Prospects for Higgs discovery at LHC

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Outline

- Introduction
- Higgs production and decay at LHC
  - Sensitivity plots
- Issues in specific channels
  - $H \rightarrow ZZ^{(*)}$, $WW^{(*)}$
  - $H \rightarrow \gamma\gamma$
  - VBF $H \rightarrow \gamma\gamma$, $\tau\tau$
  - ttH, $H \rightarrow bb$
- Conclusions

Introduction-I

- Higgs mechanism of EWSB ←→ application of 2nd order phase transition of Landau-Ginsburg theory to complex scalar doublet field (4 d.o.f.)
  - Masses for W and Z bosons are generated through non-zero vev of bosonic Higgs field (3 d.o.f. absorbed) = "Day time" job of Higgs
    - Higgs "the particle" = leftover (non-absorbed component) from the field
  - In addition fermionic masses are generated through Yukawa coupling to Higgs field = "Night time" job of Higgs
    - The number of parameters is NOT reduced ($m_f \rightarrow g_f$), but the meaning changes
- It is important
  - To discover Higgs
  - To measure couplings - verify that it is doing both its "jobs"

Introduction-II

- A LOT of studies were performed by CMS and Atlas collaborations to understand the sensitivity to Higgs boson
- I will not cover
  - Triggers
  - Specifics of detector performance
  - Details of either analysis
  - Higgs beyond SM

detectors in M. Dobbs' talk

- I will concentrate on the areas where studies from Tevatron experiments can help LHC
  - Direct and indirect constraints
  - Algorithm and analysis strategy verification
  - Background normalization

Indirect constraint on M_H

- Sensitivity to top mass:
  - ~5 GeV shift in M_t raised upper boundary on M_H by ~50 GeV

more in A. Kotwal's talk

- Rate of H decay to γγ can be suppressed if stop mass close to top mass
  - SuSy case within Tevatron's reach

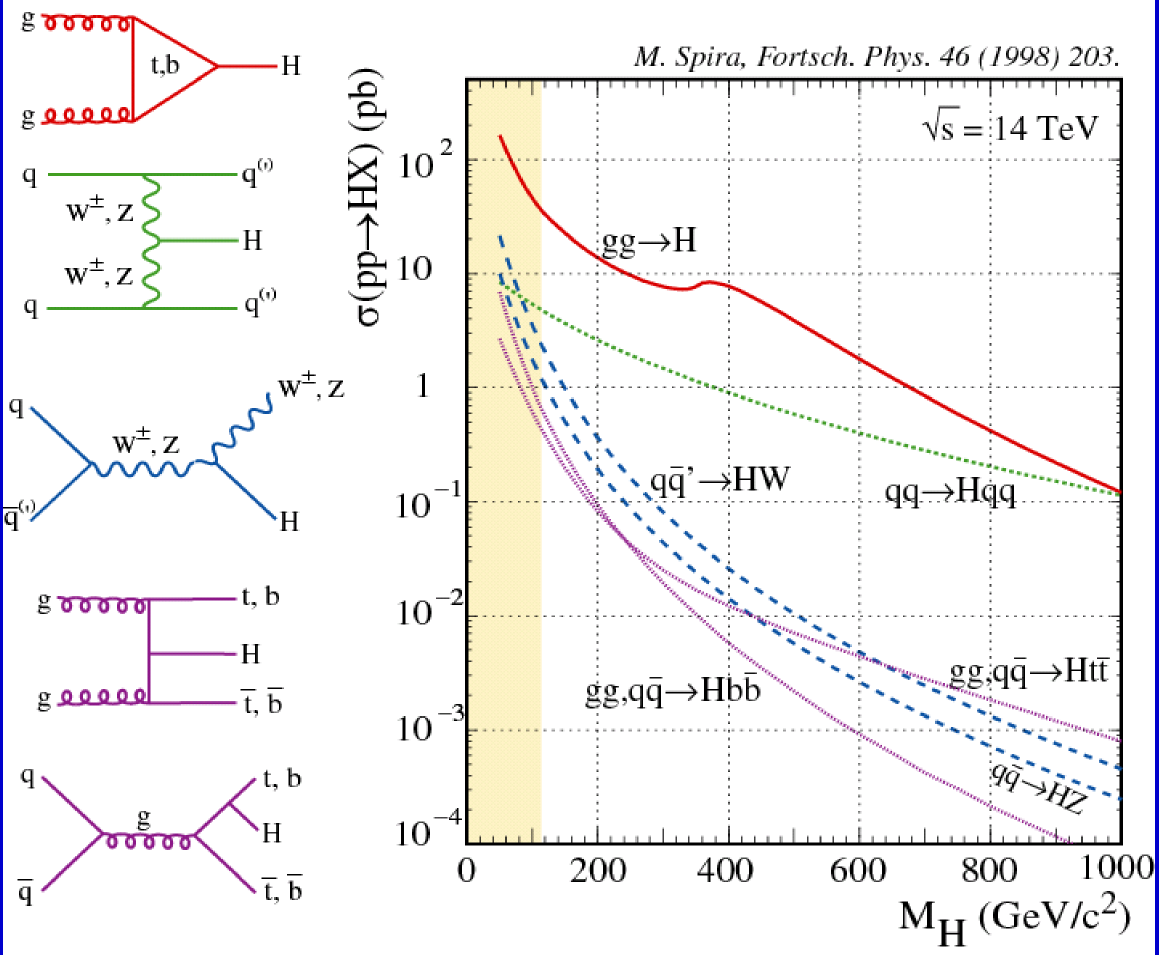
Higgs Production @ LHC

Gluon Fusion
- dominant process

Vector Boson Fusion
- 20% of gg @ 120GeV

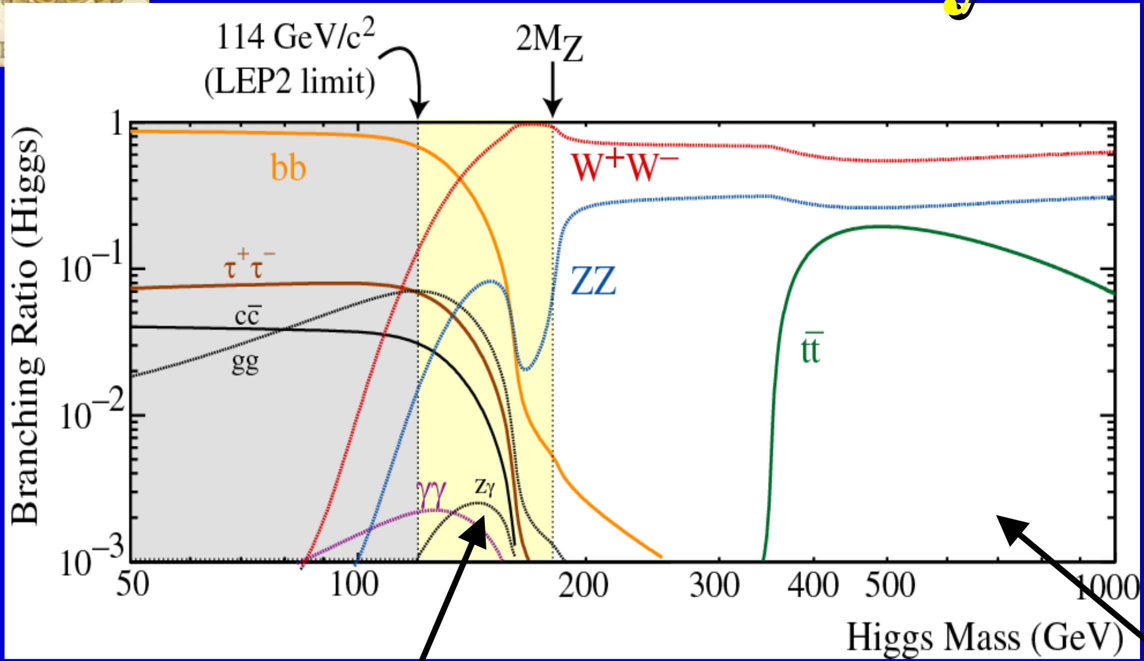
Associated Production
- W or Z (1-10% of gg)

Associated Production
- $t\bar{t}$ or $b\bar{b}$ (1-5% of gg)



4 production mechanism ➡ key to measure H-boson parameters

Main Discovery Channels



Dominant BR for $m_H < 2m_Z$:

$\sigma(H \to b\bar{b}) \approx 20$ pb;

