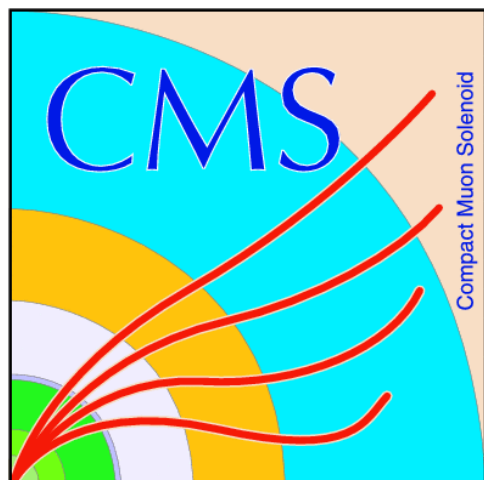


# DESY CMS Group Highlights

85th Meeting of the DESY Physics Review Committee

Open session, 8 May 2018

Chayanit Asawatangtrakuldee  
on behalf of the DESY CMS group

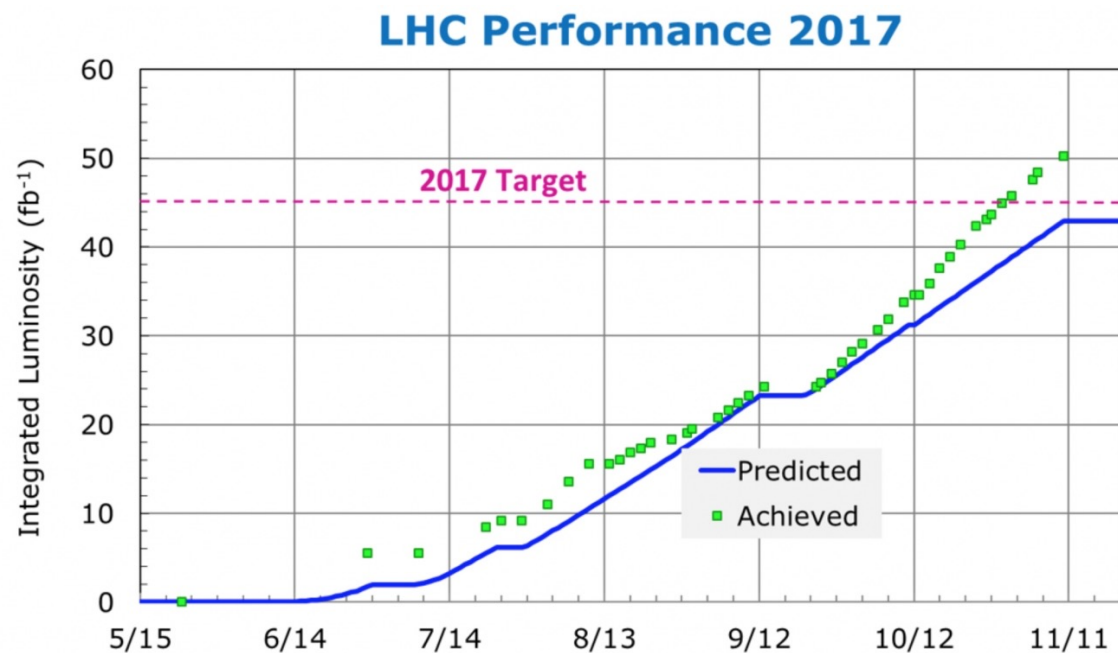
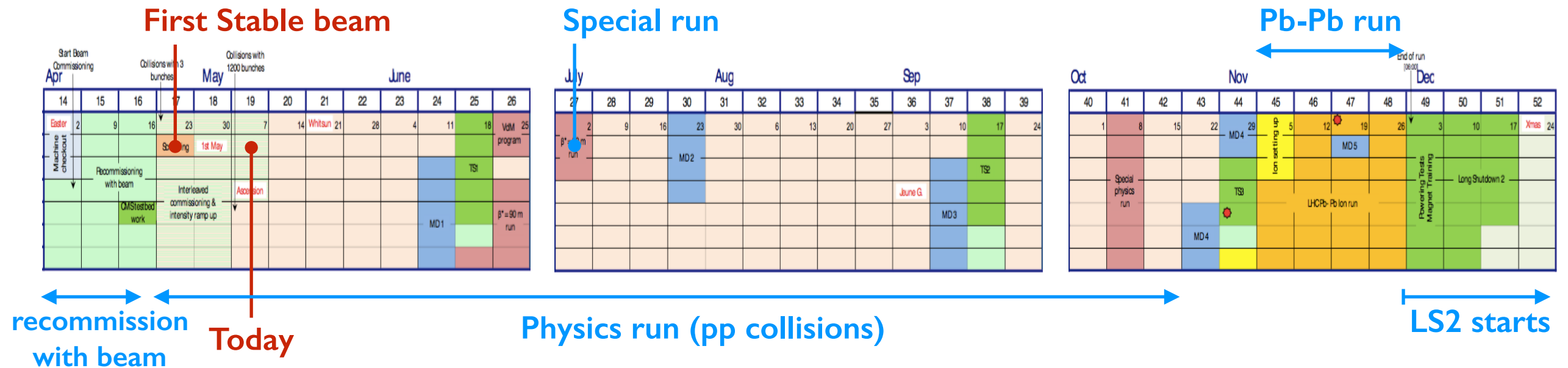


# Outline

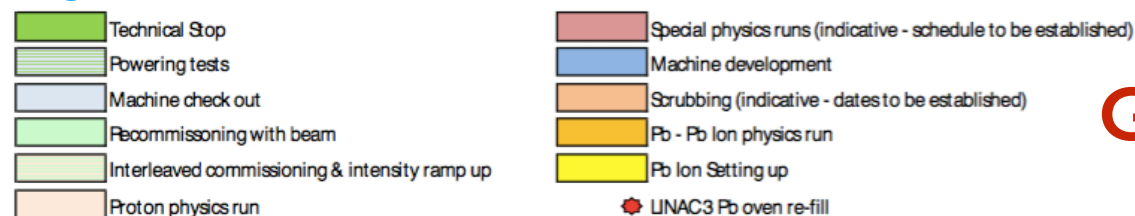
- ★ Status of LHC
- ★ CMS Data-taking
  - ◎ BCM1F Commissioning
  - ◎ Tracker Alignment
- ★ LHC Computing at DESY
- ★ CMS Phase II Tracker upgrade
- ★ Physics Highlights
  - ◎ Top, Higgs, SUSY, Exotica and QCD



# Status of LHC



## Legend

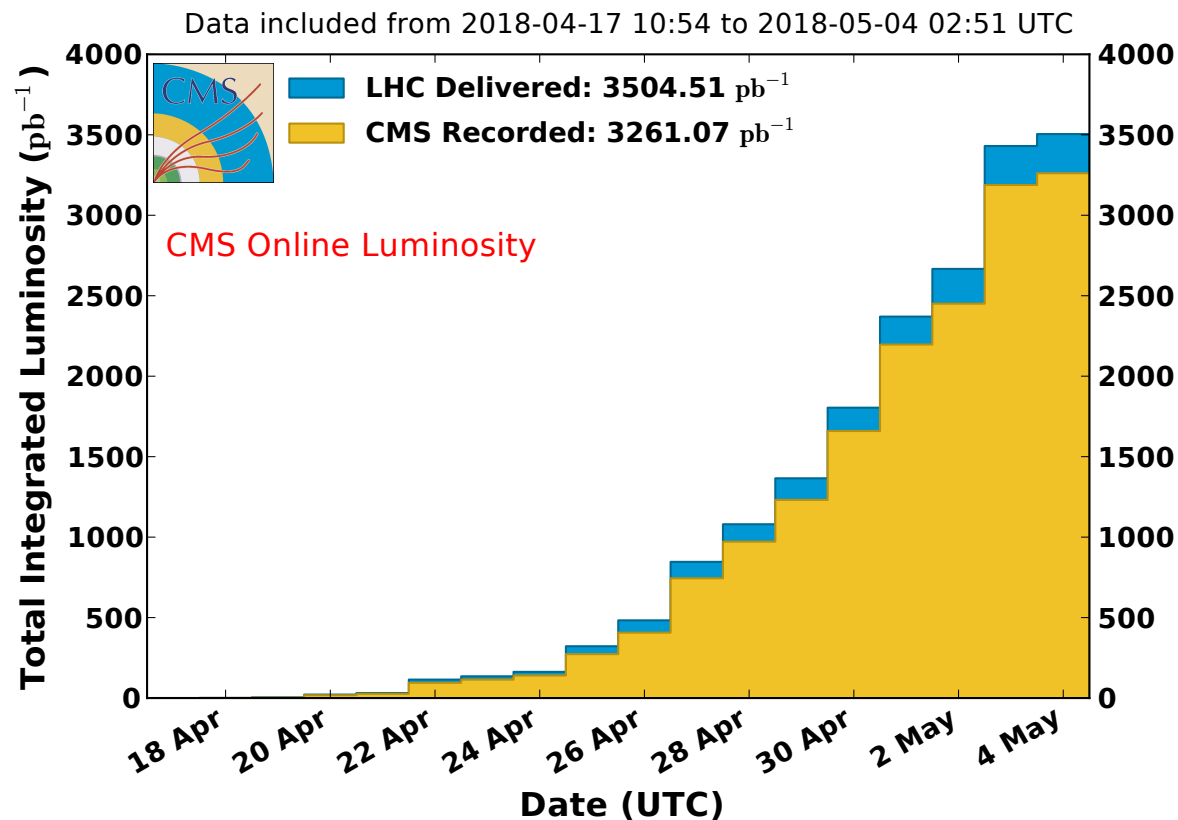


- ★ LHC exceeded 2017 target
- ★ A final production year to complete LHC Run 2
  - pp collisions ~19 weeks
  - followed by ~4 weeks Pb-Pb run
  - entering Long Shutdown 2 (2019-2020)
- ★ First beam already arrived on 12 April

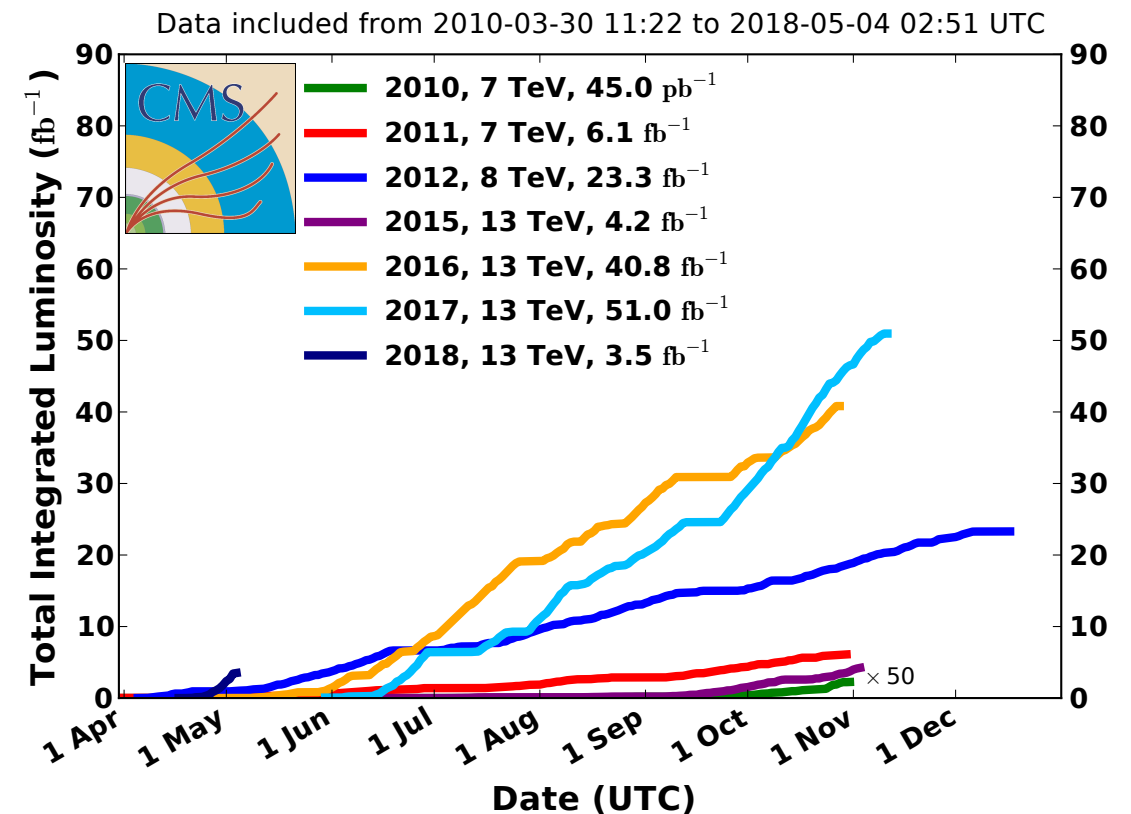
**Goal 60 fb<sup>-1</sup> to reach a total 150 fb<sup>-1</sup> of Run 2**

# CMS Data-taking

CMS Integrated Luminosity, pp, 2018,  $\sqrt{s} = 13$  TeV



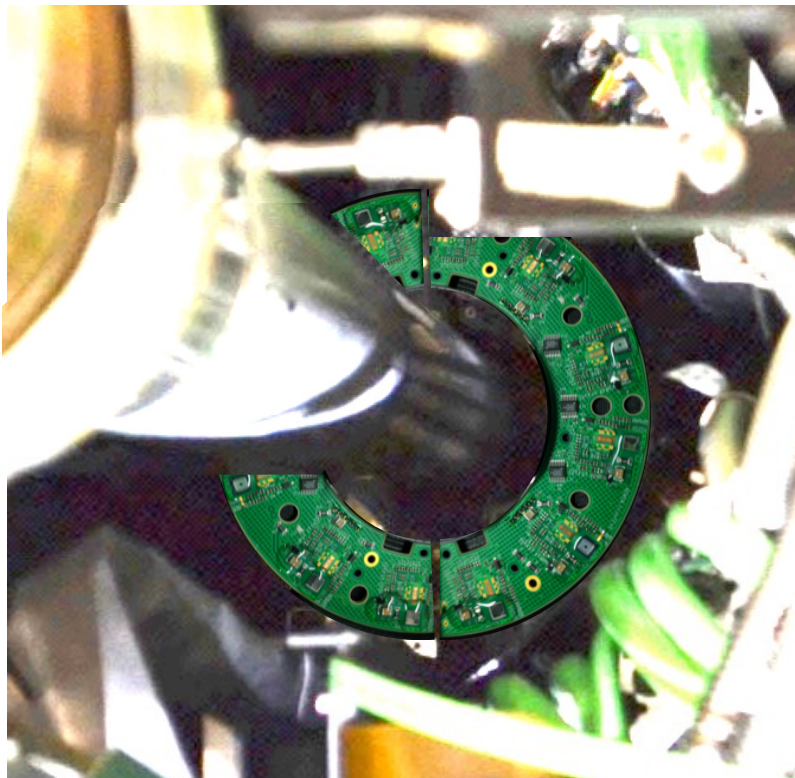
CMS Integrated Luminosity, pp



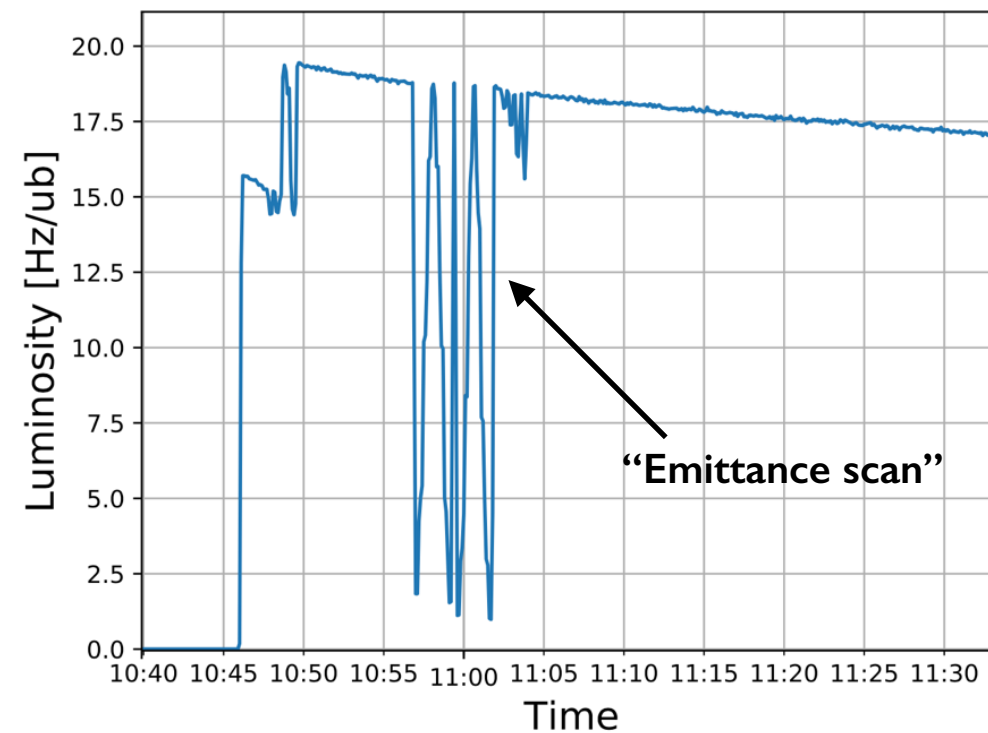
- ★ CMS started taking 2018 data : LHC delivered **3.5  $\text{fb}^{-1}$** , CMS recorded **3.3  $\text{fb}^{-1}$**  (~93%)
- ★ The (sub)detectors are all in good shape for data-taking
  - Pixel detector smoothly refurbished and re-installed
  - Phase I Upgrade HCAL Endcap Front-End completed
  - Muon system ready with high fraction of active channels

