Dissecting Jets Plus MET

Using n-body Extended Simplified Models

Matthew Dolan, University of Melbourne

with T. Cohen, S. El Hedri, J. Hirschauer, N. Tran and J. Whitbeck

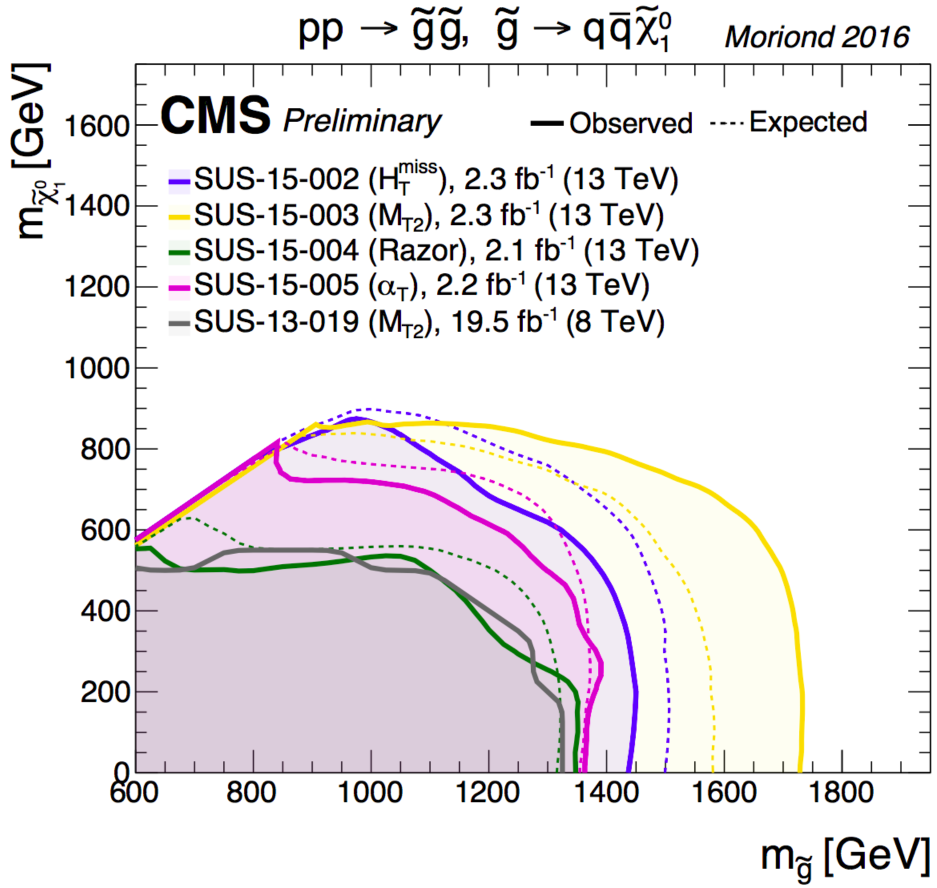
Based on 1605.01416

THE UNIVERSITY OF MELBOURNE

Searching for SUSY

- Jets + MET is the classic SUSY search channel

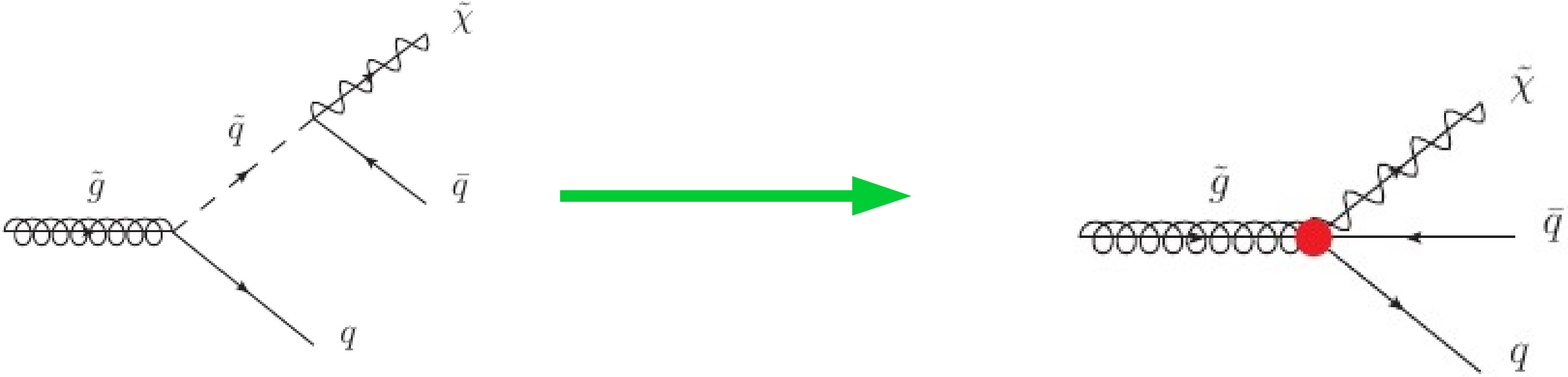
- Why are there so many searches?
- How are they related?
- Are they meant to have the same sensitvity?
- Are some variables more sensitive to certain topologies than others?
- How do we quantify this?



How do we develop intuition for an optimal analysis strategy?

Does it make sense to talk about the 'best' variable?

N-body simplified models



$$\mathcal{L} = \frac{i}{2}\,\overline{\widetilde{g}}\,\gamma^{\mu}\,D_{\mu}\,\widetilde{g} - \frac{1}{2}\,m_{\widetilde{g}}\,\overline{\widetilde{g}}\,\widetilde{g} + \frac{i}{2}\,\overline{\widetilde{\chi}}\,\gamma^{\mu}\,D_{\mu}\,\widetilde{\chi} - \frac{1}{2}\,m_{\widetilde{\chi}}\,\overline{\widetilde{\chi}}\,\widetilde{\chi} + \mathcal{L}_{\rm decay}\,,$$

- Formally an extension of gluino-neutralino SMS
- Generalised to n-partons in decay

$$\mathcal{L}^{(1)}_{\rm decay} = \frac{y^2 g_s}{16\,\pi^2\,\Lambda}\,G_{\mu\nu}\,\overline{\widetilde{g}}\,\bar{\sigma}^{\mu\nu}\,\widetilde{\chi} + {\rm h.c.}\,,$$

$$\mathcal{L}^{(2)}_{\rm decay} = \frac{y^2}{\Lambda^2}\,\overline{q}\,\widetilde{g}\,q\,\overline{\widetilde{\chi}} + {\rm h.c.}\,,$$

$$\mathcal{L}^{(3)}_{\rm decay} = \frac{y^2 g_s}{16\,\pi^2\,\Lambda^4}\,\overline{q}\,q\,G_{\mu\nu}\,\overline{\widetilde{g}}\,\bar{\sigma}^{\mu\nu}\,\widetilde{\chi} + {\rm h.c.}\,,$$

