Four-top events at the LHC from top-philic new physics

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in collaboration with

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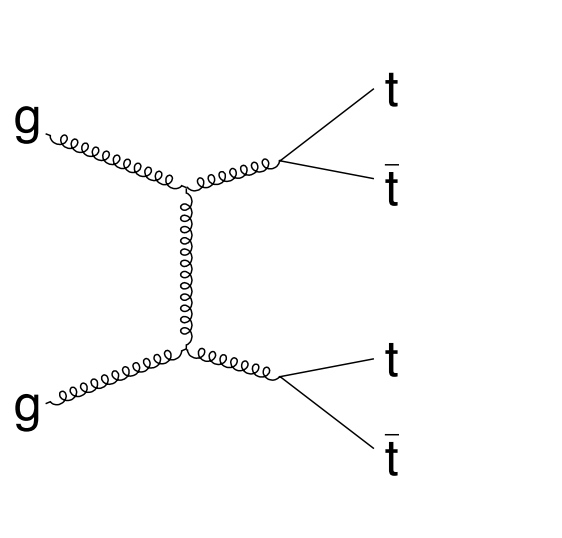
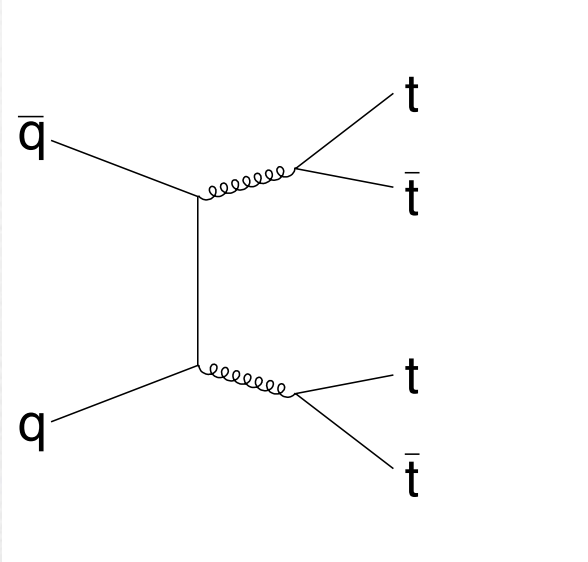
paper in preparation,
for a short preview see chapter 12, p.137 of 1005.1229

Four-top production in the Standard Model



88 %

+



+ ....

σ_{LHC} ~ 7.5 fb @ 14 TeV

σ_{LHC} ~ 0.2 fb @ 7 TeV

⇛ 4 top final state sensitive to several classes of new TeV scale physics

e.g. SUSY (gluino pair production with $\tilde{g} \rightarrow t\,\bar{t}\,\chi_0$)

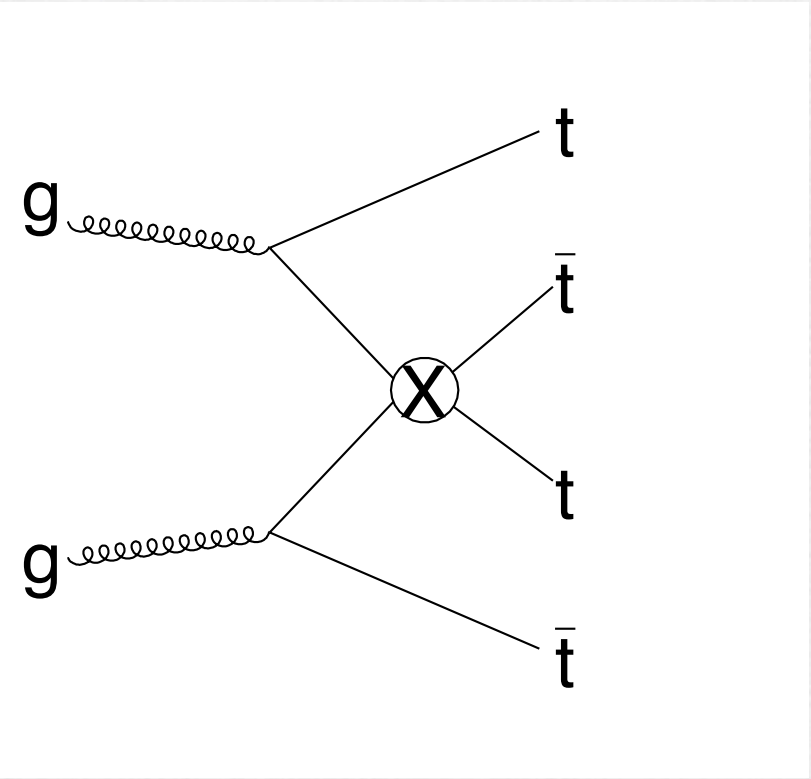
top compositeness

In particular, well-motivated models where new heavy resonances have a preference for the top quark

Low energy effective theory approach

After integrating out heavy resonances, we are left with higher dimensional operators such as $\frac{1}{\Lambda^2}(\bar{t}_R\gamma^\mu t_R)(\bar{t}_R\gamma_\mu t_R)$

leading to:



[Pomarol-Serra,'08]
[Lillie-Shu-Tait,'08]

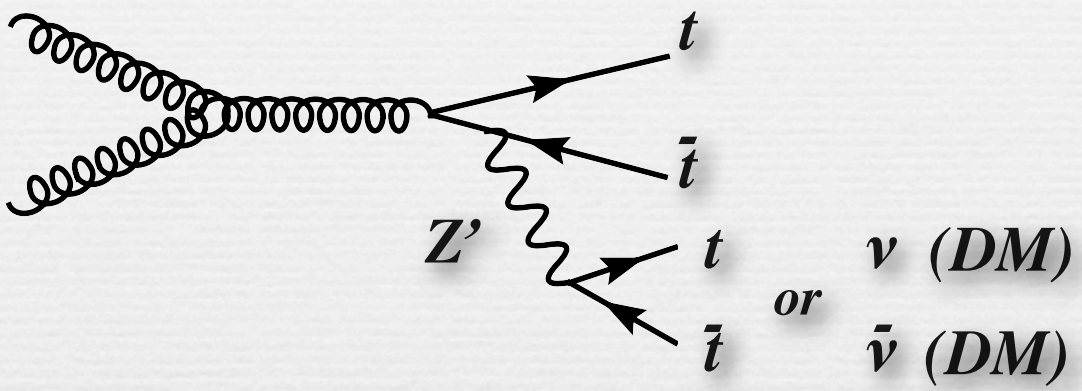
Four-top events from a top-philic and Dark Matter-philic Z'

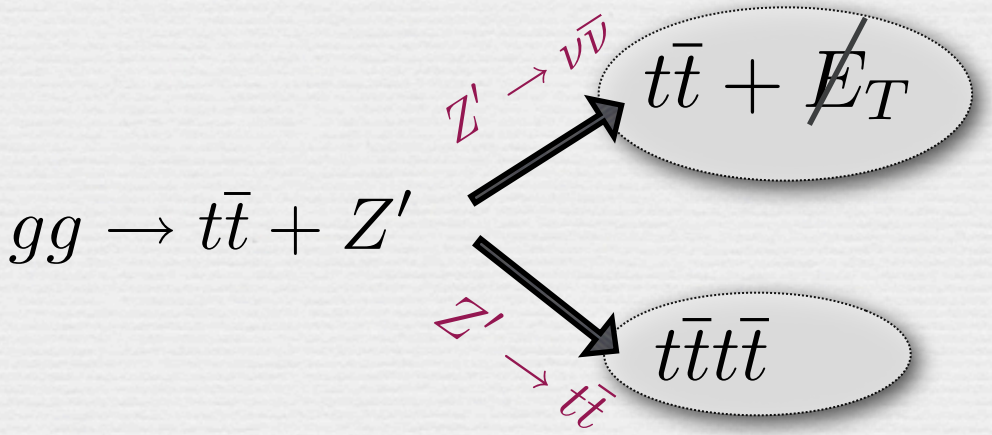
Jackson, Servant, Shaughnessy,Tait, Taoso,'09

Z' has suppressed couplings to light quarks

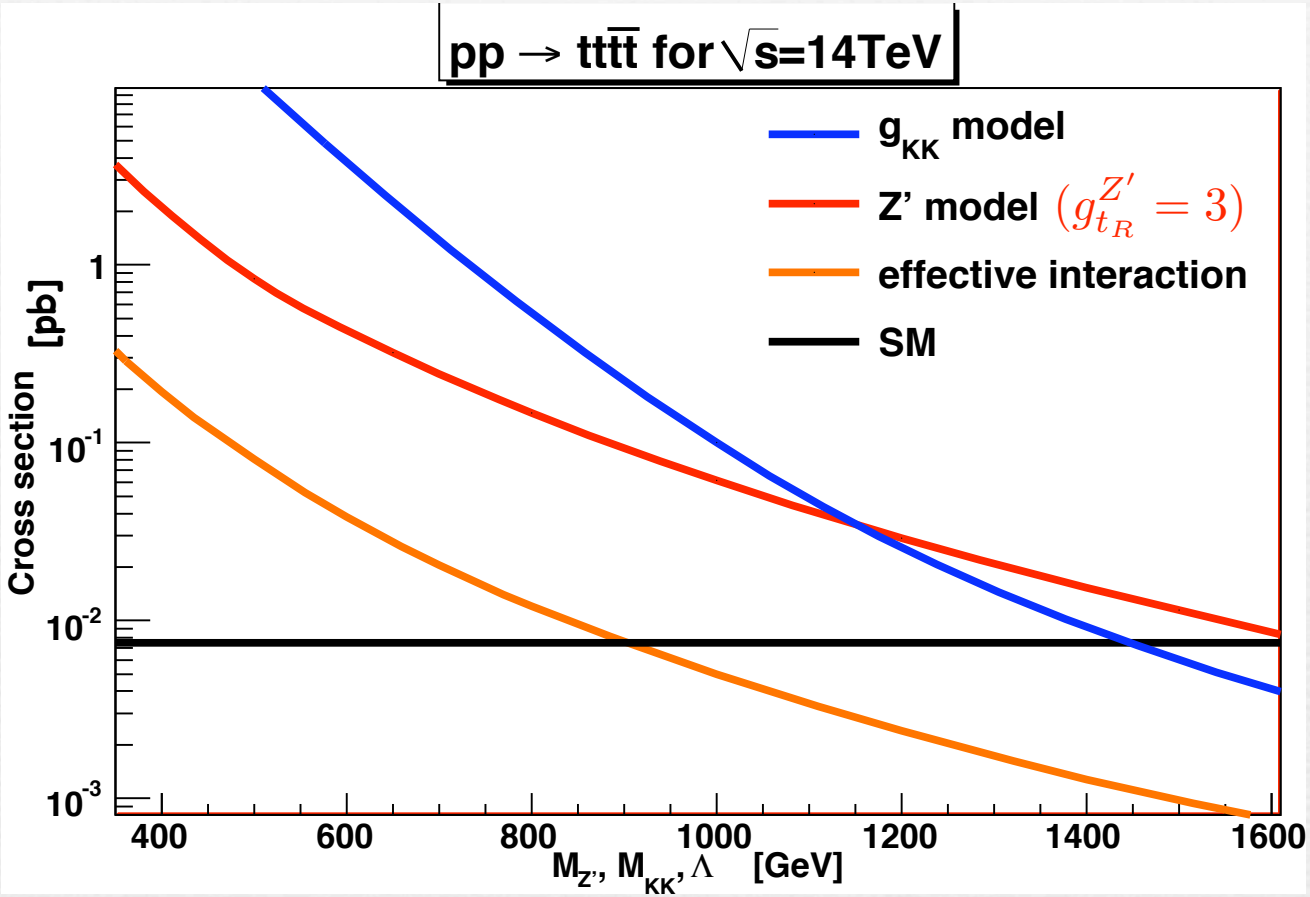
-> no observable $t\bar{t}$ resonances

instead:





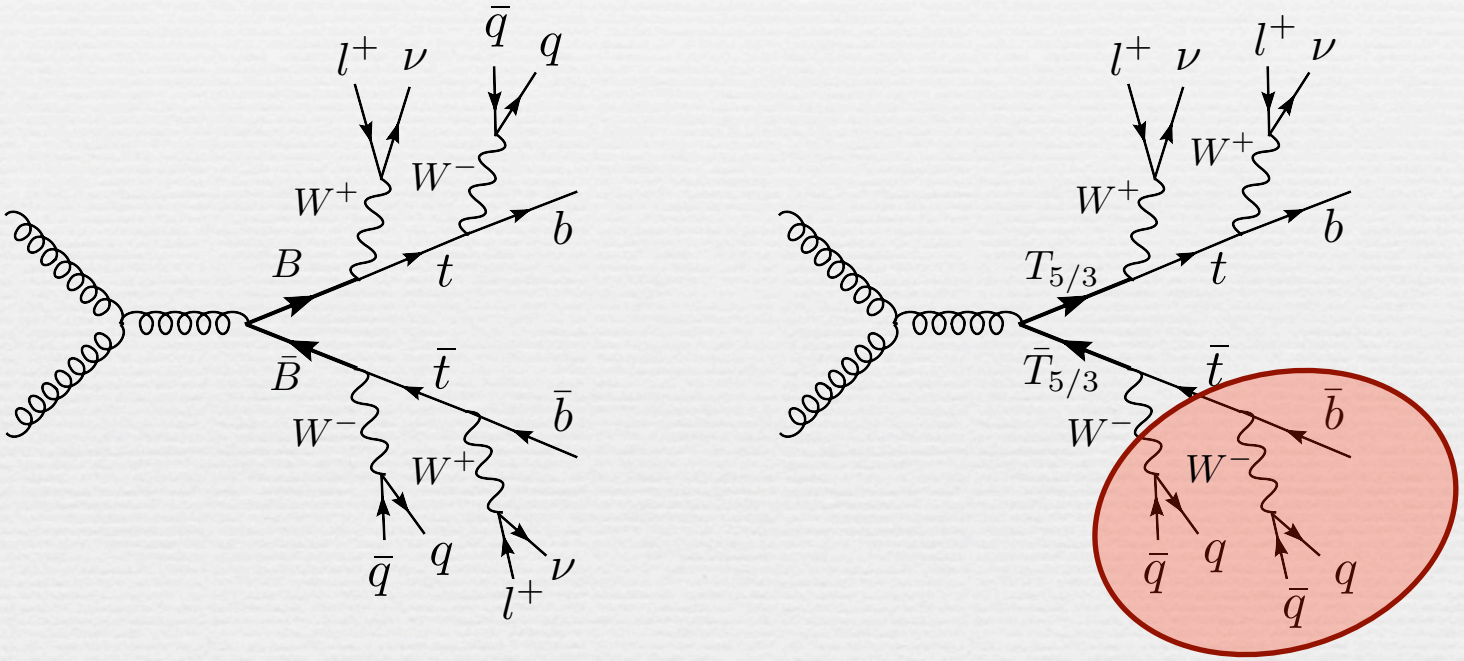
4-top production cross sections at the LHC



same-sign dilepton channel powerful to get rid of the ttbar bgd

promising to search for $t\bar{t}WW$ final states from pair production of heavy quarks (recently used by CDF to put bound on mass of 4th generation b')

[Contino & Servant, '08]

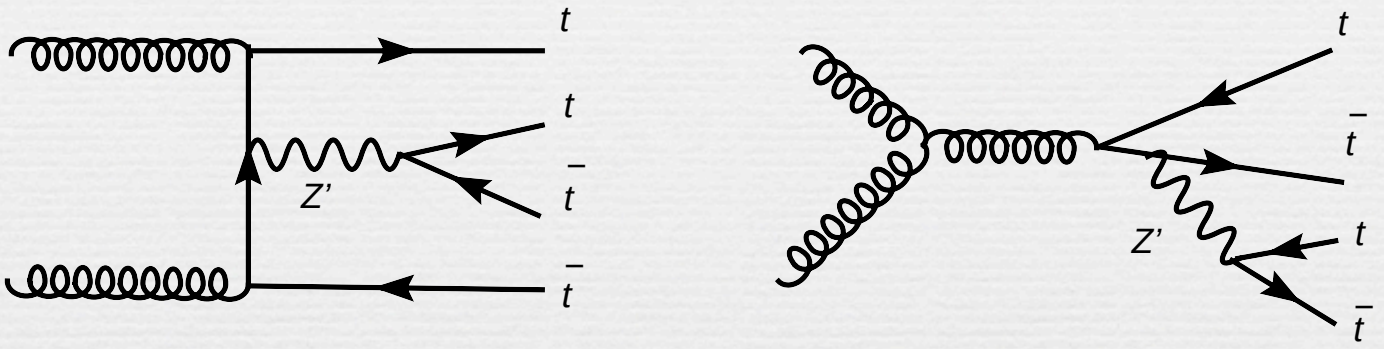


$t\bar{t}t\bar{t}$ production: similar final state but 2 additional b quarks

final state: $\ell^{\pm}\ell^{\pm}$ + *n jets* + $E_{T,missing}$

(of which 4 are b-jets)

Four-top events from a top-philic Z'



A very simple effective theory

Jackson, Servant, Shaughnessy,Tait, Taoso,'09
Agashe-Servant '04; Belanger-Pukhov-Servant '07

There is a new spontaneously broken U(1)'.

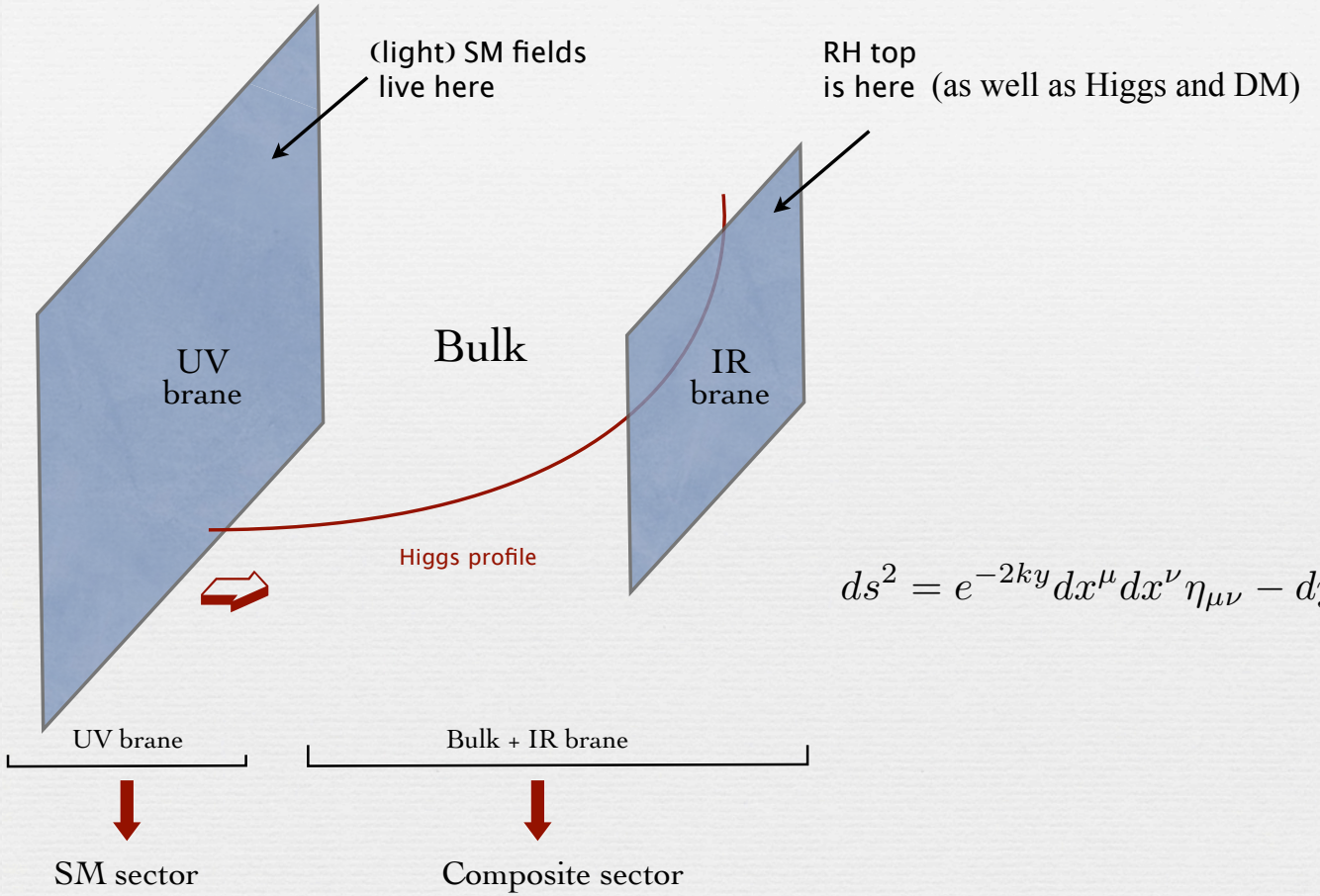
The only SM particle with a large coupling to the Z' is the top quark

$$\mathcal{L} = \mathcal{L}_{SM} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + M^2_{Z'}Z'_\mu Z'^\mu + i\bar{\nu}\gamma^\mu D_\mu \nu + g^t_R \bar{t}\gamma^\mu P_R Z'^\mu t + \frac{\chi}{2}F'_{\mu\nu}F_Y^{\mu\nu}$$

DM

$$D^\mu \equiv \partial_\mu - i\left(g^\nu_R P_R + g^\nu_L P_L\right) Z'^\mu$$

This model is inspired by the Randall-Sundrum setup (warped extra dimension):



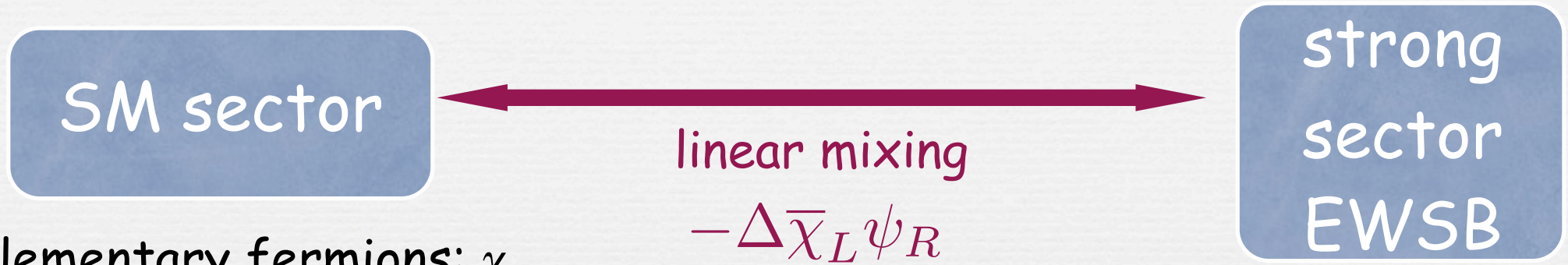
$$ds^2 = e^{-2ky}dx^\mu dx^\nu \eta_{\mu\nu} - dy^2$$

TeV KK modes (such as Z') have enhanced couplings to RH top quark

More generally, in models of partial fermion compositeness, natural to expect that only the top couples sizably to a new strongly interacting sector.

Partial compositeness: Dual picture

Higgs is part of composite sector: it couples only to composite fermions



zero mode mass eigen state is mixture of elementary and composite

- massless

$$|light>_L = \cos\phi|\chi_L> + \sin\phi|\psi_L>$$

amount of compositeness in the light dof

- massive

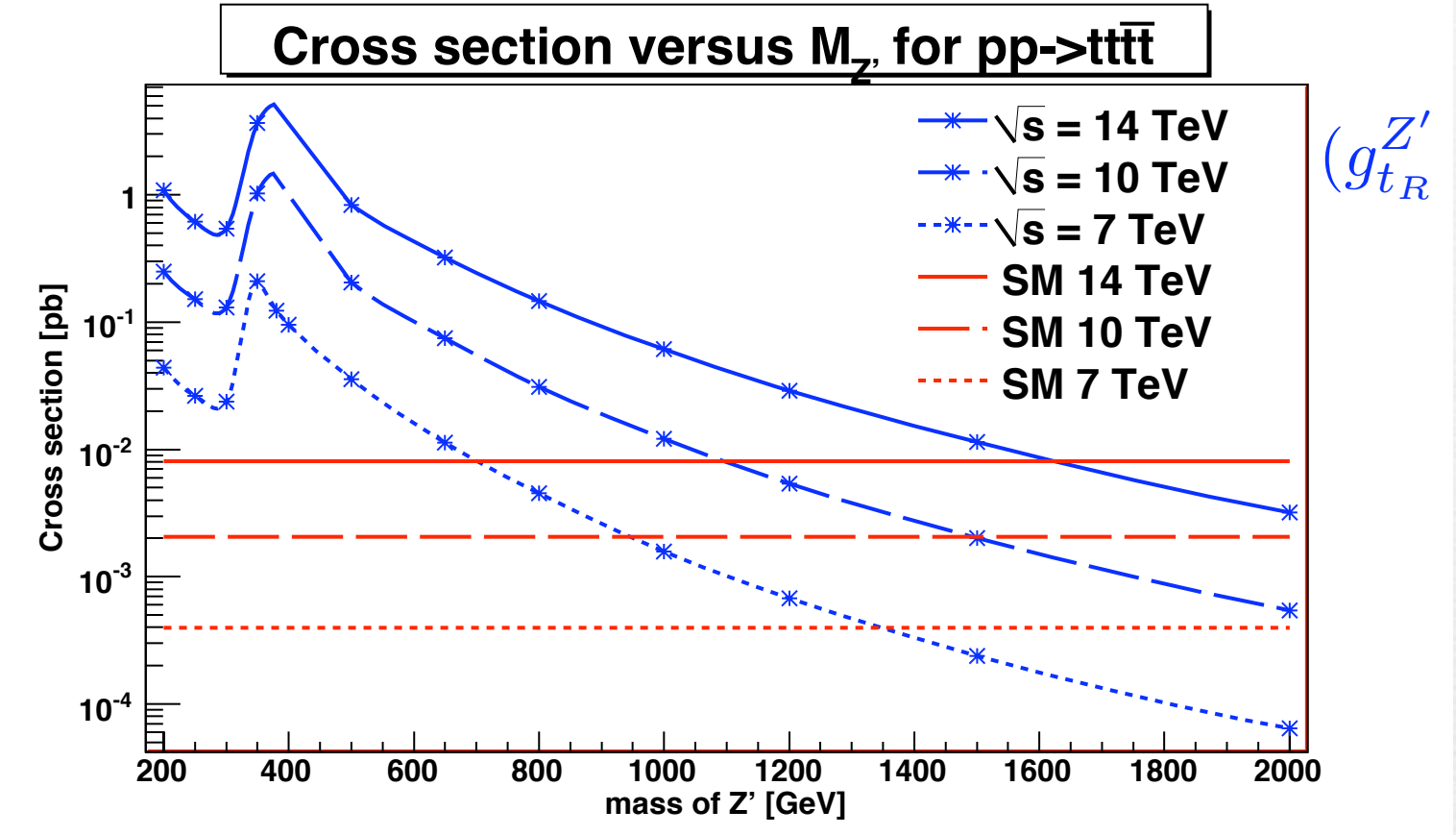
$$|heavy>_L = -\sin\phi|\chi_L> + \cos\phi|\psi_L>$$