$\sigma(b\bar{b}) \approx 500\ \mu$b

for m(H) = 120 GeV

→ no hope to trigger or extract fully had. final states

→ look for final states with ℓ, γ (ℓ = e,μ)

Low mass region: m(H) < 2 m_Z :

$H \to \gamma\gamma$: small BR, but best resolution

$H \to bb$: good BR, poor S/B ➔ ttH, WH

$H \to \tau\tau$: via VBF

$H \to ZZ^* \to 4\ell$

$H \to WW^* \to \ell\nu\ell\nu$ or $\ell\nu jj$: via VBF

m(H) > 2 m_Z :

$H \to ZZ \to 4\ell$

$qqH \to ZZ \to \ell\ell\ \nu\nu$ *

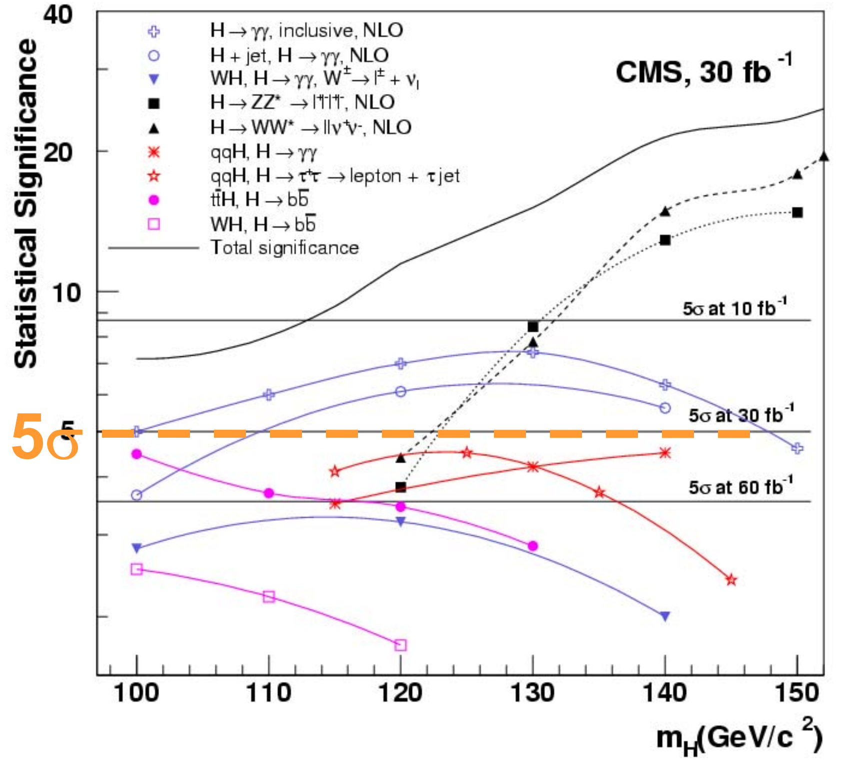
$qqH \to ZZ \to \ell\ell\ jj$ *

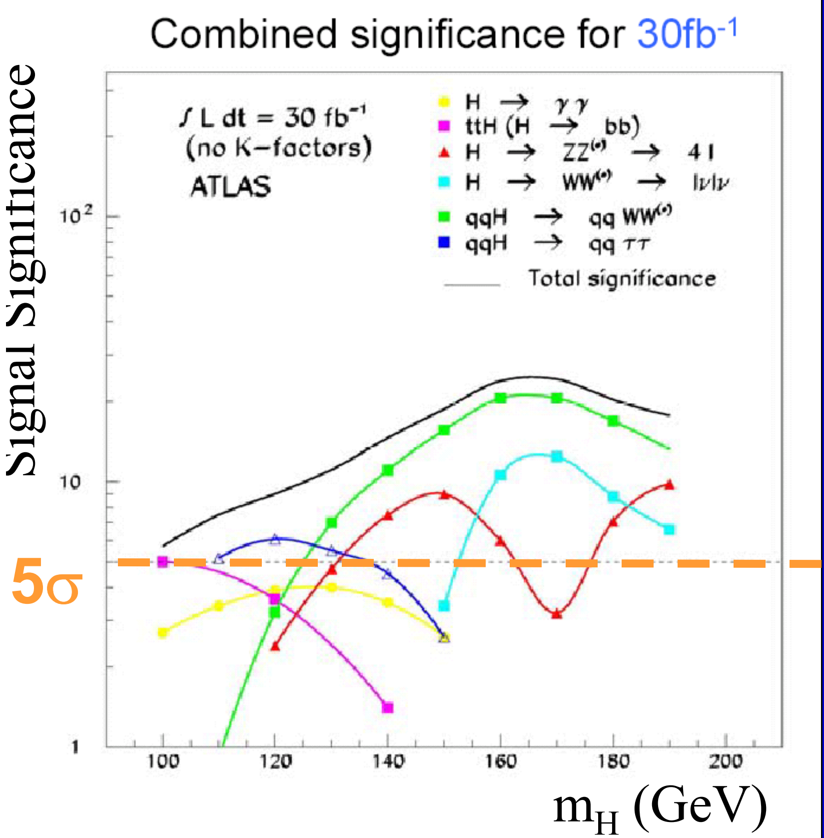
$qqH \to WW \to \ell\nu jj$ *

* for $m_H > 300$ GeV

forward jet tag

Discovery for $m_H < 2 \cdot m_Z$



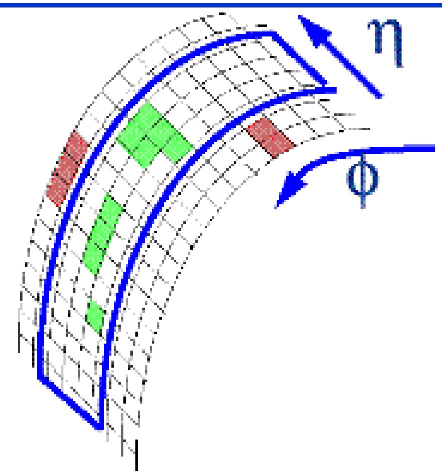


5σ significance for
$120 < m_H < 190$ GeV,
VBF channels will most likely be discovery channels

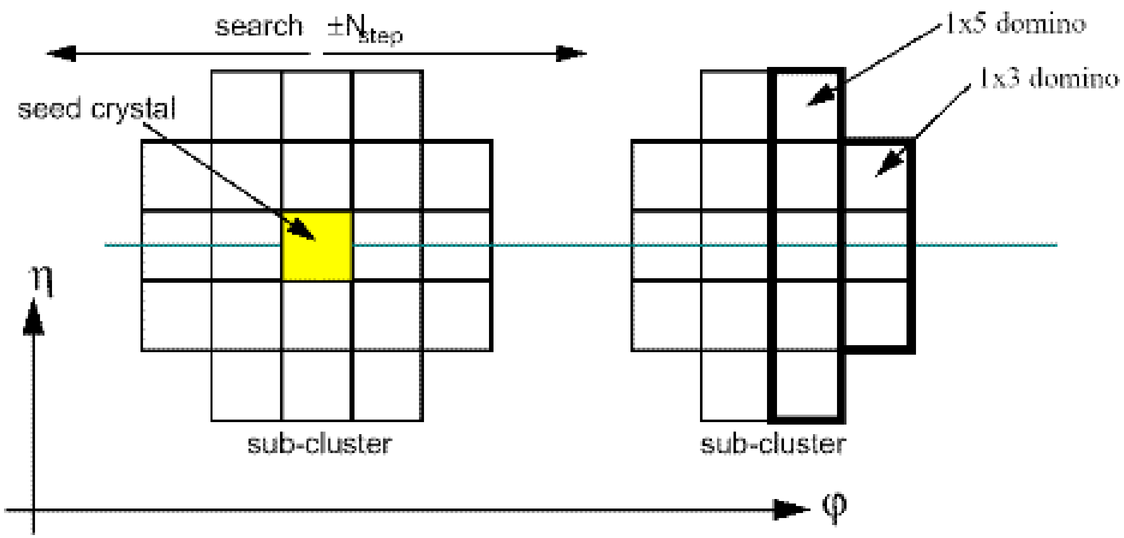
Several channels available over the full mass range

