Higgs + 1jet Signatures

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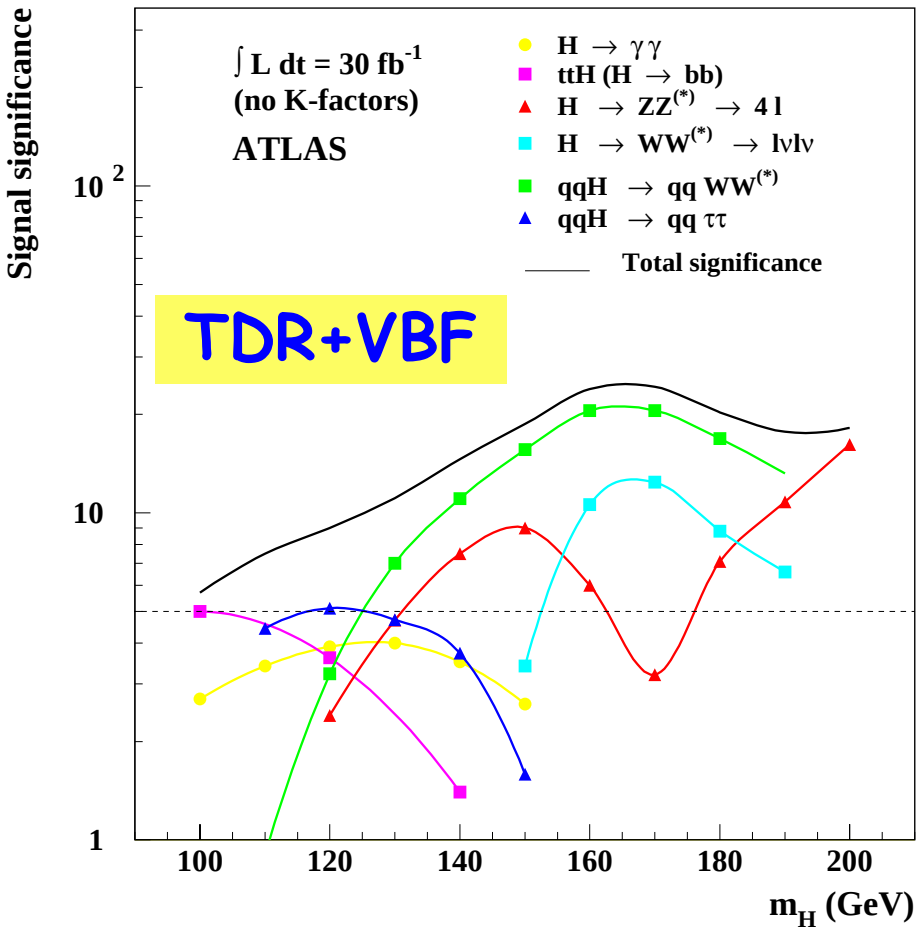
Higgs Session 02/04/05

Outline

- Introduction
- Combined $H\rightarrow\gamma\gamma$+≥0jet and $H\rightarrow\gamma\gamma$+≥1jet Analysis
- New discovery channel: $H\rightarrow\tau\tau$+≥1jet
- New discovery channel: $H\rightarrow WW^{(*)}$+≥1jet
- Calibrating Forward jets
- Outlook

- Most recent combination includes inclusive and H+2j (VBF) analyses
- Inclusion of H+2j (VBF) analyses have significantly enhanced sensitivity to SM Higgs
  - Important role at low masses of $H \to \tau\tau$+2jets (VBF)
- Need to add H+1j channels

ATLAS
Eur.Phys.J. C32S2 (2004) 19-54



Combined $H \rightarrow \gamma\gamma + \geq 0$jet and $H \rightarrow \gamma\gamma + \geq 1$jet Analysis

Motivation

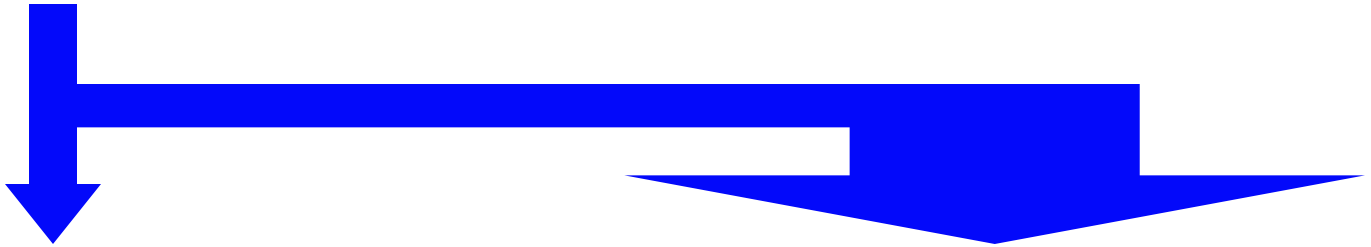
- Analysis of $H\rightarrow\gamma\gamma$+1jet was proposed by S.Abdullin et al. (Phys. Lett. B431: 410, 1998)
  - Applied in ATLAS by V.Zmushko
    - ATL-PHYS-1999-014 and ATL-PHYS-2002-020
  - Recent re-analysis by Wisconsin
- An important question was not addressed:
  - Is $H\rightarrow\gamma\gamma$+1jet, an alternative or a default analysis?
    - Can the inclusive and $H\rightarrow\gamma\gamma$+1jet analysis coexist?

Search for $\gamma\gamma$ resonances are most optimal when $H\rightarrow\gamma\gamma+\geq 0j$ and $H\rightarrow\gamma\gamma$+jets are combined

Optimization of Combined Analysis

Pre-selection

Pick event if $P_{T\gamma 1}$>40 GeV and $P_{T\gamma 2}$>25 GeV



$\gamma\gamma$+1j Analysis

Pick event if pass cuts on $P_{T\gamma 1}$, $P_{T\gamma 2}$, P_{TJ} and $M_{\gamma\gamma J}$

$\gamma\gamma$+0j Analysis

Pick rest of the events

- Four variables in the signal significance optimization
  - $P_{T\gamma 1}$, $P_{T\gamma 2}$, P_{TJ} and $M_{\gamma\gamma J}$

Optimization

Mass(GeV)	$P_{T\gamma 1}$(GeV)	$P_{T\gamma 2}$(GeV)	P_{TJ}(GeV)	$M_{\gamma\gamma J}$(GeV)
110	45	25	20	348
120	45	25	20	356
130	45	25	20	386
140	45	25	20	448

