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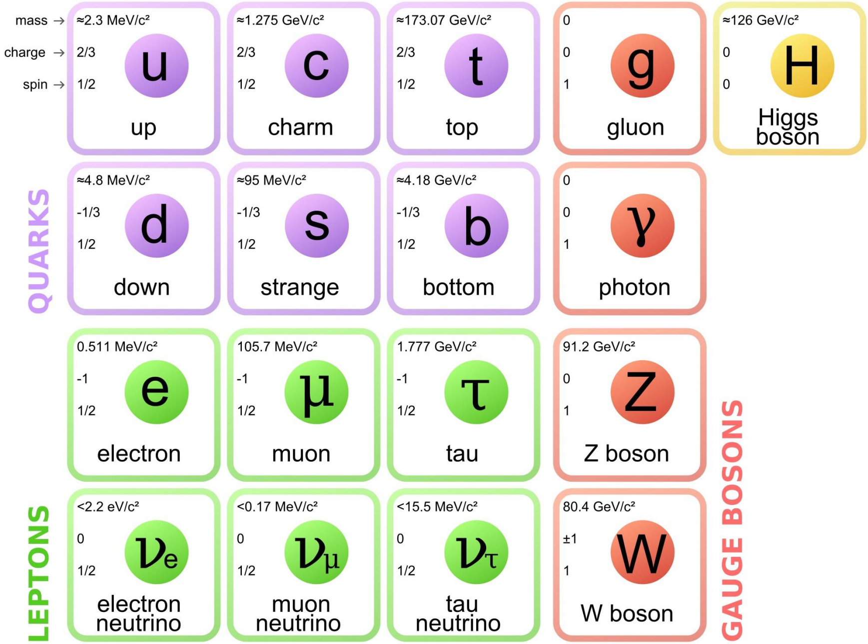
Higgs boson properties and BSM searches with H→γγ at ATLAS

Shuo Han 韩朔

EPD seminar, March 2nd 2023

The Standard Model of particle physics

- The **Standard Model (SM)** of particle physics is a successful theory for most of the observations in the experimental physics researches, it describes **3 fundamental interactions** in the universe with **quarks, leptons, gauge bosons and the Higgs boson**.
- **However,** many observations like dark matter / energy, neutrino oscillation, Baryon asymmetry, matter-antimatter asymmetry.. suggests SM is not the ultimate theory of the nature.
- **We need to explore the high energy physics beyond the SM**



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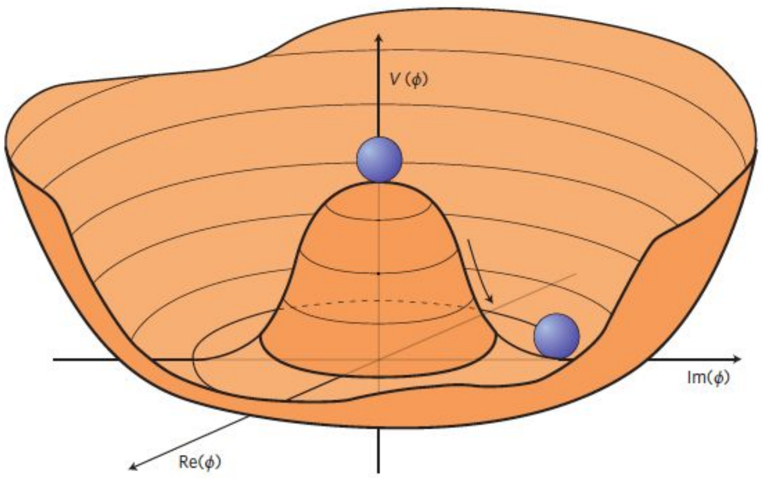
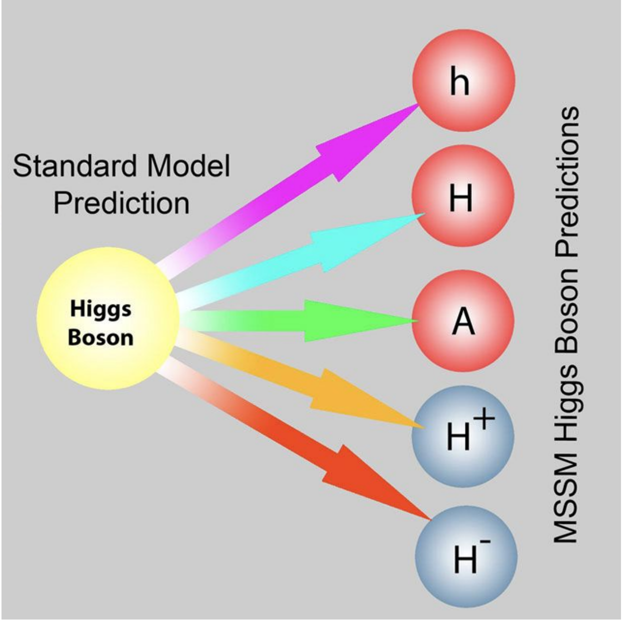
The SM Higgs boson

- The **Higgs boson** is an elementary and special particle in the SM, the Higgs mechanism explains the mass of the gauge boson and fermions in the SM.
  - **An important candidate for the precise measurements to understand the SM**
- In the meanwhile, the Higgs boson can **tag the beyond SM (BSM) processes**, for example there are Higgs + X productions in the two-Higgs doublet model (2HDM) or SUSY models.





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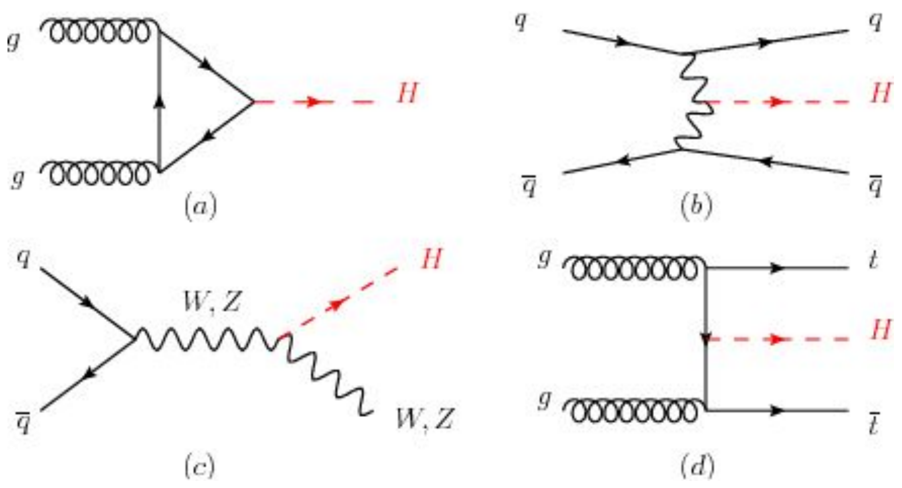
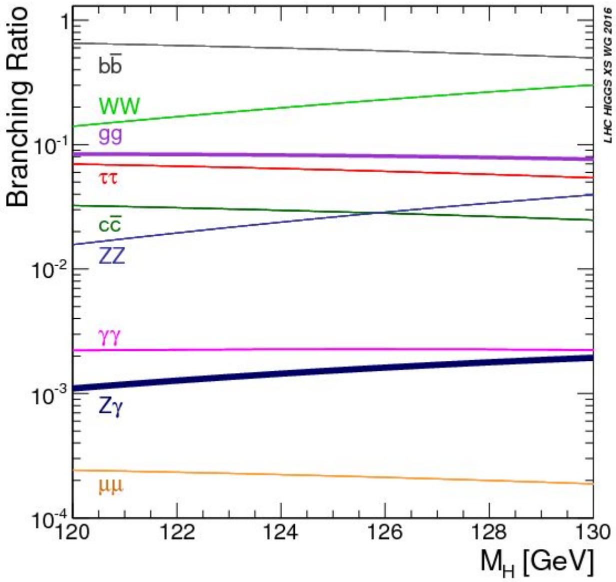
The production / decay of Higgs at LHC

- Higgs bosons can be produced with several major production modes: gluons-fusion (ggF) vector bosons fusion (VBF), in association with W/Z boson (VH), or with top quarks (ttH, tH).
- The lifetime of Higgs boson is short, and the reconstruction of Higgs boson based on its decay products with various decay branches.





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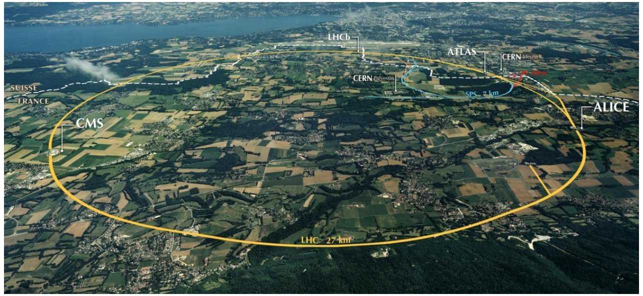
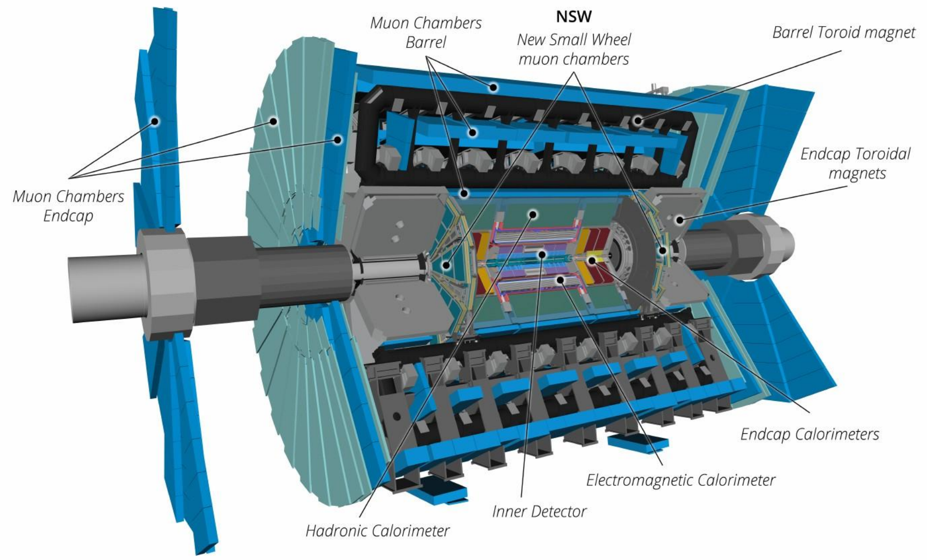
LHC and ATLAS

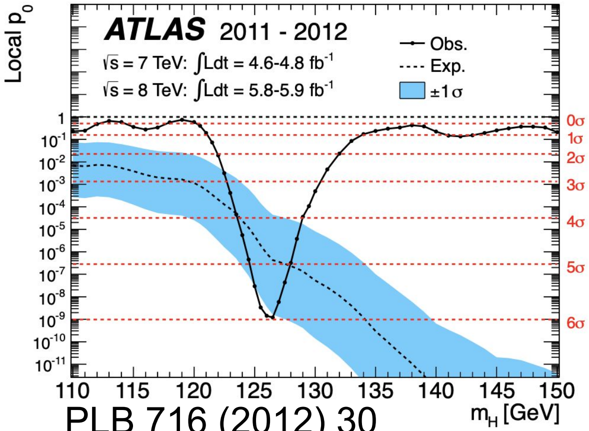
- The Large Hadron Collider (LHC) is the most powerful particle collider in the world. The proton beams inside the LHC are made to collide at four locations around the accelerator ring, corresponding to – ATLAS, CMS, ALICE and LHCb.
  - ATLAS is one of the largest, general-purpose particle detector at the LHC
- The ATLAS inner tracker, EM, Hadronic calorimeter, and muon chambers.. can reconstruct photons, leptons, jets and missing transverse energy (MET).





The observation of Higgs boson

- In 2012, with LHC Run1 data, ATLAS and CMS discovered the SM Higgs boson.
- Higgs boson discovery is a significant milestone of the SM, after this discovery, **precisely measure the SM properties** and **searching for the BSM** are 2 of the most important tasks of the high energy physics.
- With LHC Run2, ATLAS recorded 10^{16} pp collison data and 8 millon Higgs events at 139 fb^{-1} with the center of mass energy of 13TeV, the luminosity is 5.5 times as LHC Run1



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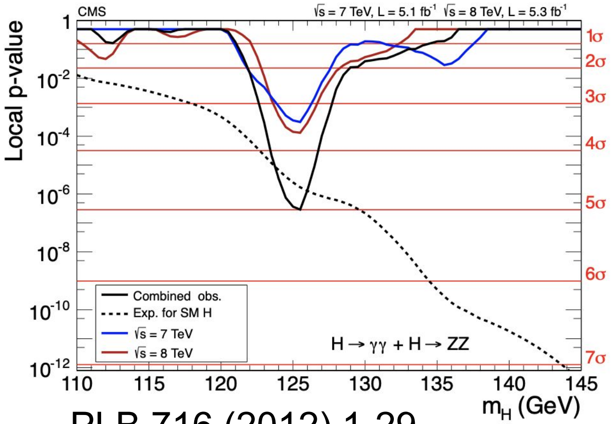

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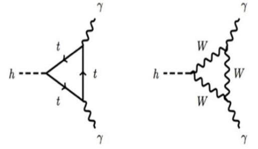
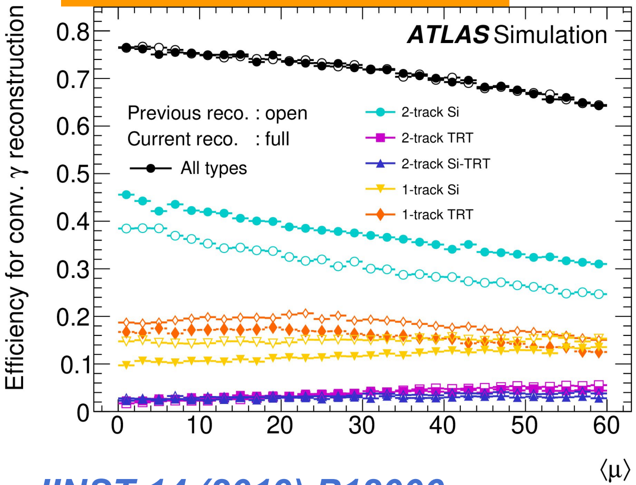
The Higgs boson property with $H \to \gamma\gamma$

The γγ channel of Higgs decay

- Higgs decays to a pair of photons via loop decays. It's one of the "golden channel" for precise Higgs property measurements.
- With relatively low branching ratio of 0.227%, the γγ signature is very "clean"
  - The high reconstruction eff. and low energy resolution of photons allows the search/measurements directly on the mass of γγ.

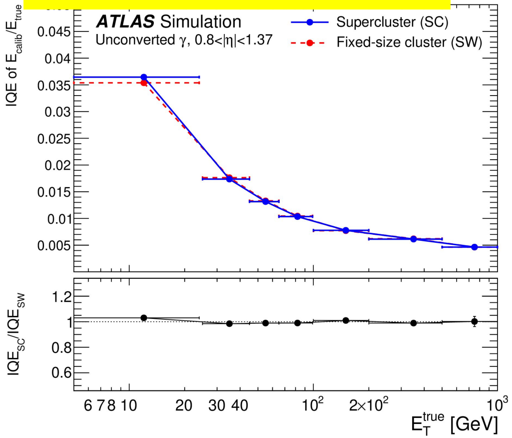


High reconstruciton eff.

