Searching for additional Higgs bosons with the ATLAS detector at the CERN LHC

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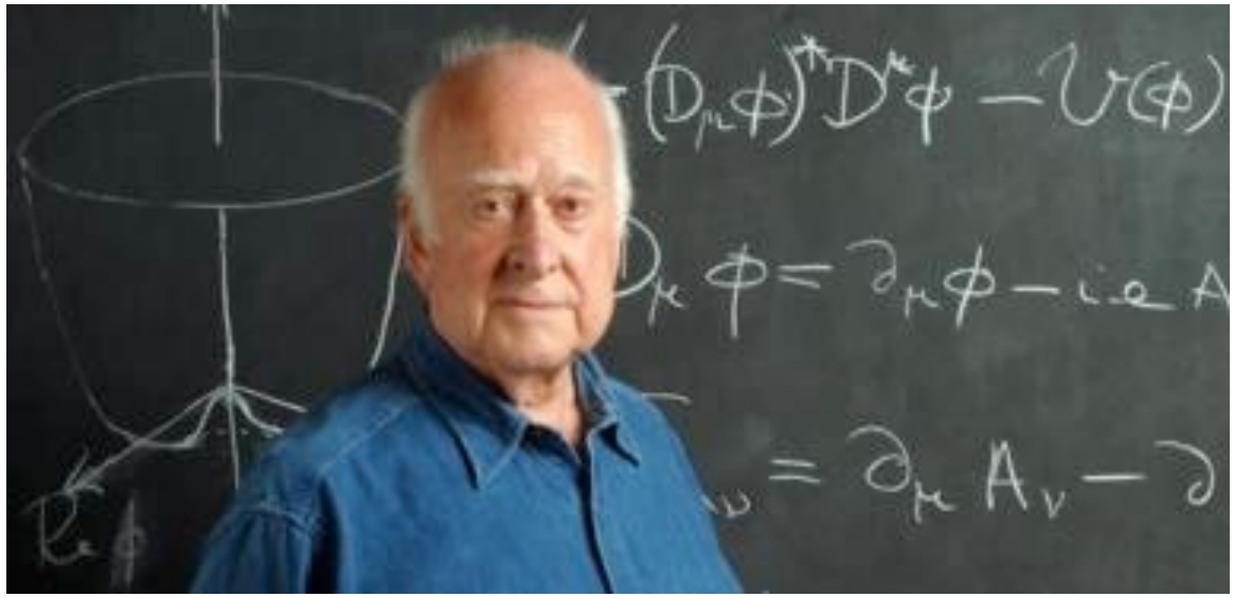
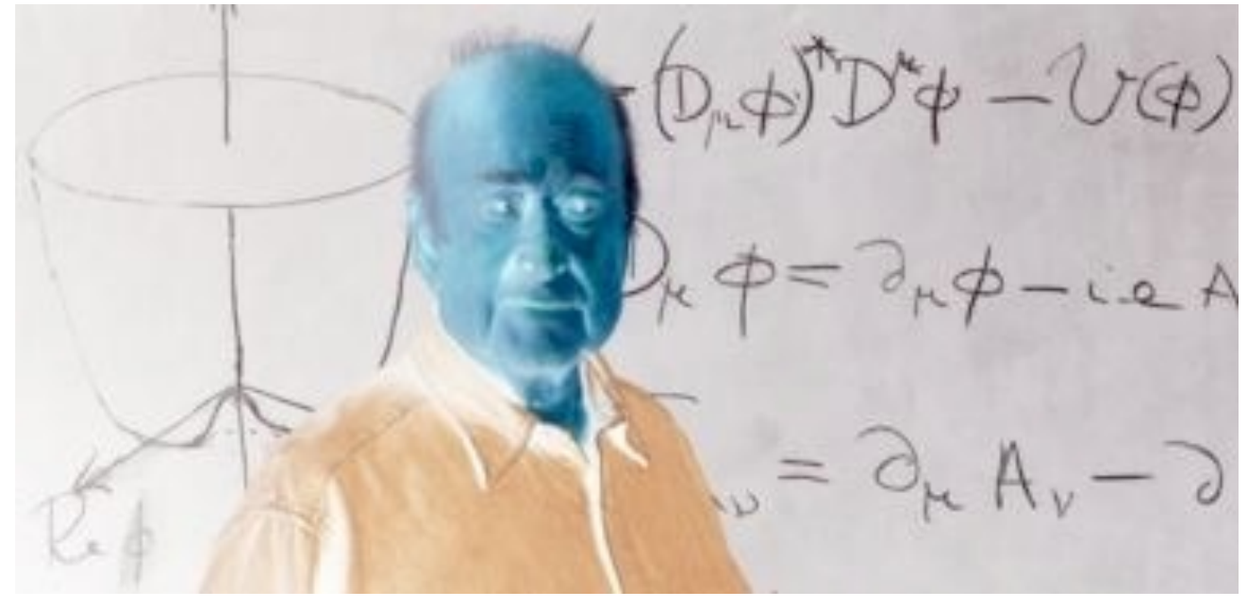
If the (light) Higgs mass is ~125 GeV, what next?



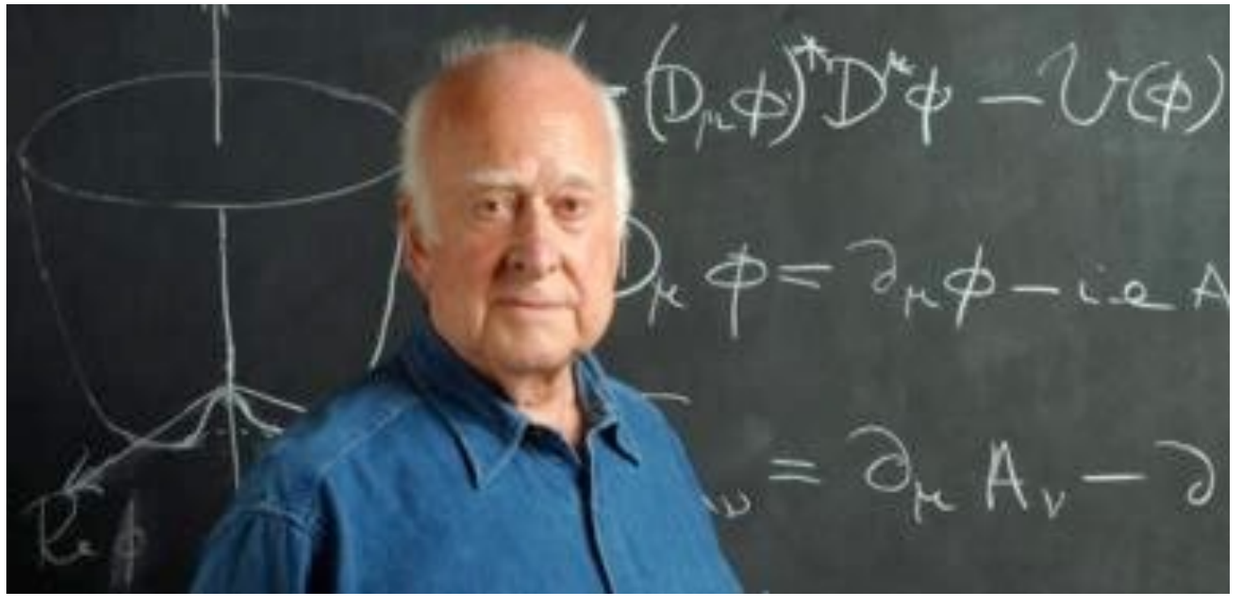
Standard Model Higgs



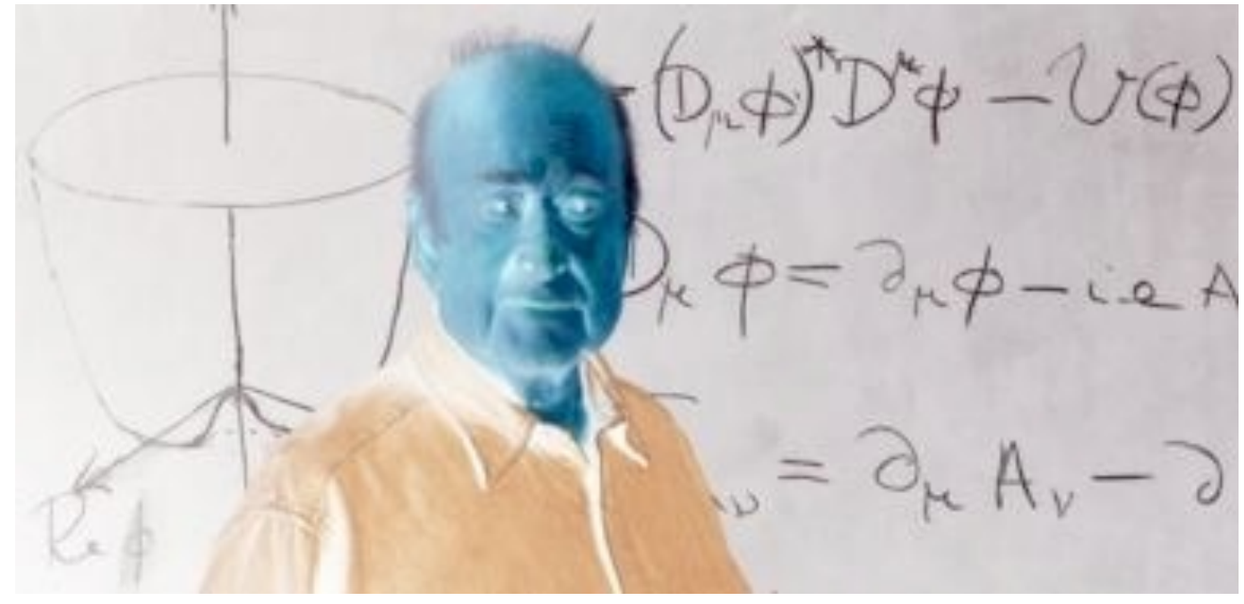
Beyond the SM Higgs

- Suppose that this is not the Standard Model Higgs…
  - Higgs with different couplings? ⇒ MSSM, Fermiophobic, Higgs impostor
  - More complicated Higgs sector? ⇒ MSSM, Doubly-charged Higgs, Composite
  - Light scalar Higgs? ⇒ NMSSM
  - Hidden Higgs sector? ⇒ Higgs to long-lived particles
- Thankfully many of these scenarios are compatible with a 125 GeV Higgs… Sadly not enough time today to discuss all of them!

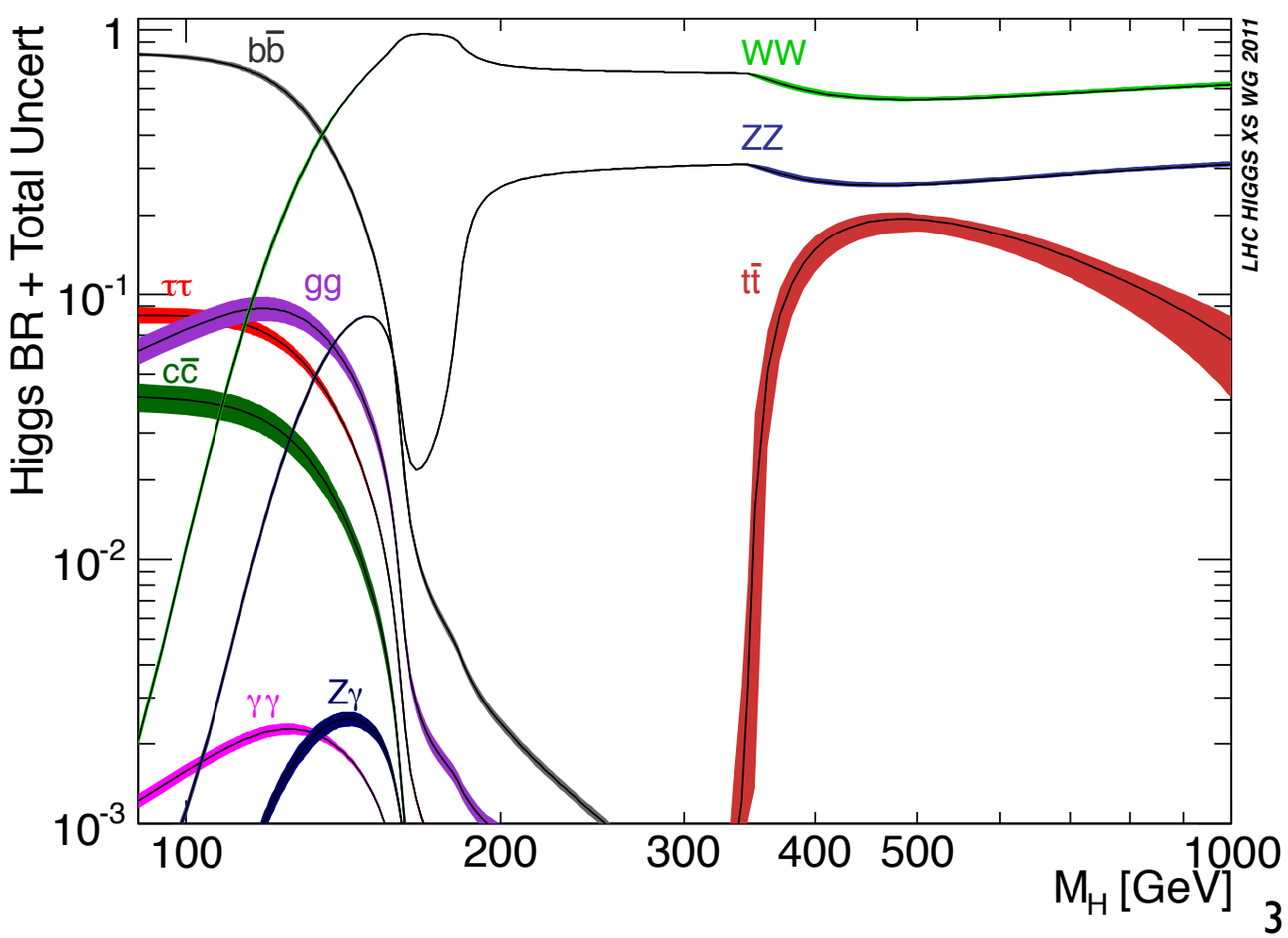
If the (light) Higgs mass is ~125 GeV, what next?

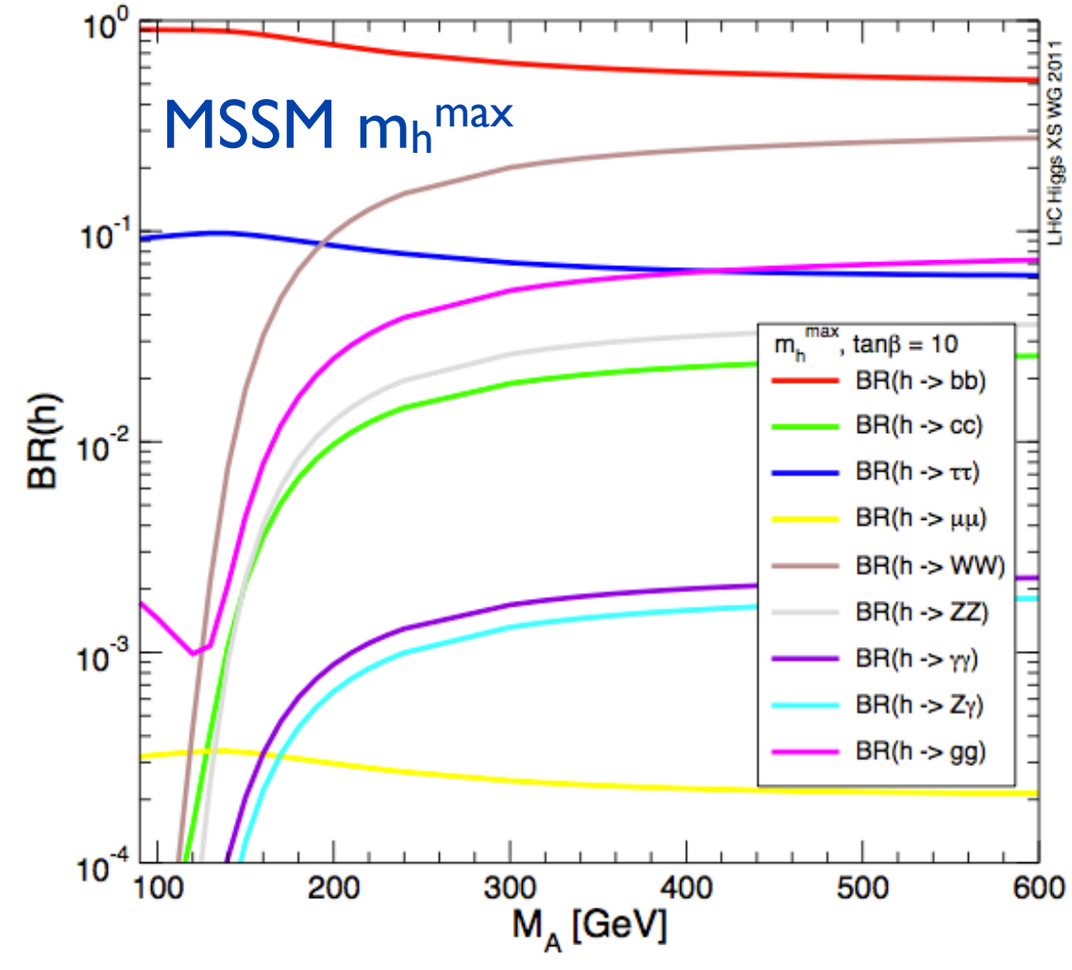


Standard Model Higgs



Beyond the SM Higgs





Generic 2HDM

- The Higgs boson with m_H = 125 GeV could be part of an extended scalar sector originating from two Higgs doublets
- Type I 2HDM: All fermions couple to just one of the Higgs doublets
- Type II 2HDM: All up-type fermions couple to one Higgs doublet and all down-type fermions couple to the other
- Lepton-specific 2HDM: All quark couplings are like in the Type I, lepton couplings are like in Type II
- Flipped 2HDM: All lepton couplings are like in the Type I, quark couplings are like in Type II

Coupling scale factor	Type I	Type II	Lepton-specific	Flipped
κ_V	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$
κ_u	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$
κ_d	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$
κ_l	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$

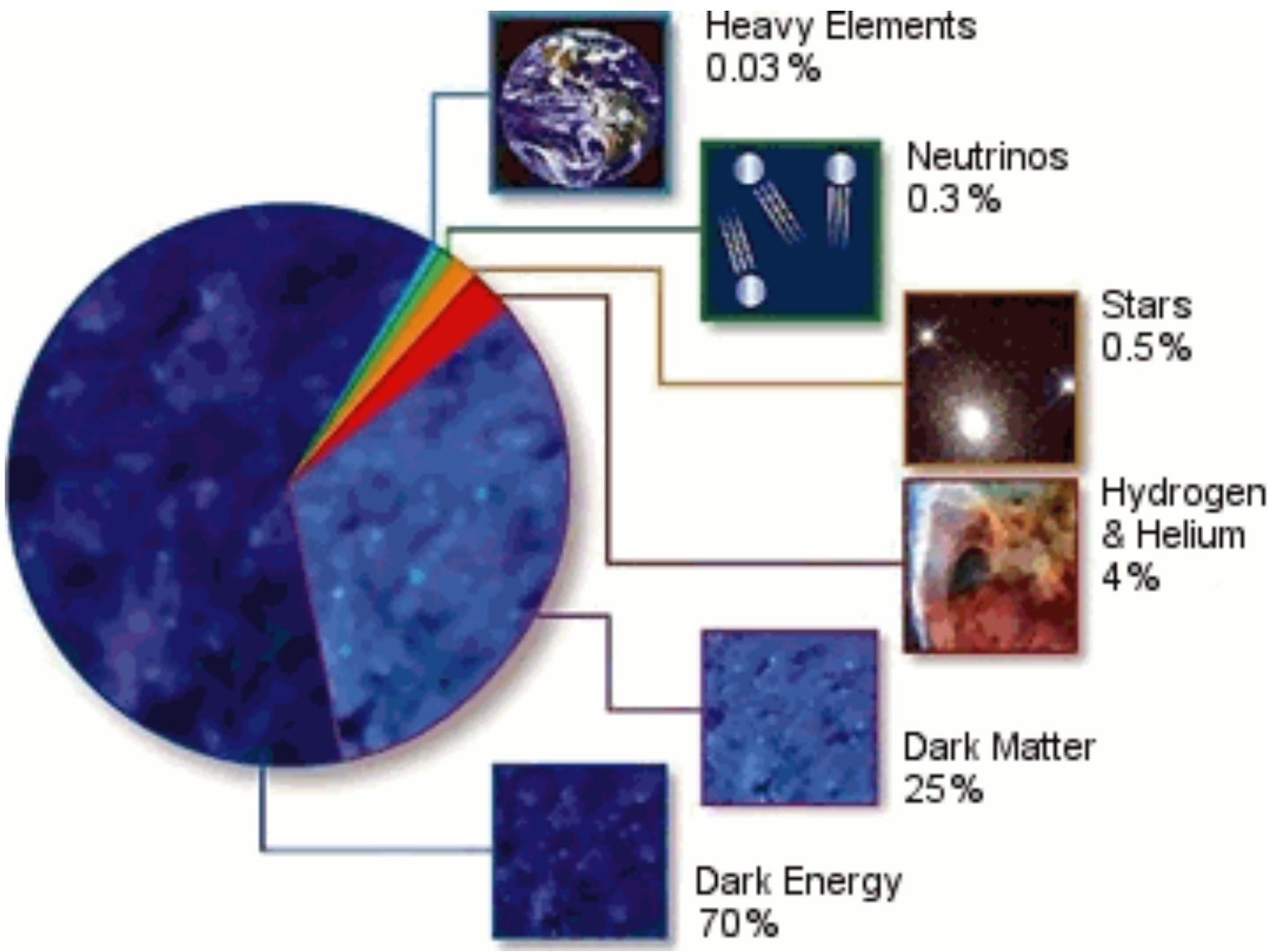
Tree-level couplings of neutral Higgs bosons to vector bosons, leptons, up-type and down-type quarks in 2HDMs

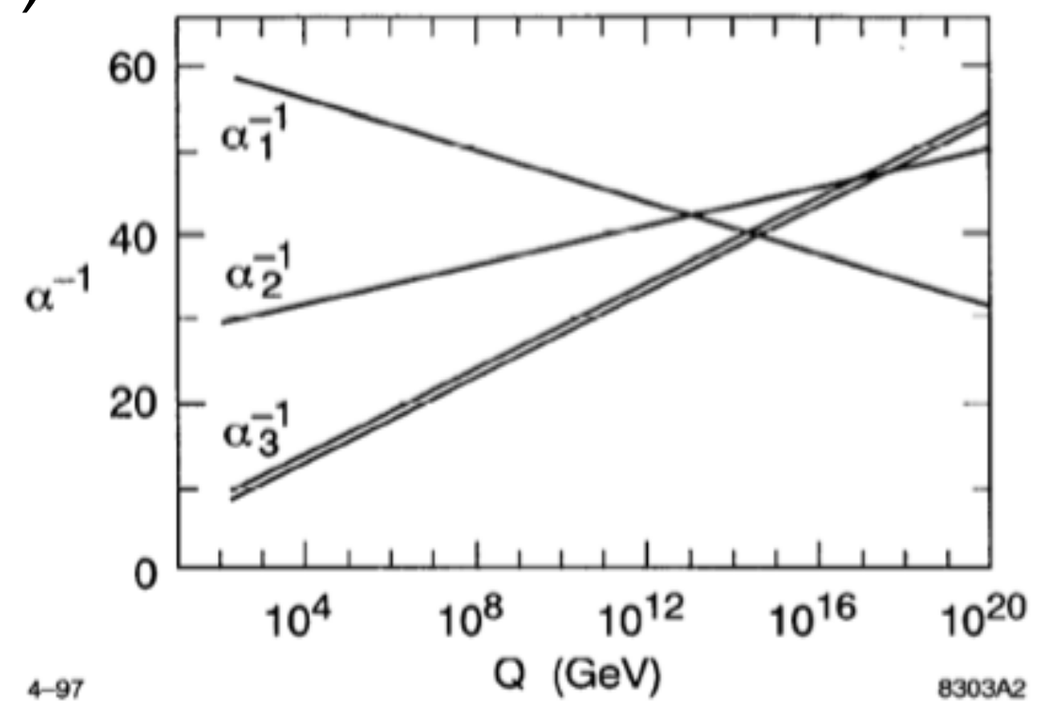
The ratio of the vacuum expectation values for the two Higgs doublets = *tan* β

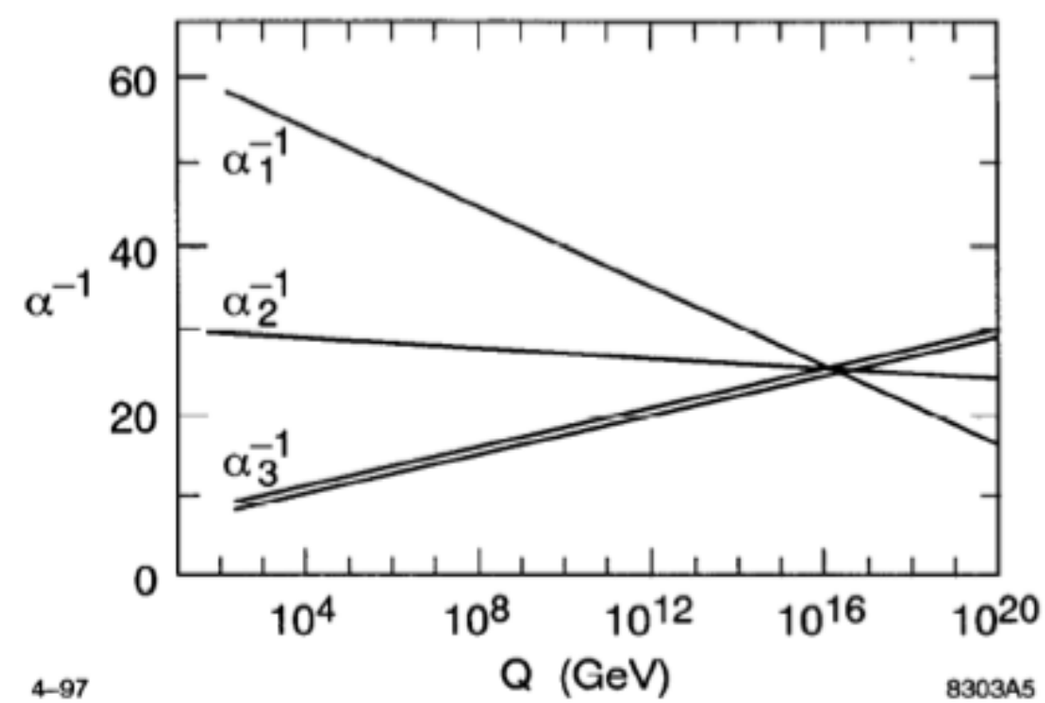
The CP-even Higgs mixing angle = α

Motivation for Supersymmetry

- Naturalness (Hierarchy Problem)
- Unification of the forces (gauge couplings)
- Provides a candidate for Dark Matter
- MSSM is a Type II 2HDM at tree level

