Search for New Physics at LHC with ATLAS Detector

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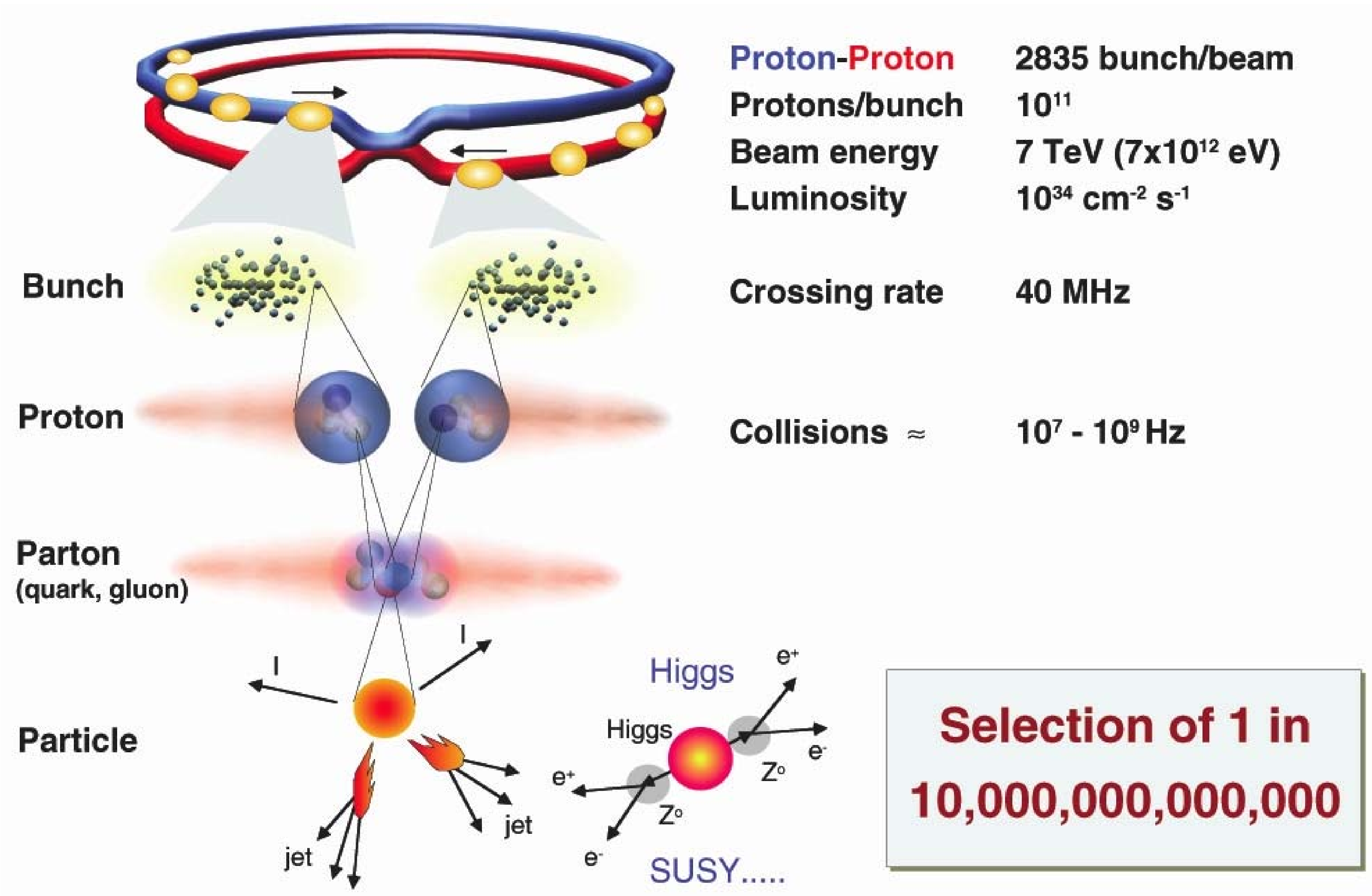
Outline

- **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 → $bbjjl\nu$
- **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 H. Yang with the Michigan ATLAS group members

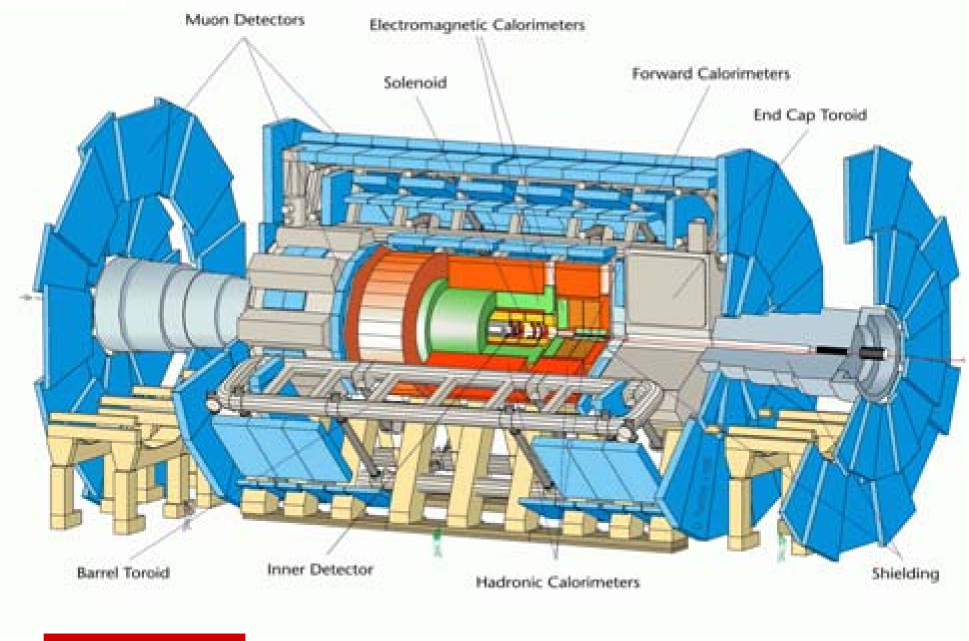
Proton-Proton Collisions at LHC

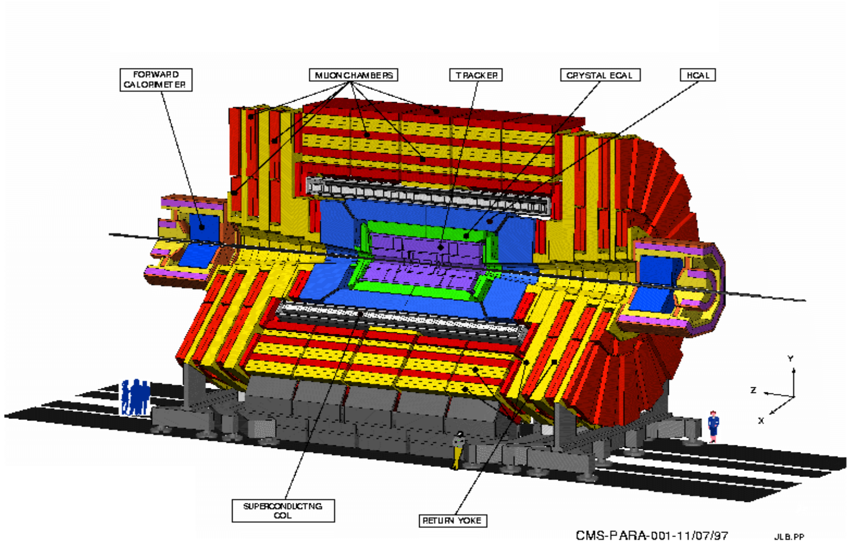
to discover the mysteries of EWSB, Dark-Matter, …



Two general purpose experiments at LHC

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





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

LHC Physics Run in 2008-2009

- Single beam injection on September 10, 2008
- pp collisions at 10 TeV will 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 150 GeV – 180 GeV)
    - W' and Z' in TeV mass region
    - SUSY signature
    - …

Re-discover Standard Model

– A Steppingstone to Discover New Physics

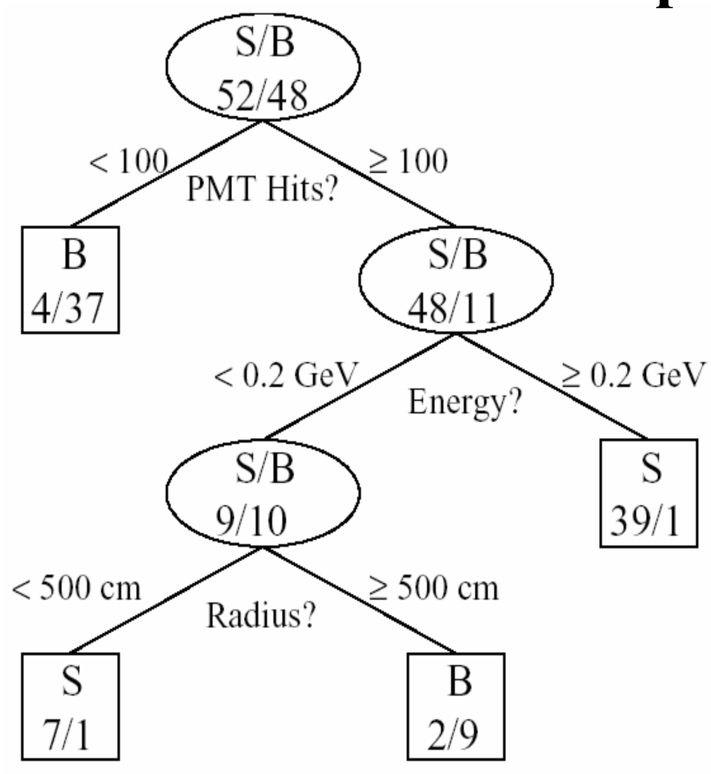
Our search for new physics at LHC will start with

- W and Z productions: the standard candles
  - demonstrate the detector performance
  - constrain the PDF
- Diboson (WW, WZ, ZZ, Wγ, Zγ) – **ATL-COM-PHYS-036(041)**
  - 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 U. of Michigan by H. Yang et al.)

Boosted Decision Trees

➔Relatively 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"



BDT Training Process

•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,

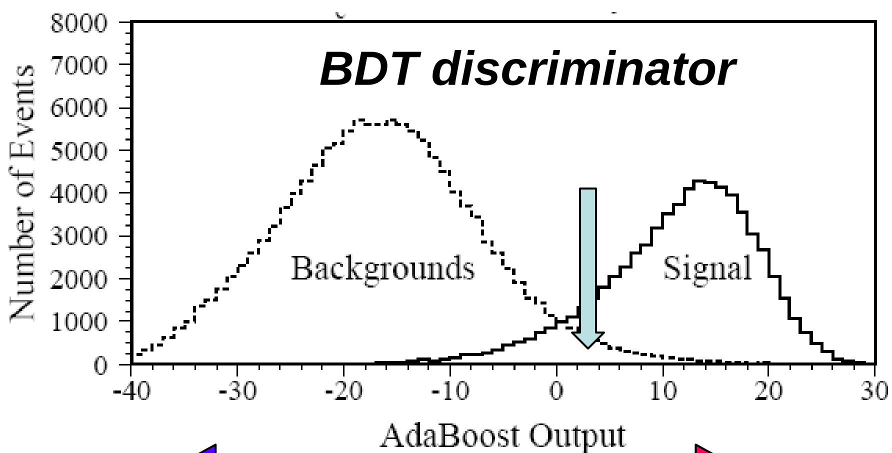
each re-weighting the events to enhance identification of backgrounds misidentified by earlier trees   ("boosting")

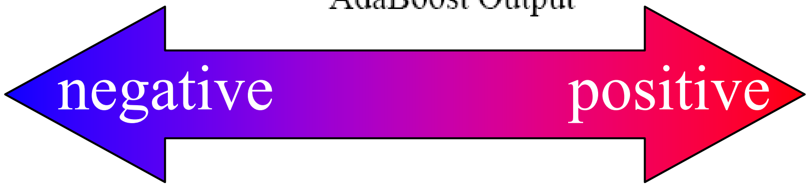
For each tree, the data event is assigned

+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

SM Diboson Studies in ATLAS

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

Diboson	Signature	Physics
$W^+ W^- \rightarrow l\nu\, l\nu$	2 opposite sign leptons + Missing E_T	Std Model WW production Std Model Higgs; Z' decays; anomalous TGC
$W^\pm Z \rightarrow l\nu\, ll$	3 leptons + Missing E_T	Std Model WZ; SUSY; Technicolor; anomalous TGC
$W^\pm\gamma \rightarrow l\nu\, \gamma$	Lepton + photon + ME_T	Std Model $W\gamma$; anomalous TGC
$ZZ \rightarrow ll\, ll$ or $ll\, \nu\nu$	4 leptons 2 lepton+ME_T	Std Model ZZ & Higgs anomalous neutral TGC; GMSB
$Z\gamma \rightarrow ll\, \gamma$	2 leptons + photon	Std Model $Z\gamma$; anomalous neutral TGC; GMSB

Diboson Detection Sensitivity with ATLAS for 1 fb^{-1} Integrated Luminosity

High sensitivity results come from the analysis based on BDT technique

Diboson mode	Signal	Background	Signal eff.	σ_{stat}^{signal}	p-value	Sig.
$W^+W^- \to e^{\pm}\nu\mu^{\mp}\nu$	347 ± 3	64 ± 5	12.6% (BDT)	5.4%	3.6×10^{-166}	27.4
$W^+W^- \to \mu^+\nu\mu^-\nu$	70 ± 1	17 ± 2	5.2% (BDT)	12.0%	8.8×10^{-30}	11.3
$W^+W^- \to e^+\nu e^-\nu$	52 ± 1	11 ± 2	4.9% (BDT)	13.9%	1.9×10^{-24}	10.1
$W^+W^- \to \ell^+\nu\ell^-\nu$	103 ± 3	17 ± 2	2.0% (cuts)	9.9%	1.4×10^{-54}	15.5
$W^{\pm}Z \to \ell^{\pm}\nu\ell^+\ell^-$	128 ± 2	16 ± 3	15.2% (BDT)	8.8%	3.0×10^{-76}	18.4
	53 ± 2	8 ± 1	6.3% (cuts)	13.7%	3.1×10^{-30}	11.4
$ZZ \to 4\ell$	17 ± 0.5	2 ± 0.2	7.7% (cuts)	24.6%	6.0×10^{-12}	6.8
$ZZ \to \ell^+\ell^-\nu\bar{\nu}$	10 ± 0.2	5 ± 2	2.6% (cuts)	31.3%	7.7×10^{-4}	3.2
$W\gamma \to e\nu\gamma$	1604 ± 65	1180 ± 120	5.7% (BDT)	2.5%	significance > 30	
$W\gamma \to \mu\nu\gamma$	2166 ± 88	1340 ± 130	7.6% (BDT)	2.1%	significance > 30	
$Z\gamma \to e^+e^-\gamma$	367 ± 12	187 ± 19	5.4% (BDT)	5.2%	1.2×10^{-91}	20.3
$Z\gamma \to \mu^+\mu^-\gamma$	751 ± 23	429 ± 43	11% (BDT)	3.6%	5.9×10^{-171}	27.8

Search for **new physics** by probing anomalous triple-gauge-couplings

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

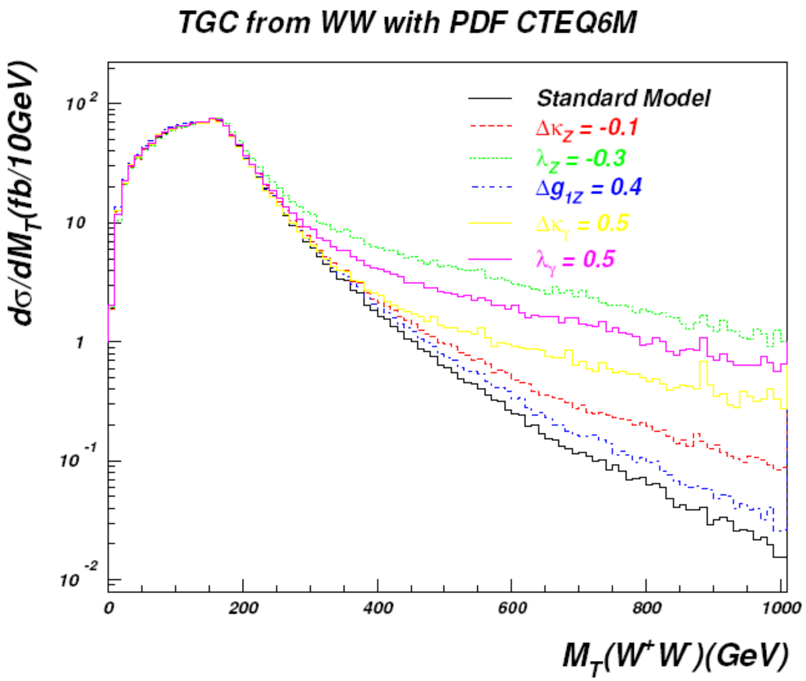
- In the standard model $g_1^V = \kappa_V = 1$ and $\lambda_V = 0$.
  The goal is to measure these values, usually expressed as the five anomalous parameters $\boldsymbol{\Delta g_1^Z}$, $\boldsymbol{\Delta\kappa_Z}$, $\boldsymbol{\lambda_z}$, $\boldsymbol{\Delta\kappa_\gamma}$, and $\boldsymbol{\lambda_\gamma}$

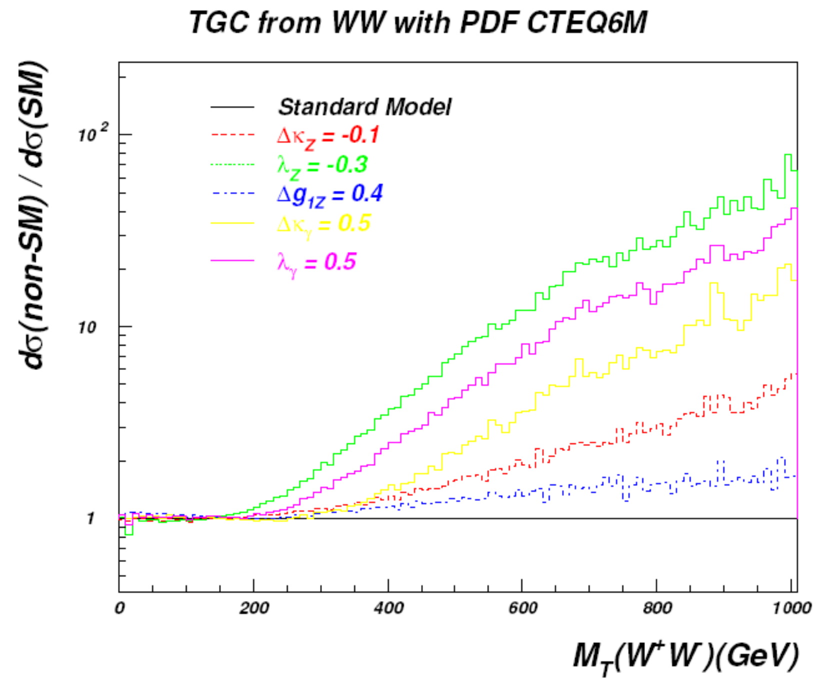
- In many cases the terms have an $\hat{s}$ dependence which means the higher center-of-mass energies at the LHC greatly enhance our sensitivity to anomalous couplings

- **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 $\hat{s}$
$W\gamma$	grow as $\hat{s}^{1/2}$	---	grow as $\hat{s}$

Anomalous spectra and reweighting ratio



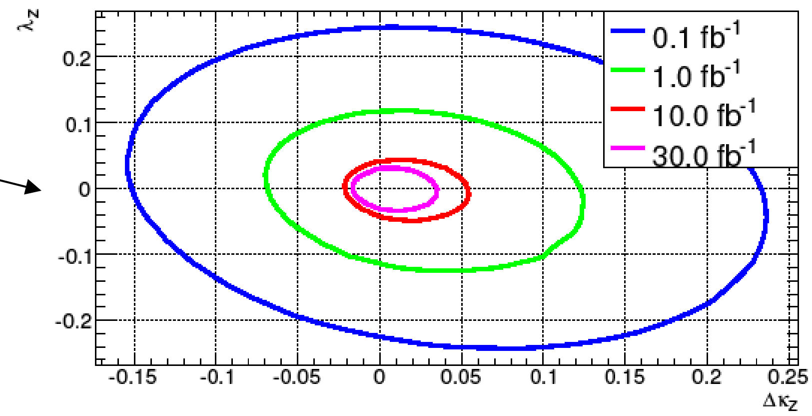


- Left: the M_T(WW) spectrum for W^+W^- events with anomalous coupling parameters using the BHO Monte Carlo.
- Right: the 'ratios = dσ(non-SM)/dσ(SM)' used to reweight fully simulated events.
- The ATLAS sensitivities on anomalous TGC couplings are extracted by comparing the 'mock SM data' with the anomalous spectra using binned likelihood fit on M_T(VV) and P_T(V) distributions.

