

Status of CMS at DESY

Report to the 79th Physics Research Committee

Open Session



Carmen Diez Pardos

On behalf of the DESY CMS group

DESY Hamburg, 11.05.2015

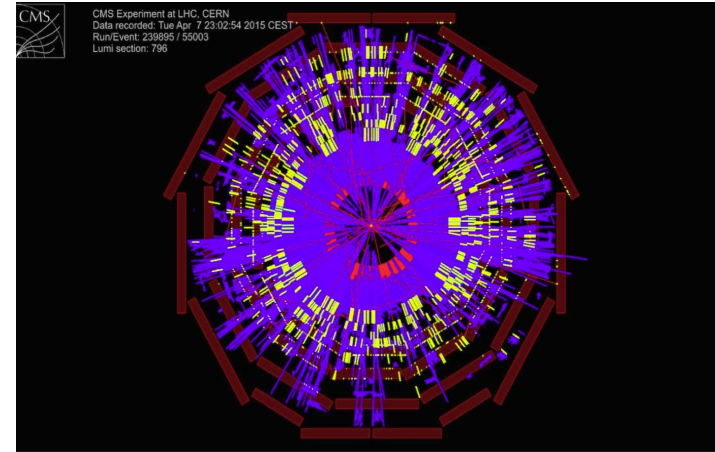
> CMS General status

> DESY-CMS status

- Operation and Components
- Upgrades
- Physics analyses



- > Upgrade and maintenance finished
- > **Detector ready for data taking**
- > CMS in Data Taking and “Splashes” mode
- > Extended cosmics muon runs with
 - No magnetic field (420h)
 - Magnetic field $B = 3.8\text{T}$ (200h)
- > Collected twice as many cosmics as needed for tracker alignment
- > Technical Proposal (TP) for Upgrade Phase II is being prepared → expected to be submitted to LHCC in June



Members:

- > 23 staff, 20 postdocs and visitors, 22 PhD students
 - 3 Phd thesis defended in the last six months
- > Plus technical staff

CMS at DESY:

- > Operations, commissioning and components
- > Upgrades
- > Physics analyses



CMS Publications with Substantial Contributions from DESY

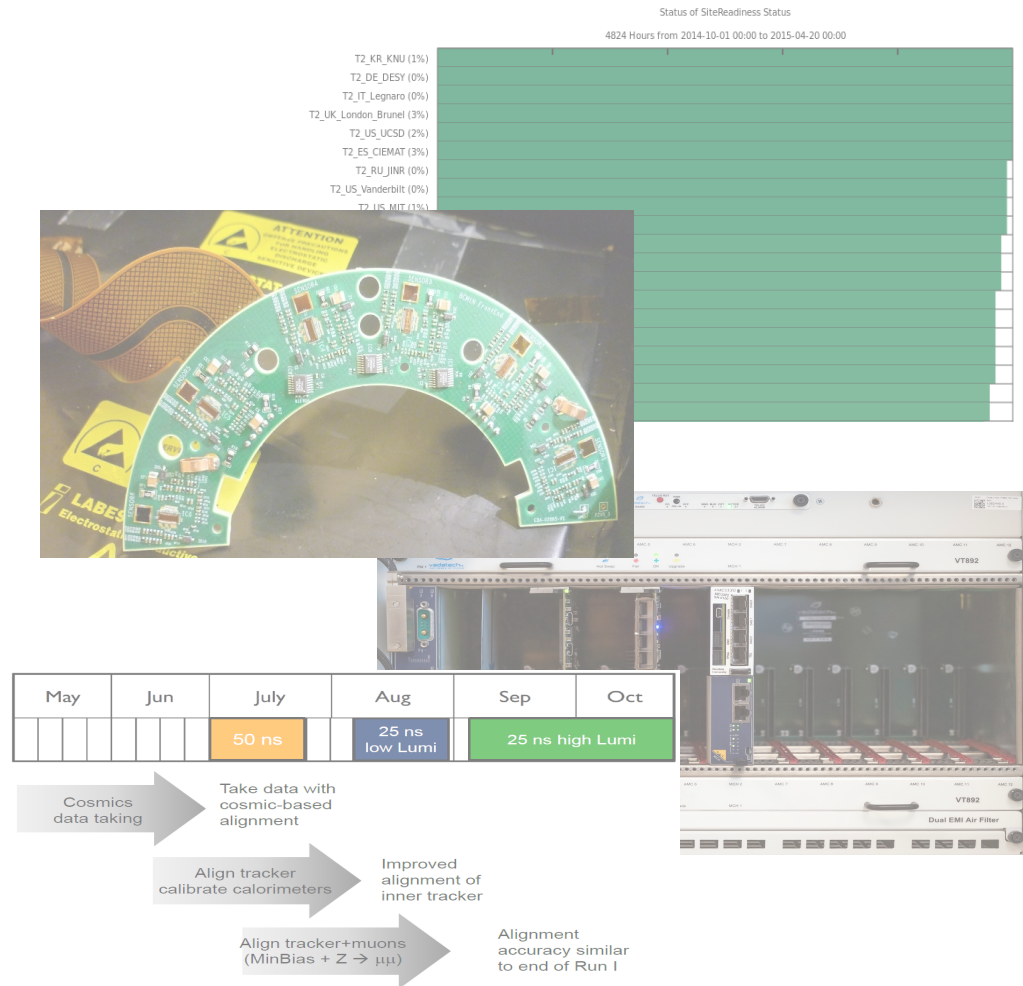
- PAS only
 - > CMS. “Supersymmetry discovery potential in future LHC and HL-LHC running with the CMS detector”, PAS-SUS-14-012
 - > CMS. “Search for a light NMSSM Higgs boson produced in supersymmetric cascades and decaying into b-quark pair”, PAS-HIG-14-030
- PAS for Publication
 - > CMS. “Studies of 2 b-jet + 2 jet production in proton proton collisions at 7 TeV”, PAS-FSQ-13-010
 - > CMS. “Measurement of the muon charge asymmetry in inclusive $pp \rightarrow W + X$ production at $\sqrt{s} = 8$ TeV”, PAS-SMP-14-022

Available on the CERN CDS information server	CMS PAS HIG-14-03	Available on the CERN CDS information server	CMS PAS SUS-14-012	Available on the CERN CDS information server	CMS PAS FSQ-13-	Available on the CERN CDS information server	CMS PAS SMP-14-022
CMS Physics Analysis Summary		CMS Physics Analysis Summary		CMS Physics Analysis Summary		CMS Physics Analysis Summary	
Contact: cms-pag-conveners-higgs@cern.ch		Contact: cms-pag-conveners-susy@cern.ch		Contact: cms-pag-conveners-fsq@cern.ch		Contact: cms-pag-conveners-smp@cern.ch	
2015/03/2		2015/01/09		2015/04		2015/05/01	
Search for a light NMSSM Higgs boson produced in supersymmetric cascades and decaying into a b-quark pair		Supersymmetry discovery potential in future LHC and HL-LHC running with the CMS detector		Studies of 2 b-jet + 2 jet production in proton-proton collisions at 7 TeV		Measurement of the muon charge asymmetry in inclusive $pp \rightarrow W + X$ production at $\sqrt{s} = 8$ TeV	
The CMS Collaboration		The CMS Collaboration		The CMS Collaboration		The CMS Collaboration	
Abstract		Abstract		Abstract		Abstract	
A search for a light neutral Higgs boson decaying to a pair of b-quarks, and produced together with at least two very energetic jets and large missing energy, is presented. Such Higgs bosons are conceivable in the Next-to-Minimal Supersymmetric Model (NMSSM), with the Higgs sector characterized by two complex Higgs doublets and an additional Higgs singlet field. This could result in a light Higgs boson with a large singlet component, which would be hard to detect in conventional searches at LEP, LHC and Tevatron, but could be copiously produced in decays of neutralinos in supersymmetric cascades. The data used in this analysis correspond to an integrated luminosity of 19.7 fb^{-1} , collected by the CMS experiment in proton-proton collisions at a centre-of-mass energy of 8 TeV. No indication of a signal is observed. The results are interpreted in terms of cross section limits and within the parameter space of certain NMSSM light Higgs boson scenarios.		The search for supersymmetry (SUSY) is a major goal of the LHC physics program. The number of SUSY scenarios is large, and both high luminosity data samples and the full set of CMS detector capabilities are required to provide sensitivity to the broad range of signatures, cross sections, and decay branching fractions that can arise. If evidence for a spectrum of new particles is discovered, an extensive program of measurements will be required to determine its properties. In this document, results are presented from a set of studies that address key questions related to the anticipated program of SUSY searches, assuming integrated luminosities from 300 fb^{-1} (LHC Run 2+3) to 3000 fb^{-1} (High Luminosity LHC). Natural SUSY models, which are motivated by the puzzle of how the low value of the Higgs mass is stabilized (the gauge hierarchy problem), are one of the most important areas of investigation. These full-spectrum natural SUSY scenarios are considered in detail, as well as other scenarios that lead to challenging experimental signatures, such as compressed mass spectra. For some studies, simulated Monte Carlo (sMC) events are used to study scenarios in which a small number of SUSY particles dominate the event sample for a particular experimental signature. Using these complementary approaches, results are presented on the sensitivities of measurements with a varying number of jets, b-tagged jets, and leptons, and with a variety of different kinematic variables. These studies, together with results from previous investigations, demonstrate the tremendous potential for discovering and elucidating SUSY with the CMS detector in future LHC running.		Measurements are presented of inclusive differential two b- and two-jet production cross sections as a function of the transverse momentum p_T , pseudorapidity η , as well as of correlations in azimuthal angle ϕ , pseudorapidity η and p_T balance among the jets. The data sample was collected from proton-proton collisions at a centre-of-mass energy of 7 TeV with the CMS detector at the LHC, corresponding to an integrated luminosity of 3.03 pb^{-1} . The jets are reconstructed with the anti- k_T jet algorithm with $p_T > 20 \text{ GeV}$. At least four jets are required: two jets need to be originated by a bottom quark within the range of pseudorapidity $ \eta < 2.4$, while the other two jets are required to be in $ \eta < 4.7$ without any flavour requirement on the initial quark. Only the two leading jets of each selection are considered. The cross section is measured to be $\sigma(pp \rightarrow 2b + 2j + X) = 64.6 \pm 2.4 \text{ (stat.)} \pm 21.6 \text{ (syst.) nb}$. Various model predictions are compared to the measured differential cross sections. The data agree within uncertainties with the predictions of parton shower Monte Carlo event generators and with NLO calculations matched to parton showers only in some regions of the phase space.		Measurements of the muon charge asymmetry in inclusive $pp \rightarrow W^\pm + X \rightarrow \mu^\pm \nu + X$ production at $\sqrt{s} = 8$ TeV are presented. The data sample corresponds to an integrated luminosity of 18.8 fb^{-1} recorded with the CMS detector at the LHC. These new results provide additional constraints on the parton distribution functions of the proton in the range of the Bjorken scaling variable x from 10^{-3} to 10^{-1} .	



