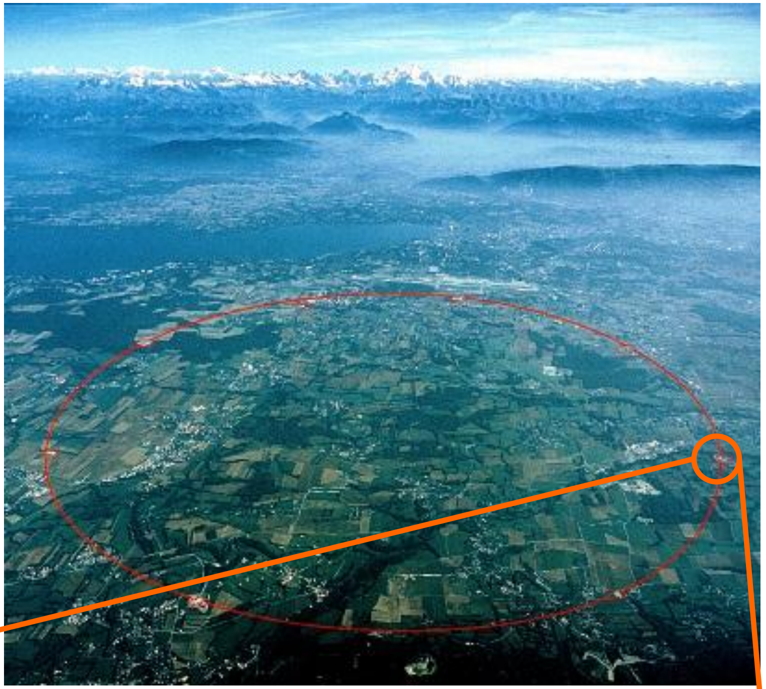
LHC status and upgrade plan (physics & detector)

'17 3/30 Yosuke Takubo (KEK)

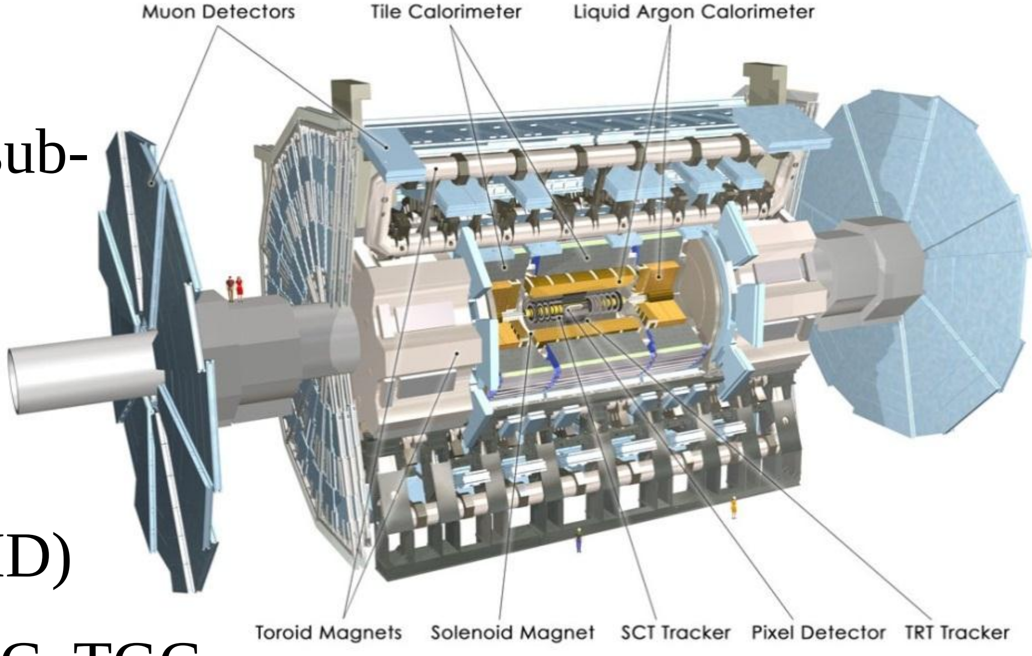
ATLAS experiment in 2016

ATLAS experiment



- The experiment started in 2008.
- Discovered Higgs in 2012.
- Run-2 operation started in 2015 with 13 TeV colliding energy.

ATLAS detector



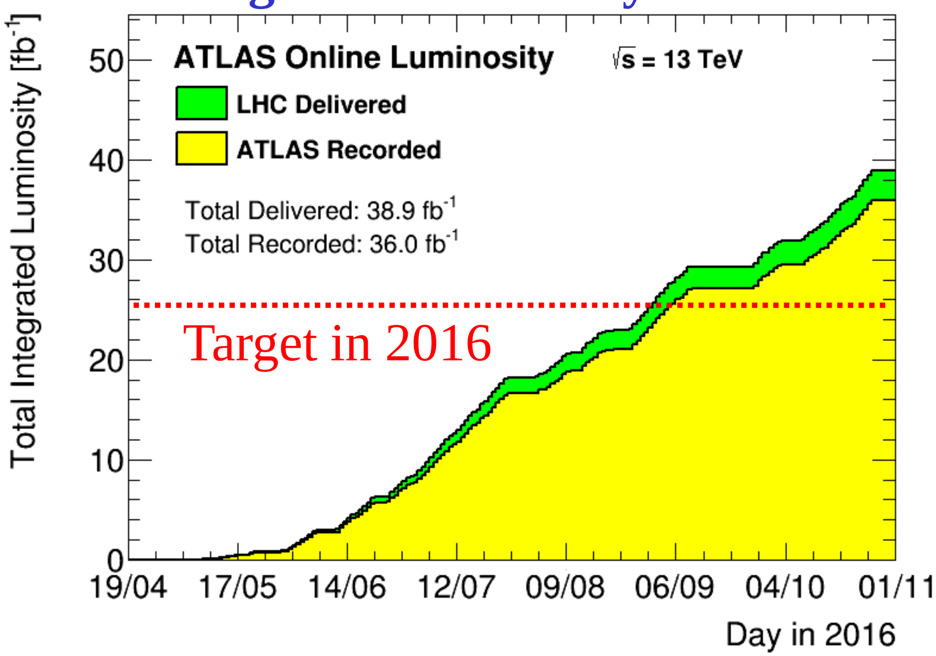
- General purpose detector with sub-detector complex
- Size: 25 m(r), 44 m (z)
- Inner tracker: Pixel, SCT, TRT
- Calorimeter: LAr (EM), Tile (HD)
- Muon detector: MDT, RPC, CSC, TGC

Current ATLAS operation condition

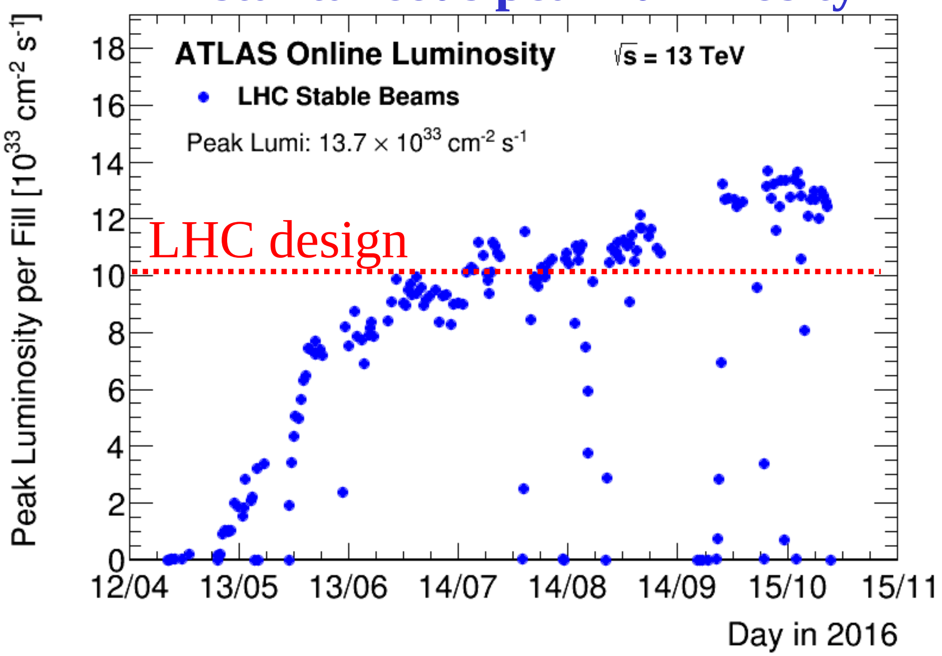
- The integrated luminosity arrived at 36.0 fb^{-1} in record.
- The peak instantaneous luminosity is increased to ~1.4×10^{34} $cm^{-2}s^{-1}$.
  - Already higher than LHC design value (1×10^{34} $cm^{-2}s^{-1}$).

→ The high luminosity causes many challenges in detector operation, especially for Pixel detector.

Integrated luminosity in 2016



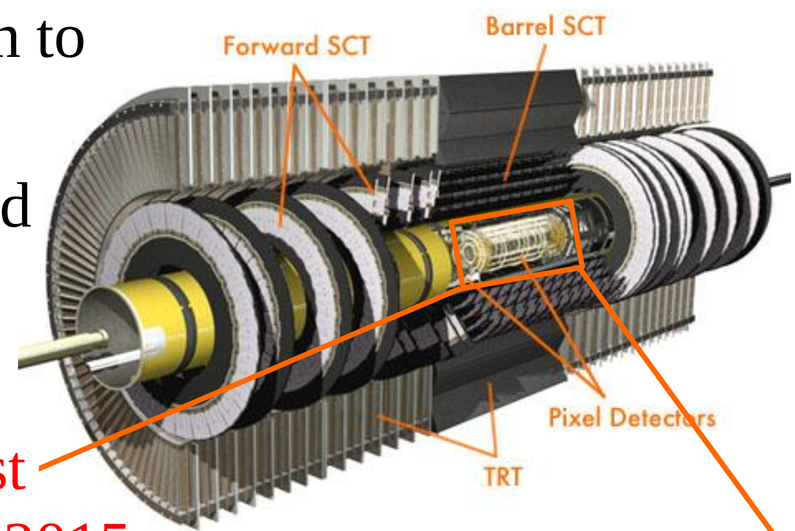
Instantaneous peak luminosity

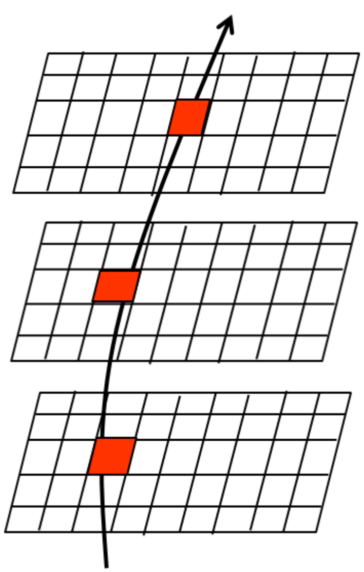


ATLAS Pixel detector

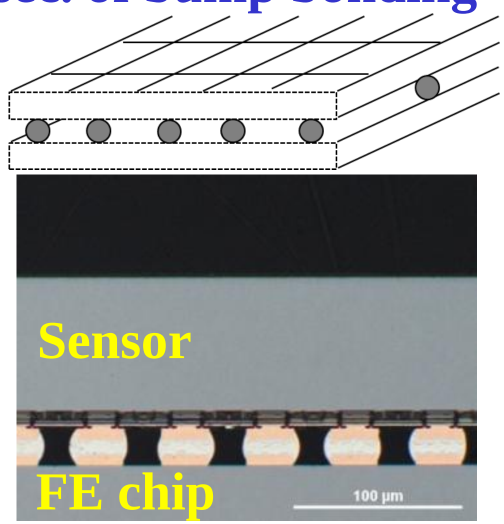
- Pixel detector is put in the closest position to the beam collision point.

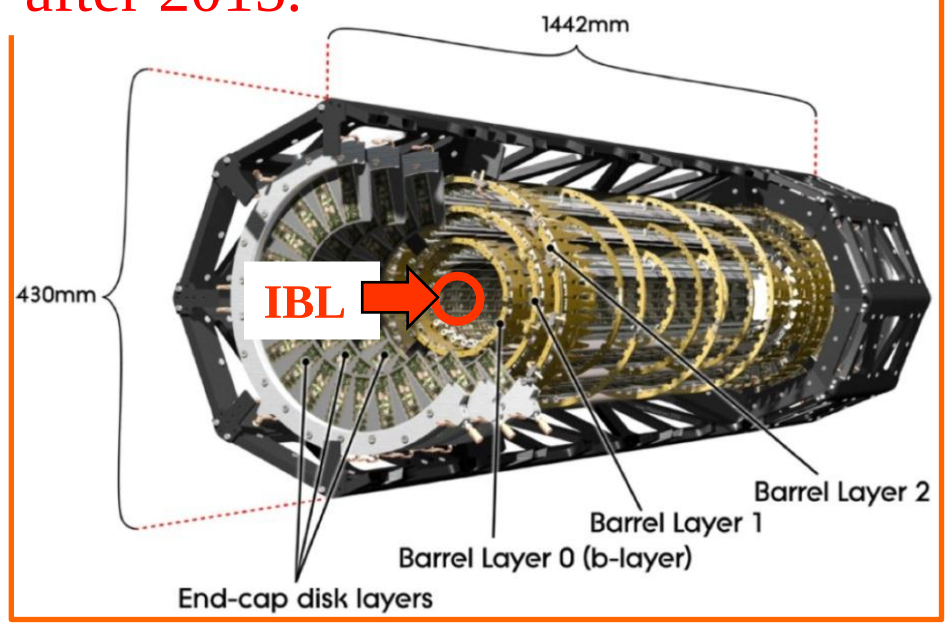
  → Operated at highest particle density and radiation.
- 4 barrel layers and 3 endcap disks
- IBL was installed in 2014 at the innermost region to cope with high luminosity after 2015.





Xsec. of bump bonding





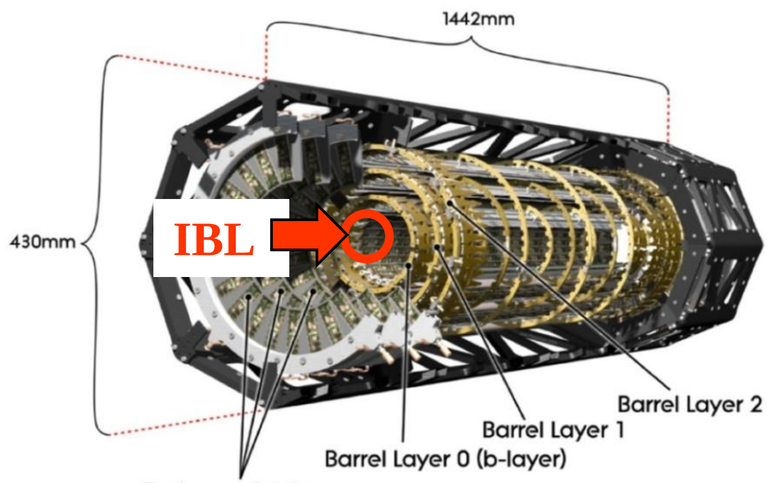
Insertable B-Layer (IBL)

What is IBL?

