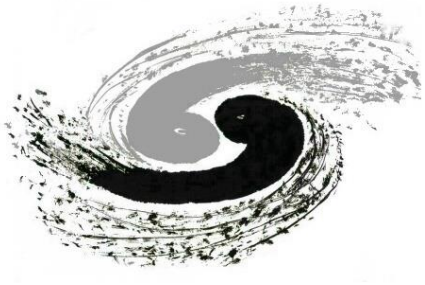


Status report of the

HH → Multi lepton analysis

Kaili Zhang

IHEP

for the Multilepton analysis team

DiHiggs Subgroup Meeting
2019-08-16

Outline

- Overview
- Multilepton: 4τ, 3had1l
- Multilepton: 2lSS
  - Selections
  - QMisID
  - Analysis Status
- $\gamma\gamma$ +Multilepton
  - Selections
  - Analysis Status
- Summary

HH → Multilepton Overview

- Established in this year, to cover low sensitivity channels together
  - $HH \rightarrow (\geq 2) leptons(e, \mu, \tau)$: $WW\ /\ ZZ\ /\ \tau\tau + WW\ /\ ZZ\ /\ \tau\tau$ ~5.7%
  - $HH \rightarrow \gamma\gamma + leptons(\geq 1)$: $WW\ /\ ZZ\ /\ \tau\tau + \gamma\gamma$ ~0.13%.
- Twiki, Reports in Feb. Dihiggs workshop and Last Harmonization meeting

HH decay mode	bb	WW	ττ	ZZ	γγ
bb	33%				
WW	25%	4.6%			
ττ	7.4%	2.5%	0.39%		
ZZ	3.1%	1.2%	0.34%	0.076%	
γγ	0.26%	0.10%	0.029%	0.013%	0.0005%

8TeV results:
CMS - Phys.Rev.D 90, 112013
ATLAS - Phys.Rev.D 92,092004

CMS multilepton comparable performance to ATLAS 8 TeV bbττ result.

Truth level category components

Done By XiaoZhong and Huirun

Category		ZZZZ	WW$\tau\tau$	$\tau\tau$ZZ	WWWW	WWZZ	$\tau\tau\tau\tau$	Total	
#l	#τ_h								
0	≥4	0.00%	0.03%	0.02%	0.00%	0.00%	0.88%	0.94%	0.94%
1	≥ 3	0.00%	0.43%	0.05%	0.01%	0.01%	1.86%	2.36%	2.36%
2 SS	0	0.04%	3.33%	0.14%	11.88%	1.08%	0.22%	16.69%	24.29%
	1	0.00%	4.82%	0.20%	1.05%	0.13%	0.59%	6.80%	
	≥ 2	0.00%	0.26%	0.03%	0.02%	0.01%	0.48%	0.81%	
2 OS	0	0.48%	7.93%	0.95%	24.73%	5.87%	0.38%	40.35%	54.60%
	1	0.03%	6.97%	0.61%	2.06%	0.45%	1.28%	11.40%	
	≥ 2	0.00%	1.48%	0.32%	0.04%	0.04%	0.96%	2.84%	
3	0	0.10%	3.30%	0.31%	7.15%	2.11%	0.31%	13.27%	16.12%
	≥ 1	0.01%	1.54%	0.35%	0.33%	0.16%	0.46%	2.85%	
≥4	≥ 0	0.05%	0.40%	0.15%	0.53%	0.51%	0.05%	1.70%	1.70%

Number		$\gamma\gamma$WW %	$\gamma\gamma$ZZ %	$\gamma\gamma\tau\tau$ %	Total %	
#l	#τ_h					
0	0	33.81	7.28	-	41.09	41.09
1	0	23.37	-	-	23.37	30.76
1	1	7.39	-	-	7.39	
2	0	5.04	1.36	1.97	8.37	27.98
2	1	2.26	0.22	9.64	12.12	
2	2	0.27	0.21	7.01	7.49	
4	0	-	0.13	-	0.13	0.16
4	1	-	0.02	-	0.02	
4	2	-	0.01	-	0.01	
4	3	-	0.00	-	0	
4	4	-	0.00	-	0	

Channels like 0L, 0~3τ_h, and 1L, 0~2τ_h are dropped due to huge hadronic background.

Also ZZbb is also one choice in 4L region.

$WW\gamma\gamma$ (1l and 2l) and $\tau\tau\gamma\gamma$(0l2tau and 1l1tau) contribute a lot.

$HH \rightarrow 4\tau$: 3had1l

This work is done by Bowen with BSMττ.

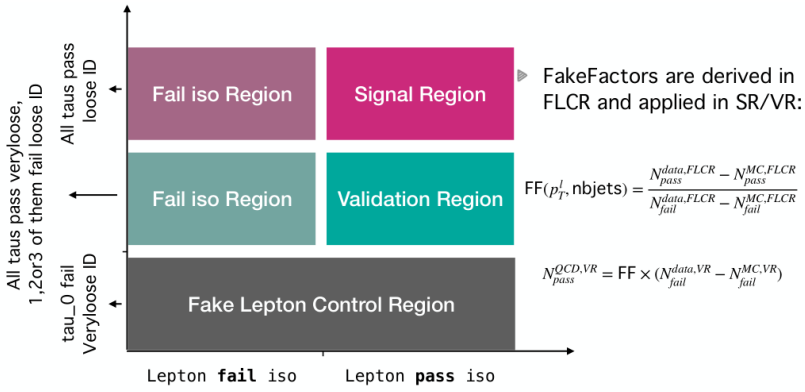
4τ: 3had1l

Bowen's talk

- Data: 15+16+17, $\sqrt{s} = 13\ \mathrm{TeV}, \int L\ =\ 79.66\ fb^{-1}$
- Backgrounds:
  - W+jets, top, Zll, ZZ->4τ(3had1lep), Dibosons, QCD
  - QCD is estimated by data-driven, other tau fakes modeled by MC.
- Signal: aMC@NLO+Herwig7 Non-resonance HH->4τ 100k
  - truth matched to 3had+1lep
- Framework: BSMττ machinery (xTauFramework (produce ntuples) + CAF)
- One Lep Trigger;

