Higgs Discovery Reach with ATLAS

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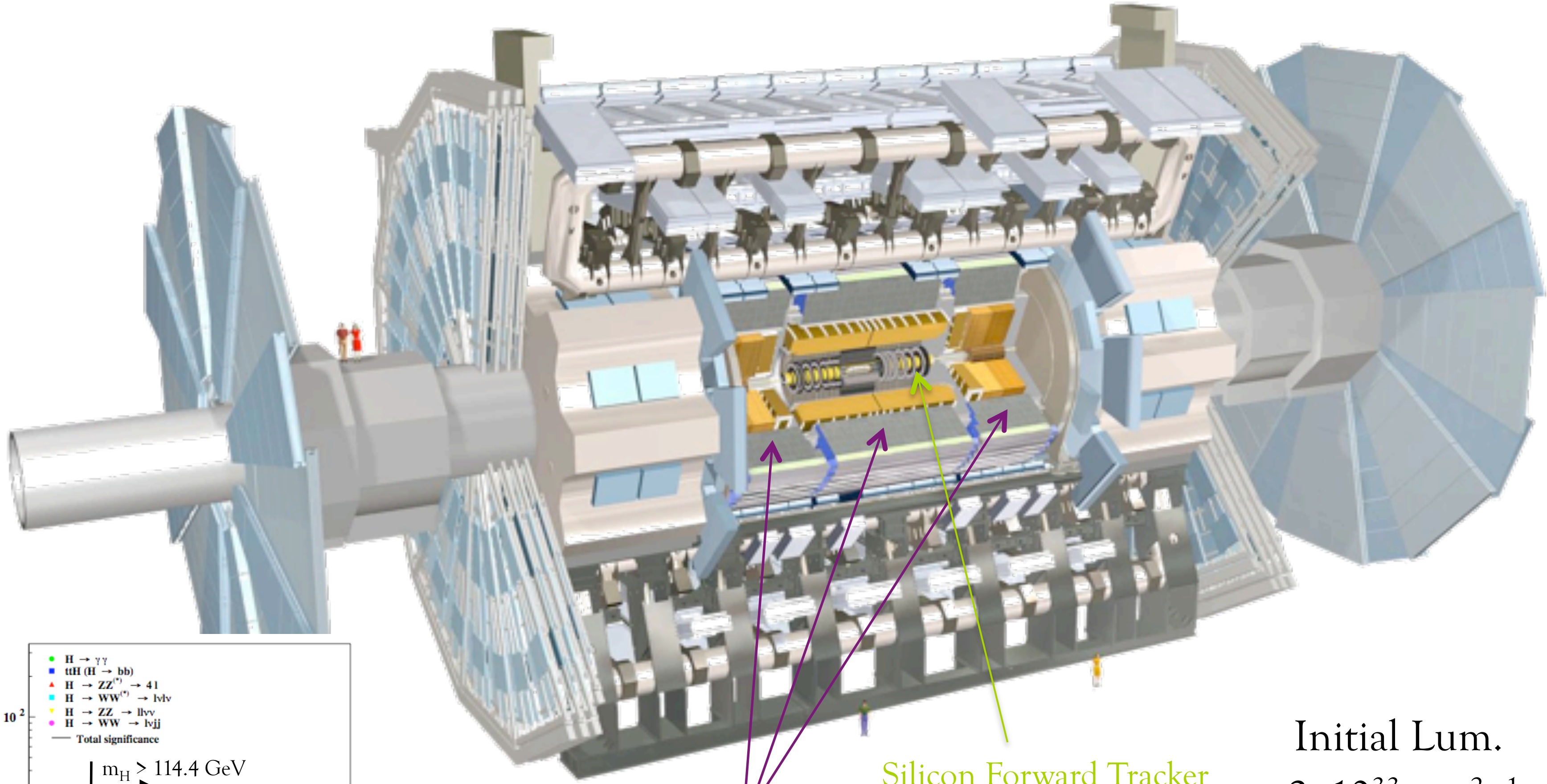
IFIC
On behalf of the ATLAS Collaboration

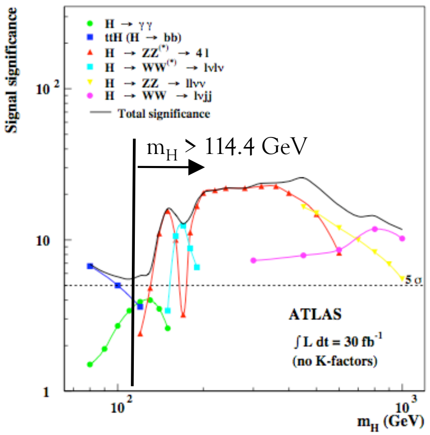
DISCRETE '08

Valencia, Dec. 2008

The ATLAS Detector



Initial Lum.
2×10^{33} $cm^{-2}s^{-1}$
(10 fb^{-1}/year)

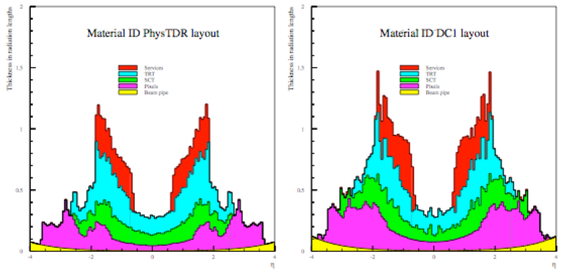


TDR (2000)

Outline

- Most relevant SM/MSSM discovery channels
  - $H \to \gamma\gamma$
  - $H \to \tau\tau$
  - $H \to bb$
  - $H \to ZZ^* \to 4l$
  - $H \to WW^* \to ll\nu\nu$
  - $bbh/H/A \to \mu\mu,\ \tau\tau$
- Higgs Properties
- Summary

Focus in the early phase
of the LHC with 10-30 fb^{-1}

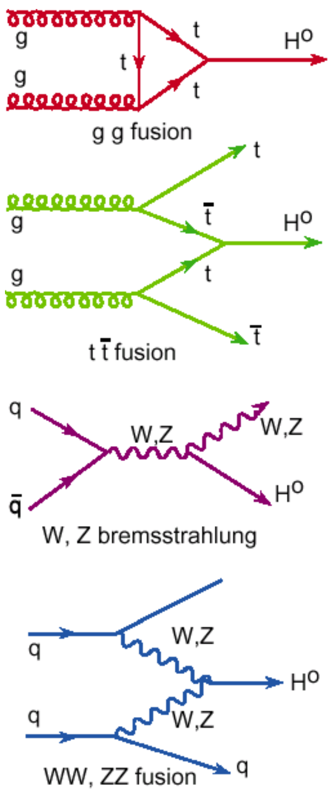


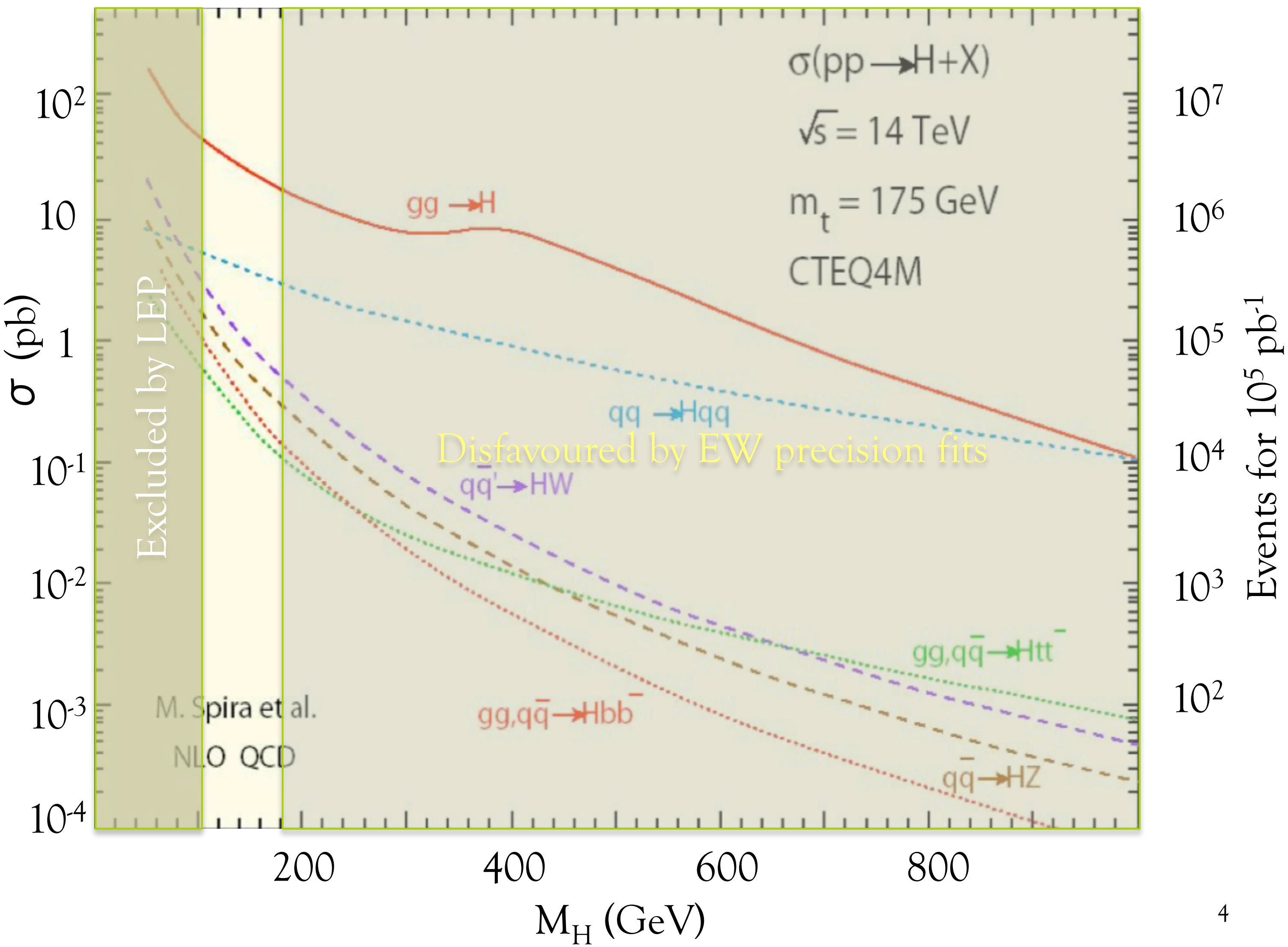
$\approx 0.15\ X_0$ increase

Updates from TDR

- More realistic simulation
- Massive MC production for CSC (Computing System Commissioning)
- Include QCD high order corrections on signal & backgrs
- Updated analysis strategies (use data-like fit likelihoods)

SM Higgs Cross Sections

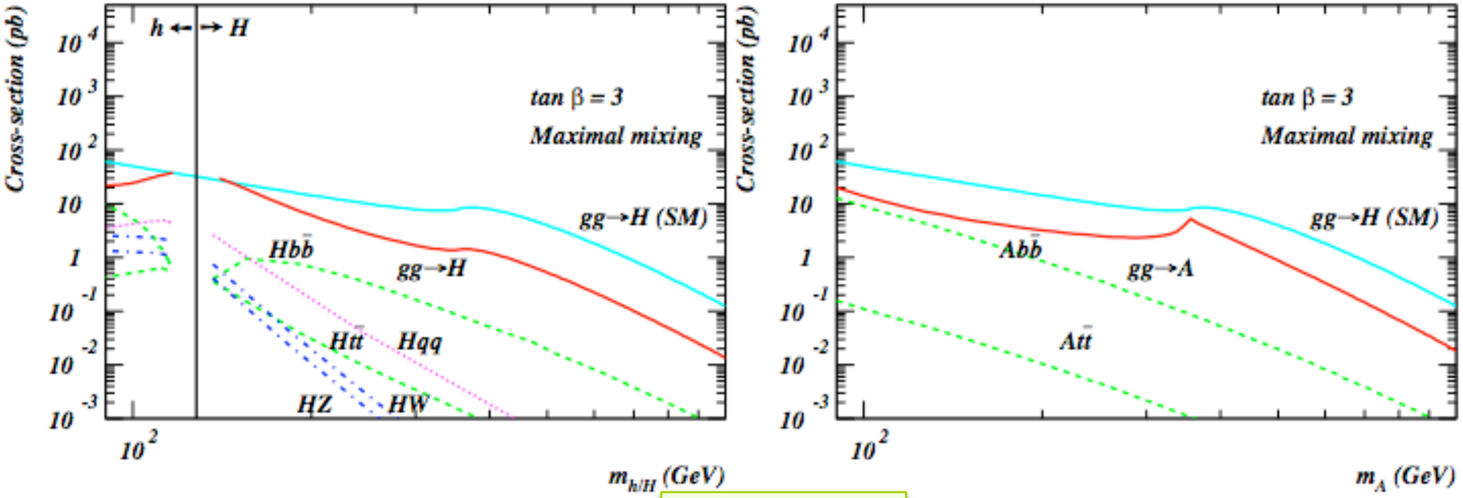




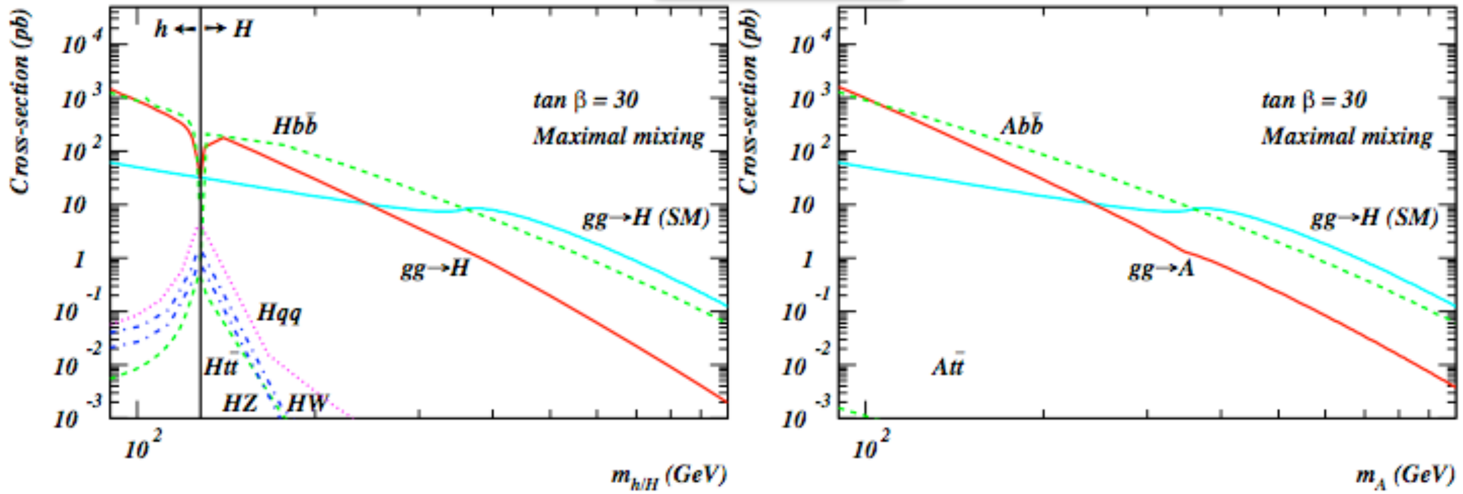
MSSM Neutral Higgs Cross Sections

√s=14 TeV (LHC)

Low tanβ



High tanβ

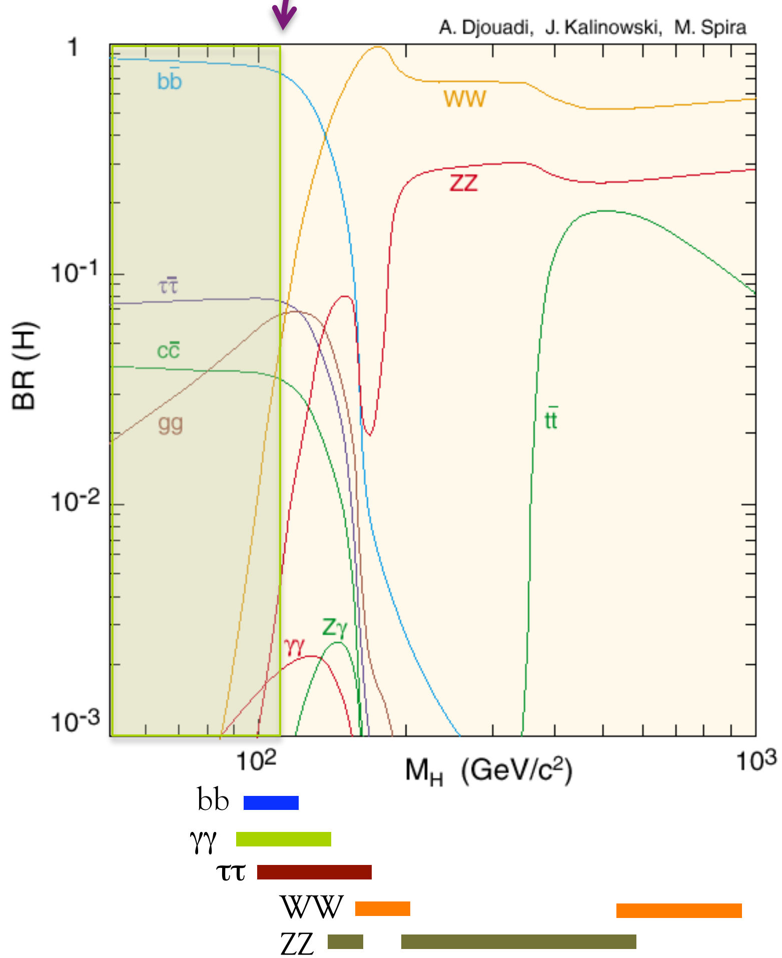


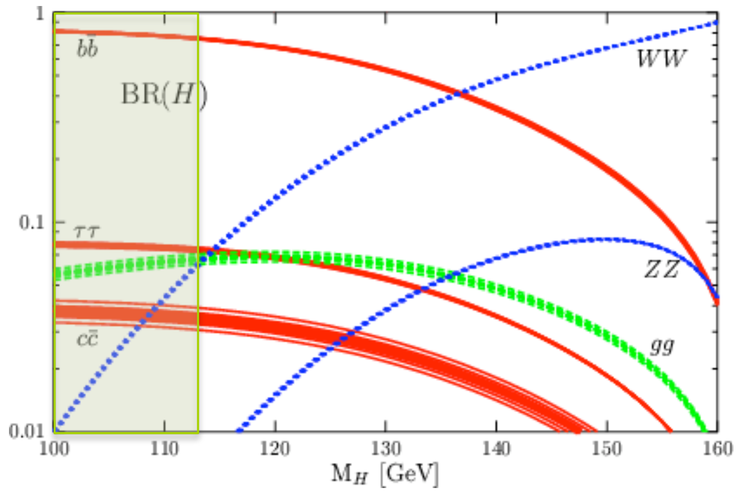
$g_{MSSM} = \xi \, g_{SM}$

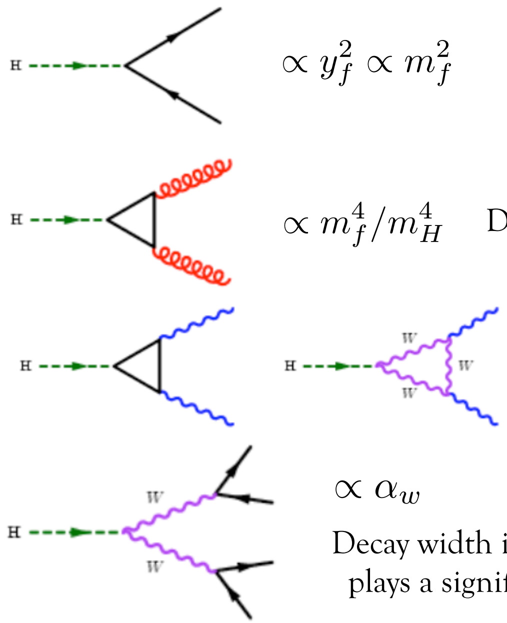
ξ	t	b / τ	W / Z
h	cosα/sinβ	-sinα/cosβ	sin(α-β)
H	sinα/sinβ	cosα/cosβ	cos(α–β)
A	cotβ	tanβ	-

