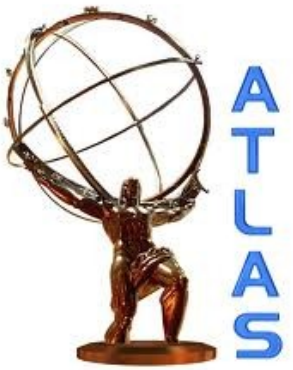


Physics with Tau Lepton Final States in ATLAS

Z. Czyczula, Yale University

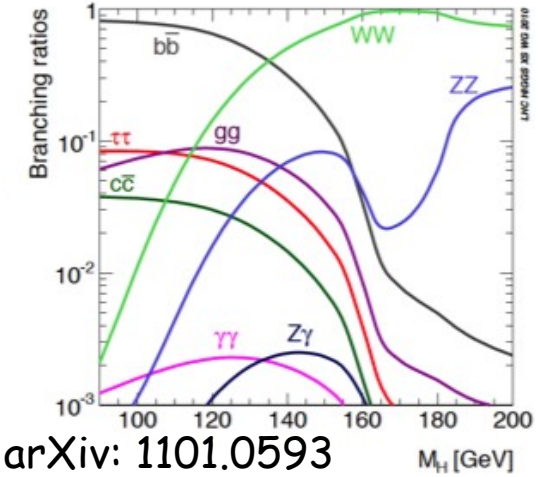
Why are taus important in ATLAS?

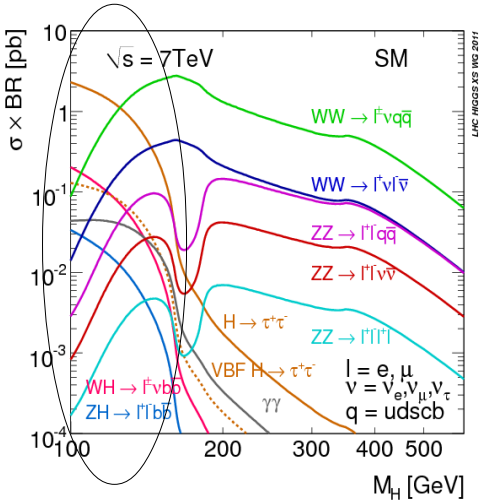
Discovery searches: Heavy object may couple preferentially to taus (heaviest leptons)

- Higgs boson couples to mass

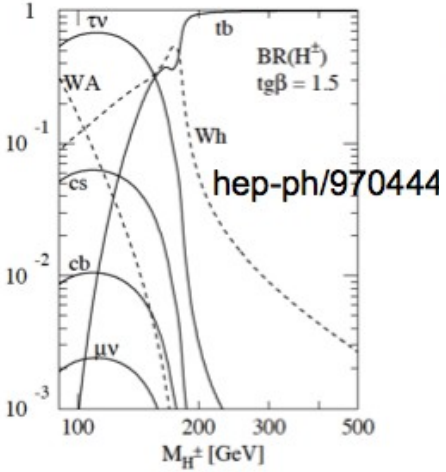
SM H->tautau
2nd largest BR for low mass

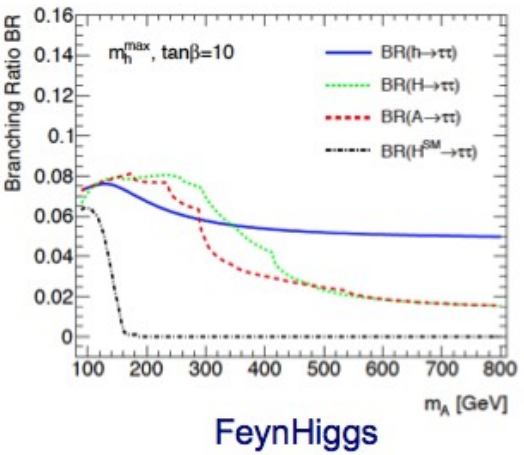
MSSM: 5 Higgs bosons h,H,A,H^+/-
For large part of parameter space BR is enhanced





arXiv: 1101.0593





- Most of theories predict universal coupling of Z' to leptons, but there are models which predict Z' coupling preferentially to the third generation (Technicolor motivated)
- SUSY decays chains contain soft taus
- Important for completeness

More than discovery probes

Taus are short lived -> spin information imprinted in tau decay product kinematics!
- experimentally possible to distinguish left-handed (LH) from right-handed (RH) taus

- Tau Polarization

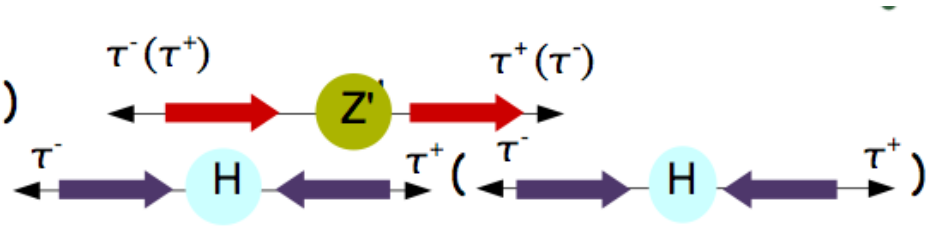
$$P_\tau = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

-Indicates tendency for production of left- and right- handed taus to violate parity

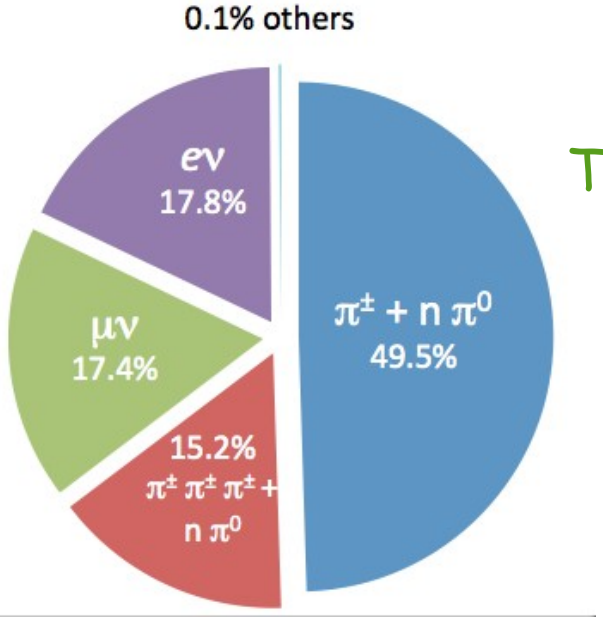
Can help establish properties of a new particle:
-> RH taus from H+'s vs. LH taus from W's
-> Z has spin 1 and couplings violate parity => P_τ = -15% vs Higgs has spin 0 => P_τ =0
-> Z' and W' degree of parity violation varies between models
(possible to constrain E6 models: Phys. Rev. D46 (1992) 290-302)

- Tau spin correlations – direct access to spin of the parent object

Possible configurations:
Spin 1 (Z') : $Z'_L \to \tau_L^- \tau_R^+$ ($Z'_R \to \tau_R^- \tau_L^+$)
Spin 0 (H) : $H \to \tau_L^- \tau_L^+$ ($H \to \tau_R^- \tau_R^+$)

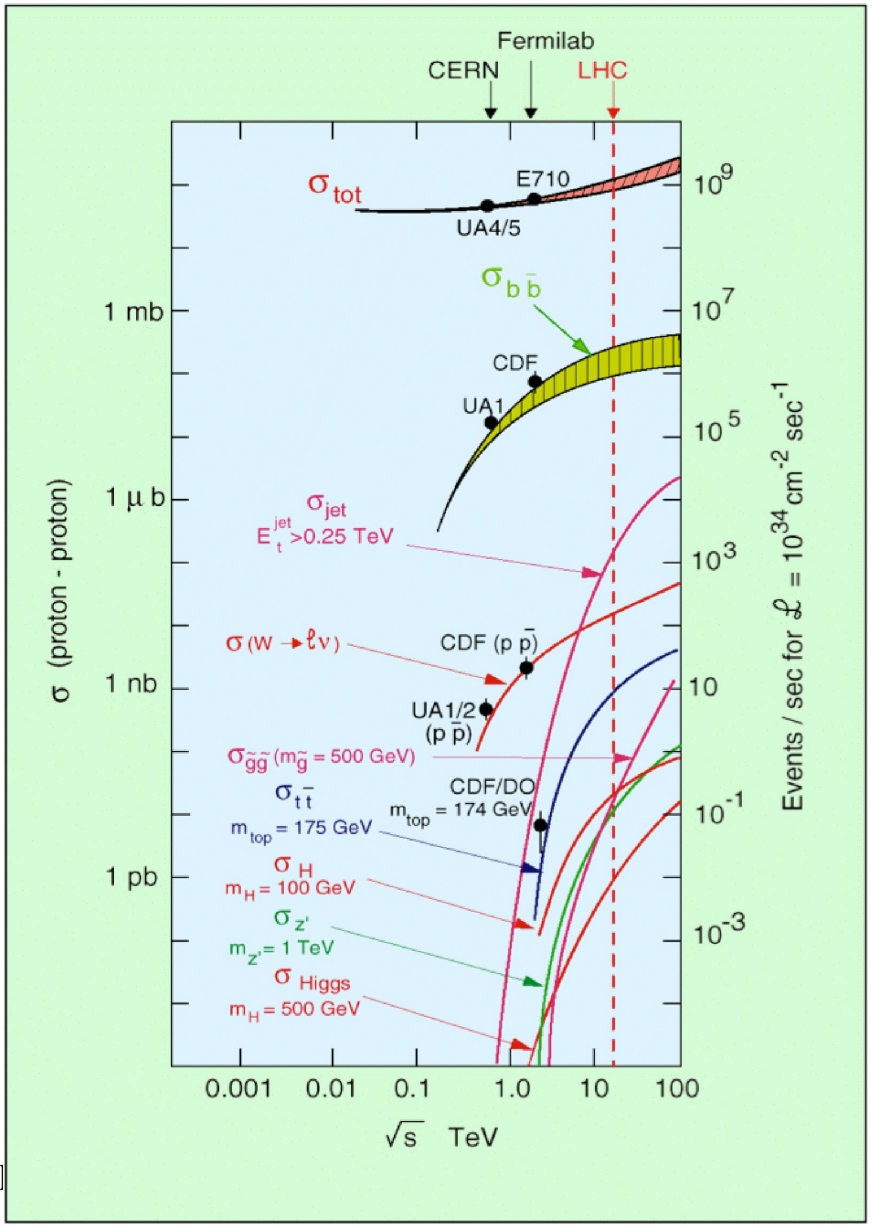


Taus are experimentally challenging !



