

# Probing top-philic sgluons with LHC Run I data

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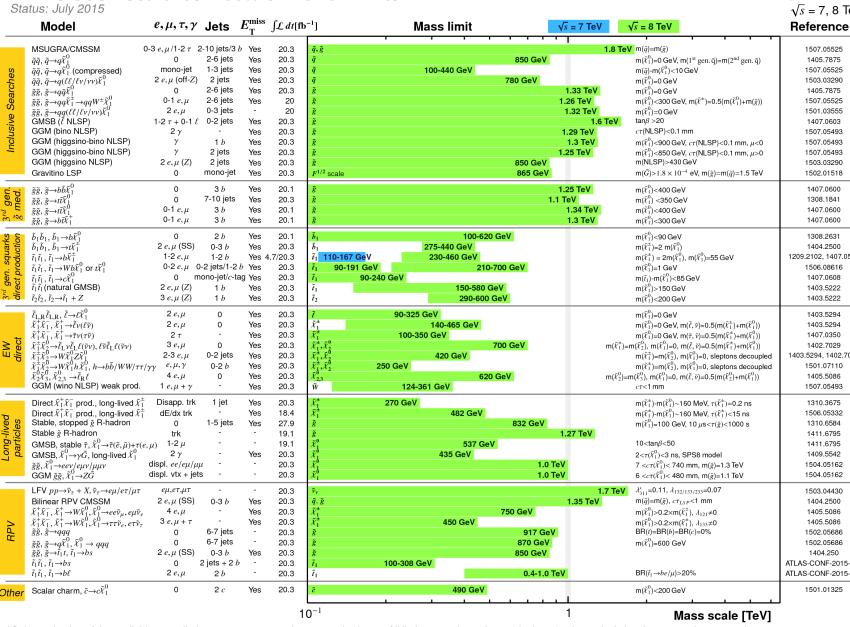


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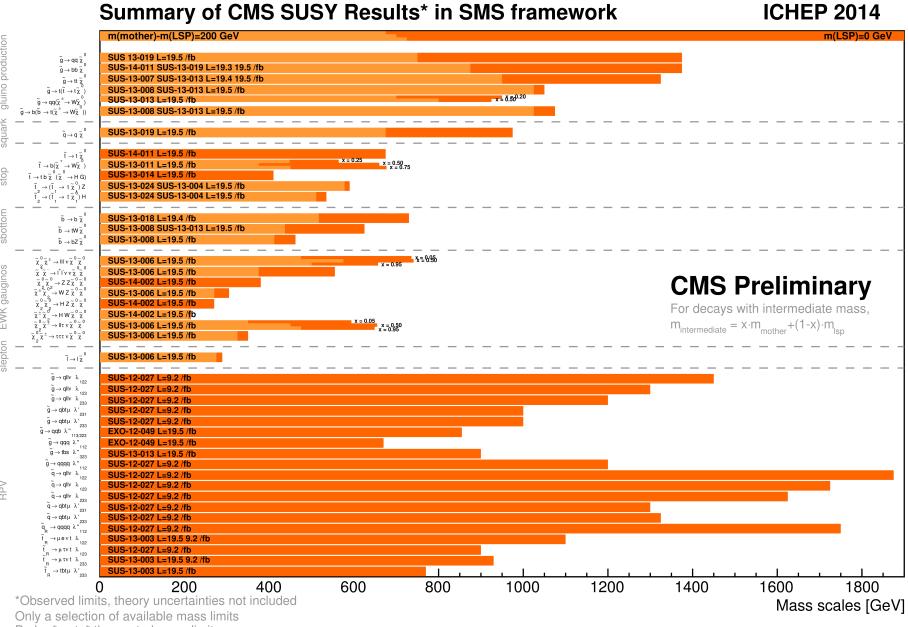
# Preamble - SUSY

LHC Run I searches focused mainly on MSSM signatures.

## ATLAS SUSY Searches\* - 95% CL Lower Limits

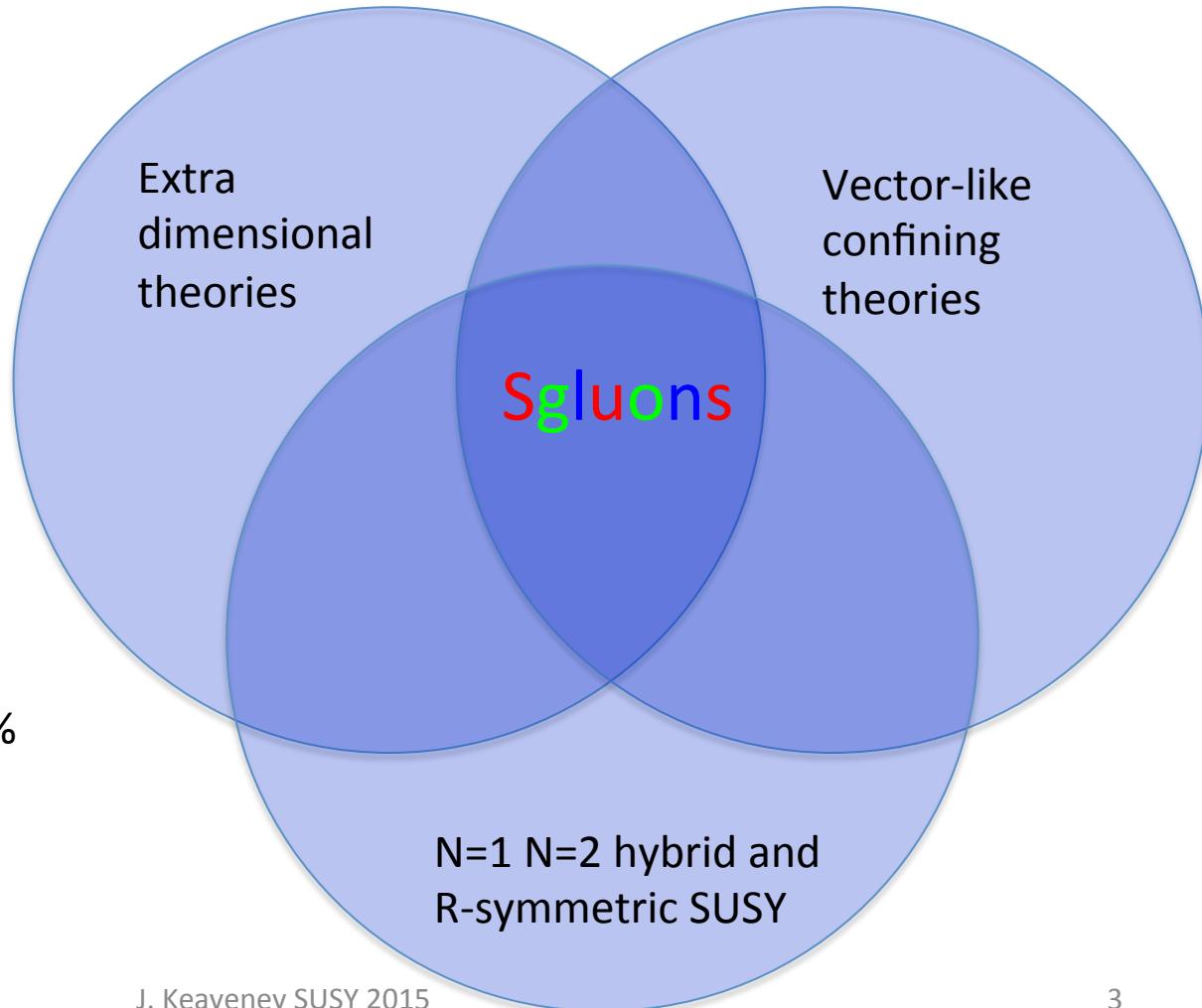


\*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1- $\sigma$  theoretical signal cross section uncertainty.