Operations, commissioning and components

- > Alignment
- > BCM1F
- > Computing
- > DAQ developments
- > DQM
- > HLT
- > HO Readout



CMS Computing at DESY

CMS Tier-2 T2_DE_DESY:

> WLCG pledges for 2015

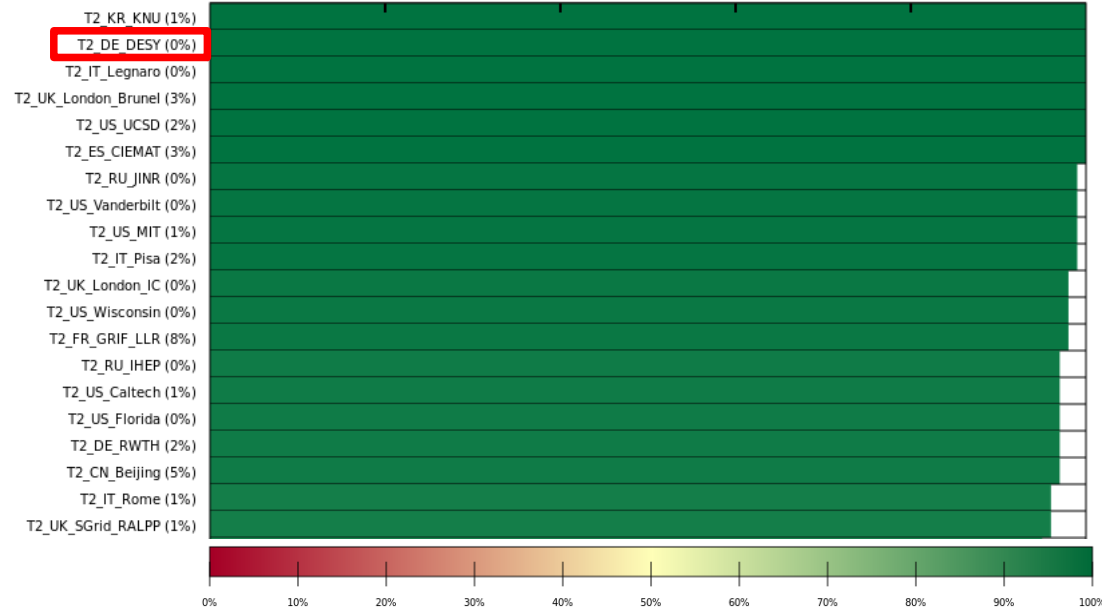
- All place since beginning of the year
- 24.2 kHS06** CPU (+25%)
- 1.510 TB Disk (+8%)

> Very reliable resource

> Ready for Run2

CMS Tier-2 Readiness (Top 20 sites)

4824 Hours from 2014-10-01 00:00 to 2015-04-20 00:00



National Analysis Facility (NAF)

- > Actively used by CMS – local and national groups
- > Service running stable
- > Established Planning meetings with IT and ATLAS twice per year

More details Computing presentation

Reliable Grid and NAF services strongly depends on continuous expert support from DESY-IT

** 1 processor core ~ 10HS06

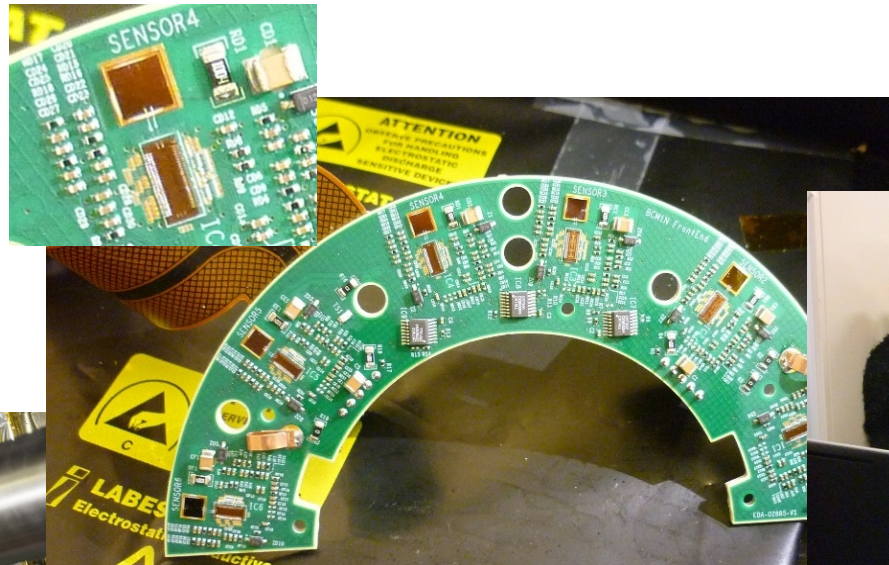


BCM: Beam Conditions Monitor & Luminometer

> Multipurpose device under responsibility of DESY Zeuthen

- Machine Induced Background → impact on tracker and trigger performance
- Online Luminometer → independent of CMS DAQ
- Feedback to LHC machine (LCC) must be on before LHC is filled

> Six completely assembled and tested C-shapes delivered between Sept.-Dec. 2014



Installation in January 2015 in CMS
All systems tested and alive



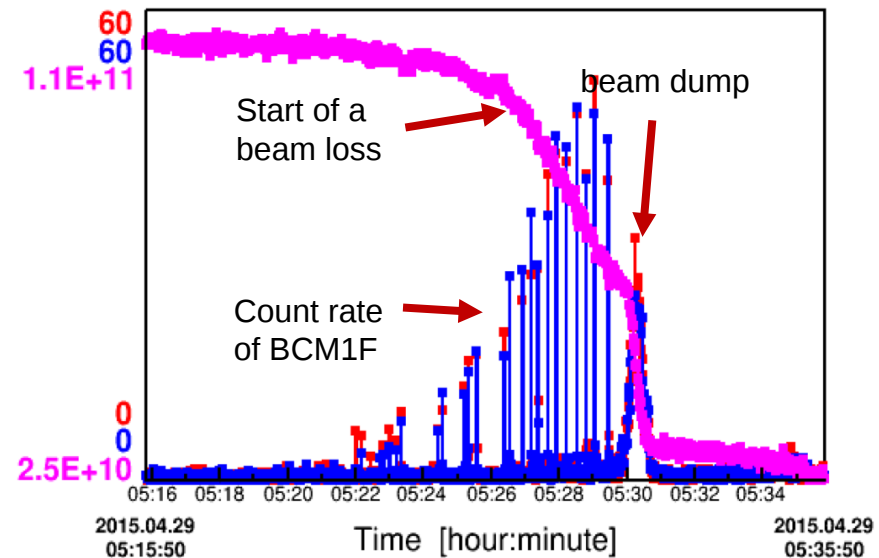
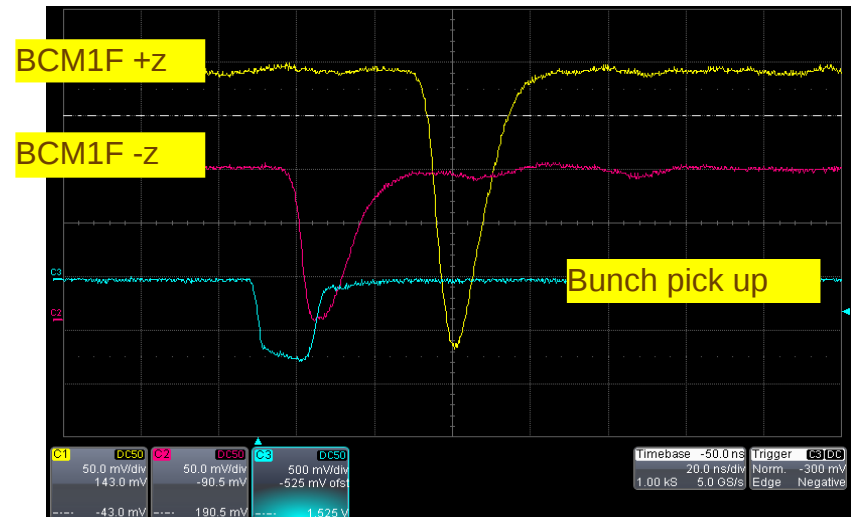
BCM: Beam Conditions Monitor & Luminometer

- > LHC delivered first beam in CMS at Easter Sunday, 10.30 a.m.
- > BCM1F was fully operational and recorded first 'splash events'

> Currently ongoing

- BCMF1 is integrated in the CMS and LHC diagnostics and monitoring
- First luminosity measurement 5 May
- Commissioning of the backend RHU (Realtime Histogram Unit), the ADC readout and DAQ

