# CMS highlights at DESY

Teresa Lenz on behalf of the DESY CMS group



HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

88th Meeting of the DESY Physics Review Committee

Open session, November 12th, 2019

# Group activities:

- **Detector/Operations/Computing:**
  - Phase-2 outer tracker upgrade
  - Beam condition monitoring with BCM1F
  - Detector R&D (ELAD, Electron-CT)
  - High Granularity Calorimeter HGCAL (contribution of the DESY-FLC group)
  - Luminosity measurements
  - Tracker alignment
  - MC simulations
- **Data analysis:**
  - QCD: PDFs, SM measurements
  - Top: top mass, tt cross sections, ttH, spin correlations
  - Higgs with $\tau$-leptons and b-quarks: SM+BSM
  - Exotica: anomalous couplings, Dark matter, Dark Higgs, Heavy Higgs
  - SUSY with $\tau$-leptons, with a lepton and b-tags, with disappearing tracks

  \+ many different POG activites

# Group activities: - Highlights -

- **Detector/Operations/Computing:**
  - Phase-2 outer tracker upgrade
  - Tracker alignment
  - Detector R&D (ELAD, Electron-CT)

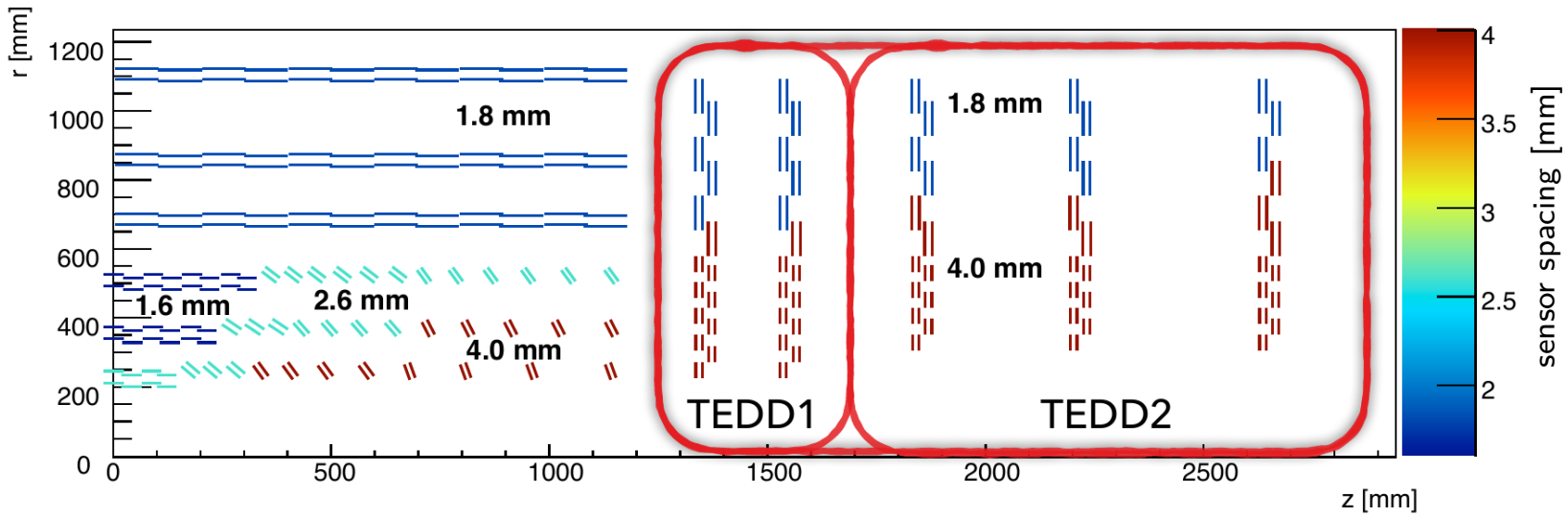
- **Data analysis:**
  - QCD: PDFs
  - Top: top mass
  - Higgs with $\tau$-leptons : BSM
  - Exotica: anomalous couplings

# Phase-2 outer tracker

**New tracker for Phase-2**

- Enable triggering on level-1.

→ $P_T$-modules (PS/2S) → reconstruction of 'stubs' possible.




**At DESY:**

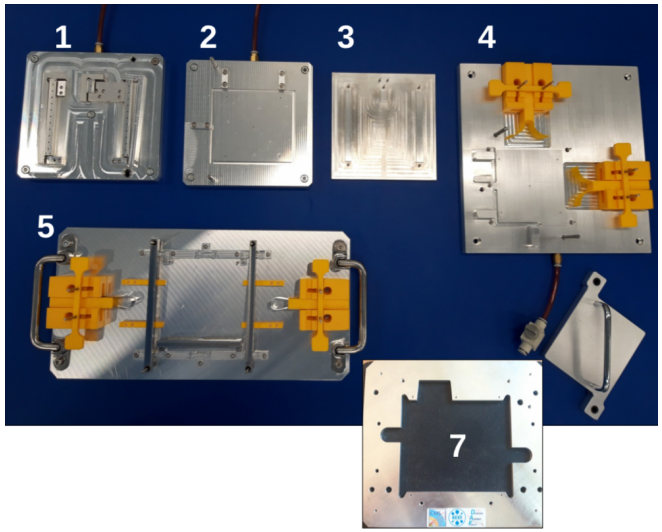
- Production of 1250 PS modules (4.0 mm).
- Construction of the TEDD1 support structures (Dee).
- Assembly of one tracker endcap.

