Review of Accelerator Based Experiment Activities

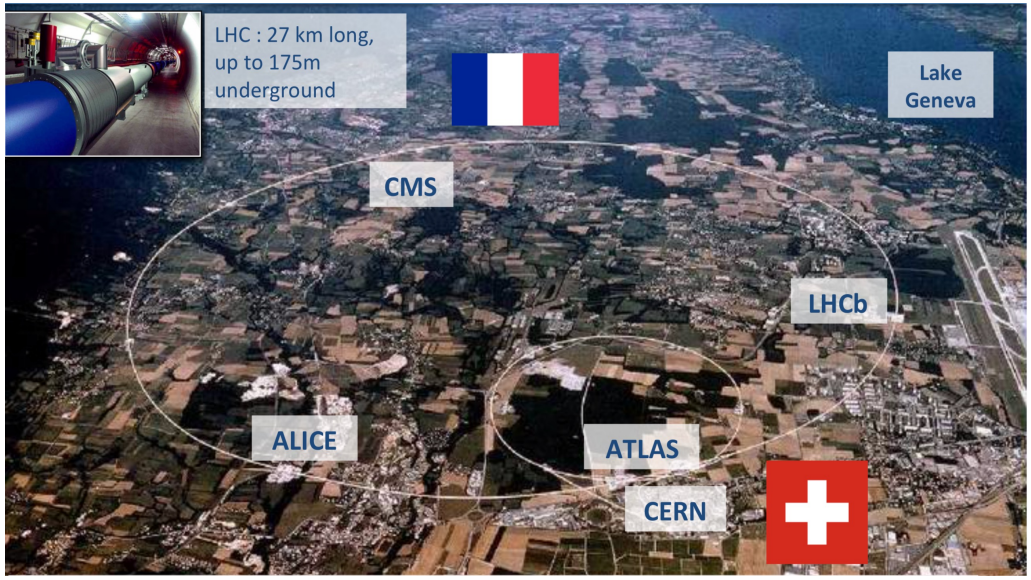
Song-Ming Wang
Institute of Phyics, Academia Sinica
AAC Meeting
August 2023

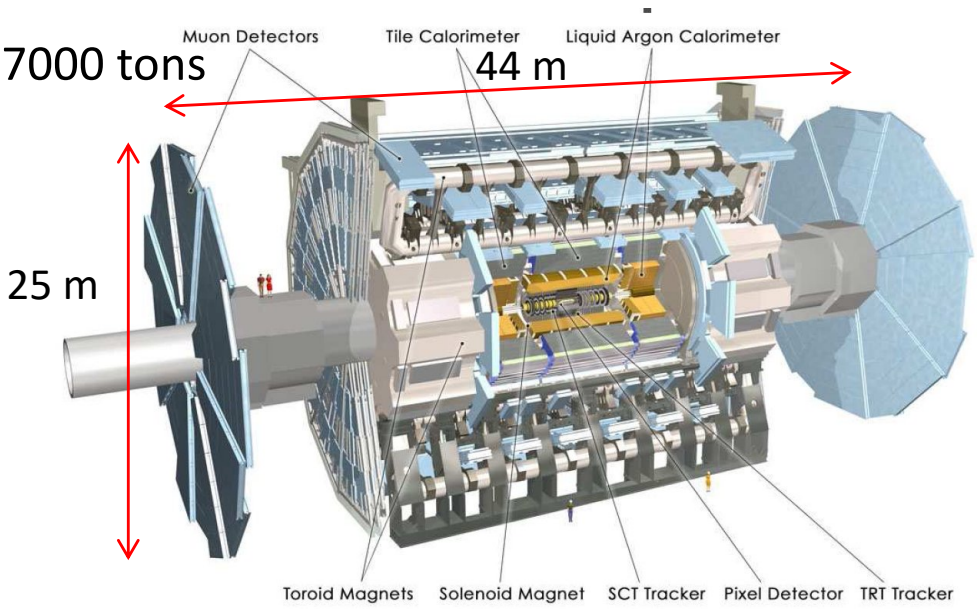
Introduction

- Brief summary of our current activities in these experiments

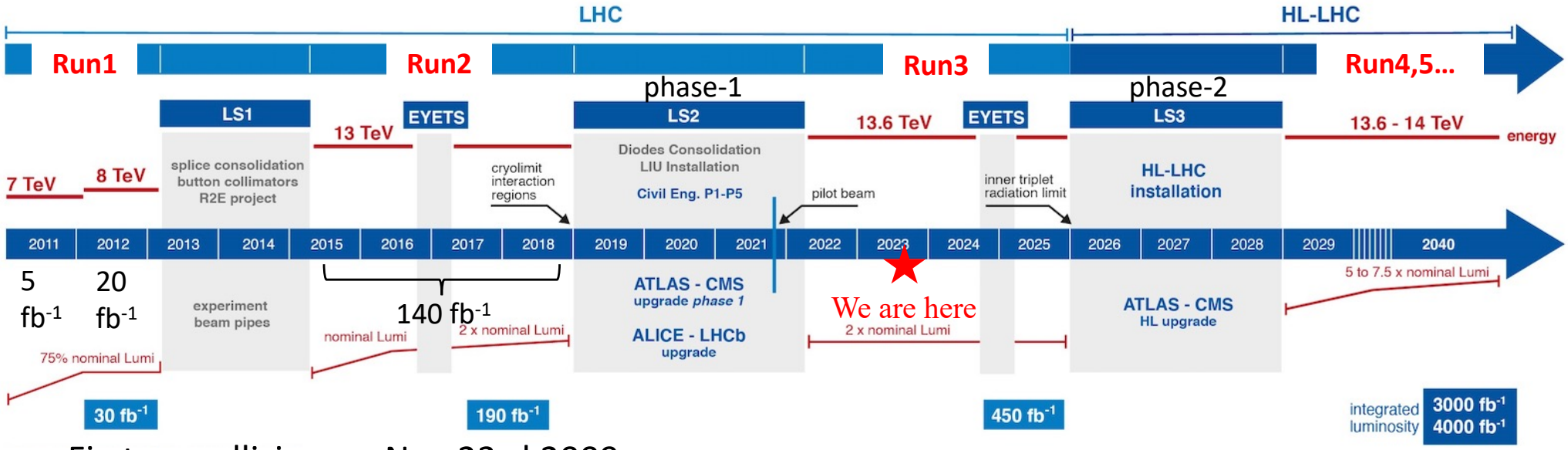
  - ATLAS
  - Compass
  - J-PARC: E16, E50
  - EIC
  - CEPC

ATLAS Experiment





- Academia Sinica (AS) joined ATLAS in 2000



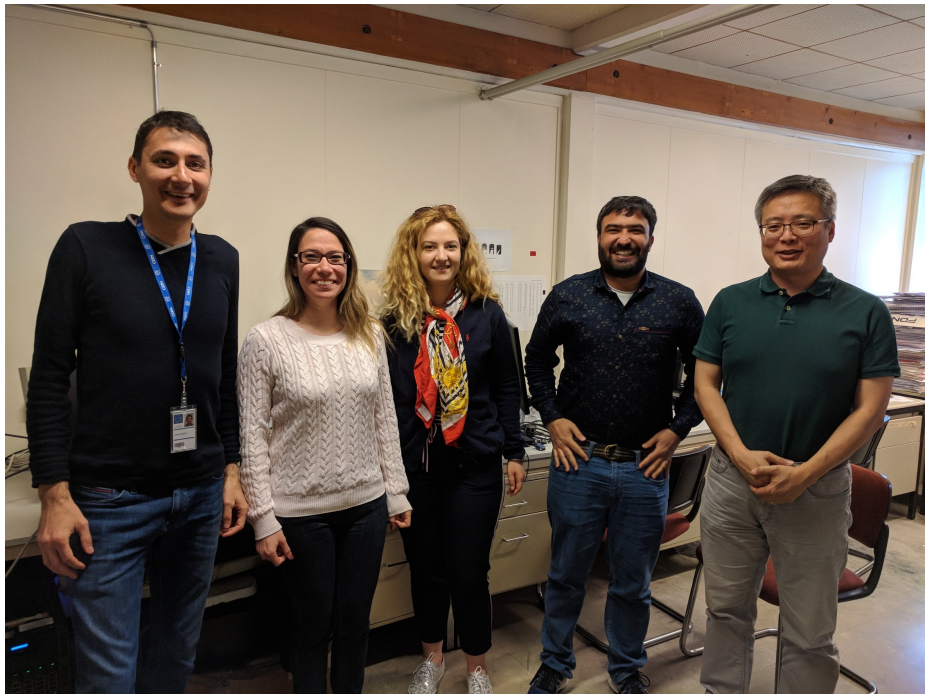
- First pp collision on Nov 23rd 2009
- Commissioning run in 2010
- Run1 started in 2011 at $\sqrt{s}$=7 TeV

AS Members in ATLAS (2018 – 2023)

Shih-Chang Lee

Suen Hou

Rachid Mazini



Adrian Buzatu, Tulin Mete, Luiza Ciucu, Shahzad Ali, Son-Ming Wang

Kiran Farman, Shahzad Ali, Jia-Yu Yan

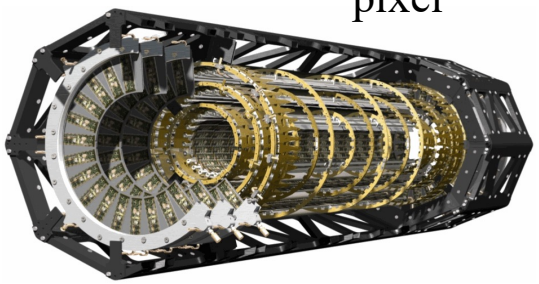
AS in ATLAS

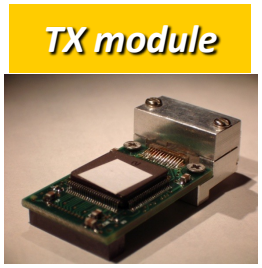
- Academia Sinica joined ATLAS in 2000
  - Participated in detector construction
  - setup Tier-1,2 centers at ASGC, provide distributed computing service for ATLAS
  - Conduct detector performance studies with testbeam and early pp collision data

Hardware :

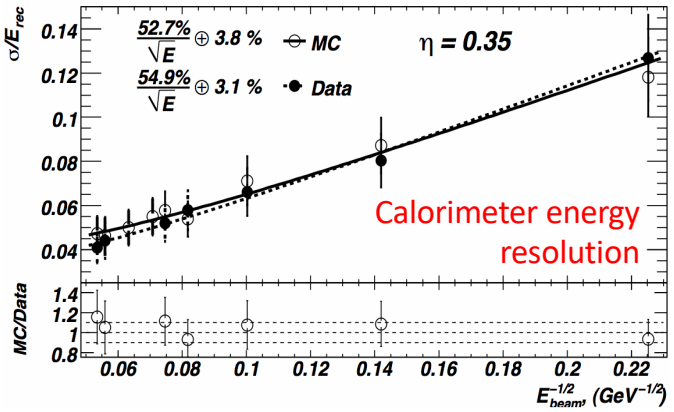
Tier-1,2 centers at ASGC

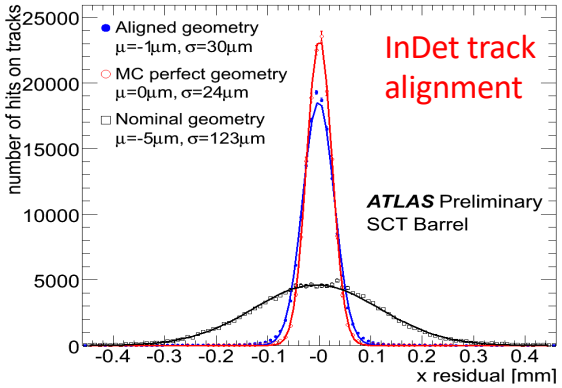
pixel

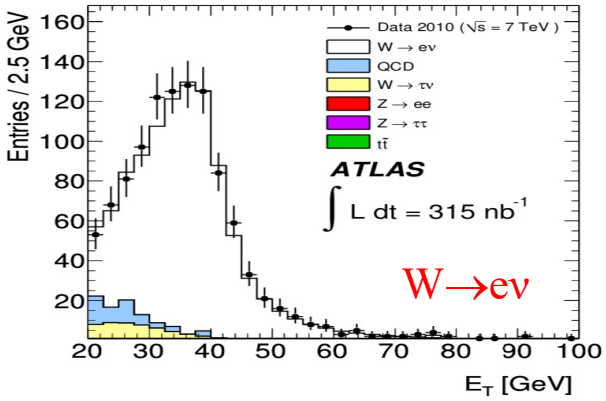




- Optical readout modules for Pixel, SCT, LAr
  - Covering ~98% of all ATLAS readout channels