# BCMIF Commissioning

- ★ Online luminosity measurement and beam condition monitoring

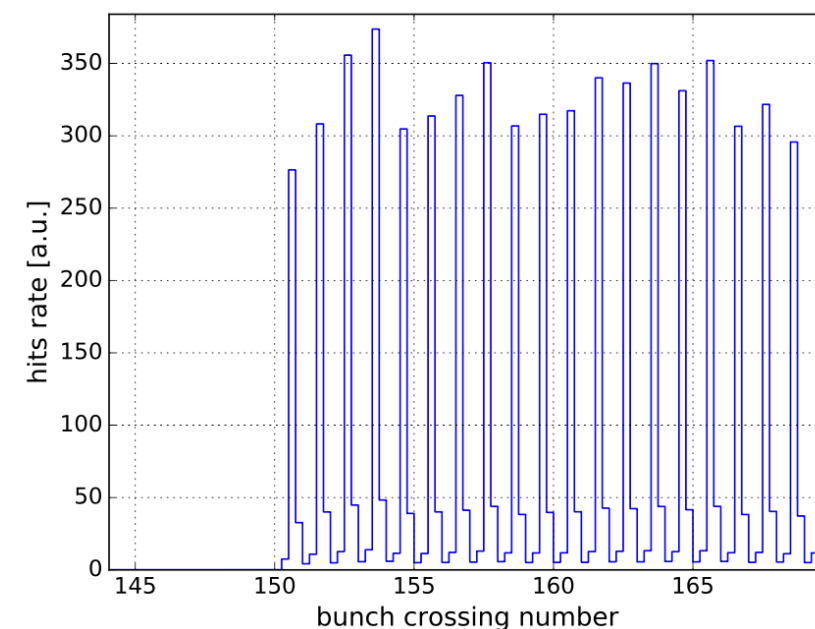


artistic view



Online luminosity from BCMIF during first stable beams 2018

- ★ DESY group built BCMIF detector situated close to the beam pipe at  $z = \pm 1.8$  m
- ★ Bunch-by-bunch luminosity measurement
- ★ Commissioning 2018 now completed
  - calibration consistent with 2017



Zoom into LHC bunch structure  
BCMIF measures rate in bins of 6.25ns

# Tracker Alignment

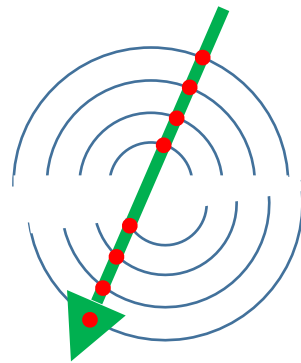
★ DESY is one of leading groups for CMS Tracker Alignment

- developed a so-called MillePede II framework

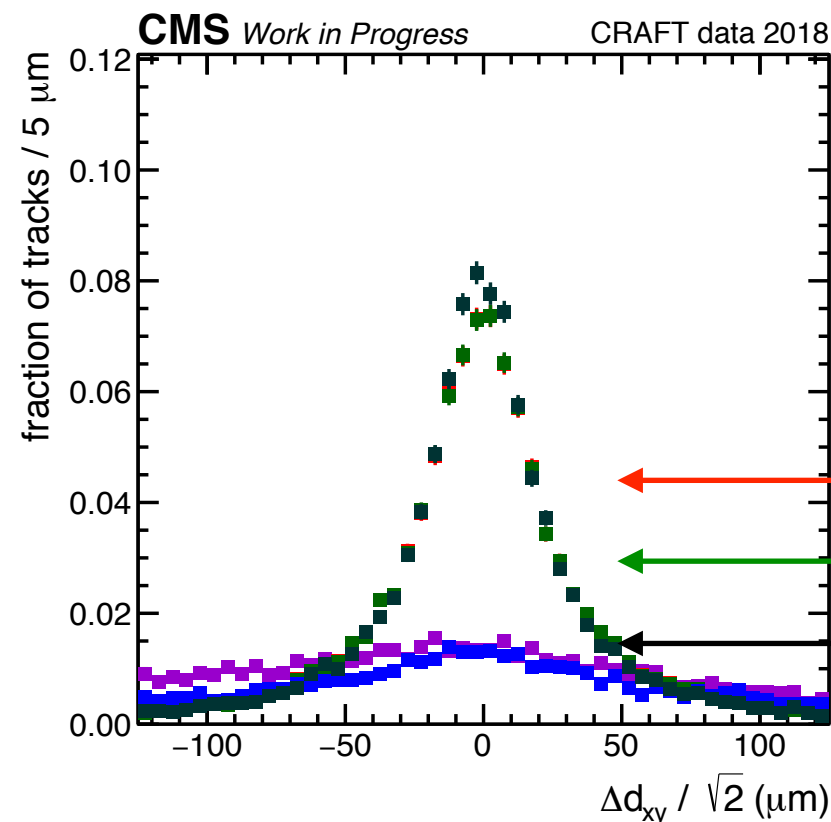
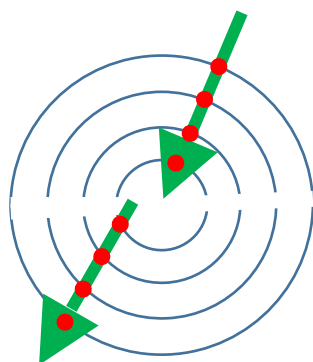


★ First tracker alignment from 2018 cosmic data

- combined 0 T (CRUZET) + 3.8 T (CRAFT) data to align pixel at module level
- introduced Lorentz Angle calibration for the first time for Run 2
  - ▶ the best alignment from CRAFT data



cosmic muon track splitting



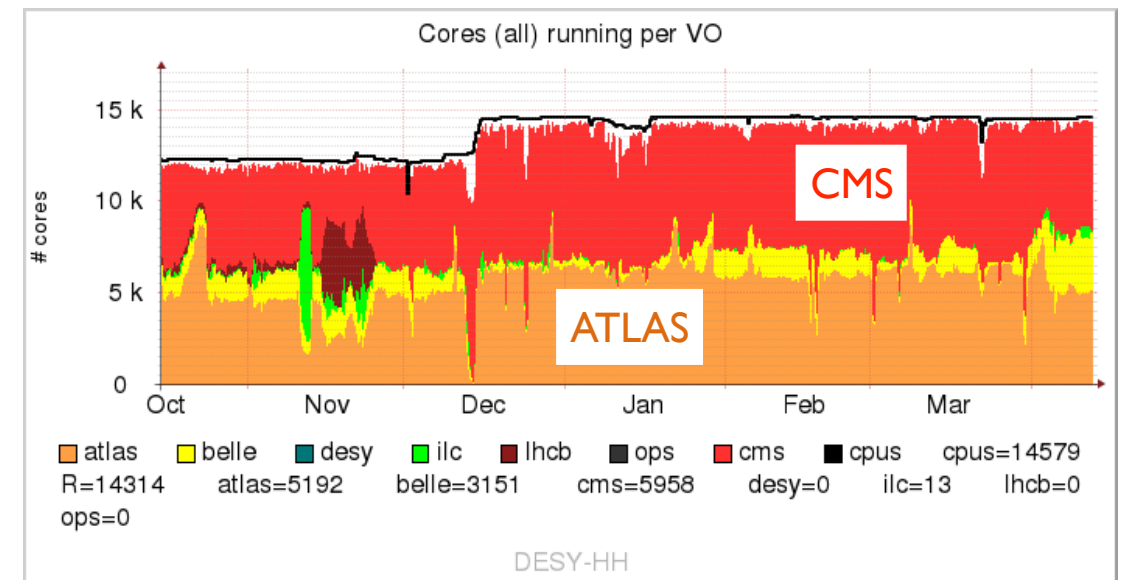
Impact parameter difference  
on transverse plane  
in split cosmic muon tracks

| Alignment                      | RMS ( $\mu\text{m}$ ) |
|--------------------------------|-----------------------|
| 2017 Alignment                 | 63.5                  |
| CRAFT only                     | 38.5                  |
| CRAFT+CRUZET<br>(high level)   | 38.5                  |
| CRAFT+CRUZET<br>(module level) | 36.7                  |

# LHC Computing at DESY

## ★ Tier-2 Grid at DESY

- major computing contributor to ATLAS, CMS, Belle 2 and ILC
- sizable resources
  - CPU: ~20k CPU cores
  - half of the CPUs upgraded from Scientific Linux 6 to CentOS 7
  - disk: ~15 PB disk for HEP in 3 dCache instances
- Worldwide LHC Computing Grid (WLCG) pledges →



|       | CPU         | Disk   |
|-------|-------------|--------|
| ATLAS | 38.7 kHS06* | 2.9 PB |
| CMS   | 45.1 kHS06* | 3.5 PB |

## ★ National Analysis Facility (NAF)

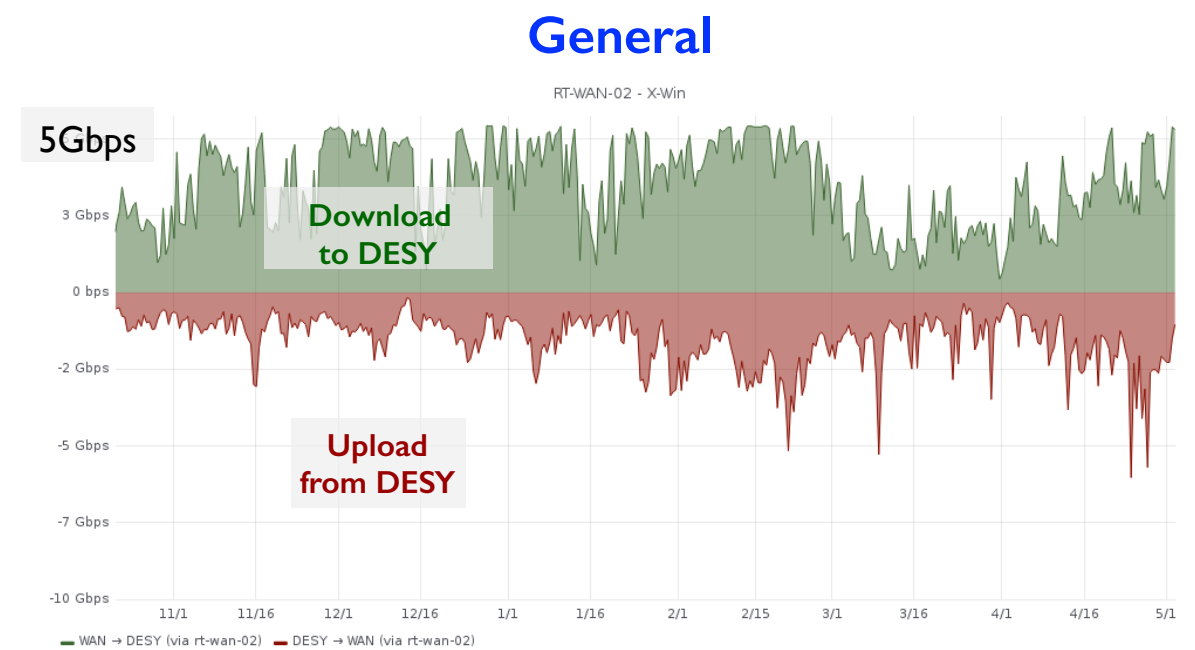
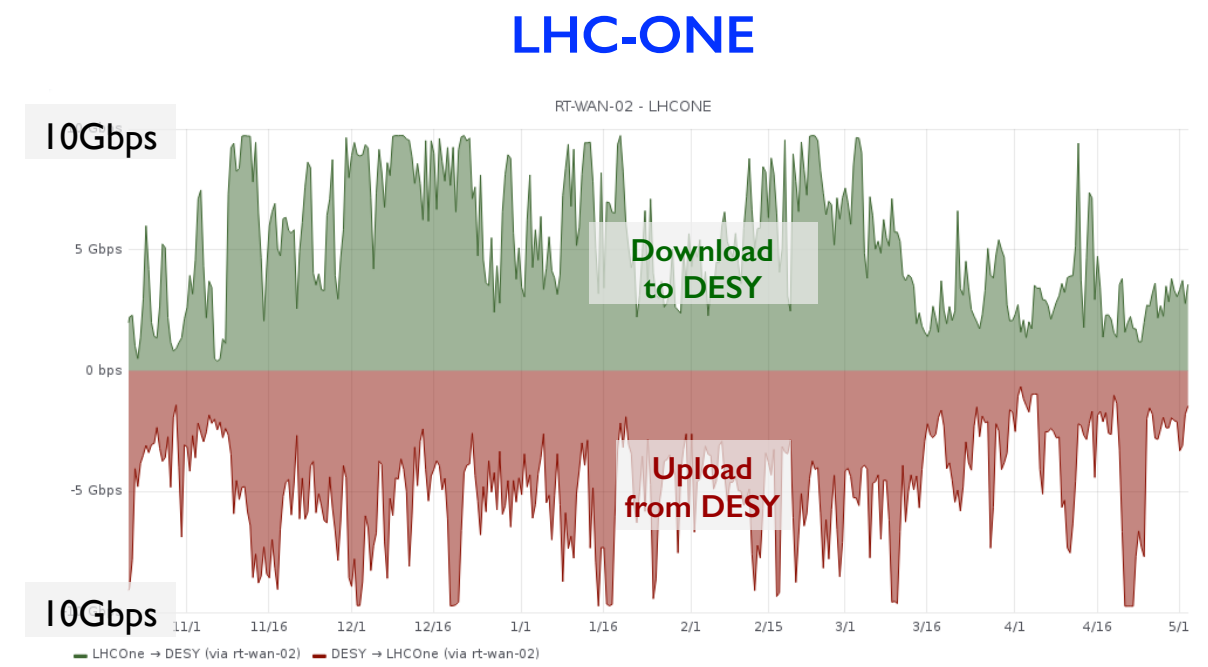
- complementary Grid resources with focus on interactive end-user analysis
- available for all German HEP groups
- fast storage system : 2.6 PB shared by all groups
- batch CPU being migrated to HTCondor
  - pilot system has turned into production service
  - users are migrating to new system

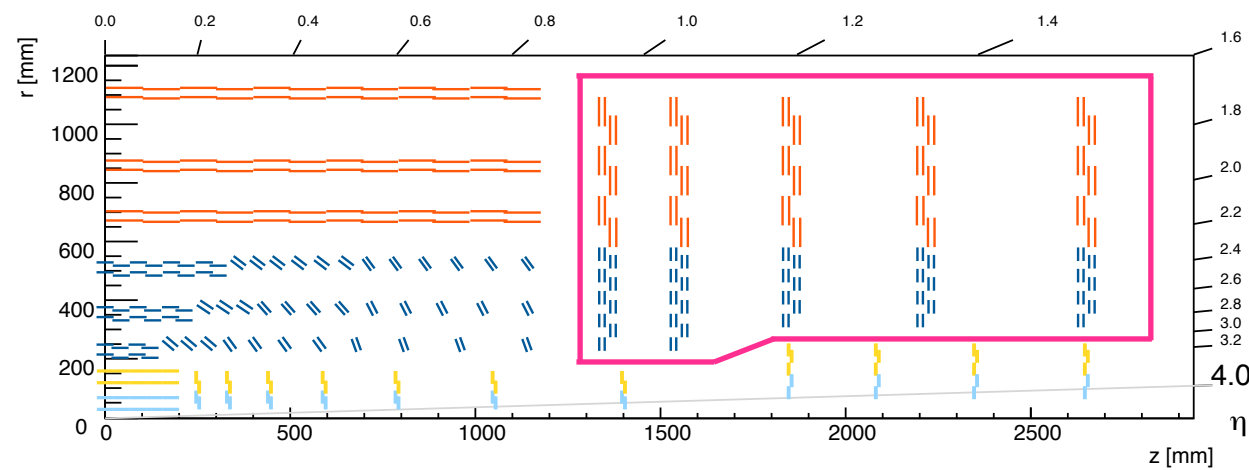
\*(1 CPU core delivers ~10 HS06)



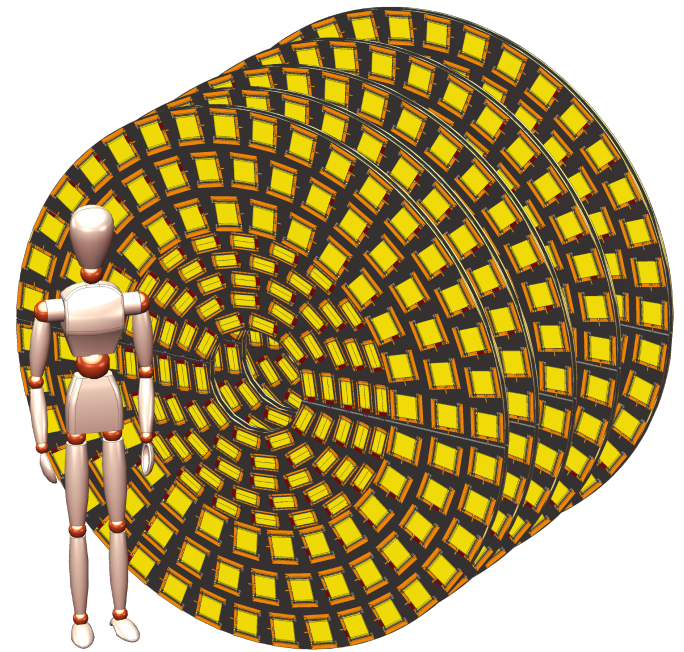
# LHC Computing at DESY

- ★ Data import and export via Wide Area Network (WAN) becoming more and more important
  - LHC Run 2 in full swing
  - Belle 2 starting data taking soon
  - increasing data volumes in Photon science
- ★ Strong utilization of WAN capacity
  - LHC-ONE (2x 10 Gbit/s connectivity)
    - dedicated LHC network
  - WAN (2x 5 Gbit/s, uplink no limit)
    - general purpose connection
    - also used for some LHC traffic
- ★ HEP groups support WAN upgrade plans
  - intense usage expected in the near future

