

Semivisible Jets from Dark Glueballs

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July 2024, University of Glasgow

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Dark Glueballs Model

“Dark Sector Glueballs at the LHC”

(Batz, Cohen, Curtin, Gemmell, Kribs. [arXiv:2310.13731](https://arxiv.org/abs/2310.13731))

SU(N) gauge group

Pure-gluon model with infinite dark colours

Higgs and Z' portals

Implemented a glueball hadronization model based on Lund string dynamics

Glueball	Mass (m_0)	Higgs Portal
0^{++}	1.00	$h^* \rightarrow \text{SM}, \text{SM}$
2^{++}	1.40	$0^{++} + h^*$
0^{-+}	1.50	-
1^{+-}	1.75	-
2^{-+}	1.78	$0^{-+} + h^*$
3^{+-}	2.11	$1^{+-} + h^*$
3^{++}	2.15	$\{2^{++}, 0^{-+}, 2^{-+}\} + h^*$
1^{--}	2.25	$1^{+-} + h^*$
2^{--}	2.35	$\{1^{+-}, 3^{+-}, 1^{--}\} + h^*$
3^{--}	2.46	$\{1^{+-}, 3^{+-}, 1^{--}, 2^{--}\} + h^*$
2^{+-}	2.48	$\{1^{+-}, 3^{+-}, 1^{--}, 2^{--}, 3^{--}\} + h^*$
0^{+-}	2.80	$\{1^{--}, 3^{--}, 2^{+-}\} + h^*$

(taken from “DS Glueballs...”)

Higgs Portal Event Generation

Added decay channels for all dark glueball species

Branching ratios and lifetimes based on dimension-6 Higgs

(Juknevich. [arXiv:0911.5616](https://arxiv.org/abs/0911.5616))

HiddenGlue Pythia8 module for dark glueball hadronization into species

Decay channel	Branching ratio
$0^{++} \rightarrow b\bar{b}$	0.326
$0^{++} \rightarrow c\bar{c}$	0.269
$0^{++} \rightarrow gg$	0.247
$0^{++} \rightarrow \tau'^-\tau'^-$	0.155
$0^{++} \rightarrow \mu^-\mu^-, s\bar{s}, \gamma\gamma$	0.003

Pythia8 settings

```
HiddenValley:FSR = on
HiddenValley:alphaOrder = 1
HiddenValley:nFlav = 0
HiddenValley:fragment = on

HiddenGlue:fragmentationFunction = 2
HiddenGlue:m0 = 10.
HiddenGlue:pTminFactor = 1.8
HiddenGlue:fragmentationFunction = 2
HiddenGlue:aBeta = 90.
HiddenGlue:kBeta = 810

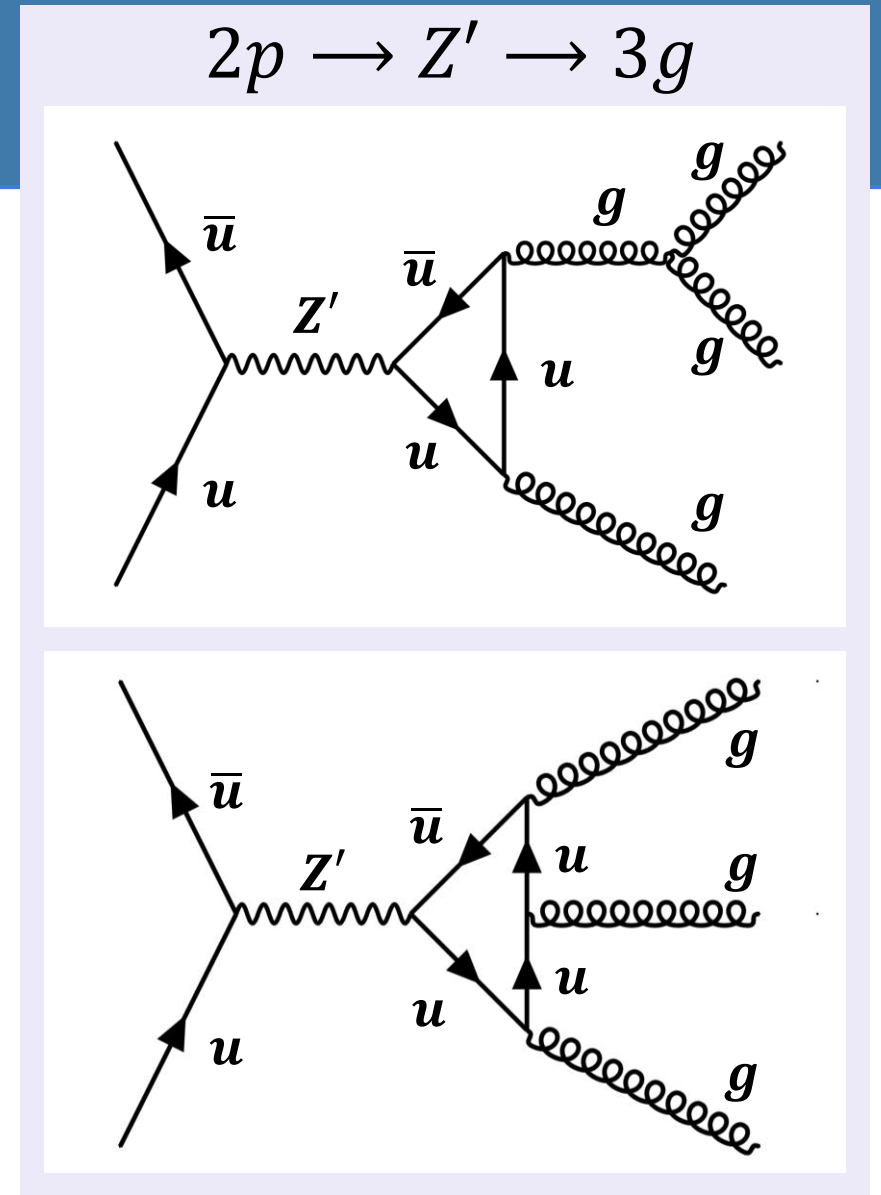
HiddenValley:aLund = 0.00019
HiddenValley:bmqv2 = 0.26
```