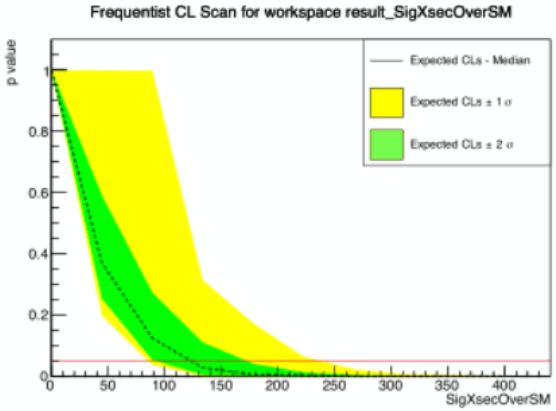
QCD estimation

Method from BSM Htautau lephad analysis



Validation Region Cutflow

$\sqrt{s}$=13 TeV, L=79.66 fb^{-1} lephad	Data	QCDFake	W+jets	Top	Z→ee/μμ/ττ	DiBoson
Have 1lep 3had	6807414	2162197.23 ± 10240.81	2633171.58 ± 9845.49	1809676.12 ± 857.13	136744.51 ± 620.45	65740.59 ± 116.23
Use 1L3H truth filter	6807414	2162197.23 ± 10240.81	2633171.58 ± 9845.49	1809676.12 ± 857.13	136744.51 ± 620.45	65624.56 ± 116.22
Taus Presel	64000	16623.12 ± 1106.88	25608.51 ± 1067.80	17873.69 ± 93.51	2892.54 ± 109.73	1002.14 ± 14.16
Lepton Presel	50080	7139.18 ± 1040.47	22968.86 ± 1006.85	16568.57 ± 90.38	2485.43 ± 101.91	917.96 ± 13.58
One iso lepton	37840	2792.40 ± 281.79	20914.45 ± 951.96	14847.87 ± 84.57	2296.68 ± 99.19	854.46 ± 13.14
Charge	16658	1266.41 ± 207.18	9403.94 ± 642.40	6911.65 ± 57.86	1126.22 ± 65.77	399.54 ± 9.14
Bveto	12180	1225.63 ± 205.74	8960.61 ± 636.03	2089.58 ± 34.10	1080.92 ± 64.13	375.81 ± 8.98



Bkg overall syst = 10%

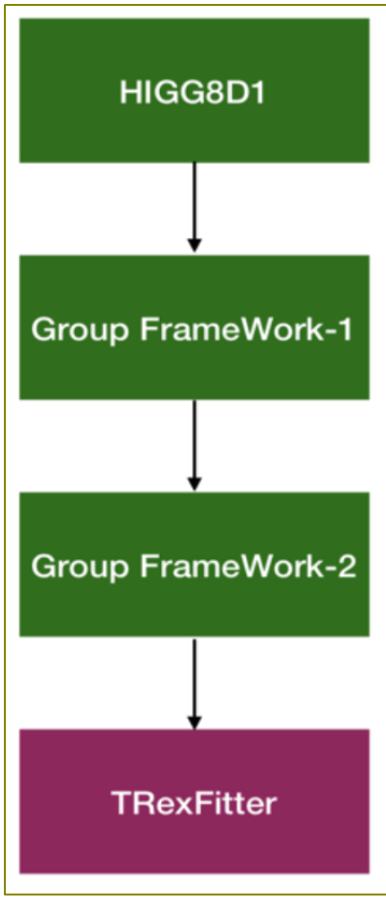
Currently, 3had1lep has done with preliminary results. Background modelling could be improved.

Current preliminary upper limit for $\sigma/\sigma_{SM} = 123$.

Would work closely with multilepton group in the next round.

$HH \rightarrow leptons$

Based in ttHMultileptonAnaTop



Object selection

Rohin's talk

- Triggers: 1l+2l+tau

	Dilepton triggers (2015)
$\mu\mu$ (asymm.)	HLT_mu18_mu8noL1
ee (symm.)	HLT_2e12_lhloose_L12EM10VH
$e\mu$, μe (~symm.)	HLT_e17_lhloose_mu14
	Dilepton triggers (2016)
$\mu\mu$ (asymm.)	HLT_mu22_mu8noL1
ee (symm.)	HLT_2e17_lhvloose_nod0
$e\mu$, μe (~symm.)	HLT_e17_lhloose_nod0_mu14
	Dilepton triggers (2017)
$\mu\mu$ (asymm.)	HLT_mu22_mu8noL1
ee (symm.)	HLT_2e24_lhvloose_nod0
$e\mu$, μe (~symm.)	HLT_e17_lhloose_nod0_mu14

	Single lepton triggers (2015)
μ	HLT_mu20_iloose_L1MU15, HLT_mu50
e	HLT_e24_lhmedium_L1EM20VH, HLT_e60_lhmedium, HLT_e120_lhloose
	Single lepton triggers (2016, 2017)
μ	HLT_mu26_ivarmedium, HLT_mu50
e	HLT_e26_lhtight_nod0_ivarloose, HLT_e60_lhmedium_nod0, HLT_e140_lhloose_nod0

	Lepton + τ triggers
$e\tau$	HLT_e24_lhmedium_nod0_ivarloose_tau35_medium1_tracktwo
$\mu\tau$	HLT_mu14_ivarloose_tau35_medium1_tracktwo

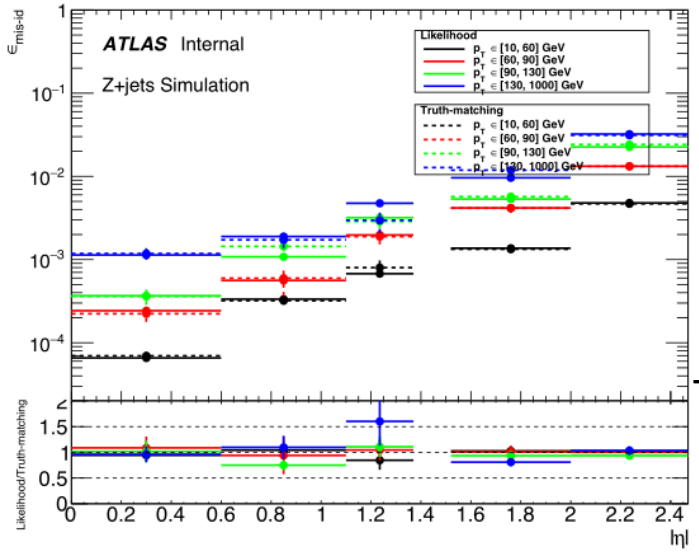
- Lepton:
  - PromptLeptonVeto(PLV)

	Electron		Muon	
	Loose	Tight	Loose	Tight
Isolation	No	FixCutPFlowLoose	No	FixCutPFlowLoose
Identification	Loose	Tight	Loose	Tight
Heavy Flavor suppression	No	PromptLeptonVeto	No	PromptLeptonVeto
Charge mis assignment	No	Yes	N/A	N/A
Conversion suppressions	No	Ambiguity bit + m_(trk,trk)	N/A	N/A
Vertex association	d0_signi < 5		d0_signi < 3	
	Z0_sinTheta < 0.5mm			

2lSS: QMisID

Shuiting's talk

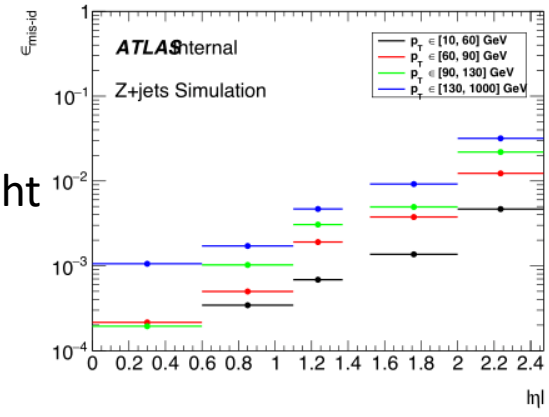
Truth-closure test
2 methods: Likelihood and Truth-matching.

