SM Higgs Searches in the Early Phase of the LHC with ATLAS

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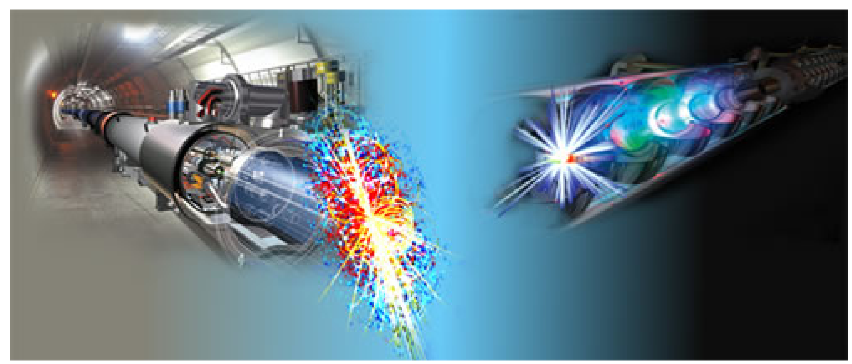
On Behalf of the ATLAS Higgs WG

ATLAS project



LHC4ILC Workshop, Fermilab 04/12/07

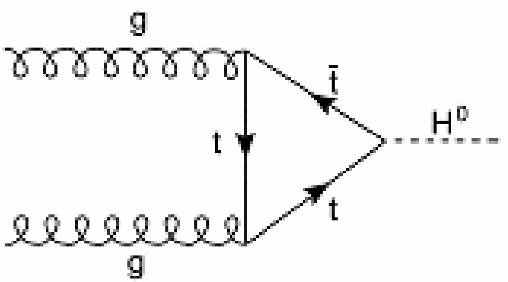
Outline

- Introduction
- Most relevant observation channels
  - $H \rightarrow \gamma\gamma$
  - $ttH \rightarrow bb$
  - $H \rightarrow \tau\tau$
  - $H \rightarrow ZZ^{(*)} \rightarrow 4l$
  - $H \rightarrow WW^{(*)} \rightarrow ll\nu\nu$
  - Other channels
- Summary

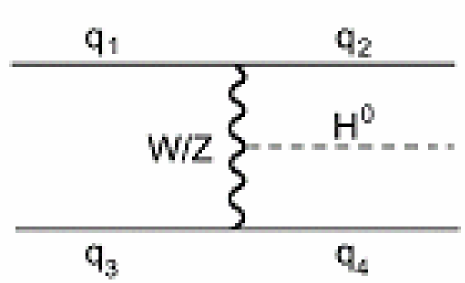
Focus on what we can do with 10 fb^{-1} of data

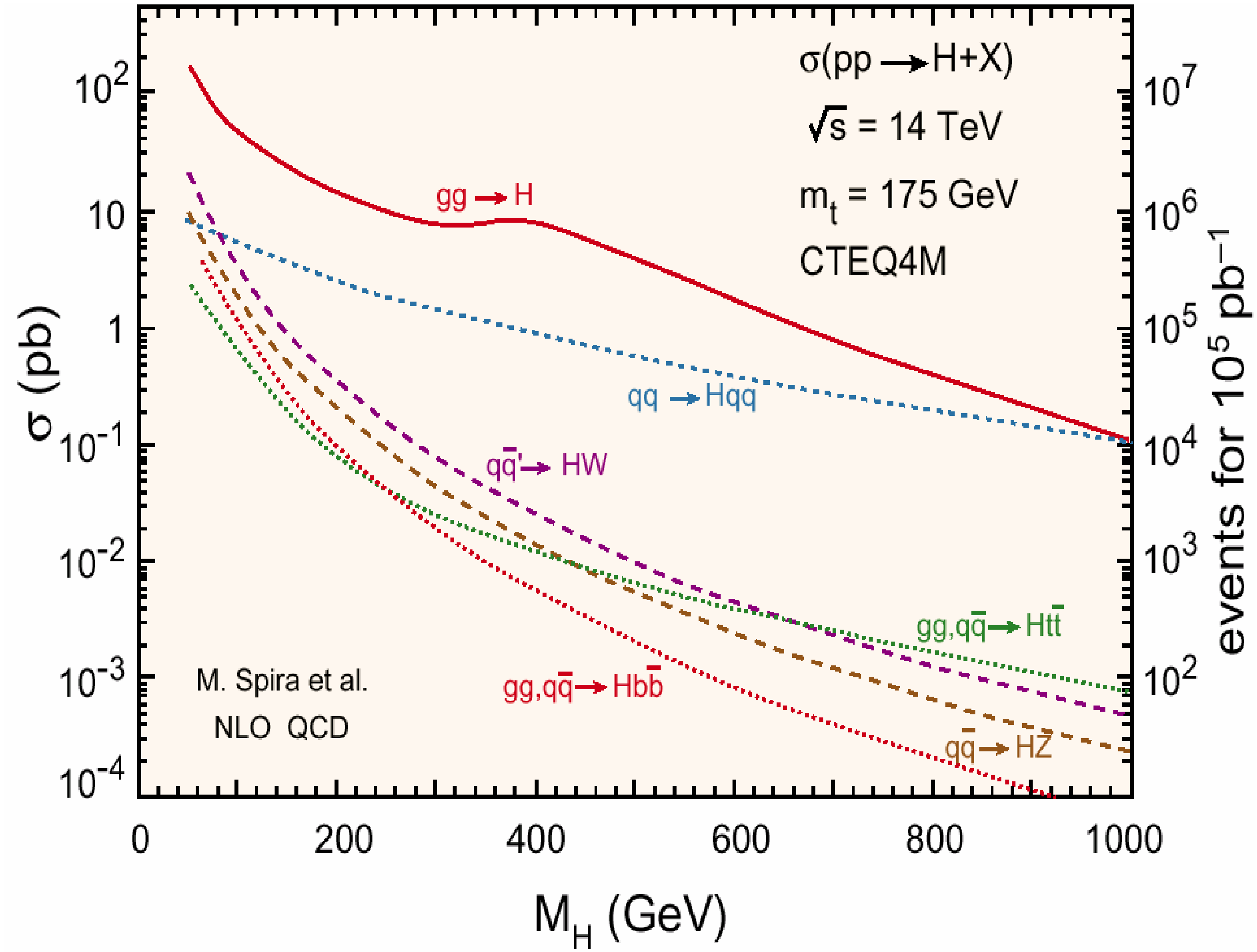
Higgs Production at LHC

Leading Process (gg fusion)

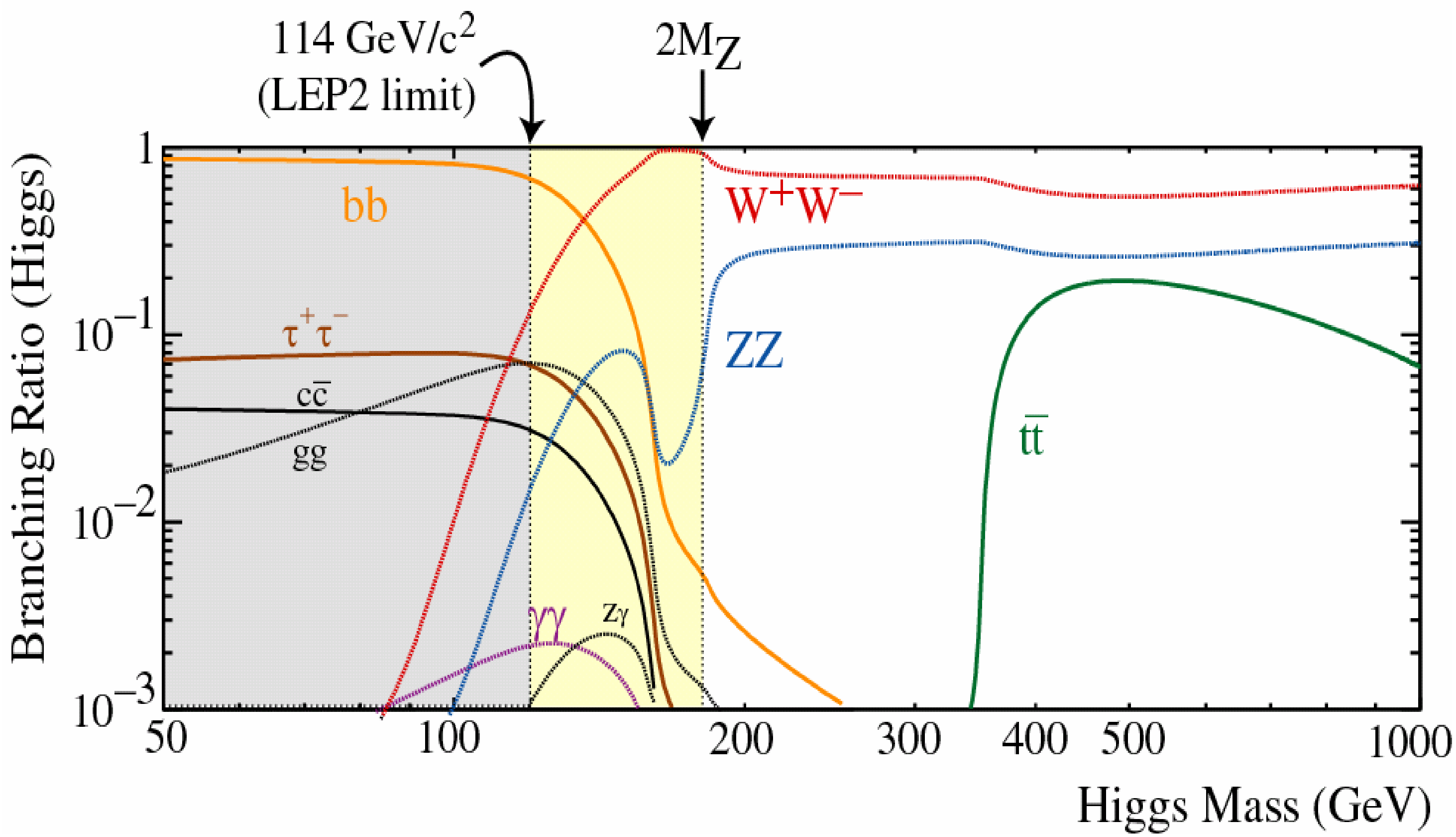


Sub-leading Process (VBF)





Main Decay Modes



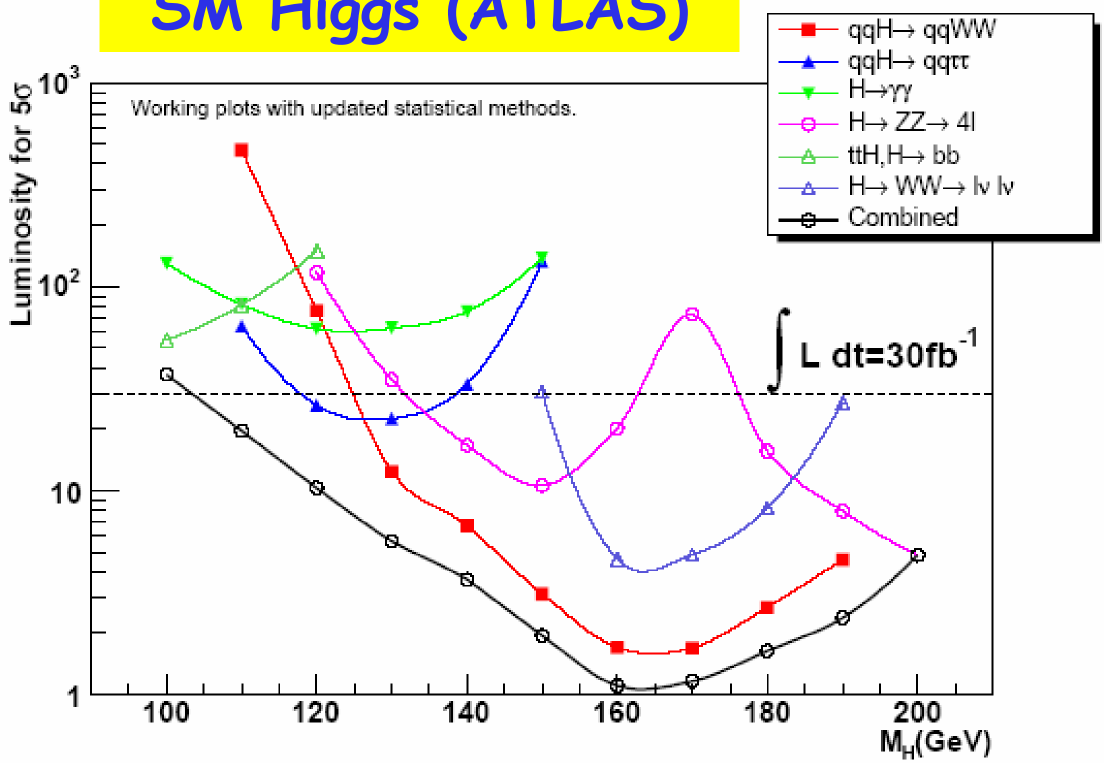
Close to LEP limit:
$H \rightarrow \gamma\gamma, \tau\tau, bb$

For M_H>140 GeV:
$H \rightarrow WW^{(*)}, ZZ^{(*)}$

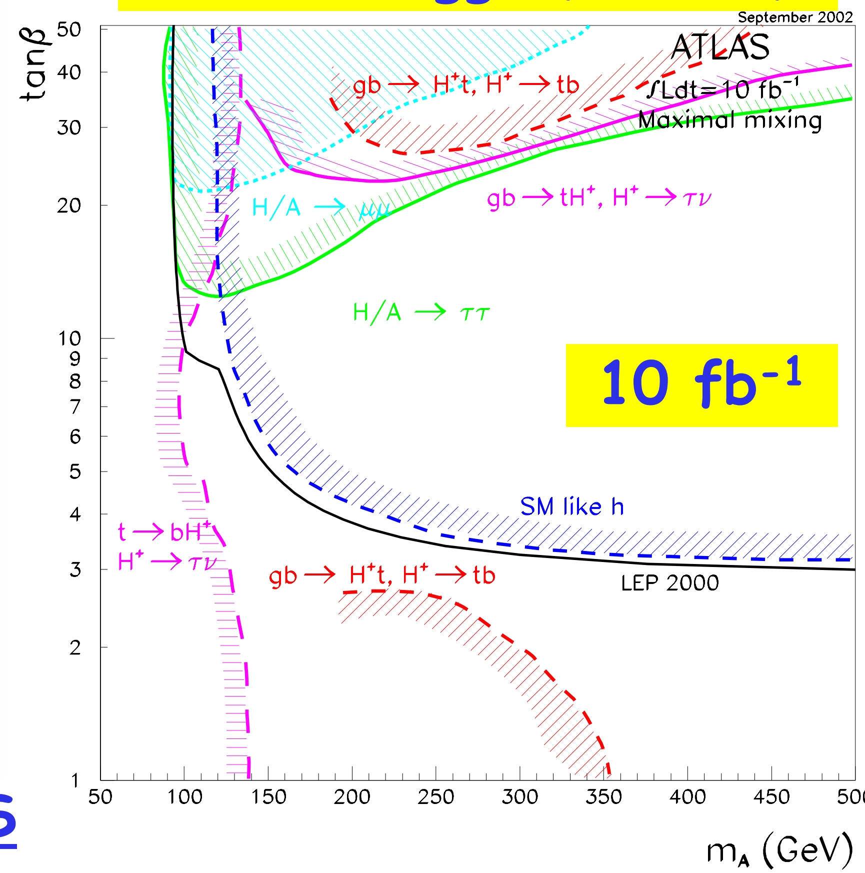
5σ signal significance may be achieved for SM M_H>120 GeV and in most of the MSSM for 10 fb^{-1} (understood data)