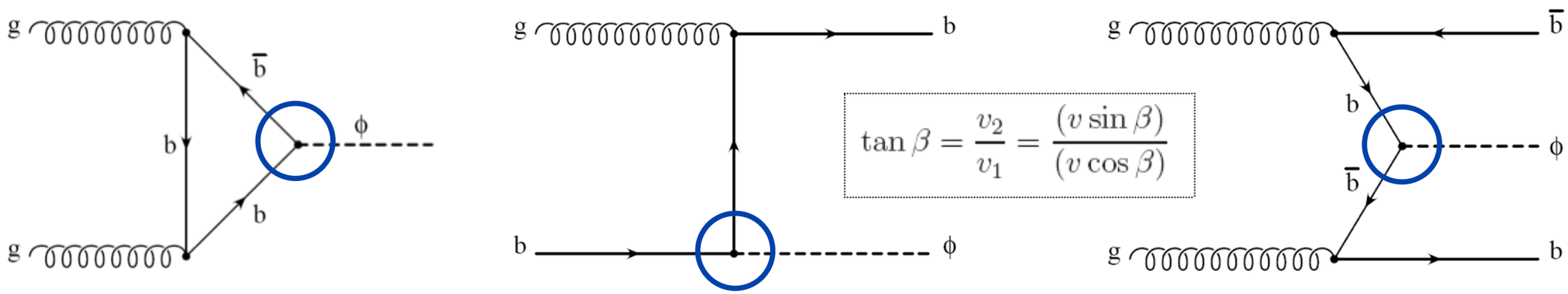






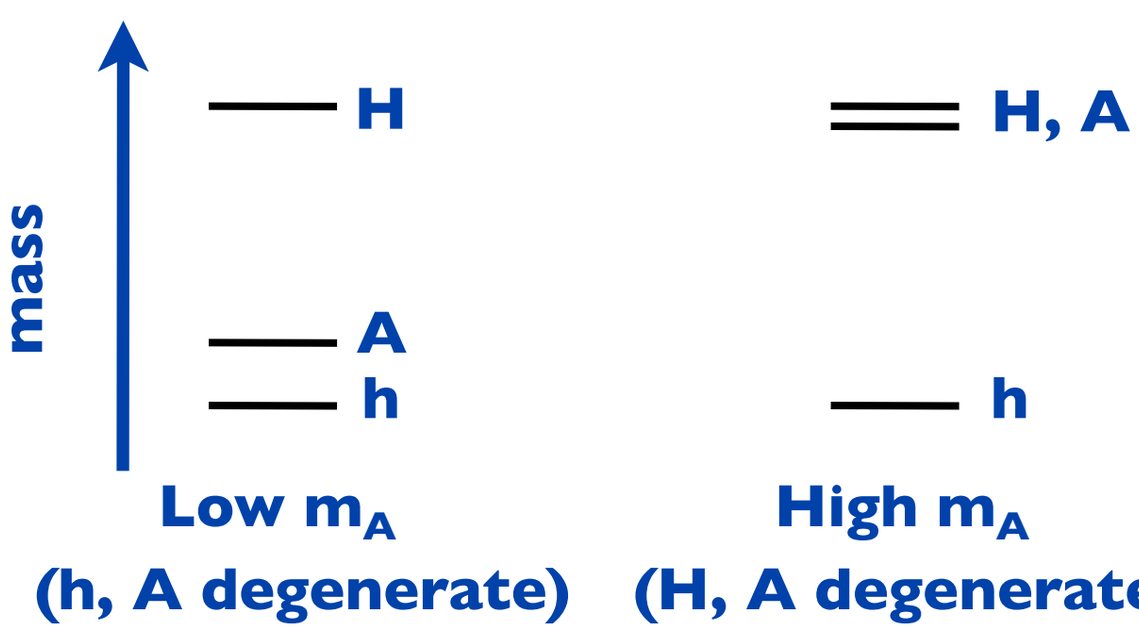
MSSM Higgs Sector

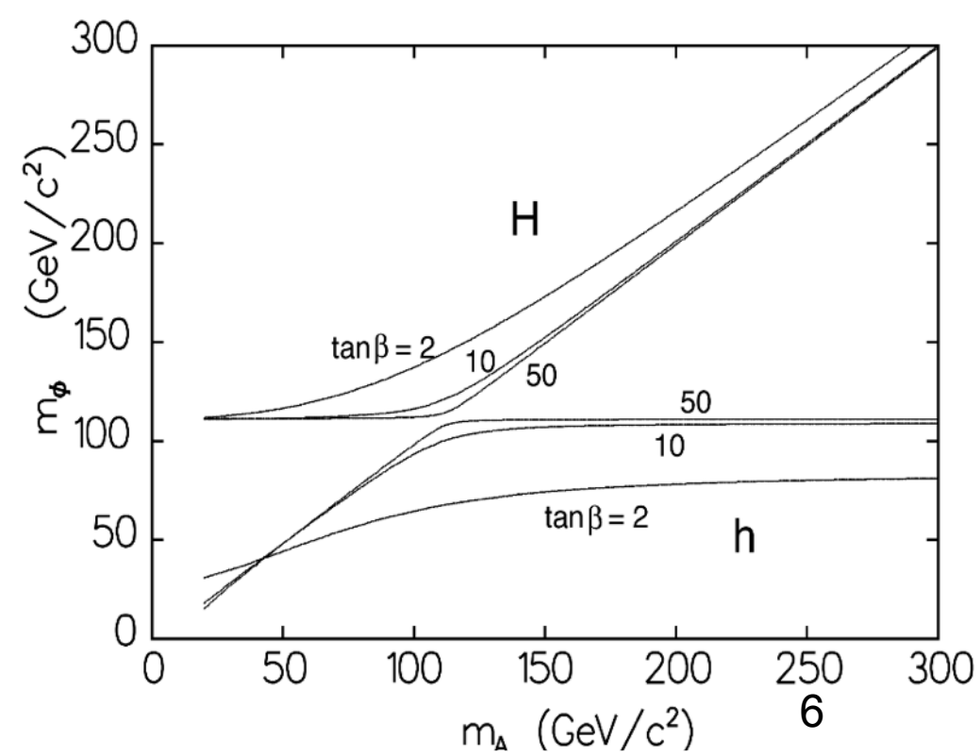
- Consider the case of an MSSM Higgs at the LHC
  - 2 Higgs doublets give rise to 5 physical Higgs bosons: h, H, A, $H^{\pm}$
  - Enhanced coupling to 3rd generation; strong coupling to down-type fermions (at large tanβ get strong enhancements to h/H/A production rates)
  - Diagrams with bbϕ vertex enhanced proportional to $\tan^2\beta$ where ϕ=h,H,A



$$\tan\beta = \frac{v_2}{v_1} = \frac{(v\sin\beta)}{(v\cos\beta)}$$

- Can parameterize the masses of the Higgs bosons with two free parameters: tanβ and m_A





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The ATLAS Experiment and the CERN Large Hadron Collider

The Large Hadron Collider (LHC) at CERN

- The world's highest-energy particle collider, just outside of Geneva, CH

Proton-proton collider

27 km in circumference

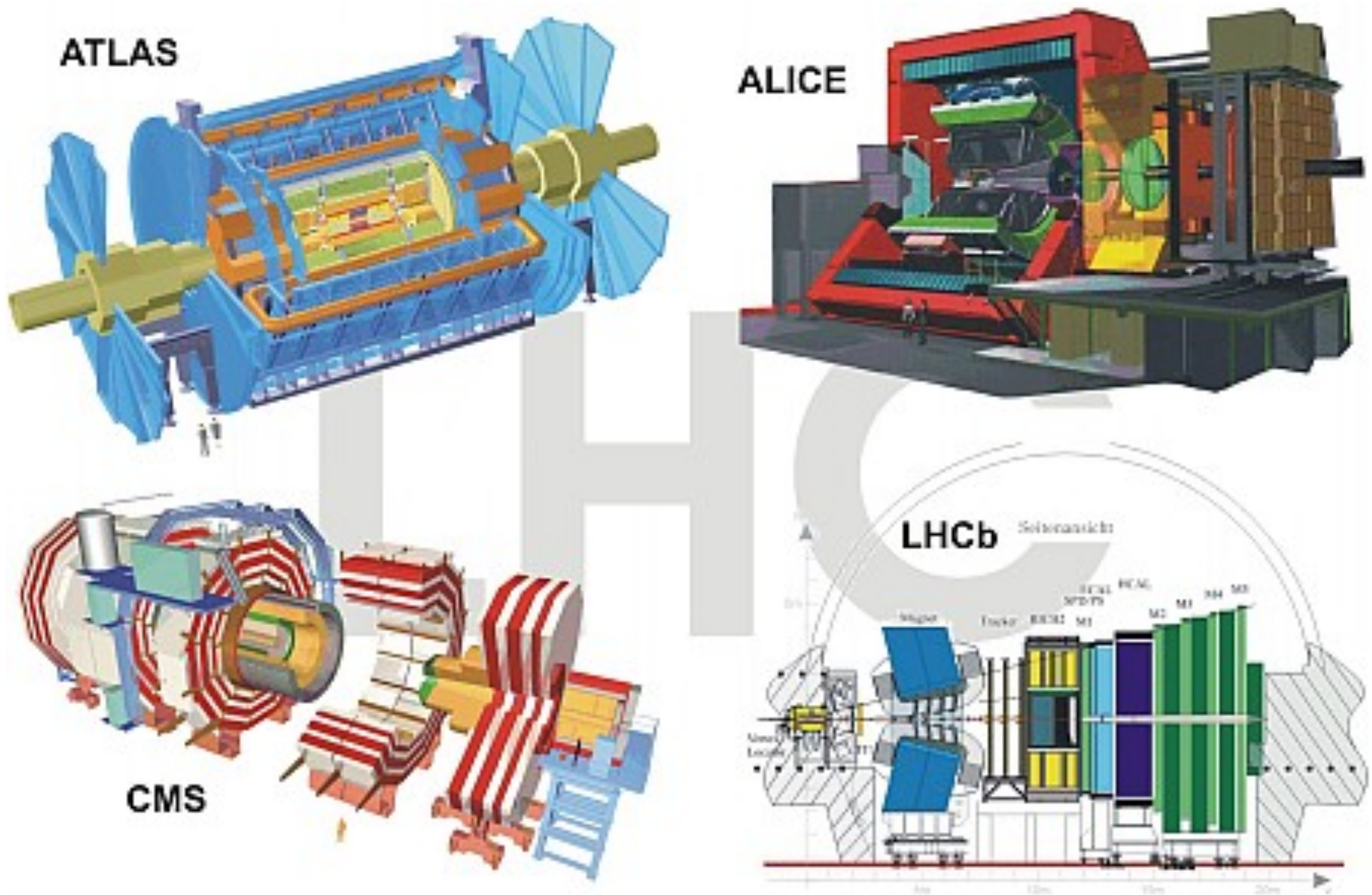
14 TeV design CME

Run-I:
7 TeV CME running in 2011
8 TeV CME running in 2012

Run-II
13 TeV CME running since 2015 (on-going)

Home to four major experiments

Major experiments at the LHC



ATLAS = A Toroidal Lhc ApparatuS
CMS = Compact Muon Solenoid

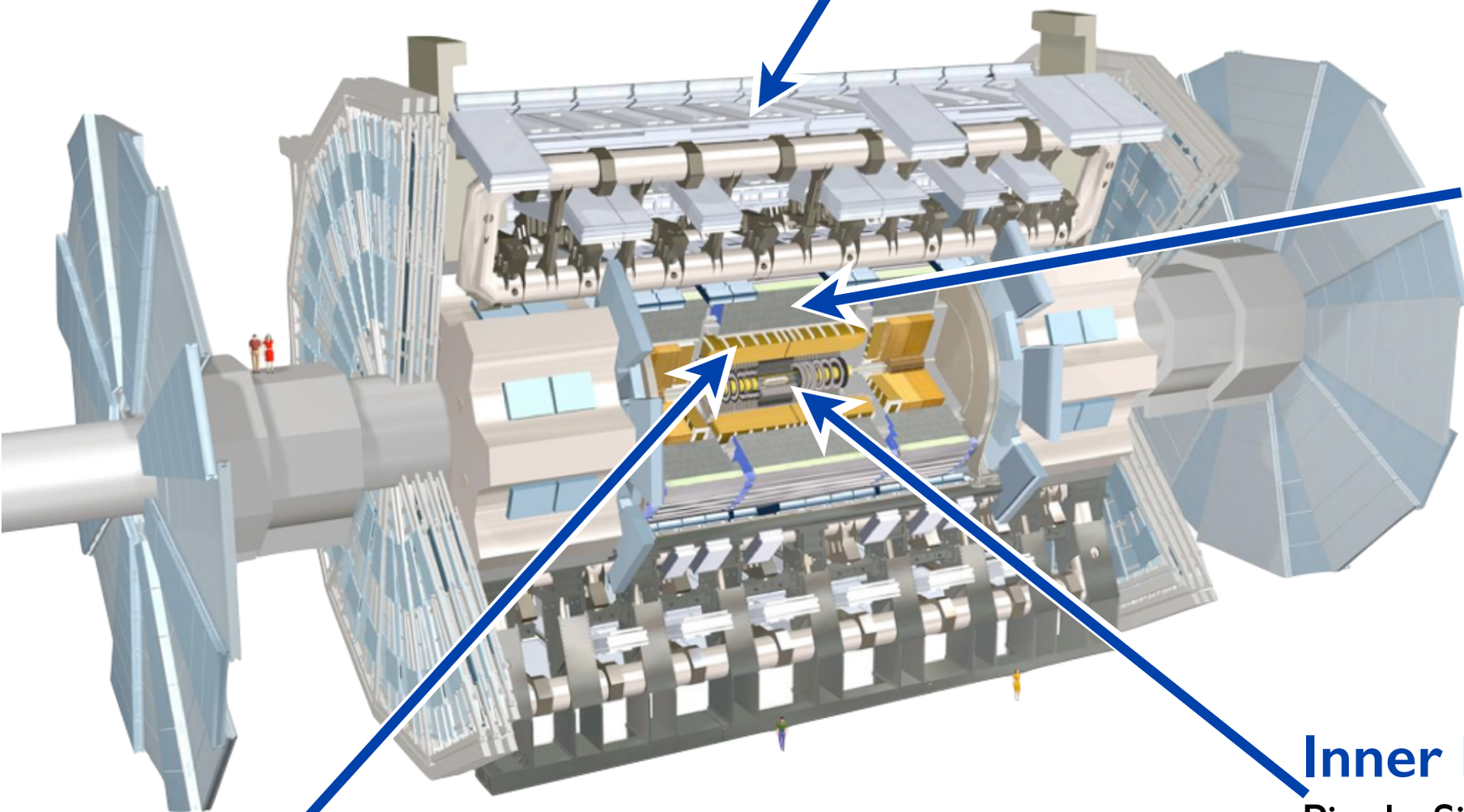
The ATLAS Experiment at the CERN LHC

3-Level Trigger

Reducing the rate from
40 MHz to 200-300 Hz

Muon Spectrometer

($|\eta|<2.7$): Air-core toroids with gas-based muon chambers; Muon trigger and measurement with momentum resolution < 10% up to $p_\mu \sim 1$ TeV



HAD calorimetry

($|\eta|<5$): hermetic and highly segmented; Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution:
$\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

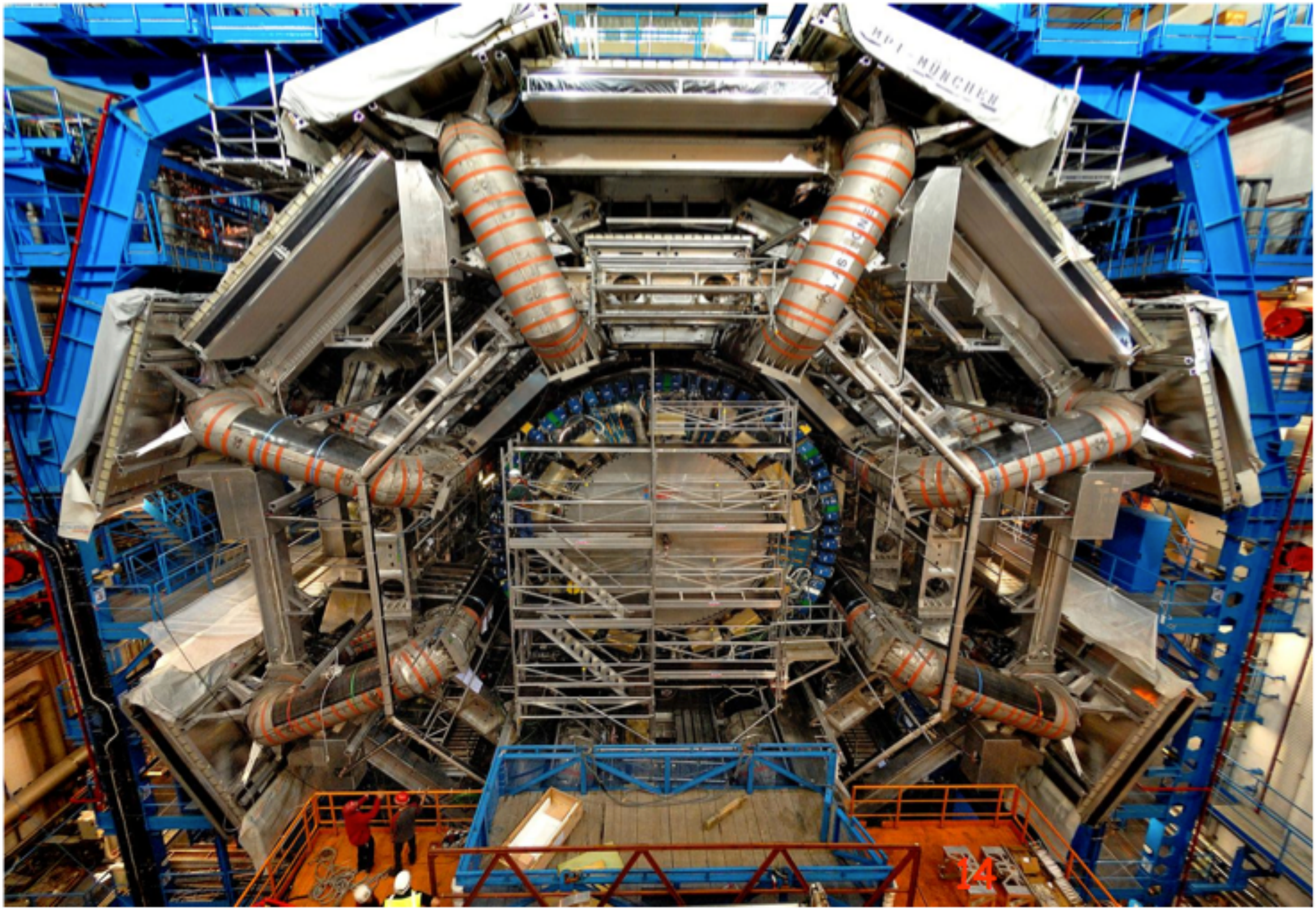
Inner Detector ($|\eta|<2.5$, B=2T): Si

Pixels, Si strips, Transition Radiation detector (straws); Precise tracking and vertexing, allows for e/π separation;
Momentum resolution:
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T\,(\text{GeV}) \oplus 0.015$
i.e. σ/p_T <2% for p_T < 35 GeV

EM Calorimeter ($|\eta|<3.2$):

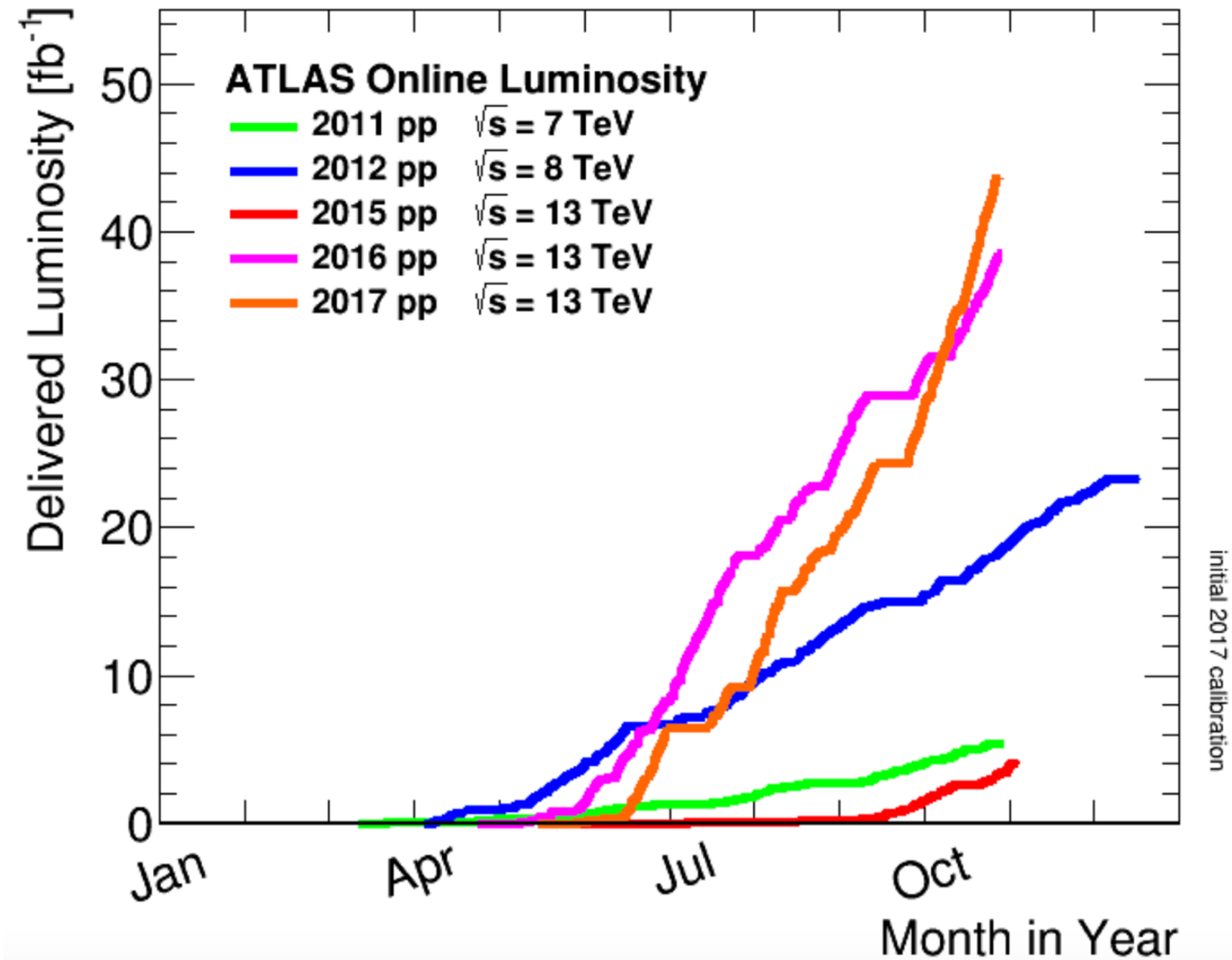
Pb-LAr Accordion; allows for e/γ triggering, identification and measurement;
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

The ATLAS detector



LHC: Integrated Luminosity

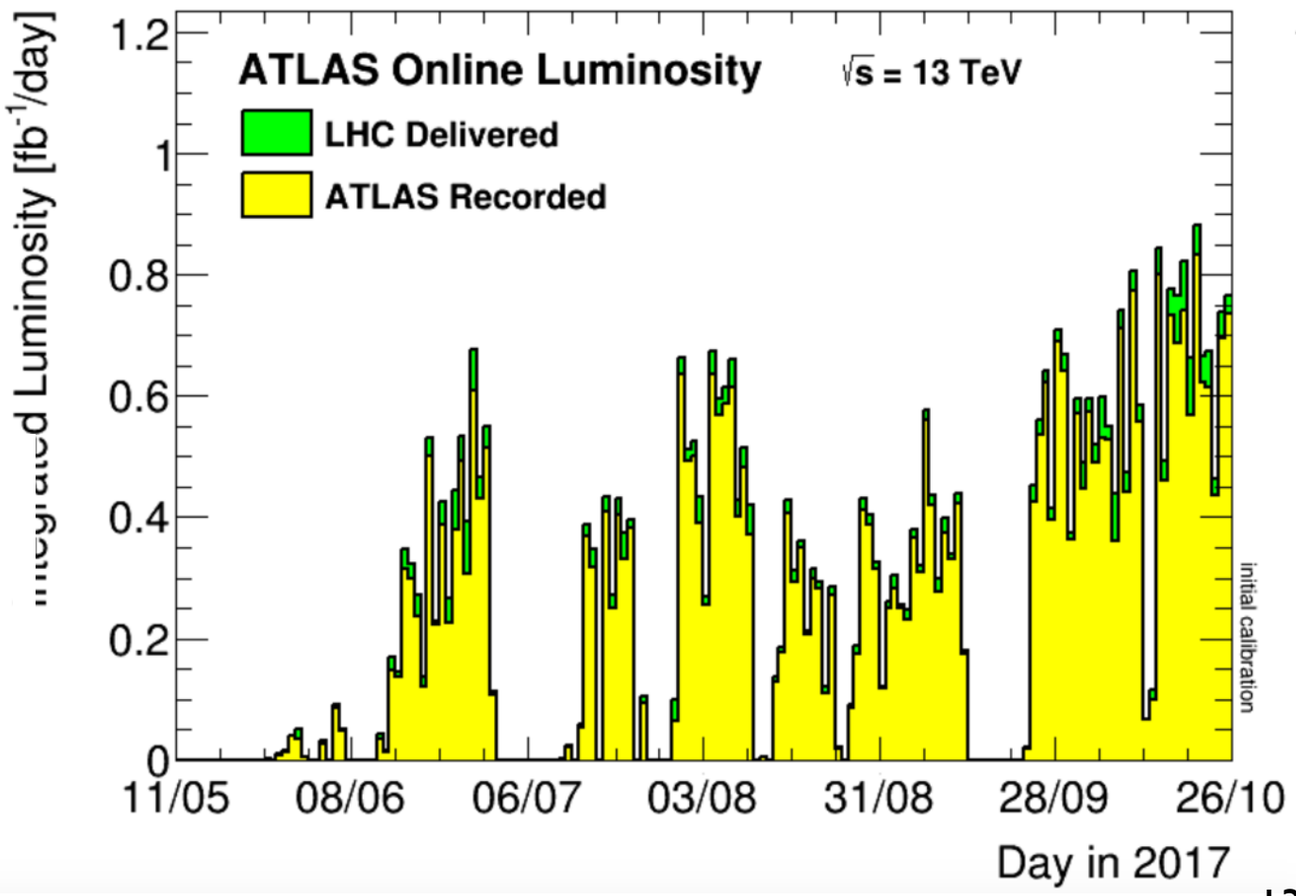
- The LHC managed to maintain a really impressive slope through much of the 2016 pp data-taking… delivered a total of 38.5 fb^{-1}
- Performance in 2017 is quite impressive as well, especially considering heavy losses related to the 16L2 issue… now very close to reaching the goal of 45 fb^{-1} delivered in 2017

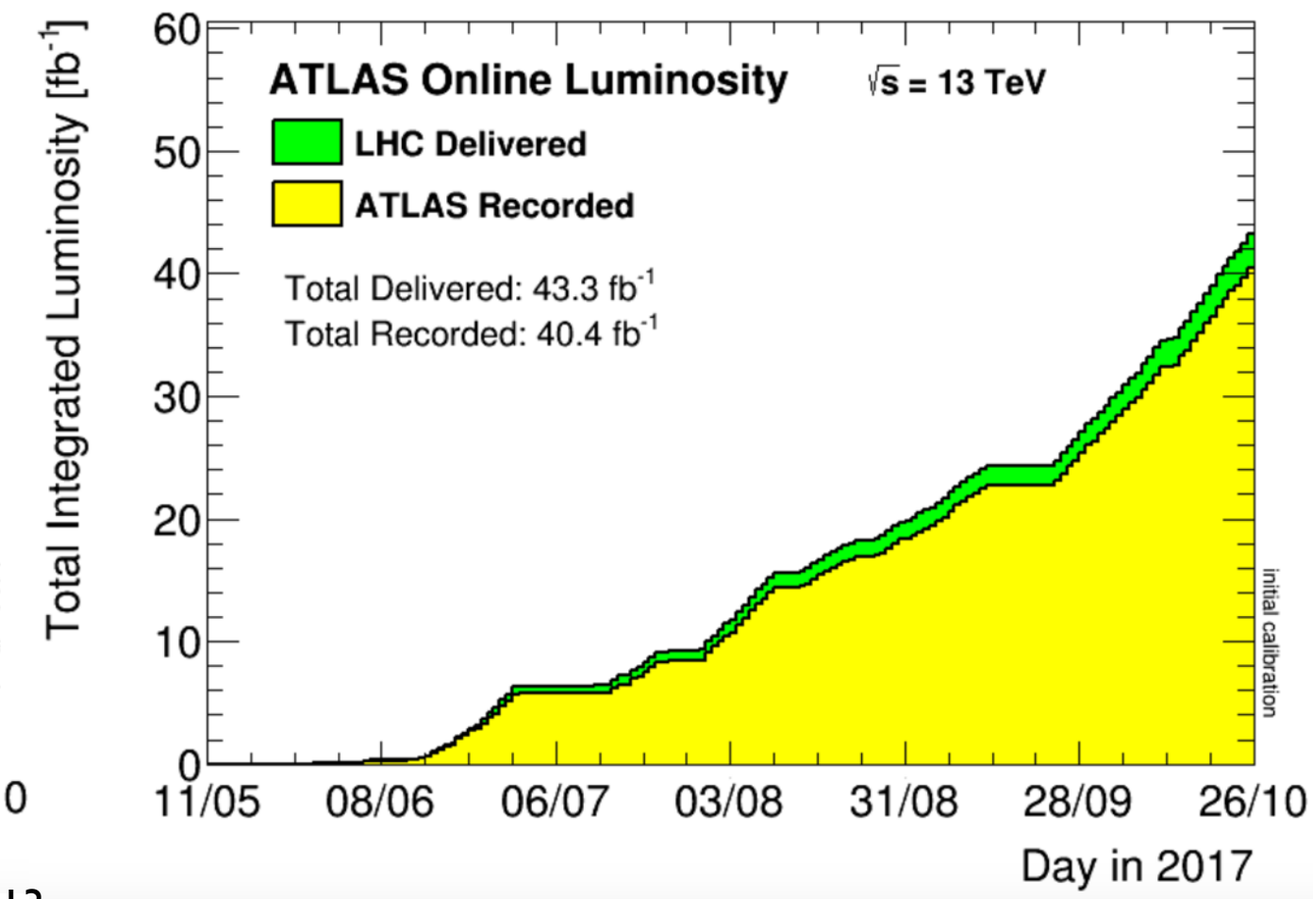


~43.5 fb^{-1} delivered so far in 2017

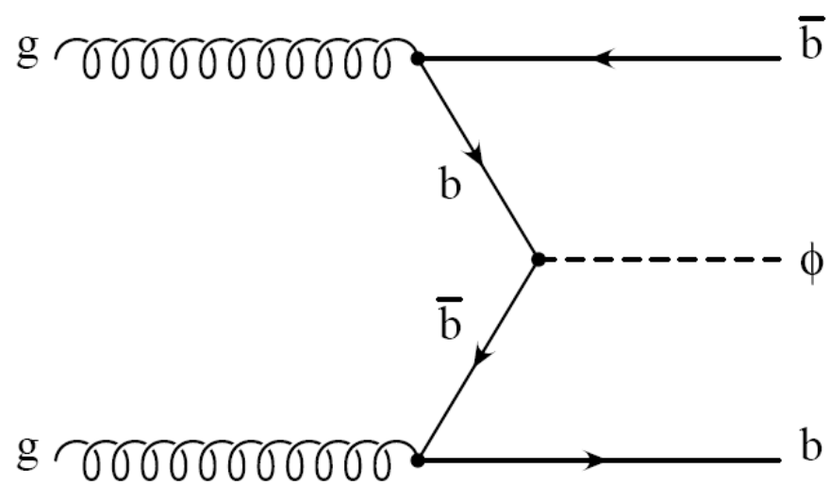
ATLAS: 38.5 fb^{-1} and 43.5 fb^{-1} Recorded

- ATLAS data-taking efficiency averaged ~92.5% for 2016
- The data-taking efficiency so far in 2017 averages ~93.5%
  - This is mostly due to individual sub-detector problems interrupting data-taking
  - ATLAS faced a very challenging environment of high peak <mu> and pile-up
- The LHC is still in a period of pp running at the moment, with ~3 weeks of 13 TeV pp running remaining in the year
  - There will be a period of Machine Development in late Nov. followed by a short 5 TeV pp reference run and a low-energy high beta* run
- Some results shown in my talk only include part of the 2016/2017 datasets… wait for Moriond 2018…





