Search for New Physics at LHC

Hai-Jun Yang
University of Michigan
Tsinghua University

Weihai Summer Forum on Frontiers of
High Energy Physics – LHC Physics
Weihai, China on July 8-12, 2008

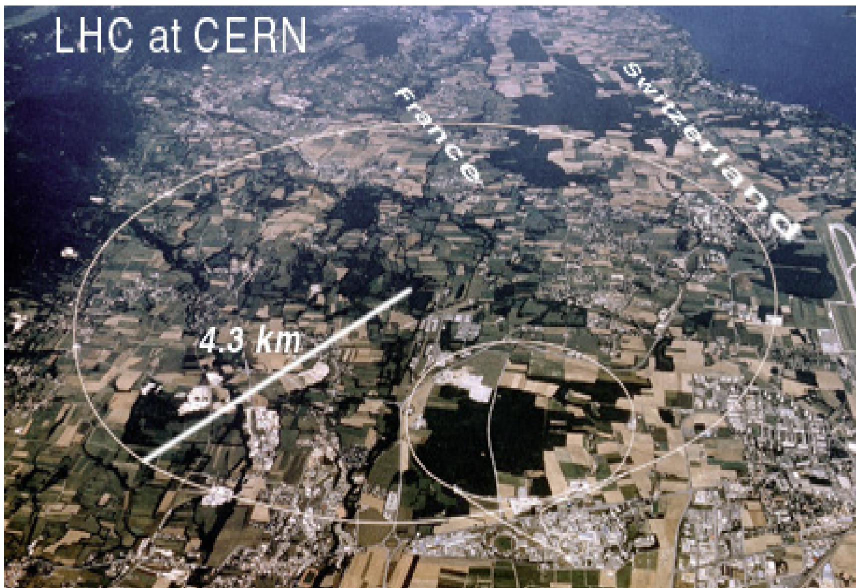
Outline

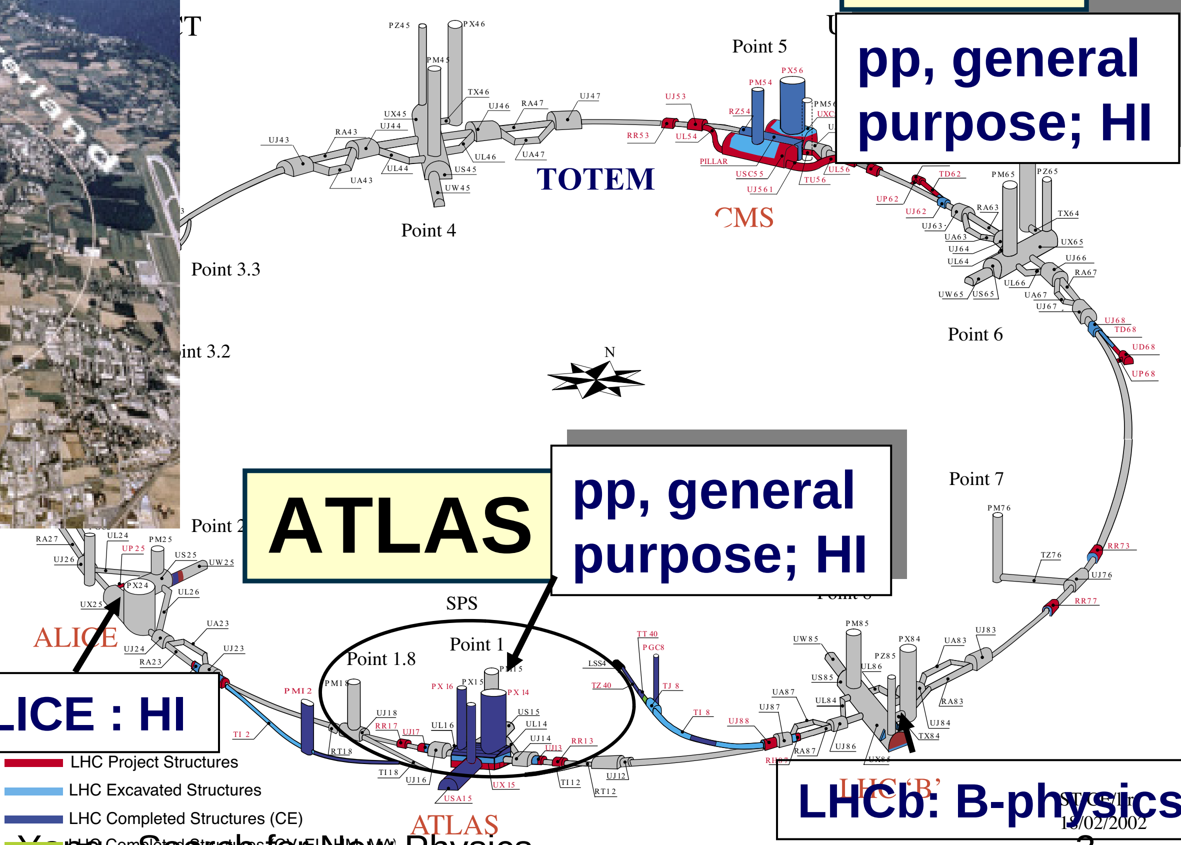
- **Introduction**
- **'Re-discover' the Standard Model with early LHC data**
  - Studies on vector gauge bosons
  - Indirect Search for new physics through anomalous Triple-Gauge-Boson Couplings
- **Search for new physics through diboson and ttbar events**
  - SM Higgs → WW → $l\nu l\nu$
  - Z' → ttbar → bbWW → bbjj$l\nu$
  - GMSB particle searches: $\tilde{\chi}^0_1 \tilde{\chi}^0_1$ → ZZ $\tilde{G}\tilde{G}$ → $l^+l^-l^+l^-$ +MET
- **Development of advanced particle identification algorithm**
  - Boosted Decision Trees, Event Weight Training Technique
  - A general search strategy to improve physics discovery potential
- Materials presented in this talk are based on LHC physics studies by Hai-Jun Yang with the Michigan ATLAS group members

The Large Hadron Collider at CERN

CME = 14 TeV, Lumi = 10^{34} cm^{-2} s^{-1}

26.7 km Tunnel in Switzerland & France





CMS

pp, general purpose; HI

ATLAS

pp, general purpose; HI

ALICE : HI

LHCb: B-physics

First Collision: Fall 2008

LHC Physics Run in 2008-2009

- First pp collisions (10 TeV) start in Fall, 2008, stop the pilot run before Christmas, 2008.
- pp collisions at 14 TeV start in April 2009, Luminosity would ramp up to 10^{33} $cm^{-2}s^{-1}$
- Integrated luminosity: a few fb^{-1}
  - Detector calibration to 1-2% accuracy
  - Detector performance validation by measuring cross sections of SM processes (dijets, W, Z, ttbar, diboson)
  - Serious searches with a few fb^{-1} include:
    - Higgs → WW (M_H from 140 GeV – 180 GeV)
    - W' and Z' in TeV mass region
    - SUSY signature

Physics Reach as Integrated Lumi. Increase

Luminosity 1 mon run	Int. Lumi. (1/fb)	Interest proc. (with e, μ, γ)	X-section	Events for calibration and measurements
10^{29}	0.0001 (100 nb^{-1})	$W\to\mu\nu$, $e\nu$(DY) J/ψ, $y\to\mu\mu$, ee	$\sigma_{\mu\nu}$ ~20nb	Detect 1000 μ ($W\to\mu\nu$) ~800 J/ψ, ~100 y
10^{30}	0.001 (1 pb^{-1})	$Z\to$ $\mu\mu$, ee ttbar	$\sigma_{\mu\mu}$ ~ 2nb σ_{tt} ~ 750pb	Detect 1500 $\mu\mu$ from Z Detect 800 tt
10^{31}	0.01 (10 pb^{-1})	Z+jet $\gamma\gamma$, $W\gamma$, $Z\gamma$	$\sigma_{q\mu\mu}$ ~ 40 pb $\sigma_{\gamma\gamma}$ ~ 24 pb	400 Zjet events, JE cali. 250 $\gamma\gamma$ with M>60 GeV
10^{32}	0.1 (100 pb^{-1})	WZ, WW, Z+ n jets	$\sigma_{e\mu}$ ~2.4pb	~50 eμ from WW selection ~10 trilepton events (WZ)
10^{33}	1.0 (10M $W\to l\nu$) (1M $Z\to ll$) Understand detect ~2%	$ZZ\to 4l$, $ll\nu\nu$ $H\to WW$? $W'\to e/\mu\ \nu$? $Z'\to ee$, $\mu\mu$? SUSY?	σ_{4l} ~ 0.08pb	~ 11 $ZZ\to 4l$, 10 $ZZ\to ll\nu\nu$ Searches: Single μ M_T > 1 TeV dilepton mass > 1 TeV Higgs $\to$WW (~165 GeV) SUSY $\to$ multi-leptons

Re-discover Standard Model
– A Steppingstone to Discover New Physics

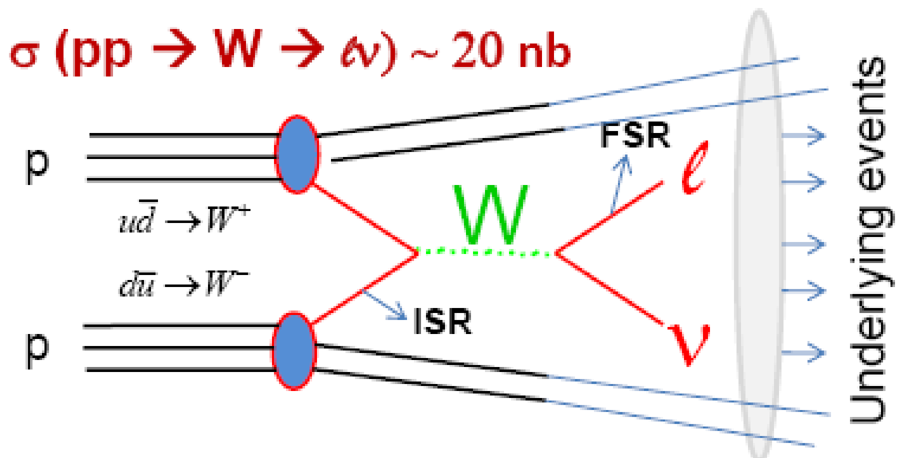
Our search for new physics at LHC will start with

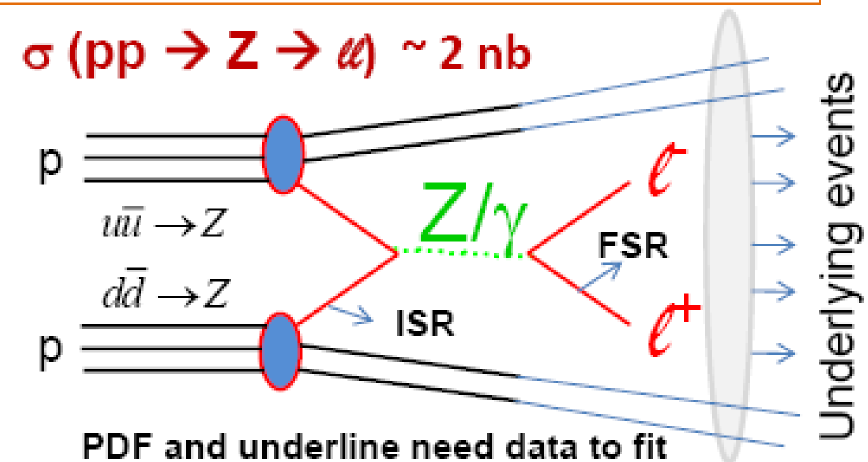
- W and Z productions: the standard candles
  - demonstrate the detector performance
  - constrain the PDF
- Diboson (WW, WZ, ZZ, Wγ, Zγ) physics
  - test the SM in high energy region
  - probe the anomalous triple-gauge boson couplings
  - understand the diboson background for new physics signature
- Two methods used in the analysis
  - Cut-based (classical method)
  - Boosted Decision Trees (a new multivariate analysis tool developed at UM by H. Yang et al.)

H. Yang et.al. NIM A555 (2005)370, NIM A543 (2005)577, NIM A574(2007) 342

W and Z Productions in Hadron Colliders

EW theory predicts '*hard scattering*' well, but in hadronic collisions, the process is complicated by parton-distributions inside protons, and associated underlying events





Standard W Candle

- σ(W→ μν) as the 1st standard candle to set LHC Luminosity
- First energy scale: $M_T(W)$ tail
- W+/W- charge asymmetry: PDF fit
- Searches:
  - M_T spectrum
  - P_T spectrum

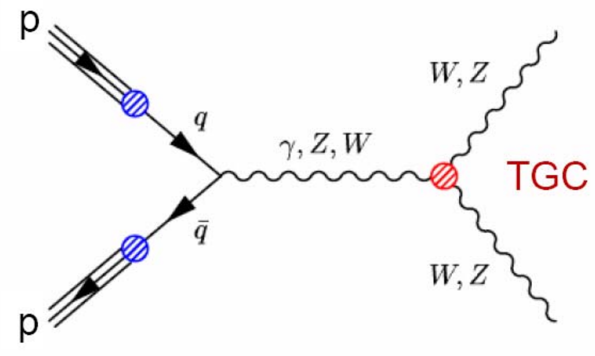
Standard Z Candle

- σ(Z→ μμ) as the standard candle to determine LHC Luminosity
- Energy scale: $M_{\mu\mu,\, ee}(Z)$ peak
  - calibration
- η_Z, $P_T(Z)$: PDF fit
- Detection effs. ($\varepsilon_{Trigger}, \varepsilon_{ID}, \varepsilon_{Isolation}$ …)
  - Tag-Probe method
- Searches: dilepton inv. high mass

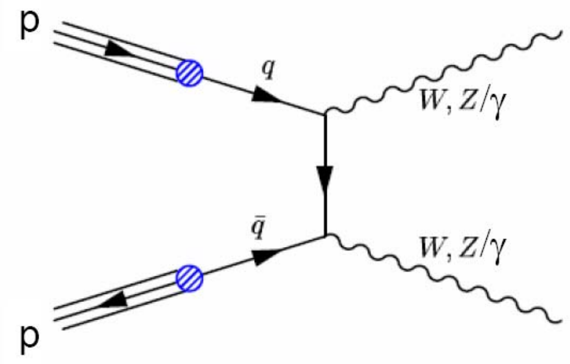
Physics Motivations - Diboson

ATL-COM-PHYS-2008-036, ATL-COM-PHYS-2008-041

- It's related to some fundamental questions:
  - Why massive bosons?
  - What is the source of the EWSB?
- There should have some new physics leading to EWSB through searching for
  - Direct evidence of new particles (Higgs, SUSY etc.)
  - Indirect evidence of observing anomalous TGCs
  - SM diboson are important control samples for new physics



s-channel



t-channel

Diboson Production Cross Sections

Diboson mode	Conditions	$\sqrt{s} = 1.96$ TeV $\sigma[pb]$	$\sqrt{s} = 14$ TeV $\sigma[pb]$
W^+W^- [14]	W-boson width included	12.4	111.6
$W^\pm Z^0$ [14]	Z and W on mass shell	3.7	47.8
Z^0Z^0 [14]	Z's on mass shell	1.43	14.8
$W^\pm\gamma$ [15]	$E_T^\gamma > 7$ GeV, $\Delta R(\ell,\gamma) > 0.7$	19.3	451
$Z^0\gamma$ [16]	$E_T^\gamma > 7$ GeV, $\Delta R(\ell,\gamma) > 0.7$	4.74	219

Production rate at LHC will be at least 100x higher at Tevatron.
10x higher cross section and 10-100x higher luminosity.

Probes much higher energy region, so sensitive to anomalous TGCs.

Diboson Results with $1fb^{-1}$ Int. Lumi

Diboson mode	Signal	Background	N_σ	Analysis (signal eff.)	σ_{stat}^{signal}
$W^+W^- \to e^\pm \nu \mu \mp \nu$	419.9 ± 3.5	80.8 ± 8.0	47	BDT (eff=15.2%)	4.9%
$W^+W^- \to \mu + \nu \mu^- \nu$	90.3 ± 1.6	20.2 ± 2.8	20	BDT (eff=6.6%)	10.5%
$W^+W^- \to e^+ \nu e^- \nu$	78.0 ± 1.6	35.4 ± 3.6	13	BDT (eff=5.7%)	11.3%
$W^+W^- \to \ell^+ \nu \ell^- \nu$	103.1 ± 2.6	16.6 ± 2.0	25	Cut based (eff=2.0%)	9.9%
$W^\pm Z \to \ell^\pm \nu \ell^+ \ell^-$	152.6 ± 1.7	16.1 ± 2.5	38	BDT (eff=17.9%)	8.1%
	53.4 ± 1.6	8.0 ± 1.1	19	Cut based (6.3%)	13.7%
$ZZ \to 4\ell$	16.5 ± 0.1	1.9 ± 0.2	7.2	Cut based (eff=7.7%)	24.6%
$ZZ \to \ell^+ \ell^- \nu \bar{\nu}$	10.2 ± 0.2	5.2 ± 2.0	3.7	Cut based (eff=2.6%)	31.3%
$W\gamma \to e \nu \gamma$	1901 ± 77	1474 ± 147	50	BDT (eff=6.7%)	2.3%
$W\gamma \to \mu \nu \gamma$	2976 ± 121	2318 ± 232	62	BDT (eff=10.5%)	1.8%
$Z\gamma \to e^+ e^- \gamma$	337.4 ± 12	187.2 ± 19	25	BDT (eff=5.5%)	5.4%
$Z\gamma \to \mu^+ \mu^- \gamma$	774.8 ± 25	466.7 ± 47	36	BDT (eff=12%)	3.6%

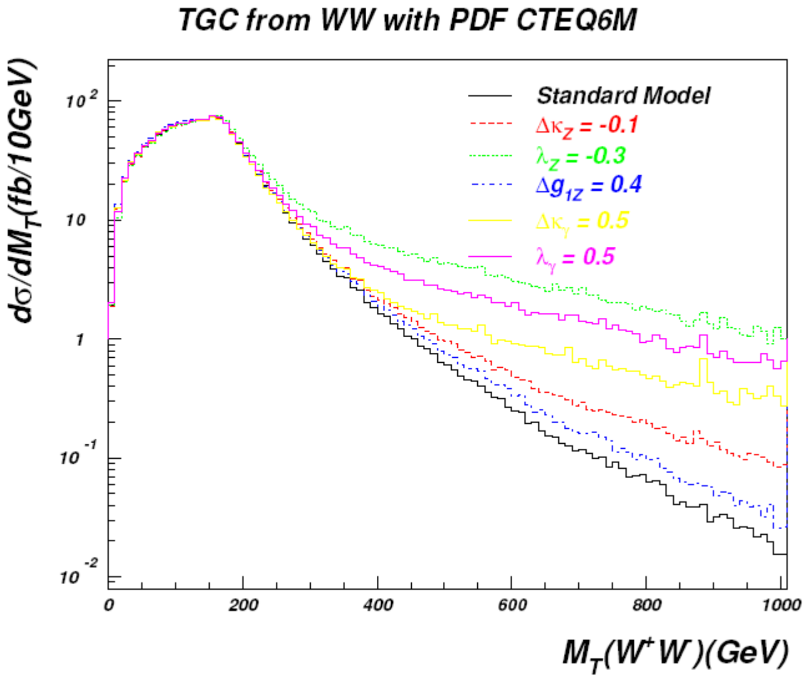
Search for **new physics** through anomalous TGCs with diboson events

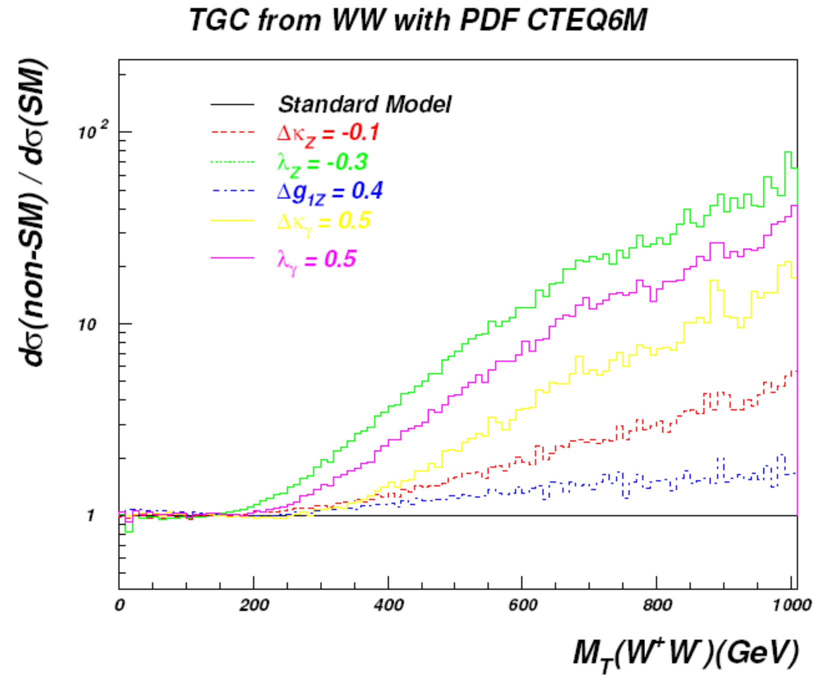
- Model independent effective Lagrangian with anomalous charged couplings
  $L_{WWV}/g_{WWV} = i\, \mathbf{g_1^V}(W^\dagger_{\mu\nu}W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu})$
  $+ i\, \boldsymbol{\kappa_V}\, W^\dagger_\mu W_\nu V^{\mu\nu} + i\, (\boldsymbol{\lambda_V}/M_W^2)\, W^\dagger_{\lambda\mu} W_\nu^{\ \mu} V^{\nu\lambda}$
  where $V = Z, \gamma$.

- In the standard model $g_1^V = \kappa_V = 1$ and $\lambda_V=0$.
  The goal is to measure these values, usually expressed as the five anomalous parameters $\boldsymbol{\Delta g_1^Z}$, $\boldsymbol{\Delta\kappa_Z}$, $\boldsymbol{\lambda_Z}$, $\boldsymbol{\Delta\kappa_\gamma}$, and $\boldsymbol{\lambda_\gamma}$
- In many cases the terms have an $\hat{s}$ dependence which means the higher center-of-mass energies at the LHC greatly enhance our sensitivity to anomalous couplings
- Complementary studies through different diboson channels

Production	**$\Delta\kappa_Z$, $\Delta\kappa_\gamma$ term**	**Δg_1^Z term**	**λ_Z, λ_γ term**
WW	**grow as $\hat{s}$**	**grow as $\hat{s}^{1/2}$**	**grow as $\hat{s}$**
WZ	grow as $\hat{s}^{1/2}$	grow as $\hat{s}$	grow as $\hat{s}$
Wγ	grow as $\hat{s}^{1/2}$	---	grow as $\hat{s}$

Anomalous spectra and reweighting ratio



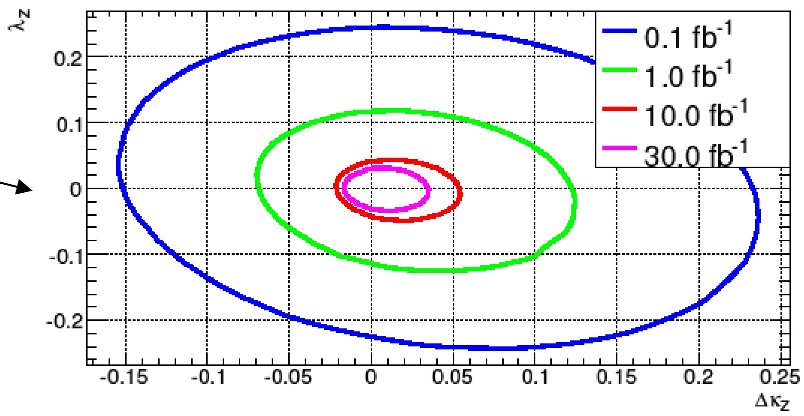


- The M_T(WW) spectrum for W^+W^- events with anomalous coupling parameters using the BHO Monte Carlo.
- At right are the 'ratios = dσ(non-SM)/dσ(SM)' used to reweight fully simulated events.

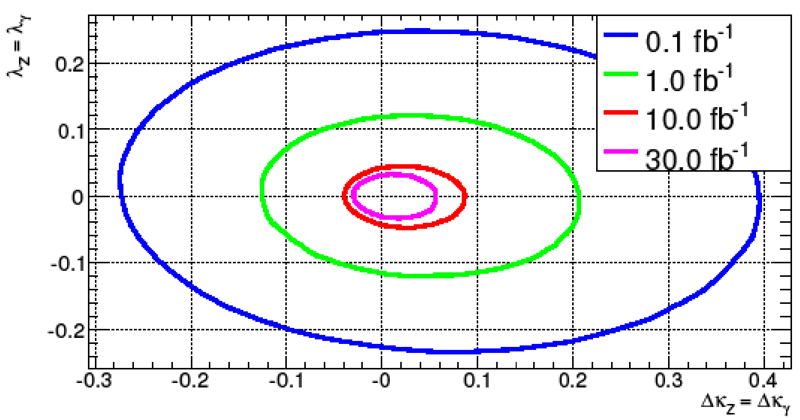
2D anomalous TGC sensitivity using $M_T(WW)$

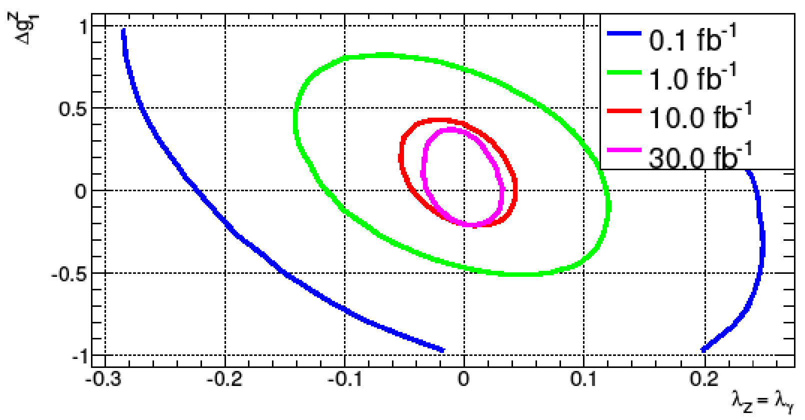
95% C.L. contours for 0.1, 1, 10, and 30 fb^{-1} integrated luminosity

Right: HISZ assumption (2 parameters)



Bottom: "Standard" assumption, Z param. = γ param. (3 parameters)





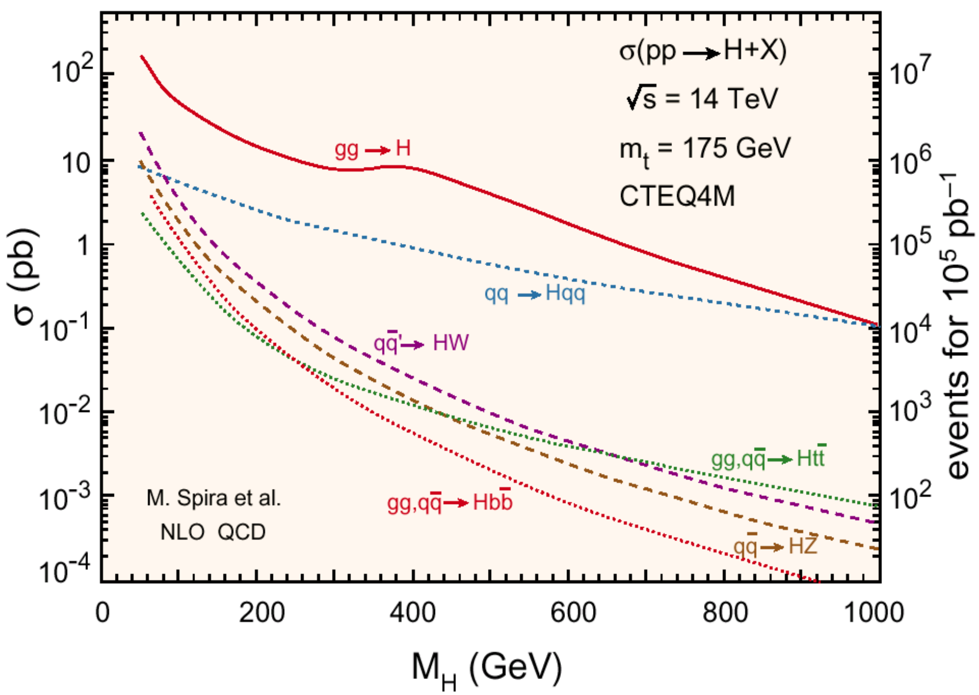
Search for New Physics with Diboson and ttbar Events

- We do not really know what new physics we could discover at LHC
- Many theoretical models predict that the new physics signature would show up in diboson, top-rich and large MET events.
- Three examples will presented based on UM group's studies

1) Search for SM Higgs → WW

(H. Yang et.al., ATL-COM-PHYS-2008-023)

Direct Search for SM H→ WW → lνlν



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

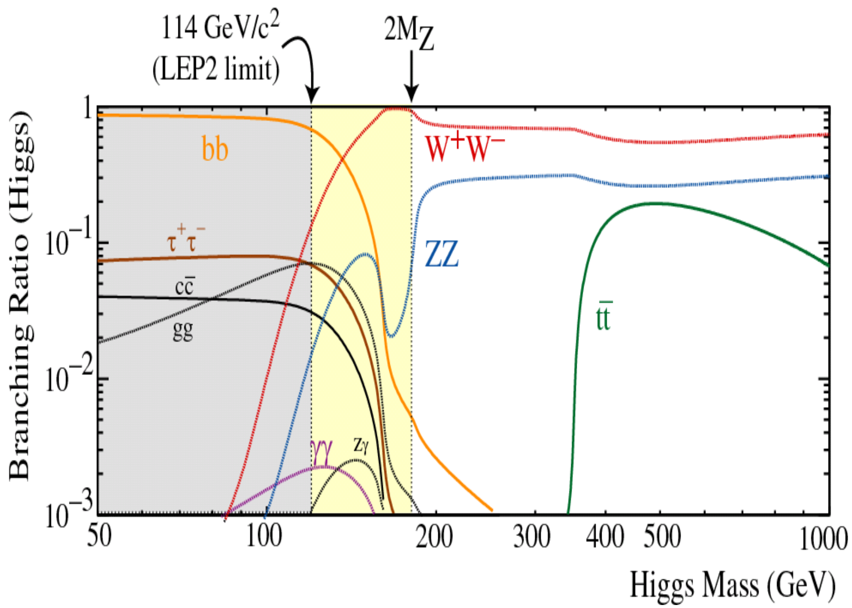
$H \rightarrow \gamma\gamma$

$H \rightarrow bb$

$H \rightarrow \tau\tau$

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

$H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$ or $\ell\nu jj$



➔Gluon-gluon fusion and WW/ZZ fusion are two dominant Higgs production mechanism

H → WW* → lνlν (l = e, μ)

- Cross sections of H → WW* → lνlν (GGF & VBF) at LO (Pythia), K-factor ~ 1.9

Higgs Mass	σ_{GGF}(fb)	σ_{VBF}(fb)	σ_{total}(fb)	filter efficiency	Br($pp \to H \to WW$)
140 GeV	328.2 (79%)	85.5 (21%)	413.2	0.9545	0.516
150 GeV	402.3 (79%)	109.8 (21%)	512.2	0.9573	0.704
160 GeV	467.0 (78%)	132.7 (22%)	600.3	0.9571	0.906
165 GeV	469.3 (77%)	135.7 (23%)	605.6	0.9579	0.960
170 GeV	448.2 (77%)	132.3 (23%)	580.4	0.9609	0.965
180 GeV	390.4 (76%)	119.3 (24%)	510.7	0.9657	0.933

H → WW signal and background simulations used ATLAS software release V12 (for CSC note)
Full ATLAS detector simulation and reconstruction

Background Studied

Process	MC sample	cross-section
• qq' → WW → lνlν (l=e,μ,τ)	372.5K,	11.72 pb
• gg → WW → lνlν (l=e,μ,τ)	209.1K,	0.54 pb
• tt → WWbb → l + X	584.1K,	450.0 pb
• WZ → lνll (l=e,μ)	281.4K,	0.7 pb
• Z → ll (l=e,μ,τ)	1.15 M,	4.6 nb

- W/Z + Jets are potential background, using 1.1M fully simulated MC events (Alpgen generator), no event is selected in our final sample
- Background estimate uncertainty ~ 15 – 20 %.