Z' Portal Event Generation

Generated SM $p p \rightarrow Z' \rightarrow g g g$ [QCD]
in MadGraph5 using “SM + W’ and Z’ at NLO
in QCD” model (Fuks, Ruiz. [arXiv:1701.05263](https://arxiv.org/abs/1701.05263))

Issue #1: MG5 colour flow not conserved in
a loop-induced process (Bug report)

Issue #2: Pythia HiddenValley dark colour
reassignment



Higgs Portal Analysis

Anti-kt jets radius = 0.4

Transverse momenta $p_T > 30$ GeV

Visible final states with pseudorapidity
 $|\eta| < 4.5$

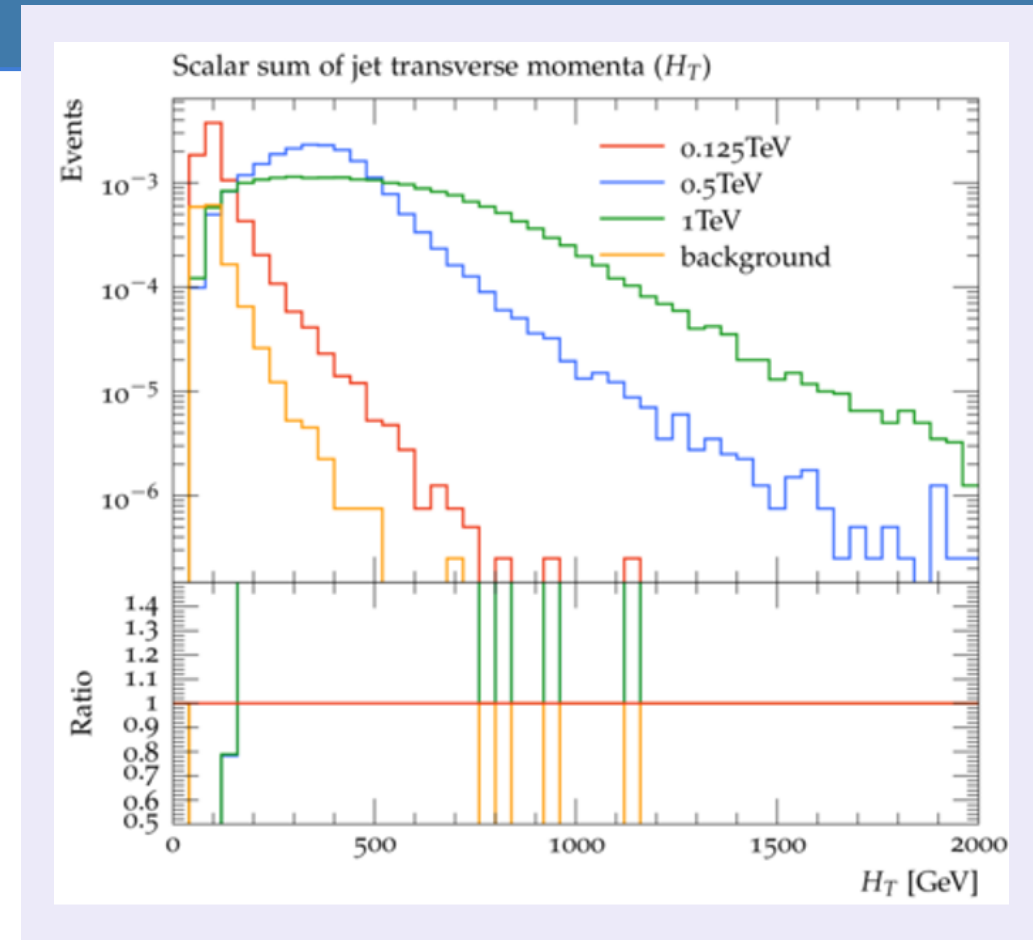
Smearred in Rivet

Background: SM QCD dijet

Normalisation: weighted sum of events

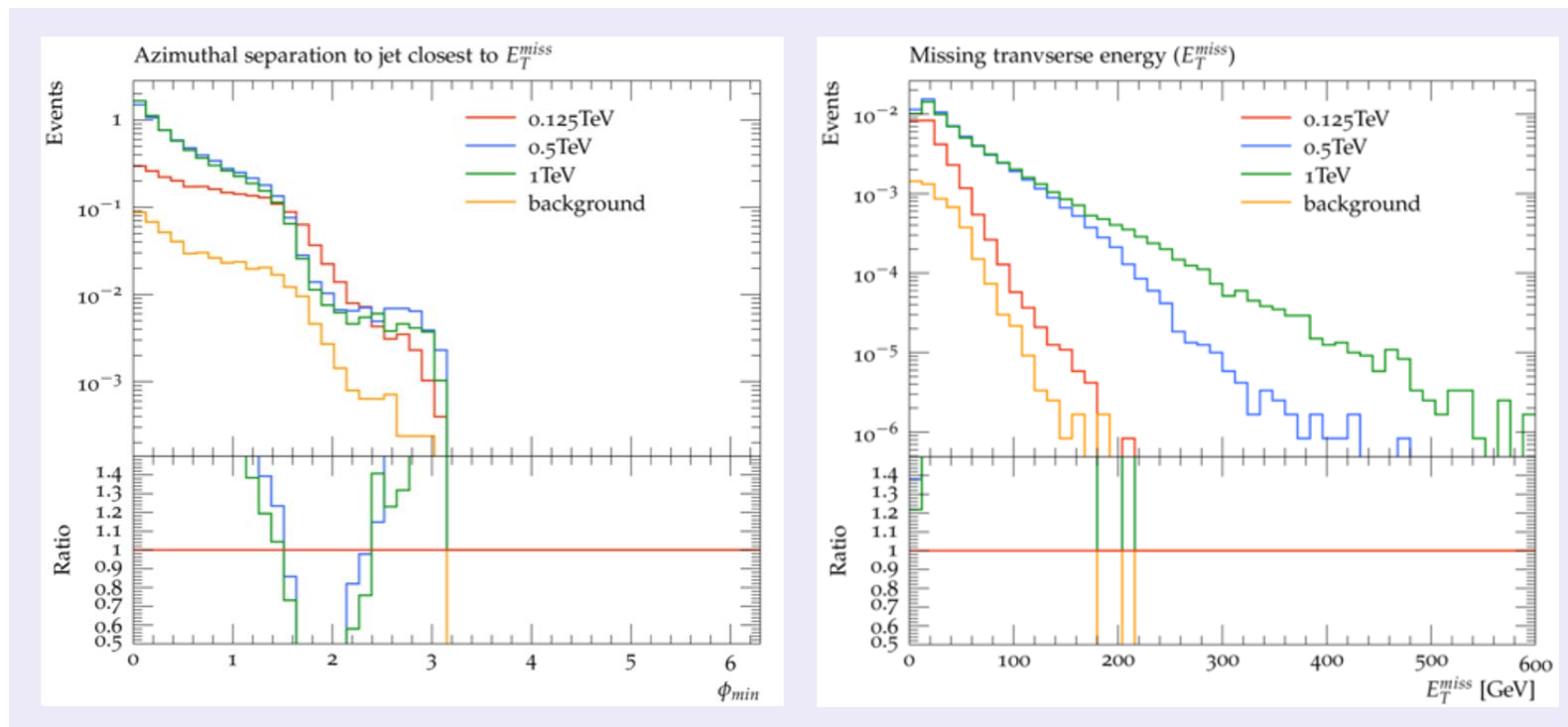
Boosted Higgs mass to 1 TeV

→ decrease in cross-section from 10^{-6} to 10^{-9} pb

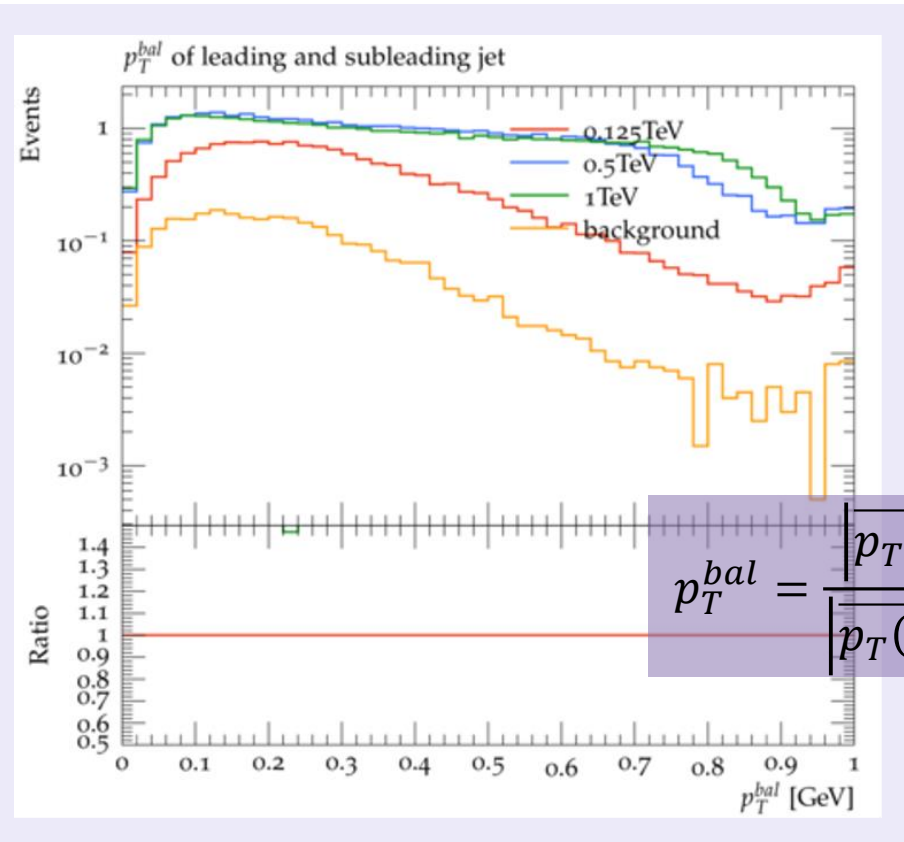
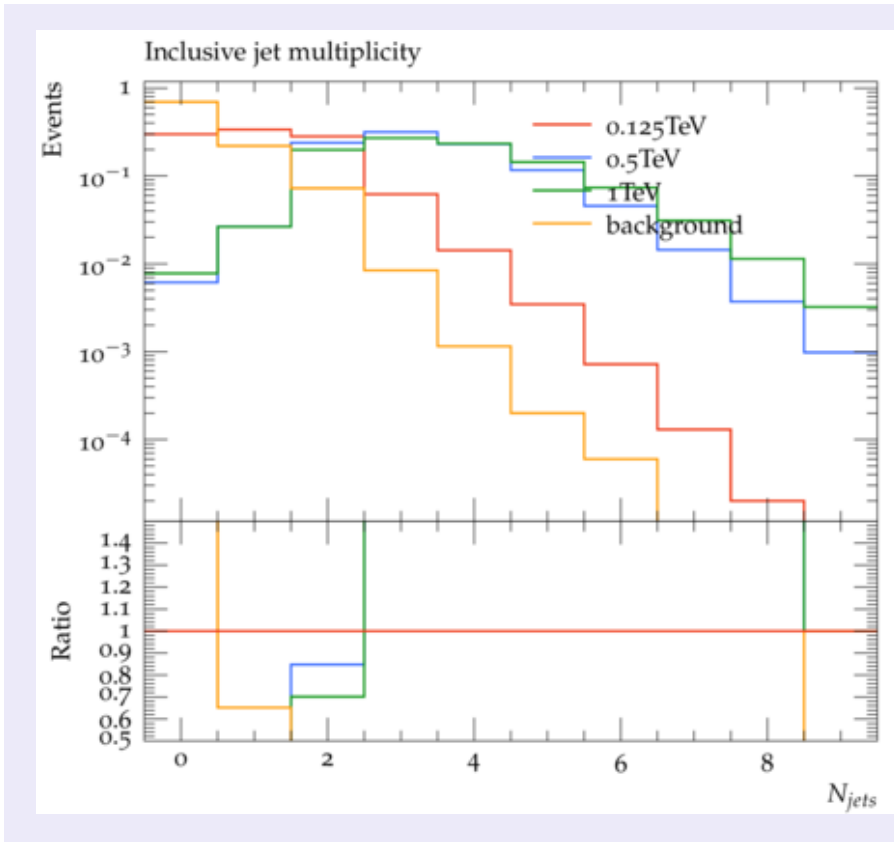


