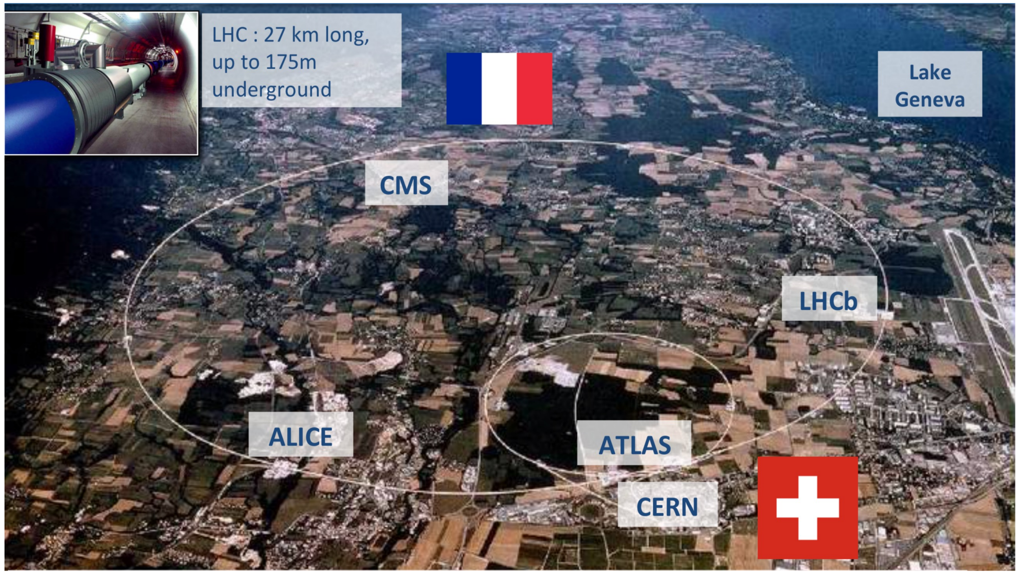
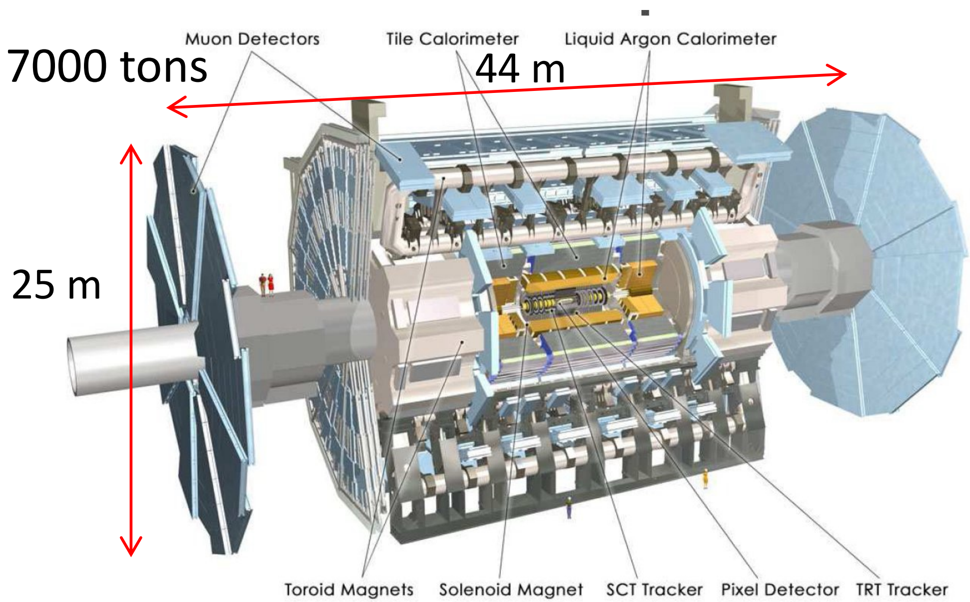
Academia Sinica at the ATLAS Experiment

AAC Meeting
June 2025

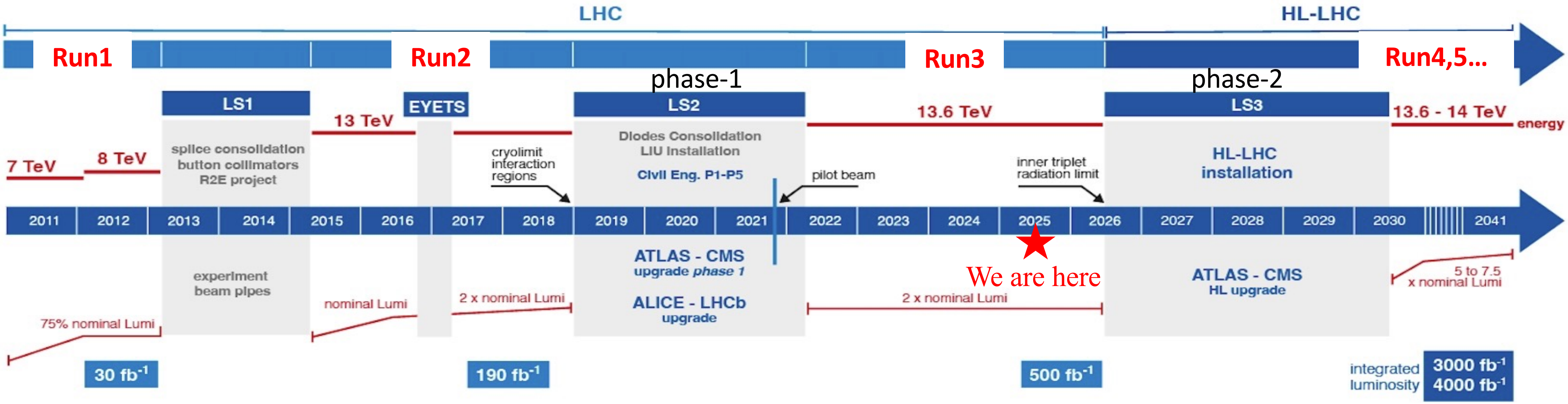
Song-Ming Wang
On behalf of the AS/ATLAS group

ATLAS Experiment



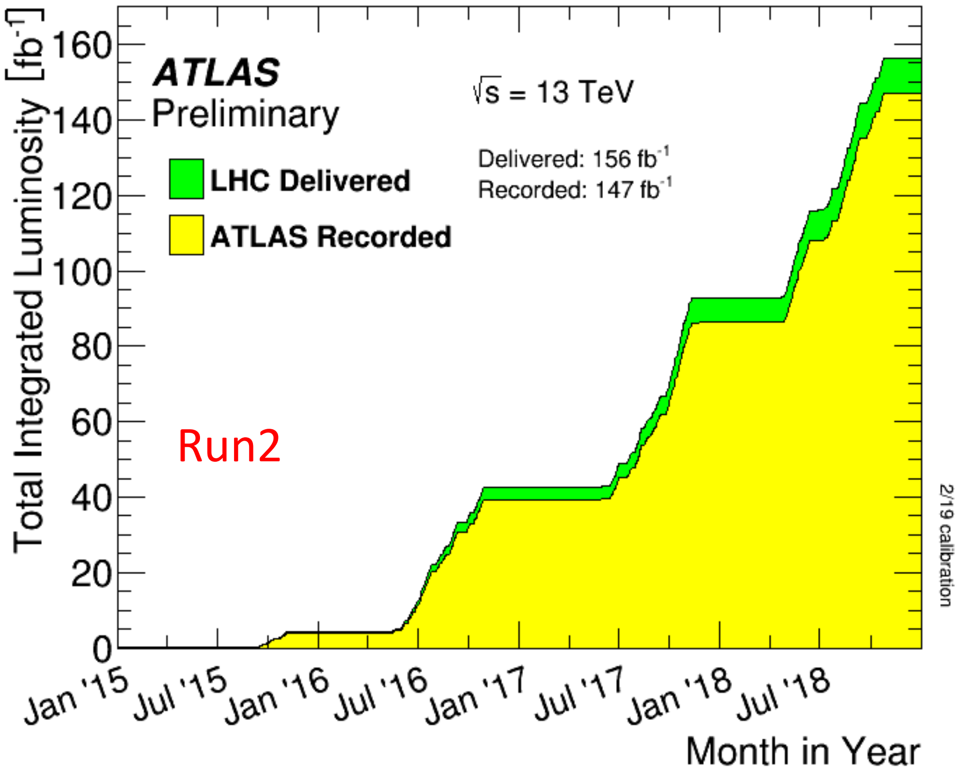


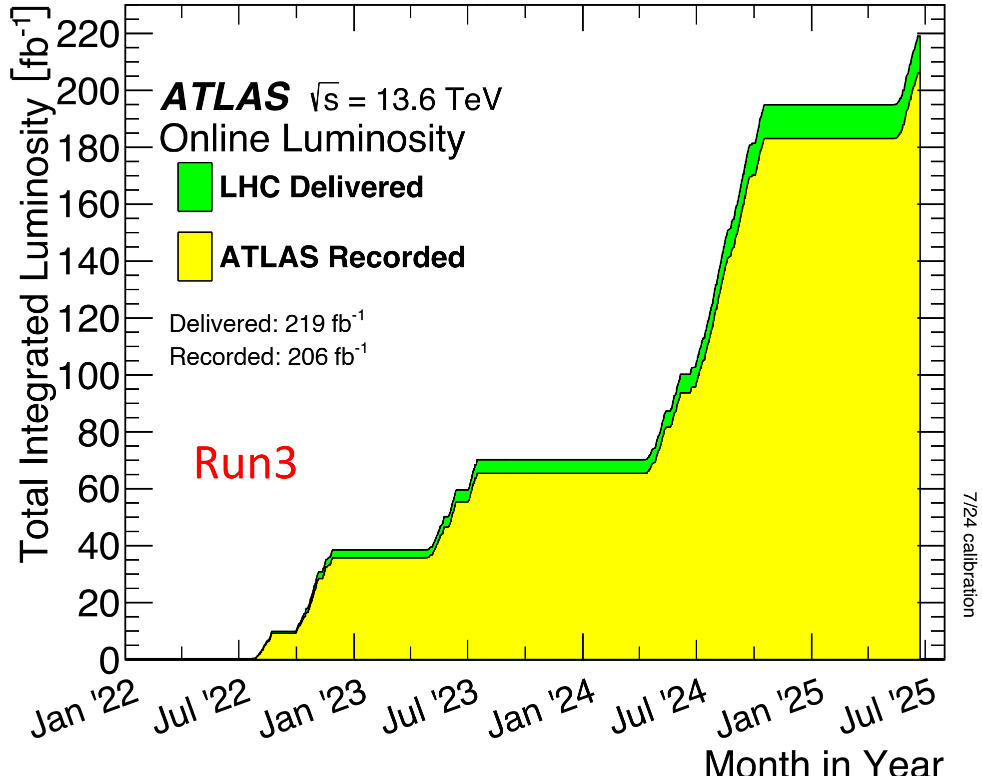
- ATLAS collaboration: ~3000 physicists



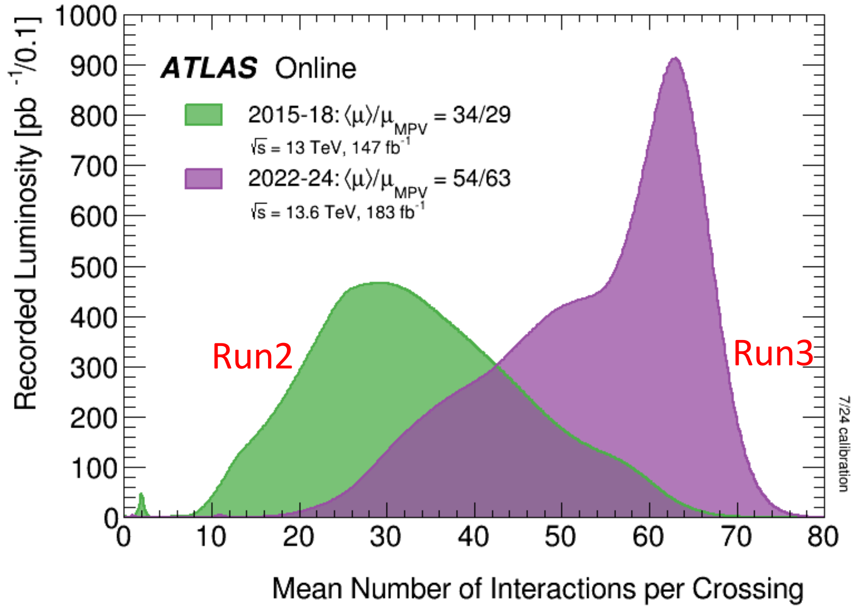
- First pp collision on Nov 23rd 2009
- Commissioning run in 2010
- Run1: 2011-2012 ($\sqrt{s}$=7,8 TeV)
- Run2: 2015-2018 ($\sqrt{s}$=13 TeV)
- Run3: 2022-2026 (June) ($\sqrt{s}$=13.6 TeV)

ATLAS Run2 & Run3





- **Run2:**
  - Recorded 147 fb-1, ~140 fb-1 good for physics
- **Run3:**
  - Recorded lumi already exceeded Run2
  - One more year of data taking!
  - Expected data size ~2X Run2
  - Average pileup ~60% higher than Run2



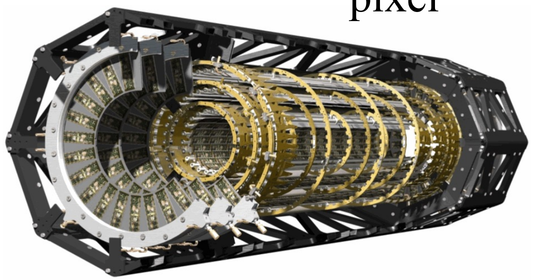
AS in ATLAS During Early Years

- Academia Sinica joined ATLAS in 2000
  - Participated in detector construction
  - setup Tier-1,2 centers at ASGC, provide distributed computing service for ATLAS
  - Conduct detector performance studies with testbeam and early pp collision data

Hardware :

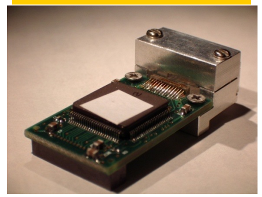
Tier-1,2 centers at ASGC

pixel

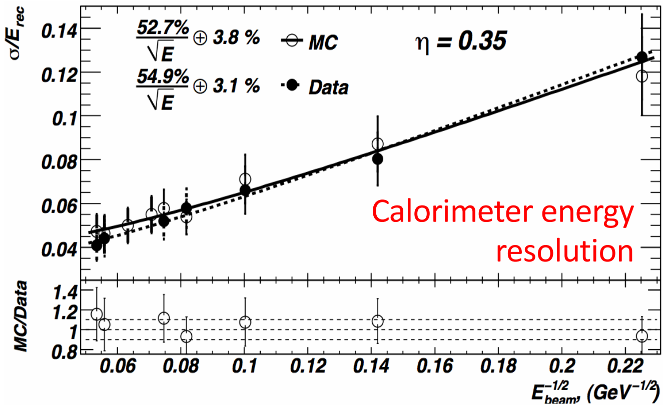


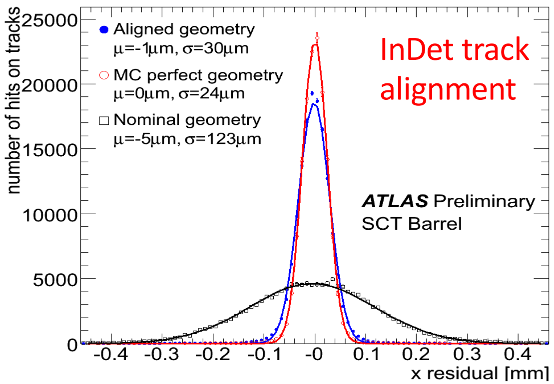
RX module

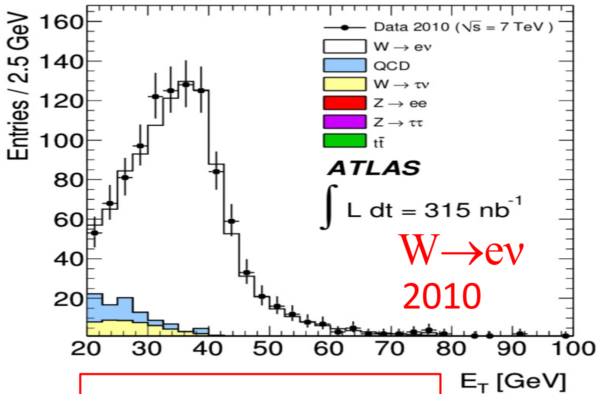
TX module



- Optical readout modules for Pixel, SCT, LAr
  - Covering ~98% of all ATLAS readout channels