Tau decays

Tau events are rare as compared to QCD



Leptonic decays:
-Not viable to distinguish from prompt leptons

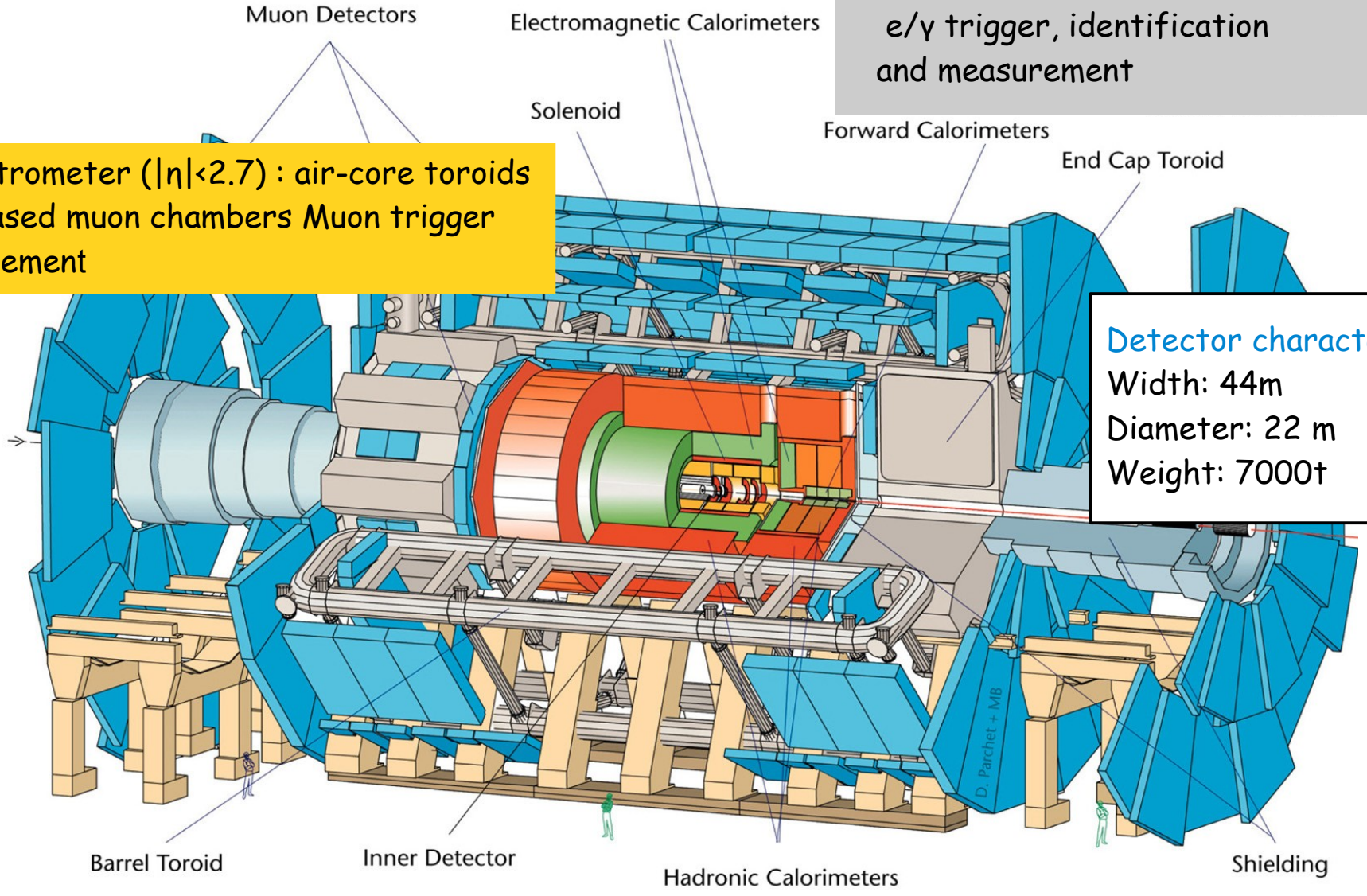
Hadronic decays:
-suffer from huge backgrounds from jets

=> challenge for both online and offline identification

The ATLAS detector

EM calorimeter: Pb-LAr Accordion
e/γ trigger, identification
and measurement

Muon Spectrometer (|η|<2.7) : air-core toroids with gas-based muon chambers Muon trigger and measurement



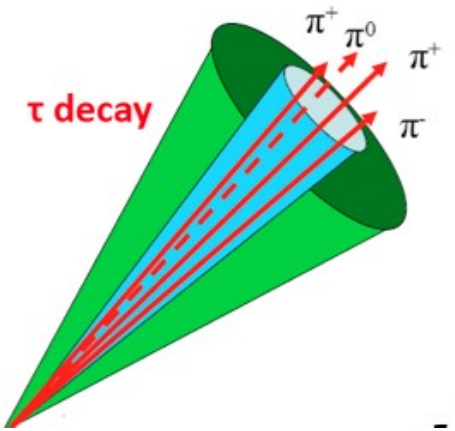
Detector characteristic
Width: 44m
Diameter: 22 m
Weight: 7000t

Inner detector (|η|<2.5): Si strips/pixels;
TRT straws. Vertexing, tracking, e/π separation

HAD calorimetry (|η|<5): segmentation,
Fe/scintillator Tiles (central), LAr (fwd)
Trigger and measurement of jets and missing E_T

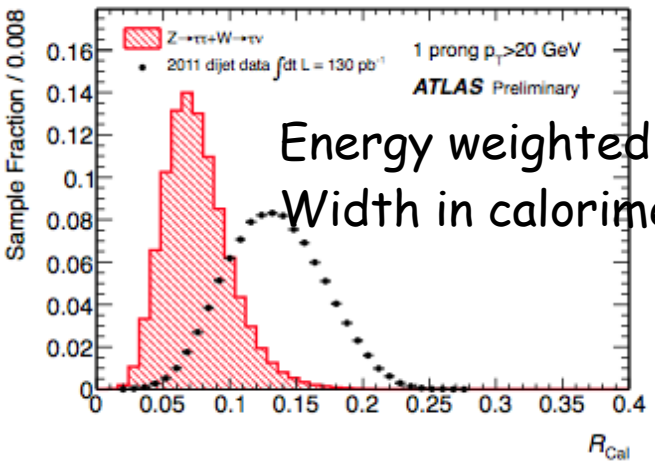
Tau reconstruction and identification (ID) in ATLAS

- Reconstructed taus: Anti-k_T jets with R=0.4
- Energy scale: jets scale + tau scale derived using MC
- data driven uncertainties using single pion response

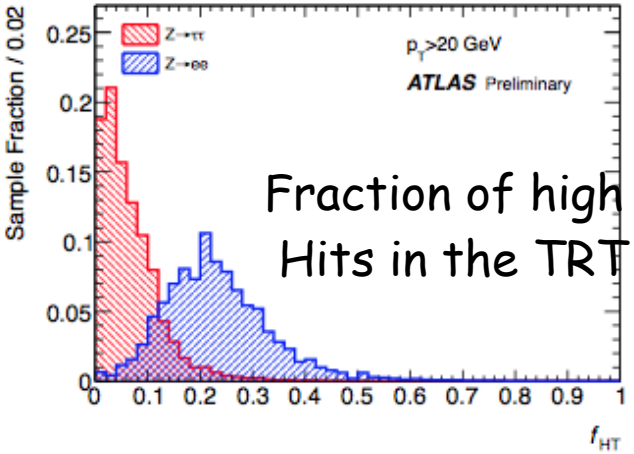


- Discrimination against QCD jets:
  - low track multiplicity
  - narrowness of the shower

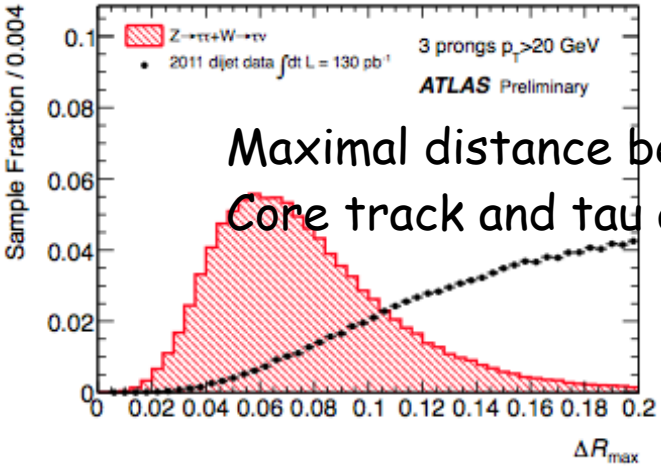
- Electron / tau separation
  - Fraction of high threshold hits in TRT & shower shape (hadronic veto)



