Heavy resonances at 100TeV

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Following work started by summer students
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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

FCC-hh Analysis Framework

- GridPack producer (adapted from CMS)
  - Makes MG5_aMC@NLO GridPacks (i.e standalone code that produces LHE files)
- LHE Producer
  - Produce LHE files on LSF/condor queues
  - About a 1.5 billion events produced
  - http://fcc-physics-events.web.cern.ch/fcc-physics-events/LHEevents.php
- FCCSW
  - Runs Pythia8 parton shower+hadronisation and Delphes with FCC detector
- Analysis
  - Python framework produces flat ROOT trees
- FlatTreeAnalyzer
  - Python framework for optimising analysis cut flows and producing
- Limit setting
  - Atlas inspired tool for limits and significance
- More info here https://indico.cern.ch/event/650465/contributions/2665116/attachments/1494904/2325547/Delphes_variations_clement.pdf

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

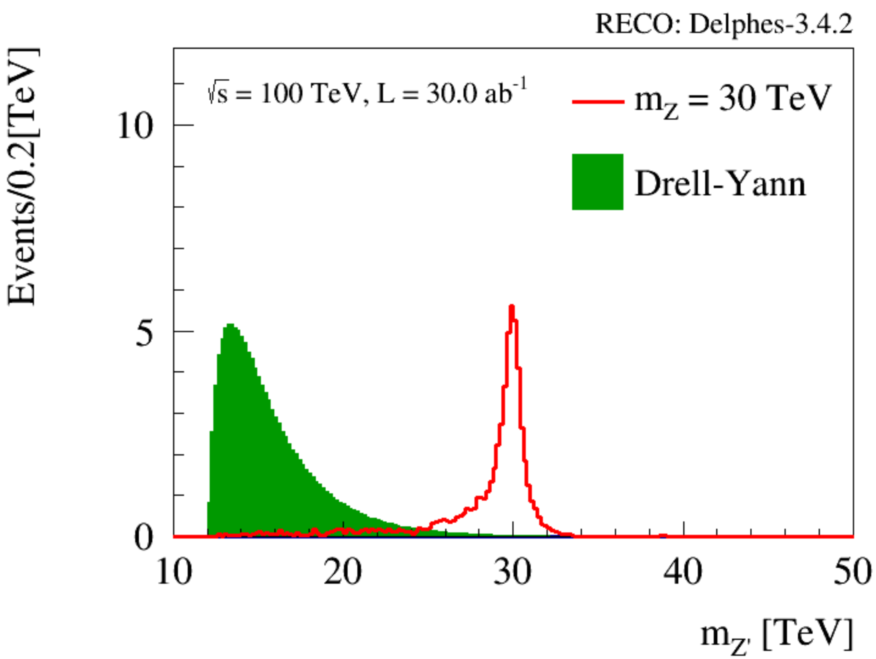
Z'->ll

- SSM Z' from Pythia8 cross-sections as well
- Simple benchmark used to check detector performance
- Helped us to reduce the originally designed muon resolution of 10%@10TeV given the reach
- Analysis selection
  - $p_T(l1)$ and $p_T(l2)>6$TeV
  - $|\eta l1|$ and $|\eta l2|<4$
  - $m_{ll}>12$TeV
- 50% uncertainty assumed on the Drell-Yann normalization when setting limits and discovery reach

Z'->ll (30TeV)

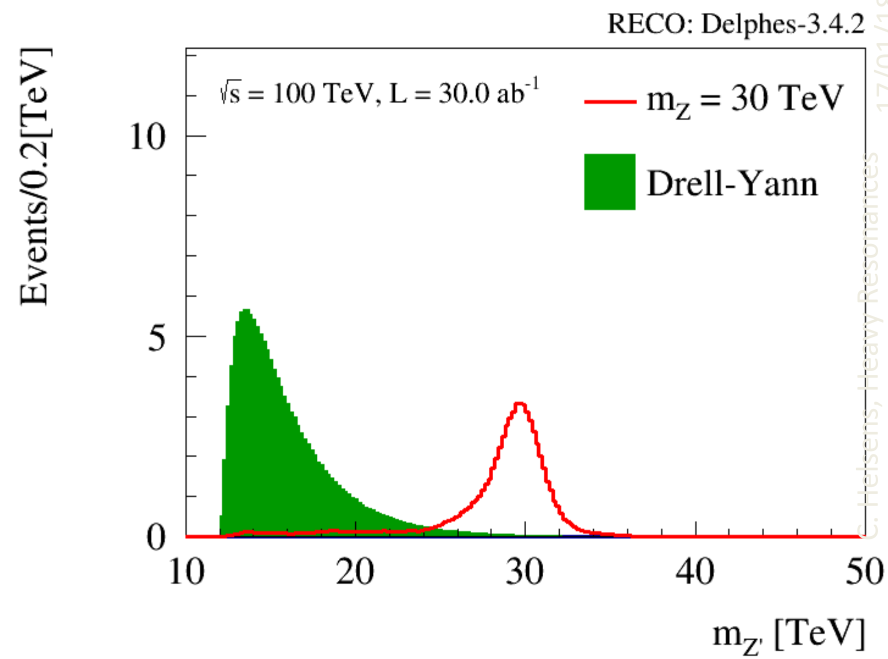
ee

process	yield (30.0 ab-1)
m_{Z} = 30 TeV	57.5
Drell-Yann	128.3



mumu

process	yield (30.0 ab-1)
m_{Z} = 30 TeV	68.3
Drell-Yann	141.6

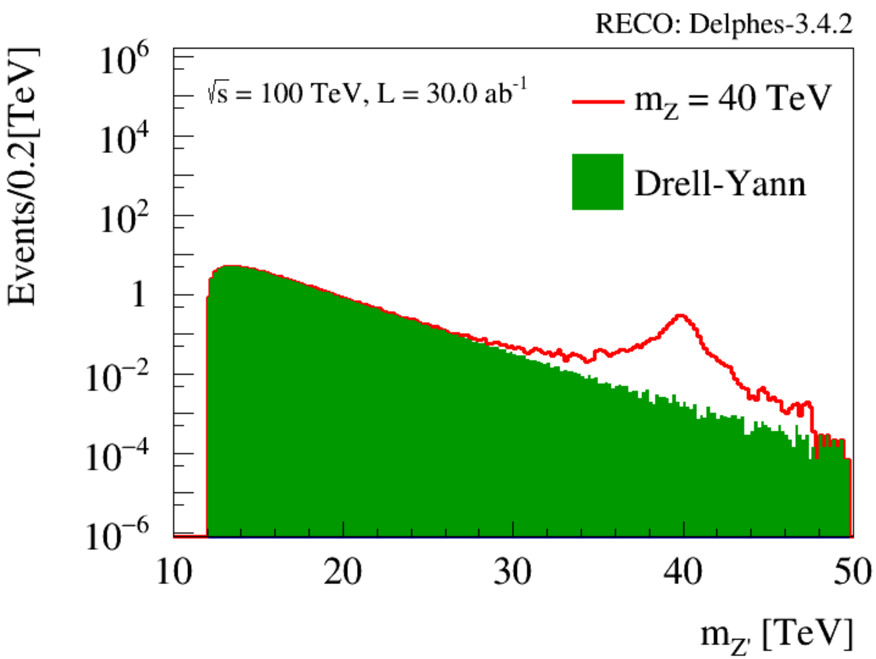


Better mass resolution for electrons…

Z'->ll (40TeV)

