Search for New Physics in events with 4 top quarks with Atlas at the LHC

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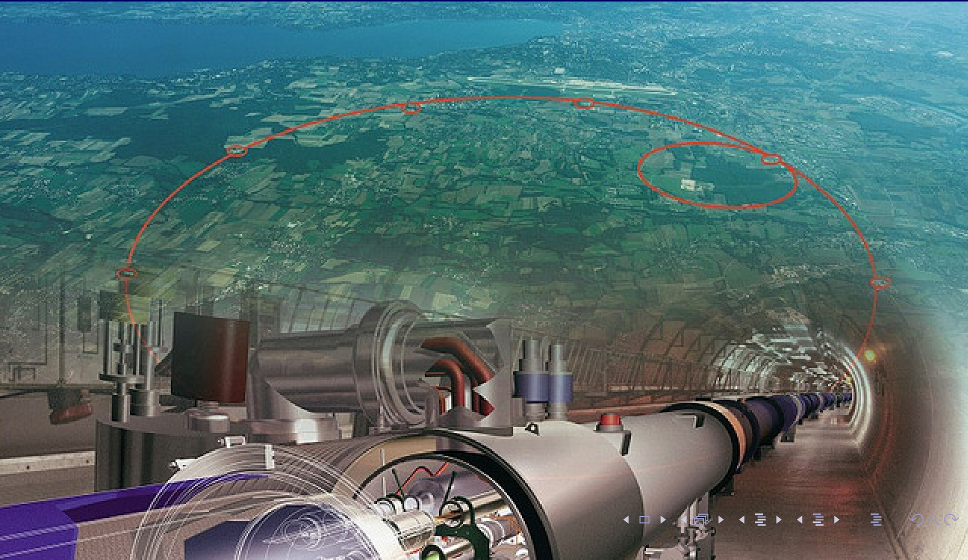
JRJC 2011