Exploitation for CMS and LHC in full Run II

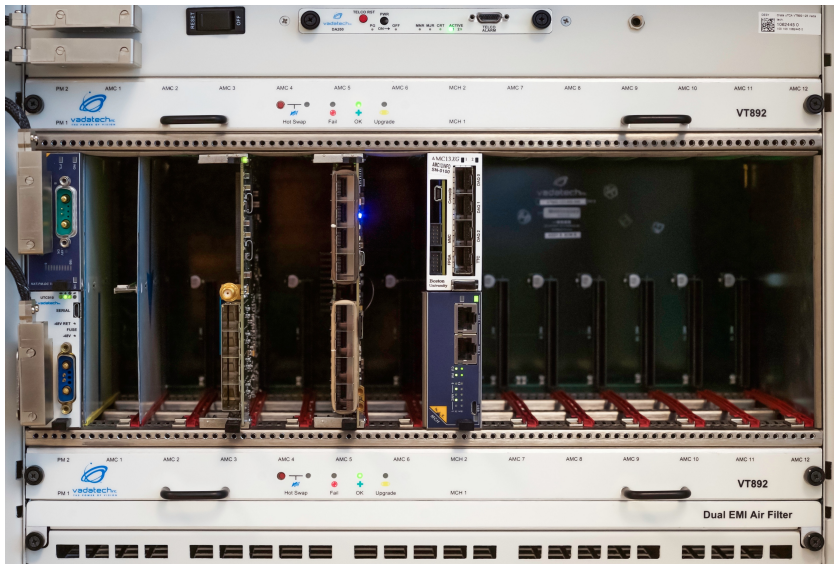


HCAL: HO Readout and DAQ development for μ TCA

> Replaced HO photo-detector

- Upgraded HO has improved muon detection efficiency (~98%)
- This allows design of an improved upgraded L1 muon trigger using HO (improvement ~5%)
- Hardware is in place at P5, commissioning ongoing

> DESY μ TCA group actively participating in the μ TCA upgrade of the CMS HCAL: development of the next generation Front End Control (ngFEC) system, and the Crate Control Module (CCM) server.



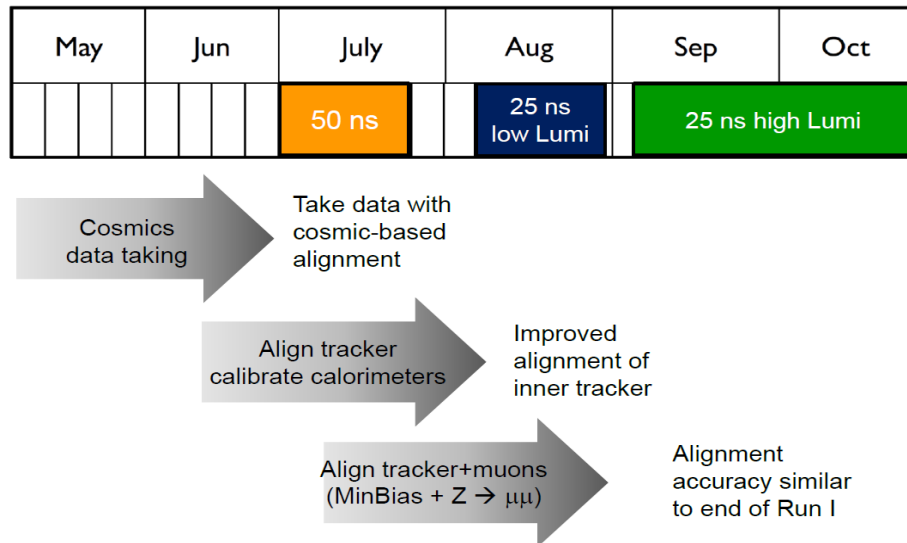
- > DESY is also contributing to the back end μ TCA upgrade by developing a new and efficient crate control software (winCC) interface. The new interface will be deployed in most of the μ TCA systems in CMS.

Tracker Alignment

- > First alignment obtained from cosmic muon run at $B=0T$ ("CRUZET")
 - Aligned in particular the replaced BPIX modules
 - re-centering of BPIX seen as expected.
 - shift of FPIX (5mm on one side) observed and corrected.
 - used for cosmic muon data-taking at $B=3.8T$ ("CRAFT")
- > Combined CRUZET and CRAFT alignment constants in preparation
 - Essential for first pp collisions

- > Later on, tracks from collisions will be used to further improve the alignment
- > DESY group involved at all levels on the alignment project and its coordination

CMS Alignment Strategy

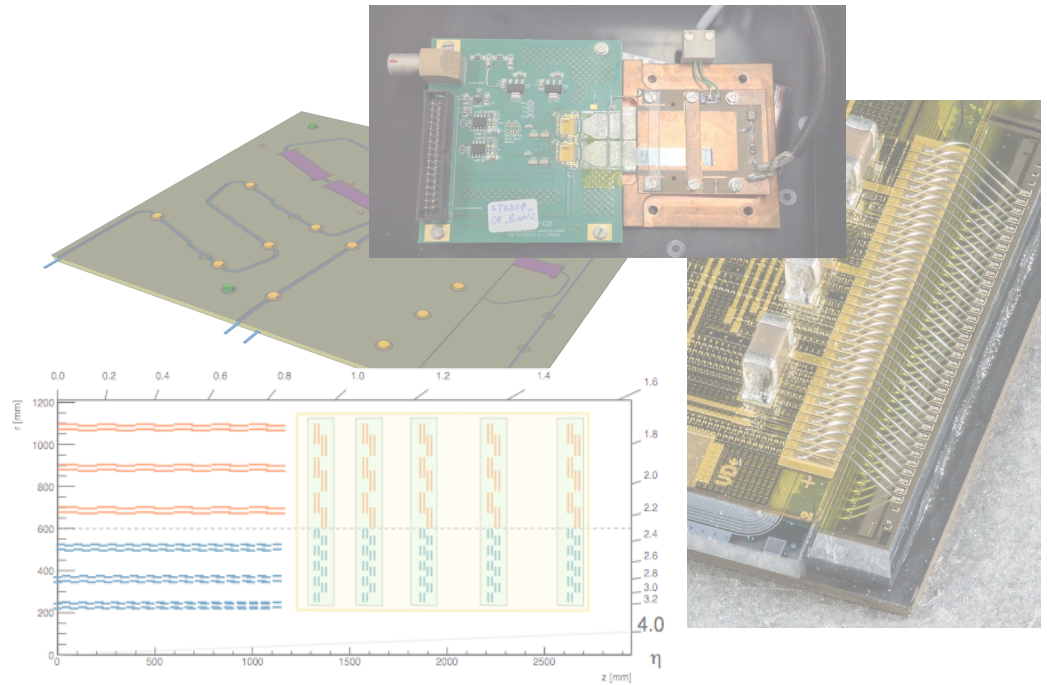


adapted from J. Olsen



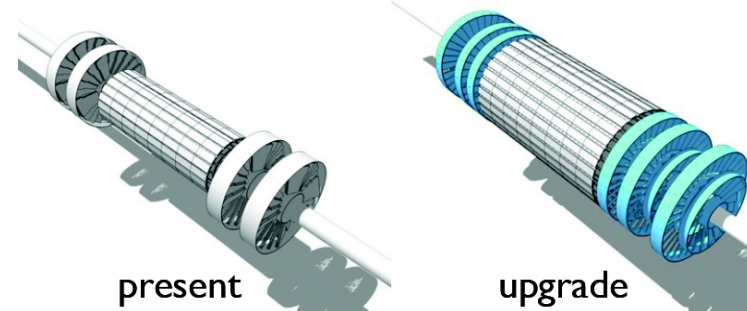
Upgrades

- > (BCM1F) – now in Operations and Components
- > (HCAL) – now in Operations and Components
- > Pixel
- > Sensors
- > Tracker



Pixel Upgrade Phase I – General status

- > Need to maintain tracking efficiency at increased occupancy
 - New readout chip, 4th barrel layer, 3rd endcap disk
- > Installation end-of-year shutdown 2016
- > German institutes build 4th barrel layer
- > DESY passed the Barrel Pixel Module Production Readiness Review at end of February: DESY is ready to start module production
 - the whole chain has been exercised on 4 good modules
- > In-house bump bonding has been established
 - sequential placement of solder balls: 2 modules per day
 - re-work of ROCs possible
- > Test procedure for bare modules established
- > Wire bonding has been learned
- > Cold and X-ray calibration stands are ready
- > Series production has started and is ramping up in speed