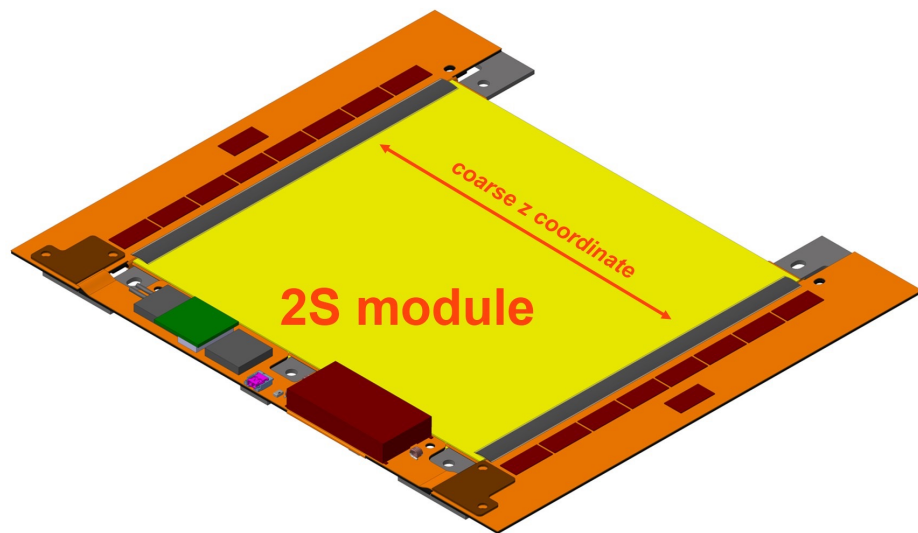




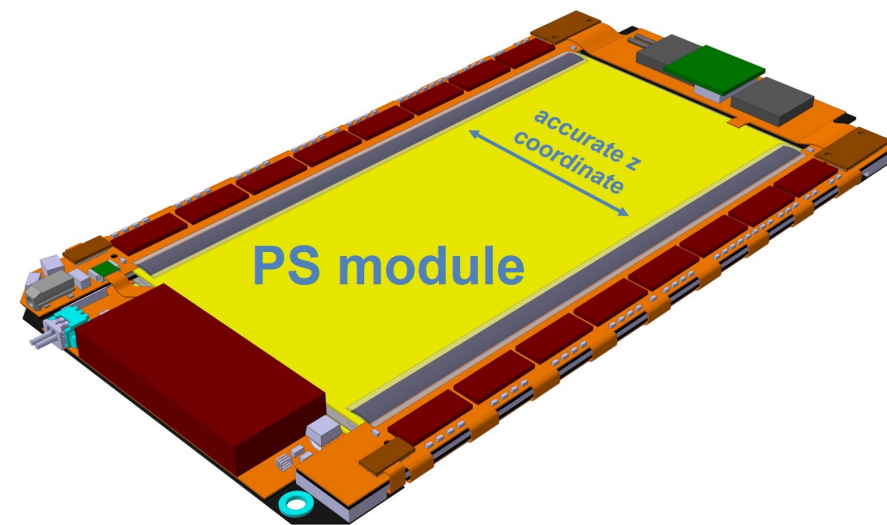
TEDD



# Phase II Tracker Upgrade



2S module



PS module

# Phase II Outer Tracker

★ Assembly plan during Long Shutdown 3 (2023-2025) for HL-LHC

★ Layout : coverage up to  $|\eta| < 2.8$

- 6 barrel layers

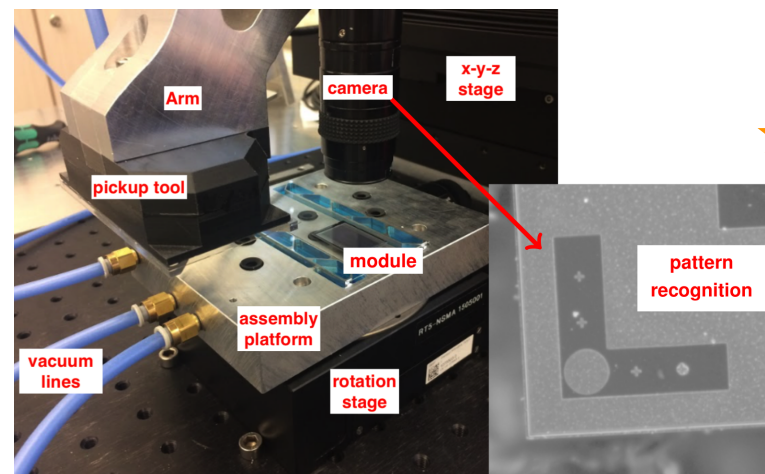
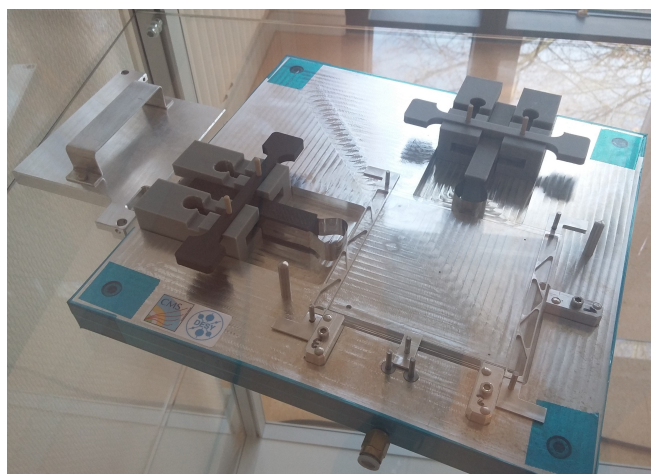
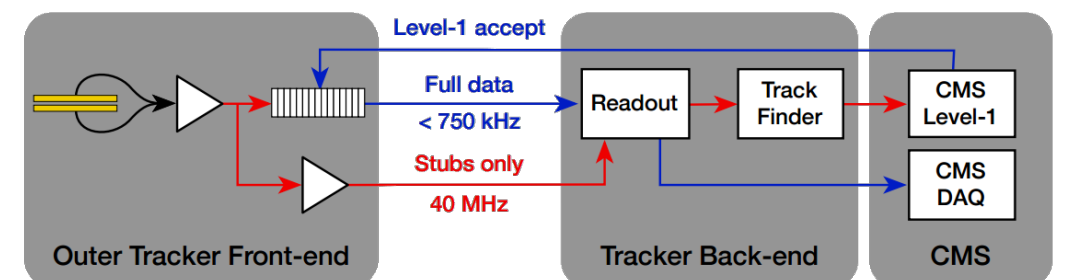
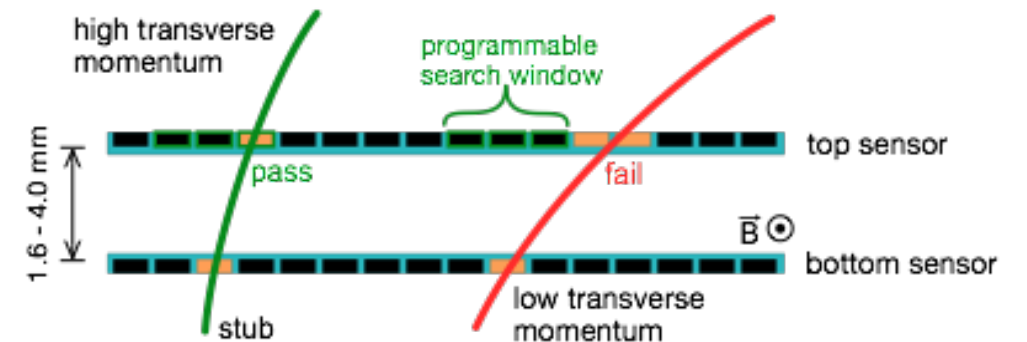
- 5 endcap double-disks

★  $p_T$  modules

- provide track momentum for L1 trigger

- **pixel+strip (PS)** module  $r < 60\text{cm}$

- **two strip (2S)** module  $r > 60\text{cm}$



★ 2S and PS modules assembly at DESY

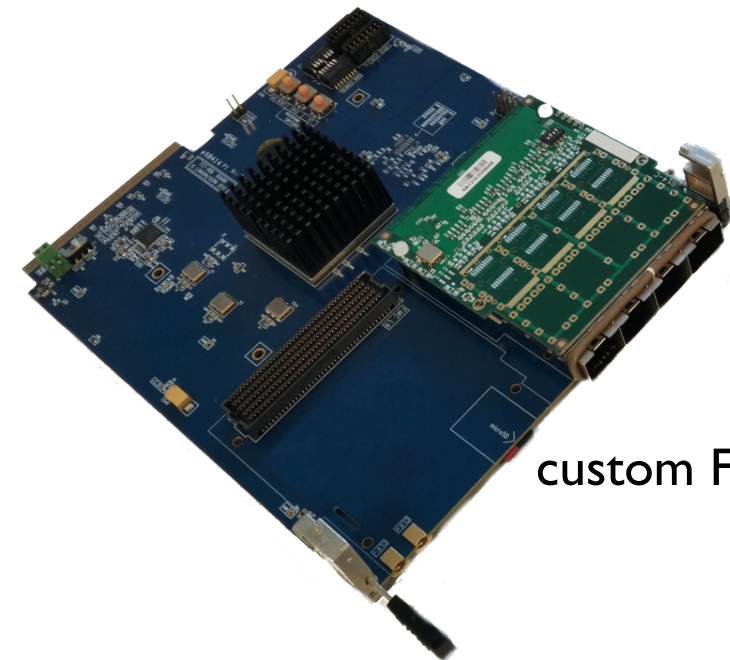
- jig-based 2S module assembly

- automated PS module assembly



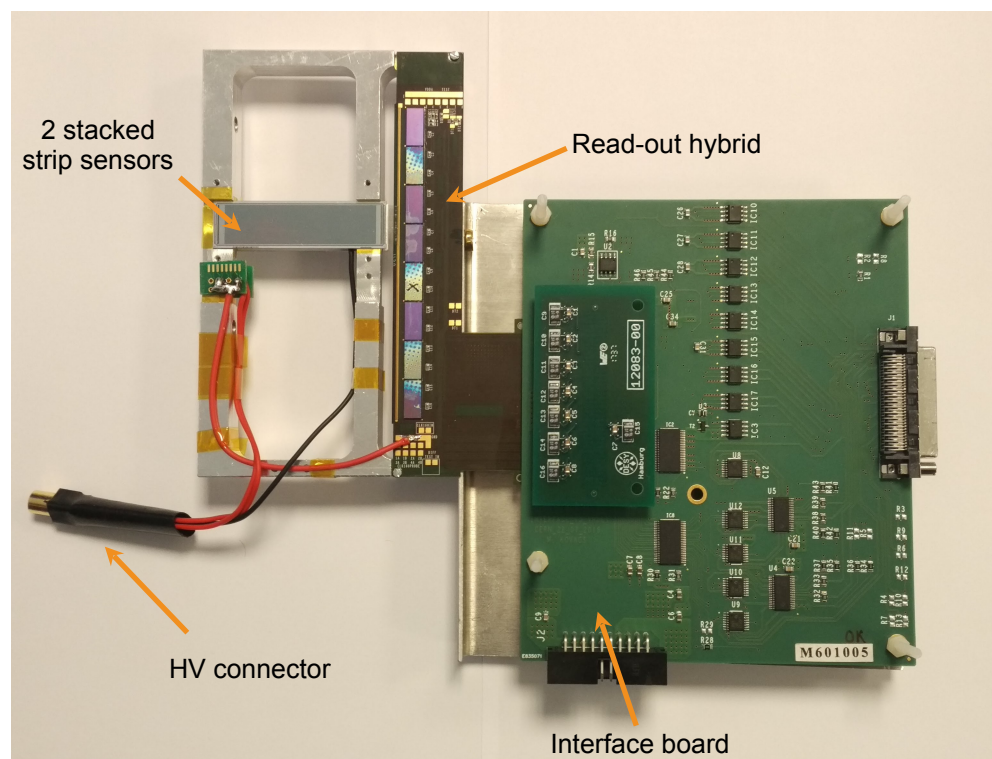
# Firmware / DAQ / Testbeam

- ★ All new read-out system for Phase II Tracker
  - based on  $\mu$ TCA communication
  - custom-built FPGA boards
    - flexible read-out possibilities for both 2S and PS
  - firmware developed at DESY



custom FPGA board

8xCBC2 used in DESY beam test

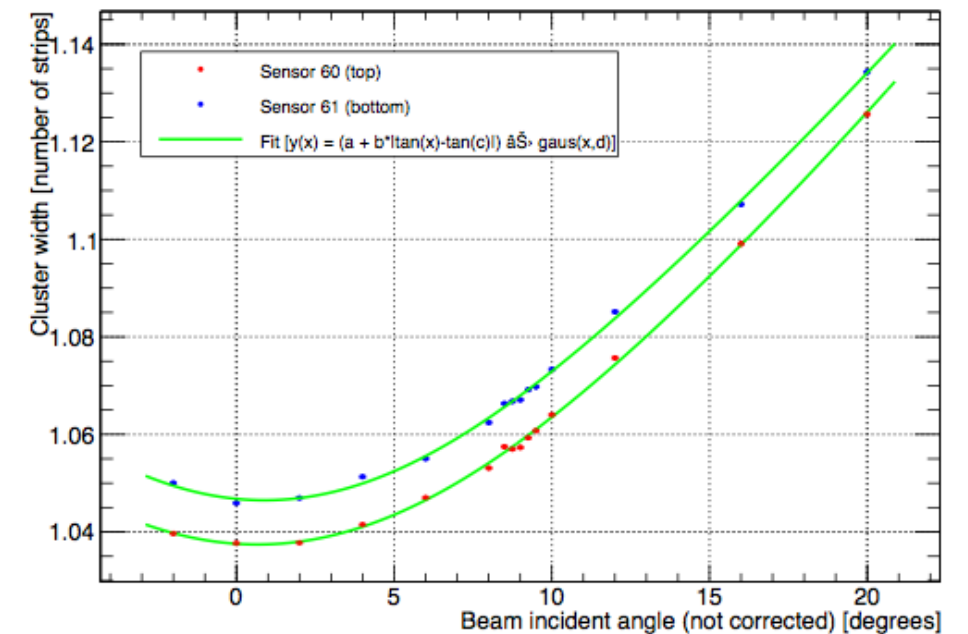


- ★ Firmware and DAQ system verified in beam tests
  - 2S module
    - Oct 2017 DESY 8xCBC2
    - Nov 2017 FNAL 2xCBC3
  - PS module
    - Apr 2018 CERN MPA
    - May 2018 DESY MPA
  - Aug 2018 DESY irradiated MPA

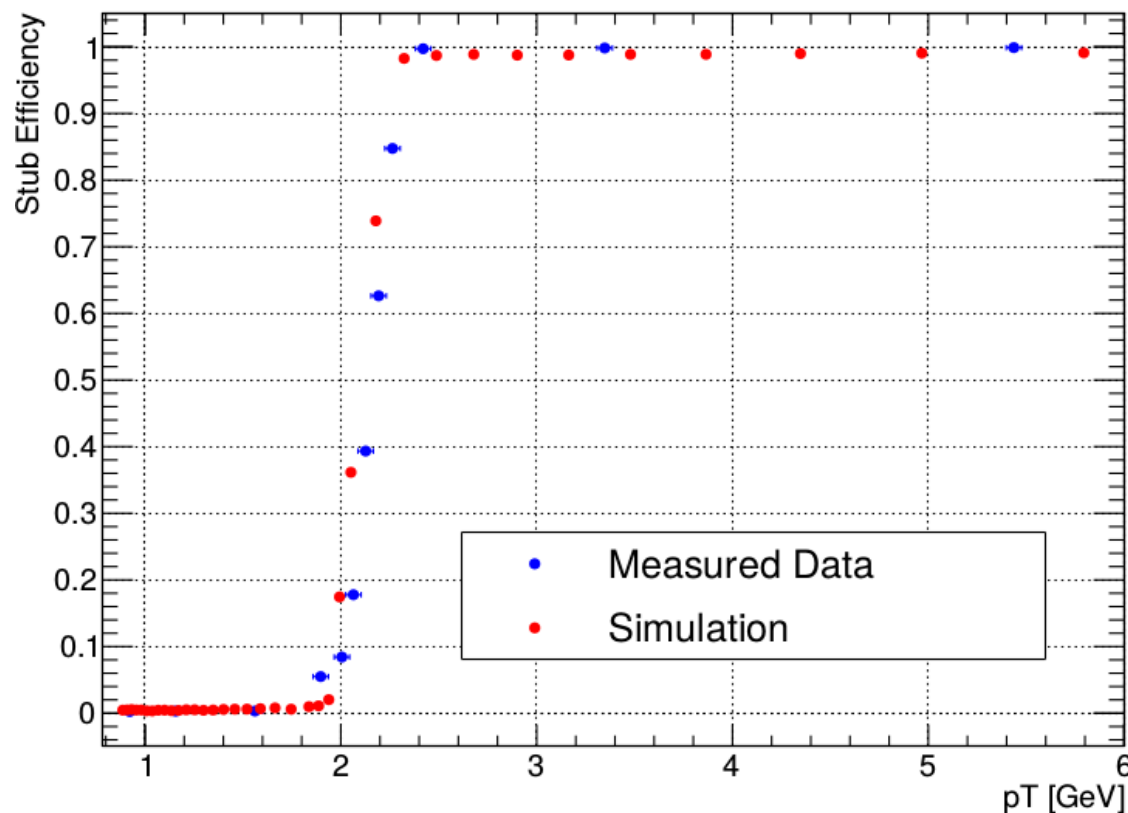
# Testbeam Analysis

- ★ Testbeam results from 8xCBC2 module at DESY
  - first functional 2S module built by DESY CMS
    - ▶ sensor spacing: 4.05 mm
    - ▶ sensor offset: 1.07 strips
    - ▶ sensor relative rotation to be determined from data
- ★ Demonstration of  $p_T$ -triggering capabilities

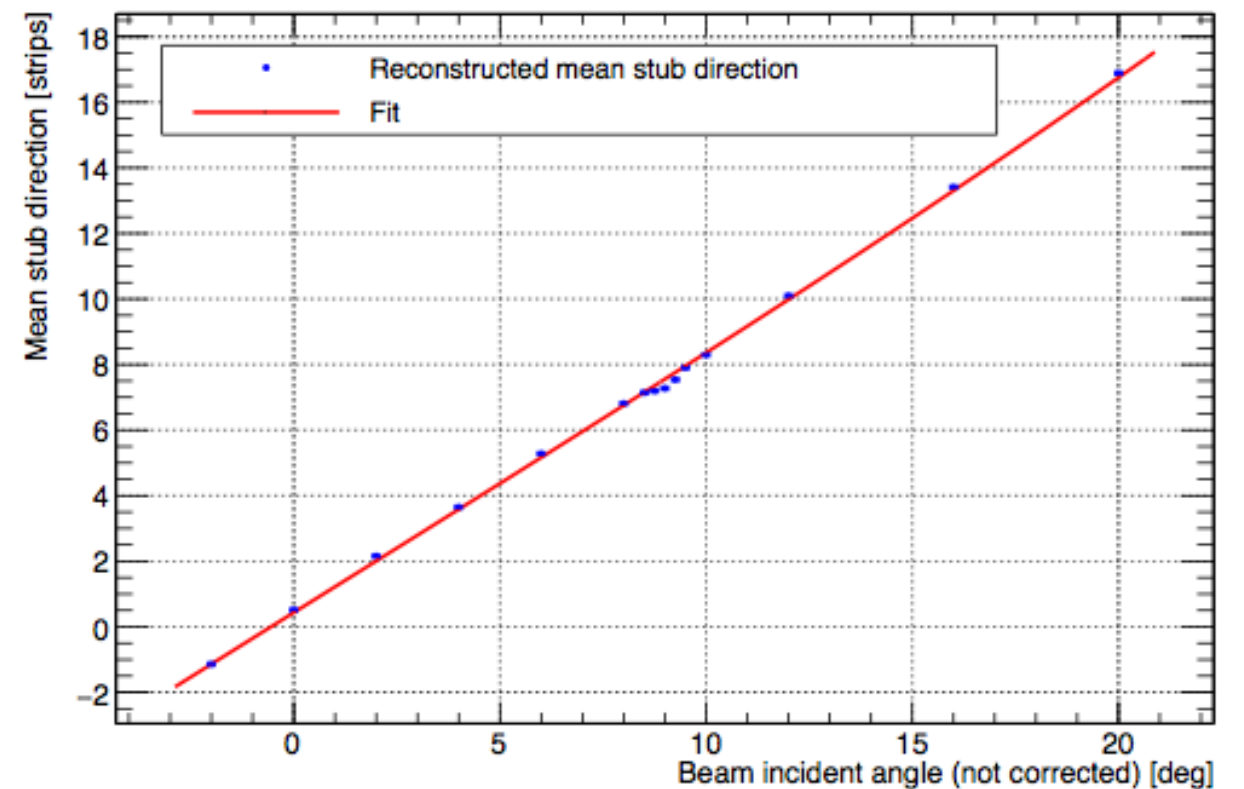
Rotation offset calibration



Stub Efficiency (R = 53.2 cm)