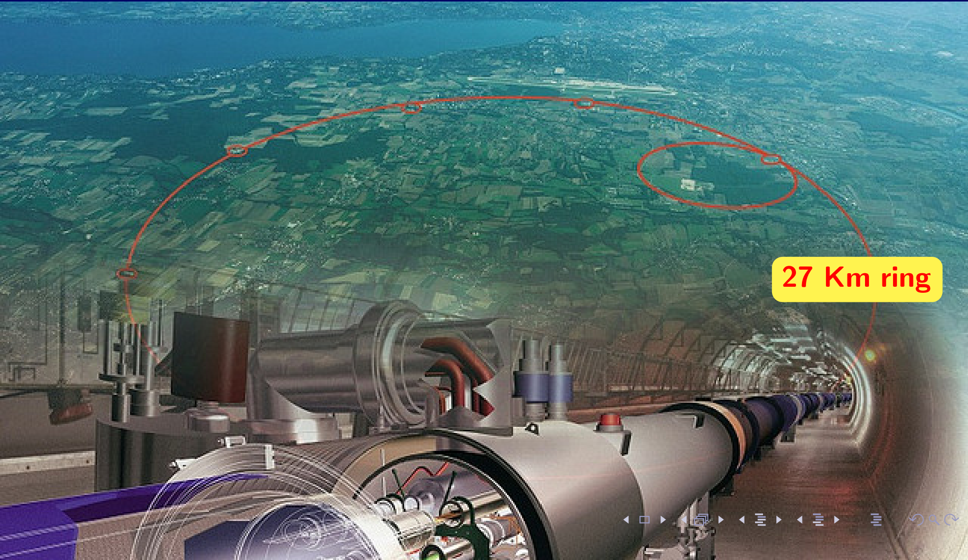
December 9, 2011

Outline

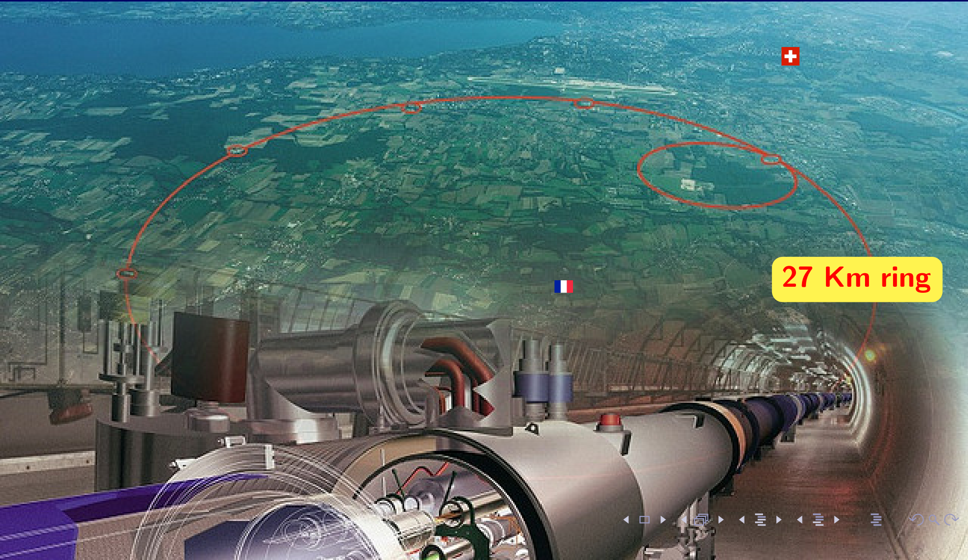
Large Hadron Collider



Large Hadron Collider



Large Hadron Collider



Large Hadron Collider

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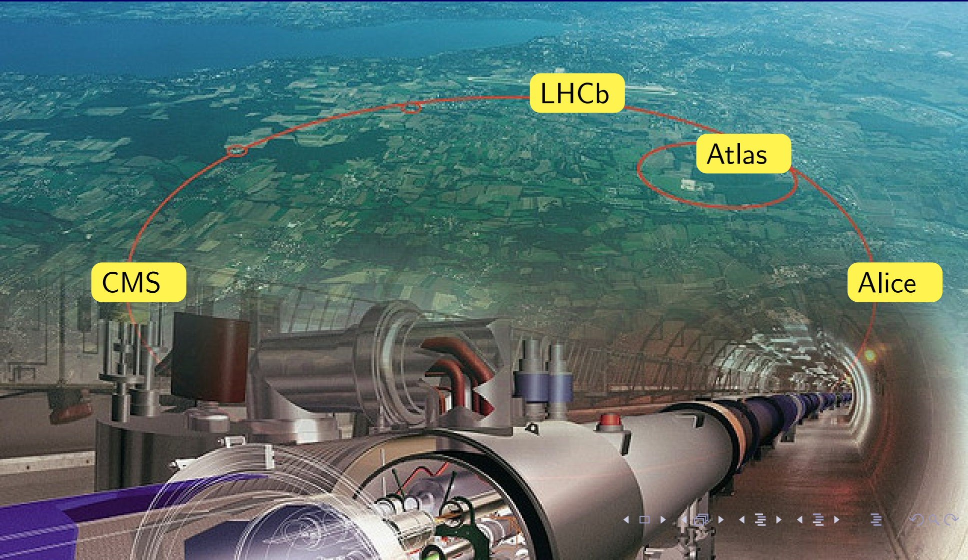
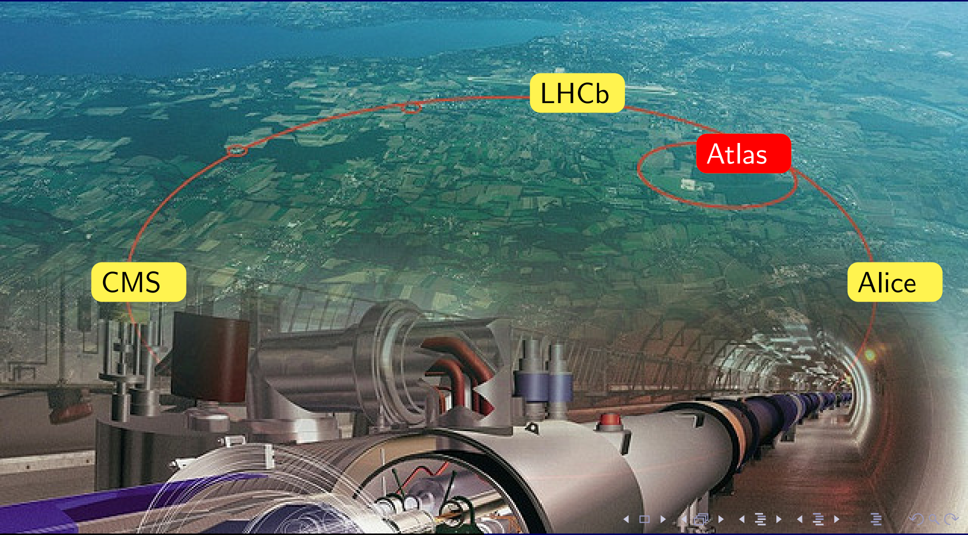
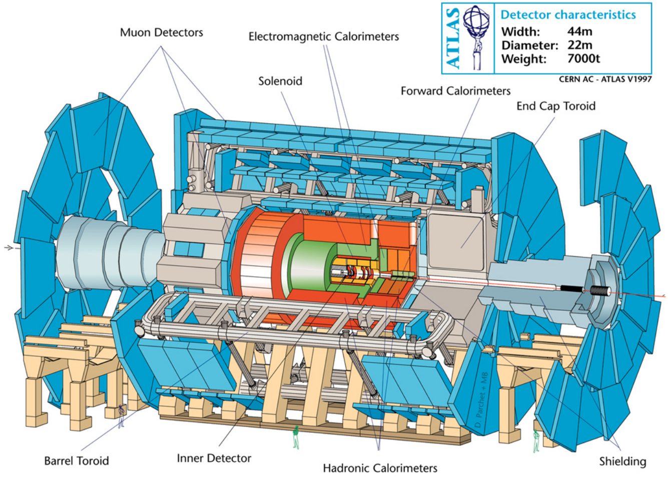


