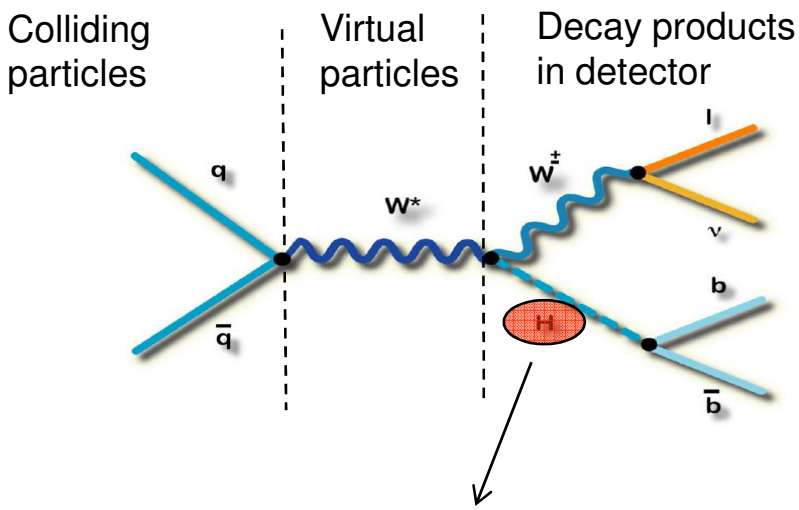
Search for Higgs Boson Produced in Association with a W Boson at CDF II

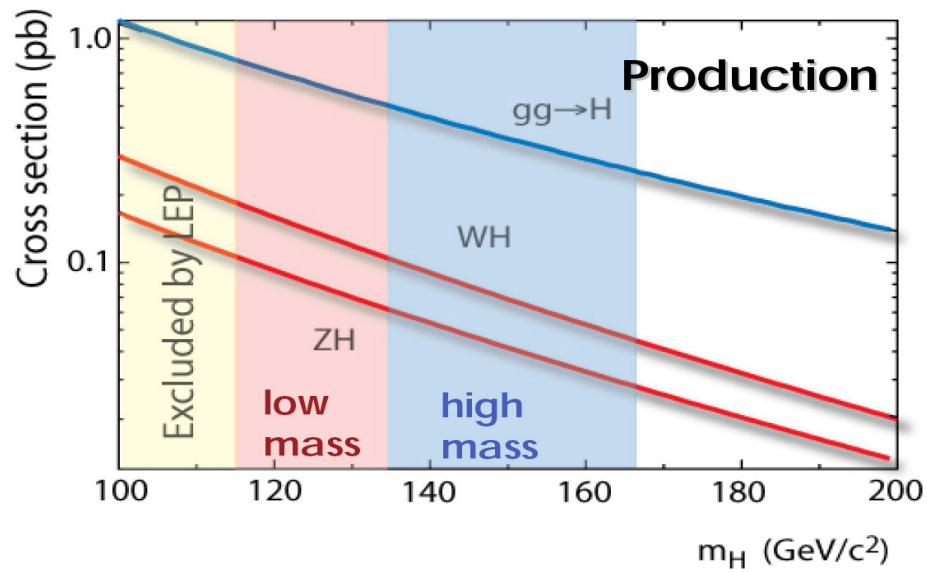
Adrian Buzatu,
McGill University

on behalf of the
CDF Collaboration

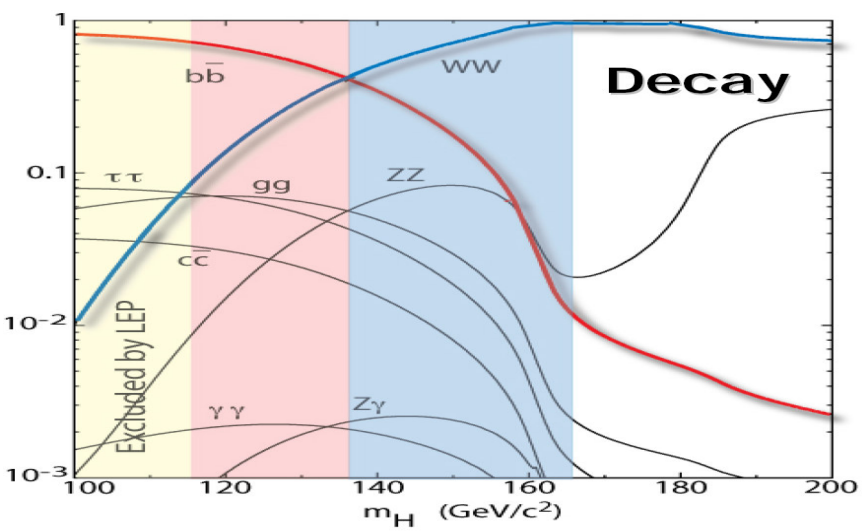
Canadian Association of Physicists Congress,
08 June 2009, Moncton

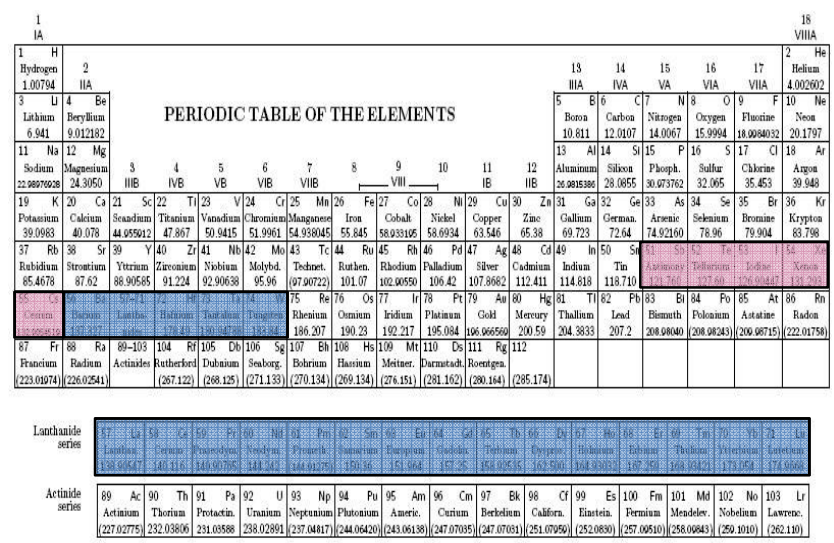
The Higgs Particle's Territory





Higgs Particle (H)
Elementary particle as massive as heavy atoms





Tevatron, CDF

Tevatron Accelerator

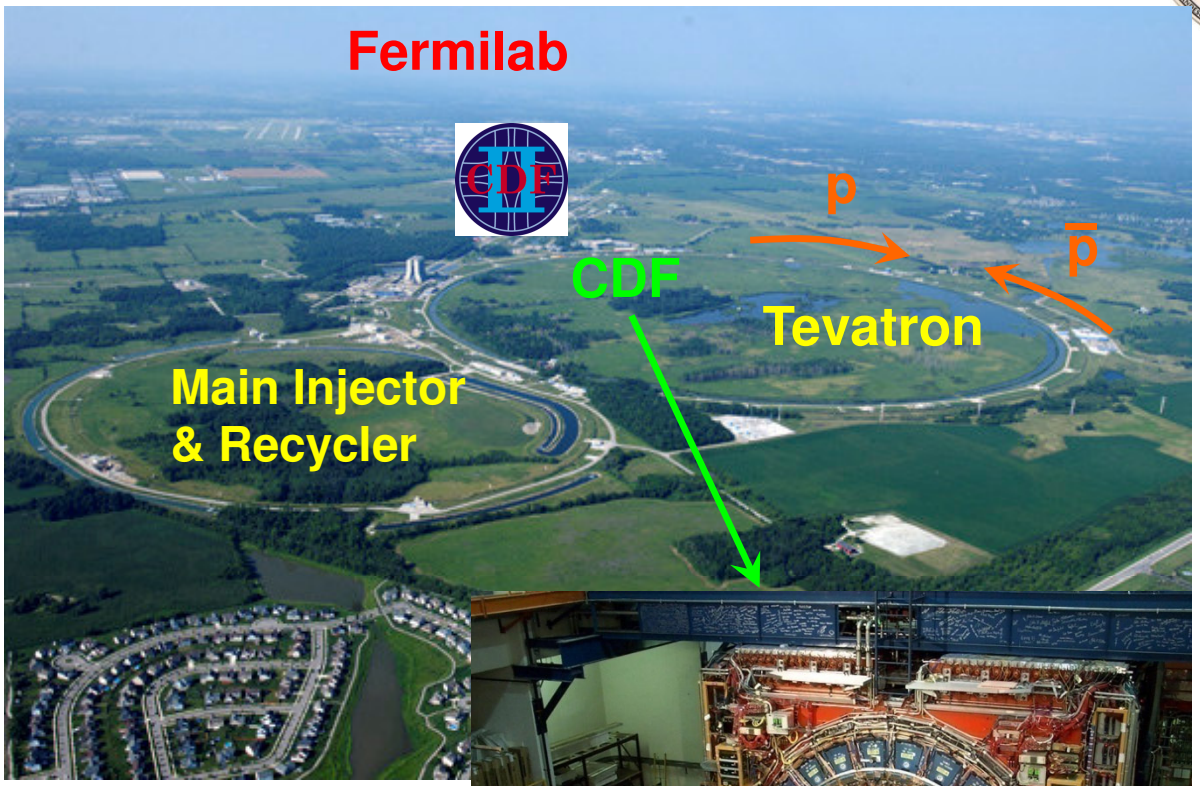
- ppbar collisions at $\sqrt{s} = 1.96\,TeV$