# The sgluon

- a Coloured, massive, scalar particle appearing in numerous BSM theories including N=1, N=2 hybrid and R-symmetric SUSY



Limits on sgluon:

mass > 300 GeV for  $\text{BR}(\text{qq}) = 100\%$

mass > 800 GeV for  $\text{BR}(\text{tt}) = 100\%$

**ATLAS-CONF-2013-051,**

**Eur.Phys.J. C73 (2013) 2263**

# Simplified Model for sgluons @LHC

## - production?

Coupling of sgluon pair to gluons given by QCD covariant derivative

$$\mathcal{L} = \frac{1}{2} D_\mu S^a D^\mu S_a - \frac{1}{2} m_S^2 S^a S_a \quad D_\mu S^a = \partial_\mu S^a + g_s f_{bc}{}^a G_\mu^b S^c$$

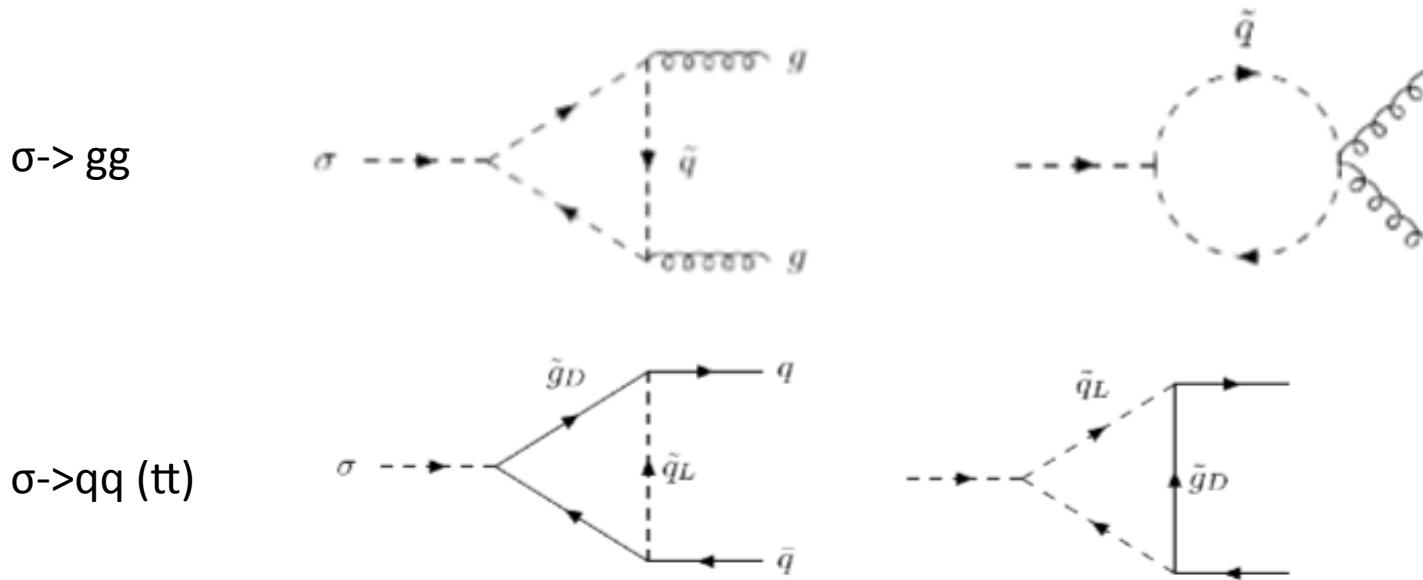


sgluons largely produced in pairs at LHC

# Simplified Model for sgluons @ LHC

- decays?

s gluon decay to gluon or quark pairs via one-loop squark diagrams



In our simplified model the loops are replaced with effective couplings  $a_g$  and  $a_t$  proportional to squark masses

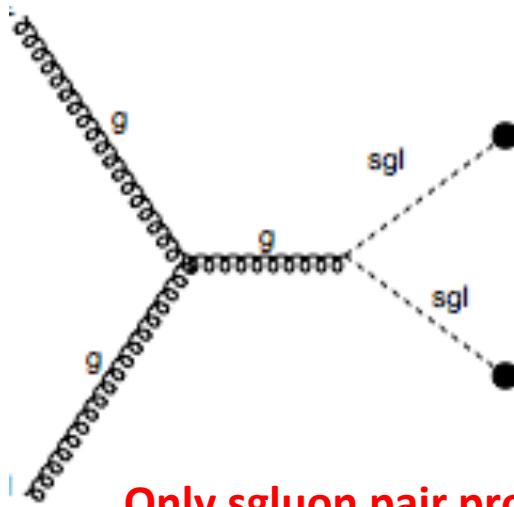
# Simplified Model for sgluons @ LHC

Model has three parameters only:  $m_s$ : mass of the sgluon

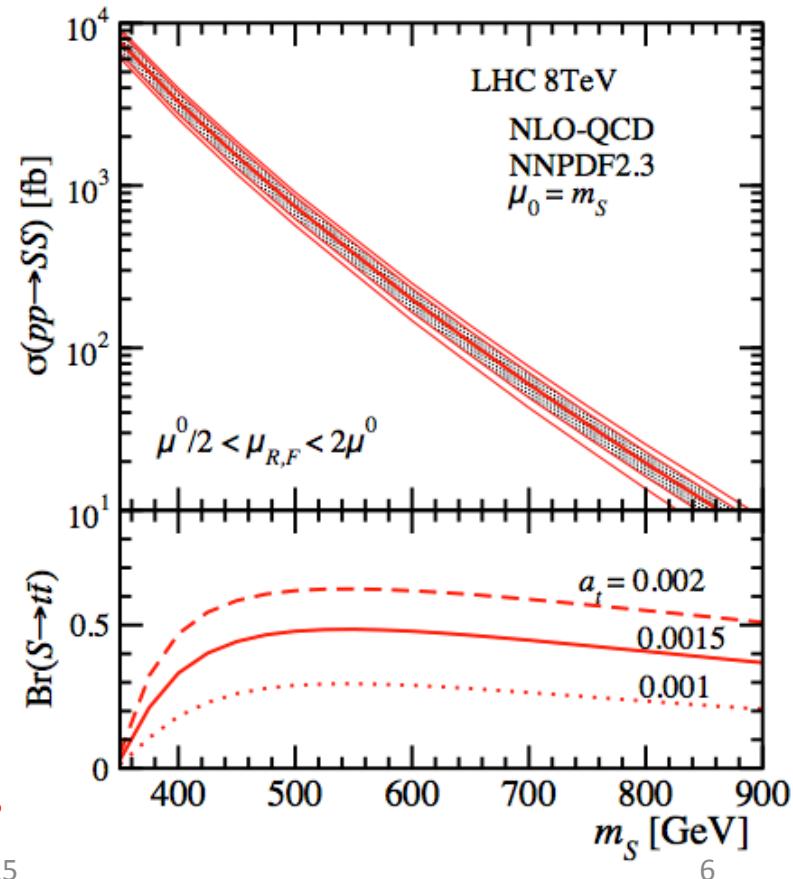
$a_t$ : effective coupling of sgluons to tops

$a_g$ : effective coupling of sgluons to gluons

- Model implemented in MG5\_aMC@NLO at LO
- k factors to give NLO cross sections



Only sgluon pair production considered here.

