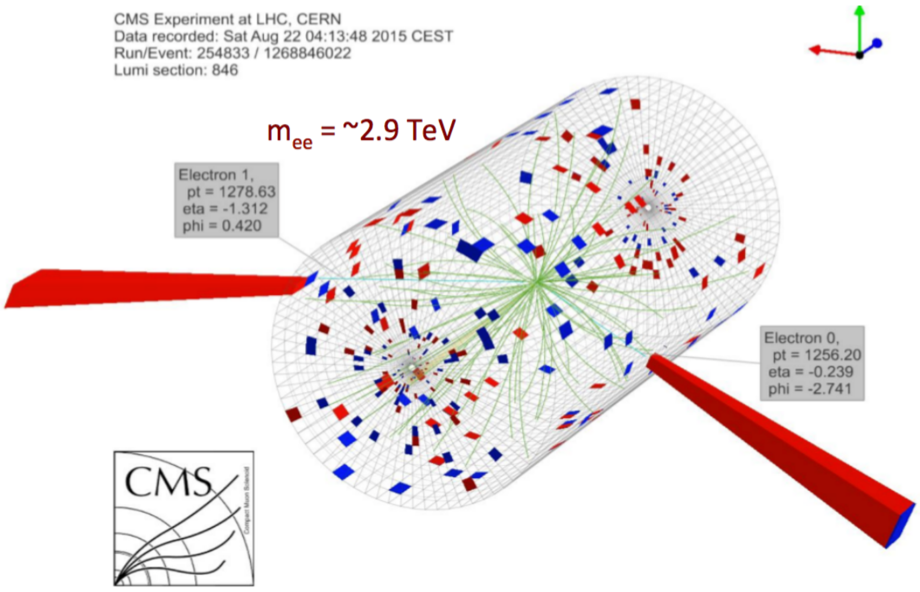
LHC and CMS Report

80th Meeting of the Physics Research Committee



Claudia Seitz
On behalf of the DESY CMS Group
Hamburg, 22.10.2015

HELMHOLTZ
ASSOCIATION

CMS

DESY

Outline and CMS activities at DESY

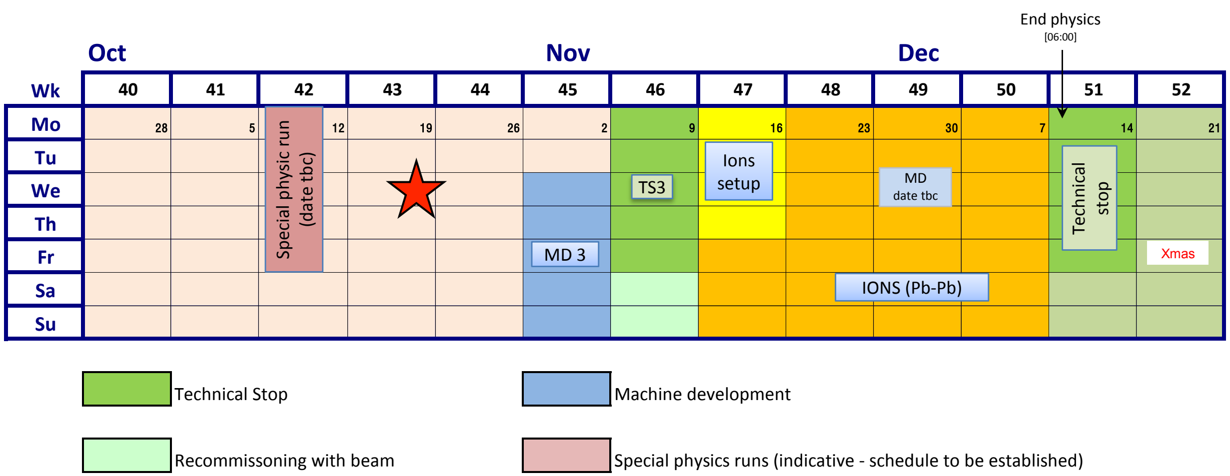
- LHC Restart at 13 TeV
- Performance of CMS
- Operations: Alignment, Computing, Open Data, Luminosity
- Physics results: Top, Higgs, QCD, SUSY
- Phase 1 upgrades: Pixel detector, μ-TCA readout
- Phase 2 upgrade: Tracker detector
- Summary and Outlook

Outline and CMS activities at DESY - Highlights

- **LHC Restart at 13 TeV**
- **Performance of CMS**
- Operations: Alignment, Computing, Open Data, Luminosity
- **Physics results: Top, Higgs, QCD, SUSY**
- **Phase 1 upgrades: Pixel detector** μ-TCA readout
- Phase 2 upgrade: Tracker detector
- **Summary and Outlook**

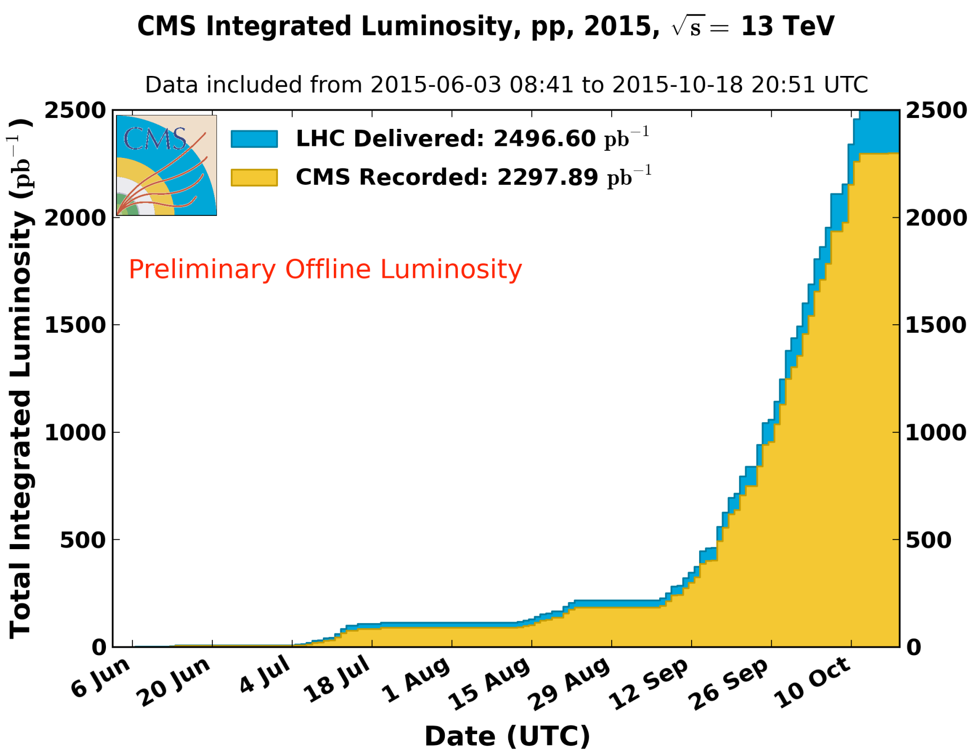
LHC status

- LHC successfully restarted operations after LS1 for the first time at a center of mass energy of 13 TeV
  - First dataset at 50 ns from July were used by CMS for publications
- Achieved stable running conditions at 25ns bunch spacing in the last weeks
  - Instantaneous luminosity slightly lower than expected
  - recently: 1825 bunches ➔ next: 2041 bunches
- Goal is to deliver around 3 fb^{-1} to ATLAS/CMS for this year

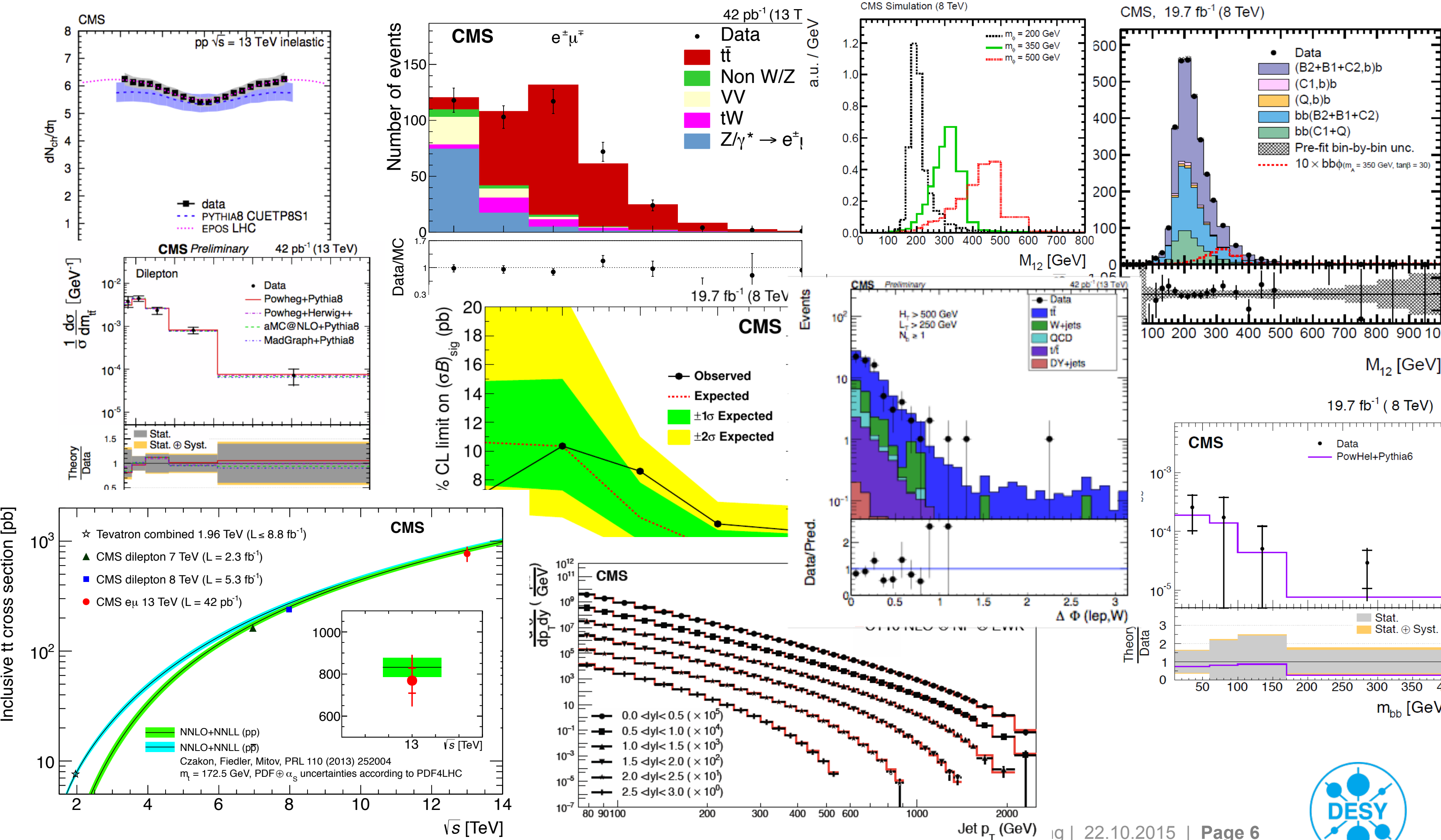


CMS status

- CMS is working again at extremely high efficiency at 3.8 T
  - Tracker is running cold at -20°C
  - Upgrades to the muon systems are performing well
  - New luminosity telescopes are delivering measurements
  - New DAQ and hardware for trigger farms
- CMS recorded up to now about 2.3 fb^{-1}



