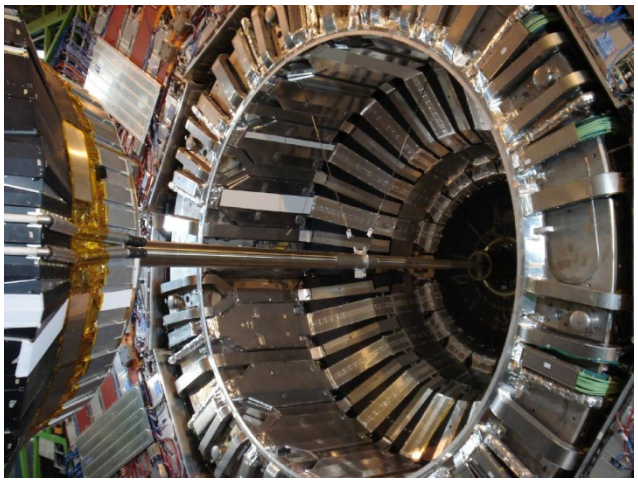
Status of CMS at DESY

Report to the 75th Physics Research Committee
Open session, April 11, 2013



Outline:

- Introduction
- Physics
- Components and Operation
- Detector Upgrades

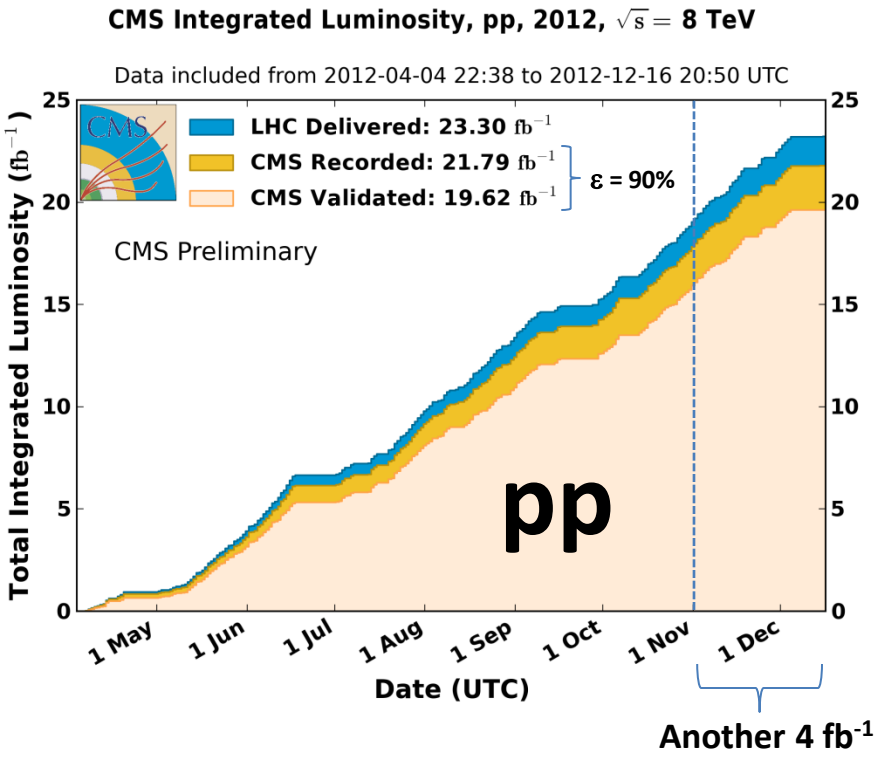
HELMHOLTZ ASSOCIATION

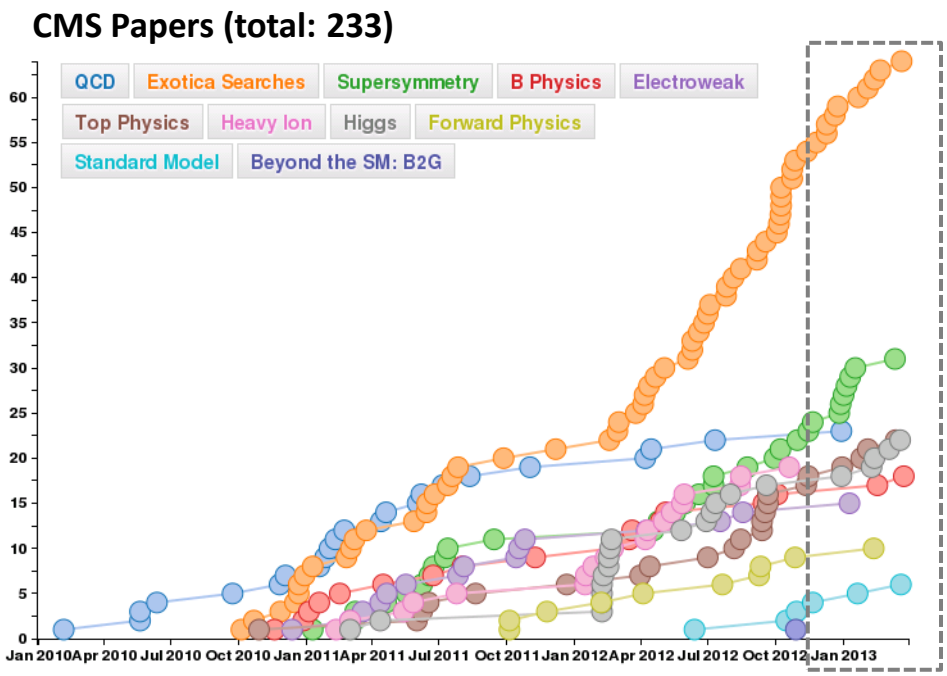
Sebastian Naumann-Emme
on behalf of the DESY-CMS Group

DESY

Performance and Results since November

Smooth operations until end of the pp running and during pPb run





Many new results from all physics groups

→ especially for HCP in November and La Thuile / Moriond in March

CMS Data Analysis School @ Hamburg

Hosted by DESY together with Uni Hamburg

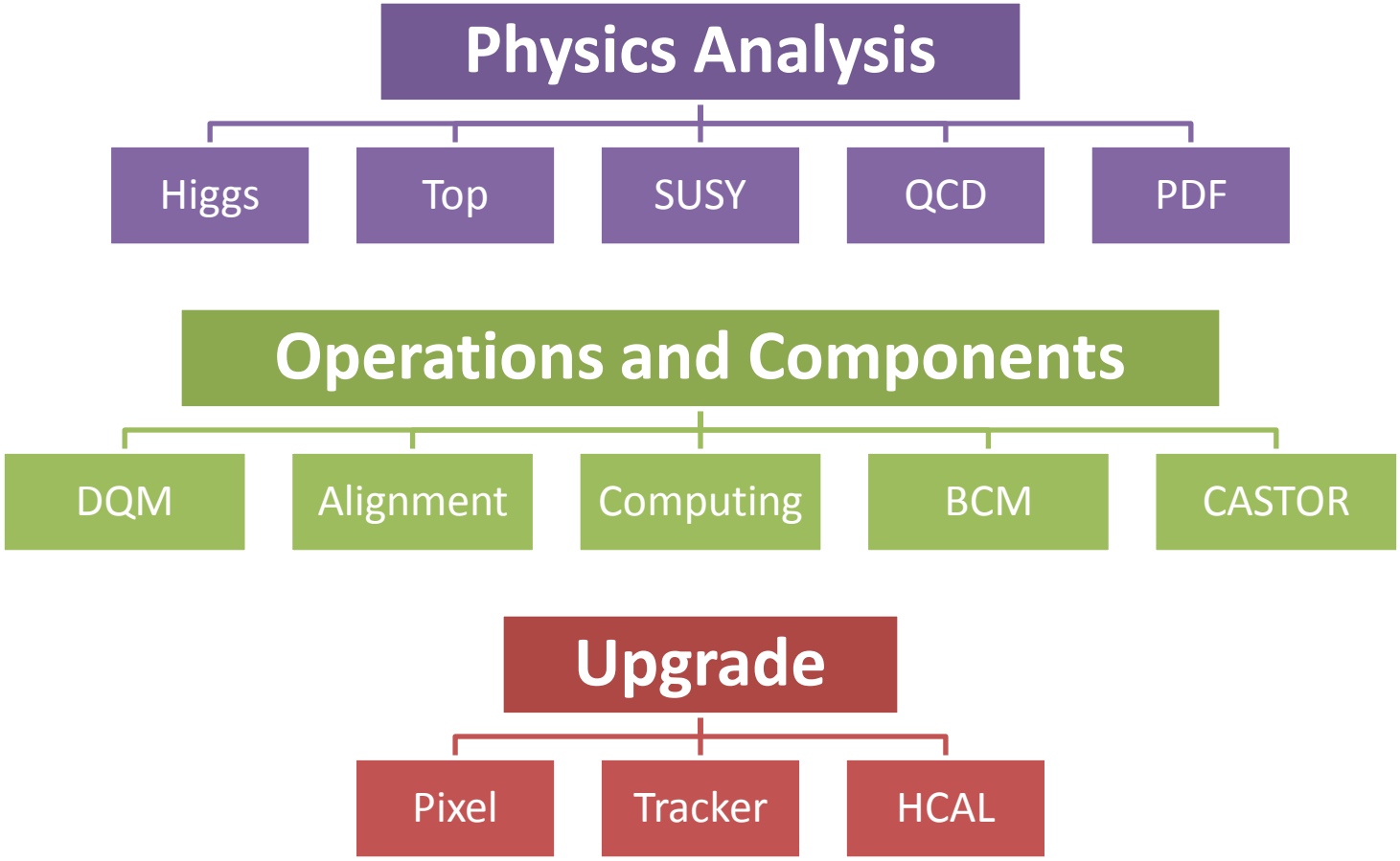
5 days of lectures and hands-on tutorials, corresponding to ongoing analyses from the various physics groups

Almost 100 participants (students and instructors), from all over Europe and beyond

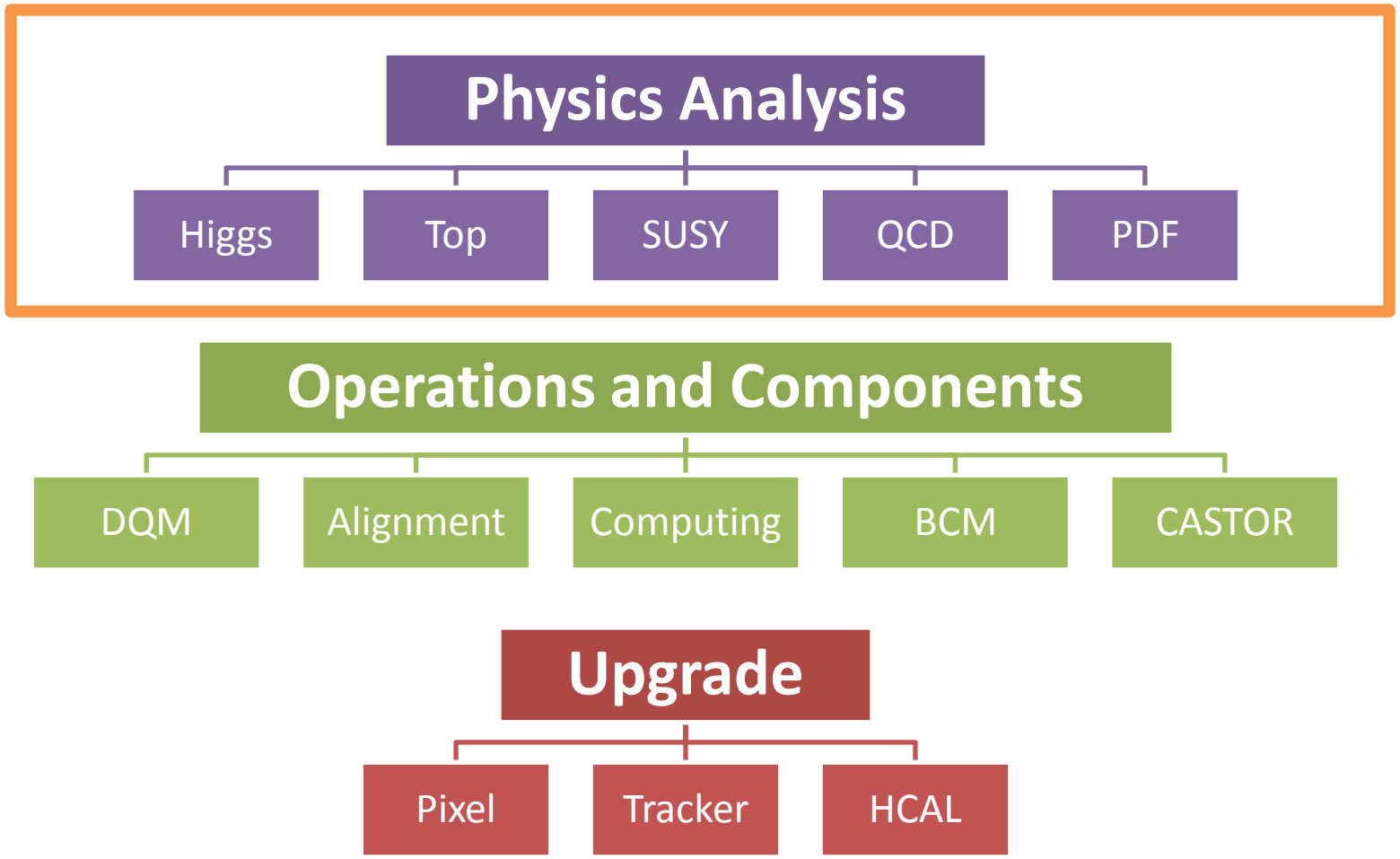
Important contribution to education of young students in CMS

