Status of the resonances : Z' → tt and RSG → WW

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FCC-hh physics analysis meeting
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Disclaimer

- Not discussing much the physic models
- Neither designing state of the art analyses
- But rather study the performance of the FCC-hh detector
- Goal of the study:
  - Discovery reach for heavy objects
  - Find ways to Discriminate QCD, ttbar and dibosons
  - To be validated with Calorimeter performances in full simulation
- No pileup assumed! (for such heavy object the effect is not large)
  - But again the effect of pileup (on,off time) on jet reconstruction and performance will be study in full simulation

Samples

- Signals produced with Pythia8
- Background with MG5 LO 10Million of each
  - K-factor of 2 assumed for all of them
  - Di-lepton ee and mumu separately with mll>10TeV
  - Di-jet with mjj>5TeV
  - Di-boson mvv>5TeV
  - V+jets with mvj>5TeV
  - Ttbar with mtt>5TeV
- Investigating NLO at the moment for the report

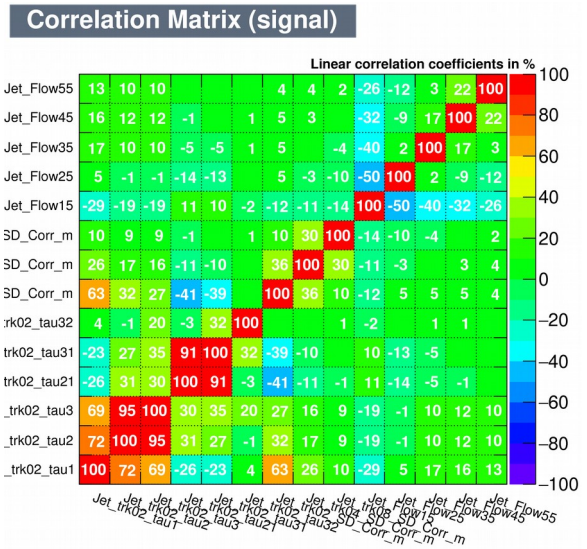
Strategy

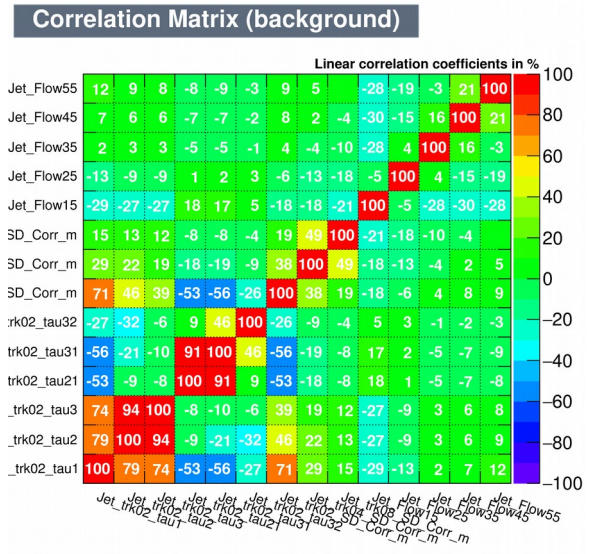
- First try with an event based BDT found to give tiny improvements.

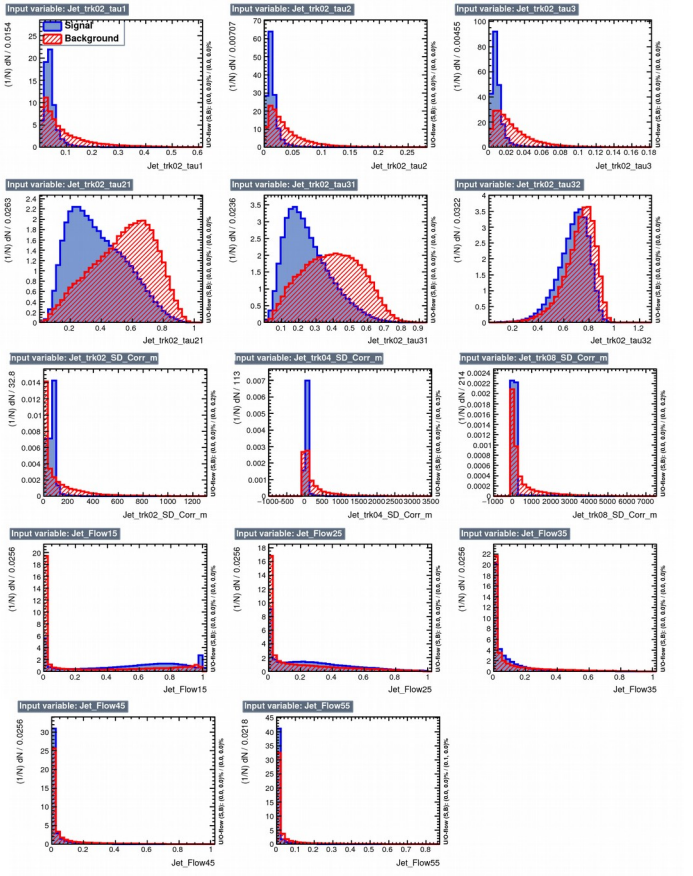
- Change strategy by training a BDT to get an anti-QCD jet tagger :
→ use leading and second leading jet in the event to build jet collection,
→ 2 taggers : t_had Vs. QCD and W_had Vs. QCD,
→ rerun 1M independent events for signal and bkgd training,
→ signals : RSG → WW and Z' → ttbar 20 TeV mass only,
→ background : p8_pp_jj_lo (pTHatMin = 2500, bias2SelectionPow = 6)
→ use only hadronic decay events,

→ set of variables similar to the CUT based ones to fully exploit them,
→ universal jet tagger that can be re-used in various analysis.

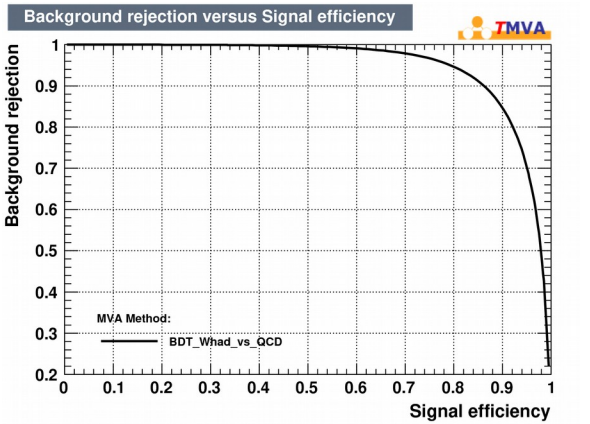
W_had Vs. QCD

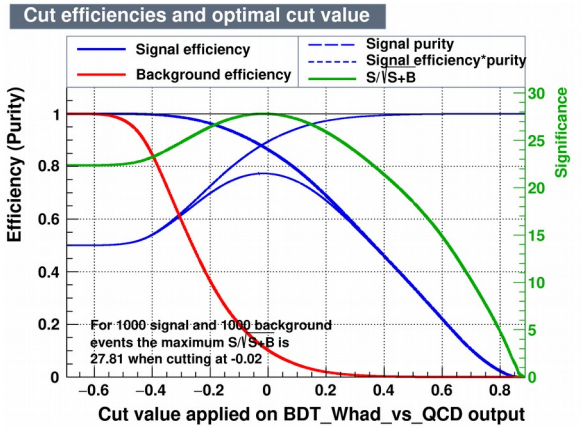


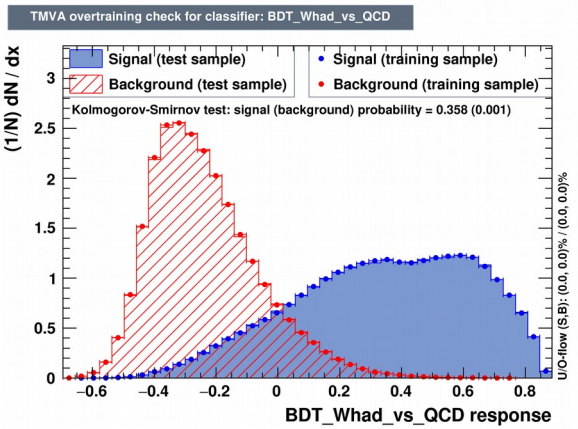





```
--------------------------------------------
Rank  : Variable            : Variable Importance
--------------------------------------------
   1  : Jet_trk02_tau3      : 1.182e-01
   2  : Jet_trk02_SD_Corr_m : 1.069e-01
   3  : Jet_trk02_tau31     : 9.761e-02
   4  : Jet_Flow55          : 9.005e-02
   5  : Jet_Flow45          : 8.706e-02
   6  : Jet_Flow15          : 7.537e-02
   7  : Jet_Flow25          : 6.787e-02
   8  : Jet_Flow35          : 6.442e-02
   9  : Jet_trk02_tau21     : 6.112e-02
  10  : Jet_trk08_SD_Corr_m : 6.082e-02
  11  : Jet_trk04_SD_Corr_m : 5.662e-02
  12  : Jet_trk02_tau1      : 5.326e-02
  13  : Jet_trk02_tau2      : 3.646e-02
  14  : Jet_trk02_tau32     : 2.424e-02
```