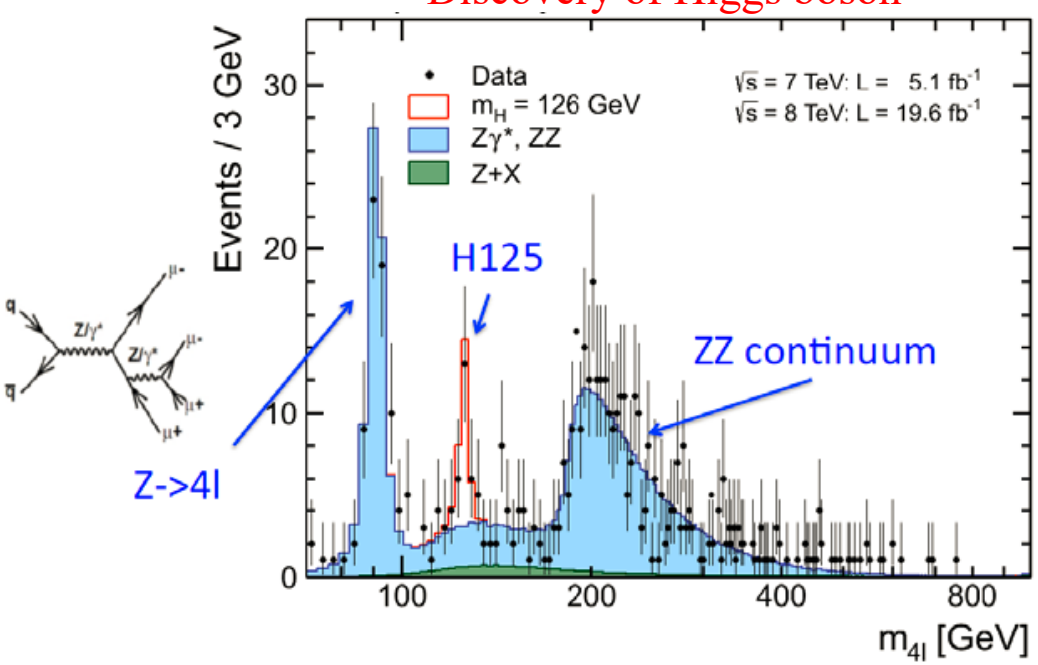




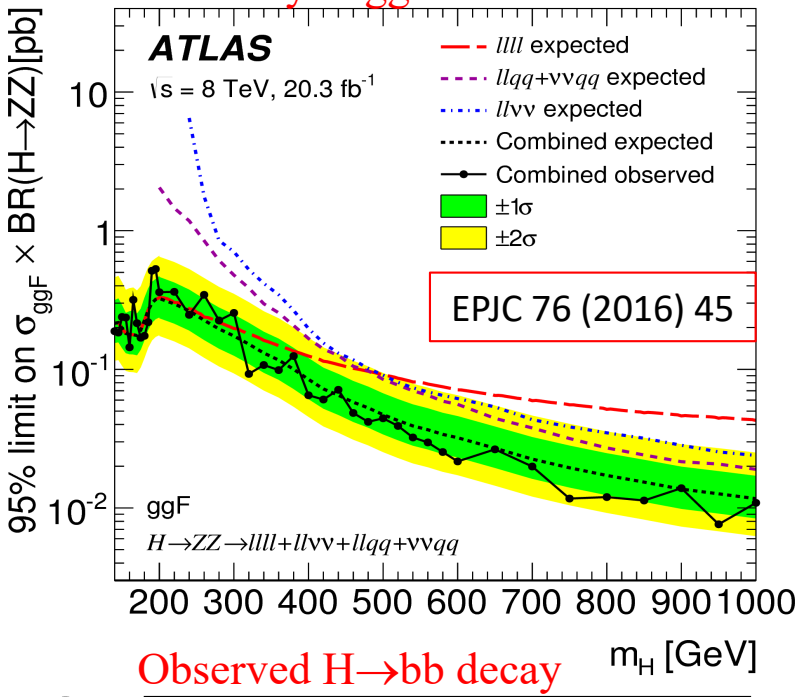


Previous Data Analyses at ATLAS

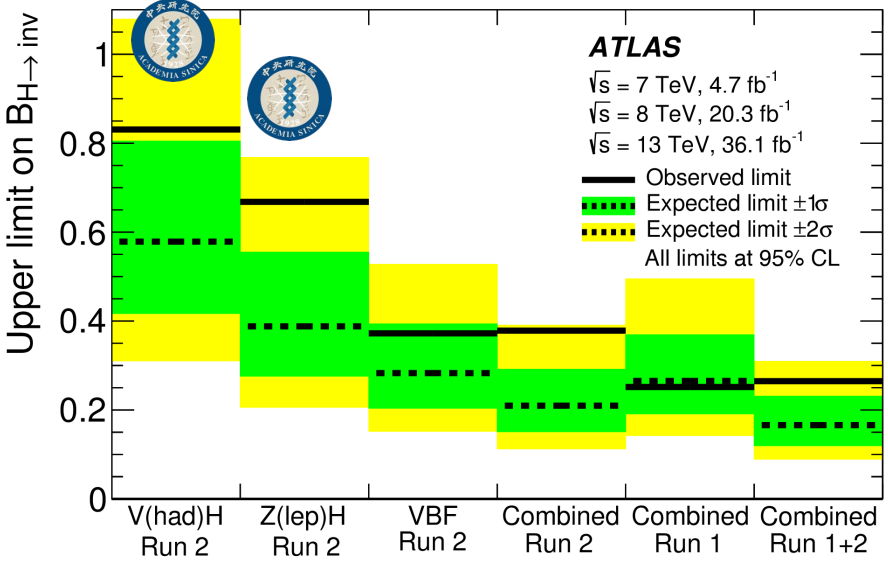
Discovery of Higgs boson



Heavy Higgs boson search

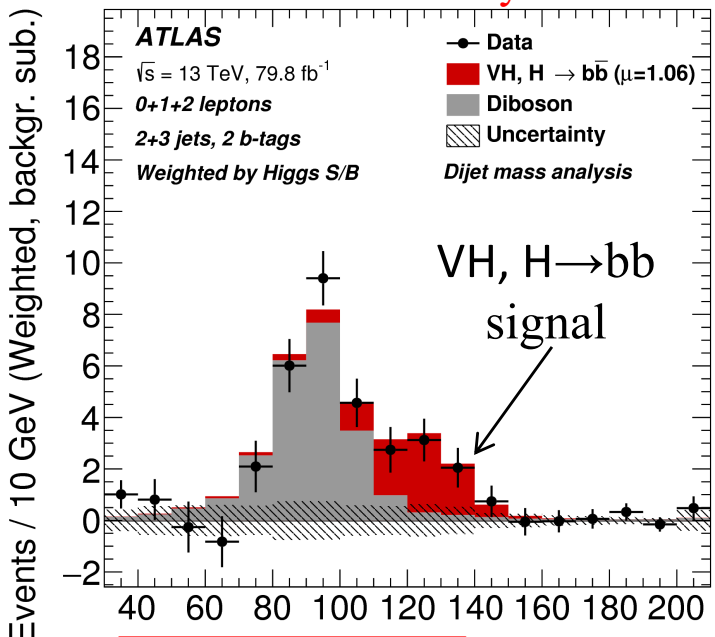


H→invisible decay



PLB 776 (2018) 318, JHEP 10 (2018) 180,
PRL 122 231801 (2019)

Observed H→bb decay

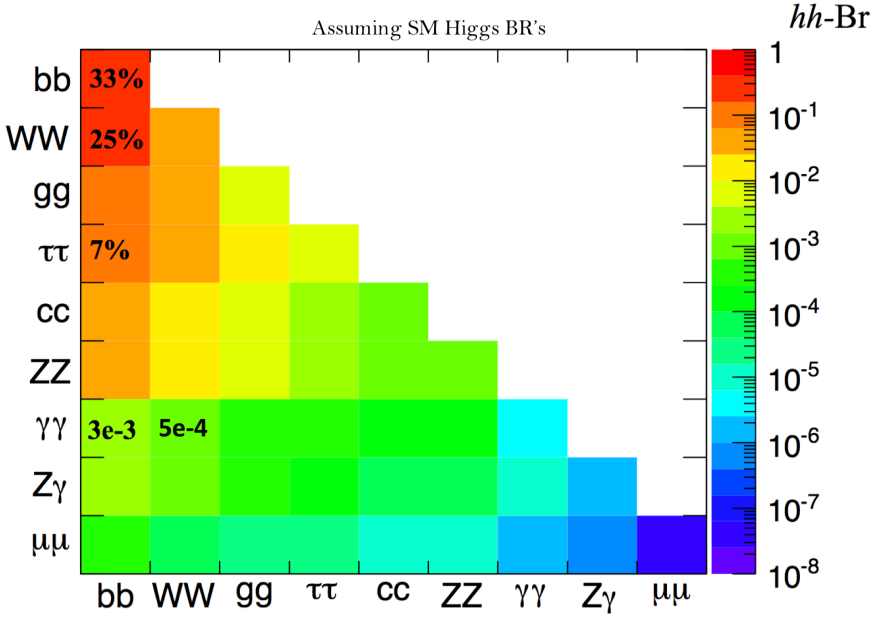


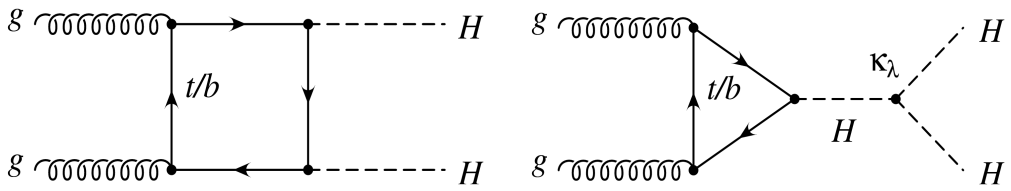
PLB 786 (2018) 59

Recent Data Analyses at ATLAS

Higgs Boson Pair Production

- Observation of Higgs pair production provides a direct measurement of the Higgs boson self-coupling λ_{HHH} and validate the Higgs mechanism
- HH pair produced predominantly through gluon fusion (ggF)



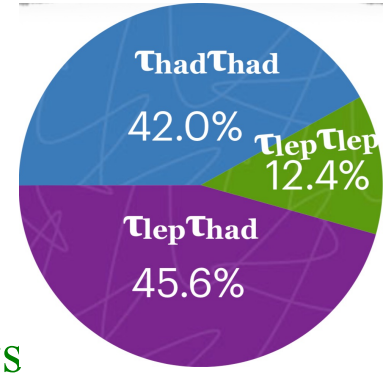


Most sensitive channels :

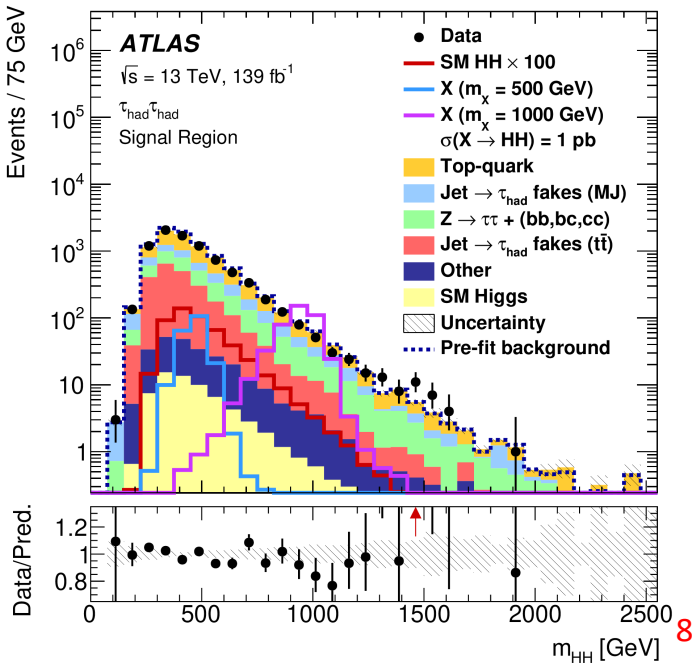
- HH→bbbb : highest BR (~33%), large BG from multi-jets
- HH→bbγγ : clean, but small BR (~0.3%)
- HH→bbττ : moderate BG and BR (~7%)

•HH→bbττ search

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



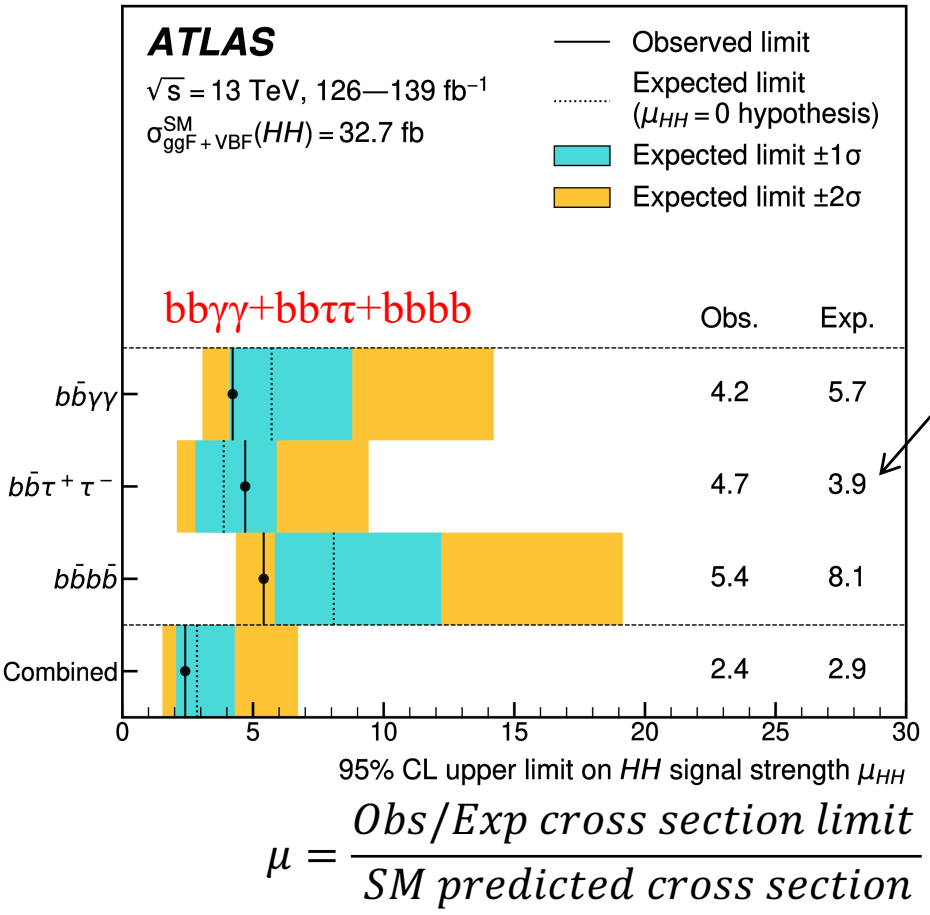
- Main background:
  - true τ_{had} : ttbar, Z+jets, single Higgs
  - fake τ_{had} : jets faking as tau in ttbar and multi-jet
    - Estimate jet faking tau rates in control regions



JHEP 07 (2023) 040

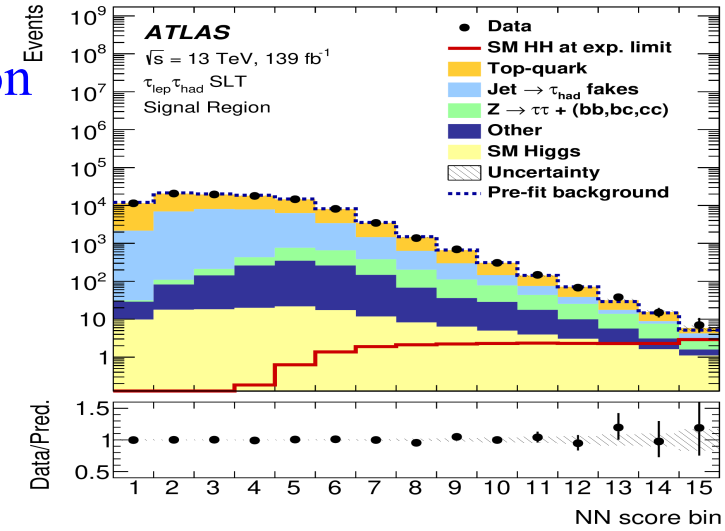
Higgs Boson Pair Production

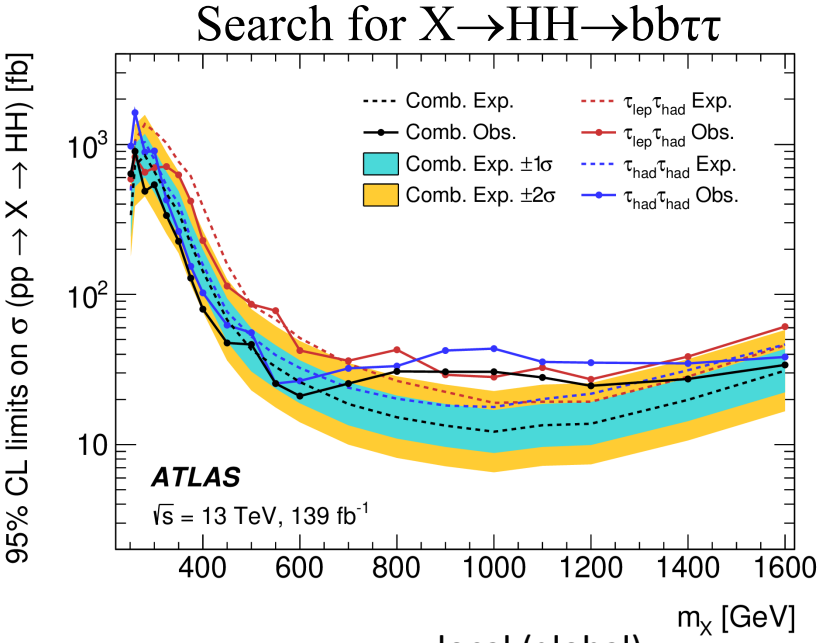
- Multivariate Analysis (MVA) algorithms are trained on signal vs background :
  - training var. : m_{HH}, m_{bb}, $m_{\tau\tau}$, $\Delta R(b,b)$, $\Delta R(\tau,\tau)$,…