Energy weighted shower Width in calorimeter



Fraction of high threshold Hits in the TRT



Maximal distance between Core track and tau axis

Tau ID performance

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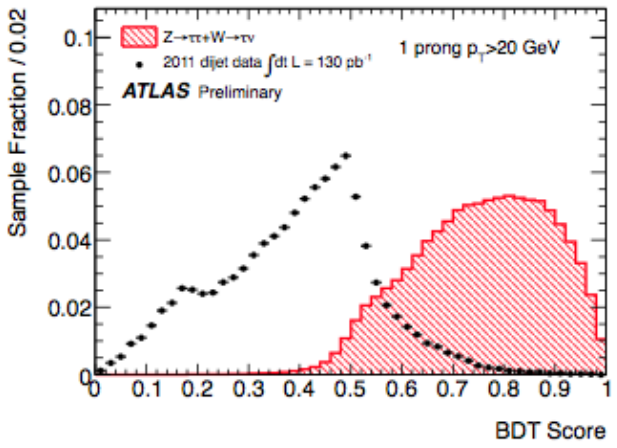
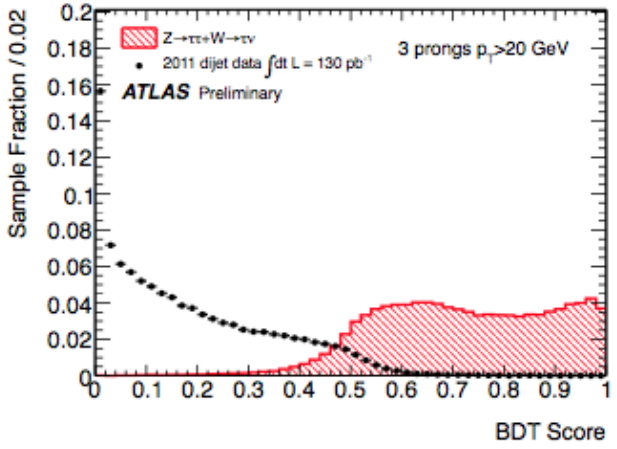
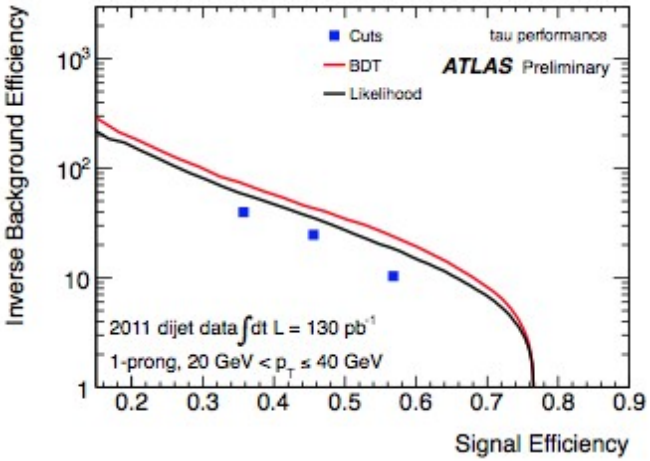
Output BDT score



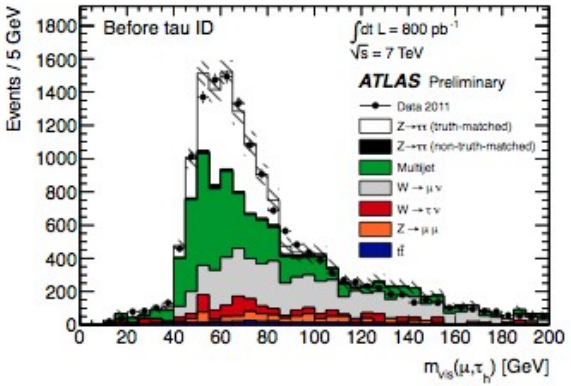


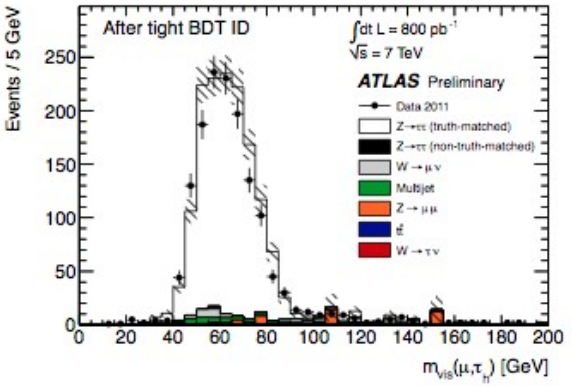
Rejection vs efficiency



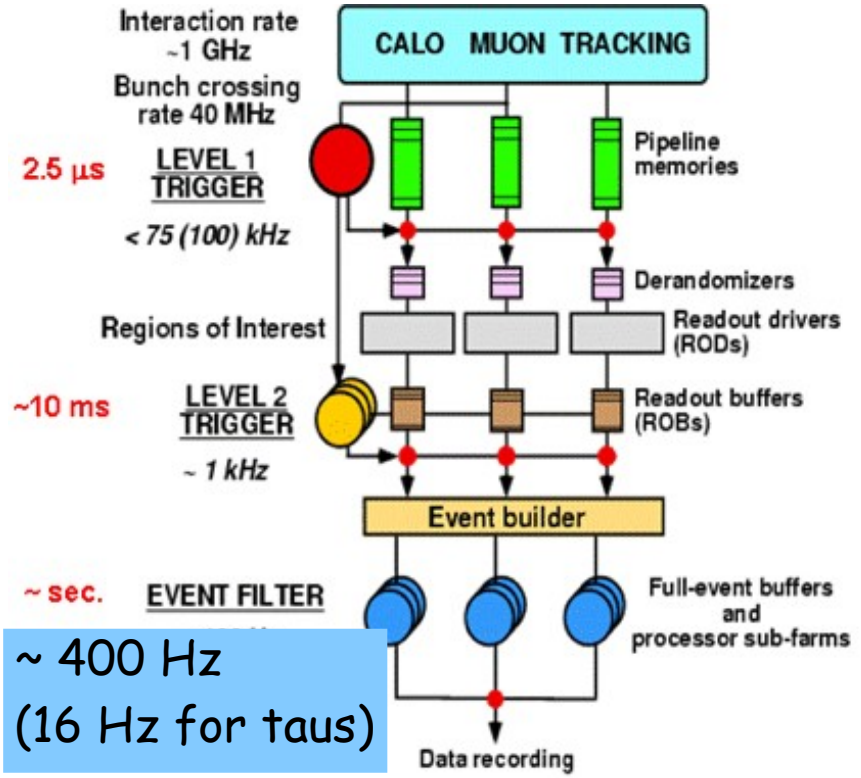
Efficiency measurement using tag-and-probe

- Z->ττ and W->τν events (jet/tau) and Z->ee (e/tau)





Triggering tau final states in ATLAS



~ 400 Hz
(16 Hz for taus)

Item	2011	2012
Single electron	e22	e24
Single muon	e18	e24
e-tau	tau16_e15	tau20_e18
mu-tau		tau20_mu15
di-tau	tau29_tau20	tau20_tau29
tau+xe	tau29_xe35	tau29_xe45
Single tau	tau125	tau125

2012 tighter thresholds & isolation
=> more analysis need to rely on the combined triggers
- Jet/MET triggers too high thresholds

Physics streams:
Electron, Muon, JetTauEtMiss

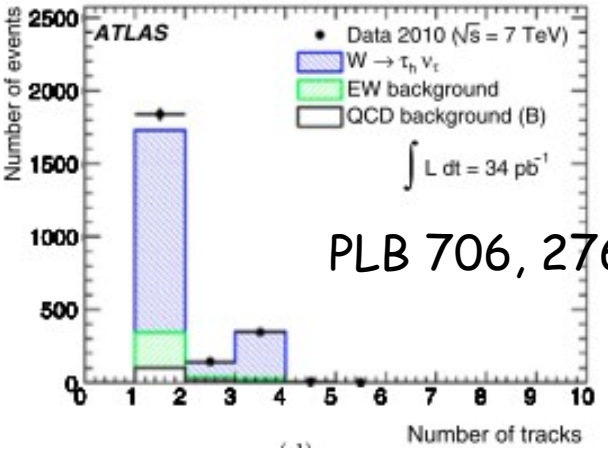
Tau Trigger

L1 based on 4x4 array of trigger towers and EM isolation
L2 adds tracking + higher granularity in the calorimeters
Applies basic tau shower shape cuts to reject QCD
EF full event building. Algorithms imitate offline.

How well do we understand taus in ATLAS?