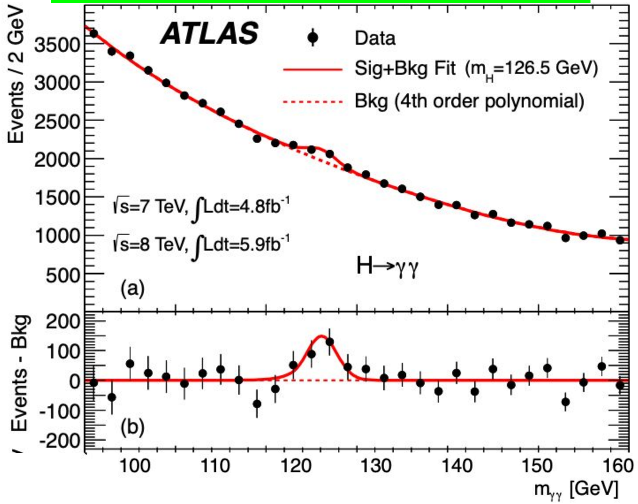


JINST 14 (2019) P12006

Low energy resolution



A "peak" on m(γγ) ~ signal mass resolution is ~1.8 GeV



H → γγ analysis with Run2 data

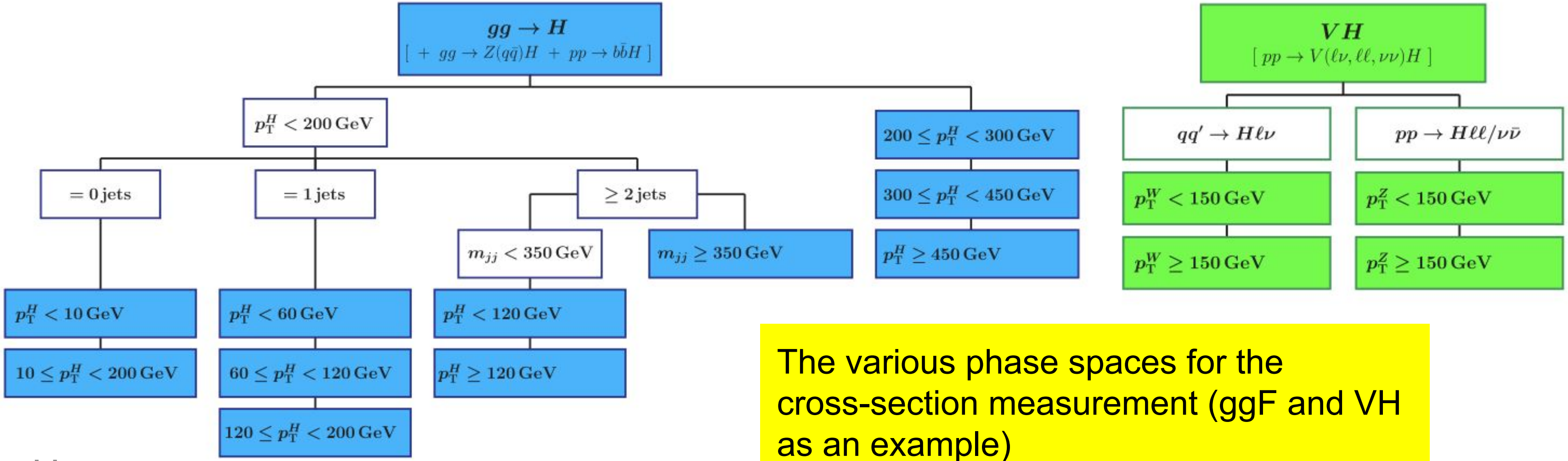
★ Where I have contributions

Higgs Properties with H → γγ (LHC Run2)

- Cross-section and coupling strength (JHEP (arXiv:2207.00348)) ★
- Differential cross-sections (JHEP 08 (2022) 027)
- Higgs CP properties and top-H Yukawa coupling PRL125(2020)061802 ★
- Higgs CP properties with VBF PRL (arXiv:2208.02338)
- Higgs → Zγ search (PLB 809(2020)135754) ★
- Higgs mass, Higgs width, charm-H Yukawa coupling.. (ongoing)

The Simplified Template Cross Sections (STXS)

- STXS is one of the most important Higgs property measurement
- STXS divides Higgs cross-section measurements in various kinematic regions, with optimized definition from theorists. (arxiv 1906.02754)
  - The simutaneous measurements on STXS precisely measures the Higgs event rates, probes any BSM clues from different coupling strength of Higgs Yukawa coupling with other particles, Higgs self-coupling, and the couplings in effective filed theories (EFT).



The various phase spaces for the cross-section measurement (ggF and VH as an example)

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STXS measurement - analysis overview

Inclusive analysis:

2 isolated photons

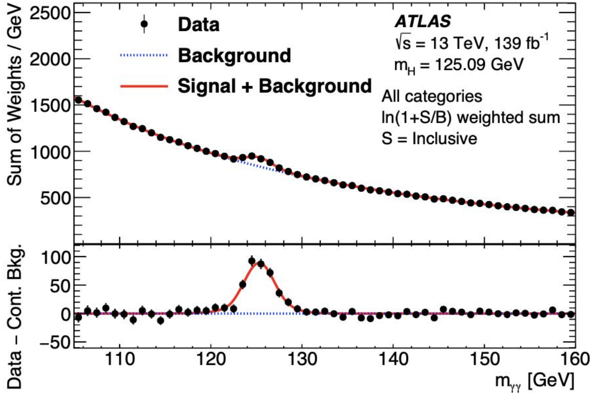
S+B fit on m(γγ)

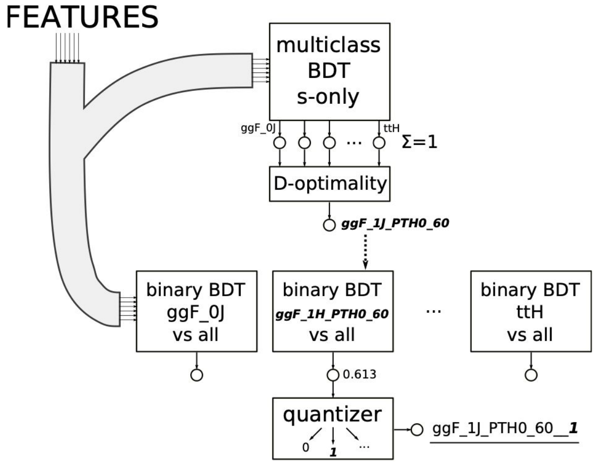
Signal: MC simulation

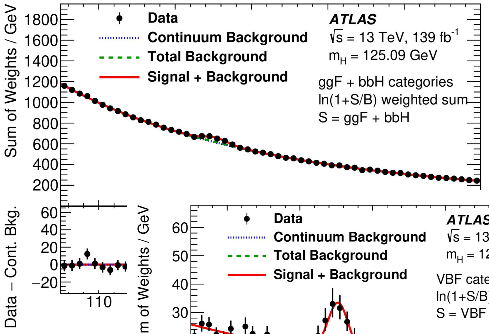
Background: analytical function based on MC γγ, Vγγ, ttγγ events

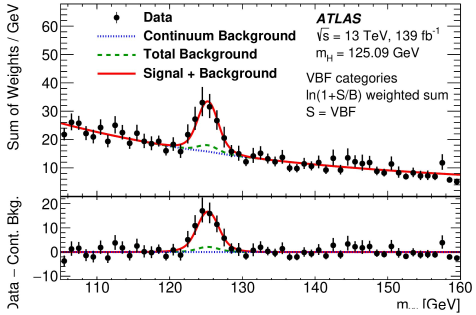
Main problem: measuring various phase spaces simultaneously

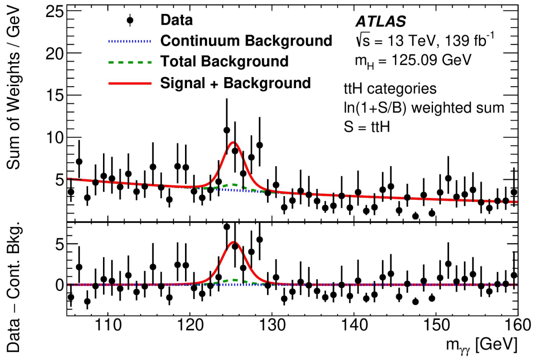
Solution: multi-class boosted decision tree (BDT) with D-optimiality (minimzation of the correlation matrix determinant)







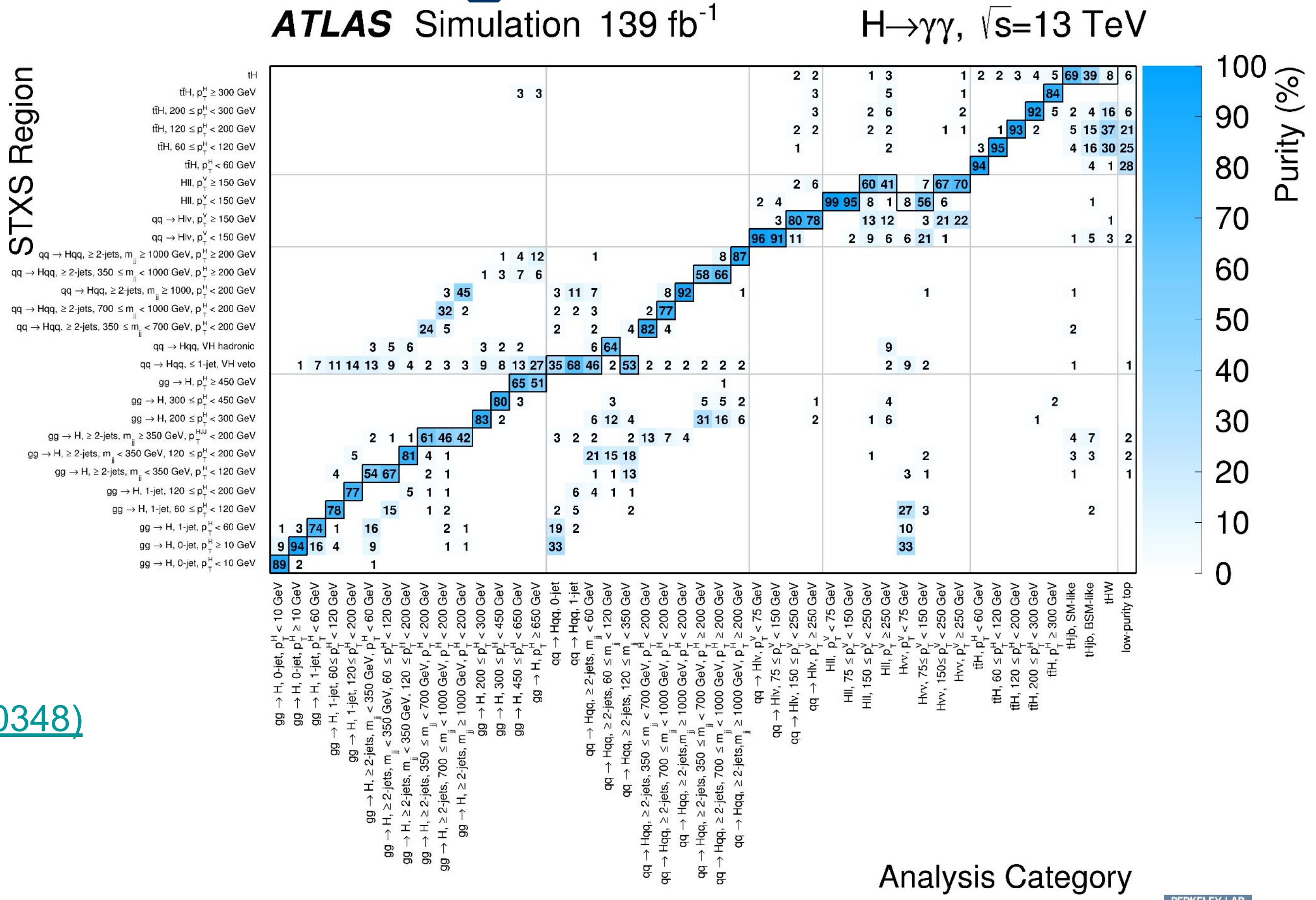




STXS measurement - categorization

A map of the “purity” of H→γγ events in various interested regions.

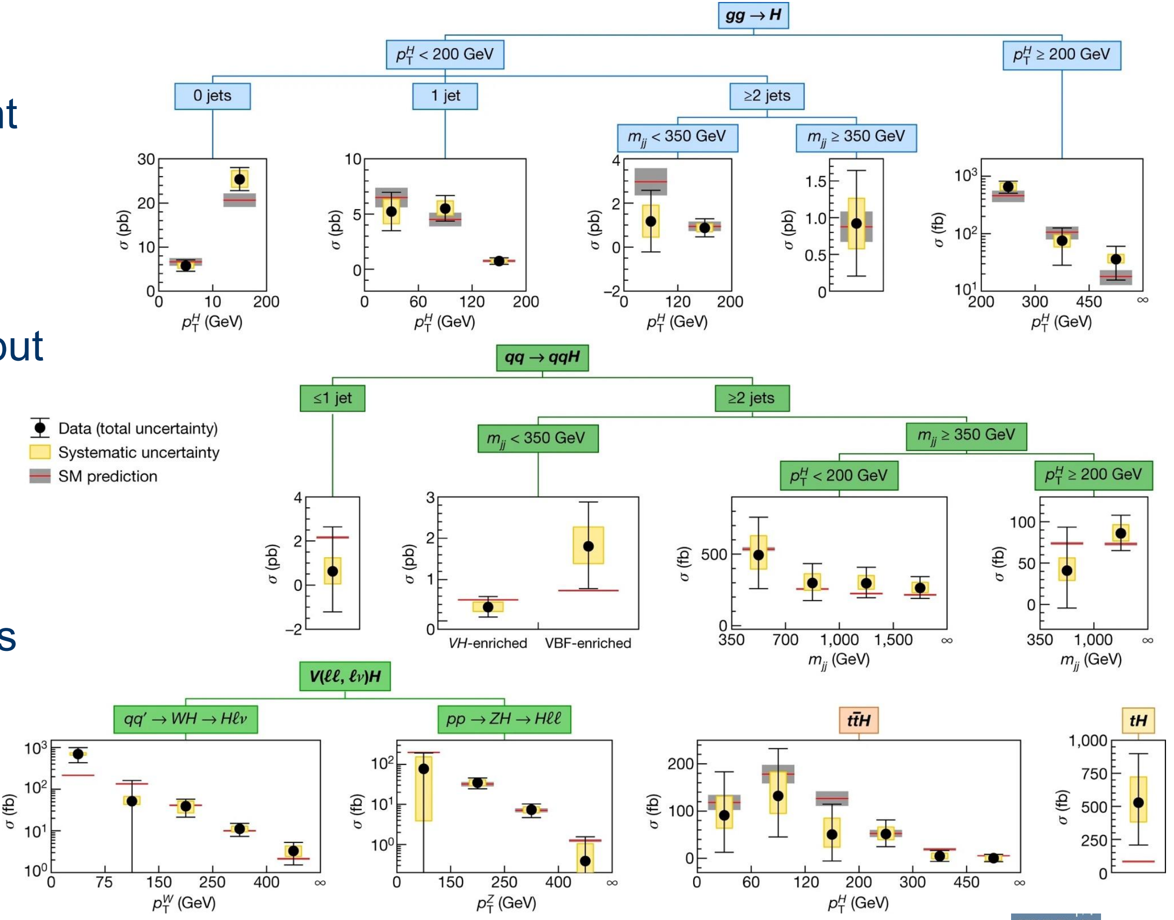
28 classes for the measurements are clearly distinguished with 101 categories, the correlations among STXS regions are under control