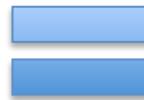


# Four top quark events via sgluons

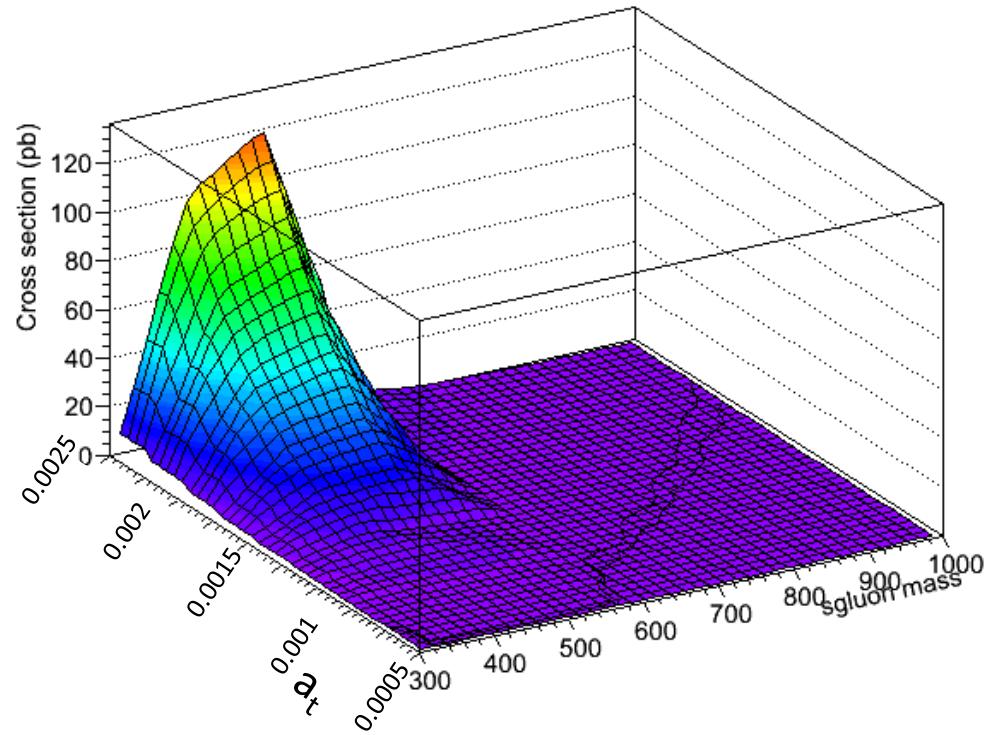
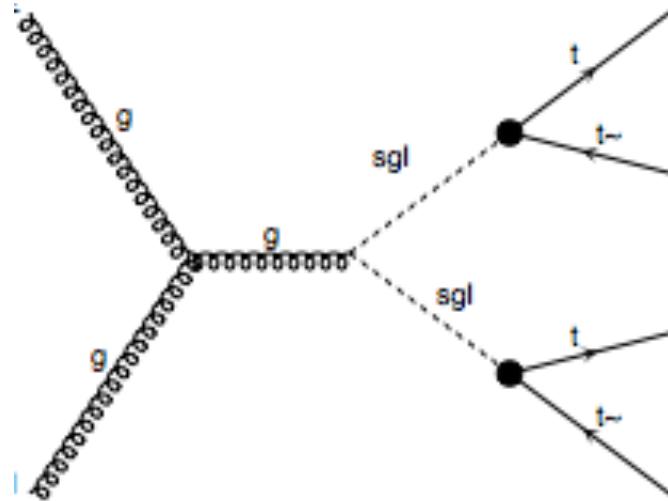
Sgluon pair production



*topophilic scenario ->*  
large  $a_t$   
large branching ratio to tops



Four top events



$\text{Br}(\sigma\sigma \rightarrow tt)$  strongly depends on  $a_t$ ,  $a_g$  and on the mass of the sgluon

# What do we know about four top events from LHC Run I?



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## Search for new physics in events with same-sign dileptons and jets in pp collisions at $\sqrt{s} = 8$ TeV



The CMS collaboration

E-mail: [cms-publication-committee-chair@cern.ch](mailto:cms-publication-committee-chair@cern.ch)

**ABSTRACT:** A search for new physics is performed based on events with jets and a pair of isolated, same-sign leptons. The results are obtained using a sample of proton-proton collision data collected by the CMS experiment at a centre-of-mass energy of 8 TeV at the LHC, corresponding to an integrated luminosity of  $19.5 \text{ fb}^{-1}$ . In order to be sensitive to a wide variety of possible signals beyond the standard model, multiple search regions defined by the missing transverse energy, the hadronic energy, the number of jets and b-quark jets, and the transverse momenta of the leptons in the events are considered. No excess above the standard model background expectation is observed and constraints are set on a number of models for new physics, as well as on the same-sign top-quark pair and quadruple-top-quark production cross sections. Information on event selection efficiencies is also provided, so that the results can be used to confront an even broader class of new physics models.

**KEYWORDS:** Supersymmetry, Hadron-Hadron Scattering

ArXiv ePRINT: [1311.6736](https://arxiv.org/abs/1311.6736)

JHEP01(2014)163



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PUBLISHED: November 27, 2014

## Search for standard model production of four top quarks in the lepton + jets channel in pp collisions at $\sqrt{s} = 8$ TeV



The CMS collaboration

E-mail: [cms-publication-committee-chair@cern.ch](mailto:cms-publication-committee-chair@cern.ch)

**ABSTRACT:** A search is presented for standard model (SM) production of four top quarks ( $t\bar{t}t\bar{t}$ ) in pp collisions in the lepton + jets channel. The data correspond to an integrated luminosity of  $19.6 \text{ fb}^{-1}$  recorded at a centre-of-mass energy of 8 TeV with the CMS detector at the CERN LHC. The expected cross section for SM  $t\bar{t}t\bar{t}$  production is  $\sigma_{\text{SM}}^{\text{tttt}} \approx 1 \text{ fb}$ . A combination of kinematic reconstruction and multivariate techniques is used to distinguish between the small signal and large background. The data are consistent with expectations of the SM, and an upper limit of  $32 \text{ fb}$  is set at a 95% confidence level on the cross section for producing four top quarks in the SM, where a limit of  $32 \pm 17 \text{ fb}$  is expected.

**KEYWORDS:** Hadron-Hadron Scattering, Top physics

ArXiv ePRINT: [1409.7339](https://arxiv.org/abs/1409.7339)

JHEP11(2014)154

## Same-sign dilepton search

- Counting experiment for  $t\bar{t}t\bar{t}$ -like signatures
- Upper limit on SM  $t\bar{t}t\bar{t}$  of 49 fb.

## Single lepton search

- Complex analysis based on BDTs
- Kinematics of the SM  $t\bar{t}t\bar{t}$  process assumed.
- Upper limit on SM  $t\bar{t}t\bar{t}$  of 32 fb