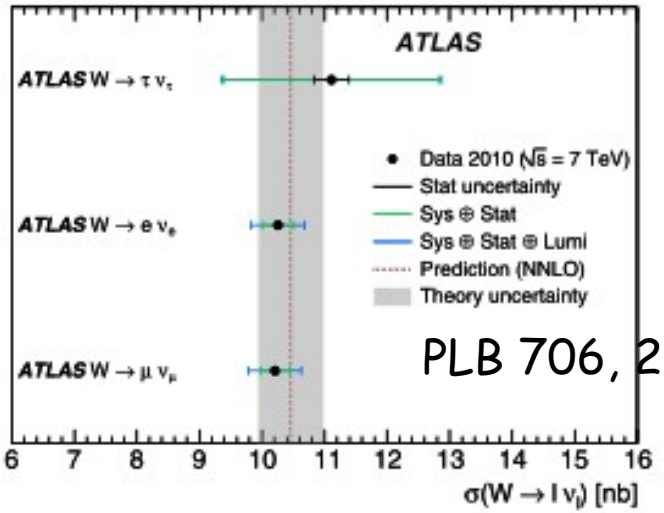
- W->τν decays : the largest source of true taus in ATLAS
  - used for first observation of true taus
  - cross section measured using full 2010 dataset
  - increasingly difficult @ higher LHC luminosity due online rates

- Main signature:
  - Hadronically decaying tau and large missing transverse energy (MET)
  - Large multi-jet estimated using data driven ABCD Method (tau ID, MET plane)
  - EW: W->eν/μν, Z->mumu backgrounds from MC
  - Purity: S/B ~ 4.4



PLB 706, 276 (201

Result



PLB 706, 276 (2012)

- Dominant systematics:
  - energy scale
  - tau ID & trigger efficiency
  - total ~ 15%

Tau polarization in W->τν decays

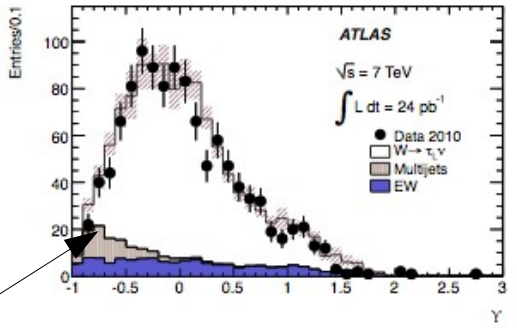
- Observable: charged asymmetry
  - energy sharing of the charged and neutral pions in the tau decay
  - inclusive: all one track tau decays

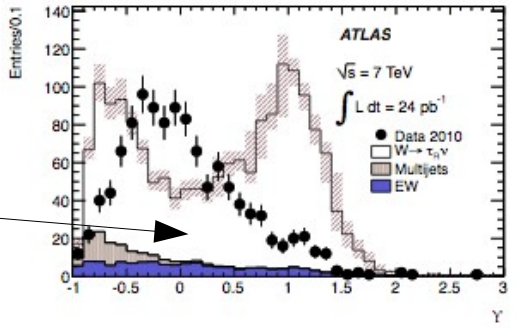
- P_τ extracted using binned log-likelihood fit of the observed distribution in data to a linear combination of the MC templates

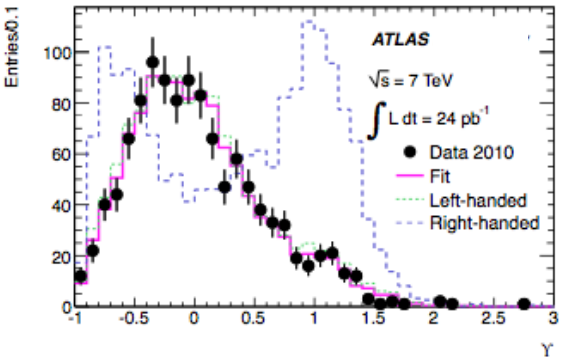
- Dominant systematics: energy scale and MC model

- Result: P_τ = =-1.06 +/- 0.04 (stat) + 0.05 - 0.07

$P_\tau \in [-1, -0.91]$ with 95% probability







arXiv:1204.6720v1

First measurement of tau polarization @ hadronic collider
Very first direct test of tau helicity structure @ $Q^2=m_W^2$

Toward Higgs searches: Z->ττ cross section

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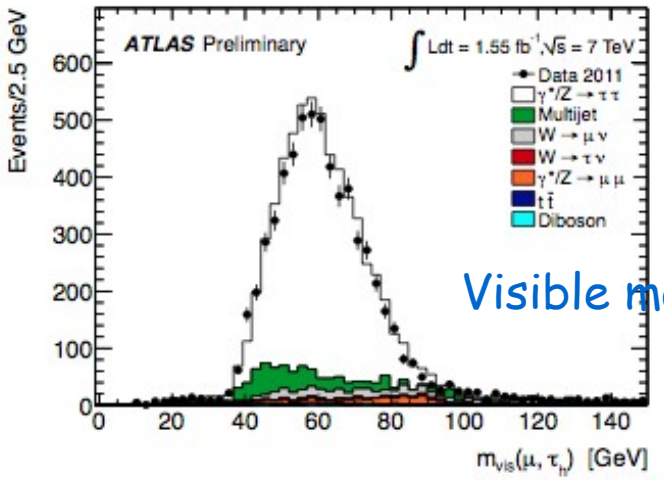
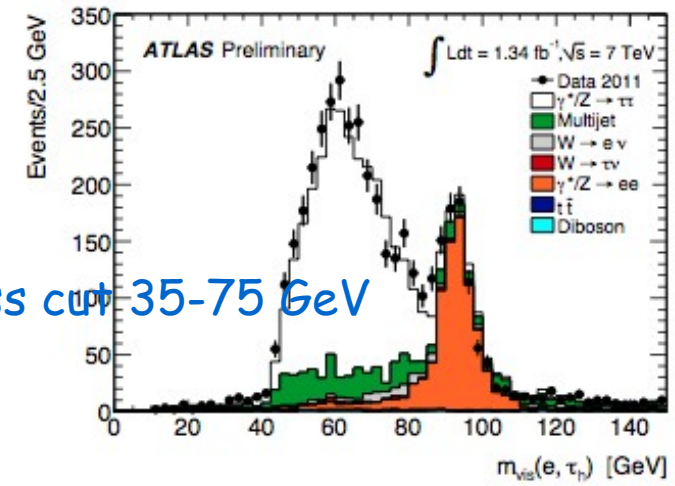
- Cross section measured in e-tau, mu-tau and e-mu channels:

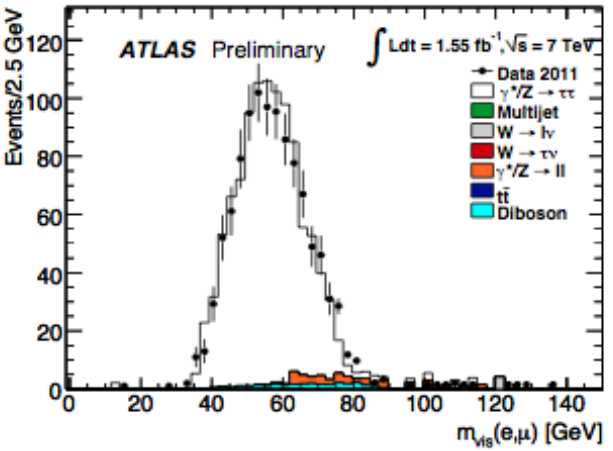


(a) $\tau_\mu\tau_h$ channel



(b) $\tau_e\tau_h$ channel

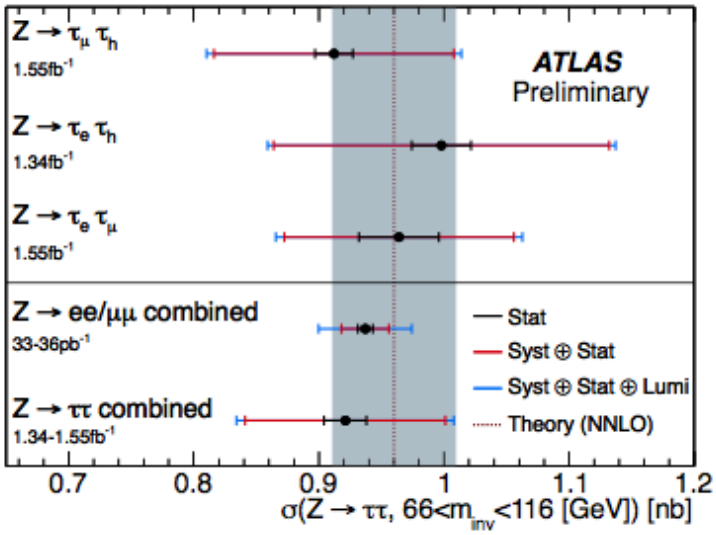
Visible mass cut 35-75 GeV



- Purity

	$\tau_\mu\tau_h$ (1.55 fb^{-1})	$\tau_e\tau_h$ (1.34 fb^{-1})	$\tau_e\tau_\mu$ (1.55 fb^{-1})
Total background	793 ± 34	449 ± 22	56 ± 8
$\gamma^*/Z \to \tau\tau$	4544 ± 49	2029 ± 25	981 ± 26
N_{obs}	5184	2600	1035

Result

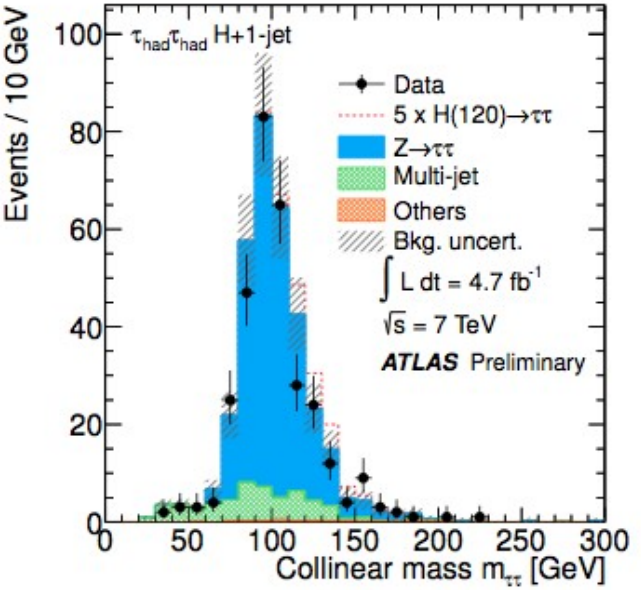


- Systematics:
  - e-tau (13%): energy scale, tau & ele ID, trigger eff
  - mu-tau (10%): energy scale, tau ID
  - e-mu (9%): electron ID & energy scale

H->ττ common challenges

Huge irreducible background from Z->ττ decays
- peaks close to H mass due to poor mass resolution

- Two – fold improvements:
- Use data driven tau embedding on lighter lepton (Z->μμ sample) to estimate Z->ττ background
- Improve mass resolution
  - visible mass
  - collinear mass: assume that visible tau decays products take direction of the parent tau
  - missing mass calculator (MMC): assumes non zero angle between visible decay products and neutrinos)