Semivisible Jet Signature: ϕ_{min}, E_T^{miss}

Alignment of MET and jet indicating SVJ but because of low MET (< 600 GeV), signature not excluded by SVJ search ([EXOT-2022-37](#))

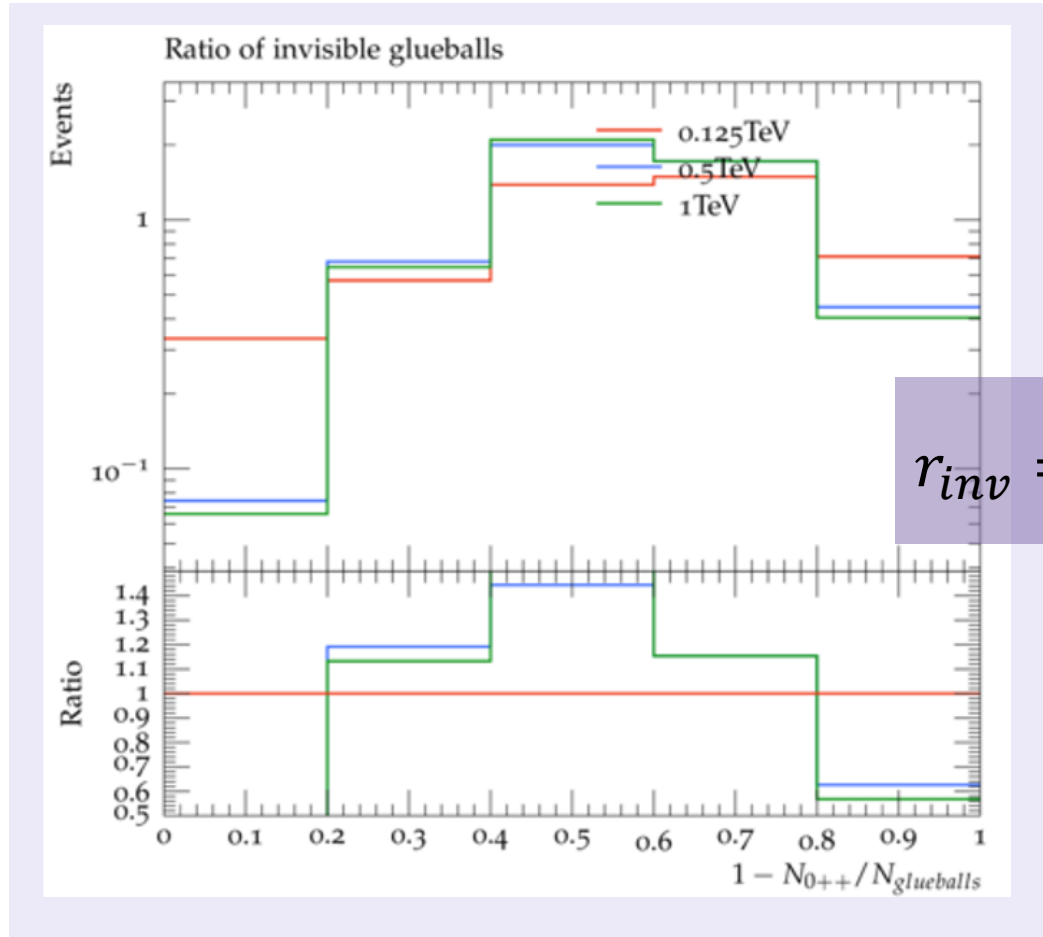


SVJ Observables: N_{jets} , p_T^{bal}



$$p_T^{bal} = \frac{|\vec{p}_T(j_1) + \vec{p}_T(j_2)|}{|\vec{p}_T(j_1)| + |\vec{p}_T(j_2)|}$$

SVJ Observables: r_{inv}



$$r_{inv} = 1 - \frac{\text{number of } 0^{++} \text{ glueballs}}{\text{number of all glueballs}}$$

Constraining Parameter Space

Reinterpretation:

- ATLAS SUSY ([SUSY-2018-22](#)) and SVJ ([EXOT-2022-37](#)) – not sensitive to our signal
- ATLAS Mono-jet ([STDM-2018-55](#)) – has some sensitivity to our signal but minimal due to the low cross-section
- Artificially boosted cross-section to 10^6 pb (increase by order 15)

Z' more promising? → can boost energy without sacrificing cross-section

Thank you!