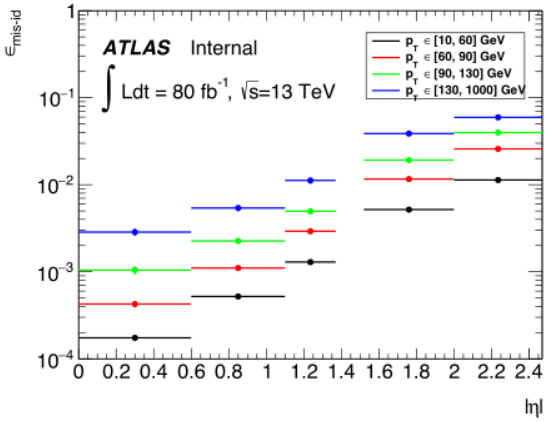


μ charge misID $<10^{-5}$ so ignored.
Electron misID rate studied;

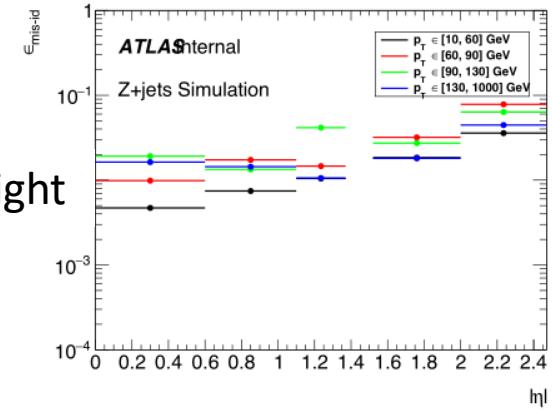
MC(Likelihood) Data

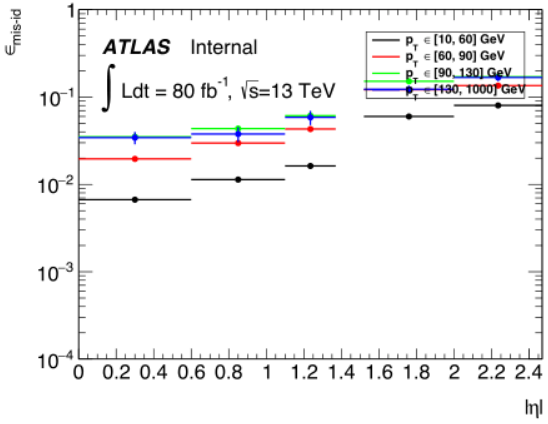
Tight





Anti-Tight



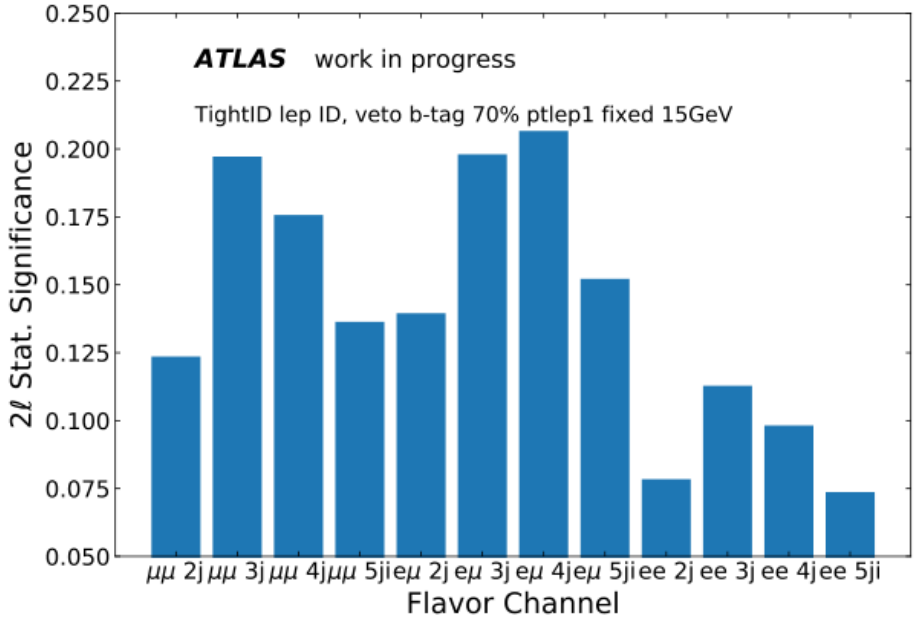


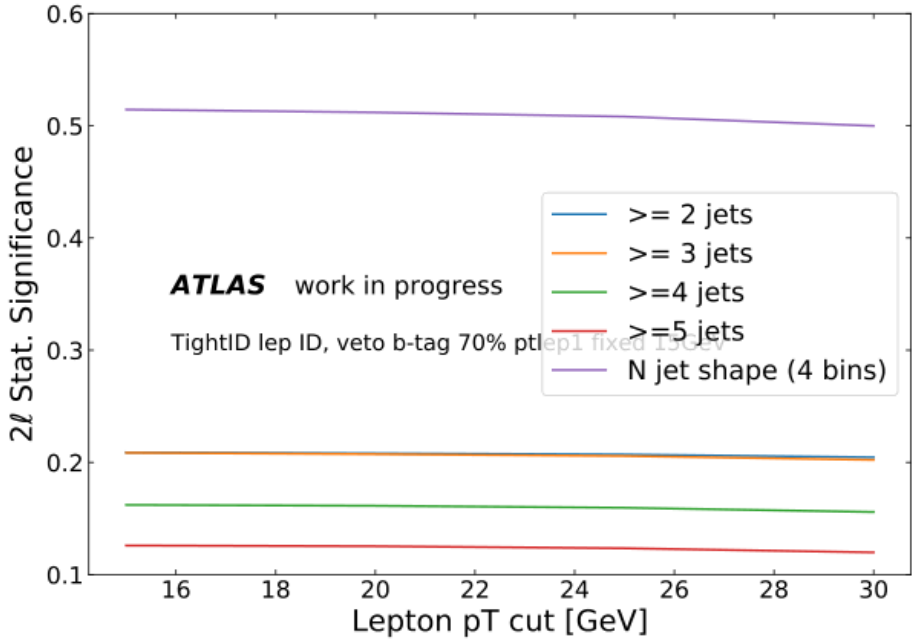
Current QmisID rates from data is agreed with note ATL-COM-PHYS-2018-410.