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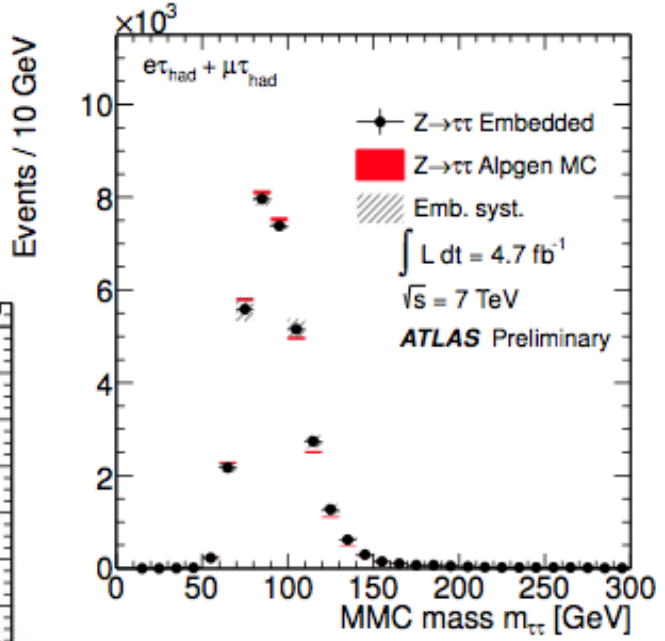
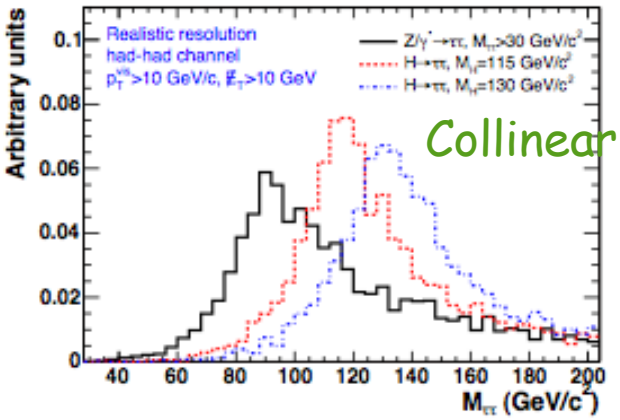
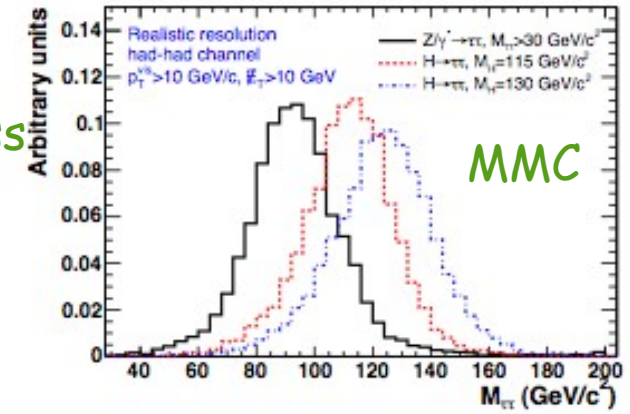




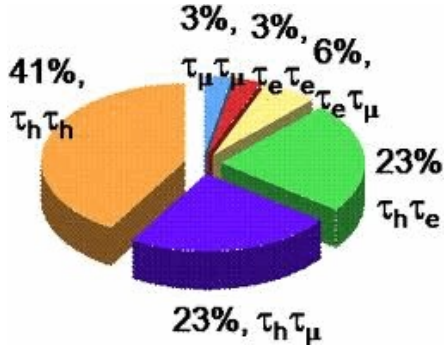
Collinear Mass



MMC

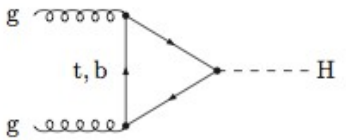
NIM A654 (2011) 481 (arXiv:1012.4686)

SM H->ττ search

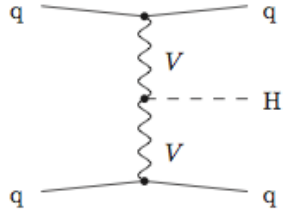


Production mechanisms considered in the search:

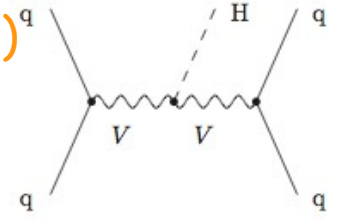
Gluon-gluon fusion



Vector boson fusion (VBF)

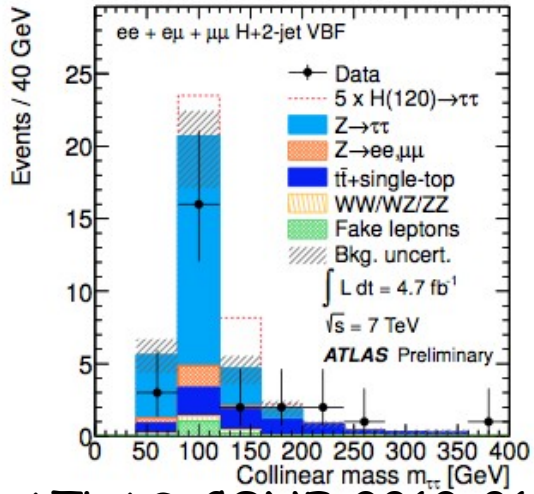


"Higgsstrahlung" (VH)



V=W,Z

H->ττ



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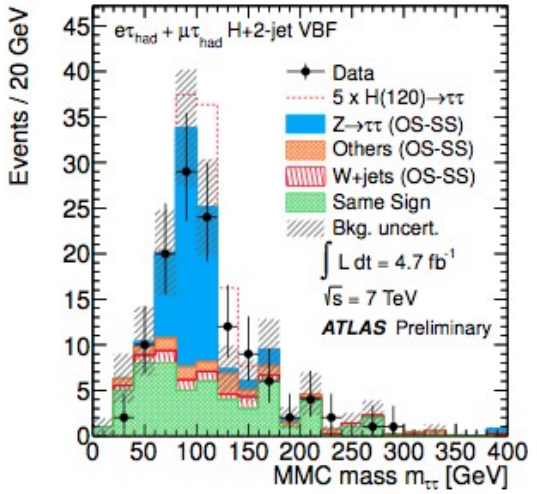
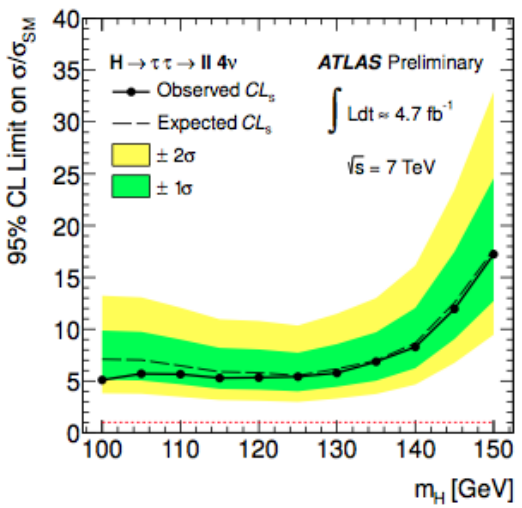


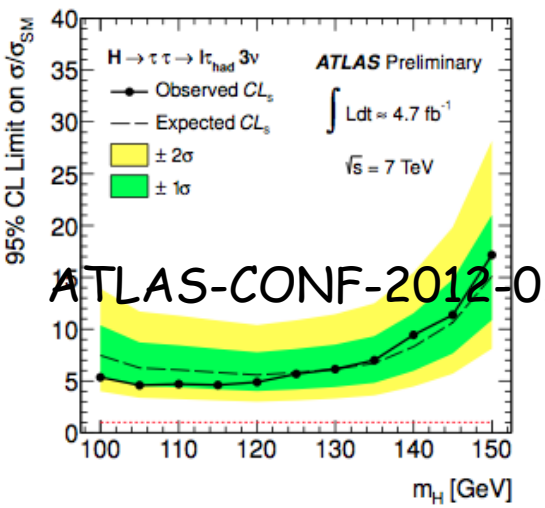
Search in all tau-pair decay channels:

- Lepton-lepton + 4v:
  - 4 categories: 0 jets, 1 jet, 2 jets VH, 2 jets (VBF)
  - Lepton background estimated using template of sub-lead lepton pt from a control region with revered isolation
- Lepton-hadron + 3v:
  - 4 categories: 0 jets (low and high MET), 1 jet, 2jets (VBF)
- - Mulit-jet background estimated using SS charge
- hadron-hadron + 2v:
  - search in 1 jet category
  - 2D track multiplicity fit in the signal region

