ATLAS Group Status.

82th DESY Physics Research Committee meeting

DESY ATLAS Group
Zeuthen
Oct 20, 2016

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On behalf of DESY ATLAS group

HELMHOLTZ | ASSOCIATION

DESY

General view of group activities

- **Operation**
  - ALFA
  - Semi Conductor Tracker (SCT)
- **Detector upgrade**
  - Fast Track Trigger (FTK, Phase 1)
  - Inner Tracker upgrade (Phase 2)
  - Test Beam Telescope
- **Computing and Software**
  - Tier 2, NAF
  - Inner Detector tracking software
  - Data processing
  - Monte Carlo (MC) software tuning, validation, management and development
  - MC production preparations
- **Physics objects performance & data analysis**
  - Luminosity determination
  - Electron and photon performance
  - Jet, large-R/variable-R jet, b-tagging performance
  - **Standard Model:** W/Z/DY production, WW production, γγ production, photon PDF fits, W mass, light-light scattering, total & elastic cross section using ALFA
  - **Higgs:** SM H→γγ (fiducial inclusive and differential cross sections), SM Higgs production and decay rates (H→ZZ, H→ γγ), BSM Higgs (H →γγ, H→Zγ), tt+Higgs production
  - **Top:** tt+jets production, top properties (charge asymmetry, spin and polarisation)
  - **BSM:** Dark matter with Higgs and W/Z, Graviton→γγ, tt resonances, search for 4 Tops productions, HH→ γγbb, VBF Higgs→ invisible, QCD background estimation for SUSY searches with Jet+MET, VBF production of SUSY partners

Outline

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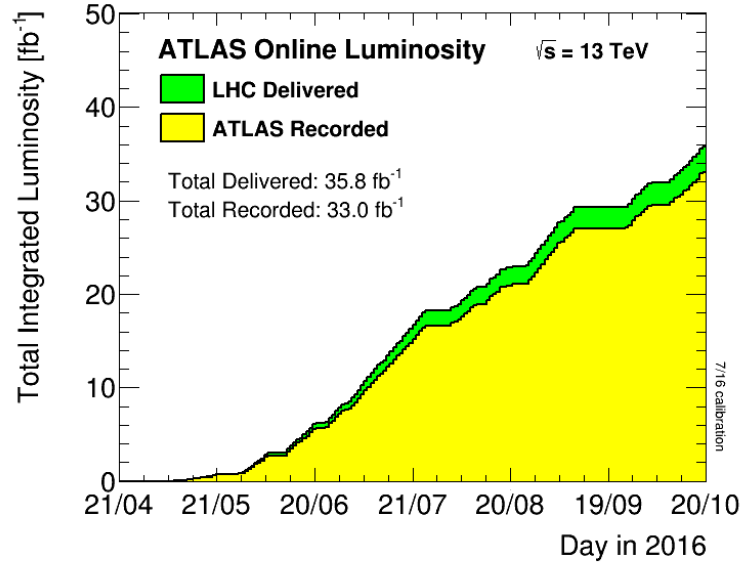
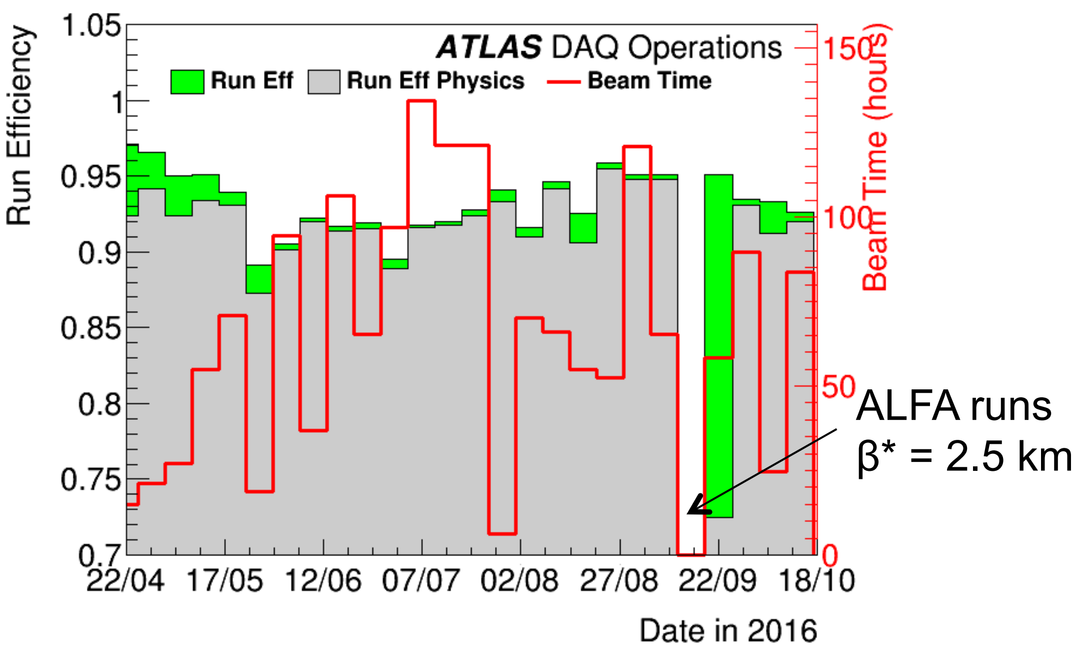
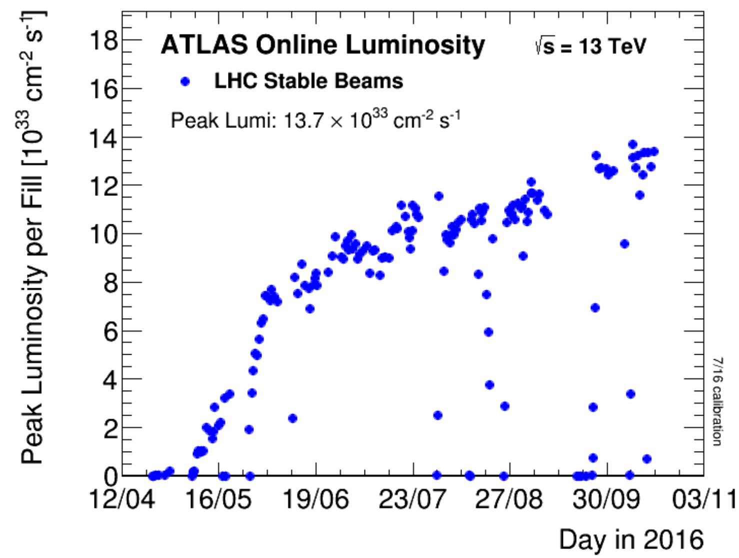
- I will talk about
  - briefly on current ATLAS status
  - measurement and search with top quark pair final state
  - ITk upgrade activities at DESY

The ATLAS detector operation status

- Successful running since April at $\sqrt{s}$=13 TeV with 25 ns bunch spacing and low β* (0.4 m) LHC conditions
  - peak luminosity reached above the design value
    - 1.37 x 10^{34} cm^2 s^{-1}
  - ~ 300 pb^{-1} per day on average recorded
- Overall data taking efficiency ~ **92%**







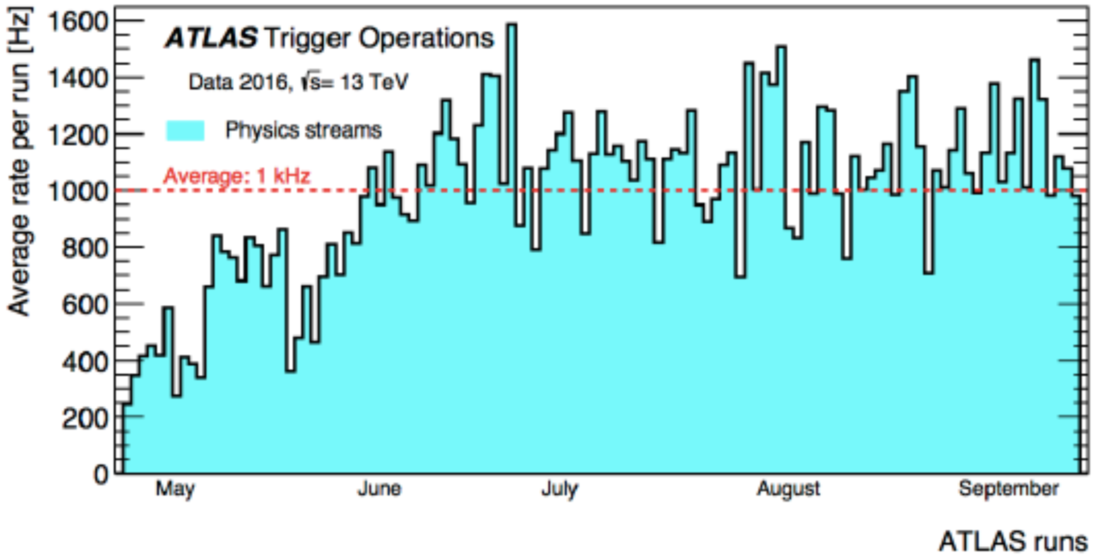
Detector operational fraction

- All subsystems have been functioning well
  - similar operational fraction as in last year
  - DESY participates in SCT and ALFA operations and monitoring
- ATLAS Forward Proton system participated in the data taking

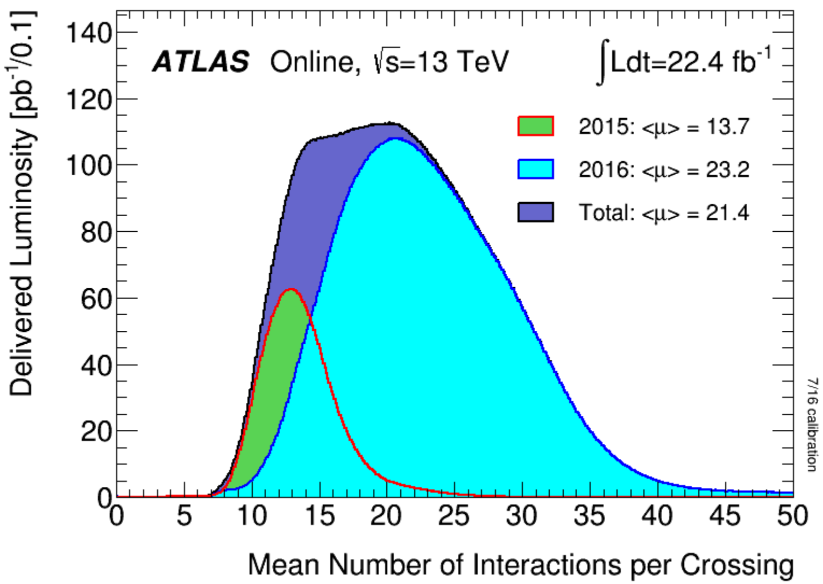
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	92 M	98.0%
SCT Silicon Strips	6.3 M	98.6%
TRT Transition Radiation Tracker	350 k	97.2%
LAr EM Calorimeter	170 k	100%
Tile calorimeter	5200	99.0%
Hadronic endcap LAr calorimeter	5600	99.5%
Forward LAr calorimeter	3500	99.7%
LVL1 Calo trigger	7160	99.9%
LVL1 Muon RPC trigger	383 k	99.8%
LVL1 Muon TGC trigger	320 k	99.9%
MDT Muon Drift Tubes	357 k	99.7%
CSC Cathode Strip Chambers	31 k	97.7%
RPC Barrel Muon Chambers	383 k	96.6%
TGC Endcap Muon Chambers	320 k	99.6%
ALFA	10 k	99.9 %
AFP NEW in 2016	188 k	98.8 %

Trigger and Pileup in 2016

- Challenges for trigger with high instantaneous luminosity
  - L1 rate ~ 85 kHz
  - HLT rate ~ 1 kHz
- Commissioning of L1Topo and Missing Et triggers for 2017



- Mean pile up <μ> ~ 23 on average
  - up to 40 or more mean number of *pp* interactions per bunch crossing at the beginning of LHC Fill



