MSSM Higgs → ττ Searches at the ATLAS Experiment

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Overview

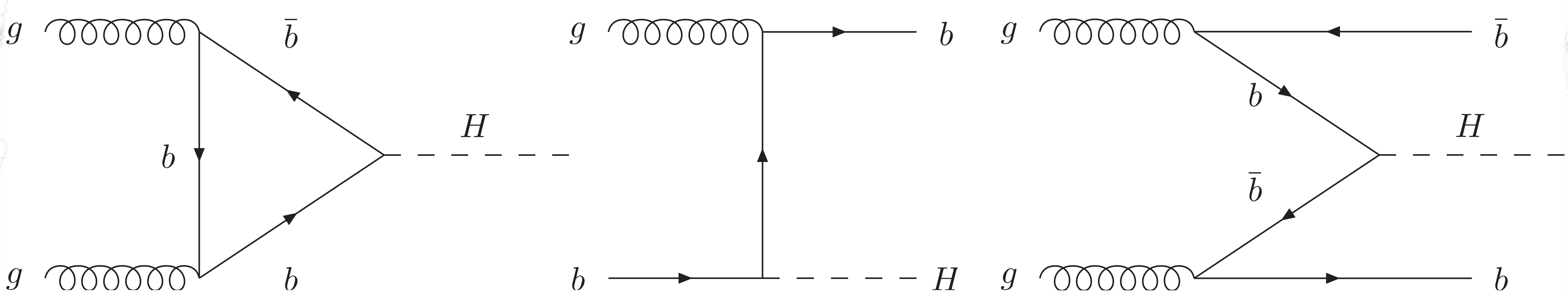
- Introduction to MSSM analysis
  - Motivations
  - Event selection.
- Tau ID in early data
- Backgrounds
  - Single top contribution
  - Angular correlations
- Summary

MSSM Higgs

Minimal Supersymmetric Standard Model requires two Higgs doublets:

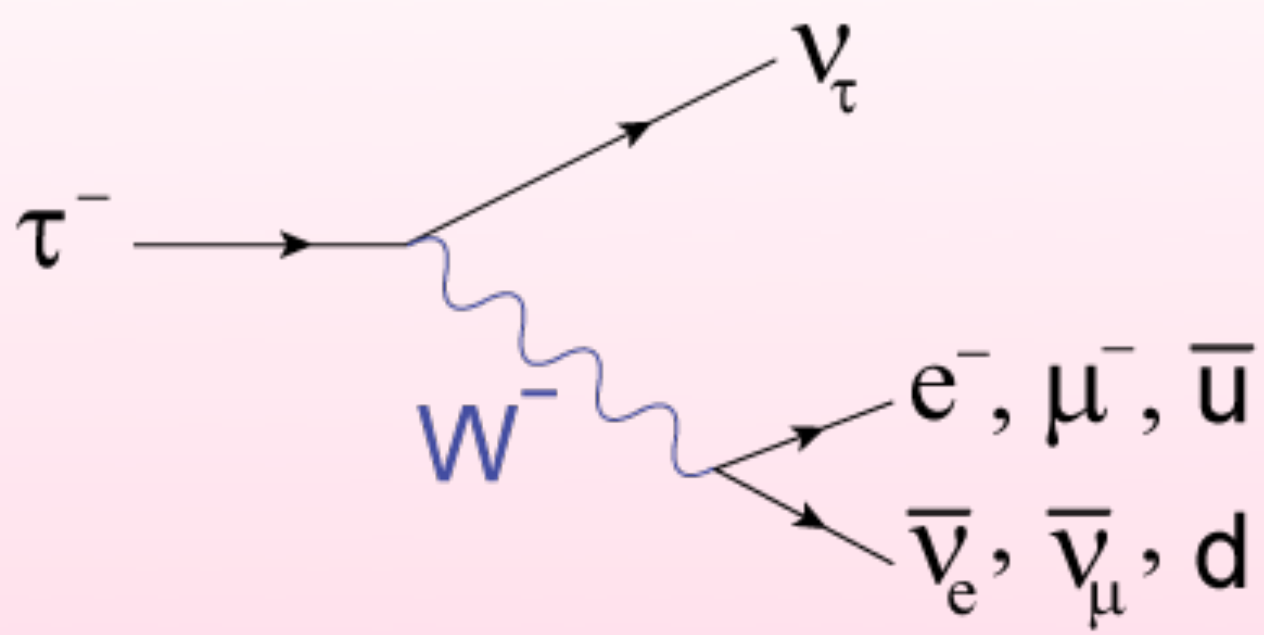
- 5 observable Higgs bosons:
  - 3 neutral (h/A/H)
  - 2 charged ($H^{\pm}$)

Higher production cross-section than for SM Higgs - potential to make discovery/ exclusion with much less data.



- Produced in association with 0, 1 or 2 b-jets
- Decays into 3rd generation fermions strongly enhanced for large regions of phase space - decays into pair of tau leptons important channel

τ-Decay Characteristics

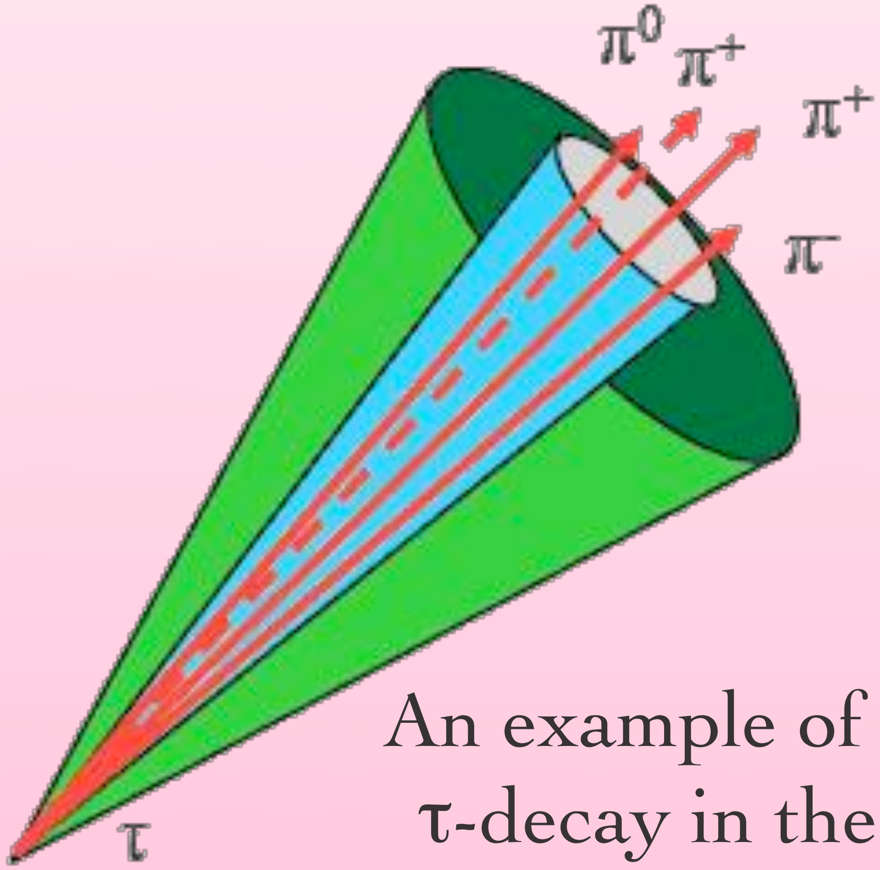


$BR(\tau \rightarrow e/\mu + \nu_\tau + \nu_{e/\mu}) \simeq 35\%$
$BR(\tau \rightarrow jets + \nu_\tau) \simeq 65\%$

Missing E_T always present due to neutrinos.

Hadronic τ-jets:

- Well collimated
- Low multiplicity
- Deposits in both hadronic and EM calorimeters.
- One or three tracks matching the calorimeter deposition.