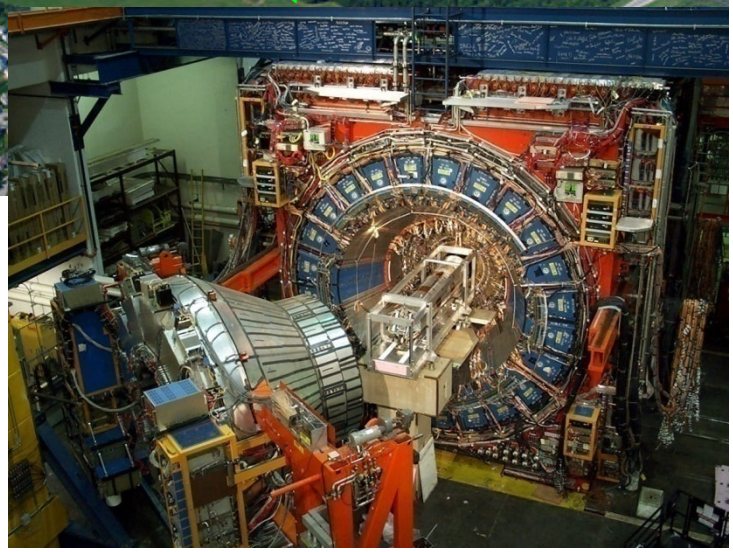
CDF Apparatus

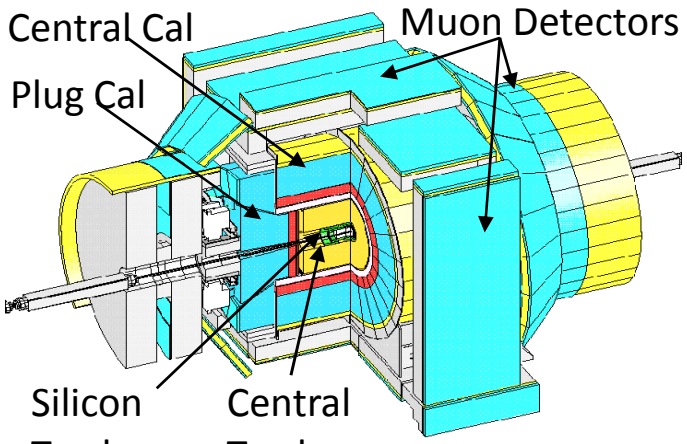
- Well understood
- General purpose detector

Integrated Luminosity

- 5.4 fb^{-1} delivered
- 3.2 fb^{-1} analyzed







WH Analysis strategy

Event Selection

Estimate signal and backgrounds

Use multivariate techniques to separate signal and background

Perform a binned likelihood fit of the discriminant distribution

Set limits on the cross section times branching fraction as a function of Higgs boson mass

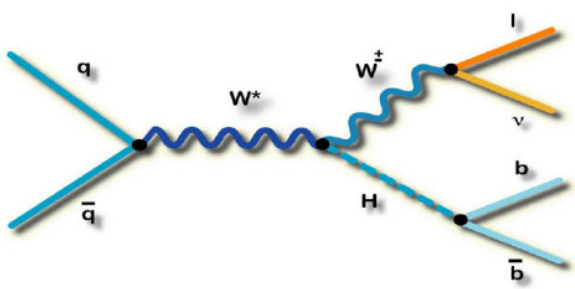
3 orthogonal charged lepton categories

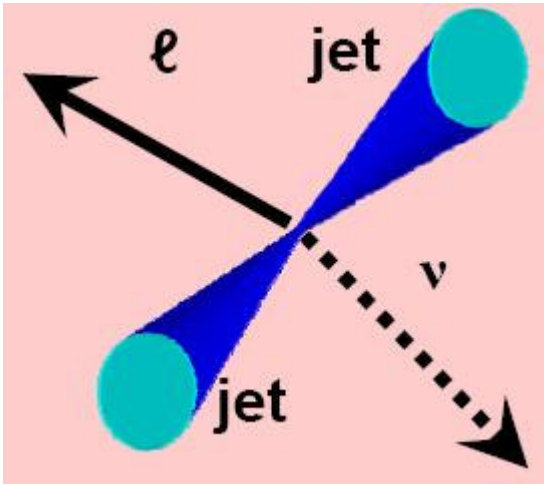
×

9

3 orthogonal b-tagging categories

WH Event Selection





3 Orthogonal Charged Lepton Categories

- **Central** (electron or muon), $|\eta|<1.1$
- **Forward** (electron), $1.1<|\eta|<2.0$
- **Isolated track** (muon, electron, tau) $|\eta|<1.2$
- For all: $P_T>20$ GeV

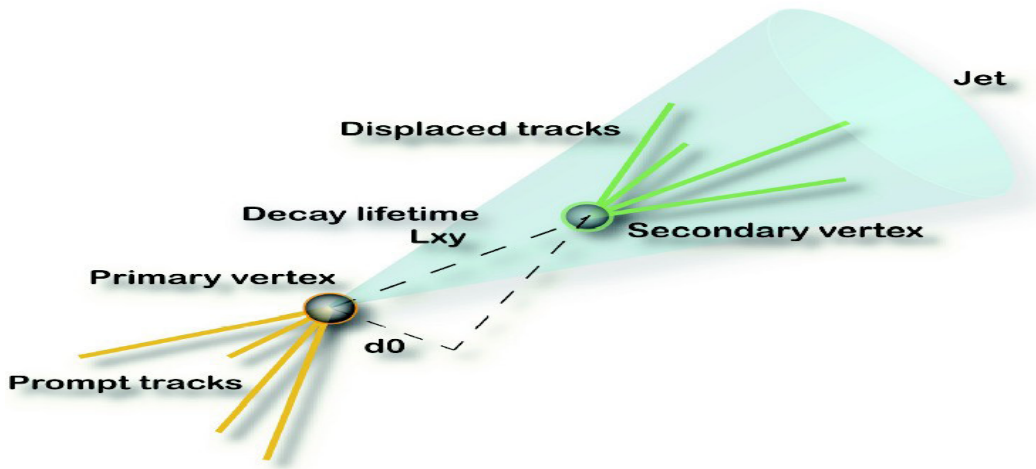
Missing Transverse Energy

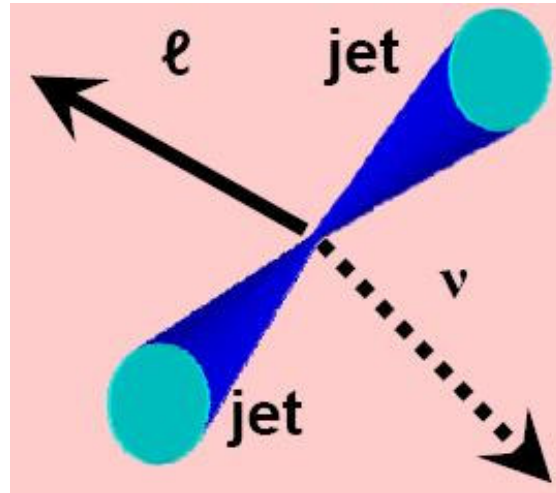
- MET > 20 GeV for central and isolated track for 2 tag
  - For 1 tag, also add a QCD veto
- MET > 25 GeV + QCD veto for forward

Jet Requirements

- Exactly 2 tight jets
- $E_T>20$ GeV, $|\eta|<2.0$ for central and forward
- $E_T>25$ GeV, $|\eta|<2.0$, one with $|\eta|<0.9$ and dR of jets > 1 for isolated track (dR is angular separation between the two jets)
- At least one jet is b-tagged

b-tagging





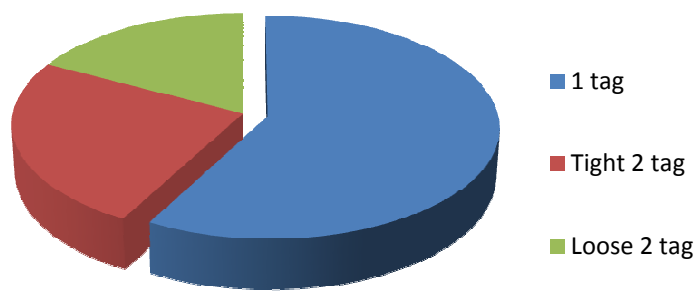
b-tagging Principles

- B hadrons are long lived
- Look for displaced vertices
- Look at impact parameters of tracks from jets

3 Orthogonal b-tagging Categories

- **Tight 2 Tag**
  - Secondary Vertex + Secondary Vertex
- **Loose 2 Tag**
  - Secondary Vertex + Jet Probability
- **1 Tag**
  - Secondary Vertex

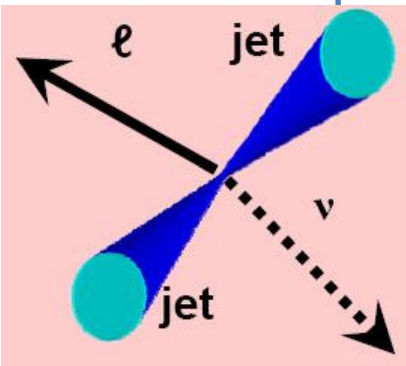
WH signal (m_H =120 GeV)
All charged lepton categories
Distribution of tag categories