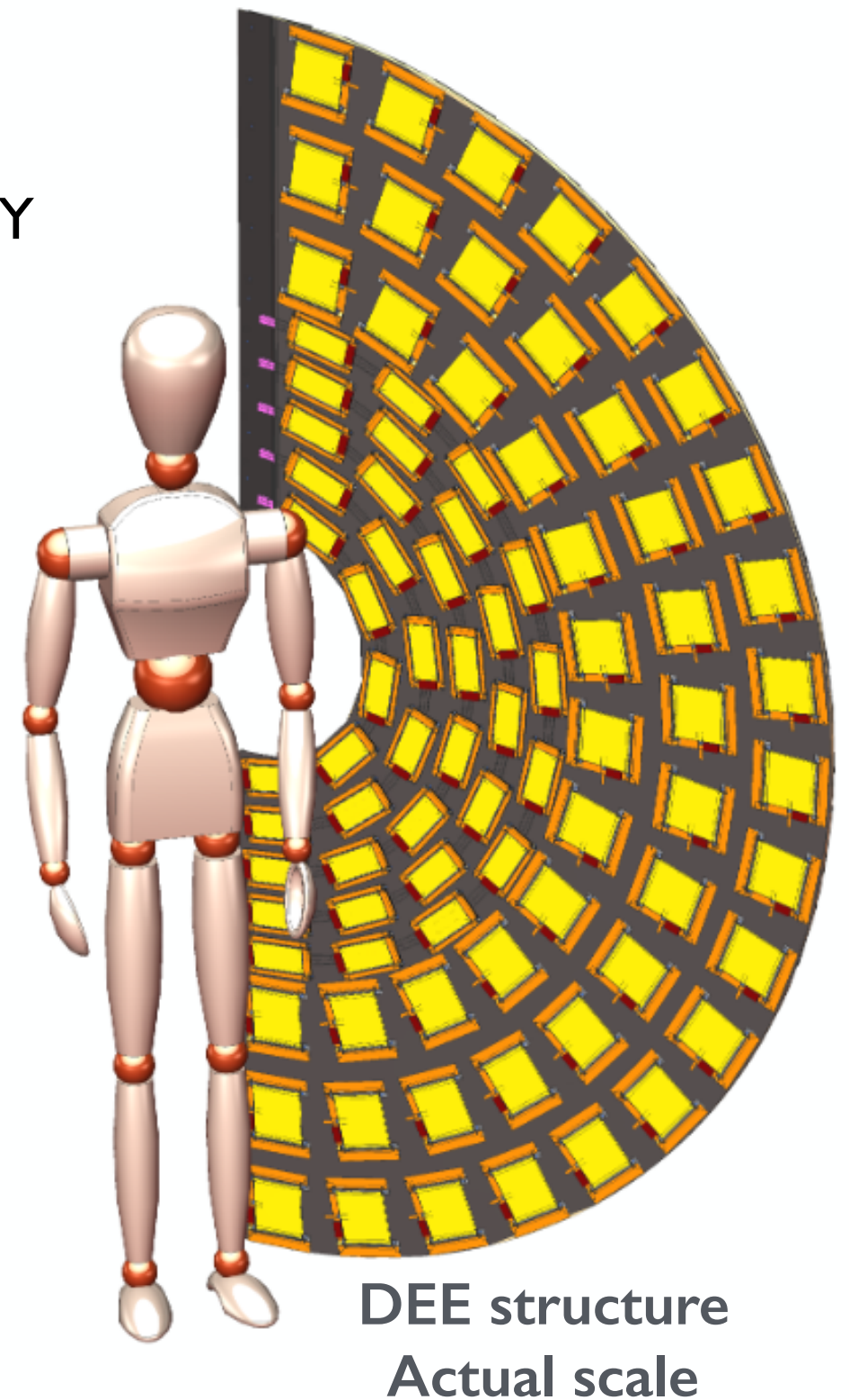
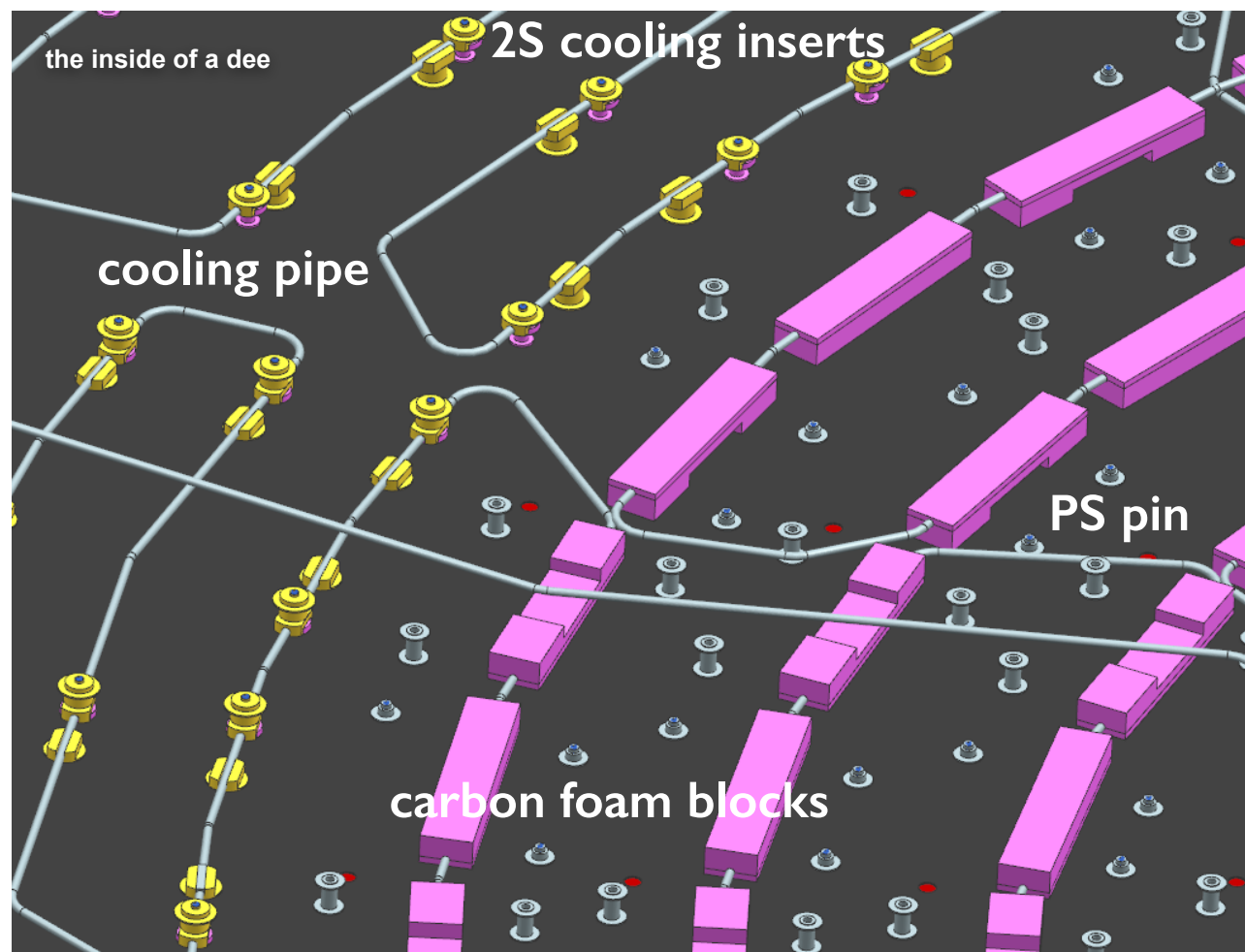


Offset calibration



# TEDD : Design and Prototyping

- ★ Concept of the disk (DEE) being finalized
- ★ A new prototype iteration is in preparation
  - small scale version ( $\sim 1:4$ ) will be produced at DESY
  - full sized version produced by industry





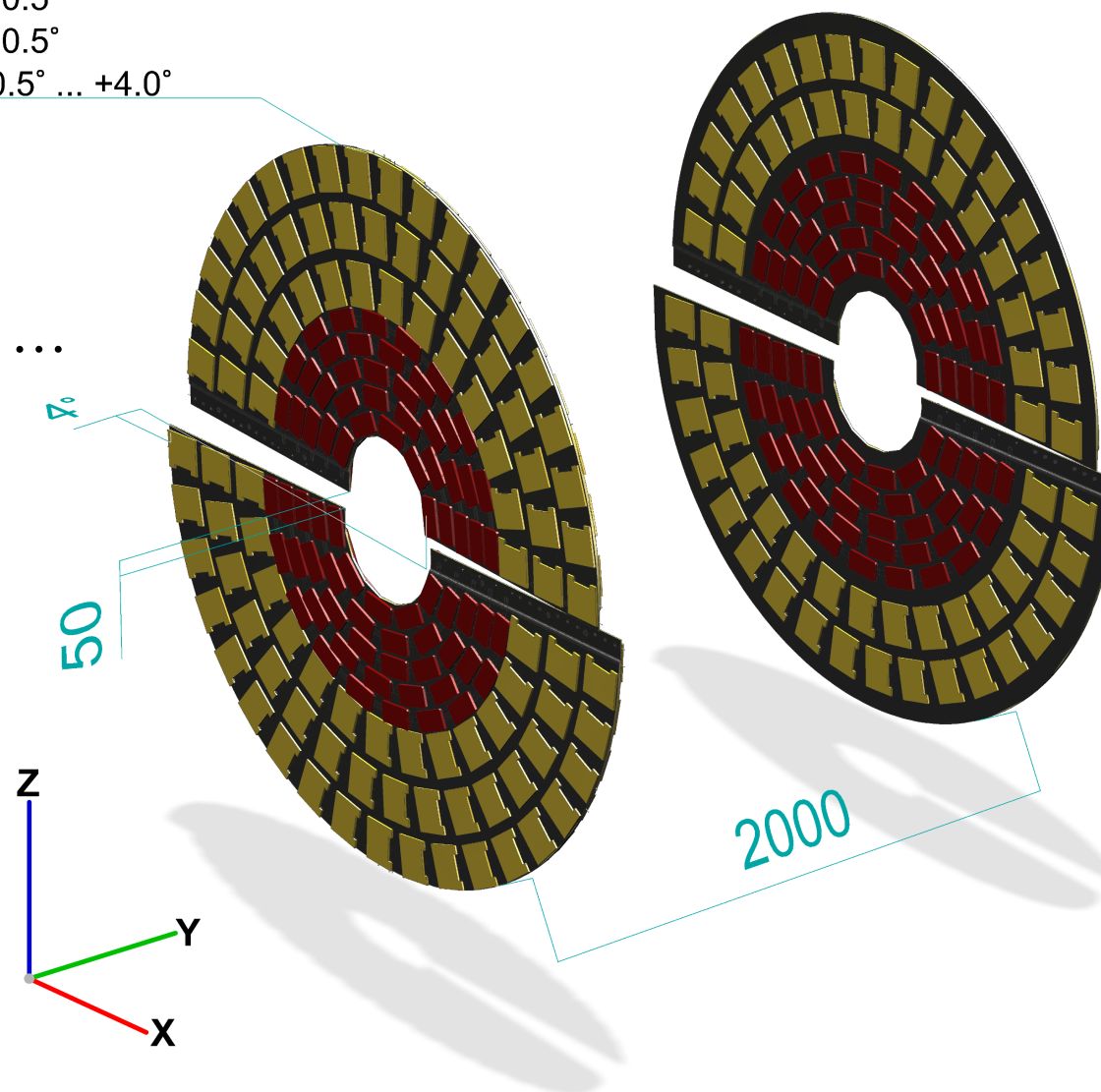
# Double-disk Assembly

- ★ Focus on integration aspects and the design of needed tooling and equipment
  - will be first tested on wooden dee dummy

$dx = \pm 10 \text{ mm}$   
 $dy = \pm 10 \text{ mm}$   
 $dz = 0 \text{ mm} \dots 150 \text{ mm}$   
 $rx = \pm 0.5^\circ$   
 $ry = \pm 0.5^\circ$   
 $rz = -0.5^\circ \dots +4.0^\circ$

2 dees  $\rightarrow$  disk  
2 disks  $\rightarrow$  double-disk  
5 double-disks  $\rightarrow$  TEDD

odd dee / disk  
modules on rings 1, 3, 5 ...



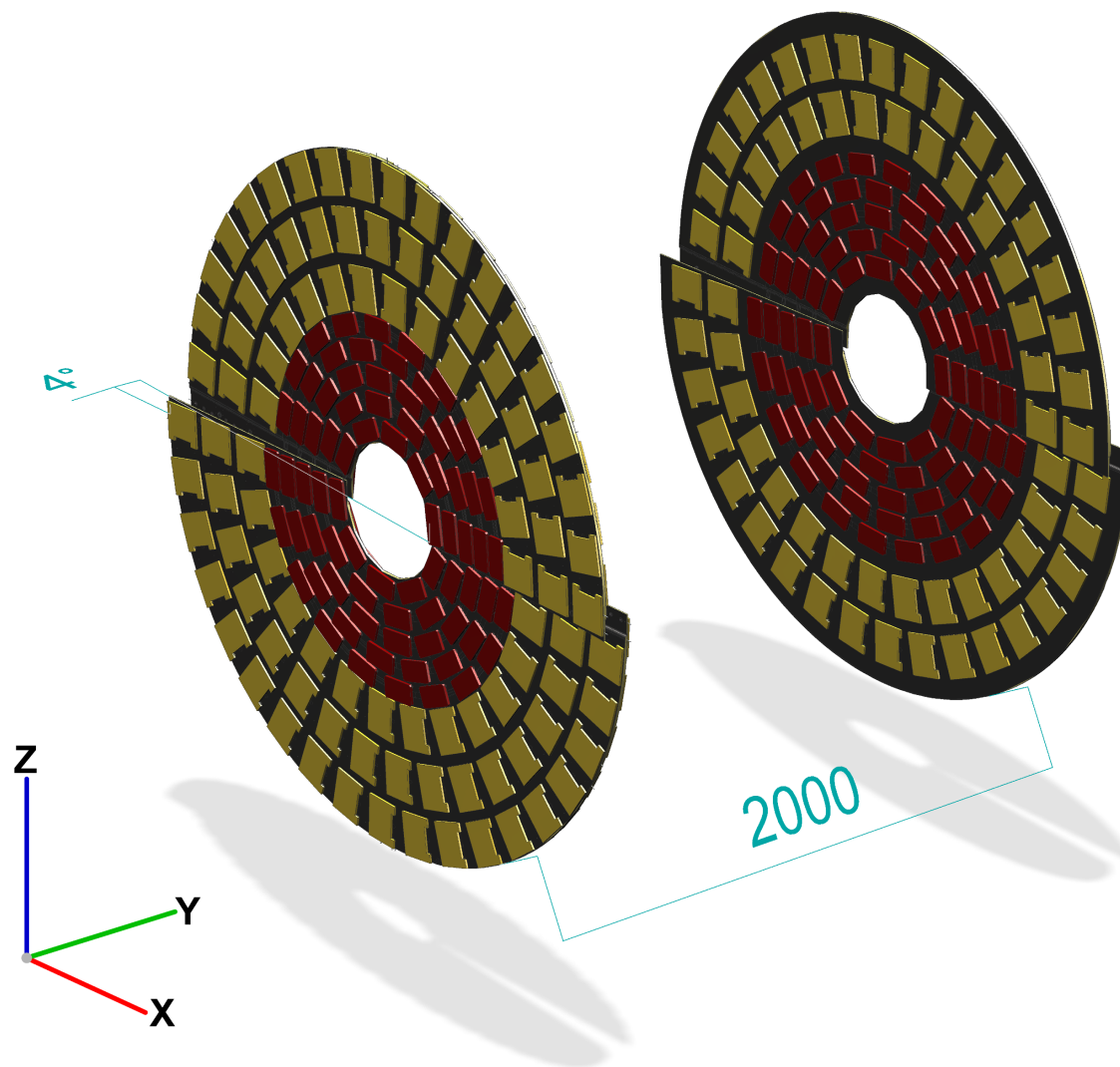
even dee / disk  
modules on rings 2, 4, 6 ...