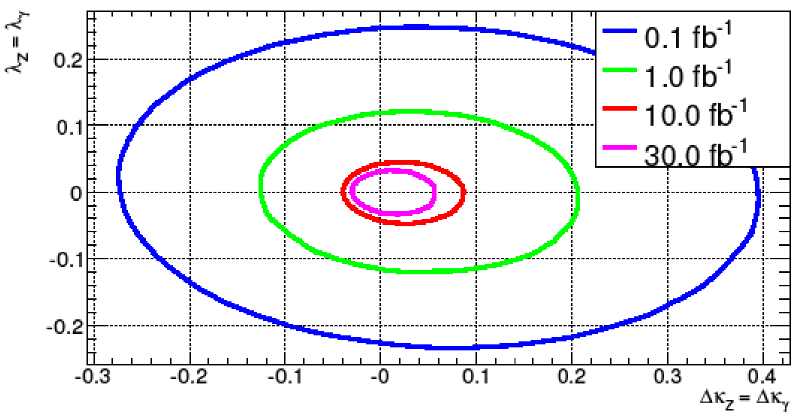
2D anomalous TGC sensitivity using $M_T(WW)$

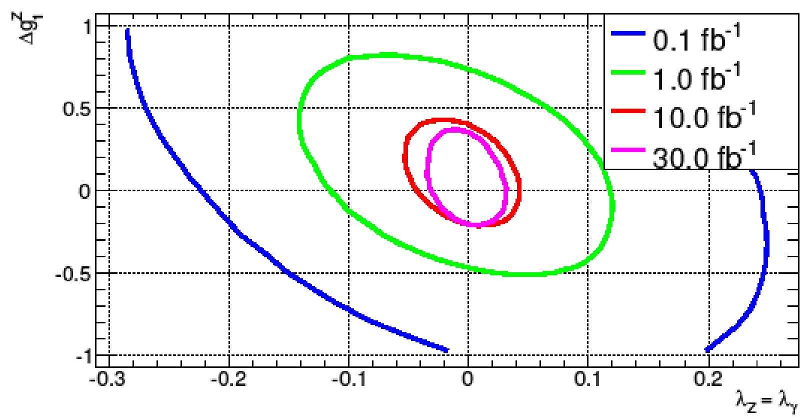
95% C.L. contours for 0.1, 1, 10, and 30 fb^{-1} integrated luminosity

Right: HISZ assumption (2 parameters)



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





Anomalous charged TGCs: Expected 1-D 95% CL limits

Source	Lumi fb^{-1}	λ_Z WZ	$\Delta\kappa_1^Z$ WW	Δg_1^Z WZ	$\Delta\kappa_1^\gamma$ WW	λ_γ Wγ
ATLAS	**0.1**	**[-.062,.056]**	**[-.44,.61]**	**[-.063,.119]**	**[-.47,0.51]**	**X**
ATLAS	**1**	**[-.028,.024]**	**[-.117,.187]**	**[-.021,.054]**	**[-.24,.25]**	**[-.09,.04]**
CDF/D0	**1.9/.16**	**[-.13,.14]**	**[-.82,1.27]**	**-**	**[-.88,.96]**	**[-.2,.2]**
	10	**[-.015,.013]**	**[.015,.013]**	**[-.011,.034]**	**[-.26,.07]**	**[-.05,.02]**
	30	[-0.012,.008]	[-.026,.0048]	[-.005,.023]	[-.056,.054]	[.02,.01]

Anomalous neutral TGC 95% CL limits

Lumi	f_4^Z	f_5^Z	f_4^γ	f_5^γ
1	[-.018,.018]	[-.018,.019]	[-.022,.022]	[-.022,.022]
30	[-.006,.006]	[-.006,.007]	[-.008,.008]	[-.008,.008]
LEP	[-.3,.3]	[-.34,.38]	[-.27,.19]	[-.32,.36]

Search for New Physics with Diboson and ttbar Events

- We do not really know what new physics could be discovered at LHC

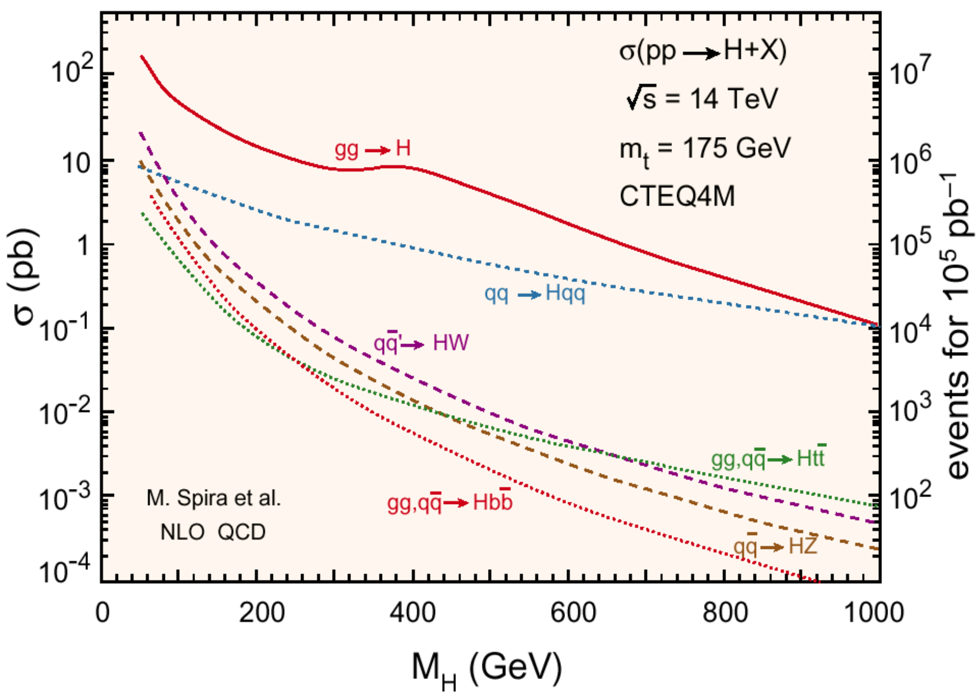
- Many theoretical models predict that the new physics signature would show up in diboson, top-rich and large MET events.

- Two examples will be 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: $m(H) < 2\, m_Z$

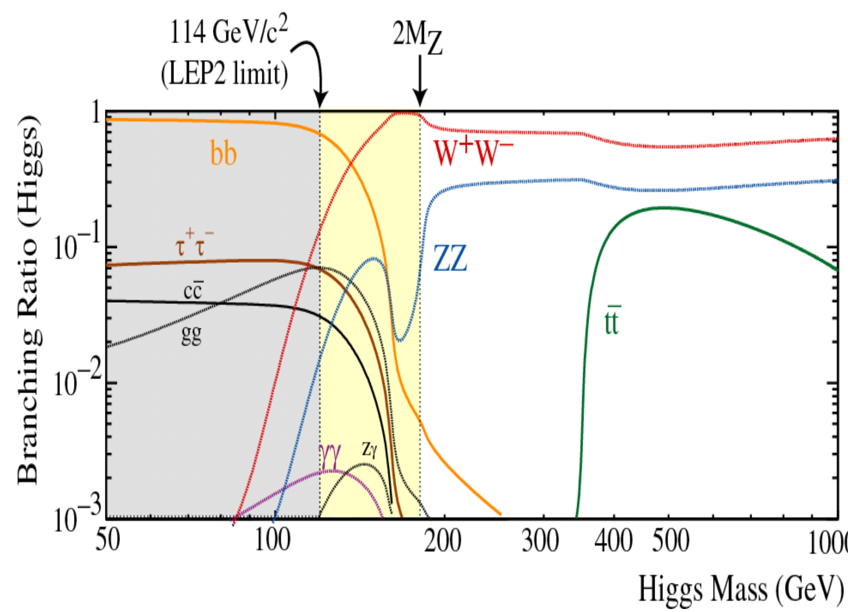
$H \to \gamma\gamma$

$H \to bb$

$H \to \tau\tau$

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

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



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

MC Higgs Signal Used in Study

- Pythia Generator (Gluon-Gluon Fusion)

$H \rightarrow WW \rightarrow e\nu e\nu, \mu\nu\mu\nu, e\nu\mu\nu$

GGF H → WW	Dataset #	MC Events	$\sigma \times$ BR (fb)
M_H = 150 GeV	3010	97400	767
M_H = 165 GeV	3025	96200	866
M_H = 170 GeV	5329	167200	825
M_H = 175 GeV	3035	193450	770
M_H = 180 GeV	3040	96250	716

- Above Higgs samples were produced at UM using jobOptions similar to official jobOption DS5320 (with diff. M_H and separate the ggF and VBF production)
- UM Pythia Higgs samples were compared to Higgs dataset 5320 by separating the ggF and the VBF events, they are in good agreement.
- UM samples are available at BNL Tier-1 center.

MC Backgrounds Used in Study

(SM samples were used for ATLAS diboson CSC note)

Backgrounds	Dataset #	MC Events	$\sigma \times$ BR (fb)
qq → WW	2821 – 2829	210 K	12503
gg → WW	5921 – 5929	370 K	648
ttbar	5200	529 K	4.6E5
WZ	5941, 5971	281 K	688
W + X:			5.75E7
W→ln	5250 – 5255	5.25 M	5.62E7
W+Jets(E>80)	4288, 4289	595 K	1.3E6
Z + X:			6.9E6
ZZ	6356, 5980	181 K	84
Drell-Yan	4295 - 4297	10.5 M	6.8E6
Z+Jets(E>80)	4293, 4294	597 K	52800
Zbb	5175 – 5177	200 K	48720

Event Pre-selection

for H→ WW→ $l\nu l\nu$

- Two leptons with opposite charges; each lepton with P_T > 10 GeV
- Missing E_T > 15 GeV
- Events must pass one of lepton trigger requirements: 2E10, 2MU6, E25I, MU20
- Physics objects:
  - Electron ID based on likelihood ratio > 0.6
  - Muon ID based on Staco algorithm
  - Jet class: C4TopoJet (E_T > 20 GeV)

Detection Sensitivity Studies
Based on Pre-selected Events

- Cut-based analysis
  - Optimize the straight cuts for better sensitivity

- Analysis based on Boosted Decision Trees (BDT)

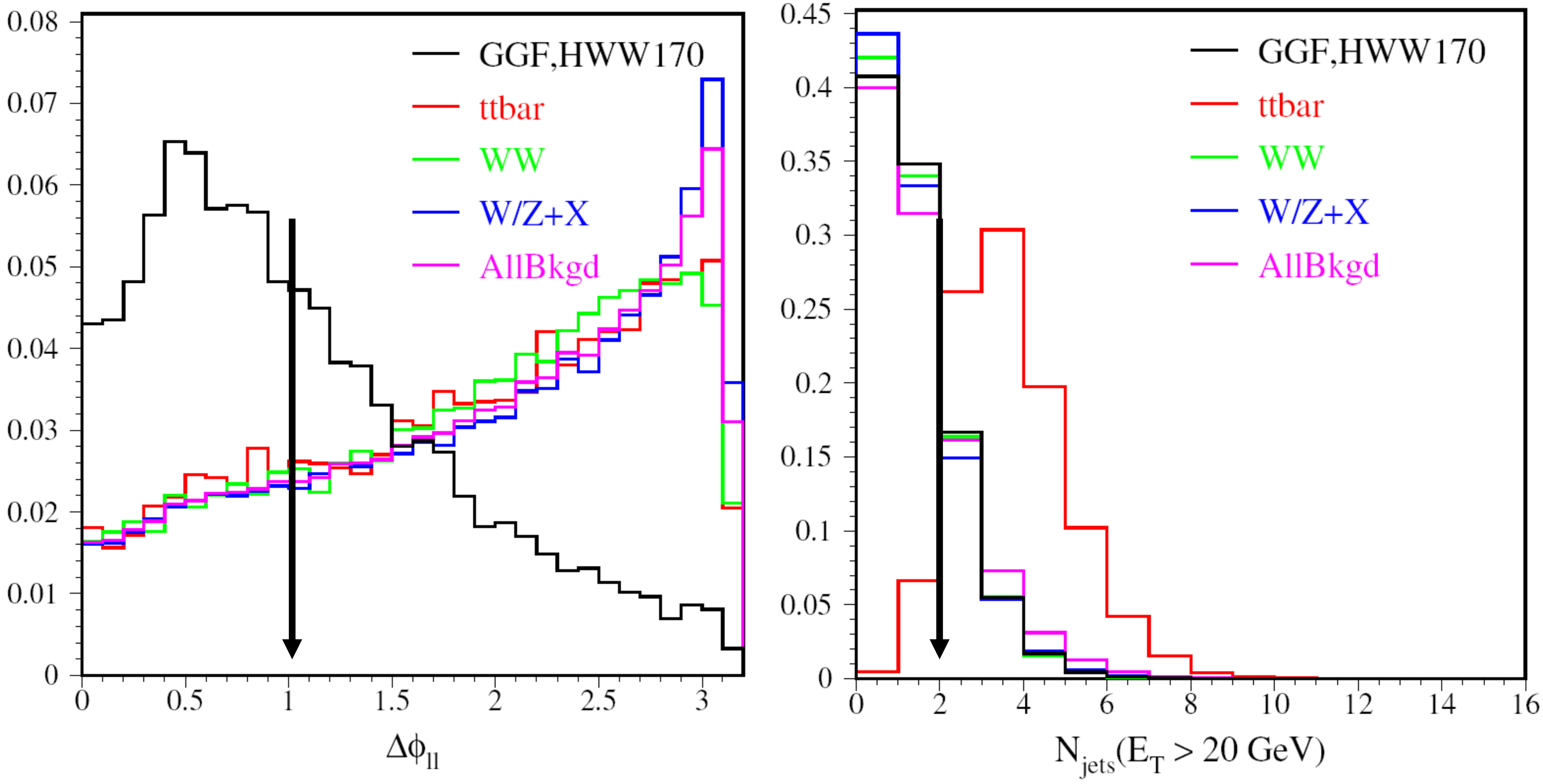
- Consider two leptons with 0-jet and 1-jet events

- Results from cut-based and BDT analyses

Select $H \rightarrow WW \rightarrow l\nu l\nu$ with Straight Cuts

- Pt (l) > 20 GeV; Max (Pt(l1),Pt(l2)) > 25 GeV
- Lepton Isolation
  - In R=0.4 cone, ΣPt(μ) < 5 GeV
  - In R=0.4 cone, ΣPt(e) < 8 GeV
- MET > 50 GeV
- N_{jet} (Et>20 GeV) = 0 or 1
- $\Delta\phi$ (l1,l2) < 1.0
- 12 < M(l1,l2) < 50 GeV

Some Variable Distributions After Pre-selection



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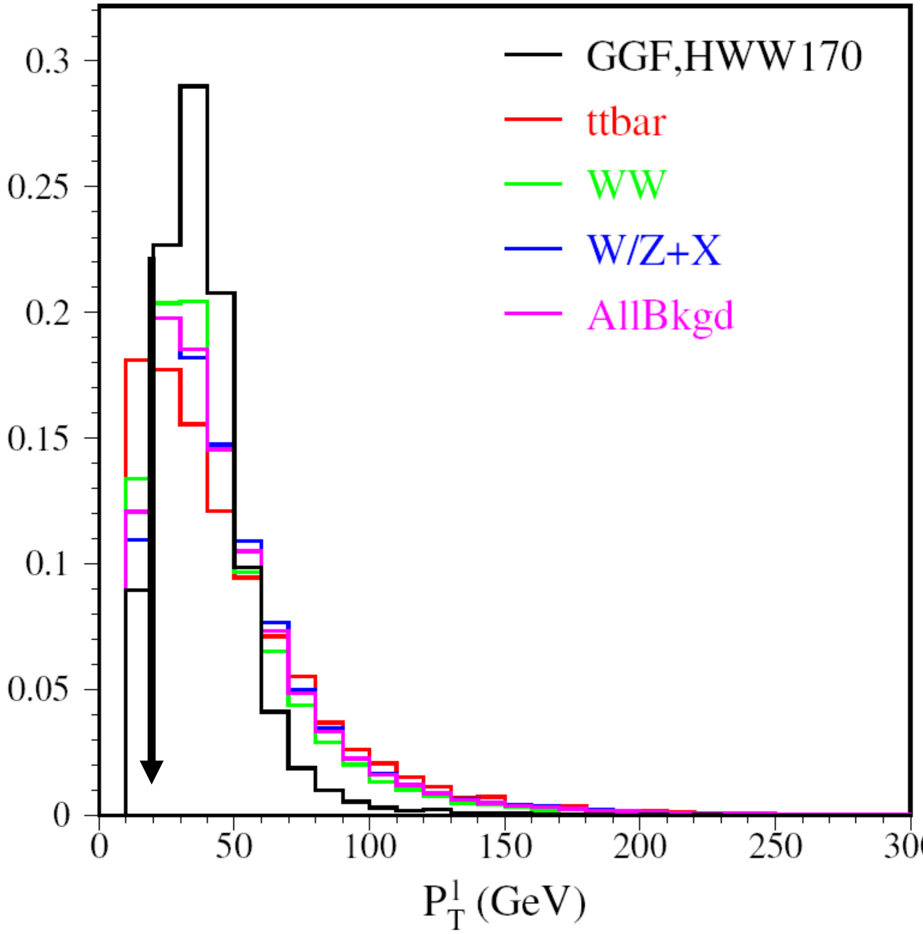
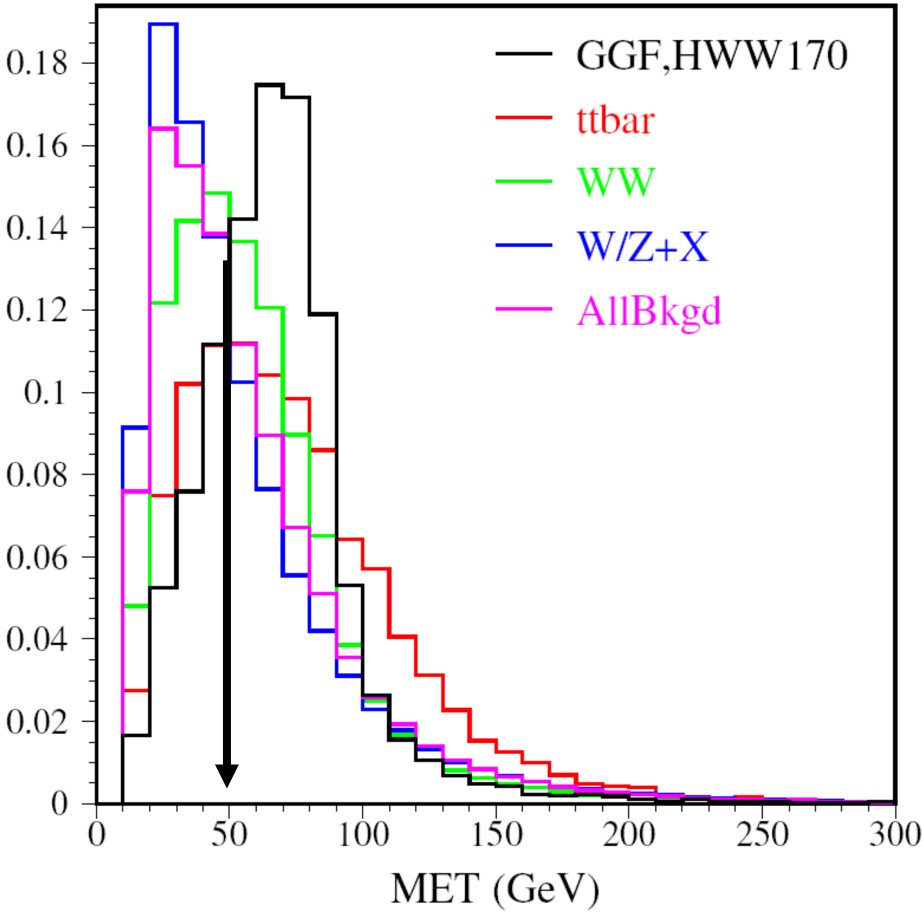
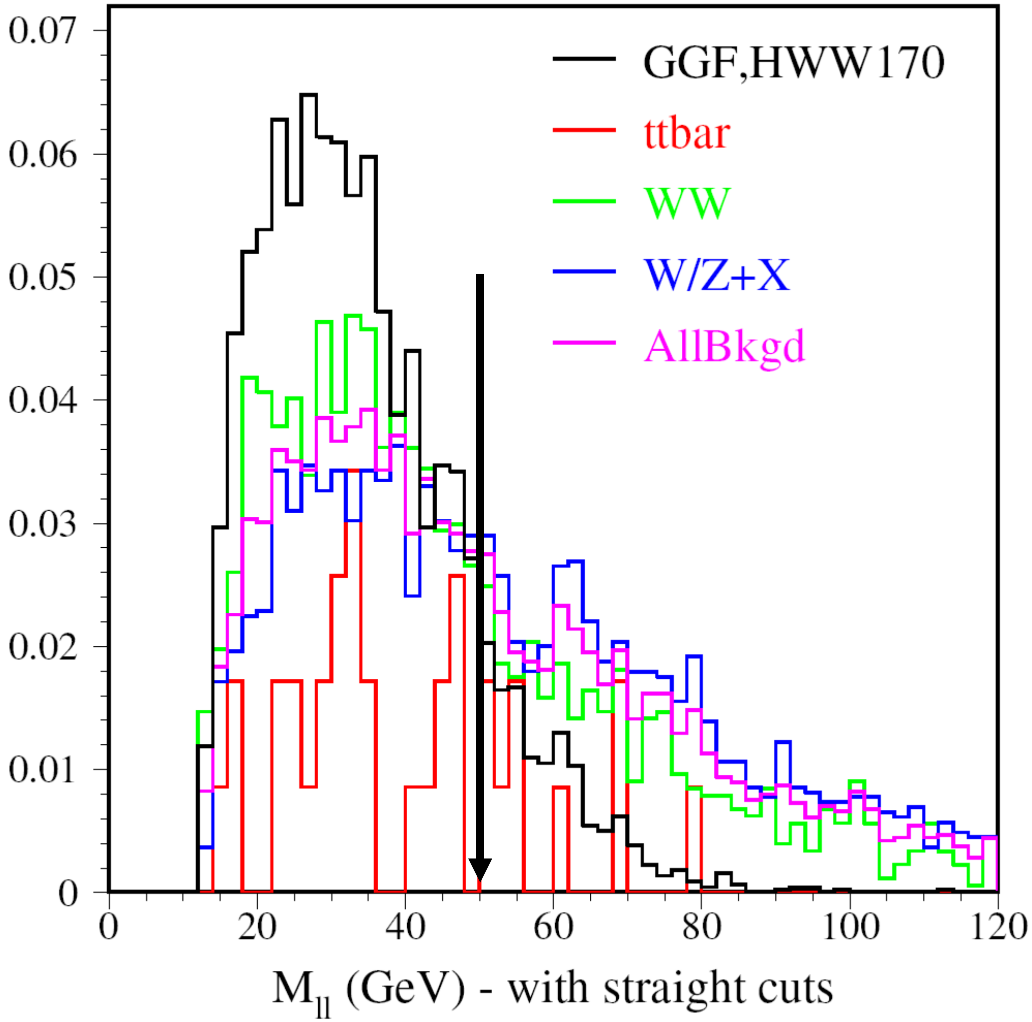




