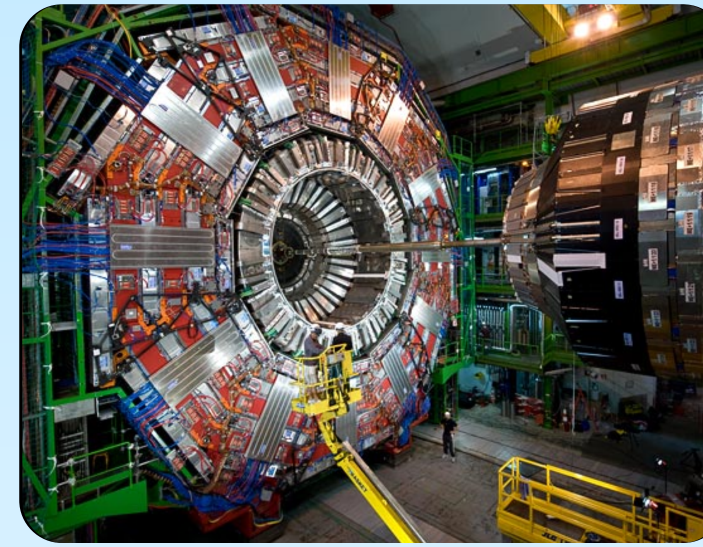
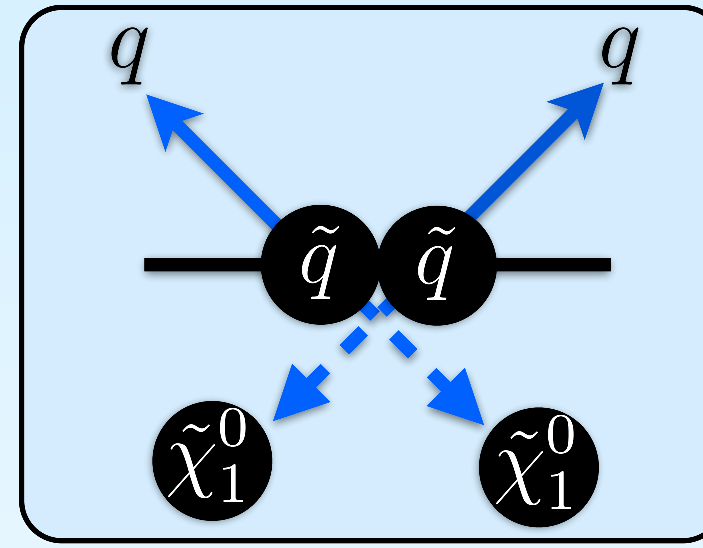
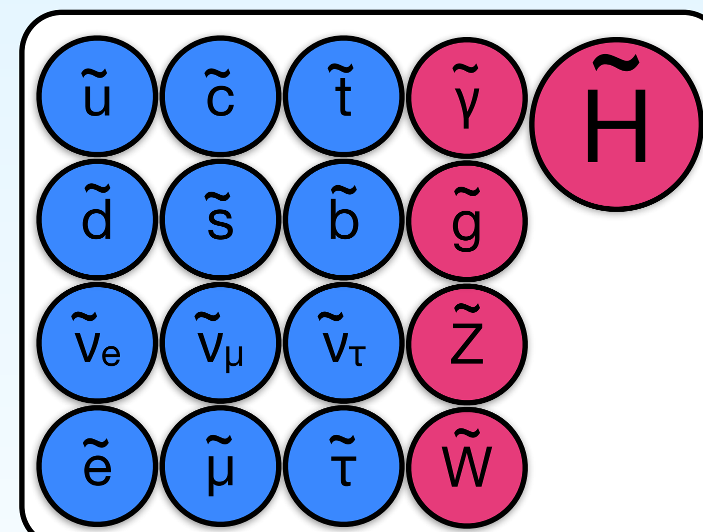
Searches for 3rd Generation Squarks at CMS







SUSY 2015
Lake Tahoe, CA
August 24, 2015

Javier Duarte
Caltech

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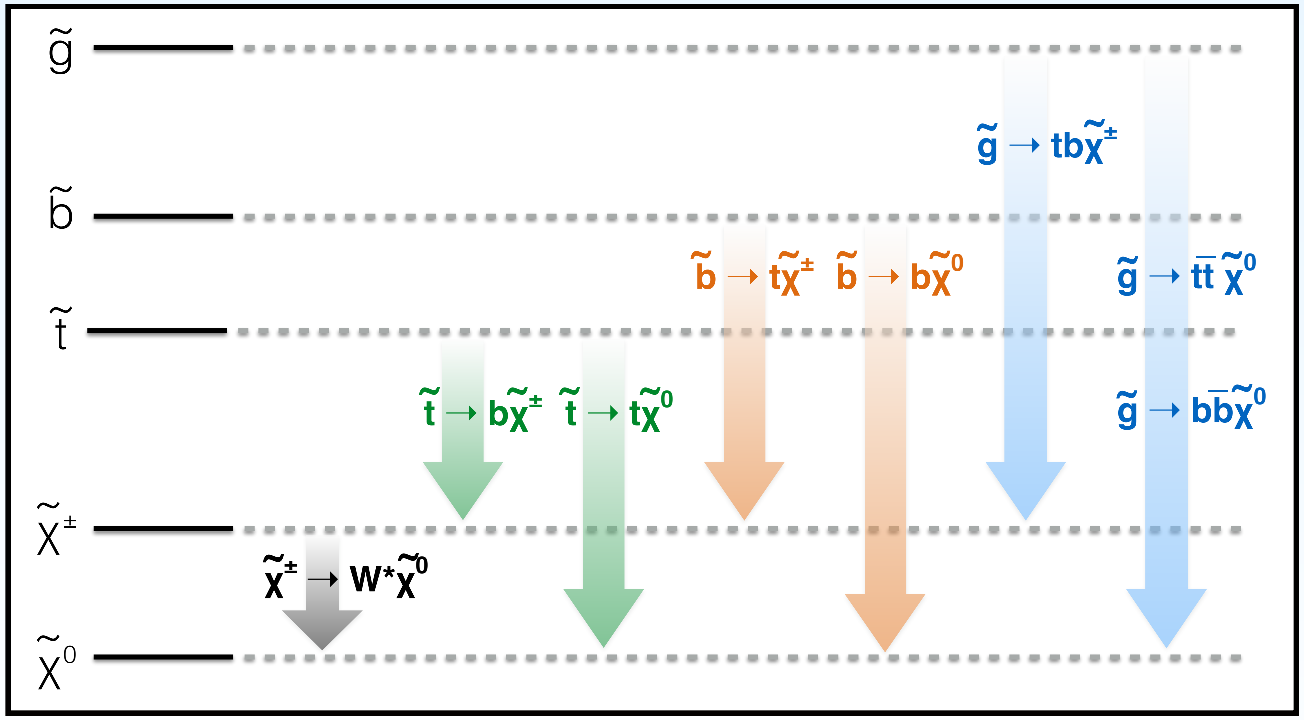
twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

Outline

- Naturalness and 3rd Generation SUSY
- Stop Pair Production Topologies
- 8 TeV Stop Search Results
  - 1-lepton BDT and 0-lepton razor combination
  - Monojet (stop to charm + LSP)
  - ***New*** all-hadronic BDT stop search
- 13 TeV Outlook and Commissioning

Naturalness and 3rd Gen. SUSY

- Due to the standard model Yukawa couplings, the lightest Higgs boson mass is
  - corrected at 1 loop-level by contribution from stops
  - corrected at 2 loop-level by contribution from gluinos
- Naturalness = all contributions are of the same order as the *physical* Higgs mass (no fine-tuning)
- "Acceptable" fine-tuning implies **stops** lighter than **~700 GeV** **gluinos** lighter than **~1.5 TeV**[1]
- Possible spectrum:



1. arXiv:1110.6926 [hep-ph]; see also arXiv:1407.6966 [hep-ph]

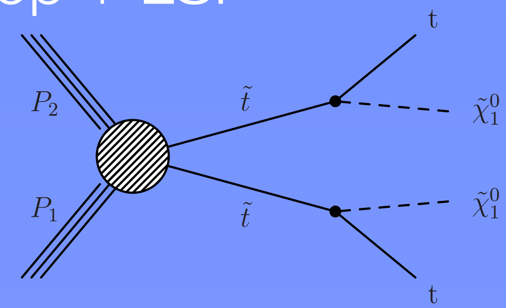
Stop Pair Production Topologies

- Simplified models target specific experimental signatures ("bottom-up" approach)

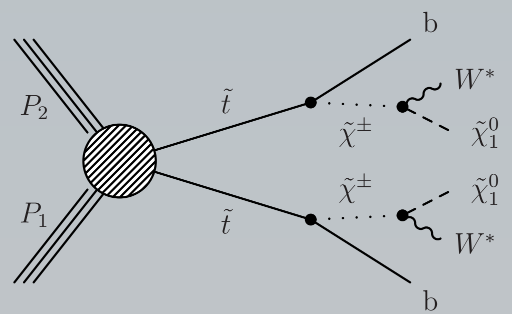
SUS-13-011 EPJC 73 (2013) 2677* (one-lepton mva)
SUS-13-004 PRD 91, 052018 (2015)* (inclusive razor)
SUS-13-023 (**new!** all-hadronic)
SUS-14-001 JHEP 06 (2015) 116* (multijet+dijet+monojet)
SUS-13-024 PLB 736 371 (2014) (H/Z tagged)
…

stop pair production

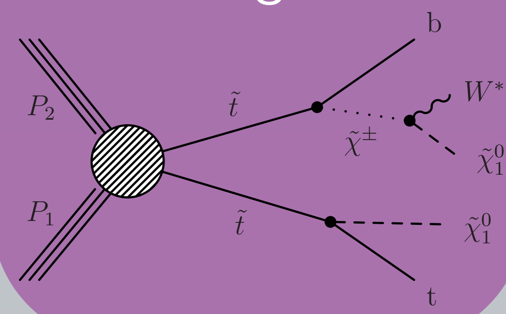
direct decay to top + LSP*



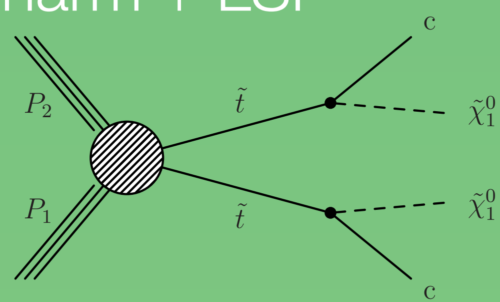
cascade decay involving electroweakinos*