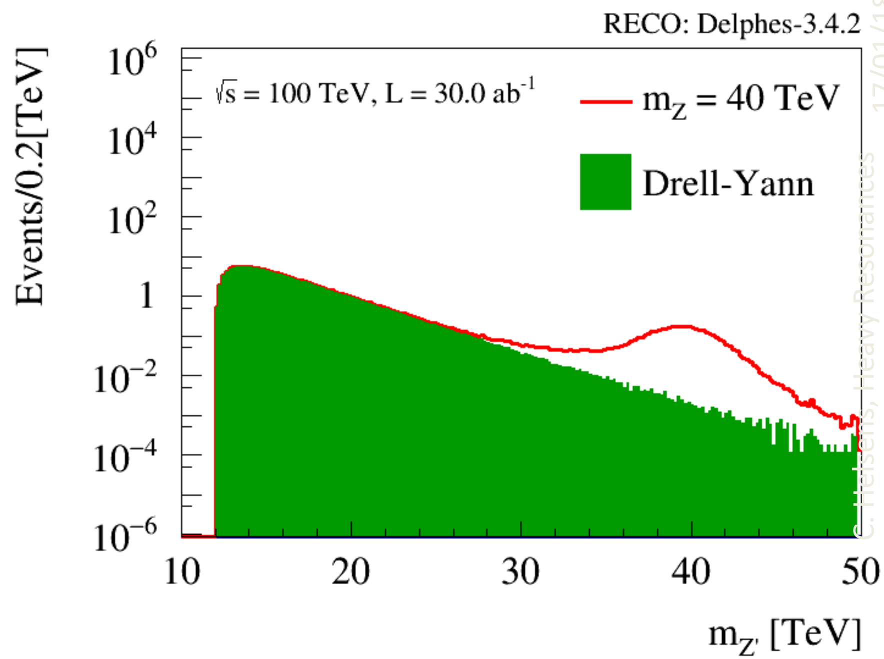
ee

process	yield (30.0 ab-1)
m_{Z} = 40 TeV	5.3
Drell-Yann	128.3



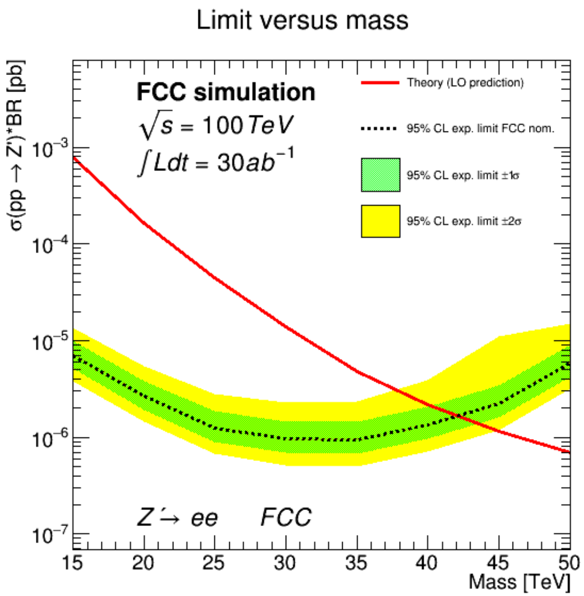
mumu

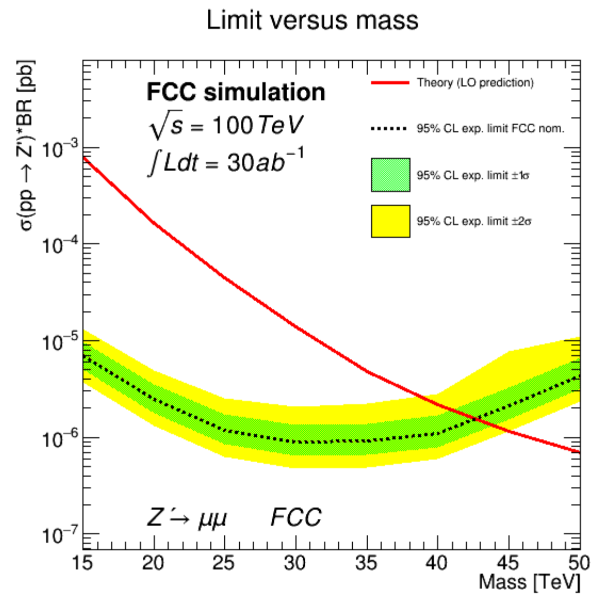
process	yield (30.0 ab-1)
m_{Z} = 40 TeV	6.6
Drell-Yann	141.6



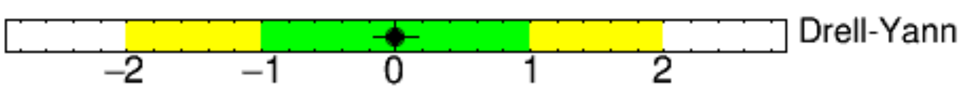
Even better mass resolution for electrons…

Limits

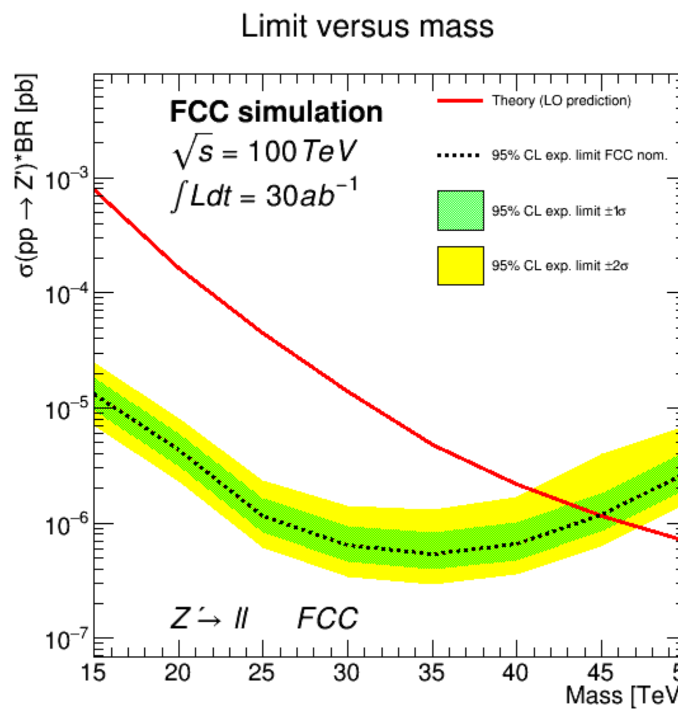




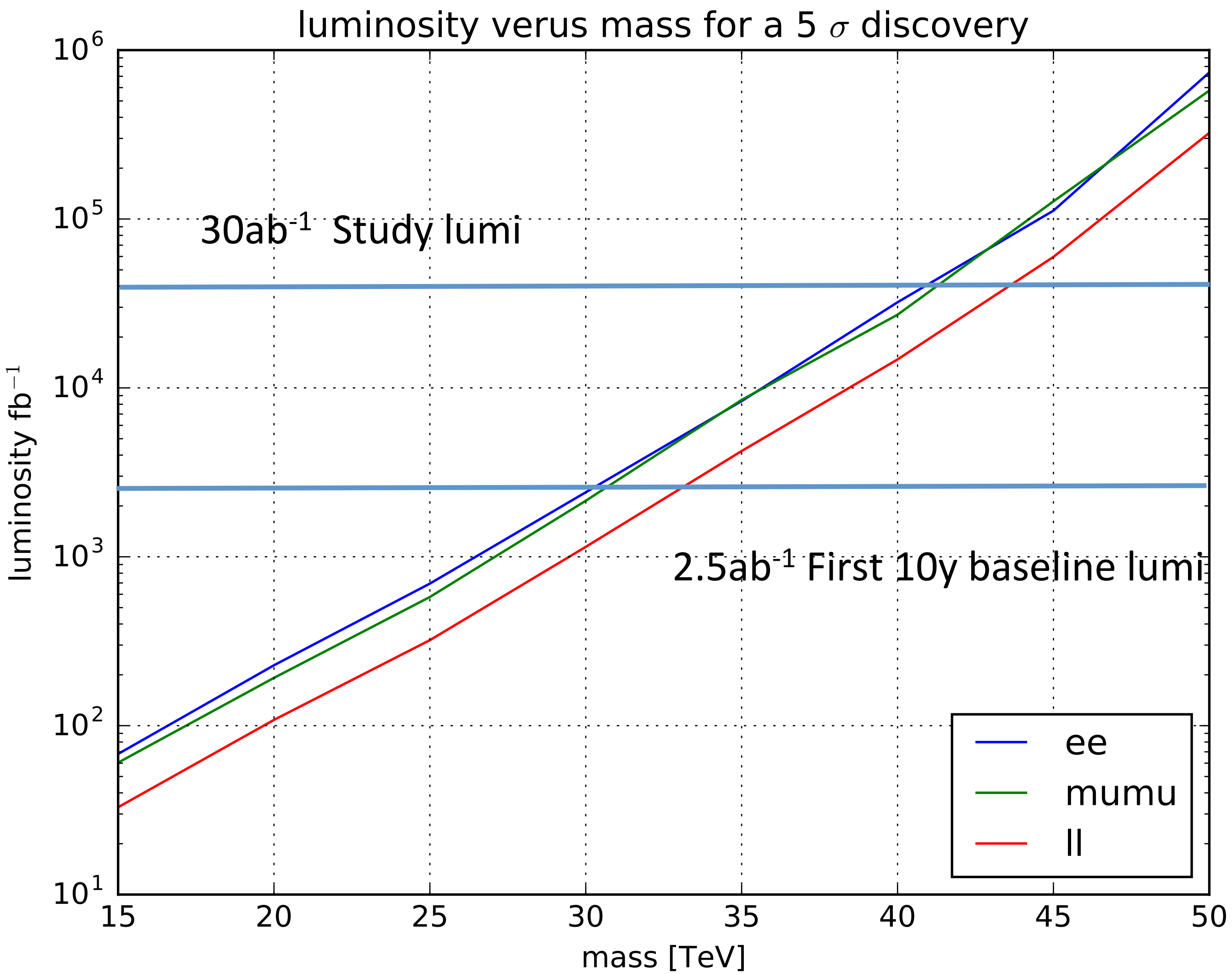
50% uncertainty on Drell-Yann Normalisation
Well constrained by profile likelihood



Reach up to 45TeV this very simple case



Z'->ll Significance



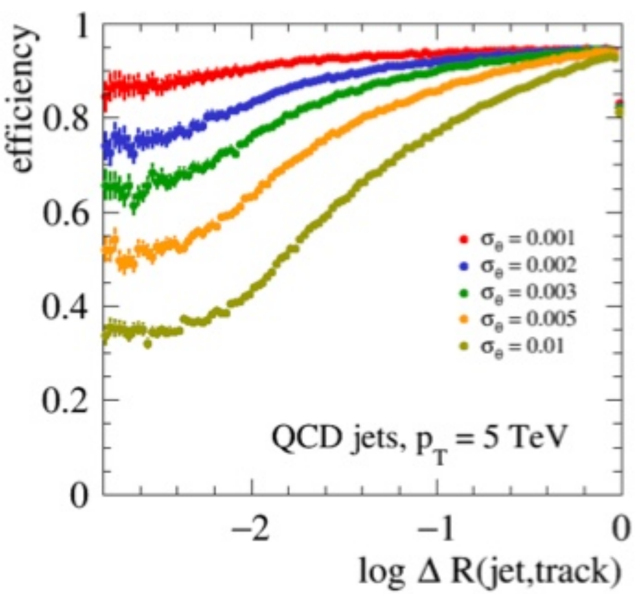
Z'->ttbar

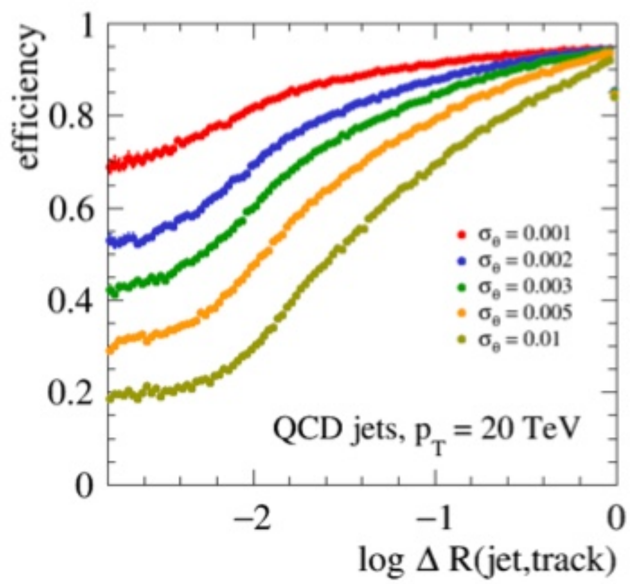
- Signal with pythia8
- Cross sections from benchmark top-color model
- Important benchmark model for detector performance on sub-structure
- Analysis selection
  - Jet Pt>3TeV, jet eta <3
  - J1,2 SoftDropped mass>100GeV
  - J1,2 Tau32<0.7   0.3<J1,2 Tau21<0.7
  - Use b-tagging
  - Do not explicitly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

