Search for New Physics at Present & Near Future

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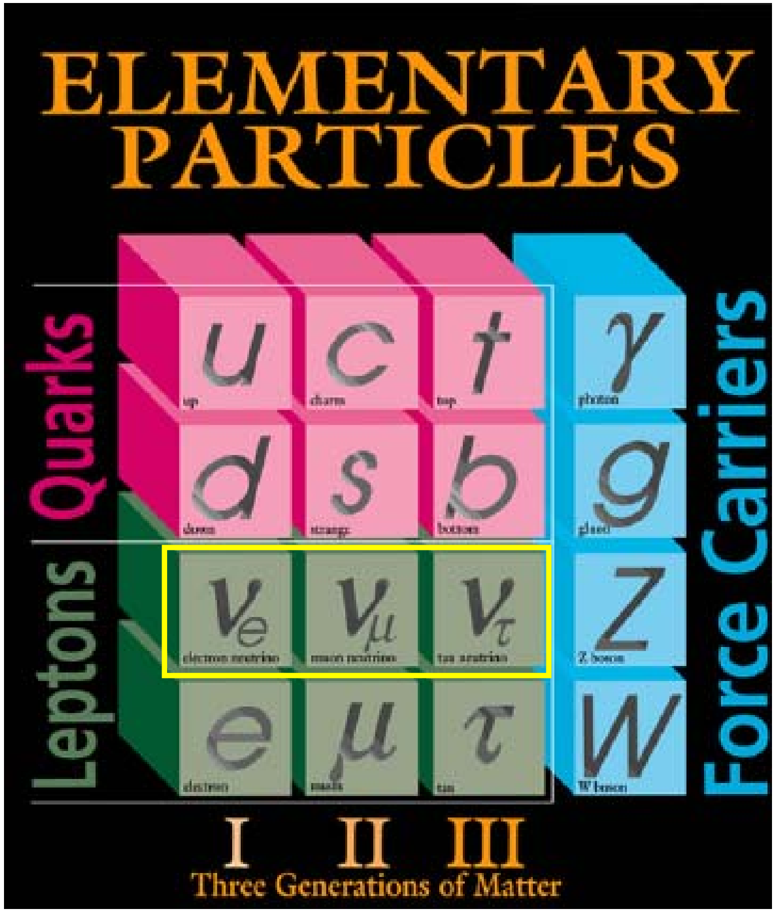
Outline

- New physics in the neutrino sector
  - – Introduction
  - – Neutrino oscillations
  - – Anomaly signature in LSND – new physics ?
  - – **MiniBooNE** neutrino experiment and results
- Explore new physics at energy frontier - LHC
  - – ATLAS physics analysis 'commissioning'
  - – Search for new physics with diboson final states
    - Direct search – Higgs → WW
    - Indirect search – anomalous triple-gauge-boson couplings

Standard Model



Higs Mechanism
– Spontaneously break electroweak symmetry
– Generate masses

- **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.**

- **Neutrinos – new physics in the past and present**
- Mystery of missing energy in β-decay

  –> Pauli postulated existence of ν (1930)
- Theory on β-decay by Fermi (1934)
- Experimental discoveries of neutrinos:
  - 1956 - ν_e discovery (nuclear reactor)
  - 1962 - ν_μ discovery at BNL
  - 2000 - ν_τ discovery at Fermilab
  - 1991 - three neutrino flavors from Z-decays (LEP)
- Standard Model of particle physics ~ 1970
  - Neutrinos are elementary particles
  - Neutrinos are massless in SM
  - Neutrinos are left-handed
  - Neutrinos only involve in weak interactions

Neutrinos Oscillations (beyond SM)

- Mystery of 'missing' solar neutrinos (1968)
  - Only about 35% of electron neutrino from sun was detected on earth
  - Homestake Experiment (Raymond Davis, Jr. and John N. Bahcall)
- Neutrino oscillation hypothesis

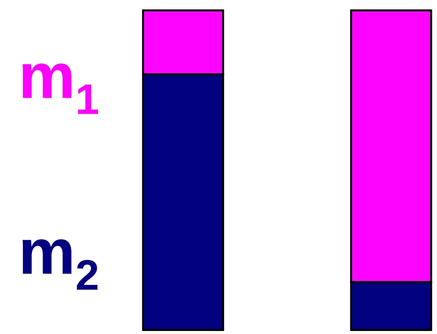
Flavor eigenstates Mass eigenstates

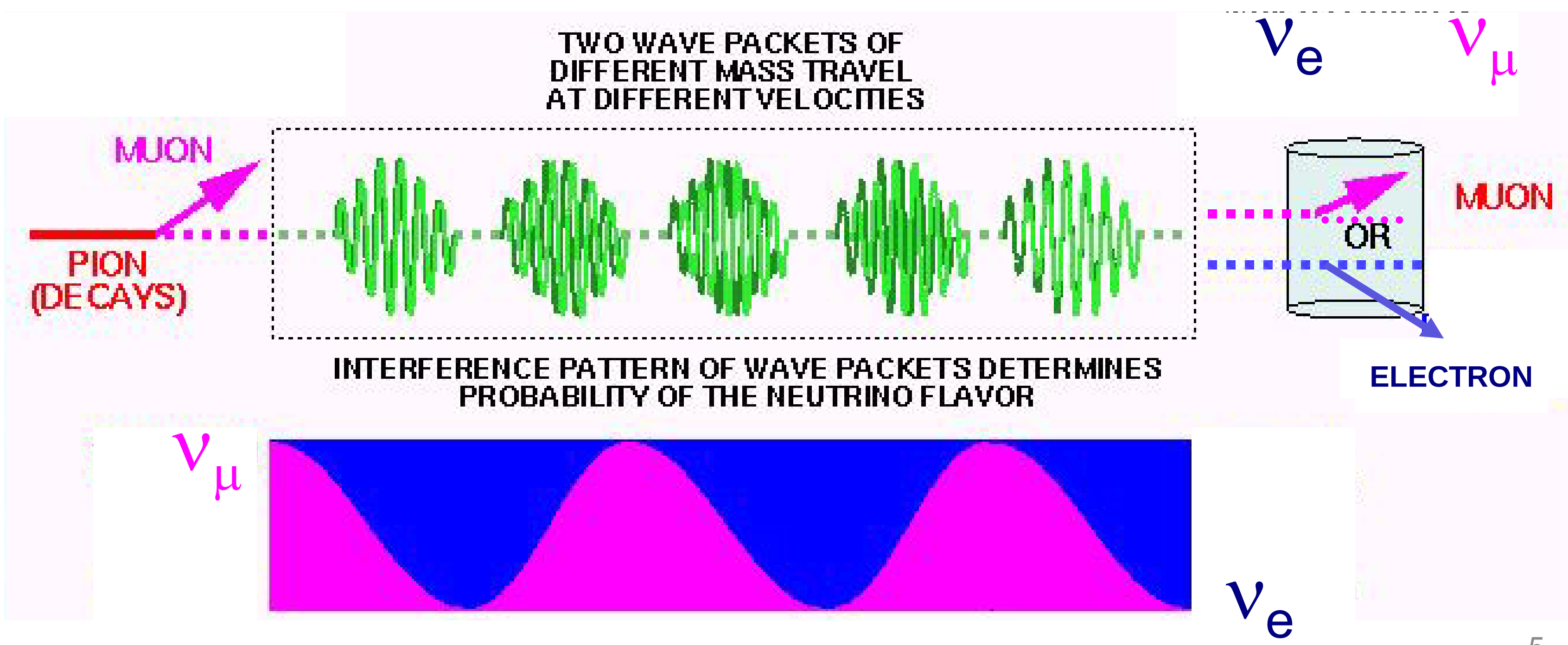
$$\begin{pmatrix} \nu_e \\ \nu_\mu \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} m_1 \\ m_2 \end{pmatrix}$$

(For 3 ν flavors mixing, it needs 3×3 unitary matrix with CP-violating phase.)

Neutrino Oscillations (2 flavors)

Neutrino flavor states are comprised of mass states





Neutrino Oscillations Probability

Δm^2 is the difference of the squared masses of the two neutrino states (eV^2)

Distance from neutrino beam creation point to detection point (m)

$$P_{osc} = \sin^2 2\theta \, \sin^2 \left(\frac{1.27 \, \Delta m^2 \, L}{E} \right)$$

θ is the mixing angle

E is the energy of the neutrino (MeV)

Neutrino Oscillation Measurements

➔ Solar Neutrino Oscillation (Homestake, GALLEX, SAGE, Kamiokande-II, Super-K, SNO etc.), confirmed by KamLAND (reactor beam)

$$\Delta m^2_{21} = \Delta m^2_{\rm sol} = 8.0^{+0.6}_{-0.4} \cdot 10^{-5}{\rm eV}^2$$

$$\tan^2(\theta_{12}) = 0.45^{+0.09}_{-0.07} \qquad \theta_{12} = \theta_{\rm sol} = 33.9°^{+2.4°}_{-2.2°}$$

➔ Atmospheric Neutrino Oscillation (IMB,MARCO,Soudan, Kamiokande-II, Super-K etc.), confirmed by K2K, MINOS (accelerator beam)

$$\Delta m^2_{31} \approx \Delta m^2_{32} = \Delta m^2_{\rm atm} = 2.4^{+0.6}_{-0.5} \cdot 10^{-3}{\rm eV}^2$$

$$\sin^2(2\theta_{23}) = 1^{+0}_{-0.1} \qquad \theta_{23} = \theta_{\rm atm} = 45 \pm 7°$$

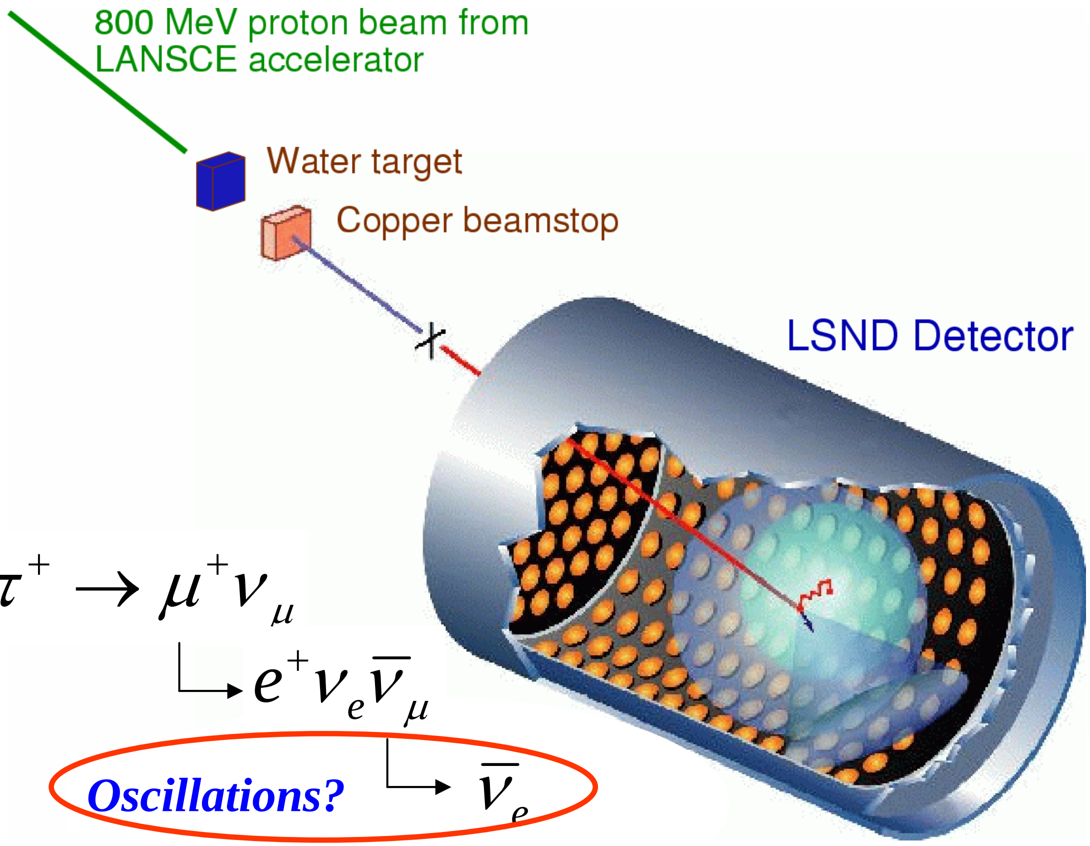
➔ Chooz (reactor beam)

future exp., Double Chooz, Daya Bay(reactor), NOvA, T2K(accelerator)

$$\sin^2(2\theta_{13}) < 0.12 \ (10^{\rm o})$$

The LSND Experiment (1993-1998)

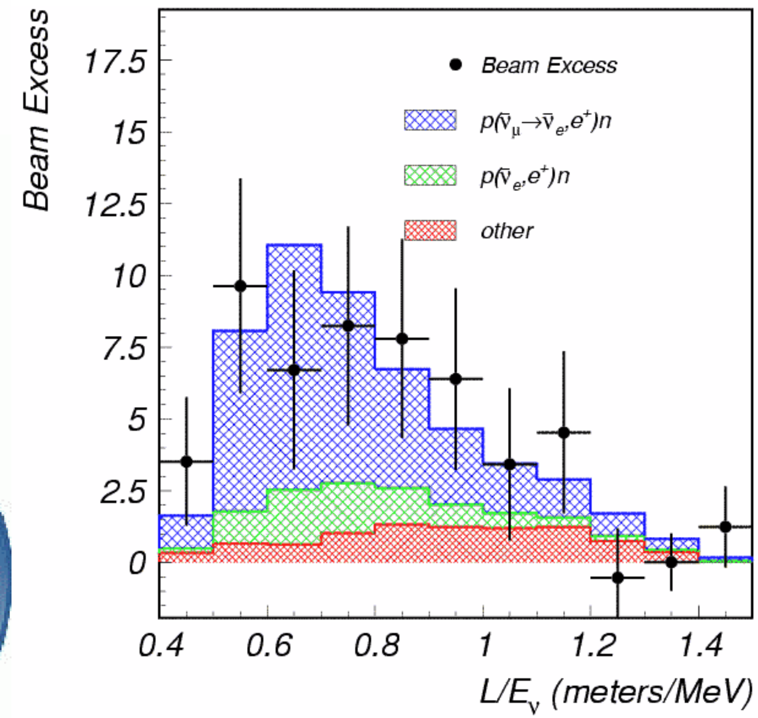
$$P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) = \sin^2(2\theta)\sin^2\left(\frac{1.27\,L\Delta m^2}{E}\right) = (0.264 \pm 0.067 \pm 0.045)\%$$



$$\pi^+ \rightarrow \mu^+ \nu_\mu$$

$$\hookrightarrow e^+ \nu_e \bar{\nu}_\mu$$

$$\hookrightarrow \bar{\nu}_e$$

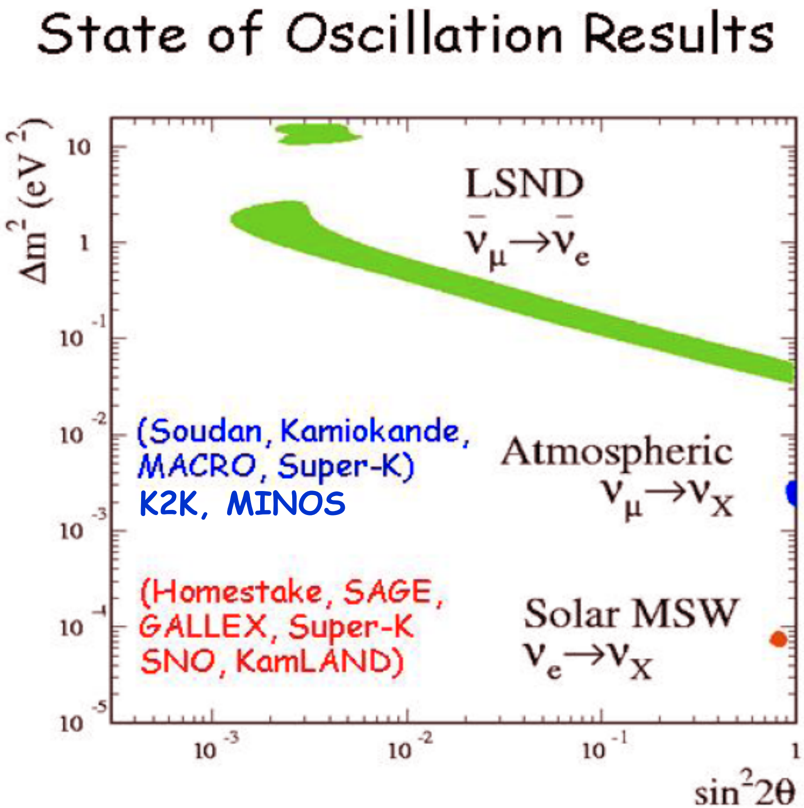


Signal: $\bar{\nu}_e$ p $\rightarrow$ e$^+$ n

n p $\rightarrow$ d γ(2.2MeV)

an oscillation signal(~3.8σ)

LSND Signal – Anomalous Oscillation



➔ Simplest model has three Neutrino mass eigenstates,

$\Delta m^2_{21} + \Delta m^2_{32} = \Delta m^2_{31}$

➔ Data indicates 3 mass differences

$\Delta m^2_{atm} \sim 2.4 \times 10^{-3}\ eV^2$

$\Delta m^2_{sol} \sim 8 \times 10^{-5}\ eV^2$

$\Delta m^2_{lsnd} \sim 0.1 \sim 2\ eV^2$

$\Delta m^2_{atm} + \Delta m^2_{sol} \neq \Delta m^2_{lsnd}$

➔ If the LSND signal does exist, it may imply new physics beyond SM.

LSND Signal: New Physics?

The MiniBooNE Experiment

- Proposed in 1998，operating since 2002
- The goal of the MiniBooNE Experiment:
  - confirm or exclude the LSND result
  - extend the explored oscillation parameter space

An order of magnitude higher energy (~500 MeV) than LSND (~30 MeV)

An order of magnitude longer baseline (~500 m) than LSND (~30 m)

MiniBooNE and LSND have similar L/E, but have different signal, background and systematics.

MiniBooNE has more neutrino events

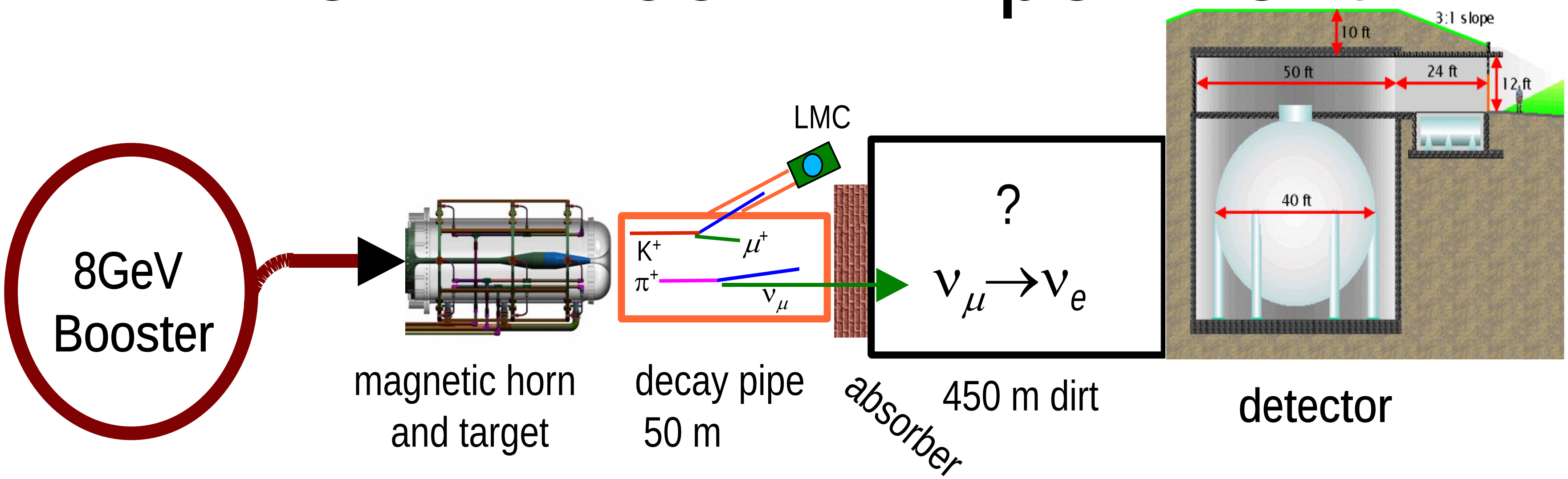
The MiniBooNE Collaboration

A. A. Aguilar-Arevalo, A. O. Bazarko, S. J. Brice, B. C. Brown, L. Bugel, J. Cao, L. Coney, J. M. Conrad, D. C. Cox, A. Curioni, Z. Djurcic, D. A. Finley, B. T. Fleming, R. Ford, F. G. Garcia, G. T. Garvey, J. A. Green, C. Green, T. L. Hart, E. Hawker, R. Imlay, R. A. Johnson, P. Kasper, T. Katori, T. Kobilarcik, I. Kourbanis, S. Koutsoliotas, J. M. Link, Y. Liu, Y. Liu, W. C. Louis, K. B. M. Mahn, W. Marsh, P. S. Martin, G. McGregor, W. Metcalf, P. D. Meyers, F. Mills, G. B. Mills, J. Monroe, C. D. Moore, R. H. Nelson, P. Nienaber, S. Ouedraogo, R. B. Patterson, D. Perevalov, C. C. Polly, E. Prebys, J. L. Raaf, H. Ray, B. P. Roe, A. D. Russell, V. Sandberg, R. Schirato, D. Schmitz, M. H. Shaevitz, F. C. Shoemaker, D. Smith, M. Sorel, P. Spentzouris, I. Stancu, R. J. Stefanski, M. Sung, H. A. Tanaka, R. Tayloe, M. Tzanov, M. O. Wascko, R. Van de Water, D. H. White, M. J. Wilking, H. J. Yang, G. P. Zeller, E. D. Zimmerman

2 National Laboratories, 14 Universities, 77 Researchers

University of Alabama
Bucknell University
University of Cincinnati
University of Colorado
Columbia University
Embry Riddle University
Fermi National Accelerator Laboratory
Indiana University
Los Alamos National Laboratory
Louisiana State University
University of Michigan
Princeton University
Saint Mary's University of Minnesota
Virginia Polytechnic Institute
Western Illinois University
Yale University

The MiniBooNE Experiment



- The FNAL Booster delivers 8 GeV protons to the MiniBooNE beamline.
- The protons hit a 71cm beryllium target producing pions and kaons.
- The magnetic horn focuses the secondary particles towards the detector.
- The mesons decay into neutrinos, and the neutrinos fly to the detector, all other secondary particles are absorbed by absorber and 450 m dirt.
- 5.6E20 POT for neutrino mode since 2002.
- Switch horn polarity to run anti-neutrino mode since January 2006.

MiniBooNE Neutrino Flux

8 GeV protons on Be target gives:

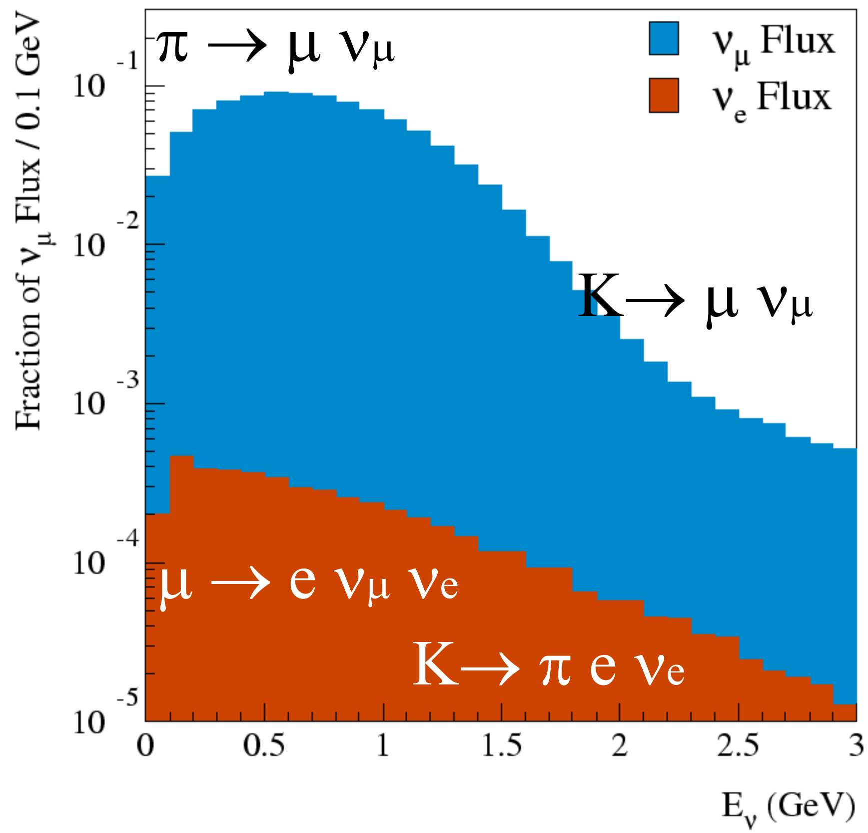
$p + Be \rightarrow \pi^+ , K^+ , K^0_L$

ν_μ beam from:

$\pi^+ \rightarrow \mu^+ \nu_\mu$ $K^+ \rightarrow \mu^+ \nu_\mu$ $K^0_L \rightarrow \pi^- \mu^+ \nu_\mu$

"Intrinsic" $\nu_e + \bar{\nu}_e$ sources:

$\mu^+ \rightarrow e^+ \bar{\nu}_\mu \nu_e$	(52%)
$K^+ \rightarrow \pi^0 e^+ \nu_e$	(29%)
$K^0 \rightarrow \pi e \nu_e$	(14%)
Other	(5%)



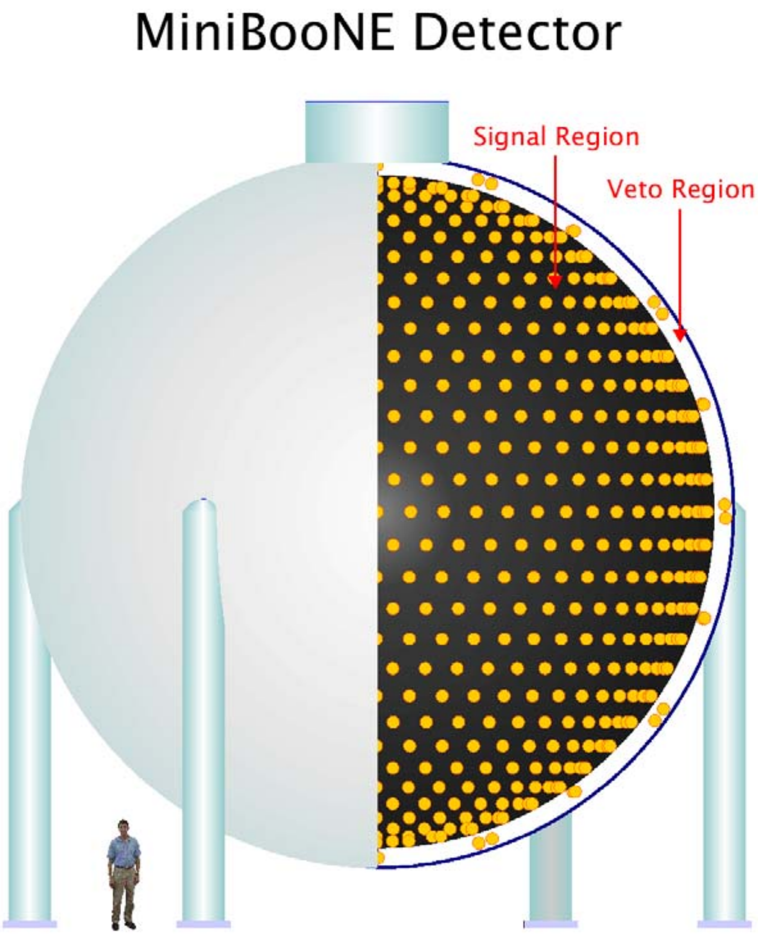
The MiniBooNE searches for ν_e appearance in the pure ν_μ beam.

