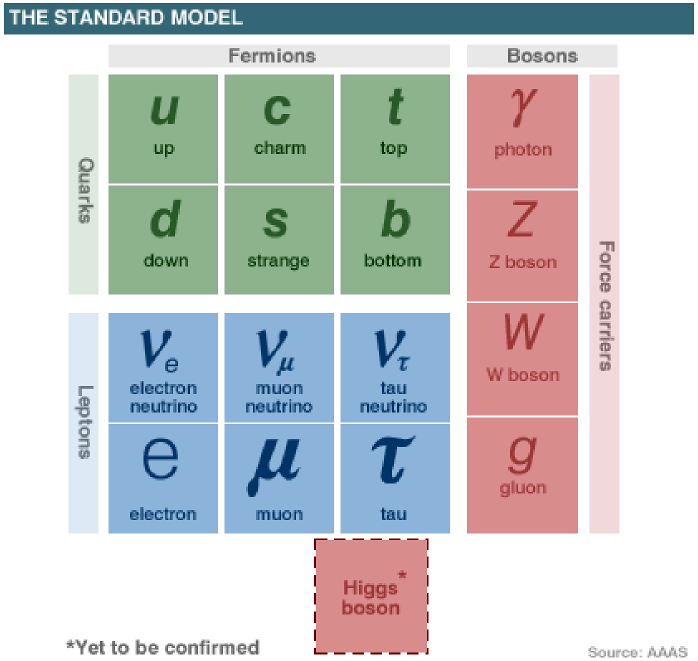
Top Cross Section

(Current Status and Early LHC Prospects)

Contents

- Top Background
- Production
- Decay
- TeVatron Results
- ATLAS and the LHC
- Tau potential

Background



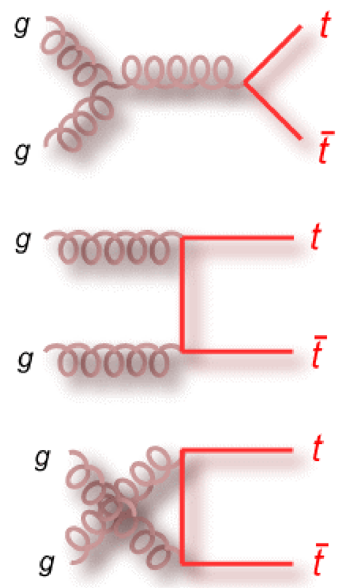
- Completes third generation of the standard model
- Observed for the first time in 1994 (Discovery papers in 1995)
- 35 times more massive than the next quark

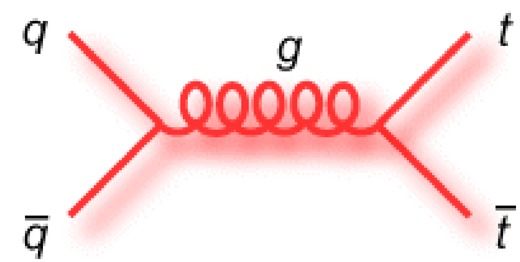
Why study top?

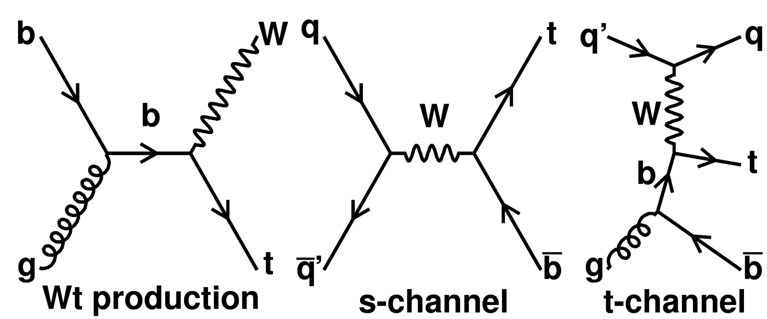
- Make precision measurements of the mass and couplings to test the standard model
- Why is the top so heavy?
- Sensitive to beyond standard model physics (eg. New particles lighter than the top)

Top Production

- Occurs in pairs or singularly (Evidence for in 2009)
- Production typically via hadron collisions

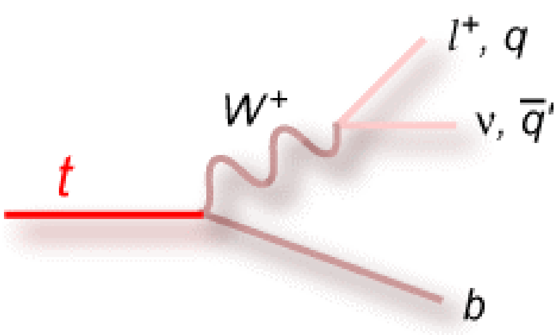




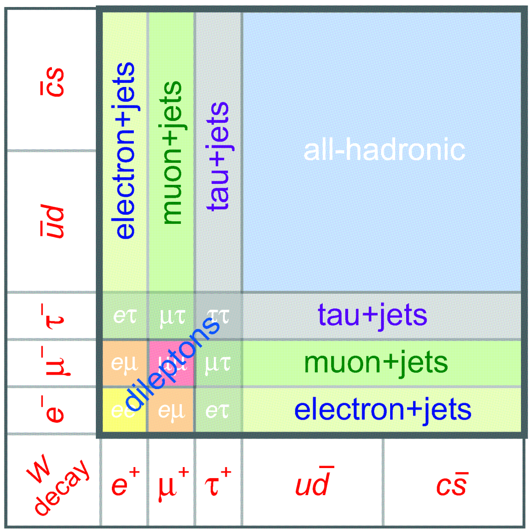


Top Decay

- Within the standard model the top decays with a branching ratio of ~0.998 via $t \rightarrow Wb$
- For ttbar pair decay is characterised by the decay products

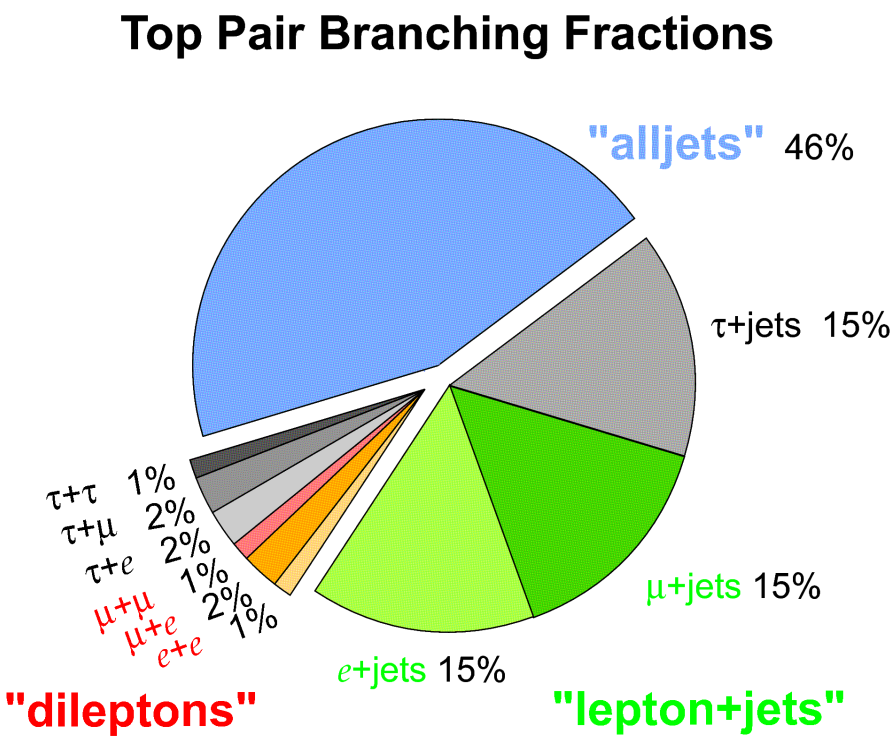


Top Pair Decay Channels



Decay Classification

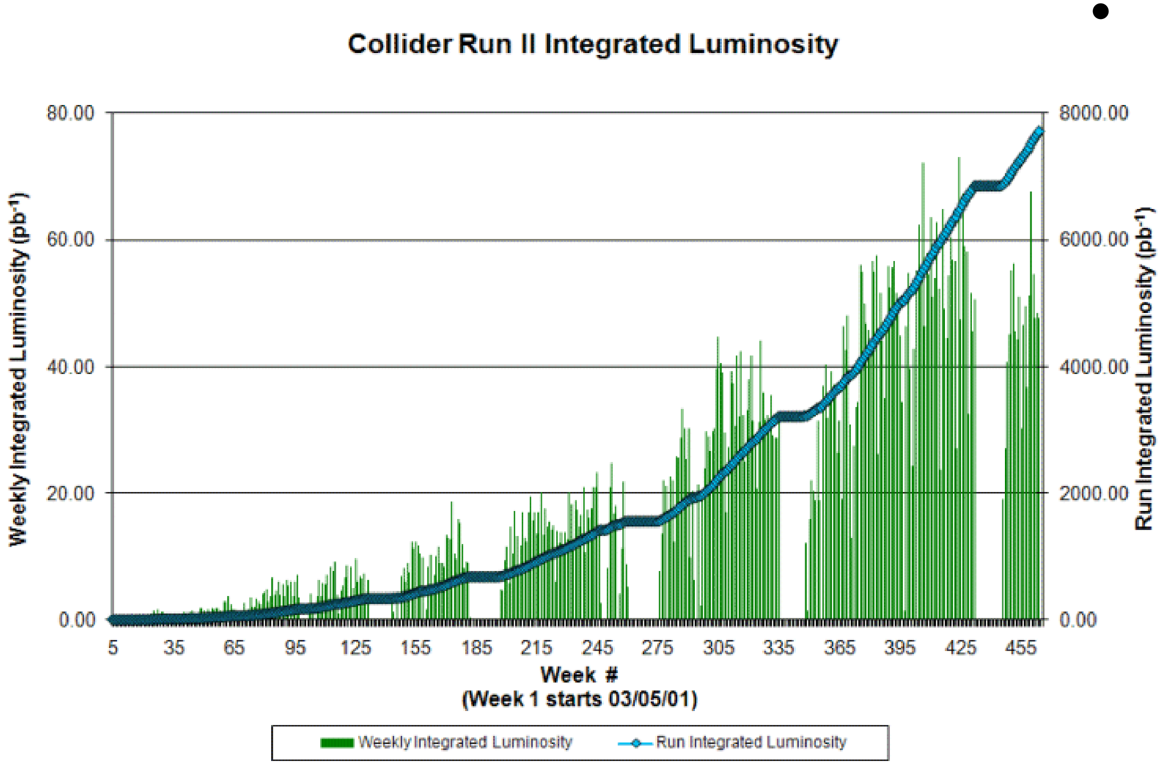
- Decays identified as:
  - Fully hadronic
  - Semi leptonic (e,μ)
  - Dileptonic (e,μ)
  - τ + X
- Studies have typically focused on the leptonic channels



Discovery

- Took place at the Fermilab TeVatron in 1994/5 (Run I $\sqrt{s}$ = 1.8TeV) by the CDF and D0 collaborations