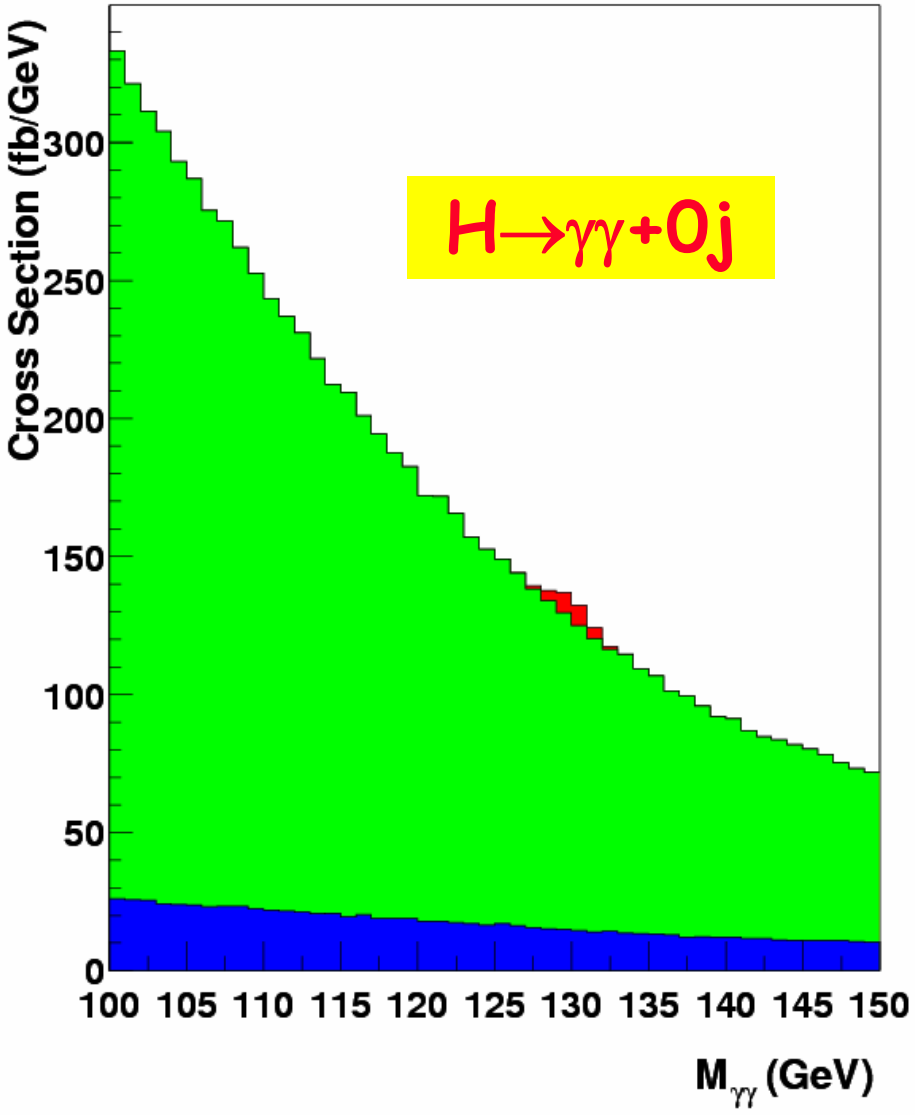
Fixed

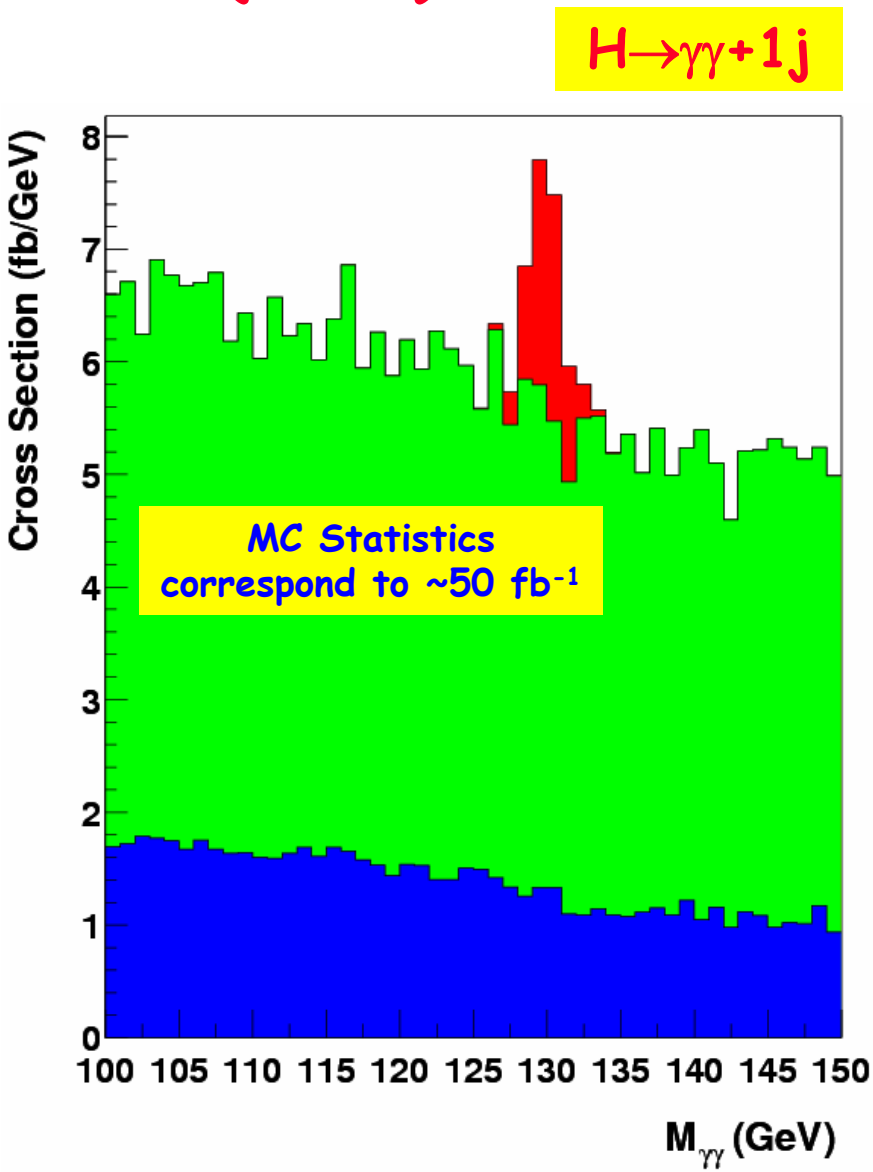
Fixed

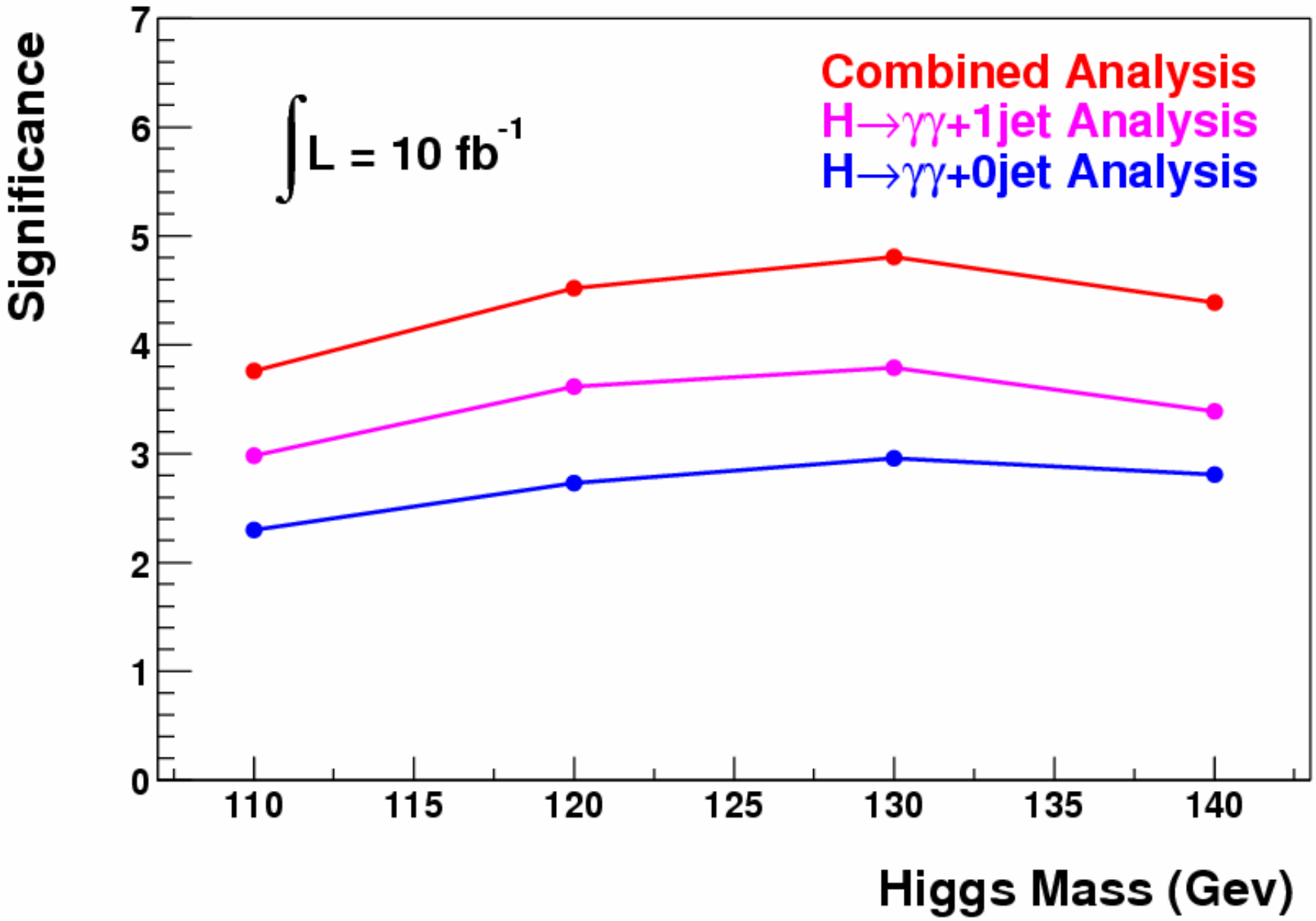
Effective cross-sections in $\pm 2\sigma$ window