DESY-CMS Group

23 staff, 15 post-docs, 23 PhD students; engineers & technicians

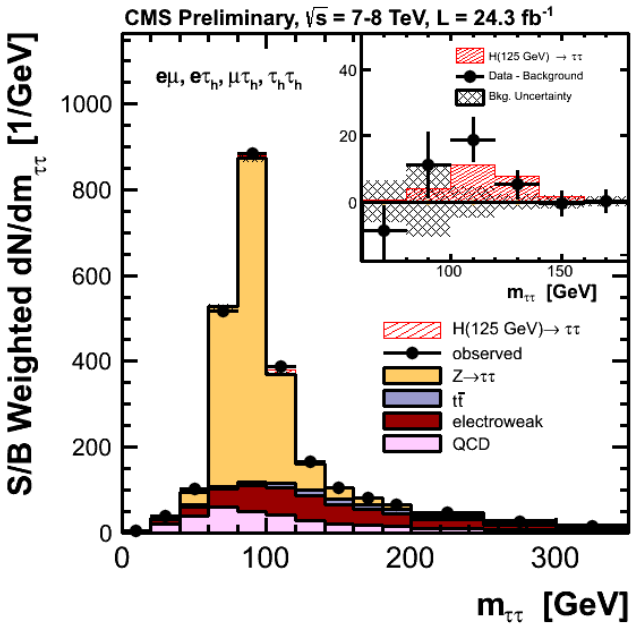


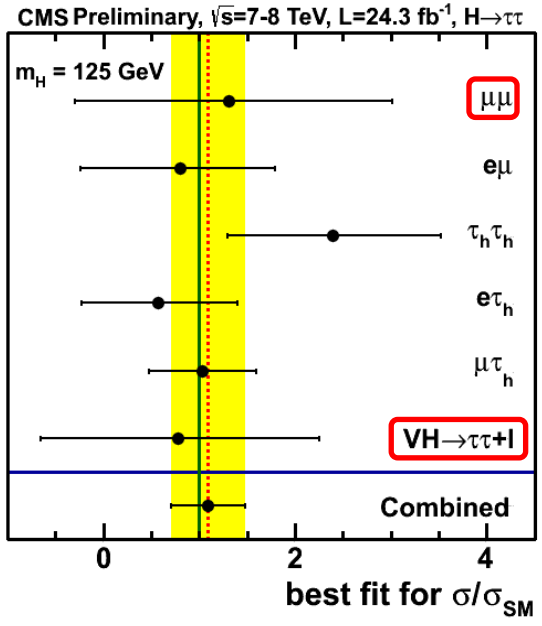
Part 1: Physics Analysis

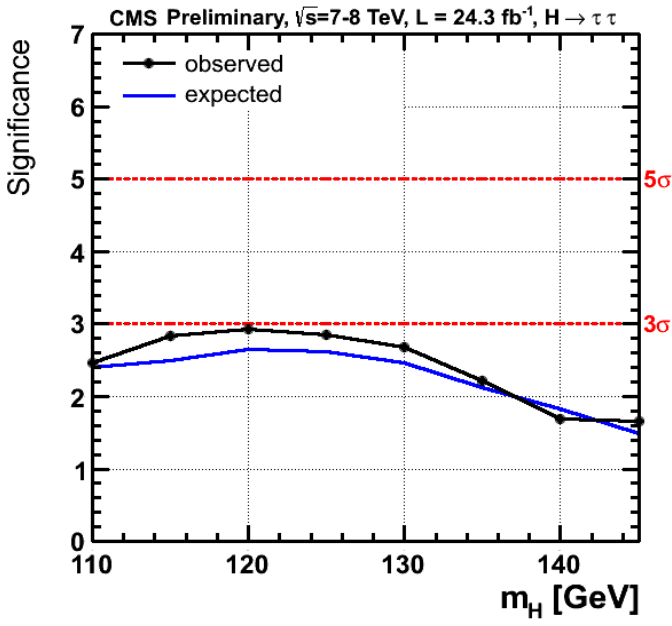


Higgs: H → ττ Search

Full 2011 / 2012 statistics analyzed





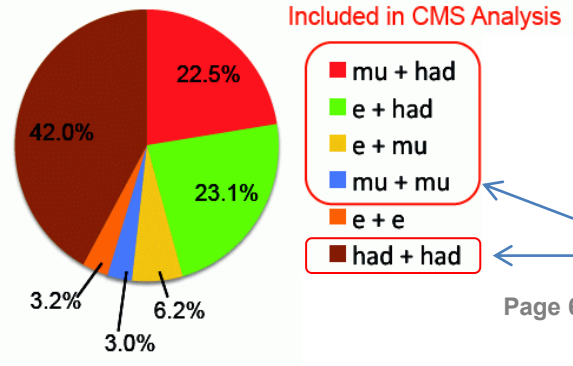


2.9σ excess, compatible with SM Higgs near 125 GeV

→ first indication of coupling to leptons!

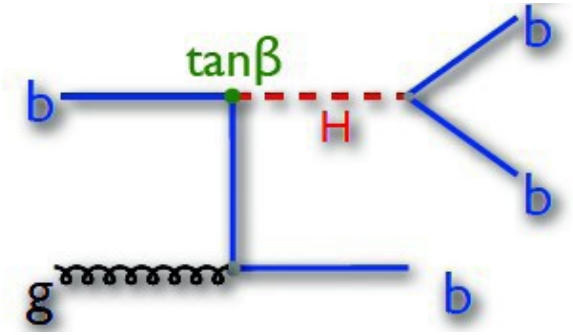
DESY contributions to PAS HIG-13-004:

- Analysis of H→ττ→μμ channel
- Analysis of WH→ττ+ℓν channel
- Development and maintenance of tools evaluation of Z→ττ background



Higgs: MSSM bΦ → 3b Search

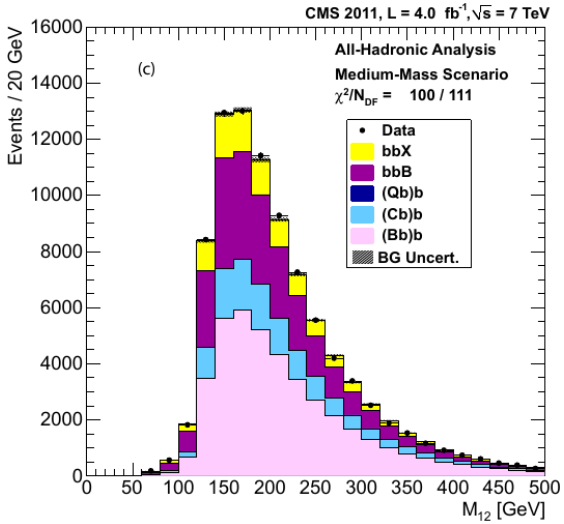
- Developed & maintained all-hadronic trigger
- Performed the all-hadronic analysis
- Played crucial role in combination

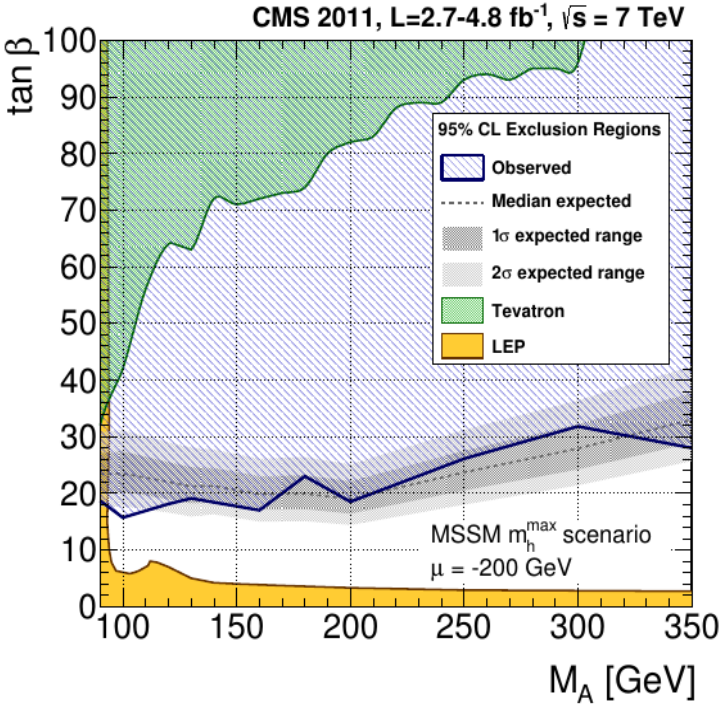


New: combination with the semileptonic analysis

Paper accepted by PLB (arXiv:1302.2892)

Currently world-best sensitivity in this channel



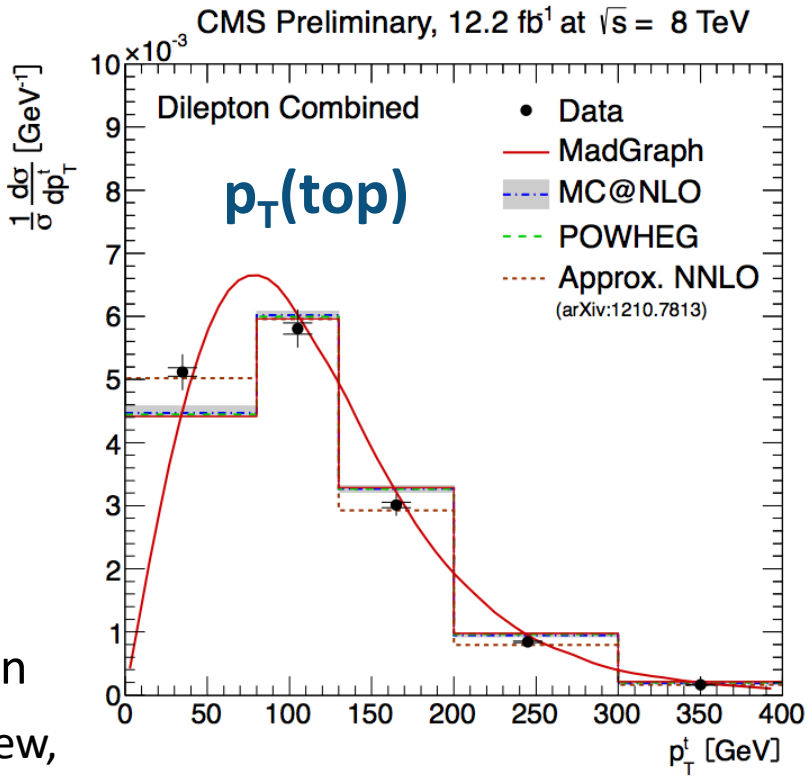


No signal observed
→ constraints on MSSM parameters

Modest excess observed in this channel at Tevatron not confirmed

Top-Quark Measurements

- Differential $t\bar{t}$ cross sections
  - Published measurement at 7 TeV, together with l+jets (arXiv:1211.2220, accepted by EPJC)
  - First results at 8 TeV (PAS TOP-12-028)
- $t\bar{t}$+jets cross sections
- Inclusive $t\bar{t}$ cross section at 8 TeV and cross-section ratios (tt/Z and 8/7 TeV)
- Top-quark mass and α_S from the $t\bar{t}$ cross section
  - Paper updating the preliminary 7 TeV results in review, using brand-new prediction at full NNLO QCD



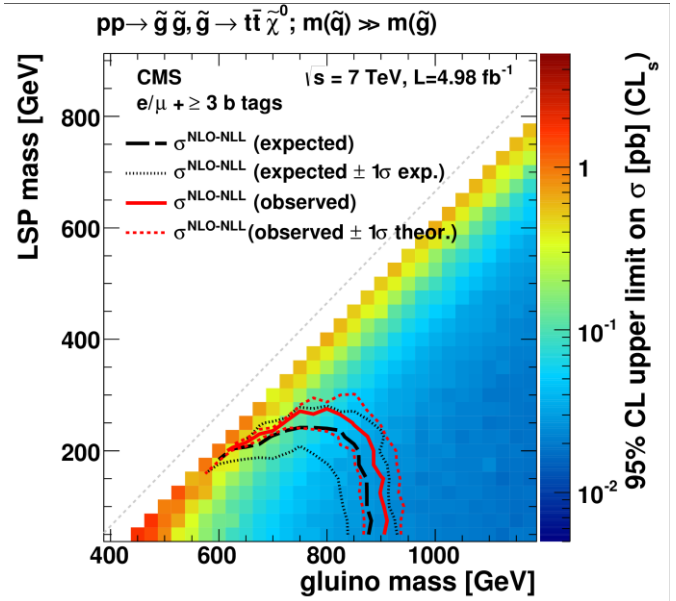
- Trigger and lepton-ID efficiencies
  - Contribution to several analyses: $\mathbf{t\bar{t}}$ cross section, single-top tW cross sections, $\mathbf{t\bar{t}H}$ and stop searches
- Associated $t\bar{t}H$ production (with Higgs group), started

SUSY Searches

- Single lepton, b-jets and missing transverse energy
  - Light gluinos decaying to top final states

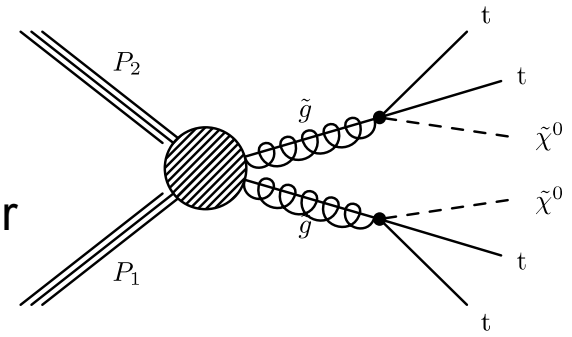
Improved limit on simplified model "T1tttt" due to small uncertainties from background estimation

Paper published (Phys.Rev. D 87 (2013), 052006)



- Opposite-sign dileptons
  - New method for distinguishing background and signal in invariant dilepton mass developed

- Direct stop production with MT and MT2W
  - To be followed by combined (0,1,2- lepton) stop paper