- Improvements and new final states with $H\to\gamma\gamma,\tau\tau,WW^{(*)}$ not included
- Caveat: Higgs feasibility assumes nominal detector performance and present understanding of cross-sections

SM Higgs (ATLAS)



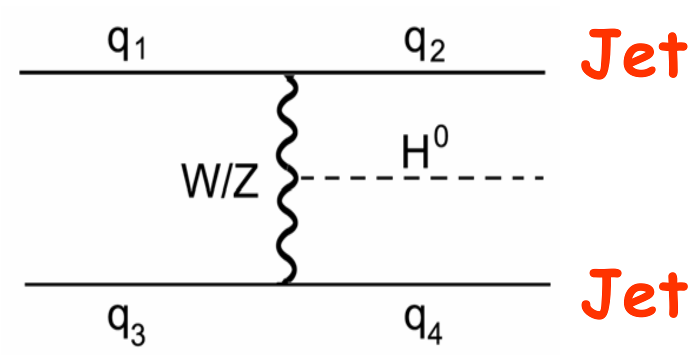
MSSM Higgs (ATLAS)



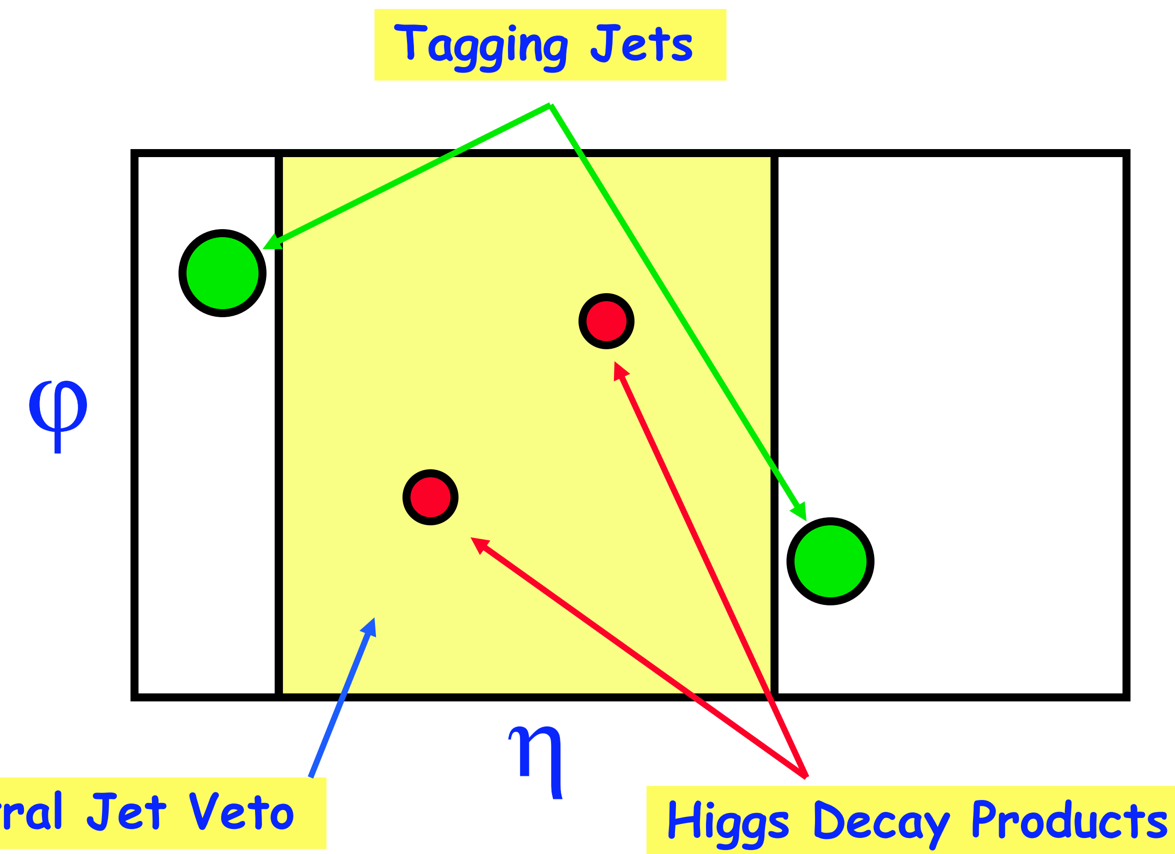
Many updates are underway in ATLAS

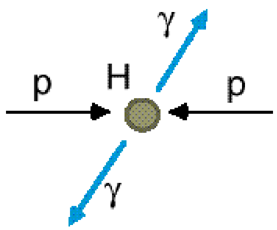
SM Higgs + ≥2jets at the LHC

- Wisconsin Pheno (D.Zeppenfeld, D.Rainwater, et al.) proposed to search for a Low Mass Higgs in association with two jets with jet veto
  - Central jet veto initially suggested in V.Barger, K.Cheung and T.Han in PRD 42 3052 (1990)

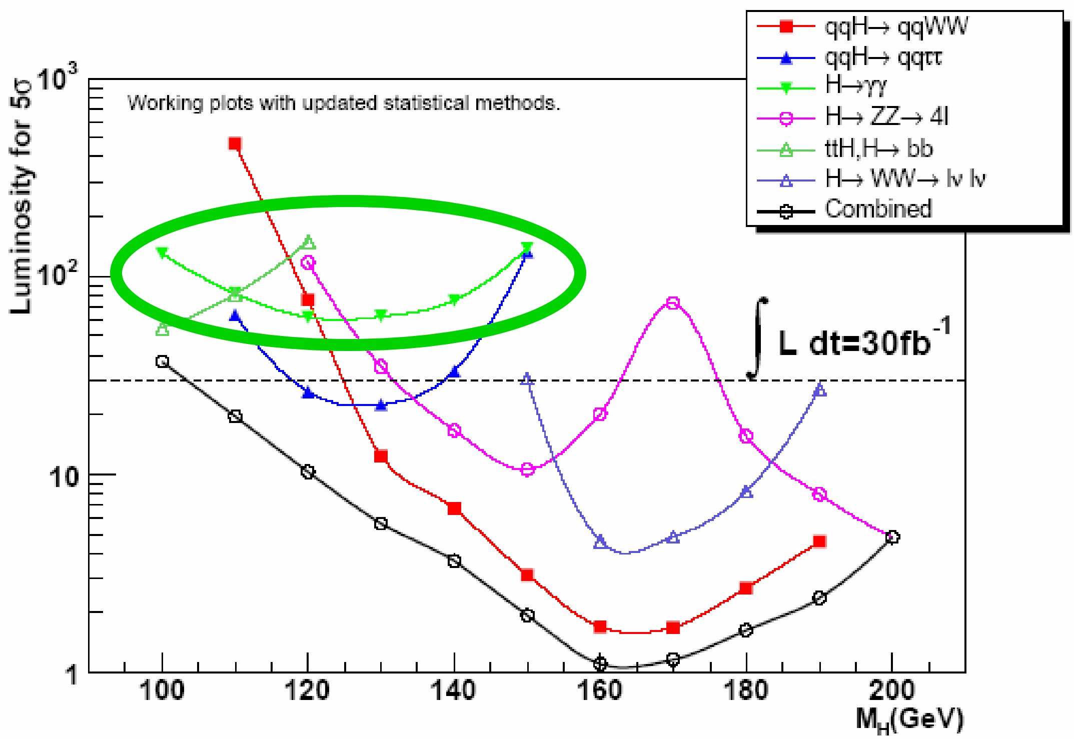


$$\eta_{J1} \cdot \eta_{J2} < 0$$
$$\Delta\eta_{JJ} > 3.5 \div 4$$
$$M_{JJ} > 500 \div 700\text{GeV}$$
c.j.v.





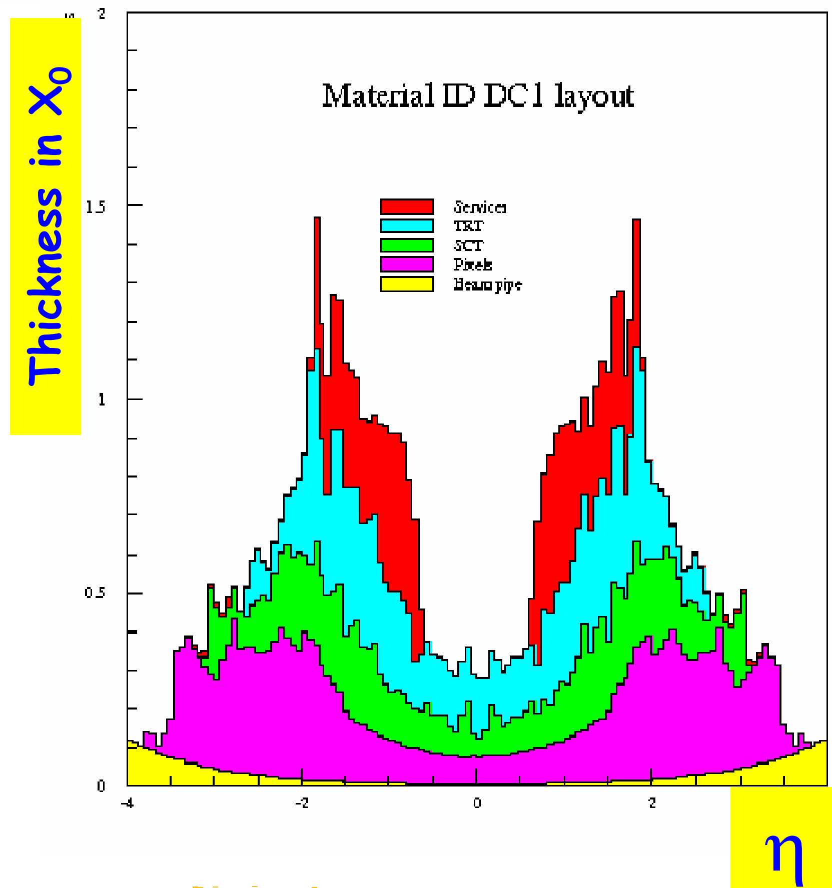
Low Mass SM Higgs: H→γγ



ATLAS TDR (low lumi)

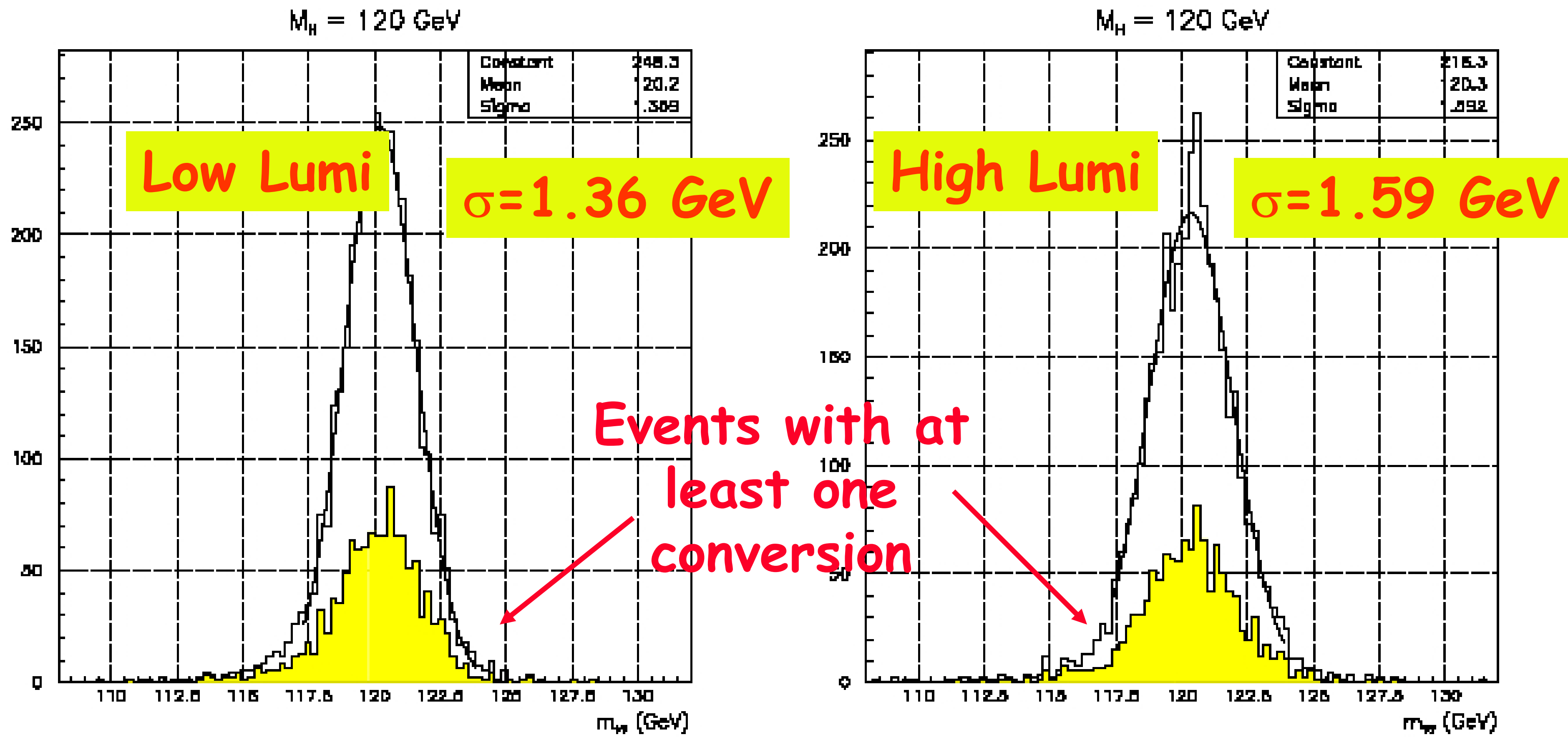
Higgs mass (GeV)	80	90	100	110	120	130	140	150
Cross-section (pb)	38.4	32.4	27.8	24.2	21.2	18.8	17.0	15.4
Branching ratio (%)	0.089	0.119	0.153	0.190	0.219	0.222	0.193	0.138
$\sigma \times$ BR (fb)	34.2	38.6	42.5	46.0	46.4	41.8	32.8	21.2
Acceptance	0.29	0.38	0.44	0.48	0.51	0.53	0.55	0.58
Mass resolution (GeV)	1.11	1.20	1.31	1.37	1.43	1.55	1.66	1.74