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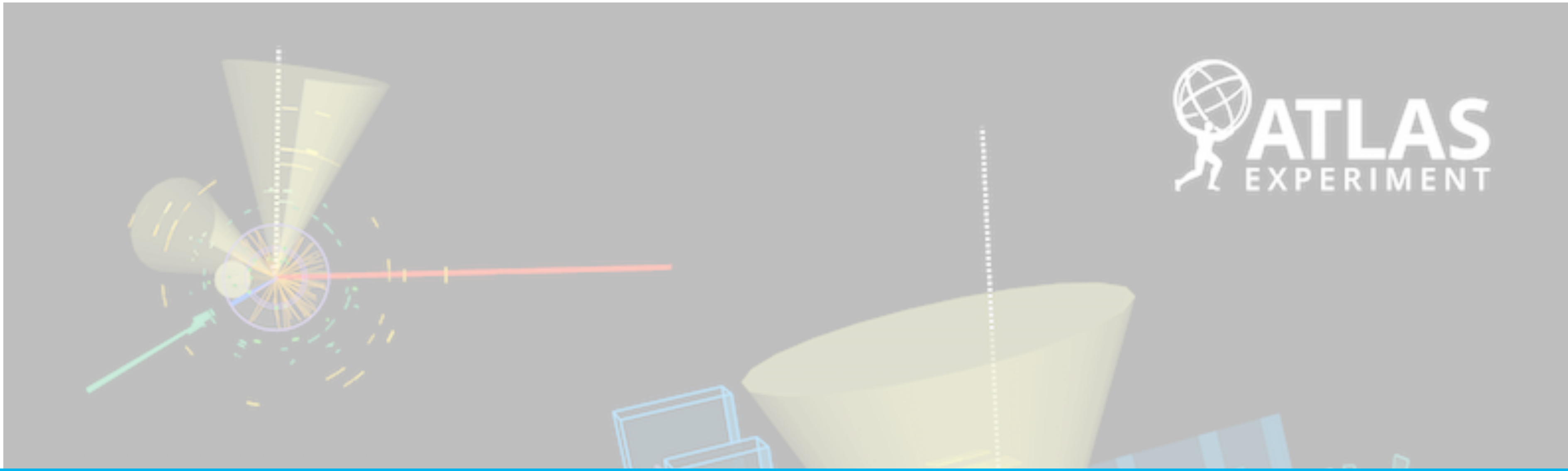
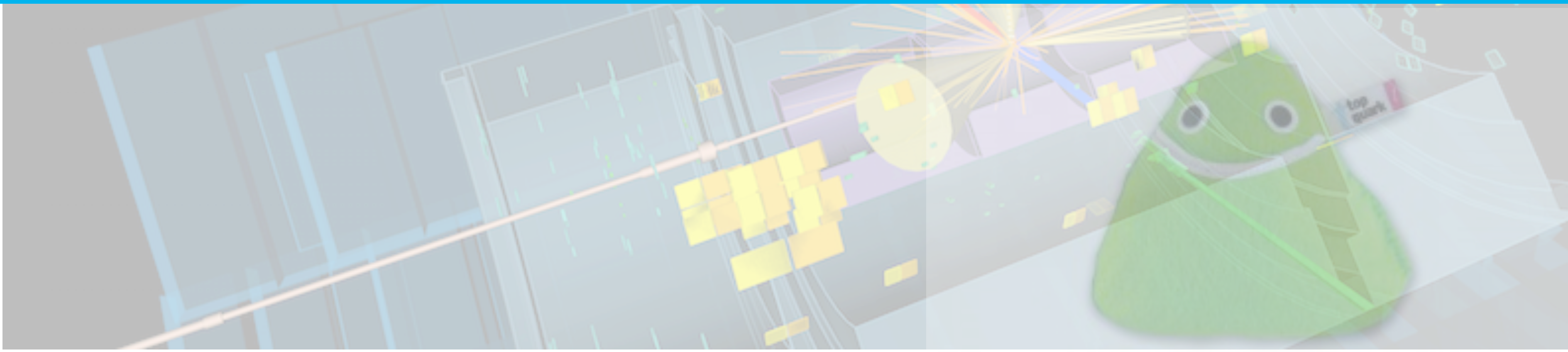
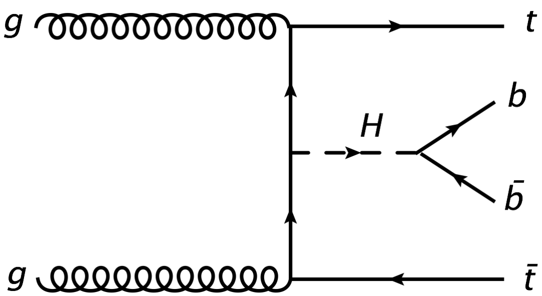


Measurements & search with top quark

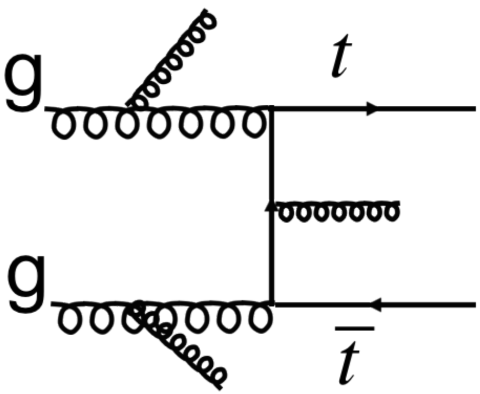


Top pair production

- Top quark is special due to its highest mass observed so far (sorry no X(750) → γγ)
  - mass close to electroweak symmetry breaking scale
  - large Yukawa coupling



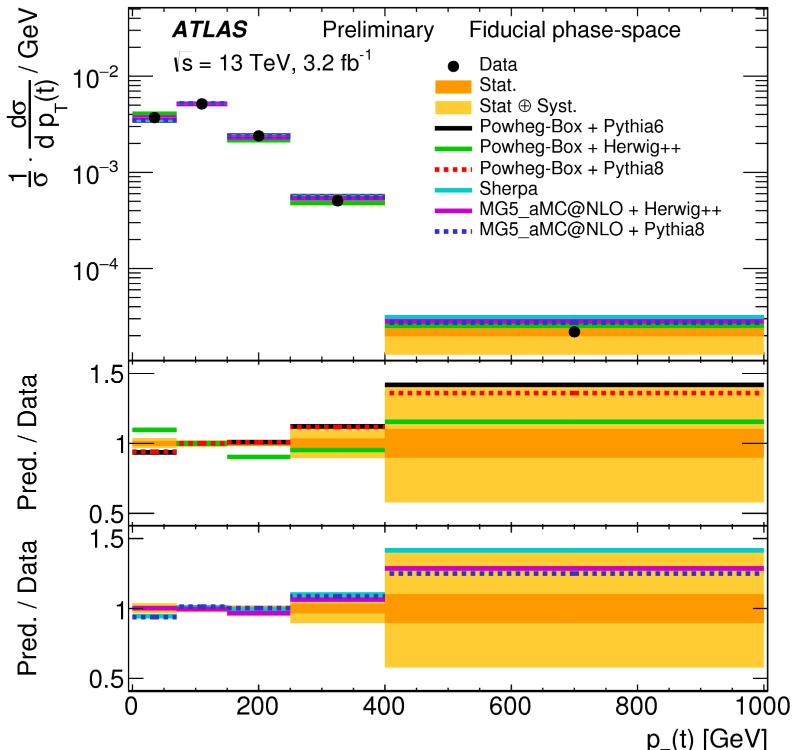
- Observation of Higgs production with top pair would allow direct measurement of Yukawa coupling
- Precise modeling of SM tt final state is crucial for search for rare SM processes (e.g ttH) and BSM models (e.g heavy resonances decaying to tt)
  - tt with additional jets is one of the largest background to ttH(→bb) channel
  - heavy flavor fraction in particular is not well constrained by experiments (~30% uncertainty in fiducial cross section)



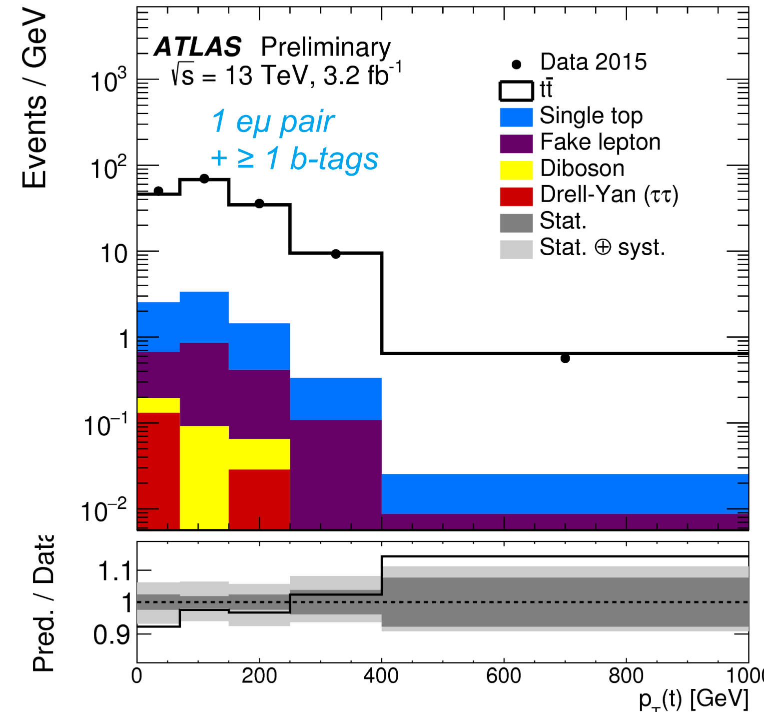
- Differential cross section measurements for top pair production are needed to test SM predictions from various state-of-the-art calculations
  - process determined by the top mass scale
  - QCD radiation in top events is difficult to model due to different scales involved

Measurement of tt differential variables

- Measure kinematics of top quark at particle-level in fiducial phase space
  - top p_T and invariant mass of tt system useful for higher order QCD modeling
  - rapidity |y| of top and tt system helpful to constrain gluon PDF
  - p_T spectrum of tt system tests modeling of first hard emission



Particle-level top p_T



top reconstructed after applying constraints on the W and top masses ~ 95% tt events

- Unfold the reco-level distribution to particle level to correct for detector inefficiencies and resolution
  - particle-level top constructed from truth lepton, missing E_T and jets
- First measurement for top p_T in this channel

Top p_T measurement

- Measured distribution compared to next to leading order (NLO) matrix element generators matched with parton shower

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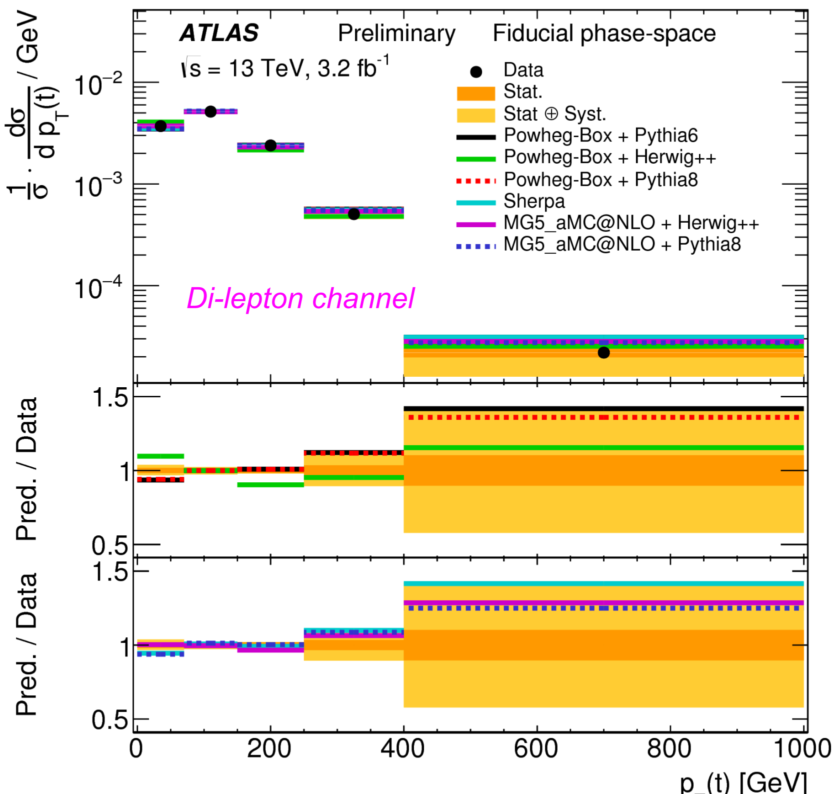
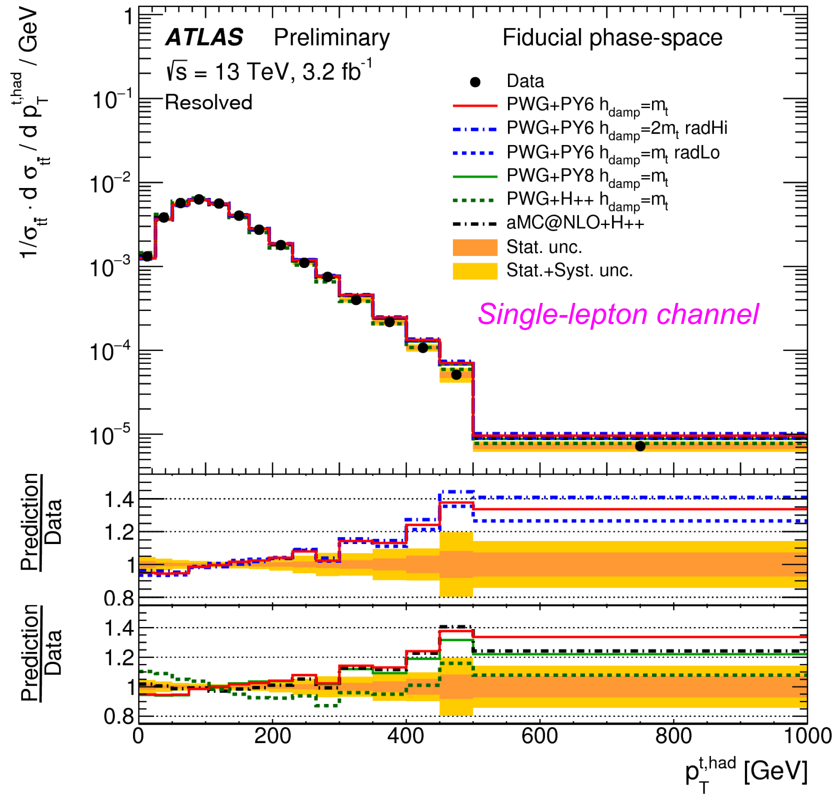




