DPF2006+JPS2006

29 Oct – 3 Nov, Honolulu, Hawaii

Tau in ATLAS: Performance and Studies to be done with First Data

Markus Bischofberger

The University of Melbourne

On behalf of the ATLAS Collaboration

Outline

- Motivation
- The ATLAS experiment
- Tau reconstruction and identification
- Physics studies with first data: $W \to \tau \upsilon$ and $Z \to \tau\tau$
- Higgs searches: MSSM: $H/A \to \tau\tau$
- SUSY prospects

Why are tau leptons important at LHC

Taus:

- Massive particles with only EW interaction
- Non-negligible Yukawa coupling to SUSY particles
- Lifetime long enough for potential measurement of polarization, spin correlations, parity
- Decay well measured in low-energy experiments

➔ Ideal to probe for “New Physics”

But: jet-like signature difficult because of QCD background at hadron machines

At LHC:

- Large statistics already in first data: $W \rightarrow \tau\upsilon$, $Z \rightarrow \tau\tau$
- Discovery potential for Higgs boson(s)
- Discovery potential for SUSY
- Polarization sensitive to SUSY parameters
- Possible signature for "extra dimensions"

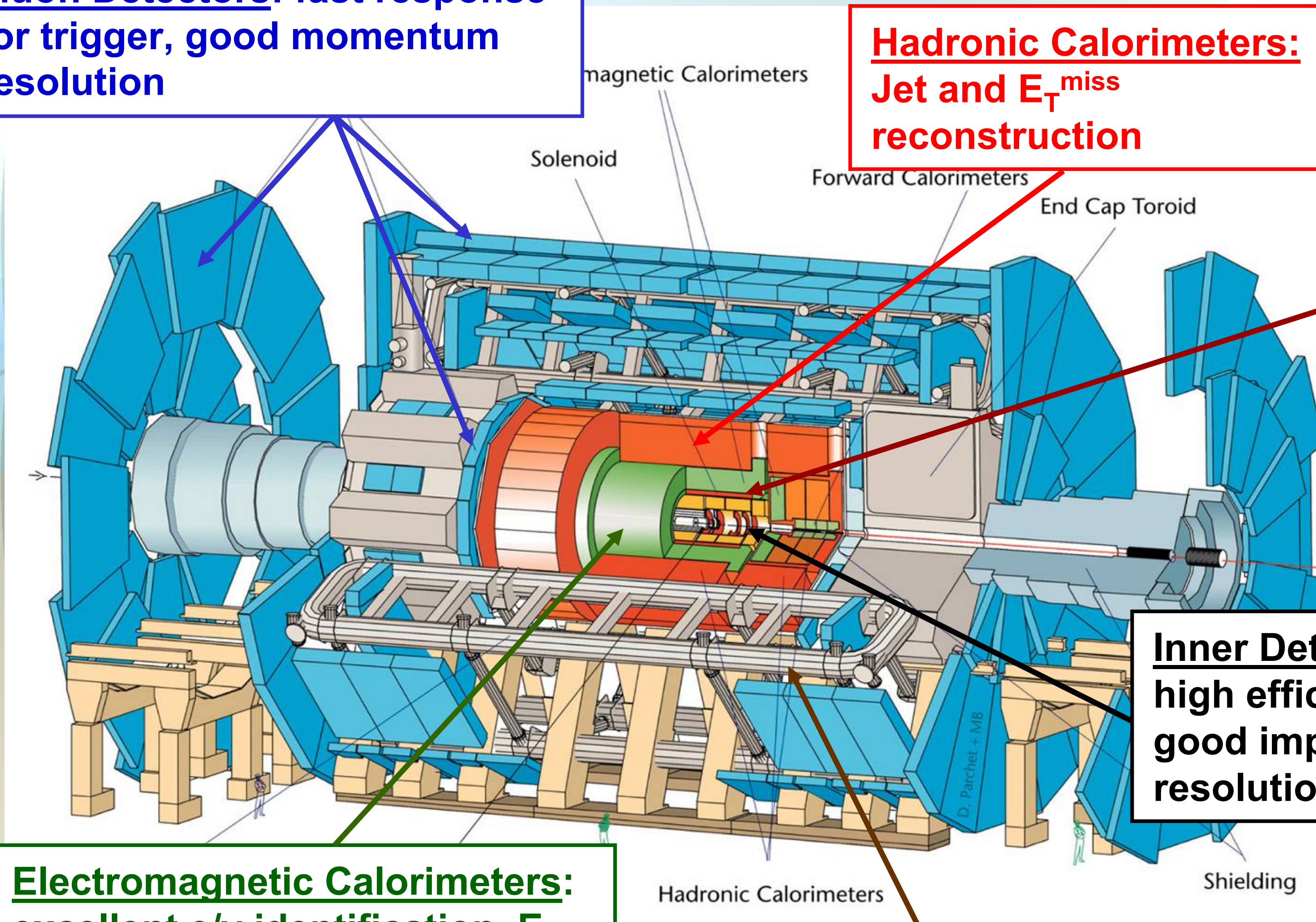
ATLAS Detector

Detector characteristics
Width: 44m
Diameter: 22m
Weight: 7000t
CERN AC - ATLAS V1997

Muon Detectors: fast response for trigger, good momentum resolution

Hadronic Calorimeters: Jet and E_T^{miss} reconstruction

Solenoid: B=2T



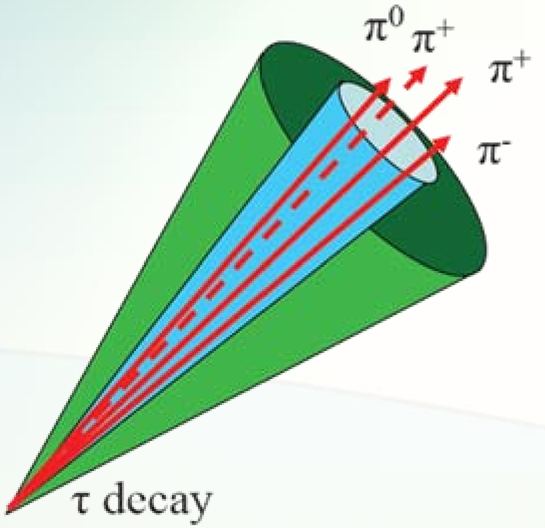
Inner Detector: high efficiency tracking, good impact parameter resolution

Electromagnetic Calorimeters: excellent e/γ identification, E and angular resolution, response uniformity

Barrel Toroid

40MHz beam crossing
Raw data = 1 TB/h

Tau Facts



Properties:

- M_τ=1.78 GeV
- $c\tau$ = 87 μm

Tau Decays

- Leptonic Decays: 35.2 %
  - $\tau \rightarrow l\nu\nu$
  - Identification by lepton (e/μ) and missing E_T
- Hadronic Decays

  1 prong: 49.5 %
  - $\tau \rightarrow \nu_\tau + \pi^\pm + n(\pi^0)$

  3 prong: 15.2 %
  - $\tau \rightarrow \nu_\tau + 3\pi^\pm + n(\pi^0)$

Tau Jets:

very collimated:

- 90% of the energy is contained in a 'cone' of ΔR=0.2 ($\Delta R^2=\Delta\eta^2+\Delta\varphi^2$) around the jet direction for E_T>50 GeV