- Signal to background for inclusive $H\rightarrow\gamma\gamma$ is 3-4% need excellent Higgs mass resolution of about 1%
- Constant term in EM resolution needs to be understood to c_{tot}<0.7%
  - Use cosmics, minimum-bias for first crude look at cell inter-calibration
  - Use $Z\rightarrow ee$ for absolute EM scale and refined cell inter-calibration
    - Need $O(10^5)$ events or <1 fb^{-1}
  - Use $Z\rightarrow ee\gamma,\mu\mu\gamma$ to study detector response to photons



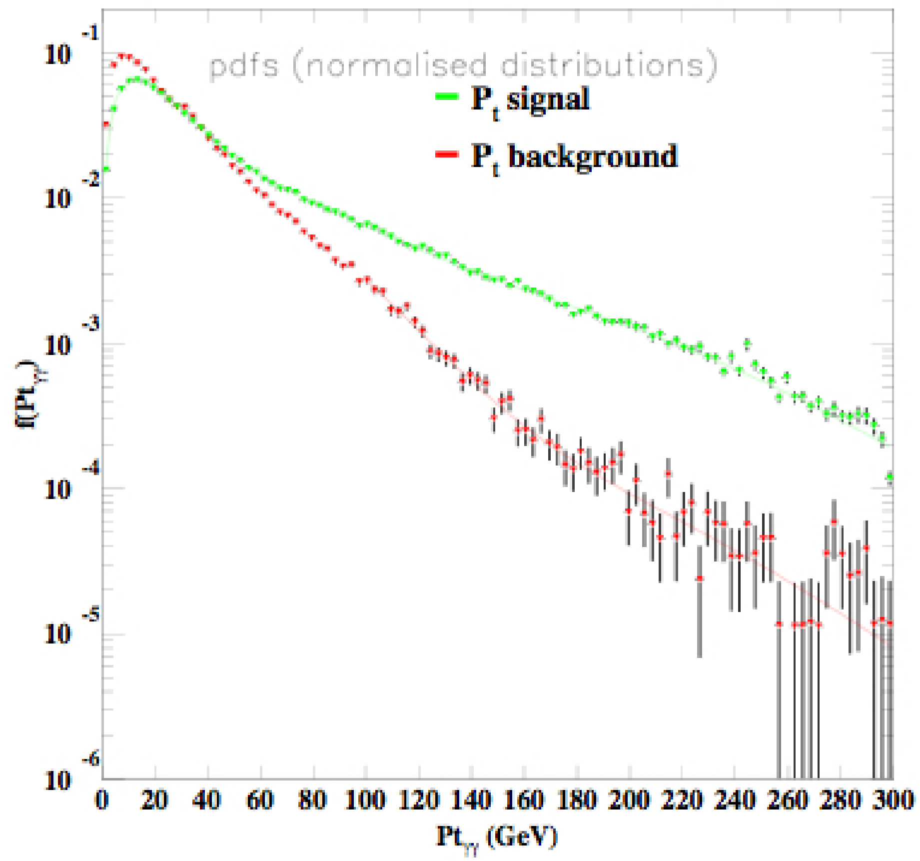
Higgs Mass Reconstruction

- Expect about 50% of events to have at least one converted photon, but can achieve <1.2% mass resolution

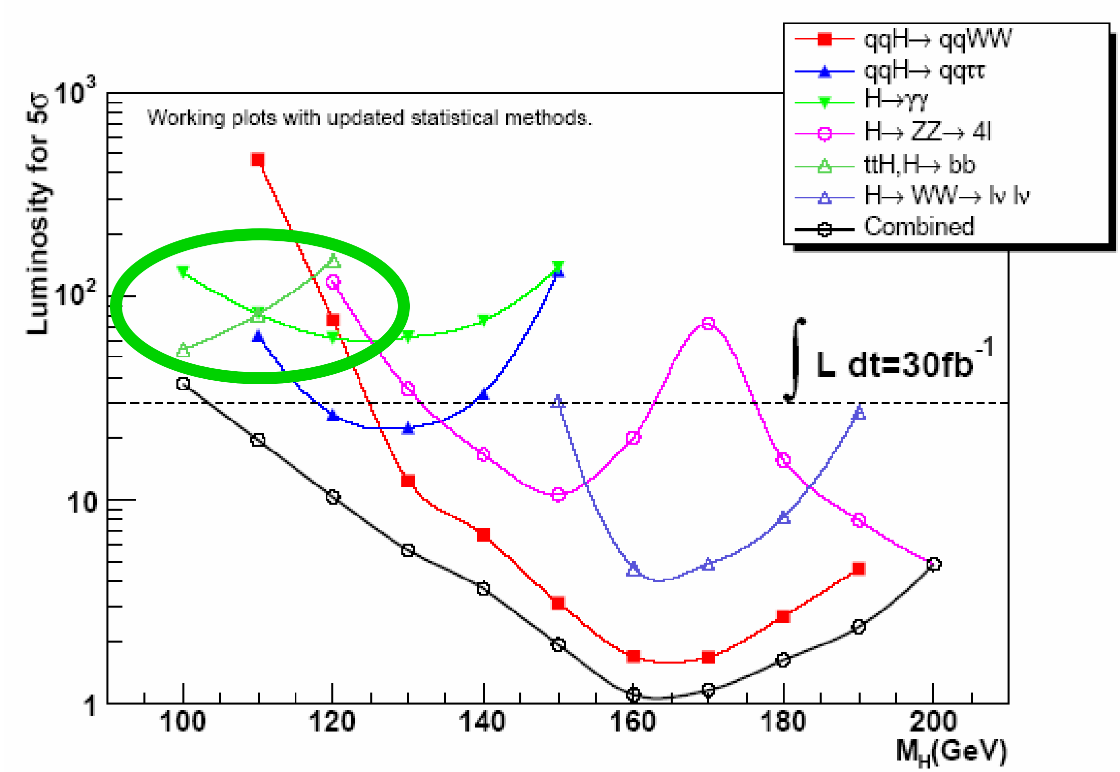


Improvements to Baseline Inclusive Analysis

- ATLAS is working on significant improvements
  - QCD Higher order corrections
  - Use of discriminating variables
    - For instance, we get 30-40% improvement from Higgs P_T in likelihood analysis
  - Classification of events according to jet multiplicity
  - Classification of events according to Higgs mass reconstruction quality

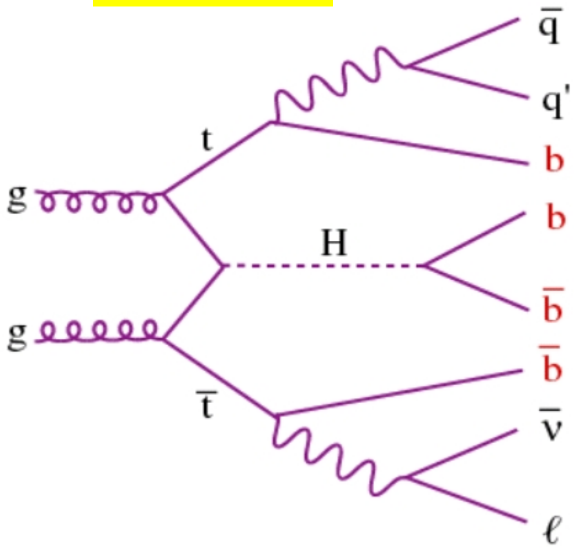


Low Mass SM Higgs: ttH→bb



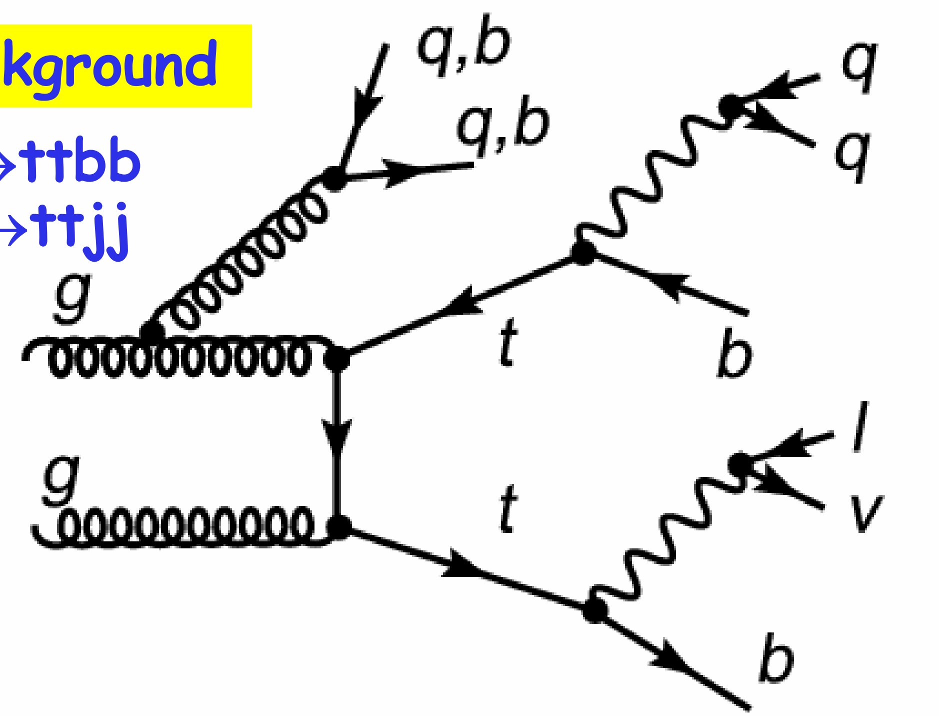
Complex final state: ttH($\rightarrow$bb)$\rightarrow$lepton+ν+bbbb+jj