Courtesy of NBI

An example of a 3-prong τ-decay in the detector

MSSM H → ττ → lh

Three possible decay channels:
1). Two leptons (~12%)
2). Two hadronic τ's (~42%)
3). One lepton and one hadronic τ (~46%)

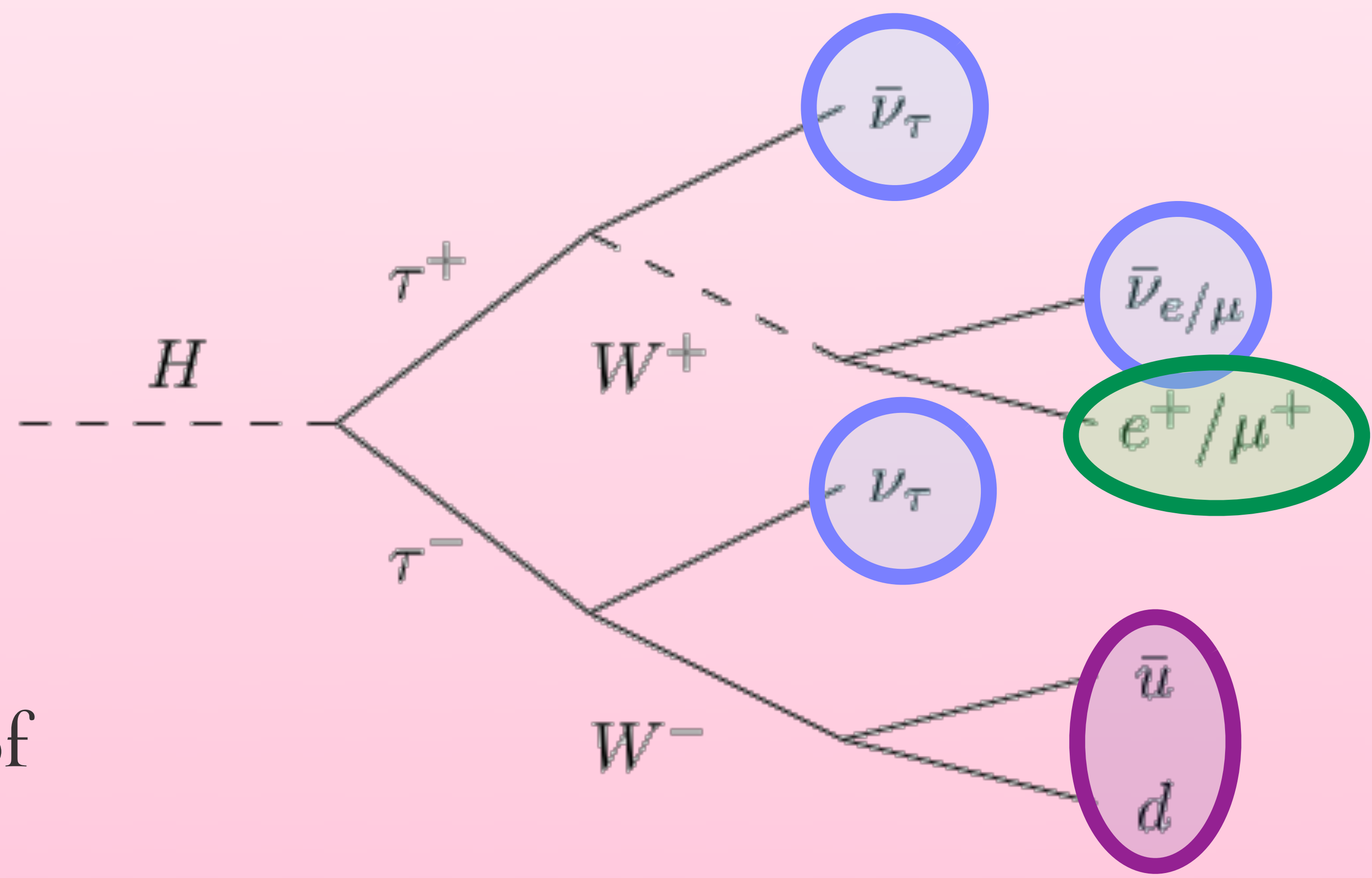
Small BR

Hard to trigger on

Good compromise

Lepton-Hadron Channel
Event Selection:

- Exactly one **e/μ** and exactly one hadronic **τ** (with opposite charges)
- Missing E_T (from neutrinos)
- Transverse mass (lepton-MET) < 25 GeV (to reject W+jets)
- $N_{jets} < 3$ (to reject ttbar)
- Angular correlations between φ of lepton/τ and missing E_T



ATLAS Tau ID Evolution

T I M E

Start to understand and validate calorimeter.
Use cut-based tau-ID calculated with just a handful of calorimeter variables; e.g. EM Radius, isolation fraction.

Tau Cut Safe Calo Only

Start to understand and validate tracking.
Incorporate some tracking info into cut-based tau-ID; e.g. E_T/P_T (lead track), $E_T(EM)/\Sigma P_T$ (tracks).

Tau Cut Safe Calo+Tracking

Intermediary steps:
Provide likelihood based tau-ID using only "safe" variables(?)
Validate other variables and use to provide cut based ID.

Tau Llh Safe?

Tau Cut

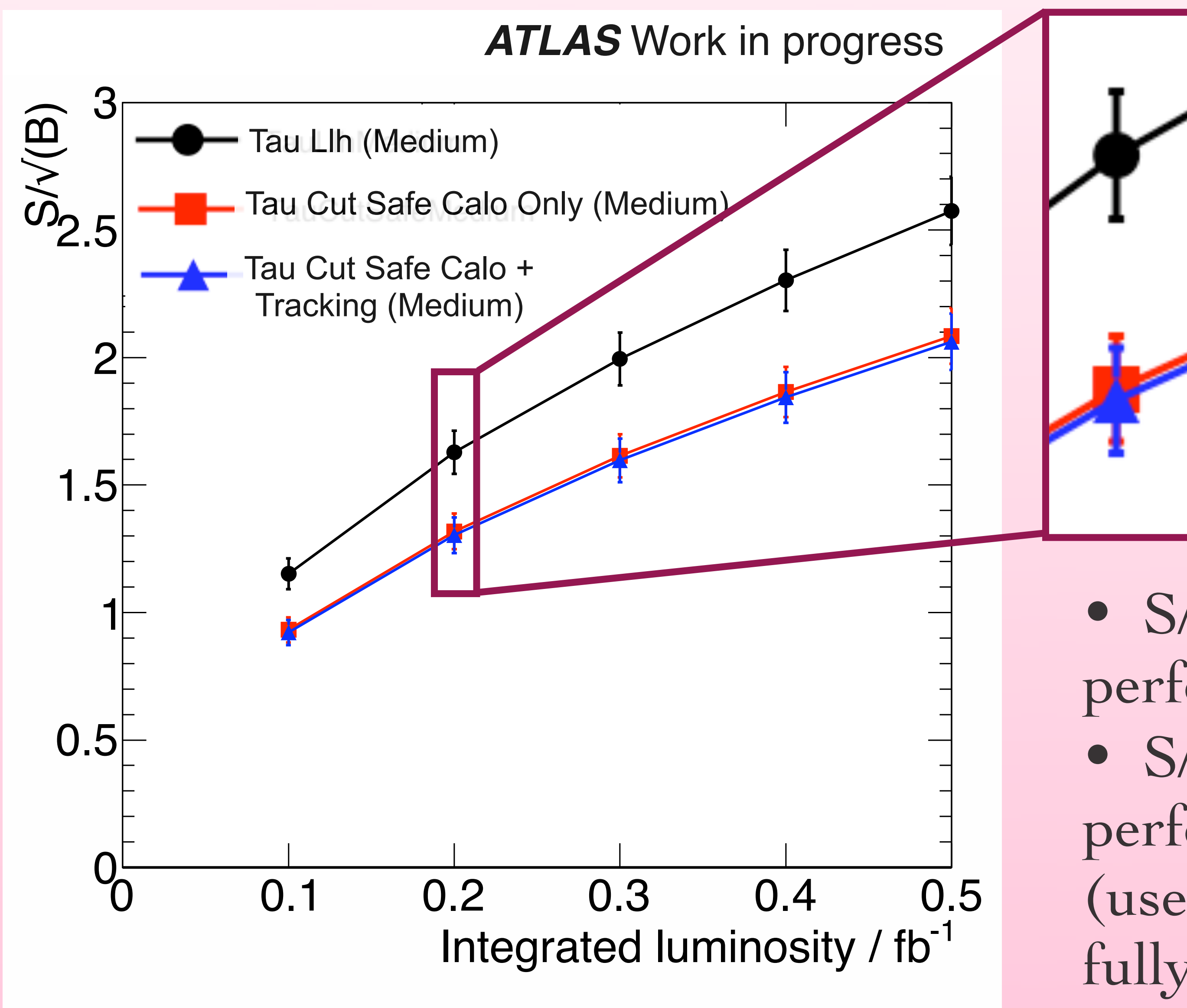
Gain understanding of calorimeter & tracking.
Validate other variables and incorporate into likelihood based tau-IDs (full tau ID).

Tau Llh

Each available in: Loose (ε = 70%), Medium (ε = 50%) and Tight (ε = 30%)

Effects of Using “Safe” Tau ID

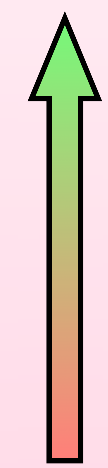
- Studied performance of analysis using different safe tau ID options:
  - Looser tau ID better when background has many real taus (statistical feature).
  - Tighter tau requirements better when background has many jets faking taus.
  - Medium provides best results once all backgrounds are considered.



Tau Llh (Medium)

Tau Cut Safe Calo Only (Medium)

Tau Cut Safe Calo + Tracking (Medium)



- $S/\sqrt{B}$ = 1.2 at 200 pb^{-1}, using best performing “safe” ID
- $S/\sqrt{B}$ = 1.6 at 200 pb^{-1}, using best performing likelihood based tau ID (uses all variables - for once detector is fully understood and validated).