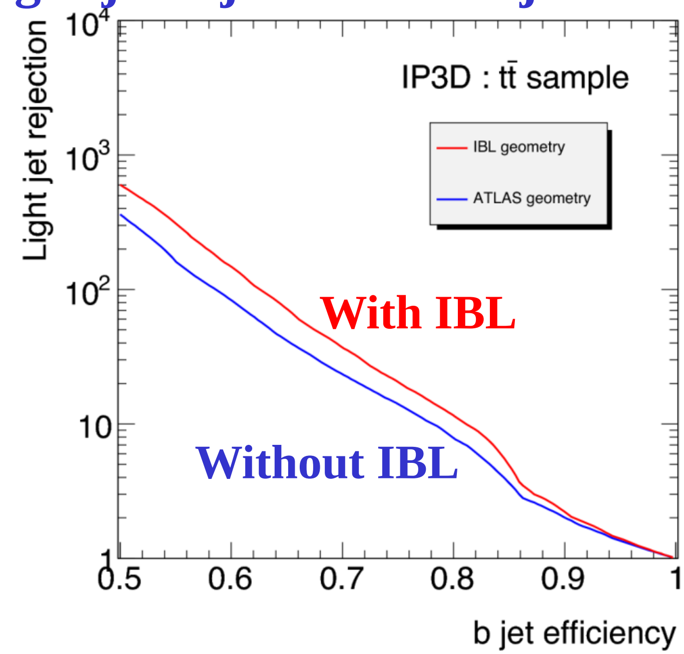
- The new innermost pixel layer installed in 2014 (r=33mm).
- Installation of IBL is the first upgrade activity in ATLAS experiment.
- KEK contributed to construction, installation and commissioning of IBL.

Motivation

- To keep efficiency after 2015.
  - FE chip was designed to work at up to 1×10^{34} $cm^{-2}s^{-1}$ in the innermost layer.
- Tracking and physics performance improvements mainly for b-tagging.

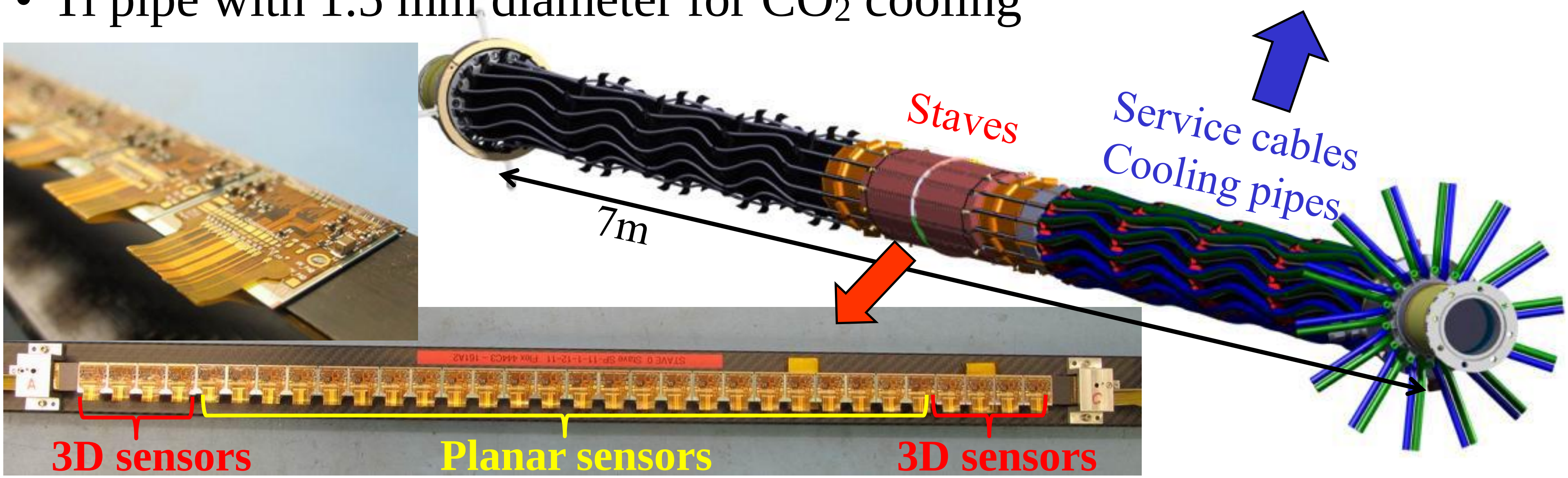


light jet rejection v.s. b-jet eff.



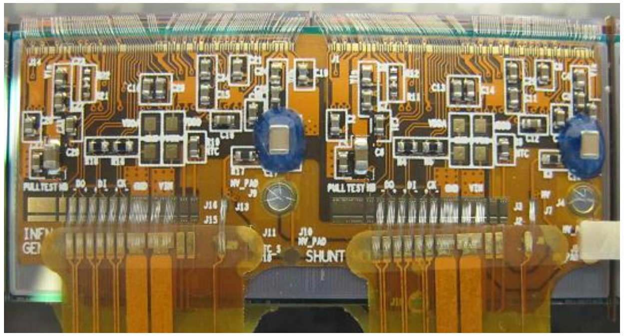
IBL on-detector components

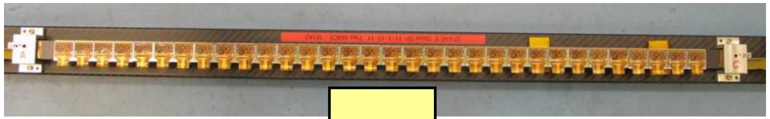
- Sensor modules :
  - Planar sensor (75%), 3D sensor (25%)
  - The first time to use 3D sensor in HEP experiment
  - Pixel size: 50 x 250 um^2
- 14 staves (12 planar and 8 3D modules per stave)
- Service cables: installed with the detector
- Ti pipe with 1.5 mm diameter for CO_2 cooling

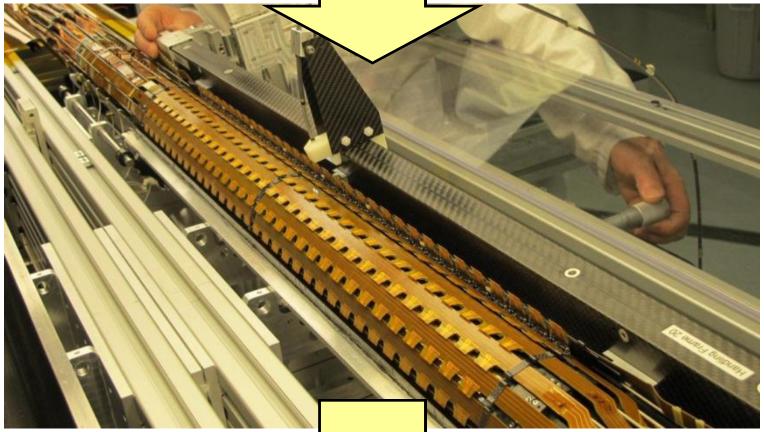


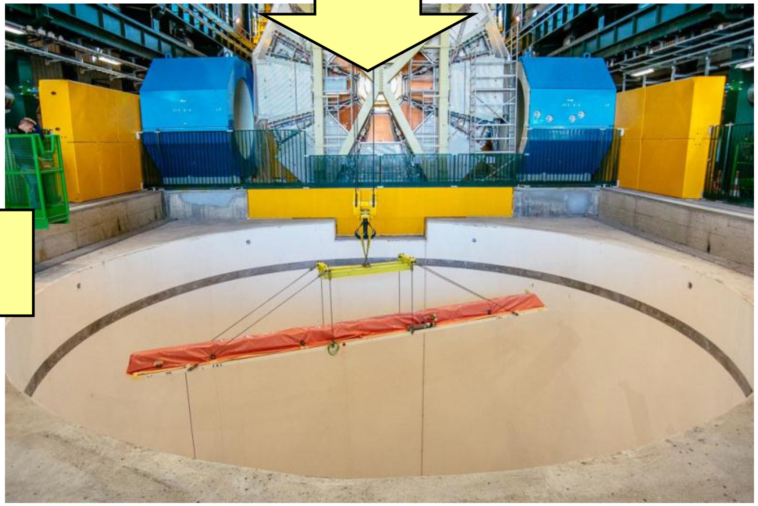
IBL installation

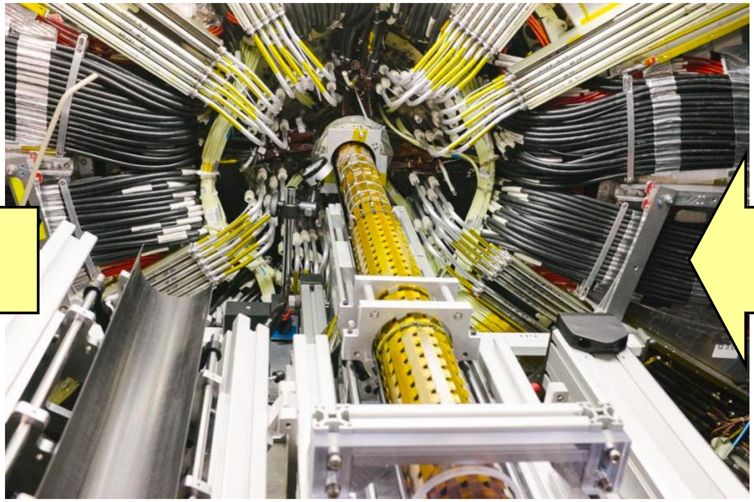
- The modules are mounted on the staves.
- The 14 staves were integrated on a support tube on surface.
- 7 m long of IBL package was contained within the limited radial envelop space (10 mm).
- IBL was moved to ATLAS experimental hall at 90 m underground and installed into the ATLAS on May, 2014.
  - The insertion clearance less than 0.1 mm

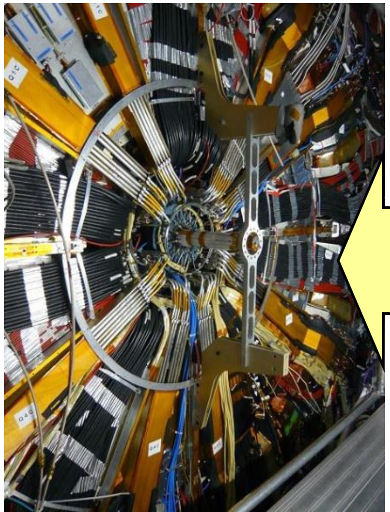








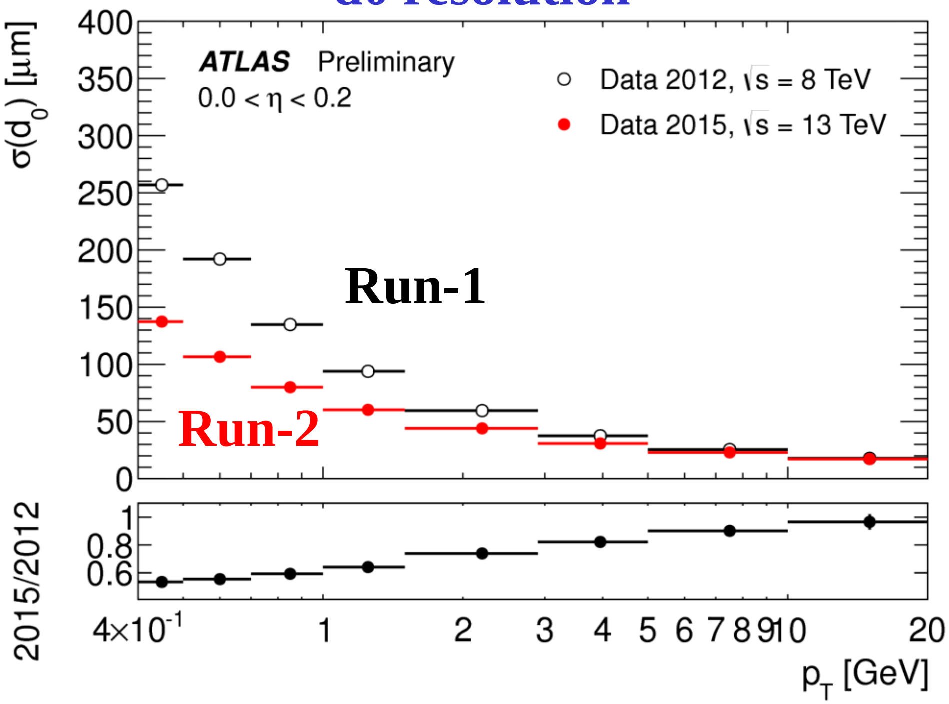




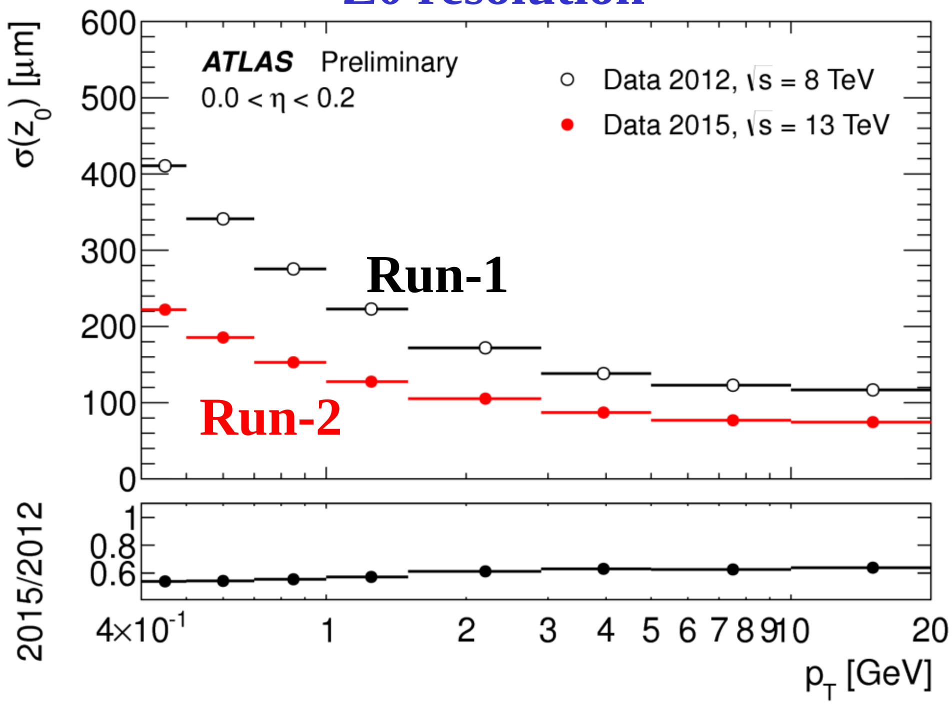
Benefit with IBL (tracking performance)