Signal



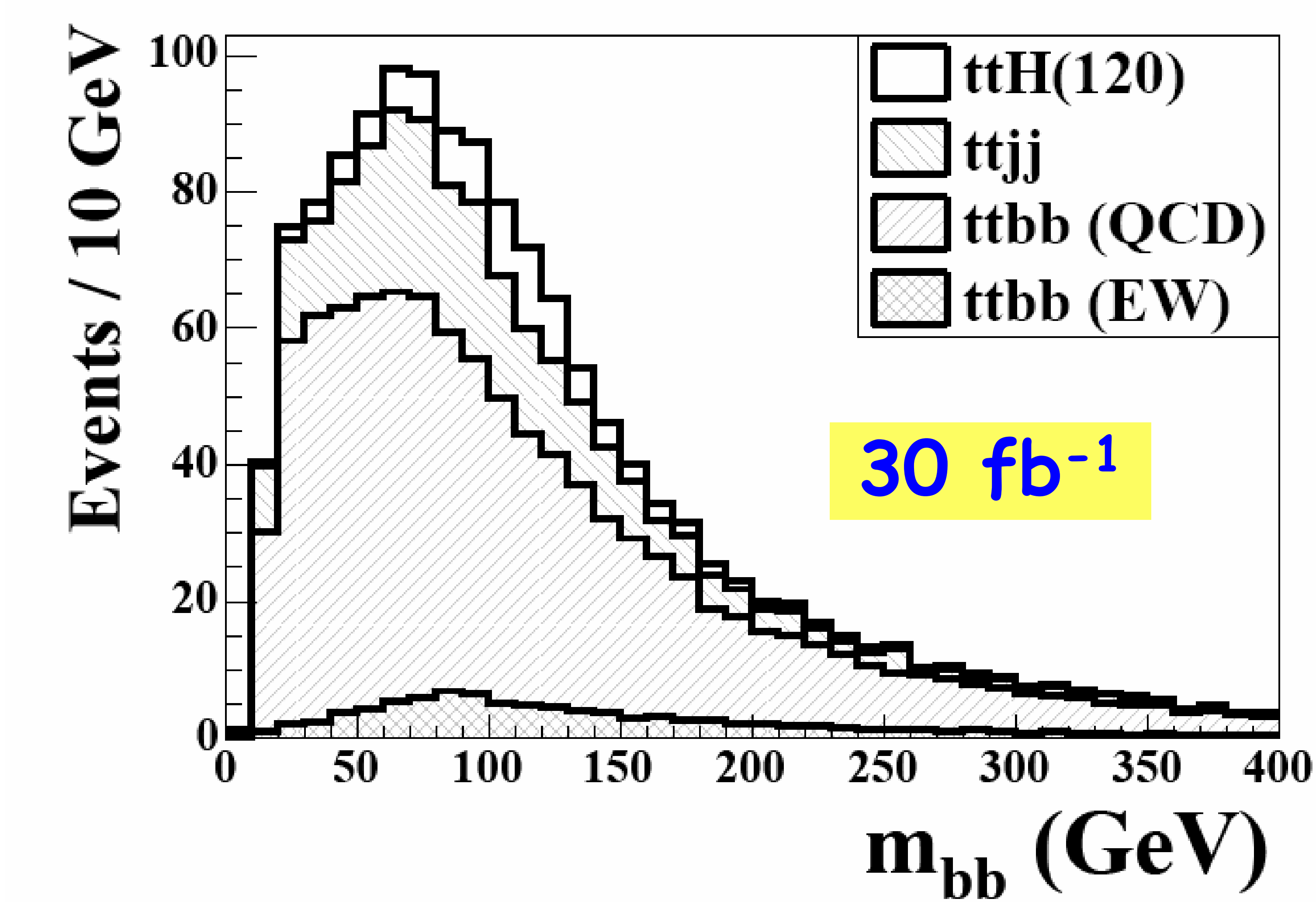
Background

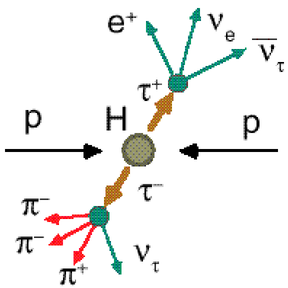
pp$\rightarrow$ttbb
pp$\rightarrow$ttjj



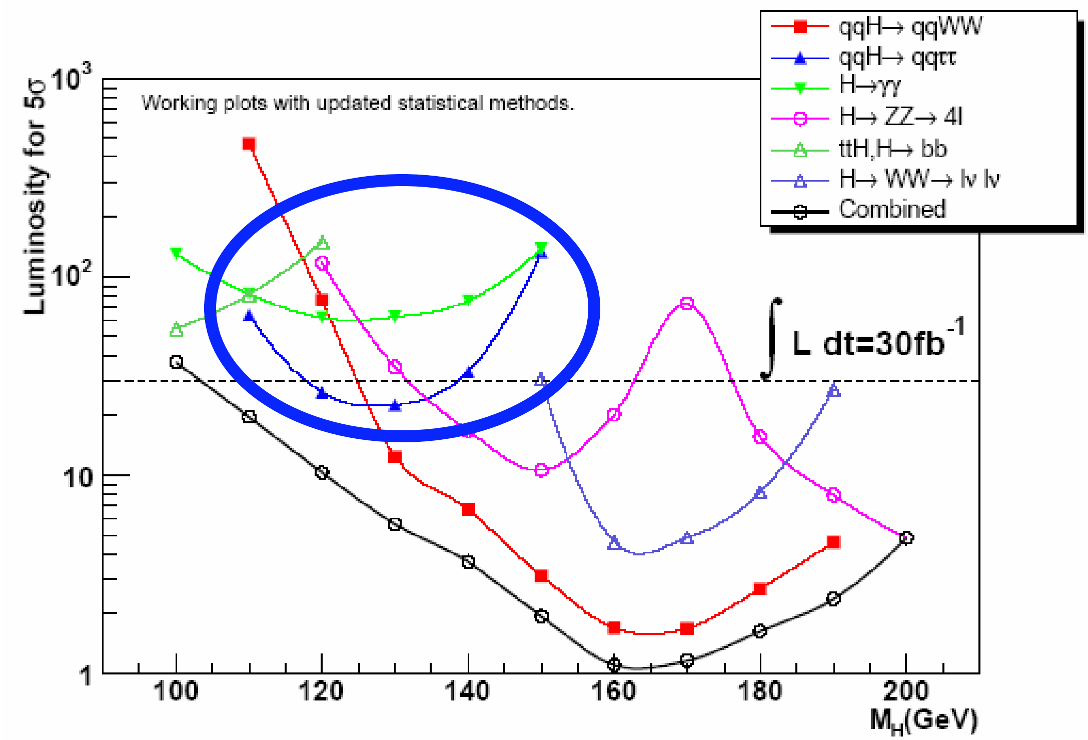
- Analysis very sensitive to b-tagging efficiency (ε_b^4)
  - Parton/Hadron level studies $\rightarrow$ ε_b $\geq$60% needed
- Need ~100 times rejection against light jets and ~10 times against charm to suppress ttjj

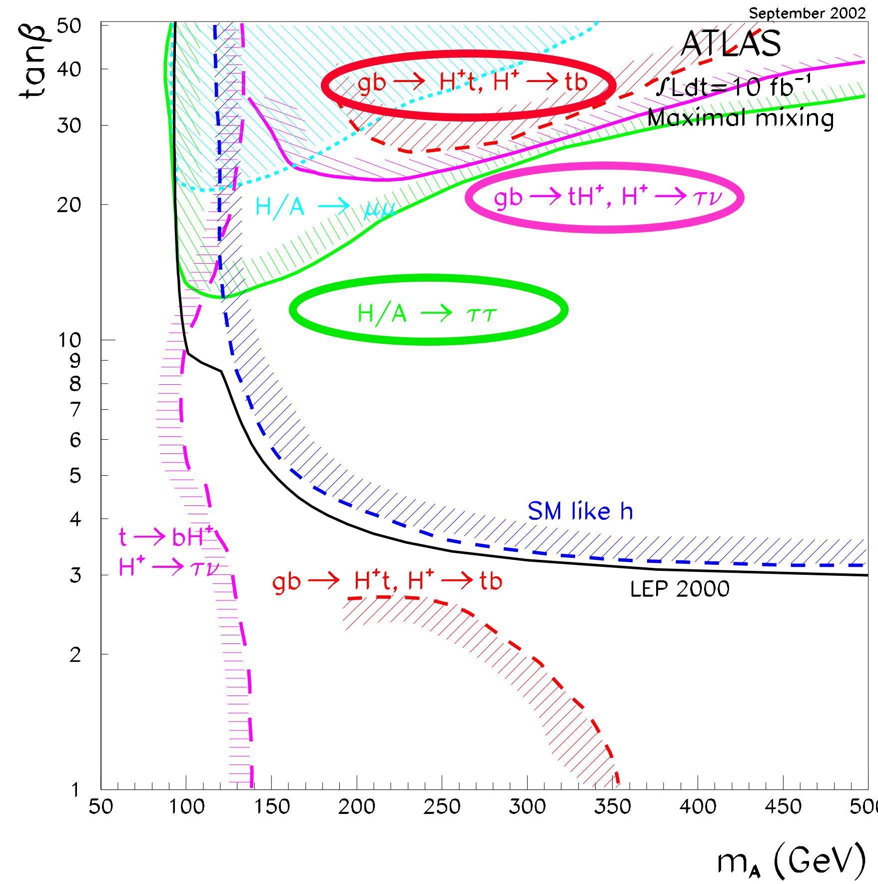
- May achieve 3-5σ effect for M_H=120 GeV and 30 fb^{-1}
  - Need to address issues related to background shapes and differences in hadronic scales for light and b-jets




e+
ν e
ν τ
τ+
p
H
p
τ−
π−
π−
π+
ν τ

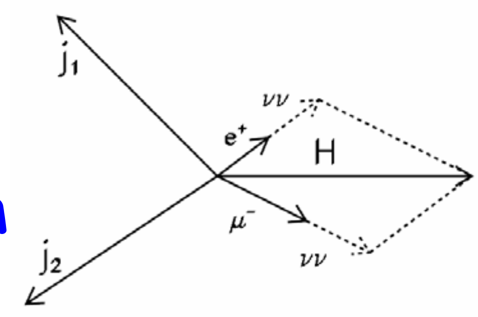
h,A→ττ; H±→τ±ν


Working plots with updated statistical methods.
qqH→ qqWW
qqH→ qqττ
H→γγ
H→ ZZ→ 4l
ttH,H→ bb
H→ WW→ lν lν
Combined
∫ L dt=30fb-1
Luminosity for 5σ
M_H(GeV)
100
120
140
160
180
200

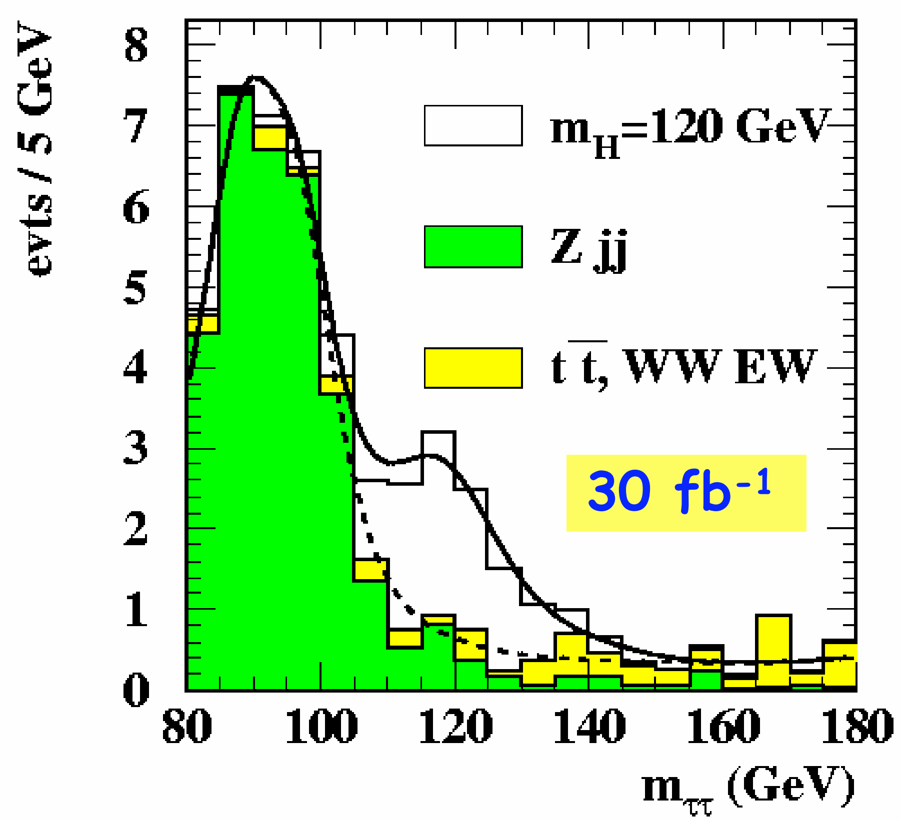

September 2002
ATLAS
∫Ldt=10 fb-1
Maximal mixing
tanβ
gb → H+t, H+ → tb
gb → tH+, H+ → τν
H/A → μμ
H/A → ττ
SM like h
t → bH+
H+ → τν
gb → H+t, H+ → tb
LEP 2000
m_A (GeV)

Low Mass SM H→ττ+jets

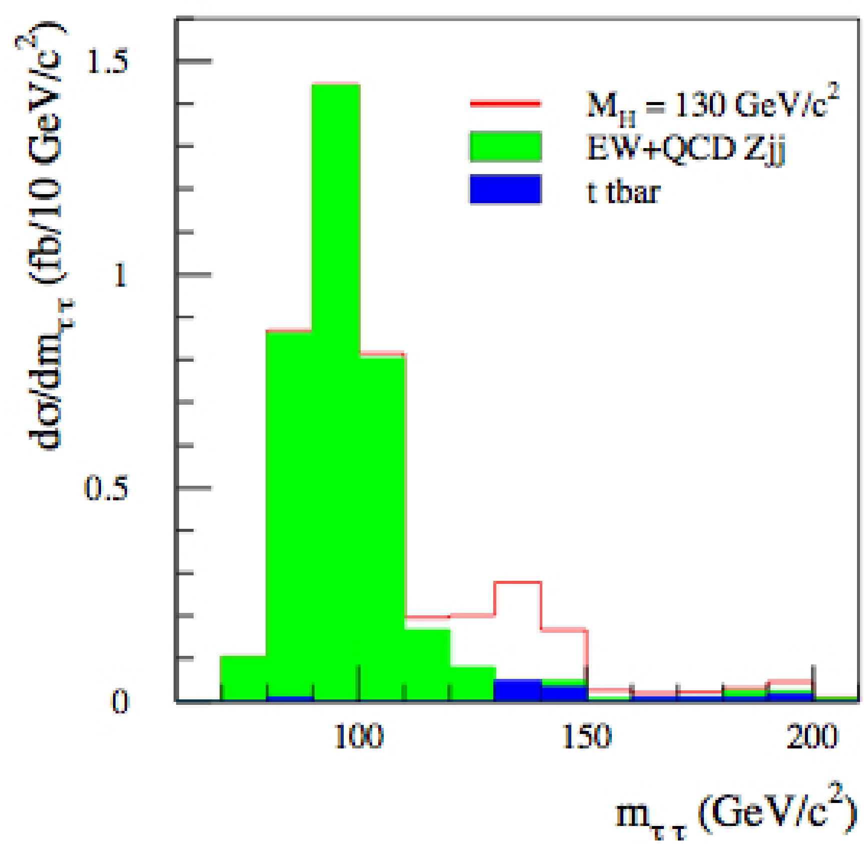
- Reconstruct Higgs mass with collinear approxim



H(→ττ→ll) +≥2jets (VBF)



H(→ττ→lh) +≥2jets (VBF)



Main Detector Requirements (ATLAS)

- Missing E_T reconstruction is a challenge (even with MC!)
- Missing E_T is crucial to reconstruct Higgs mass
  - Require mass resolution of <10%
  - Hadronic calibration with data: combination of
    - Minimum bias (low P_T depositions)
    - di-jets, $Z \rightarrow ll$+jets (γ-jet) events, $W \rightarrow \tau\nu$ for high P_T depositions.
    - Enough data with 1 fb^{-1} to cover necessary phase space to calibrate detector for Higgs discovery
- In order to suppress fake leptons (QCD background) to a level <10% of the irreducible background we need to achieve combined 10^7 rejection with lepton ID
  - May be achieved for $H \rightarrow \tau\tau \rightarrow ll$ ($l=e,\mu$)
    - May achieve >10^4 per lepton
  - Checking TDR QCD rejection estimates for $H \rightarrow \tau\tau \rightarrow lh$

Two independent ways of extracting $Z\rightarrow\tau\tau$ shape

- Data driven and MC driven
- Similar procedure has been defined for $H\rightarrow WW^{(*)}$

Control Sample 1
$Z \rightarrow ee,\mu\mu$
Loose cuts on Jets

MC extrap. is validated →

Control Sample 3
$Z \rightarrow ee,\mu\mu$
Tight cuts on Jets

$85<M_{ll}<95$ GeV

↓ Replace $Z\rightarrow ee,\mu\mu$ by $Z\rightarrow\tau\tau$

Control Sample 2
$Z \rightarrow\tau\tau$
Loose cuts on Jets

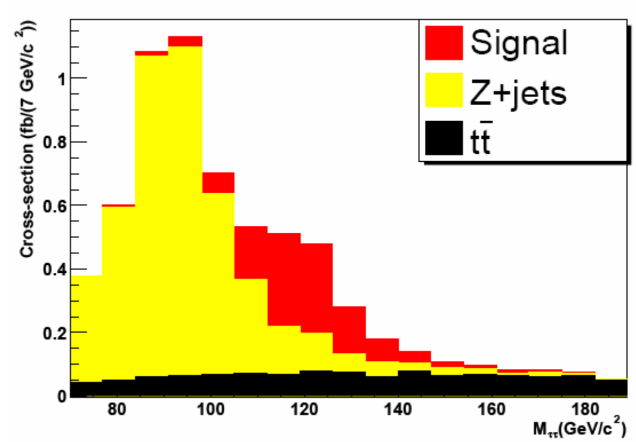
MC extrap. →

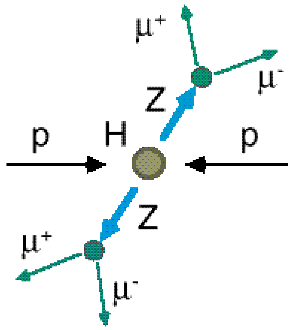
Signal Region
$Z \rightarrow\tau\tau$
Tight cuts on Jets