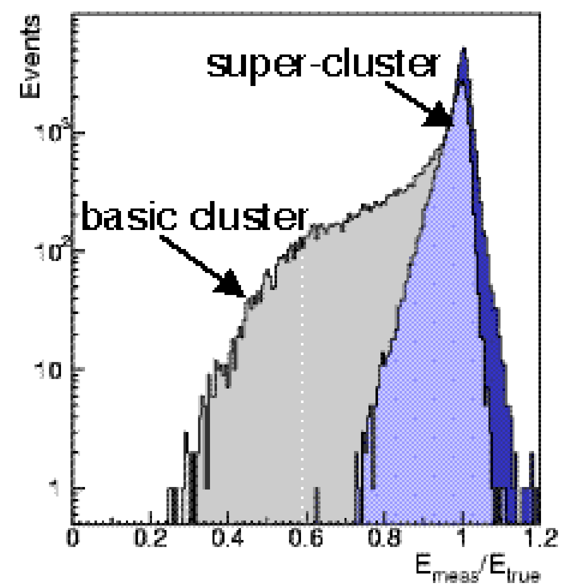
H→ZZ(*), WW(*): e reco

- Electron reco in high B=4T
- Shower shape reconstruction
- D0 – B=2T, interesting to try

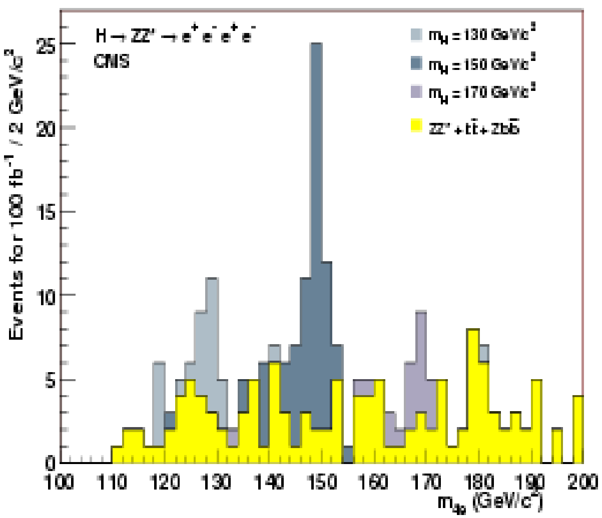


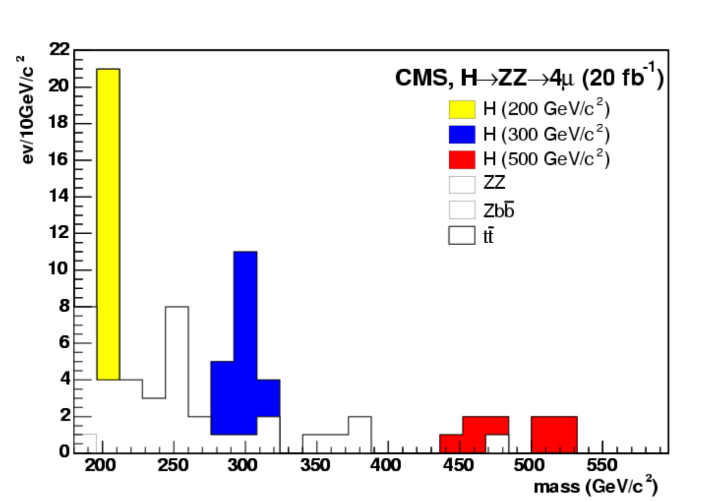
- *Brem recovery:*
  - Road along φ — in narrow η-window around seed
  - Collect all sub-clusters in road → "super-cluster"

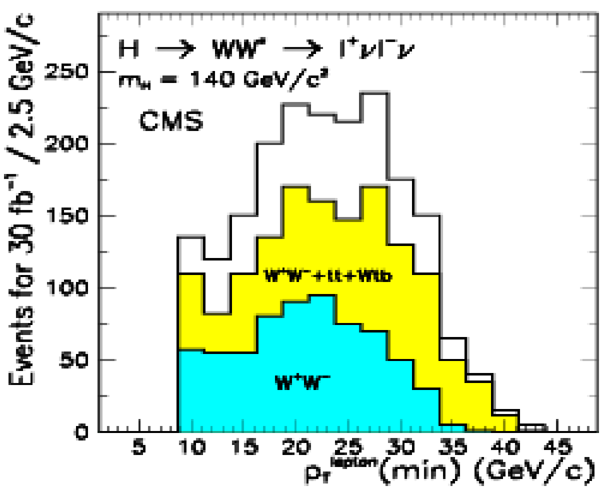




H→ZZ$^{(*)}$, WW$^{(*)}$



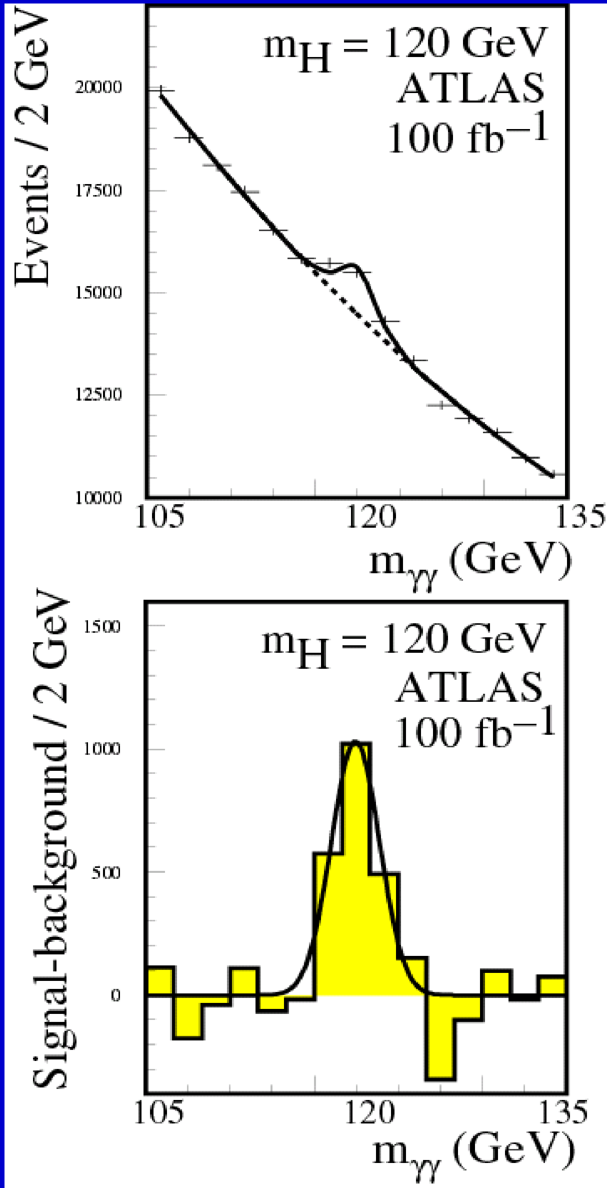




- Leading background processes:
  - Diboson production
  - tt
  - Z(W)+heavy flavor
- Production rates can be verified with TeV data