# Phase-2 outer tracker

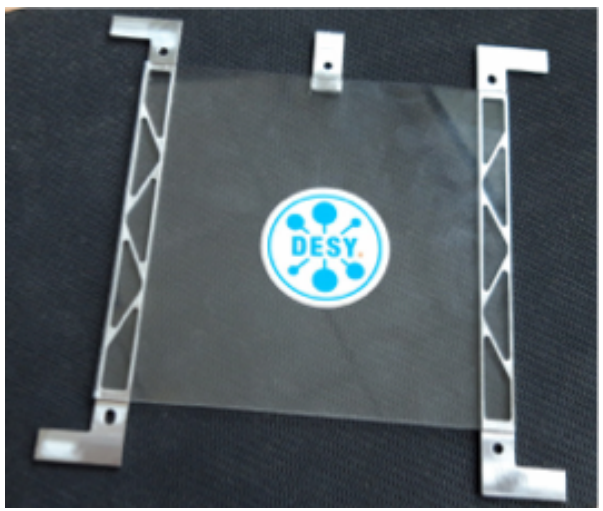
**2S module assembly:**

- For testing production steps and gaining experience (no 2S-module series production at DESY).
  - All assembly jigs available.
  - Successful performance of each of the 2S gluing steps.

  → Set of jigs would qualify for functional module production.




- Next: Test with silicon and hybrid dummies.
  - 4 dummy sensors available.
  - Requested: 4 dummy hybrids.

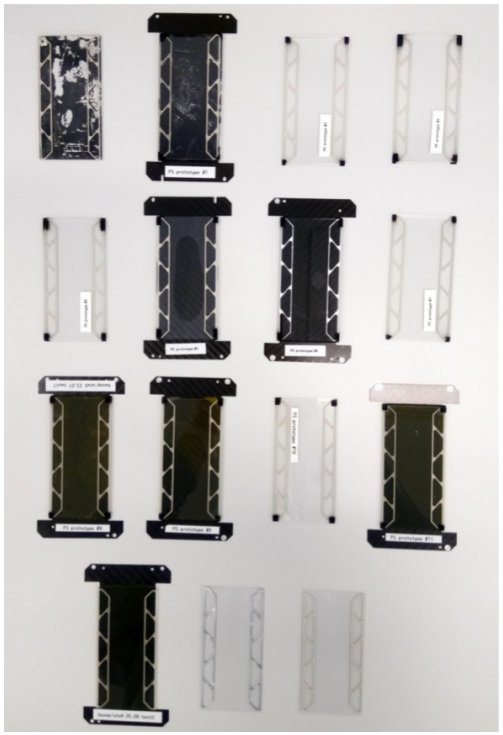



- Afterwards: production of functional modules.

# Phase-2 outer tracker

**PS module automated assembly:**

- Production of $> 10$ mechanical prototypes using glasses of different thicknesses:
  - Validate alignment markers (700 $\mu$m), test handling (200 $\mu$m), ...
  - Testing and optimising assembly steps.
- Slow+fast glue validated via pull and bleeding tests.
- Gluing jig for readout and service hybrids being developed.
- Next steps:
  - $\rightarrow$ Production of silicon-based PS module prototypes.
  - $\rightarrow$ Testing slow+fast glue under irradiation.
  - $\rightarrow$ Prototyping hybrid gluing jig with dummy hybrids.



# Phase-2 outer tracker

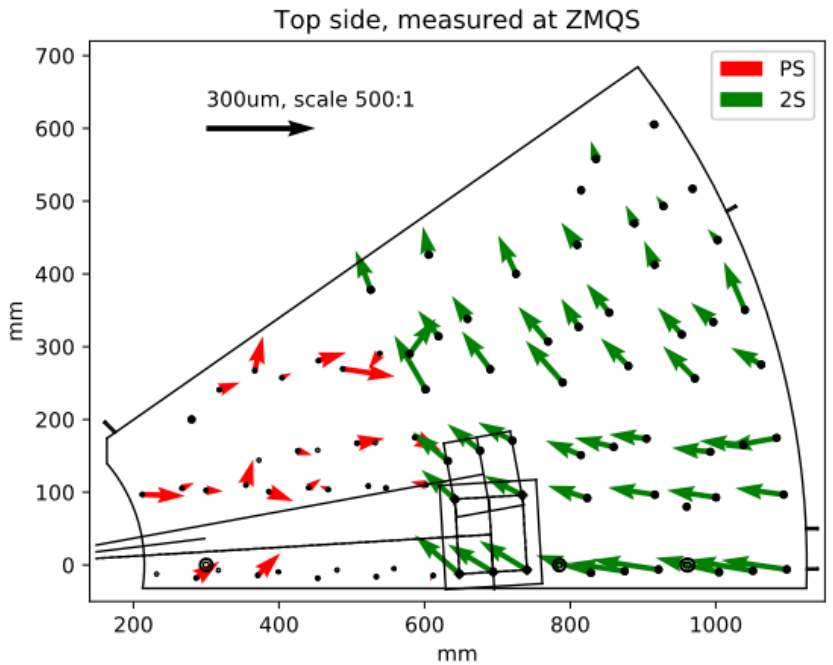
**Dee prototyping:**

- Dee : support structure for stability + cooling + module positioning.
- Production of one cooling sector Dee prototype finished.

→ Position of PS module inserts within specifications.