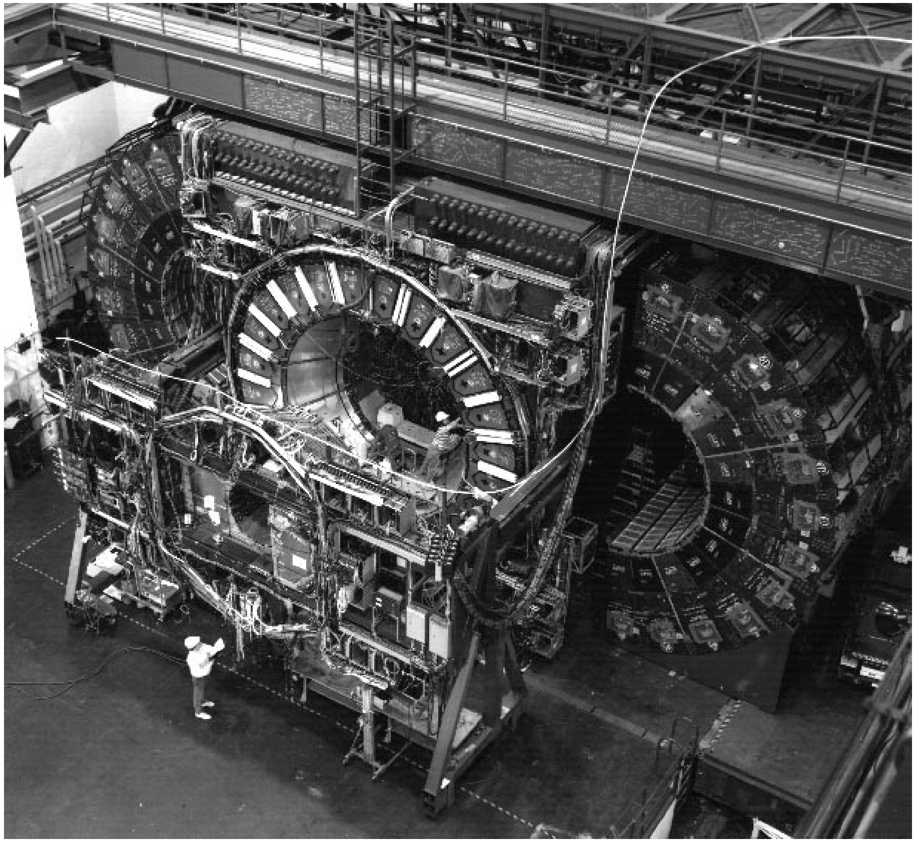
The TeVatron



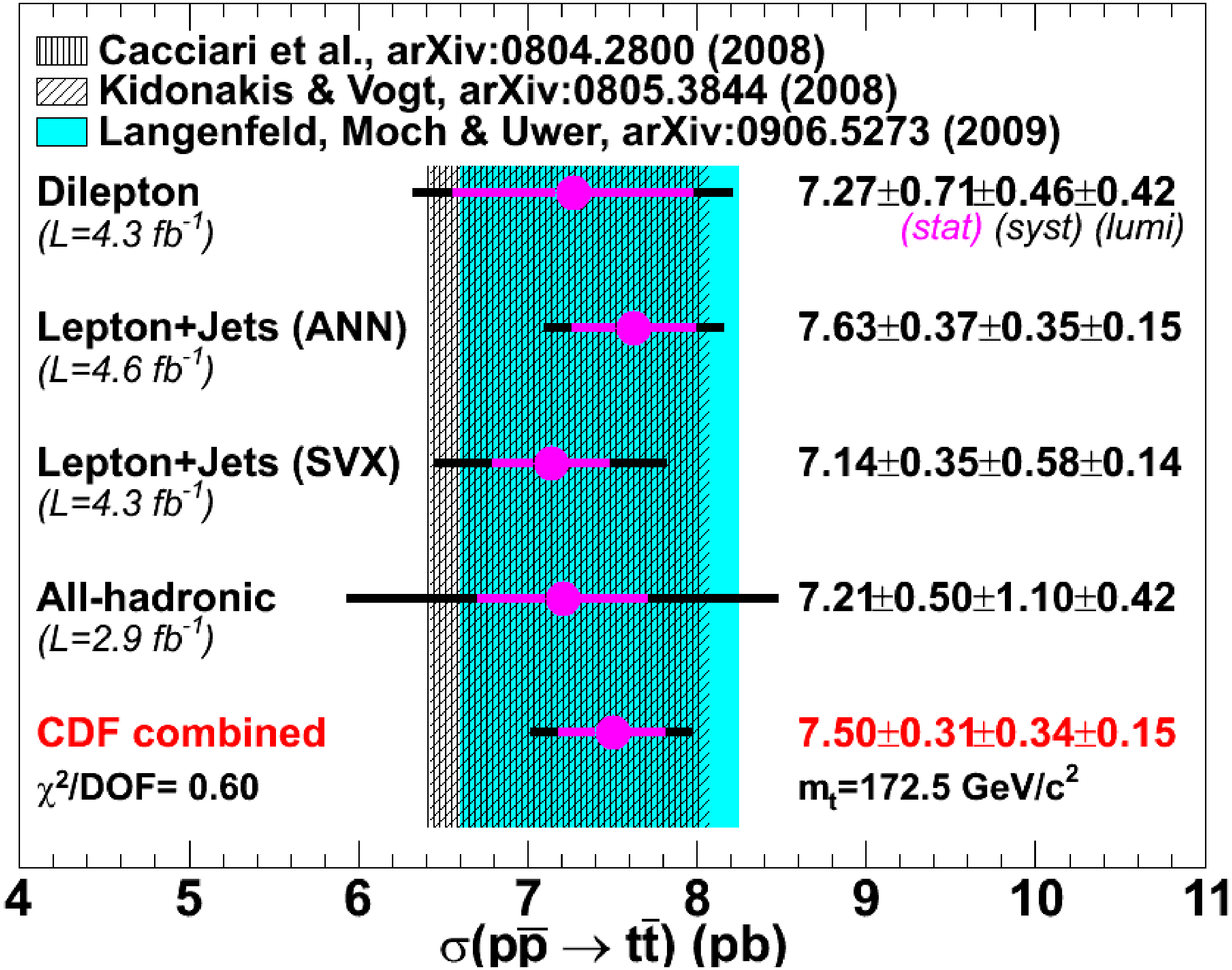
- Proton – antiproton collider operational since 1992:
  - Run I : 1992 – 1996 : 1.8TeV : 160pb^{-1} (Per experiment)
  - Run II : March 2001 – date : 1.96TeV

CDF Cross Section

- Most recent value combines four independent measurements of the total cross section:
  - Semileptonic channel (Artifical neural net)
  - Semileptonic channel (Secondary vertex b-tag)
  - Dileptonic channel (Secondary vertex b-tag)
  - Hadronic channel (Likelihood fit to top mass)
- Measurements combined using a matrix technique (Gives a weight to each channel)



CDF Cross Section



Theoretical values:

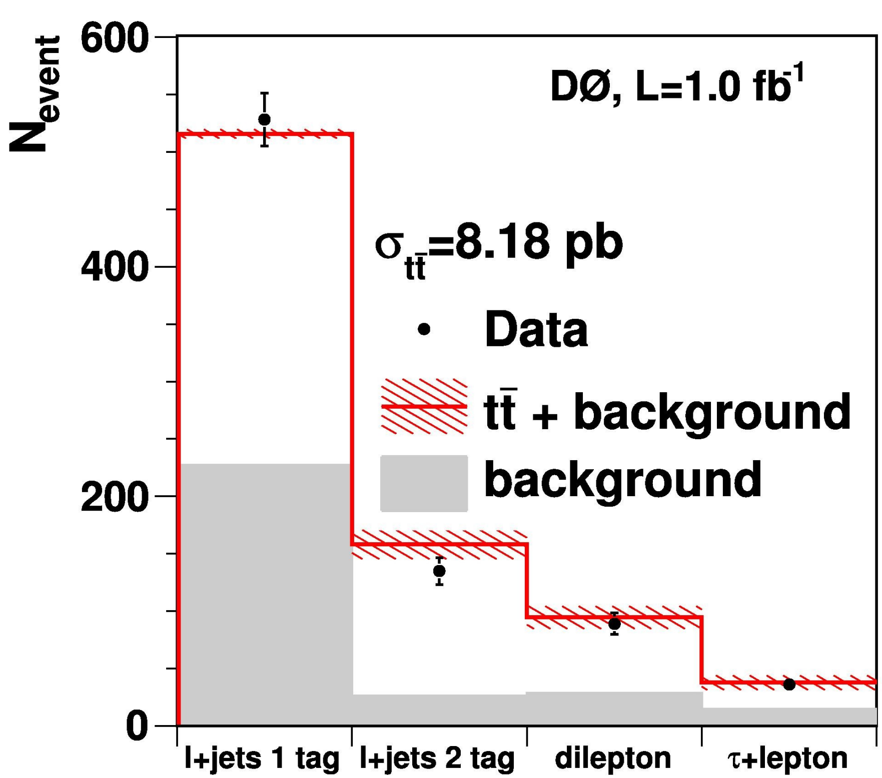
M_{TOP} = 172.5GeV

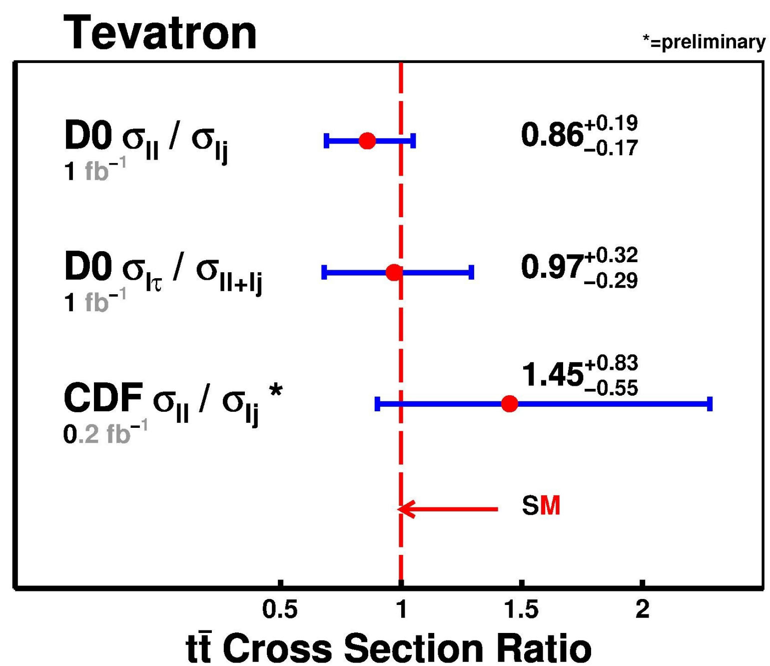
$\sqrt{s}$ = 1.96TeV

D0 Cross Section

- Produce a series of measurements for different channels and selections
- Take cross section ratios to aid systematics and look for new physics
- Assumed top mass of 170GeV/c^2 and SM branching ratios
- 1fb^{-1} data
- All measurements in agreement with each other and with the SM

D0 Cross section





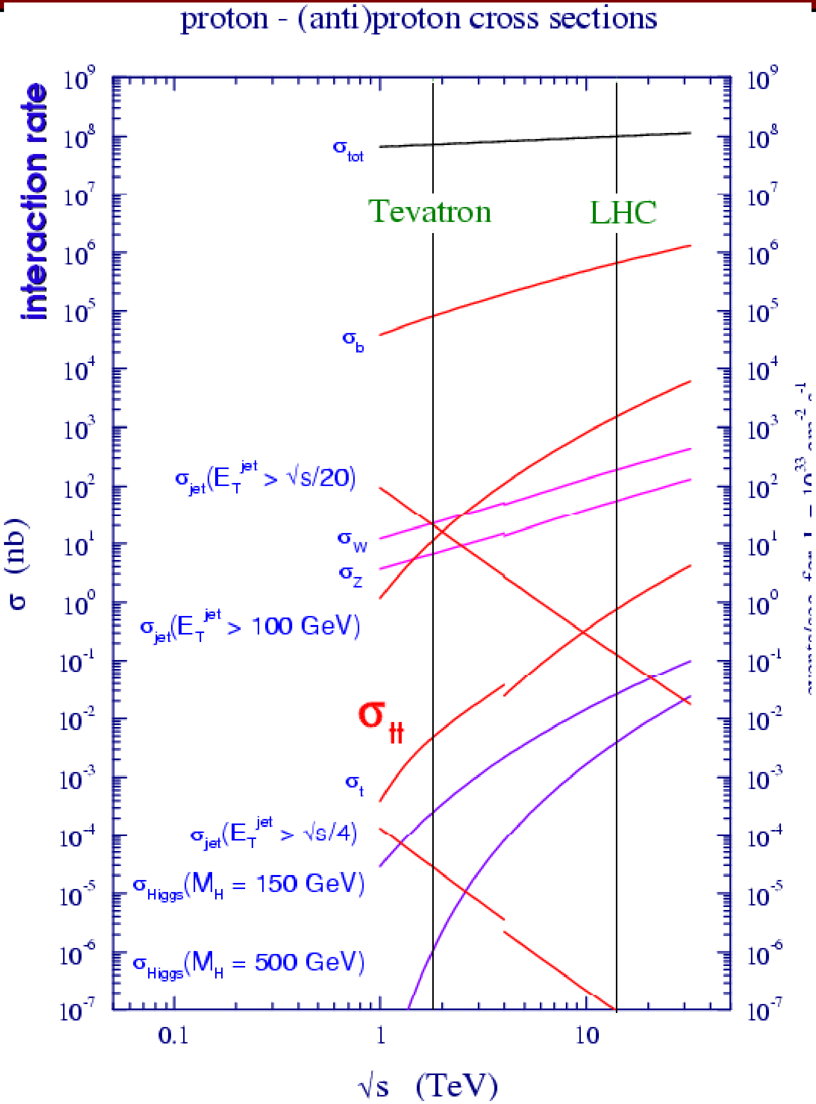
Channel	$\sigma_{t\bar{t}}$ (pb)
ℓ+jets	$8.46^{+1.09}_{-0.97}$
$\ell\ell$ [7]	$7.46^{+1.60}_{-1.37}$
ℓ+jets and $\ell\ell$	$8.18^{+0.99}_{-0.87}$
$\tau\ell$ [7]	$7.77^{+2.90}_{-2.47}$
ℓ+jets, $\ell\ell$ and $\tau\ell$	$8.18^{+0.98}_{-0.87}$