Neutral BSM Higgs Searches in ATLAS



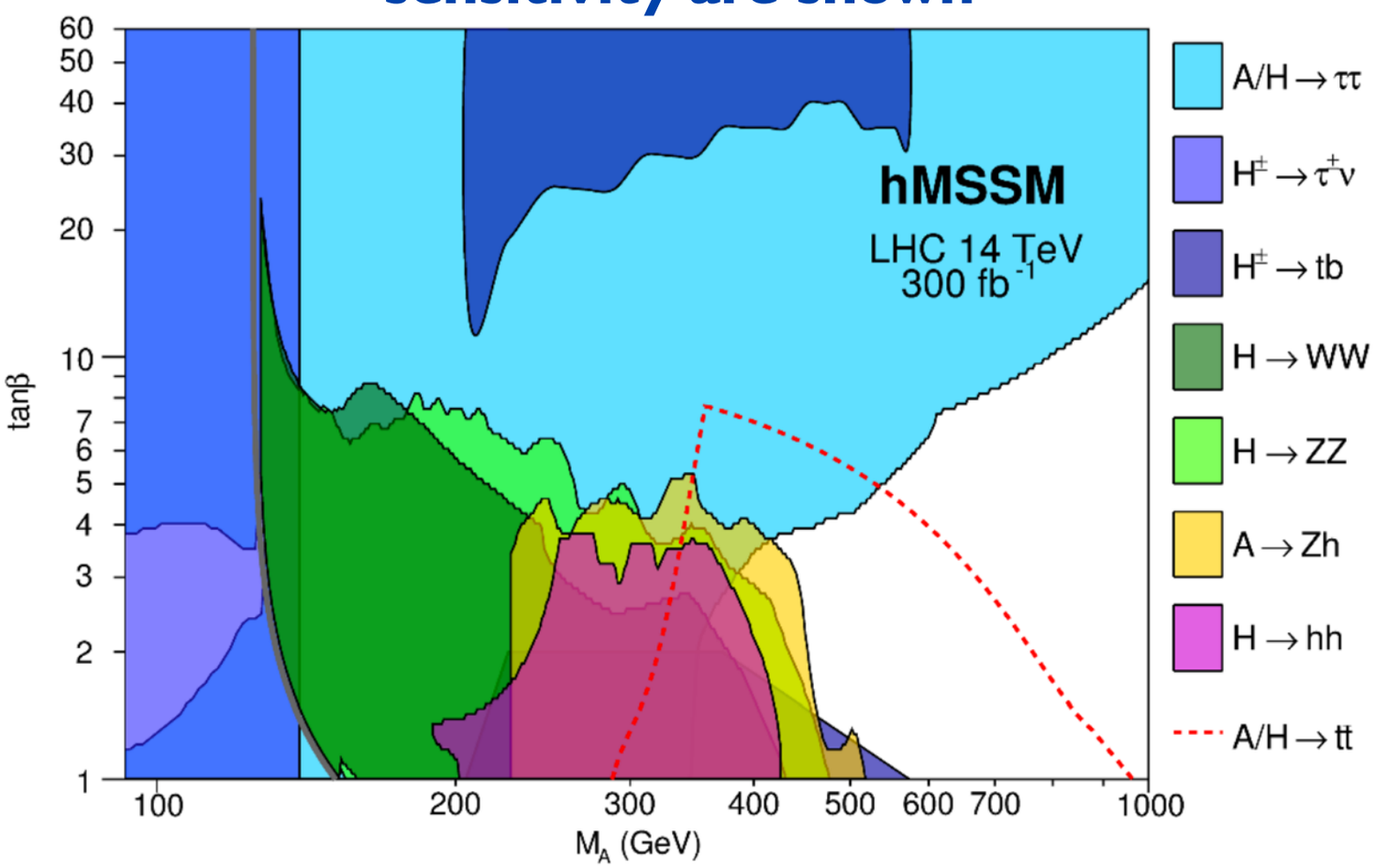
MSSM ϕ=h/A/H

MSSM Higgs Sector and a 125 GeV Higgs

- The MSSM (h, A, H, $H^{\pm}$) is compatible with a 125 GeV Higgs… for example:
  - hMSSM scenario: the measured value of 125 GeV can be used to predict masses and decay branching ratios of the other Higgs bosons
  - m_h^{mod+} scenario: the lightest CP-even Higgs is assigned to be the 125 GeV boson

- I have two new ATLAS high-mass neutral Higgs searches using fermions to show you…
  - A/H to ττ using 36.1 fb^{-1} of 13 TeV pp collision data arXiv: 1709.07242
  - A/H to ttbar using 13.2 fb^{-1} of 13TeV pp collision data arXiv:1707.06025

Theory projections for 2σ sensitivity are shown

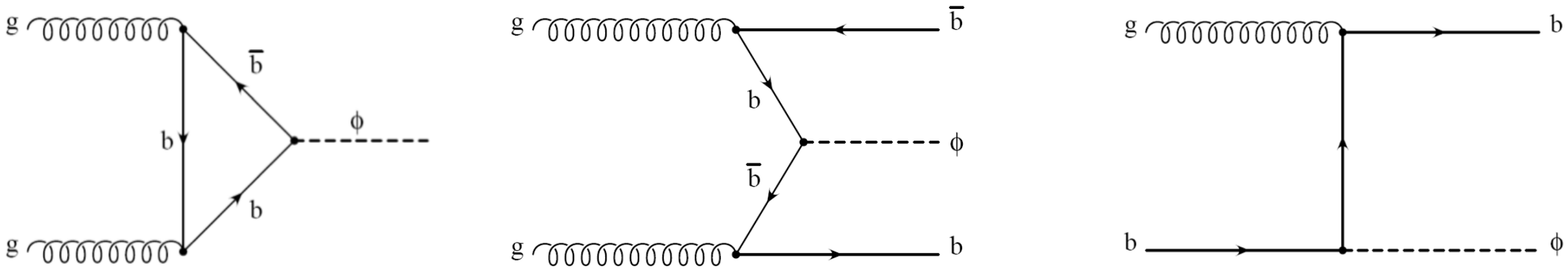


A/H to ττ and A/H to ttbar are each very important channels at mid- to high-m_A

Djouadi, A., Maiani, L., Polosa, A. et al. JHEP 06 (2015) 168

ATLAS Run-II MSSM Higgs Search ($A/H \rightarrow \tau^+\tau^-$)

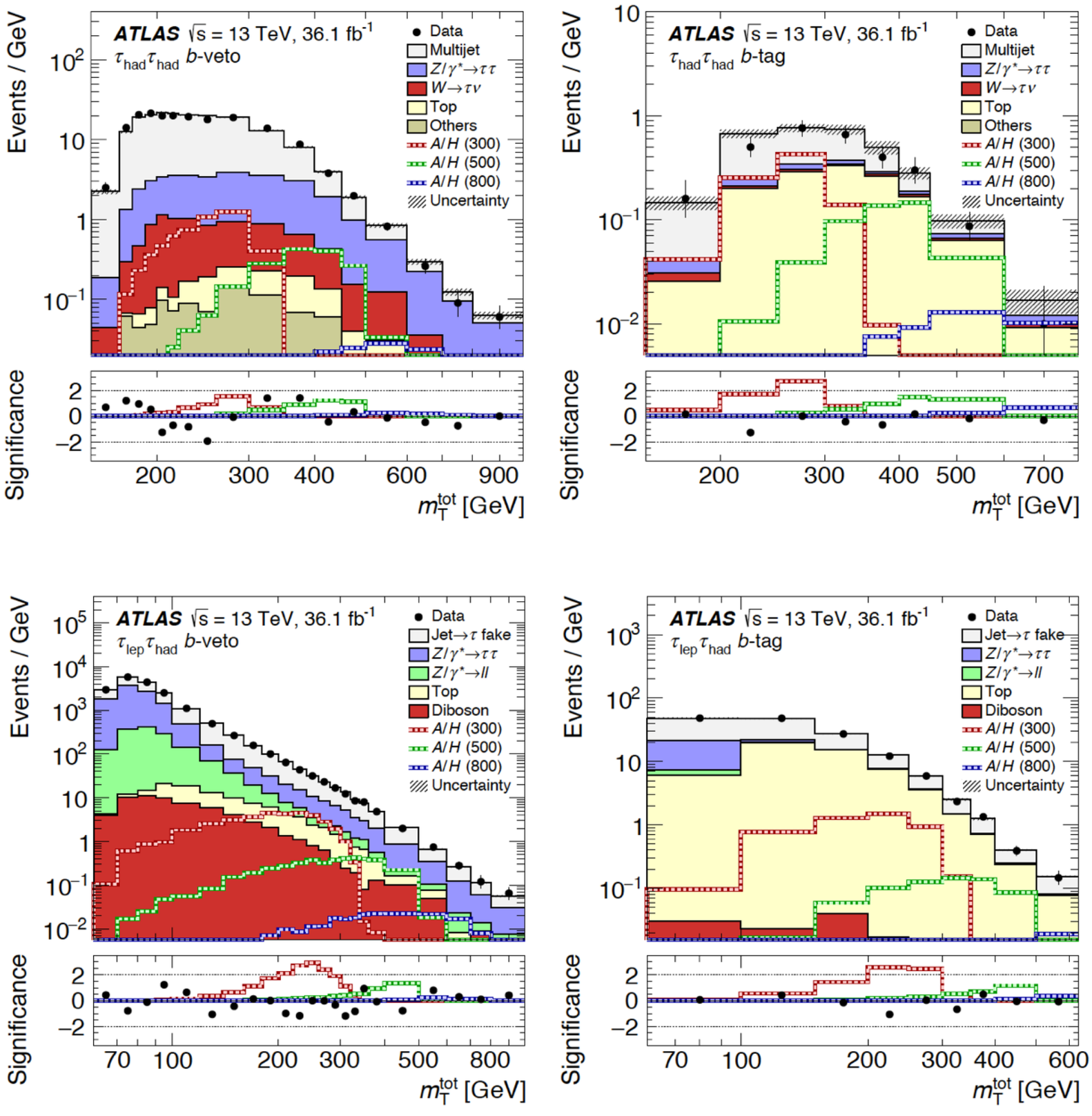
- New ATLAS MSSM neutral Higgs search for ICHEP 2016 uses 36.1 fb^{-1} of 13 TeV data
  - Improvement on the limits from the 2015 result published: Eur. Phys. J. C (2016) 76: 585
- Can use different categories to target main production mechanisms
  - "no b-tag" targets gluon-fusion (dominant mode at small tanβ)
  - "b-tag" targets b-associated production (dominant mode at large tanβ)



- Can also separate based on the τ lepton decay mode (here lepton-hadron or hadron-hadron)
- So in total, there are 4 categories considered by the analysis

- Monte Carlo samples used:
  - A/H to ττ signal: Powheg+Pythia8 (ggH) and aMC@NLO + Pythia8 (bbH)
  - Backgrounds:
    - Powheg+Pythia8 (W+jets in lep-had, Z+jets and top)
    - Sherpa (W+jets in had-had and dibosons)

Post-fit Plots for the 4 Categories ($A/H \rightarrow \tau^+\tau^-$)

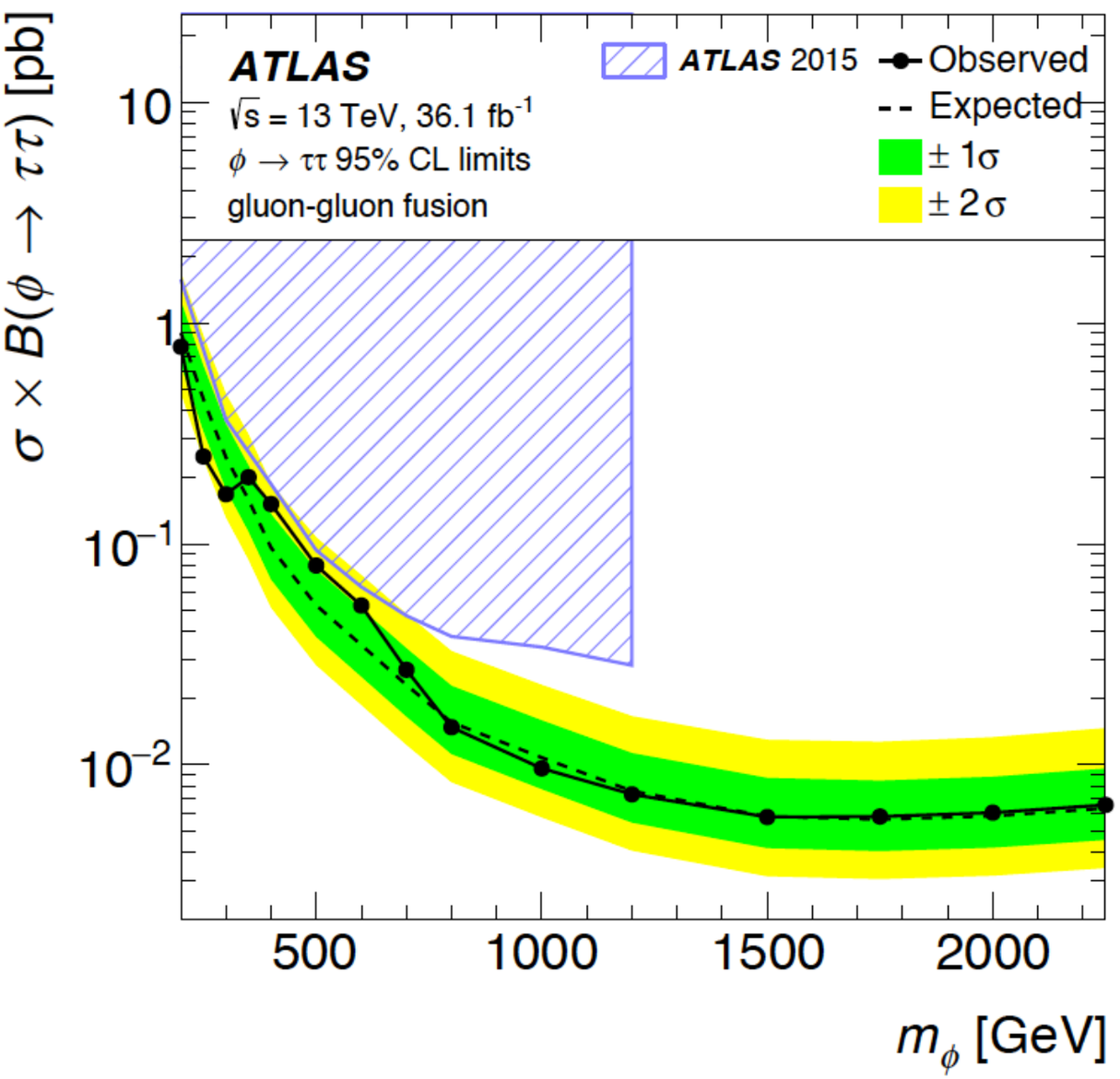


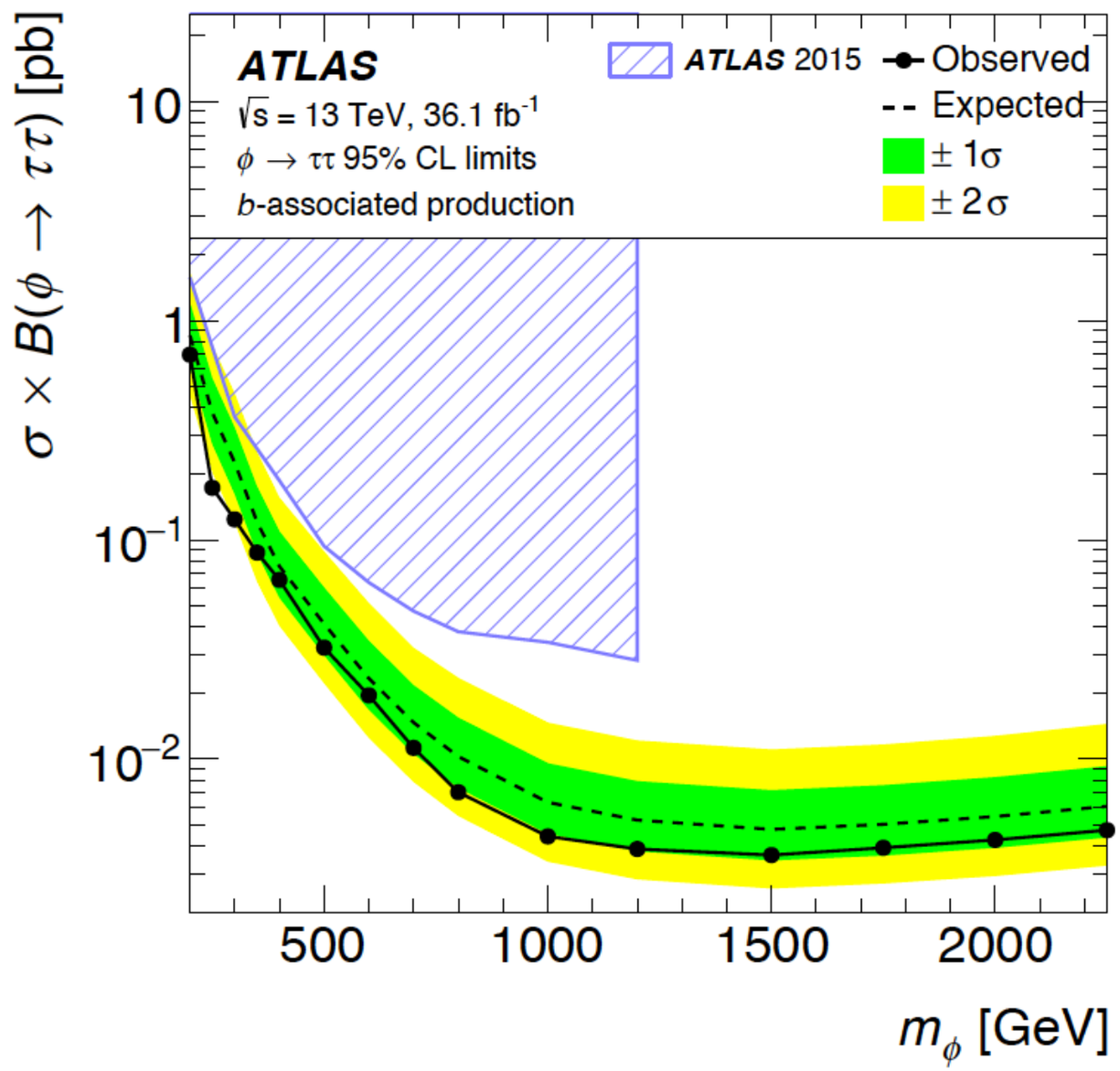
- Background modeling simulation for backgrounds with true leptons faking taus
- Data-driven methods for some backgrounds where jets fake taus
- Fake-factors when Monte Carlo used for some backgrounds where jets can fake taus
- Discriminant used is the m_T^{tot} variable, as it offers good separation of signal from backgrounds due to fake τs

$$m_T^{tot} \equiv \sqrt{(p_T^{\tau_1} + p_T^{\tau_2} + E_T^{miss})^2 - (\mathbf{p}_T^{\tau_1} + \mathbf{p}_T^{\tau_2} + \mathbf{E}_T^{miss})^2}$$

Run-II MSSM Neutral Higgs Search ($A/H \rightarrow \tau^+\tau^-$)

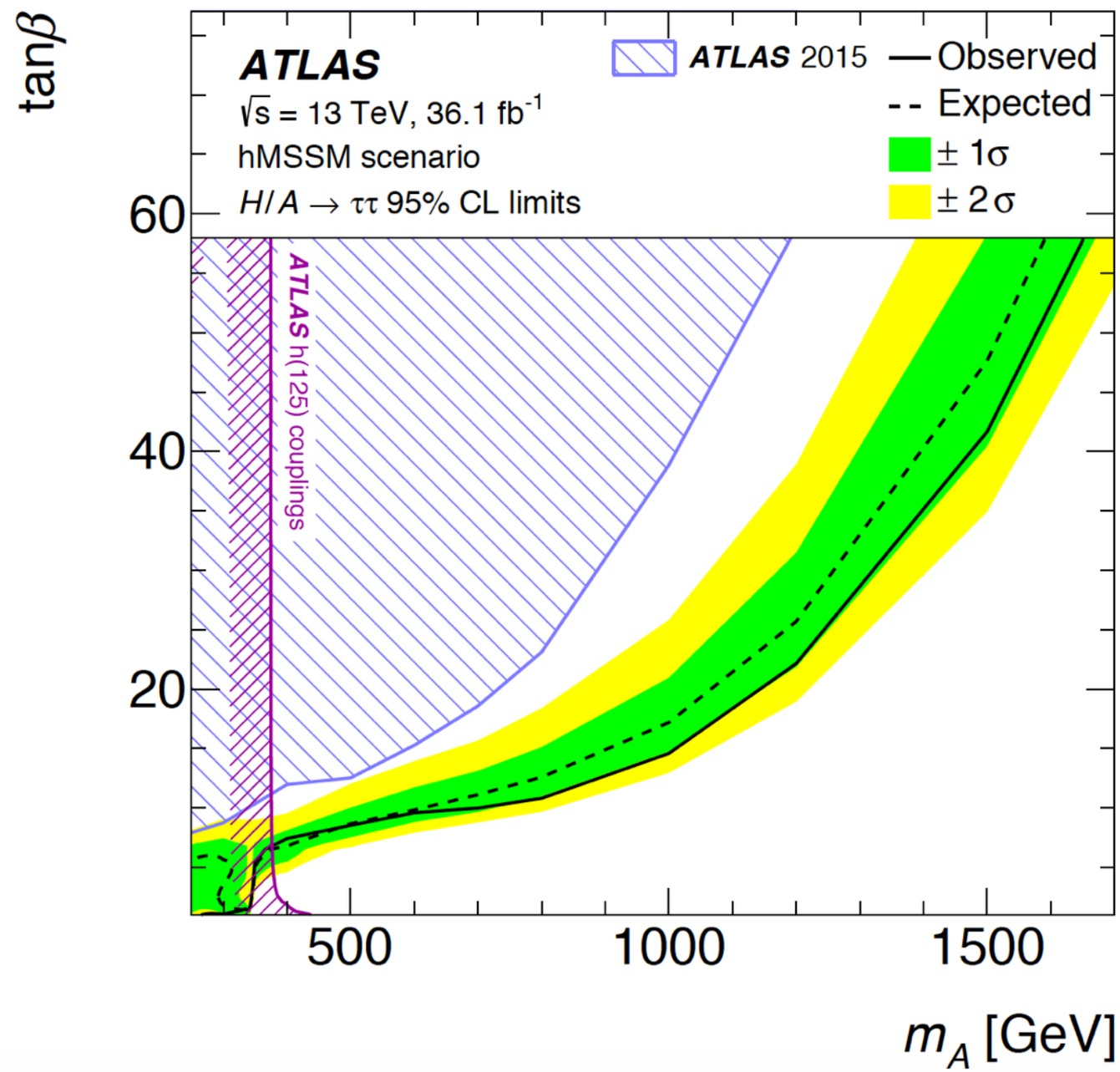
- Dominant systematics: τ energy scale, τ trigger, jet fake-related (lep-had), top modeling (had-had)
- Statistically combine the τ_{lep}-τ_{had} and τ_{had}-τ_{had} channels for one exclusion limit
- We determine a σ x BR limit ($A/H \rightarrow \tau\tau$) for gluon-fusion and b-associated production separately; exclusions range from ~0.9 pb to ~4.0 fb, depending on the Higgs mass and production mechanism





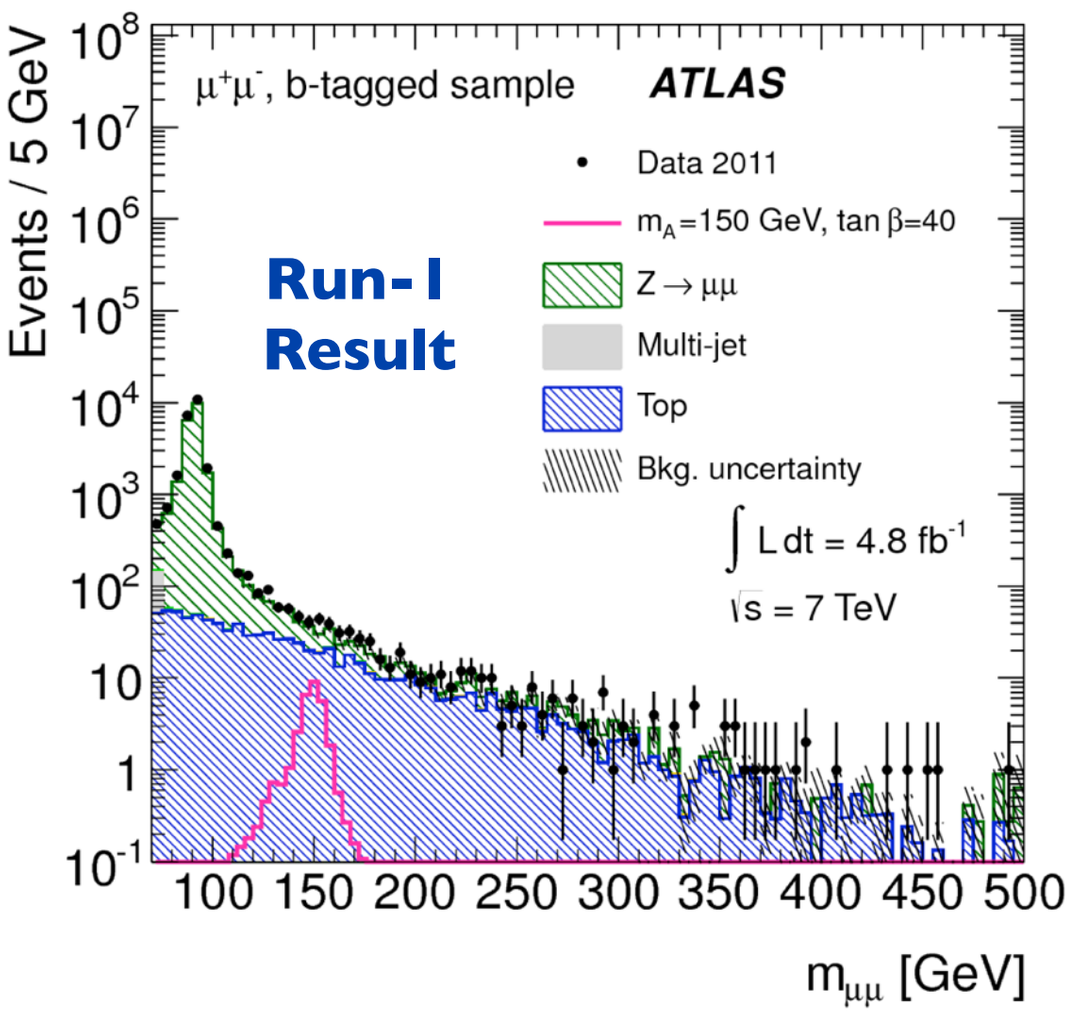
Run-II MSSM Neutral Higgs Search ($A/H \rightarrow \tau^+\tau^-$)

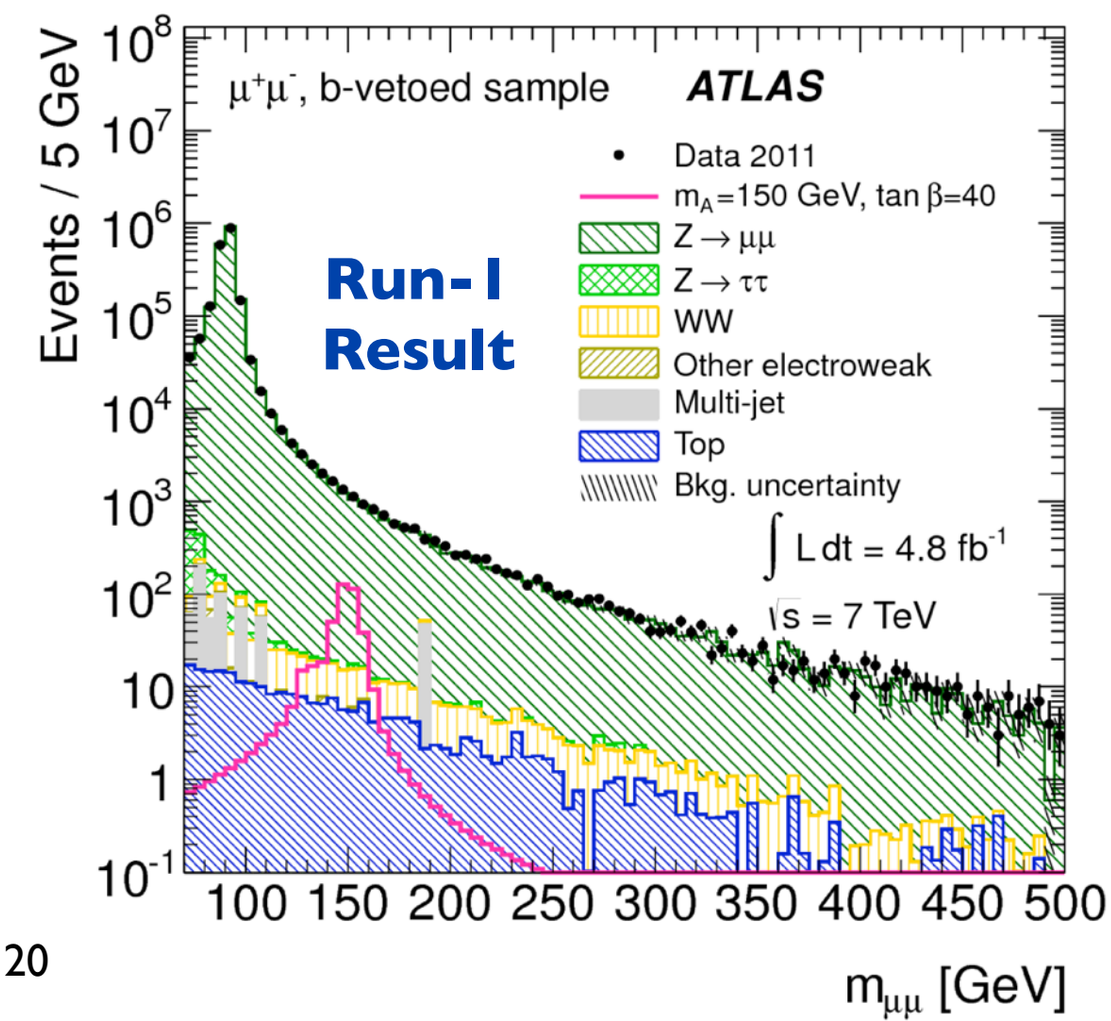
- We also show limits in the hMSSM benchmark scenario
- In this scenario, we exclude $\tan\beta > \sim 10$ for $m_A = 500$ GeV and $\tan\beta > 40$ for $m_A = 1.5$ TeV
- hMSSM plot shows Run-1 couplings exclusion (κ_V, κ_u and κ_d)



ATLAS Run-1 MSSM Higgs Searches ($\phi \rightarrow \mu^+\mu^-$)