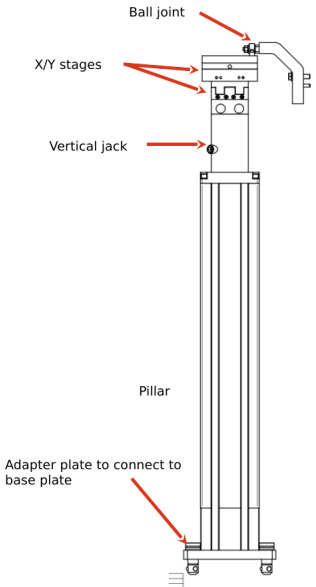
→ Position of 2S module insert group (5 inserts) within specifications.

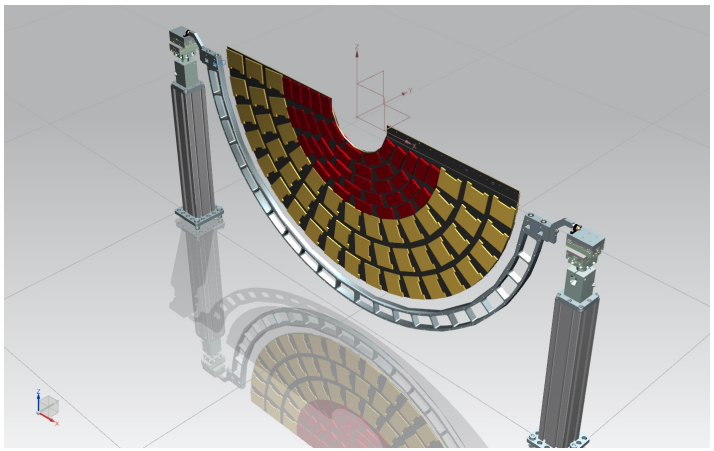
- Next: Thermal test with IR camera.

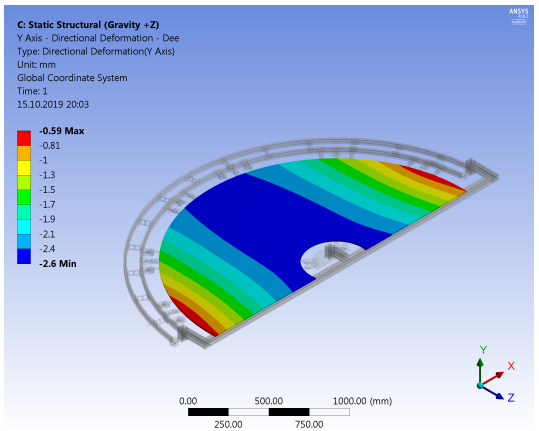


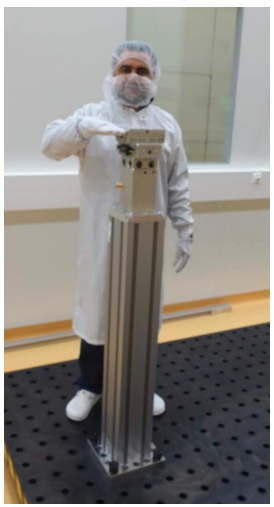
# Phase-2 outer tracker

## TEDD integration tooling:





- New baseline design of Arc Frame developed
  - → compatible with integration tooling and test setups.
  - → checked with FEA analysis → Dee deformation $\sim 2\,\mathrm{mm}$
- Prototype Disk/Double-Disk integration setup available in DAF.
  - → Will be checked with preliminary Arc Frames and wooden dummy dees.

# Tracker alignment

- Main effort in 2019 on Ultra-Legacy (UL) reprocessing → finished.
  - Increased time granularity (∼200 distinct periods).
  - Inclusion of finer high-level structures.

  → up to 600k fit parameters.

→ Clear improvement with phase-I upgrade and Ultra-Legacy reprocessing.

**Next:** Preparing Run 3 (much higher inst. lumi.) & Phase-2 (new detector).

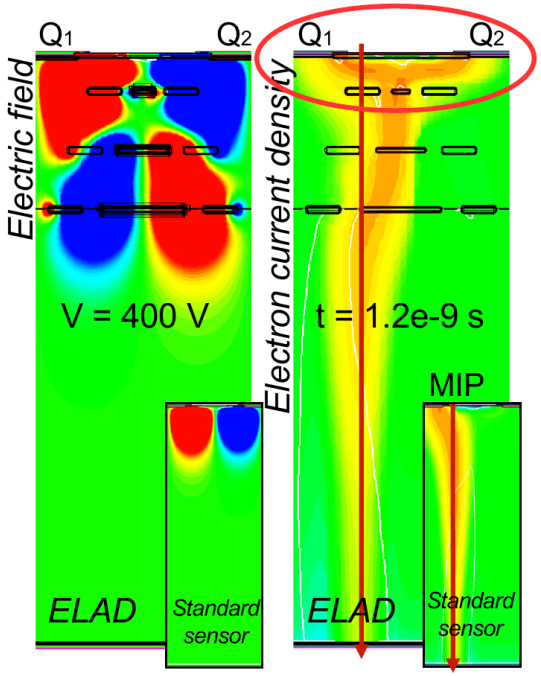
# Detector R&D: Enhanced Lateral Drift sensor (ELAD)

**Goal:**

- Achieve the theoretical optimum of position resolution by optimal charge sharing.

**Method:**

- Lateral electric field component deep in sensor bulk.
- Tunable charge sharing mechanism enabled by buried implants.