Invariant Mass of two leptons (applied all cuts except M_{ll} cut)



Results from Cut-based Analysis (1/fb)

$H \rightarrow WW \rightarrow l\nu l\nu$ Events / fb	M_H=150 GeV	M_H=165 GeV	M_H=170 GeV	M_H=175 GeV	M_H=180 GeV	Bkgd
Cuts (eμ + 0 jet)	18.8	33.3	28.5	24.9	19.7	64.2
Cuts (eμ + 1 jet)	12.4	25.2	20.3	17.8	14.9	76.8
Cuts (eμ)	**31.2**	**58.5**	**48.8**	**42.7**	**34.6**	**141.0**
Cuts ($\mu\mu$ + 0 jet)	10.1	18.5	15.7	13.3	10.3	33.3
Cuts ($\mu\mu$ + 1 jet)	7.0	13.3	11.2	10.4	8.7	58.4
Cuts ($\mu\mu$)	**17.1**	**31.8**	**26.9**	**23.7**	**19.0**	**91.7**
Cuts (ee + 0 jet)	6.3	11.3	9.9	8.1	6.8	80.6
Cuts (ee + 1 jet)	4.3	9.0	7.9	6.4	5.3	38.7
Cuts (ee)	**10.6**	**20.3**	**17.8**	**14.4**	**12.1**	**119.3**
Cuts (ee+$\mu\mu$+eμ)	**58.9**	**110.6**	**93.5**	**80.8**	**65.7**	**352.0**
Efficiency	**7.7%**	**12.8%**	**11.3%**	**10.5%**	**9.2%**	

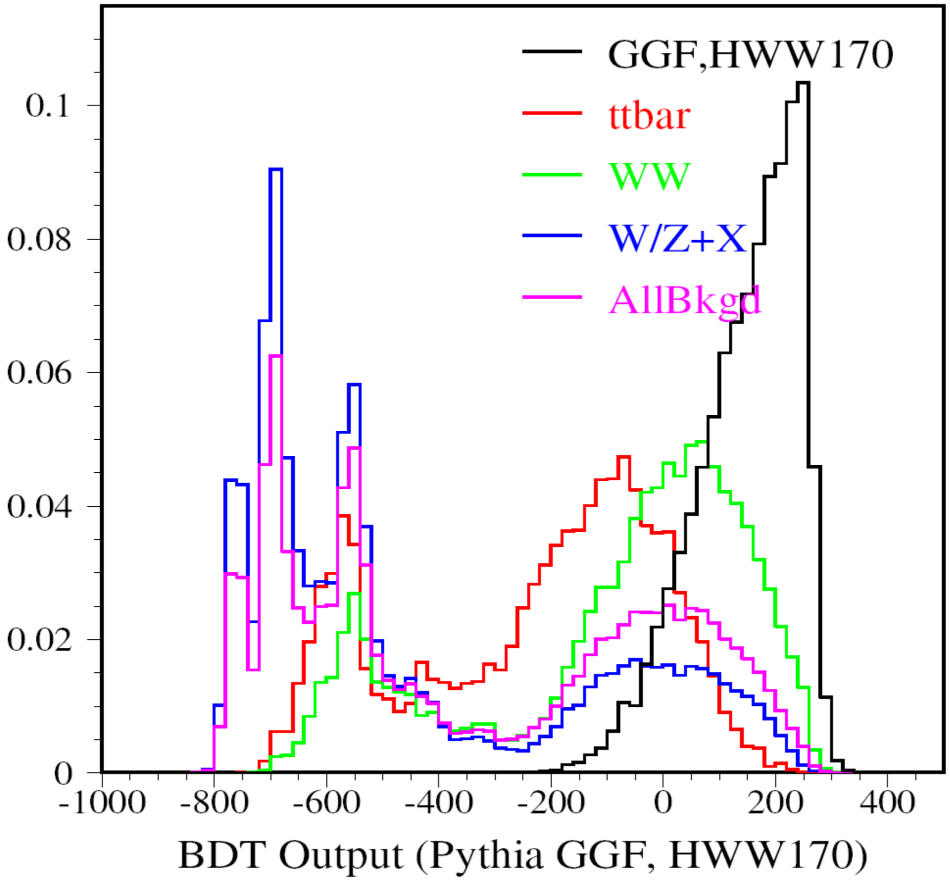
BDT Analysis

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

- **Signal for Training:** PYTHIA Gluon-Gluon fusion H → WW
- **Backgrounds for Training:** WW, ttbar, WZ, W+X and Z+X
- **Input variables for training:**

- 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
- Event Topology
  - Number of Jets with $E_T > 20$ GeV
  - $E(\ell)/P(\ell)$
  - 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$(\ell$,MET)

BDT Discriminator



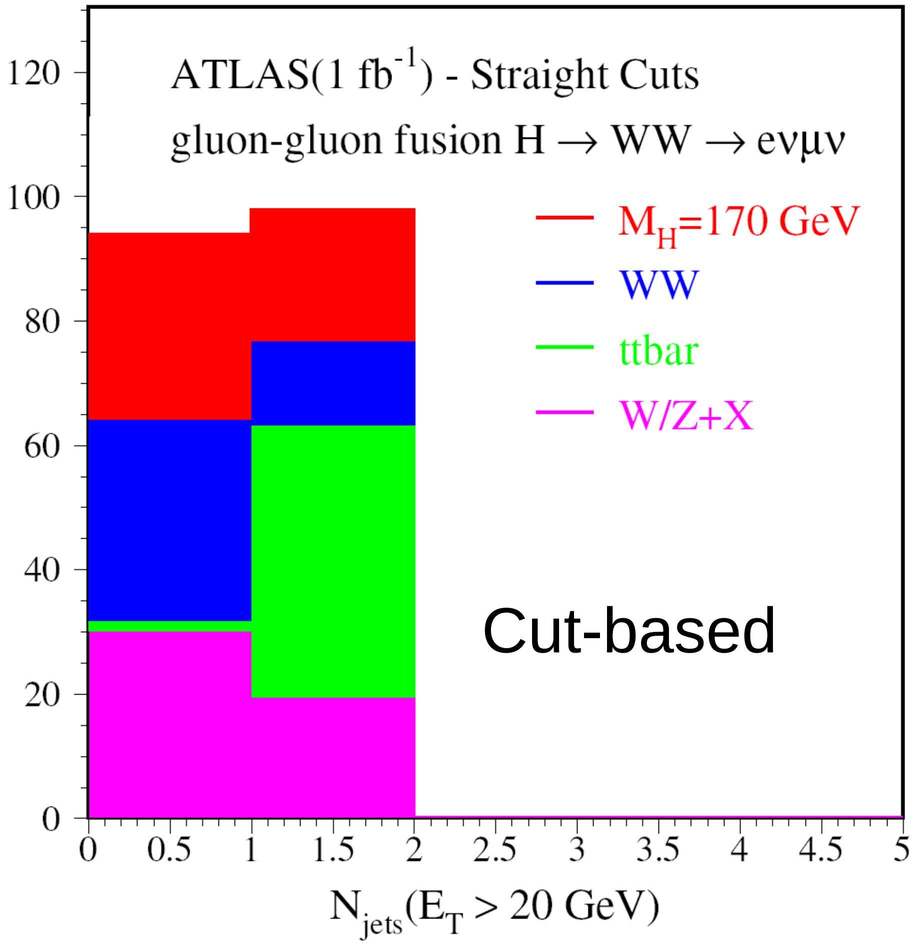
BDT discriminator is the total score of the BDT output as shown in left plot.

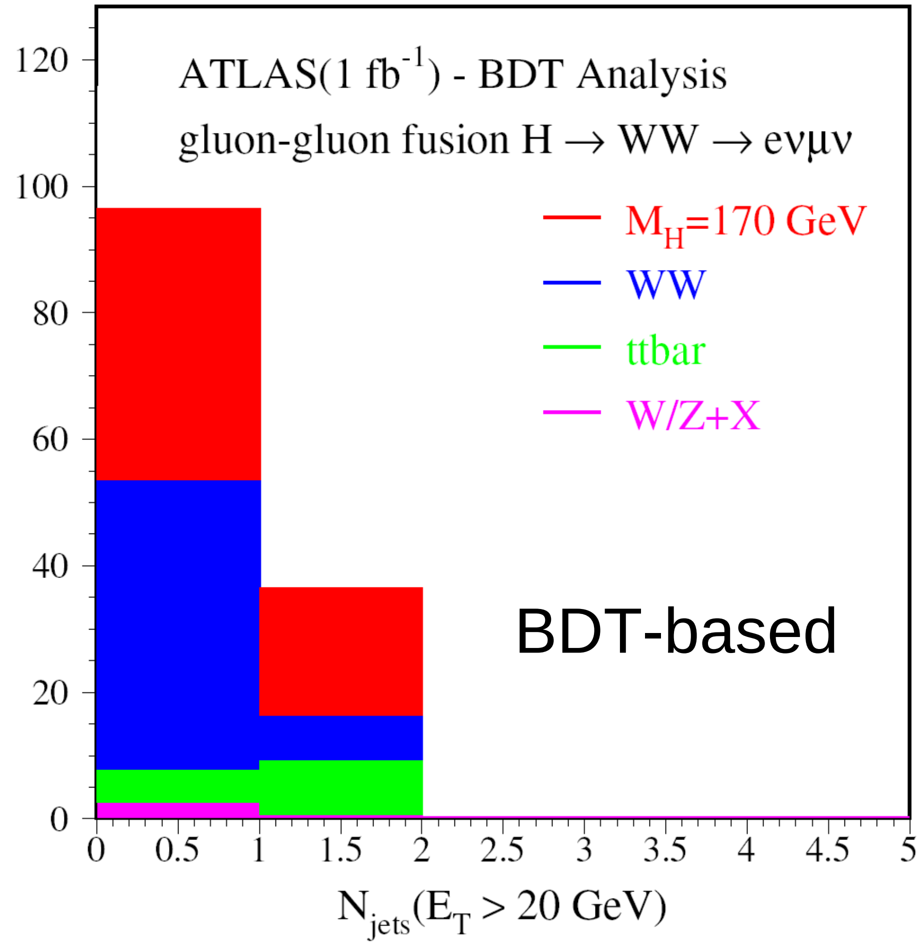
Event Selection:

1) **For 0-jet events: BDT >=200**
2) **For 1-jet events: BDT >=220**

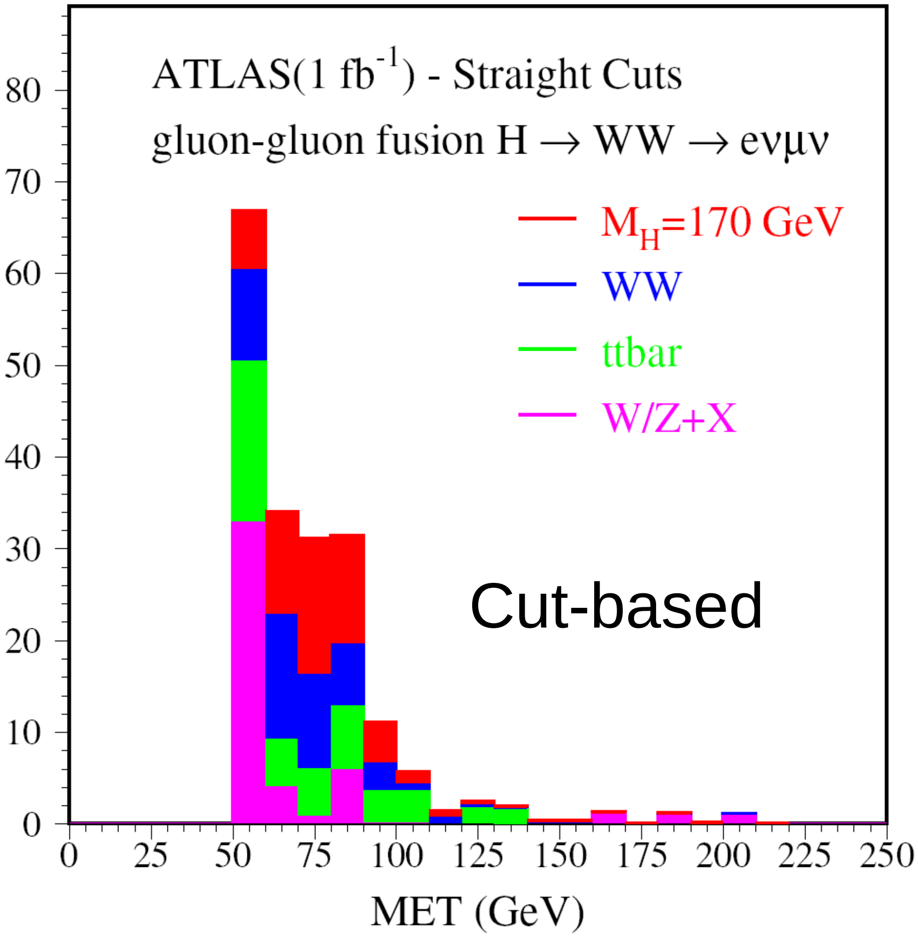
Detection sensitivity is defined as Significance = $N_S/\sqrt{N_B}$
(With or without systematic error)

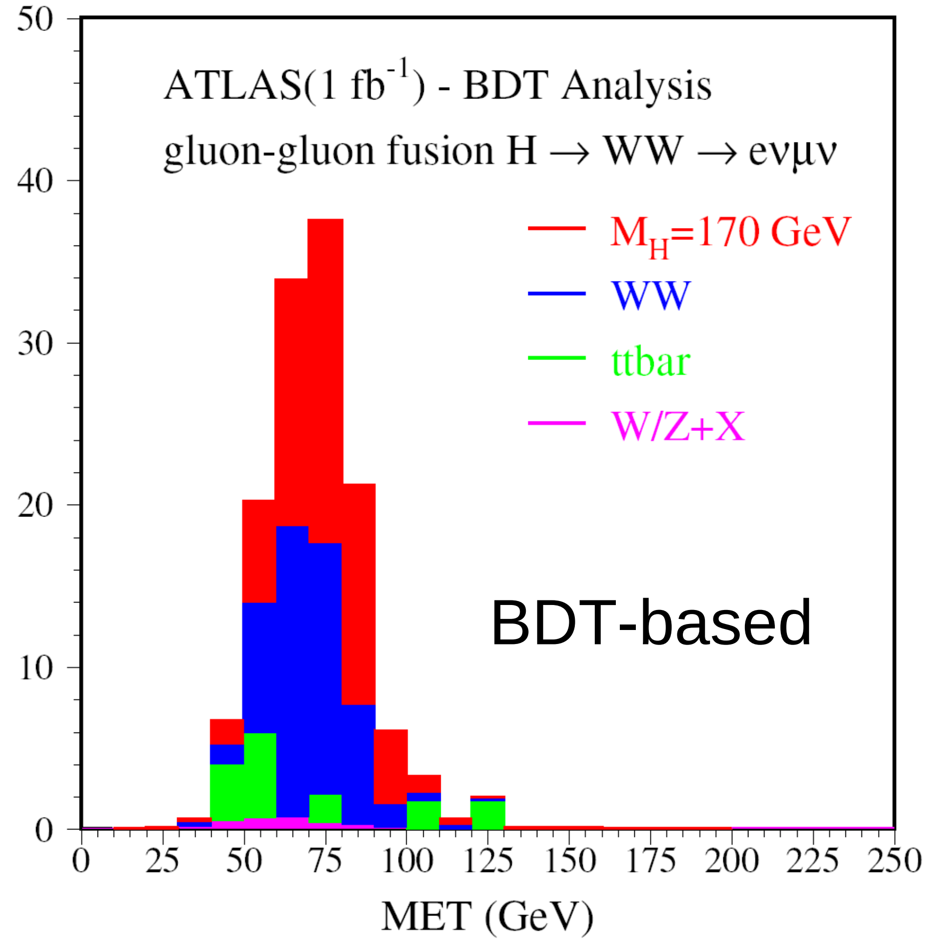
Results (1/fb): Straight Cuts vs BDT





Results (1/fb): Straight Cuts vs BDT





BDT Results: H → WW → lνlν (1/fb)

H→WW→lνlν Events / fb	M_H=150 GeV	M_H=165 GeV	M_H=170 GeV	M_H=175 GeV	M_H=180 GeV	**Bkgd**
BDT (eμ-0 jet)	22.5	45.1	41.0	36.6	29.4	53.6
BDT (eμ-1 jet)	9.3	21.8	19.2	16.4	13.3	16.3
BDT (0 jet+1 jet)	**31.8**	**67.0**	**60.2**	**53.0**	**42.7**	**69.8**
BDT (μμ-0 jet)	13.2	25.3	22.8	20.6	17.1	39.1
BDT (μμ-1 jet)	7.9	16.3	13.1	11.4	8.4	19.3
BDT (0 jet+1 jet)	**21.1**	**41.6**	**35.9**	**32.0**	**25.5**	**58.4**
BDT (ee-0 jet)	11.2	17.8	16.7	15.1	14.2	56.8
BDT (ee-1 jet)	6.3	12.8	11.0	9.2	7.8	33.2
BDT (0 jet+1 jet)	**17.5**	**30.6**	**27.7**	**24.3**	**22.0**	**90.0**
BDT (ee+μμ+eμ)	**70.4** **9.2%**	**139.2** **16.1%**	**123.8** **15.0%**	**109.3** **14.2%**	**90.2** **12.6%**	**218.2**