All measurements consistant

Top at the LHC

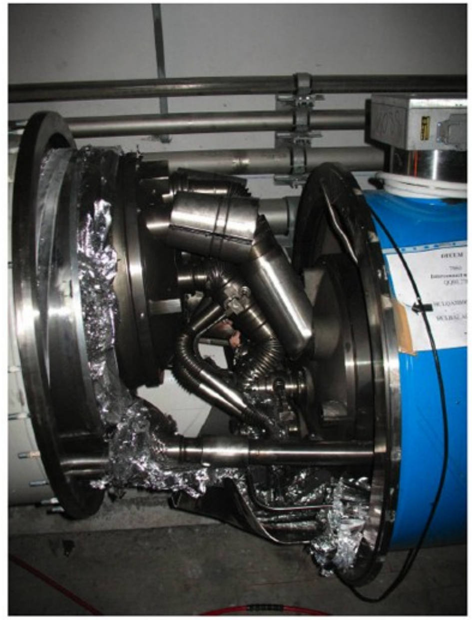
- All current direct top measurements come from the TeVatron (Due to cease running in 2012?)
- The LHC is the future of top physics!

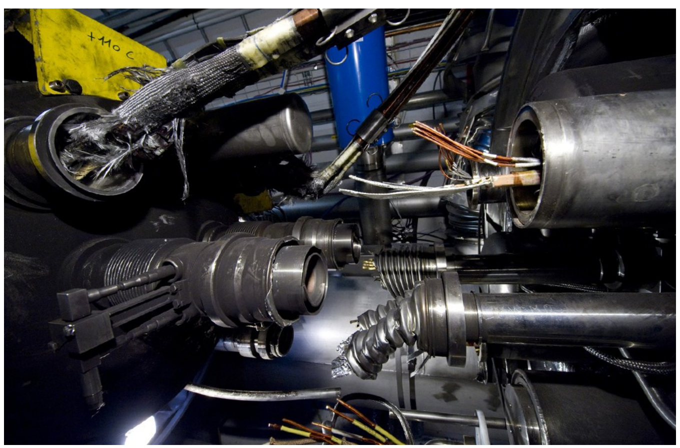
A Top Factory



- The LHC was designed as a $\sqrt{s}$ = 14TeV proton – proton collider with an initial integrated luminosity of 10fb^{-1}/ year
- Standard model ttbar cross section at 14TeV is ~886pb
- Expected number of top pairs ~9×10^{6} / year
- Total number of pairs seen at CDF is ~35000
- **The LHC is a top factory!**

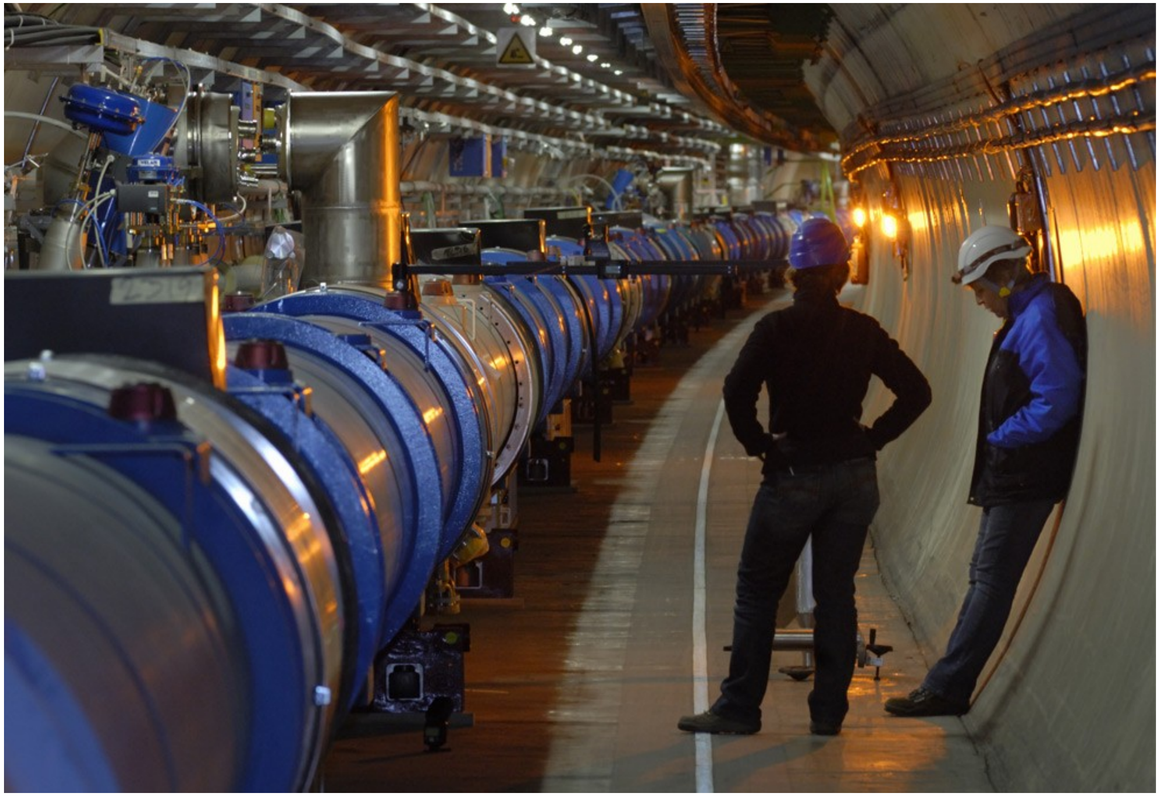
LHC Startup Sep. 2008





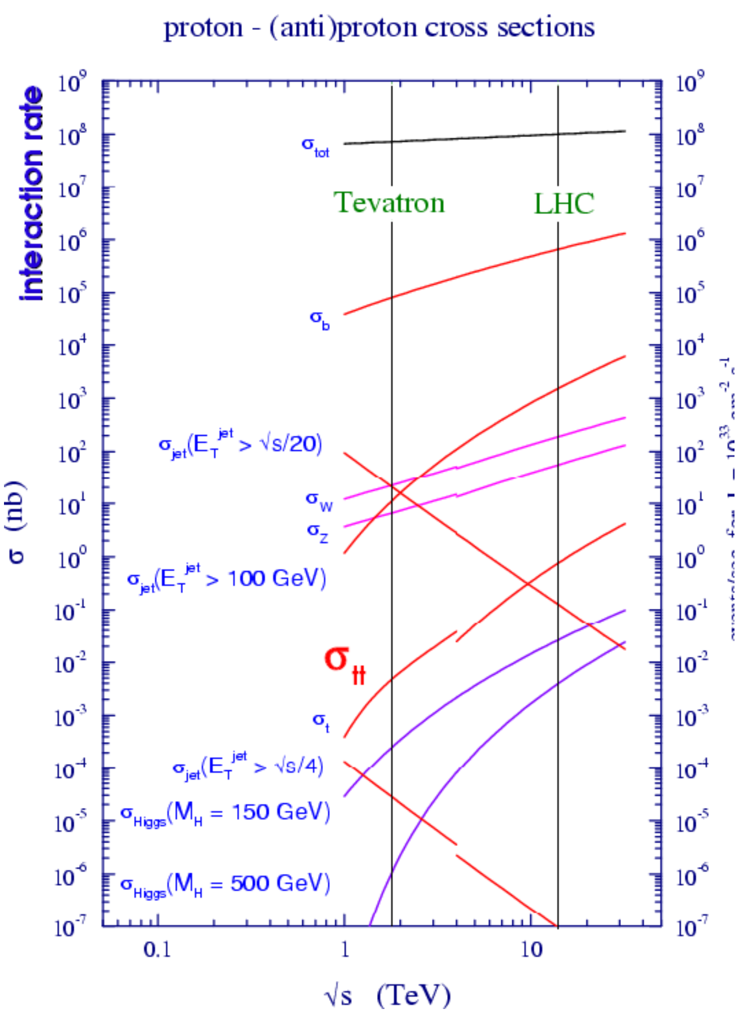
Static magnet test prior to 14TeV running

Impact on top physics



- Damaged sections were repaired and upgraded
- Non damaged sectors were not treated in the same way to avoid warming up
- 14TeV running postponed
- 10TeV and 7TeV running considered

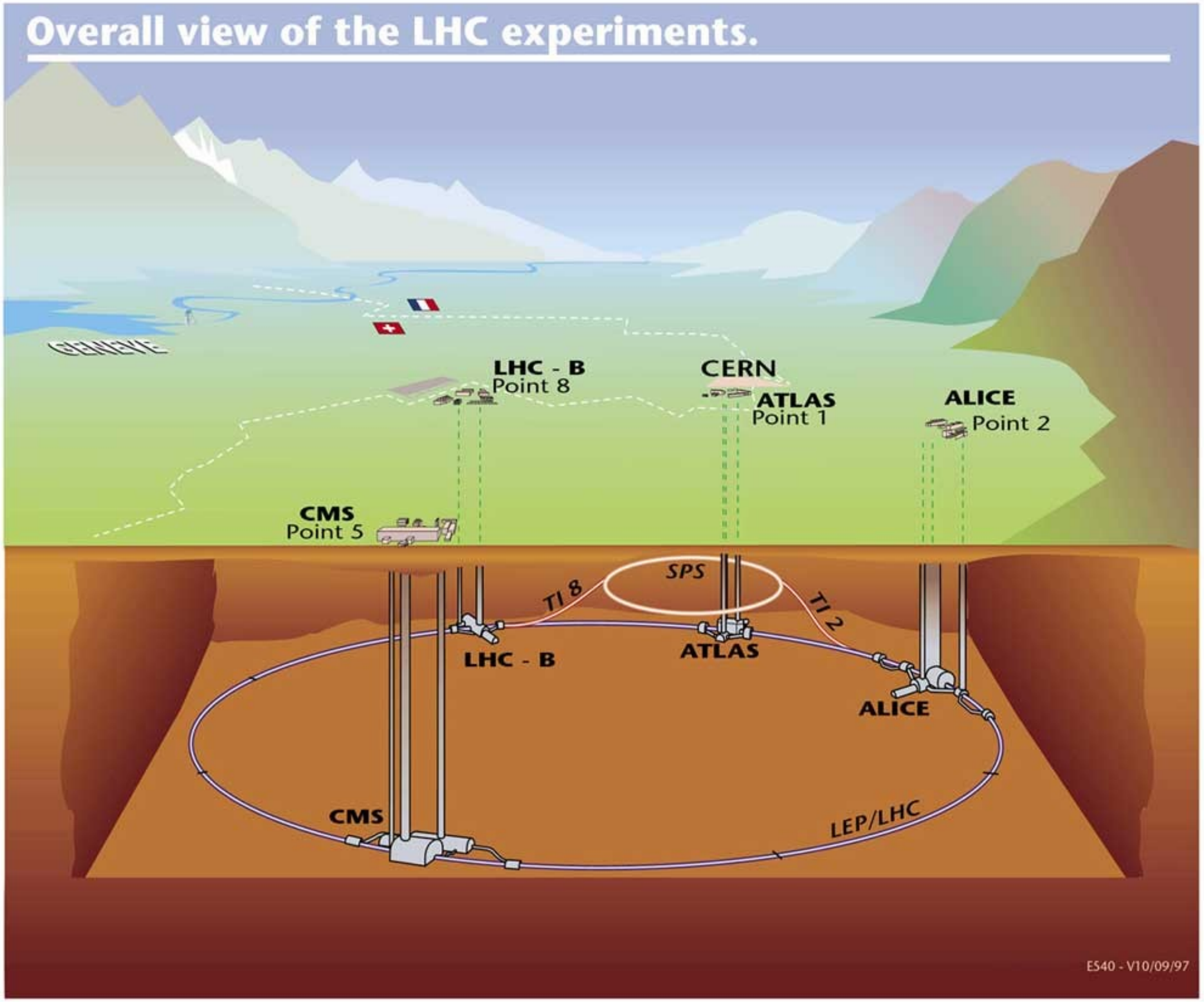
Impact on top physics



- σ_{tt} ($\sqrt{s}$ = 14 TeV) ≈ 886 pb
- σ_{tt} ($\sqrt{s}$ = 10 TeV) ≈ 403 pb
- σ_{tt} ($\sqrt{s}$ = 7 TeV) ≈ 161 pb