Background Estimation

Estimated from Data

- QCD events that fake a W boson signature
  - MET faked by jet energy mismeasurement
  - Charged Lepton faked by a jet
- W boson + Light Flavour



Estimated from Data and MC

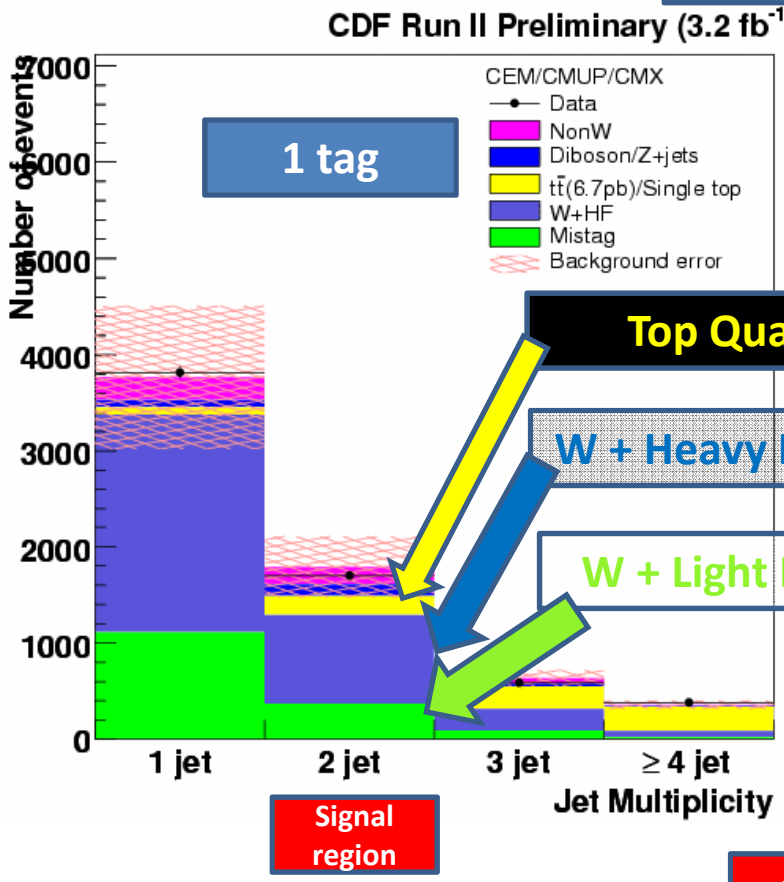
- W boson + Heavy Flavour (W+bb, W+cc, W+c)

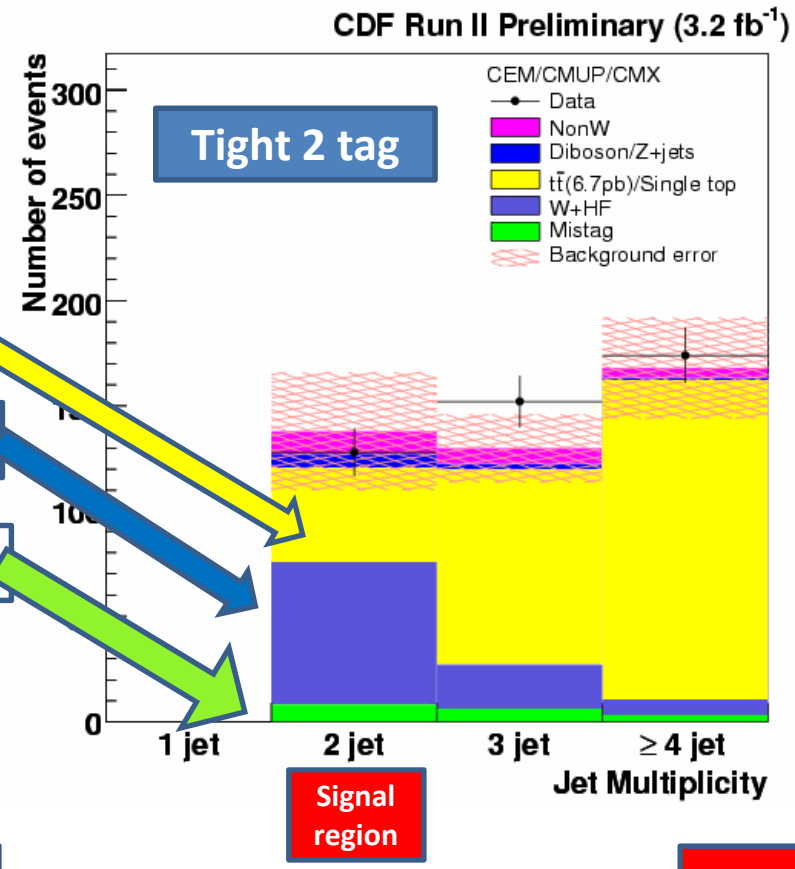
Estimated from MC

- Top quark events (ttbar, single top)
- Diboson events (WW, WZ, ZZ)
- Z boson Events (Z + jets)

Backgrounds example

Central Charged Lepton





Top Quark

W + Heavy Flavour

W + Light Flavour

1.7+-0.1

Main backgrounds for 1 tag

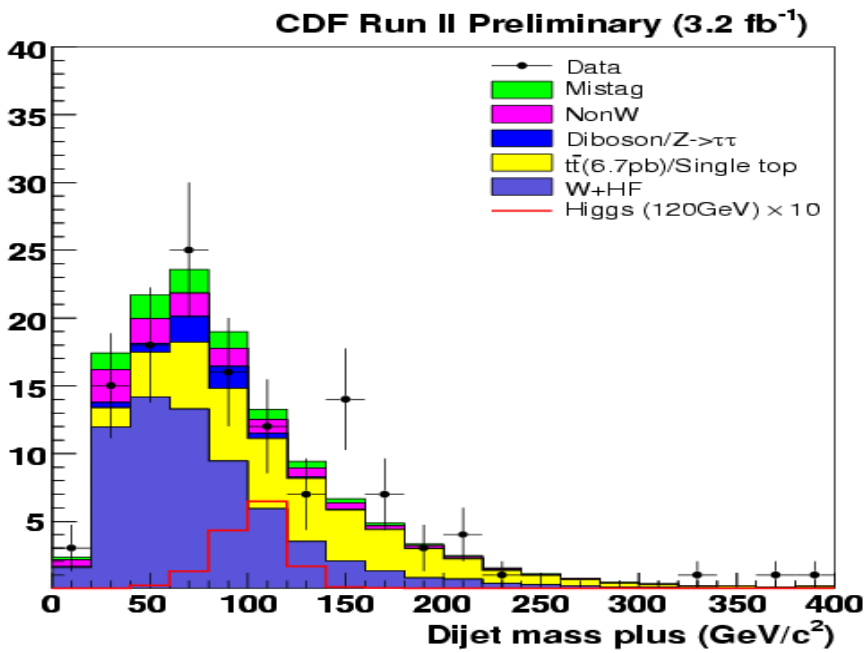
- W boson + Heavy Flavour (HF: bb, cc)
- W boson + Light Flavour (LF: mistag)

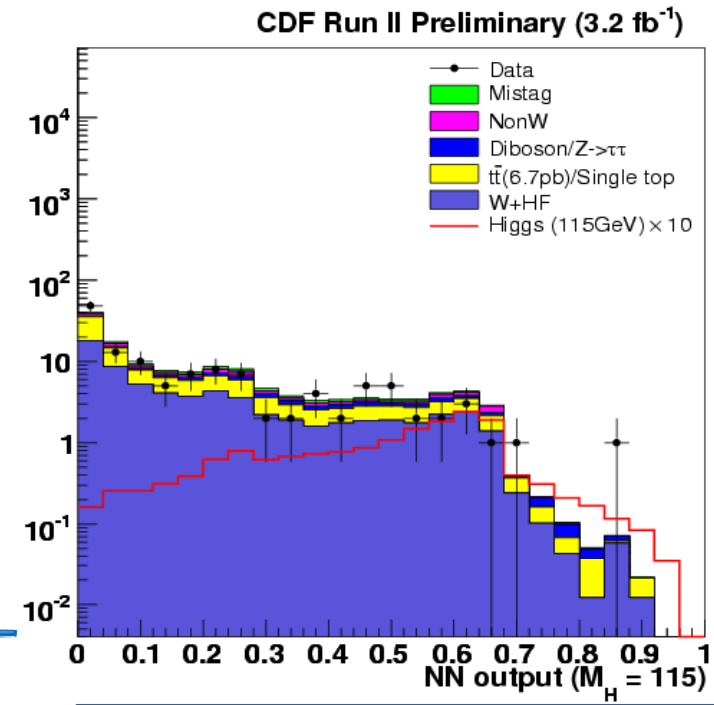
4.2+-0.4

Main backgrounds for 2 tag

- W boson + Heavy Flavour (HF: bb, cc)
- Top Quark (ttbar, also single top)