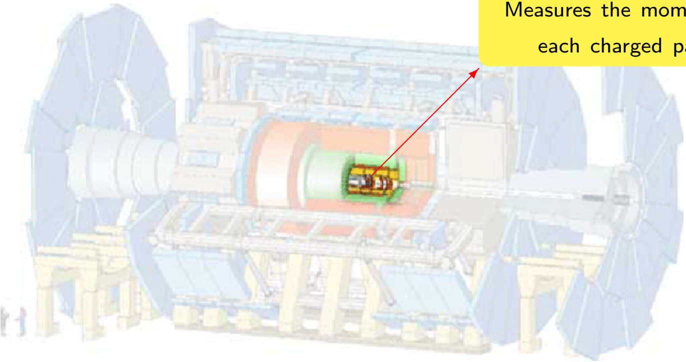
Large Hadron Collider



Atlas detector



Atlas detector



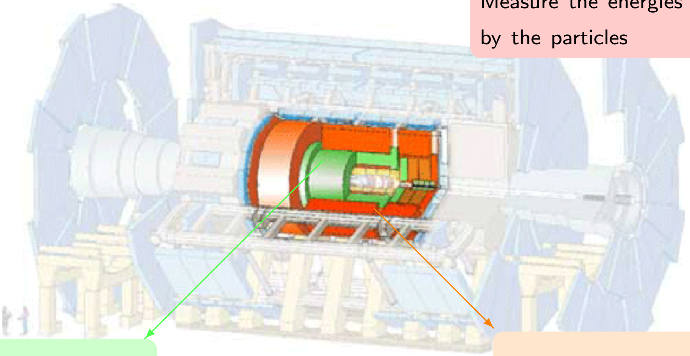
Inner detector

Measures the momentum of each charged particle

Atlas detector

Calorimeters

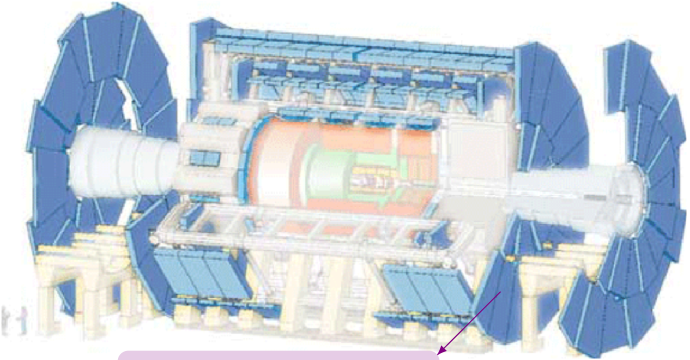
Measure the energies carried by the particles



EM Calorimeter

Hadronic calorimeter

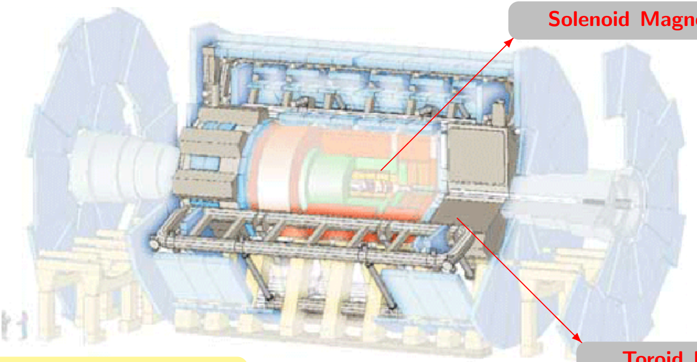
Atlas detector



Muon spectrometer

Identifies and measures the momenta of muons

Atlas detector



Magnet system

Bending charged particles for momentum measurement

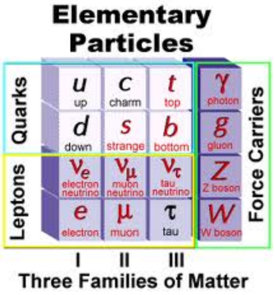
Standard Model

The Standard Model explains all the hundreds of particles and complex interactions only with :