Low multiplicity

- 1 or 3 tracks

Hadronic, EM energy deposition

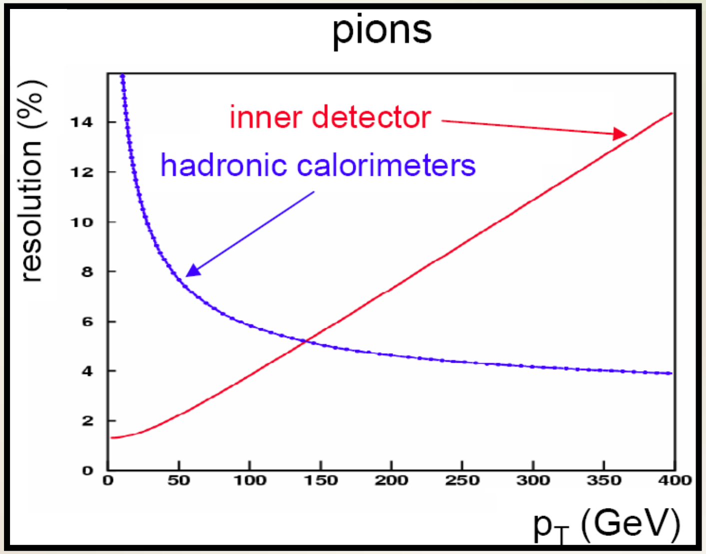
- Charged pions
- Photons from π^0

Tau Reconstruction

Characteristics of tau jets (collimation, multiplicity) can be exploited for tau identification

➢**2 Algorithms in ATLAS**

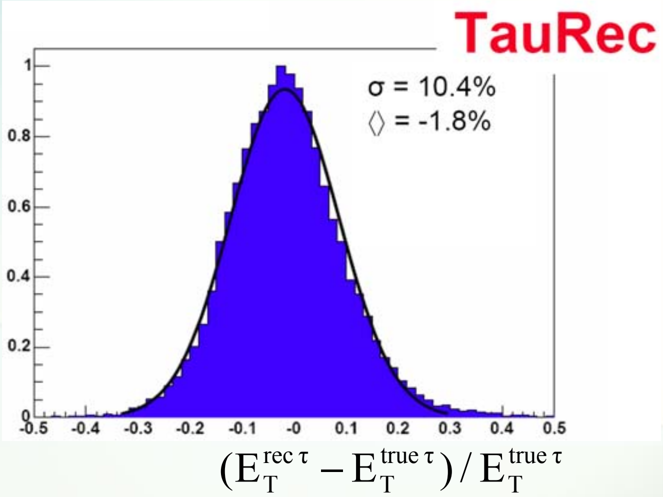
- **TauRec (default):**
  - **starts from cluster in calorimeter (or isolated track)**
  - **Associate tracks to τ jet candidate**
  - **Energy calibration by direct weighting of calorimeter cells (H1-style)**
- **Tau1P3P (new):**
  - **starts from good leading track**
    1 prong or 3 prong τ jet candidate
    depending on number of nearby tracks
  - **Calibrated energy from inner detector (charged) and calorimeter (neutrals):**
    ➡ **"Energy Flow"**



Fake τ jets:

- **QCD jets**
- **Electrons: late showers, strong Bremsstrahlung**
- **Muon interactions in calorimeter**

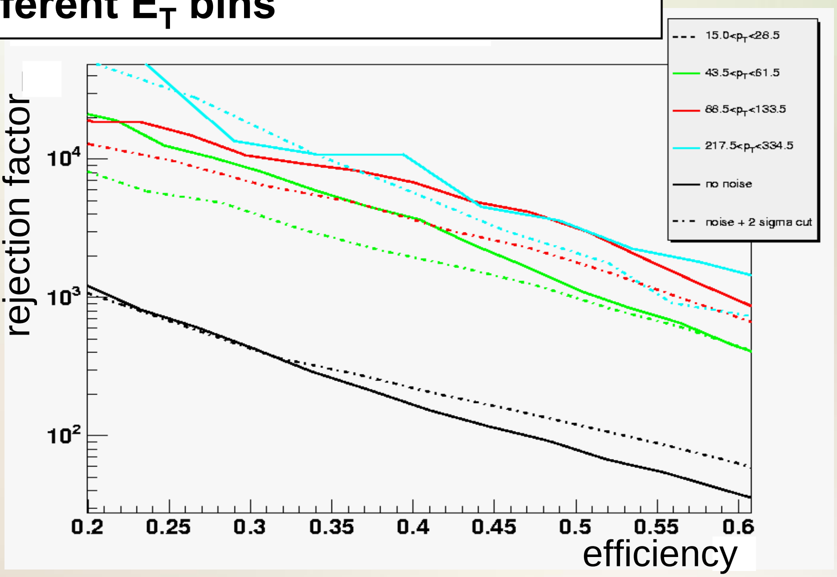
TauRec



Reconstruction of tau candidates:

- **Start from calorimeter cluster (E_T > 15 GeV) (or track p_T > 2 GeV)**
- **Associate nearby tracks**
  $(\Delta R = \sqrt{\Delta\eta^2 + \Delta\varphi^2} < 0.3$ and $p_T > 2\mathrm{GeV})$
- **Acceptance: |η|<2.5**

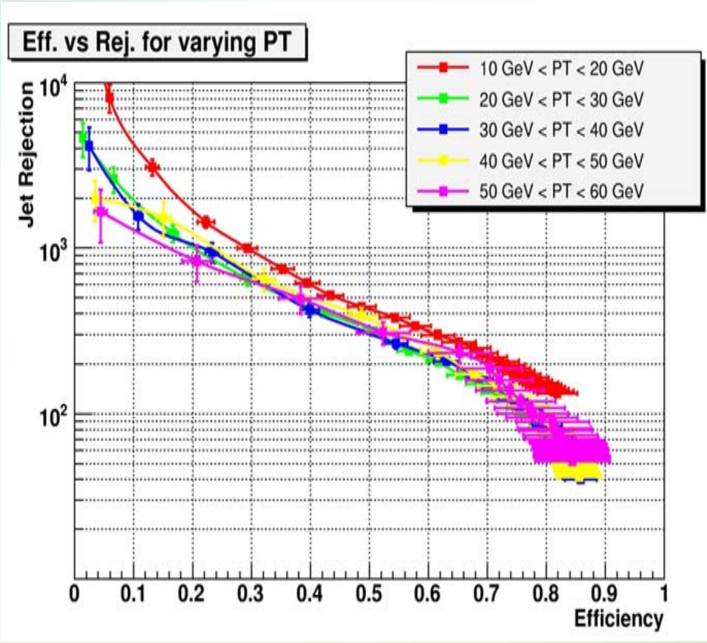
Rejection vs. efficiency curves for different E_T bins



Tau identification:

- **cut on likelihood constructed from discriminating variables:**
  - **e.g. for ε(τ)=30%, 15< p_T< 334.5**
    → Rejection(QCD jets) = 400 - 10 000
- **good energy resolution: ~10%**

Tau1P3P



new algorithm for tau reconstruction and ID in ATLAS:

- not typical τ jet but 1 prong and 3 prong decays:
  - $\tau \rightarrow$ 1 track + n π^0 (Tau1P)
  - $\tau \rightarrow$ 3 tracks + n π^0 (Tau3P)