# Double-disk Assembly

- ★ Focus on integration aspects and the design of needed tooling and equipment
  - will be first tested on wooden dee dummy

Step 1 : upper dees are lowered

2 dees → disk  
2 disks → double-disk  
5 double-disks → TEDD

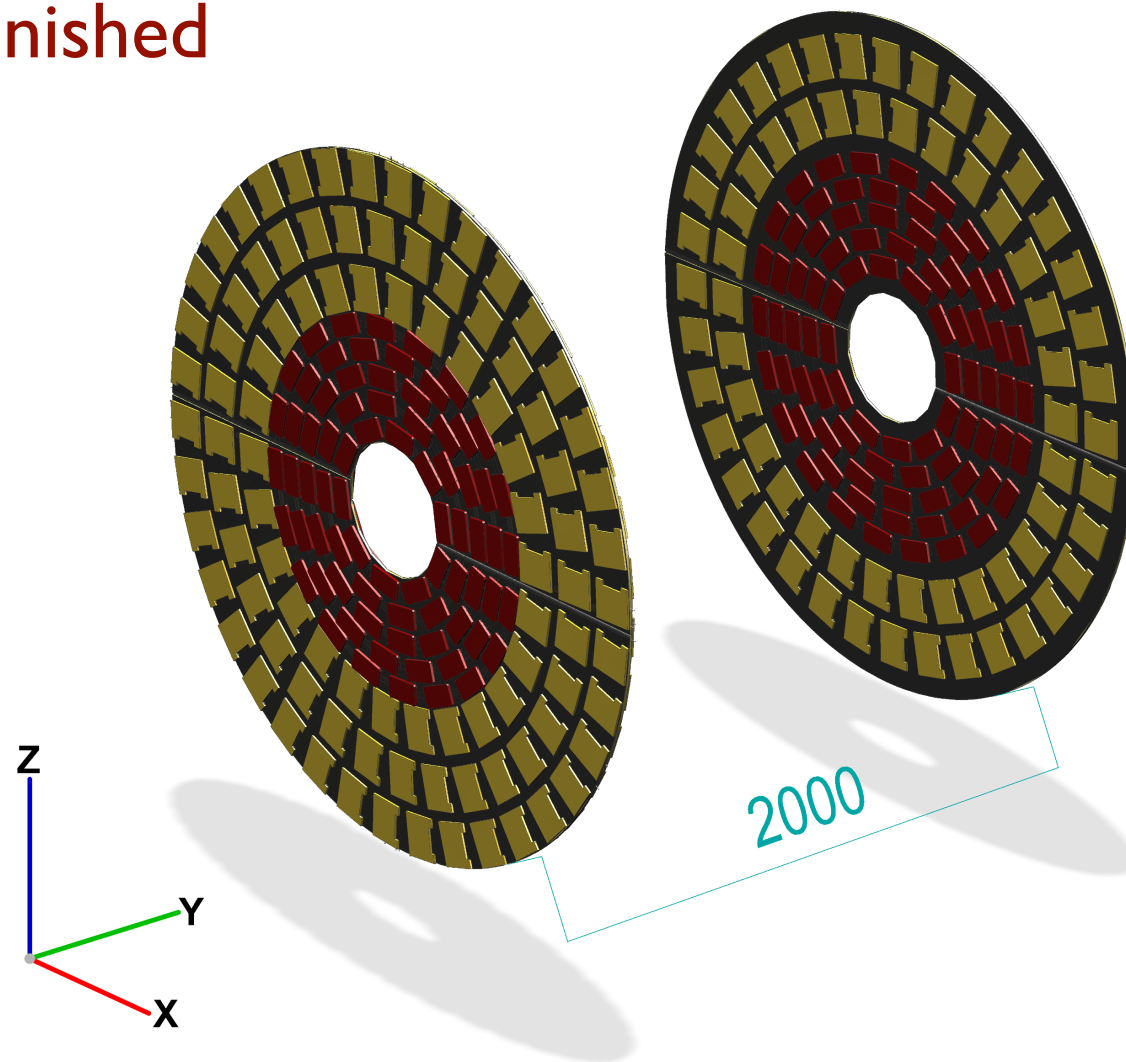


# Double-disk Assembly

- ★ Focus on integration aspects and the design of needed tooling and equipment
  - will be first tested on wooden dee dummy

Step 2 : upper dees are rotated  
⇒ disk assembly finished

2 dees → disk  
2 disks → double-disk  
5 double-disks → TEDD

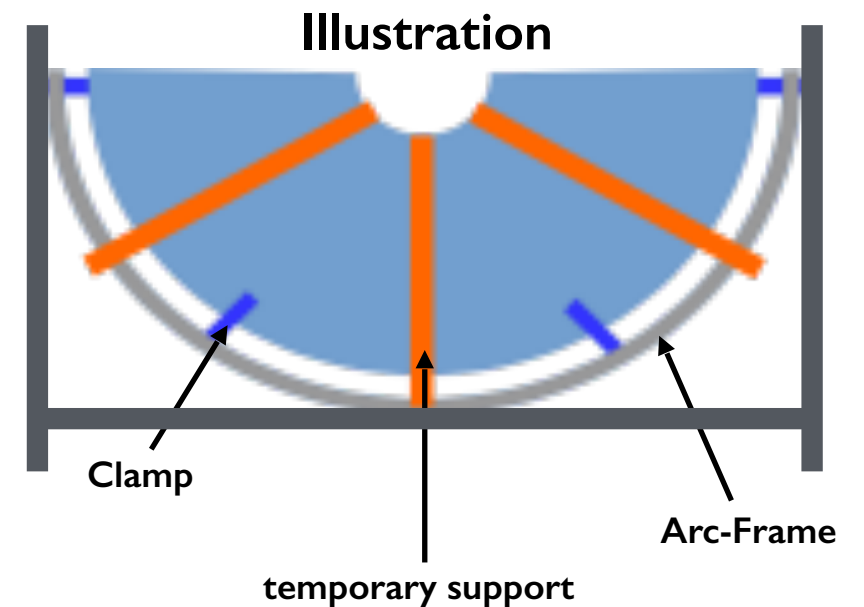
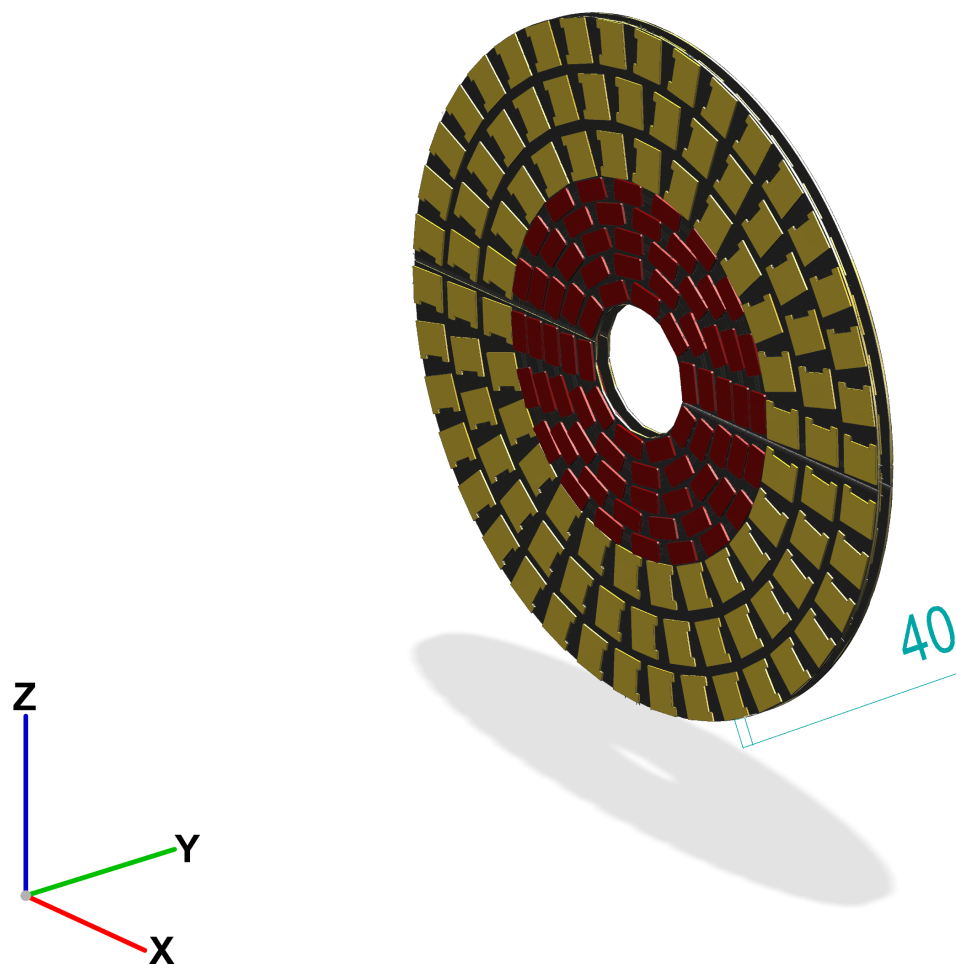


# Double-disk Assembly

- ★ Focus on integration aspects and the design of needed tooling and equipment
  - will be first tested on wooden dee dummy

Step 3 : odd and even disks are combined  
⇒ double-disk assembly finished

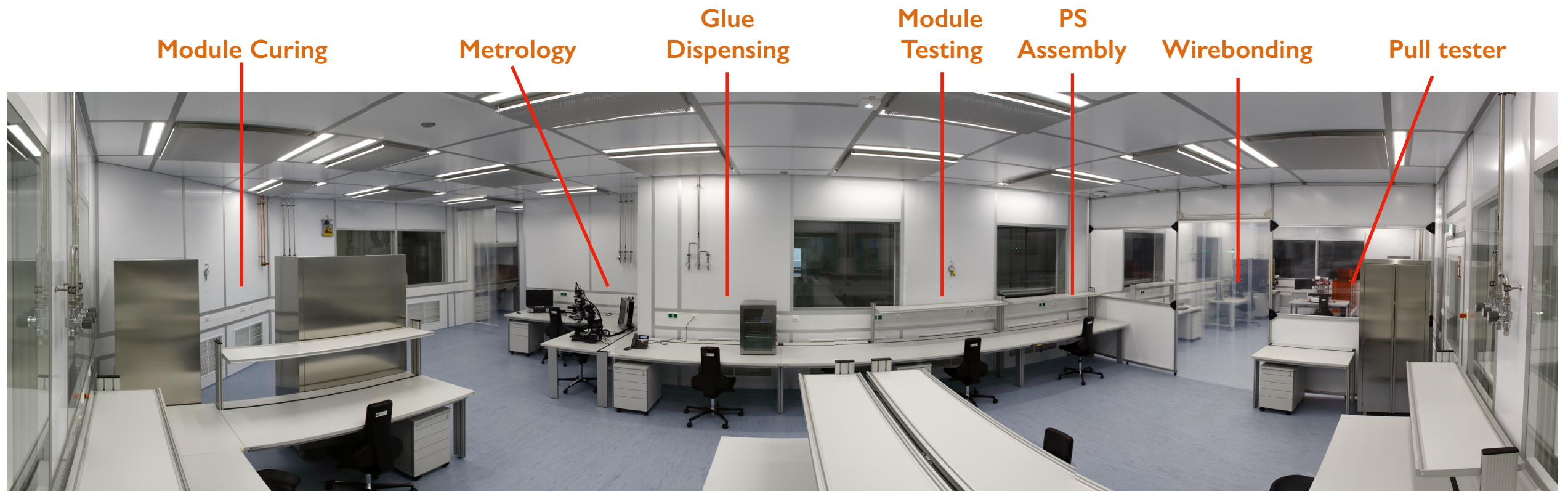
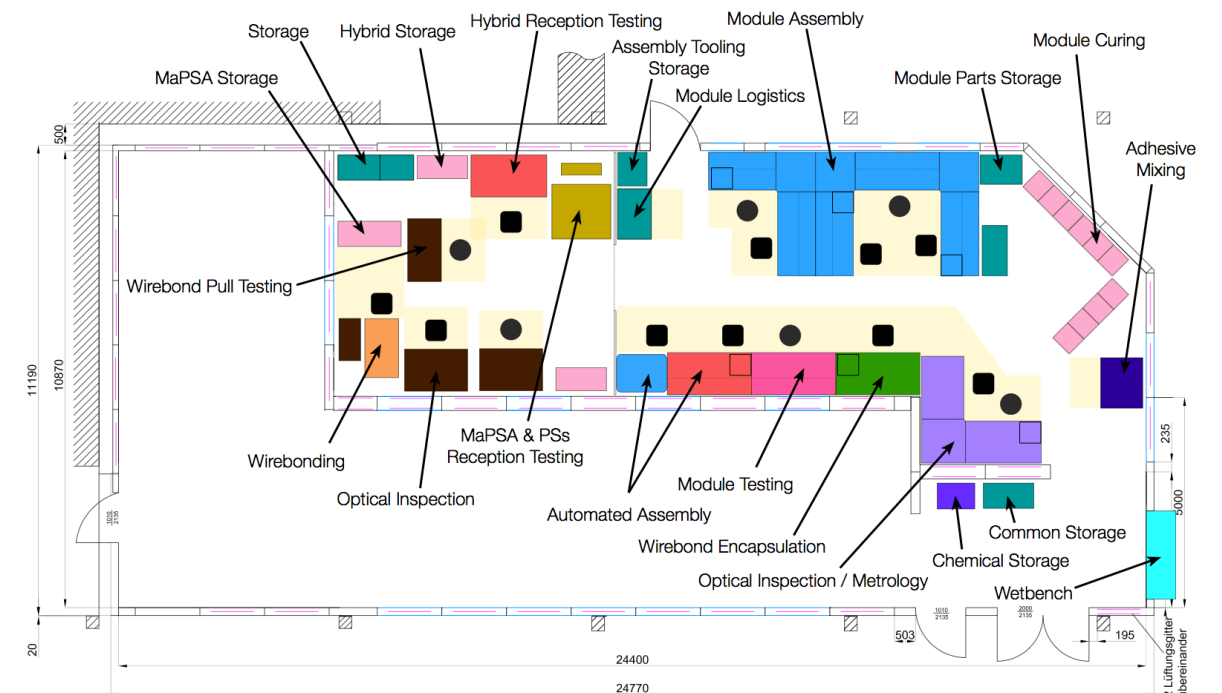
2 dees → disk  
2 disks → double-disk  
5 double-disks → TEDD



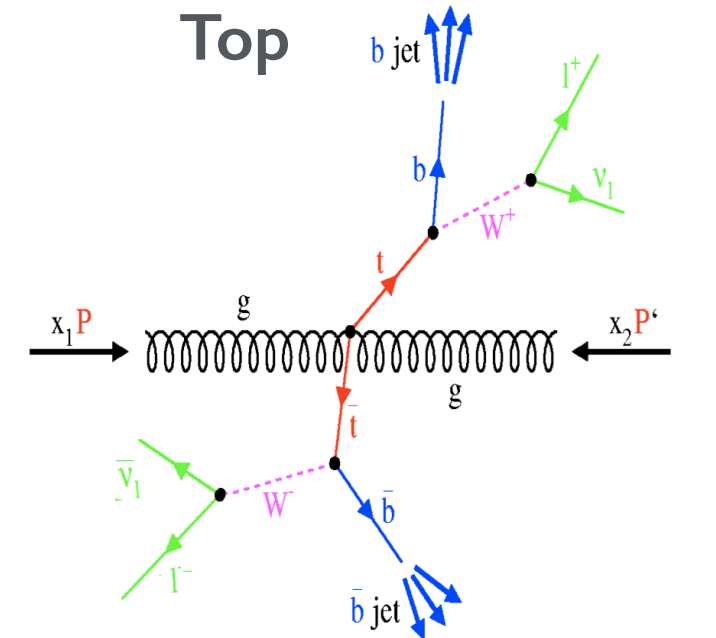
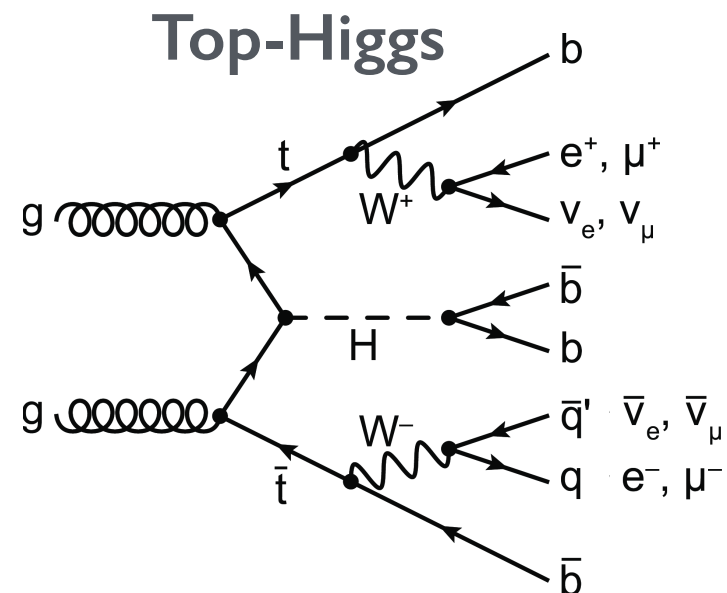
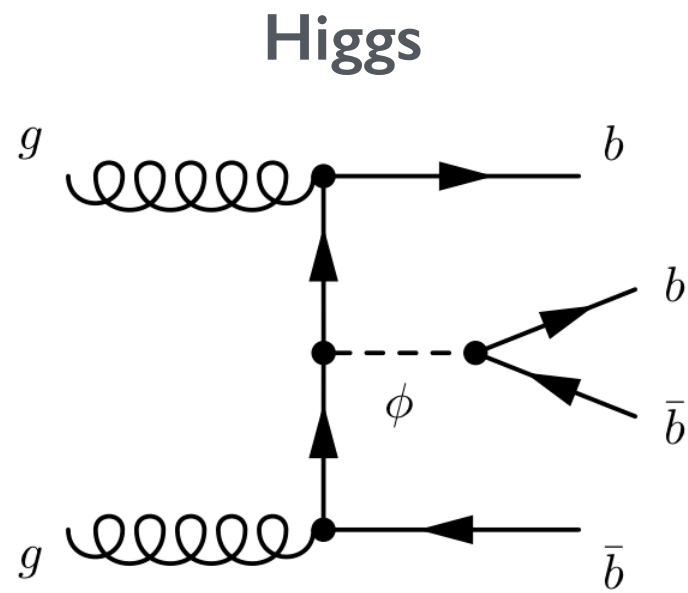