Backgrounds

Dominant backgrounds to MSSM analysis are $Z \rightarrow \tau\tau$, W & ttbar.

$Z \rightarrow \tau\tau$ (+ jets)

- Irreducible.
  - True di-tau final state.
  - Similar kinematics.
- Important for low mass scenarios, where signal falls on tail of Z-peak.

$W \rightarrow e/\mu/\tau_l + \nu$ (+ jets)

- Large production cross-section.
- Real lepton + missing E_T.
- Jets in event fake hadronic tau.

ttbar

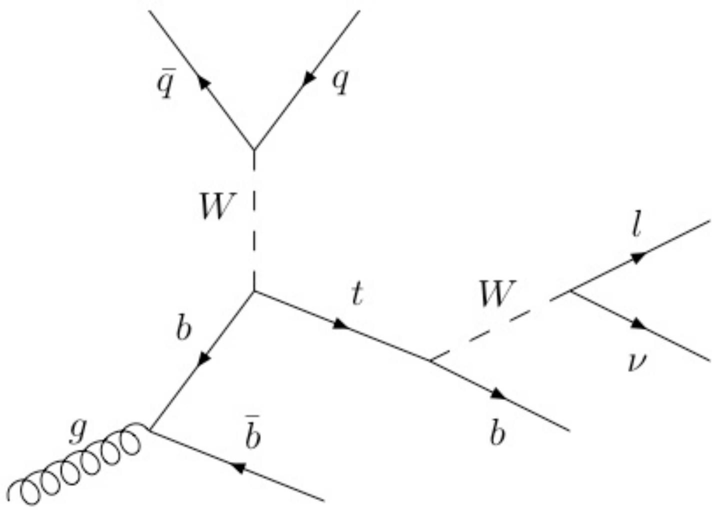
- $tt \rightarrow WbWb$ (W's $\rightarrow e/\mu/\tau+\nu$ or jets).
  - Possibility to have true lepton plus hadronic tau final state.
  - Hadronic jets (from W-decay) faking taus.
  - b-jets in signal and background.
  - Leptons from b-decay.
- More significant as m_H increases.

Others include $Z \rightarrow ll$ (+ jets), $W \rightarrow \tau_h \nu$ (+ jets), QCD.
Single top was previously considered negligible, due to it's small cross-section.

Single Top Background

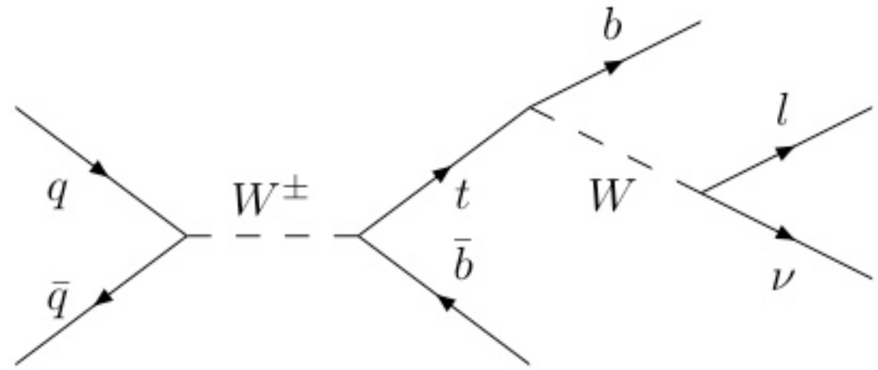
t-channel:

σ (xBR to e/μ/τ) = 43.38 pb



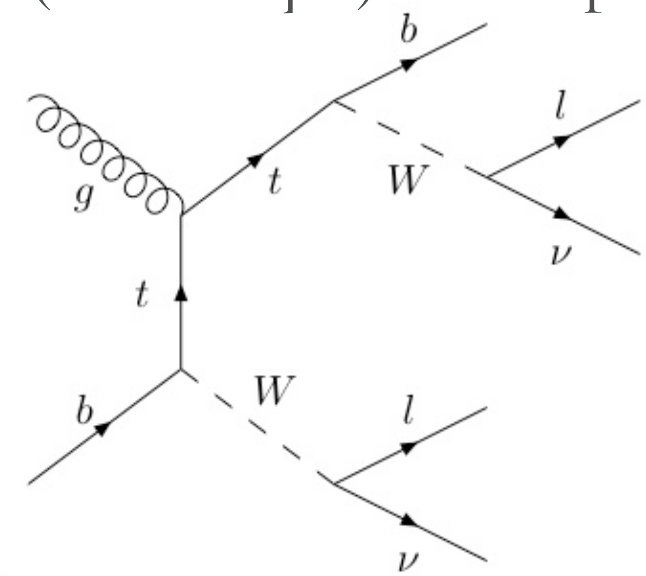
s-channel:

σ (xBR to e/μ/τ) = 2.27 pb



Associated production (Wt):

σ (xBR to e/μ/τ) = 14.41 pb

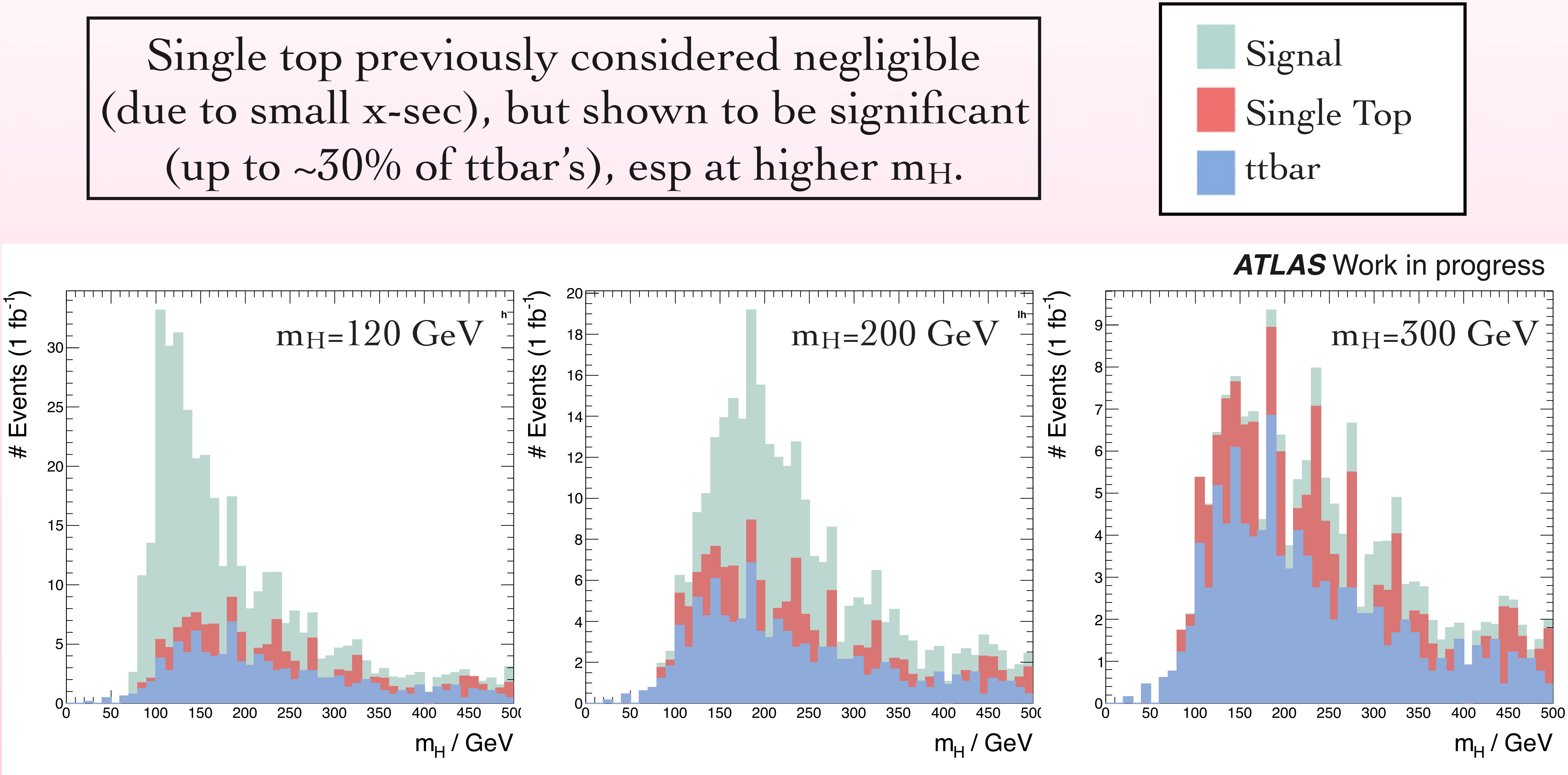


- One or two b-jets:
  - Can fake tau jets
  - Can decay to leptons
  - MSSM Higgs can be produced in association with b-jets too.
- Real tau or leptons from W decay.
- Missing E_T from neutrino(s).