N-body simplified models

PRODUCTION	DECAY CHANNEL	FINAL STATE
$\widetilde{q}\,\widetilde{q}$	$\widetilde{q} \to q\,\widetilde{\chi}$	2 partons + $\not{H}_T$
$\widetilde{q}\,\widetilde{g}$	$\widetilde{g} \to q\,\overline{q}\,\widetilde{\chi}$ $\widetilde{q} \to q\,\widetilde{\chi}$	3 partons + $\not{H}_T$
$\widetilde{g}\,\widetilde{g}$	$\widetilde{g} \to q\,\overline{q}\,\widetilde{\chi}$	4 partons + $\not{H}_T$
$\widetilde{q}\,\widetilde{g}$	$\widetilde{g} \to q\,\overline{q}\,Z^0\,\widetilde{\chi}$ $\widetilde{q} \to q\,\widetilde{\chi}$	5 partons + $\not{H}_T$
$\widetilde{t}\,\widetilde{t}$	$\widetilde{t} \to t\,\widetilde{\chi}$	6 partons + $\not{H}_T$
$\widetilde{q}\,\widetilde{g}$	$\widetilde{g} \to t\,\bar{t}\,\widetilde{\chi}$ $\widetilde{q} \to q\,\widetilde{\chi}$	7 partons + $\not{H}_T$
$\widetilde{g}\,\widetilde{g}$	$\widetilde{g} \to q\,\overline{q}\,Z^0\,\widetilde{\chi}$	8 partons + $\not{H}_T$

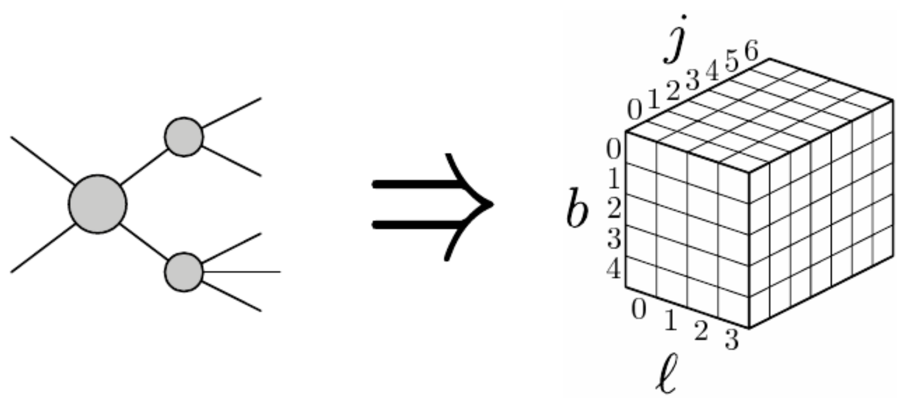
- Want to understand behaviour of search variables as a function of n-partons.

N-body simplified models

- What about on-shell vs off-shell intermediate states?
- Matters if you use kinematic features to search for a signal (we don't).

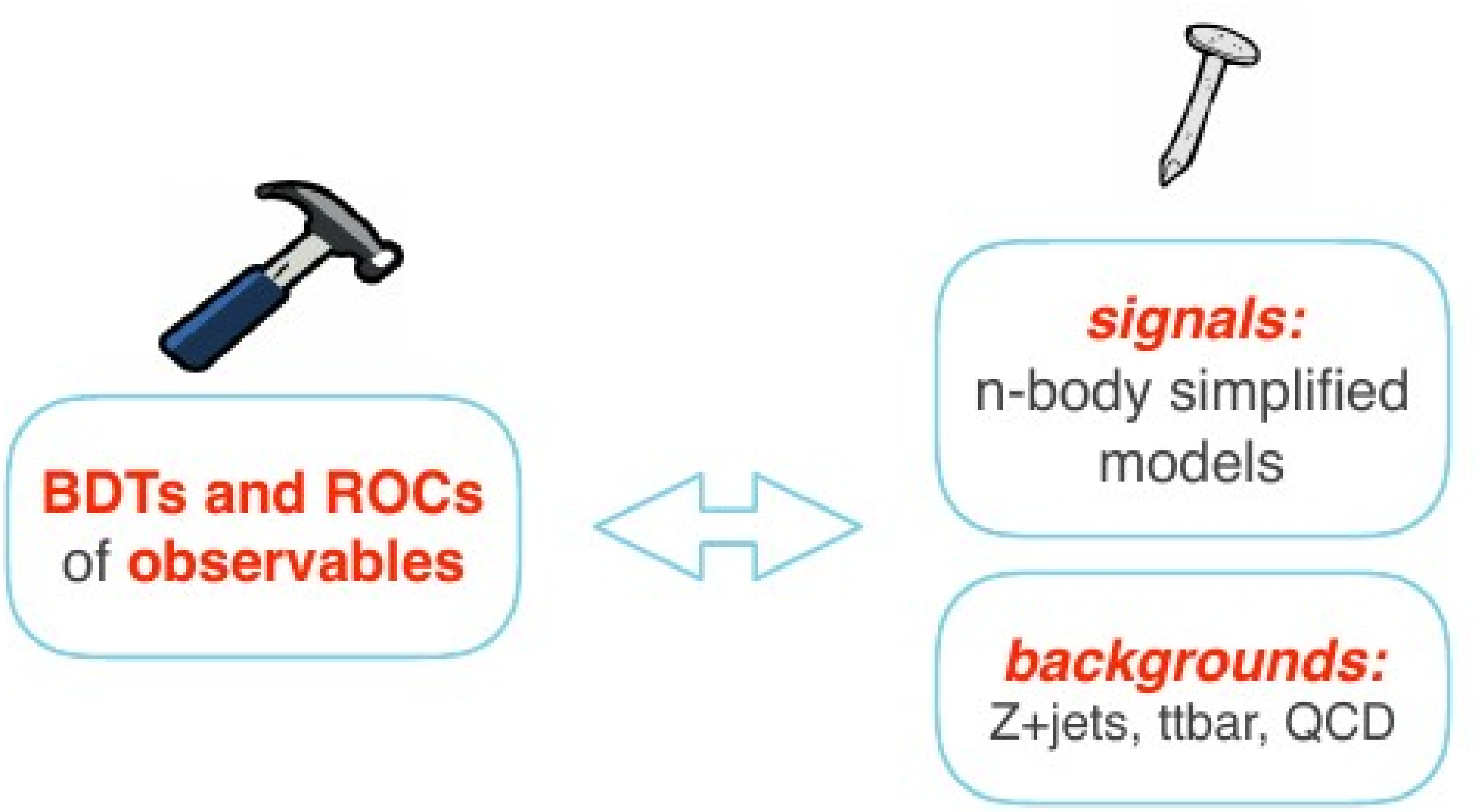
Relation to OSETs

- Proposed in context of LHC inverse problem.
- N-body SMs are Lagrangian based and admit straightforward ISR/FSR modelling a la SMSs.
- N-body SMs are signature based and admit straightforward exploration of phase space like OSETs