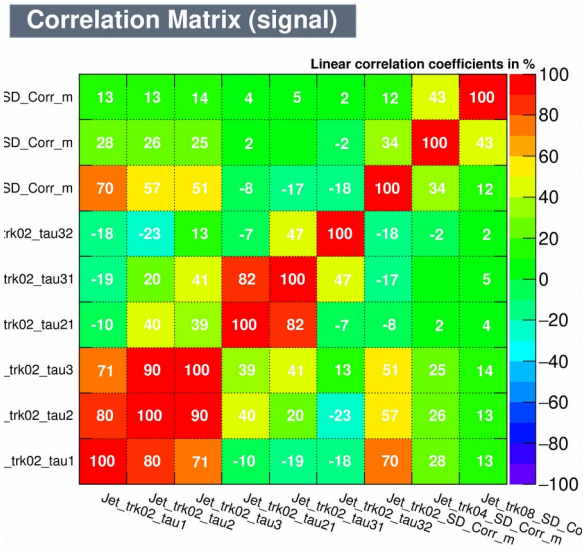


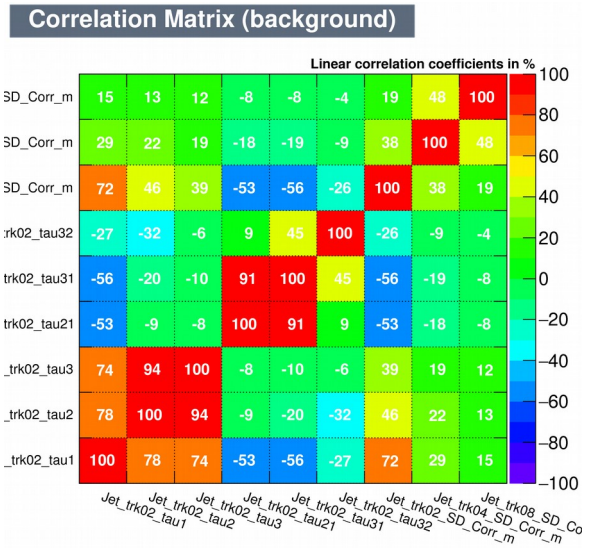


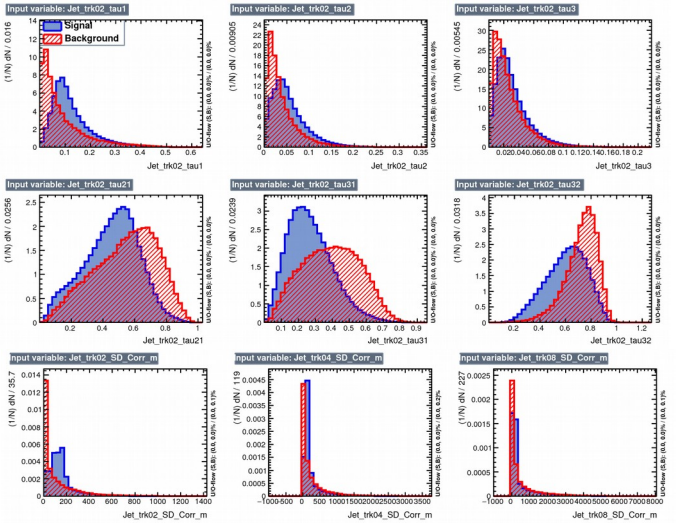
Changed R 0.2 →0.05
for jet flow vars

→ cut > 0 → cut > 0.15
effS~85% effS~75%
effB~15% effB~5%

t_had Vs. QCD








```
--------------------------------------------
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--------------------------------------------
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   2 : Jet_trk02_SD_Corr_m : 1.739e-01
   3 : Jet_trk02_tau31     : 1.074e-01
   4 : Jet_trk02_tau2      : 9.671e-02
   5 : Jet_trk02_tau3      : 9.472e-02
   6 : Jet_trk08_SD_Corr_m : 8.779e-02
   7 : Jet_trk04_SD_Corr_m : 8.600e-02
   8 : Jet_trk02_tau32     : 8.590e-02
   9 : Jet_trk02_tau21     : 5.773e-02
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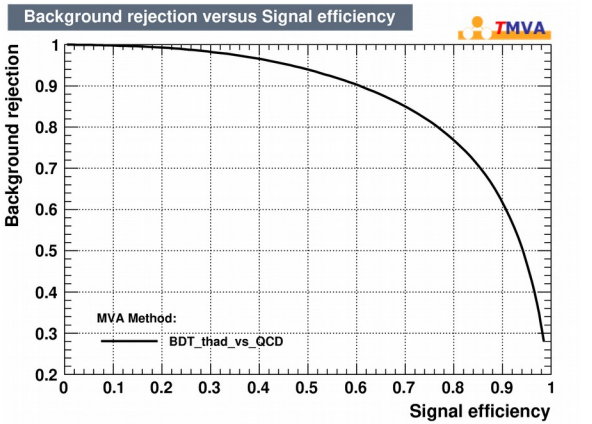
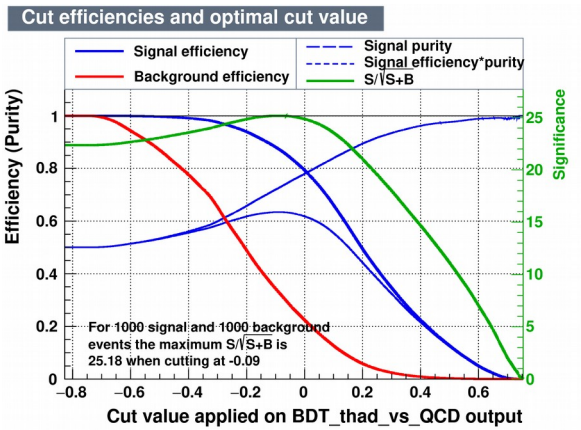
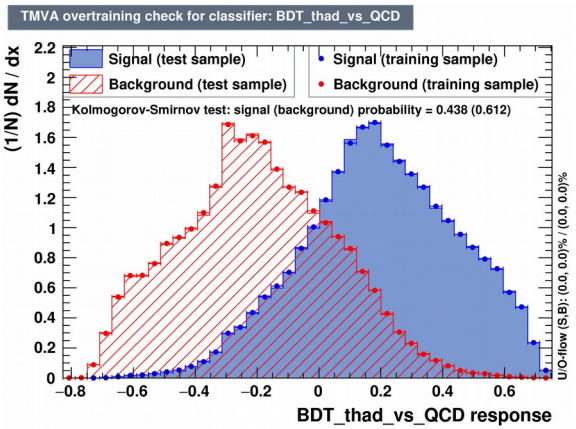






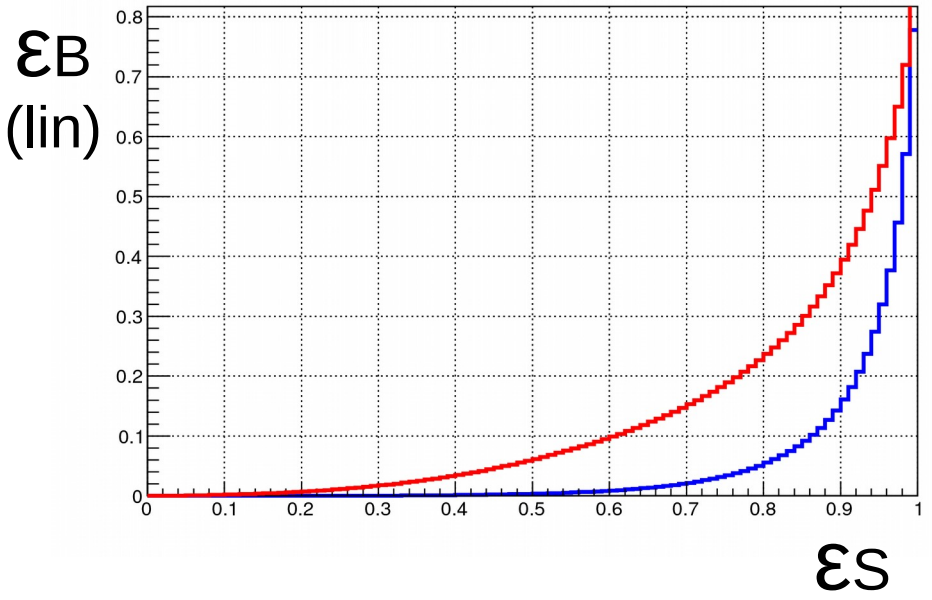
→ cut > -0.1 → cut > 0.15

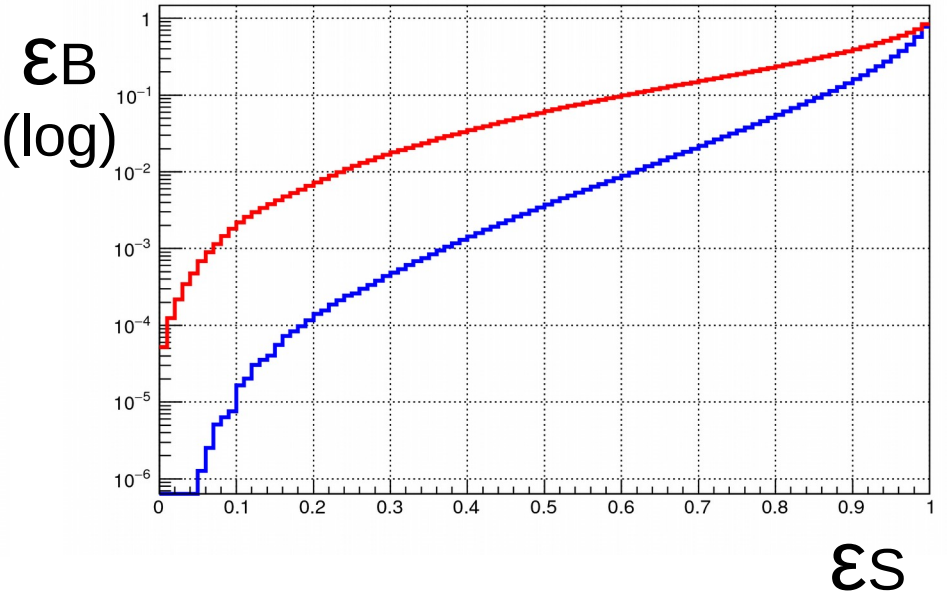
effS~90% effS~60%

effB~35% effB~10%

ROC comparison

Whad Vs QCD tagger
thad Vs QCD tagger





Z'->ttbar

- Signal with pythia8
- Cross sections from benchmark top-color model
- Important benchmark model for detector performance on sub-structure
- Analysis selection
  - Jet Pt>3TeV, jet eta <3
  - J1,2 SoftDropped mass>100GeV
  - J1,2 Tau32<0.7 0.3<J1,2 Tau21<0.7
  - Use b-tagging
  - Do not explicitly select leptons, but "correct" Mjj for MET

OR

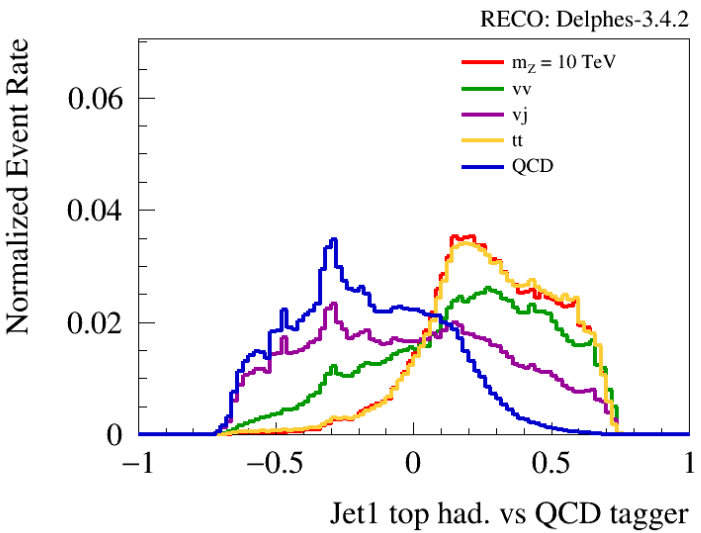
anti-QCD jet tagger cut

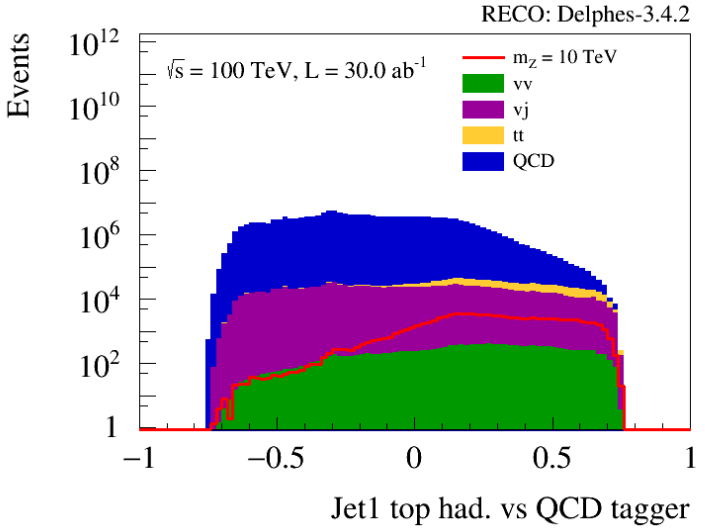
- 20% uncertainty assumed on the ttbar normalization when setting limits and discovery reach