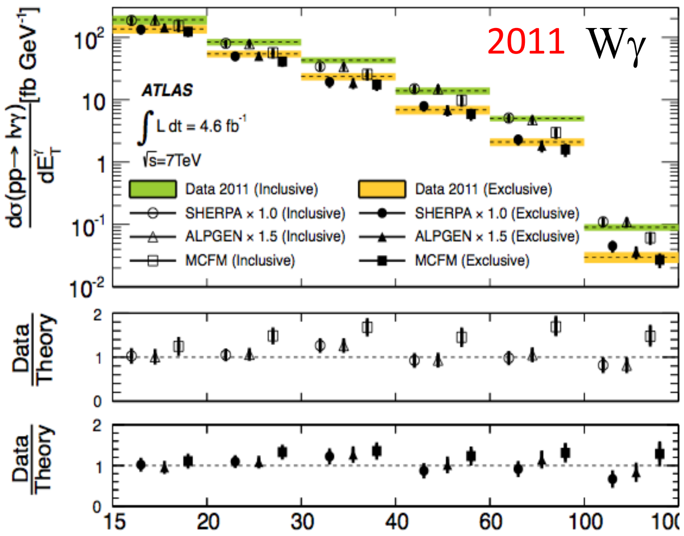


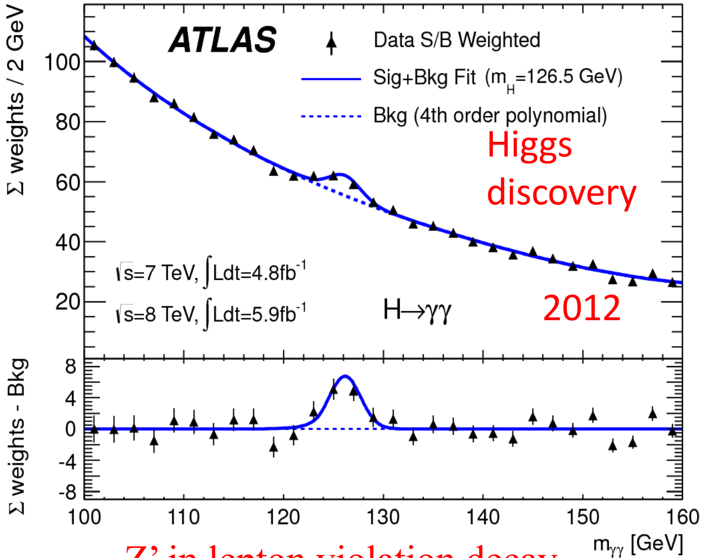


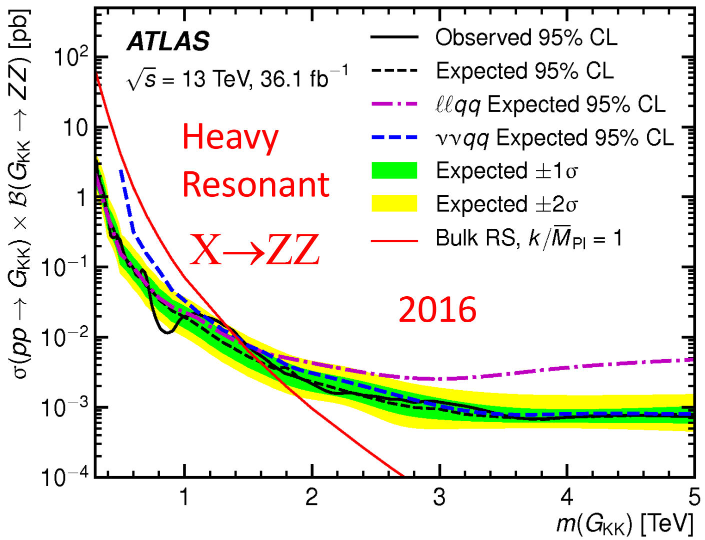
JHEP 12 (2010) 060

AS in ATLAS During Early Years

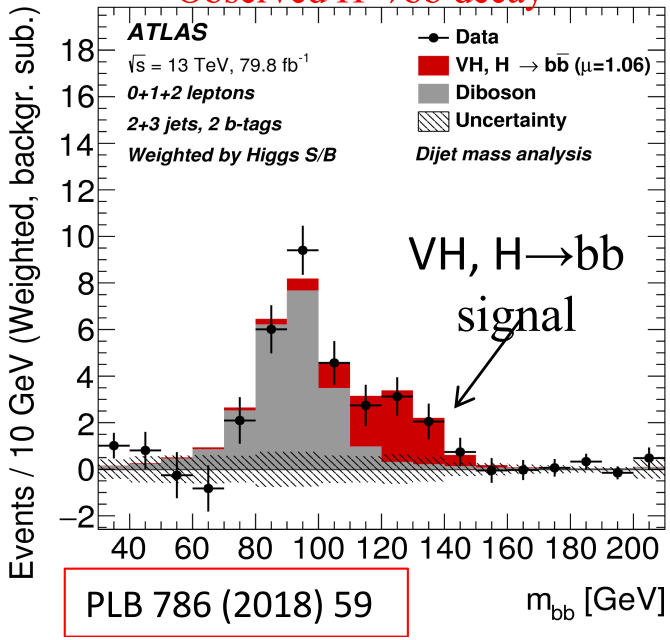
- Data analyses
  - Performed Standard Model measurements, contributed to the Higgs boson discovery, and new physics searches





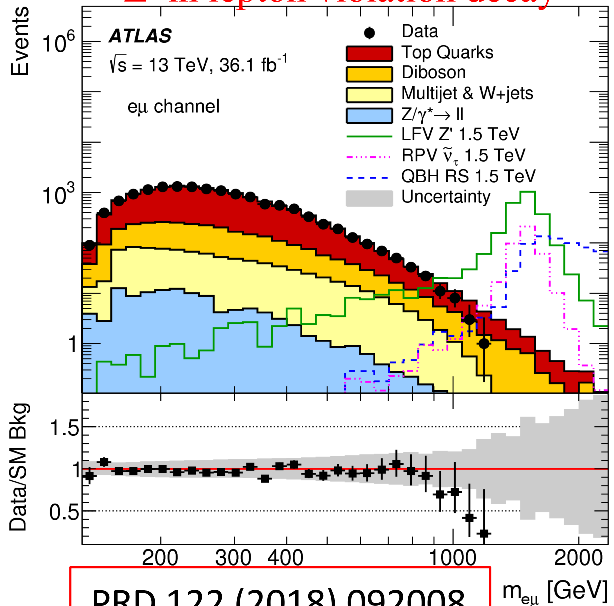


Observed H→bb decay



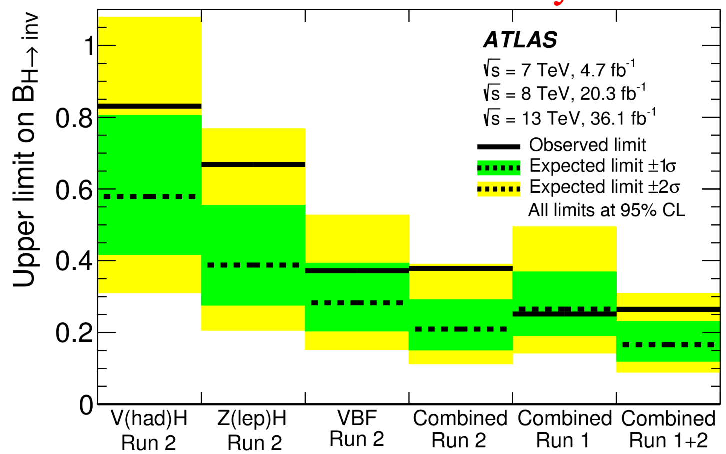
PLB 786 (2018) 59

Z' in lepton violation decay



PRD 122 (2018) 092008

H→invisible decay



PRL 122 231801 (2019)

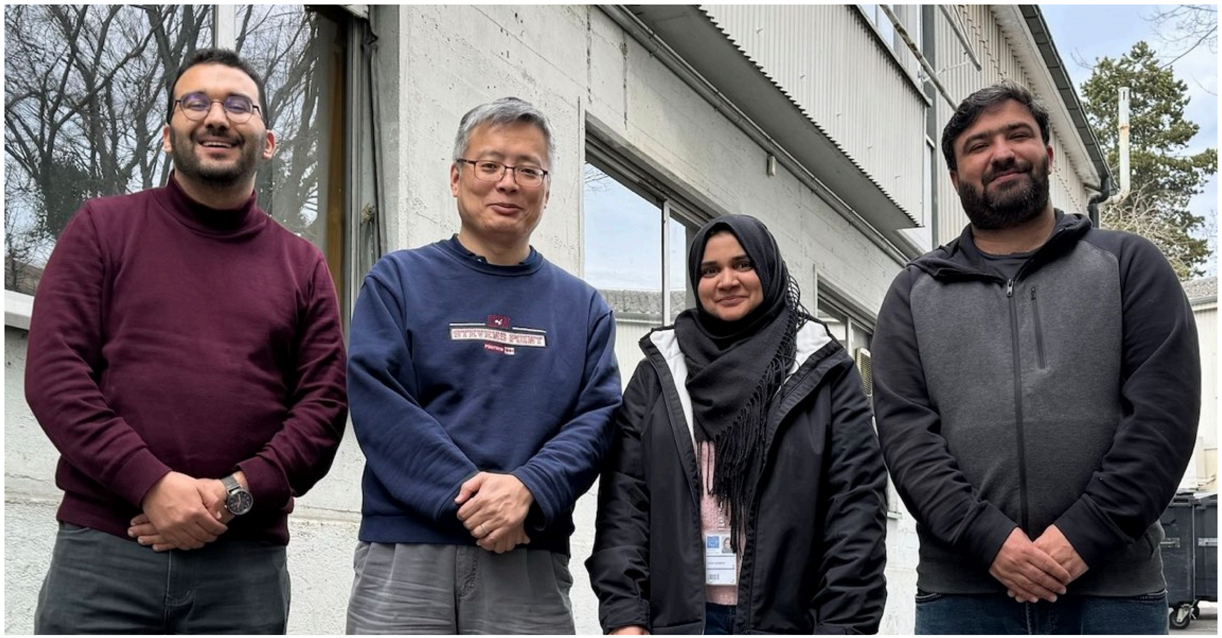
Current AS Members in ATLAS

Suen Hou

Yun-Ju Lu

Yi Yang
(New faculty
joined in 2024)

Pu-Kai Wang (postdoc), Roger Bing-Hong Pan (research assistant), David Ta-Yu Chen (PhD student), Kuan-Yu Huang, Guang Ting Chen (master students)



Ijaz Ahmad (PhD student)

(Left to Right): Salah-Eddine Dahbi (postdoc), Song-Ming Wang, Kiran Farman (PhD student), Shahzad Ali (PhD student, graduated in 2024)

Highlights of AS in ATLAS in the Last Five Years

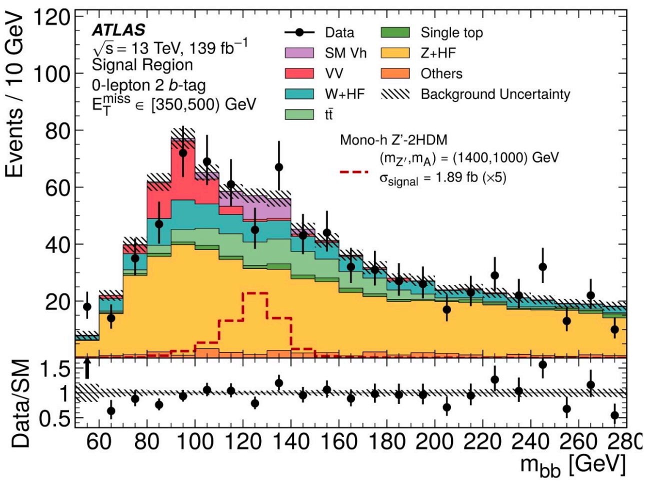
Data Analyses

Dark Matter Search in 2HDM extension models

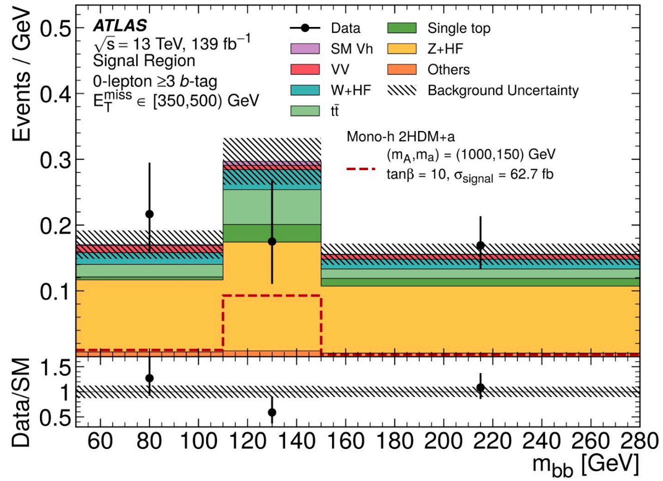
- Collaborated with UMich and USTC on SM boson (Z), Di-boson (ZZ) final state measurements, and SUSY searches
- Recently: Search dark matter production in association with a Higgs boson
- Dark matter un-detected, and assume $H \rightarrow bb$ decay
    - Missing E_T + ≥2b-jets signature
- Data consistent with SM
- Interpret results in Z'+2HDM and 2HDM+a benchmark models
- Group member was convenor for 2HDM+a topic