$H \rightarrow WW$ Pre-selection

- At least one lepton pair (ee, μμ, eμ) with $P_T > 10$ GeV, $|\eta|<2.5$
- Missing $E_T > 20$ GeV, $\max(P_T(l), P_T(l)) > 25$ GeV
- $|M_{ee} - M_z| > 10$ GeV, $|M_{\mu\mu} - M_z| > 15$ GeV to suppress background from $Z \rightarrow ee, \mu\mu$

Higgs Mass (GeV)	Eff($e\nu e\nu$)	Eff($\mu\nu\mu\nu$)	Eff($e\nu\mu\nu$)
140	26.3%	49.9%	34.2%
150	28.5%	51.1%	37.0%
160	29.9%	53.3%	39.9%
165	30.5%	54.1%	40.8%
170	30.5%	52.7%	42.2%
180	29.3%	50.1%	43.2%

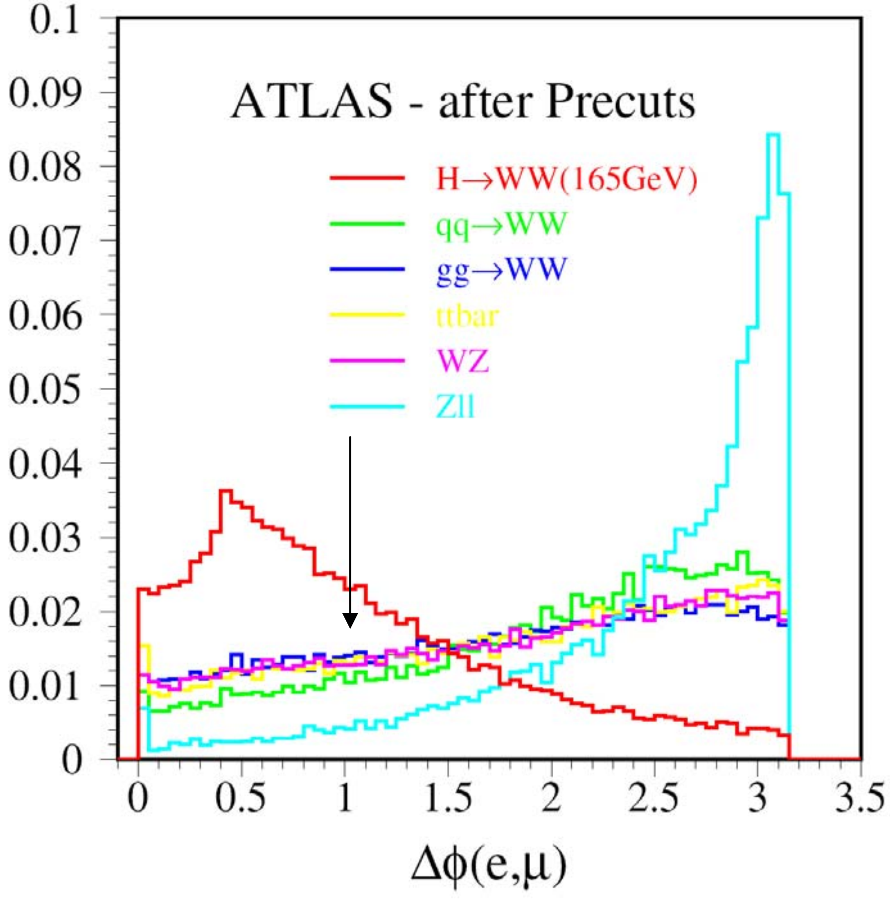
ATLAS electron ID: IsEM & 0x7FF == 0 (tight electron id cuts)
ATLAS Muon ID: Staco-muon id

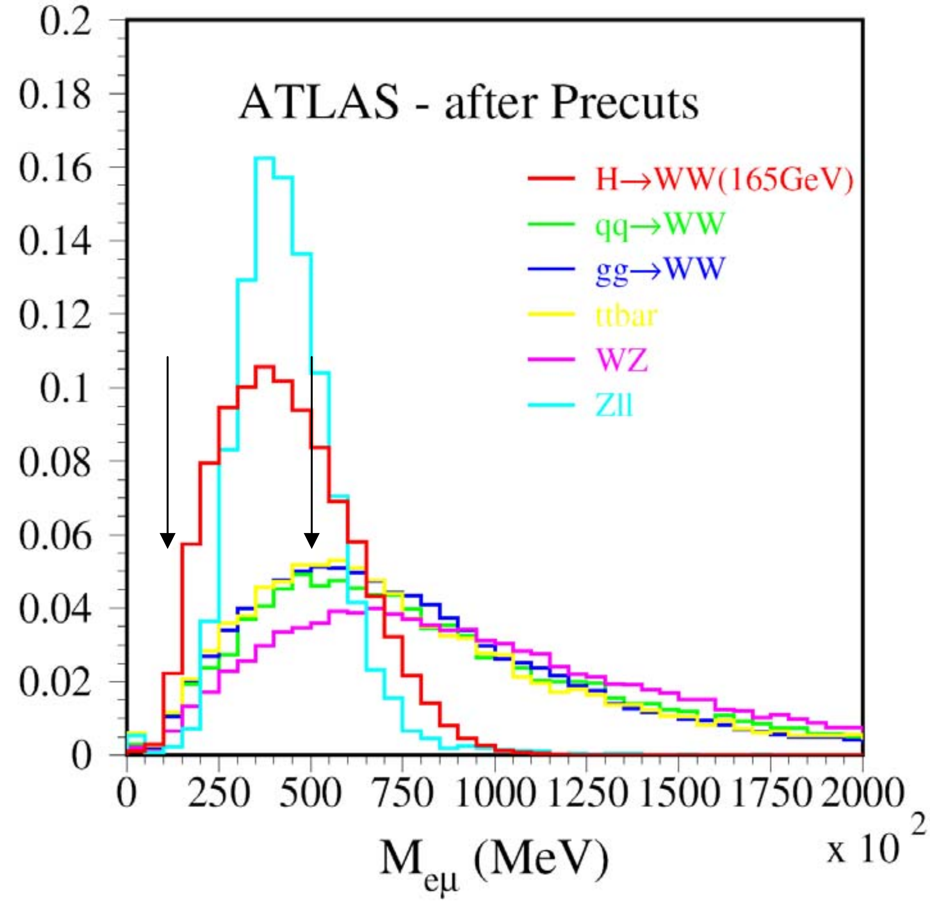
H → WW Selection with Straight Cuts

- the most energetic lepton has $P_T > 25$ GeV,
- no jet with $E_T^{jet} > 30$ GeV,
- angle between two leptons $\phi_{\ell\ell} < 1$,
- $MET > 50$ GeV,
- invariant mass of two leptons, $12 < M_{\ell\ell} < 50$ GeV,
- Sum of E_T^{jet} in $\Delta R < 0.4$ cone around e or μ is less than 8 or 5 GeV.

→ Signal efficiency is about 2.5% – 6%.
→ S/B ratio is about 0.3 – 1.1
→ Significance N_σ is about 2.7 – 8.6 (stat. only)

Angular Distributions & Invariant Mass





Angle between two leptons

Invariant mass of two leptons

BDT Analysis based on pre-selected events

Input physics variables to BDT program (1)

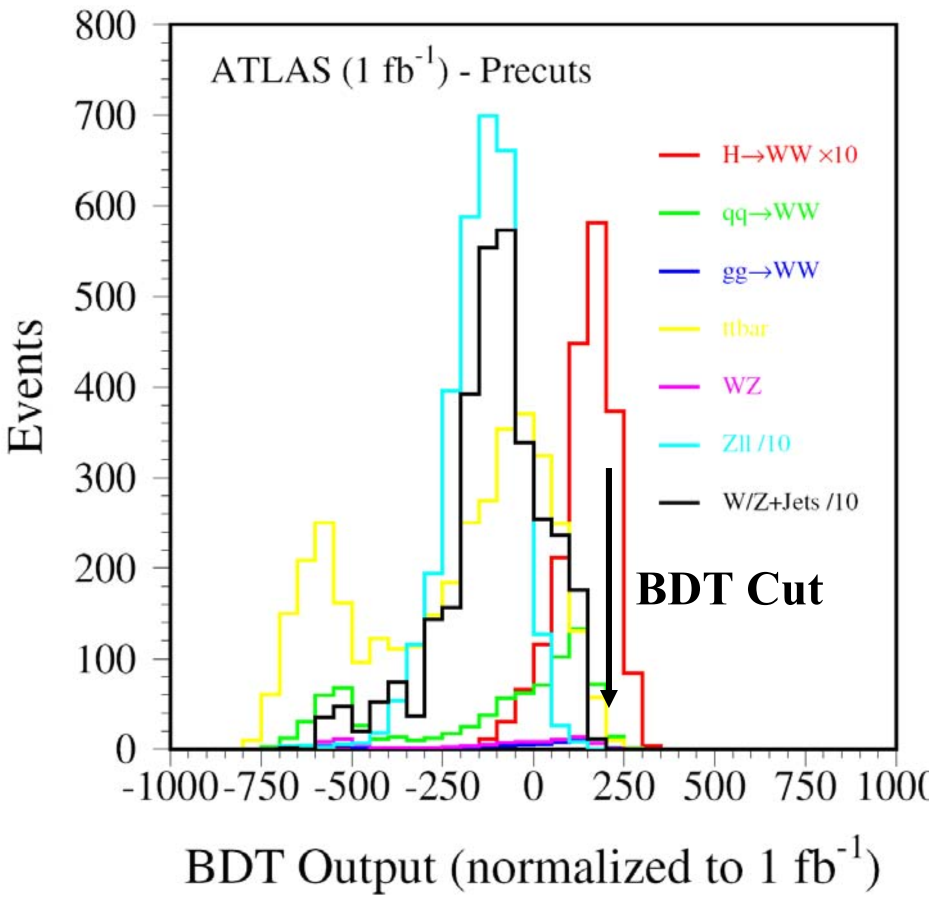
- Energy and Momentum
  - $p_T(\ell)$, $p_T(\ell,\ell)$
  - MET, total recoil E_T
  - scalar $\sum E_T(jet)$, vector $\sum E_T(\ell, MET)$
- Lepton Isolation
  - Number of tracks in $\Delta R < 0.4$ cone around ℓ
  - Sum of track p_T in $\Delta R < 0.4$ cone around ℓ
  - Sum of jet E_T in $\Delta R < 0.4$ cone around ℓ

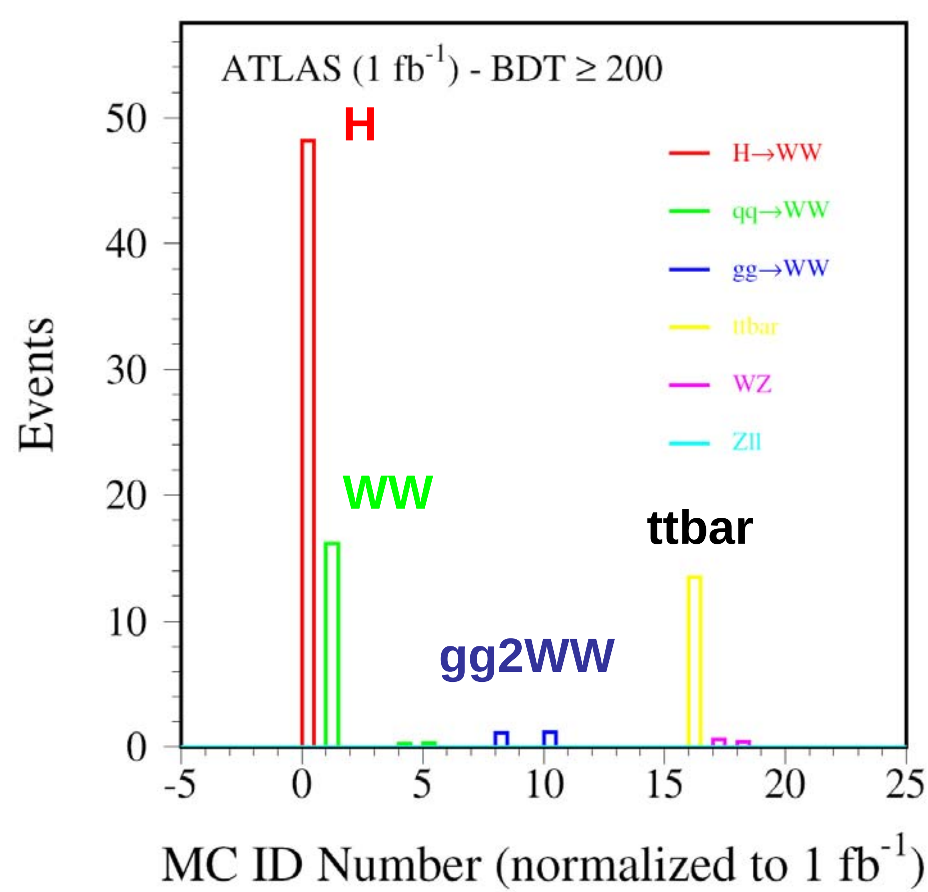
Input physics variables to BDT program (2)

- Event Topology
  - Number of Jets with E_T >30 GeV
  - E(ℓ)/P(ℓ)
  - A0 (impact parameter) of ℓ, $\Delta A0(\ell,\ell)$, $\Delta Z(\ell,\ell)$
  - $\Delta R(\ell,\ell)$, $\Delta\phi(\ell,\ell)$, $\Delta\phi(\ell,MET)$
  - $\Delta\Omega(\ell,\ell)$ - opening angle of two leptons
- Mass Information
  - Invariant mass(ℓ,ℓ)
  - Transverse mass($\ell\ell$,MET)
  - Transverse mass(ℓ,MET)

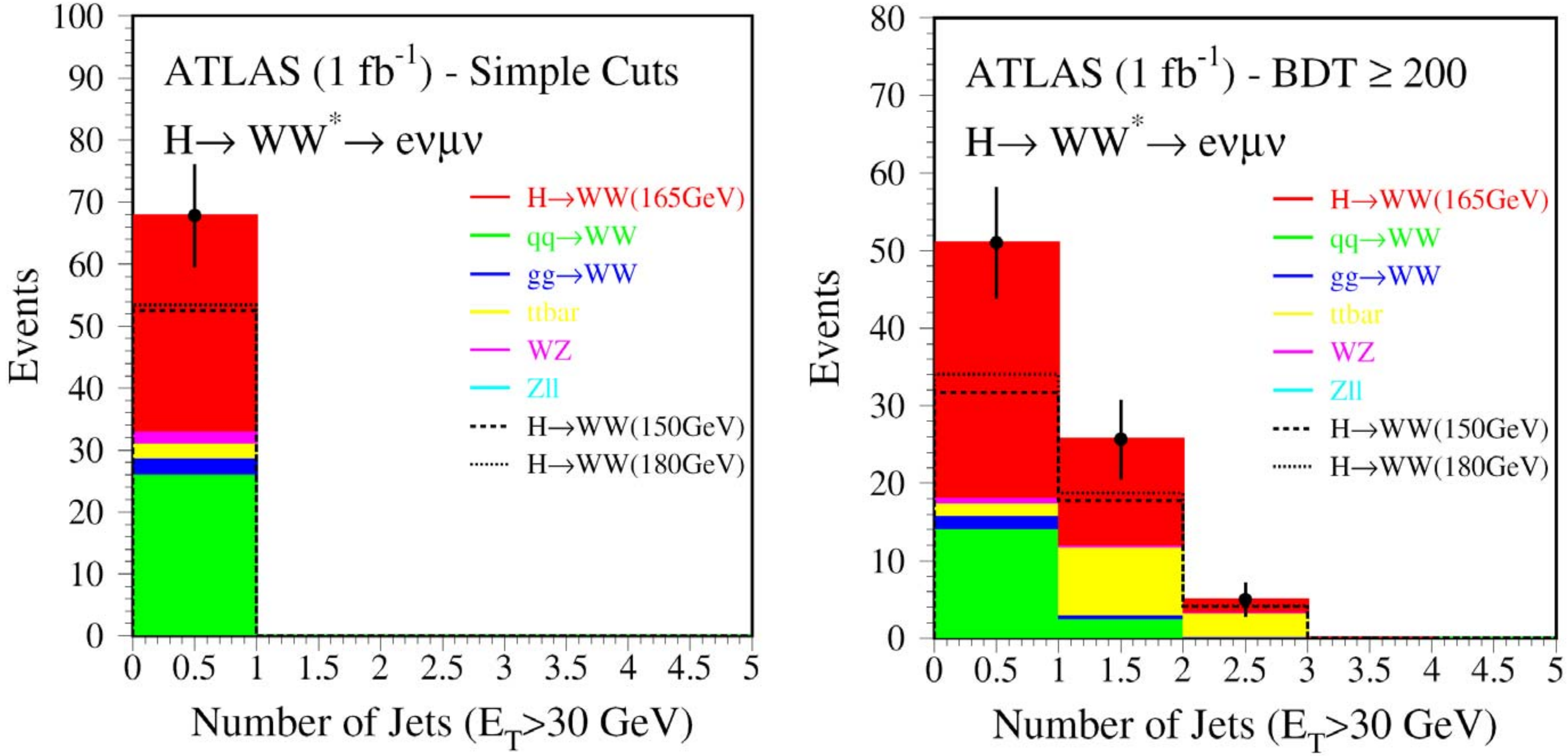
H→WW→eνμν (M_H=165 GeV)

BDT output and selected signal & background events for 1fb^{-1}

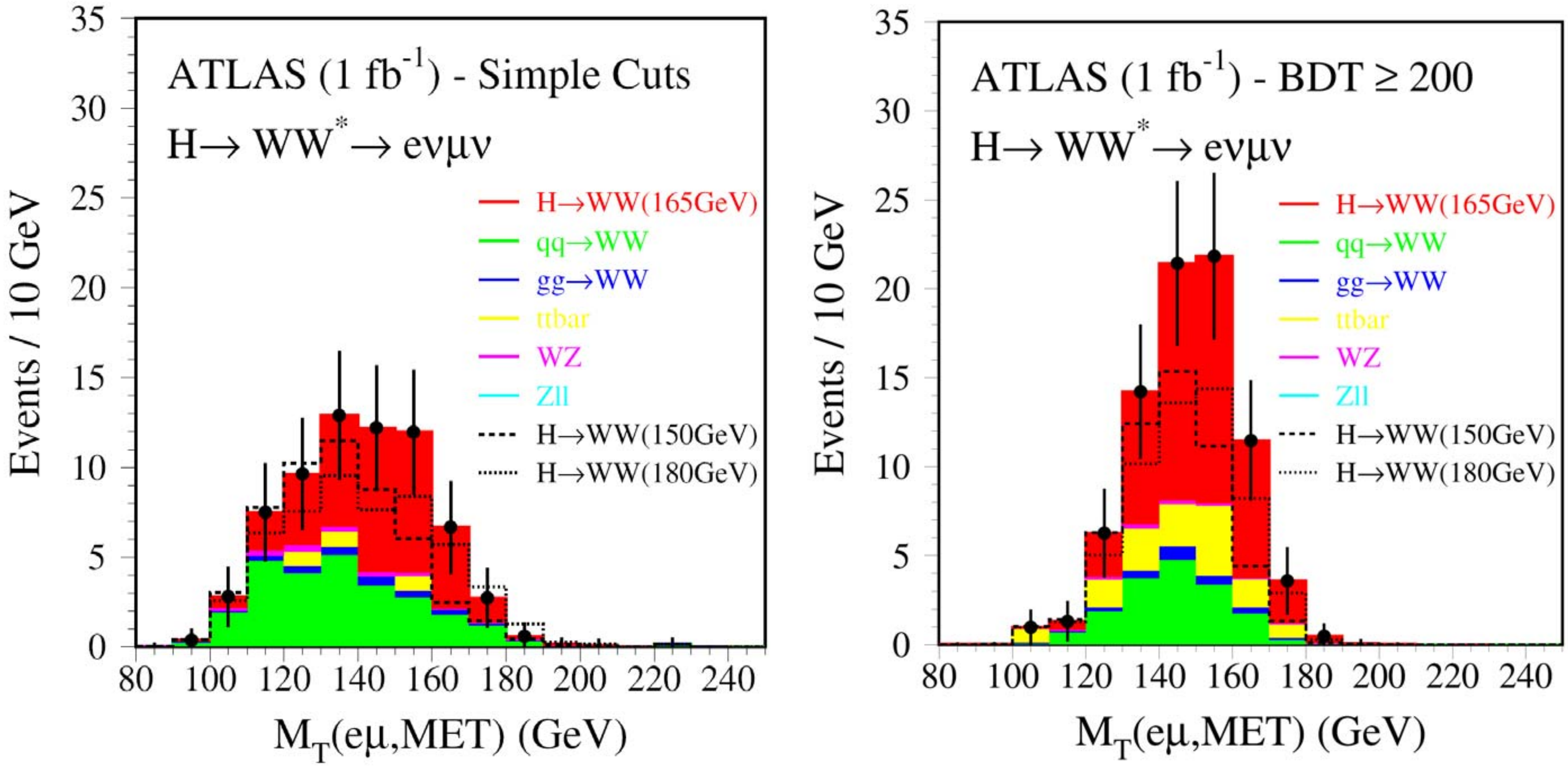




Straight Cuts vs BDT Selection (N_{jets})



Straight Cuts vs BDT (Mass)

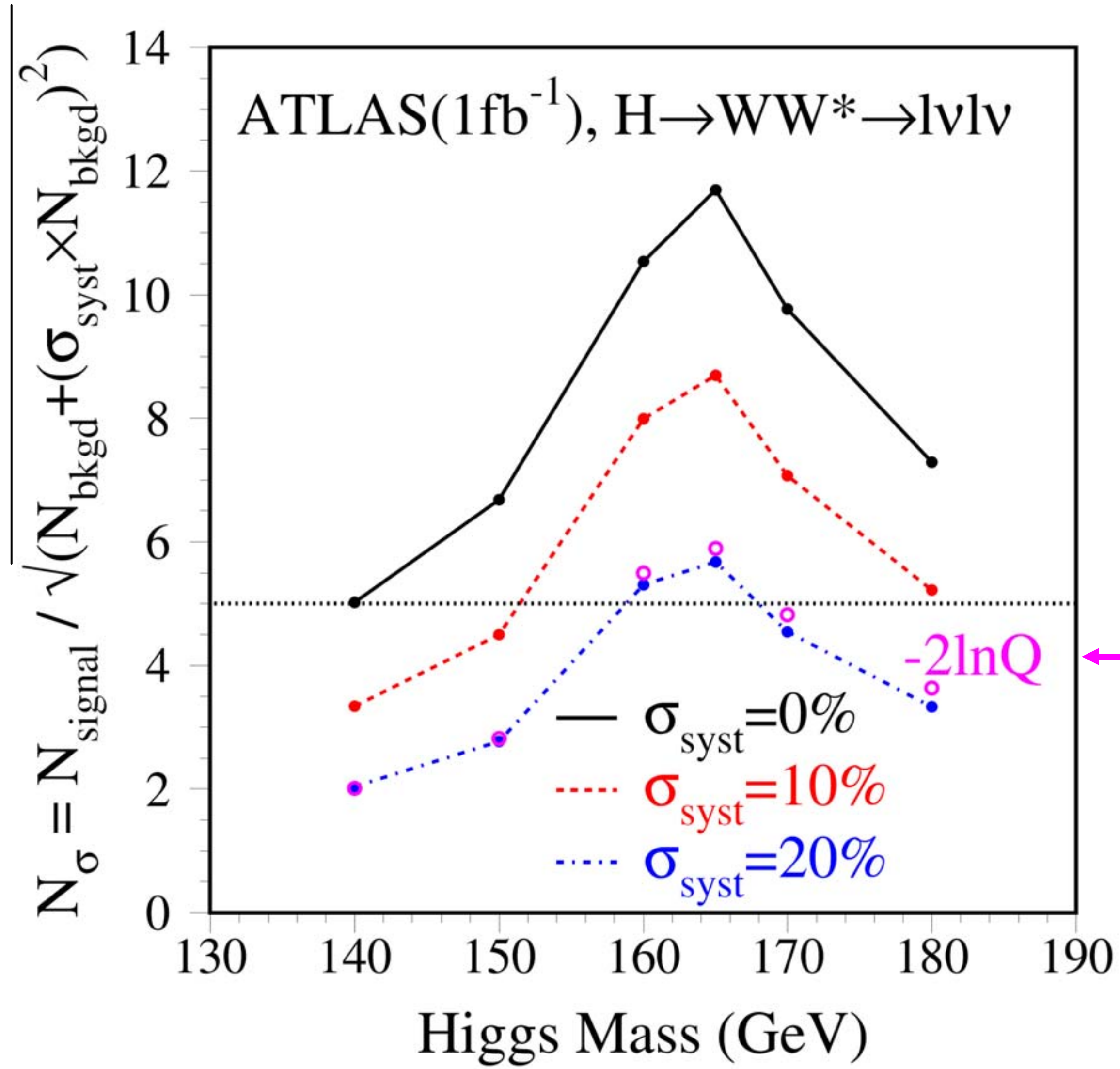


BDT Results ($H \rightarrow WW^* \rightarrow l\nu l\nu$, for $1fb^{-1}$)

M_{Higgs} (GeV)	Eff_s	N_s	N_{bg}	N_σ (stat. only)	$N_{\sigma 10}$ (10% syst)	$N_{\sigma 20}$ (20% syst)	$N_{\sigma 20}$ (-2lnQ)
140	6.7%	56.5	126.4	5.0/2.7	3.3	2.0	2.0
150	7.2%	73.2	120.0	6.7/4.7	4.5	2.8	2.8
160	7.8%	90.6	73.8	10.5/8.1	8.0	5.3	5.5
165	9.0%	105.3	81.1	11.7/8.6	8.7	5.7	5.9
170	8.4%	93.0	90.6	9.8/7.5	7.1	4.5	4.8
180	7.3%	71.0	94.8	7.3/5.0	5.2	3.3	3.6

BDT Results **Straight cuts**

ATLAS Sensitivity of H → WW* → lνlν

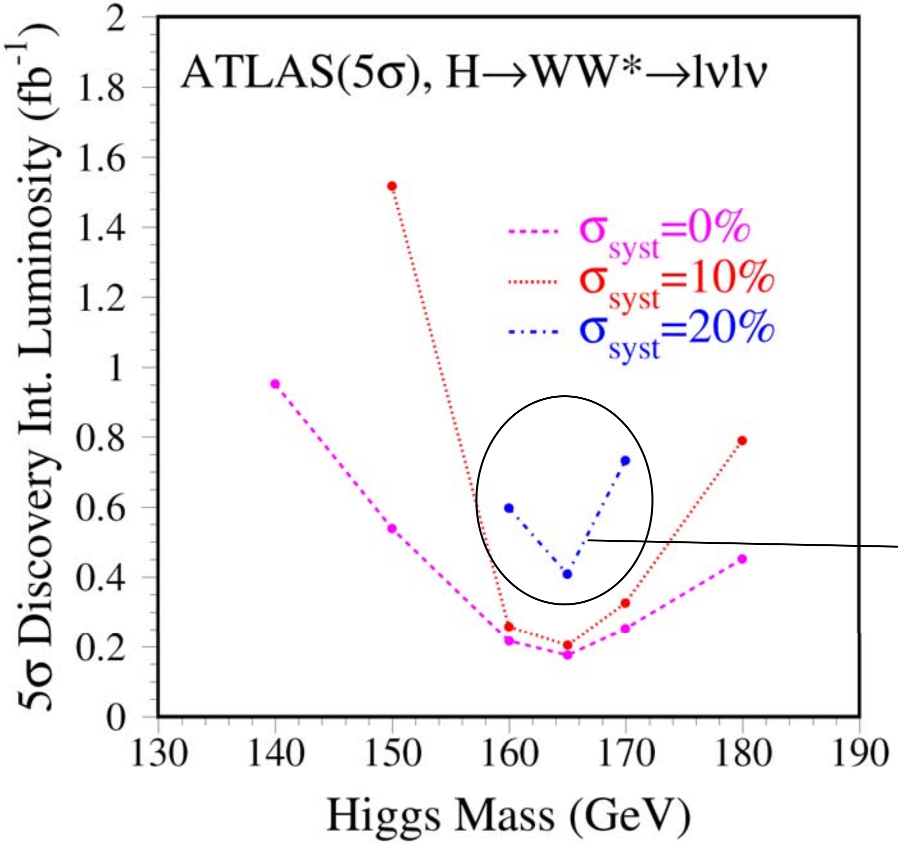


$$Q = \frac{L(s+b)}{L(b)}$$

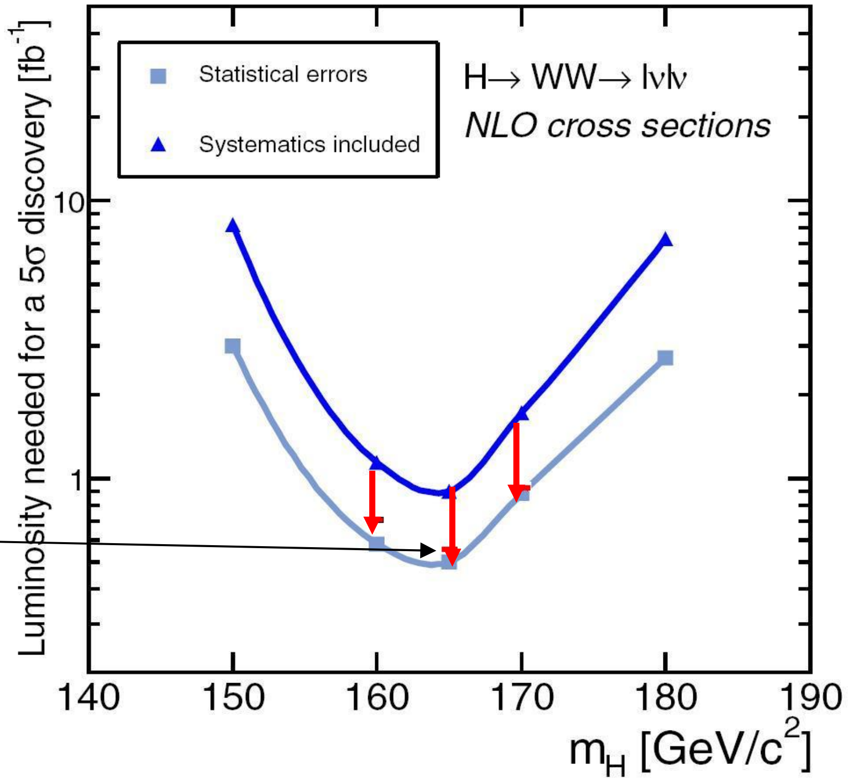
Log-likelihood Ratio with 20% syst. error

Required Int. Lumi. for 5σ Discovery

BDT Analysis, H → WW* → lνlν (l=e,μ)



CMS Phys. TDR 2006



σ_{syst} = 19%, 16%, 11% for 1, 2, 10 fb^{-1}

2) Search for Z’ → $t\bar{t}$

Physics Motivations

- Look for top-rich signature in ttbar final state. There are many models predict the ttbar final state, using TeV Z'→ ttbar as the *benchmark* studies.

- Additional U(1)' gauge symmetries and associated Z' gauge boson are one of many motivated extensions of the SM (Ref: Paul Langacker, arXiv:0801.1345v2).

- Traditional search for Z' via leptonic decay production (ee, $\mu\mu$) have been conducted at Tevatron ($M_{Z'}$ > 850 GeV from CDF, Ref: Phys. Rev. D70:093009, 2004) and will be carried out at LHC.

- But, these searches do not rule out the existence of a Z' resonance with suppressed decays to leptons, so called "leptophobic" Z'. Several models (RS Kaluza-Klein states of gluons, weak bosons and gravitons; Topcolor leptophobic Z'; Sequential Z' etc.) suggest that Z'-like state would decay predominantly to heavy quark-antiquark pairs, e.g. ttbar if the Z' mass is larger than 2 $M_{top.}$

Search for Z' → $t\bar{t}$

- If there is a Z' with typical electroweak scale couplings to the ordinary fermions (ee, $\mu\mu$, eμ, $\tau\tau$, $q\bar{q}$, $t\bar{t}$), it should be observable at,
  - LHC for masses up to ~ 4 - 5 TeV (for 100/fb)
  - Tevatron for masses up to ~ 900 GeV (for ~10/fb)
- The latest results from CDF with 955 /pb data
  - ruled out Topcolor Z' below 720 GeV/c^2
  - the cross section of Z'-like state decaying to $t\bar{t}$ is less than 0.64 pb at 95% C.L. for $M_{Z'}$ above 700 GeV/c^2
  - Ref: T. Aaltonen et.al., PRD 77, 051102(R) (2008).