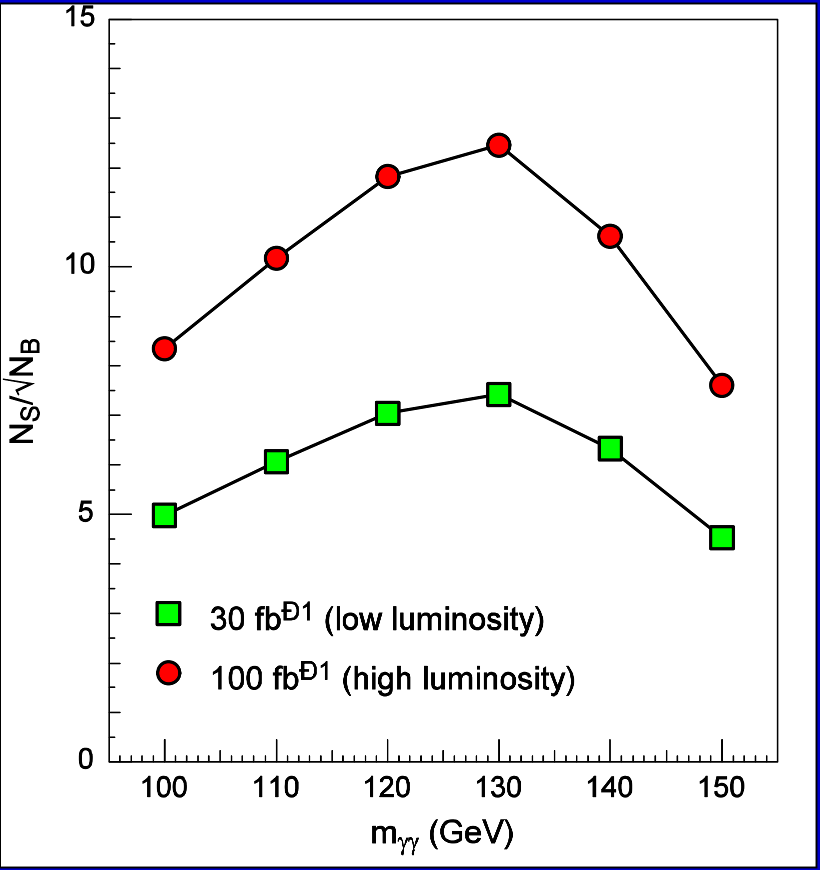
Higgs Search: H → γγ

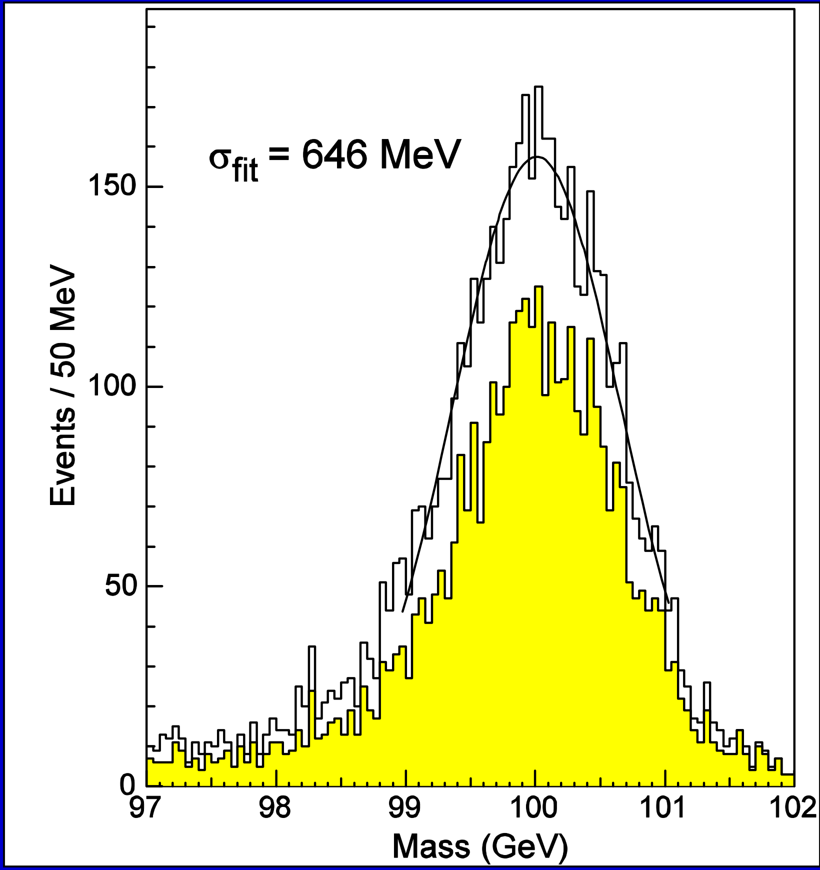
- Rare decay mode accessible for
  - $100 < m_H < 150$ GeV
- EM Cal to achieve ≈1% resolution on m_H
- Production mechanisms:
  - Gluon Fusion
  - Associated production (WH, ZH, ttH)
- Background:
  - dominated by smooth continuum of γγ pairs
  - Excellent γ/jet separation needed
- Fraction of converted γ: reco
- Signal significance: 2.8 to 4.3σ for 100 fb^{-1}



$H \rightarrow \gamma\gamma$

- Due to new CMS tracker design 42.0 (59.5)% of photons convert before reaching barrel (endcap) ECAL

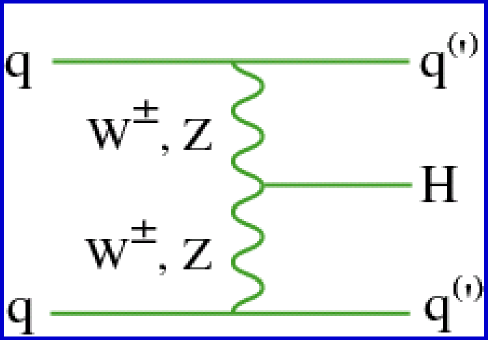




Converted – reco algorithms

Nonconverted γ

Light Higgs Search: VBF



Motivation

- Strong discovery potential for $m_H < 150$ GeV
- Determine Higgs parameters

Production

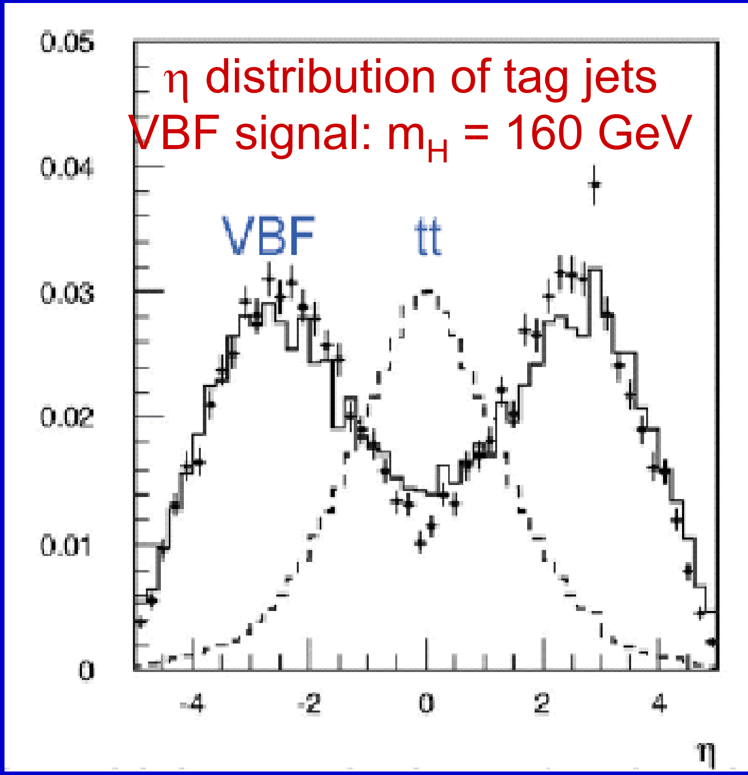
- $\sigma = 4$ pb = 20% of total σ ($m_H = 120$ GeV)

Decays

- $H \to WW^* \to \ell\nu\ell\nu, \ell\nu qq'$
- $H \to \tau\tau \to \ell\nu\nu\ell\nu\nu, \ell\nu\nu j$
- $H \to \gamma\gamma$

Distinct Final States

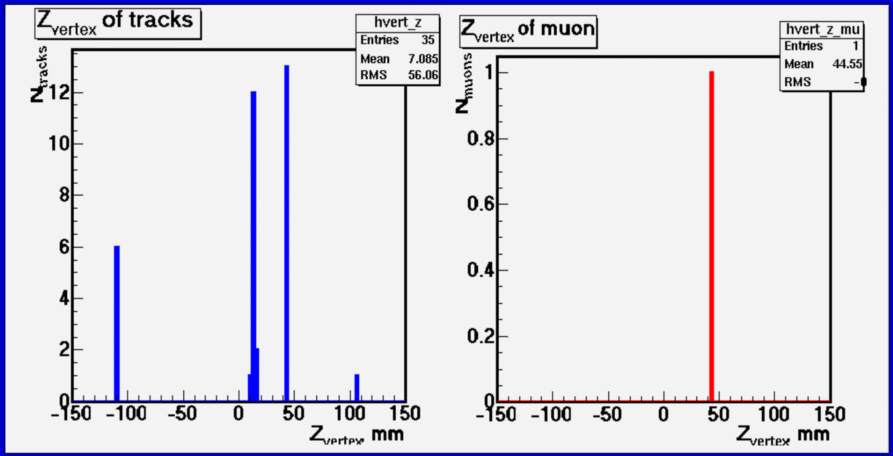
- Fragmentation of q which emitted W,Z
  - ➔Two high p_T jets with large $\Delta\eta$ (opposite hemispheres)
- Lack of color exchange in initial state
  - ➔Little jet activity in central region ➔ central jet veto