Antineutrino content: 6%

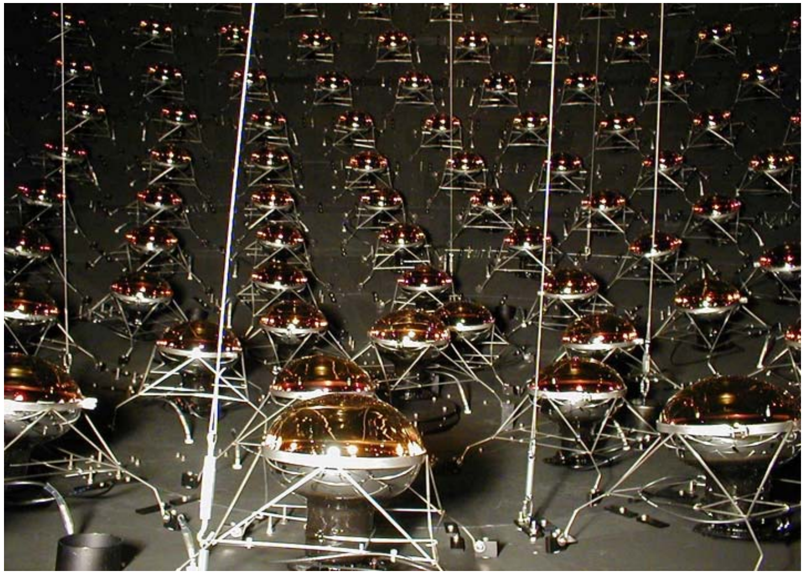
$\nu_e/\nu_\mu = 0.5\%$

LSND: 0.26% oscillation prob.

The MiniBooNE Detector



- 12m diameter tank
- Filled with 800 tons of ultra pure mineral oil
- Optically isolated inner region with 1280 PMTs
- Outer veto region with 240 PMTs.
- 10% PMT coverage



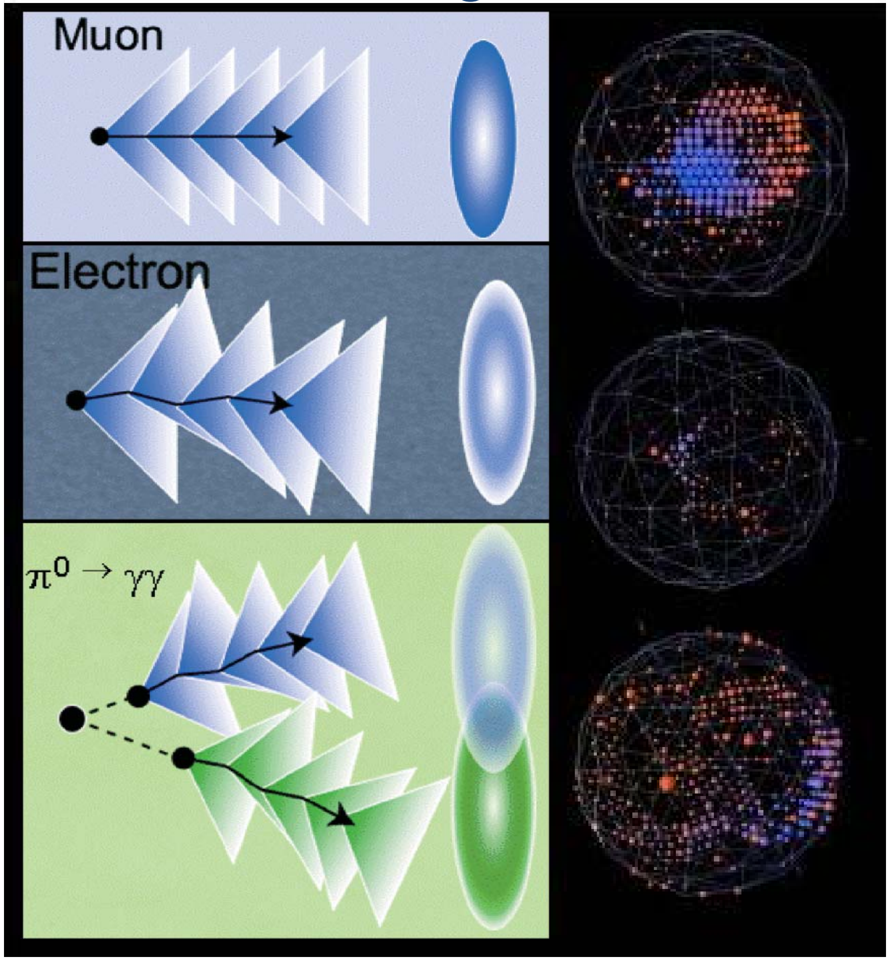
Particle Detections in MiniBooNE

Muons:
Produced in most CC events, MIP, long track.

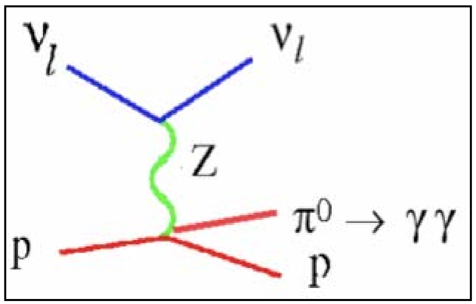
Electrons:
Tag for $\nu_\mu \rightarrow \nu_e$ CCQE signal, multi-scattering, fuzzy ring.

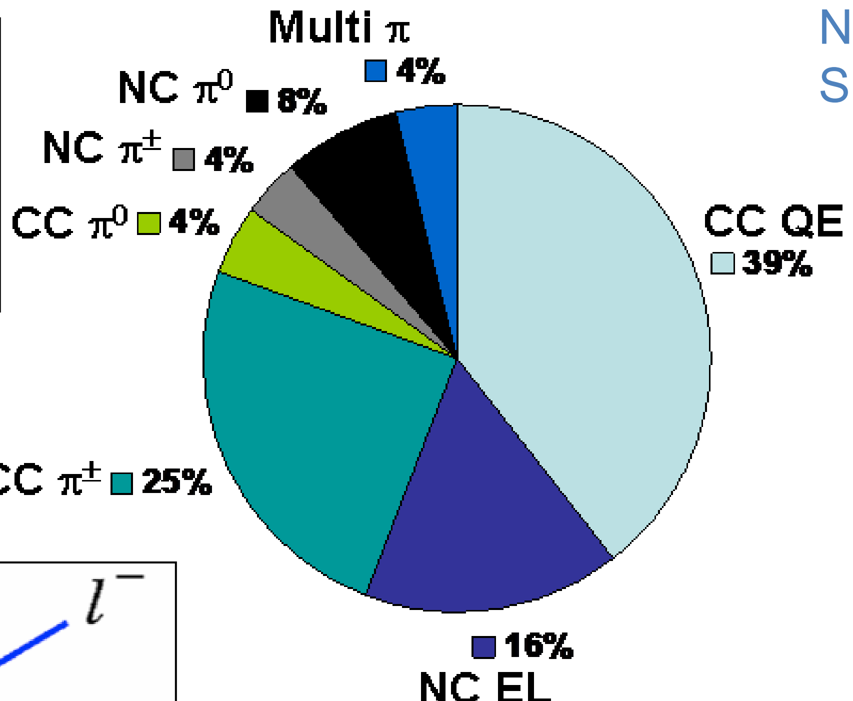
π^0s:
Two fuzzy rings, can form a background if one photon is weak or exits tank.

Cherenkov ring

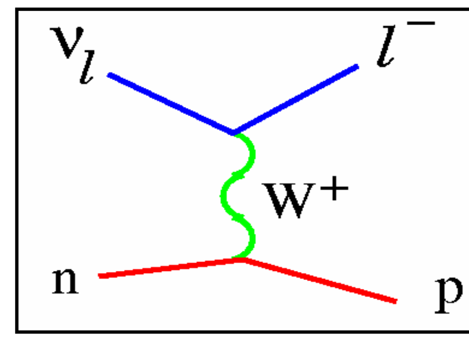


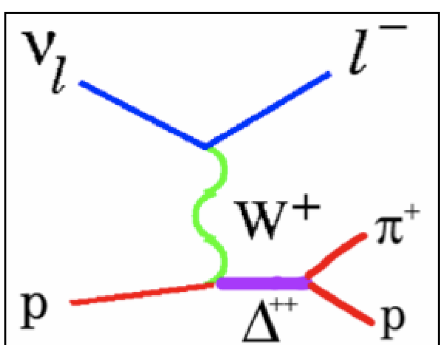
Neutrino Induced Events in MiniBooNE Detector





Neutrino Oscillation Signal (ν_e charge current)



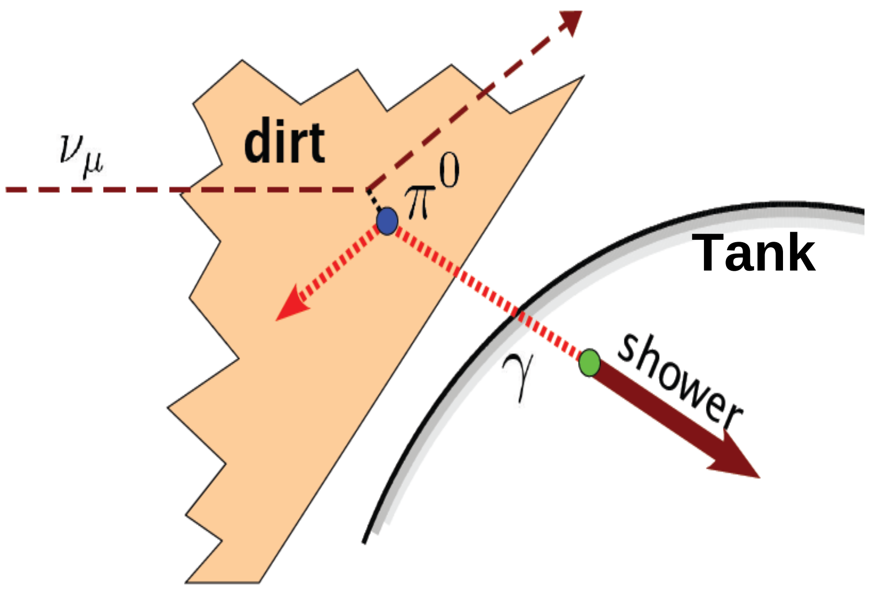


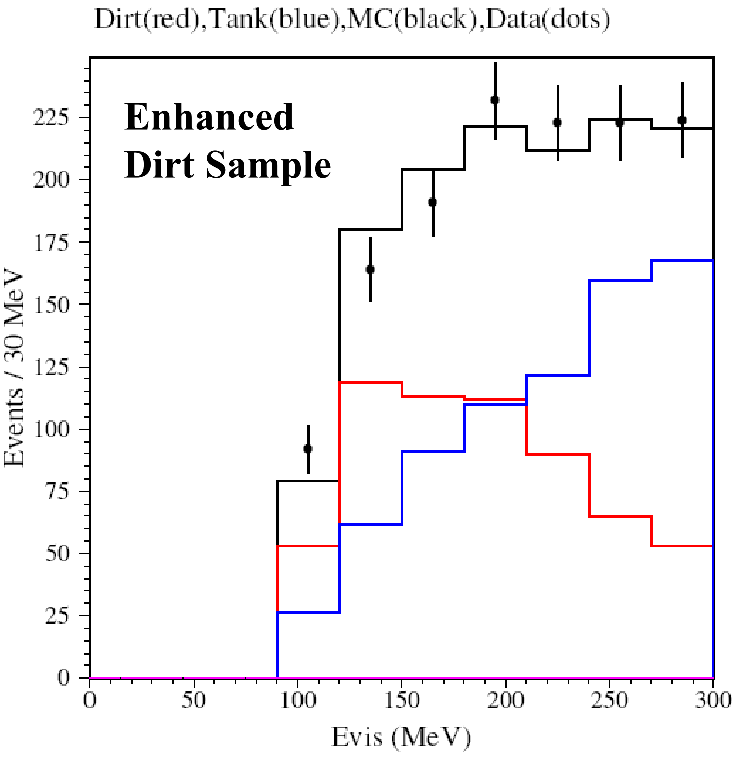
External Sources of Background

Cosmic Rays: measured from out-of-beam data: 2.1 ± 0.5 events

"Dirt" Events:

ν interactions outside of the detector $N_{data}/N_{MC} = 0.99 \pm 0.15$





MiniBooNE Data Analysis

This is a **counting** experiment. The key element of data analysis is to identify electrons, muons and pions in the events. Two complementary methods used in MiniBooNE:

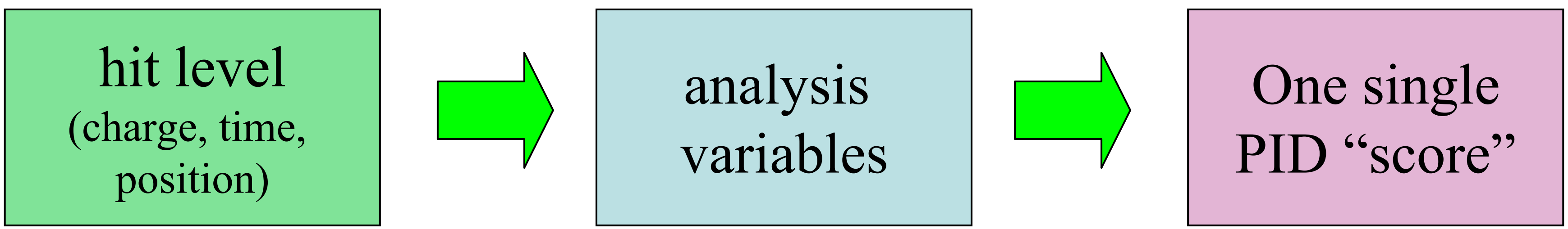
- Log-likelihood technique (Track-Based)
  - Uses detailed, direct reconstruction of particle tracks, and ratio of fit likelihoods to identify particles.
  - With electron, muon or π^0 hypotheses

- **Boosted Decision Trees**
  - Non-linear combination of input variables
  - combine many decision trees to build a powerful discriminate variable to improve signal efficiency.

Boosted Decision Trees

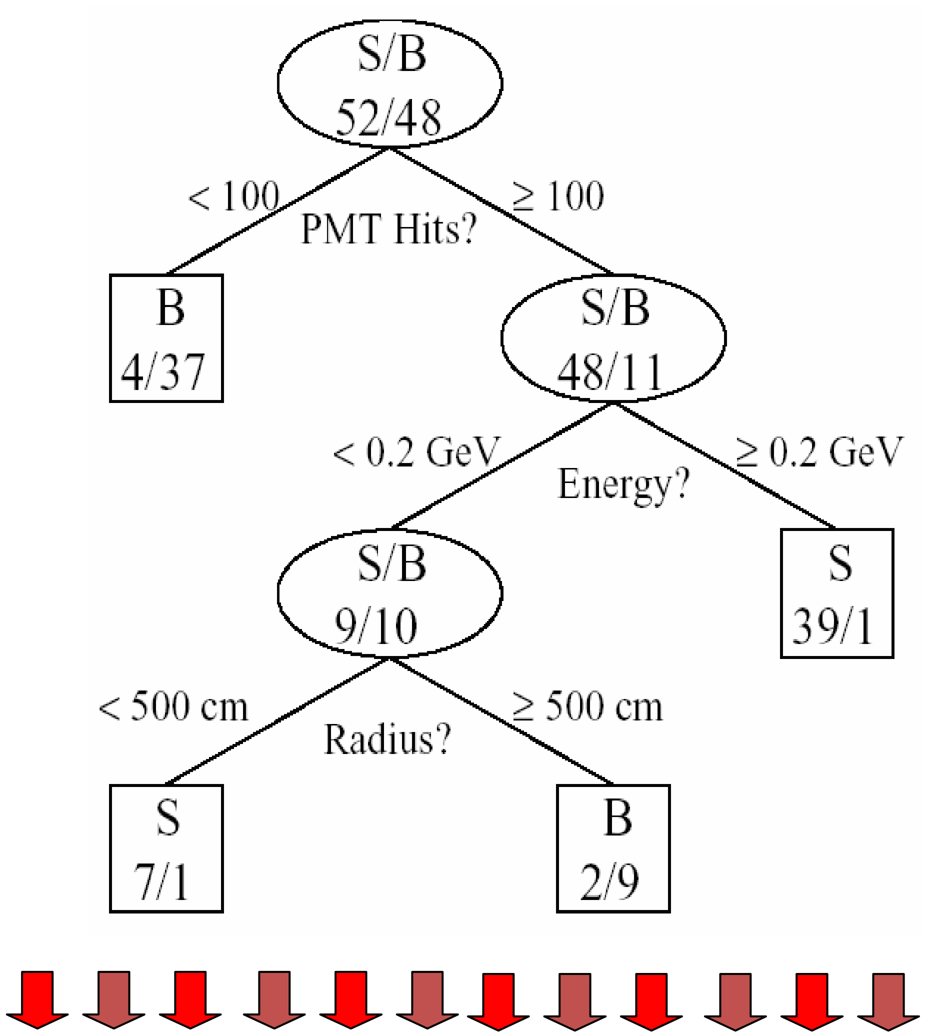
➔Relative new in HEP – MiniBooNE, BaBar, D0(single top discovery), ATLAS
➔Advantages: robust, understand 'powerful' variables, 'not a black box', …

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



Byron P. Roe, Hai-Jun Yang, Ji Zhu et.al., NIM A543 (2005) 577, physics/0408124
Hai-Jun Yang, Byron P. Roe, Ji Zhu, NIM A555 (2005) 370, physics/0508045
Hai-Jun Yang, Byron P. Roe, Ji Zhu, NIM A574 (2007) 342, physics/0610276

Algorithm of the Boosted Decision Trees



This tree is one of many possibilities...

- 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)

A set of decision trees can be developed,

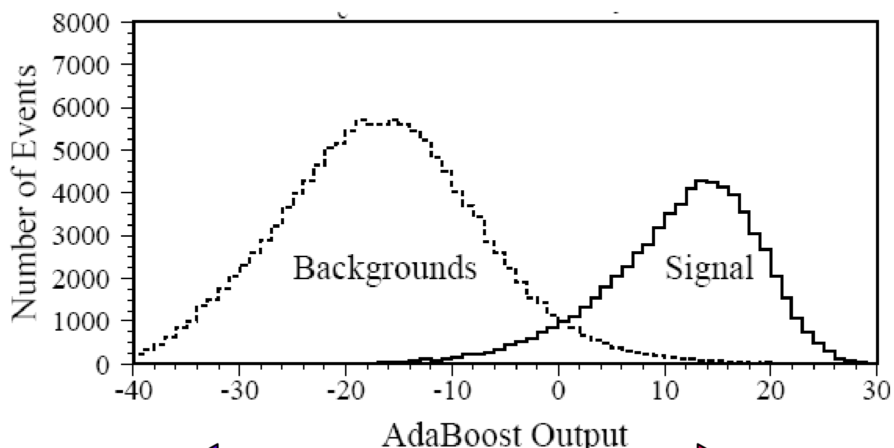
each re-weighting the events to enhance identification of backgrounds misidentified by earlier trees   (“boosting”)

For each tree, the data event is assigned

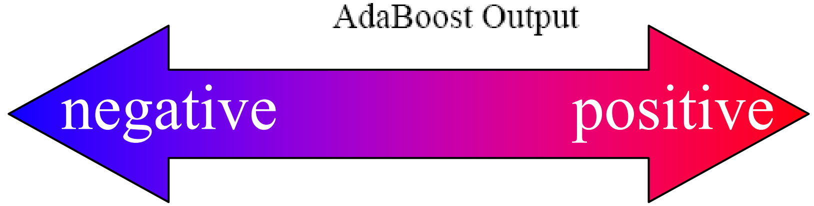
+1 if it is identified as signal,

-1 if it is identified as background.

The total for all trees is combined into a “score”



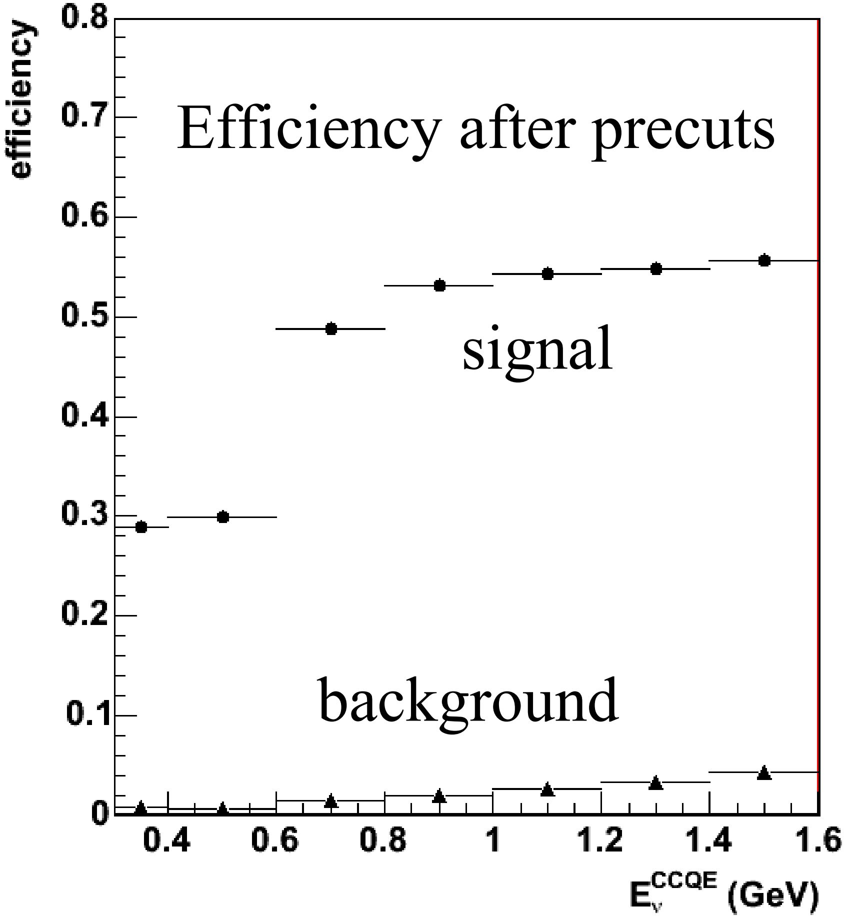
Background-like

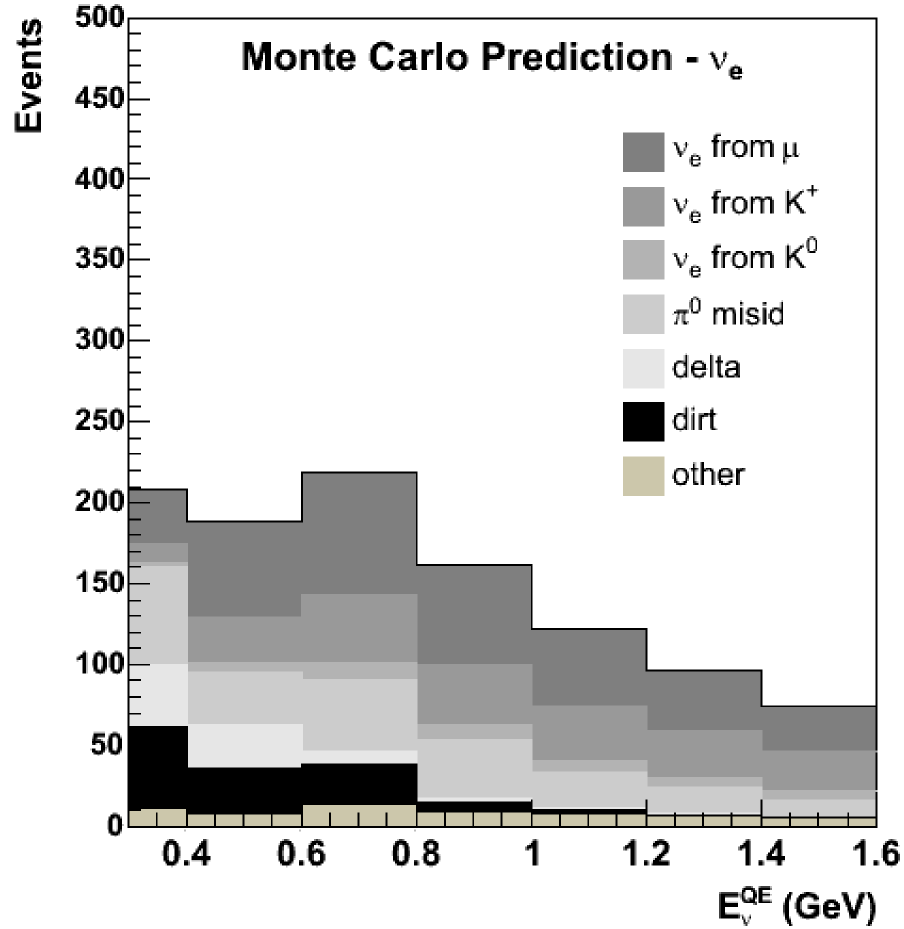


signal-like

BDT Efficiency and backgrounds after cuts:

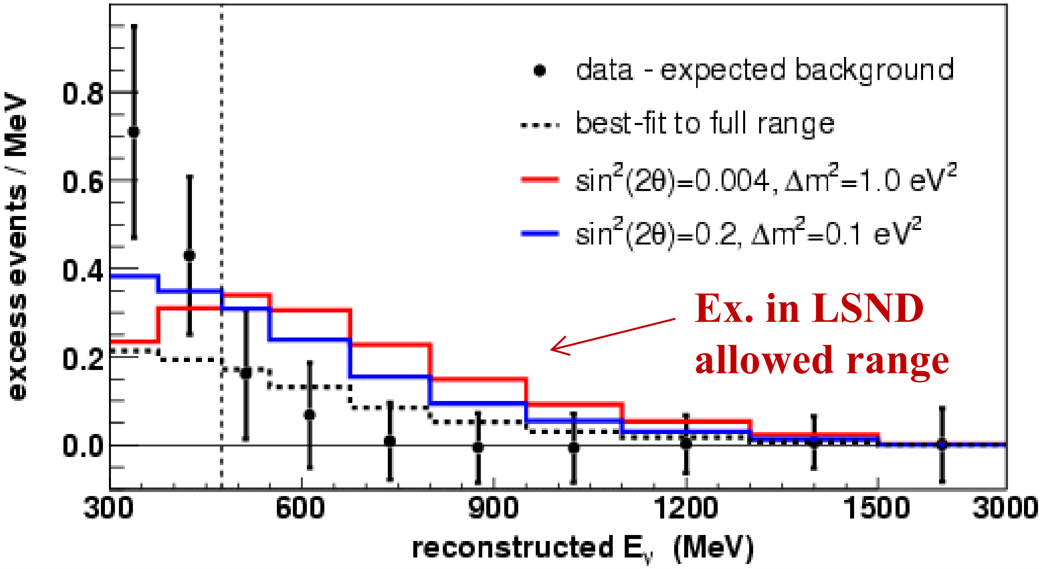
Analysis cuts on PID score as a function of Energy





"One neutrino anomaly has been resolved" by MiniBooNE

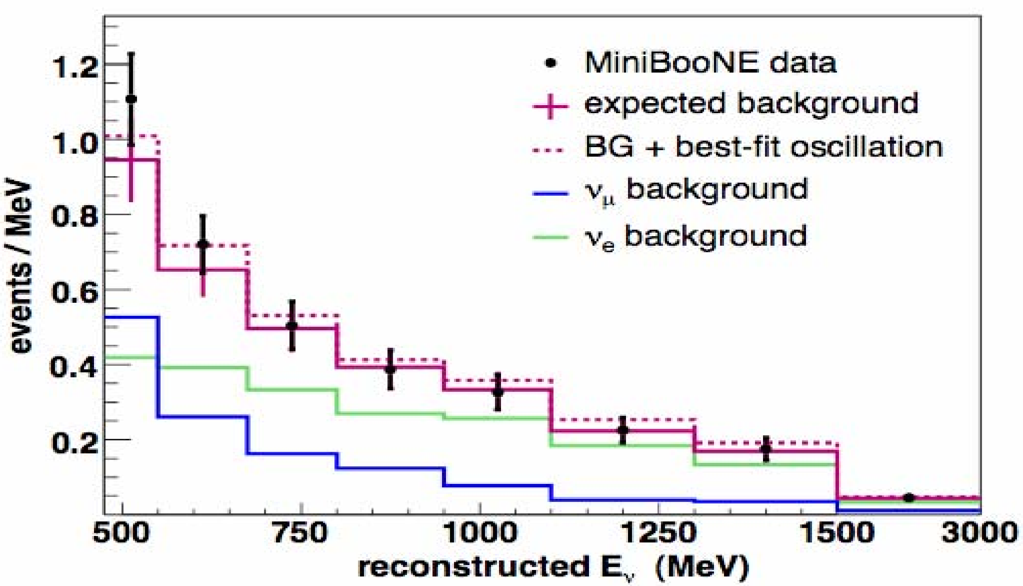
– one of AIP Top Ten Physics News in 2007



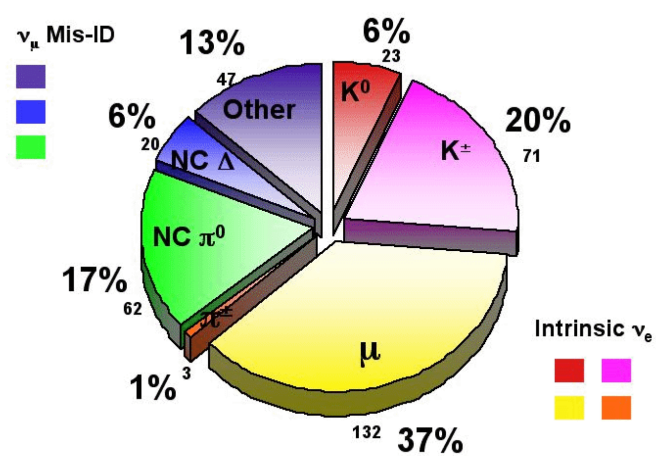
Phys. Rev. Lett. 98, 231801

Low E excess cannot be explained with $\nu_\mu \rightarrow \nu_e$ oscillation!

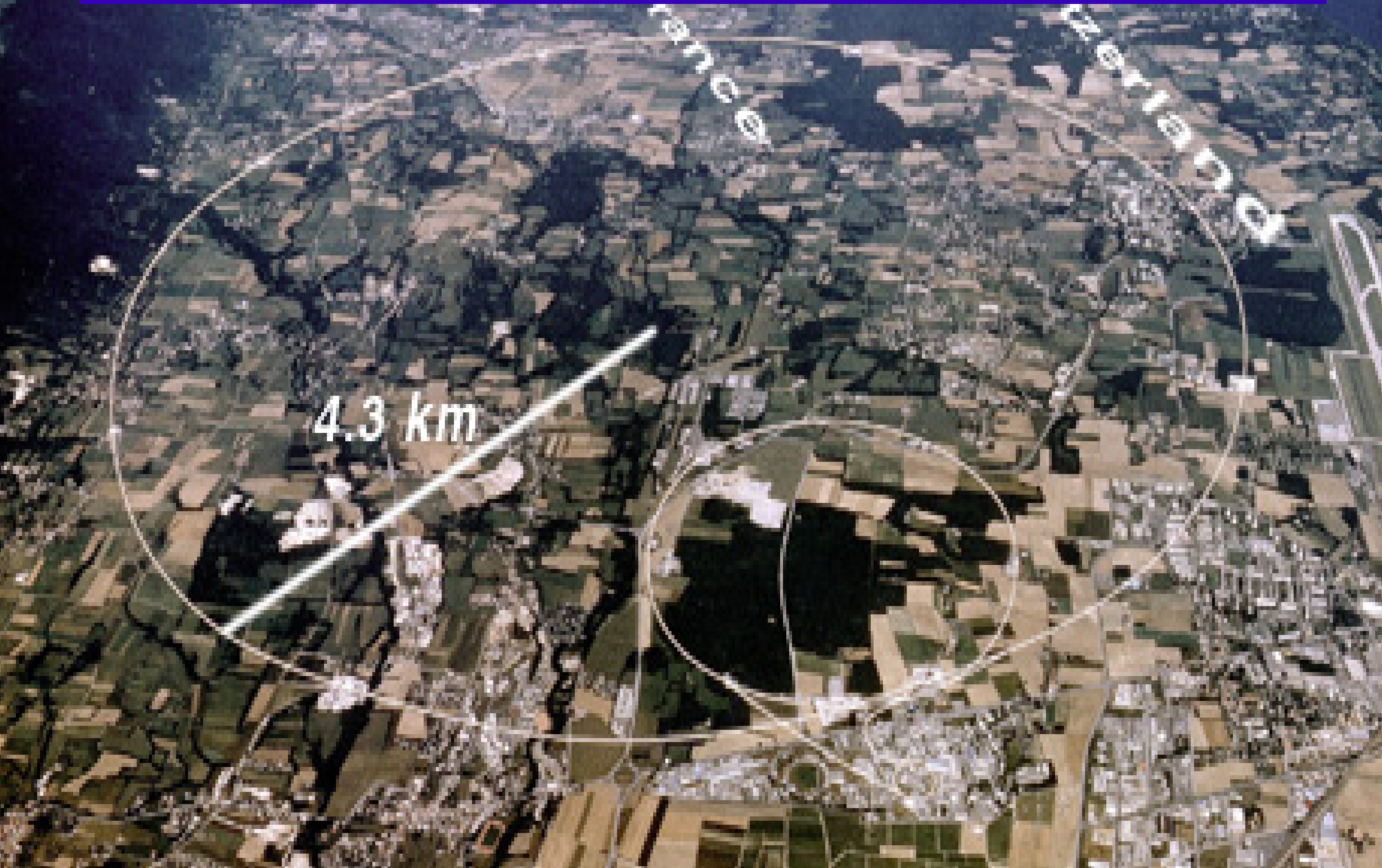
Neutrino physics will maintain as a hot topic in particle physics.



Main Backgrounds

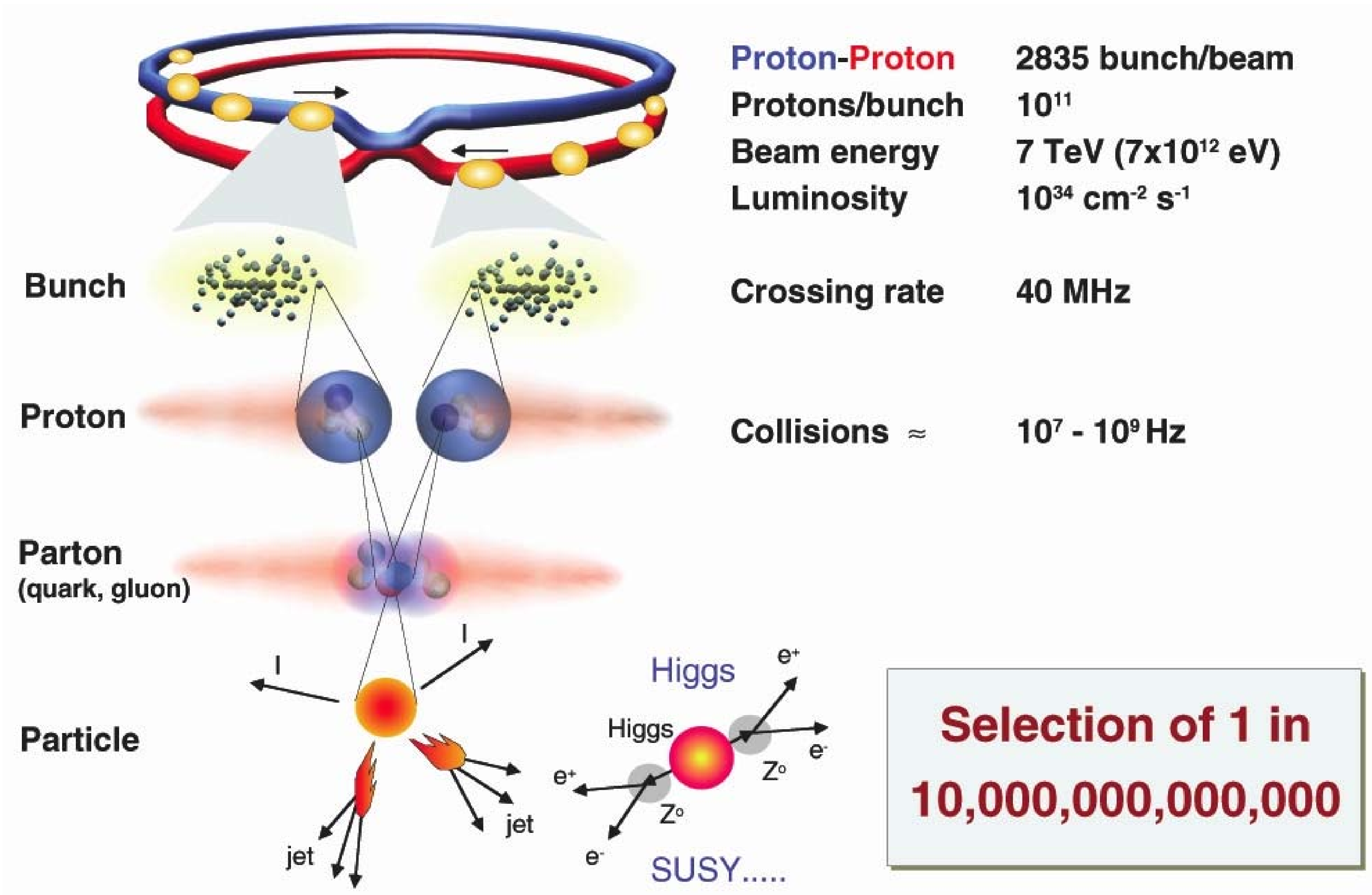


Explore New Physics in Near Future at LHC
LHC will start operation in 2008



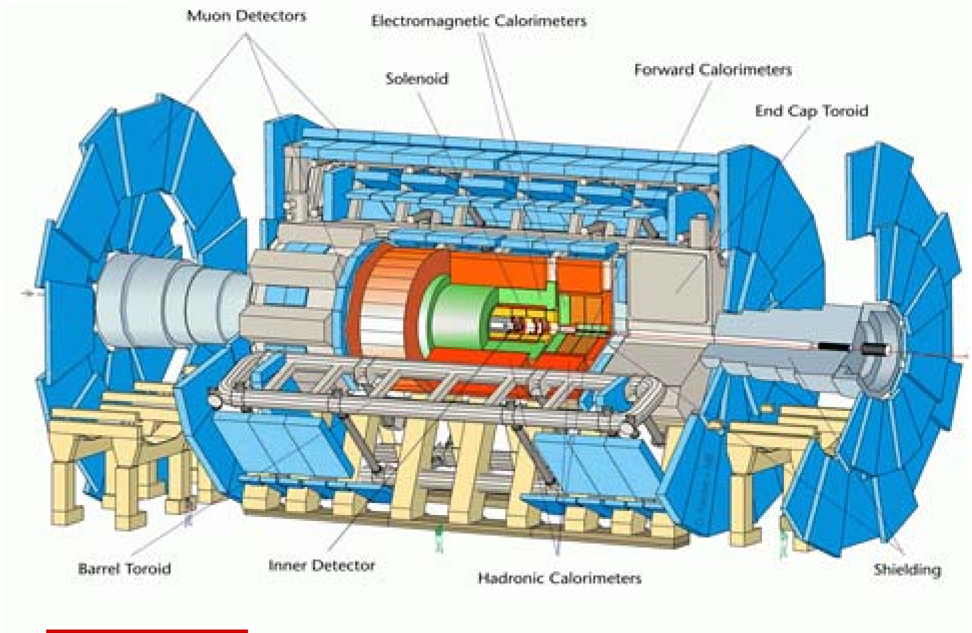
Proton-Proton Collisions at LHC

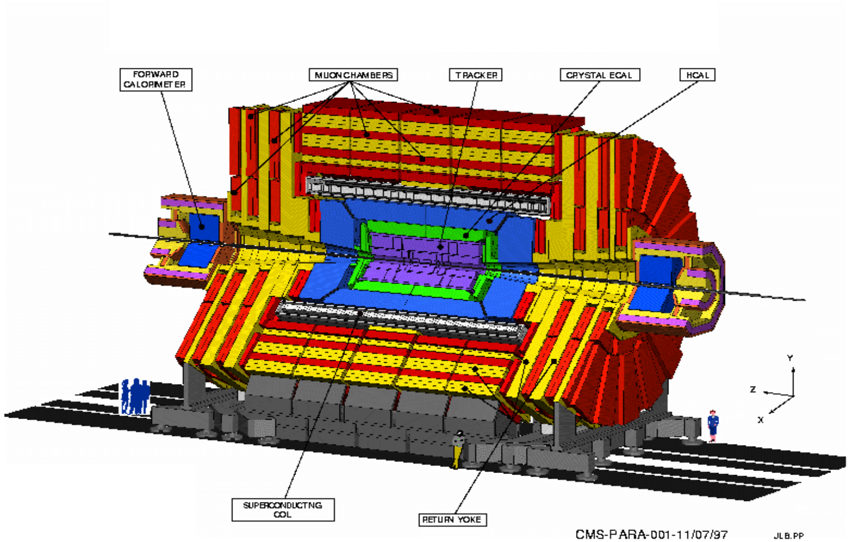
to discover the mysteries of EWSB, Dark-Matter, …



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

ATLAS Physics ‘Commissioning’

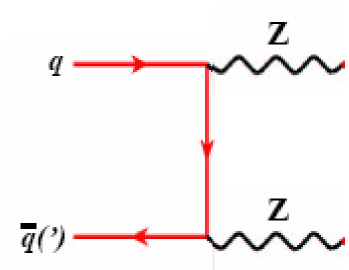
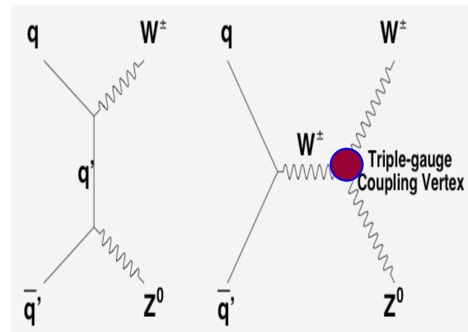
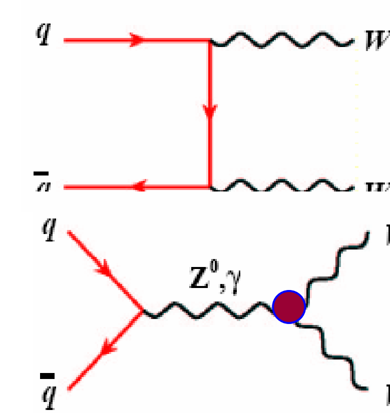
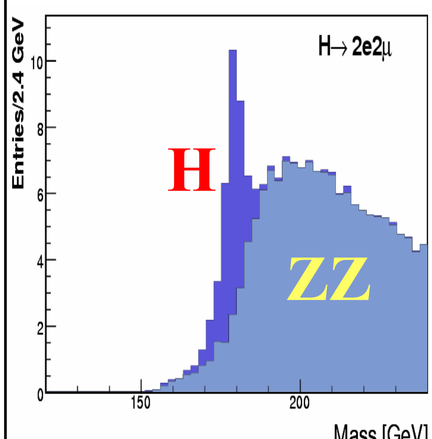
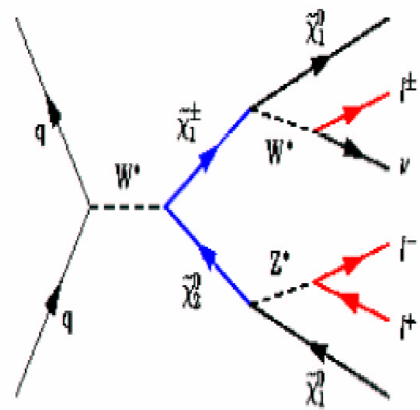
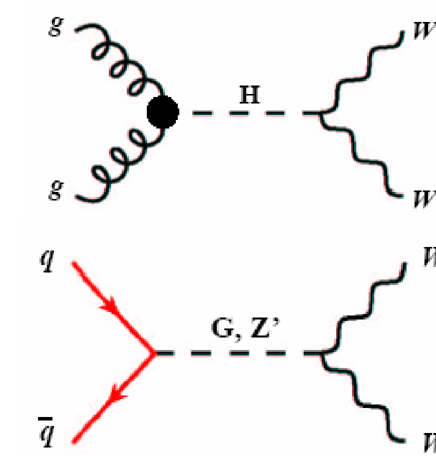
- Study the new physics discovery potential with CSC (computing system commissioning) program (started from summer of 2006).

- Physics ‘TDR’ will be updated soon with ATLAS CSC notes using many million fully simulated CSC MC data sets and with advanced analysis tools.

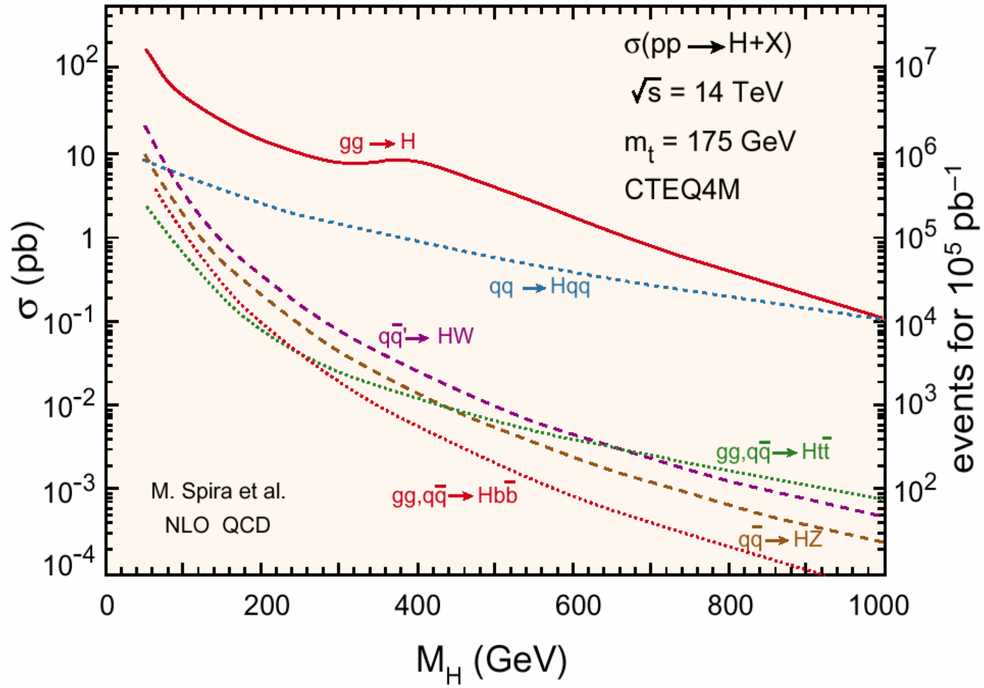
- We have developed and applied the BDT technique in diboson physics and Higgs discovery studies with the ATLAS CSC program.

- I Will present studies of direct search: H→ WW, and indirect search through the measurement of anomalous triple gauge boson couplings.