More on Z' Portal Issues

Issue #1: MG5 colour flow not conserved in a loop-induced process

→ Inconsistency with origin of gluon in ~20% of events

	ID	mothers				colours				momentum			E	m
6	0	+4.2132600e-06	5.58592700e+02	7.81616400e-03	9.99524400e-02									
u~	-1	-1	0	0	0	501	-0.0000000000e+00	+0.0000000000e+00	+1.5088814324e+02	1.5088814324e+02	0.0000000000e+			
u	1	-1	0	0	502	0	+0.0000000000e+00	-0.0000000000e+00	-1.2092649481e+03	1.2092649481e+03	0.0000000000e+			
Z'	32	2	1	2	0	0	+1.4577003710e+02	-2.4060206713e+02	-8.1568436041e+02	9.8861859630e+02	4.8258418406e+			
g	21	1	3	3	502	501	-1.5695140227e+02	-9.1149680481e+01	-4.7720519126e+02	5.1055538533e+02	0.0000000000e+			
g	21	1	1	2	503	504	-1.4577003710e+02	+2.4060206713e+02	-2.4269244449e+02	3.7153449508e+02	0.0000000000e+			
g	21	1	3	3	504	503	+3.0272143937e+02	-1.4945238665e+02	-3.3847916915e+02	4.7806321096e+02	0.0000000000e+			

<mgrwt>

Fig. 1: Example Feynman diagrams

Issue #2: Pythia Hidden Valley dark colour reassignment

→ HV assumes partons come in pairs, third gluon assigned same colour as first, infinite loop during hadronization



More on Z' Portal Issues

wrong color assignment for loop-induced process

Bug #2073272 reported by  Olivier Mattelaer on 2024-07-16

This bug affects 1 person

 10

Affects	Status	Importance	Assigned to	Milestone
 MadGraph5_aMC@NLO	New	Undecided	 Olivier Mattelaer	

Bug Description

In loop-induced event, the color can be incorrectly assigned to an event:

<event>

```
6 0 0.5076118E-002 0.8388664E+02 0.7546771E-02 0.1318370E+00
-1 -1 0 0 0 501 -0.000000000000E+00 0.000000000000E+00 0.32789629232E+03 0.32789629232E+03 0.000000000000E+00 0. 1.
1 -1 0 0 502 0 0.000000000000E+00 -0.000000000000E+00 -0.10279929998E+02 0.10279929998E+02 0.000000000000E+00 0. -1.
23 2 1 2 0 0 0.21346295775E+02 0.22576458130E+02 0.25154876616E+03 0.26516740047E+03 0.77920521751E+02 0. 0.
21 1 3 3 502 501 0.19443749397E+01 0.49621995708E+02 0.13062326965E+03 0.13974463004E+03 0.000000000000E+00 0. 1.
21 1 3 3 503 504 0.19401920836E+02 -0.27045537578E+02 0.12092549651E+03 0.12542277043E+03 0.000000000000E+00 0. 1.
21 1 1 2 504 503 -0.21346295775E+02 -0.22576458130E+02 0.66067596153E+02 0.73008821840E+02 0.000000000000E+00 0. -1.
```

<mgrwt>

This is for

$p p > z > 3g$ [noborn=QCD]

(first event in the G4_1 directory).

One can see that color is consistent with a Z decaying with the last two gluon, but the momenta are consistent with the first two gluon coming from the z.

Checking further inside G4 and deactivating the channel symmetry (from G5 and G6):

G4 still has the issue

G5 does not have any Z written (which can just be an unlucky seed)

G6 has the issue too.

So does not seems to be related to a configuration symmetry handling.