Physics highlights from DESY CMS



Publications since May with substantial contributions from DESY CMS

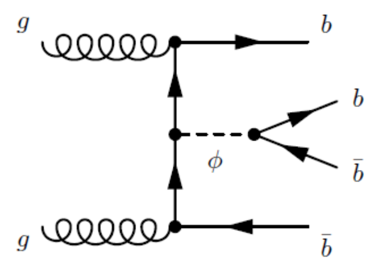
- Search for neutral MSSM Higgs bosons decaying into a pair of bottom quarks, arxiv:1506.08329, accepted by JHEP
- Measurements of the Higgs boson production and decay rates and constraints on its couplings from a combined ATLAS and CMS analysis of the LHC pp collision data at $\sqrt{s}$ = 7 and 8 TeV, ATLAS-CONF-2015-044, CMS-PAS-HIG-15-002
- Inclusive jet production at CMS at 8 TeV, SMP-14-001
- Run 2 - Pseudorapidity distribution of charged hadrons in proton-proton collisions at $\sqrt{s}$ = 13 TeV, FSQ-15-001, arXiv:1507.05915
- Run2 - Inclusive tt cross section in eμ channel (L = 42 pb-1), TOP-15-003, arXiv:1510.05302
- Run2 - Differential tt cross sections in dilepton channels (L = 42 pb-1), TOP-15-010
- Inclusive tt cross sections: Run-I legacy measurement (7 and 8 TeV), TOP-13-004
- Differential tt cross sections at 8 TeV, arXiv:1505.04480, accepted by EPJC
- tt production with additional jet activity, incl. b quark jets, 8 TeV, arXiv:1510.03072
- SUSY - Follow-up paper on 14 TeV LHC-ILC study, DESY Report 15-145, arXiv:1508.04383, submitted to EPJC
- Run 2 - SUSY - Early analysis commissioning plots, presented at SUSY2015, DP-15-035, SUS-15-001

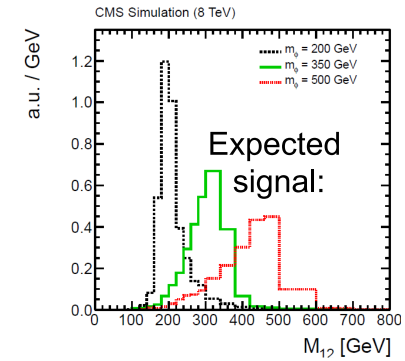
Publications since May with substantial contributions from DESY CMS

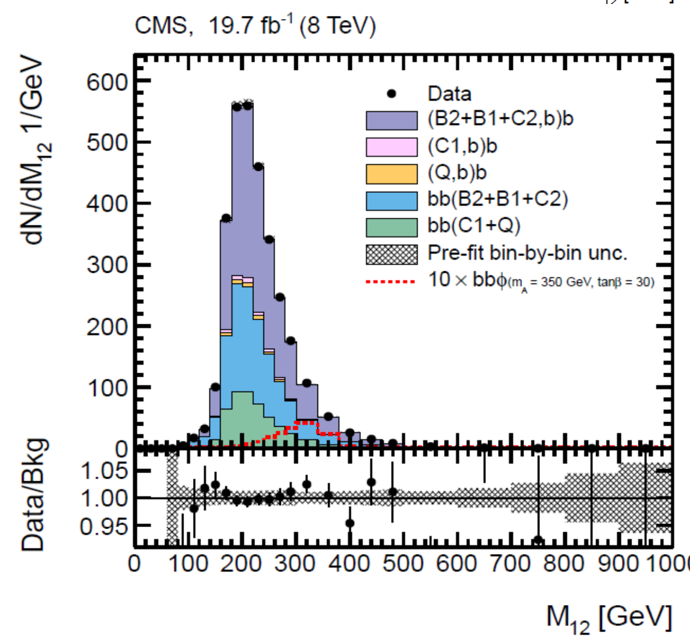
- **Search for neutral MSSM Higgs bosons decaying into a pair of bottom quarks, arxiv:1506.08329, accepted by JHEP**
- Measurements of the Higgs boson production and decay rates and constraints on its couplings from a combined ATLAS and CMS analysis of the LHC pp collision data at $\sqrt{s}$ = 7 and 8 TeV, ATLAS-CONF-2015-044, CMS-PAS-HIG-15-002
- Inclusive jet production at CMS at 8 TeV, SMP-14-001
- **Run 2 - Pseudorapidity distribution of charged hadrons in proton-proton collisions at $\sqrt{s}$ = 13 TeV, FSQ-15-001, arXiv:1507.05915**
- **Run2 - Inclusive tt cross section in eμ channel (L = 42 pb-1), TOP-15-003, arXiv:1510.05302**
- **Run2 - Differential tt cross sections in dilepton channels (L = 42 pb-1), TOP-15-010**
- Inclusive tt cross sections: Run-I legacy measurement (7 and 8 TeV), TOP-13-004
- Differential tt cross sections at 8 TeV, arXiv:1505.04480, accepted by EPJC
- tt production with additional jet activity, incl. b quark jets, 8 TeV, arXiv:1510.03072
- SUSY - Follow-up paper on 14 TeV LHC-ILC study, DESY Report 15-145, arXiv:1508.04383, submitted to EPJC
- **Run 2 - SUSY - Early analysis commissioning plots, presented at SUSY2015, DP-15-035, SUS-15-001**

MSSM Higgs boson decay to bb at 8 TeV

- Search for degenerate H and A in higher mass region
- Main challenge: huge background rate from QCD multijet production
- b-associated production: cross section enhanced by $\sim 2\tan^2\beta$, better background control
  - require at least three b-tagged jets
  - dedicated trigger
- Background-only hypothesis describes data well
  - no signal observed
- CMS analysis is unique at the LHC
- **Best sensitivity in this channel to date**
- Outlook for 13 TeV
  - Commissioning of the analysis has started
  - New triggers for 13 TeV have been developed, implemented and are active for 25 ns running





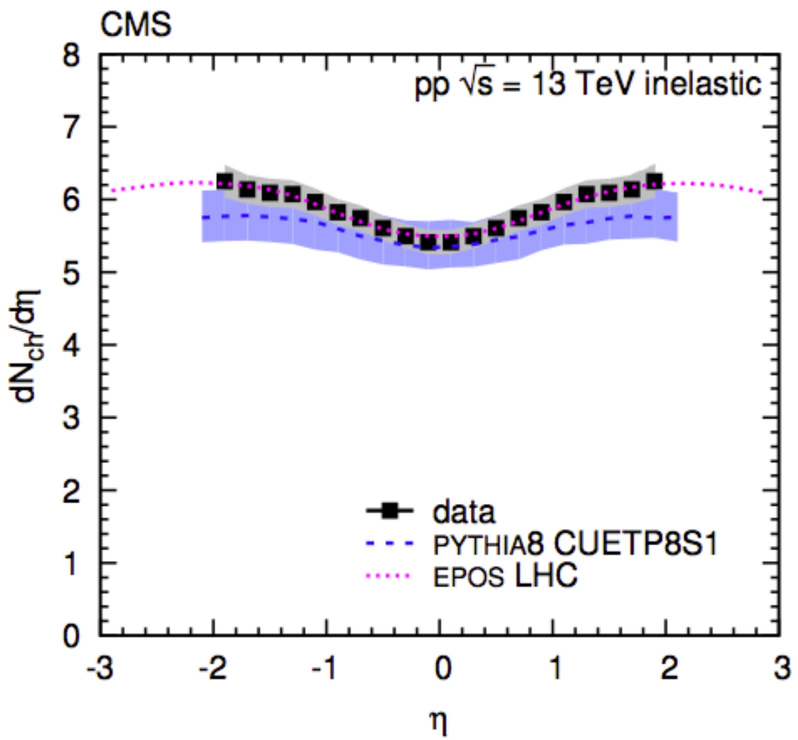


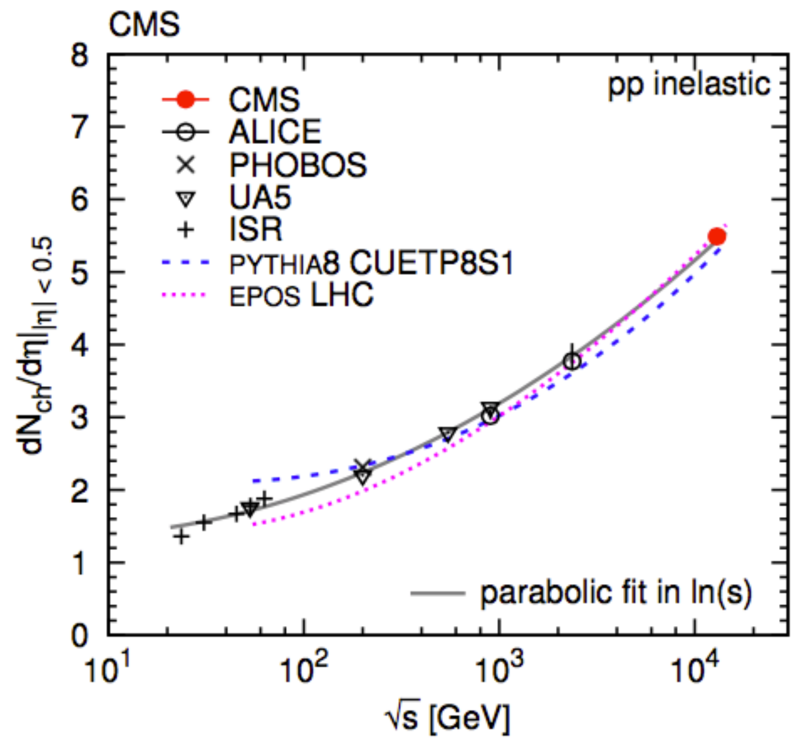
arxiv:1506.08329, accepted by JHEP

First 13 TeV LHC measurement

July'15

- Pseudorapidity distribution of charged hadrons in proton-proton collisions at $\sqrt{s}$ = 13 TeV





- Very essential measurement
  - Measurement with tracking at 0T magnetic field
  - Crucial input for pileup simulation

FSQ-15-001, arXiv 1507.05915

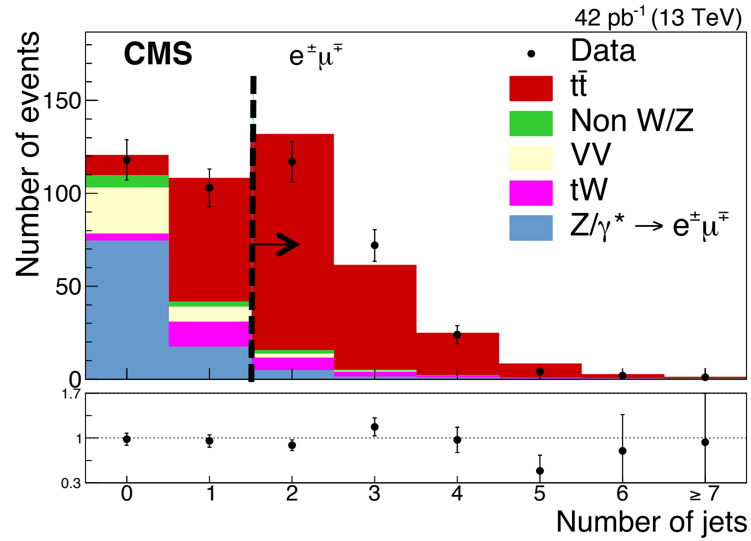
Inclusive $t\bar{t}$ cross section in $e\mu$ channel at 13 TeV