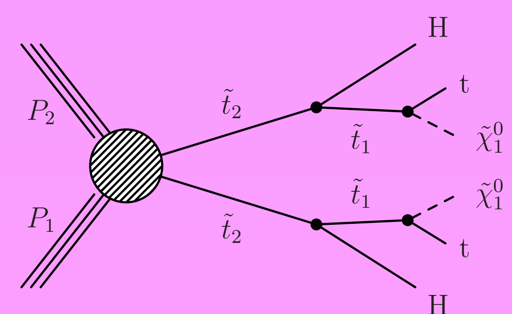
including mixed branching ratios*

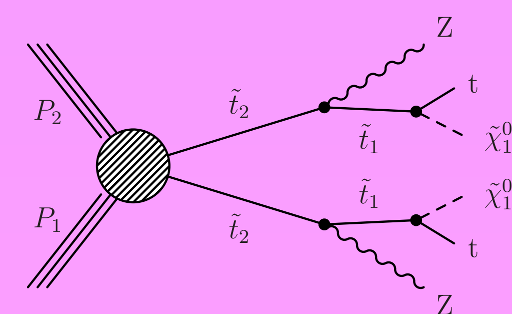


loop-induced decay to charm + LSP*



cascade decay involving two light stops





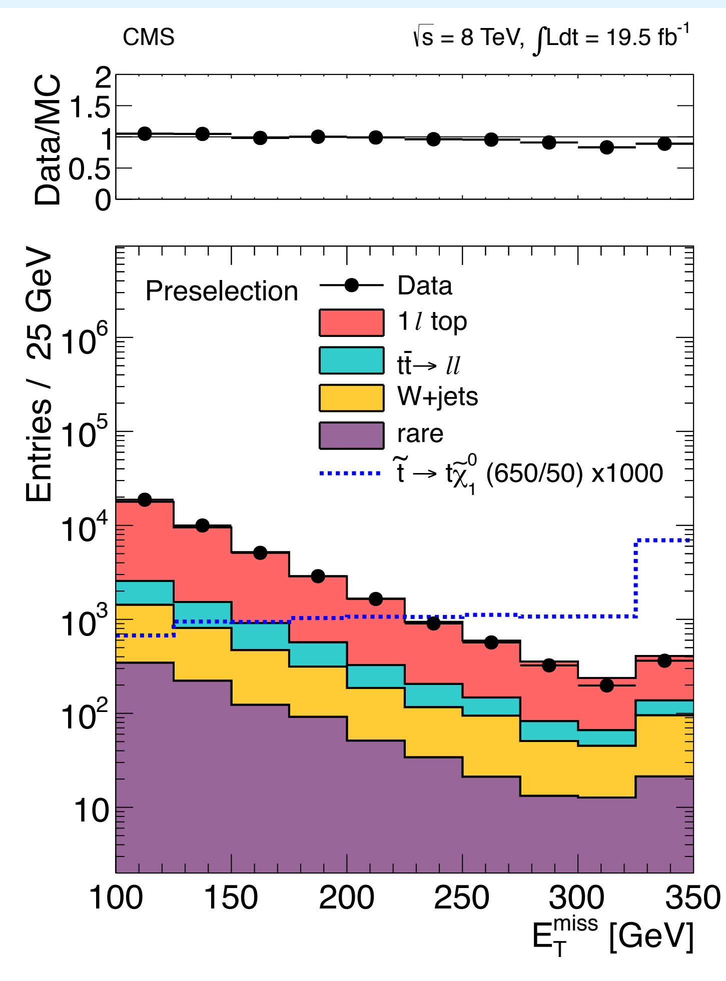
*discussed in this talk

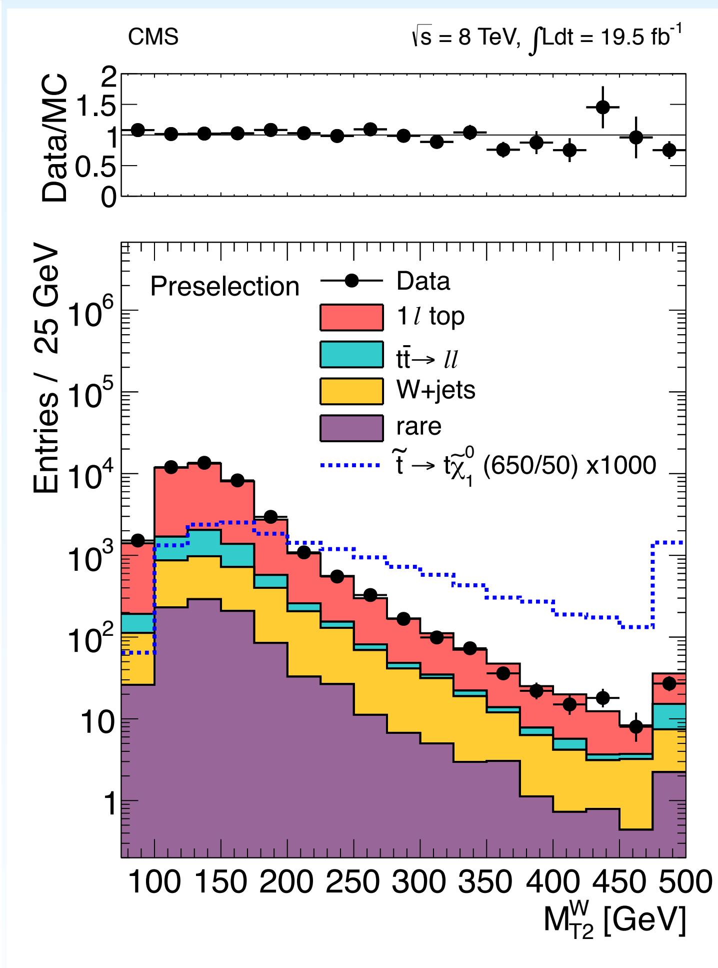
SUS-13-011
EPJC 73 (2013) 2677

1-Lepton BDT

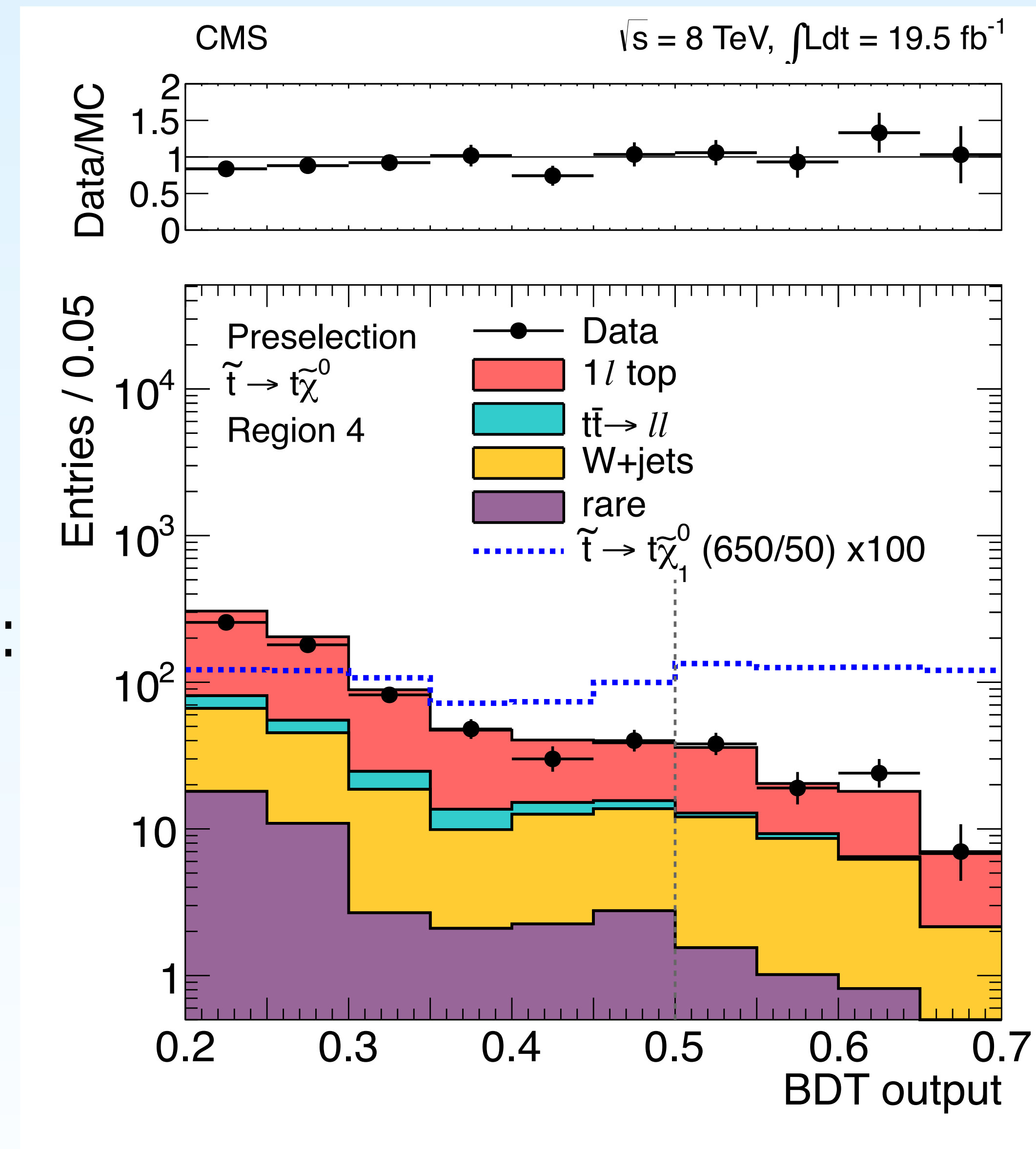
- After tight single lepton selection, optimize different multivariate boosted decision trees (BDTs) for different regions of phase space based on signal-sensitive observables

example inputs:





output:
→



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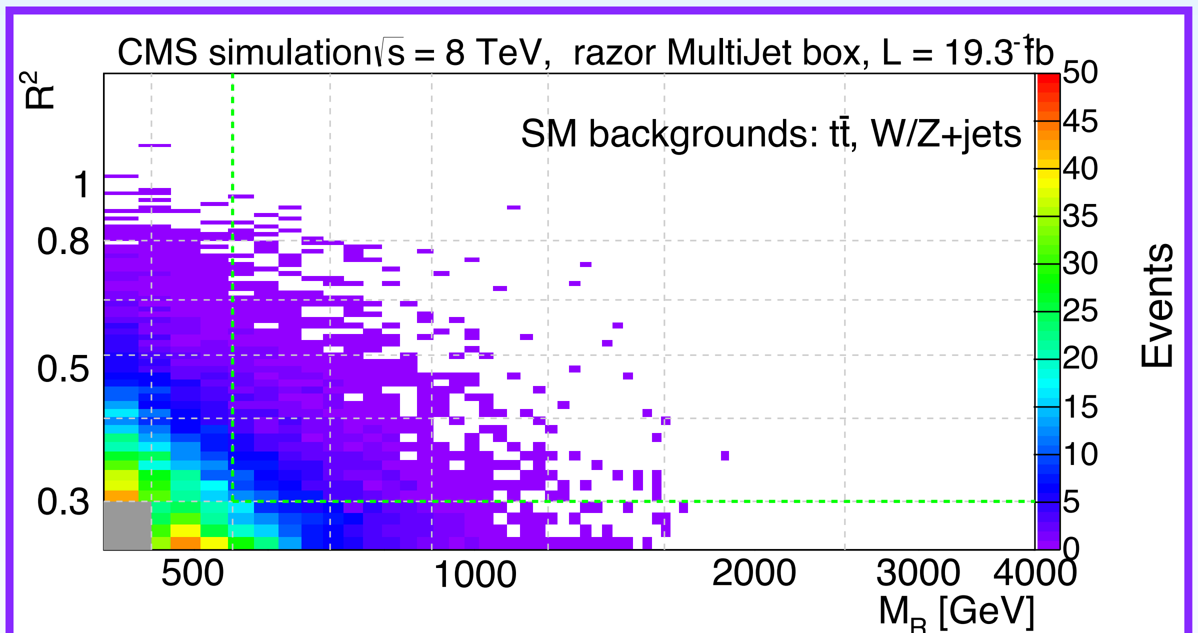
0-Lepton Razor

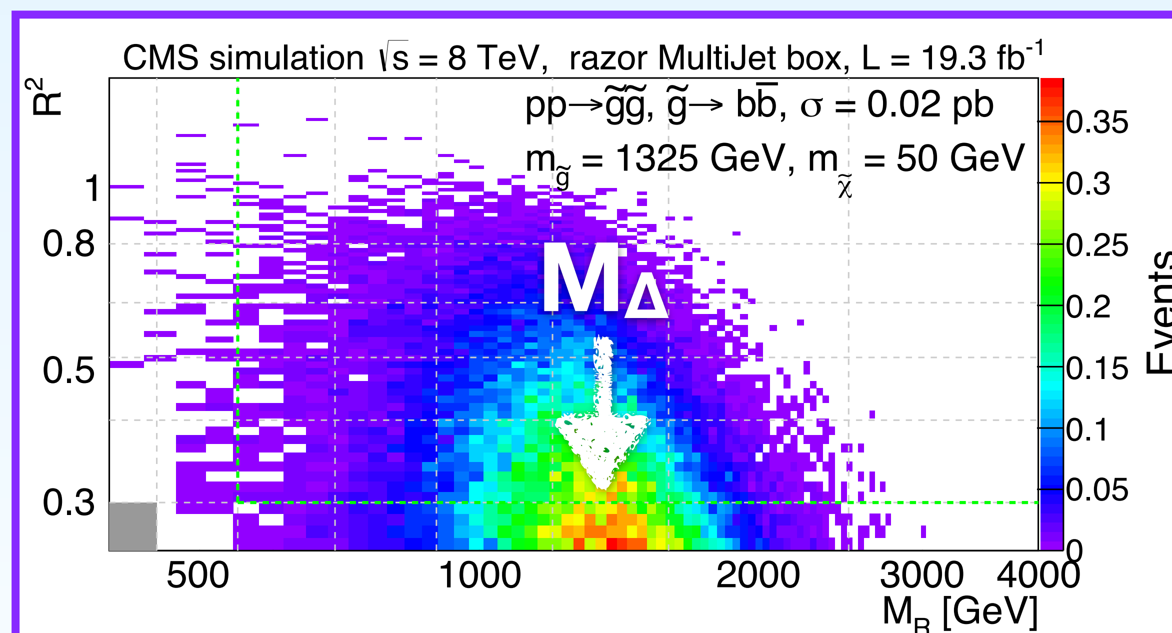
- Razor variables computed from “megajets” (forcing dijet topology)
- Events are sorted into “boxes” based on number of leptons, jets, and b-jets

$$M_R = \sqrt{(|\vec{p}_{j1}| + |\vec{p}_{j2}|)^2 - (p_z^{j1} + p_z^{j2})^2}$$

$$R \equiv \frac{M_T^R}{M_R} \qquad M_T^R \equiv \sqrt{\frac{E_T^{\text{miss}}(p_T^{j1} + p_T^{j2}) - \vec{E}_T^{\text{miss}} \cdot (\vec{p}_T^{j1} + \vec{p}_T^{j2})}{2}}$$

R^2 related to MET





M_R peaks at char. mass scale

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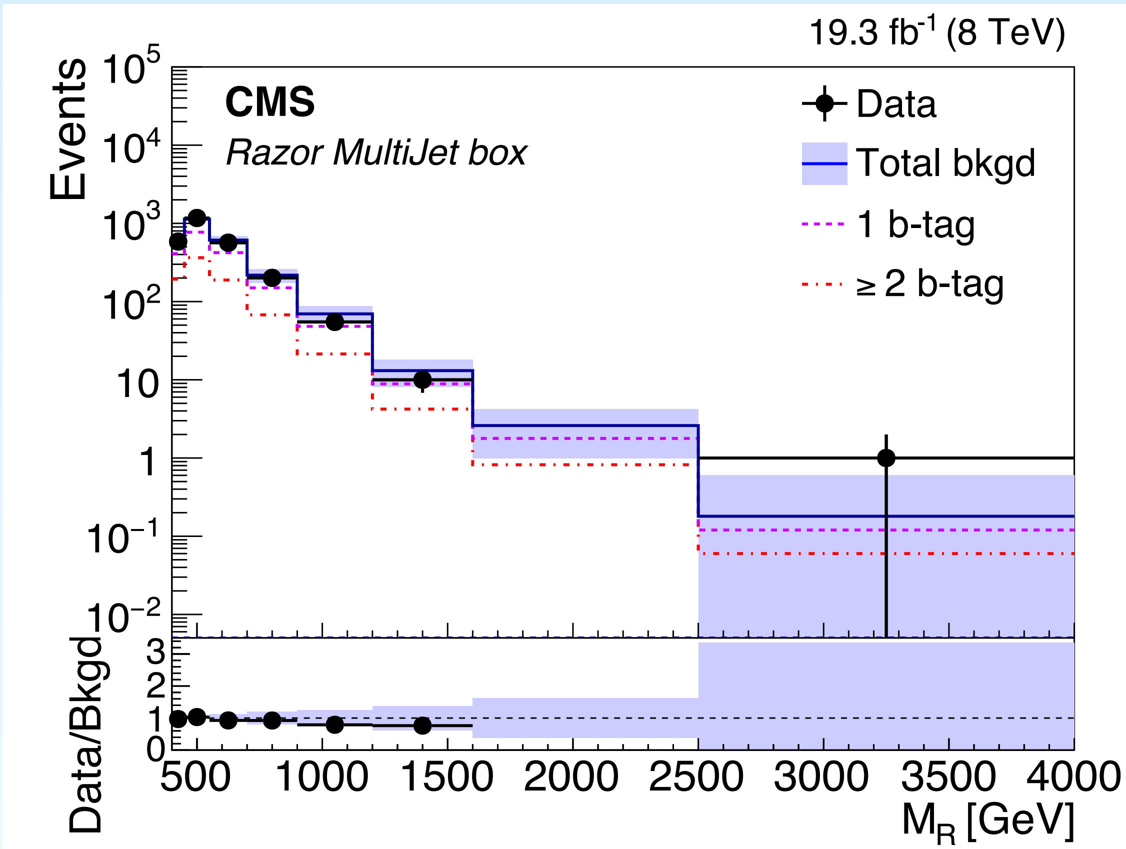
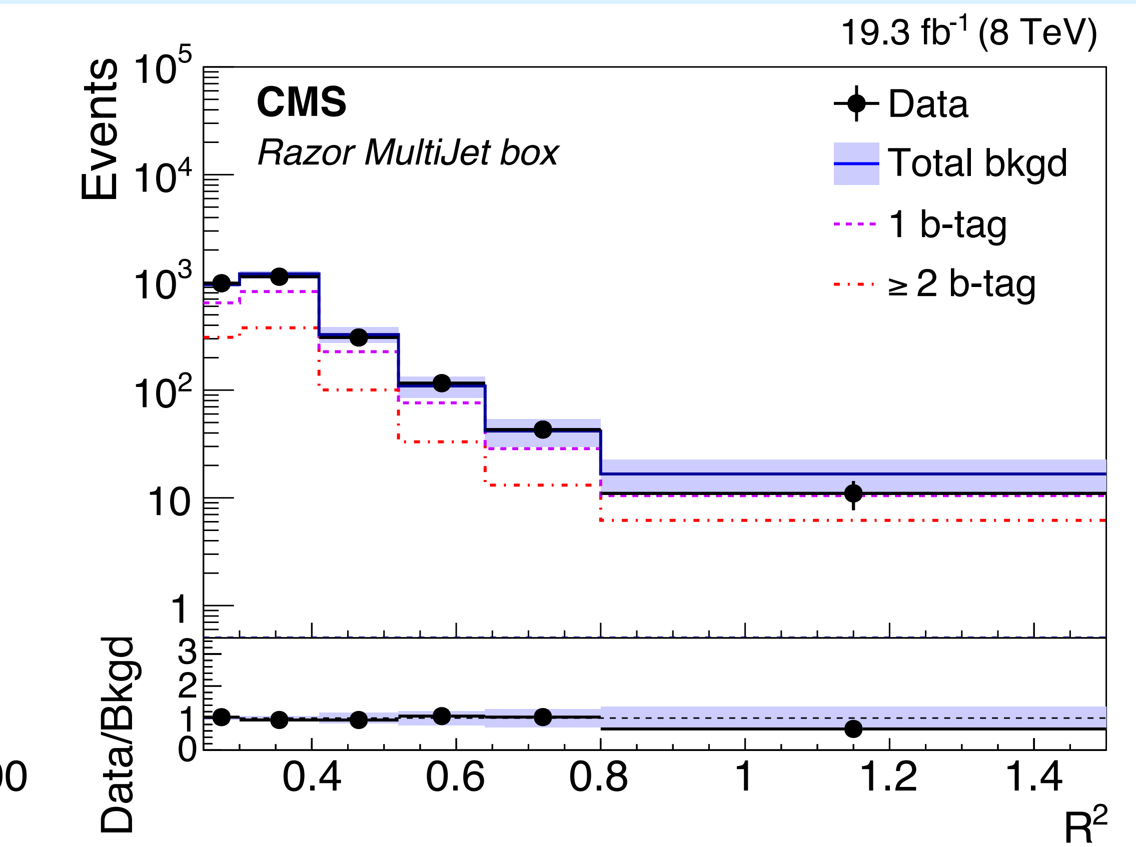
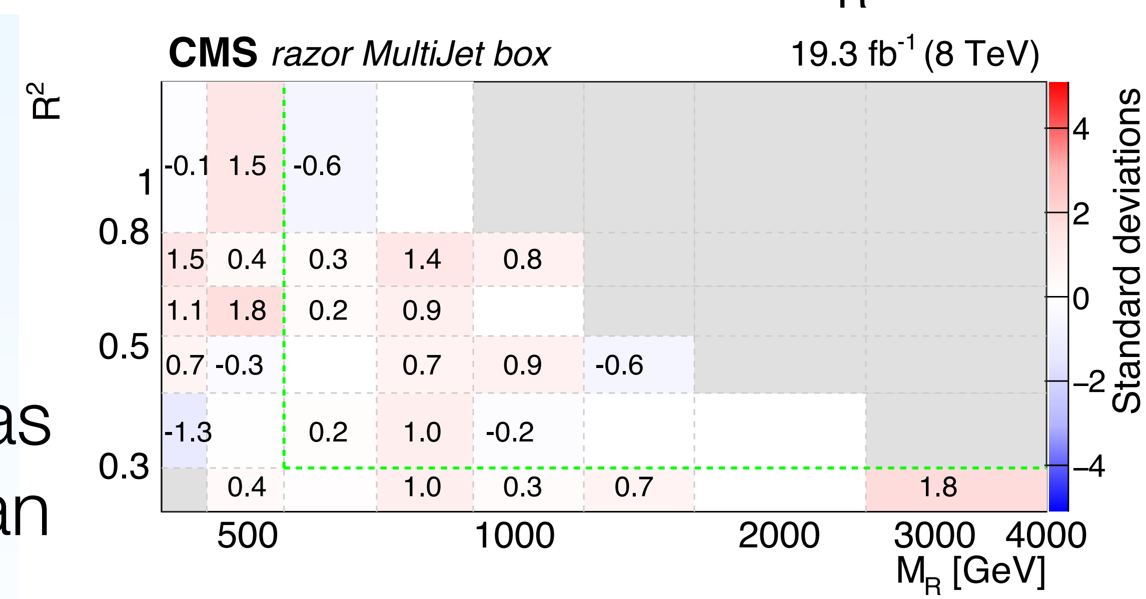
Razor Backgrounds

$$f_{\text{Razor}}(x,y) \propto \left(b[(x-x_0)(y-y_0)]^{1/n} - 1\right) \text{Exp}\{-bn[(x-x_0)(y-y_0)]^{1/n}\}$$