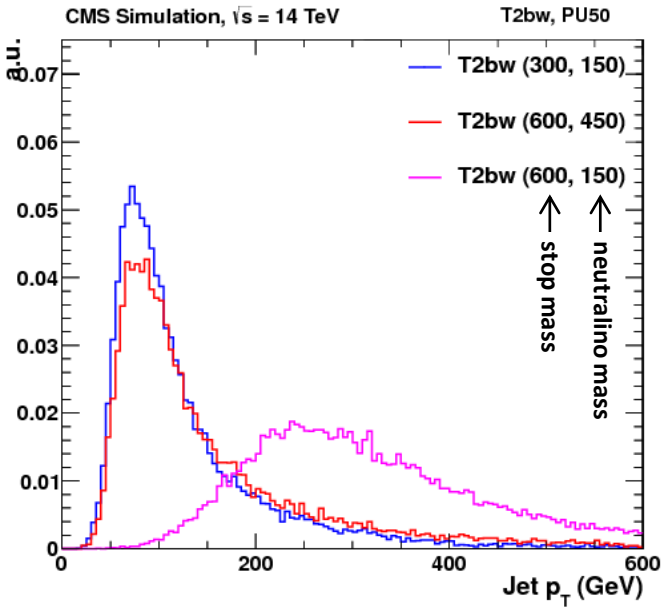
SUSY Searches: Trigger Studies

- Level-1 trigger will be upgraded (hardware and algorithms) to achieve maximum physics efficiency within the given bandwith despite the increased pile-up after LS1

- Studied trigger efficiencies for √s = 14 TeV, 25 and 50 ns bunch spacing and 50 pile-up collisions
  - Direct stop production

    → Similar results for $\tilde{t} \rightarrow t\chi_1^0$ (T2tt)

    and $\tilde{t} \rightarrow bW\chi_1^0$ (T2bw)
  - RPV stops decaying to two jets each



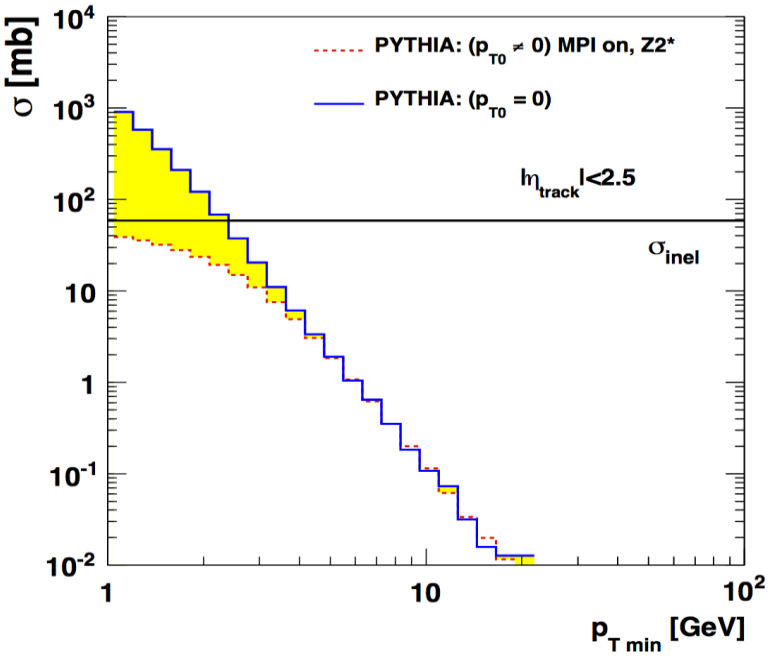
- Leptons and jets very soft for compressed spectra

  → Up to 50% efficiency loss for some scenarios without trigger upgrade

- Contribution to L1-trigger upgrade TDR

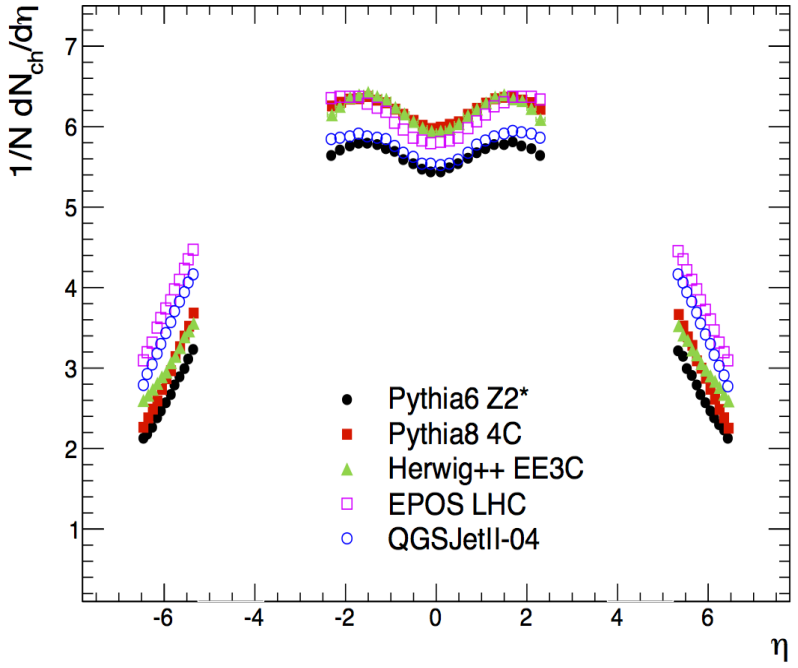
QCD at the Extremes: Small x

- Following predictions by A. Grebenyuk et al. (DESY-12-135, to appear in PRD): measure leading-track distribution with data of common CMS-TOTEM run



- Measure taming behavior of mini-jet cross-section and test of MC models
- Information on transition from perturbative to saturated region

- Measurement of dN/dη over full acceptance range of CMS+TOTEM

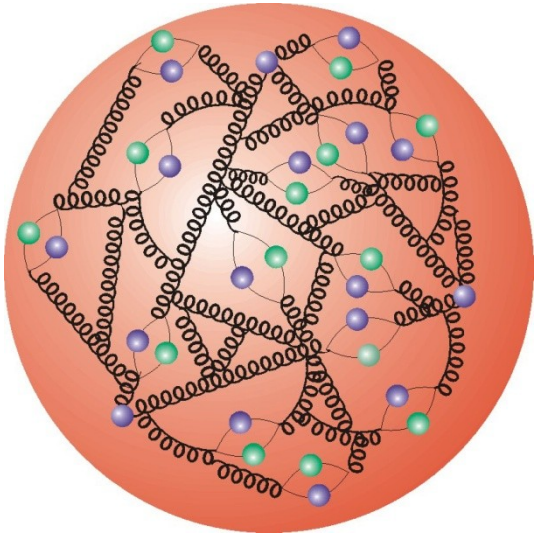


- Measurement in an unexplored phase-space region
- Test of model predictions from central to forward rapidities

Parton Density Functions

Monthly PDF@CMS meetings

- Co-initiated by DESY-CMS and well established within the Collaboration
- Active work on several QCD analyses and studies of impact on PDFs of various CMS data
  (DY, W asymmetry, W+charm, inclusive jet data, top)



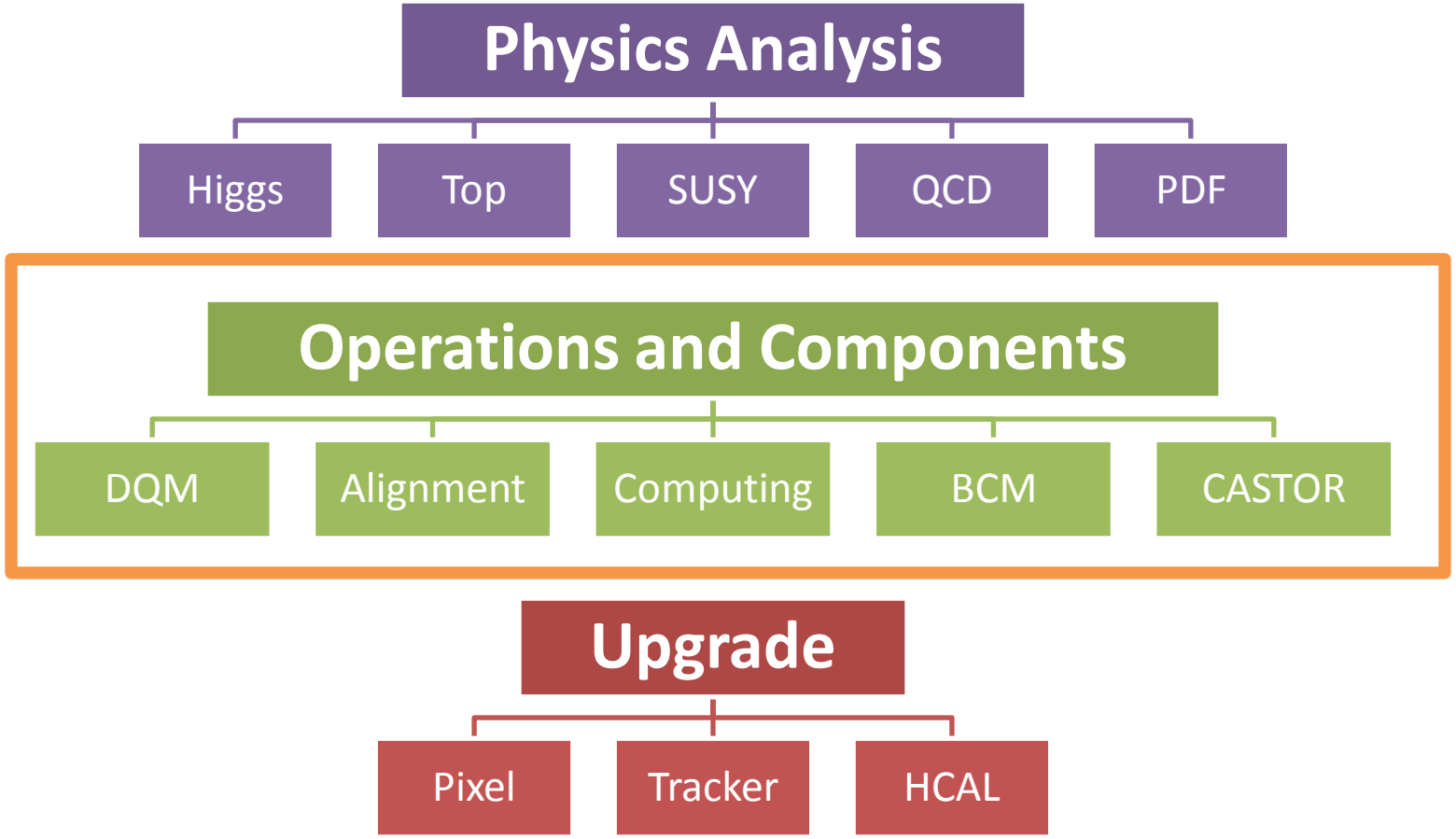
HERAFitter project (www.herafitter.org)

- Open-source QCD framework for PDF studies and extraction
- Tool actively used in QCD analyses with CMS data

DESY-CMS in close collaboration with PDF / theory groups

→ Especially ABM (DESY Zeuthen / Uni Hamburg) and CTEQ (SMU Dallas)

Part 2: Operations and Components



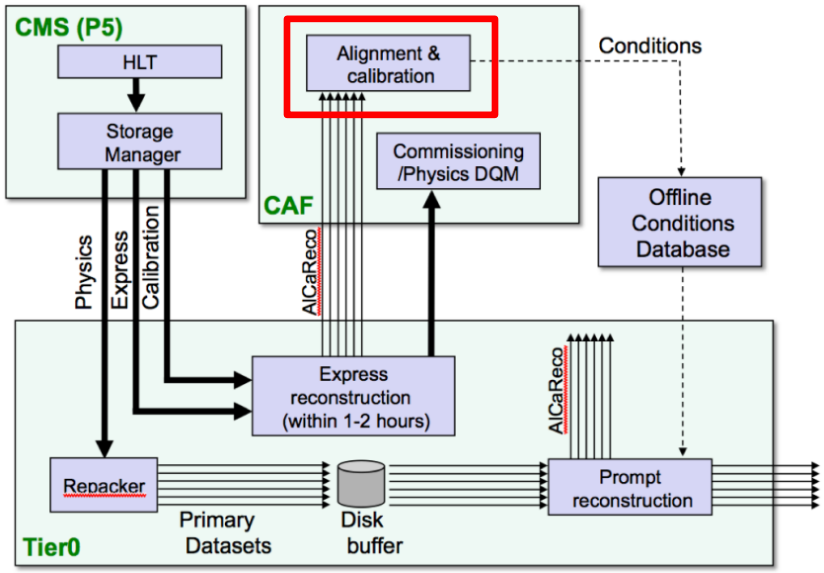
Data Quality Monitoring

Maintained commitments in Data Quality Monitoring and Certification:

- Core software development and subsystem integration
- Offline DQM
  - Histogram harvesting
  - 1/4 of shifts performed at DESY
- Data certification (weekly good-run lists)

Tracker Alignment

- Reliable performance in crucial phase of operations (Higgs discovery)
  - Basis for excellent physics performance of the CMS tracking system
- New: routine use of alignment in prompt-calibration loop
  - Fast turn-around for alignment corrections
  - Applied already in prompt reconstruction
- Alignment constants for 2012 reprocessing campaigns