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

Tracking in dense environment

- define tracker granularity in (eta x phi)
  - worst case scenario represented by pitch size in the first pixel layer:
    - reso = (2-3)*10um/(0.025) ~ 0.001
- inefficiency when two or more tracks hit same pixel
  - keep only highest pT track (arbitrary of course and probably conservative, considering that this is only first pixel layer ...)
- Conservative value of 0.001 used for FCC studies



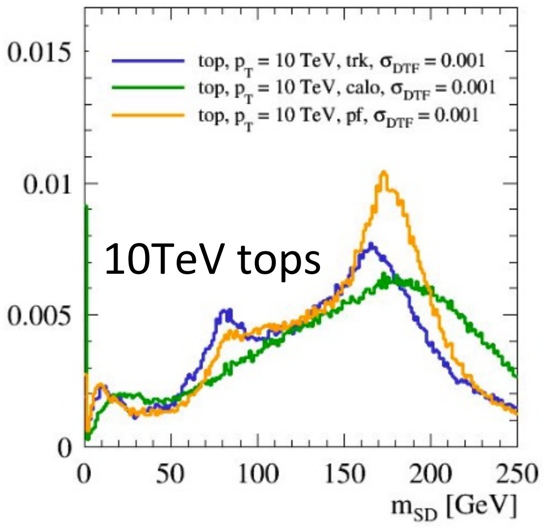


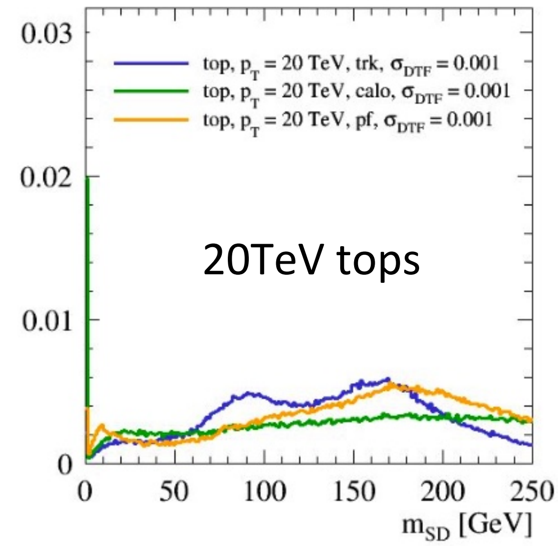
Boosted objects

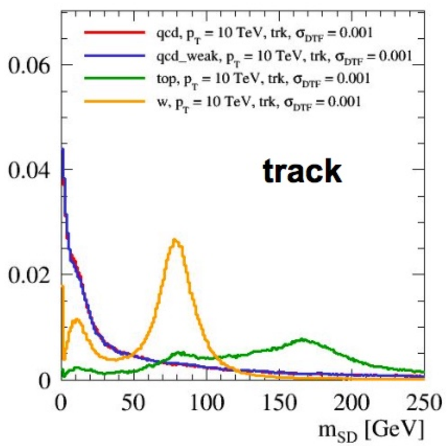
- What is:
  - Optimal jet collection
  - minimal track angular resolution?
- Assessed using :
  - QCD, QCD+weak shower, W and Top jets
  - GenJets, CaloJets, Particle Flow Jets, Track Jets with 2-5-10-20 TeV
- Outcome: use track jets for sub-structure corrected to pf jets

- More information in Michele's talk here

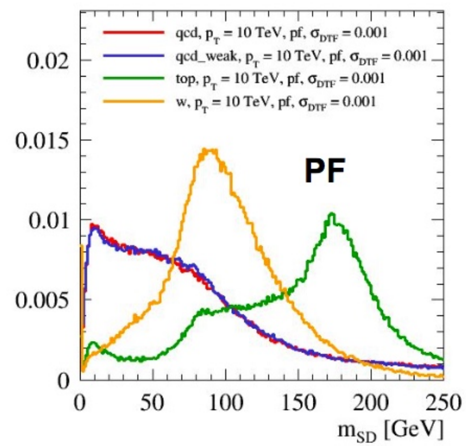
- Performance of reconstructing such boosted objects Will be further checked in full simulation for the report