- Six quarks.
- Six leptons.
- Force carrier particles.

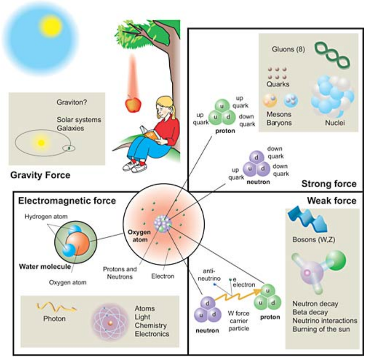
The SM explains the four fundamental forces as resulting from matter particles exchanging other particles (force carrier particles).

... but it does not tell the whole story!



Standard Model

- Inelegant → 19 numerical constants unrelated and arbitrary.
- Gravity is not incorporated.
- Generations matter → Why are there three generations of particles?
- Antimatter → Why is there more matter than antimatter in the universe?
- EWSB → Which is its origin?



One of the priorities of the LHC is to search the origin of the electroweak symmetry breaking (EWSB).

One possibility (inspired by QCD):

EWSB occurs in a new strong sector at energies of few TeV.

- Technicolor models.
- Composite Higgs scenarios.

In all these examples the SM fields that get masses from EWSB must at least be coupled to this new sector with a strength proportional to their masses.
This suggests...

TOP QUARK!

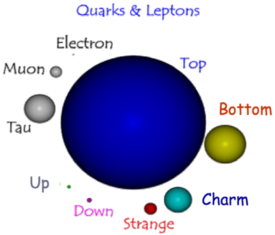
... as the most sensitive to New Physics.

The top quark

$$m_t \approx 172 GeV \quad (1)$$

$$m_e \approx 0.5 MeV \quad (2)$$

$$m_t \approx 344000 m_e! \quad (3)$$



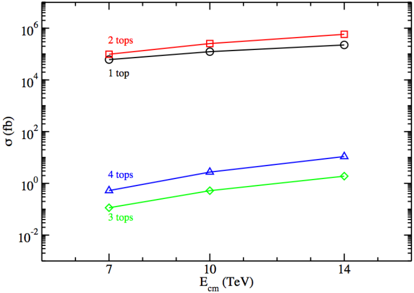
Top is the heaviest standard model particle:

→ Its large mass can be an indication that it is special in some way!

→ It can constrain New Physics.

Why do we study 4 top quarks?

The SM prediction for 4 top production at the LHC is very small ≈ 0.5 fb at 7 TeV.

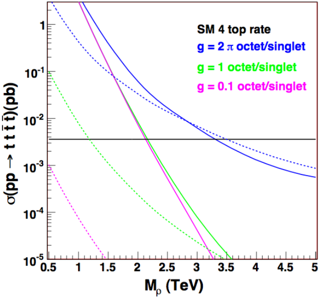


Cross sections for multi-top production in the Standard Model with $m_H = 130 GeV$

arXiv:1001.0221v3 [hep-ph]

Why do we study 4 top quarks?

Some models with New Physics predict an enhancement of the $t\bar{t}t\bar{t}$ production rate at the LHC compared to the SM $\rightarrow$ Top composite $\approx 10^3$ compared to the SM!

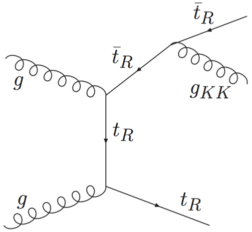


The rate for $t\bar{t}t\bar{t}$ at the LHC as a function of mass M for several values of the coupling g.

arXiv:0712.3057v1 [hep-ph]

Models with New Physics

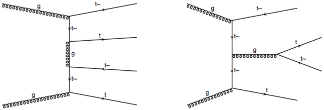
- Composite top.
- Randall-Sundrum.
- Universal Extra Dimensions model.
- SUSY signal.
- ...