H → WW → $l\nu l\nu$ Selection

statistical sensitivity (1/fb) for each dilepton channel

GGF H→WW **$N_s / \sqrt{N_b}$ (1/fb)**	**M_H=150 GeV**	**M_H=165 GeV**	**M_H=170 GeV**	**M_H=175 GeV**	**M_H=180 GeV**
Cuts (eμ)	**2.6**	**4.9**	**4.1**	**3.6**	**2.9**
Cuts (μμ)	**1.8**	**3.3**	**2.8**	**2.5**	**2.0**
Cuts (ee)	**1.0**	**1.9**	**1.6**	**1.3**	**1.1**
BDT (eμ)	**3.8**	**8.0**	**7.2**	**6.3**	**5.1**
BDT (μμ)	**2.8**	**5.4**	**4.7**	**4.2**	**3.3**
BDT (ee)	**1.8**	**3.2**	**2.9**	**2.6**	**2.3**

H → WW → lνlν Selection
Combined Statistical Sensitivity (1/fb)

GGF H→WW Events / fb	M_H=150 GeV	M_H=165 GeV	M_H=170 GeV	M_H=175 GeV	M_H=180 GeV	Bkgd
Cuts (ee+μμ+eμ) Efficiency	**58.9 7.7%**	**110.6 12.8%**	**93.5 11.3%**	**80.8 10.5%**	**65.7 9.2%**	**352.0**
$N_s / \sqrt{N_b}$ (no syst) **Cuts (ee+μμ+eμ)**	**3.1**	**5.9**	**5.0**	**4.3**	**3.5**	**N/A**

BDT (ee+μμ+eμ) Efficiency	**70.4 9.2%**	**139.2 16.1%**	**123.8 15.0%**	**109.3 14.2%**	**90.2 12.6%**	**218.2**
$N_s / \sqrt{N_b}$ (no syst) **BDT (ee+μμ+eμ)**	**4.8**	**9.4**	**8.4**	**7.4**	**6.1**	**N/A**

Systematic Uncertainties

Understand the systematic errors is crucial for H→WW detection, which is a 'Counting' experiment, no shape mass peak! Major uncertainties come from

1) Signal modeling (cross-sections, spin-spin correlations, …)
2) Detector response modeling (resolutions, energy scale, efficiencies…)
3) The background model (cross-sections, distribution shapes,…)

Systematic uncertainties based on theoretic papers, Tevatron experience and our own studies are listed below:

- 6.5% Luminosity uncertainty (ref. Tevatron)
- 5% Parton Density Function uncertainty
- 3% Lepton identification acceptance uncertainty
- 5% Energy scale uncertainty (3% on lepton energy and 10% on hadronic energy)
- 6% BDT training uncertainty due to energy scale uncertainty and MC cross section uncertainties of major backgrounds
- 15% background estimation uncertainty due to limited MC data sample statistics (W/Z+X)

Study the background model uncertainties

- To estimate systematic uncertainty caused by background model uncertainties both in cross-sections and in overall distribution shapes, we vary the major background cross-sections in the BDT training process (reweighting), which effectively changing the overall background distributions.
- WW and ttbar weighting are changed by $\pm$20% for BDT training. The relative change of background acceptance with fixed signal efficiency are listed in the table.

Relative change of background	$H \rightarrow WW$ $(e\nu\mu\nu)$	$H \rightarrow WW$ $(\mu\nu\mu\nu)$	$H \rightarrow WW$ $(e\nu e\nu)$
σ_{WW} +20%	4.6%	2.0%	2.3%
σ_{WW} - 20%	6.8%	6.8%	8.4%
σ_{ttbar} +20%	2.4%	4.0%	3.1%
σ_{ttbar} - 20%	5.7%	1.1%	1.2%

Uncertainty from lepton and Jet Energy Scale and Resolution

- To estimate the systematic uncertainties due to detector modeling, all energy-dependent variables in testing samples are modified by adding additional energy uncertainty, 3% for lepton and 10% for jets. The relative changes of signal and background efficiencies are calculated by using same BDT cut.

Relative change	$H \to WW$ ($e\nu\mu\nu$)	$H \to WW$ ($\mu\nu\mu\nu$)	$H \to WW$ ($e\nu e\nu$)
Signal (resolution)	<0.1%	0.1%	<0.1%
Signal (Scale)	1.1%	1.7%	2.6%
Background (resolution)	0.4%	0.9%	0.4%
Background (Scale)	3.1%	2.0%	5.6%

H → WW Detection Sensitivity (1/fb, with 20% systematic error)

GGF H→WW $N_s / \sqrt{N_b}$ (1/fb)	M_H=150 GeV	M_H=165 GeV	M_H=170 GeV	M_H=175 GeV	M_H=180 GeV
Cuts (eμ)	1.0	1.9	1.6	1.4	1.1
Cuts (μμ)	0.8	1.5	1.3	1.1	0.9
Cuts (ee)	0.4	0.8	0.7	0.5	0.5
BDT (eμ)	2.0	4.1	3.7	3.3	2.6
BDT (μμ)	1.5	3.0	2.6	2.3	1.8
BDT (ee)	0.9	1.5	1.4	1.2	1.1

Further Improvement is Achievable

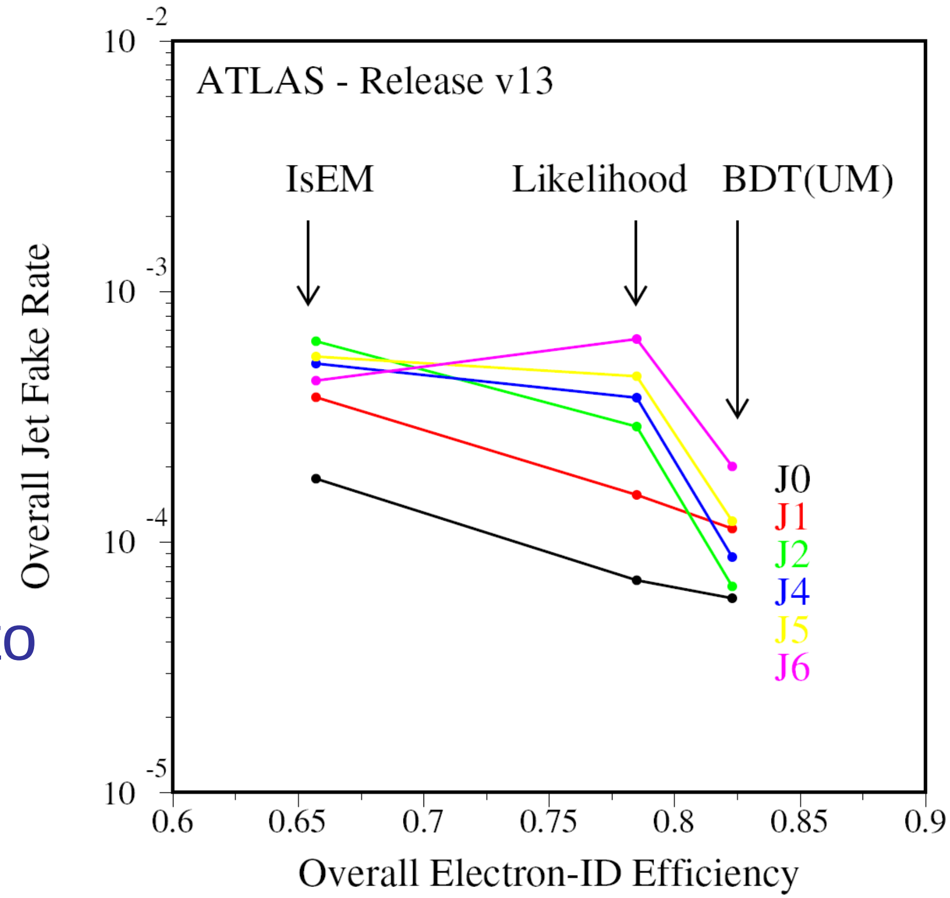
➔ Electron-ID efficiency

IsEM: 65.7% (V13)

Likelihood: 78.5% (V13)

BDT(UM): 82.3% (V13)

BDT has high e-ID efficiency and low jet fake rate



➔Using B-tagging variables to suppress ttbar background

➔Ref: H.Yang's talk on 'Electron Identification Based on Boosted Decision Trees' at ATLAS Performance and Physics Workshop on October 2, 08

http://indico.cern.ch/conferenceDisplay.py?confId=39296

2) Search for Z' → ttbar

- Physics motivation
- W / Top reconstruction from jets
- Event selections
- Z' → ttbar search strategies
- Expected detection sensitivities

Physics Motivation

- There are many models predict the signatures with top-rich events. Z'→ ttbar has been used as the *benchmark* for such 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). Searches for Z' via leptonic decay productions (ee, $\mu\mu$) have been conducted at LEP and Tevatron (current limit: $M_{Z'}$ > 850 GeV from CDF, Ref: Phys. Rev. D70:093009, 2004).

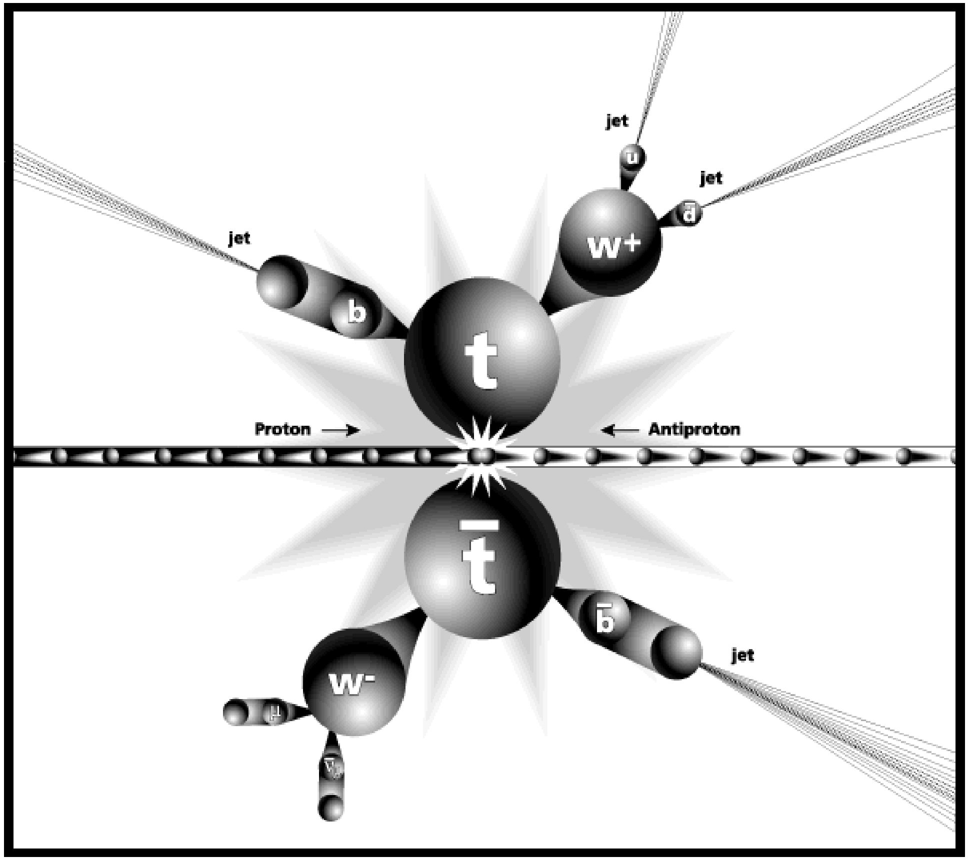
- But, the searches through leptonic channels do not rule out the existence of a Z' resonance with suppressed decays to leptons, so called "leptophobic" Z'. Several models (RS Kaluza-Klein states of gluons, weak bosons and gravitons; Topcolor leptophobic Z'; Sequential Z' etc.) suggest that Z'-like state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

MC Samples Used in Our Study

- 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 and Top Reconstruction with jets final states

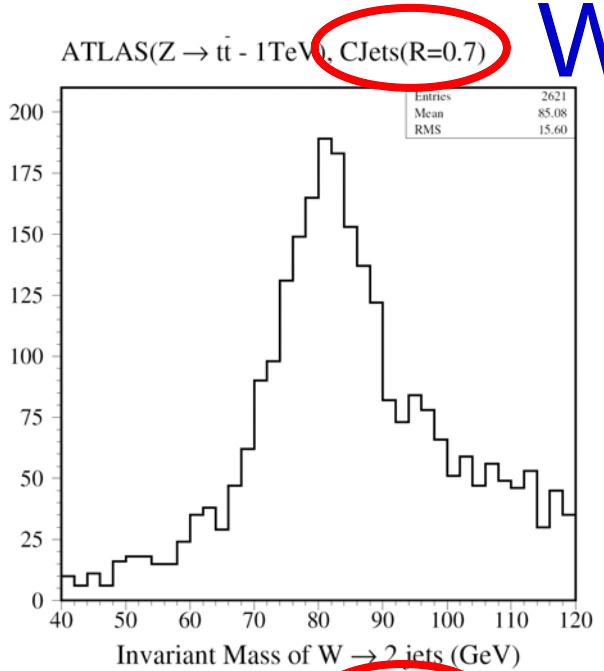
➔ With the increase of Z' mass, the energy of Top/W from Z' decay increase and the decay jets are boosted and located in a relative small region. In order to reconstruct Top/W efficiently, it's critical to use a suitable jet finding algorithm.

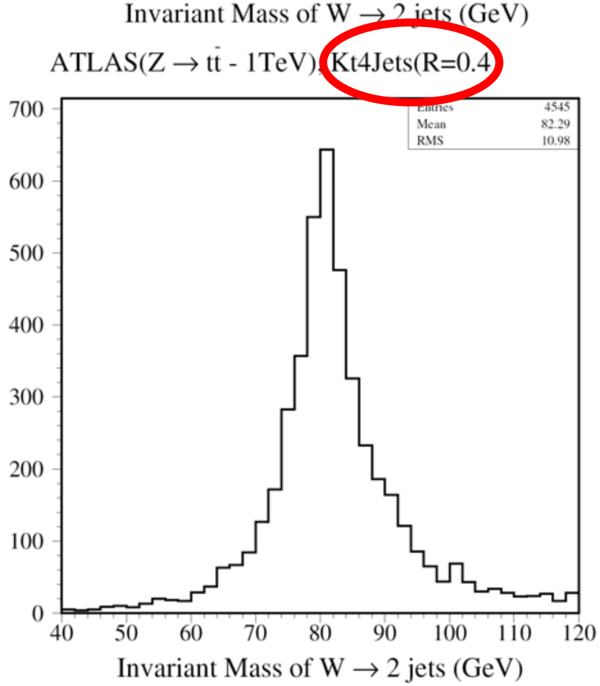


➔ATLAS employs two jet finding algorithms (Cone, Kt),

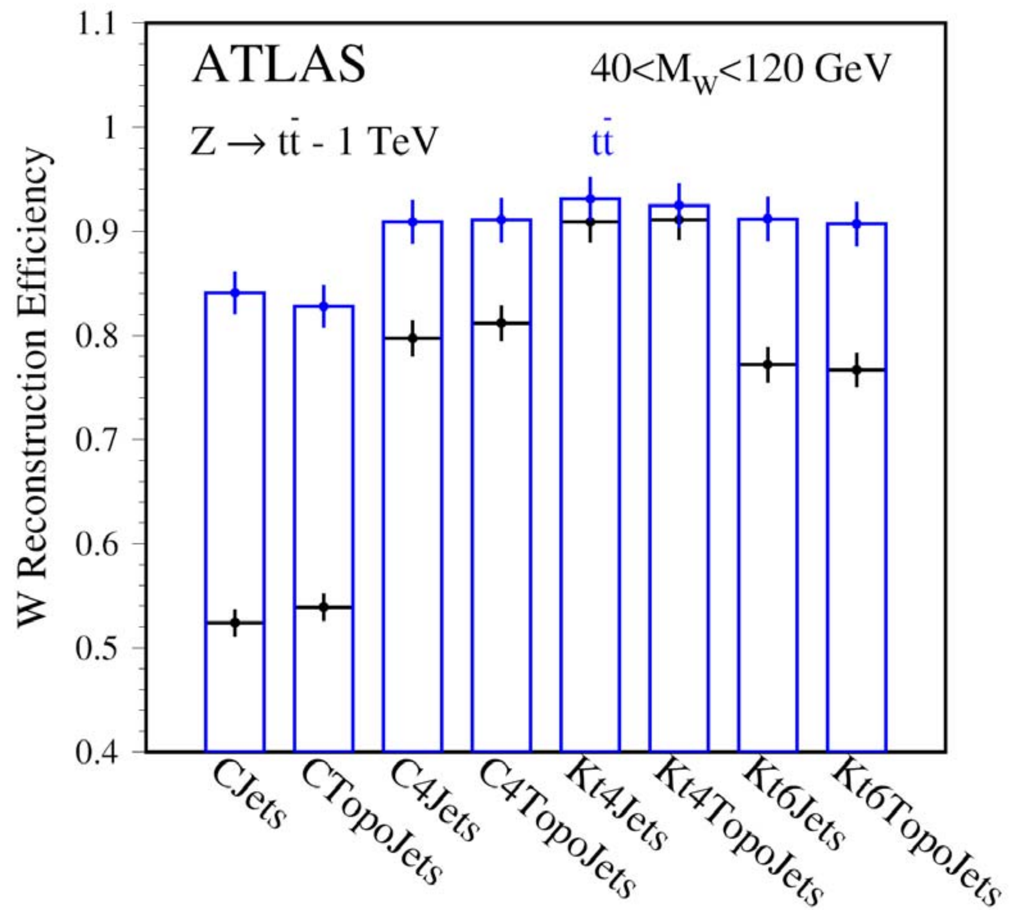
- CJets (R=0.7)
- CTopoJets (R=0.7)
- C4Jets (R=0.4)
- C4TopoJets (R=0.4)
- Kt4Jets (R=0.4)
- Kt4TopoJets (R=0.4)
- Kt6Jets (R=0.6)
- Kt6TopoJets (R=0.6)