$$|heavy>_R = |\psi_R>$$

$$\tan\phi = \frac{\Delta}{M_*}$$

Yukawa hierarchy comes from the hierarchy of compositeness

pp->tt̄Z'->tt̄tt̄ production cross section



$(g_{t_R}^{Z'} = 3)$

We work with √s = 14 TeV

We have :

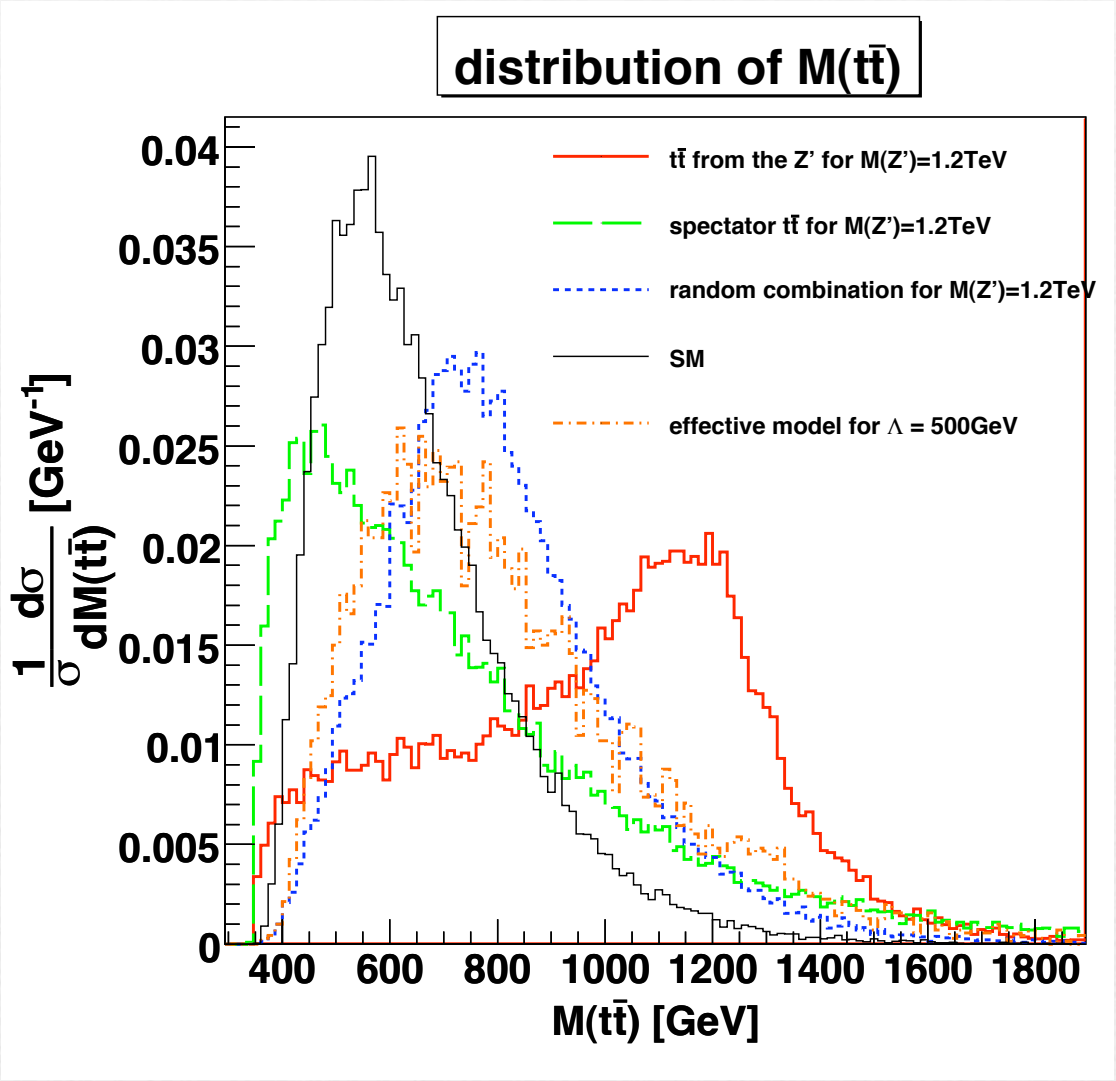
σ = 838 fb for m(Z') = 500GeV

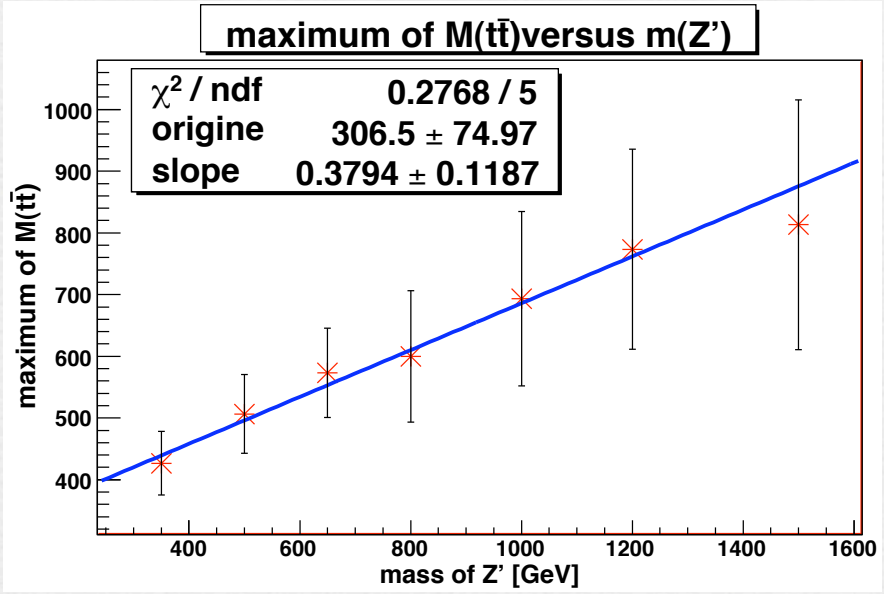
σ = 61 fb for m(Z')= 1 TeV

If we work with √s = 7TeV

σ = 110 fb for m(Z') = 400GeV

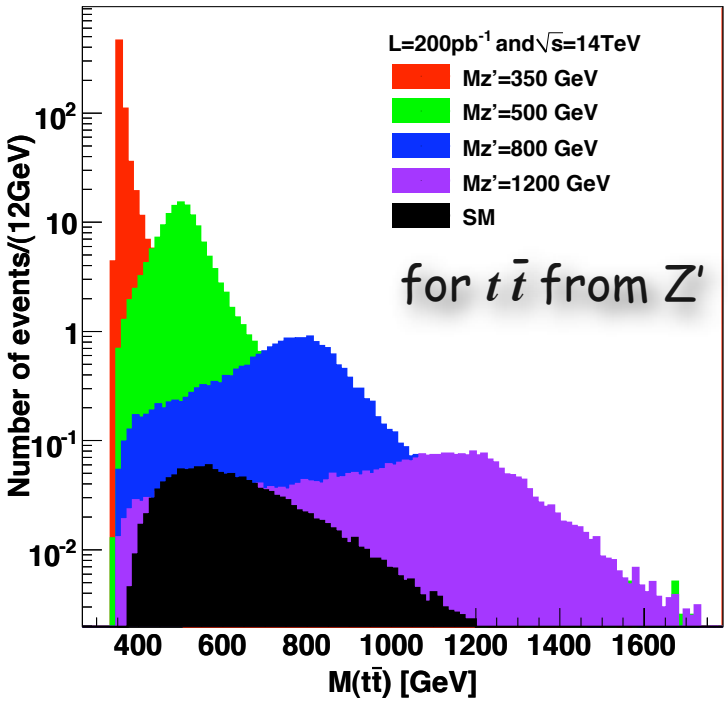
t t̄ invariant mass

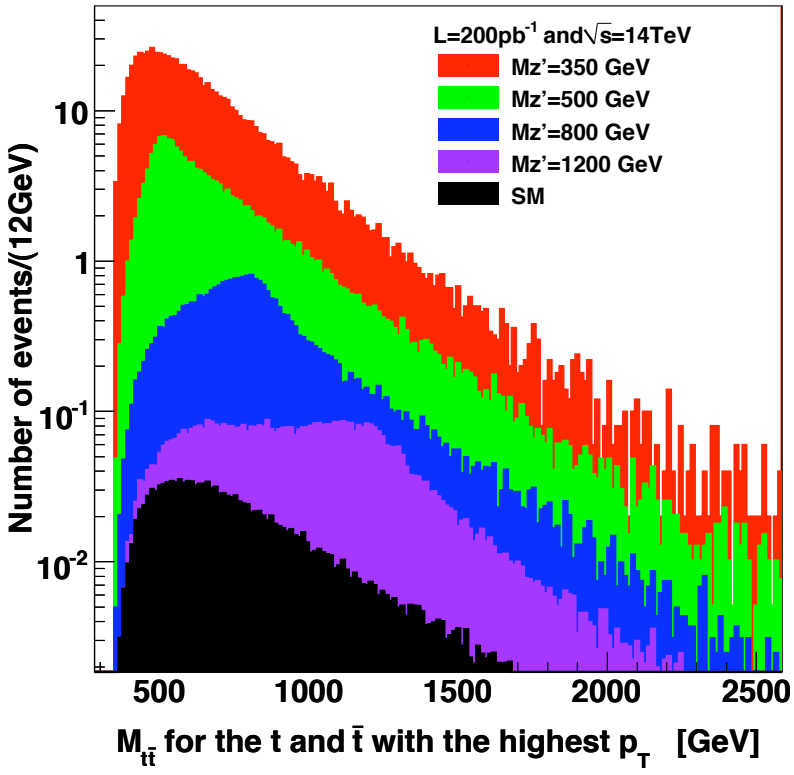




for random combination

$t\,\bar{t}$ invariant mass versus $M_{Z'}$





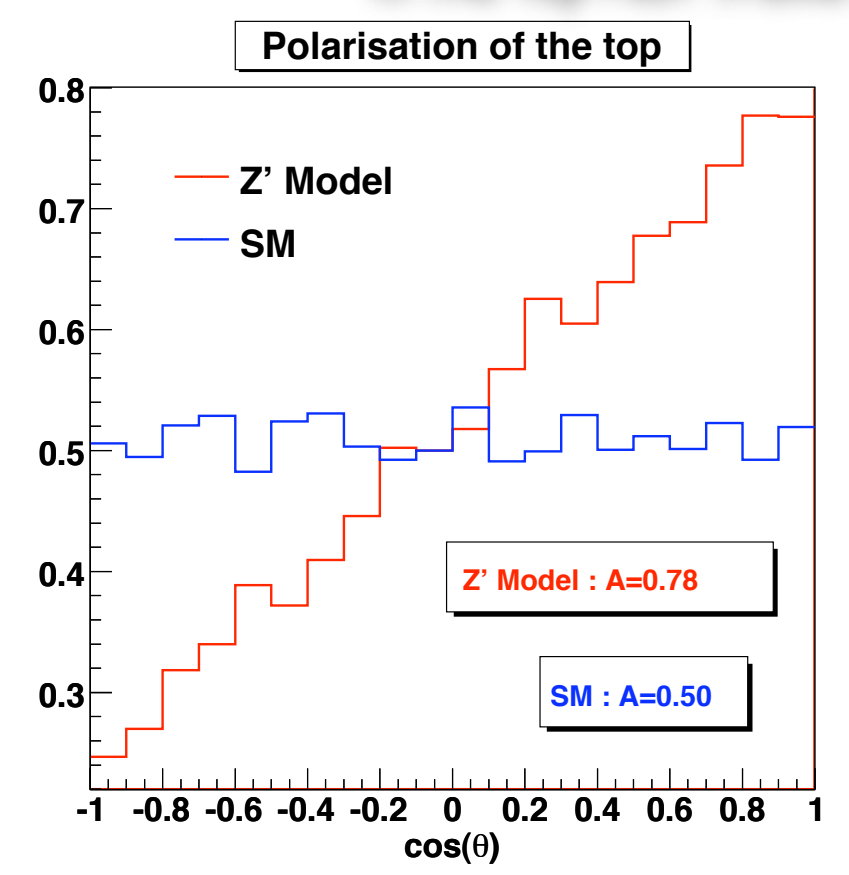
top polarization

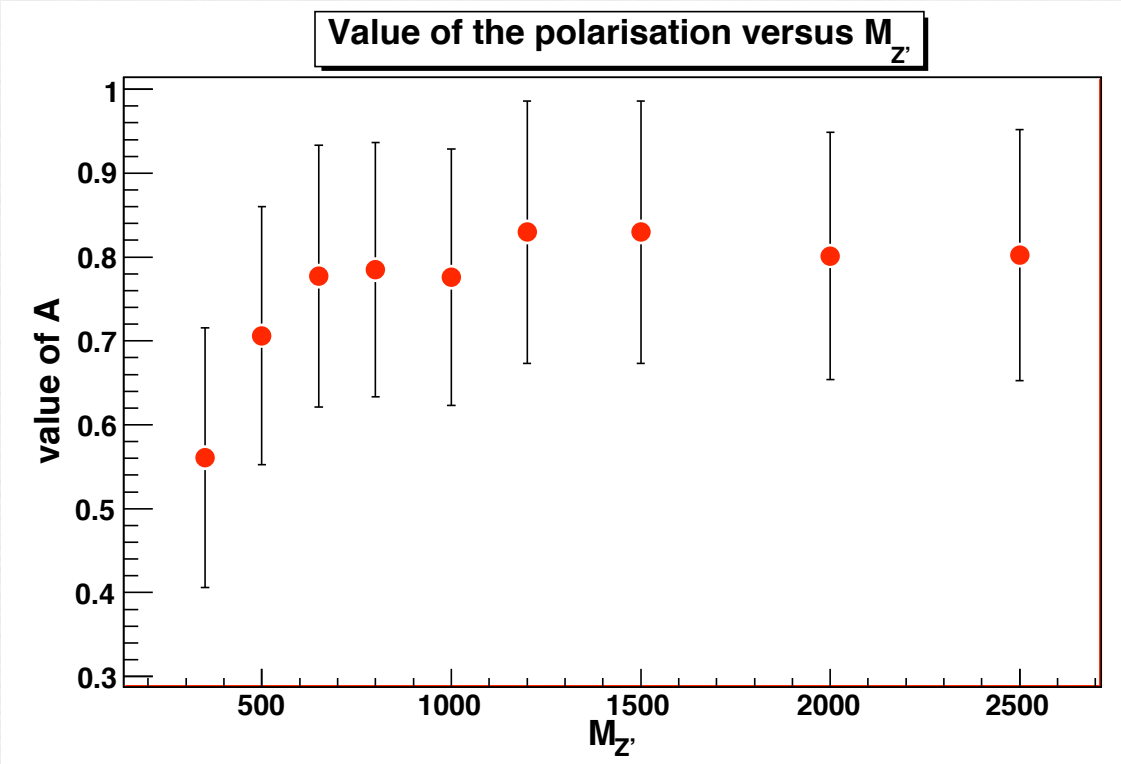
In the models of interest, 4-top production yields an excess of right-handed tops

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta} = \frac{A}{2}(1+\cos\theta) + \frac{1-A}{2}(1-\cos\theta)$$