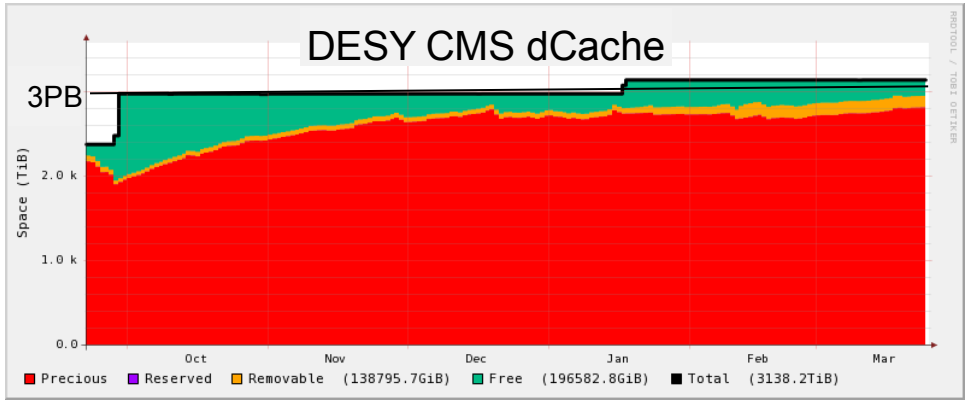


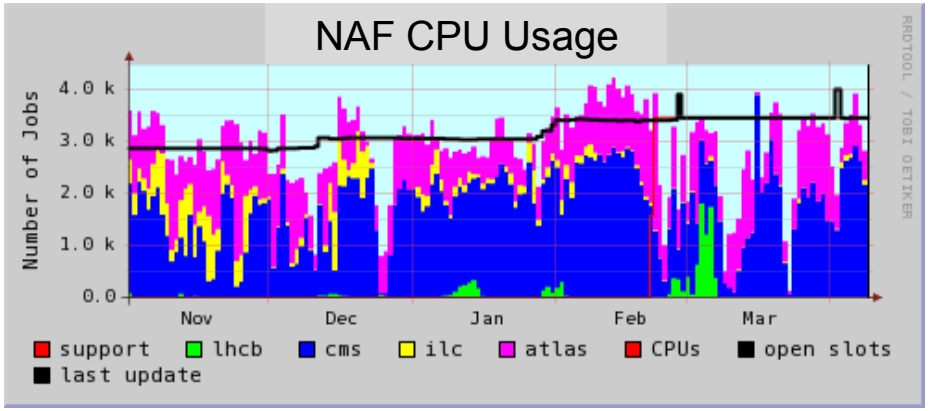
- Further methodical improvements in progress
  - Simultaneous determination of alignment and Lorentz-angle calibration constants → now being extended to the strip tracker
  - Software consolidation and preparation for startup in 2015

DESY continues to be a key player of the CMS tracker alignment group

Computing

- Recent extensions of Tier-2s and NAF
  - Based on remaining funds end of 2012
  - Slight upgrade in storage: Maintain flexibility to host data for national community
  - Additional NAF CPUs: Utilization still satisfactory for an end-user facility



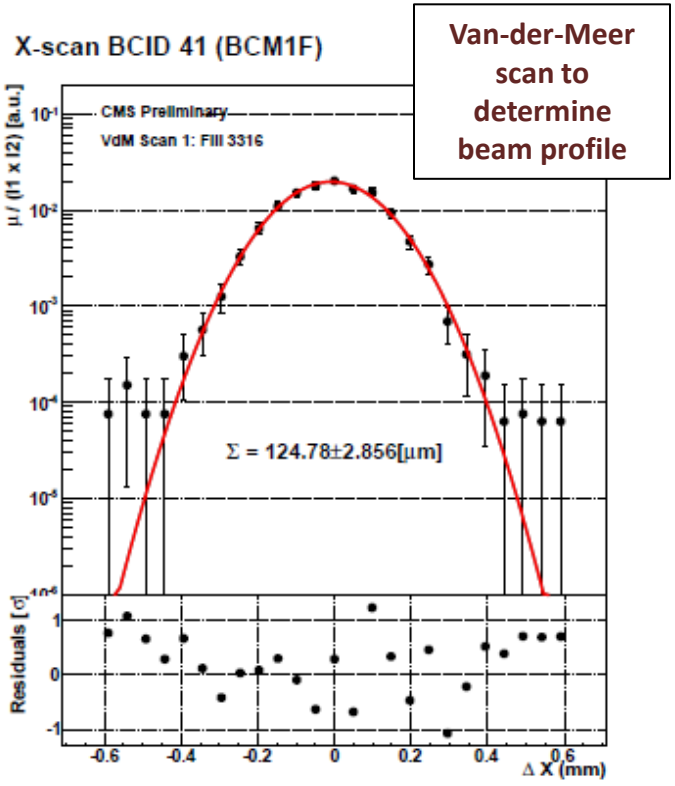


- NAF2.0 (and Lustre → Sonas) migration progressing well
  - Planning with IT: “quarterly strategic meeting” and NAF User Committee

Fast Beam Conditions Monitor (BCM1F)

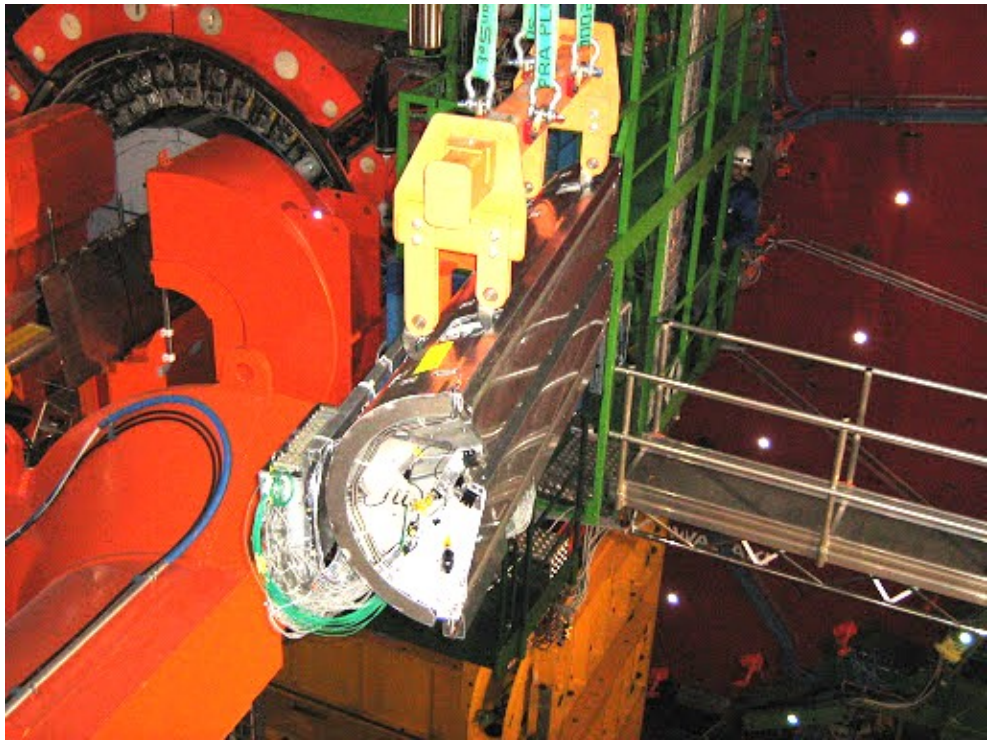
- Reliably delivered background and online luminosities up to the end of data taking
- Separate system for the LHC machine fully operational
- New histogramming unit (RHU) and multiple gate delay (MGD) commissioned during the pPb run

- LS1 activities:
  - Front-end ASIC development
  - Sensor procurement
  - Metallization
  - Assembly, test and installation of new sensors
  - DAQ back-end architecture development



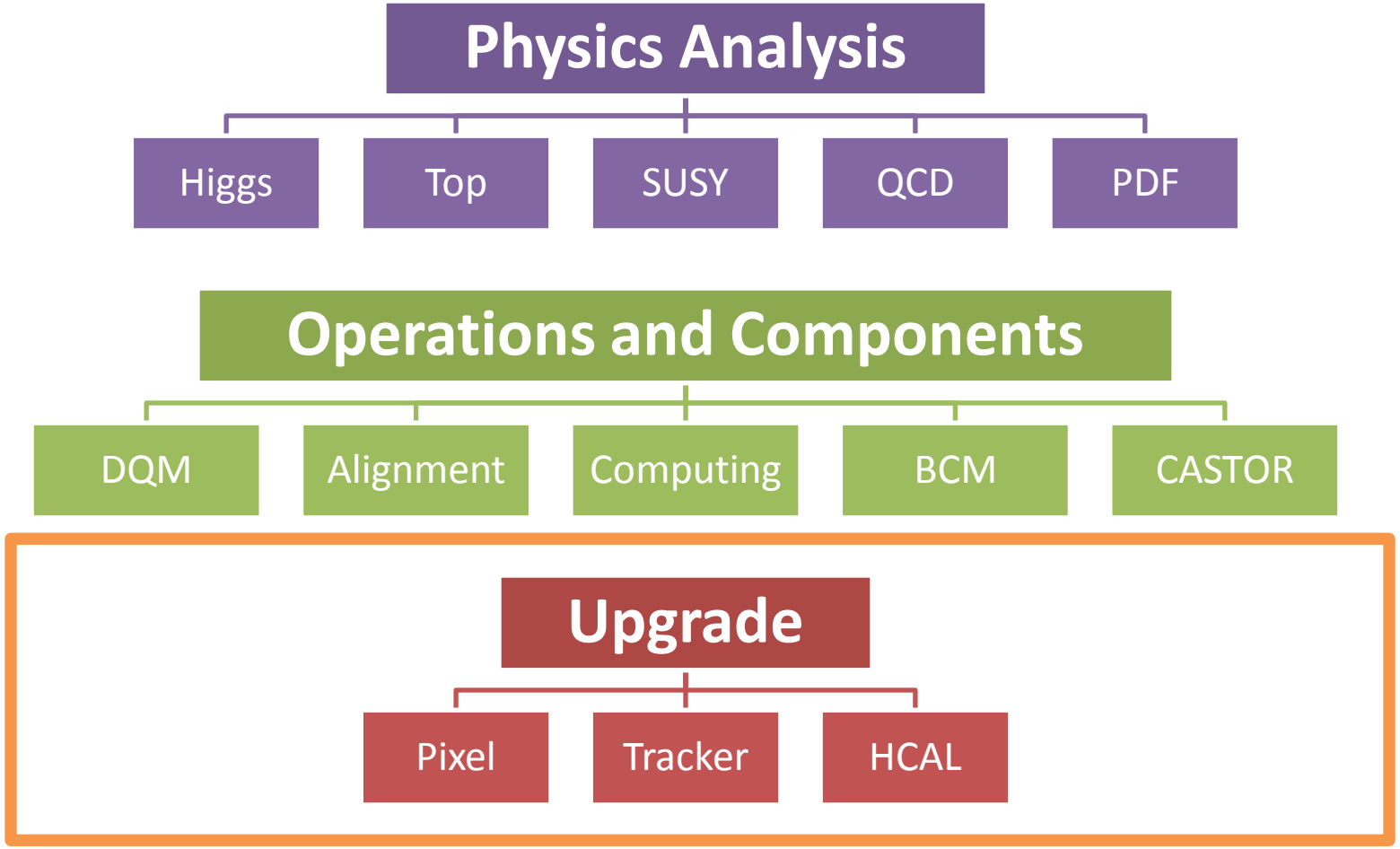
Forward Calorimeter CASTOR

- Partly replaced PMTs, upgraded monitoring and high-voltage systems
- Re-installed for pPb run, stable data taking within CMS
  - Inter-calibration with beam-halo muons
  - Electromagnetic trigger (e^+e^- final states) $\rightarrow$ First CASTOR-based physics trigger

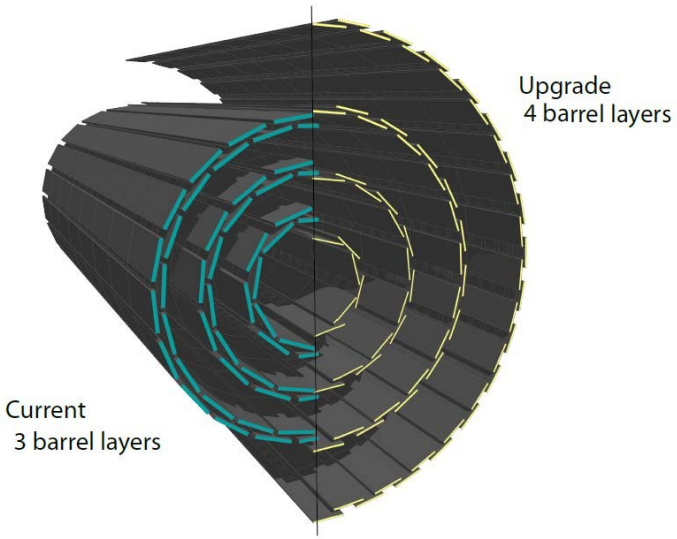


- Removed again end of February
- LS1 activities:
  - Calibration and monitoring in dedicated cosmic setup (in surface hall)
  - Investigation of possible instrumentation of blind region in the shield gap
  - Preparations for 25ns running

Part 3: Detector Upgrade



Pixel Upgrade: Scope and Timeline



CMS replaces current pixel with improved version:

- 4 barrel layers and 3 end cap discs
- Improved readout, less material
- Installation planned end of 2016

DESY and German Universities build outer layer:

- In total 512 modules + spares = 768 modules
- Assembly of modules (bump bonding, gluing)
- Testing and calibration

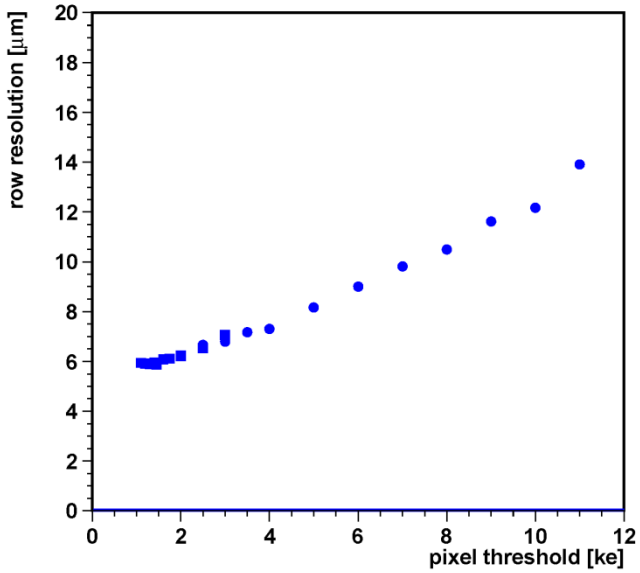
Series production of 384 pixel modules will start in 2014