- t-channel dominates (x-sec ~20 times larger than for s-channel.
- Wt has smaller x-sec than t-channel, but has 2 W's, so possibility to produce a true lepton + hadronic tau final state.

Single Top Background

Single top previously considered negligible (due to small x-sec), but shown to be significant (up to ~30% of ttbar's), esp at higher m_H.

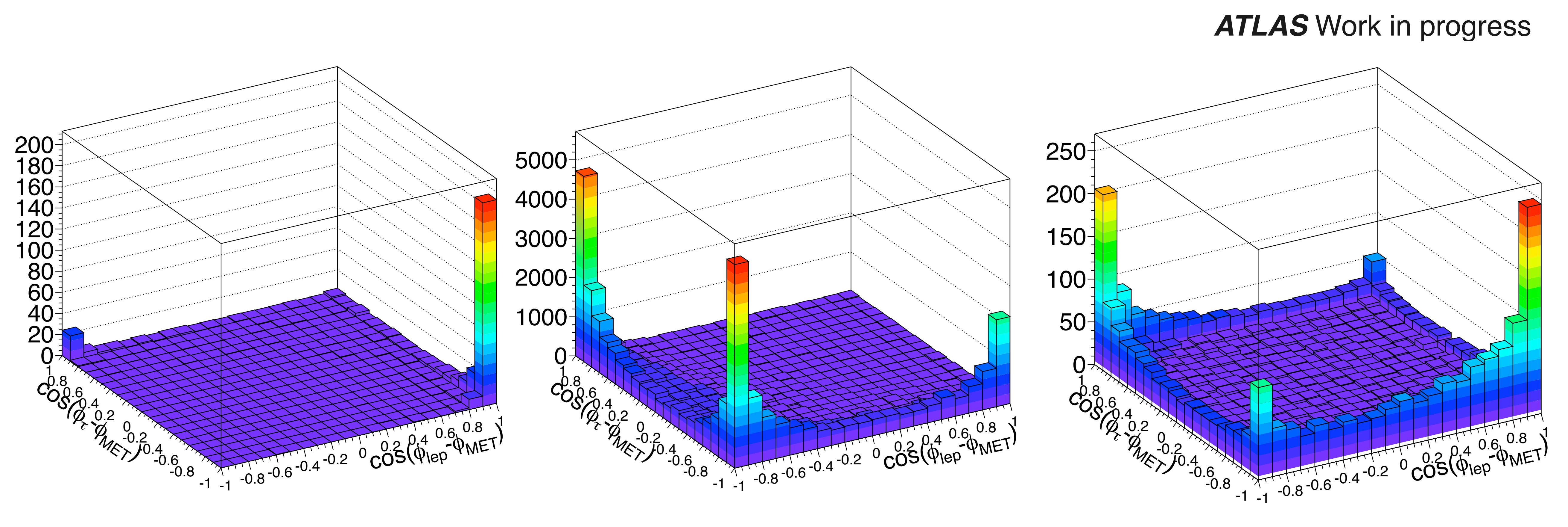


- Dominant contribution from associated production (Wt) mode.
- Modes where W → e/μ more significant than those where W → τ.

Angular Correlations

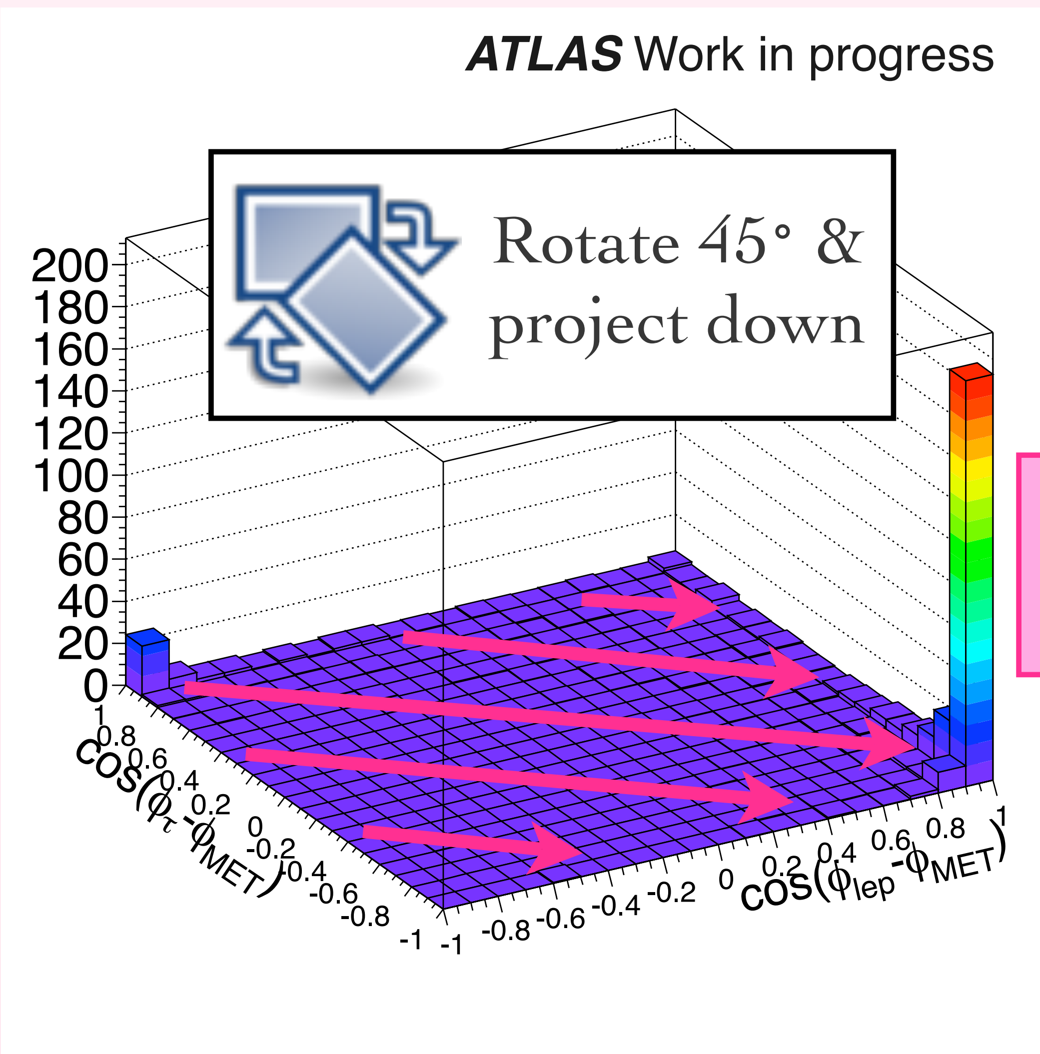
Plotting $\cos(\phi_{lep} - \phi_{MET})$ vs. $\cos(\phi_{\tau} - \phi_{MET})$ we see very different distributions for signal and background processes.

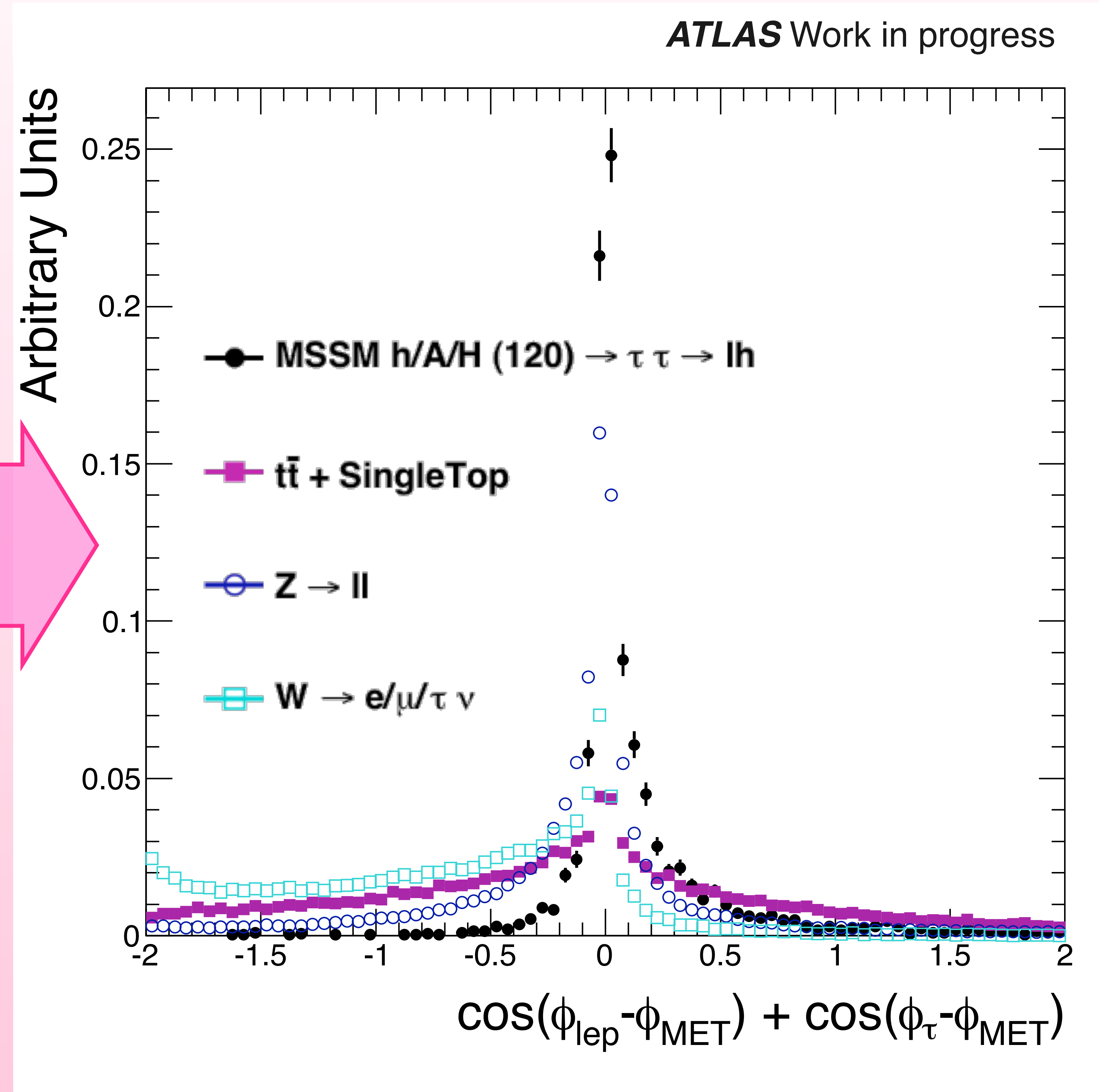
(Unfortunately, not useful to reject $Z \rightarrow \tau\tau$ which has same kinematics.)