A: fraction of RH tops

θ is the angle between the direction of the (highest p_T) lepton in the top rest frame and the direction of the top polarisation

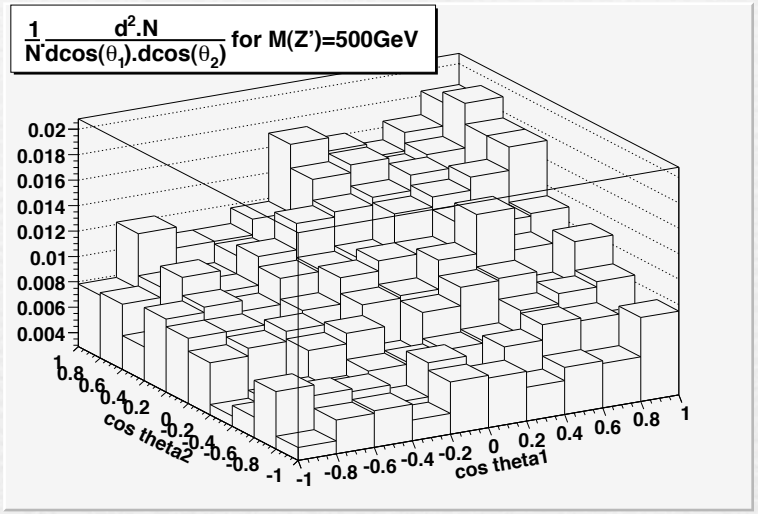




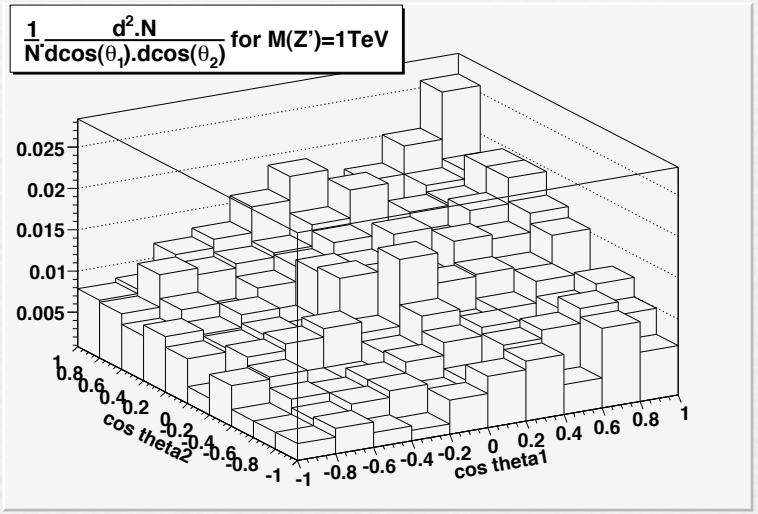
Spin correlations

$$\frac{1}{N}\frac{d^2N}{d\cos\theta_1 . d\cos\theta_2} = \frac{1}{4}(1 - A\cos\theta_1\cos\theta_2 + b_1\cos\theta_1 + b_2\cos\theta_2)$$

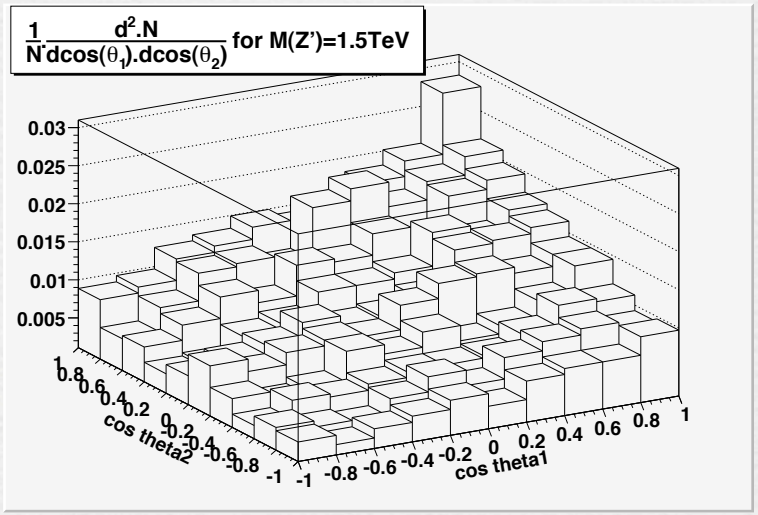
-	Z'(500GeV)	Z'(1TeV)	Z'(1.5TeV)	SM
A	-0.14±0.29	-0.22±0.27	-0.26±0.23	-0.11±0.3
b_1	0.43±0.32	0.56±0.32	0.64±0.29	-0.0051±0.29
b_2	0.53±0.32	0.61±0.31	0.57±0.33	-0.03±0.29

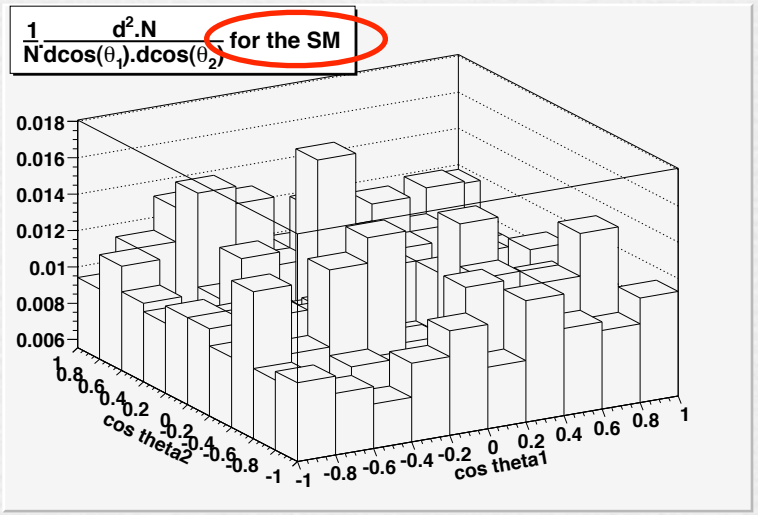


(a)



(b)





background in same-sign dilepton channel @LHC

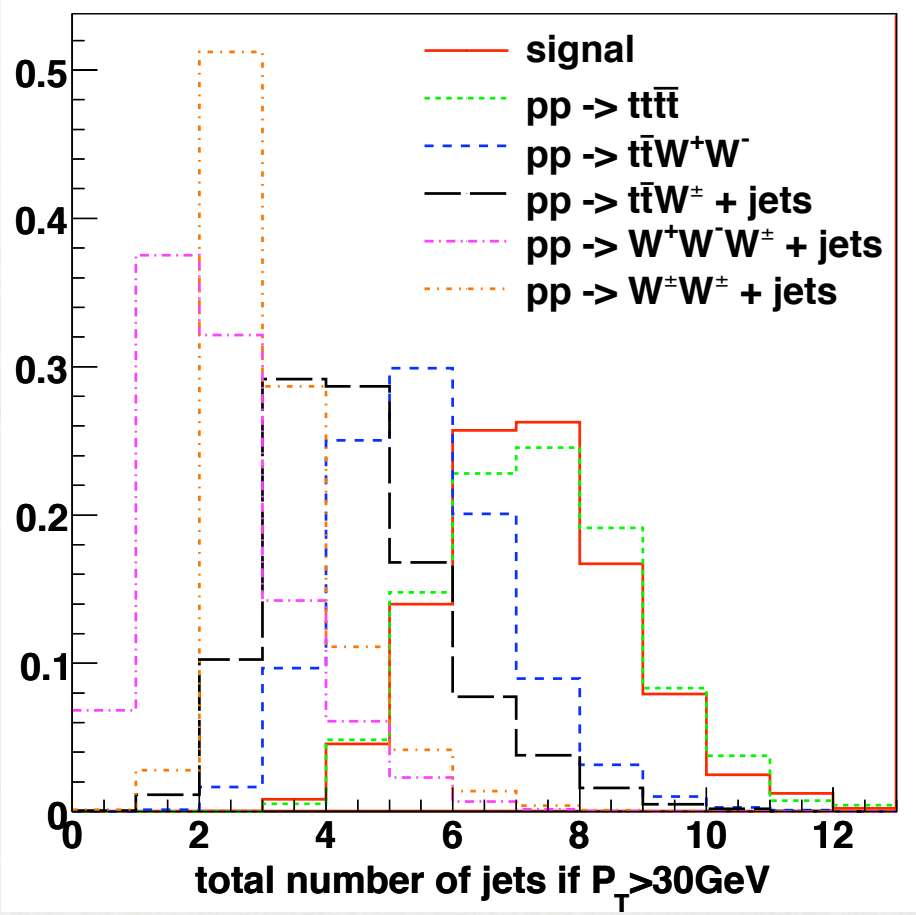
final state: $\ell^{\pm}\ell^{\pm} + n$ jets $+ \not{E}_T$