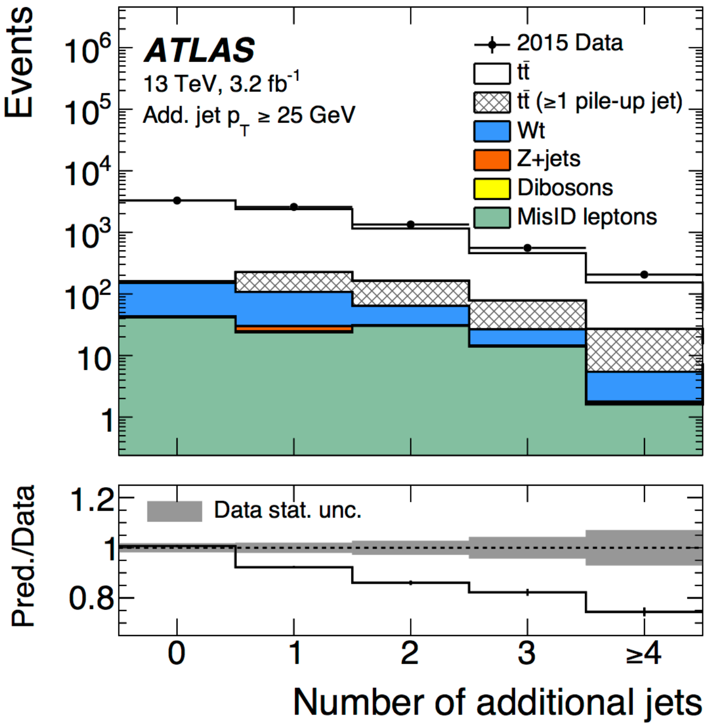
- Measurement complementary to more precise result in the single-lepton channel, which show softer p_T spectrum than most MC generator predictions
  - signal modeling is one of the dominant source of uncertainties
- To model the SM tt background for searches, the top p_T is reweighted to NNLO calculations which describe the data better

Results first shown at Top2016 paper to EPJC very soon

Measurement of jet activity in tt+jets

- Additional jets produced with tt are sensitive to parton shower tuning parameters and matching/merging parameters for the matrix element MC generators
  - NLO matrix element generators predict fixed number of additional jets only at LO accuracy
- Count additional jets with a certain p_T threshold in events with 1 eμ pair and ≥ 2 b-tagged jets
  - consider two leading b-jets as being from top decay

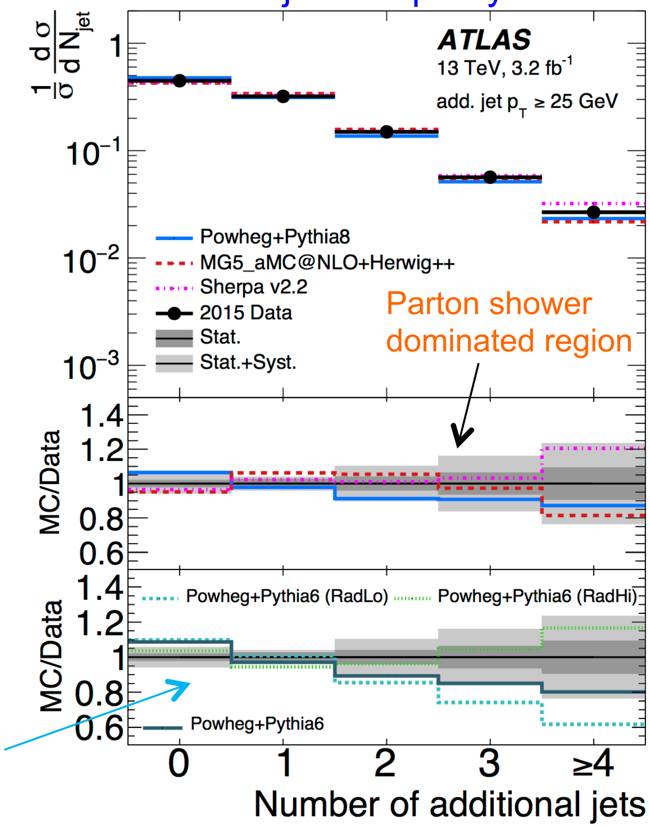
Reco-level jet multiplicity distribution



No requirement on full event reconstruction

~ 95% tt events

Particle-level jet multiplicity distribution



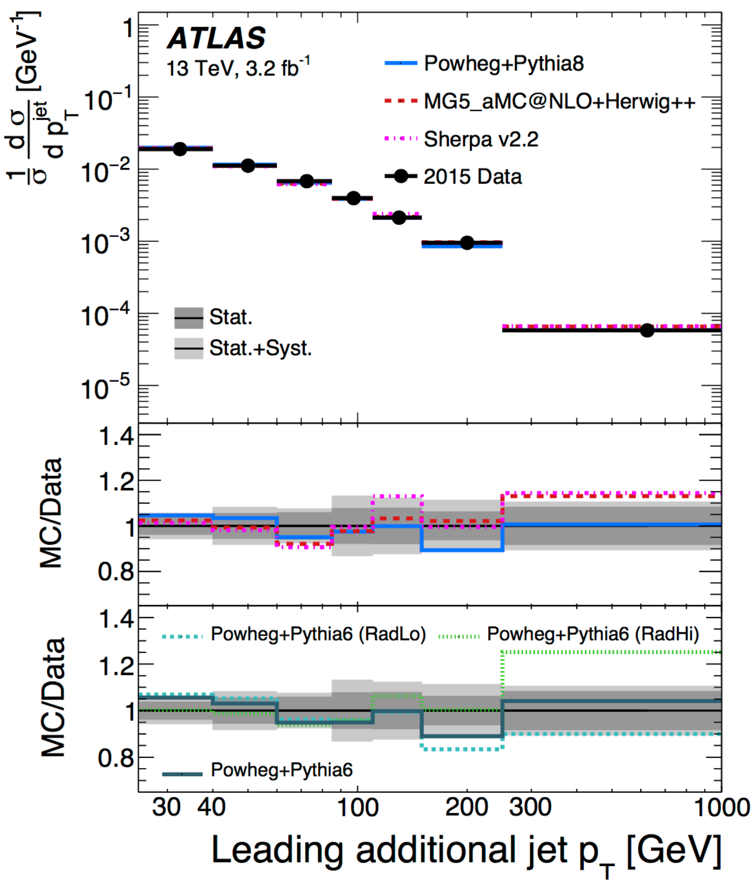
Dependence on QCD radiation scale variations

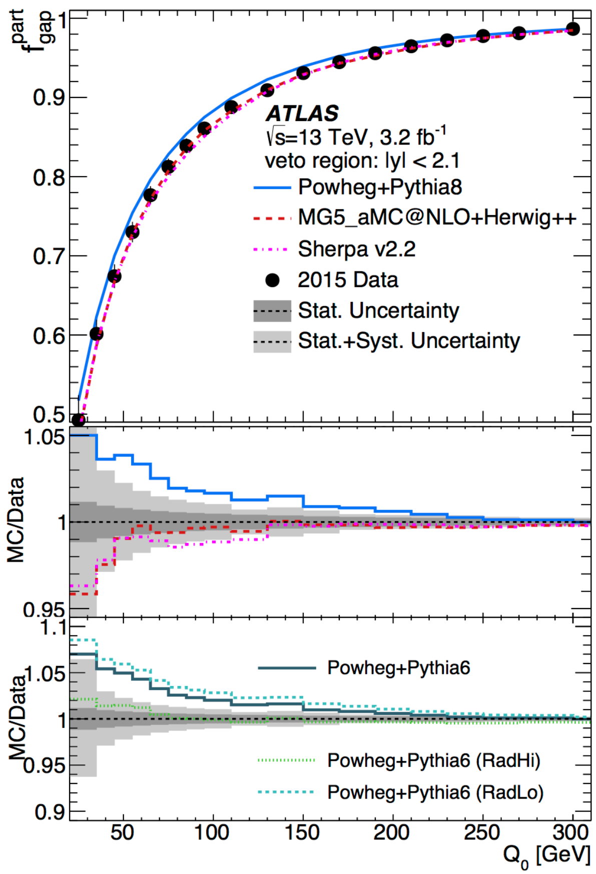
Reco-level distribution suffers from pile-up dependence for soft jets

CERN-EP-2016-218

Measurement of jet activity in tt+jets

- Leading additional p_T
  - sensitive to modeling of first hard emission and recoil to tt system
  - consistent description as in additional jet multiplicity measurement
- Fraction of events with no additional jet activity above a certain p_T threshold (Q_0) in various rapidity regions
  - sensitive to first hard emission modeling
  - complementary to jet multiplicity measurement, but smaller uncertainties



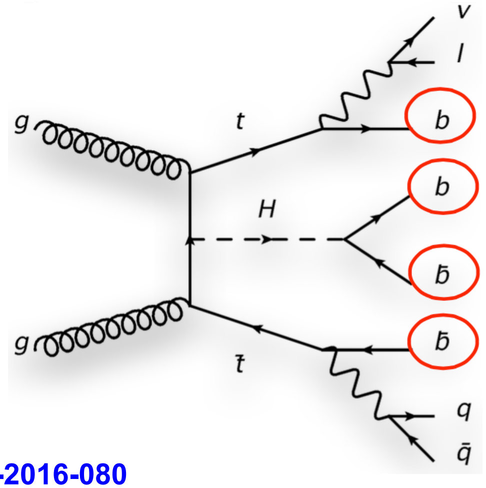


$$f_{gap}(Q_0) = \frac{n(Q_0)}{N_{t\bar{t}}}$$

CERN-EP-2016-218

Search for ttH (→bb)

- Largest BR(H→bb) ~ 58%, but difficult background and complex combinatorics in final state
  - very challenging analysis!
- Events classified into signal and control regions depending on no. of jets and no. of b-jets
  - analysis with events containing one or two leptons using partial data at 13 TeV
  - S/B ratio is 5.2% in the most enhanced ttH region
    - large contribution from additional heavy flavor (HF) jets produced with SM tt
  - poor description of data in events with more heavy flavor jets
- Multivariate analysis employed for signal regions in two stages:
  - first stage to reconstruct Top and Higgs
  - second stage to separate ttH from background