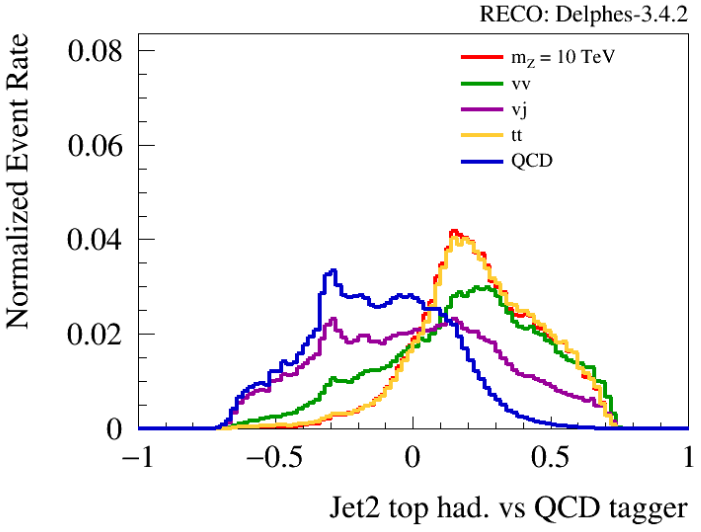
Z'->ttbar

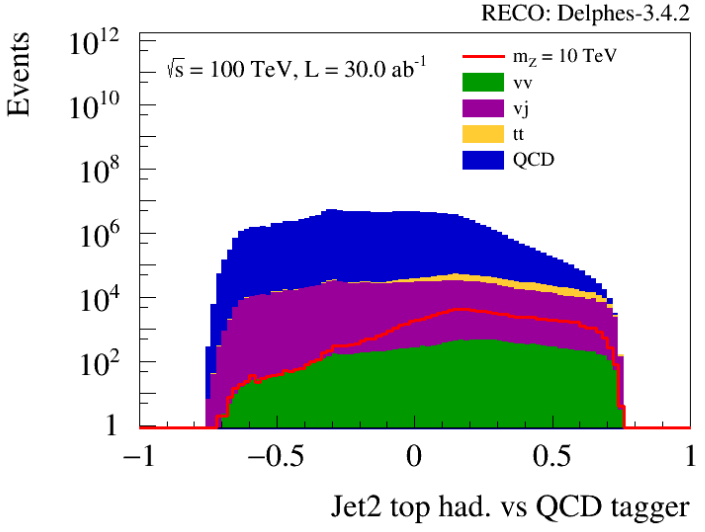
Jet pt1,2>3TeV,
eta<3
+ jet1,2 tauXY>0

process	yield (30.0 ab-1)	stat. error	raw
m_{Z} = 10 TeV	101628.1	260.4	152296
vv	15908.7	16.1	980204
vj	1435042.6	2192.2	430244
tt	474156.1	657.6	520741
QCD	165674068.7	215748.7	591789
signal	101628.085	16.137	
background	167599176.139	215760.856	





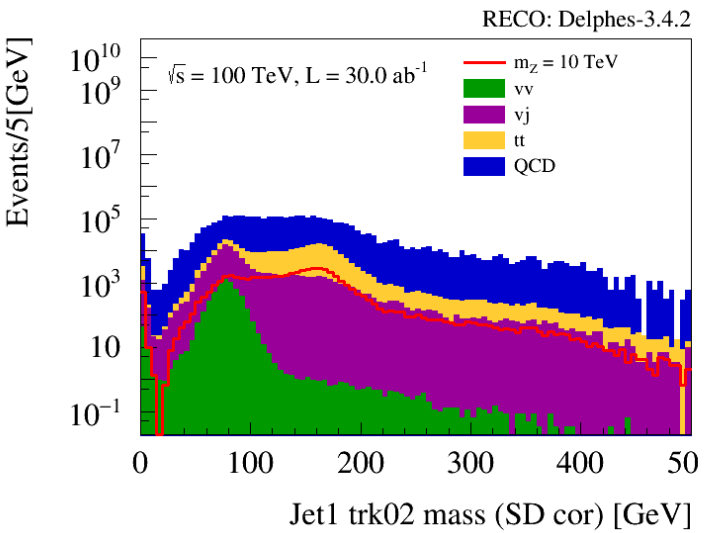


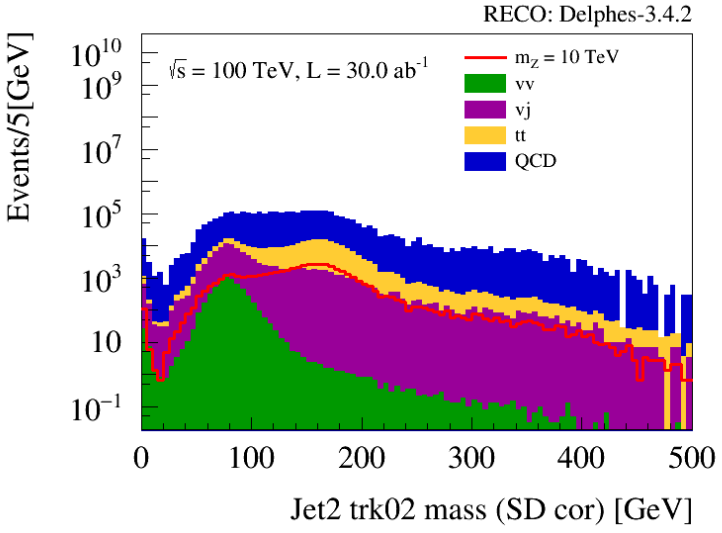


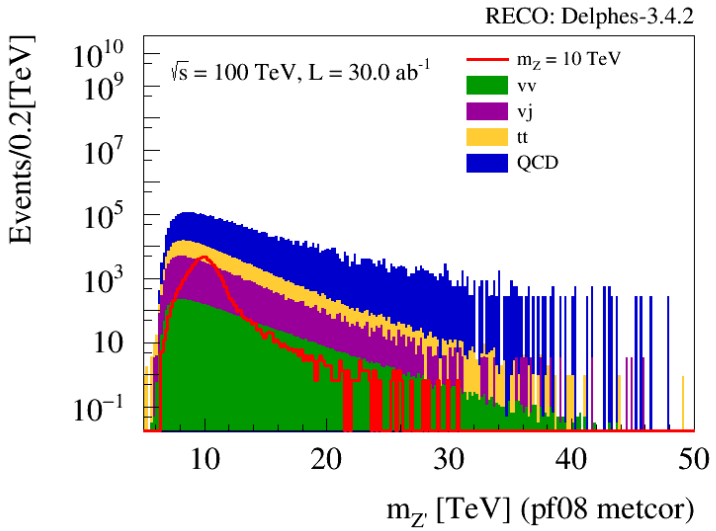
Z'->ttbar

+ jet1,2 tagger > 0.15

process	yield (30.0 ab-1)	stat. error	raw
m_{Z} = 10 TeV	49213.8	181.2	73750
vv	5645.1	9.6	347680
vj	105117.1	593.3	31518
tt	233874.5	461.8	256853
QCD	3007330.0	29060.7	10737
signal	49213.842	13.462	
background	3351966.595	29070.439	







Z'->ttbar

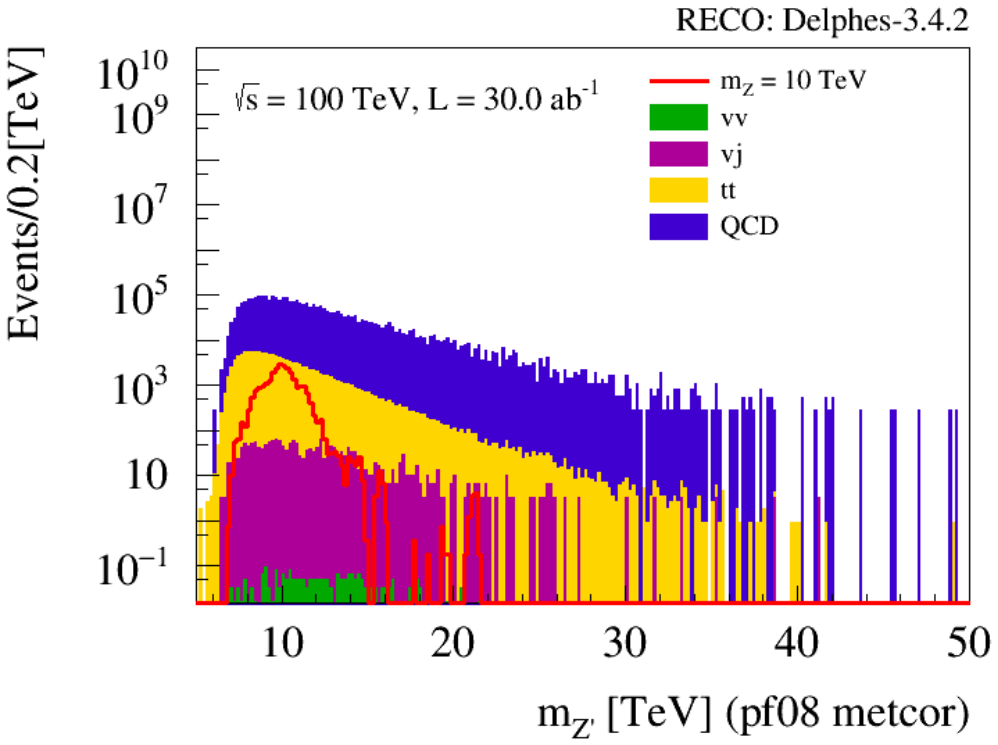
All cuts before b-tag

+ jet1,2 m > 40 GeV

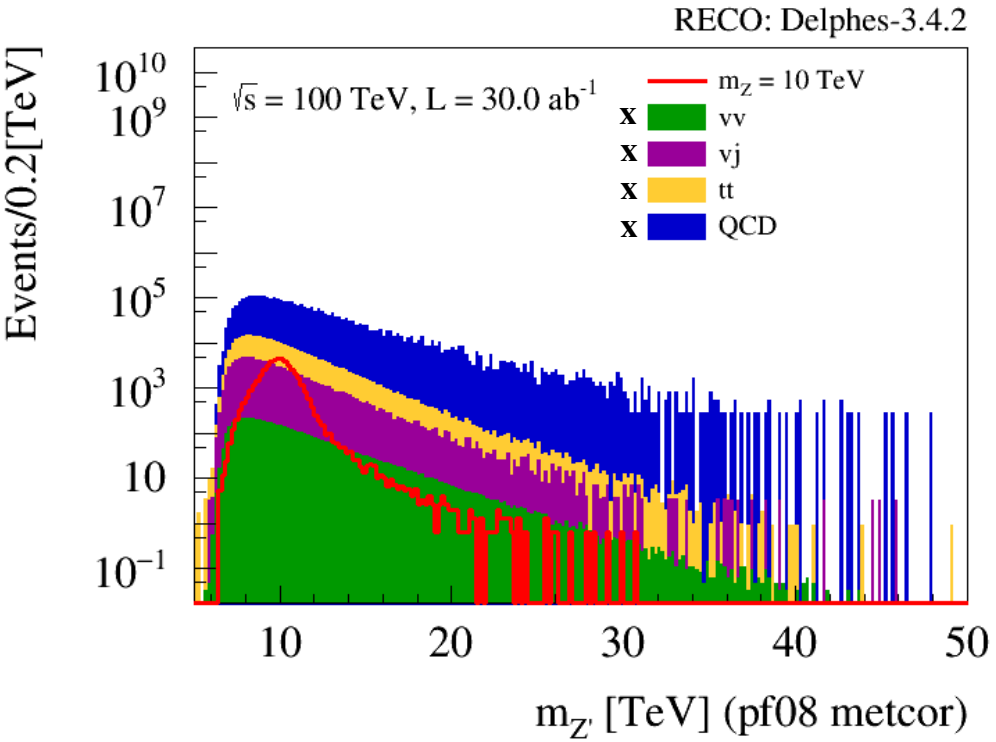
process	yield (30.0 ab-1)	stat. error	raw
m_{Z} = 10 TeV	26806.2	69.7	147971
vv	2.5	0.2	155
vj	2038.1	82.9	613
tt	133003.2	348.4	146028
QCD	2895102.2	28524.9	10321
signal	26806.243	8.348	
background	3030146.033	28527.139	

process	yield (30.0 ab-1)	stat. error	raw
m_{Z} = 10 TeV	48429.1	179.8	72574
vv	5531.2	9.5	340671
vj	101958.8	584.3	30567
tt	230679.5	458.7	253347
QCD	2919547.2	28634.0	10424
signal	48429.09	13.408	
background	3257716.669	28643.633	

CUT analysis



tagger analysis



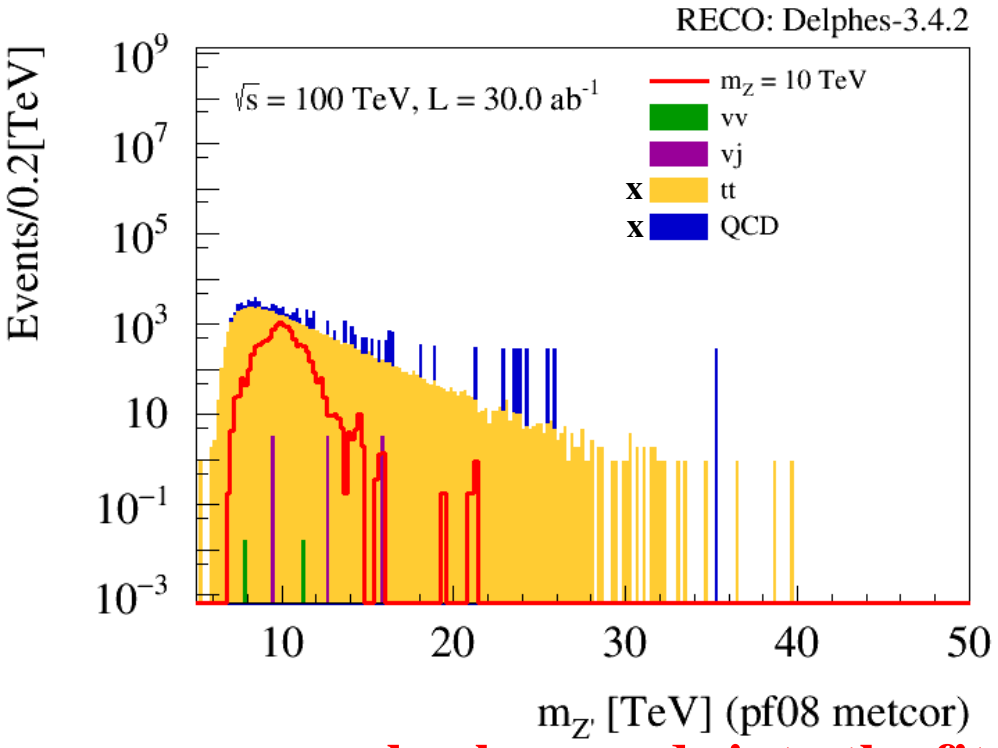
Z'->ttbar

+both leading
pT tagged

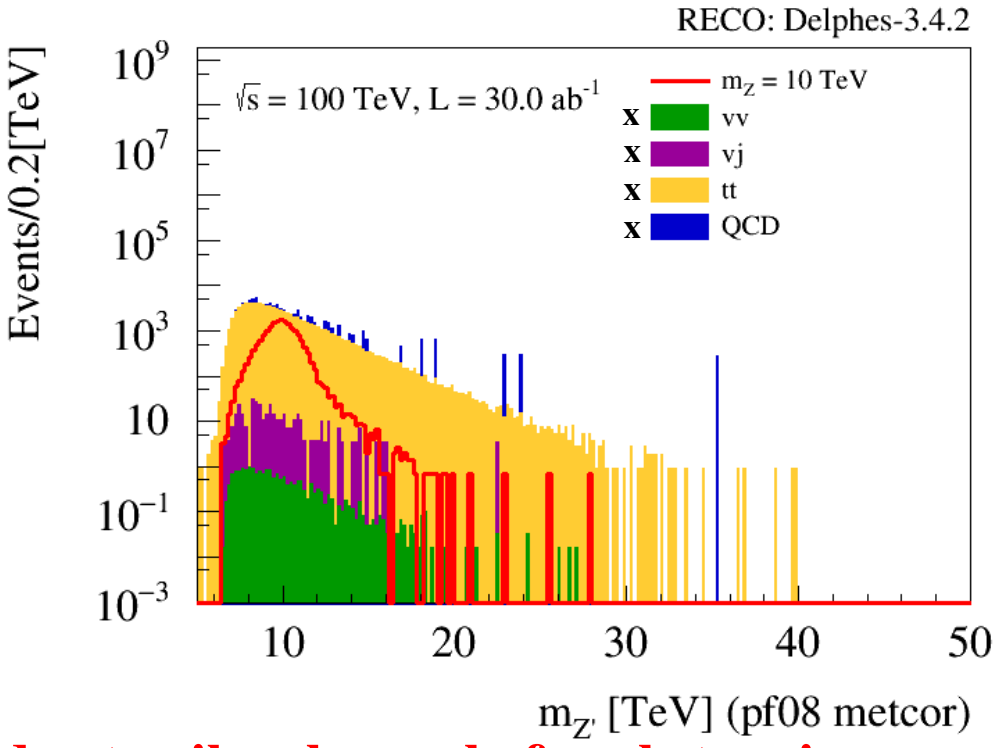
process	yield (30.0 ab-1)	stat. error	raw
m_{Z} = 10 TeV	9937.1	42.4	54853
vv	0.0	0.0	2
vj	10.0	5.8	3
tt	50554.0	214.8	55493
QCD	24427.7	2618.9	87
signal	9937.102	6.514	