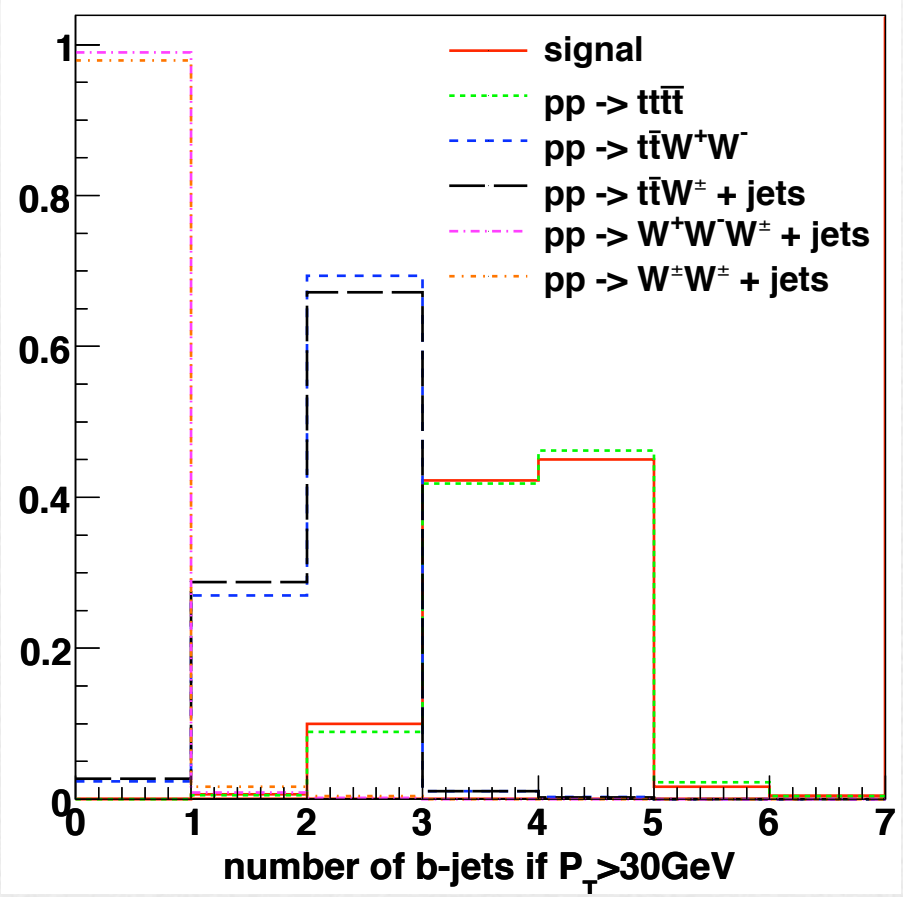
(of which 4 are b-jets)

process	σ [fb]	σ.BR(l±l±) [fb]
signal m(Z') = 500GeV	838.18	17.5
signal m(Z') = 1 TeV	61.19	1.3
tttt	7.52	0.15
ttWW	120.8	5.1
ttW + (0,1,2) jets	595	18.4
WWW + (0,1,2) jets	603	18.7
WW + (0,1,2,3,4) jets	324	15.5

$t\bar{t}$+jets with charge mis-ID not included here (but will be)

of jets


signal
pp -> tttt̄
pp -> tt̄W+W-
pp -> tt̄W± + jets
pp -> W+W-W± + jets
pp -> W±W± + jets
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
total number of jets if P_T>30GeV


signal
pp -> tttt̄
pp -> tt̄W+W-
pp -> tt̄W± + jets
pp -> W+W-W± + jets
pp -> W±W± + jets
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
number of b-jets if P_T>30GeV

four-top events from a top-philic Z' @LHC in same-sign dilepton channel

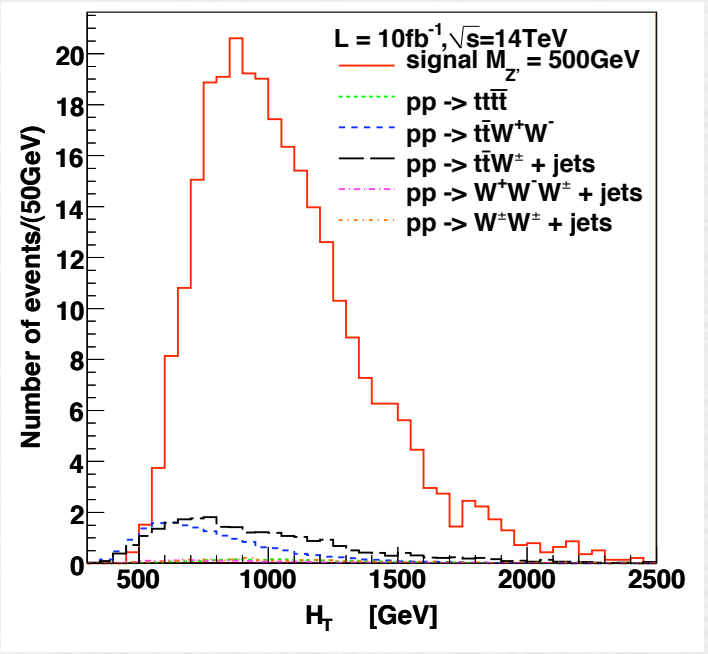
$$n_j \geq 6, p_T > 30\ \text{GeV}$$

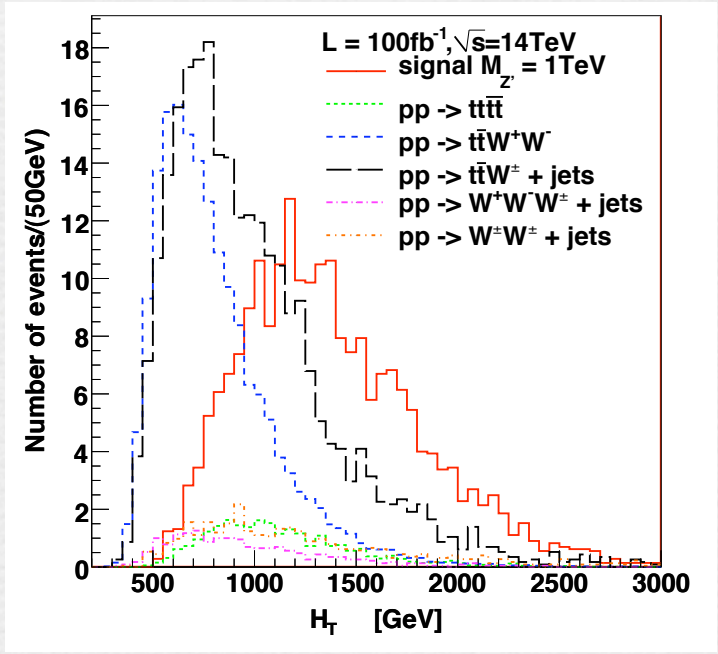
$M_{Z'} = 500$ GeV

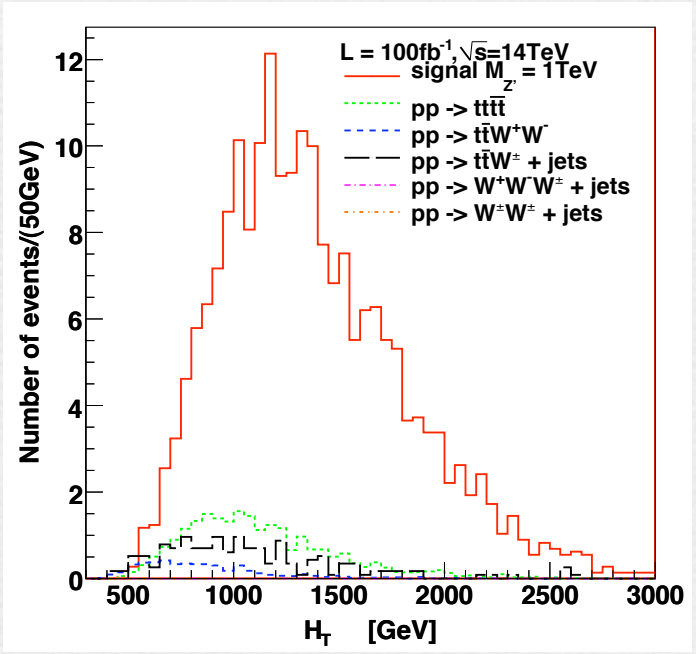
$M_{Z'} = 1$ TeV

preliminary

$n_{\text{b jets}} \gtrsim 3$

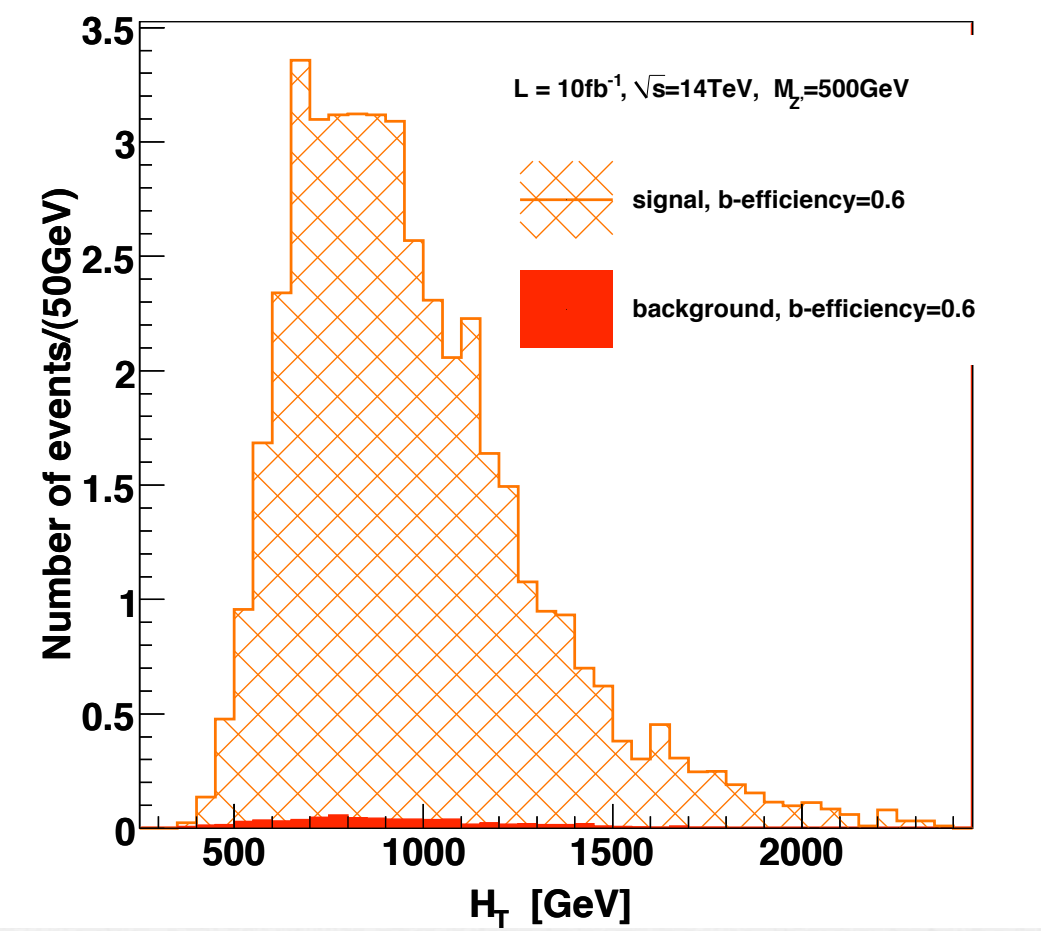


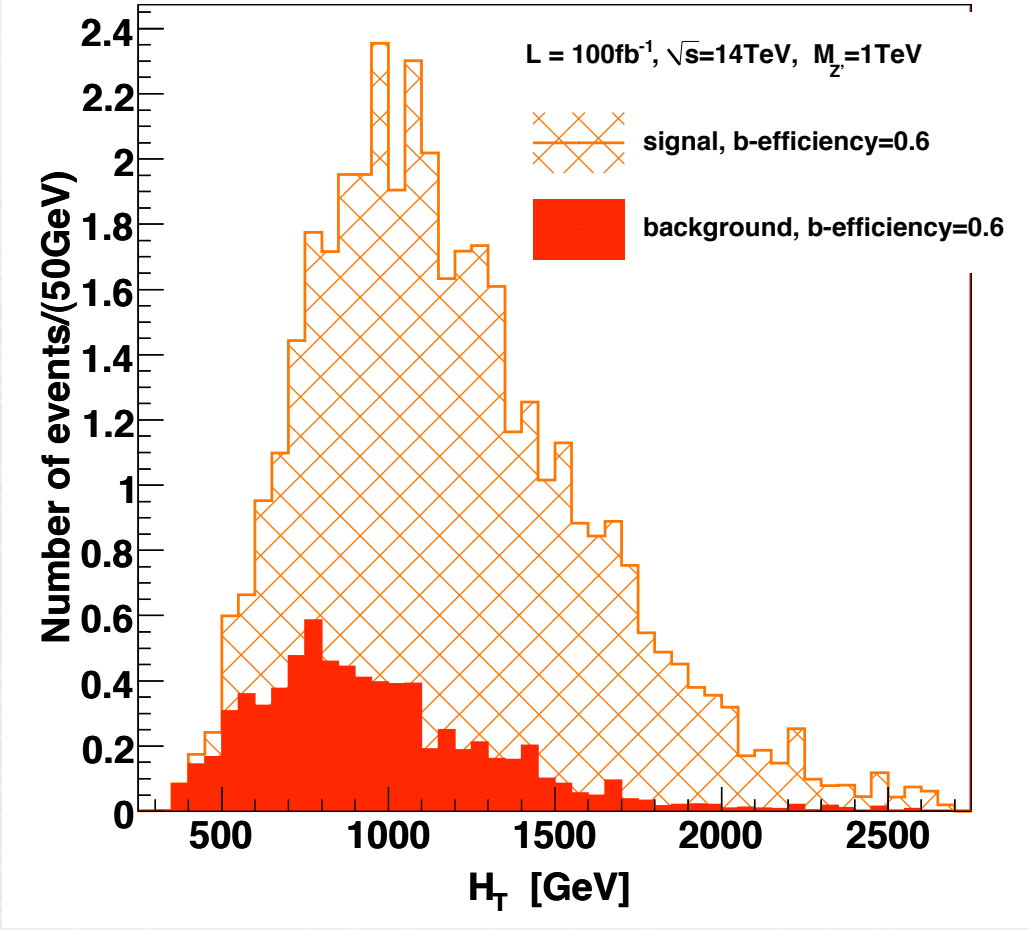




with b-tagging efficiency=1

with b-tagging efficiency of 60%





with only the very simple cuts:

$$n_j \geq 6, p_T > 30\ \mathrm{GeV} \quad , \quad n_{\mathrm{b\ jets}} \gtrsim 3$$

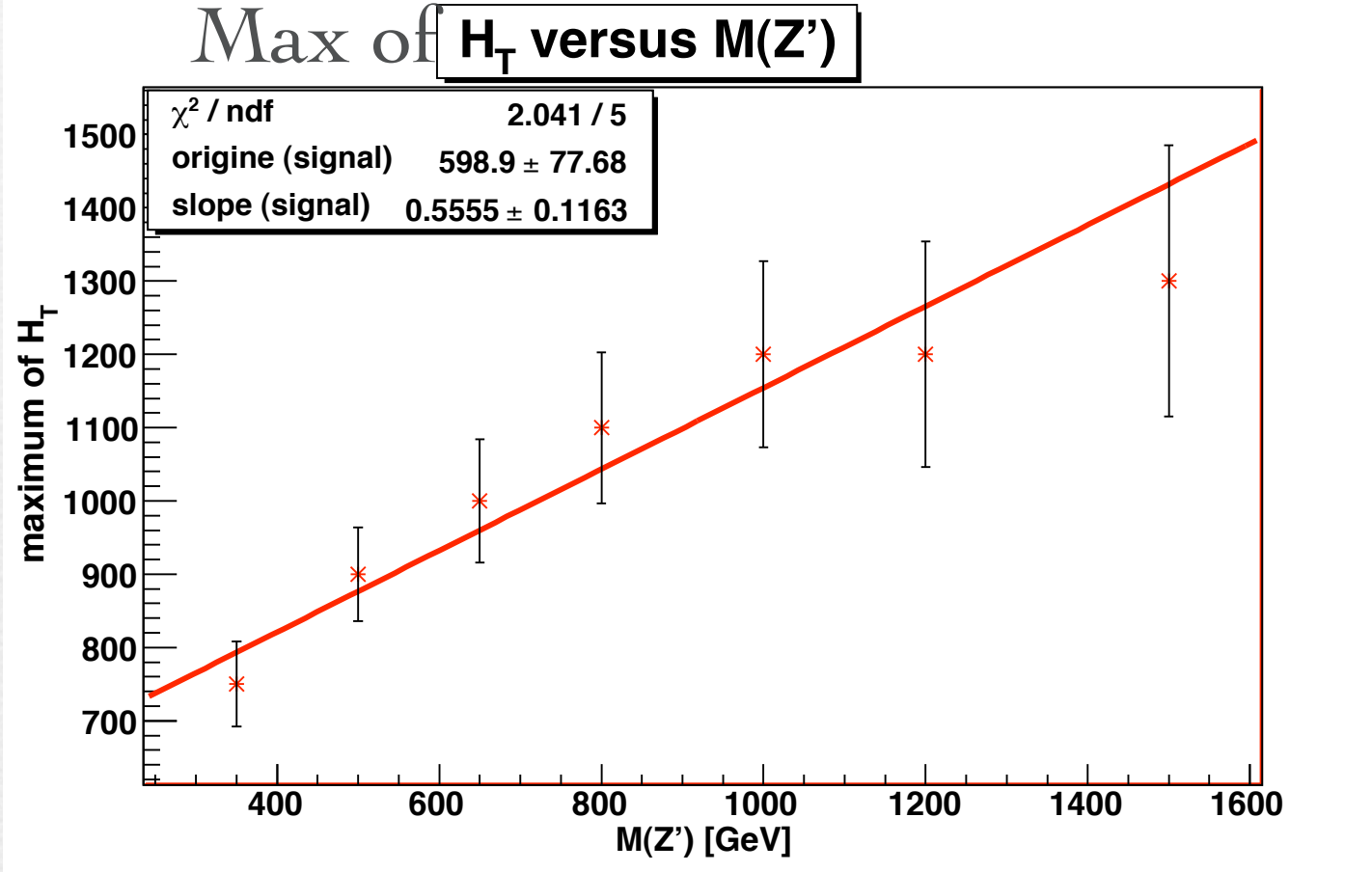
preliminary

$M_{Z'}$ =500 GeV $(g_{t_R}^{Z'} = 3)$ 5σ excess luminosity~ 150 pb^{-1}

$M_{Z'}$ =1 TeV 5σ excess luminosity~ 25 fb^{-1}

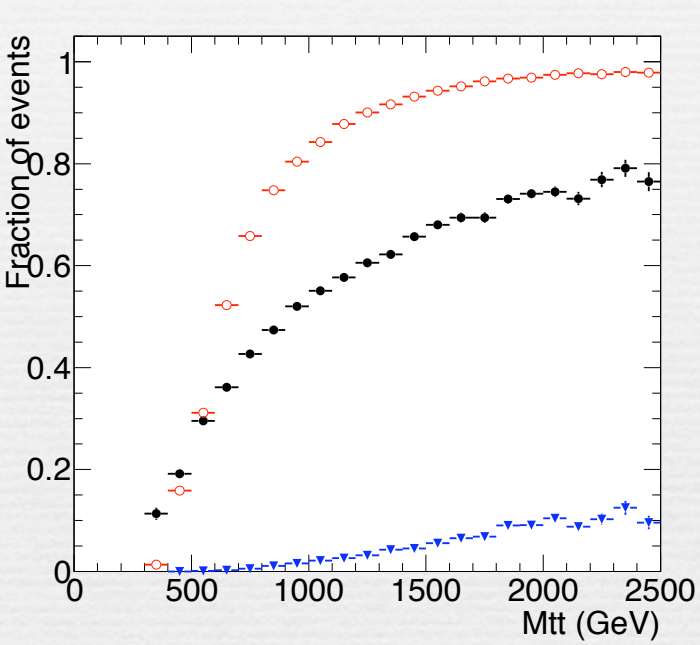
Λ = 500 GeV 5σ excess luminosity~ 15 fb^{-1}

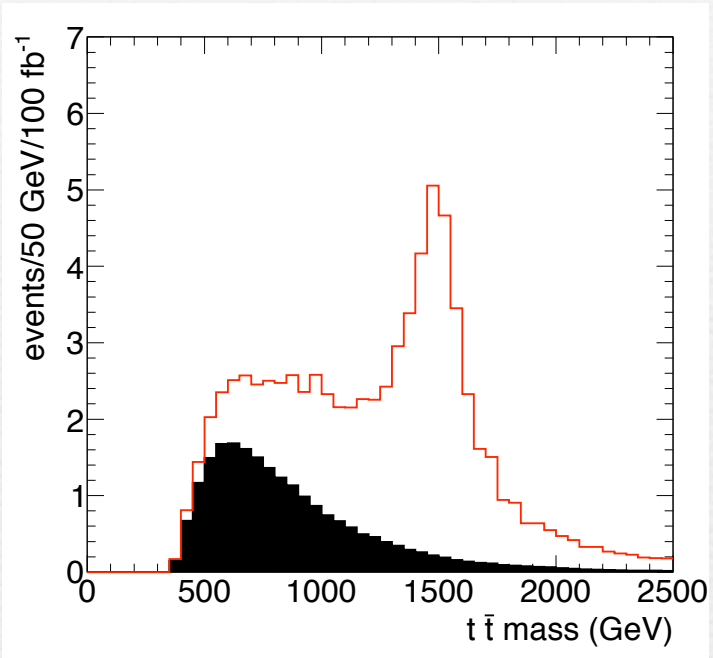
Max of


H_T versus M(Z')
χ² / ndf 2.041 / 5
origine (signal) 598.9 ± 77.68
slope (signal) 0.5555 ± 0.1163
maximum of H_T
M(Z') [GeV]
1500
1400
1300
1200
1100
1000
900
800
700
400
600
800
1000
1200
1400
1600

Top reconstruction

challenge of assigning 12 final state fermion particles to the 4 top candidates.





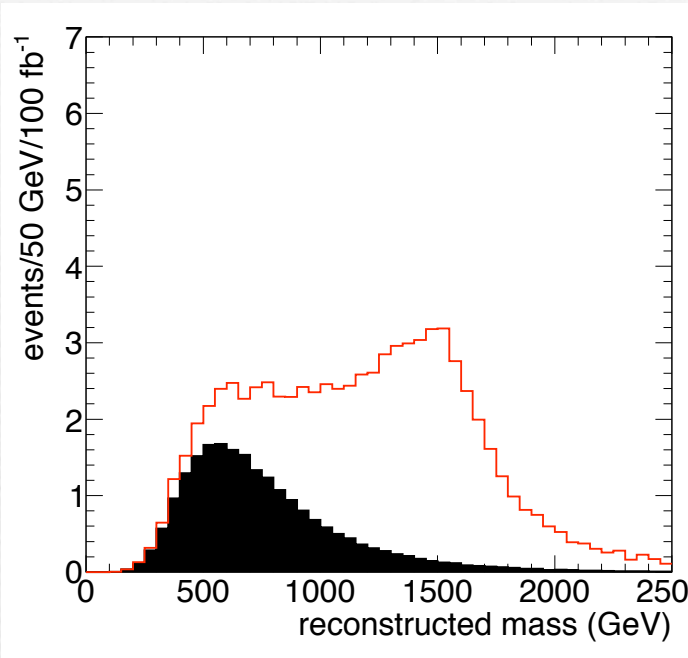


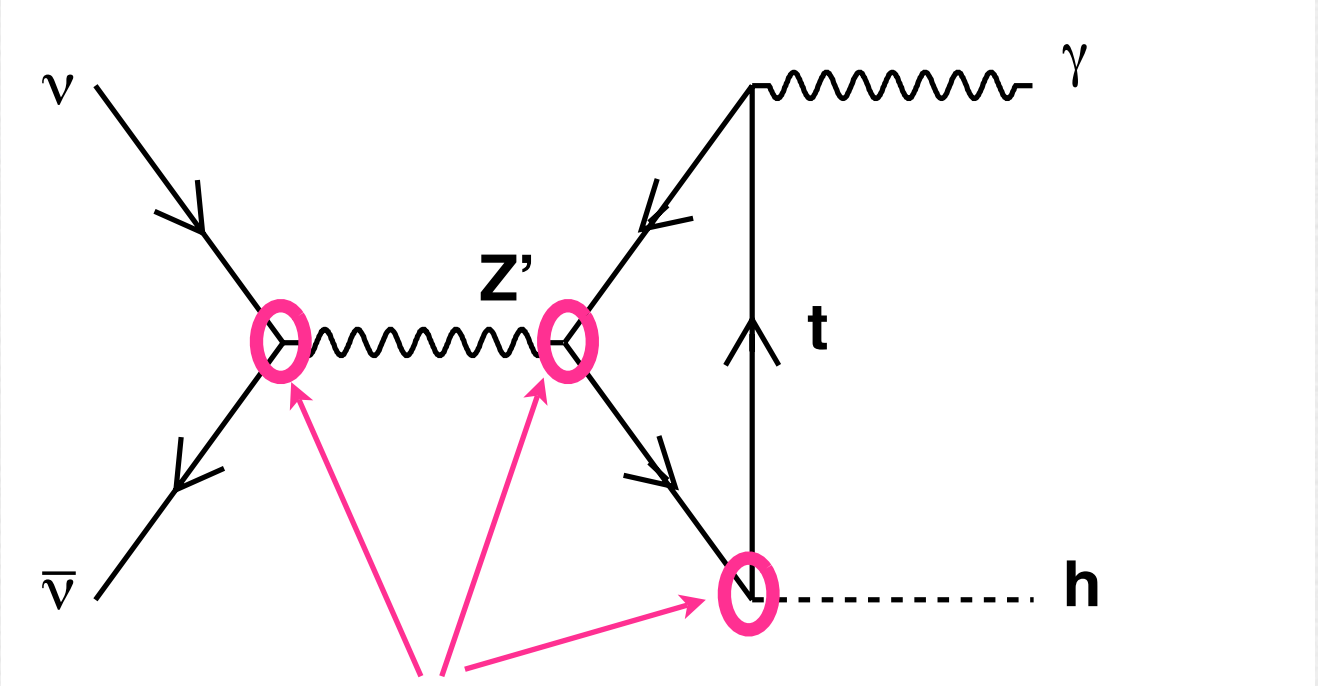
Fig. 8: The probability as a function of resonance mass that final state fermions are correctly assigned to top and anti-top quarks in $t\bar{t}$ production (open circles) and $t\bar{t}t\bar{t}$ production. The filled circles (triangles) indicate the probability to find two (four) correctly paired top quarks. The central panel shows the invariant mass distribution of the two top quarks with highest p_T in SM $t\bar{t}t\bar{t}$ production (filled histogram) and for production through a 1.5 TeV KK gluon. The rightmost panel shows the invariant mass of the two reconstructed clusters with highest p_T. (from 1005.1229)