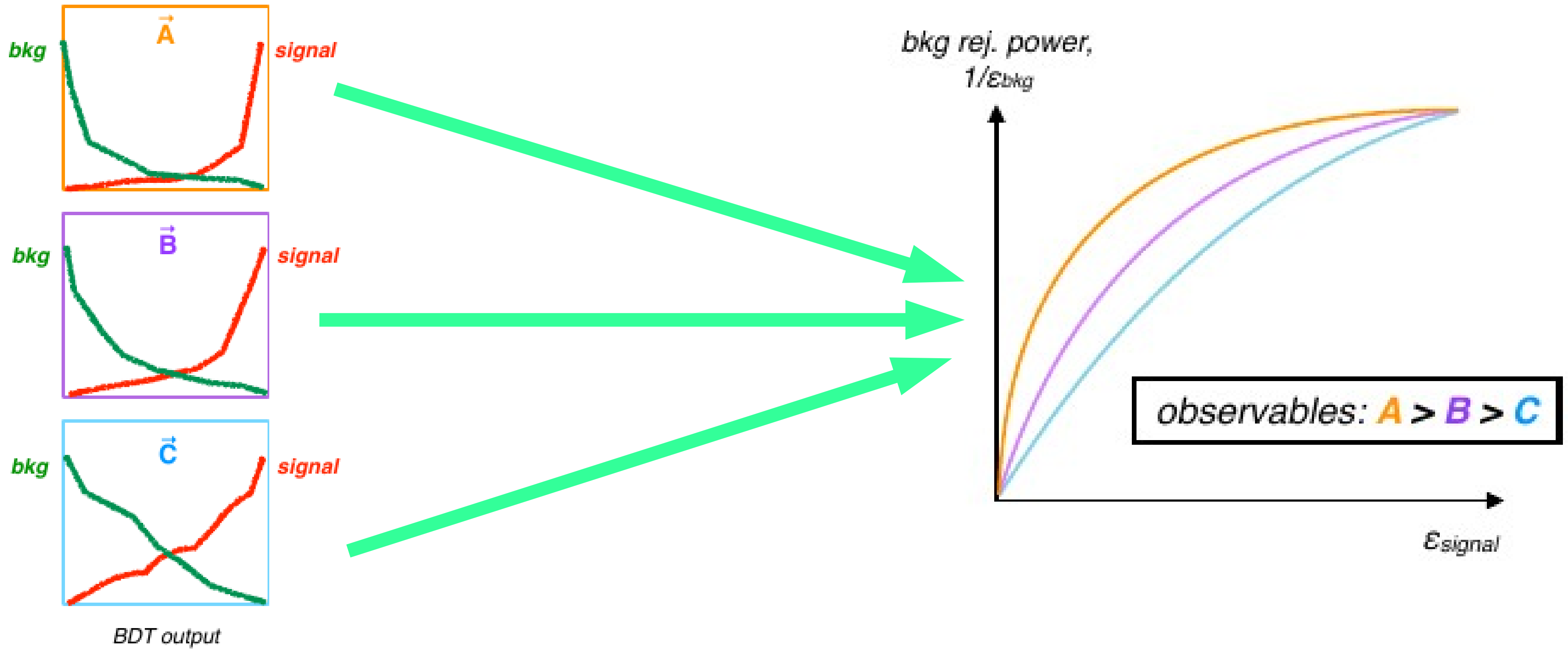
Arkani-Hamed et al, hep-ph/0703088

Our dissection toolkit



BDTs and ROCs

- BDT output visualised using ROC curve: signal versus background efficiency.



Observables

- There are many variables proposed and used in BSM searches:

$$E_T^{\text{miss}},\ H_T^{\text{miss}},\ H_T,\ S_T,\ L_T,\ M_{eff},\ \frac{E_T^{\text{miss}}}{M_{eff}}$$

$$\frac{E_T^{\text{miss}}}{\sqrt{H_T}},\ M_{T2},\ M_{CT},\ M_{CT\perp},\ M_R,\ R$$

Chris Rogan's talk

$$L_p,\ \ \min\Delta\phi_{\text{jet},\ E_T^{miss}},\ \alpha_T,\ dE/dx,\ \beta$$

$$M_{jj},\ \Sigma M_{\text{jet}},\ \bar{M}_{\text{jet}},\ M_{\text{fat jet}},\ M_{\gamma\gamma},\ M_{\ell\ell}$$

$$N_{\text{jet}},\ N_{\text{b-tag}},\ N_\ell,\ N_\gamma,\ \cdots$$

We focus on a subset of these:

H_T	**M_{T2}**
MHT	**$M_{T2}^{(CMS)}$**
N_{jets}	**M_R, R^2**
MHT/√HT	**α_T**
m_{eff}	**ΣM_J**

Classifying Variables

Useful to classify into three types:

$\not{H}_T$-*type*: The **missing energy variables** $\left\{\vec{\not{H}}_T, M_{T2}^{\mathrm{CMS}}\right\}$ are sensitive to the properties of the invisible states, *e.g.* how many neutralinos in the event, what is their mass, etc.;

E scale-type: The **energy scale variables** $\left\{H_T, M_{T2}, M_R, m_{\mathrm{eff}}\right\}$ are sensitive to the overall energy scale of the event, *e.g.* the gluino mass;

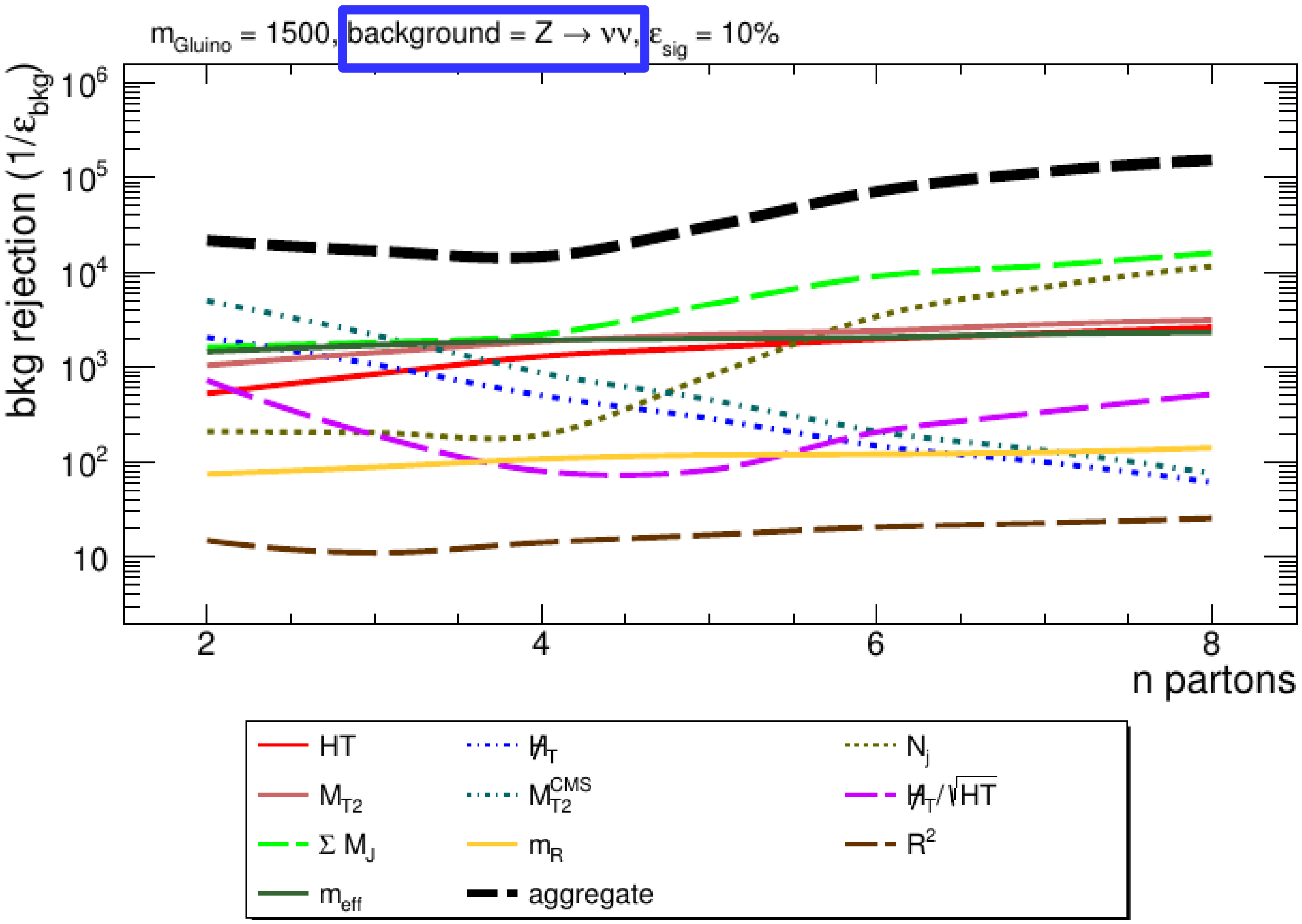
E struc-type: The **energy structure variable** $\left\{N_j\right\}$: is sensitive to the structure of the visible energy, *e.g.* how many partons are generated in the decay;