W → jet-jet Reconstruction

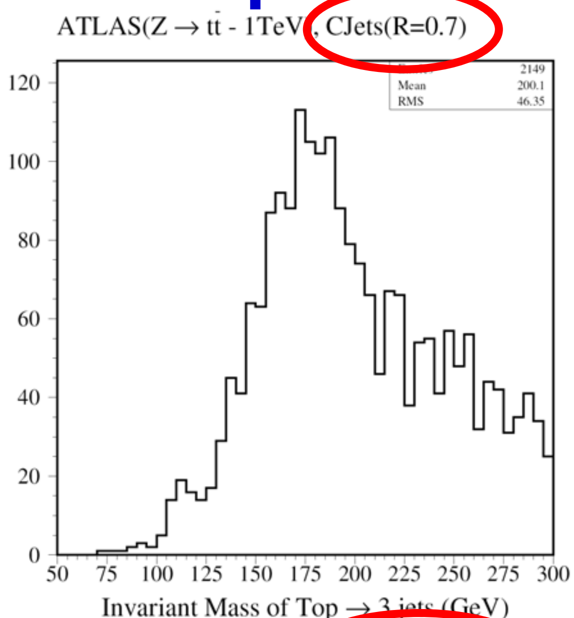


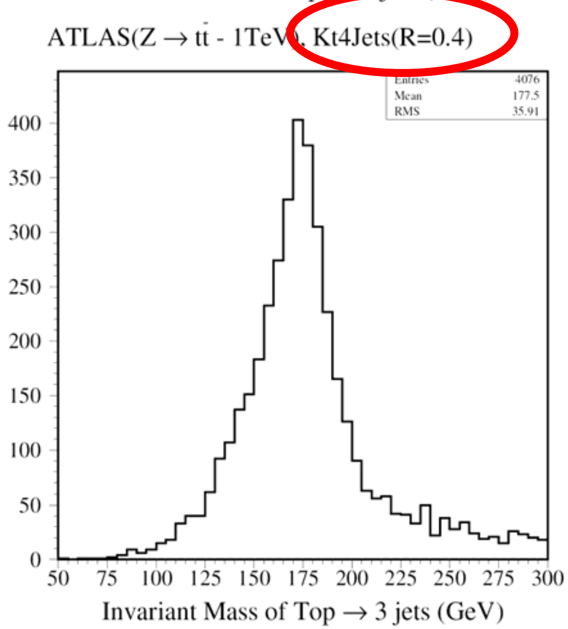


Efficiency of W → jj Reconstruction

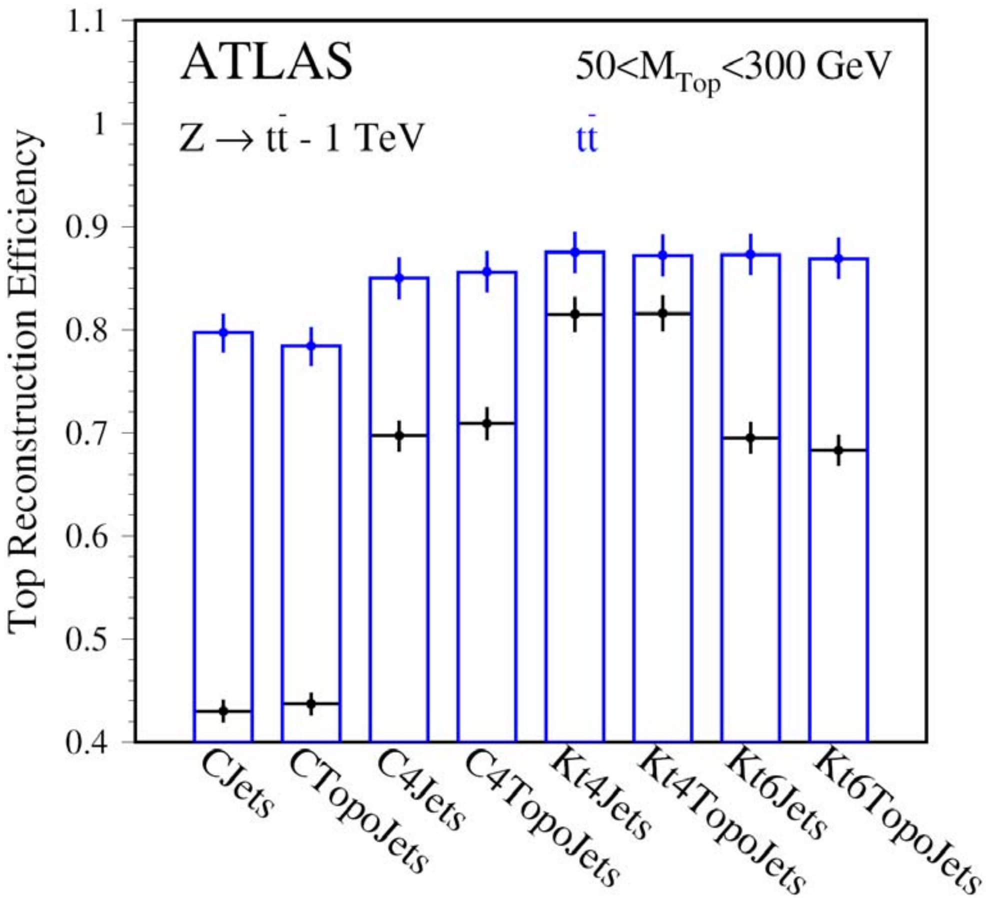


Top → bW(→jj) Reconstruction





Efficiency of Top → bjj Reconstruction



Analysis Strategy

- Event selection (to suppress most of background events):
  - Pre-selection cuts
  - Cut-based analysis for further event selection
  - BDT multivariate technique for event selection, training the initial decision trees using Z’ with the **combination** of various mass (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.

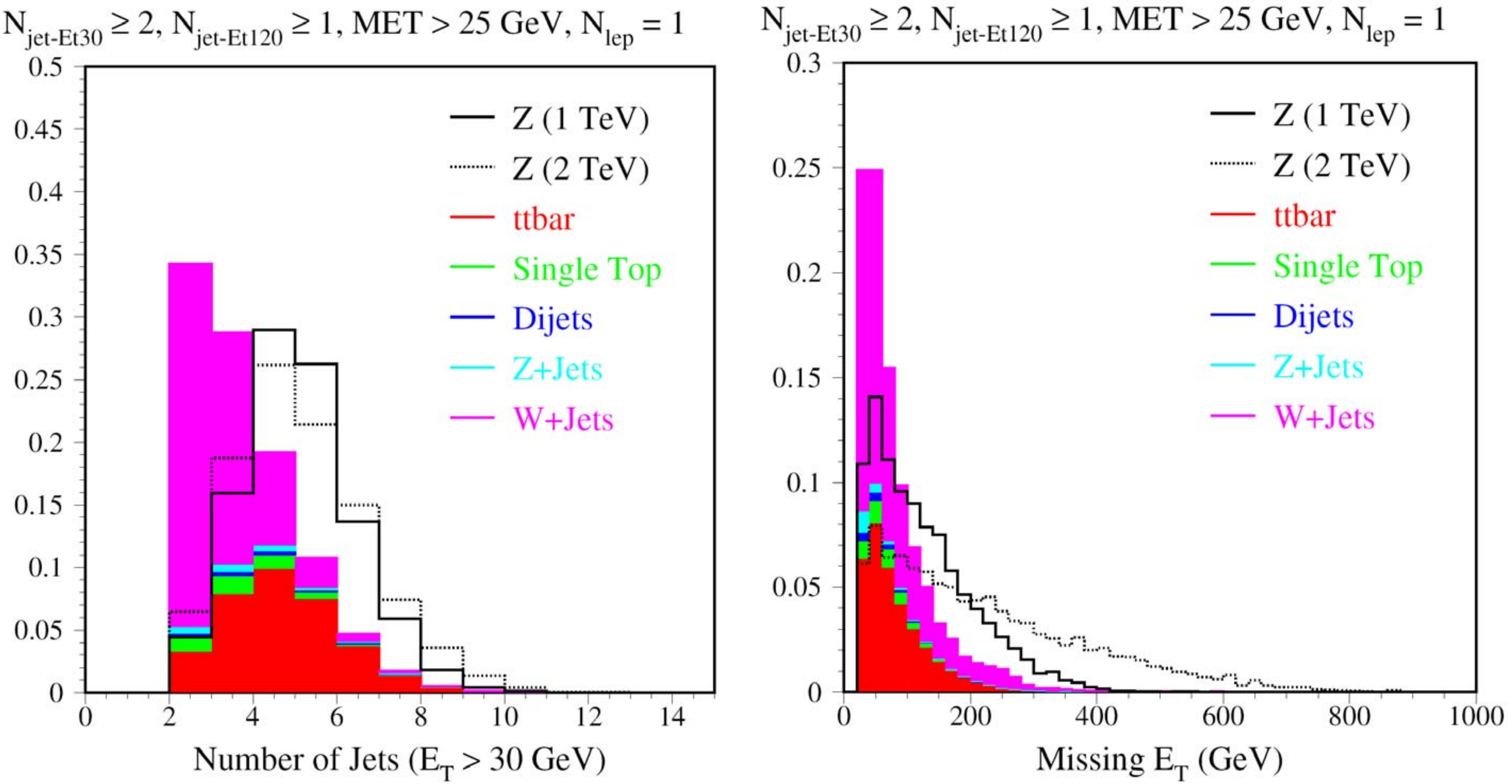
- If an interesting “signal” is found (e.g. $>3\sigma$), we will use Z’ with estimated mass as signal to re-train the BDT to confirm if the ‘signal’ being ‘real’.

Event Pre-selection

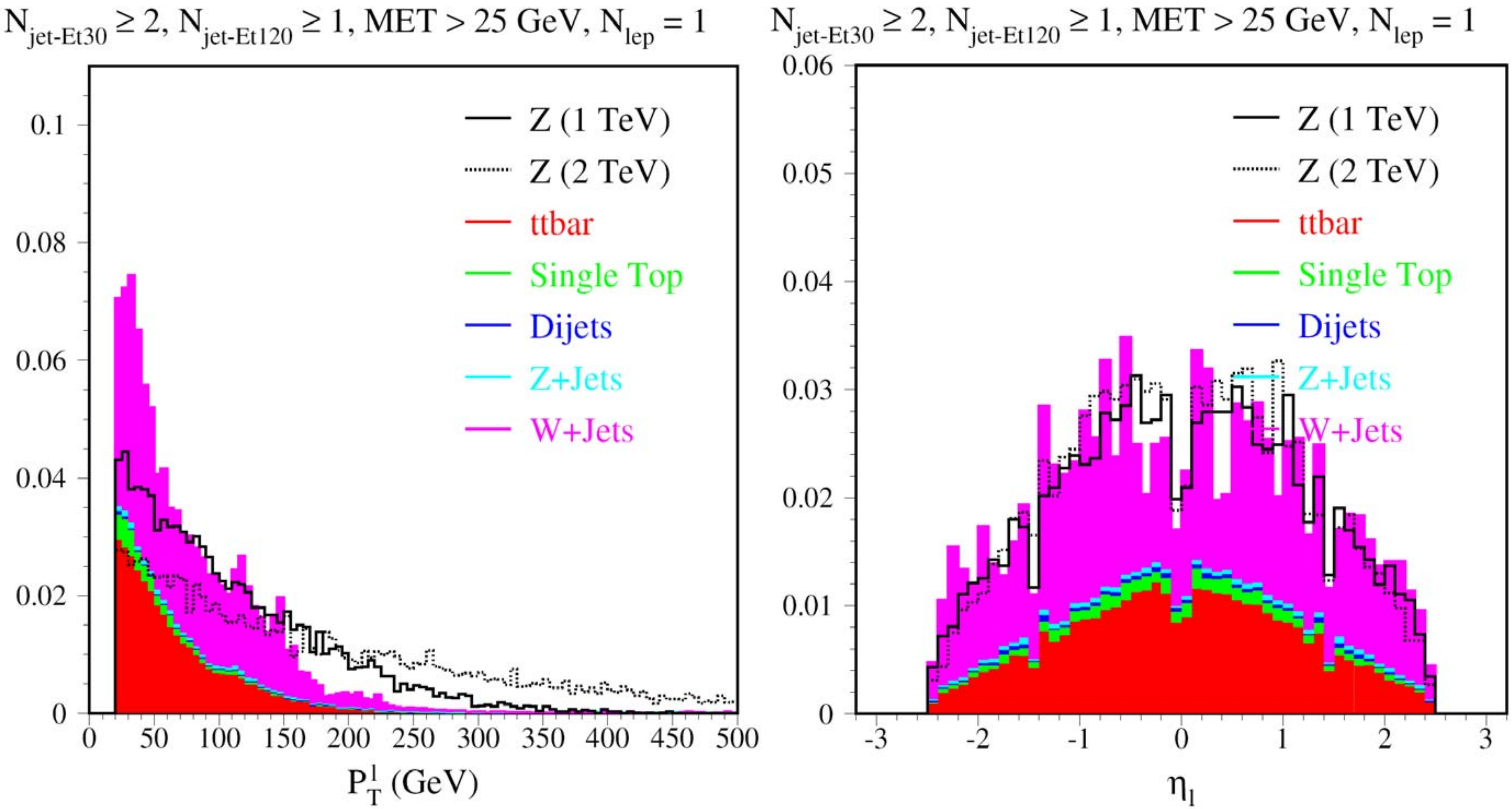
- At least 2 jets with Et > 30 GeV
- At least 1 jet with Et > 120 GeV
- Missing transverse momentum > 25 GeV
- Only one lepton (e or μ) with Pt > 20 GeV

Variable Distributions After Pre-selection

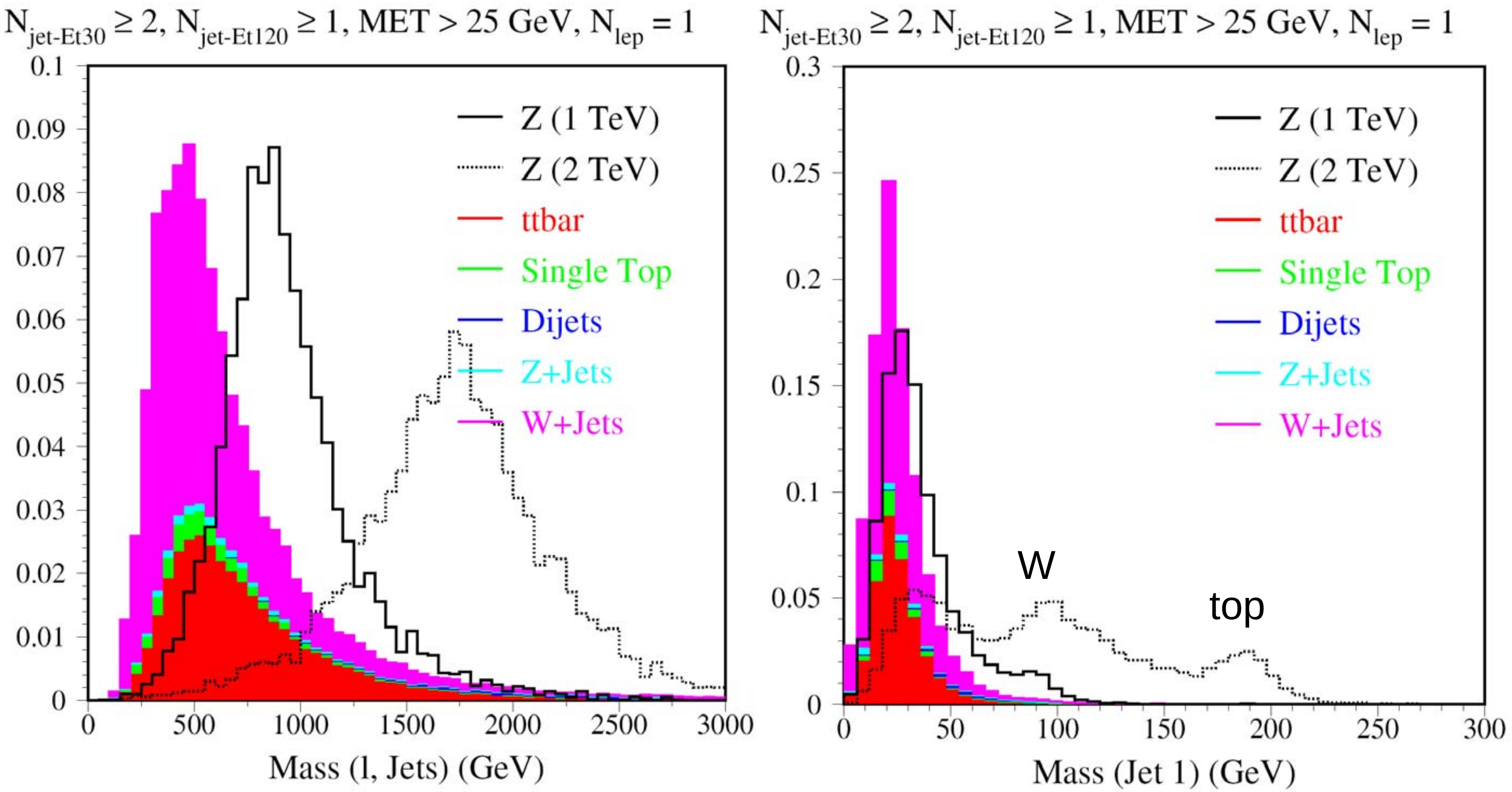
Number of Jets and MET



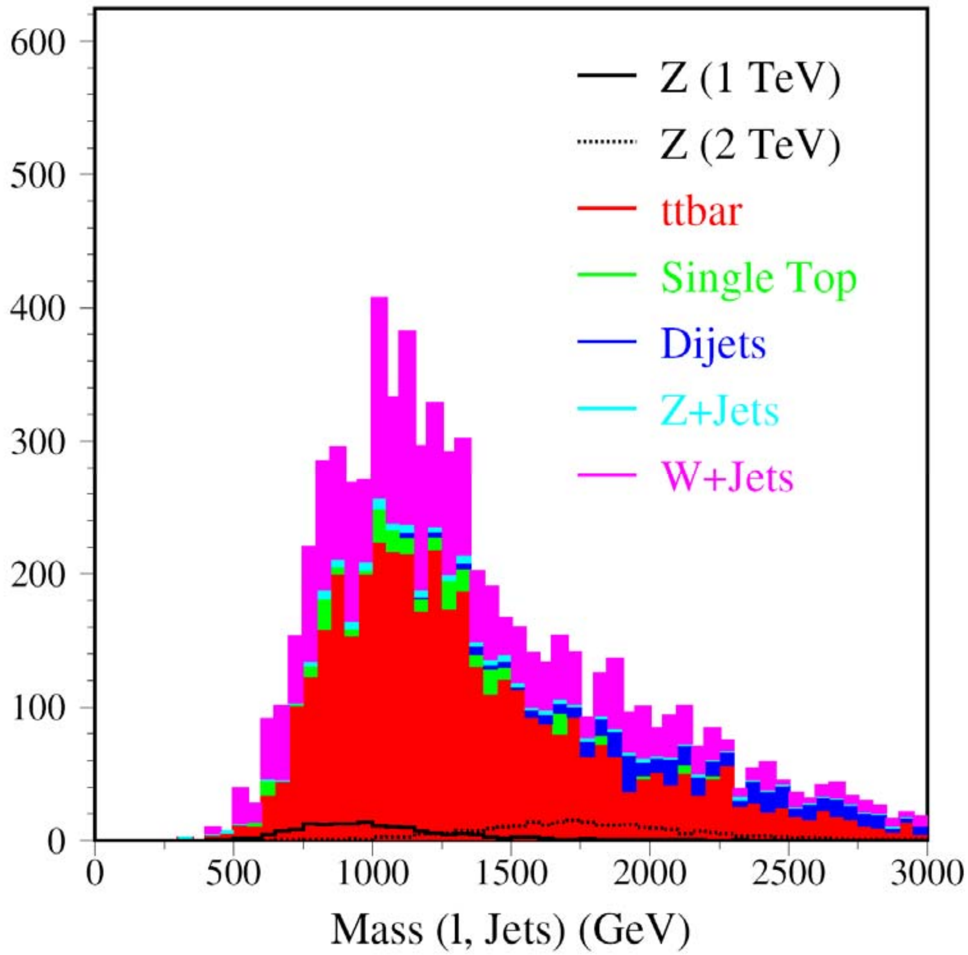
Lepton Pt and Eta



Mass of the 1st Energetic Jet



Z' Selection with Straight Cuts (normalization to 1/fb)



- $40 \leqslant M_W \leqslant 120$ 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 (assuming σ=1pb)**
- 170 from Mz' = 1.0 TeV
- 269 from Mz' = 1.5 TeV
- 261 from Mz' = 2.0 TeV
- 215 from Mz' = 3.0 TeV

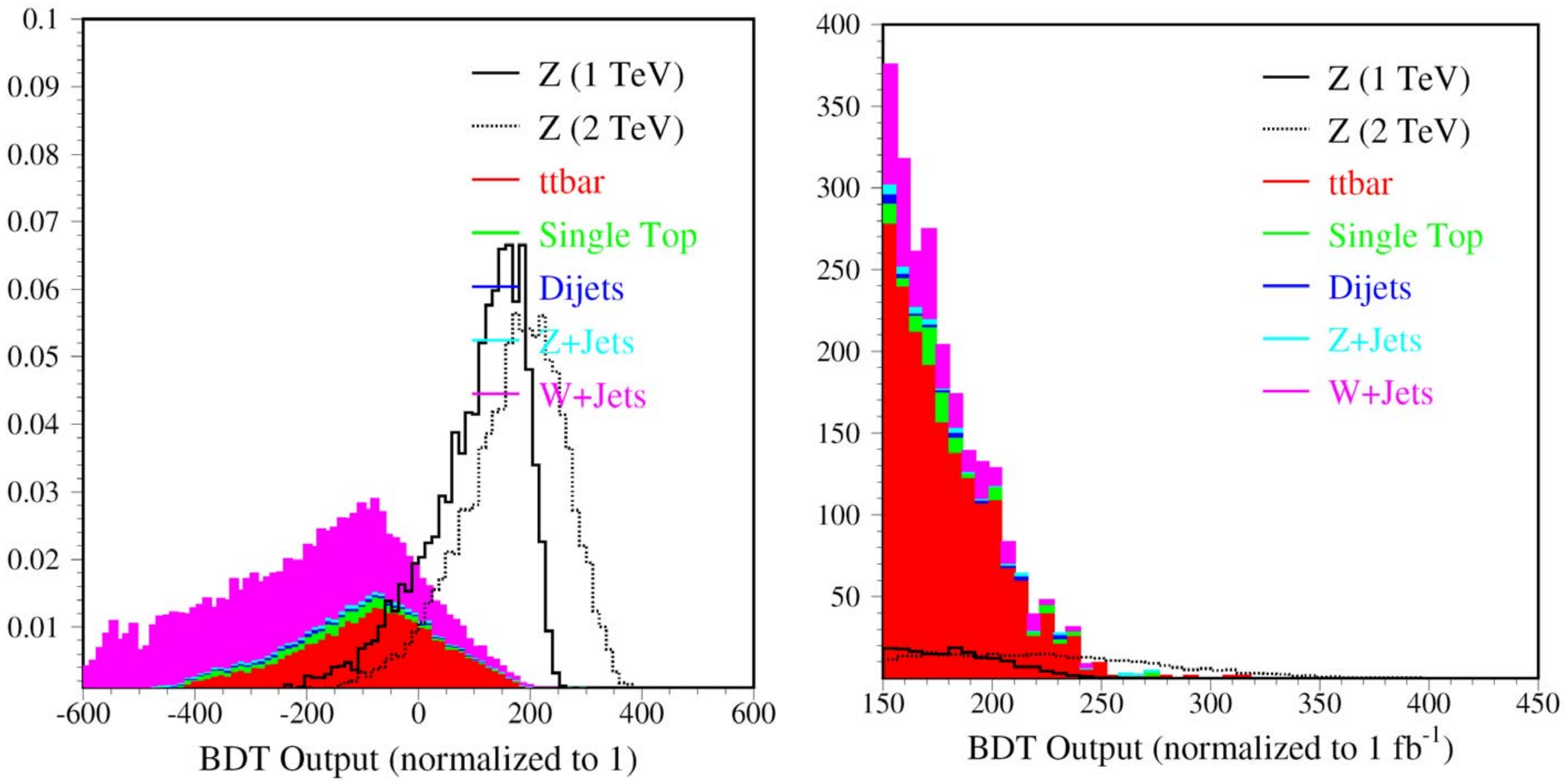
➔**Backgrounds (7258)**
- 4188 from ttbar
- 247 from single top
- 500 from dijet
- 2189 from W+Jets
- 134 from Z + Jets

