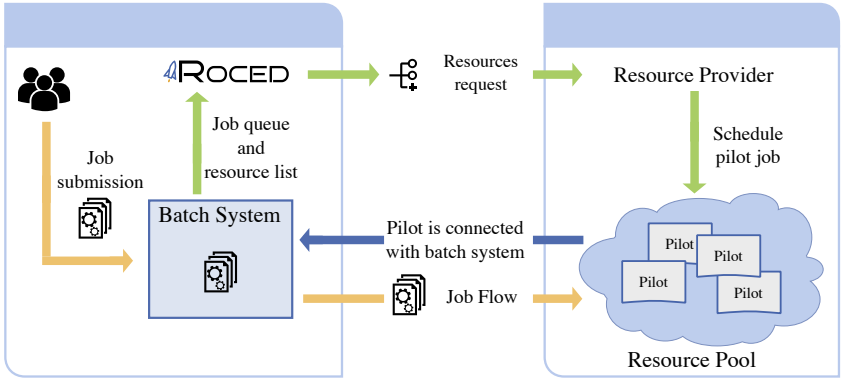
- 10% of **Worldwide LHC Computing Grid** (WLCG):
  - 27,400 CPU cores, 200 file servers → 112M CPU hours/year
  - Storage: 25 petabytes disk space, 26 petabytes tape capacity
  - Experiments supported: ALICE, ATLAS, CMS, LHCb, BABAR, Belle/Belle 2, Compass, Auger
- IT education for physicists: annual GridKa school



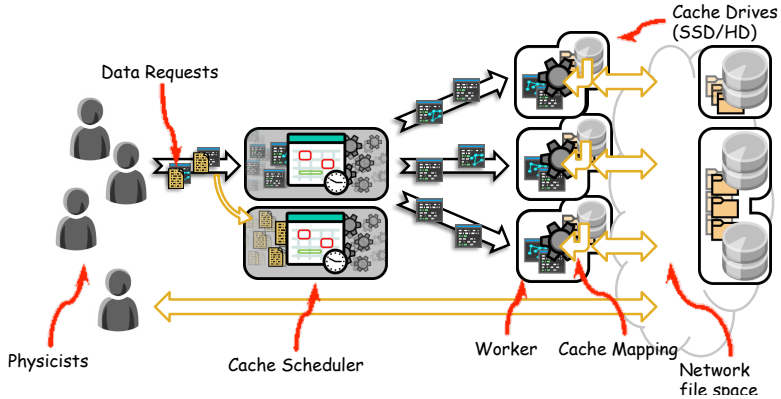
GridKa

Scientific Computing R&D

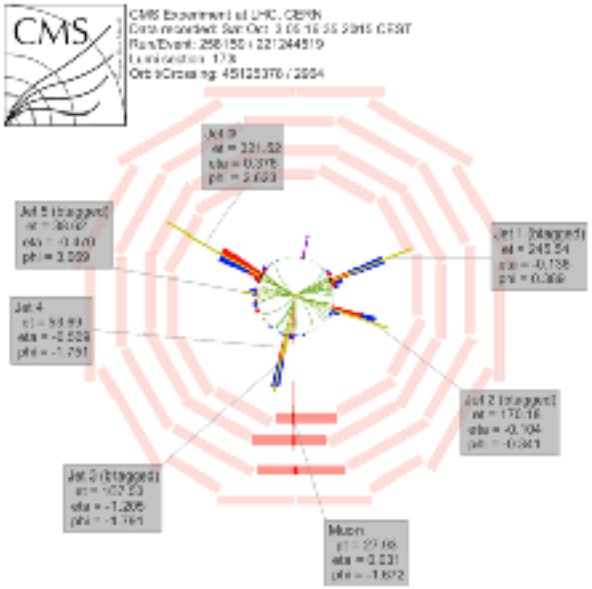
- Dynamic utilization of **opportunistic resources** (e.g. cloud service)



- **High-throughput** data analysis utilizing data locality (caches)



- Exploring novel **deep learning techniques** (e.g. based on Google's TensorFlow) on today's powerful CPUs and GPUs