Some variables are hybrids, probing more than one type

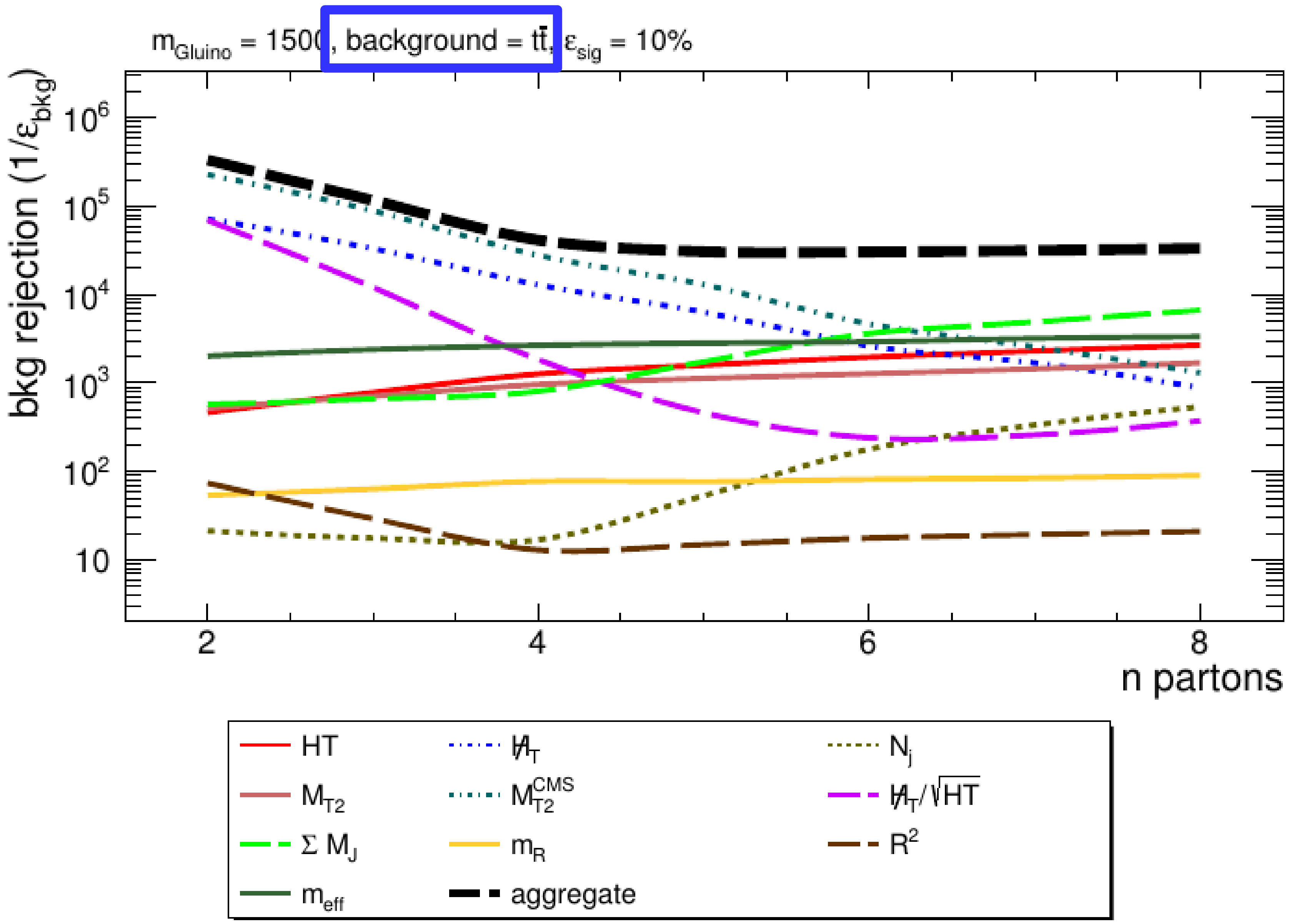
- *Hybrid-type*: The **hybrid variables** $\left\{\text{Razor } R^2, \not{H}_T/\sqrt{H_T}, M_J\right\}$ exhibit characteristics from multiple types depending on the number of decay partons in the event.[6]

The hybrid variables can be categorized as Razor R^2 $\left[\not{H}_T\text{-}/\ E\ \textit{scale-type}\right]$; $\not{H}_T/\sqrt{H_T}$ $\left[\not{H}_T\text{-}/\ E\ \textit{struc-type}\right]$ and M_J $\left[E\ \textit{scale-}/E\ \textit{struc-type}\right]$.