[JHEP (arXiv:2207.00348)](https://arxiv.org/abs/2207.00348)

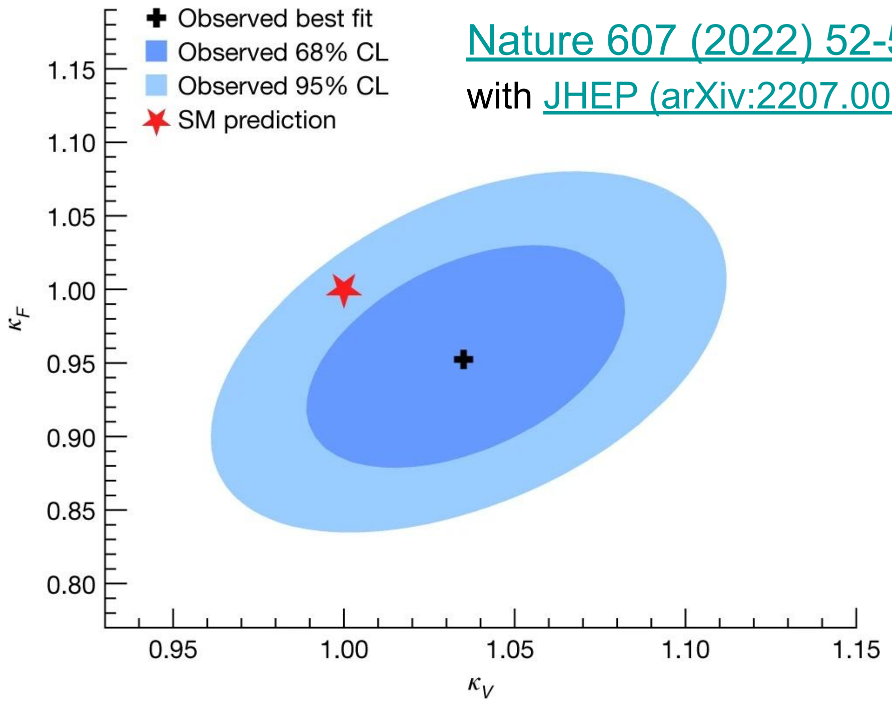
The most precise STXS with ATLAS Run2

- ATLAS published the most accurate combined measurement on Higgs properties with Run2 data Nature 607 (2022) 52-59 .
- The Higgs → γγ STXS measurement is the essential input (with ZZ, WW, ττ, bb, μμ, Zγ chanels).
- γγ channel has **highest sensitivity in various ggF, VBF and ttH regions** (γγ-only result is in backup)



The most precise STXS with ATLAS Run2

- The STXS in most regions (except some ggF regions) are dominated by statistical uncertainty
- The leading systematics are
  - Photon energy scale and resolution
  - Photon efficiencies
  - Background modeling
  - Theoricial uncertainties (Higher order QCD term, underlying event and parton shower..)
- **The result is consistent with SM**



Nature 607 (2022) 52-59
with JHEP (arXiv:2207.00348)

Interpretation with effective coupling strength modifiers between Higgs and fermions/vector bosons

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The BSM searches with the Higgs boson

BSM searches with H → γγ

- The SM-like Higgs boson can be considered as the “tag” of the BSM searches
- 2 strategies: new particle production with Higgs, or Higgs decay to new particles

★ Where I have contributions

ATLAS Run2
Higgs + X, H → γγ

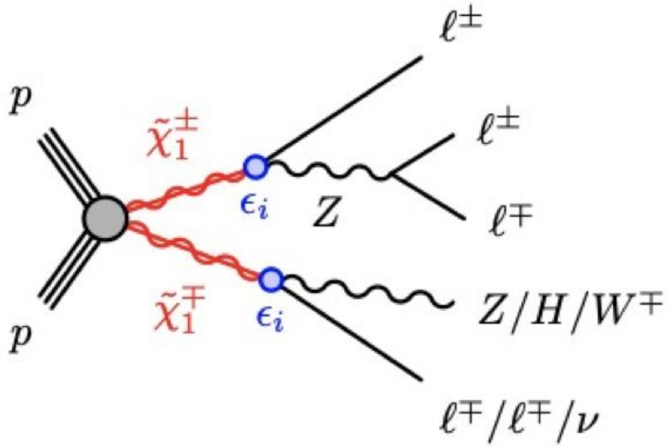
- Search for H to γγ with missing transverse energy (JHEP10(2021)13)
- ★ Model independent search for new physics with H→γγ (JHEP (arXiv:2301.10486))

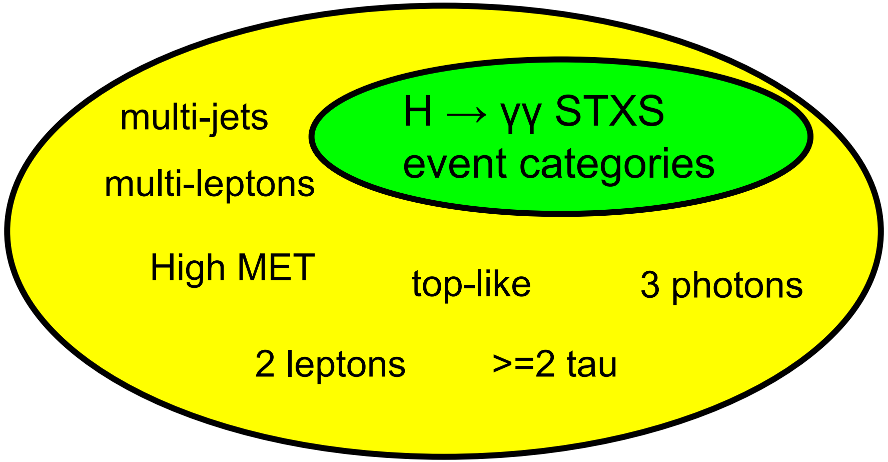
H → YY, Y → γ + X

- ★ Search for displaced photons in Higgs exotic decays (PRD (arXiv:2209.01029))

Model independent H+X search

- Although the STXS measurement covers various kinematic regions, or with different production modes, there are still many regions not covered by the SM measurements, like with high multiplicity of jets, leptons, photons..
  - We expect enhancements of Higgs boson events if there are H+X production
- The $H \rightarrow \gamma\gamma$ channel is again the most sensitive channel of BSM search of H+X





Example: H + X production with multi-leptons in the EW SUSY model

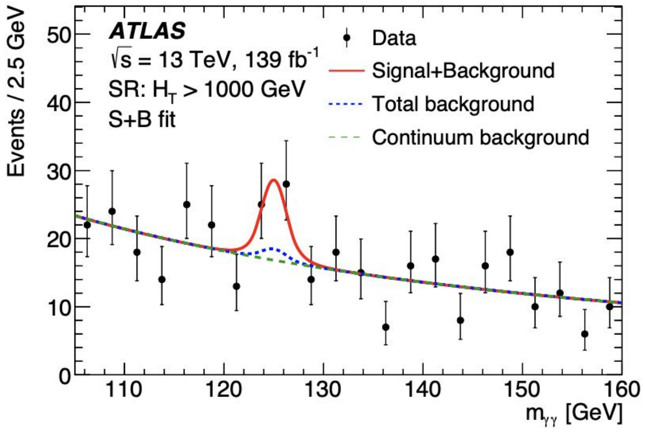
H+X search: signal regions

- Different BSM theories are used to motivate different event categories.
  - EW SUSY models: multi-lepton, high MET
  - Strong SUSY models: multi-jets, multi-b, tops
  - pp→X→γH : 3 photons
- 22 cut-based categories are defined with different jet, flavor tagging, lepton, photon, MET, and photon properties.
- The searches are performed independently in all the signal regions.

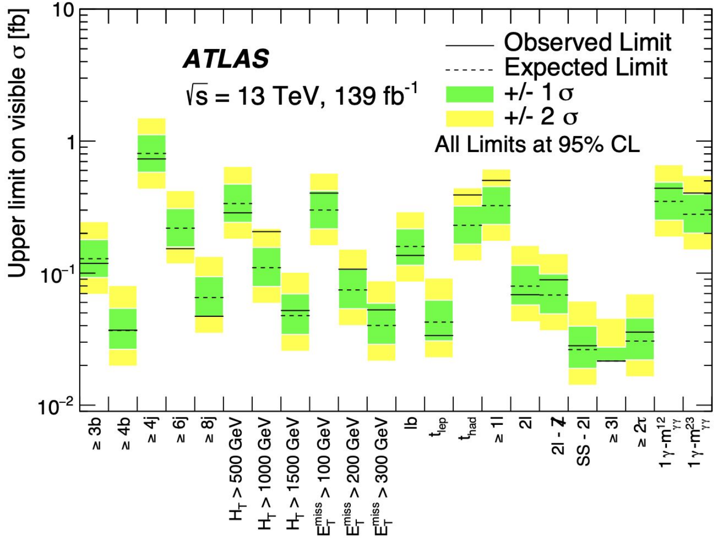
Target	Region	Detector Level
Heavy flavor	$\geq 3b$	$n_{b-\text{jet}} \geq 3$, 85% W.P.
	$\geq 4b$	$n_{b-\text{jet}} \geq 4$, 85% W.P.
High jet activity	$\geq$4j	$n_{\text{jet}} \geq 4$, $\lvert\eta_{\text{jet}}\rvert < 2.5$
	$\geq$6j	$n_{\text{jet}} \geq 6$, $\lvert\eta_{\text{jet}}\rvert < 2.5$
	$\geq$8j	$n_{\text{jet}} \geq 8$, $\lvert\eta_{\text{jet}}\rvert < 2.5$
	H_T >500 GeV	H_T > 500 GeV
	H_T >1000 GeV	H_T > 1000 GeV
	H_T >1500 GeV	H_T > 1500 GeV
E_T^{miss}	$E_T^{\text{miss}} > 100$ GeV	$E_T^{\text{miss}} > 100$ GeV
	$E_T^{\text{miss}} > 200$ GeV	$E_T^{\text{miss}} > 200$ GeV
	$E_T^{\text{miss}} > 300$ GeV	$E_T^{\text{miss}} > 300$ GeV
Top	ℓb	$n_{\ell=e,\mu} \geq 1$, $n_{b-\text{jet}} \geq 1$, 70% W.P.
	t_{lep}	$n_{\ell=e,\mu} = 1$, $n_{\text{jet}} = n_{b-\text{jet}} = 1$, 70% W.P.
	t_{had}	$n_{\ell=e,\mu} = 0$, $n_{\text{jet}} = 3$, $n_{b-\text{jet}} = 1$, 70% W.P., BDT_{top} >0.9
Lepton	$\geq 1\ell$	$n_{\ell=e,\mu} \geq 1$
	2ℓ	ee, $\mu\mu$, or $e\mu$
	2ℓ-Z	ee, $\mu\mu$, or $e\mu$, $\lvert m_{\ell\ell} - m_Z\rvert > 10$ if leptons are same flavor
	SS-2ℓ	ee, $\mu\mu$, or $e\mu$ with the same charge
	$\geq 3l$	$n_{\ell=e,\mu} \geq 3$
	$\geq 2\tau$	$n_{\tau,had} \geq 2$ †
Photon	$1\ \gamma$-$m_{\gamma\gamma}^{12}$	$n_\gamma \geq 3$, $m_{\gamma\gamma}$ defined with γ_1,γ_2
	$1\ \gamma$-$m_{\gamma\gamma}^{23}$	$n_\gamma \geq 3$, $m_{\gamma\gamma}$ defined with γ_2,γ_3

H+X search: results

- S+B fits on the mγγ distributions.
- With full Run2 data, no obvious excess of H+X production. The largest deviation from SM has a local significance 1.8σ in the HT > 1000 GeV region. The detector level limits are set on the BSM cross-sections. We also report the detector eff. of each BSM models.
  - **The first result covers various final states with H → γγ**



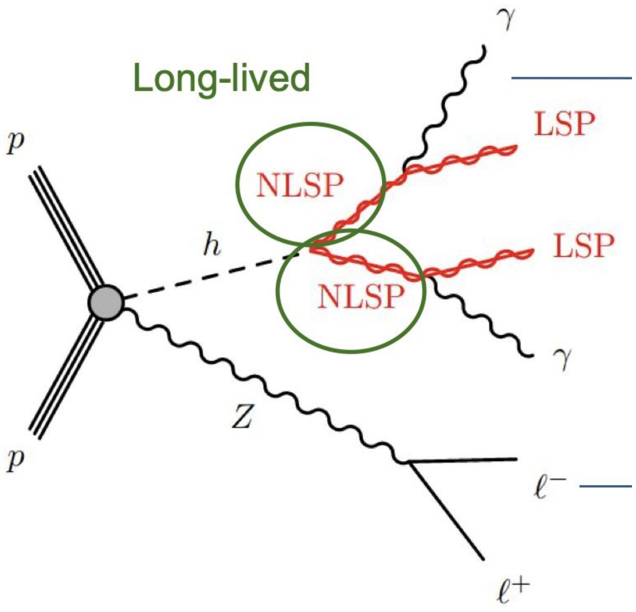
1.8σ significance with H→γγ and HT > 1000 GeV



JHEP (arXiv:2301.10486)

Displaced photons - introduction

- Another approach to search BSM physics with the SM-like Higgs boson: Higgs decay to new particles, with photons as the final objects.
- SUSY models can predict Higgs decay to displaced photons and invisible new particles as missing transverse energy (MET).



The pointing and arriving time of photons will be different from the prompt decay of H → γγ

The leptons form VH and ttH Higgs production modes can trigger the event selection

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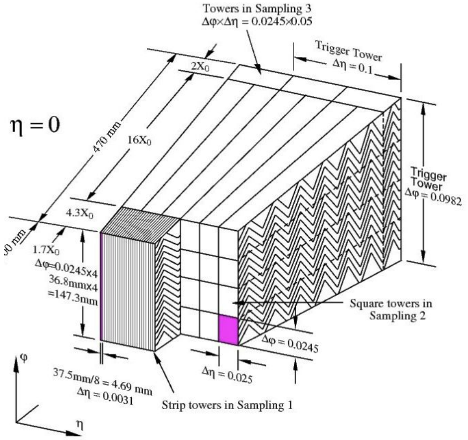
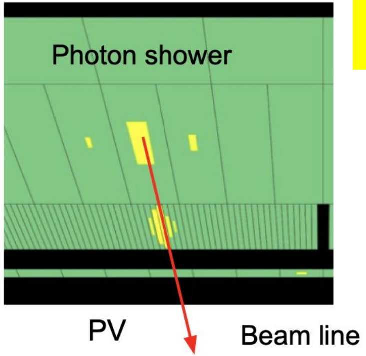
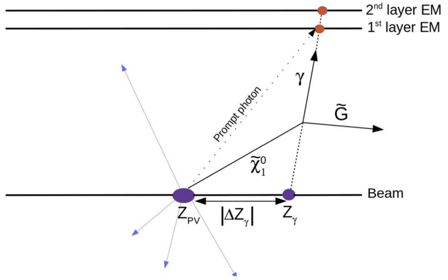
Displaced photons - pointing and timing

- **ATLAS EM calorimeter has 3 layers with different granulariy (different from CMS)**
- **Photon pointing** is the separation along the beam line between the extrapolated origin of photon and the primary vertex.
- **Photon timing:** the delay of the arrival time of photons comparing to prompt photons, based on the highest energy cell of the second layer of EM-calorimeter.

