ATLAS Physics

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For BNL ATLAS Group

Physics program for ATLAS (and LHC) is very broad:

- Study Standard Model (SM) processes at 14 TeV.

  Essential both for calibration and for backgrounds.

- Search for Supersymmetry (SUSY) with $M \lesssim 1\,\mathrm{TeV}$.

  Well motivated extension of SM. Could be early discovery.

- Search for Higgs bosons.

  Widely expected — but new kind of particle.

- Other searches (Exotics) and detailed measurements.

Plus studies of diffraction, B physics, heavy ions, ...

Standard Model Physics

First (usable) data: measure minimum bias and low-p_T jet events to tune Monte Carlo simulations [Moraes].

Running at $10^{31}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for one day $\Rightarrow 1\,\mathrm{pb}^{-1}$, producing about 1000 $Z \to ee$ events.

Measure $Z \to ee, \mu\mu$ and $W \to e\nu, \mu\nu$ to test EM calibration [Snyder], muon performance [Adams], and trigger [Rajagopalan].

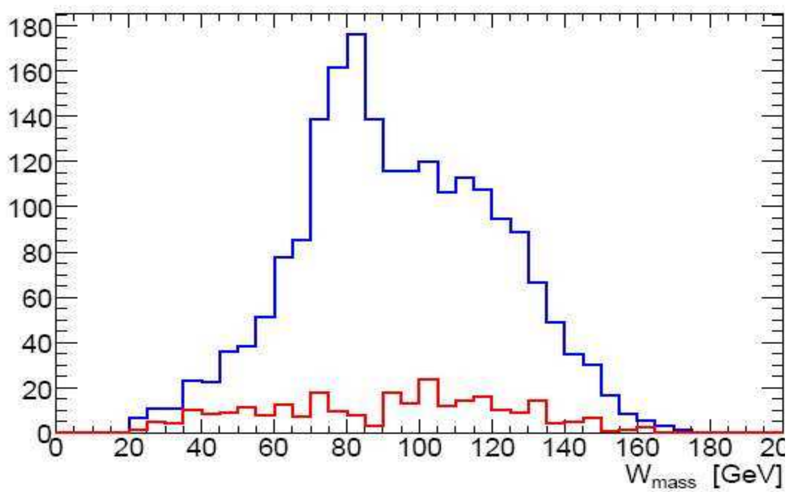
Also measure $Z + \mathrm{jets}$, $W + \mathrm{jets}$, both backgrounds for new physics.

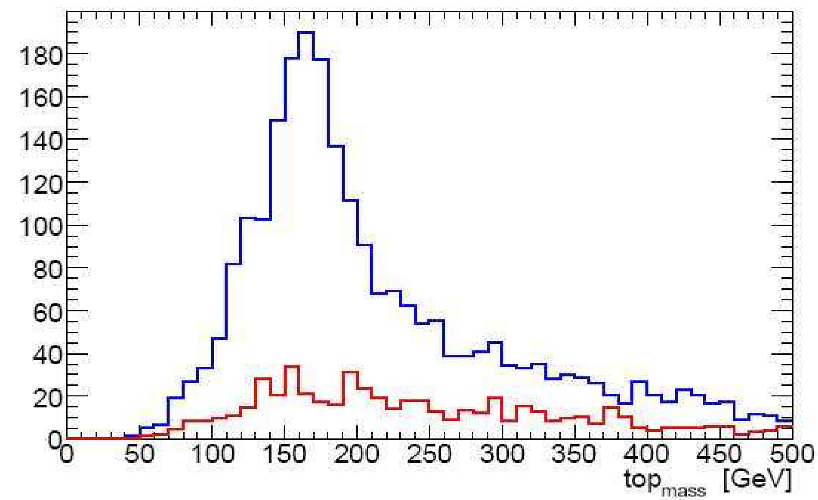
Test jet calibration [F.P.] using p_T balance in dijets and $\gamma + \mathrm{jet}$. Note higher LHC energy $\Rightarrow$ more gluon radiation.

Measure $\not{E}_T$ distribution and understand contributions: cosmics, detector problems, mismeasured jets and μ, real ν.