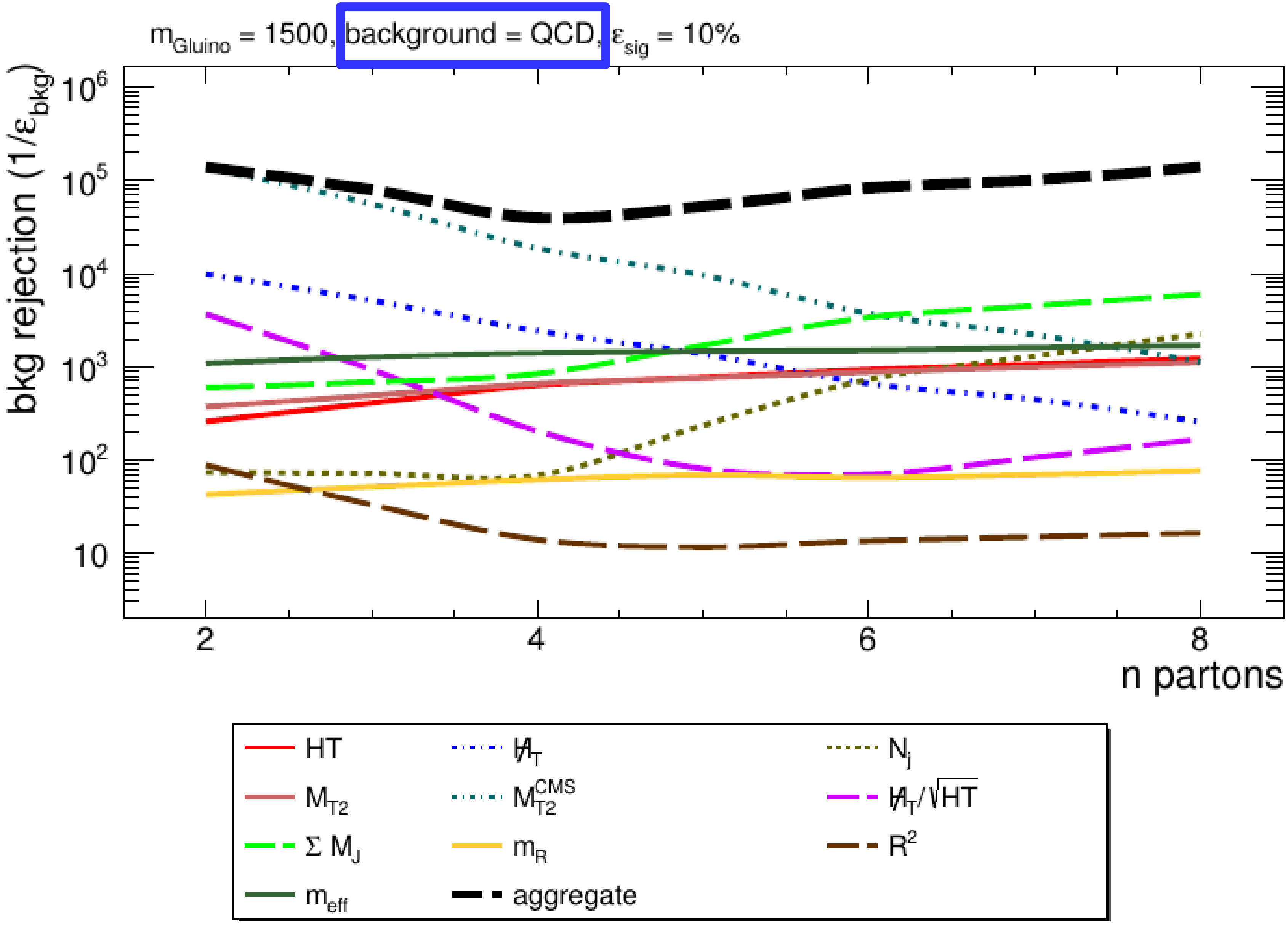
Uncompressed



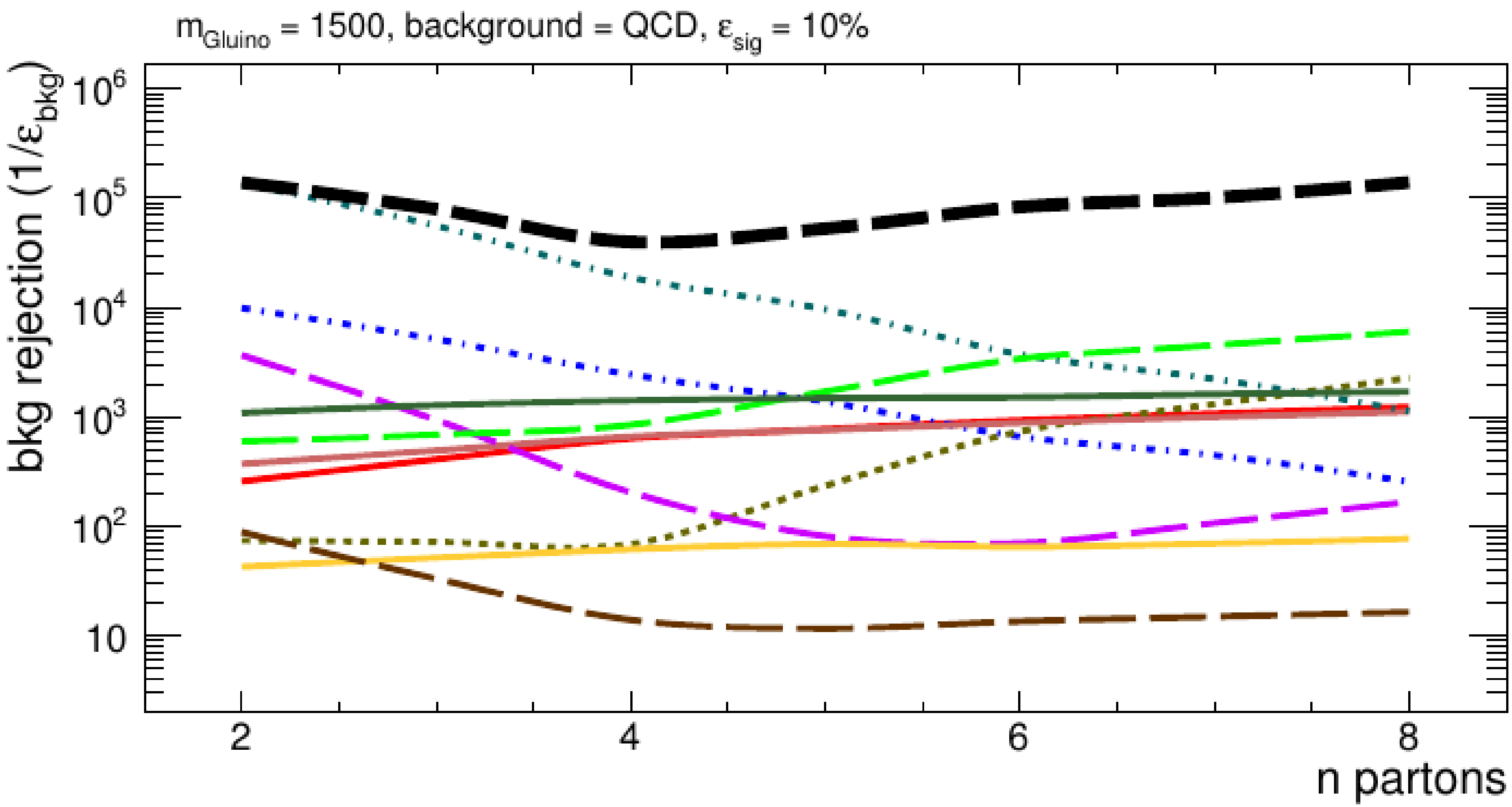
Uncompressed



Uncompressed

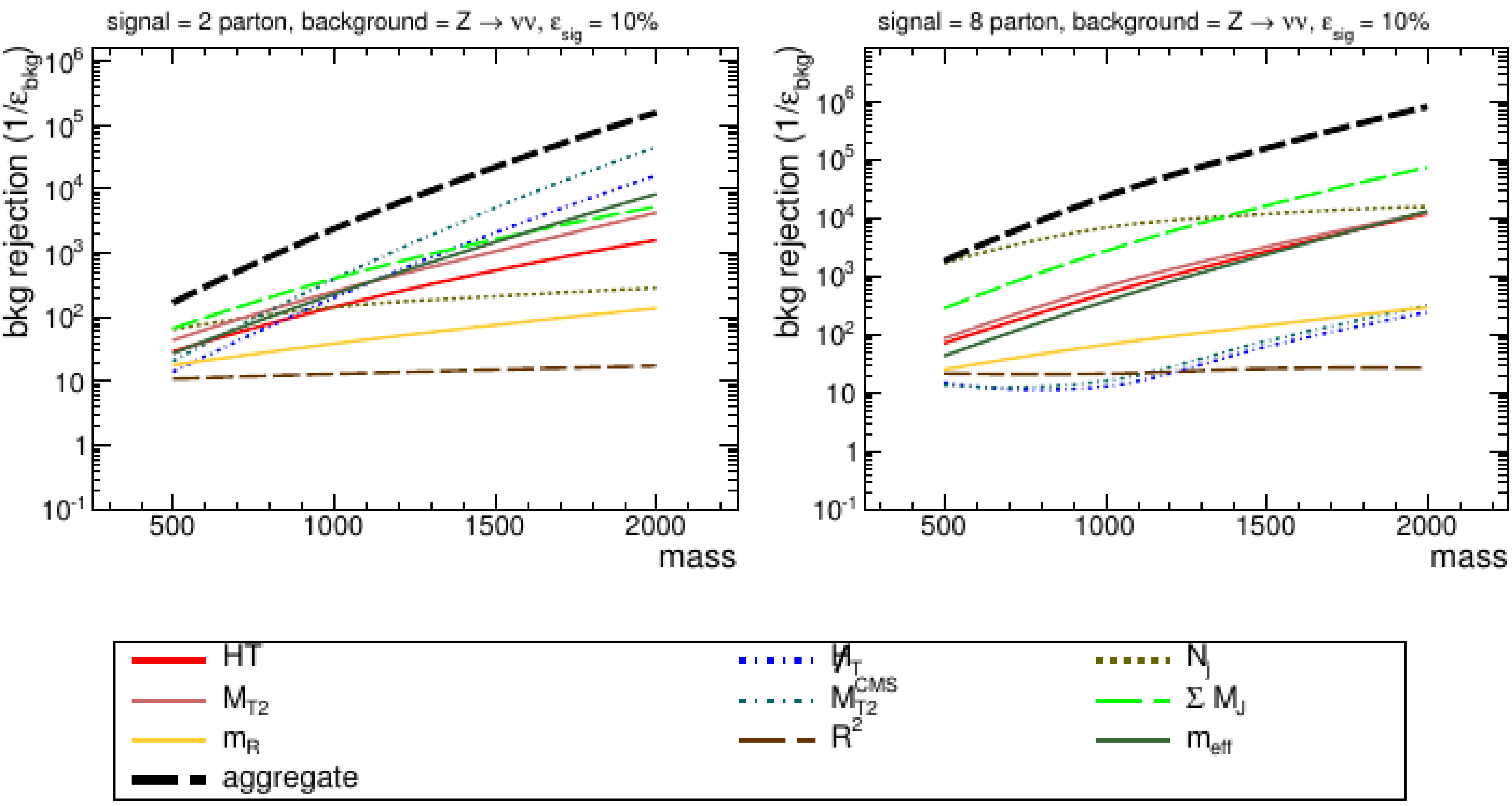