[figures from Marcel Vos]

The top quark-Dark Matter connection

Jackson, Servant, Shaughnessy,Tait, Taoso,'09

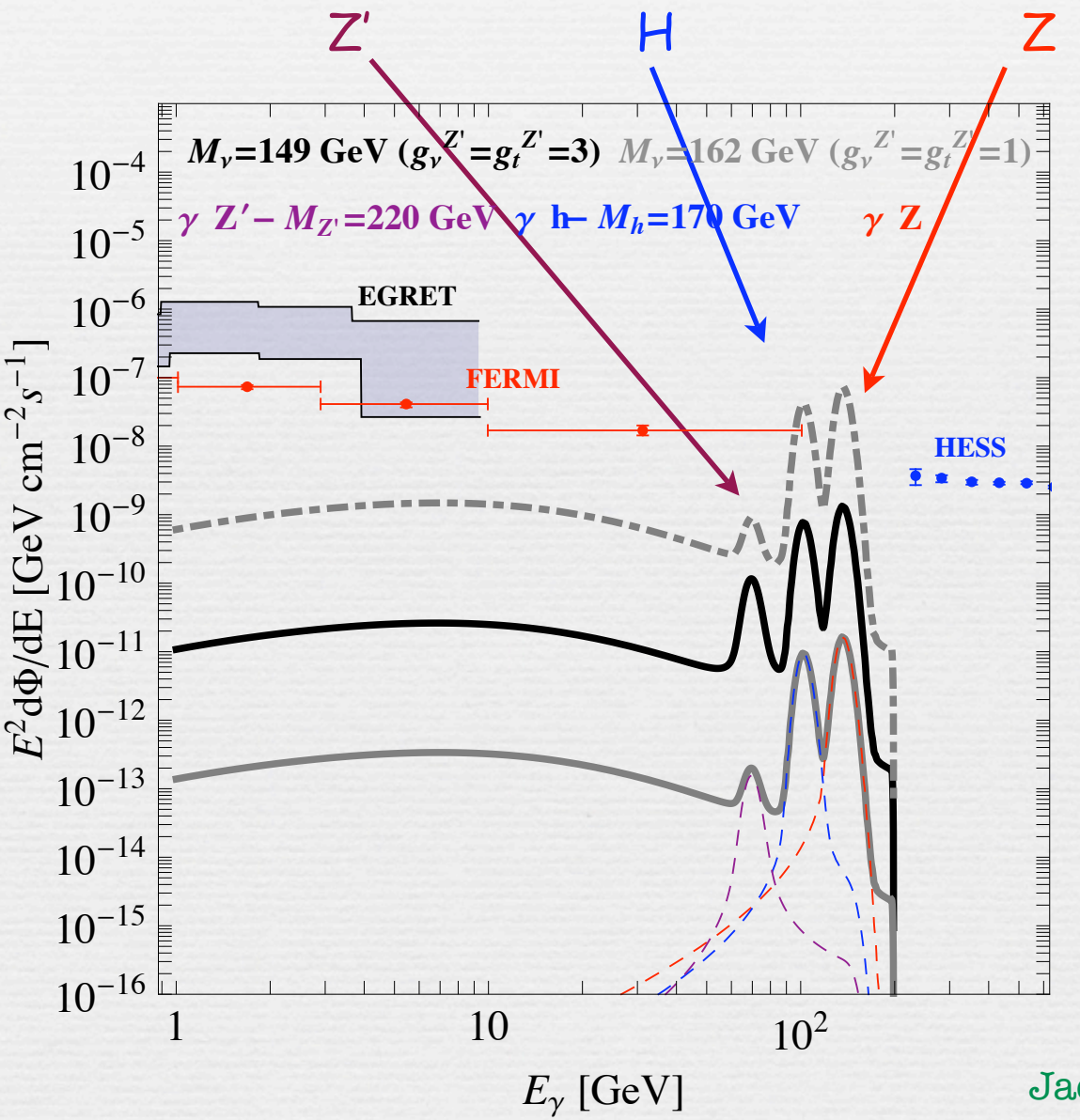
Dirac Dark Matter annihilation into γ H



~ O(1) couplings

Higgs in Space!

γ-ray lines from the Galactic Center $\Delta\Omega = 10^{-5}$ sr



Spectra for parameters leading to correct relic density and satisfying direct detection constraints

NFW profile

adiabatically contracted

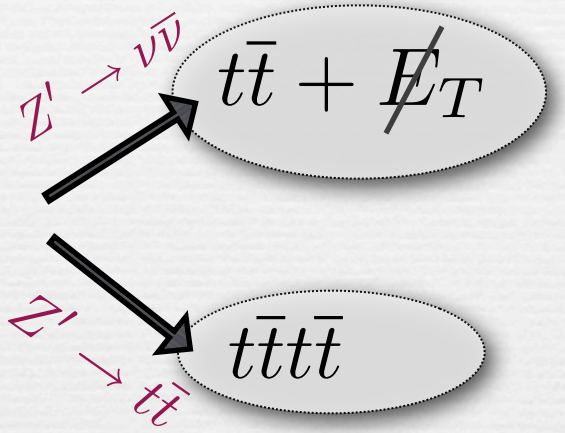
Jackson, Servant, Shaughnessy,Tait, Taoso,'09

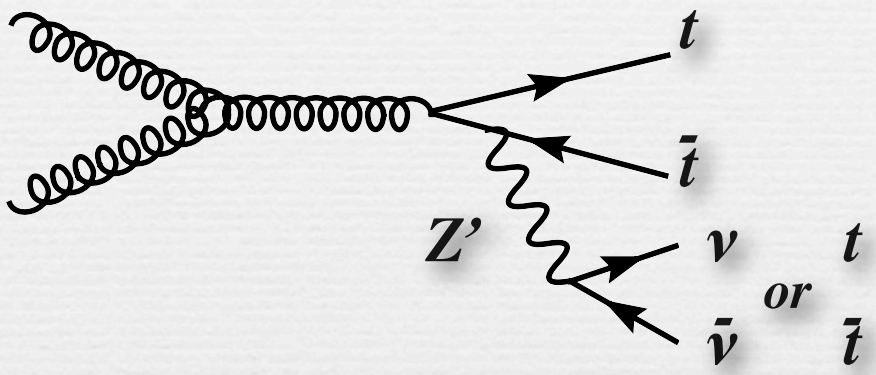
Collider signatures of a top (and DM)-philic Z'