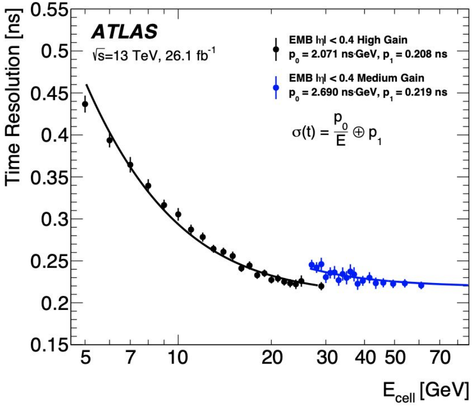




Pointing resolution ~15mm



Lowest time resolution: 208ps



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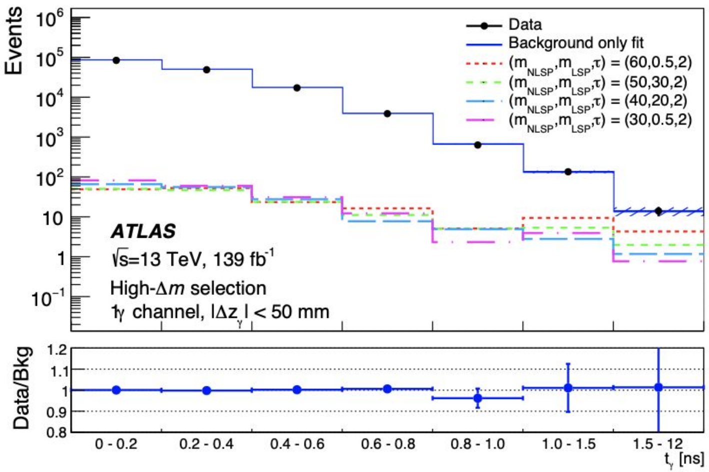
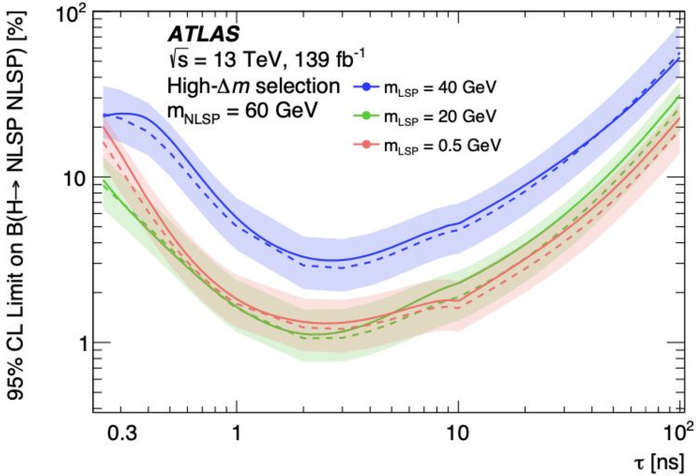
Displaced photons - result

- The analysis selects >=**1 lepton, >=1 photon**, with high MET and EM calorimeter cell energy.
- A **binned S+B fit** measurement is done with the **leading photon pointing + timing**, where
  - Signal model is from MC SUSY simulation; Backgrounds are from data control regions.
- With Full Run2 data. No excess found beyond SM. Limits set on the Br of Higgs exotic decays, with different lifetime and the mass of lightest suppersymmetry particles.





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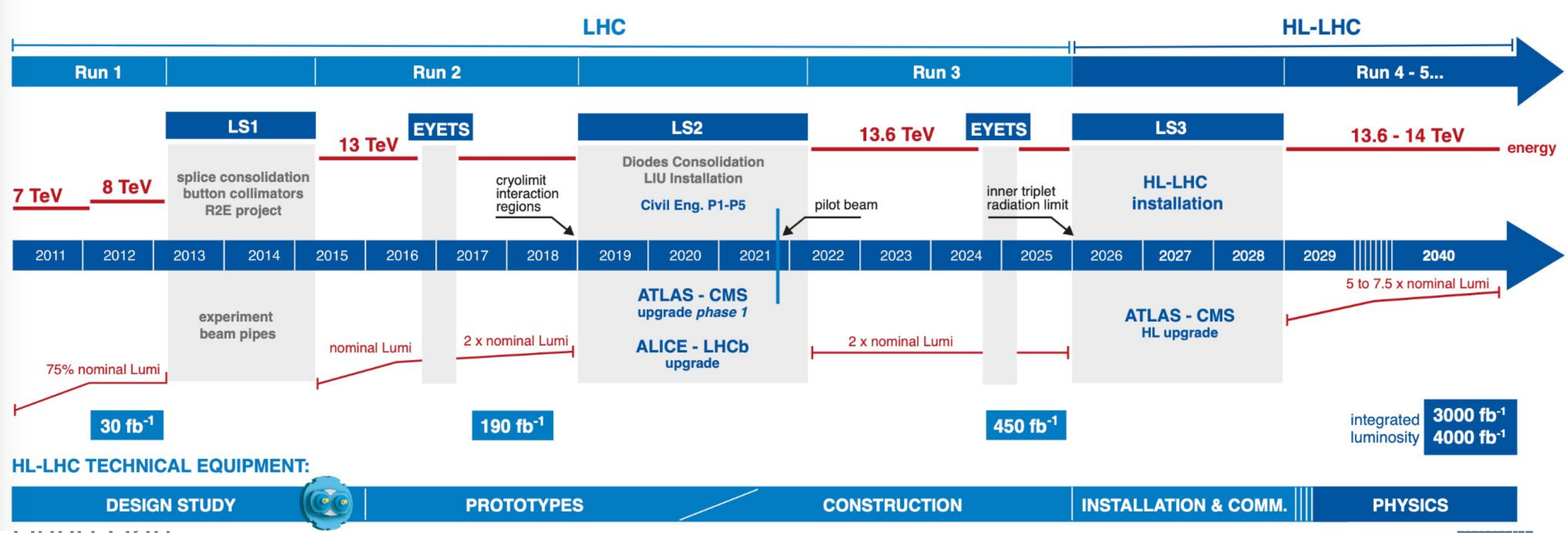
PRD (arXiv:2209.01029)

The outlook of Run3 and HL-LHC

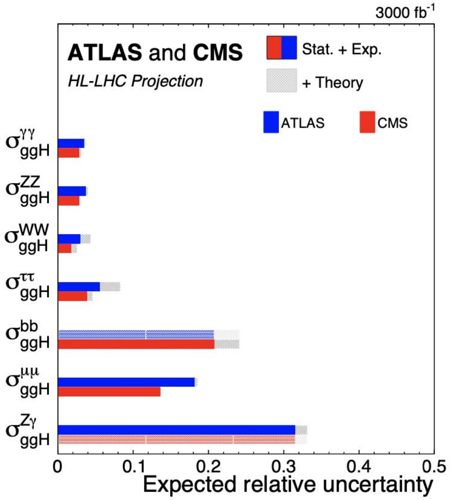
Run3 and HL-LHC

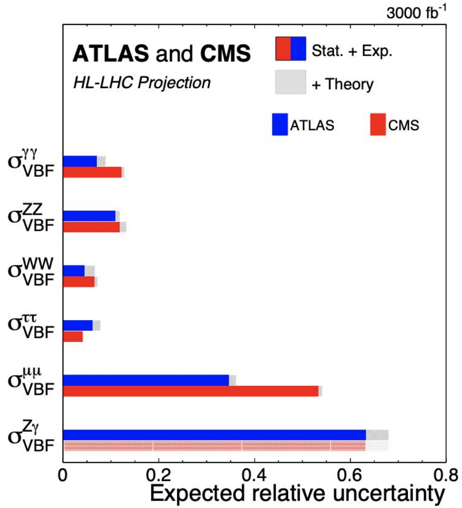
- In July 2022, the LHC returned with 13.6 TeV in its first stable-beam collisions. The luminosity of Run3 (2022-2025) will be around 2 times as Run2.
- From 2026, LHC will have another long shutdown for the High Luminosity LHC (HL-LHC)
- In the HL-LHC we plan to take >=3000 fb^{-1} pp collision data at 14 TeV. (6-7 times as the sum of Run1-3)
  - We need upgraded detector, better object reconstruction, and optimized analysis strategy

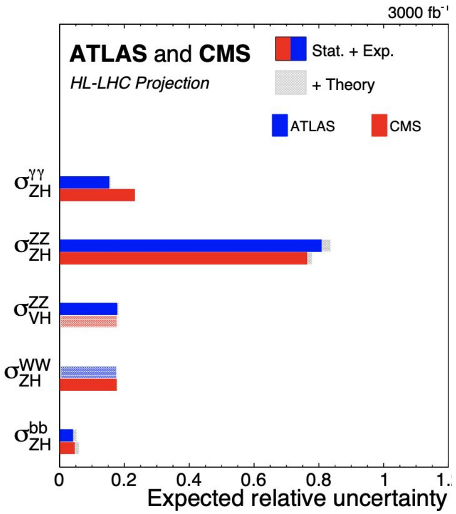


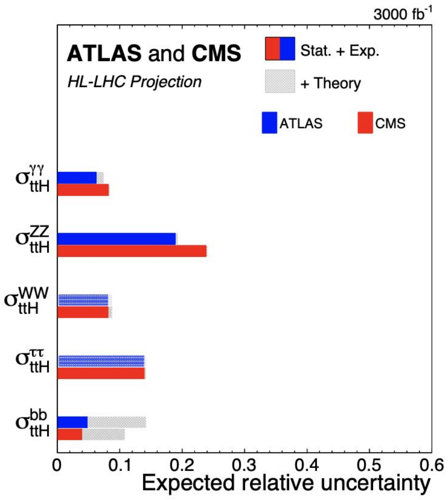
Higgs physics at HL-LHC

- Using the Run2 results at LHC, the projection of expected sensitivities at HL-LHC are calculated for the various Higgs decay channels.
- The di-photon channel remains to be the most sensitive channel to measure the Higgs properties, the accuracy with VH and ttH will also be significantly improved.









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CERN-LPCC-2018-04

Outlook in Run3 2022-2025

ATLAS EXPERIMENT

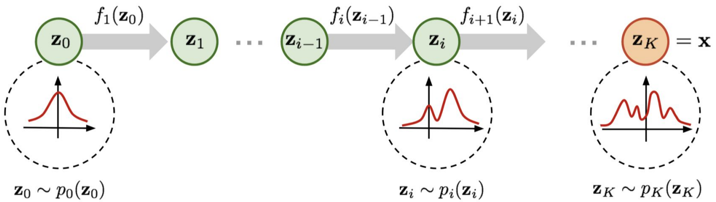
ATLAS Run3 analysis

- The precise measurements of the Higgs properties with $H \rightarrow \gamma\gamma$
- The precise measurements of the SM multi-top production and the Higgs-top Yukawa coupling with multi-lepton final states
- The combined measurements of the SM properties with ATLAS and CMS results
- The developments of silicon detectors

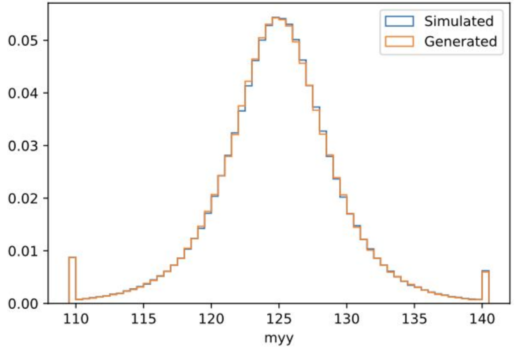
This outlook is just to highlight a few directions, there are a lot of other interesting topics

Run3: Higgs properties with H → γγ

- H→γγ remains to be the most sensitive channels to measure Higgs properties at Run3 and HL-LHC
- 3 main challenges
    - **Multi-classification -** the remained correlations in the measurements
    - **Background samples** - need high statistic γγ sample to model the background, no efficient way to generate the minor background (γ+jet).
    - **High interaction per bunch crossing (pileup) -** Run3 and HL-LHC are high pileup events, it decrease the photon and diphoton vertex efficiencies with current algorithms
- All the above chanllages are the chances to develop new methods, like introducing more advanced machine learning techniques than BDTs, or new methods of background modeling.
    - The Run3 analysis already started, we expect the first result in March



R&D example: normalizing-flow method to generate the detector resolution and compute signal m(γγ) (Moriond 2023)



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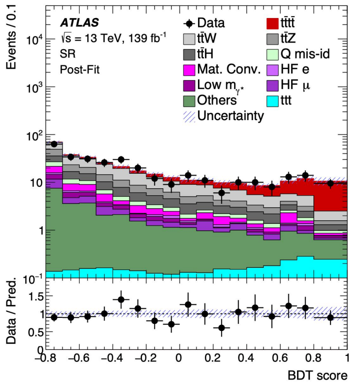
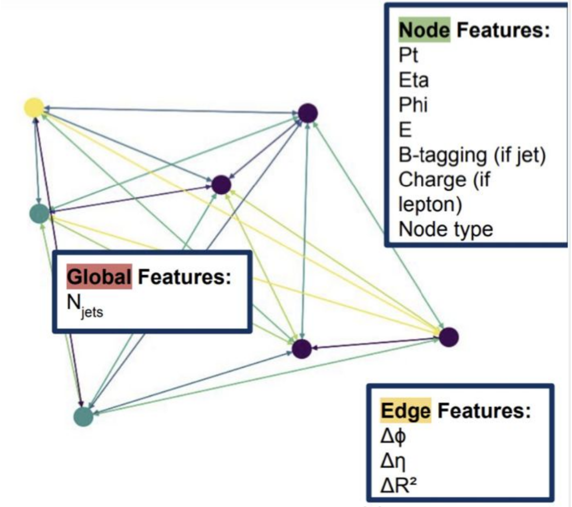
Run3: SM measurements with multi-top

- Top quark is the heaviest elementary particle and has a strong connection to the SM Higgs boson. The rare multi-top processes like 4top are not observed.
- The multi-lepton final state is sensitive to measure the 4top process, but the background is very complicated with more than 5 major components.
- With a simple BDT classfier in Run2, we already found the evidence of SM 4top
  - Re-analysis with optimized analysis procedures is ongoing, we are close to declare the observation of 4top process. More multi-top and ttH analysis will be triggered in Run3.