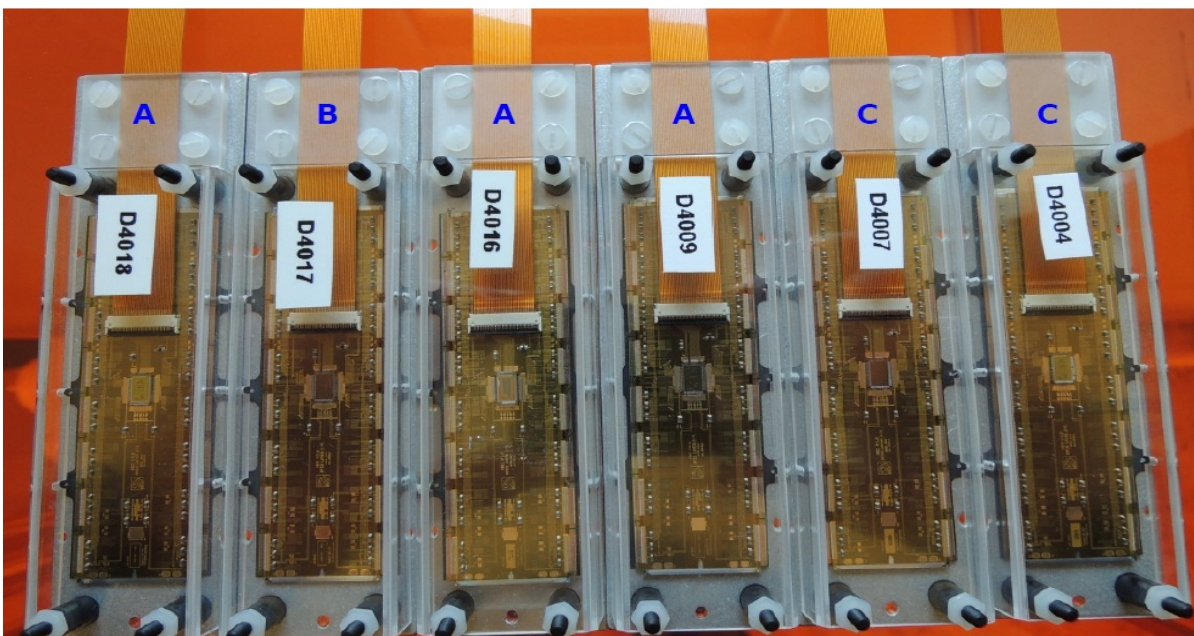


Pixel Phase I – Wire bonding/Module Production

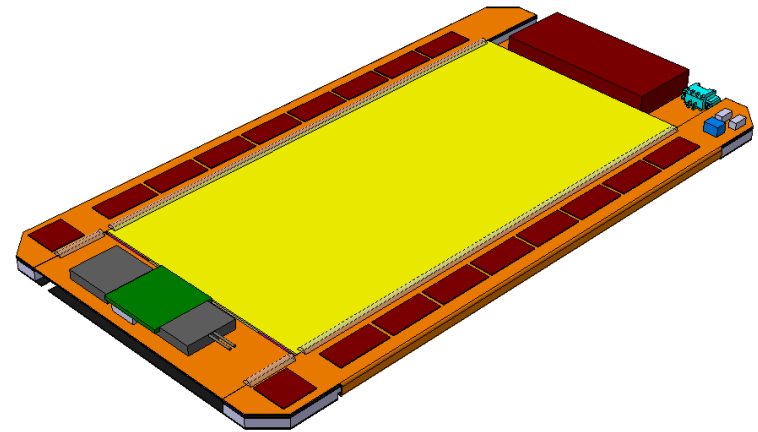
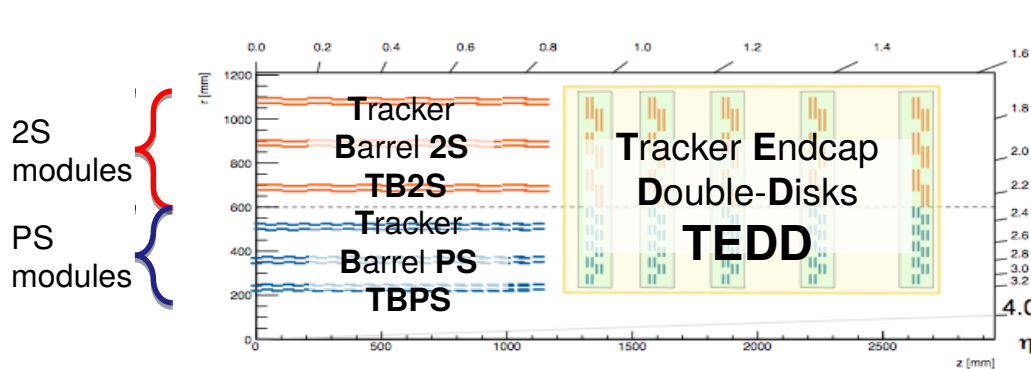


- > Issue with wire bonding overcome
 - Upgraded high power machine

- > 6 modules assembled (4 good full)

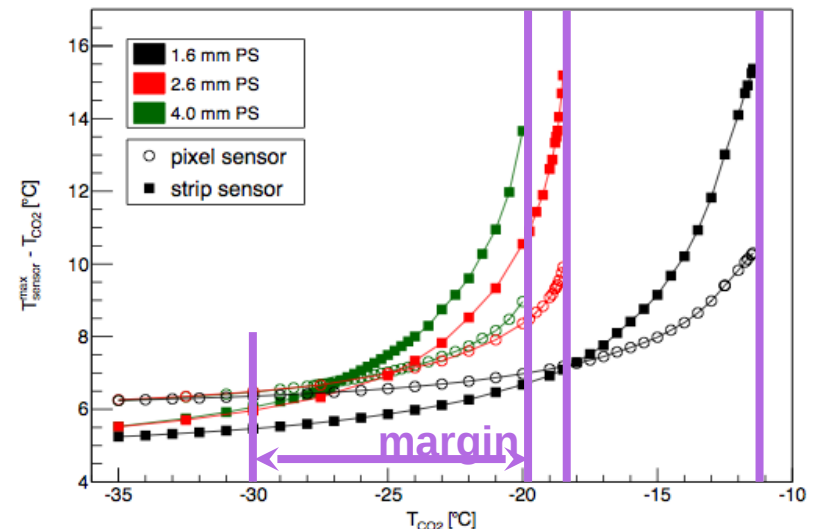


Tracker Phase II – Outer Tracker Modules



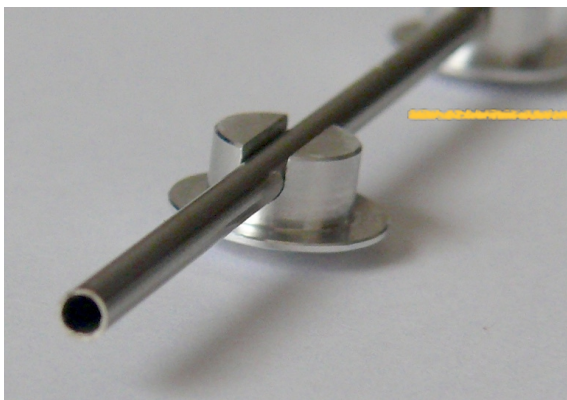
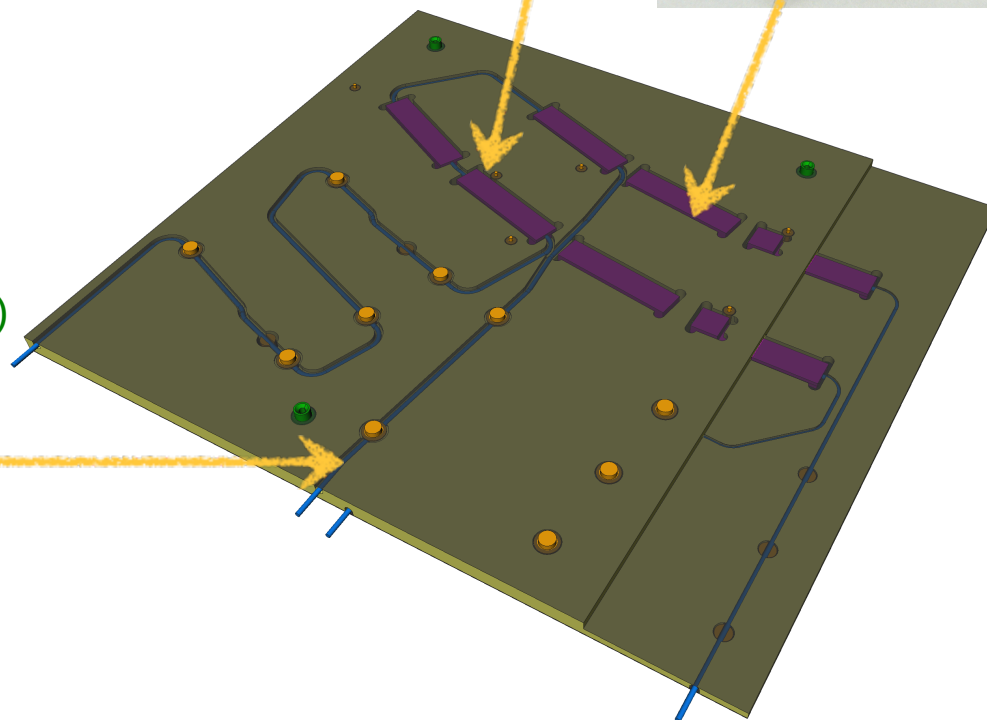
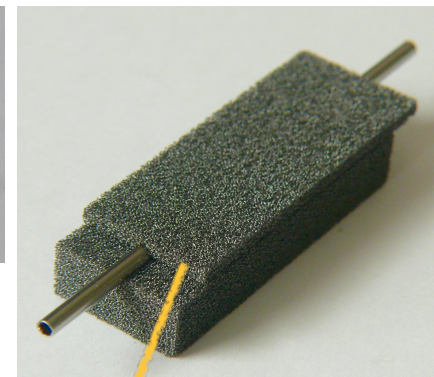
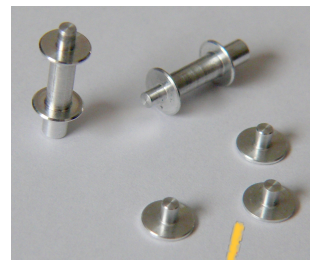
- > All module designs have been updated to variants with 320 μm sensors
- > Thermal performance slightly improved compared to 200 μm variants
 - ΔT between coolant and hottest point on any sensor is below 10 $^{\circ}\text{C}$
 - Sufficient margin to thermal runaway
- > Baseline and preferred sensor thickness remains 200 μm
- > 320 μm is backup solution in case yield problems with thinner sensors would significantly increase cost

thermal runaway



Tracker Phase II – TEDD Prototype Dee

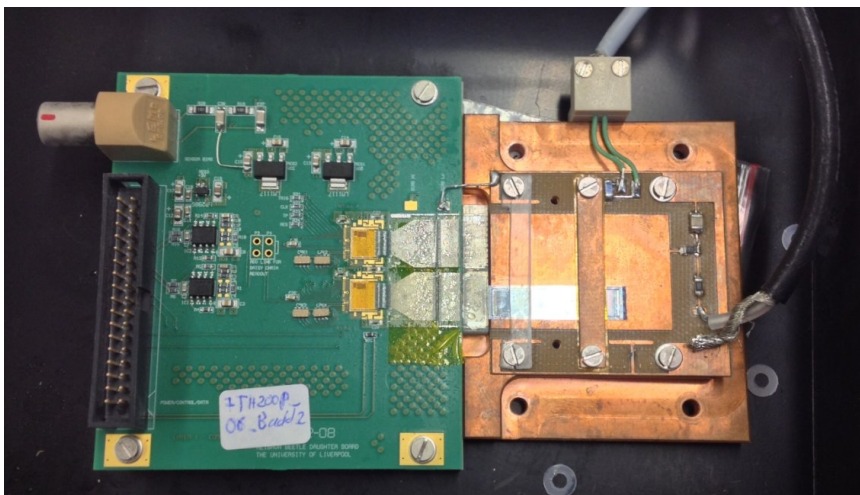
- > Endcap support structure combines various functionalities in large objects
 - 2.4 m diameter
 - several cooling loops
 - positioning and cooling elements
- > TEDD prototype will prove feasibility of concept: covers all features of a full-sized structure
- > Most part for prototyping available
- > Gluing test ongoing
- > Production of prototype will start when all parts are available (middle/end May)