JHEP 11 (2021) 209

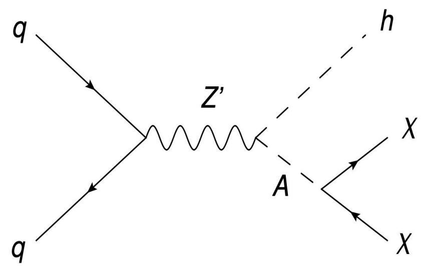
2bjets, 350<MET<500 GeV



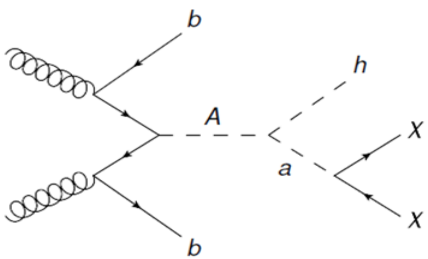
3bjets, 350<MET<500 GeV



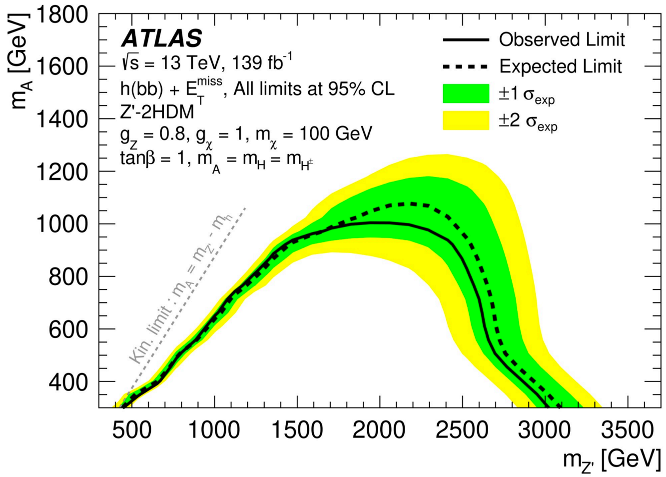
Z'+2HDM



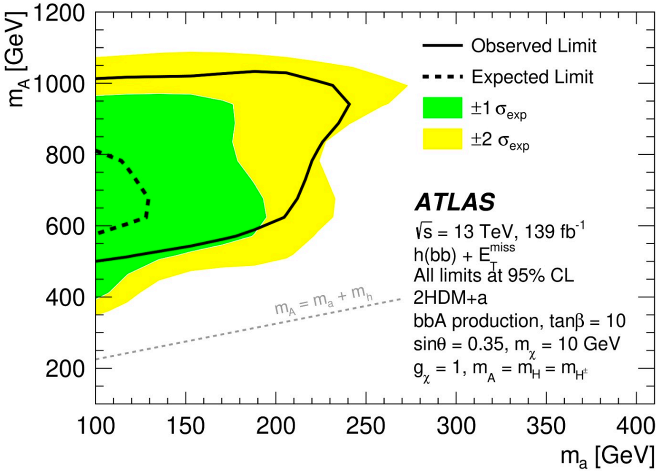
2HDM+a



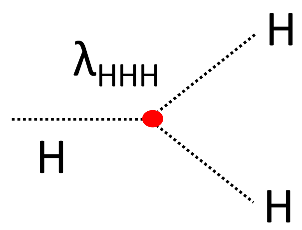
Z'+2HDM



2HDM+a



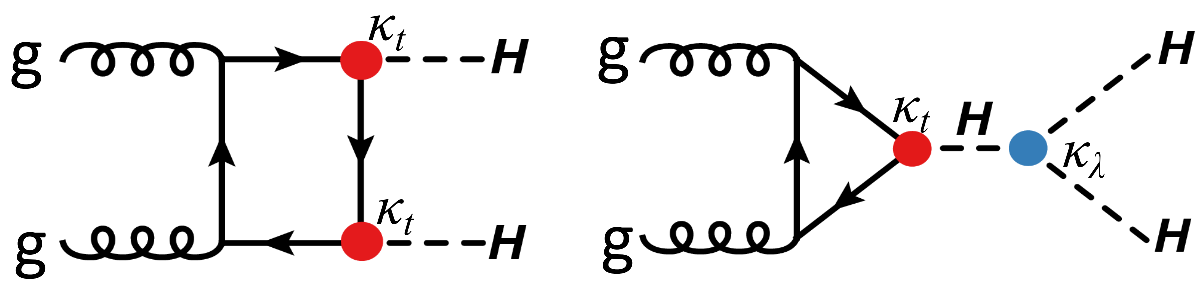
Higgs Boson Pair Production

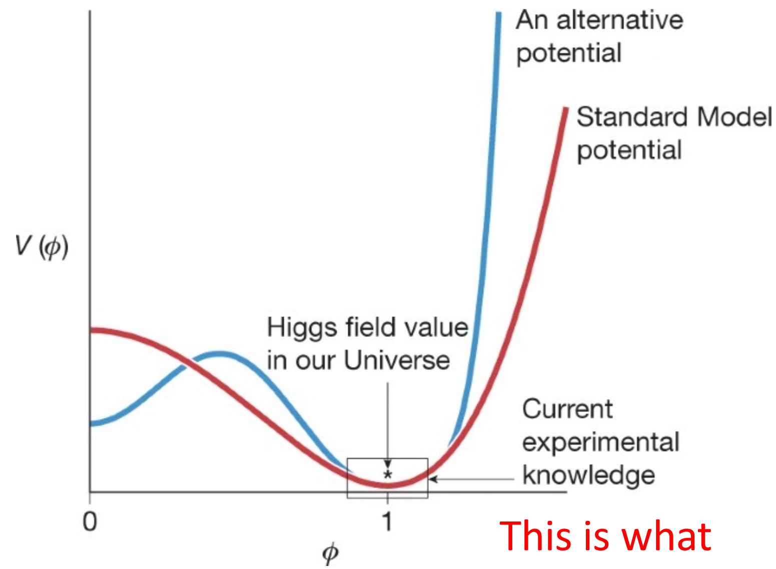


- Higgs pair production provides direct measurement of Higgs boson self-coupling λ_{HHH}
  - Determine the shape of the Higgs potential, connected to phase of early universe from unbroken to broken electroweak symmetry
- HH pair produced predominantly through gluon fusion (ggF)

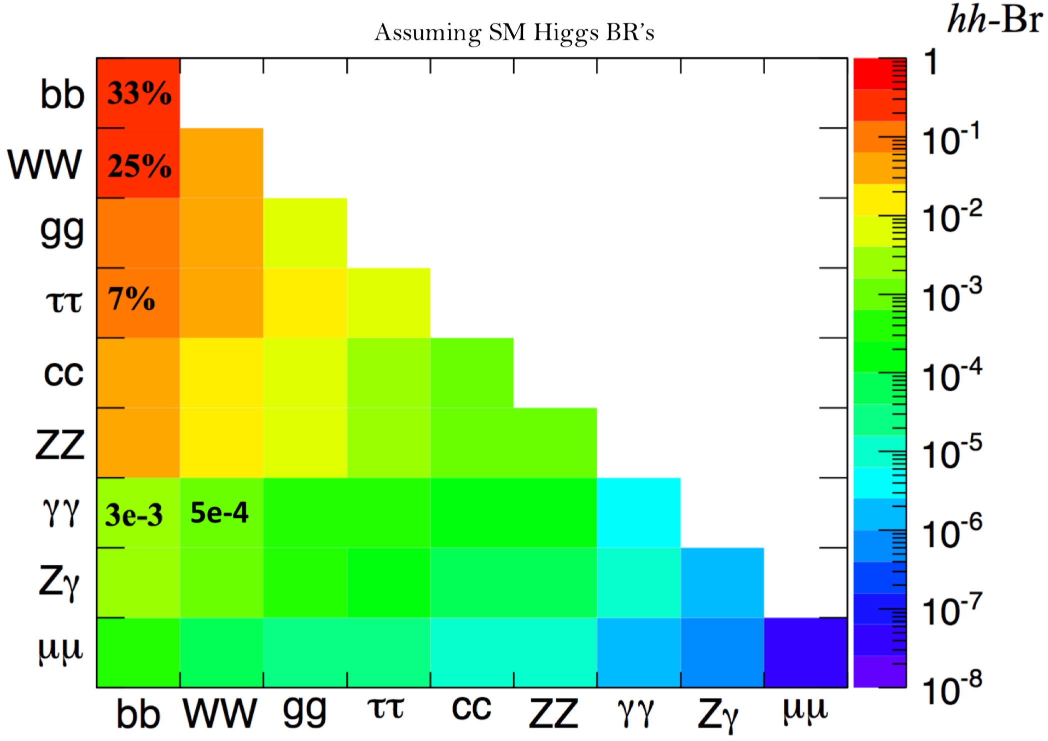
$$\kappa_\lambda = \frac{\lambda_{HHH}}{\lambda_{HHH}^{SM}}$$

(SM:=1, BSM: ≠ 1)





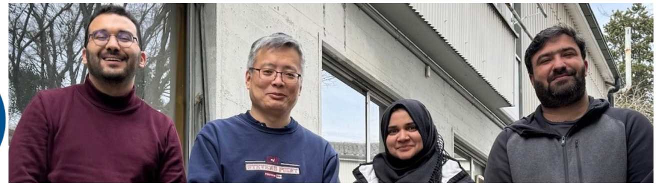
This is what we know



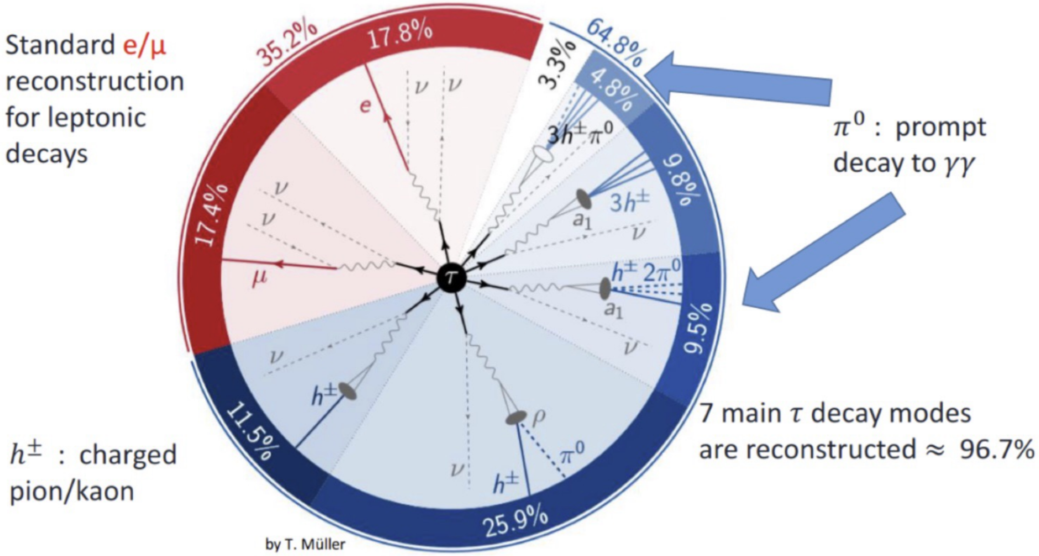
Most sensitive channels :

- HH→bbbb : highest BR (~33%), large BG from multi-jets
- HH→bbγγ : clean, but small BR (~0.3%)
- HH→bbττ : moderate BG and BR (~7%)

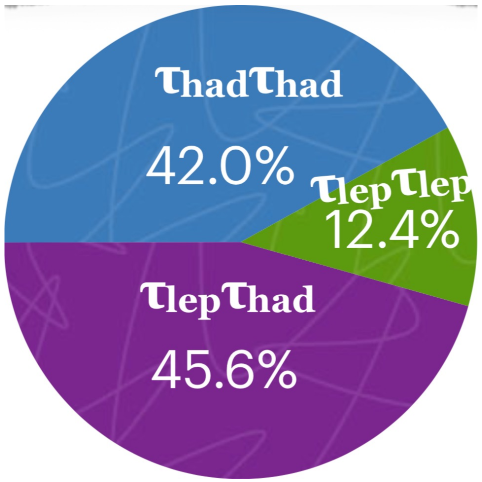
HH→bbττ Search

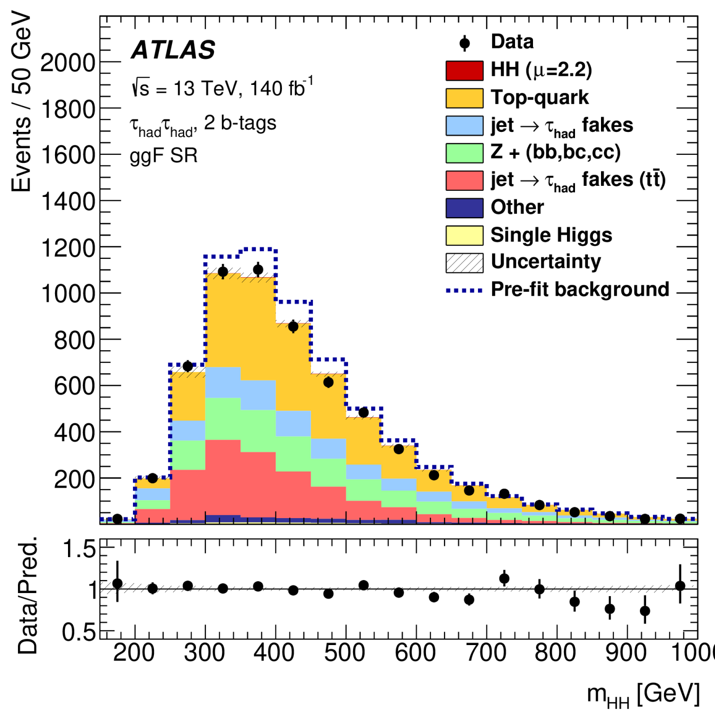


- Tau decay:
  - ~35% leptonic decay (e, μ + neutrinos)
  - ~65% hadronic decay



- Select di-tau decays :
  - $\tau_{lep}\tau_{had}$, $\tau_{had}\tau_{had}$ (opposite charged)



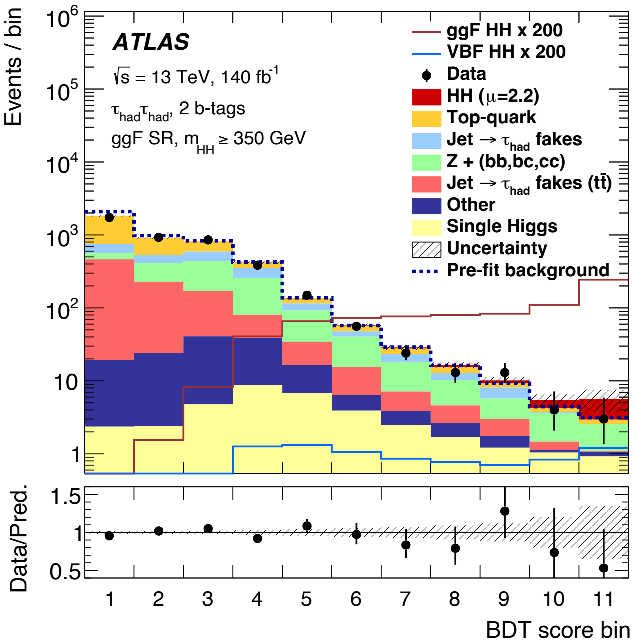


- Main background:
  - true τ_{had} : ttbar, Z+jets, single Higgs
  - fake τ_{had} : jets faking as tau in ttbar and multi-jet
    - Estimate jet faking tau rates in control regions

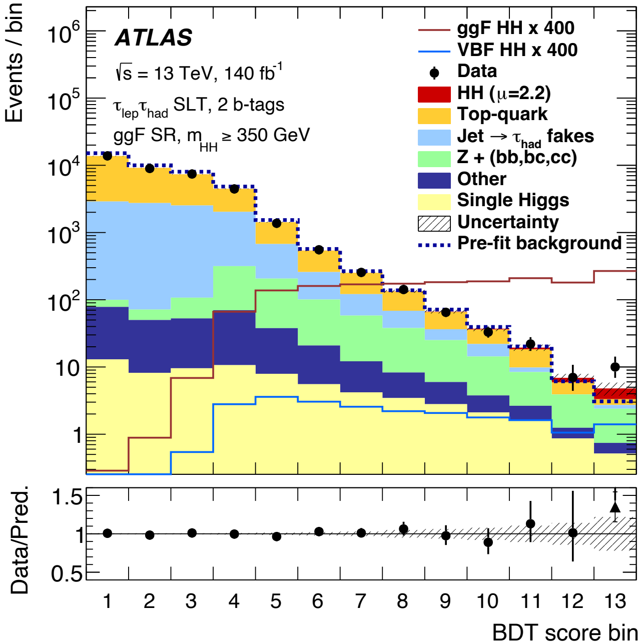
HH→bbττ Search

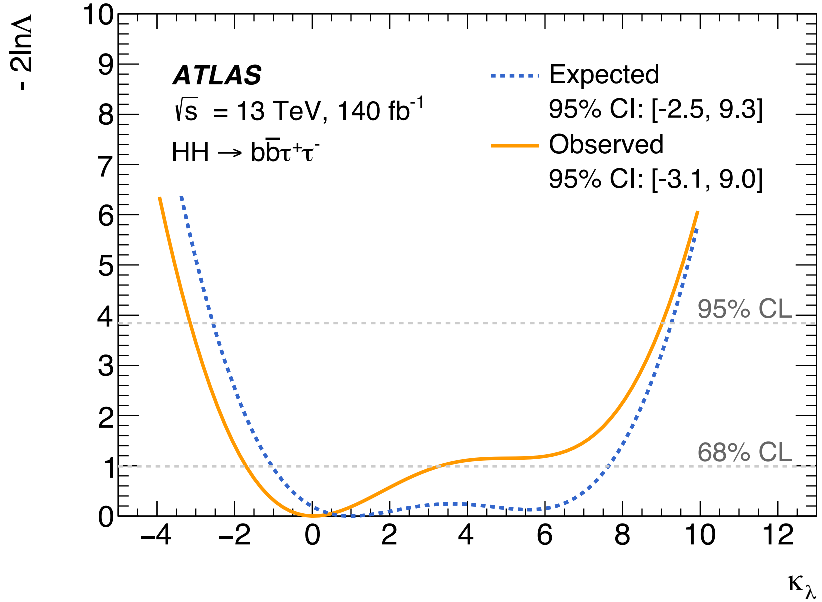
- Re-analyzed full Run2 data sample, introduced new improvements
  - Optimized event classification to enhance sensitivity to κ_λ
  - Improved machine learning training to increase sensitivity to SM HH production