Uncompressed

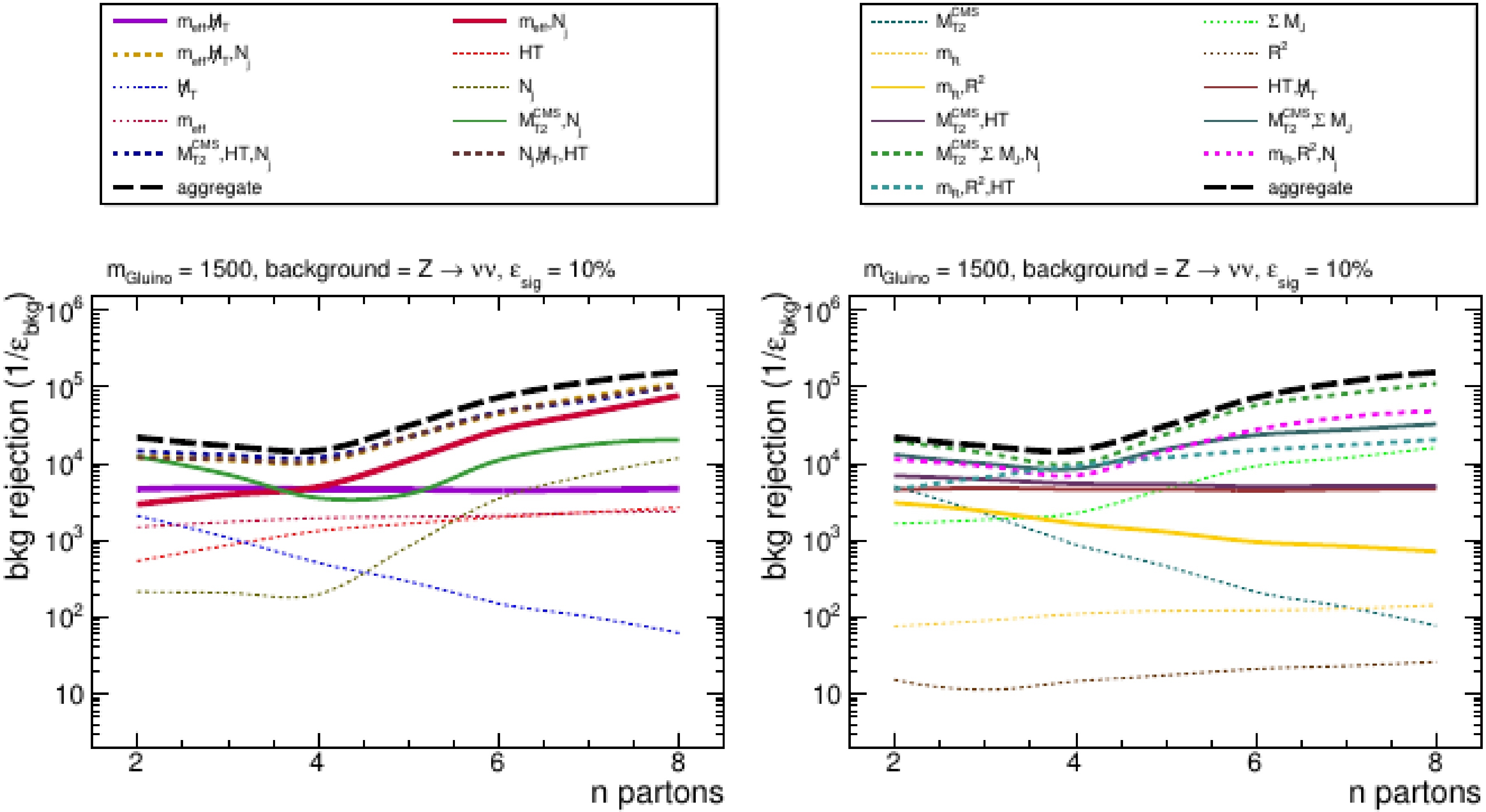


No single variable is efficient over the full phase space. Need to look at combinations.