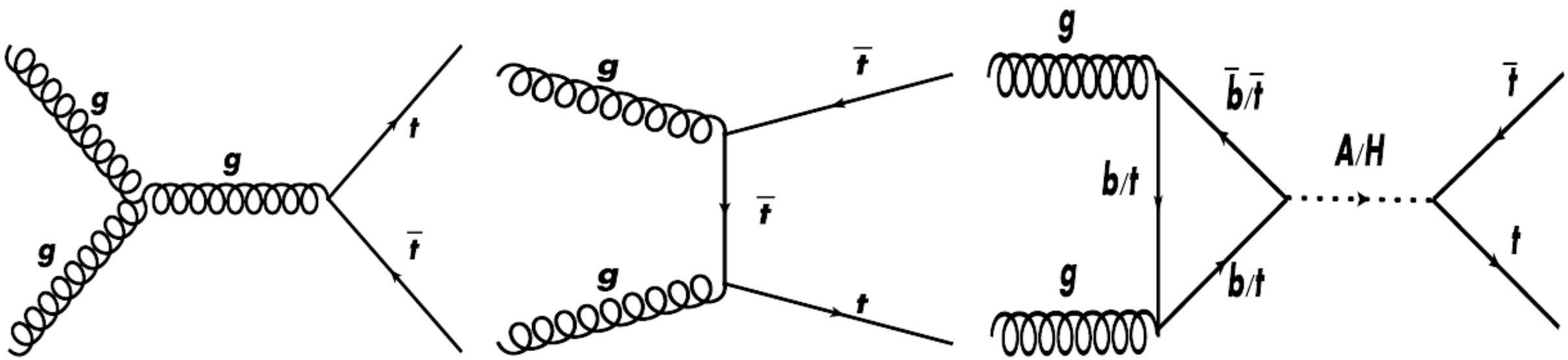
- MSSM $\phi \rightarrow \mu^+\mu^-$ channels
- Small BR but very clean final state
- Main event selection: JHEP02 (2013) 095
  - Lowest unprescaled single muon trigger
  - 2 isolated muons of opposite charge with p_T>20 GeV, $|\eta|$<2.5
  - MET < 40 GeV
- Again, separation into b-tagged and b-vetoed categories
- Total background from sideband fits to di-muon invariant mass spectrum
- This is an older publication from Run-1… result being looked at for Run-2 now





Run-I High-mass Higgs Search (A/H→ttbar)

- We revisited a Run-1 ttbar resonance search that used 20.3 fb^{-1} of 8 TeV proton-proton collision data: ATLAS collaboration, JHEP 08 (2015) 148
- This analysis uses the ttbar lepton+jets channel, and takes the interference between the signal and ttbar background production modes into account for the first time

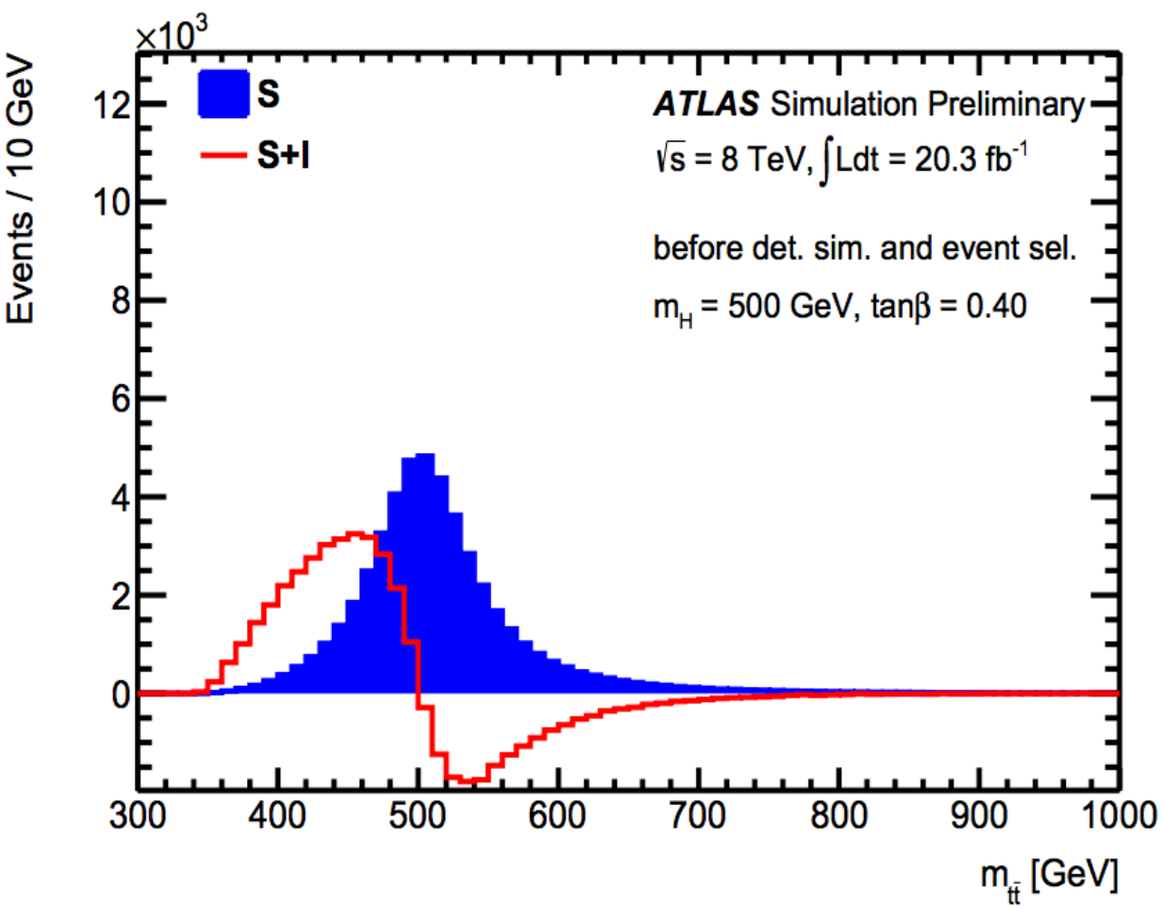


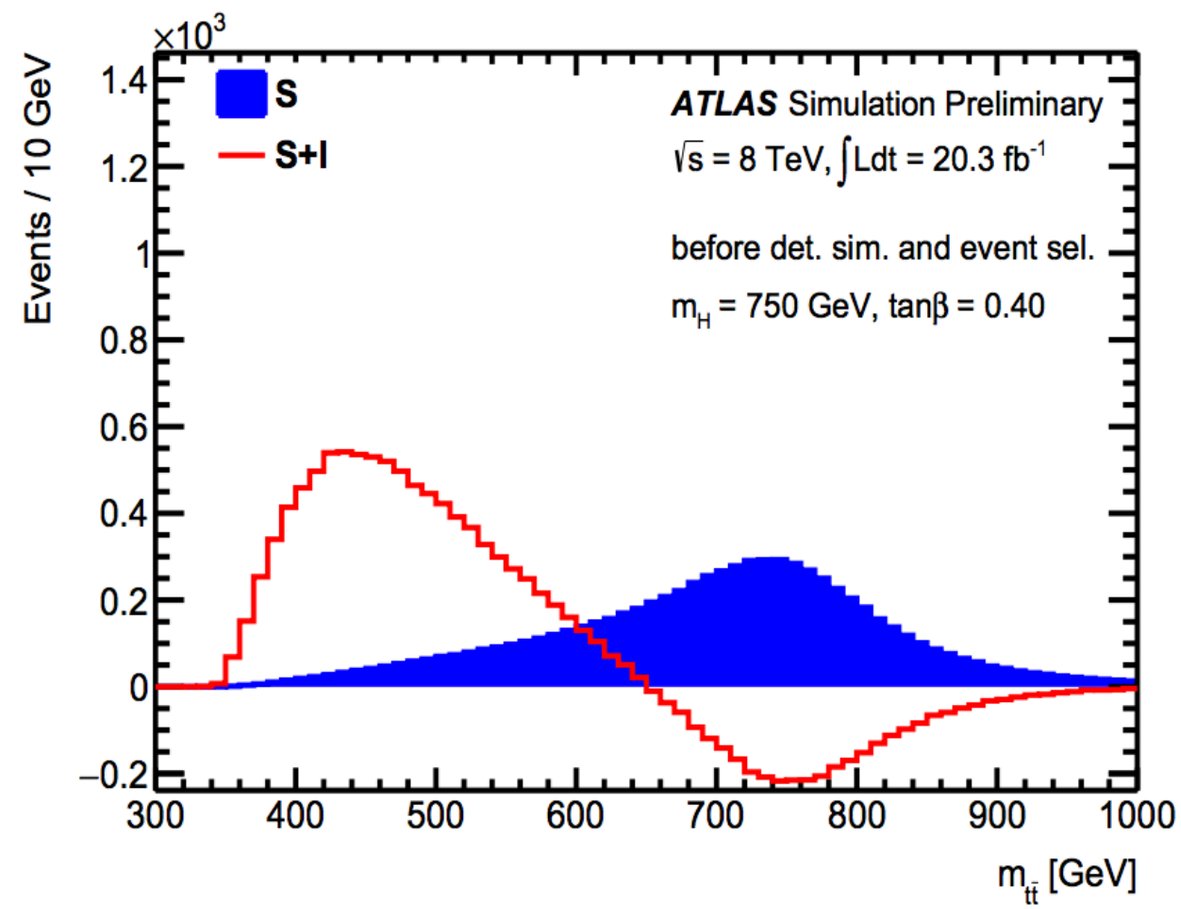
- Monte Carlo samples used:
  - A/H to ttbar signal: MadGraph5+Pythia6
  - Backgrounds:
    - ttbar: Powheg-Box+Pythia6
    - ttbar + V: Madgraph5+Pythia6
    - single top: Powheg+Pythia6
    - W+jets and Z+jets: Alpgen+Pythia6
    - Diboson: Sherpa

MadGraph5 used for both Direct and Indirect A/H signal generation (Direct used; difference taken as a modeling systematic)

Signal Modeling (A/H→ttbar)

- The signal process is simulated using the generator MadGraph5 v2.0.1 with the Higgs Effective Couplings Form Factor model (implements the production of scalar and pseudoscalar particles through loop-induced gluon fusion)
  - Loop contributions from both bottom and top quarks are taken into account
  - Signal shape is distorted from a simple Breit-Wigner peak, to a peak-dip structure
  - Statistical interpretation of measured event rates in data are compared to the total sum of Signal + Interference + Background (S + I + B)
  - The mass of the SM-like Higgs boson, h, is chosen to be 125 GeV and sin(β-α) is set to 1



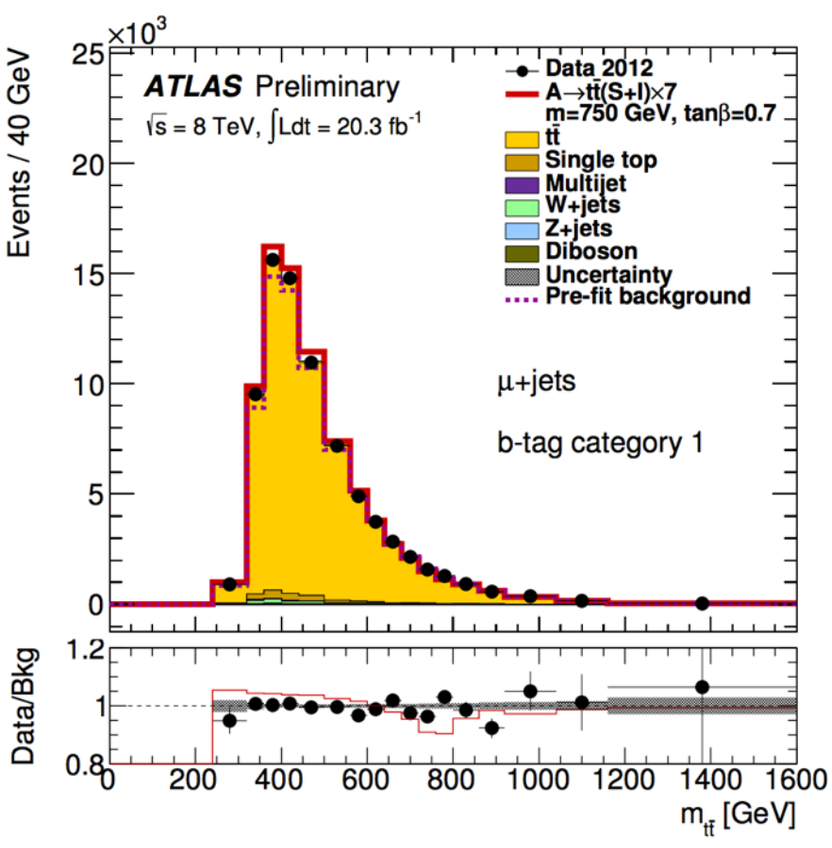


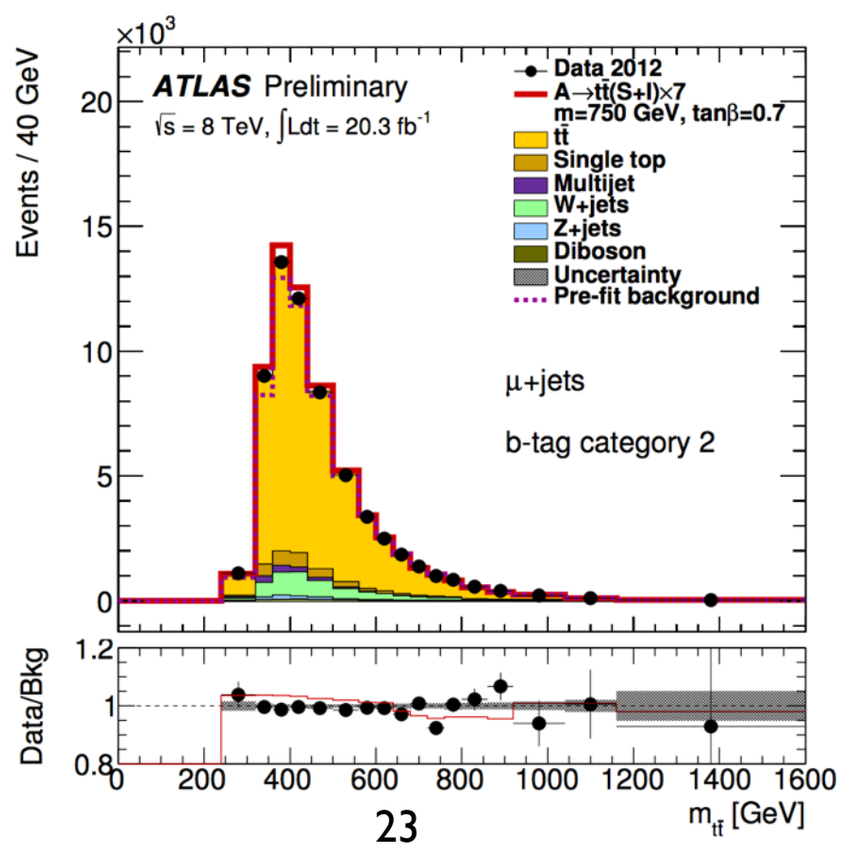
Event Selection / Mass Reconstruction (A/H→ttbar)

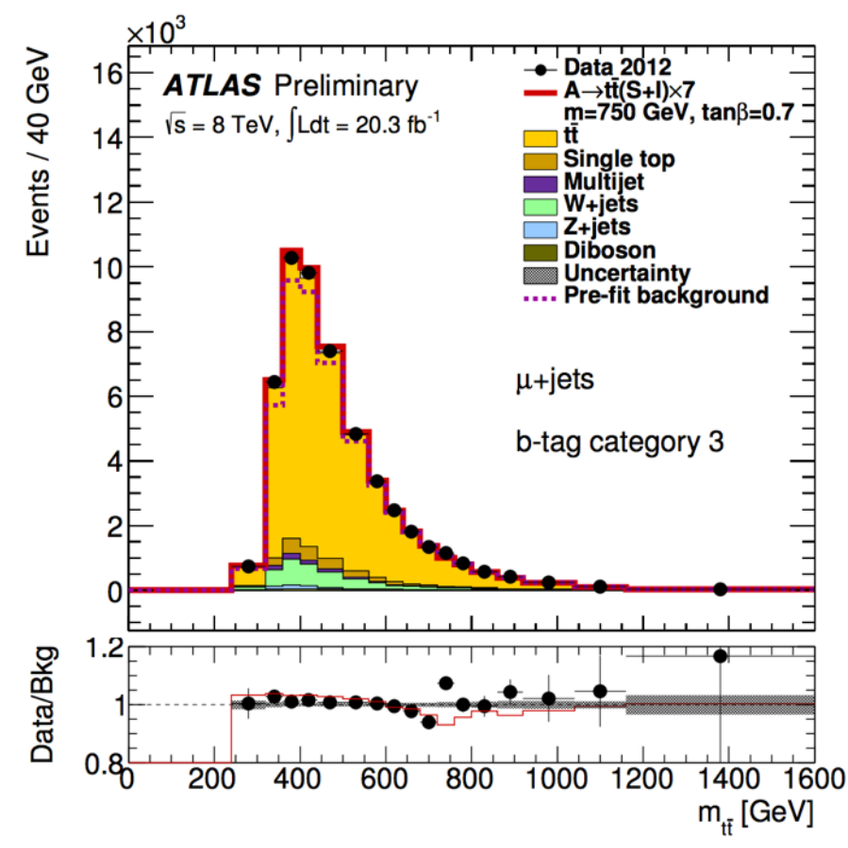
- Analysis targets the ttbar lepton+jets channel (one W to hadrons one to leptons)
  - Single electron or single muon triggers are used—2 categories (one for e; one for μ)
  - One high p_T electron or muon; high MET from the escaping neutrino; presence of at least 4 high p_T jets in the event; at least one jet originating from b quarks must be tagged (70%); Sum of MET and m_T > 60 GeV (multi-jets suppression) $m_T^W = \sqrt{2 \cdot p_T^\ell \cdot E_T^{miss} \cdot (1 - \cos\phi_{\ell\nu})}$
- A chi-squared fit is used for assignment of the decay products, then m_{tt} is reconstructed
  - Events further classified depending on the b-tagged jet(s) assignment—3 categories

$$\chi^2 = \left[\frac{m_{jj} - m_W}{\sigma_W}\right]^2 + \left[\frac{m_{jjb} - m_{jj} - m_{t_h - W}}{\sigma_{t_h - W}}\right]^2 + \left[\frac{m_{j\ell\nu} - m_{t_\ell}}{\sigma_{t_\ell}}\right]^2 + \left[\frac{(p_{T,jjb} - p_{T,j\ell\nu}) - (p_{T,t_h} - p_{T,t_\ell})}{\sigma_{\mathrm{diff}\,p_T}}\right]^2$$

6 categories in total (2 lepton types) x (3 b-tagging classifications)

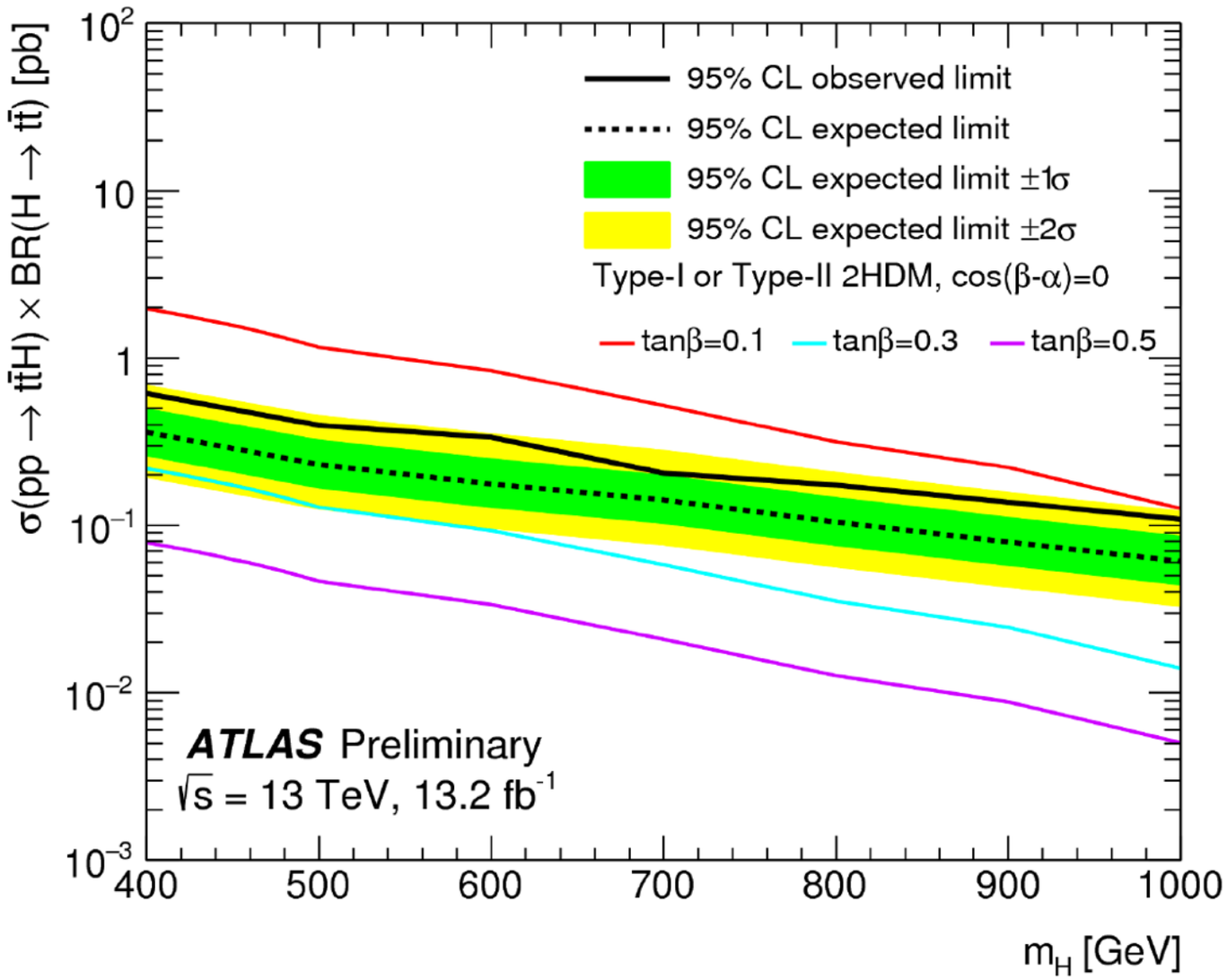






Run-II High-mass Higgs Results (A/H→ttbar)

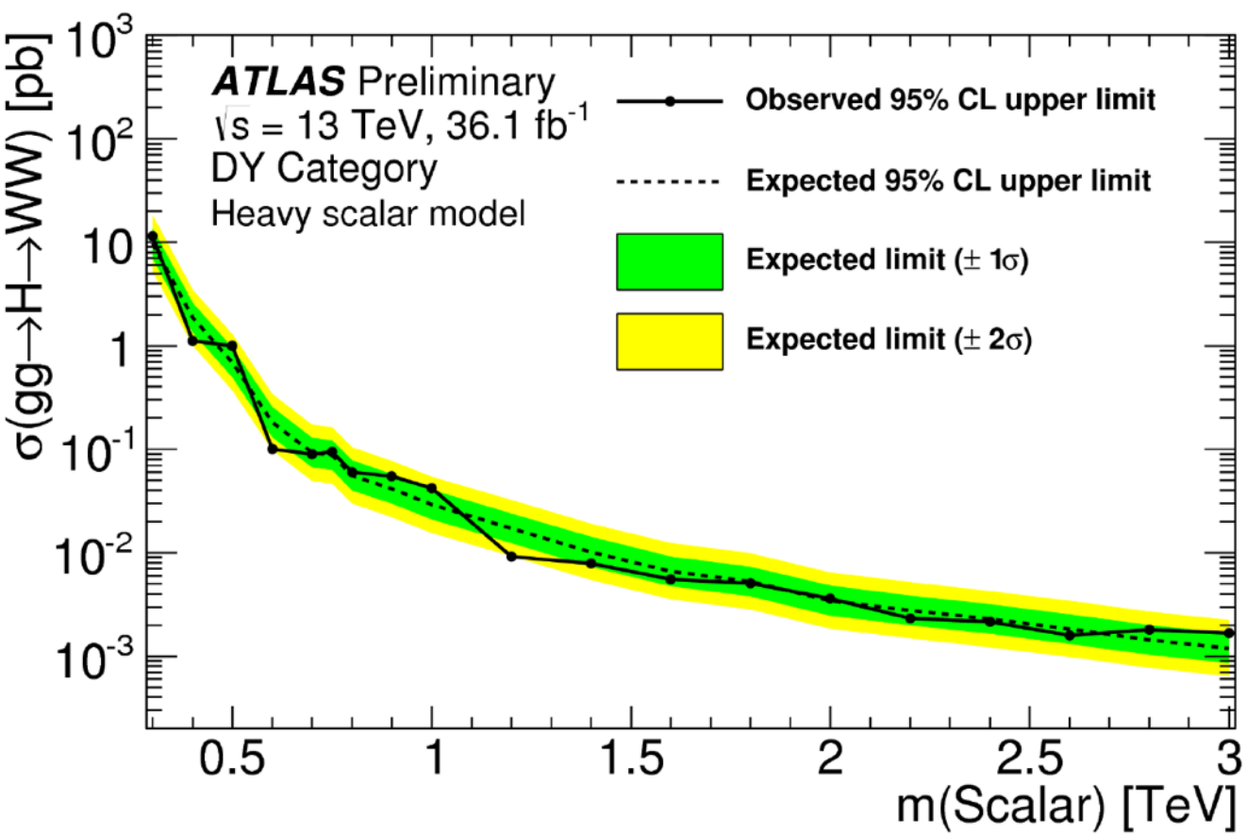
- No significant excess over Standard Model background expectation is observed
- Also look into associated production of a heavy Higgs with tab at 13 TeV. We set upper limits on the signal production cross section x BR for a heavy Higgs mass between 400 GeV and 1000 GeV

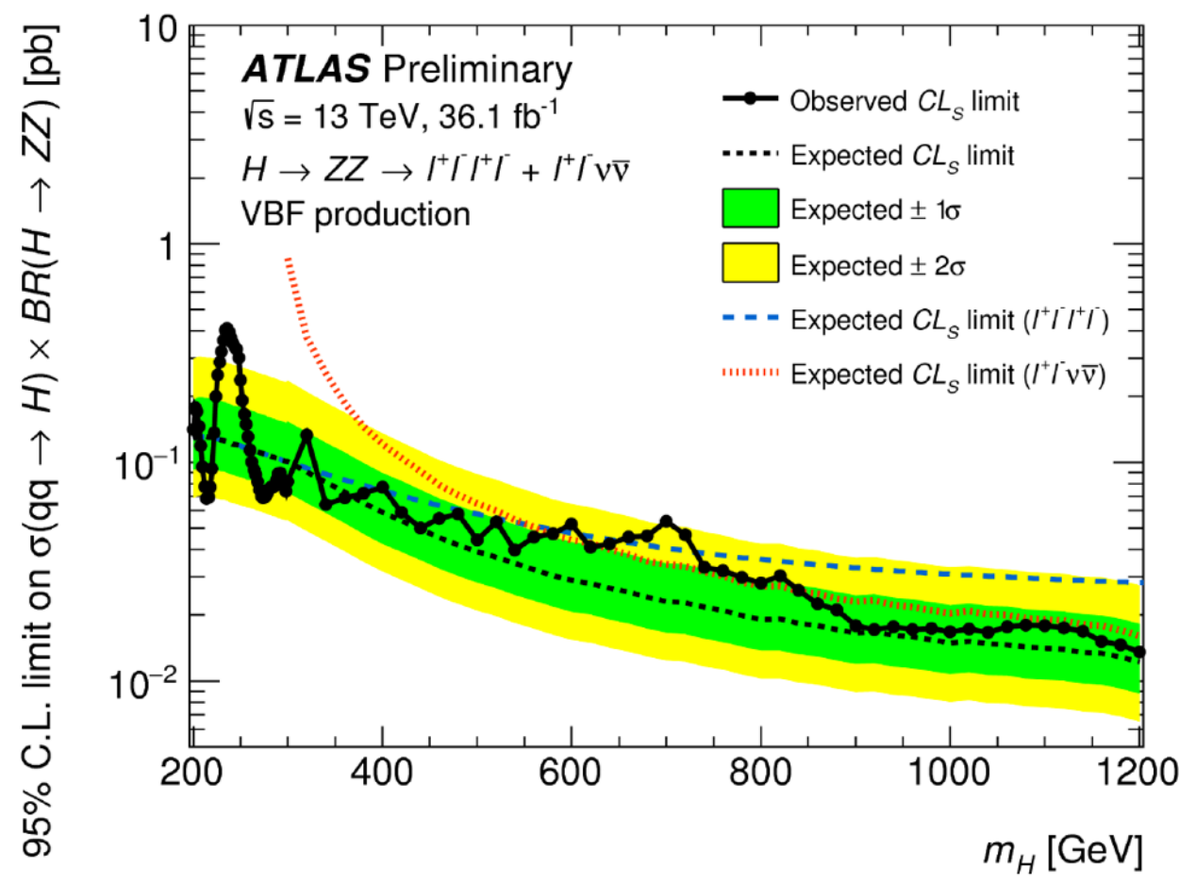


High-mass Searches (H→WW→lνqq and ZZ)

- H→WW→lνqq (l=e,μ) uses 36.1 fb^{-1} of 13 TeV pp data
- Selection: e,μ + MET > 100 GeV, ≥1 R=1 jet
- Likelihood fit with dedicated control regions for ttbar and W+jets
- Signal Regions:
  - High and low-purity selections
  - Inclusion of a jet substructure variable for boosted boson vs. QCD separation