EPJC 80 (2020) 1085

4.3 (2.4) standard deviation





BDT -> Graph Neural Network (GNN), updated selections, modeling, systematics in the re-analysis

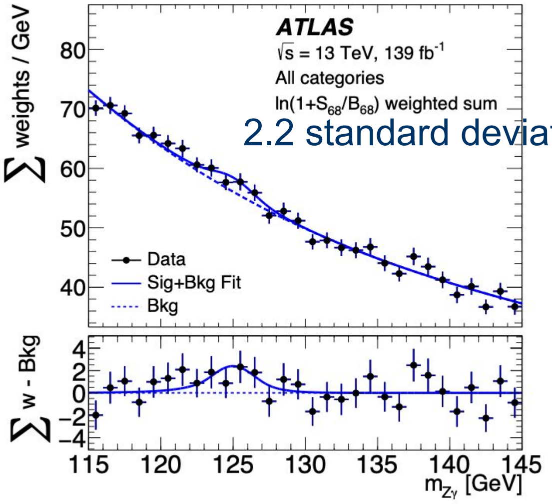
New result (Moriond 2023)

Run3 analysis (4top, ttH & H→WW, 3top)

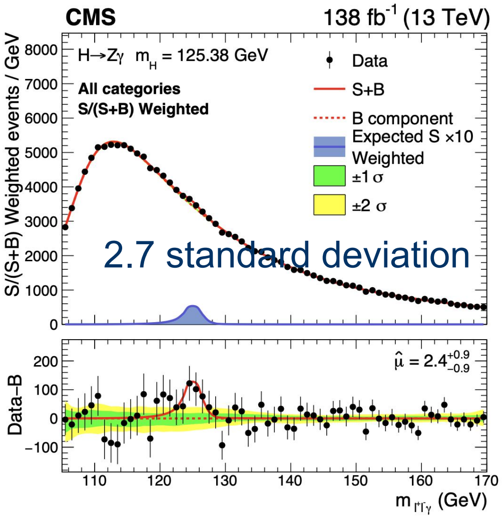
Shuc

Run3: ATLAS + CMS combinations

- CMS is another general purpose detector with LHC pp collocation data and fully independent detector performance. The ATLAS + CMS combination will significantly reduce statistical uncertainties.
- The ATLAS + CMS combination is meaningful for particular analysis constrained by statistical power
  - H → Zγ is another important Higgs rare decay channel to probe BSM enhancements. The combined H → Zγ search is ongoing, where we expect to observe the first evidence.
  - There'll be much more ATLAS + CMS combined measreuments with ATLAS Run2 and Run3 data



2.2 standard deviation



2.7 standard deviation

Combined result
-> expect a significance of >3 standard deviation (LHCP 2023)

Other ATLAS + CMS combination with Run2 and Run3 data

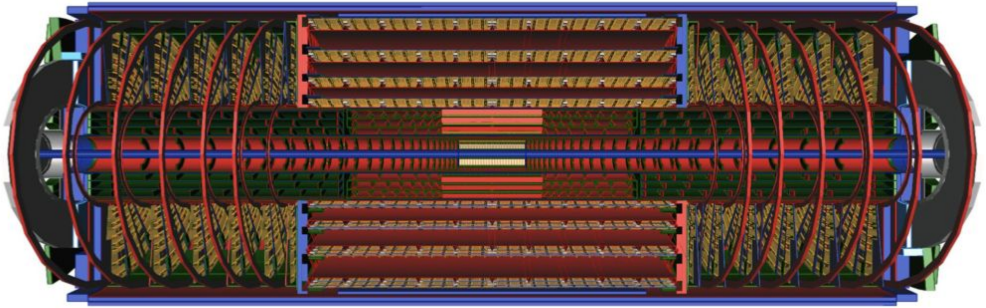
ATLAS Phase-II upgrade

The ATLAS upgrade for HL-LHC

- At HL-LHC, ATLAS needs to collect 3000 fb^{-1} dataset with much higher actual interactions per bunch crossing (pileup), it requires the Phase-II upgrade of ATLAS.
- **The major updates are the new inner trackers, muon chamber, a high granularity timing detector (HGTD), and upgraded trigger, DAQ, electronics**

New HGTD based on LGAD to disentangle pileup

Full upgraded Inner tracker (ITK) - pixel and strip detectors, with finer layers, reduction of material, redesigned ASICS ..



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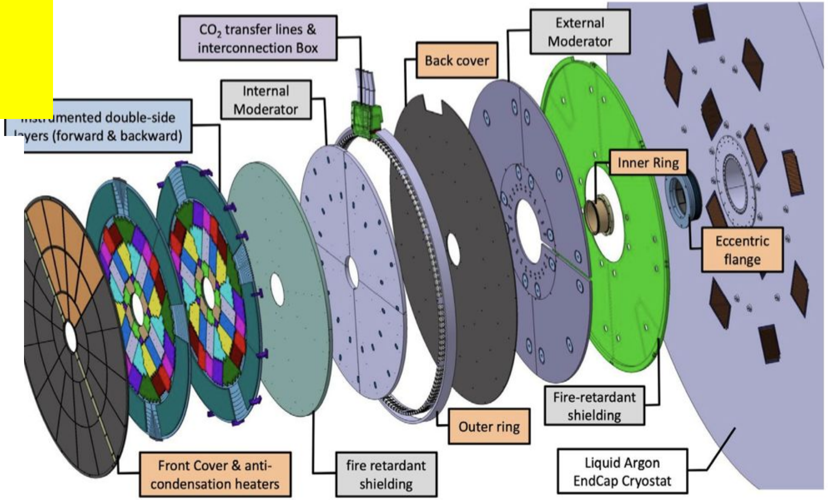

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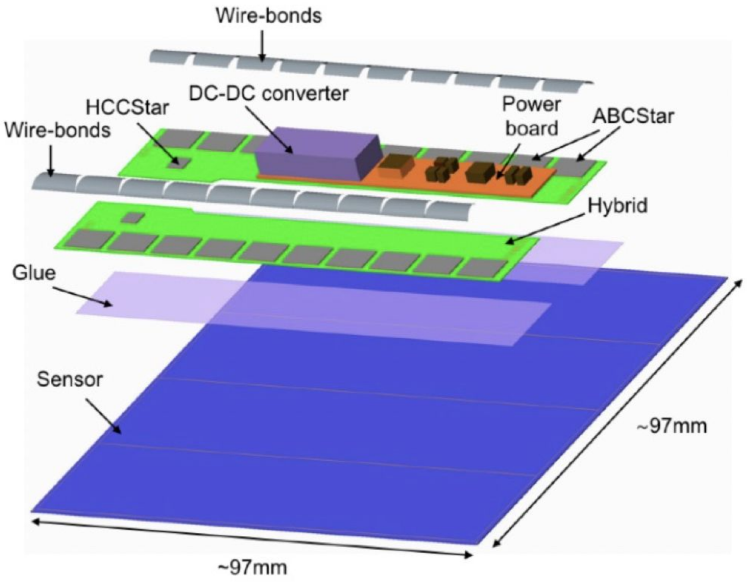
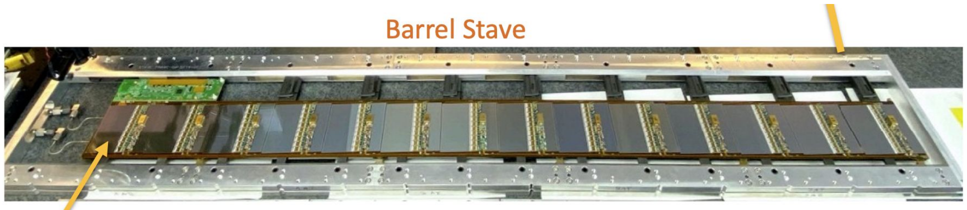
The ATLAS upgrade at LBL

- At the LBNL site, we work on the new pixel and strip inner trackers. I’m involved in the pre-production of barrel strip modules by verifying several production procedures at LBNL. We eventually need 11000 barrels strip modules for 4 layers of strip detectors and 6+6 disks of endcap strip detectors.



Short-strip module

- Strip modules
    - Silicon sensors with 1280 strips with a 75 μm pitch and 2.5 or 5.0 cm length
    - Hybrids: PCB holding the read-out ASICs.
        - 10 ABCStar (amplifier/discriminator), one HCCStar (hybrid controller)
    - Powerboard:



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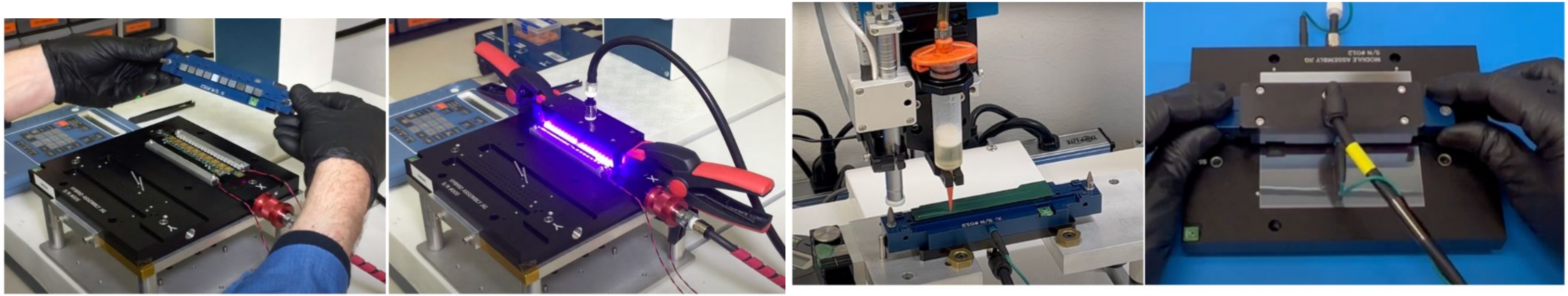
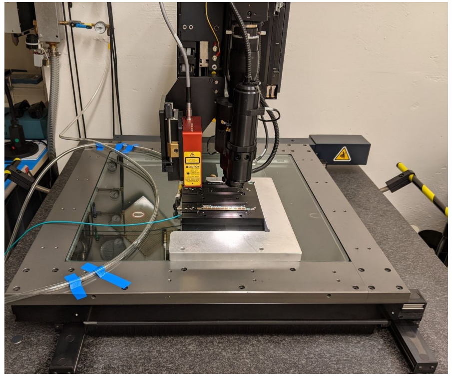
The strip module assembly workflow

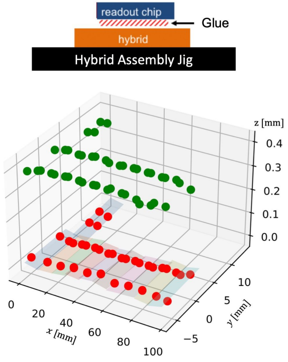
ATLAS EXPERIMENT

Assembly & Bonding

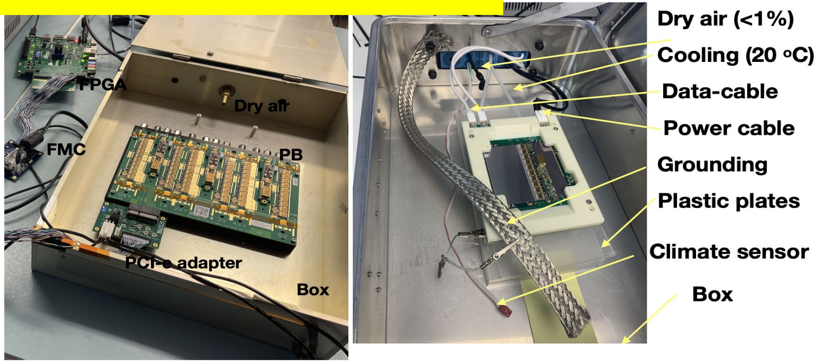


Metrology





Electrical tests



The workflows are in parallel for each components (sensors/hybrids/power-boards) and the module

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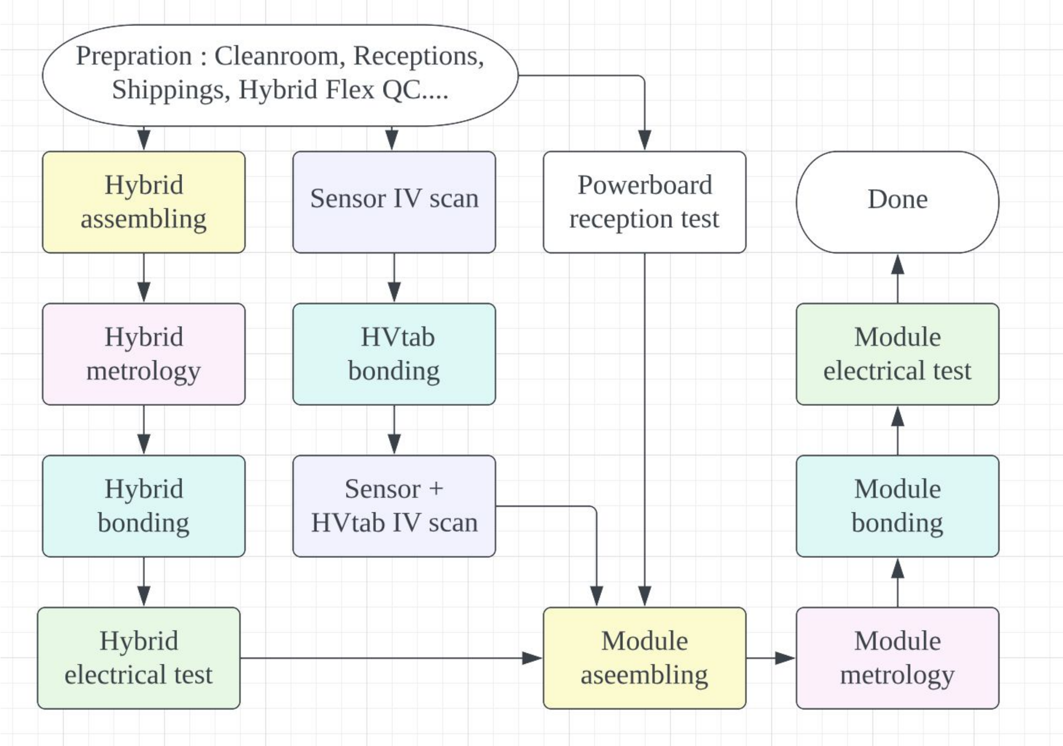
The strip module assembly workflow

Two labs for module assembly

- Cleanroom
  - Hybrid/Module Assembling
  - Sensor/Hybrid/Module bonding
  - **Hybrid/Module metrology**
- Testing lab
  - **Sensor IV tests**
  - **Hybrid electrical tests**
  - **Module electrical tests**
  - Powerboard reception tests
  - Module thermal cycling
  - **Hybrid burn-in tests**
- The baseline procedures passed the "site-qualifications" for the pre-production of strip modules. In 2022, we worked on "pre-production B" and built 46 modules