Neural Network





Invariant mass of two jets

- **Most sensitive variable**
- Also a third loose jet, if close to tight jets

+ other kinematic variables

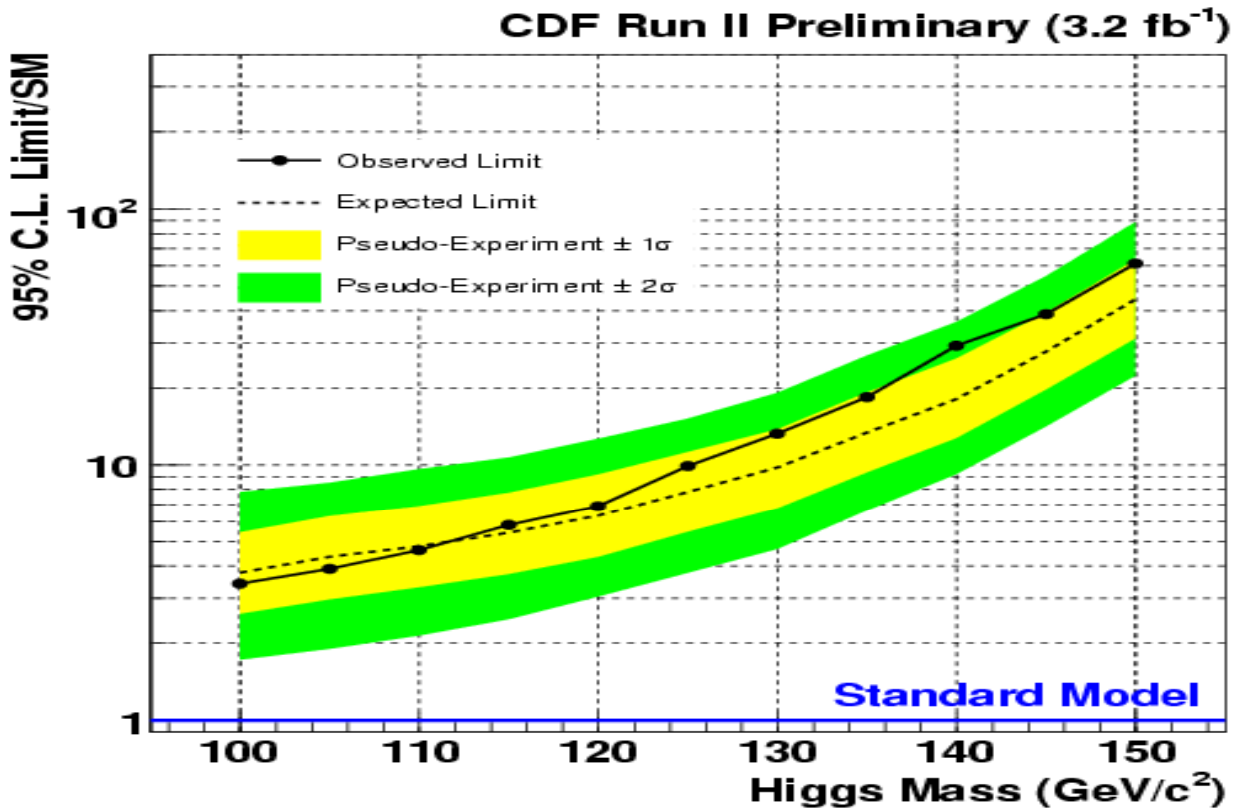
- **Sensitive to Top Quark Pair or to W+ HF**

Charged lepton
Tight 2 tag
115 GeV Higgs mass

× **11**

From 100 GeV to 150 GeV, with 5 GeV steps

NN Result: $\sigma(p\bar{p} \to W^{\mp}H) \cdot BR(H \to b\bar{b})$



Upper limit on WH cross section times the branching fraction, as a ratio with the SM prediction (limit as a function of Higgs boson mass)

9 orthogonal categories combined in this result

11 Higgs boson **mass points**

WH Search at CDF

Event Selection

3 orthogonal categories of charged lepton

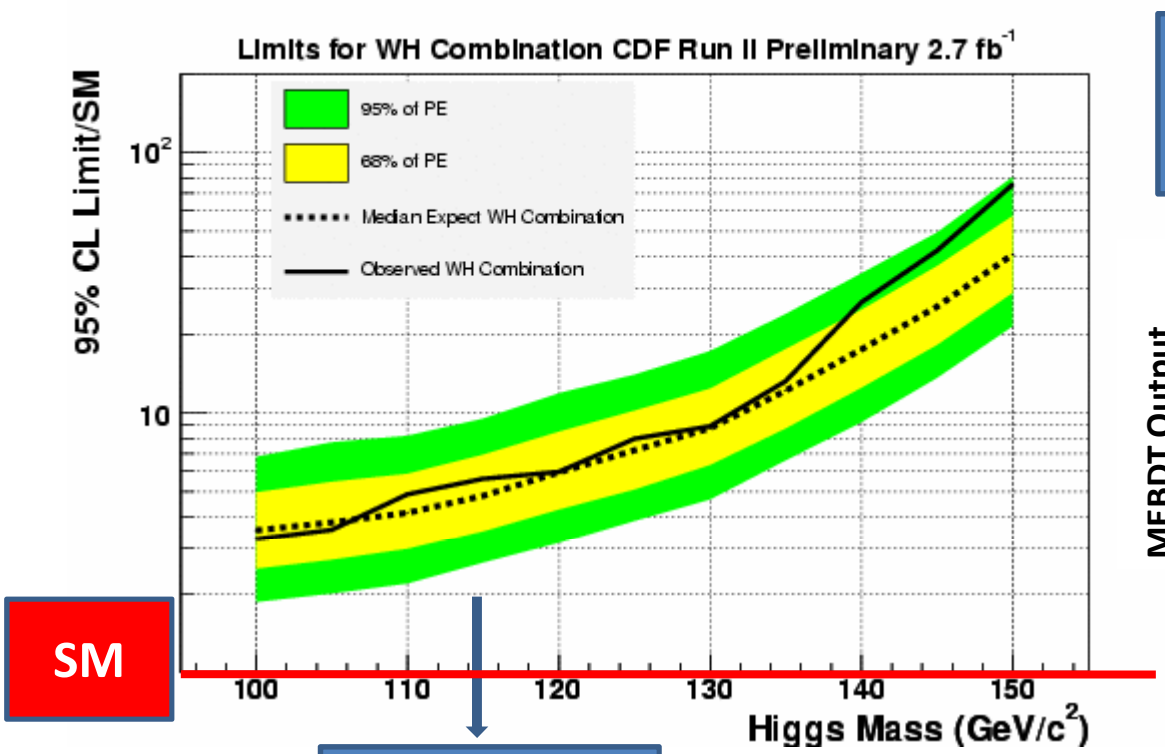
3 orthogonal categories of b-tag

Neural Network Discriminant (NN)

Matrix Element + Boosted Decision Tree Discriminant (MEBDT)

Super-Discriminant Combines NN and MEBDT

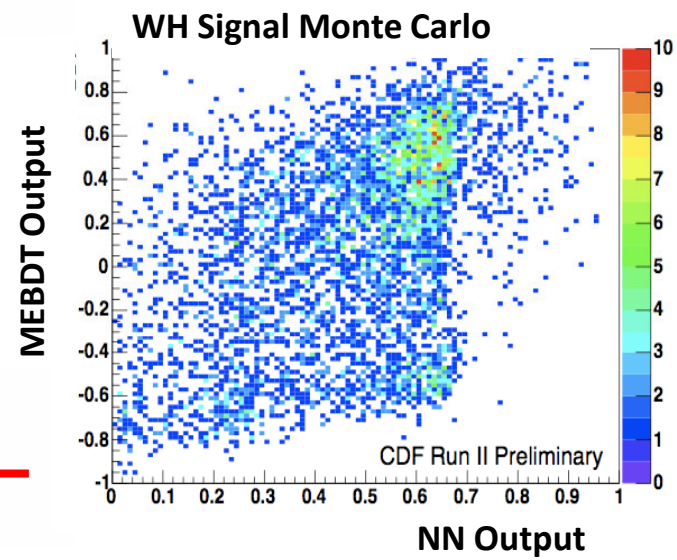
NN and ME+BDT Combined: $\sigma(p\bar{p} \to W^{\mp}H) \cdot BR(H \to b\bar{b})$



SM

m_H=115 GeV

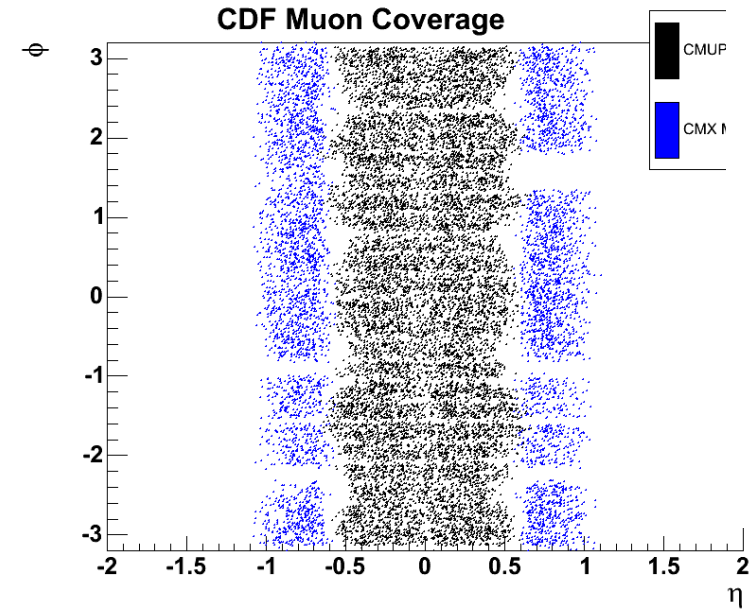
NN and MEBDT discriminants are not fully correlated, so we can improve the sensitivity by combining the two analyses