Z' Selection with BDT Analysis (A)

with 24 input variables for training

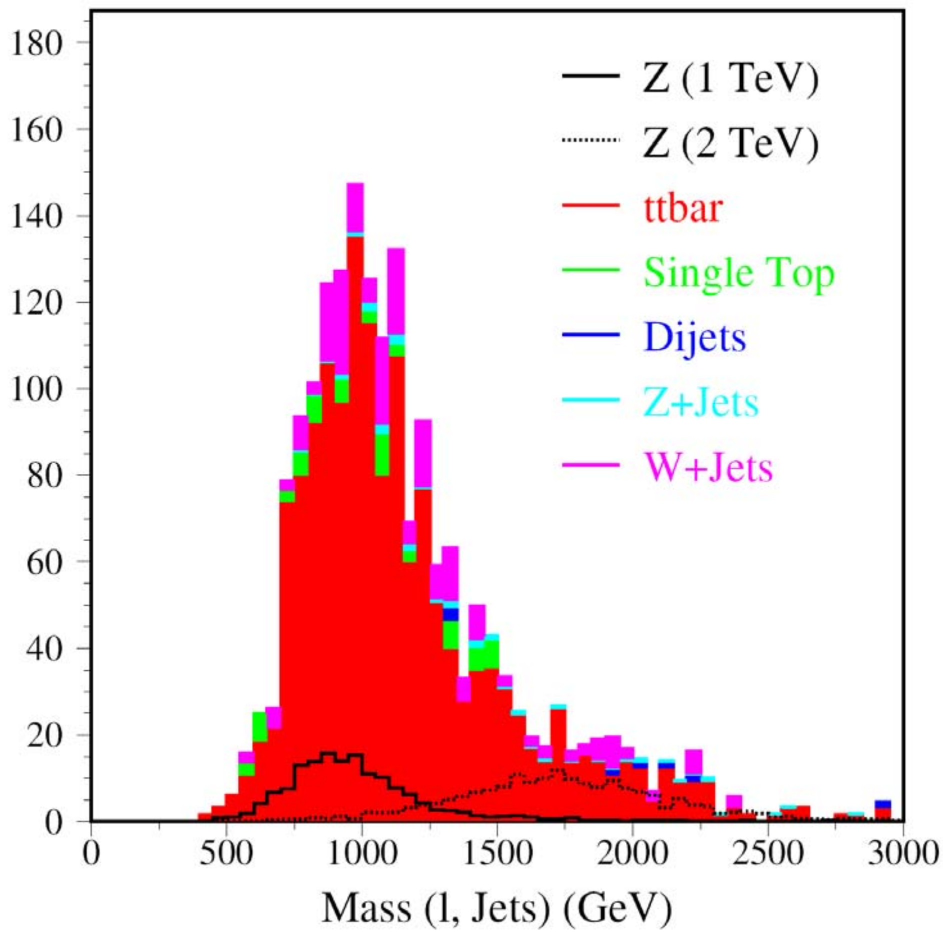
- P_t^L, $N_{track}(R=0.2)$, $\sum P_t(track) / E_t^L\ (R=0.2)$
- N_{jet}(Et>30GeV), Size(J1), E_{em}(J1)
- E_t(J1), E_t(J2), E_t(L,MET), MET
- M(J1), M(Jets), M(Jets,L), M_t(L,MET)
- H_t(L,Jets), H_t(L,Jets,MET), V_t(L,MET)
- $\Delta\phi$(J1,J2), ΔR(J1,J2), ΔR(J1,J3)
- $\Delta\phi$(J1,L), $\Delta\phi$(J2,L),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

BDT Analysis *Discriminator* (A)



Selected Events (1 fb^{-1})

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



Signal (assuming σ=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%)

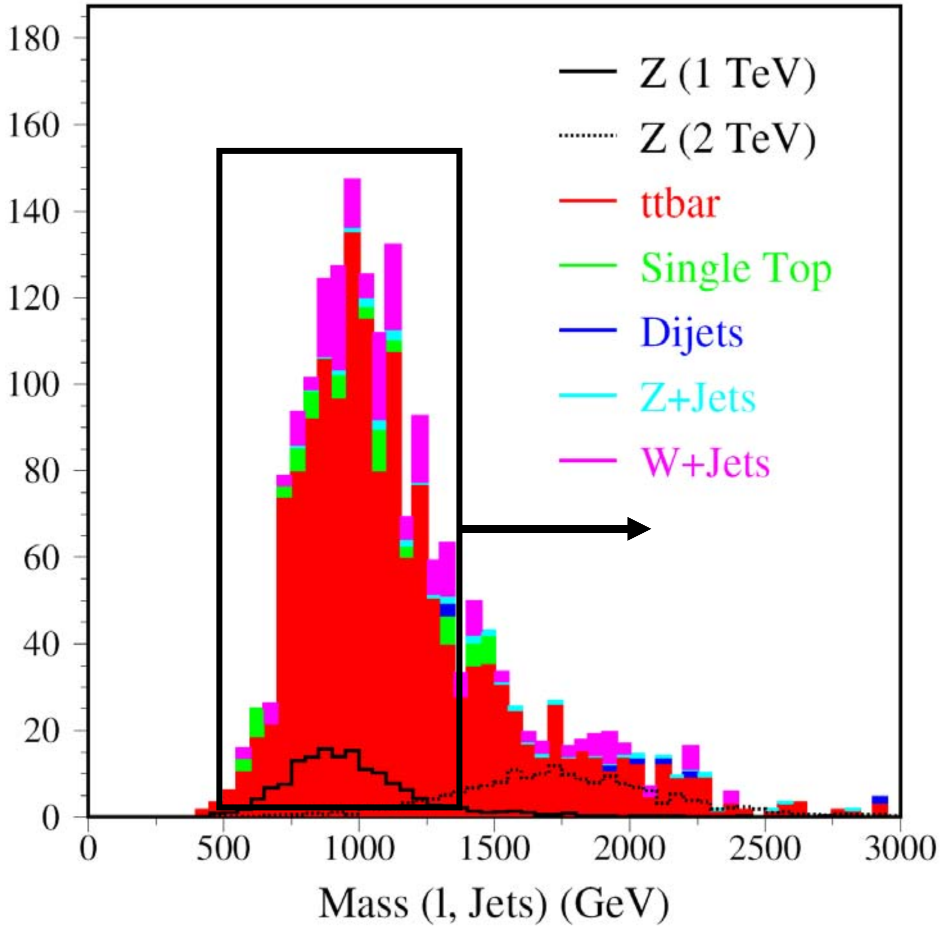
→ Z + Jets – 24 Events(1.3%)

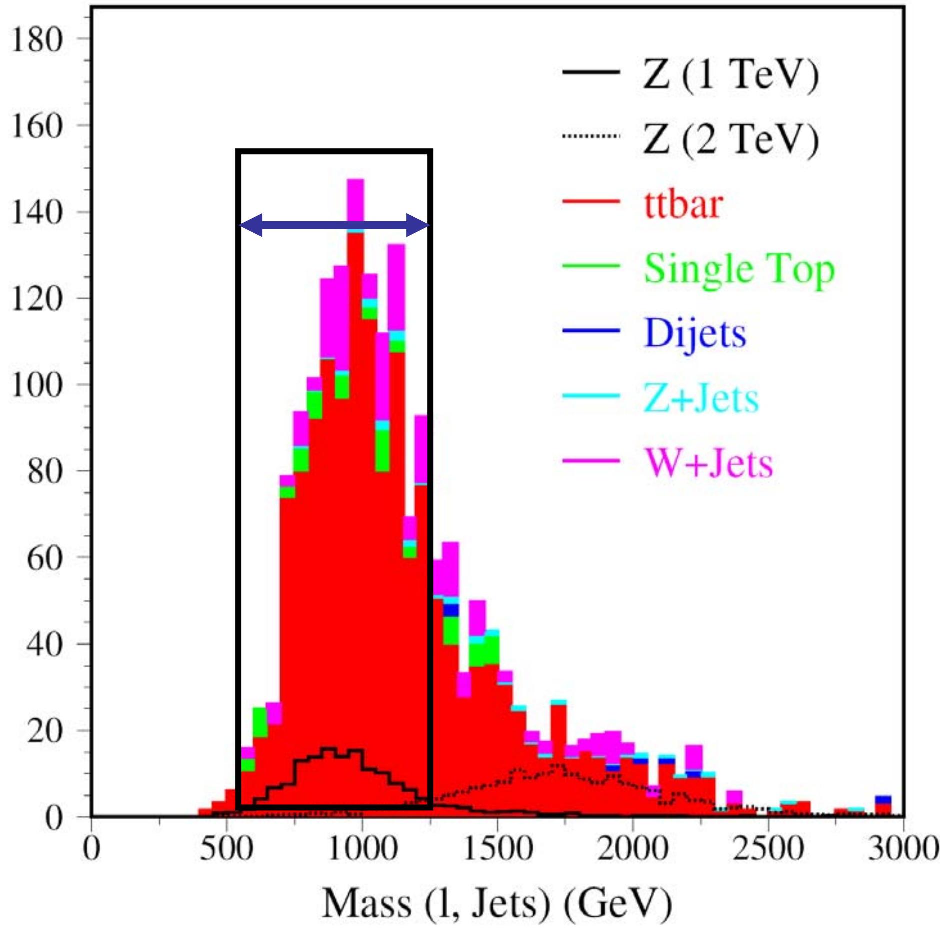
→ Dijets – 10 Events(0.54%)

Scan the Mass Window

Sliding mass window to find the IR

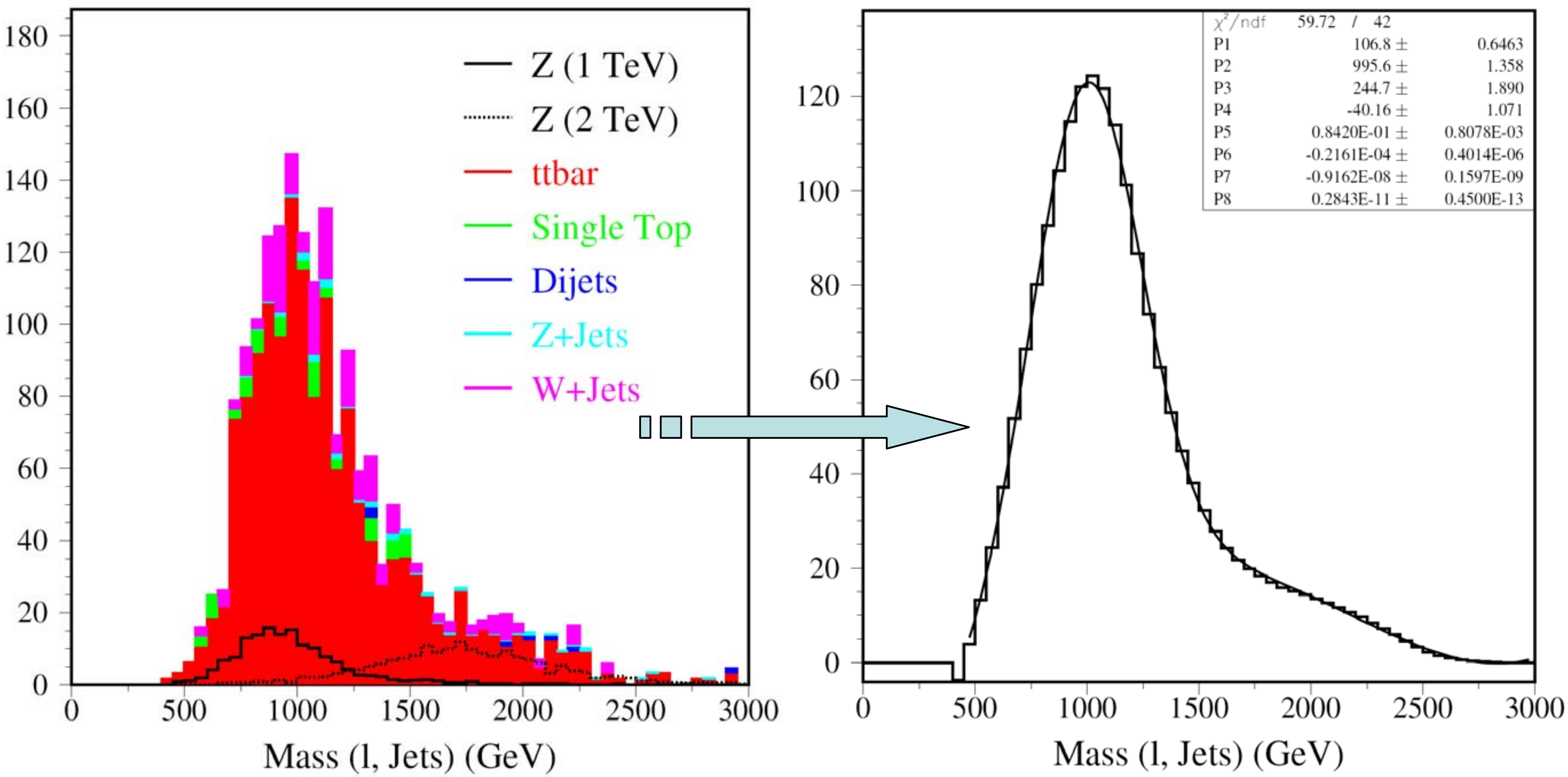
Opt. sensitivity by varying mass window



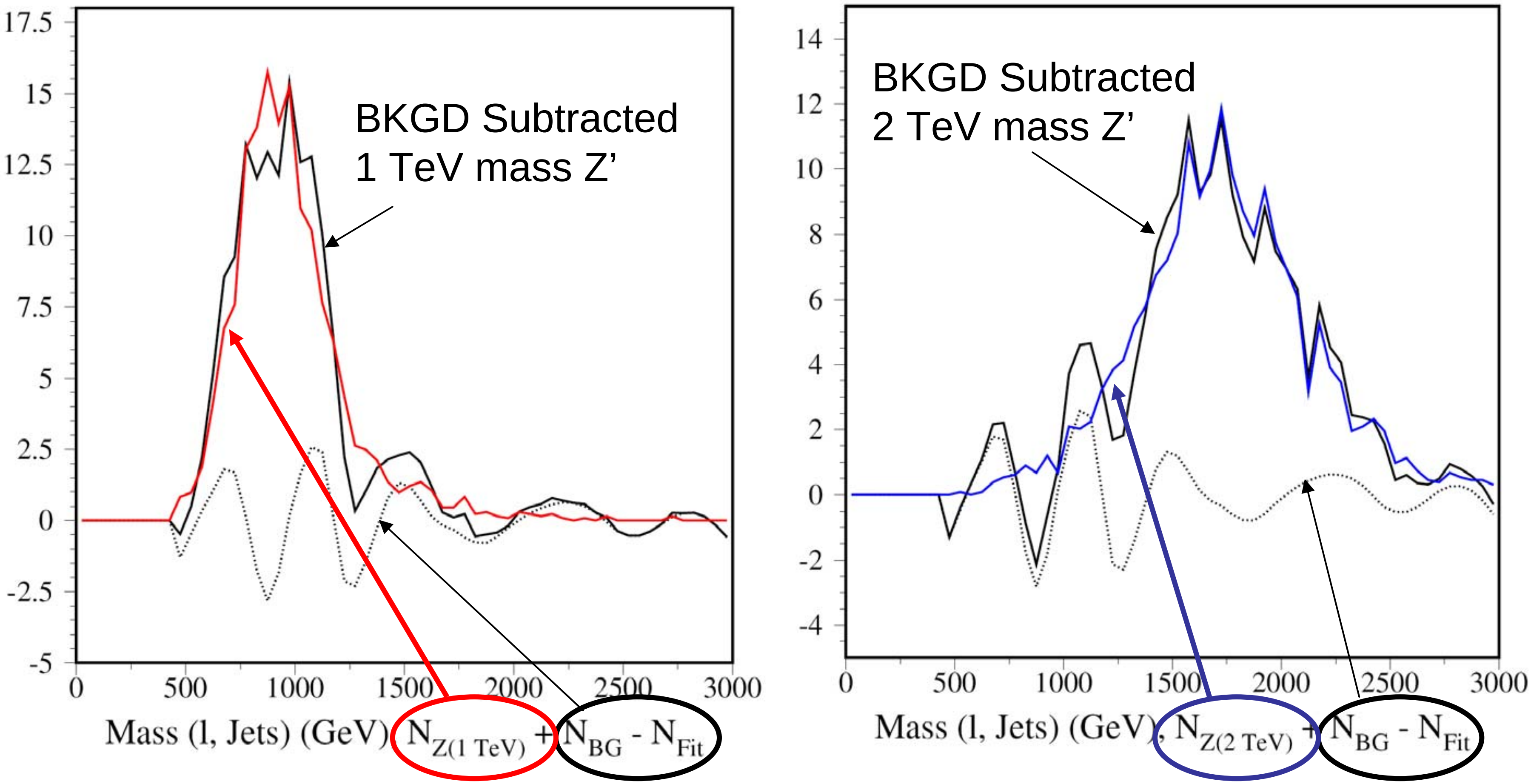


Fitting Background Events

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 X-section for Z' → $t\bar{t}$

Signal	SM-like 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-like 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	< 44.6 fb
Z'(1.5 TeV)	37 fb	< 196 fb	< 60.7 fb	< 19.6 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