# CMS DAF Status

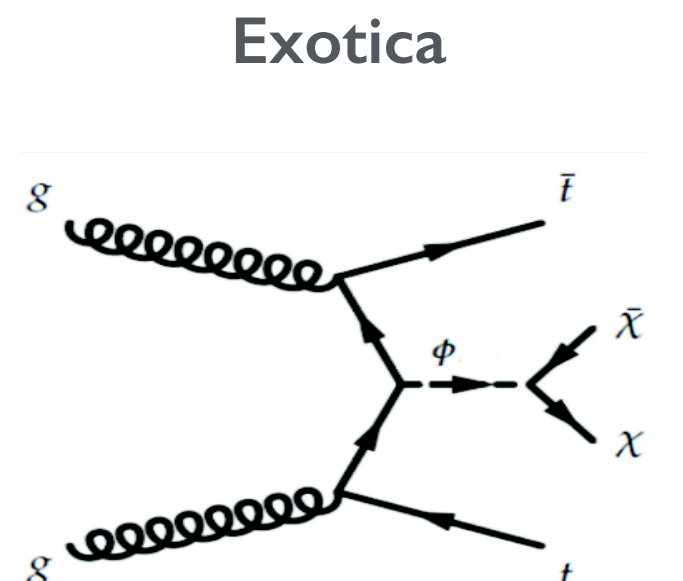
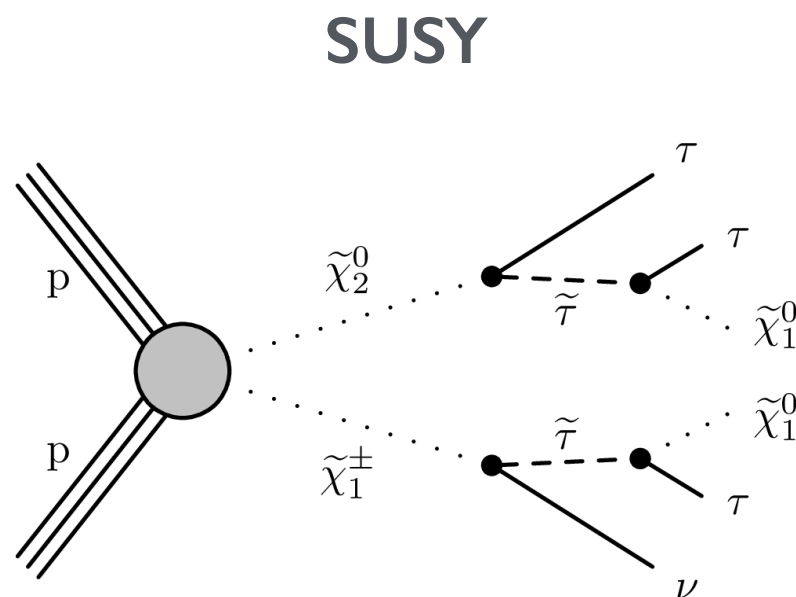
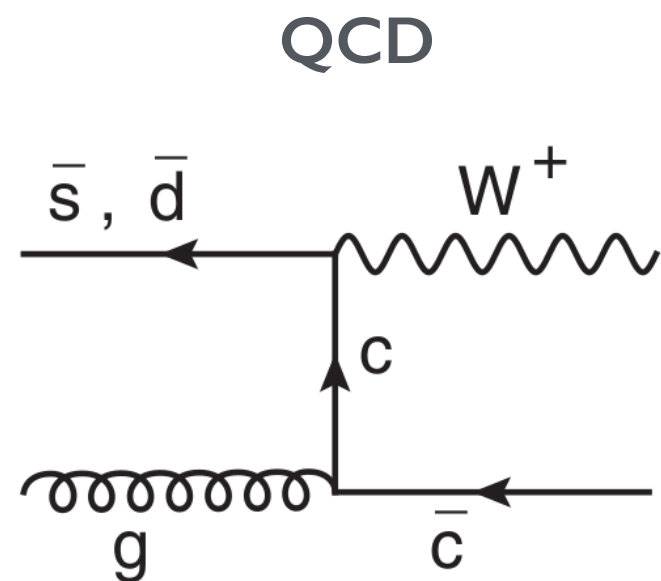
- ★ Building infrastructure is being finalized
  - dry air
  - purified water
  - etc.
- ★ In preparation of moving devices and R&D activities to the DAF
  - time scale: 2-3 months







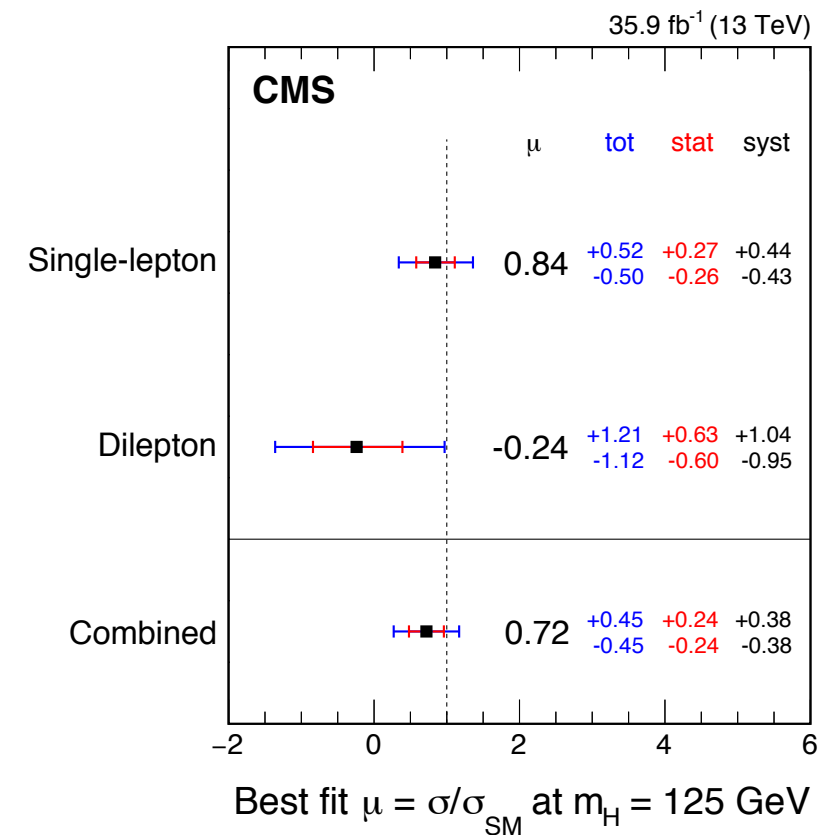
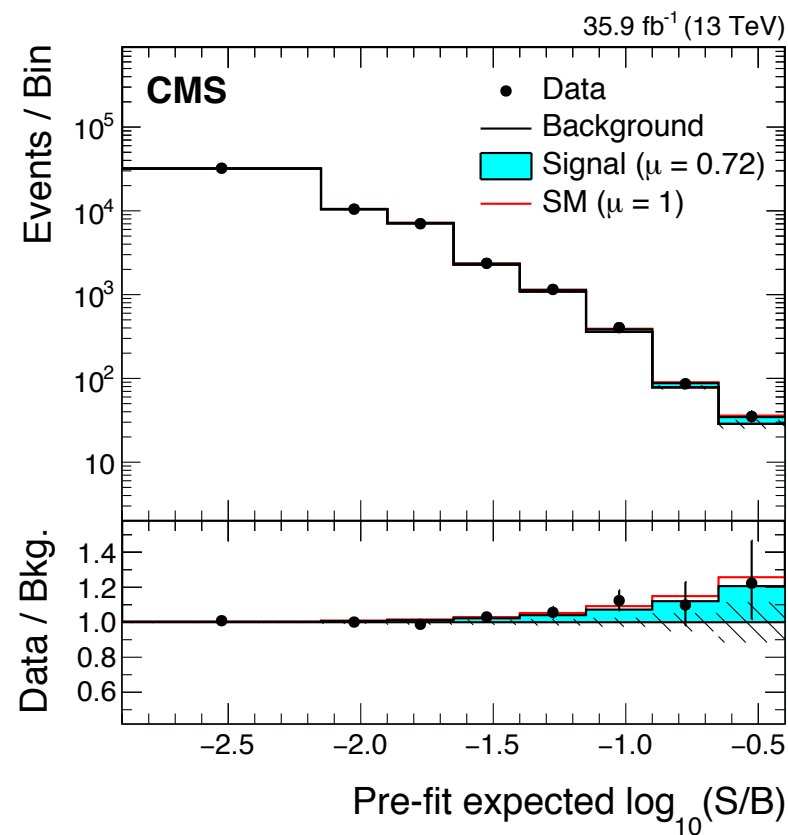
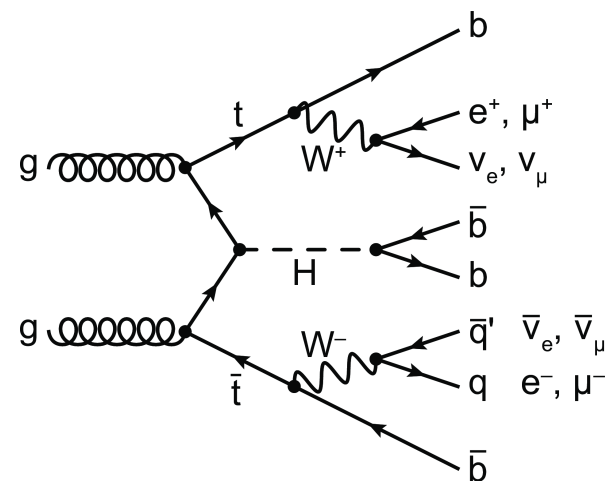
# Physics Highlights



# Top : $ttH$ $H \rightarrow bb$

- ★ Direct probe of the top-Higgs Yukawa couplings
  - gain from largest  $\text{BR}(H \rightarrow bb)$
- ★ DESY is a key contributor in dileptonic top decay channel
  - developed BDT analysis technique to further improve sensitivity in Run 2
- ★ Paper submitted to JHEP

$$\text{signal strength } \mu = \sigma \cdot \text{BR} / \sigma_{\text{SM}} \cdot \text{BR}_{\text{SM}}$$

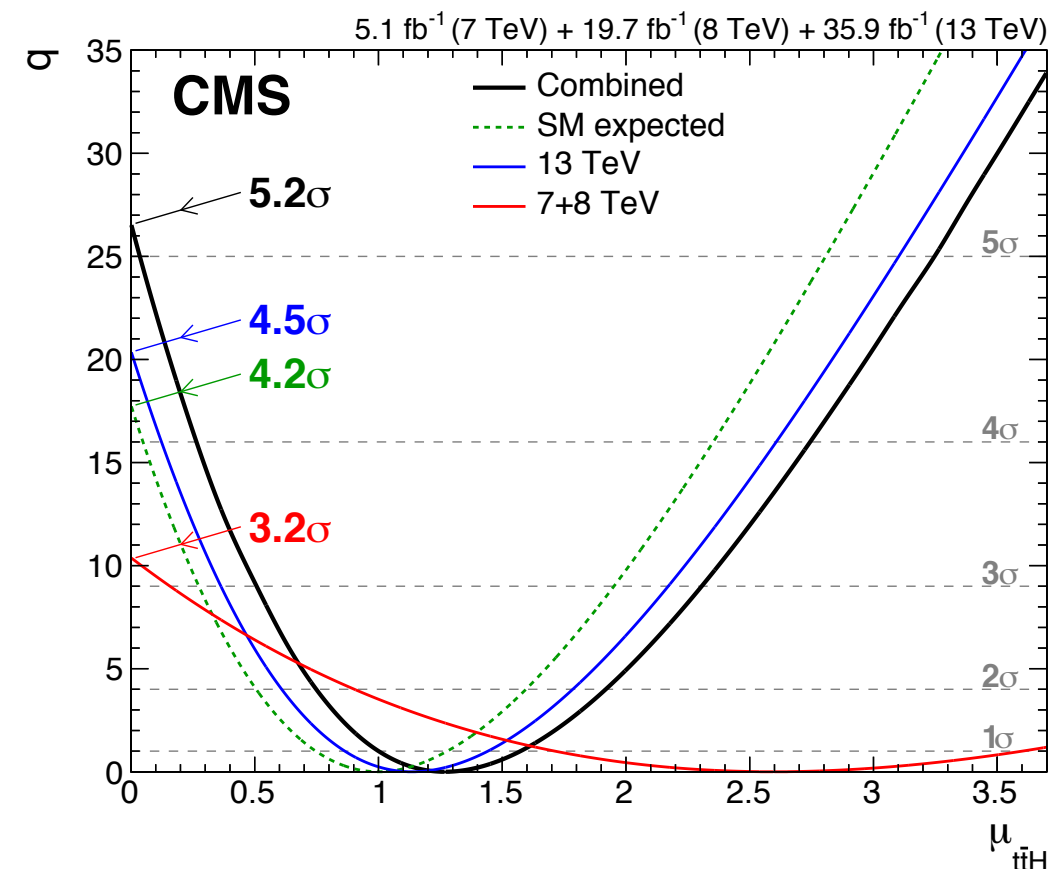
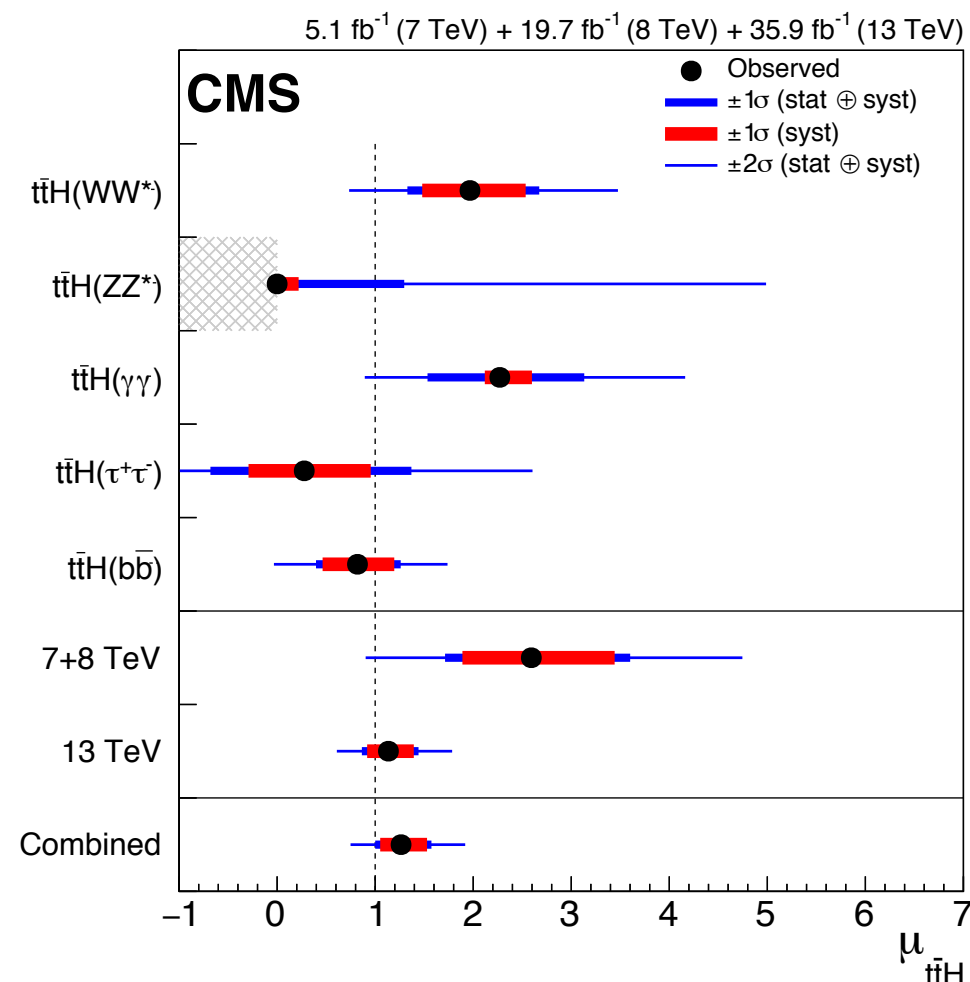