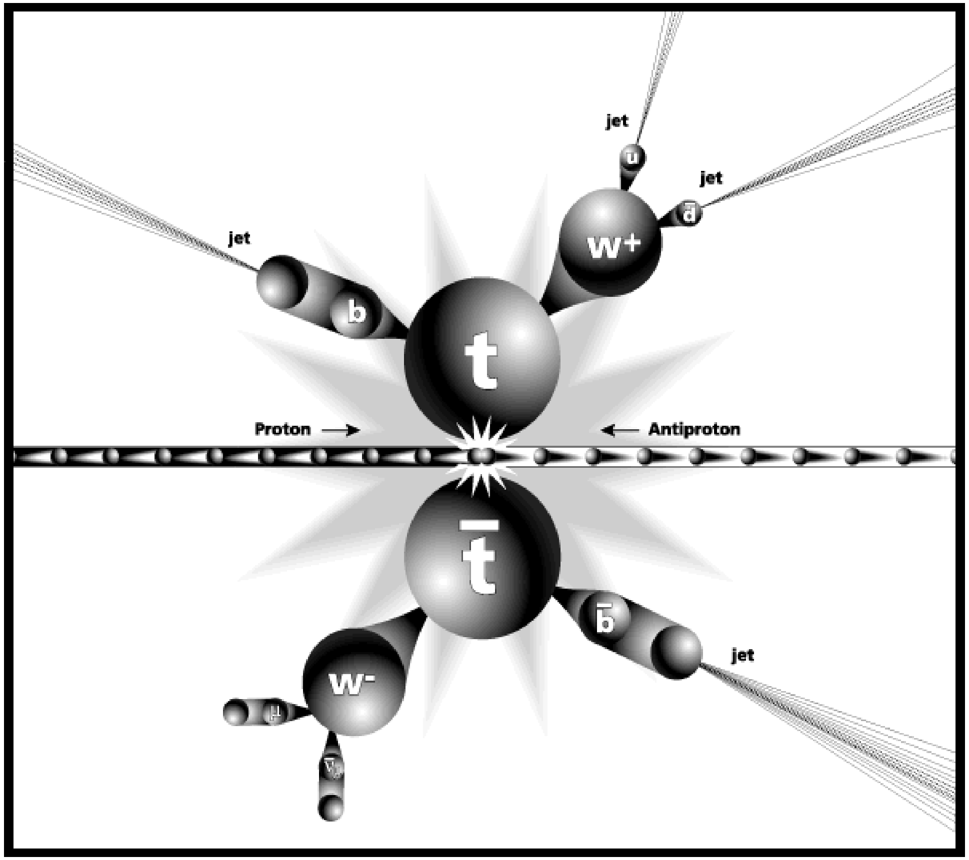
MC Samples (V12)

- Signal: Z' →ttbar → bbww →bbjjlν
  - Dataset: 6231, 20000 Events, M_Z' = 1.0 TeV
  - Dataset: 6232, 19500 Events, M_Z' = 1.5 TeV
  - Dataset: 6233, 20000 Events, M_Z' = 2.0 TeV
  - Dataset: 6234, 19500 Events, M_Z' = 3.0 TeV
- Major Backgrounds:
  - Ttbar: 5200(>=1 lep), 450100 Events
  - Ttbar: 5204(W hadronic decay), 97750 Events
  - Single Top: 5500(Wt,14950 Events), 5501(s-channel, 9750 Events), 5502(t-channel, 18750 Events)
  - W/Z+Jets (1.1 Million Alpgen Events)
  - Dijets: 5014(14500 Events), 5015 (381550 Events)

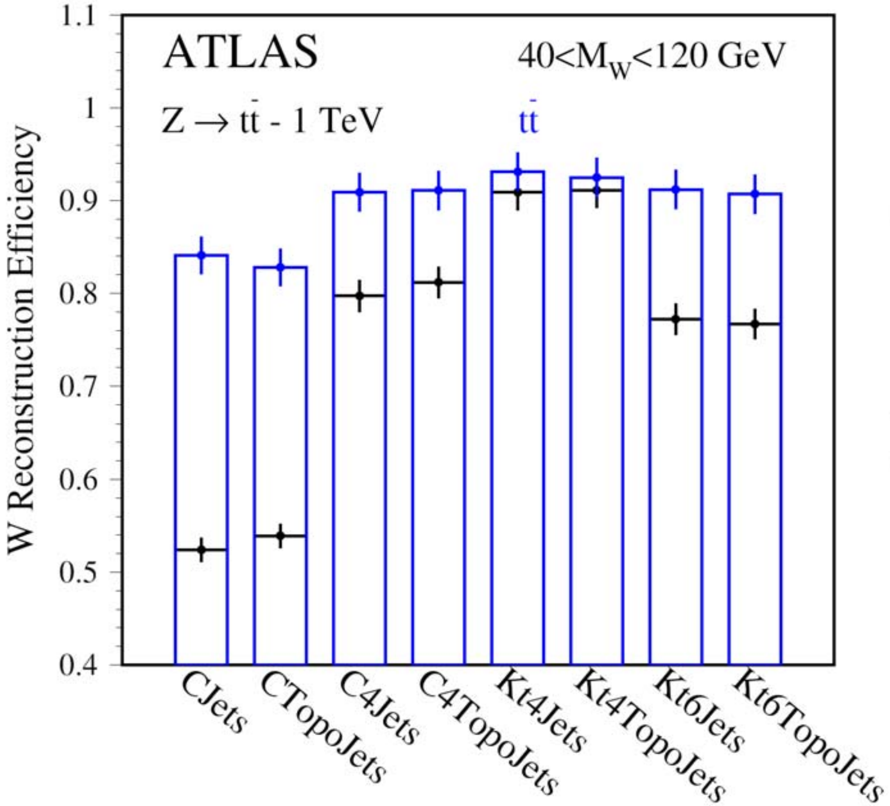
W / Top Reconstruction

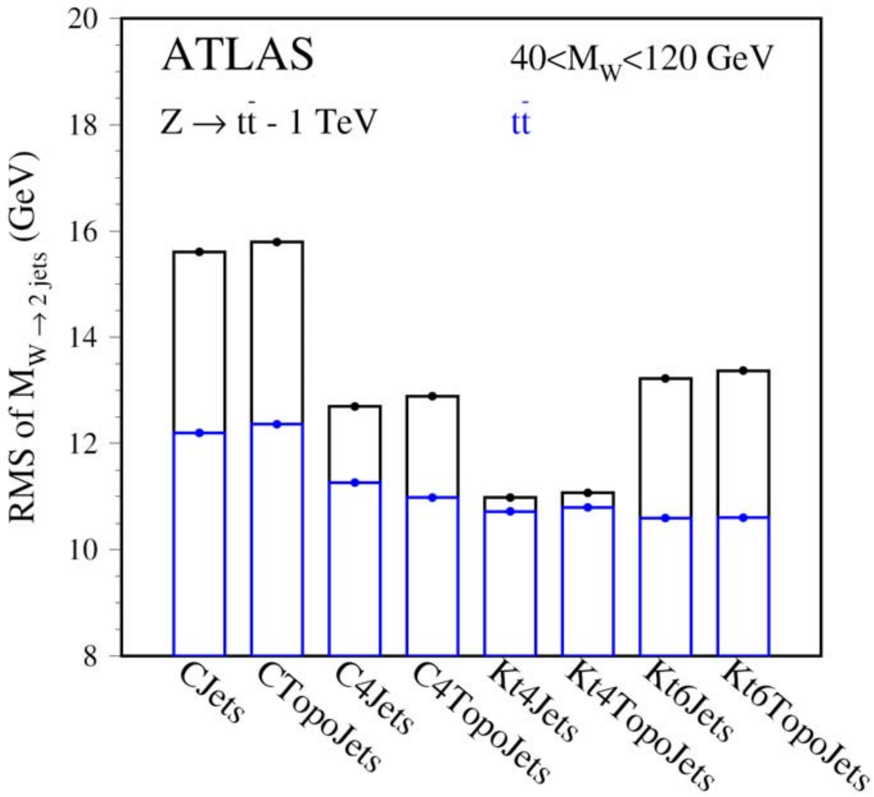
➔ With the increase of Z’ mass, the energy of Top/W from Z’ decay increase and the decay jets are boosted and located in a relative small region. In order to reconstruct Top/W efficiently, it’s critical to use a suitable jet finding algorithm.

➔ATLAS employs two jet finding algorithms (Cone, Kt),
- CJets (R=0.7)
- CTopoJets (R=0.7)
- C4Jets (R=0.4)
- C4TopoJets (R=0.4)
- Kt4Jets (R=0.4)
- Kt4TopoJets (R=0.4)
- Kt6Jets (R=0.6)
- Kt6TopoJets (R=0.6)



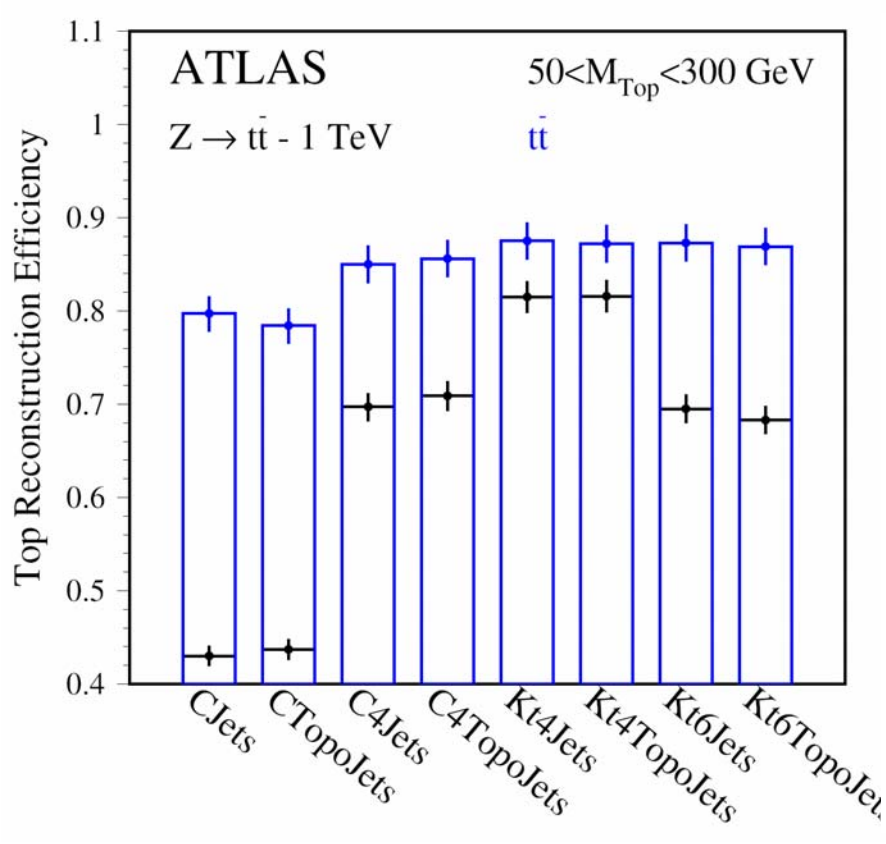
Efficiency of W → jj Reconstruction

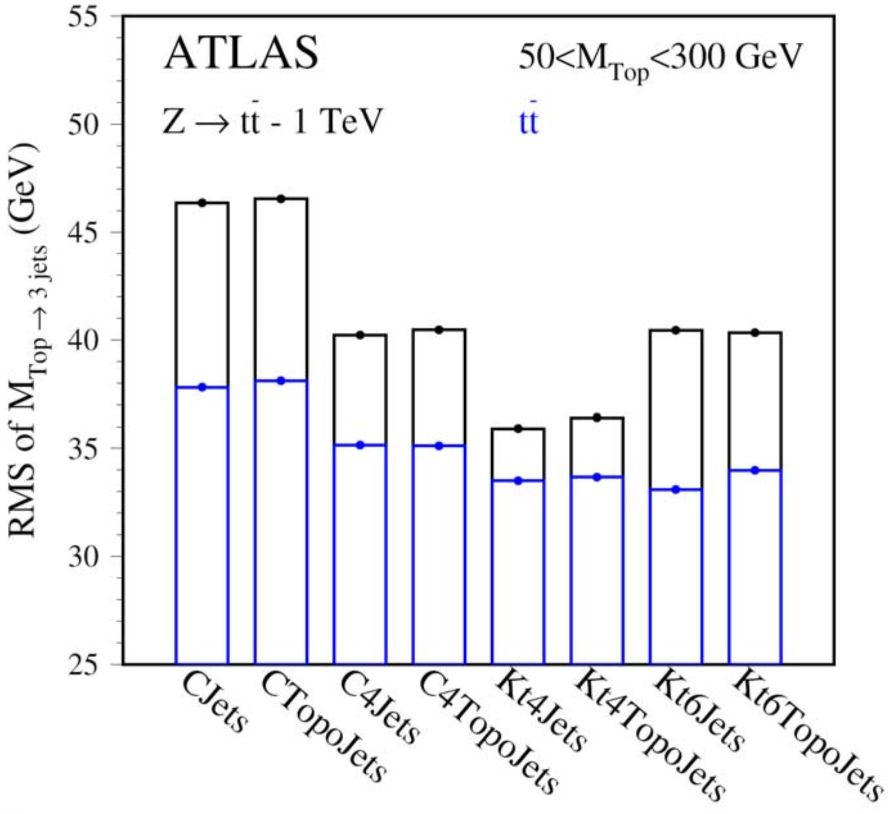




RMS of M_W ~ 11 GeV

Eff. of Top → bjj Reconstruction





RMS of M_{Top} ~ 35 GeV

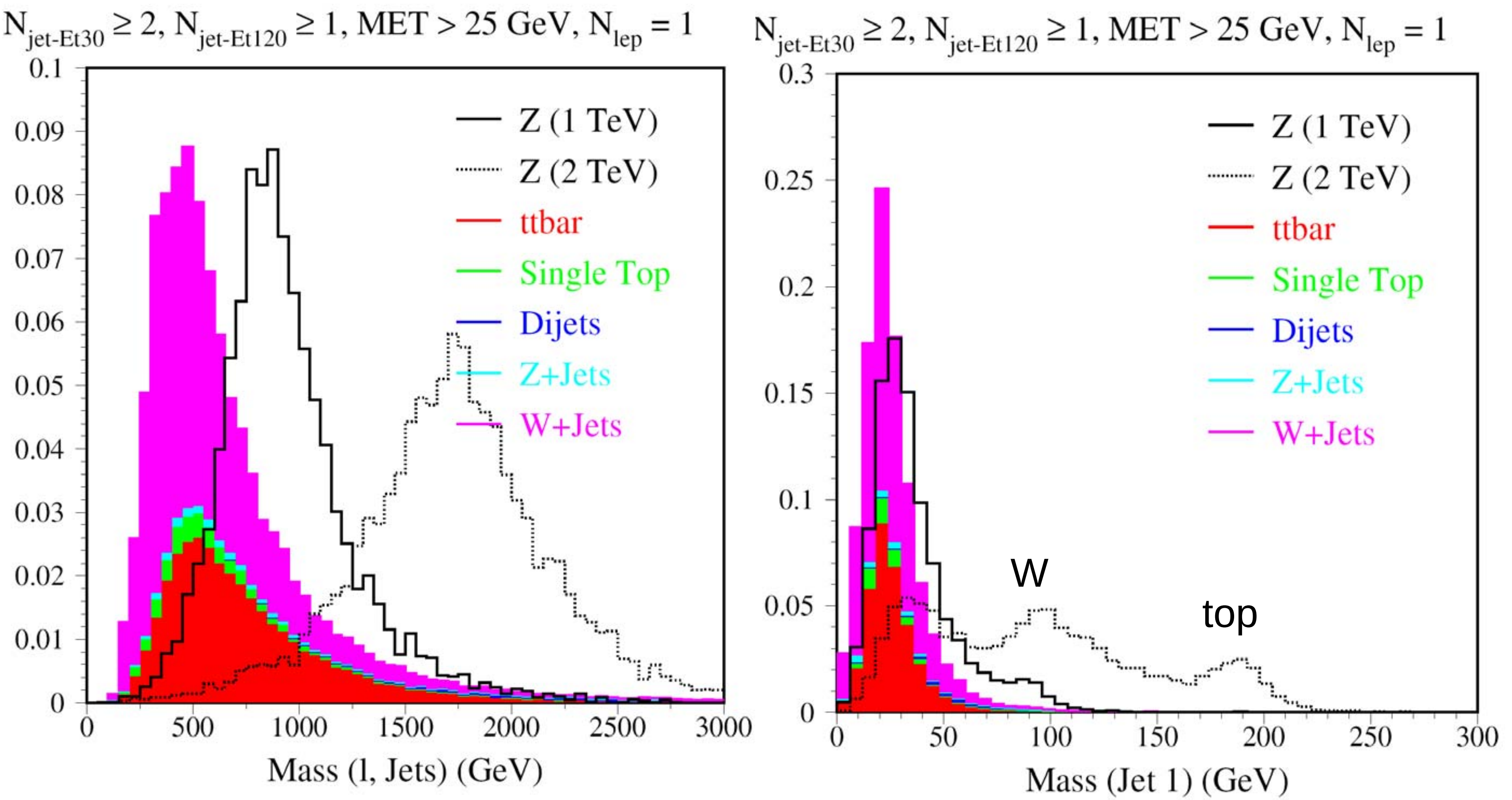
Search Strategy for Z’→ $t\bar{t}$

- Event selection (to suppress most of background events):
  - Pre-selection cuts
  - With cut-based analysis
  - With BDT multivariate technique, trained decision trees using Z’ with the combination of various masses (1, 1.5, 2, 3 TeV)
- Scan the “mass window” to find the most interest region (IR) in Mass(lep,jets) spectrum after selection, then enlarge or shrink mass window to optimize the “signal” sensitivity.
- To extract possible “signal” by fitting the background distributions.
- If an interesting “signal” is found (e.g. >3σ), we will use Z’ with estimated mass as signal to re-train BDT which could enhance the signal sensitivity if the signal does exist.

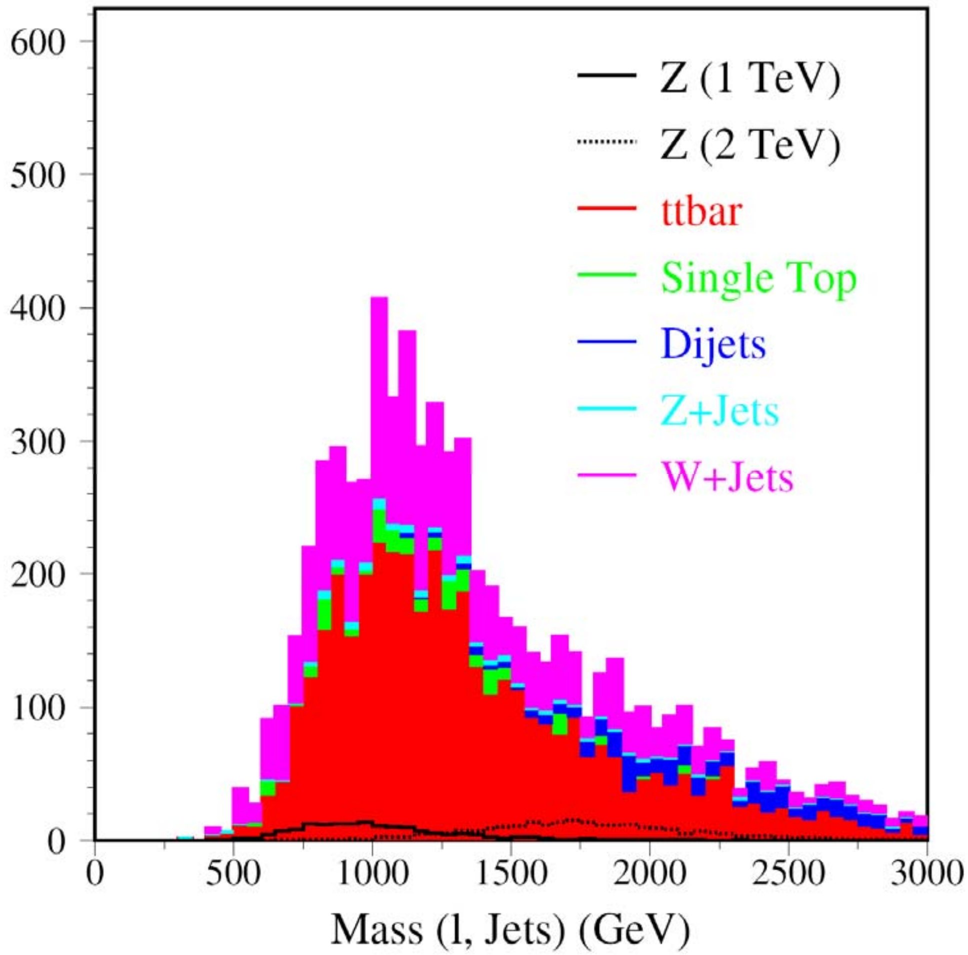
$t\bar{t}$ Pre-selection Cuts

- At least 2 Jets with Et > 30 GeV
- At least 1 Jet with Et > 120 GeV
- Missing Transverse Momentum > 25 GeV
- Only one lepton (e or μ) with Pt > 20 GeV

E_T & Mass of the 1st Energetic Jet



Selection with Straight Cuts (1 fb^{-1})



- $40 \leqslant M_W \leqslant 120$ GeV
- $50 \leqslant M_{Top} \leqslant 300$ GeV
- Et(J1) > 200 GeV
- Ht(L,Jets,MET) > 800 GeV
- Vt(L,MET) > 150 GeV

➔**Z' Signal (1 pb)**

- 170 from Mz' = 1.0 TeV
- 269 from Mz' = 1.5 TeV
- 261 from Mz' = 2.0 TeV
- 215 from Mz' = 3.0 TeV

➔**Backgrounds (7258)**

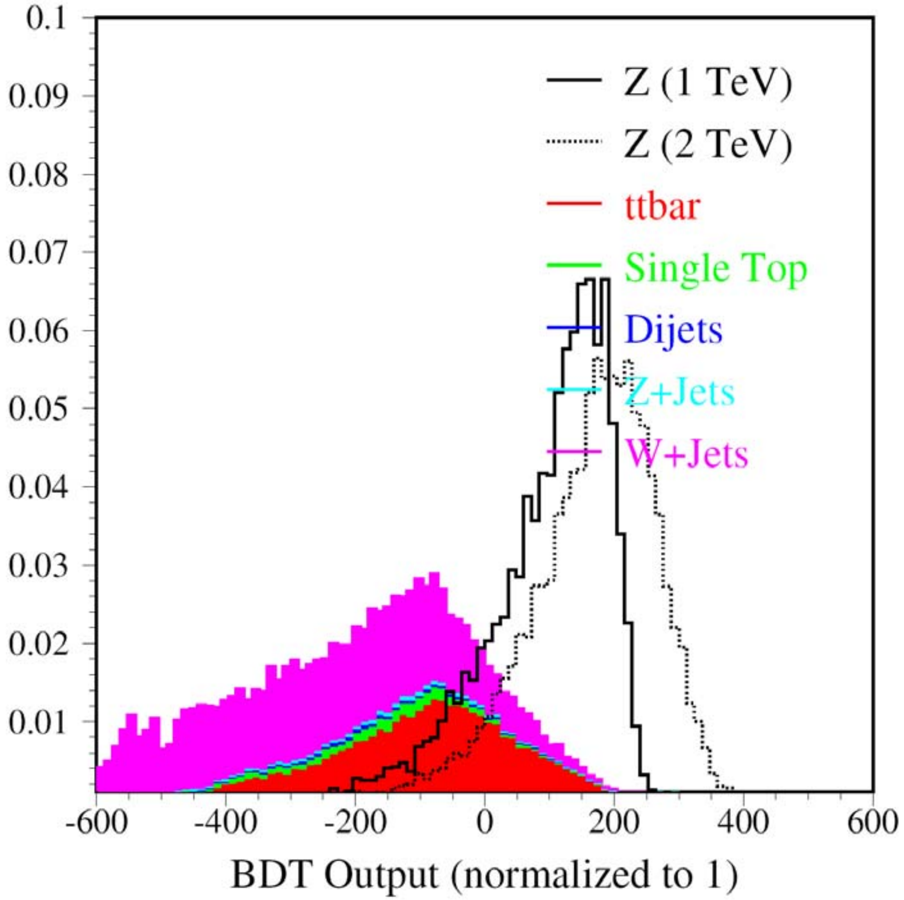
- 4188 from ttbar
- 247 from single top
- 500 from dijet
- 2189 from W+Jets
- 134 from Z + Jets

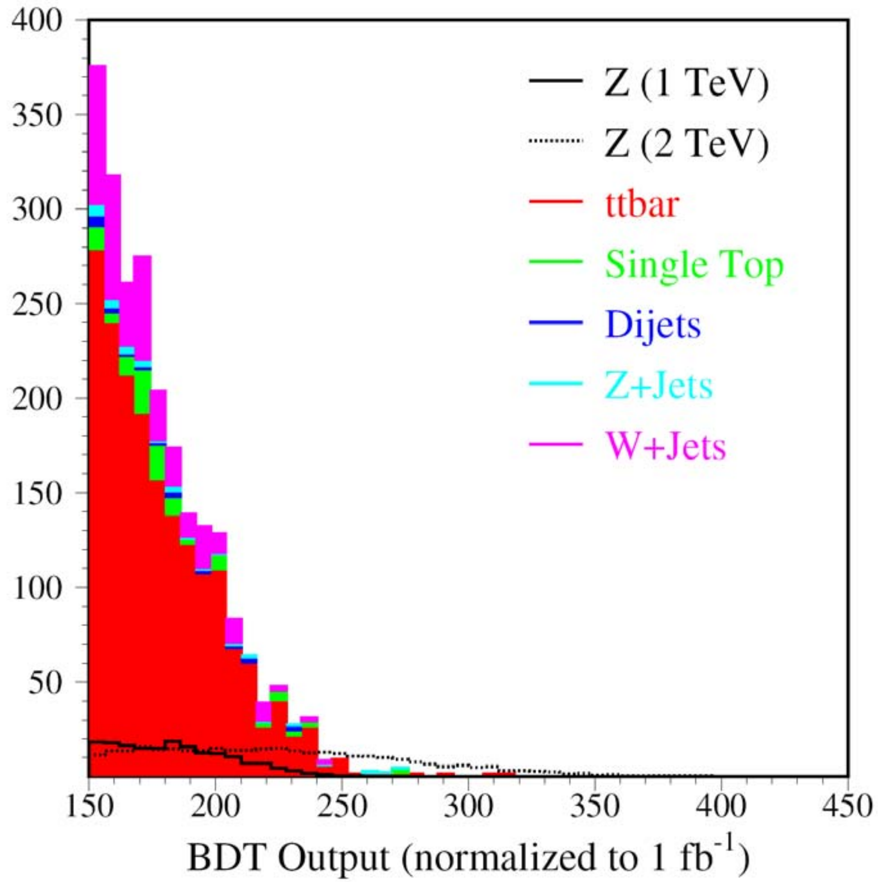
Selection with BDT Analysis (A)

with 24 input variables for training and test

- P_t^L, N_{track}(R=0.2), $\sum P_t$(track) / E_t^L (R=0.2)
- N_{jet}(Et>30GeV), Size(J1), E_{em}(J1)
- E_t(J1), E_t(J2), E_t(L,MET), MET
- M(J1), M(Jets), M(Jets,L), M_t(L,MET)
- H_t(L,Jets), H_t(L,Jets,MET), V_t(L,MET)
- $\Delta\phi$(J1,J2), ΔR(J1,J2), ΔR(J1,J3)
- $\Delta\phi$(J1,L), $\Delta\phi$(J2,L), ΔR(J1,L), ΔR(J2,L)

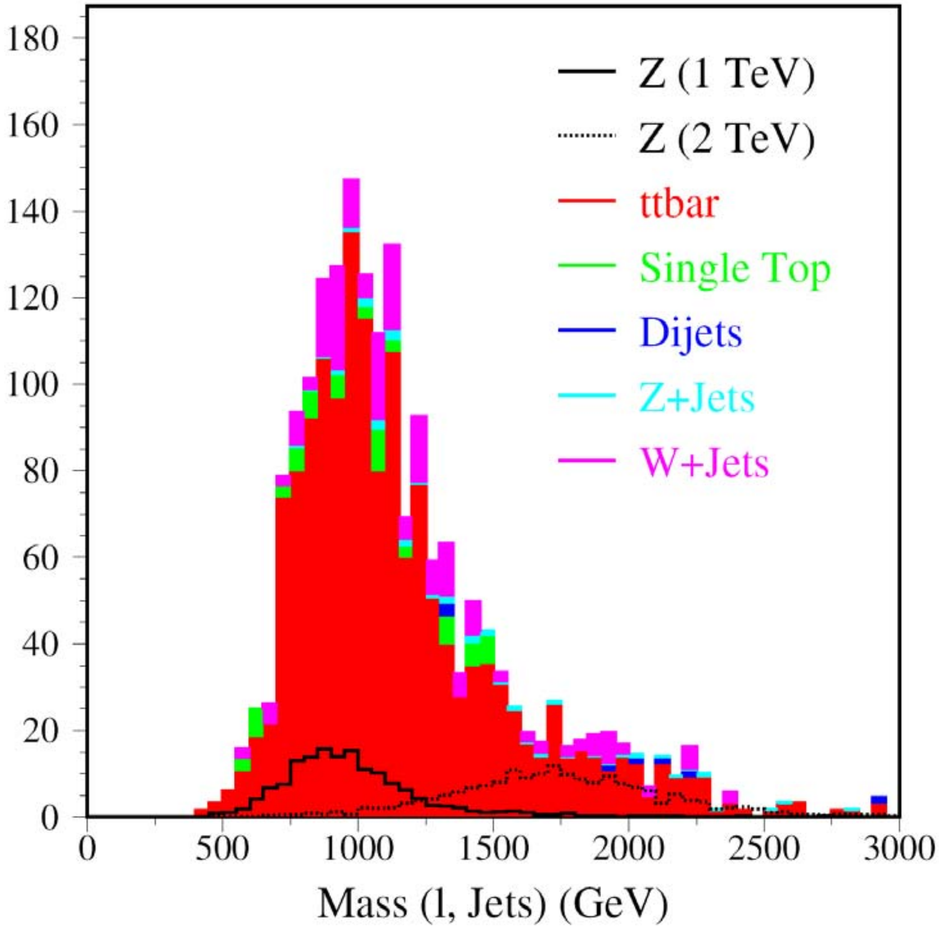
BDT Analysis Output (A)





Selected Events (1 fb^{-1})

$$BDT \geq 150,\ 40 \leq M_W \leq 120,\ 50 \leq M_{Top} \leq 300\ \text{GeV}$$



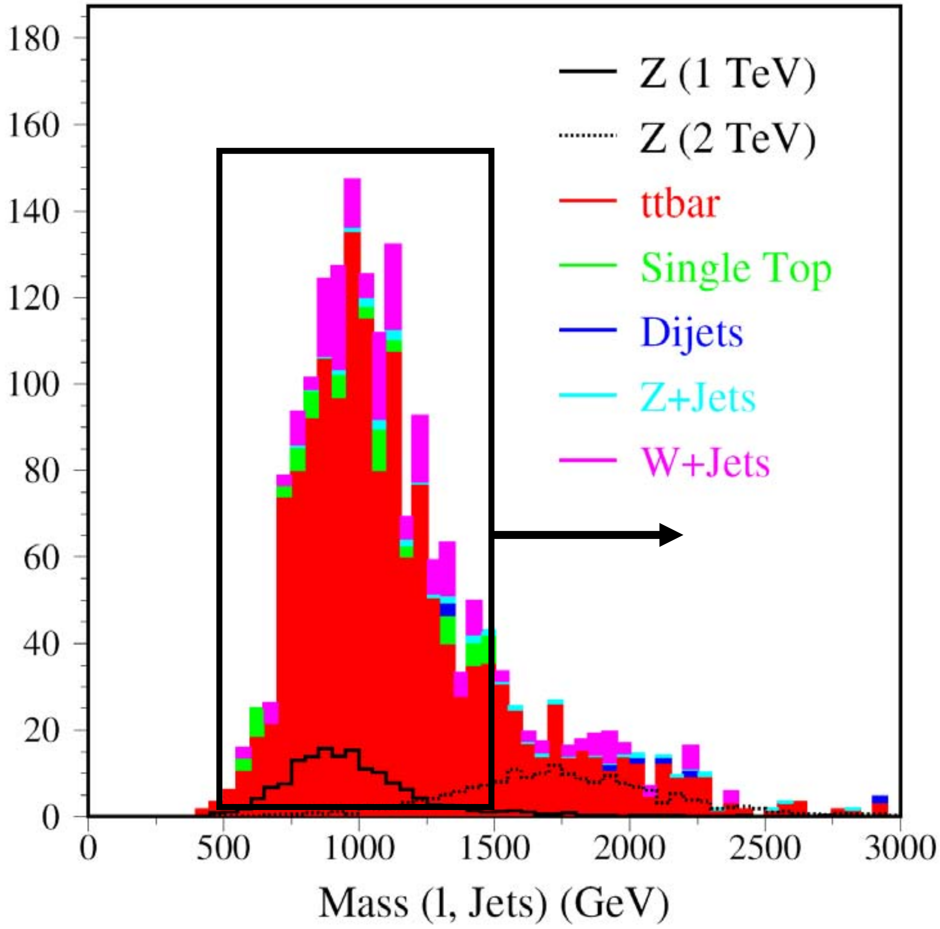
Signal (assuming 1 pb):
- → Z' (1.0 TeV) – 150.5 Events
- → Z' (1.5 TeV) – 215.2 Events
- → Z' (2.0 TeV) – 186.2 Events
- → Z' (3.0 TeV) – 124.9 Events

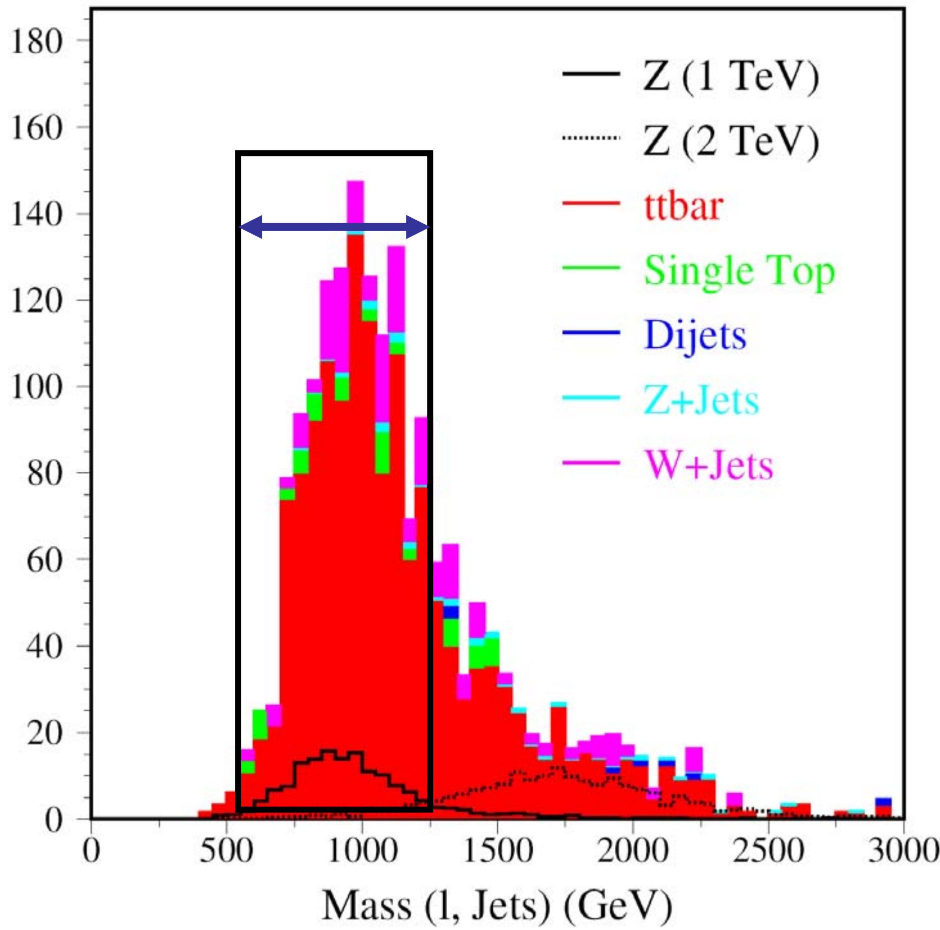
Backgrounds (1844):
- → Ttbar – 1536 Events (83.3%)
- → Single top – 65 Events(3.5%)
- → W+ Jets – 209 Events(11.3%)
- → Z + Jets – 24 Events(1.3%)
- → Dijets – 10 Events(0.54%)