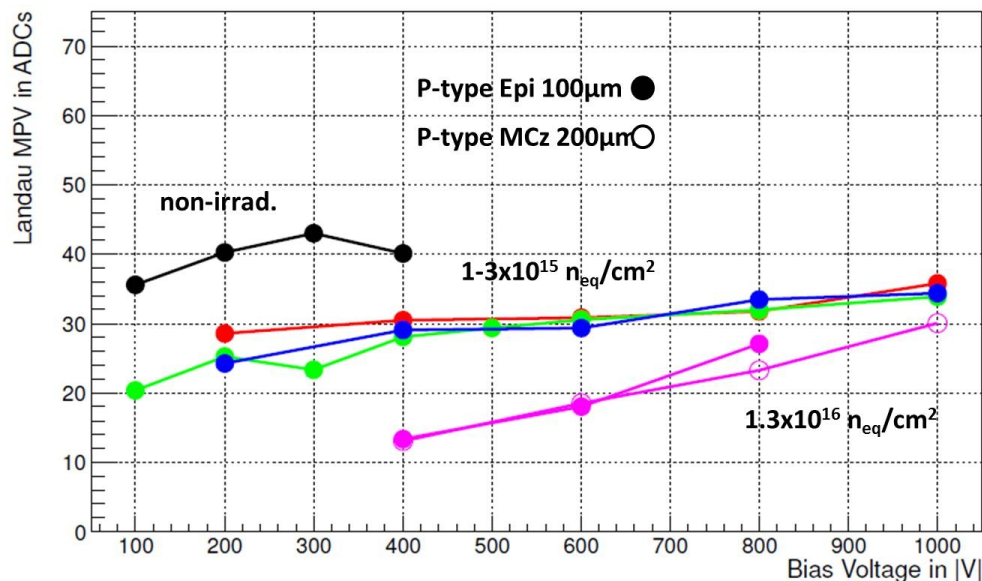
CMS Tracker Upgrade – Sensor R&D

- > Sensors from HPK campaign – various materials
 - Explore potential of epitaxial silicon for Phase-II Tracker
- > Mini-strip sensors in DESY testbeam - analysis finalized
- > Compare with other materials
- > Epitaxial sensor collects more than 80% charge after $3 \times 10^{15} n_{eq}/cm^2$
- > Epi is suitable for outer layers of a Phase-II pixel detector

Strip sensor mounted on AliBaVa daughter board as used for testbeam

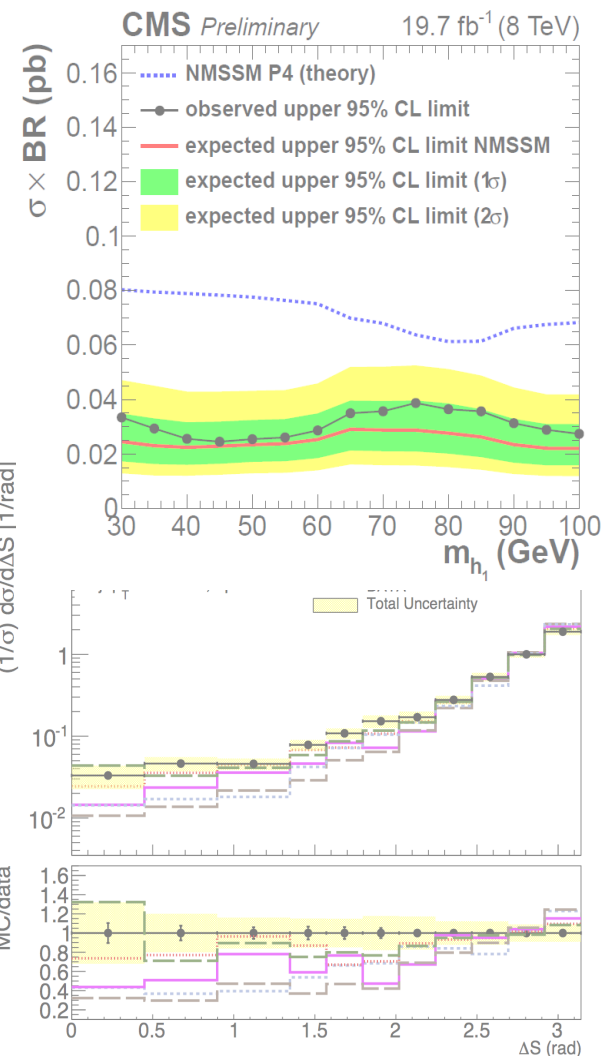
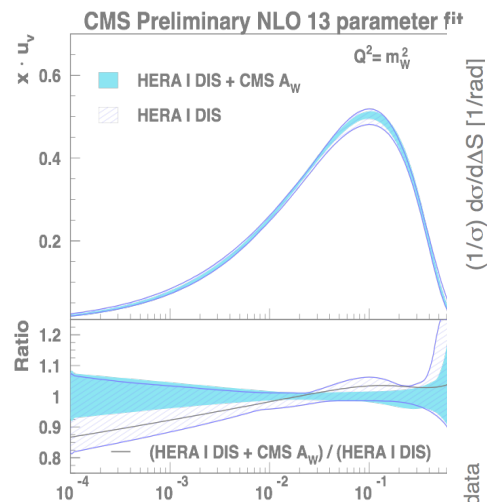


Signal measured in different Materials before and after irradiation



- > Higgs
- > PDF
- > QCD
- > SUSY
- > Top

→ Finalising Run I analyses
→ Preparation for Run II



Higgs Physics: NMSSM Light Higgs Search

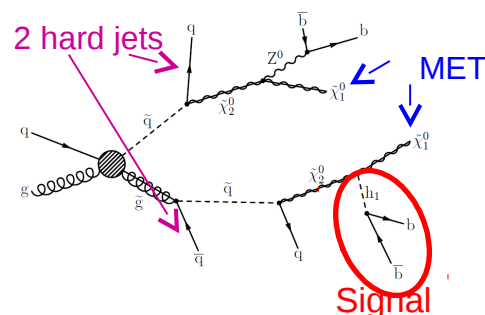
- > Novel analysis searching for very light Higgs $h_1 \rightarrow bb$ ($m = 30\text{-}100$ GeV)
- > Could unveil a NMSSM h_1 boson with a large singlet component

- P4 benchmark scenario (G. Weiglein, O. Stål, *JHEP* **01**, 071 (2012))

→ Not excluded by LEP

→ Suppressed in SM production mechanisms like gluon-gluon fusion

- Search in SUSY cascades



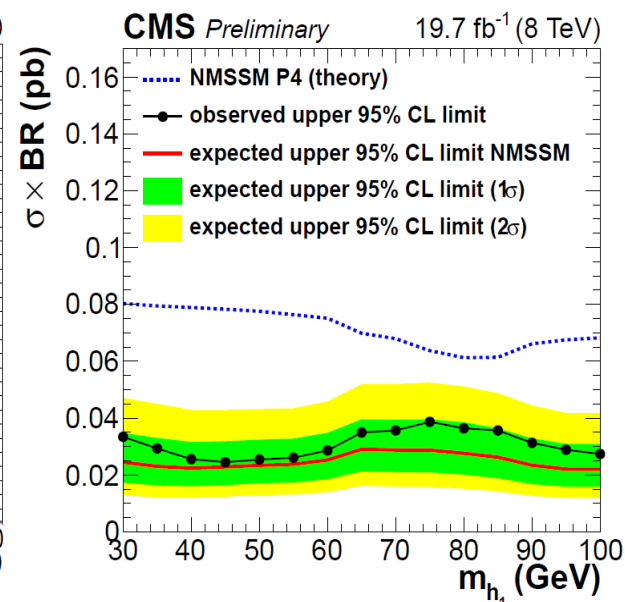
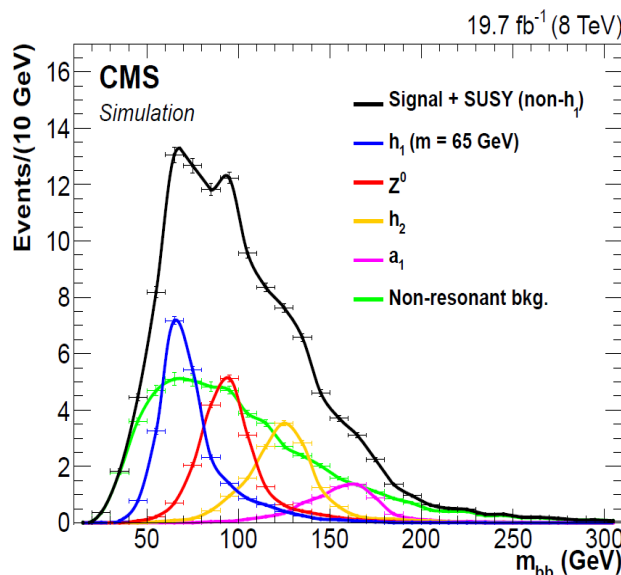
CMS-PAS-HIG-14-030

- > After unblinding, observed mass spectrum well described by SM background: no indication of a signal

→ Analysis excludes the P4 scenario with $M_3 = M_{\text{SUSY}} = 1$ TeV

- > Detailed NMSSM parameter scan performed

First analysis of this kind at the LHC!