- The good impact parameter resolution is important for b-jet tagging, pile-up suppression and object identification.
- The impact parameter resolution is significantly improved with IBL especially at low-pT.
  - reduced by ~40% for d0 and Z0 at the maximum

d0 resolution



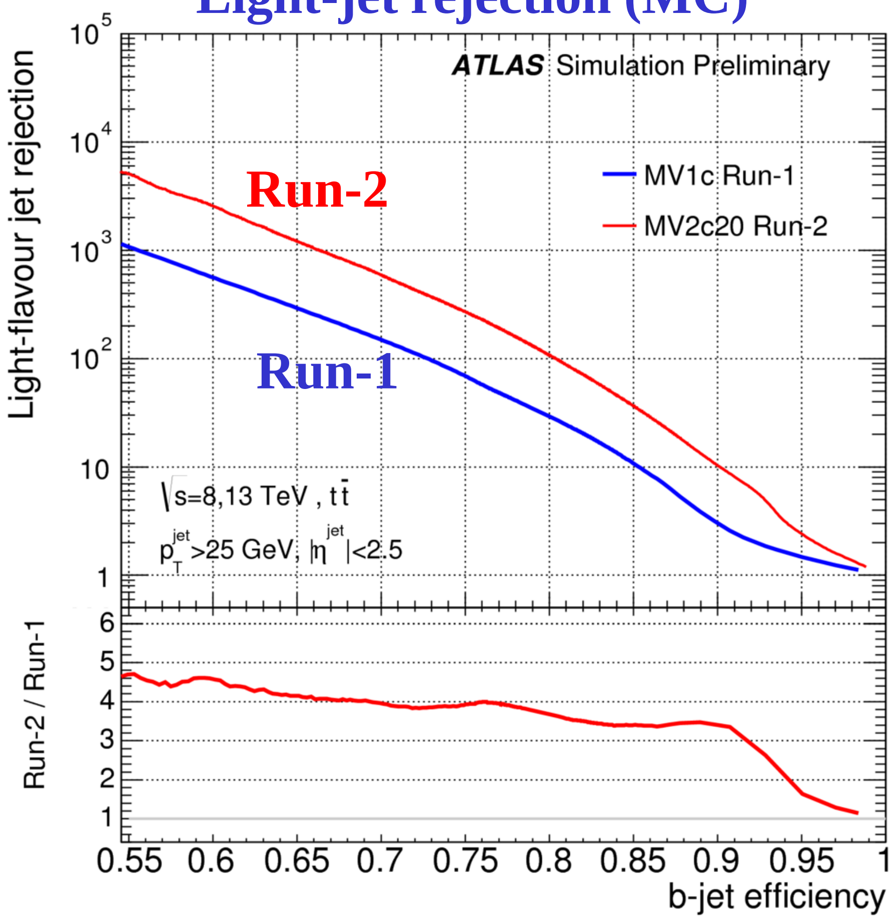
Z0 resolution



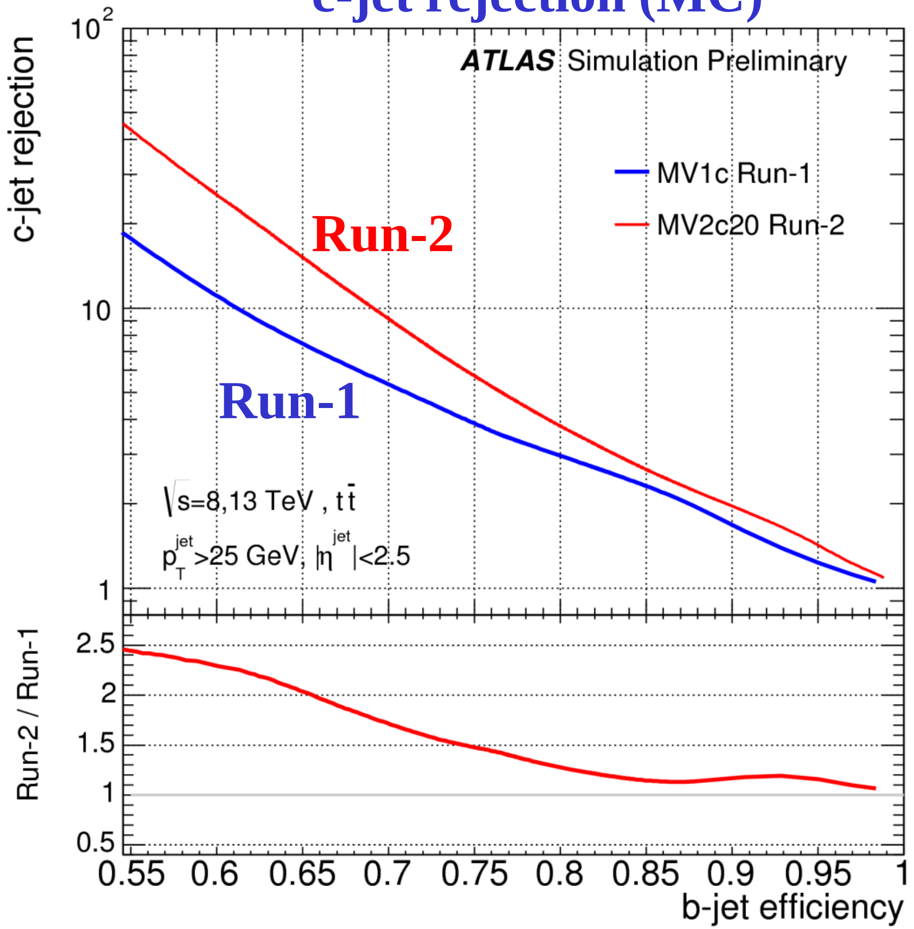
Benefit with IBL (b-tagging)

- The better track extrapolation resolution improves b-tag performance.
- The light jet rejection is increased by ~4 times for ε_b=70%.

Light-jet rejection (MC)



c-jet rejection (MC)



Data-taking overview in 2016

- Pixel detector works with good data-taking eff. at higher peak luminosity than $1.0 \times 10^{34}\ cm^{-2}s^{-1}$.
- Other sub-detectors were also operated in very stable condition.
- About 95% of data are used for physics analyses in 2016.

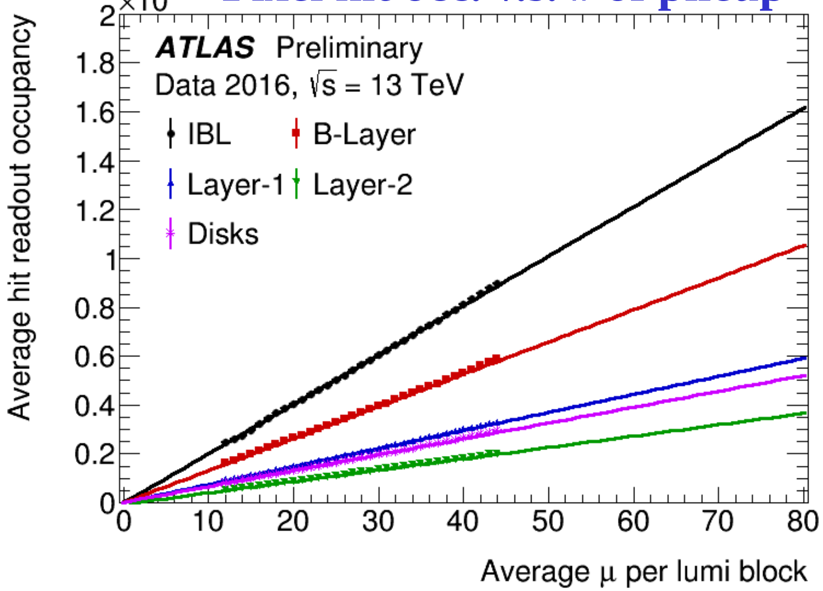
ATLAS pp 25ns run: April-October 2016											
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets		Trigger
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid	L1
98.9	99.9	99.7	99.3	98.9	99.8	99.8	99.9	99.9	99.1	97.2	98.3
Good for physics: 93-95% (33.3-33.9 fb^{-1})											

Luminosity weighted relative detector uptime and good data quality efficiencies (in %) during stable beam in pp collisions with 25ns bunch spacing at $\sqrt{s}$=13 TeV between April-October 2016, corresponding to an integrated luminosity of 35.9 fb^{-1}. The toroid magnet was off for some runs, leading to a loss of 0.7 fb^{-1}. Analyses that don't require the toroid magnet can use that data.

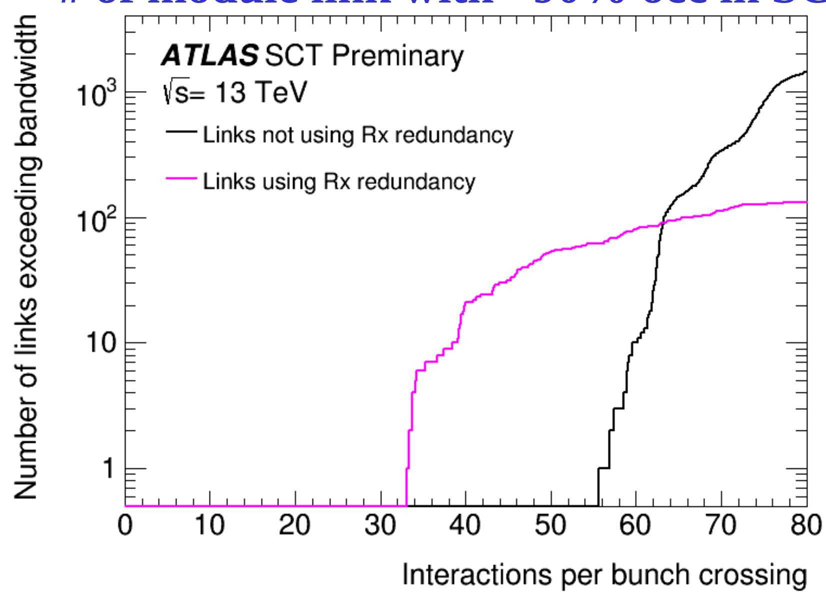
Challenges with high luminosity

- LHC will be operated with higher instantaneous luminosity than the design value ($1\text{x}10^{34}\text{cm}^{-2}\text{s}^{-1}$).
  - ➢ Already $1.4\text{x}10^{34}\text{cm}^{-2}\text{s}^{-1}$ in 2016. ($1.7\text{x}10^{34}\text{cm}^{-2}\text{s}^{-1}$ in 2017)
- The luminosity will be increased up to $3\text{x}10^{34}\text{cm}^{-2}\text{s}^{-1}$ at the maximum.
- Each sub-detector group is investigating operationability of the detector and limitation in data-taking.

Pixel hit occ. v.s. # of pileup



# of module link with >90% occ in SCT



Quick overview of recent physics results

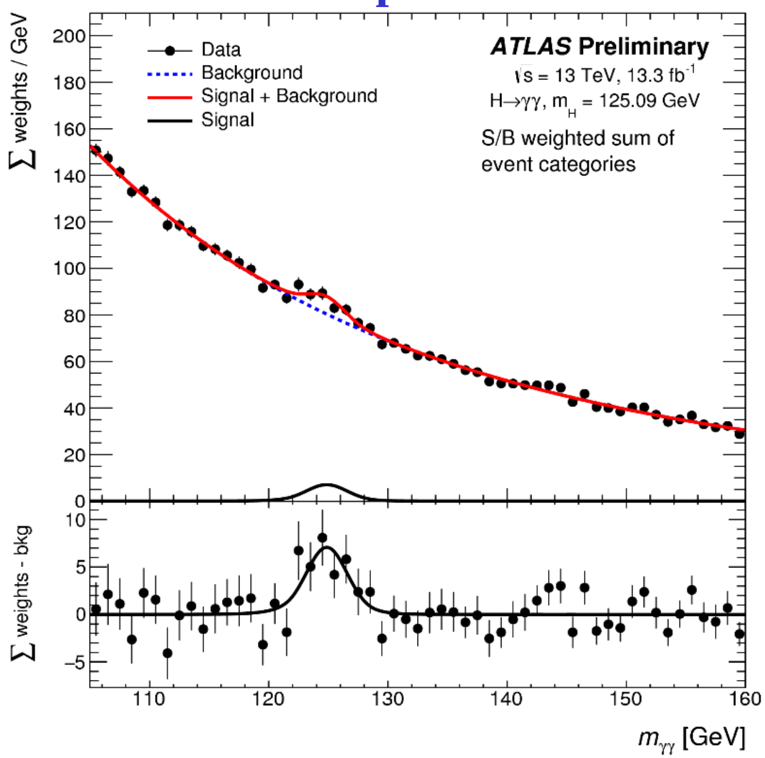
See the latest results in Moriond:

- https://indico.in2p3.fr/event/13763/other-view?view=standard
- http://moriond.in2p3.fr/QCD/2017/MorQCD17Prog.html

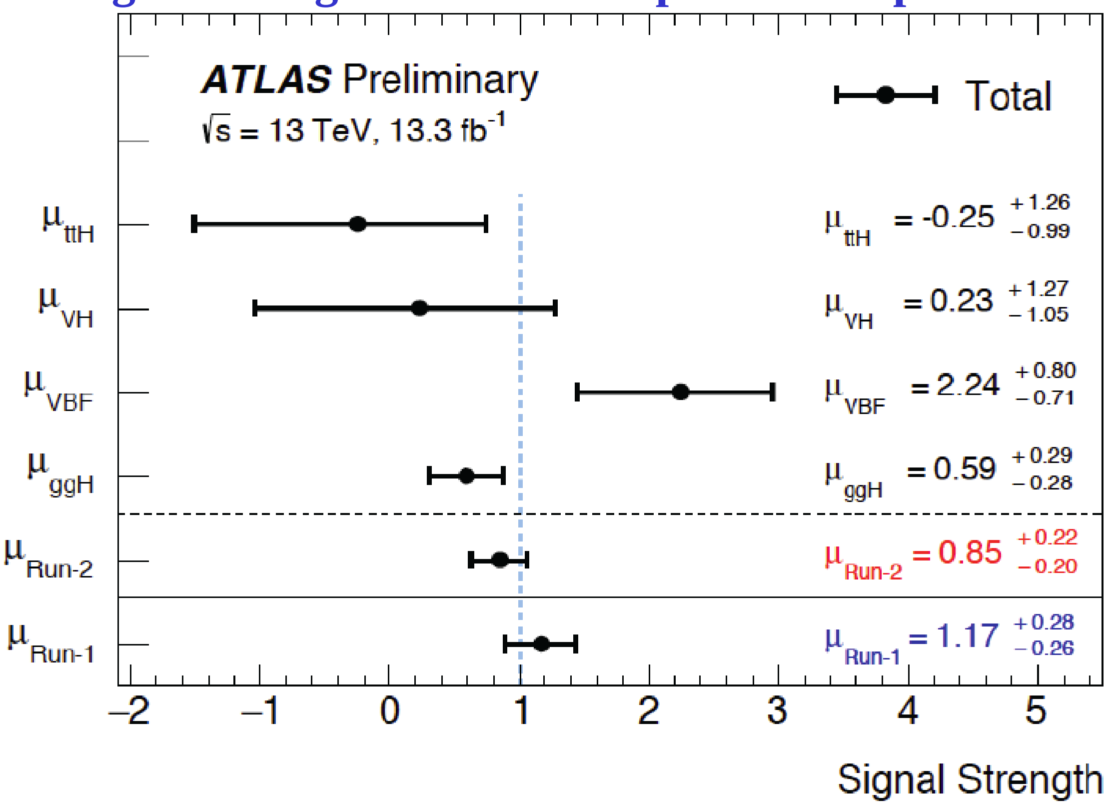
$H \rightarrow \gamma\gamma$

- $H \rightarrow \gamma\gamma$ with 13.3 fb^{-1} at Run2 (ATLAS-CONF-2016-067).
- Clear peak is observed with 13 TeV at m_H=125.09 GeV.
- Consistent results with different final states.