- For early physics at 10TeV considered 200pb^{-1}:
  - Corresponds to 80600 events
- For 7TeV considered 1fb^{-1}:
  - Corresponds to 161000 events
- Current TeVatron run II:
  - Corresponds to 34500 events

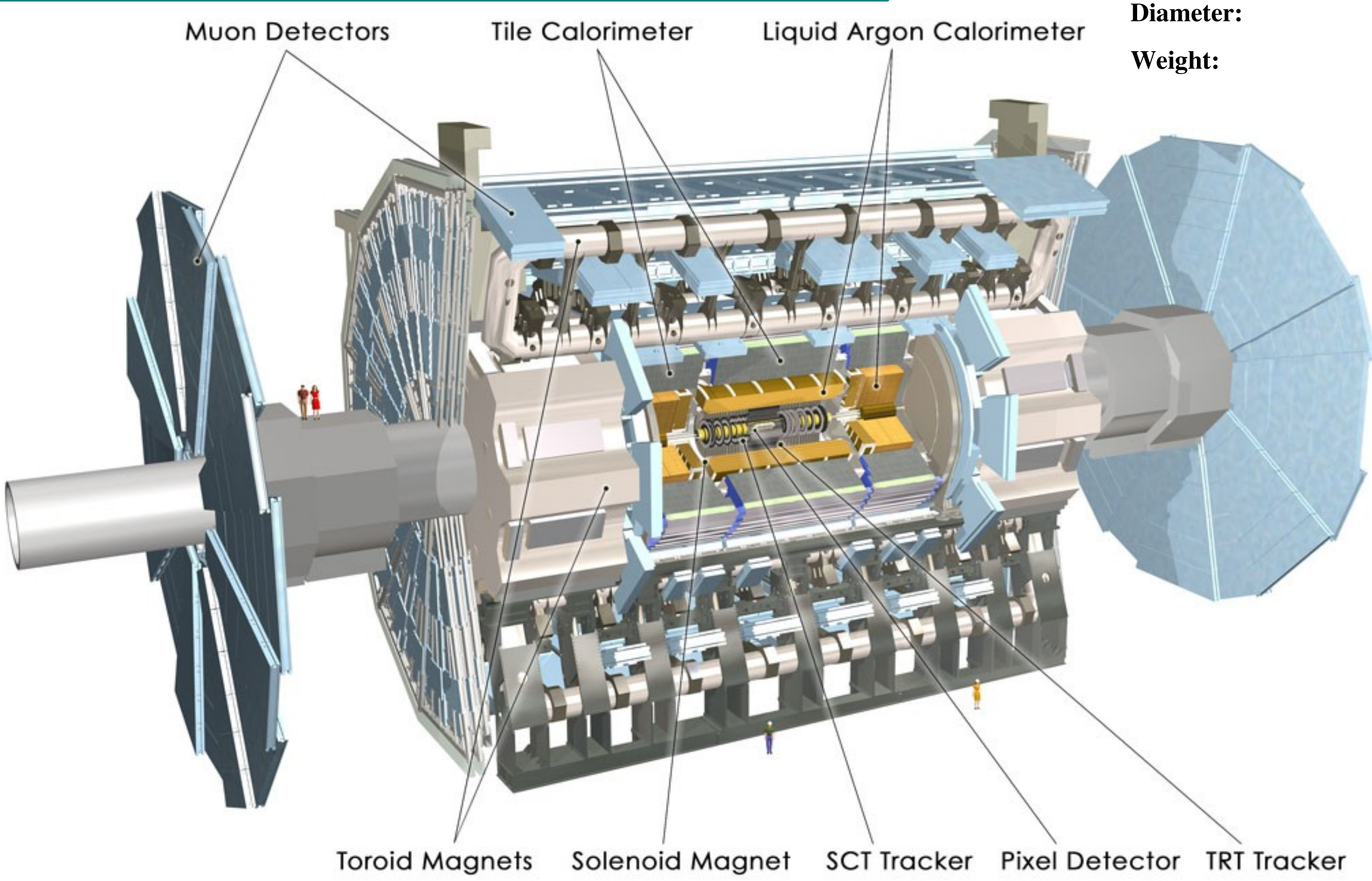
ATLAS at the LHC



The ATLAS Detector

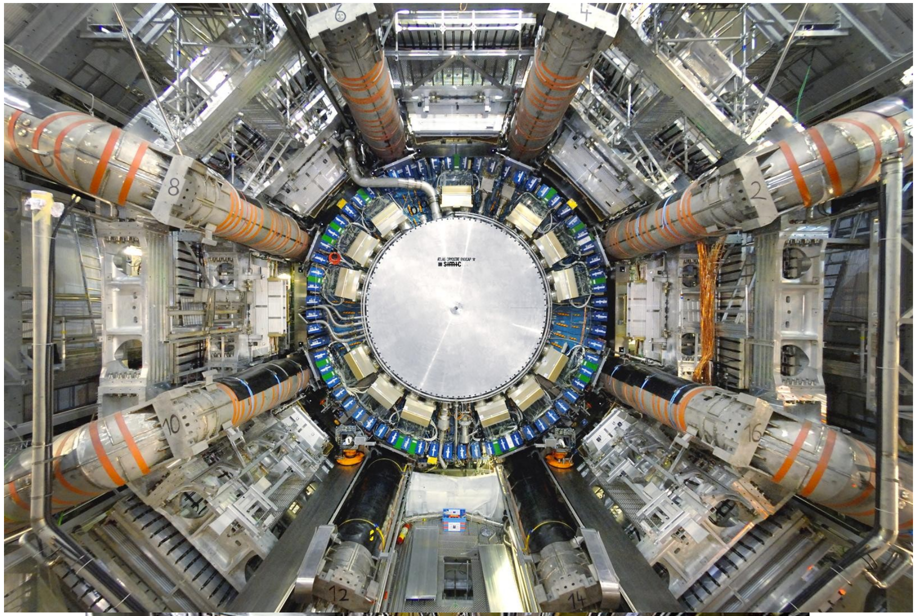
ATLAS (A Toroidal LHC ApparatuS)

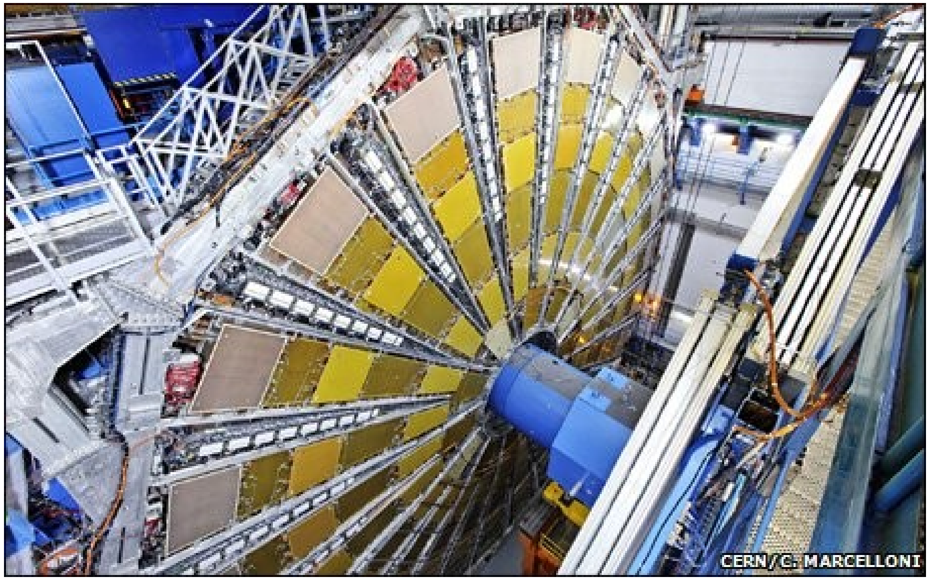
Width: 44m
Diameter: 22m
Weight: 7000t

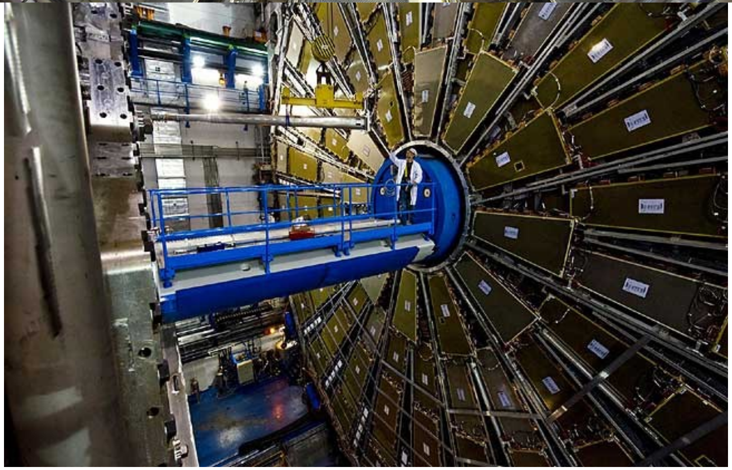


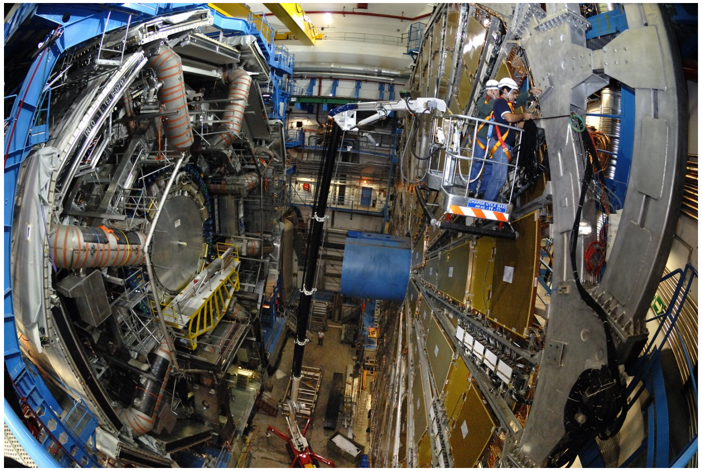
The ATLAS experiment is a collaboration of approximately 2100 scientists from 167 institutions in 37 different countries