Di-Boson Analysis – Physics Motivation

Decay modes	ZZ → $l^+l^-\ l^+l^-$	ZW → $l^+l^-\ l\nu$	WW → $l^+\nu\ l^-\nu$
Standard Model • Triple-gauge-bosons couplings • New physics control samples			
Discovery H→ WW, ZZ SUSY Z'→ WW G → WW ρ_T→ ZW		 SUSY signal	

Direct Search of the SM Higgs From H→ WW → lνlν



Low mass region: m(H) < 2 m_Z

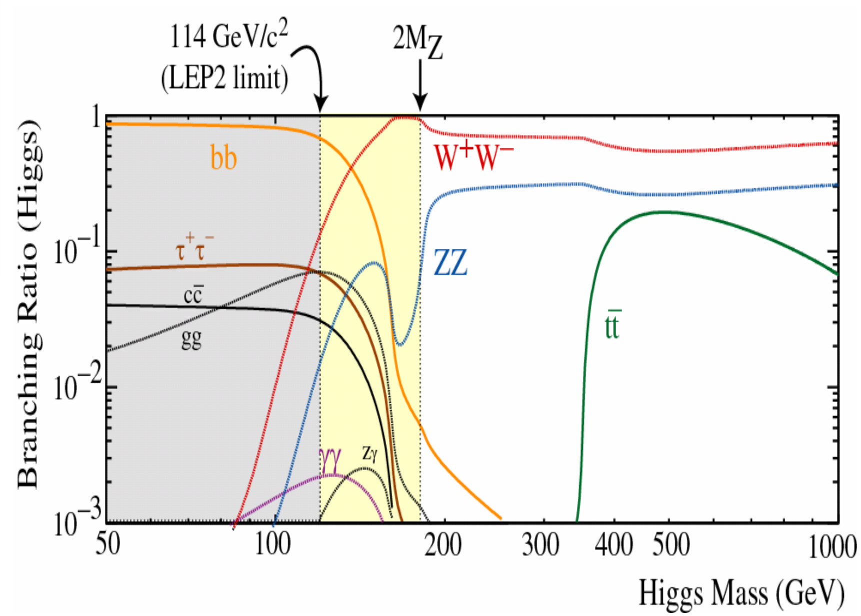
$H \to \gamma\gamma$

$H \to bb$

$H \to \tau\tau$

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

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

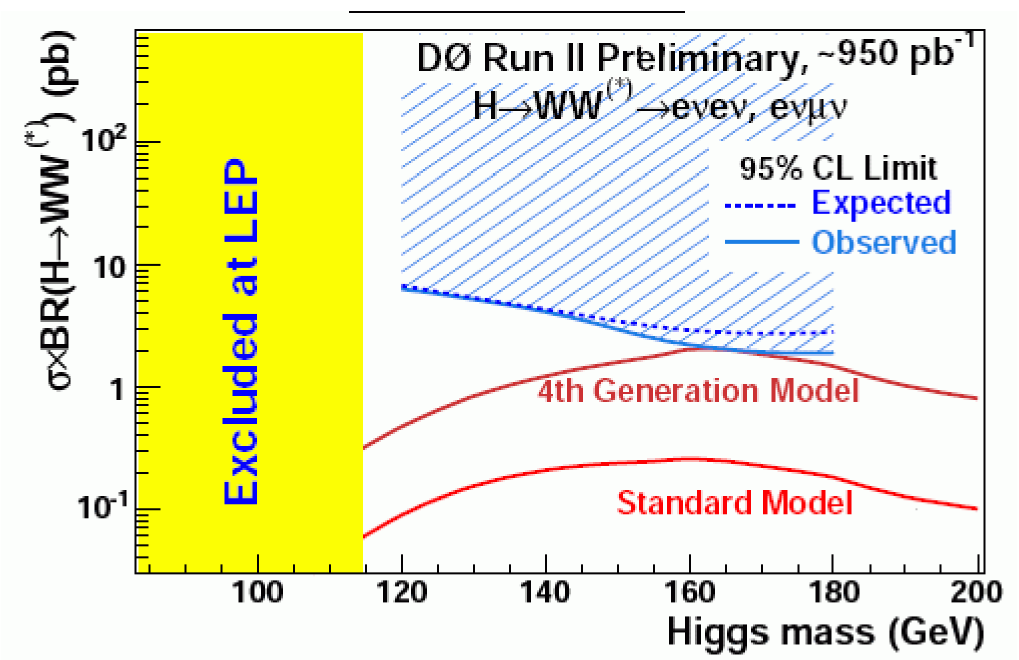


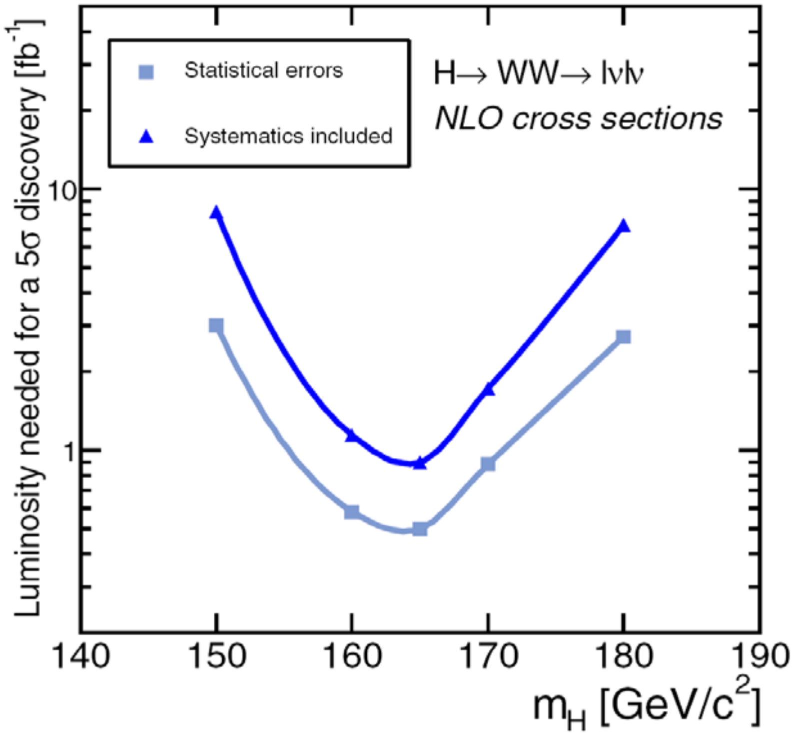
➔Gluon-gluon fusion and WW/ZZ fusion are two dominant Higgs production mechanism

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

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

CMS Phys. TDR 2006





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($pp \rightarrow H \rightarrow WW$)
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 →lvlv (l=e,m,t)	372.5K,	11.72 pb
• gg→WW → lvlv (l=e,m,t)	209.1K,	0.54 pb
• tt→ WWbb →l + X	584.1K,	450.0 pb
• WZ → lvll (l=e,m)	281.4K,	0.7 pb
• Z → ll (l=e,m,t)	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→ WW Pre-selection

- At least one lepton pair (ee, μμ, eμ) with P_T > 10 GeV, |η|<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 → ee, μμ

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%

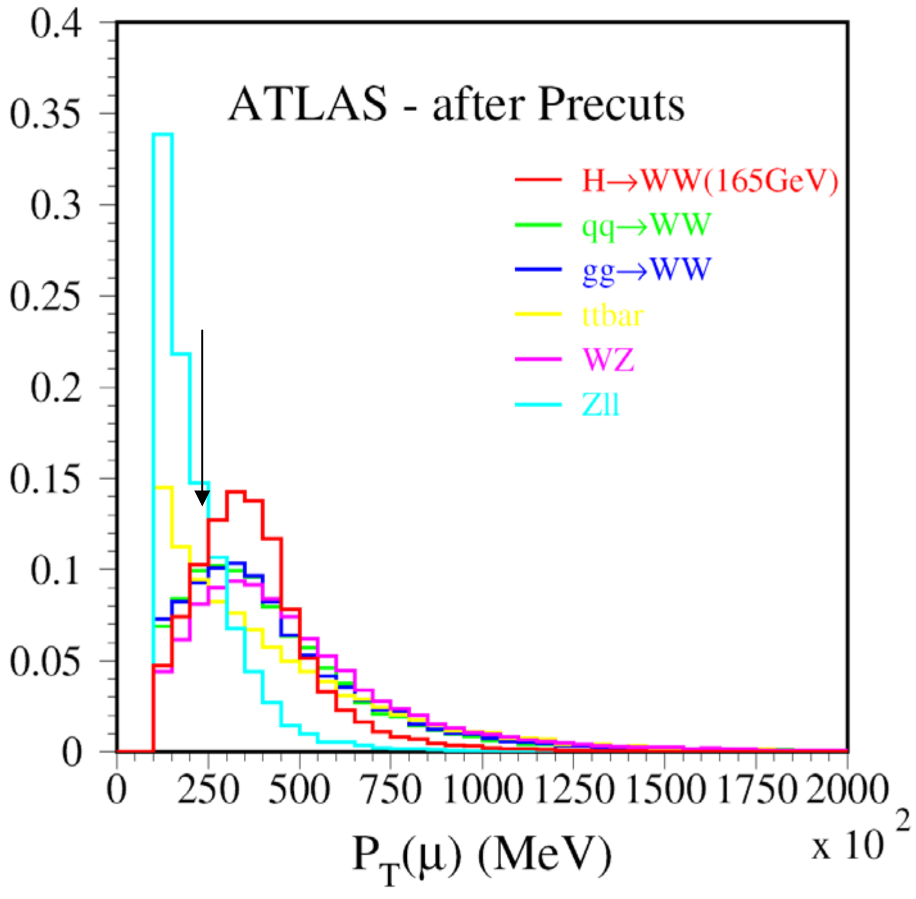
ATLAS electron ID: IsEM & 0x7FF == 0 (tight electron id cuts)
ATLAS Muon ID: Staco-muon id

H → WW Selection with Straight Cuts

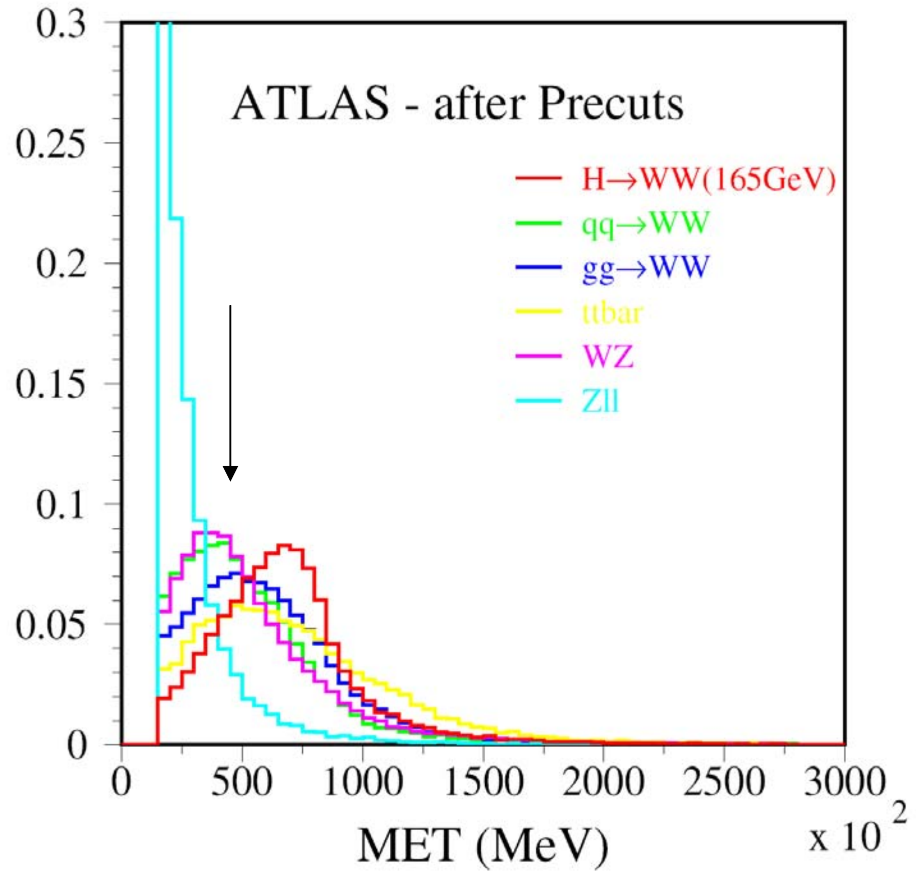
- the most energetic lepton has $P_T > 25$ GeV,
- no jet with $E_T^{jet} > 30$ GeV,
- angle between two leptons $\phi_{\ell\ell} < 1$,
- $MET > 50$ GeV,
- invariant mass of two leptons, $12 < M_{\ell\ell} < 50$ GeV,
- Sum of E_T^{jet} in $\Delta R < 0.4$ cone around e or μ is less than 8 or 5 GeV.

→ 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)

P_T of leptons and MET

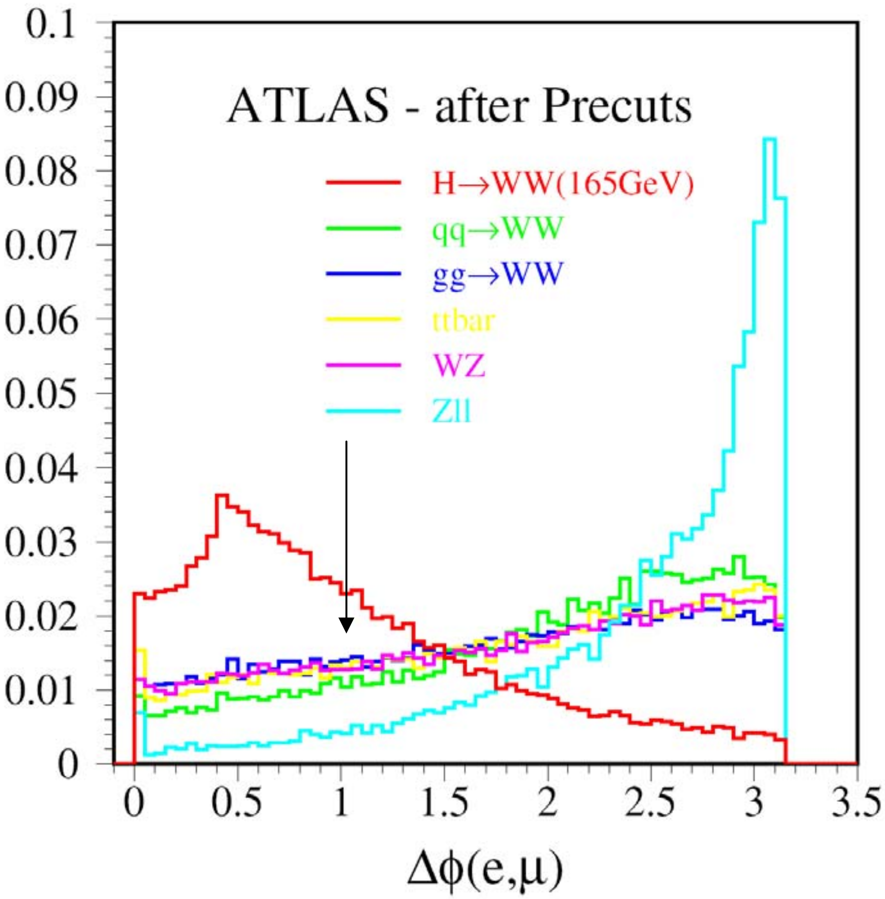


Transverse Momentum of Lepton

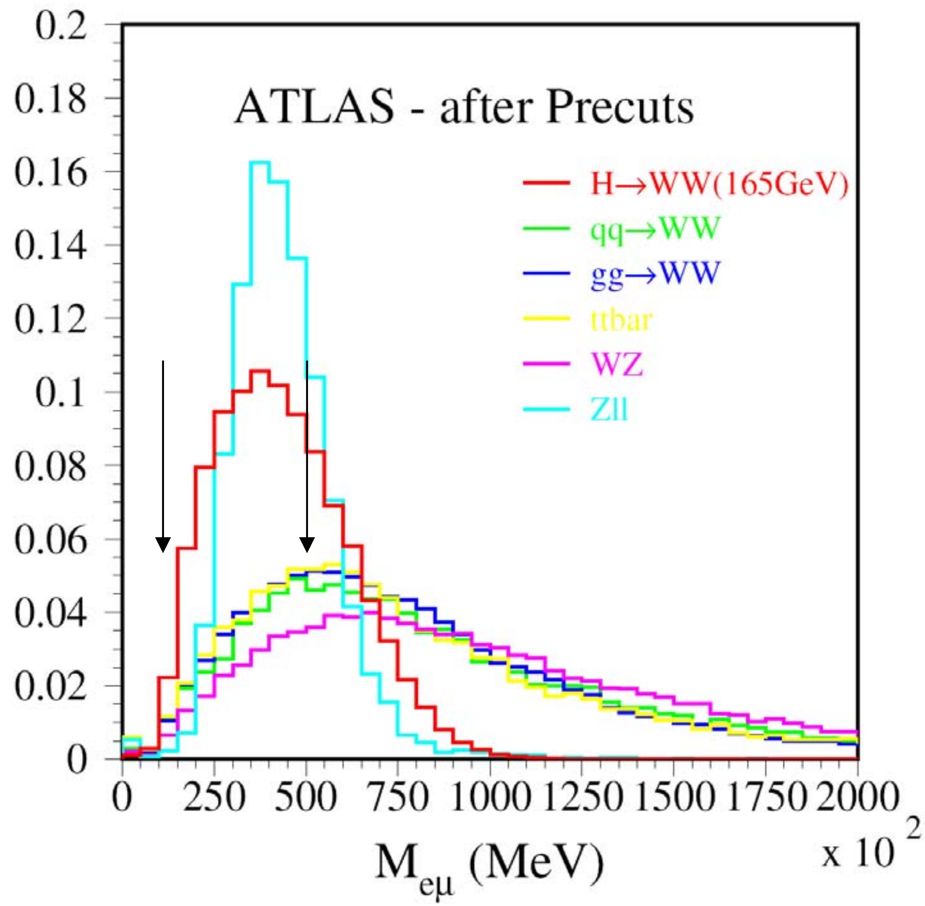


Missing Transverse Energy

Angular Distributions and Invariant Mass

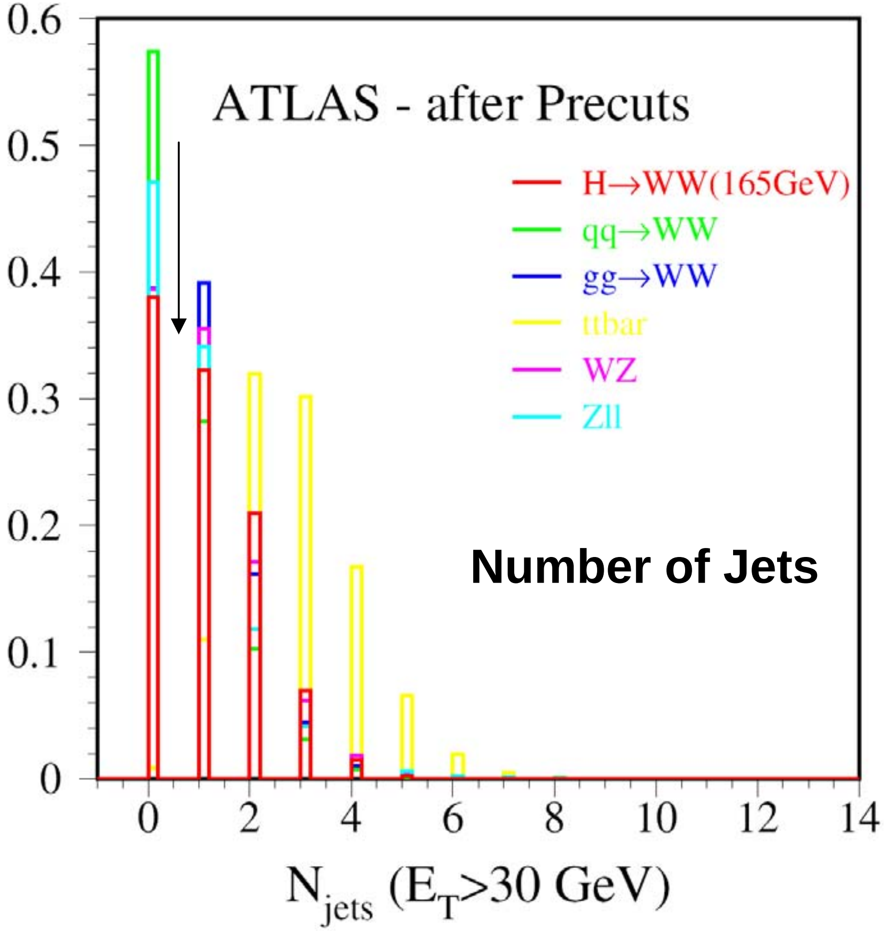


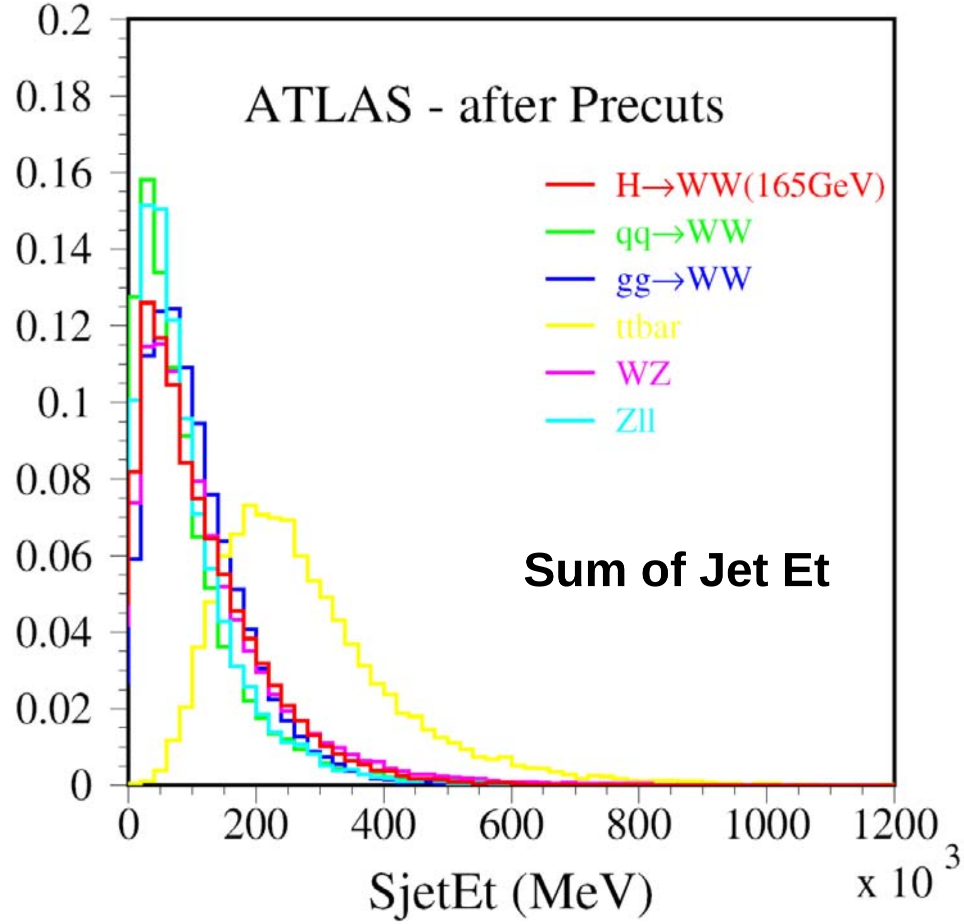
Angle between two leptons



Invariant mass of two leptons

No. of Jets & Jet Energy





BDT Analysis based on pre-selected events

Input physics variables to BDT program (1)

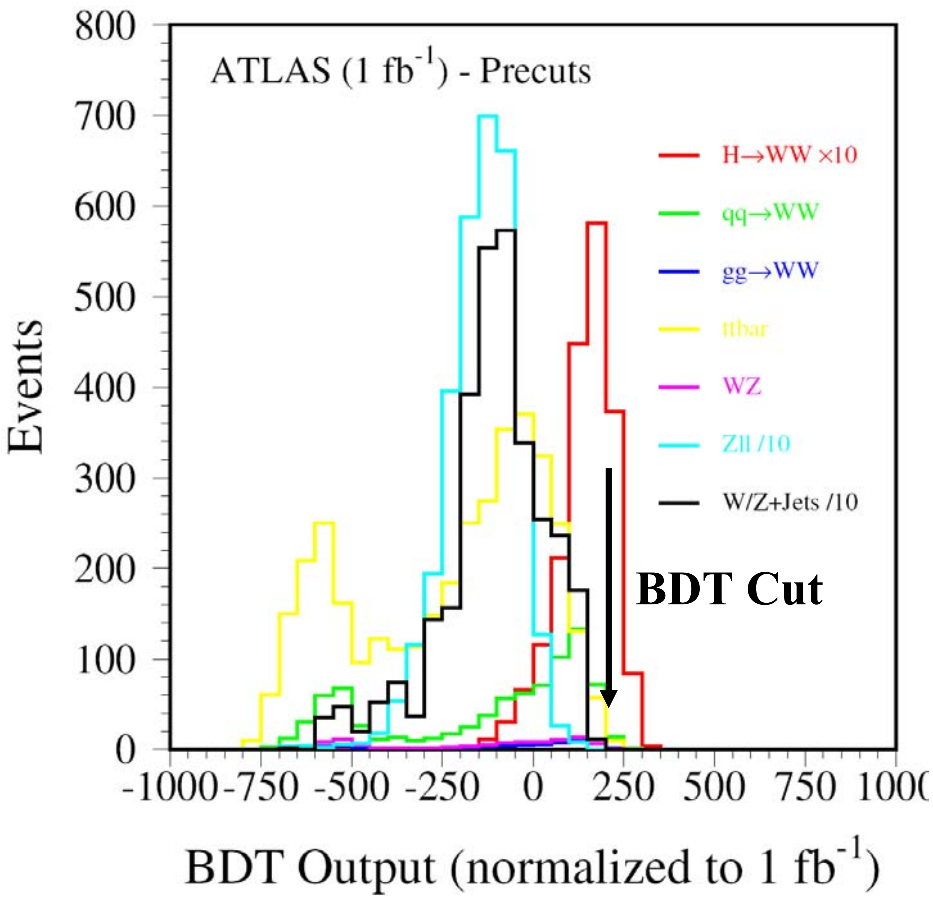
- Energy and Momentum
  - $p_T(\ell)$, $p_T(\ell, \ell)$
  - MET, total recoil E_T
  - scalar $\sum E_T(jet)$, vector $\sum E_T(\ell, MET)$
- Lepton Isolation
  - Number of tracks in $\Delta R < 0.4$ cone around ℓ
  - Sum of track p_T in $\Delta R < 0.4$ cone around ℓ
  - Sum of jet E_T in $\Delta R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

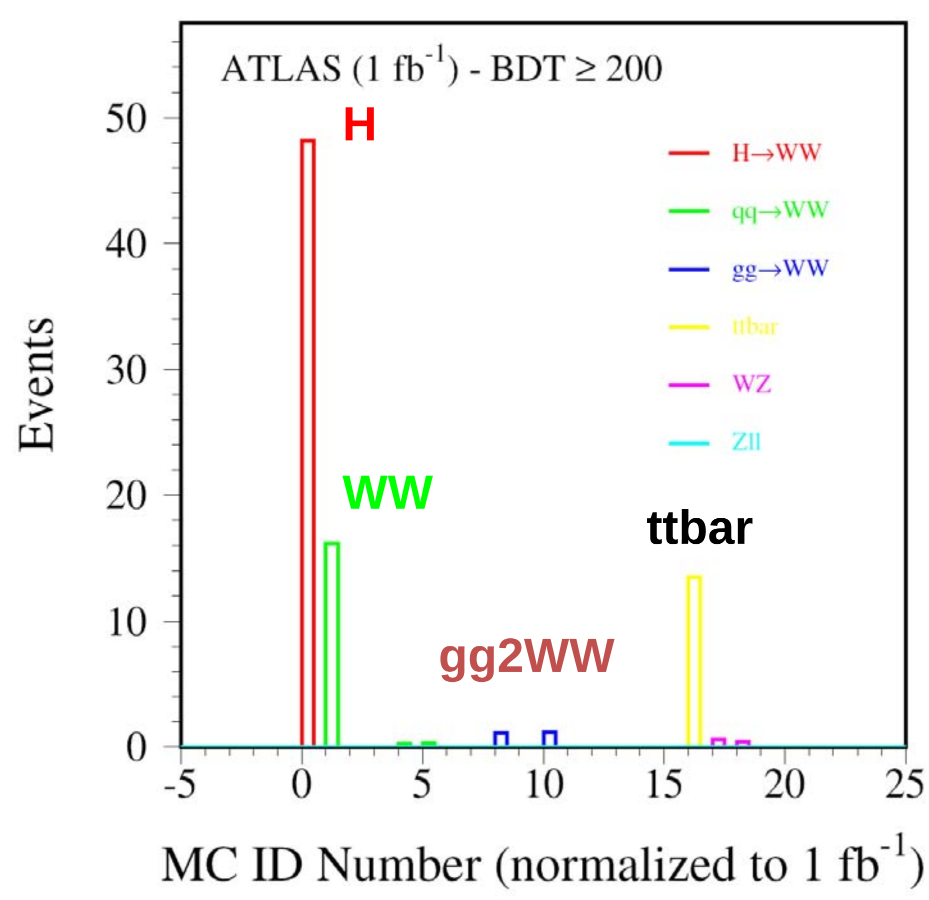
Input physics variables to BDT program (2)