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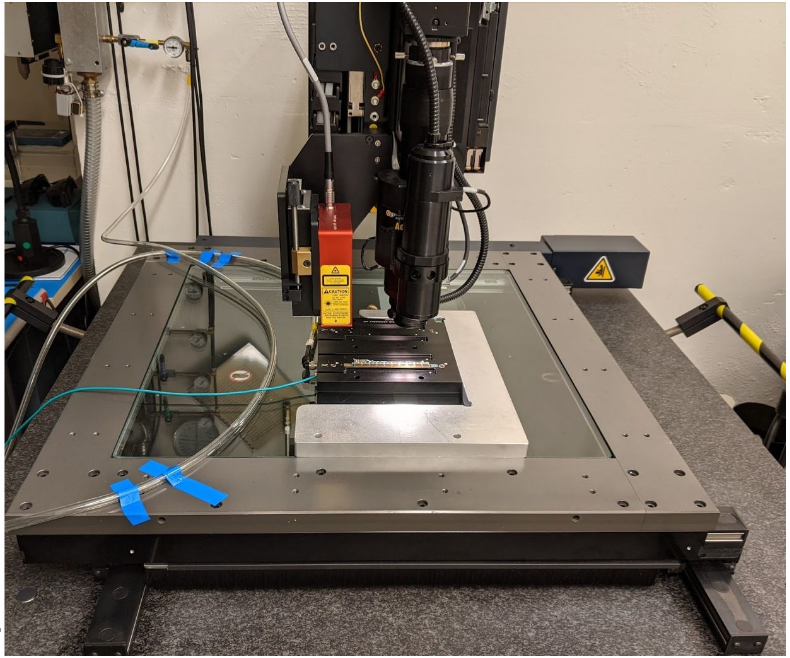
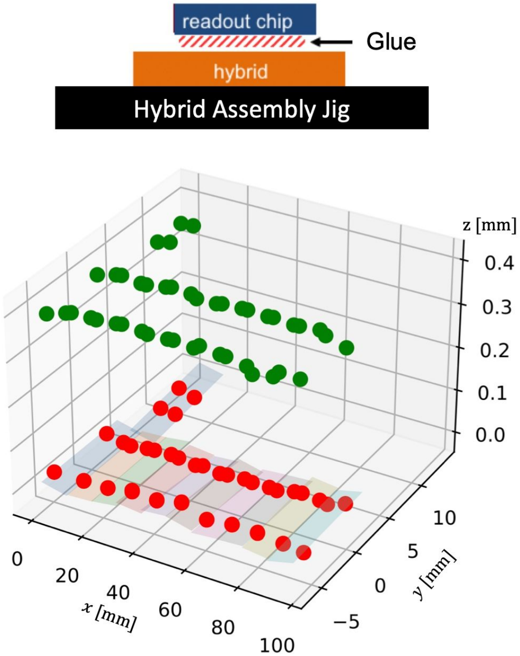
Strip modules - Metrology

- Use OGP SmartScope to measure x, y, z data.
  - Stage moves in the xy-plane. Optics and laser assembly move in the z-direction.
- The parameter of interests
  - Hybrid metrology: total package height, ASIC glue height, XY position, and tilt.
  - Moudle metrology: Hybrid and power-board XY-position and glue height, bow of the module





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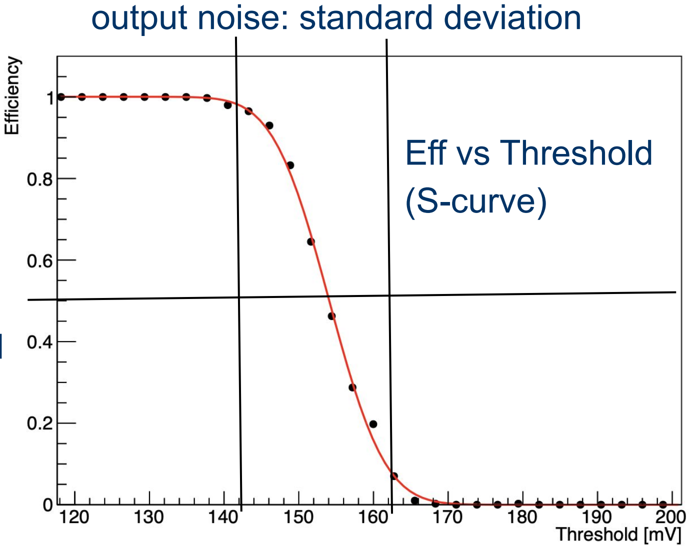
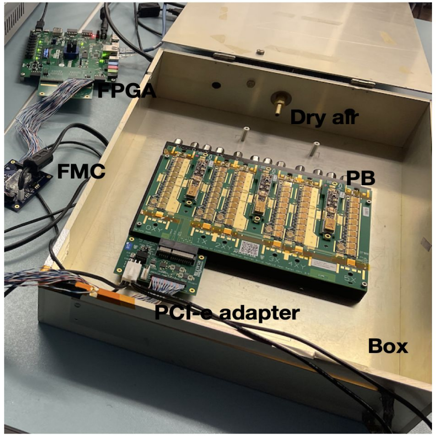
Strip modules - electrical tests

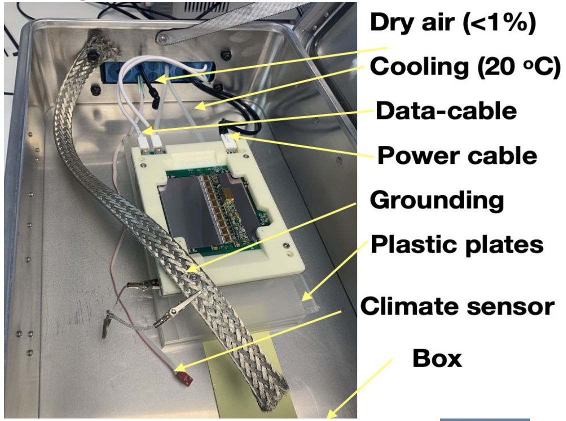
- **The most important electrical tests on hybrids and modules is the front-end response curve test:** The trend of the S-curve with several injected charges. The "input noise" is defiend as the S-curve output noise divided by the gain on the S-curve median threshold with higher injected changes.
  - The input noise of each of the 1280 channels will be compared with the average.

Vt50: median threshold



Baseline test setup for hybrid and modules
Hybrid/Module - FMC - FPGA - DAQ software



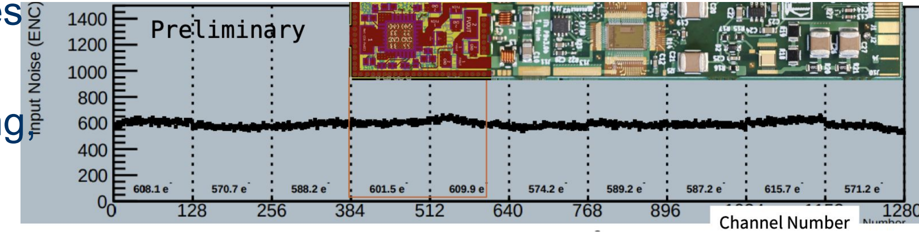


Shuo

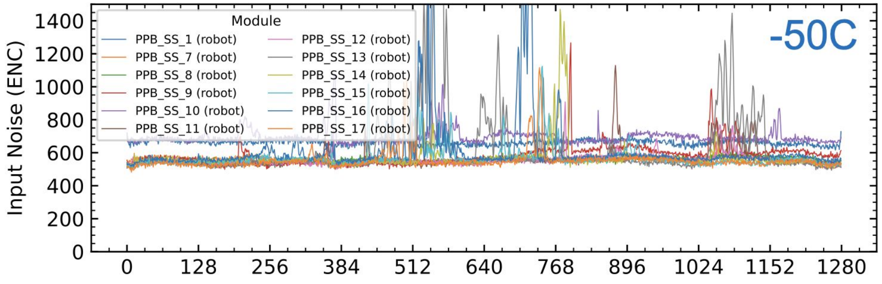
Strip modules - challenges

- The LBL site has built a large amount of strip modules (PPA, PPB1, PPB2), we met different types of challenges with module assembling
    - **Mechanical:** metrology requirements on gluing, bonding routines, shield of DCDC converter
    - **Electrical:** environment in the testing boxes, FPGA firmware and DAQ developments, connection bandwidth
    - **Thermal:** cold noise
        - The most significant problem of the current production
        - Noisy channels with low temperature - can be mitigated by softer glue or thicker glue layer, but still investigating the source

DCDC converter impact on the input noise



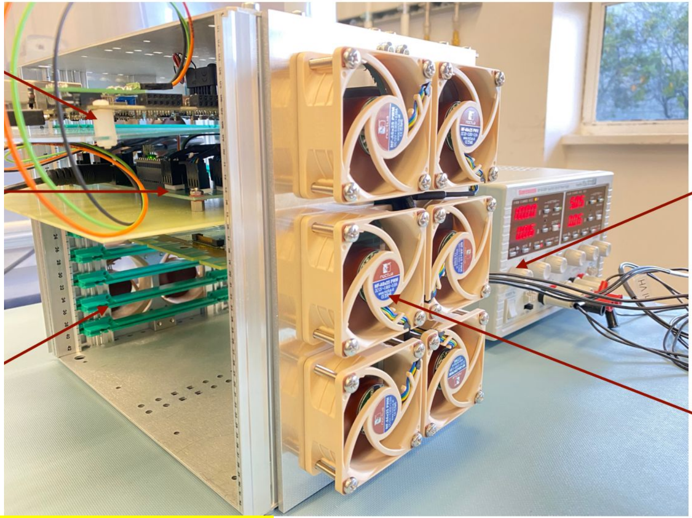
The “cold noise” issue



Strip modules - ongoing works

- **Cold box:** it can test 4 modules at one time, and performs the module tests with thermal cycling between +40℃ and -30℃

- **Burn-in crate:** it can test 36 hybrids at one time, and performs the hybrid burn-in tests by cycling the hybrid tests >100 hours



Power supply throug the backplane

Cooling using 6 X 2 fans

The ongoing works

Summary

Summary

- Measuring the properties of SM and searching for BSM are 2 of the most important tasks of the high energy physics.
- This reports highlights the physics analysis with Higgs boson and photons, and a few interesting topics in the near future (during Run3 and long shutdown)
- LHC Run3 and HL-LHC are coming
  - More SM quantities can be precisely measured, and systematic uncertainties will dominant the physics analysis, we'll need
    - ATLAS phase-II detector upgrade
    - Reconstruction and identification of analysis objects with high pileup
    - New analysis strategies and tehniques, for example more advanced machine learning techniques.
  - As Run3 is ongoing, the R&D of physics analysis and silicon detectors can become the baseline strategies for full Run3 and HL-LHC

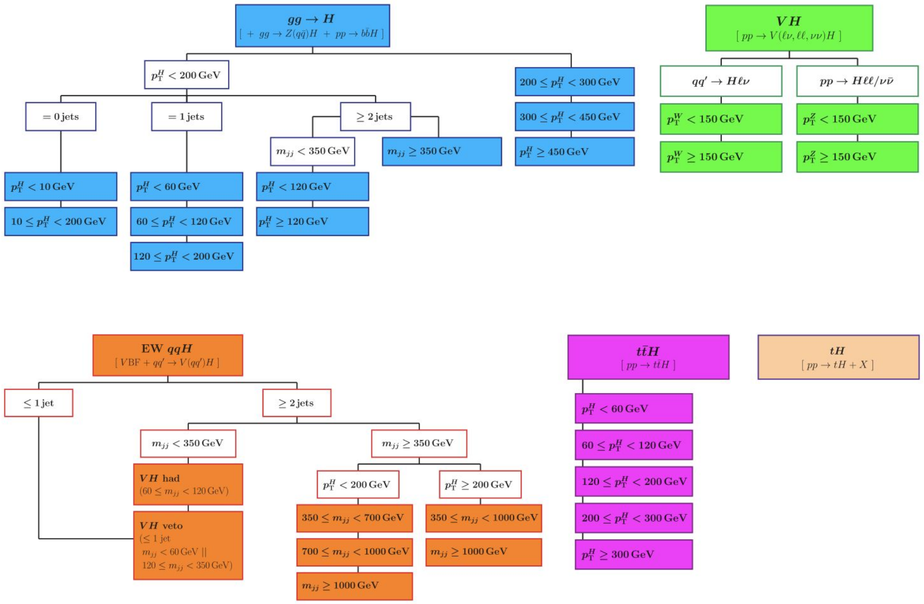
Backup

Self introduction

- Shuo Han. Date of Birth: 1991 June
- Education
  - 2014.9 - 2019.7 IHEP, CAS, particle physics, PhD
    - *Thesis：Measurement of Higgs boson properties and search for new particles in the final states with photons or leptons with the ATLAS detector。Supervisor：Shan Jin*
  - 2017.1 - 2019.1 DESY, visiting PhD student.
- Work experence
  - 2015.8 - now. Member of the ATLAS collaboration at CERN
    - The analysis contact of the major Higgs property mesaurements in the diphoton channel with LHC Run2/Run3 data.
  - 2019.11 - now. Postdoctoral scholar at LBNL
    - Physics analysis with the ATLAS experiment.
    - ATLAS ITK strip detector upgrade at LBNL.

The Simplified Template Cross Sections (STXS)

- The simplified template cross-section (STXS) divides Higgs cross-section measurements in various kinematic regions, with optimized definition for reducing theoretical uncertainties, multivariate analysis, and the combined measurements.