Aug'15

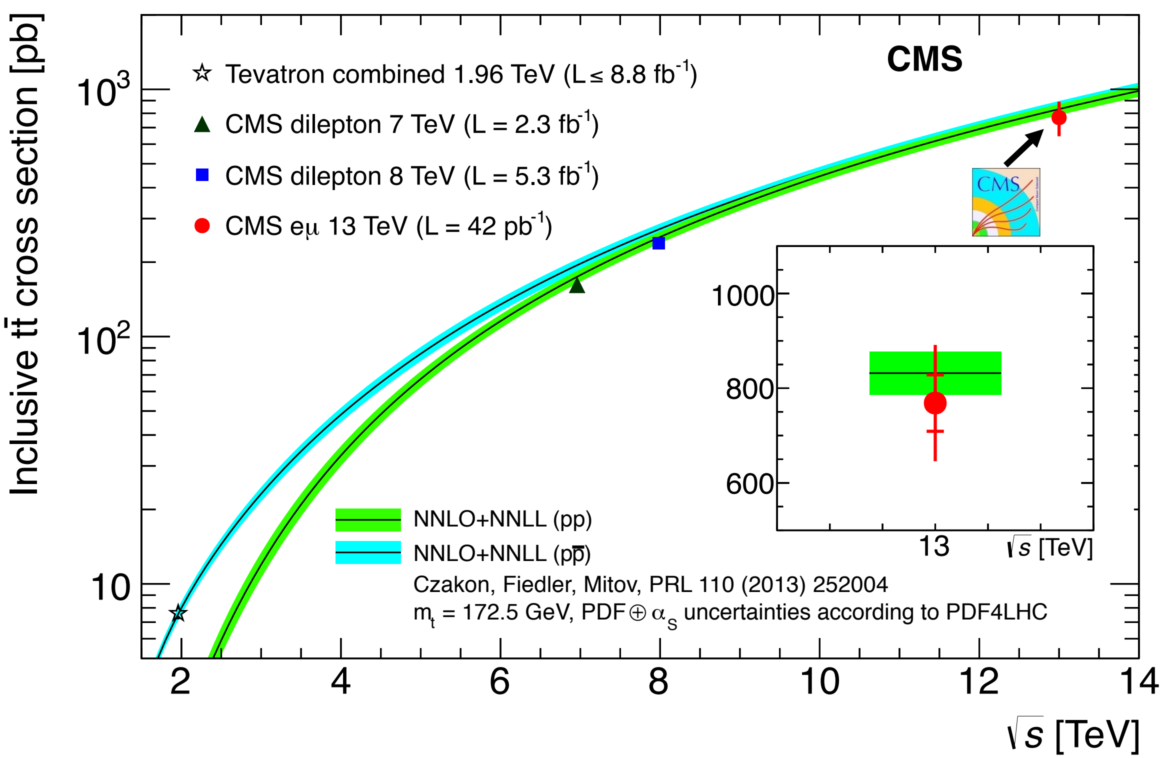
Selection: opposite-sign isolated $e\mu$ pair ($p_T > 20$ GeV), ≥ 2 jets ($p_T > 30$ GeV), no b-tags

> Cut & count approach (robust):

$$\boxed{\sigma_{t\bar{t}} = 772 \pm 60\,(\text{stat}) \pm 62\,(\text{syst}) \pm 93\,(\text{lumi})\ \text{pb}}$$



L = 42 pb^{-1}



> Dominant systematics:
luminosity (12%), trigger (5%), lepton efficiencies (4.3%), lepton energy scale (2.6%)

> Good agreement with:
- CMS l+jets, ATLAS results
- theoretical prediction

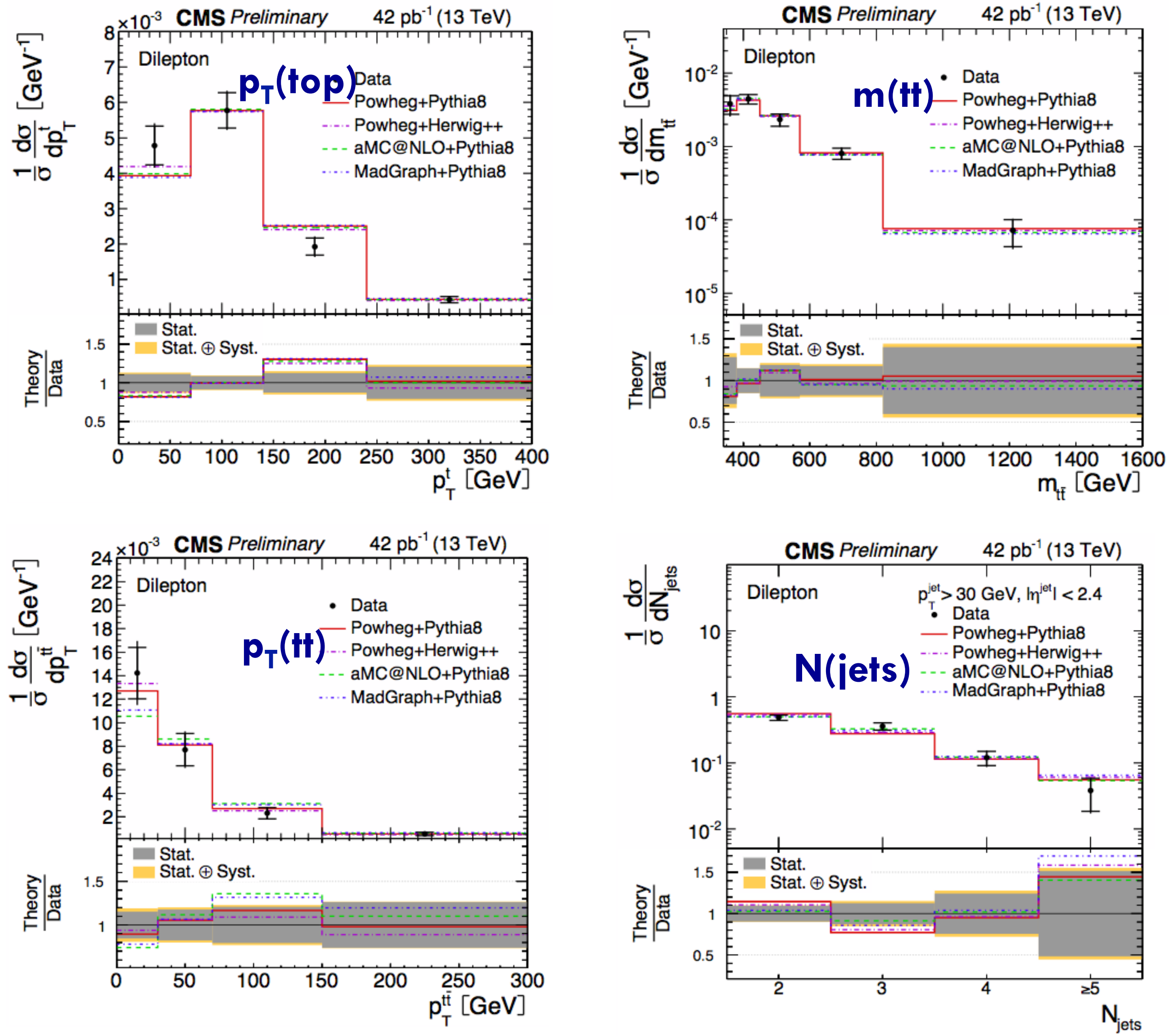
Submitted to PRL

TOP-15-003, arXiv:1510.05302

$t\bar{t}$ differential cross sections in dileptons at 13 TeV

Aug'15

- Top & $t\bar{t}$: parton level, full phase space
- N(jets): particle level, fiducial phase space
- $p_T(t\bar{t})$: differences between models consistent with MC validation studies
- **Good agreement between data and predictions**
- More statistics will lead to important very high accuracy measurements

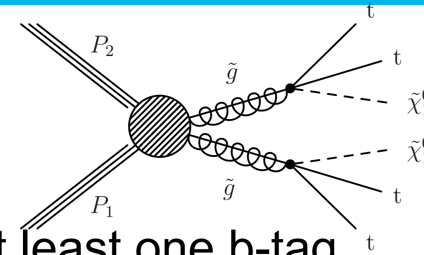


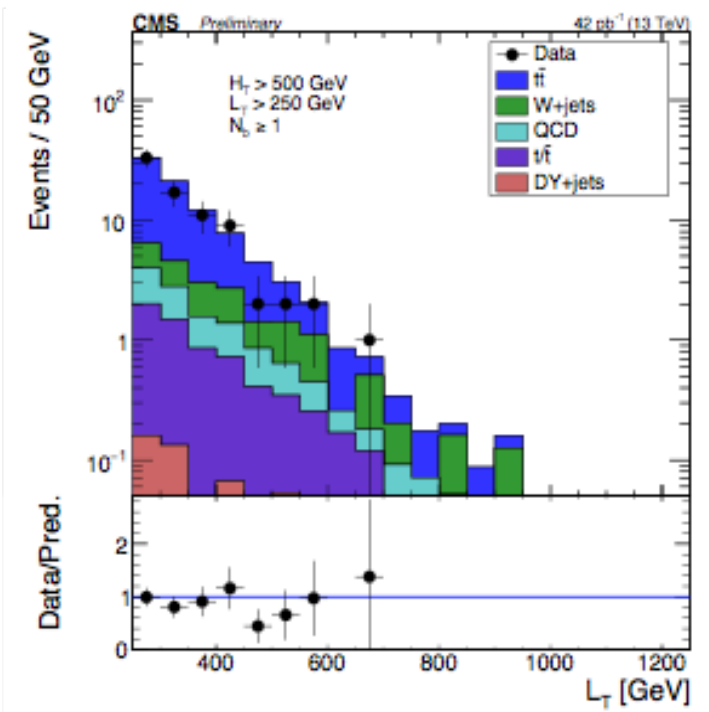
TOP-15-010

SUSY commissioning document

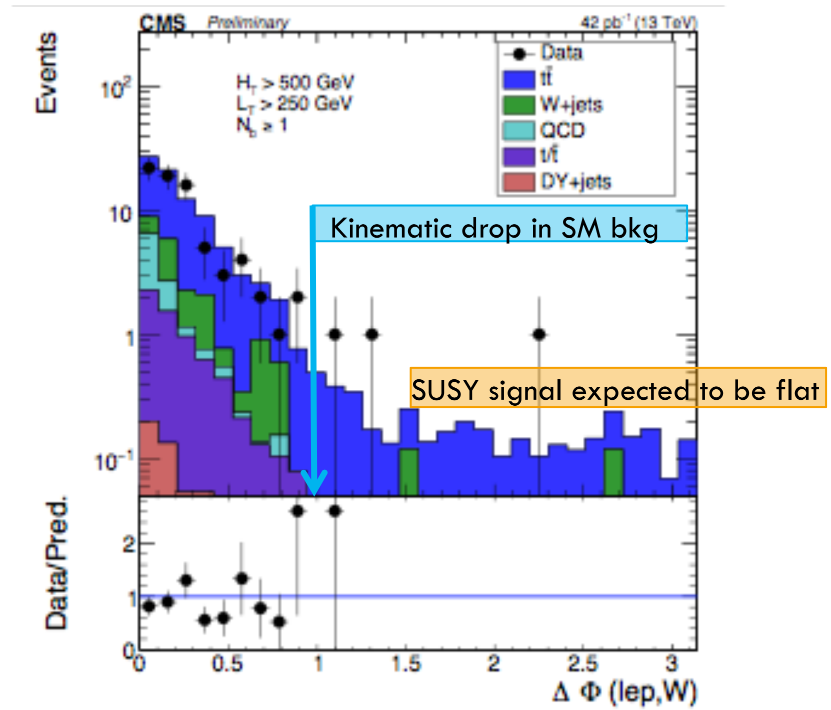
Aug’15

- Early analysis commissioning plots with $42pb^{-1}$ of 50 ns data
- Presented at SUSY2015 conference
- Inclusive gluino search in final states with a single lepton and at least one b-tag





