Razor variables in the search for Top Partners

Matteo Abis
matteo.abis@cern.ch

Università di Padova and INFN

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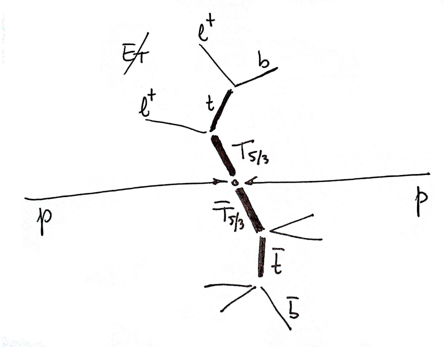
A.Avetisyan, P.Azzi, S.Bhattacharya, T.Bose, P.Checchia, S.Lewin, M.Narain, M.Nespolo, S.Vanini

Top Partners

- couple to third generation
- solve hierarchy problem
  - *Contino, Servant*, JHEP 0806:026 (2008)
  - *Mrazek, Wulzer*, Phys. Rev. D81, 075006 (2010)
- focus on pair production of $\mathrm{T}_{5/3}$
- experimental signature: same-sign leptons + jets



Signal MC
Fall11 production

mass (GeV)	$\sigma \times$ BR (pb)	events
400	0.295	86205
450	0.139	86211
500	0.069	86684
550	0.036	86724
600	0.019	86965
650	0.011	87592
700	0.006	88145
750	0.004	88410

Table: Signal Monte Carlo samples. The branching ratio is 0.21.

Background MC

Summer11 production

process	MC generator	σ (pb)	events
WZJets	MADGRAPH	0.879	1221134
$\mathrm{ZZ}+$Jets	MADGRAPH	0.076	1185188
$\mathrm{W^+W^+}+$Jets	MADGRAPH	0.165	130000
$\mathrm{W^-W^-}+$Jets	MADGRAPH	0.055	160000
$\mathrm{WWW}+$Jets	MADGRAPH	0.038	1201777
$\mathrm{t\bar{t}W}$	MADGRAPH	0.169	1029608
$\mathrm{t\bar{t}Z}$	MADGRAPH	0.139	793155

Table: Details of the background Monte Carlo samples used for the analysis.

Data

2011 golden JSON, 5.0 fb^{-1}

Dataset	Run range
/DoubleMuon/Run2011A-May10ReReco-v1/AOD	160329-163869
/DoubleMuon/Run2011A-PromptReco-v4/AOD	165071-168437
/DoubleMuon/Run2011A-05AugReReco-v1/AOD	170053-172619
/DoubleMuon/Run2011A-PromptReco-v6/AOD	172620-175770
/DoubleMuon/Run2011B-PromptReco-v1/AOD	175832-180296
/DoubleElectron/Run2011A-May10ReReco-v1/AOD	160329-163869
/DoubleElectron/Run2011A-PromptReco-v4/AOD	165071-168437
/DoubleElectron/Run2011A-05AugReReco-v1/AOD	170053-172619
/DoubleElectron/Run2011A-PromptReco-v6/AOD	172620-175770
/DoubleElectron/Run2011B-PromptReco-v1/AOD	175832-180296
/MuEG/Run2011A-May10ReReco-v1/AOD	160329-163869
/MuEG/Run2011A-PromptReco-v4/AOD	165071-168437
/MuEG/Run2011A-05AugReReco-v1/AOD	170053-172619
/MuEG/Run2011A-PromptReco-v6/AOD	172620-175770
/MuEG/Run2011B-PromptReco-v1/AOD	175832-180296

Triggers

HLT_DoubleMu7_v1,2 or HLT_Mu13_Mu8_v2,3,4,6,7 or HLT_Mu17_Mu8_v10,11
HLT_Ele17_CaloIdL_CaloIsoVL_Ele8_CaloIdL_CaloIsoVL_v1,2,3,4,5,6 or HLT_Ele17_CCTT_Ele8_CCTT_v6,7,8,9,10
HLT_Mu10_Ele10_CaloIdVL_v2,3,4,or HLT_Mu17_Ele8_CaloIdVL_v1,2,3,4,5,6,8 or HLT_Mu17_Ele8_CaloIdT_CaloIsoVL__v4,7,8 or HLT_Mu8_Ele17_CaloIdL_v1,2,3,4,5,6 or HLT_Mu8_Ele17_CaloIdT_CaloIsoVL_v3,4,7,8

Table: List of triggers used in the analysis.