Scan the Mass Window

Sliding mass window to find the IR

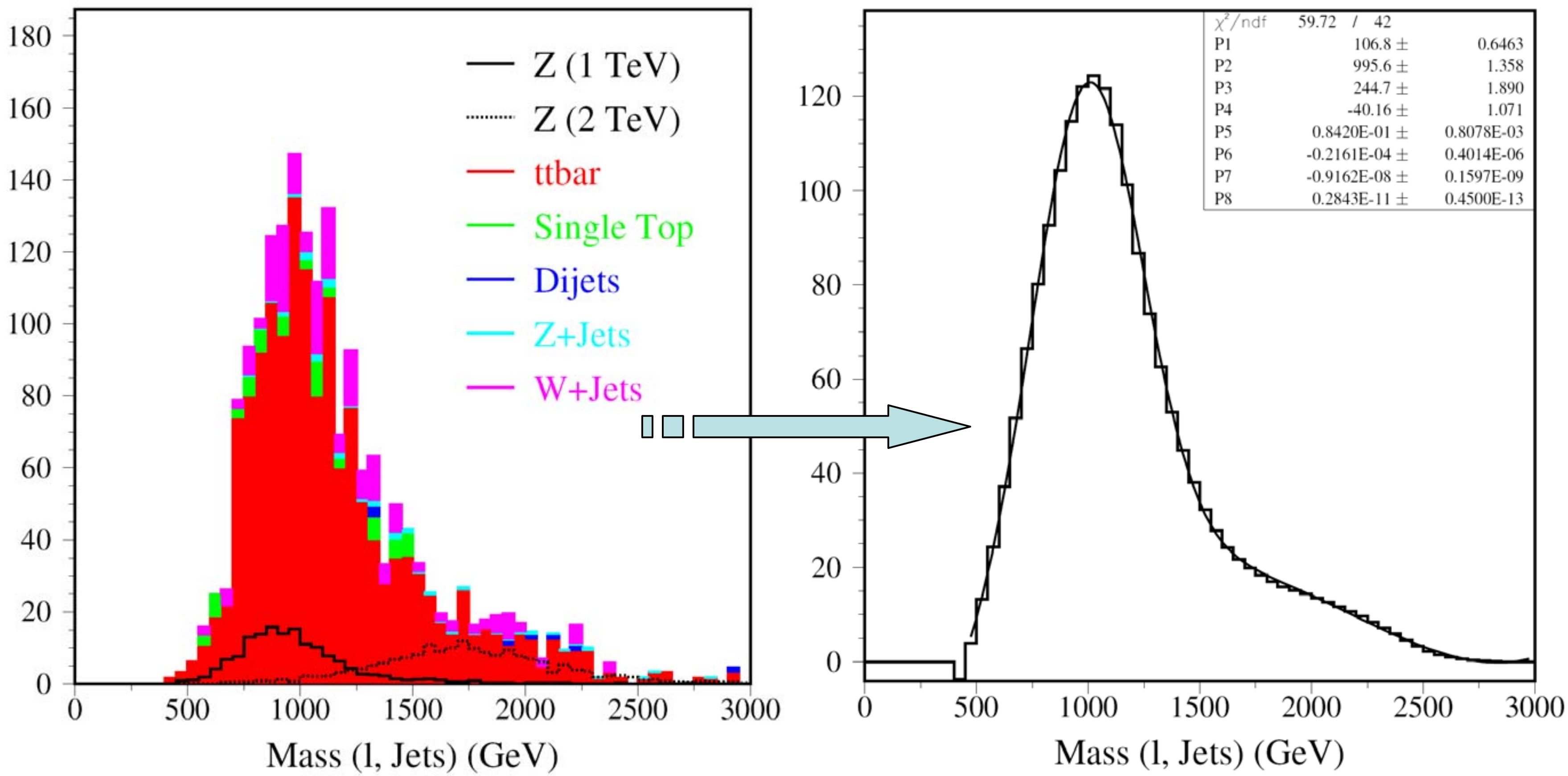
Opt. sensitivity by varying mass window



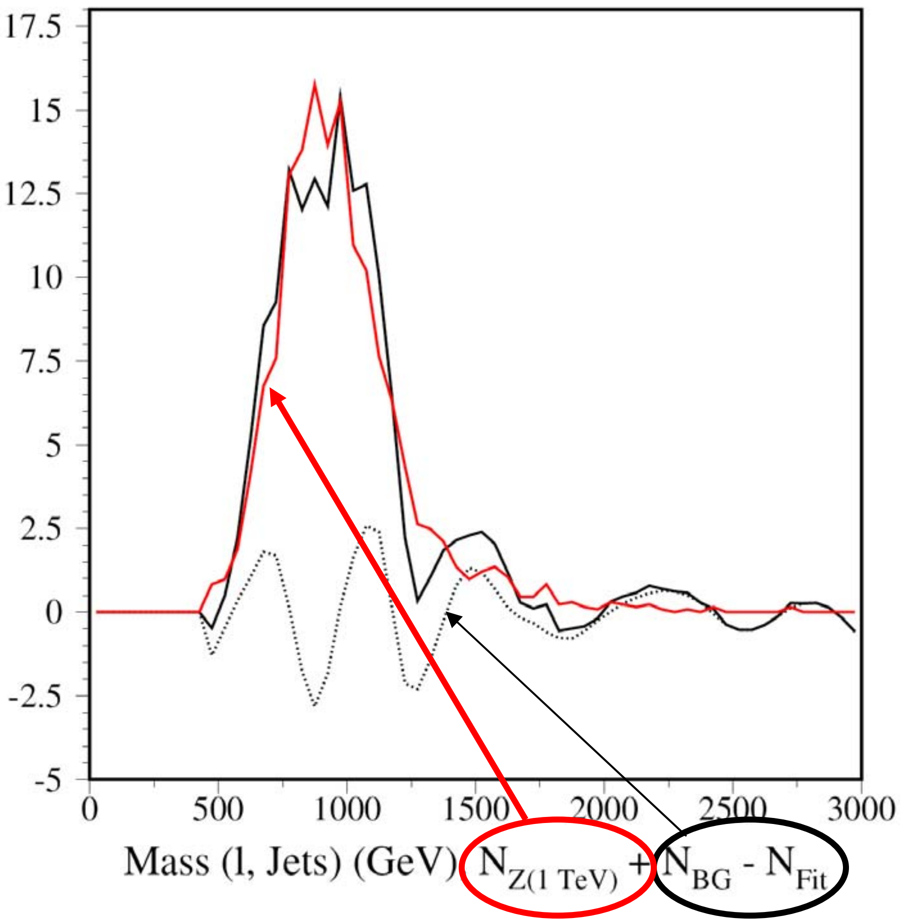


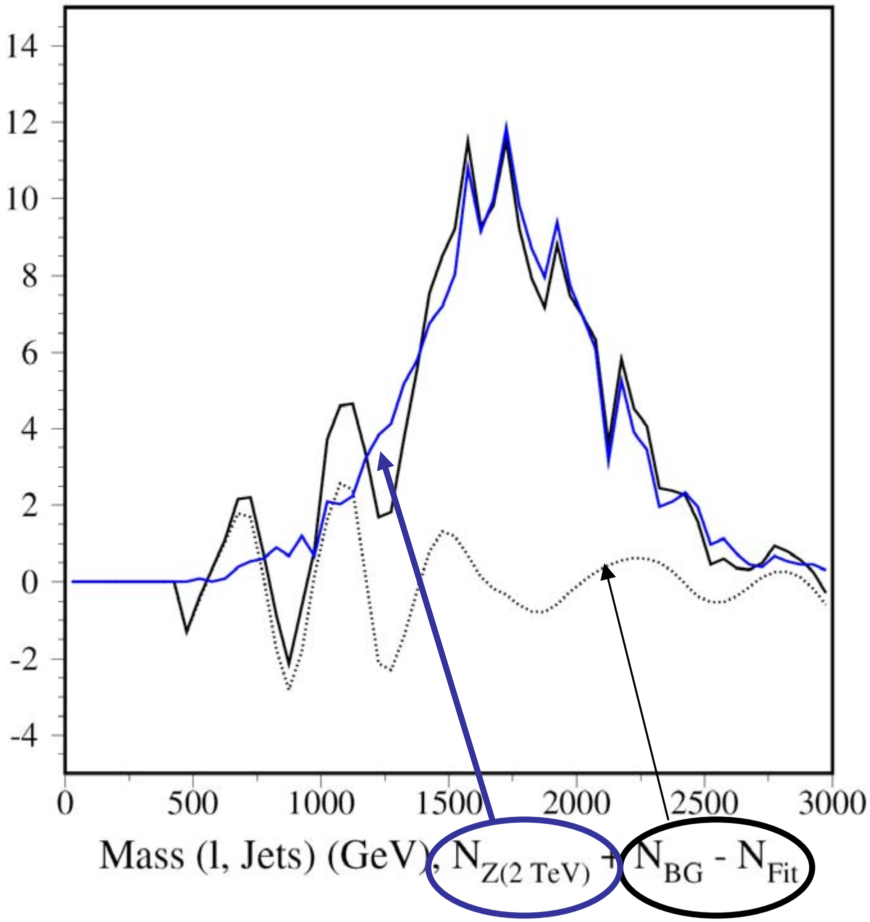
Fitting Background Events

1. Smooth background events; 2. Fit background using gaussian + polynomial



Extracting Signal by Subtracting Background From Fitting





Further BDT Training (B)

- If an interesting "signal" is found (>3σ), we will use Z' with estimated mass as signal to re-train BDT (**B**) which could enhance the signal sensitivity if it's real.

Assuming cross section of Z'→ ttbar is 1 pb & for 1 fb^{-1} int. lumi.

- Z'(1.0 TeV): Ns = 128.9, Nb = 3183, Nσ = 2.3 (Cuts)
  Ns = 129.0, Nb = 1186, Nσ = 3.75 (BDT-A)
  Ns = 123.3, Nb = 1076, Nσ = 3.76 (BDT-B)
- Z'(1.5 TeV): Ns = 99.0, Nb = 399.0, Nσ = 5.0 (Cuts)
  Ns = 106.0, Nb = 250.0, Nσ = 6.7 (BDT-A)
  Ns = 102.2, Nb = 135.2, Nσ = 8.8 (BDT-B)
- Z'(2.0 TeV): Ns = 22.4, Nb = 12.2, Nσ = 6.4 (Cuts)
  Ns = 41.7, Nb = 7.2, Nσ = 15.5 (BDT-A)
  Ns = 40.7, Nb = 3.1, Nσ = 23.0 (BDT-B)
- Z'(3.0 TeV): Ns = 39.1, Nb = 4.8, Nσ = 17.8 (Cuts)
  Ns = 50.8, Nb = 4.6, Nσ = 23.7 (BDT-A)
  Ns = 66.6, Nb = 3.1, Nσ = 38.0 (BDT-B)

5σ Discovery for Z' → $t\bar{t}$

Signal	SM cross section	$\sigma_{Z'} \times Br(Z' \to tt)$ (1fb^{-1})	$\sigma_{Z'} \times Br(Z' \to tt)$ (10fb^{-1})	$\sigma_{Z'} \times Br(Z' \to tt)$ (100fb^{-1})
Z'(1.0 TeV)	190 fb	> 1330 fb	> 420.6 fb	> 133 fb
Z'(1.5 TeV)	37 fb	> 570 fb	> 180.3 fb	> 57 fb
Z'(2.0 TeV)	10 fb	> 220 fb	> 69.6 fb	> 22 fb
Z'(3.0 TeV)	1 fb	> 130 fb	> 41.1 fb	> 13 fb

95% C.L. Limits for Z' → $t\bar{t}$

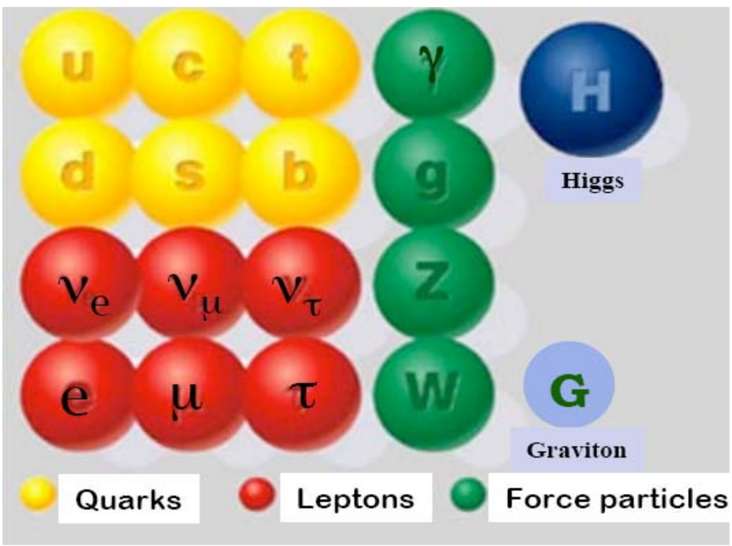
Signal	SM cross section	95% C.L. Ex. Limit ($1fb^{-1}$)	95% C.L. Ex. Limit ($10fb^{-1}$)	95% C.L. Ex. Limit ($100fb^{-1}$)
Z'(1.0 TeV)	190 fb	< 446 fb	< 139.5 fb	< 43.8 fb
Z'(1.5 TeV)	37 fb	< 196 fb	< 60.7 fb	< 18.8 fb
Z'(2.0 TeV)	10 fb	< 74 fb	< 24.6 fb	< 7.4 fb
Z'(3.0 TeV)	1 fb	< 45 fb	< 15 fb	< 4.5 fb

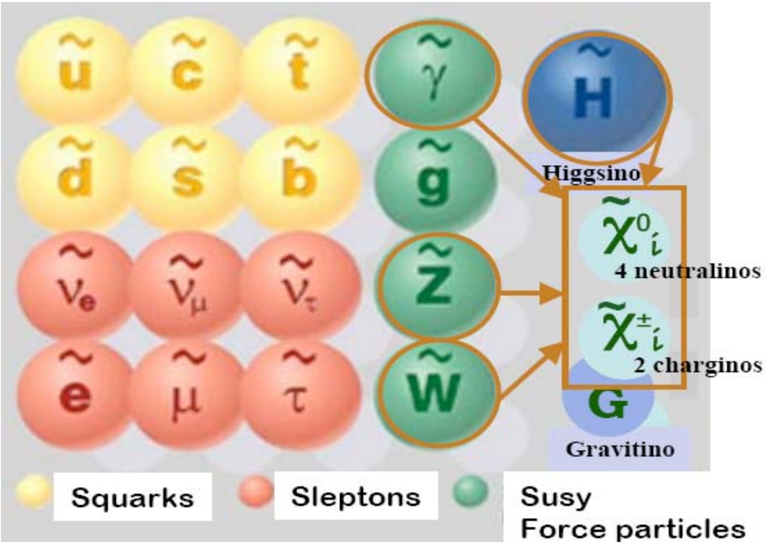
3) Search for Supersymmetry

Extends the Standard Model by predicting a new symmetry
Spin ½ matter particles (fermions) ⇔ Spin 1 force carriers (bosons)

SM particles

SUSY particles





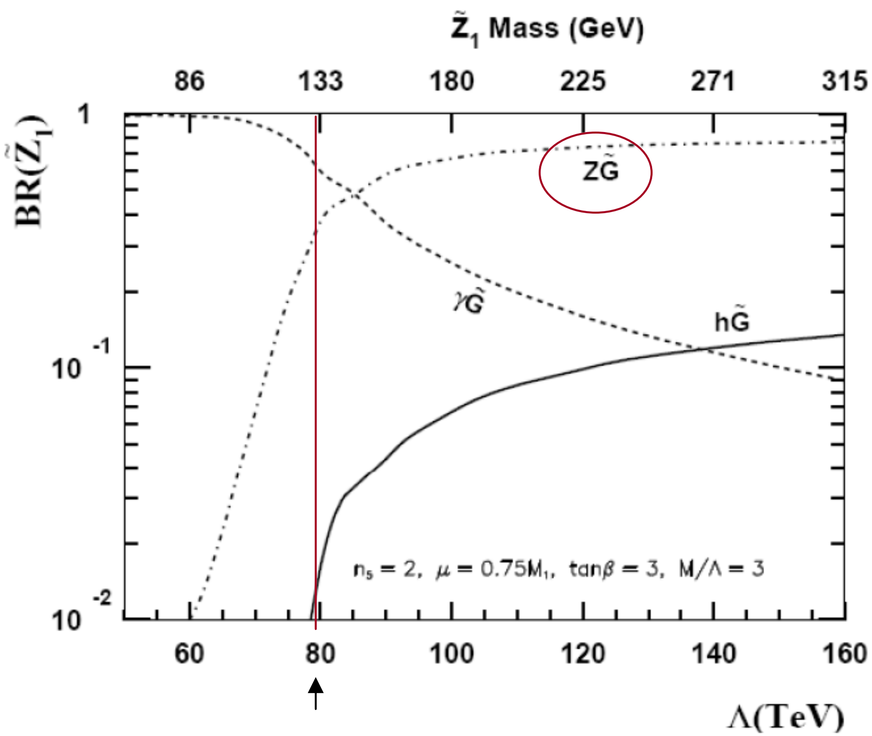
New Quantum number: R-parity: $R_p = (-1)^{B+L+2s}$ = +1 SM particles
-1 SUSY particles

Search for $\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow ZZ+MET(\tilde{G}\tilde{G})$

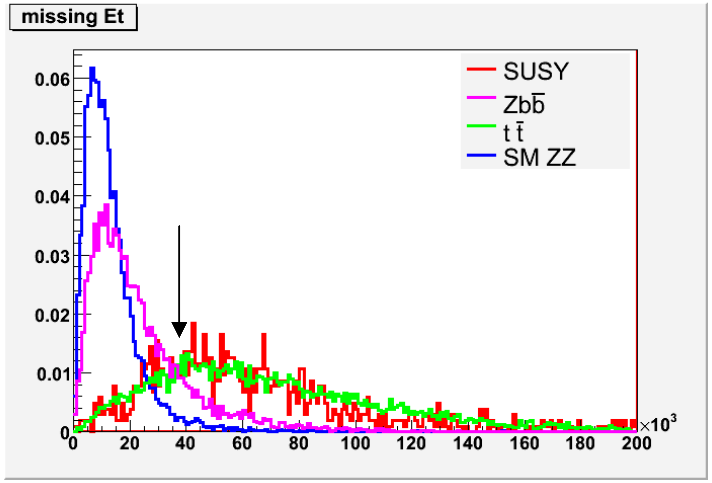
Gauge mediated supersymmetry breaking model (Physics Reports 322(1999)419)

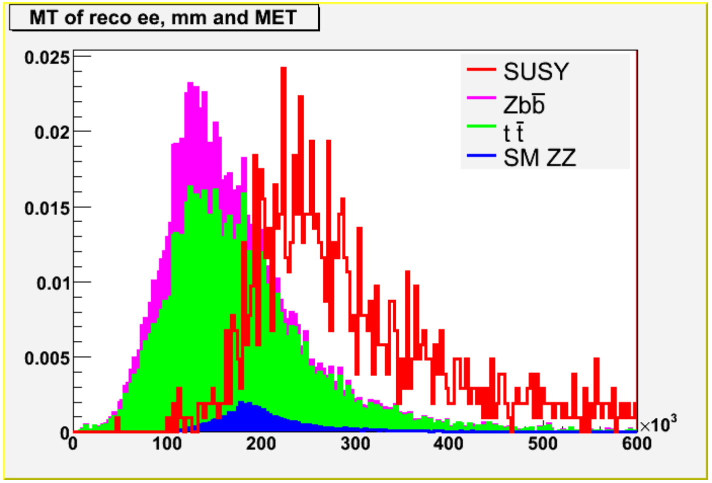
NLSP - Neutralino $\tilde{\chi}_1^0 \rightarrow (\gamma, Z, h)\tilde{G}$

Experimental signature: 4 leptons from ZZ decay + MET



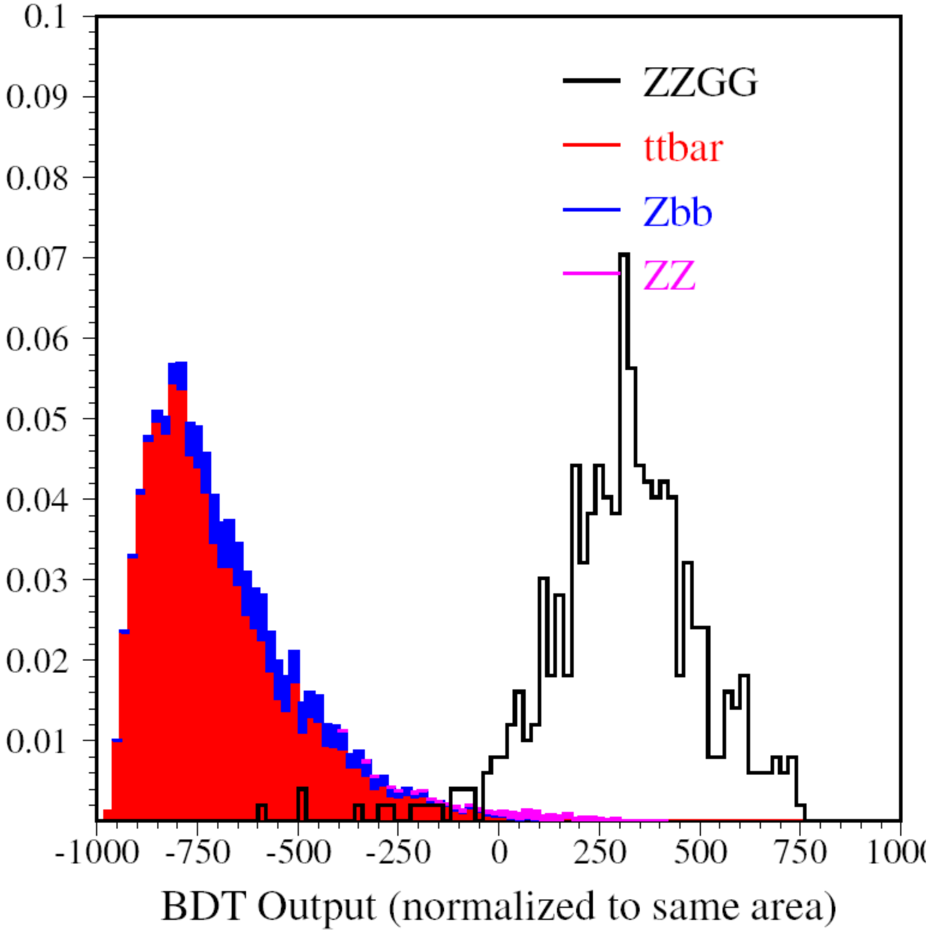
Simulation parameter



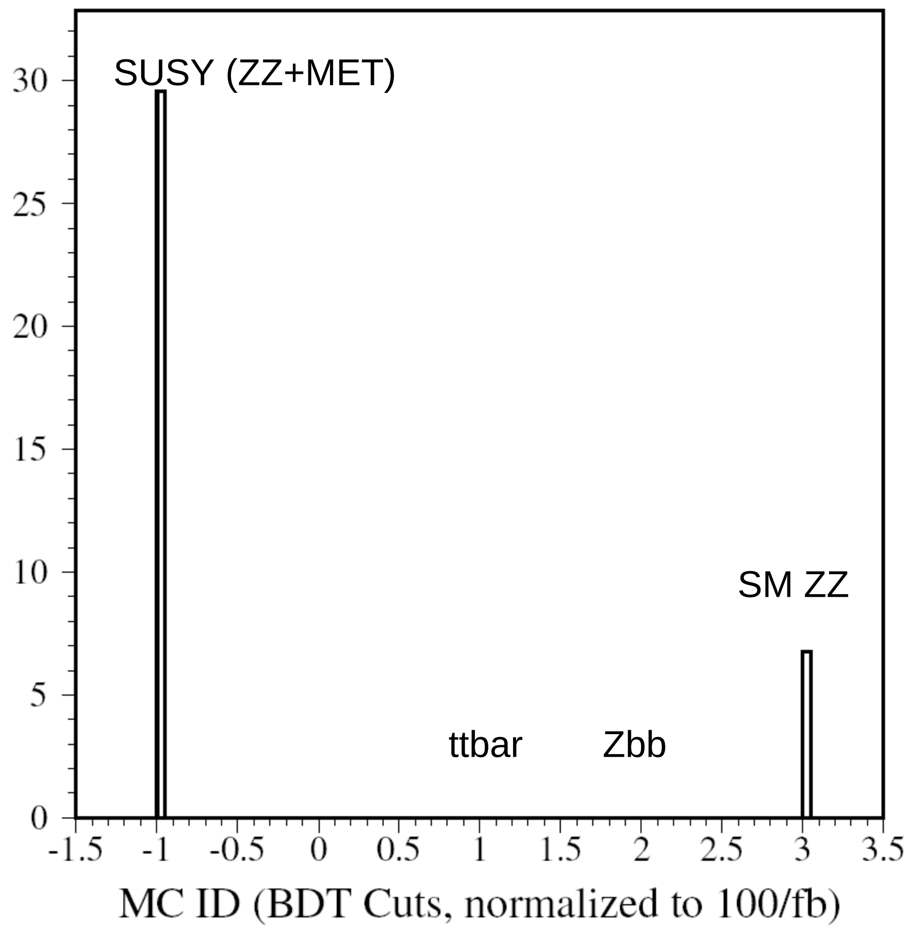


BDT analysis : ZZ+MET ($\tilde{G}\tilde{G}$)

BDT Output Spectra



Selected number of events



SUSY GMSB ZZ+MET

Straight Cuts:

- 4e or 4μ or 2e + 2μ
- MET > 40 GeV, Vt < 250 GeV
- SumEtJet < 350 GeV
- Pt(l1) > 30 GeV, minΔR(l,l) > 0.2
- 70< M_{Z1}, M_{Z2} < 100 GeV
- Mass (ZZ) > 150 GeV
- MT(ZZ+MET) > 120 GeV
- Number of Track(lep) < 4
- Sum of Track Pt (lep) < 5 GeV

Results (100/fb):

MC	4e	4μ	2e2μ	total
Signal	2.4	7.1	12.4	21.9
ZZ	1.6	14.1	13.3	29.0

Ns/Nbg = 0.76 ; Nσ = 4.1

BDT Analysis:

- 4e or 4μ or 2e + 2μ
- MET > 40 GeV
- $|M_{Z1} - M_Z| < 15$ GeV
- $|M_{Z2} - M_Z| < 15$ GeV
- BDT Output >= 290

Results (100/fb):

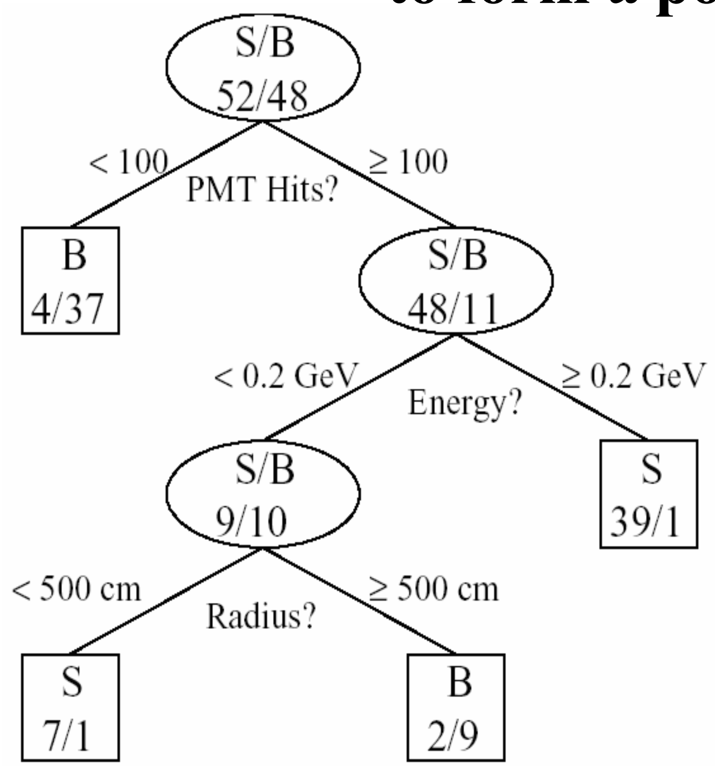
MC	4e	4μ	2e2μ	total
Signal	4.3	11.3	14.0	29.6
ZZ	1.1	3.3	2.4	6.8

Ns/Nbg = 4.35; Nσ = 11.4

Boosted Decision Trees

➔Relative new in HEP – MiniBooNE, BaBar, D0(single top discovery), ATLAS
➔Advantages: robust, understand ‘powerful’ variables, relatively transparent, …

“A procedure that combines many weak classifiers to form a powerful committee”



- Split data recursively based on input variables until a stopping criterion is reached (e.g. purity, too few events)
- Every event ends up in a “signal” or a “background” leaf
- Misclassified events will be given larger weight in the next decision tree (boosting)

H. Yang et.al. NIM A555 (2005)370, NIM A543 (2005)577, NIM A574(2007) 342

A set of decision trees can be developed,

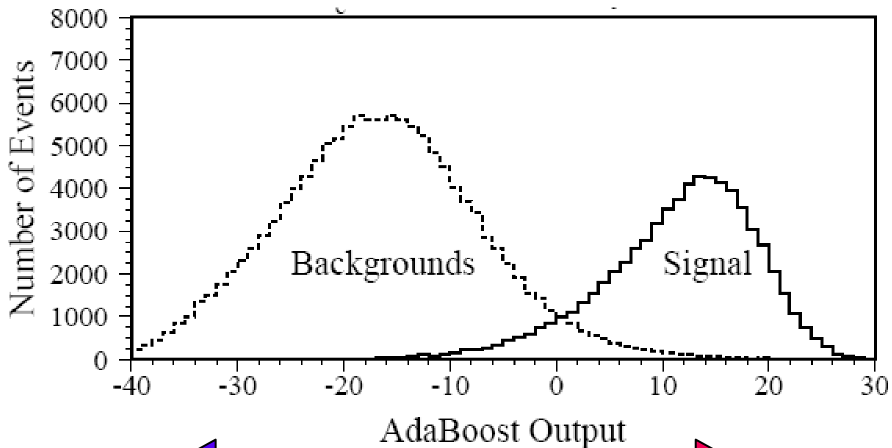
each re-weighting the events to enhance identification of backgrounds misidentified by earlier trees ("boosting")

For each tree, the data event is assigned

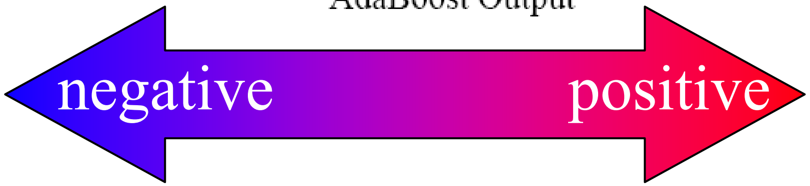
+1 if it is identified as signal,

- 1 if it is identified as background.

The total for all trees is combined into a "score"



Background-like



signal-like

Major Achievements using BDT

- MiniBooNE neutrino oscillation search using BDT and Maximum Likelihood methods
  - Phys. Rev. Lett. 98 (2007) 231801
  - One of top 10 physics stories in 2007 by AIP
- D0 – discovery of single top using BDT, ANN, ME
  - Phys. Rev. Lett. 98 (2007) 181802
  - One of top 10 physics stories in 2007 by AIP
- BDT was integrated in CERN TMVA package
  - Toolkit for MultiVariate data Analysis
  - http://tmva.sourceforge.net/
- Event Weight training technique for ANN/BDT
  - H. Yang et.al., JINST 3 P04004 (2008)
  - Integrated in TMVA package within 2 weeks after my first presentation at CERN on June 7, 2007

Summary

- It is very important to establish the SM signals at LHC with the first fb^{-1} data. Vector-boson productions are key to demonstrate the large, complex detector performance.
- Indirect search of new physics will be performed through the anomalous triple gauge boson coupling studies at ATLAS. The sensitivities from LHC/ATLAS can be significantly improved over the results from Tevatron and LEP using a few fb^{-1} data.
- The discovery of the SM Higgs via W-pair leptonic decay modes could be achieved by using a few fb^{-1} integrated luminosity if $140<M_H<180$ GeV.
- Supersymmetry has very rich experimental signatures. Multi-leptons with large MET and multi-bosons with large MET give the most clean signature.
- The discovery of Z' →ttbar is possible if non-gauge-coupling involved with Z' mass around a few TeV.

The most exciting and challenge phase of LHC is coming!

Backup

SUSY GMSB ZZ+MET Signal and Background

SUSY GMSB ZZ+MET search summery table							
Process	cross-s	filter ef	MC eve	Presele	Final se	Acc. X-	BDT sel
Signal	2.1 fb	1	2986	1009	469	0.33	0.44
4 muons				376	171		
4 electrons				155	51		
2e + 2 mu				478	247		
Backgrund							
tt	833 pb	0.007	4E+05	7710	4	0.061	0.03
4 muons				5135	3		
4 electrons				50	0		
2e + 2 mu				2525	1		
Zbb	73.84 p	0.009	3E+05	29603	10	0.02	0.004
4 muons				17672	3		
4 electrons				574	1		
2e + 2 mu				11357	6		
ZZ	14.8 pb	0.005	49250	11050	1454	1.973	0.33
4 muons				4674	587		
4 electrons				1297	156		
2e + 2 mu				5079	711		

Event Weight Training Technique

Ref: H.Yang et.al., JINST 3 P04004, 2008

- In the original BDT training program, all training events are set to have same weights in the beginning. It works fine if all MC processes are produced based on their production rates (eg. MiniBooNE).
- But, it's unrealistic and inefficient to generate MC for all physics processes with full detector simulation based on their production rates at hadron collider (eg. LHC).
- Example: 1K Background A(80%), 1K Background B(20%)
  - Equal event weight training, Wt_A = 50%, Wt_B = 50%
  - Event weight training, Wt_A = 80%, Wt_B = 20%

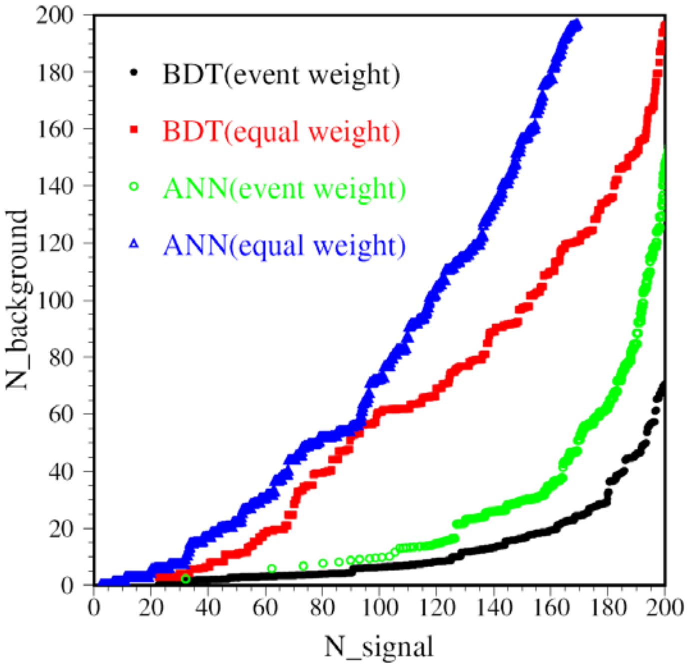
- If we treat all training events with different weights equally using "standard" training algorithm, ANN/BDT tend to pay more attention to events with lower weights (high stat.) and introduce training bias.