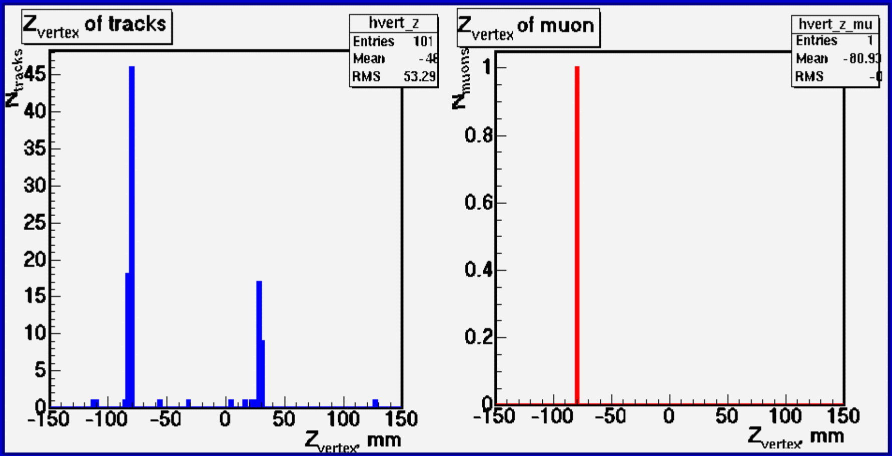


VBF: H→WW→μνjj

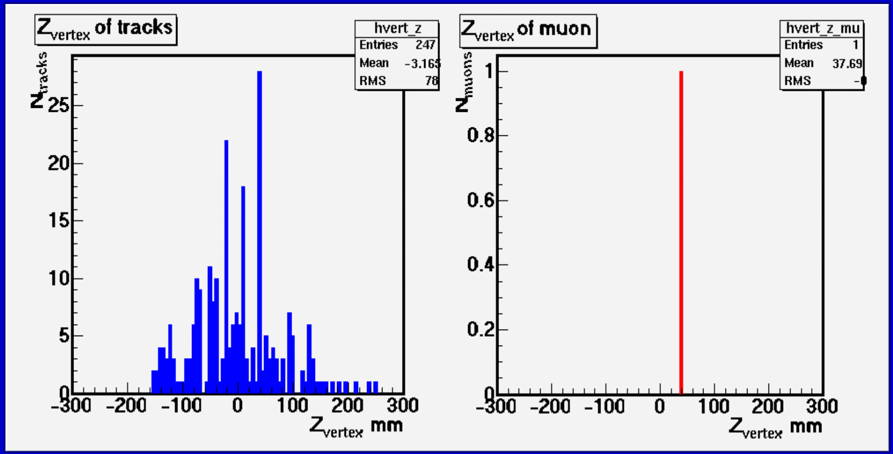
Muon's vertex – the good parameter for signal tracks determination

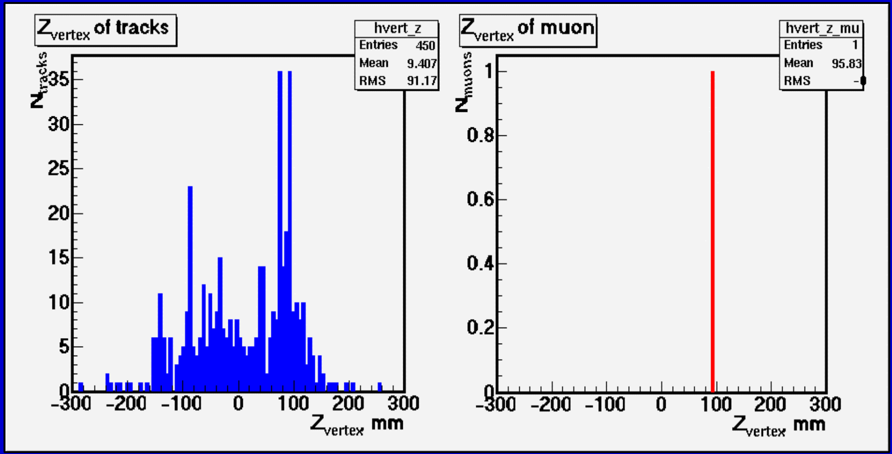
Low luminosity





High luminosity

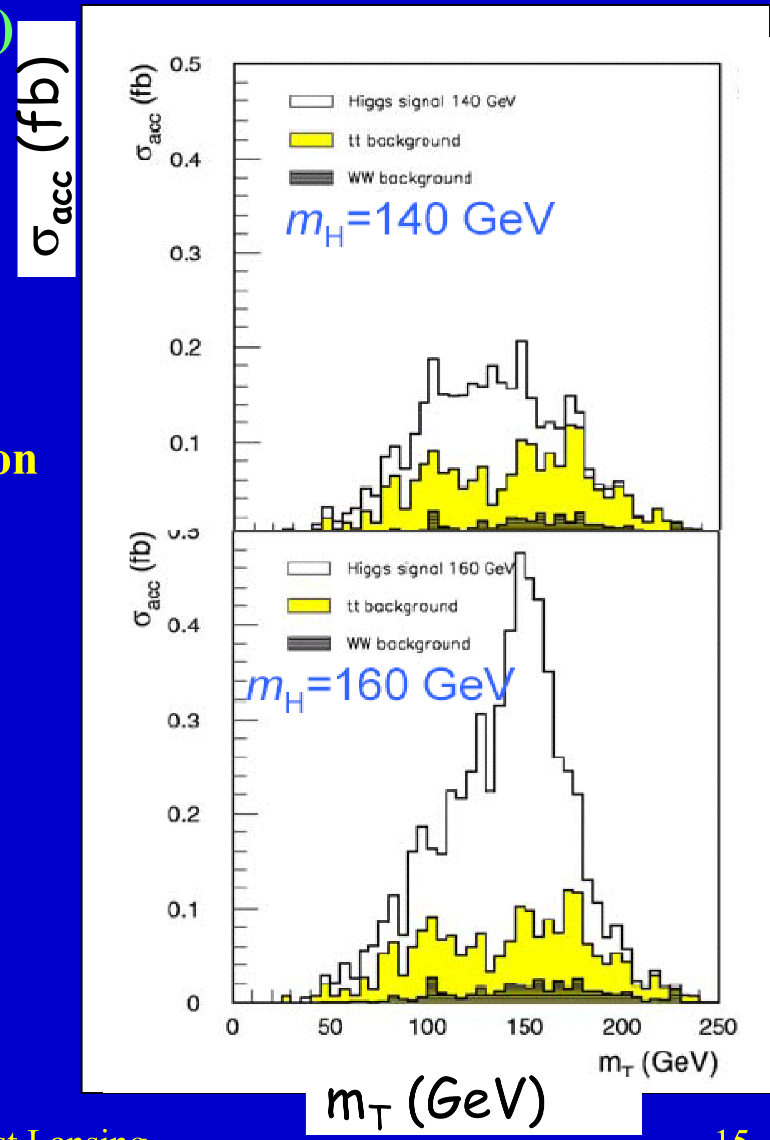




VBF: $H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$

- **Two isolated leptons** $p_T >$ (20 GeV, 15 GeV)
- **Two forward tag jets:**
  - $p_T >$ (40 GeV, 20 GeV); $\Delta\eta > 3.8$
    (e ≈ 50% with fake ≈ 1% @ 10^{34})
- **Central jet veto:** $p_T < 20$ GeV
- **lepton angular correlations** (anti-correlation of W spins from H decay)
  - $\delta\phi_{\ell\ell}$, $\cos\theta_{\ell\ell}$, $m_{\ell\ell}$