SM Higgs Discovery Modes

114 GeV/c² (LEP2 limit)







$\propto y_f^2 \propto m_f^2$

$\propto m_f^4/m_H^4$ Dominated by y_t

Dominated by EW coupling

$\propto \alpha_w$

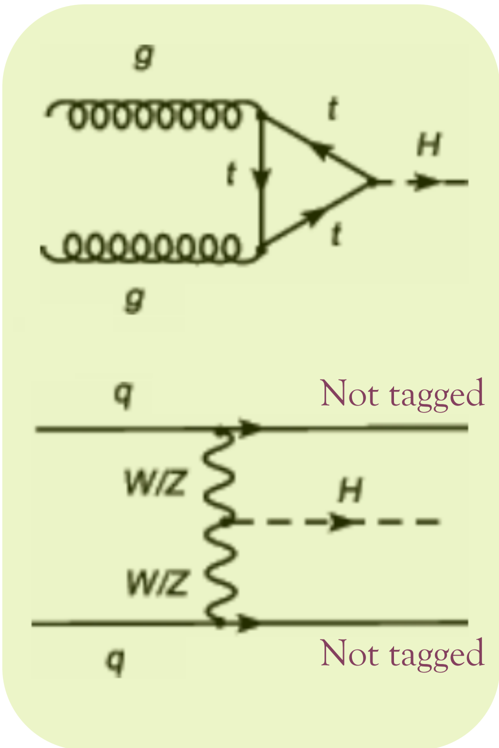
Decay width into W*W* plays a significant role

Close to LEP limit: H→γγ, ττ, bb

For M_H>140 GeV: H→WW*, ZZ*

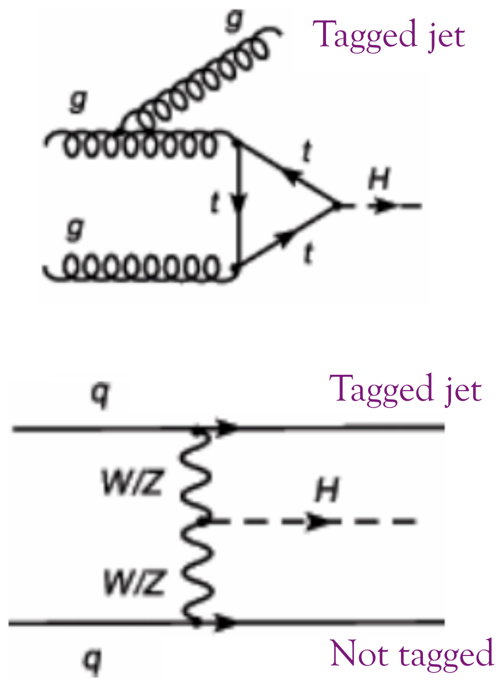
Low Mass Higgs Associated with Jets

Inclusive



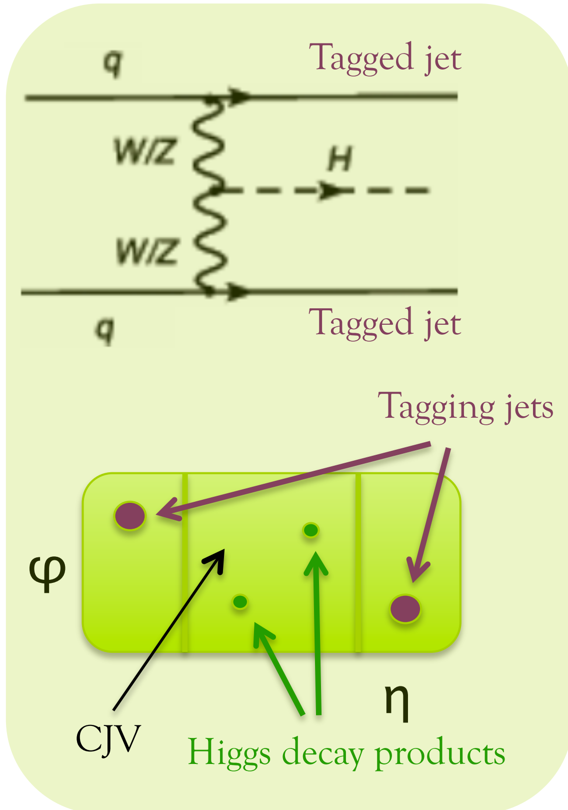
Analysis in TDR were
mostly inclusive

H + 1 jet



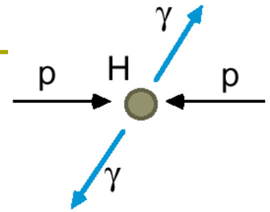
LO diagrams for
Higgs + 1 jet production

H + 2 jets

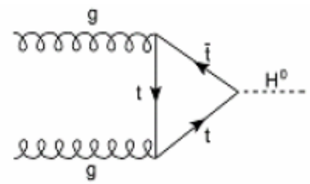


$\eta_{j1} \cdot \eta_{j2} < 0$
$\Delta \eta_{jj} > 3.5 - 4$
Mjj > 500 – 700 GeV
CJV

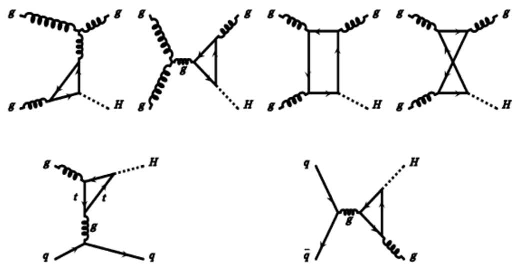
Low Mass Higgs: H→γγ

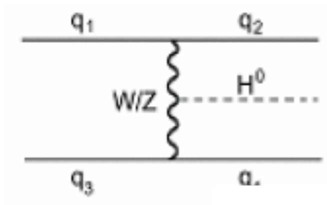


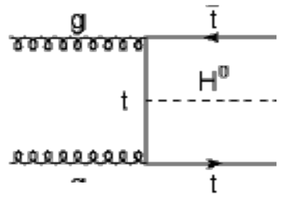
- Most significant decay channel (low mass)
- Reconstructed mass peak on top of continuum di-photon background
- ATLAS: inclusive (γγ only) and exclusive (γγ+jets) searches

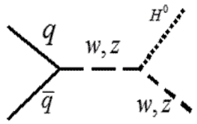


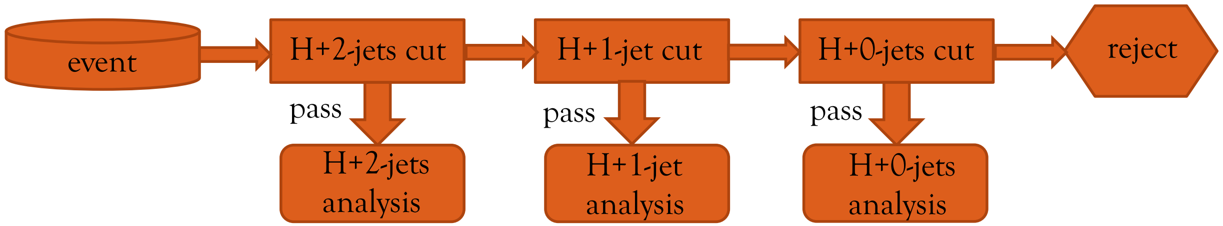
High order corrections











Combined analysis
0-jets+1-jet+2-jets

- Events passing inclusive cuts divided into H+0-jet (not inclusive), 1-jet and 2-jets sub-channels.
- All events from inclusive analysis used, and each one used only once.
- Gain in sensitivity from individual sub-channels.
- Improves significances by ≈25% wrt inclusive analysis

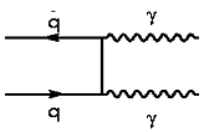
Main γγ Backgrounds H→γγ

$pp \to \gamma\gamma$

Irreducible

Real γγ+jets

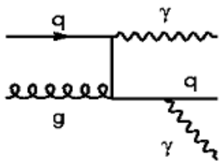
$\mathcal{O}(\alpha^2)$



$q\bar{q} \to \gamma\gamma$

LO Born

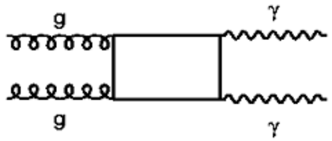
$\mathcal{O}(\alpha_s\alpha^2)$



$qg \to q\gamma\gamma$

Bremsstrahlung

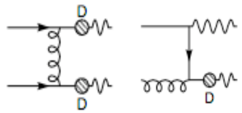
$\mathcal{O}(\alpha_s^2\alpha^2)$



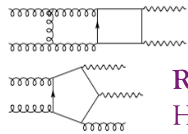
$gg \to \gamma\gamma$

LO Box

+



Diphox
Single/double
γ-fragmentation
at LO/NLO

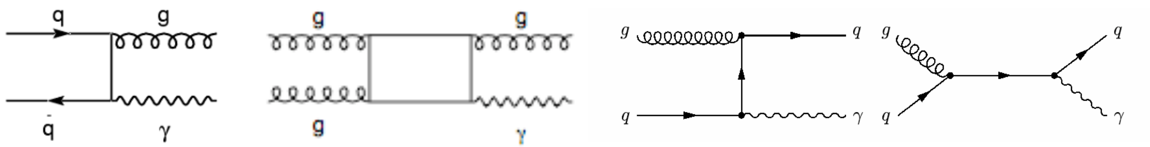


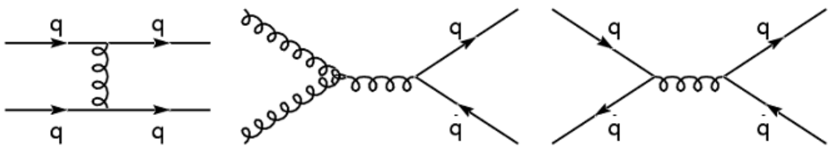
ResBos
HO diagrams for Box

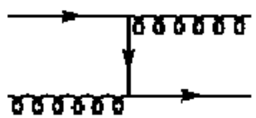
$pp \to \gamma j, jj$

Reducible

Fake γγ







Huge rates:
≈20 × 10^6 above signal (for dijets).
≈1000 above signal (for γj).

Need large jet reject. factors ≈5000 to reduce it below the irreducible level

Jets from g (58%)

Jets from q (4.7%)

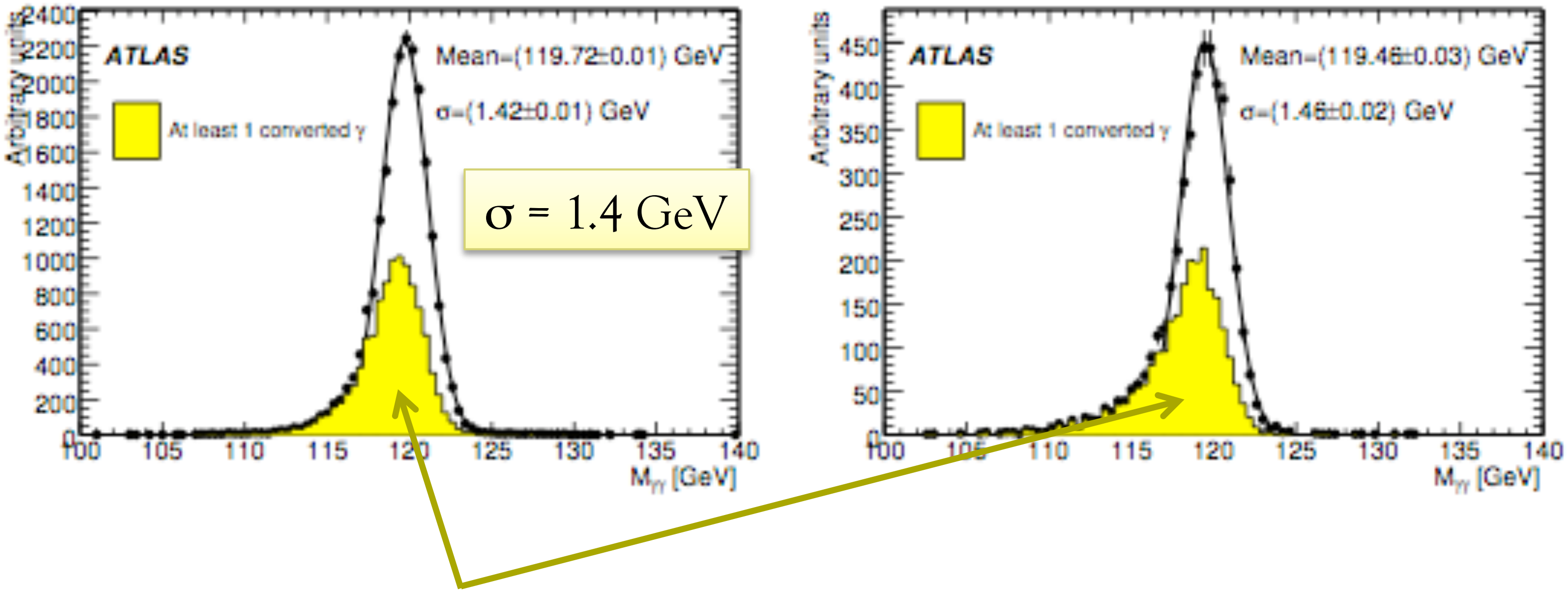
Jets from q,g (37,3%)

Mγγ Resolutions H→γγ

Issues for the mass resolution

- Photon energy calibration
- Photon direction
- Photon ID & jet rejection (high γ/π^0 separation, isolation)
- Converted photons

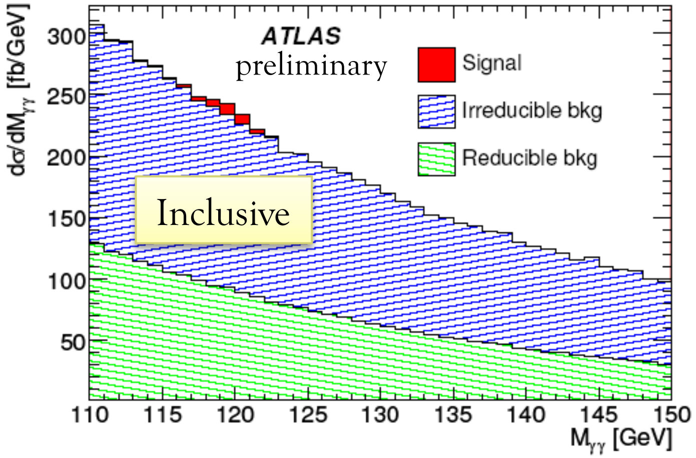
$$\frac{\sigma_{M_H}}{M_H} = \frac{1}{2}\left[\frac{\sigma_{E_{\gamma 1}}}{E_{\gamma 1}} \oplus \frac{\sigma_{E_{\gamma 2}}}{E_{\gamma 2}} \oplus \frac{\sigma_{\alpha}}{\tan(\alpha/2)}\right]$$

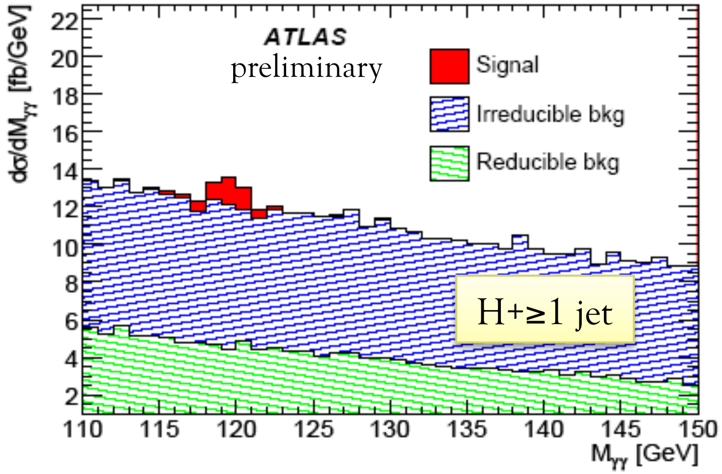


Events with at least one conversion

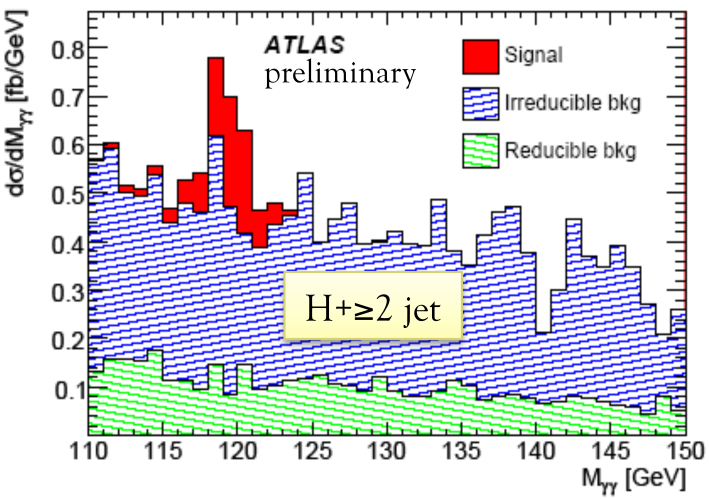
May achieve ≈ 1.2% mass resolution
(small degradation with pile-up)