- 2d analytic shape is fit in a background-enriched sideband and extrapolated
- Agreement is quantified between prediction and data as a two-sided p-value, expressed as a number of standard deviations for a gaussian



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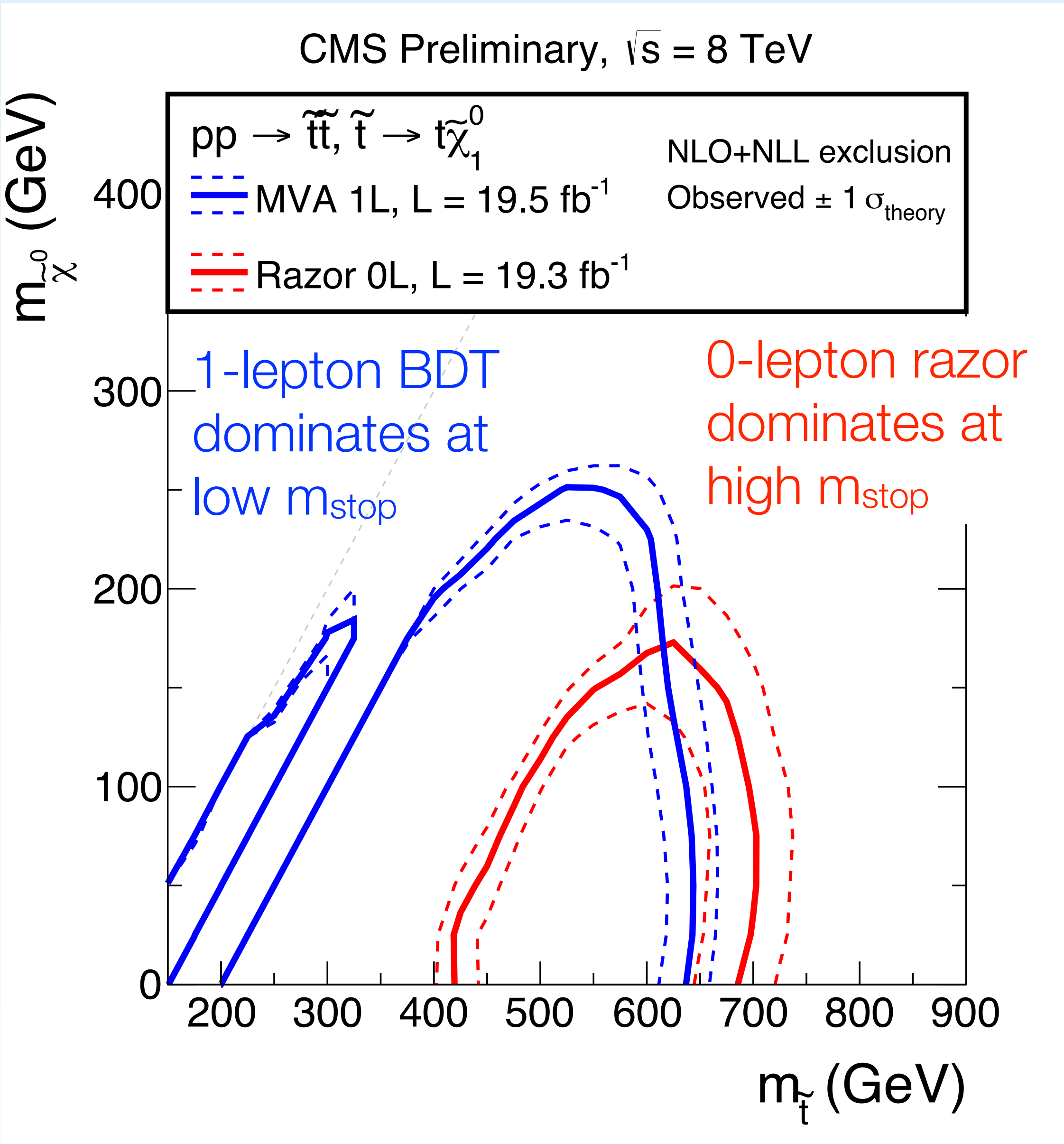
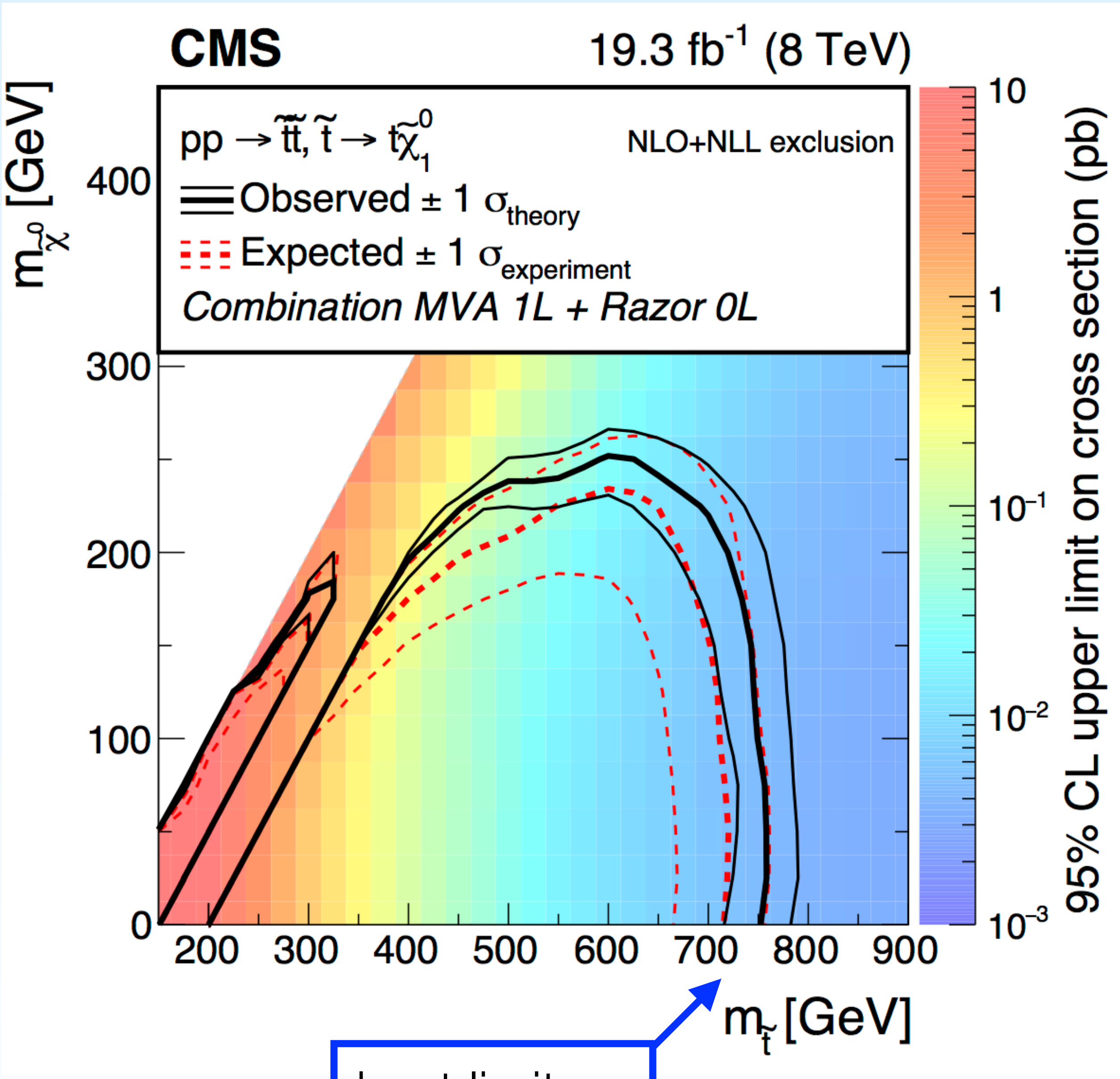
0-Lepton + 1-Lepton Combination

- Combining 1-lepton BDT and 0-lepton razor yielded the strongest CMS limit on the stop mass





best limit on stop mass = 750 GeV

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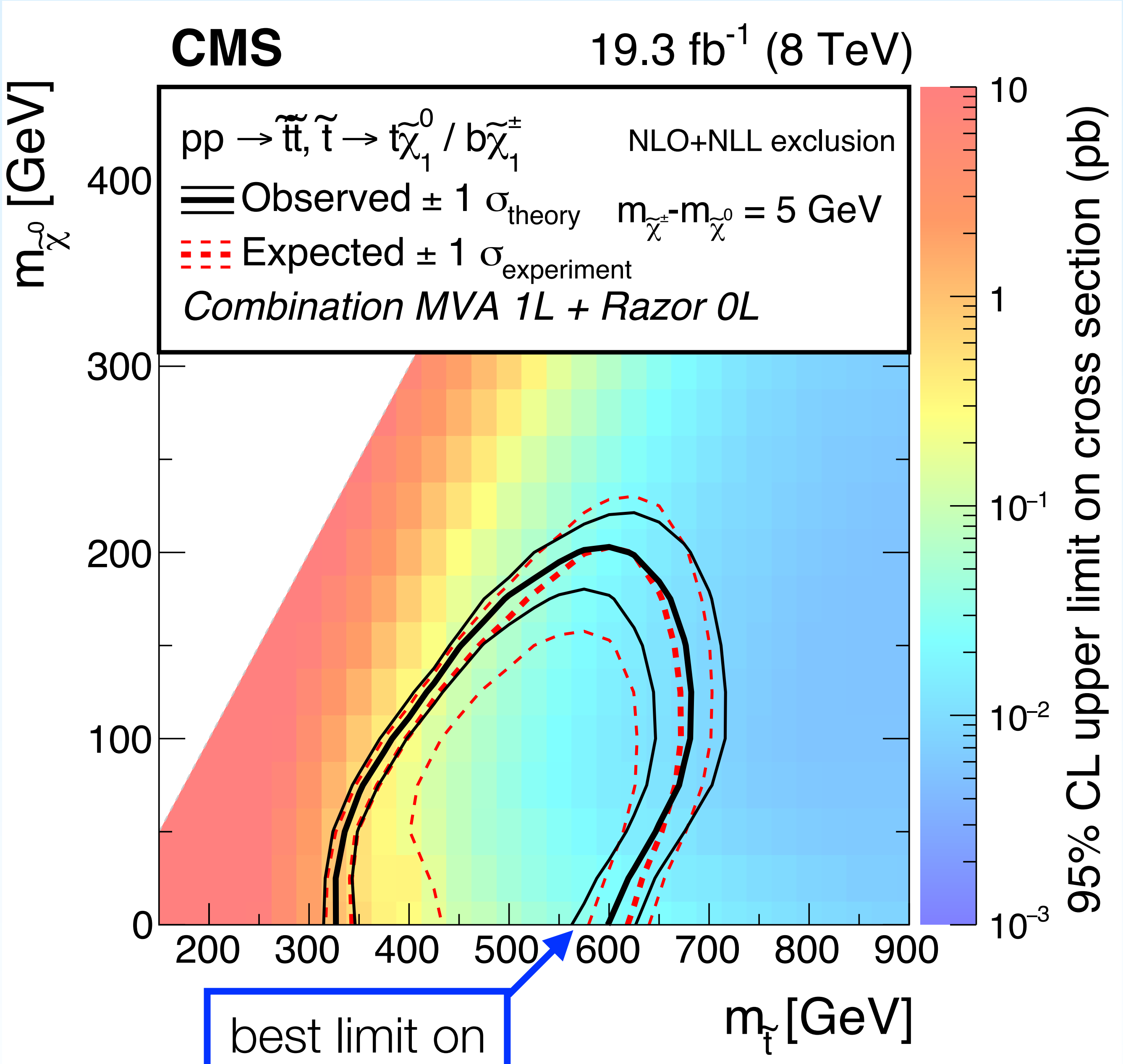
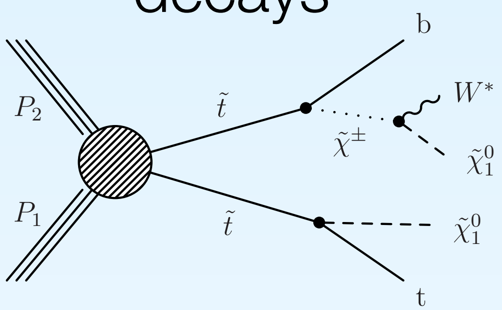
0-Lepton + 1-Lepton Combination

- Generic branching-ratio independent limit was also derived considering most *conservative* limit after scanning over branching ratios: x = BR($\tilde{t} \rightarrow t\tilde{\chi}^0$), 1-$x$ = BR($\tilde{t} \rightarrow b\tilde{\chi}^\pm$)