It probes any BSM clues on event rates from different coupling strength of Higgs Yukawa coupling with other particles, Higgs self-coupling, and the model-independent couplings in effective filed theories. The definition of kinematic regions are based on:

- Higgs production modes
- Higgs pT or Higgs+jet pT
- Number of jets, mass of di-jet
- vector boson pT

STXS and coupling - analysis overview

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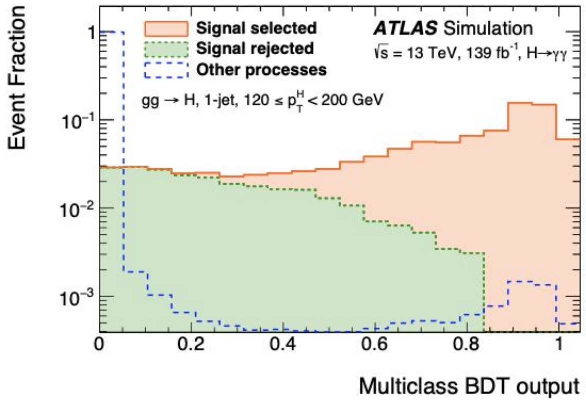
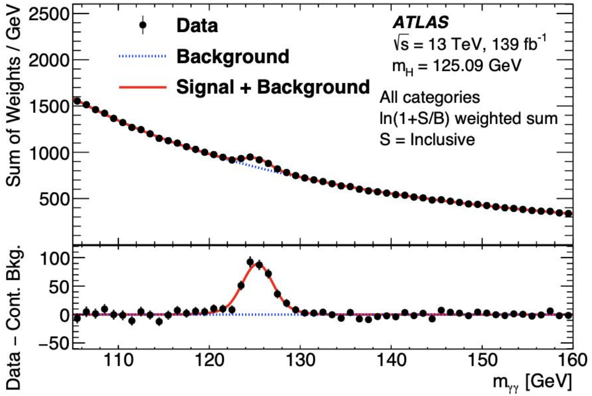
- **STXS** is adopted to be the primary goal of the analysis.
- **Two prompt isolated photons** as pre-selection.
- **101 orthogonal categories based on multi-class BDT** is developed for the simultaneous measurement in different STXS truth regions.
- **A simultaneous S+B fit will be performed on mγγ**,
  - **Signal** is a resonance on mγγ, the signal model is from the MC simulation
  - **Background** comes from SM γγ, γ+jet, di-jet, Vγγ, and ttγγ, the background is modeled with analytical functions





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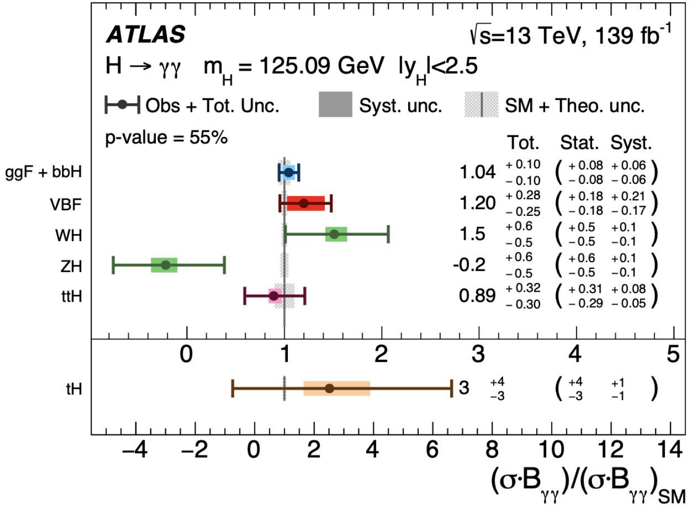
Inclusive and 6 production modes cross-section

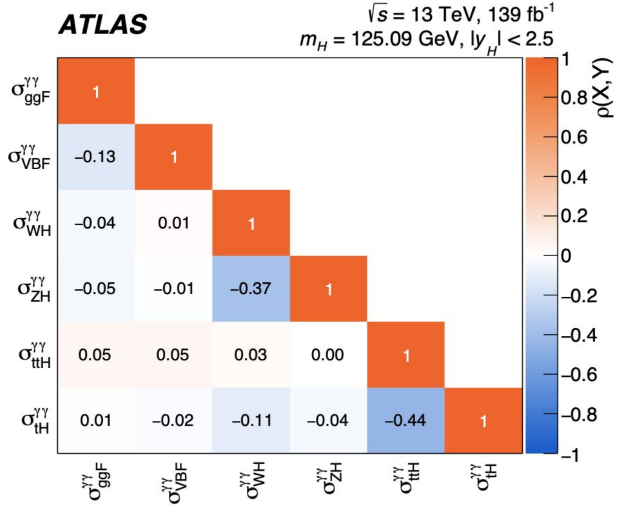
- Inclusive single strength (observed / expected cross-section)

$$\mu = 1.04^{+0.10}_{-0.09} = 1.04 \pm 0.06\,(\text{stat.})^{+0.06}_{-0.05}\,(\text{theory syst.})\,^{+0.05}_{-0.04}\,(\text{exp. syst.}).$$

Production mode cross-section result is shown below, which is compatible with SM.

- Main systematics: theoretical (higher order QCD terms, parton-shower), experimental (photon energy scale and resolution, background modeling, luminosity of dataset)

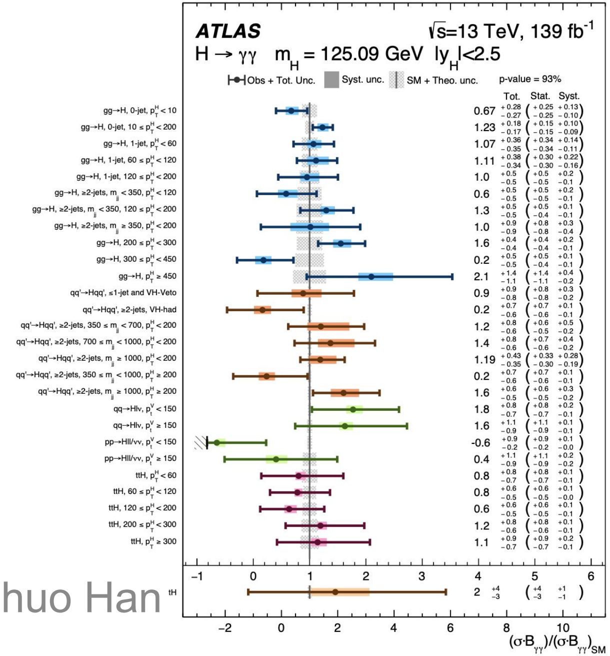


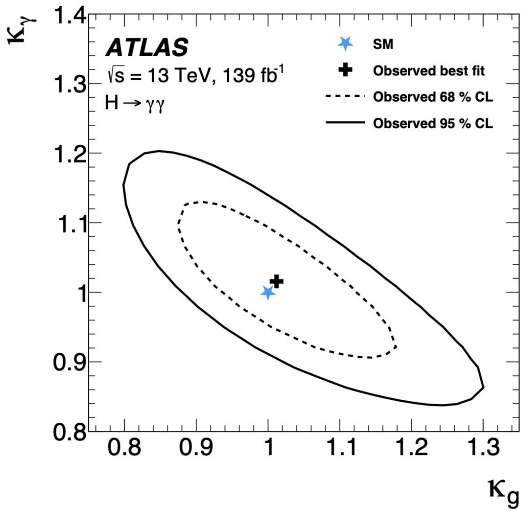


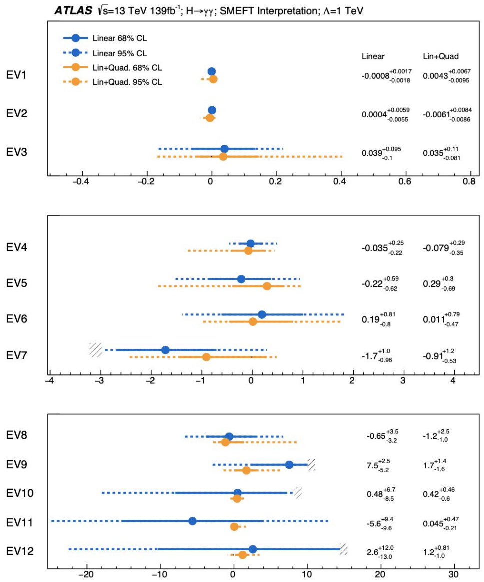
Shuo Ha...

STXS result and interpretations

- STXS cross-sections is measured in 28 merged STXS truth regions.
- Result is compatible with SM, and has good sensitivities in several truth regions (ggH high pTH, qq-Hqq high mjj and ttH/tH)
- The interpretation results of coupling strength (κ-modifiers) and Effective Field Theory (SMEFT) are also compatible with the SM.



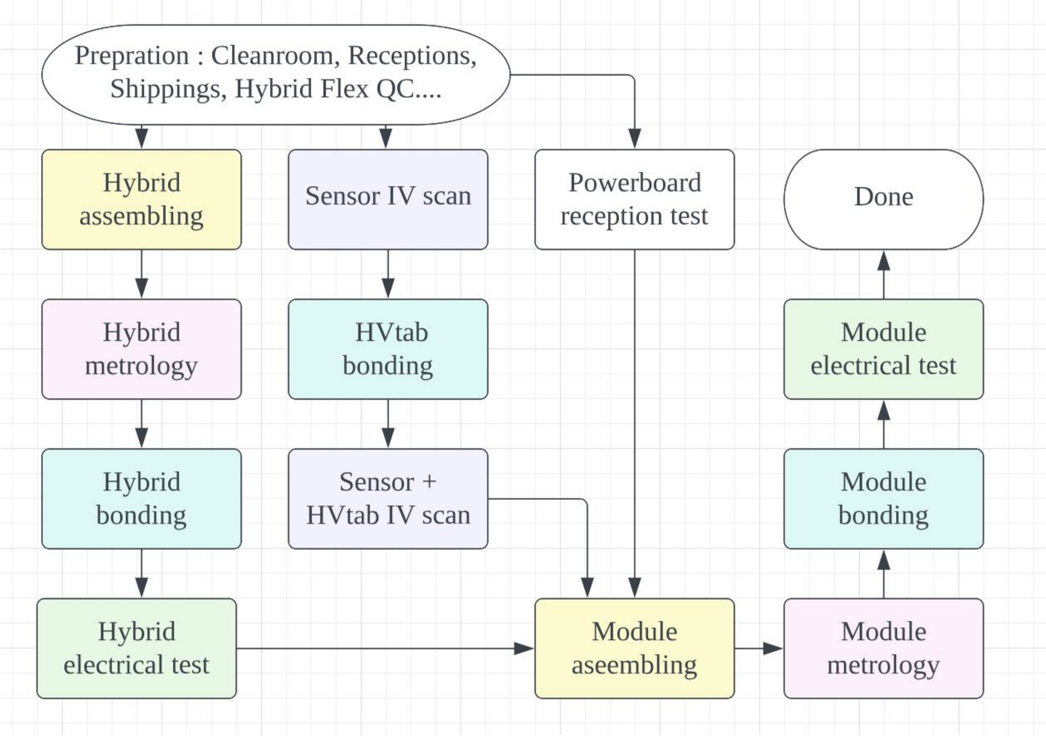




The ITK strip module assembling at LBL

At LBNL, the module assembling takes place in two labs

- Cleanroom
  - Hybrid/Module Assembling
  - Sensor/Hybrid/Module bonding
  - **Hybrid/Module metrology**
- Testing lab
  - **Sensor IV tests**
  - **Hybrid electrical tests**
  - **Module electrical tests**
  - Powerboard reception tests
  - Module tests with cold box
  - **Hybrid tests with burn-in crate**
- Multiple modules and be assembled at the same time, the turn around time is about one week. **In 2022, we worked on "pre-production B", built 32 short strip modules, 14 long strip modules**
- All data need to be uploaded to ITK production database; all procedures need to be documented and pass "site qualification"



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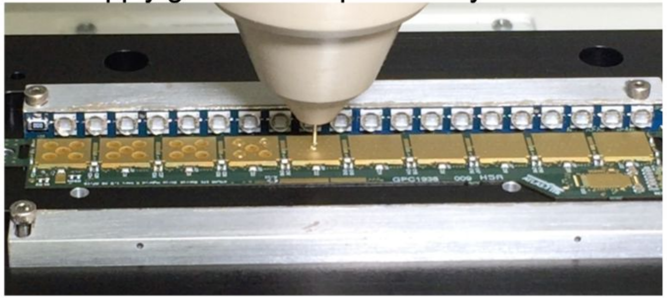
Assembling and Wire bonding

Assembling and bonding are done by technicians

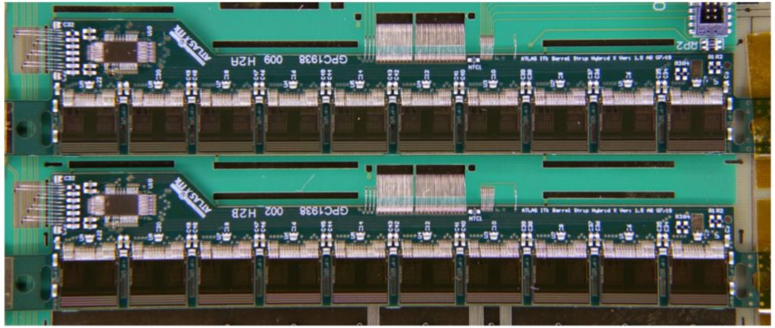
Apply glue to ASIC pads on hybrid flex



Place ASICs in alignment tray, then pickup with vacuum tool

Place ASICS on hybrid flex and UV cure the glue

Place hybrid on electrical test panel and wire bond



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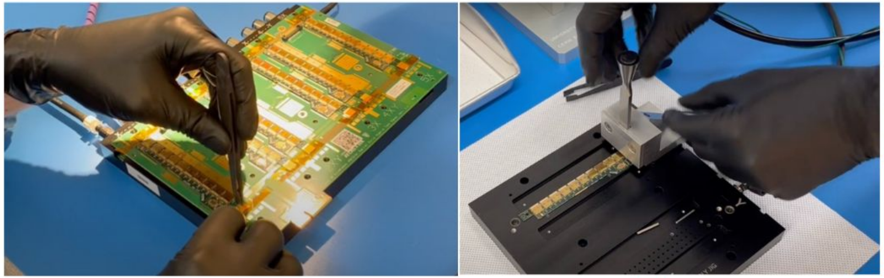
Assembling and Wire bonding

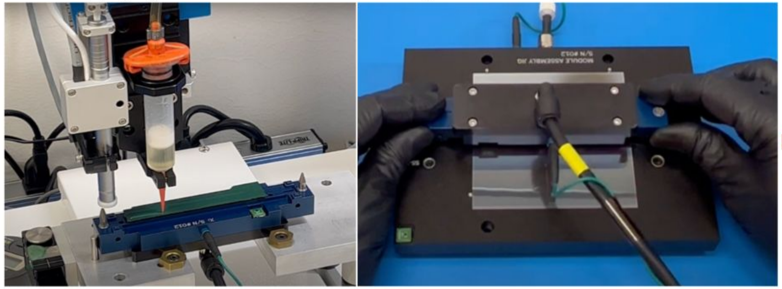
Assembling and bonding are done by technicians

Weld HV-tab to sensor backplane

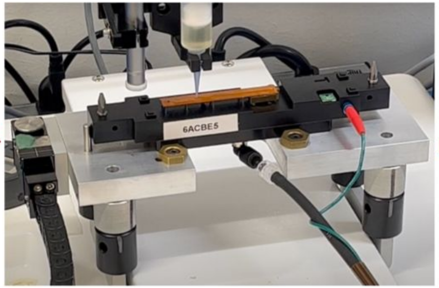
Remove hybrid from test panel & cut off alignment tabs



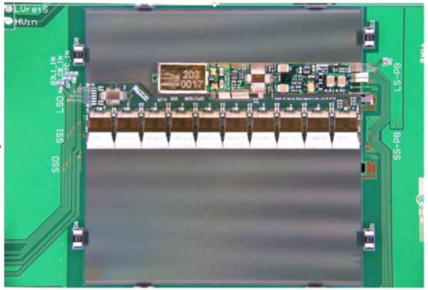
Apply glue to underside of hybrid and place on sensor