Inclusive, H+≥1 jet, H+≥2 jet





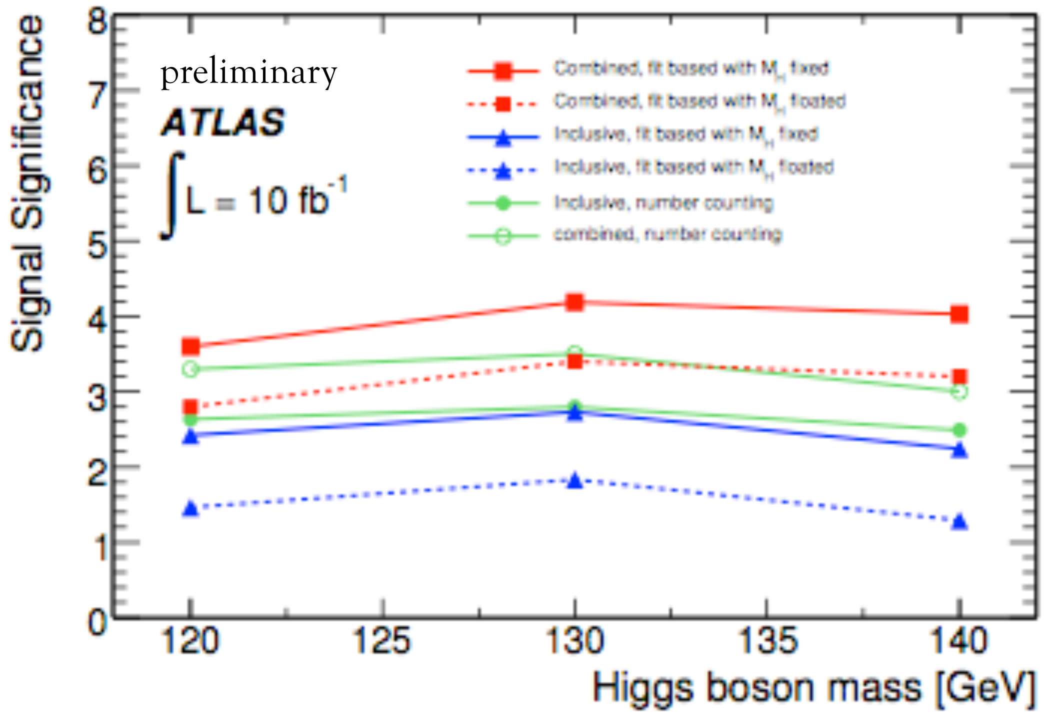
M_H=120 GeV



	Inclusive (K-factors)	H+≥1 jet (no K-factors)	H+≥2 jet (no K-factors)	Combined
$S/\sqrt{B}$	2.6	1.8	1.9	3.3

Results for 10 fb^{-1}
Event-counting
Mass-bin $\pm 1.4\,\sigma$

Expected Significances H→γγ



Inclusive H→γγ (Counting)

Event counting
Gaussian/Poisson significances
for a ±1.4 σ mass bin
(around central value)

Inclusive H→γγ (Fit)

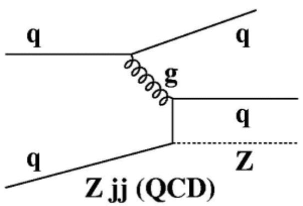
Combined H→γγ+0-j, 1-j, 2-j

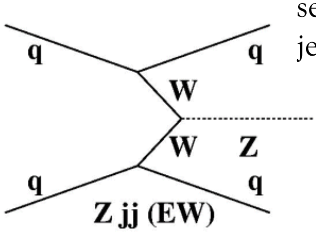
Significances from fit profile likelihood method with either M_H fixed and floated

Low Mass Higgs: $H \rightarrow \tau\tau$

- Due to poor Higgs mass resolution for $H \rightarrow \tau\tau$, inclusive analysis not possible
- Reduce QCD backgrounds by using distinct topology of jets in association with Higgs (VBF)
- Exclusive (VBF) searches, use $H \rightarrow \tau\tau \rightarrow$ ll, lh, hh

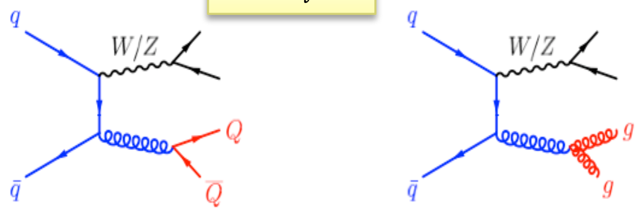
QCD and EW Z + jets





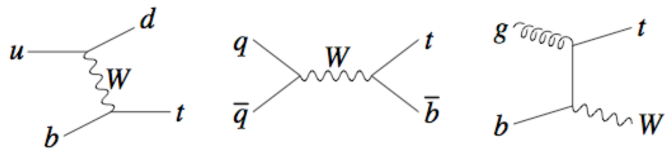
- Use QCD topological cuts (CJV and well separated forward jets)

W + jets



Single top

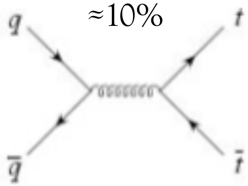
LO

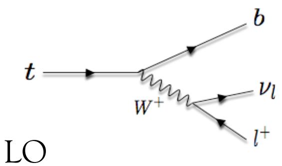


$pp \rightarrow tqX$ $\quad pp \rightarrow t\bar{b}X$ $\quad pp \rightarrow tWX$

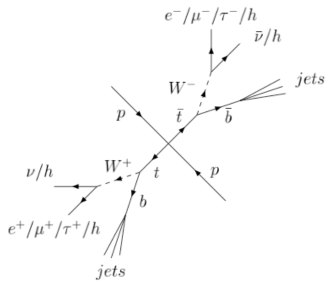
$pp(q\bar{q}, gg) \rightarrow t\bar{t}\,(\rightarrow W^+bW^-\bar{b})$

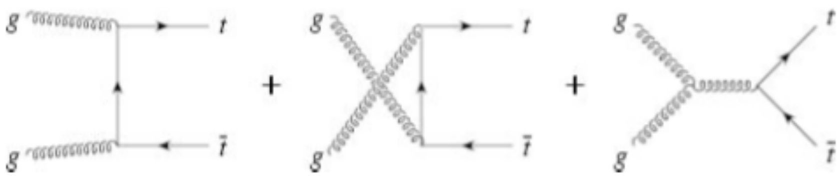
≈10%





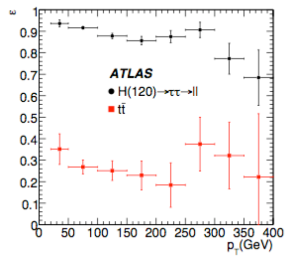
LO





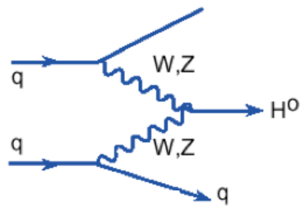
≈90%

- Largest background for ll channel. Use b-jet veto
- Use QCD topological cuts

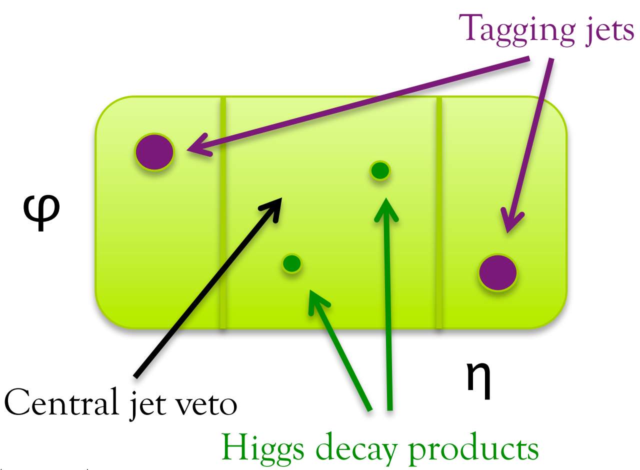


Low Mass Higgs: H→ττ Topology

H→ττ + ≥ 2 jets



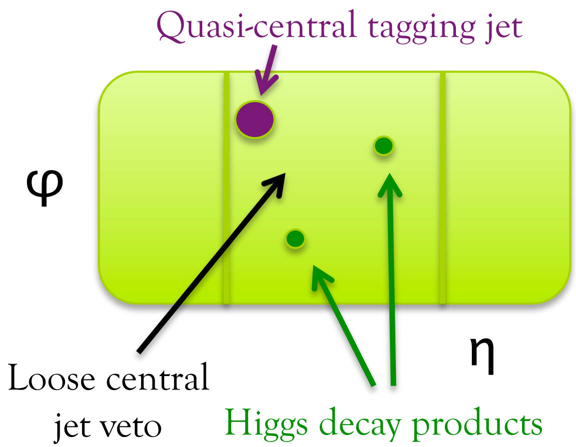
H→ττ + ≥ 1 jets



Veto events with extra jets in the central region

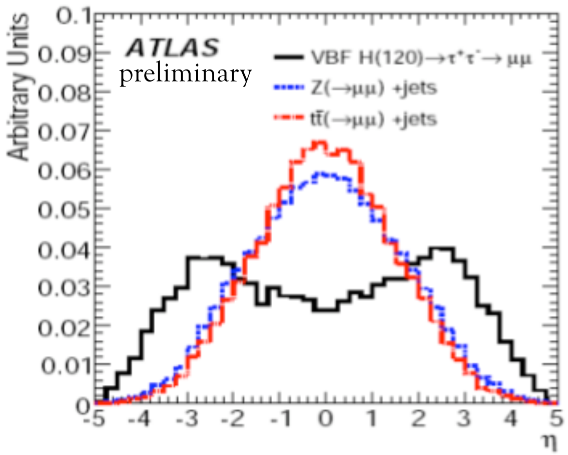
Initially suggested in Phys. Rev. D42 3052 (1990)

$\eta_{j1} \cdot \eta_{j2} < 0$
$\Delta\eta_{jj} > 3.5 - 4$
Mjj > 500 – 700 GeV
CJV

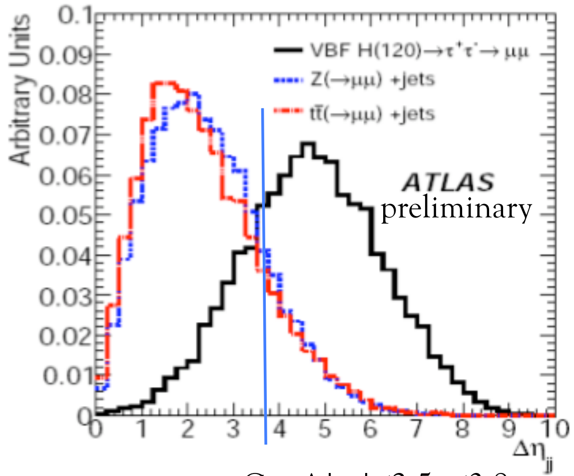


$P_{TH} > 100$ GeV
$M_{JH} > 700$ GeV
Loose CJV ("top killer")

Signal Topology Issues in VBF

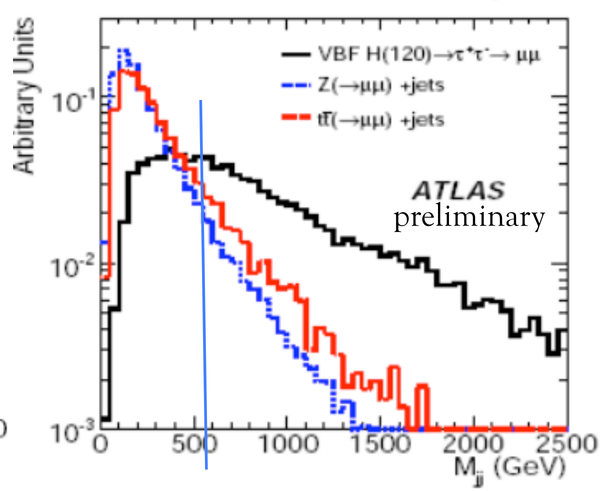


Leading P_T jet η_j



Cut $\Delta|\eta|<2.5_{jj}<3.8$

η gap $\Delta\eta_{jj}$

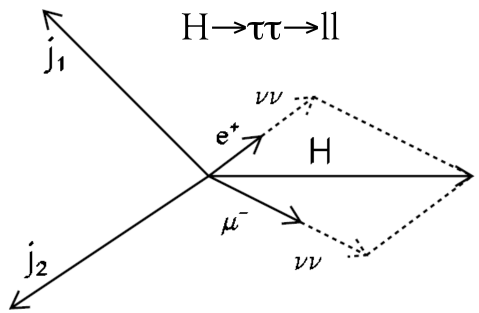


Cut M_{jj}>550 GeV

M_{jj}

- Pseudorapidity Gap, Leading P_T jet
- Central Jet Veto (CJV): no jets p_T > 20 GeV in η spanned by tagging jets

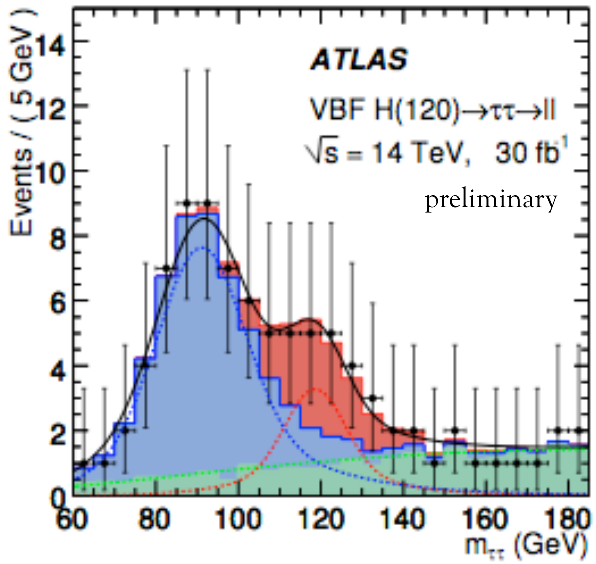
Mass Reconstruction H→ττ



Mass reconstruction via collinear approximation:

- Tau decay products collinear to tau direction
- Approximation breaks down when the two taus are back-to-back
- Mass resolution limited by missing E_T (8-10 GeV) and tau reconstruction (≈10-13 GeV)

H(→ττ→ll) + ≥ 2jets



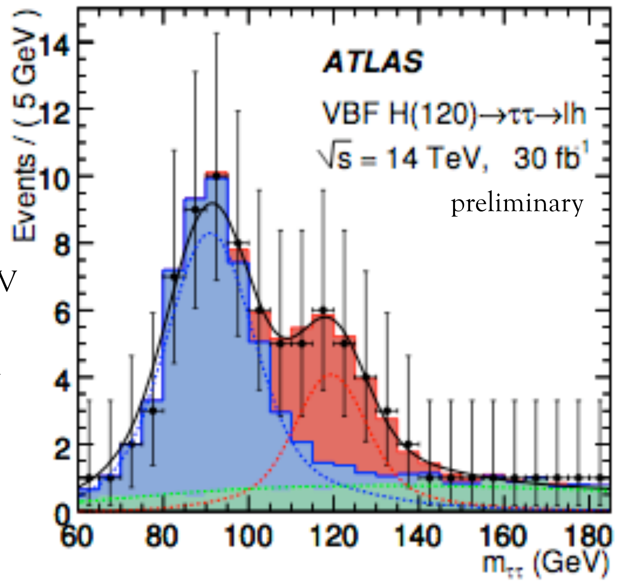
30 fb^{-1}

M_H=120 GeV

Z jj

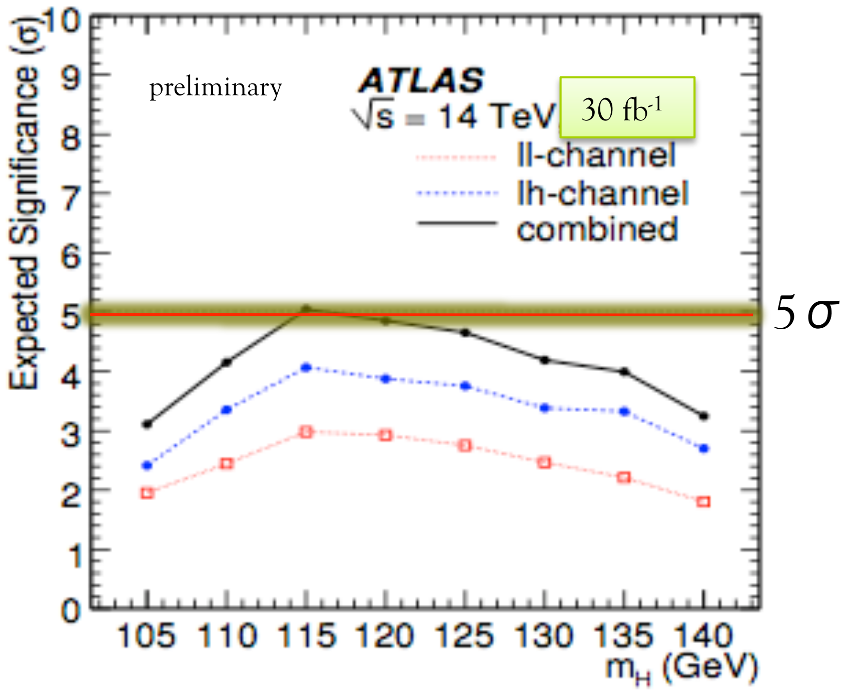
tt, WW EW

H(→ττ→lh) + ≥ 2jets



σ_M≈10 GeV (3.5%)

Expected Significances H→ττ



m_H	*ll*-channel	*lh*-channel	combined
105	1.95	2.41	3.10
110	2.44	3.35	4.15
115	2.98	4.07	5.04
120	2.92	3.87	4.85
125	2.75	3.75	4.65
130	2.46	3.38	4.18
135	2.21	3.32	3.99
140	1.80	2.70	3.24

110 – 125 GeV
30 fb^{-1} (≈5 σ)

- CSC 2008 preliminary results
- Profile likelihood fit
- ll (ee,μμ,eμ), lh and combined
- Not fully addressed yet pile-up effects

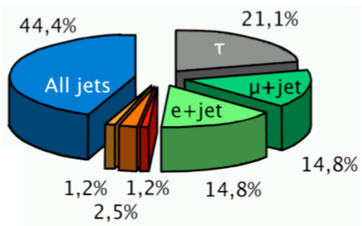
Low Mass SM Higgs: ttH(→bb)

- Complex final state ttH(→bb)→lepton+ν+bbbb+j
- Analysis aimed to reconstruct tt pairs
- May achieve 3-5 σ for M_H=120 GeV and 30 fb^{-1}