background	74991.783	2627.72	

process	yield (30.0 ab-1)	stat. error	raw
m_{Z} = 10 TeV	18312.2	110.5	27442
vv	19.4	0.6	1193
vj	371.0	35.2	111
tt	88399.9	283.9	97078
QCD	14864.2	2041.8	53
signal	18312.22	10.514	
background	103654.5	2061.699	

CUT analysis



tagger analysis



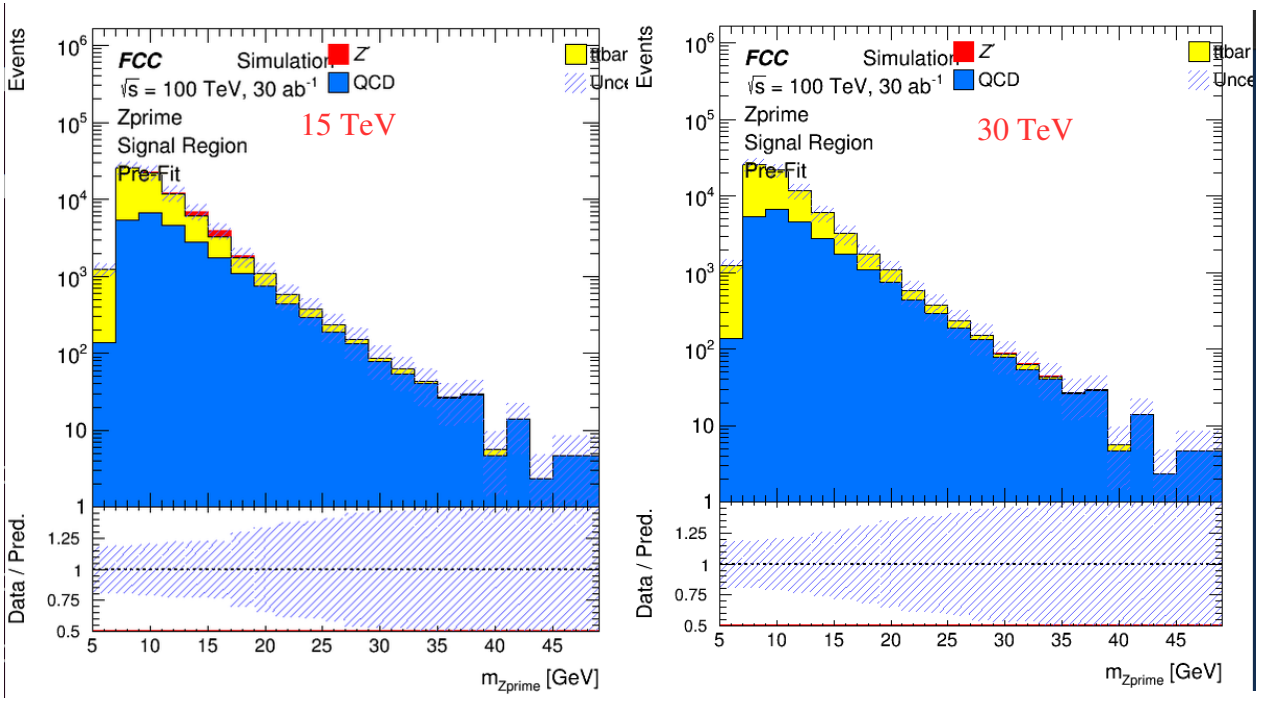
→ **use x backgrounds into the fit and get spiky shapes before b-tagging**

Z'->ttbar

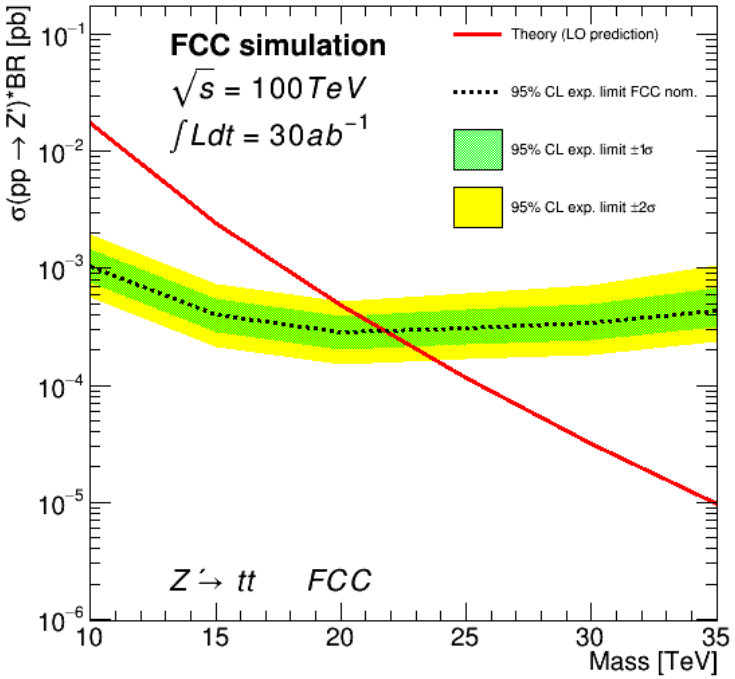
ttbar 20% QCD 50%, VV 20%, VJ 40%

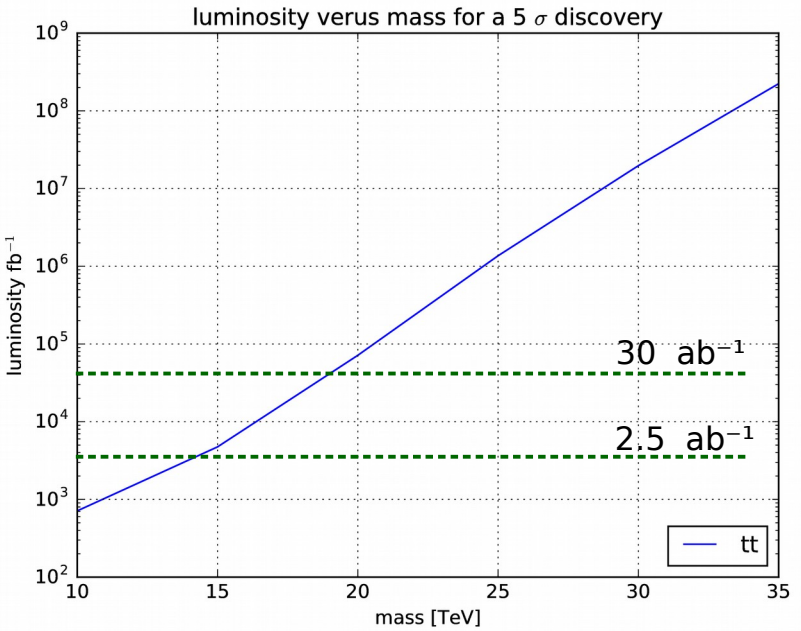
CUT analysis

m_{Z} = 10 TeV	9937.1
m_{Z} = 15 TeV	2197.1
m_{Z} = 20 TeV	397.9
m_{Z} = 25 TeV	76.7
m_{Z} = 30 TeV	14.2
m_{Z} = 35 TeV	3.5
tt	50554.0
QCD	24427.7



Limit versus mass

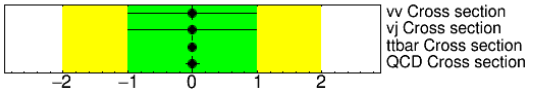




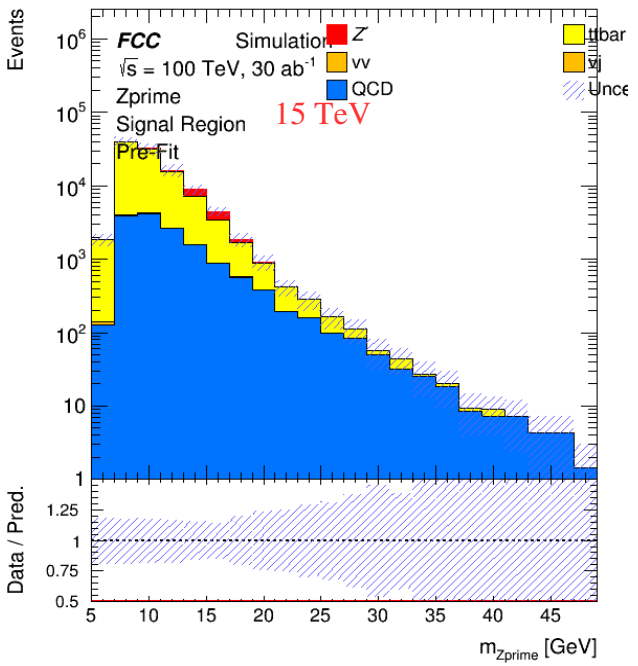
Z'->ttbar

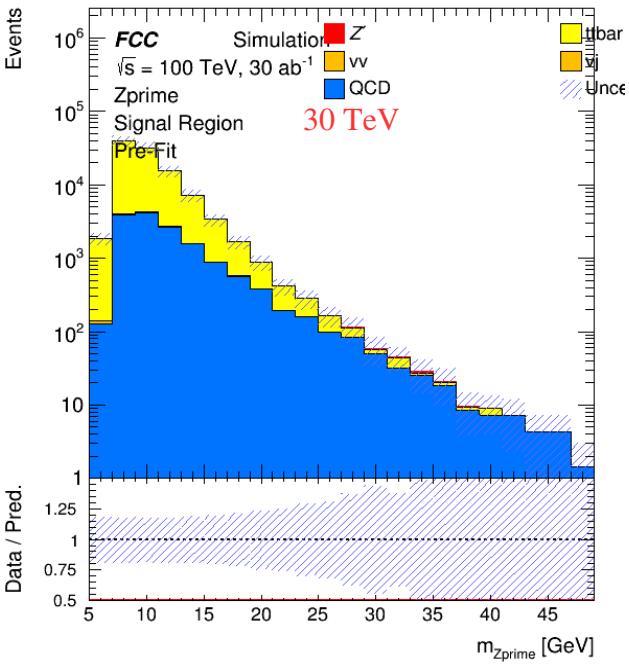
tagger analysis

m_{Z} = 10 TeV	18312.2
m_{Z} = 15 TeV	3976.0
m_{Z} = 20 TeV	667.4
m_{Z} = 25 TeV	113.9
m_{Z} = 30 TeV	22.4
m_{Z} = 35 TeV	5.2
tt	88299.9
QCD	14864.2
Vj	371.0
VV	19.4

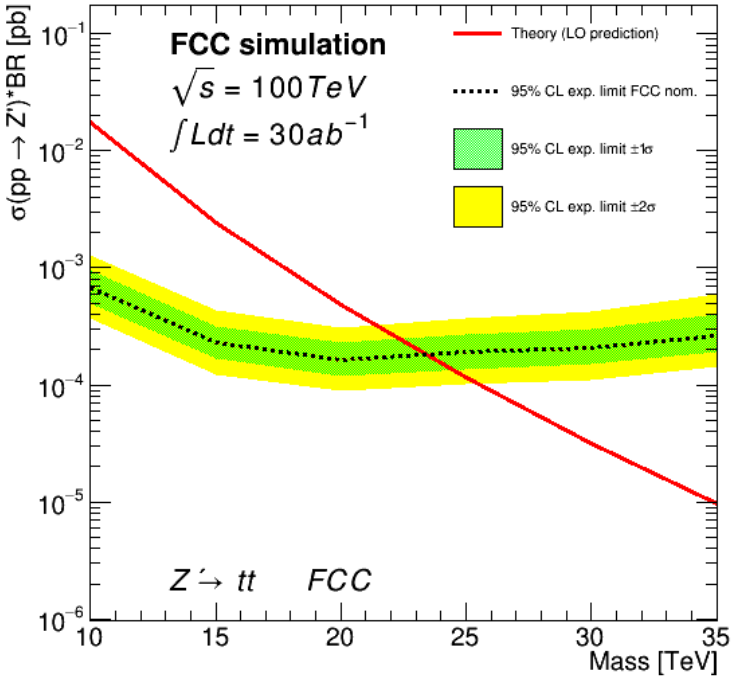


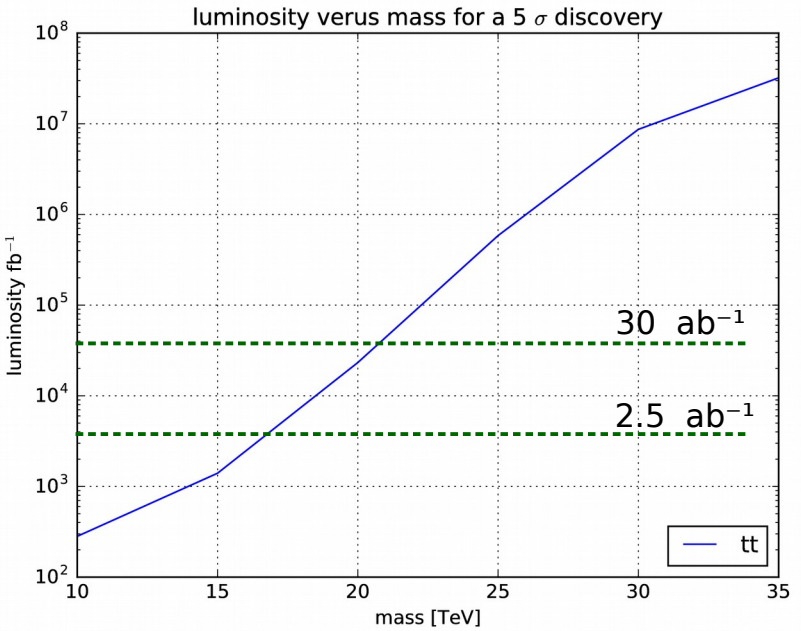
ttbar 20% QCD 50%, VV 20%, VJ 40%





Limit versus mass





Di-boson resonance

- Signal with pythia8
- Cross sections from Pythia8
- Important benchmark model for detector performance on sub-structure
- Analysis selection (Fully hadronic)
  - Jet Pt>3TeV, jet eta <3
  - J1,2 SoftDropped 100<mass<50GeV
  - J1,2 Tau21<0.6
  - Jet 1,2 flow 1-5>0.85
  - Jet 1,2 flow 2-5<0.05
- Norm uncertainties
  - ttbar 20% QCD 50%, VV 20%, VJ 40%

OR

anti-QCD jet tagger cut

$$\mathrm{Flow}_{n,5} = \sum_k \frac{|p_T^k|}{|p_T^{\mathrm{jet}}|}$$

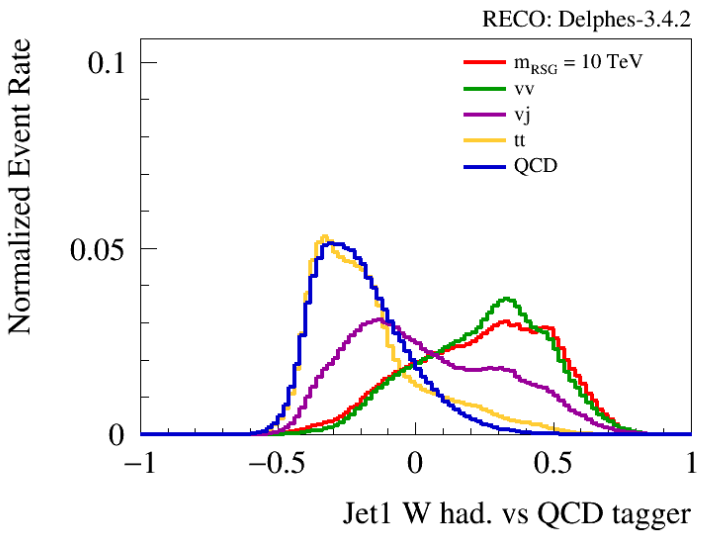