ANN/BDT Comparison (WZ)

➔Event weight training technique works better than equal weight training for both ANN(x5-7) and BDT(x6-10)

➔BDT is better than ANN by reducing more background(x1.5-2)

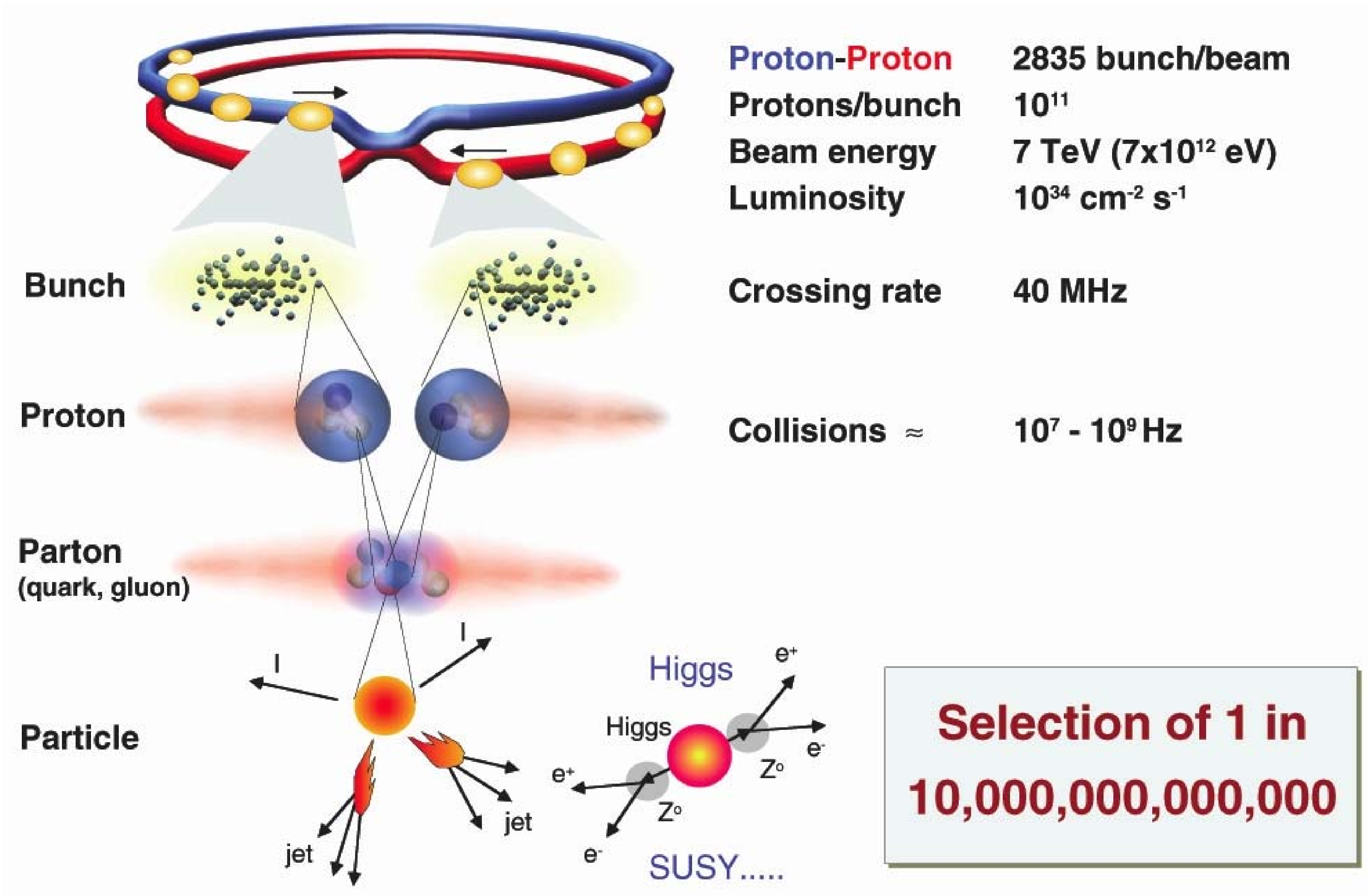
➔ I reported it at CERN on June 7, 2007, CERN TMVA package added event weight function on June 19, 2007



N_{signal}	60	80	100	120	140	160
N_{bg1} for ANN-equal-weight	30.5	51.9	72.4	104.7	133.3	177.6
N_{bg2} for ANN-event-weight	5.8	7.7	9.8	14.7	25.9	34.9
$Ratio = N_{bg1}/N_{bg2}$ for ANN	5.3	6.7	7.4	7.1	5.1	5.1
N_{bg3} for BDT-equal-weight	18.5	39.4	60.7	69.1	88.9	110.1
N_{bg4} for BDT-event-weight	3.1	4.0	6.3	8.4	13.2	19.3
$Ratio = N_{bg3}/N_{bg4}$ for BDT	6.0	9.9	9.6	8.2	6.7	5.7
$Ratio = N_{bg2}/N_{bg4}$ for ANN/BDT	1.90	1.93	1.56	1.75	1.96	1.81

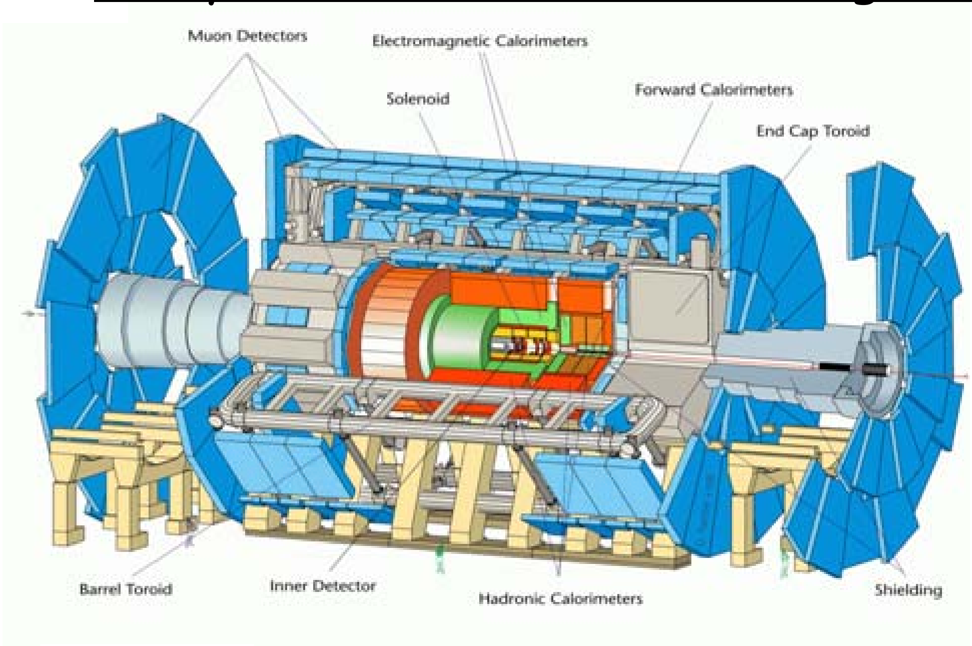
Proton-Proton Collisions at LHC

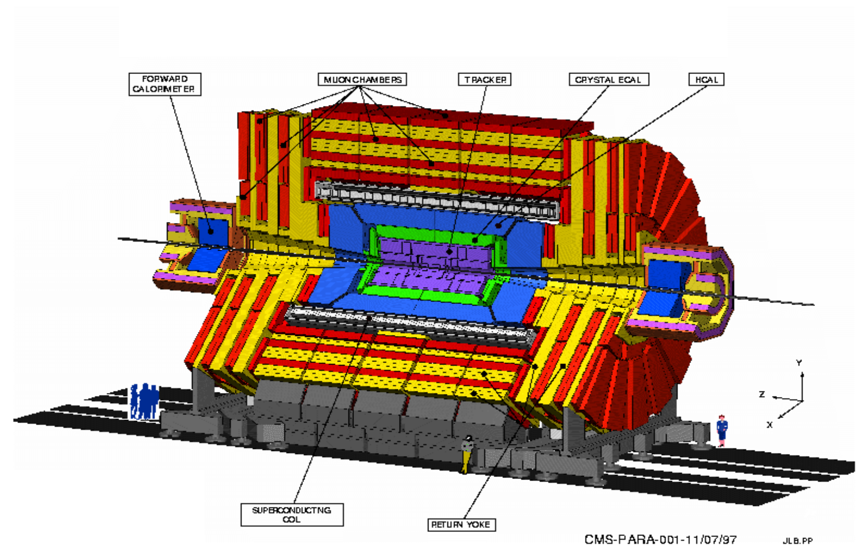
to discover the mysteries of EWSB, Dark-Matter, …



Two general purpose experiments at LHC

<u>> 10 years of hard work in design and constructions, ready for beams</u>





ATLAS

Length : ~45 m
Diameter : ~24 m
Weight : ~ 7,000 tons
Electronic channels : ~ 10^8
Solenoid : 2 T
Air-core toroids

Excellent Standalone Muon Detector

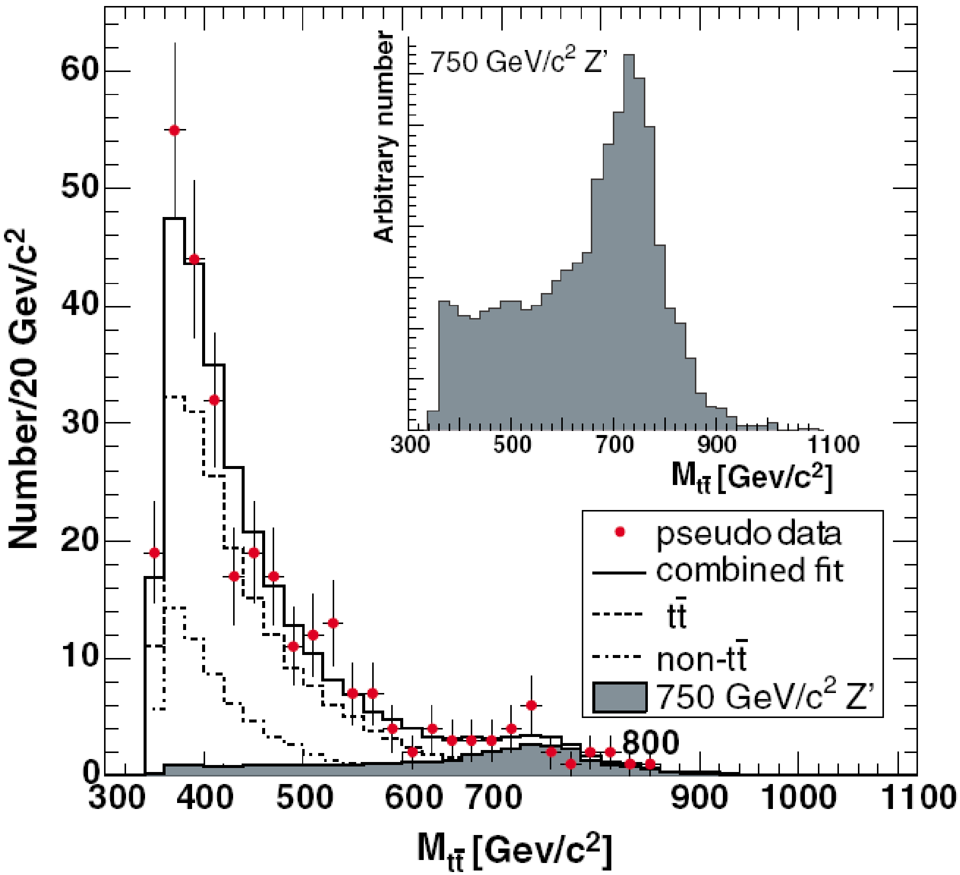
CMS

Length : ~22 m
Diameter : ~14 m
Weight : ~ 12,500 tons
Solenoid : 4 T
Fe yoke
Compact and modular

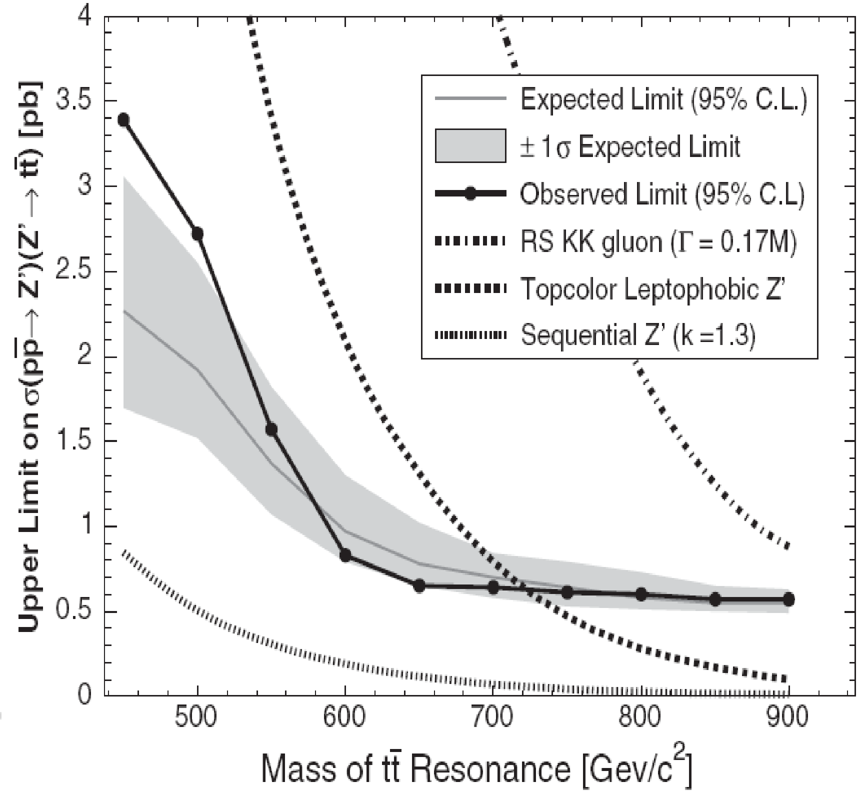
Excellent EM Calorimeter

Search for Z'→ $t\bar{t}$ at CDF

PHYSICAL REVIEW D **77**, 051102(R) (2008)



σ_{tt} = 7.8 ± 0.7 pb



W / Top Mass (Kt4)

- Algorithm-A1, W→2 jets, Top→3 jets
- Algorithm-A2, W→1,2 jets, Top→1,2,3 jets
- Tight cuts: 60<M_w<100 GeV, 125<M_w<225 GeV

MC(1000 Events)	A1	A2	Ratio
Ttbar	652	652	1.0
Z' – 1TeV	660	687	1.04
Z' – 1.5TeV	573	703	1.23
Z' – 2 TeV	436	641	1.47
Z' – 3 TeV	348	586	1.68

Search for New Gauge Boson W'/Z'

Z' → μμ

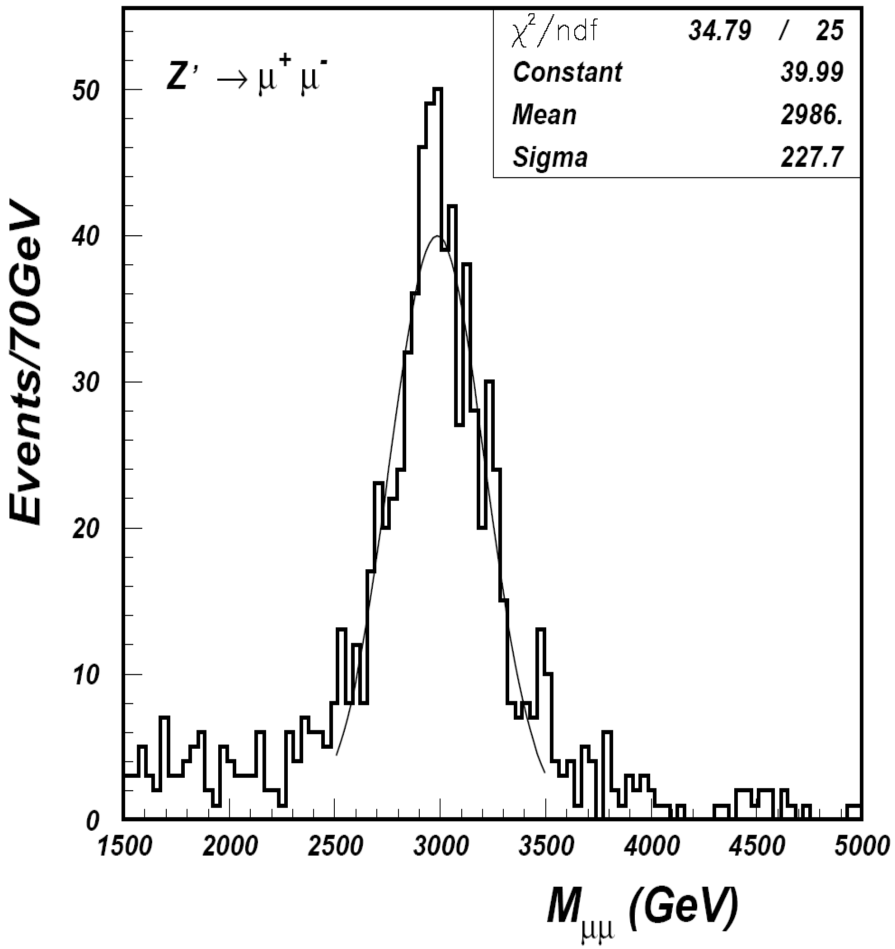
B. Zhou
J. Shank
F. Taylor

With full detector simulation and reconstruction, we determined the parameters of $Z' \to \mu^+\mu^-$ detection shown in the following table:

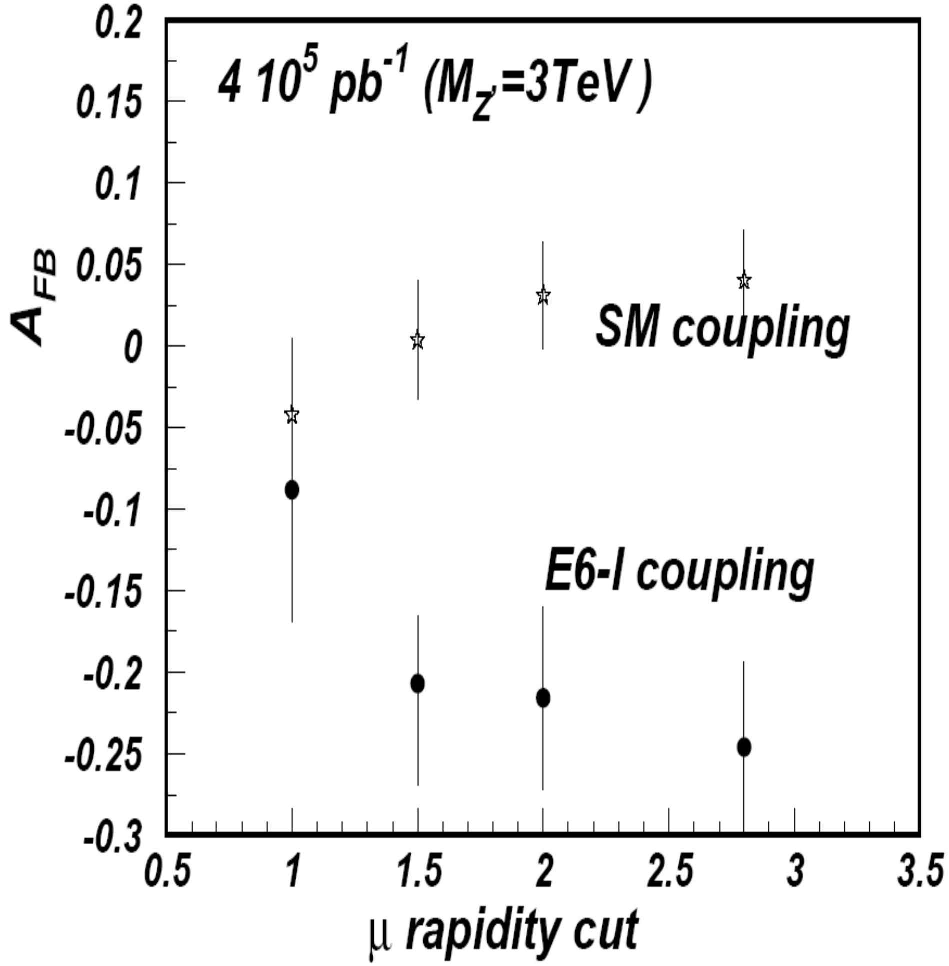
Model	SM	SM	$E_6 - I$	$E_6 - I$
Z' Mass (TeV)	1	3	1	3
$\sigma \times BR$(pb)	0.51	2.5×10^{-3}	0.24	9.9×10^{-4}
rec. events $> 1\mu$	93.0%	92.4%	92.8%	93.4%
fract. same charge events	2.2%	4.1%	1.3%	3.8%
events for A_{FB}	90.8%	88.3%	91.5%	89.6%
events for $10^5 pb^{-1}$	4.6×10^4	221	2.2×10^4	89

at LHC

Z' → μμ ($M_{Z'}$ = 3 TeV)



Z' → μ+ μ-
χ2/ndf 34.79 / 25
Constant 39.99
Mean 2986.
Sigma 227.7
Events/70GeV
Mμμ (GeV)



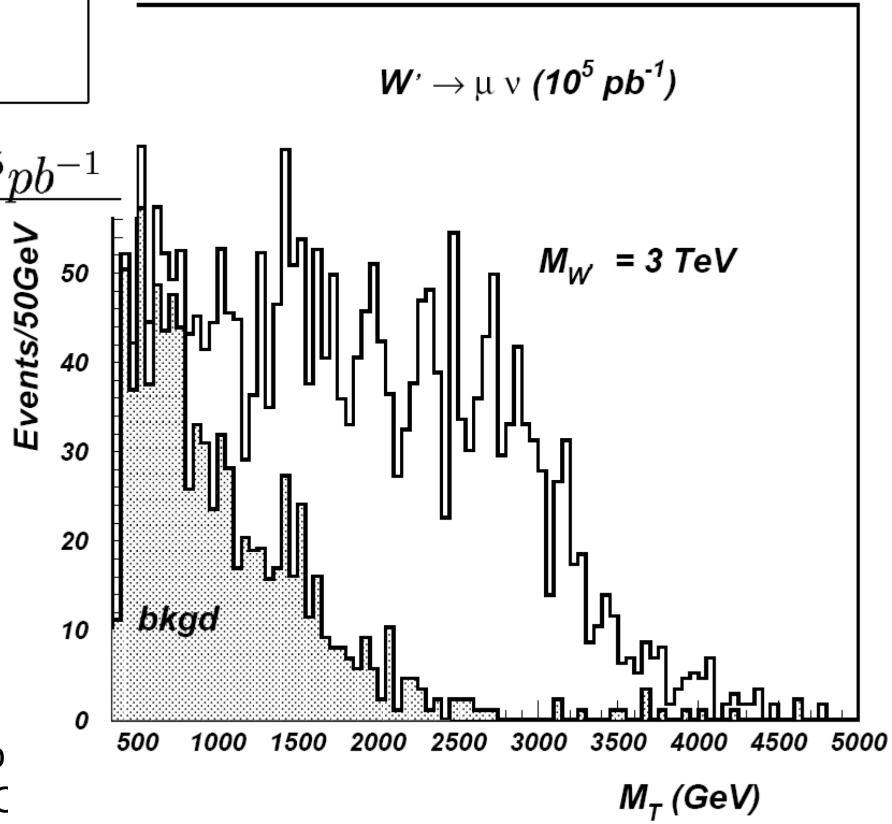
4 10^5 pb^-1 (MZ'=3TeV)
AFB
SM coupling
E6-I coupling
μ rapidity cut

W' → μ ν

$M_{W'}$ (TeV)	$\sigma_{W' \to \mu\nu}$ (pb)	N_{events} (no cut)
1.0	3.78	378000
2.0	1.552×10^{-1}	15520
3.0	1.740×10^{-2}	1740
4.0	2.489×10^{-3}	249
5.0	3.870×10^{-4}	39
6.0	6.348×10^{-5}	6

Reachable in early LHC data

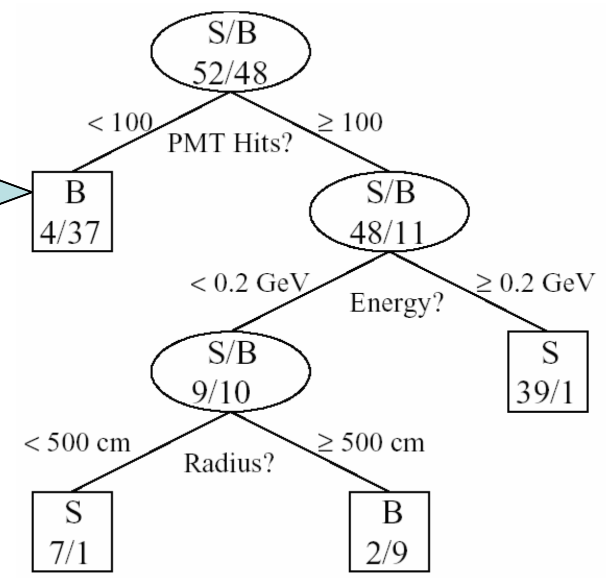
Expected W' Events at $\sqrt{s}$=14 TeV for $10^5 pb^{-1}$



Boosted Decision Trees

How to build a decision tree ?

For each node, try to find the best variable and splitting point which gives the best separation based on Gini index.
Gini_node = Weight_total*P*(1-P), P is weighted purity
Criterion = Gini_father – Gini_left_son – Gini_right_son
Variable is selected as splitter by maximizing the criterion.

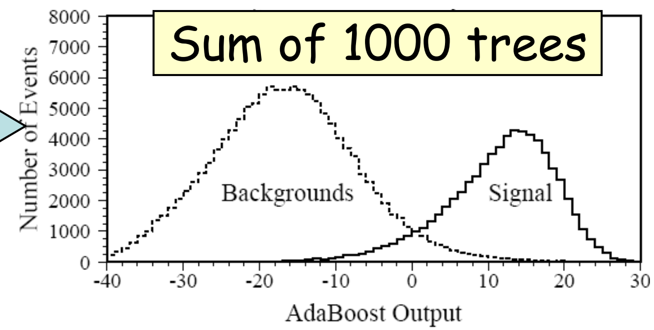


How to boost the decision trees?

Weights of misclassified events in current tree are increased, the next tree is built using the same events but with new weights. Typically, one may build few hundred to thousand trees.

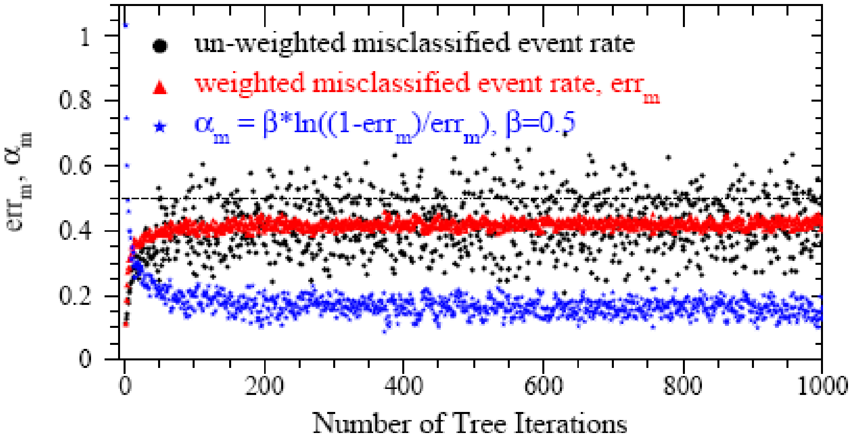
How to calculate the event score ?

For a given event, if it lands on the signal leaf in one tree, it is given a score of 1, otherwise, -1. The sum (probably weighted) of scores from all trees is the final score of the event.

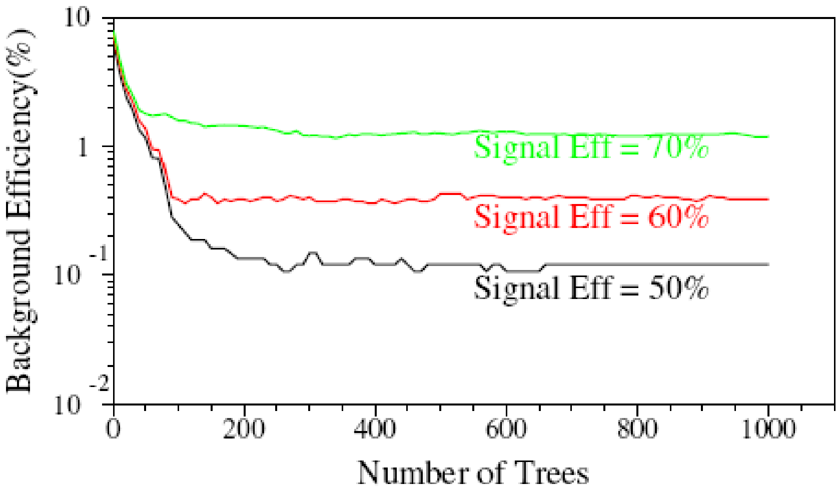


Ref: B.P. Roe, H.J. Yang, J. Zhu, Y. Liu, I. Stancu, G. McGregor, "*Boosted decision trees as an alternative to artificial neural networks for particle identification*", physics/0408124, NIM A543 (2005) 577-584.

Weak → Powerful Classifier



➔The advantage of using boosted decision trees is that it combines many decision trees, "weak" classifiers, to make a powerful classifier. The performance of boosted decision trees is stable after a few hundred tree iterations.



➔ Boosted decision trees focus on the misclassified events which usually have high weights after hundreds of tree iterations. An individual tree has a very weak discriminating power; the weighted misclassified event rate err_m is about 0.4-0.45.

Ref1: H.J.Yang, B.P. Roe, J. Zhu, "*Studies of Boosted Decision Trees for MiniBooNE Particle Identification*", physics/0508045, Nucl. Instum. & Meth. A 555(2005) 370-385.
Ref2: H.J. Yang, B. P. Roe, J. Zhu, " *Studies of Stability and Robustness for Artificial Neural Networks and Boosted Decision Trees* ", physics/0610276, Nucl. Instrum. & Meth. A574 (2007) 342-349.