Invariant diphoton mass



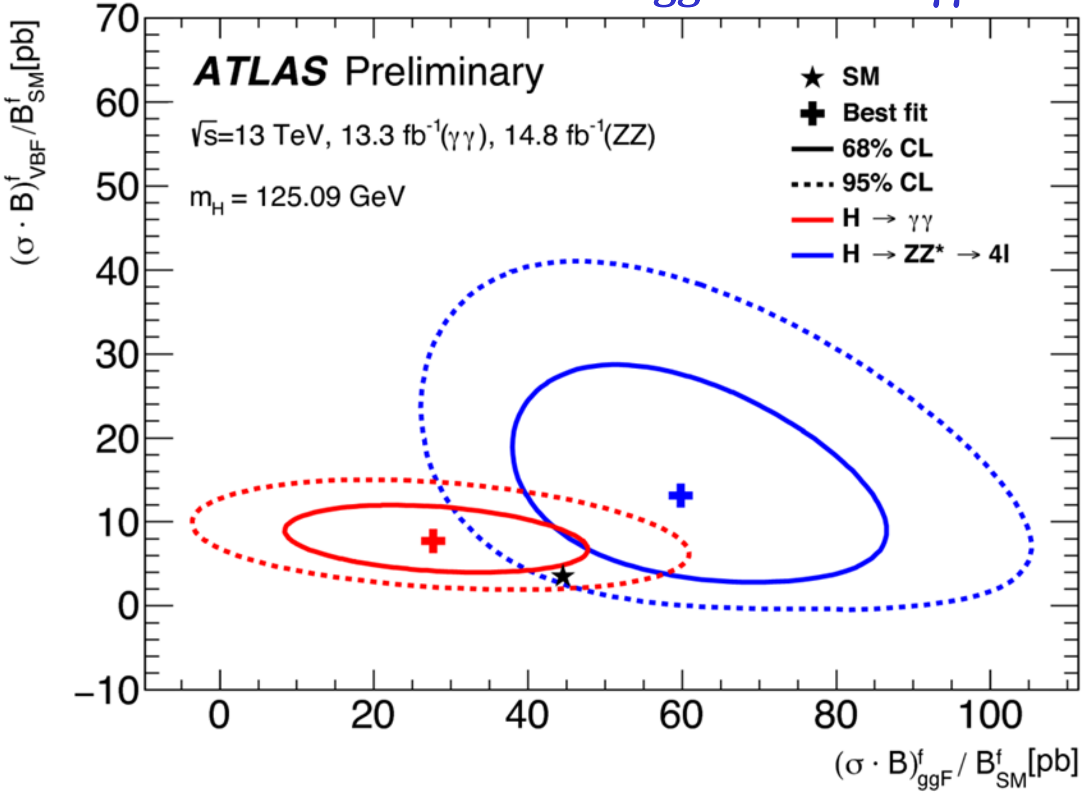
Signal strength for different production processes

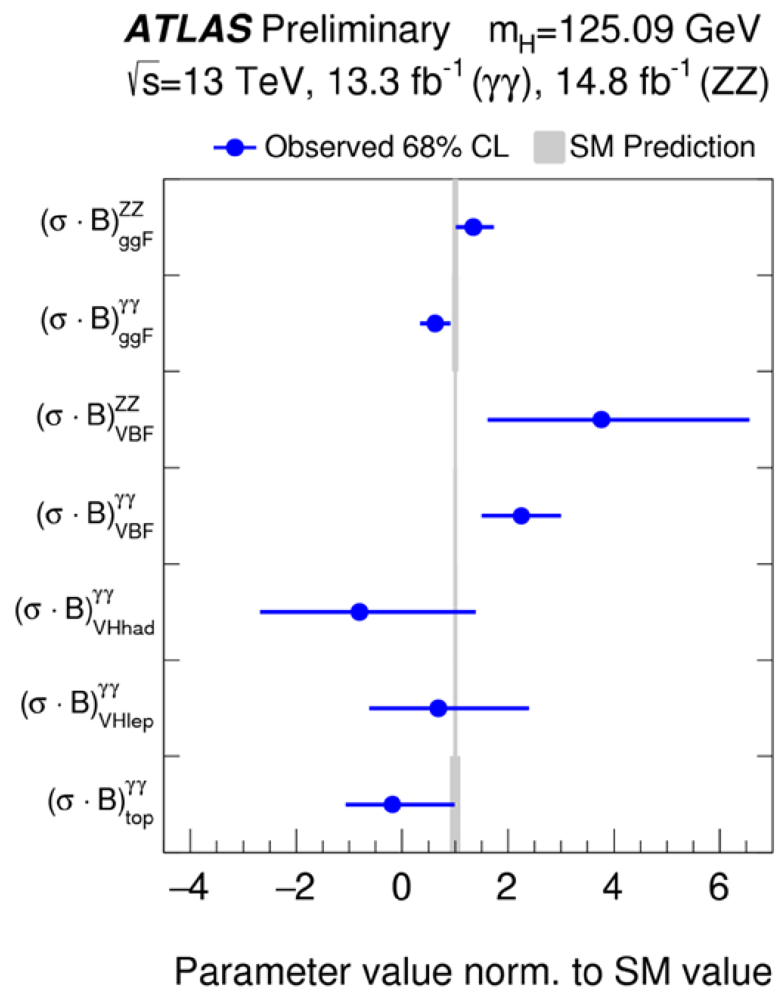


H → γγ and ZZ*

- Combined results of H→γγ/ZZ* at Run2 (ATLAS-CONF-2016-081)
- The xsec is consistent with SM for different production processes.
- Inclusive: $\mu = 1.13^{+0.18}_{-0.17}$

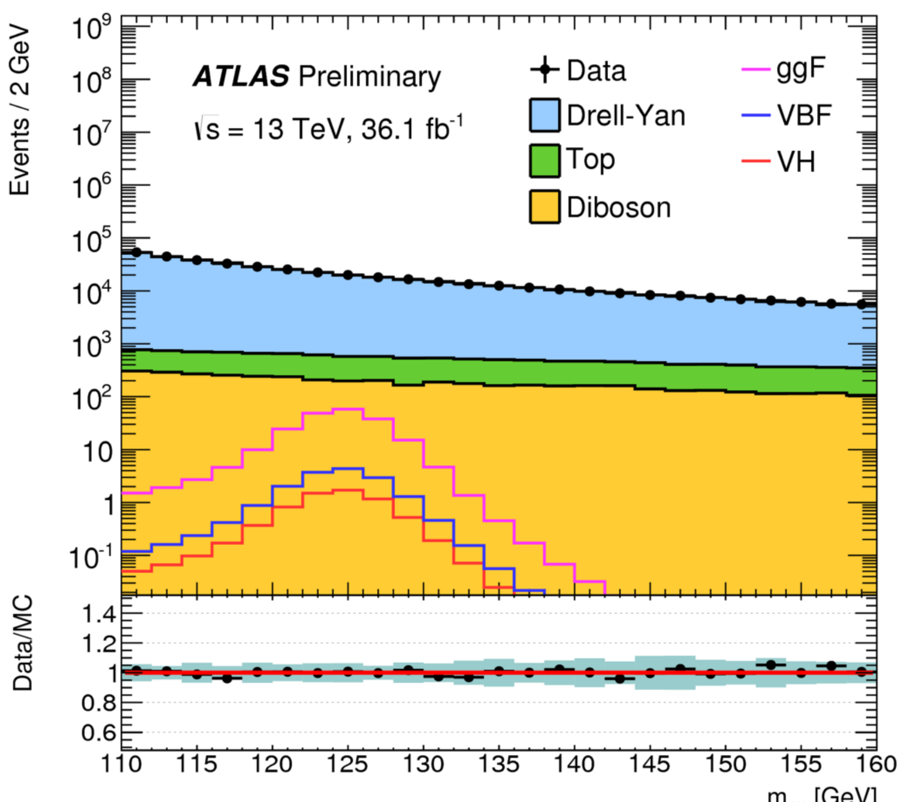
Contour of xsec of VBF and ggF with H→γγ/ZZ*

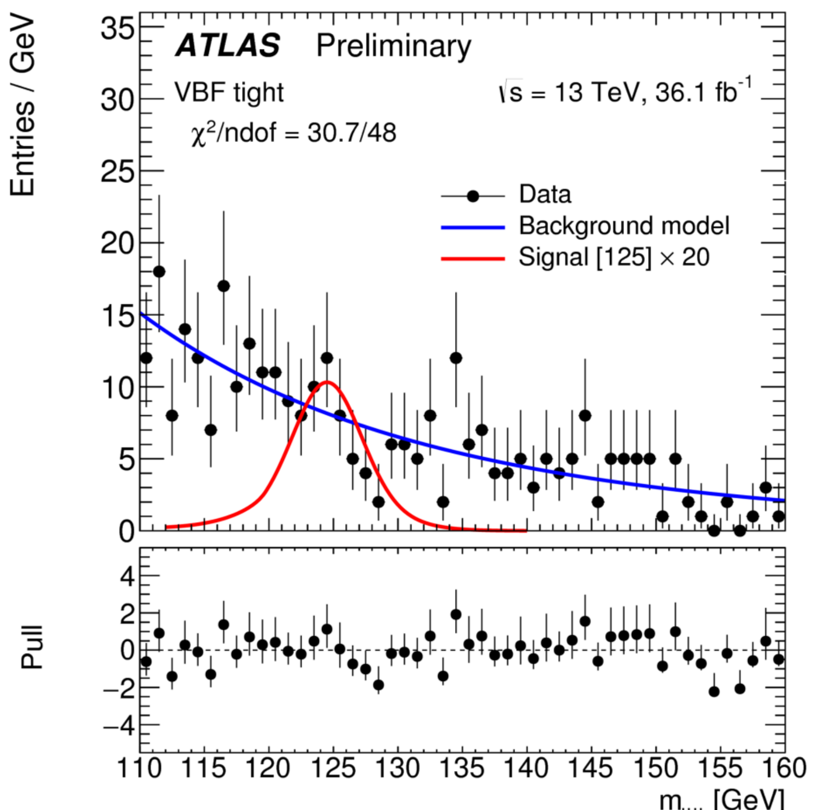




H → μμ (New)

Data set	Upper limit @95% CL Observed (expected)	Signal strength
Run2 (13TeV)	3.0 (3.1)	-0.07 ± 1.5
Run1 + Run2 (7/8/13 TeV)	2.7 (2.8)	-0.13 ± 1.4





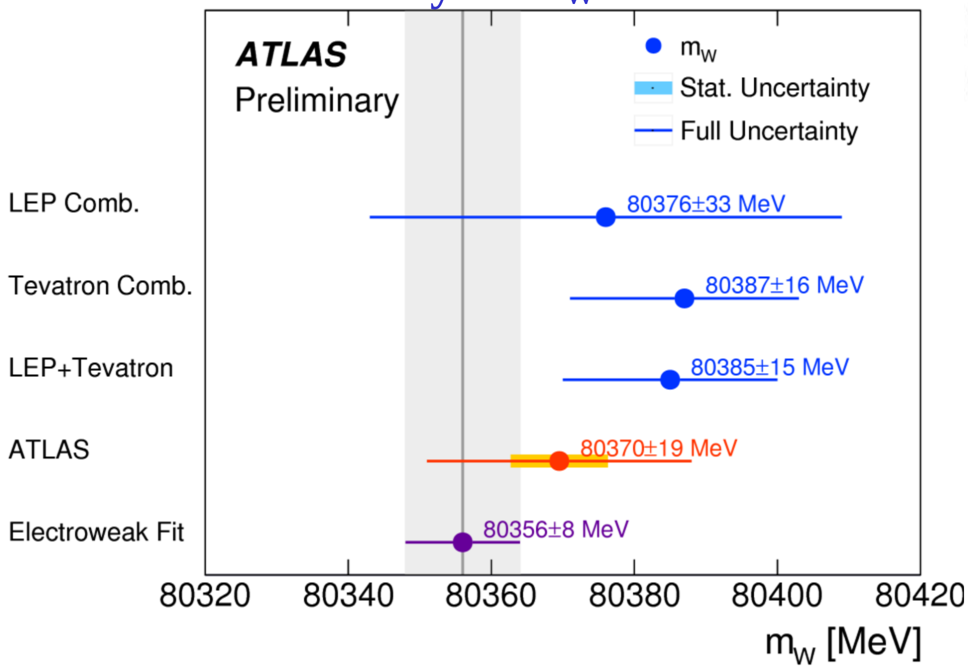
Measurement of W boson mass

- W boson mass is precisely measured at ATLAS (arXiv:1701.07240).

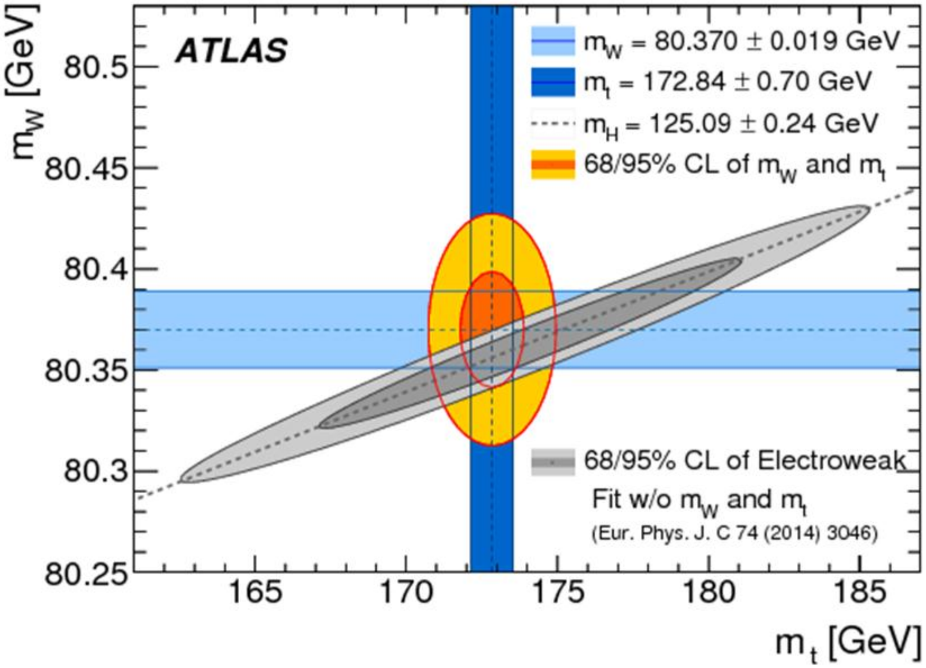
$$M_W = 80370 \pm 7\ (\text{stat.}) \pm 11\ (\text{exp. syst.}) \pm 14\ (\text{mod. syst.})\ \text{MeV}$$
$$= 80370 \pm 19\ \text{MeV}$$

- The precision in ATLAS only measurement is similar level as combined results of LEP/Tevatron.