$M_{ll}<75$ GeV

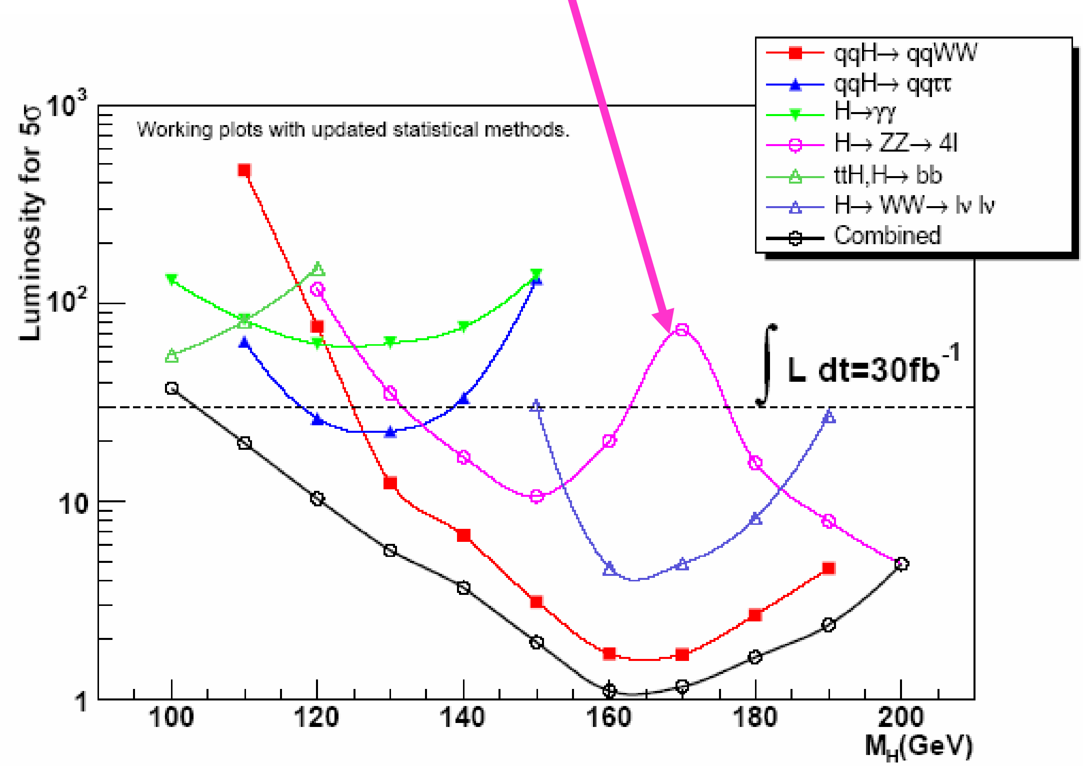
M_{HJ}, $\Delta\eta_{JJ}$ →

Determine shape and normalization of $Z\rightarrow\tau\tau$ background

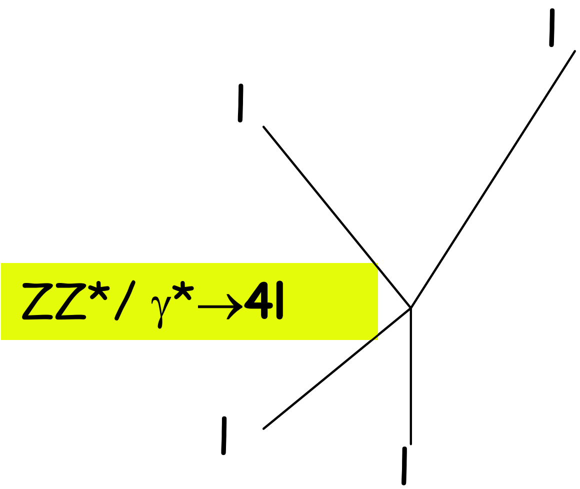




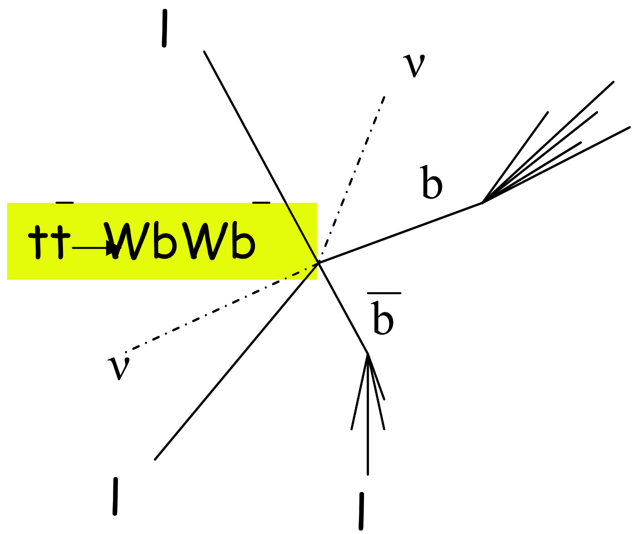
SM Higgs: $H \rightarrow ZZ^{(*)} \rightarrow 4l$



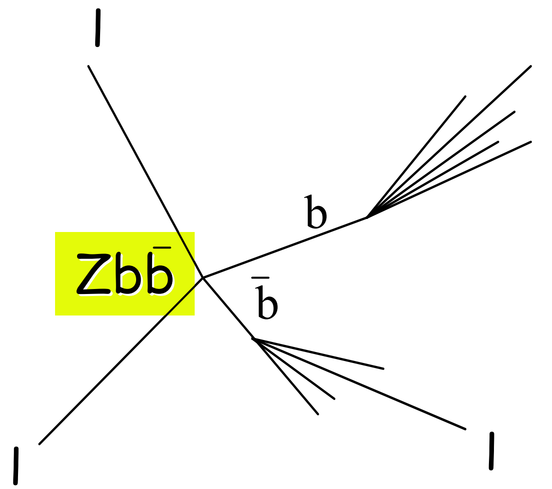
Backgrounds Higgs→$ZZ^{(*)}$→4l (l=eμ)