Signal

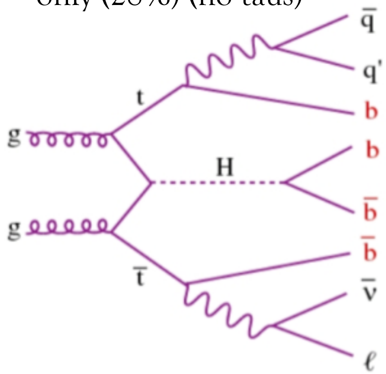
$W \to e, \mu, \tau + \nu$ (1/9 ~ 11.1% each)

$\to q\bar{q}'$ (2/3 ~ 66.6%)

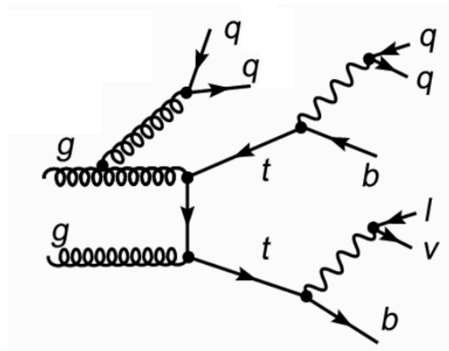


Final states classified according to W decays

Consider semileptonic decays only (28%) (no taus) → trigger



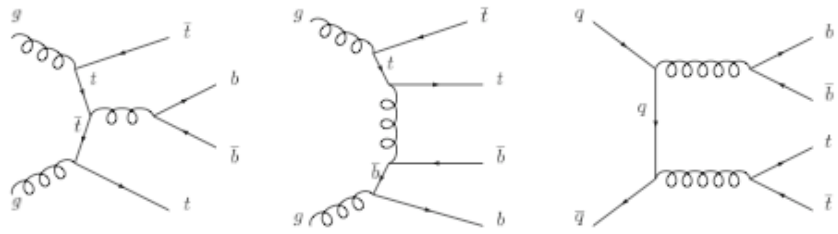
Backgrounds



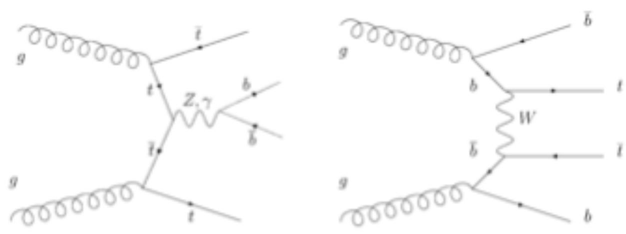
$t\bar{t} + jets$

- 4 b-tags (optimize for light jet rejection)

QCD $t\bar{t}b\bar{b}$



EW $t\bar{t}b\bar{b}$



- Irreducible
- Use kinematic properties in likelihood

Other backgrounds: W+jets, Wbb+jets, tW, bbbb,…

Mass Reconstruction ttH(→bb)

Cut based analysis
M_H=120 GeV

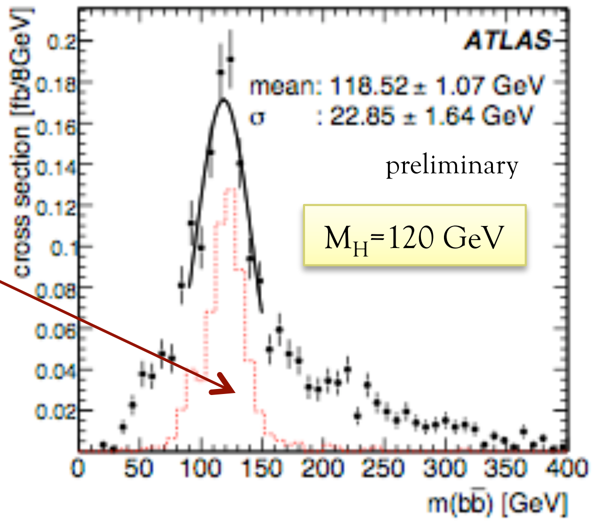
Correct b-jet combinatorics (≈30%)

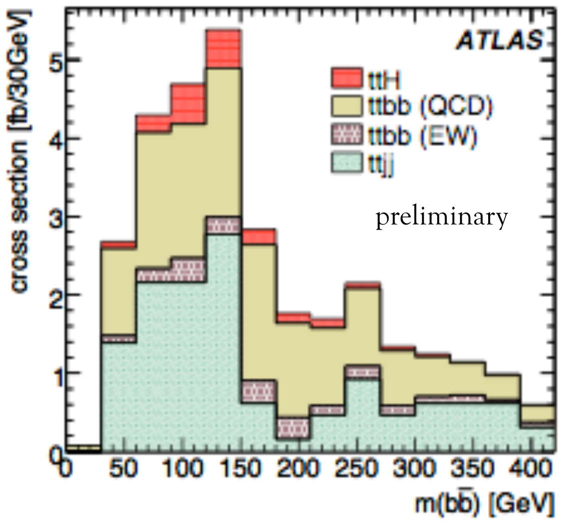
$$\chi^2 = \left(\frac{m_{jjb} - m_{top}}{\sigma_{m_{jjb}}}\right)^2 + \left(\frac{m_{l\nu b} - m_{top}}{\sigma_{m_{l\nu b}}}\right)^2$$

$$\sigma_{m(jjb)} = 13\,\text{GeV}$$
$$\sigma_{m(l\nu b)} = 19\,\text{GeV}$$

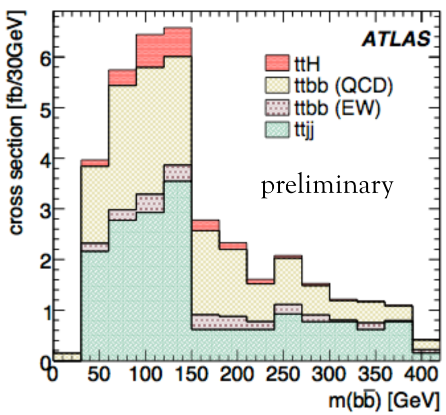
For significances consider a ±30 GeV mass window around nominal Higgs mass

S/B=0.11

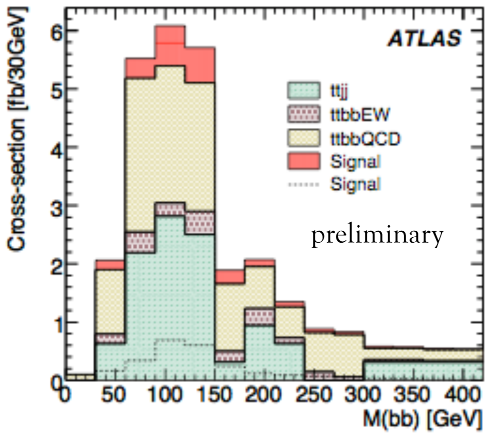




Other techniques →

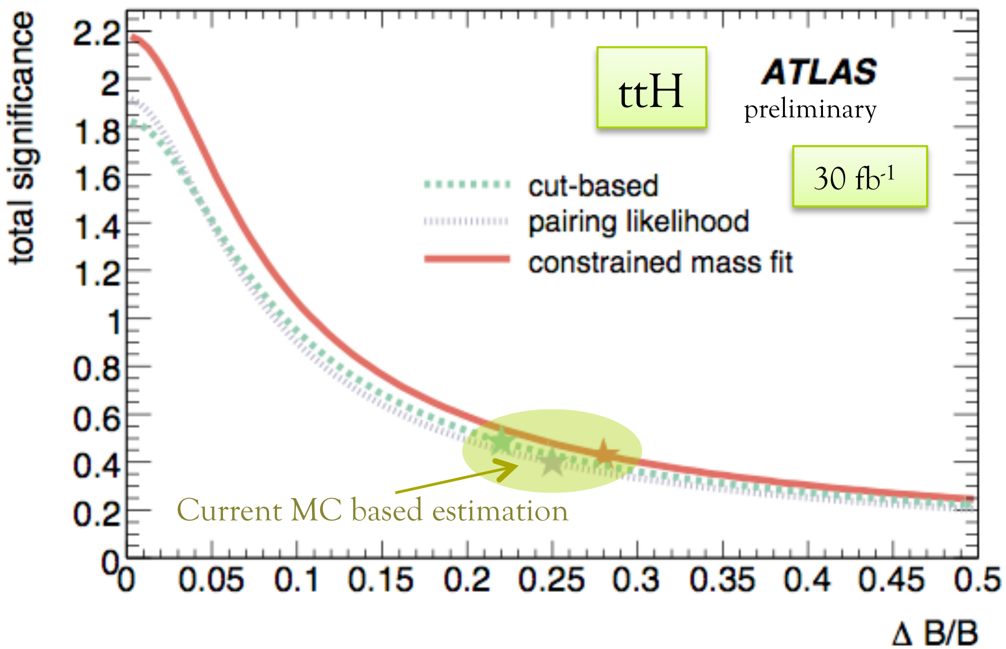


Pairing Likelihood



Constrained fit

Expected Significances ttH(→bb)



(Relative error on background systematics)

Significance

$$S/\sqrt{B + (\Delta B)^2}$$

Detector performance uncertainty

	Signal	Backgr
Jet energy scale	≲ 9%	≲ 5%
Jet resolution	≲ 1%	≲ 7%
b-tag eff	≲ 16%	≲ 20%
Light jet mistag	≲ 1%	≲ 5%

Total: 18% / 22% (cut-based)

tt backgr MC statistical uncertainty: 20%

Issues:

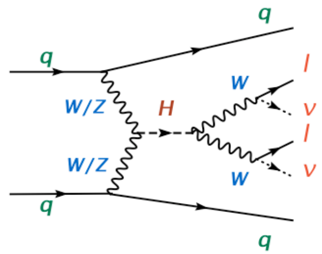
- Analysis sensitive to b-tagging efficiencies (ε_b^4) and jet energies
  - Parton/hadron level studies: $\varepsilon_b \geq 60\%$ needed
- Need ≈100 times rejection against light jets and ≈10 times against charm for ttjj suppression.
- Need to address issues related to background shapes and normalizations

→ Need data-driven background estimation
(large theoretical uncertainties for S and B)

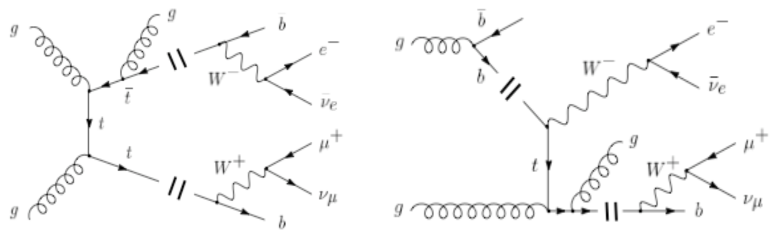
Need background uncertainty ≈5% to achieve reasonable significance

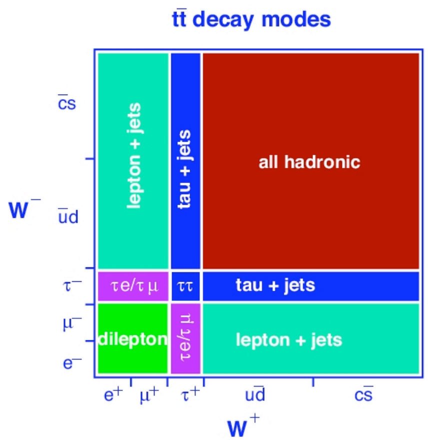
Low Mass Higgs: H→WW*

- Strong discovery potential due to large signal yield, but no narrow resonance. Left basically with event counting experiment.
- Accurate background estimate, critical.
- ATLAS:
  - Inclusive (TDR), use WW→2l2ν
  - Exclusive (VBF) searches, use WW→2l2ν, lνqq

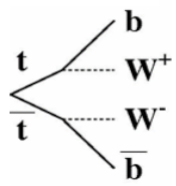


$$pp(q\bar{q}, gg) \rightarrow t\bar{t}\,(\rightarrow W^{+}bW^{-}\bar{b})$$
$$pp, p\bar{p} \rightarrow tqX, t\bar{b}X, tWX$$



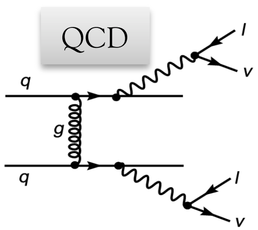


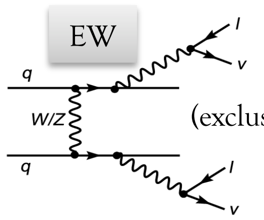
11% dileptons



Removed with jet veto (inclusive search) and b-jet veto (exclusive search)

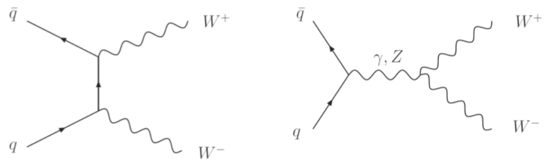
$$pp \rightarrow W^{+}W^{-}jj$$

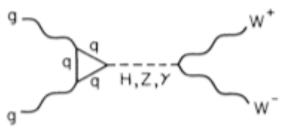




(exclusive search)

$$pp \rightarrow W^{+}W^{-}$$

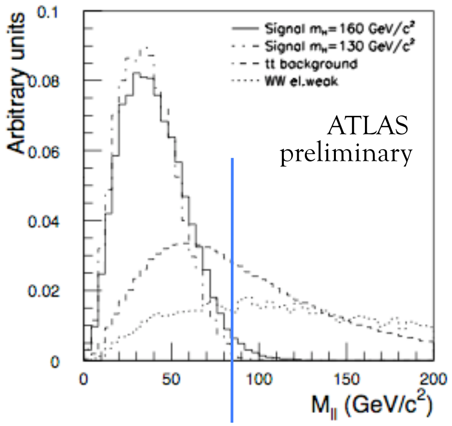




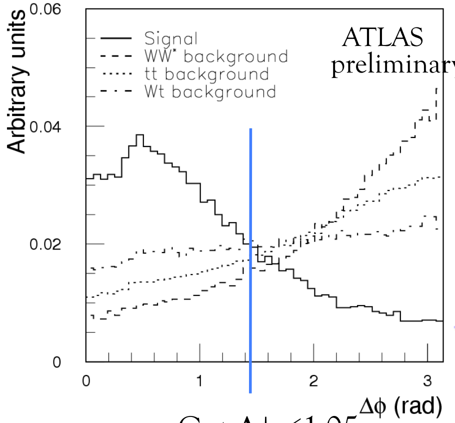
(inclusive search)

H→WW*→2l2ν Lepton Cuts

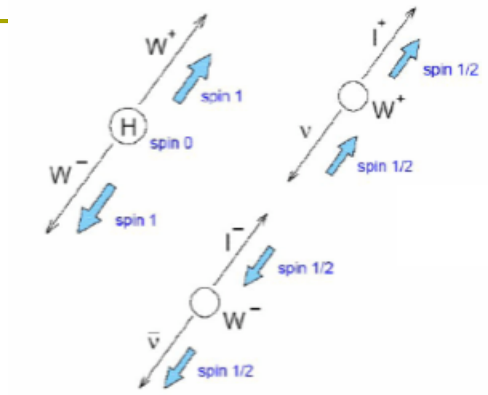
- Lepton cuts to remove tt, WW, Wt backgrounds
- Remove also DY ee, μμ with missing p_T and M_{ll} cuts



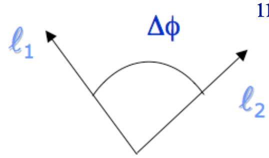
Cut M_{ll}<85 GeV



Cut $\Delta\phi_{ll}$<1.05

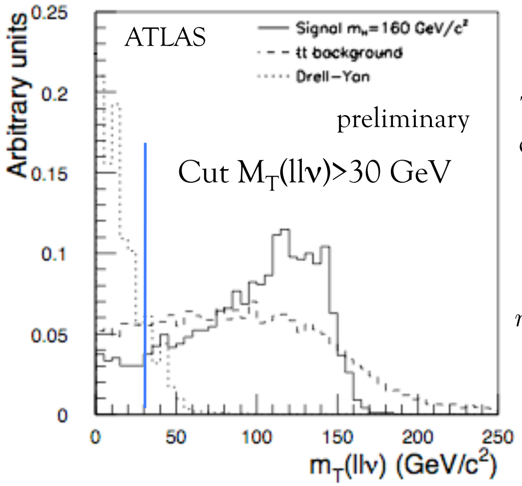


- Higgs scalar decay leads to WW's with opposite spins
- Leptons emitted in the same direction (left-handed weak interaction)



Transverse plane
Transverse Opening Angle

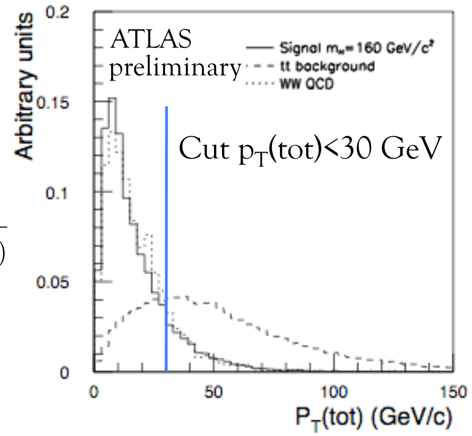
$$\vec{p}_T^{tot} = \vec{p}_T^{l,1} + \vec{p}_T^{l,2} + \vec{p}_T^{miss} + \vec{p}_T^{j,1} + \vec{p}_T^{j,2}$$



Transverse mass of the di-lepton and neutrino system

$Z/\gamma^*,\ Z \to \tau\tau$ rejection

$$m_T(ll\nu) = \sqrt{2p_T(ll)p_T^{miss} \cdot (1 - \cos\Delta\phi)}$$

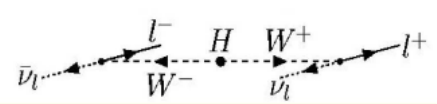


p_T Higgs balanced with p_T of tagged jets

Mass Reconstruction H→WW*

H→WW*→lνlν

- No mass peak
- Use transverse mass
- Side-band like analysis possible for background estimation