$g_{KK} \rightarrow t\bar{t}$

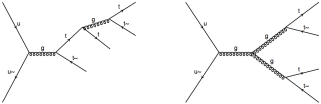
4 tops production in SM

- $gg \rightarrow t\bar{t}t\bar{t}$ (85% at the LHC at 7 TeV)



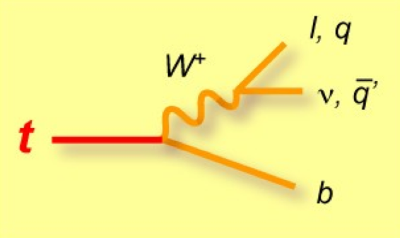
76 Feynman diagrams!

- $q\bar{q} \rightarrow t\bar{t}t\bar{t}$ (15%)



28 Feynman diagrams!

Top decay



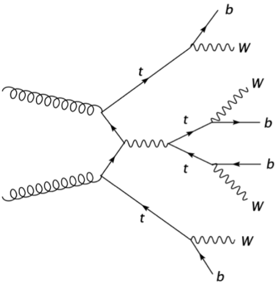
leptonic	hadronic
$W^+ \to l^+\nu$	$W^+ \to q\bar{q}'$
$W^- \to l^-\bar{\nu}$	$W^- \to q\bar{q}'$

How many final states can we obtain from 4 top quarks?

Final states

There are 35 final states from 4 top quarks depending on the W decay (h, e, μ, τ), which are constituted of 5 different classes of channels:

- Full hadronic : $8j + 4b$
- Most hadronic: $1l + 6j + 4b + MET$
- Semi leptonic: $2l + 4j + 4b + MET$
- Most leptonic: $3l + 2j + 4b + MET$
- Full leptonic: $4l + 4b + MET$



Branching ratio

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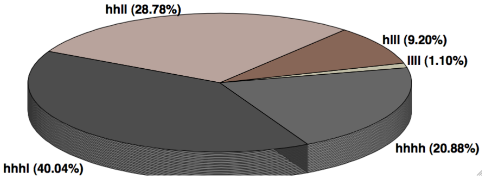
- Semi leptonic: $2l + 4j + 4b + MET$
- Most leptonic: $3l + 2j + 4b + MET$
- Full leptonic: $4l + 4b + MET$



Branching Ratios

- Most probable decay comes from the 1 lepton + jets!
  → But... 1 lepton can be produced easily by SM.
- Two leptons + jets is more promising.
  → It's less probable in SM.

Analysis: Procedure

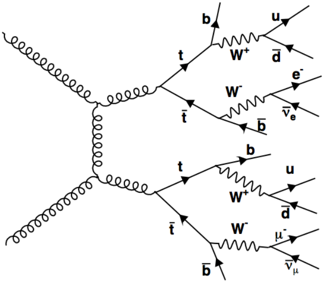
- Select channel of decay.
- Preselection criteria of events.
- Estimation background.
- Generate events using different models (those that imply New Physics) and comparing the results among them.
- Establish selection criteria of events.
- Calculate cross section or at least put the limit.

Channel of decay

Easiest channel to select is with two leptons: $hhl^{\pm}_{e/\mu}l^{\pm}_{e/\mu} \rightarrow BR = 4.15\%$

Channel topology:

- Two charged leptons, possibly with same sign.
- Eight jets, including four b-jets.



Preselection criteria of events

- Separate in three samples:
  - μ sample: at least one good μ, no good electron.
  - e sample: at least one good electron, no good μ.
  - μe sample: at least one good μ and one good electron.
- Lepton selection:
  - μ: $p_t > 20$ GeV/c
  - e: $p_t > 25$ GeV/c
- Jets selection:
  - $p_t > 20$ GeV/c
  - $|\eta| < 2.5$
  - Separation between light and b-jets.

Background and data generated

Background

Background	L $[fb^{-1}]$
W+$b\bar{b}$+jets	$\sim$ 10
WW($\ell\nu\ell\nu$) +jets	24-57
WZ	72
ZZ	257
Z(ee)+jets	$\sim$ 10
Z($\mu\mu$)+jets	10-13
Z($\tau\tau$)+jets	10-13
$t\bar{t}$	145
single top	42-62
W+$c\bar{c}$+jets	$\sim$10

Data generated

- Standard Model $t\bar{t}t\bar{t}$: 10000 events, $\sigma \approx 0.25$ fb.
- New Physics model giben by C. Degrande[1]: 10000 events, $\sigma \approx 12.6$ fb
- Event generation with MadGraph/MadEvent.
- Full simulation with pile-up.