World best expected limit for single search

$$\mu = \frac{Obs/Exp\ cross\ section\ limit}{SM\ predicted\ cross\ section}$$





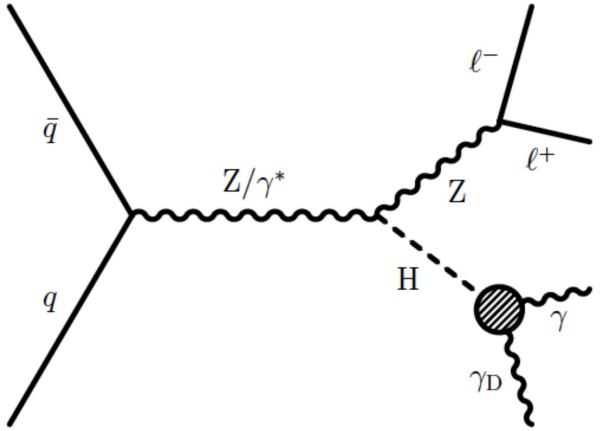
local (global) significance: 3.1 (2.0) σ

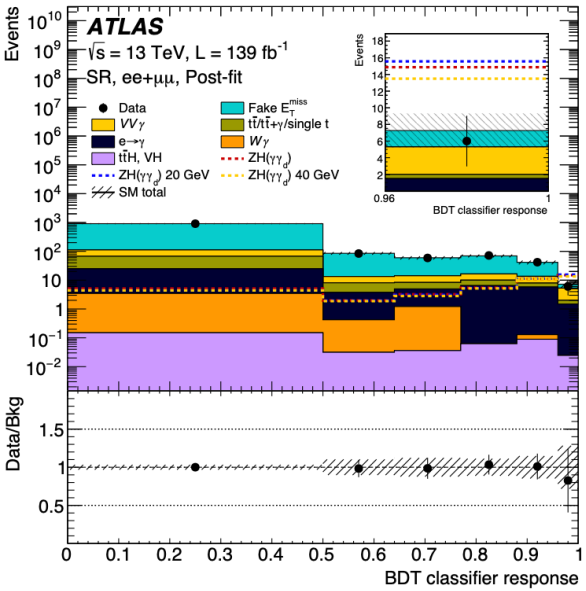
- **Academia Sinica** contributed significantly in the HH→bbττ search
- Involved in optimization studies, code development, and paper editing
- **Tulin Mete** (postdoc) : co-led analysis (2022-2023)
- ATLAS briefing : https://atlas.cern/updates/briefing/two-Higgs-better-one

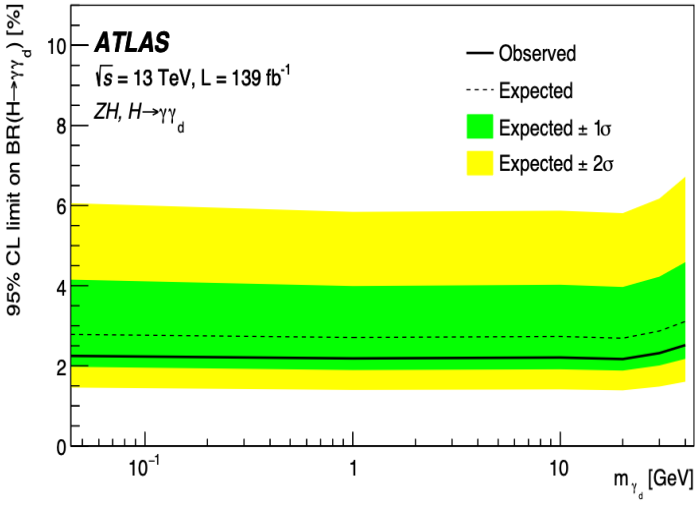
Search for Dark Photons

- Some dark matter models predict existence of dark photons (γ_D) in the dark sector
  - may solve the small-scale structure formation problems
- Search signal in ZH production
  - $Z \rightarrow l^+l^-$, $H \rightarrow \gamma\, \gamma_D$
  - γ_D : undetected => E_T^{miss}
- Background :
  - Fake E_T^{miss} : from $Z\gamma$+jets , Z+jets (data driven)
  - e faking as γ : e from VV, VVV (data driven fake factor)
  - top, $VV\gamma$, $W\gamma$, Higgs : estimate from simulation
- Train BDT classifier to separate signal from background

arXiv 2212.09649







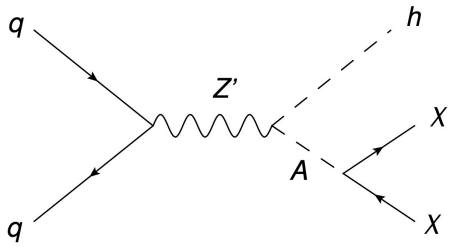
(for massless γ_D)

limit	BR($H \rightarrow \gamma\, \gamma_D$)
ATLAS	<2.3 (<2.8) %
CMS	<4.6 (<3.6) %

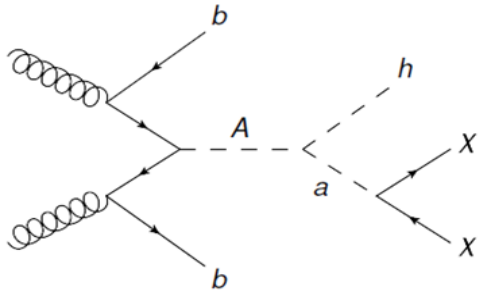
Dark Matter Search in 2HDM extension models

- Search dark matter production in association with a Higgs boson
- Dark matter un-detected, and assume H→bb decay
  - Missing E_T + 2b-jets signature
- Data consistent with SM
- Interpret results in Z'+2HDM and 2HDM+a benchmark models

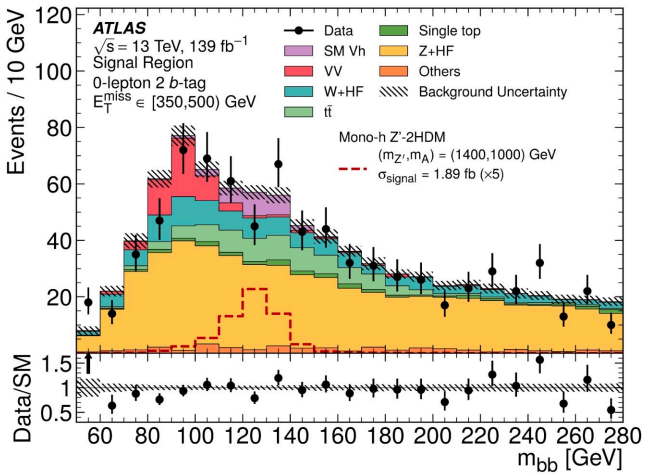
Z'+2HDM



2HDM+a



2bjets, 350<MET<500 GeV



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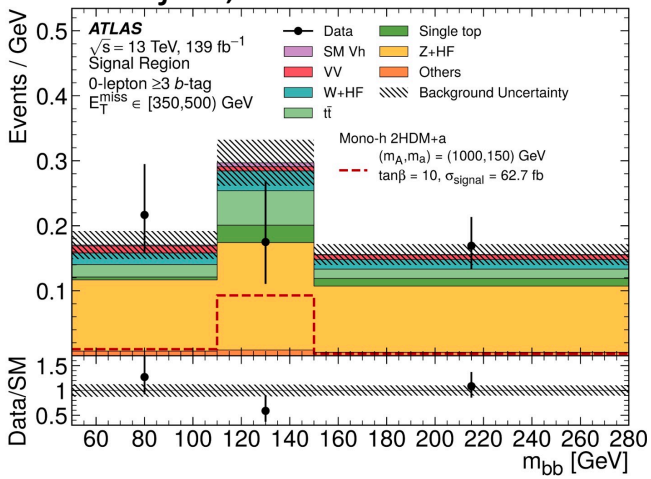
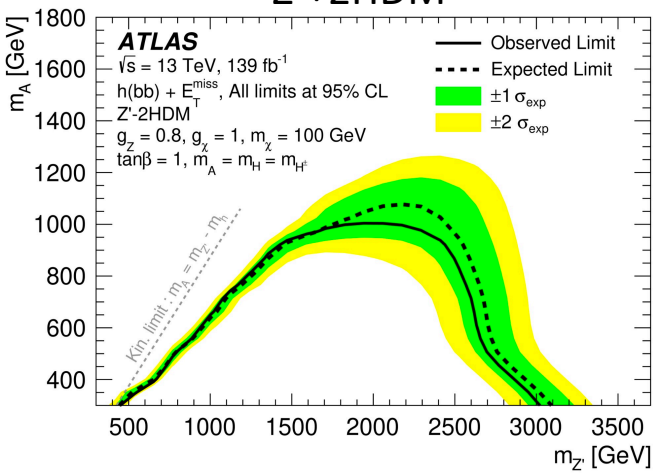
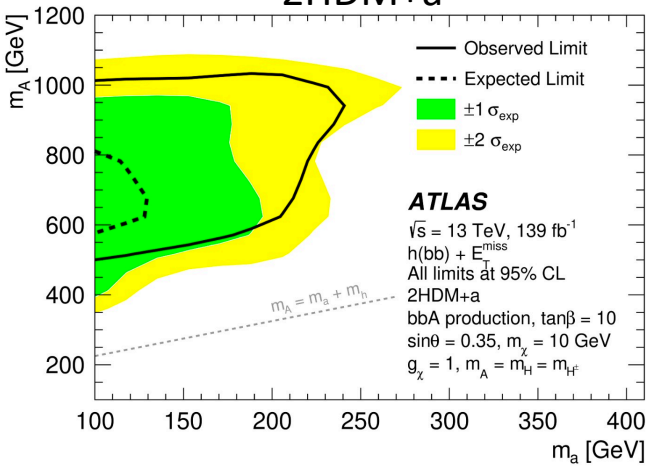


Z'+2HDM



2HDM+a



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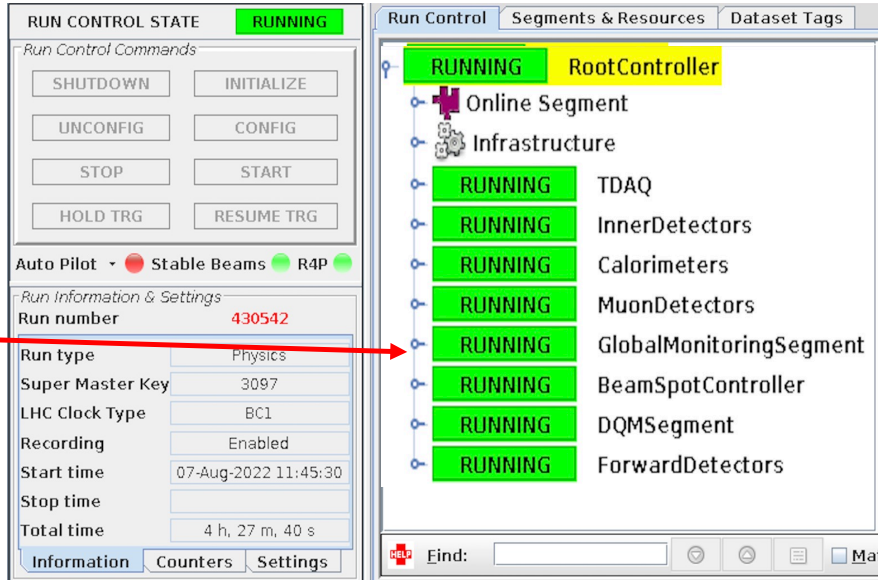
ATLAS Operation

ATLAS Operation

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

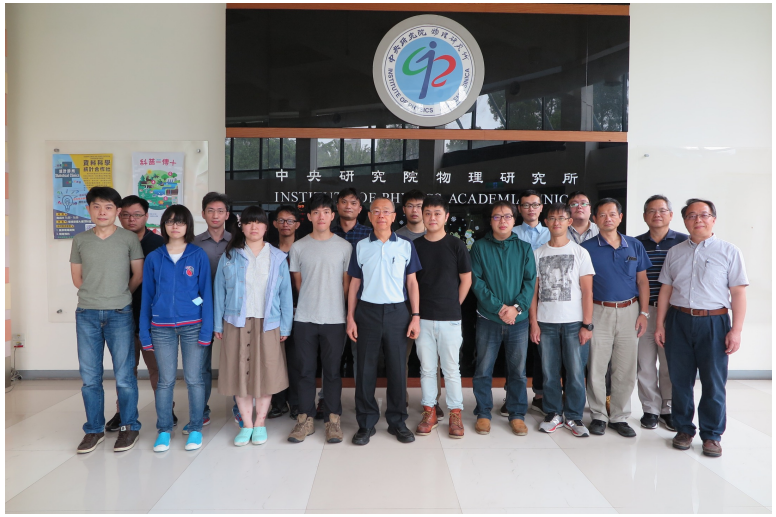
- AS members actively taking Control Room (CR) rooms as
  - Shift leader
  - Data Quality (DQ)
- Served as Online DQ coordinator: manage DQ shifts in CR, train shifters
  - Song-Ming (2017, 2018), Shahzad Ali (2023 -)

- Responsible for monitoring tools use by DQ shifters (institute commitment) :
  - Global Monitoring
    - Process data events in real time
  - OHP (Online Histogram Presenter)