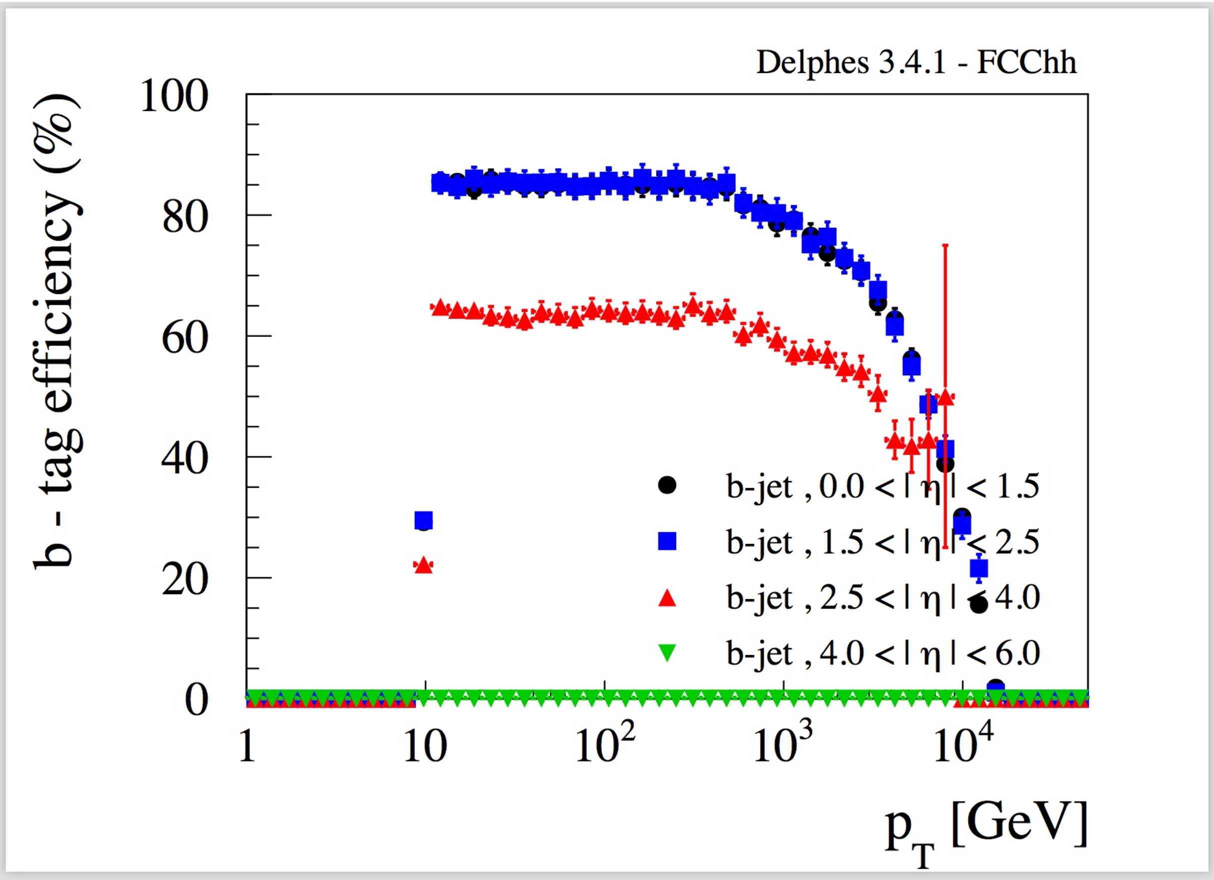
10TeV objects



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

B-tagging

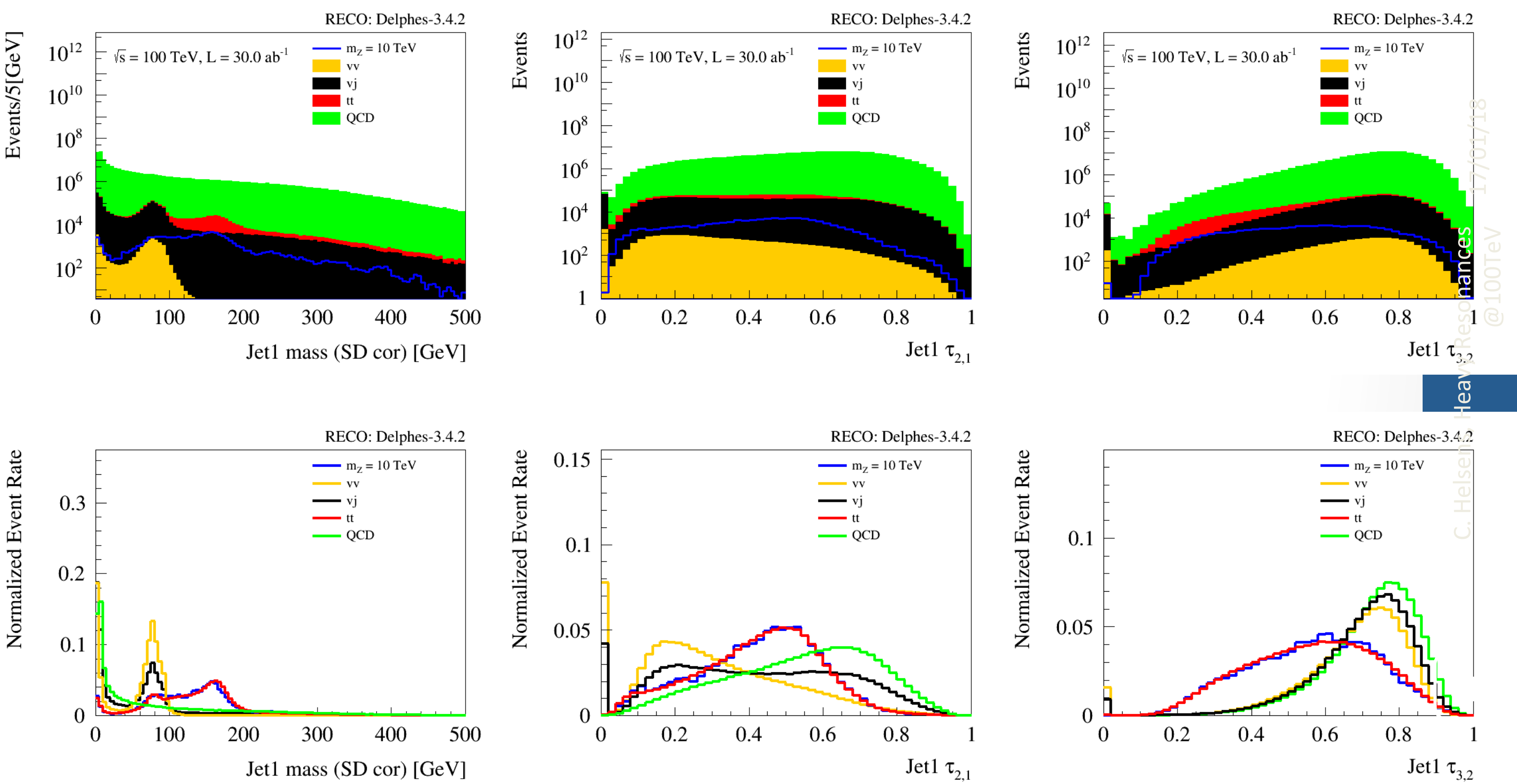
- b-tagging to match first results from full simulation study without tracks (hit multiplicity jump)



Z’->ttbar

Jet pt1,2>3TeV, eta<3

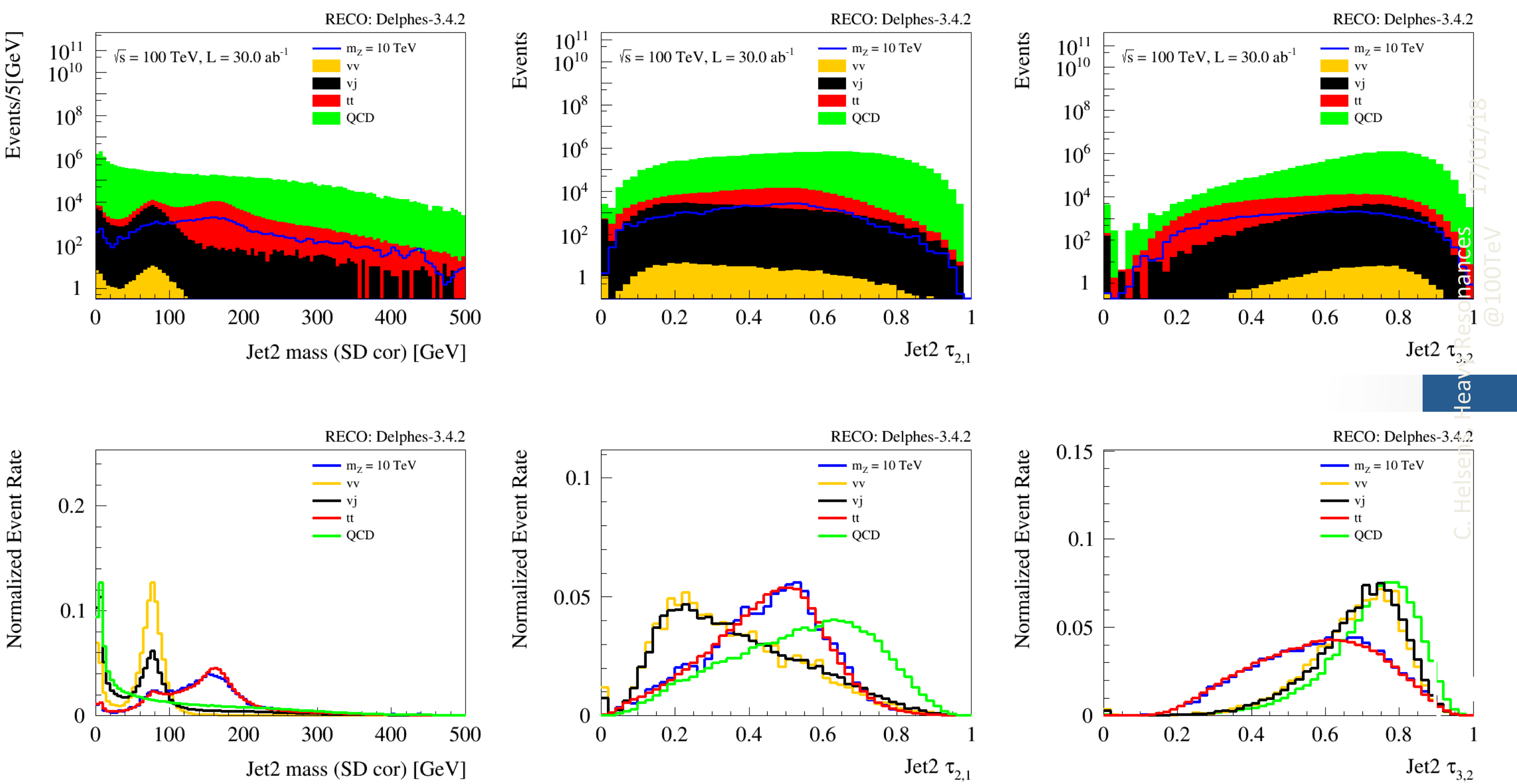
process	yield (30.0 ab-1)	stat. error	raw
m_{Z} = 10 TeV	100153.4	134.7	552849
vv	19580.0	17.9	1204391
vj	1587200.9	2311.2	473507
tt	467335.5	653.4	512472
QCD	158736169.8	211305.6	566364
signal	100153.441	11.606	
background	160810286.131	211319.212	



Z’->ttbar

+jet1m, tau21, tau32

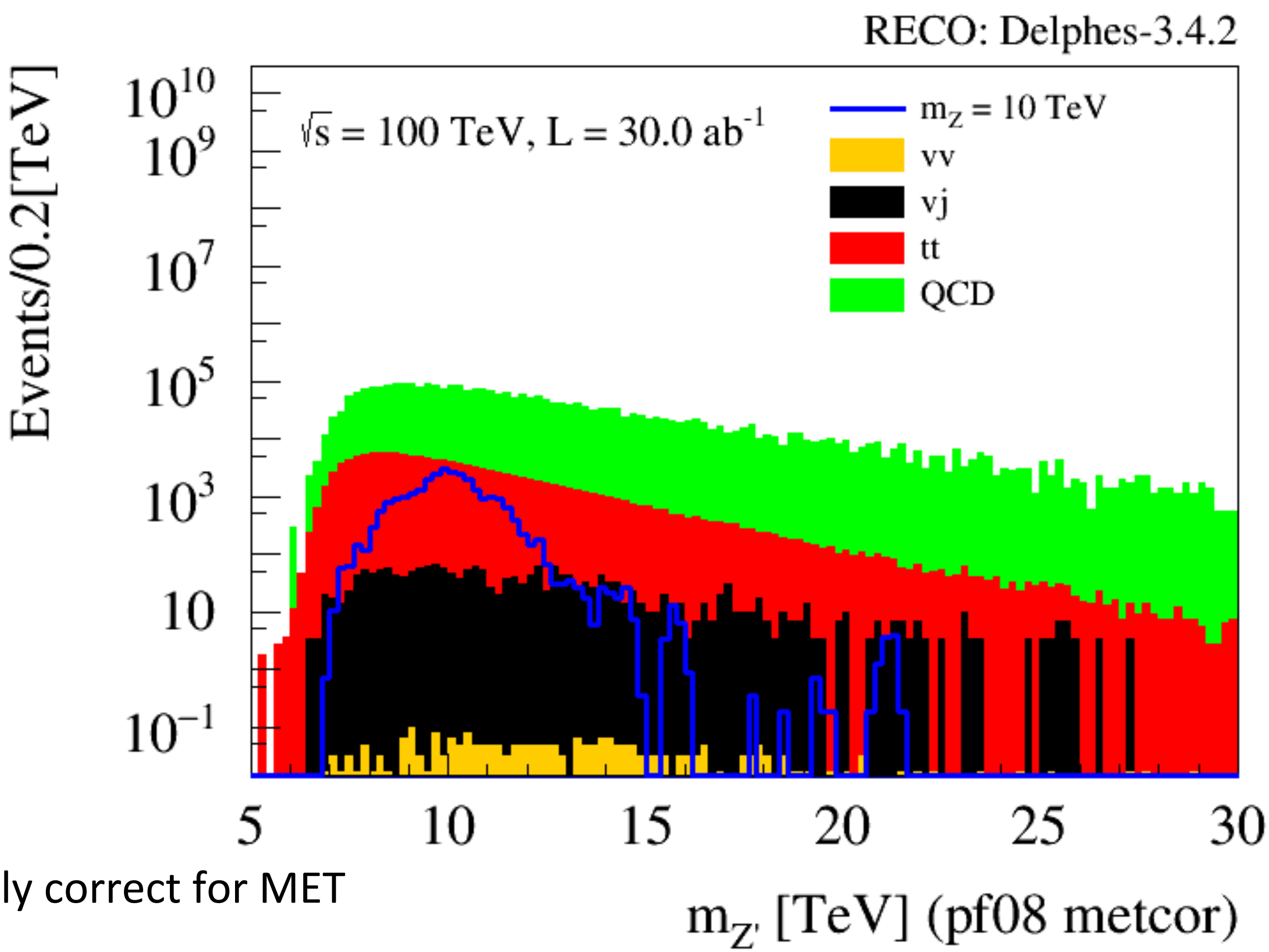
process	yield (30.0 ab-1)	stat. error	raw
m_{Z} = 10 TeV	48067.9	93.3	265336
vv	93.1	1.2	5729
vj	62562.4	458.8	18657
tt	228862.6	457.2	250961
QCD	17054457.0	69249.2	60828
signal	48067.942	9.66	
background	17345975.104	69252.248	