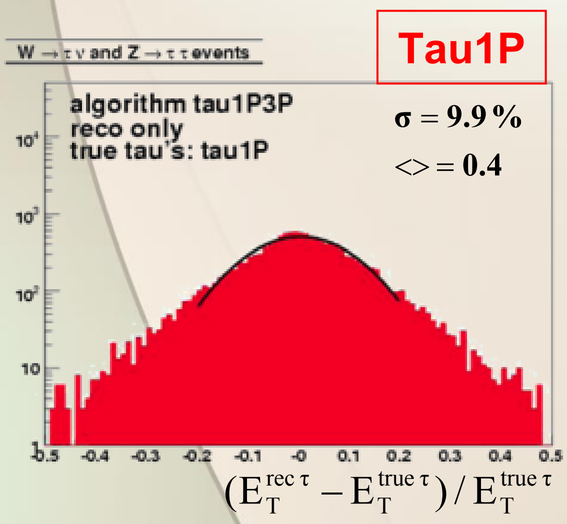
Reconstruction of tau candidates:

- Start from hadronic track (p_T> 9 GeV)
- find nearby tracks (p_T>1 GeV, ΔR<0.2)

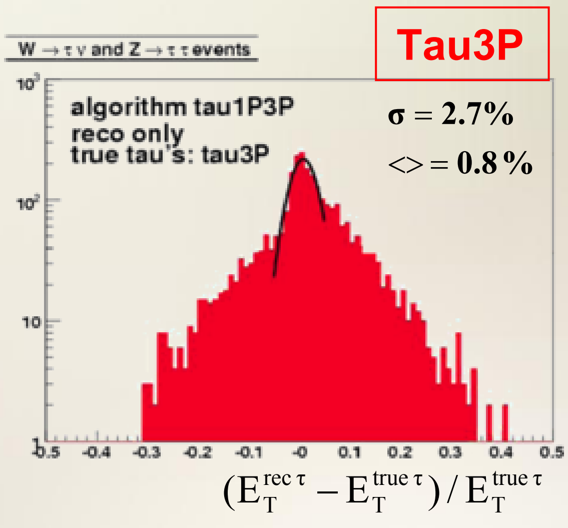
Identification:

- Combination of observables to one discriminating variable

→ e.g.: $\varepsilon(\tau)$=30%, 10 GeV< p_T< 60 GeV
Jet rejection = 600 - 1000



- Energy resolution comparable to TauRec
- better energy resolution for 3 prong



Physics with First Data: $W \rightarrow \tau\upsilon$, $Z \rightarrow \tau\tau$

First few weeks of data taking with luminosity of 10^{31-32} $cm^{-2}s^{-1}$:

Prospects for taus with 10-100 pb^{-1}

- Use the single-prong τ decays to check hadronic scale
- Initial low luminosity provides unique opportunity to study hadronic signature of low energy τ in ATLAS
- Extract τ signal from most abundant τ sources as early as possible

  → requires powerful τ and E_T^{miss} trigger from very start
- Signal/Background expected to 10x worse than at Tevatron:

$$\frac{\sigma_{LHC}(W,Z)}{\sigma_{LHC}(bkg)} \approx \frac{10\times\sigma_{TEV}(W,Z)}{100\times\sigma_{TEV}(bkg)}$$

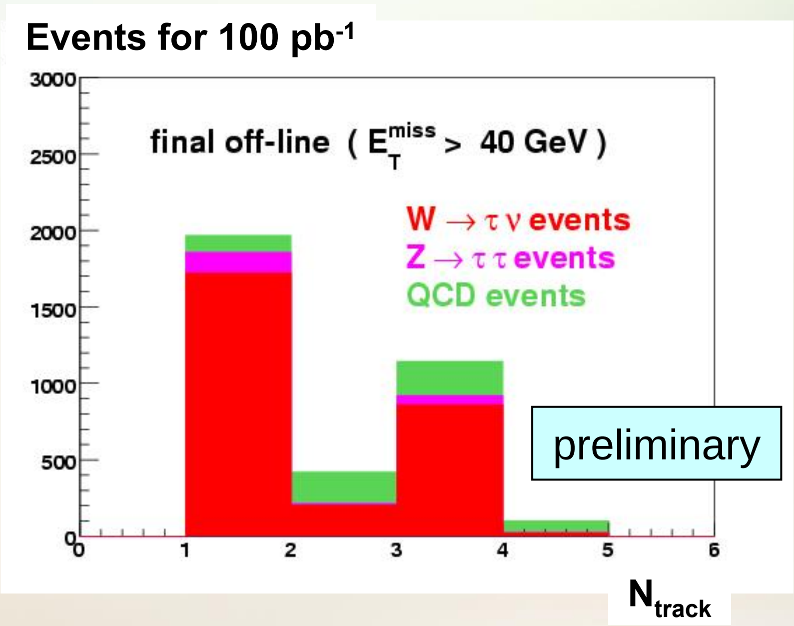
Physics with First Data: $W \rightarrow \tau\upsilon$

Expected Trigger Rates:
- Signal: ~0.01 Hz
  - → 10^5 signal events for 100 pb^{-1}
- QCD background: ~20 Hz
  - → Inclusive S/B ~ 0.0005!

Expected rates for 100 pb^{-1}	$W \rightarrow \tau\nu$, $\tau \rightarrow$hadron	$W \rightarrow e\nu$	$Z \rightarrow \tau\tau$, $1\tau \rightarrow$hadron
σ.B (pb)	11200	17300	1500
τ30i + xE35	~ 15 000	~ 250 000	~ 1300
τ20i + xE25	~ 60 000	~ 560 000	~ 3500

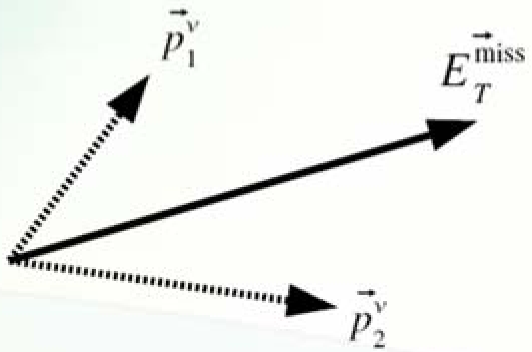
Assuming eff ~ 80% for τ trigger, ~ 50% for τ reco/id

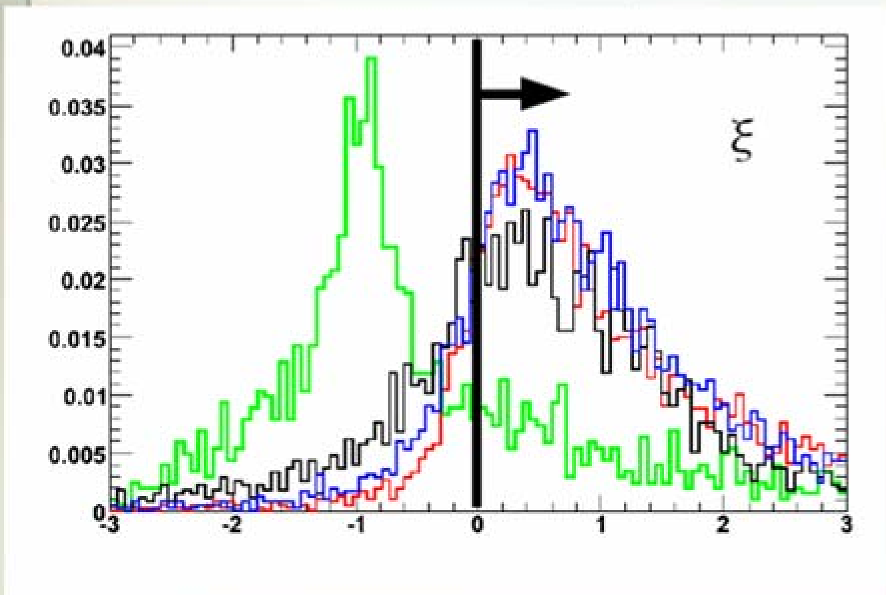
"Counting" experiment
- Evidence in N_{track} spectrum
- Trigger at lowest possible thresholds for low-luminosity operation:
  - E_T^{miss} >20 GeV
  - tau jet with p_T > 15 GeV (τ15i)
- Raise missing E_T cut as luminosity goes up