2lSS: Lepton optimization

Boumediene's talk

4 variables are checked:
QMisID rejection, PLV weight, pT, QMisID, b veto WP;



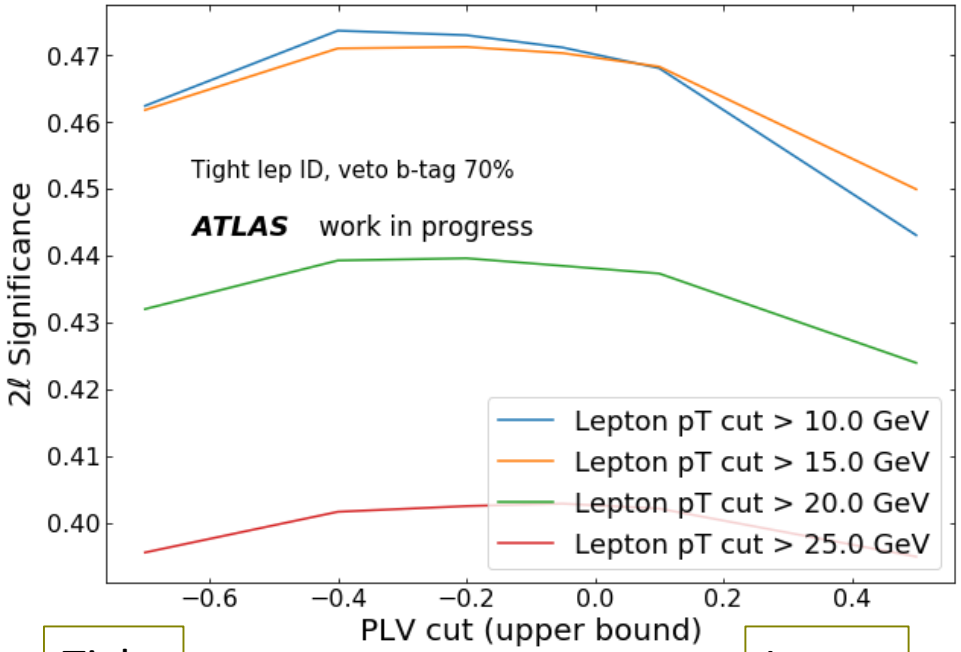


bkg origins also studied, mainly prompt leptons from VV.
no big impact from QMisID BDT (except on ee channel that is much less sensitive than $\mu\mu$/eμ)

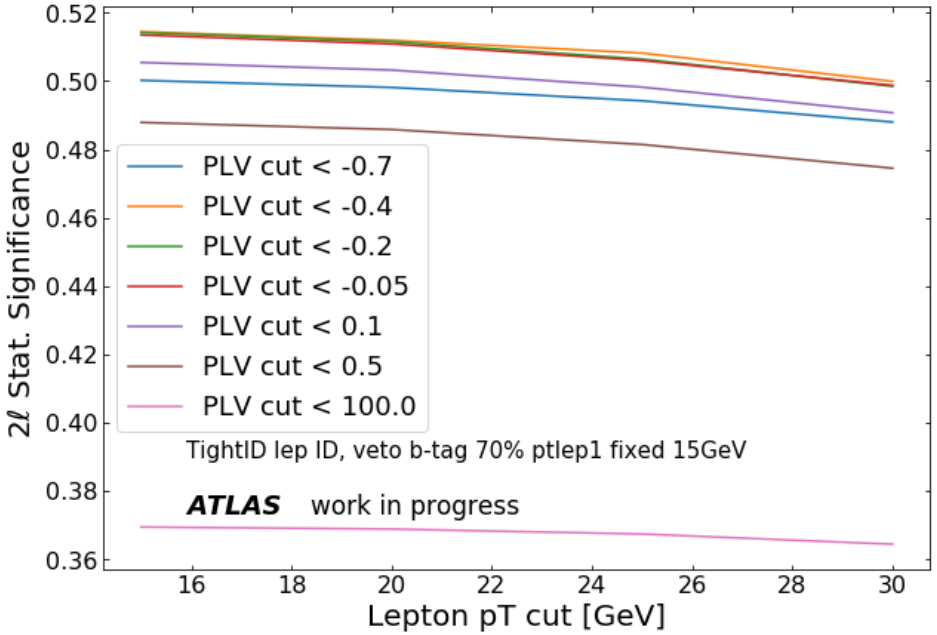
Combination of all regions are applied to calculate significance.

Prompt Lepton veto

Optimal cut ~-0.4. more loose than default ttH(-0.7).
PLV is independent from other cut like pT.
-0.7 ~ +0.5 varies about 6%. No PLV cut would drop ~20%.