Z'->ttbar

+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	153
vj	2018.6	82.6	605
tt	130927.3	345.8	143590
QCD	2788968.1	28000.5	9945
signal	26806.243	8.348	
background	2921916.38	28002.739	

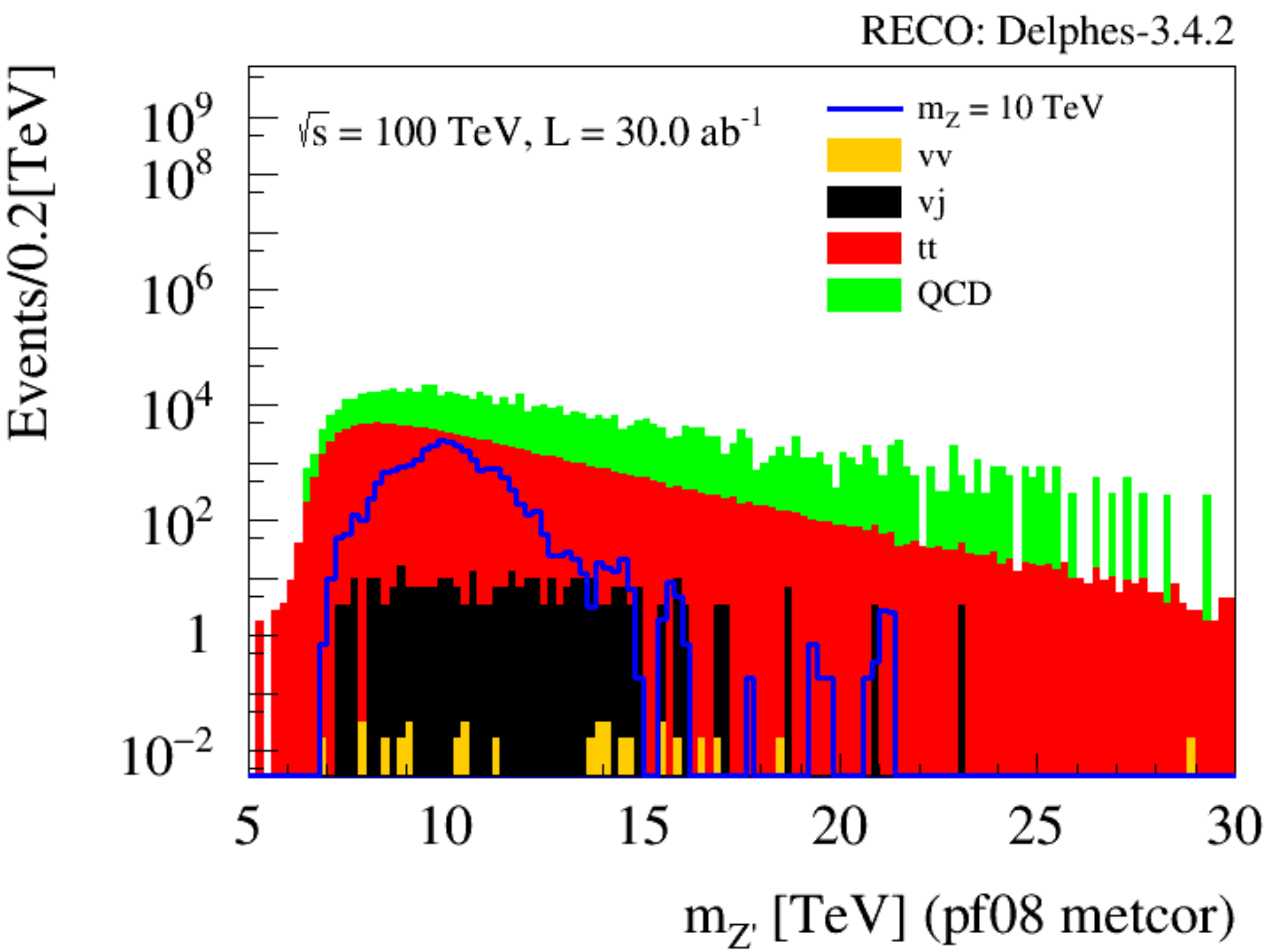


Naively correct for MET

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	25
vj	315.7	32.6	94
tt	111158.0	318.6	121897
QCD	475357.2	11559.7	1695
signal	22706.62	8.009	
background	586831.337	11564.174	

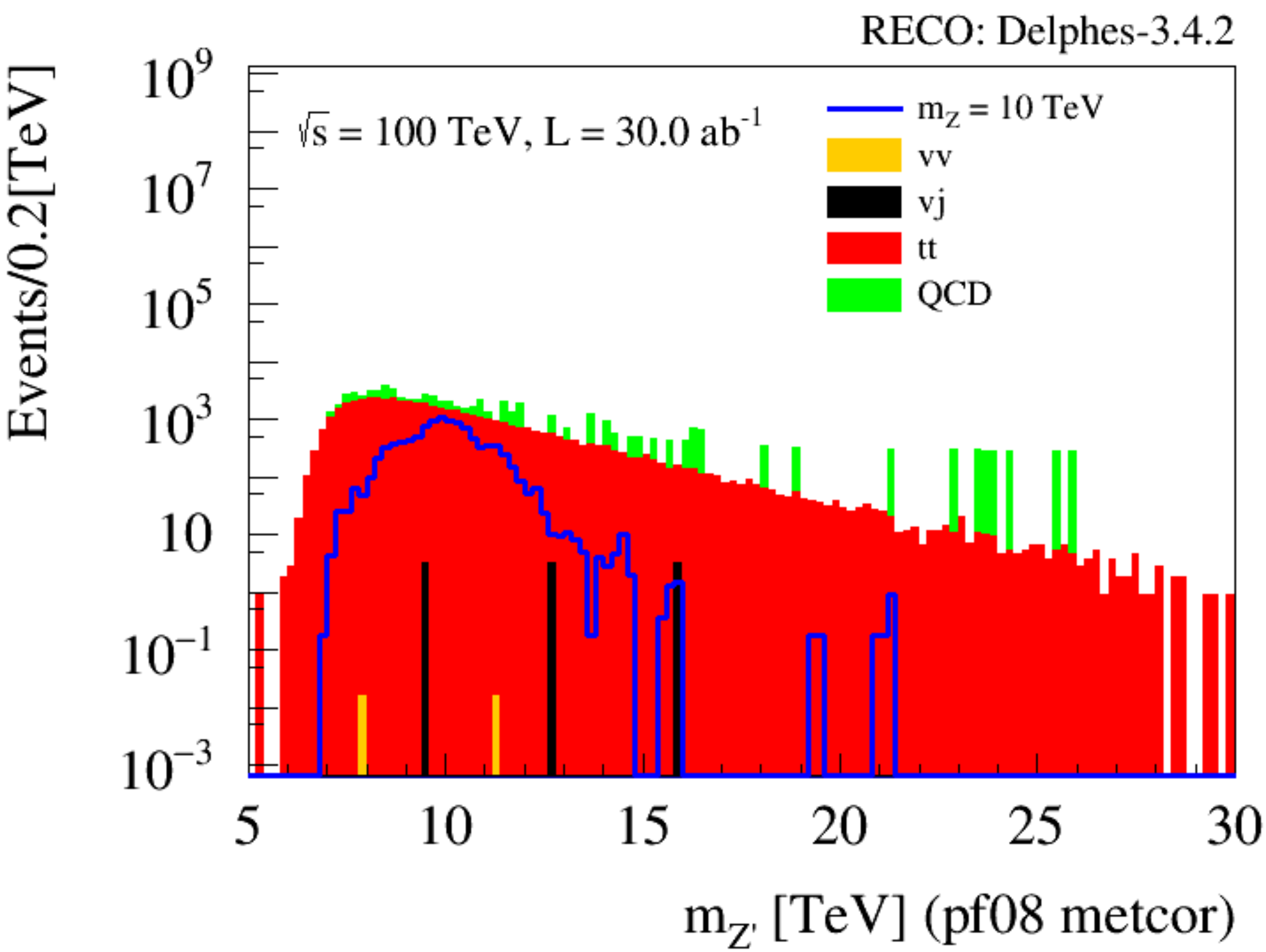


C. Helsens, Heavy Resonances @100TeV 17/01/18

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	10.1	5.8	3
tt	49747.5	213.2	54548
QCD	24146.9	2603.8	86
signal	9937.102	6.514	
background	73904.557	2612.545	