including asymmetric decays



best limit on stop mass = 680 GeV

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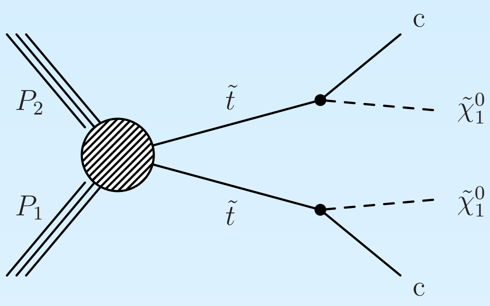
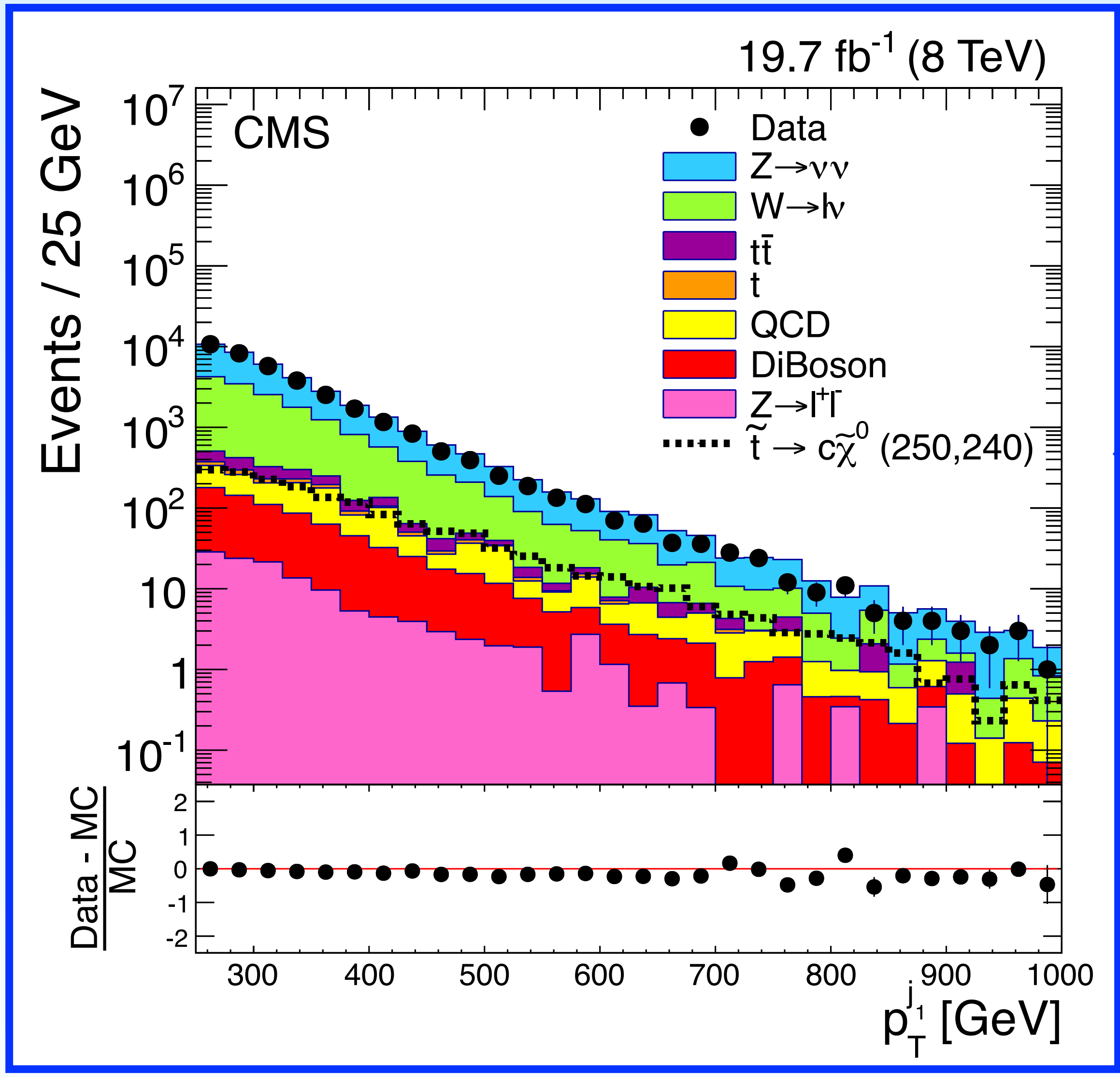
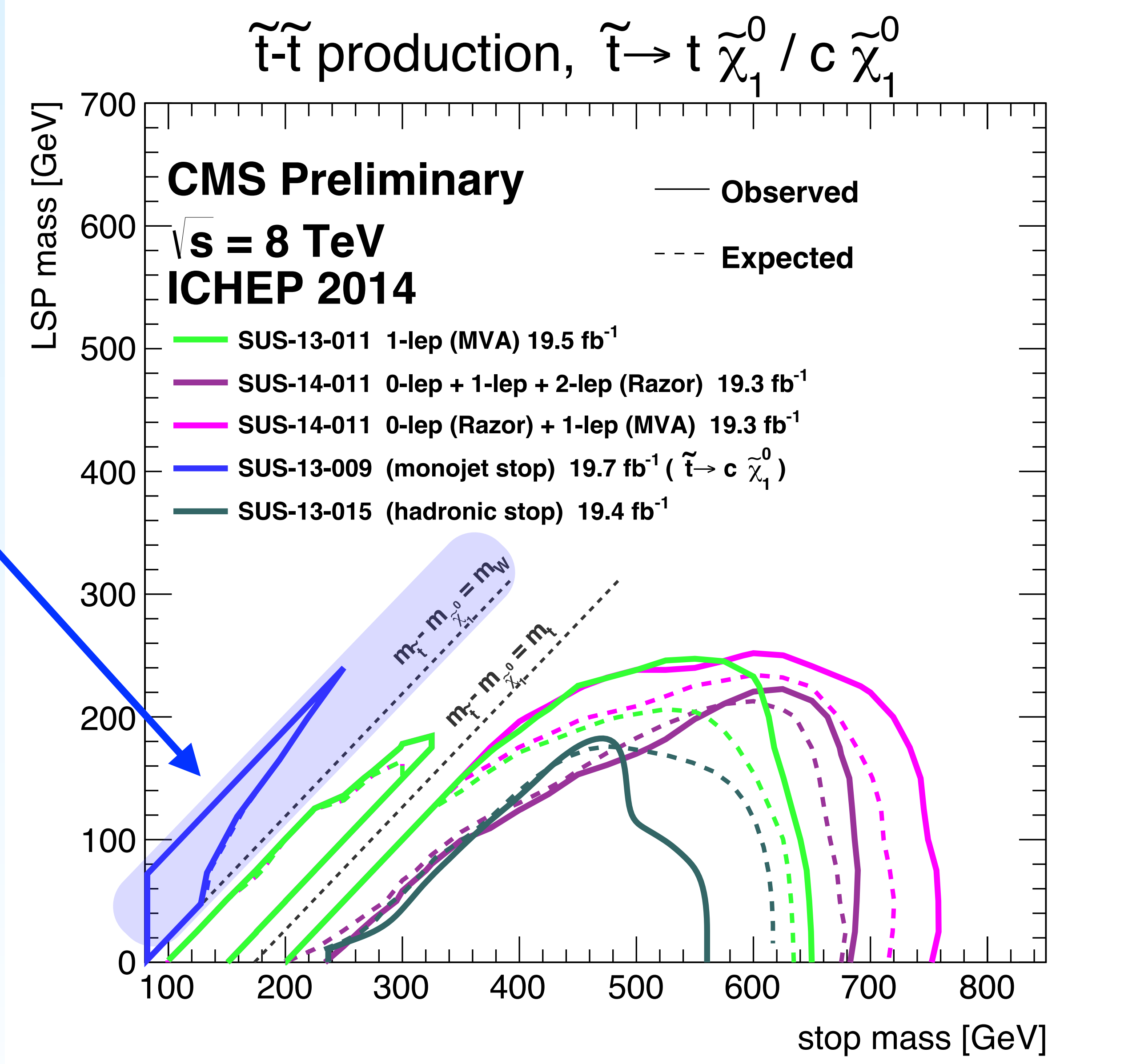
Monojet Stop Search

- Monojet search covers compressed region, where stop to charm + LSP decay is favored







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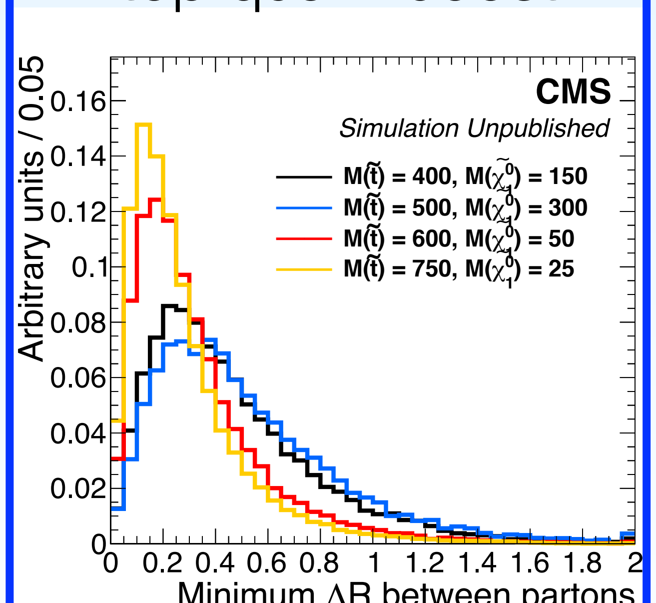
SUS-13-023 All-hadronic BDT: Top Reconstruction

- Dedicated high efficiency top pair reconstruction

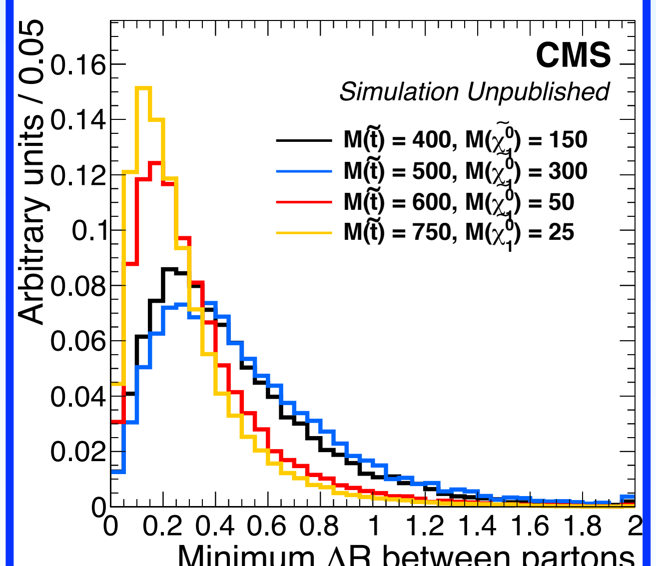
ΔR between patrons differs based on top quark boost



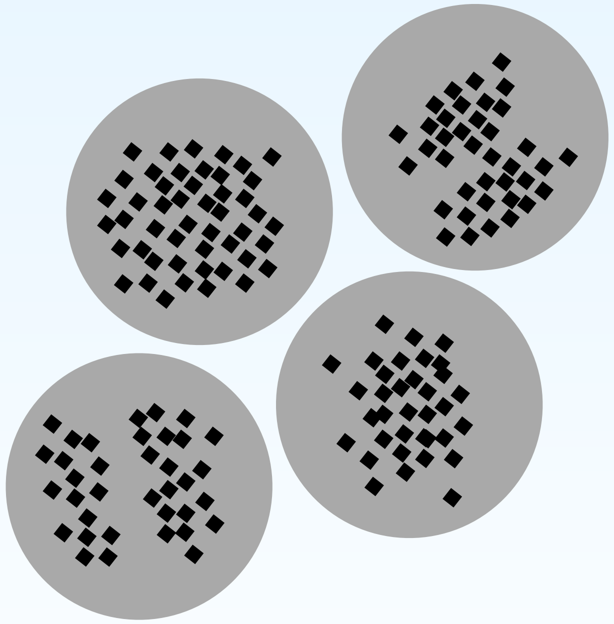
SUS-13-023 All-hadronic BDT: Top Reconstruction

- Dedicated high efficiency top pair reconstruction
- Input “fat jets”

ΔR between patrons differs based on top quark boost



Cambridge-Aachen
ΔR=1
“fat jets”



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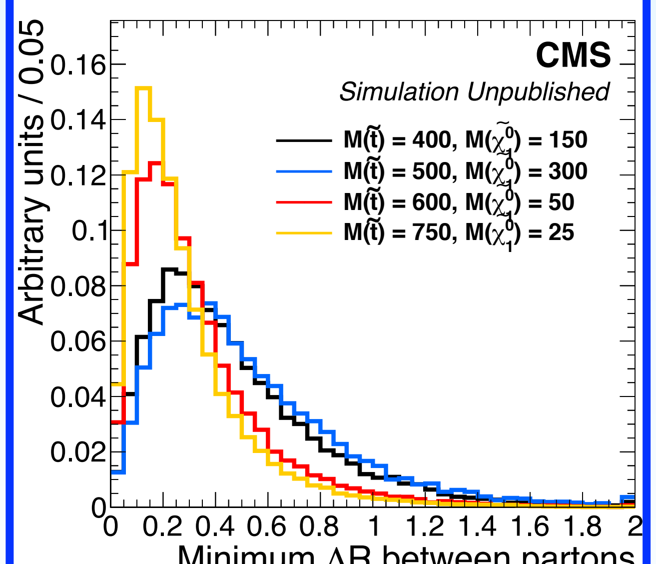
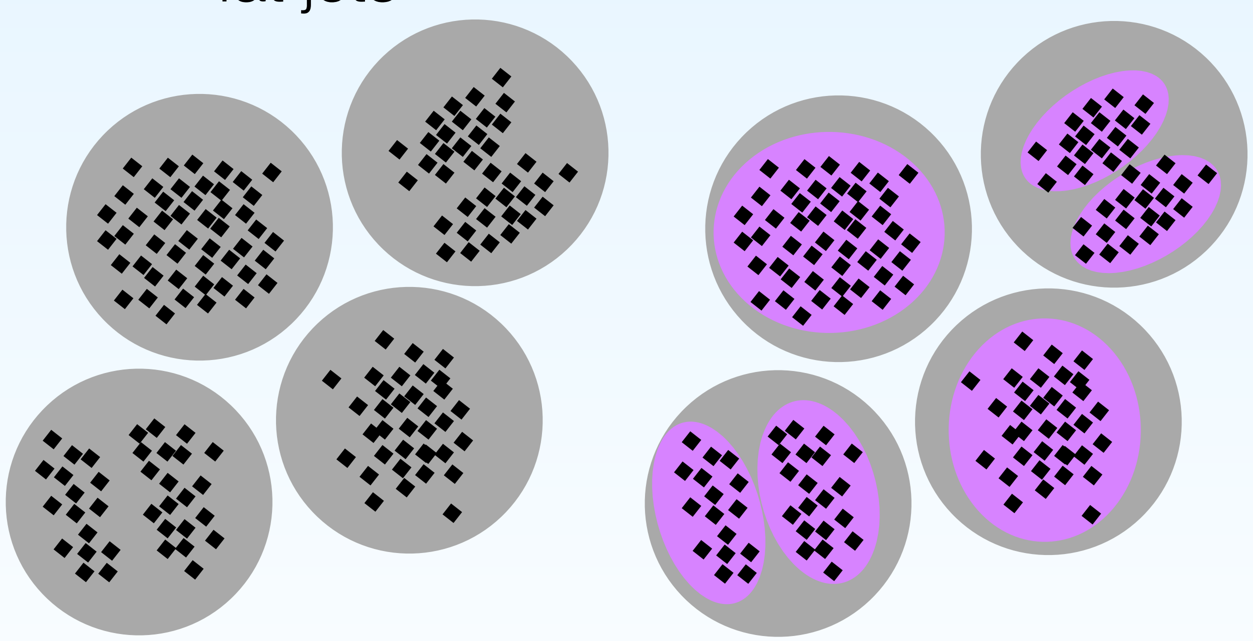
All-hadronic BDT: Top Reconstruction

- Dedicated high efficiency top pair reconstruction
- Input “fat jets” are split into up to 2 subjets to create “picky jets”

ΔR between patrons differs based on top quark boost



Cambridge-Aachen ΔR=1 “fat jets” → “picky jets”



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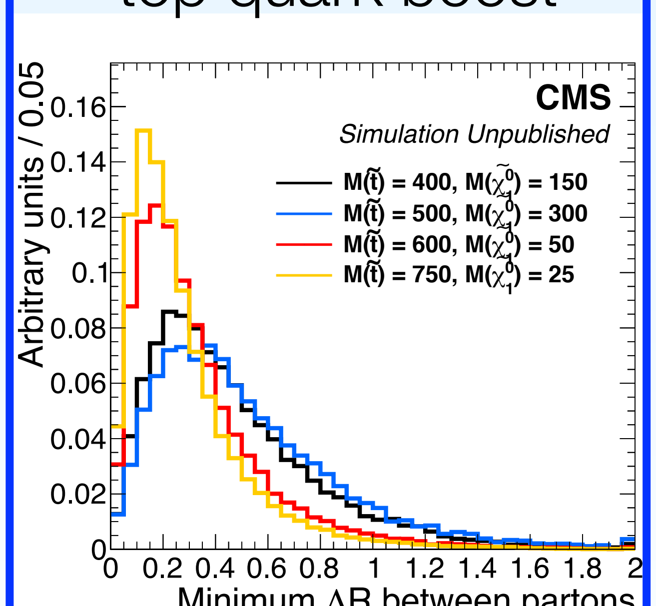
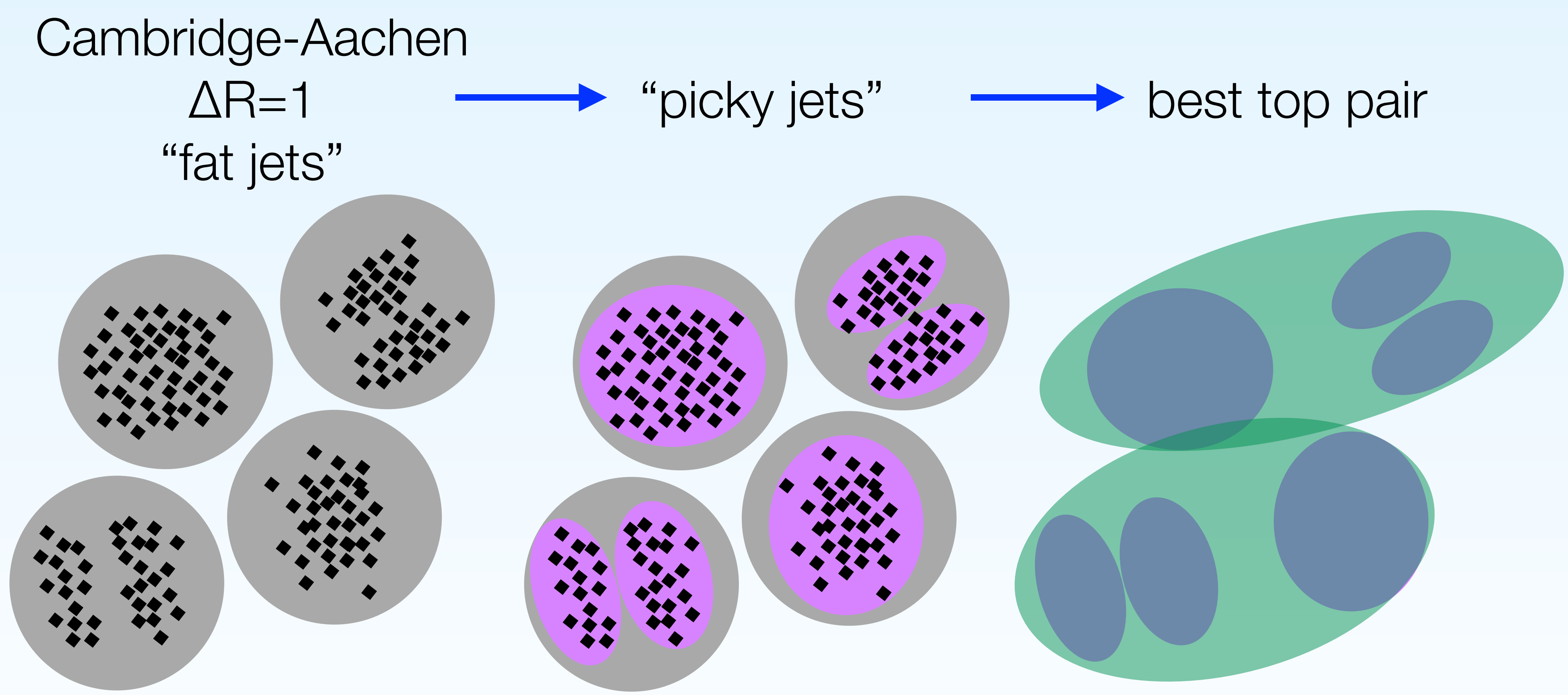
All-hadronic BDT: Top Reconstruction