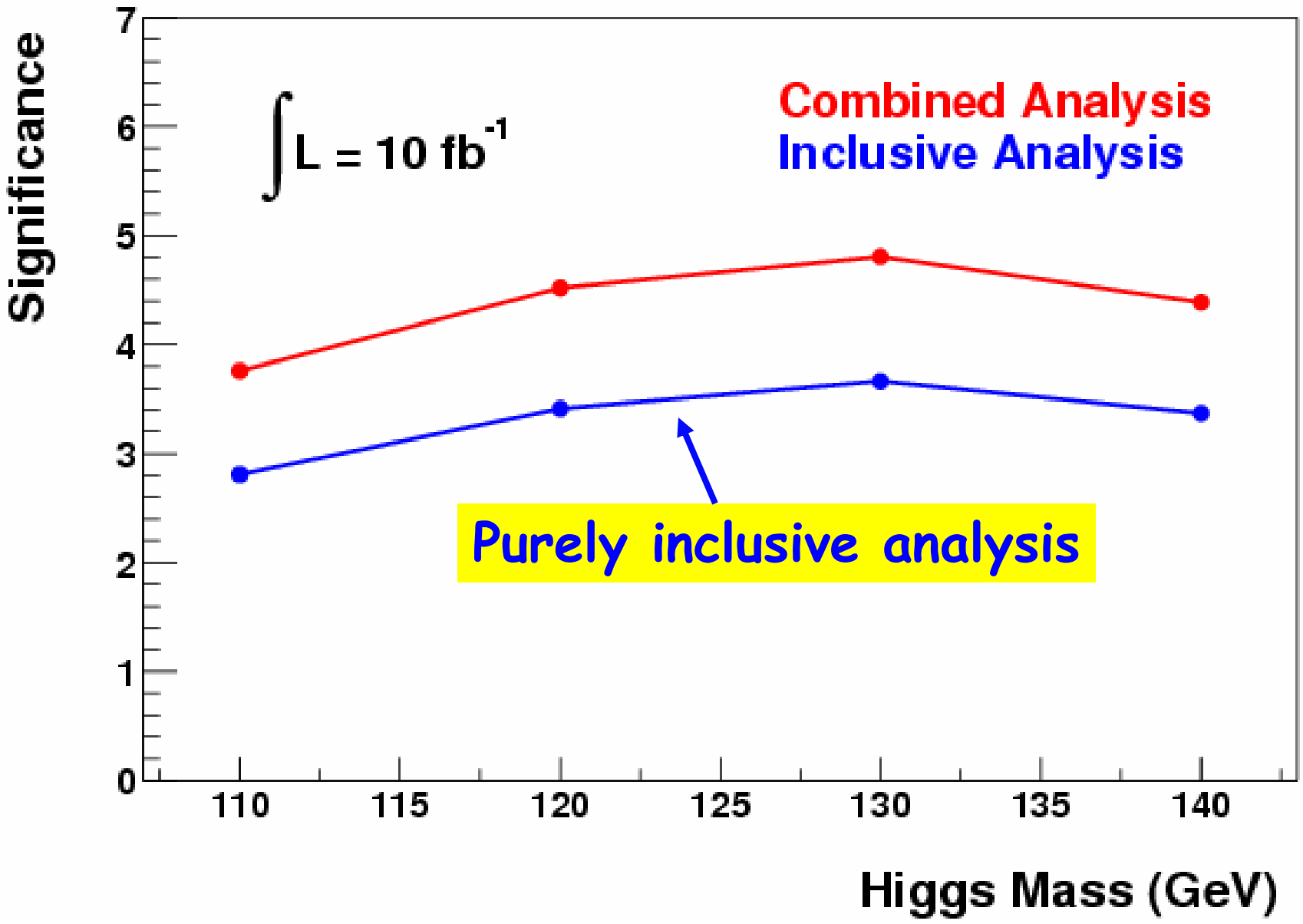
Mass (GeV)		Signal: $gg \to H$ (fb)	Signal: VBF (fb)	Bkg: Real $\gamma\gamma j$ (fb)	Bkg: Fake $\gamma\gamma j$ (fb)	Significance
110	H→γγ+0j	24.16	1.68	1152.16	112.42	3.76
	H→γγ+1j	4.66	1.61	33.91	10.36	
120	H→γγ+0j	23.97	1.83	803.63	90.77	4.52
	H→γγ+1j	5.25	1.89	29.89	9.17	
130	H→γγ+0j	22.37	1.94	598.08	79.20	4.81
	H→γγ+1j	4.69	1.82	22.93	6.59	
140	H→γγ+0j	18.35	1.94	454.17	68.89	4.39
	H→γγ+1j	3.15	1.35	13.44	4.22	

Optimization (cont)






Significance
7
6
5
4
3
2
1
0
∫L = 10 fb-1
Combined Analysis
H→γγ+1jet Analysis
H→γγ+0jet Analysis
110
115
120
125
130
135
140
Higgs Mass (Gev)


Significance
7
6
5
4
3
2
1
0
$\int L = 10\ fb^{-1}$
Combined Analysis
Inclusive Analysis
Purely inclusive analysis
110
115
120
125
130
135
140
Higgs Mass (GeV)

Overview and Plans for Combined $\gamma\gamma$ Analysis

- Most optimal way of searching Higgs with $\gamma\gamma$ is to combine $H\rightarrow\gamma\gamma+\geq 0j$ and $H\rightarrow\gamma\gamma+\geq 1j$ analysis
  - Enhances significance by at least 30%
- Enhancement will grow because of a number of factors, which will be addressed with full simulation

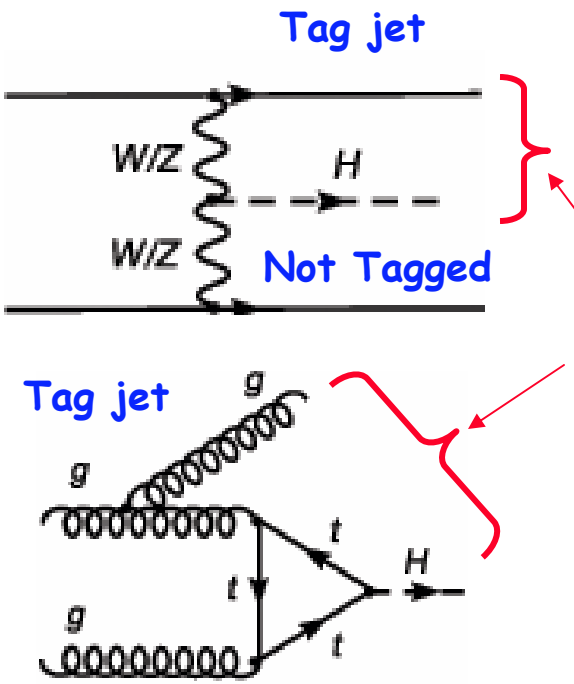
- Resolution $\gamma\gamma$ improves with Higgs P_T
- Photon efficiency improves with $P_{T\gamma}$ (ID relaxation for large $P_{T\gamma}$)
- Well defined vertex with in $\gamma\gamma j$ final state
- $\gamma\gamma j$ Analysis has more kinematic variables to use in multivariate analysis

$H \rightarrow \tau\tau$ + ≥1 jet

B.Mellado, W.Quayle and Sau Lan Wu (hep-ph/0406095) Accepted by referee in PL

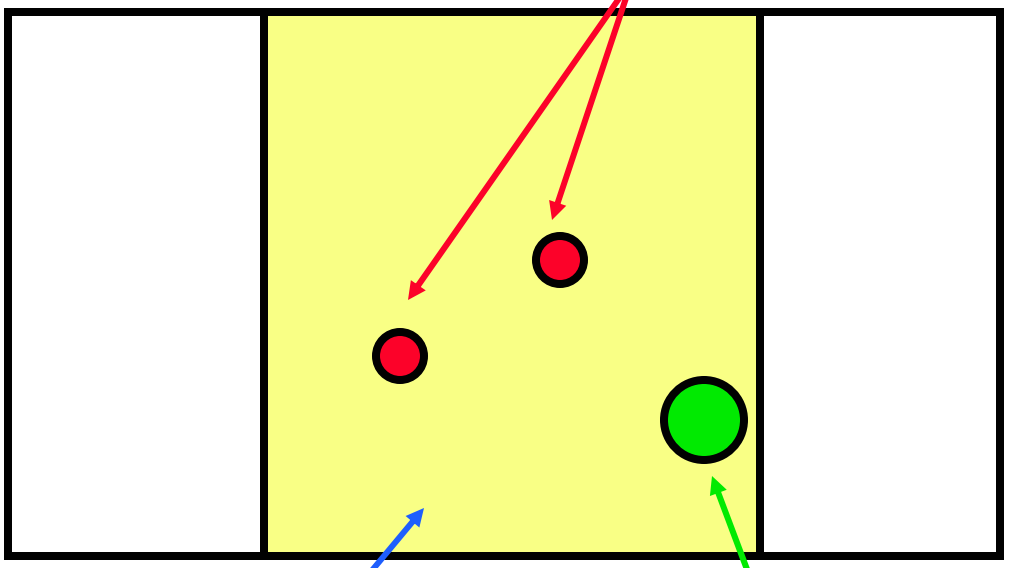
H(→ττ)+1jet at the LHC

- Tag one semi-central jet, require P_{TH}>100 and M_{HJ}>700 GeV and a loose central jet veto ("top killer")
  - Allow significant contribution from gg→h



M_{HJ}

φ



Higgs Decay Products
P_{TH}>100 GeV

Loose Central Jet Veto
("top killer")

η

Quasi-central
Tagging Jet

LO effective cross-sections (M_H=120 GeV)