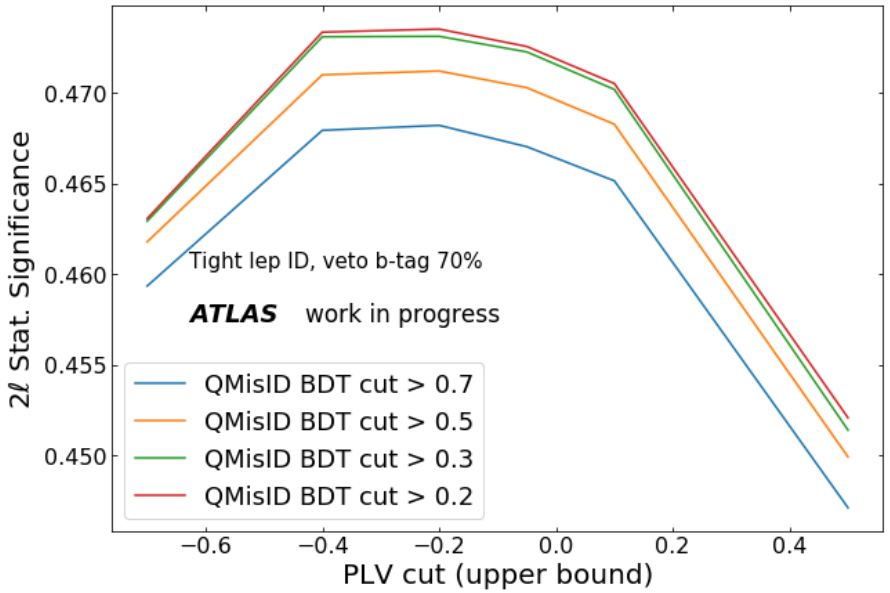


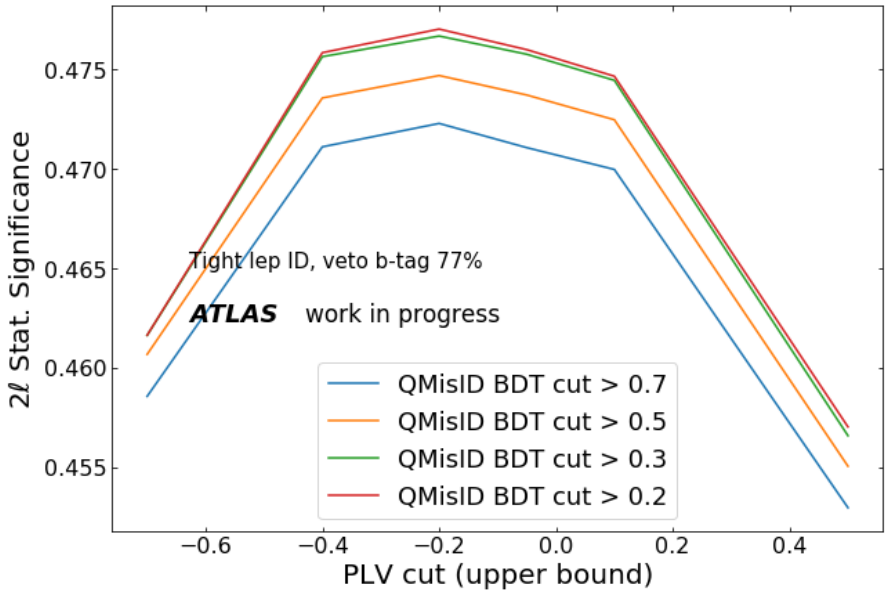
Tight

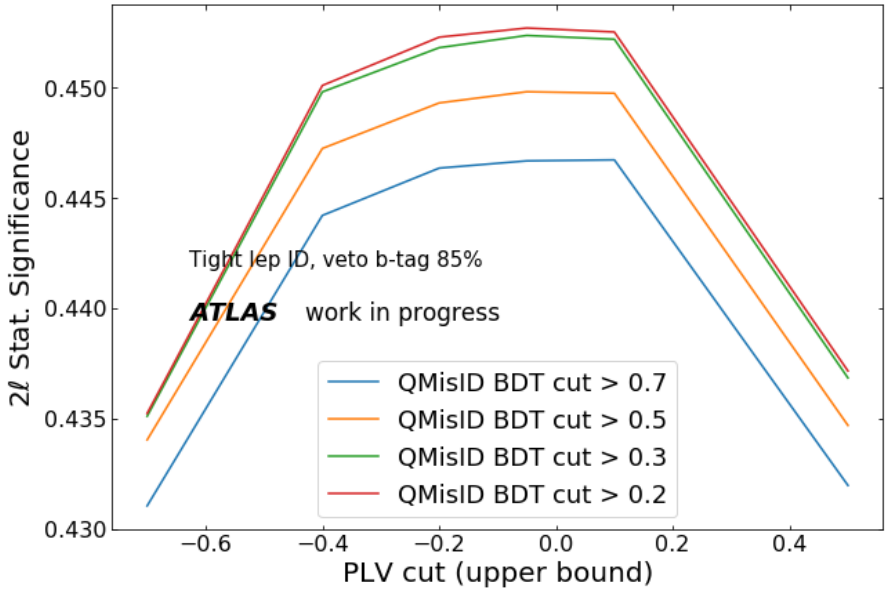


Loose

B veto





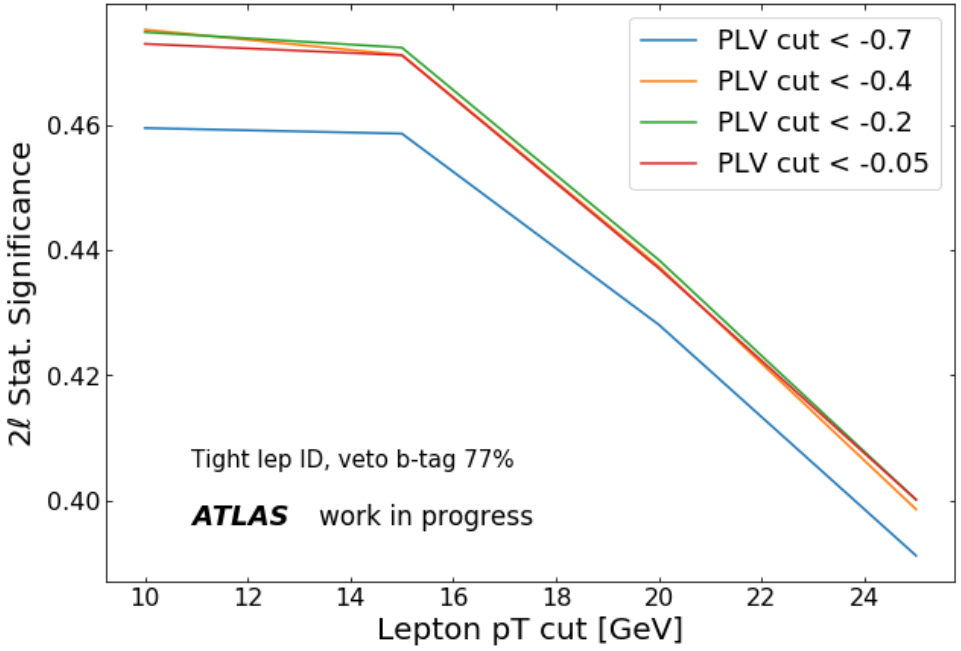


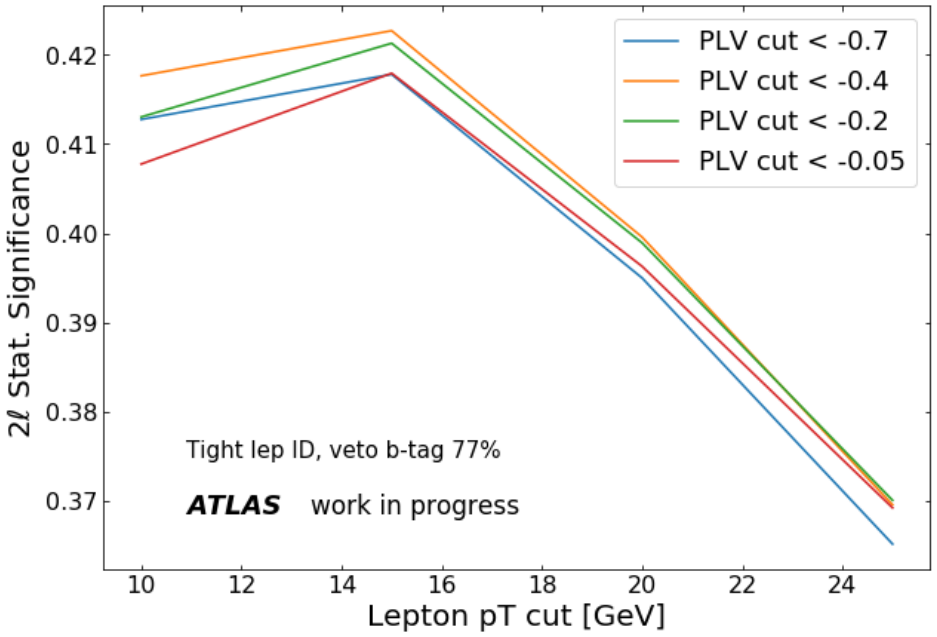
Besides universal b veto for orthogonality (70%), Tight b veto allows a more loose lepton selection by rejecting fake leptons from tt.

77% could be one choice.

Add bkg systematics

Adding a 5% systematic on the background in each category (uncorrelated)





Currently suggested cut:

PLV < -0.4

lepton pT > 15 GeV

2LSS: Signal Efficiency

JianNan's talk.
Based in mc16a;

Electrons
$p_T > 10$GeV (**lep_Pt**)
$|\eta| < 2.47$ (**lep_Eta**) and the crack region $1.37 < |\eta| < 1.52$ is excluded
Loose selection
- ID: LooseLH (**lep_isLooseLH=1**) electron quality
- Isolation: The Loose (**lep_isolationLoose=1**) isolation working point
- $|z_0 \sin\theta| < 0.5$mm (**lep_Z0SinTheta<0.5**) and $d_0/\sigma(d_0) < 5$ (**lep_sigd0PV<5**)

Tight selection:
- Pass the Loose selection
- ID: TightLH (**lep_isTightLH=1**) electron
- Isolation: FixedCutTight (**lep_isolationFixedCutTight=1**) working point

Muons
$p_T > 10$GeV (**lep_Pt**)
$|\eta| < 2.5$ (**lep_Eta**)
Loose selection
- ID: Loose (**lep_isLoose=1**) muon quality
- Isolation: The Loose (**lep_isolationLoose=1**) isolation working point
- $|z_0 \sin\theta| < 0.5$mm (**lep_Z0SinTheta<0.5**) and $d_0/\sigma(d_0) < 3$ (**lep_sigd0PV<3**)

Tight selection:
- Pass the Loose selection
- ID: Tight (**lep_isTight=1**) muon
- Isolation: FixedCutTightTrackOnly (**lep_isolationFixedCutTightTrackOnly=1**) working point