Event cleanup

Standard from TLBSM recipes

scraping

- at least 25% of the tracks must be high-purity for events with at least ten tracks

good primary vertex

- at least 4 degrees of freedom
- less than 25 cm from interaction point in z
- less than 2 cm radially

HBHE noise filter

Electrons

Standard top selection, plus charge consistency

- $p_{\mathrm{T}} > 30\,\mathrm{GeV}$
- $|\eta| < 2.4$, except EBEE gap
- HyperTight1MC electron identification
- relative isolation < 0.15
- conversion rejection
- transverse impact parameter $< 0.02\,\mathrm{cm}$
- GSF, CFT, ScPix charge consistency

Muons

Standard top selection

- $p_{\mathrm{T}} > 30\,\mathrm{GeV}$
- $|\eta| < 2.4$
- Global and Tracker muon
- relative isolation < 0.20
- $\chi^2/\mathrm{NDF} < 10$
- at least one muon hit
- at least one pixel hit
- at least eleven silicon hits
- at least two chambers with matching segments

Jets

Standard top selection

- anti-k_T particle flow jets
- $p_{\mathrm{T}} > 30\,\mathrm{GeV}$
- $|\eta| < 2.4$
- Charged hadron subtractions, L1FastJets corrections, L2L3 jet energy scale corrections
- loose particle flow identification
- $\Delta R(\text{lepton, jet}) > 0.3$

Same-sign non-prompt background

Data-driven estimate, with the “tight-loose” method

- details in AN-2010/261, AN-2010/257, AN-2011/258
- define looser lepton selection
- measure the probability that a lepton passing the loose selection also passes the tight one
- estimate the number of non-prompt leptons passing the tight selection

The old selection
AN-11-419

- at least four jets
- $H_T > 300\,\mathrm{GeV}$

Thanks to the whole group of B2G-12-003, still in the approval process.

The razor variables

Rogan, *Kinematical variables towards new dynamics at the LHC*, arXiv 1006.2727

The standard razor

Two pair-produced massive particles, both decaying to a final state with one visible particle and $E_{\mathrm{T}}^{\mathrm{miss}}$.

The simple version

$$M_R = \sqrt{(a^0 - b^0)^2 - (a^3 + b^3)^2}$$

$$M_R^T = \sqrt{\frac{|\vec{m}|}{2}(|\vec{a}_T| + |\vec{b}_T|) - \frac{\vec{m}}{2} \cdot (\vec{a} + \vec{b})}$$

$$R = M_R^T / M_R$$

Notation:

- a^μ and b^μ are the four momenta of the visible particles
- $\vec{m}$ is the $E_{\mathrm{T}}^{\mathrm{miss}}$
- $\vec{v}_T$ is a vector with the transverse components $(v_x, v_y, 0)$

Properties of the razor variables

M_R independent of a longitudinal boost, related to the heavy particle mass

R another measurement of the scale of the process, in the transverse plane

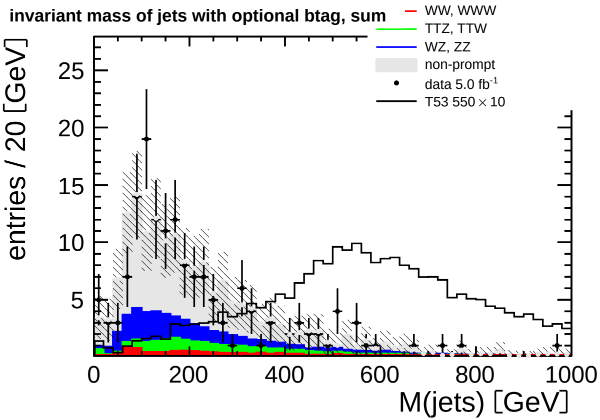
Additional corrections

The formulae in this analysis are corrected for the momentum of the system as a whole by boosting the vectors with the sum $\vec{a} + \vec{b} + \vec{m}$.

Hadronic invariant mass

The easy part

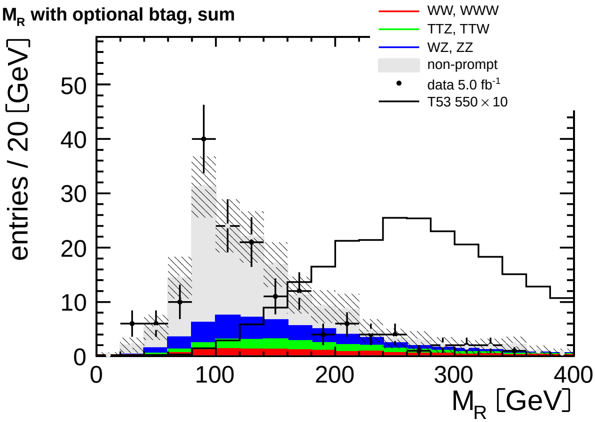
Mass of the sum of the jets in the event.