**Best fit:  $\mu = 0.72 \pm 0.45$ , at 1.6 (2.2) $\sigma$  obs. (exp.) significance**

# Observation of $t\bar{t}H$ production

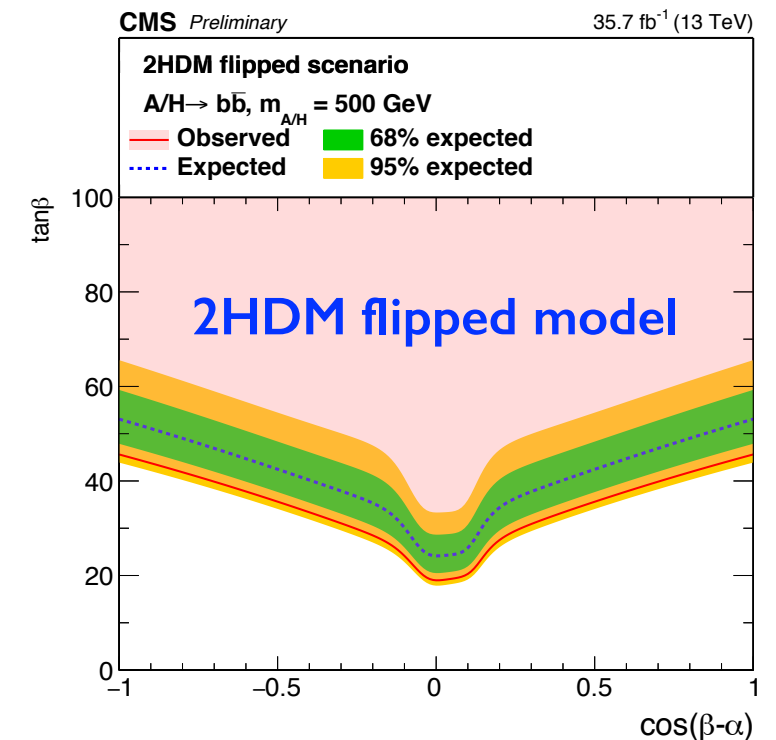
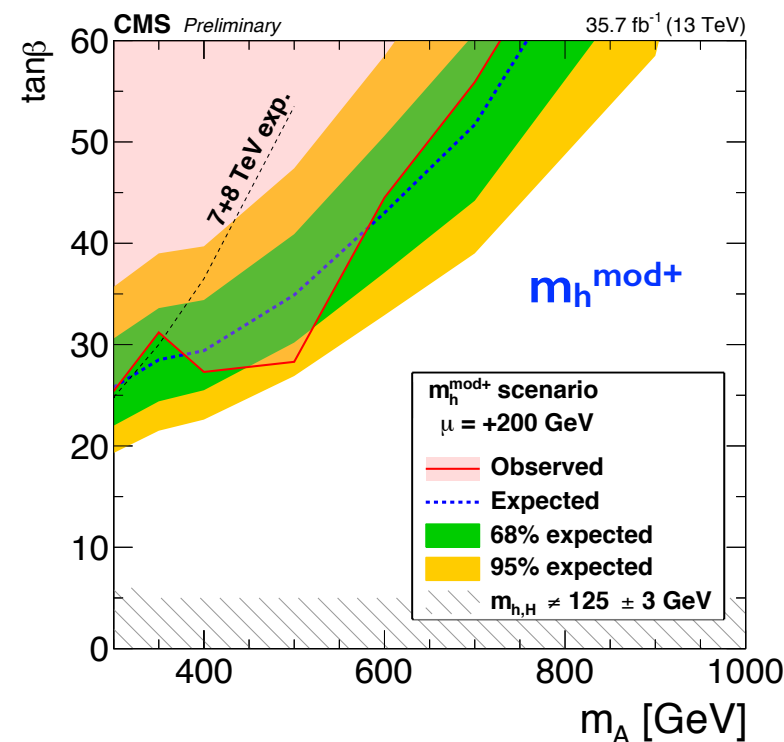
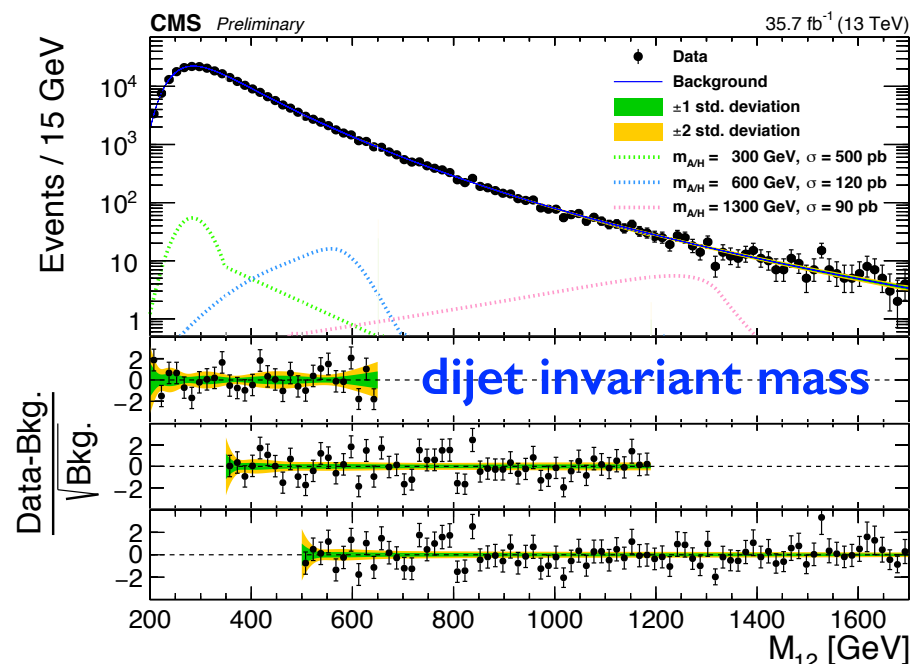
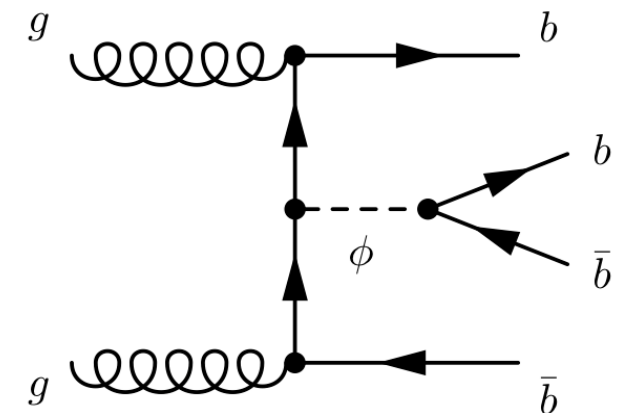
- ★ First observation of the  $t\bar{t}H$  production process!
  - combination of 7, 8 and 13 TeV results from 5 decay channels
- ★ **Observed significance  $5.2\sigma$  ( $4.2\sigma$  exp.)** with respect to the  $\mu_{t\bar{t}H} = 0$  hypothesis
  - measured production rate consistent with SM prediction within  $\pm 1\sigma$
- ★ Paper submitted to PRL

**Best fit**  $\mu_{t\bar{t}H} = 1.26^{+0.31}_{-0.26}$



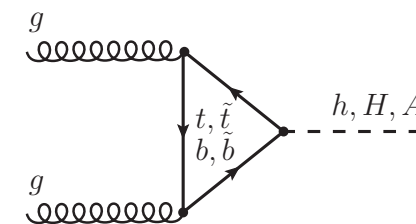
# Higgs : $b\bar{b}A/H \rightarrow b\bar{b}$

- ★ Search for heavy neutral Higgs bosons in the bottom quarks final state
- ★ CMS analysis is unique at the LHC
- ★ DESY group plays a leading role in this analysis
- ★ Preliminary results at 13 TeV based on  $35.7 \text{ fb}^{-1}$  of 2016 data
  - improved sensitivity and extended mass region searches
  - exclusions in MSSM and 2HDM parameter spaces
- ★ Paper ready for final reading → will submit to JHEP

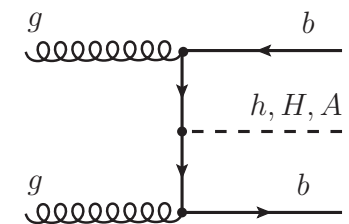


# Higgs : MSSM $\Phi \rightarrow \tau\tau$

- ★ Search for additional neutral Higgs bosons in the ditau final state
  - ⦿ focus on Minimal Supersymmetric Standard Model (MSSM)
- ★ 4 most sensitive channels :  $e\mu$ ,  $e\tau_h$ ,  $\mu\tau_h$ ,  $\tau_h\tau_h$  ( $\tau_h$  = hadronic tau)
- ★ Targeted production modes :
  - ⦿ full analysis in the  $e\mu$  channel

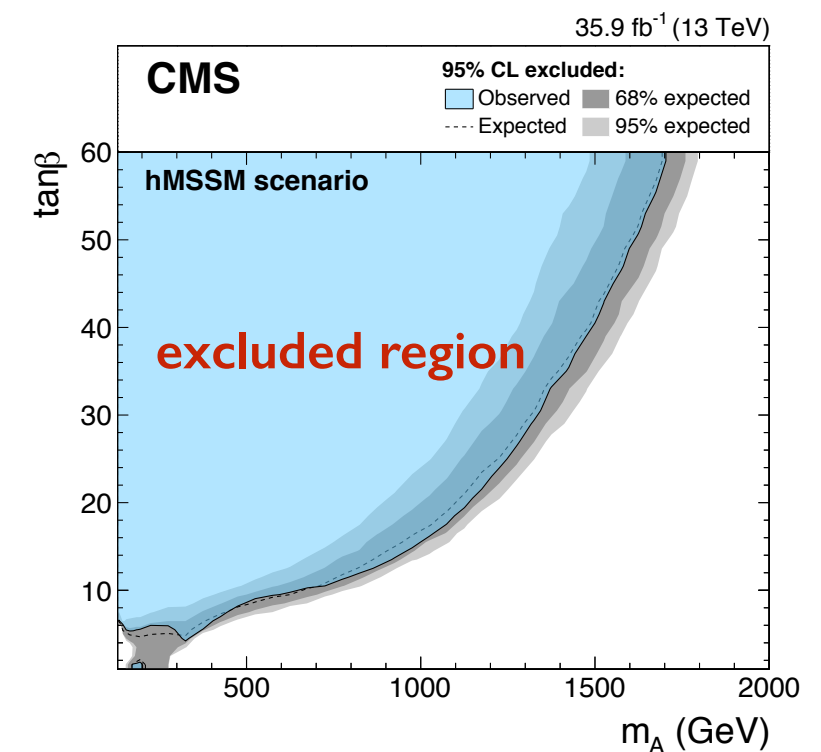
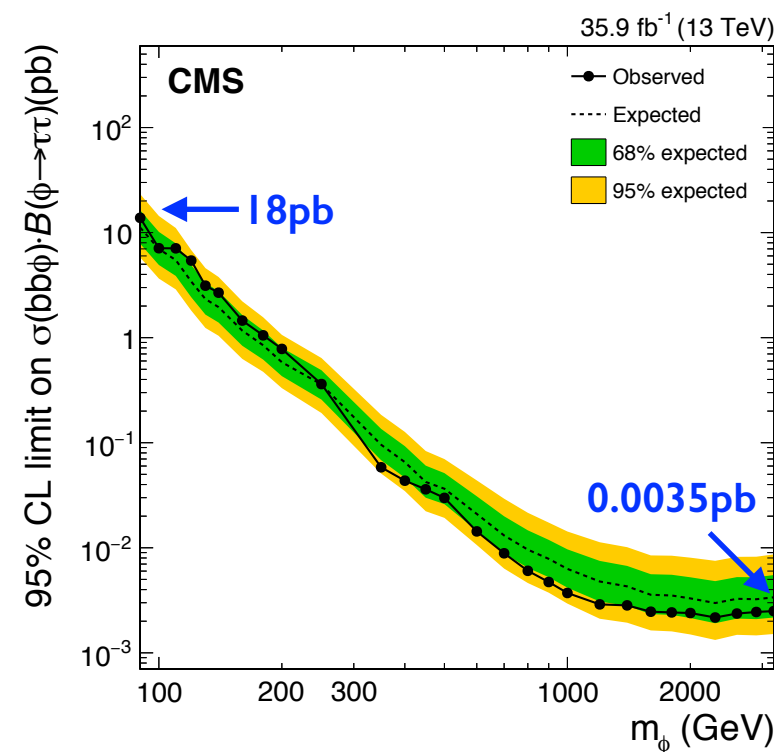


gluon fusion



b association

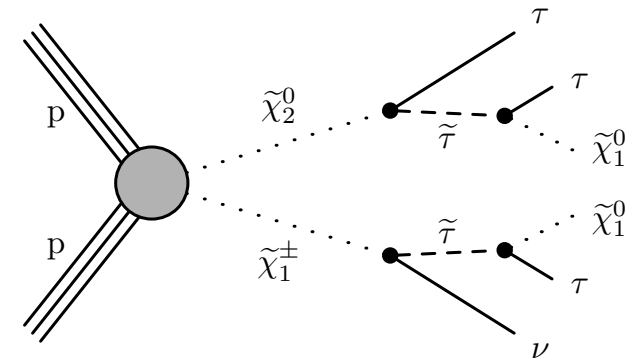
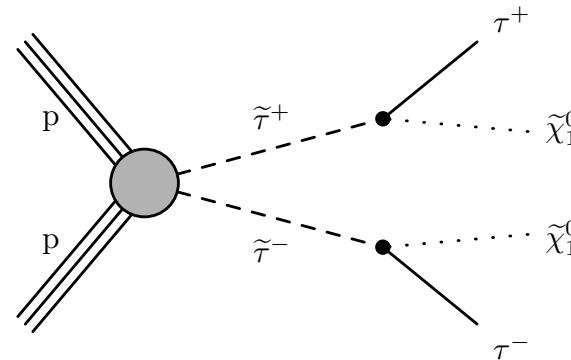
- ★ Paper submitted to JHEP



# Supersymmetry Searches

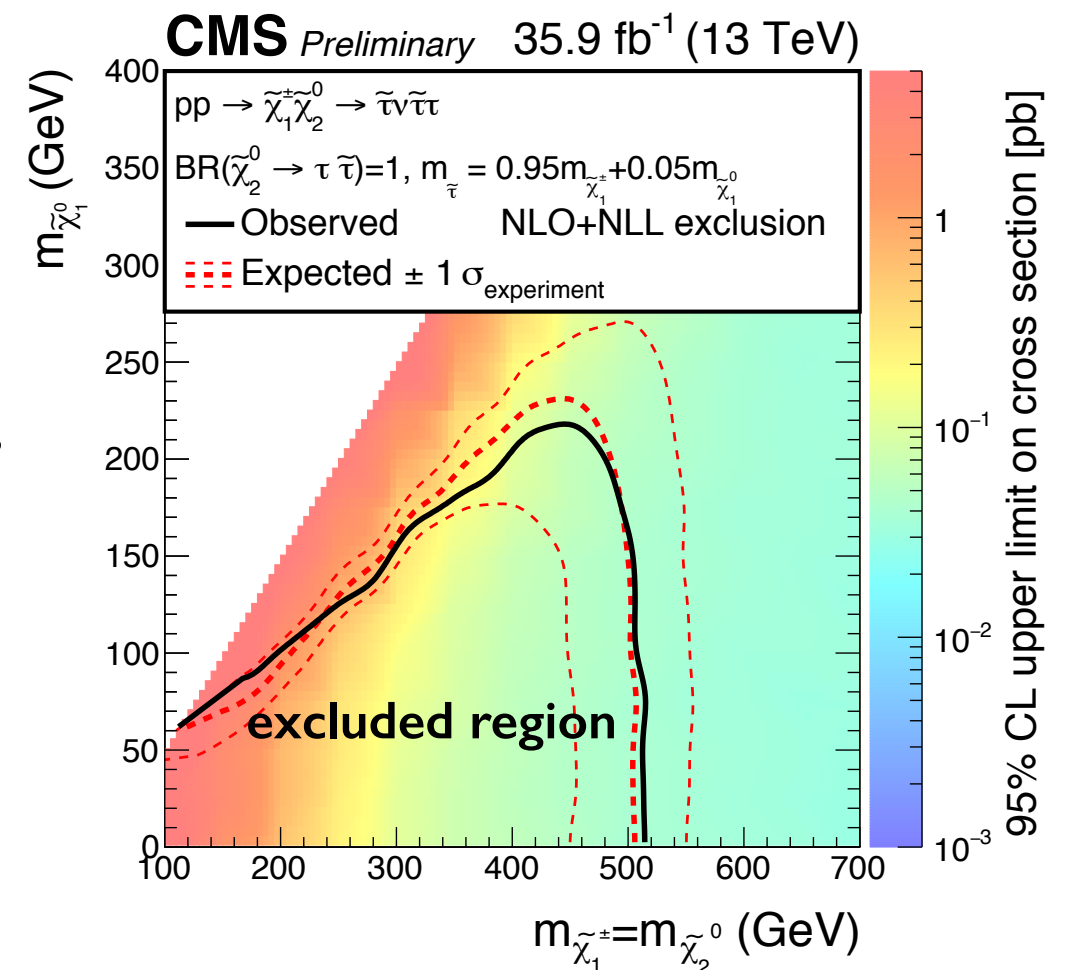
- ★ Search for supersymmetry in events with tau leptons and missing transverse momentum ( $p_T^{\text{miss}}$ )

direct stau production



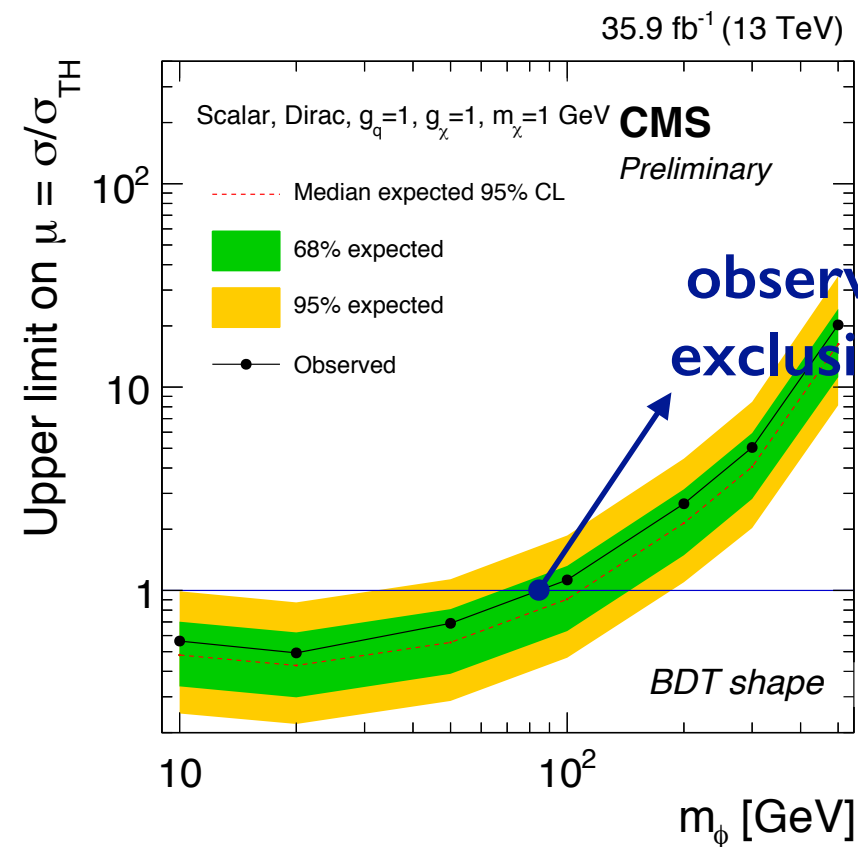
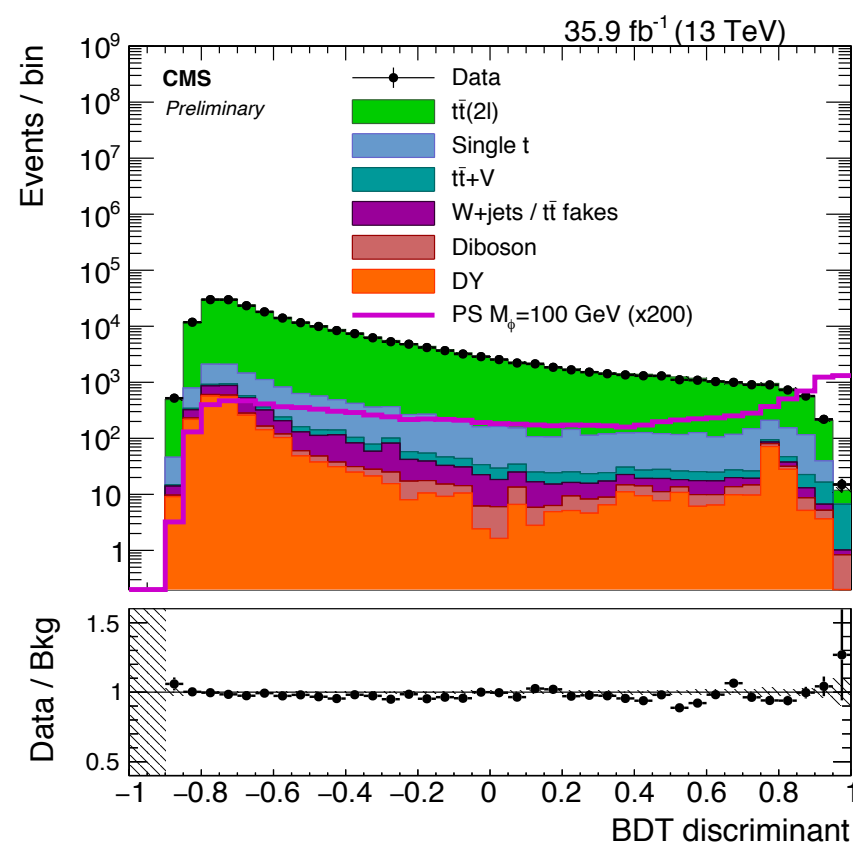
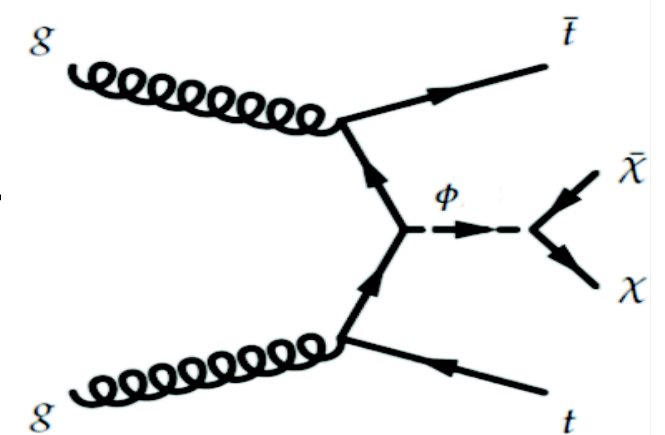
chargino-neutralino production