$$\frac{n-1}{5}R \leq \Delta R(k, \mathrm{jet}) < \frac{n}{5}R,$$

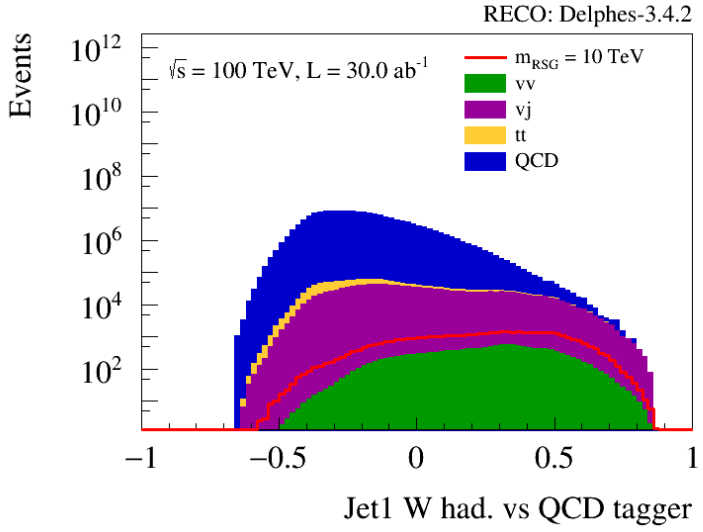
Changed R 0.2 → 0.05

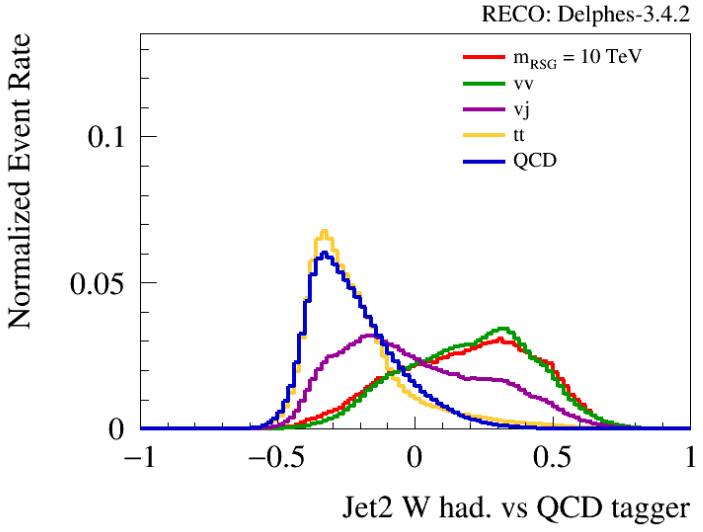
Di-boson res

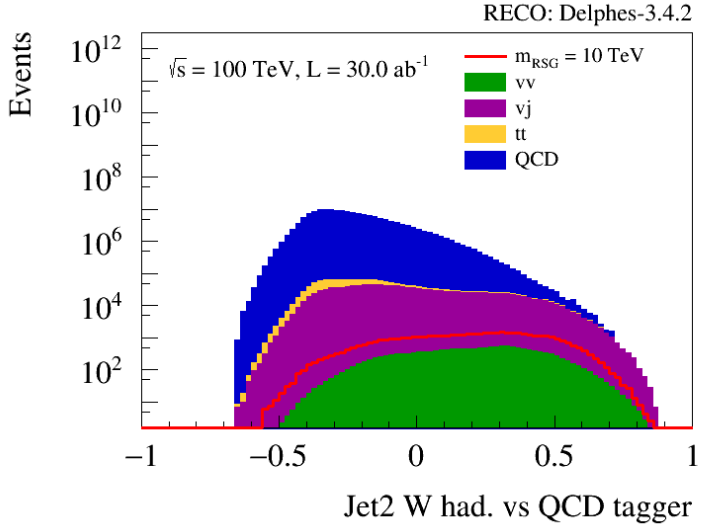
Jet pt1,2>3TeV,
eta<3
+ jet1,2 tauXY>0

process	yield (30.0 ab-1)	stat. error	raw
m_{RSG} = 10 TeV	48214.8	116.4	171464
vv	15907.9	16.1	980158
vj	1434922.3	2192.1	430208
tt	474152.5	657.6	520737
QCD	165674068.7	215748.7	591789
signal	48214.84	10.791	
background	167599051.428	215760.855	





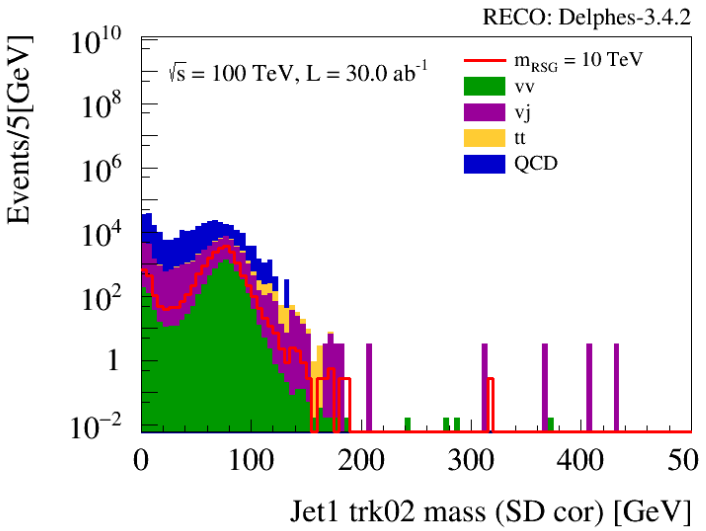


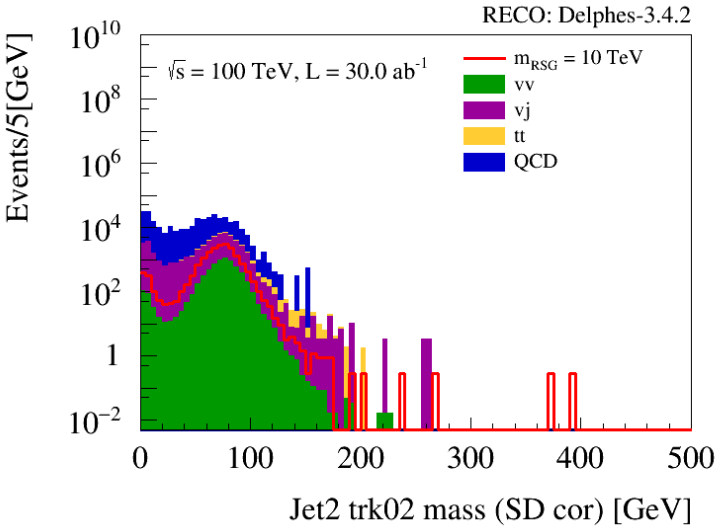


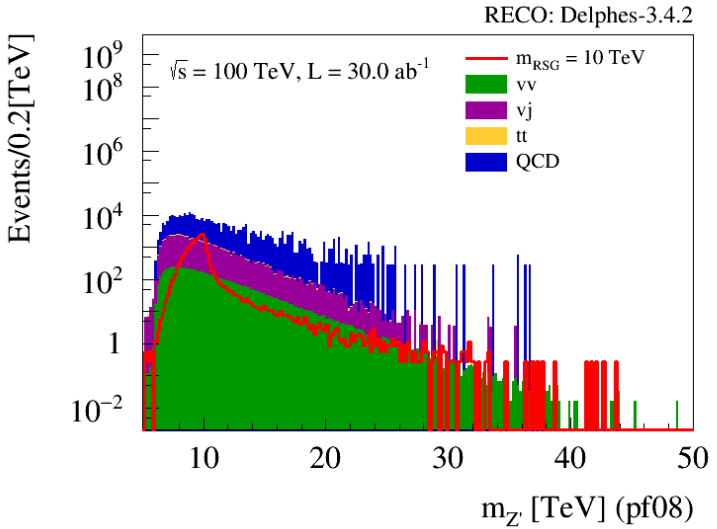
Di-boson res

+ jet1,2 tagger > 0.15

process	yield (30.0 ab-1)	stat. error	raw
m_{RSG} = 10 TeV	18194.2	71.5	64703
vv	6437.7	10.3	396715
vj	49396.9	406.9	14822
tt	3463.8	56.2	3809
QCD	254093.2	8451.0	908
signal	18194.168	8.457	
background	313391.479	8460.975	







Di-boson res

All cuts

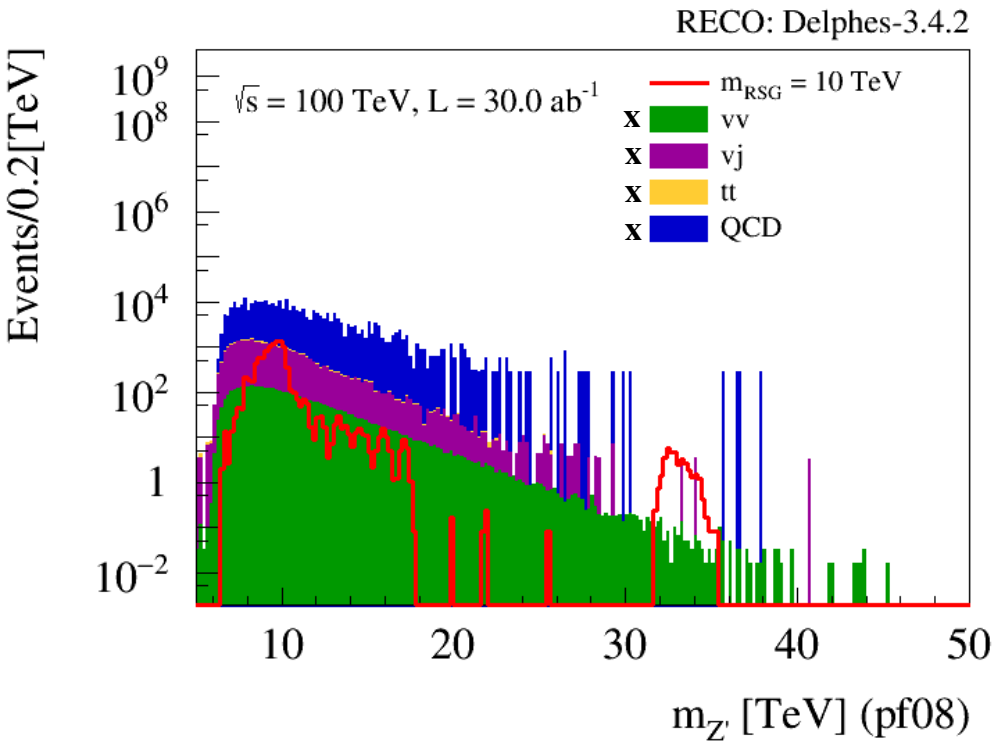
(+ Jet 1,2 flow 1,5>0.85
Jet 1,2 flow 2,5<0.05)

+ jet1,2 m > 40 GeV

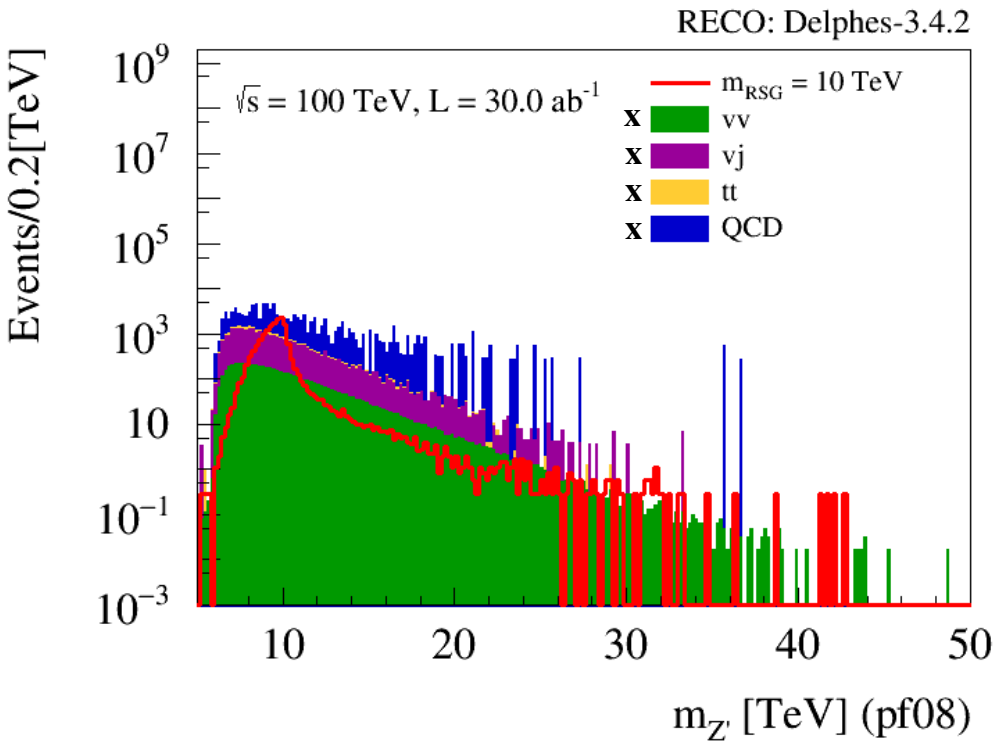
process	yield (30.0 ab-1)	stat. error	raw
m_{RSG} = 10 TeV	10173.3	28.7	125302
vv	3782.0	7.9	232668
vj	29872.7	316.8	8960
tt	1922.7	41.9	2115
QCD	280497.2	8874.5	999
signal	10173.287	5.361	
background	316074.633	8880.295	

process	yield (30.0 ab-1)	stat. error	raw
m_{RSG} = 10 TeV	15763.0	66.6	56057
vv	5748.7	9.7	354171
vj	25263.3	291.0	7583
tt	2967.1	52.0	3262
QCD	83575.9	4841.4	298
signal	15762.955	8.159	
background	117554.98	4850.45	

CUT analysis

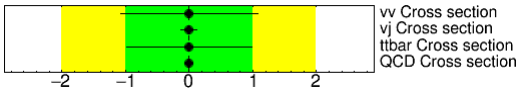


tagger analysis



→ **use x backgrounds into the fit and get QCD shape after preselection**

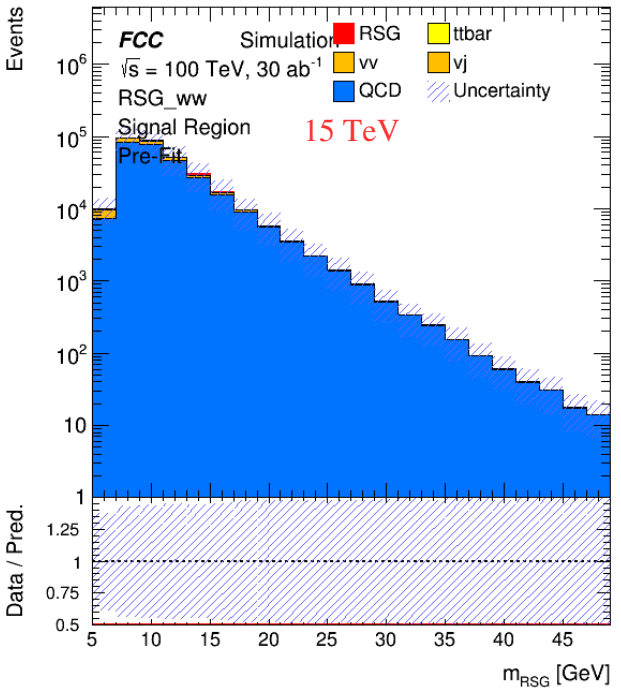