- Test and calibration procedures established
- Bump-bonding technology decided, infrastructure being installed
- Prototype module production (40 μm bumps) planned by summer of 2013
- Preparation for module assembly series production

→ Fully assembled, tested and calibrated 4th layer by end of 2015

Pixel Upgrade: Test and Calibration

- DESY ROC pre-series tested at DESY test beam:
  - ROC & test-board software commissioned
  - Pre-series digital ROC and analog ROC tested
  - Irradiated ROCs tested
  - Essential experience gained
  - Important feedback for final ROC production



- Next steps:
  - April: pre-series digital ROC radiation damage assessments
  - May: 2nd pre-series ROC (final prototype) tests in DESY test beam
  - Summer 2013: establish cold calibration procedure
  - Autumn 2013: finalize test and calibration procedures

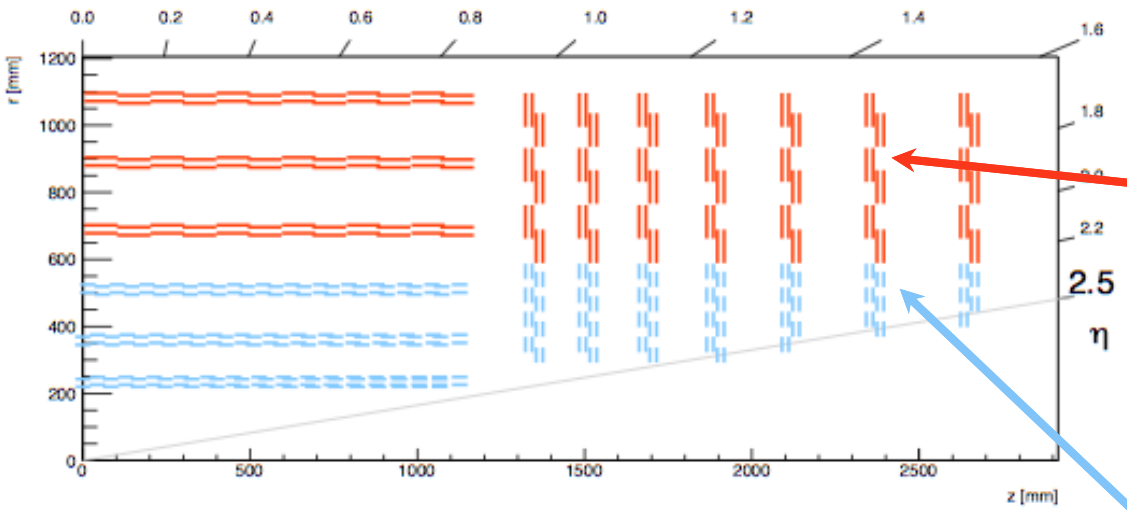
Pixel Upgrade: Bump Bonding

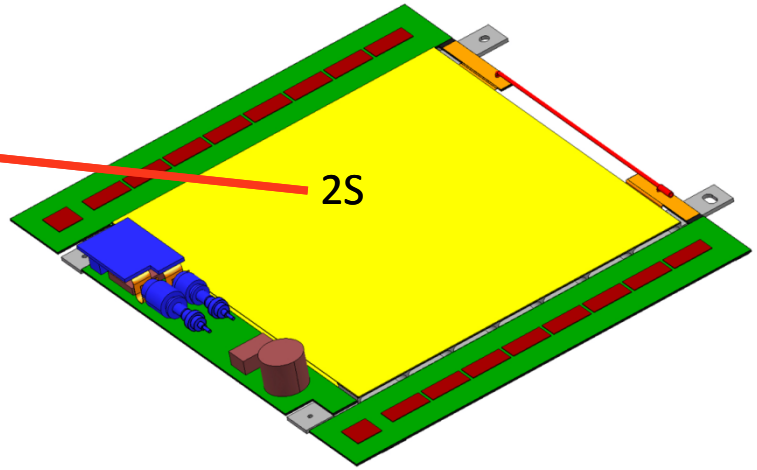
- DESY bump-bonding infrastructure (FEC):
  - New cleanroom installed and commissioned
  - Installation of process-media infrastructure (N2, formic-acid exhaust) being finished
  - Flip-chip bonder delivered in February, now being commissioned
  - Solder jetter to be delivered and installed in April

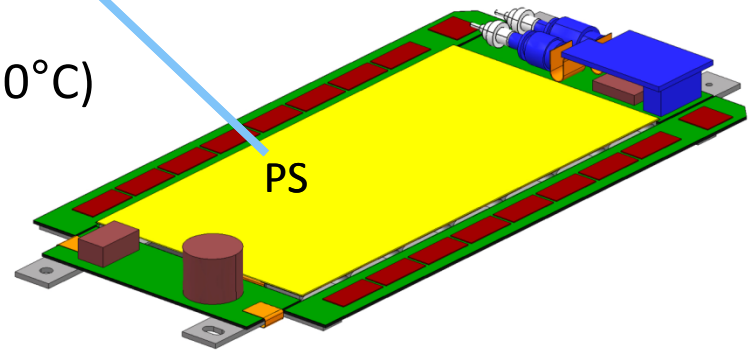
- Next steps:
  - April/May: pre-series prototype; preparation for quality control
  - Summer 2013: final pre-series; first bump-bonding test at DESY
  - Milestone: production readiness Autumn 2013

→ Project is on schedule for series production to start 2014

Tracker Upgrade for HL-LHC







Main objectives:

- Higher granularity
- Radiation hardness (sensors operated at -20°C)
- Reduced material budget
- Provide information to Level-1 trigger

> Two-strip (2S) and pixel-strip (PS) modules allow for p_T discrimination on module level

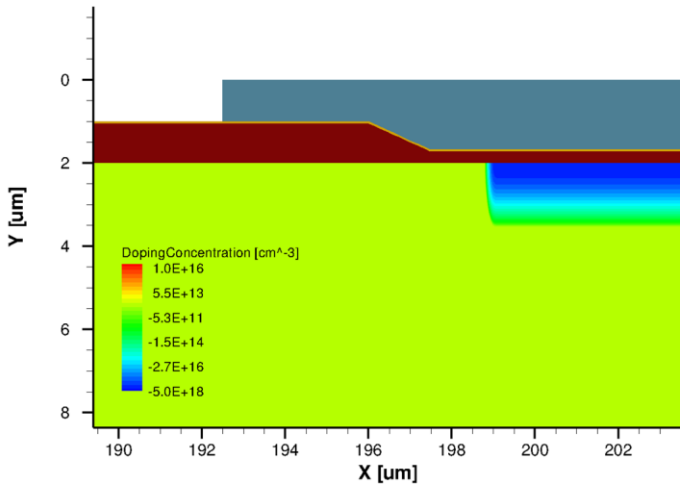
> Modules consist of a stack of two sensors with 2-4 mm spacing

> Modules deliver trigger information (stubs) at each bunch crossing

Tracker Upgrade for HL-LHC

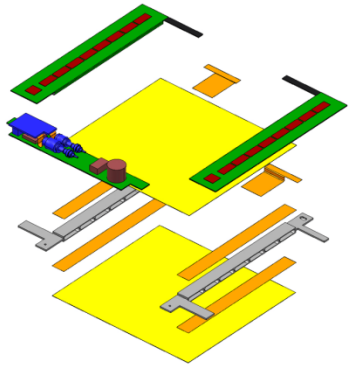
- Diodes and materials studies
  - Aim to identify the technological baseline for the phase-2 tracker upgrade
- Contribution to T-CAD simulations:
  - Provide input to sensor design
- Sensor R&D Review in February 2013:

  Very positive evaluation, encouraging the continuation of device simulations and detailed defect and field analyses



- Design of 2S module is well advanced
  - Optimization of design with respect to mass and thermo-mechanical performance has started
- DESY contributes to 4 out of 9 work packages
- First prototype module expected in 2013
  - Will be characterized in common DESY CMS & ATLAS lab infrastructure
  - Further design iterations based on measurements and finite-element analyses

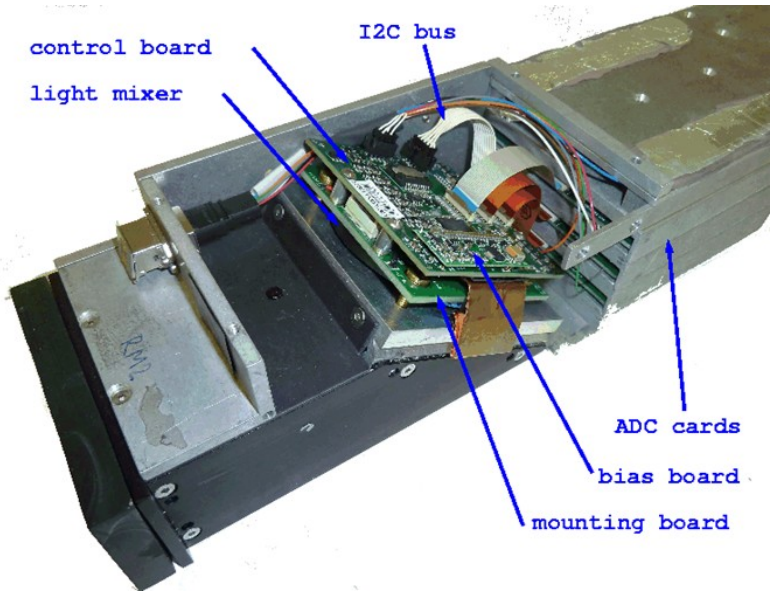
Component	Mass [g]
sensors	9.03
bridges	6.72
CFRP	5.66
hybrid	1.60
glue	0.81
ASICs	0.53
Kapton	0.11
foam	0.03
optical transmitter	3.00
connector	0.29
DCDC	2.07
total	29.85



Current mass estimate per module

Hadron Calorimeter

HCAL Outer (HO): Replacement of HPDs by SiPM during LS1



DESY is one of the key players:

- Purchased 1/3 of SiPMs
  (funding from LEXI Cluster Hamburg)
- Strong R&D participation
  - Light-mixer tests
  - Test beam
- Setup and supervision of electronics burn-in
- Coordination of the upgrade work

→ Now starting the actual installation in the cavern

Upgrade of HCAL back-end electronics to micro-TCA standard

- Setup of test stands at DESY (for development and production) progressing well

CMS Upgrade Week 2013

Will be hosted by DESY together with Uni Hamburg

Expecting 150 participants

Focusing on “phase-2” upgrades

CMS preparation for the HL-LHC EFCA Workshop at CERN in October

Summary

- Strong impact on physics analyses
  - Precision measurements based on the full 7 and 8 TeV datasets
  - After Higgs discovery, emphasis moving to measurements of its properties
  - Studies for upgrade scenarios
- Significant contributions to CMS operations
  - Finishing data operation, consolidation, methodological improvements
- Substantial involvement in detector upgrades
  - Pixel: Preparations for module production for phase 1 on time
  - Tracker: R&D for phase-2 upgrades well established and highly acknowledged
  - HCAL: LS1 work in the cavern started; phase-1 preparation well progressing