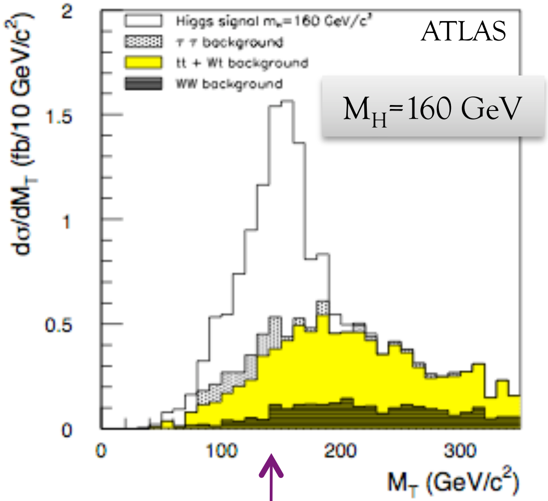


For $M_H < 2M_W \rightarrow M_{ll} \approx M_{\nu\nu}$

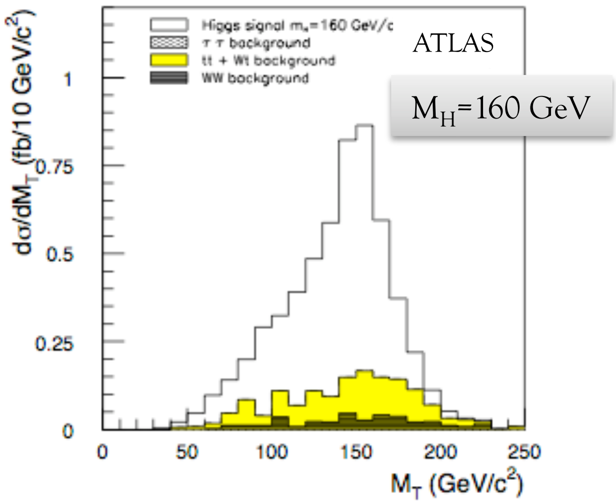
$$M_T = \sqrt{(E_T^{ll} + E_T^{\nu\nu})^2 + (\vec{p}_T^{\,ll} + \vec{\not{p}}_T)^2}$$

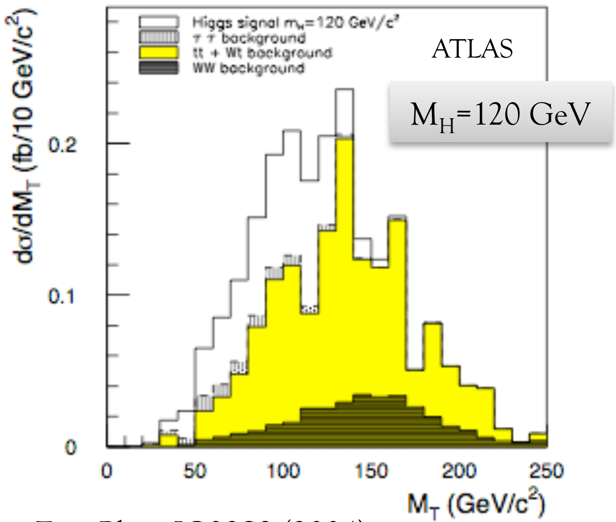
$$E_T^{ll} = \sqrt{(p_T^{ll})^2 + m_{ll}^2}$$

$$E_T^{\nu\nu} = \sqrt{(\not{p}_T)^2 + m_{ll}^2}$$



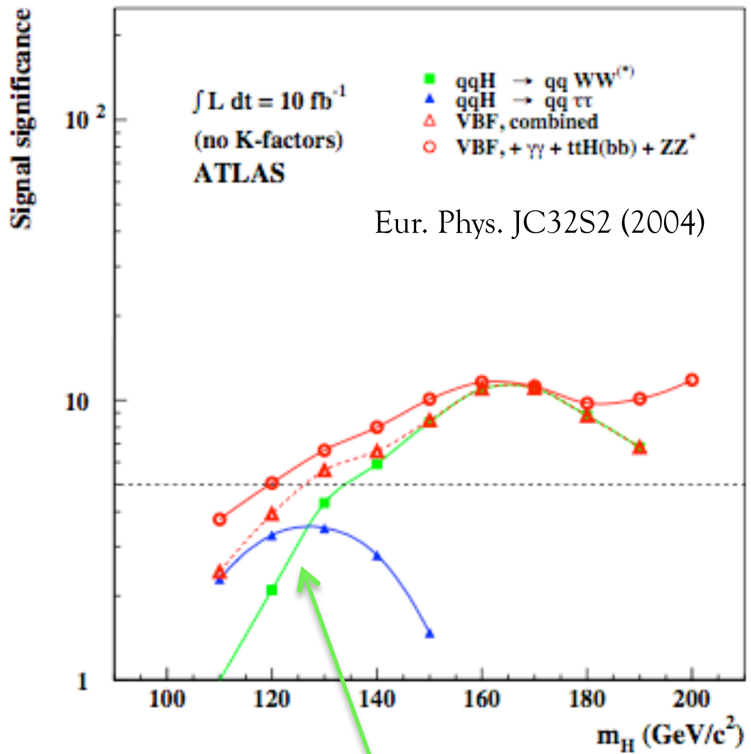
No lepton cuts

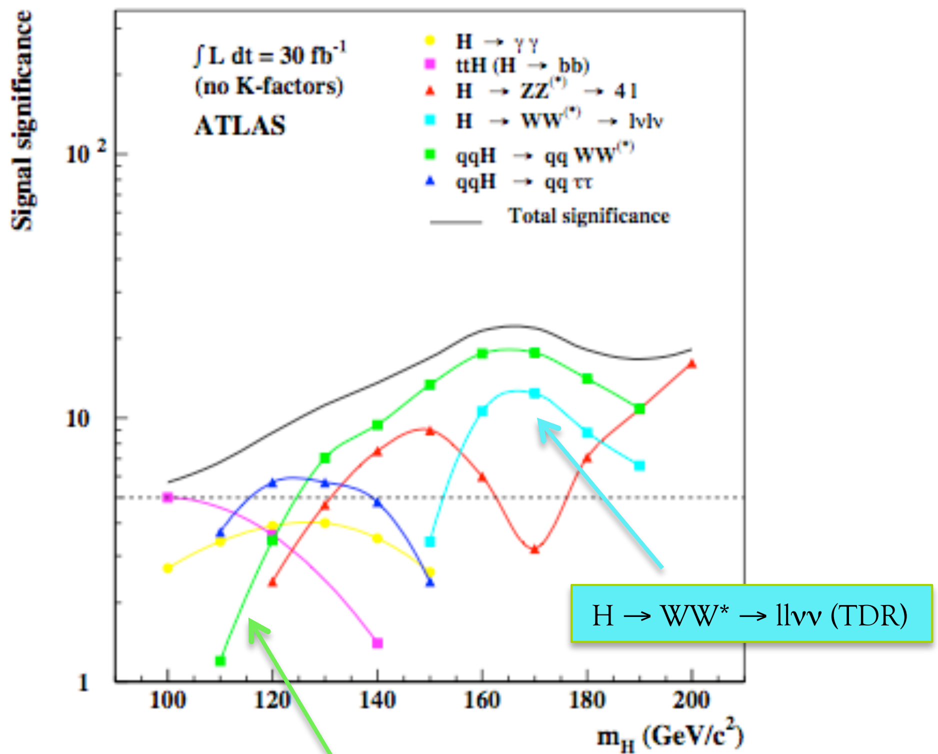




Eur. Phys. JC32S2 (2004)

Expected Significances H→WW*





VBF H → WW* → ll + lh

VBF H → WW* → ll + lh

110 – 130 GeV
10 fb^{-1} (1 – 4 σ)

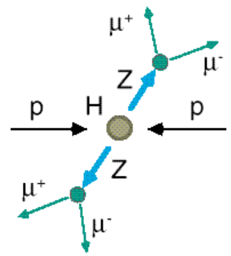
130 – 190 GeV
10 fb^{-1} (>5 σ)

110 – 130 GeV
30 fb^{-1} (1 – 5 σ)

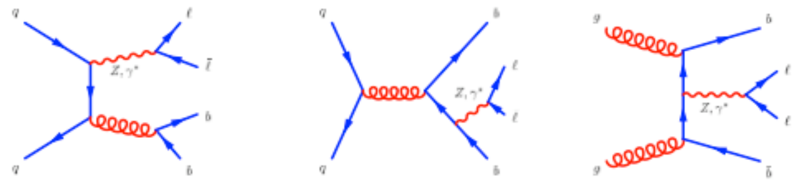
130 – 190 GeV
30 fb^{-1} (>5 σ)

High Mass H→ZZ*→4l

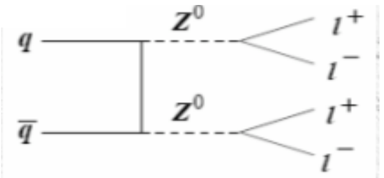
- Cleanest experimental signature: 4 leptons (4e, 4μ, 2e2μ)
- Narrow peak over small background
- Excellent mass resolution (≈1.5%, ≈2 GeV for M_H=130 GeV)
- Leads to powerfull analysis in a wide mass range

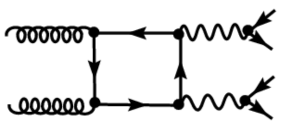


- Backgrounds
  - QCD ZZ production (irreducible)
  - Zbb
  - tt, WZ, inclusive Z

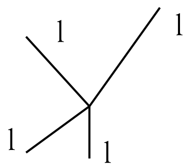


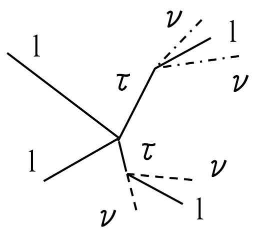
Irreducible $q\bar{q} \rightarrow ZZ$



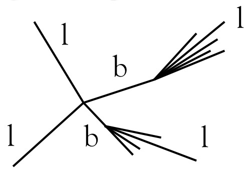


Known at NLO, 20% added to account for gg→ZZ

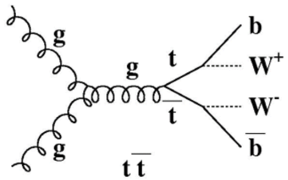


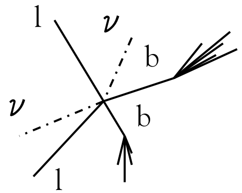


$q\bar{q}, gg \rightarrow Zb\bar{b}$ Reducible



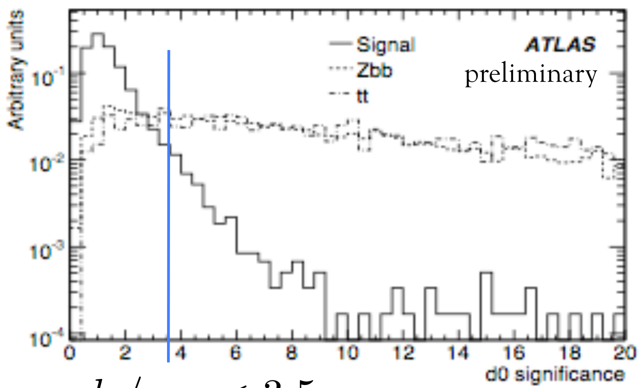
$t\bar{t} \rightarrow WbWb \rightarrow 4l$ Reducible





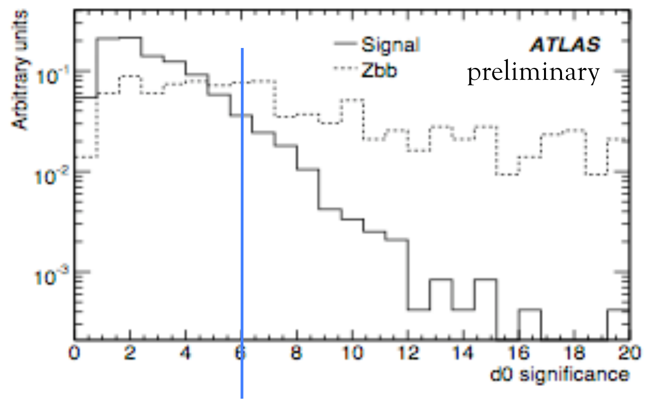
Lepton Selection H→ZZ*→4l

- Reducible Zbb and tt rejection
  - Leptons non-isolated, with activity around leptons in the calorimeter and tracker
  - High impact parameter significance
- O(10^2) rejection for Zbb, O(10^3) for tt, for signal efficiency of O(80%)



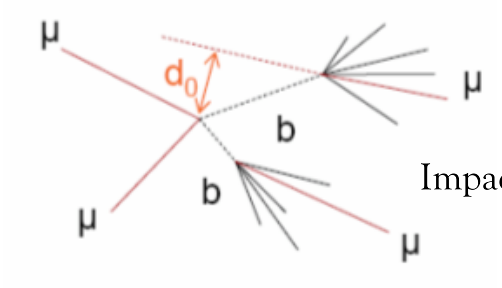
$d_0/\sigma_{d_0} < 3.5$

muons



$d_0/\sigma_{d_0} < 6$

electrons

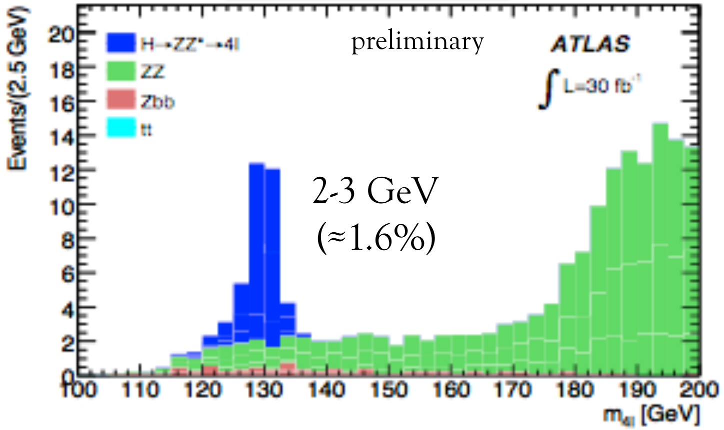


Impact parameter, d_0

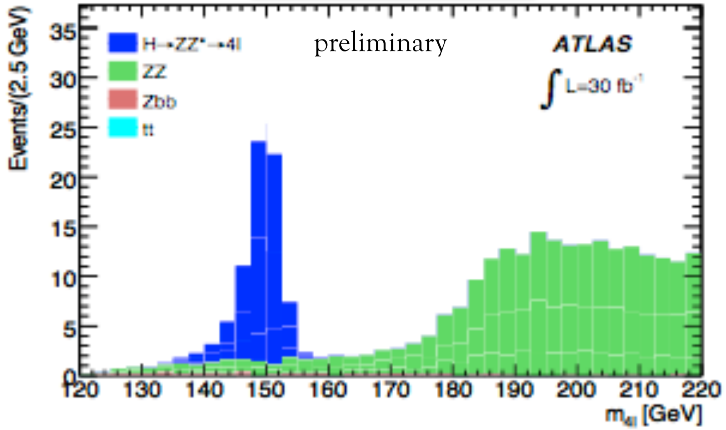
Mass Reconstruction H→ZZ*→4l

30 fb^{-1}

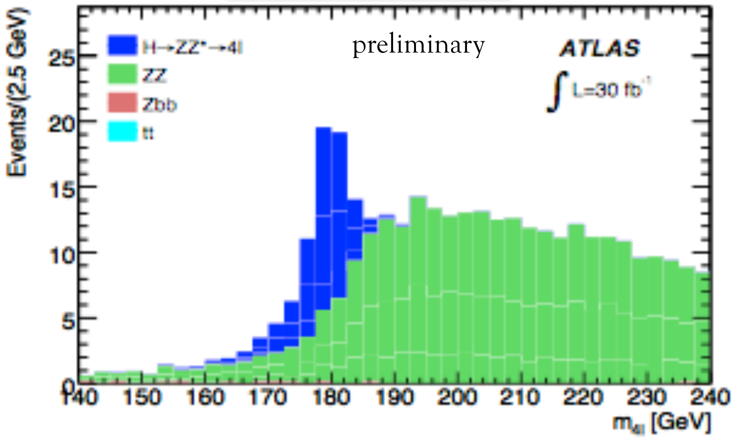
M_H=130 GeV



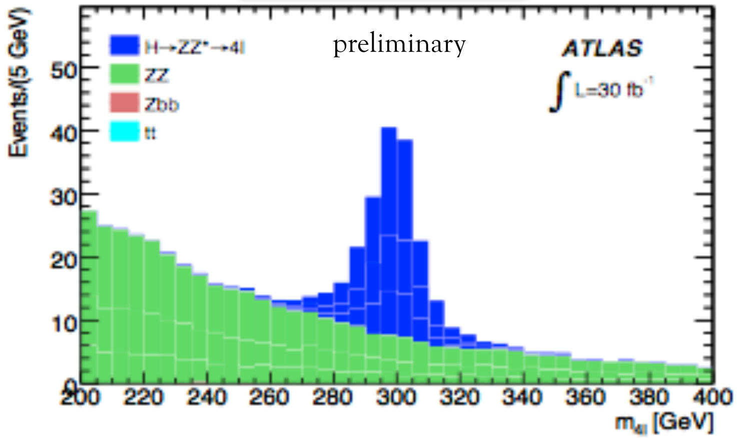
M_H=150 GeV



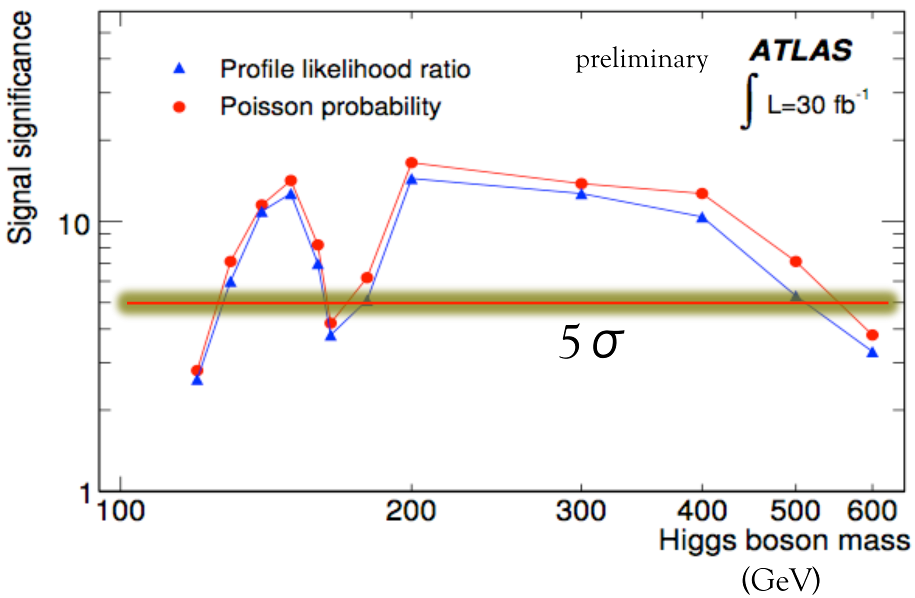
M_H=180 GeV



M_H=300 GeV

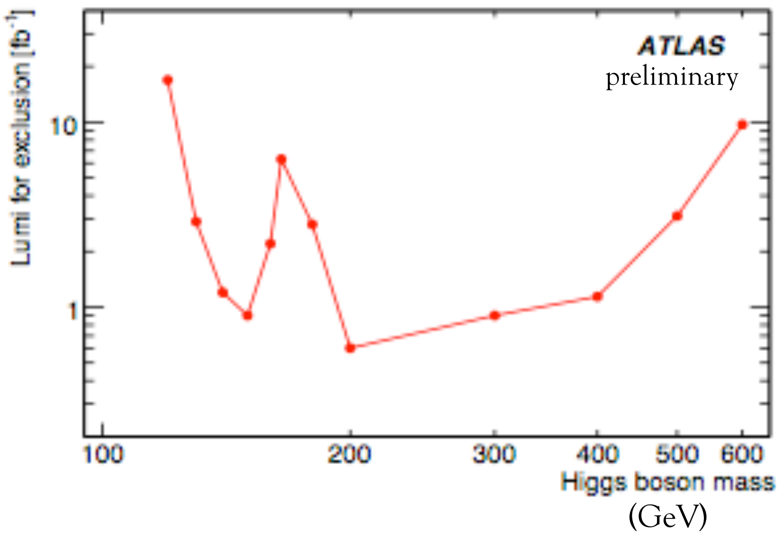


Significance H→ZZ*→4l



Combined results for all channels (4e, 4μ, 2e2μ)