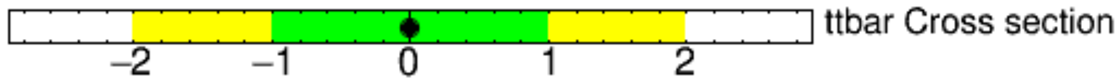


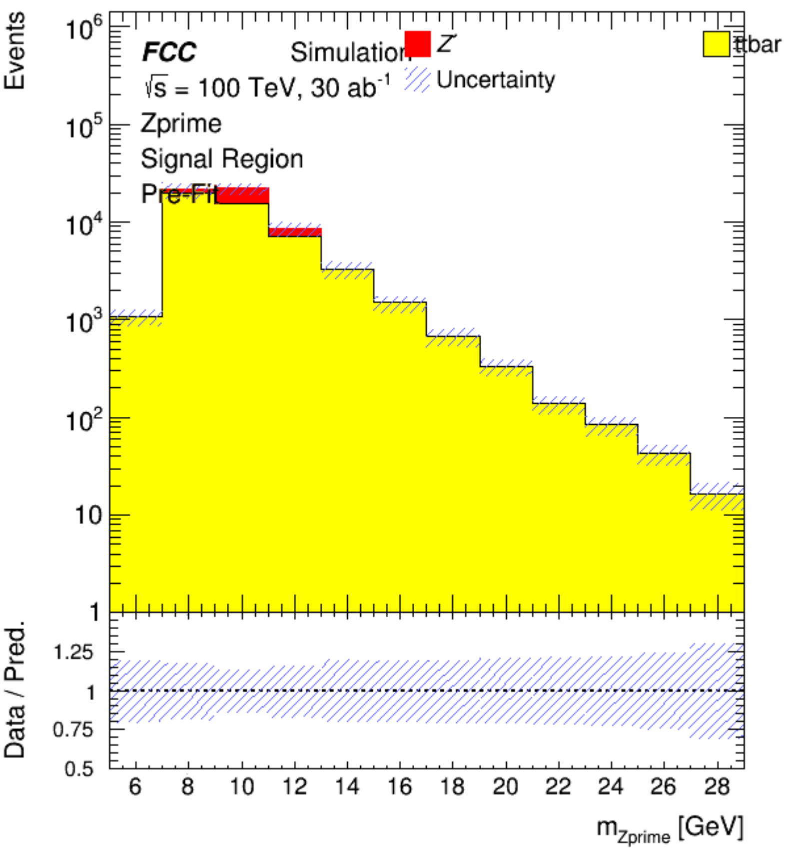
Will keep only ttbar for limits

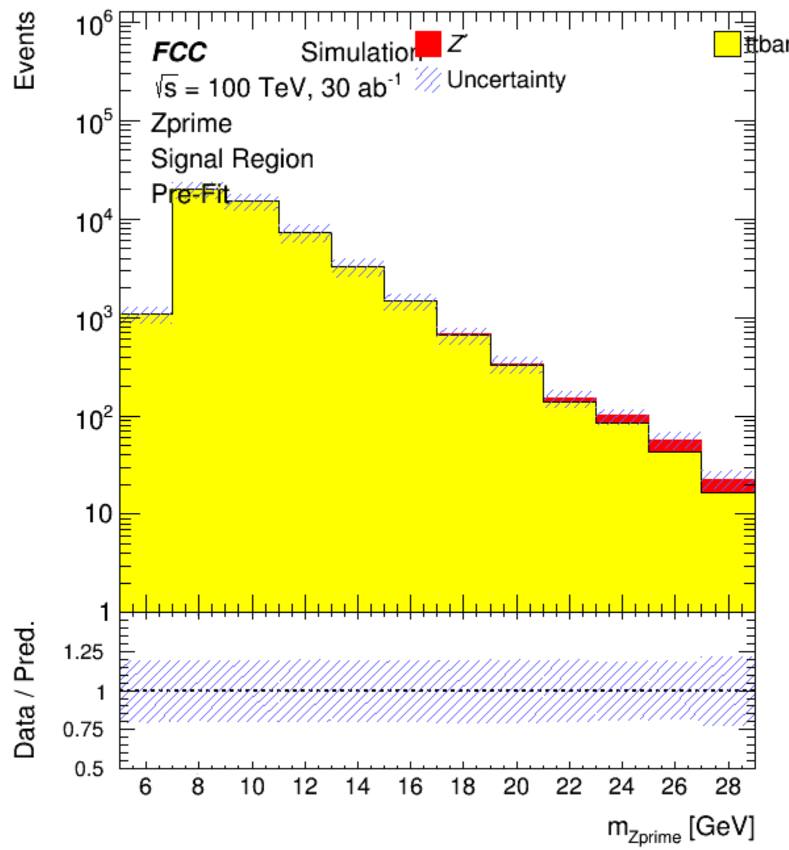
Z'->ttbar

process	yield (30.0 ab-1)
m_{Z} = 10 TeV	9937.1
m_{Z} = 15 TeV	2176.6
m_{Z} = 20 TeV	397.9
m_{Z} = 25 TeV	76.7
m_{Z} = 30 TeV	14.2
tt	49747.5

20% on ttbar cross section
Very well constrained given the large ttbar background







Z'->ttbar

process	yield (30.0 ab-1)
m_{Z} = 10 TeV	9937.1
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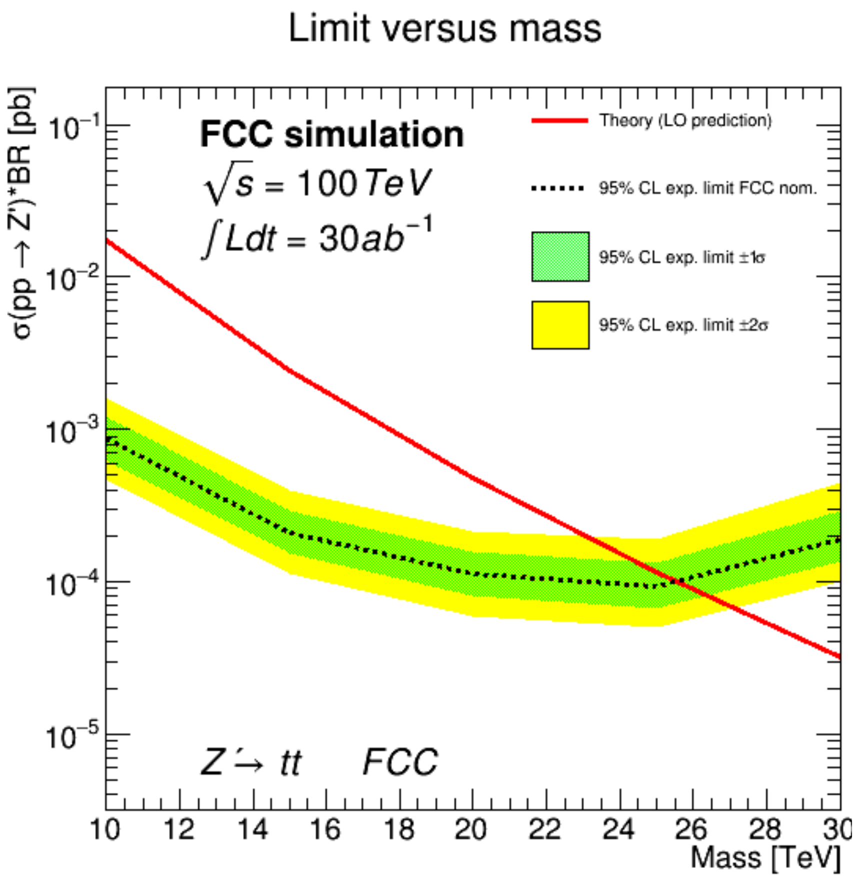
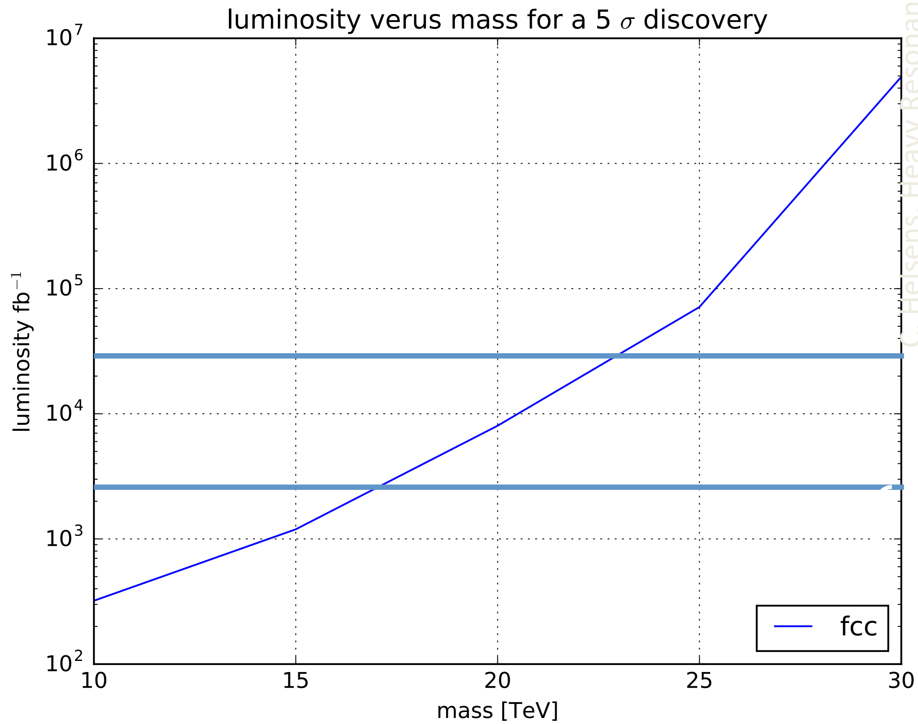
m_{Z} = 25 TeV	76.7
m_{Z} = 30 TeV	14.2
tt	49747.5