Cut	$gg \to H$	VBF H	$pp \to Z/\gamma^* + X$			$pp \to t\bar{t} + X$
a	74.40	11.04	10.44×10^3	10.44×10^5	43.22	5.60×10^3
b	67.20	10.22	10.32×10^3	10.39×10^4	41.84	1760
c	47.3	8.91	5690	2.34×10^4	32.13	350
d	26.51	8.57	1870	2440	31.40	347
e	16.73	4.93	1030	1370	12.21	46.43
f	1.72	2.05	81.6	25.2	3.38	16.66
g	0.43	0.76	3.22	0.60	1.11	5.48
	0.32	0.59	0.38	0	0.11	0.41

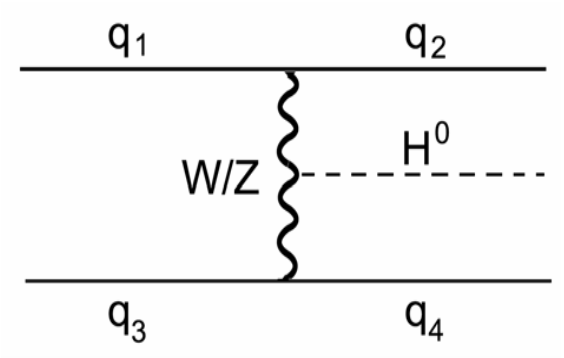
Signal Significance for 30 fb^{-1}

(M_H=120 GeV 10% systematic error on background)

Higgs Mass (GeV/c^2)	110	120	130	140	150
Signal Significance for cut analysis (σ)	4.3	5.0	4.8	3.6	2.1
Signal Significance for NN analysis (σ)	5.5	6.6	6.3	4.8	2.8

Overlap With H+≥2jets (VBF)

- D.Zeppenfeld, D.Rainwater, et al. proposed to search for a Low Mass Higgs in association with two jets



Jet

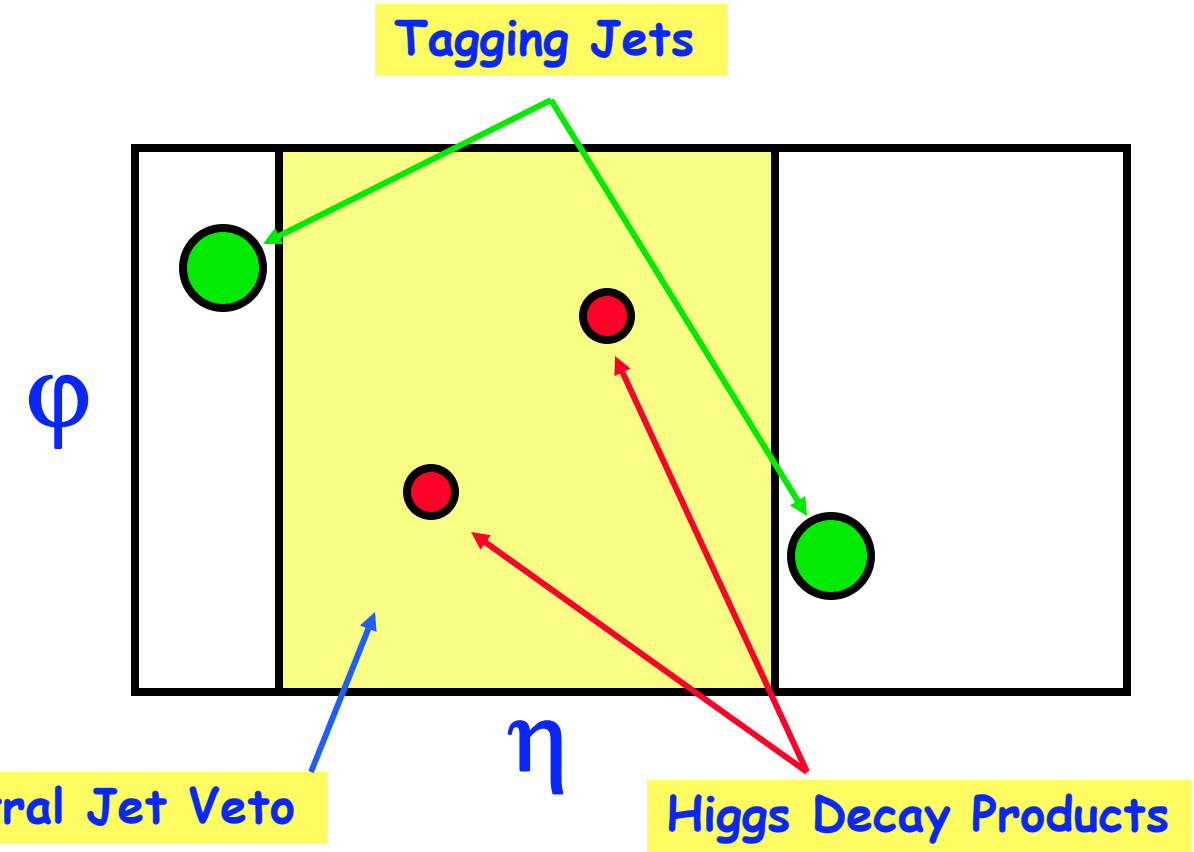
Jet

$\eta_{J1} \cdot \eta_{J2} < 0$

$\Delta\eta_{JJ} > 3.5 \div 4$

$M_{JJ} > 500 \div 700\text{GeV}$

c.j.v.



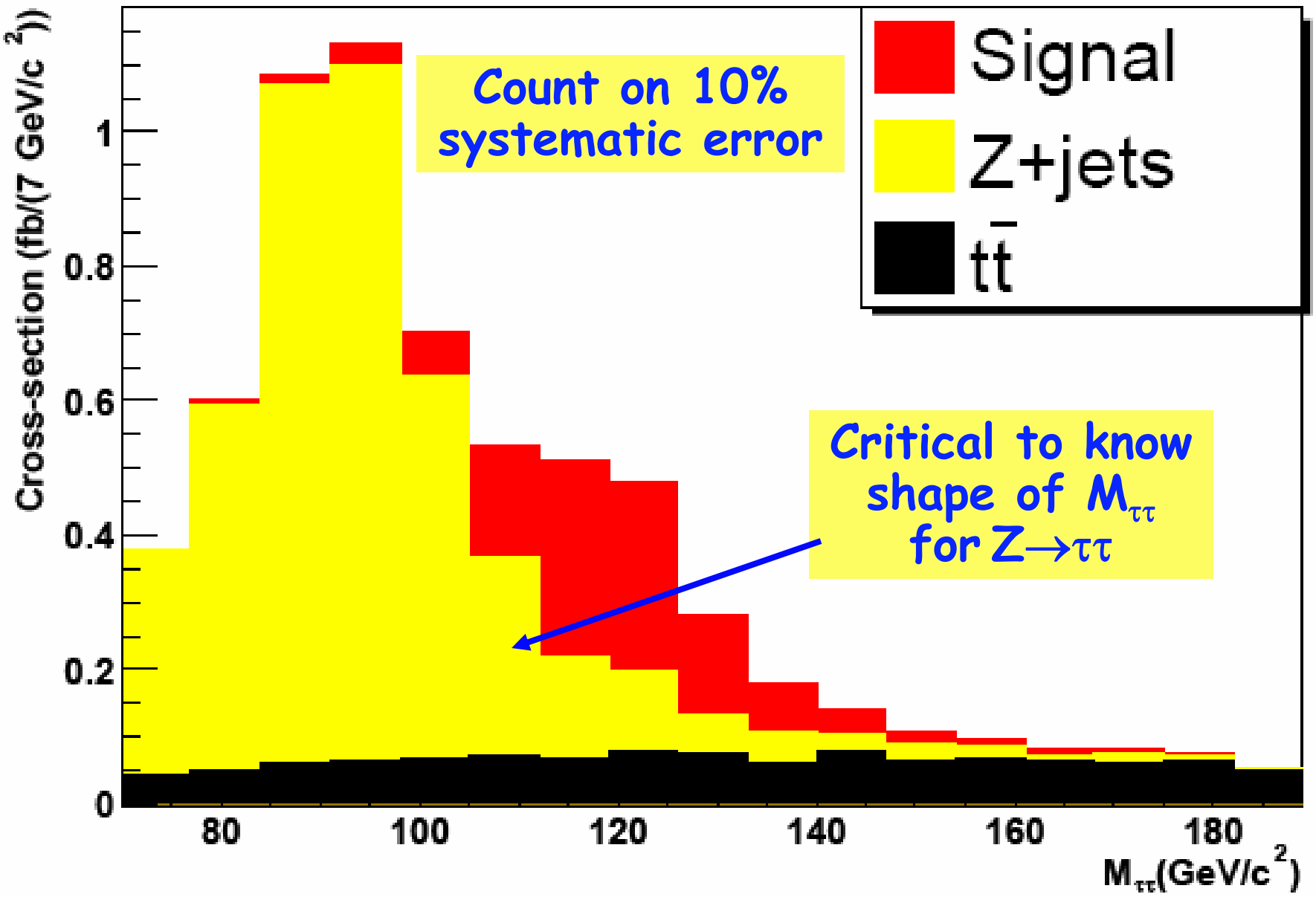
Overlap With H+2jets (VBF)