The Scientific Harvest

PHYSICS ANALYSIS

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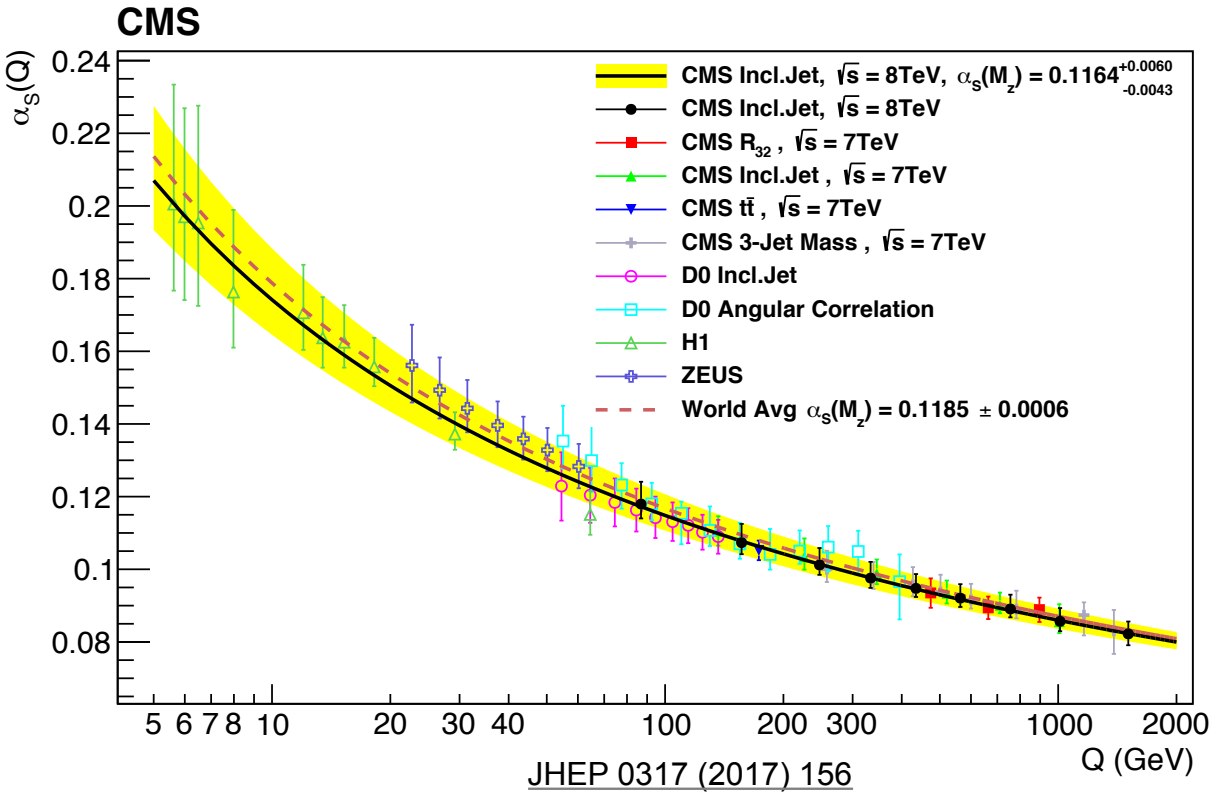
Jets & Strong Coupling Constant



JHEP 0317 (2017) 156

- Improved precision of **gluon density** in the proton with dijet data
- Precise determination of **strong coupling constant α_S** and extended test of its running **up to 2 TeV** with jet data