M_R

An indicator of the heavy particle mass scale

Peak expected around $M(\mathrm{T}_{5/3})/2$.

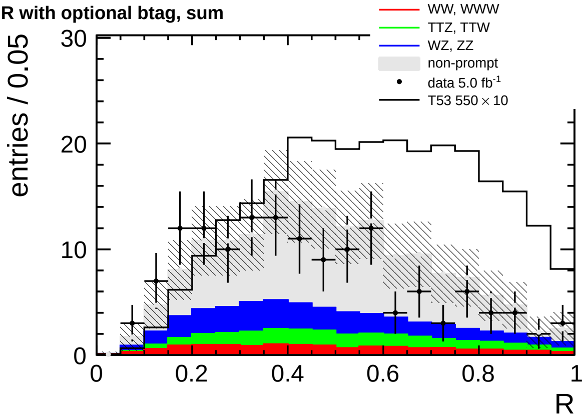


R

A dimensionless variable related to the $E_{\mathrm{T}}^{\mathrm{miss}}$

Theory:

- peaks near 0.5 for signal
- falls of exponentially for backgrounds after an endpoint



Improving the variables

One of the b-jets belongs to the leptonic system: can we collect it?

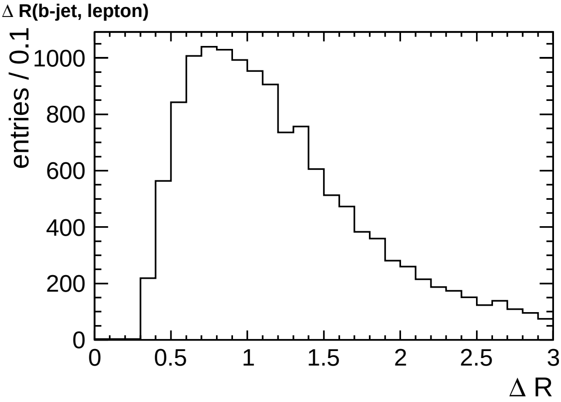


Figure: ΔR between the b-jet and the lepton from the top decay. MC truth from the 550 GeV mass point.

MC suggests it should be the close to one of the leptons.

Event reconstruction enhancement and b-tagging

Many jets and two leptons

The closest jet-lepton pair is the right one only in $1/3$ of the events.

Improvements with b-tagging: If two b-tagged CSVL jets are found, the closest in ΔR to a lepton is associated with the lepton subsystem
MC truth: improves reconstruction for $1/2$ of the signal events

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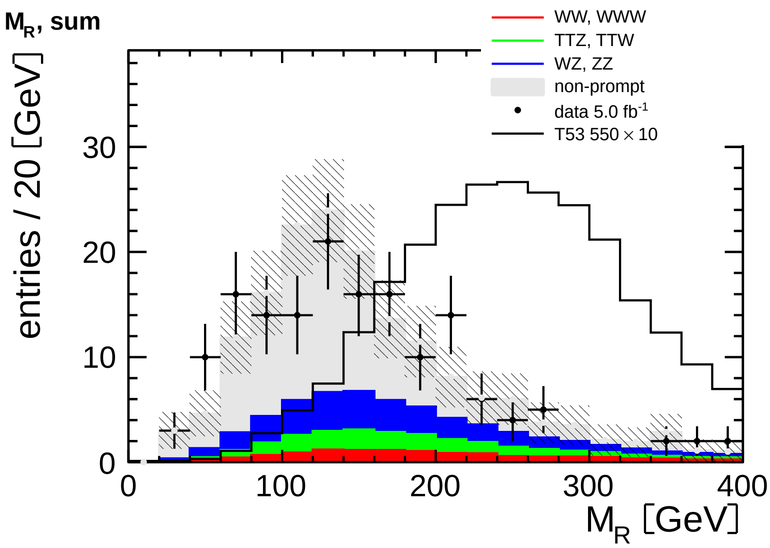
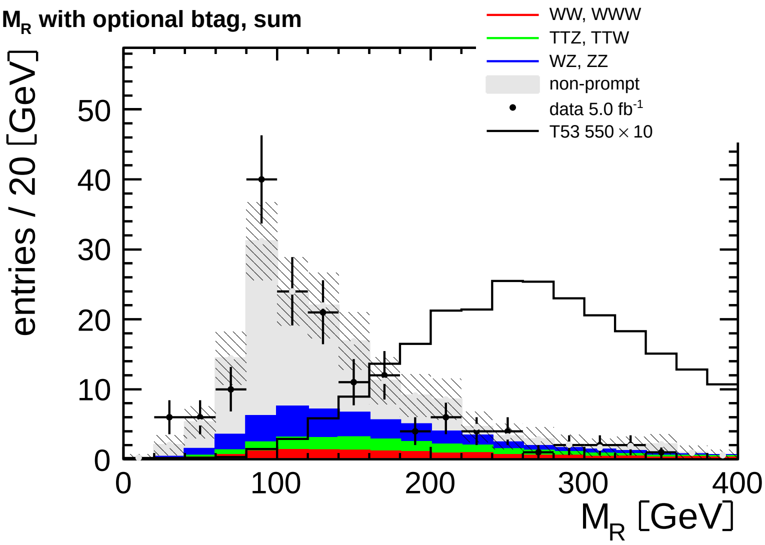
Improvements for the M_R