Fraction of signal events in H+1j analysis that pass H+2j analysis after successive cuts

	Tagging Jets	Central jet veto	$\Delta\phi_{jj}<2.2$	Other Cuts
VBF	62%	57%	47%	44%
ggh	17%	15%	13%	13%

- **With conservative K factors the overlap is 24%**
  - Higher order corrections on ggh are large
    - Under investigation in collaboration with SHERPA authors

H+1j and H+2j (VBF) analyses should run in parallel, adding significant power to H->ττ


Count on 10% systematic error
Signal
Z+jets
$t\bar{t}$
Critical to know shape of $M_{\tau\tau}$ for $Z\rightarrow\tau\tau$
Cross-section (fb/(7 GeV/c^2))
0
0.2
0.4
0.6
0.8
1
80
100
120
140
160
180
$M_{\tau\tau}$(GeV/c^2)

From my talk at Higgs session of TEV4LHC 17/09/04

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

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

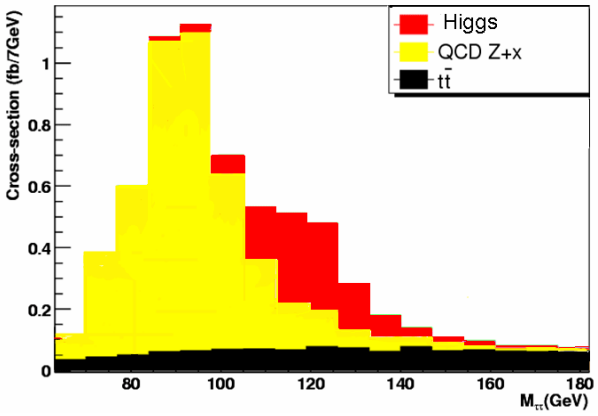
$Z \rightarrow \tau\tau$

Tight cuts on Jets

$M_{ll} < 75$ GeV

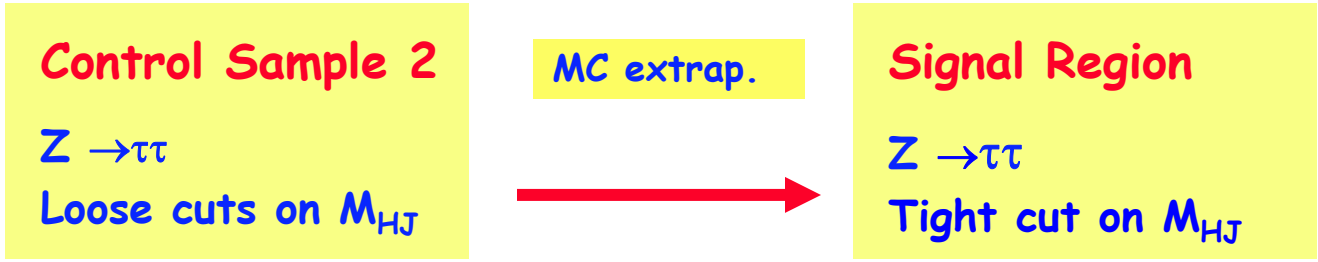
M_{HJ}

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



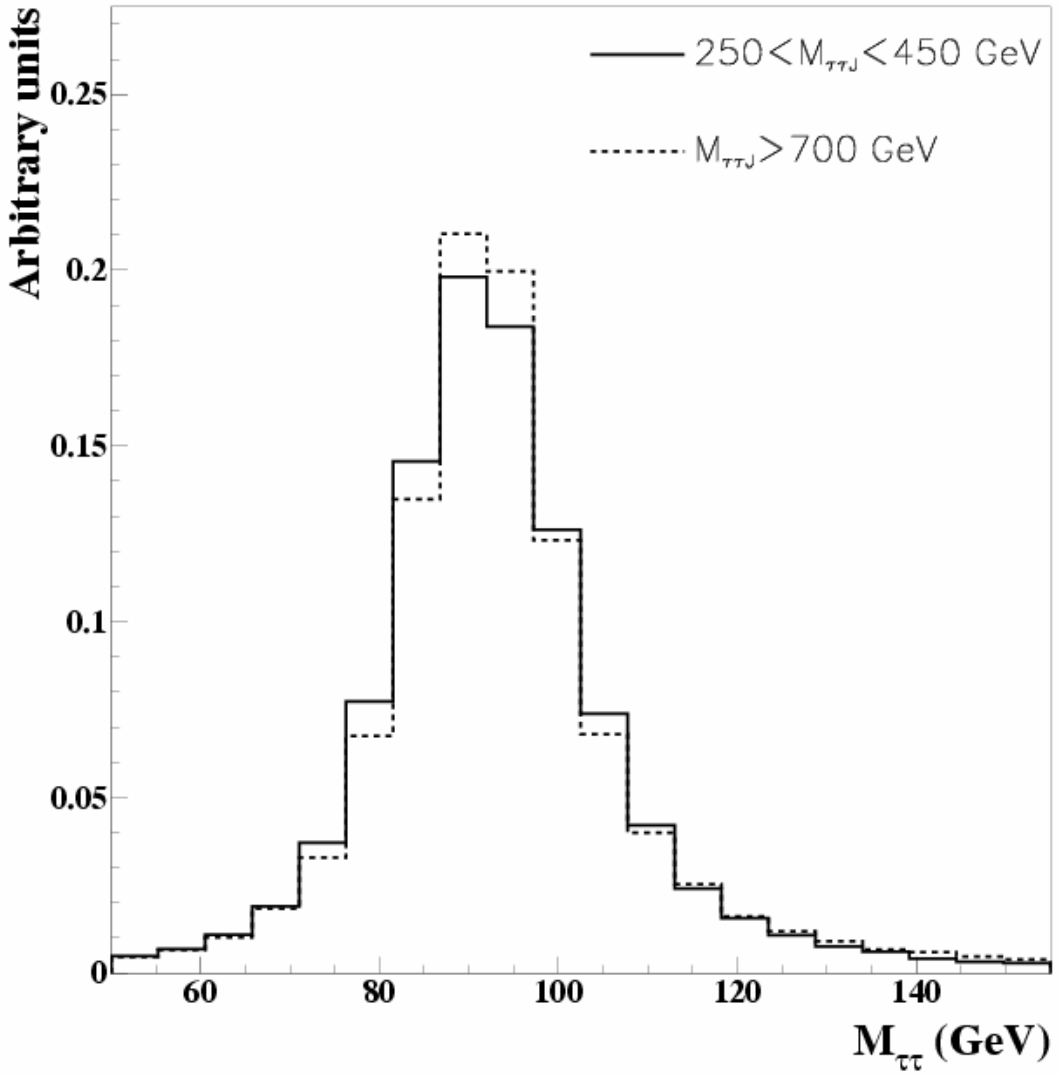
Shape of $M_{\tau\tau}$ in $Z \rightarrow \tau\tau$ (Method I)

- All cuts are kept the same except for the invariant mass of the Higgs candidate and the tagging jet
  - Assume electrons, muons, jets and missing E_T have been calibrated with $Z \rightarrow ee, \mu\mu$
  - Jet activity in MC is validated with $Z \rightarrow ee, \mu\mu$
    - Go from Box 1 to Box 3
  - Use MC to obtain $M\tau\tau$ shape in signal-like region



Shape of $M_{\tau\tau}$ in $Z \rightarrow \tau\tau$ (Method I)

- **Shape of $M_{\tau\tau}$ stable with $M_{\tau\tau J}$**
  - Changes in spectrum can be corrected with MC
  - <u>Need to verify this statement with full simulation</u>



Shape of $M_{\tau\tau}$ in $Z \rightarrow \tau\tau$
(Method II)

- Use data with $Z \rightarrow ee, \mu\mu$ and apply same cuts on jets as in the signal-like region.
- Remove the two electrons/muons (both calorimeter and tracking) and replace them with τ's, which have the same momenta
  - Needs to be tested with full simulation at ATLAS