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%

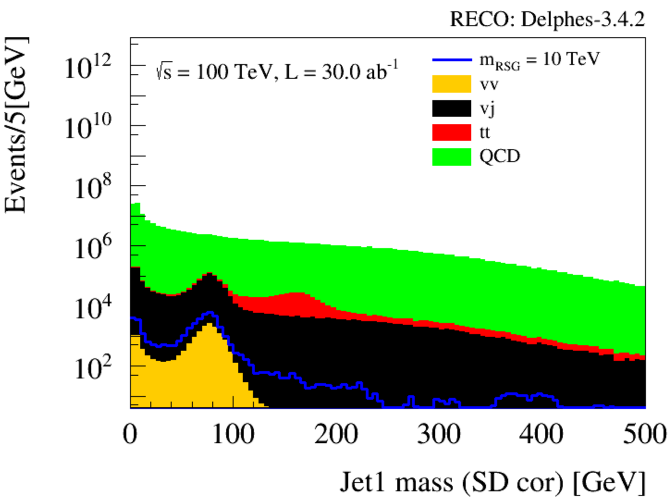
$$\mathrm{Flow}_{n,5} = \sum_k \frac{|p_T^k|}{|p_T^{\mathrm{jet}}|}$$

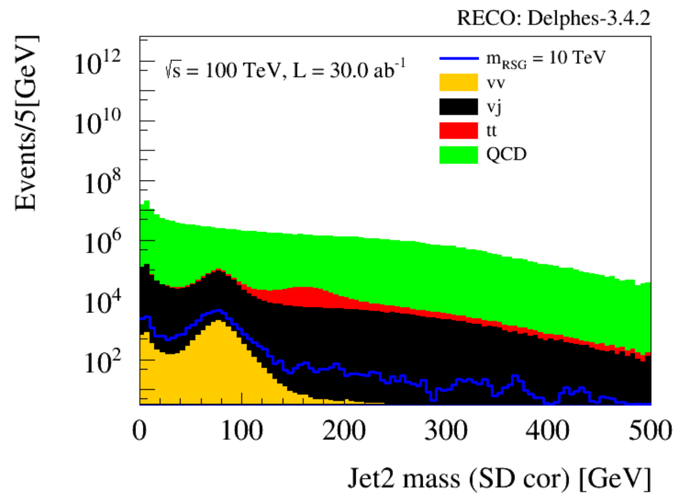
$$\frac{n-1}{5} R \leq \Delta R(k, \mathrm{jet}) < \frac{n}{5} R,$$

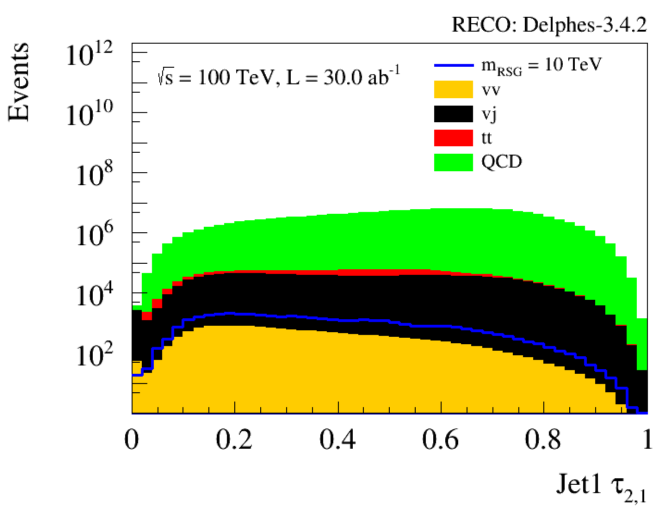
Di-boson res

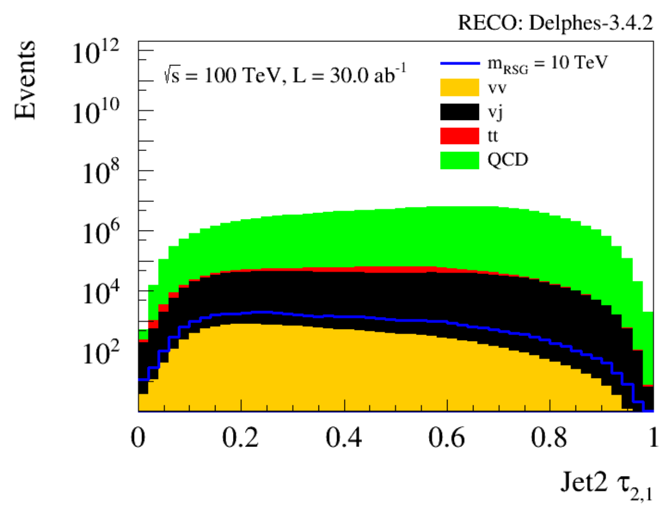
Jet pt1,2>3TeV,
eta<3

process	yield (30.0 ab-1)	stat. error	raw
m_{RSG} = 10 TeV	43159.5	57.6	561118
vv	15936.9	16.1	980158
vj	1399932.5	2156.4	423139
tt	474364.9	658.2	520182
QCD	165864281.4	215996.4	591789
signal	43159.499	7.591	
background	167754515.684	216008.188	







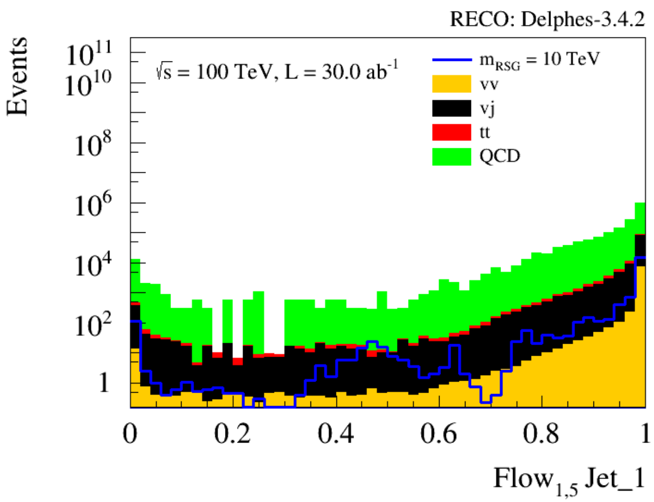


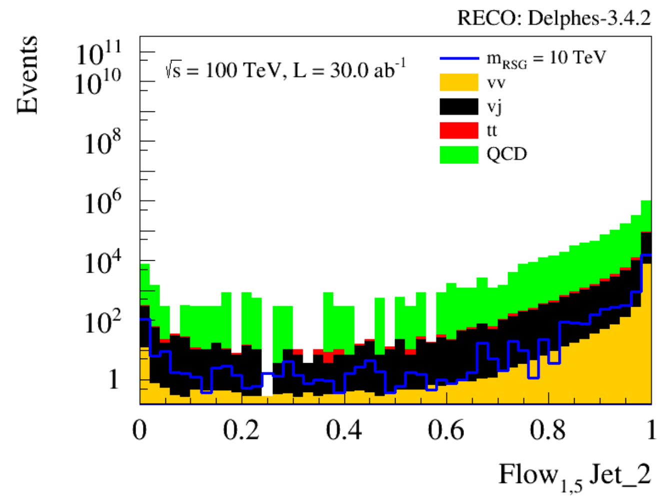
Di-boson res

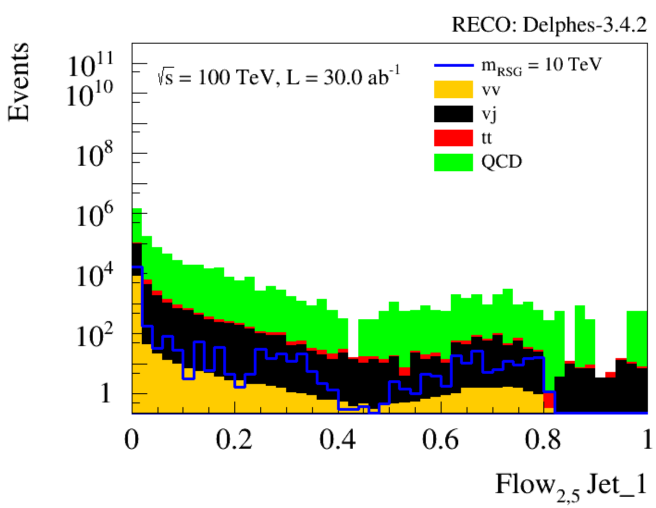
Jet pt1,2 SD 50<m <100

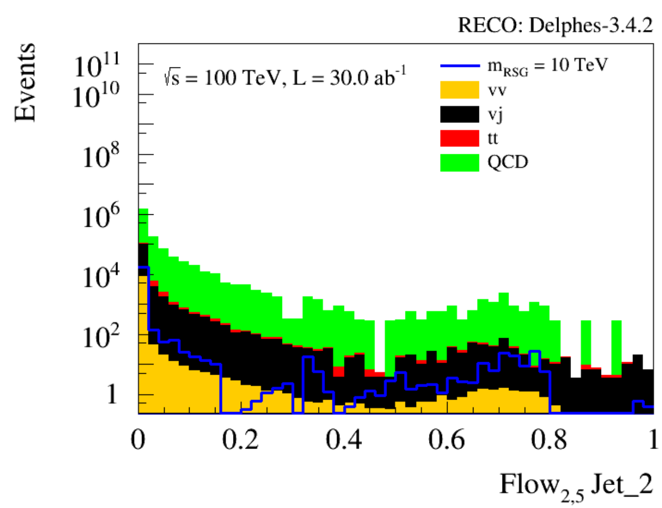
Jet 1, 2 tau21<0.6

process	yield (30.0 ab-1)	stat. error	raw
m_{RSG} = 10 TeV	17680.1	36.9	229860
vv	8452.6	11.8	519686
vj	101099.8	579.7	30581
tt	11966.9	104.6	13126
QCD	1787713.7	22411.3	6371
signal	17680.136	6.073	
background	1909232.945	22419.037	