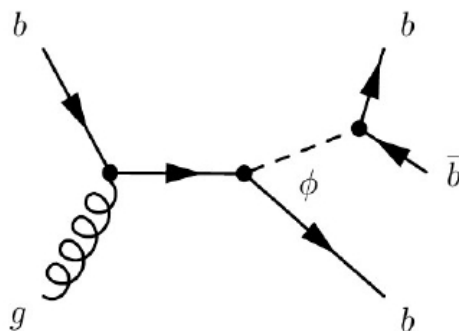


Higgs: Ongoing Run I & Planned Analyses Run II

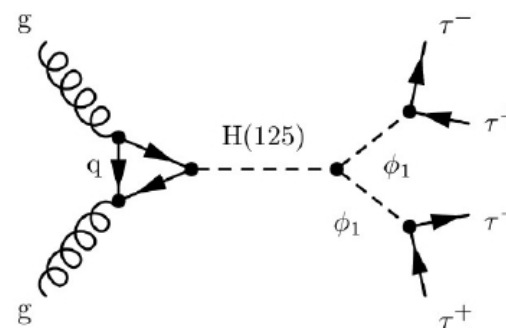
> Publication of two more analyses performed on 8 TeV anticipated

- Since last PRC: analyses are completed and in final stage of review by collaboration

HIG-14-017 : MSSM Higgs boson search in $b\phi \rightarrow b(bb)$ channel



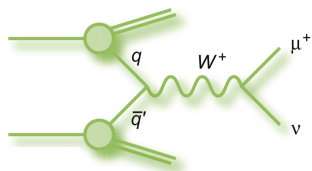
HIG-14-019 : NMSSM Higgs boson search in $H(125) \rightarrow 2\phi \rightarrow 4\tau$ channel



> Run II analyses:

- study of Higgs properties in $\tau\tau$ decay mode : coupling, mass and parity measurements
- search for SUSY Higgs bosons in fermionic decay modes : $\phi \rightarrow \tau\tau$ and $\phi \rightarrow b\bar{b}$
 - > analyses are being optimized for 13 TeV data-taking
 - > dedicated triggers are being developed, e.g. multijet trigger with online b-jet tagging for $\phi \rightarrow b\bar{b}$ search

PDF – Improved valence quark distributions

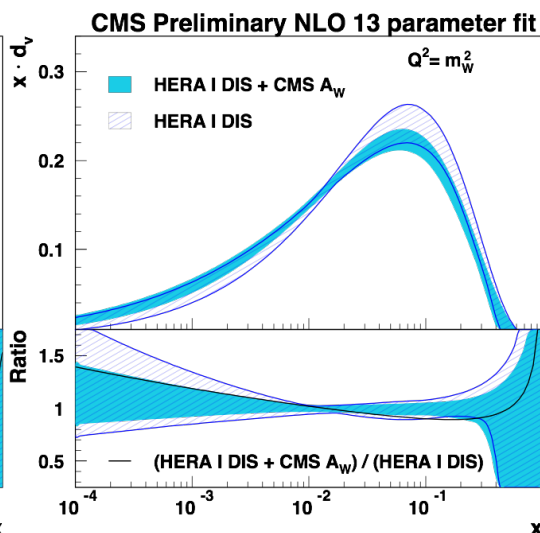
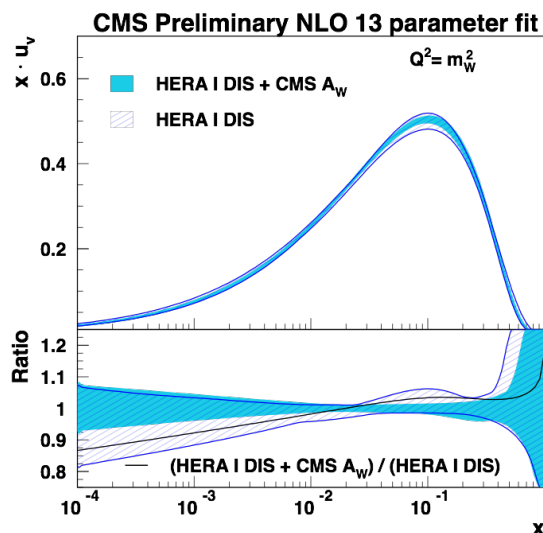


Lepton asymmetry in W production probes valence quark distributions

$$A_W = \frac{W^+ - W^-}{W^+ + W^-} \approx \frac{u_v - d_v}{u_v + d_v + 2u_{sea}}$$

QCD analysis at NLO using HERAFitter

- HERA inclusive DIS [*JHEP 1001:109 (2010)*]
- CMS muon charge asymmetry in W production

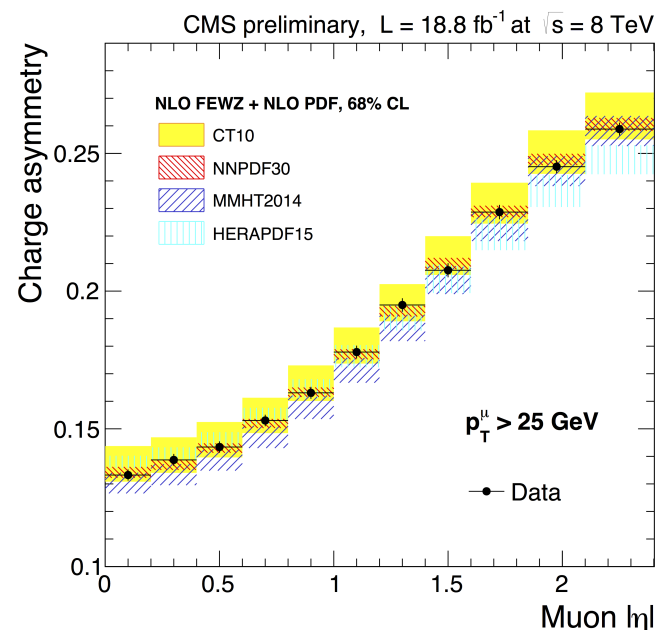


change of PDF and uncertainties similar to 7 TeV result [*PRD 90 (2014) 032004*]

valence distributions further constrained

> Released for DIS2015

CMS-PAS-SMP-14-022



most precise data on A_W to date
probe quark distributions in

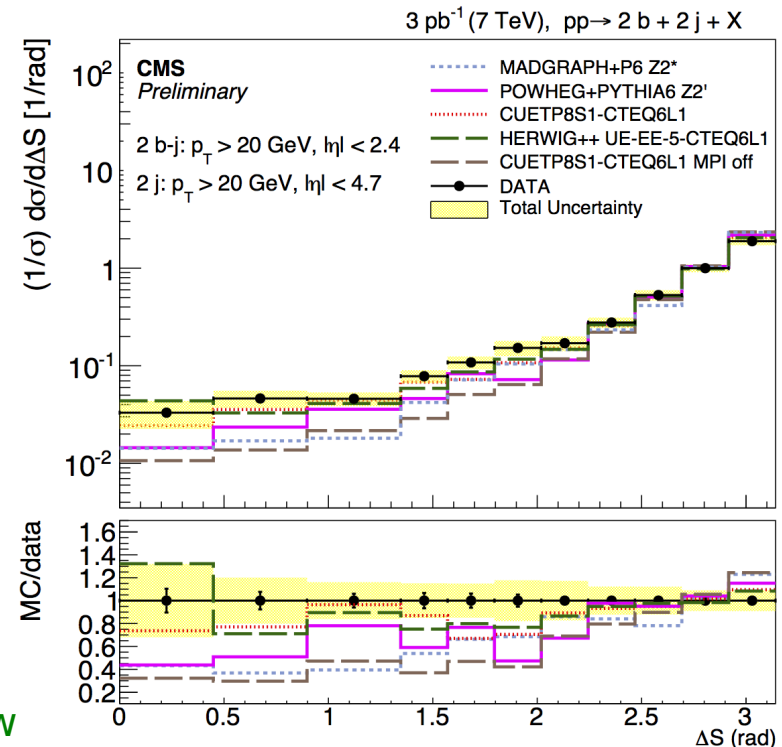
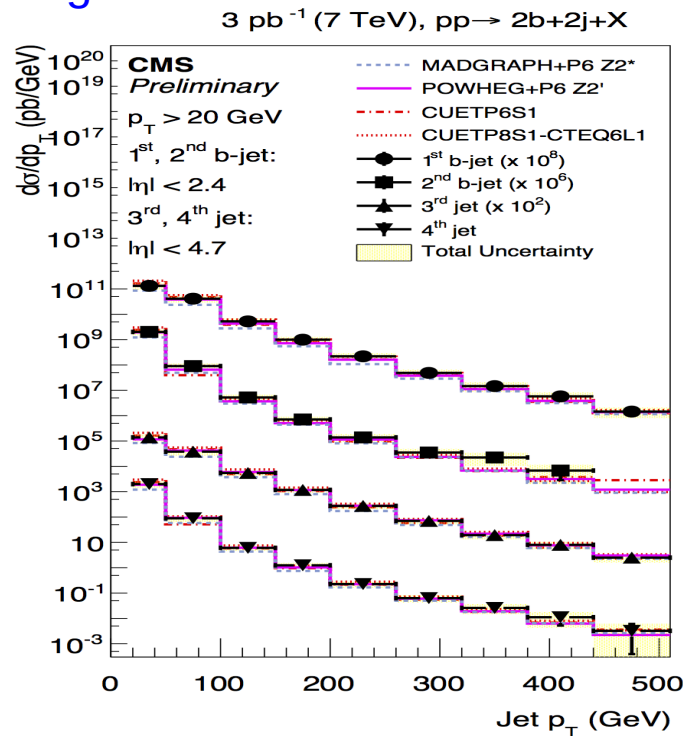
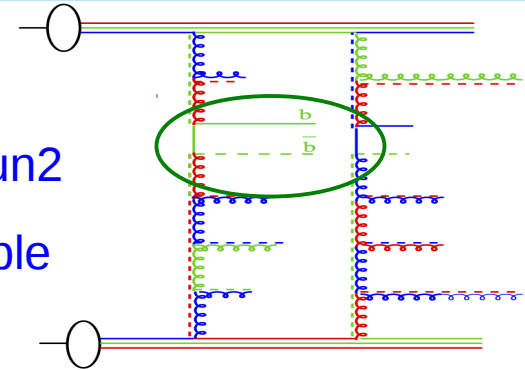
$$10^{-3} < x < 10^{-1}$$