[1] arXiv:1010.6304

Cross sections after preselection

Sample	$\sigma(\mu\mu)$ [fb]	$\sigma(ee)$ [fb]	$\sigma(\mu e)$ [fb]
4 *top* NP	0.28	0.21	0.49
4 *top* SM	0.01	0.01	0.02
W+b$\bar{b}$+jets	1.77	2.76	6.09
WW($\ell\nu\ell\nu$)+jets	194	104	281
WZ	178	104	46
ZZ	145	85	10
Z(ee)+jets	0	153901	1
Z($\mu\mu$)+jets	296502	0	82
Z($\tau\tau$)+jets	705	291	896
t$\bar{t}$	888	475	1280
Single top	113	61	155

- Main source of background for $\mu\mu$: Z($\mu\mu/\tau\tau$)+jets, t$\bar{t}$.
- Main source of background for ee: Z(ee/$\tau\tau$)+jets, t$\bar{t}$.
- Main source of background for μe: t$\bar{t}$, WW($\ell\nu\ell\nu$)+jets, Z($\tau\tau$)+jets.

Cross sections after the cut # 1: Same sign dilepton

Sample	$\sigma(\mu\mu)$ [fb]	$\sigma(ee)$ [fb]	$\sigma(\mu e)$ [fb]
4 *top* NP	0.093	0.070	0.150
4 *top* SM	0.0030	0.0023	0.0064
W+b$\bar{b}$+jets	0.6	1.0	3.0
WW($\ell\nu\ell\nu$)+jets	1.1	1.9	4.1
WZ	12.1	8.8	14.2
ZZ	2.3	2.5	1.8
Z(ee)+jets	0	1677	0.4
Z($\mu\mu$)+jets	18.5	0	21.0
Z($\tau\tau$)+jets	0.1	2.3	6.2
t$\bar{t}$	2.2	7.0	11.5
Single top	0.5	1.5	2.2

Preliminary cuts

- There is a lot of background to remove!
- It can be eliminated by applying very simple cuts:
  - $Nb_{bjets} > 0$
  - $Nb_{ljets} > 2$
- These cuts are applied on all channels.
- Maintain the New Physics signal above 80% with respect to the first cut (same sign dilepton).

Cross sections after cut # 2: $Nb_{bjets} > 0$

Sample	$\sigma(\mu\mu)$ [fb]	$\sigma(ee)$ [fb]	$\sigma(\mu e)$ [fb]
4 *top* NP	0.092	0.068	0.140
4 *top* SM	0.0025	0.0022	0.0060
W+b$\bar{b}$+jets	0.2	0.3	0.4
WW($\ell\nu\ell\nu$)+jets	0.02	0	0.14
WZ	0.11	0.04	0.1
ZZ	0.03	0.12	0.03
Z(ee)+jets	-	9.5	0
Z($\mu\mu$)+jets	0.2	-	0.1
Z($\tau\tau$)+jets	0	0	0
t$\bar{t}$	1.1	4.6	7.2
Single top	0.16	0.58	0.94

Cut Effect:

- $\mu\mu$ channel: Kills all Z($\tau\tau$)+jets.
- ee channel: Kills all Z($\tau\tau$)+jets and WW($\ell\nu\ell\nu$)+jets.
- μe channel: Kills all Z($\tau\tau$)+jets and Z(ee)+jets.

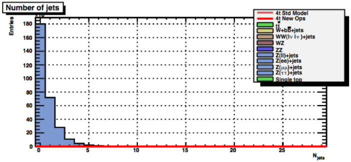
Cross sections after cut # 3: $Nb_{ljets} > 2$

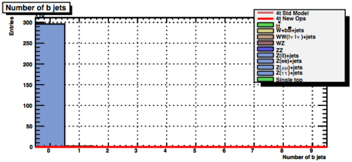
Sample	$\sigma(\mu\mu)$ [fb]	σ(ee) [fb]	$\sigma(\mu$e) [fb]
4 *top* NP	0.084	0.062	0.130
4 *top* SM	0.0024	0.00215	0.0054
W+b$\bar{\text{b}}$+jets	0	0	0.3
WW($\ell\nu\ell\nu$)+jets	0	0	0.03
WZ	0.014	0	0.030
ZZ	0	0.030	0.008
Z(ee)+jets	-	1.8	-
Z($\mu\mu$)+jets	0.1	-	0
Z($\tau\tau$)+jets	-	-	-
t$\bar{\text{t}}$	0.5	1.4	2.3
Single top	0.02	0.05	0.20

Cut Effect:

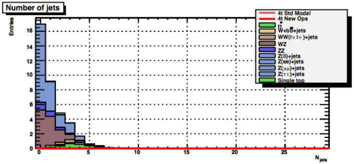
- $\mu\mu$ channel: Kills all W+b$\bar{\text{b}}$+jets, WW($\ell\nu\ell\nu$)+jets and ZZ.
- ee channel: Kills all W+b$\bar{\text{b}}$+jets, WW($\ell\nu\ell\nu$)+jets and WZ.
- μe channel: Kills Z($\mu\mu$)+jets.