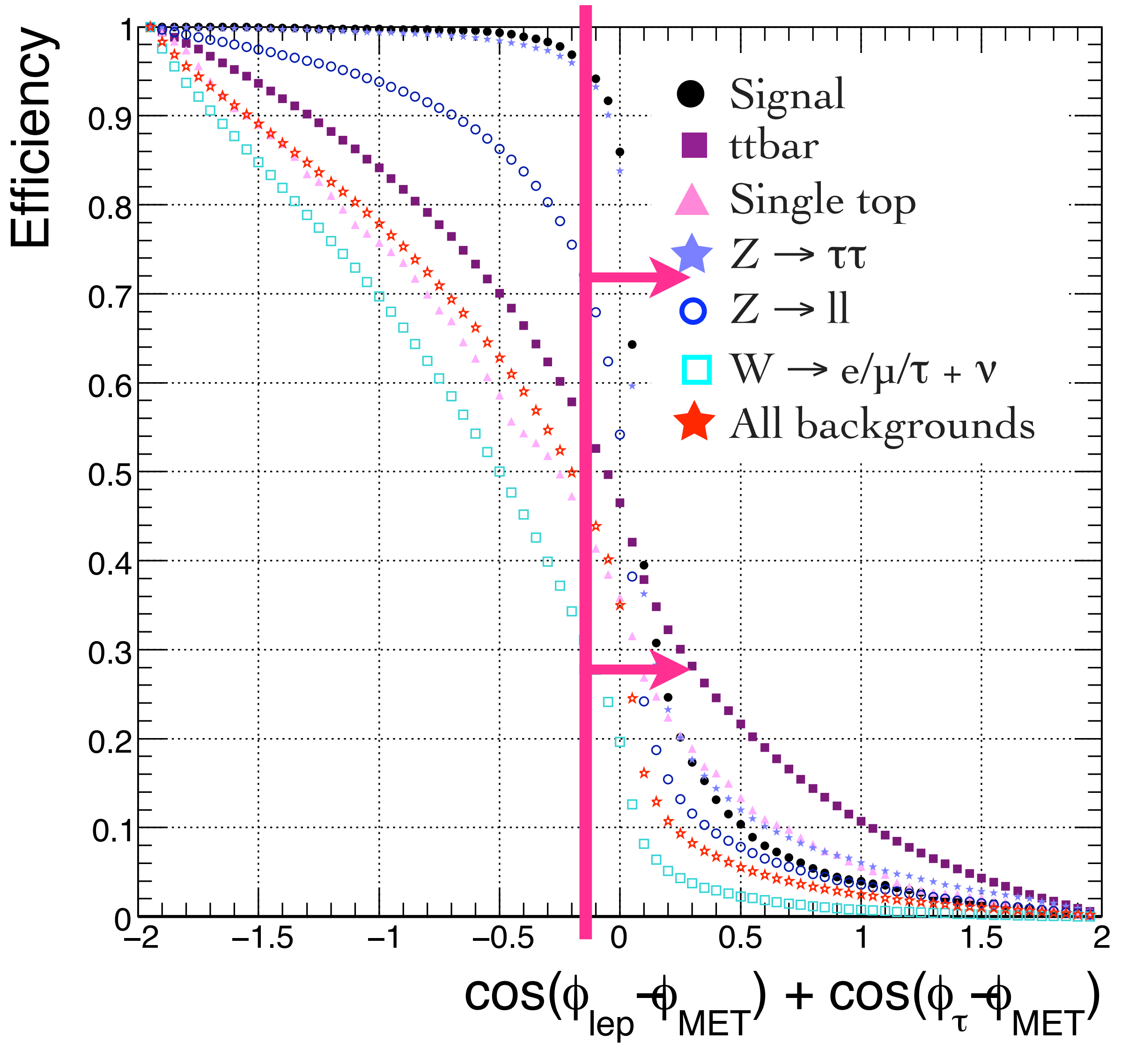
MSSM H → ττ | W → e/μ/τ ν | ttbar

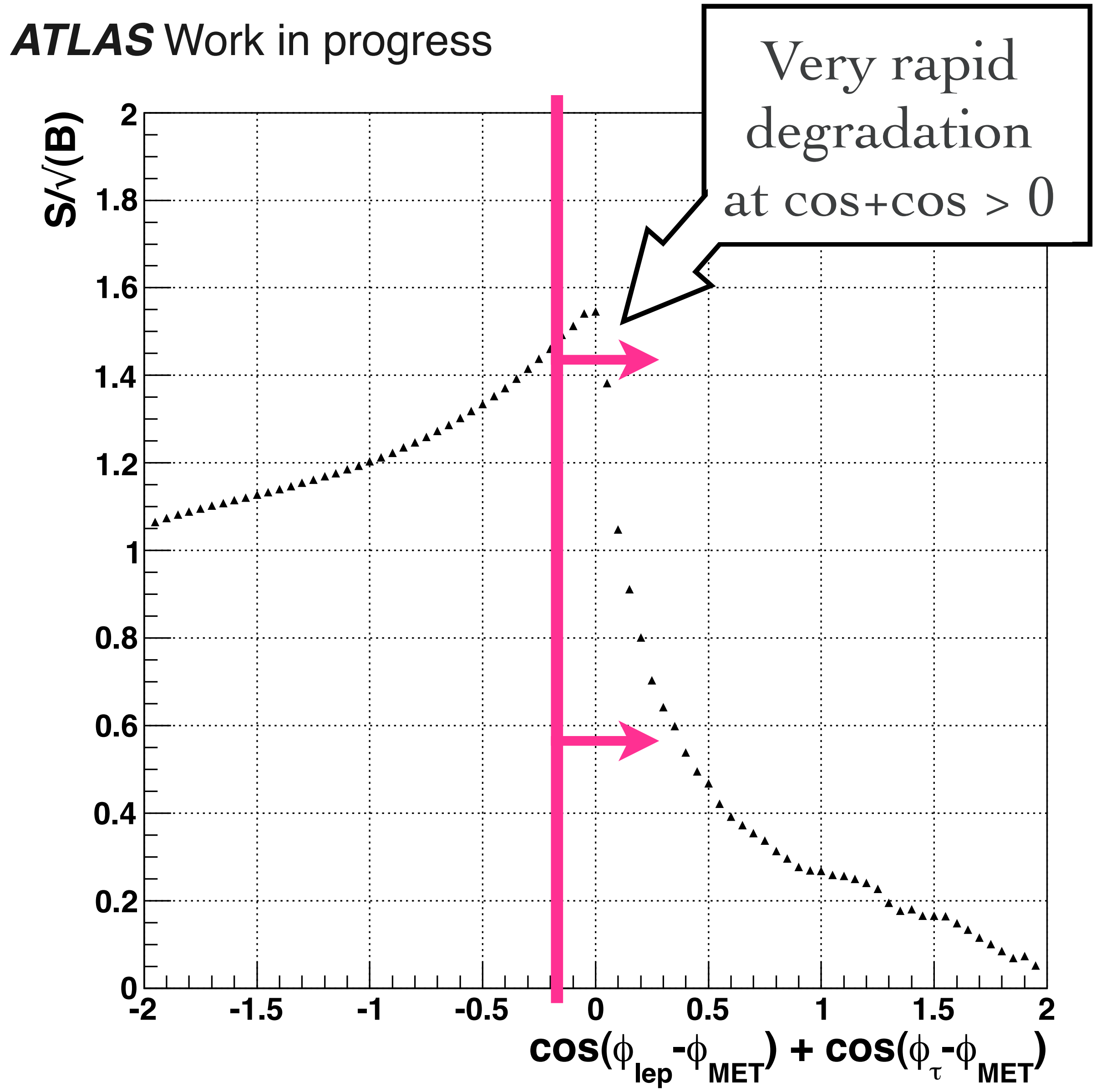
Angular Correlations





Angular Correlations





- Cut on $\cos(\phi_{lep} - \phi_{MET}) + \cos(\phi_{\tau} - \phi_{MET}) > -0.15$.
  - (Slightly higher significance at 0, but then in dangerous 'shoulder' region.)
- Cut at > -0.15 maintains high signal efficiency and good $S/\sqrt{B}$.
  - Distribution will depending strongly on ϕ_{MET} distribution.