ATLAS Operation

Computing & Software

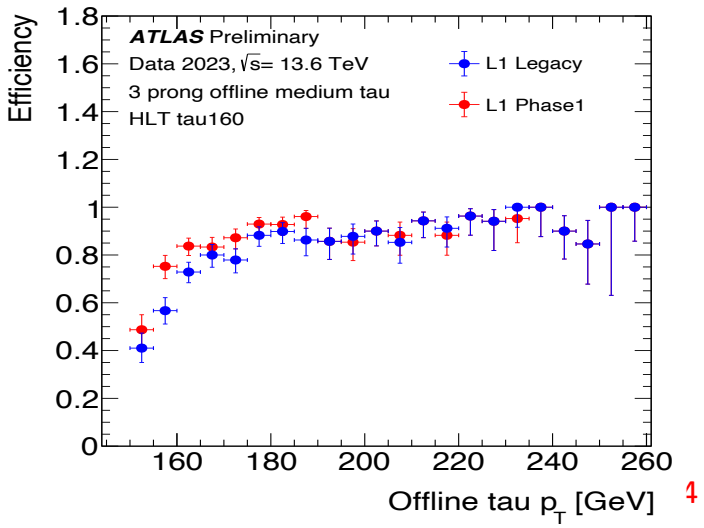


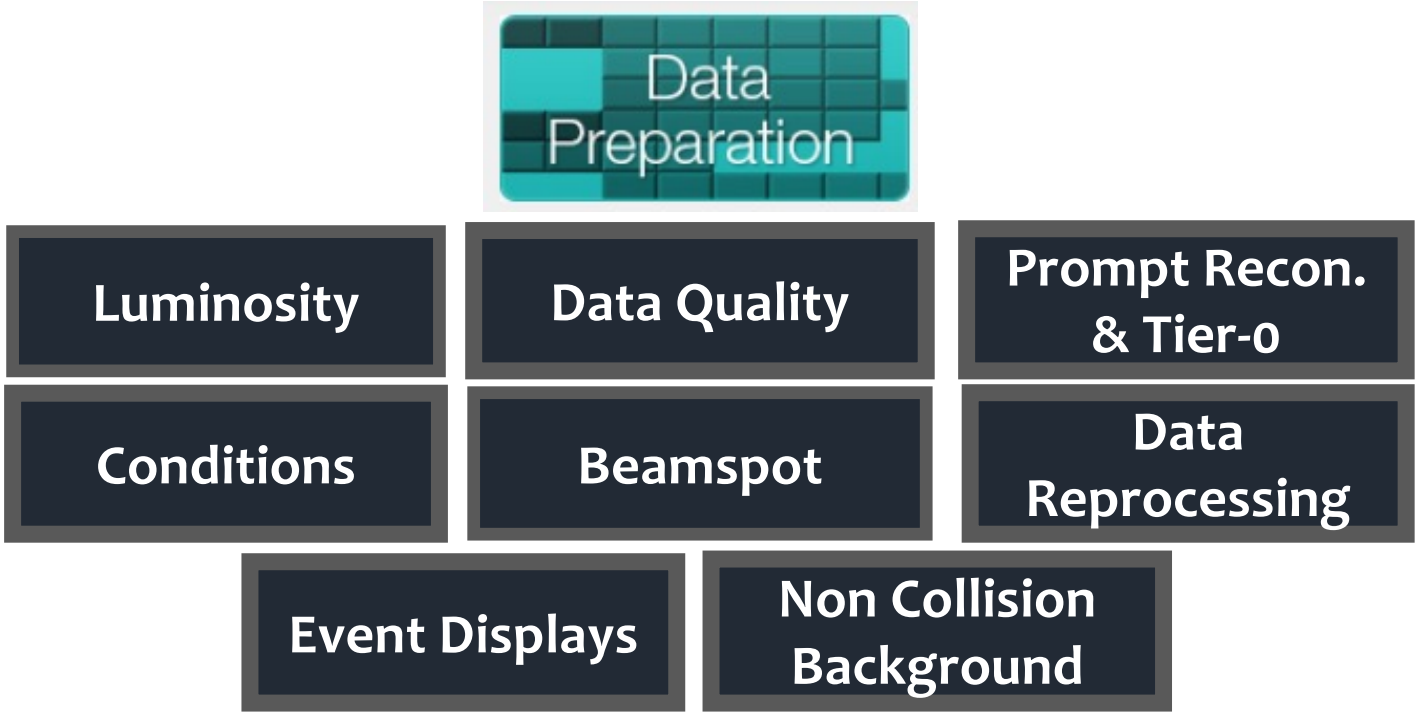
Physics

- Higgs H→bb subgroup co-convener : Song-Ming (2015– 2016)
- Di-Higgs HH→bbττ analysis co-contact : Tulin Mete (2022– 2023)

Trigger

- Tau Trigger Signature Group
  - Subgroup of the ATLAS Trigger group.
  - In charge of triggers used to select data events contain tau candidates
  - Monitor tau triggers' performance
  - Efficiency measurements in data and simulation.
- Tau trigger group co-coordinator : Song-Ming (2023 -)

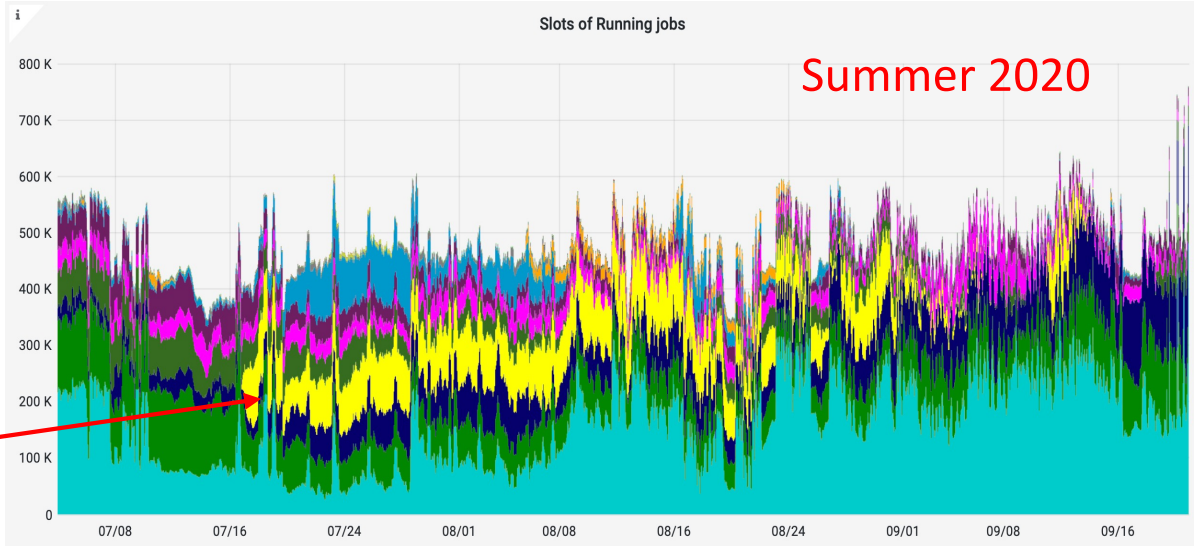




- Data Preparation (DP) : consists of 8 subgroups
  - Provides links between online data and offline physics analyses
  - Work closely with other ATLAS activity areas

- DP coordinator : Song-Ming (2019-21)
- Online DQ coordinator :
  - Song-Ming, Shahzad
- Prompt Recon : Rachid Mazini (2020-2022)

- Reprocessed Run-2 sample (2020) : ~17 billion events, 18 pB data size
- Took 2 months with ~100k cpu slots

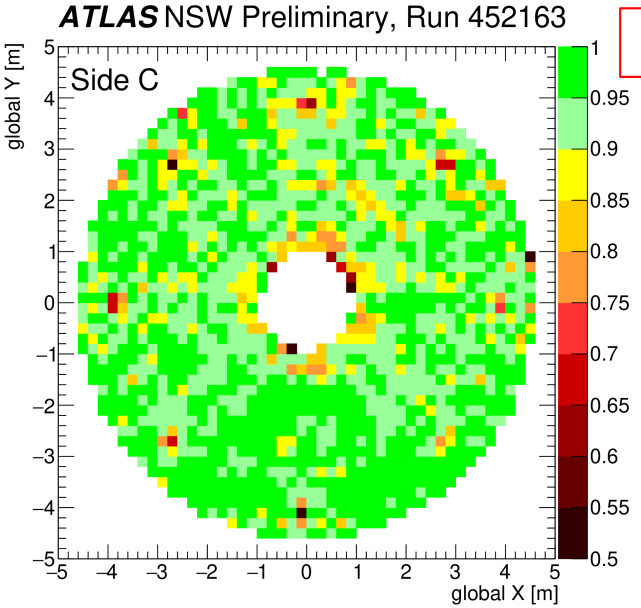


ATLAS Upgrades

Phase-1 Upgrade

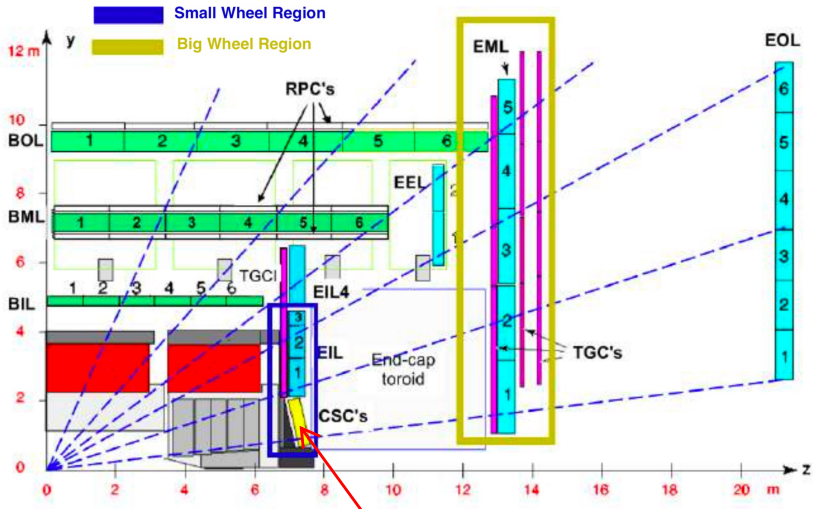
New Small Wheel (NSW) Muon Detector

- To suppress fake forward muon
- Allow to trigger on low pT muon at threshold ~20-25 GeV with manageable L1 trigger rates (~10-20 kHz) at $L=3\times10^{34}cm^{-2}s^{-1}$
- AS contributes in fabrication of Router boards
  - Transmit trigger signal from muon FEB to Level-1 electronics
- Delivered 300 boards (winter 2019)
- Built 4k optical transceiver modules (collab. with SMU) for LAr and NSW
  - working well in Run3

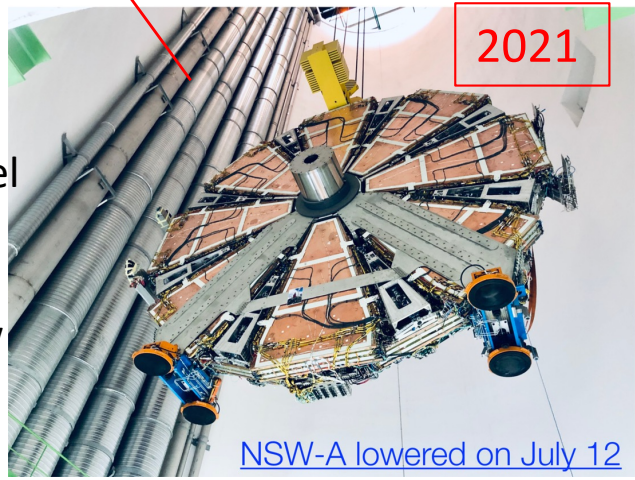


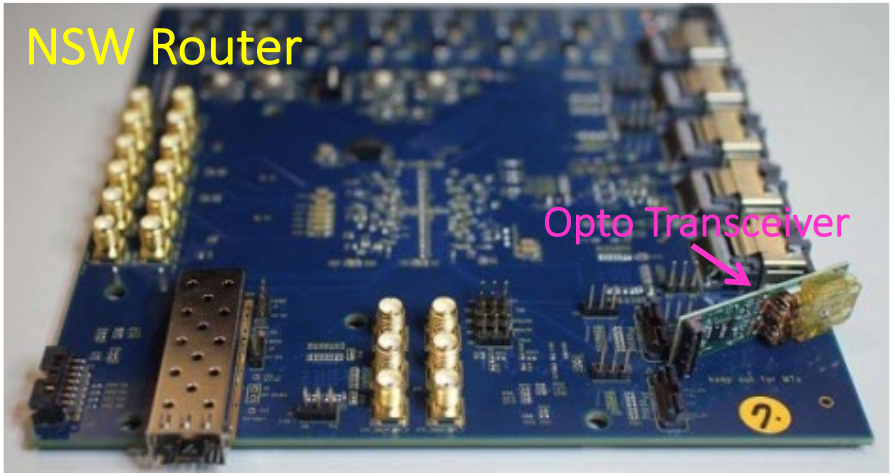
Commissioning NSW

- Efficiency for at least 4 out of 8 layers of either MM or sTGC associated to a reconstructed muon track



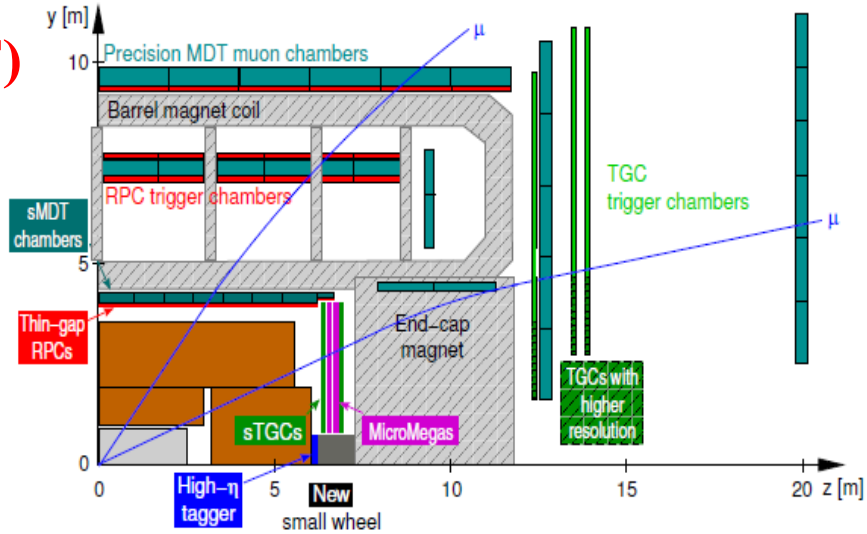
- Replace small wheel muon detector with a new one