Channel	ee	$\mu\mu$	$e\mu$	Efficiency(ee)	Efficiency($\mu\mu$)	Efficiency($e\mu$)
Lepton Type	48651	49121	76753	27.9%	28.1%	44.0%
Loose quality	42973	37144	58172	24.6%	21.3%	33.3%
Tight quality	22420	30153	39500	12.8%	17.3%	22.6%
pT>10GeV	22420	30153	39500	12.8%	17.3%	22.6%
Lepton eta	20007	30153	36819	11.5%	17.3%	21.1%
SS2L	4716	6727	11154	2.70%	3.85%	6.39%
$lep_{chargeIDBDTTight} > 0.067$ ChargeIDBDT	4106		10458	2.35%		5.99%
pT(pre-selection)	3227	4816	7827	1.85%	2.76%	4.48%

$lep_{pT_0} > 30GeV, lep_{pT_1} > 20GeV$

$HH \rightarrow \gamma\gamma + leptons$

Based in HGamFramework, HIGG1D1.

Huirun added the tau handler to HgamFramework, so τ information is now available in Hgam.

Object selection

Currently all the selections are default configuration in HgamFramework.

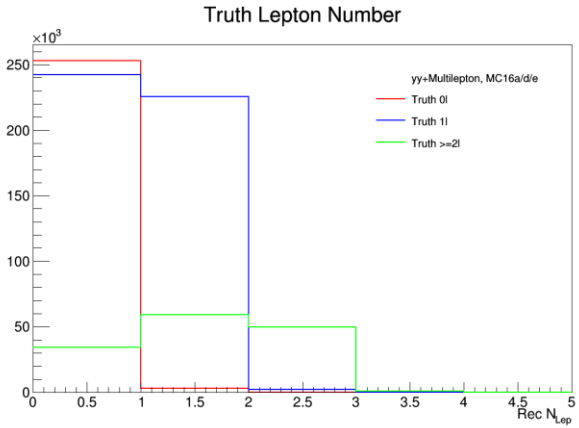
- Basically followed by $H \rightarrow yy$ practice;
- Good Event
  - Derivation; Duplicate; GRL; Trigger; DQ; Vertex……
  - B veto: 70%
- 2 Tight photons
  - Trigger: HLT_g35_loose_g25_loose/ HLT_g35_medium_g25_medium_L12EM20VH
  - Tight PID
  - $\frac{pT_{y1}}{m_{yy}} > 0.35,\ \frac{pT_{y2}}{m_{yy}} > 0.25,\ pT_{y1} > 35\mathrm{GeV},\ pT_{y2} > 25\mathrm{GeV}$
- TMW(Tight Mass Window): $\left|m_{yy} - 125.09\right| < 5\mathrm{GeV}$

Object selection: yy, leptons

- Electron:
  - OQ, HV, IP, pT> 10GeV, $|\eta|$<1.37 or 1.52<$|\eta|$<2.47, IP
  - Medium PID
- Muon:
  - MuQuality, IP, pT> 10GeV, $|\eta|$<2.47
  - Medium PID
- τ:
  - pt > 20GeV, $|\eta|$< 1.37 or 1.52<$|\eta|$< 2.5
  - N_{tracks} = 1 or 3, BDT > 0.01
  - Medium τ ID.