- $f\bar{f} \to Z' \to t\bar{t}$

light $t\bar{t}$ resonances

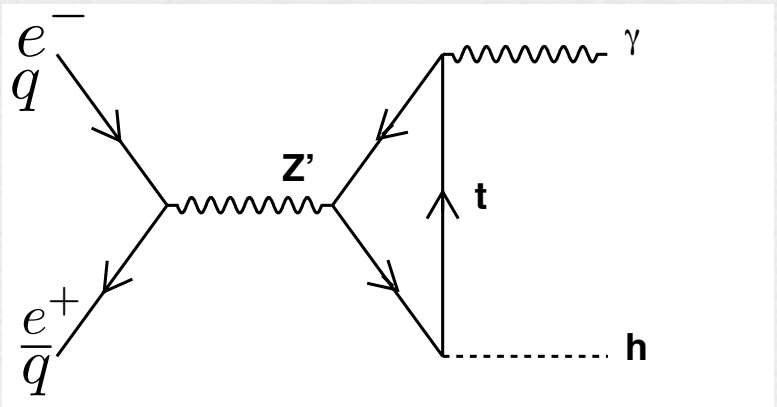
- $gg \to t\bar{t} + Z'$





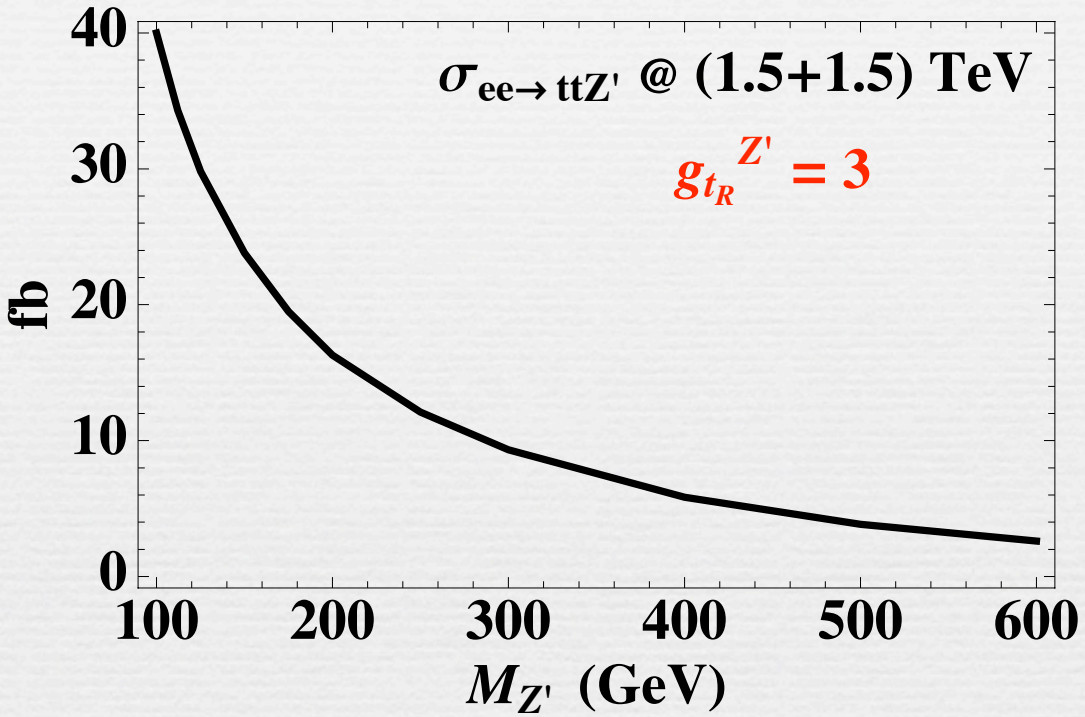
- $f\bar{f} \to Z' \to \gamma H$

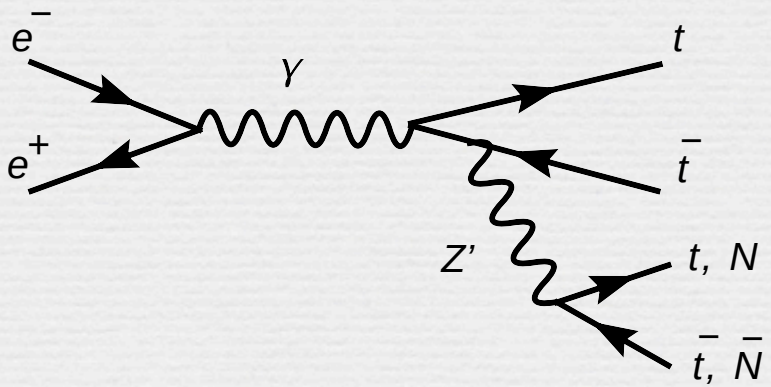
energetic monochromatic γ



four-top events at Multi-TeV e+e- colliders

Battaglia-Servant 1005.4632



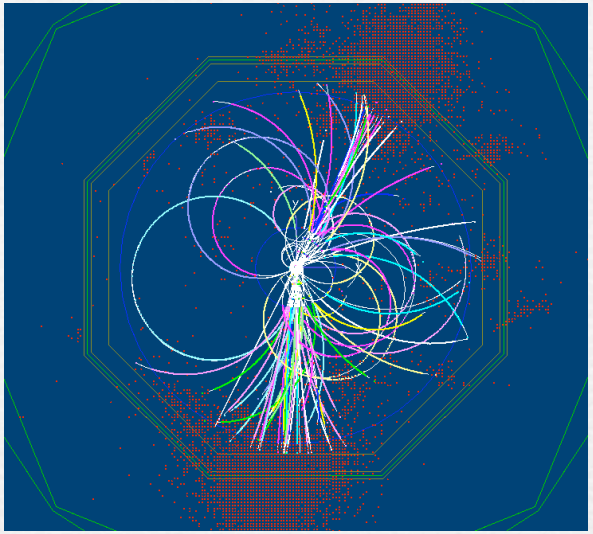


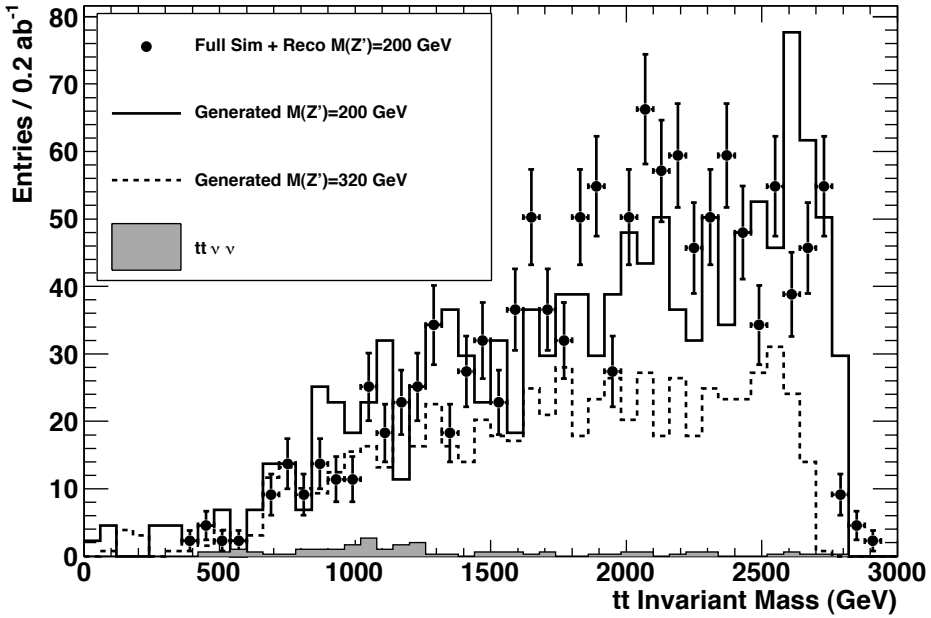
$e^+ e^- \to t\bar{t} + \not{E}_T$ @ 3 TeV CLIC

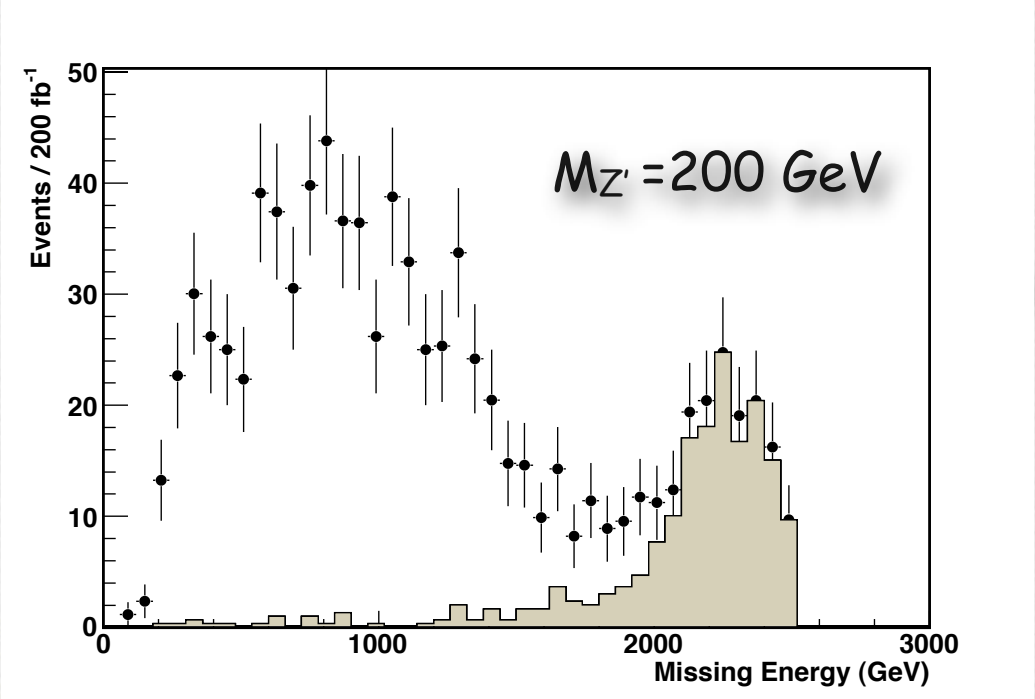
$\sigma_{ttveve} = 4.1$ fb

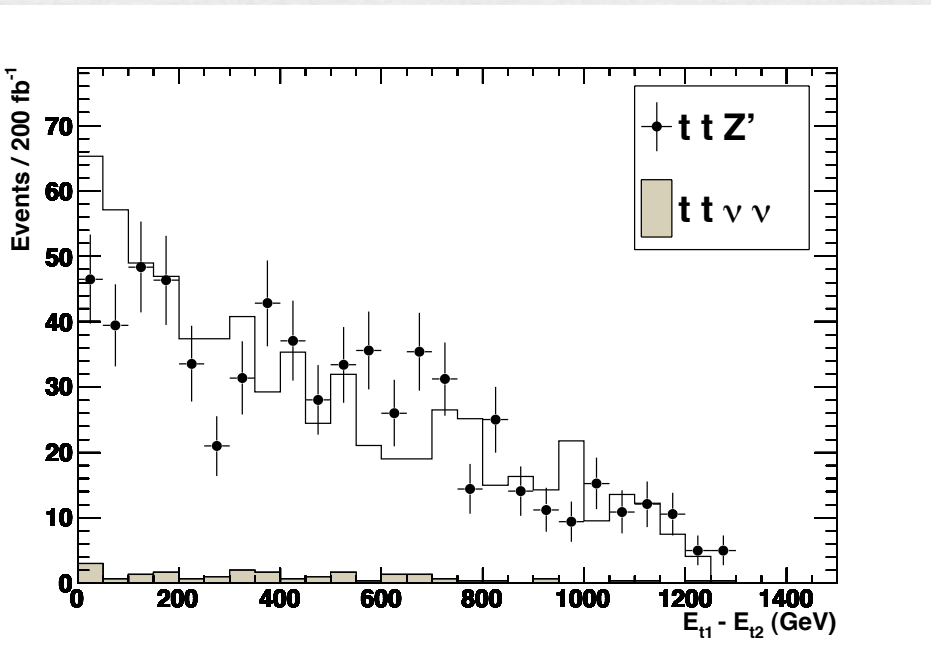
$\sigma_{4t \text{ in SM}} = 0.03$ fb

$(g^{Z'}_{t_R} = g^{Z'}_{DM} = 3)$

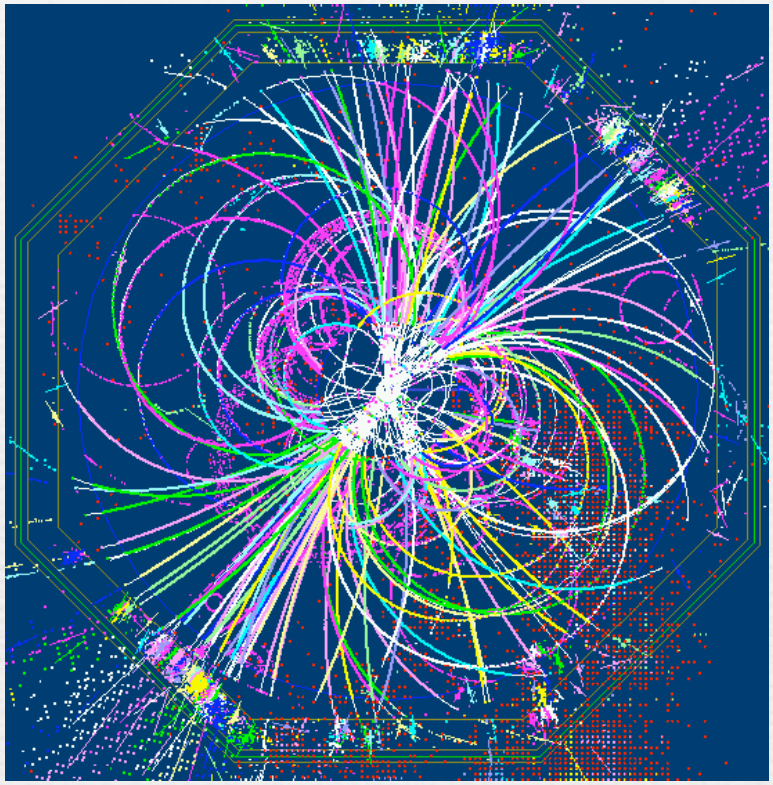


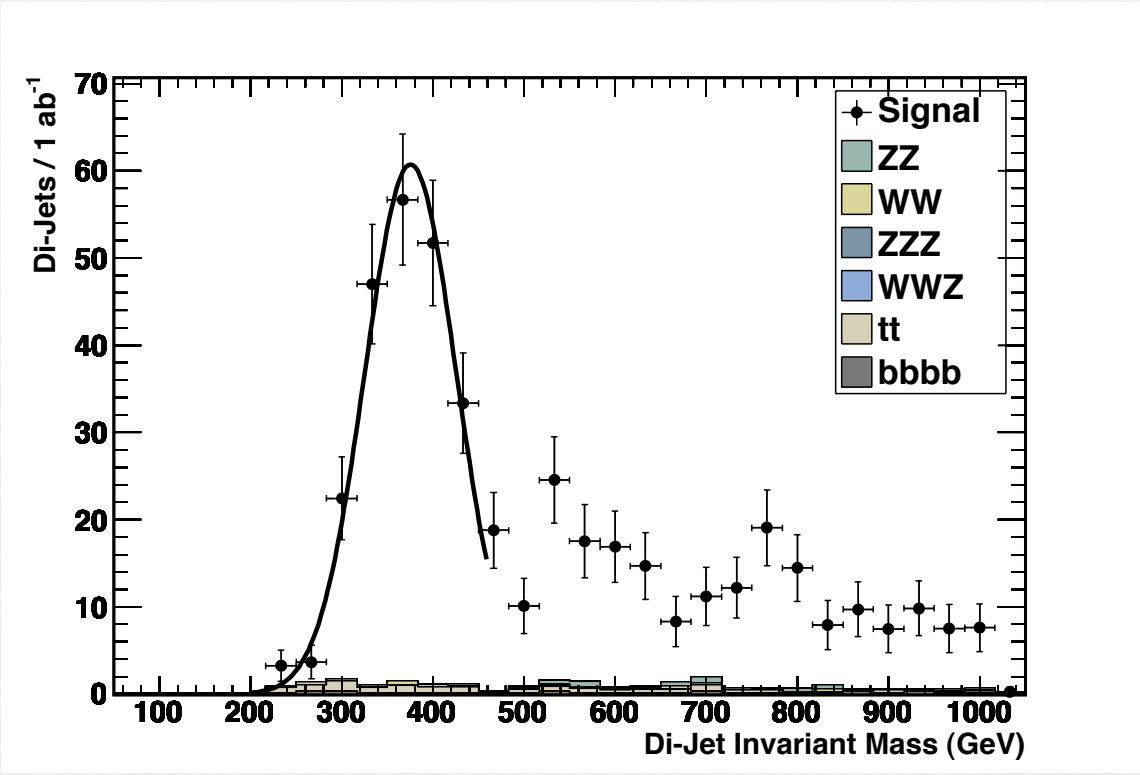






$e^+ e^- \to t\bar{t}t\bar{t}$ @ 3 TeV CLIC





$M_{Z'}$ =360 GeV

$$(g_{t_R}^{Z'} = 3)$$

Summary

four-top events: in a large class of BSM models
(susy, top composite models, top-philic resonances)

four-tops: key channel to probe top compositeness
(although not at 7 TeV)

so far, there was no detailed study

we found good prospects in the very clean
2 same-sign dilepton channel

b-tagging crucial to probe the O(10 fb) cross sections

future plans: full ATLAS simulation
(events already generated at 7 TeV)