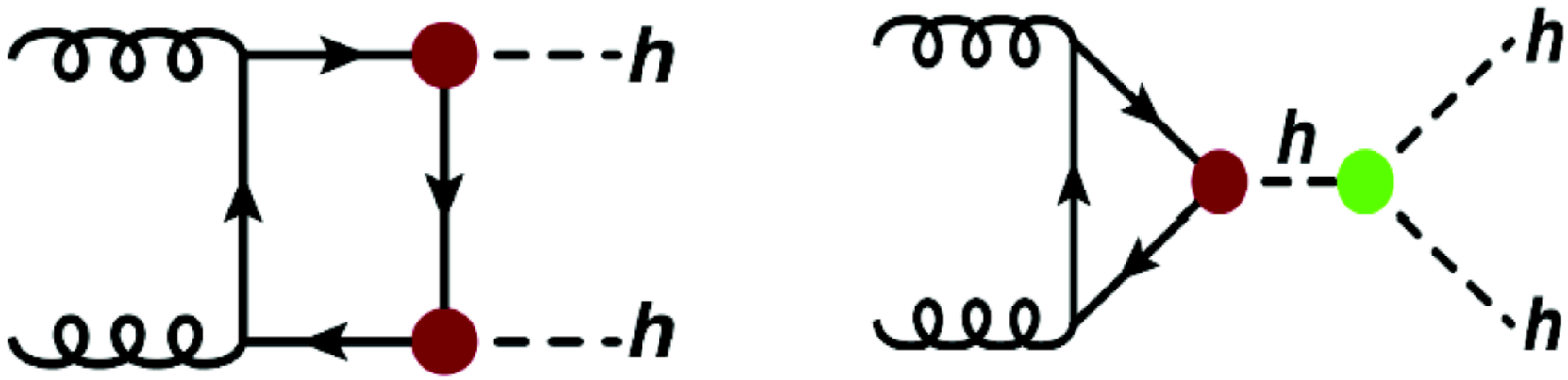
- H→ZZ→4l and llνν (l=e,μ) uses 36.1 fb^{-1} of 13 TeV pp data
- Uses the same selection as the SM search, but requires both Z bosons to be on-shell
- Signal Regions:
  - VBF enriched category
  - ggF enriched category
- Limits are set using various widths
- Excesses at 240 and 700 GeV, but only 1.3 sigma globally



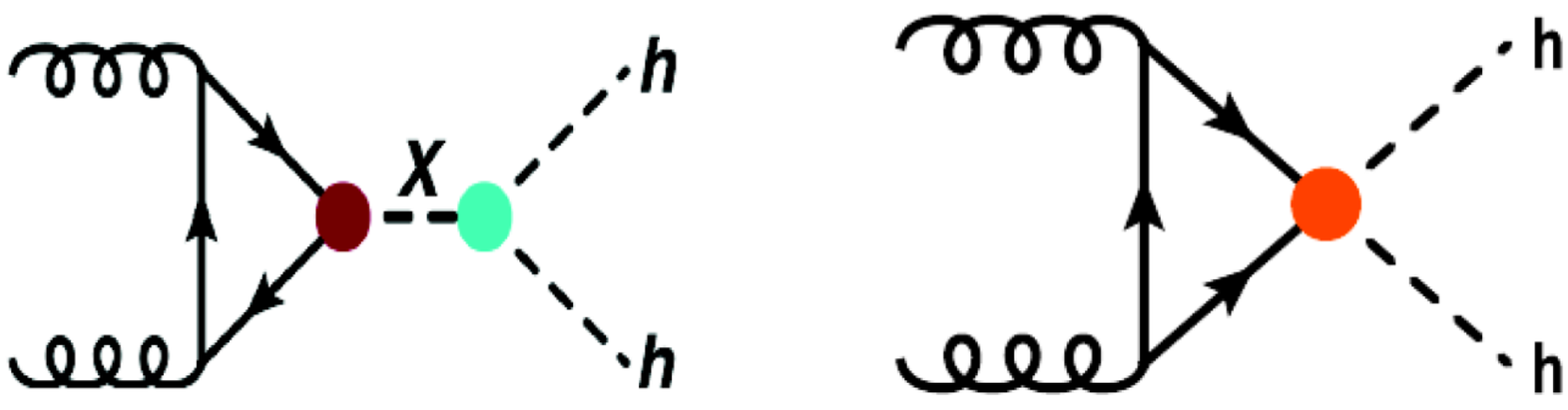


Run-1 Di-Higgs Search Results (H→hh)

- Di-Higgs production is very small in the Standard Model due to destructive interference
  - 33.7 fb for proton-proton collisions with CME of 13 TeV (non-resonant)

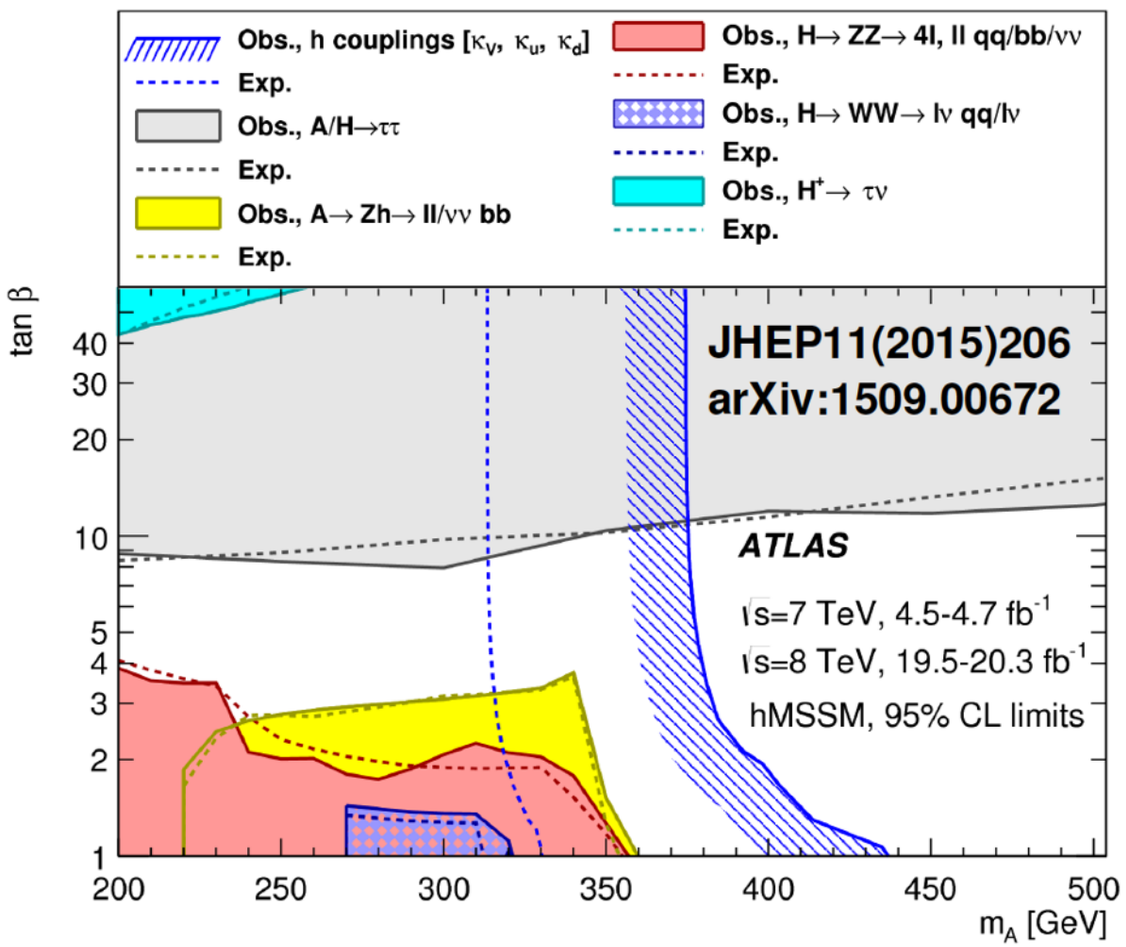


- With physics Beyond the Standard Model, this can be enhanced by:
  - Modified top Yukawa coupling or λ_{hhh} (non-resonant production)
  - Resonant production: 2HDM H→hh, KK gravitons, etc.

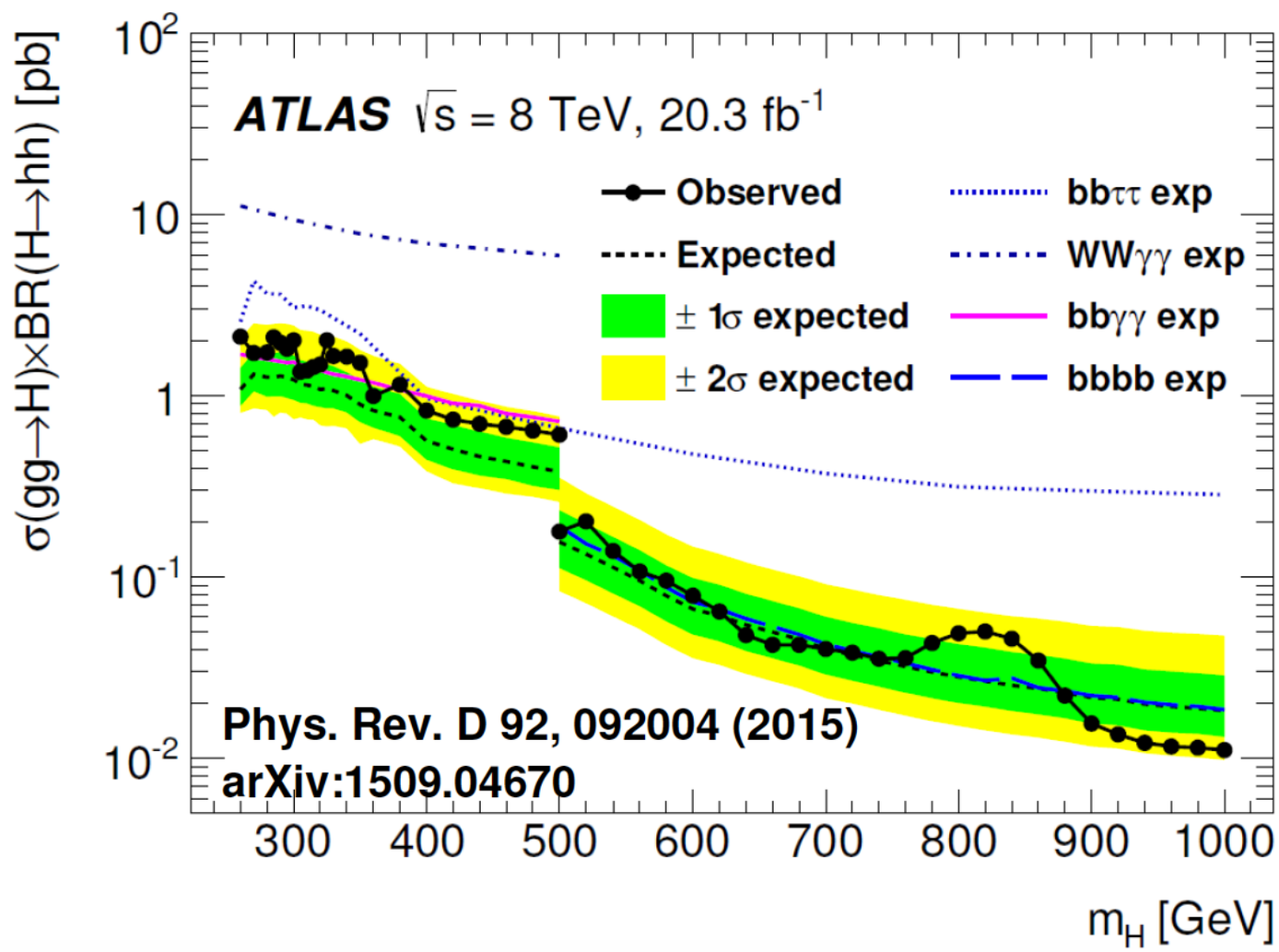


Run-1 Di-Higgs Search Results (H→hh)

- MSSM: Couplings to down-type fermions dominate for high tanβ
- Couplings to bosons and up-type fermions are more important for low tanβ.
- Public ATLAS Di-Higgs results available from Run-1 for some time…
  - This is a combined result of bbbb, bb$\gamma\gamma$, bb$\tau\tau$ and $\gamma\gamma$WW



Run-1 ATLAS Summary plot for hMSSM



Run-II Di-Higgs Search Results (this talk: bbbb)

- Public ATLAS Di-Higgs result for Run-II uses 13.3 fb^{-1} of 13 TeV data
- Resolved search: Optimized for low-mass and non-resonant regimes
  - 4 b-tagged jets (R=0.4), jet pairing using ΔR_{jj} and m_h constraints
- Boosted search: Optimized for high-mass resonances, where the two b-jets of the Higgs boson decay cannot be resolved (events splits into 2-, 3- and 4-tag categories)
- Main background to both searches is multi-jets and ttbar
  - For the Resolved search, ttbar is modeled using Monte Carlo; multi-jets is data-driven
  - For the Boosted search, multi-jets is data-driven, ttbar shape from Monte Carlo and normalization comes from data
  - Largest systematic uncertainty come from the b-tagging

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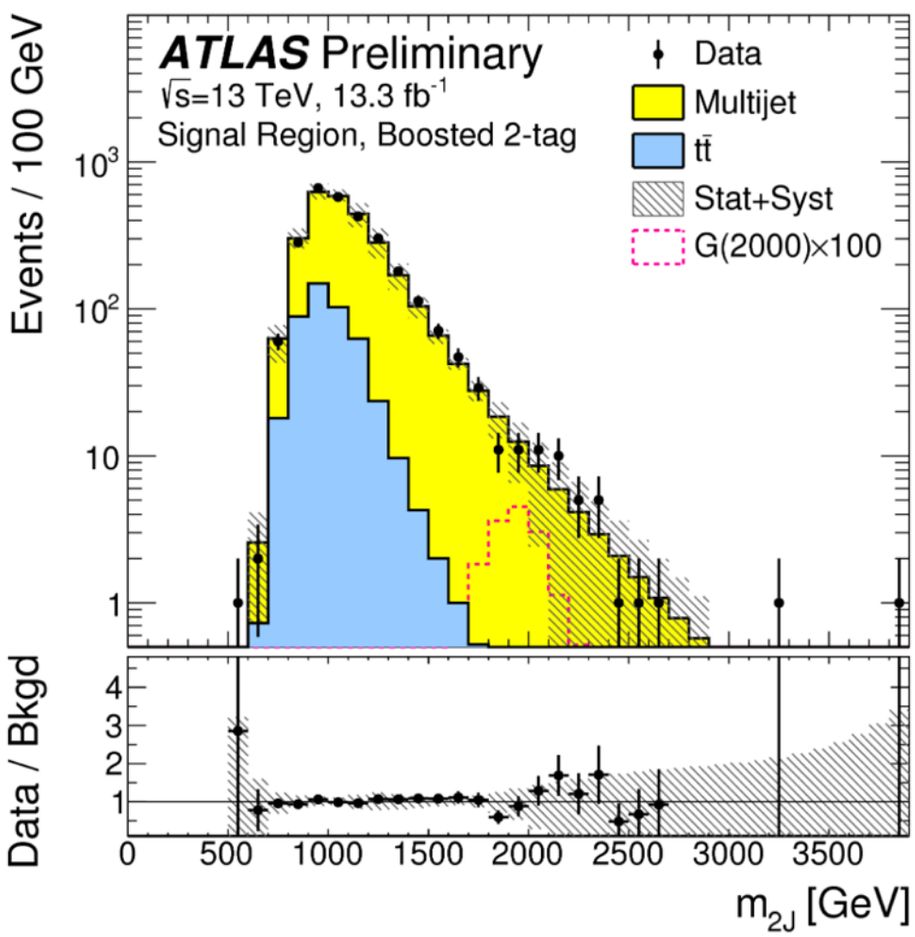
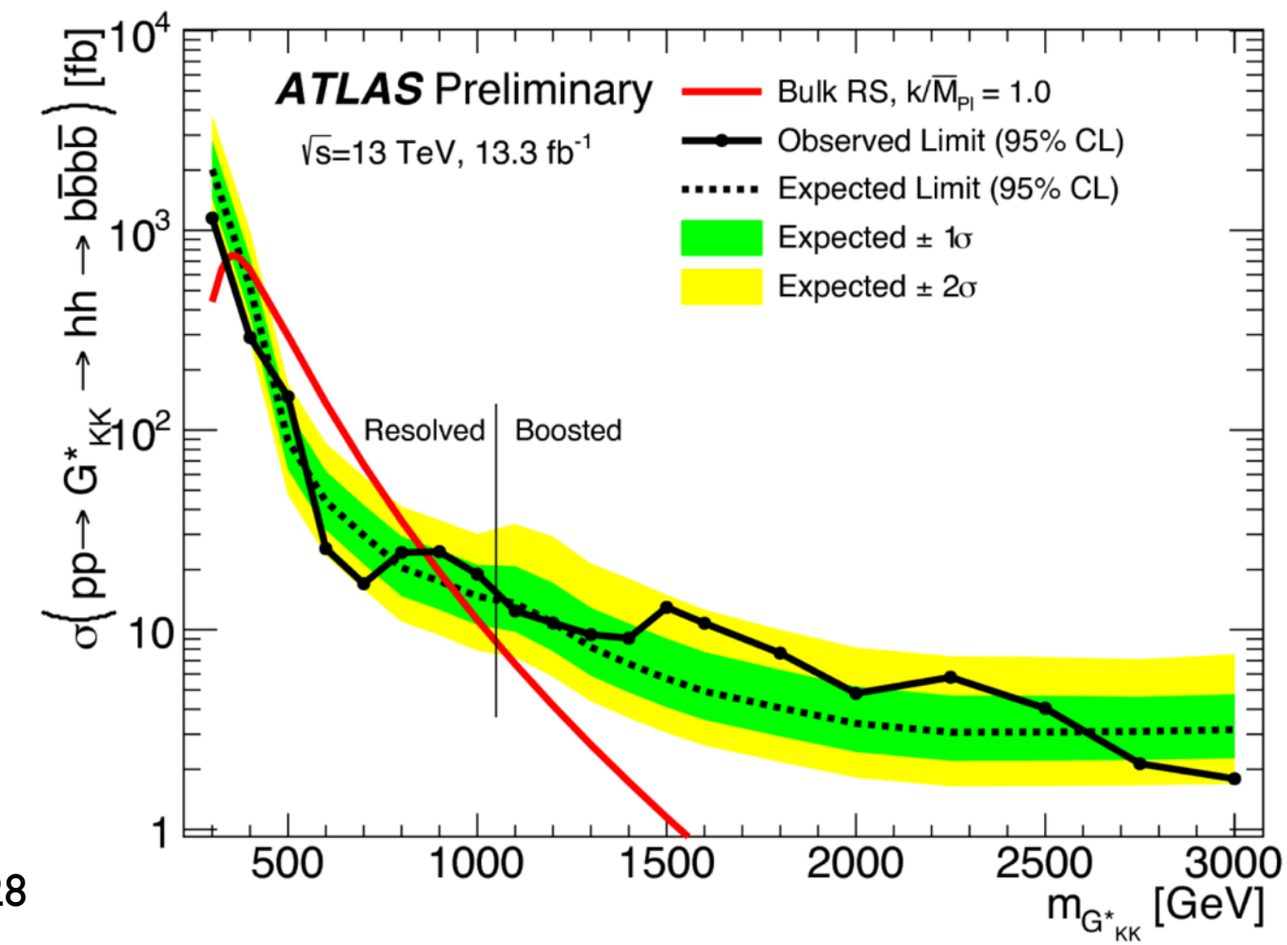
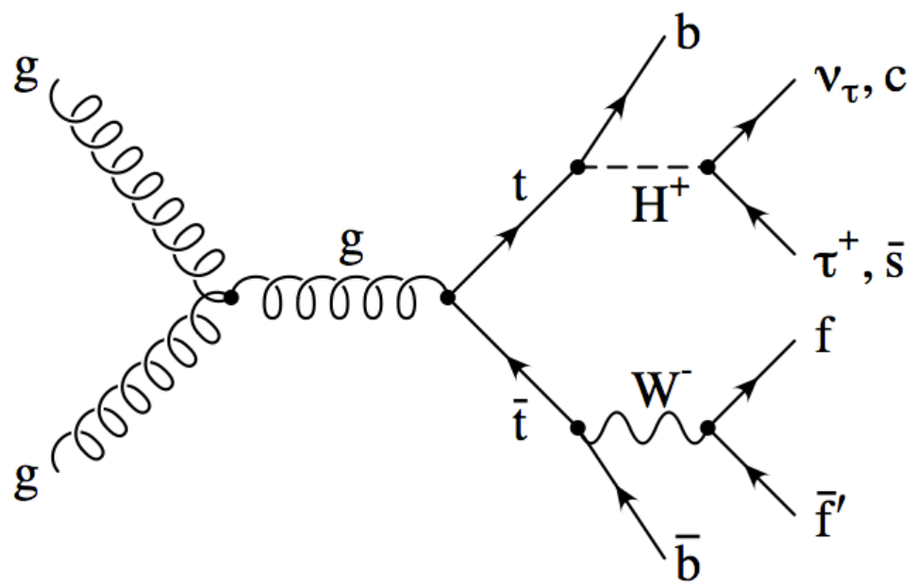
- Results: Limit at 95% CL for pp→hh→bbbb) < 330 fb
  - Excluded mass range: 360 GeV < $m(G_{KK})$ < 860 GeV (expected 380 GeV < $m(G_{KK})$ < 910 GeV)





Charged Higgs Searches in ATLAS

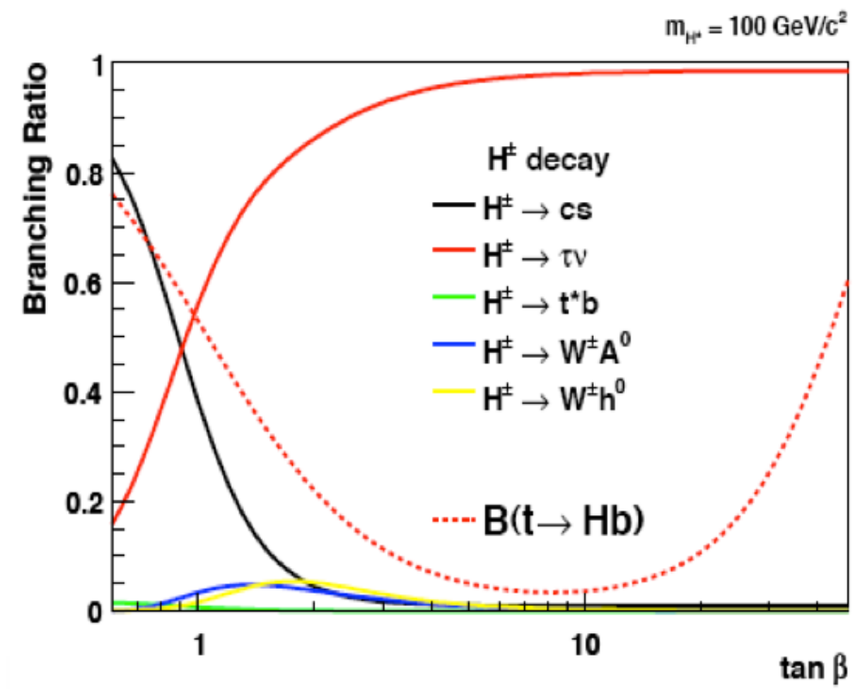


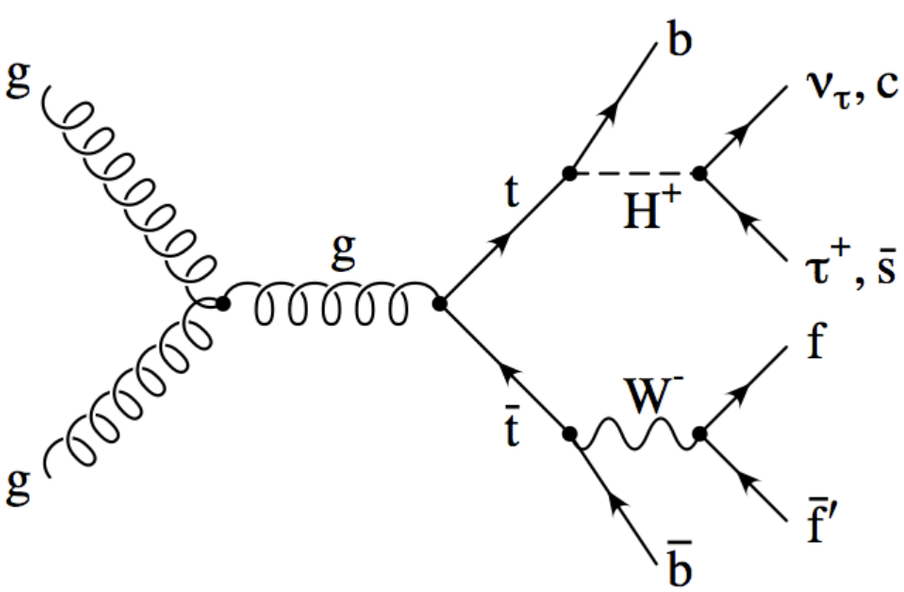
Charged Higgs $H^{\pm}$

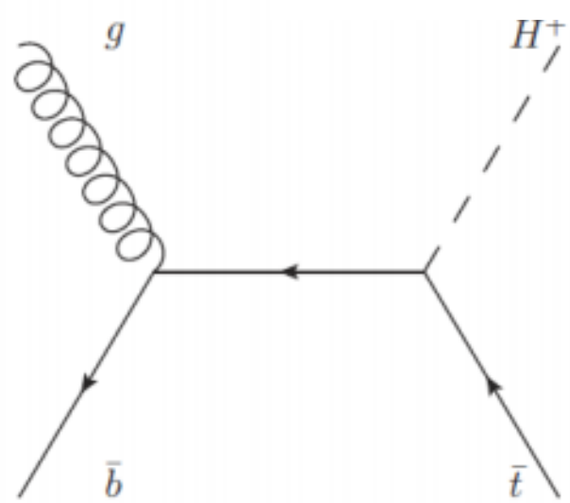
(or maybe $H^{\pm\pm}$)

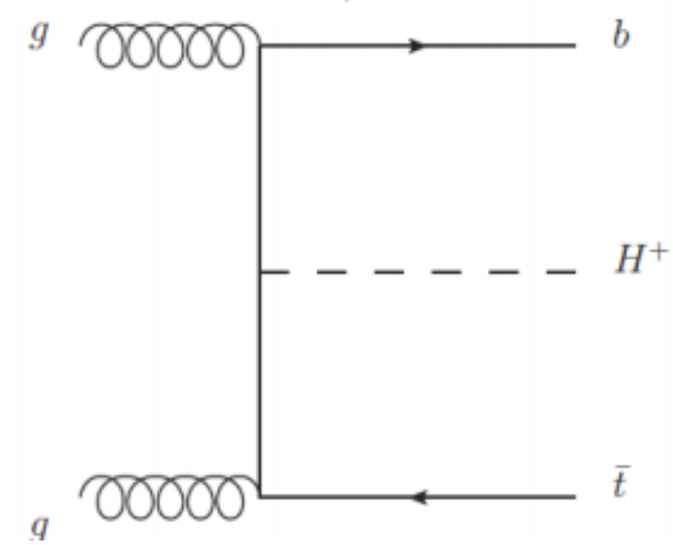
Charged Higgs Searches

- Charged Higgs bosons could be expected from the MSSM Higgs sector (or more generally 2HDM)
- H^+ Production:
  - Light H^+: $pp \rightarrow tt \rightarrow bW\,bH^+$
  - Heavy H^+: $gb \rightarrow tH^+$ and $gg \rightarrow tbH^+$
- H^+ Decay:
  - Light H^+: Almost exclusively to $\tau\nu$ (at low $\tan\beta$ predominantly to $c\bar{s}$)
  - Heavy H^+: tb; $\tau\nu$; $\chi^+\chi^0$
- ATLAS charged Higgs searches with taus:
  - Use final states with $\tau\nu jjb$ and $\tau\nu jjbb$
  - $tt \rightarrow [H^\pm b][Wb] \rightarrow [\tau\nu b][qqb]$
  - $gb \rightarrow [t][H^\pm] \rightarrow [qqb][\tau\nu]$
  - $gg \rightarrow [tb][H^\pm] \rightarrow [qqbb][\tau\nu]$