Sum of lepton p_T and MET



Angle between lepton and W direction (reconstructed from lepton and MET)

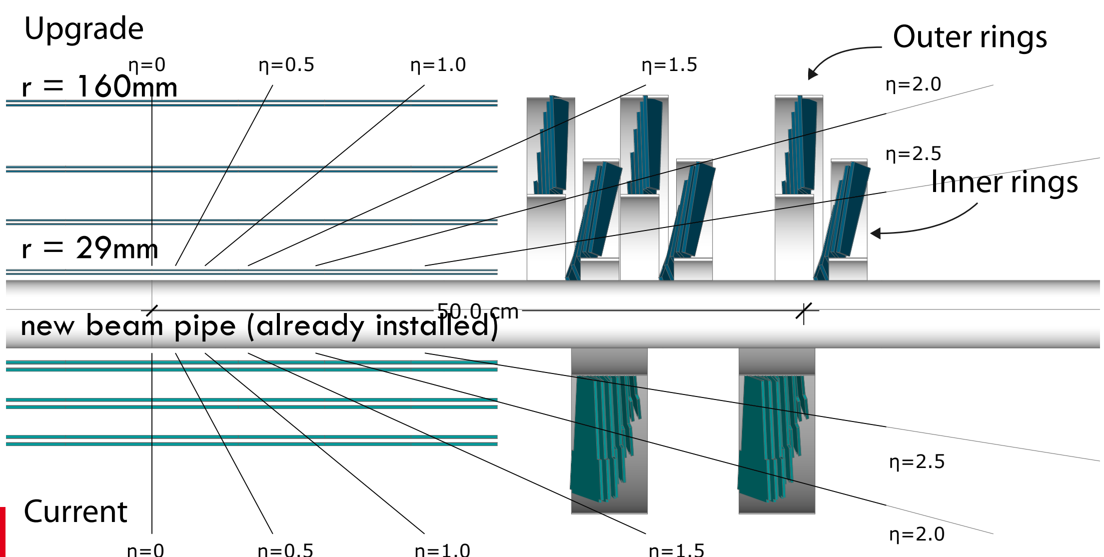
- Analysis is being commissioned and is waiting for more data

DP-15-035, SUS-15-001

Pixel Phase 1 upgrade project

Pixel Phase 1 upgrade

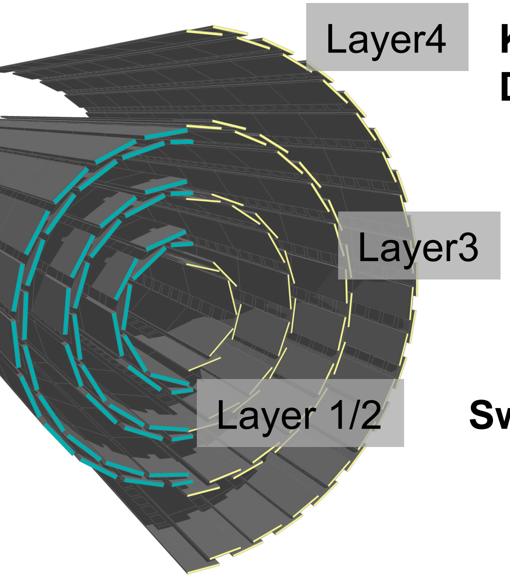
- CMS pixel upgrade planned for winter 2016/17
- One layer and one disk more than current detector
  - Improved efficiency beyond design luminosity
  - 4 hit coverage up to $|\eta| < 2.5$
- Increased buffer size on the readout chip and digital output
  - Improved efficiency at high fluxes
  - Gain in communication speed



- Improved Material budget
  - New cabling
  - Carbon fiber support structure
  - CO_2 cooling

CMS Pixel Phase 1 upgrade at DESY and UniHH

- Multiple production sites for the entire detector
- Project is a close collaboration between different groups at DESY (FEC - microelectronics, SZE - service electronics, CMS) and the Uni Hamburg



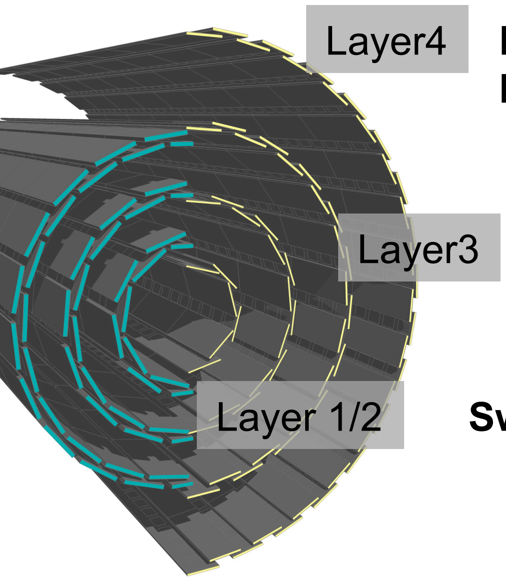
KIT/Aachen
DESY/Uni HH

CERN/Taiwan
Italy/Finland

Switzerland

CMS Pixel Phase 1 upgrade at DESY and UniHH

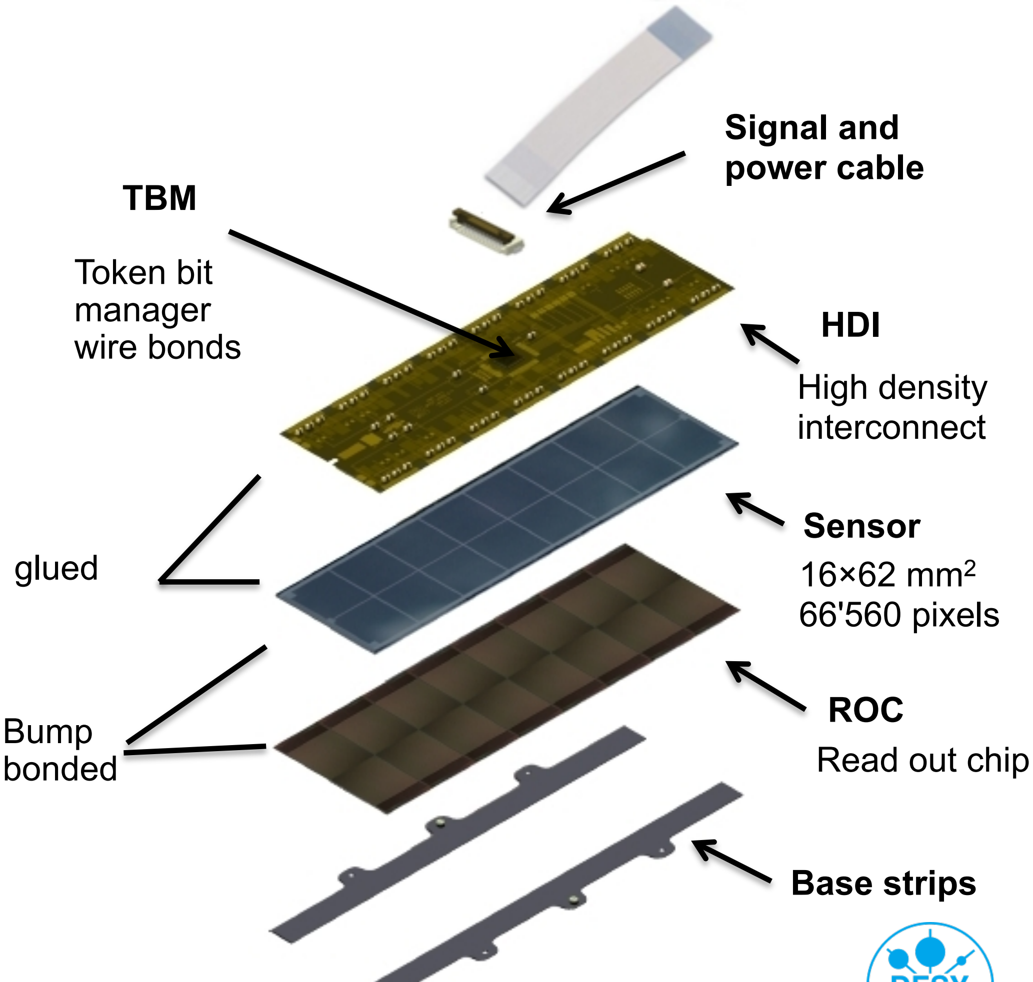
- Multiple production sites for the entire detector
- Project is a close collaboration between different groups at DESY (FEC - microelectronics, SZE - service electronics, CMS) and the Uni Hamburg



KIT/Aachen
DESY/Uni HH

CERN/Taiwan
Italy/Finland

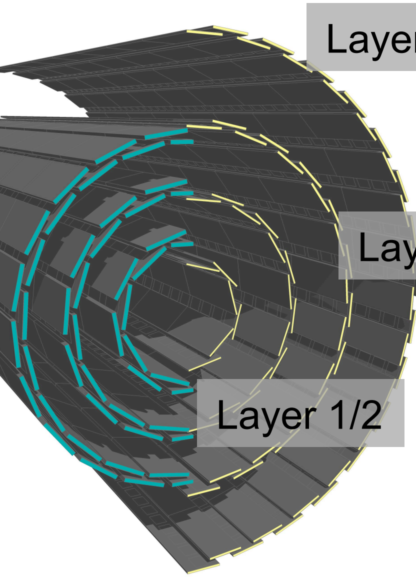
Switzerland



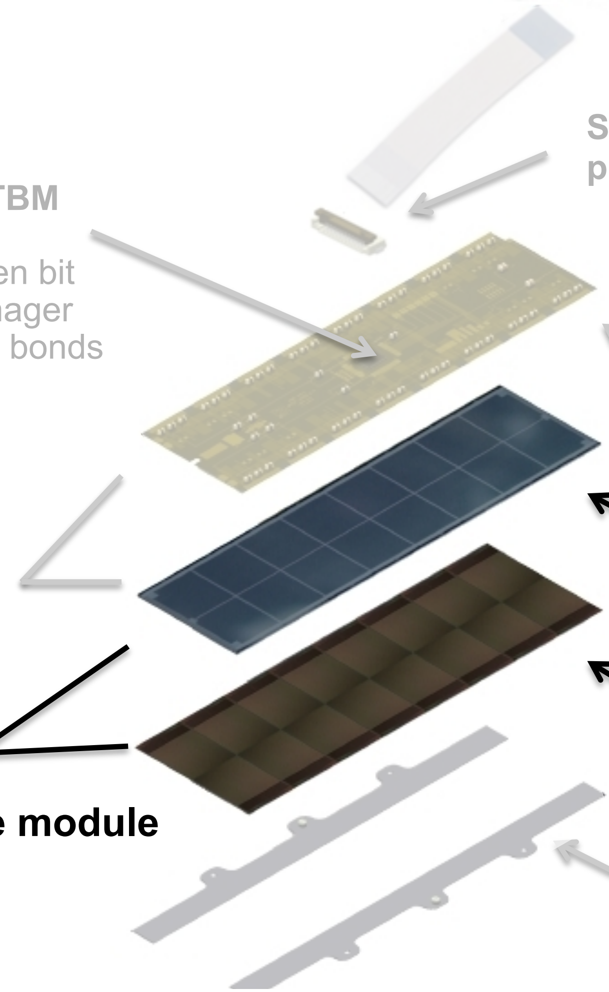
DESY/UniHH pledged to produce 308 modules including spares

CMS Pixel Phase 1 upgrade at DESY and UniHH

- Multiple production sites for the entire detector
- Project is a close collaboration between different groups at DESY (FEC - microelectronics, SZE - service electronics, CMS) and the Uni Hamburg