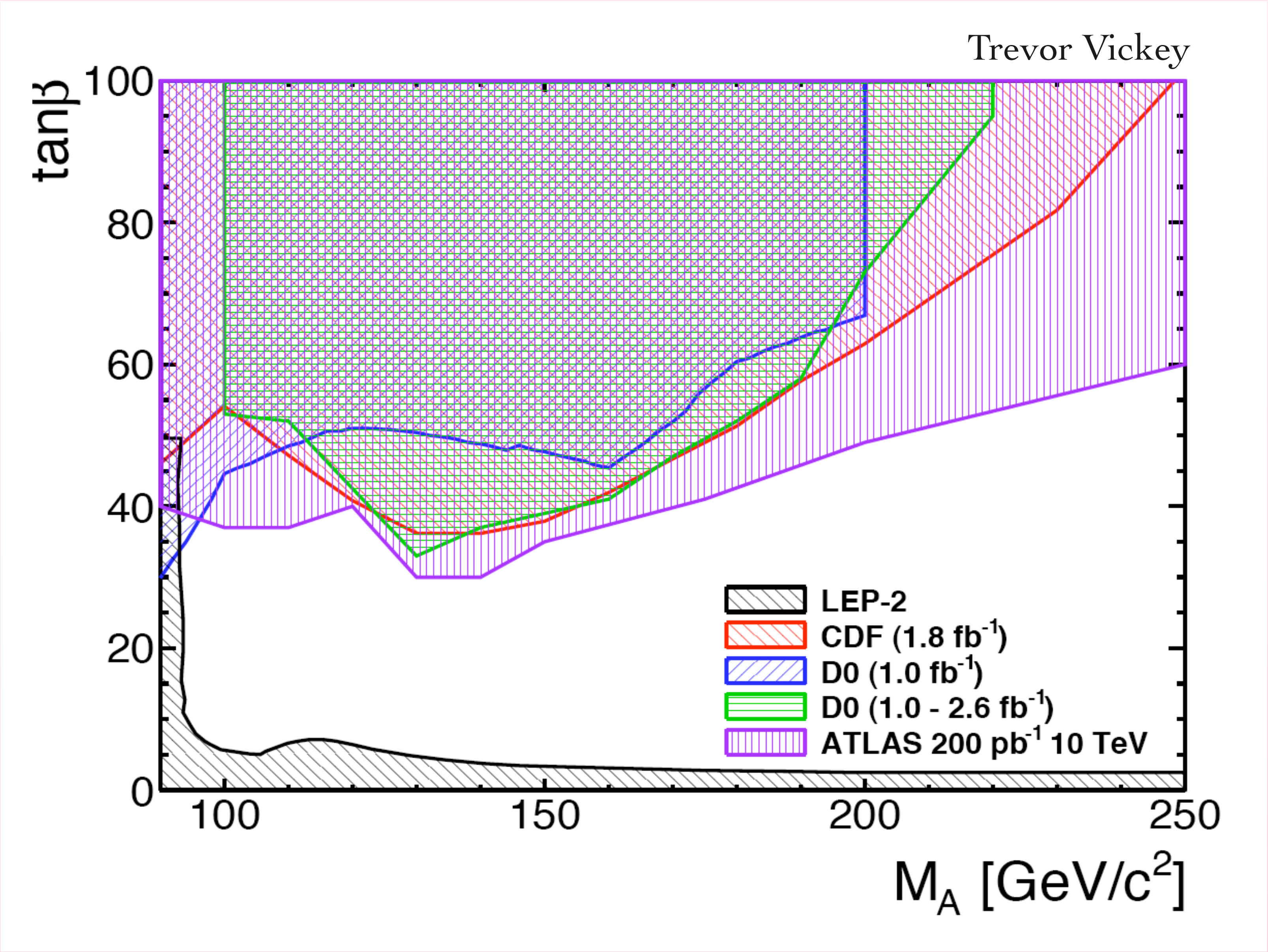
Cross-Sections (pb): m_H = 120 GeV

	$MSSM\ H(120) \rightarrow \tau\tau$	$Z \rightarrow \tau\tau$	$t\bar{t}$	$Single\ Top\ (Wt)$	$Single\ Top\ (s+t-channels)$
$Start$	8.96 ± 0.05	1.36e+03 ± 1.75e+00	218.07 ± 0.21	14.41 ± 0.14	45.65 ± 0.25
$Trigger$	4.00 ± 0.03	243.43 ± 0.74	136.72 ± 0.17	8.83 ± 0.11	24.10 ± 0.19
$Lepton\ p_T$	2.84 ± 0.03	156.47 ± 0.60	110.11 ± 0.15	7.36 ± 0.10	19.53 ± 0.18
$Di-lepton\ Veto$	2.80 ± 0.03	141.54 ± 0.57	97.40 ± 0.14	6.58 ± 0.10	19.41 ± 0.18
$Tau\ ID$	0.70 ± 0.01	13.50 ± 0.17	8.29 ± 0.04	0.47 ± 0.03	0.67 ± 0.03
$Charge\ Correlation$	0.70 ± 0.01	12.84 ± 0.17	5.87 ± 0.03	0.35 ± 0.02	0.41 ± 0.03
$Missing\ p_T$	0.31 ± 0.01	3.96 ± 0.09	5.34 ± 0.03	0.30 ± 0.02	0.37 ± 0.03
$Sum2Cos \leq -0.15$	0.30 ± 0.01	3.80 ± 0.09	2.72 ± 0.02	0.15 ± 0.01	0.11 ± 0.01
$Transverse\ Mass$	0.27 ± 0.01	3.43 ± 0.09	0.62 ± 0.01	4.04e-02 ± 7.63e-03	3.26e-02 ± 6.97e-03
$N_{Jets} < 3$	0.26 ± 0.01	3.27 ± 0.09	0.13 ± 0.01	2.16e-02 ± 5.58e-03	2.52e-02 ± 6.48e-03
$Collinear\ Approximation$	9.16e-02 ± 4.92e-03	0.74 ± 0.04	1.00e-02 ± 1.43e-03	4.32e-03 ± 2.50e-03	2.17e-03 ± 1.04e-03
$Visible\ Mass$	1.67e-02 ± 2.10e-03	9.74e-02 ± 1.49e-02	9.13e-03 ± 1.44e-03	0.00e+00 ± 0.00e+00	1.57e-04 ± 1.57e-04
Mass Window	0.17	0.84	0.019	0.006	

	$Z \rightarrow ll$	$W \rightarrow l\nu$	$W \rightarrow \tau\nu$	$QCD\ (single\ lepton\ filter)$
$Start$	2.61e+03 ± 8.35e-01	2.42e+04 ± 8.17e+00	1.32e+04 ± 1.02e+01	2.54e+10 ± 3.74e+07
$Trigger$	2.06e+03 ± 7.42e-01	1.48e+04 ± 6.37e+00	1.29e+03 ± 3.25e+00	2.49e+09 ± 1.13e+07
$Lepton\ p_T$	1.88e+03 ± 7.09e-01	1.27e+04 ± 5.88e+00	805.88 ± 2.57	9.98e+07 ± 2.07e+06
$Di-lepton\ Veto$	971.57 ± 0.51	1.27e+04 ± 5.88e+00	805.66 ± 2.57	9.97e+07 ± 2.07e+06
$Tau\ ID$	12.51 ± 0.06	68.14 ± 0.43	5.92 ± 0.22	4.72e+04 ± 1.09e+04
$Charge\ Correlation$	9.45 ± 0.05	47.50 ± 0.36	3.99 ± 0.18	1.57e+04 ± 4.70e+03
$Missing\ p_T$	0.91 ± 0.02	38.57 ± 0.32	3.25 ± 0.16	2.69e+03 ± 8.38e+02
$Sum2Cos \leq -0.15$	0.37 ± 0.01	8.52 ± 0.15	1.47 ± 0.11	1.88e+03 ± 6.93e+02
$Transverse\ Mass$	0.12 ± 0.01	2.04 ± 0.08	1.11 ± 0.10	1.86e+03 ± 6.93e+02
$N_{Jets} < 3$	0.12 ± 0.01	1.93 ± 0.07	1.07 ± 0.09	1.39e+03 ± 6.09e+02
$Collinear\ Approximation$	1.04e-02 ± 1.67e-03	0.13 ± 0.02	9.02e-02 ± 2.72e-02	16.43 ± 16.43
$Visible\ Mass$	4.53e-03 ± 1.10e-03	5.32e-02 ± 1.20e-02	3.28e-02 ± 1.64e-02	0.00e+00 ± 0.00e+00
Mass Window	0.015	0.18	0.12	(Too few statistics)

Exclusion Prospects

Possibility to exclude MSSM Higgs at higher values of tan β over wide mass range using first ATLAS data: 200 pb^{-1} @ 10 TeV - expect this to scale to ~ 500 pb^{-1} @ 7 TeV.