Analysis: yy+ML

Kailis' talk



	$N_{truth}^{lep}=0$	$N_{truth}^{lep}=1$	$N_{truth}^{lep}>1$
$N_{rec}^{lep}=0$	29.0%	27.8%	4.0%
$N_{rec}^{lep}=1$	0.4%	25.9%	6.8%
$N_{rec}^{lep}>1$	0.0%	0.2%	5.8%
Total	29.4%	54.0%	16.6%

Samples are generated with MultiElecMuTauFilter, not by truth lepton information.

So samples are combined and effiencicy separated with truth lepton number.

mc 16a/d/e have no significant difference.

Eff_{com}	$N_{truth}^{lep}=0$	$N_{truth}^{lep}=1$	$N_{truth}^{lep}>1$
Total	100.00%		
Good event+B veto	77.99%		
2 good photons	45.57%		
≥ 1 good leptons	0.10%	15.80%	25.40%
≥ 2 good leptons			11.44%
> 2 good leptons			0.08%

not considering τ in this slide

Photon and Lepton effiencicy

2 tight photon ~45%, similar with other diphoton study.

Photon Effiencicy	1l	2l
Total	100.00%	100.00%
Good Event	82.36%	86.19%
B veto	76.38%	79.31%
2 Loose Photons	61.53%	63.37%
Photon Trigger	55.95%	57.50%
Tight ID	50.90%	52.33%
Isolation	46.81%	48.00%
Relative Pt	46.51%	47.47%
105<m_yy<160	46.15%	46.68%
2 Tight Photos	46.15%	46.68%
120<m_yy<130	**44.69%**	**45.26%**

Eff_{lepton}:	$N_{truth}^{lep}=0$	$N_{truth}^{lep}=1$	$N_{truth}^{lep}>1$
Total	100.00%	100.00%	100.00%
Good event+B veto	77.99%	77.99%	77.99%
>=1 loose leptons	75.15%	75.60%	76.56%
Pt>10 GeV	74.00%	74.96%	76.18%
IP Cut	64.12%	69.86%	71.81%
Isolation	59.32%	68.17%	71.19%
PID: Medium	13.14%	57.78%	68.76%
>=1 good leptons	0.84%	34.69%	55.74%
2 good leptons			25.86%
Opposite Sign+Z veto			25.12%
Final	0.84%	34.69%	25.12%

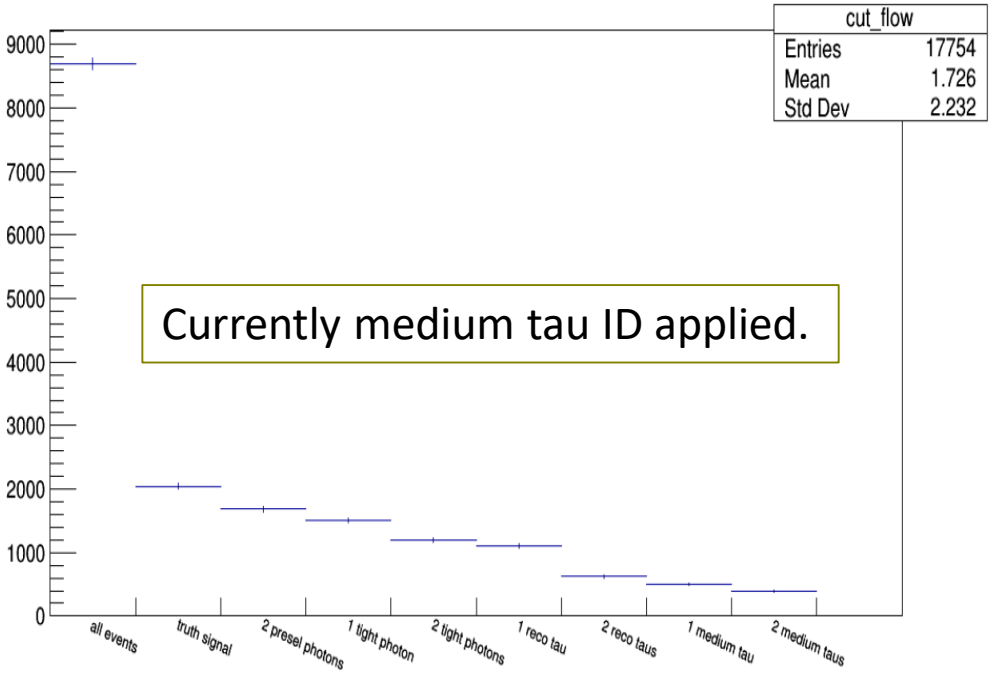
Current lepton selection dropped shapely in medium PID. Need further check.