DESY/UniHH pledged to produce 308 modules including spares

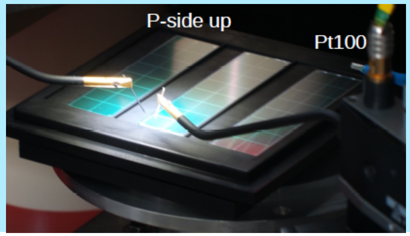


Bare module production

Sensors from CiS
UBM, dicing,
shipping at Pactech

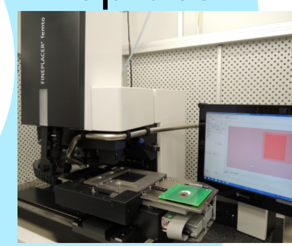
ROCs from IBM
UBM, thinning, dicing
shipping at Pactech

Sensor I-V curves
at UniHH



Solder ball placement
SB2 Jet on sensor at DESY

Known good
die test for
ROCs on Femto
Fineplacer



Flip chip
bonding
with Femto

in-situ reflow
on Femto

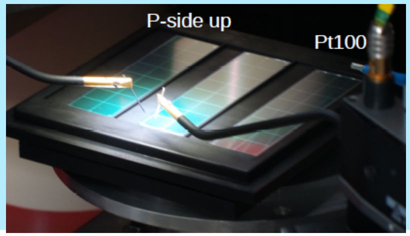
Optical inspection
& bare module test

Bare module production

Sensors from CiS
UBM, dicing,
shipping at Pactech

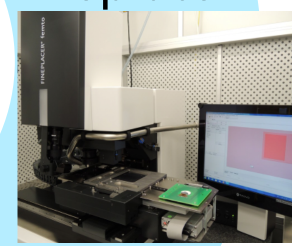
ROCs from IBM
UBM, thinning, dicing
shipping at Pactech

Sensor I-V curves
at UniHH



Solder ball placement
SB2 Jet on sensor at DESY

Known good
die test for
ROCs on Femto
Fineplacer



Flip chip
bonding
with Femto

in-situ reflow
on Femto

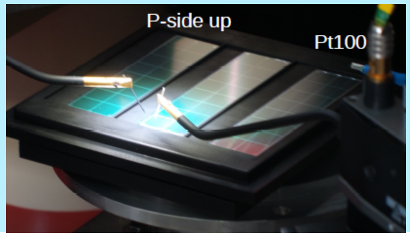
Optical inspection
& bare module test

Bare module production

Sensors from CiS
UBM, dicing,
shipping at Pactech

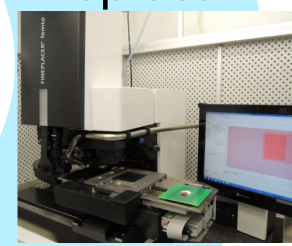
ROCs from IBM
UBM, thinning, dicing
shipping at Pactech

Sensor I-V curves
at UniHH



Solder ball placement
SB2 Jet on sensor at DESY

Known good
die test for
ROCs on Femto
Fineplacer



Flip chip
bonding
with Femto

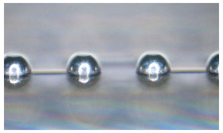
in-situ reflow
on Femto

Optical inspection
& bare module test

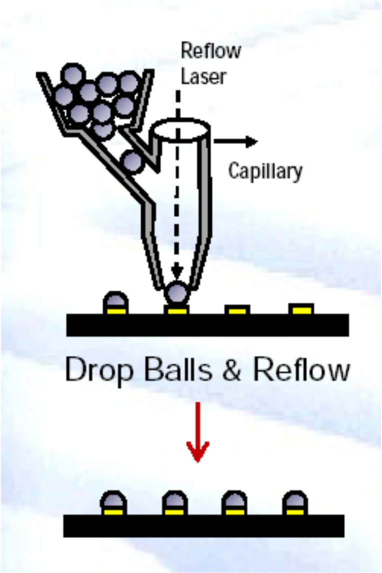
SB2 jet solder ball placement

- High-precision SnAg solder balls
  - 40 µm diameter
- Singulate and drop through capillary
  - N_2 flow against humidity and statics
- Melt by laser pulse
  - Solidify on pad
- Re-try missing balls
- Step-motor controlled
  - Up to 4 balls / second
  - < 6 h / module (limited by self-cleaning)
- Production of 2 per day

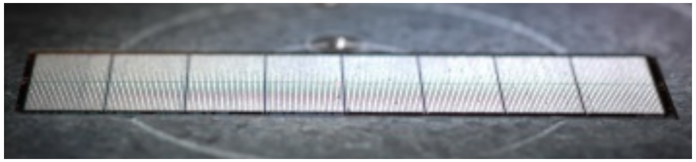
At DESY FEC



40 µm SnAg balls



66'560 balls in 6 h

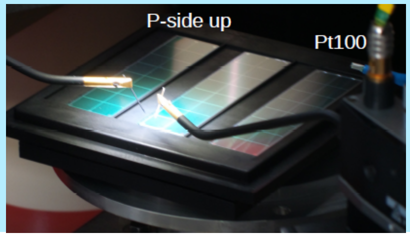


Bare module production

Sensors from CiS
UBM, dicing,
shipping at Pactech

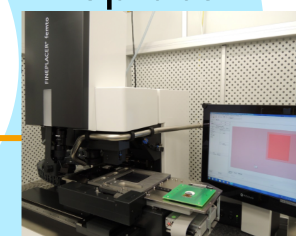
ROCs from IBM
UBM, thinning, dicing
shipping at Pactech

Sensor I-V curves
at UniHH

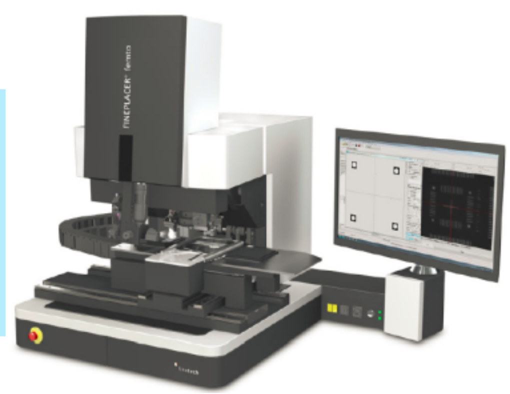


Solder ball placement
SB2 Jet on sensor at DESY

Known good
die test for
ROCs on Femto
Fineplacer



Flip chip
bonding
with Femto

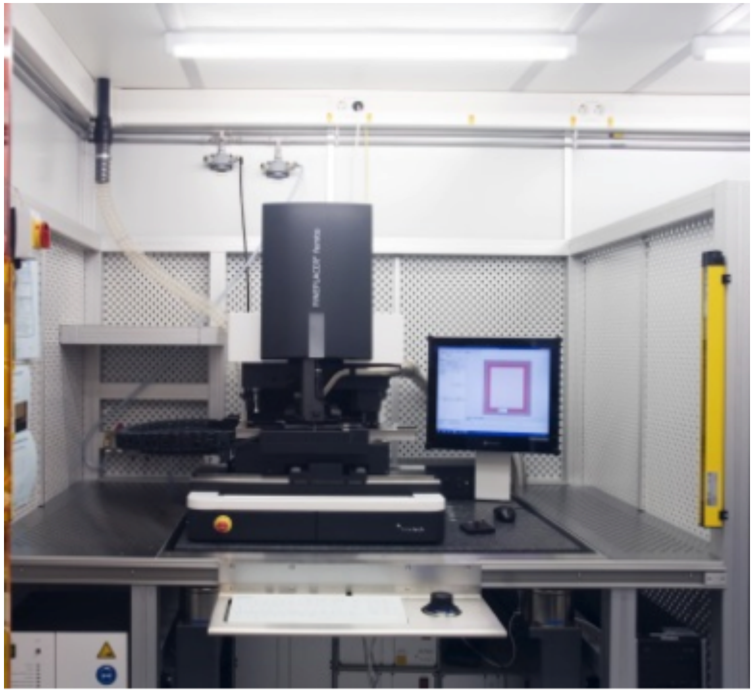


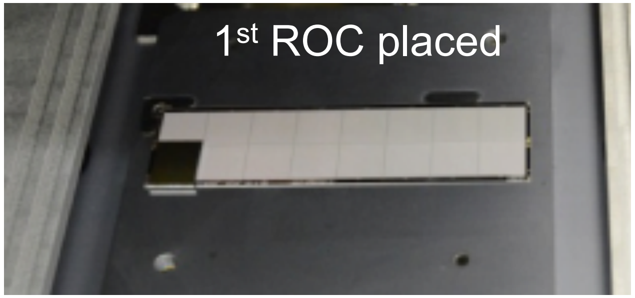
in-situ reflow
on Femto

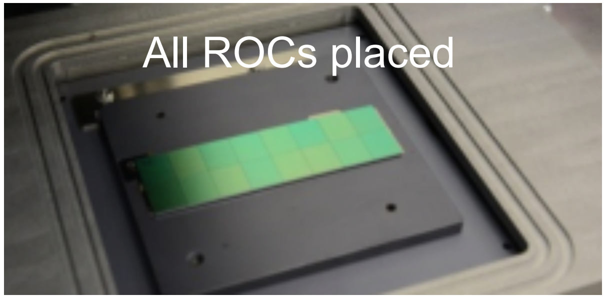
Optical inspection
& bare module test

Flip chip bonding

- Femto Fineplacer from Finetech
  - High precision step motors
  - Automatic with image recognition
- Before usage each ROC is tested
- Formic acid atmosphere
- Tacking: 1N → 15N → 160 N at 200°C
- In-situ common reflow at 230°C
- < 3 hours per module
- 3 bare modules per day





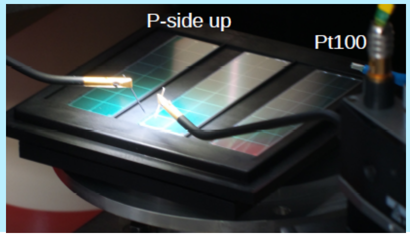


Bare module production at DESY

Sensors from CiS
UBM, dicing,
shipping at Pactech

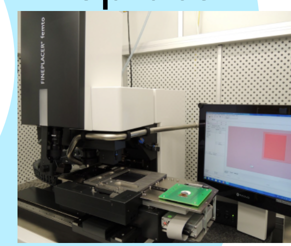
ROCs from IBM
UBM, thinning, dicing
shipping at Pactech