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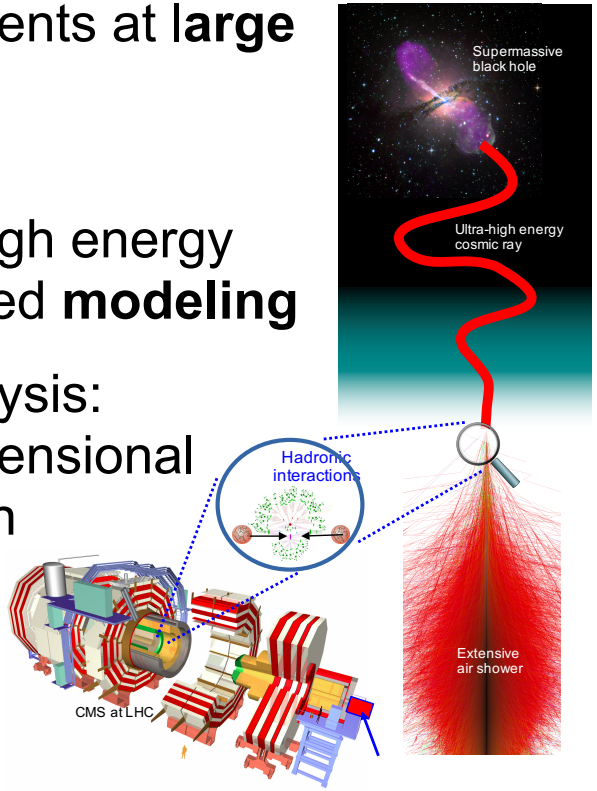
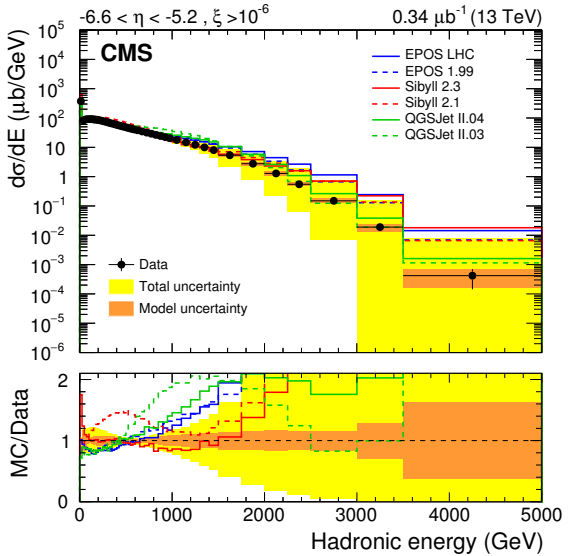
Forward Physics

- Dedicated measurements at l**arge pseudorapidities**
  → (very) forward
- Connection to ultra-high energy **cosmic rays**: improved **modeling**
- Global likelihood analysis: multivariate, high-dimensional sampling, optimization





JHEP 08 (2017) 046

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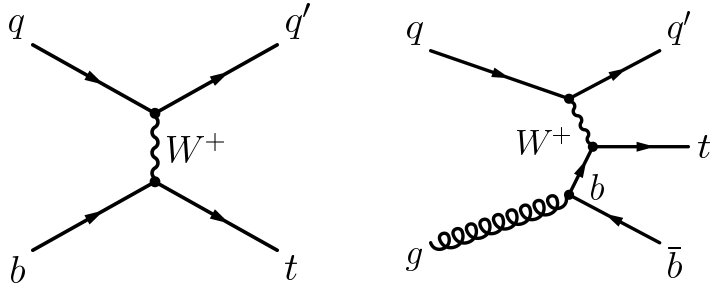
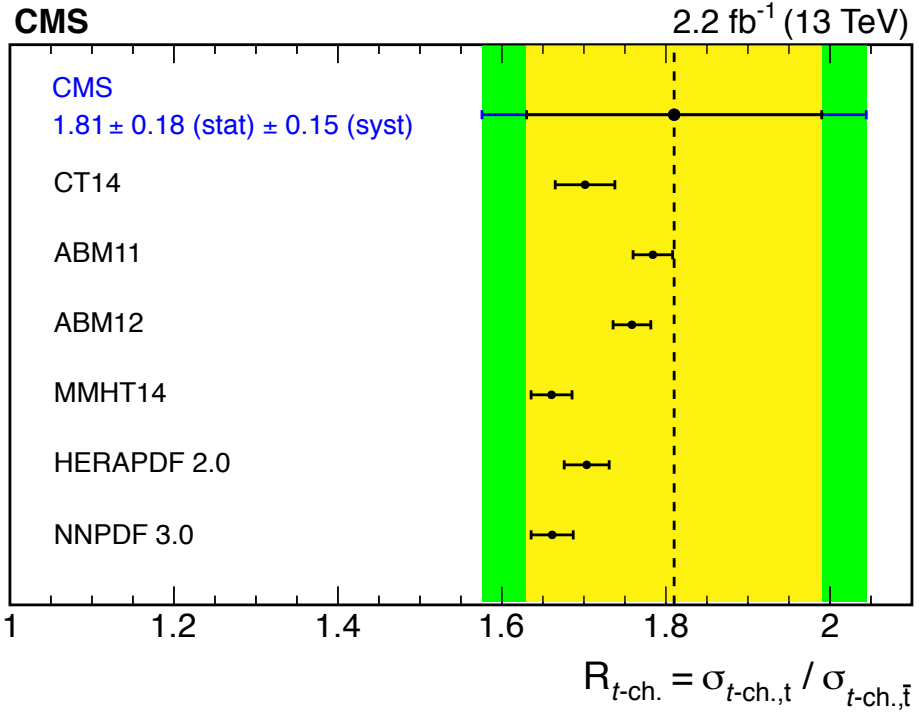
Top Quarks