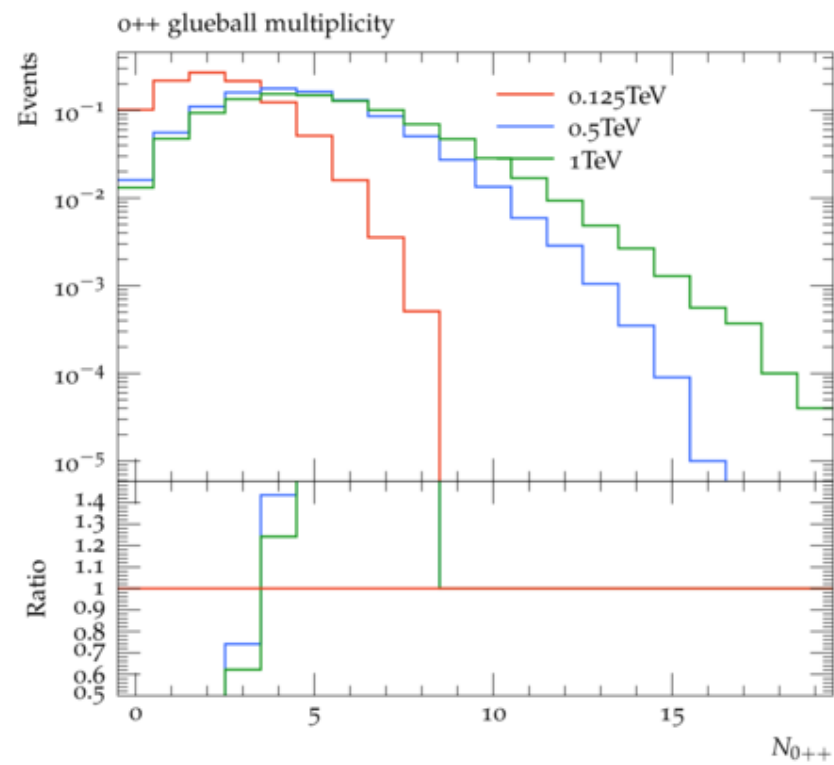
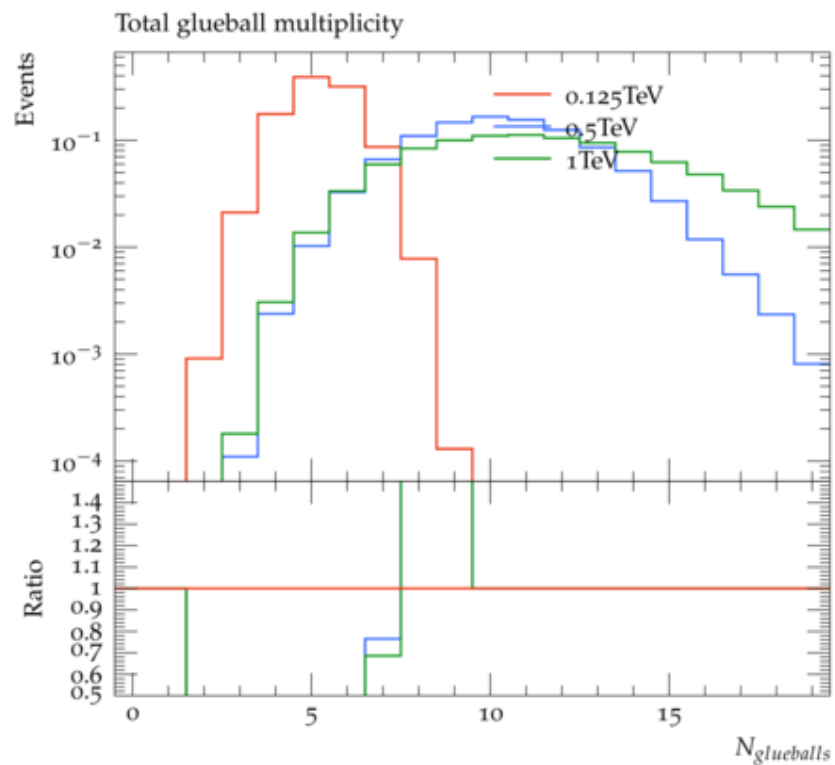
More on Lifetimes

Last column: lifetimes in mm/c

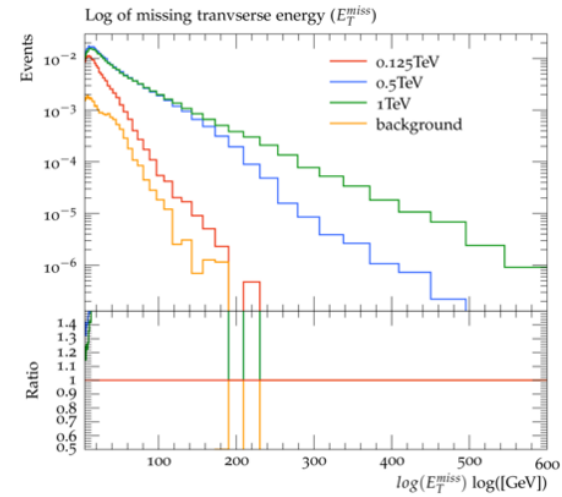
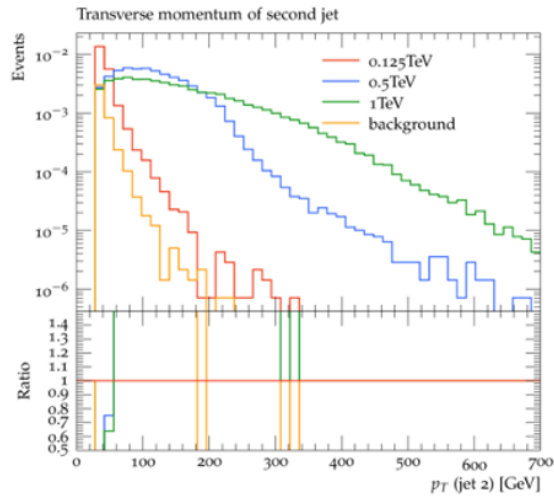
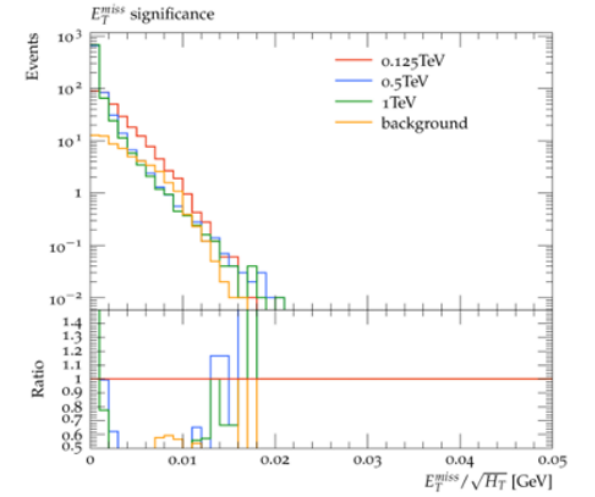
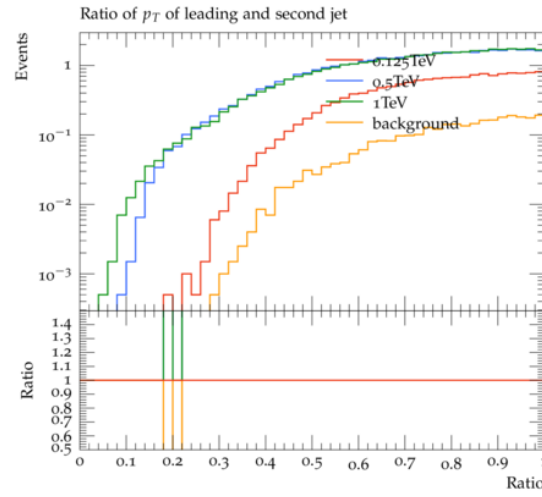
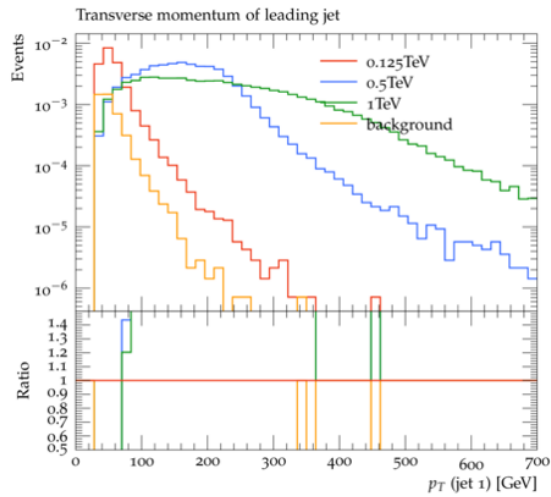
```
5900001:all = fGS(0++) void 1 0 0 10 1.e-18 0. 0. 3.001312378846069e8
5900002:all = fGS(2++) void 5 0 0 14. 1.e-18 0. 0. 1.5862465870679062e14
5900003:all = fGS(0-+) void 1 0 0 15. 1.e-18 0. 0. 1e18
5900004:all = fGS(1+-) void 3 0 0 17.5 1.e-18 0. 0. 1e18
5900005:all = fGS(2-+) void 5 0 0 17.8 1.e-18 0. 0. 2.150275020542972e16
5900006:all = fGS(3+-) void 7 0 0 21.1 1.e-18 0. 0. 4.193713743490581e15
5900007:all = fGS(3++) void 7 0 0 21.5 1.e-18 0. 0. 2.1249152066469e11
5900008:all = fGS(1--) void 3 0 0 22.5 1.e-18 0. 0. 1.594926887756735e11
5900009:all = fGS(2--) void 5 0 0 23.5 1.e-18 0. 0. 1.6608417495887217e12
5900010:all = fGS(3--) void 7 0 0 24.6 1.e-18 0. 0. 2.2958898060798477e12
5900011:all = fGS(2+-) void 5 0 0 24.8 1.e-18 0. 0. 4.8629493857846954e11
5900012:all = fGS(0+-) void 1 0 0 28. 1.e-18 0. 0. 2.227848124243123e12
```