Back Up

Object Selection

Electron:

- pT>10GeV
- |eta|<2.7
- ElectronAuthor=1 or 3
- ElectronMediumNoIso
- ElectronEtcone20/pT<0.2

Muon:

- pT>8GeV
- |eta|<2.7
- StacoIsCombinedMuon
- StacoBestMatch
- StacoMatchChi2<100
- StacoFitChi2<500
- StacoEtcone20/pT<0.2

Tau:

- pT > 20 GeV
- |eta|<2.7
- TauCutSafeCaloMedium
- TaujetNTrack = 1 or 3
- |TaujetCharge| = 1
- ElectronVeto
- MuonVeto

Jet:

- Cone4 Topo
- pT > 20GeV
- |eta| < 4.8

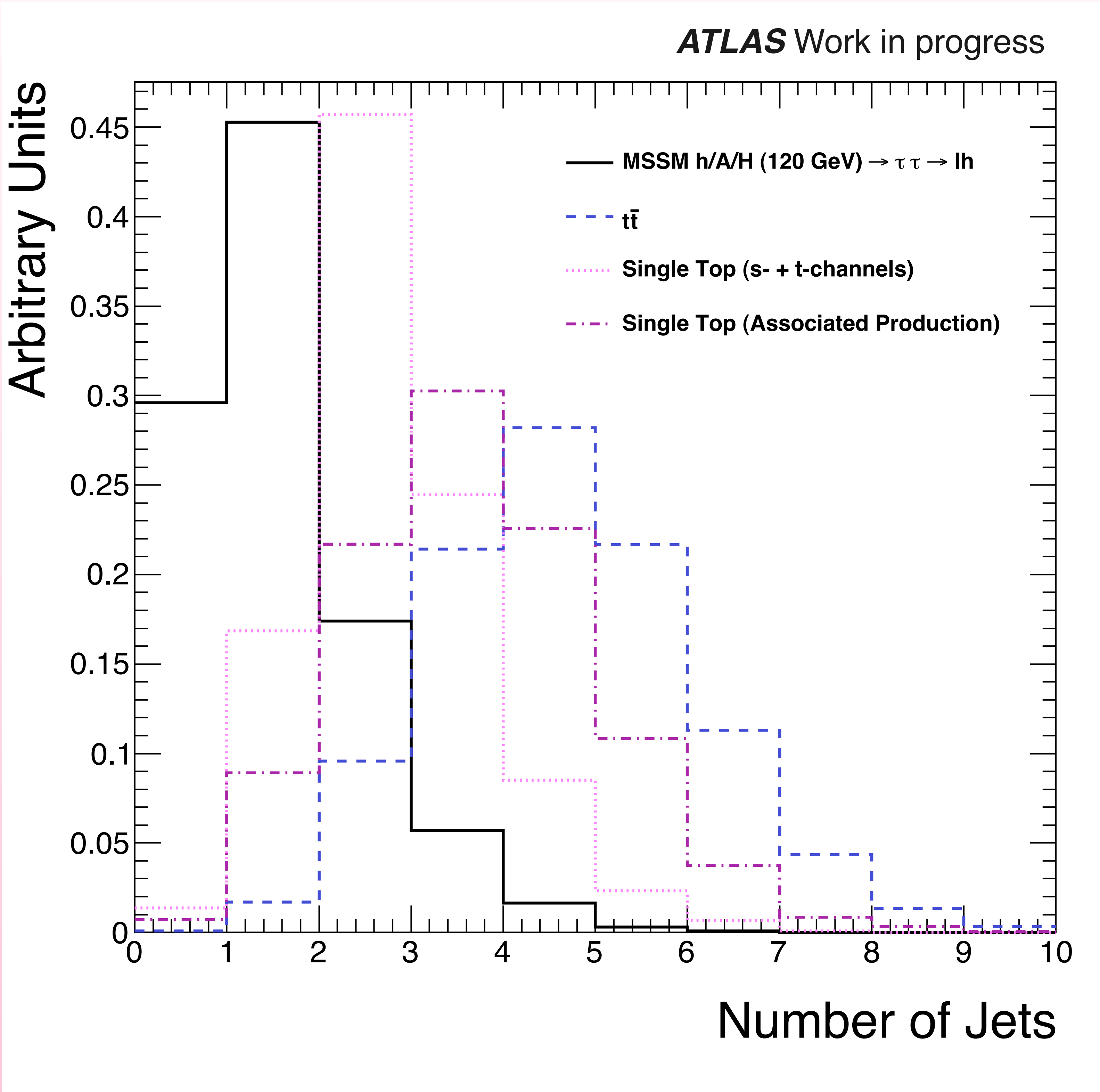
Missing Et:

- RefFinal

Overlap Removal: muon → electron → tau → jet

Triggers: EF_e12_medium, EF_mu10

Jet Multiplicity



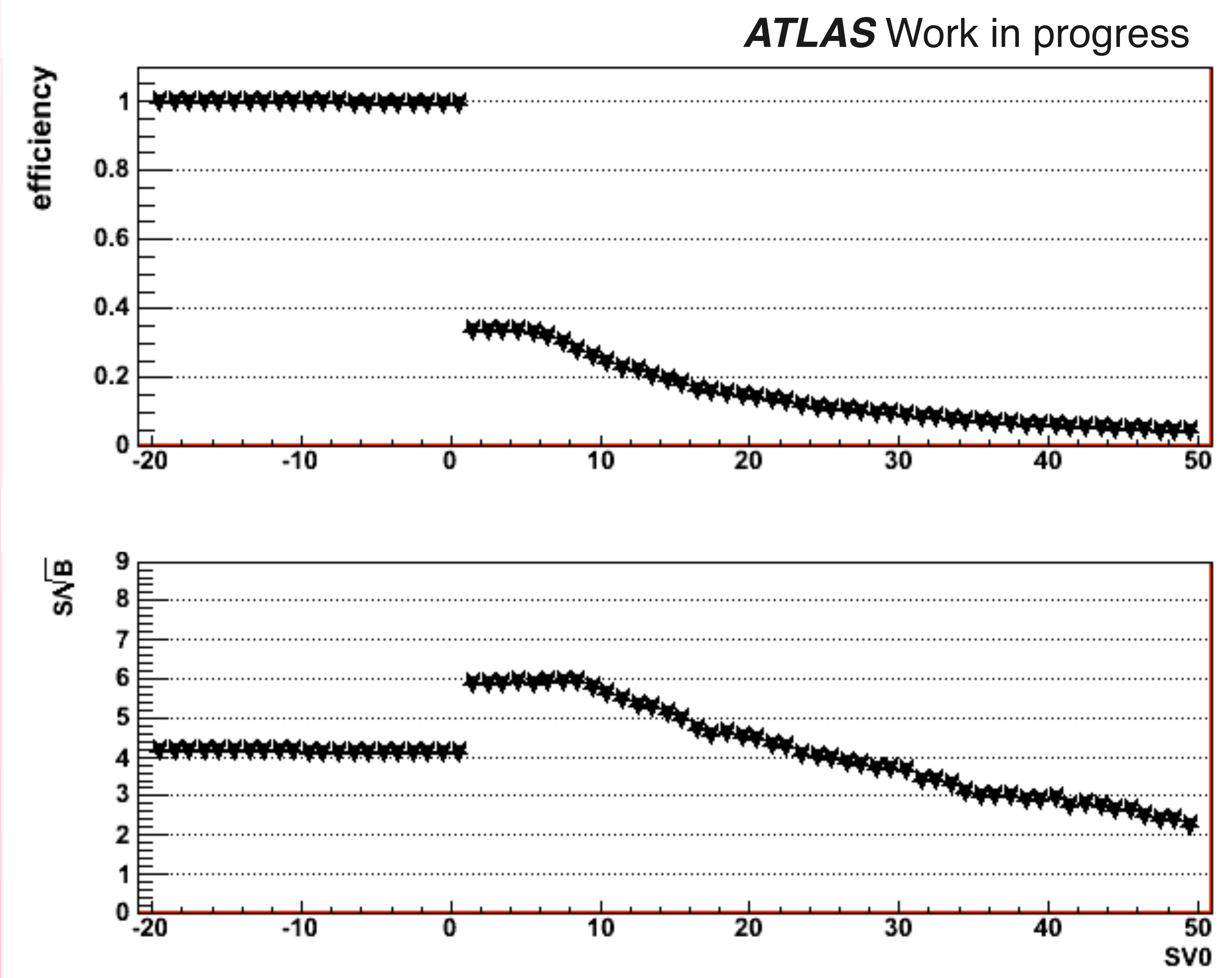
Cut on $N_{jets} < 3$

- Effective at removing ttbar and single top backgrounds.