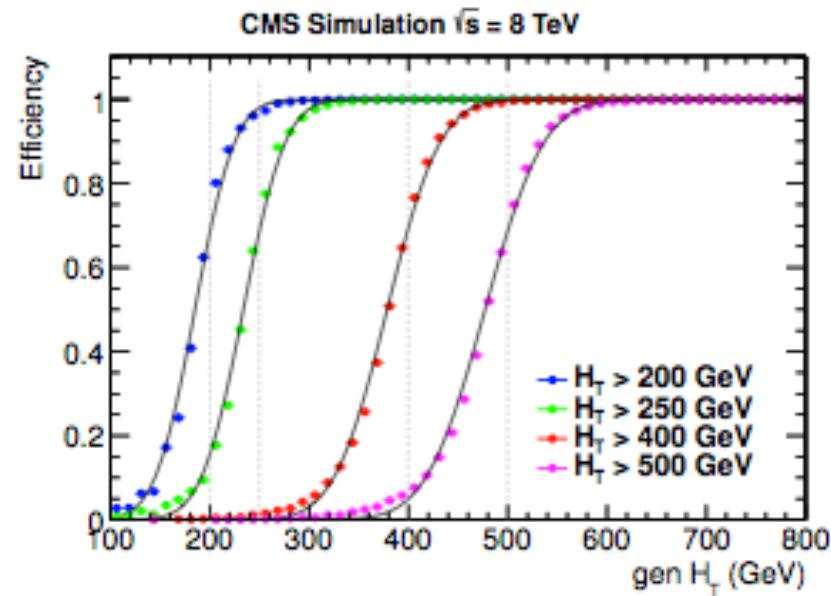
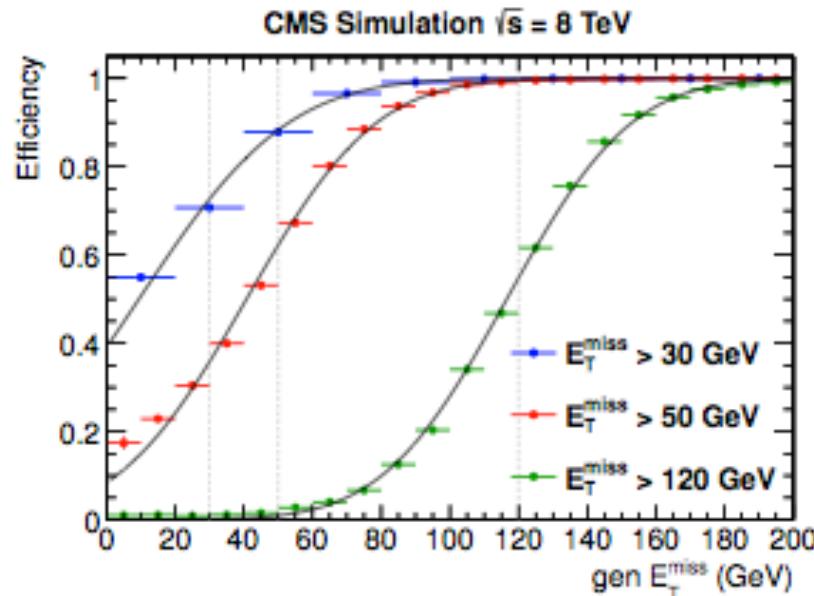
**Competitive results from ATLAS on SM  $t\bar{t}t\bar{t}$  arXiv:1504.04605**

# Same-sign dilepton search

Counting experiments in **Search Regions** corresponding to various MSSM signatures:

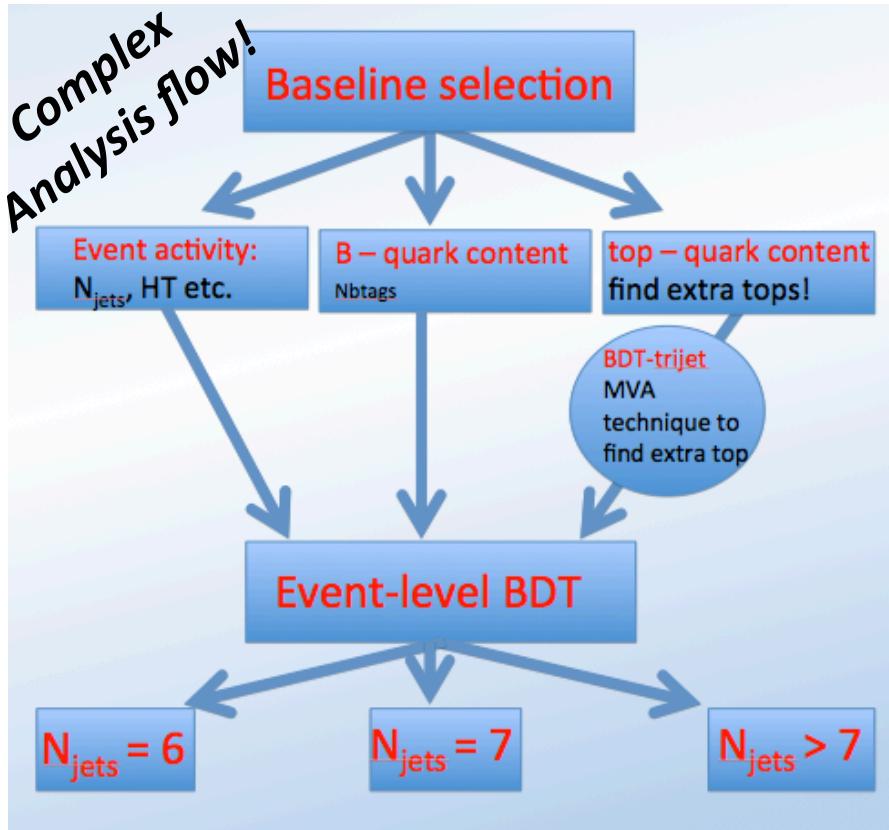
- > Requirements on Jets, B-tags, MET, HT
- > Some Search Regions correspond closely to a tttt signature

Model of the selection efficiencies allows emulation of the analysis



1. Pass sgluon events through efficiency model to predict  $N_{\text{expected}}$  in Search Region
2. Exclude parameter space points where  $N_{\text{expected}}$  exceeds upper limit on  $N_{\text{Signal}}$

# single lepton search



Intuitively expect the limit of 32 fb on SM ttt to exclude some sgluon parameter space...



However...