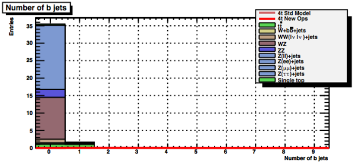
Example of cut for $\mu\mu$ channel





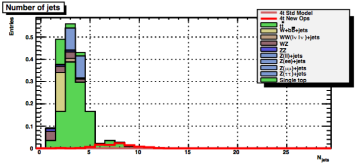
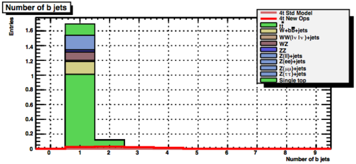
Distributions for N_{jets} and N_{bjets} for 2 leptons channel before cuts



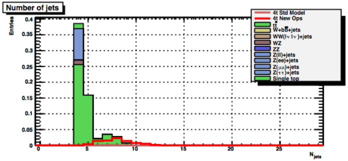
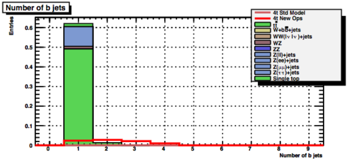


Distributions for N_{jets} and N_{bjets} after the cut 2 leptons of the same sign

Example of cut for $\mu\mu$ channel

Distributions for N_{jets} and N_{bjets} after cut $Nb_{bjets} > 0$

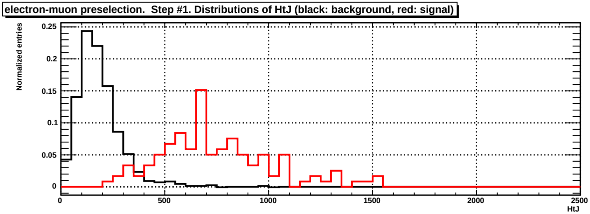
Distributions for N_{jets} and N_{bjets} after cut $Nb_{ljets} > 2$

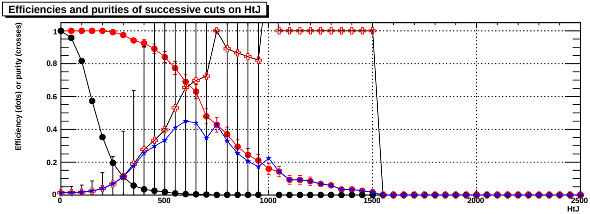
Selection criteria of events

- Cuts → Done with New Physics signal and $t\bar{t}$ for background with an automatic cutter acting on the following variables:
  - Ht
  - Ht+ Lt+MET.
  - MET
  - NbbJets
  - NbbJets+NbLJets
  - El1Pt
  - Mu1Pt
  - B1Pt
  - J1Pt
  - J2Pt
- Strategy → Maximize efficiency×Purity.
- Efficiency → Maintain the New Physics signal above 40% with respect to the first cut.
- Background → Remove as much $t\bar{t}$ background as possible.

⇒Try to find similar cuts for the 3 channels.

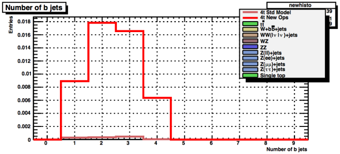
Example of Cut # 4 $Ht \geq 600 GeV$



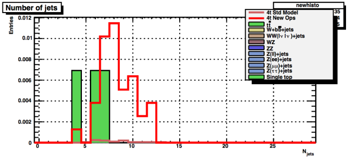


Efficiency×Purity in blue

Example of Cut # 4 $Ht \geq 600 GeV$



Distributions for N_{bjets} after cut # 4 $Ht \geq 600 GeV$ for $\mu\mu$ channel



Distributions for N_{jets} after cut # 4 $Ht \geq 600 GeV$ for ee channel

Cut Effect:

→ Kills all background for $\mu\mu$ channel.

→ Only $t\bar{t}$ remains for both ee and μe channel!