"Safe" b-Tagging

MSSM Higgs produced in association with 0, 1 or 2 b-jets.

- Use b-tagging methods suitable for use in early data to select b-jets
  - 4 different variables available.
  - Even best performer offers very low efficiency (~35%) for relatively little gain in significance (4.2 to 6.2).
  - Expect actual performance to be worse, so don't make any requirements on b-jets in early analysis.
- Review results as b-tagging methods mature.



E.g. SV0: Returns signed distance (in 3D) between found inclusive SV and the PV, divided by its error.

Effects of Using "Safe" Tau ID

- Studied performance of analysis using different safe tau ID options:
  - $S/\sqrt{B}$ = 1.2 at 200 pb^{-1}, using best performing "safe" ID
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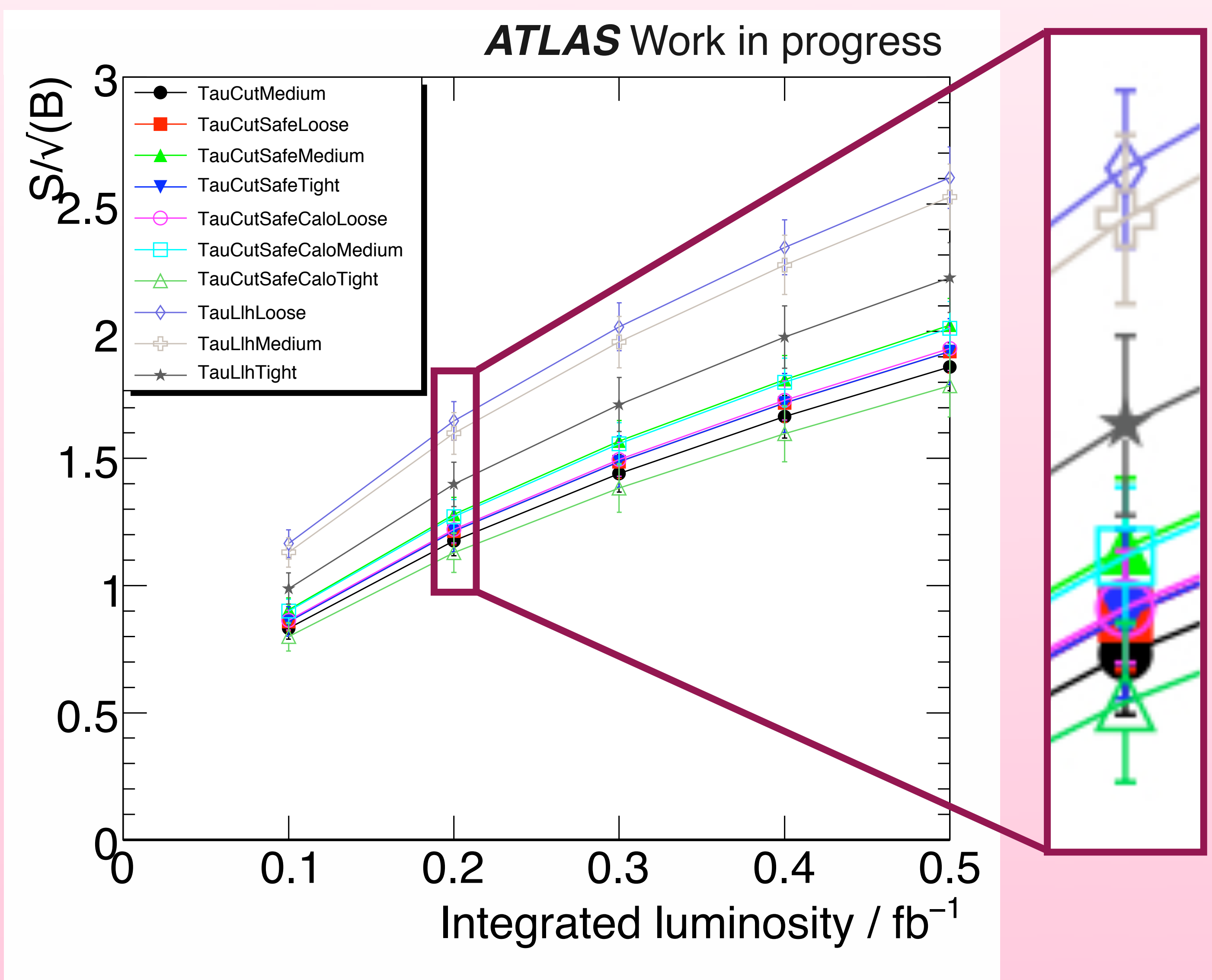
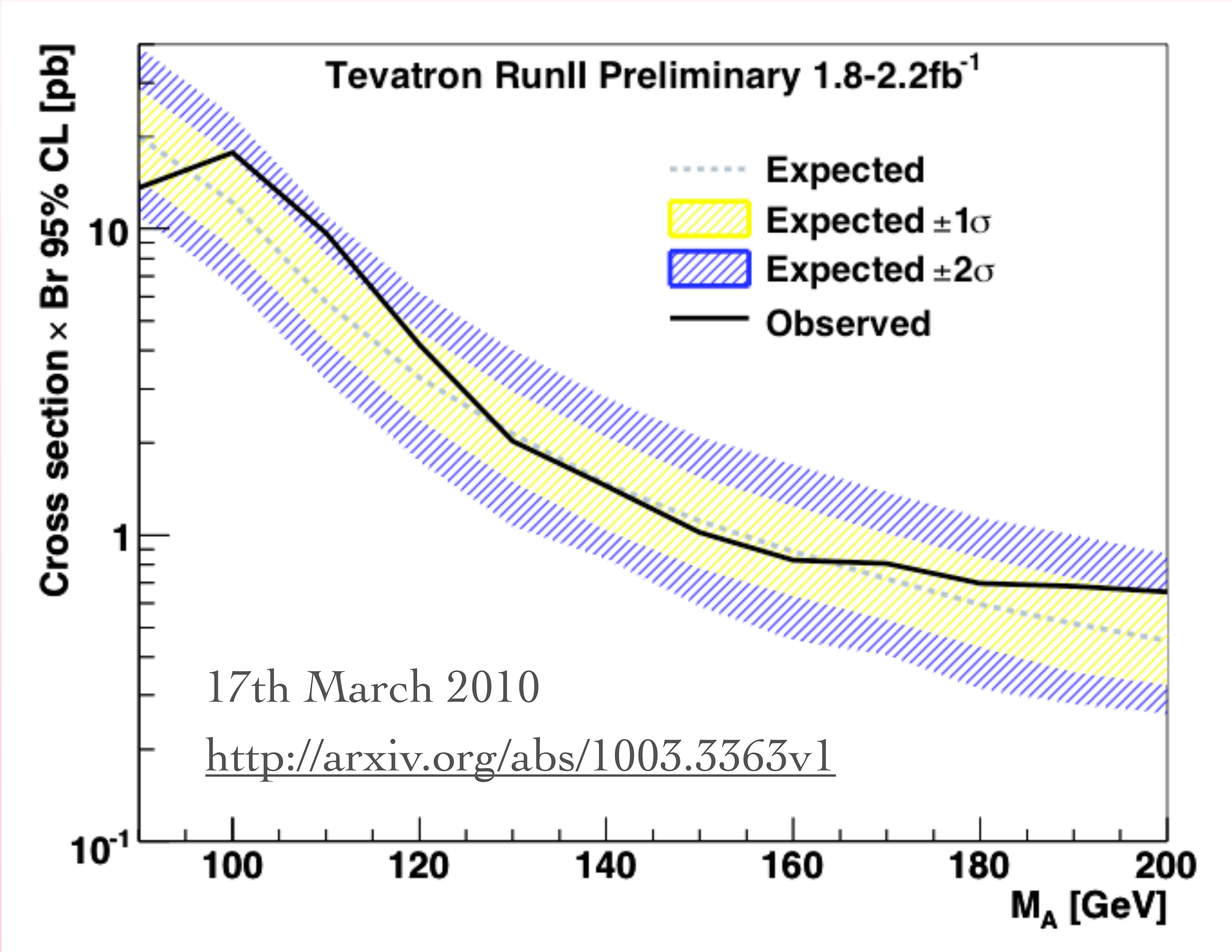


LlhLoose
LlhMedium
LlhTight
CutSafeCaloMedium
CutSafeMedium
CutSafeCaloLoose
CutSafeTight
CutSafeLoose
CutMedium
CutSafeCaloTight

Latest Tevatron Results



17th March 2010

http://arxiv.org/abs/1003.3363v1