Control Sample 3

$Z \rightarrow ee, \mu\mu$

Tight cuts on M_{HJ}

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

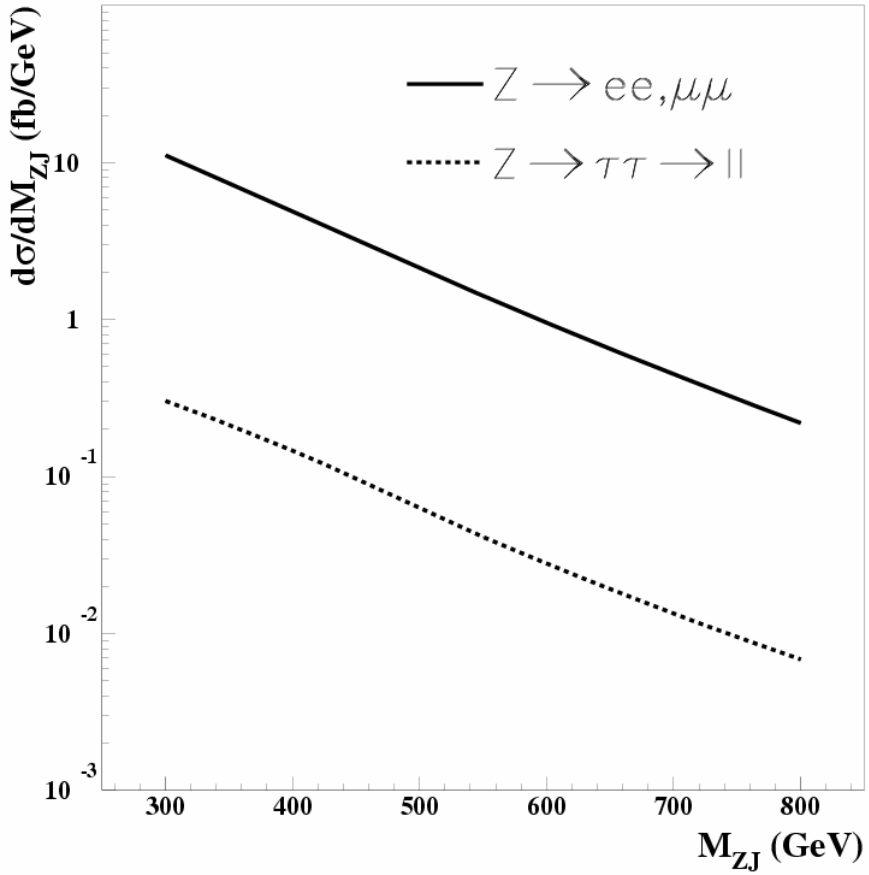
Signal Region

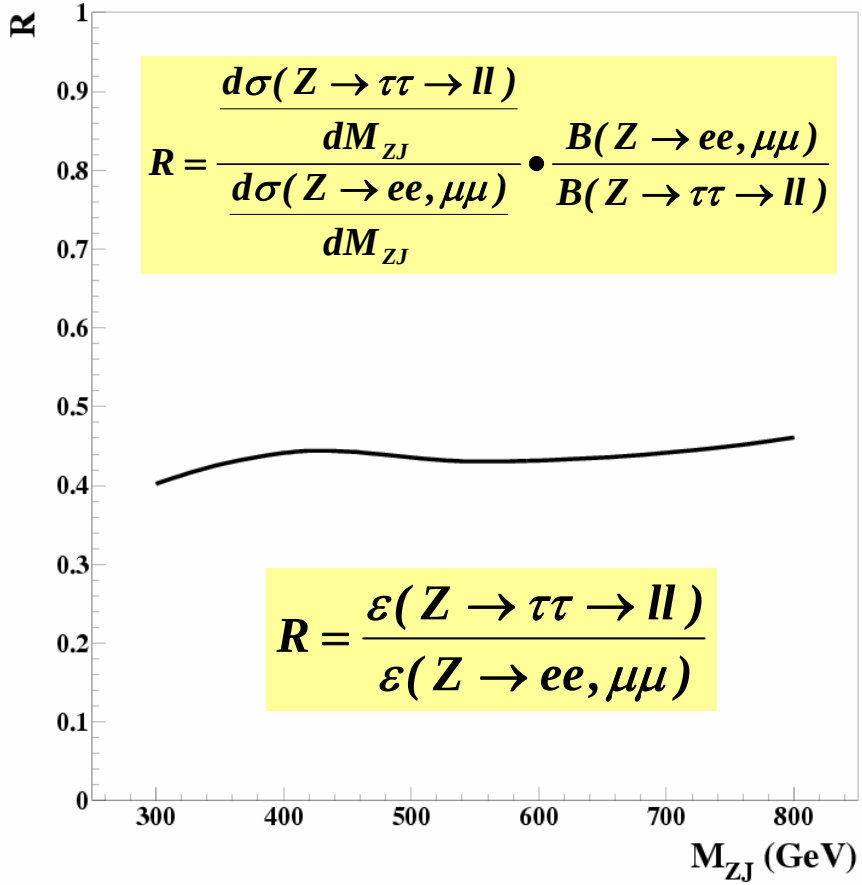
$Z \rightarrow \tau\tau$

Tight cuts on M_{HJ}

Normalization of $Z\to\tau\tau$ using $Z\to ee,\mu\mu$

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

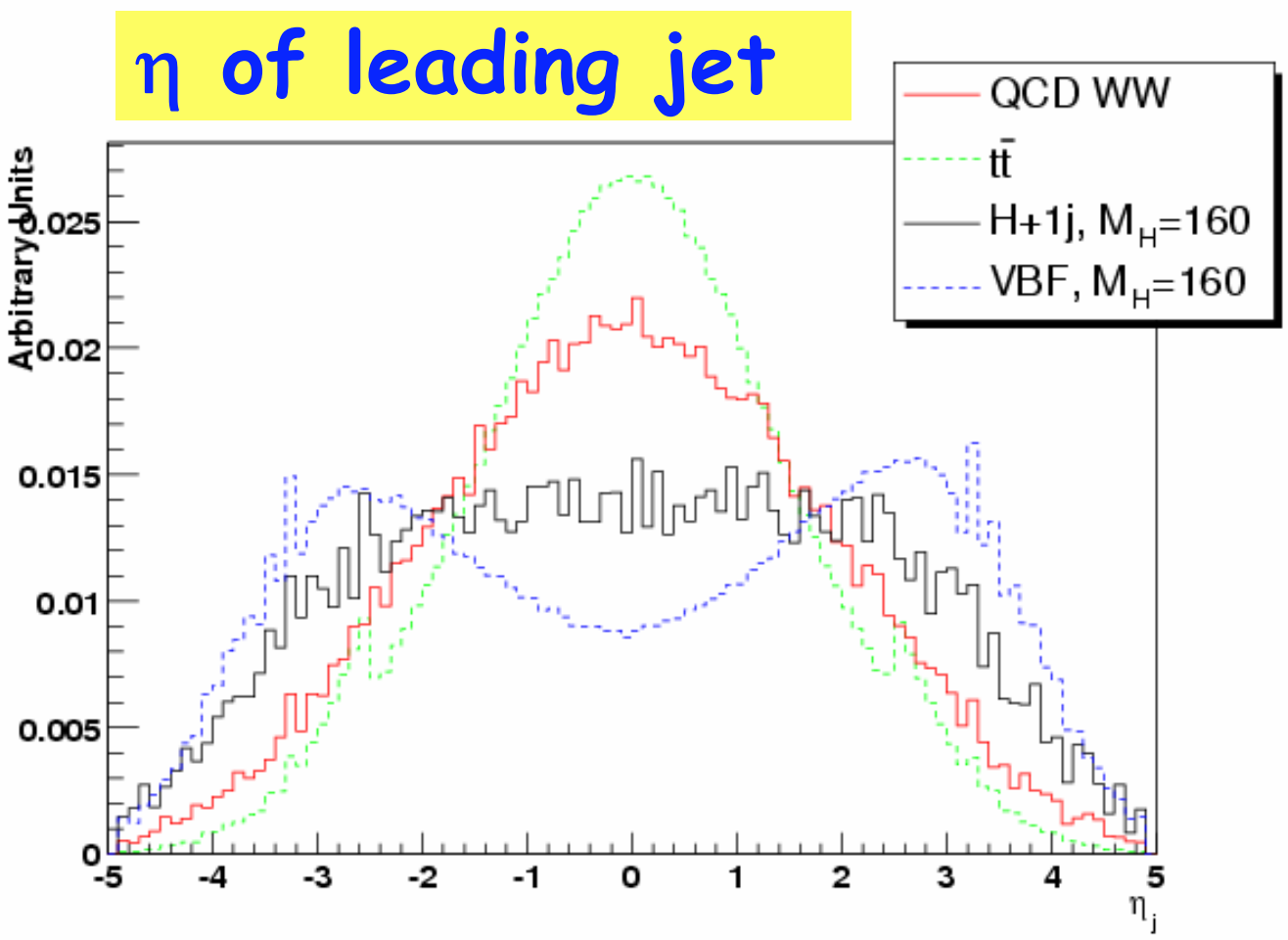




$H \rightarrow WW^{(*)} + \geq 1$ jet

B.Mellado, W.Quayle and Sau Lan Wu
to be submitted to journal

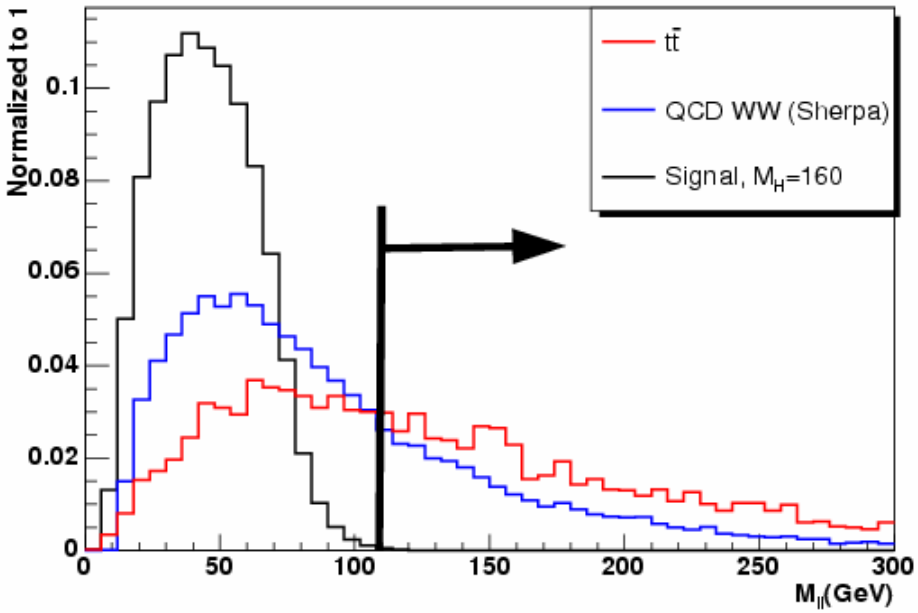