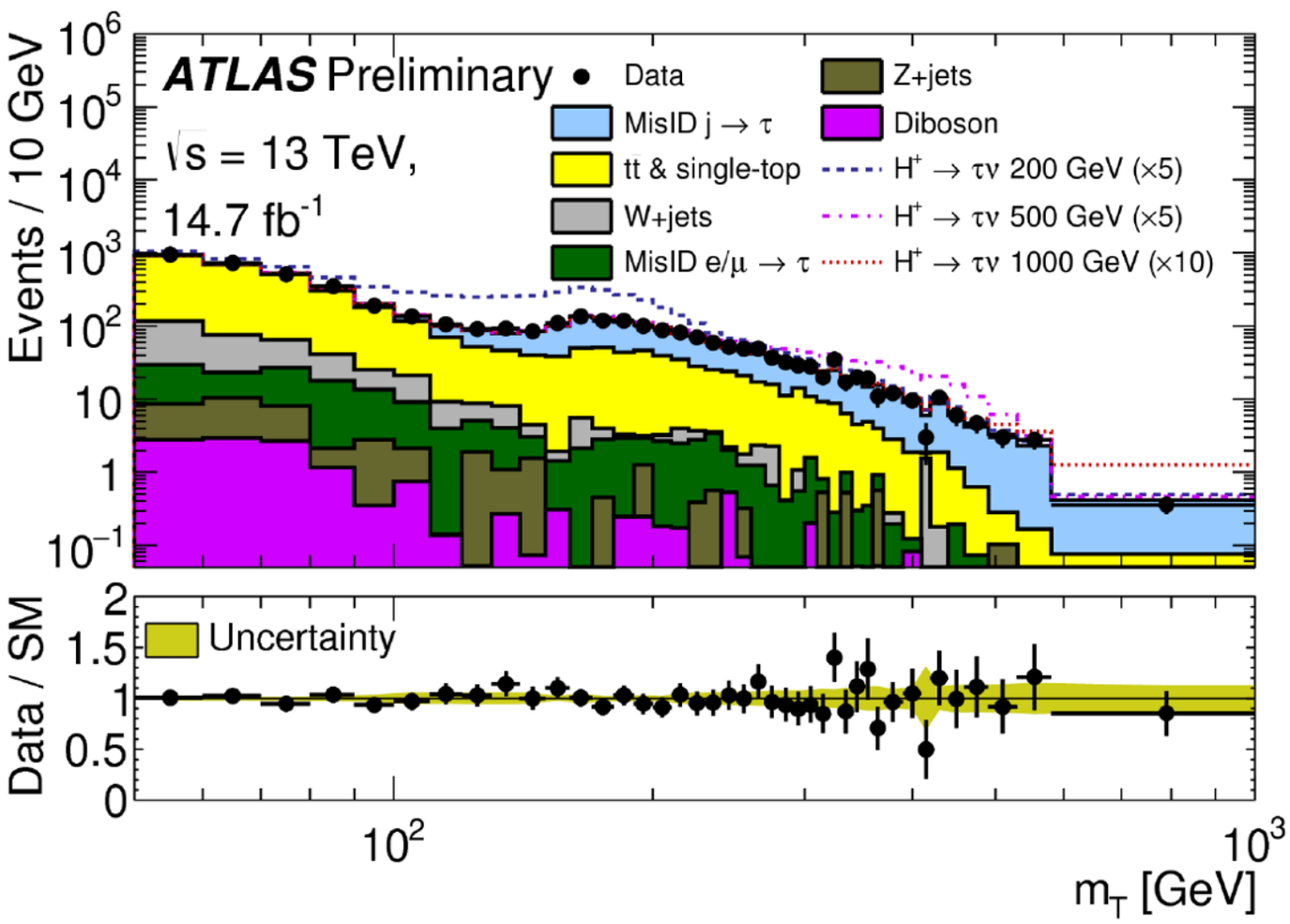


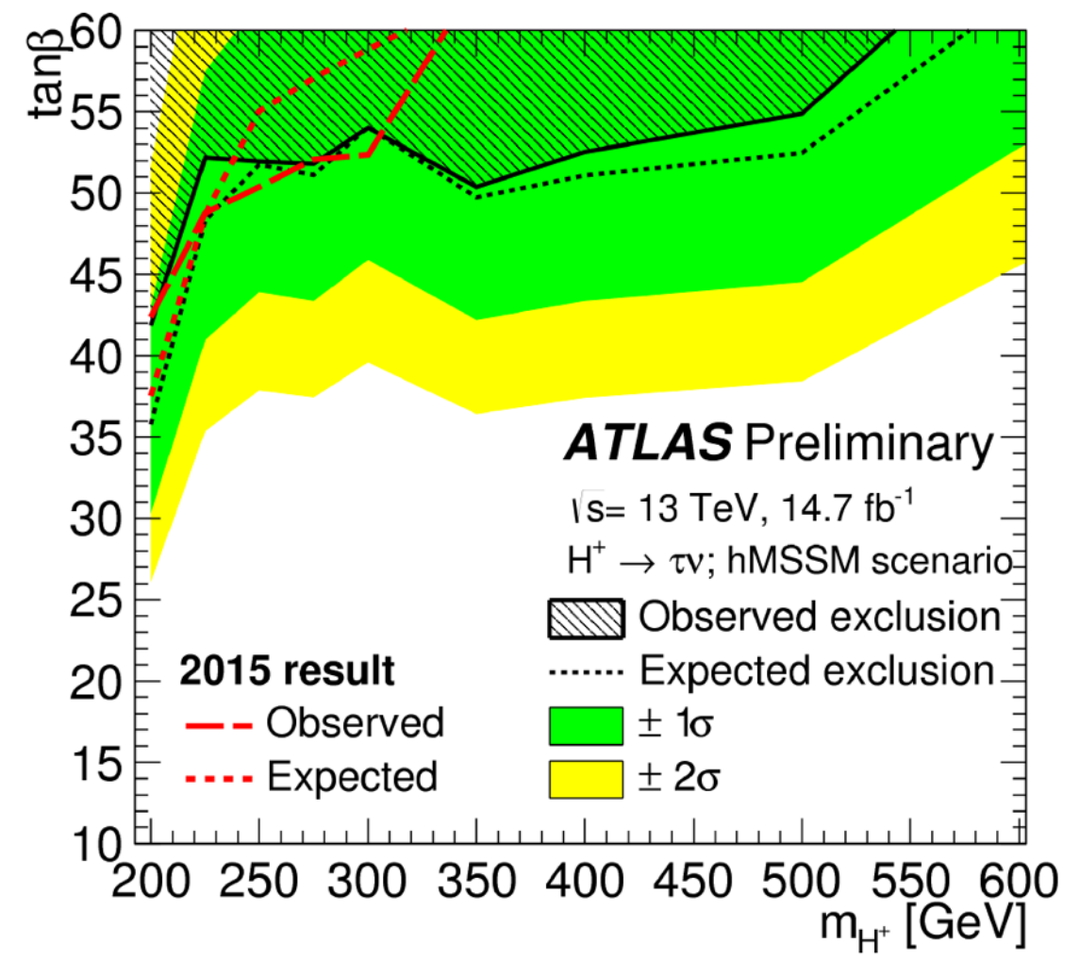




Run-II: Charged Higgs: $H^+ \rightarrow \tau\nu$

- For $M_{H+} > m_t$, production in association with a top-quark is dominant
- Discriminating variable is m_T $$m_T = \sqrt{2 p_T^{\tau} E_T^{miss} (1 - \cos \Delta\phi_{\tau, E_T^{miss}})},$$
- Signal region: 1 hadronic tau with $p_T > 40$ GeV; 3 jets with $p_T > 25$ GeV ($\geq$1 b-tagged jet); MET > 150 GeV
- Backgrounds: True hadronic taus using Monte Carlo which is normalized / checked in Control Regions with low mT; jet-to-tau fakes are estimated using a fake-factor method
- Observed hMSSM exclusion: $\tan\beta > 42$-60 at $m_{H+} = 200$-540 GeV





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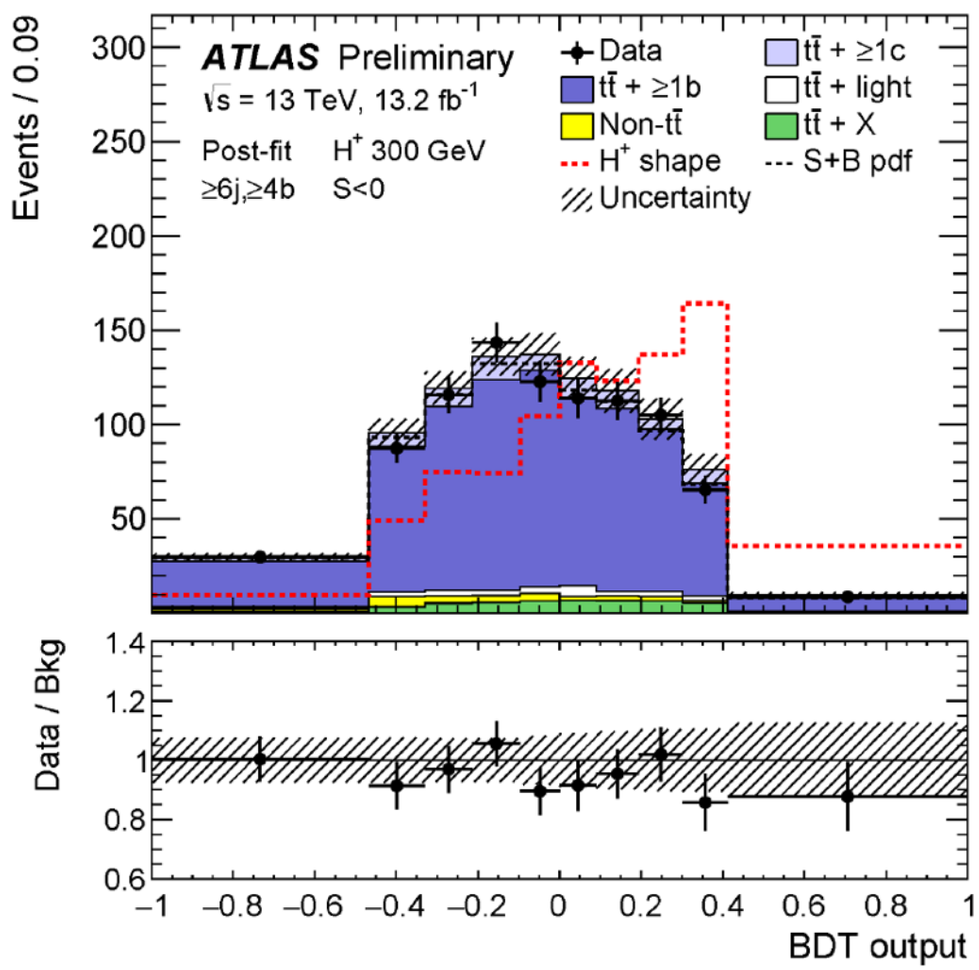
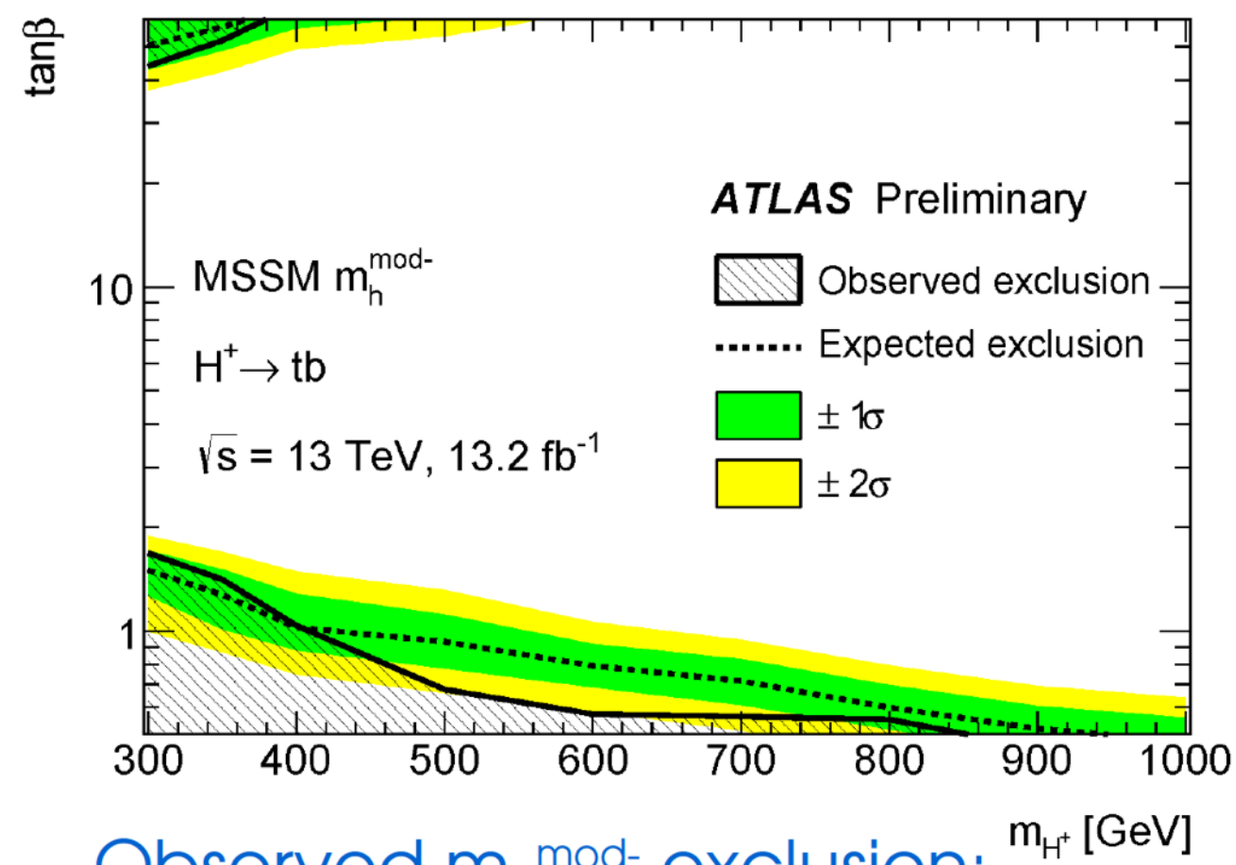
Run-II: Charged Higgs: $H^+ \rightarrow tb$

- For $M_{H+} > m_t$, production in association with a top-quark is dominant
- Here the lepton + jets final state is used (lepton = e, μ)
- Discriminant is a BDT-score calculated from 12 input variables
- Signal Regions: 1 lepton with $p_T > 25$ GeV; 5j3b, 5j≥4b, ≥6j3b and ≥6j≥4b
- Backgrounds: ttbar+jets production dominates, modeled using Powheg + Pythia6: reweigh ttbar+light and ttbar+≥1c to NNLO and ttbar+≥1b to NLO
- Control Regions: 4j2b, 4j≥3b, 5j2b and ≥6j2b
- $H_{T\ had}$ (sum of pT of selected jets) used for Control Region





Observed m_h^{mod-} exclusion:

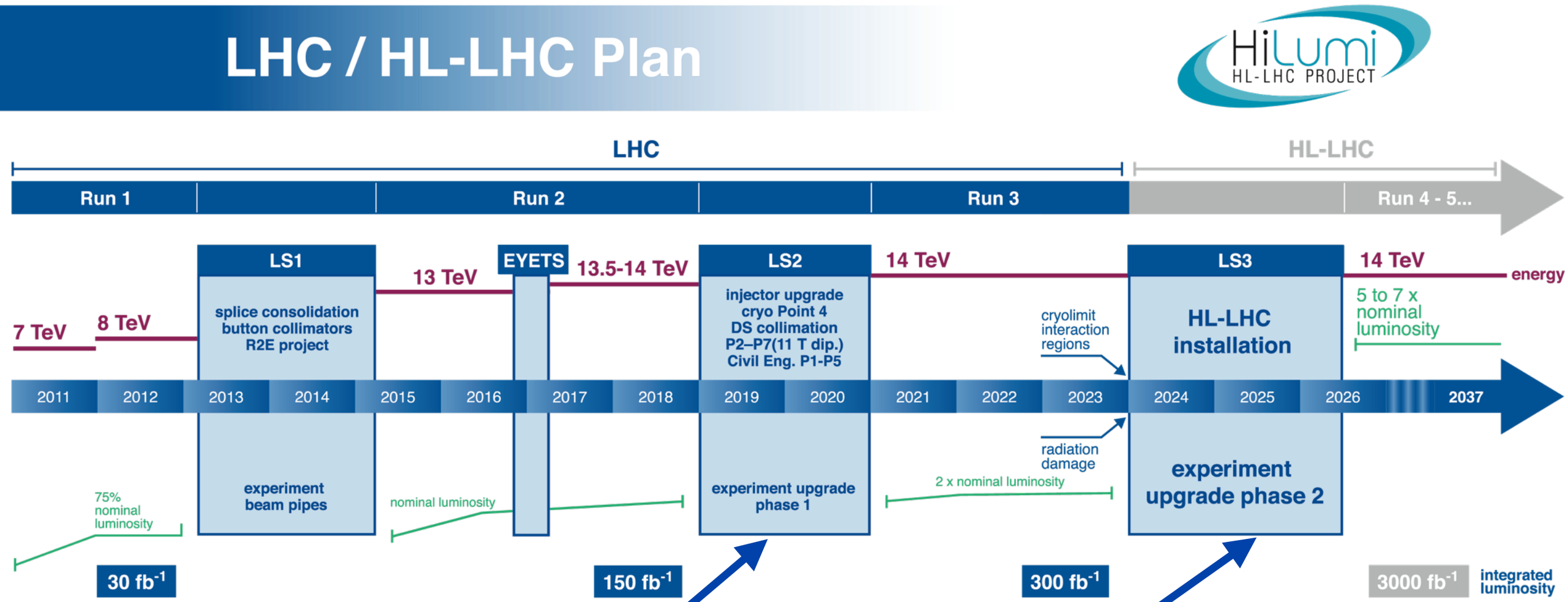
$\tan\beta < 1.7\text{-}0.5$ @ $m_{H^\pm}$ = 300-855 GeV

ATLAS-CONF-2016-089

Beyond Run-2

CERN LHC Plans for Run-3, 4-5,…

- ATLAS recording pp data for another 3 weeks in 2017… then all of 2018
- From all of Run-2, we expect to record ~150 fb^{-1}
- The long-term plan is to have about 3000 fb^{-1} of integrated luminosity
- ATLAS will need an upgrade…



Phase-I Upgrade for $L=2\text{-}3 \times 10^{34}\ cm^{-2}s^{-1}$ In the advanced stages… starting production

Phase-II Upgrade for $L=5\text{-}7.5 \times 10^{35}\ cm^{-2}s^{-1}$ In the design and prototyping stage

CERN LHC Plans for Run-3, 4-5,…

- ATLAS recording pp data for another 3 weeks in 2017… then all of 2018
- From all of Run-2, we expect to record ~150 fb^{-1}
- The long-term plan is to have about 3000 fb^{-1} of integrated luminosity
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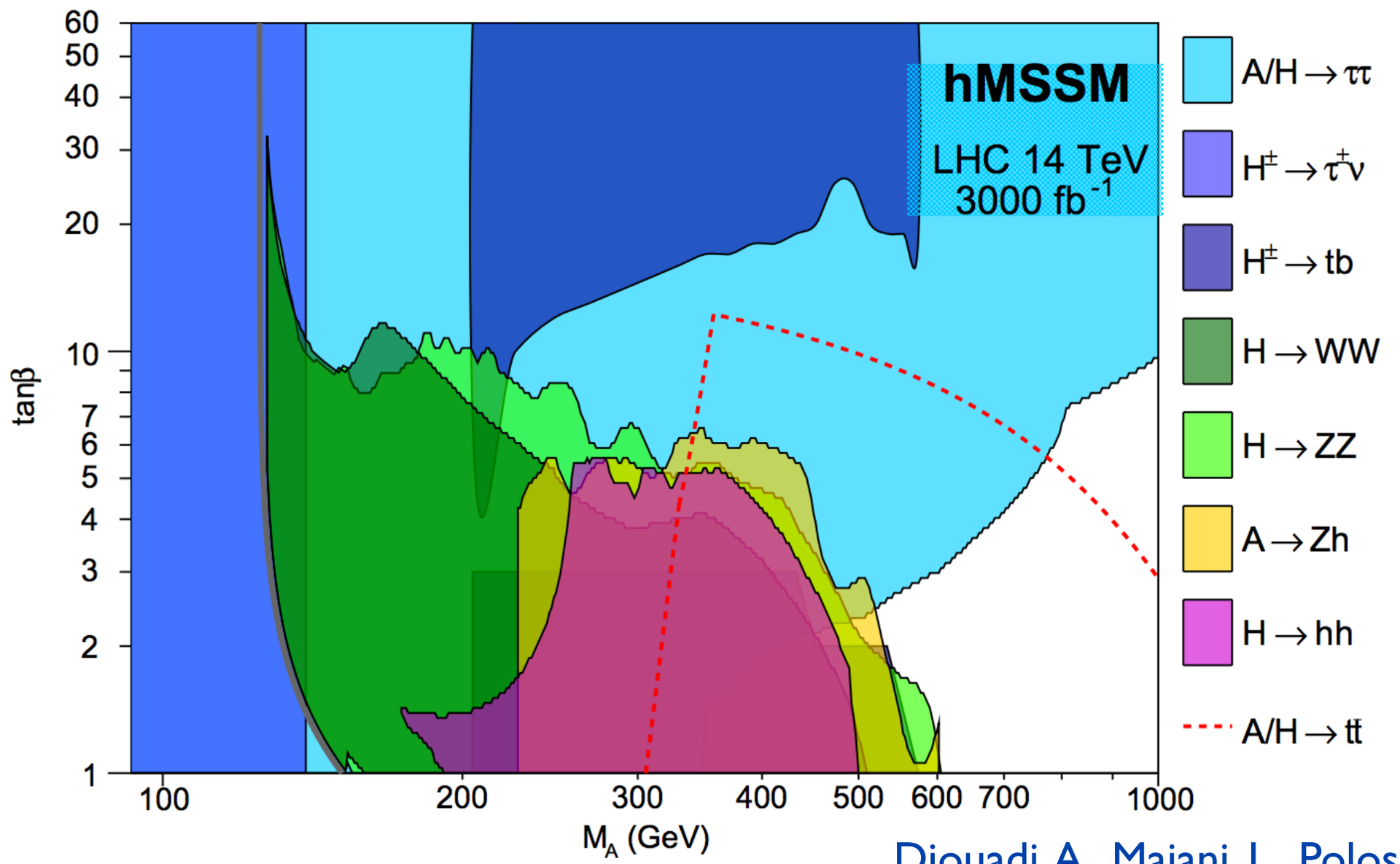
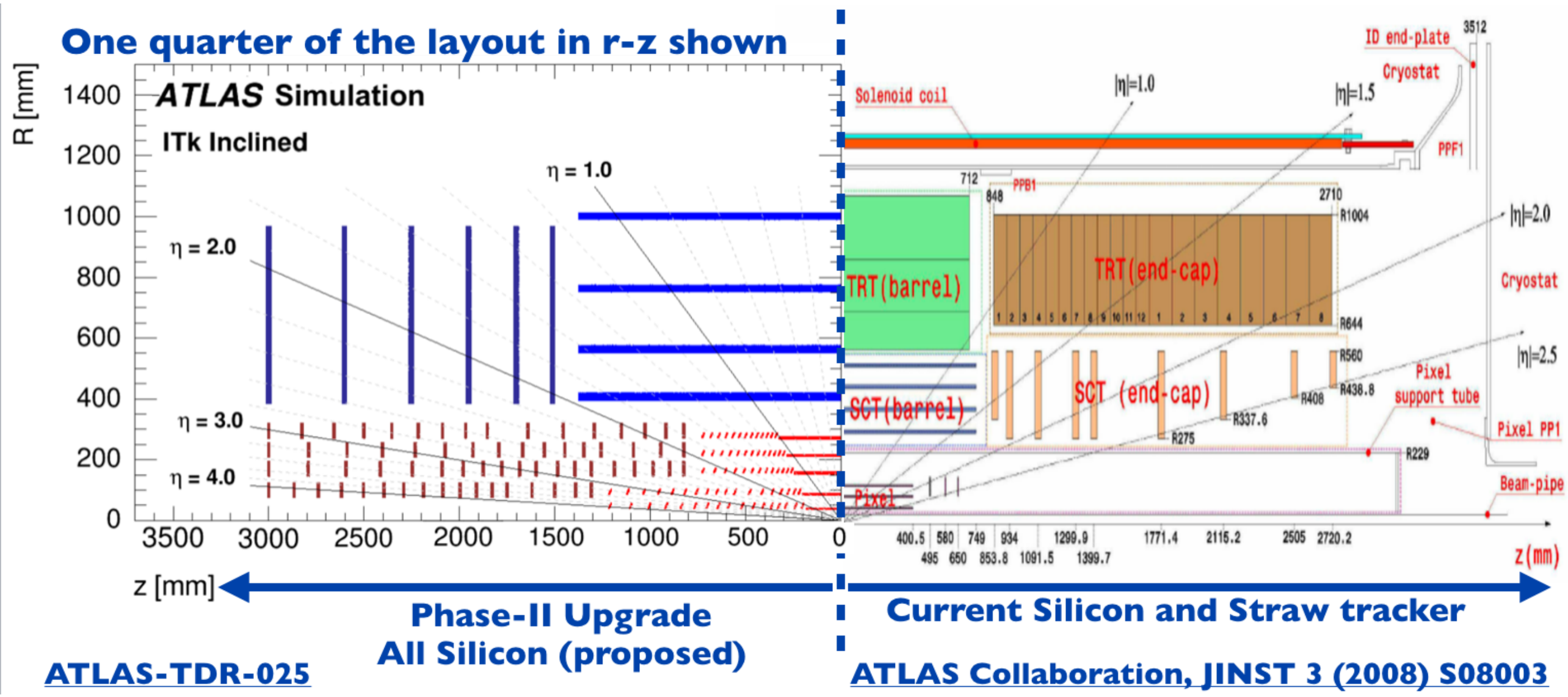


Djouadi, A., Maiani, L., Polosa, A. et al. JHEP 06 (2015) 168

Phase-II: All-Silicon Tracking Detector for ATLAS

- Increased radiation hardness
- Higher granularity to keep occupancies low
- Larger readout bandwidth capabilities
- Reduced material in front of calorimeters
- Extended coverage at high η

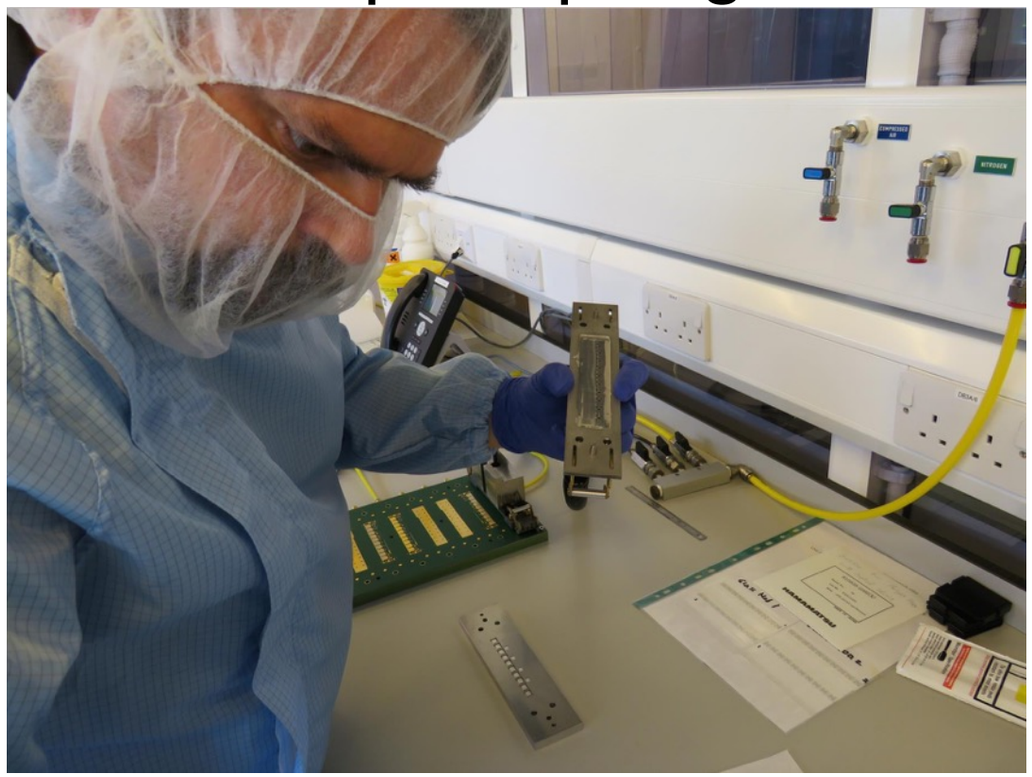


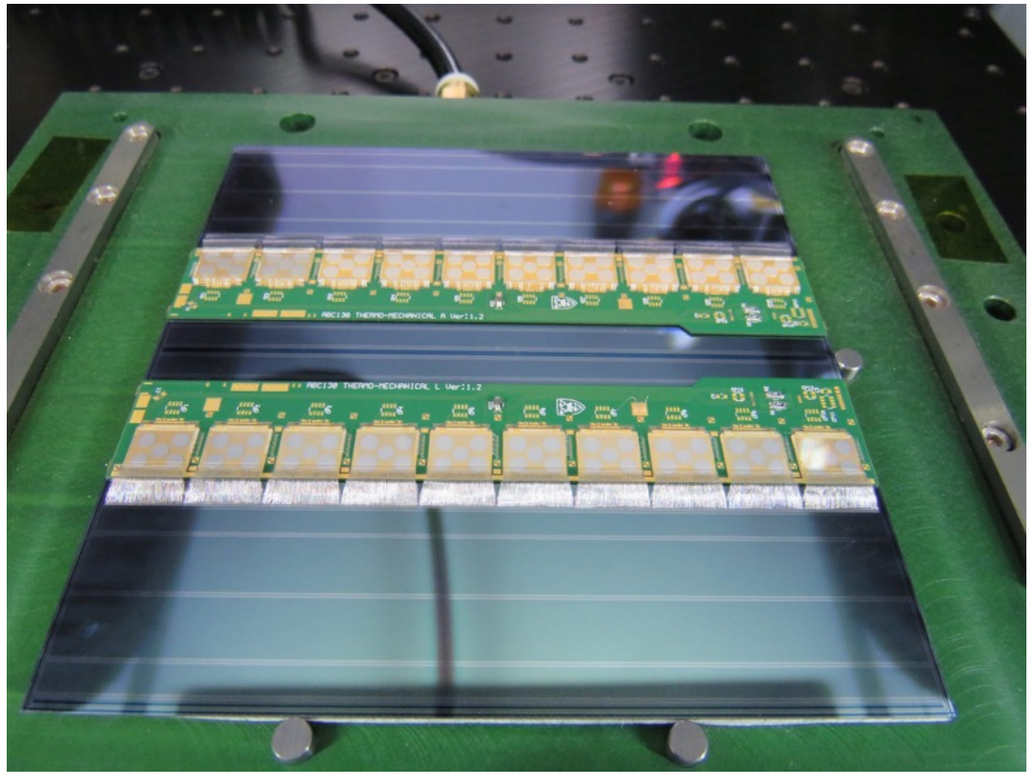
ATLAS-TDR-025

ATLAS Collaboration, JINST 3 (2008) S08003

Sheffield Semiconductor Development Facility

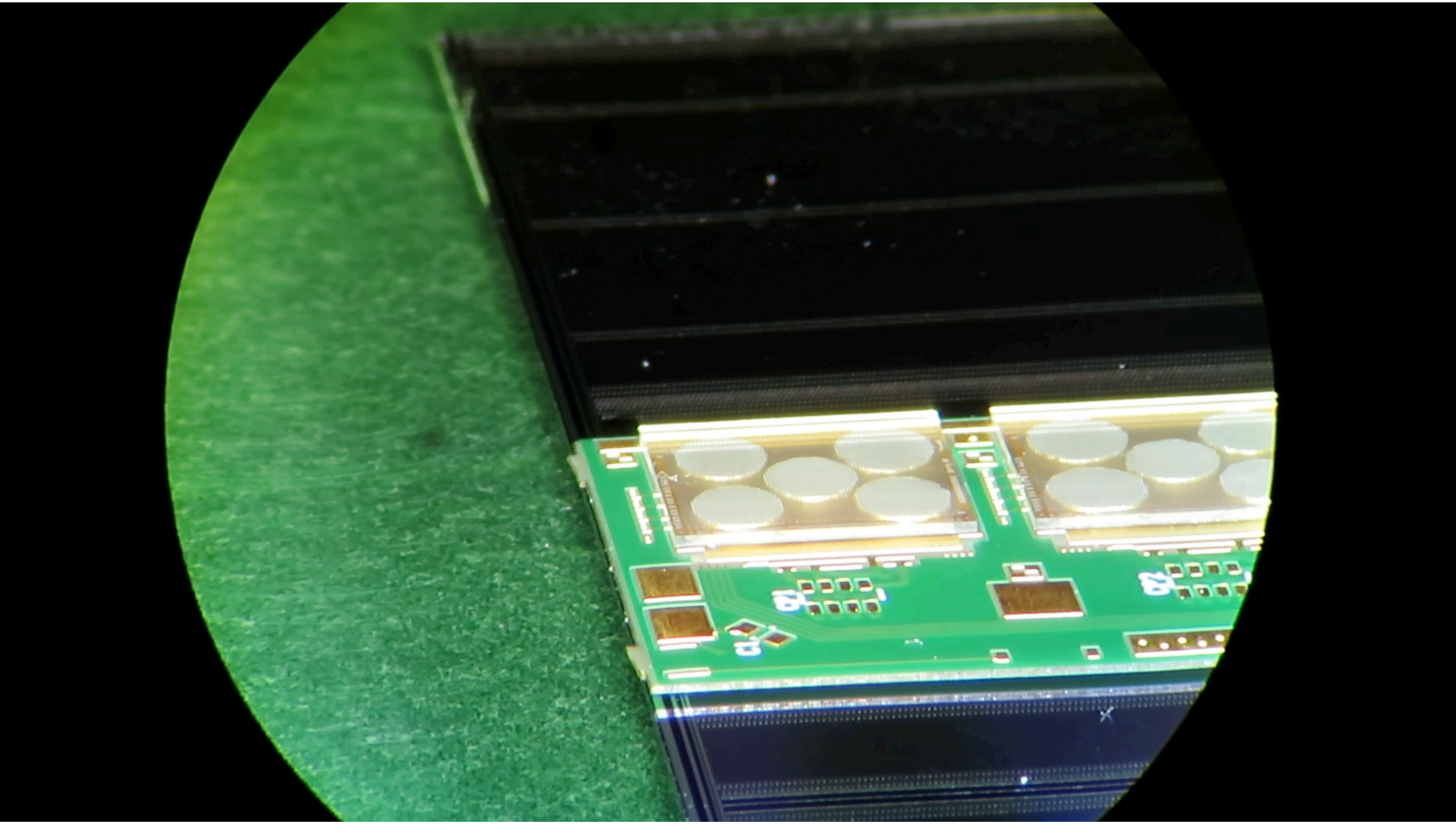
- Have been participating in ATLAS ITk detector module pre-production