Mass Reconstruction: $Z \rightarrow \tau\tau$, $H \rightarrow \tau\tau$

- $\vec{E}_T^{\text{miss}} = \vec{p}_T^{\nu_1} + \vec{p}_T^{\nu_2}$
- Collinear Approximation: $\vec{p}_i^{\nu} = \xi \cdot \vec{p}_i^{\tau,\text{vis}}$
- Solve two linear equations for ξ_1 and ξ_2
- Physical Solutions: $\xi_{1,} \; \xi_2 > 0$





Cuts:

- **2 τ with p_T > 15 GeV**
- **$|\sin(\theta_{\tau\tau})| > 0.2$**
- **E_T^{miss} > 15 GeV**

Z->tautau
A->tautau (M=150GeV)
A->tautau (M=300GeV)
WW->tau nu tau nu

Good E_T^{miss} reconstruction is essential!

Physics with First Data: $Z \rightarrow \tau\tau$

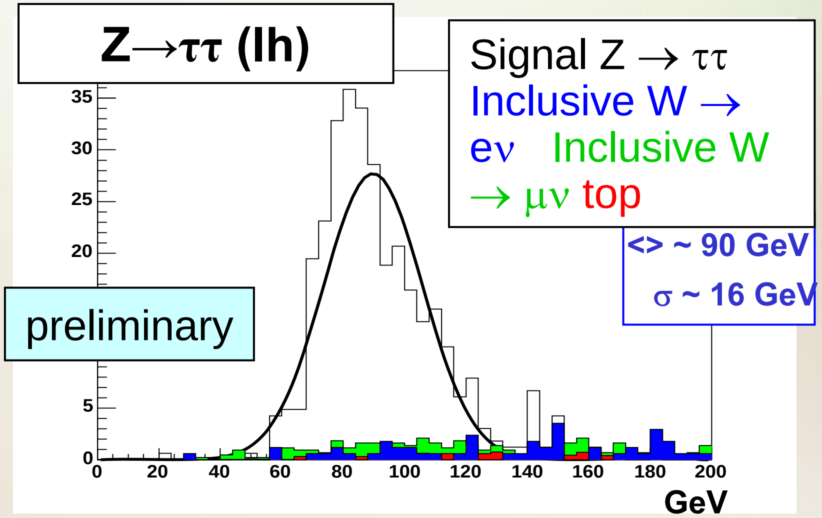
- Fundamental benchmark for $H \rightarrow \tau\tau$
- Less abundant than $W \rightarrow \tau\upsilon$ (~10x less)

BUT:

- Can trigger on lepton (e,μ) of 1st τ (lep-had final state)
- Use same sign (lepton, τ) events to control background
- N_{track} spectrum and M_{vis} of lep-had system
- Invariant mass of Z with collinear approximation
  - Mass resolution dominated by E_T^{miss} resolution

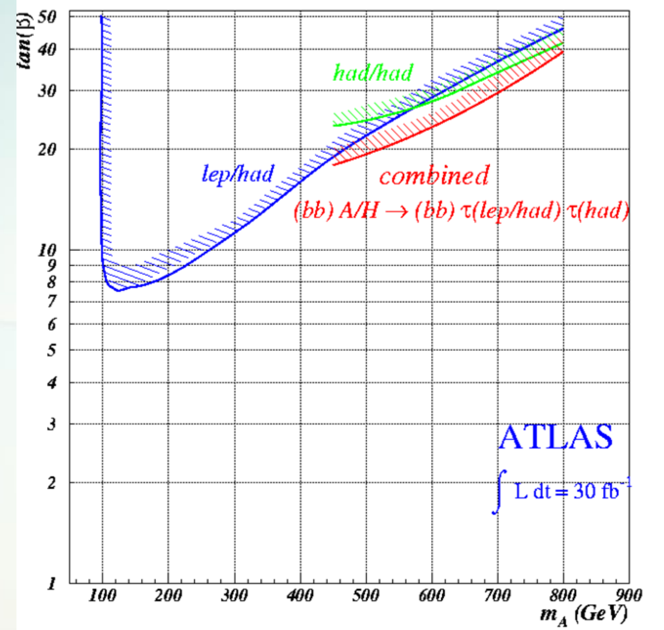
With $10^{31}cm^{-2}s^{-1}$ luminosity:
Start with 15 GeV threshold for lepton and tau.
Tighten selection to improve resolution of invariant mass.

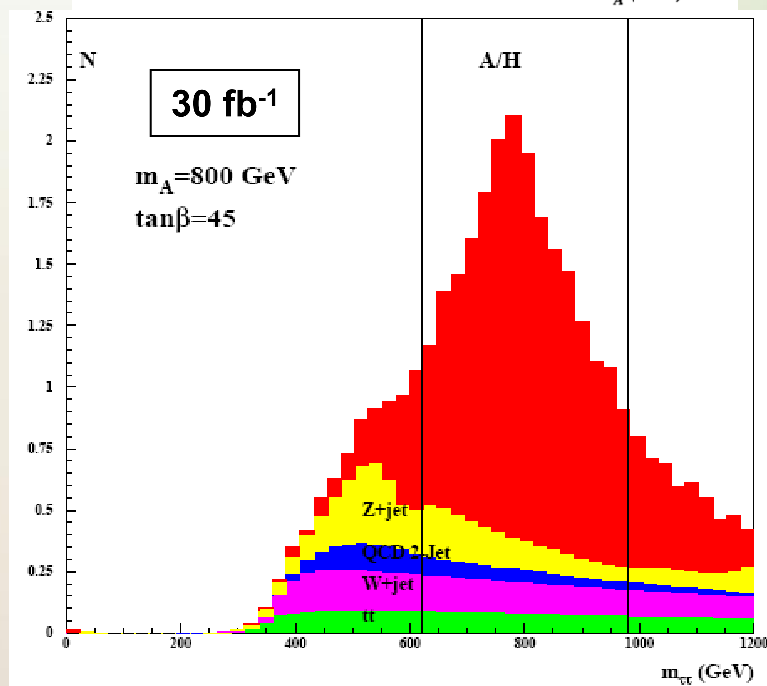
Expect to observe about 300 events (e,μ) in $100pb^{-1}$ with 20% background.
Possibility to loosen cuts?
bb background still to be included/checked



MSSM Neutral Higgs: $A/H \rightarrow \tau\tau$

- Direct (gg→A) and associate (gg→bbA) production
- The τ decays provide the cleanest signature for the discovery of A/H at high mass (and relatively high tanβ)
- All the final states (lep-lep, lep-had, had-had) contribute at different mass range
- Mass resolution (collinear approx.) < 15% in all channels
- Backgrounds:
  - W+jets, Z+jets, tt, bb and QCD
- The dominant background changes depending on m_A
- Associate production (bbA/H) provides additional rejection by b-tagging against the main backgrounds: Z+jet, W+jet, QCD