hadhad, ggF, high mHH



lephad, ggF, high mHH



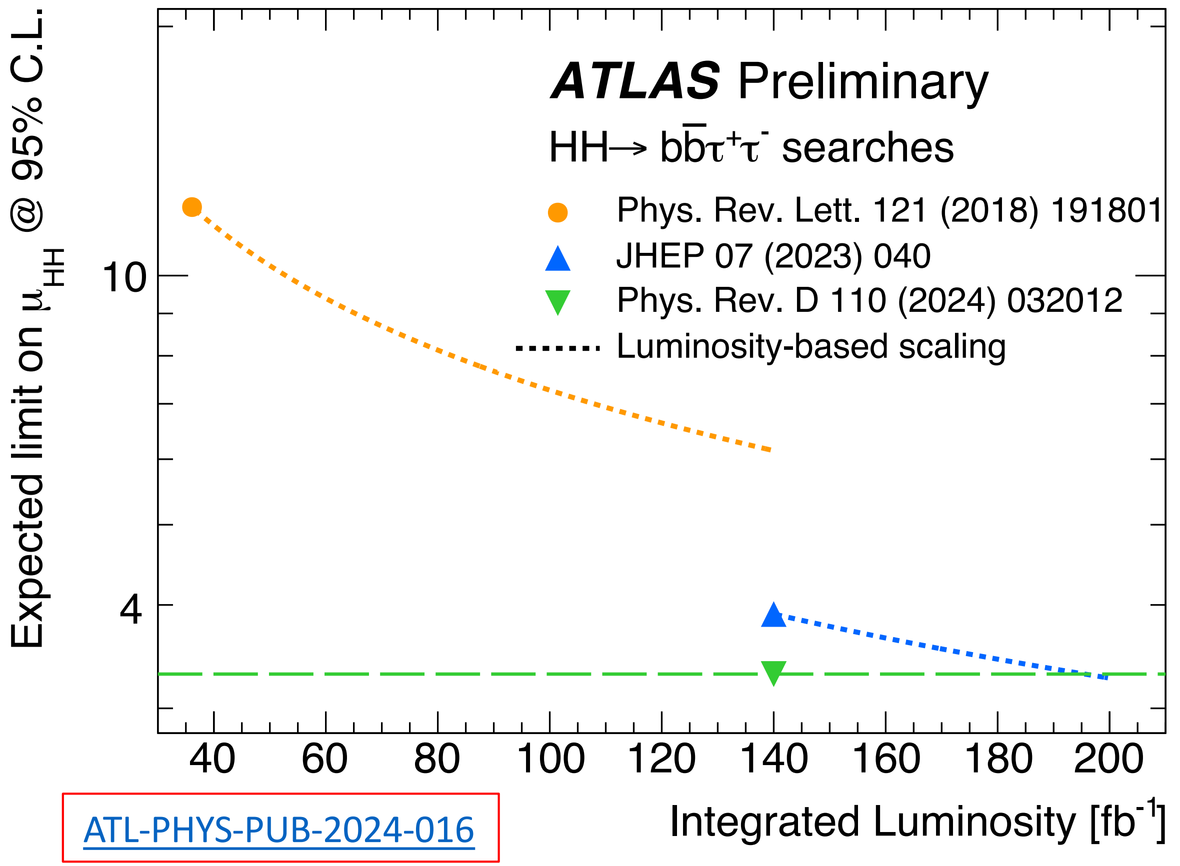


- Do not observe significant excess in data over background prediction
- Set upper limit on HH production rate at 95% CL:
  - Observed (expected) : 5.9 (3.9) times the SM prediction
- κ_λ constrained at 95% CL interval:
  - [-3.2, 9.1] ([-2.5, 9.2])

PRD 110 (2024) 032012

HH→bbττ Search

- Improvement in $HH \rightarrow bb\tau\tau$ search sensitivity over the past 3 papers exceeded that from only by increasing data size
- From 1st analysis to 2nd analysis: Data size increased by ~4x
  - Without improving analysis method, expected exclusion limit will only improve by ~2x
  - We achieved improvement of ~3.8x
- From 2nd analysis to 3rd analysis: Same data size
  - Expected exclusion limit improves by ~15% (= gain of additional 60 fb^{-1} data)

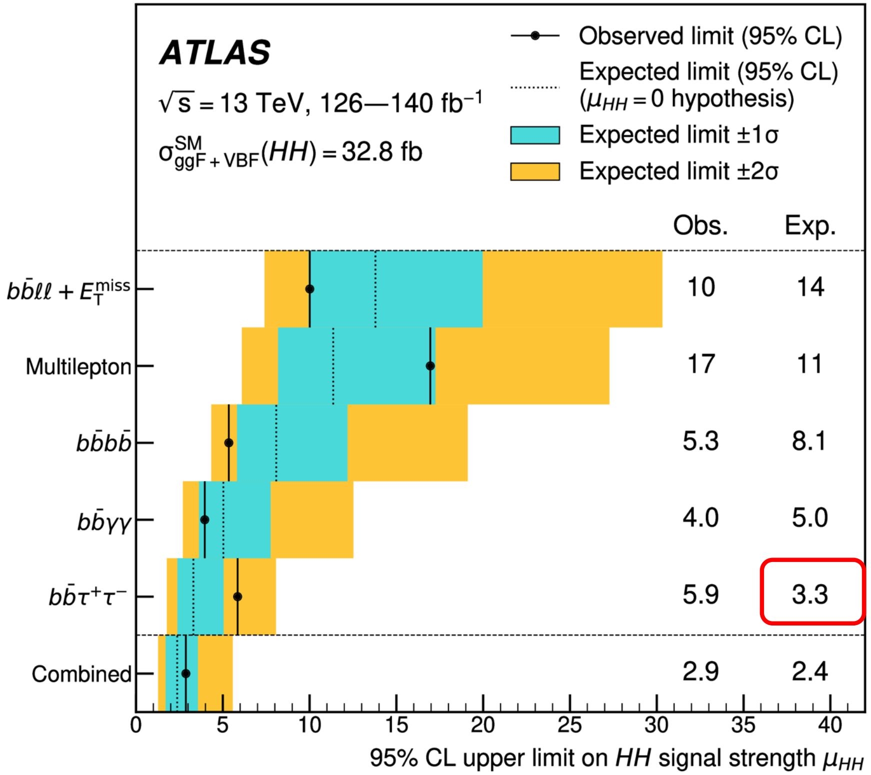


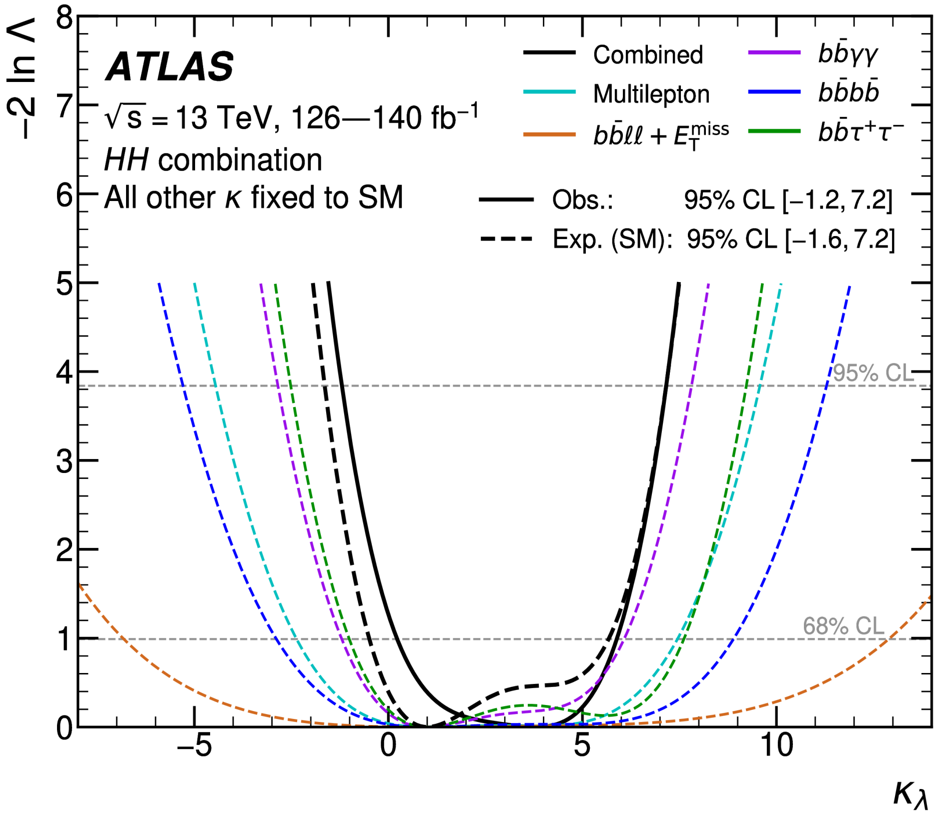
ATL-PHYS-PUB-2024-016

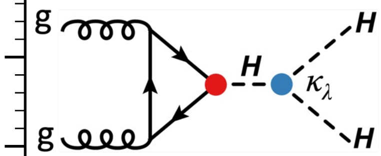
- AS took part all these 3 papers.
- Key contributions:
  - 1st : Editorial Board Chair
  - 2nd : code development, analysis, paper co-editor
  - 3rd : postdoc co-lead analysis, code development, background study

HH Searches at ATLAS

•Combined all ATLAS HH search results based on full Run2 data:







$$\kappa_\lambda = \frac{\lambda_{HHH}}{\lambda^{SM}_{HHH}}$$

•Limits on HH production rate at 95% CL
- Obs (exp) = 2.9 (2.4) × SM

•Significance : Obs (exp) = 0.4 (1.0) σ

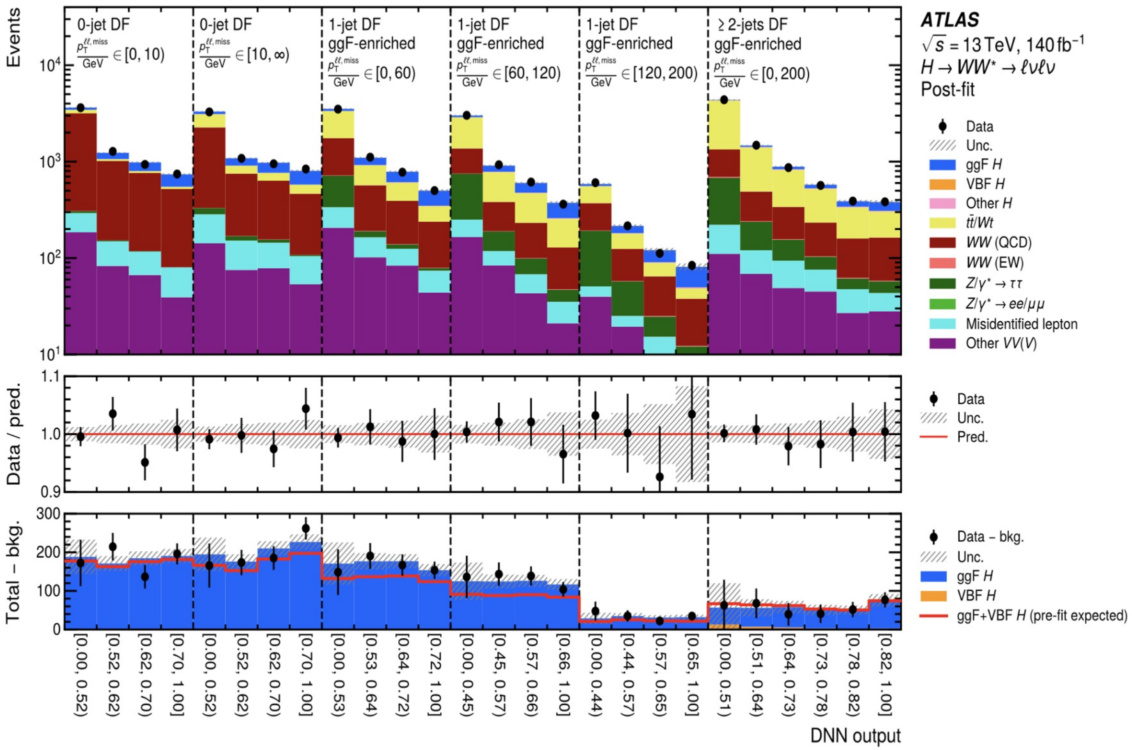
•Likelihood scan on κ_λ (self-coupling modifier)

•κ_λ constrained at 95% CL interval:
- Obs (exp) = [-1.2, 7.2] ([-1.6, 7.2])

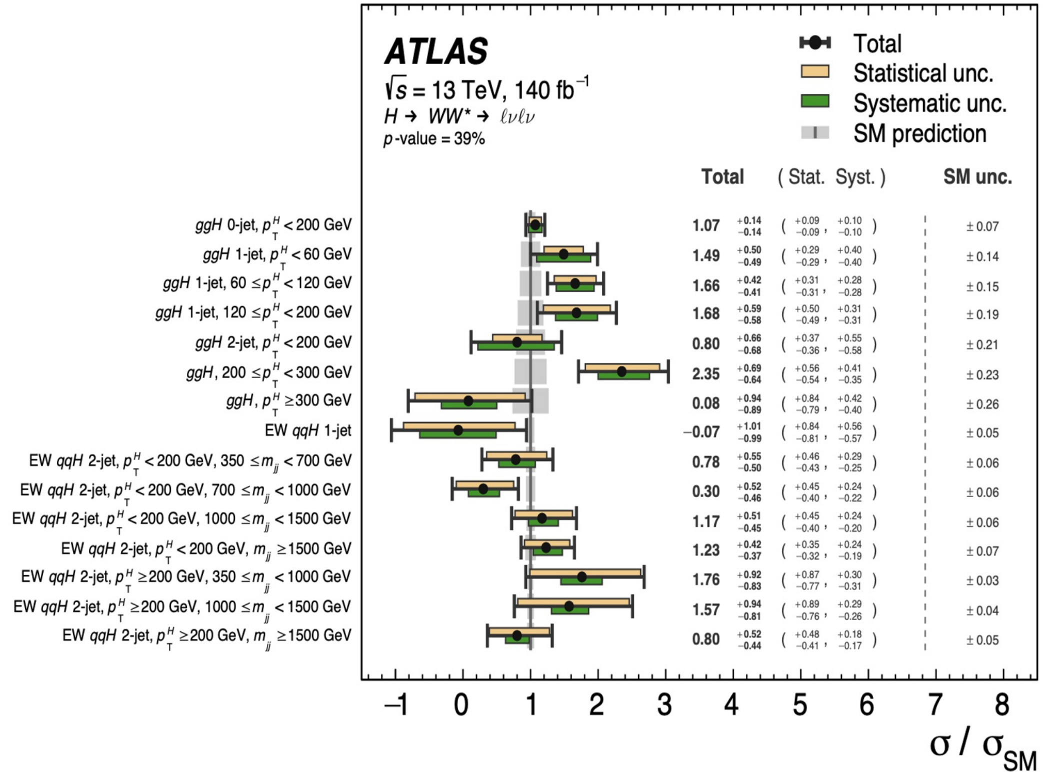
- *$bb\tau\tau$* channel has the best expected limit on the HH production rate in ATLAS using full Run2 data

Measurement of Higgs Boson Properties in $H \rightarrow WW^*$

- H->WW*->lvlv (Run 2)
  - Reanalyzed LHC run-2 dataset : results are ATLAS published ([Submitted to EPJC]())
  - Improvements/additions to the previous publication ([Phys. Rev. D 108 (2023) 032005]())
    - Deep neural network(DNN) instead of m_T for fit discriminant
    - Suppression of misidentified leptons (Improved isolation utilized closest track jet)
    - Adding final states of two same flavor leptons(two electrons or two muons)
    - An overall 20%-30% improvements across different kinematic regions