Required luminosity for exclusion



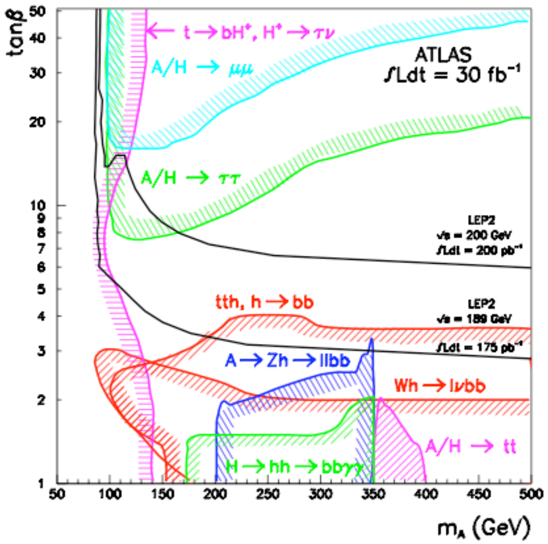
- All results from CSC 2008 preliminary
- Counting results with Poisson stats. and no systmatics included
- Profile likelihood ratio results from fit likelihoods

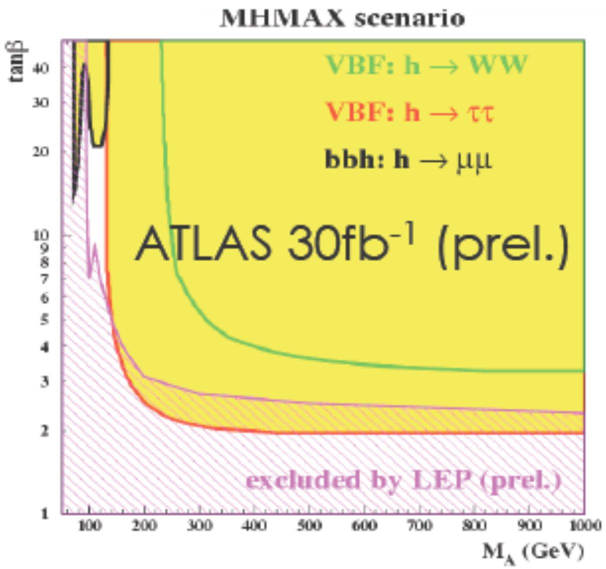
130 – 500 GeV
30 fb^{-1} (≈5σ)

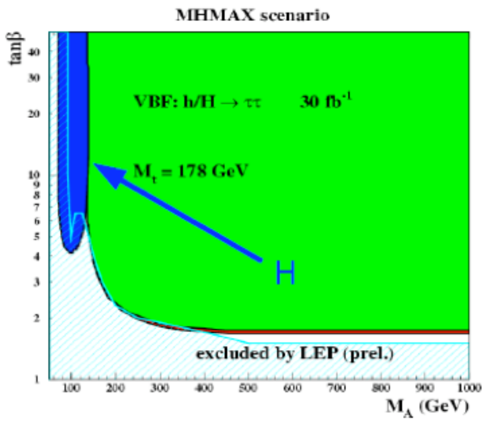
except 4σ for WW turn-on (160 GeV)

MSSM Coverage

TDR original results



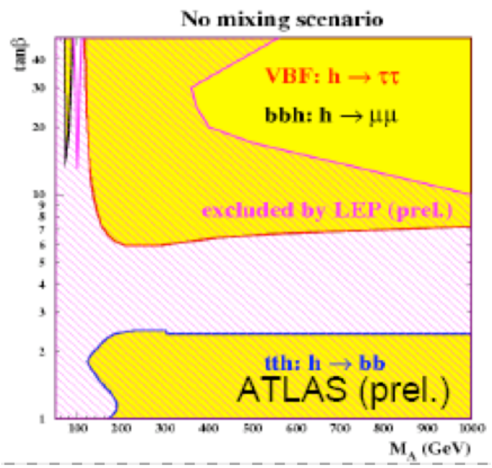


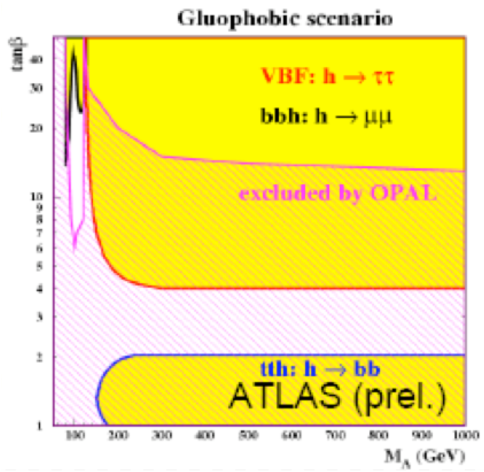


Hole at low M_A=90-100 GeV (h unobservable, all scenarios)

Covered by the $H \rightarrow \tau\tau$ (H observable)

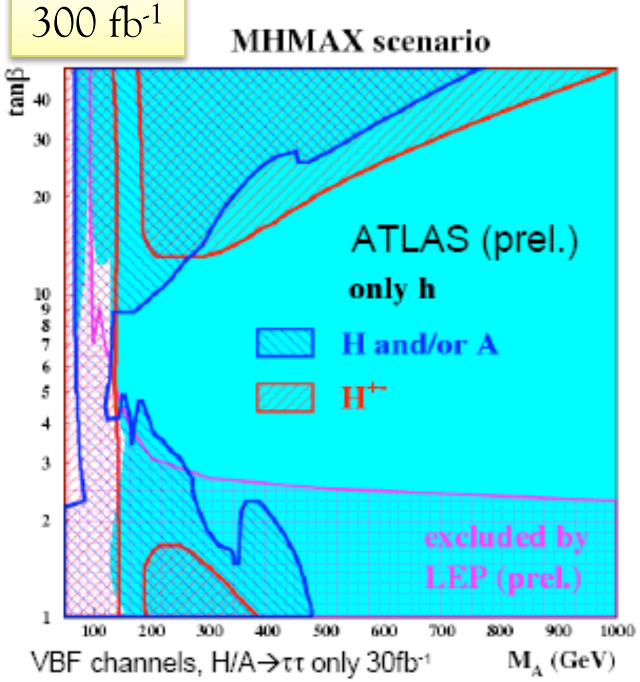
Other benchmark scenarios





MSSM Full Luminosity

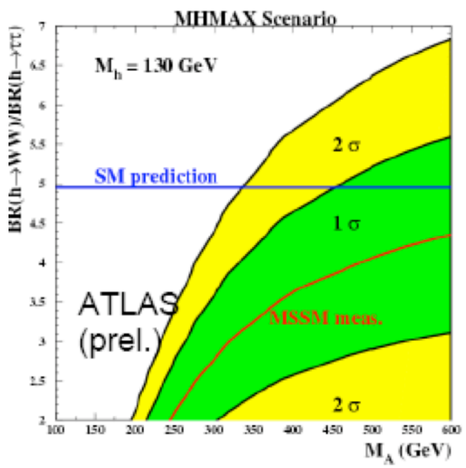
300 fb^{-1}

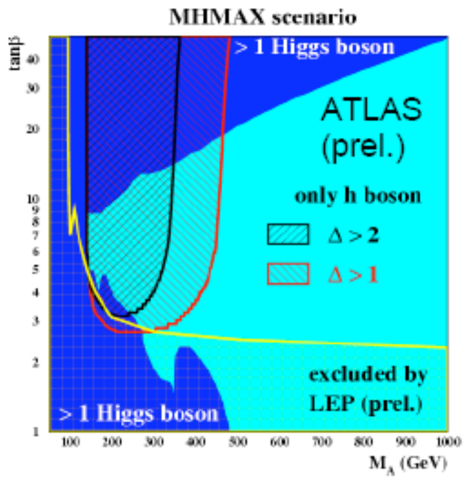


- Complete parameter space with at least one Higgs boson observable

Could we distinguish between SM/MSSM sectors ?

- Some regions with more than one boson → direct method





Sensitivity to discriminate between SM and MSSM from Δ

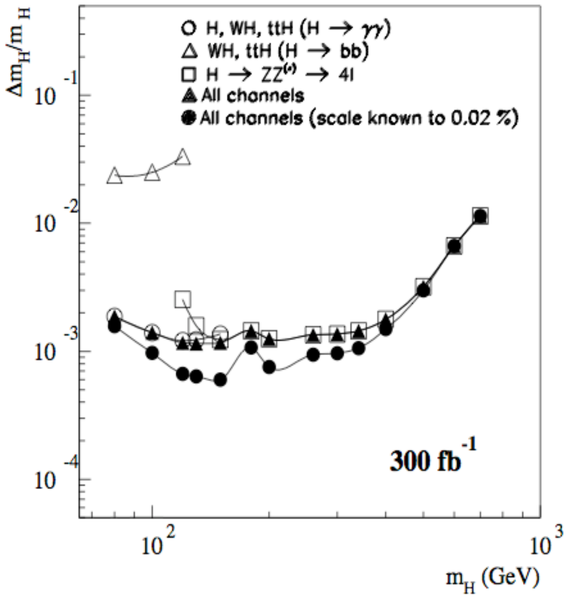
- Use VBF channels to measure R
- σ_{exp} is uncertainty on R for a particular MSSM point
- No systematics included. M_h known precisely

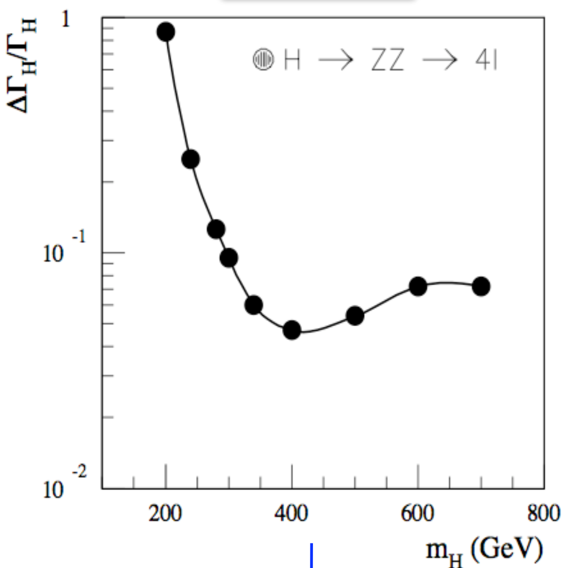
$$R = \frac{BR(h \to \tau\tau)}{BR(h \to WW)} \longrightarrow \Delta = \frac{|R_{MSSM} - R_{SM}|}{\sigma_{exp}}$$

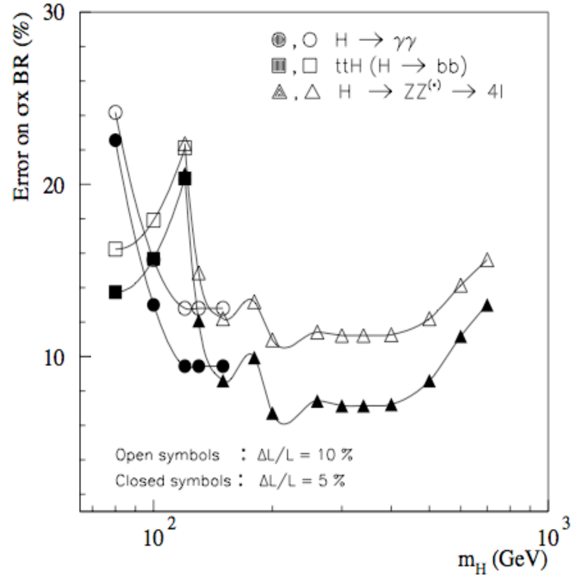
Higgs Properties (Mass, Width, Rates)

300 fb^{-1}

from TDR





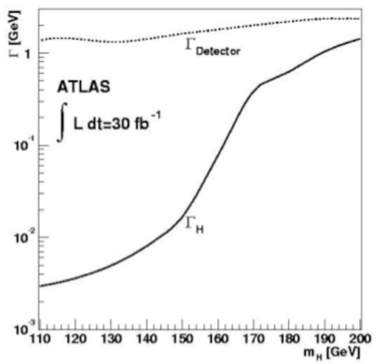


≈10% on rates

Higgs mass measurement (channels with reconstr. mass):

- $H \to \gamma\gamma$, $H \to ZZ^* \to 4l$
- $H \to \tau\tau$ at low luminosity

≈0.1% for 80-400 GeV



Width only accessible above 200 GeV

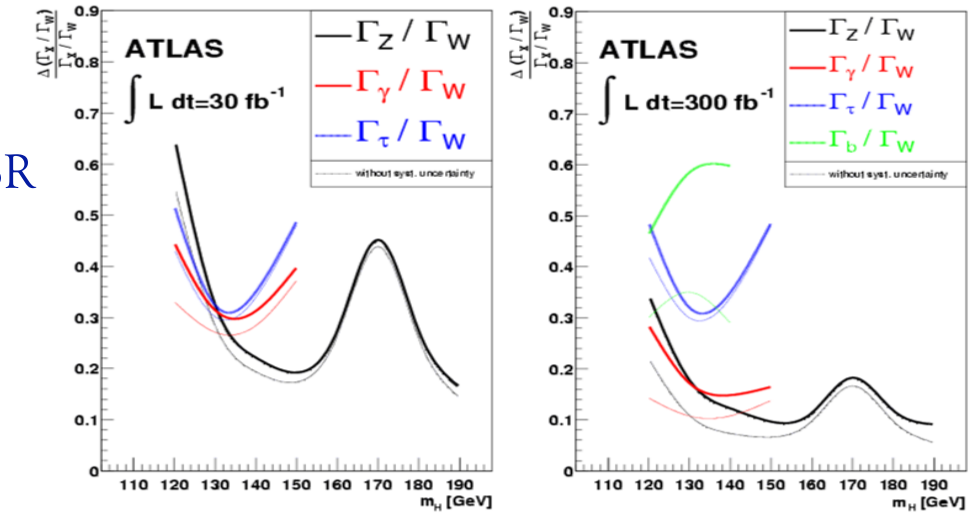
Above 250 GeV reach precision of ≈6%

Higgs Properties (Couplings)

Assumptions:

- CP-even, Spin 0 → measure σxBR
- Only one Higgs → measure ratio of BR
- Express σ, BR = f(g_W, g_Z,g_t,g_b, g_τ)

Global maximum likelihood fit based analysis
(theoretical and systematic errors included)



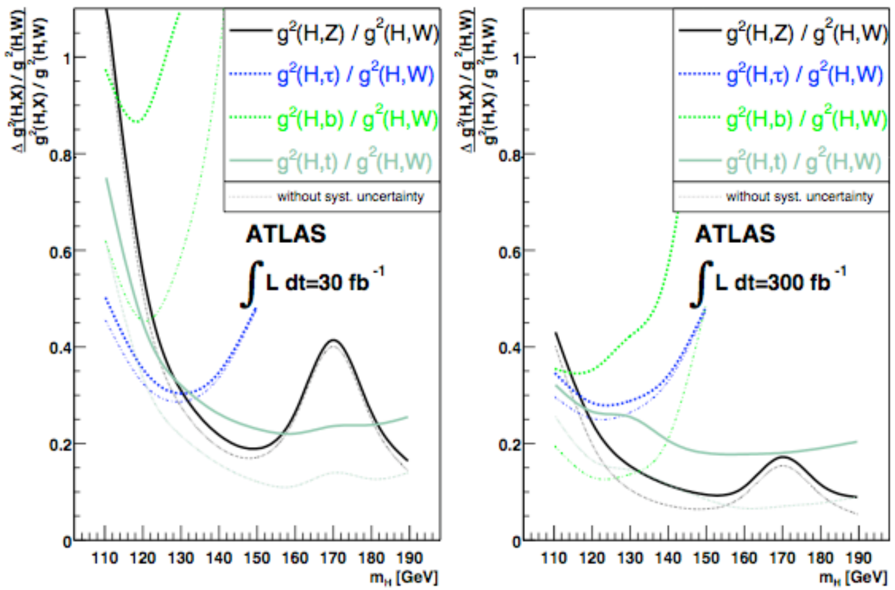
Example:

$$\sigma_{VBF} = \alpha_{WF} \cdot g_W^2 + \alpha_{ZF} \cdot g_Z^2$$

$$BR(H \to \gamma\gamma) = \frac{(\beta_{\gamma(W)} \cdot g_W - \beta_{\gamma(t)} \cdot g_t)^2}{\Gamma_H}$$

$$\frac{\Delta g^2(H,X)/g^2(H,W)}{g^2(H,X)/g^2(H,W)}$$ →

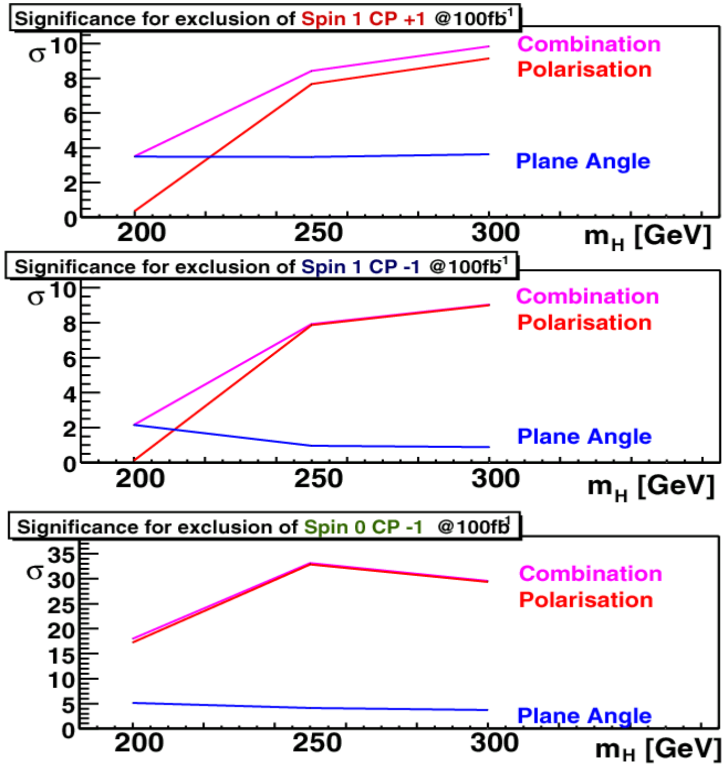
10-40% for 300 fb-1



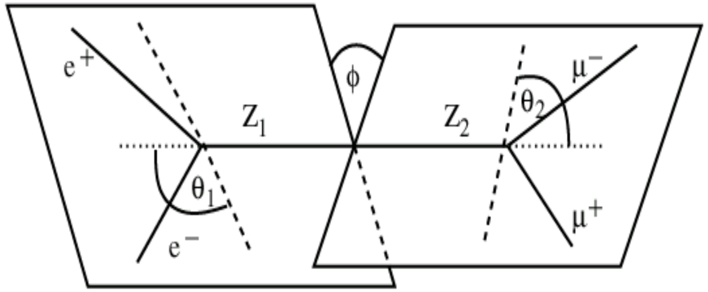
Higgs Properties (Spin, CP)