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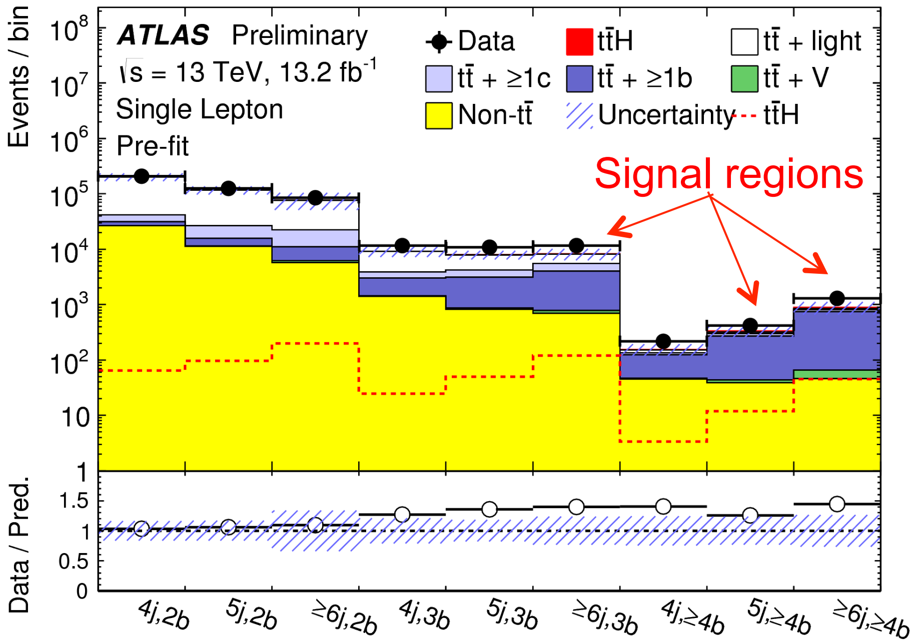

Background modeling for tt + additional heavy flavor (HF) jets

> State-of-the-art NLO predictions for major backgrounds
  - MC are tuned and validated using the observables reported earlier (e.g. top $p_{T,}$ tt+jets)
  - large differences in various MC predictions for tt+HF jets
  - uncertainties on relative contributions from various tt+HF jets components are evaluated by comparing different MC models
    - used as constraints in fit for the shape of tt+HF jets contributions

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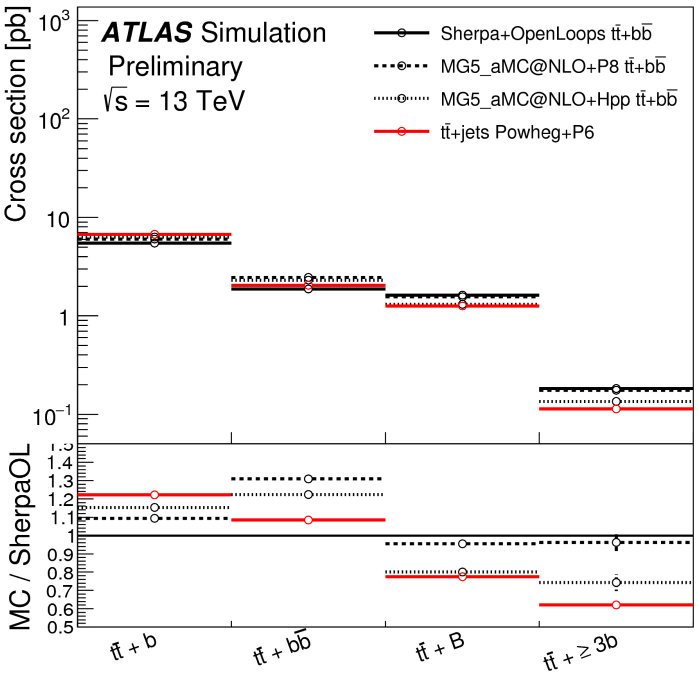

modeling for
tt + additional b-jets

modeling for
tt + additional c-jets

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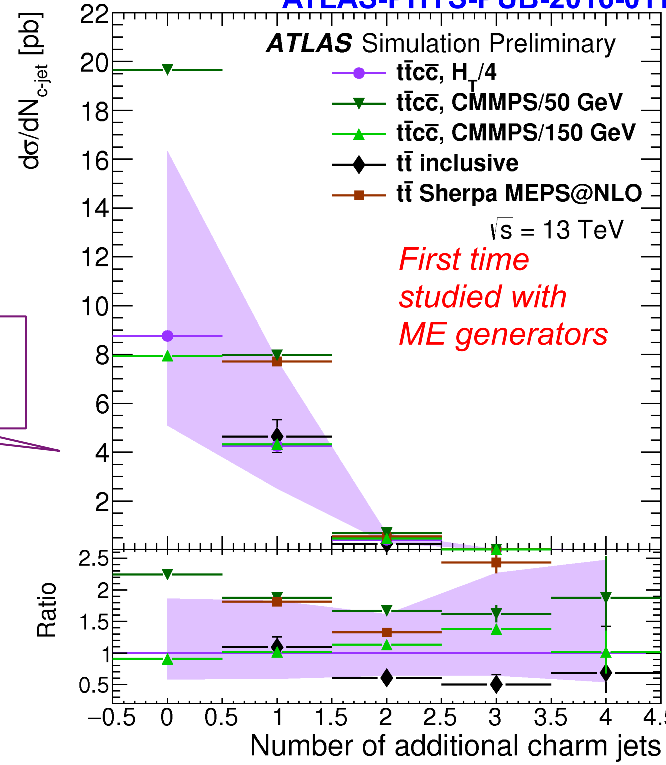

Results for ttH (→bb)

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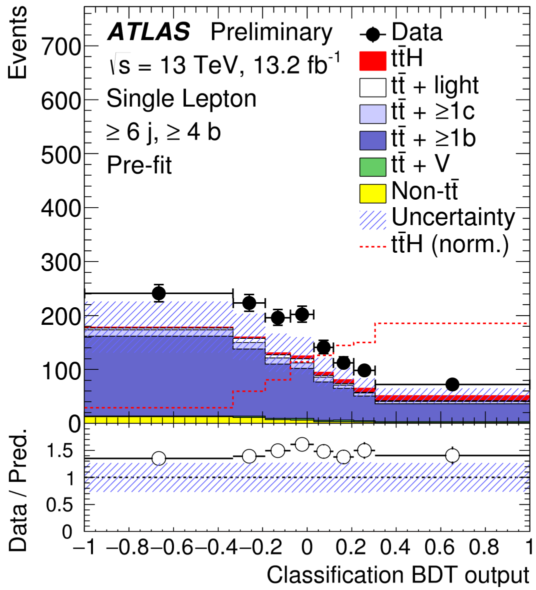
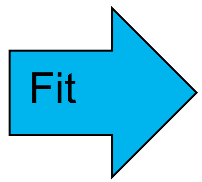
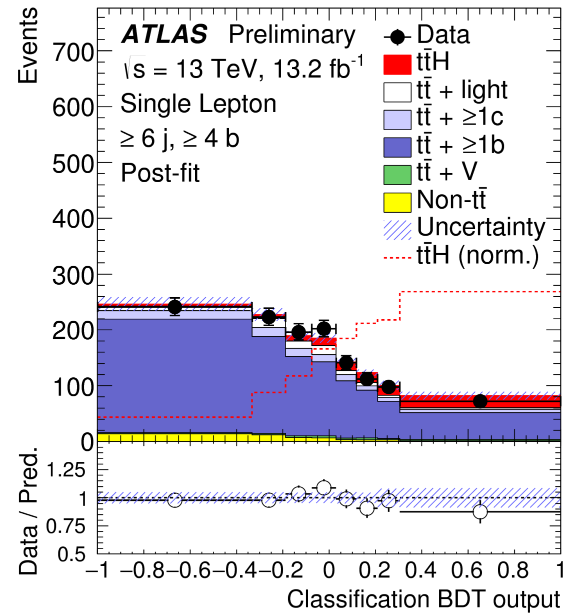


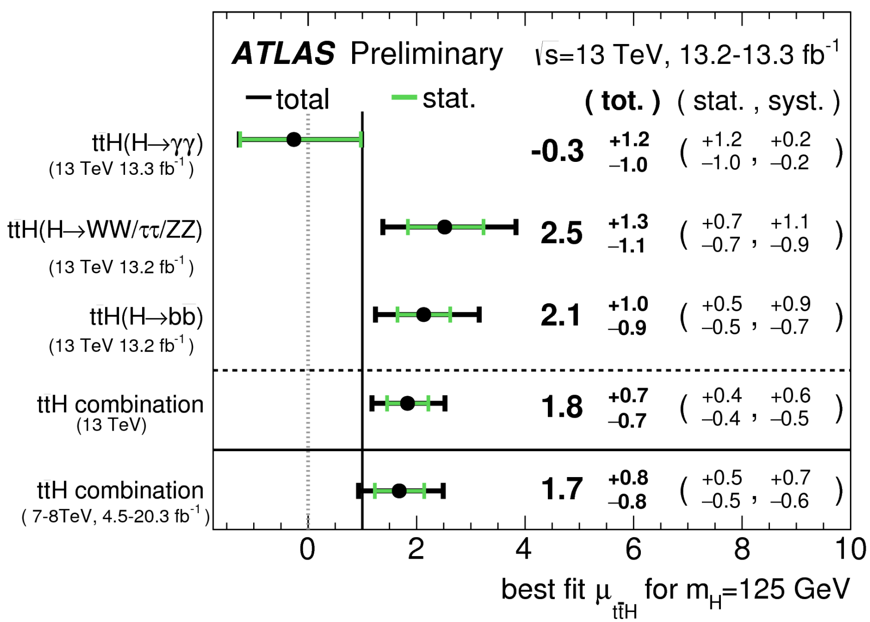
Simultaneous fit in 6 signal regions and 8 control regions for ttH and major background





ttH signal is enhanced after fit

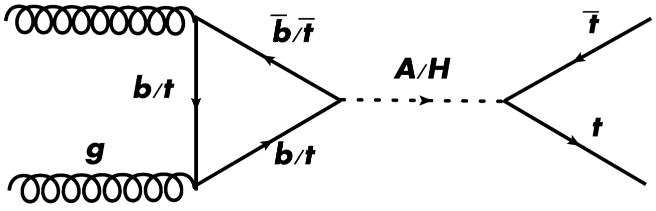
tt+HF jets contribution scaled by ~ 30% after fit



- Best fit signal strength $\mu = \sigma/\sigma_{SM}$ in H→bb channel is $\mu = 2.1 \pm 1.0$
  - most precise measurement from ATLAS to date
- Combination with other ttH channels yields $\mu = 1.8 \pm 0.7$
- Consistent with SM, but improvement needed to reduce the uncertainties

Search for heavy resonance decaying to top pair

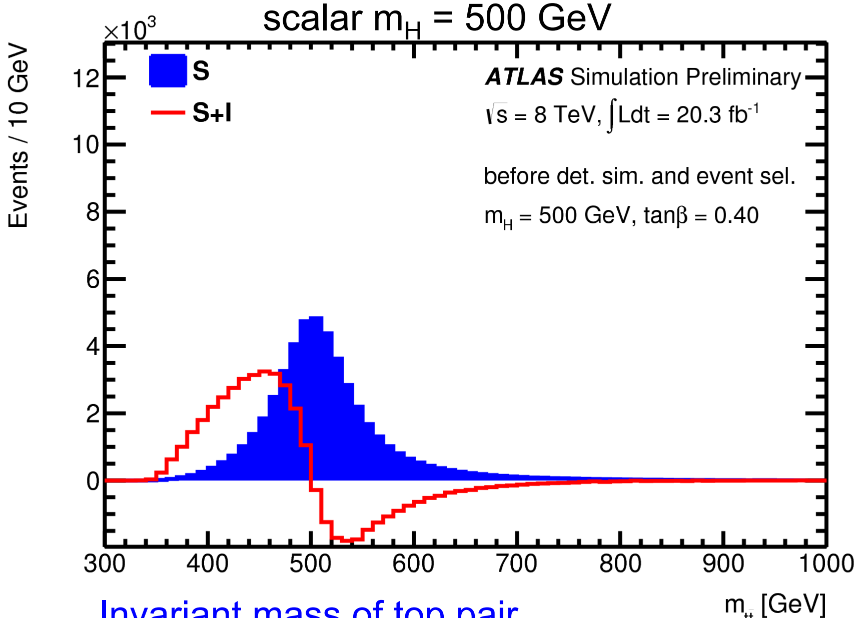
- Search for heavy (pseudo) scalar coupling to tt is predicted by many BSM models (e.g in SUSY and axion models)
  - benchmark: type-II 2 Higgs double model (2HDM)
  - low *tanβ* and mass > $2.m_{top}$
- First LHC search accounting for interference between signal and SM tt
  - challenging due to peak-dip structure represented by the signal including the interference



H: scalar Higgs
A: pseudo scalar Higgs

Couplings to top quark scale inversely with *tanβ*

scalar m_H = 500 GeV



Invariant mass of top pair predicted by MC at parton level

S = Signal for pure resonance gg→A/H→ tt
I = Interference with SM gg→ tt

Negative interference between signal and SM tt final state

LO effects in QCD are considered for MC event generation
Normalised to cross section predicted by 2HDM model for pure signal S