- 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)

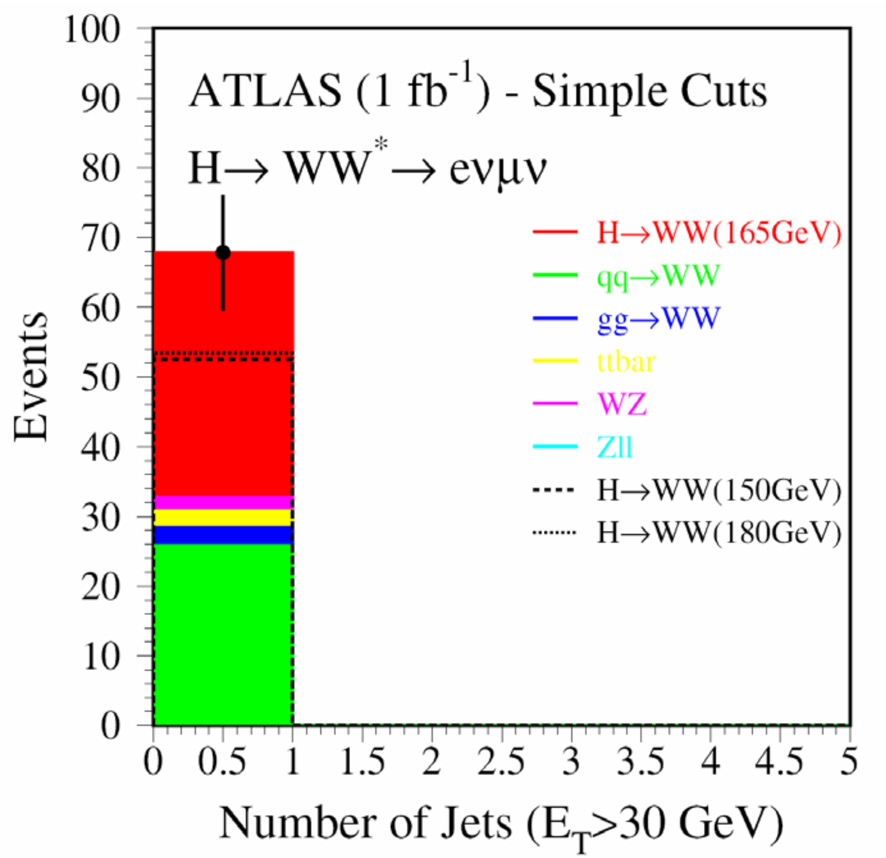
H→WW→eνμν (M_H=165 GeV)

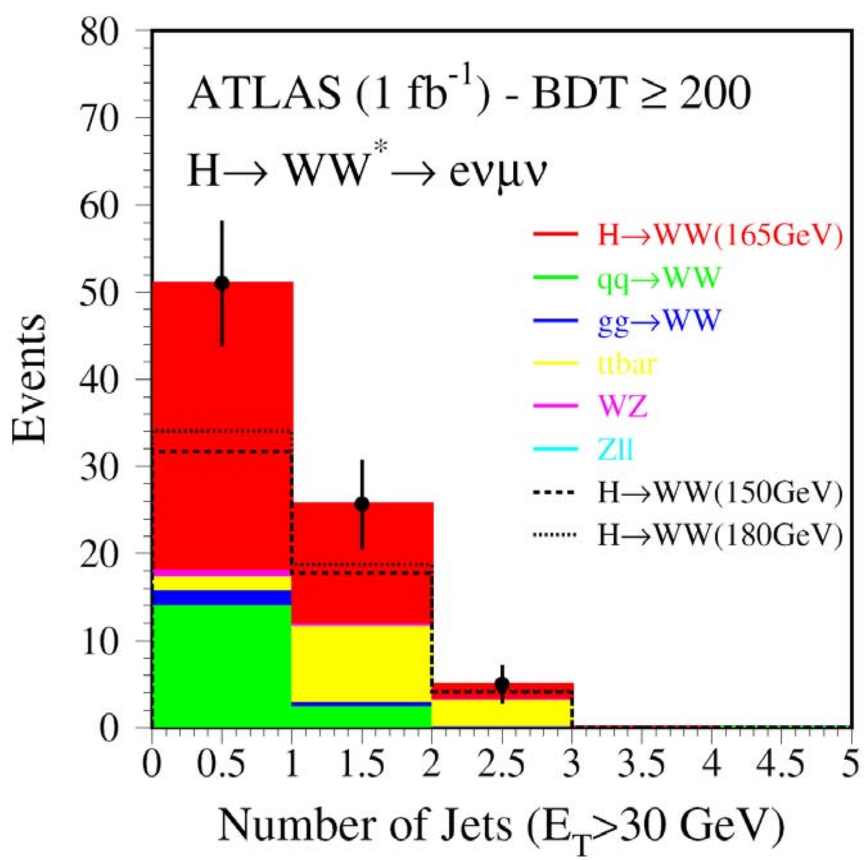
BDT output and selected signal & background events for 1fb^{-1}



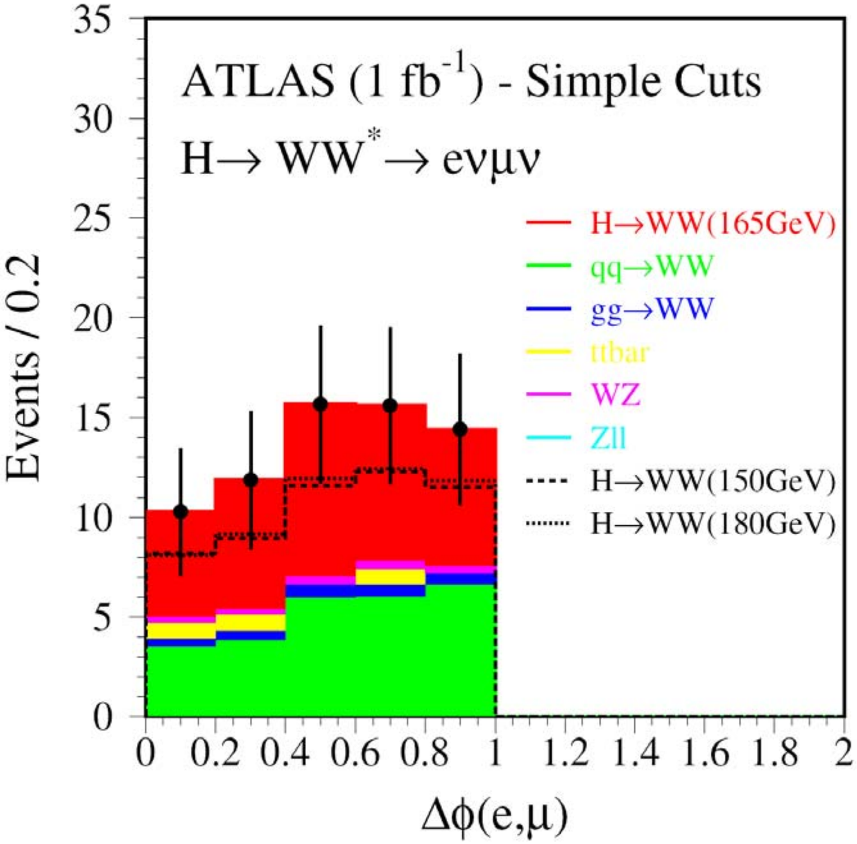


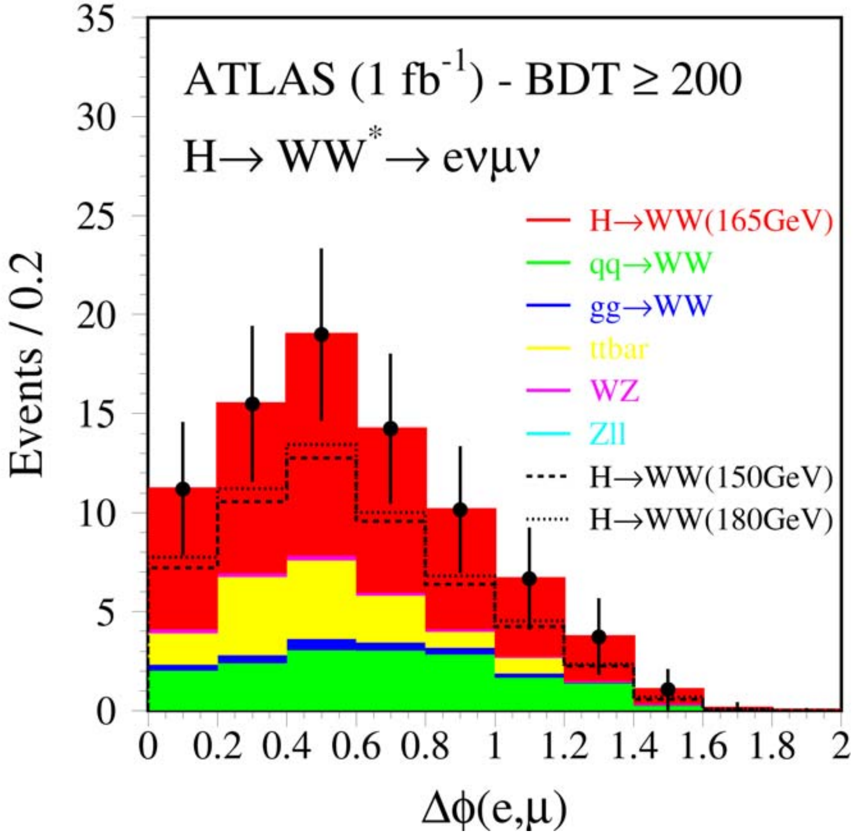
Straight Cuts vs BDT Selection (N_{jets})



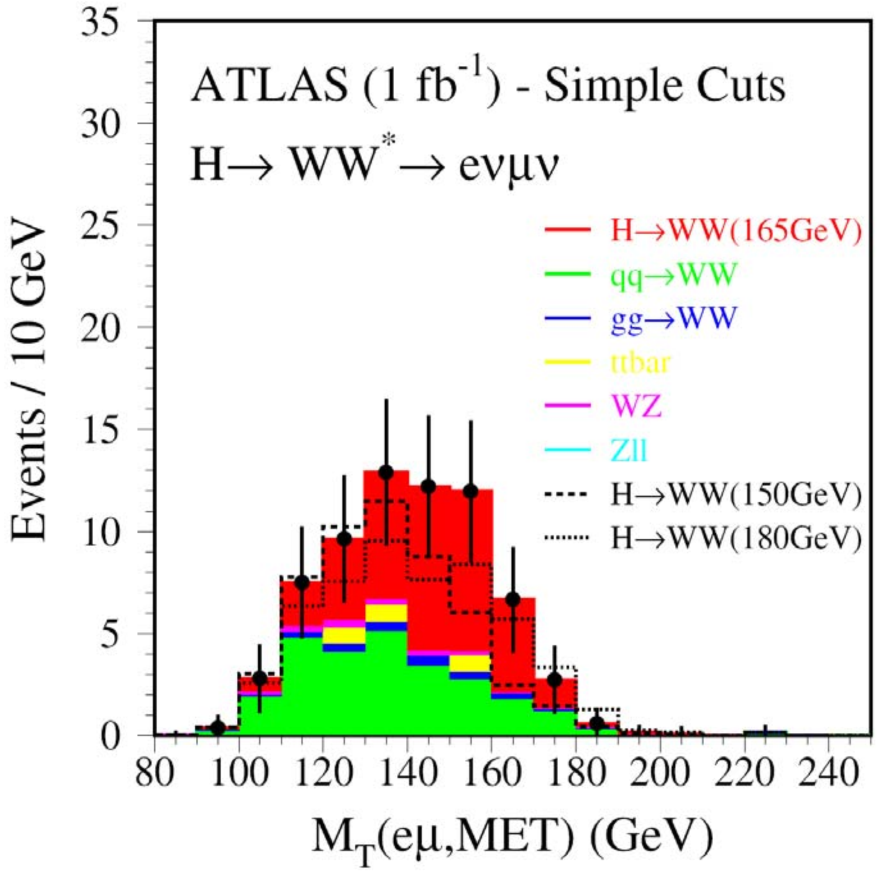


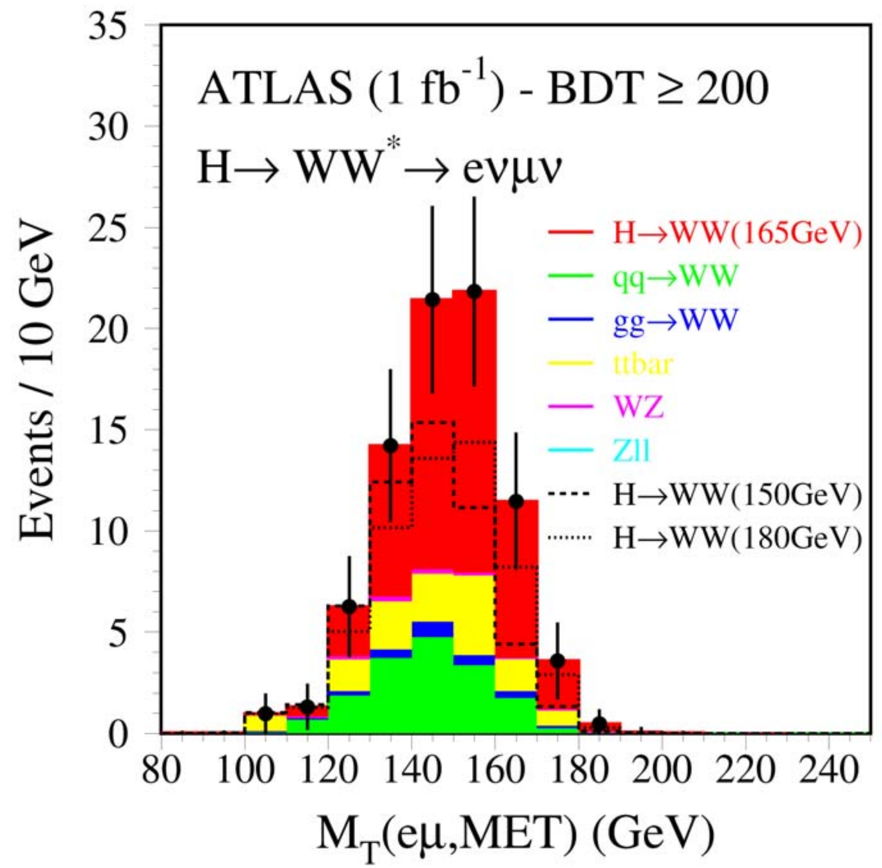
Straight Cuts vs BDT (Angle)





Straight Cuts vs BDT (Mass)





Discovery Confidence Level Calculation

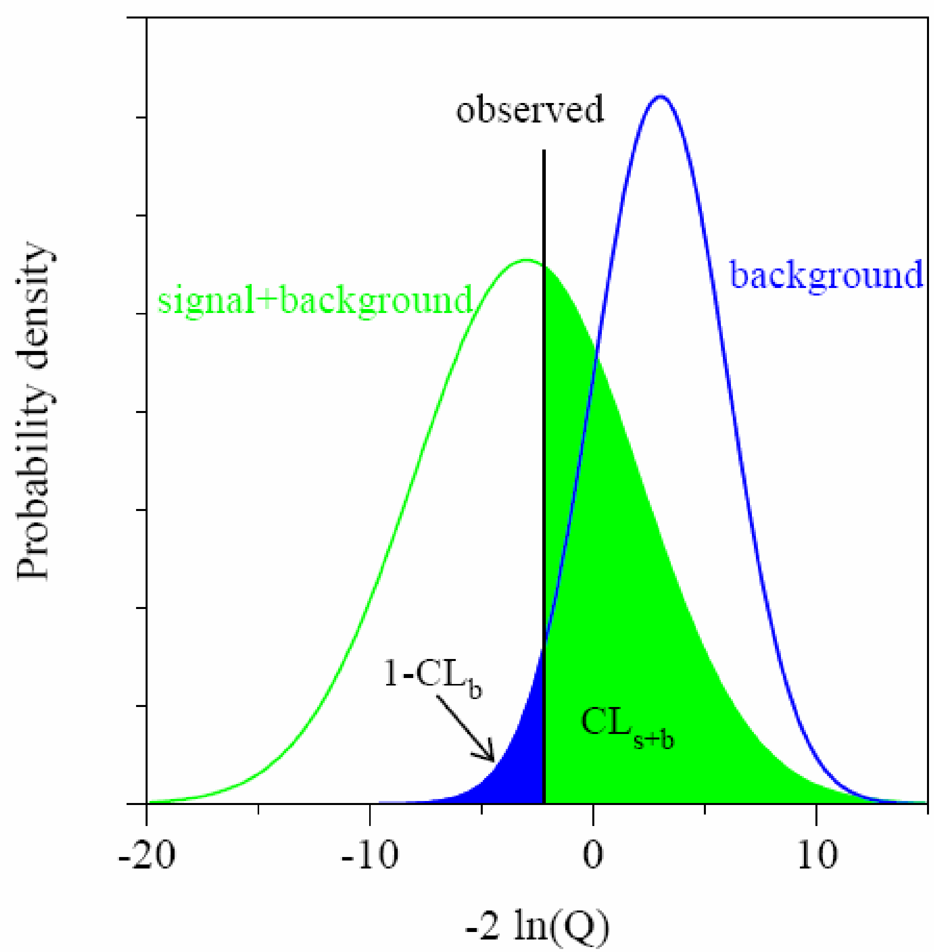
➔ Log-likelihood ratio test-statistics by using BDT bins and 3 Higgs decay channels

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

➔ MC experiments are based on Poisson statistics

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

(used for LEP Higgs Search)

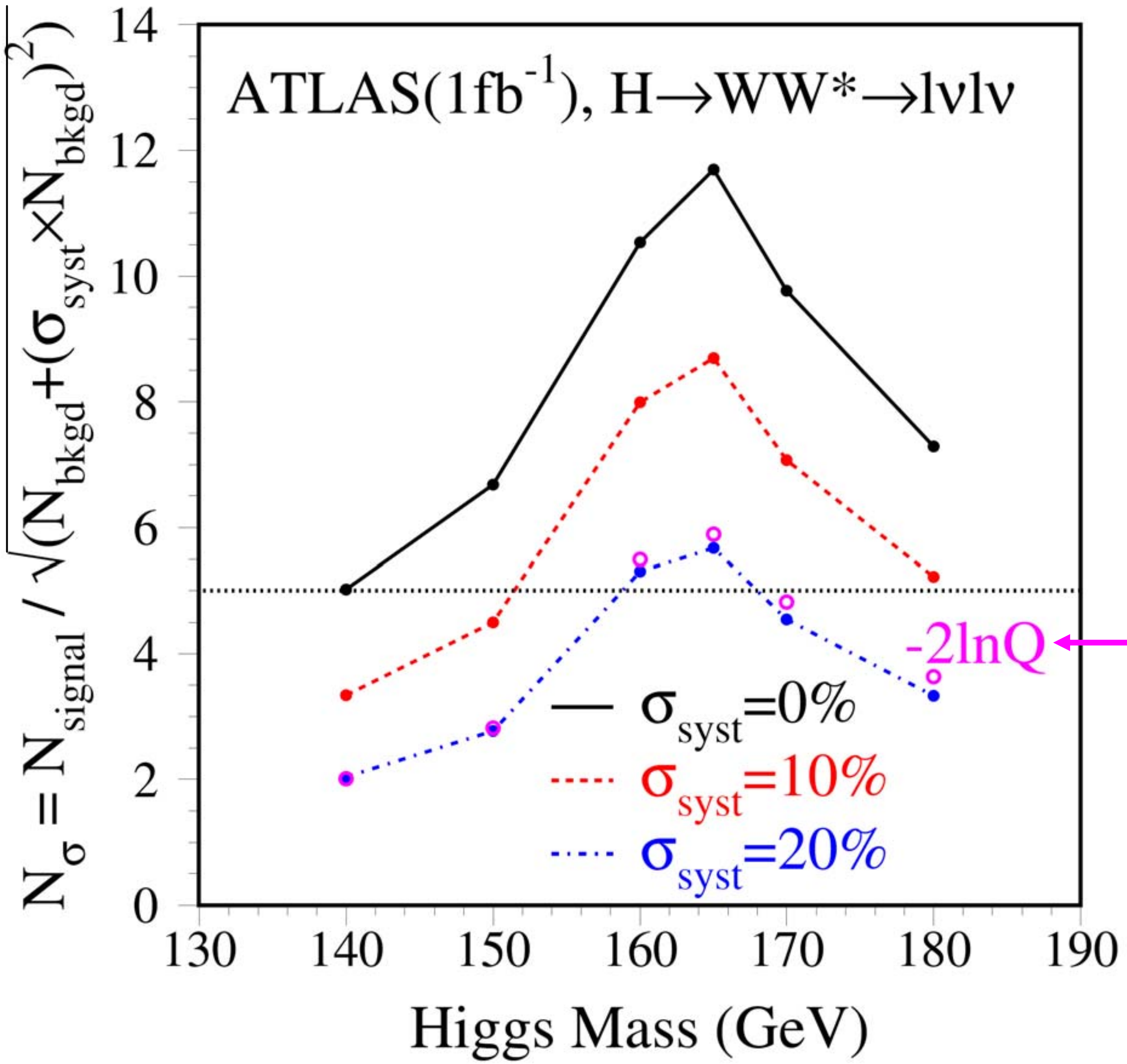


BDT Results ($H \rightarrow WW^* \rightarrow l\nu l\nu$, for 1fb^{-1})

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



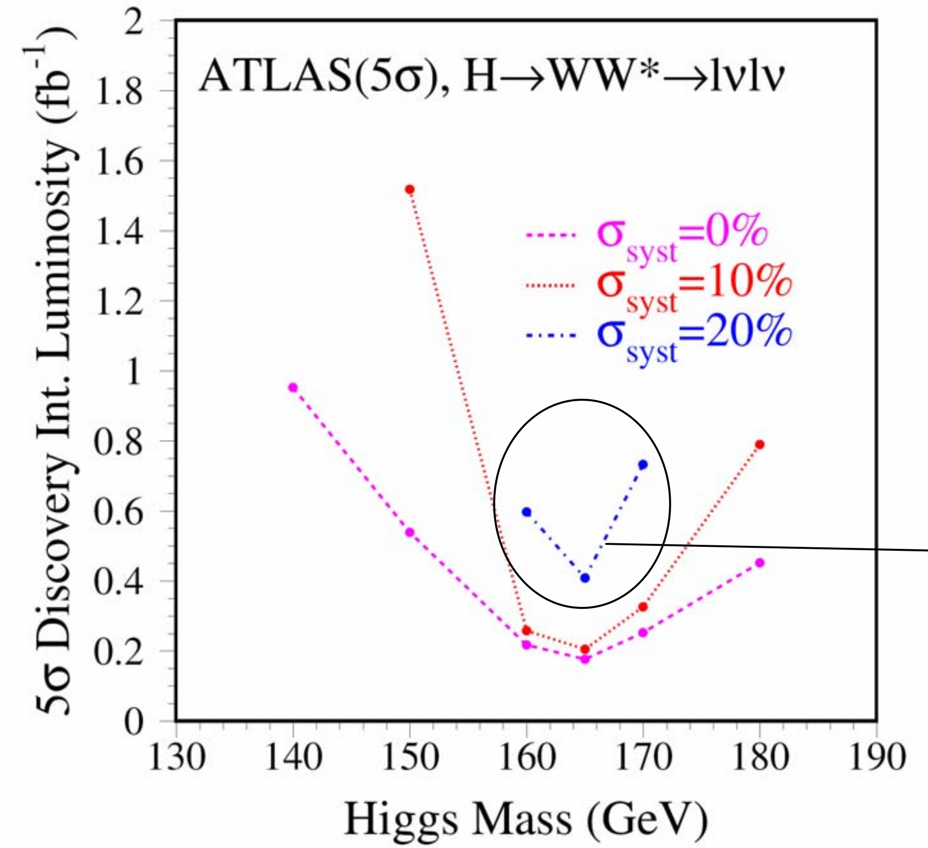
$$Q = \frac{L(s+b)}{L(b)}$$

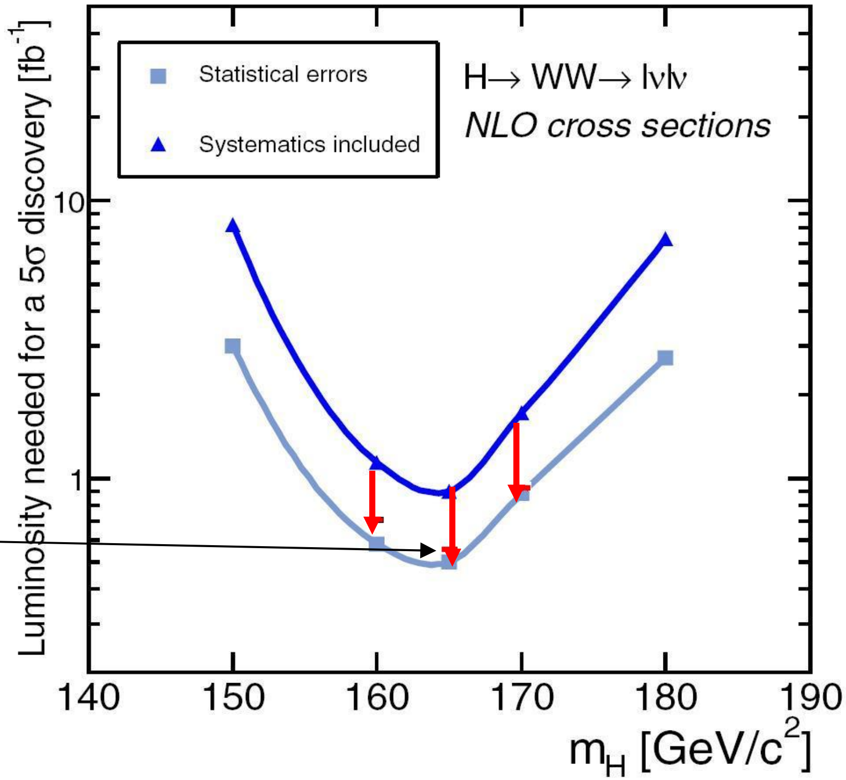
Log-likelihood Ratio with 20% syst. error