Uncompressed

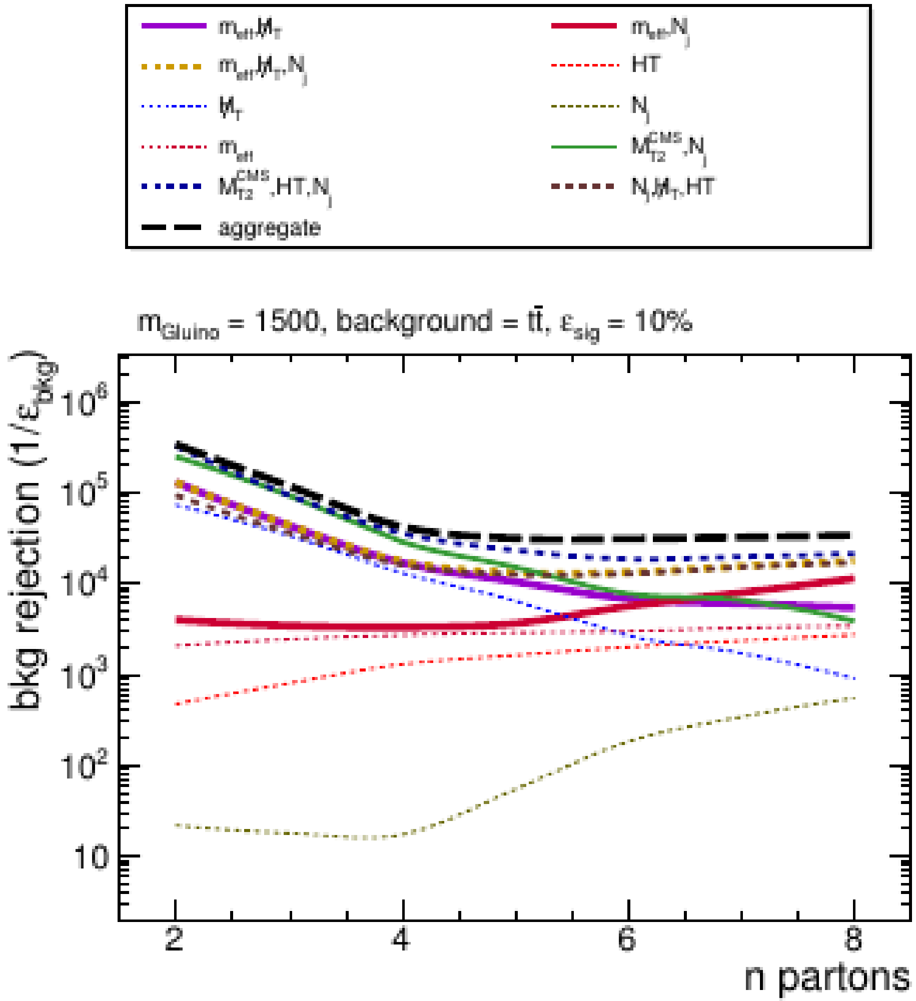


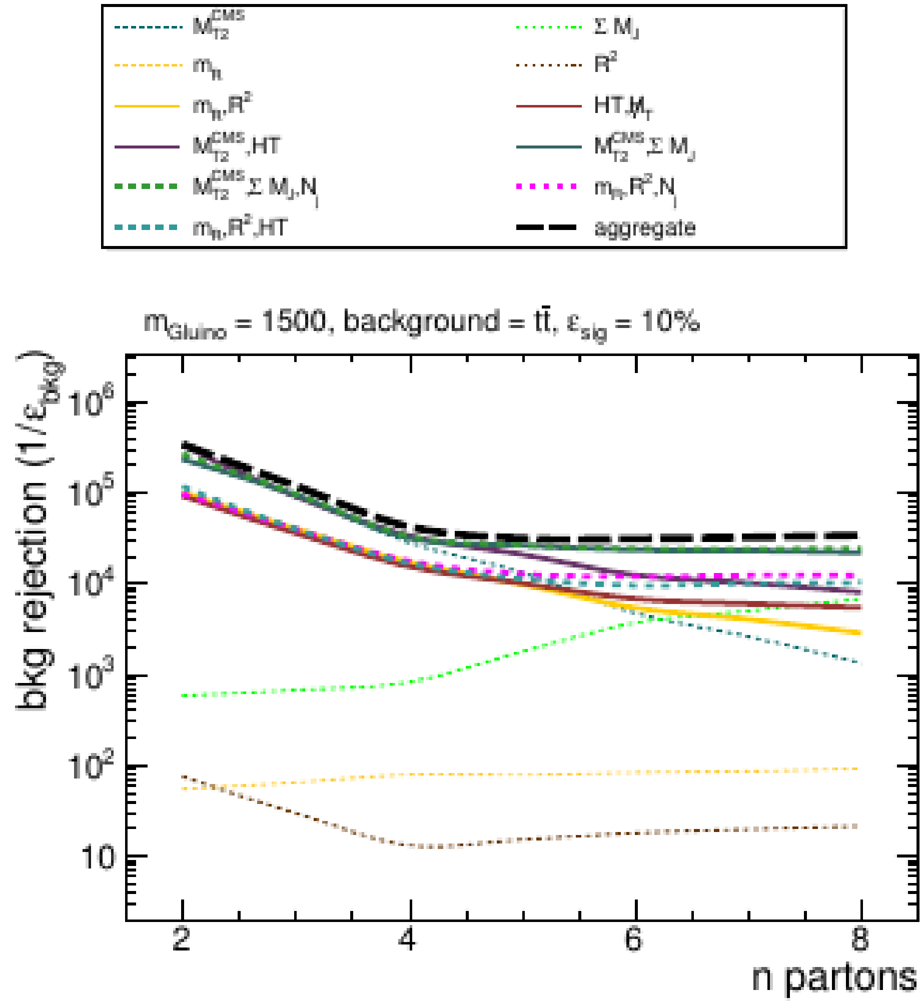
Uncompressed - Multivariable



Thin dotted – 1D   Solid – 2D   Thick dashed - 3D

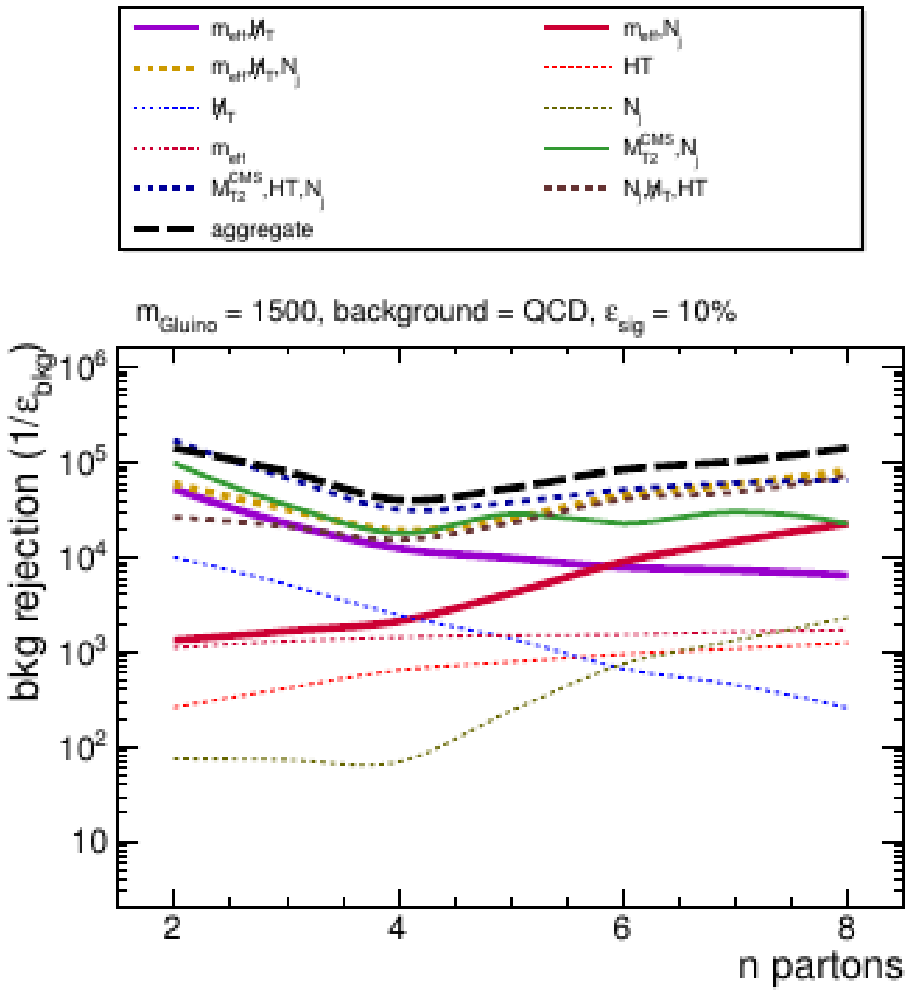
Uncompressed - Multivariable

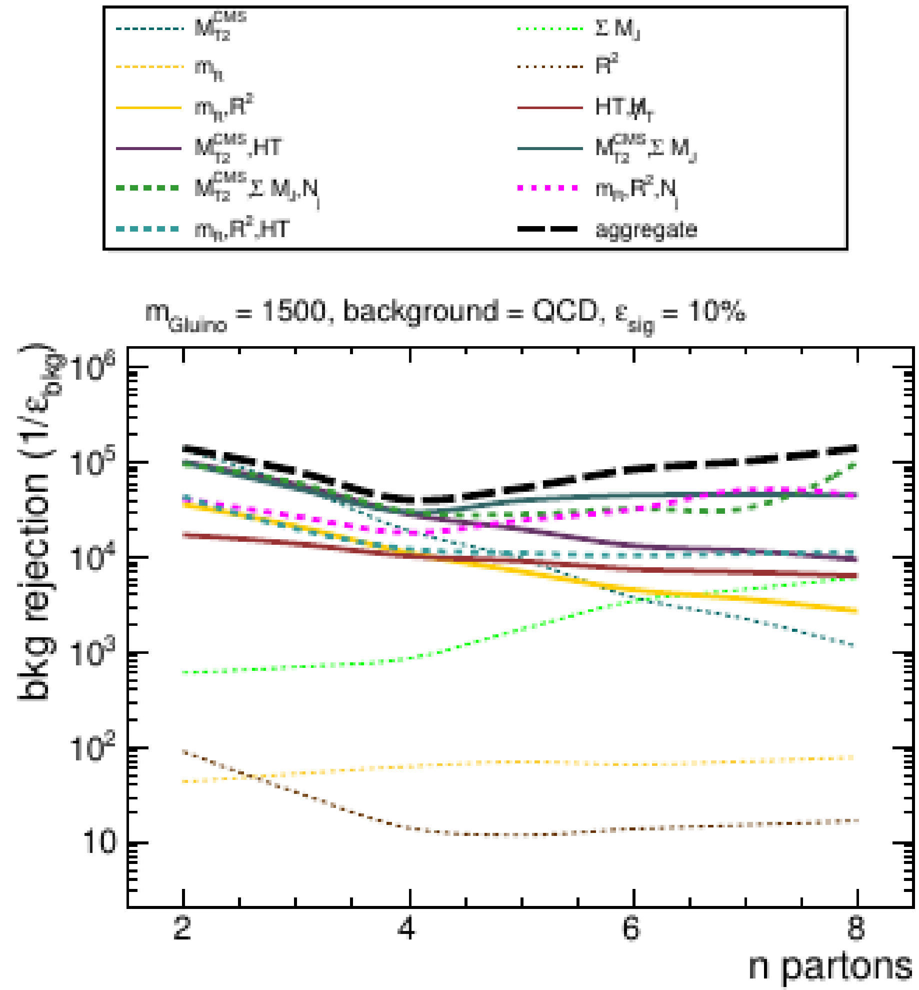




Thin dotted – 1D   Solid – 2D   Thick dashed - 3D

Uncompressed - Multivariable





Thin dotted – 1D Solid – 2D Thick dashed - 3D

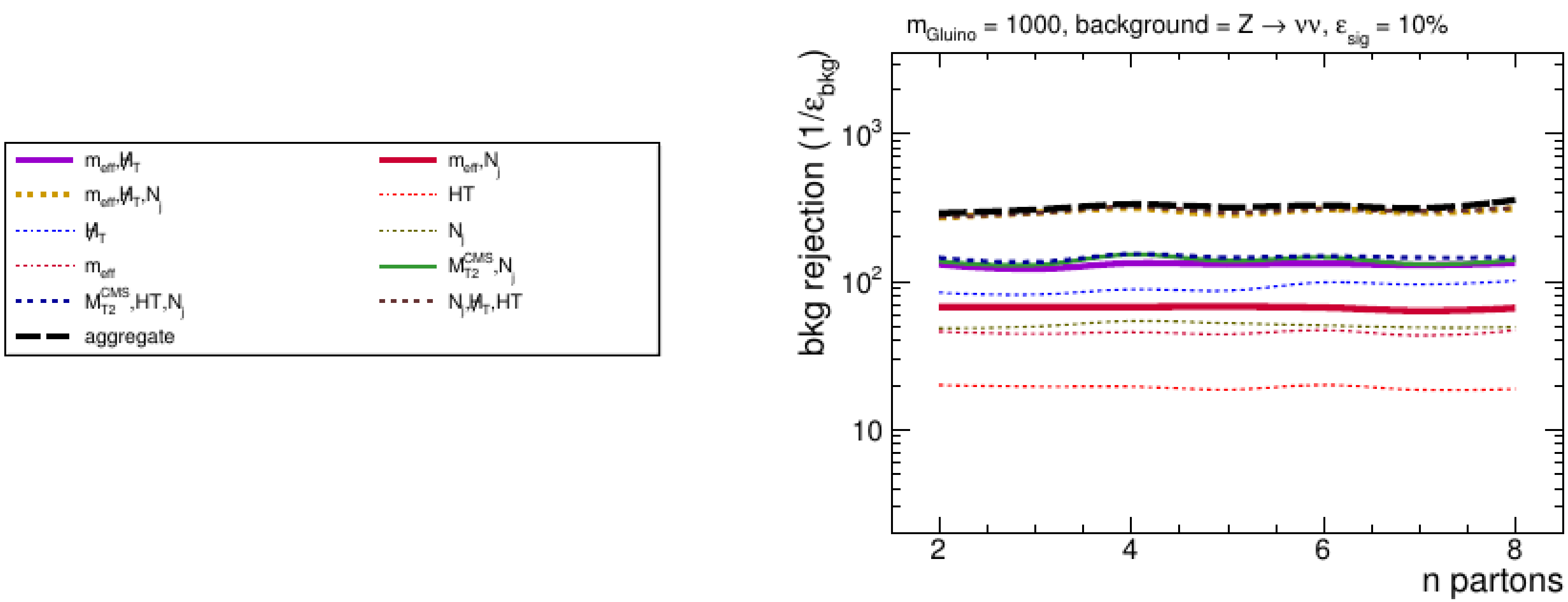
Uncompressed - Conclusions

- No 2 variable combination optimal over all phase space. For combinations:
  - $\not{H}_T$-/ E *struc-type*: deficient at high n partons where N_j is more important;
  - $\not{H}_T$-/ E *scale-type*: deficient at medium to high n partons where visible energy becomes more important;
  - E *scale-/E struc-type*: deficient at low n partons where missing energy variables are most dominant.

- But $(M_{T2}^{\mathrm{CMS}}, M_J)$ is pretty good and $(M_{T2}^{\mathrm{CMS}}, H_T \text{ or } M_J, N_j)$ is near optimal.

Compressed

- We also looked in detail at a compressed spectrum scenario
- Similar conclusions: 2-variable combinations are not optimal over whole parameter space
- 3 again near optimal: $(H_T, \not{H}_T, N_j)$ and $(m_{\text{eff}}, \not{H}_T, N_j)$
- Combinations with Razor also do well



Summary

- Introduced n-body extension of simplified models
- Systematic attempt to quantify relationships between variables in inclusive jets + MET searches
- Re-learn some things we know (e.g. n-jets important for many partons)
- And things we don't: 3 variable combos required to achieve near-optimal performance over full phase-space
- Interesting to extend to more leptons, jets, intermediate states...many possibilities!