- Dedicated high efficiency top pair reconstruction
- Input “fat jets” are split into up to 2 subjets to create “picky jets”
- MVA-based top pair reconstruction: choose best pair of “top candidates”

ΔR between patrons differs based on top quark boost





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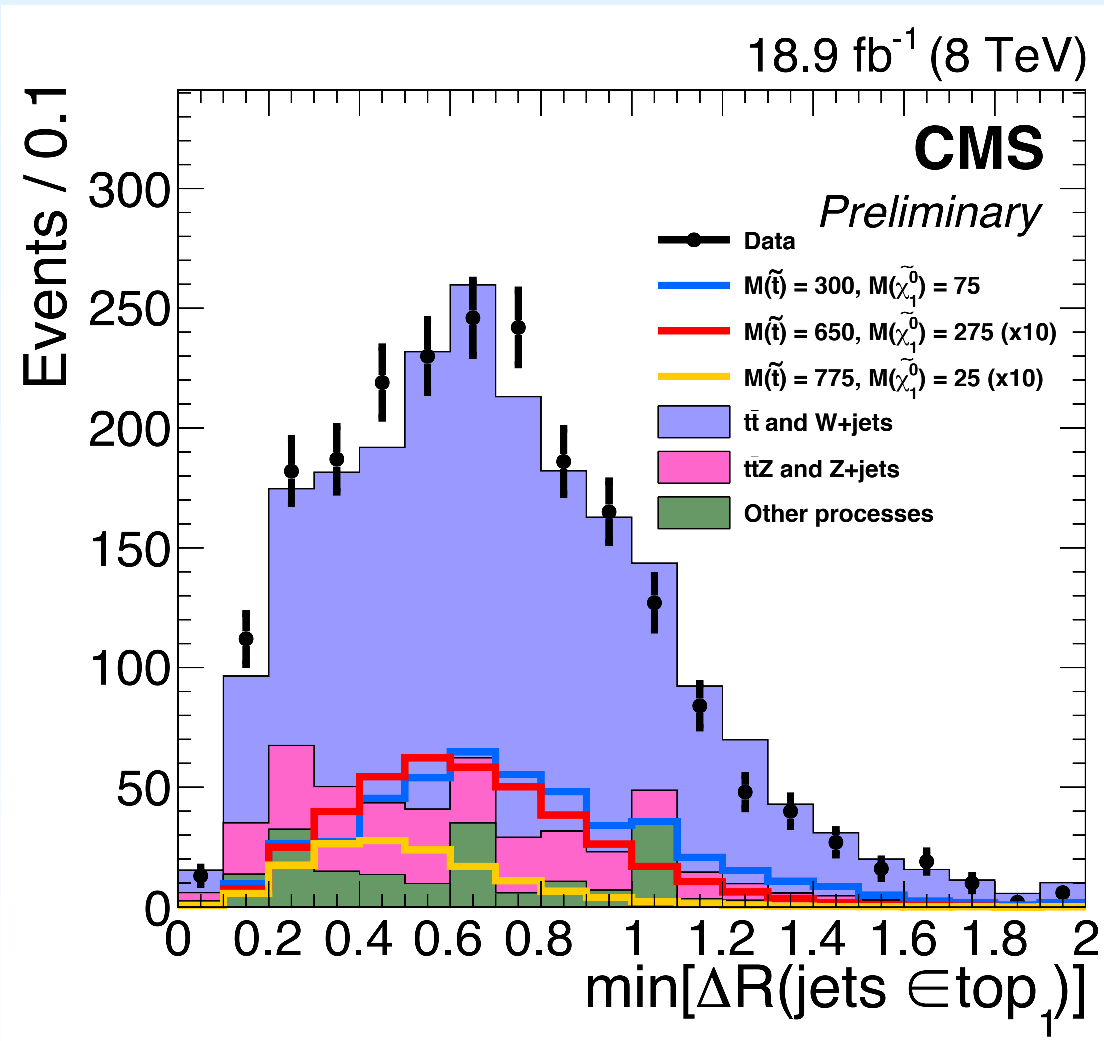
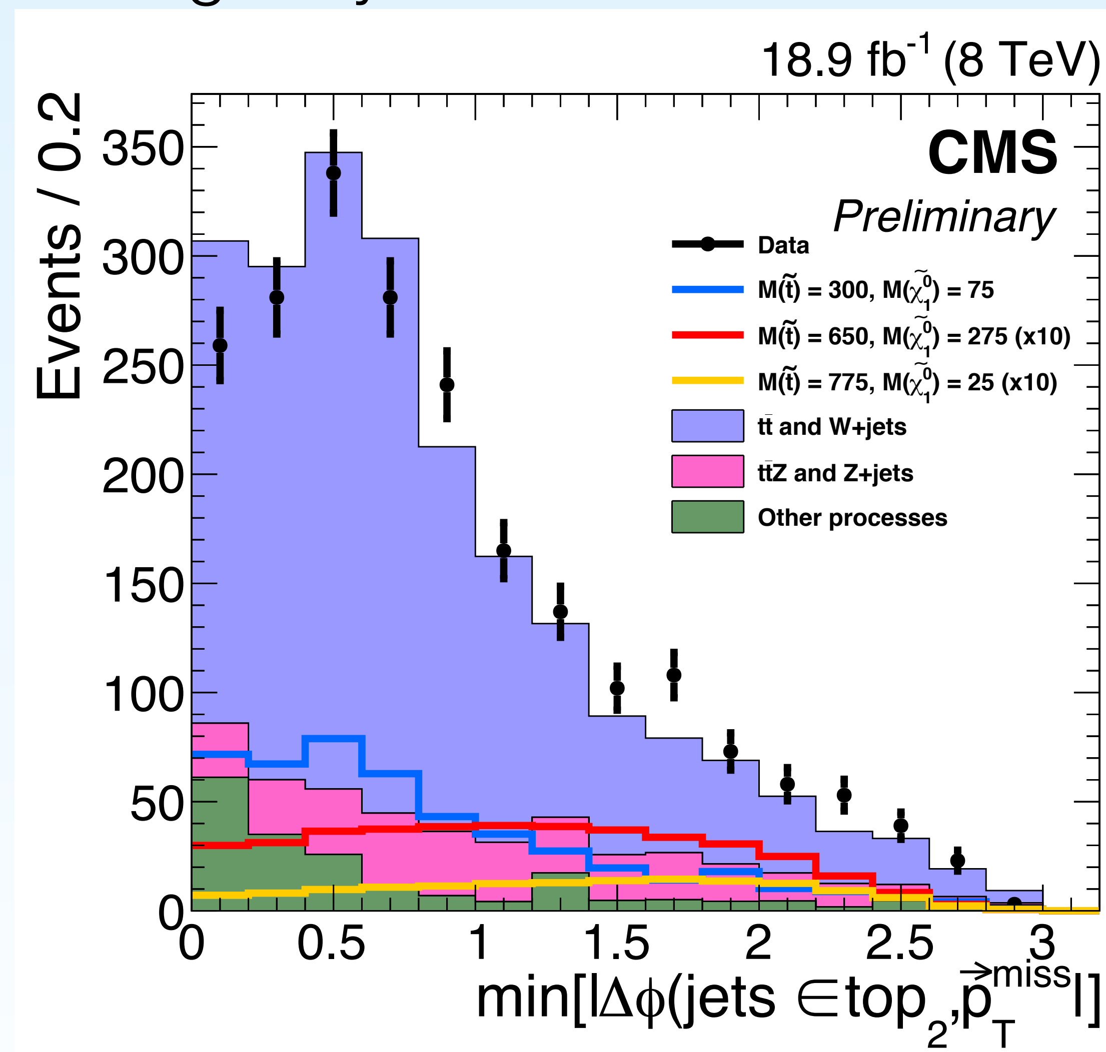
All-hadronic BDT: Top Pair Kinematics

- Top pair kinematics are used to discriminate signal from background

tops from signal are collimated

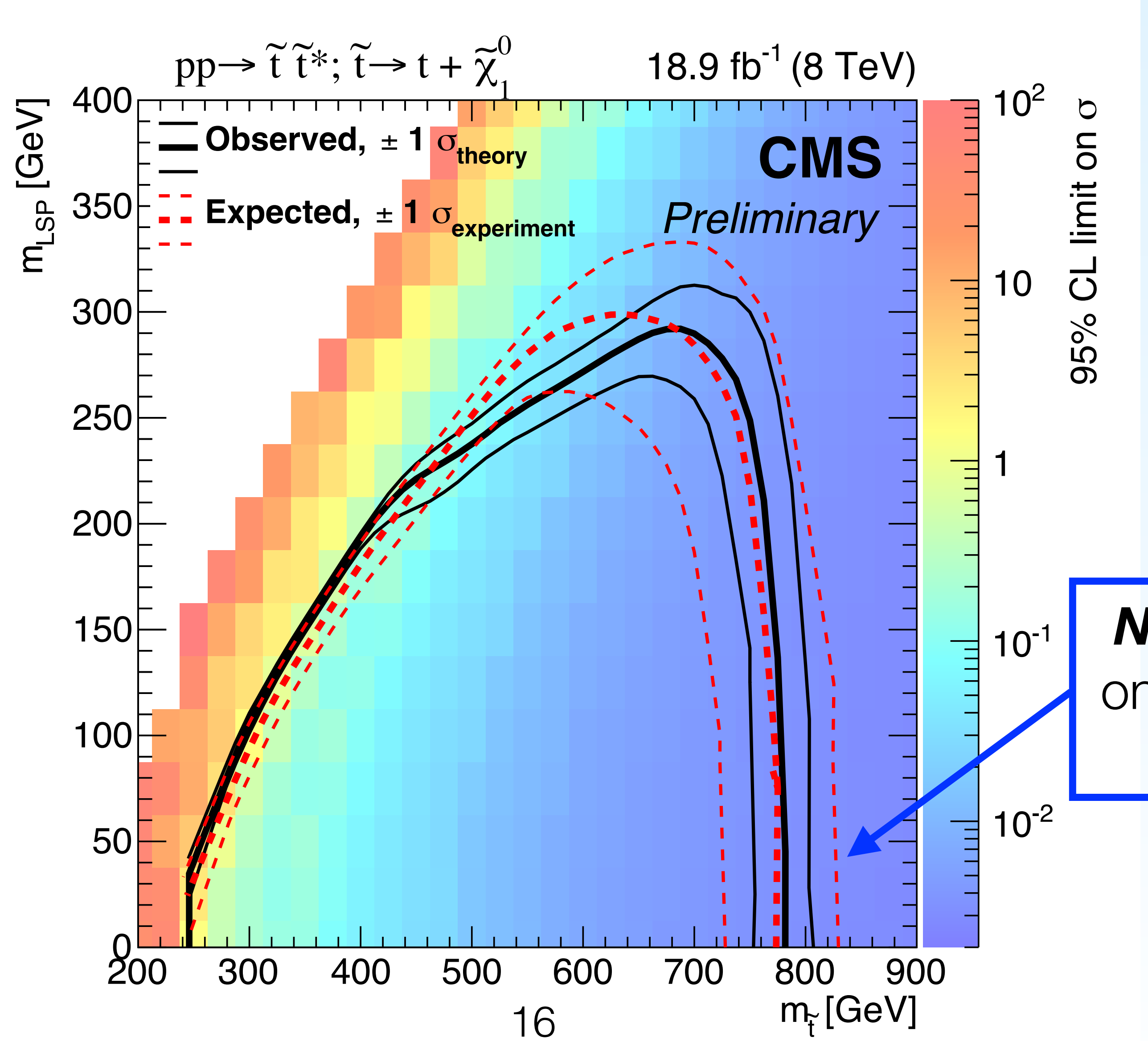


tops from signal are not angularly correlated with MET



All-hadronic BDT Results

- 4 BDTs (optimized for different stop mass) are trained with 24 input variables, including MET, “top candidate” MVA values, etc.
- MC mis-modeling is corrected using data-driven scale factors: lepton id., b-tagging, jet momentum, and MET



New best limit on stop mass = 775 GeV

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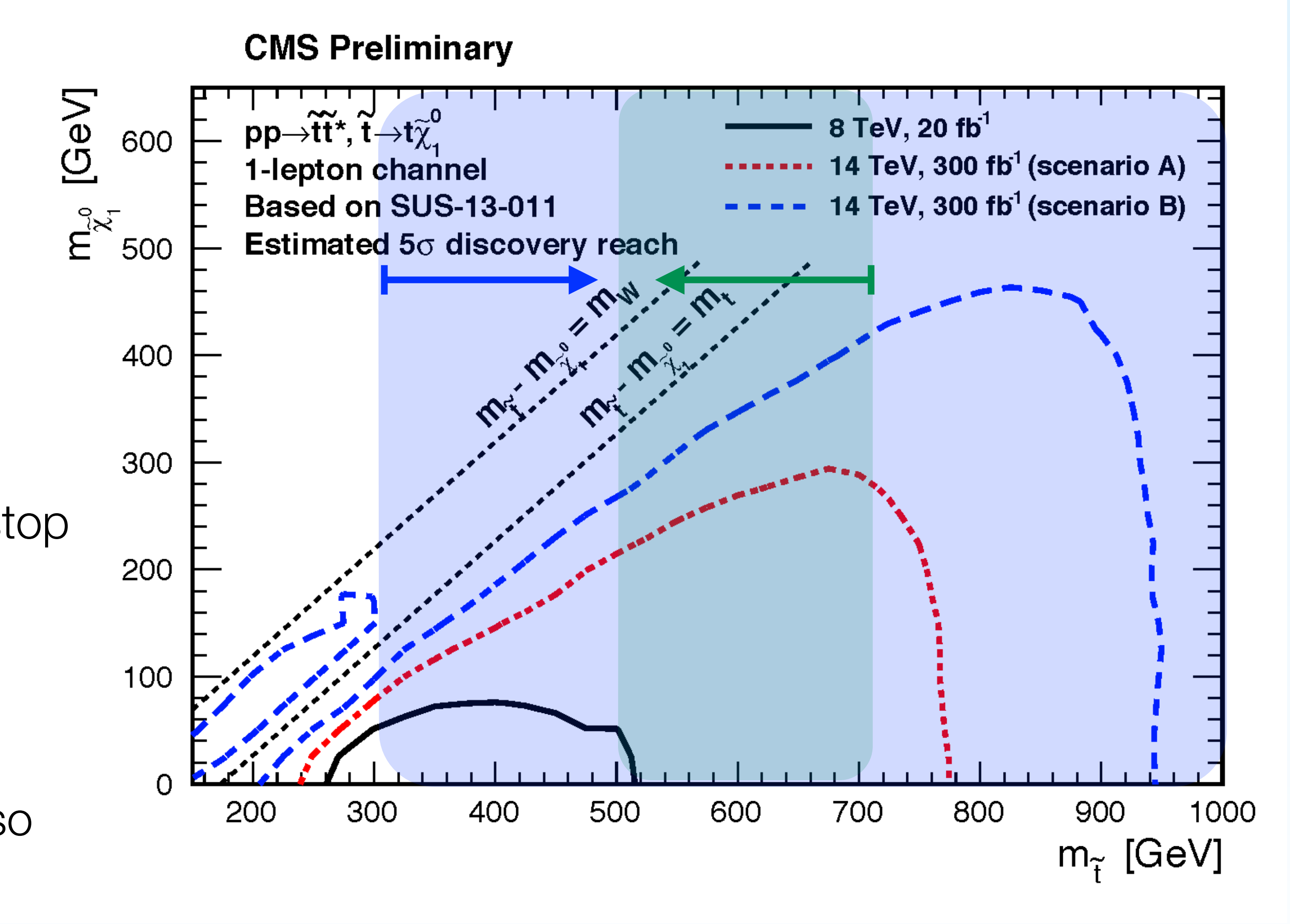
Outlook for 13 TeV

- 5σ discovery reach in stop mass will reach 800 GeV in a conservative scenario
- Crucial region for testing naturalness and whether SUSY has a role in Electroweak symmetry breaking