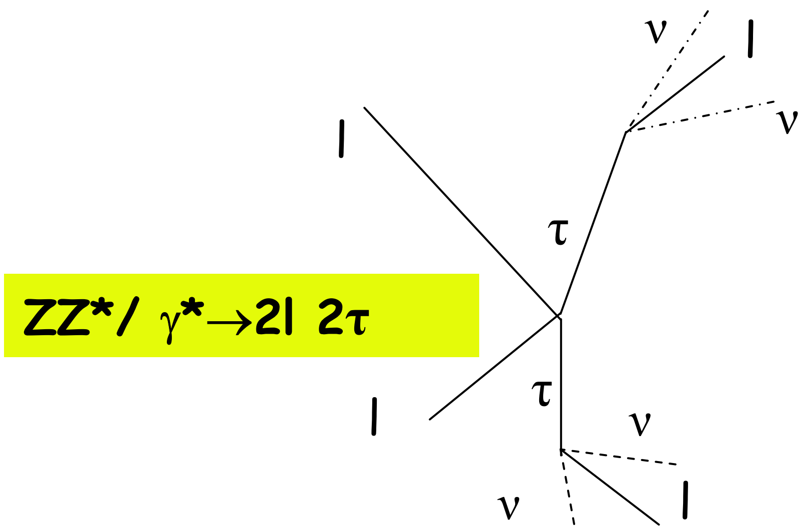
Continuum Irreducible



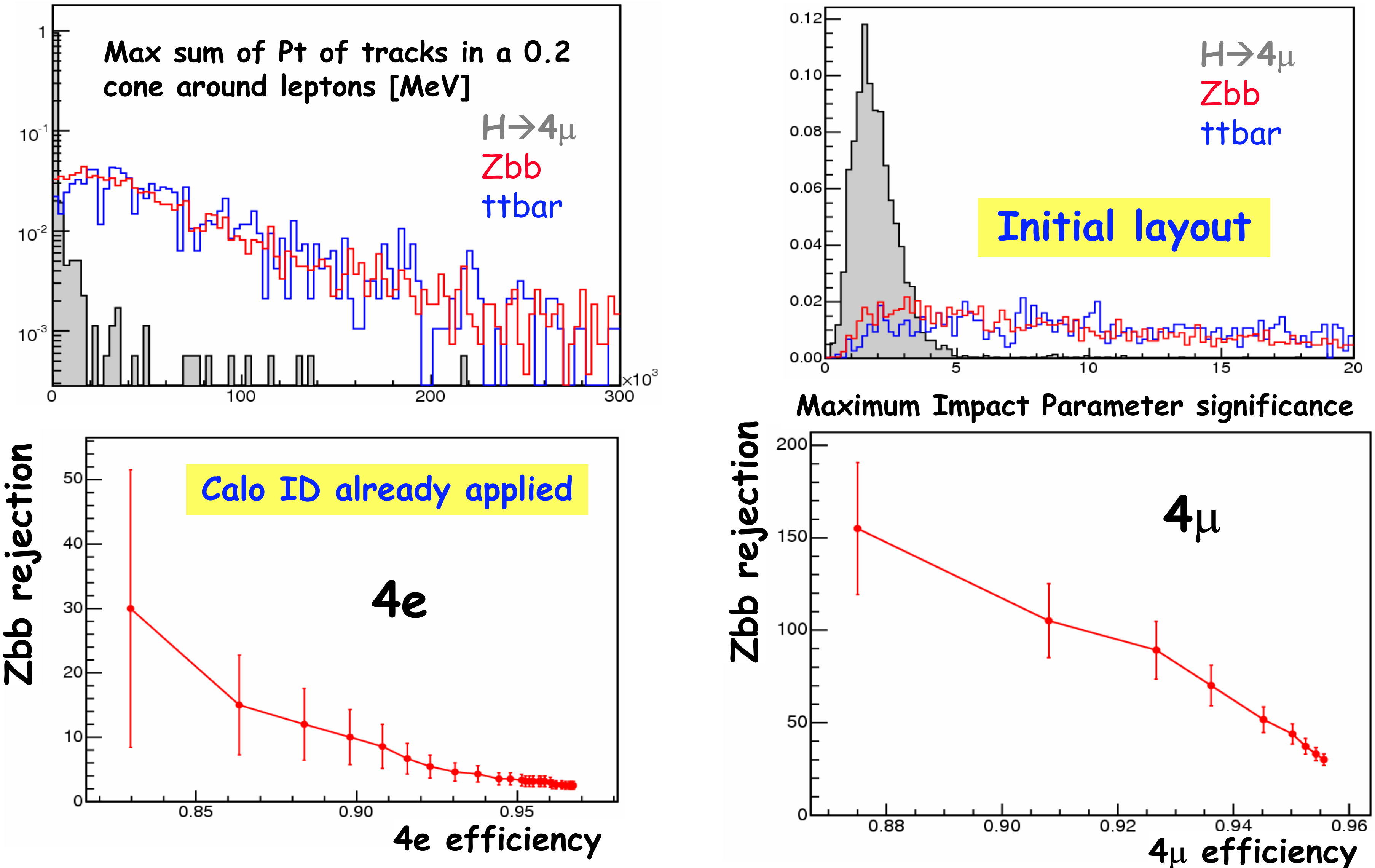
Non-Resonant reducible



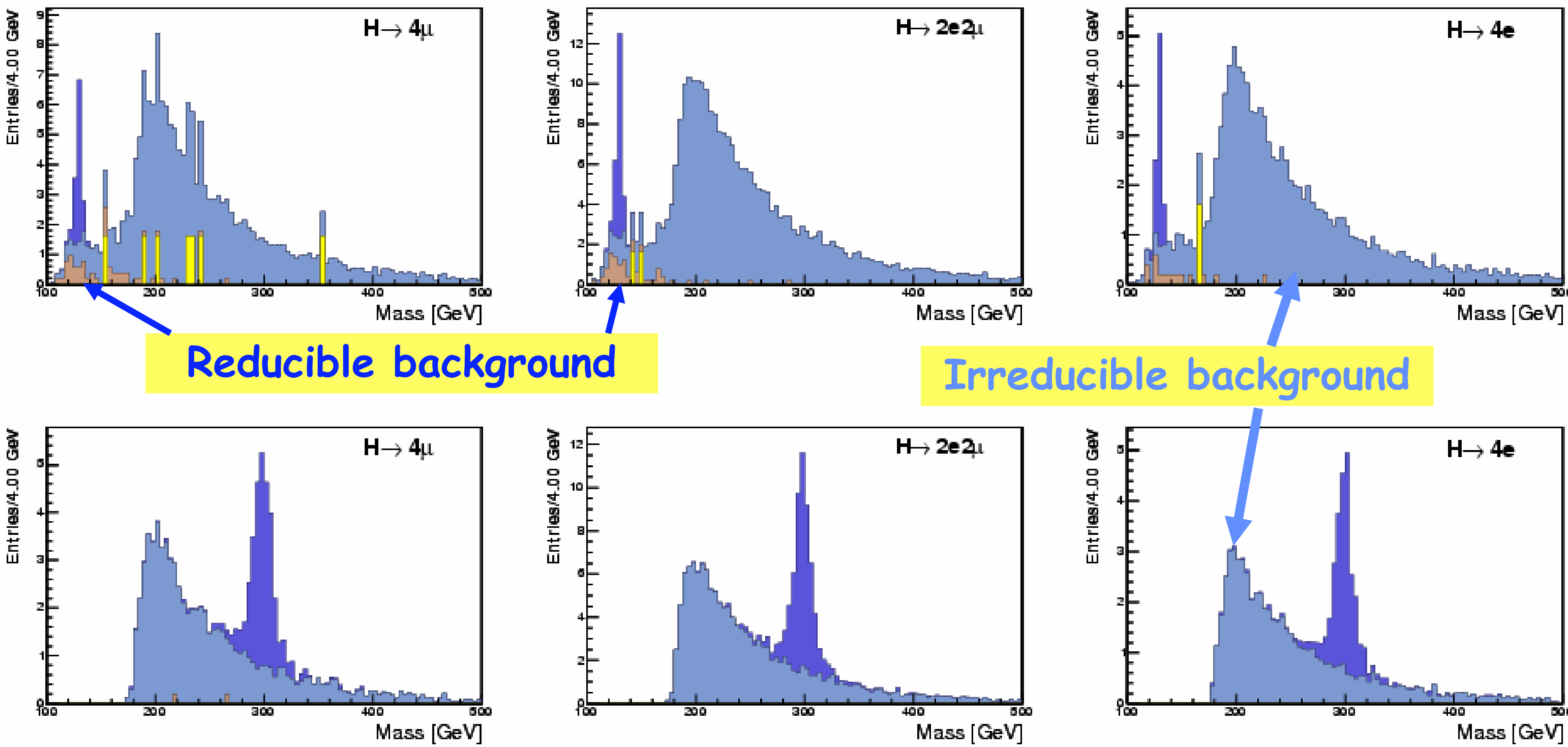
Resonant reducible



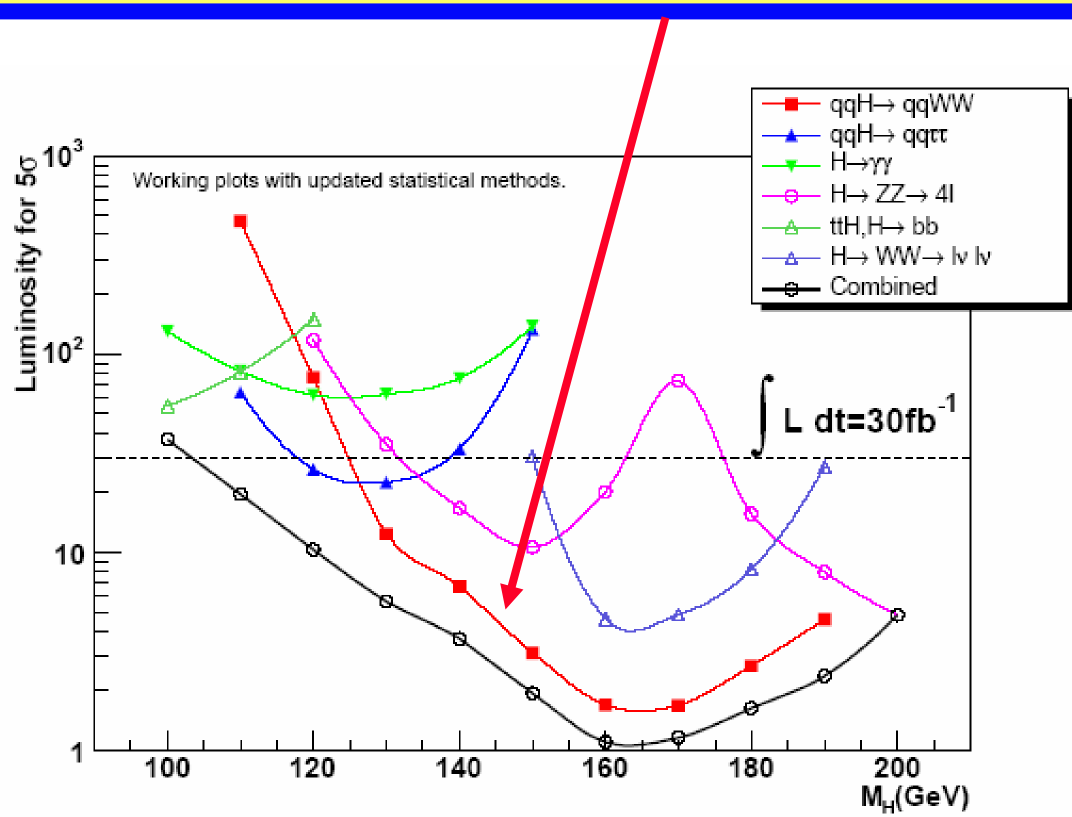
Zbb→4l rejection versus signal efficiency using track isolation and track impact parameter



$H \to ZZ^{(*)} \to 4l$ event rates using for 30 fb^{-1} using NLO rates for signal and backgrounds.

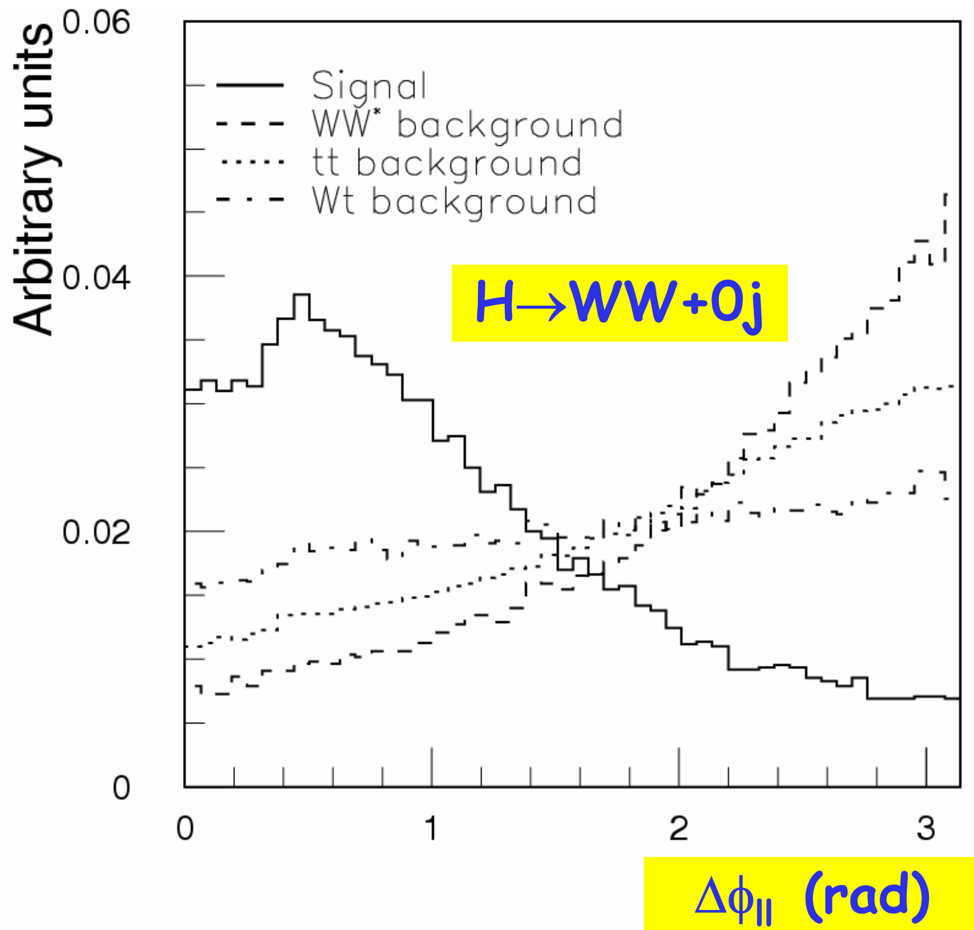


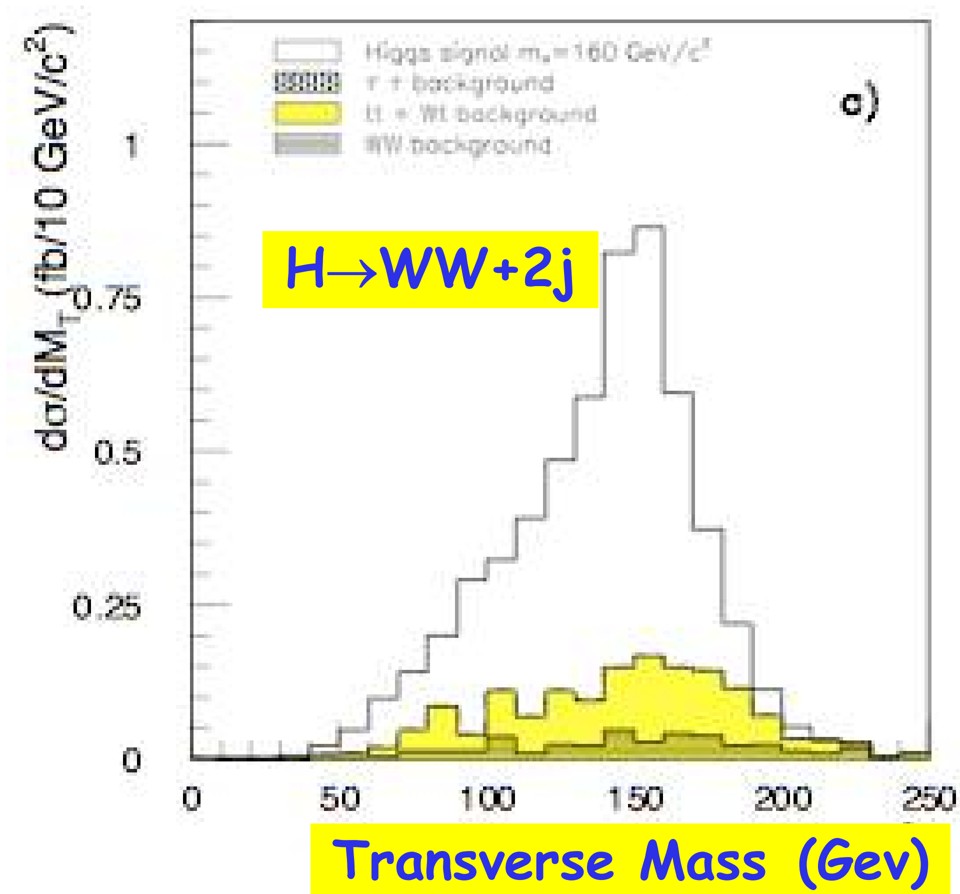
SM Higgs: $H \rightarrow WW^{(*)} \rightarrow 2l2\nu$



SM Higgs $H \to WW^{(*)} \to 2l2\nu$

- Strong potential due to large signal yield, but no narrow resonance. Left basically with event counting experiment



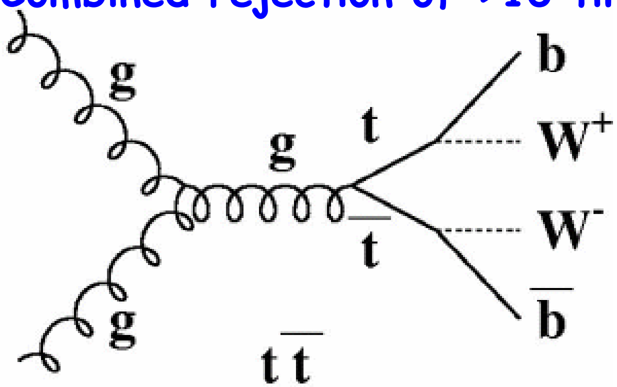


Background Suppression and Extraction

- Not able to use side-bands to subtract background. This makes signal extraction more challenging. Need to rely on data rather than on theoretical predictions
- Definition & understanding of control samples is crucial

ttbar suppression

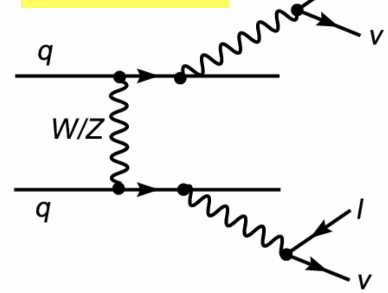
- Jet veto (understand low P_T jets)
- Semi-inclusive b-tagging or "top killing" algorithm
- Combined rejection of >10 times



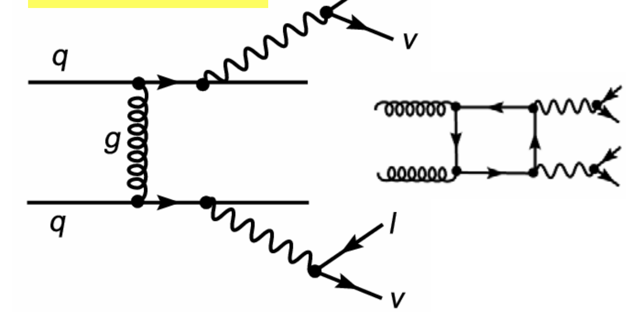
Non-resonant WW suppression

- $\Delta\phi_{ll}$ and $M_{ll,}$ very important variables
- Transverse momentum of WW system
  - Higgs production is harder
  - Missing E_T reconstruction plays a role

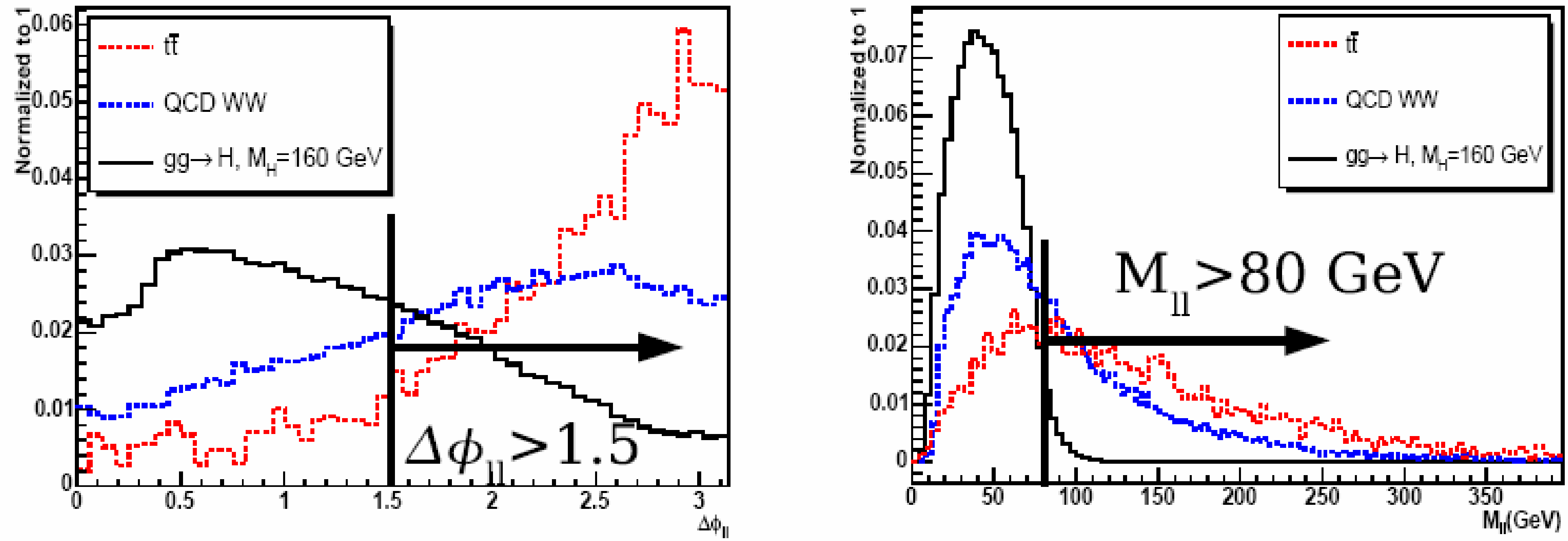
EW WW



QCD WW



Control Samples for H→WW(*)



- **Main control sample is defined with two cuts**
  - $\Delta\phi_{ll}$>1.5 rad. and M_{ll}>80 GeV
- **Because of tt contamination in main control sample, need b-tagged sample (M_{ll} cut is removed)**