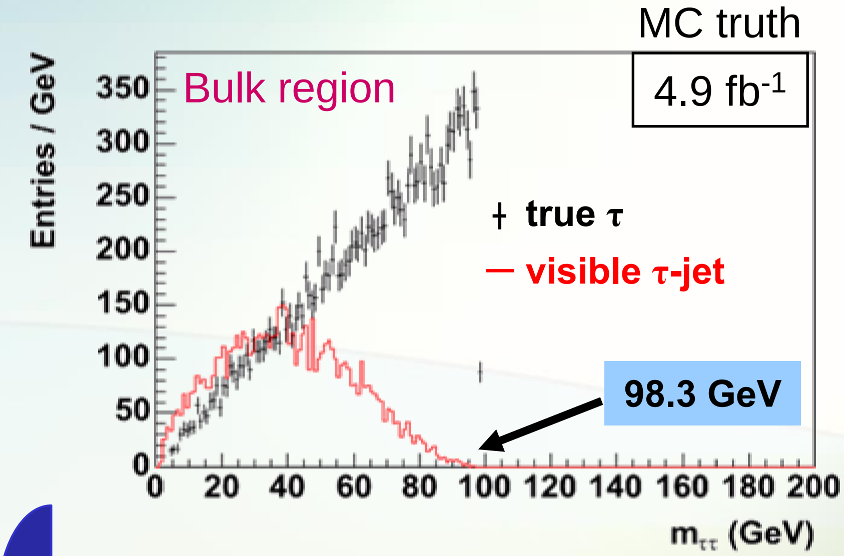


SUSY events with taus in final state

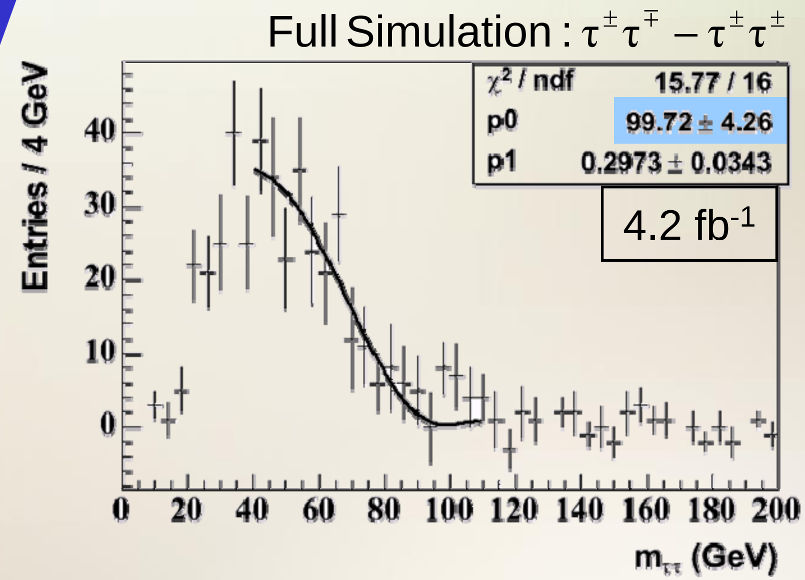
- In mSUGRA and most SUSY models, all SUSY particles decay into invisible $\tilde{\chi}_1^0$
    - no mass peaks
    - measure kinematic endpoints of mass combinations
- Tau signatures important in many regions of mSUGRA parameter space especially for $\tan\beta >> 1$

SUSY Decays: $\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1^{\pm}\tau^{\mp} \rightarrow \tilde{\chi}_1^0\tau^{\pm}\tau^{\mp}$

- Challenging because of escaping neutrino
    - distorted mass distribution, but endpoint can still be measured
- Interesting because:
    - Non-negligible Yukawa coupling
    - Large left-right mixing (~$m_\tau \tan\beta$)
    - Tau polarization measurement can be used to constrain SUSY model
- Tau can dominate in some region of mSUGRA parameter space (e.g. funnel)



Parameterize MC truth and fit obtained function to reconstructed distribution



Conclusion

- Tau jet reconstruction algorithms in ATLAS:
  - TauRec: good results, seeded from cluster (or track)
  - Tau1P3P: Track based, identification of 1 or 3 prong tau decays, most powerful for low p_T

  ➡ two complementary tau algorithms, so robust tau reconstruction should be available to be tested with first data

- Taus from $W \rightarrow \tau \upsilon$ and $Z \rightarrow \tau\tau$ will be available with first data of LHC:

  ➡ excellent possibility to understand detector performance

- Efficient tau identification is crucial for discovery of new physics:
  - MSSM Higgs:
    - $H/A \rightarrow \tau\tau$
    - $(H^+ \rightarrow \tau\upsilon)$
  - SUSY signatures with taus in final state
  - extra dimensions, new theories?

BACKUP SLIDES

SM Higgs: $qqH \rightarrow qq\tau\tau$

Production: Vector Boson Fusion (VBF):

- only ~20% of total cross section but signature can be exploited for bkg suppression

Dominant backgrounds: Zjj, WWjj (EW+QCD), tt

Forward tagging jets:

- difficult forward region: jet calibration

Central-Jet Veto:

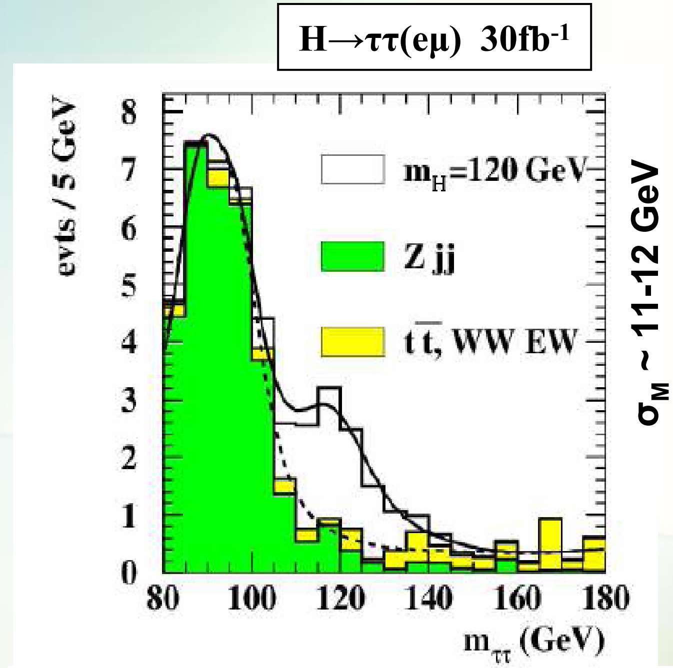
- sensible to pile-up

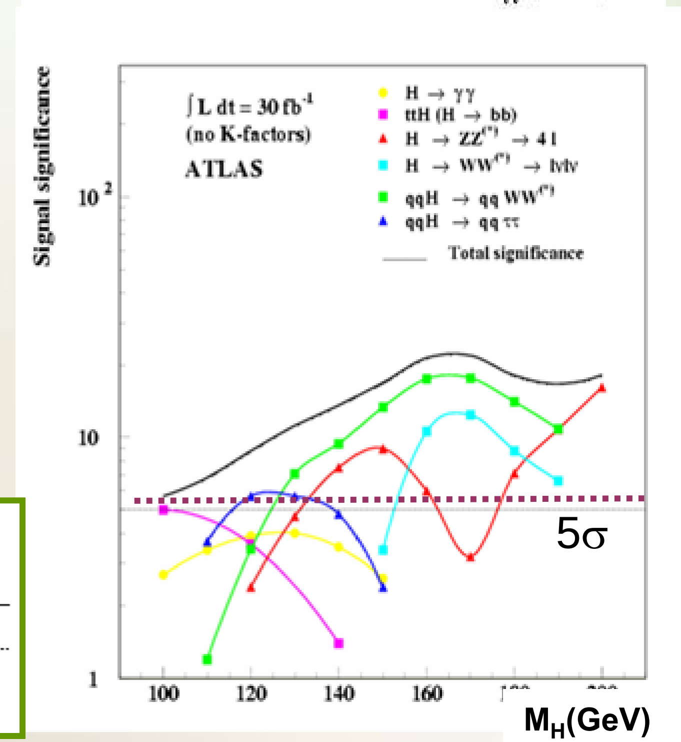
Mass reconstruction (collinear approx.):

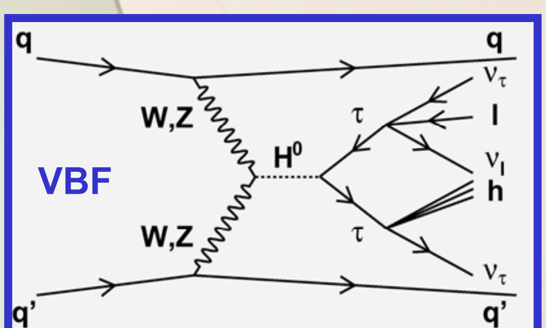
- E_T^{miss} is essential
- dominant experimental issue

Combined results for lep-had, lep-lep (e,μ trigger)

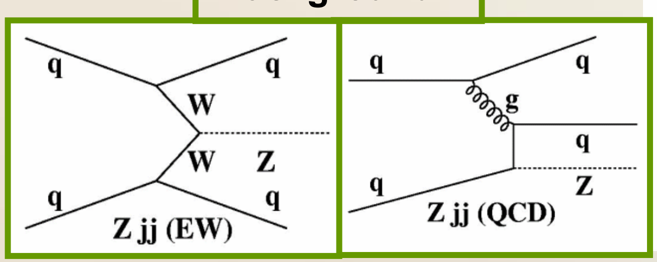
- better performance for lep-had (mass resolution)
- About 5 sigma for 110 GeV < m_H < 140 GeV







Background



Search for MSSM Higgs boson

Neutral H and A

Production:

- $gg \to H/A$
- $gg \to bbH/A$ for high $\tan\beta$

Decay:

- BR($H/A \to bb$) ~ 90%
- BR($H/A \to \tau\tau$) ~ 10%

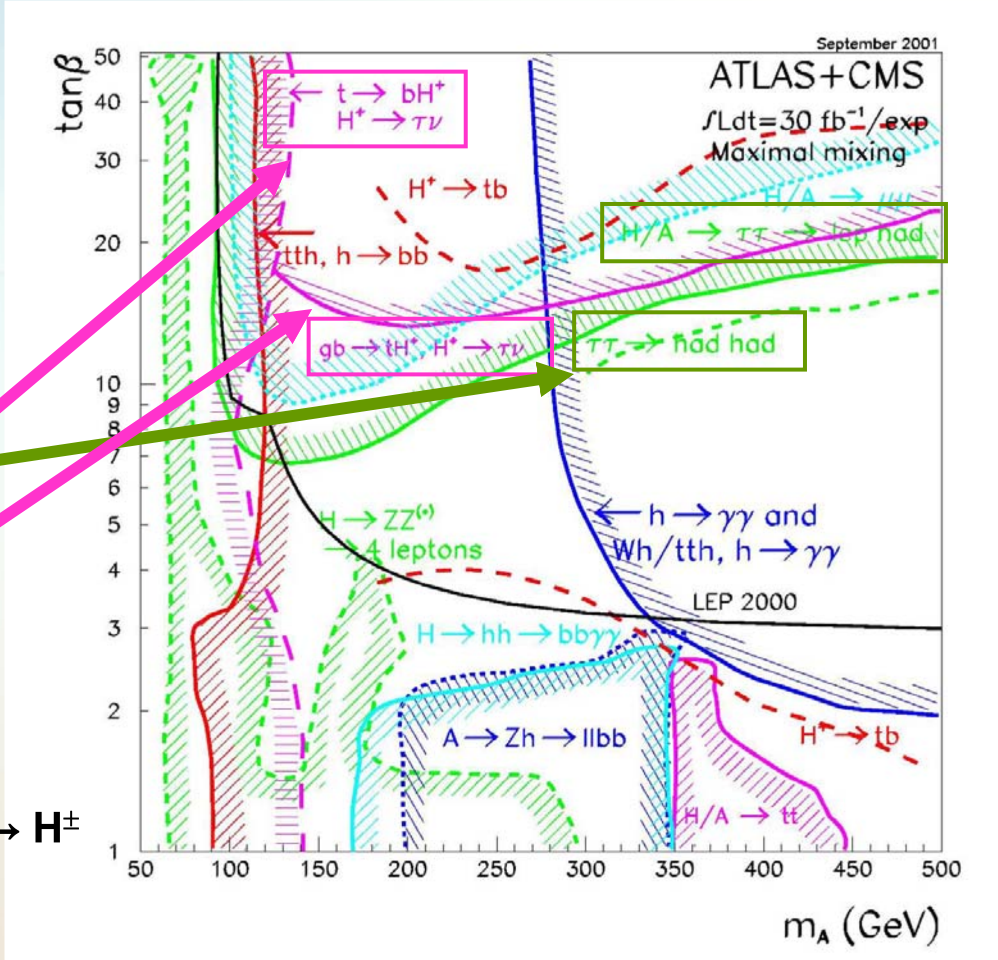
Charged Higgs

Production

- $m_H<m_t$: $tt \to Wb\, bH^{\pm}$
- $m_H>m_t$: $gb \to tH^{\pm}$, $gg(qq) \to tb\, H^{\pm}$, $qq \to H^{\pm}$

Decay:

- $m_H<m_t$: $H^{\pm} \to \tau\nu$ dominant
- $m_H>m_t$: $H^{\pm} \to \tau\nu$, $H^{+-} \to tb$



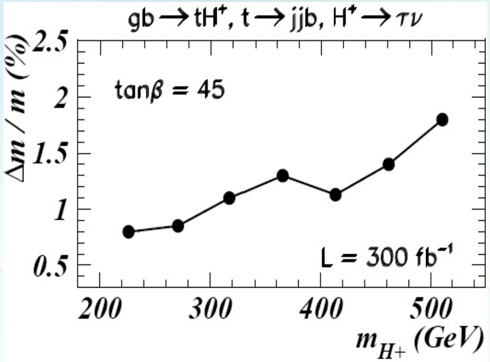
- Discovery modes for large and moderate $\tan\beta$
- Measurement of $\tan\beta$