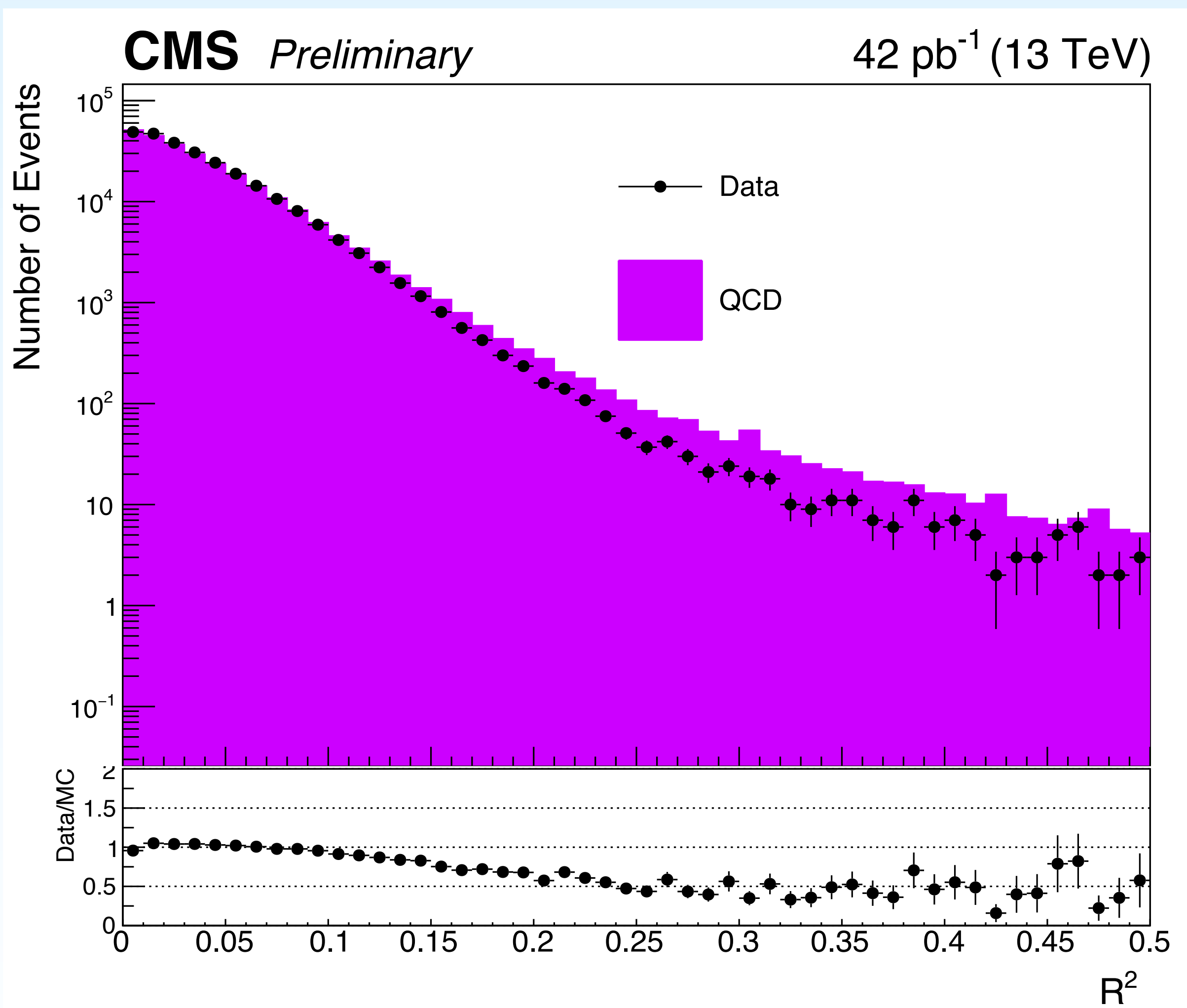
- naturalness prefers m_{stop} lighter than 700 GeV
- m_H = 126 GeV prefers m_{stop} heavier than 300 GeV[1]

1. arXiv:1110.6926 [hep-ph]; see also arXiv:1407.6966 [hep-ph]

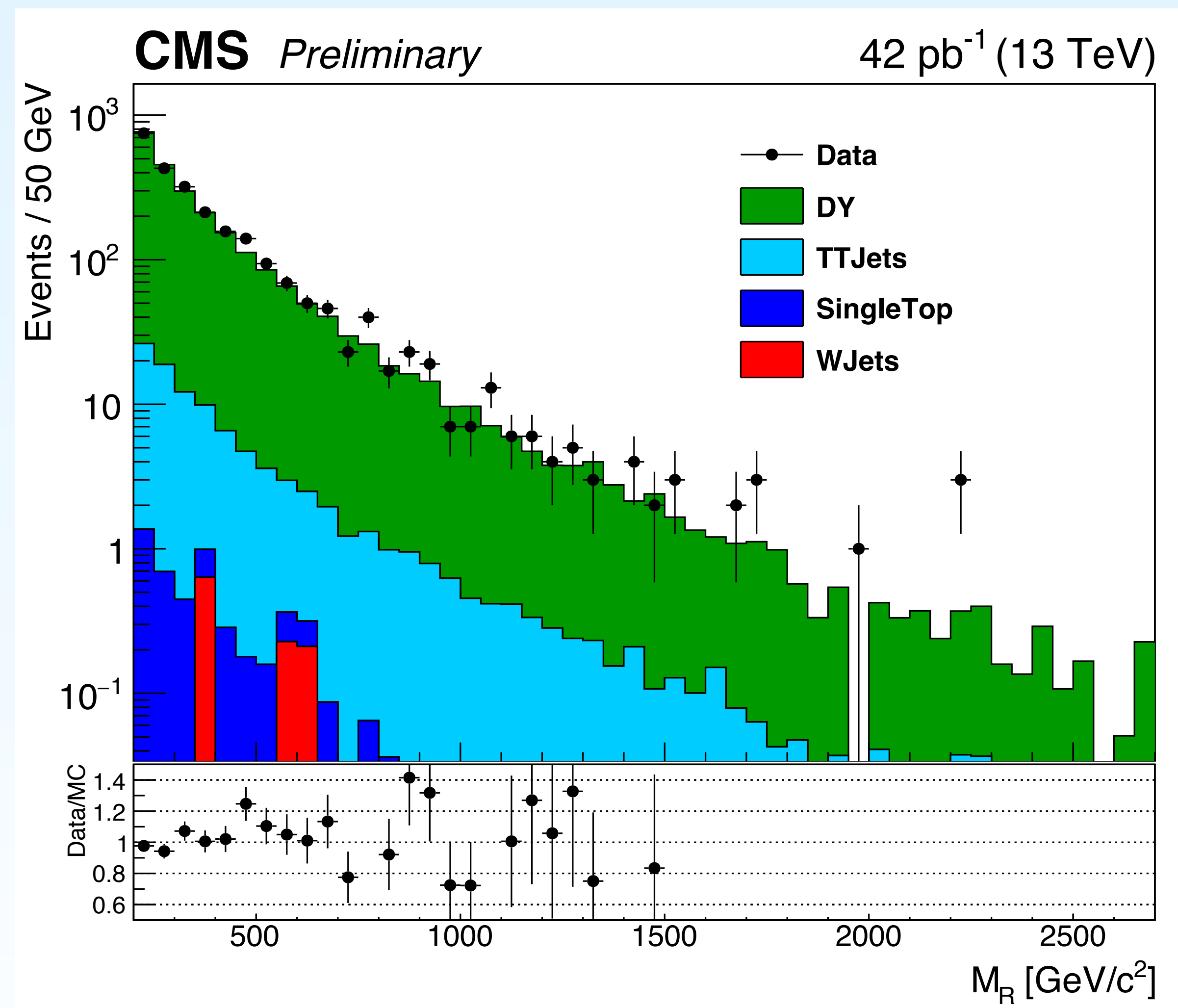
13 TeV Commissioning

- Good agreement in dilepton M_R distribution (DY and $t\bar{t}$ dominated) in early 13 TeV data
- Improving our understanding of QCD MET and R^2 tails in 0 b-tag control sample

R^2 distribution in 0 b-tag sample



M_R distribution in dilepton sample



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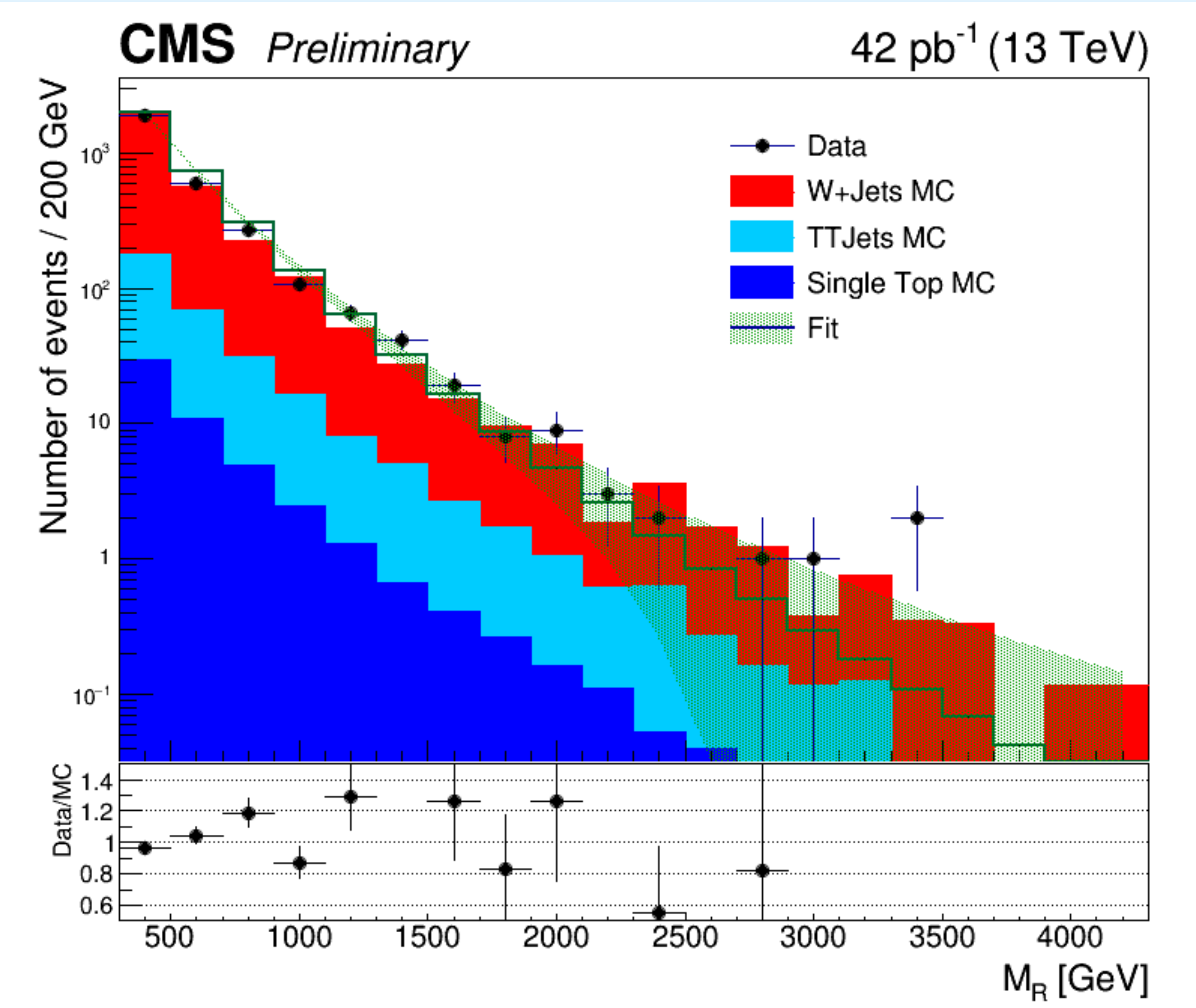
SUS-15-001

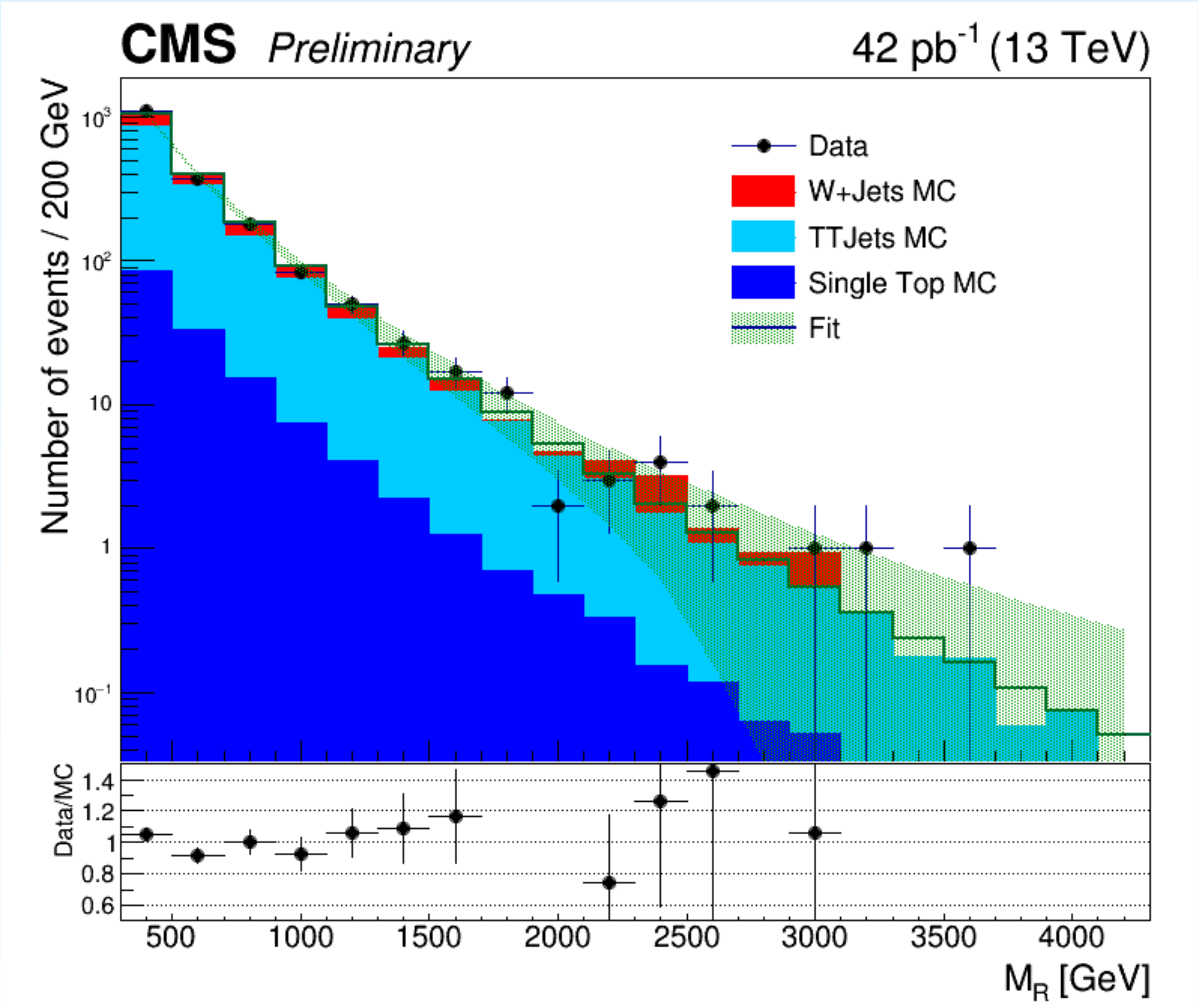
13 TeV Commissioning

- M_R and R^2 sideband fit procedure has been commissioned in $t\bar{t}$ and W single lepton control regions

W single lepton control region



$t\bar{t}$ single lepton control region



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twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

Summary

- The CMS SUSY search program at 8 TeV has produced stringent limits on many “natural” SUSY scenarios
  - Up to 775 GeV limit on stop mass (decay to tops)
  - Compressed region (stop to charm + LSP) covered by monojet search
- Commissioning of triggers, kinematic variables, and methods underway with early 13 TeV data
- Stay tuned in 2015-2016: we will probe interesting regions in natural SUSY phase space at *5σ discovery level*