**Simulated resolution results (AllPix2):**

| | Thickness [$\mu m$] | Pitch [$\mu m$] | TimePix3 [$\mu m$] | Low thres. ASIC [$\mu m$] |
|---|---|---|---|---|
| Standard | 50 | 55 | $\sim 15$ | $\sim 15$ |
| ELAD | 50 | 55 | 9.3 | 7.6 |
| Standard | 50 | 25 | $\sim 7$ | $\sim 7$ |
| ELAD | 50 | 25 | 4.9 | 3.9 |

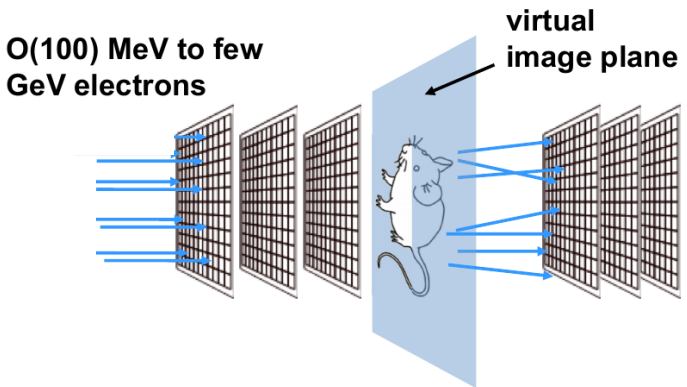
Up to 2 times improved resolution in simulation $\rightarrow$ Sensors now in production.

# Detector R&D: Electron computed tomography

**Explore low-dose imaging technique with electrons.**

**Working principle**:

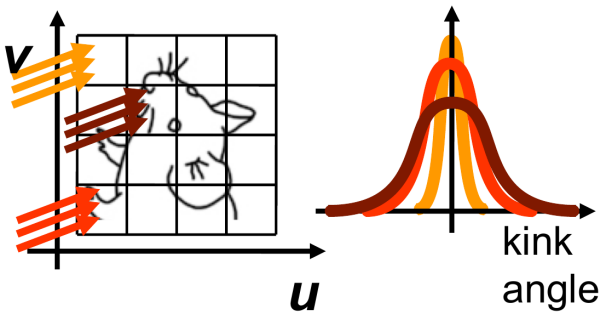
- Multiple coulomb scattering at sample.
- Measure full electron trajectories (including scattering angle at sample)




- **Width** of scattering angle distribution

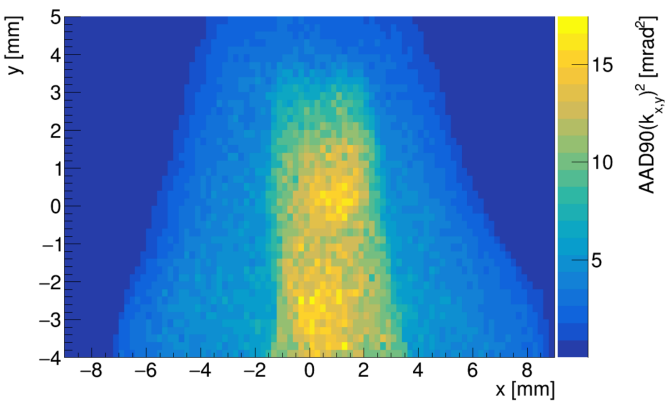
→ estimate **material budget traversed**.

- Get 3D tomography picture with 200 rotations.

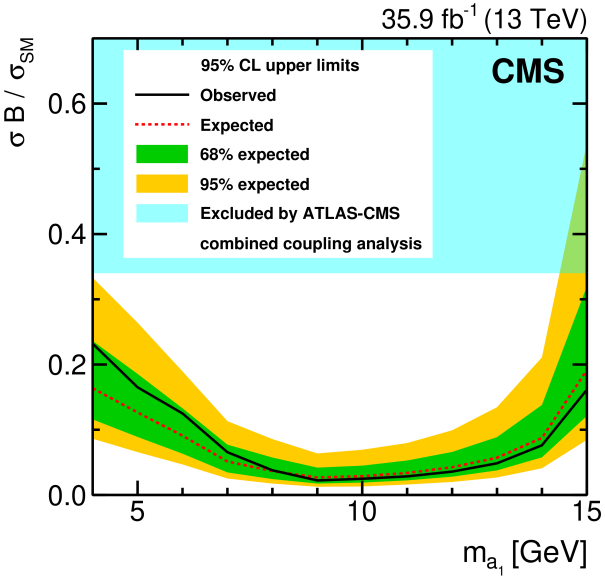



**Test beam with rat phantoms**

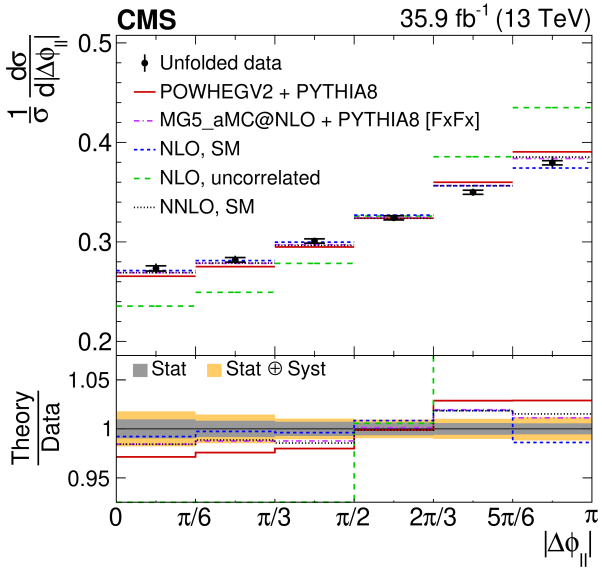
- Bone: aluminium + epoxy.
- Tissue: rubber.
- 500 MeV/c electrons