- Use basic property that leading jet associated with Higgs is tends to be more forward than in QCD backgrounds



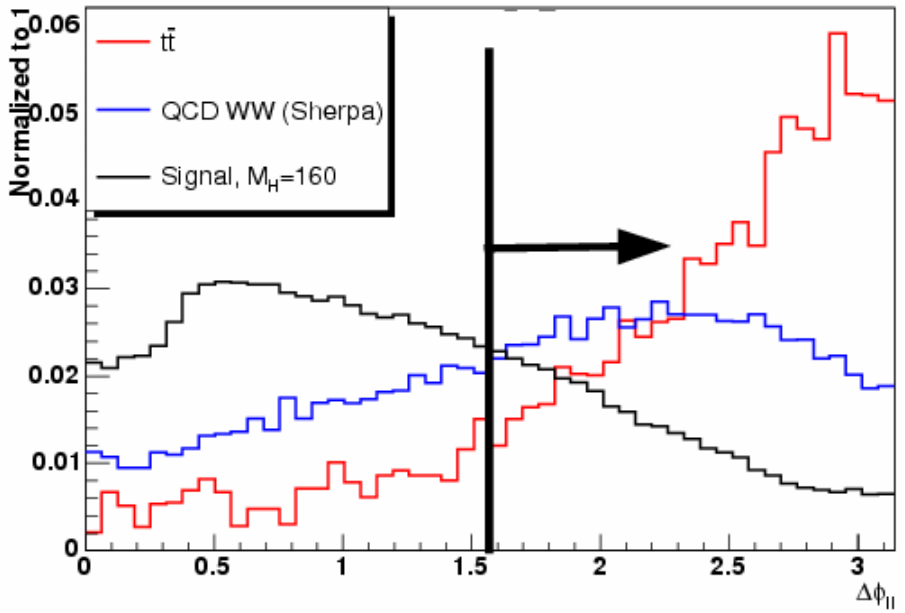
Control samples in data well defined

- W.Quayle will elaborate on this point during next workshop at CERN

$\Delta\phi_{ll}$



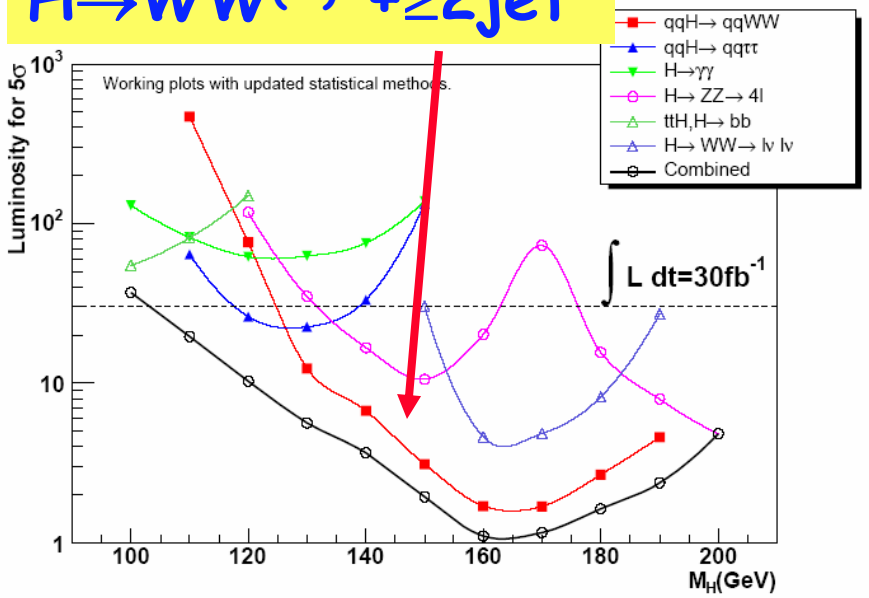
M_{ll}



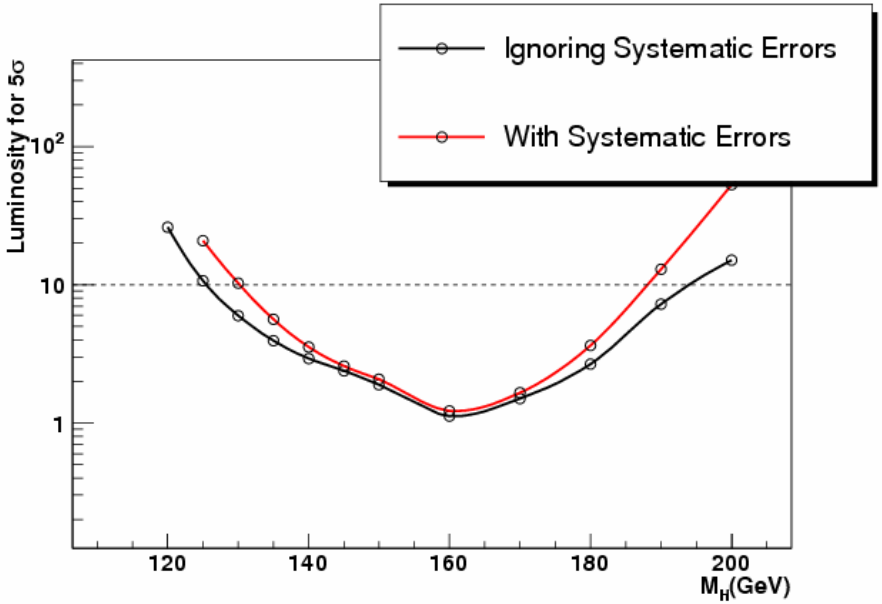
Preliminary results for combined H →WW(*) analysis

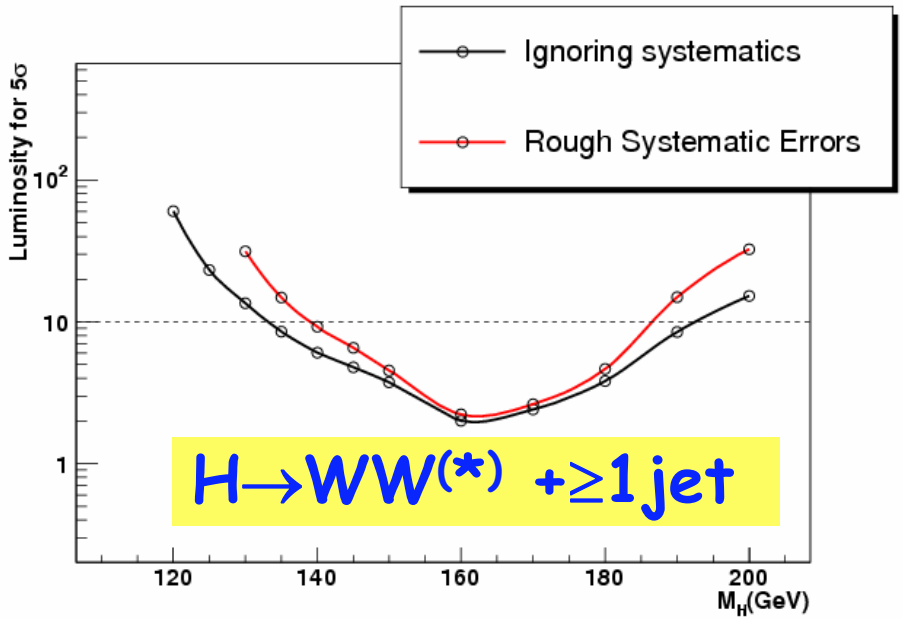
- Three non-overlapping analysis defined
- Background subtraction using data