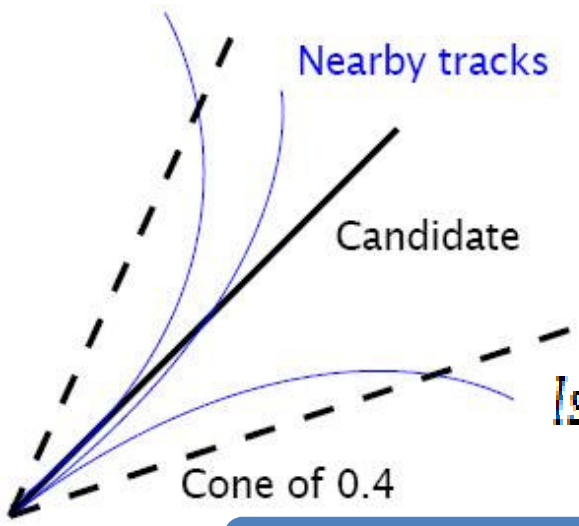


Discriminant	Expected Limit	Observed Limit
NN	5.8 x σ_{SM}	5.2 x σ_{SM}
ME+BDT	5.2 x σ_{SM}	6.2 x σ_{SM}
COMBINED	4.8 x σ_{SM}	5.6 x σ_{SM}

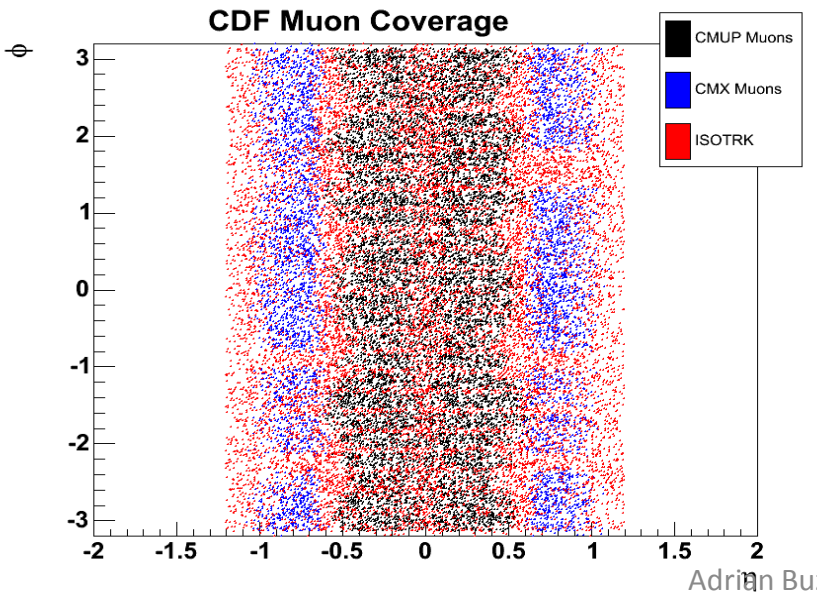
At m_H=115 GeV, sensitivity improves by 8% over the most sensitive multivariate technique

Charged Lepton as Isolated Track





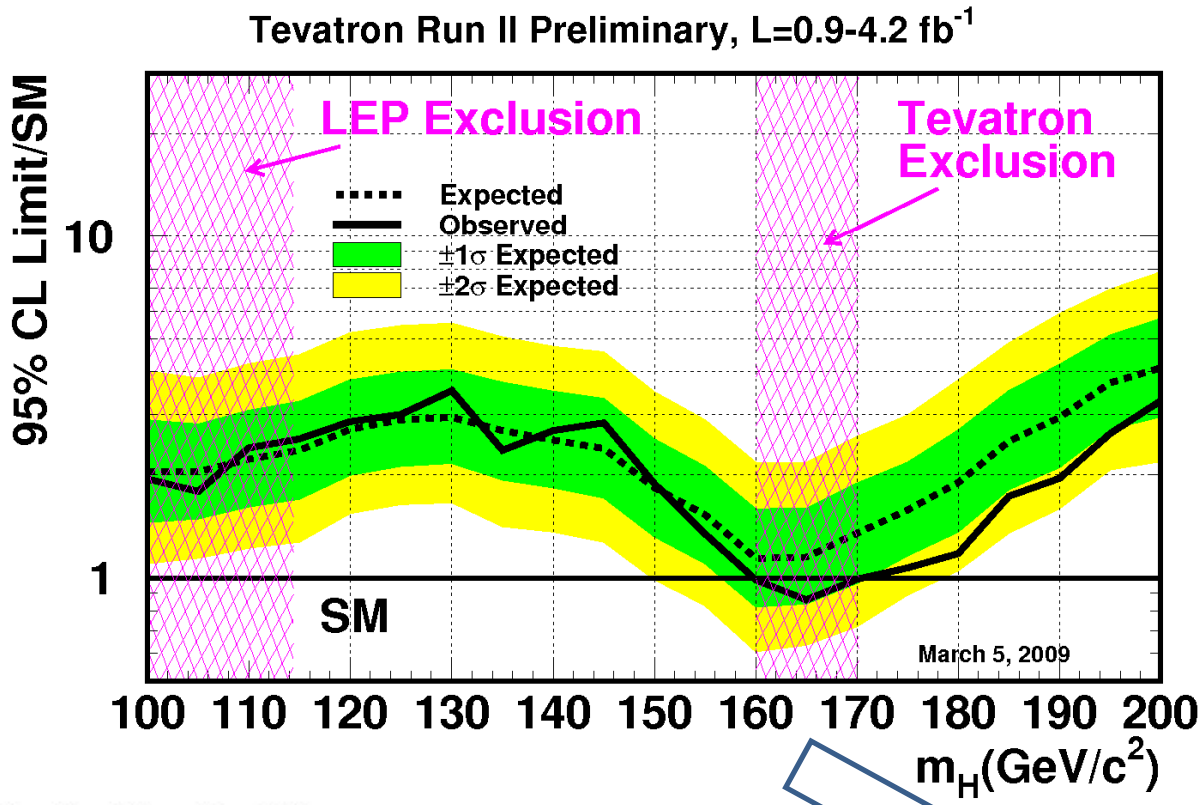
$$Isol = \frac{P_T(cand)}{P_T(cand) + \sum P_T(trk)}$$



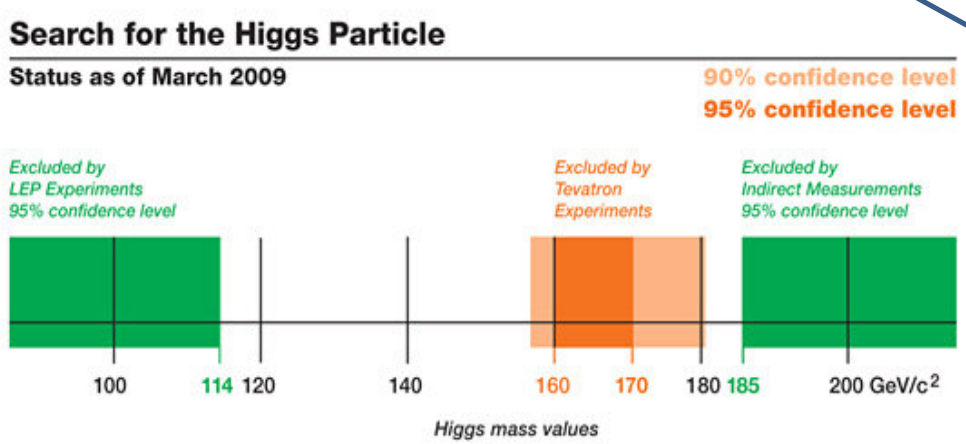
Isolated Track

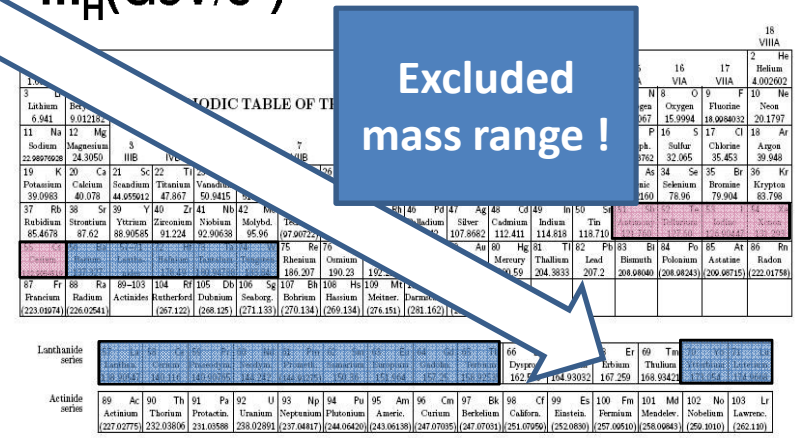
- High-P_T track (> 20 GeV)
- Isolated from other tracks (Isol > 0.9)
- Is not Central or Forward charged lepton
- Is not required to match a calorimeter tower or a muon chamber
- **Fills in the gaps, adds 25% more acceptance!**
- 85% muon, 7% electron and 7% tau candidates

Latest Tevatron Higgs Combination



First SM Higgs mass exclusion through direct searches at Tevatron





Excluded mass range !