Backup

SUS-13-023

All-hadronic BDT Results

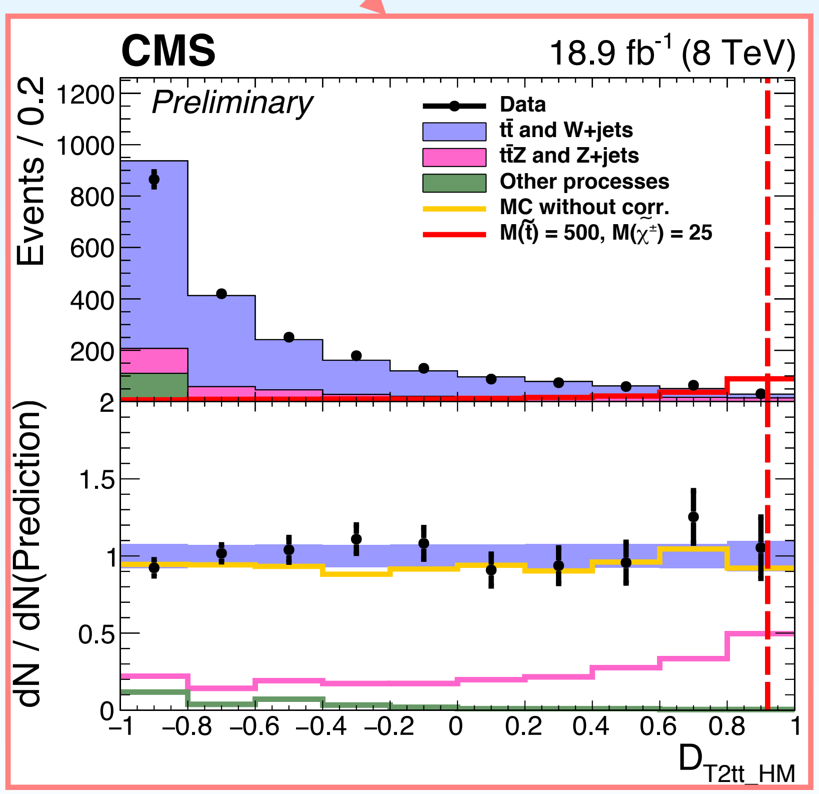
- Four different BDTs (optimized for different stop mass phase space) are trained with 24 input variables, including MET, mT(b-tag, MET), jet multiplicity, CORRAL top candidate MVA value, and others
- MC are corrected using data-driven scale factors for mis-modeling of lepton id efficiency, b-tagging efficiency, jet momentum, and MET

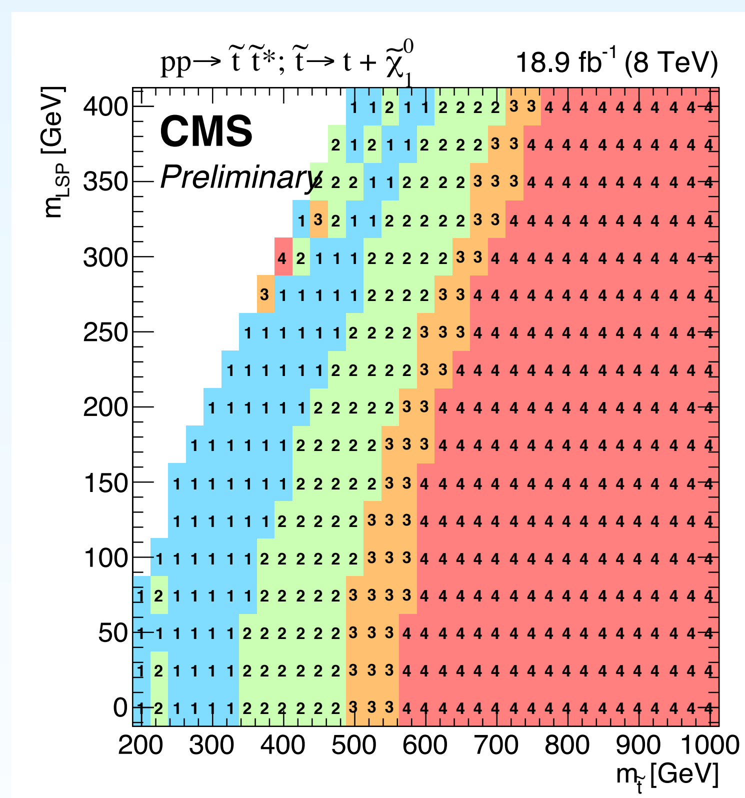
systematics uncertainties and relative sizes

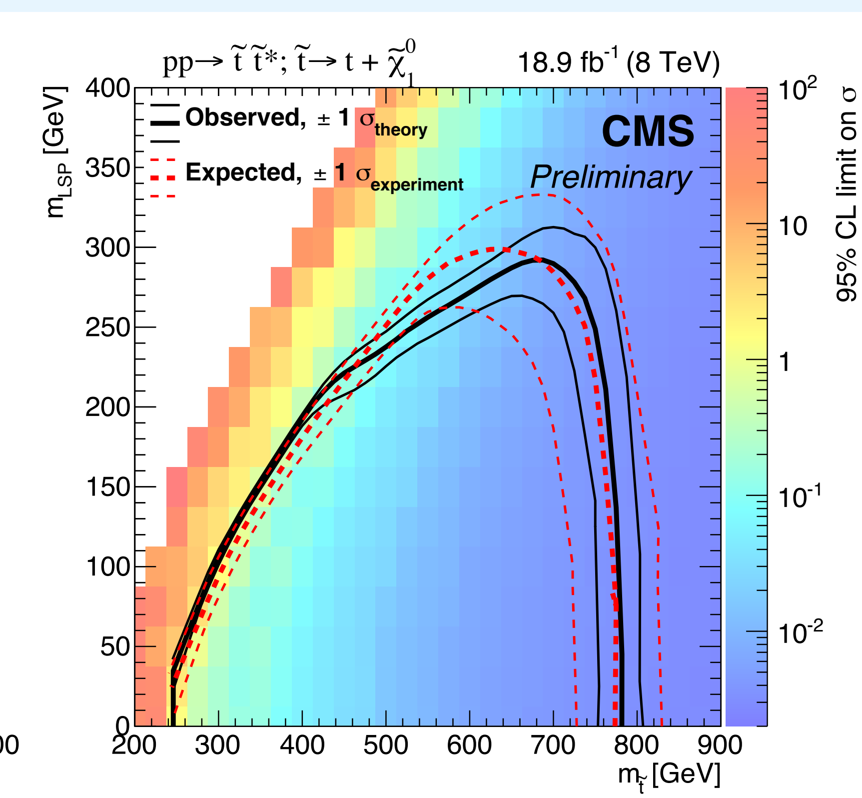
Systematics source	Magnitude (%)
b-tagging	5% - 10%
JES	5% - 20%
JER	< 5%
ISR	1%-20%
PDF	1%-15%
Luminosity	2.6%
CORRAL FastSim (T2tt)	1%-20%
CORRAL dependence on PS (T2tt)	5%
CORRAL reconstruction (T2tt)	5%

Search Region Name	$M(\tilde{t})$[GeV]	$M(\tilde{\chi}^0_1)$[GeV]	x	Cut	Signal efficiency
1 T2tt_LM	300	25	-	0.79	8%
2 T2tt_MM	425	75	-	0.83	16%
3 T2tt_HM	550	25	-	0.92	25%
4 T2tt_VHM	675	250	-	0.95	19%

Best limit on stop mass 775 GeV







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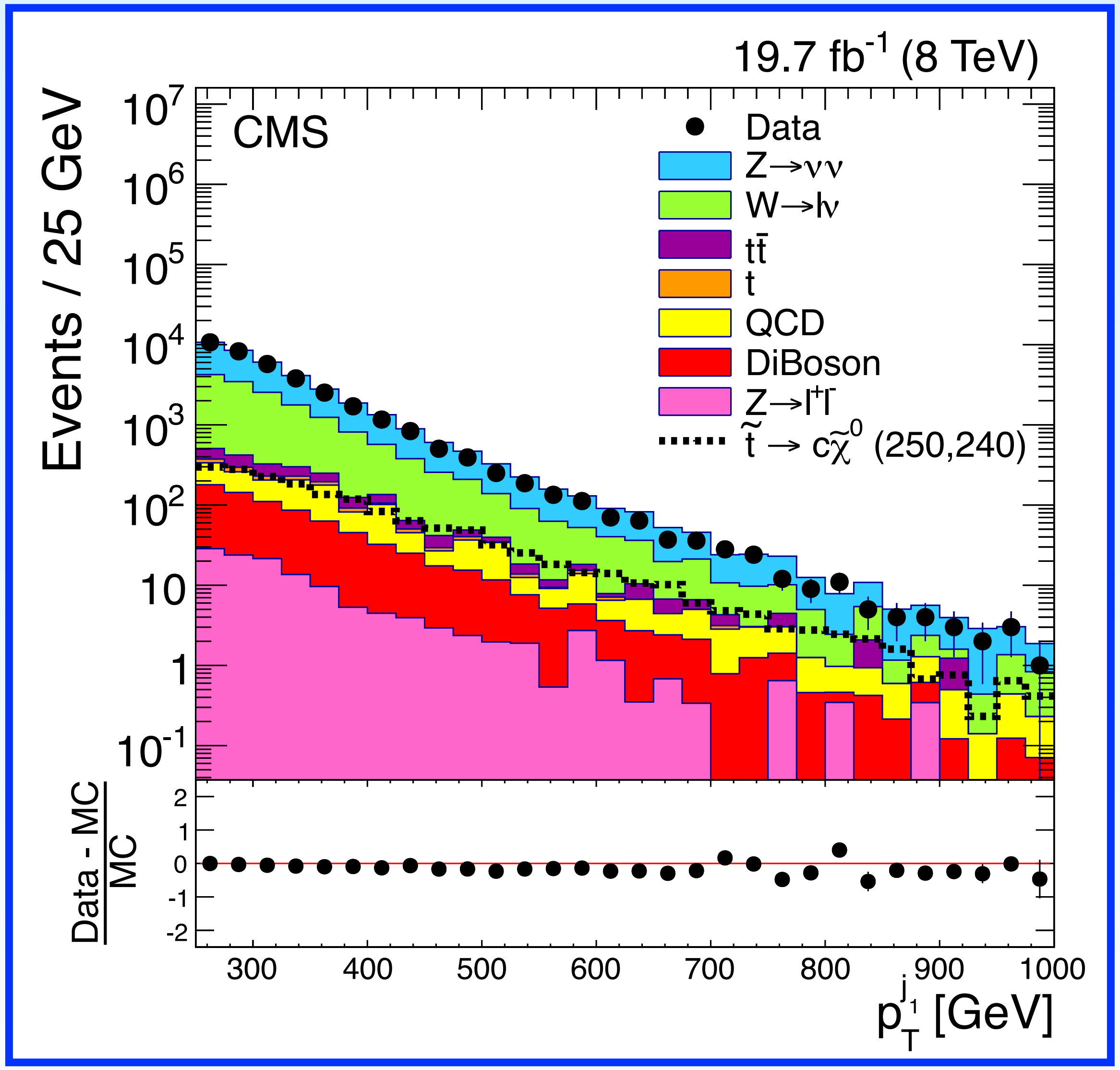
Monojet Stop to Charm LSP

- Monojet search covers compressed region, where stop to charm + LSP decay is favored

Monojet search	SM Pred.	Obs.
$p_T^{j_1} > 250$ GeV	35900±1500	36600
$p_T^{j_1} > 300$ GeV	17400±800	17600
$p_T^{j_1} > 350$ GeV	8060±440	8120
$p_T^{j_1} > 400$ GeV	3910±250	3900
$p_T^{j_1} > 450$ GeV	2100±160	1900
$p_T^{j_1} > 500$ GeV	1100±110	1000
$p_T^{j_1} > 550$ GeV	563±71	565



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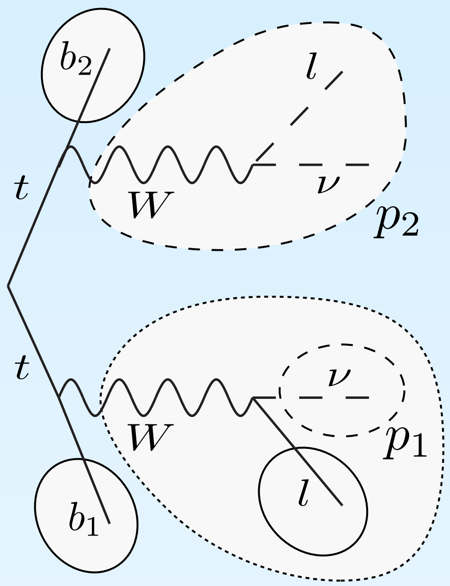
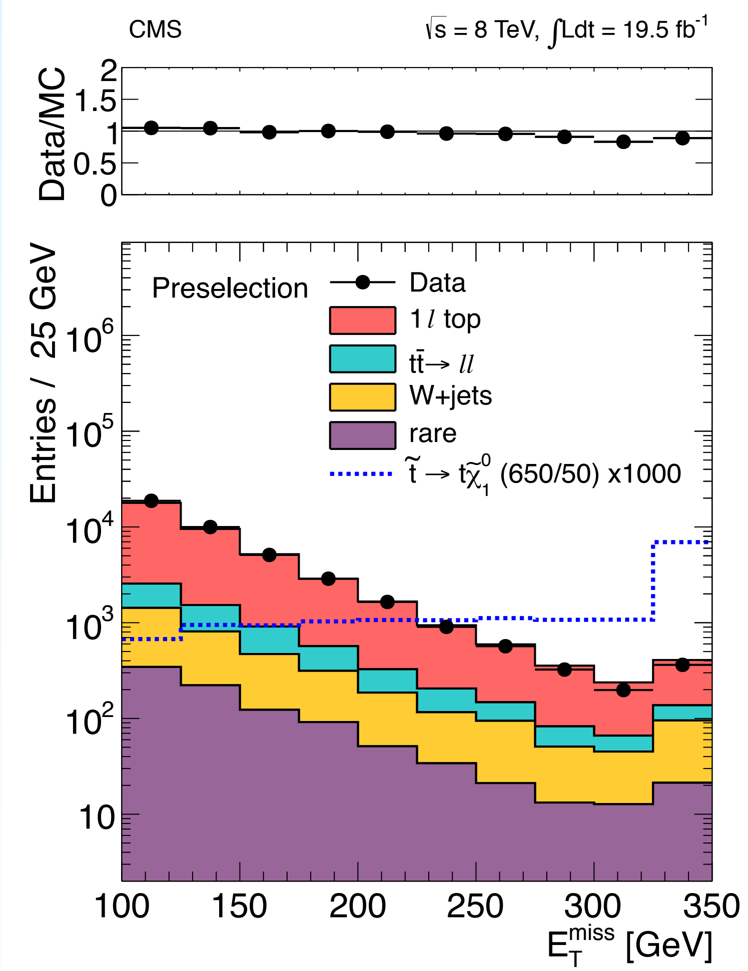
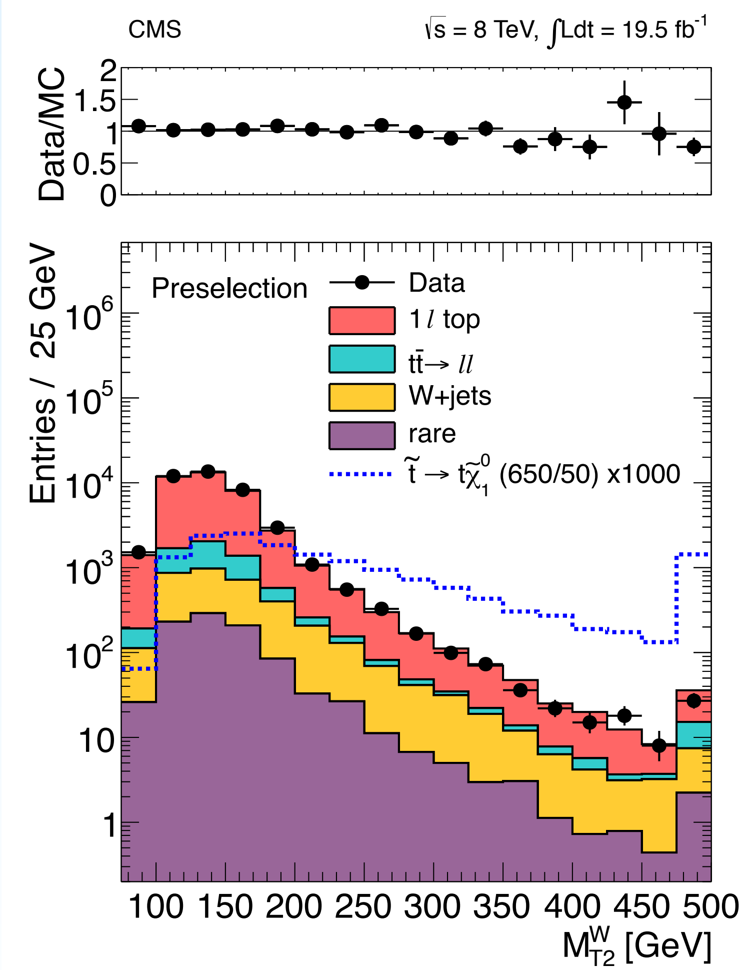
1-Lepton Methodology