not considering τ in this slide

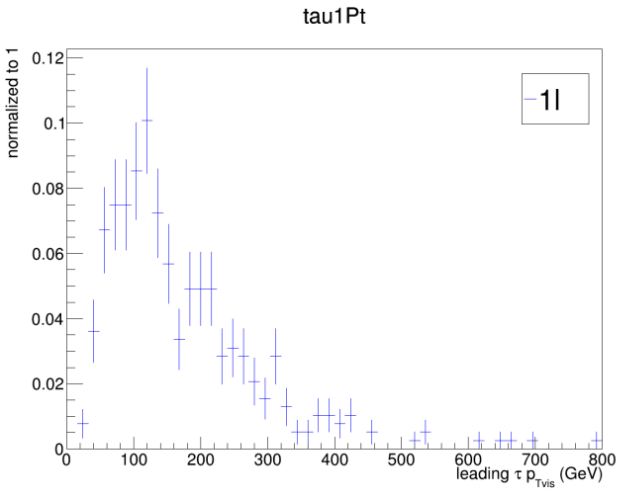
Tau Performance in HGam

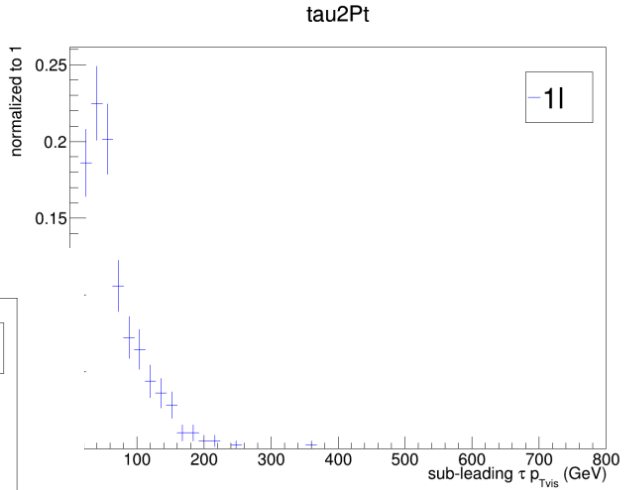
Huirun's talk

Final states: Truth $2\tau_h$

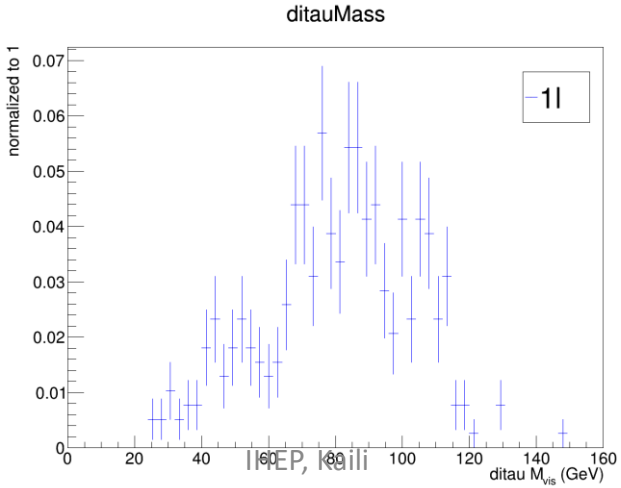


Currently medium tau ID applied.





Tau information now readable in Hgam. Further validation would be done.



Summary

- Lots of R&D done since ML group established
  - Tools in ttH and Hgam framework developed
  - Benchmarks like QMisID and τ validated;
  - 2LSS and yy+ML analysis undergoing

- Aim for 2020's non-resonance combination note

backup

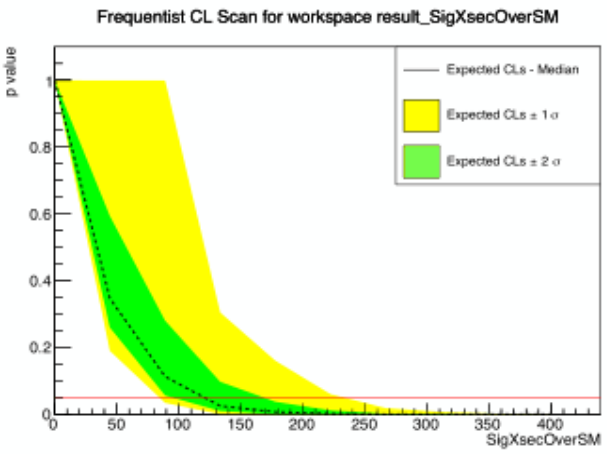
3Had1lep Event selection

10xSignal

Efficiency 1.6%

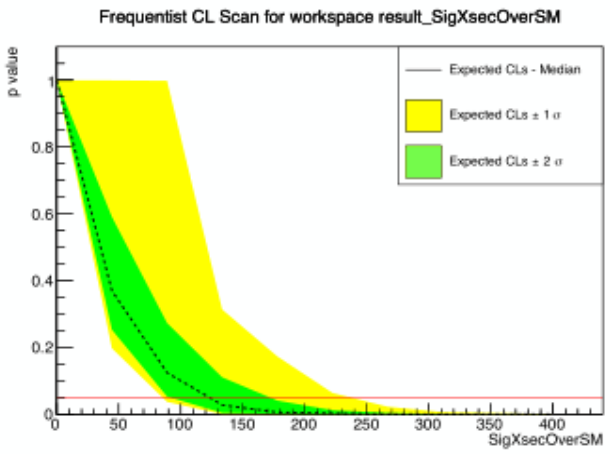
$\sqrt{s}$=13 TeV, L=79.66 fb^{-1} lephad	Data	Total Bkg	HH→$\tau_l\tau_h\tau_h\tau_h$
Have 1lep 3had	6807414	6807530.03 ± 14245.73	5.42 ± 0.15
Use 1L3H truth filter	6807414	6807414.00 ± 14245.73	2.21 ± 0.10
Taus Presel	64000	64000.00 ± 1544.79	1.52 ± 0.08
Lepton Presel	50080	50080.00 ± 1454.32	1.36 ± 0.08
One iso lepton	37840	41705.85 ± 1001.40	1.27 ± 0.07
3 JetBDT loose taus	260	286.08 ± 61.57	0.82 ± 0.06
Charge	114	180.37 ± 53.17	0.81 ± 0.06
BVeto	50	89.96 ± 36.08	0.75 ± 0.06
LepMetTransMassLow	18	9.41 ± 3.47	0.36 ± 0.04
lephadLow, hadhadLow	3	0.74 ± 0.34	0.09 ± 0.02
lephadLow, hadhadHigh	3	2.72 ± 2.10	0.10 ± 0.02
lephadHigh, hadhadLow	2	4.02 ± 2.50	0.02 ± 0.01
lephadHigh, hadhadHigh	3	1.19 ± 1.02	0.10 ± 0.02
LepMetTransMassHigh	32	80.56 ± 35.91	0.39 ± 0.04
lephadLow, hadhadLow	4	7.85 ± 5.21	0.07 ± 0.03
lephadLow, hadhadHigh	2	2.83 ± 1.49	0.01 ± 0.01
lephadHigh, hadhadLow	5	7.94 ± 5.71	0.10 ± 0.02
lephadHigh, hadhadHigh	6	17.92 ± 11.44	0.10 ± 0.02

3Had1lep Limit Setting

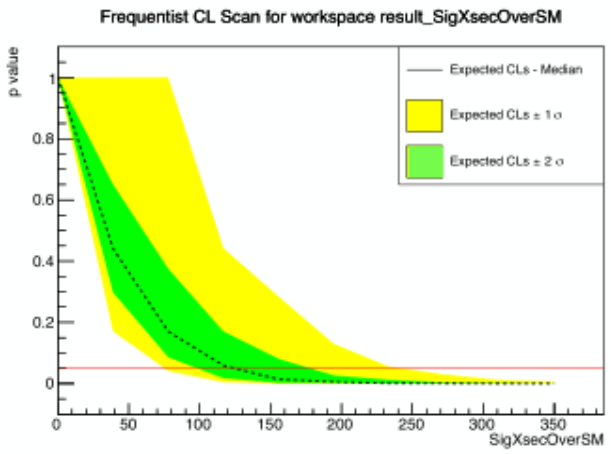


Bkg overall syst = 0

expected limit (median) 120.701



Bkg overall syst = 10%



Bkg overall syst = 20%

expected limit (median) 124.838

```
Expected upper limits,
using the B (alternate) model :
expected limit (median) 123.079
expected limit (-1 sig) 91.5765
expected limit (+1 sig) 171.939
expected limit (-2 sig) 85.3218
expected limit (+2 sig) 237.25
```

Current upper limit for $\sigma/\sigma_{SM} = 123$.