Conclusion & Discussions
WH Search at CDF

Super discriminant

8 % increase in sensitivity

over best method

NN

- Central Charged Lepton
- Forward Charged Lepton

ME+BDT

Isolated Track

-Adds 25% WH acceptance (by filling in the gaps)

- Improves resolution by 10% on $\sigma(p\bar{p} \to W^{\mp}H) \cdot BR(H \to b\bar{b})$

- Will add new triggers for this chnallel

-Machinery already in place

- Expect 3.6 fb^{-1} for Lepton Photon (3.0 fb^{-1} now)

Backup Slides

Improvements for Lepton-Photon 09

Improve WH signal acceptance

Improve W boson acceptance
- Add new trigger paths for isolated track

Improve Higgs boson acceptance
- Incorporate Roma tagger and KIT flavor separator to improve loose b-tagging categories

Optimize event selection
- Include 3-jet bin

Improve measurement precision

Dijet invariant mass distribution
- Use b-quark specific jet corrections

Optimize multivariate technique discriminants
- NN, BDT, super-discriminant

Optimize event selection
- Reject events with extra isolated track
- Optimize jet E_T cuts

Improve background modeling
- Especially for QCD

Triggers for Isolated Track

No dedicated isolated track triggers at CDF

- MET + 2 Jets
- MET45
- MET + DIJET
- Muon Gap Triggers

Used for ICHEP 08: 25% improvement in acceptance over Central

To be added for Lepton Photon 09 & Estimate
25-30% acceptance improvement over MET + 2 Jets

Measure turnon curves for analysis
and systematic uncertainties

Use turnon curves in data and MC

Evaluate trigger systematic
uncertainty for isolated tracks

Measure turnon curves

Select an orthogonal trigger

Select events that mimic WH

Cuts on the selection variables of the trigger, as to be in the plateau region, for them except for the parameterization variable

These events form the Denominator. The Numerator is formed by events that also fire our trigger

We divide numerator and denominator to get turnon curve

Three trigger levels

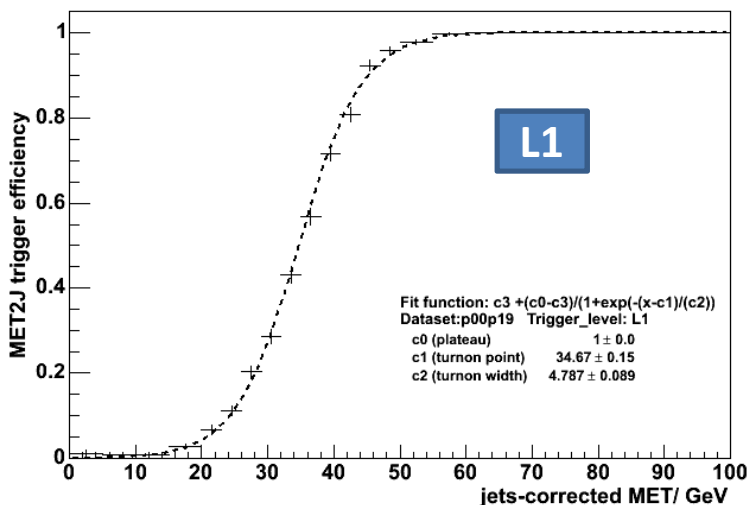
3

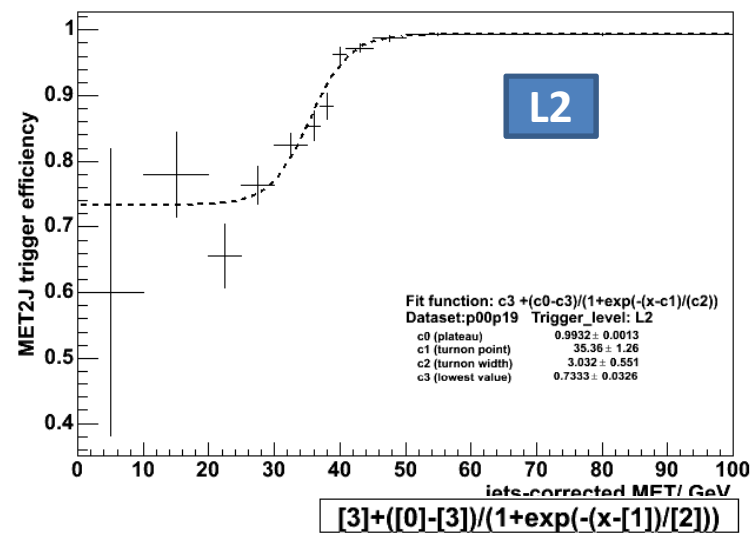
Multiply the three turnon curves to get the final one

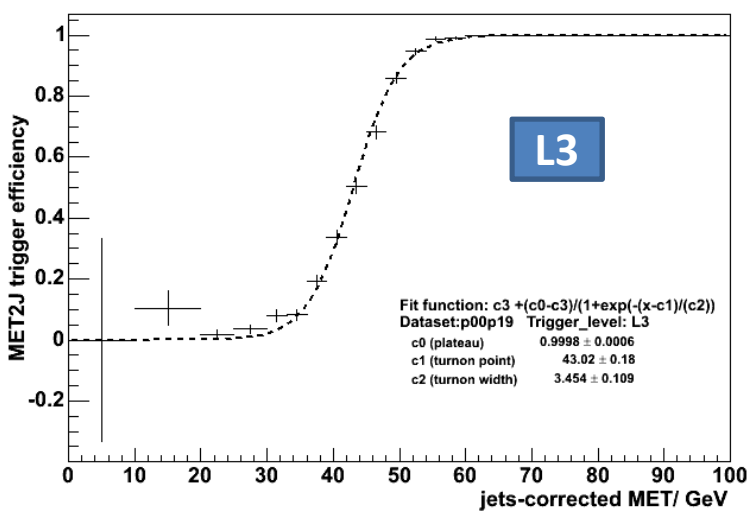
Keep in mind to correct each weight by the effective prescale

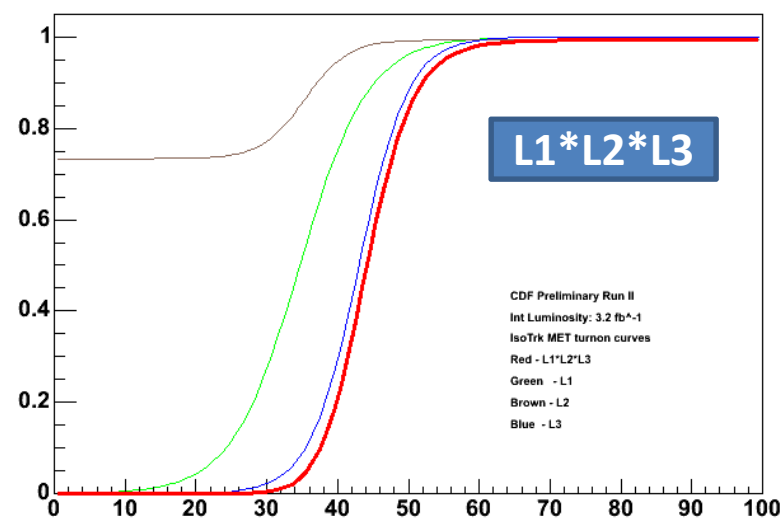
MET + 2 Jets turnon curves

3.0 fb^{-1}, Central muon trigger P_T>20 GeV
2 jets with E_T>25GeV, |η|<2.0, dR>1, one with |η|<0.9