Measure $t\bar{t}$ — cross section is 100 times larger than at Tevatron. Initial analysis using no b tagging:

Require e/μ, $\not\!\!E_T$, and ≥ 4 jets. Choose 3 jets giving maximum p_T. Plot dijet masses and t mass after M_W cut.





S/B much better with b tagging.

No current BNL involvement, but Tevatron experience [Snyder].

SUSY Physics

SUSY with $M \lesssim 1\,\mathrm{TeV}$ is plausible extension of SM. Implies partner (denoted by tilde) with $\Delta J = \pm\frac{1}{2}$ for each SM particle. MSSM is well defined, but 105 soft breaking parameters.

With R parity, SUSY particles produced in pairs and decay to invisible LSP $\tilde{\chi}_1^0 \Rightarrow$ no mass peaks.

Expect $\tilde{g}$ and $\tilde{q}$ production to dominate at LHC. These decay via long cascades to stable and invisible $\tilde{\chi}_1^0$, e.g.

$$\tilde{g} \to \tilde{q}\bar{q} \to \tilde{\chi}_2^0 q\bar{q} \to \tilde{\ell}_R^{\pm}\ell^{\mp}q\bar{q} \to \tilde{\chi}_1^0 \ell^+\ell^- q\bar{q}$$

Such decays give multiple jets, possible leptons, and $\not{E}_T$ from $\tilde{\chi}_1^0$.

Backgrounds from all SM processes with real ν, mismeasured jets/ fake $\not{E}_T$ [F.P.], and detector problems.

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Backgrounds include SM $t\bar{t}$ and $W +$ jets, $Z +$ jets, and detector problems. Generally difficult to calculate/simulate, so rely on data.

Simplest example: use $Z \to \ell^+\ell^- + n$ jets data to determine $Z \to \nu\bar{\nu} + n$ jets.

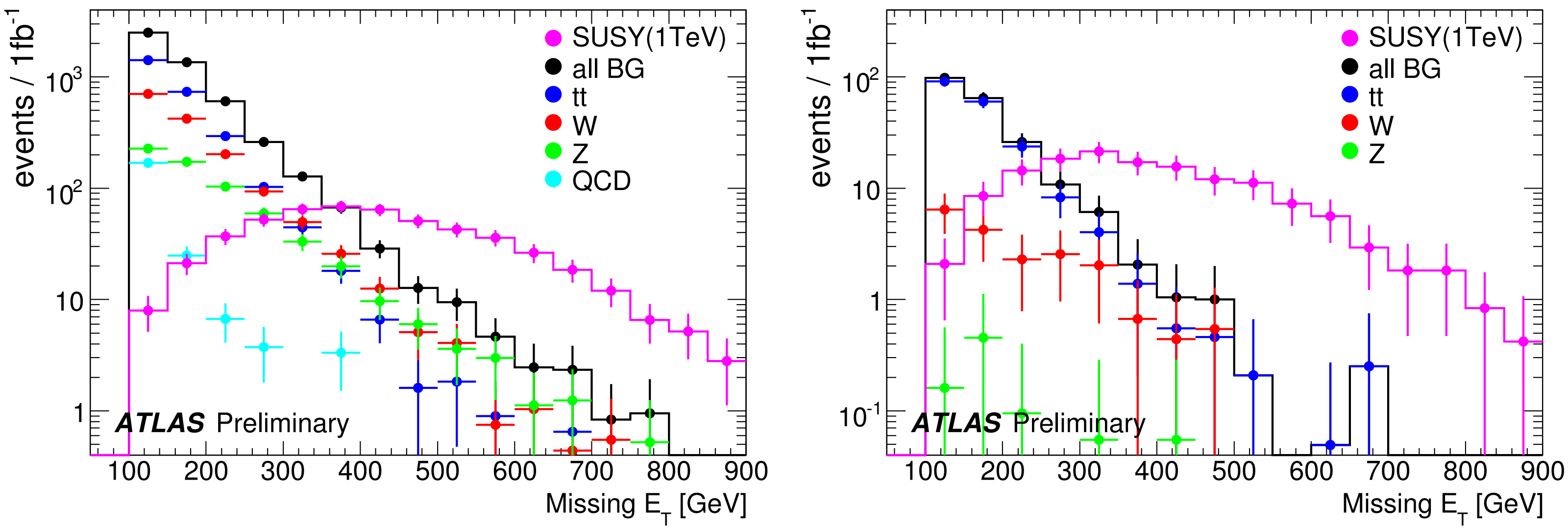
Expect simple relationship between $W +$ jets and $Z +$ jets. For QCD, measure n jet distributions with low $\not\!\!E_T$ and fold with jet response from $\gamma +$ jet and dijets. Top is more complicated but easier to calculate — lowest order QCD already contributes.