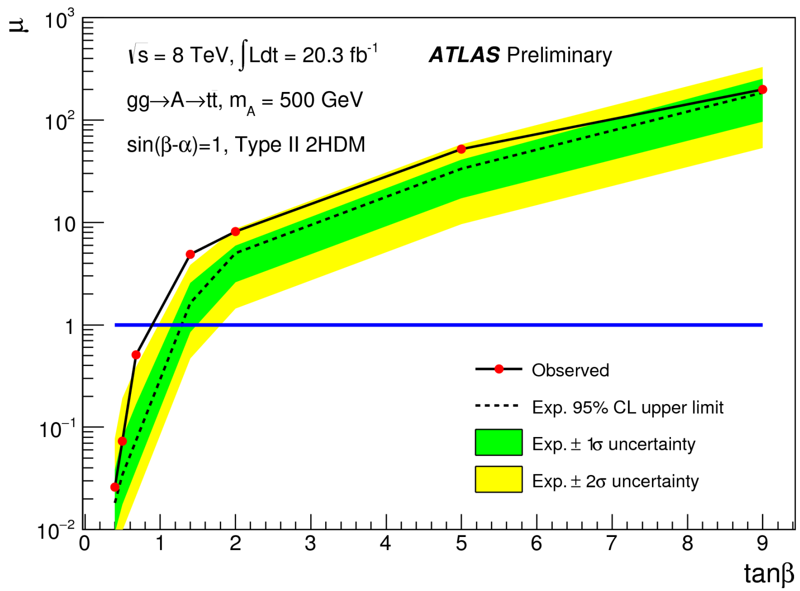
ATLAS-CONF-2016-073

Results for A/H → tt search

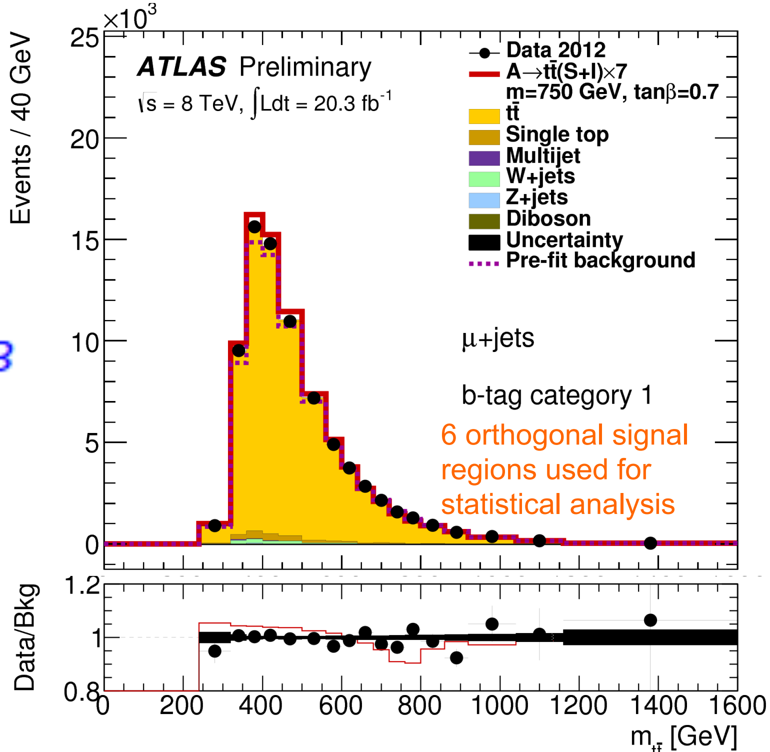
- Event reconstruction using kinematic fit based on a χ^2 algorithm for a tt event
  - SM tt is the largest background component
- Binned invariant mass m_{tt} parameterized in terms of signal strength (μ)

$$\mu \cdot S + \sqrt{\mu} \cdot I + B = \sqrt{\mu} \cdot (S + I) + (\mu - \sqrt{\mu}) \cdot S + B$$

μ = 1 implies signal model



Upper limit on μ with assumption that shape of m_{tt} for *S* and *S+I* do not change under variations in μ



Data agree well with background prediction in invariant mass distribution of reconstructed top pair

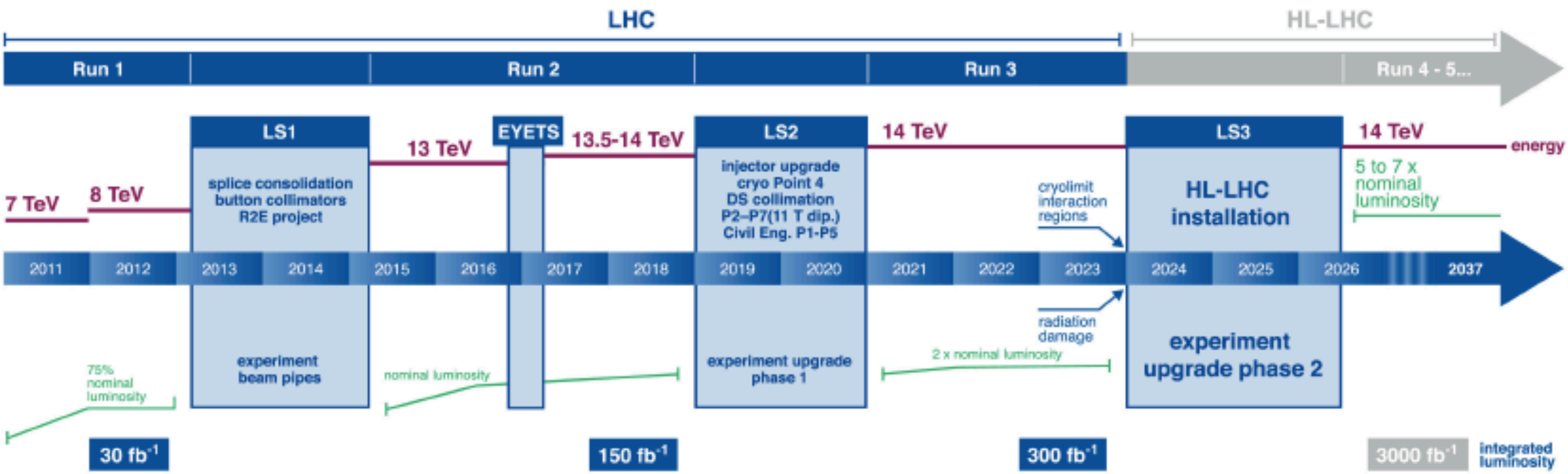
- Results are interpreted in terms of 2HDM model for various *tanβ* regions
  - *tanβ < 0.45* for m_H = 500 GeV @ 95 %CL
  - *tanβ < 0.85* for m_A = 500 GeV @ 95 %CL
- Improved sensitivity than previous searches

ATLAS-CONF-2016-073

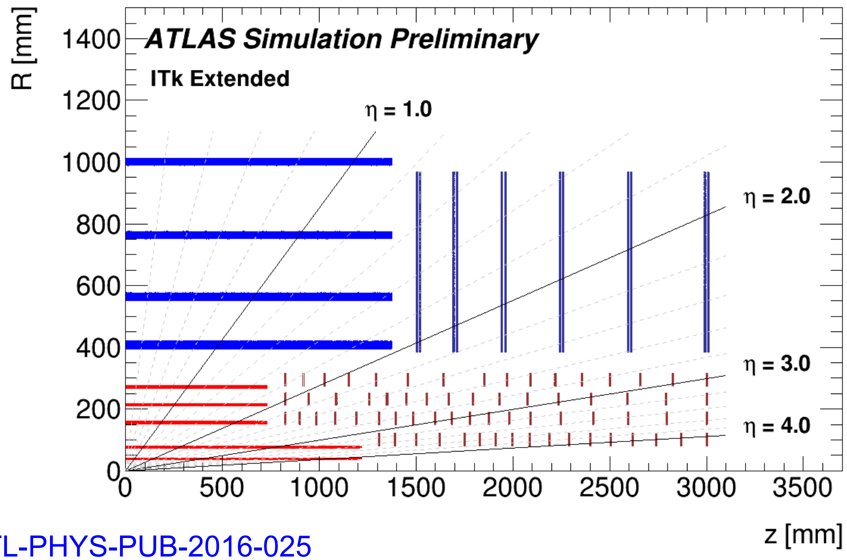
HL-LHC ATLAS upgrade (Phase II)

ATLAS Inner tracker (ITk) upgrade

- LHC is expected to deliver pp collisions with ~ 1 x 10^{34} cm^{-2} s^{-1} until 2023 (~ 300 fb^{-1} would be achieved)
- HL-LHC will operate with up to **7.5 x 10^{34} cm^{-2} s^{-1}** after phase II upgrade
  - current ATLAS Inner detector will be replaced with all silicon (pixel and strips) detector tracker (ITk)
  - cope with high fluences (up to **~10^{15} n_{eq}/cm^2**) and high pile-up environment (up to **<μ> ~ 200** on average)
- DESY is heavily involved in ITk upgrade:
  - ITk simulation and tracking performance studies
  - instrumentation of ITk strip tracker (large contribution from DESY for end-cap strip tracker)



ITk tracking overview



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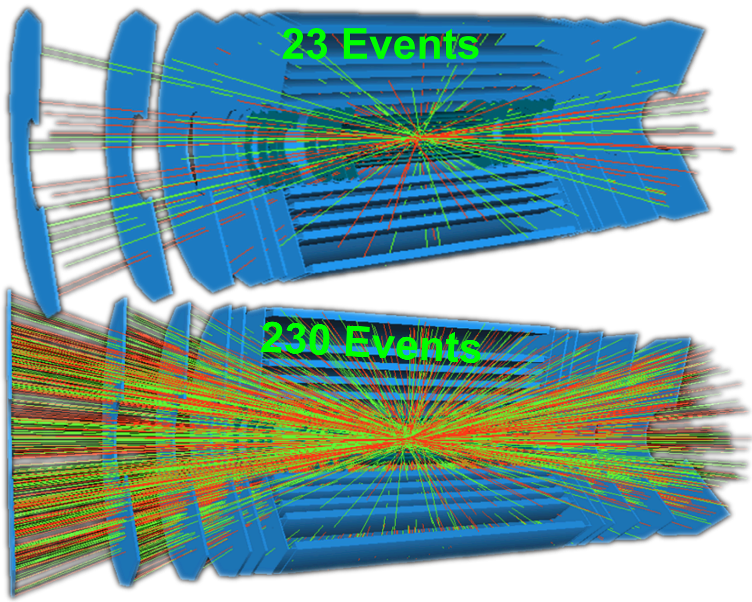
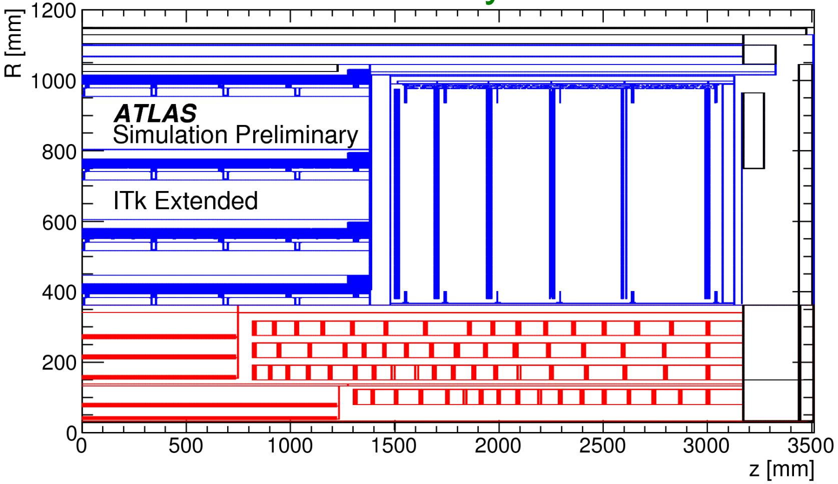


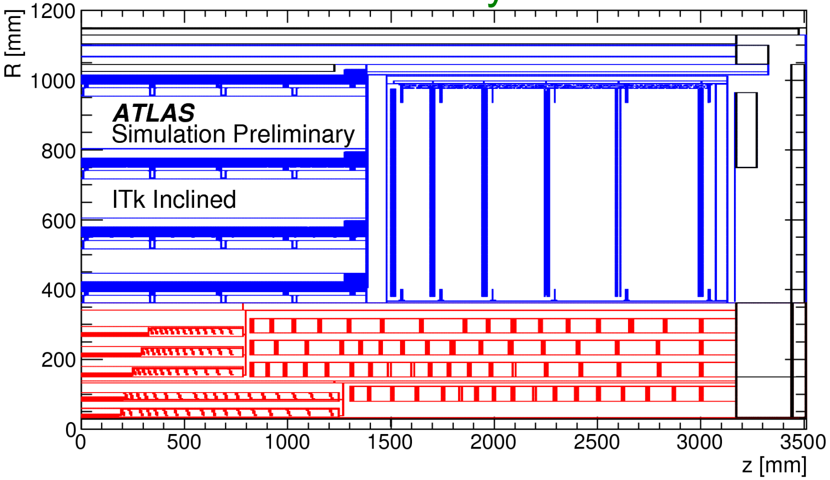
- ITk is designed to allow uniform coverage for tracking up to |η| = 4
  - reduce pile-up jets in the forward region by using tracking information
- Less material is envisaged in the path of charged particle to reduce multiple Coulomb scattering
- Improved precision measurements of track parameters
  - ≥ 13 clusters per track on average in central |η|