Applications of BDT in HEP

- Boosted Decision Trees (BDT) has been applied for some major HEP experiments in the past few years.
  - MiniBooNE data analysis (BDT reject 20-80% more background than ANN)
    - physics/0408124 (NIM A543, p577), physics/0508045 (NIM A555, p370),
    - physics/0610276(NIM A574, p342), physics/0611267
    - " A search for electron neutrino appearance at dm^2 ~ 1 eV^2 Scale", hep-ex/0704150 (submitted to PRL)
  - ATLAS Di-Boson analysis, ww, wz, wγ, zγ
  - ATLAS SUSY analysis – hep-ph/0605106 (JHEP060740)
  - LHC B-tagging, physics/0702041, for 60% b-tagging eff, BDT has 35% more light jet rejection than that of ANN.
  - BaBar data analysis
    - "Measurement of CP-violating asymmetries in the B0->K+K-K0 dalitz plot", hep-ex/0607112
    - physics/0507143, physics/0507157
  - D0 data analysis
    - hep-ph/0606257, Fermilab-thesis-2006-15,
    - "Evidence of single top quarks and first direct measurement of |Vtb|", hep-ex/0612052 (to appear in PRL), BDT better than ANN, matrix-element likelihood
  - More are underway …

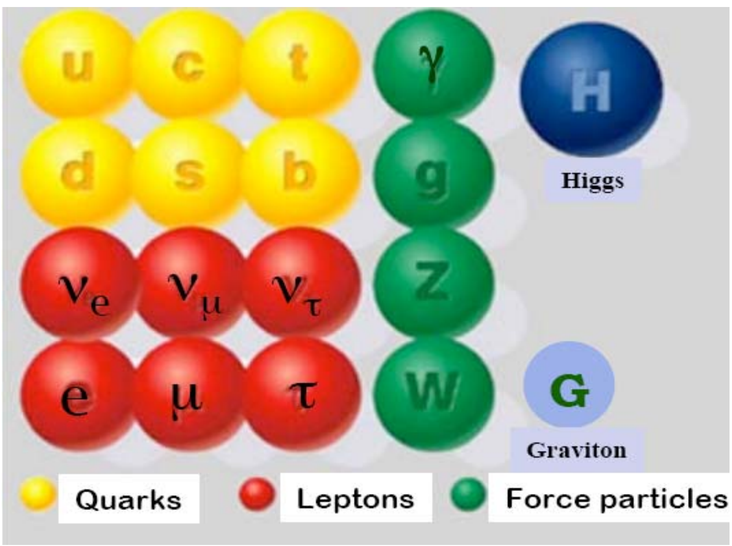
BDT Free Softwares

- http://gallatin.physics.lsa.umich.edu/~hyang/boosting.tar.gz
- TMVA toolkit, CERN Root V5.14/00
  http://tmva.sourceforge.net/
  http://root.cern.ch/root/html/src/TMVA__MethodBDT.cxx.html

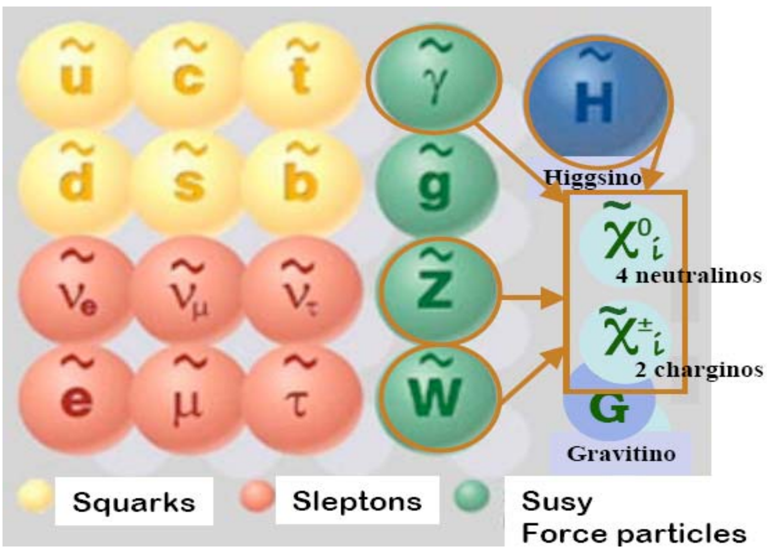
Supersymmetry

Extends the Standard Model by predicting a new symmetry
Spin ½ matter particles (fermions) ⇔ Spin 1 force carriers (bosons)

SM particles



SUSY particles



New Quantum number: R-parity: $R_p = (-1)^{B+L+2s}$ = +1 SM particles
-1 SUSY particles

Consequences of R-parity conservation

- SUSY particles are produced in pairs
- Lightest Supersymmetric Particle (LSP) is stable.
  In most models LSP is also weakly interacting:
  LSP $\equiv \chi^0_1$ (lightest neutralino)

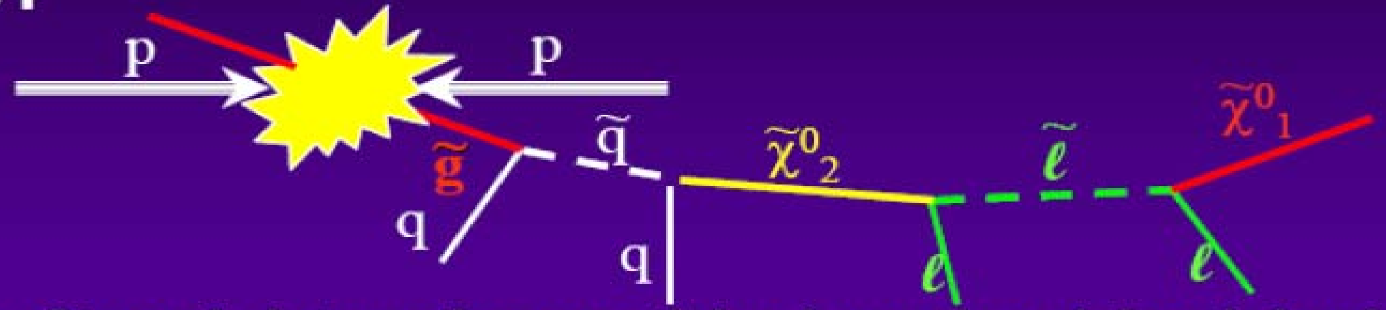
  - LSP is a good candidate for cold dark matter

  - LSP behaves like a ν $\rightarrow$ it escapes detection

  - very large E_T^{miss} (typical SUSY signature)

Quick Search for SUSY Particles

Typical SUSY event at LHC:

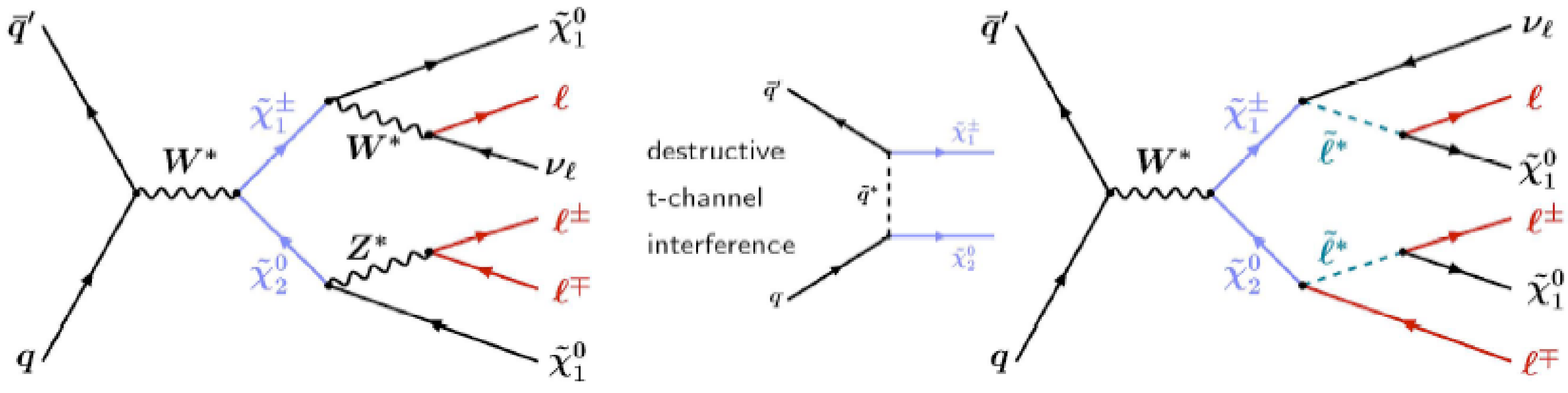


- Strongly interacting sparticles (squarks, gluinos) dominate production
  - Can have high cross-sections ⇒ good candidate for early discovery
- sleptons, gauginos etc. $\tilde{g}$ cascade decays to LSP.
- Long decay chains and large mass differences between SUSY states
  - Many high pT objects observed (leptons, jets, b-jets).
- If R-Parity conserved LSP stable and sparticles pair produced.
  - Large ETmiss signature
- Closest equivalent SM signature $t \rightarrow Wb$ with $W \rightarrow \ell \nu$

Charginos and Neutralinos

- Search for Charginos and Neutralinos:
  Multilepton + E_T^{miss}
  produced via electroweak processes (associated production)

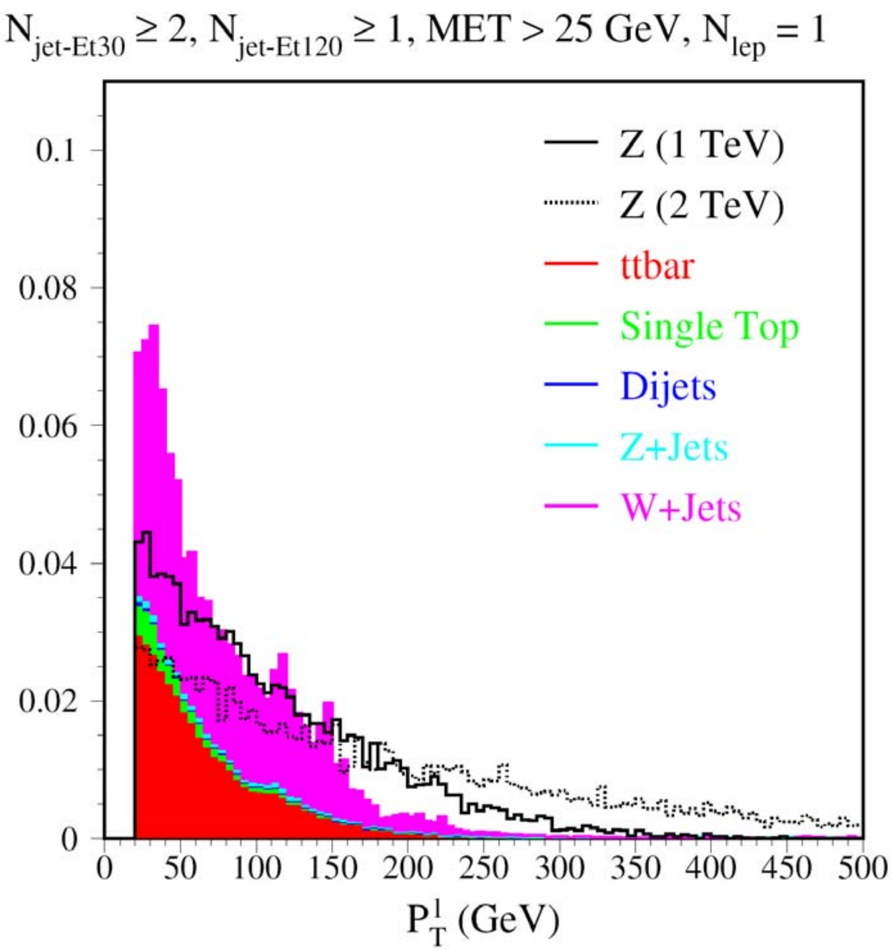
$$\tilde{\chi}_2^0 \tilde{\chi}_1^\pm \rightarrow l^\pm l^\mp l^\pm \tilde{\chi}_1^0 \tilde{\chi}_1^0 X$$

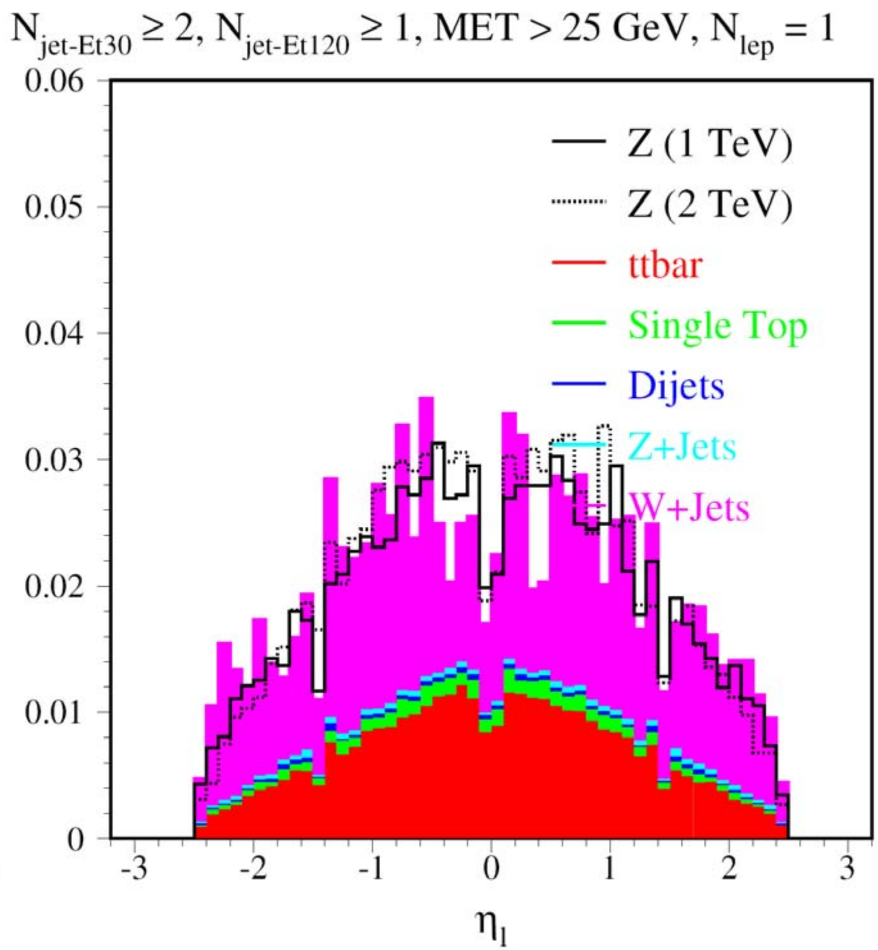


Physics Implications of Z’

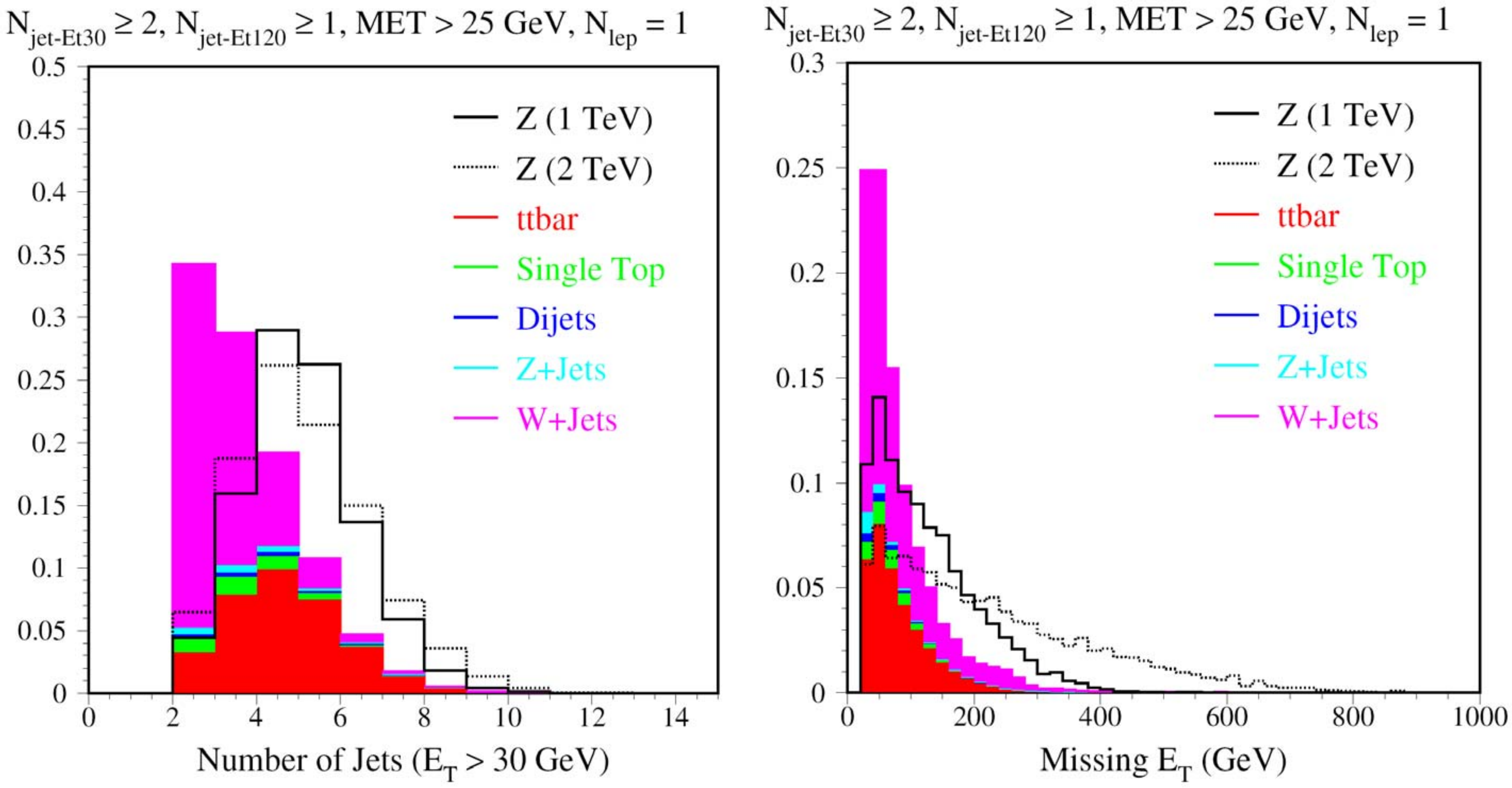
- Additional U(1)' gauge symmetries and associated Z' gauge boson are one of the best motivated extensions of the SM, it would have profound implications for particle physics and cosmology. Possible implications of a Z' including,
  - an extended Higgs sector
  - extended neutralino sector
  - exotic fermions needed for anomaly cancellation
  - possible flavor changing neutral current effects
  - neutrino mass
  - possible Z' mediation of supersymmetry breaking
  - cold dark matter and electroweak baryogensis
  - **(Ref: Paul Langacker, arXiv:0801.1345v2)**

Lepton Pt and Eta

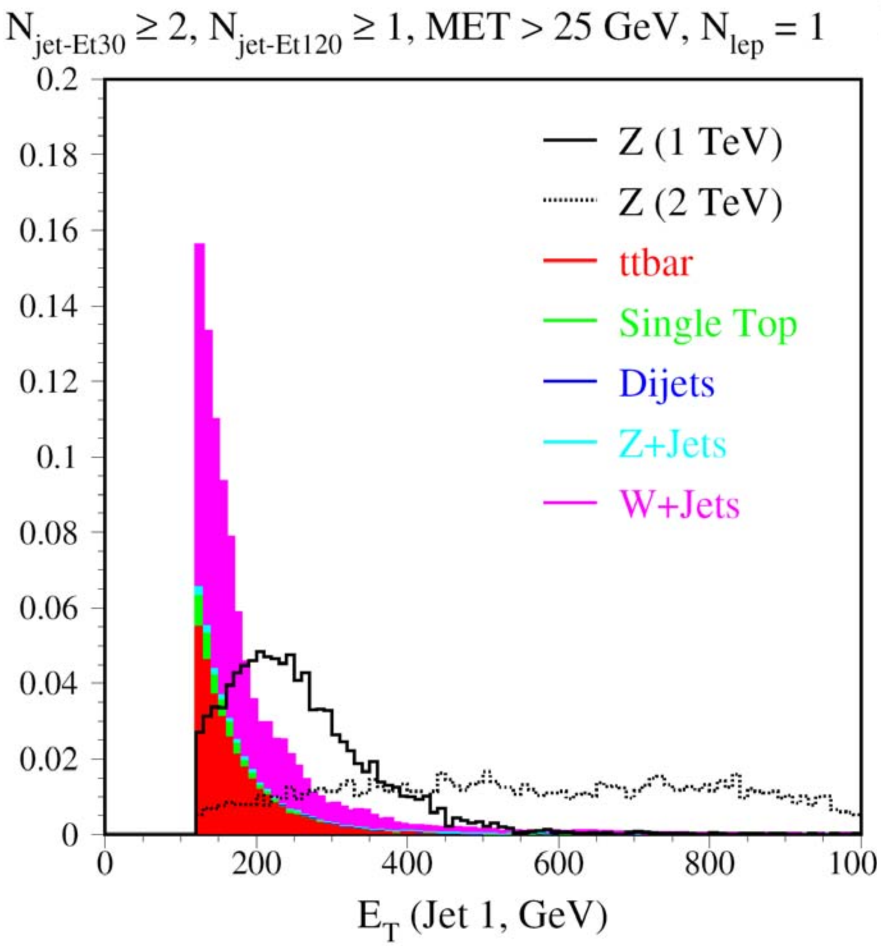


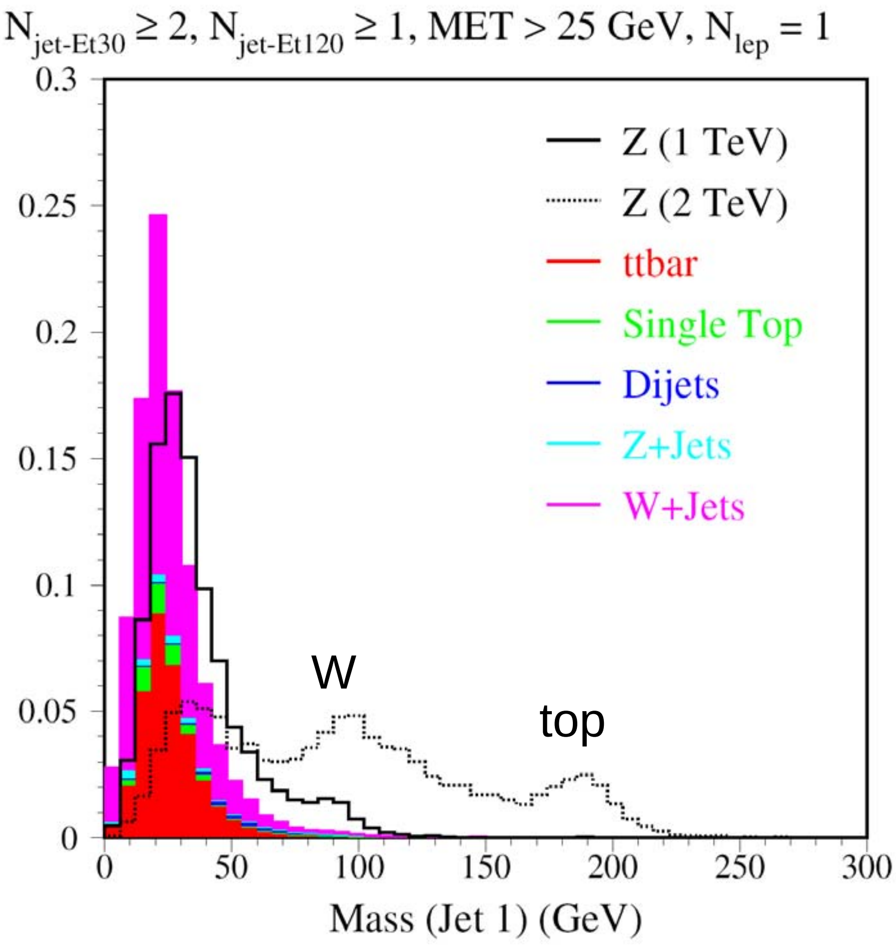


After Pre-selection Number of Jets and MET

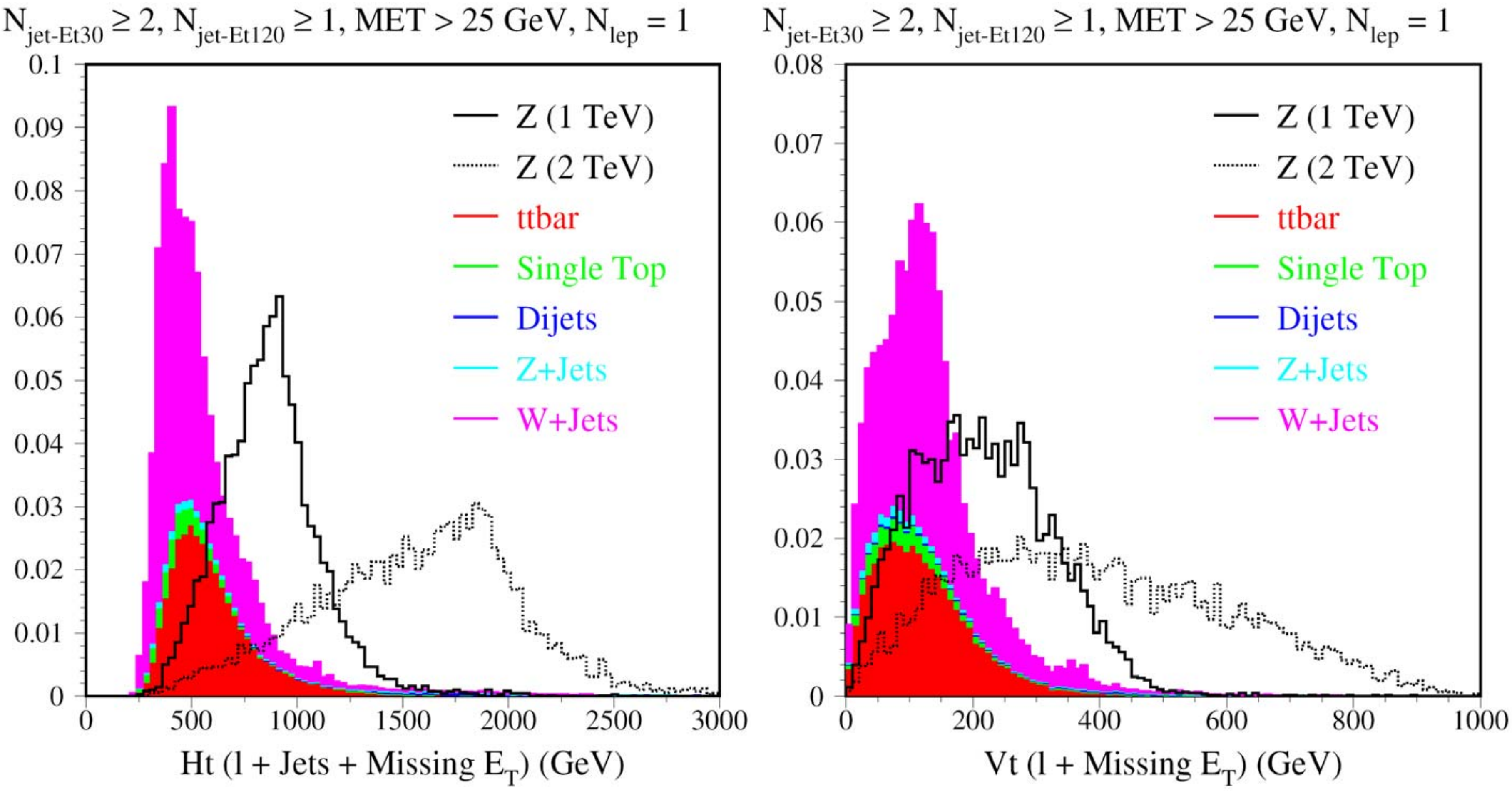


E_T & Mass of the 1st Energetic Jet

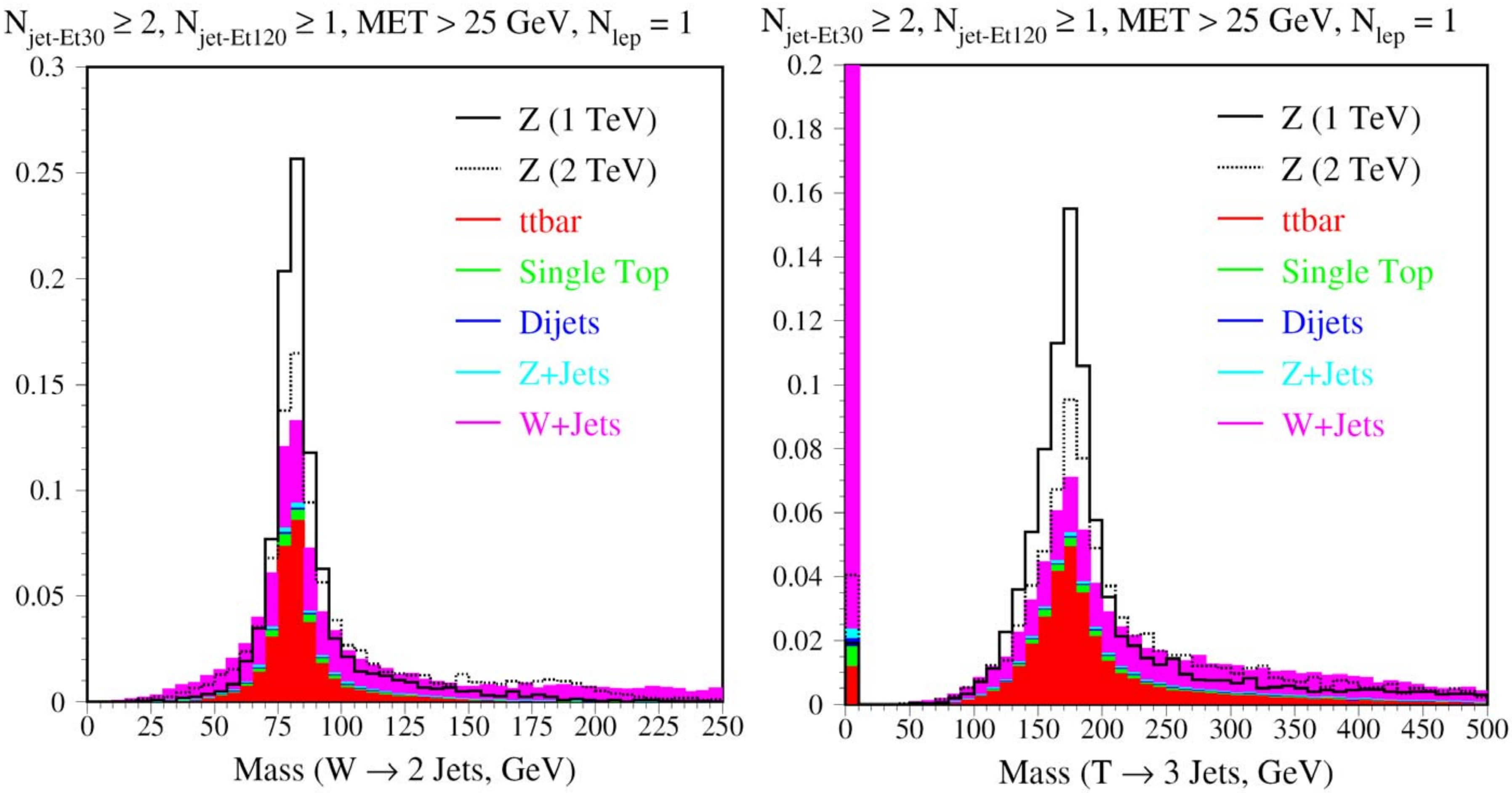




Distributions of H_T and V_T



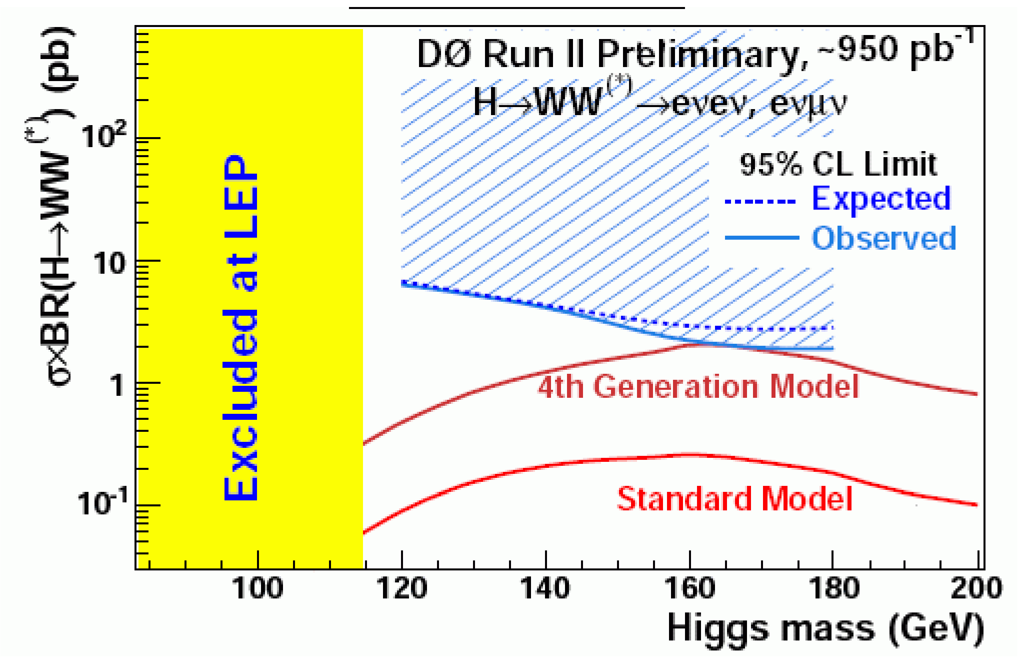
W and Top Mass

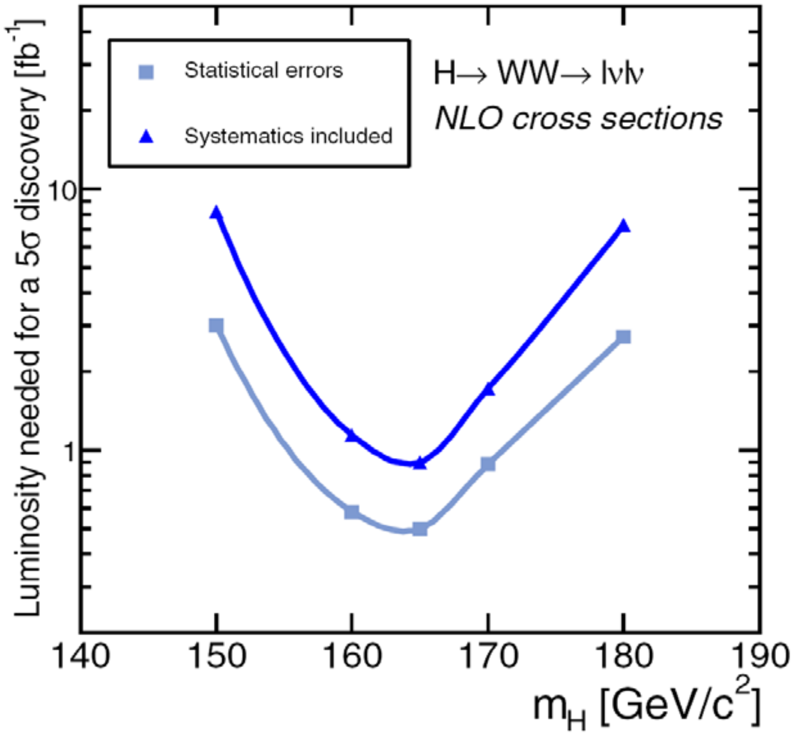


H → WW* → lνlν
Current limit and discovery potential at LHC

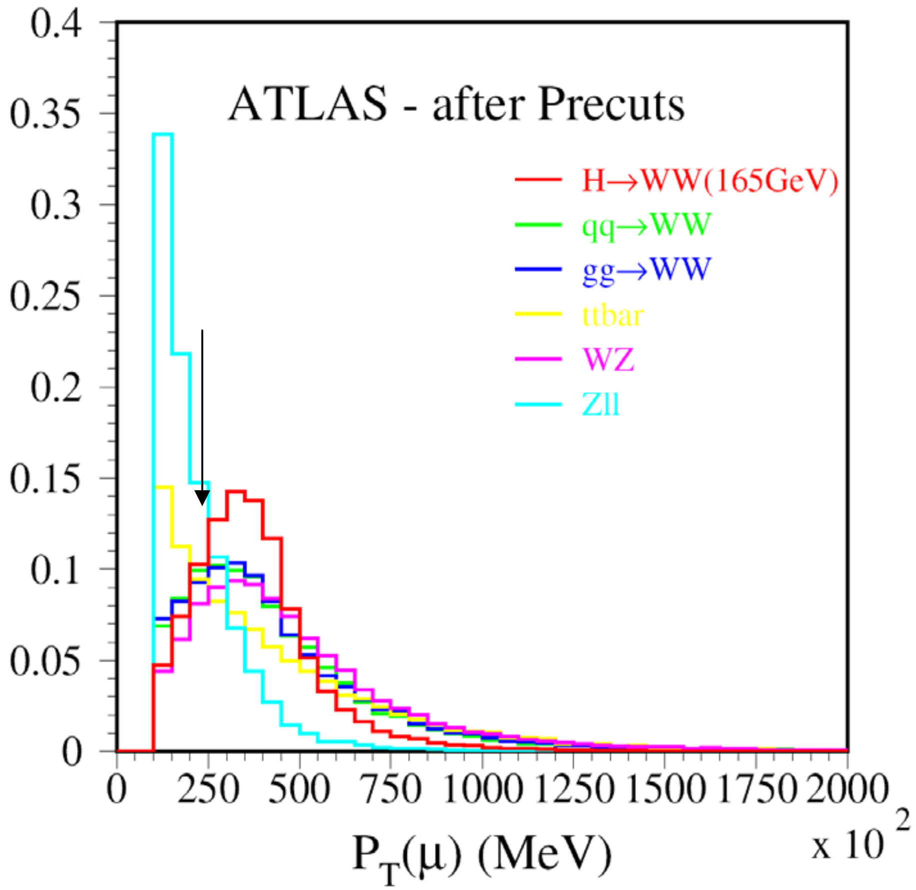
Excluded cross section times Branching Ratio at 95% C.L.