Without b-tagging



Improvements for the M_R

With b-tagging



Future improvements for the event reconstruction

- the double b-tag is a tough requirement ($\varepsilon \approx 2/3$ on signal)
- wrong lepton close to a b-jet by chance ($\approx 1/3$)
- jet energy threshold

Selection efficiencies for backgrounds

A better signal to noise ratio

Final razor selection optimized for $S/\sqrt{B}$. The old analysis requires two same-sign leptons, four jets, H_T. We are using the razor instead of H_T.

- hadronic mass $> 350\,\mathrm{GeV}$
- $M_R > 200\,\mathrm{GeV}$
- $R > 0.2$

dataset	SS + 2jets	$H_T > 300$	razor
WW (SS)	11.62±5.84	0.64±0.33	0.23±0.12
TTW	14.60±7.32	3.18±1.59	1.10±0.55
TTZ	3.97±1.99	0.97±0.49	0.29±0.14
WWW	1.66±0.83	0.09±0.05	0.04±0.02
WZ, ZZ	34.62±6.17	1.18±0.22	0.38±0.07
total MC	66.47±11.42	6.06±1.71	2.04±0.59
non-prompt	105.24±52.80	4.67±2.55	0.76±0.56
T53 700	5.00±0.25	3.85±0.20	3.30±0.17

Table: Event yields including statistical and systematic uncertainties.

Selection efficiencies for signal

A better signal to noise ratio

dataset	SS + 2jets	$H_T > 300$	razor
T53 400	211.10±10.73	136.03±6.97	53.40±2.84
T53 450	104.52±5.31	72.04±3.68	40.57±2.11
T53 500	52.76±2.68	37.75±1.93	25.10±1.29
T53 550	28.53±1.45	21.39±1.09	15.94±0.82
T53 600	15.34±0.78	11.54±0.59	9.20±0.47
T53 650	8.65±0.44	6.60±0.34	5.46±0.28
T53 700	5.00±0.25	3.85±0.20	3.30±0.17
T53 750	2.97±0.15	2.27±0.12	1.96±0.10

Table: Event yields including statistical and systematic uncertainties.

Limit

Expected: 658 GeV (it is 645 GeV in AN-11-419)

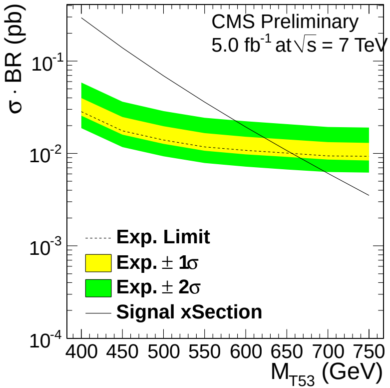


Figure: 95% CL limit with the RooStats CL95 tool for an event counting experiment.

Conclusions

- much improved rejection of background, particularly $\mathrm{t\bar{t}}$
- many areas for improvement in the event reconstruction
- need improved treatment of systematics

Backup slides

Systematics

Effect	Uncertainty (%)
Electron trigger	5.0
Muon trigger	5.0
Lepton efficiency	3.0
Luminosity	2.2

Table: Systematic uncertainties.

Systematics for MC

Sample	JES	Pileup	Normalization
WZ	5.0%	1.8%	17%
ZZ	1.1%	0.6%	7.5%
$\mathrm{W^{\pm}W^{\pm}}$	4.5%	2.4%	50%
WWW	3.7%	0.5%	50%
$\mathrm{t\bar{t}W}$	3.4%	0.94%	50%
$\mathrm{t\bar{t}Z}$	3.7%	0.25%	50%

Table: Systematic uncertainties for Monte Carlo backgrounds.