SM Higgs limits

95% Cls limits per channel





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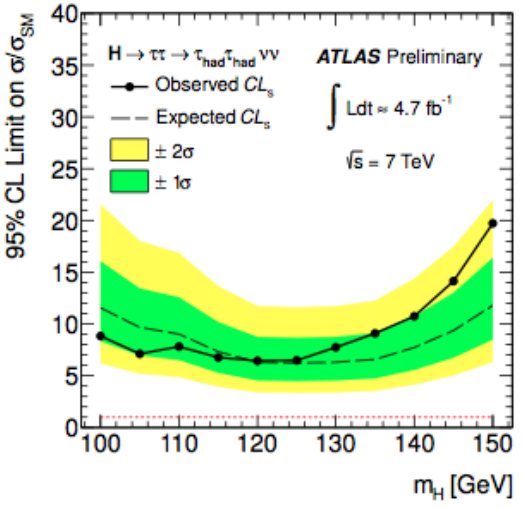
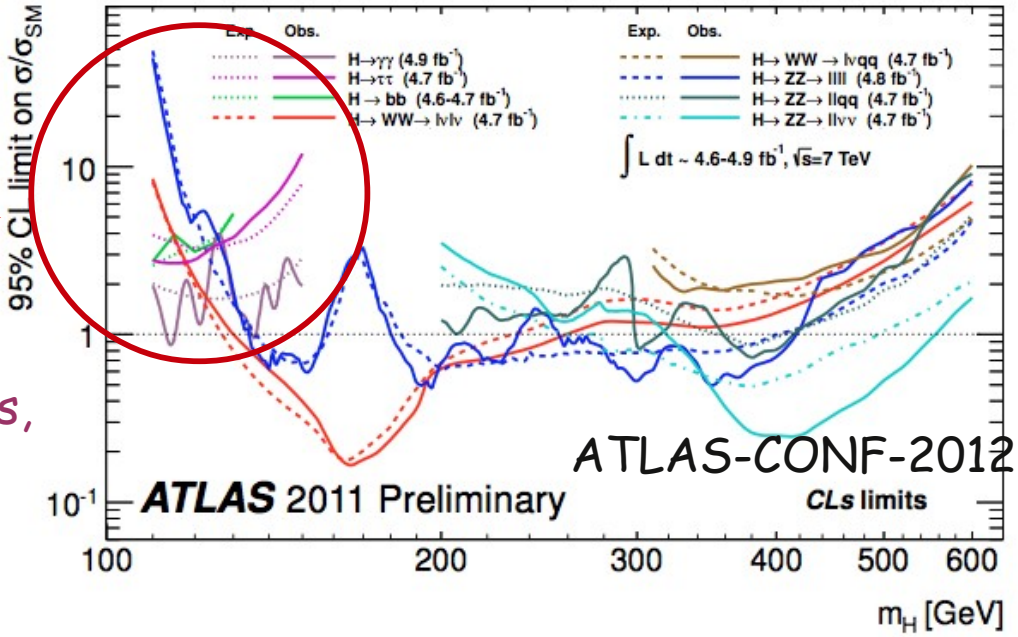


95% exclusion limit
combined for all tau channels:
- Mass range: 100-150 GeV
- Expected:3-8
- Observed:3-12



ATLAS-CONF-2012-019

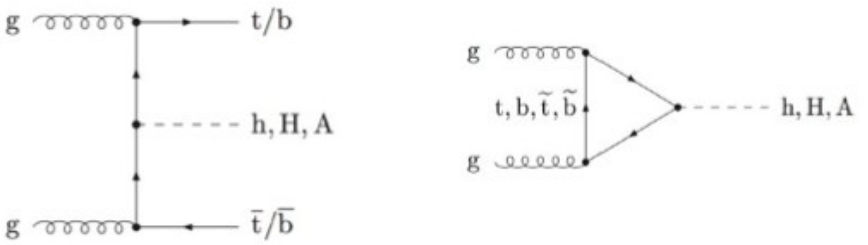
Several improvements to the analysis,
(tau ID and selection/methods)
are being investigated

Quick overview of MSSM H->ττ search

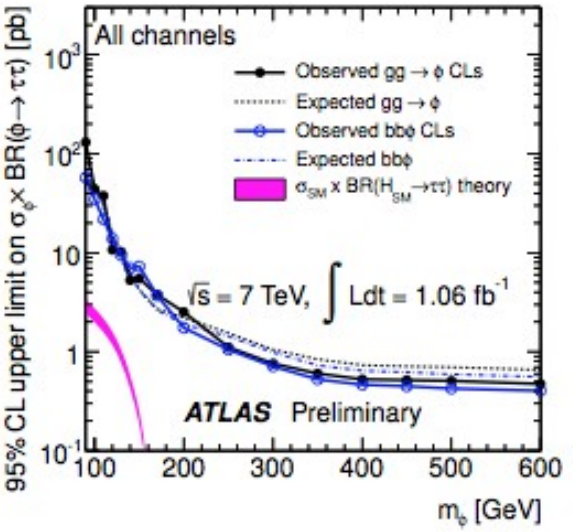
- Search in all tau-pair channels
- Separation in b-associated production using b-tagging not yet explored

Analysis methods similar to SM Higgs boson searches

Production mechanism



Combined limits on σ x BR



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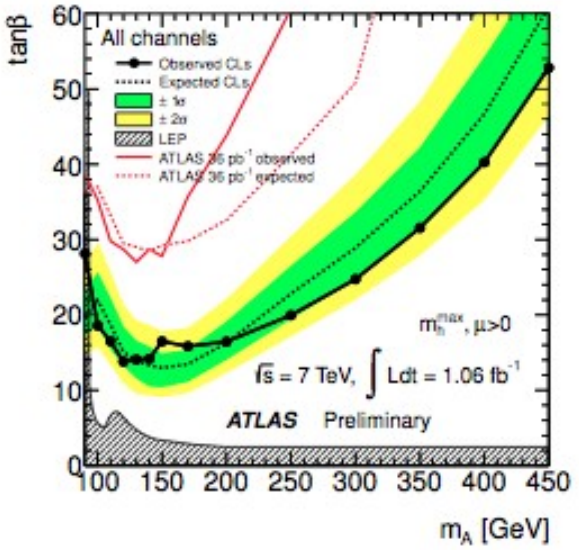
combined limits in "tanβ-m_A" space

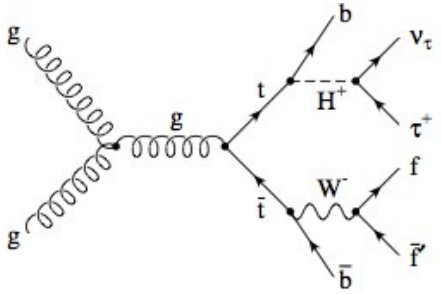


Quick overview of H->τν search

ATLAS-CONF-2012-011

- Charged Higgs predicted by 2HDM (also other BSM models)

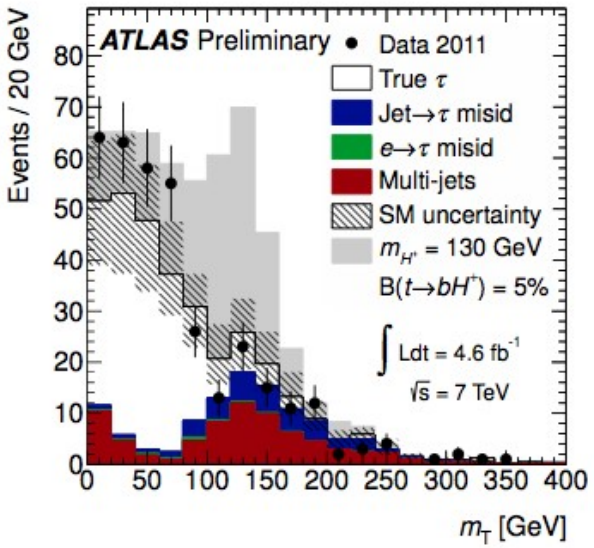
Light Higgs Production in MSSM ($m_H < m_{top}$)



Search channels

- Lepton +jets: $t\bar{t} \to b\bar{b}WH^+ \to b\bar{b}(q\bar{q}')(\tau_{lep}\nu)$
- Tau+ lepton: $t\bar{t} \to b\bar{b}WH^+ \to b\bar{b}(l\nu)(\tau_{had}\nu)$
- tau+jets $t\bar{t} \to b\bar{b}WH^+ \to b\bar{b}(q\bar{q}')(\tau_{had}\nu)$

- Some analysis highlights
  - tau + jets is the most sensitive channel

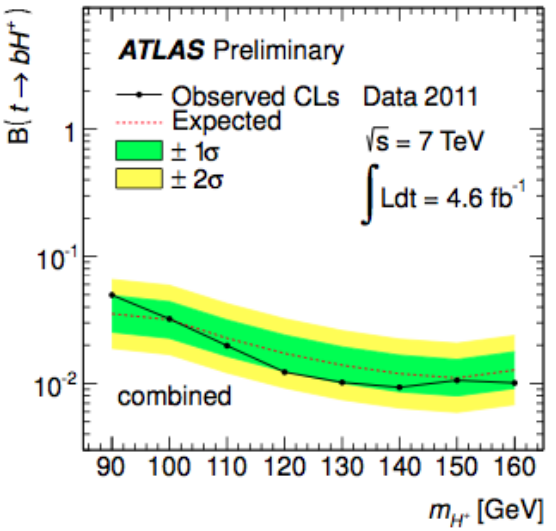


- lepton + jets challenging!
  suppress W->lν using inv mass of b-lep & m_T^H

=> require b-t association

$$\chi^2 = \frac{(m_{jjb} - m_{top})^2}{\sigma_{top}^2} + \frac{(m_{jj} - m_W)^2}{\sigma_W^2}$$

Combined limits on BR 1-5%



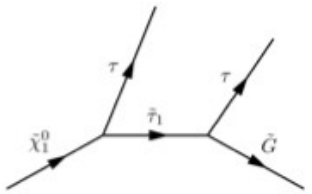
MSSM (m^{max}_h) excluded values of Tanβ >13-26 for 90GeV<m_{H+} <150GeV.