Charged Higgs: $H^{\pm} \rightarrow \tau\upsilon_{\tau}$

Production: $gb \rightarrow tH^{+}$

Decay: $t \rightarrow bjj,\ H^{+} \rightarrow \tau\upsilon$

➡ **Final State:** τ, 3jets, E_T^{miss}

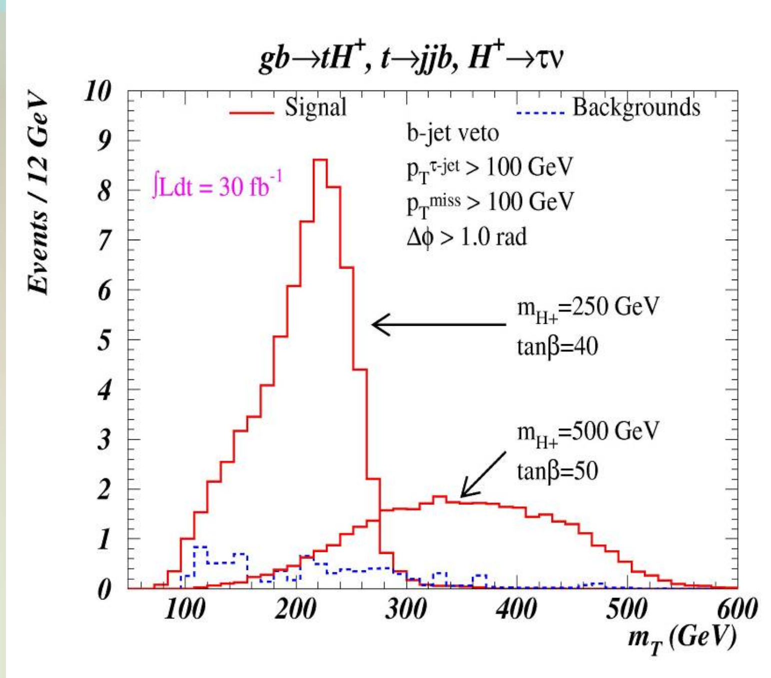


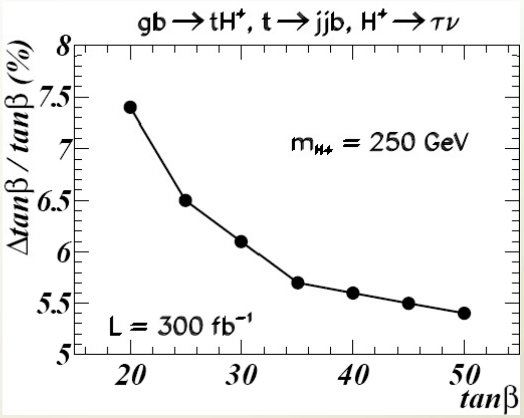
Invariant mass cannot be reconstructed because of υ in final state but m_H can be determined with likelihood method

Backgound suppression:

- **tt: b-tag / b-veto**
- **Wt: transverse mass (τ-E_T^{miss})**
- **τ from H^+ is 100% polarized:**
  - **further signal enhancement with respect to W bkg**

➡ **almost background free, limited by signal**



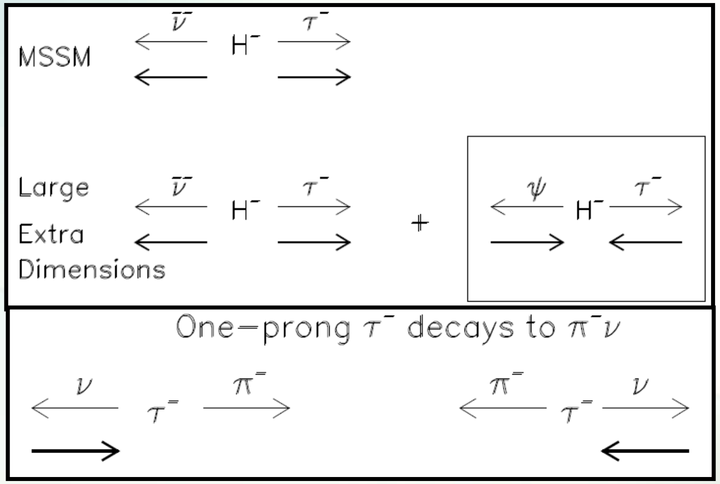


tanβ determination by measuring rate of this channel: $\sigma(gb \rightarrow tH^{\pm}) \times BR(H^{\pm} \rightarrow \tau\upsilon) \propto \tan^2\beta$

- **statistical uncertainty dominates**

➡ **precision improves as rate $H^+ \rightarrow \tau\upsilon$ increases with tanβ**

Charged Higgs and Large Extra Dimensions



In MSSM (general: 2 Higgs Doublet of Type II, 2HDM-II)

τ from H 100% polarized: $H^- \rightarrow \tau_R \bar{\upsilon}$

In Large Extra Dimension (LED) right handed "bulk" neutrino can exist. Coupling to Higgs enhanced by large number of Kaluza-Klein states:

$$H^- \rightarrow \tau_R \bar{\nu} + \tau_L \psi$$

Bulk neutrino

Polarization asymmetry:

$$A = \frac{\Gamma(H^- \rightarrow \tau_L \psi) - \Gamma(H^- \rightarrow \tau_R \bar{\upsilon})}{\Gamma(H^- \rightarrow \tau_L \psi) + \Gamma(H^- \rightarrow \tau_R \bar{\upsilon})}$$

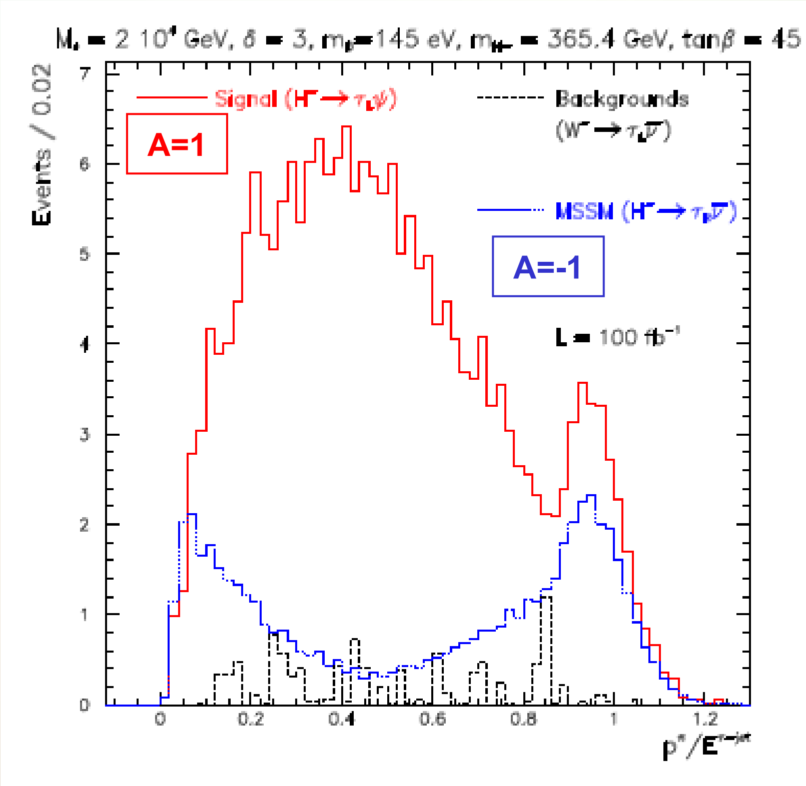
model dependent:

- **MSSM: A=-1**
- **LED: -1<A<1**

For 1 prong τ decays:

- **reconstruction of p_π/E_{jet} could be used to distinguish between MSSM and LED scenarios**

Further measurement of asymmetry may provide a distinctive signature for LED



Systematic Uncertainties: $A/H \rightarrow \tau\tau$

- **Detector resolution:**
  - Resolution of E_T^{miss}:
    - increase mass window by 20%,
    - signal acceptance unchanged
- **Identification of the τ and b-jets:**
  - decrease tau-ID efficiency from 55% to 40%
  - decrease b-tagging efficiency from 70% to 60%
  - rejection factors unchanged
- **Jet energy scale:**
  - Absolute jet energy scale in ATLAS estimated to be known with 3% accuracy:
    - all jet energies raised by 3% which alters acceptance due to cuts of the transverse energy

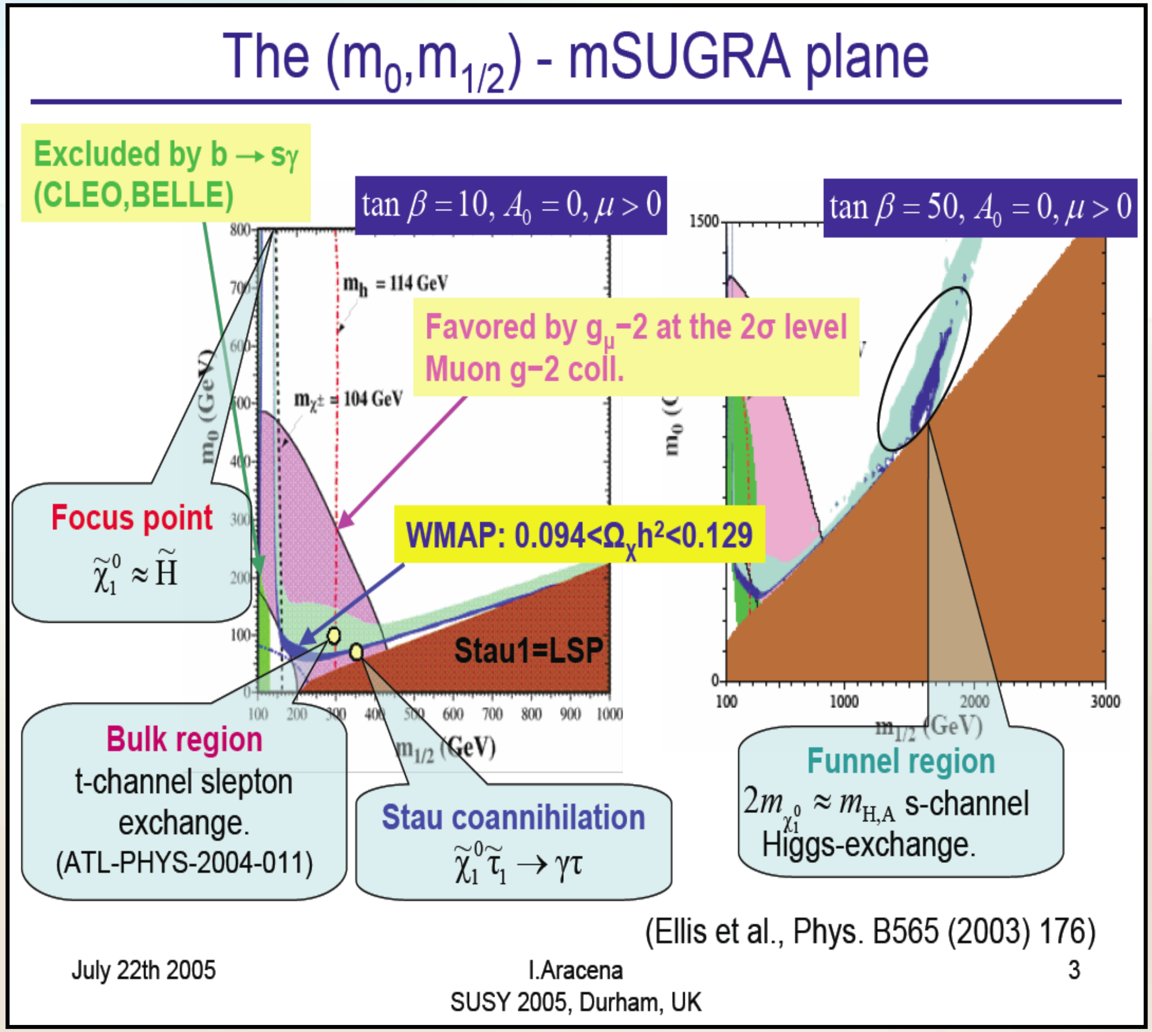
	$m_{A/H}$	$\tan\beta$	Signal	Background	Significance
Standard analysis	600	30	20.4	7.4	5.8 σ
	800	45	19.6	6.8	5.8 σ
Detector resolution	600	30	20.4	9.4	5.2 σ
	800	45	19.6	8.3	5.3 σ
τ identification	600	30	14.9	7.5	4.3 σ
and b-tagging	800	45	13.8	5.7	4.4 σ
jet energy scale	600	30	18.6	8.6	5.0 σ
	800	45	16.7	7.3	4.8 σ

Table 10: Study of the influence of systematic uncertainties of the significance of the channel $(b\bar{b})A/H \rightarrow (b\bar{b})\,\tau\,(had)\,\tau\,(had)$.

mSUGRA

4 Parameters + 1 sign:

1. m_0: Common scalar mass at GUT scale
2. $m_{1/2}$: Common gaugino mass at GUT scale
3. A: trilinear coupling parameter
4. tanβ: ratio of VEV's at weak scale
5. sgn(μ) of Higgsino Mass



Experimental Conditions at LHC

- Proton-proton collisions with cms energy of 14 GeV
- Luminosity:
  - First run with 14 GeV in 2008:
    increasing to reach ~10^{33} $cm^{-2}s^{-1}$ = “low luminosity” phase
    → 30 fb^{-1} between 2008 and 2010/2011
  - “high luminosity” phase: ~10^{-34} $cm^{-2}s^{-1}$
  → ~300 fb^{-1} by 2014/2015
- Pile-up:
  - low luminosity: ~2
  - high luminosity: ~24

  pp interactions per bunch crossing every 25 ns (40MHz)
- Trigger output rate for offline analysis: ~200 Hz

The ATLAS detector

γ-electrons, jets, E_t^{miss}, σ_E
$|\eta|$ coverage, b-tagging

Thin Superconducting Solenoid (B=2T)

LAr EM Calorimeter ($|\eta|<3.2$):
$L \times R = 13.3m \times 2.25m$
$|\eta| \leq 3.2$ (4.9)
$\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$
PB-LAr

Hadronic Calorimeter :
End caps: LArg
Barrel: Scintillator-tile
$L \times R = 12.2m \times 4.25m$
$\sigma_E/E = 50\%/\sqrt{E} \oplus 3\%$ ($|\eta| \leq 3$)

Large Superconducting
Air-Core Toroids

Muon Spectrometer
$L \times R = 25\ (46)\ m \times 11m$

σ(EtMiss)=0.46*sqrt(SumET))

Inner Detector :
Semiconductor Pixel and Strips
Straw Tube Tracking Detector (TRT)
$L \times R = 7m \times 1.15m$
$\sigma_{R\phi}$=12-16μm, σ_Z=66-580μm
$\sigma(P_T)/P_T = 0.05\% P_T \oplus 1\%$