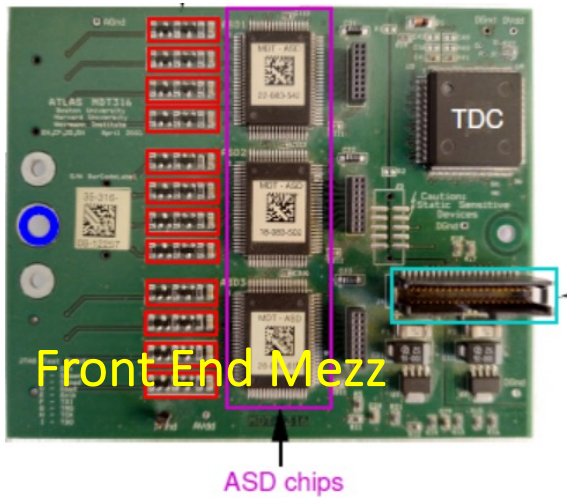


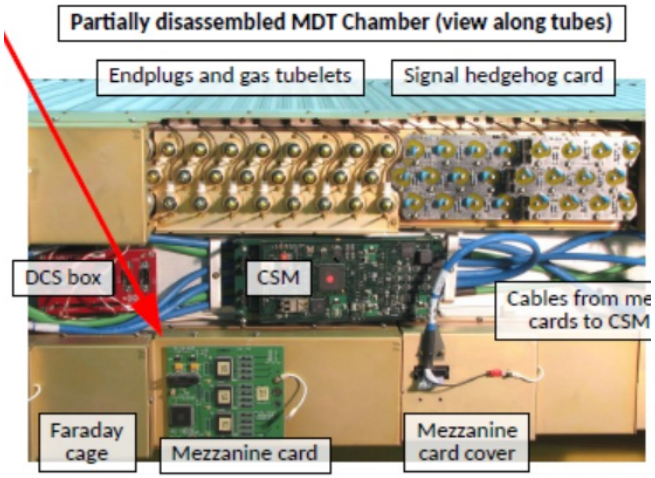


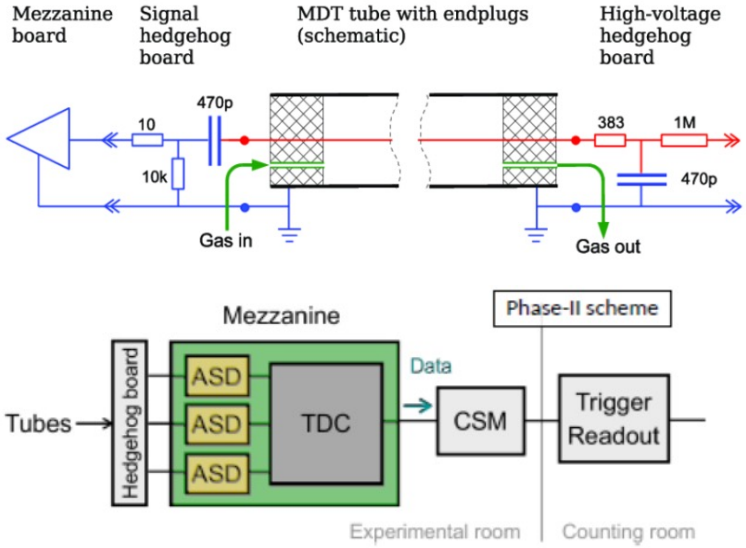
Phase-2 Upgrade

- **Muon detector: Monitored Drift Tube (MDT)**
- Upgrade readout electronics
- Taiwan (AS+NTHU) contributes to build MDT mezzanine cards that process raw signals from detector
  - Amplified/digitized/discriminate, and extract arrival time
- Taiwan group will produce 10k boards
- Funding: MOST+IPAS+MOE (TWD 50M/10 yr)



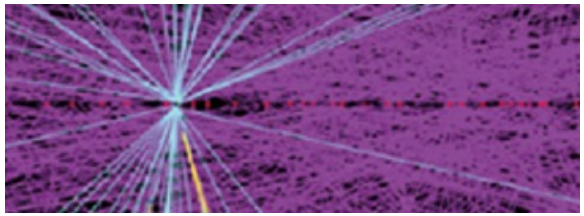




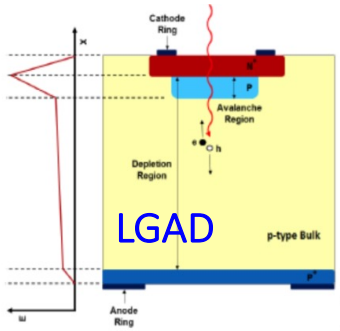


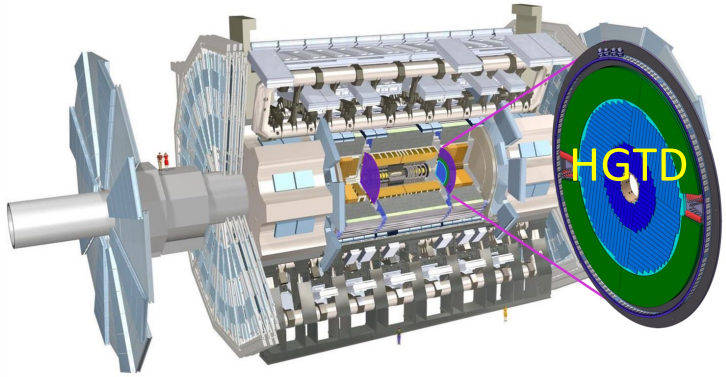
Phase-2 Upgrade

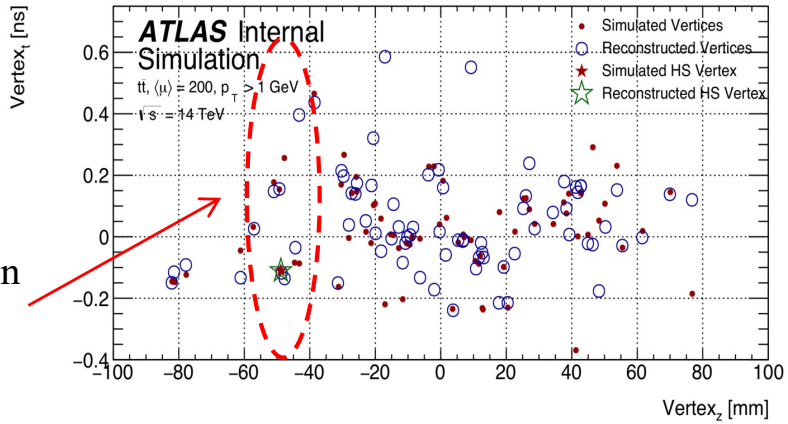
JINST 17 (2022) P09026
JINST 18 (2023) P05005



- **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
- Taiwan's (AS+NTHU) contributions:
  - optical fibers and cables production
  - simulation and test beam
  - production database and data quality
  - peripheral electronics (collab. with IHEP+NJU)
- Serve as Level-3 conveners in HGTD group
  - S. Hou : Rad-Hard fiber readout
  - S. Wang : Data Quality
- R&D on MUX, optical links

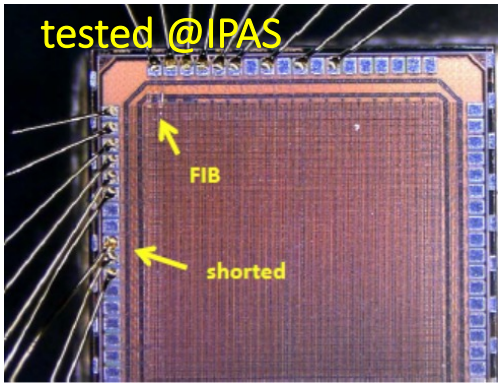




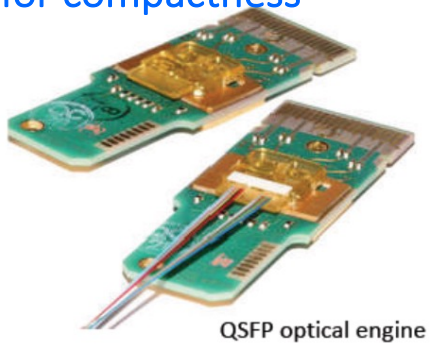


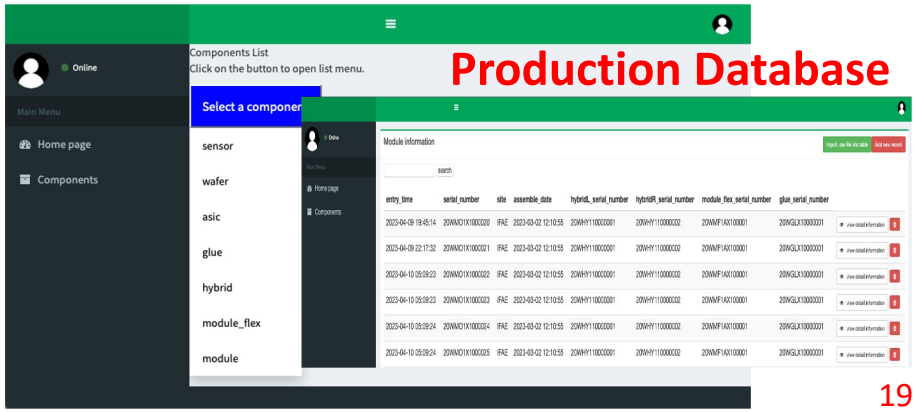
Close in Z but well separated in time

MUX wire-bond tested @IPAS



4Tx 4Rx transceiver for compactness



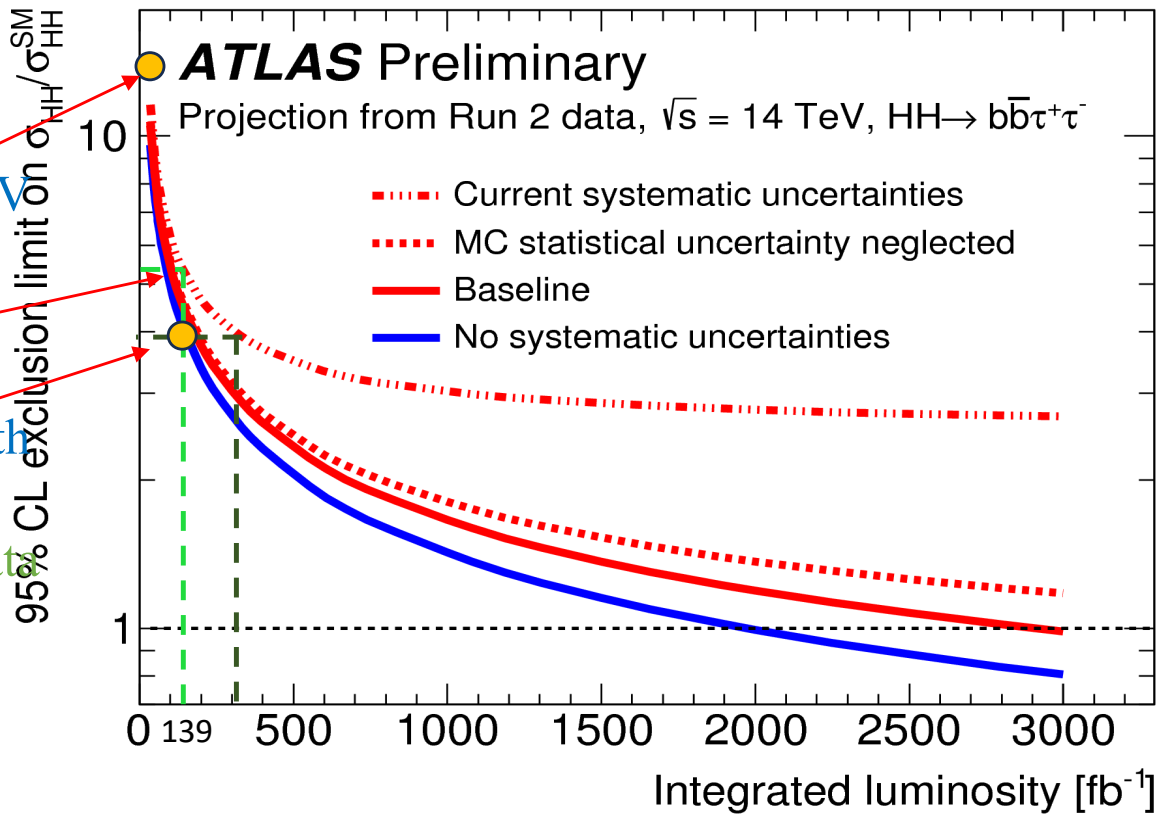


Future Plans

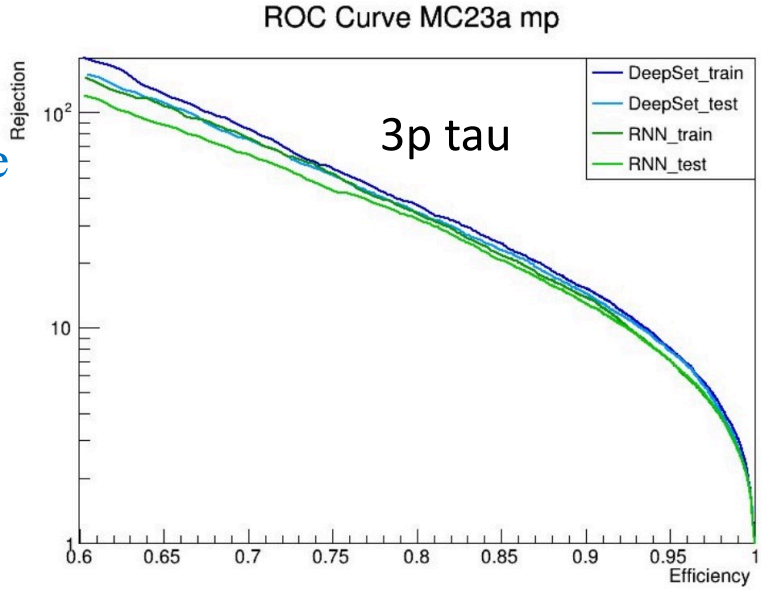
Higgs Boson Pair Production Search

ATL-PHYS-PUB-2018-053
arXiv:1902.00134

- Di-Higgs search is one of the key analyses for the HL-LHC
- Projection for HL-LHC using HH->bbtautau results with 36 fb^{-1} at 13 TeV
  - expected limit : 15xSM
- Projected limit at 139 fb^{-1} is ~5.3xSM (assuming just add data)
- Expected limit from latest analysis with 139 fb^{-1} is 3.9xSM
  - Half of improvement from larger data sample
  - 2nd half of improvement is mostly from tau and b-jet identification



- Di-Higgs search is currently still limited by statistics
- One area of improvement is to increase signal acceptance
  - Recently reduced di-tau trigger pT threshold by 5 GeV, expect signal increase by ~15%
  - Improve tau lepton identification efficiency at the trigger level
- As tau trigger co-coordinator, will push for the improvement from trigger side



Beyond the Standard Model Searches

- Search for BSM with bbtautau signature:
  - Re-visit the excess we observed at mX=1 TeV in the narrow scalar resonant search
  - Search for CP-odd Higgs
    - A->ZH->bbtautau (Z->bb or tautau, H->bb or tautau)
  - Search for dark matter via axion-like particles : H->aa, Za->bbtautau