SUSY and taus

- Taus are important probes of SUSY breaking mechanism
- GMSB : soft SUSY breaking by gauge interactions

– chiral super-multiplets (messengers) couple to ultimate source of SUSY breaking and (s)quarks, (s)leptons, Higgs(inos) of MSSM

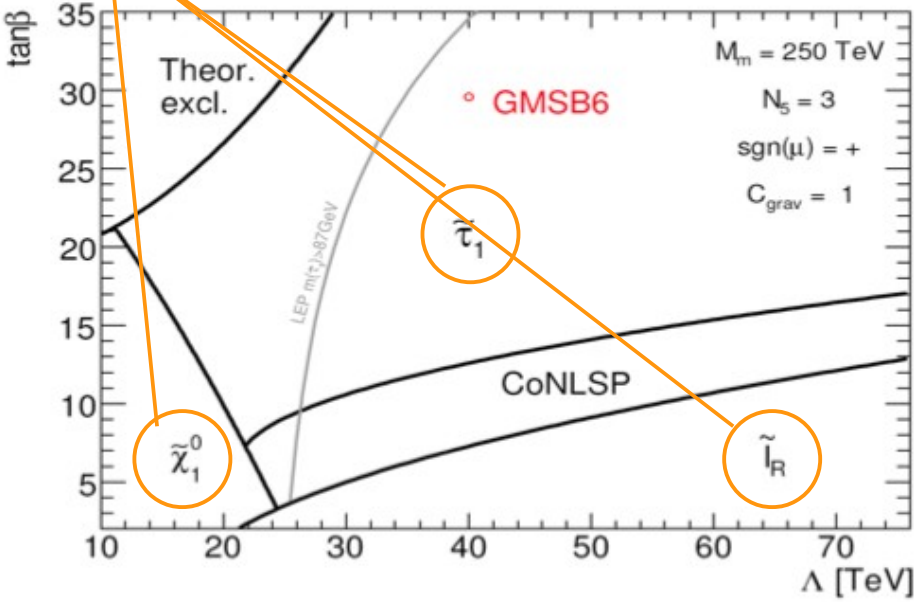
Tau production



$$\tilde{\chi}_2^0 \rightarrow \tau^+\tau^-\tilde{\chi}_1^0$$
$$\tilde{\chi}_1^\pm \rightarrow \tau^\pm\nu_\tau\tilde{\chi}_1^0 .$$
$$\tilde{\chi}_1^0 \rightarrow \tau^+\tau^-\tilde{G} .$$

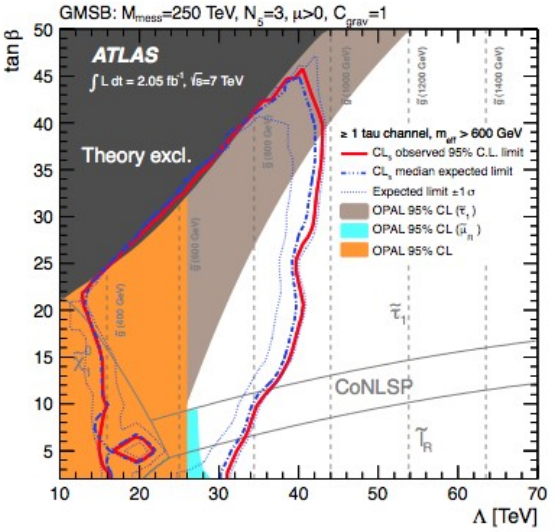
NLSP

LSP



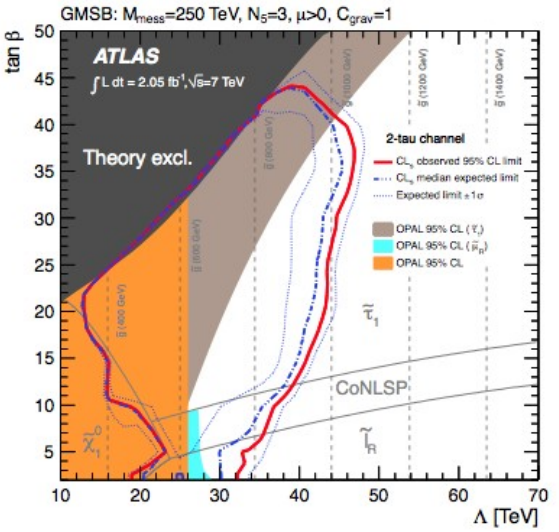
Jets + MET + at least 1 tau
(CERN-PH-EP-2012-076)

SUSY particles excluded up to breaking scale
Λ = 30 TeV
(up to Λ = 43 TeV for large tan β)



Jets + MET + at least 2 taus
(CERN-PH-EP-2012-054)

SUSY particles excluded up to breaking scale
Λ = 32 TeV
(up to Λ = 47 TeV for large tan β)



Summary

- Tau leptons are vital probes of new physics in ATLAS
  - Heavy objects may couple preferentially to taus (Higgs, technicolor Z' ,..)
  - The only leptons which provide insight in spin nature of the parent object
  - Decay chains with tau sensitive to SUSY breaking mechanism

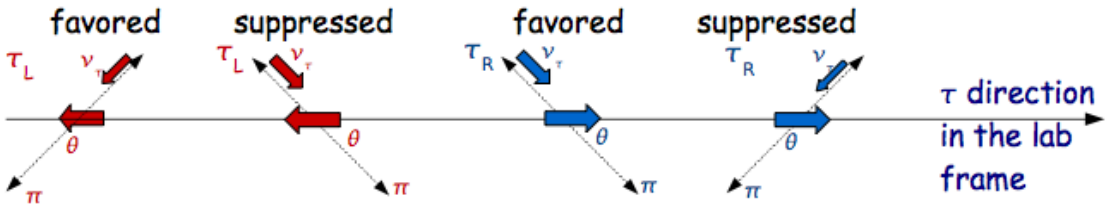
- Shown several new results of searches with tau final states
  - No discoveries
  - Most cases limits exceed previous experiments

- Shown first measurement of tau polarization at hadron collider
  - efficacy of the method (& relatively low systematic uncertainty) confirms potential for future spin measurements using taus
  - the first direct measurement of helicity structure in W->τν events

Back-up slides

How can we measure tau polarization ?

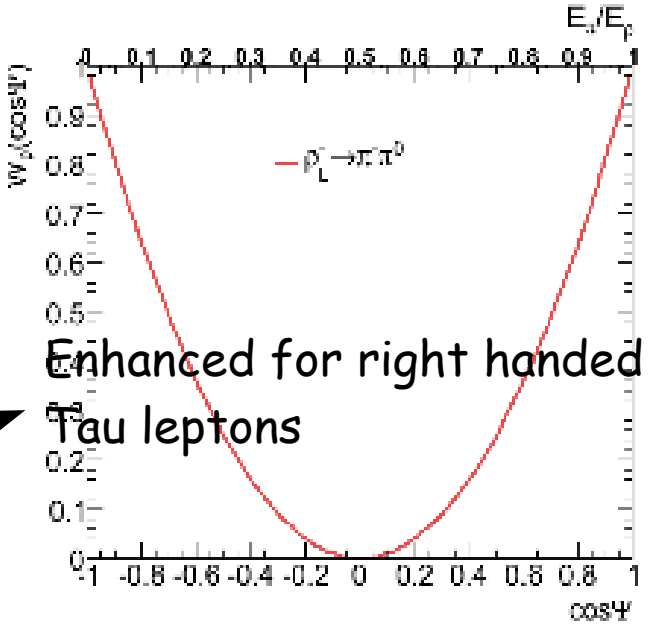
LH taus - soft, RH taus - hard

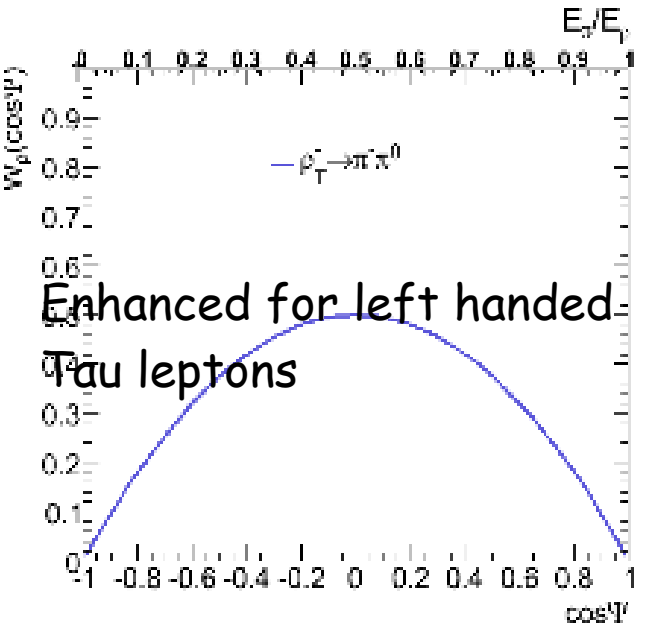


n.a in W-> tau nu decays, Z/H->tautau requires tau rest frame (e.g. coll approx)

Explore helicity of rho

$$\cos\psi = \frac{m_v}{\sqrt{m_v^2 - 4m_\pi^2}} \frac{E_{\pi^-} - E_{\pi^0}}{|\mathbf{p}_{\pi^-} + \mathbf{p}_{\pi^0}|},$$





Using tau polarization to constrain models

- If parity violation - Z' couples differently to left- and right-handed fermions

Forward – backward asymmetry

$A_{FB} = (N_F - N_B)/(N_F+N_B)$

- ✓ Can be measured in all di-lepton final states
- ✗ Difficult to define at symmetric pp collisions
- ✗ Need to be convoluted with PDF's