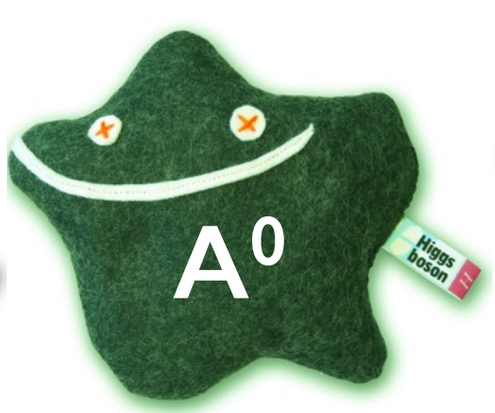
Movie Time: Our Hesse BJ-820 Wire-Bonder

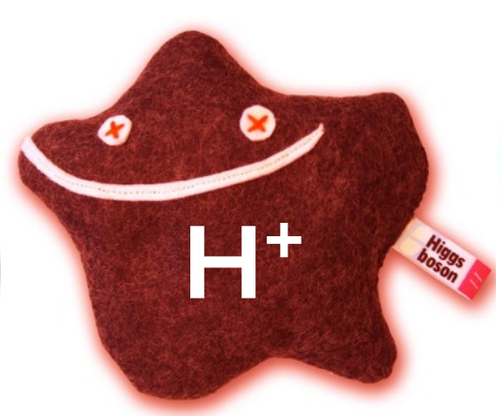
- Here is Sheffield's BJ-820 automatic wire-bonder in action…

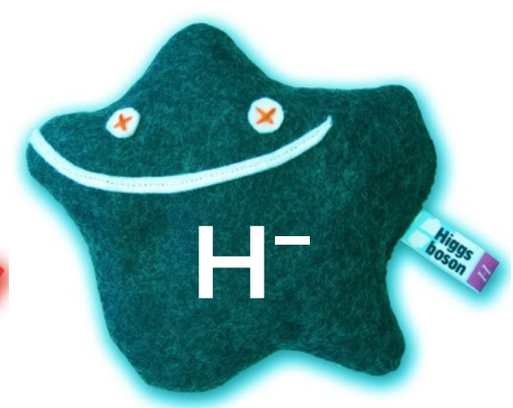


Conclusions and Outlook

- During Run-I ATLAS had a very active search program for Beyond the Standard Model Higgs bosons and we've been exploring the MSSM Higgs sector
  - Some searches in 7 TeV data not yet repeated at 8 TeV (e.g., MSSM $\phi \rightarrow \mu^+\mu^-$)
  - No hint of an extended Higgs sector during Run-I; We already pushed the constraints much further than previous searches (e.g., Tevatron)
- Even with a SM-like Higgs observed, BSM Higgs searches continue to be relevant (e.g., there are still regions of MSSM parameter space that are compatible with the observed Higgs at 125 GeV)
- Many new results using Run-II data… but this is only a fraction of what is available… no hit of an extended Higgs sector yet
- Impossible for me to touch on everything here… many models and searches…
- We have at least one new boson… maybe more! These are very exciting times!







Back-up Slides

Remaining LHC Schedule for 2017

LHC Schedule 2017 v1.5

LHC Draft Schedule for 2018

LHC Schedule

2018 v0.3

MSSM Benchmarks Used

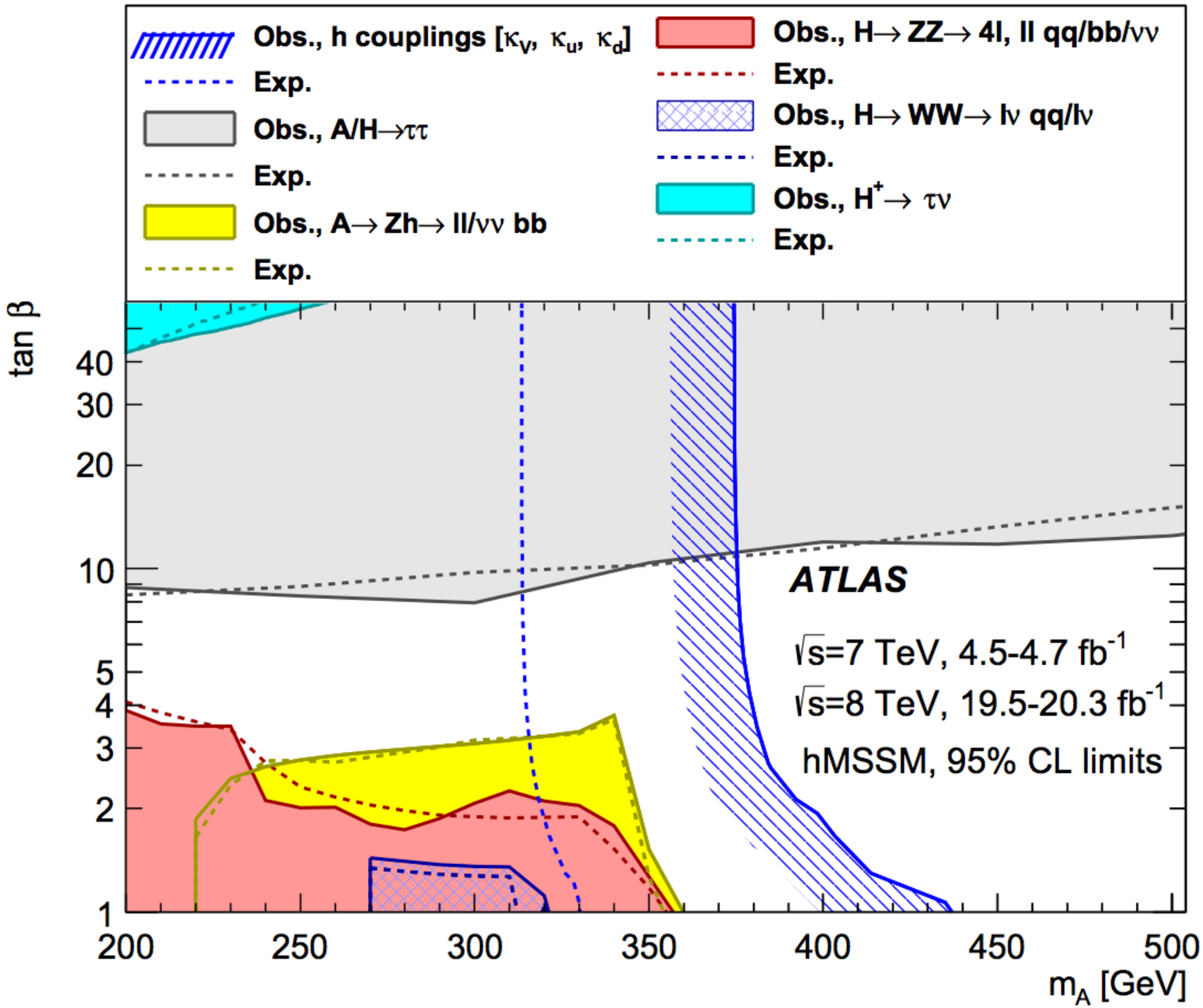
- Alternative benchmark scenarios

arXiv: 1302.7033v2

m_h^{max}	m_h^{mod+}	m_h^{mod-}
$m_t = 173.2$ GeV,	$m_t = 173.2$ GeV,	$m_t = 173.2$ GeV,
$M_{\rm SUSY} = 1000$ GeV,	$M_{\rm SUSY} = 1000$ GeV,	$M_{\rm SUSY} = 1000$ GeV,
$\mu = 200$ GeV,	$\mu = 200$ GeV,	$\mu = 200$ GeV,
$M_2 = 200$ GeV,	$M_2 = 200$ GeV,	$M_2 = 200$ GeV,
$X_t^{\rm OS} = 2\, M_{\rm SUSY}$ (FD calculation),	$X_t^{\rm OS} = 1.5\, M_{\rm SUSY}$ (FD calculation),	$X_t^{\rm OS} = -1.9\, M_{\rm SUSY}$ (FD calculation),
$X_t^{\overline{\rm MS}} = \sqrt{6}\, M_{\rm SUSY}$ (RG calculation),	$X_t^{\overline{\rm MS}} = 1.6\, M_{\rm SUSY}$ (RG calculation),	$X_t^{\overline{\rm MS}} = -2.2\, M_{\rm SUSY}$ (RG calculation),
$A_b = A_\tau = A_t$,	$A_b = A_\tau = A_t$,	$A_b = A_\tau = A_t$,
$m_{\tilde g} = 1500$ GeV,	$m_{\tilde g} = 1500$ GeV,	$m_{\tilde g} = 1500$ GeV,
$M_{\tilde l_3} = 1000$ GeV .	$M_{\tilde l_3} = 1000$ GeV .	$M_{\tilde l_3} = 1000$ GeV .

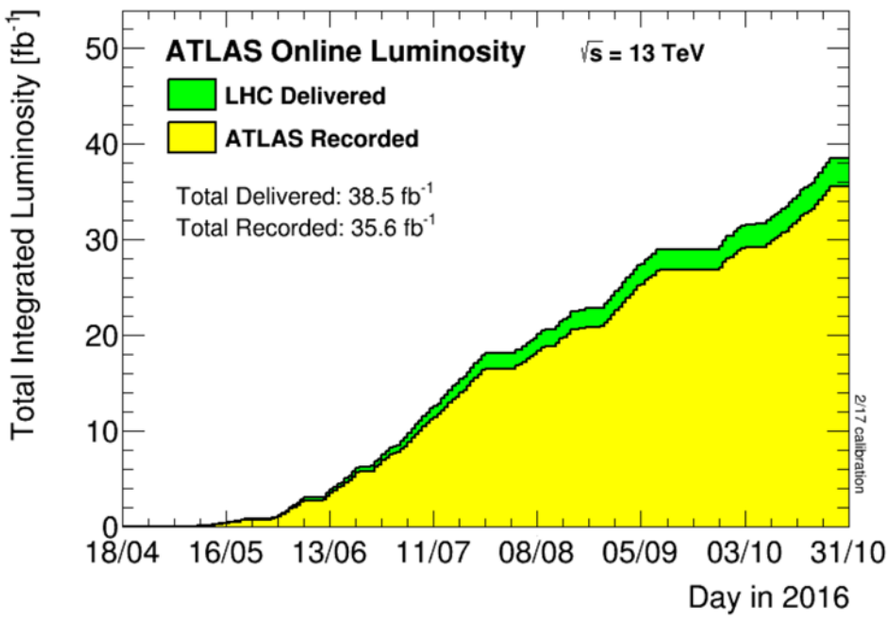
ATLAS Run-1 hMSSM Exclusion

arXiv: 1509.00672

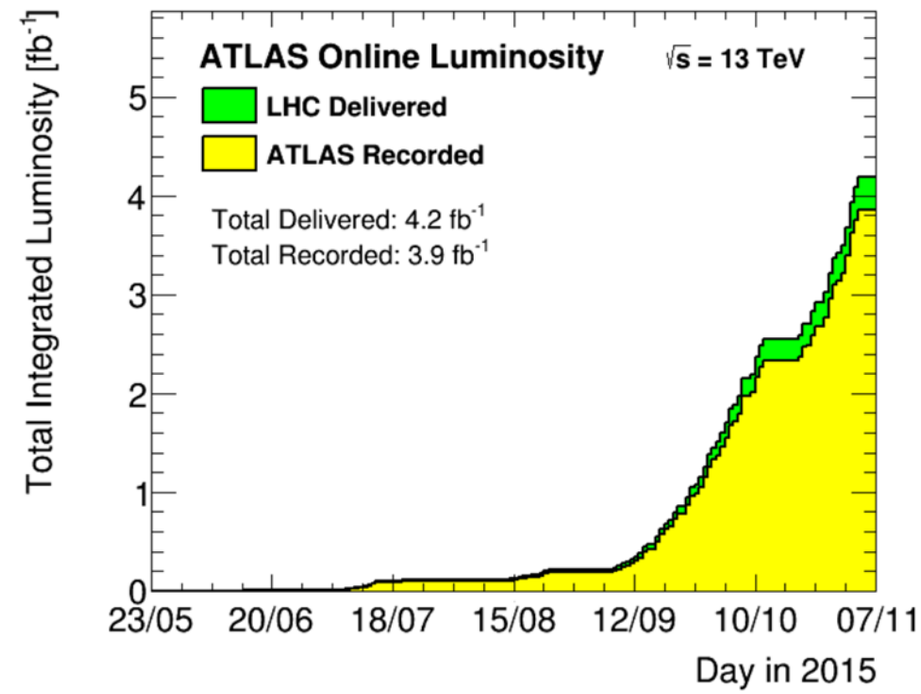


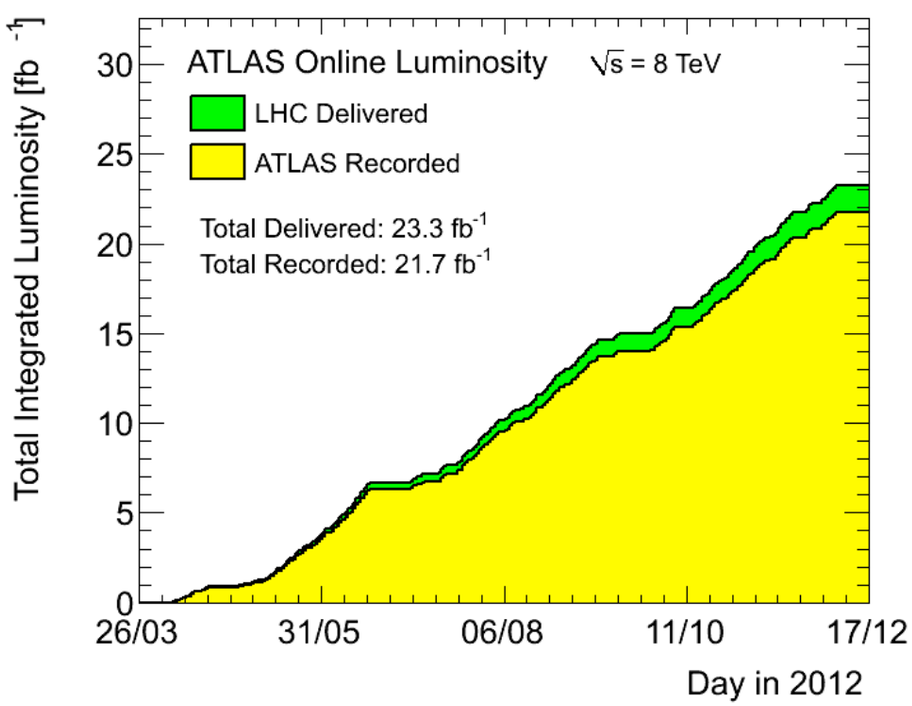
ATLAS Datasets

2016 13 TeV

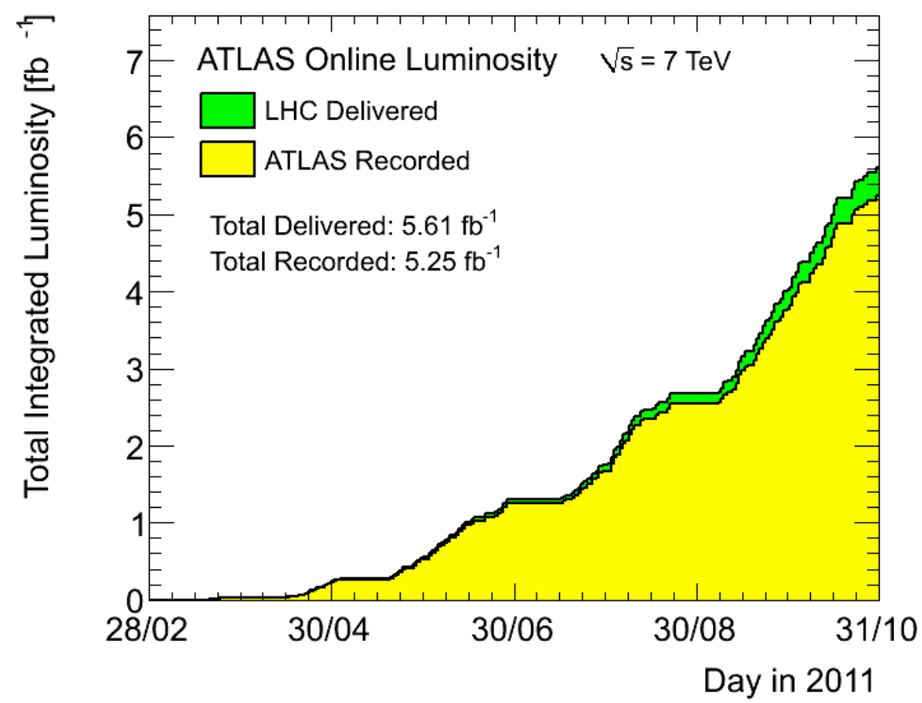


2015 13 TeV





2012 8 TeV



2011 7 TeV

Backup Slides for Doubly-Charged H^{++}

Run-1: Doubly Charged Higgs (H^{++})

- Predicted by many models
  - Left-Right symmetric models, "Seesaw Type-II" models including Higgs triplet models (H^0, H^+, H^{++}) and "Little Higgs" models
  - Possible observation of H^{++} at the LHC could provide more insight into neutrino masses
  - Predominantly produced in pairs via Drell-Yan $pp \rightarrow H^{++}H^{--}$
- This is performed as a generic same-sign di-lepton spectrum search

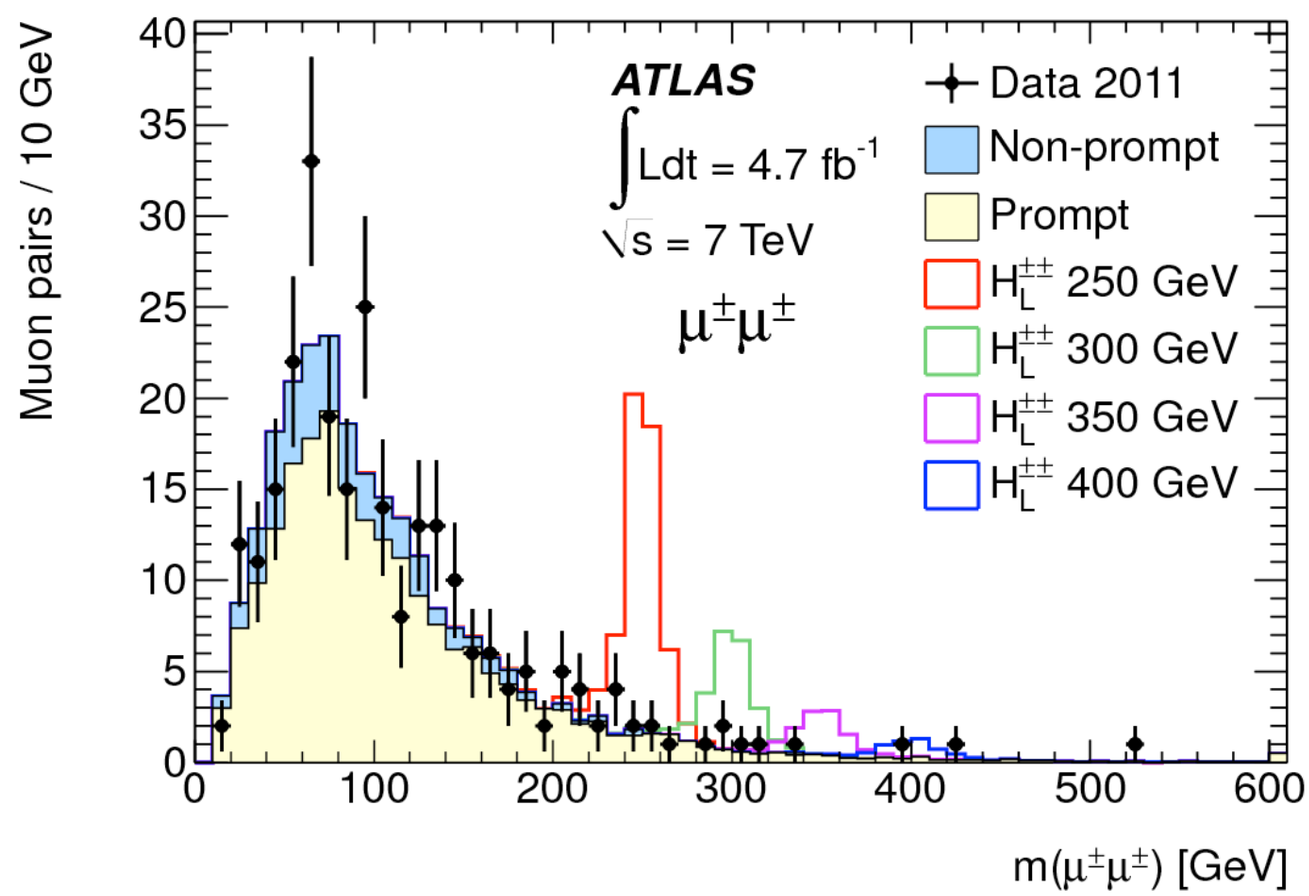
Dominant background to di-muon search at low masses comes from non-prompt muons (from heavy-flavor decays, or decays in-flight of pions or kaons)

- ATLAS Run-I paper on 7 TeV:

  Eur. Phys. J. C 72 (2012)

- And on 8 TeV:

  JHEP 03 (2015) 041



Run-1: Doubly Charged Higgs (H^{++})

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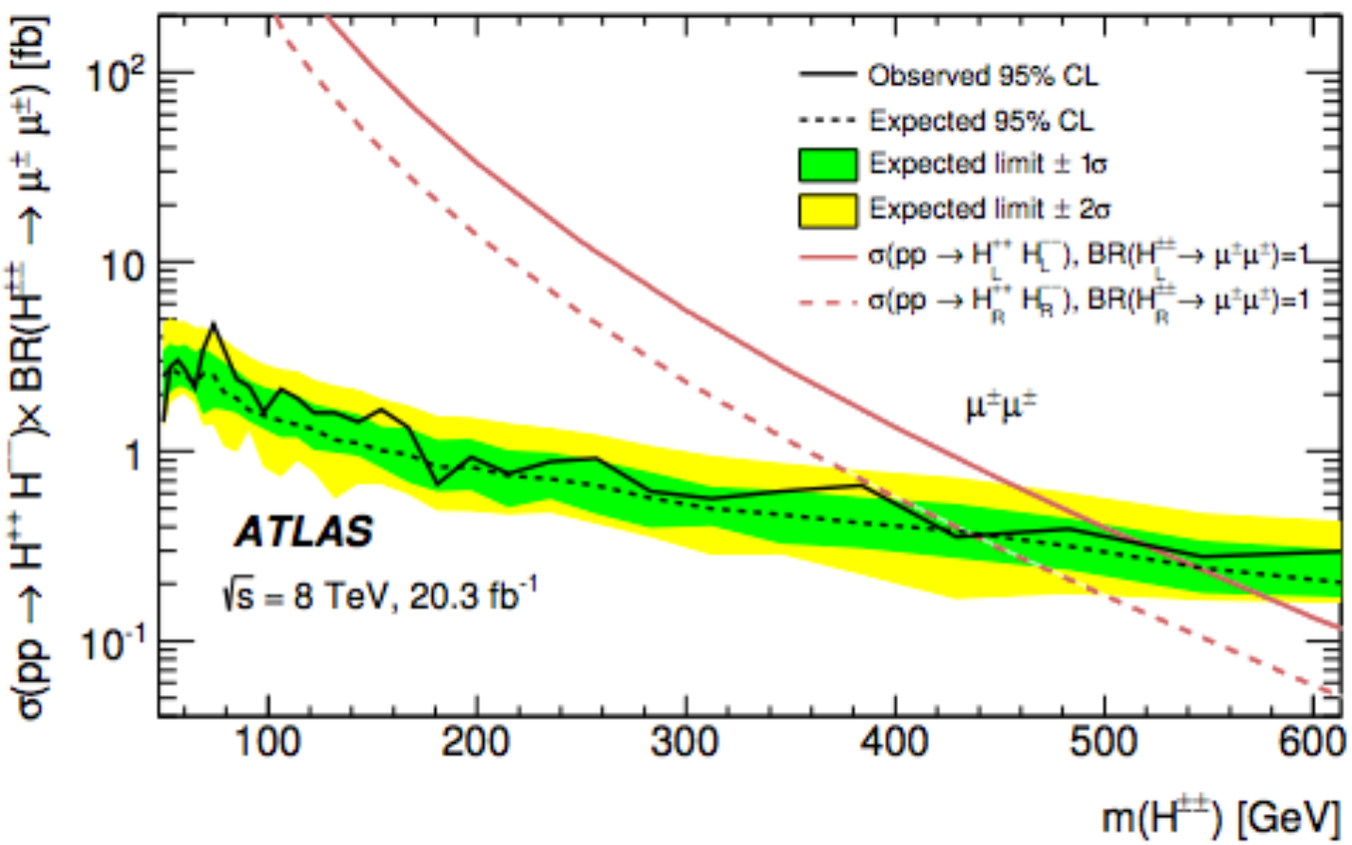
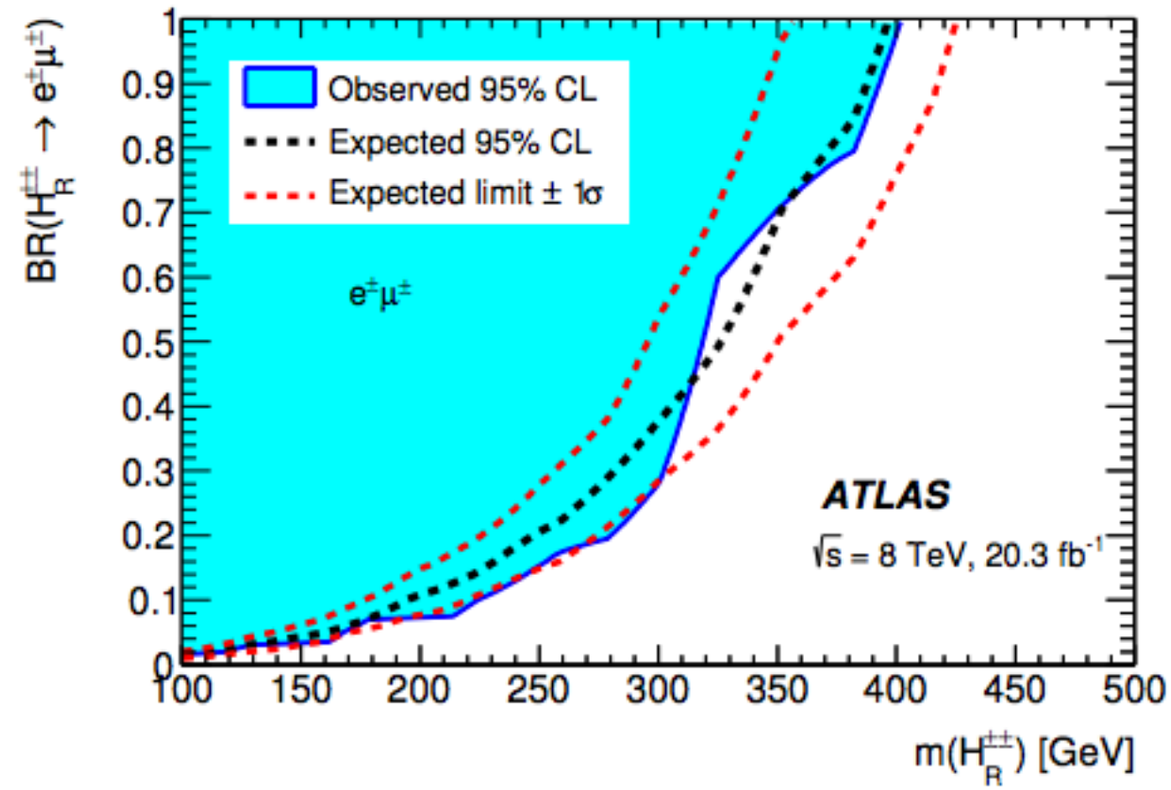
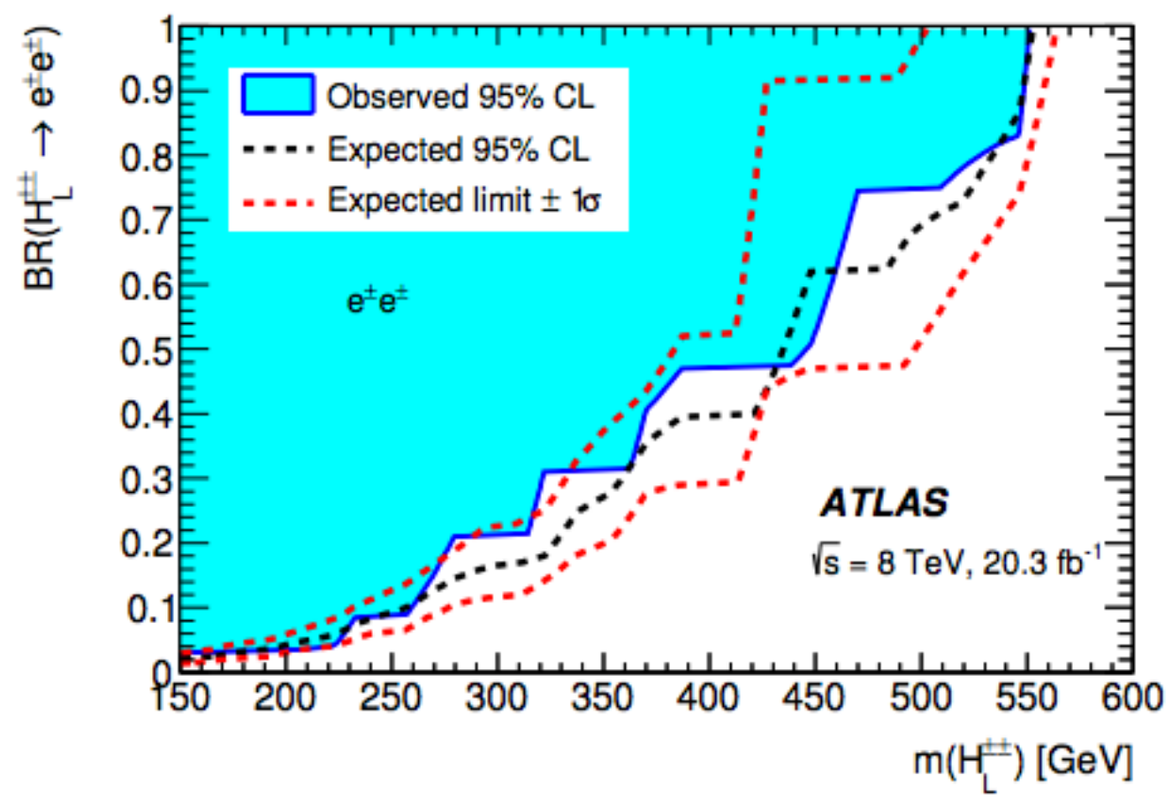
- Exclusion limits from 8 TeV in 20 fb^{-1}
  - Assuming $qq \rightarrow Z/\gamma^* \rightarrow H^{++}H^{--}$ to pairs of $\mu^\pm\mu^\pm$, $e^\pm e^\pm$, $e^\pm\mu^\pm$
  - Limits on $H^{\pm\pm}$ mass of 396 GeV - 553 GeV; BR=100%

$H_L^{\pm\pm}$ couple to both the Z and photons
$H_R^{\pm\pm}$ only couple to photons







Run-II: Doubly Charged Higgs (H^{++})

- Looks like $H^{++}H^{--}$ production cross section ~doubles going from 8 to 13 TeV
- Strong limits from 8 TeV data with 20 fb^{-1}… 13 TeV doubly charged Higgs searches start to get interesting in ~5 - 10 fb^{-1} range?