Simulation of ITk upgrade layout

Extended layout



Inclined layout



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> Simulation of two candidate layouts for ITk

- differences in pixel system; 'Extended' and 'Inclined' concepts under consideration

> Simulation of strip system includes Petal-based end-caps and full description of strip sensor design

> More accurate and detailed material description in ITk simulation

- will provide input into Strip Technical Design Report (TDR)

ITk tracking performance

> Updated track reconstruction for ITk
  - carried out performance studies based on MC simulations
  - including full HL-LHC beam conditions

> Excellent performance obtained
  - comparable or improved to current Inner Detector despite much more challenging environment
  - still more improvement expected as reconstruction software improves further

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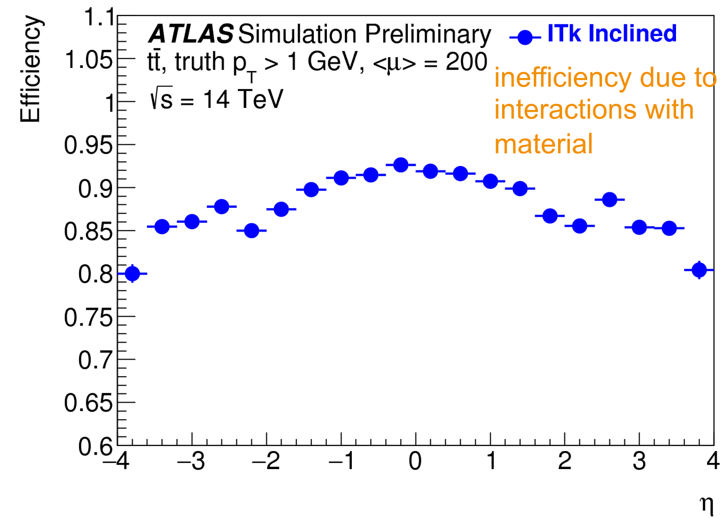
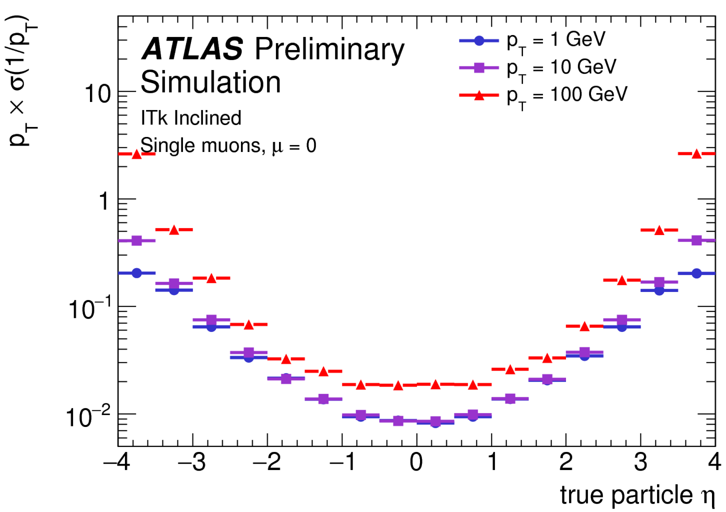
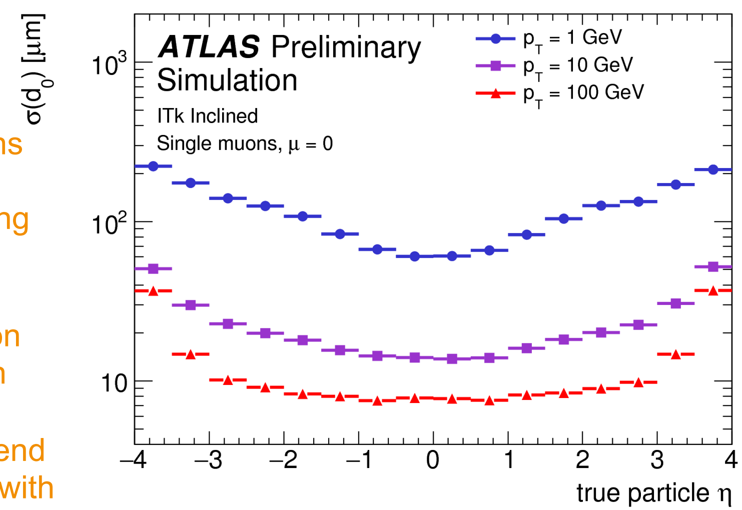




Track parameter resolutions degrades with p_T due to multiple Coulomb scattering for softer tracks

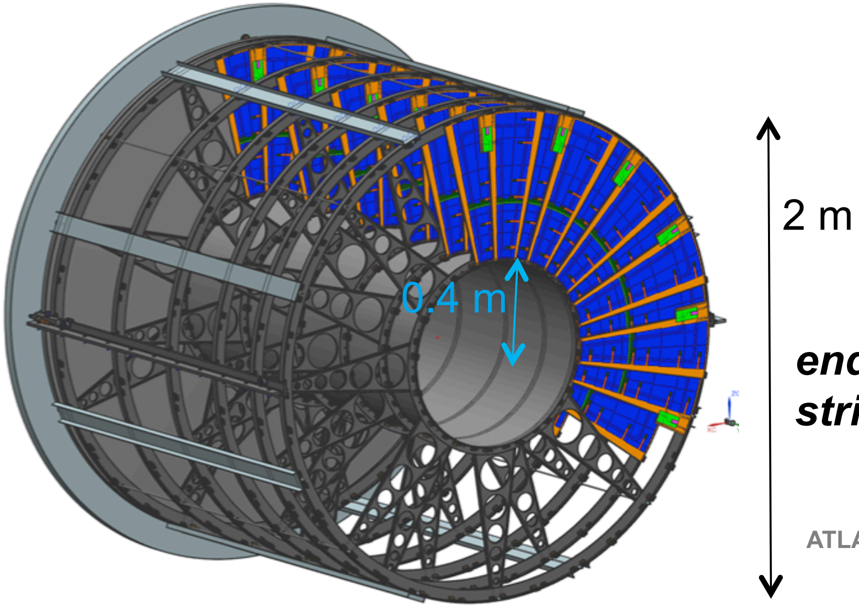
Resolution also depends on intrinsic detector resolution

Curvature resolutions depend on the length of lever arm with respect to magnetic field

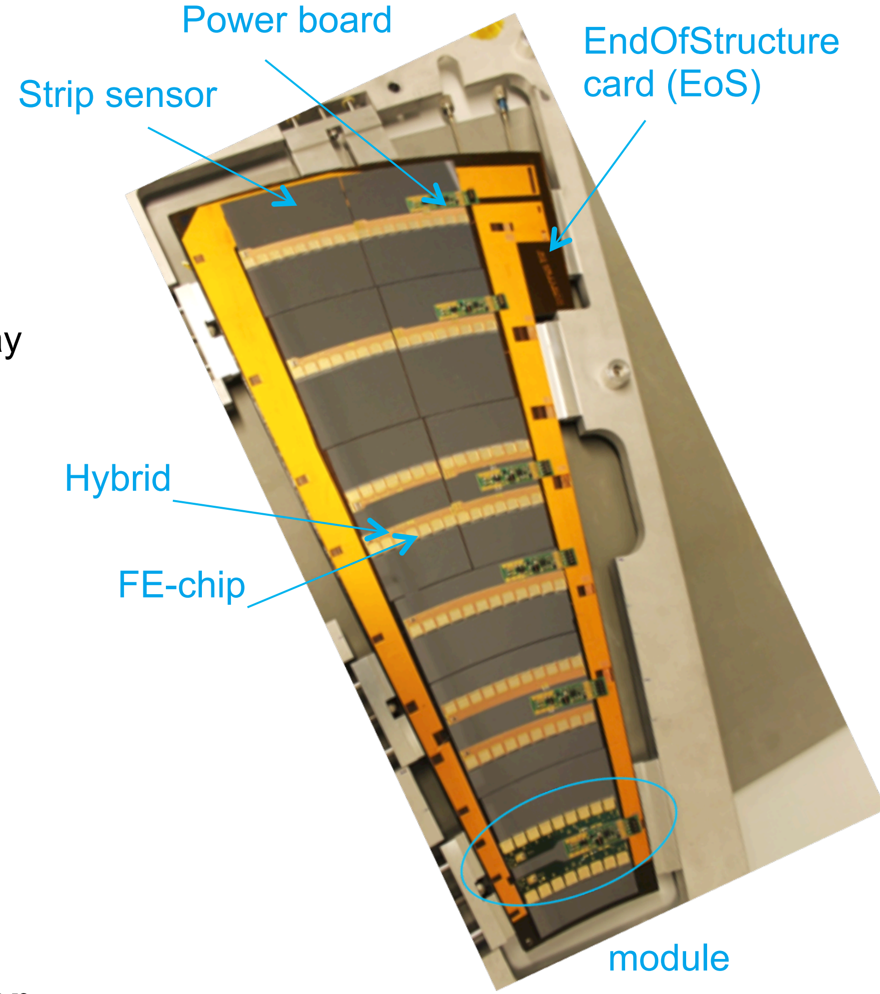


ITk strip instrumentation

- Strip sensors (320 µm thickness) mounted on petals in end-cap discs
  - 9 modules (petalets) per Petal; 32 Petals per disc; 6 discs each side
  - radiation hardness to 2 x 10^{15} n_{eq}/cm^2
- DESY contributes for end-cap Strip tracker
  - characterization studies for module/sensor using X-ray facilities and Test beam telescope, support structure design, module assembly, etc…
  - one end-cap is assembled at DESY
  - leadership in preparing ITk TDR