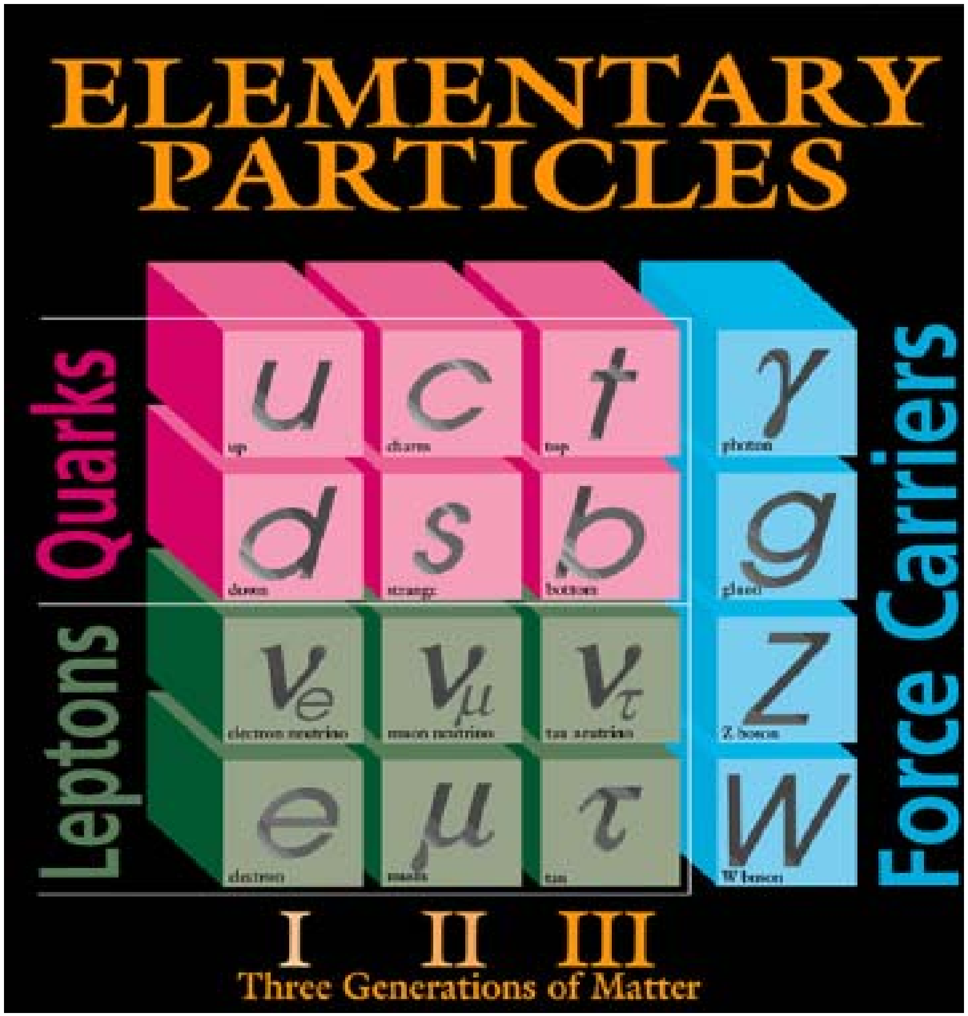
Summary

- 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 $150<M_H<180$ GeV.
- The discovery of Z' $\rightarrow$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 Slides

Standard Model

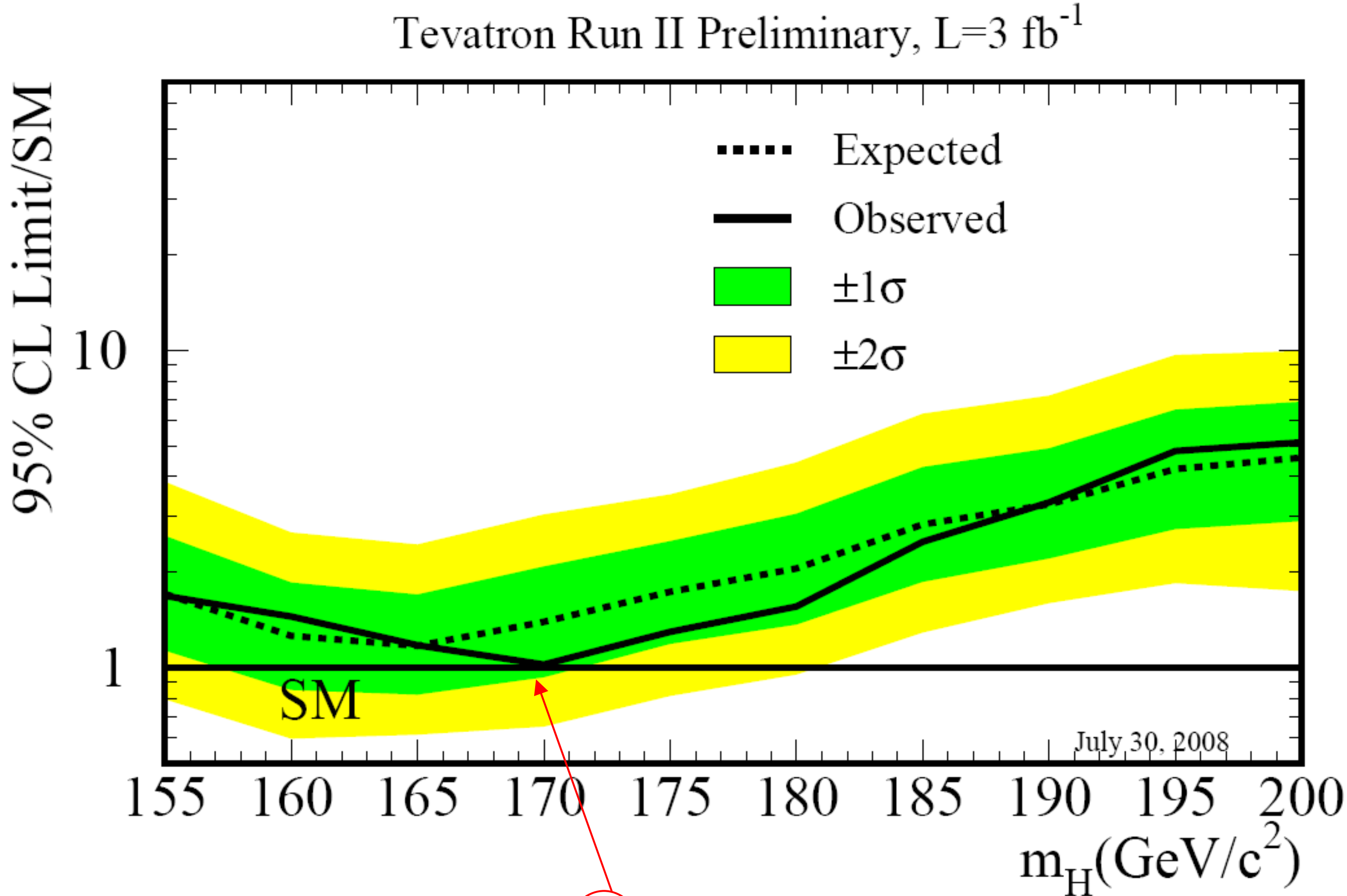


- **Gauge** sector and **matter** sector are very successfully tested! But the **Higgs** sector which describes the EWSB is totally **dark.**
- **To find the mystery of EWSB is one of the major motivations for experimental high energy physics (LEP, Tevatron, LHC …).**

Higgs Mechanism
– Spontaneously break electroweak symmetry
– Generate masses

SM Higgs Searches at Tevatron

(Ref: arXiv:0808.0534)

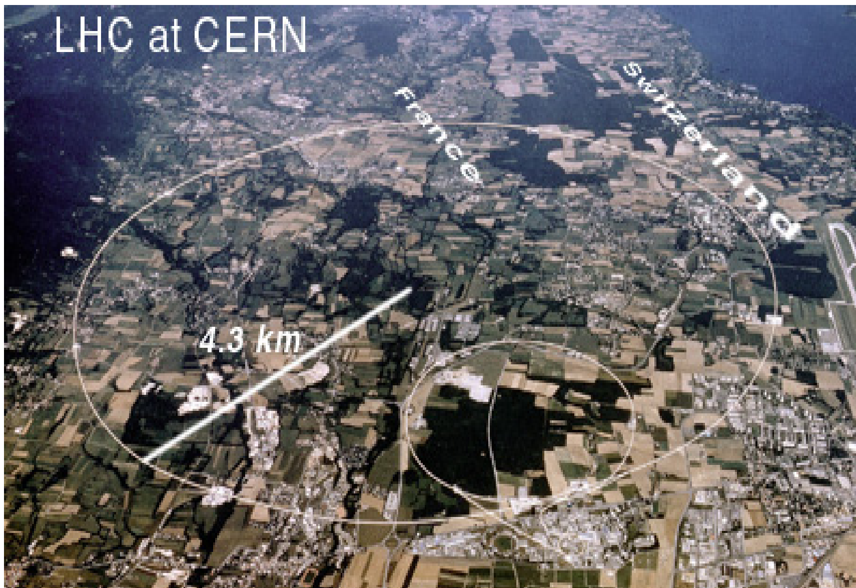


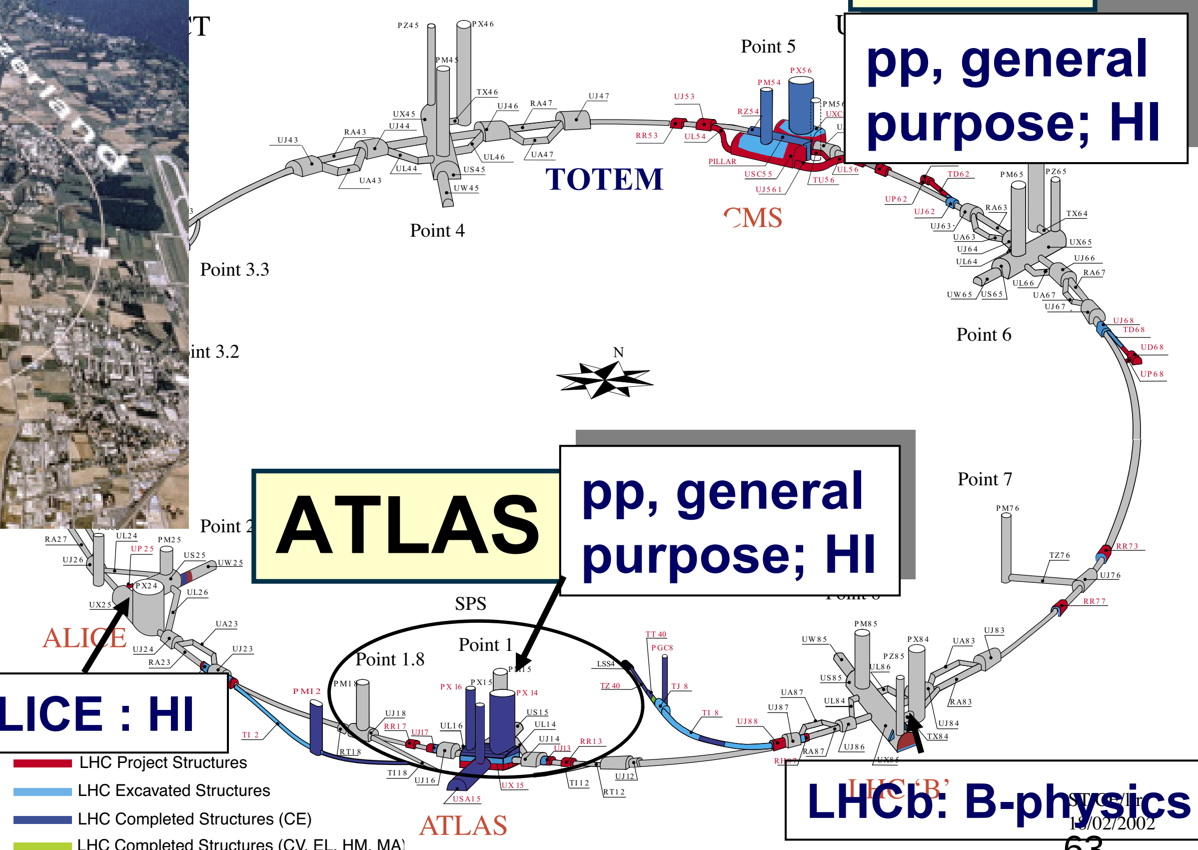
	155	160	165	170	175	180	185	190	195	200
Expected	1.7	1.3	1.2	1.4	1.7	2.0	2.8	3.3	4.2	4.6
Observed	1.7	1.4	1.2	1.0	1.3	1.6	2.5	3.3	4.8	5.1

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

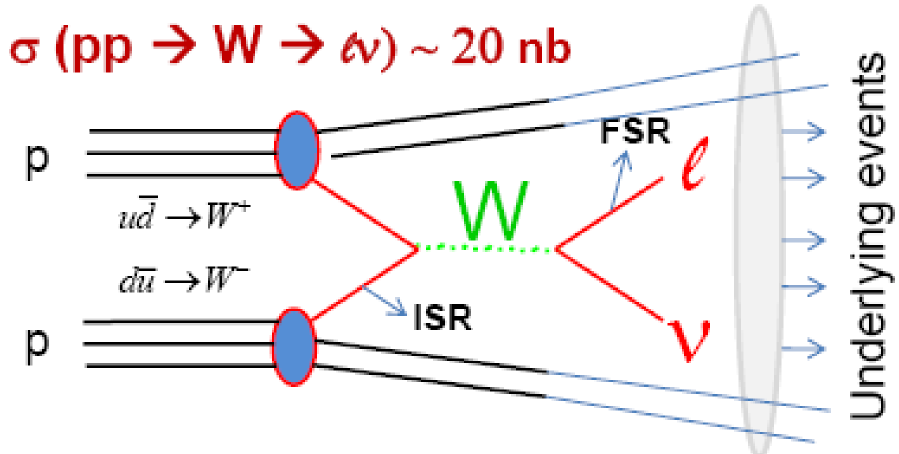
First p-beam: Sept. 10, 2008

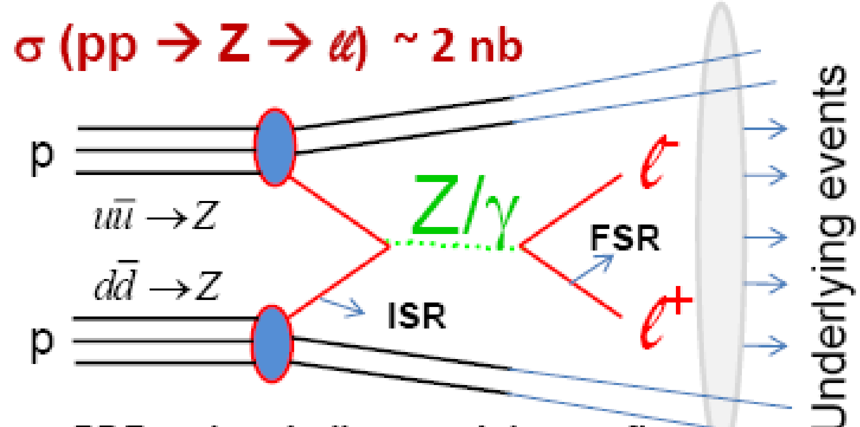
Physics Reach as Integrated Lumi. Increase

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

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





PDF and underline need data to fit

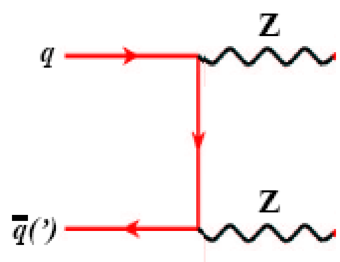
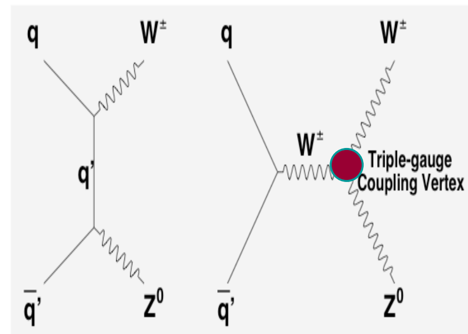
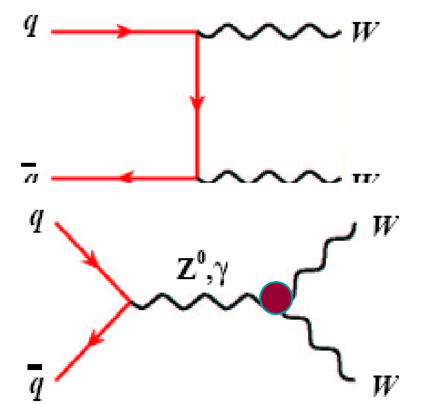
Standard W Candle

- $\sigma(W \to \mu\nu)$ 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

- $\sigma(Z \to \mu\mu)$ 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. $(\varepsilon_{Trigger}, \varepsilon_{ID}, \varepsilon_{Isolation} \ldots)$
  - Tag-Probe method
- Searches: dilepton inv. high mass

Di-Boson Analysis – Physics Motivation

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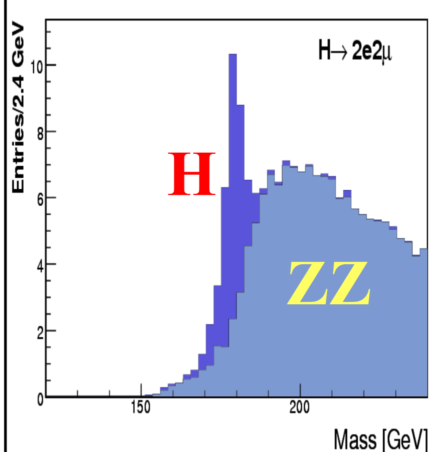
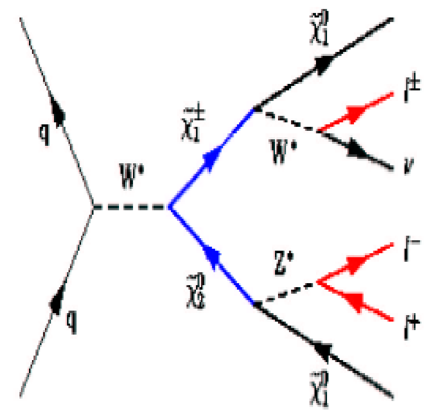
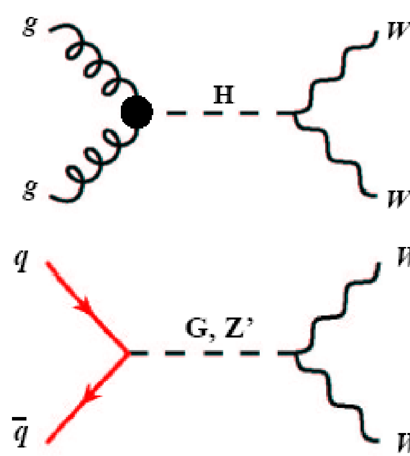
<tr><td>Discovery
H→ WW, ZZ
SUSY
Z'→ WW
G → WW
ρ_T→ ZW</td><td>
</td><td>

SUSY signal</td><td>
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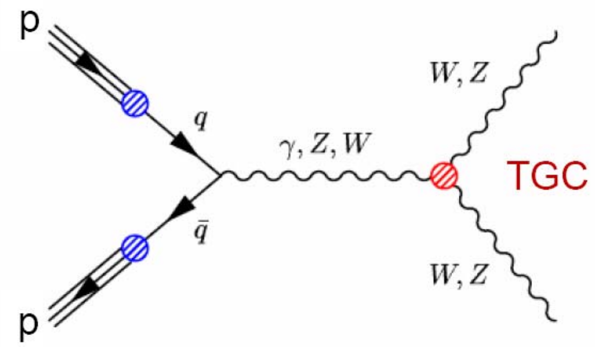
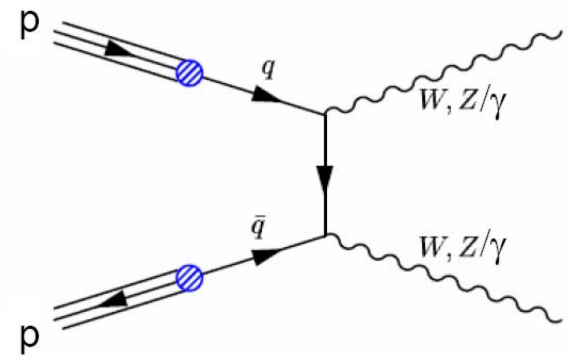
Physics Motivations - Diboson