Summary of Detector Performance Requirements (ATLAS)

- Combination of multiple channels will require a certain understanding of all signatures and sub-detectors
  - One fb^{-1} of usable data (or less) will be needed for calibration

$H\rightarrow\gamma\gamma$ (+0,1,2 jets)	$100<M_H<150$	γ calibration ($c_{tot}<0.7\%$) γ/jet separation (>1000 rejection for quark jets for $\varepsilon_\gamma=80\%$)
ttH, $H\rightarrow bb$	$80<M_H<130$	b-tagging ($\varepsilon_b=60\%$, 100/10 rejection against light/c jets) extraction of background shape

Summary of Detector Performance Requirements (ATLAS)

$H\to\tau\tau$, $\tau\to l,h$ (+0,1,2 jets)	$110<M_H<150$	Missing E_T (<10% Higgs mass resolution), lepton ID (>10^7 fake suppression with ID), jet tagging (5%/10% energy scale uncertainty for central/forward jets), central jet veto (need to address low E_T jet resolution requirements)
$H\to ZZ^{(*)}$, $Z\to 4l$	$120<M_H<600$	Lepton isolation/efficiency (achieve ~100/1000 rejection against Zbb/tbb for ε_{lepton}~90%)
$H\to WW^{(*)}$, $W\to l\nu$ (+0,1,2 jets)	$120<M_H<200$	"top killer" (>10 rejection), jet tagging (5%/10% energy scale uncertainty for central/forward jets), jet veto

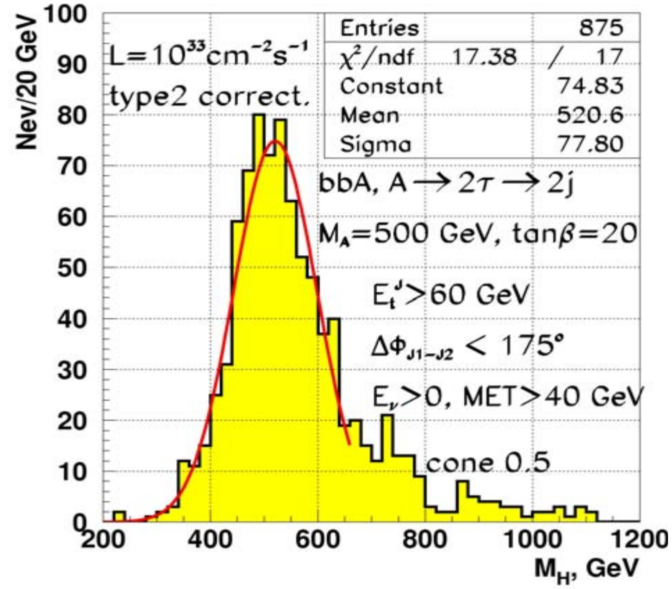
Summary and Outlook

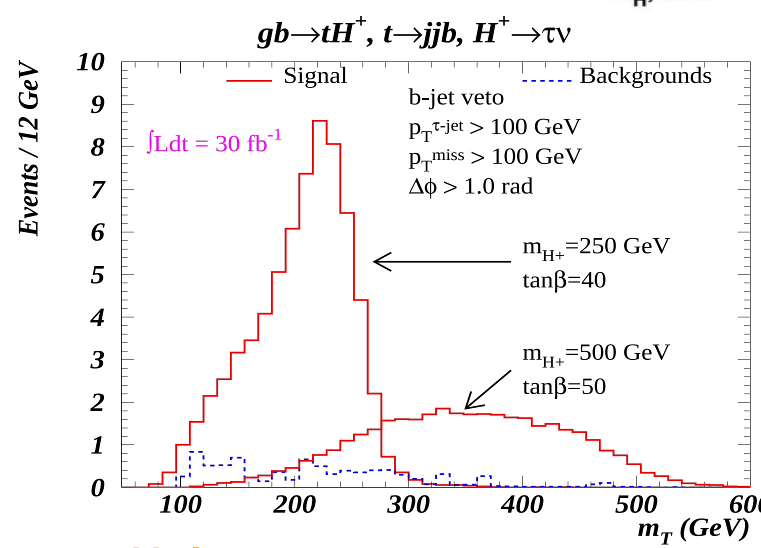
- Early discovery of low mass Higgs is challenging. Combination of multiple independent channels adds robustness to analyses
  - One fb^{-1} of usable data (or less) will be needed for calibration
- ATLAS is currently re-evaluating sensitivity to observation of SM Higgs. Final results expected this year
  - Significant improvement of sensitivity expected
- Data-driven methods for the extraction of background are well defined for Higgs searches
  - The background extraction in $H \rightarrow WW^{(*)}$ analyses is complex. Need input from theorists to improve theoretical uncertainties on contribution from $gg \rightarrow WW$ and single top production (contributing to $gg \rightarrow WWbb$)
  - Need to address the issue of extracting the shape of the bb inv. mass spectrum in ttbb and ttjj final states

Back-Up

Heavy MSSM Higgs

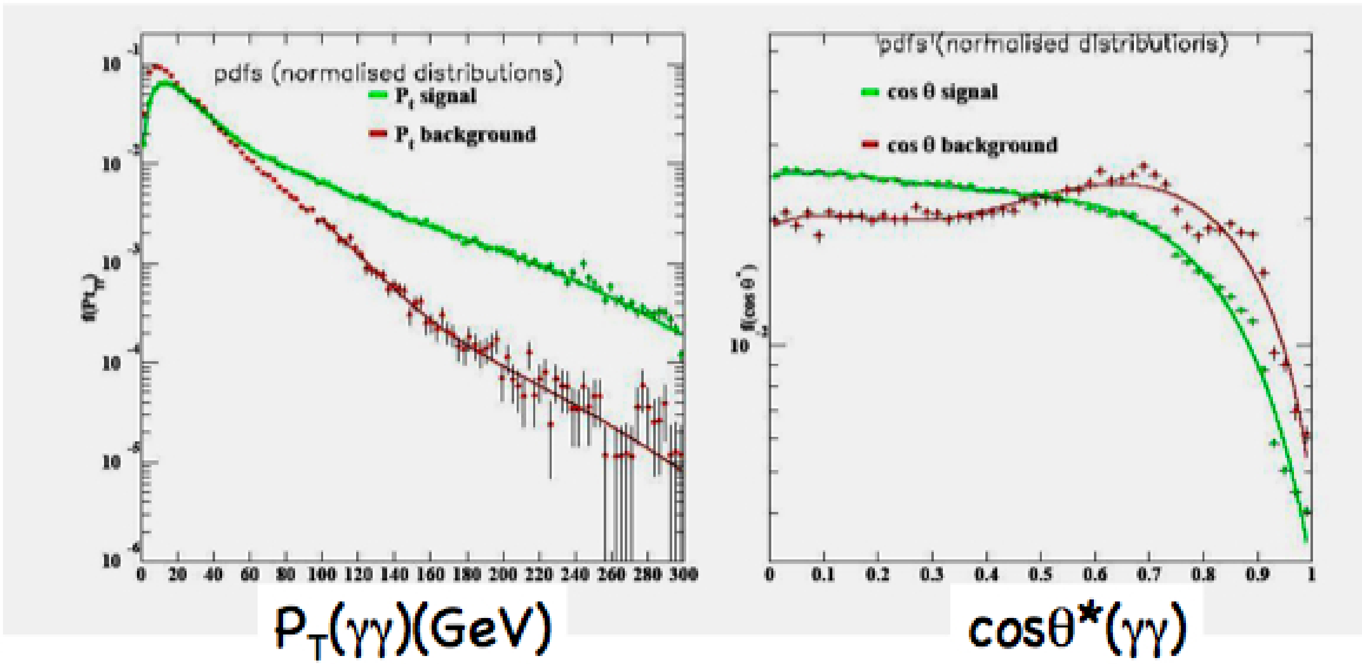
- bbH/A→ττ→had had νν:
  - Full simulation studies
    - Trigger efficiency
    - τ-jets efficiency
    - Mass reconstruction
      - 15% resolution
      - Reconstruction efficiency
- gb→tH±, H±→τ±ν:
  - Only transverse mass
  - Almost background free
    - 100% τ polarization enhances signal





Improvement to the standard inclusive analysis

improve the discovery potential using the shape of kinematical variables ⇒ one has to assume kinematical knowledge



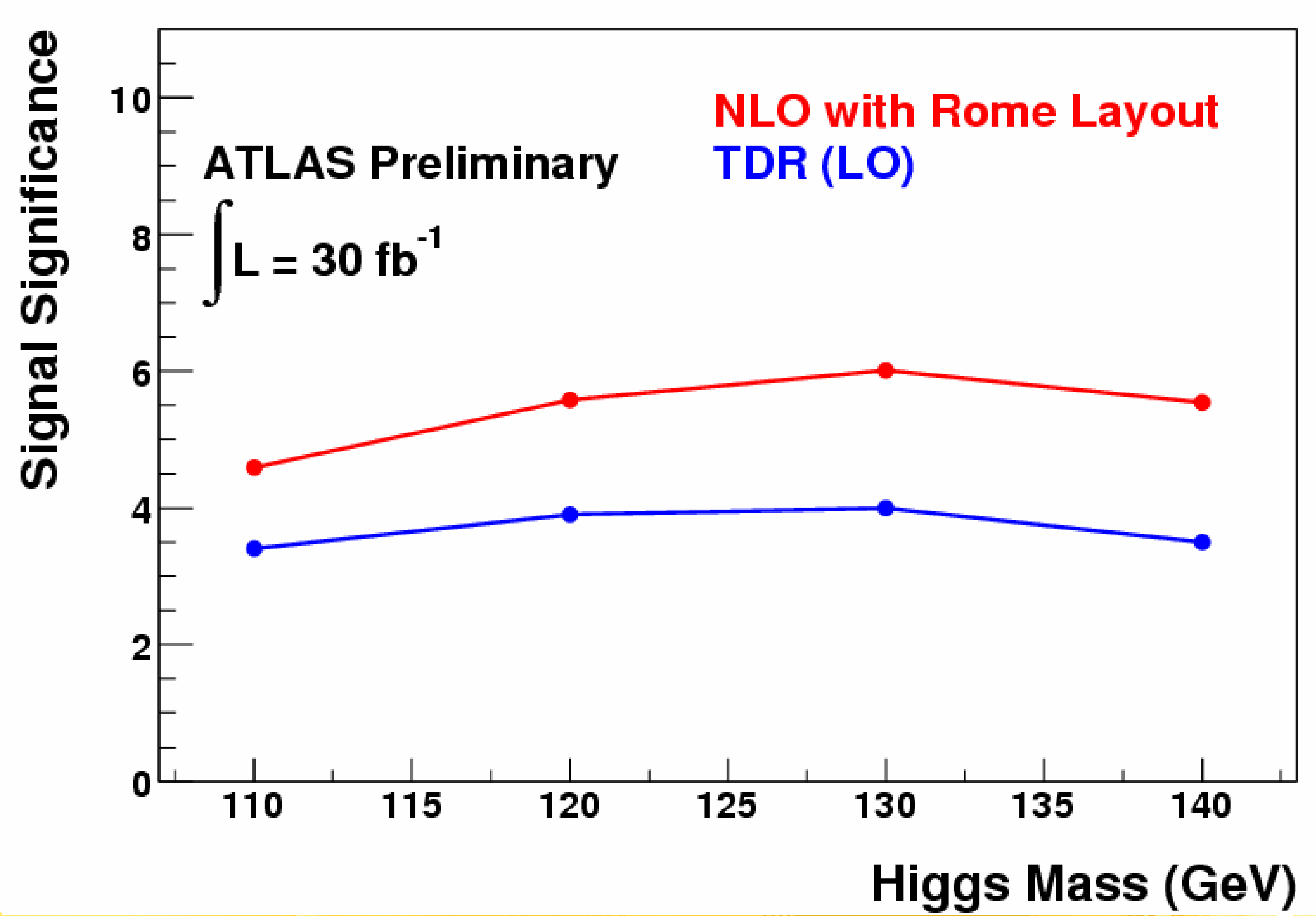
Create a likelihood based on $P_T(\gamma\gamma)$ and $\cos\theta^*(\gamma\gamma)$

⇒ 30-40% improvement of the statistical significance

⇒ Currently study of robustness of this

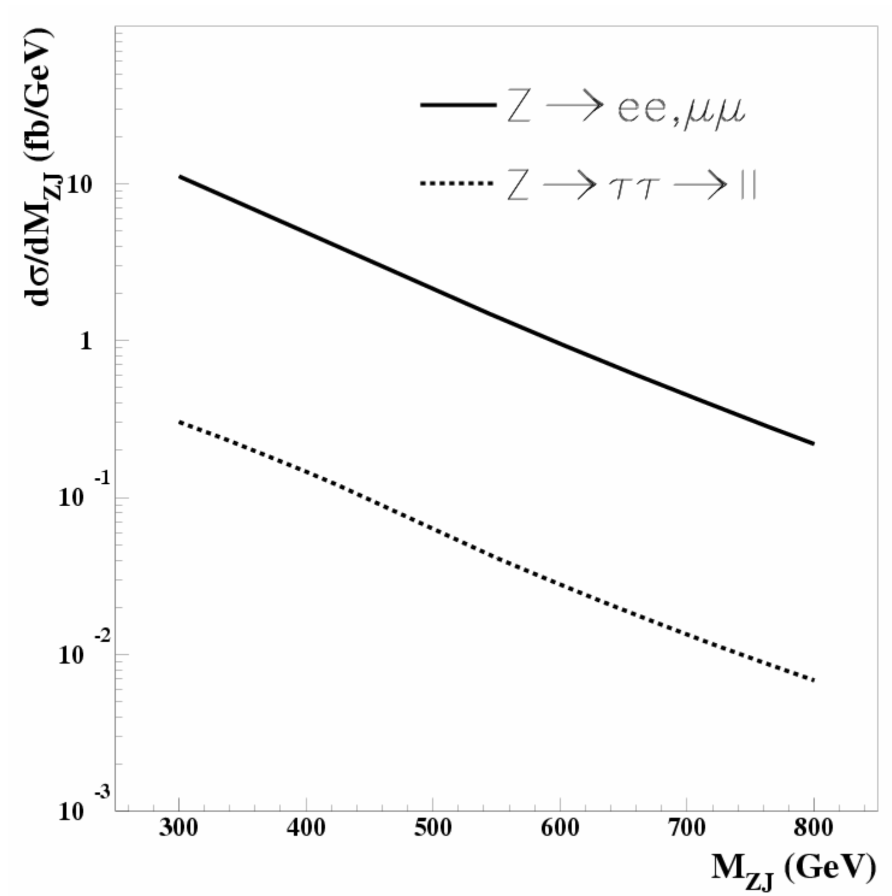
⇒ Other studies : number of jets (related to VBF analysis)