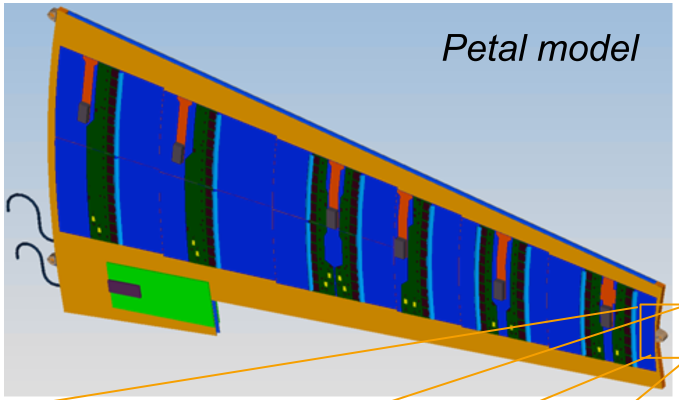
end-cap strip tracker

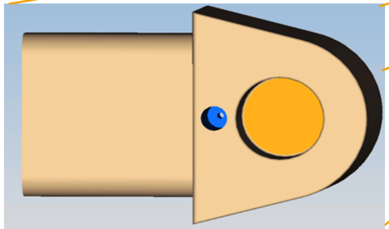


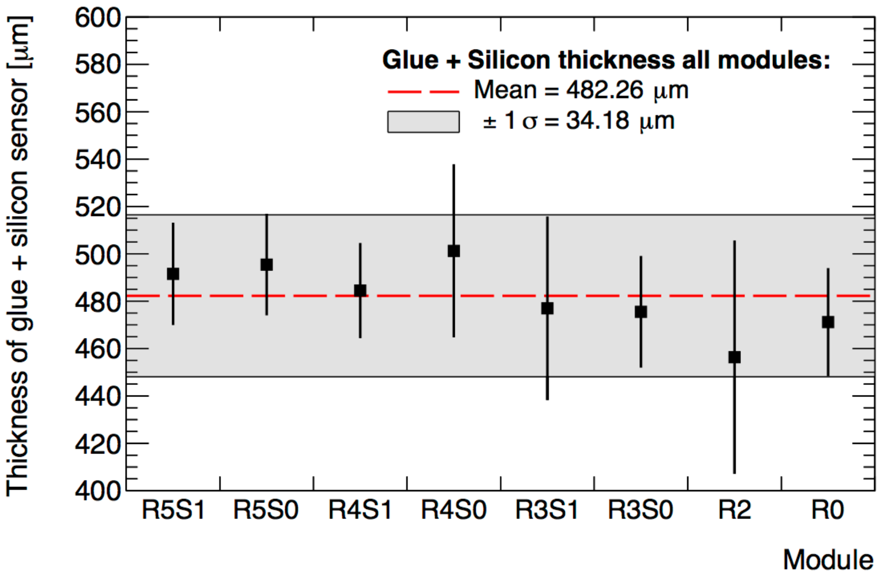
Thermo-mechanical Petal prototype

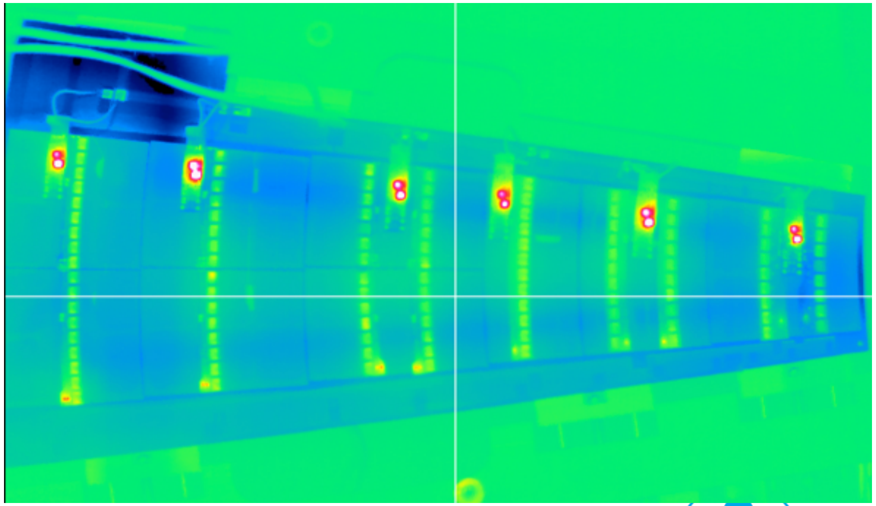
Petal model and thermo-mechanical Petal prototype

- Petal model is being refined based on the studies with real samples
- Full thermo-mechanical (TM) Petal are built
  - TM modules built in Zeuthen, Petal assembly and test in Hamburg
- First preliminary automated IR measurements using custom thermal chamber
- Optical inspection with CNC Smartscope



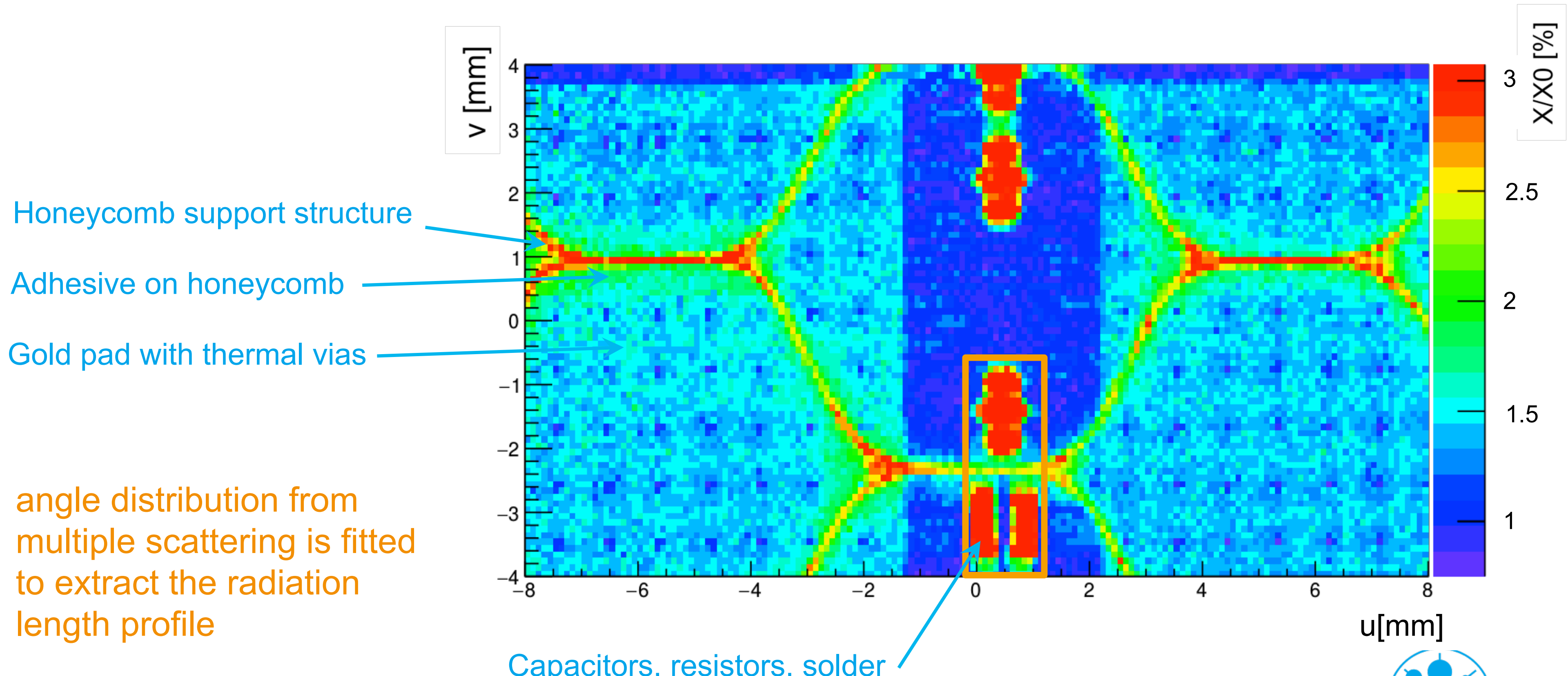






X/X0 measurements of TM module on support structure

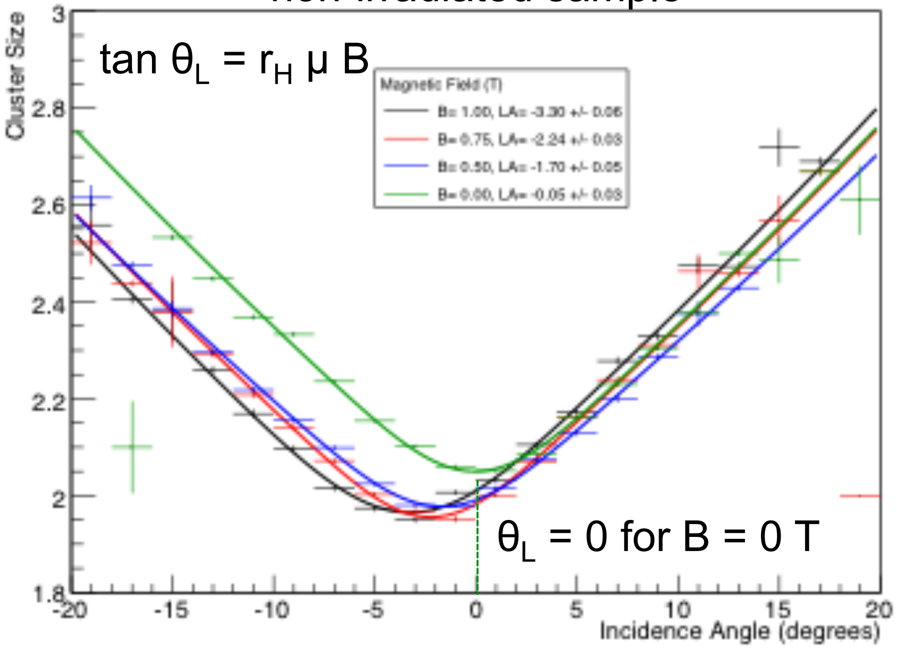
- DESY testbeam telescope (DURANTA) is used to determine radiation length X/X0 profile of
  - material with unknown radiation length (carbon foam, carbon fibre sheets)
  - petal-like structure (silicon strip module on mechanical support structure)



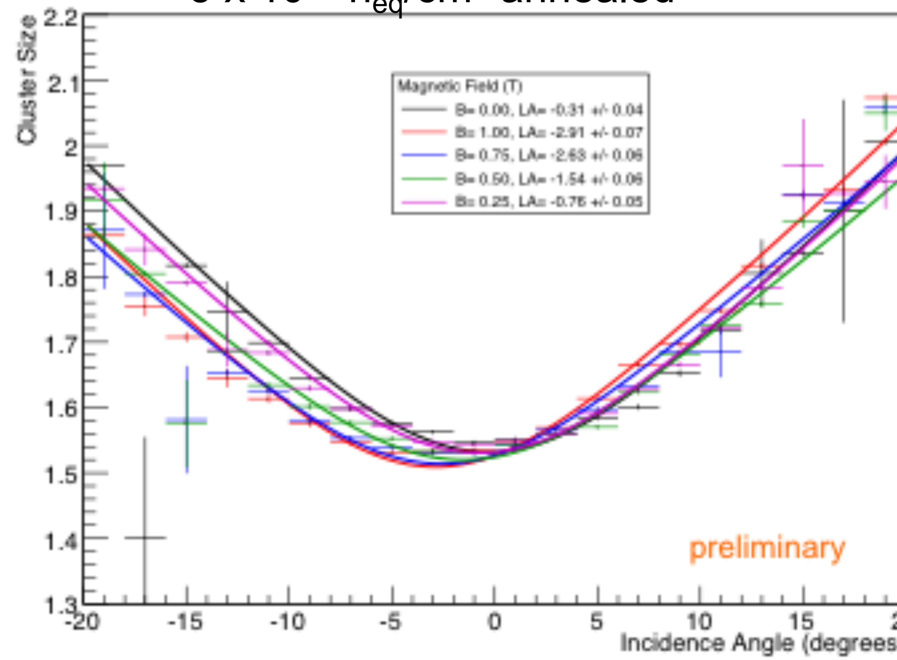
angle distribution from multiple scattering is fitted to extract the radiation length profile

Lorentz angle (θ_L) measurements

non-irradiated sample



5 x 10^{14} n_{eq}/cm^2 annealed



- Measured Lorentz angle in test beam (non-irradiated and irradiated sensors at up to 1 T)
- Results for non-irradiated samples in agreement with existing model calculations
- Difficulty for measurement with irradiated samples due to reduction in signal
  - but behavior in agreement with expectations
- In general:
  - effect of Lorentz angle on cluster size is small for higher fluences
  - digital readout with higher thresholds in ITk strip will reduce the effect of Lorentz angle on tracking, especially for higher irradiation levels

Summary

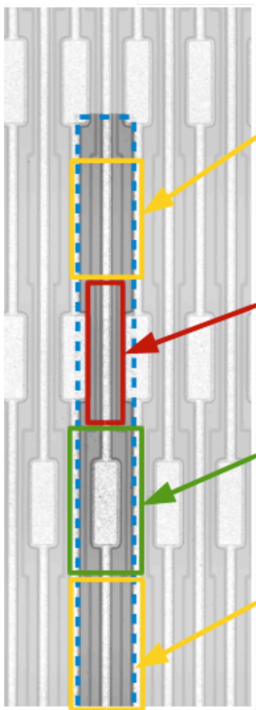
- Excellent performance of the ATLAS detector in operation at higher instantaneous luminosity than ever before
  - ~ 33 fb^{-1} data already on tape, could be above 35 fb^{-1} in ~10 more days
- Rich physics program within ATLAS group at DESY covering various key aspects
  - first results toward the measurement of the Yukawa coupling in ttH channel
  - differential measurements of top pair production sensitive to the QCD modeling
  - started to improve and expand these measurements with full Run 2 dataset
- Progressing well on ITk upgrade
  - good track reconstruction performance in ITk simulation already achieved
  - prototype module/sensor characterization and behavior after irradiation are consistent with expectations
  - preparation for production ongoing
- Several milestones to achieve next year for both physics data analysis and ITk upgrade