and a lot more plots...

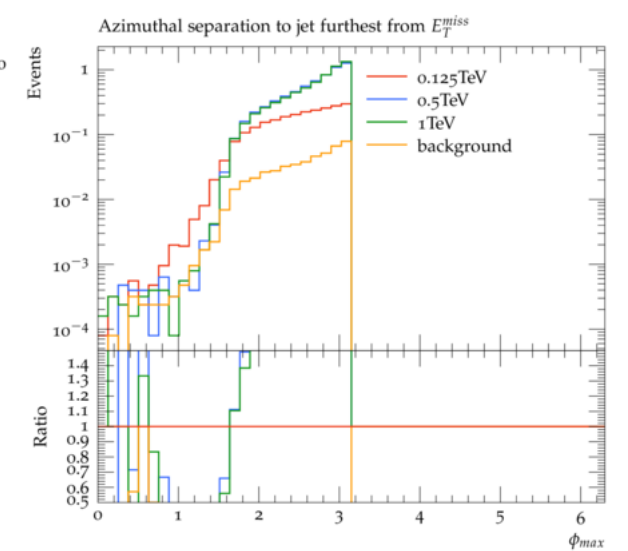
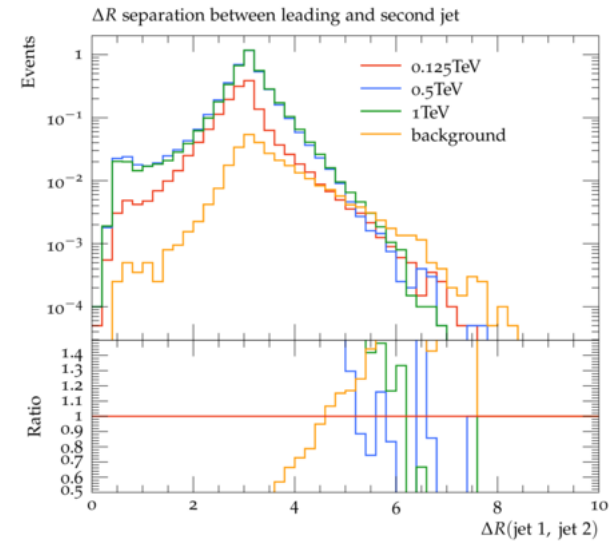
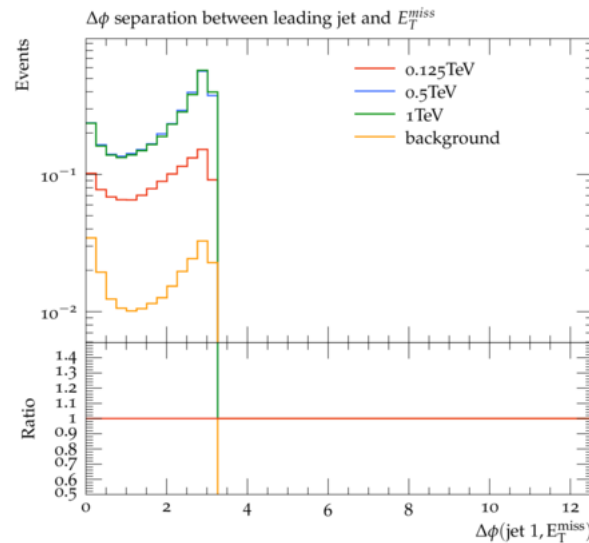
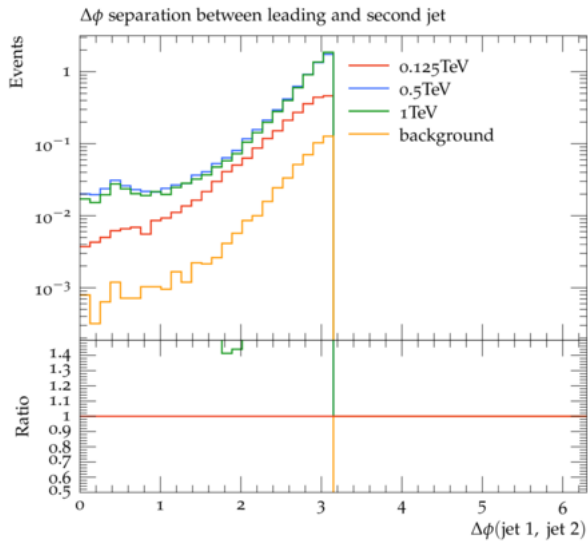
Glueballs