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

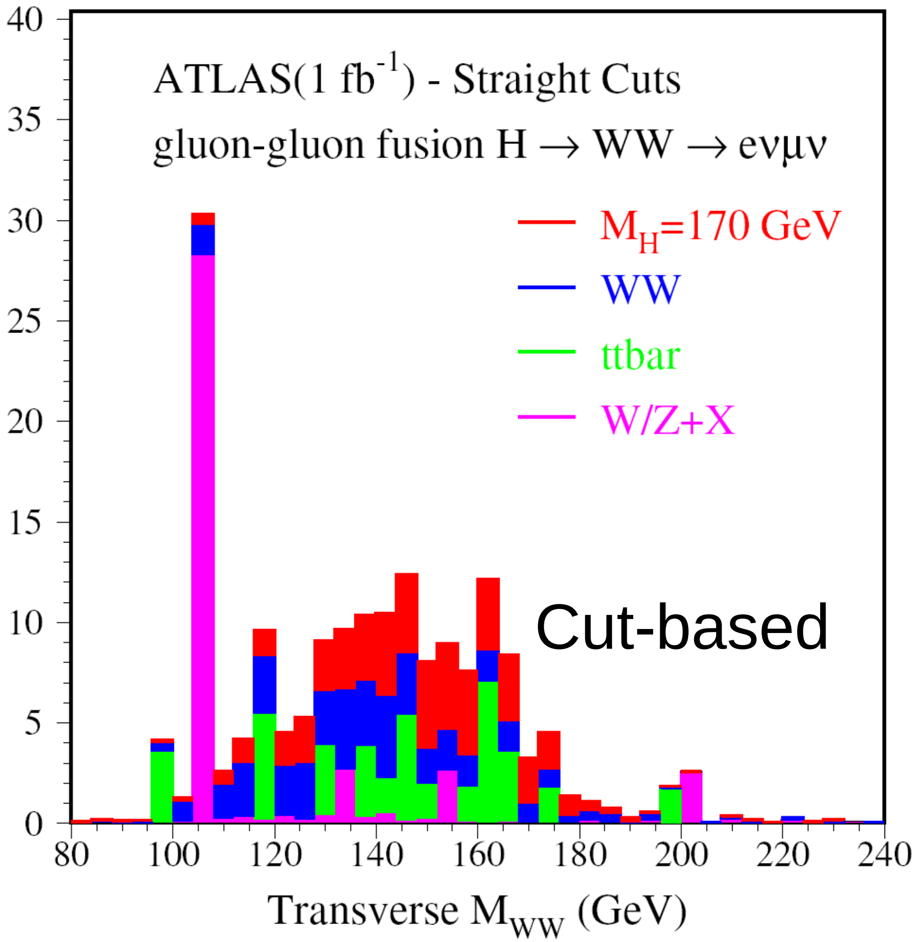
Diboson Production Cross Sections

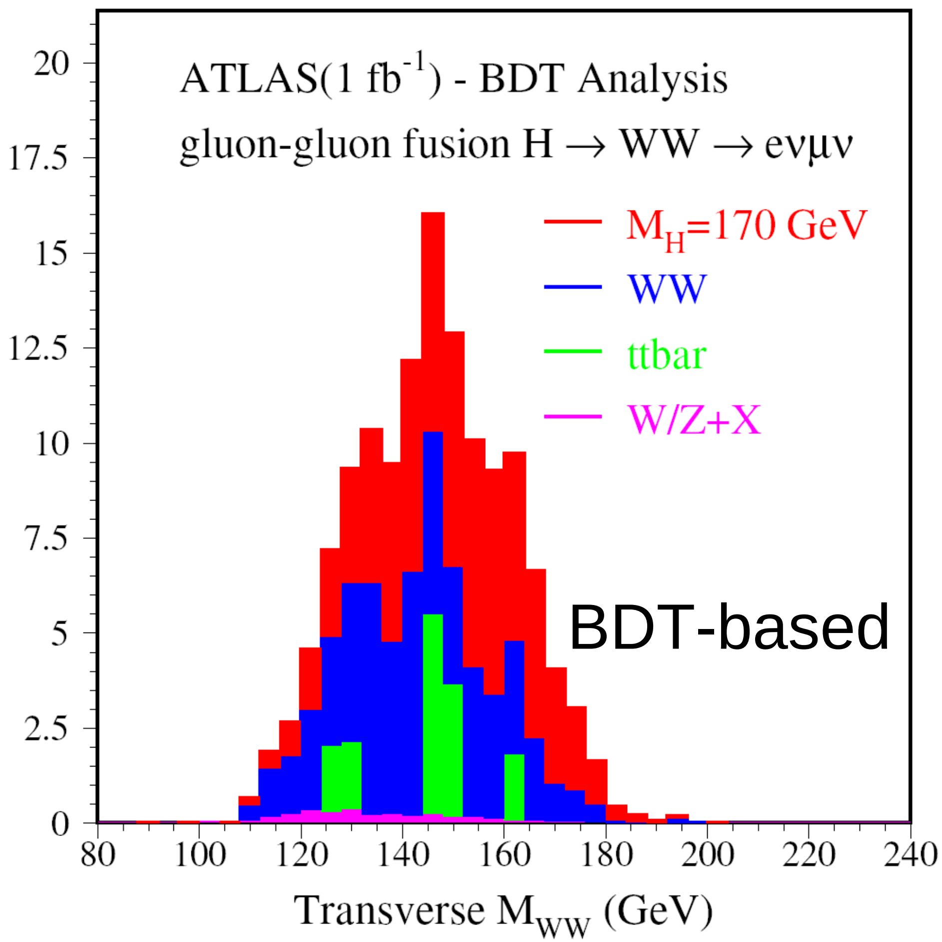
Diboson mode	Conditions	$\sqrt{s} = 1.96$ TeV $\sigma[pb]$	$\sqrt{s} = 14$ TeV $\sigma[pb]$
W^+W^- [14]	W-boson width included	12.4	111.6
$W^\pm Z^0$ [14]	Z and W on mass shell	3.7	47.8
Z^0Z^0 [14]	Z's on mass shell	1.43	14.8
$W^\pm\gamma$ [15]	$E_T^\gamma > 7$ GeV, $\Delta R(\ell,\gamma) > 0.7$	19.3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

Results (1/fb): Straight Cuts vs BDT





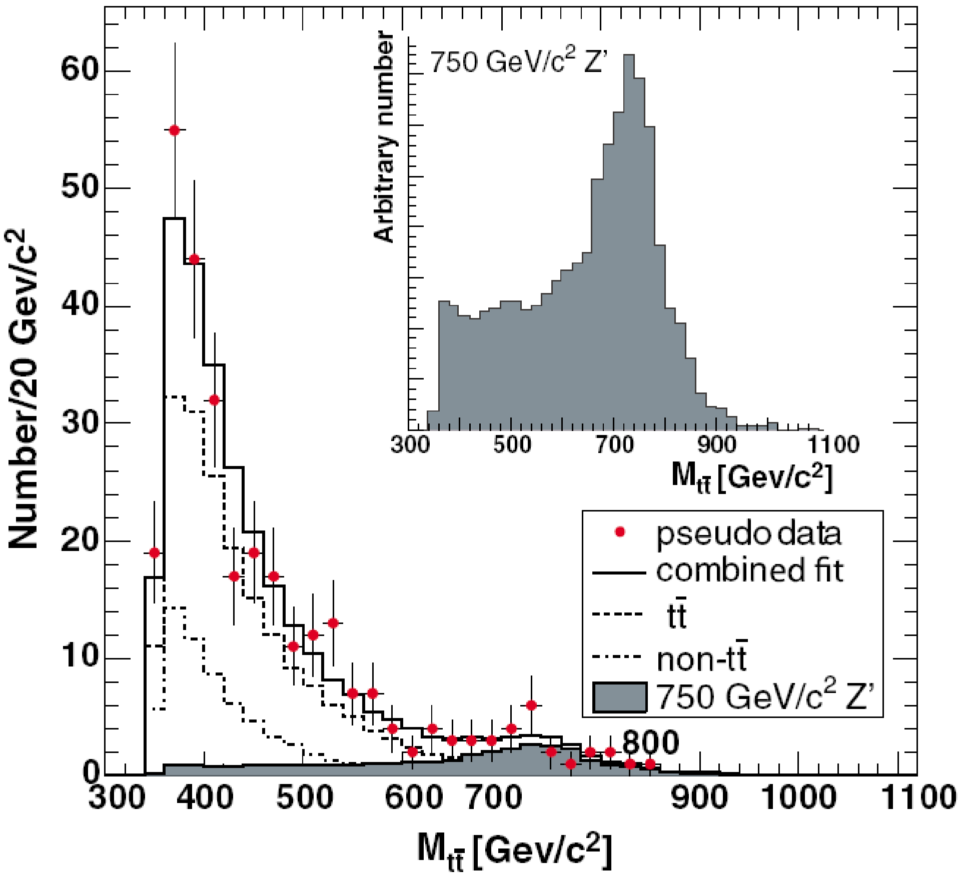
H → WW Detection Sensitivity (1/fb, with 20% systematic error)

GGF H→WW Events / fb	M_H=150 GeV	M_H=165 GeV	M_H=170 GeV	M_H=175 GeV	M_H=180 GeV	Bkgd
Cuts (ee+μμ+eμ)	**58.9**	**110.6**	**93.5**	**80.8**	**65.7**	**352.0**
$N_s / \sqrt{N_b + (0.2*N_b)^2}$ **Cuts (ee+μμ+eμ)**	**0.8**	**1.5**	**1.3**	**1.1**	**0.9**	**N/A**
$N_s / \sqrt{N_b + (0.2*N_b)^2}$ **Cuts (eμ)**	**1.0**	**1.9**	**1.6**	**1.4**	**1.1**	**N/A**

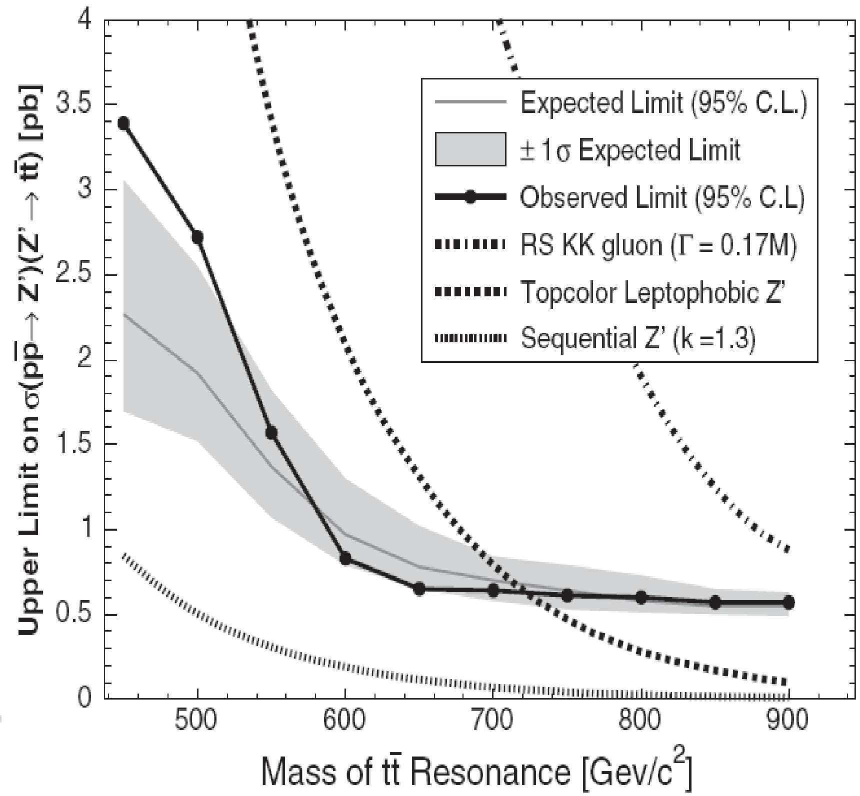
BDT (ee+μμ+eμ)	**70.4**	**139.2**	**123.8**	**109.3**	**90.2**	**218.2**
$N_s / \sqrt{N_b + (0.2*N_b)^2}$ **BDT (ee+μμ+eμ)**	**1.5**	**3.0**	**2.7**	**2.4**	**2.0**	**N/A**
$N_s / \sqrt{N_b + (0.2*N_b)^2}$ **BDT (eμ)**	**2.0**	**4.1**	**3.7**	**3.3**	**2.6**	**N/A**

Search for Z’→ $t\bar{t}$ at CDF

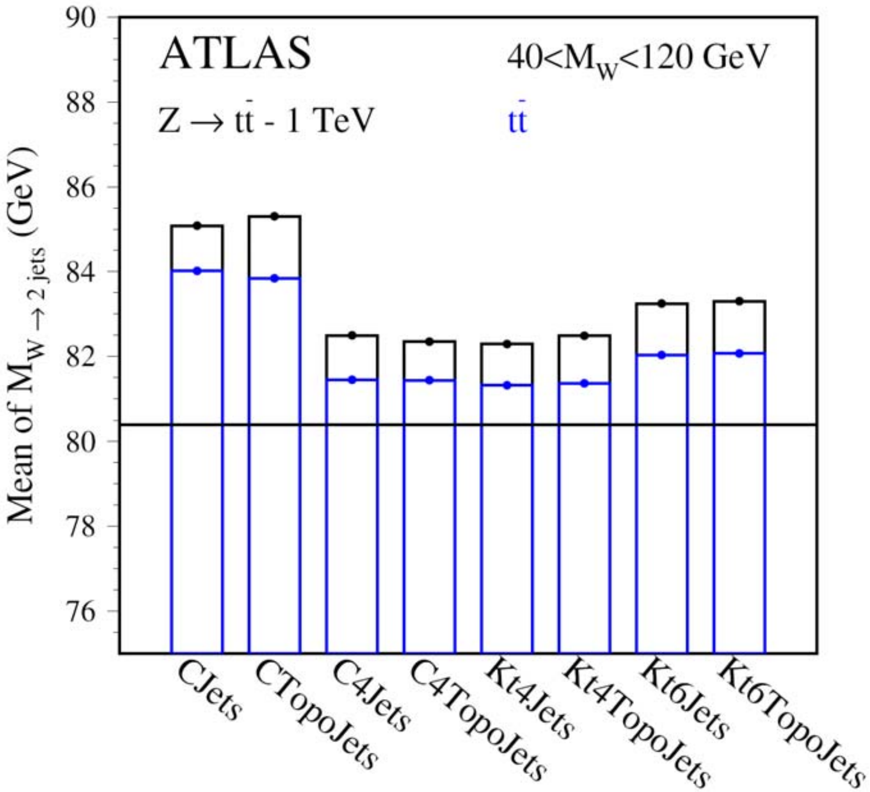
PHYSICAL REVIEW D **77**, 051102(R) (2008)

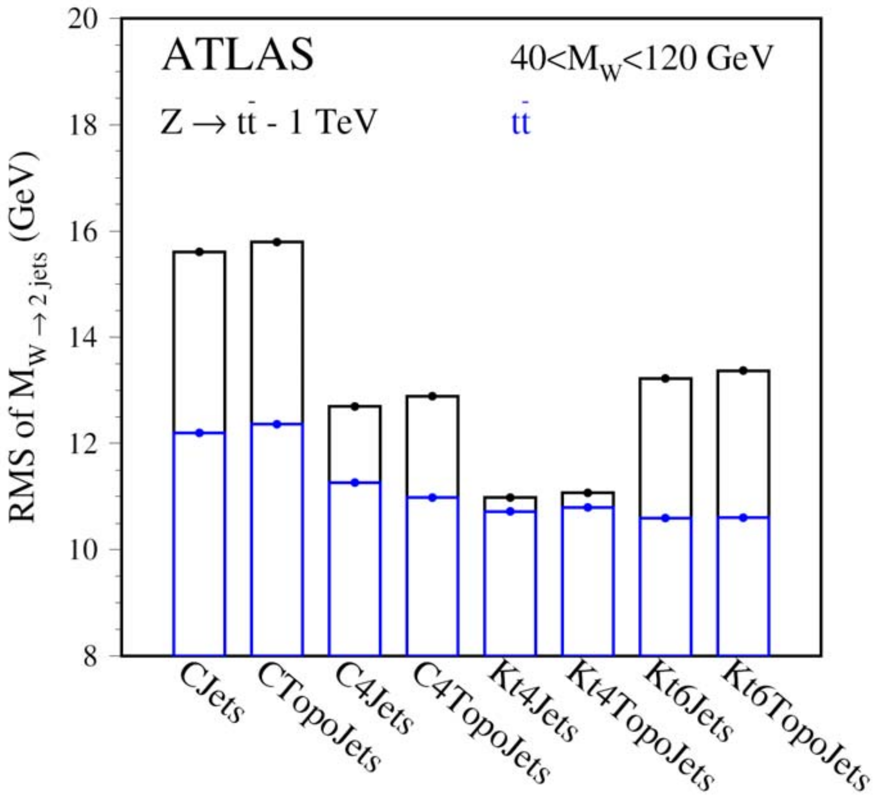


σ_{tt} = 7.8 $\pm$ 0.7 pb



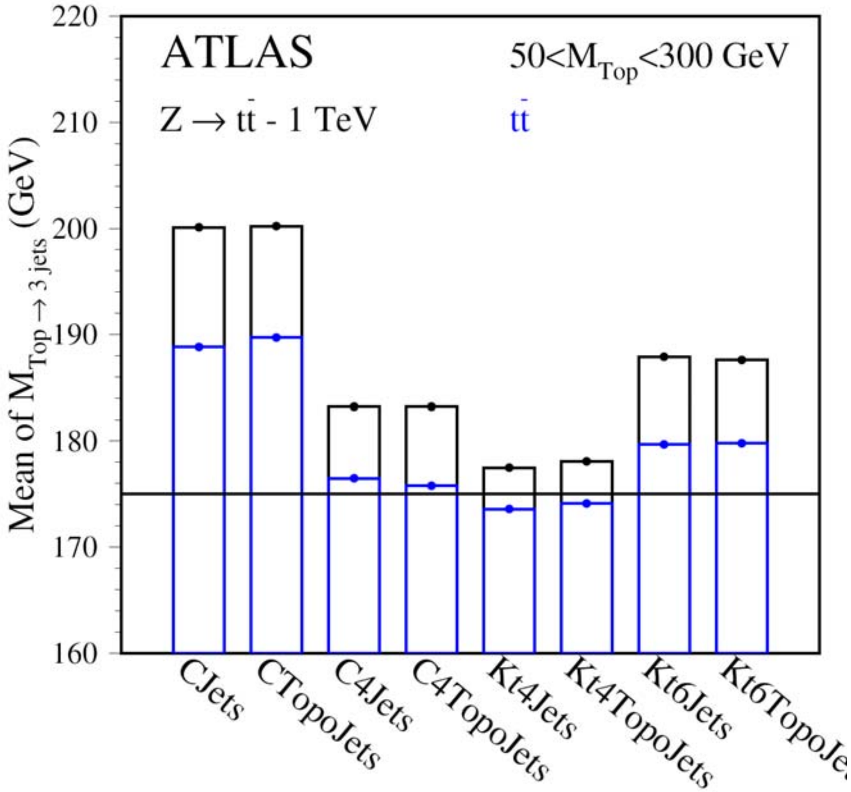
Mass Reconstruction of W → jj

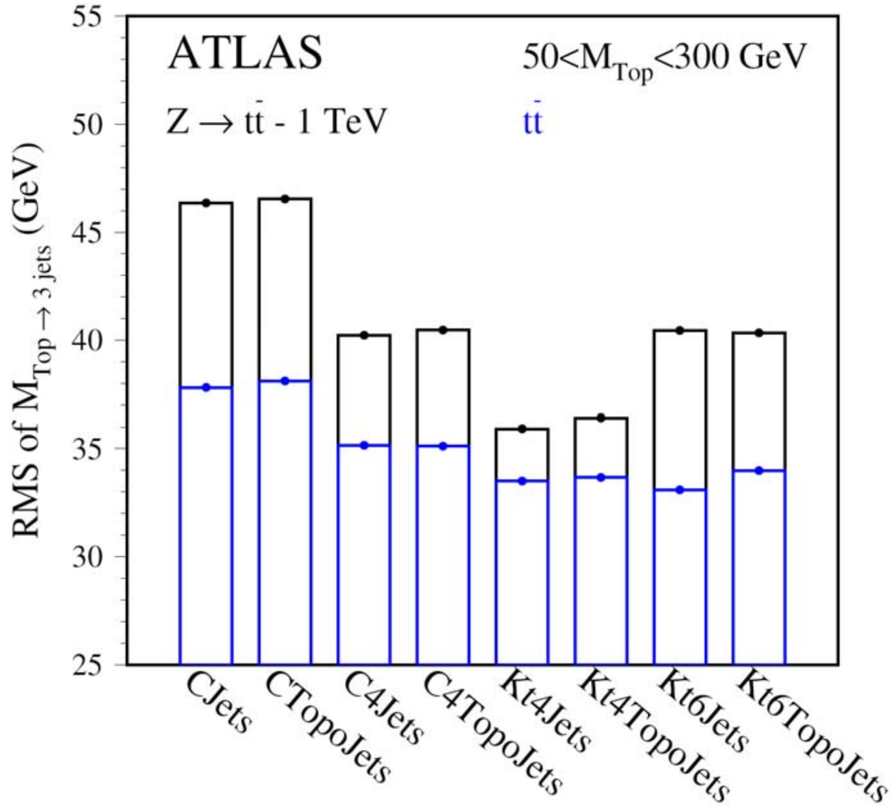




RMS of M_W ~ 11 GeV

Mass Reconstruction of Top → bjj





RMS of M_{Top} ~ 36 GeV

W / Top Mass Reconstruction

- 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_{top}<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