Summary of M_W measurement

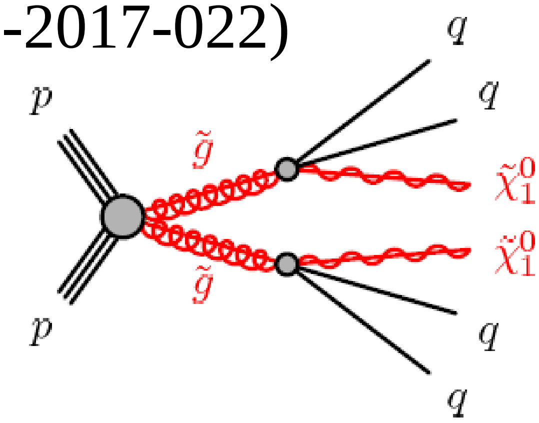


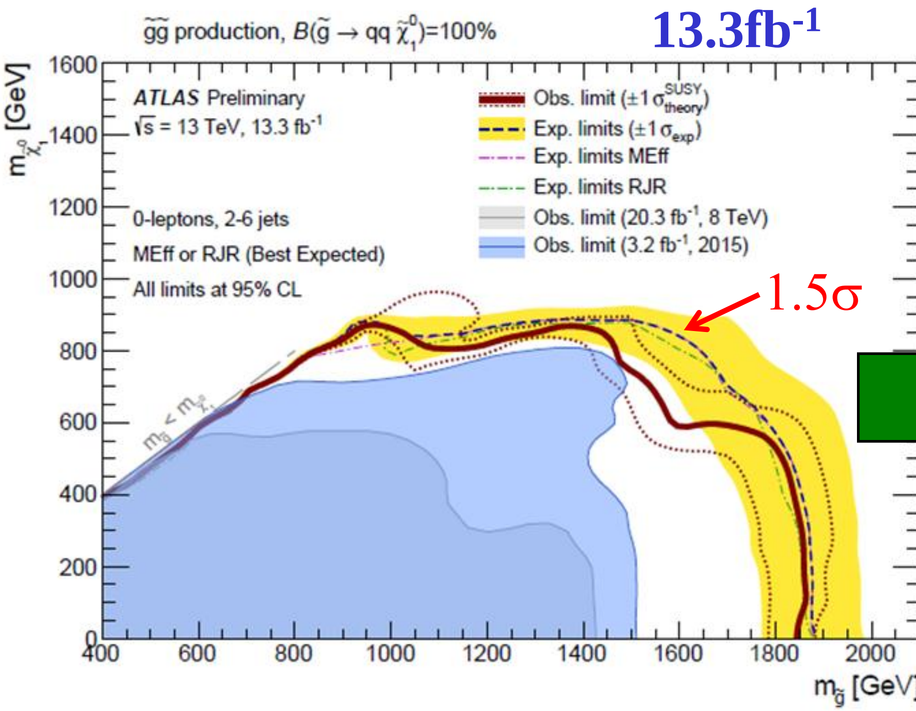
Measured M_W/M_t and EW fit with M_H

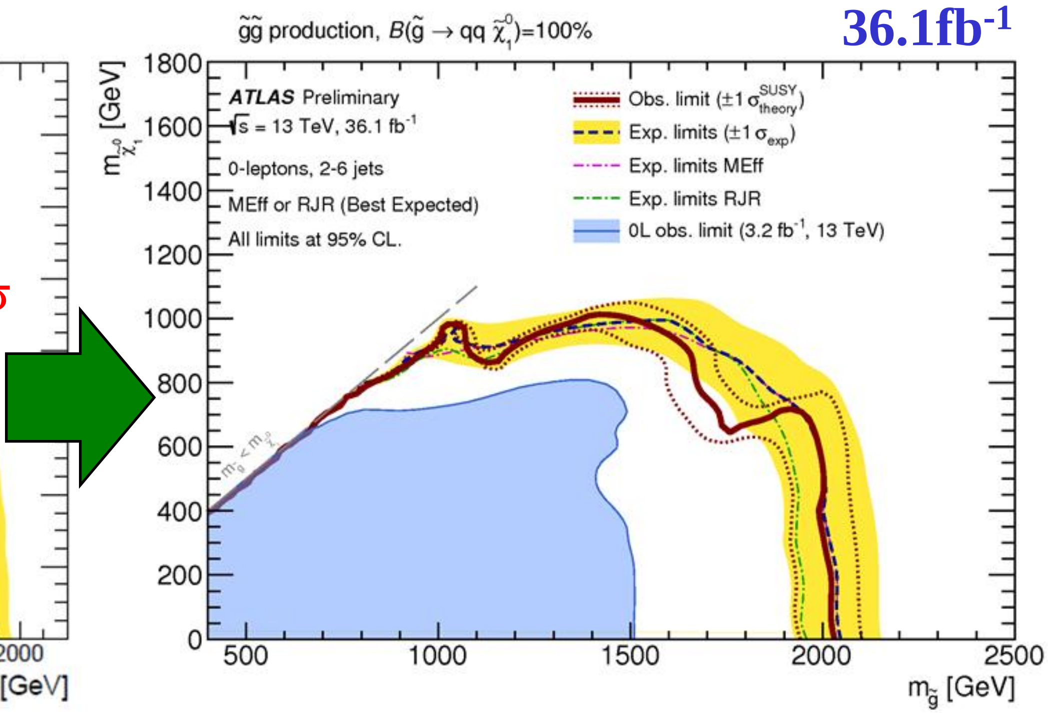


SUSY search

- Final state: 0-lepton + jets + E_t^{miss} (ATLAS-CONF-2017-022)
- Search for pair production of squark/gluino
- 1.5σ excess at $m(\tilde{g})$=1.6TeV and $m(\tilde{\chi}_1^0)$=800GeV in gluino pair production.
- The excess became smaller in the latest result.

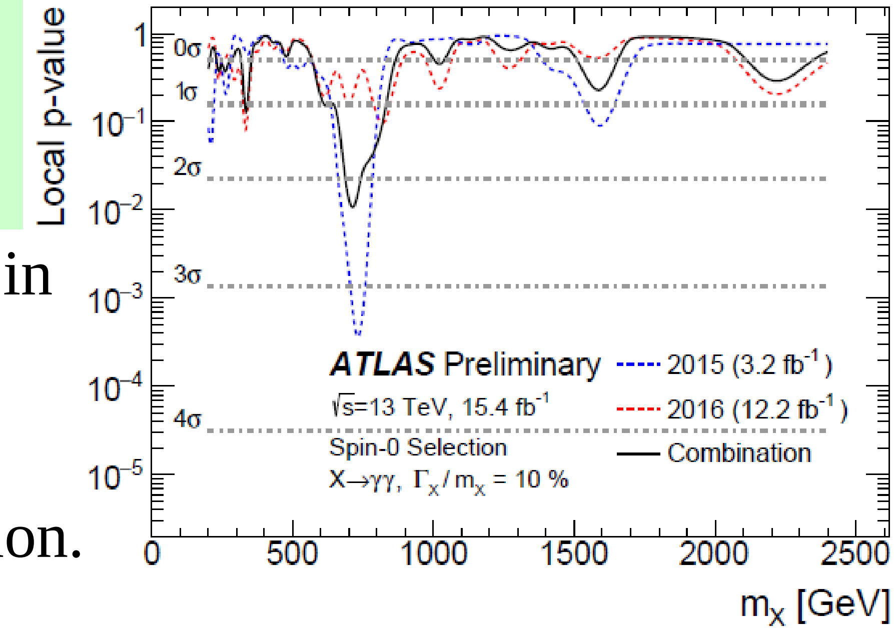




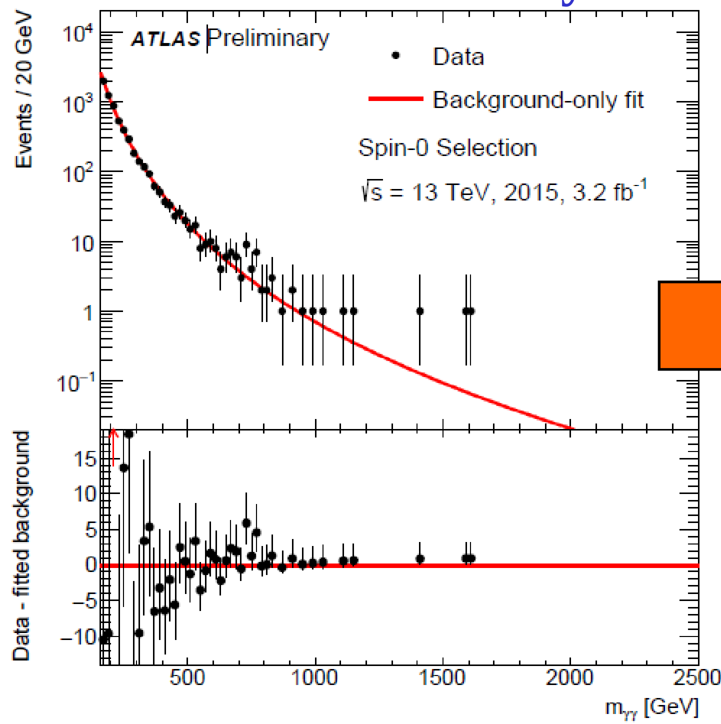


Diphoton resonance

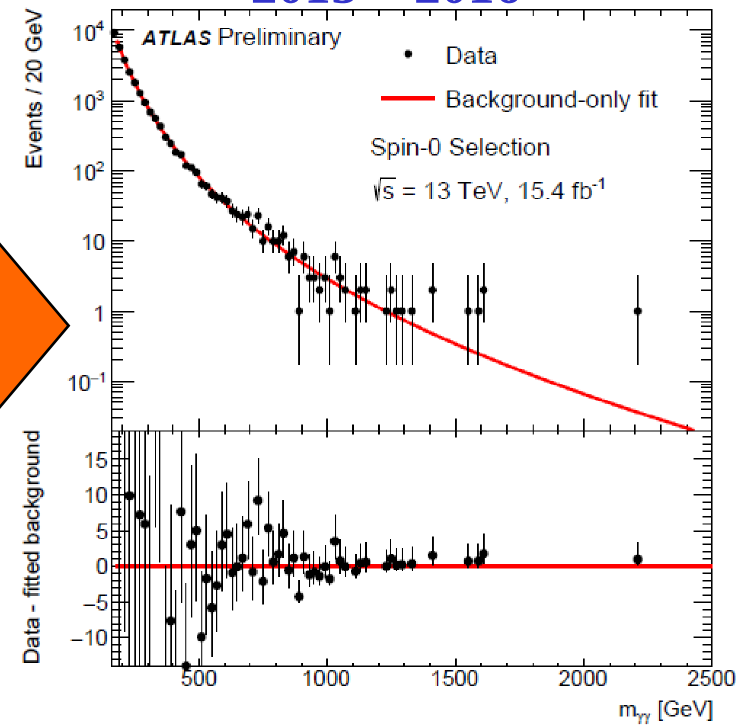
- An excess was observed at 750 GeV in diphoton resonance search in 2015.
- But…, the peak disappeared in 2016.
- Considered due to statistical fluctuation.
- ATLAS-CONF2016-059



2015 only

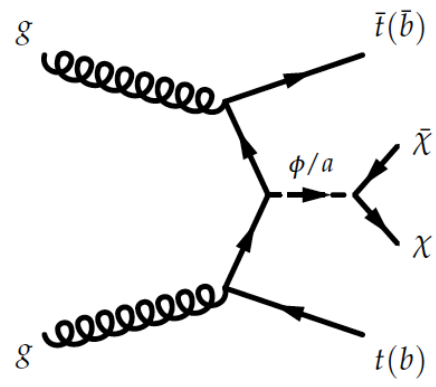


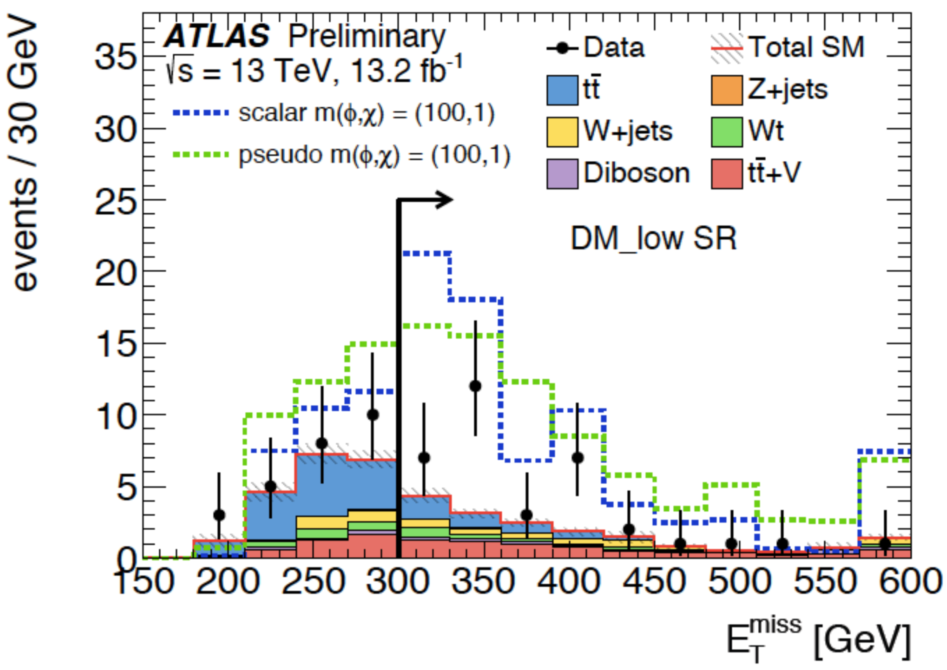
2015 + 2016

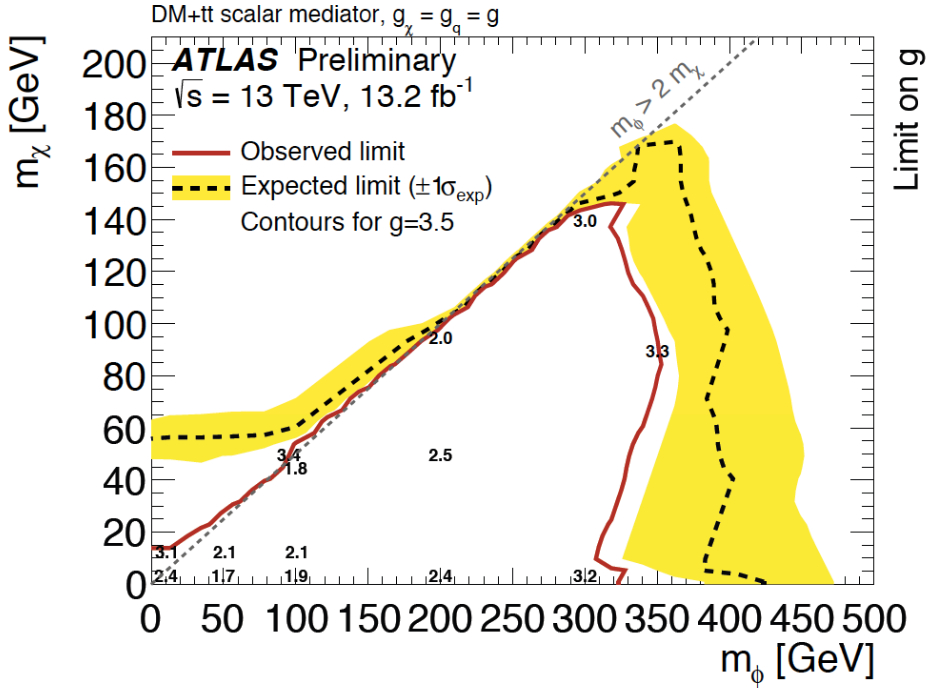


Dark matter + heavy flavour

- Final states: dark matter + heavy flavour
- 3.3 sigma excess was observed in 13 fb^{-1} in DM with two top quarks.
- No update in Moriond and looking forward to new results.