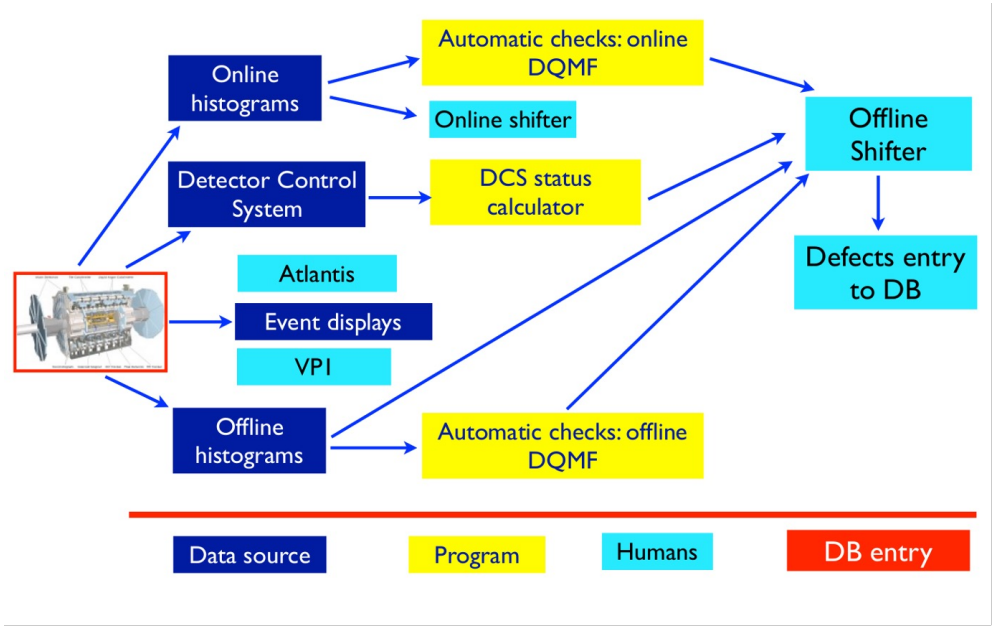
ATLAS Operation

- Continue our activities in the Data Quality and Trigger groups

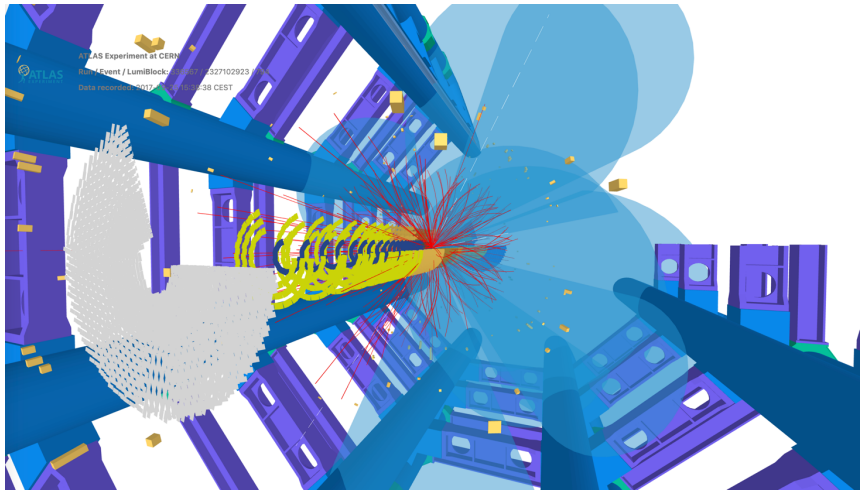
ATLAS Phase-2 Upgrades

- Start production in 2024, delayed 2 years due to Covid19
  - mezzanine cards for muon MDT electronics readout
  - optical fibers and HV cables to the LGAD detector modules of HGTD
    - Radiation-hard optical fiber has qualified the TID (total ionizing dose) test, will be fabricated in Taiwan
- Complete implementing the production database by summer of 2024, before the start of the production of the HGTD module sensors
- Start setting up the HGTD data quality monitoring software in second half of 2024, to monitor the detector status during the HL-LHC data taking
- Participate in the installing and testing of the HGTD

ATLAS DQ Evaluation

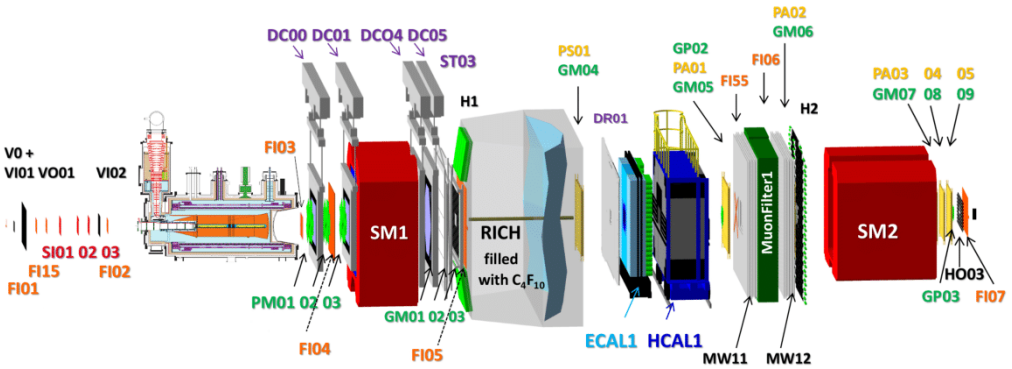


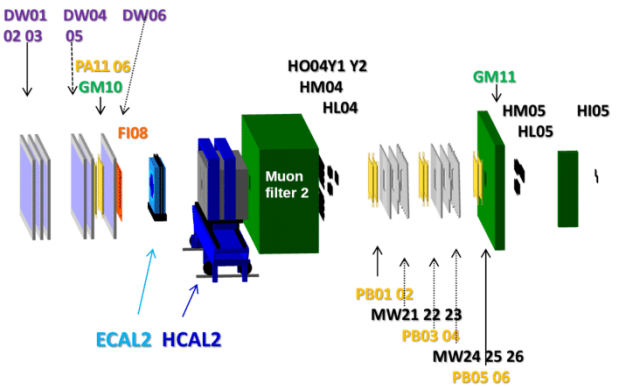
HGTD in Event Display



Probing Hadron Structure

Compass Experiment

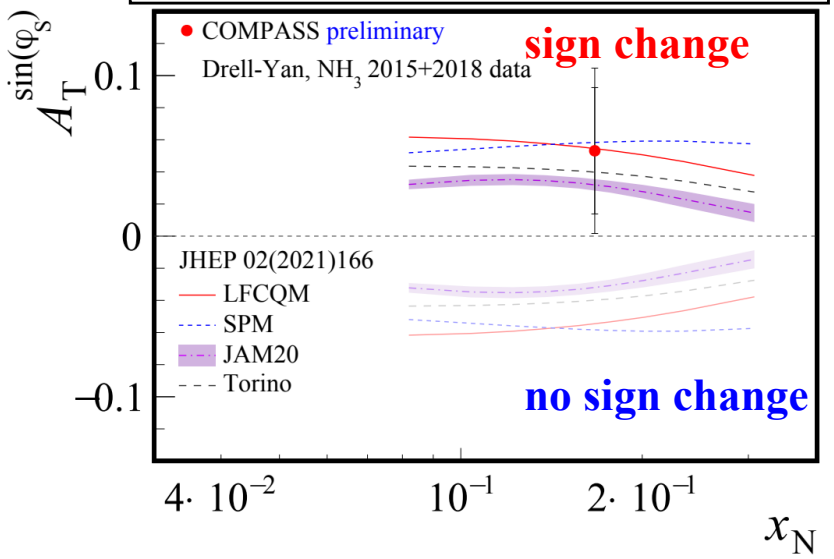




- Joined Compass from 2012 to 2022
- Physics goals are the investigation of the hadron structure and hadron spectroscopy.
- Muon/pions on polarized target

Probing Nucleon Transverse Momentum Distributions (TMD) by 190 GeV pions

TMD Sivers Asymmetry in Drell-Yan



Integrated, compared to predictions.
Curves: [Bastami *et al.*, JHEP 02 (2021) 166]

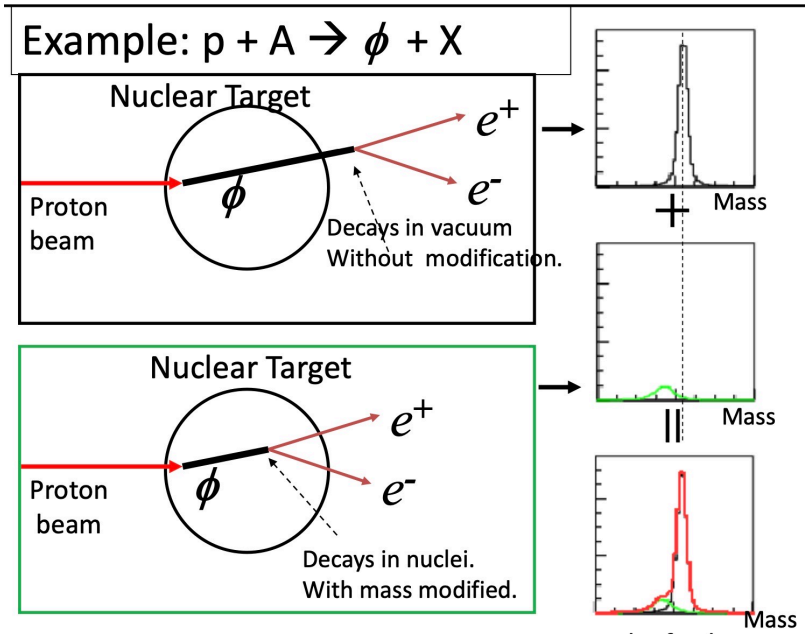
- Measured the transverse-momentum dependent Sivers Asymmetry in Drell-Yan process.
- Preliminary results show a hint of sign change of the Sivers function in semi-inclusive-deep-inelastic-scattering (SIDIS).
- Verification of the sign change of the Sivers function is one of the milestones of DY programs of COMPASS (arXiv:1501.01220).
- Measurements to constraint pion PDFs and TMDs

COMPASS, https://tinyurl.com/4b83yna7

E16 and E50 at J-PARC

E16 Experiment:

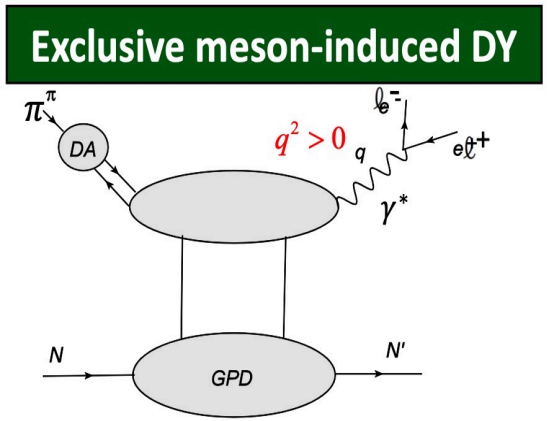
- Study of hadron mass origin via mass modification of vector mesons

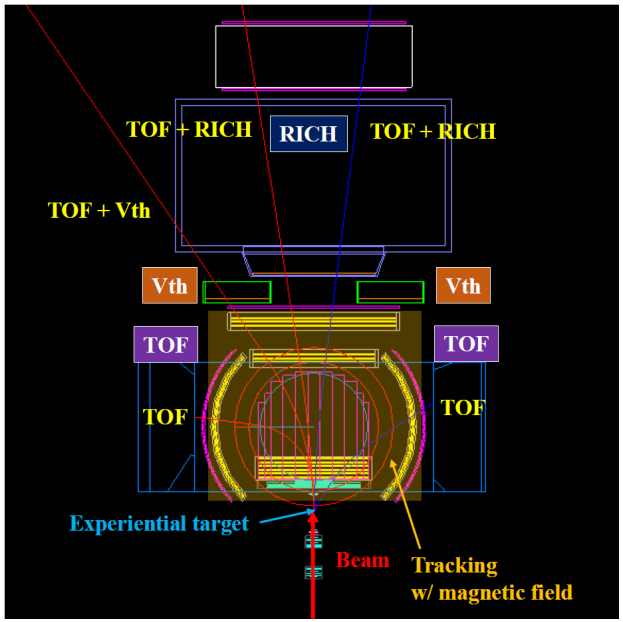


- Large acceptance e+e- spectrometer
- Commission runs: 2020, 2021, 2023
- Run 1: September 2023

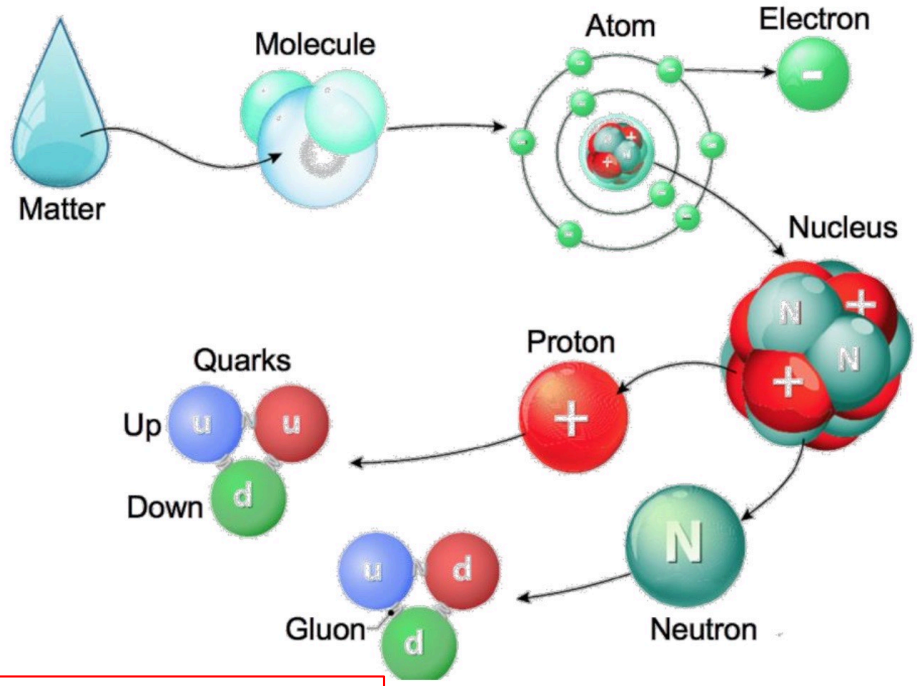
E50 Experiment:

- Probing Nucleons with 15-GeV Pions, to study Generalized Parton Distributions (GPDs) with Exclusive Drell-Yan process
- Experiment commissioning expected around 2025





Electron-Ion Collider (EIC)