Sensor I-V curves
at UniHH



Solder ball placement
SB2 Jet on sensor at DESY

Known good
die test for
ROCs on Femto
Fineplacer

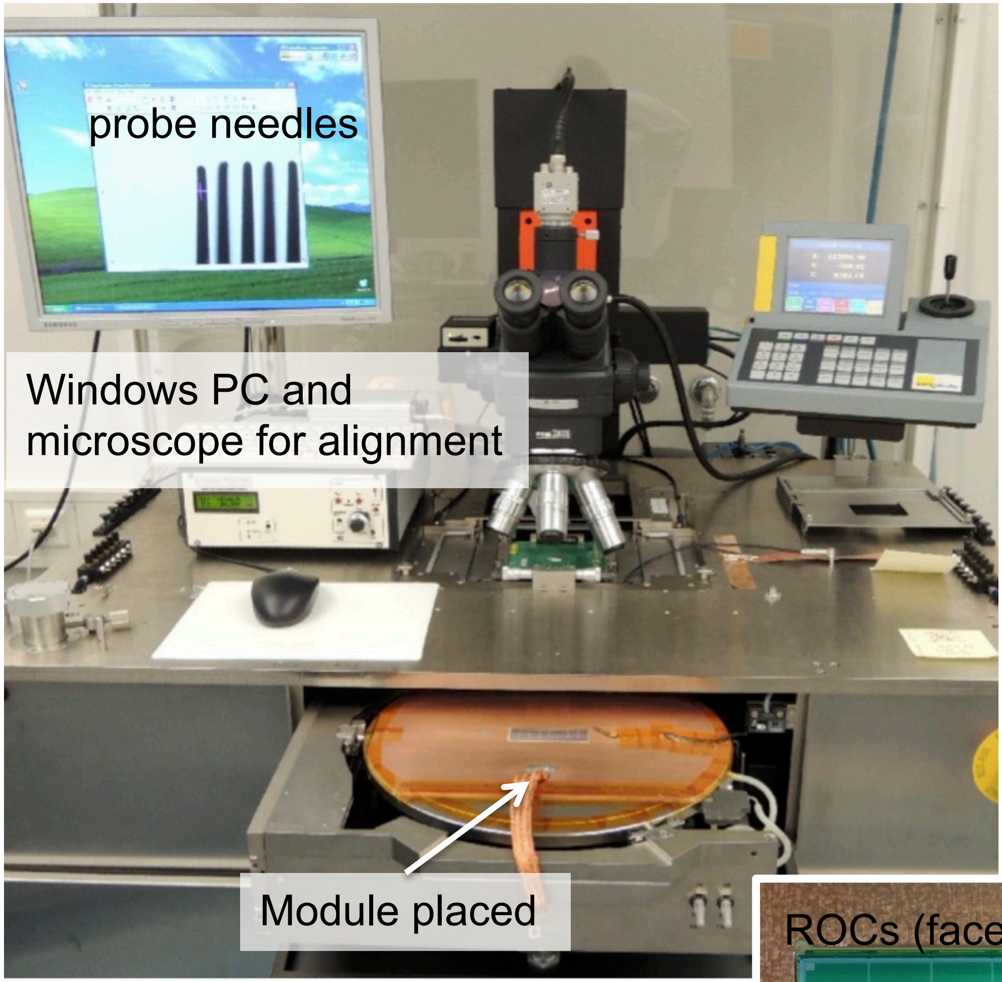


Flip chip
bonding
with Femto

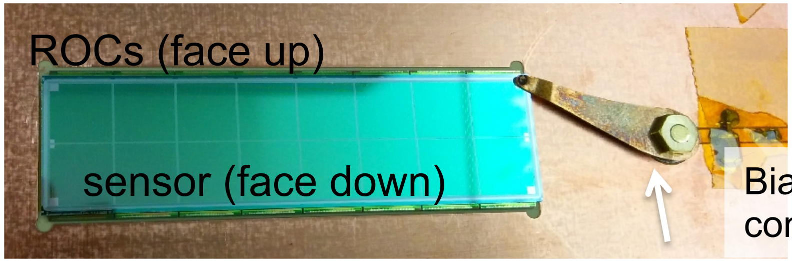
in-situ reflow
on Femto

Optical inspection
& bare module test

Probe station setup

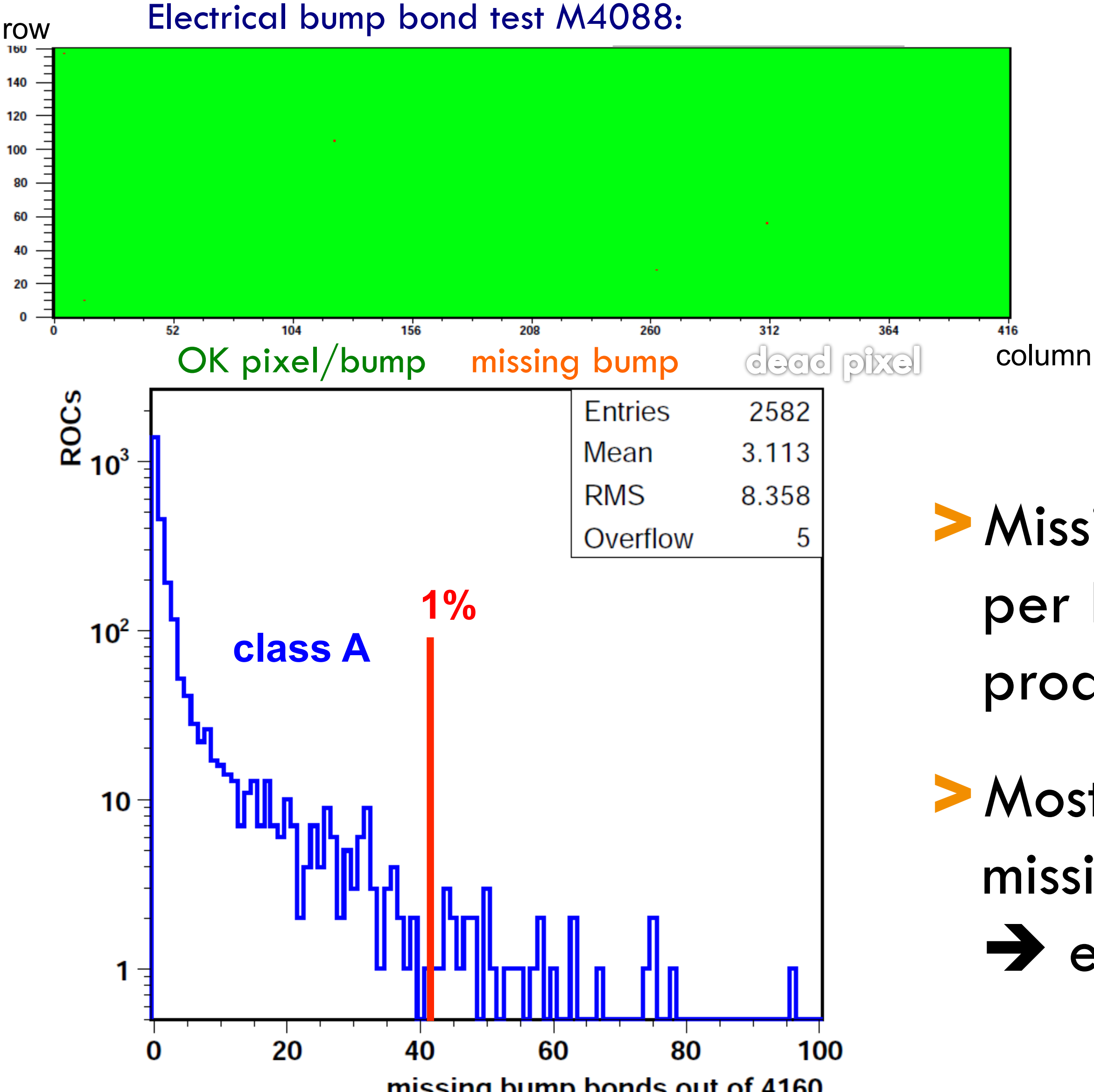


- Each ROC tested separately with a probe card
- Programing of the chip
  - Should draw 25 - 35 mA digital current
- Bias voltage applied -150 V
- Set analog current to 25 - 30 mA
- Adjust test pulse timing
- Measure pixel response map
  - Identify dead pixels to distinguish from missing bumps
- Bump bond test



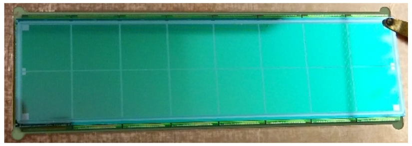
Bare module tests

Electrical bump bond test M4088:



- Bump bond connection and response for each pixel is checked
- Bad ROCs can be reworked
- Missing bump connections per ROC for 155 produced bare modules
- Most have << 1 % missing bumps per ROC ➔ excellent quality

Bare to Full Module procedure



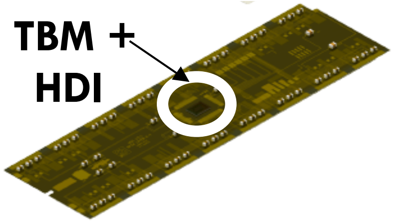
Completed Bare Module

Sensor IV test

Glue TBM on HDI

Wire bond (ZE)