- ★ Events contain at least one lepton (e,  $\mu$ ) from leptonic decaying tau lepton
- ★ 95% CL observed exclusion on chargino and neutralino masses in different stau mass scenarios
- ★ Paper will combine with fully hadronic channel and submit to JHEP (CMS SUS-17-003)



# Exotica : Search for $t\bar{t} + \text{DM}$

- ★ A promising channel to search for WIMP DM with scalar mediators at LHC
- ★ DESY group performed search in dileptonic final state using BDT
  - combined missing transverse momentum with novel observables sensitive to  $t\bar{t}$  spin configuration
  - best sensitivity in dileptonic channel i.e. 30% improvement over classical strategy

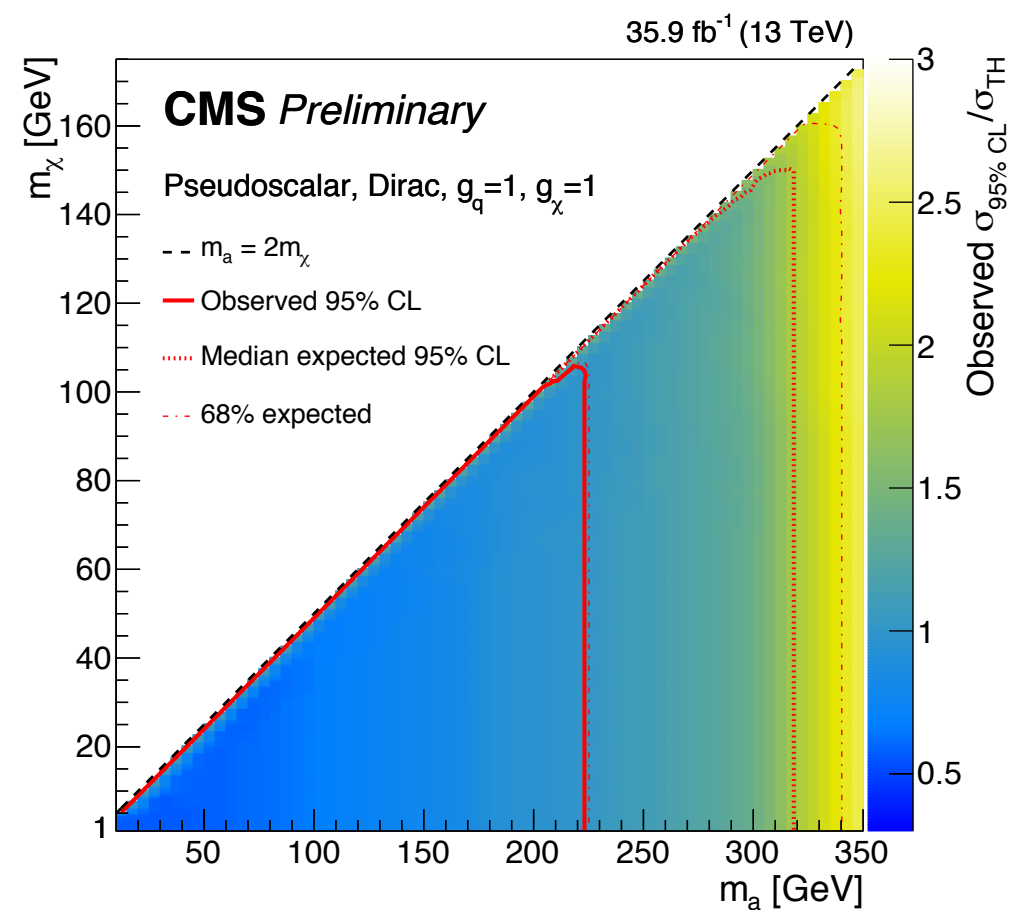
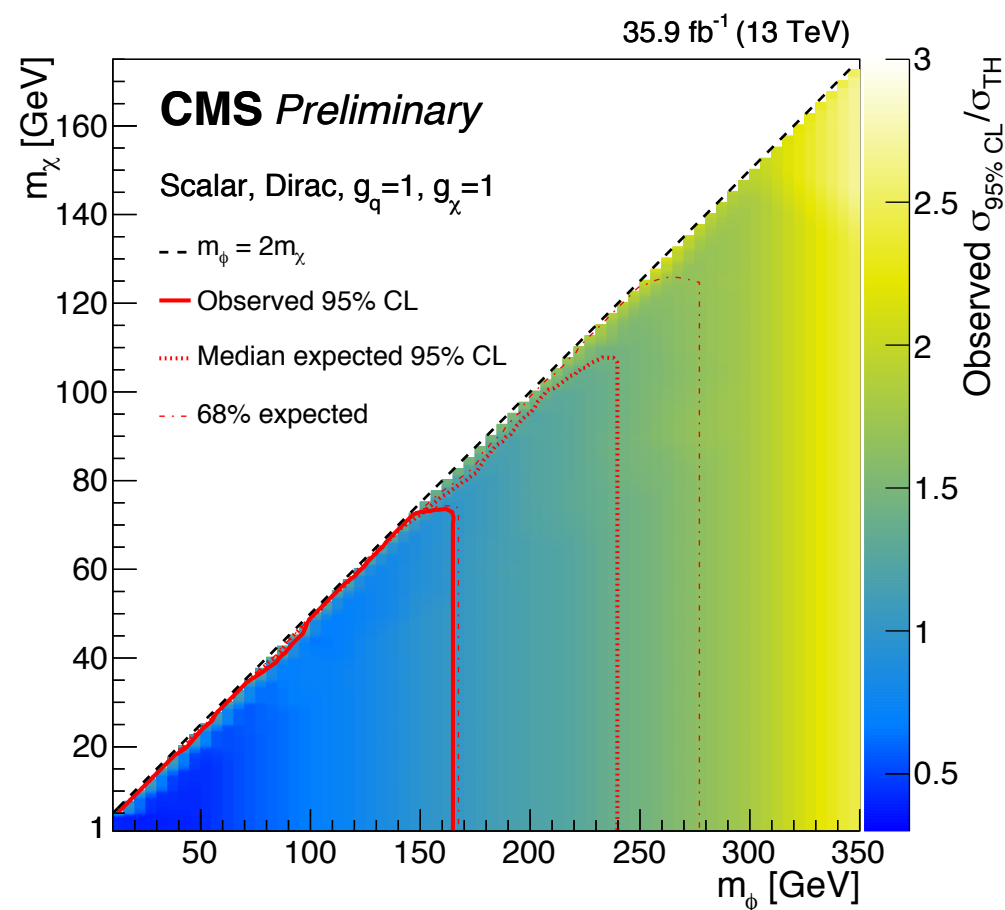




# Exotica : Search for $t\bar{t} + \text{DM}$

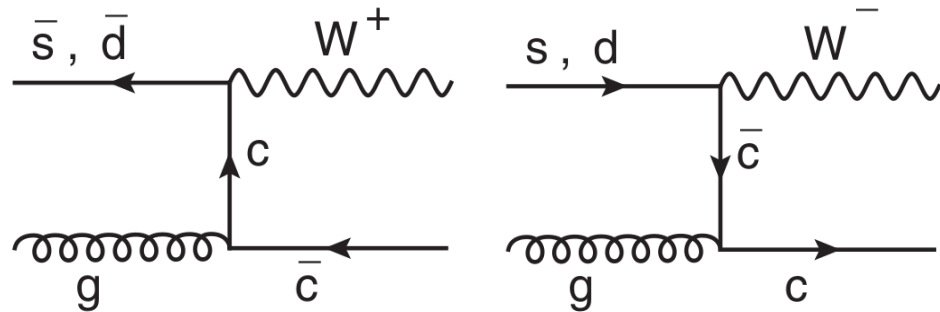
- ★ First combination of all possible top quark pairs final states
  - dileptonic, semileptonic and fully hadronic decay of top-quark
- ★ The most stringent limits for the case of CP-even scalar DM mediators from LHC
- ★ Paper to be submitted to PRL soon

95% CL exclusions of (pseudo)scalar scenarios with mediator masses up to (223)165 GeV



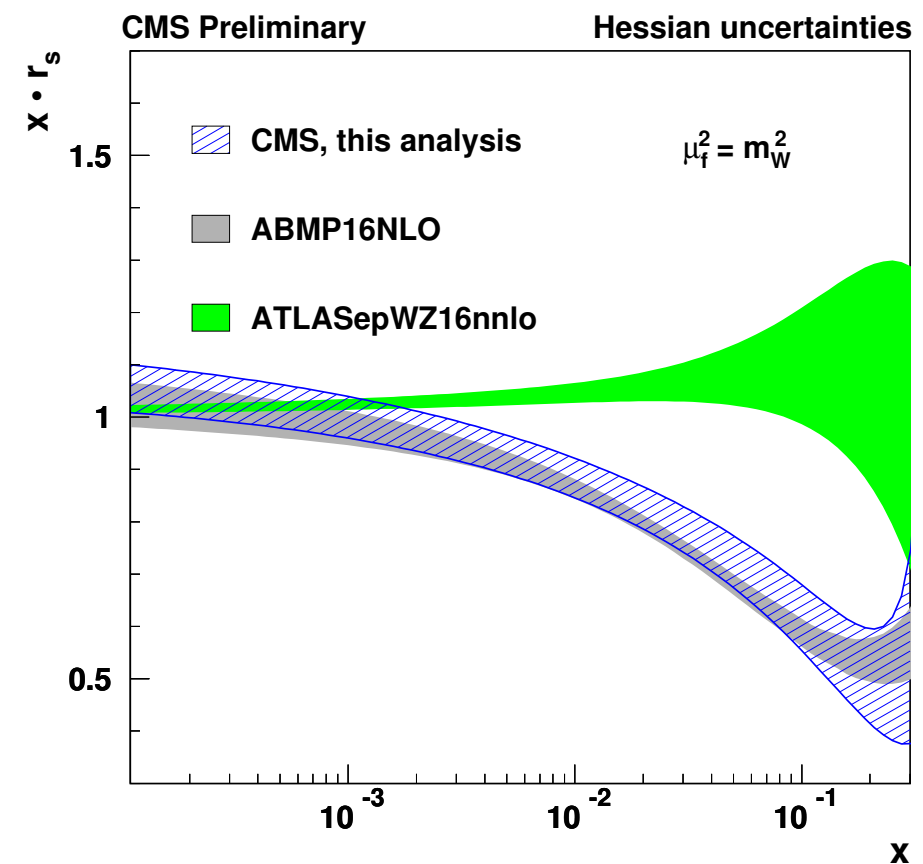
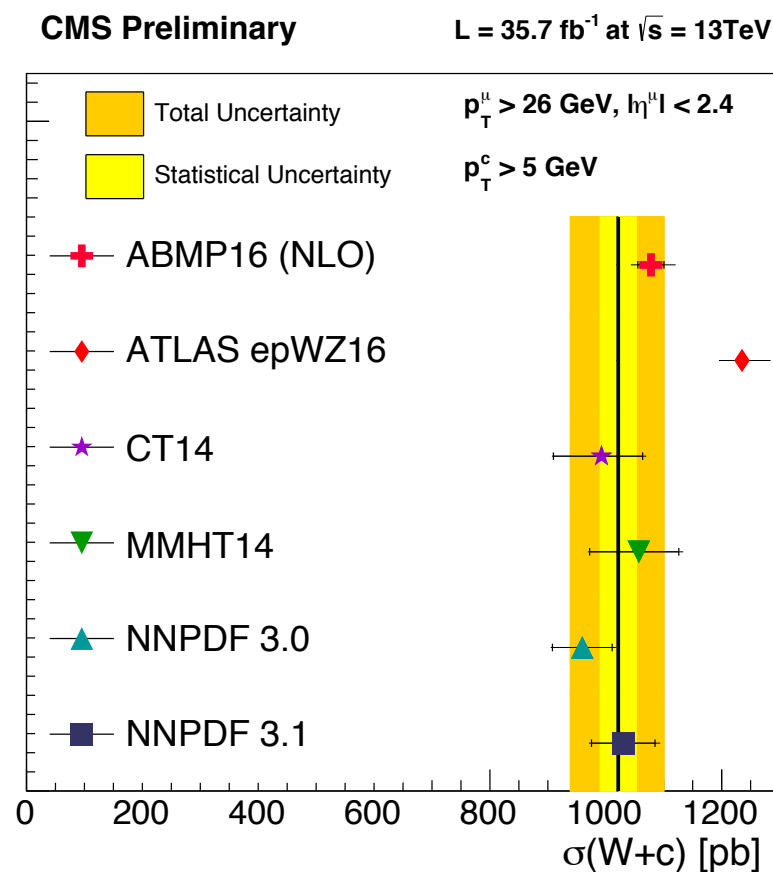


# QCD : Proton Structure



- ★ Measurement of  $W+c$  production at 13 TeV
- ★ Direct probe of strange quark content in proton
- ★ No enhancement observed
- ★ Paper will be submitted to EPJC

$$\sigma(W+c) = 1026 \pm 31 \text{ (stat)} \pm_{72}^{76} \text{ (syst) pb}$$



**Results are in good agreement with findings of  $\nu$ -scattering experiments**

# Summary

- ★ Final year of LHC Run 2 and proton-proton collisions just started
- ★ CMS started taking data (recorded  $1.5 \text{ fb}^{-1}$ )
  - ◉ BCM1F detector continues to deliver robust and accurate online luminosity
  - ◉ excellent performance on Tracker Alignment
- ★ CMS Phase II Tracker detector upgrade project at DESY well on track
  - ◉ R&D progressing towards production readiness
- ★ DESY CMS group strongly contribute to wide range of Physics Analysis in CMS
  - ◉ key contributors and coordinators in Top, Higgs, QCD and SUSY/Exotica groups
  - ◉ leading role in observation of  $H \rightarrow \tau\tau$  decay and the  $t\bar{t}H$  production
- ★ 7 physics publications + 2 detector papers since last PRC and more to come

# Backup

# DESY Coordinating Roles in CMS

## ★ Management

- Collaboration Board Chair
- Head of Engagement Office (L1)

## ★ Committees

- Management Board (2 + chair)
- Finance Board (3)
- Statistics Committee (chair)
- Open data and preservation (co-chair)
- Theorist Committee (chair)
- Conference Committee
- School Committee Publication Committee (5)

## ★ Tracker

- Management/Finance Board (+ Phase 2)
- Tracker Pub. Comm. Member
- Strip-Tracker Module-Design group convener
- SiPM-on-Tile convener (L2)

## ★ Beam Radiation Instrumentation & Luminosity (BRIL)

- Institutional Board (chair)
- BRIL DPG convener (L2)
- BCMIF DPG convener (L3)
- BCMIF technical coordinator (L3)

## ★ Physics analysis

- Top physics group convener (L2)
- Top mass group convener (L3)
- Top properties group convener (L3)
- Top, Higgs PubComm member
- B-tagging triggers convener (L3)
- Higgs to bb group convener (L3)
- MC validation & integration convener (L3)
- Matrix element and future generators convener (L3)
- SMP-jets convener (L3)
- SMP Combination Group convener (L3)
- Top-Higgs forum contact
- EFT contact in LHC top working group
- Differential cross sections in LHC top working group contact
- Key contacts in trigger, object, performance, MC, and statistical methods

## ★ Computing, Operation

- Operation (L2)
- Web-based monitoring (L2)
- AICaDB Software Coordinator (L3)

## ★ HL-LHC physics workshop, perspectives at HE-LHC

- Steering committee contact for CMS

# Publications since last PRC

- ★ Measurement of the inclusive  $t\bar{t}$  cross section in pp collisions at  $\sqrt{s} = 5.02$  TeV using final states with at least one charged lepton (*JHEP 03 (2018) 115*)
- ★ Search for supersymmetry in events with one lepton and multiple jets exploiting the angular correlation between the lepton and the missing transverse momentum in proton-proton collisions at  $\sqrt{s} = 13$  TeV (*PLB 780 (2018) 384*)
- ★ Search for vector-like light-flavor quark partners in proton-proton collisions at  $\sqrt{s} = 13$  TeV (*PRD 97 (2018) 072008*)
- ★ Search for  $t\bar{t}H$  production in the  $H \rightarrow b\bar{b}$  decay channel with leptonic  $t\bar{t}$  decays in proton-proton collisions at  $\sqrt{s} = 13$  TeV (*arXiv:1804.03682*)

# Publications since last PRC

- ★ Observation of  $t\bar{t}H$  production (*arXiv:1804.02610*)
- ★ Search for additional neutral MSSM Higgs bosons in the  $\tau\tau$  final state in proton-proton collisions at  $\sqrt{s} = 13$  TeV (*arXiv:1803.06553*)
- ★ Measurement of the  $Z/\gamma^* \rightarrow \tau\tau$  cross section in pp collisions at  $\sqrt{s} = 13$  TeV and validation of  $\tau$  lepton analysis techniques (*arXiv:1801.03535*)