ATLAS







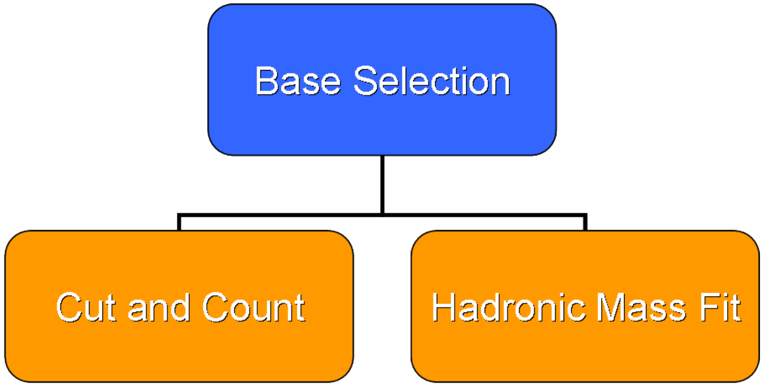


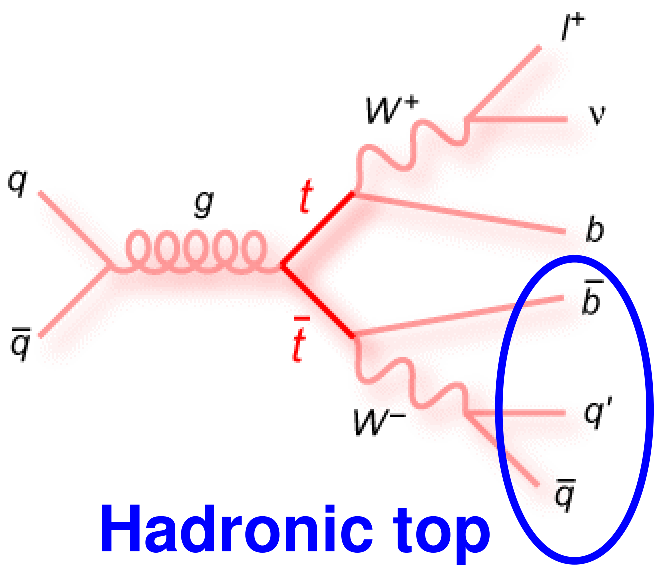
ATLAS Early Physics

- Two ttbar cross section notes prepared last summer based on 200pb^{-1} at 10TeV
  - Single Lepton channel
  - Dilepton channel
- Theoretical SM ttbar cross section of 400pb±11% (NLO) and 400pb±6% (NNLO) for M_{TOP} = 172.5GeV
- Analyses deliberately designed to be simple until the detector is fully understood (I.e. Cuts based, no b-tag)
- Work currently in progress on 7TeV equivalent (Monte Carlo now available)

Semileptonic Channel

- Assumes 200pb^{-1} at 10TeV
- Base selection:
  - 1 lepton (e or μ) with p_T > 20 GeV
  - Lepton to have passed 15GeV single lepton trigger (efficiency from data)
  - Et_{MISS} > 20 GeV
  - ≥ 4 jets with p_T > 20GeV
  - ≥ 3 jets with p_T > 40GeV
- Reconstruct the hadronic top as the three jets with the highest combined p_T (35% efficient)
- Option to require one of the hadronic top two jet combinations to lie within 10GeV of the reconstructed W mass (Measured from peak of W combination distribution)



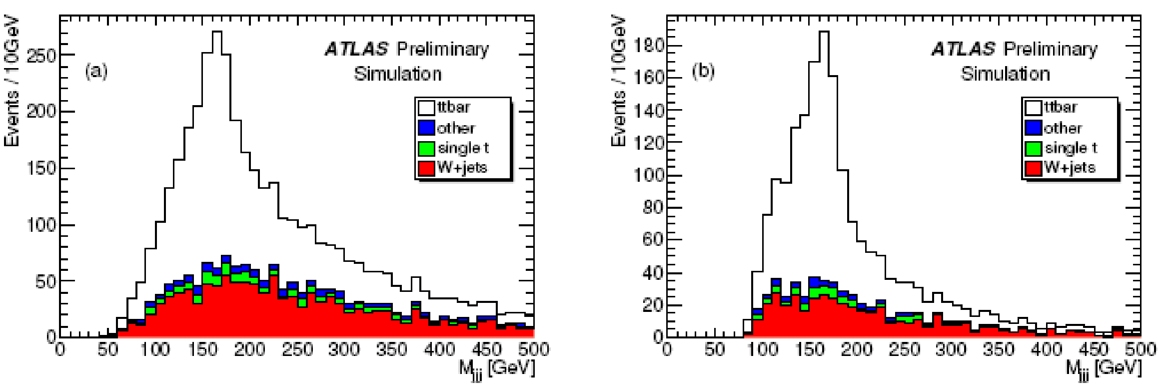


Semileptonic selection

Numbers of Selected Events				
	Electron Analysis		Muon Analysis	
Sample	default	$+M_W$-cut	default	$+M_W$-cut
$t\bar{t}$	2600	1286	3144	1584
W+jets	1305	448	1766	628
single top	210	81	227	98
$Z \rightarrow ll$ +jets	148	43	144	49
hadronic $t\bar{t}$	16	10	11	5
W $b\bar{b}$	21	7	32	10
WW	11	6	14	7
WZ	3	1	5	2
ZZ	0.4	0.2	0.5	0.2
Signal	2600	1286	3144	1584
Background	1715	598	2199	799
S/B	1.5	2.1	1.4	2.0

- Applying the W_{MASS} cut halves the statistics but increases the S/B ratio by a factor of 1.4

Table and plots normalised to $200pb^{-1}$



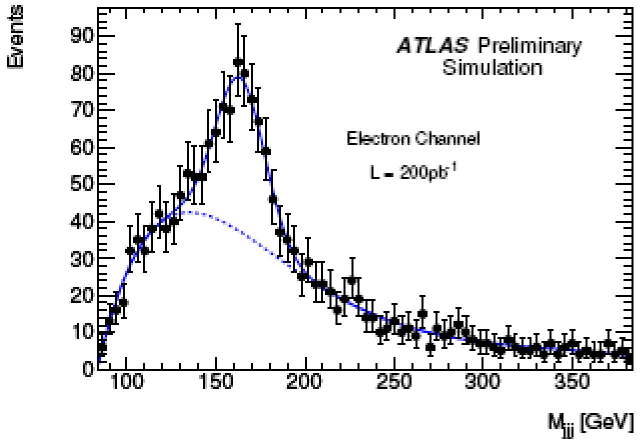
Cut and Count

- Measure cross section by counting events
- Obtain ε from monte carlo and N_{bkg} fr om Monte Carlo and data

$$\sigma = \frac{N_{\rm sig}}{\mathscr{L} \times \varepsilon} = \frac{N_{\rm obs} - N_{\rm bkg}}{\mathscr{L} \times \varepsilon}$$

Mass Fit

- Plot the three jet invariant mass distribution after the W mass cut
- Use a maximum likelihood fit with a gaussian to replicate the combined signal and background
- Integrate the gaussian to estimate the number of ttbar events



Results

Source	Cut and Count method				Fit method	
	e-analysis		μ-analysis		e-analysis	μ-analysis
	default (%)	$+M_W$-cut (%)	default (%)	$+M_W$-cut (%)	$+M_W$-cut (%)	$+M_W$-cut (%)
Stat.	$\pm$ 2.5	$\pm$ 3.4	$\pm$2.3	$\pm$3.1	$\pm$ 14.1	$\pm$ 15.2
Lepton ID eff.	$\pm$1.0	**$\pm$1.0**	$\pm$1.0	**$\pm$1.0**	**$\pm$ 1.0**	**$\pm$ 1.0**
Lepton trig. eff.	$\pm$1.0	**$\pm$1.0**	$\pm$1.0	**$\pm$1.0**	**$\pm$ 1.0**	**$\pm$ 1.0**
50% W+jets	$\pm$25.1	$\pm$17.4	$\pm$28.1	$\pm$19.8	$\pm$ 3.3	$\pm$ 5.6
20% W+jets	$\pm$10.0	**$\pm$7.0**	$\pm$11.2	**$\pm$7.9**	**$\pm$ 1.5**	**$\pm$ 2.6**
JES (10%,-10%)	+24.8-23.4	+15.9-19.1	+20.5-22.3	+11.9-17.9	-14.4	-15.4
JES (5%,-5%)	+12.3-11.9	**+8.6-9.3**	+10.4-10.9	**+6.1-8.4**	**-3.7**	**-3.9**
PDFs	$\pm$1.6	**$\pm$ 1.9**	$\pm$1.2	**$\pm$ 1.4**	**$\pm$ 1.9**	**$\pm$ 1.4**
ISR/FSR	+9.1-9.1	**+7.6-8.2**	+8.2-8.2	**+5.2-8.3**	**-12.9**	**-12.9**
Signal MC	$\pm$3.3	**$\pm$4.4**	$\pm$0.3	**$\pm$2.8**	**$\pm$ 4.5**	**$\pm$ 1.4**
Back. Uncertainty	$\pm$0.6	**$\pm$0.4**	$\pm$0.5	**$\pm$0.4**	-	-
Fitting Model	-	-	-	-	**$\pm$ 3.3**	**$\pm$ 4.7**
10% Lumi.	$\pm$11.6	$\pm$11.2	$\pm$11.4	$\pm$11.1	$\pm$10	$\pm$10
20% Lumi.	$\pm$23.2	**$\pm$22.3**	$\pm$22.8	**$\pm$22.2**	**$\pm$20**	**$\pm$ 20**
Tot. without Lumi.	+18.8-18.5	**+14.4-15.2**	+17.5-17.7	**+11.9-14.7**	**+6.4 -14.9**	**+6.0 - 14.8**

Error improved in the cut and count method by application of W mass cut

Results

- Assume lepton trigger, 5% JES error, 20% uncertainty on W+jets and 20% luminosity error

Baseline Cut and Count

$$\mathtt{ElectronCutandCount}\frac{\Delta\sigma}{\sigma} = (3(\mathtt{stat})^{+14}_{-15}(\mathtt{syst}) \pm 22(\mathtt{lumi}))\%$$

$$\mathtt{MuonCutandCount}\frac{\Delta\sigma}{\sigma} = (3(\mathtt{stat})^{+12}_{-15}(\mathtt{syst}) \pm 22(\mathtt{lumi}))\%$$

Include W mass cut

Baseline Fit

$$\mathtt{ElectronFit}\frac{\Delta\sigma}{\sigma} = (14(\mathtt{stat})^{+6}_{-15}(\mathtt{syst}) \pm 20(\mathtt{lumi}))\%$$

$$\mathtt{MuonFit}\frac{\Delta\sigma}{\sigma} = (15(\mathtt{stat})^{+6}_{-15}(\mathtt{syst}) \pm 20(\mathtt{lumi}))\%$$

Analysis without the use of MET

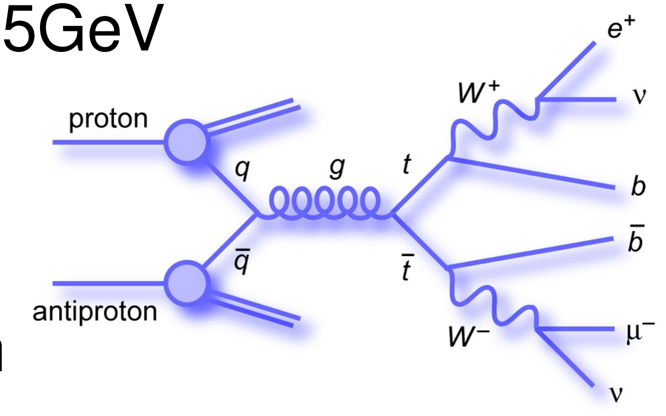
$$\mathtt{VariantAnalysis:ElectronCutandCount}\frac{\Delta\sigma}{\sigma} = (3(\mathtt{stat})^{+19}_{-21}(\mathtt{syst}) \pm 26(\mathtt{lumi}))\%$$

$$\mathtt{VariantAnalysis:MuonCutandcount}\frac{\Delta\sigma}{\sigma} = (3(\mathtt{stat})^{+20}_{-20}(\mathtt{syst}) \pm 23(\mathtt{lumi}))\%$$