- Long history of landmark top-quark physics results from KIT, e.g. $t\bar{t}$ **production asymmetry**
- Recent example: single top-quark production cross section (ratio of t and $\bar{t}$ in the *t* channel)

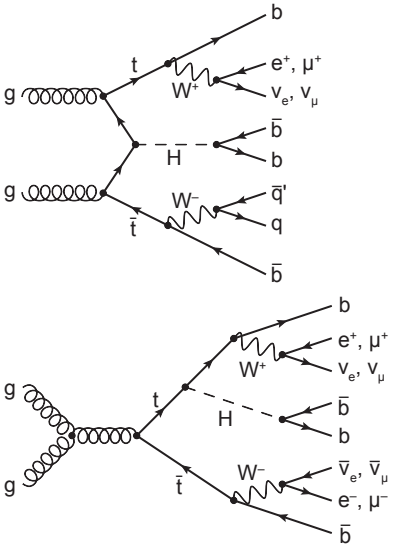




arXiv:1610.00678, accepted by PLB

Top-Higgs Associated Production

- $t\bar{t}$ + Higgs: access to top-quark **Yukawa coupling**
- Single top + Higgs: search for **anomalous** tH couplings



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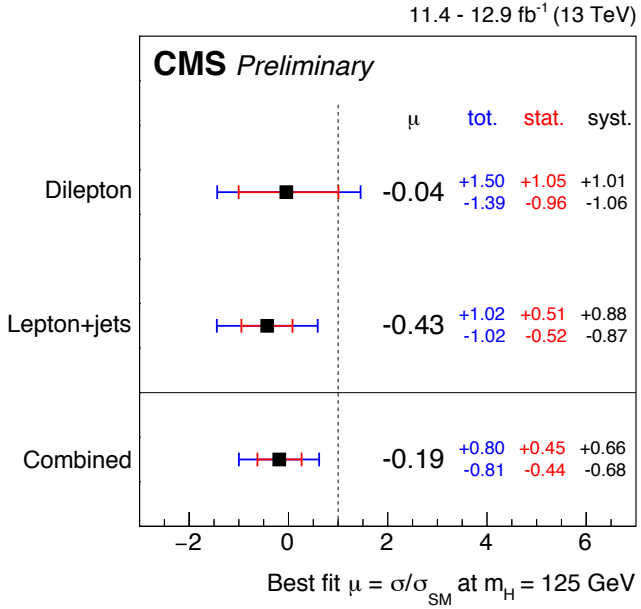