Glue PB to sensor in similar fashion

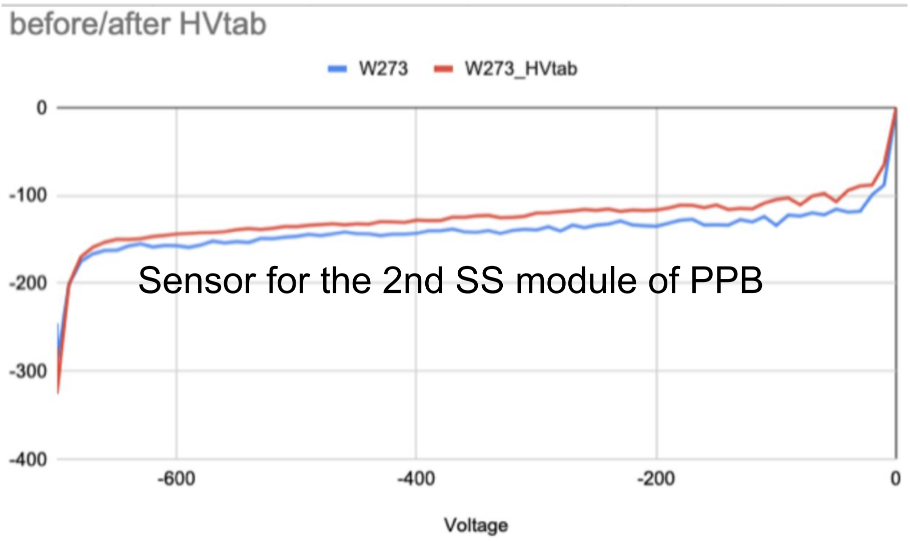


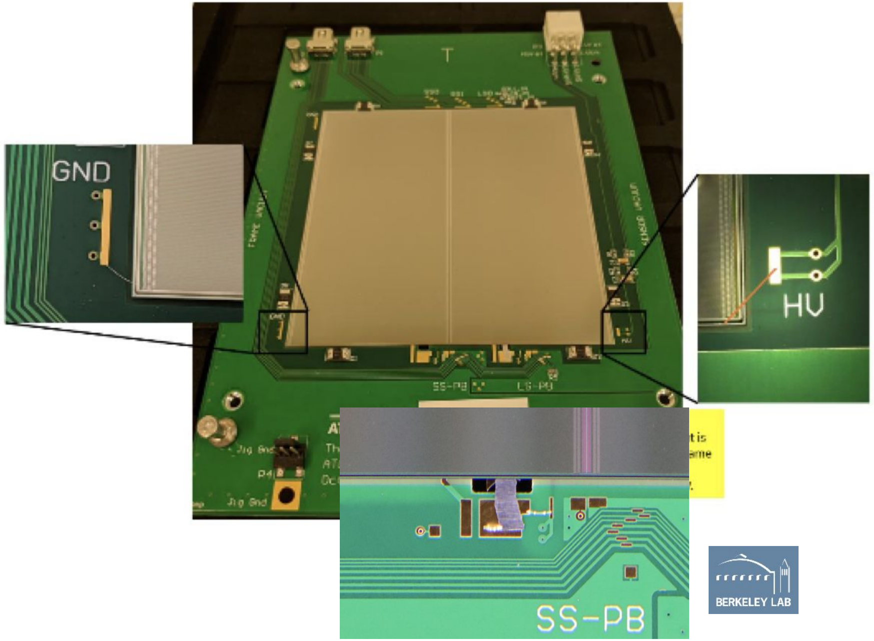
Wire bond module on test frame



Sensor IV scans

- IV scan is one of the sensor reception tests, it'll be done before/after HV tab
- Special bonds are required for the high-voltage input
- The criteria is there's no "breakdown voltage" higher than -500V
- I/O: a webapp based on the ITK database





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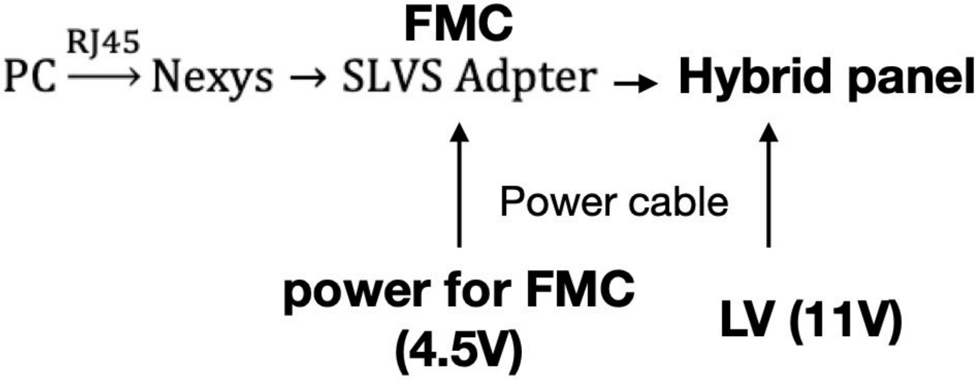
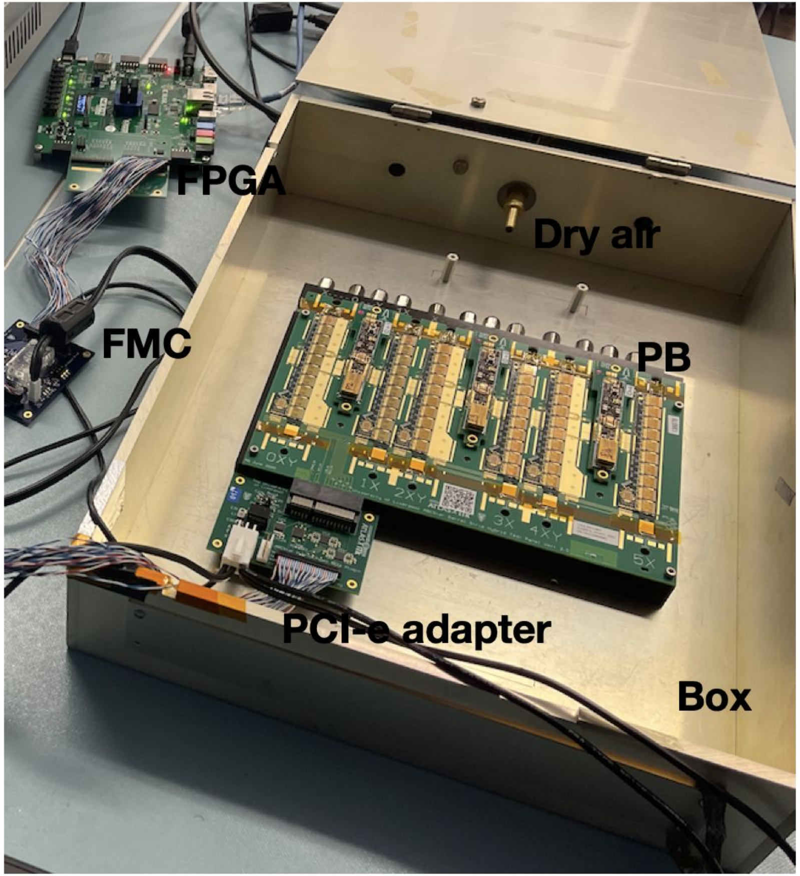
Single hybrid panel test

- For hybrid electrical tests
  - 6 hybrids per test
  - 3 insertable powerboard per test
- Dry air is pumped into the test box





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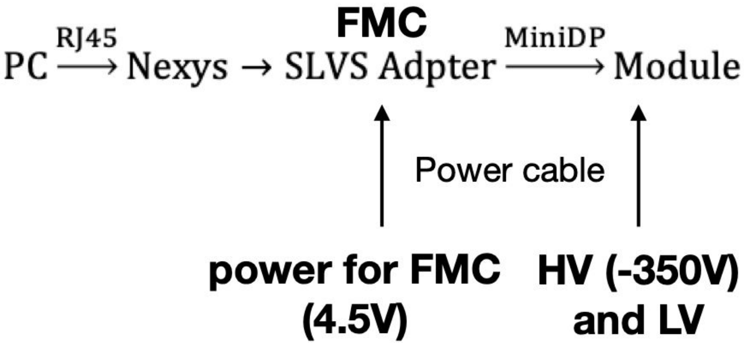
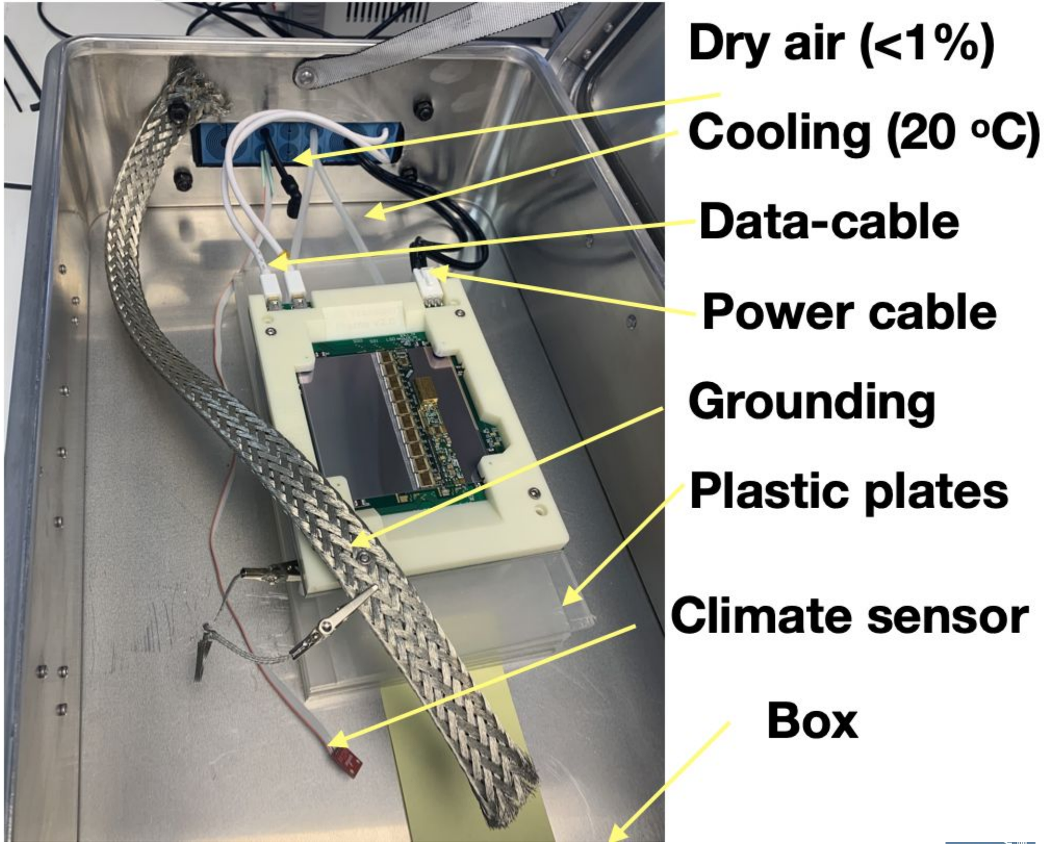
Single module test

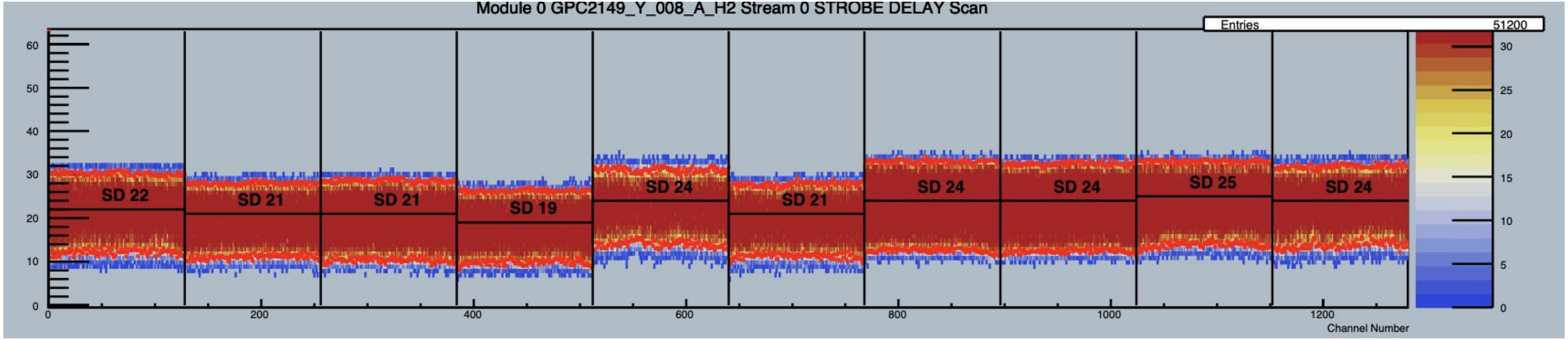
- Testing setup for the module electrical tests and sensor IV scan (with both HV and LV connections)
- A chiller works at 20 ℃, the lowest temperature is 0 ℃
- The dry air can decrease the humidity to <1%
- Should prevent any lights in the box.





Electrical tests

- DAQ: the latest version of **ITk Strips DAQ (itsdaq)**
- Firmware: depends on SLVS adapter, currently **nexysv_itsdaq_vb567_FIB_STAR.bit**
- I/O: JSON output for the ITK database
- **Strobe delay:** scans over the possible delay of pulse wrt the system clock while injecting a large charge into FE. (Before any charge injection tests).

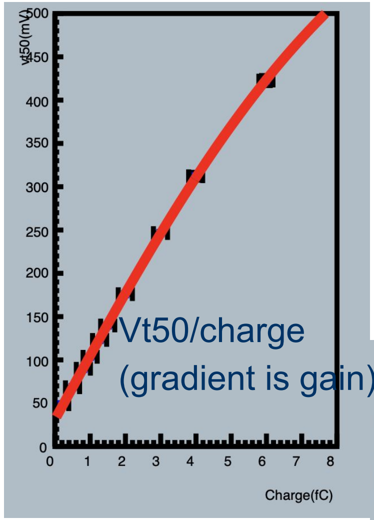


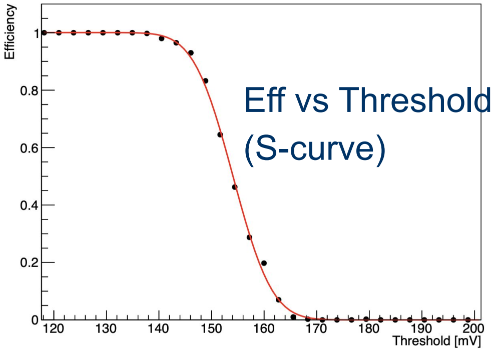
X - channels, Y - delay time, Z- efficiency
The 26th PPB SS module this year

Shuo Han

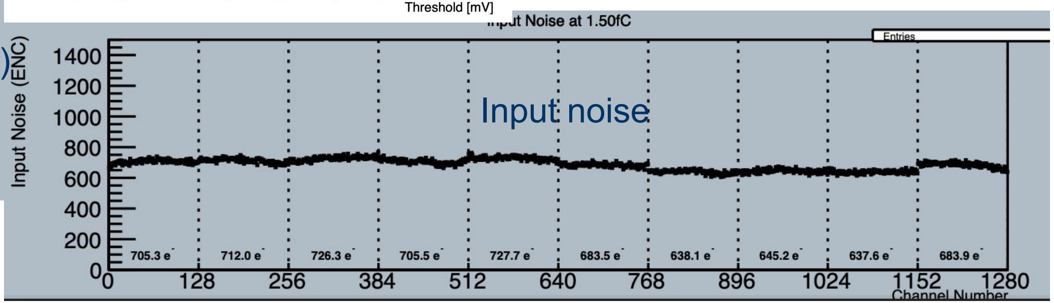
Electrical tests

- **The electrical tests are based on the response curve:** The response of the front end (in mV or DAC counts) to the injection of a calibration charge. This is done by carrying out a series of scans over the threshold DAC. For each scan, a different charge is injected into the front-end. The output is an S-curve for each channel for each charge.





Vt50: S-curve median threshold
Output noise: S-curve standard deviation
Chip gain: gradient of vt50 vs charge
Input noise : output noise / gain



Typical input noise
Hybrids ~ 400
Short strip module ~ 700
Long strip module ~ 900
A channel will fail if a it has very high/low input noise comparing to the average

Shuo Han