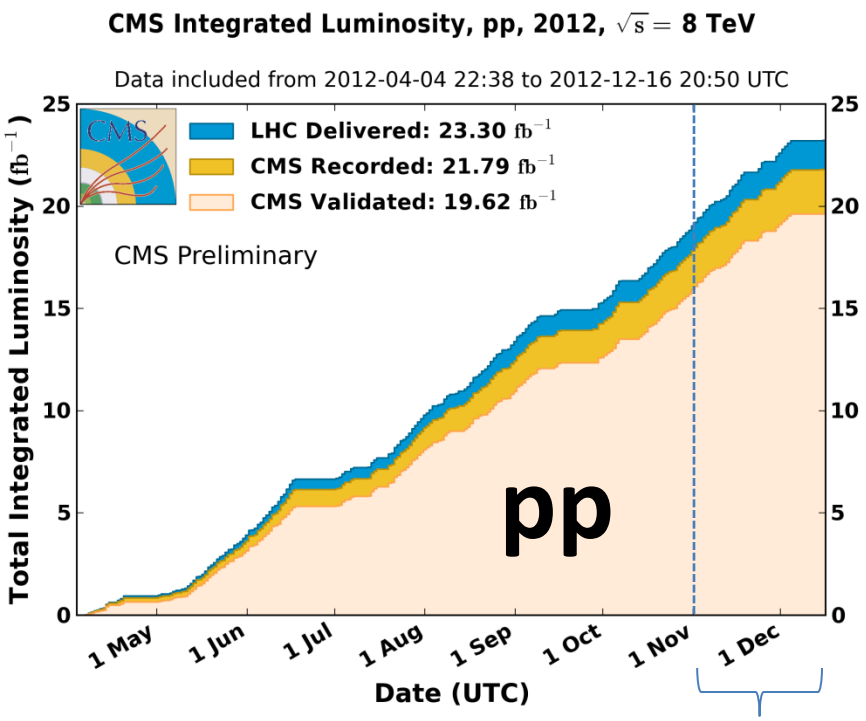
→ DESY has a strong position in CMS

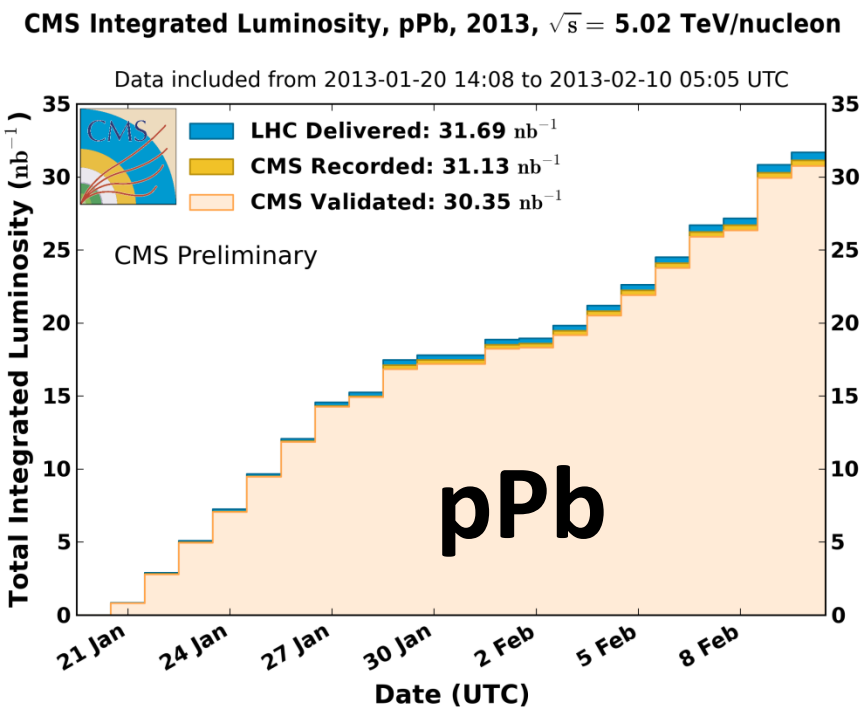
Backup

Coordinating Roles within CMS

- Level-1 Management
  - M. Kasemann: Chair of the Authorship Board
  - K. Borras: Chair of the Conference Committee; CB, FB
- Physics
  - H. Jung: Convener of Forward Physics subgroup (L3); HIG-FSQ Pub. Committee
  - I. Melzer-Pellmann: Convener of SUSY Future subgroup (L3)
  - A. Meyer: Convener of top cross sections subgroup (L3)
  - S. Naumann-Emme: Convenor of top quark mass subgroup (L3)
  - K. Lipka, R. Placakyte: Coordinators of PDF@CMS Forum
- Computing
  - C. Wissing: Integration (L2) $\rightarrow$ Operation (L2)
  - M. Kasemann: Chair of Computing Resource Board
- Data Quality Monitoring
  - D. Krücker: Organizer of remote DQM shifts (L3)
  - E. Ron: DQM for MC simulation (L3)
- Alignment
  - G. Flucke: Convener of Tracker Alignment group (L3)
- Tracker
  - G. Eckerlin: Tracker Upgrade Steering Committee, Tracker Finance Board
  - D. Eckstein, W. Lange: CEC Sensor & Qualifying
  - A. Mussgiller: Convenor of Strip-Tracker Module-Design group
- BCM1F operation, upgrade & BCM @ LHC
  - W. Lohmann
- Hadron Calorimeter Outer
  - B. Lutz: Coordinator for HO Upgrade at Point 5

CMS Performance





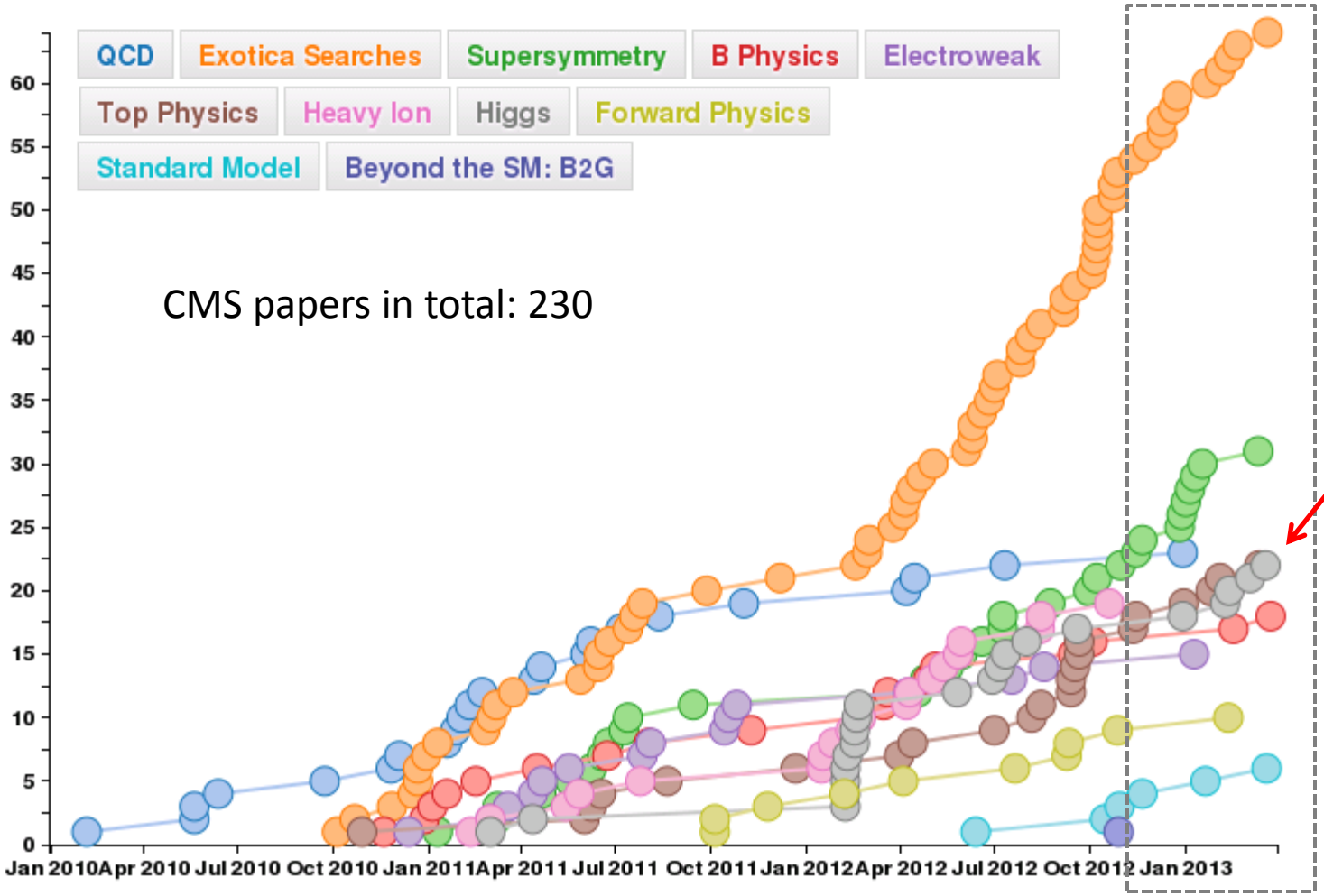
Another 4 fb^{-1} since last PRC

Smooth operations with high data-taking efficiencies / minimal downtimes until the end of the pp running and during the pPb run

CMS Results and Publications

Many new (preliminary) results from all physics groups

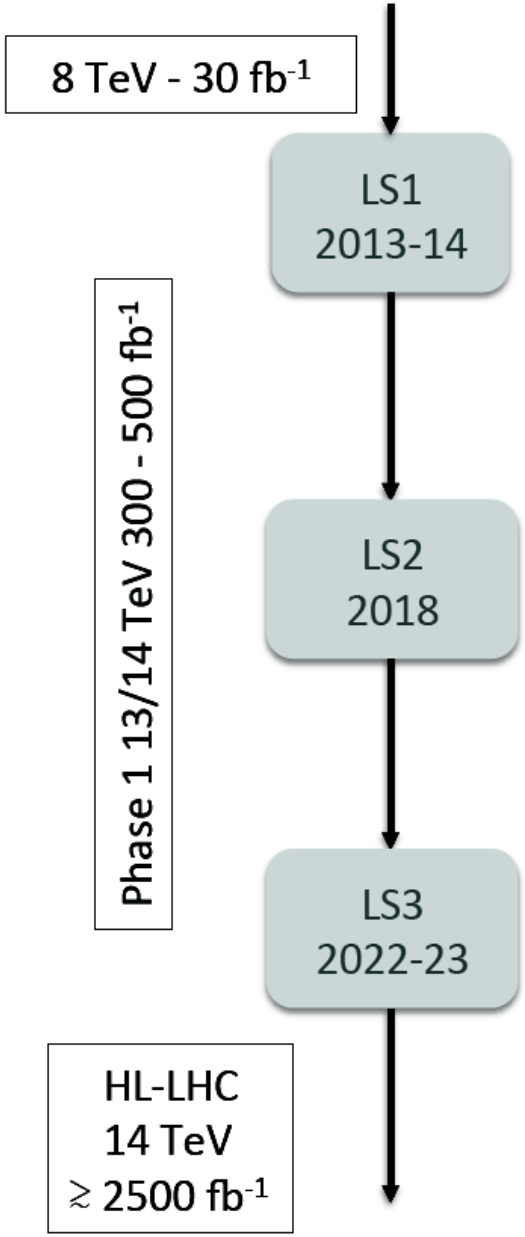
→ especially for HCP in November and La Thuile / Moriond in March



Long Higgs paper

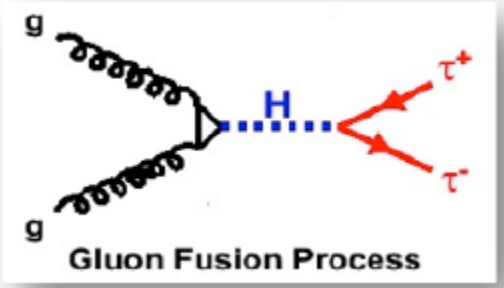
"Observation of a new boson with mass near 125 GeV in pp collisions at $\sqrt{s}$ = 7 and 8 TeV" (arXiv:1303.4571, submitted to JHEP)

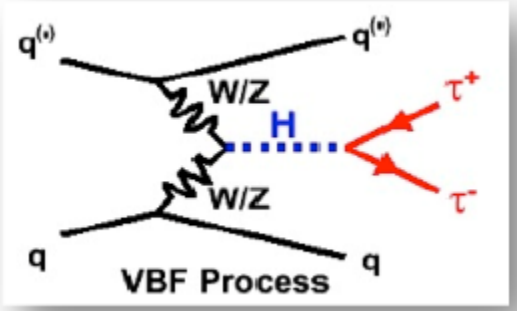
Reminder: LHC / CMS Schedule



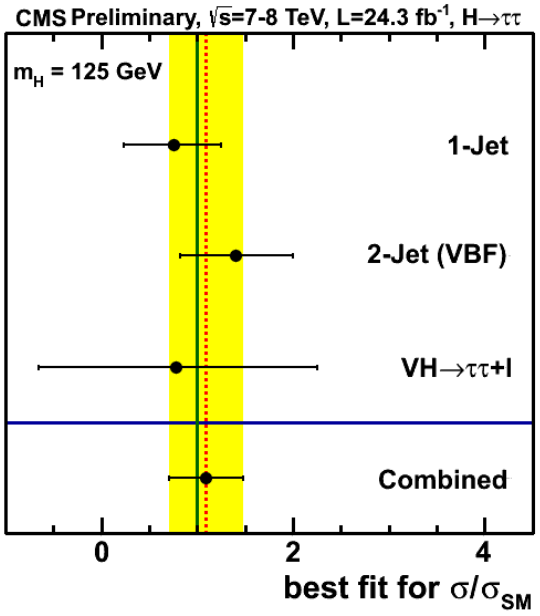
Higgs: H → ττ Search

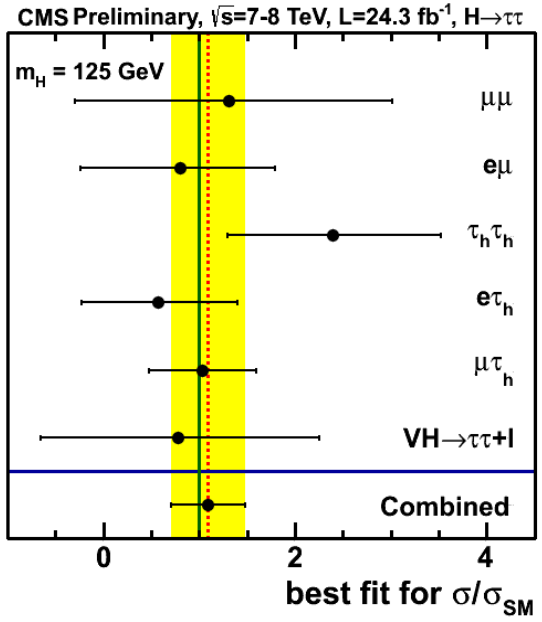
Exploited Higgs production mechanisms:

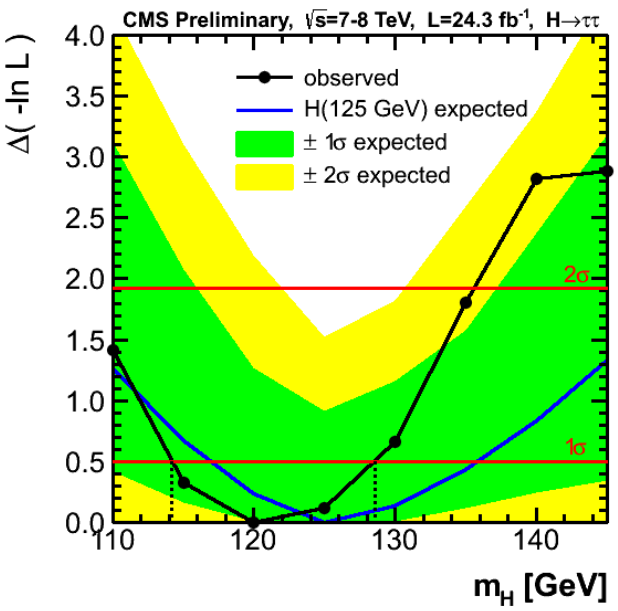




PAS HIG-13-004:

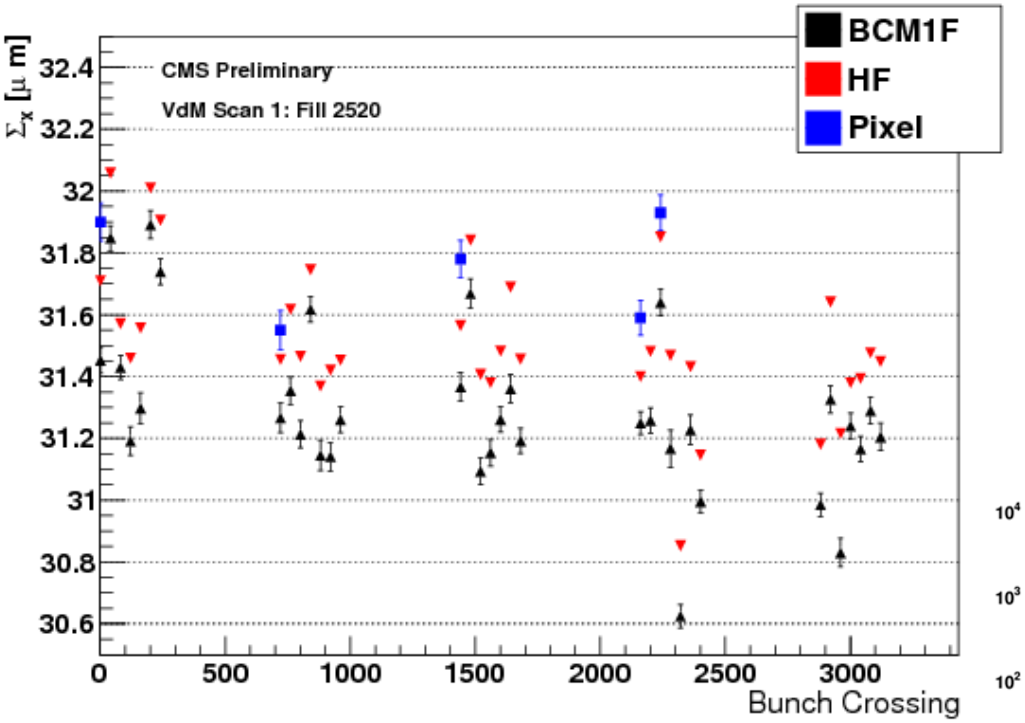




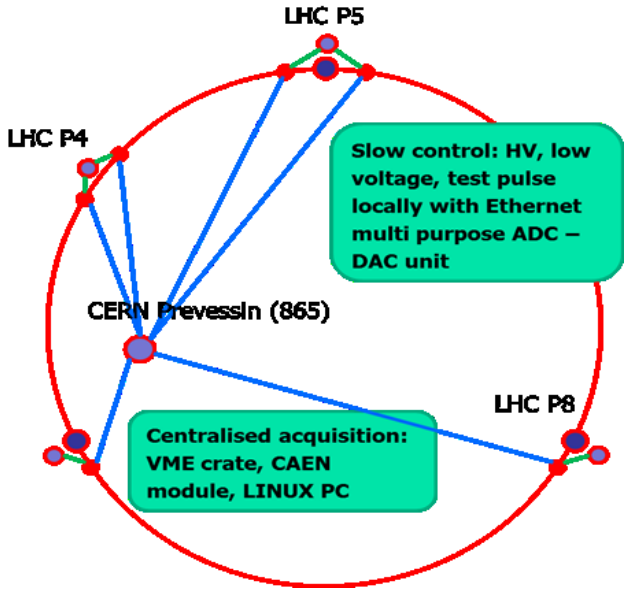


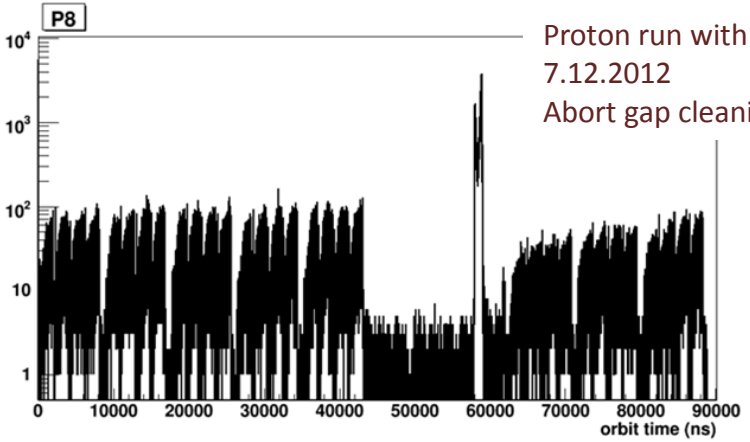
Beam Conditions Monitor & Luminometer

BCM1F delivered background and online-luminosities reliably up to the end of 2012/13 data taking!



The separate system for LHC was operated successfully



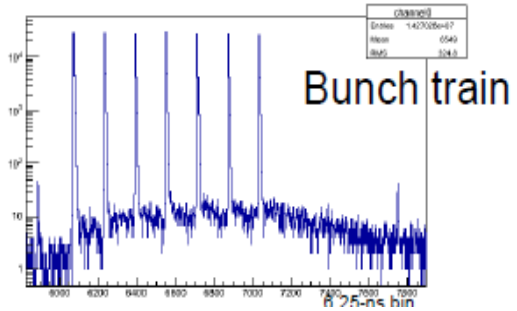


Proton run with 25 ns
7.12.2012
Abort gap cleaning

Beam Conditions Monitor & Luminometer

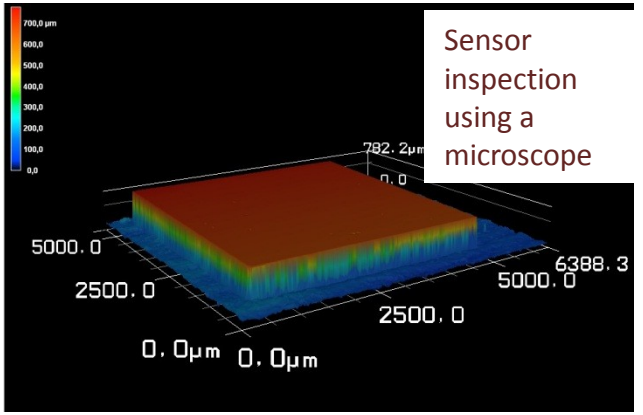
Dedicated electronics

- RHU (Histogramming Unit) and MGD (Multiple Gate/Delay) commissioned during the heavy ion run)
- Production and test of 15 RHU units at DESY for luminosity measurement after 2014
- Design upgrade for MGD (higher rate, more channels)



Upgrade in the current shut-down (CERN, DESY, Princeton, AGH-UST)

- Dedicated FE ASIC development (CERN, AGH-UST), submission done, delivery in May
- Sensor procurement (CERN, DESY)
- Metallization (DESY, Princeton)
- Assembly and test (DESY)
- Installation (CERN, DESY, Princeton)
- DAQ back-end architecture development (CERN, DESY)



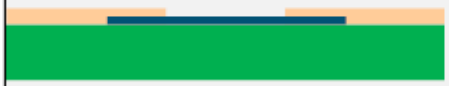
Sensor inspection using a microscope

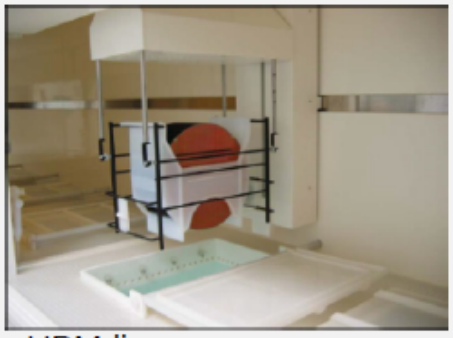
Beam conditions monitoring and luminosity measurement are foreseen to form a new Project within CMS

Pixel Upgrade

Step 1:UBM Process

CIS sensor wafers
IBM ROC wafers
AlSiCu or Al pads

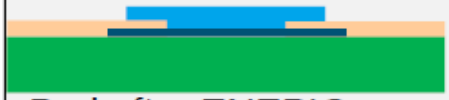




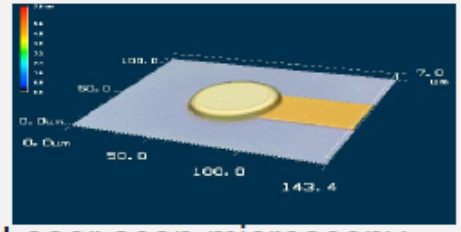
UBM-line

bath:
electro
-less
growth

ENEPIG:
e-less Ni 5µm,
e-less Pd 200 nm,
immersion Au 50 nm



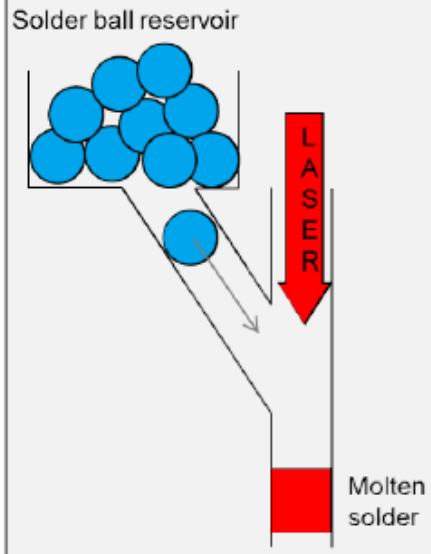
Pad after ENEPIG deposition



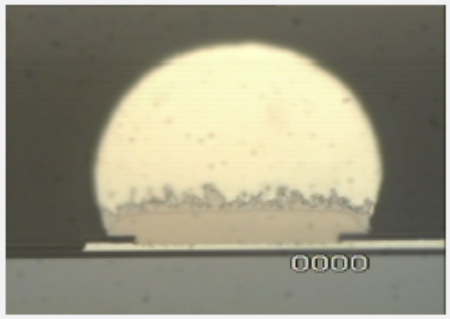
Laser scan microscopy

Step 2: Solder bump Jetting Process

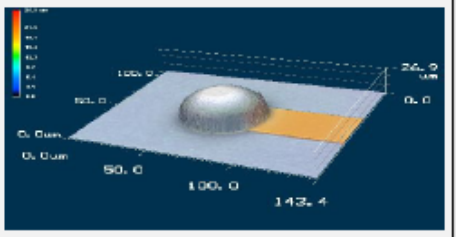
40 µm SnAgCu (96% 3.5% 0.5%)



SB2 Jet:
bumps at 5 Hz
=> 4 h / sensor



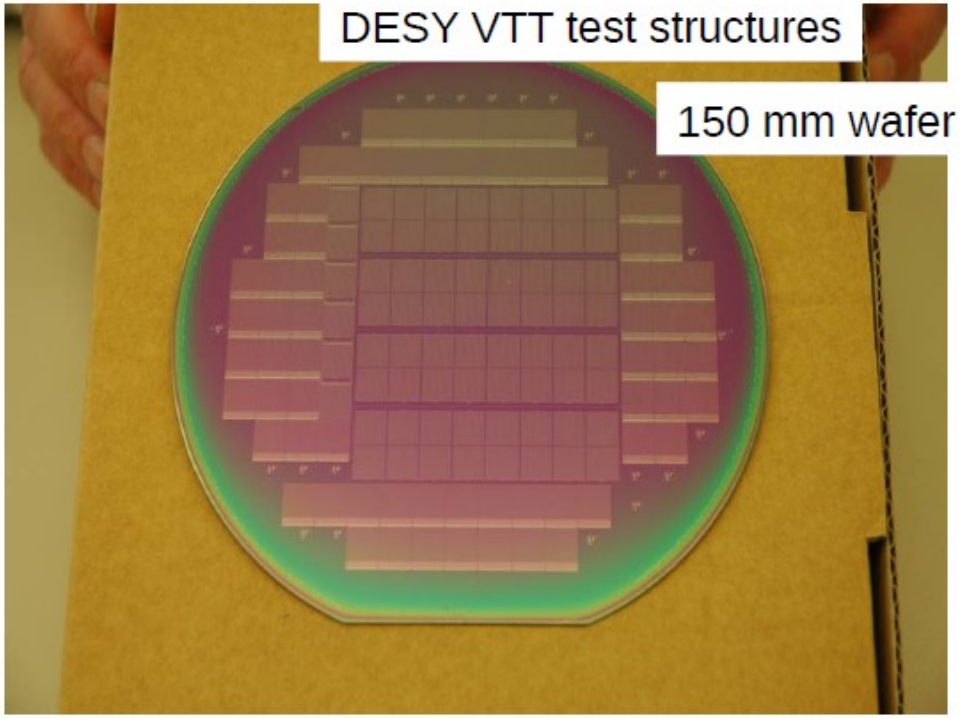
Cross section micrograph



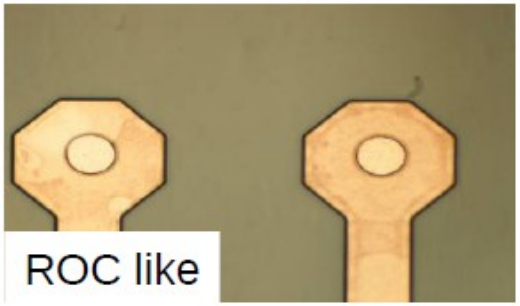
Laser scan image of pad with SAC solder bump

Pixel Upgrade

- 160-pad daisy chain structures
- Sensor-like structures and matched ROC-like structures
- AlSiCu metallization
- Realistic bump bond pad structures
- VTT currently also processes plated SnPb solder bumps



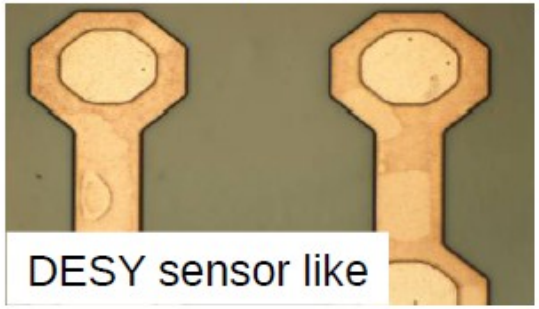
15 µm +2/-0



Chip distribution:

- 4 full sensors (30 µm)
- 6 single sensors (30 µm)
- 70 ROCs (15 µm)