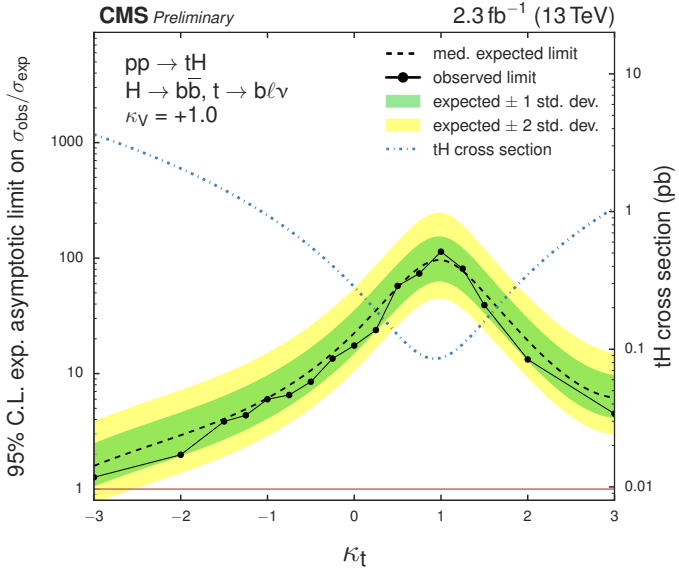

CMS-PAS-HIG-16-019

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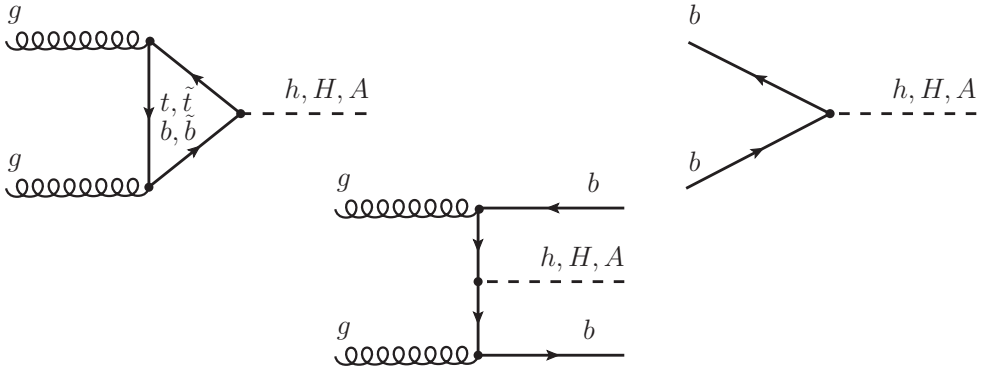
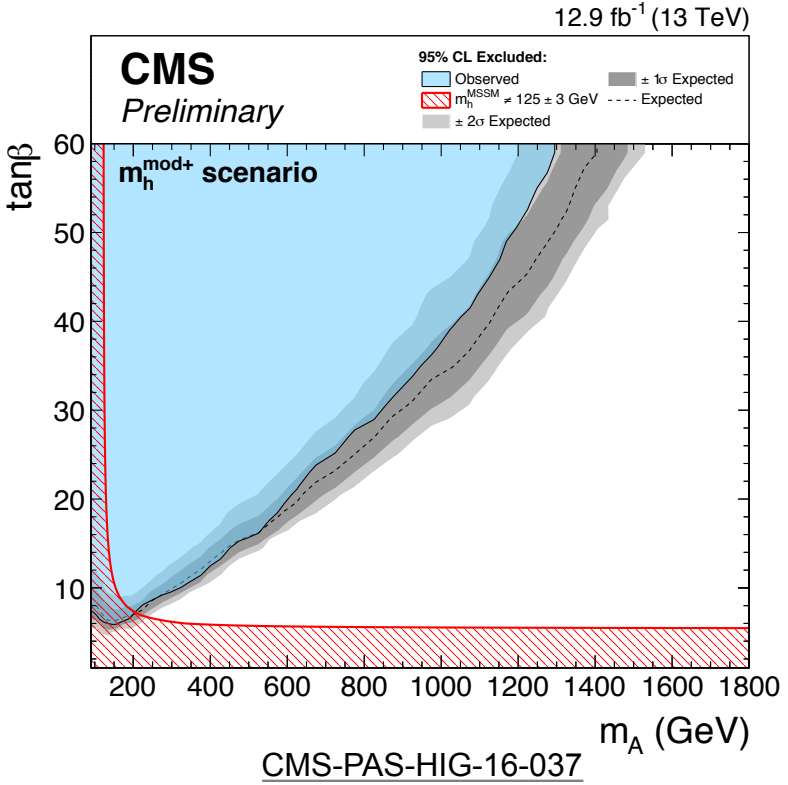
Higgs-Boson Decays to Tau Leptons