- Analysis complexity prevents a standard reinterpretation



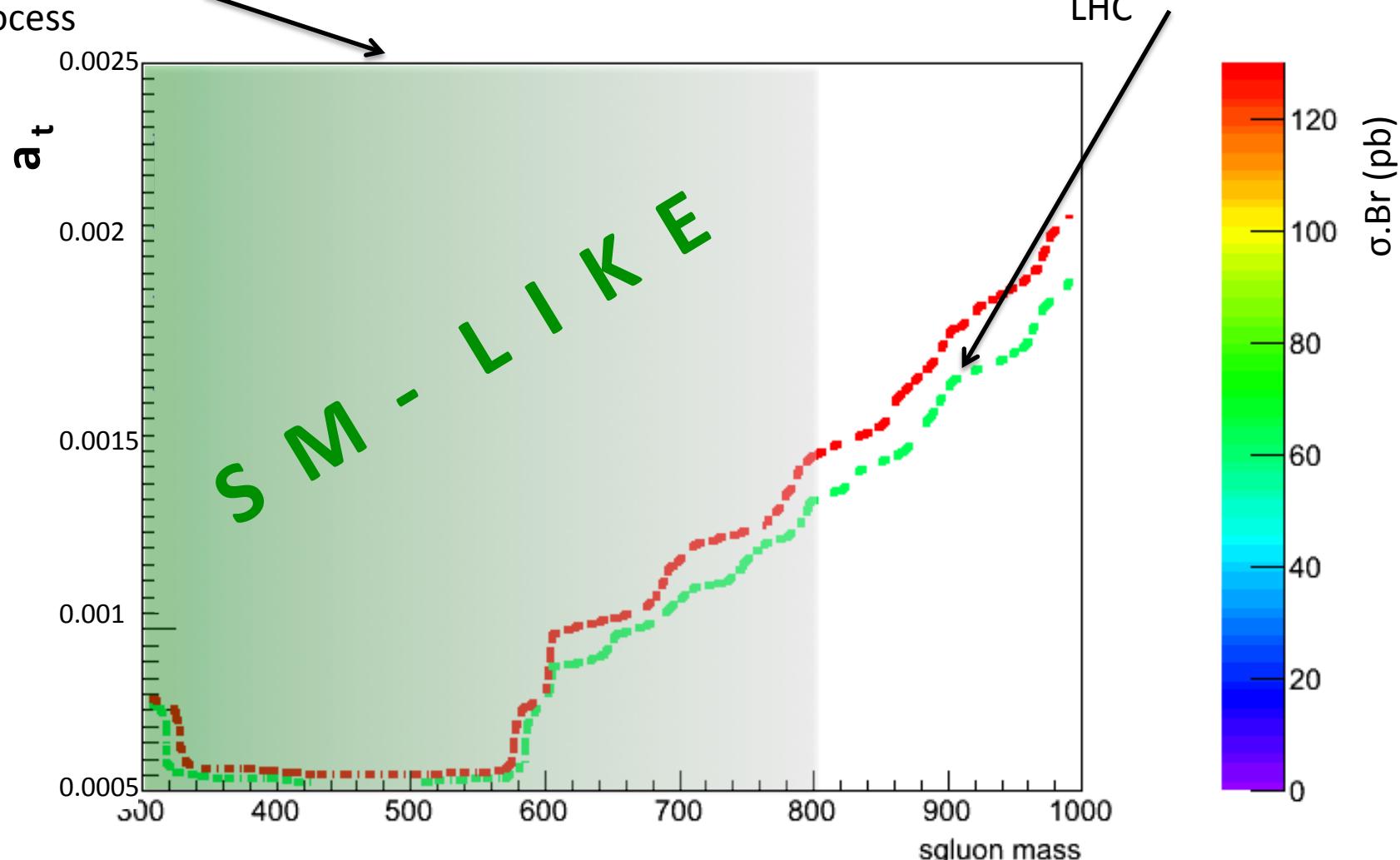
**Novel approach needed!**



# Novel approach

Estimate region of parameter space in which the event kinematics are very similar to the SM tttt process

Draw contour corresponding to the SM tttt limits from LHC



# How can we determine the SM-like region?

Matrix Element methods can determine precisely the region of BSM parameter space in which the tttt kinematics are *SM-like*.

# In what region do the SM tttt limits apply?

Matrix Element methods can determine precisely the region of BSM parameter space in which the tttt kinematics are *SM-like*.

## ME Calculator

1. Smears parton-level events to account for detector resolutions
2. Calculates the  $ME^2$  of a parton-level event under the SM tttt hypothesis

# In what region do the SM tttt limits apply?

Matrix Element methods can determine precisely the region of BSM parameter space in which the tttt kinematics are *SM-like*.

Feed routine with parton-level sgluon events -> scan parameter space!

## ME Calculator

1. Smears parton-level events to account for detector resolutions
2. Calculates the  $ME^2$  of a parton-level event under the SM tttt hypothesis

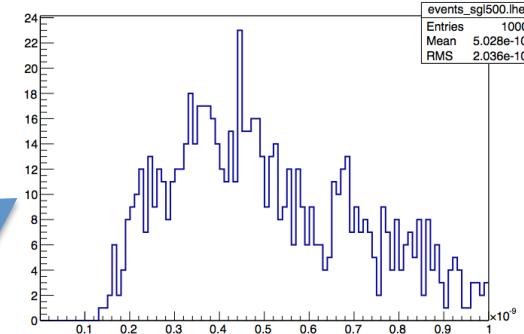
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s gluon->tttt  
events  
 $M_{sgl} = 500 \text{ GeV}$

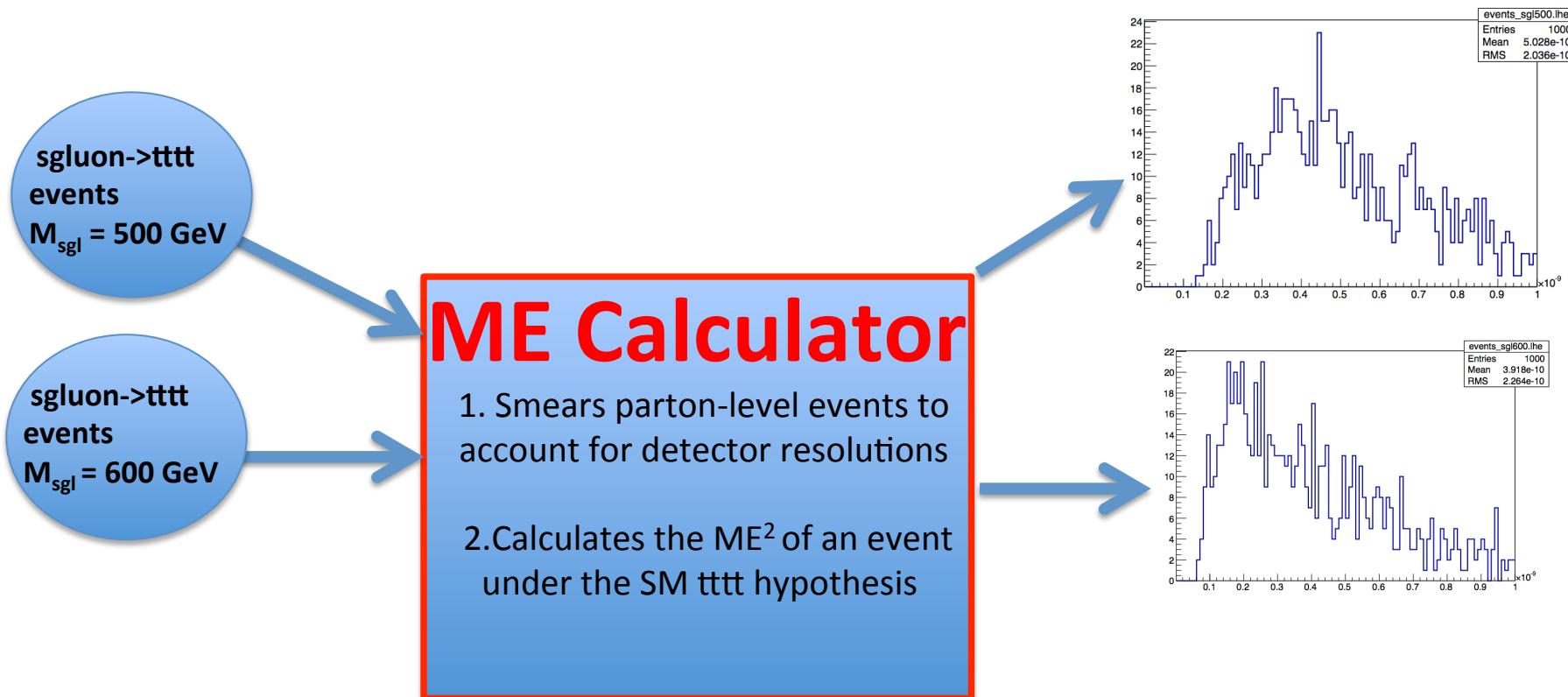
## ME Calculator

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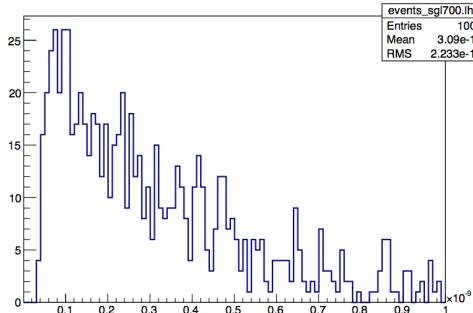
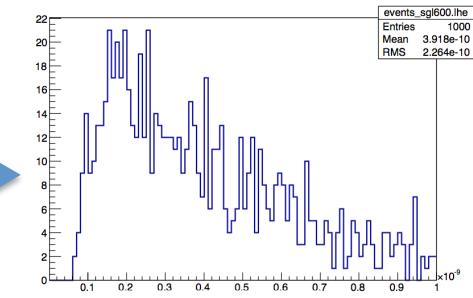
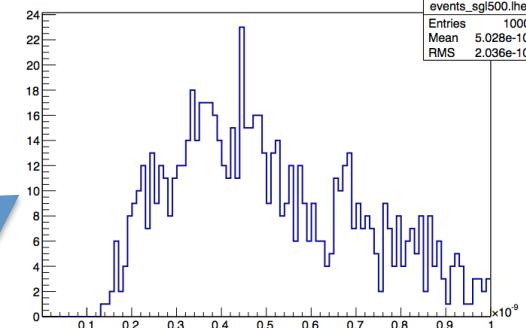
s gluon- $\rightarrow$ tttt  
events  
 $M_{sgl} = 600 \text{ GeV}$