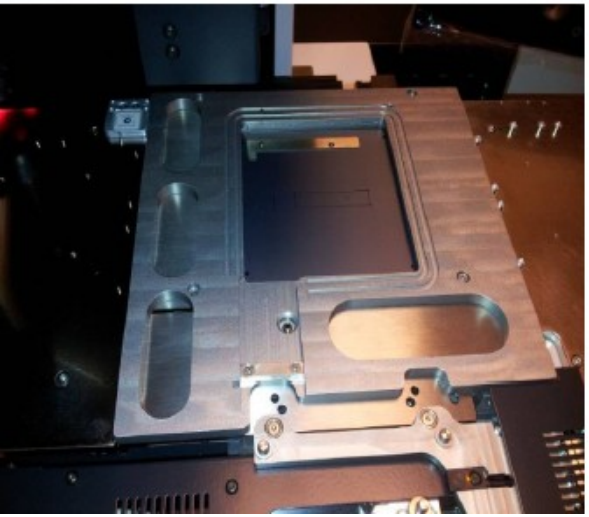
30 µm +2/-0



Pixel Upgrade

Flip-chip bonder: Femto from Finetech

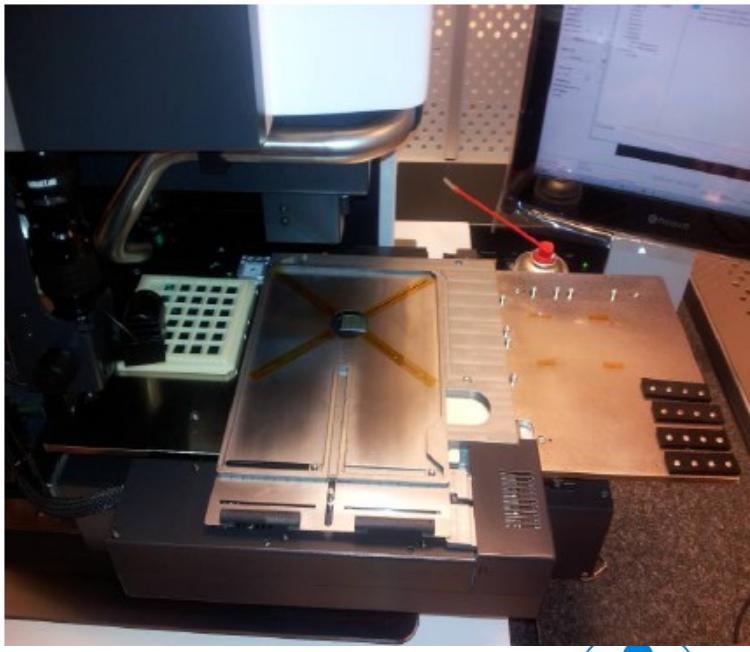
- Sensor is placed into the chamber on a heated chuck
- Cover has opening for one ROC and moves by step motors
- Bond head tool places one ROC at a time and covers the opening



Formic acid chamber

opened

closed



Tracker upgrade sensors R&D

- **Phase-2 Outer TK Sensors Review held in February**
  - Review of work done so far and recommendations on how to continue
  - CMS internal and external reviewers
- **Review report :**

Device simulations

Device simulations have reached a remarkable accuracy. While understanding the properties of irradiated sensors remains based on experimental measurements, the optimization of the sensors design is often best done (or greatly helped) by simulation. It is important to maintain the effort in the coming 1-2 years, to support the design of the final sensors prototypes, and possible further optimization with the selected vendors.

Detailed defect and field analysis

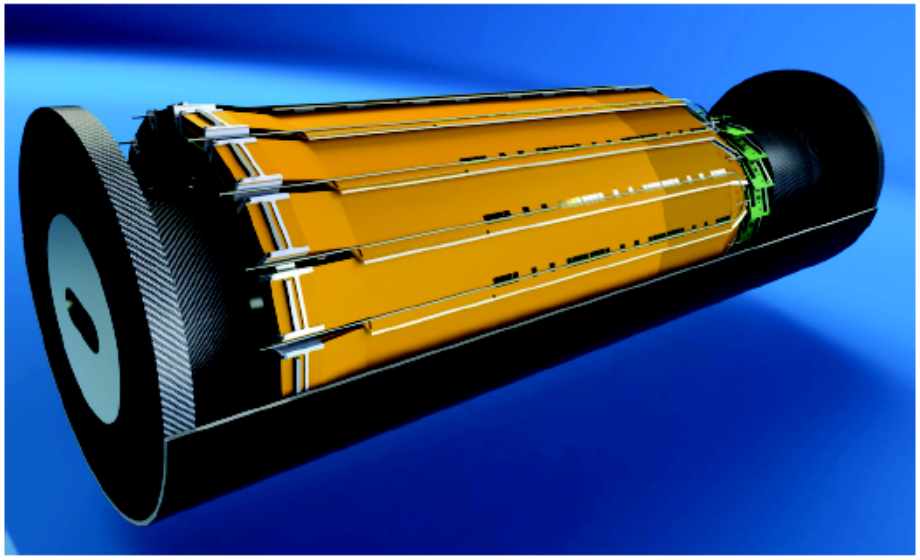
The understanding of the sensors properties and the production process is absolutely impressive. Maintaining the ability and expertise to perform these measurements is top priority in view of the procurement phase, in particular the qualification of the vendors.

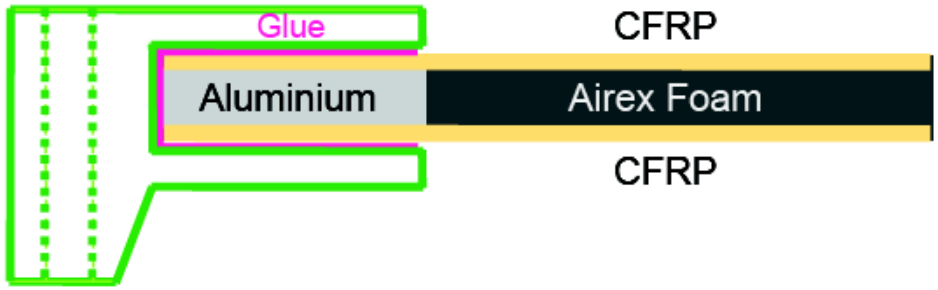
Mechanical Laboratory

Common DESY-FH infrastructure

- mechanical workshop dedicated to detector development
  - under construction - expected to become available early 2013
- besides standard tools it will be equipped with
  - tools for machining for carbon based materials

    needs special dust offtake system - was not possible before
  - autoclave for the production of carbon fibre reinforced plastic (CFRP) structures
- ideal for R&D and production of high performance detector elements
- like the support shell for the Belle II vertex detector

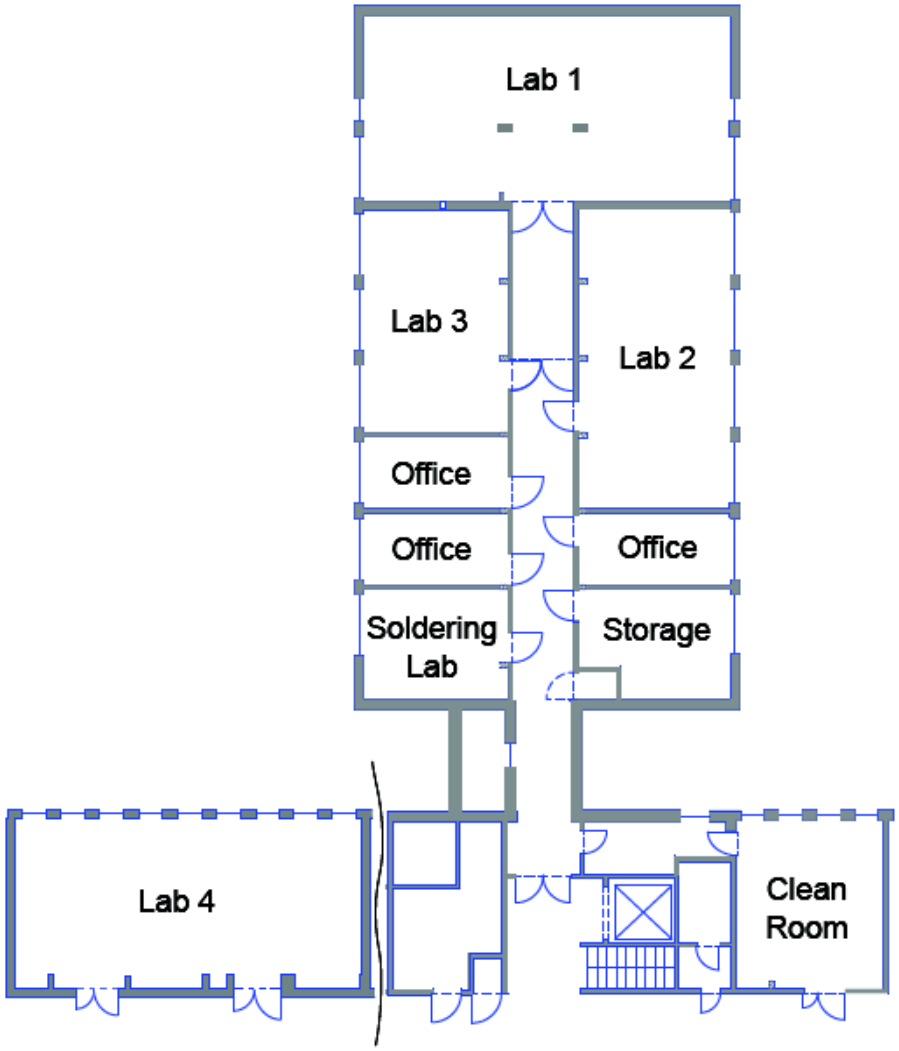




Electronics Laboratory

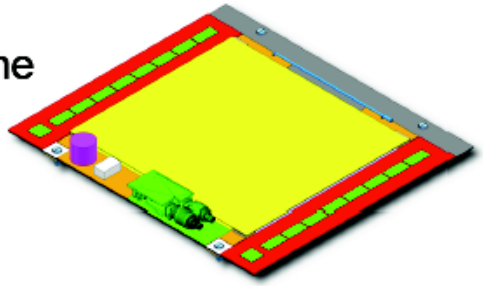
Common DESY-FH infrastructure

- electronics laboratory dedicated to detector development needs
  - clean room
  - four labs with dedicated infrastructure
  - soldering lab
  - office space
  - storage
    for frequently used electronics components
  - 360 square meters in total
- available equipment
  - nitrogen and dry air (-70 °C) supplies
  - various cooling systems
    conventional and CO_2 (soon)
  - microscope and infrared camera
  - setup for thermal measurements
  - setup for deformation measurements
  - setup for silicon sensor qualification (soon)
  - environmental chamber (soon)
- available also to test beam users

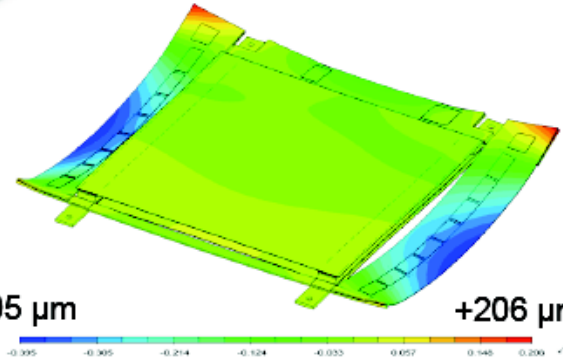


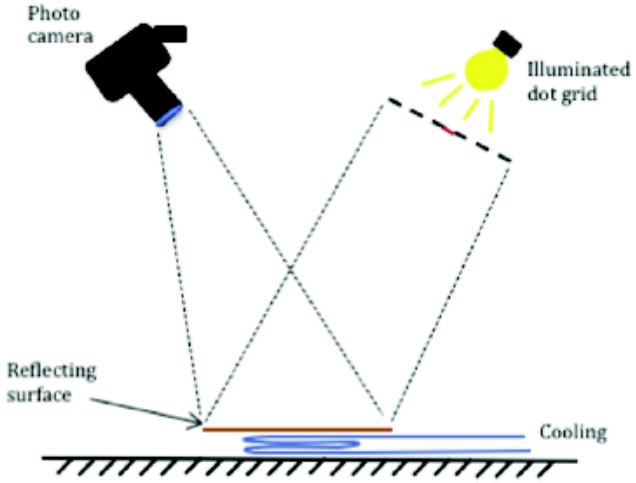
Optical Deformation Setup

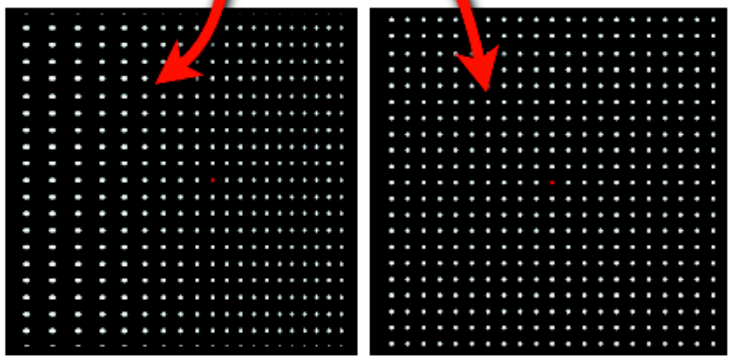
- deformation due to thermal stress is an issue for detectors
  - multi-layer sandwiches of materials with different coefficient of thermal expansion (CTE)
  - operation at -20 °C
  - mechanical stress on sensors reduces lifetime
    e.g. CMS tracker modules



- deformation is reconstructed from two images
  - Mirror image off the undeformed surface
  - Mirror image off the deformed surface







Optical Deformation Setup (cont.)

- setup will be able to measure components up to 60 cm x 75 cm in size
  - from e.g. CMS tracker modules (15 cm x 15 cm) to ATLAS Petals (40 cm x 60 cm)
- 10 µm precision is the goal
  - measurements with smaller test system suggest ~5 µm
- currently in final commissioning phase
- available to external users
- e.g. optical fibres with Bragg grating for stress measurements
  - under development by Santander and INTA in the framework of the AIDA project
  - fibres will be calibrated with the DESY setup