Di-boson res



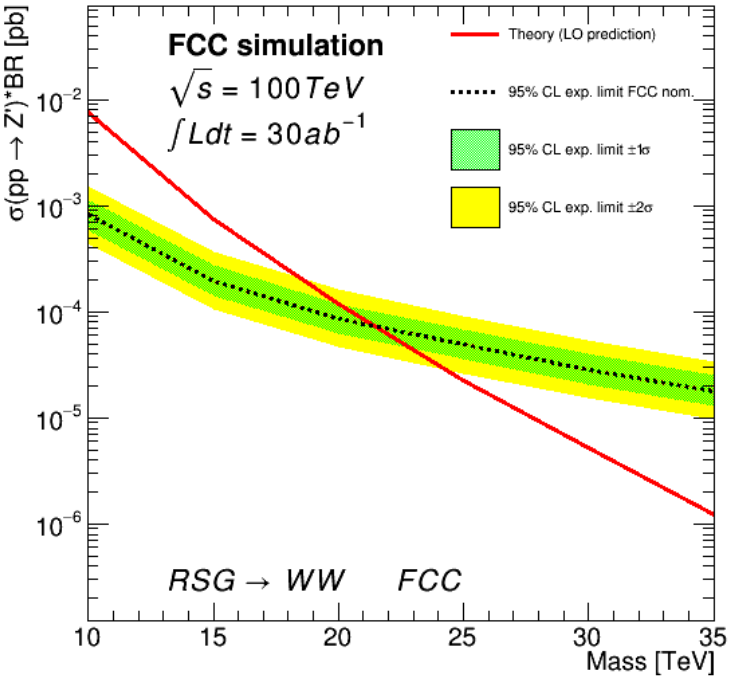
ttbar 20% QCD 50%, VV 20%, VJ 40%

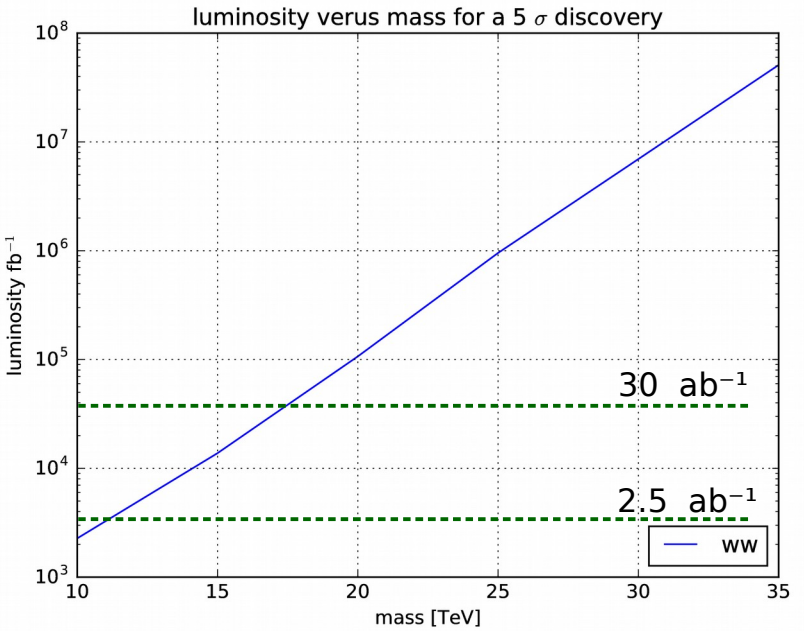
CUT analysis

m_{RSG} = 10 TeV	10173.3
m_{RSG} = 15 TeV	2239.8
m_{RSG} = 20 TeV	446.7
m_{RSG} = 25 TeV	91.9
m_{RSG} = 30 TeV	22.1
m_{RSG} = 35 TeV	5.3
tt	1922.7
QCD	280497.2
Vj	29872.7
VV	3782.0



Limit versus mass

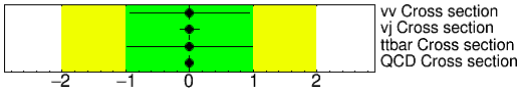




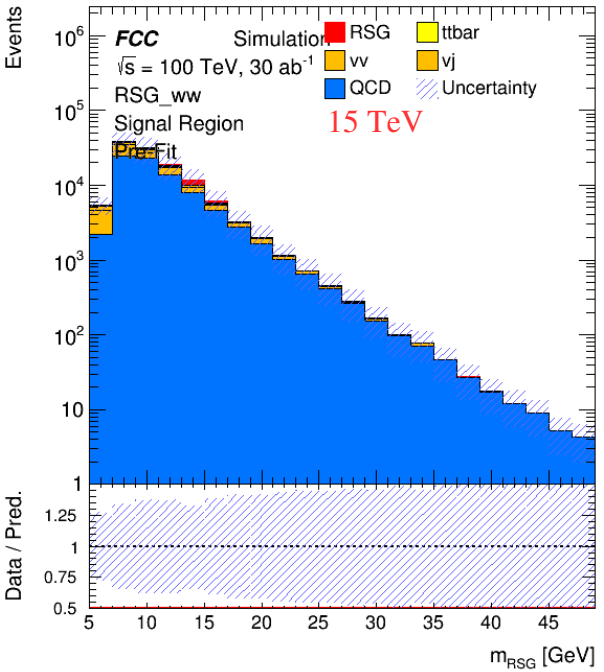
Di-boson res

tagger analysis

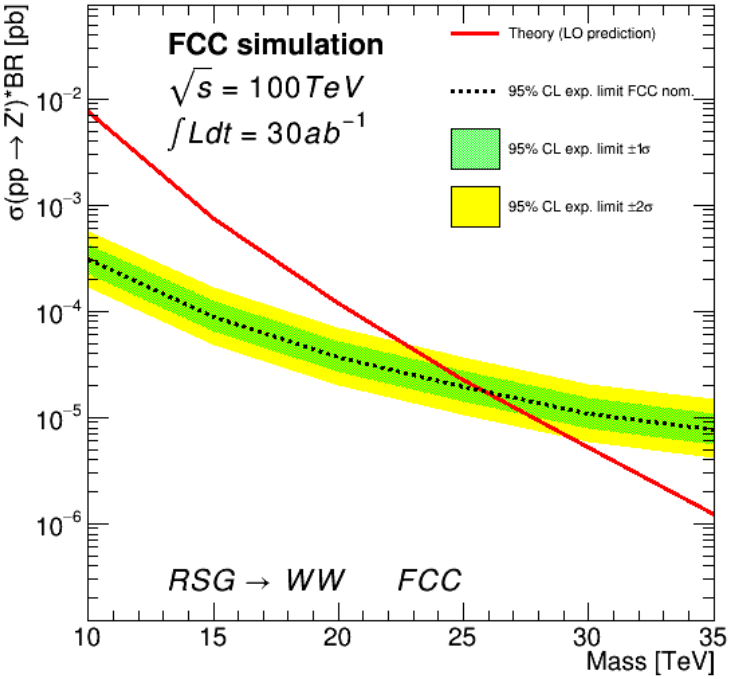
m_{RSG} = 10 TeV	15763.0
m_{RSG} = 15 TeV	3029.5
m_{RSG} = 20 TeV	627.5
m_{RSG} = 25 TeV	136.3
m_{RSG} = 30 TeV	33.7
m_{RSG} = 35 TeV	8.1
tt	2967.1
QCD	83575.9
Vj	25263.3
VV	5748.7

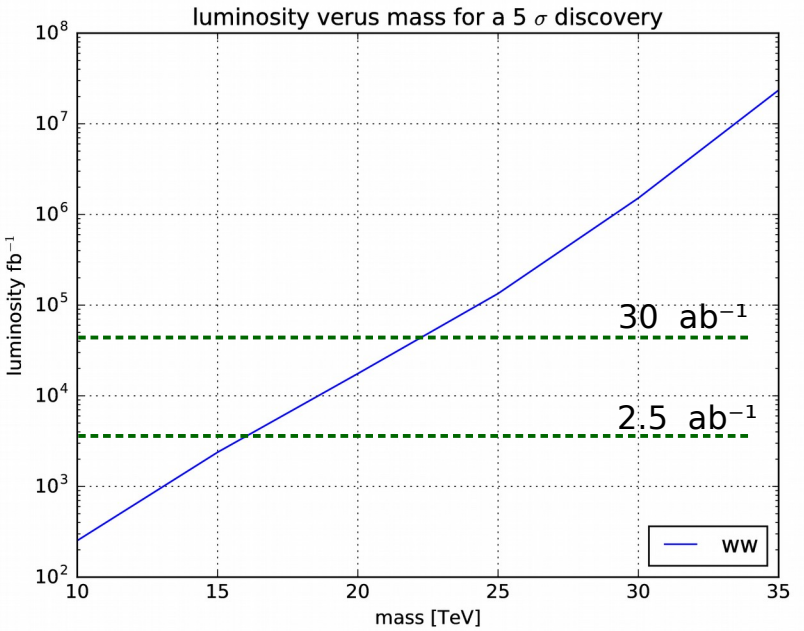


ttbar 20% QCD 50%, VV 20%, VJ 40%



Limit versus mass





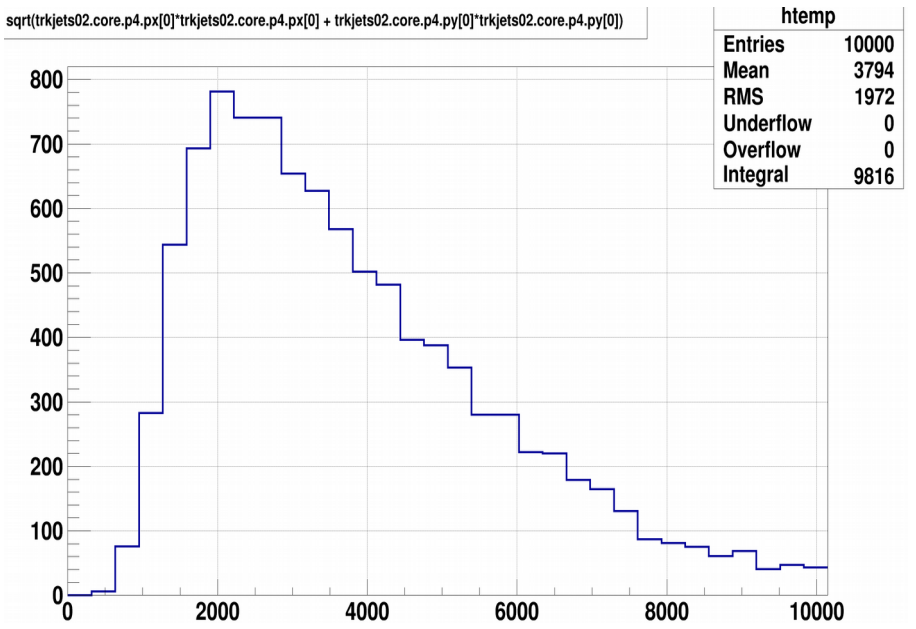
Summary

- Defined anti-QCD jet taggers for t_had and W_had :
  → simple cut on these taggers + 1 cleaning cut on jet mass reproduces and improves the whole CUT based analysis.

- Next steps :
  → document all these studies in a standalone note/paper.
  → go to detector level, compare DELPHES / Full sim performances and reproduce these analysis and the taggers.

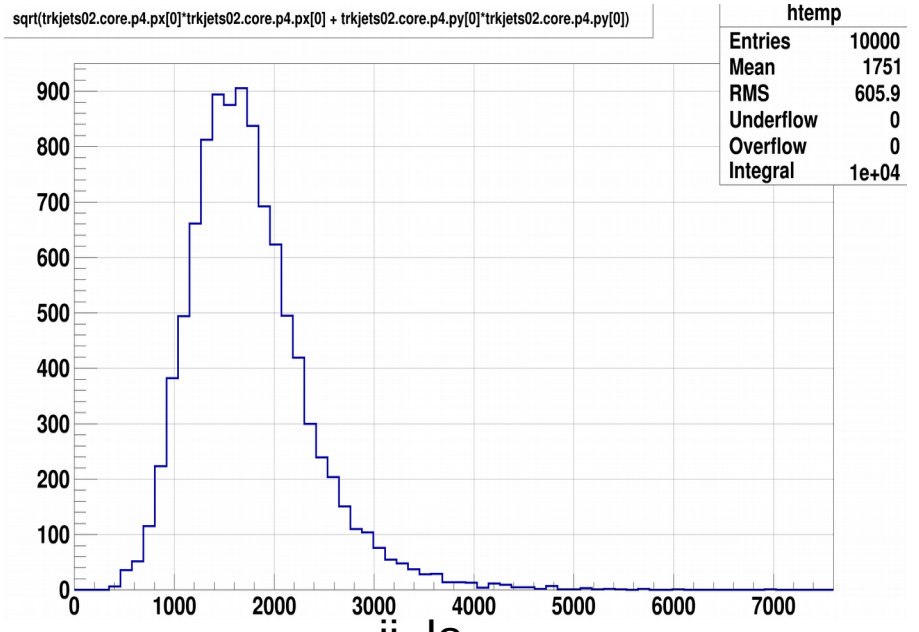
Back-up

Training samples leading jet pT



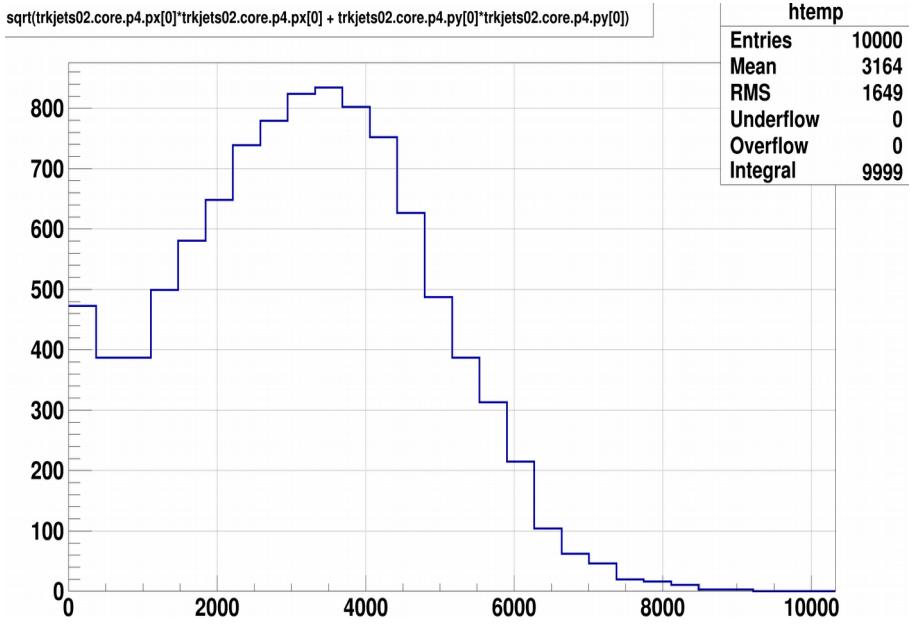
jj_lo

pTHatMin = 2500, bias2SelectionPow = 6

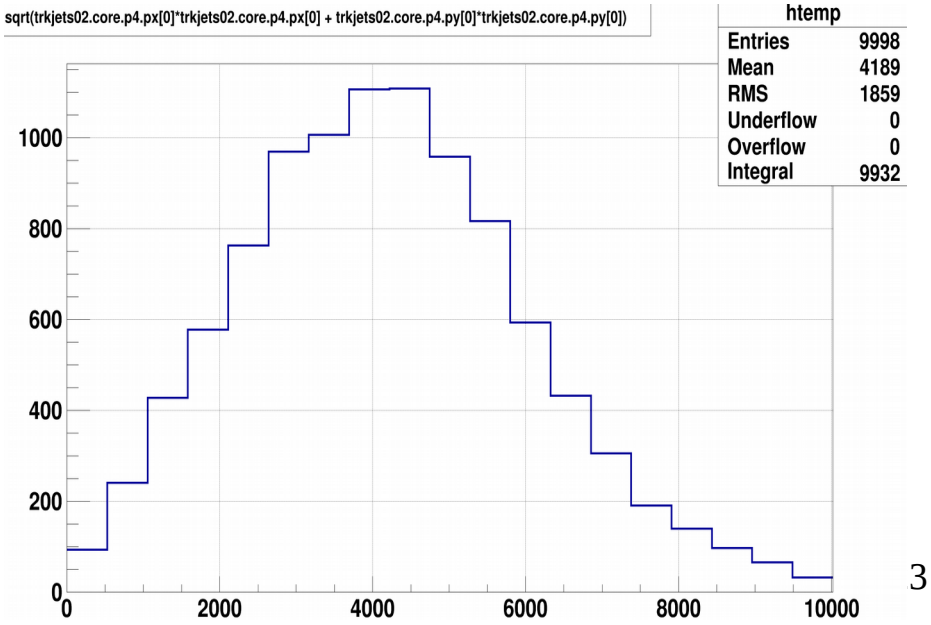


jj_lo

pTHatMin = 2500



Zprime_20TeV_ttbar



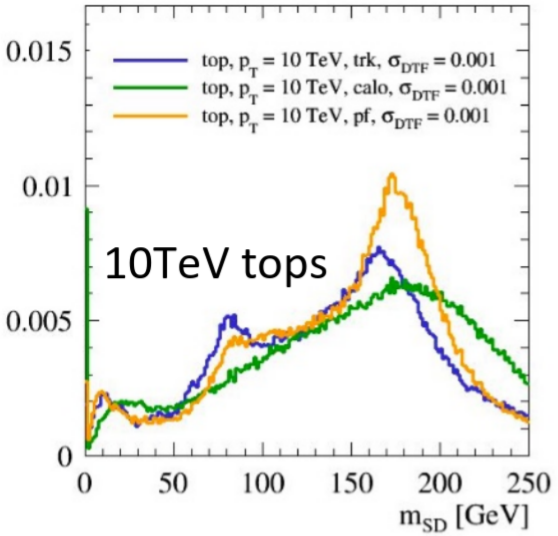
RSGraviton_20TeV_ww

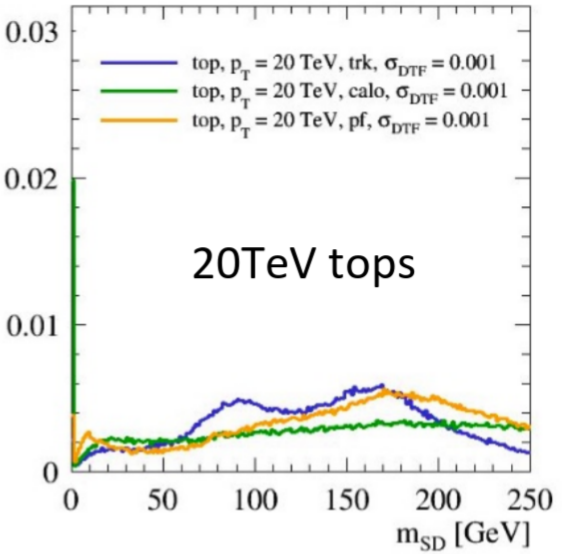
Boosted objects

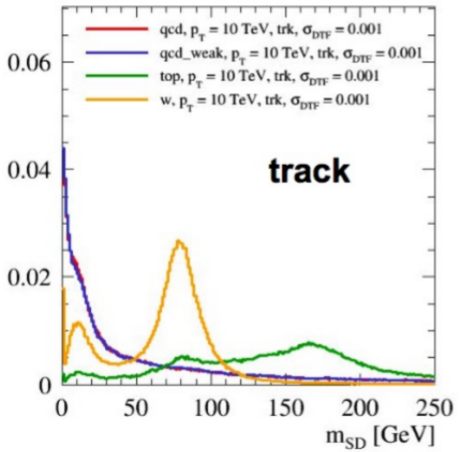
- What is:
  - Optimal jet collection
  - minimal track angular resolution?
- Assessed using :