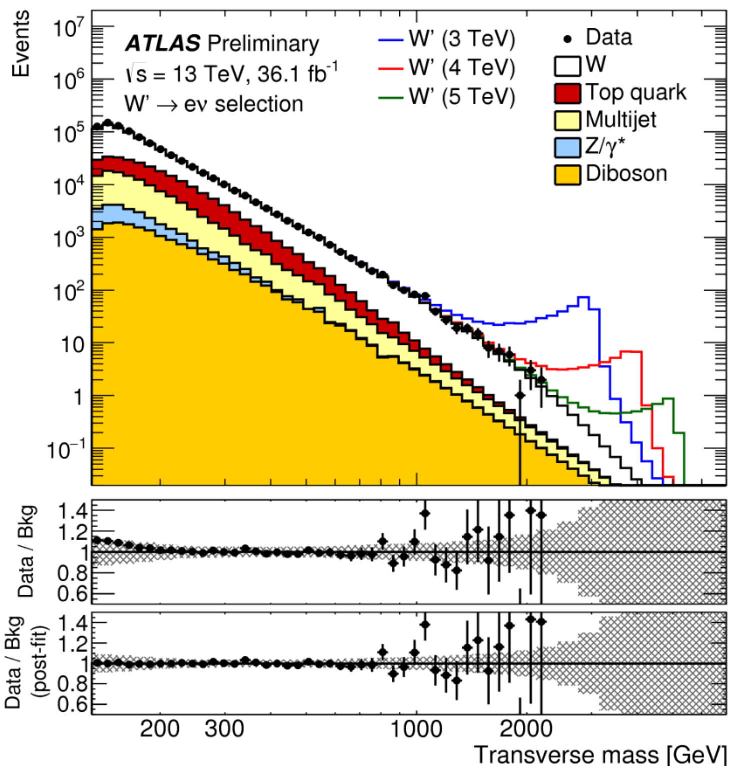




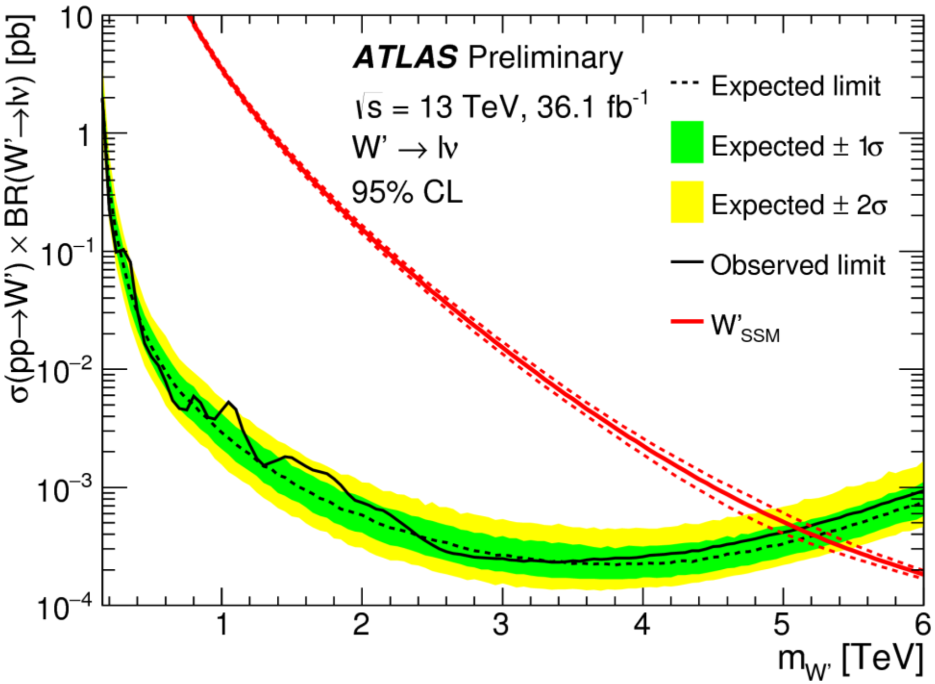
Search for W’ (New)

- Search for W’→lv
- The mass limit is improved a lot from Run-1 with 13 TeV colliding energy (ATLAS-CONF-2017-016)
- Run-1: 3.2 TeV → Run-2: 5.22 TeV (in SSM)

Transverse mass in electron mode



Mass limit of W’ on cross-section



Prospects toward HL-LHC

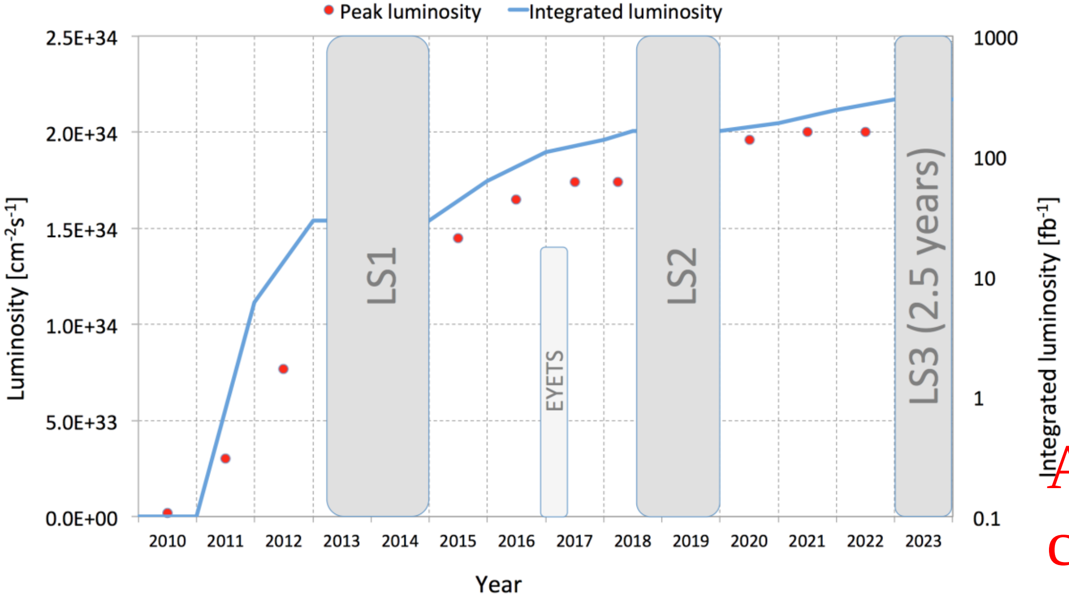
From LHC to HL-LHC

LHC will be upgraded to High-Luminosity (HL-) LHC after stopping the operation in the end of 2022.

Condition at HL-LHC

LHC design value

- Ins. lumi.: up to $7.5 \times 10^{34} cm^{-2}s^{-1}$ — x7.5 → $1 \times 10^{34} cm^{-2}s^{-1}$
- Int. lumi.: $3000 fb^{-1}$ — x10 → $300 fb^{-1}$
- # of pileup: 200 — x9 → 23



ATLAS will also be upgrade to cope with high lumi. at HL-LHC.

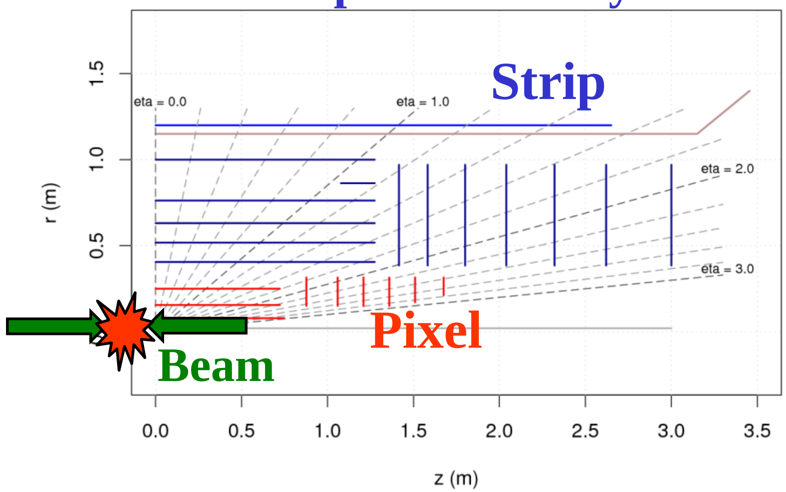
ATLAS Phase-II upgrade

- Inner detector (PIX, SCT, TRT) → Replaced by silicon detectors (ITK: Inner TracKer)
- EM calorimeter
- HD calorimeter
- Muon detector

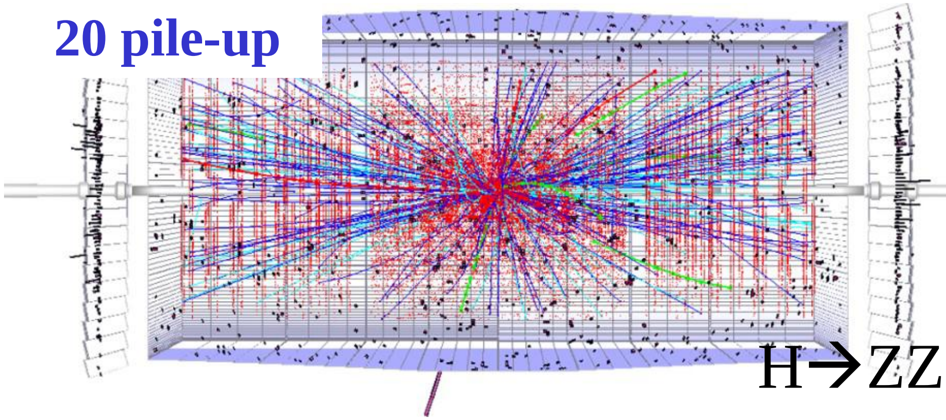
(EM calorimeter, HD calorimeter, Muon detector:) New front-end and back-end readout

Replacement of the inner detector by ITK is one of the biggest challanges in ATLAS upgrade for HL-LHC.

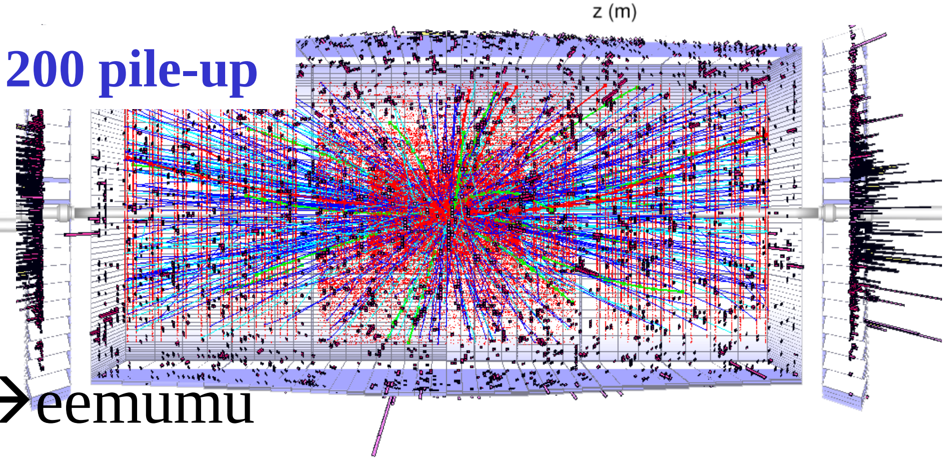
Example of ITK layout



20 pile-up



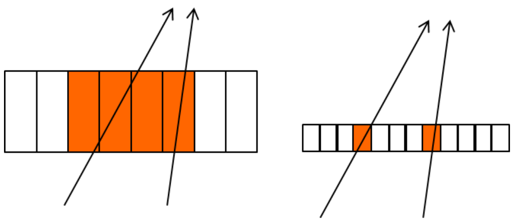
200 pile-up



H→ZZ→eemumu

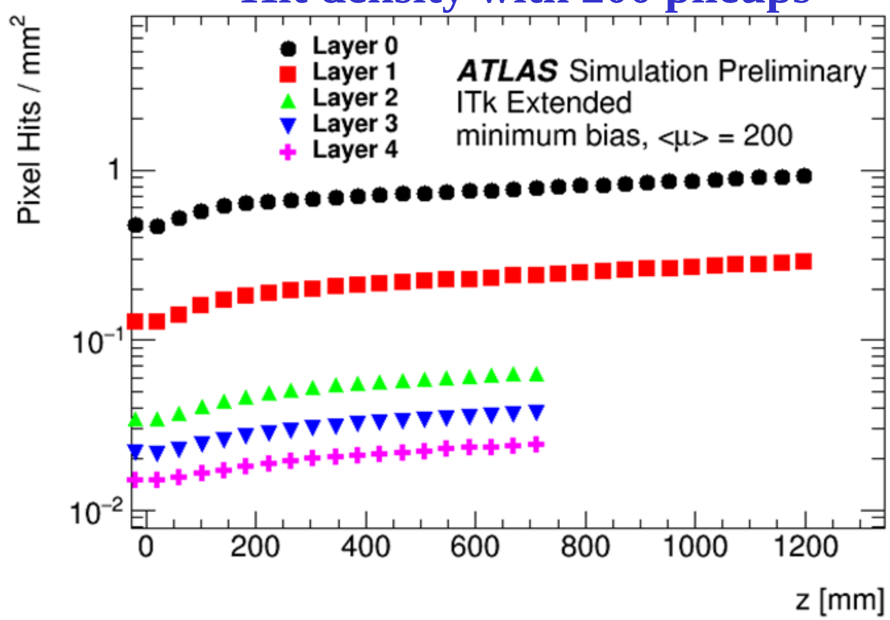
ITK-Pixel (overview)

- Required radiation tolerance: 2×10^{16} 1MeV n_{eq}/cm^2
  - ➢ 4 times larger than LHC
- The sensors is designed to have fine pixel pitch and thin thickness to work in high pileup condition.
  - Pixel size (um^2): 50 x 250 → x 0.2 → 50 x 50
  - Thickness (um): 200 → x 0.75 → 150



Sensor with fine pixel pitch and high radiation tolerance is the most important development items.

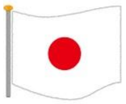
Hit density with 200 pileups



Sensor candidate

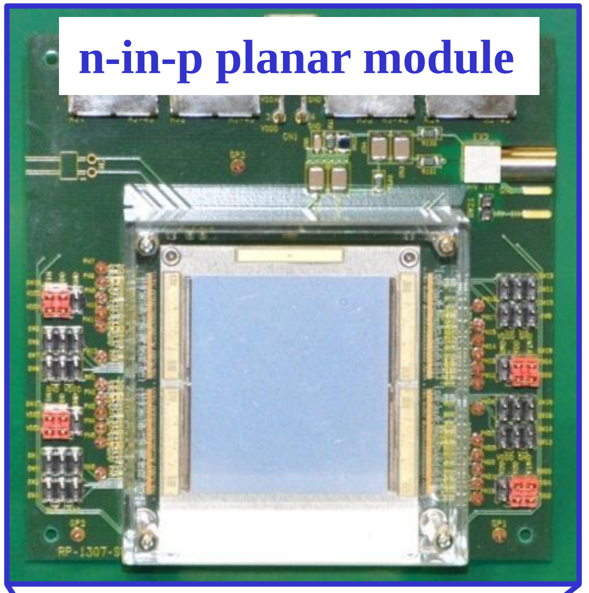
3D CMOS Diamond

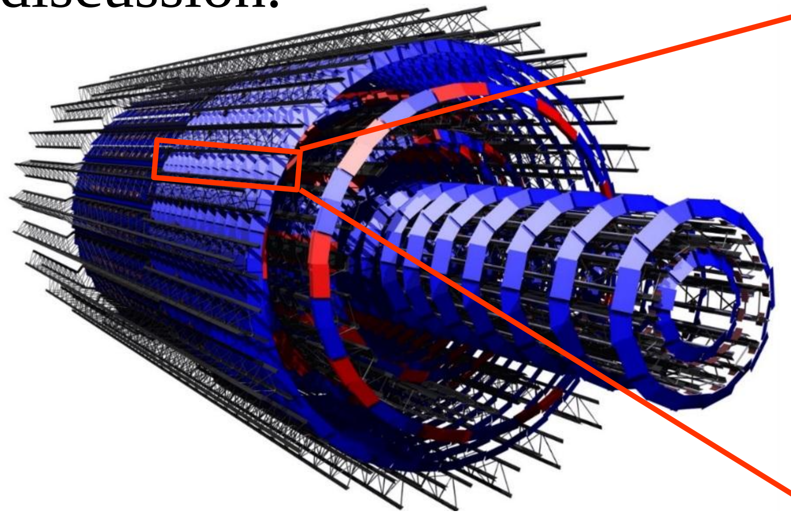
n-in-n planar n-in-p planar

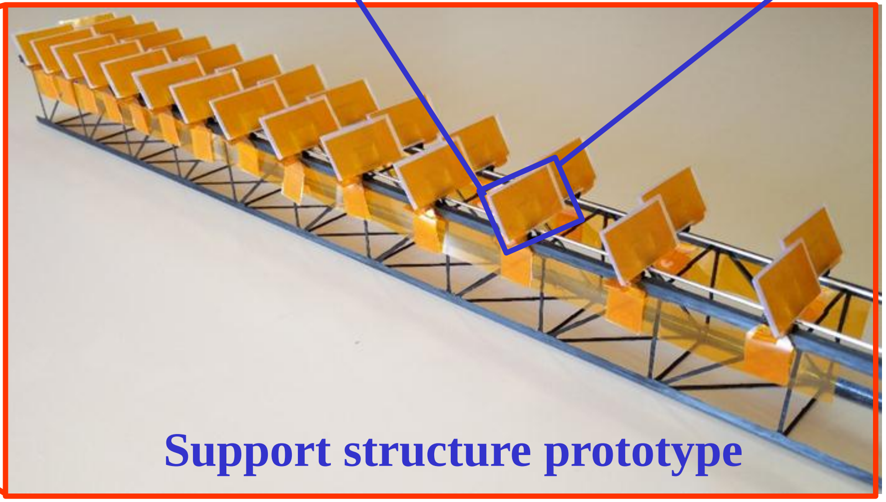


ITK-Pixel (module/loading)

- ITK-Pixel consists of ~6000 modules for 5 barrel layers. (IBL: ~400 modules)
- Japan plans to produce ~2000 modules (~30%).
- TDR will be submitted in the end of 2017.
- The preproduction of the modules will start in ~2018.
- The way of loading modules (layout) is still under discussion.