Required Int. Lumi. for 5σ Discovery

BDT Analysis, H → WW* → lνlν (l=e,μ)

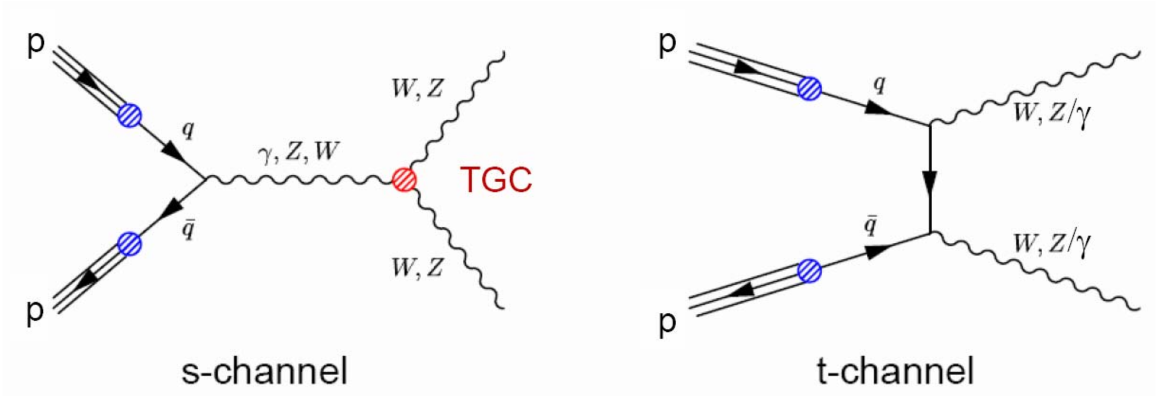
CMS Phys. TDR 2006





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

Search for new physics through anomalous Triple-Gauge-Boson Couplings



- Model independent effective Lagrangian with anomalous couplings

  $$L_{WWV}/g_{WWV} = ig_1^V(W^\dagger_{\mu\nu}W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu}) + i\kappa_V W^\dagger_\mu W_\nu V^{\mu\nu} + i(\lambda_V/M_W^2) W^\dagger_{\lambda\mu}W_\nu^{\ \mu}V^{\nu\lambda}$$

  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
- 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 (WW, WZ and Wγ)

ATLAS diboson Event Selection

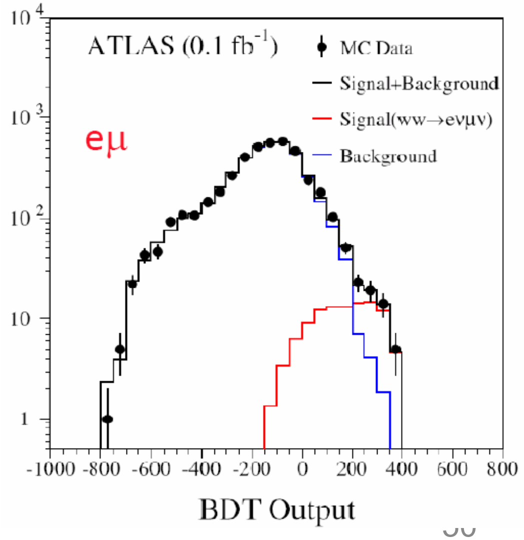
Process	Selection	1 fb^{-1}
$W^+W^- \rightarrow \ell^+\nu\, \ell^-\, \nu$ σ_{WW} = 113.3 pb	2 isolated leptons with P_T > 25 GeV, opposite charges, $\Delta R(\ell\ell)$>0.2, Missing transverse energy > 30 GeV, $\lvert M_Z\text{-}Mee/\mu\mu\rvert$ > 30 GeV N_{jet} (E_T>30 GeV) < 2, |Vector-sum (lep, MET)|<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, $\lvert M_Z\text{-}Mee/\mu\mu\rvert$ < 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 $\lvert M_Z\text{-}M_{ll}\rvert$<10 GeV, $P_T(\ell\ell)$ > 100 GeV veto the 3^{rd} 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, $\lvert M_Z\text{-}Mee/\mu\mu\rvert$ < 10 GeV, one photon with PT>20GeV, Jet veto $\Delta R(\ell\gamma)$>0.7, $\lvert M_Z\text{-}Mee\gamma/\mu\mu\gamma\rvert$ > 30 GeV	Ns=1201 Nb=503

Probing Anomalous TGCs in ATLAS

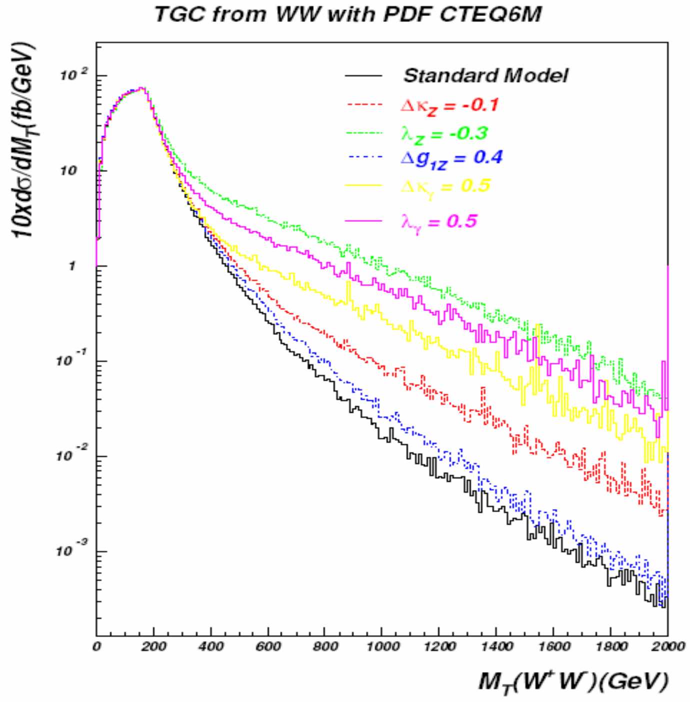
- To probe the anomalous couplings we need a model of the kinematic distributions for various couplings. To do this we use
  - NLO generators
    - MC@NLO produces events that are fully simulated in ATLAS
    - BHO MC is used to generate events with anomalous couplings
  - Reweighting
    - Using kinematic distributions from BHO we reweight the fully simulated MC@NLO events to produce expected distributions for a range of anomalous couplings.
- Boosted decision tree selection

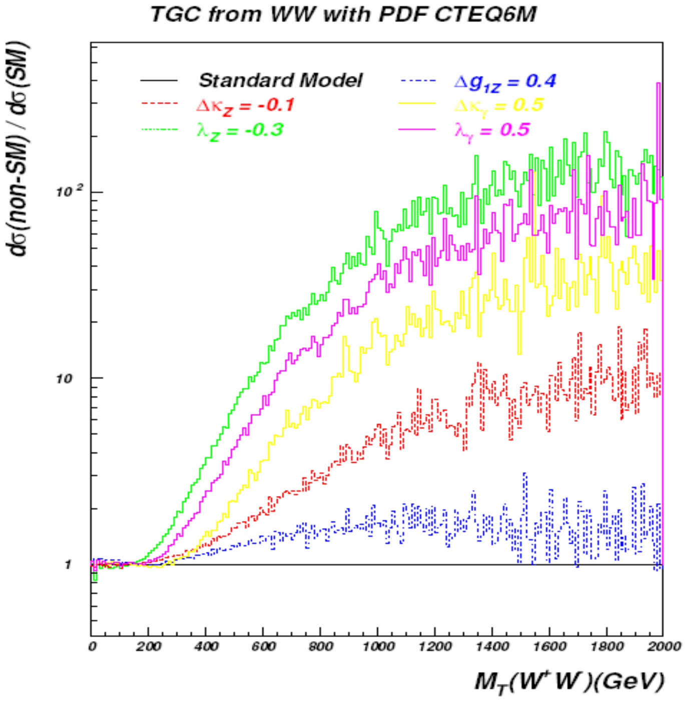
  A multivariate event selection method that is

  Very effective, stable, and relatively transparent.



Anomalous spectra and reweighting ratio

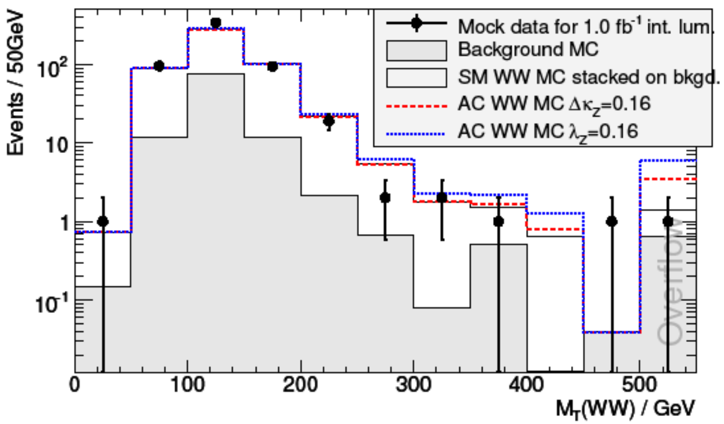




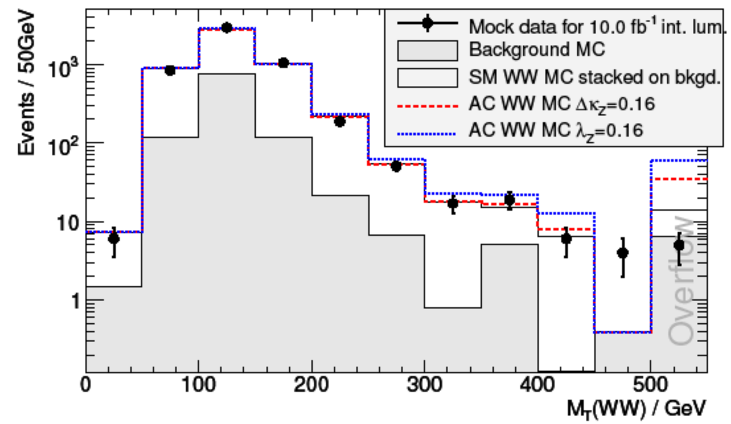
- The $M_T(WW)$ spectrum for W^+W^- events with anomalous coupling parameters using the BHO Monte Carlo.
- At right are the 'weights = $d\sigma$(non-SM)/$d\sigma$(SM)' used to reweight fully simulated events.

M_T(WW) sensitive to WWZ & WWγ couplings

$1\ fb^{-1}$



$10\ fb^{-1}$

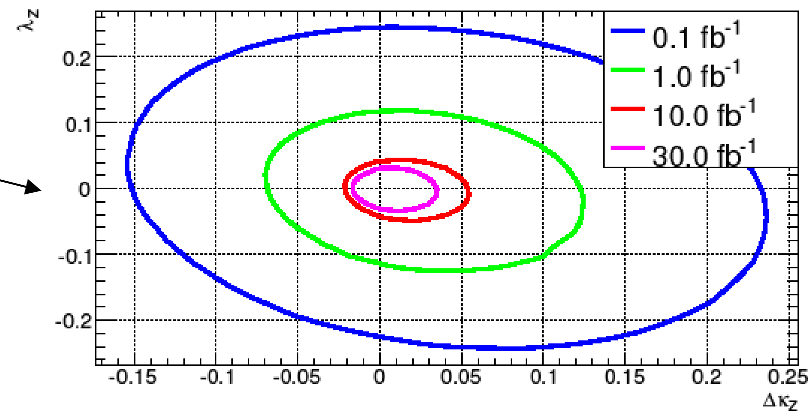


- Binned likelihood comparing mock SM observations to a SM profile and two reweighted anomalous profiles
- Using 10 bins from 0-500GeV and one overflow bin.
- In addition, the three decay channels, ee, eμ, and $\mu\mu$, are binned separately for a total of 33 bins.

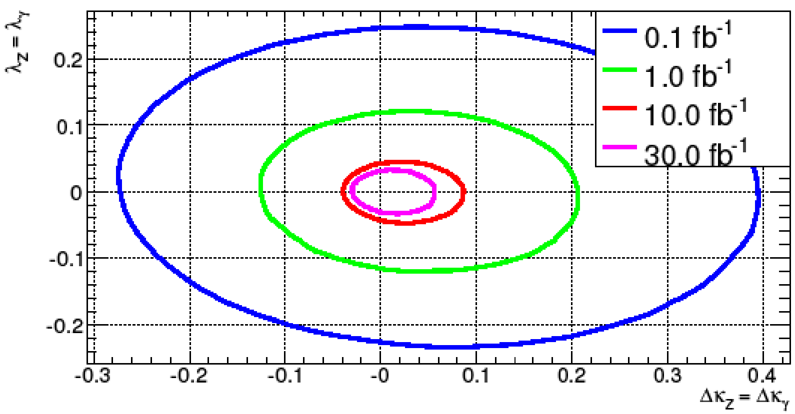
2D anomalous TGC sensitivity using $M_T(WW)$

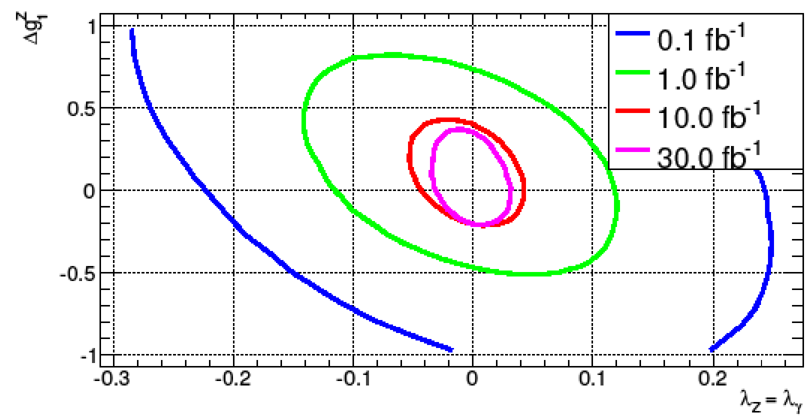
95% confidence contours for 0.1, 1, 10, and 30 fb^{-1} integrated luminosity

Right: HISZ assumption (2 parameters)



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



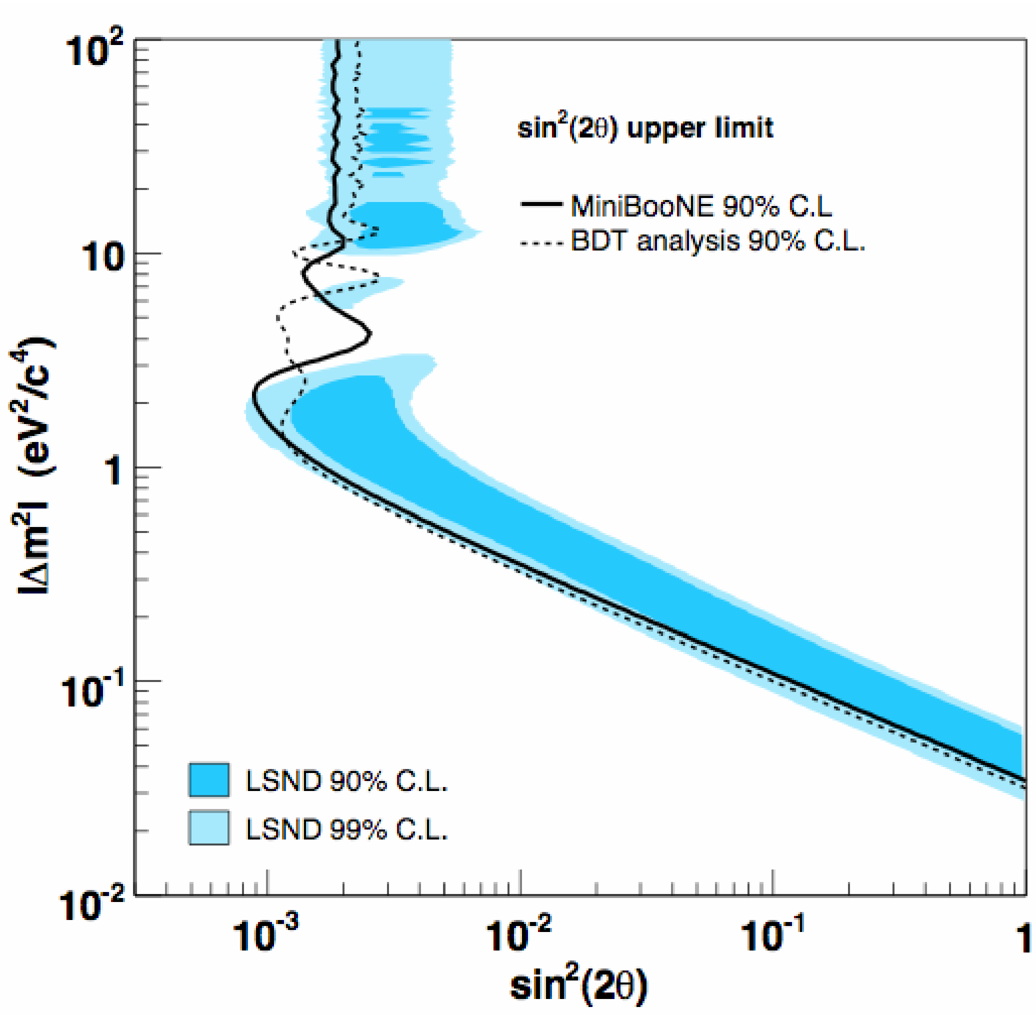


Summary

- In the past decades, the new physics beyond the SM is the discovery of neutrino oscillations.
- The anomaly oscillation signal from LSND experiment has been excluded by MiniBooNE experiment. However, the low E neutrino event excess still need further investigation.
- Neutrino physics will remain to be a hot topic.
- LHC will start operation in 2008. It will provide a superb physics opportunities for discoveries. Diboson final states will play crucial roles in experiments to find new physics signatures.
- If the Higgs mass is in a range of 150 – 180 GeV, it could be detected through the WW final state with early LHC data (~ a few fb^{-1}).

Backup Slides

MiniBooNE First Results show no evidence for $\nu_\mu \rightarrow \nu_e$ appearance-only oscillations

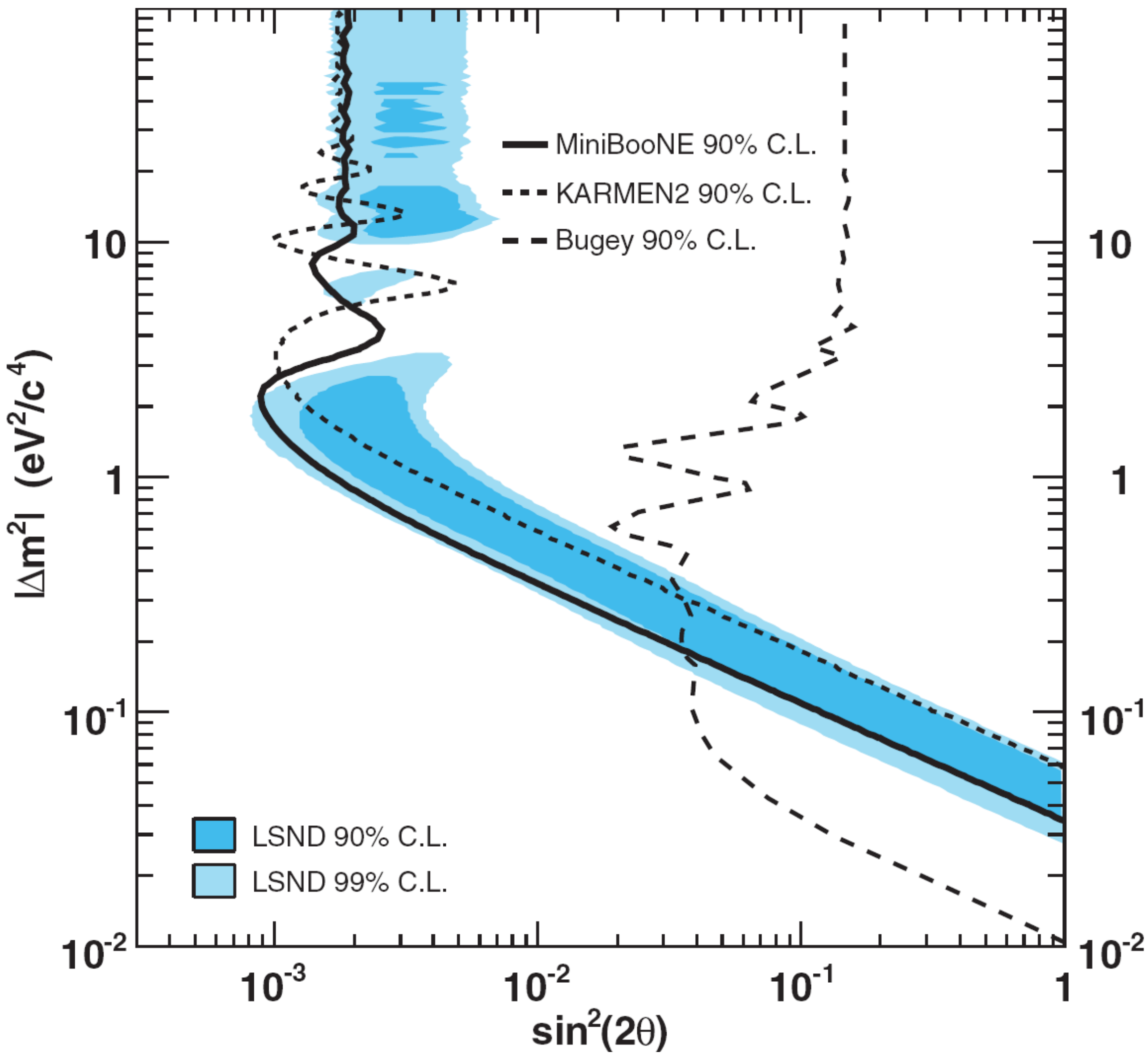


Energy-fit analysis:
solid: TB
dashed: BDT

Independent analyses are in good agreement.

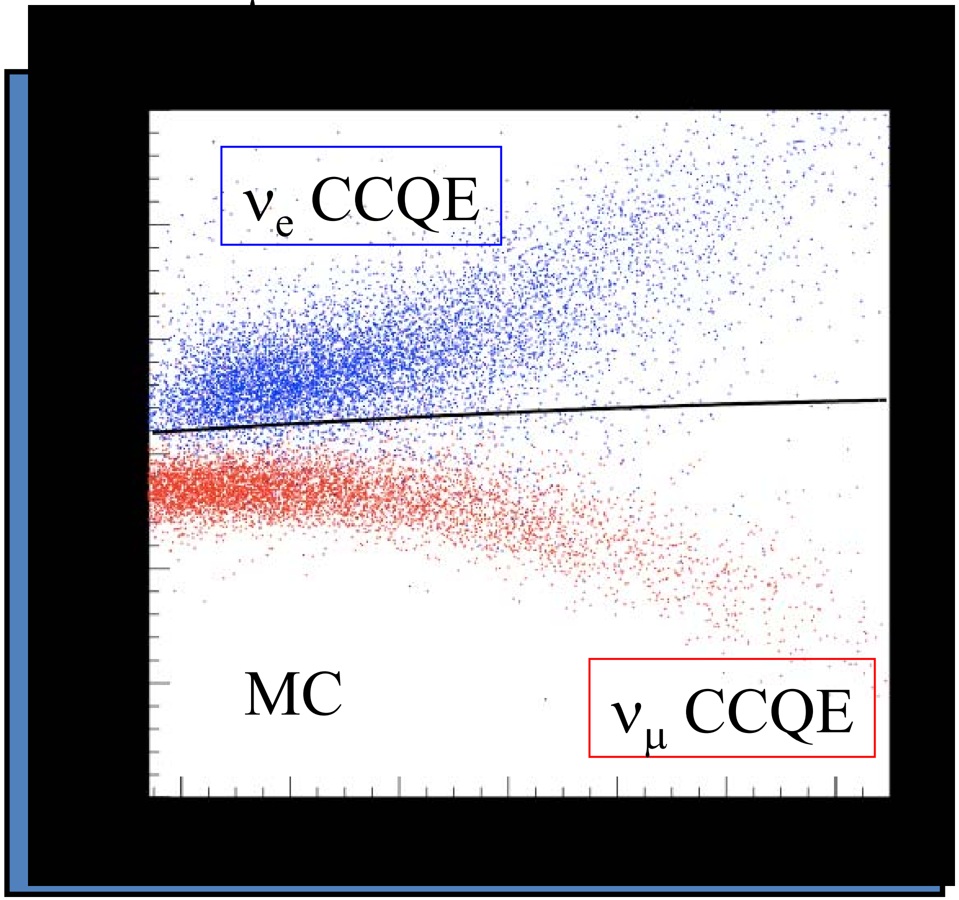
MiniBooNE first results
arXiv:0704.1500
Phys. Rev. Lett. 98, 231801

Exclusion Limits (90% CL)



e / μ Separation

$\log(L_e/L_\mu) > 0$ favors electron-like hypothesis

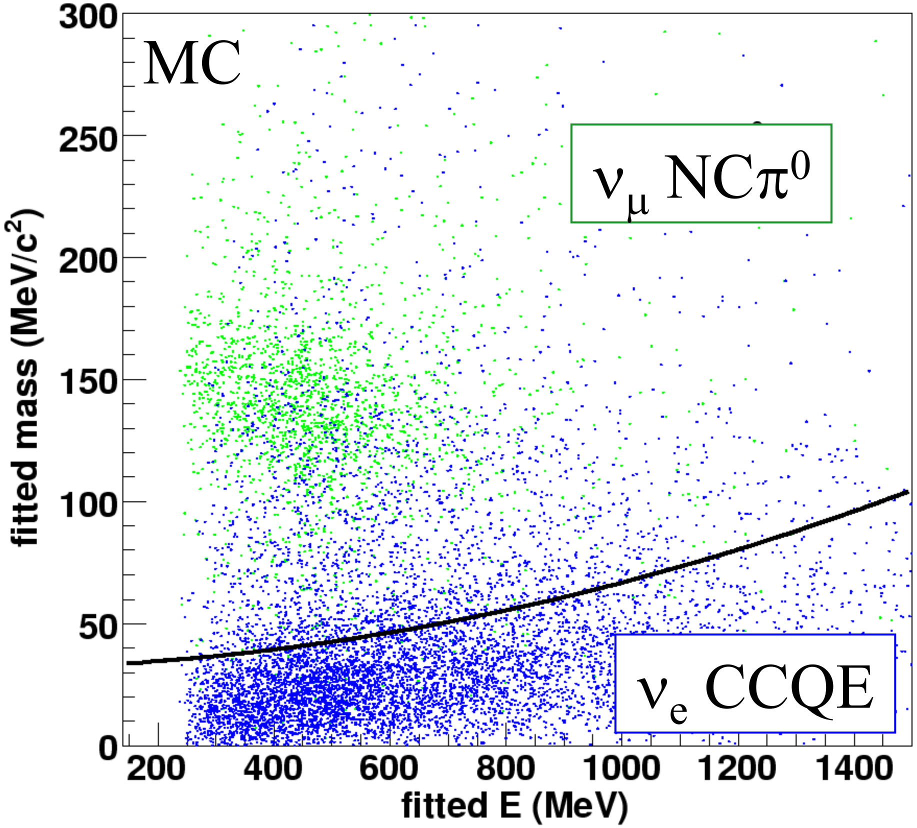


Separation is clean at high energies where muon-like events have long tracks.