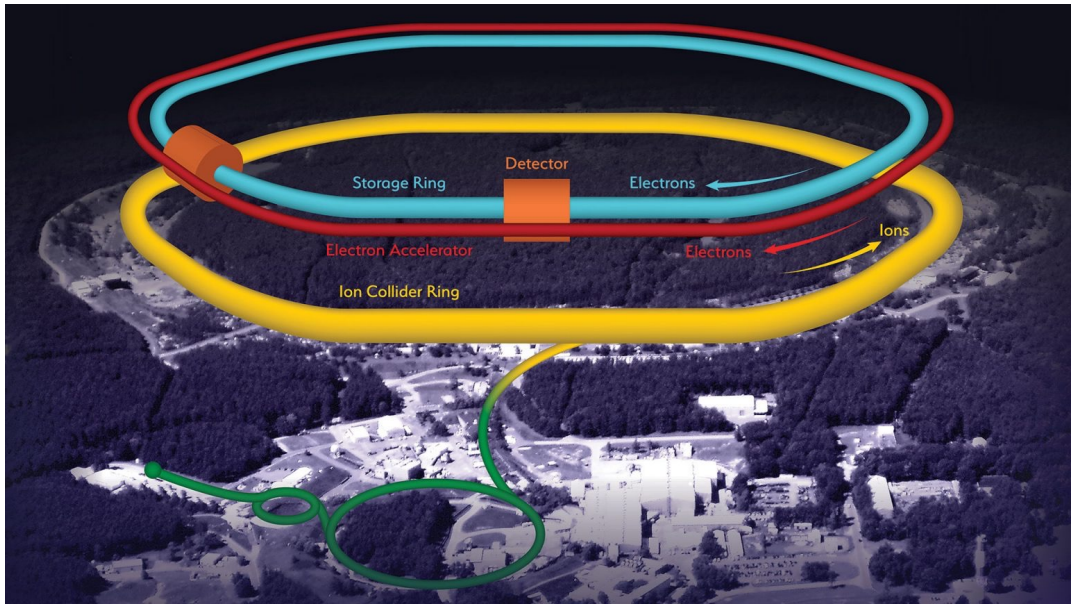


Andrei Seryi, 01/31/22

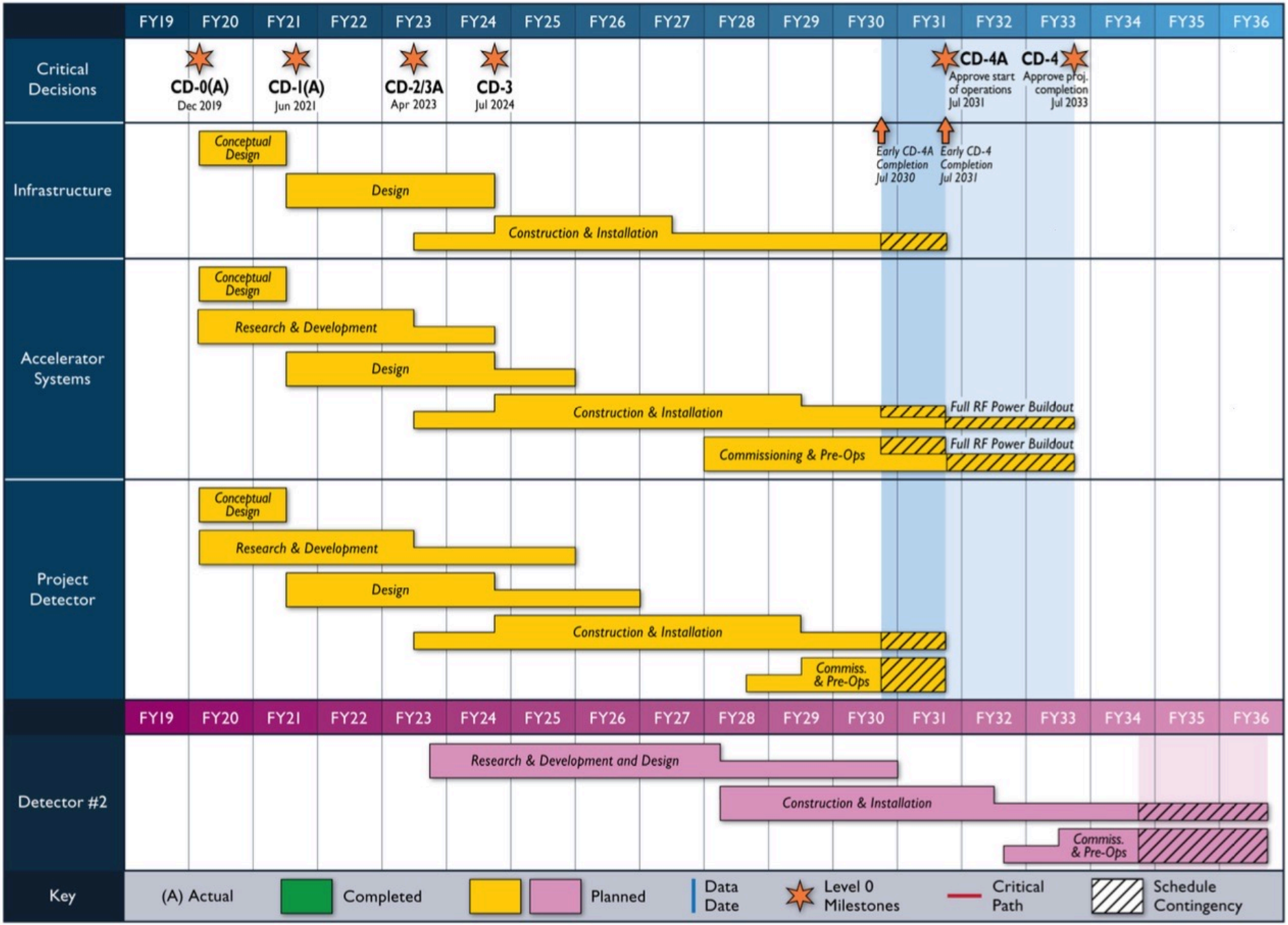
- Strong force, mediated by gluons, has the strongest interaction strength among the four forces of nature.
- It confines quarks into protons and neutrons, and binds them to create nuclei.
- Still limited quantitative understanding how it works. Example:
  - How does mass of proton/neutron arise?
    - gluons are massles, Sum(mass of quarks) ~ 1% of p/n mass
  - How does spin of p/n arise ?

EIC at Brookhaven National Lab

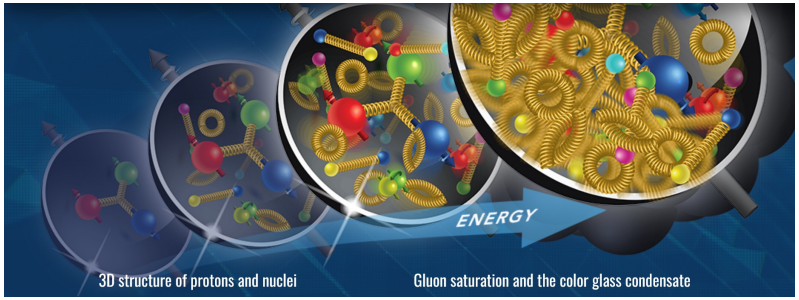
- To probe the structure of p/n with high energy electrons
- High luminosity : up to 10^{34} cm^{-2} s^{-1}
- Highly poloarized beams (~70%)
- Center of mass energy : ~20 - 140 GeV
- Ion species range : proton – Uranium
- To accommodate 2nd interaction region



EIC : Reference Schedule



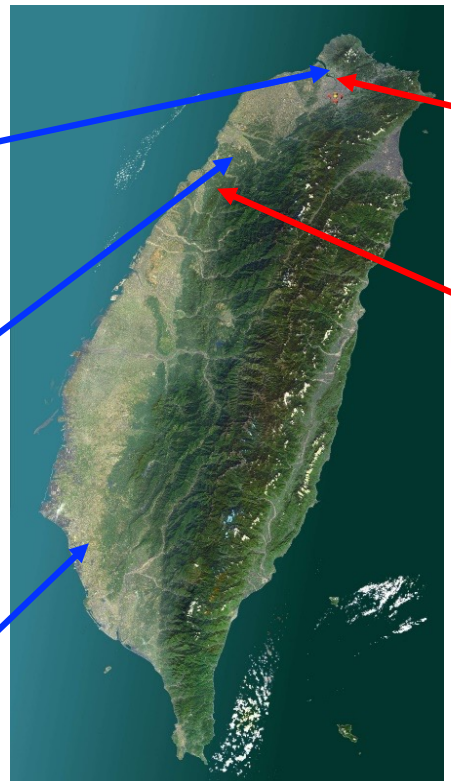
EIC and Taiwan



NTU

NCU

NCKU



AS

NTHU

Long Term Plan :

- AS and several Taiwan universities will join ePIC collaboration at EIC

Interested Physics Programs

- Pion and Kaon PDFs (tagged-DIS)
- GPDs (Generalized Parton Distributions) (DVCS, TCS, DVMP)
- CGC (Color Glass Condensate) (di-jet, di-hadron DIS)
- Hard Probe (jet, heavy quarks)

EIC Activities in Taiwan

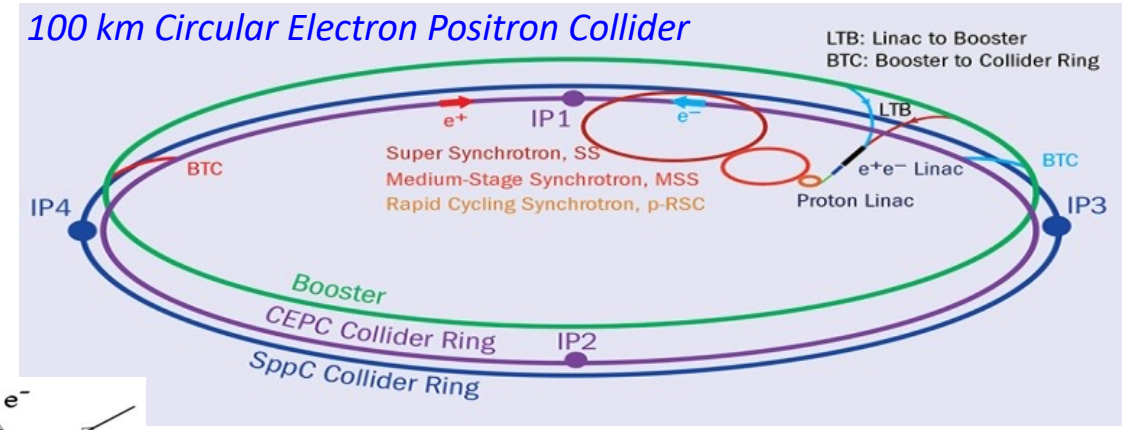
- TIDC EIC workshop (Aug 18-19, 2022)
- NCU workshop on EIC physics and detectors (Dec 9-10, 2022)
- The 2nd TIDC EIC workshop (Jan 3, 2023)
- TIDC Autumn School On Electron-Ion Collider (EIC) (Aug 28-29, 2023)

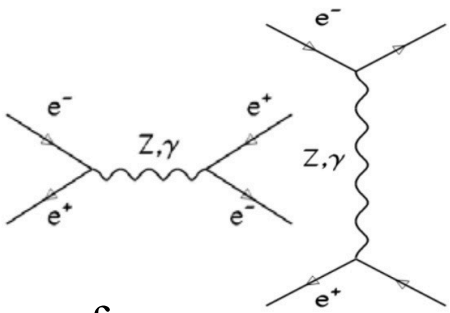
Zero-degree calorimeter

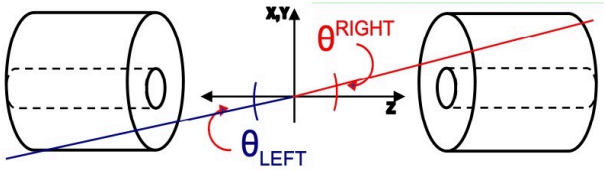
- Collaborating with Japan and Korea EIC teams
- Detector crucial for meson PDFs and GPDs

LumiCal for Future e+e- Experiments

- Several future e+e- machines proposed for high precision test of the SM and to study the Higgs boson (e.g. ILC, CLIC, CEPC, FCC-ee)
- Precise integrated luminosity measurement is very important
  - δ L ~ 10^{-4}
- Luminosity measurement by detecting Bhabha ($e^+e^- \rightarrow e^+e^-$) elastic scattering
  - QED process, small theory uncertainty
- Energy and polar angle measurements of the scattered electrons are keys to control the systematics



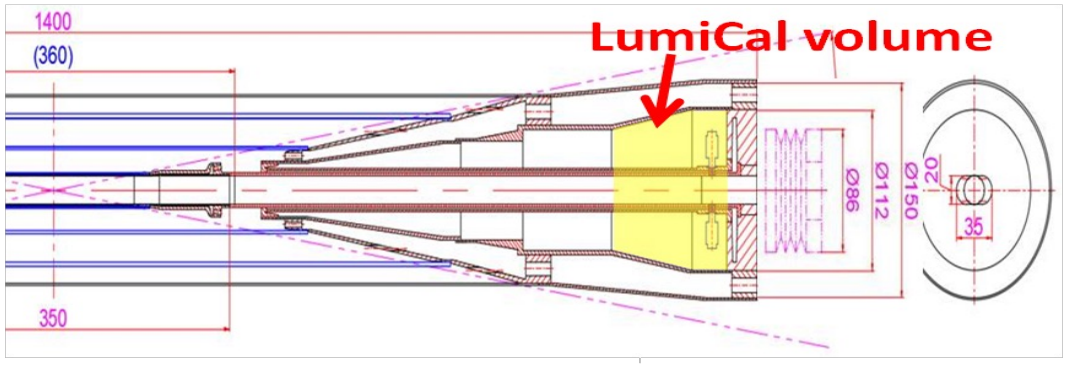




$\Delta\theta \equiv \theta_{RIGHT} - \theta_{LEFT}$

- Published a conceptual design of LumiCal in 2018

- Machine-Detector Interface is designed for 10^{36} cm^{-2} s^{-1} luminosity, beam crossing at 33 mRad



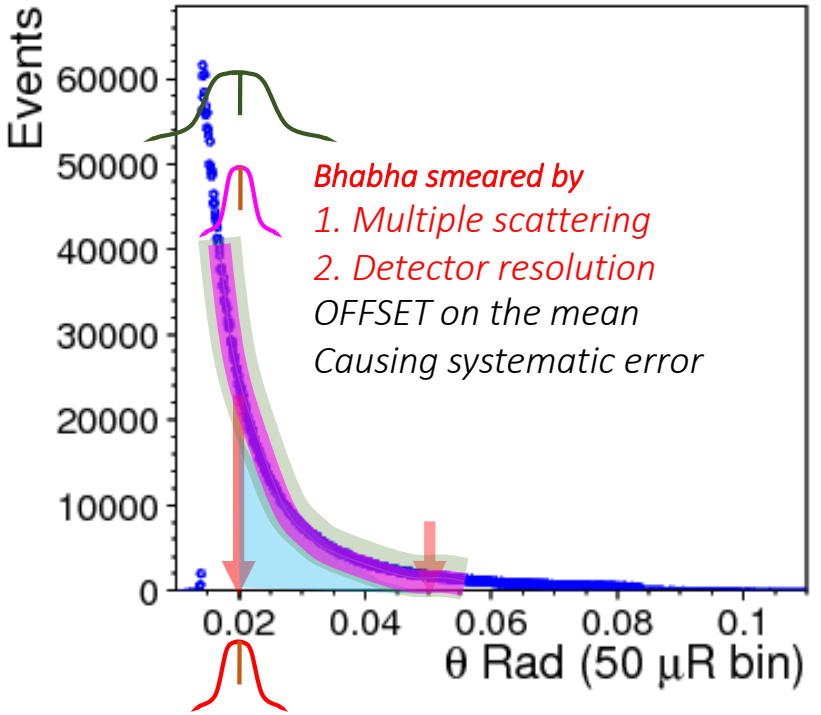
LumiCal for CEPC

Detect Bhabha elastic scattering electrons

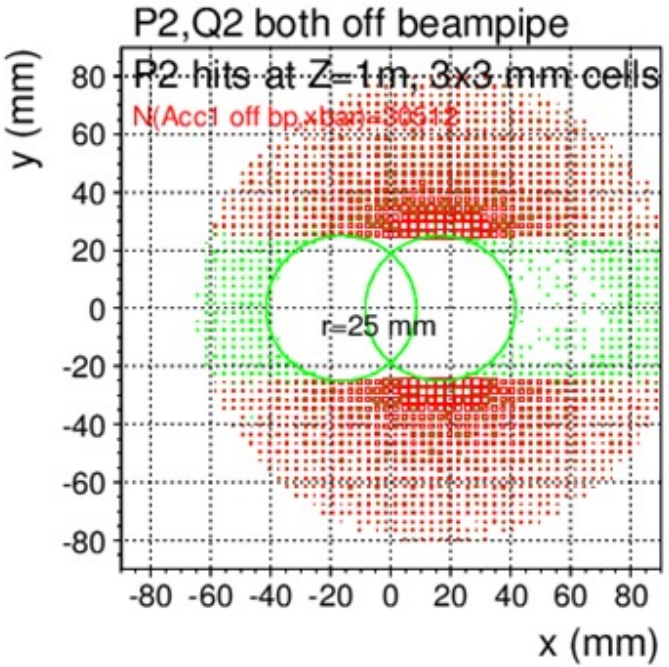
- QED (BHLumi) calculation for cross section with θmin =25 mRad
- GEANT simulation for multiple scattering and shower
- Evaluate smearing effect and method for counting events correctly for 10^{-4} precision