Efficiency of cuts

$\mu\mu$

Cut	#1 same sign	#2 $Nb_{bjets} > 0$	#3 $Nb_{lJets} > 2$	# 4 $Ht \geq 600 GeV$
4 *top* NP	34%	97%	91%	67%
4 *top* SM	26%	92%	92%	50%
$t\bar{t}$	0.3%	33%	60%	0 %

ee

Cut	#1 same sign	#2 $Nb_{bjets} > 0$	#3 $Nb_{lJets} > 2$	# 4 $Ht \geq 600 GeV$
4 *top* NP	33%	97%	91%	72%
4 *top* SM	33%	94%	98%	46%
$t\bar{t}$	1.5%	67%	30%	1%

$e\mu$

Cut	#1 same sign	#2 $Nb_{bjets} > 0$	#3 $Nb_{lJets} > 2$	# 4 $Ht \geq 600 GeV$
4 *top* NP	32%	91%	93%	74%
4 *top* SM	31%	94%	90%	50%
$t\bar{t}$	0.9%	40%	30%	1.5%

Results

Sample	$\sigma(\mu\mu)$ [fb]	σ(ee) [fb]	$\sigma(\mu$e) [fb]	$\sigma(all)$
4 *top* NP	0.050	0.045	0.097	0.192
4 *top* SM	0.0012	0.0010	0.0027	0.0049
$t\bar{t}$	0	0.014	0.035	0.049

Cross sections after cut # 4: $Ht \geq 600 GeV$

For 20 fb^{-1} (expected at end of 2012)

- 3.8 New Physics events.
- 1.1 SM events ($t\bar{t} + t\bar{t}t\bar{t}$).

Conclusion and Outlooks

- Discovery potential for 5 $fb^{-1} \rightarrow$ 1 New Physics event .
- Including other channels like opposite sign leptons, single lepton...
- Probable improvement by tuning selection.
- Comparison with data have to be done.

$\Rightarrow$ **Still a lot of work to do!**

BACKUP

Efficiencies after cuts for $\mu\mu$ channel

Cut	#1 same sign	#2 $Nb_{bjets} > 0$	#3 Nb_{lJets}	# 4 $Ht \geq 600GeV$
4 *top* NP	34%	33%	30%	20%
4 *top* SM	26%	24%	22%	11%
W+b$\bar{b}$+jets	31%	10%	0	-
WW($\ell\nu\ell\nu$)+jets	0.6%	0.01%	0	-
WZ	6.8%	0.06%	0.01%	0
ZZ	1.6%	0.02%	0	-
Z(ee)+jets	0	-	-	-
Z($\mu\mu$)+jets	0.006%	7×10^{-5}	4×10^{-5}	0
Z($\tau\tau$)+jets	0.01%	0	-	-
t$\bar{t}$	0.3%	0.1% %	0.06%	0?
Single top	0.4%	0.1%	0.01%	0

Efficiencies after cuts for ee channel

Cut	#1 same sign	#2 $Nb_{bjets} > 0$	#3 Nb_{lJets}	# 4 $Ht \geq 600 GeV$
4 *top* NP	33%	32%	29%	21%
4 *top* SM	33%	31%	30.5%	14%
W+b$\bar{b}$+jets	36%	10%	0	-
WW($\ell\nu\ell\nu$)+jets	1.8%	0%	-	-
WZ	0.5%	0.04%	0%	-
ZZ	3%	0.1%	0.03	0
Z(ee)+jets	1.1%	0.01%	0.001%	0
Z($\mu\mu$)+jets	0	-	-	-
Z($\tau\tau$)+jets	0.8%	0	-	-
t$\bar{t}$	1.5%	1%	0.3%	0.003%
Single top	2.4%	1%	0.1%	0

Efficiencies after cuts for eμ channel

Cut	#1 same sign	#2 $Nb_{bjets} > 0$	#3 Nb_{lJets}	# 4 $Ht \geq 600GeV$
4 *top* NP	32%	29%	27%	20%
4 *top* SM	31%	29%	26%	13%
W+b$\bar{b}$+jets	49%	6%	5	0
WW($\ell\nu\ell\nu$)+jets	1.5%	0.05%	0.01%	0
WZ	31%	0.2%	0.06%	0
ZZ	18%	0.3%	0.1%	0
Z(ee)+jets	40%	0%	-	-
Z($\mu\mu$)+jets	26%	0.1%	0	-
Z($\tau\tau$)+jets	0.7%	0	-	-
t$\bar{t}$	0.9%	0.6%	0.2%	0.003%
Single top	1.4%	0.6%	0.1%	0