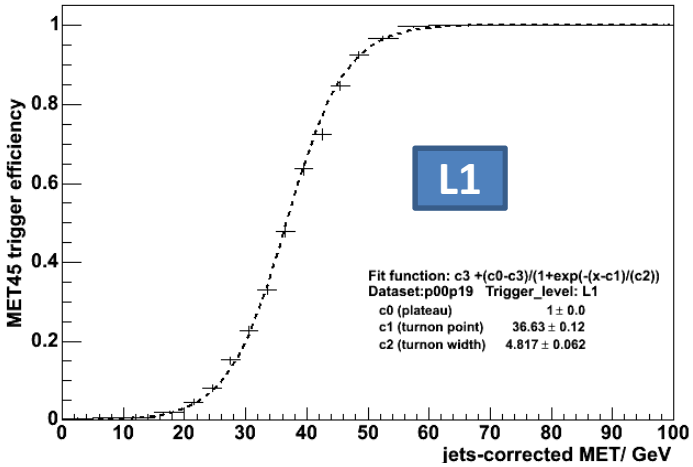


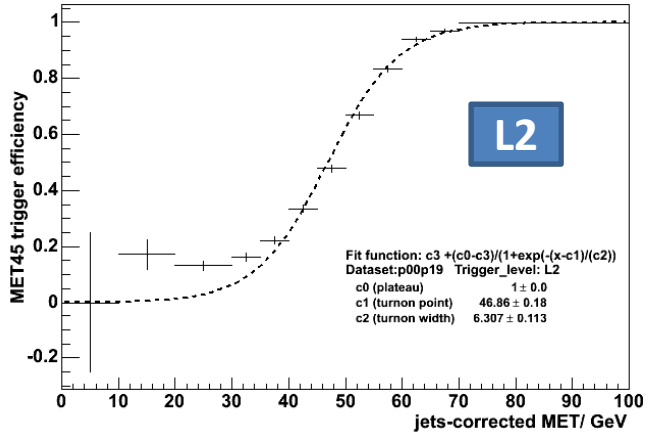


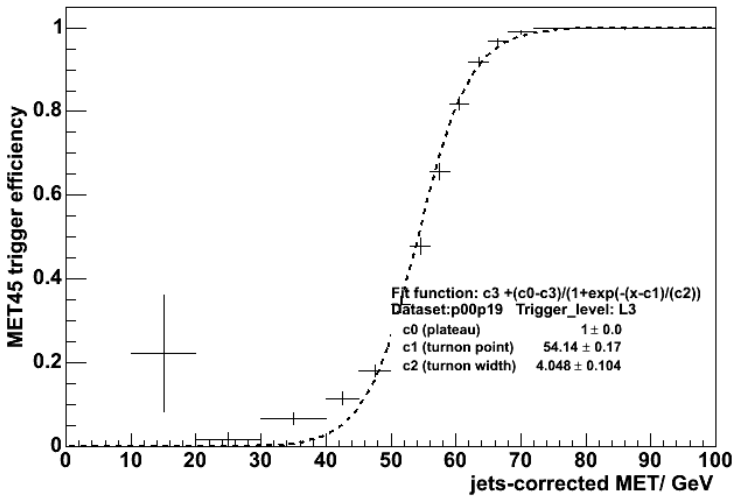


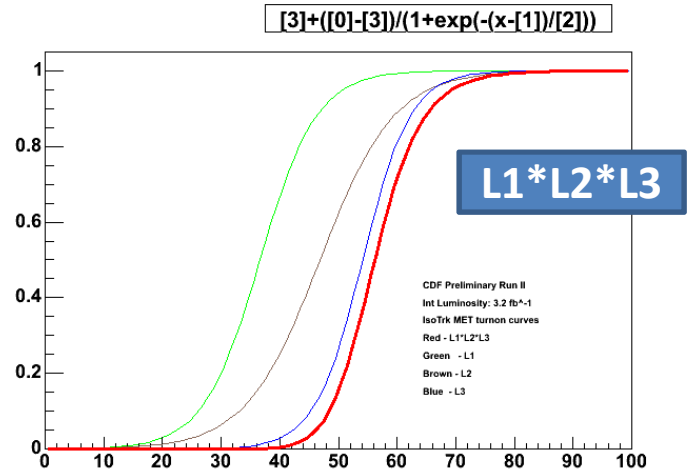
MET45 turnon curves

3.0 fb^{-1}, Central muon trigger P_T>20 GeV
2 jets with E_T>20GeV, |η|<2.0, dR>0, one with |η|<0.9









Use Turnon Curves

Measure weight for all desired triggers

- Measure weight given by each trigger for that event
- Correct for effective prescale of that trigger
- If jet selection fails for that trigger, return weight of zero

Pick the correct trigger

- Pick the trigger that returns the largest weight.
- Check the trigger bits for that trigger.
- If it passed, keep the event in data and assign it its weight in MC
- Can not do OR for the 3 MET-based triggers as there is overlap
- However, once the weight is measured, it can be OR-ed with the weight from the muon gap triggers

Measure trigger systematic

Measure turnon curves for systematic

- Besides turnon curve for the entire dataset, divide the dataset in bins of various variables and for each bin measure the turnon curve
- Variables: jet quantities, number of event, fully corrected MET, etc

Measure systematic uncertainty

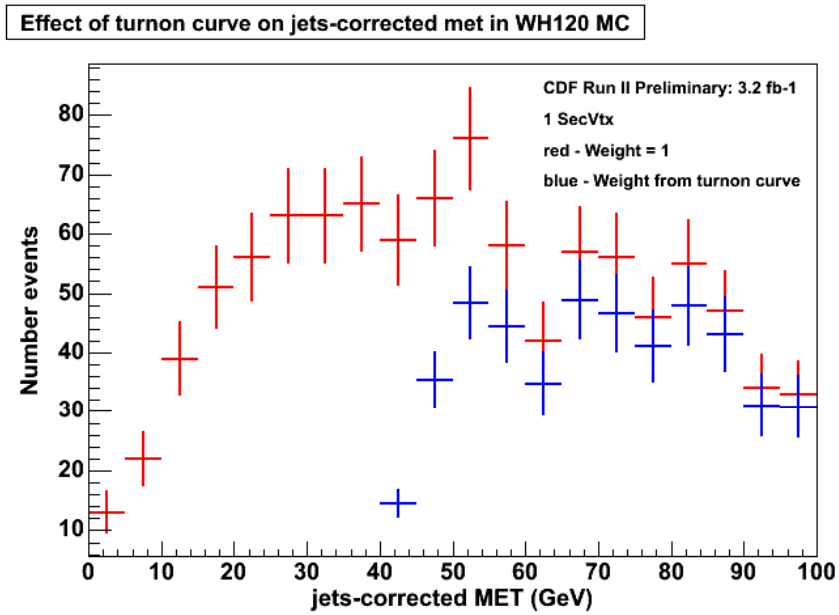
- For signal, have event selection and count the acceptance using turnon curve for the entire dataset
- Then count acceptance for a given variation quantity (check this quantity in which bin it is, pick its turnon curve and get the weight)
- Compare acceptance of central and for all variations
- Add percentages of difference in quadrature

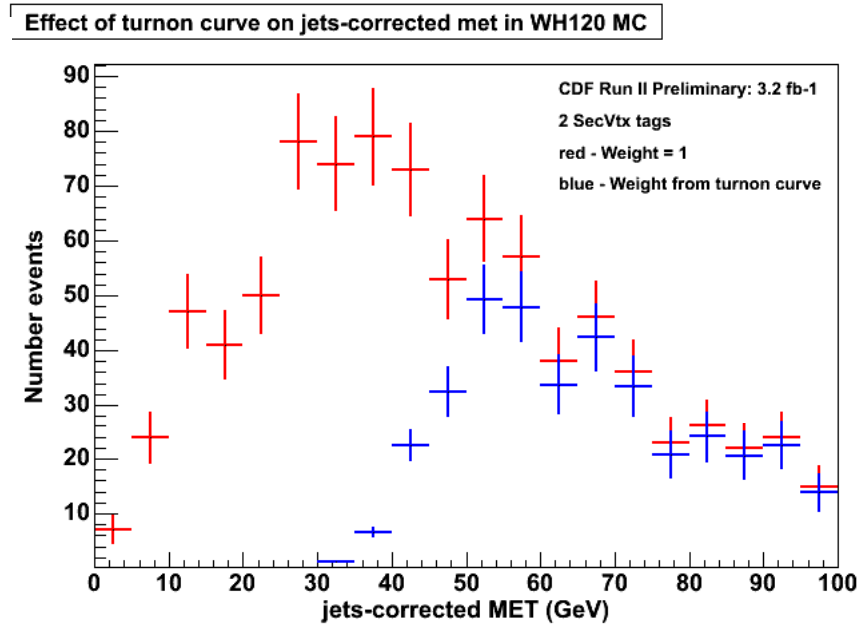
Result

- Systematic uncertainty < 3% for MET + 2 Jets and for MET 45

(MET+2 Jets) + (MET45)

WH120 MC, isolated treack with P_T>20 GeV and 2 jets with E_T>20 and full analysis selection





1 tag

Triggers (1 tag)	Acc.	Syst.	Impr.
MET2J (PS=0.93)	603	2.4%	0%
MET2J (PS=0.93) + MET45 (PS=1.00)	756	**2.3%**	**25%**

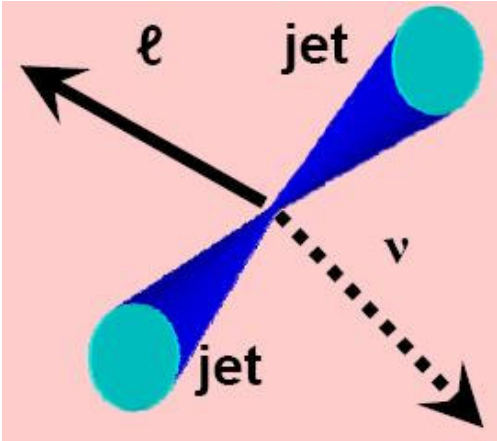
Tight 2 tag

Triggers (2 tag)	Acc.	Syst.	Impr.
MET2J (PS=0.93)	170	2.3%	0%
MET2J (PS=0.93) + MET45 (PS=1.00)	200	**2.6%**	**17%**

Boosted Decision Tree Discriminator

Use Boosted Decision Tree (BDT)

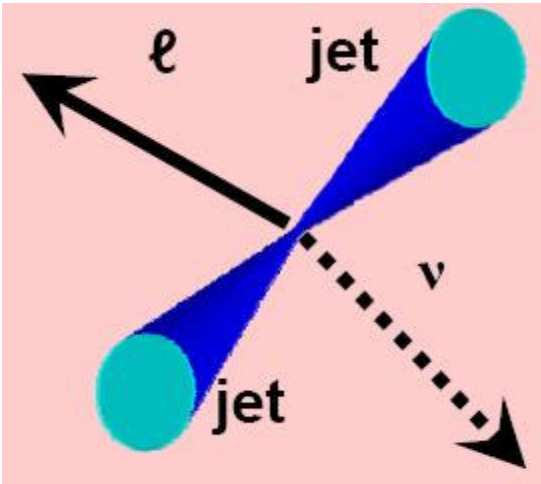
- S/B too small
- Counting experiments are hopeless
- Use BDT as multivariate technique



Choose kinematic variables as inputs to the BDT

- Matrix Element values – most sensitive
- Variables sensitive to specific backgrounds
- Dijet invariant mass – next to most sensitive