- For a standard model assumption, the error on the cross section for 200pb^{-1} at 10TeV is expected to be less than 20% (Plus luminosity error)

Dileptonic Channel

- Assumes 200pb^{-1} at 10TeV
- Consider ee, μμ and eμ channels
- Base selection:
  - Two oppose sign leptons with $p_T > 20$GeV
  - Require single lepton trigger of $p_T > 15$GeV
  - ≥ 2 jets with $p_T > 20$GeV
  - $Et_{MISS} > 20$GeV
- Cut and count method for cross section calculation
- Assume 20% luminosity error



Results

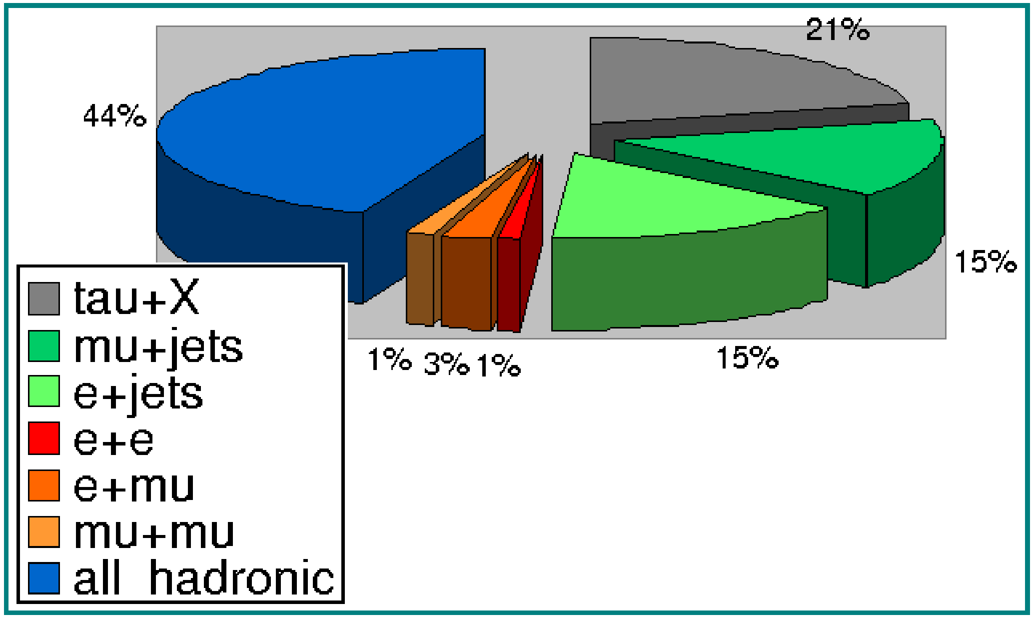
$\Delta\sigma/\sigma$ (%)	ee channel	$\mu\mu$ channel	$e\mu$ channel	combined
Stat only	-7.5 / 7.8	-6.0 / 6.2	-4.0 / 4.1	-3.1 / 3.1
Luminosity	-17.3 / 26.3	-17.4 / 26.2	-17.4 / 26.2	-17.4 / 26.2
Electron Efficiency	-4.5 / 5.0	0.0 / 0.0	-2.2 / 2.4	-1.9 / 1.9
Muon Efficiency	0.0 / 0.0	-4.6 / 5.2	-2.1 / 2.2	-2.2 / 2.3
Lepton Energy Scale	-0.3 / 1.6	-2.4 / 2.0	-0.5 / 0.5	-0.8 / 0.8
Jet Energy Scale	-3.4 / 3.2	-3.0 / 4.5	-2.5 / 2.5	-2.8 / 3.0
PDF	-2.1 / 2.3	-1.4 / 1.6	-1.6 / 1.8	-1.7 / 1.8
ISR FSR	-4.0 / 4.2	-3.6 / 3.7	-3.5 / 3.5	-3.6 / 3.7
Signal Generator	-4.7 / 5.4	-4.6 / 5.4	-4.7 / 5.3	-4.7 / 5.3
Cross-Sections	-0.3 / 0.3	-0.3 / 0.3	-0.3 / 0.3	-0.3 / 0.3
Drell Yan	-1.4 / 1.3	-2.2 / 2.2	-0.5 / 0.5	-0.8 / 0.9
Fake Rate	-9.7 / 9.5	-1.1 / 1.1	-6.2 / 6.2	-4.0 / 4.0
All syst but Luminosity	-12.7 / 13.9	-8.9 / 10.2	-9.4 / 10.2	-8.7 / 9.6
All systematics	-21.0 / 30.3	-19.3 / 28.3	-19.5 / 28.5	-19.3 / 28.1
Stat + Syst	-22.3 / 31.3	-20.2 / 29.0	-19.9 / 28.8	-19.5 / 28.3

Overall error ($200pb^{-1}$): $3.1(\mathrm{stat})^{+9.6}_{-8.7}(\mathrm{syst})^{+26.2}_{-17.4}(\mathrm{lumi})\%$

Why look at taus?

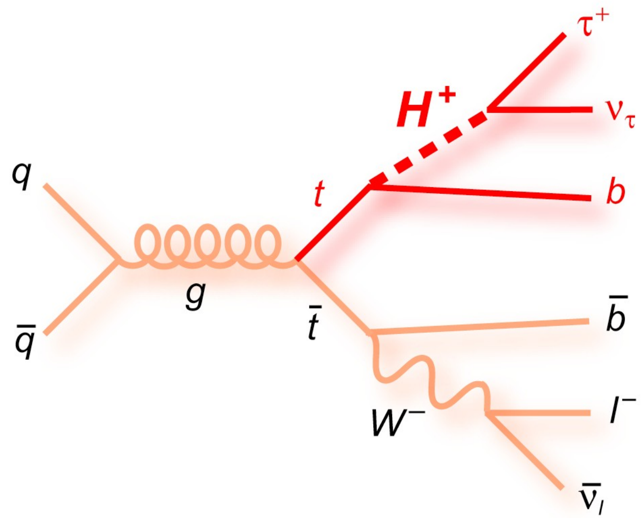
Why look at taus?

- Make better use of the available ttbar events:
  - Many ttbar studies use the semileptonic channel but usually only considering the electron or muon cases. These together have a combined branching ratio of 30%.
  - 21% of ttbar events contain one or more decays to taus. By making use of ttbar events containing a single tau lepton the size of the useful semileptonic dataset may be extended.



Why look at taus?

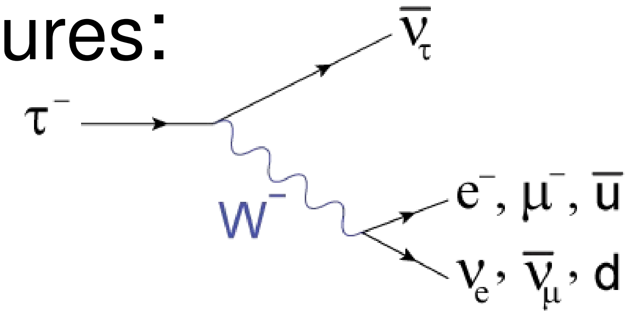
- Tau final states are predicted for a number of as yet unseen processes:
  - Standard model higgs boson (ttH→ttττ)
  - MSSM Higgs (H/A→ττ)
  - Non standard model top decays



Charged Higgs would be expected to couple preferentially to the tau

Tau Problems

- Unlike electrons and muons, taus decay within the detector volume (Electroweak)
- Decay produces two signatures:
  - Leptonic
    - 17.8% $\tau \to e\nu$
    - 17.8% $\tau \to \mu\nu$
  - Hadronic
    - 64.8% Decays to pions, kaons etc
- Both decays have problems
  - Leptonic decays are almost indistinguishable from electron/muon production
  - Hadronic decays produce narrow jets (in a hadronic enviroment)



Tau Classification

- “Leptonic” taus
- Hadronic taus
  - 1 prong (1 charged pion/kaon)
  - 3 prong 3 charged pions/kaons)
  - 5 prong(5 charged pions/kaons)
- Note that the hadronic modes can also include any number of neutral pions.

TeVatron work

- D0 measurement in the dileptonic channel with one tau in the final state
- Used 1.2fb^{-1} data and observed
  - 19 signal events in the μ+τ channel
  - 17 signal events in the e +τ channel
- Combining channels for a 170GeV top mass:

$$\ell + \tau : \sigma(t\bar{t}) = 6.75^{+1.91}_{-1.70}(\text{stat})^{+1.49}_{-1.31}(\text{syst}) \pm 0.39(\text{lumi}) \;\; \text{pb.}$$

- Combining with an earlier 1fb^{-1} measurement and using a top mass of 175GeV:

$$\ell + \tau : \sigma(t\bar{t}) = 7.32^{+1.34}_{-1.24}(\text{stat})^{+1.20}_{-1.06}(\text{syst}) \pm 0.45(\text{lumi}) \;\; \text{pb.}$$

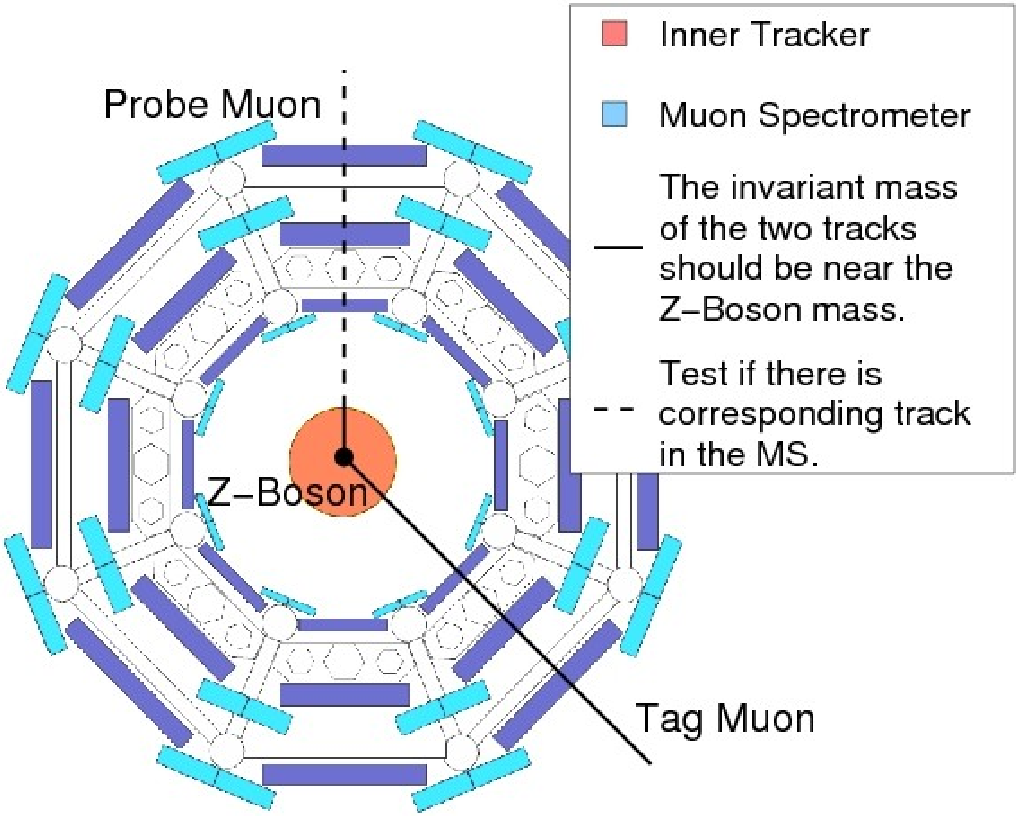
- All results consistent with other D0 measurements and the standard model