QCD – Publication of Run I analyses

CMS-PAS-FSQ-14-010

- > Released for DIS2015 to be published before LHC run2
- > First measurement of $bb+jj$ in CMS, sensitive to Double Parton Scattering



- > FSQ-13-003 (DY+jets) under collaboration review and paper on generator tunes to be published before Run II

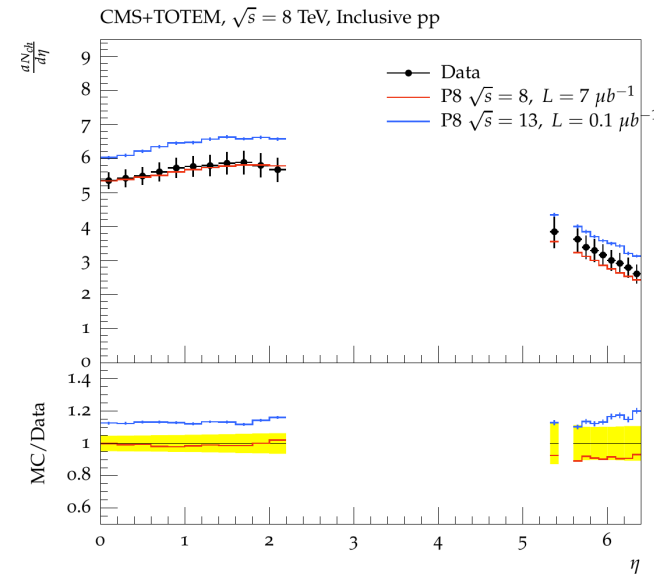
QCD – Preparation for Run II

Preparation for first data analysis (first hours/days)

> Prepare for very early day:

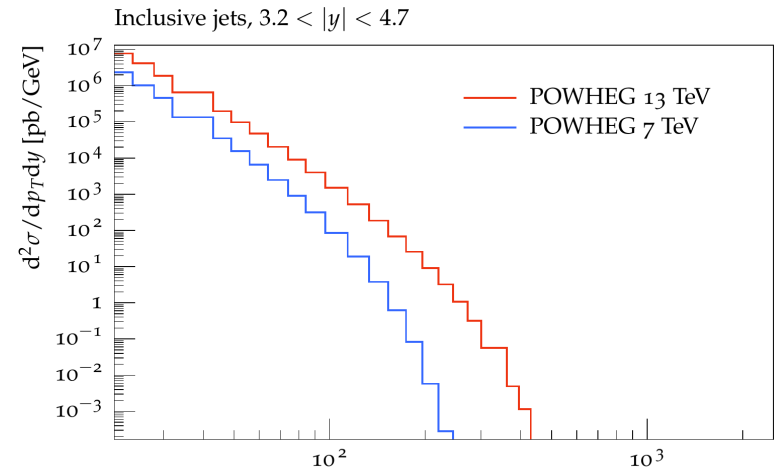
charged particle spectra - $dn/d\eta$, dn/dp_T (8 of June)

- Luminosity $\sim \mu b$
- Development of min-bias trigger using E , E_T in HF
- Analysis developments, tracker alignment



> Within SMP high priority analysis on inclusive jets started, from low p_T to highest p_T covering for the first time $|\eta| \leq 5$

- DESY responsible for code development,
- NP corrections, PS corrections and
- NLO-matched predictions



SUSY Studies

> Technical contributions finalised

CMS-PAS-SUS-14-012

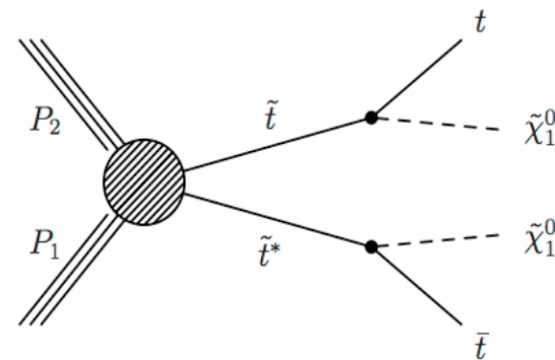
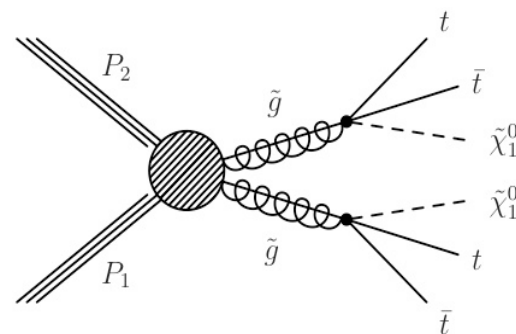
- SUSY Future analysis studies (Full model analyses and SUSY signal generation)
 - Public, going to HL-LHC TP

> Started topics/analyses

- Preparation of inclusive single-lepton search, targeting gluino-gluino and gluino-squark production (need 3-4 fb⁻¹)
- Follow-up paper on 14 TeV LHC-ILC study (outside CMS – using Snowmass MC samples) - *next slide*

> Targeted topics (long-term for 13 TeV)

- 1-lepton stop analysis (need at least 15 fb⁻¹)
- Search for SUSY in di-tau final states (common framework with Higgs group)
- In collaboration with top group: di-lepton SUSY search by measurement of polarization-sensitive variables (need high luminosity)



SUSY Studies for LHC and ILC

> Examples for possible discovery with full SUSY models (preliminary ILC-LHC study going for paper)

> Stau coannihilation models well motivated as it can account for the correct dark matter density

> Two models with different mass parameters chosen:

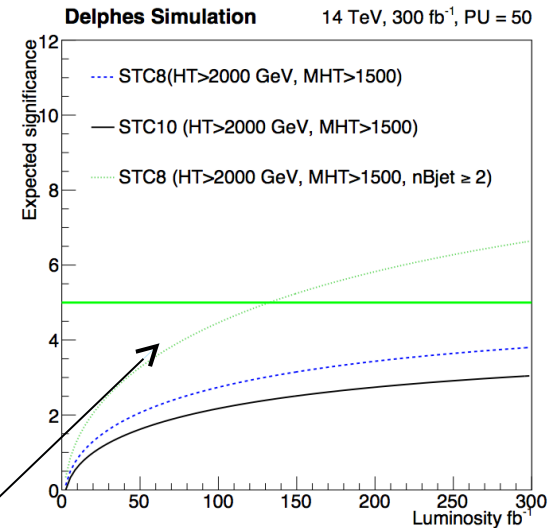
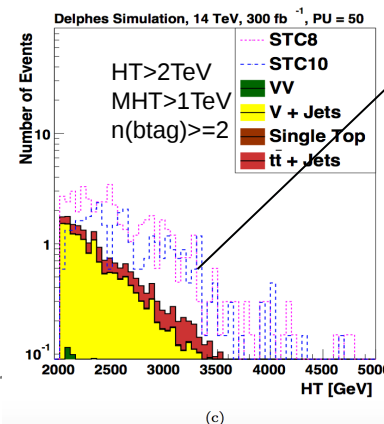
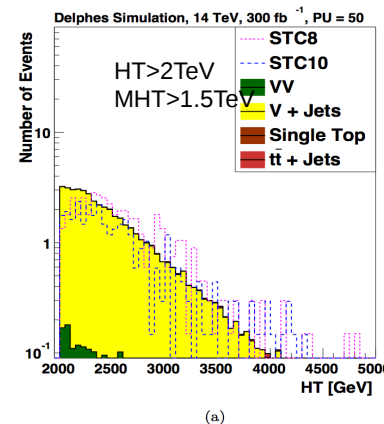
- STC8 (STC10):

- $M(\text{sbottom}) = 795$ (1008) GeV
- $M(\text{stop}) = 736$ (944) GeV
- $M(\text{gluino}) = M(\text{squark}) = 2.04$ TeV (same in both models)

> Investigate several different analyses at LHC (and ILC) and their interplay, DESY CMS group members studied:

- full-hadronic inclusive search
- full-hadronic sbottom search
- single-lepton stop search

> Example: discovery sensitivity in full-hadronic search



→ Fast discovery in b-tagged channel
strong hint on either direct
third-generation production or gluino
production with decay through third-
generation squarks



Top Quark Physics – finalizing Run-I publications

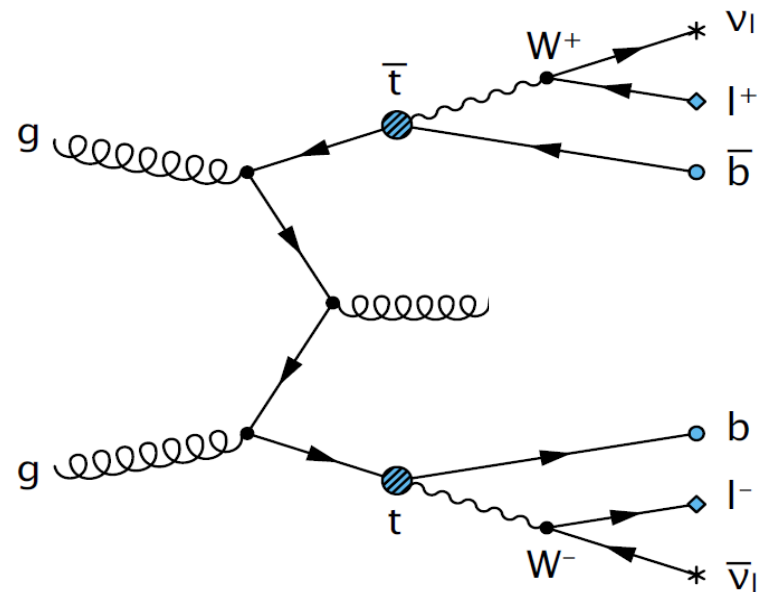
All analyses focus on $t\bar{t}$ dilepton final states

Inclusive $t\bar{t}$ cross sections Run-I Legacy paper (7 and 8 TeV) → preapproved