$$m_T = \sqrt{2 p_T^{\ell\ell} E_T^{miss} (1-\cos\phi)}$$

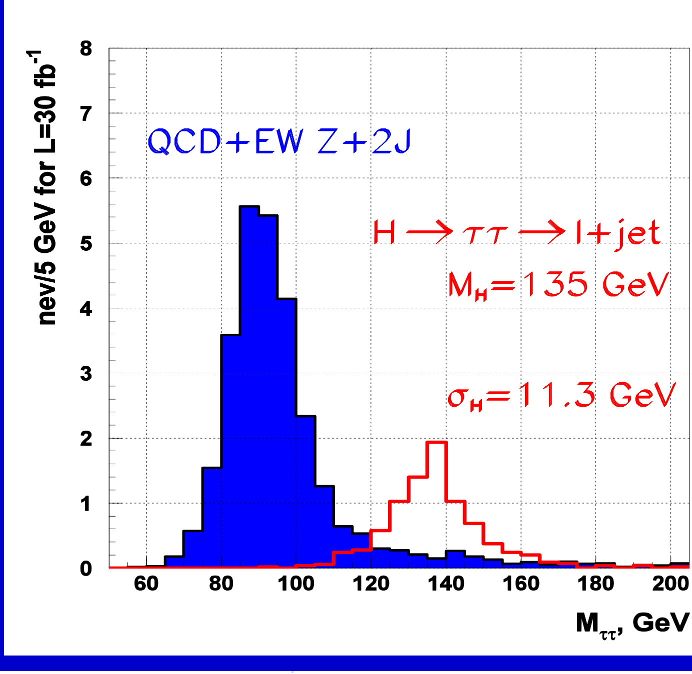


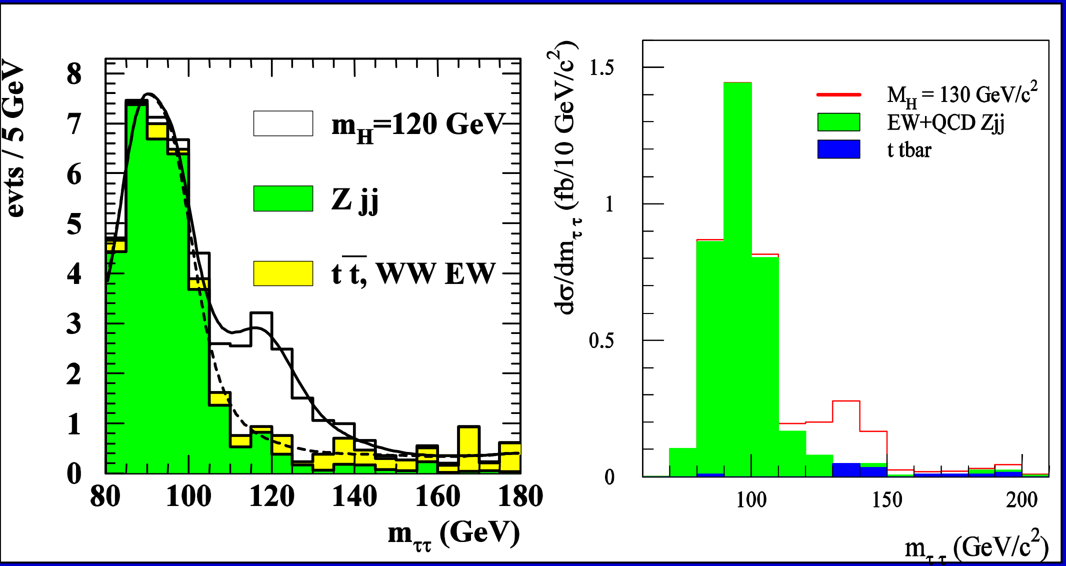
Results for 5 fb^{-1}, 5% background syst.

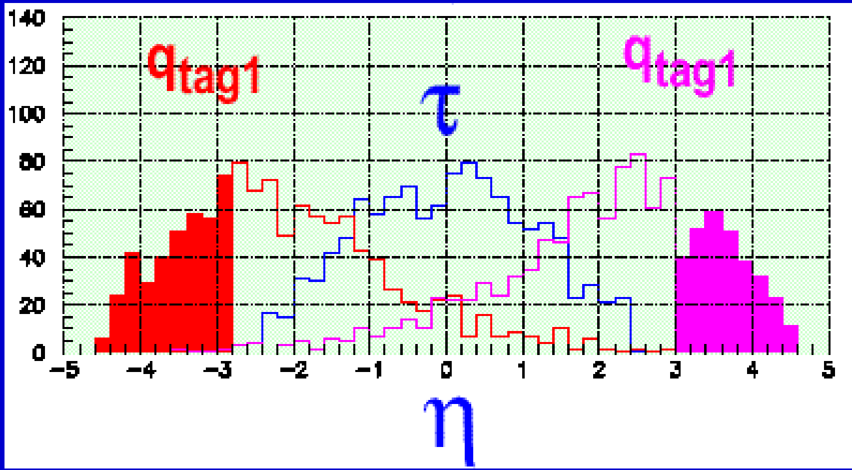
m_H (GeV)	130	150	170	190
Signal	5	13	22	14
Background	3	4	5	7
Significance	2.1	4.7	6.5	4.2

VBF: H→ττ

- $H \rightarrow \tau\tau \rightarrow \ell\nu\nu\ell\nu\nu, \ell\nu\nu j$
- Tau ID
- MT(lν)<30 GeV
- ET miss, mass window







Higgs Search: $t\bar{t}H \to t\bar{t}b\bar{b}$

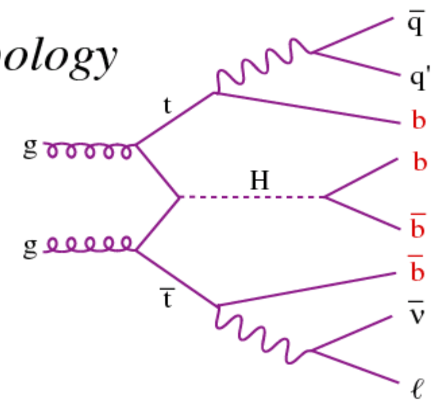
Challenging and complex topology

4 b-jets, 2 jets, 1 lepton

$H \to b\bar{b}$

$t \to b\bar{q}q'$

$\bar{t} \to \bar{b}\ell\nu$

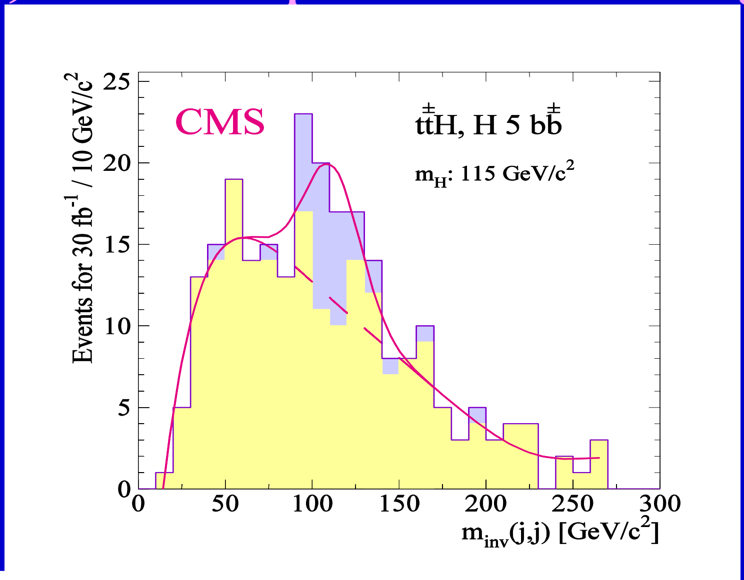


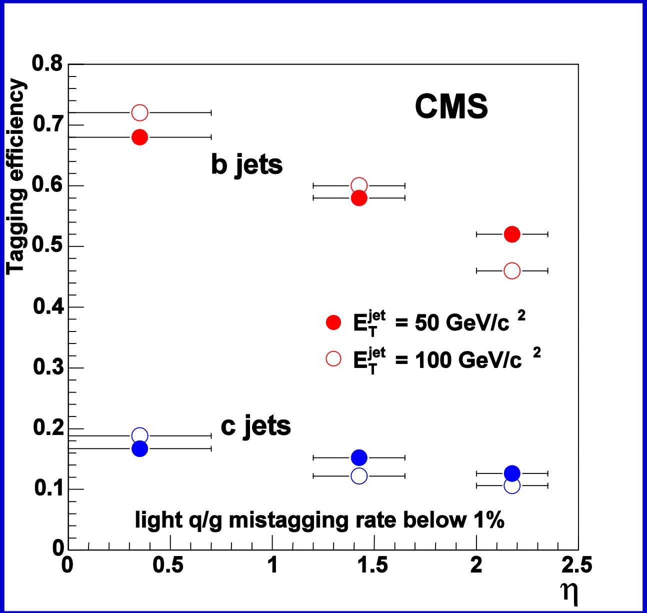
$\sigma \times BR \approx 300$ fb

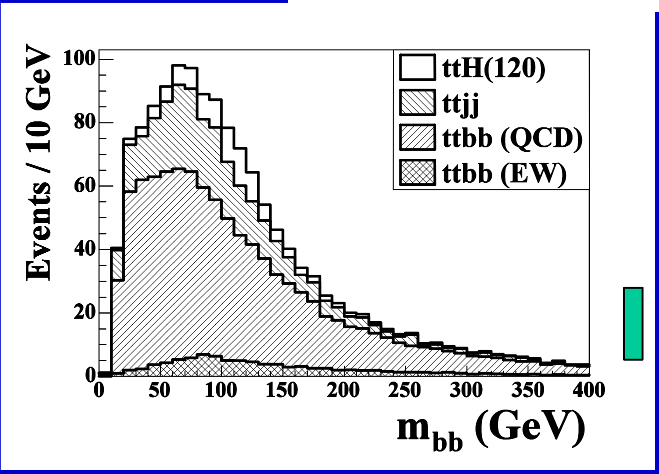
- Complementary to $H\to\gamma\gamma$
- Fully reconstructed final state (except ν)
- Requires good b-tagging
  - $\varepsilon_b \approx 60\%$, $R_{uds} \approx 100\%$
- Backgrounds:
  - Combinatorial from signal
  - Irreducible $t\bar{t}b\bar{b}$ ($t\bar{t}jb$, $t\bar{t}jj$)
- Signal significance (5σ) :
  - $m_H < 120$ GeV needs 100 fb^{-1}
  - $m_H < 130$ GeV needs 300 fb^{-1}