  - QCD, QCD+weak shower, W and Top jets
  - GenJets, CaloJets, Particle Flow Jets, Track Jets with 2-5-10-20 TeV
- Outcome: use track jets for sub-structure corrected to pf jets

- More information in Michele's talk here

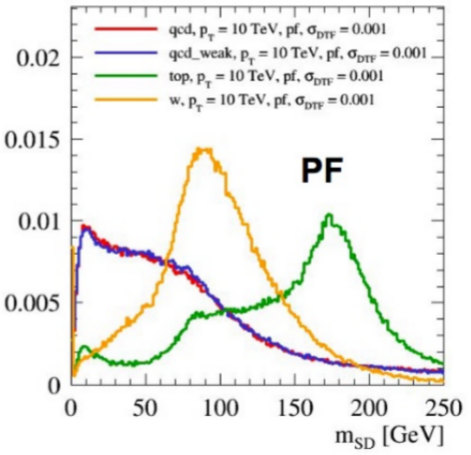
- Performance of reconstructing such boosted objects Will be further checked in full simulation for the report







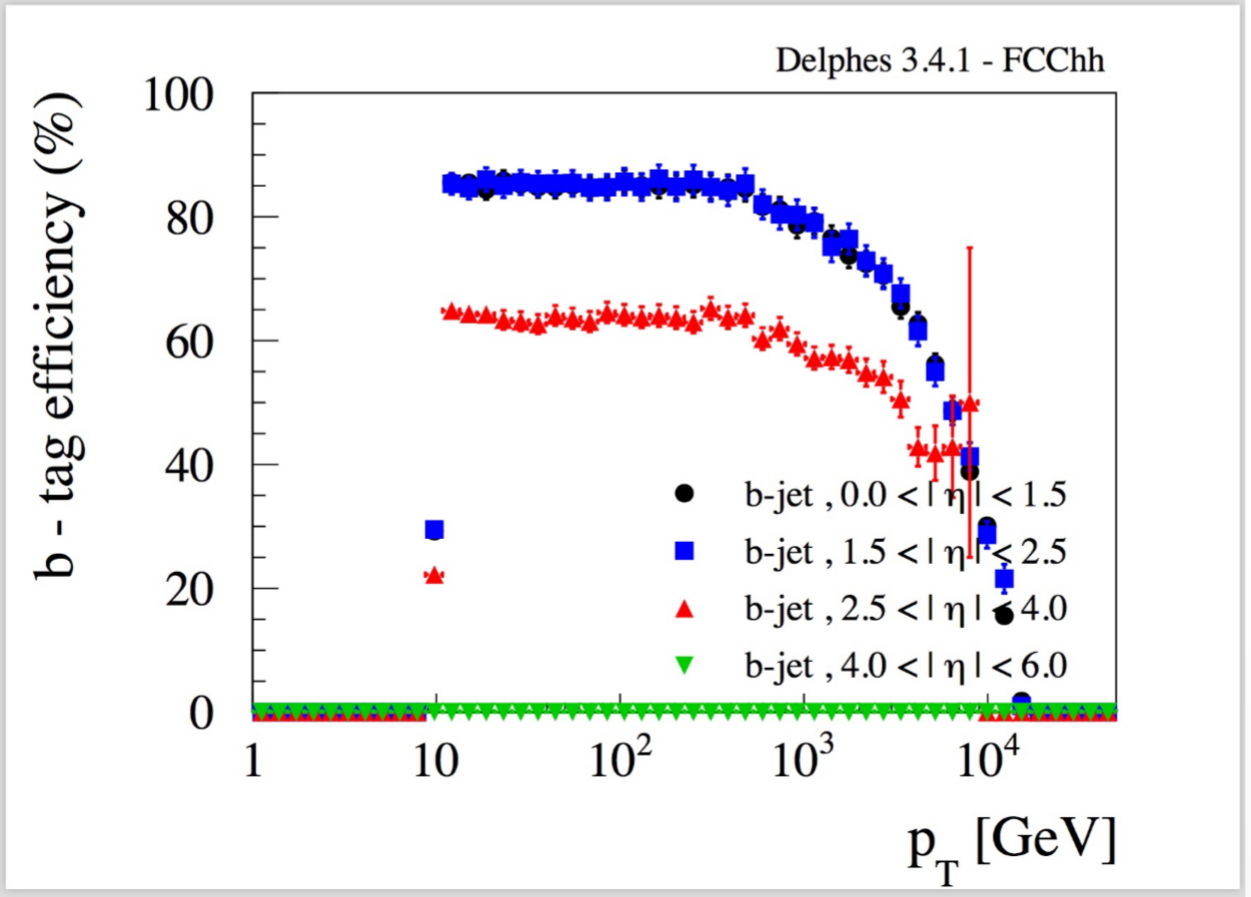
10TeV objects



- Track jets seems to be more robust and better understood at high pT
- Use those corrected by p-flow jet pT

B-tagging

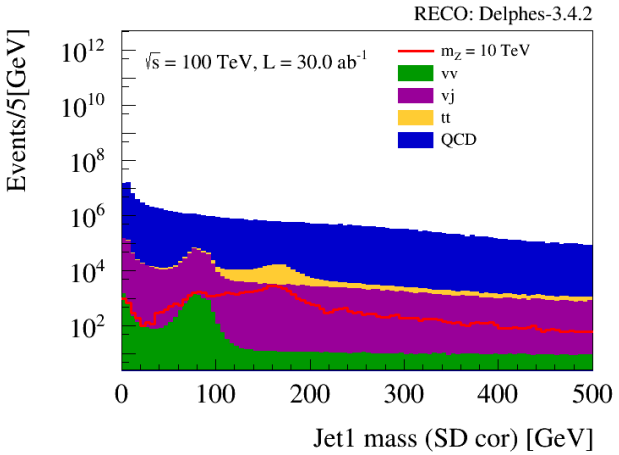
- b-tagging to match first results from full simulation study without tracks (hit multiplicity jump)

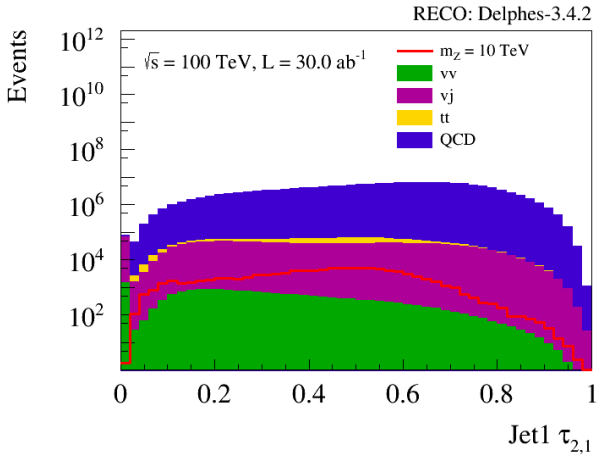


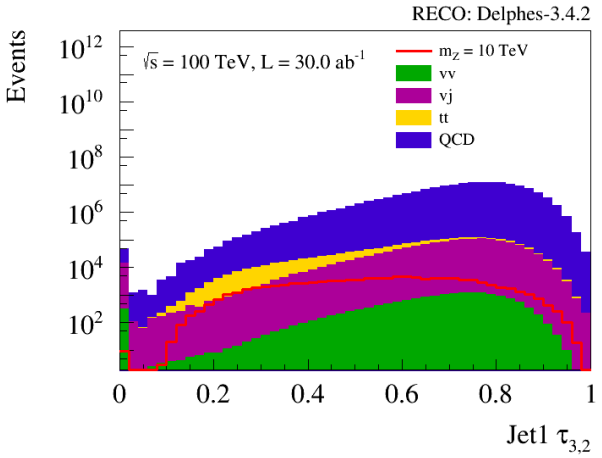
Z'->ttbar

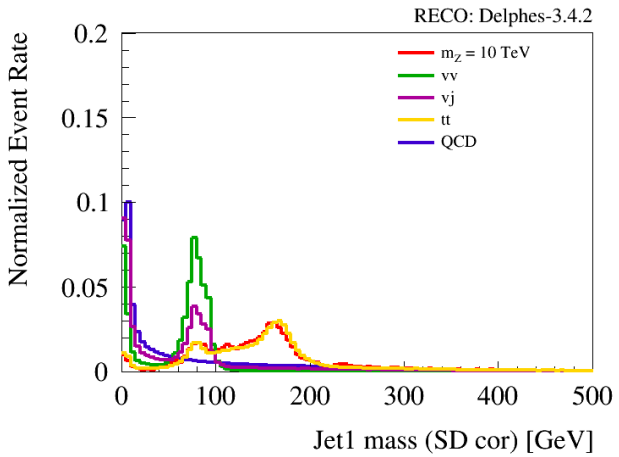
CUT 1 Jet pt1,2>3TeV, eta<3

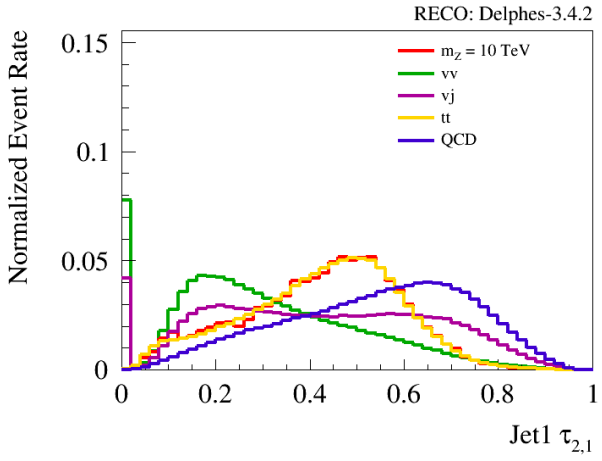
process	yield (30.0 ab-1)	stat. error	raw
m_{Z} = 10 TeV	100153.4	134.7	552849
vv	19782.5	18.0	1216831
vj	1602606.0	2318.2	479825
tt	474716.2	658.1	521145
QCD	164516827.7	215118.1	586986
signal	100153.441	11.606	
background	166613932.371	215131.612	

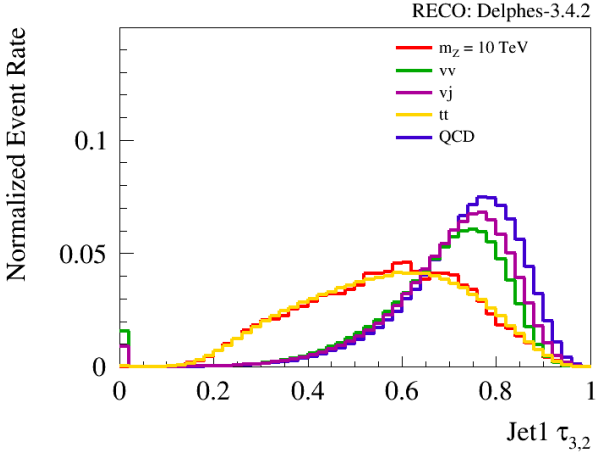










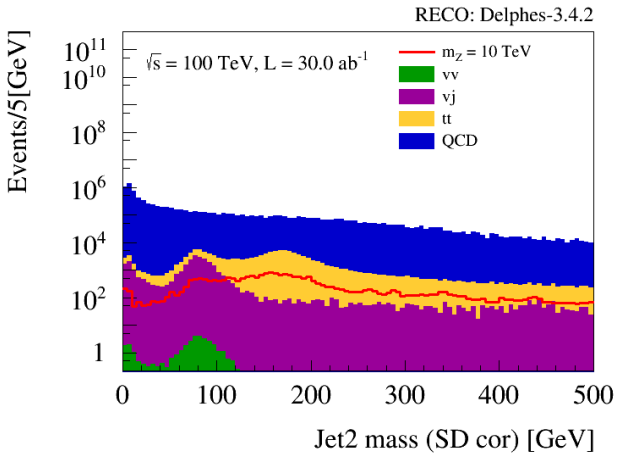


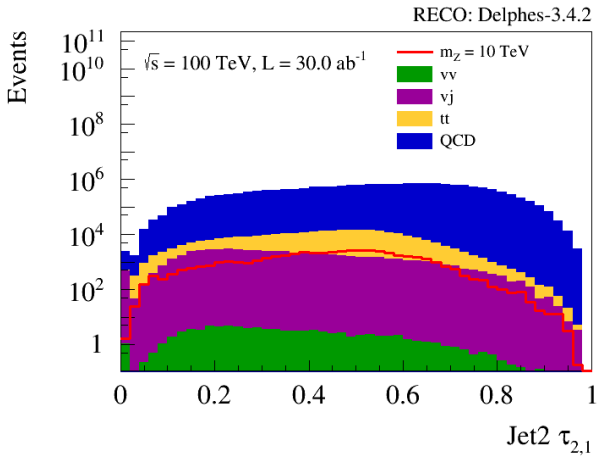
Z'->ttbar

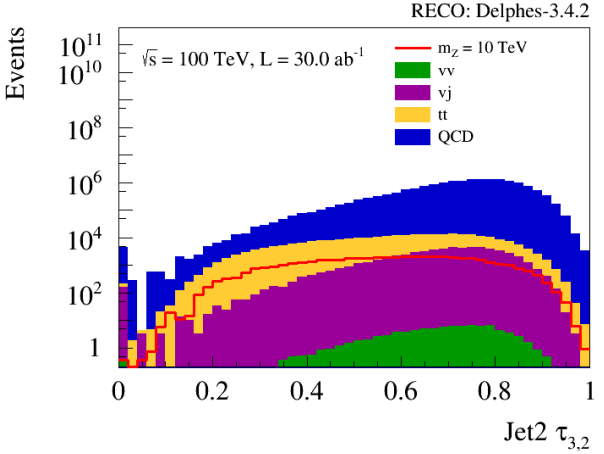
+jet1m, tau21, tau32

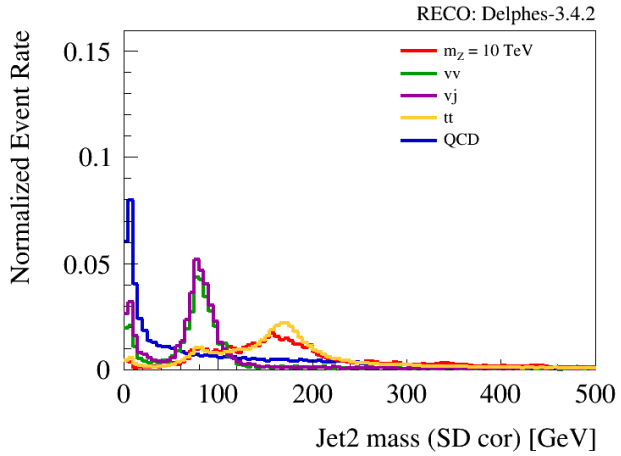
CUT 2

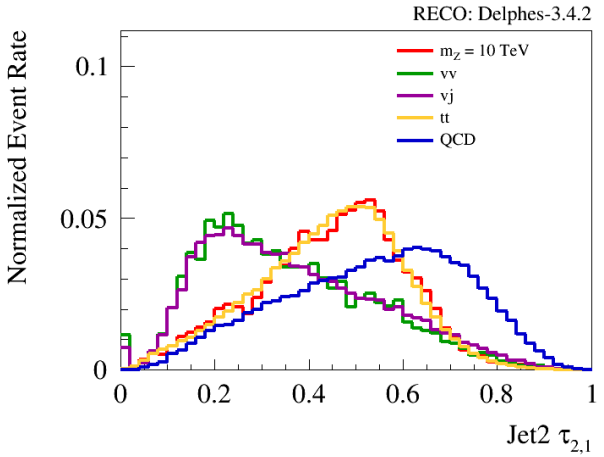
process	yield (30.0 ab-1)	stat. error	raw
m_{Z} = 10 TeV	48067.9	93.3	265336
vv	94.0	1.2	5781
vj	63145.6	460.1	18898
tt	232437.5	460.5	255166
QCD	17676380.3	70501.0	63047
signal	48067.942	9.66	
background	17972057.373	70504.012	