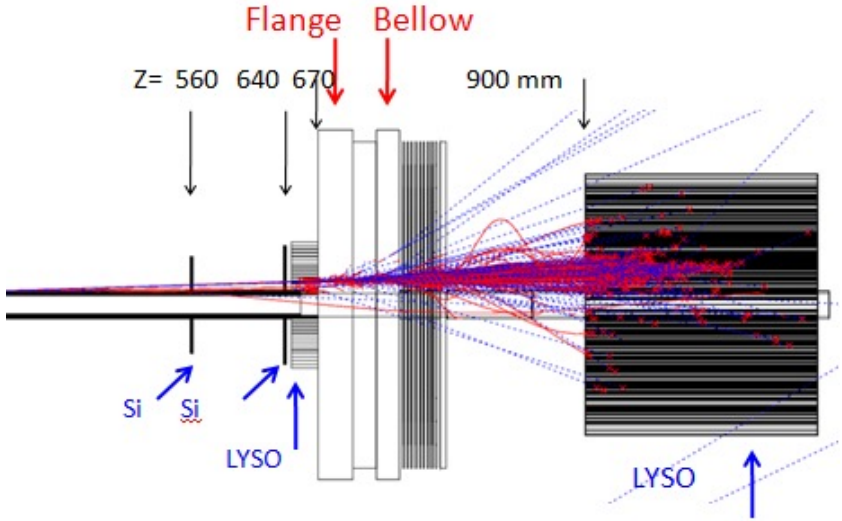
Acceptance in LAB both e^+, e^- detected

θ>25 mRad
85.4 nb
θ>25mR & |y|>25mm
78.0 nb



Acceptance @z=1m, r>25mm, |y|>25mm





50 GeV electron: θ = 32 mRad, ϕ=90° 1mm Be pipe

Shower deposition

in front LYSO: 1.0% , In back LYSO: 61%

➔ 33% shower in flange+bellow

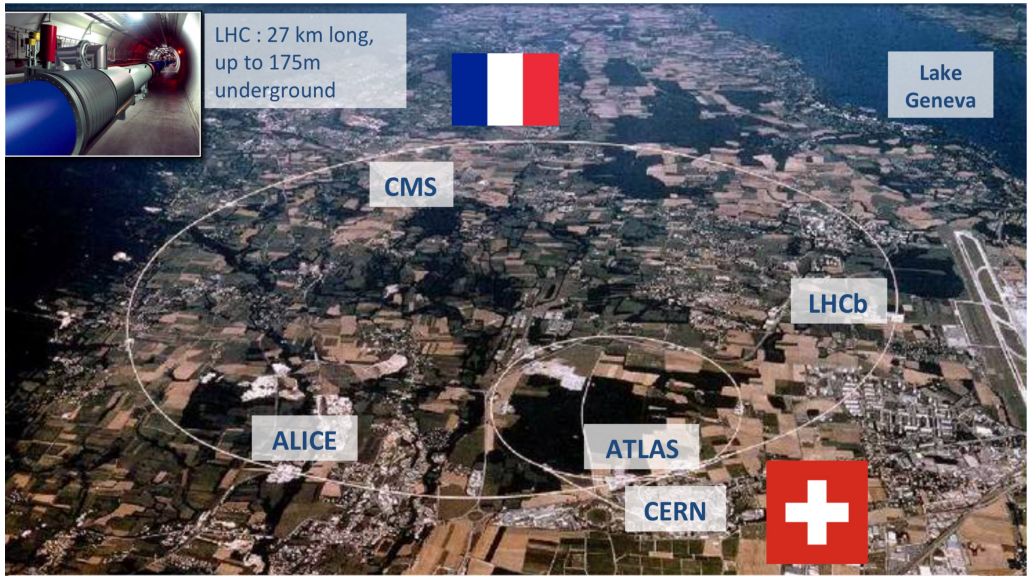
Summary

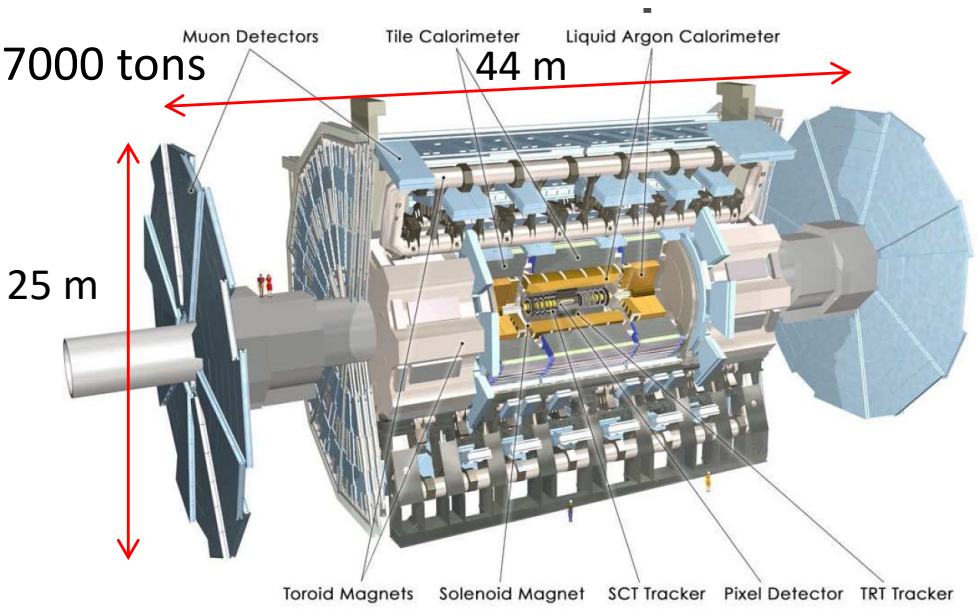
- AS has been an ATLAS collaborator for two decades
  - active and productive in the experiment
- The experiment still has another two decades of running and a lot more data to be collected.
- Important to remain as an active collaborator of ATLAS

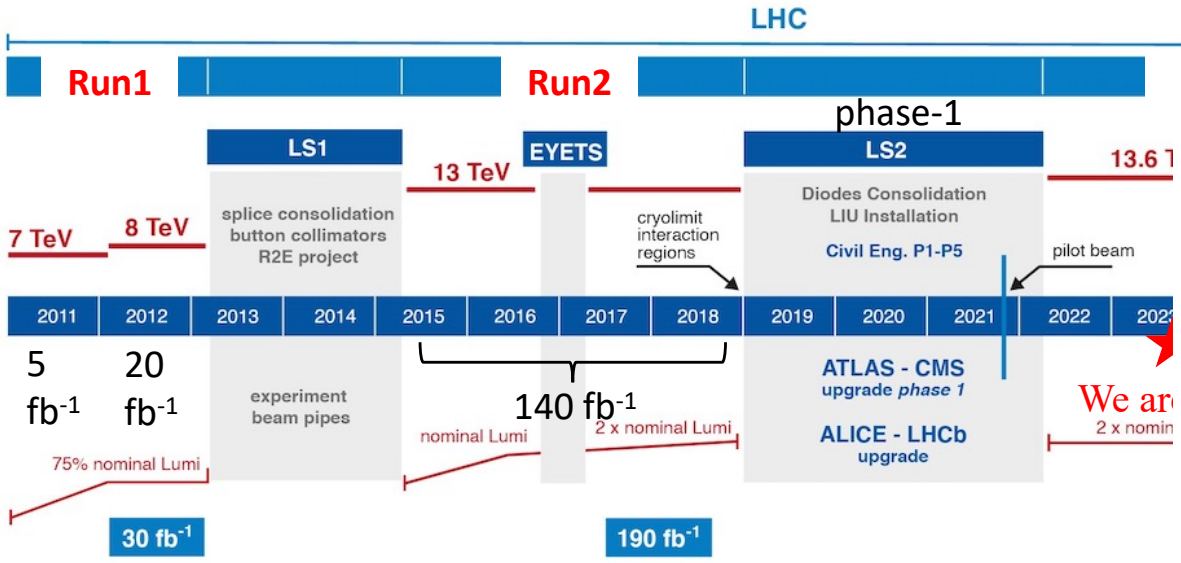
- We are also planning for future new experiments, collaborating with several Taiwan institutes
- This will create a great opportunity for the Taiwan HEP community to work closely together

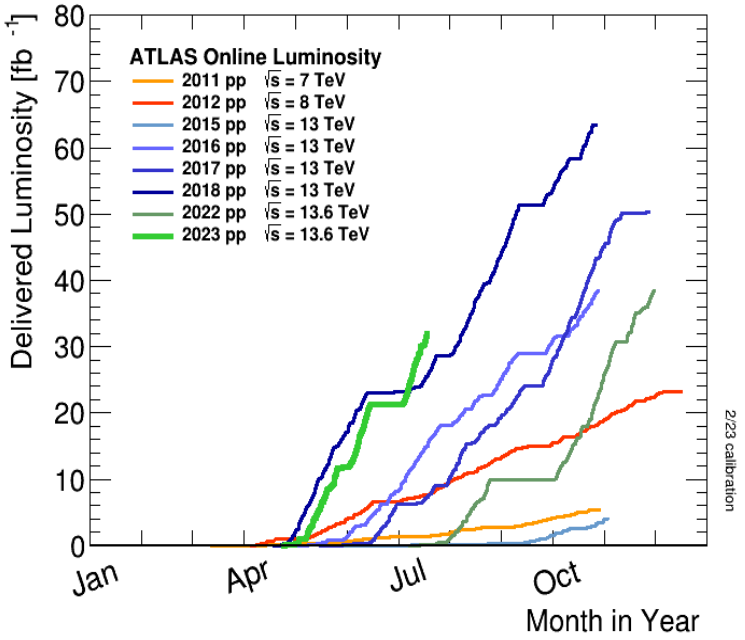
Back Up

ATLAS Experiment

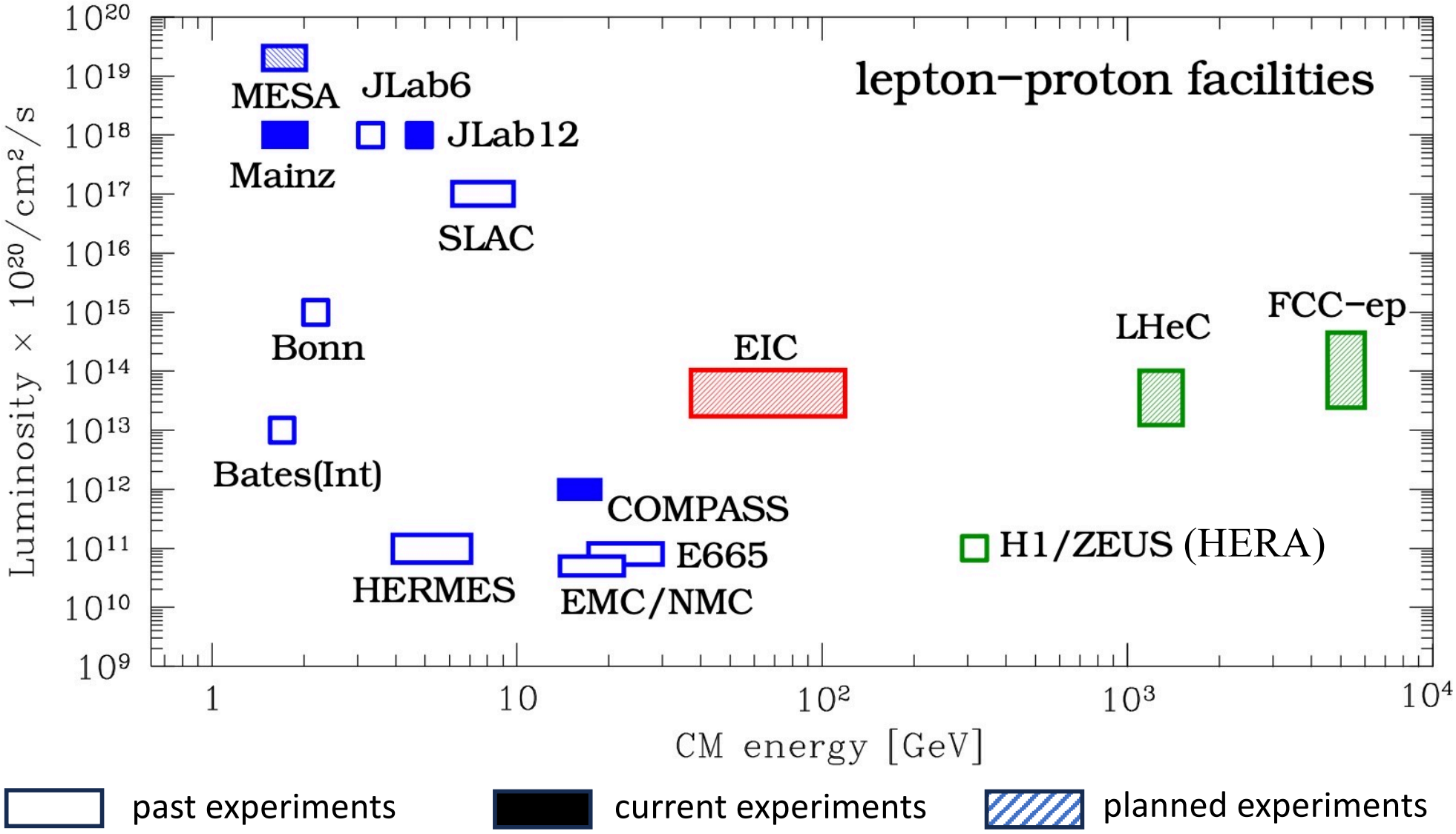








Lepton-Proton Experiments



- Poloarized protons or ion beams available at EIC, but not available at HERA, LHeC and FCC-ep