LHC: ttH, H→bb

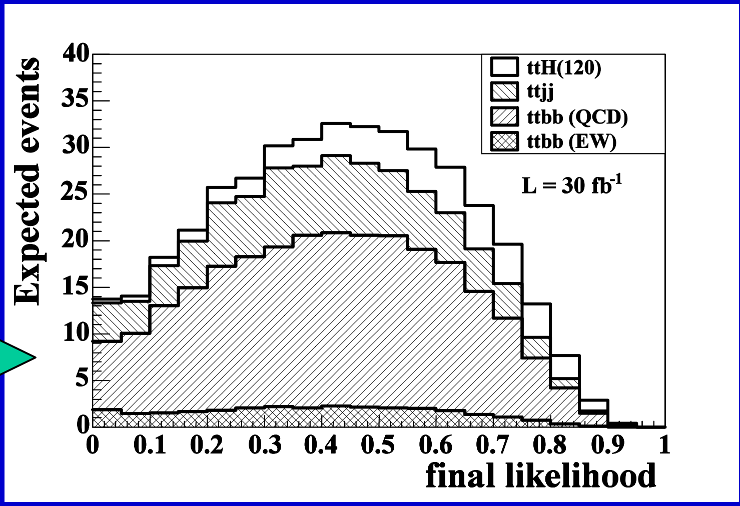
- CMS, Atlas – parametric b-tag







Atlas



LHC: ttH, H→bb

- Main uncertainty –normalization for ttH, ttbb, ttjj

	CMS	ATLAS
Structure function	CTEQ4L	CTEQ5L
Q^2_{QCD}	m^2_H for $t\bar{t}H$, $t\bar{t}Z$ $m_t^2 + \left(p^2_{T\,t_1} + p^2_{T\,t_2} + p^2_{T\,q_1} + p^2_{T\,q_1}\right)/4$ for $t\bar{t}q\bar{q}$	$(m_t + m_H/2)^2$ for all but $t\bar{t}jj$
LO cross sections in pb		
$ttH(100)\times BR_{H\to bb}$	1.09	0.69
$ttH(115)\times BR_{H\to bb}$	0.65	0.43
$ttH(130)\times BR_{H\to bb}$	0.32	0.24
$t\bar{t}b\bar{b}$	3.3 **Generation level cuts**	8.6
$t\bar{t}jj$	507	474
CMS: $t\bar{t}Z$	0.65	
ATLAS: $gg\to Z/\gamma/W\to t\bar{t}b\bar{b}$		0.9

Table 17: Settings and cross sections in the CMS and in the current ATLAS analysis (no K factors).

ttH, H$\rightarrow$bb

- ttH – discovery mode at low M(H)
- Tree level couplings at production and decay
- Probes top-Yukawa coupling – particularly interesting since ~1

more in T.Tait's talk

- Background processes
  - ttbb (dominates if 4 b-tags are required);
  - ttjj (comparable if >=3 b-tags=2 b's from tt+1mistag)
- Background processes are best calibrated in the absence of signal
  - Tevatron can help

Production mechanisms

- tt production
  - Tevatron (ppbar, 1.98 TeV): 85% quark annihilation, 15% gluon fusion
  - LHC (pp, 14 TeV) → 100% gluon fusion
- tt+jets
  - Initial state radiation — different
  - B-jet radiation
  - W-decay product radiation
  - t-radiation

  (B-jet, W-decay product and t-radiation: similar)

Production rates and statistics

- Production rates

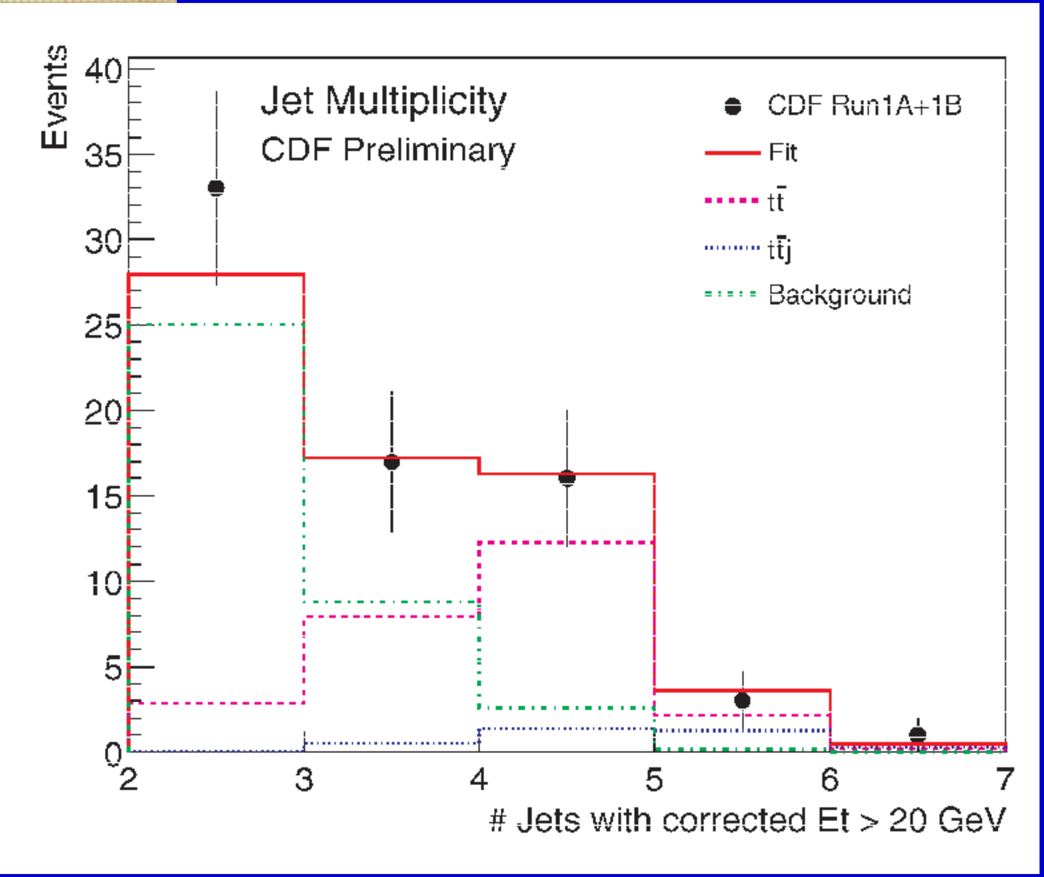
	ttH, fb	tt+0j, pb	tt+1j, pb	tt+2j, pb	tt+2b, pb
TeV	5	6	2.5	0.56	0.0066
LHC	700	533	665	273	3.2

- Expected number of events in W→lν +jets channel
  - Tevatron: L=5 fb^{-1}
  - LHC: L=$10^4 pb^{-1}$

	ttH	tt+0j	tt+1j	tt+2j	tt+2b
TeV	3.625	4350	1813	406	4.75
LHC	1015	772850	964250	395850	4631