- Define a multivariate boosted decision tree (BDT) based on several signal sensitive observables, e.g. E_T^{miss}, M_{T2}^W
- M_{T2}^W = minimum mother particle mass consistent with observed and assumed kinematic constraints

$$M_{T2}^W = \min\left\{m_y \text{ consistent with: } \left[\begin{array}{c} \vec{p}_1^T + \vec{p}_2^T = \vec{E}_T^{\text{miss}},\ p_1^2 = 0,\ (p_1 + p_\ell)^2 = p_2^2 = M_W^2, \\ (p_1 + p_\ell + p_{b_1})^2 = (p_2 + p_{b_2})^2 = m_y^2 \end{array}\right]\right\}$$





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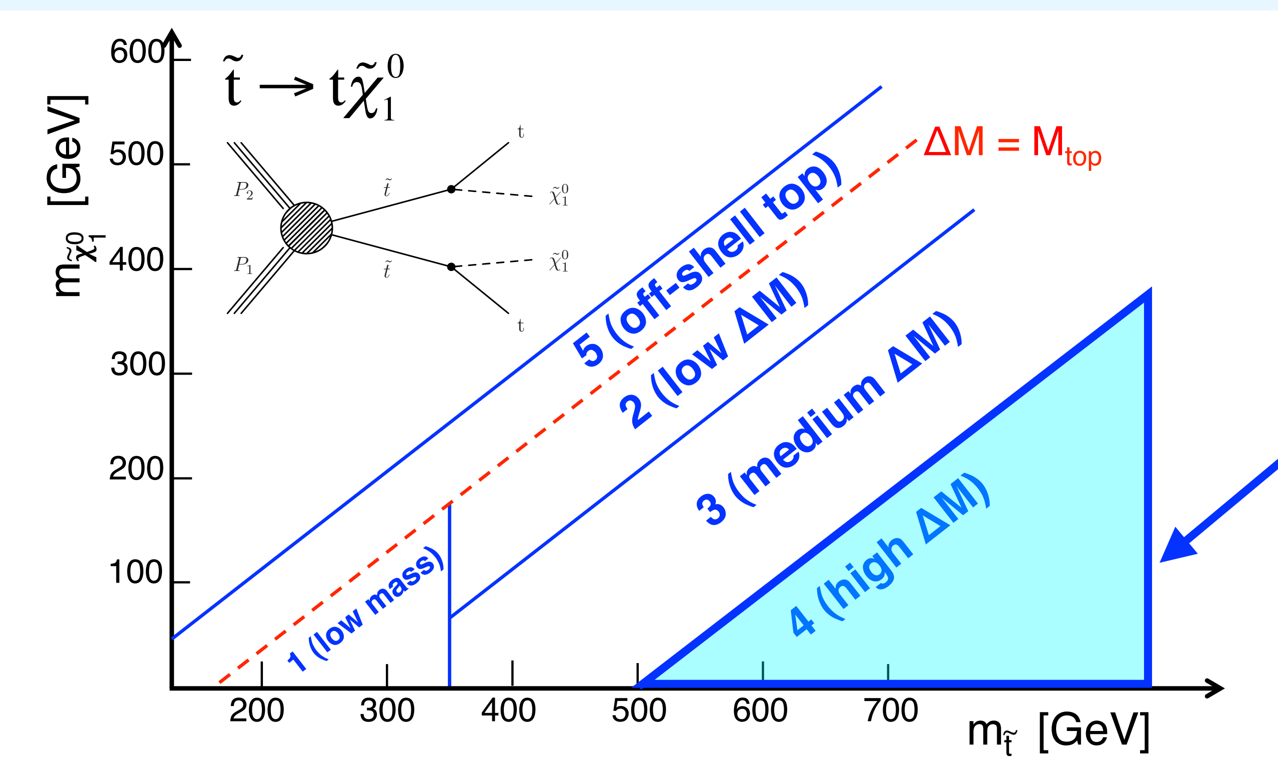
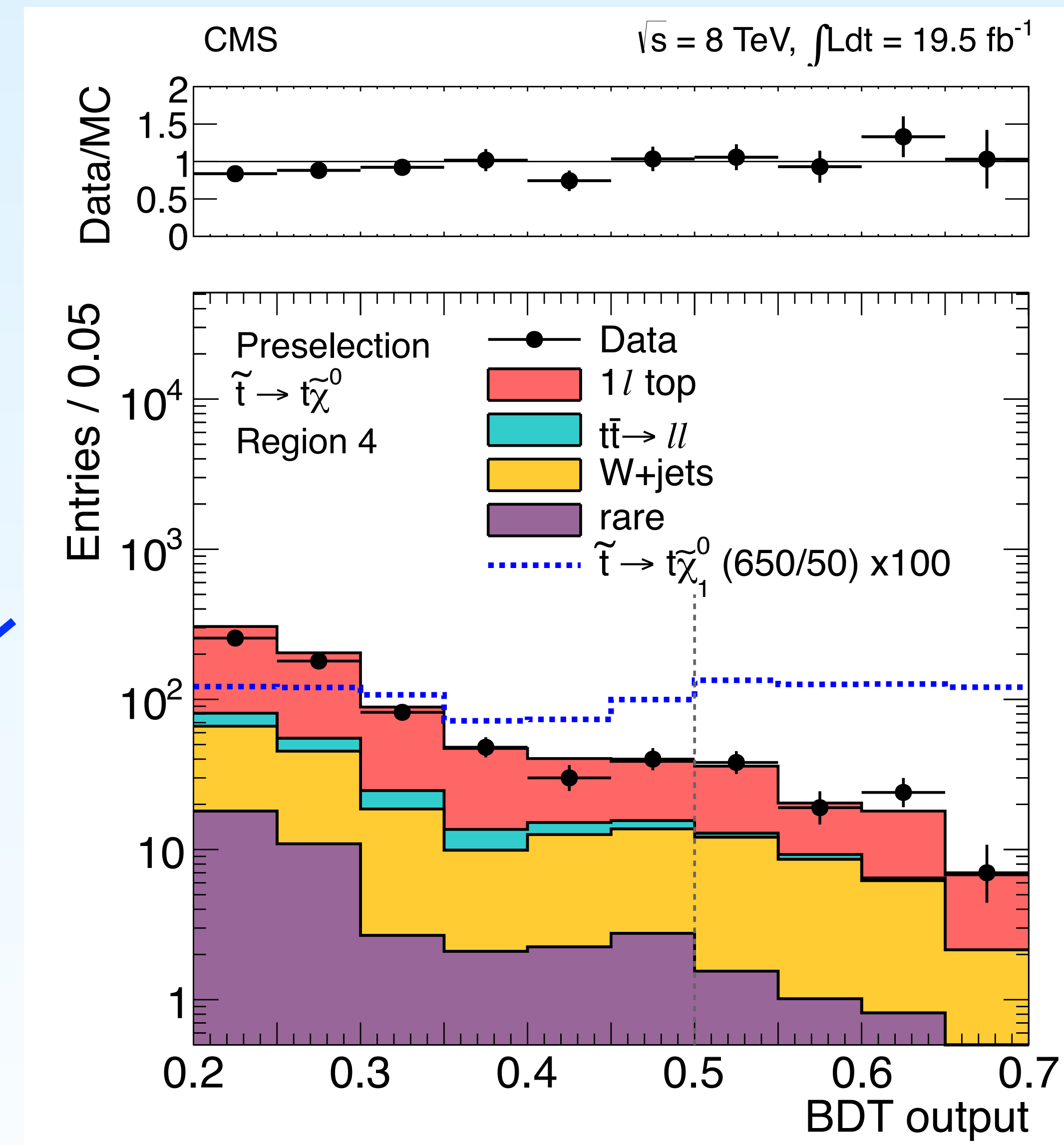
1-Lepton BDT

- Separate BDTs optimized for different several regions of parameter space within four models

	$\tilde{t} \to t\tilde{\chi}_1^0$		
		cut-based	
Selection	BDT	Low ΔM	High ΔM
E_T^{miss}(GeV)	yes	$> 150, 200, 250, 300$	$> 150, 200, 250, 300$
M_{T2}^{W} (GeV)	yes		> 200
min $\Delta\phi$	yes	> 0.8	> 0.8
H_T^{ratio}	yes		
hadronic top χ^2	(on-shell top)	< 5	< 5
leading b-jet p_T (GeV)	(off-shell top)		





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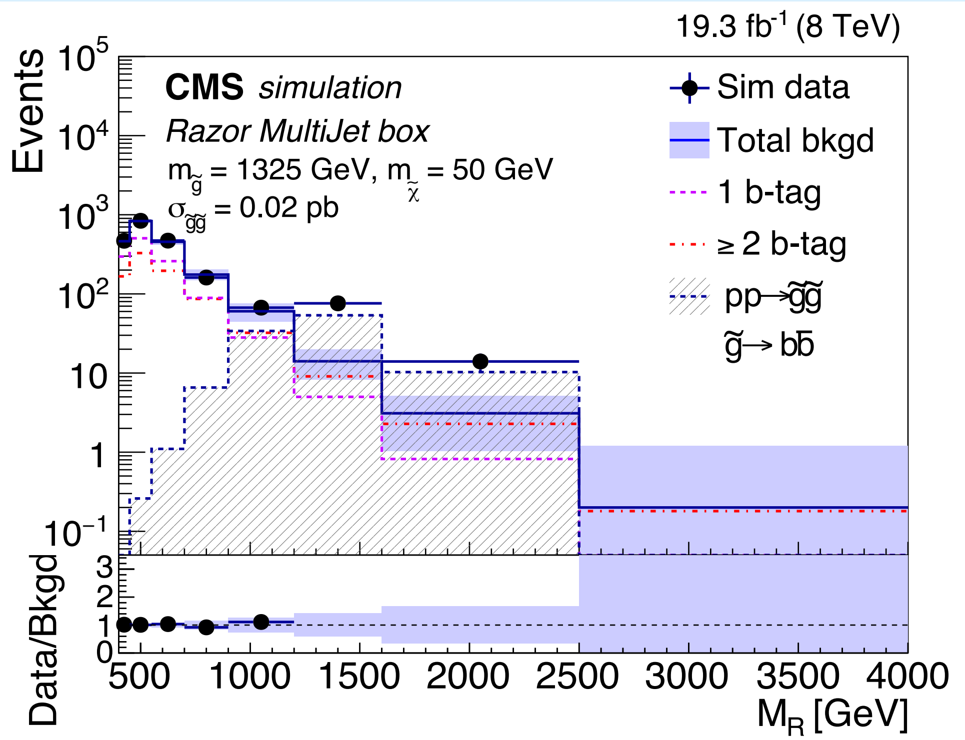
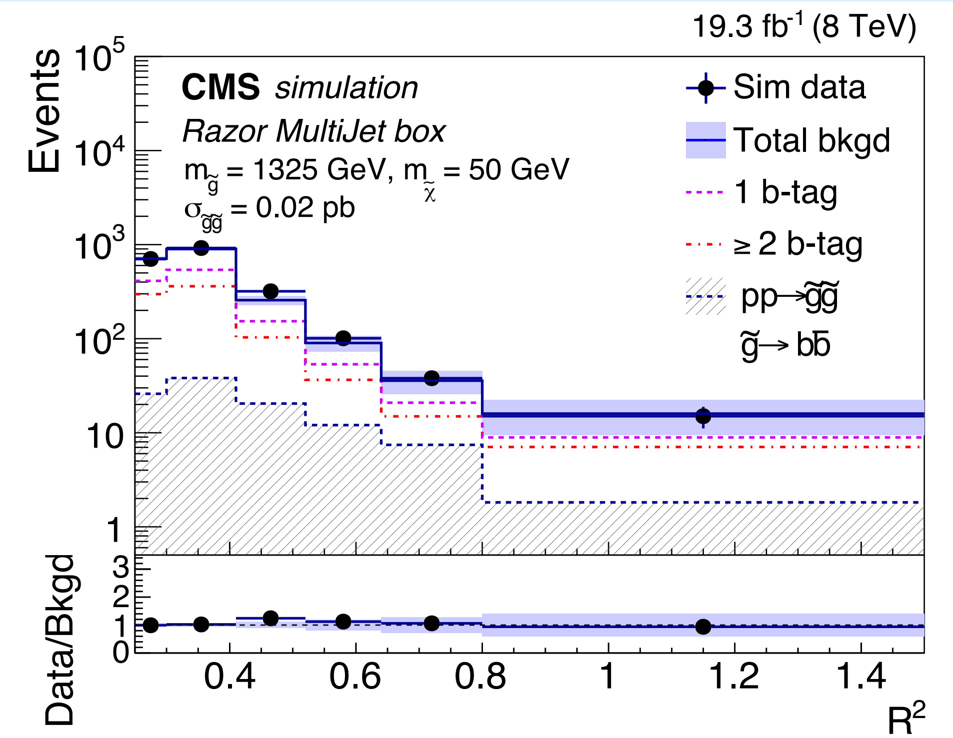
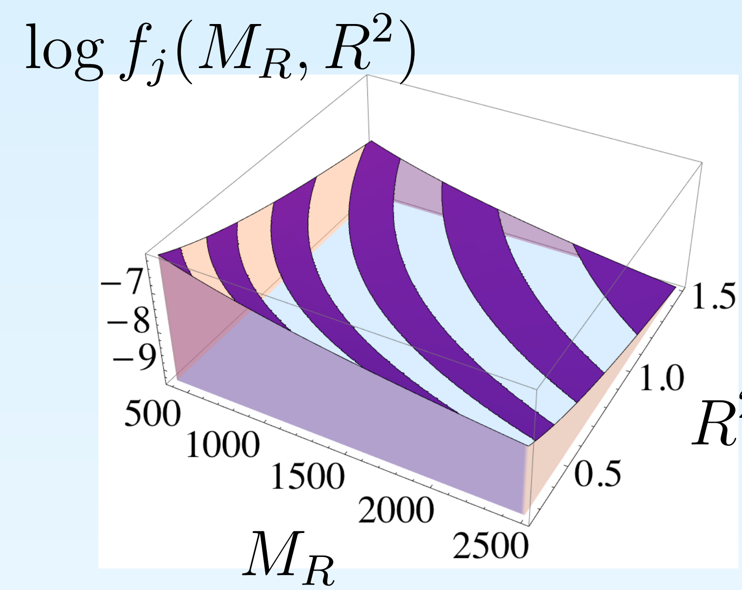
SUS-13-004
PRD 91, 052018 (2015)

Razor Signal Injection

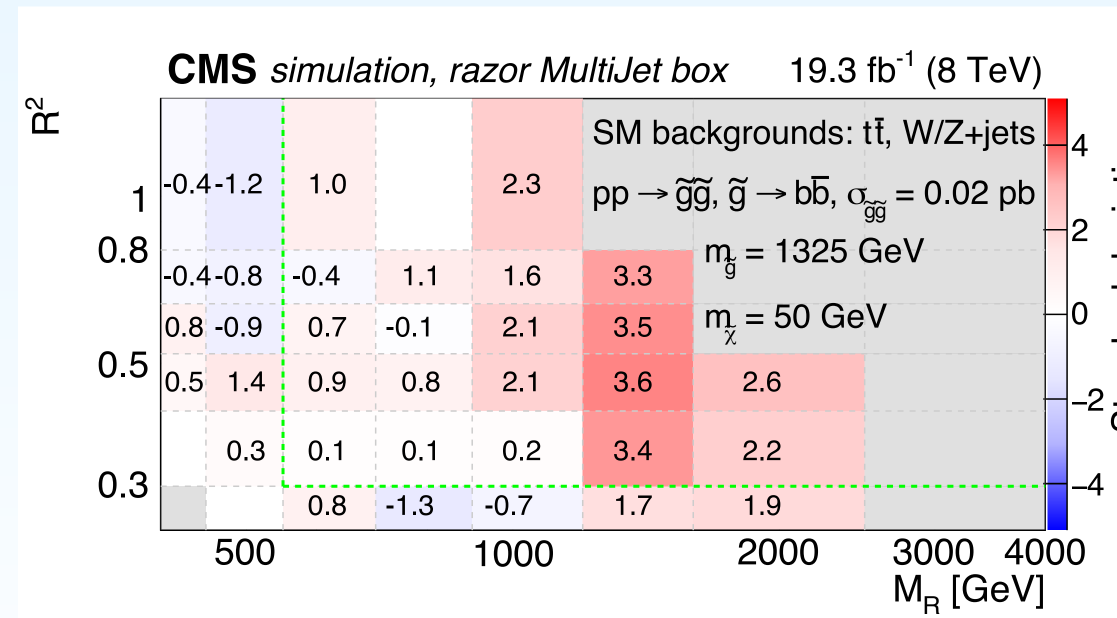
$$f_{\mathrm{Razor}}(x,y) \propto (b[(x-x_0)(y-y_0)]^{1/n}-1)\,\mathrm{Exp}\{-bn[(x-x_0)(y-y_0)]^{1/n}\}$$







- Injected signal $\tilde{g}\tilde{g} \rightarrow b\bar{b}b\bar{b}\tilde{\chi}^0\tilde{\chi}^0$ distorts shape, so signal emerges



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