ITK-Strip (overview)

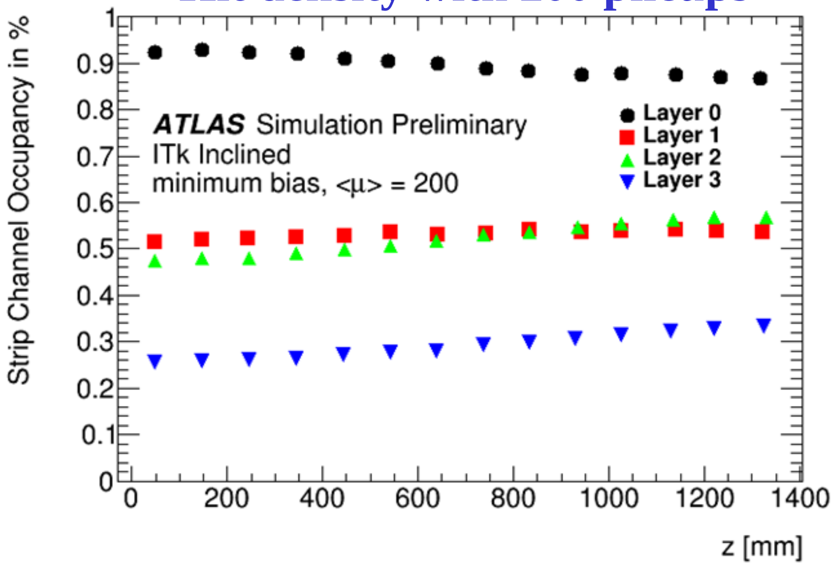
- Required radiation tolerance: 2×10^{15} 1MeV n_{eq}/cm^2
- The sensor must be fine pitch to work in high pileup condition.

Inner layer
- Strip pitch (um): 80 → 74.5
- Strip length (cm): 12.8 → (x ~ 0.2) 2.4 (outer layer: 4.8)

- Sensor coverage: 193m^2(current ATLAS SCT: 61m^2)

→ Production and construction are big deal.

Hit density with 200 pileups

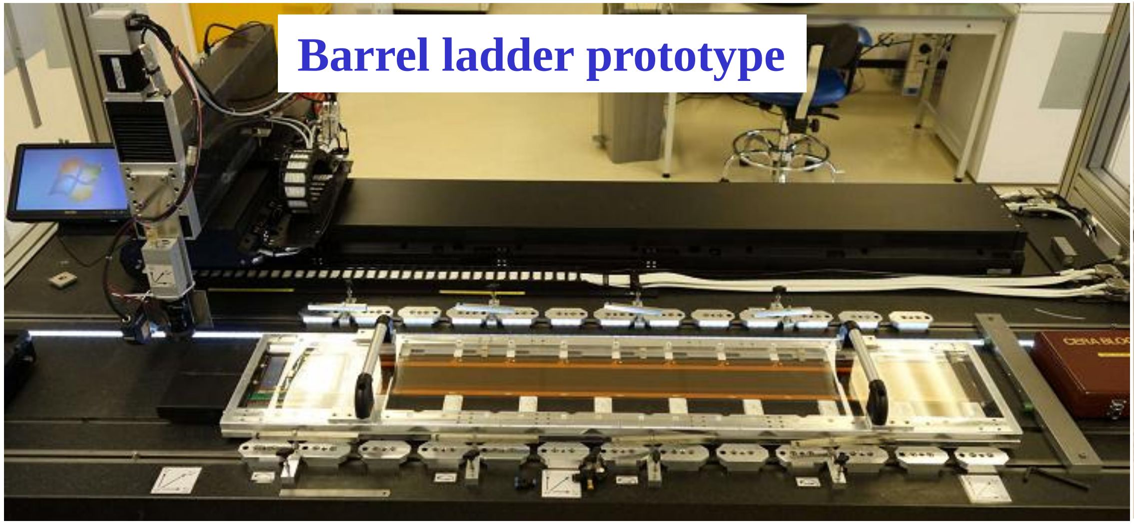


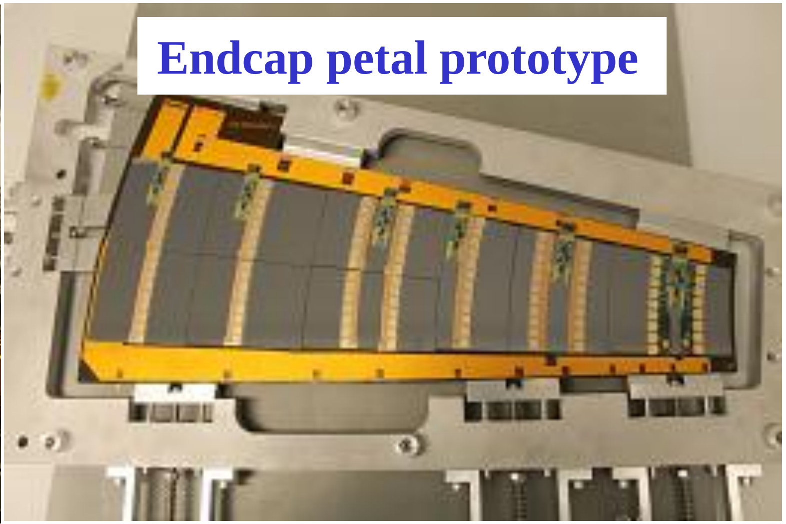
Key technology

- Senor with fine pitch and high radiation tolerance
- Large size sensor ladder with low material budget

ITK-Strip (ladder)

- ITK-Strip needs ~400 ladders for both barrel and endcap with 18k modules.
  - Japan will provide sensors in collaboration with HPK.
- A barrel stave consists of 12 modules attached on PCB directly.
- The same design is used also for endcap, and 400 petals are used to construct 2 endcaps of 6 layers.
- This design can realize low material budget with advanced technology.



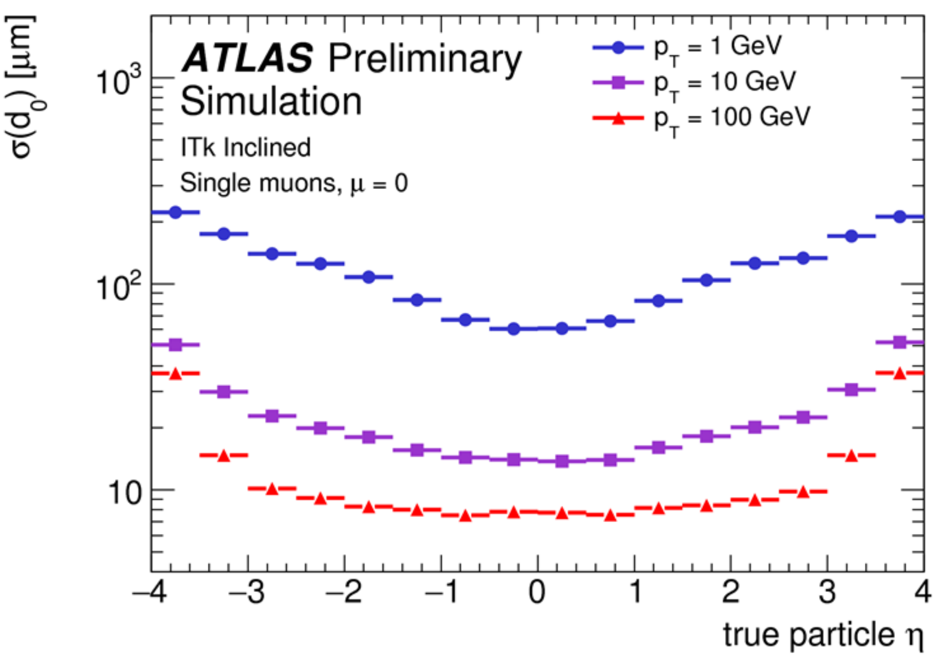


Tracking performance with ITK

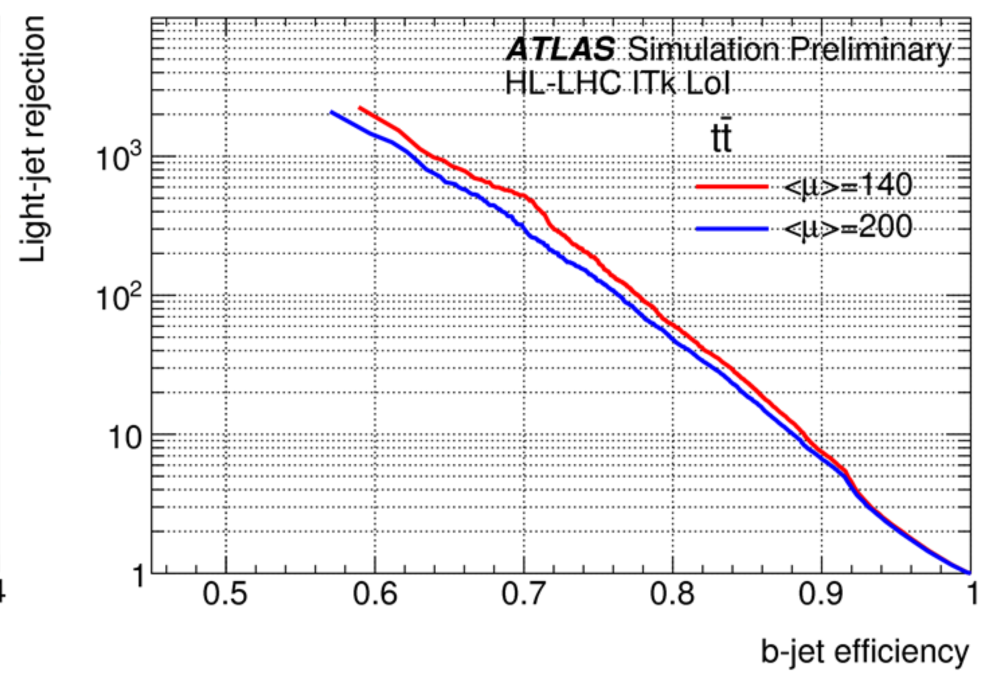
The better or similar impact parameter resolution and b-tagging performance are expected even with high pile-up condition.

→ Good tracking performance can be kept at HL-LHC thanks to new technologies used in ITK.

d0 resolution with ITK

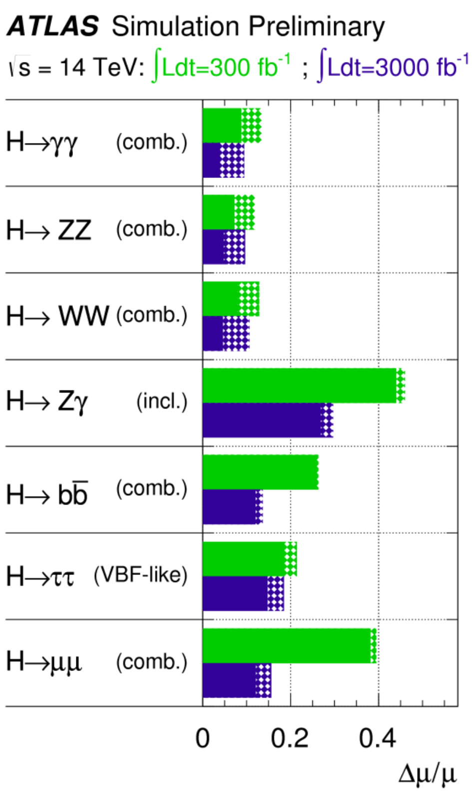


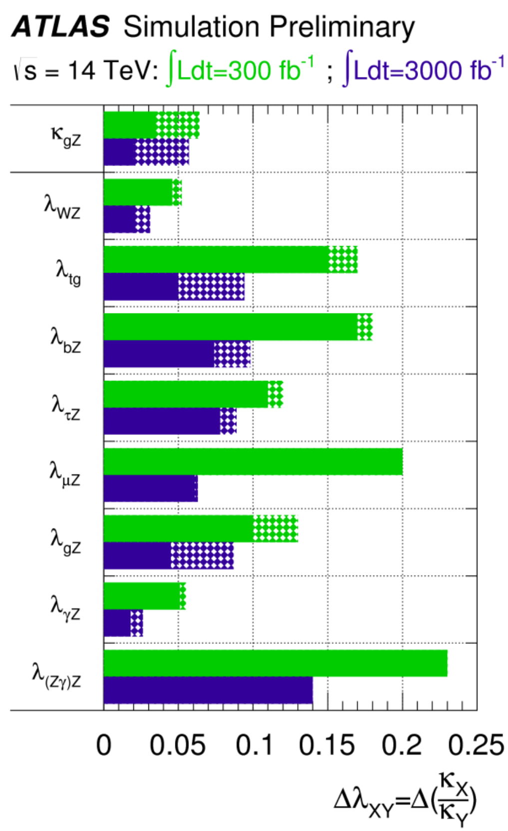
Light-jet rejection v.s. b-tag eff. with ITK



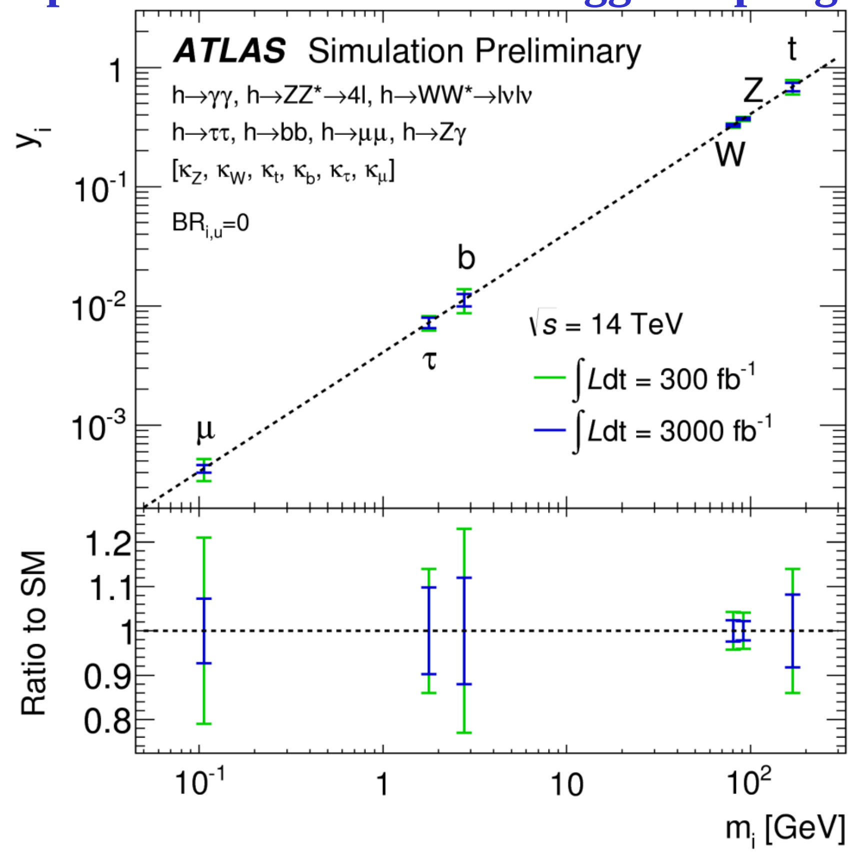
Expected physics performance (Higgs)

- The signal strength will be improved significantly, compared with results at LHC (ATL-PHYS-PUB-2014-016).
- The most of relative coupling ratio will be determined in accuracy of less than 10%.