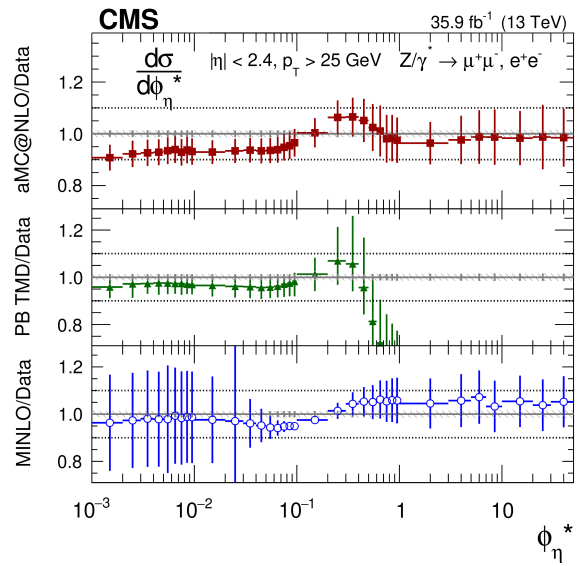


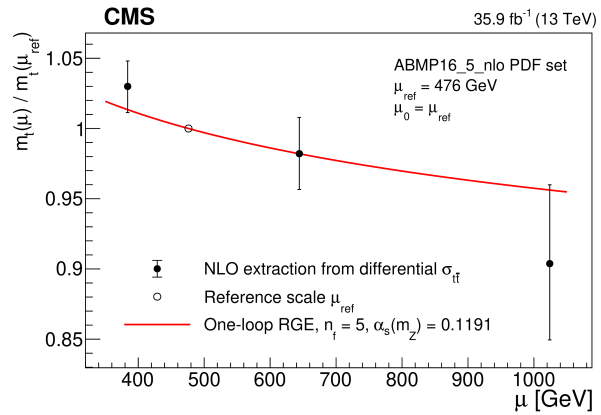
# Physics analyses highlights




- Higgs
- QCD
- Exotica
- Top

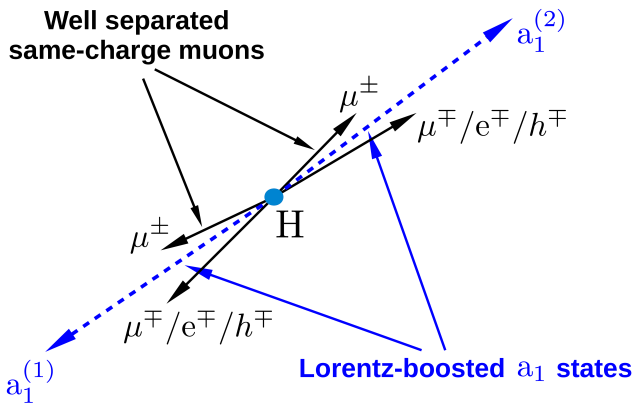


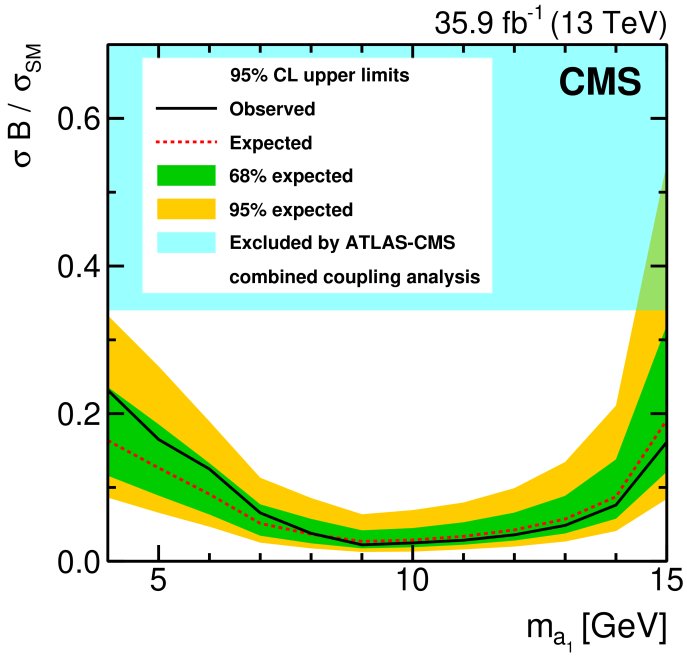
# Higgs: Search for a light pseudoscalar Higgs boson

arXiv:1907.07235 → accepted by PLB




- Many BSM models contain a light Higgs '$a_1$':
  - → Might emerge in pairs from decays of $H(125)$.
  - → For $2m_\tau < m_{a_1} < 2m_b$: $H(125) \to a_1 a_1 \to 4\tau$ highly sensitive.

- Select signatures compatible with
  - $a_1 \to \tau_\mu \tau_{1-prong}$ decays.
  - highly boosted $a_1$ bosons.
- Dominant background: multi-jet events (data-driven estimation).




→ Most competitive $H \to a_1 a_1$ analysis in $4 - 15$ GeV mass range.