Big ATLAS effort to understand SUSY backgrounds [Redlinger].

Most generic SUSY signature is $\not\!\!E_T +$ jets, but fake multijet background difficult to control.

Cascade decays often produce e, μ either directly or through τ decays. Easier to understand backgrounds for $\not\!\!E_T + \ell +$ jets

Current results after $\not{E}_T$ and multi-jet cuts for 0-ℓ (left) and 1-ℓ (right) modes for SUSY with $M_{\tilde{g}} \approx M_{\tilde{q}} \approx 1\,\mathrm{TeV}$:



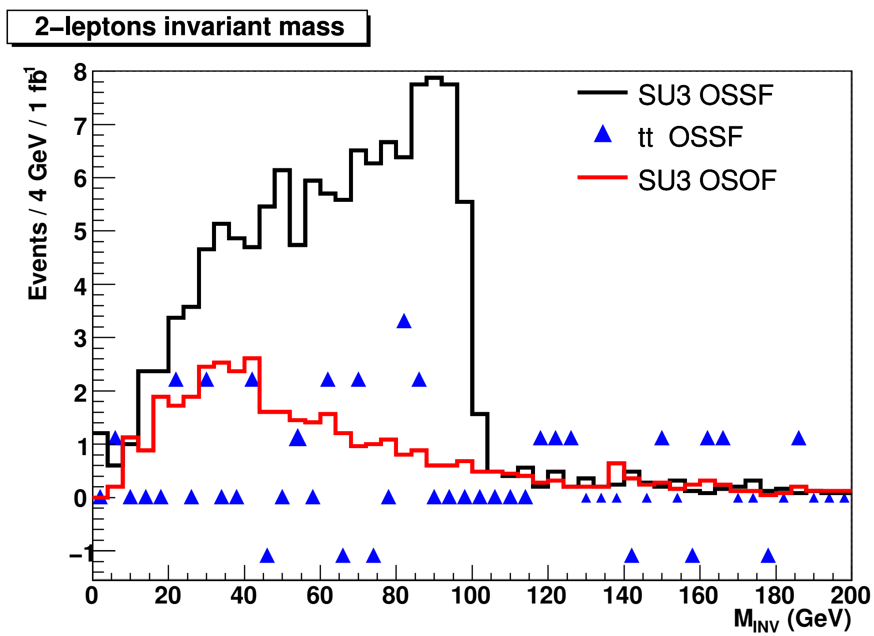
A lot like old results but more robust. CSC note in preparation [F.P., Polesello, ed.].

Note 10–100 events/bin/fb^{-1} with good S/B. Early discovery of TeV-scale SUSY possible — if it exists.

After discovery must measure SUSY properties. No mass peaks, so use kinematic edges. E.g., $\tilde{\chi}_2^0 \to \tilde{\ell}_R^\pm \ell^\mp \to \tilde{\chi}_1^0 \ell^+ \ell^-$ gives edge at

$$M_{\ell\ell} = \frac{\sqrt{(M^2_{\tilde{\chi}_2^0} - M^2_{\tilde{\ell}_R})(M^2_{\tilde{\ell}_R} - M^2_{\tilde{\chi}_1^0})}}{M_{\ell_R}}$$

Signal is only OSSF ee and $\mu\mu$, while SUSY and SM backgrounds also give OSOF $e\mu$. Result after cuts:



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In favorable cases can make many such measurements. Can measure mass differences and perhaps even absolute masses.

Might find SUSY quickly, but detailed exploration would require full power of ATLAS and LHC. Need detailed understanding to calculate, e.g., contribution of $\tilde{\chi}_1^0$ to cold dark matter.

Discovery of SUSY would provide strong justification for future e^+e^- accelerator.