s gluon- $\rightarrow$ tttt  
events  
 $M_{sgl} = 700 \text{ GeV}$

## ME Calculator

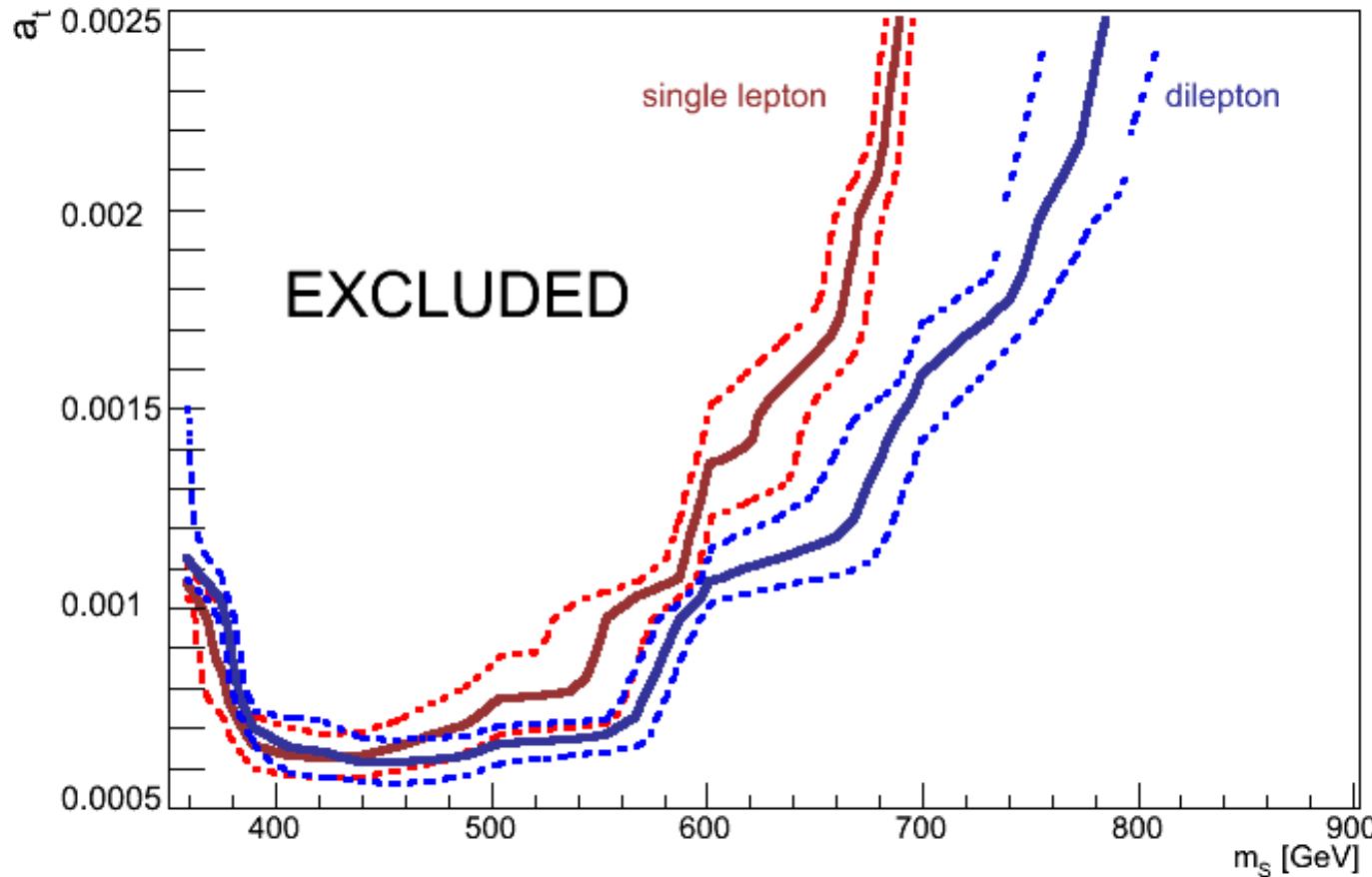
1. Smears parton-level events to account for detector resolutions
2. Calculates the  $ME^2$  of an event under the SM tttt hypothesis

**SS  $\rightarrow$  tttt indistinguishable from SM tttt for  $M_S < 1 \text{ TeV}$**   
**Limits can be safely applied in this region.**



# Combining exclusions

Superimposing the exclusion regions from each search.



First exclusions as a function of couplings:  $M_{\text{sgluon}} < \sim 800$  GeV excluded for large couplings

# Summary

Reinterpretation of two LHC run I results to place constraints on the sgluon – a key signature of non-minimal SUSY realisations

Simplified model for sgluon pair production with coupling to top quarks

Exclusions obtained by complementary methods:

- Emulation of Cut & Count with Efficiency Model
- Novel Matrix Element to compare SM and Sgluon tttt events to determine parameter space where the SM tttt limit can be applied

Constraints:

- exclusions as a function of sgluon coupling to tops derived for the first time.
- sgluons of mass  $< 700$  GeV excluded for topophilic scenario

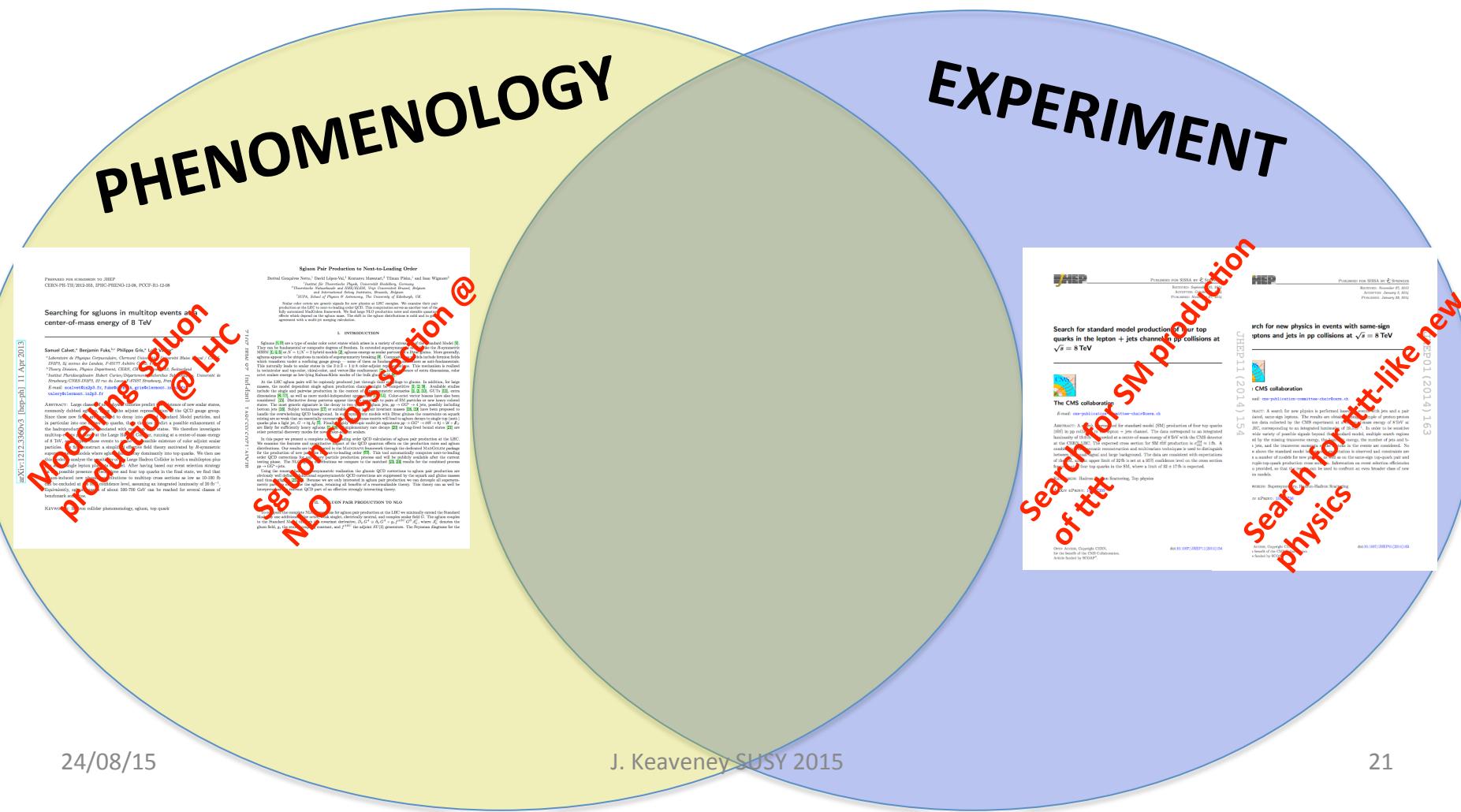
Outlook:

- Some BSM signatures have similar kinematics to already excluded signatures process -> allows constraints!

# BACKUP

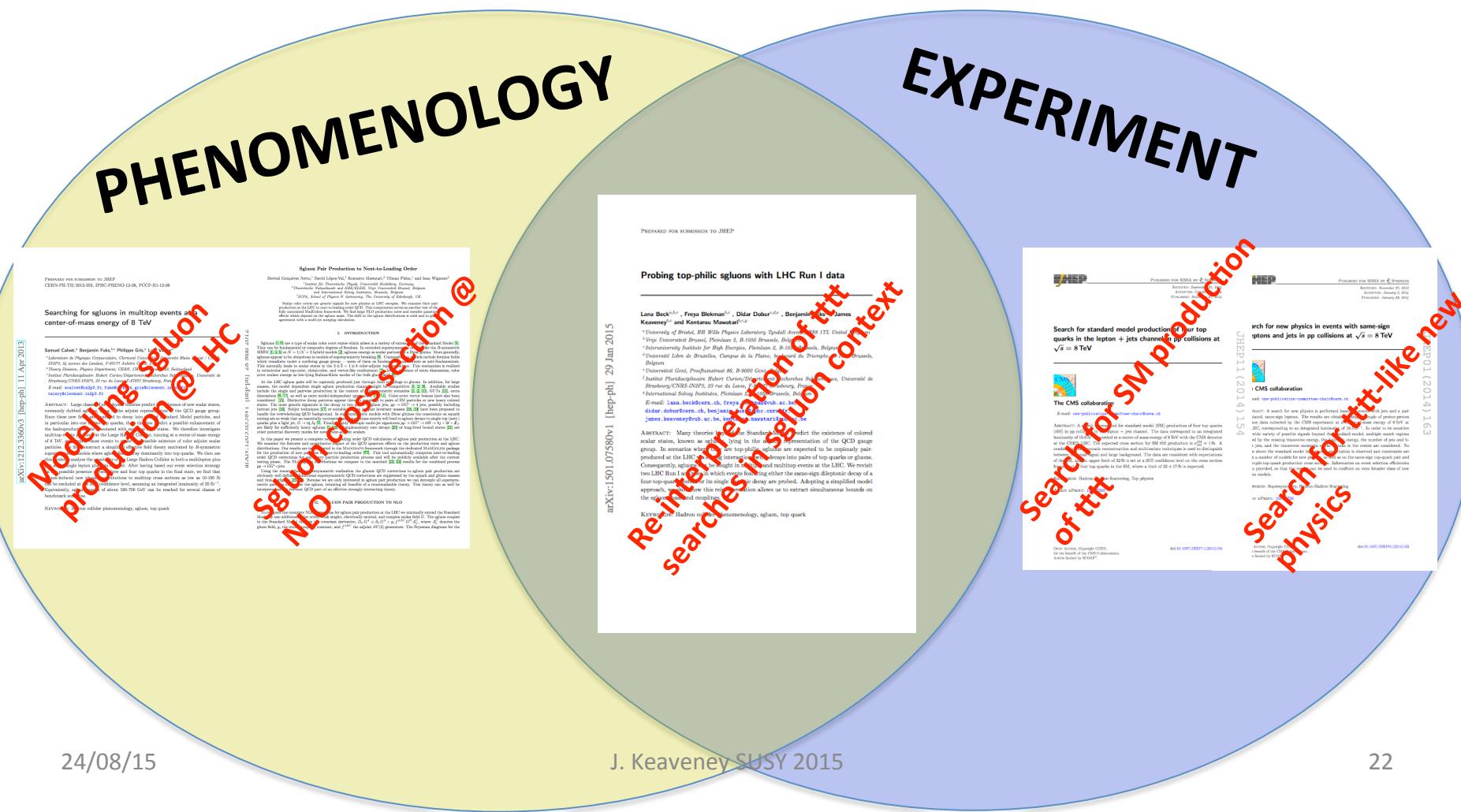
# The overall concept

- Investigate the overlap between experiment and phenomenology to probe BSM models



# The overall concept

- Investigate the overlap between experiment and phenomenology to probe BSM models



# What figure of merit to define SM-likeness?

\*Perhaps\* a better variable to investigate would be :

ME<sup>2</sup> in SM hypothesis

ME<sup>2</sup> in sgluon hypothesis

as now events are weighted by their probability in the sgluon hypothesis  
i.e. events which are not likely in the sgluon hypothesis are de-weighted  
when determining the SM-likeness

**BUT** (ME<sup>2</sup> in sgluon hypothesis) value depends strongly on  $M_{\text{sgl}}$ ... we need  
to factor that out

Don't fully understand preliminary results... re-checking...

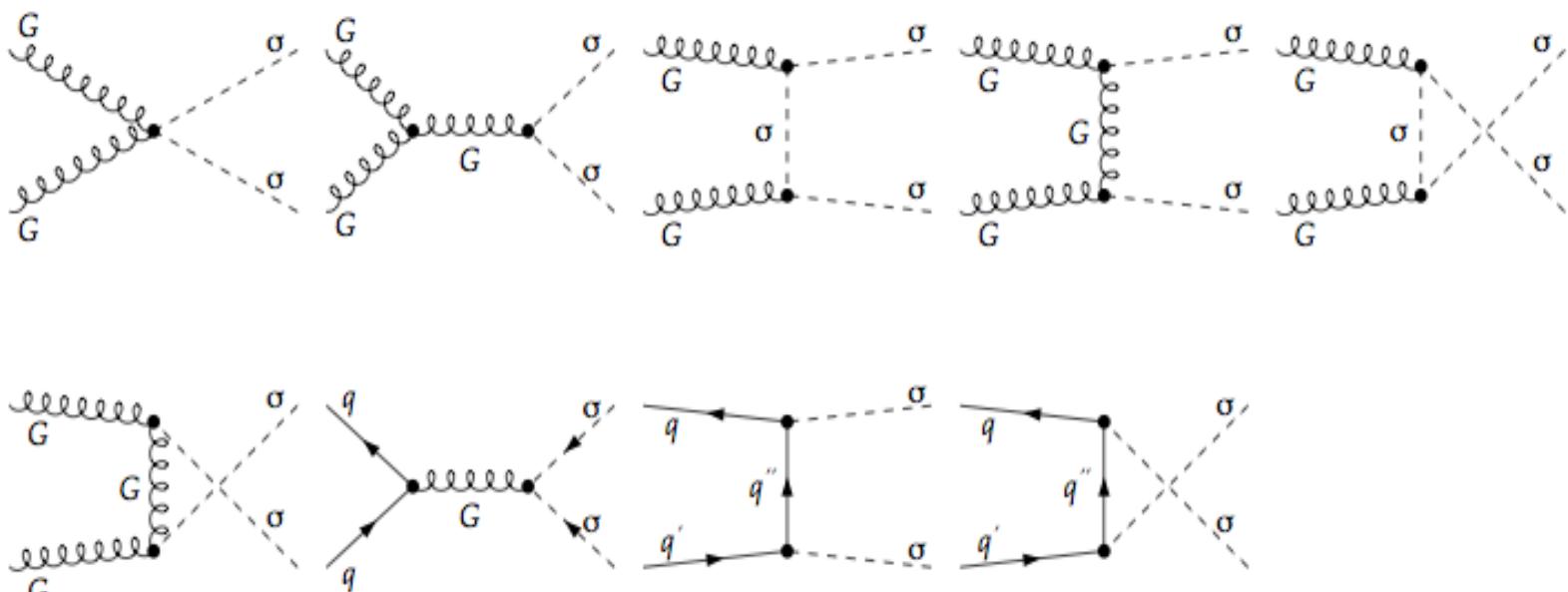
Not sure if it is really better.