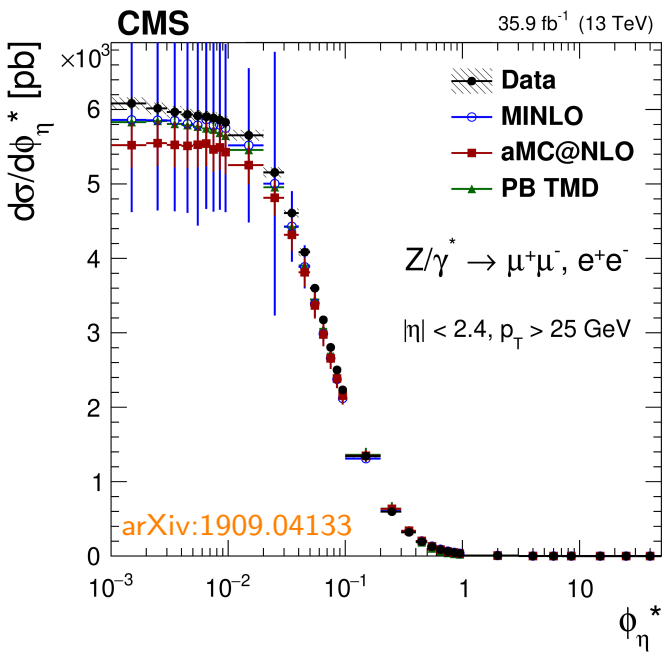
# QCD: Transverse momentum of the Z boson at 13 TeV

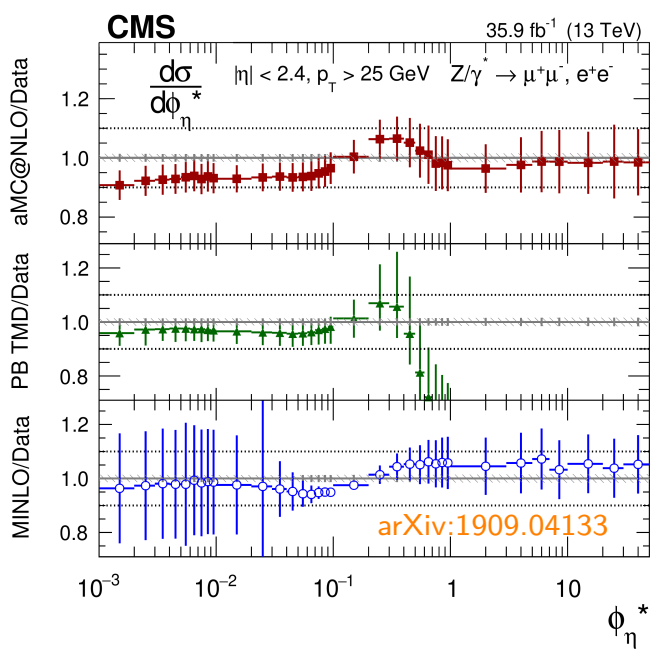
Phys. Rev. D 100, 074027 (2019)

**At low particle $p_T$ → transverse momentum of partons become important**

- Transverse momentum dependent (TMD) pdfs obtained by parton branching method (developed together with theorists).
- Obtained from and fitted to HERA data → no further tuning to data needed.
- First NLO prediction of Z boson $p_T$ with PB TMD parton density functions.

**Confronting with CMS data:**



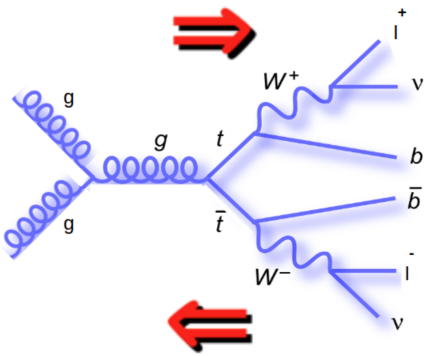




$\phi_\eta^* \sim p_T^Z / m_{\ell\ell}$

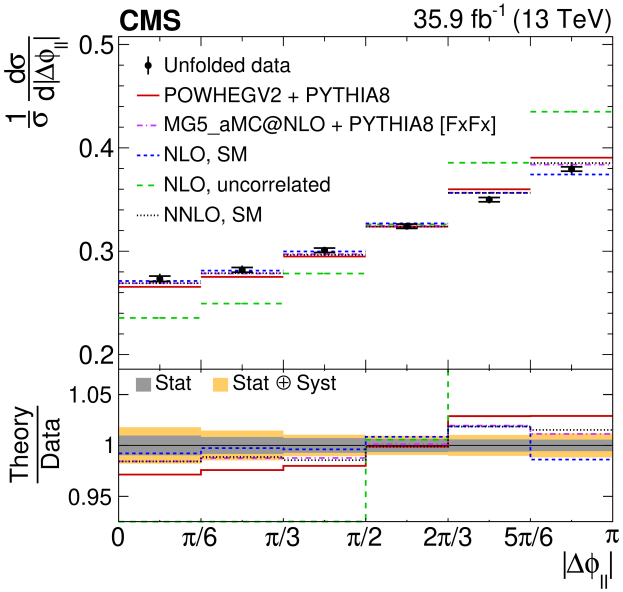
→ **Very good description at low $\phi_\eta^*$.**