- ttbb – the rate is too small to observe at Tevatron

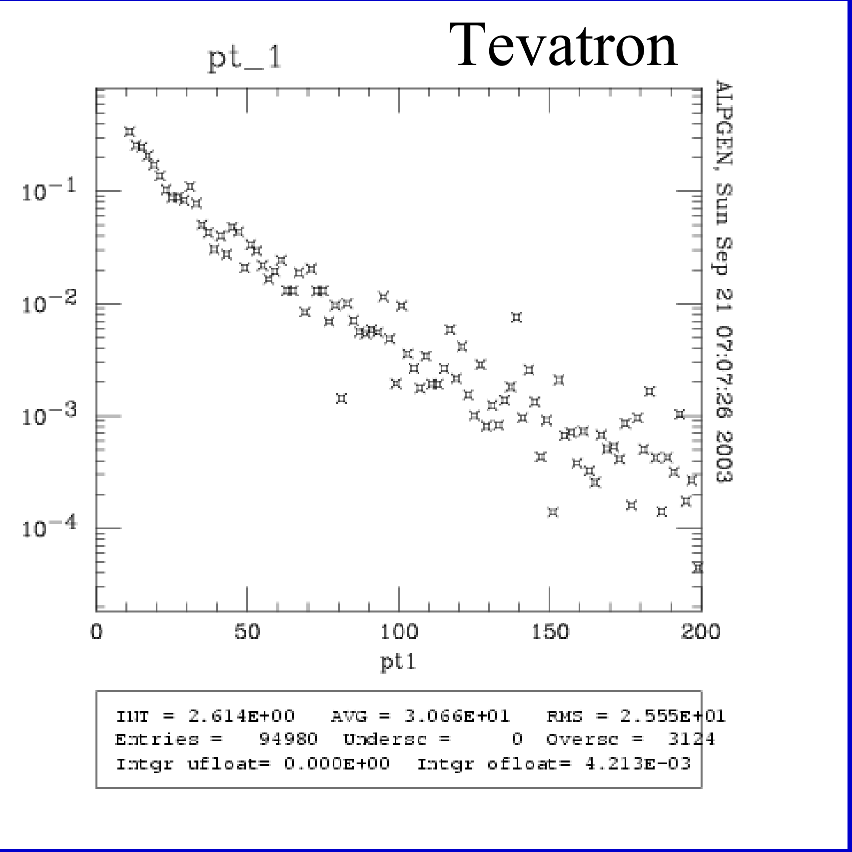
CDF Run 1 result

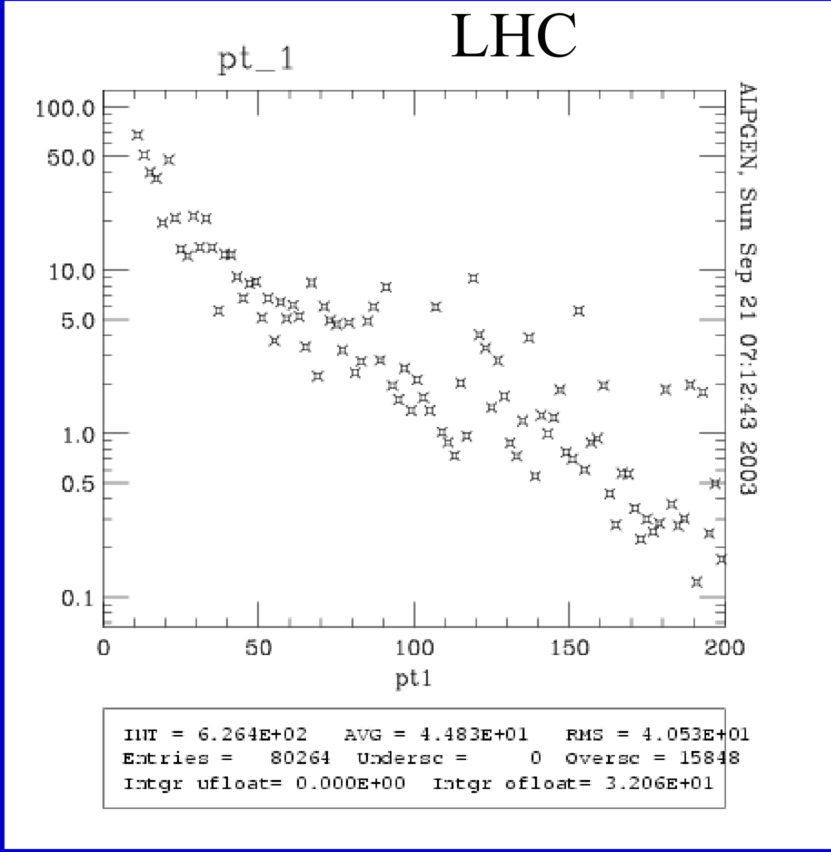


- Integrated luminosity 100 pb^{-1}, W+njets (>=1b-tag)
- Contributions:
  - W+jets; tt, tt+j
- $F(ttj)=5.1^{+8.4}_{-5.9}\%$
- $\sigma(ttj)/\sigma(ttX)<0.48$ @90%
- Theory 0.42

Kinematics

- Good news – very similar jet Et spectrum:
  - <Et>(TeV)=30GeV
  - <Et>(LHC)=45GeV





Tevatron contribution

- Monte Carlo verification and tuning for ttjj production
  - Final state radiation is very similar to LHC
  - Initial state radiation must be studied on gluon fusion dominated processes, e.g. bb production
  - Separation can be done with invariant mass selection:
    - M(bWj)=~M(t) – b-jet radiation
    - M(jjj)=~M(W) – W decay products radiation
    - Forward jets - ISR
- Analyses methods development and verification
  - B-tagging
  - B-charge tagging
  - Kinematic constraints

Summary

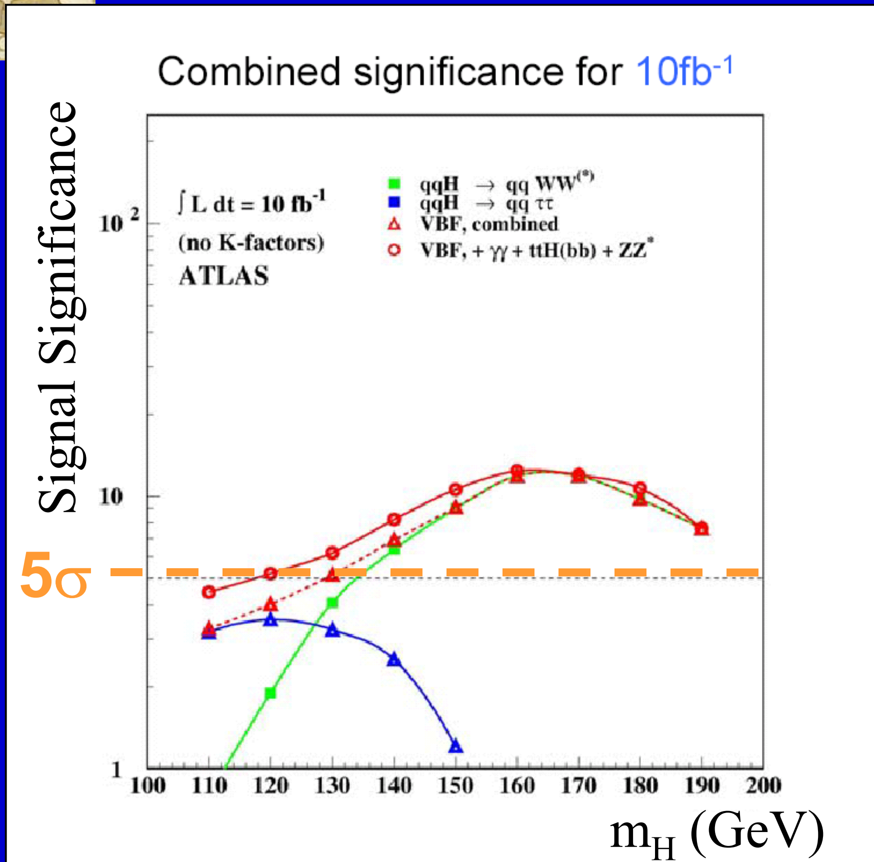
- LHC Higgs discover reach covers entire range of interesting Higgs masses
- Many different channels contribute to sensitivity
- Understanding of the background processes is the key
  - Tevatron will be able to help constraint production parameters for many background processes
    - Diboson, tt, ttjj, W/Z+heavy flavor production
  - Several new algorithm approaches can also be tested in TeV environment

Fermilab LHC physics center

- LHC Tracking Workshop at Fermilab, August 3-4
  - http://web.pas.rochester.edu/~regina/trk_wksh.html
- TeV4LHC workshop, September 16-18
  - http://cepa.fnal.gov/personal/mrenna/tev4lhc/

Backup slides

Discovery for $m_H < 2 \cdot m_Z$



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Several channels available over the full mass range