Taus in Top at ATLAS

- Triggering
- Event selection

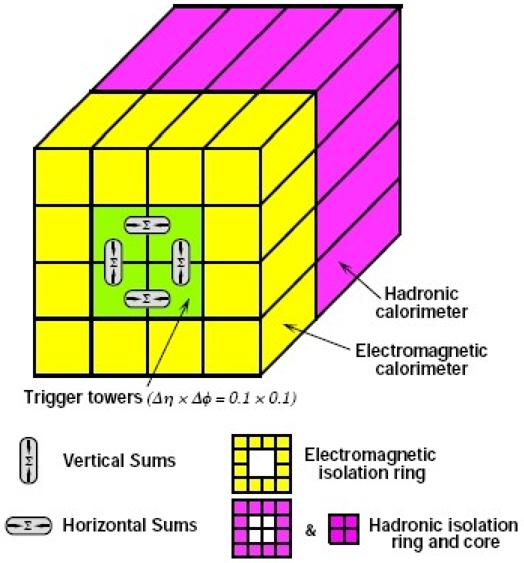
Triggering Taus in ATLAS

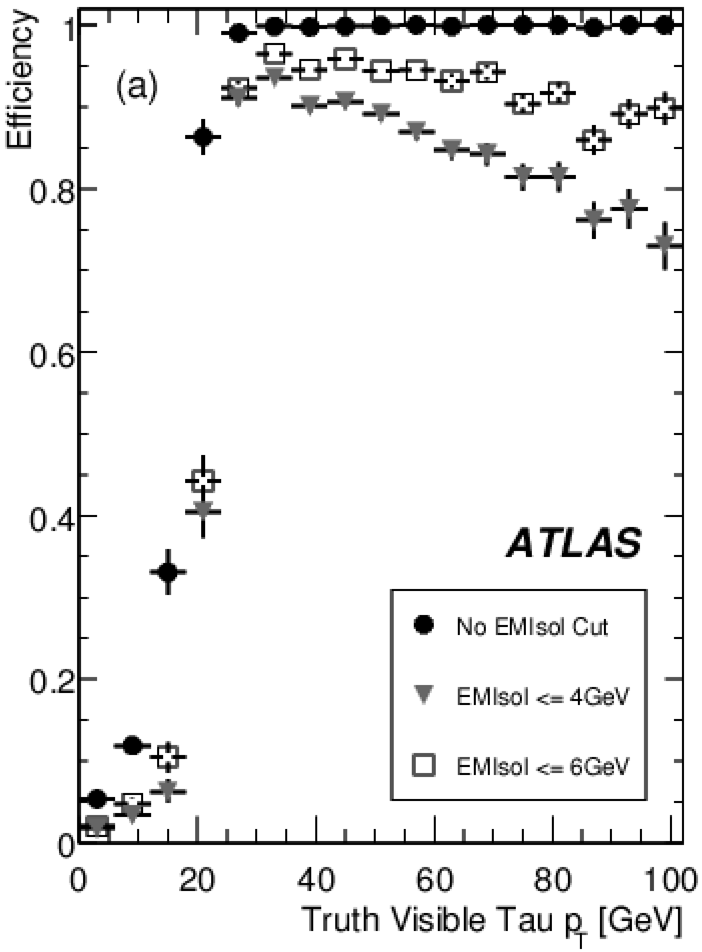
- For standard leptonic tops, trigger efficiencies are estimated from data by Z→ll decays (Tag and probe)
- Examined whether it is possible to do the same for taus



Triggering Taus in Top

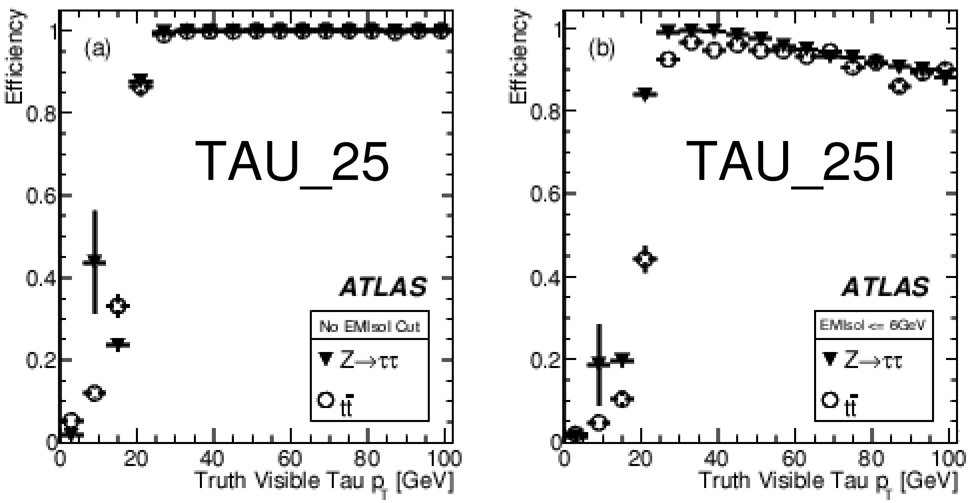
- ATLAS trigger has 3 levels
- L1 Calorimeter trigger:
  - Looks for high pt electrons and photons, jets and taus decaying into hadrons, and large missing and total Et (transverse energy)
  - For electron, photon and tau triggers, isolation can be applied to reduce the jet background





Triggering taus in tops

- L1 Continued.....



Comparison of TAU_25 and TAU_25I triggers for ttbar and Z→ττ events

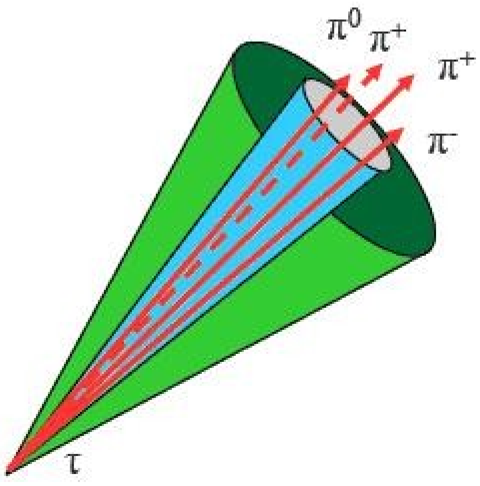
- Whole Trigger

Trigger Item	$W_{\tau\to hX}$	$Z_{\tau\tau}$	$t\bar{t}$
tau12	74.8 ± 0.3	88.8 ± 0.1	88.6 ± 0.2
tau16i	73.5 ± 0.3	86.0 ± 0.1	83.5 ± 0.3
tau20i	75.9 ± 0.3	85.3 ± 0.2	84.1 ± 0.3
tau29i	78.9 ± 0.5	83.3 ± 0.2	83.9 ± 0.4
tau38i	78.8 ± 0.9	78.7 ± 0.4	81.2 ± 0.5
tau50	71.7 ± 1.6	67.7 ± 0.7	70.0 ± 0.7
tau84	78.8 ± 4.0	80.3 ± 1.7	74.5 ± 1.5

Tau trigger efficiencies in top events compare well with those in cleaner environments

Good Tau Selection

- Selection relies on identifying narrow jets with low track multiplicity
- Select hadronic taus only
- Dependant on highly correlated calorimeter variables:
  - Shower width
  - Jet isolation



Must have strong rejection power against QCD jets (main background)

Tau Safe Cuts

- For established running multivariant techniques will be used for good tau selection
- In early data a set of simple “safe cuts” based on 4 calorimeter variables in 5 p_T bins (10-25, 25-45, 45-70, 70-100 and >100GeV) have been developed
- Selection subdivided into:
  - Loose, medium and tight cuts
  - 1-Prong and 3-Prong taus
- Cuts optimized by comparing the shapes of the variable distributions for signal and background samples
  - Signal: Mix of $Z \rightarrow \tau\tau$ and $A \rightarrow \tau\tau$ events
  - Background: Pythia QCD multijet (p_T 10-500GeV)
  - Originally optimized for 14TeV

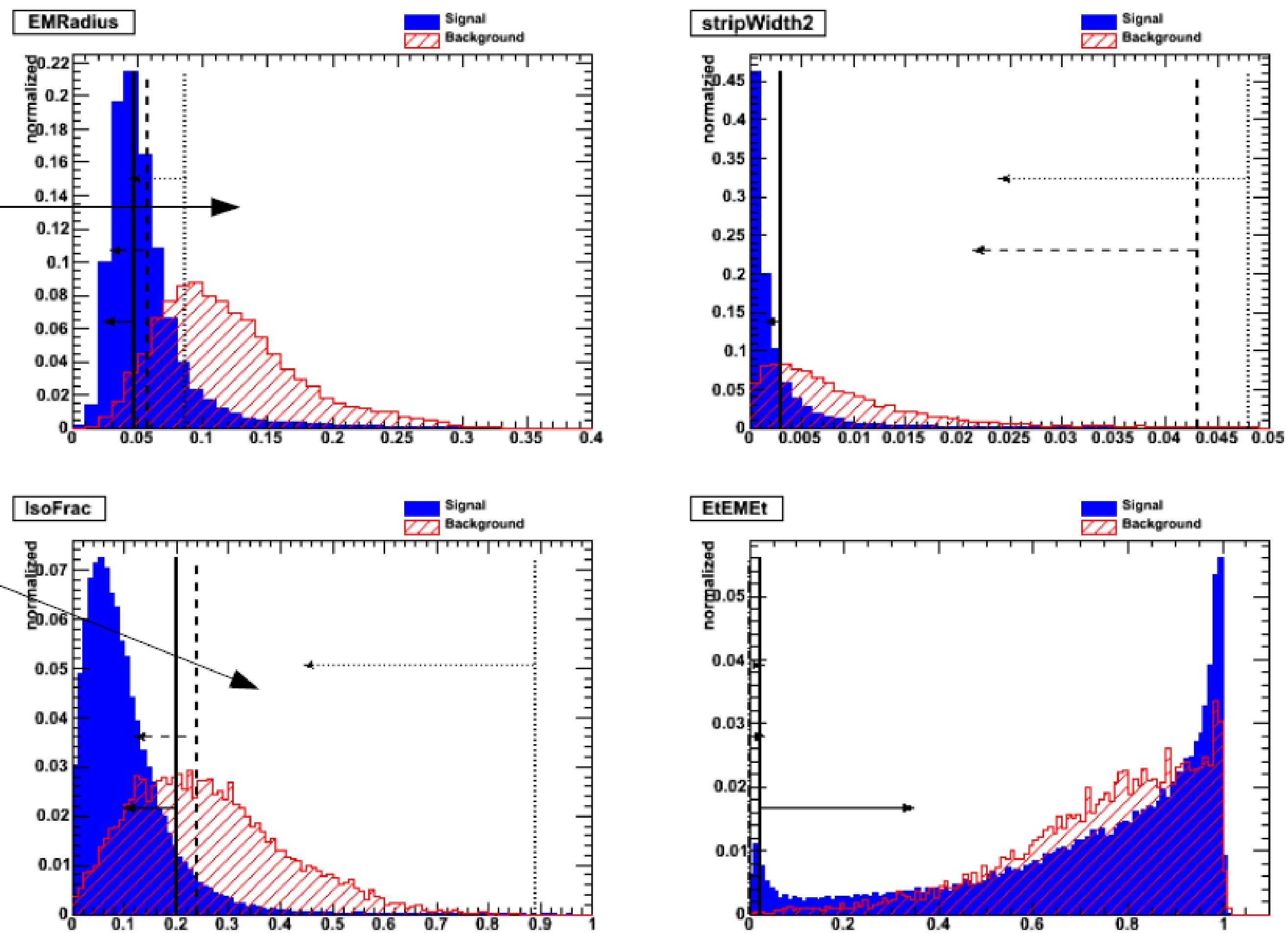
Tau Safe Cuts

Safe Variables for calo approach

Bjorn Gosdzik DESY

EMRadius:
taus have a smaller transverse shower profile than QCD-jets
<u>This is the strongest variable</u>