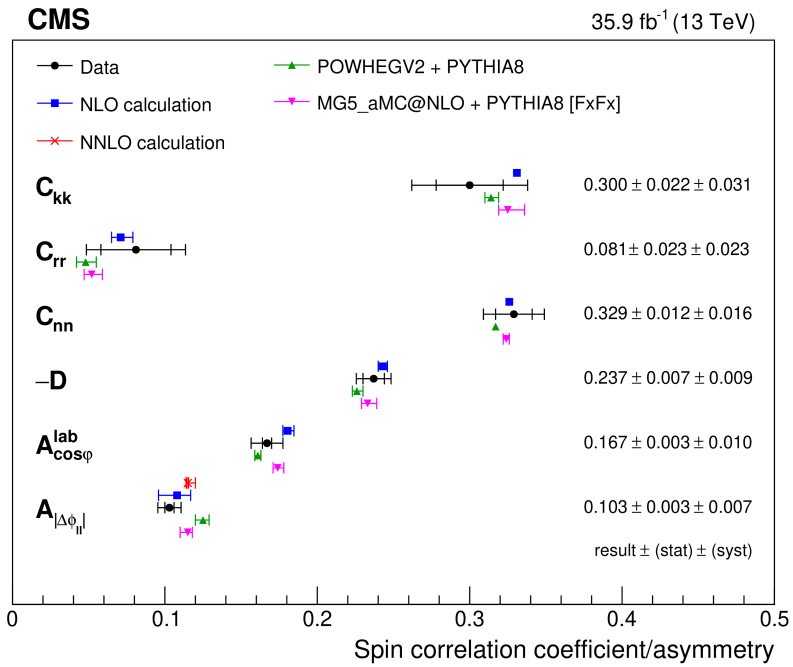
# Exotica: Top quark polarisation and $t\bar{t}$ spin correlation

Phys. Rev. D 100, 072002 (2019)




- Dileptonic final state ($e^+e^-/e^\pm\mu^\mp/\mu^-\mu^+$).
- Unfolding of distributions sensitive to $t\bar{t}$ spin and top polarization.



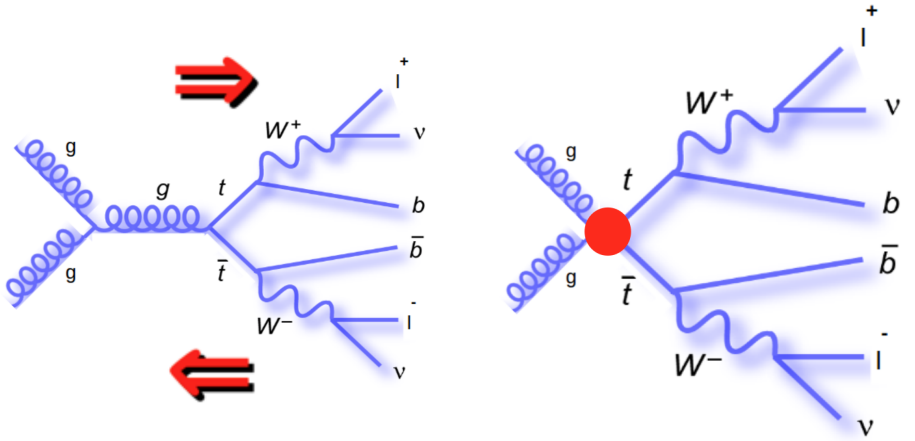



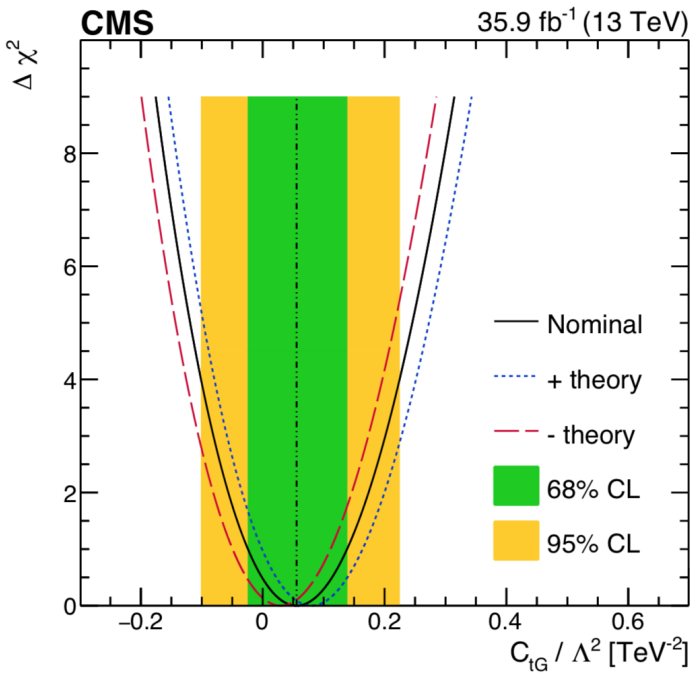

- Measurement of spin density matrix consistent with SM.
- $3\,\sigma$ deviation claimed by ATLAS understood as caused by perturbative expansion effects in MC simulation.

# Exotica: Top quark polarisation and $t\bar{t}$ spin correlation

Phys. Rev. D 100, 072002 (2019)

- Utilize measurement for searching for new physics.




- E.g. chromomagnetic dipole moment.
- Interpretation within EFT.

→ Strongest direct constraint.