Neural Network Discriminator

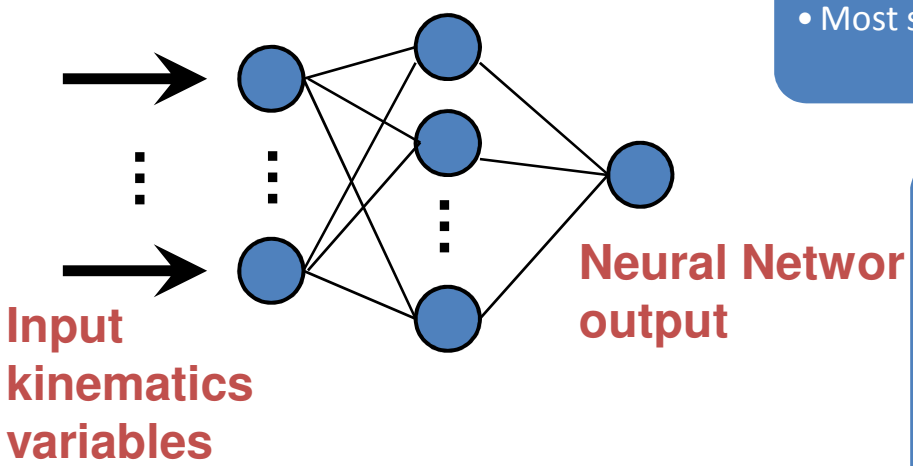


Use Neural Network (NN)

- S/B too small
- Counting experiments are hopeless
- Use Neural Network as multivariate technique

Choose kinematic variables as inputs to the NN

- Variables sensitive to specific backgrounds
- Most sensitive is dijet invariant mass

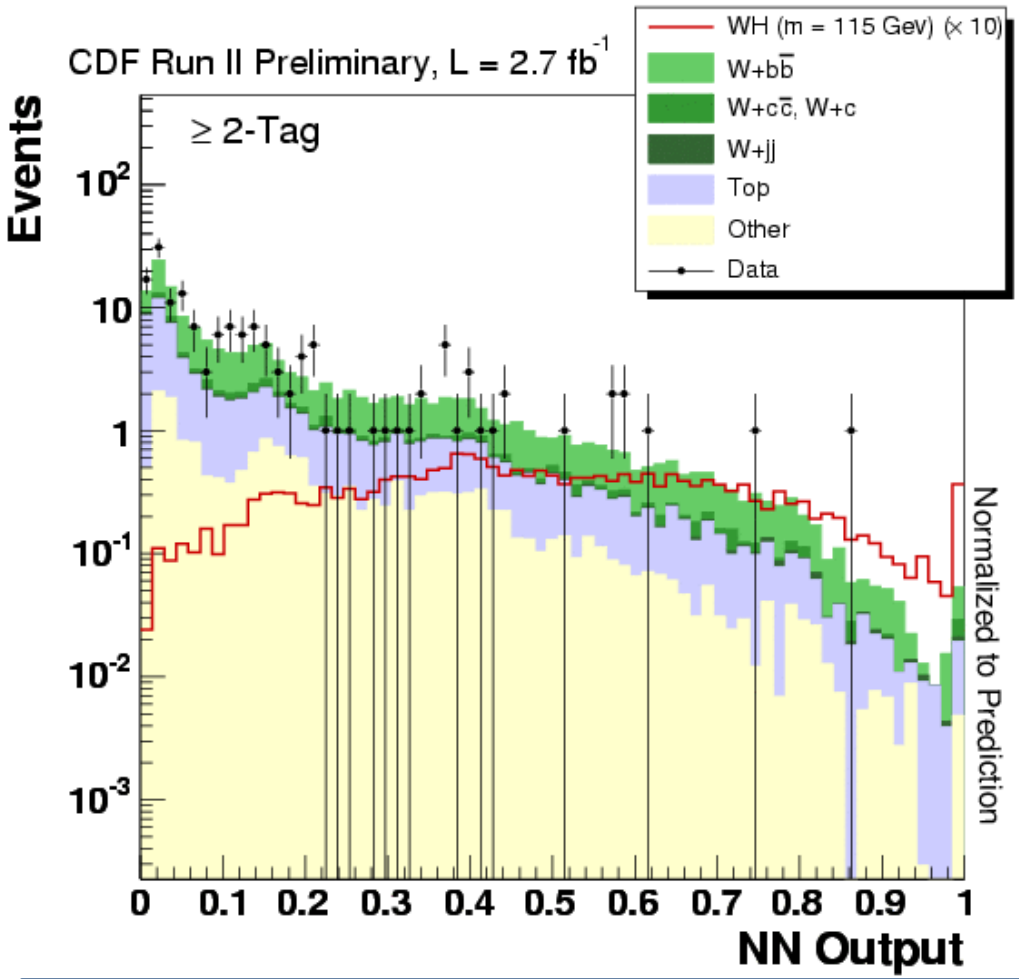


Train the Neural Network

- Using signal and background

NN and ME+BDT Combination Output

Super-discriminant (NEAT)
Neuro-evolution of augmented topologies



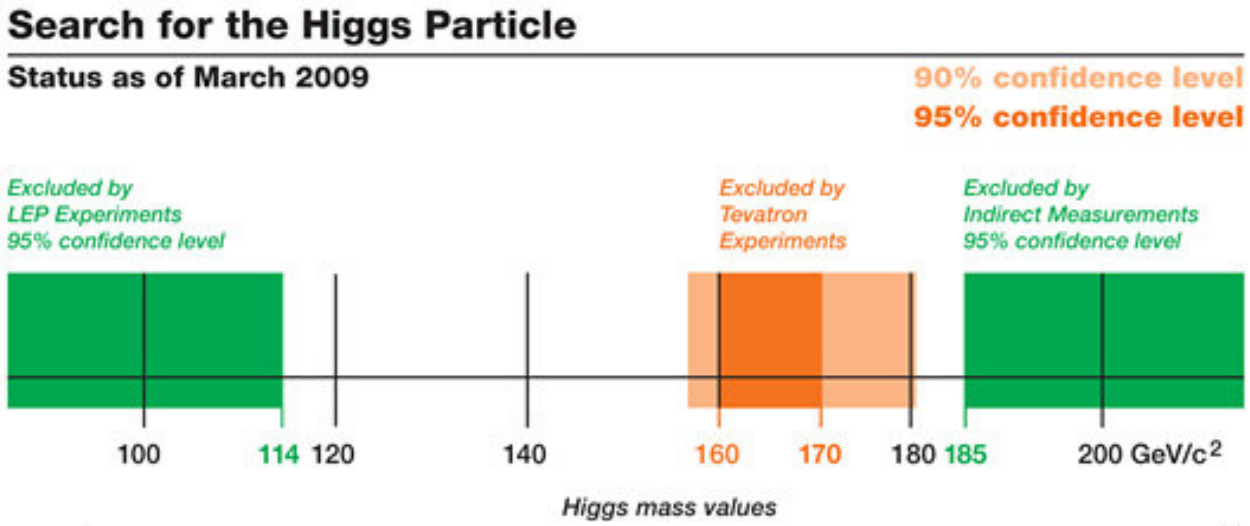
Tight 2 tag

Different Higgs mass points

× 11

From 100 GeV to 150 GeV, with 5 GeV steps

Winter Tevatron Higgs Combination



PERIODIC TABLE OF THE ELEMENTS

1 IA																	18 VIIIA
1 H Hydrogen 1.00794	2 IIA											13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	2 He Helium 4.002602
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.0067	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
11 Na Sodium 22.98976928	12 Mg Magnesium 24.3050	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIII	10	11 IB	12 IIB	13 Al Aluminum 26.9815386	14 Si Silicon 28.0855	15 P Phosph. 30.973762	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955912	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938045	26 Fe Iron 55.845	27 Co Cobalt 58.933195	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge German. 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybd. 95.96	43 Tc Technet. (97.90722)	44 Ru Ruthen. 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293
55 Cs Cesium 132.9054519	56 Ba Barium 137.327	57–71 Lantha-nides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.94788	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.966569	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98040	84 Po Polonium (208.98243)	85 At Astatine (209.98715)	86 Rn Radon (222.01758)
87 Fr Francium (223.01974)	88 Ra Radium (226.02541)	89–103 Actinides	104 Rf Rutherford (267.122)	105 Db Dubnium (268.125)	106 Sg Seaborg. (271.133)	107 Bh Bohrium (270.134)	108 Hs Hassium (269.134)	109 Mt Meitner. (276.151)	110 Ds Darmstadt. (281.162)	111 Rg Roentgen. (280.164)	112 (285.174)						

Lanthanide series	57 La Lanthan. 138.90547	58 Ce Cerium 140.116	59 Pr Praseodym. 140.90765	60 Nd Neodym. 144.242	61 Pm Prometh. (144.91275)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolin. 157.25	65 Tb Terbium 158.92535	66 Dy Dyspros. 162.500	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.9668
Actinide series	89 Ac Actinium (227.02775)	90 Th Thorium 232.03806	91 Pa Protactin. 231.03588	92 U Uranium 238.02891	93 Np Neptunium (237.04817)	94 Pu Plutonium (244.06420)	95 Am Americ. (243.06138)	96 Cm Curium (247.07035)	97 Bk Berkelium (247.07031)	98 Cf Californ. (251.07959)	99 Es Einstein. (252.0830)	100 Fm Fermium (257.09510)	101 Md Mendelev. (258.09843)	102 No Nobelium (259.1010)	103 Lr Lawrenc. (262.110)