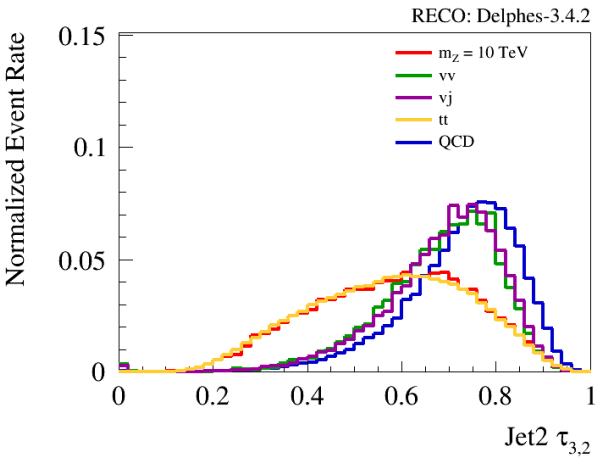










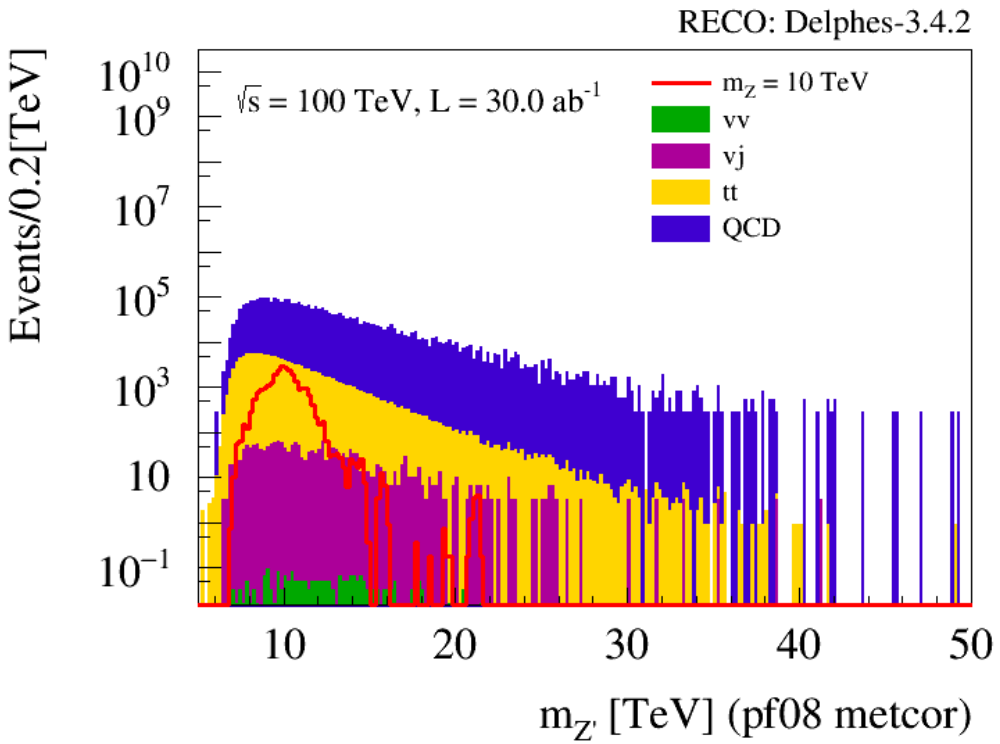


Z'->ttbar

CUT 3 +jet2m, tau21, tau32

process	yield (30.0 ab-1)	stat. error	raw
m_{Z} = 10 TeV	26806.2	69.7	147971
vv	2.5	0.2	155
vj	2038.1	82.9	613
tt	133003.2	348.4	146028
QCD	2895102.2	28524.9	10321
signal	26806.243	8.348	
background	3030146.033	28527.139	

CUT analysis



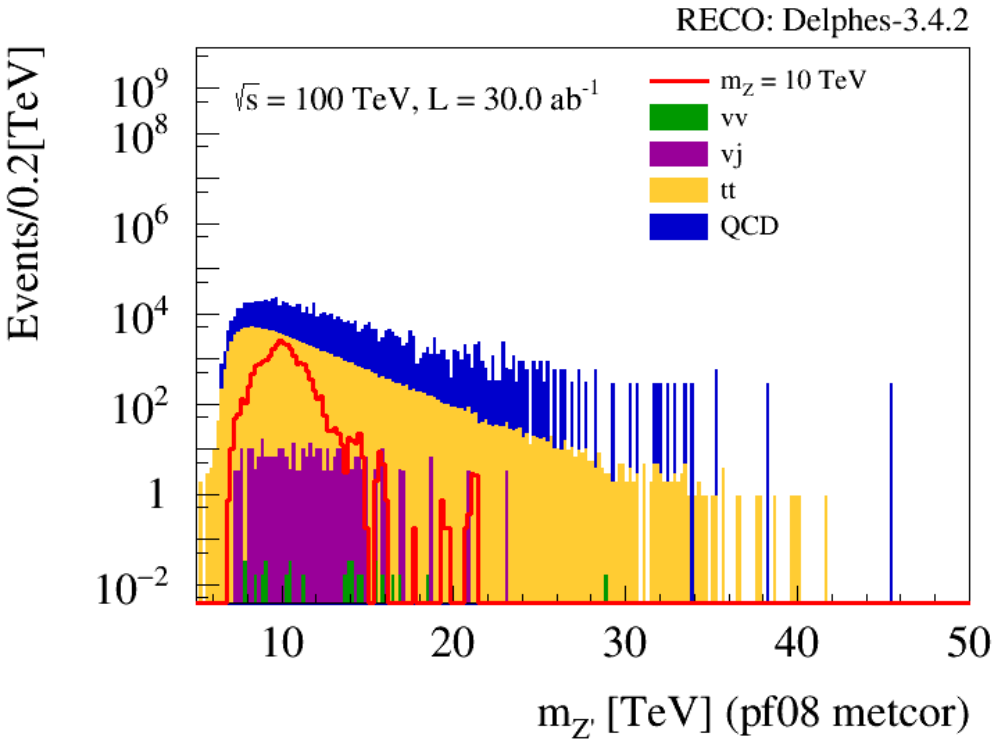
Z'->ttbar

+at least 1tag

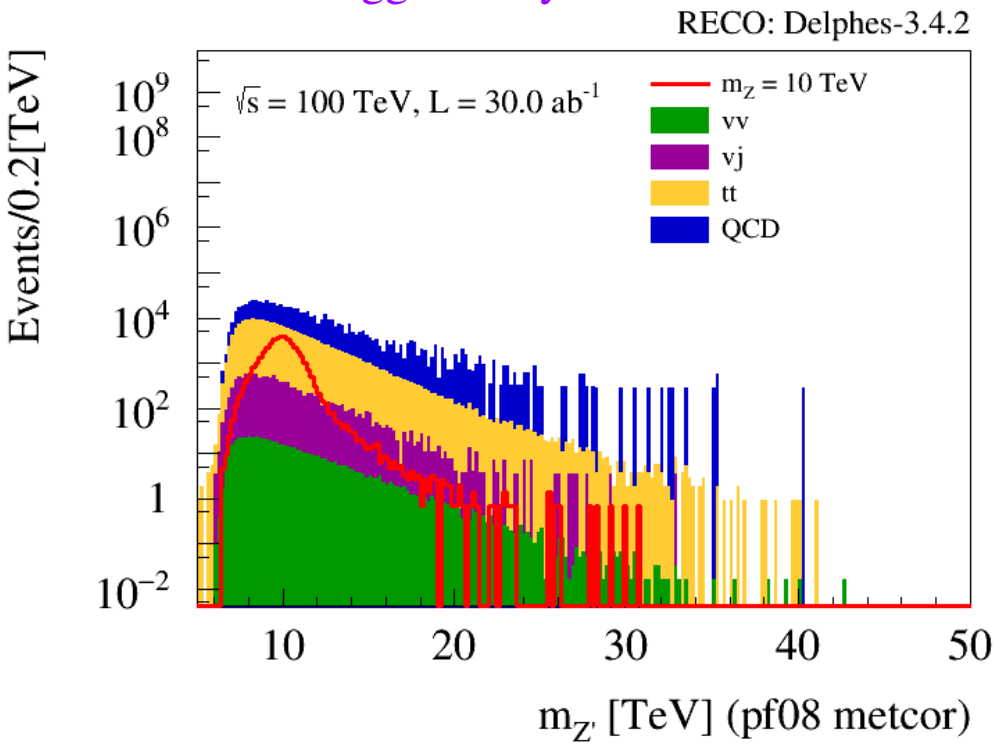
process	yield (30.0 ab-1)	stat. error	raw
m_{Z} = 10 TeV	22706.6	64.1	125341
vv	0.4	0.1	26
vj	317.9	32.6	95
tt	112929.5	321.0	123977
QCD	492765.4	11769.3	1757
signal	22706.62	8.009	
background	606013.267	11773.677	

process	yield (30.0 ab-1)	stat. error	raw
m_{Z} = 10 TeV	41183.5	165.8	61716
vv	567.2	3.0	34937
vj	11924.8	199.8	3574
tt	196730.5	423.6	216041
QCD	411709.4	10752.8	1470
signal	41183.477	12.875	
background	620931.981	10763.041	

CUT analysis



tagger analysis

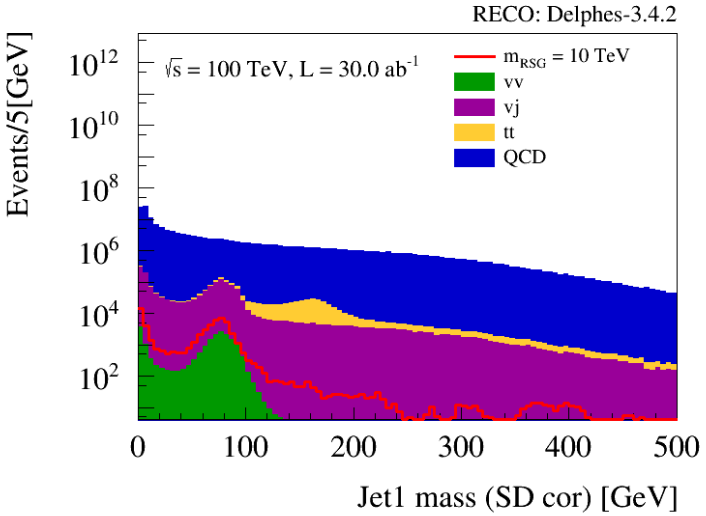


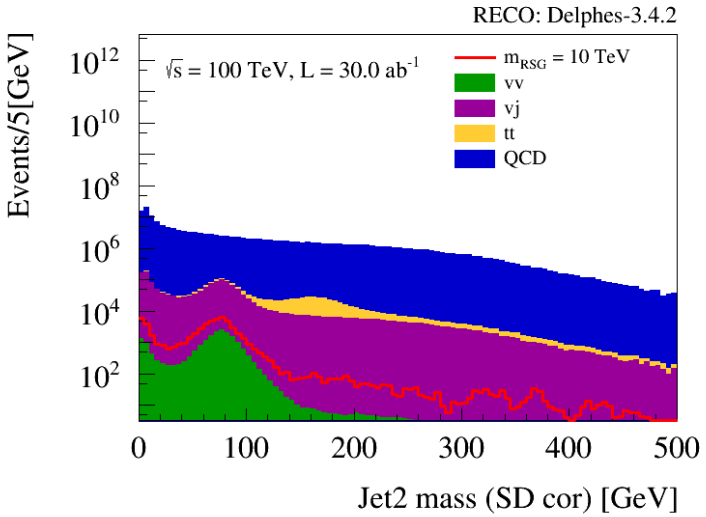
Di-boson res

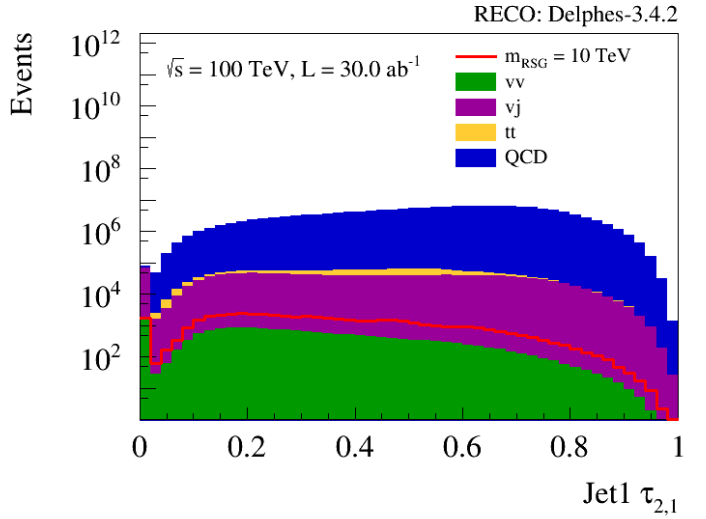
CUT 1

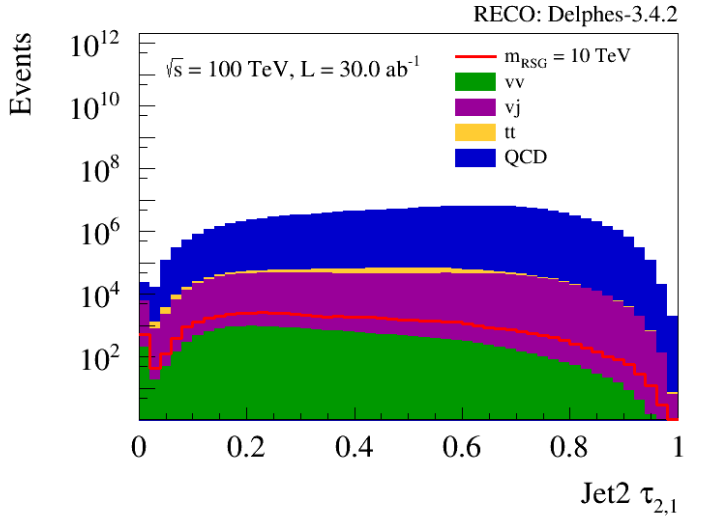
Jet pt1,2>3TeV, eta<3

process	yield (30.0 ab-1)	stat. error	raw
m_{RSG} = 10 TeV	59840.1	69.7	737037
vv	19781.2	18.0	1216755
vj	1602435.3	2318.1	479774
tt	474712.6	658.1	521141
QCD	165979400.4	216071.2	592199
signal	59840.138	8.349	
background	168076329.517	216084.668	









Di-boson res

CUT 2

\+ Jet pt1,2 SD 50<m <100
Jet 1, 2 tau21<0.6

process	yield (30.0 ab-1)	stat. error	raw
m_{RSG} = 10 TeV	19704.9	40.0	242701
vv	9077.5	12.2	558149
vj	107857.6	601.6	32318
tt	11970.9	104.5	13145
QCD	1787713.7	22411.3	6371
signal	19704.928	6.324	
background	1916619.695	22419.614