CMS Phys. TDR 2006

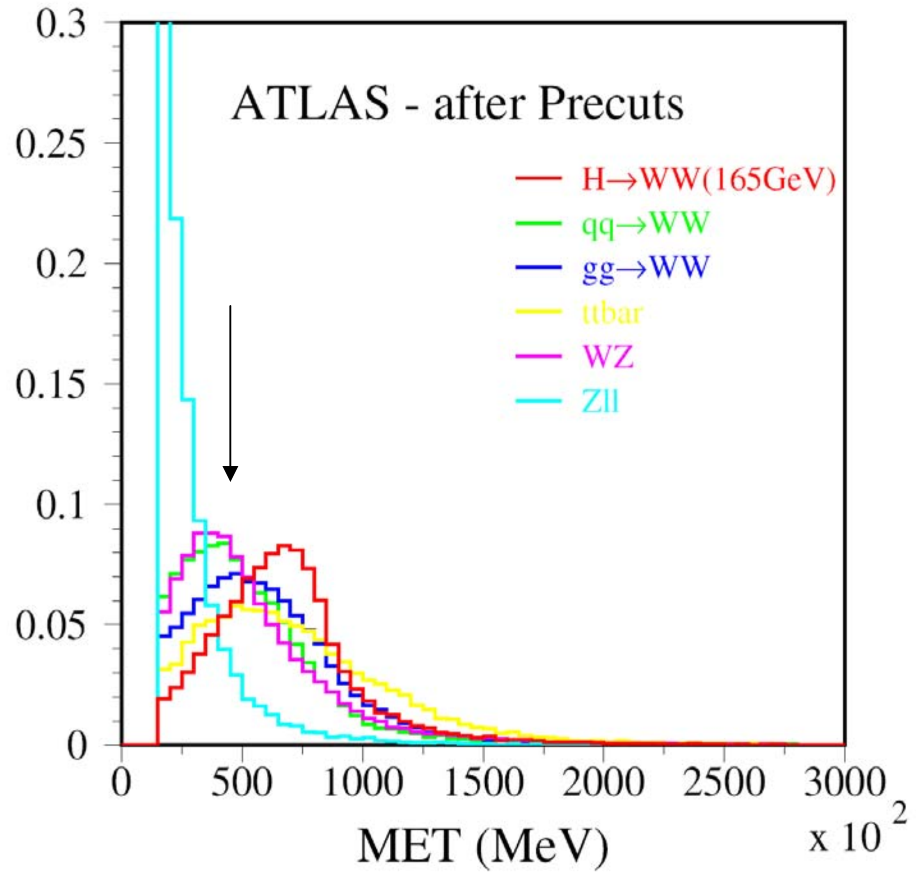




P_T of leptons and MET

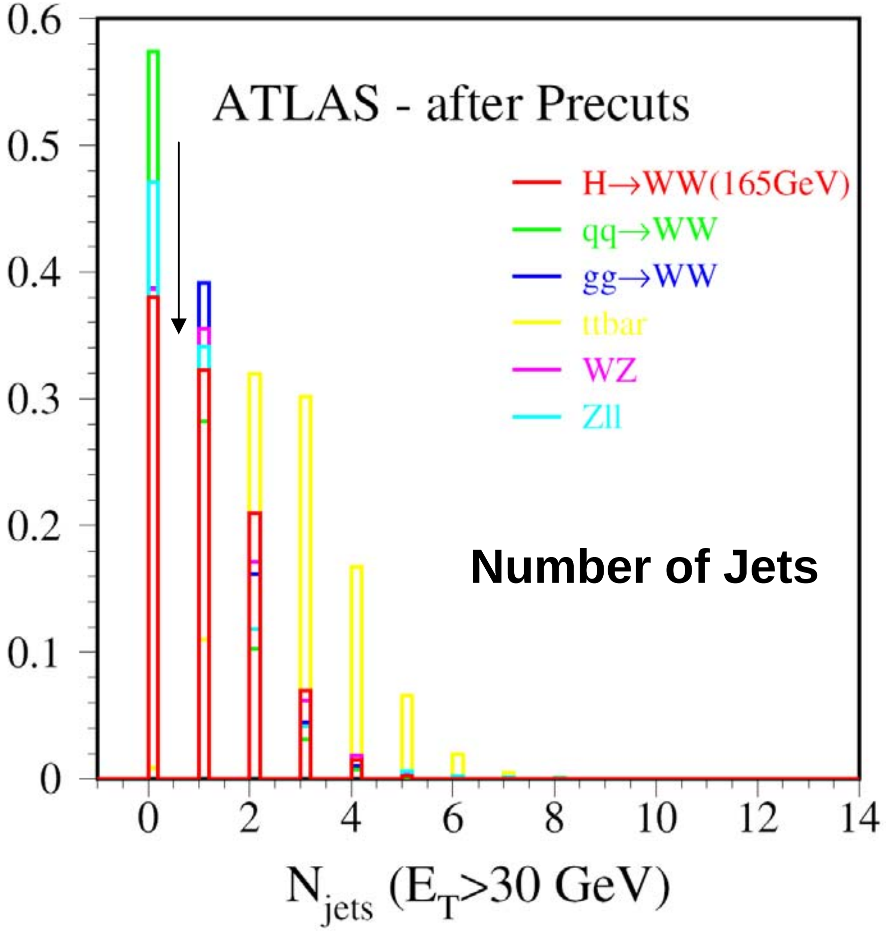


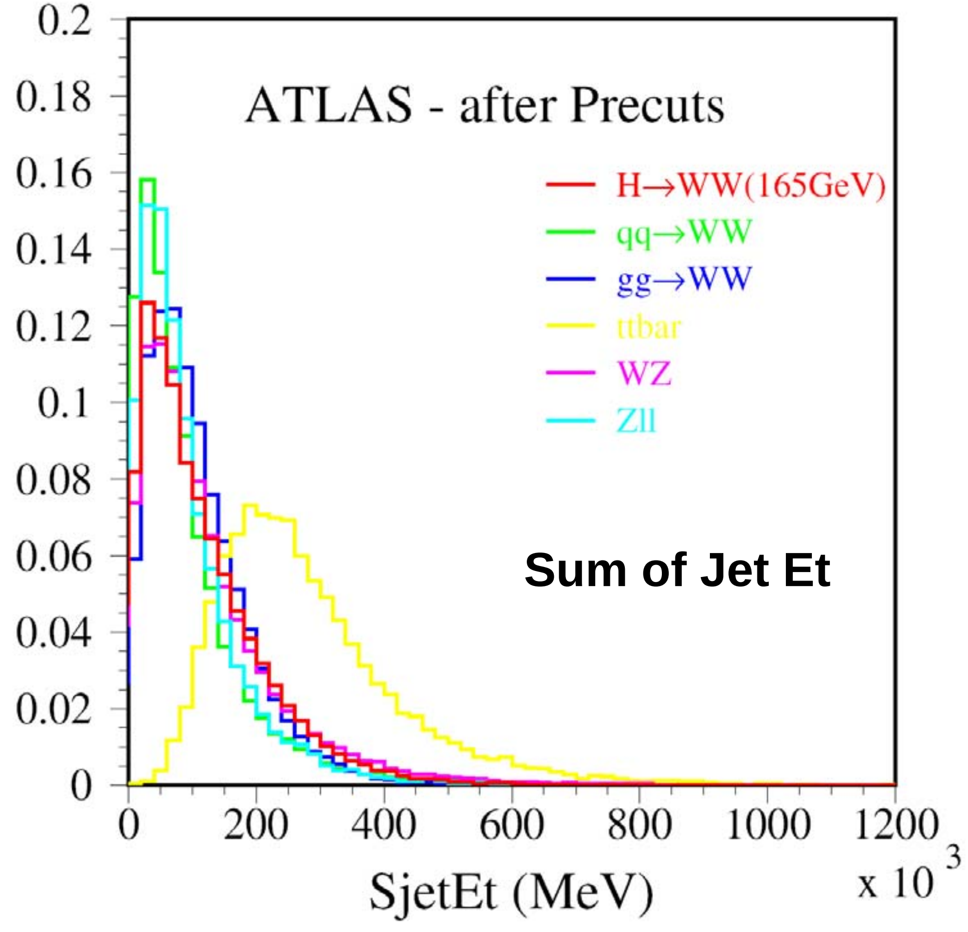
Transverse Momentum of Lepton



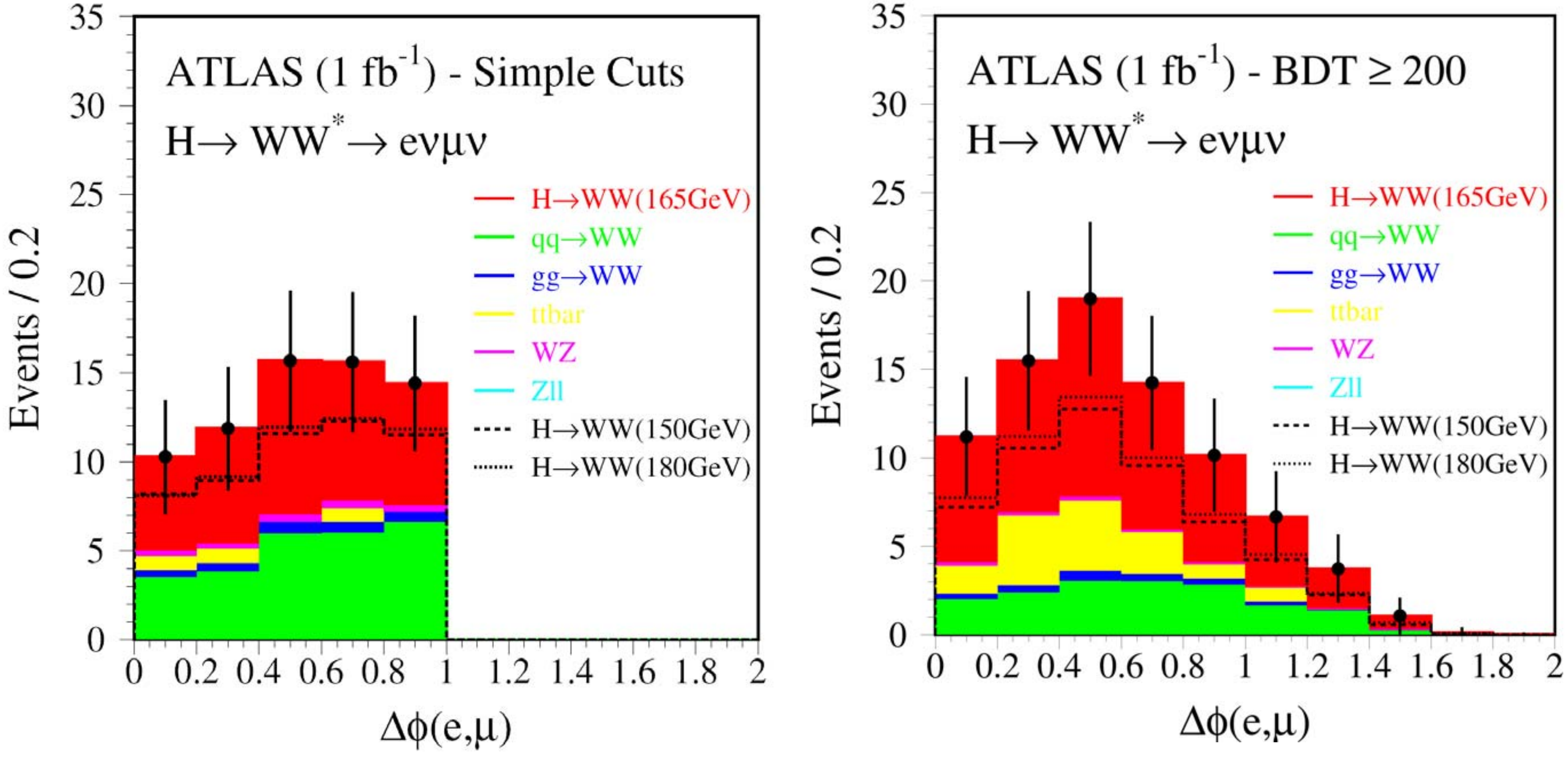
Missing Transverse Energy

No. of Jets & Jet Energy





Straight Cuts vs BDT (Angle)

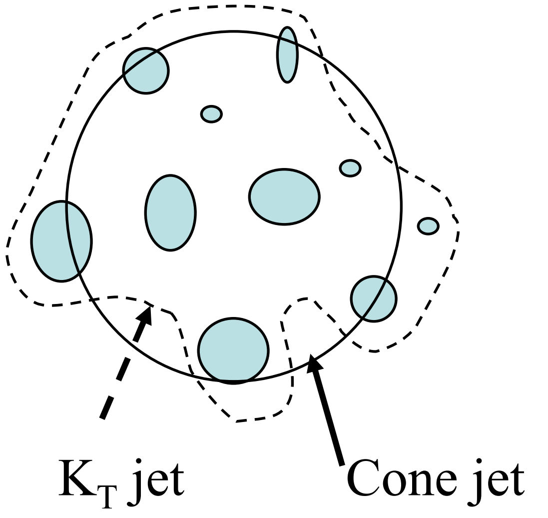


Jet Finder – Cone Algorithm

- Draw a cone (eg. R=0.4, 0.7) around a "seed" (Pt >1 GeV)
- Calculate sum ET, and ET-weighted position (jet center)
- Draw new cone at jet center and recalculate sum ET, ET-weighted position
- Re-iterate until stable

$$R_{ij} = \sqrt{\Delta\eta_{ij}^2 + \Delta\varphi_{ij}^2}$$

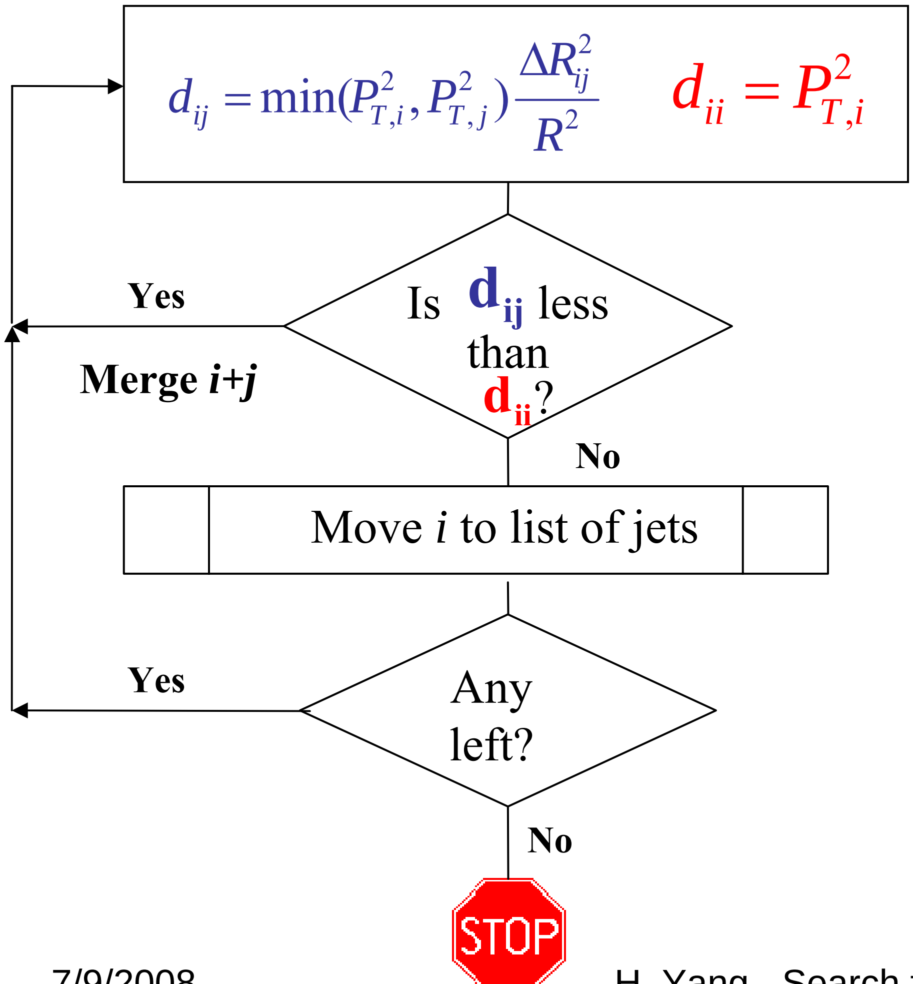
➔The cone jets always have well defined, smooth boundaries. However, it is possible with two equally energetic protojets located near opposite edges of the cone and nothing in the center of the cone.



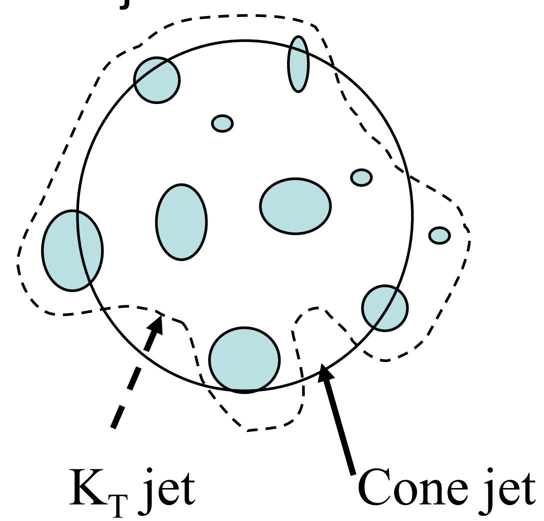
Jet Finder – Kt Algorithm

(Ref: S.D.Ellis & D.E.Soper, PRD 48 (1993) 3160)

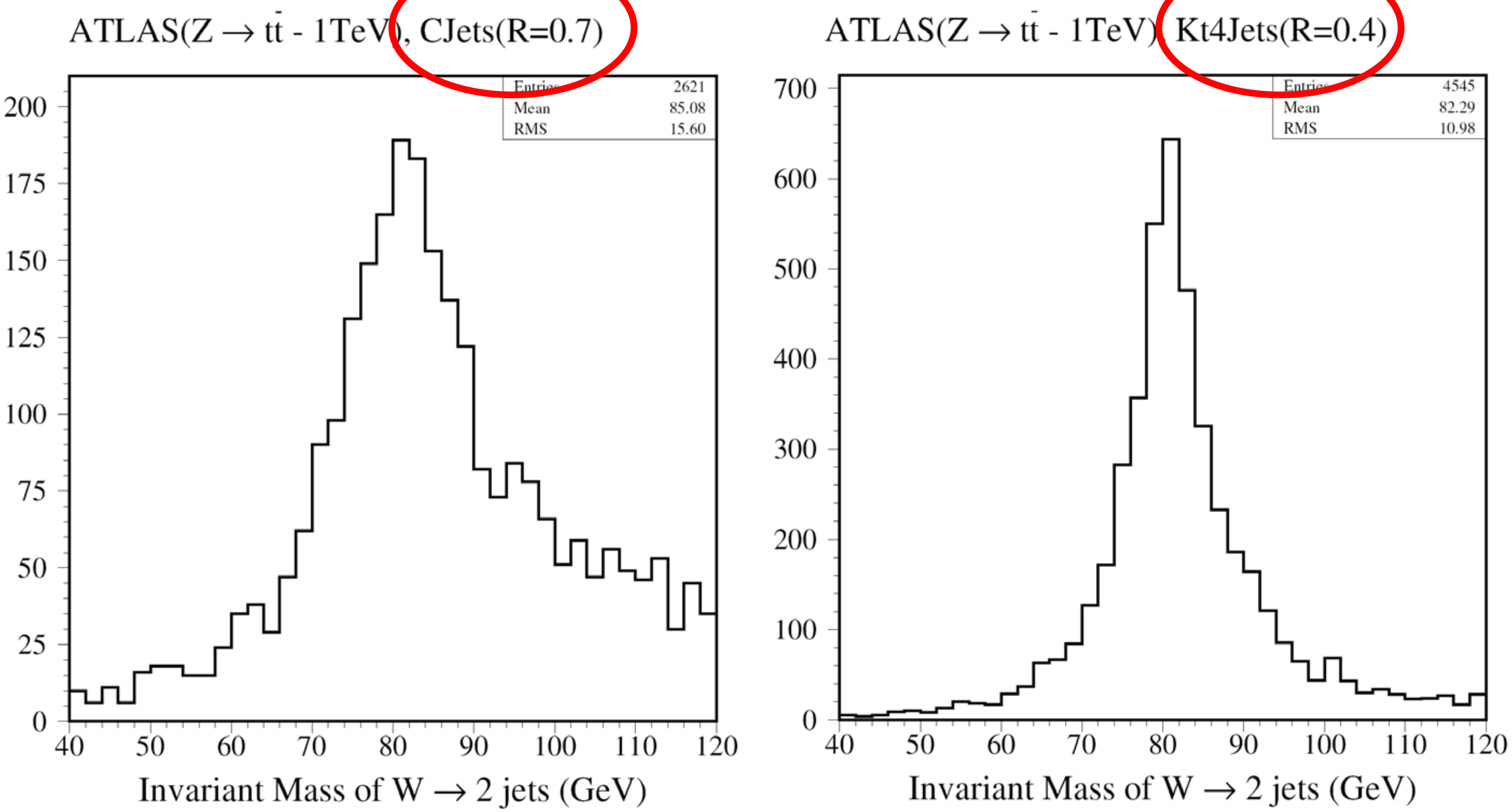
$$R_{ij} = \sqrt{\Delta\eta_{ij}^2 + \Delta\varphi_{ij}^2}$$



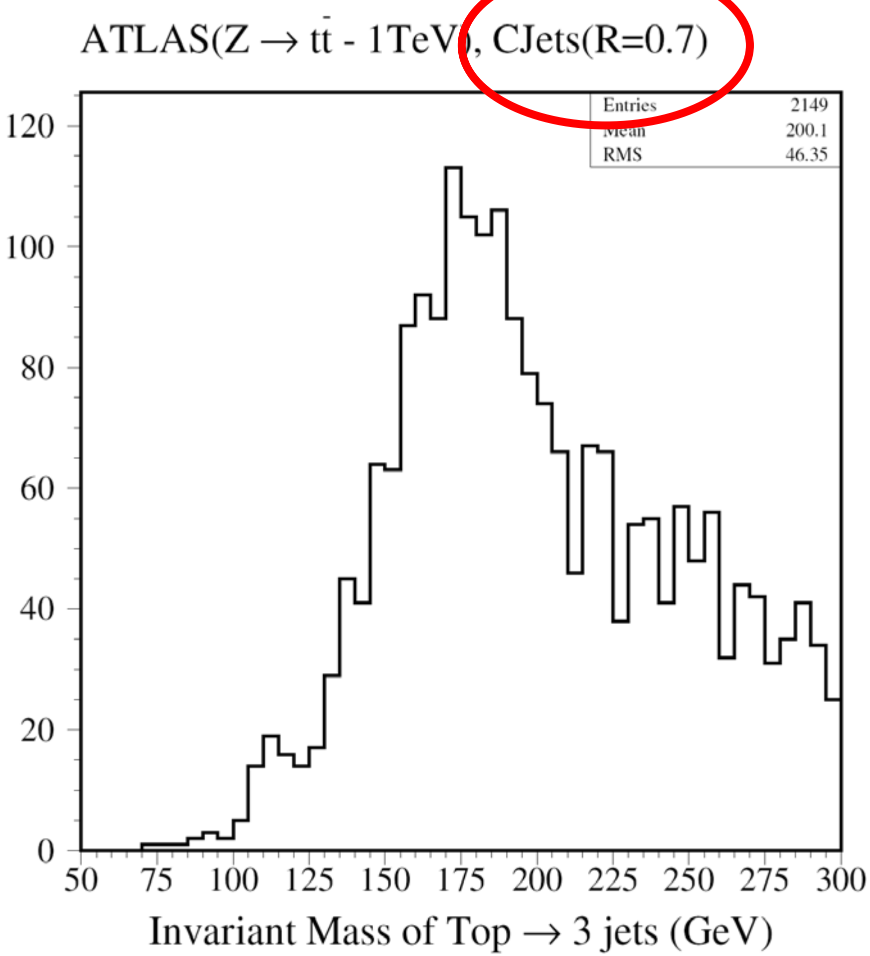
➔the lower Et protojet can be far from jet axis, up to a max separation R, while the higher Et protojet must be closer to the jet axis.