Higgs quantum numbers in SM: $\mathcal{J}^{\mathcal{PC}} = 0^{++}$

- Observation of gg→H, H→γγ rules out spin 1
- Focus on ZZ Higgs decays: $ZZ \to l_1^+ l_1^- l_2^+ l_2^-$



Eur. Phys. J. C32 209 (2004)



$$F(\phi) = 1 + \alpha \cdot \cos\phi + \beta \cdot \cos 2\phi$$
$$G(\theta) = T \cdot (1 + \cos^2\theta) + L \cdot \sin^2\theta$$
$$R = \frac{L - T}{L + T}$$

- Exploit angular correlations between SM Higgs-like particle and hypothetical scalar CP-odd and vector particles (CP-even, CP-odd)
- Results in terms of exclusion significance
  - CP-odd scalar Higgs ruled out < 100 fb^{-1}
  - M_H>230 GeV spin 1 ruled out (100 fb^{-1})
  - M_H≈200 GeV needs more data

Summary and Conclusions

- Good sensitivity for a SM Higgs-like resonance, already with $\approx 10\ fb^{-1}$
  - All results assuming nominal performance and present knowledge of theoretical SM backgrounds
    - Need around 1 fb^{-1} of usable data for calibration
  - Early discovery at low mass challenging. Need combination of independent channels to add robustness to analyses
- Complete sensitivity for the MSSM Higgs parameter space for at least one boson (also with ≈1 year running, initial lum.)
  - Much more data to confirm it is actually a Higgs (SM/MSSM) resonance
- Developed new analysis strategies and new data-driven methods for background normalization (like fit likelihoods) to optimize significance in the early phase of the experiment

Backups

Backup slides

On Significances

- For a counting method in a prospect experiment
  - n_{obs} events observed in an experiment
  - n_b estimated background rate
  - Calculate p-value to observe n_{obs} events under the null-signal hypothesis

Gaussian limit

$$\mathcal{P}(n \geq n_{obs}) = \int_{n_{obs}}^{\infty} G(x; n_b; n_b)dx = \frac{1}{\sqrt{2\pi}} \int_s^{\infty} \exp\left(-\frac{x^2}{2}\right) dx = \frac{1}{2}\left[1 - erf(s)\right]$$

$$\rightarrow \quad s = \frac{n_{obs} - n_b}{\sqrt{n_b}} = \frac{n_s}{\sqrt{n_b}}$$

Poisson limit

$$\mathcal{P}(n \geq n_{obs}) = \sum_{n=n_{obs}}^{\infty} P(n; n_b) = \sum_{n=n_{obs}}^{\infty} \frac{\exp(-n_b)n_b^n}{n!} = \frac{1}{\sqrt{2\pi}} \int_s^{\infty} \exp\left(-\frac{x^2}{2}\right) dx = \frac{1}{2}\left[1 - erf(s)\right]$$

$$\mathcal{P}(n \geq n_{obs}) \leq 2.85 \times 10^{-7} \ (s = 5, 5\sigma \ \text{discovery})$$
$$\mathcal{P}(n \geq n_{obs}) \leq 0.0228 \ (s = 2, 2\sigma)$$
$$\mathcal{P}(n \geq n_{obs}) \leq 0.1587 \ (s = 1, 1\sigma)$$

On Significances

- Profile likelihood method
  - Based on data likelihood fits to signal and background
  - Use parametric forms os signal and background shapes from MC
  - Use test statistics $\lambda(\mu)$ defined as:

conditional maximum likelihood estimator → Maximize the likelihood under μ constrain

$$\lambda(\mu) = \frac{\mathcal{L}(\mu, \hat{\hat{\vec{p}}})}{\mathcal{L}(\hat{\mu}, \hat{\vec{p}})}$$

μ is the signal to SM cross-section ratio
μ = 0: no signal
μ = 1: SM signal rate

maximum likelihood estimators

to either:

- Reject null-signal hypothesis (discovery): μ =0 $\quad p_\mu, \; q_\mu = -2\ln\lambda(\mu)$

$$p_0 = \int_{q_{0,obs}}^{\infty} f(q_0|0)dq_0$$

$q_{0,obs}$ from data generated under μ =1 assumption

- Reject signal+background hypothesis (exclusion): μ =1

MSSM Higgs

- MSSM: Minimal Supersymmetric extension of the Higgs sector in the SM
- Five physical states: h (light), H, A, $H^{\pm}$
- Parameter space reduced to: M_A, tan β

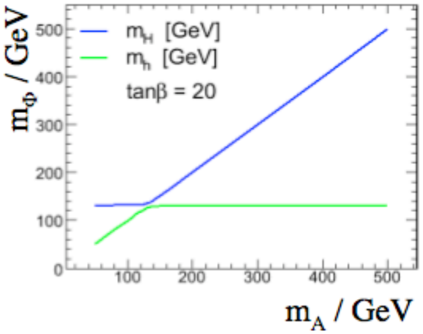
Signal Properties

S. Heynemeyer, W. Hollik, W.B.Kilgore
Phys. Rev. D 68 (2003) 013001

S. Dittmaier, M. Kramer, M. Spira
Phys. Rev. D70 (2004) 074010

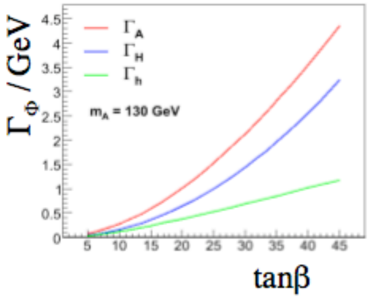
NLO

Mass degeneration



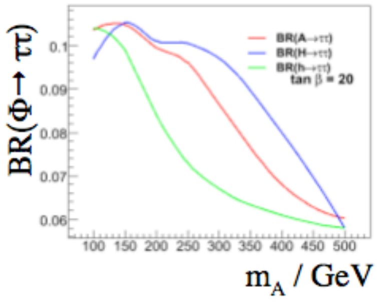
Add up cross sections

Natural width



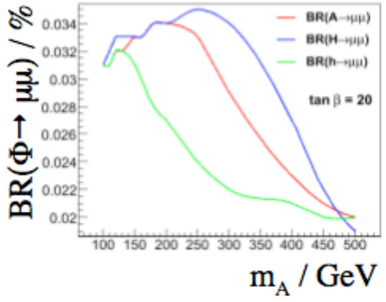
Irrelevant for h/A/H → ττ due to mass resolution