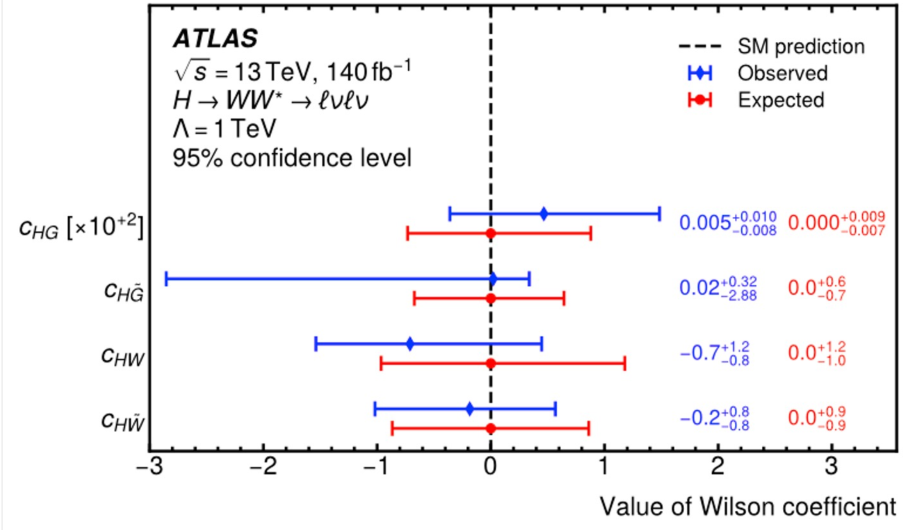
DNN distributions of events in ggH signal regions



Measured cross section values of ggH and VBF (EW qqH) production in various kinematic regions

Measurement of Higgs Boson Properties in $H \to WW^*$

- Probe CP-violation effect within Higgs boson production phase space with 2 jets
  - Measure production cross section in kinematic regions sensitive to CP-violation effect
  - Analyze the shape of $\Delta\phi_{jj}$
  - Extract the Wilson coefficients of 4 EFT (effective field theory) operators that induce CP-violation
    - C_{HG} , $C_{HG\sim}$, C_{HW} , $C_{HW\sim}$ (=0 if SM)

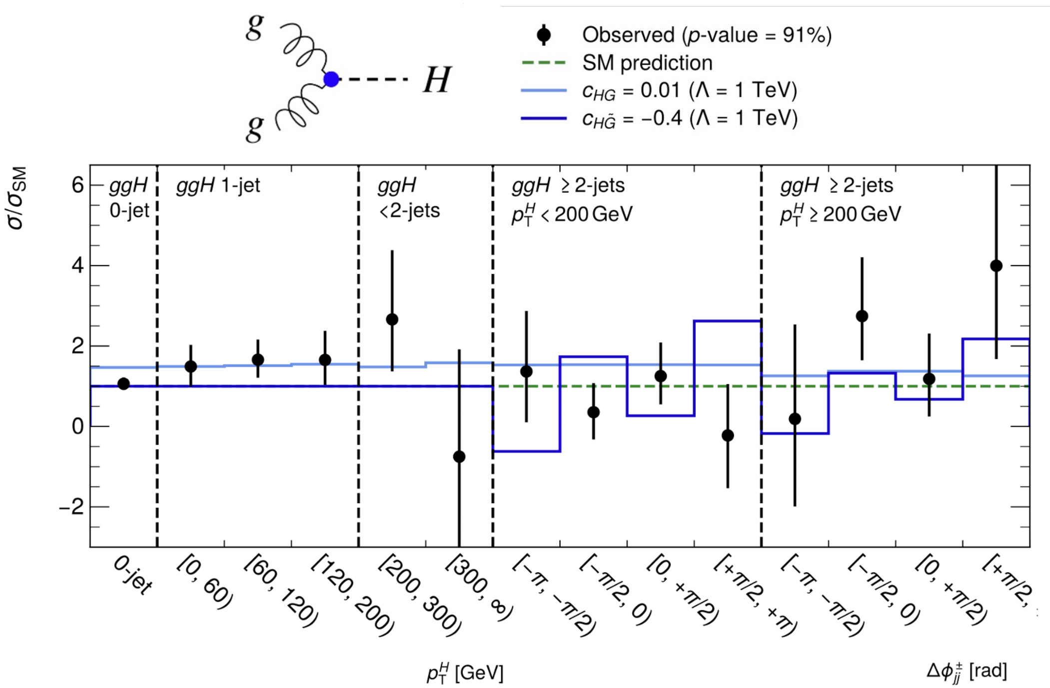


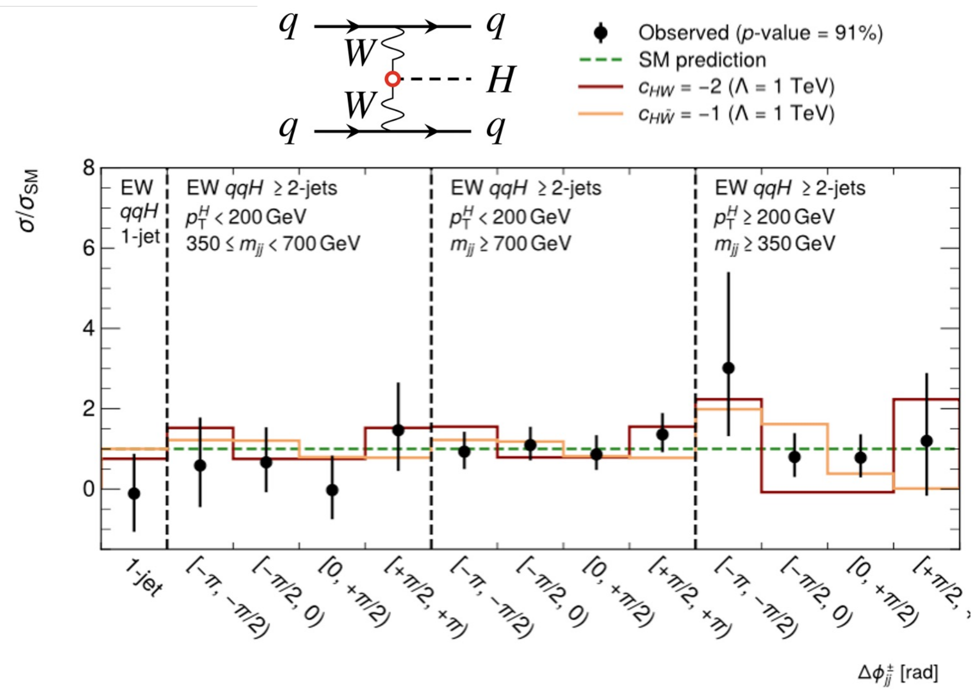
***O* : Operators(op)**

***C* : Wilson Coefficients (WCs)**

Λ : New physics scale

$$\mathcal{L}_{\text{EFT}} = \mathcal{L}_{\text{SM}} + \sum_d \sum_i \frac{c_i^{(d)}}{\Lambda^{(d-4)}} O_i^{(d)}, \text{ for } d > 4.$$





Highlights of AS in ATLAS in the Last Five Years

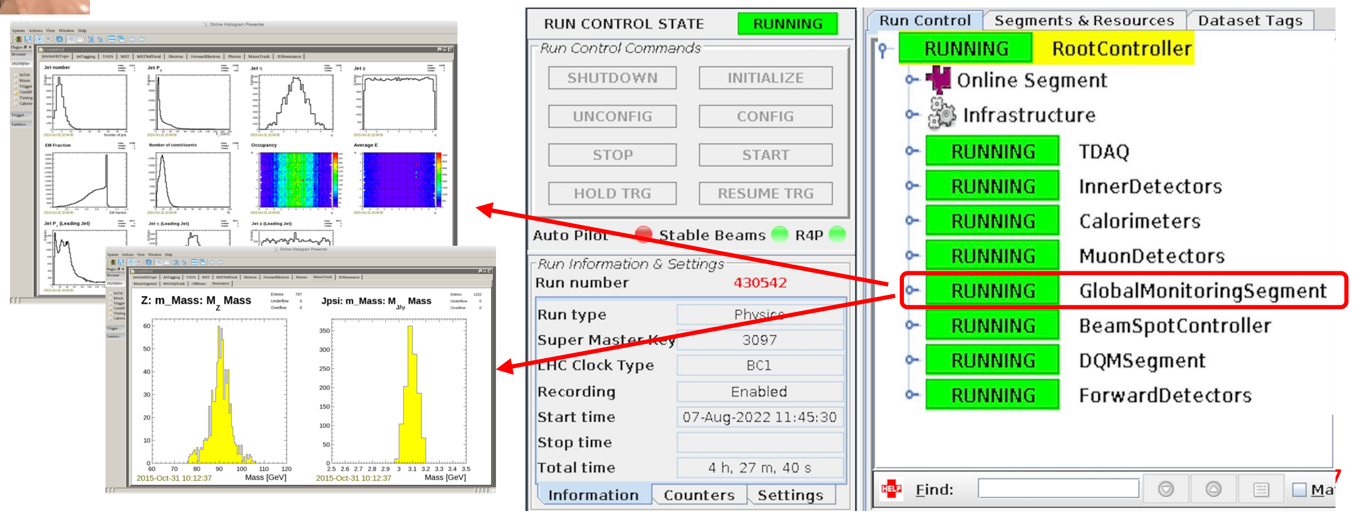
Experiment Operation

ATLAS Operation

- ATLAS experiment operation are organized by 5 activity groups
- AS has contributed in all these groups !

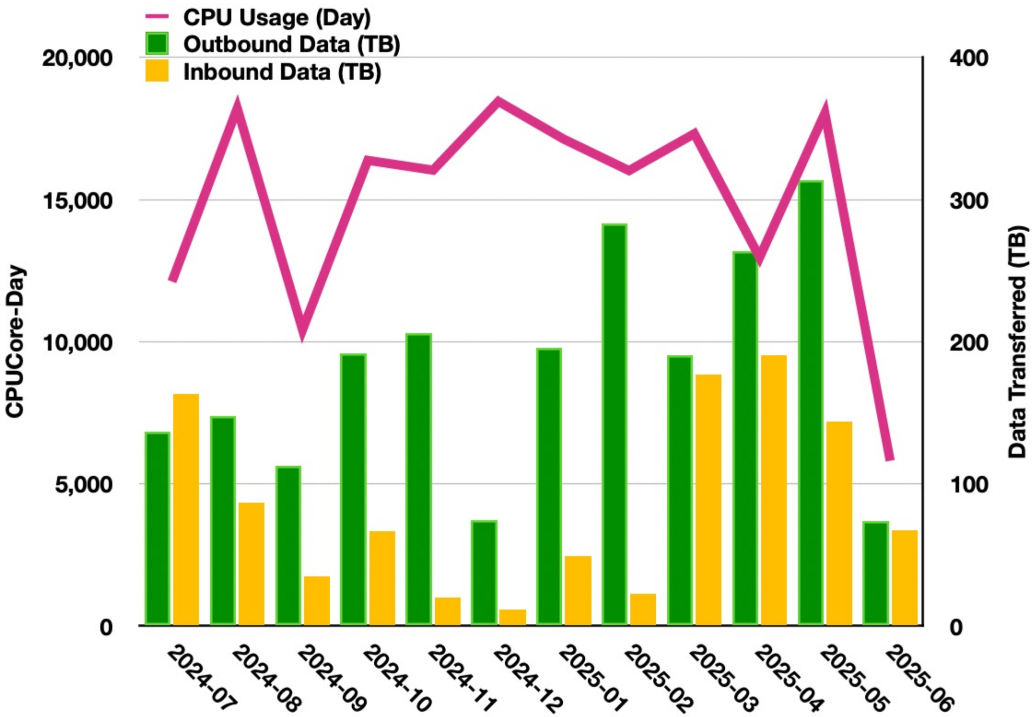
- AS members actively taking Control Room (CR) shifts as:
  - Shift leader, Run Control, Data Quality (DQ)
- Served as Online DQ coordinator: manage DQ shifts in CR, train shifters
  - Song-Ming (2017, 2018)
  - Shahzad Ali (2023, 2024)
  - Salah-Eddine Dahbi (2025 -)

- Responsible for online monitoring tool: **GlobalMonitoring**:
  - Process raw data events in real time to produce plots to monitor all sub-detector systems' performance
  - **Our Institute Commitment to ATLAS**



ATLAS Operation

- ASGC currently hosting a Tier-2 center for ATLAS
- Supporting MC simulation jobs and analysis jobs
- Current status (1 Aug 2024 – 1 June 2025):
  - 147736 CPUCore-Day
  - Data transmission (inbound + outbound) = 0.8 + 1.98 = 2.78 PB, with efficiency >92%



July 2024 – June 2025

ATLAS Operation

- Luminosity
- Data Quality
- Prompt Recon. & Tier-0
- Event Displays
- Conditions
- Beamspot
- Data Reprocessing
- Non Collision Background

•Data Preparation (DP) : consists of 8 subgroups

- •Prepare the collected Raw Data and transform it to the level for data analysis
- •Work closely with all other ATLAS activity groups to get data ready for analysis

•Data Preparation coordinator : Song-Ming (2019-21)

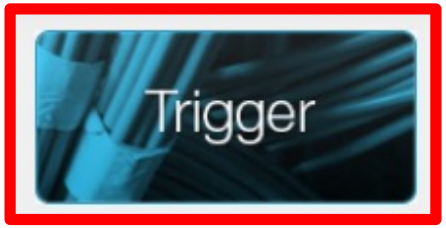
•Online DQ coordinator :

- •Song-Ming (2017-18) , Shahzad (2023-24), Salah-Eddine (2025 -)

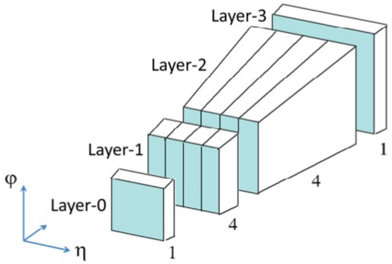
•Higgs: $H\rightarrow bb$ subgroup co-convener : Song-Ming (2015–16)

•Di-Higgs: co-lead $HH\rightarrow bb\tau\tau$ analysis : Tulin Mete (2022–23)

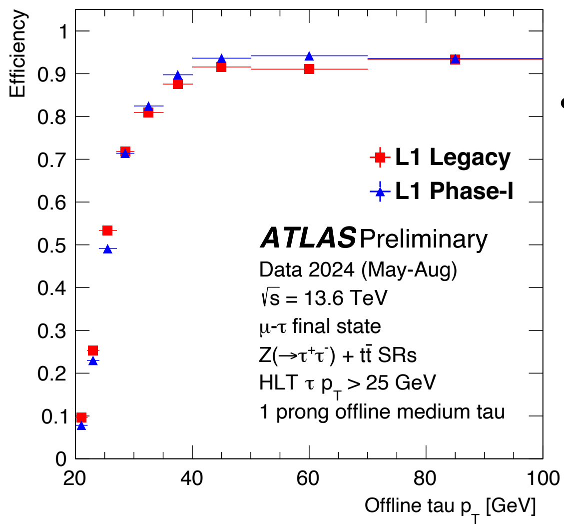
ATLAS Operation



- **Tau Trigger Signature Group**
  - Subgroup of the ATLAS Trigger group.
  - In charge of all tau related triggers used for data taking
    - Monitor triggers' performance during data taking, measure triggers' efficiencies
    - Work with physics groups to implement new triggers for new physics analysis topics, to improve existing triggers' performance
- Tau trigger group co-coordinator : Song-Ming (2023 - 2025)