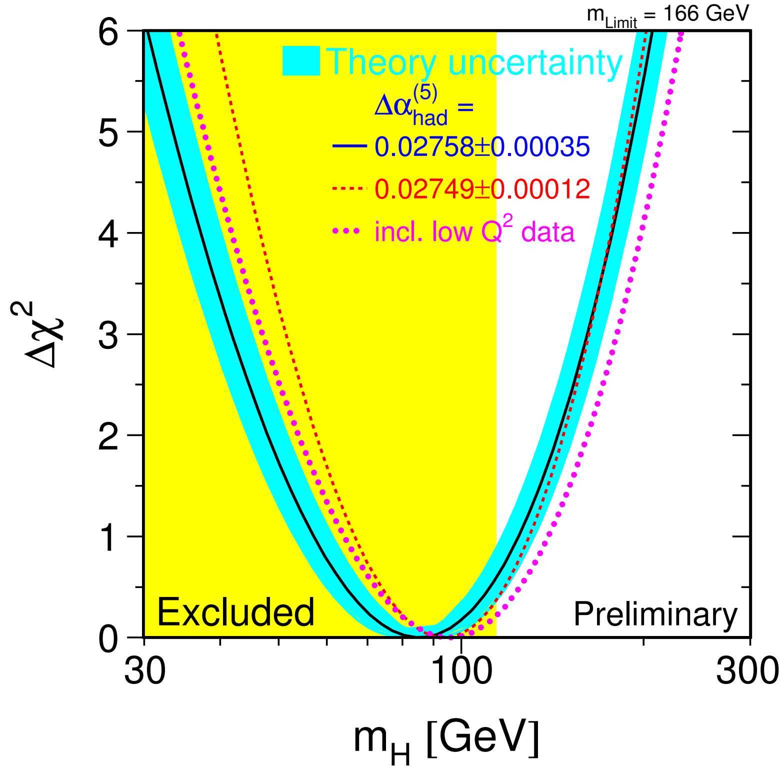
Higgs Physics

Higgs boson(s) expected — would be first fundamental scalsr.

SM has been tested to 0.1%.

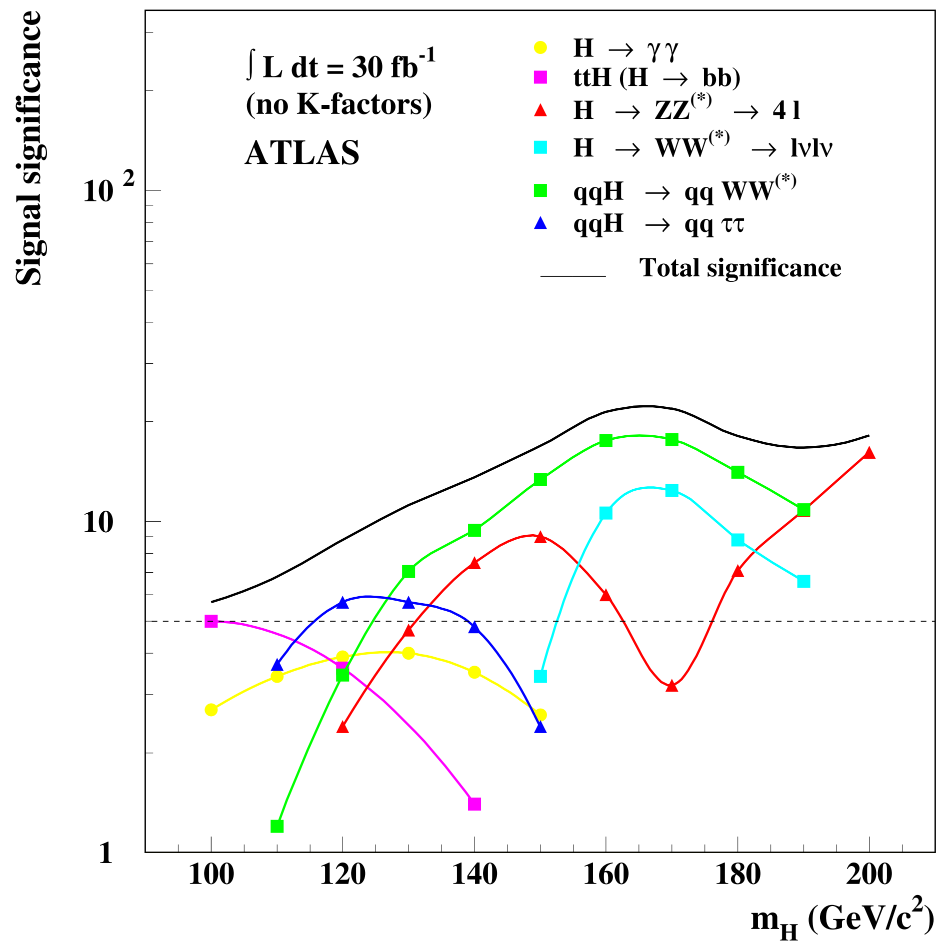
SM radiative corrections sensitive to log M_h. Best fit is below direct LEP limit (114 GeV).