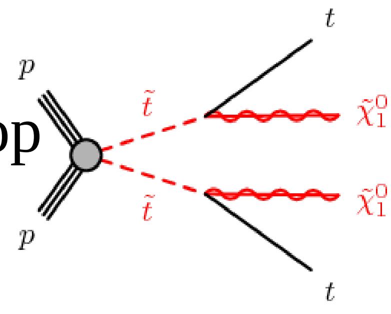


Expected uncertainties on Higgs couplings

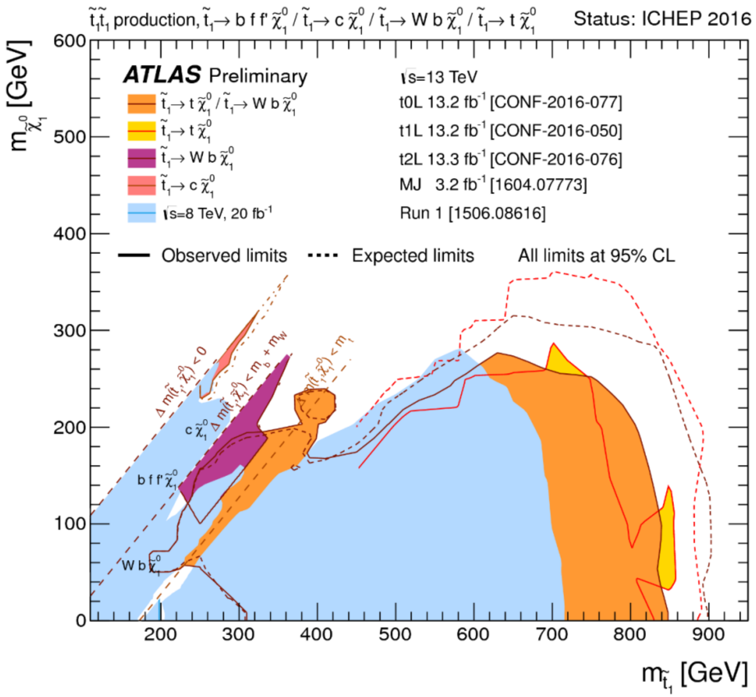


Expected performance (SUSY-1)

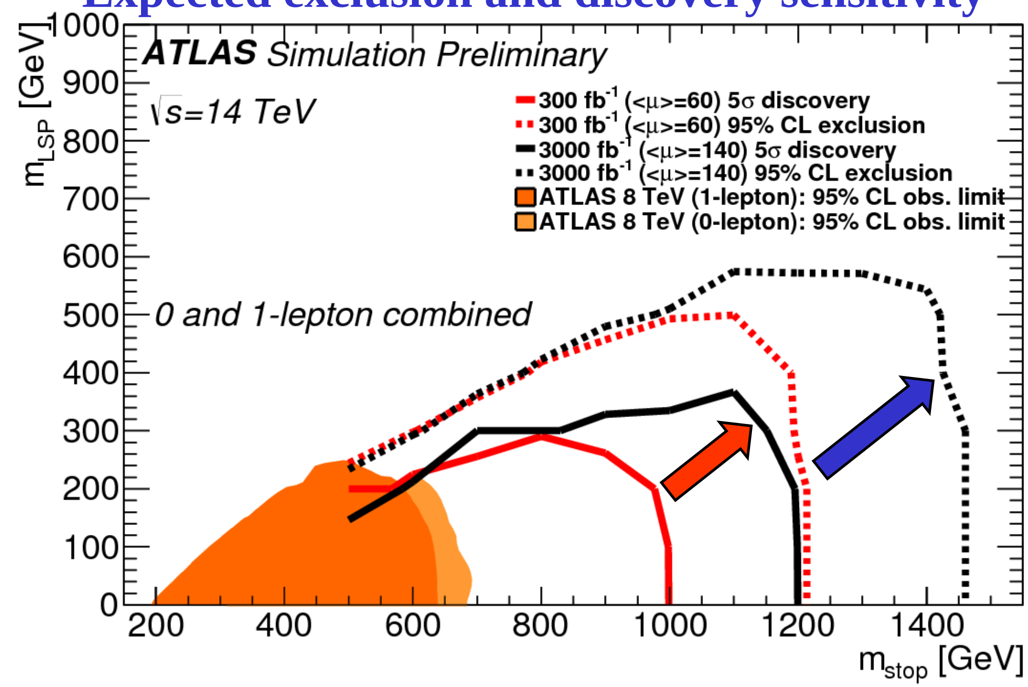
- Scalar top is expected to be light (<1 TeV) with Higgs mass radiative correction.
- HL-LHC has sensitivity to stop mass >1.2 TeV with a stop decaying to a neutralino-1 and top in simplified model.
- ATL-PHYS-PUB-2013-011.



Exclusion limit in 2016

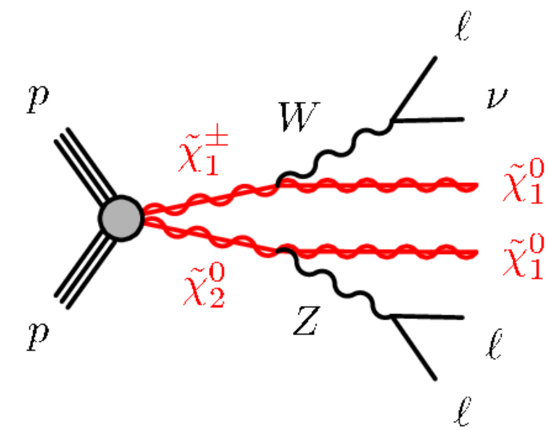


Expected exclusion and discovery sensitivity

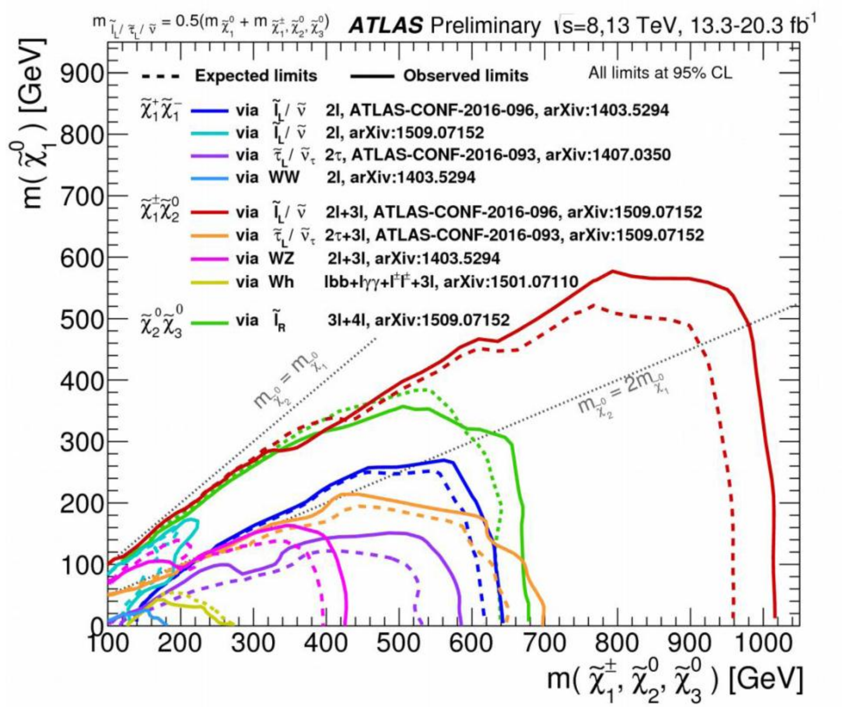


Expected performance (SUSY-2)

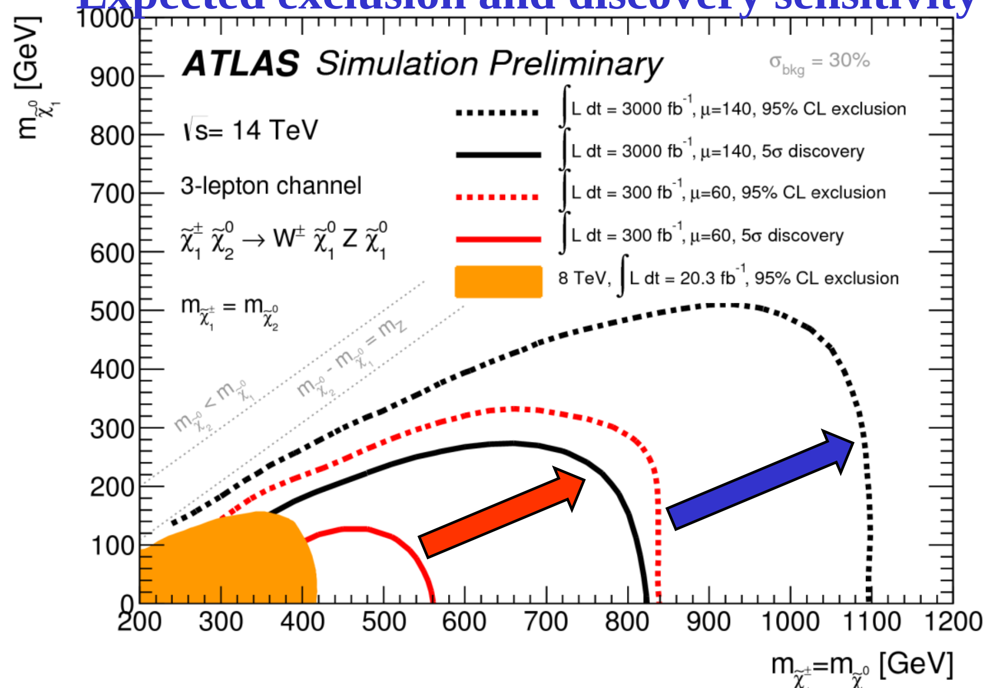
- If EW gaugino is dark matter, their mass is expected to be O(100 GeV)~O(1TeV).
- The sensitivity will be improved to ~250 GeV for neutralino and ~850 GeV for chargeno.
- ATL-PHYS-PUB-2014-010



Exclusion limit in 2016



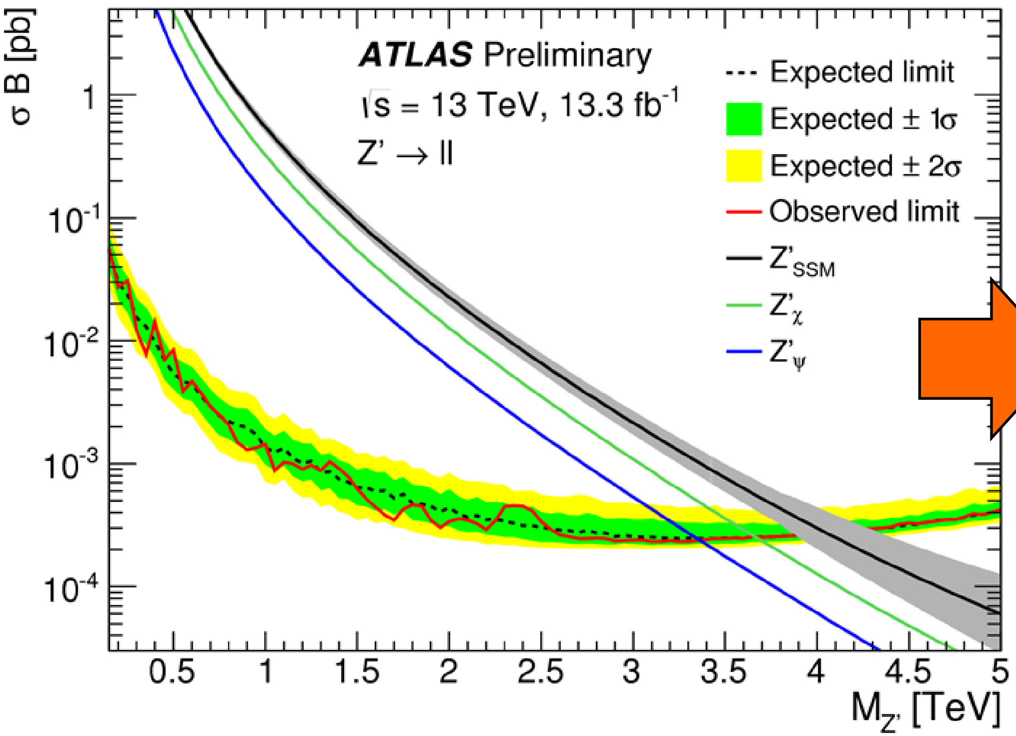
Expected exclusion and discovery sensitivity



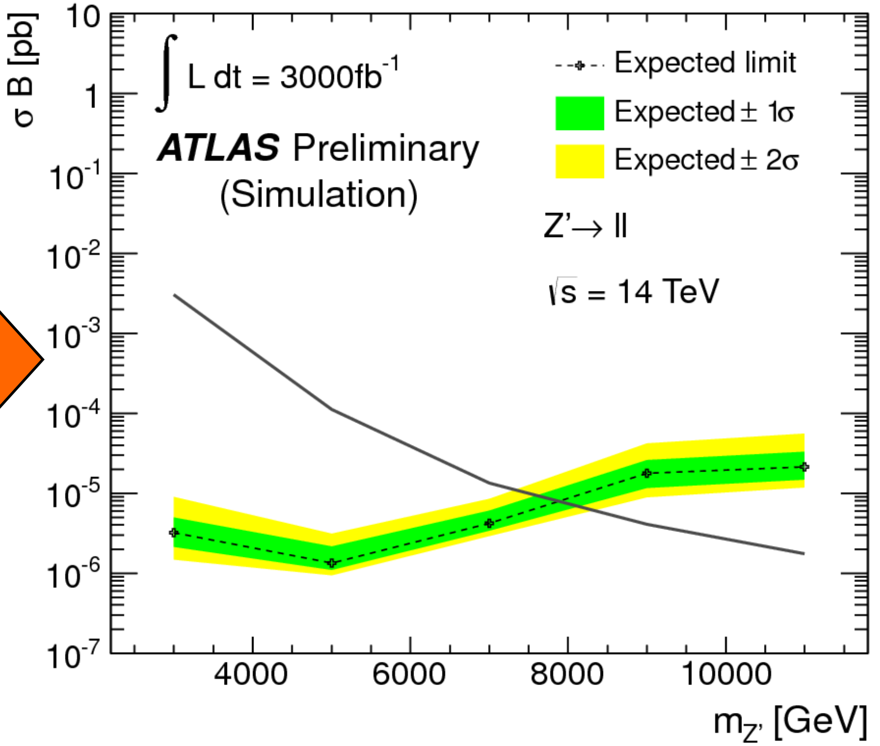
Expected physics performance (Exotic)

- HL-LHC will also improve sensitivity to exotic processes in BSM.
- ATL-PHYS-PUB-2013-003
- The studies with realistic detector configuration just started for different exotic physics modes.

13.3 fb^{-1} @13TeV



3000 fb^{-1} @14TeV



Summary & Conclusions

- ATLAS has been operated in stable condition even at higher luminosity of LHC design value.
- The tracking performance was improved significantly in Run-2 with the new innermost layer, IBL.
- A lot of physics results at 13 TeV are being published with larger integrated luminosity.
- HL-LHC is planned to start in 2026 and the integrated luminosity of 3000 fb^{-1} will be provided.
- ATLAS inner trackers will be replaced by new silicon detectors (ITK: Pixel and Strip) to cope with high luminosity at HL-LHC.
- ATLAS experiment will keep to provide hint or indication of physics beyond the standard model.