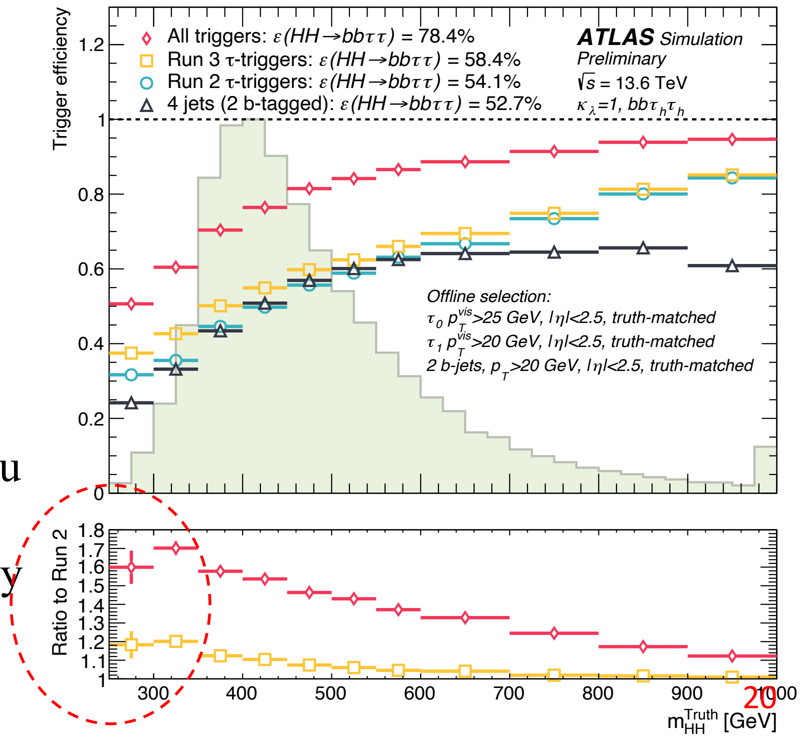
- **Level-1 Calorimeter Trigger (L1Calo) Phase-1 Upgrade**
- Finer granularity information to improve energy resolution and mitigate effect from high pile-up.
  - 1 trigger tower : $\Delta\varphi\times\Delta\eta=0.1\times0.1$
- L1Calo Phase-1 Upgrade propagated to the Level-1 Tau triggers



- Successfully commissioned Phase-1 Tau triggers in 2024
- Phase-1 trigger has sharper turn-on in efficiency than Legacy

Measured by Kiran Farman

- Worked with $HH \rightarrow bb\tau\tau$ group, introduced new di-tau triggers
- Significant gain in efficiency to trigger on $HH \rightarrow bb\tau\tau$ signal for Run-3

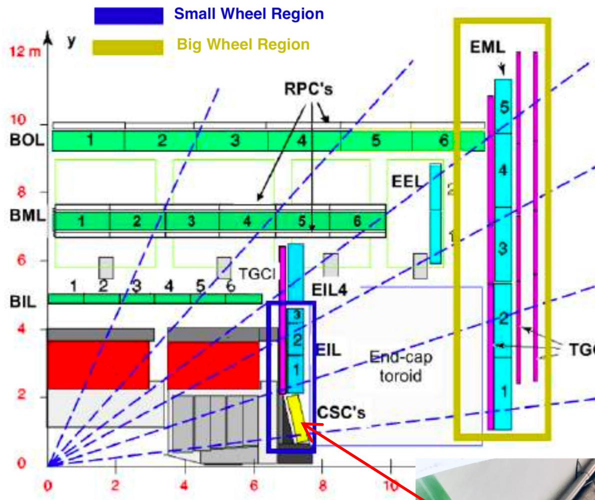


ATLAS Upgrades

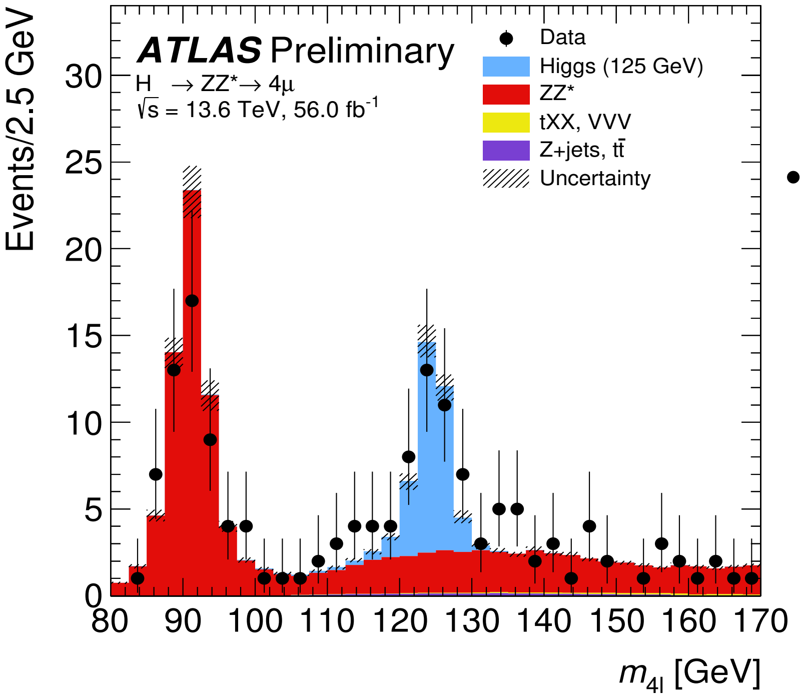
Phase-1 Upgrade

New Small Wheel (NSW) Muon Detector

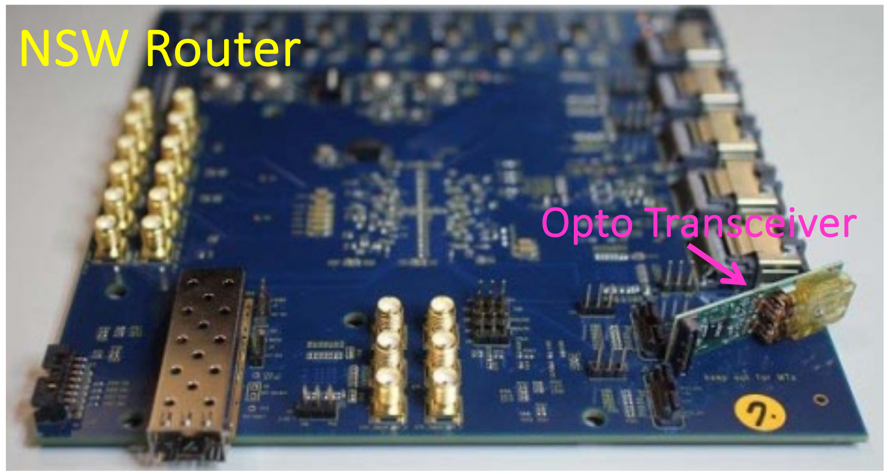
- Suppress fake forward muon
- Allow to trigger on low pT muon at pT ~20-25 GeV with manageable L1 trigger rates (~10-20 kHz) at $L=3\times10^{34}cm^{-2}s^{-1}$
- AS contributed to fabrication of NSW Router boards
  - Transmit trigger signal from muon FEB to Level-1 electronics
- Already in used in Run3 data taking



- Replace small wheel muon detector with a new one

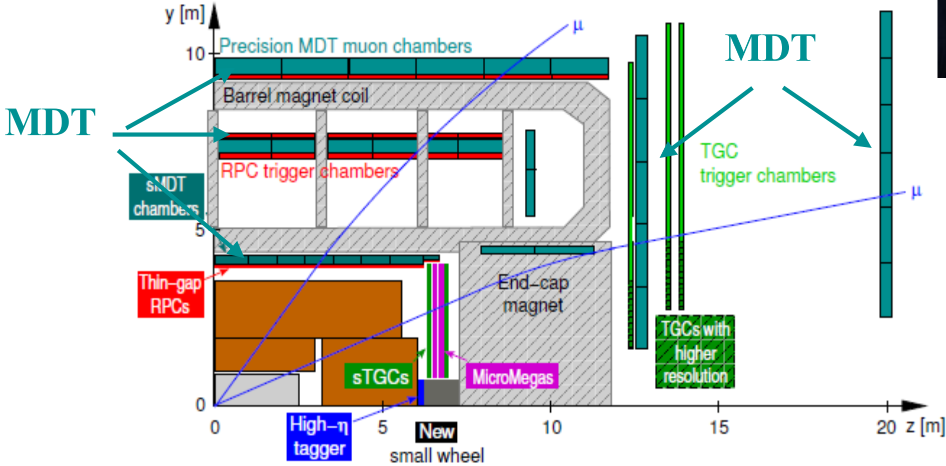


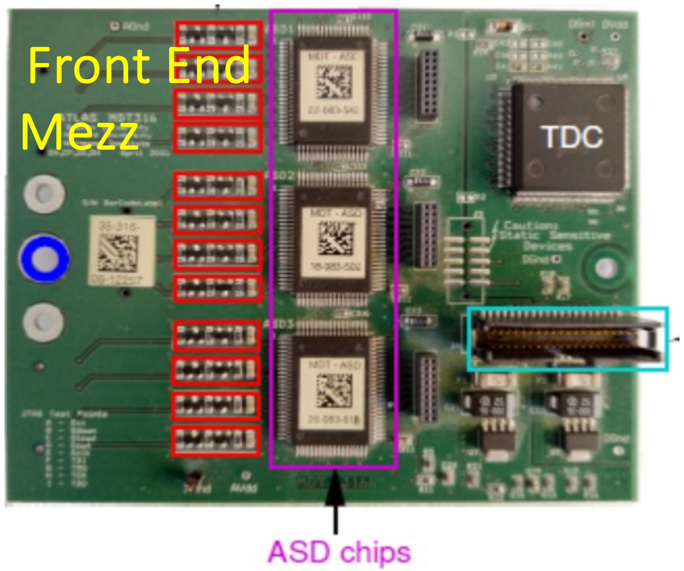
- Can see nice $H \to ZZ^* \to 4\mu$ signal in Run3 data

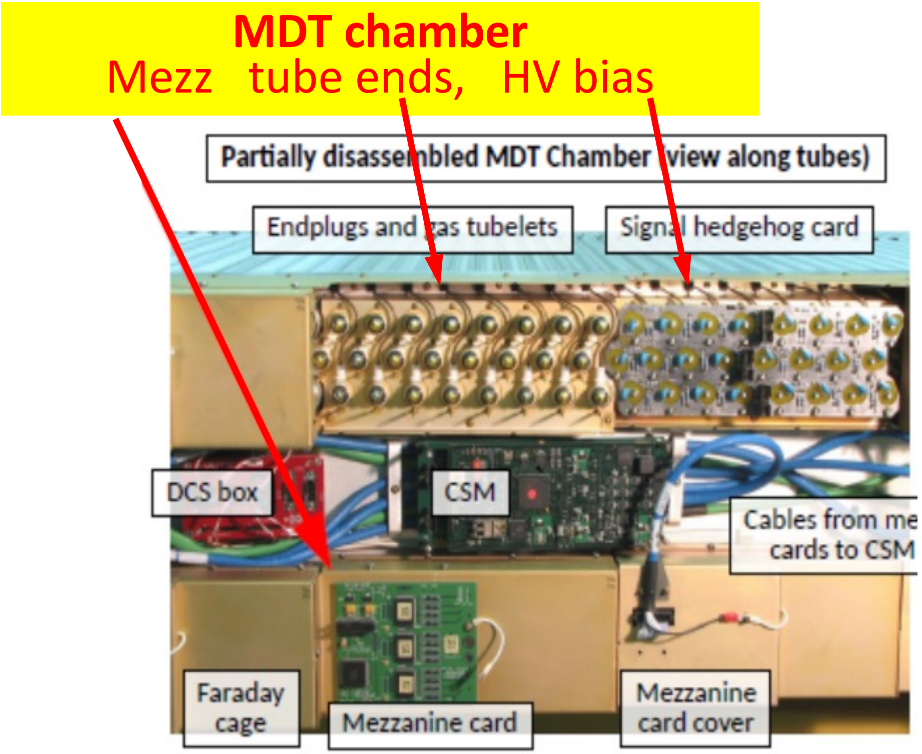


Phase-2 Upgrade

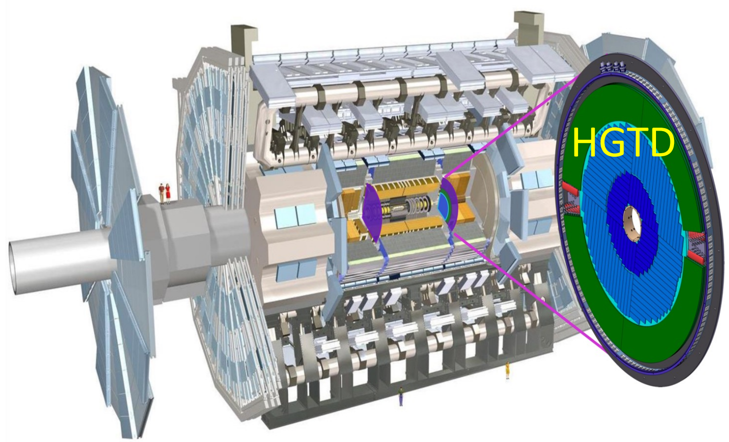
- **Muon detector: Monitored Drift Tube (MDT)**
- Upgrade readout electronics
- AS+NTHU is building 10k boards of MDT front end mezzanine cards
  - Process raw signals from detector
  - Amplified/digitized/discriminate, extract arrival time



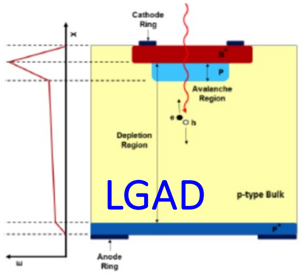




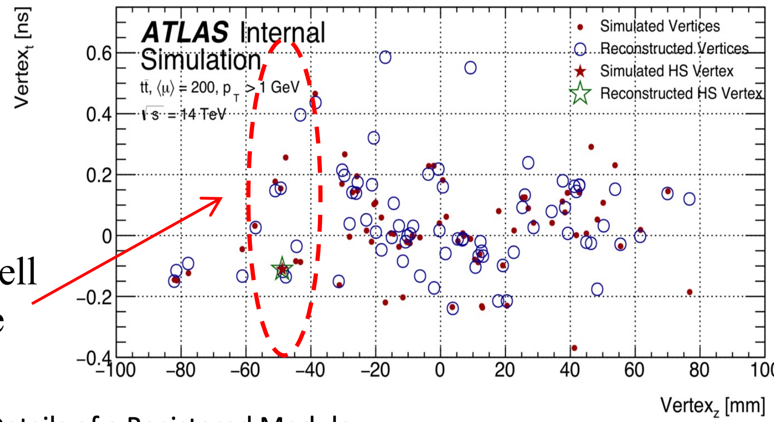
Phase-2 Upgrade



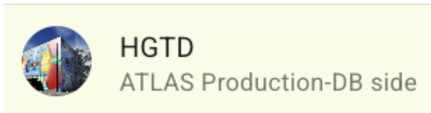
- **High Granularity Timing Detector (HGTD) :**
- ~200 pp interactions per bunch crossing at HL-LHC
- HGTD, with LGAD (Low Gain Avalanche Detector) sensors (timing resolution ~30 ps) to help resolve the individual interactions
- AS+NTHU contributes to
  - optical fibers and cables production
  - simulation studies and test beam
  - production database and data quality
- HGTD going into pre-production soon



Close in Z but well separated in time

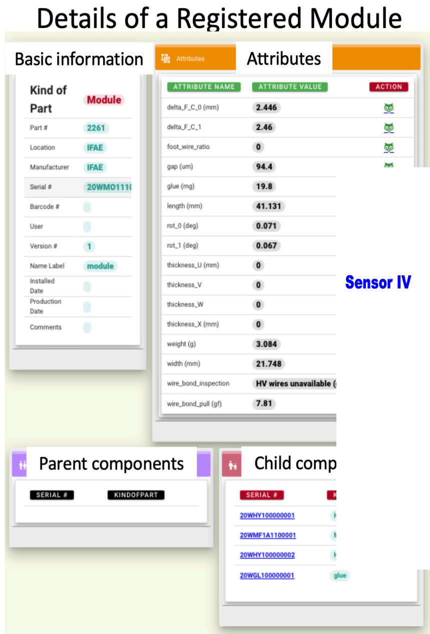


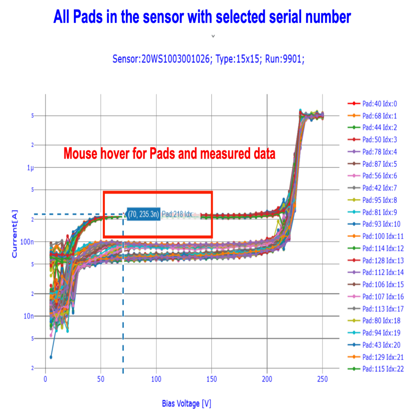
- **Production Database**
- HGTD: ~10k sensor modules, assembled together and connected to front end electronics boards and HV/LV power supplies
- Need a Database to record all these parts, store test measurements and Quality Control info
  - Record need to keep until end of HL-LHC
- Implemented majority functions of Database
- Ready in 2nd half of 2025 for pre-production