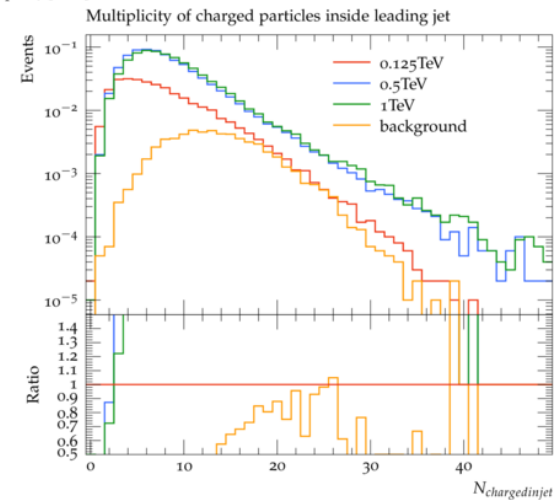
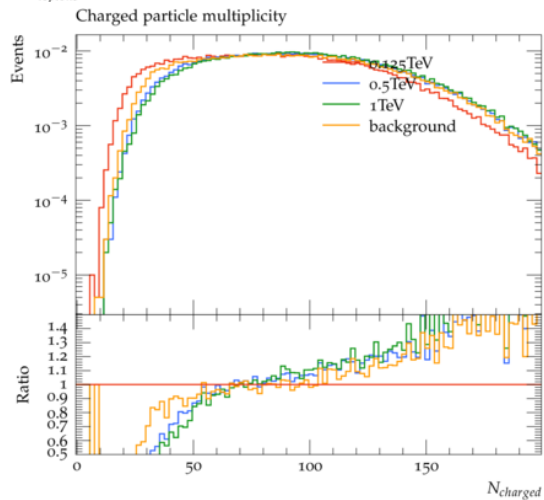
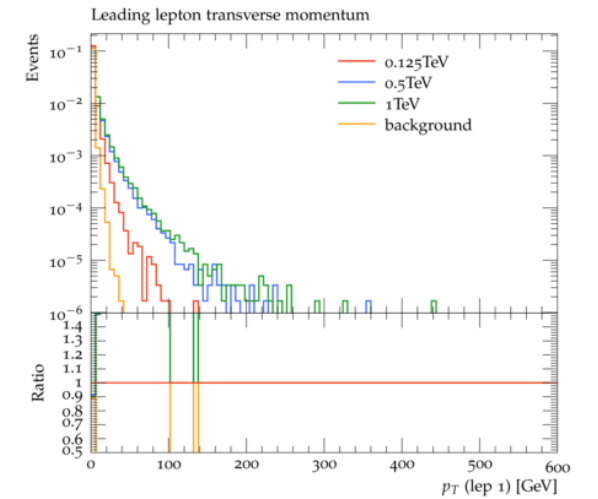
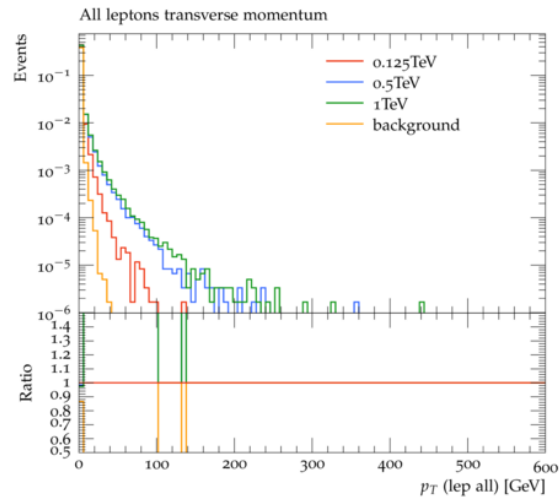
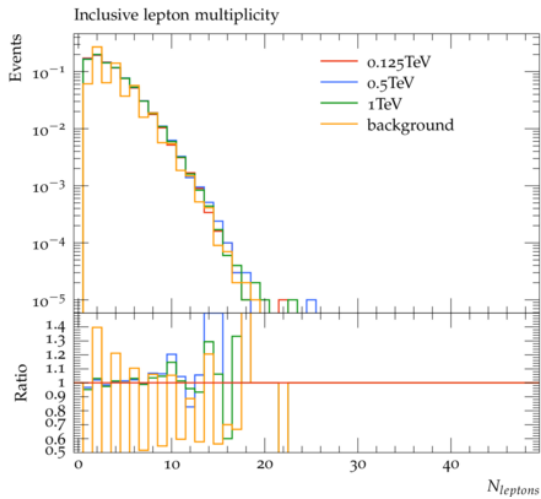
Momenta and MET



Angular Separations



Leptons and charged particles



Jets