TBM + HDI

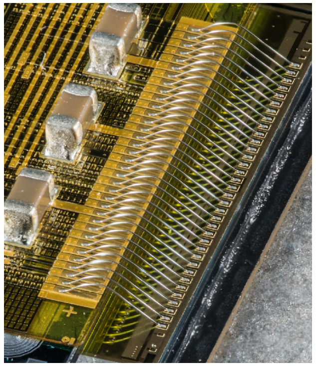


Bare Module test

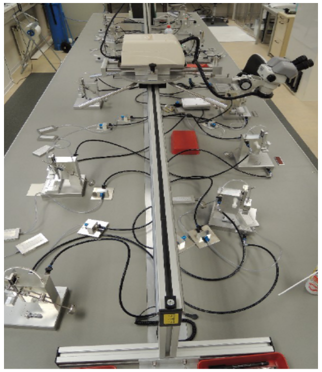
Glue Base Strips

HDI & TBM test

Wire bonds



Glue HDI

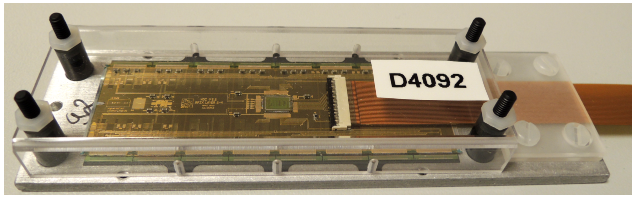


Wire Bonding:
Sensor bias & 16 Rocs

Gluing stations at UniHH

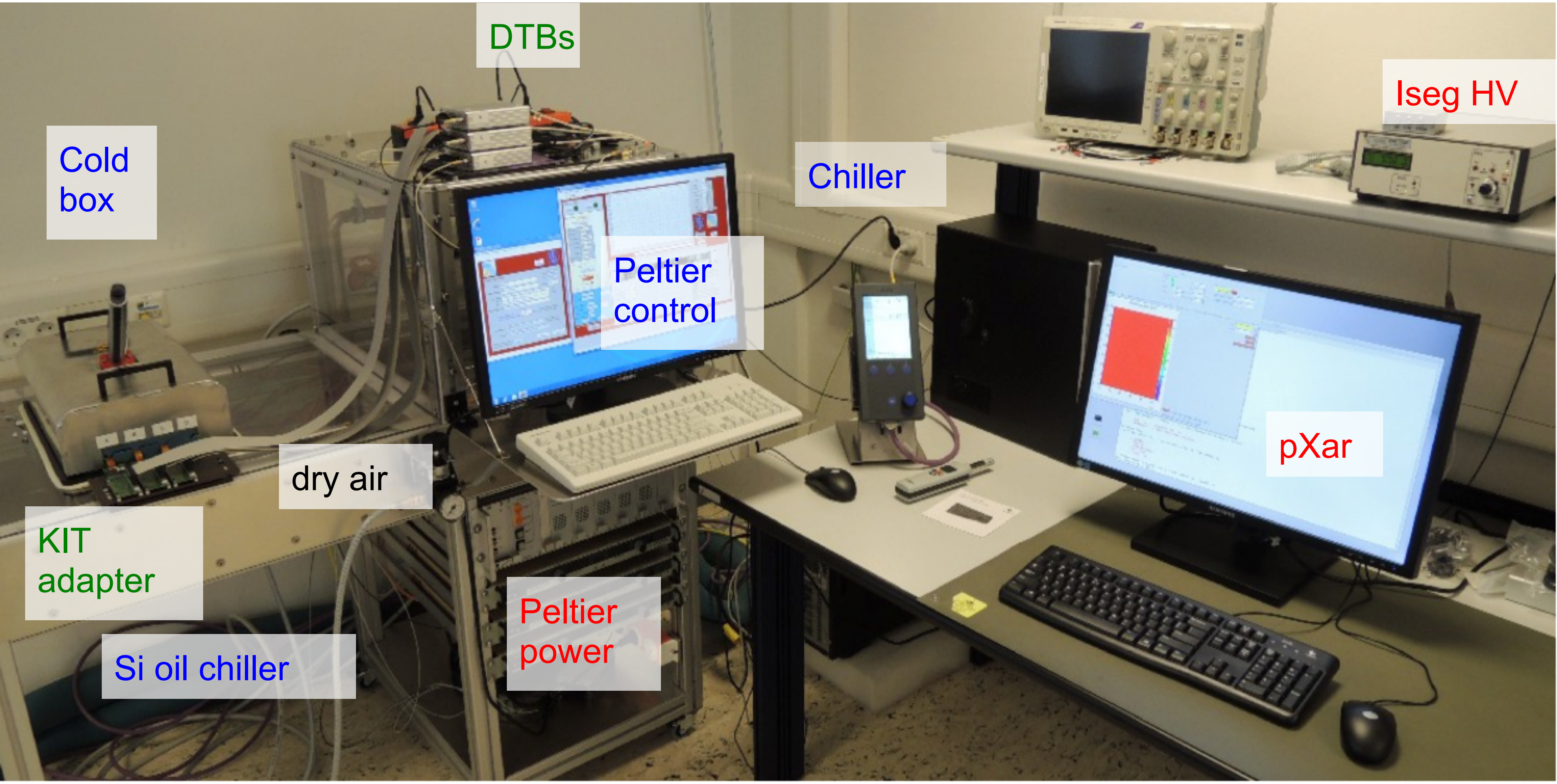
Mount on module handle
Attach cable

Full module with protective cap



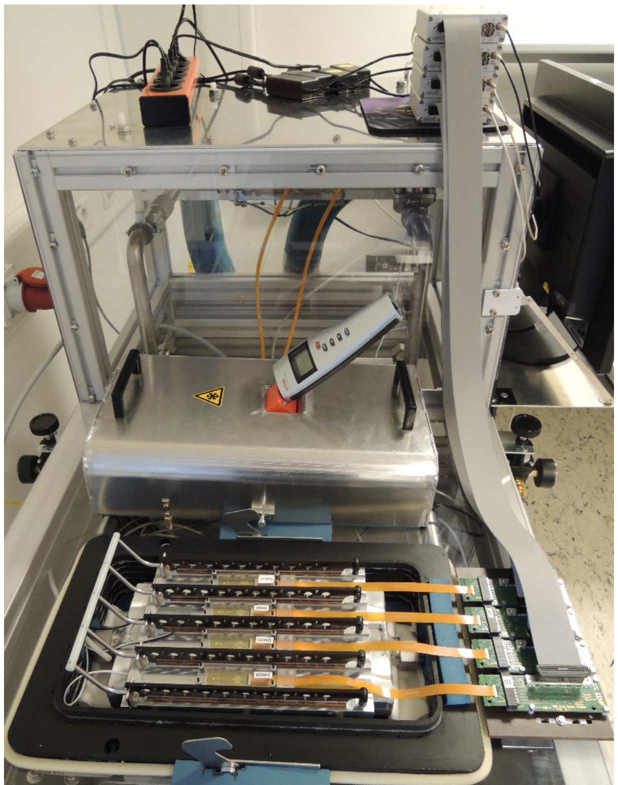
Cold Calibration **Xray Calibration**

Cold calibration setup at DESY



PC provides temperature control of the cold box and second computer is used for data taking

Cold calibration and Xray tests

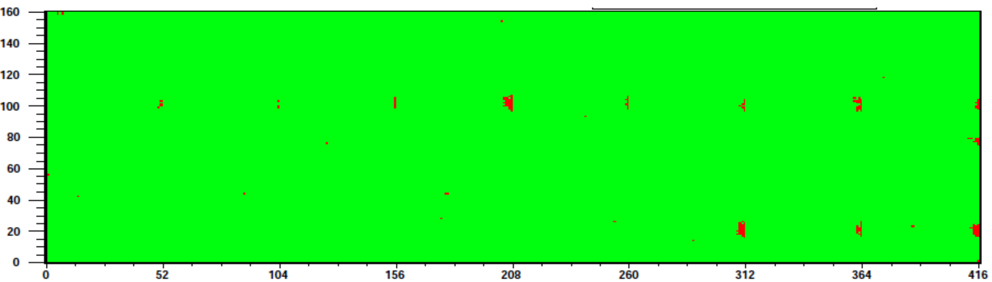


4 modules placed in the cold box

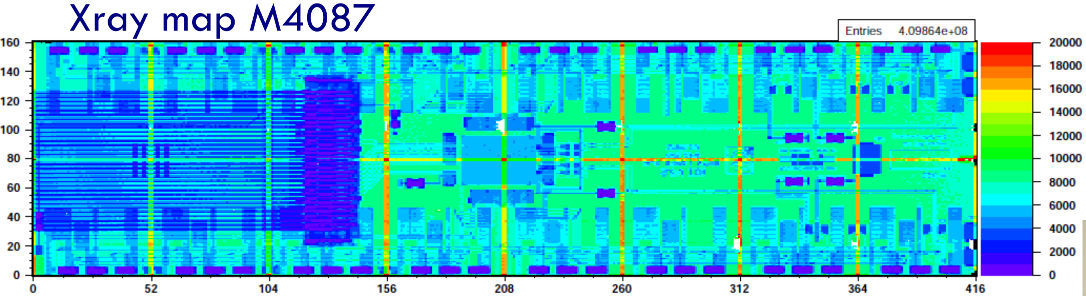
- Calibration at -20°C and +17°C
- Sensor I-V measurements
- Thermal cycling
  - 10 cycles from -25 °C to +17 °C in one hour
- Testing of 4 modules simultaneously possible
  - Semi-automated with PC control and operator
  - 6 – 7 hours
- Setup runs stable multiple times per week
- In synch with module production
- 41 full modules produced and calibrated so far for installation