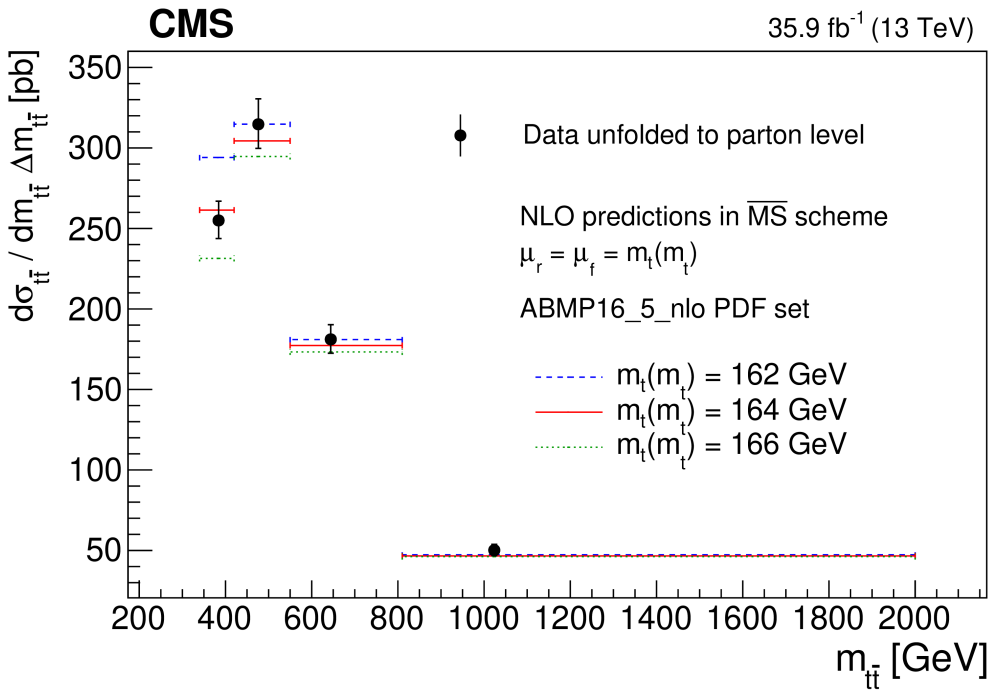
# Top: The running of the top quark mass

arXiv:1909.09193 → submitted to PLB

**First ever probe of the scale dependence ("running") of the top quark mass.**

**Method:**

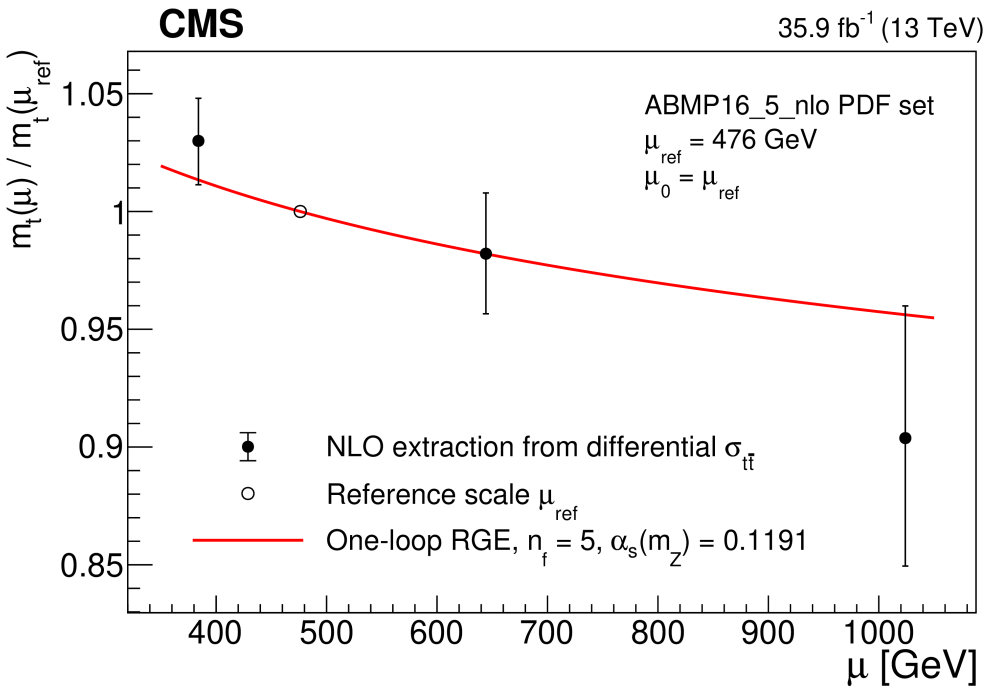
- Measure $\sigma_{t\bar{t}}$ differentially as a function of $m_{t\bar{t}}$ using $e\mu$ data.
  - Unfolding: Fit multidifferential distributions in each $m_{t\bar{t}}^{\text{reco}}$ bin.
  - Extract $m_t(m_t)$ at NLO as function of parton-level $m_{t\bar{t}}$.



# Top: The running of the top quark mass

arXiv:1909.09193 → submitted to PLB

- $m_t(m_t)$ converted to $m_t(\mu_k)$.
  - Using one-loop RGE solutions.
  - $\mu_k$: centre-of-gravity of each $m_{t\bar{t}}$ bin k.




In agreement with 1-loop precision RGE within 1.1 $\sigma$.

# Summary

- **Detector/Operations**:
  - Large progress in Phase-2 outer tracker upgrade: module prototypes, DEE prototypes, TEDD integration.
  - Strong contributions to Run 2 ("Ultra Legacy") reprocessing, e.g. tracker alignment.
  - Detector know-how (of the group) successfully transferred to technology applications beyond CMS.

- **Physics analyses:**
  - DESY successfully contributing in many different fields.
  - Excellent results in SM measurements as well as BSM searches.

→ **Last 6 months:** 6 CMS publications + 2 pheno papers + 6 PhD theses.

Thank you.