H→WW(*) +≥2jet



H→WW(*) with jet veto



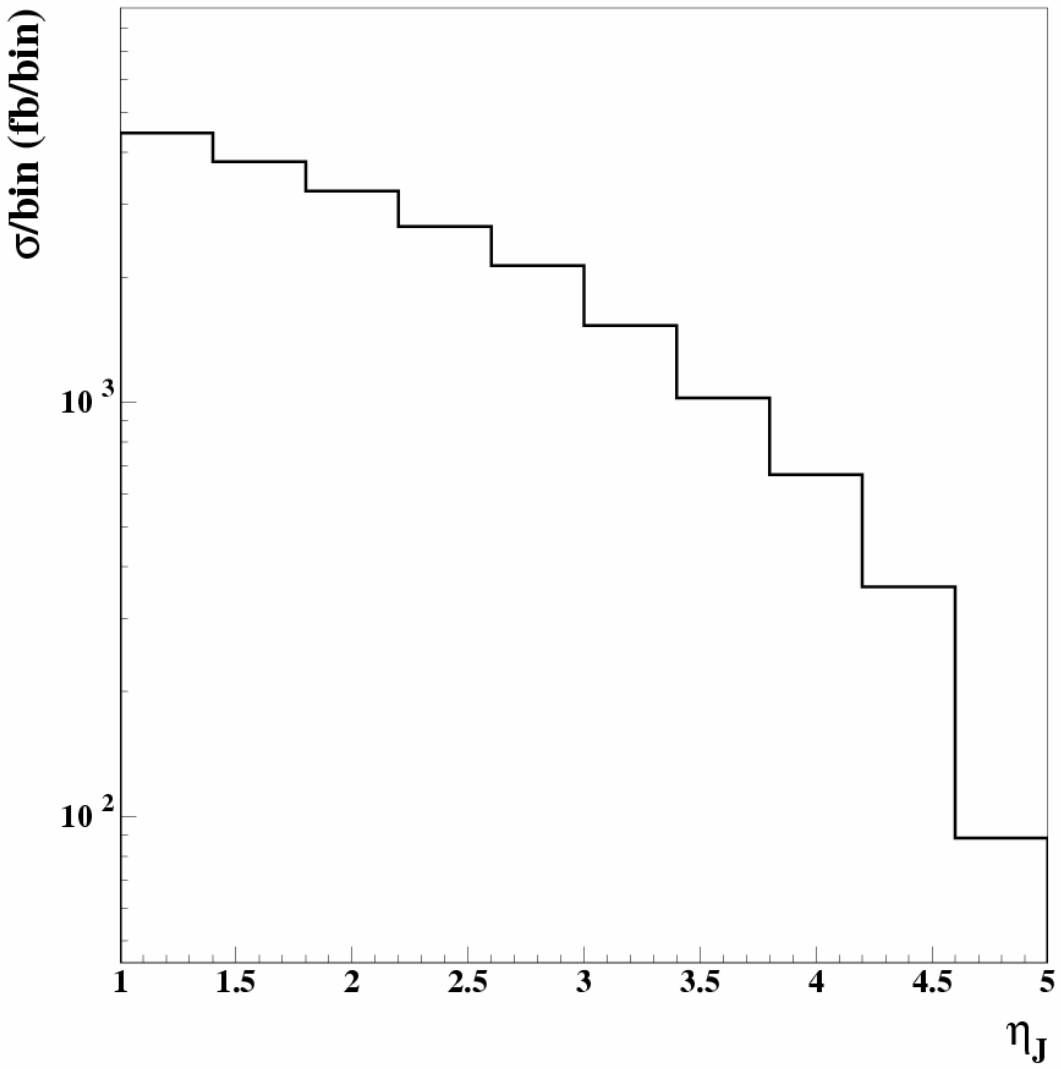


H→WW(*) +≥1jet

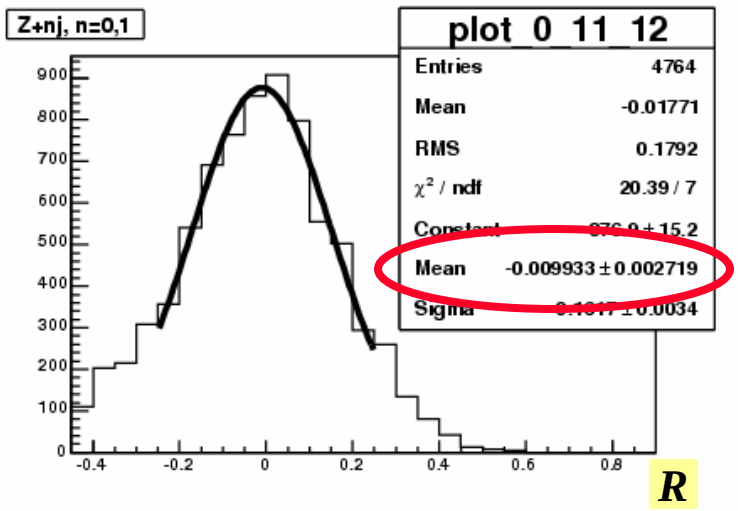
Calibrating Forward Jets

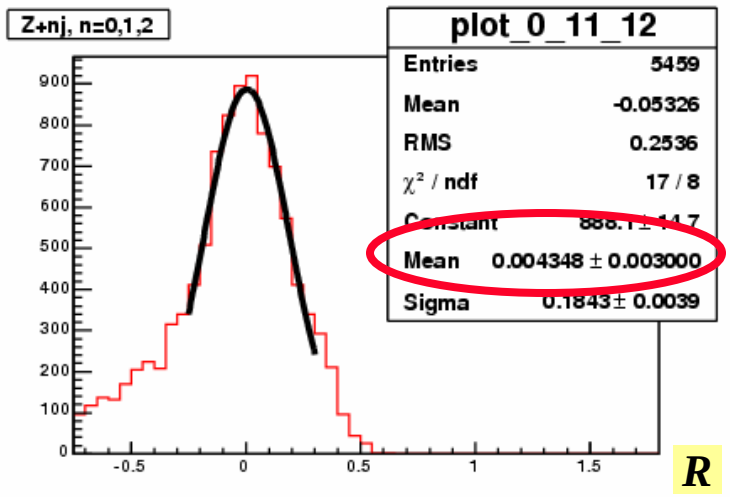
Rate of leading jet in $Z \rightarrow ee, \mu\mu$ after c.j.v.

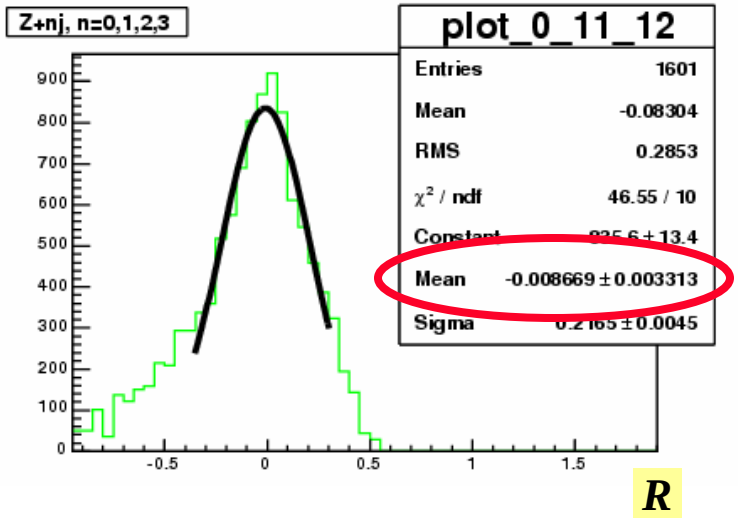
- $Z \rightarrow ee, \mu\mu$ in association with jets gives a large statistics sample for the calibration of jets and missing E_T



$$R = 1 - \frac{P_{TJ}}{P_{TZ}}$$







$P_{TJ} > 30GeV$

$|\eta| > 2.5$

central jet veto

- Used SHERPA to generate Z→ee in association with at least one jet. Use P_T balance between Z→ee and leading jet to calibrate forward jets
  - The addition of extra legs to model sub-leading jets changes the position of the peak by less than 2%
    - Gives upper bound on theoretical errors

Outlook and Plans

- Combined $H\to\gamma\gamma+\geq 0j$ and $H\to\gamma\gamma+\geq 1j$ enhances signal significance by at least 30%
- Inclusion of new channel, $H\to\tau\tau+\geq 1j$, enhances further the power of $H\to\tau\tau$ channels
  - Pursue combined analysis of $H\to\tau\tau\to ll+\geq 1j$, $H\to\tau\tau\to ll+\geq 2j$ and $H\to\tau\tau\to lh+\geq 1j$, $H\to\tau\tau\to lh+\geq 2j$
- Assessed new discovery channel: $H\to WW^{(*)}+\geq 1j$
  - Combination of $H\to WW^{(*)}$ with 0j, ≥1j and ≥2j, as three non-overlapping analyses enhances tremendously sensitivity to Higgs

Re-evaluate the ATLAS significance with combined H+0,1,2j analyses with full simulation