KindOfParts Summary

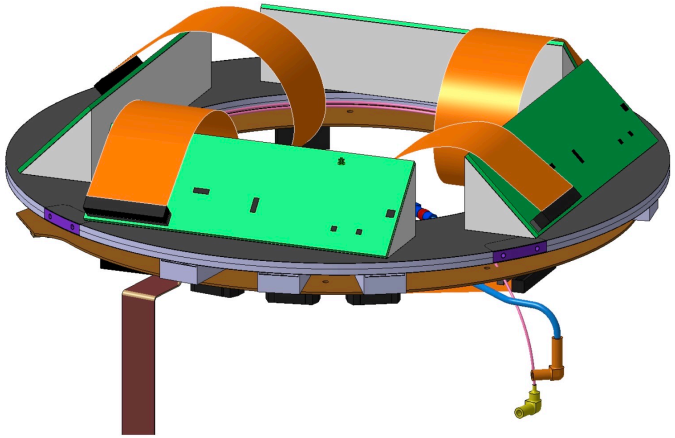
SR#	NAME	TOTAL
1	Slot	8032
2	Sensor	4328
3	PEB_MUX64	1811
4	Hybrid	220
5	Wafer	217
6	Module	147
7	Detector Unit	13
8	Flex_tail	9
9	ASIC	7
10	glue	7
11	Module_flex	5
12	Detector	5
13	Support Unit	5
14	PEB	1

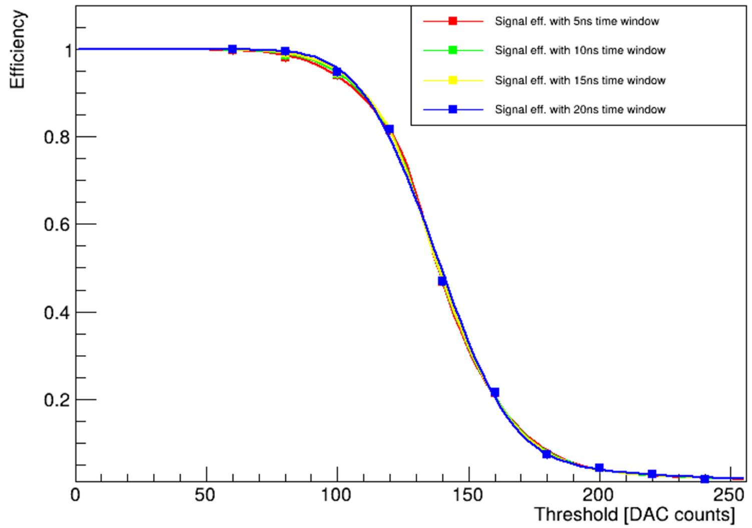


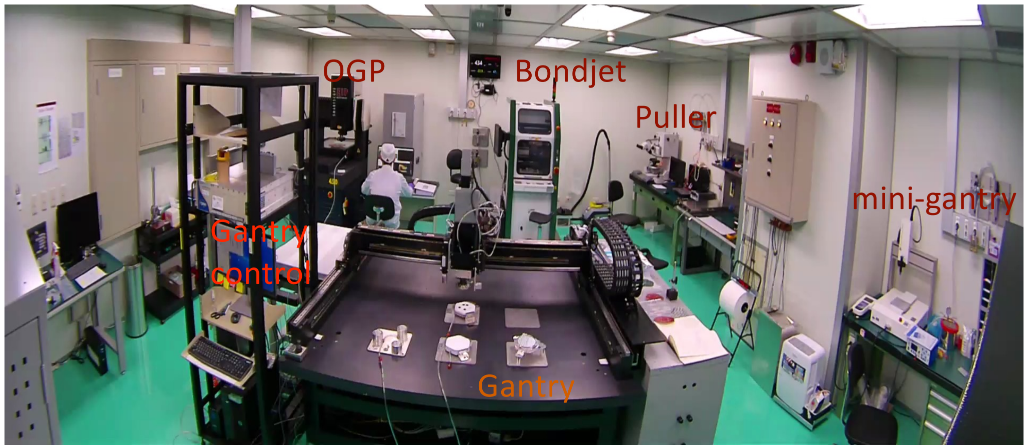


Phase-2 Upgrade

- **Beam Conditions Monitoring Prime (BCM') :**
- HL-LHC: large increase in luminosity and density of particles hitting on ATLAS detector
- Need to protect the inner silicon tracking detector
- BCM' : radiation hard beam monitor detector
  - Monitor background activity to safeguard inner silicon tracking detector
  - To trigger abort of the LHC beam under dangerous particle showers condition
  - Also function as a luminometer
  - Detector made of polycrystalline Chemical Vapor Deposition (pCVD) diamond sensors
- AS contributions:
  - Analyzing test beam data
  - To assemble BCM' at TIDC, build test stand at AS







Future Plans

Future plan for $H \rightarrow WW^*$ analysis

➤ Cross section measurement

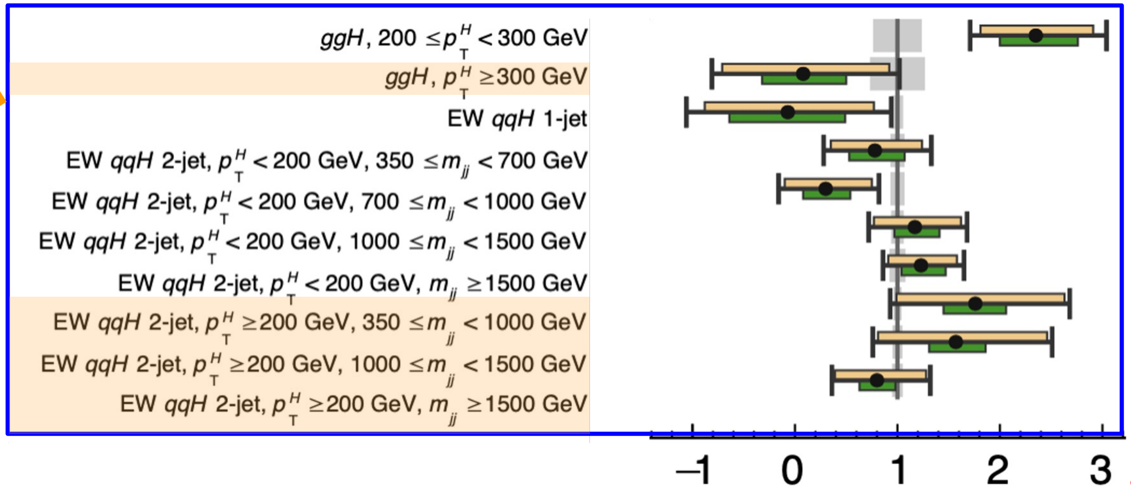
- ➢ Run 3 ggF/VBF H->WW->lvlv* ATLAS internal kicked off
  - Plan to utilize full LHC Run 3 data. SMEFT interpretation
  - High priority to measure statistical dominated STXS bins
  - Analysis targeting 2027-2028
- ➢ Boosted H->WW*->lvqq
  - Plan to utilize full Run 2+3 data
  - Focus on H_{pT} > 300 GeV bins for ggH and H_{pT} >200 GeV for EW qqH
  - Analysis targeting 2027

Targeting Run 3 ggF/VBF H->WW->lvlv*

➤ Probe quantum entanglement with Run2+Run3 data

- ➢ Use kinematics of the charged leptons to determine the polarization states of W bosons
- ➢ Focus on detector acceptance effects and W boson rest frame reconstruction
- ➢ Collaborating with NTHU
- ➢ Analysis targeting 2027

Targeting Boosted H->WW*->lvqq



Physics Analyses at ATLAS




- Di-Higgs via VVbb (V=W,Z) decay channel using Run 2 and Run 3 data
- Search for new resonance in J/psi → eeX(1835) channel
- Quarkonium (J/psi, Upsilon) in heavy-ion collisions:
  - Production with jet activity
  - Nuclear modification factor

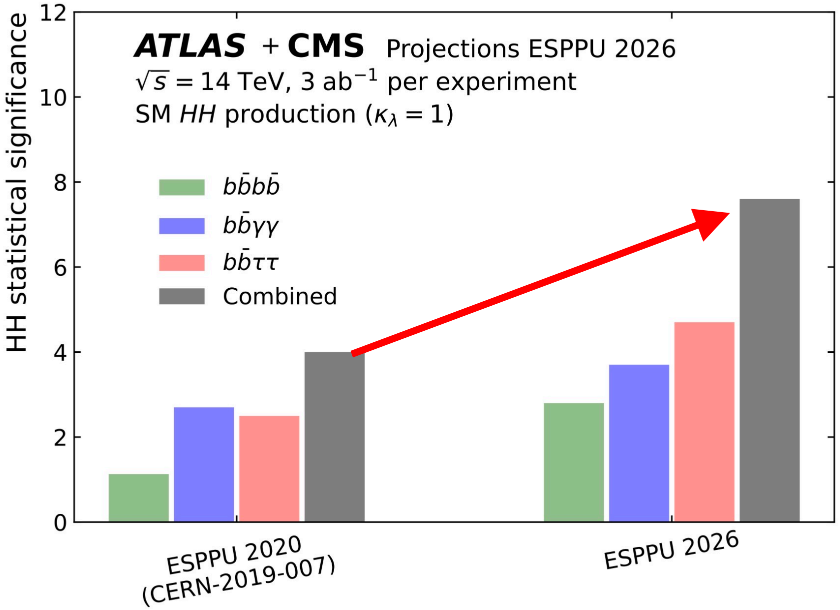
Projection for *HH* Searches at the HL-LHC (ATLAS+CMS)

- Extrapolation based on ATLAS and CMS results with full Run2 data

ATL-PHYS-PUB-2025-018

	2 ab^{-1} (S2) ATLAS	2 ab^{-1} (S2) CMS	3 ab^{-1} (S2) ATLAS	3 ab^{-1} (S2) CMS
	HH statistical significance			
$b\bar{b}\tau^+\tau^-$	$3.0^\dagger$	1.9	$3.5^\dagger$	2.4
$b\bar{b}\gamma\gamma$	$2.1^\dagger$	$2.0^\dagger$	$2.4^\dagger$	$2.4^\dagger$
$b\bar{b}b\bar{b}$ resolved	0.9	$1.0^\dagger$	1.0	$1.2^\dagger$
$b\bar{b}b\bar{b}$ boosted	–	$1.8^\dagger$	–	$2.2^\dagger$
Multilepton	$0.8^\dagger$	–	$1.0^\dagger$	–
$b\bar{b}\ell^+\ell^-$	$0.4^\dagger$	–	$0.5^\dagger$	–
Combination	3.7	3.5	4.3	4.2
ATLAS+CMS	6.0		7.2	
	κ_3 68% confidence interval			
$b\bar{b}\tau^+\tau^-$	$[0.3,\ 1.8]^\dagger$	$[0.1,\ 3.0]$	$[0.4,\ 1.7]^\dagger$	$[0.2,\ 2.2]$
$b\bar{b}\gamma\gamma$	$[0.3,\ 2.0]^\dagger$	$[0.2,\ 2.3]^\dagger$	$[0.4,\ 1.8]^\dagger$	$[0.3,\ 2.0]^\dagger$
$b\bar{b}b\bar{b}$ resolved	$[-0.7,\ 6.3]$	$[-0.6,\ 7.6]^\dagger$	$[-0.5,\ 6.1]$	$[-0.3,\ 7.3]^\dagger$
$b\bar{b}b\bar{b}$ boosted	–	$[-0.6,\ 8.5]^\dagger$	–	$[-0.4,\ 8.2]^\dagger$
Multilepton	$[-0.2,\ 4.9]^\dagger$	–	$[-0.1,\ 4.7]^\dagger$	–
$b\bar{b}\ell^+\ell^-$	$[-2.4,\ 9.3]^\dagger$	–	$[-2.2,\ 9.2]^\dagger$	–
Combination	$[0.6,\ 1.5]$	$[0.4,\ 1.7]$	$[0.6,\ 1.5]$	$[0.5,\ 1.6]$
ATLAS+CMS uncertainty	−32% / +37%		−27% / +31%	

† *used in the ATLAS+CMS combination*



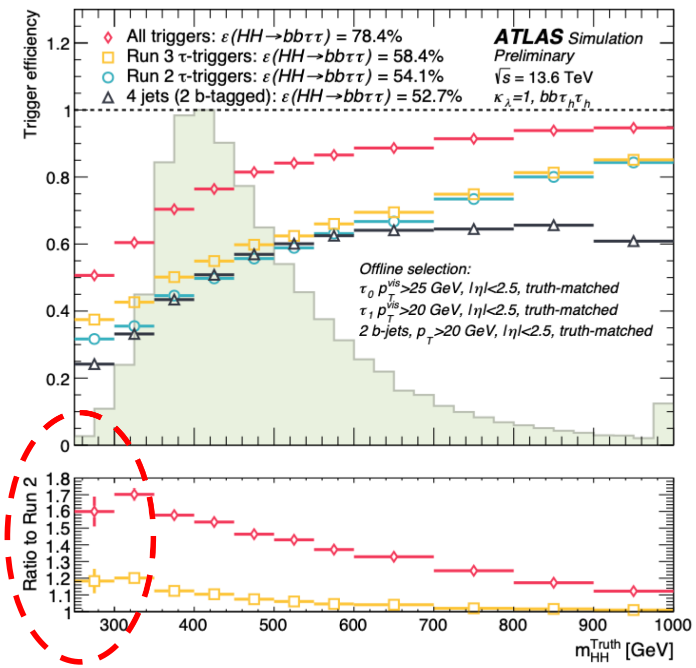
- Huge improvements in sensitivity between two projections, due to adding new channels and analysis optimizations
- HH observation is within reach
  - 7.2σ significance expected
  - <30% precision on κ_λ
    - Previous projection was ~50% precision

Plans for $HH \rightarrow bb\tau\tau$ Search

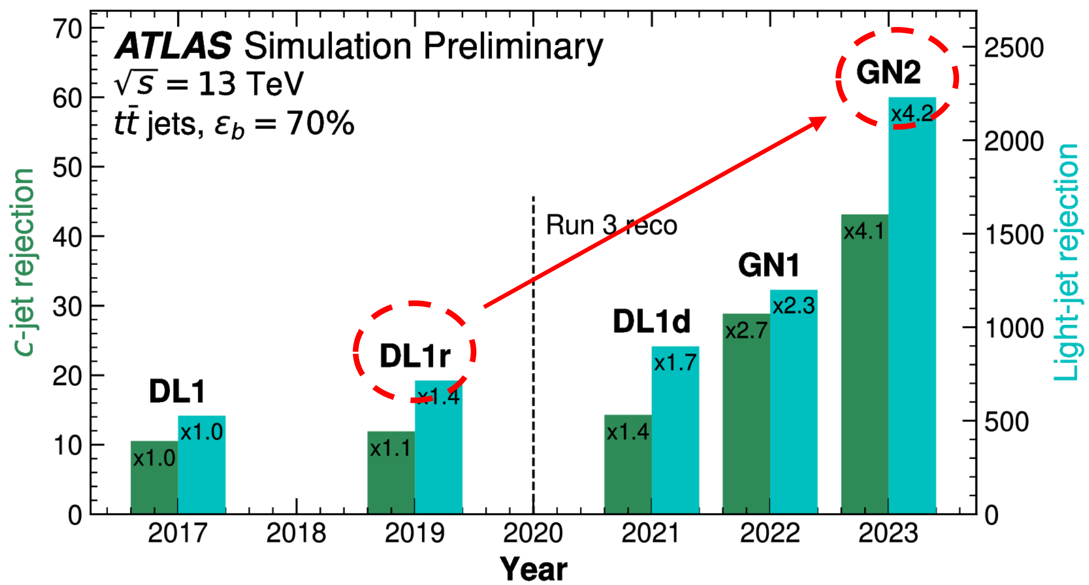
- Currently analyzing Run2+Run3 data
  - Add improved tau triggers in Run3
  - Use better b-jet identification algorithm
  - Train signal vs background separation with more advanced ML (Graphical Neural Net)
- Preparing for HL-LHC
  - Participate in trigger development beneficial to $bb\tau\tau$ analysis
  - Collaborate with NYCU, UW and UIUC on track reconstruction at High Level Trigger using GPU (contributing ASGC GPU resource)