MSSM also predicts light Higgs with $M_h \lesssim 130\,\mathrm{GeV}$.



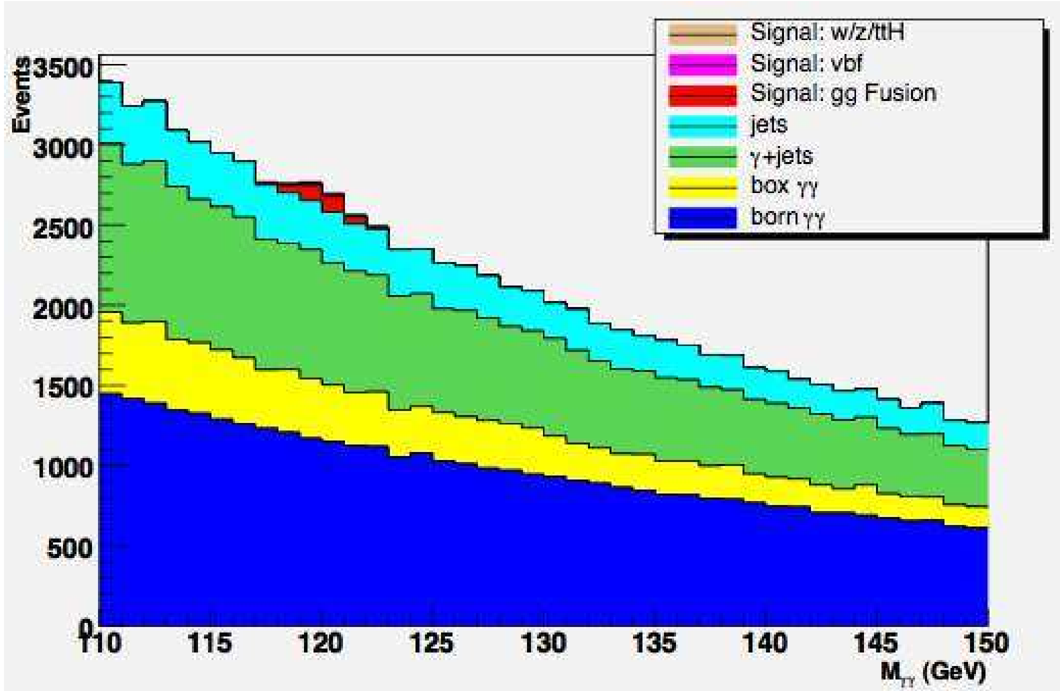
ATLAS should detect Higgs bosons over whole allowed mass range.

Significance for observing Higgs bosons in ATLAS with $30\,\text{fb}^{-1}$ (three years at 1/10 of design luminosity):



Note several modes are observable for each mass.

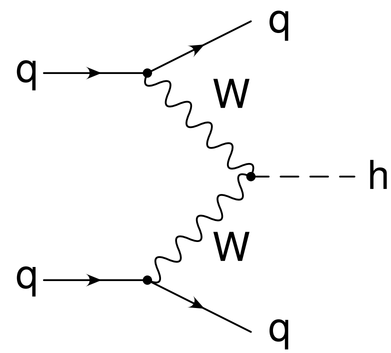
ATLAS designed to detect $h \to \gamma\gamma$ ($B \sim 10^{-3}$). Expect small bump on smooth background. Current result using full simulation for both signal and backgrounds:



Hard! Need best possible EM performance $\Rightarrow \mathcal{O}(1\%)$ corrections crucial [Snyder]. Also needed for $h \to ZZ^* \to 4\ell$ at higher mass.