# tttt via sgluons

“Searching for sgluons in multitop events at a center-of-mass energy of 8 TeV” B. Fuks et al <http://arxiv.org/abs/1212.3360>

Seeking Sgluons

<http://arxiv.org/abs/0810.3919>



# SUS-13-013

Counting experiments in *Search Regions* corresponding to various MSSM signatures:

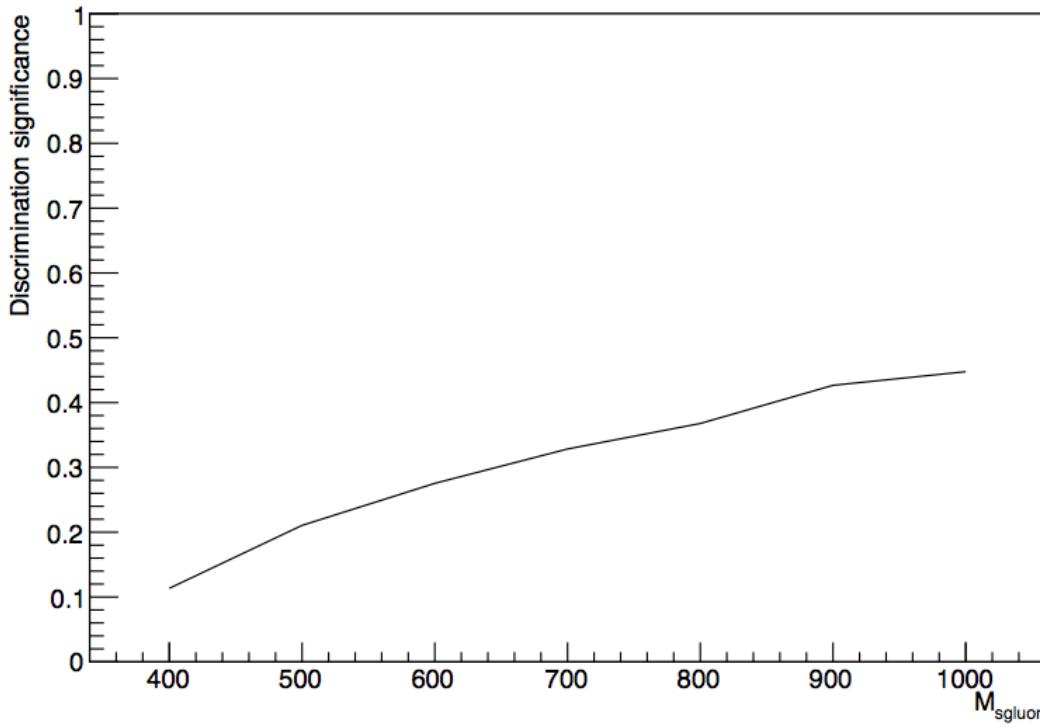
Search Region 28 can be fully emulated  
using the efficiency parameterisations  
and closely corresponds to a tttt  
signature

Region	Low- $p_T$		High- $p_T$	
	Expected	Observed	Expected	Observed
SR01	44 ± 16	50	51 ± 18	48
SR02	12 ± 4	17	9.0 ± 3.5	11
SR03	12 ± 5	13	8.0 ± 3.1	5
SR04	9.1 ± 3.4	4	5.6 ± 2.1	2
SR05	21 ± 8	22	20 ± 7	12
SR06	13 ± 5	18	9 ± 4	11
SR07	3.5 ± 1.4	2	2.4 ± 1.0	1
SR08	5.8 ± 2.1	4	3.6 ± 1.5	3
SR11	32 ± 13	40	36 ± 14	29
SR12	6.0 ± 2.2	5	3.8 ± 1.4	5
SR13	17 ± 7	15	10 ± 4	6
SR14	10 ± 4	6	5.9 ± 2.2	2
SR15	13 ± 5	9	11 ± 4	11
SR16	5.5 ± 2.0	5	3.9 ± 1.5	2
SR17	4.2 ± 1.6	3	2.8 ± 1.1	3
SR18	6.8 ± 2.5	11	4.0 ± 1.5	7
SR21	7.6 ± 2.8	10	7.1 ± 2.5	12
SR22	1.5 ± 0.7	1	1.0 ± 0.5	1
SR23	7.1 ± 2.7	6	3.8 ± 1.4	3
SR24	4.4 ± 1.7	11	2.8 ± 1.2	7
SR25	2.8 ± 1.1	1	2.9 ± 1.1	4
SR26	1.3 ± 0.6	2	0.8 ± 0.5	1
SR27	1.8 ± 0.8	0	1.2 ± 0.6	0
SR28	3.4 ± 1.3	3	2.2 ± 1.0	25

# In what region do the SM tttt limits apply?

How can we convert the ME information into a definition of the SM-like region?

$$D = \frac{\bar{P}_{\text{SM}} - \bar{P}_{\text{Sgluon}}}{\sqrt{(P_{\text{SM}}^{\text{RMS}})^2 + (P_{\text{Sgluon}}^{\text{RMS}})^2}}$$



Even for 1 TeV sgluons the  
ME2 differ by only 0.5 sigma

So we can safely apply the SM tttt limit below 1 TeV.

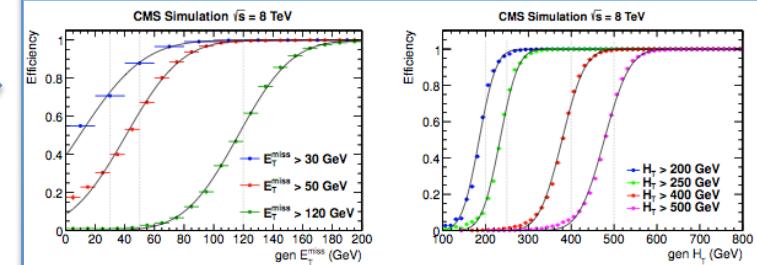
# Emulating CMS-SUS-13-013

## Sgluon Monte Carlo

- > Range of sgluon masses
- > effect of  $a_t$ ,  $a_g$  investigated with event-level weights



## Parameterised Efficiency model



Predict expected number of sgluon events in Search Region 28

Comparison to results of SUS-13-013



Constraints on sgluon model

# What do we know about the sgluon?

- a **coloured**, massive, scalar particle