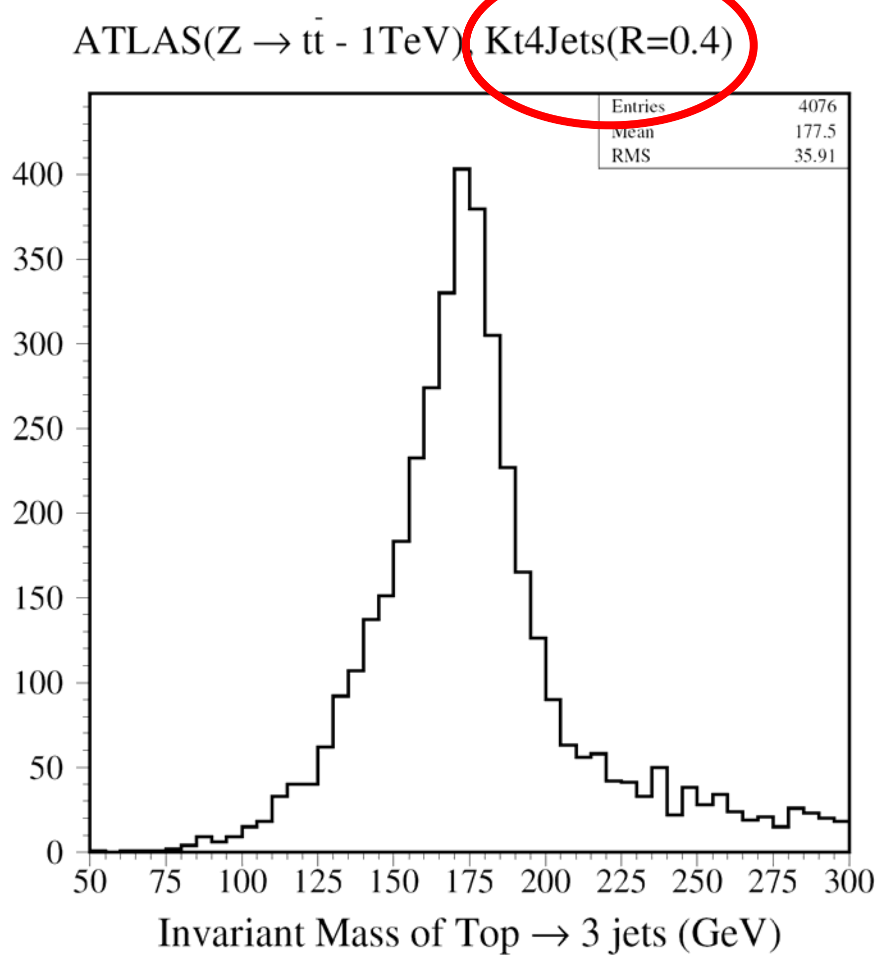


W → jj Reconstruction

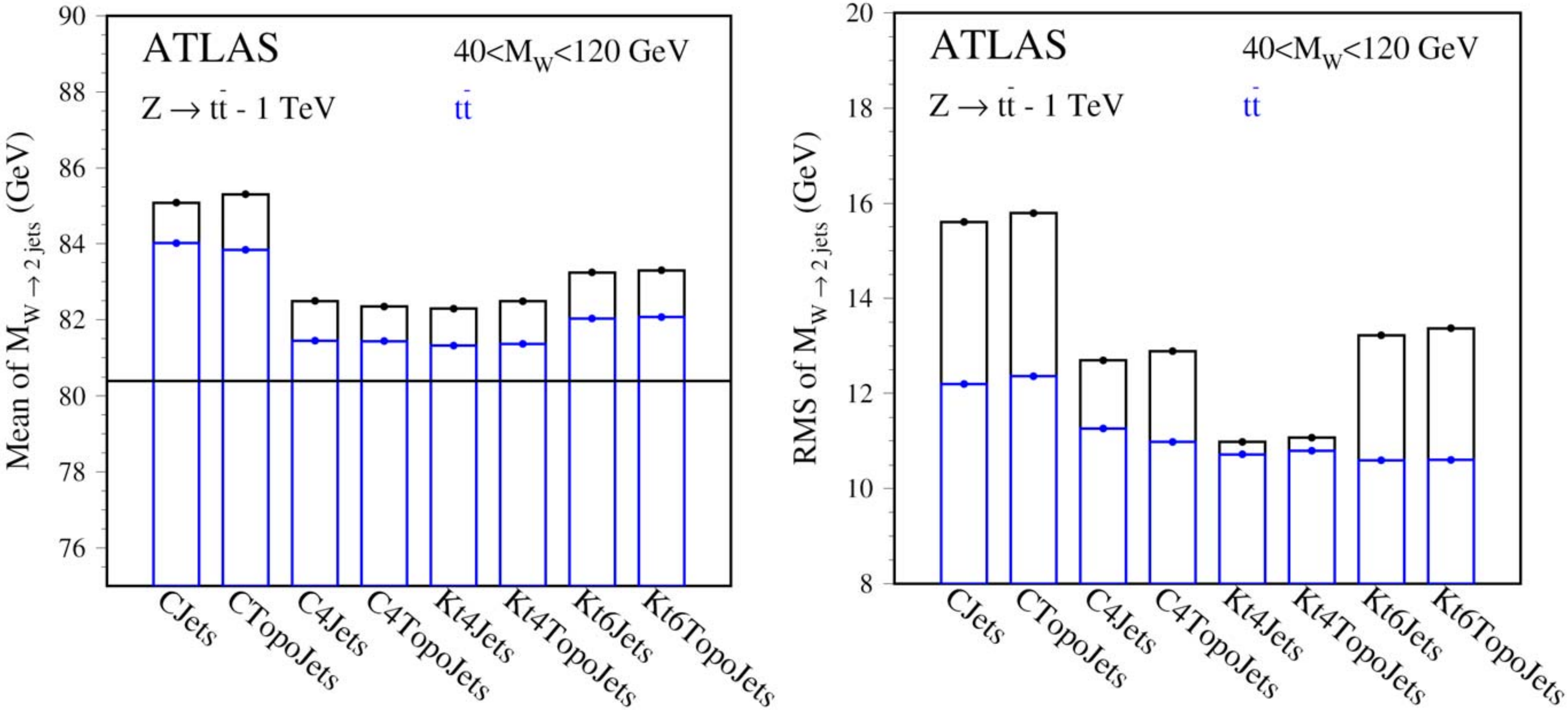


Top → bW(→jj) Reconstruction



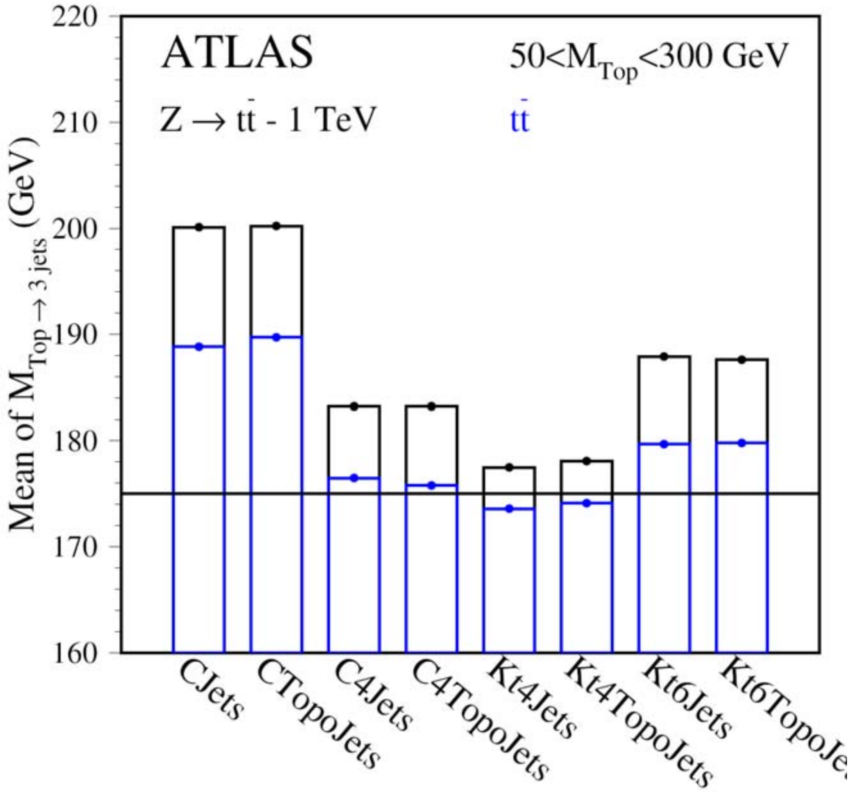


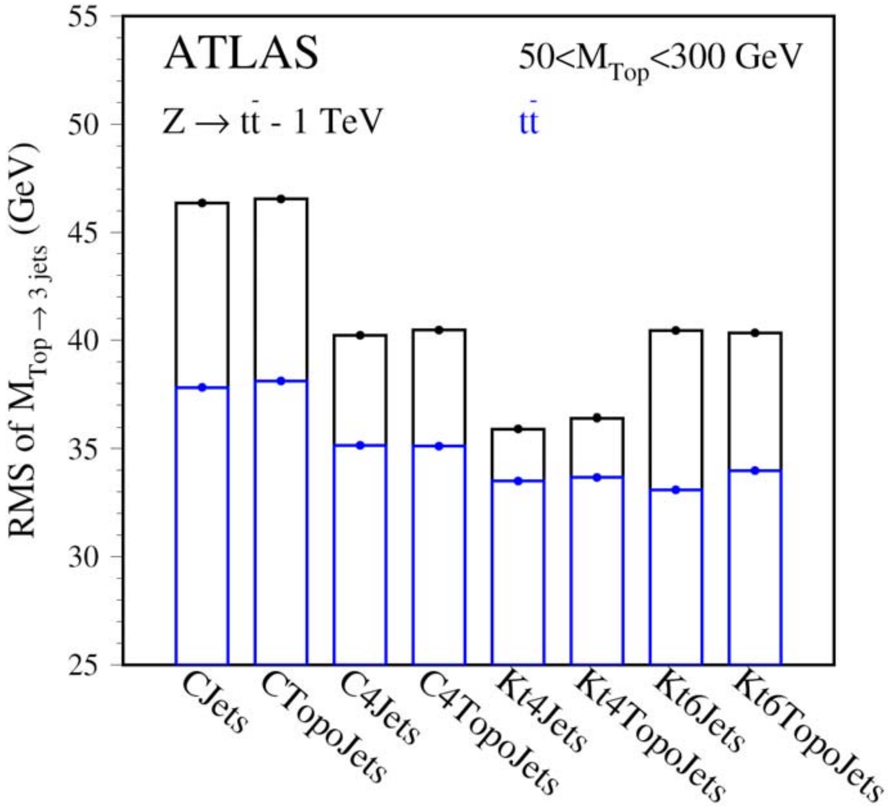
Mass Reconstruction of W → jj



RMS of M_W ~ 11 GeV

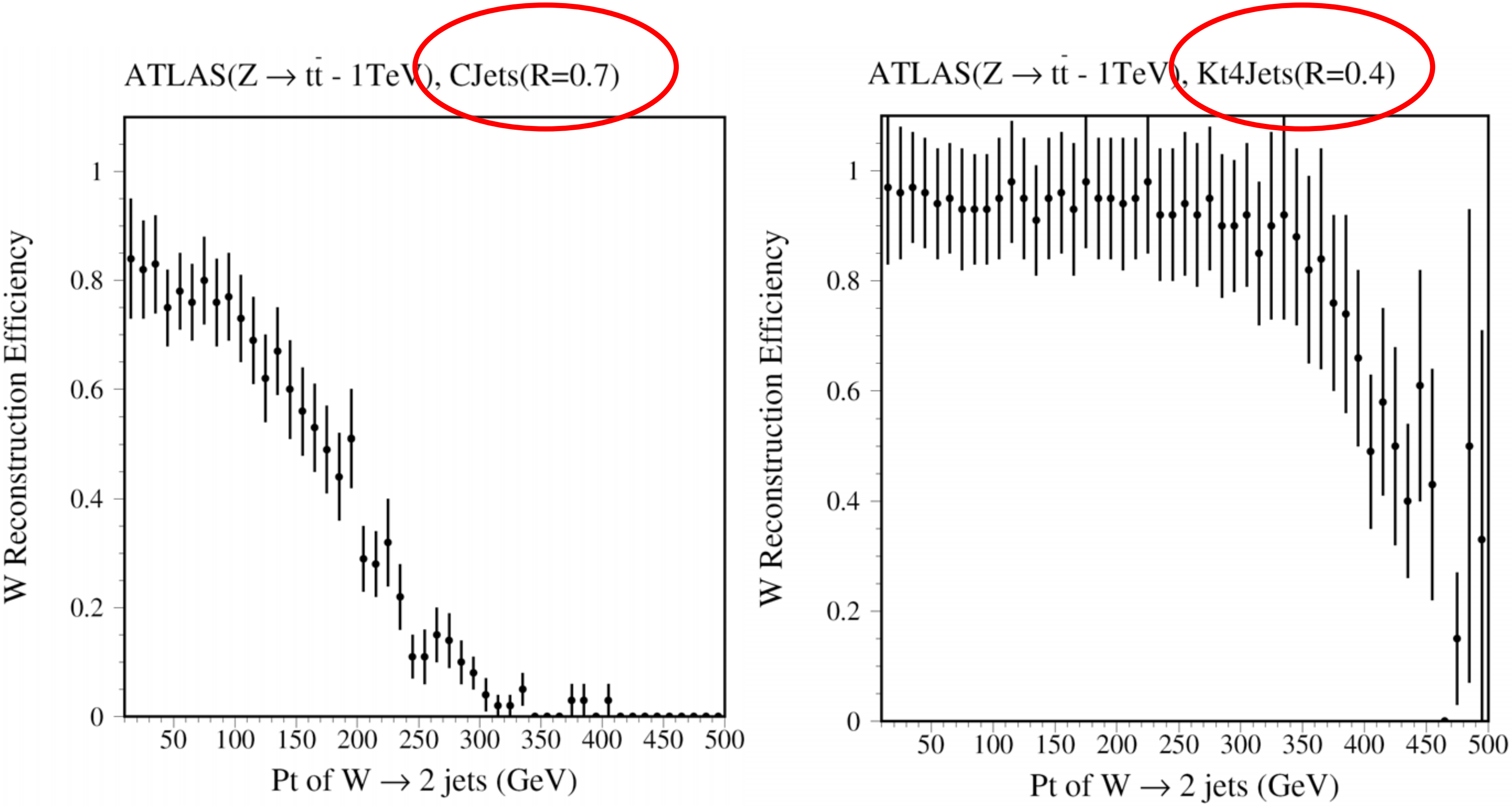
Mass Reconstruction of Top → bjj



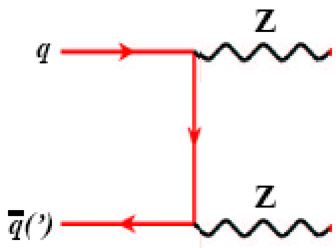
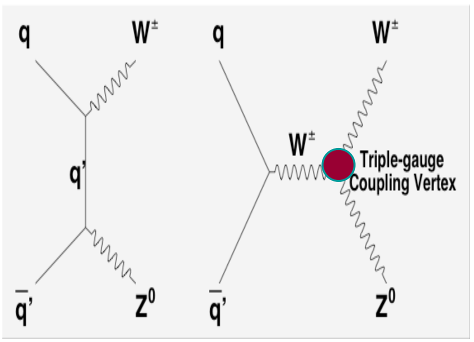
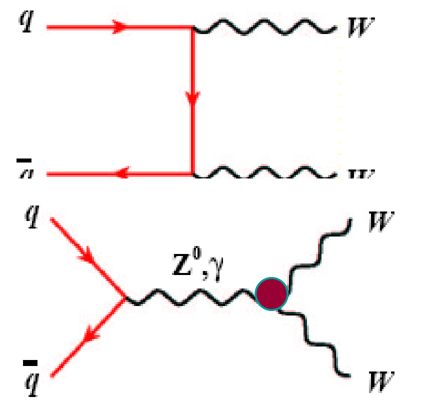
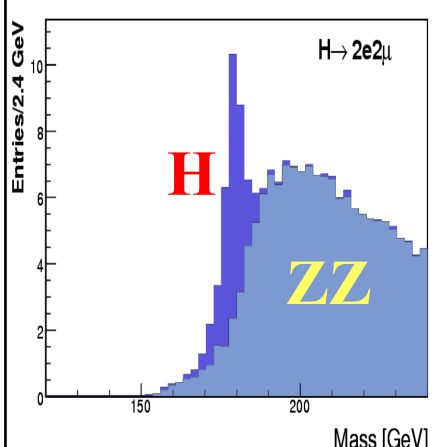
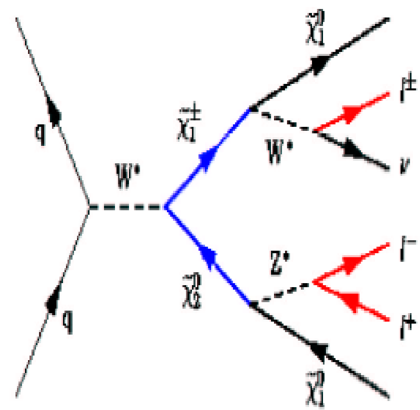


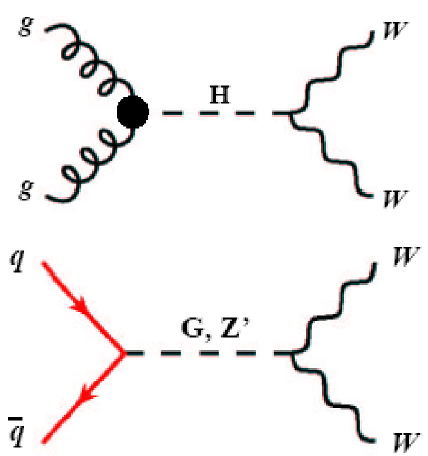
RMS of M_{Top} ~ 36 GeV

Eff of W Reconstruction vs. Pt



Di-Boson Analysis – Physics Motivation

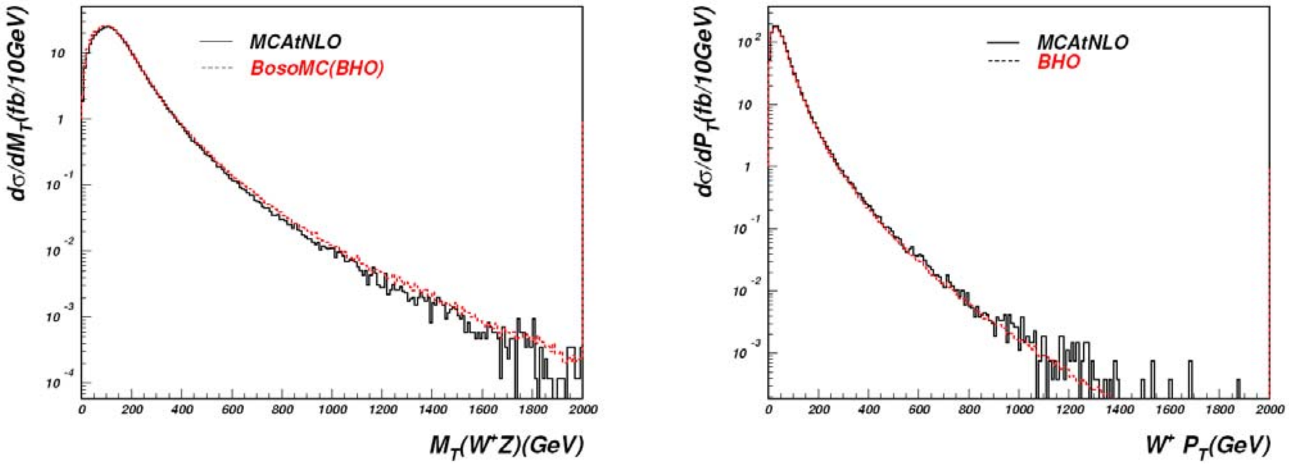
<table>
<tr><td>Decay modes</td><td>ZZ → $\ell^+\ell^-\ \ell^+\ell^-$</td><td>ZW → $\ell^+\ell^-\ \ell\nu$</td><td>WW → $\ell^+\nu\ \ell^-\nu$</td></tr>
<tr><td>Standard Model
• Triple-gauge-bosons couplings
• New physics control samples</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Discovery
H→ WW, ZZ
SUSY
Z’→ WW
G → WW
ρ_T→ ZW</td><td>
</td><td>

SUSY signal</td><td>
</td></tr>
</table>

93

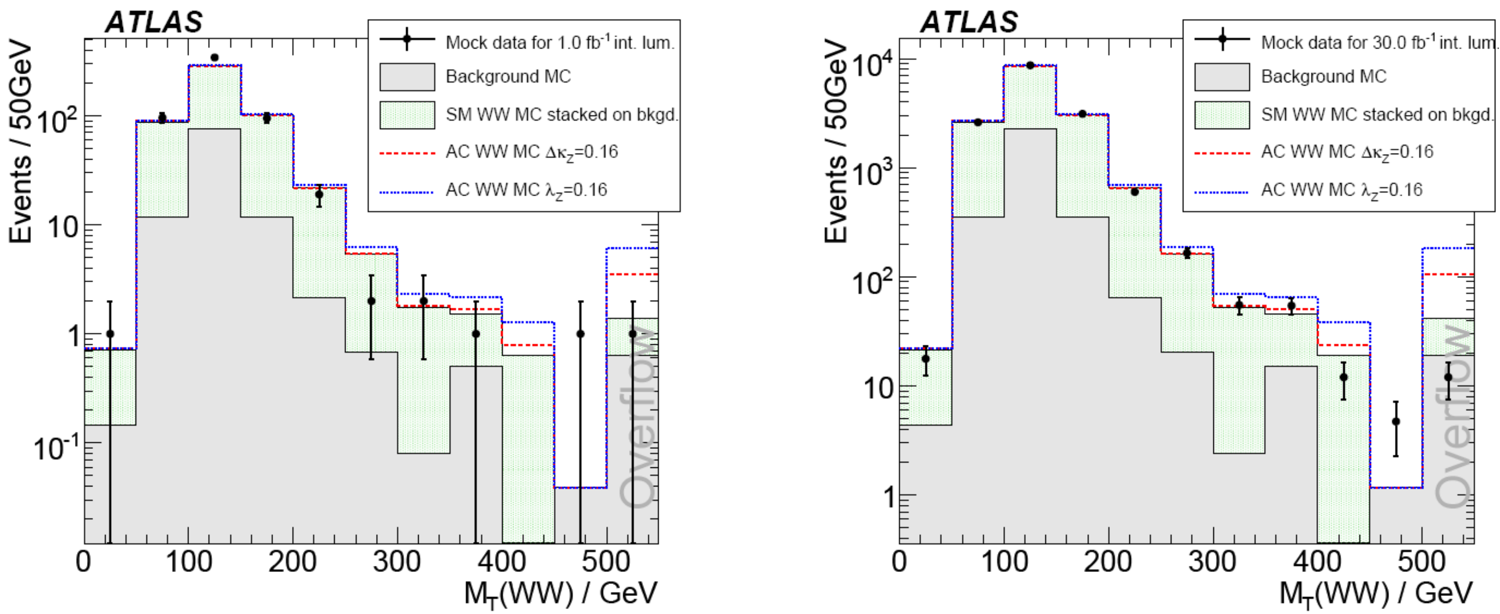
Probing Anomalous TGCs in ATLAS

- To probe the anomalous couplings we need a model of the kinematic distributions for various couplings. We use:
  - NLO generators
    - MC@NLO produces events that are fully simulated in ATLAS
    - BHO MC generates events with anomalous couplings



  - Reweighting
    - Using kinematic distributions from BHO we reweight the fully simulated MC@NLO events to produce expected distributions for a range of anomalous couplings.

M_T(WW) sensitive to WWZ & WWγ couplings



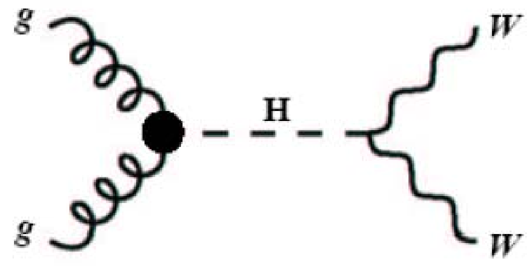
- Binned likelihood comparing mock SM observations to a SM profile & two reweighted anomalous profiles
- Using 10 bins from 0-500GeV and one overflow bin.
- In addition, the three decay channels, ee, eμ, and $\mu\mu$, are binned separately for a total of 33 bins.

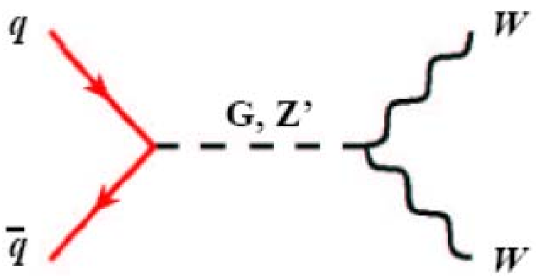
Physics Run in 2008-09

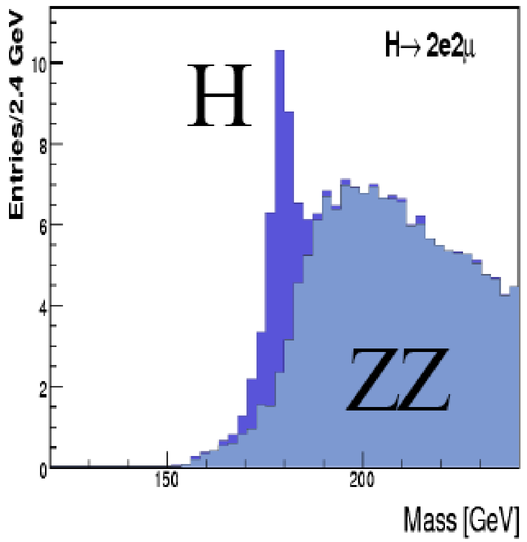
- First pp collisions (10 TeV) start in Sept (?), stop at Nov. 30, 2008.
- Luminosity would ramp up to 10^{33} in 2009
- Integrated luminosity: a few fb^{-1}
  - Detector calibration to 1-2% accuracy
  - Detector performance validation by measuring the SM processes (W, Z, tt, diboson) cross sections
  - Serious searches with the first year data (eg.)
    - Higgs → WW
    - W' and Z' in TeV mass region
    - SUSY signature

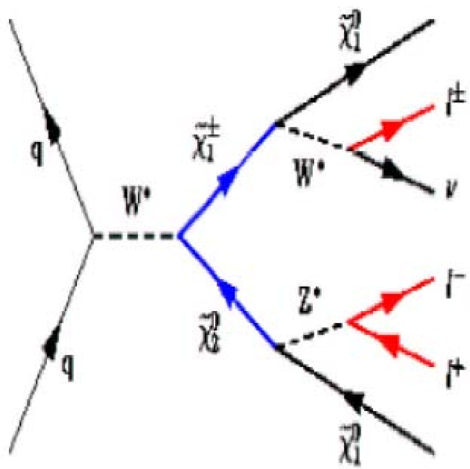
New Physics with Diboson

- WW – Higgs, Z’, G, TGCs
- WZ – SUSY, technicolor, W’, TGCs
- ZZ – Higgs, TGCs
- Wγ – TGCs
- Zγ – TGCs









Cross Sections of Diboson

Diboson mode	Conditions	$\sqrt{s} = 1.96$ TeV $\sigma[pb]$	$\sqrt{s} = 14$ TeV $\sigma[pb]$
W^+W^- [14]	W-boson width included	12.4	111.6
$W^\pm Z^0$ [14]	Z and W on mass shell	3.7	47.8
$Z^0 Z^0$ [14]	Z's on mass shell	1.43	14.8
$W^\pm \gamma$ [15]	$E_T^\gamma > 7$ GeV, $\Delta R(\ell, \gamma) > 0.7$	19.3	451
$Z^0 \gamma$ [16]	$E_T^\gamma > 7$ GeV, $\Delta R(\ell, \gamma) > 0.7$	4.74	219

Production rate at LHC will be at least 100x higher at Tevatron.
10x higher cross section and 10-100x higher luminosity.

Probes much higher energy region, so sensitive to anomalous TGCs.

ATLAS TGC sensitivity for 1.0 fb^{-1}

95% CL intervals for anomalous TGCs, cutoff $\Lambda = 2$ TeV

Diboson	λ_z	$\Delta\kappa_z$	Δg_1^z	$\Delta\kappa_\gamma$	λ_γ
WZ(ATLAS) 1.0 fb^{-1}	[-0.028,0.024]	[-0.203,0.339]	[-0.021,0.054]		
WZ(D0) 1.0 fb^{-1}	[-0.17,0.21]	[-0.12,0.29]	$\Delta g_1^z = \Delta\kappa_z$		
WW(ATLAS) 1.0 fb^{-1}	[-0.108,0.111]	[-0.117,0.187]	[-0.355,0.616]	[-0.240,0.251]	[-0.259,0.421]
WW(LEP)	$\lambda_z = \lambda_\gamma$	$\Delta\kappa_z = \Delta g_1^z - \Delta\kappa_\gamma \tan^2\theta_w$	[-0.051,0.034]	[-0.105,0.069]	[-0.059,0.026]
$W\gamma$(ATLAS) 1.0 fb^{-1}				[-0.43,0.20]	[-0.09,0.04]
$W\gamma$(D0) 0.16 fb^{-1}				[-0.88, 0.96]	[-0.2,0.2]

WW → $\ell\nu\ell\nu$ selection (BDT)

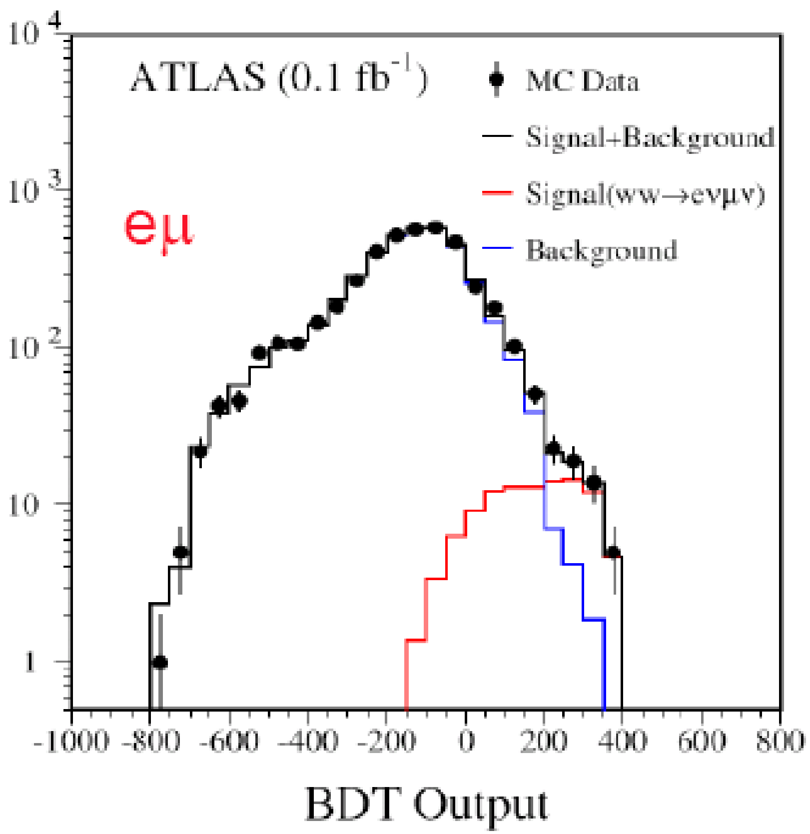
H. Yang
B. Zhou
A. Wilson

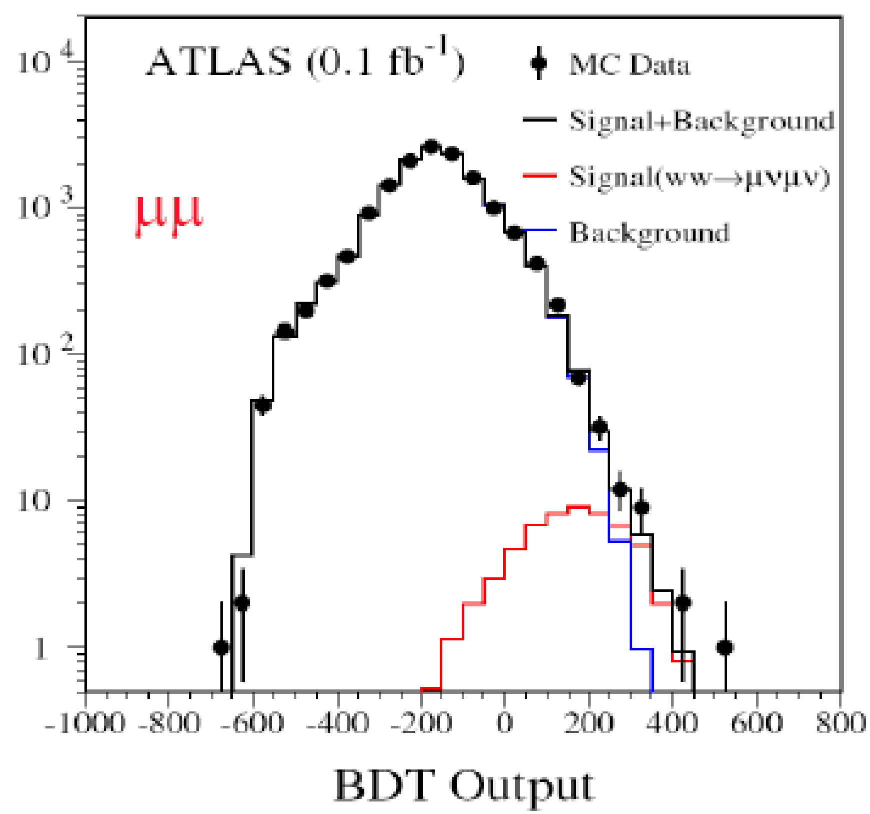
Event Pre-selection

- o At least one electron + one muon with Pt>10 GeV
- o Missing Et > 15 GeV
- o Signal efficiency is 39%

Final Selection

- **Boosted Decision Trees** with 15 input variables
- cut BDT>220, eff. ~ 39%, significance=40 (1/fb)



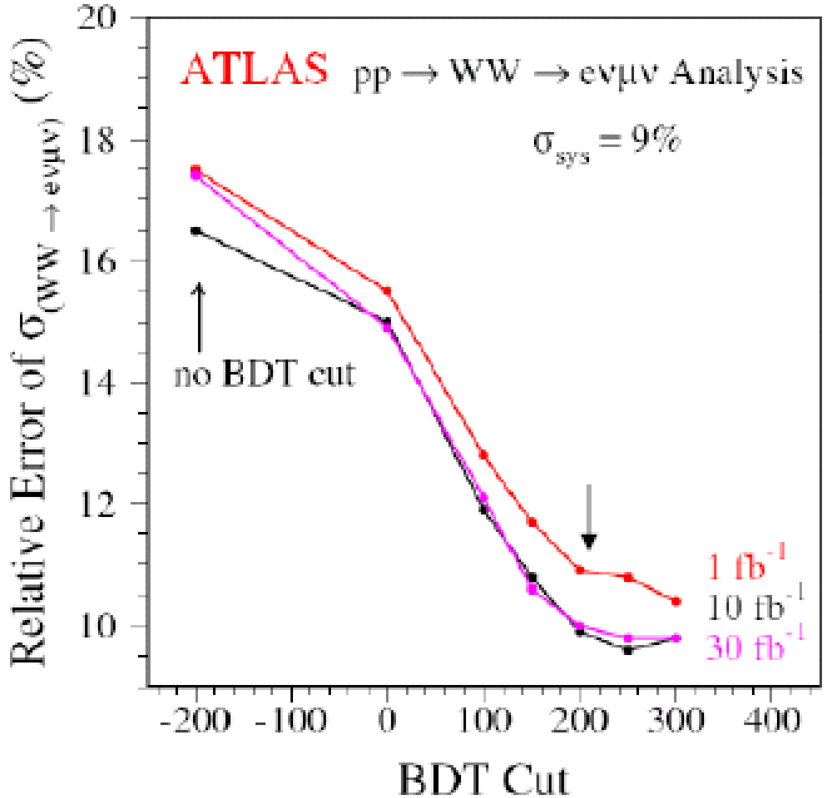


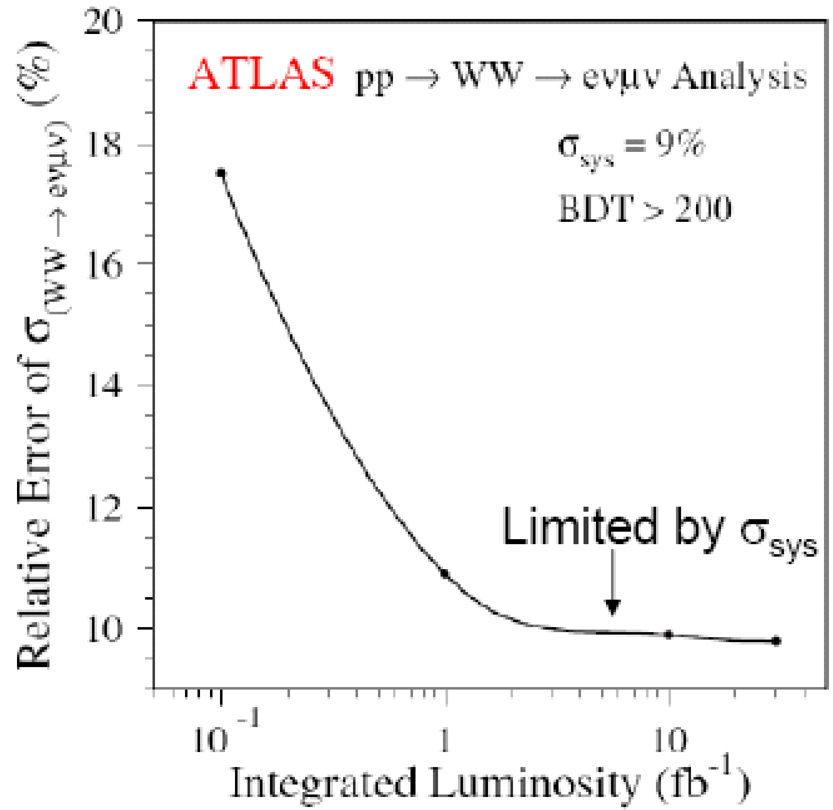
WW Cross-section Error Studies

Log-likelihood Method, using BDT distribution

- $-2\ln L = -2 \ln \prod P_i(Ndata; Ns(\sigma)+Nbg)$, $i=1,Nbin$
- $P(k;\lambda) = \lambda^k \; e^{-\lambda} / k!$

➔ The BDT cut should be optimized to minimize the cross section error

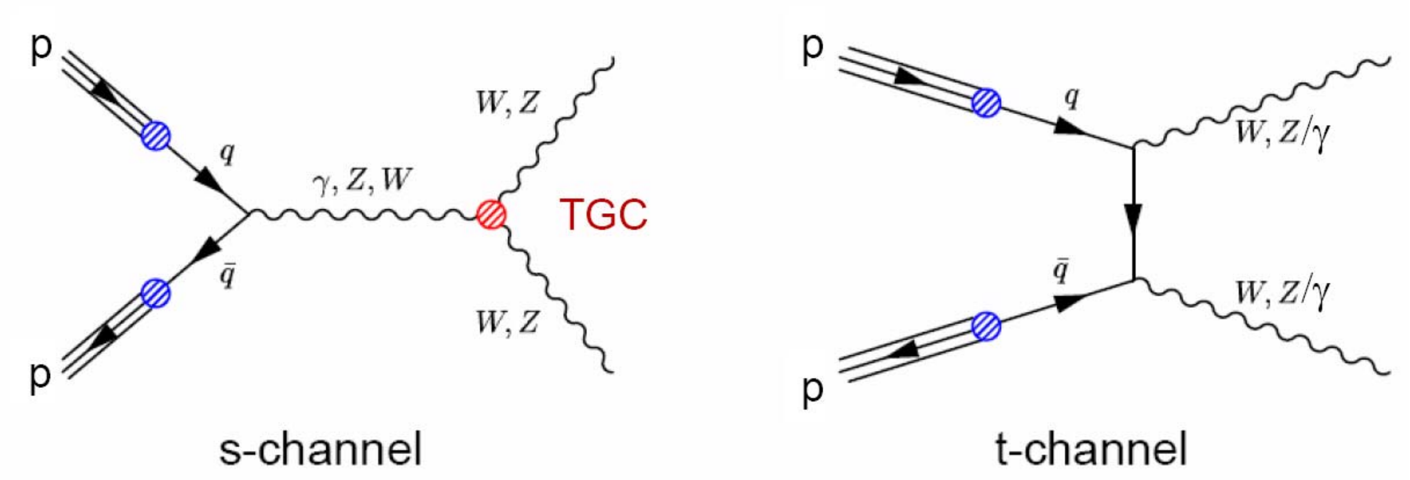




ATLAS Diboson Events in 1 fb^{-1}

$W^+W^- \rightarrow \ell^+\nu\, \ell^-\, \nu$ σ_{WW} = 113.3 pb	2 isolated leptons with P_T > 25 GeV, opposite charges, $\Delta R(\ell\ell)$>0.2, Missing transverse energy > 30 GeV, $\lvert M_Z$-Mee/$\mu\mu\rvert$ > 30 GeV N_{jet} (E_T>30 GeV) < 2, |Vector-sum (lep, MET)|<100GeV	Ns=588.2 Nb=136.4
$W\,Z \rightarrow \ell\nu\, \ell^+\ell^-$ σ_{W+Z} = 29.4 pb σ_{W-Z} = 18.4 pb	3 isolated leptons with $P_{T(max)}$ > 25 GeV, $\Delta R(\ell\ell)$>0.2 vertex cut for each lepton pair: ΔZ<1mm, ΔA<0.1mm MET > 30 GeV, $\lvert M_Z$-Mee/$\mu\mu\rvert$ < 10 GeV, 40GeV < M_T < 250GeV N_{jet} (E_T>30 GeV) < 2, |Vector-sum (lep, MET)|<100GeV	Ns=152.6 Nb=16.1
$ZZ \rightarrow \ell^+\ell^-\, \ell^+\ell^-$ σ_{ZZ} = 18.8 pb	4 isolated leptons with at least one P_T > 20 GeV Separation between each lepton pair $\Delta R(\ell\ell)$>0.2 All the lepton come from the same vertex, no hadron jets	Ns=16.4 Nb=1.9
$ZZ \rightarrow \ell^+\ell^-\, \nu\nu$ σ_{ZZ} = 18.8 pb	2 lepton with P_T > 20 GeV, and $\lvert M_Z$-$M_{ll}\rvert$<10 GeV, $P_T(\ell\ell)$ > 100 GeV veto the 3rd lepton, MET > 50 GeV, N_{jet} (E_T>30 GeV) =0, $\Delta\phi$(Z, MET) > 35 deg, |MET-PT(Z)|/PT(Z) < 0.35	Ns=10.2 Nb=5.2
$W\,\gamma \rightarrow \ell\nu\, \gamma$ $\sigma_{\mu\nu\gamma}$=(51.8+38.8)*1.4pb	1 isolated lepton with PT > 20 GeV 1 isolated photon with ET > 20 GeV MET > 30 GeV, 40GeV < M_T < 250Ge, Jet veto, $\Delta R(\ell\gamma)$>0.7	Ns=6317 Nb=2917
$Z\,\gamma \rightarrow \ell^+\ell^-\gamma$ $\sigma_{\mu\mu\gamma}$ = 20.2*1.4pb	2 isolated leptons with P_T > 20 GeV, opposite charges, $\Delta R(\ell\ell)$>0.2, $\lvert M_Z$-Mee/$\mu\mu\rvert$ < 10 GeV, one photon with PT>20GeV, Jet veto $\Delta R(\ell\gamma)$>0.7, $\lvert M_Z$-Meeγ/$\mu\mu\gamma\rvert$ > 30 GeV	Ns=1201 Nb=503

SM Diboson Production at LHC (TGC)



- Model independent effective Lagrangian for charged triple gauge boson interactions with anomalous couplings (C & P Conservation)

$$L/g_{WWV} = ig_1^V(W^*_{\mu\nu}W^\mu V^\nu - W_{\mu\nu}W^{*\mu}V^\nu) + i\kappa^V W^*_\mu W_\nu V^{\mu\nu} + \frac{\lambda^V}{M_W^2} W^*_{\rho\mu} W^\mu_\nu V^{\nu\rho}$$

where V = Z, γ.

- In the Standard Model: $g_1^V = \kappa_V = 1$ and $\lambda_V = 0$.
- Five anomalous coupling parameters: Δg_1^Z, $\Delta\kappa_Z$, λ_z, $\Delta\kappa_\gamma$, and λ_γ

Discovery Confidence Level Calculation

➔ Log-likelihood ratio test-statistics by using BDT bins and 3 Higgs decay channels

$$Q = \frac{L(s+b)}{L(b)}$$

➔ MC experiments are based on Poisson statistics

➔ CL_b represents C.L. to exclude "background only" hypothesis

(used for LEP Higgs Search)