- $H \rightarrow \tau\tau$: first channel to establish Higgs-boson **couplings to fermions**
- Important channel to search for **additional neutral Higgs bosons**, e.g. in the minimal supersymmetric standard model (MSSM)





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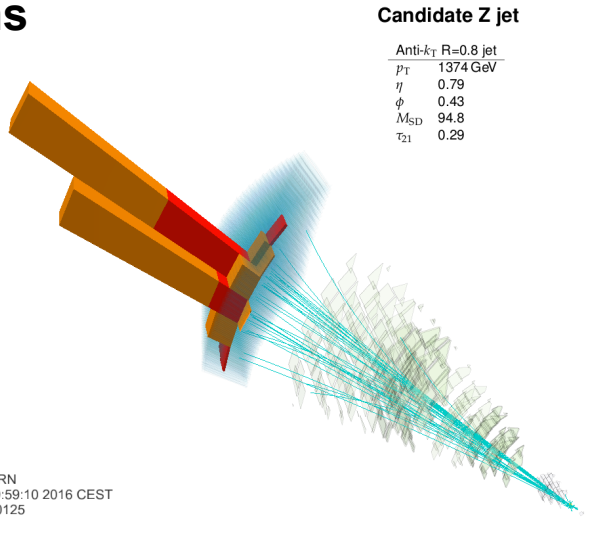
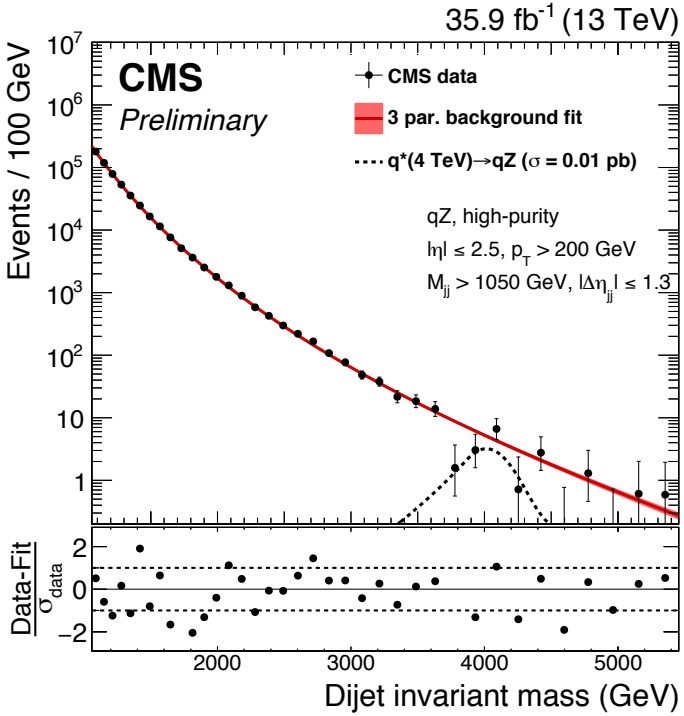
Pairs of Vector Bosons

- Search for **massive resonances** (e.g. excited quarks, heavy W'/Z', gravitons) decaying to pairs of vector bosons
- Novel reconstruction techniques for **"boosted" vector bosons**





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Summary and Conclusions

- The LHC: today's **flagship** of accelerator-based particle physics
- KIT: **deeply involved** in the CMS experiment at the LHC
  - Detector R&D – operations – computing – data analysis
  - Key **detector** expertise: silicon tracking detectors, fast electronics
  - **Computing**: WLCG Tier1 center GridKa, cloud resources
  - Advanced **algorithms**, e.g. machine learning
  - **Broad physics interests**: from precision standard-model physics to searches for Higgs bosons (and more) beyond the standard model