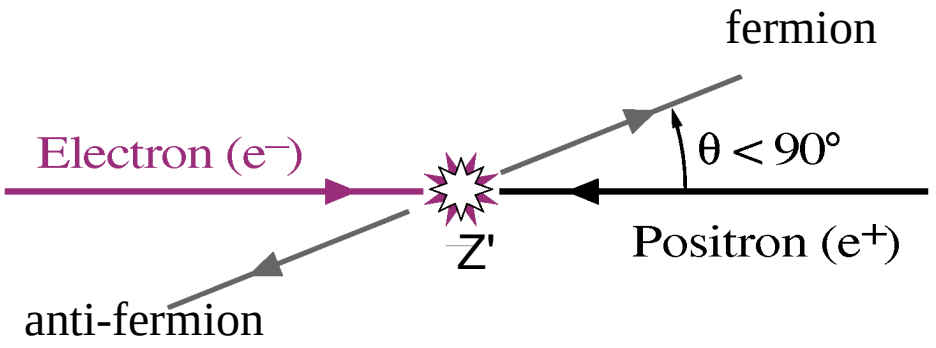
Polarisation asymmetry

$A_{pol} = (N_L - N_R)/(N_L+N_R) = -P_{\tau}$

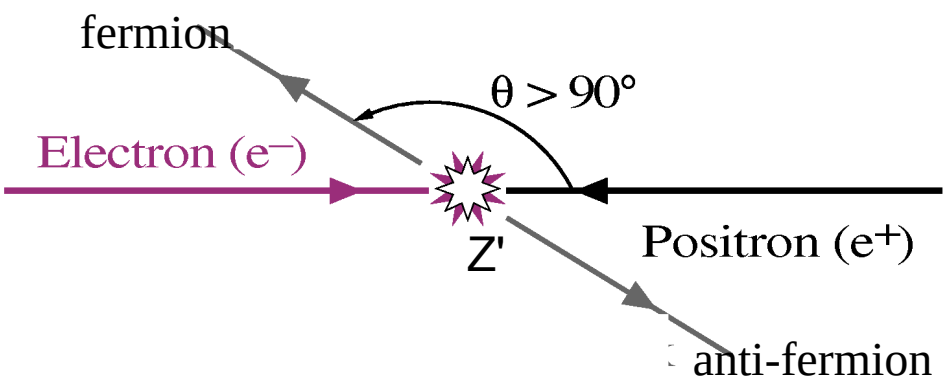
P_{τ} - longitudinal polarisation of tau

- ✗ Only in tau-pair final states (of leptonic)
- ✓ Does not require the knowledge of PDF's

Forward



Backward



- A_{pol} helpful in constraining E_6 model

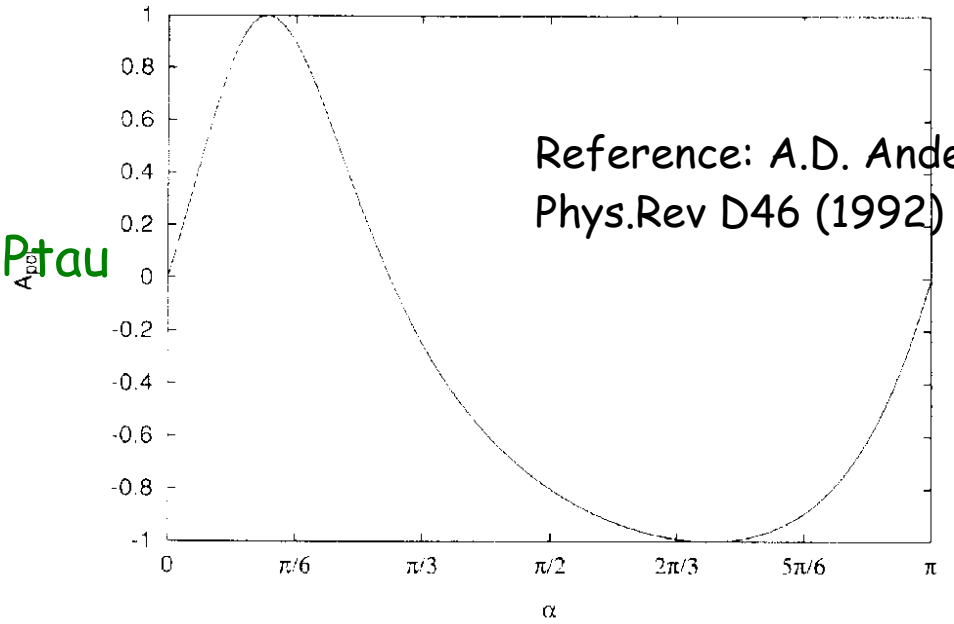
Using tau polarization to constrain models

- E_6 model: two Z' bosons

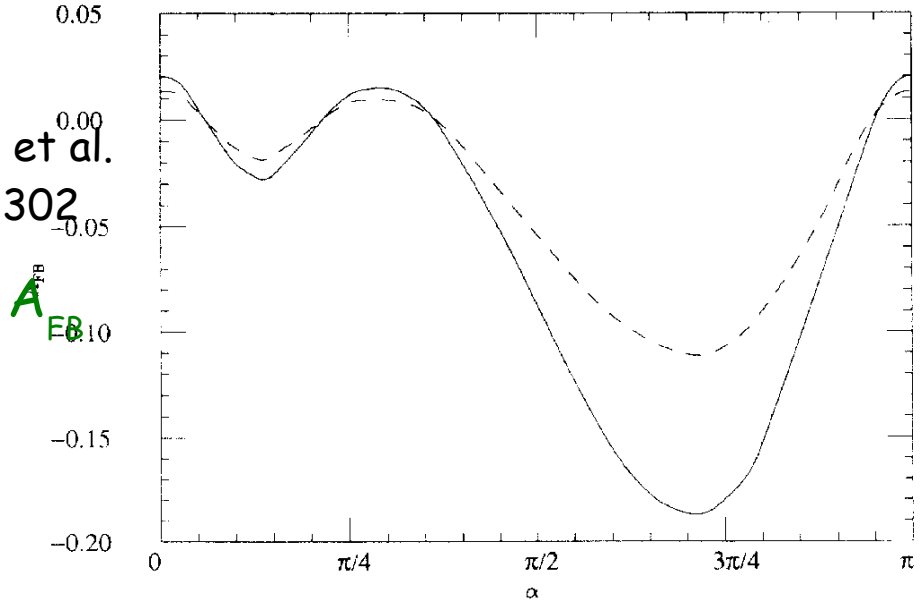
Linear combination $Z'(\alpha) = Z'_\chi \cos\alpha + Z'_\psi \sin\alpha$

is assumed to have mass ~ TeV (within the LHC reach)

Parameter α is free and can by constraint by measurement of Ptau and A_{FB}

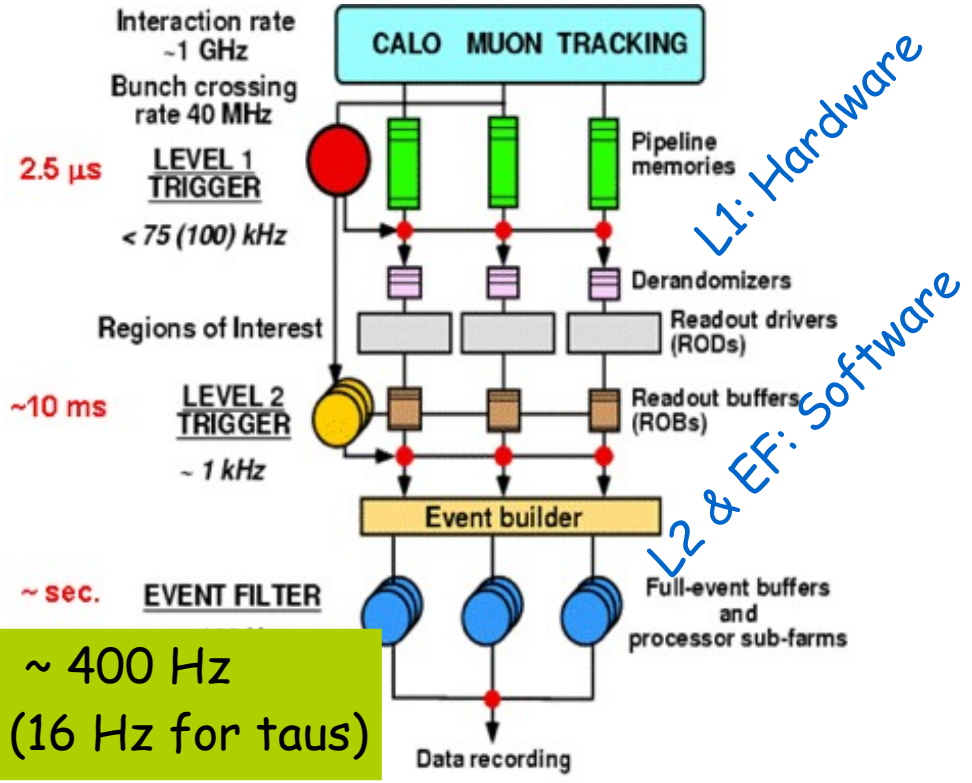


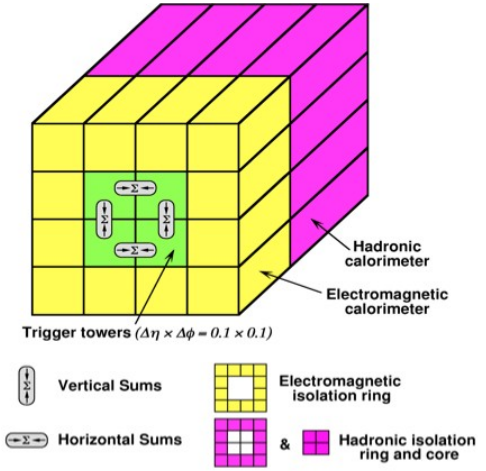
Reference: A.D. Anderson et al.
Phys.Rev D46 (1992) 290-302



Ptau provides better determination of α than equally precise measurement of A_{FB}

(Tau) trigger in ATLAS





~ 400 Hz
(16 Hz for taus)

L1 based on 4x4 array of trigger towers and EM isolation
L2 adds tracking + higher granularity in the calorimeters
Applies basic tau shower shape cuts to reject QCD
EF full event building. Algorithms imitate offline.