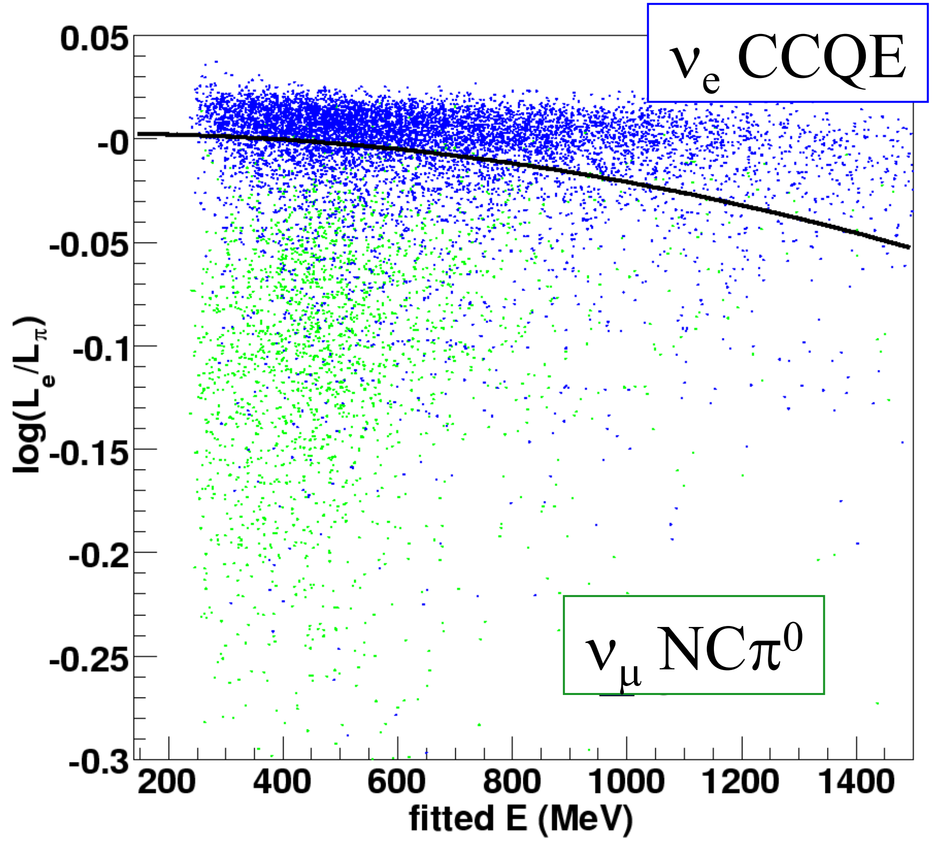
Analysis cut was chosen to maximize the $\nu_\mu \rightarrow \nu_e$ sensitivity

e / π^0 Separation

Using a mass cut



Using $\log(L_e/L_\pi)$



Cuts were chosen to maximize $\nu_\mu \rightarrow \nu_e$ sensitivity

Summary of Track-Based Cuts

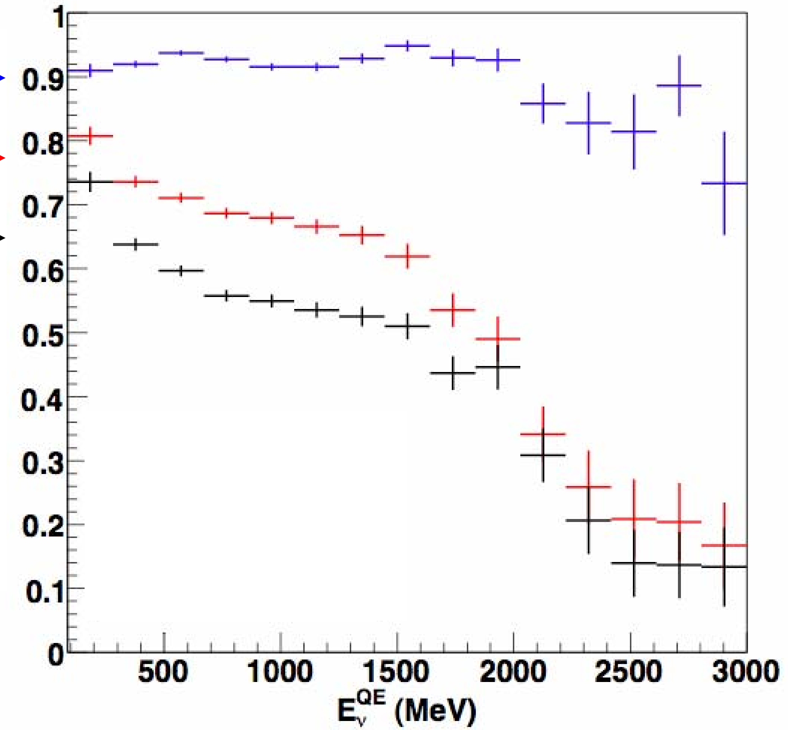
"Precuts" +

$Log(L_e/L_\mu)$

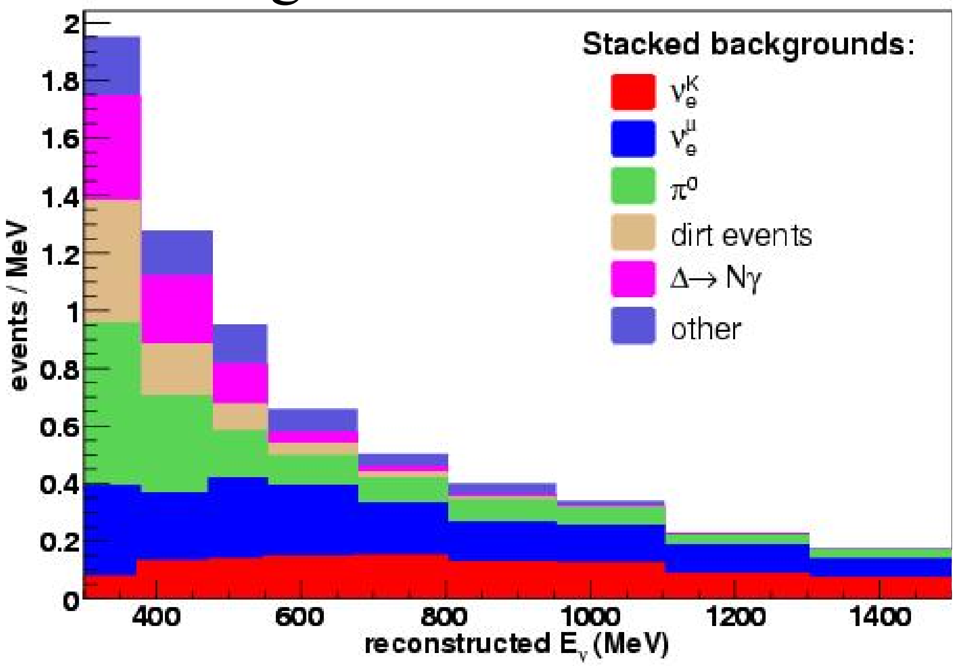
$Log(L_e/L_\pi)$

invariant mass

Efficiency:



Backgrounds after cuts



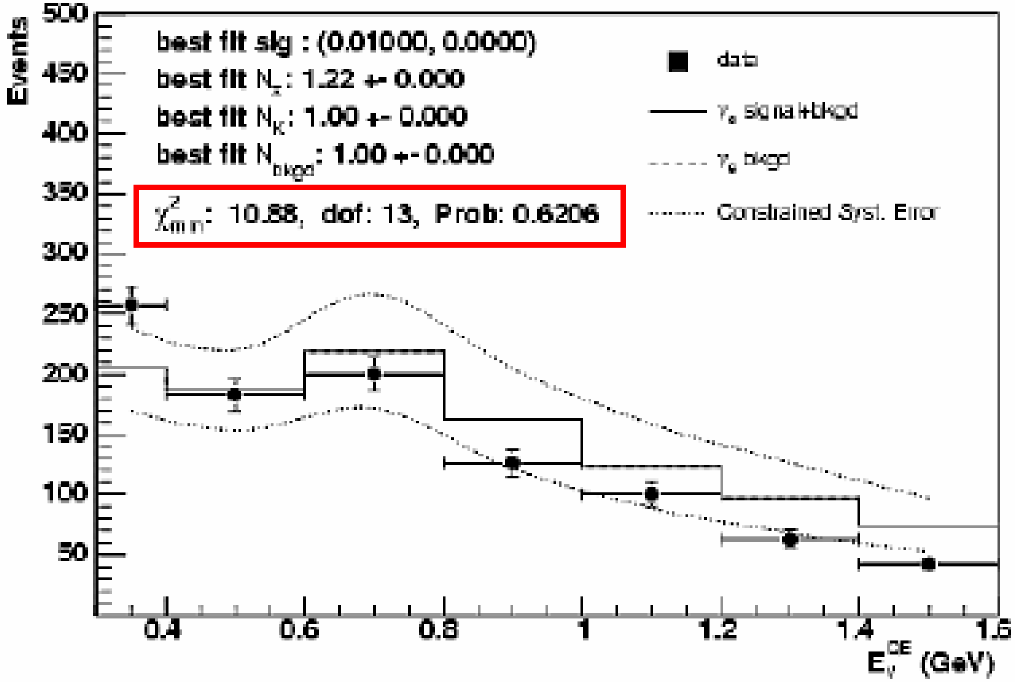
Low E Excess (current status)

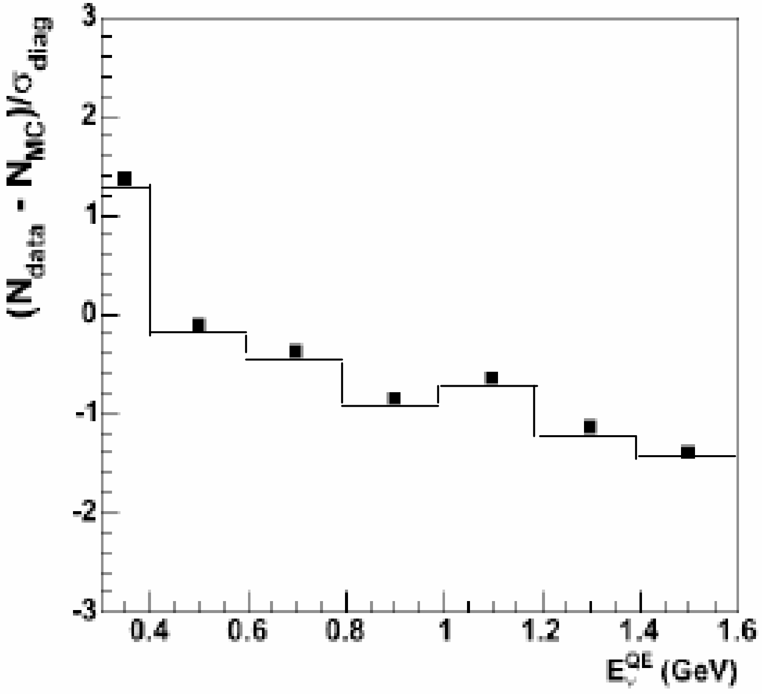
- ? Instrumental background: NO
- ? Study the excess with both Track and Boosting analysis
- Are they consistent in energy and numbers: YES
- Are there any reco issues (sidebands, etc): TB NO
- Excess down to 200 MeV with systematic errors.
- Is the excess electron/gamma-ray like: YES
- ? Is it a source of background
- Dirt/Delta rays: NO
- Pion or muon mis-id (including brem): NO
- Evis and UZ (low stats) shapes favor numu background(?)
- Photonuclear: ~20% of excess. Needs systematic errors.
- Other source of backgrounds? Still Investigating
- ? Do other data sets have low E excess
- NuMI -- different source, energy, baseline, backgrounds:
- appears consistent in energy and scales with nue rate.

Low E Excess

- Future Work
- ? Continue checking reconstruction/PID.
- ? Study PN contribution to excess, confirm in data.
- ? Study new sources of backgrounds.
- ? Understand systematics below ~200 MeV
- Apply to other distributions.
- ? Continue investigating forward excess.
- ? NuMI analysis matured, study correlations with
- MB excess, i.e. excess/numu, excess/nue,
- excess/pi0, etc. Does it scale with anything?
- ? Check excess with CCPi+ sample
- ? Check excess in Horn-off and anti-neutrino data.
- Look for POT or (flux*xsec) scaling.

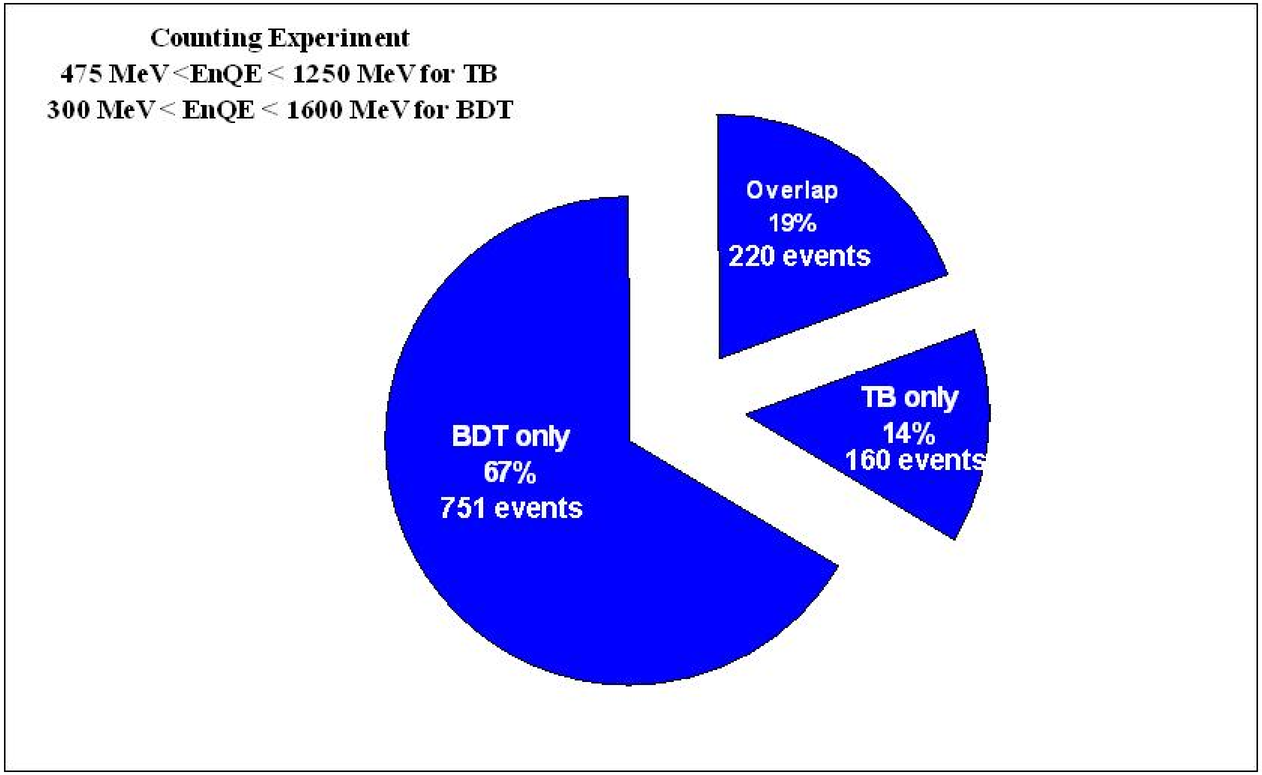
Boosted Decision Tree E_ν^{QE} data/MC comparis



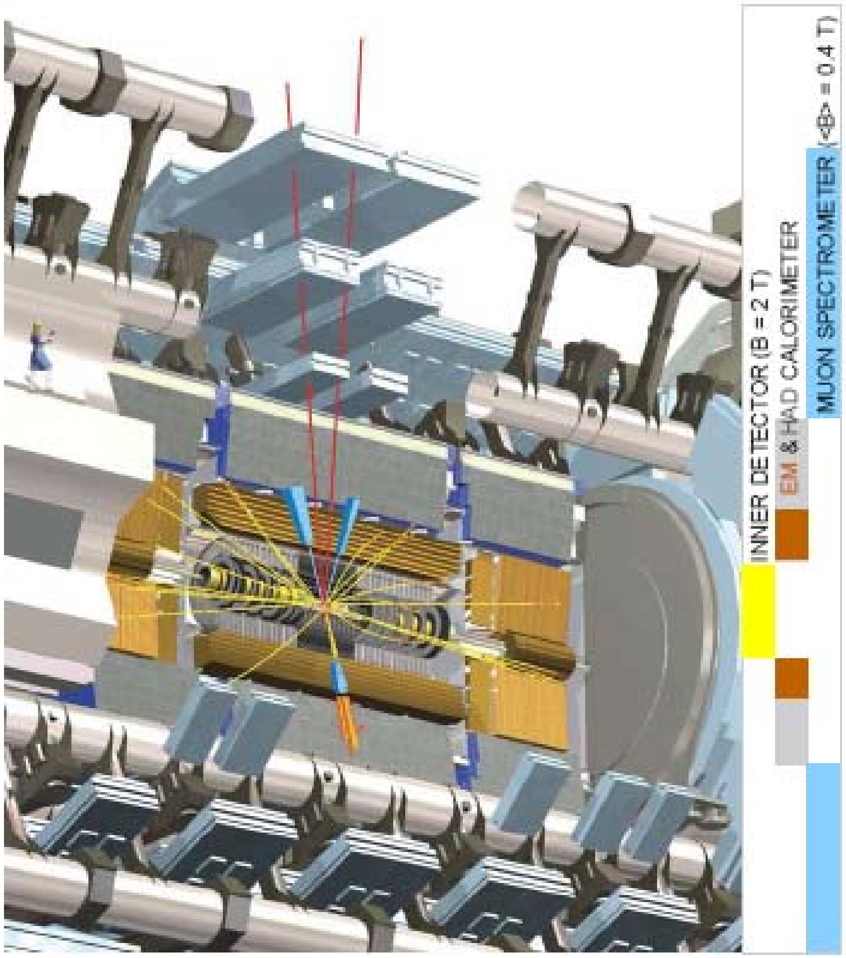


Boosted Decision Trees Analysis

Counting Experiment: $300 < E_\nu^{QE} < 1600$ MeV
data: 971 events
expectation: 1070 ±33 (stat) ± 225 (sys) events
significance: –0.38 σ



ATLAS Muon and Electron Identifications



Muons:

- Muon spectrometer track (MS: trigger + drift-tube chamb.), can be combined with the inner detector track. (ID: silicon detector + TRT)
- Low-p_T muons: ID track combined with MS hits.

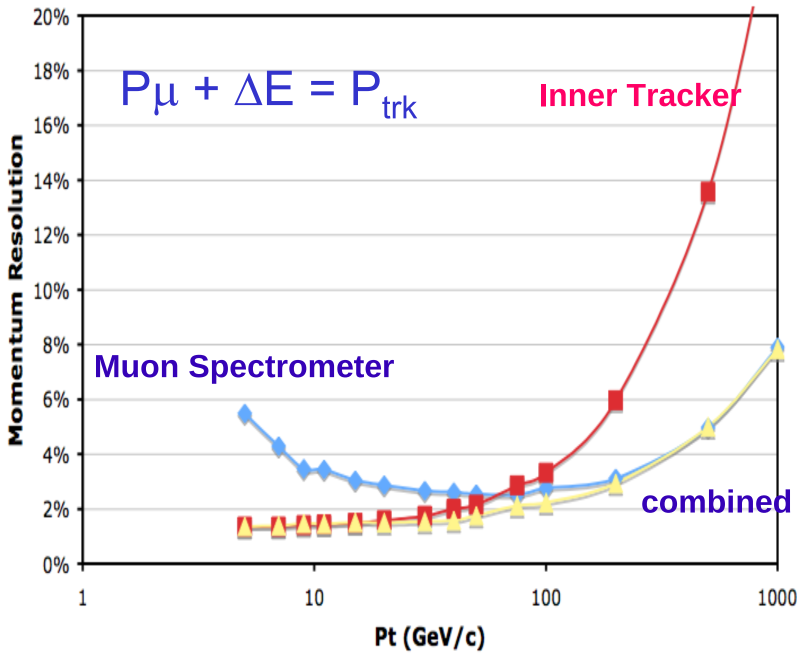
Electrons:

- Shower-shape analysis in the fine-granularity calorimeter, clusters are always matched with the ID track.
- Low-p_T electrons: ID combined with clusters.

Isolation criteria (given by the calorimeter or by the inner detector): suppressing leptons which come from jets.