Inclusive $h \to \tau\tau$ swamped by $Z \to \tau\tau$. But may be possible for Higgs produced by WW fusion:

WW fusion $\Rightarrow$ two forward jets, no central ones. Can reject most Z background.

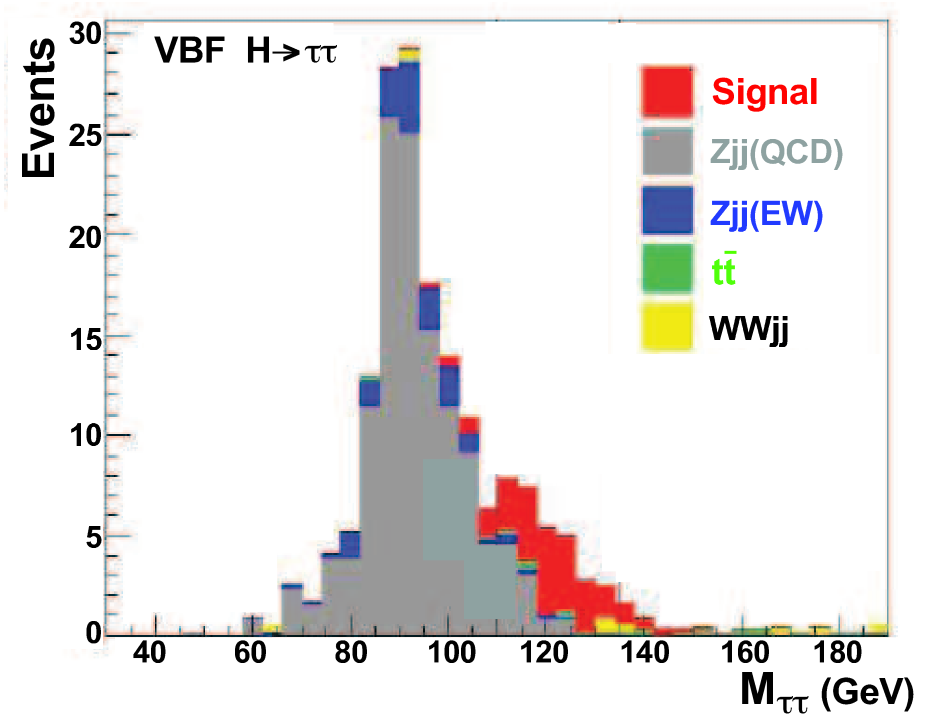


Since $p_{T,h} \sim M_W \sim M_h$, can project $\not{E}_T$ on τ directions and reconstruct $\tau\tau$ mass.

Signal observable with fast simulation. Crucial issues for full simulation [Cranmer, Patwa, Tarrade]:

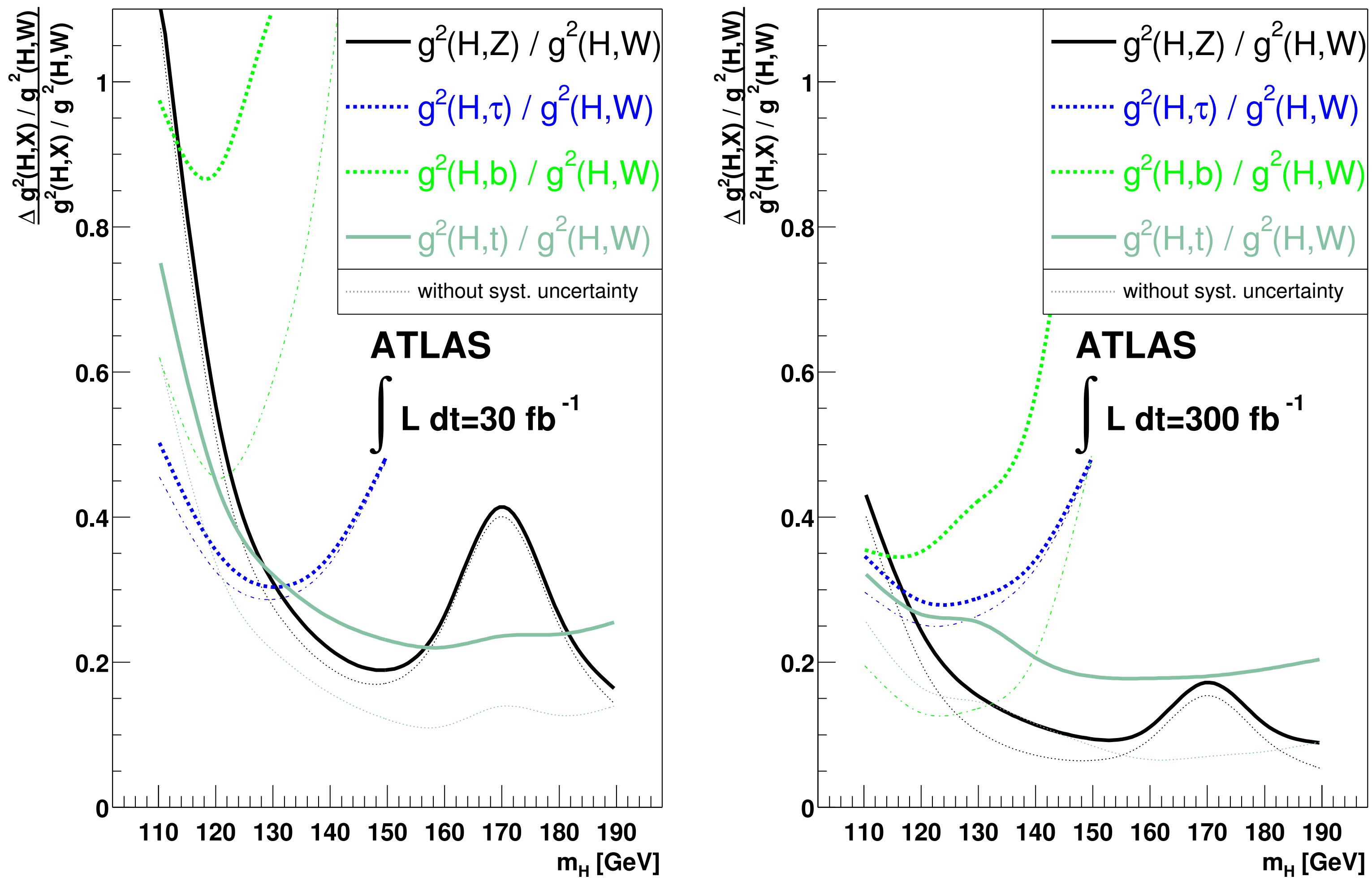
- Trigger: require at least one τ to decay leptonically.
- $\not{E}_T$ resolution: needs careful treatment of LAr noise.
- Selection: instead of just projecting $\not{E}_T$ on τ directions, test whether event is more consistent with Z or h.
- Use data to determine backgrounds.

Current status using full simulation for both signal and backgrounds for $30\,\text{fb}^{-1}$:



Possible with less luminosity than $h \to \gamma\gamma$ but requires excellent $\not\!\!E_T$ performance. May be difficult with early data.

Separating gg and WW fusion contributions to Higgs production is essential for determining Higgs couplings. Can potentially measure coupling ratios to $\lesssim 20\%$:



Exotic Physics

Covers a large range of possibilities.

Some are easy, e.g., $Z' \to e^+e^-, \mu^+\mu^-$ near Tevatron bound.

Some are hard, e.g., signatures for modern Randall-Sundrum extra dimension models. C.f. recent work by BNL HET [Davoudiasl, et al.].

Perhaps most spectacular is black hole production. In ADD model expect black hole production with geometric cross sections for $M_{\mathrm{BH}} \gtrsim 1\,\mathrm{TeV}$. Decay via Hawking radiation into multiple jets, leptons, γ, W, Z, h, ...

Expect the unexpected!

Currently no involvement in such physics at BNL.

Outlook

BNL ATLAS group currently focused mainly on detector performance and core infrastructure. Important for any physics.

We want to be effective participants in ATLAS physics ⇒ need increased involvement. I think we must:

- Focus BNL group on a few physics topics.
- Add additional experienced people from CDF, D0, BaBar, ...
- Form alliances with other US groups.
- Learn how to participate in overall ATLAS from outside CERN.

LHC offers wide range of exciting physics — it will be the center of high energy physics for the next decade at least. We can and should be major players.