(triggers for $bb\tau\tau$)

(ATLASTauTriggerPublicResults)



(FTAG-2023-01) (b-tagging algorithm)



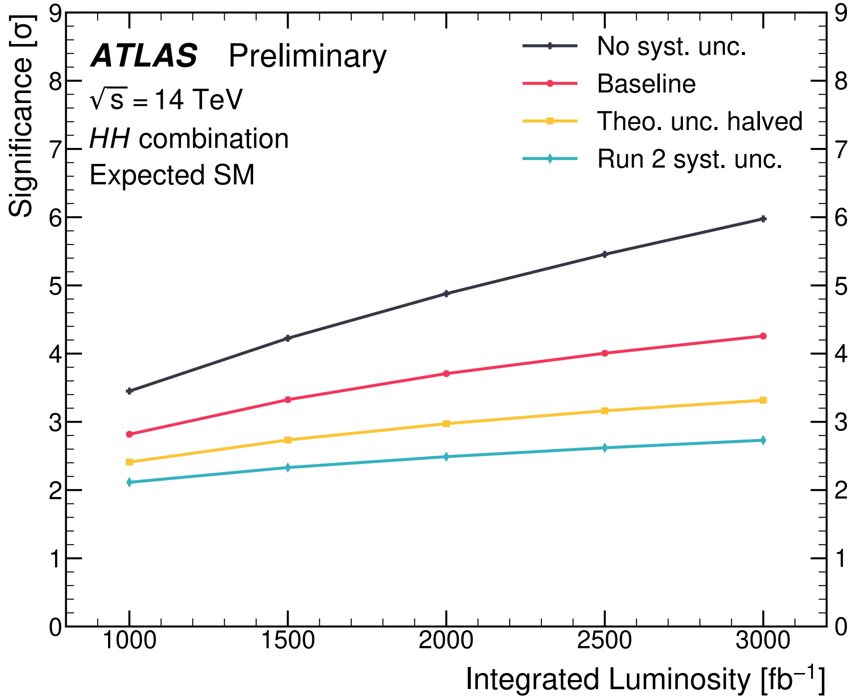
Summary

- Academia Sinica has been an ATLAS collaborator for more than 20 years
- Continue to be active in the experiment
  - Involves in data taking operation, data analyses and detector upgrades for HL-LHC
- A young faculty (Yi Yang) joined our group bringing in new projects and new energies !
- We have exciting physics topics and inclusion of Run3 data will triple our total data size, compare to Run2
- Long Shut Down 3 will begin in summer 2026
- A lot of preparations to be done to be ready for the start of HL-LHC in 2030.

BackUp

Projection for *HH* Searches at the HL-LHC (ATLAS)

- Extrapolated the full Run 2 results of several search channels to project reach at HL-LHC
- Assume several different scenarios



- **HH discovery significance:**
  - New individual and combined projection significantly improved over previous projection from 2019
  - New ATLAS combined projection reach 5.9σ (4.3σ) for "No syst. unc." ("Baseline") scenario

CERN-2019-007 | ATL-PHYS-PUB-2025-006

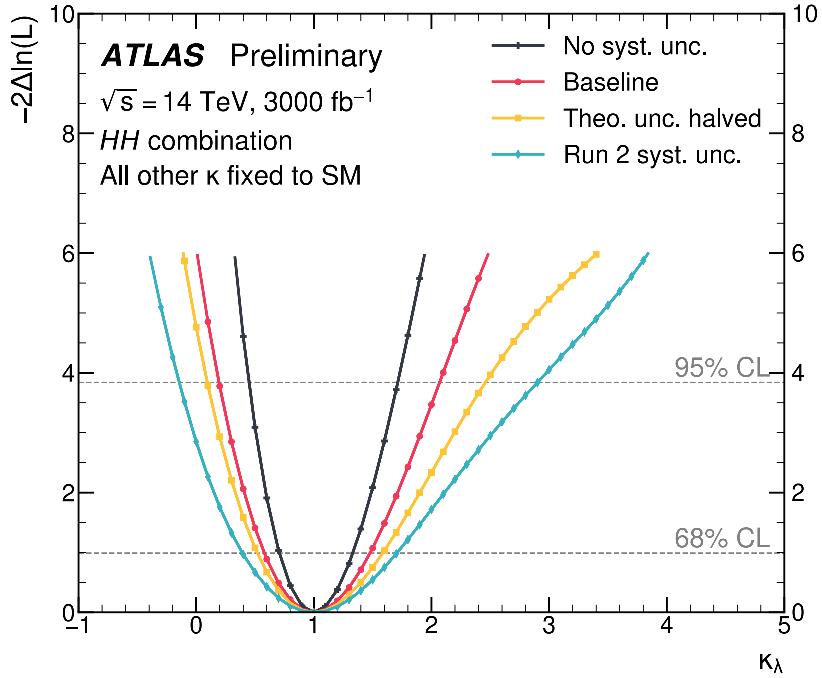
ATLAS

Uncertainty scenario	Significance [σ]						68% CI on μ_{HH} (%)
	$b\bar{b}\gamma\gamma$	$b\bar{b}\tau^+\tau^-$	$b\bar{b}b\bar{b}$	ML	$b\bar{b}\ell^+\ell^- + E_T^{miss}$	Combination	
$L' = 2000\ \mathrm{fb}^{-1}$							
Run 2 syst. unc.	1.76	1.84	0.62	0.69	0.33	2.49	$+51/-40$
Theory unc. halved	2.04	2.03	0.62	0.74	0.44	2.97	$+37/-35$
Baseline	2.06	3.00	0.89	0.84	0.45	3.71	$+32/-29$
No syst. unc.	2.23	3.76	1.44	0.98	1.31	4.88	$+23/-22$
$L' = 3000\ \mathrm{fb}^{-1}$							
Run 2 syst. unc.	2.00	1.93	0.65	0.79	0.37	2.73	$+47/-36$
Theory unc. halved	2.39	2.17	0.65	0.85	0.48	3.32	$+33/-31$
Baseline	2.43 (2.0)	3.54 (2.1)	0.99 (0.61)	0.99	0.48	4.26 (3.0)	$+28/-25$
No syst. unc.	2.73 (2.1)	4.60 (2.5)	1.76 (1.4)	1.20	1.60	5.98 (3.5)	$+18/-18$

- Numbers in red are from ESPPU2020 projection
- Large improvement achieved over last few years

Projection for *HH* Searches at the HL-LHC (ATLAS)

- Higgs self-coupling modifier (κ_λ) :
  - Constraint within (Baseline scenario) :
    - [0.58, 1.48] at 68% CL interval



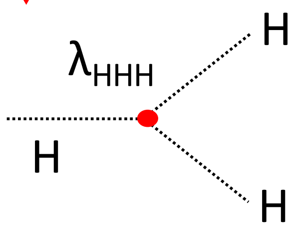
Di-Higgs Production : Higgs Potential

- Higgs potential => $V(H) = \lambda v^2 H^2 + \lambda v H^3 + \frac{1}{4}\lambda H^4 \; ; \; M_H^2 = 2\lambda v^2$

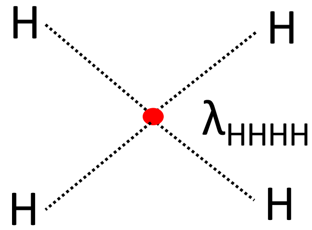
- Higgs mass term
- Minimum of the potential

$$m_H = \sqrt{2\lambda v^2} \approx 125 \text{ GeV}$$

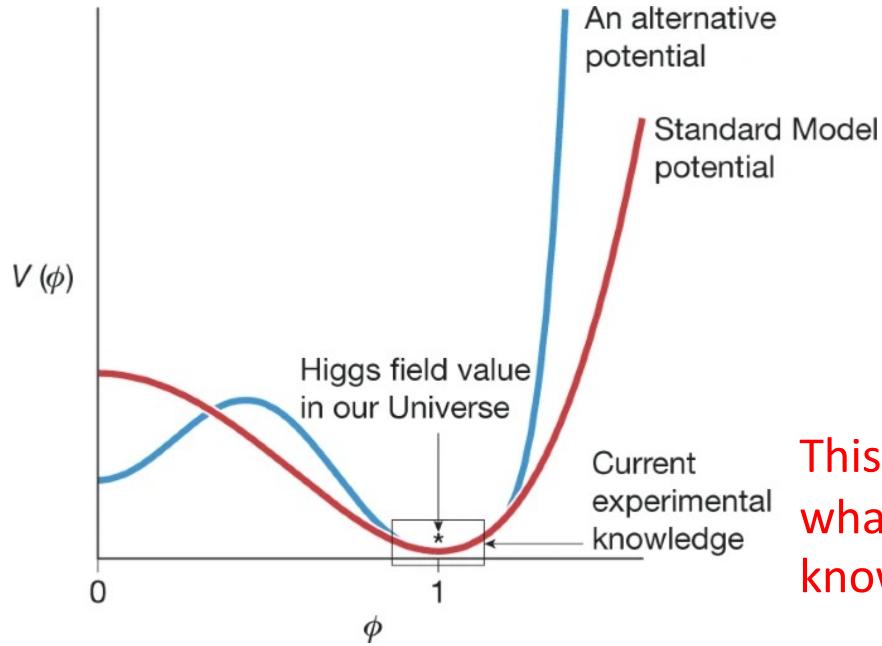
- Higgs self-coupling
- Measure λ_{HHH} via HH production



- Higgs quartic coupling
- Maybe out of reach at HL-LHC



- Investigate the HH production allows for direct measurement of the Higgs self-coupling, and discriminate between different scenarios and models



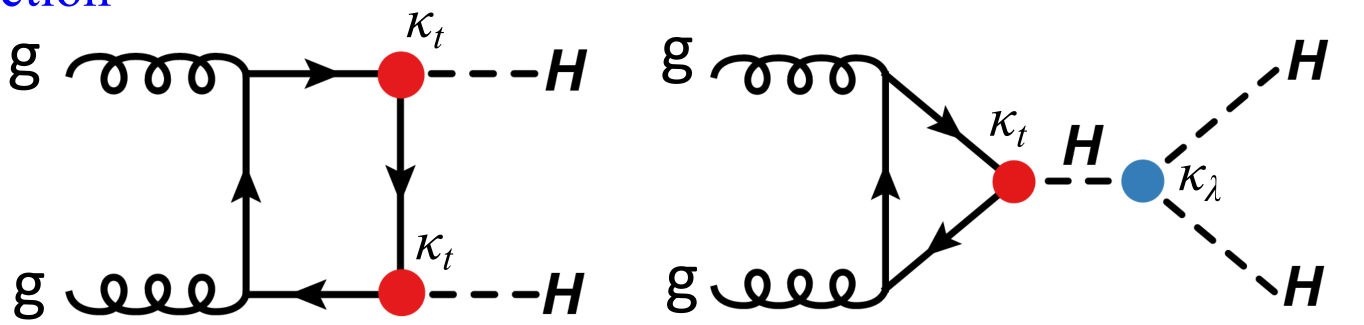
This is what we know

Search for Di-Higgs Production

•Searched in ggF + VBF production

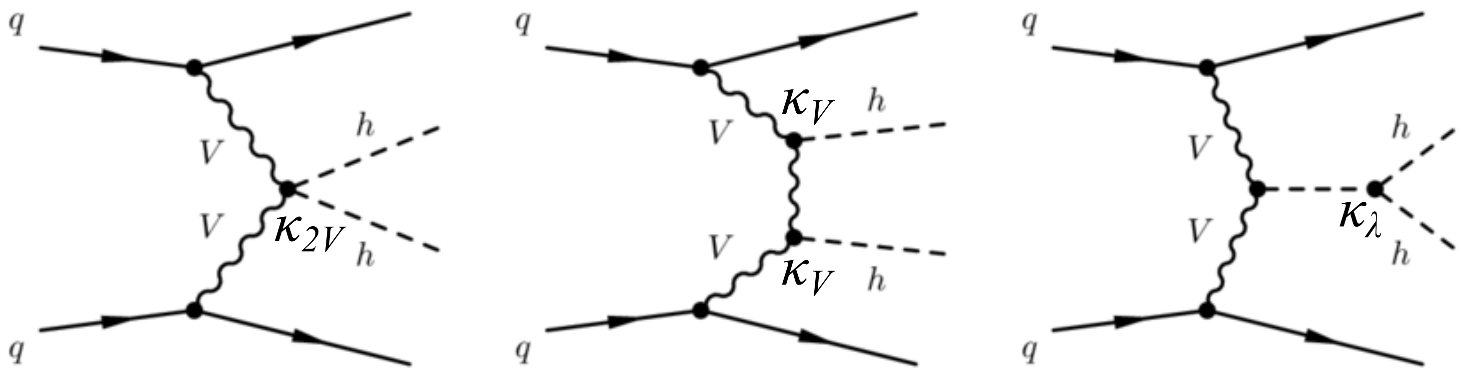
Gluon funsion (ggF)

• σ(pp→HH)=31.05 fb



Vector Boson Fusion (VBF)

• σ(pp→HH)=1.726 fb

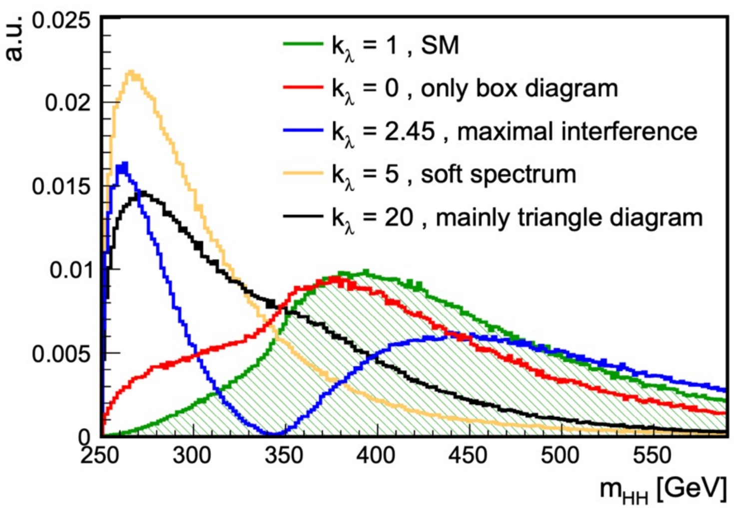


•Total HH production cross section is about ~1000 X smaller than single H production

• κ parameters : are the coupling modifiers.

•Example : $\kappa_\lambda = \frac{\lambda_{HHH}}{\lambda_{HHH}^{SM}}$

•In SM : $\kappa_\lambda=1$, $\kappa_{2V}=1$, $\kappa_V=1$



Physics Projection to HL-LHC

- Assume center of mass energy at 14 TeV and total integrated luminosity is 3000 fb^{-1}
- **Methods for projection:**
  - **Detailed simulations** are used to access performance of upgraded detector and HL-LHC condition
  - **Extrapolate** existing results or **parametric simulations** to allow full re-optimization of the analyses
- **Systematic uncertainties scenarios :**

- **Run 2 ("S1") :**
  - Use Run2 uncertainties, assuming the higher pile-up effects will be compensated by detector upgrades
- **Theoretical uncertainties halved :**
  - Use Run 2 uncertainties, but reduce theoretical uncertainties by half
- **No systematic uncertainties :**
  - Only consider statistical uncertainty

- **Baseline ("S2") :**
  - Theory uncertainties ½ of Run 2
  - No simulation statistical uncertainty
  - luminosity uncertainty ~1%
  - Statistical uncertainty reduced by $1/\sqrt{L}$
  - Uncertainties due to detector limitations remain unchanged or revised according to simulation studies of upgraded detector.

*** Baseline scenario is used in presented projected results, unless specified otherwise

ATL-PHYS-PUB-2022-053