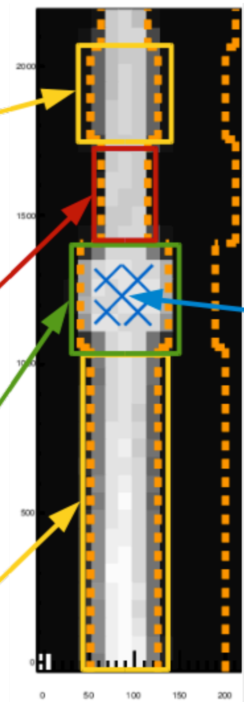
THANK YOU

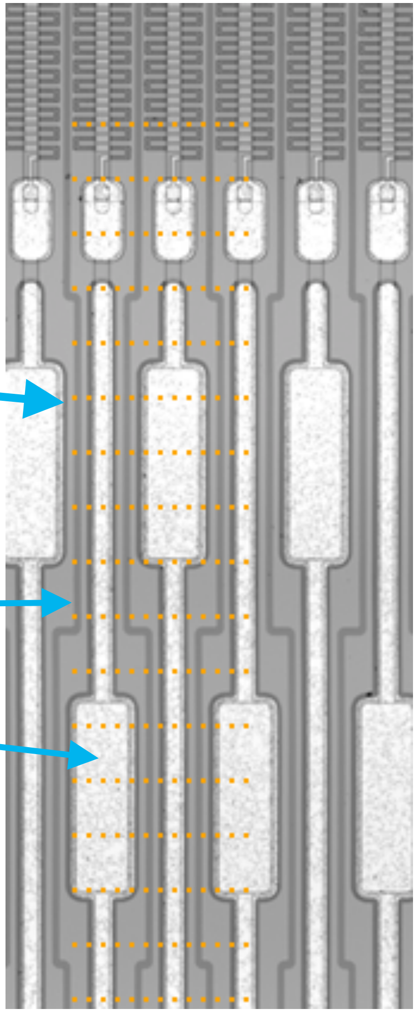
Sensor strip response studies

- Measurements at Diamond Light Source
- Study sensor strip response in a sensor region with bond pads
- Micro-focused X-ray beam (2 x 3 μm^2) pointed at sensor, number of hits collected for constant number of triggers

Collected hits over a grid of (0.2 x 2 mm)

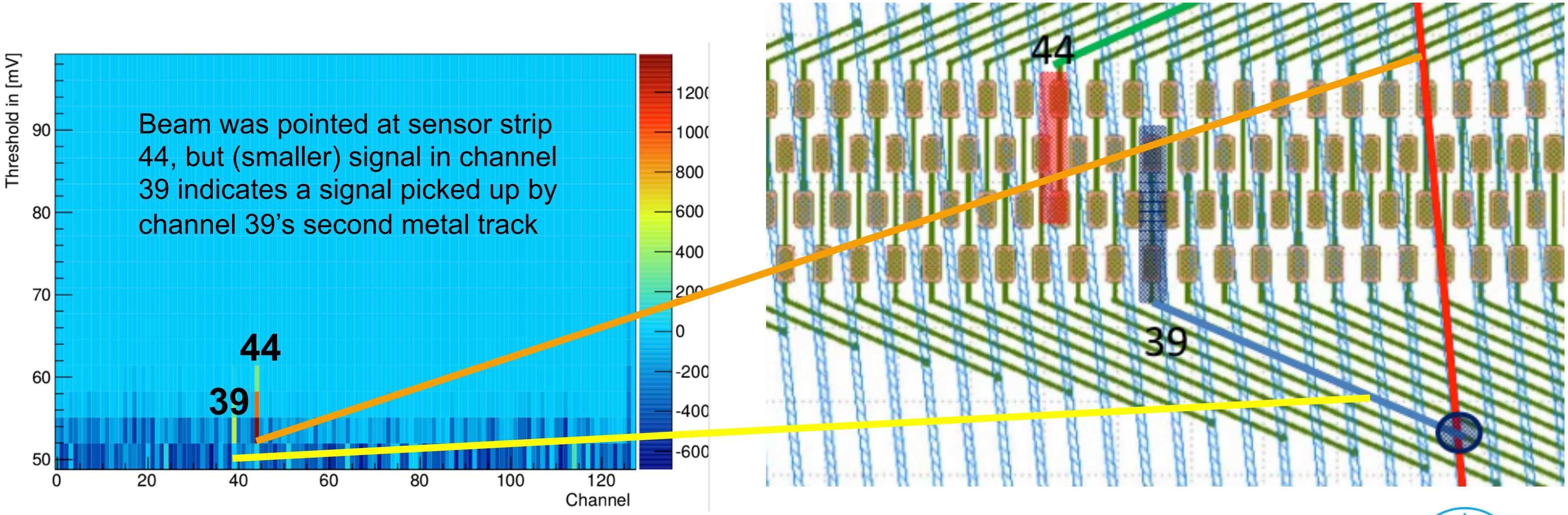






Sensor with embedded pitch adapters

- Investigate alternative sensor layouts with second metal layer (embedded pitch adapters)
- Studies of irradiated sensor modules in micro-focused X-ray beam at Diamond Light Source
  - collaboration with CNM
- Investigate impact of second metal layer on sensor performance (pick-up, cross-talk) as seen for similar sensors (e.g. LHCb Velo)

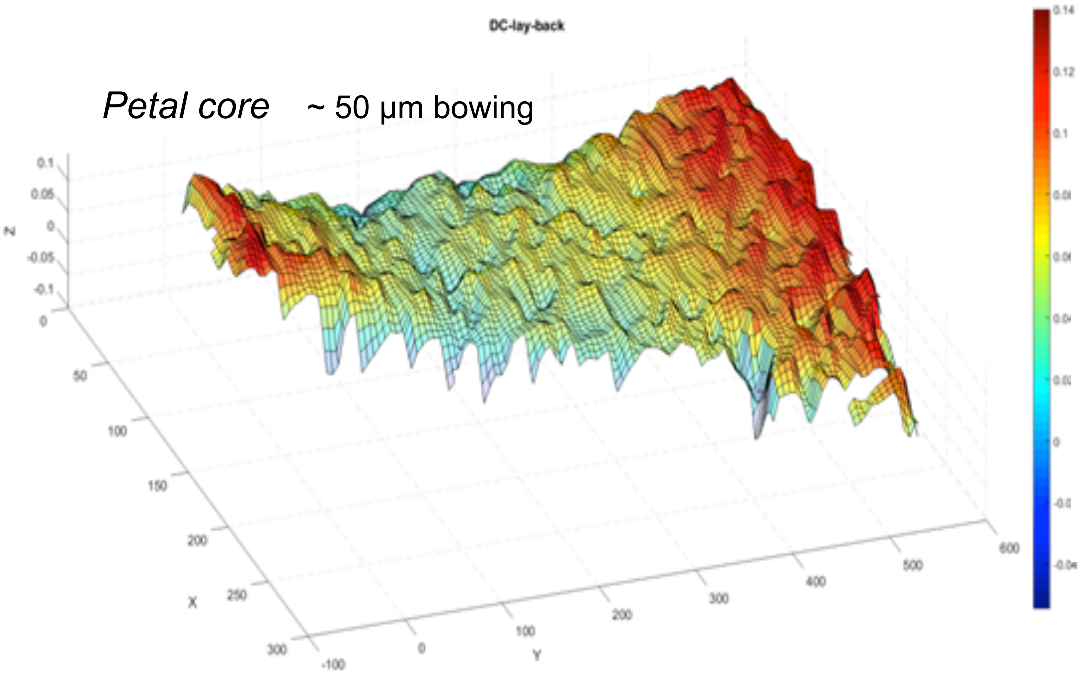


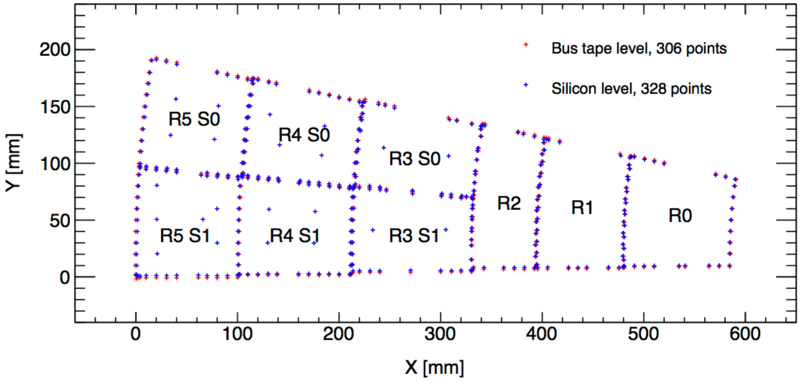
Petal alignment measurements

- SmartScope is used for mechanical quality control of cores and petal components
- Height measurements at various points in xy-plane of modules/petal
  - location of modules on core
  - module-to-core glue thickness
  - petal core flatness
  - C-channels thickness, planarity

New CNC 670 SmartScope at Hamburg

Petal core ~ 50 µm bowing





DESY

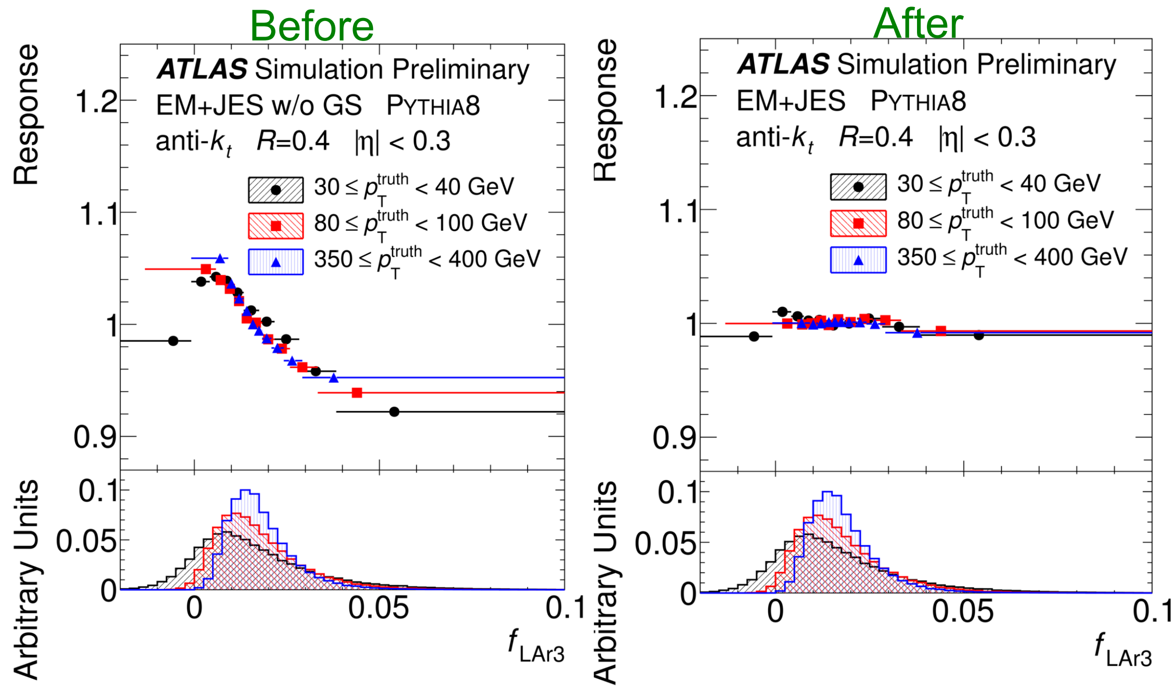
Jet calibration

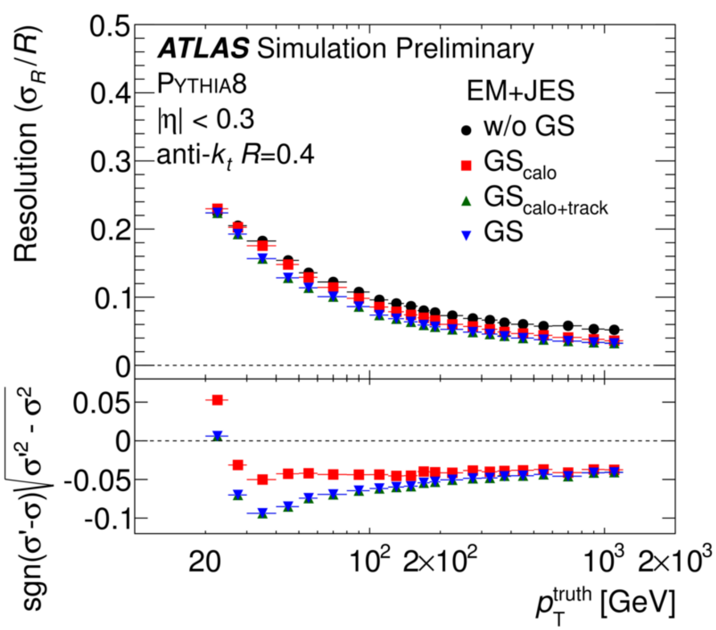
Jet calibration is critical to many ATLAS analyses

> DESY contributes in improving jet response

> Employ MC based correction on jets

- example: correct jet response based on charged particle fraction





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> After a few global sequential (GS) corrections, based on different variables, clear improvement in the jet resolution

> Calibration is used in almost all analyses involving jet selection