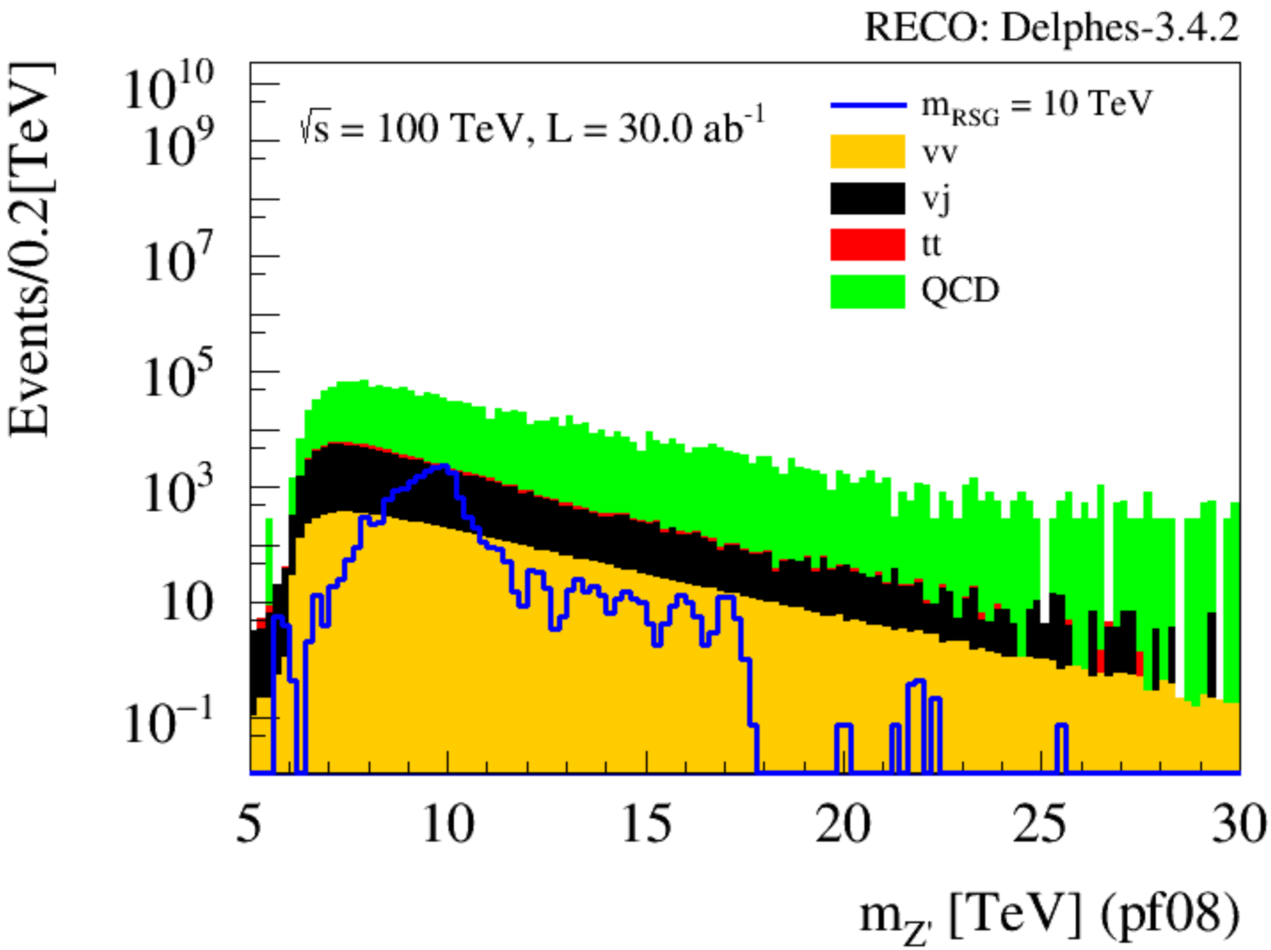




Di-boson res

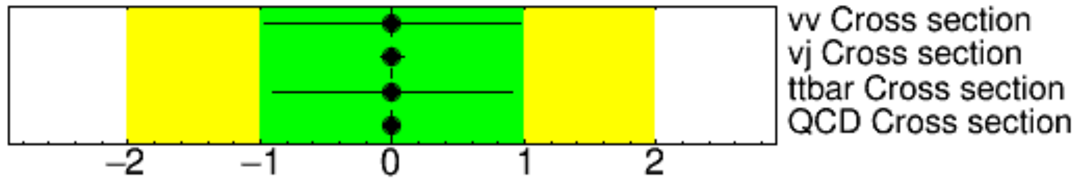
Jet 1,2 flow 1,5>0.85
Jet 1,2 flow 2,5<0.05

process	yield (30.0 ab-1)	stat. error	raw
m_{RSG} = 10 TeV	16597.8	35.7	215788
vv	8215.7	11.6	505109
vj	88711.4	543.1	26840
tt	9429.7	92.8	10340
QCD	1355315.5	19511.5	4829
signal	16597.76	5.977	
background	1461672.234	19519.329	

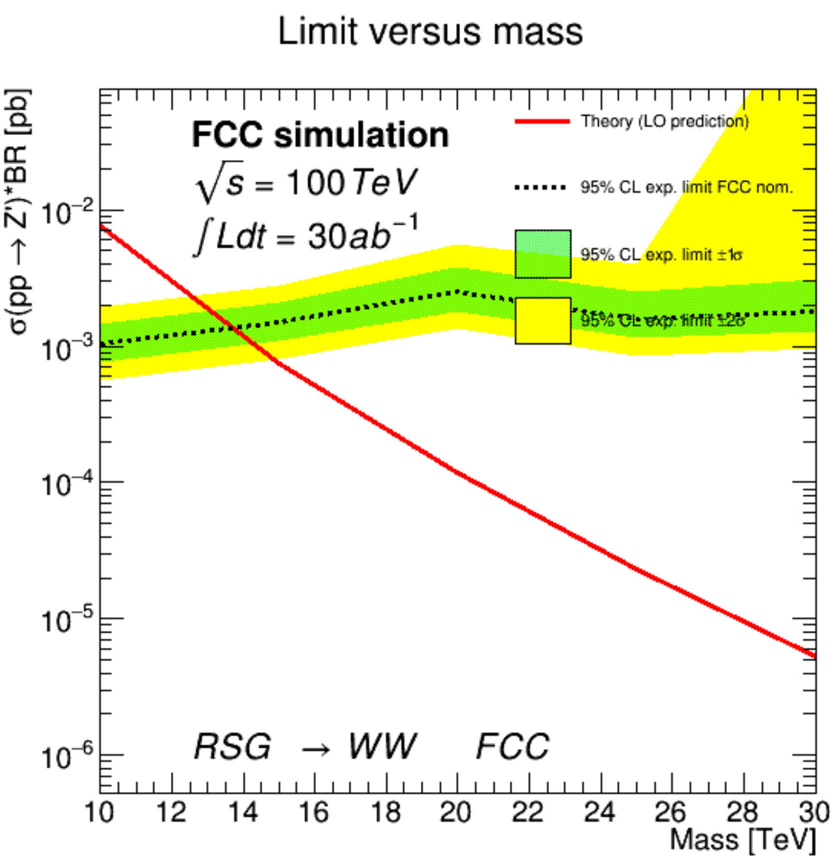


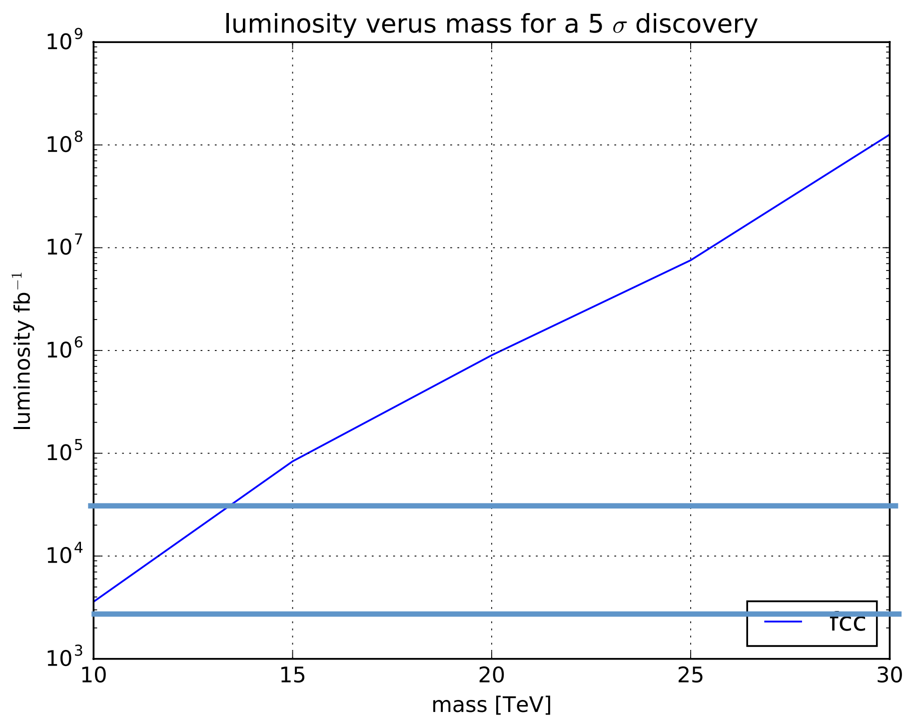
ttbar 20% QCD 50%, VV 20%, VJ 40%

Di-boson res



Pessimistic results
Need further optimizations!!!





Summary

- Z'->ll
  - background free analysis
  - Discovery reach ~40TeV with full dataset
- Z'->ttbar
  - Leading uncertainties are ttbar modeling, not considered here
  - Need a better handling of multi-jet
  - Sub-structure performance to be checked with full sim
  - Could implement a proper chi-2 to find neutrino pz solution
  - Could properly divide in channels
  - Simple MVA
- Di-boson
  - Need a better handling of multi-jet
  - Sub-structure performance to be checked with full sim
  - Could properly divide in channels
  - Simple MVA