BR h/A/H → ττ

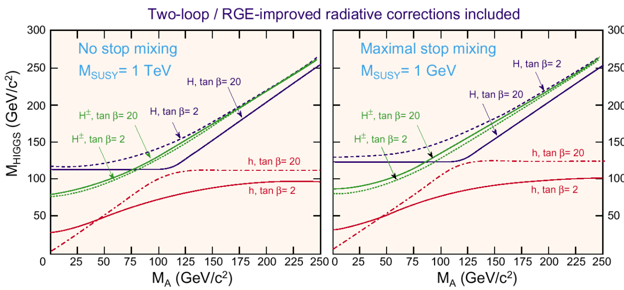


≈ 10 % for low m_A

BR h/A/H → μμ



≈ 0.03 % for low m_A



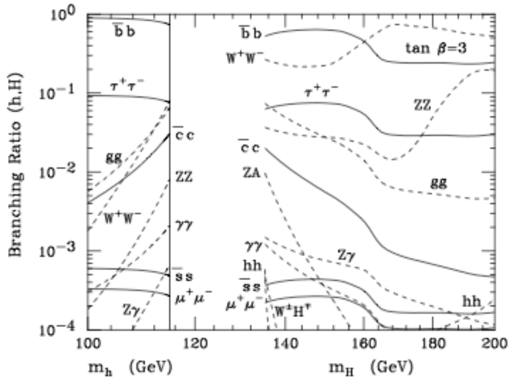
MSSM BRs

Low tanβ

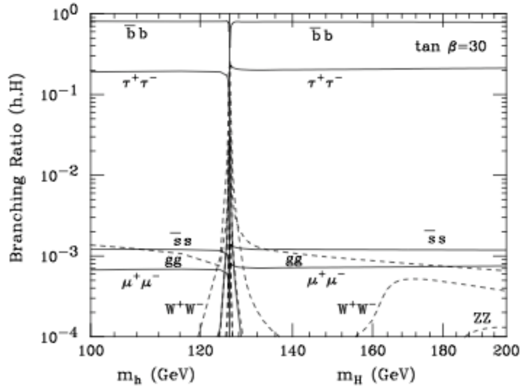
High tanβ

Low tanβ

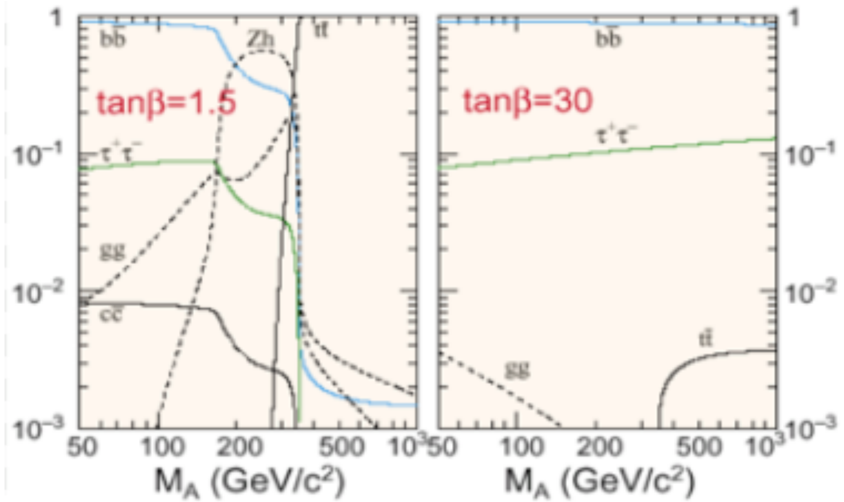
High tanβ

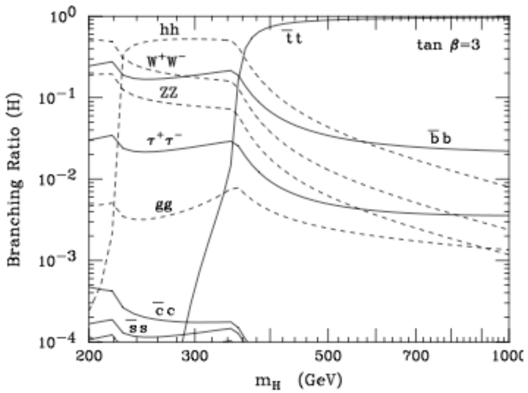


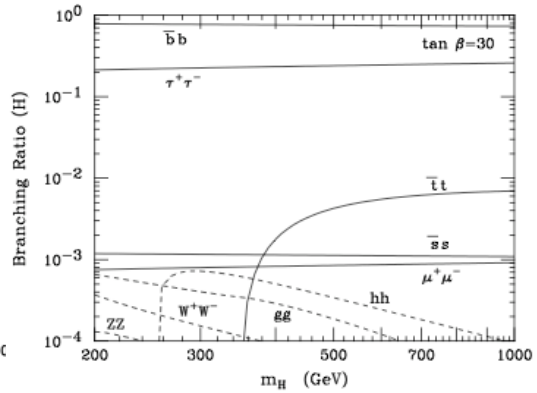
M_h



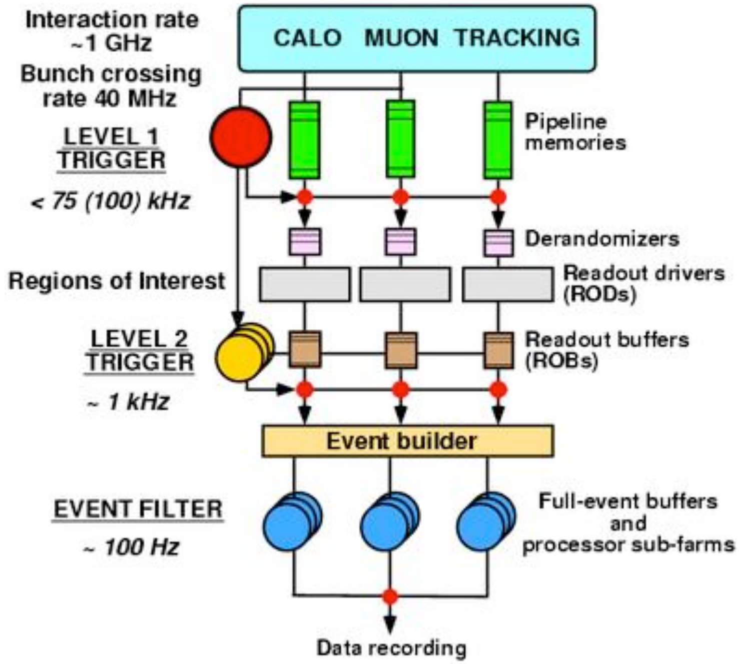
M_h

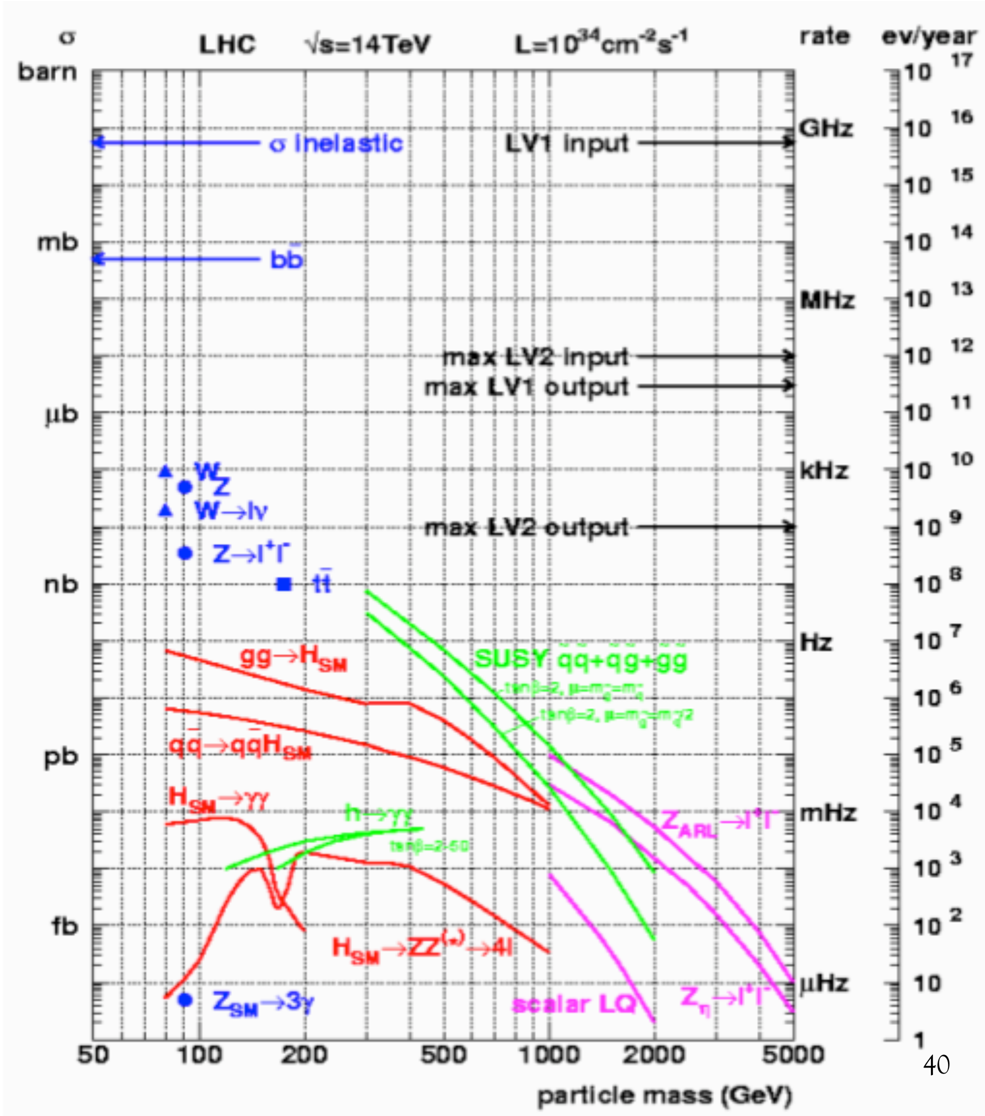




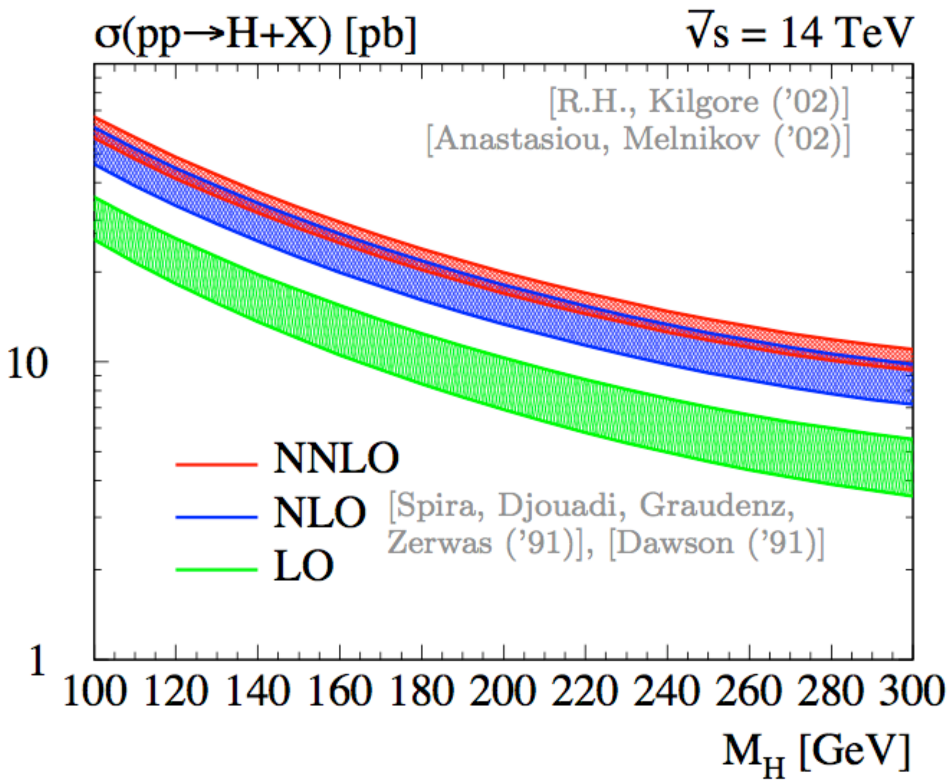


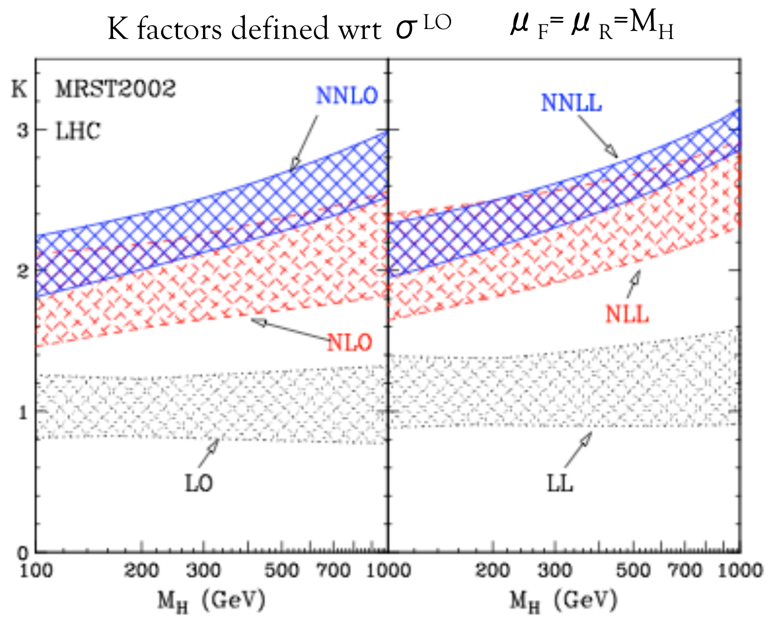
ATLAS Trigger System

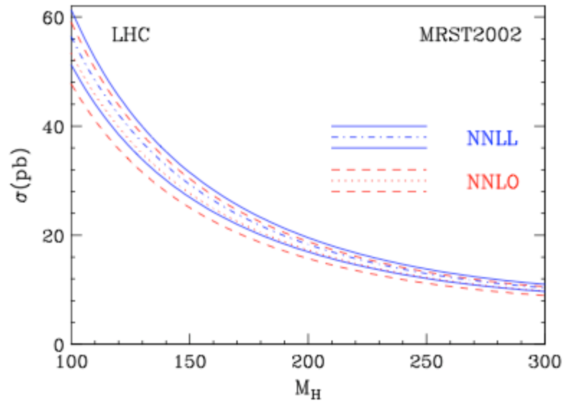




Total gg→H+X Cross Sections





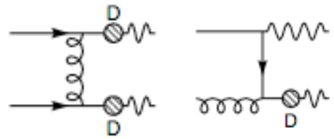


From S. Catani et. al. (JHEP 2003)

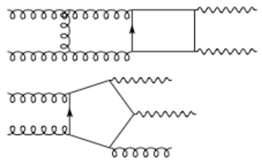
- Use MC@NLO: NLO + NNLL to fully evaluate the discriminating power of $P_T(\gamma\gamma)$
- σ evaluated at NLO

MC Background Estimation H→γγ

- Irreducible
  - Use NLO ME for $P_T(\gamma\gamma)$ normalization and shapes
    - Diphox:
      - NLO for Born and Bremss, $\mathcal{O}(\alpha^2\alpha_s)$, LO for Box.
      - Single/double-γ fragmentation at LO/NLO.
      - No soft-gluon ressum. → low $P_T(\gamma\gamma)$ spectrum not reliable < 20-25 GeV.



    - ResBos
      - Full NLO ME (including Box)
      - Only single-γ fragmentation at LO.
      - Ressum. of soft gluons (at NNLL) → reliable low $P_T(\gamma\gamma)$ spectrum.



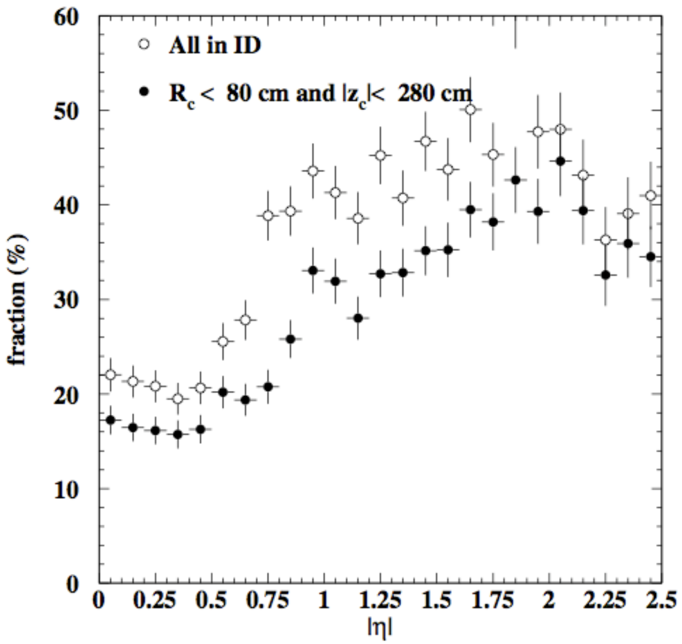
ResBos
HO diagrams for Box

  - Use PYTHIA with Born+Box at LO with (above) normalized cross-sections and re-weighted M(γγ) and $P_T(\gamma\gamma)$ shapes
  - Uncertainties: PDFs (10%), renormalization and factorization scales (5%) and fragmentation (6%), for a total of ≈18%

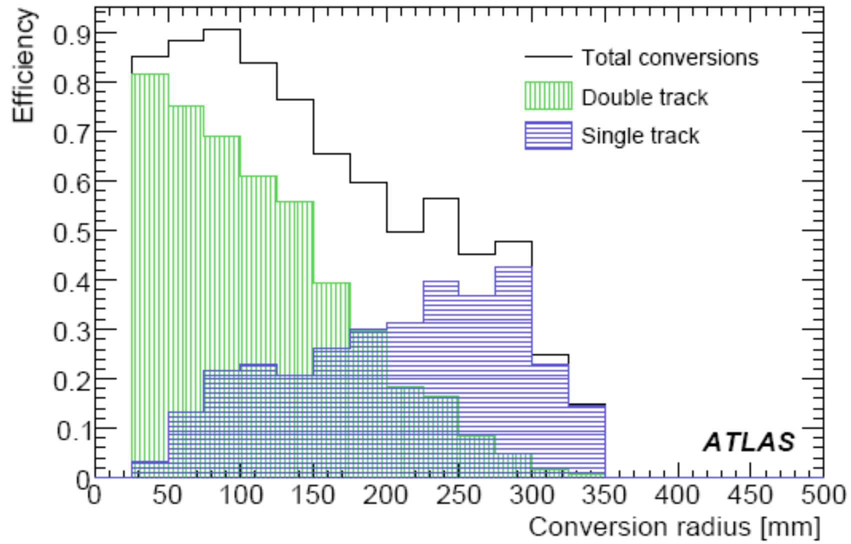
MC Backgrouns Estimation $H \rightarrow \gamma\gamma$

- Reducible
  - Use JETPHOX for γj normalization
    - Includes direct production and single-γ fragmentation production
  - Use NLOJET++ for jj normalization
    - Includes QCD NLO
  - Use ALPGEN for γj and jj with (above) normalizaed cross-sections
    - Uses $2 \rightarrow N$ LO ME (with N=2-5)
  - Uncertainties: PDFs (7%), renormalization and factorization scales (22%), fragmentation (2%), for a total of ≈23%

Reconstructing Conversions H→γγ



Fraction of converted photons in fiducial region as a funcion of eta ≈50%



Double tracks

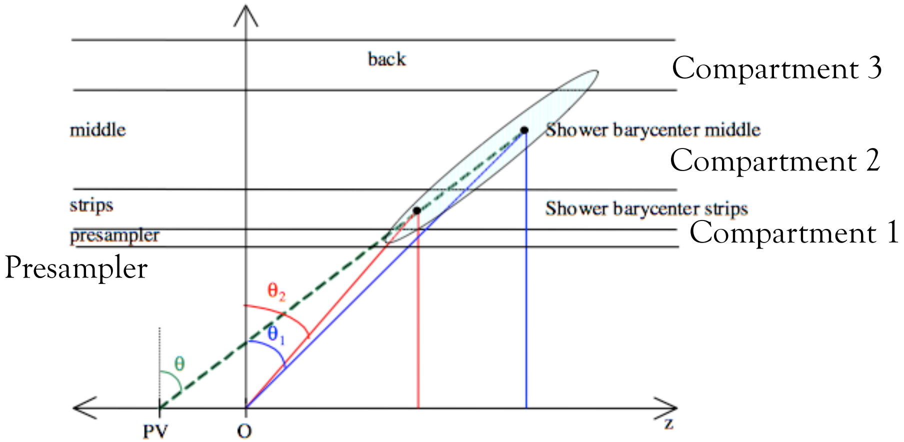
Single tracks

Efficiency for photon conversion reconstruction = f(radius) ≈66%

Photon Direction and Z Vertex H→γγ

- A precise measurement of the photon directions important to improve the Higgs mass resolution. Improve it even more with Z vertex from ID if possible

$$M_{\gamma_1\gamma_2} = \sqrt{2E_T^{\gamma_1} E_T^{\gamma_2}[1 - \cos(\theta_{\gamma_1} - \theta_{\gamma_2})]}$$

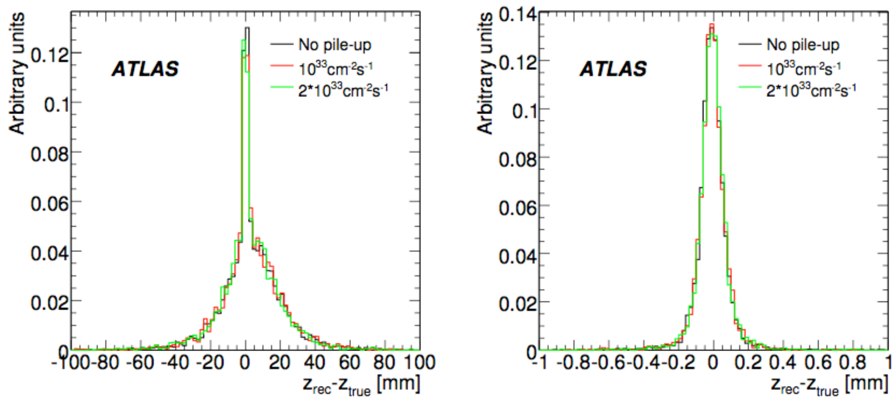


Photon direction reconstruction

$$\chi^2 = \sum_i w_i(aR_i + b - z_i) \qquad w_i = 1/\sigma_z^2$$

$$\theta = \arctan(1/b)$$

$$z_v = -a/b$$



LHC

$\sigma_{x,y} \approx 15\ \mu m$

$\sigma_z \approx 56$ cm

M_H = 120 GeV

$\sigma_z \approx 40\ \mu m$ (ID)

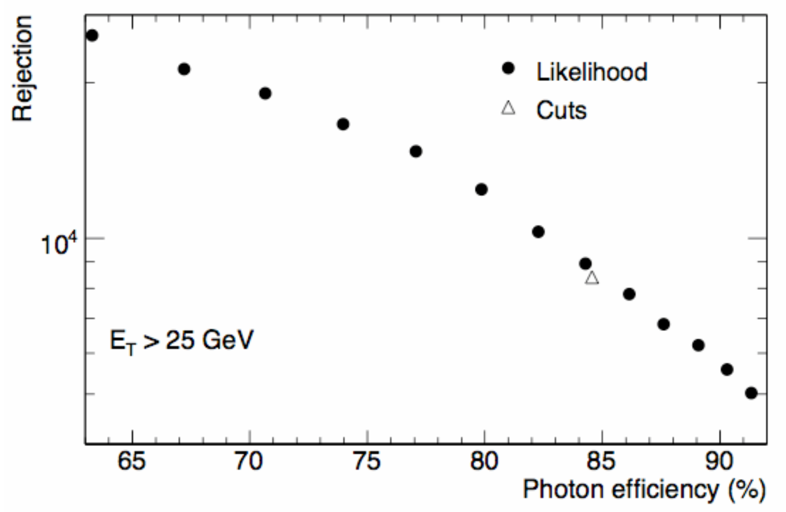
$\sigma_z \approx 18$ mm (Calo)

Primary vertex

Photon ID and Jet Rejection H→γγ

- Jet/photon separation crucial for Higgs discovery
- Need rejection of >1000 against quark-initiated jets for ε_γ=80% to keep fake background ≈20% of total background
- Expect rejection against gluon-jets to be 4-5 times larger

- Evaluate jet rection with data by looking into sub-leading jets in multi-jets final states for different p_T thresholds
  - Avoid trigger bias
  - Apply trigger pre-scaling when needed
  - Correct for prompt photon contributions



Experimental Issues Regarding $H \to \tau\tau$

- Main detector requirements for $H \to \tau\tau$
  - Missing E_T reconstruction
    - Require mass resolution < 10%
    - Hadronic jet scale from data (≈1 fb^{-1}). Use a combination of:
      - Minimum bias (low P_T deposition)
      - Di-jets, $Z \to ll$+jets (γ+jets), $W \to \tau\nu$ for high P_T depositions
- Need to suppress fake leptons (QCD backgrounds)
- Data-driven Z+jets background estimation (applied also for WW*)

Hadronic Tau Reconstruction and Id

Single tau BR decay

Final State	Br. Frac (%)	Decay Type
$e\ \nu_e\ \nu_\tau$	17.8	Leptonic 35.2
$\mu\ \nu_\mu\ \nu_\tau$	17.4	
$\pi\ \nu_\tau$	11.1	One-Prong 46.5
$\rho(\pi\ \pi^0)\ \nu_\tau$	25.1	
$\pi \geq 2\pi^0\ \nu_\tau$	10.3	
$\pi\pi\pi\ \nu_\tau$	9.5	Three-Prong 13.9
$\pi\pi\pi \geq 1\pi^0\ \nu_\tau$	4.4	

$\tau_e\ \tau_\mu$

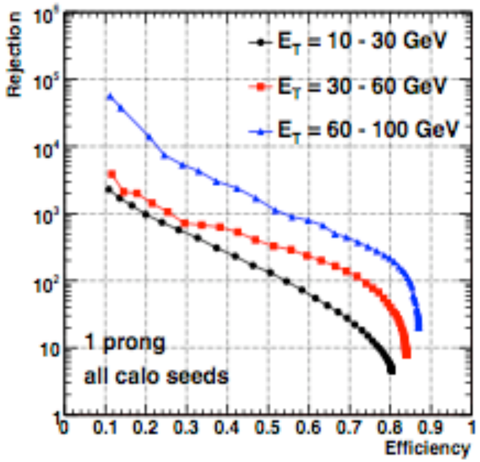
τ_h 65%

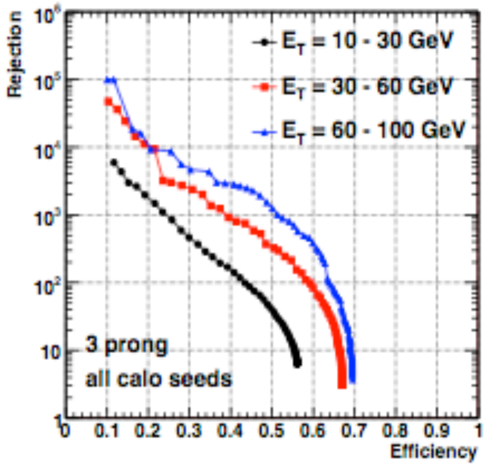
Tau pairs BR decays

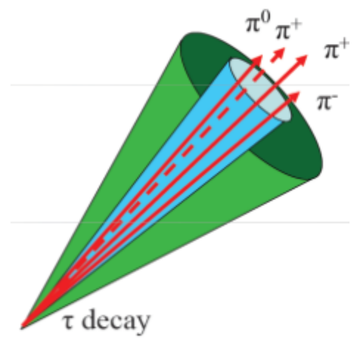
$\tau\tau$ decay mode	BR
$\ell\ell\,\nu$	12 %
ℓjet ν	46 %
jet jet ν	42 %

42% hh

- Match narrow calorimeter clusters with tracks ("calo seeded")
  - Start with a calo jet $\Delta R<0.4$
  - Add TopoJets $E_T>10$ GeV and $|\eta|<2.5$
  - Associate tracks within $\Delta R<0.3$







Evaluate performance in terms of rejection vs efficiency

Toolbox for Higgs studies in ATLAS

- Event generation (4-momenta)
  - Full MC generators (LO ME + PS, hard process, ISR/FSR
    - PYTHIA, HERWIG ISAJET
  - ME MC generators (hard process only
    - AcerMC, ALPGEN, COMPHEP, MADGRAPH II, MadCUP, MadEvent,...
  - NLO MC generators
    - MC@NLO, GRACE
- For comparison studies
  - Semi-inclusive MC generators
    - ResBOS
- For evaluation of xsec or BR
  - Integrators (only total xsec or BR)
    - HIGLU, QQH, VVH, HDECAY, FEYNHIGGS

MC Simulation Caveats

- Application of N(N)LO corrections in MC's crucial for proper understanding of backgrounds and increase power of inclusive analyses
  - Not just a question of normalization (P_T distributions)
  - Vast majority of physics studies: LO ME + PS
    - Restrict for discovery with a narrow resonance or large excess of events
    - Fails for more complex exclusive signatures
  - Re-weight LO MC to reproduce NNLO P_T ?
- NLO MC integrators (like MCFM) and NLO event generators (like GRACE or MC@NLO) keep adding new processes. Good