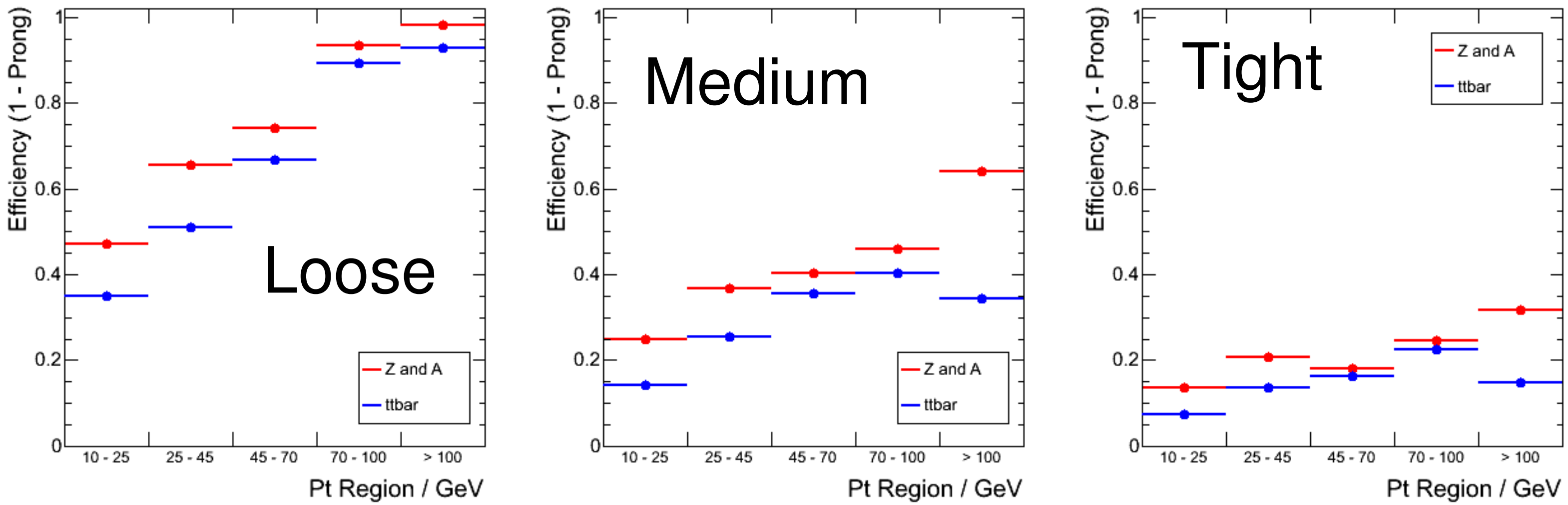
Clusters from had. decaying taus are well collimated => tighter isolation criteria are used



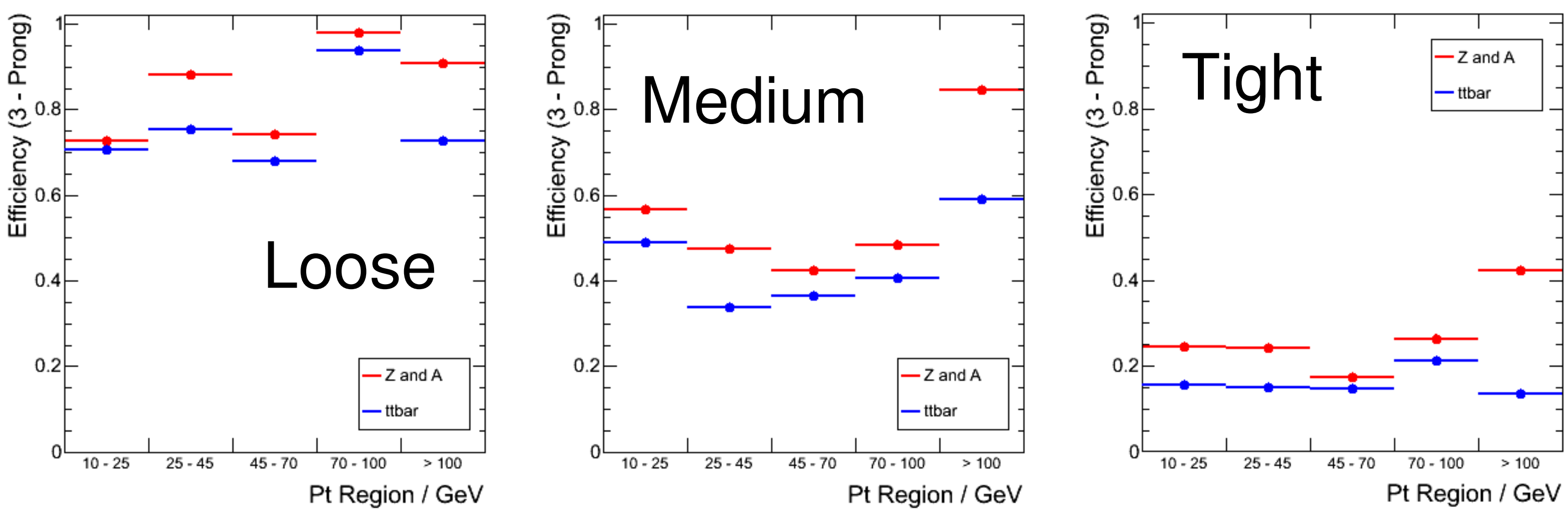
Tight cuts
Medium cuts
Loose cuts

Safe Cuts with Top

1-Prong



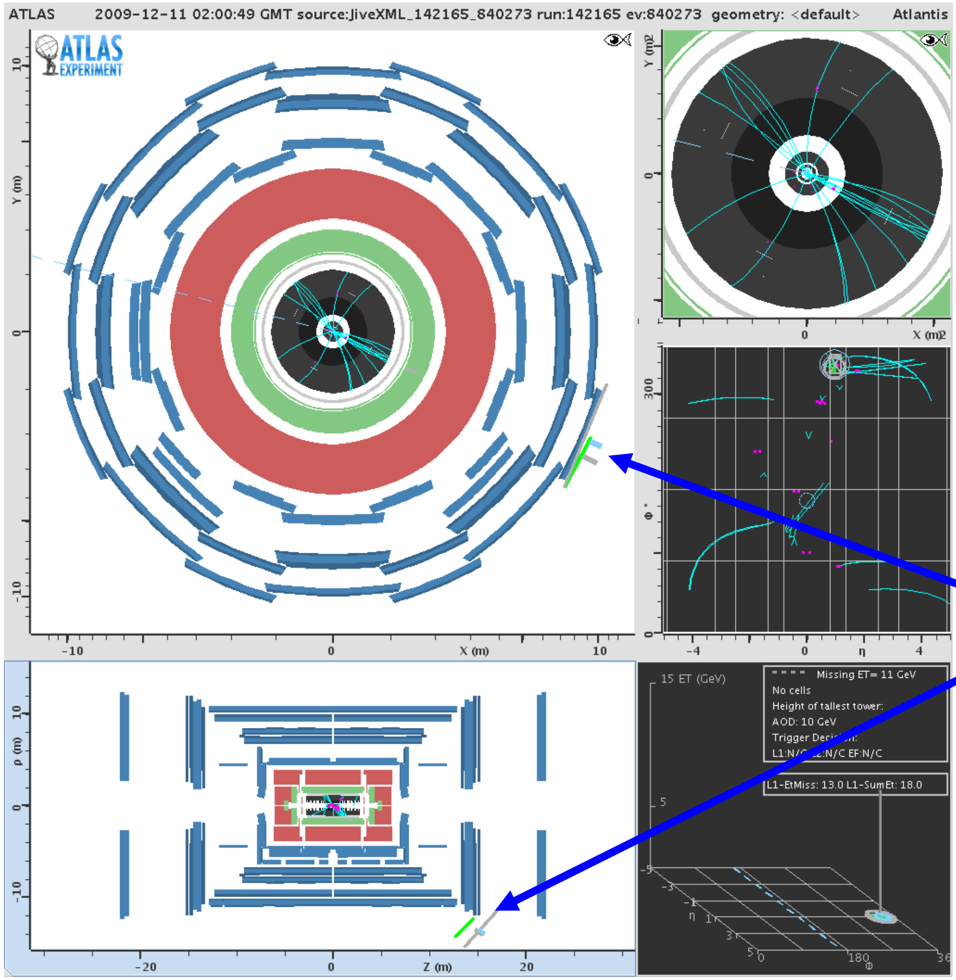
3-Prong



Ttbar
Z and A

Data!

Trigger and selection work!

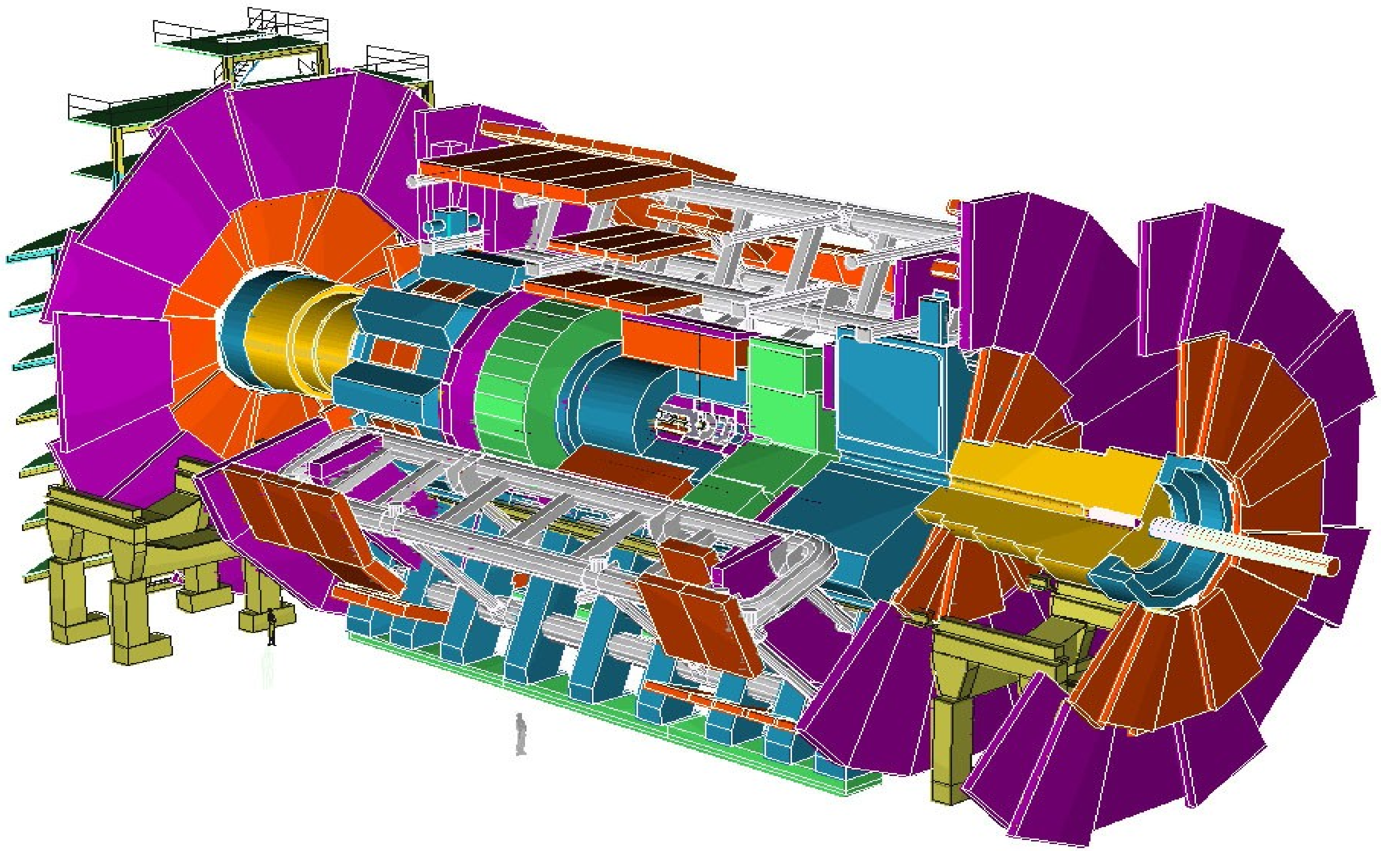


22GeV hadronic tau which has passed both the trigger and the safe cuts

The Future

- Possible to trigger on taus in tops
- Selection cuts seem useable
- LHC run I statistics compare well to TeVatron dataset
- Future looks bright for ATLAS top cross section measurements with the potential for exciting new work in the tau sector

ATLAS



Backup