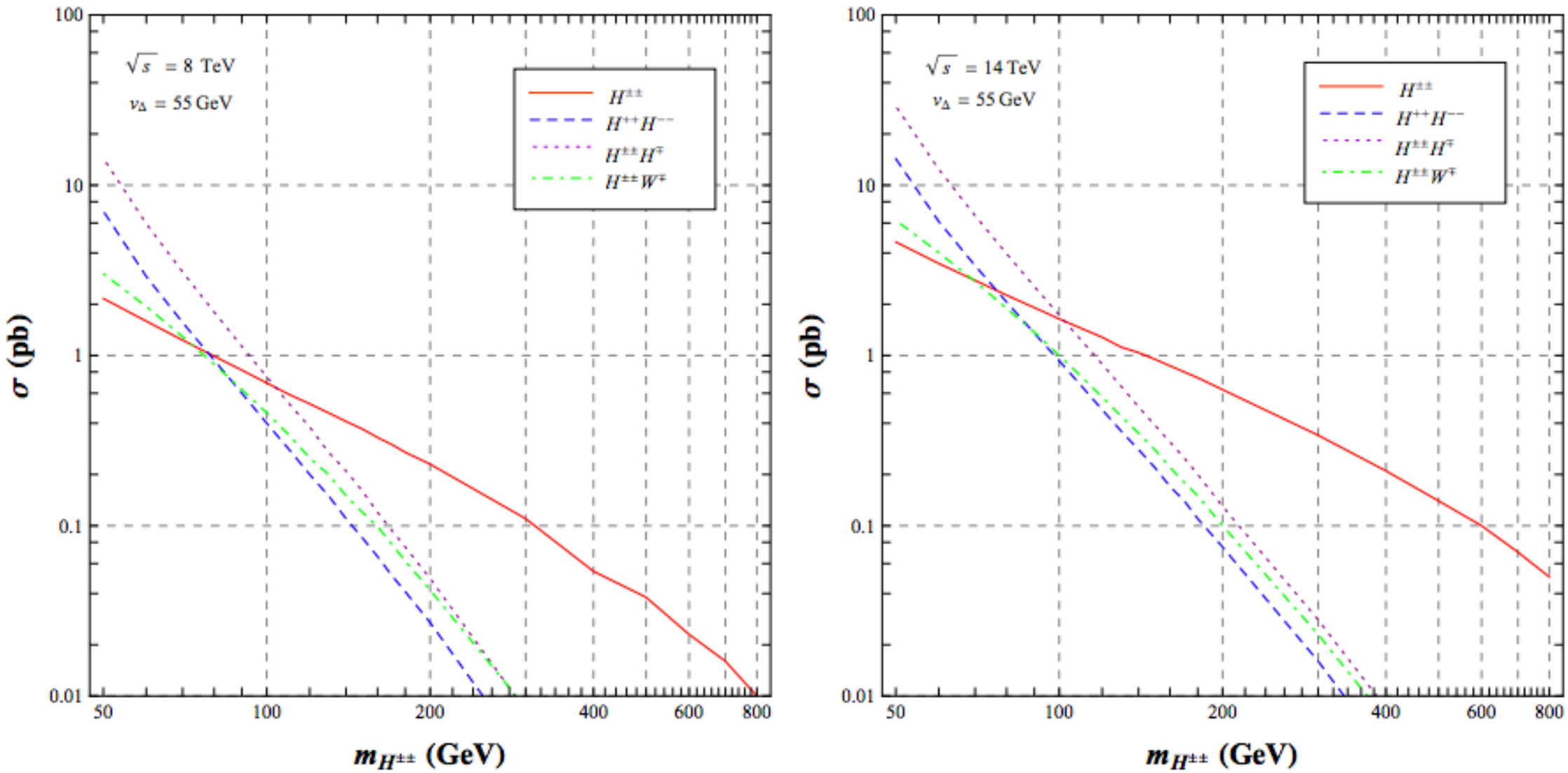
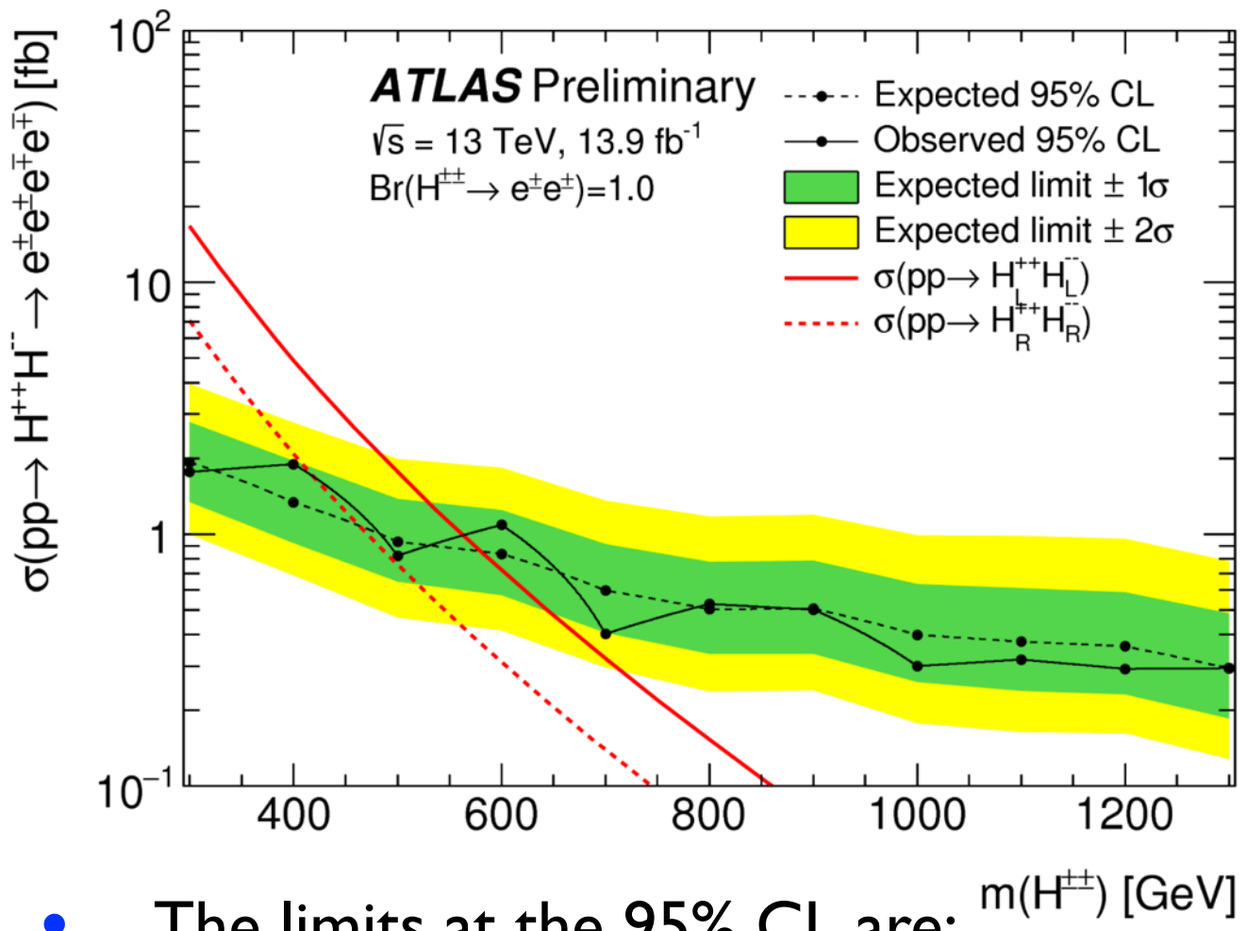
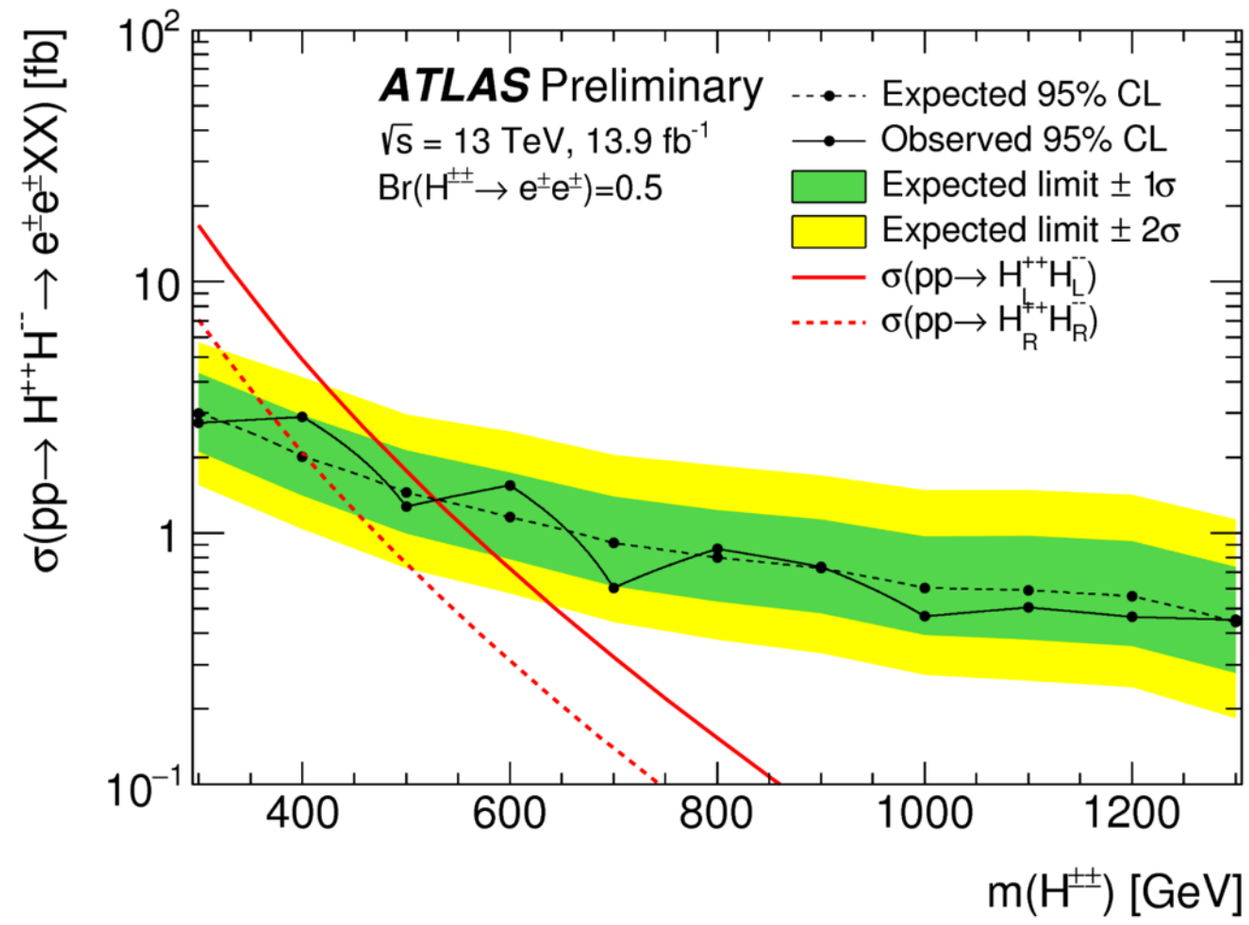


FIG. 1: Cross sections of the doubly charged Higgs bosons in various production channels for $v_\Delta = 55$ GeV. The collision energy is assumed to be 8 TeV in the left plot and 14 TeV in the right plot. The CTEQ6L PDF's are used. Phys. Rev. D85 (2012) 095023

Run-II: Doubly Charged Higgs (H^{++})

- Only publicly-available ATLAS result from Run-II for doubly charged Higgs is for the $e^{\pm}e^{\pm}$ channel… consider different fractions of the total BR.





- The limits at the 95% CL are:
  - For 100% BR: Lower limit of 420 GeV for a doubly-charged Higgs boson coupling to right-handed leptons ($H^{\pm\pm}_R$) and 570 GeV for a doubly-charged Higgs boson coupling to left-handed leptons ($H^{\pm\pm}_L$).
  - For 50% BR: Lower limits of 380 GeV for $H^{\pm\pm}_R$ and 530 GeV for $H^{\pm\pm}_L$.

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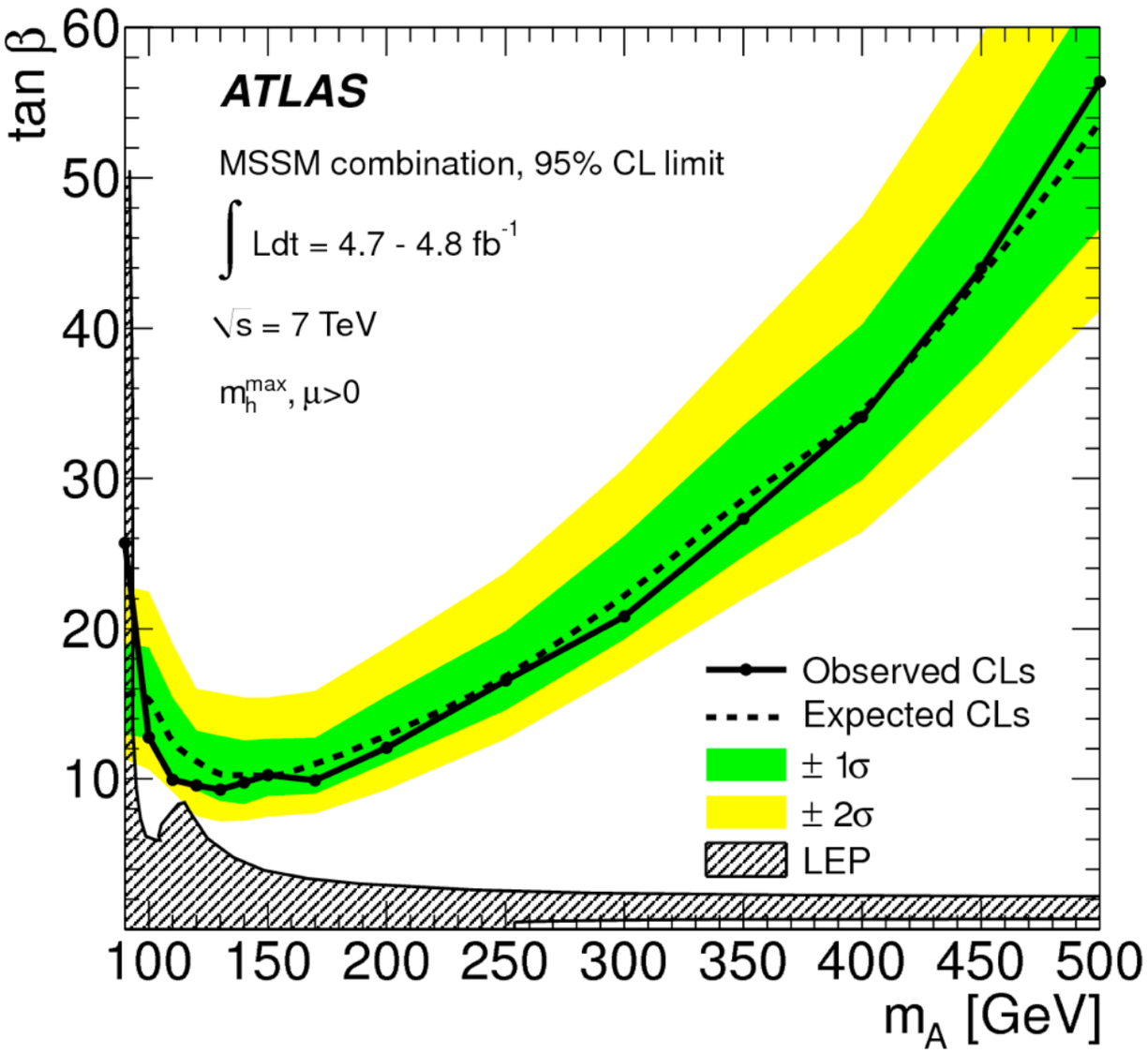
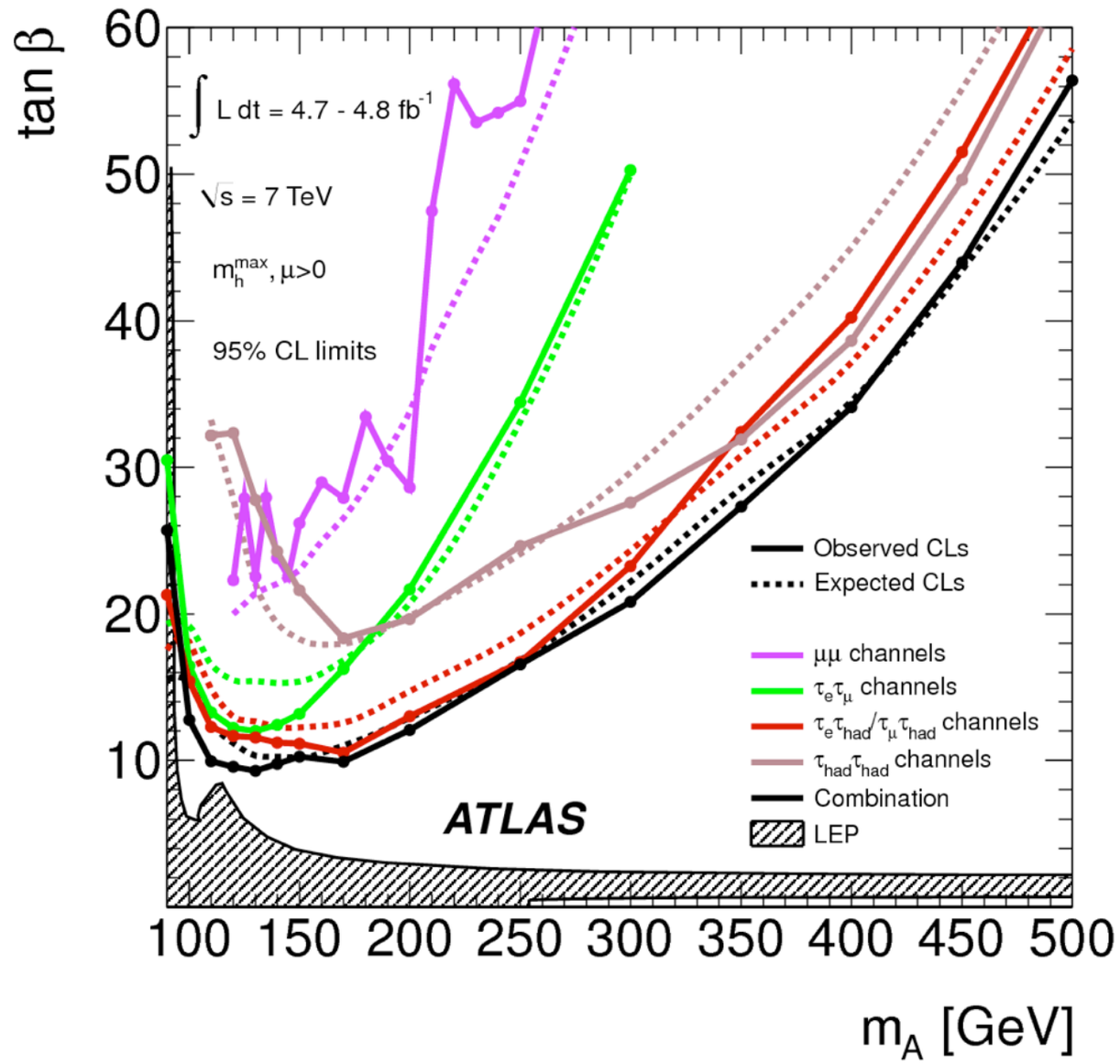
Backup Slides for $A/H \rightarrow \tau^+\tau^-$ and $\mu^+\mu^-$

ATLAS Run-1 MSSM Higgs Searches ($\phi \rightarrow \mu^+\mu^-$)

- Combine the τ_{lep}-τ_{had}, τ_{had}-τ_{had}, τ_e-τ_μ and $\mu\mu$ channels for one exclusion limit
  - Limit with the m_h^{max} benchmark scenario
  - Also determine a σ x BR limits

JHEP02 (2013) 095

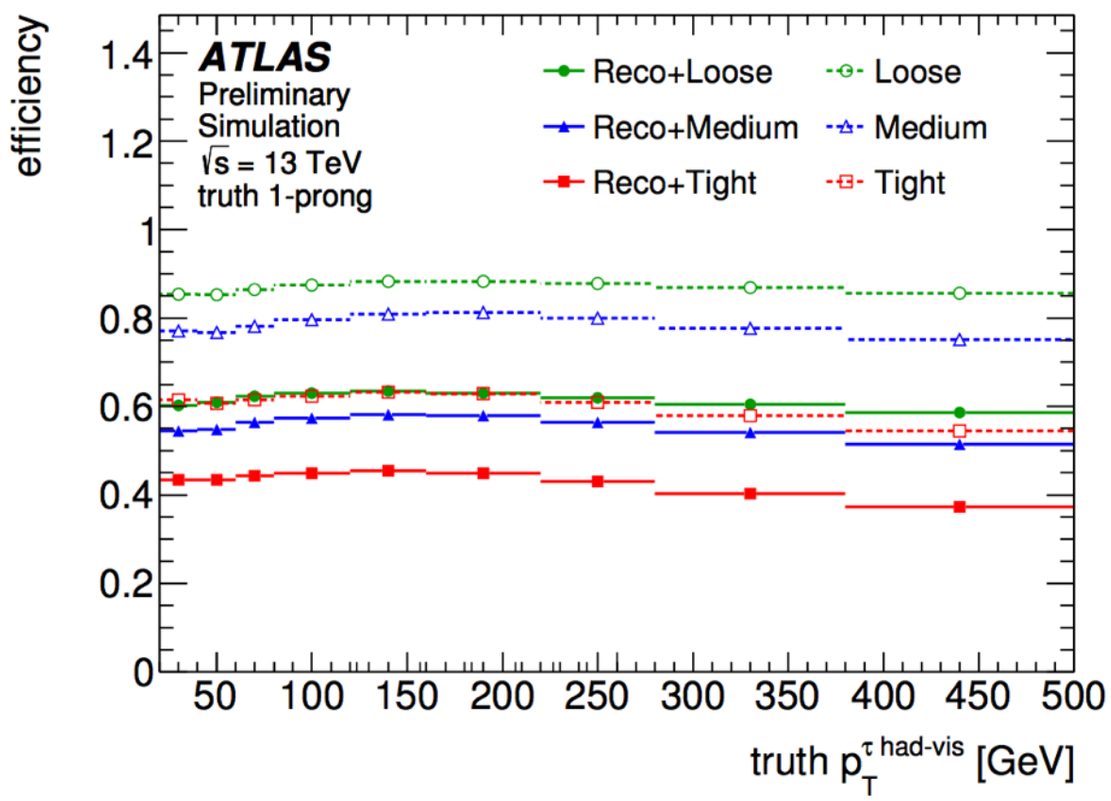


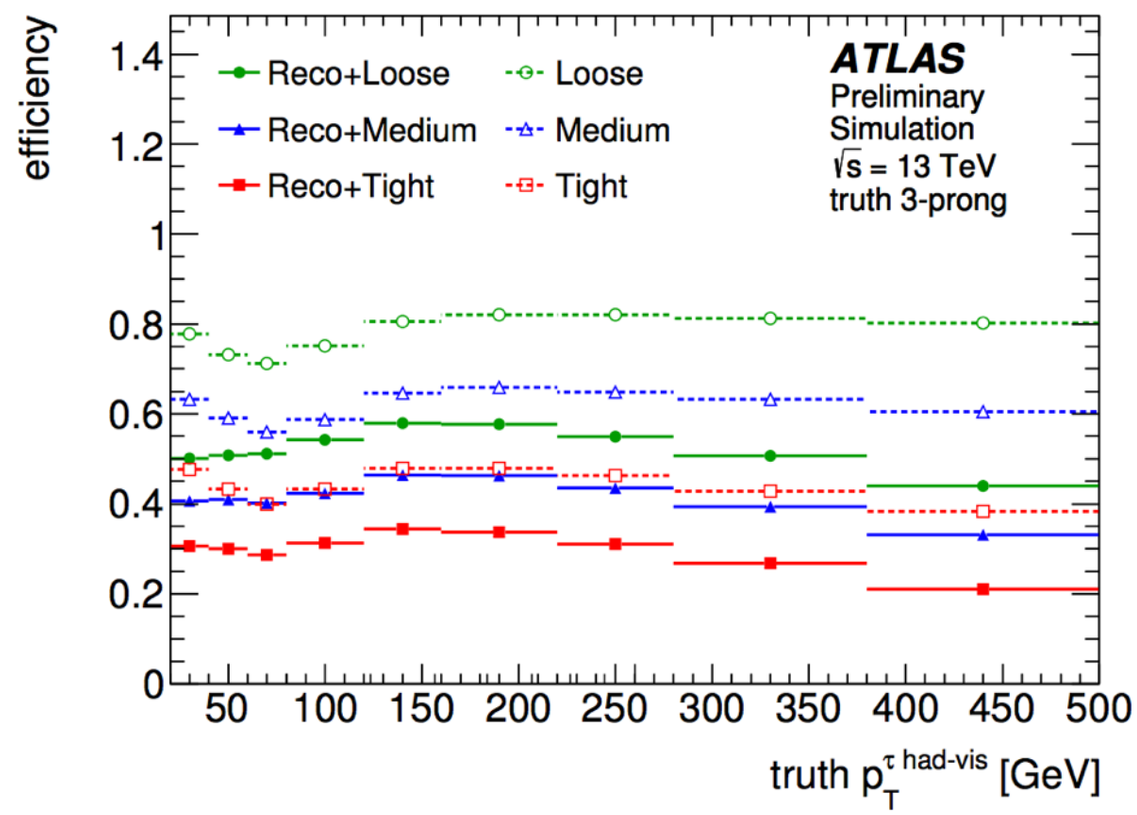


Reconstruction of hadronic τ decays

- The signature of hadronic τ decays are 1 or 3 tracks, collimated jet, possibly EM clusters

- Objects compatible with this signature are reconstructed
  - Seed from jet objects by considering each of them as a τ candidate
  - Identify a vertex consistent with a τ decay
  - Associate tracks within a core cone ($\Delta R \leq 0.2$) of the τ axis to jet objects





- Backgrounds from QCD jets, electrons and muons are rejected using dedicated algorithms (e.g., BDT used for rejection of jets) ATL-PHYS-PUB-2015-045
  - Discriminate using tracking information and cluster topology variables