- > Full phase space and fiducial cross sections
- > Cross section ratio 7/8 TeV
- > Top pole mass determination from cross section
- > Limits to stop quark models using extracted $\sigma(t\bar{t})$

Differential $t\bar{t}$ cross sections at 8 TeV

- > Cross section as a function of top, $t\bar{t}$, lepton, b-jet kinematic variables → Final reading May
- > $t\bar{t}$ +jets, $t\bar{t}$ +bb cross sections → In publication procedure
- > 2D $t\bar{t}$ differential cross sections → In publication procedure
- > Top quark mass determination from $t\bar{t}$ +1jet cross section → preapproved



Top Quark Physics – Run II analyses

Working on “Early Analysis” with 13 TeV data

- > Total $t\bar{t}$ cross section ($\sim 1 \text{ fb}^{-1}$ of data)
- > Differential $t\bar{t}$ cross section ($\sim 1 - 5 \text{ fb}^{-1}$)

→ Aiming at summer 2015 conferences

Started:

- > $t\bar{t}+H(bb)$ (full 2015 dataset)

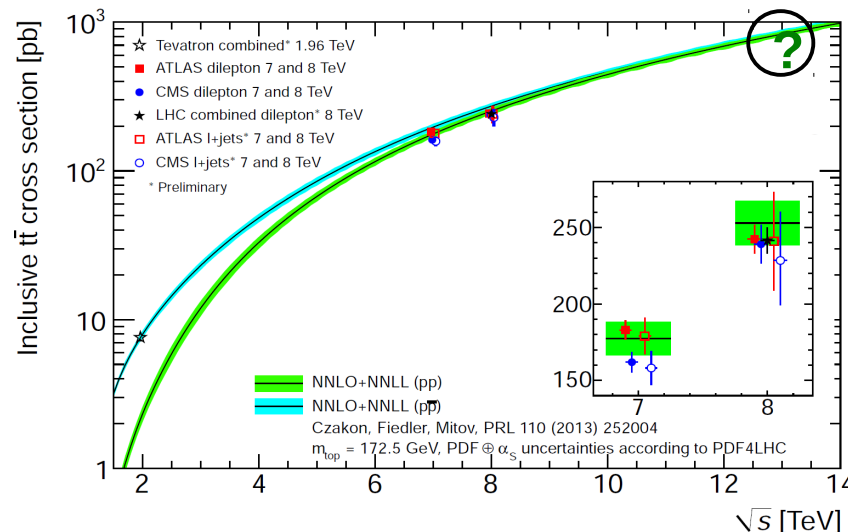
Focus on reconstruction of Higgs mass from jets

Discovery/exclusion limits of $t\bar{t}+H$

Planned:

- > $t\bar{t}+\text{jets}$, $t\bar{t}+bb$, $t\bar{t}+Z$ (full 2015 dataset)

→ Aiming at winter 2016 conferences



Summary

- > Eagerly waiting for data at 13 TeV!
- > Well prepared for the next data taking period
 - Many analyses with “very early” data (charged particle spectra - $dn/d\eta$, dn/dp_T , jet spectra) to the “early” data few fb^{-1} (tt, Higgs, SUSY) and in the longer time scale
- > LS1 contributions accomplished
 - HO upgraded, BCML installed - ready for exploitation in full Run II
- > Physics Analyses: major results with Run I data
 - novel searches for very light Higgs $h_1 \rightarrow b\bar{b}$, W production: constraint valence quark distributions, first measurement of $b\bar{b}+j\bar{j}$, etc.
 - Remaining 7/8 TeV analyses close to finalisation
- > On track with contributions to upgrades
 - Phase I pixel: series production started
 - Phase II tracker: optimising sensor design, prototype development advanced



Back up



DESY CMS – Coordinating Roles in CMS

> Level-1 Management

- K. Borras: Deputy Spokesperson (Jan. 2014 – Aug 2016); FB member
- M. Kasemann: Chair of the Authorship Board; FB member, CB advisory

> Physics

- H. Jung: FSQ-PRF Pub. Committee, Chair of Theorists in CMS committee, Convener of Physics Comparison and Generator Tunes group (MC group)
- I. Melzer-Pellmann: Convener of SUSY Future subgroup (L3), Member of SUSY
- A. Kalogeropoulos: Dataset Definition Team (DDT) coordinator (L3 within PPD mandate), [SUSY Cross-PAG/Trigger/MC Convener \(L3\)](#)
- A. B. Meyer: Convener of Top group (L2)
- A. Nayak: Convener of tau identification group (L3)

> Computing

- C. Wissing: Operation (L2)
- M. Kasemann: Chair of Computing Resource Board

> Data Quality Monitoring (DQM)

- M.Schröder/T. Schörner-Sadenius: Organizer of remote DQM shifts (L3 coordinate)
- R. Placakyte: Data Certification (L3)

> Alignment: [M.Schröder: Tracker Alignment convenor \(L3\)](#)

> Tracker

- G. Eckerlin: Tracker Upgrade Steering Committee, Tracker Finance Board
- D. Eckstein, W. Lange: CEC Sensor & Qualifying, Member of Tracker Pub.Comm.
- A. Mussgiller: Convener of Strip-Tracker Module-Design group

> Beam Radiation Instrumentation & Luminosity (BRIL)

- W. Lohmann: Chair of Institutional Board



Collaborations with Other Groups – Upgrade

- > **BCM1F**
 - CERN
- > **HCAL**
 - HO SiPM: Aachen, TIFR
 - HO trigger: INFN, Warsaw, Boston
 - μ TCA: CERN
- > **Pixel Phase I**
 - 4th barrel layer: German Institutes (esp. UHH)
- > **Sensors Phase II**
 - UHH, KIT
- > **Tracker Phase II**
 - Dee prototype: Lyon, CERN



Collaborations with Other Groups – Physics Analysis

> TOP

- Inclusive cross sections: IFCA, Oviedo, Strasbourg
- Differential cross sections (1D): UHH
- $t\bar{t}+H$: KIT, Ohio, Notre Dame, Virginia, ETH, Zurich U., etc.

> PDF

- Exchange program: DESY – Southern Methodist U
- Close collaboration with CTEQ, ABM PDF groups
- Member of physics project of Alliance (UHH, Mainz, Freiburg, Wuppertal, KIT)
- DiffTop: UHH

> QCD

- Double-parton scattering, forward jets: Antwerp
- Phenomenology: Oxford, Moscow

> SUSY

- 1-lepton stop: UHH
- 13 TeV 1-lepton search: Athens, CERN
- LHC-ILC study: DESY ILC

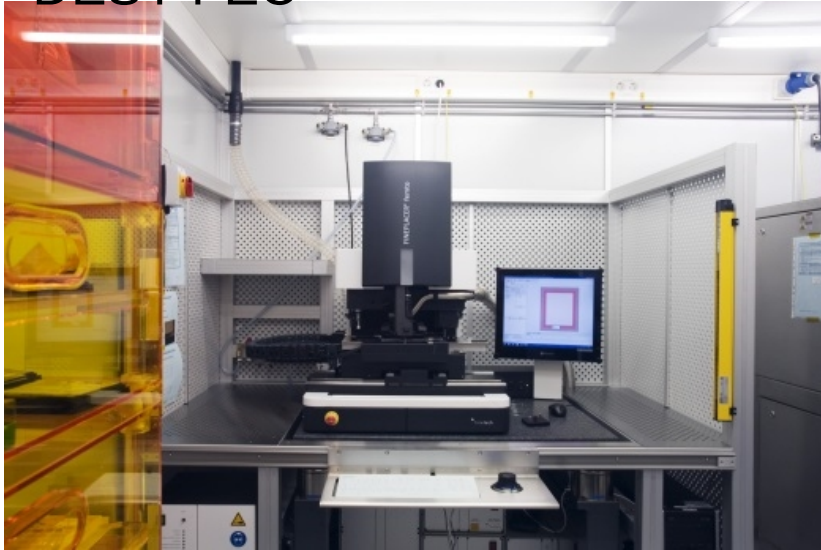
> Higgs

- $H \rightarrow \tau\tau$: KIT, CERN, Ecole Polytechnique
- MSSM $H \rightarrow b\bar{b}$: Zurich, Moscow, Beijing
- NMSSM $H \rightarrow b\bar{b}$: UHH
- $h_{1,2} \rightarrow \phi_1 \phi_1 \rightarrow (\tau\tau)(\tau\tau)$: IC, Rutherford Appleton Lab, Riverside

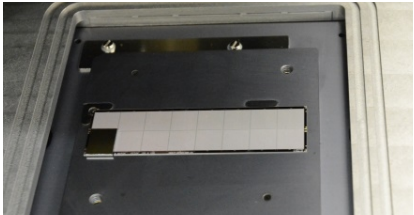


Flip chip bonding

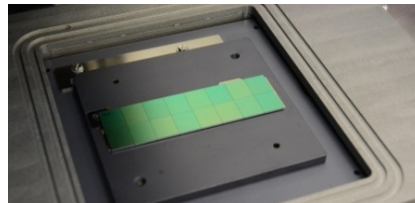
DESY FEC



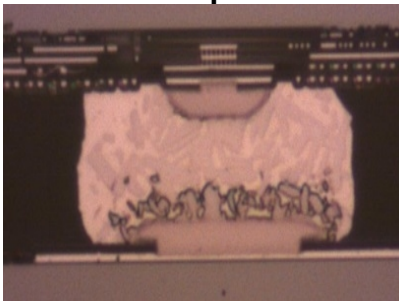
- Femto Fineplacer from Finetech:
 - ▶ high precision step motors
 - ▶ automated, with image recognition
 - ▶ one ROC at a time
 - ▶ known good die test with probe card
 - ▶ chuck and bond head heating
 - ▶ formic acid atmosphere
 - ▶ tacking: 3 N → 50 N → 160 N at 200°C
 - ▶ in-situ common reflow at 230°C
 - ▶ ≤ 3 hours per module



1st ROC placed



16 ROCs



ROC
solder ball
height: 24 μ m
sensor