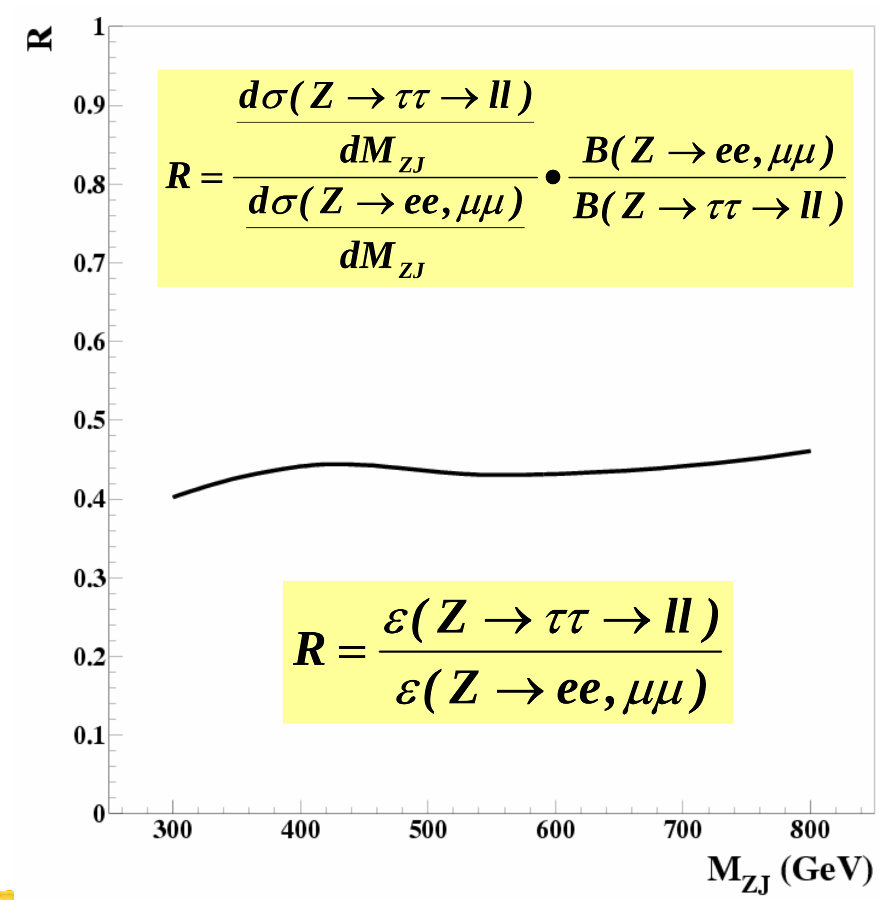
Inclusive $H \to \gamma\gamma$



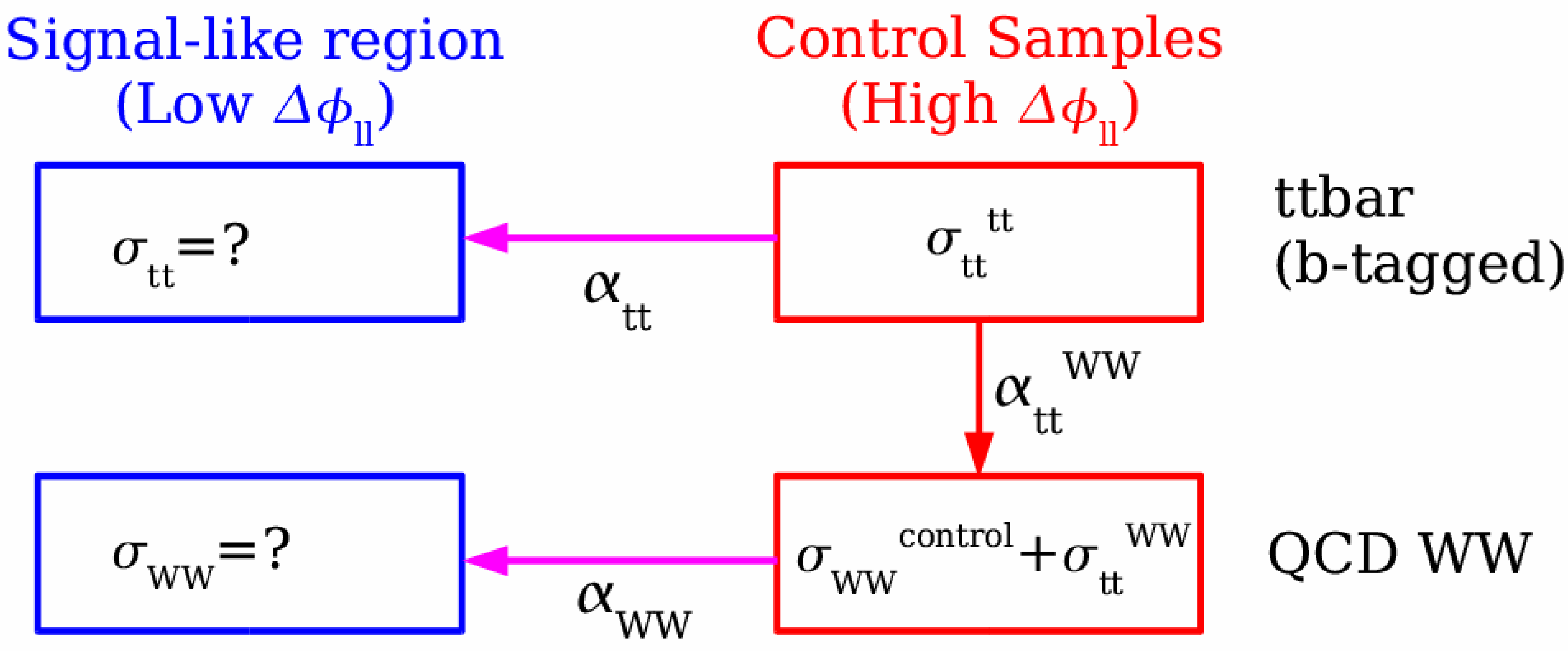
Normalization of Z→ττ using Z→ee,μμ

- Z→ee,μμ offers about 35 times more statistics w.r.t to Z→ττ→ll
  - Ratio of efficiencies depends weakly with M_{HJ} and can be easily determined with MC after validation with data





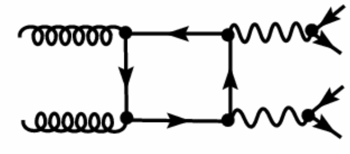
Control Samples for $H \to WW^{(*)}$

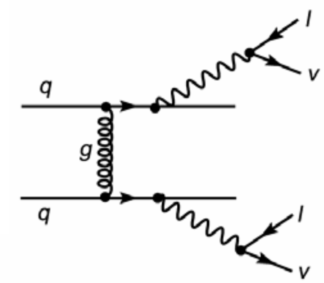


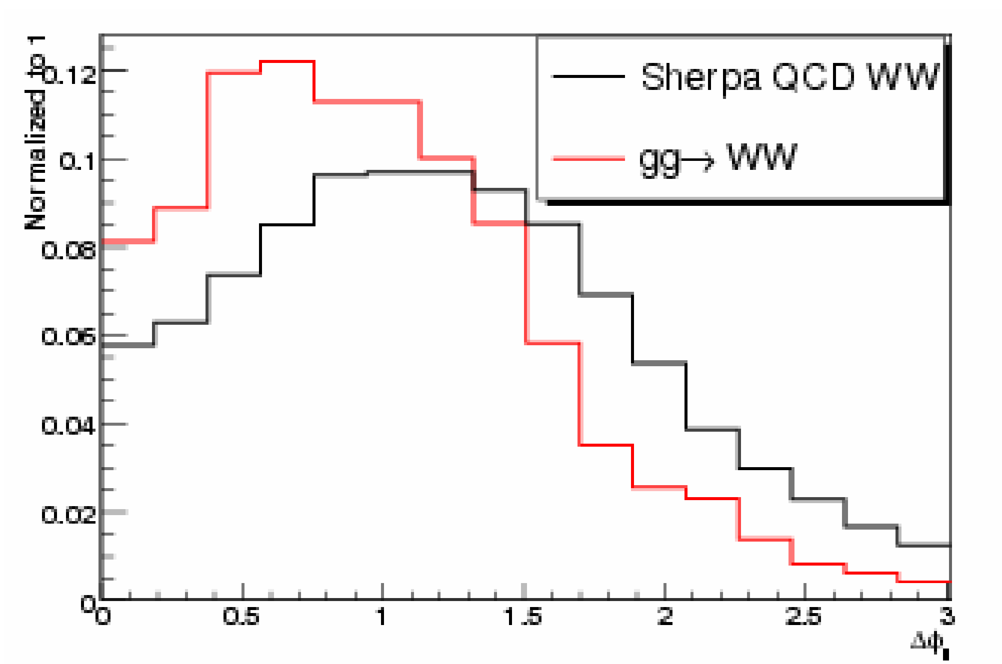
- **Define:**
  - α_{WW}=(QCD WW bg)/(QCD WW in control samp.)
  - α_{tt}=(tt bg)/(tt in b-tagged control sample)
  - α_{tt}^{WW}=(tt in WW sample)/(tt in b-tagged sample)

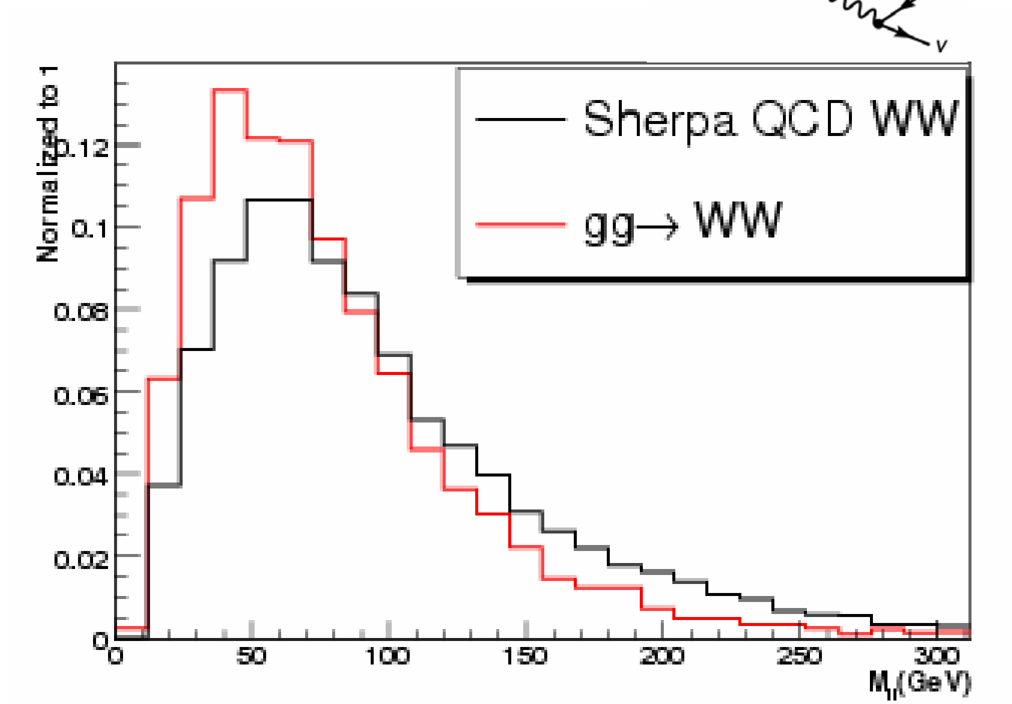
Thanks to N.Kauer

- **Contribution in signal-like region from gg→WW is small is 10-15%. Very hard to separate gg→WW from qq →WW in data . Unfortunately, kinematics are different** (gg→WW is more signal-line)
  - So far we have assumed a 100% uncertainty on the cross-section
  - Need input from theorists to improve this

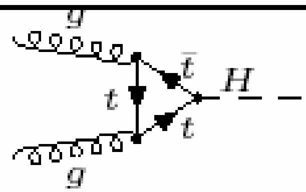
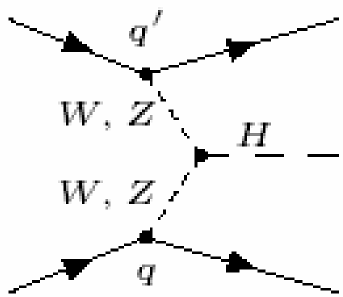
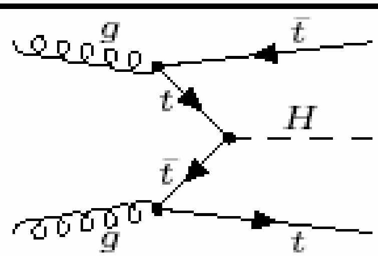
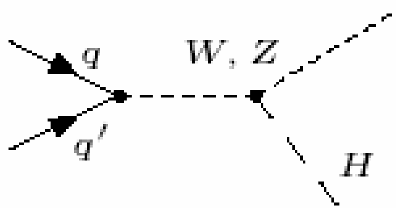








List of Feasible Channels (SM Higgs with M_H<200 GeV)

Production		Decay	mass ranges
	Gluon-Fusion $(gg \to H)$	$H \to ZZ \to 4l$	110 GeV - 200 GeV
		$H \to WW \to l\nu\, l\nu$	110 GeV - 200 GeV
		$H \to \gamma\gamma$	110 GeV - 150 GeV
	WBF (qqH)	$H \to ZZ \to 4l$	110 GeV - 200 GeV
		$H \to WW \to l\nu\, l\nu$	110 GeV - 190 GeV
		$H \to \tau\tau \to l\nu\nu\, l\nu\nu$	110 GeV - 150 GeV
		$H \to \tau\tau \to l\nu\nu\, \mathrm{had}\nu$	110 GeV - 150 GeV
		$H \to \gamma\gamma$	110 GeV - 150 GeV
	$t\bar{t}H$	$H \to WW \to l\nu\, l\nu\, (l\nu)$	120 GeV - 200 GeV
		$H \to b\bar{b}$	110 GeV - 140 GeV
		$H \to \tau\tau$	110 GeV - 150 GeV
		$H \to \gamma\gamma$	110 GeV - 120 GeV
	WH	$H \to WW \to l\nu\, l\nu\, (l\nu)$	150 GeV - 190 GeV
		$H \to \gamma\gamma$ $H \to bb$	110 GeV - 120 GeV
	ZH	$H \to \gamma\gamma$ $H \to bb$	110 GeV - 120 GeV