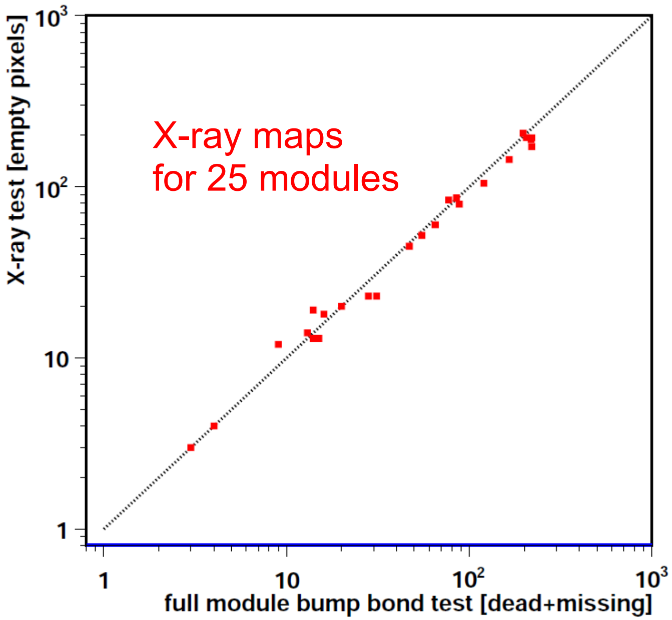
Xray calibration at UniHH

Electrical bump bond test M4087

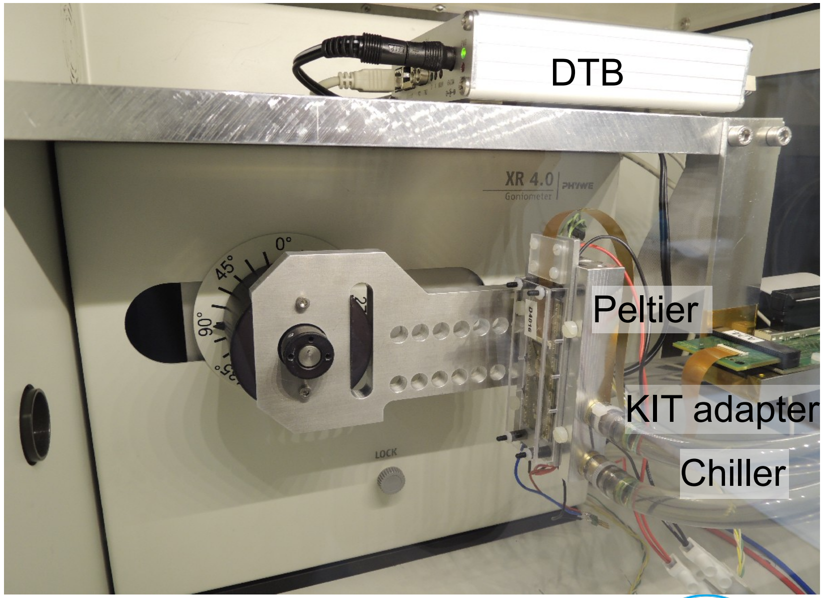


Xray map M4087

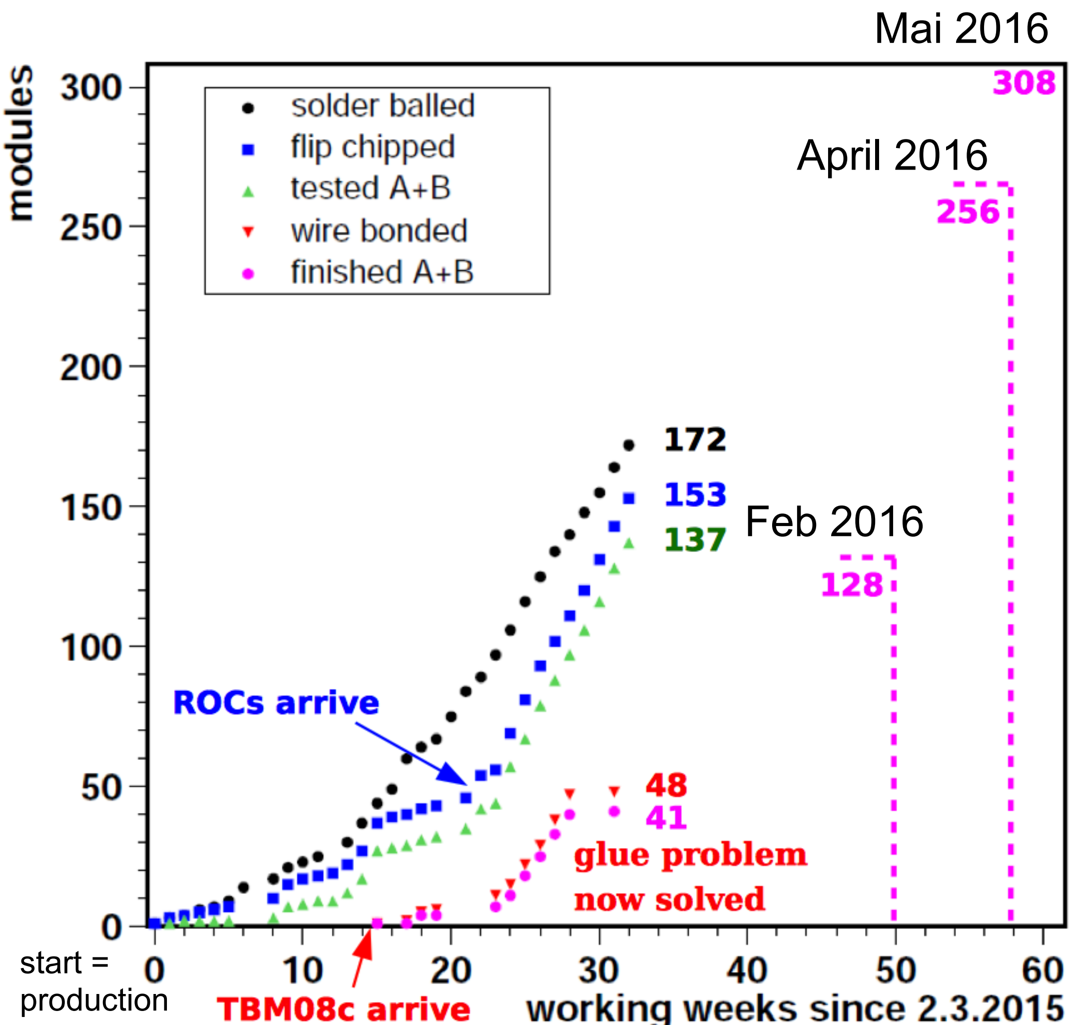




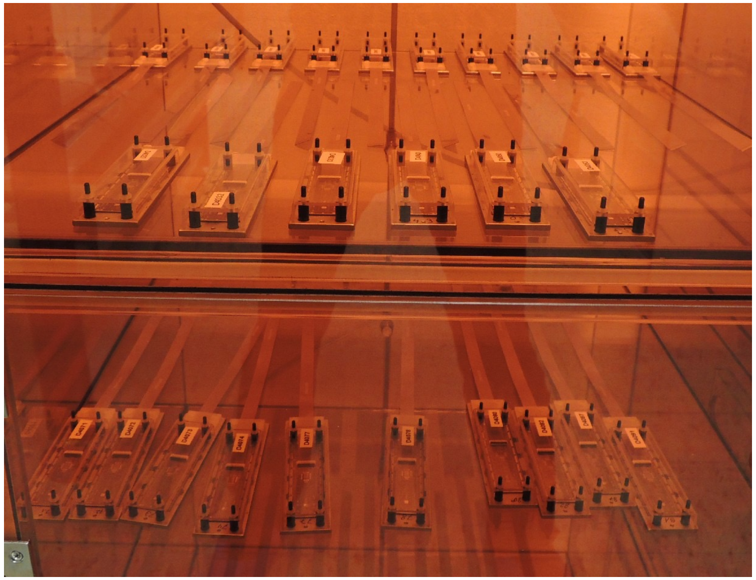
- Final check of bump bond quality with Xray map
- Missing bumps well correlated
  ➔ Electrical test gives reliable results at an early stage of production



Production status



start = production readiness review



- 41 usable modules in N_2 storage
  - cold calibration done
  - X-ray calibration done

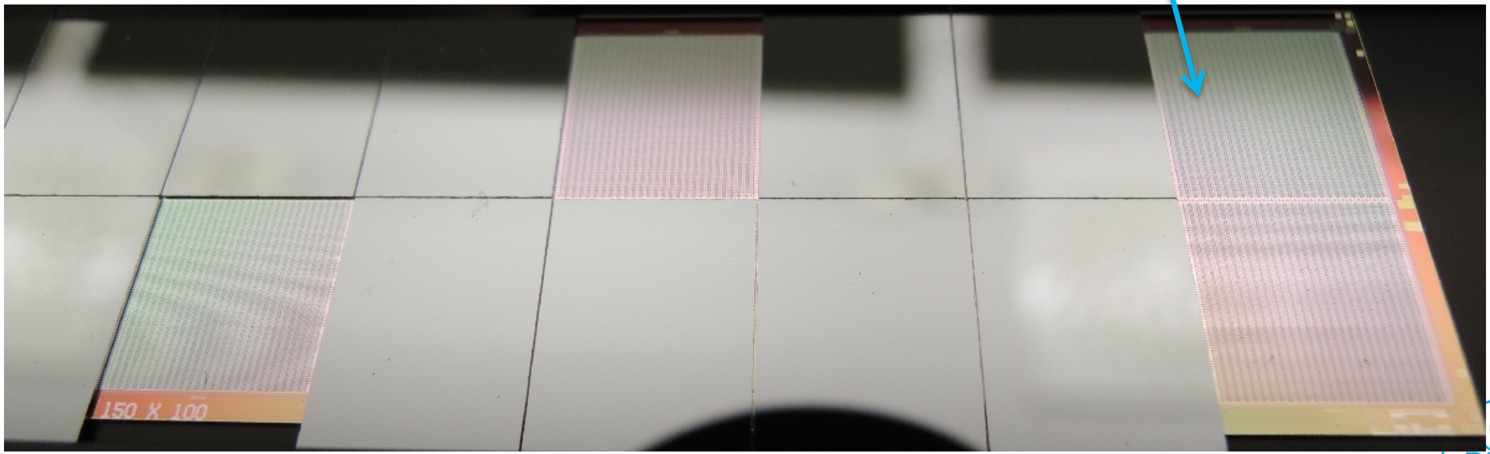
Outlook and Summary

- Physics analyses progressing well
  - Run1 analyses are being completed
  - Several Run 2 results with DESY contribution already public
  - Many more under way
- Pixel Phase I upgrade
  - Close collaboration between different parts of DESY and Uni HH
  - There was an initial learning curve but issues have been resolved
  - 41 good quality modules have already been produced
  - Module production is well underway to deliver 308 modules for installation at PSI by mid 2016
- Contributions to CMS operations and Phase 2 upgrade
  - Alignment, Computing, Open Data, Luminosity
  - Tracker detector upgrade

Backup

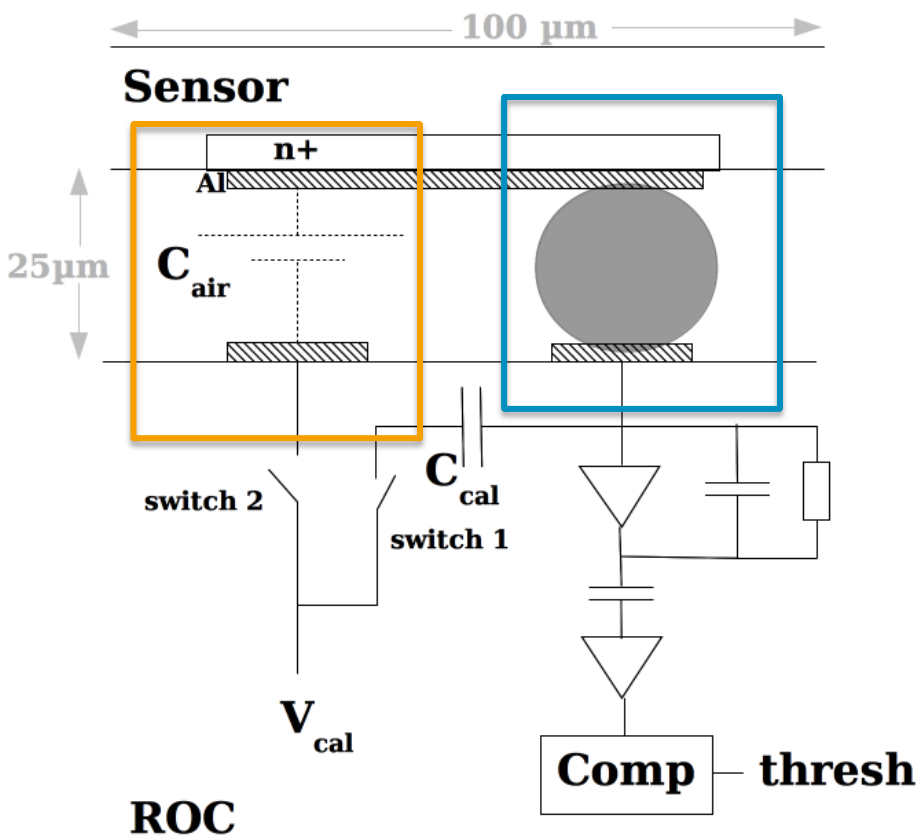
Chip replacement procedure (re-work)

- ROC removal using the Femto Fineplacer
  - Heat sensor chuck to 200°C (below SnAg melting point)
  - Heat bond head to 260-280°C (above melting point)
  - Lift ROC with 0.2 bar under-pressure
  - Solder balls remain on the sensor
  - Place new readout chip
- **Reliable procedure established**

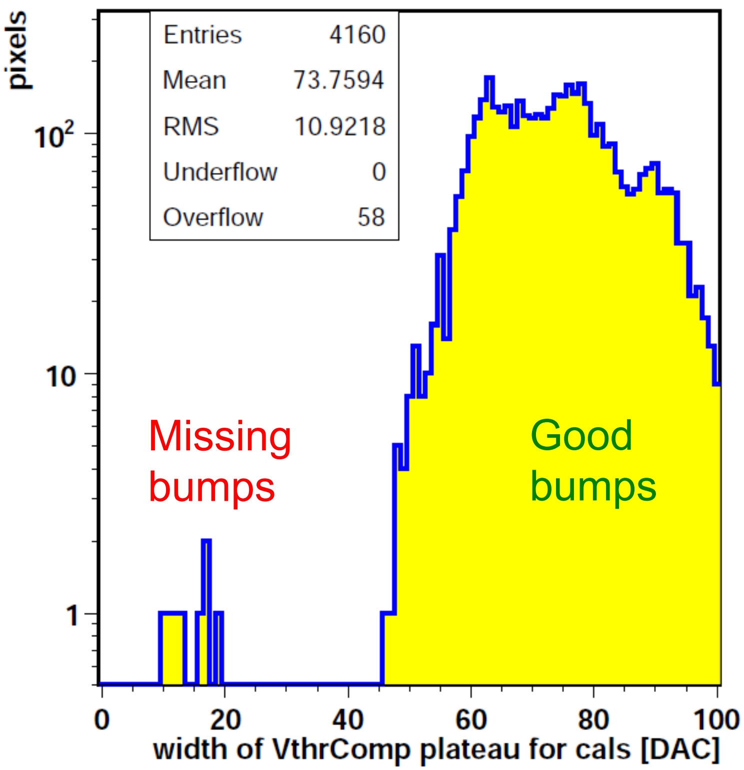


Bump bond test

- Test pulse applied via sensor pad and air capacitance
- If bump bond is good then signal can be measured



- Each pixel is pulsed 10 times for different comparator thresholds
- Range of comparator threshold where pixel responds is measured



Pixel module production planning

- Start 2.3.2015 (after the CMS production readiness review)
- Module mounting at PSI starts mid March 2016, in stages:
  - attach micro twisted pair cable and module cap, test
  - mount on half shells (128+128)
  - connect to supply tubes (-z and +z), test, pull address wire bonds
- 50 working weeks until end of Feb 2016:
  - deliver 128 full modules (class A+B)
- +8 working weeks until end of April 2016:
  - deliver another 128 full modules (class A+B)
- +4 working weeks end of May 2016:
  - deliver 50 spare modules

Magnet Cryogenics

- The CMS magnet has been operating intermittently due to persistent problems in the cryogenic system, consistent with the clogging effect of contaminants in the "Cold Box" that provides liquid helium.
- Last two Technical Stops: several complex and invasive interventions (change absorbers and filters) made in the cold box
  - to make system more tolerant to contamination.

- Still, maintenance procedures to clear contamination are having to be performed much more frequently than normal;
  - Some require stopping the cold-box; which means turning off the magnetic field
  - Trying to synchronize stops with accelerator to minimize impact on CMS data-taking.
- Response to the problem managed by joint CMS-CERN task force. Besides interventions already made:
  - Intensive diagnostic and analysis efforts to improve understanding and optimize interim strategy.
  - In parallel: organizing comprehensive program of component replacement or cleaning for forthcoming technical stops.

Many thanks to TE and EN departments for their exceptional effort