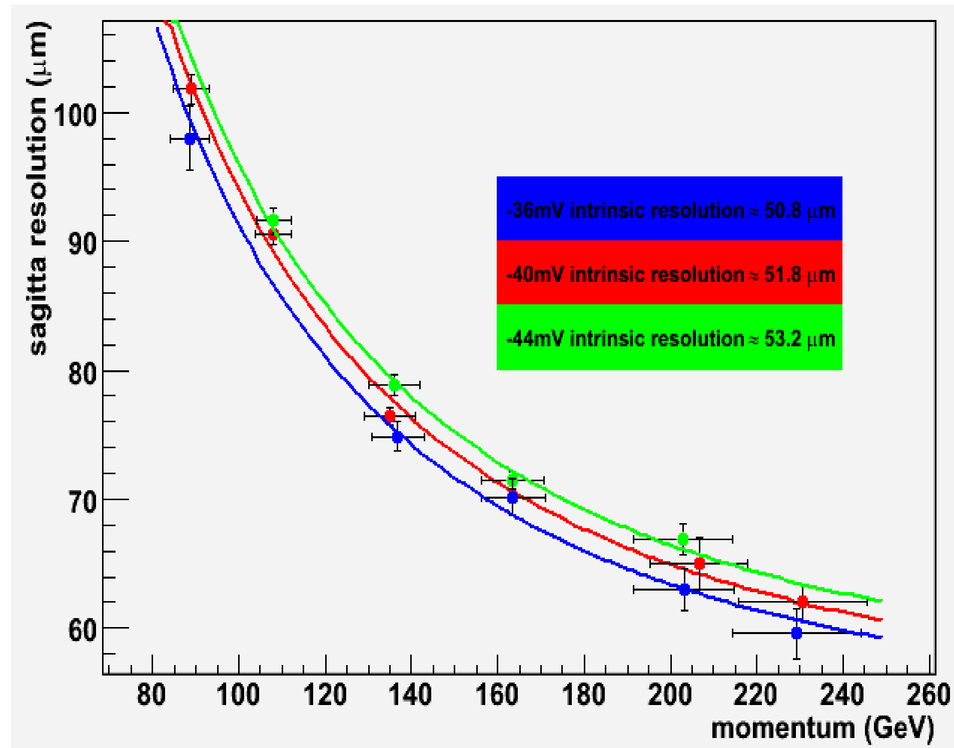
High Precision Tracking for Muon Detections

ATLAS



$|\eta|$ coverage to 2.7,
$\Delta p/p$ ~ 8% @ 1TeV
($\Delta s/s$ ~ 50 μ)

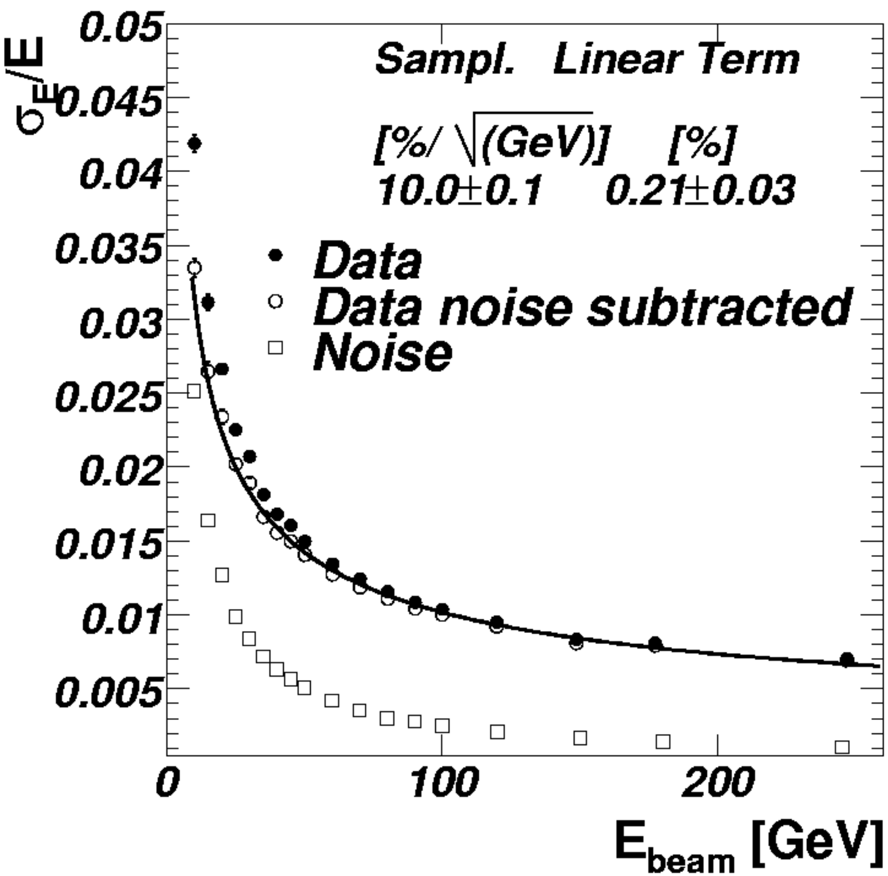
Precision tracking with MDT
With gas pressure of 3 bar



Test Beam results

ATLAS: ECAL Energy Resolution

Resolution with new reconstruction at η=0.68



Local energy resolution well understood since Module 0 beam tests and well reproduced by simulation :

-Sampling term given by lead/argon sampling fraction and frequency : quality control measurements during construction

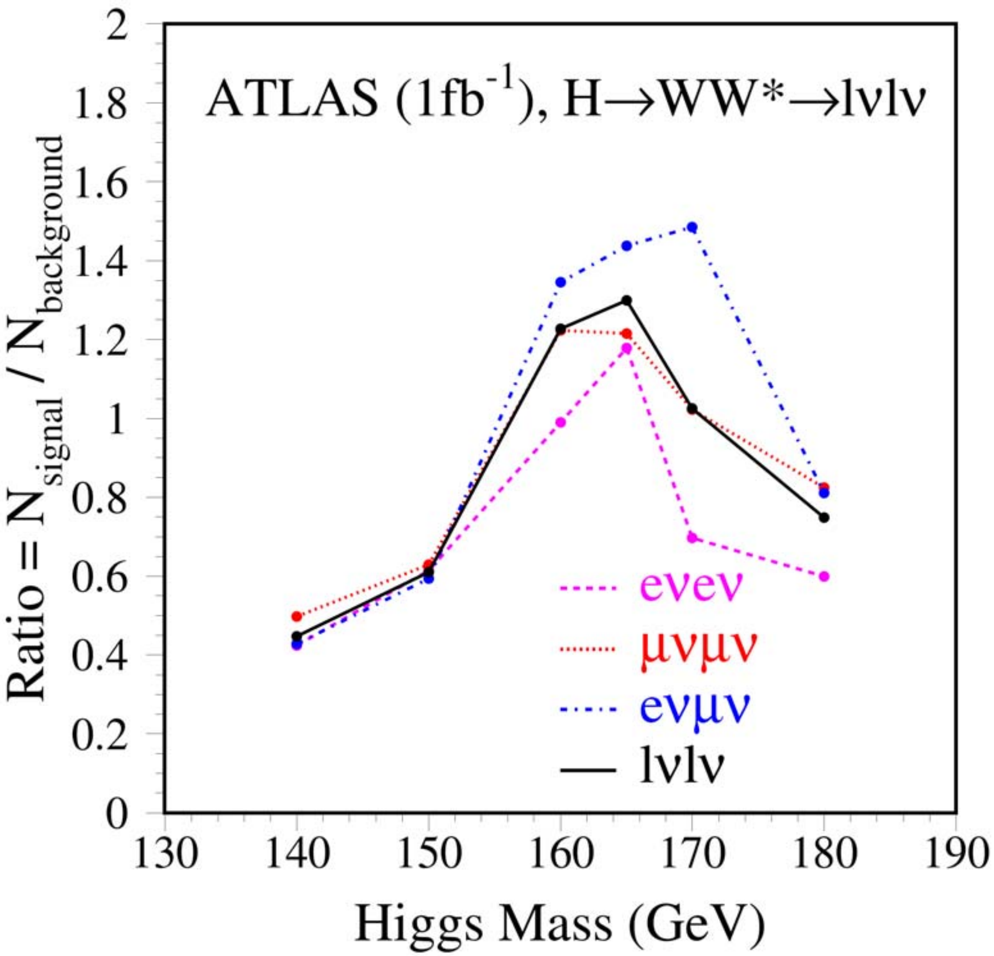
- Noise term under control

- Local constant term (within a cell) given by impact point correction

→Uniformity is at 1% level quasi online but achieving ATLAS goal (0.7 %) needs a lot of work, and most of the time was used to correct for setup problem…

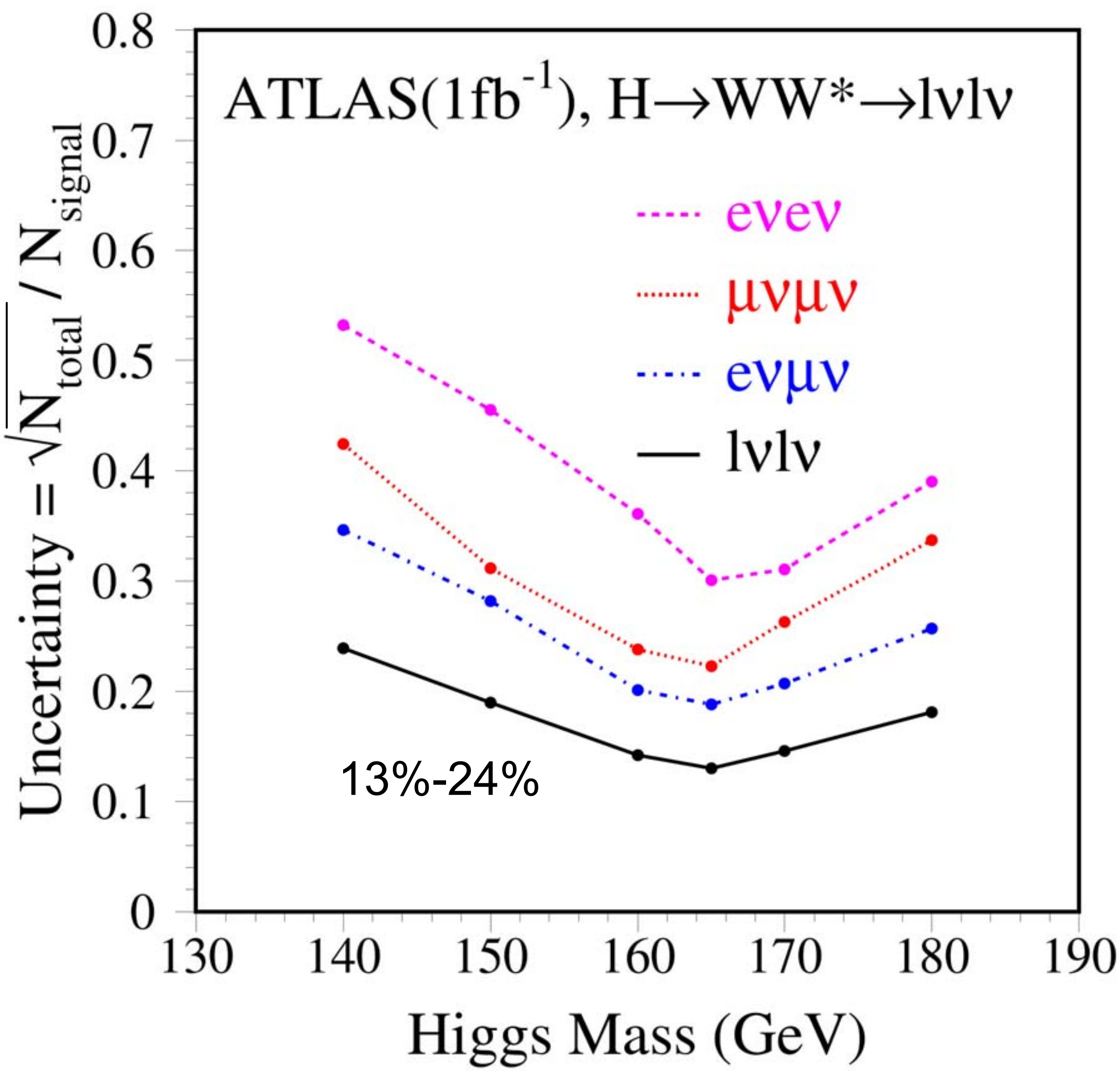
S/B Ratio of H → WW* → lνlν (BDT)

Straight Cuts: S/B ~ 0.3 – 1.1, Eff ~ 3-6%
BDT Cut: S/B ~ 0.4 – 1.3, Eff ~ 7-9%



$1\ fb^{-1}$	eνeν	μνμν	eνμν
BG140	27.9	33.6	64.9
H140	11.8	16.8	27.9
BG150	20.6	42.5	57.0
H150	12.7	26.7	33.8
BG160	15.6	26.2	32.0
H160	15.4	32.0	43.1
BG165	17.3	30.3	33.5
H165	20.4	36.8	48.2
BG170	36.3	27.9	26.4
H170	25.3	28.6	39.1
BG180	29.3	23.7	41.9
H180	17.5	19.5	33.9

Cross Section Uncertainty of $H \rightarrow WW^* \rightarrow l\nu l\nu$



Systematic Uncertainties

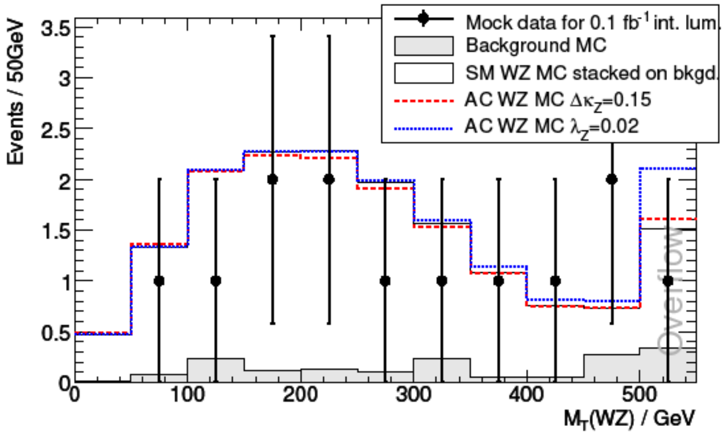
- Signal systematics ~9%
  - Luminosity measurement 6.5%
  - PDF assumption 3%
  - NLO scaling 5%
  - Particle ID 3%
- Background systematics ~18%
  (in addition to the above)
  - MC sample statistics 15% (may drop to 10%)
  - Calibration on lepton, jet energy 5%
- The systematic errors start to dominate the cross-section measurement uncertainties after 5-10 fb^{-1}.

Diboson sensitivity with 1 fb^{-1} int. lum.

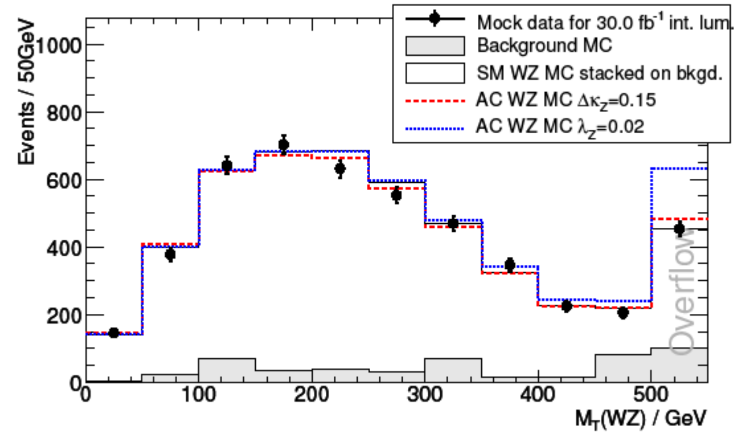
Diboson mode	Signal	Background	$S/\sqrt{B}$	Analysis
$W^+W^- \rightarrow e^+\nu e^-\nu$	78.0±1.6	35.4±3.6	13	BDT (ε =4.1%)
$W^+W^- \rightarrow \mu^+\nu\mu^-\nu$	90.3±1.6	20.2±2.8	20	BDT (ε =6.6%)
$W^+W^- \rightarrow e^+\nu\mu^-\nu$	419.9±3.5	80.8±6.0	47	BDT (ε =15.2%)
$W^+W^- \rightarrow l^+\nu l^-\nu$	104.4±2.4	19.3±2.4	24	Cut based (1.3%)
$W Z \rightarrow l\nu\, l^+l^-$	152.6±1.7	16.1±2.5	38	BDT (ε =17.9%)
$W Z \rightarrow l\nu\, l^+l^-$	53.4±1.6	6.7±1.2	20	Cut based (6.3%)
$ZZ \rightarrow 4l$	16.4±0.14	1.9±0.2	12	Cut based (8.4%)
$ZZ \rightarrow l^+l^-\, \nu\nu$	10.2±0.2	5.2±2.6	4.5	Cut based (2.6%)
$W\gamma \rightarrow e\nu\gamma$	2462±61	1134±34	73	BDT (ε =67%)
$W\gamma \rightarrow \mu\nu\gamma$	3855±77	1783±42	91	BDT (ε =67%)
$Z\gamma \rightarrow e^+e^-\gamma$	374±17	144±13	31	BDT (ε =67%)
$Z\gamma \rightarrow \mu^+\mu^-\gamma$	827±25	359±19	44	BDT (ε =67%)

M_T(WZ) spectrum sensitive to WWZ couplings

0.1 fb^{-1}

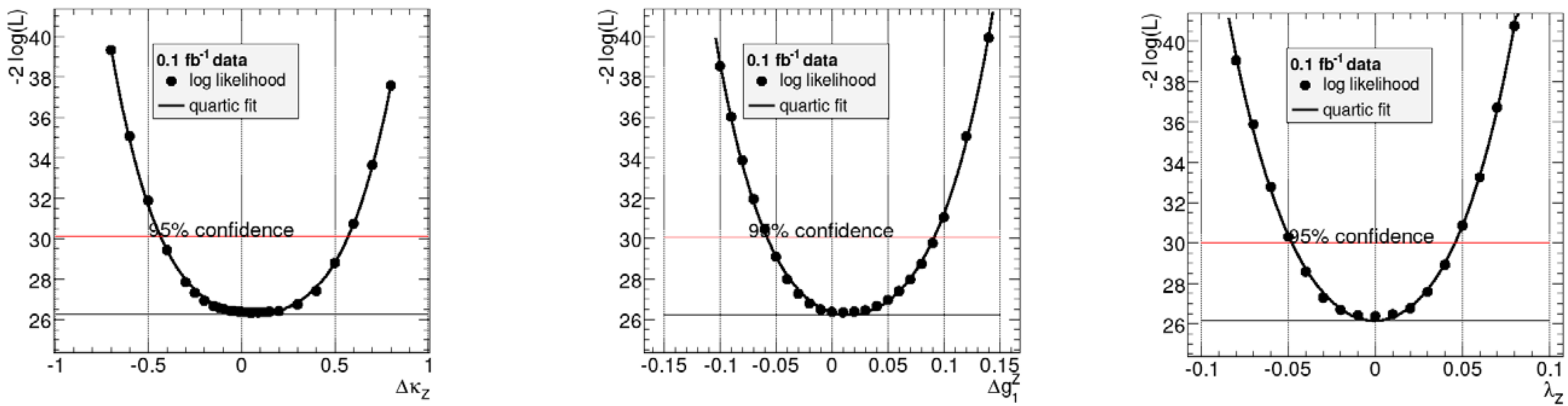


30 fb^{-1}



- Binned likelihood comparing mock SM observations to a SM profile and two reweighted anomalous profiles
- M_T(WZ) was found to be the most sensitive kinematics quanitity (P_T(Z), M(ll), and others are also useful, but not as sensitive).
- Using 10 bins from 0-500GeV and one overflow bin.

TGC sensitivity using $M_T(WZ)$ with $0.1 fb^{-1}$ integrated luminosity



One parameter limits (assuming other couplings are SM)

$-0.4 < \Delta\kappa_Z < 0.6$

$-0.06 < \Delta g_1^Z < 0.1$

$-0.06 < \lambda_z < 0.05$

<u>Tevatron results</u>

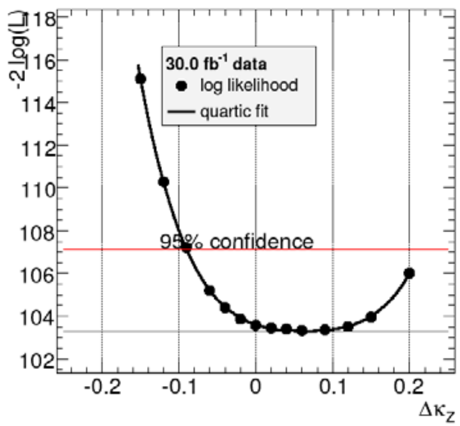
$-0.12 < \Delta\kappa_z < 0.29$ 2 TeV D0 with $1.0\ fb^{-1}$

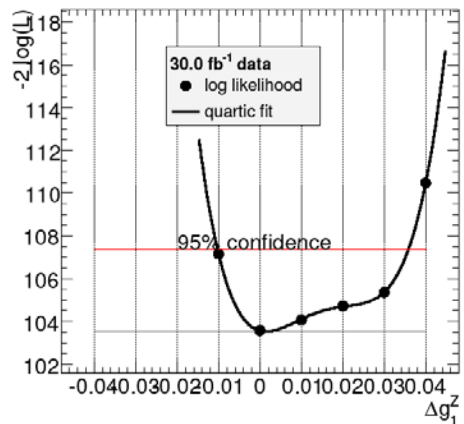
$-0.17 < \lambda_z < 0.21$

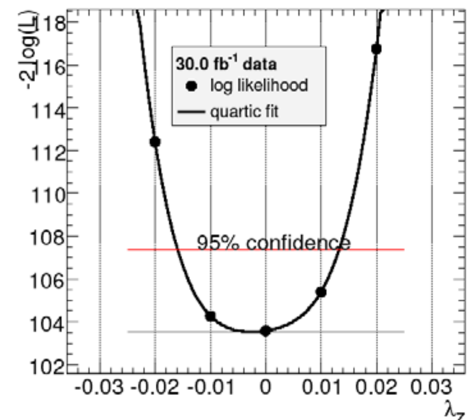
$-0.82 < \Delta\kappa_z < 1.27$ 2 TeV CDF with $1.9\ fb^{-1}$

$-0.13 < \lambda_z < 0.14$

TGC sensitivity using $M_T(WZ)$ with $30 fb^{-1}$ integrated luminosity







One parameter limits (assuming other couplings are SM)

Λ=2 TeV

$-0.08 < \Delta\kappa_Z < 0.17$

$-0.01 < \Delta g_1^Z < 0.008$

$-0.005 < \lambda_z < 0.023$

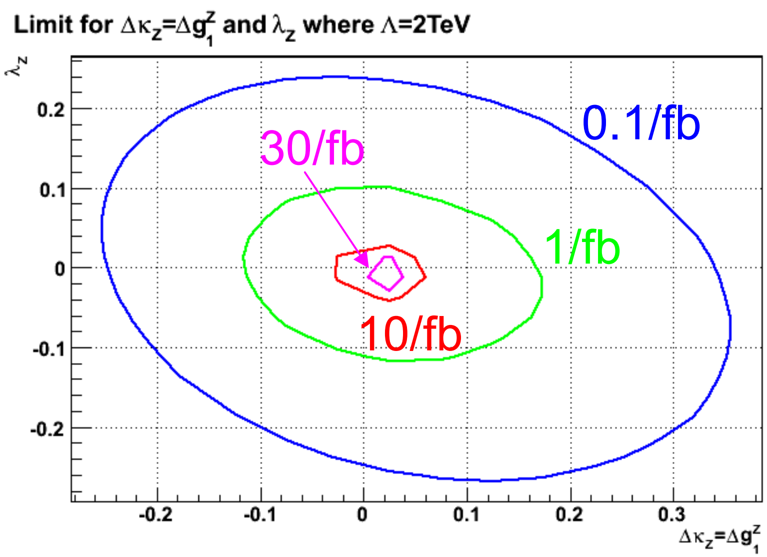
Λ=3 TeV

$-0.07 < \Delta\kappa_Z < 0.13$

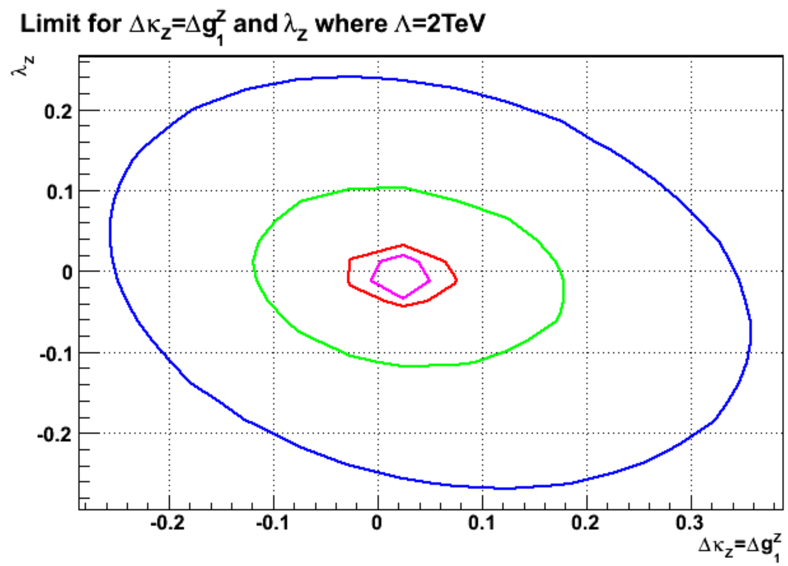
$-0.003 < \Delta g_1^Z < 0.018$

$-0.008 < \lambda_z < 0.005$

Systematic Error Effect on TGCs 2D Limits, Λ=2TeV, using $P_T(Z)$



No systematic errors



9.2% signal, 18.3% background

Atlas TGC sensitivity for the first 10 fb^{-1}

95% CL intervals for anomalous charged TGCs Compared with Tevatron and LEP limits

Diboson, (fit spectra)	λ_Z	$\Delta\kappa_Z$	Δg_1^Z	$\Delta\kappa_\gamma$	λ_γ
WW, (M_T)	[-0.040, 0.038]	[-0.035, 0.073]	[-0.149, 0.309]	[-0.088, 0.089]	[-0.074, 0.165]
WZ, (M_T)	[-0.015, 0.013]	[-0.095, 0.222]	[-0.011, 0.035]		
$W(e\nu)\gamma$, $(P_T(\gamma))$				[-0.34, 0.12]	[-0.07, 0.03]
$W(\mu\nu)\gamma$, $(P_T(\gamma))$				[-0.30, 0.09]	[-0.05, 0.02]
$W^\pm\gamma$ (D0), L = 0.16fb^{-1}				[-0.88,0.96]	[-0.2,0.2]
WZ, (D0) L = 1.0fb^{-1}	[-0.17, 0.21]	[-0.12, 0.29] $(\Delta g_1^Z = \Delta\kappa_Z)$			
WW, (LEP)	$(\lambda_\gamma = \lambda_Z, \Delta\kappa_Z = \Delta g_1^Z - \Delta\kappa_\gamma \tan^2\theta_W)$		[-0.051,0.034]	[-0.105,0.069]	[-0.059,0.026]

Details can be found in the ATLAS Diboson CSC note

MiniBooNE first results arXiv:0704.1500

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ATLAS CSC NOTE

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Diboson Physics Studies With the ATLAS Detector

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Abstract

We present studies of the Standard Model (SM) diboson (W^+W^-, $W^\pm Z^0$, Z^0Z^0, $W^\pm\gamma$, and $Z^0\gamma$) productions in pp collisions at $\sqrt{s} = 14$ TeV, through their leptonic decay channels with electron, muon and photon final states. Our studies use the ATLAS CSC (Computer-System-Commissioning) datasets, which include the trigger information and the detector calibration and alignment corrections. We aim to establish the SM diboson detection sensitivities with the ATLAS experiment in early LHC physics runs (for 0.1 to 1 fb^{-1} integrated luminosities). We have included large fully simulated background events in our studies to understand the sources of background for diboson detection. We estimate the cross section measurements uncertainties (both statistic and systematic) as a function of integrated luminosity (from 0.1 to 30 fb^{-1}) and to establish the ATLAS experiment sensitivities to anomalous triple gauge boson couplings. This note shows that the SM W^+W^-, $W^\pm Z^0$, $W^\pm\gamma$, $Z^0\gamma$ signals can be established with the signal statistical sensitivity better than 5σ for the first 0.1 fb^{-1} integrated luminosity, and the Z^0Z^0 signals can be established with 1.0 fb^{-1} integrated luminosity with ATLAS detector. The anomalous triple gauge boson coupling sensitivities can be significantly improved even with 0.1 fb^{-1} data over the results from Tevatron based on 1 fb^{-1} data.