Looking for the Invisible

- Higgs Exo -

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motivation

combining all CMS approved results for Moriond'13:

- $BR_{BSM}=\Gamma_{BSM}/\Gamma_{tot}$ assuming that couplings to the electroweak bosons are bound by the SM expectation ($\kappa_V \leq 1$)
- $0 \leq BR_{BSM} \leq 0.64$ at 95% C.L. (more details in CMS-PAS-HIG-13-005)

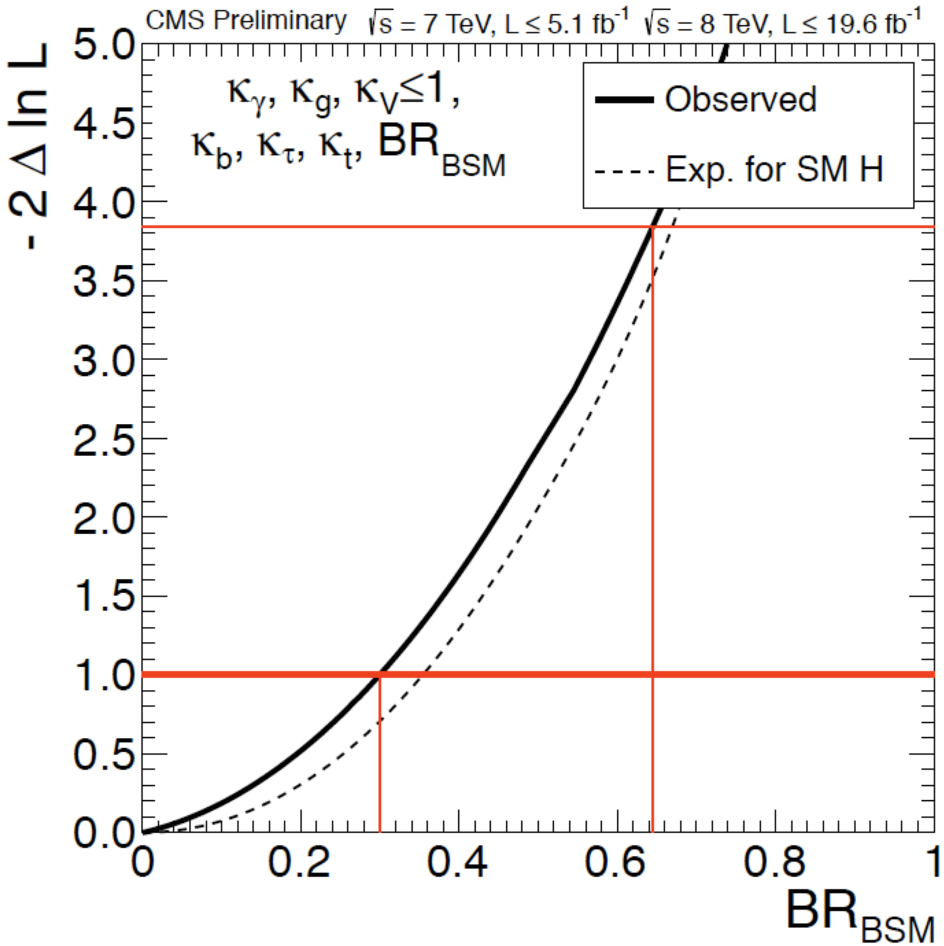
what is invisible?

- H->2Z->4ν (SM with BR ~0.1%)
- BSM

- Higgs decays into a pair of LSPs
- large extra dimensions:

Higgs oscillates to a graviscalar and disappears from our brane

- Higgs decays into graviscalars
- Higgs decays into dark matter particles



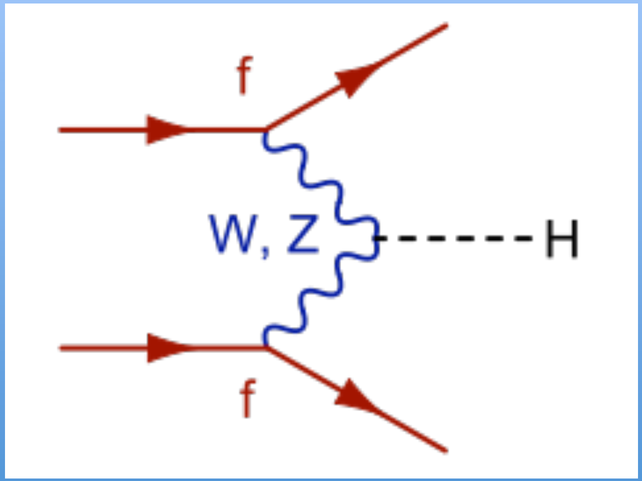
what do we test?

$$R_{inv} = \sigma^{BSM}_{qqH} B(H \to \text{invisible}) / \sigma^{SM}_{qqH}$$

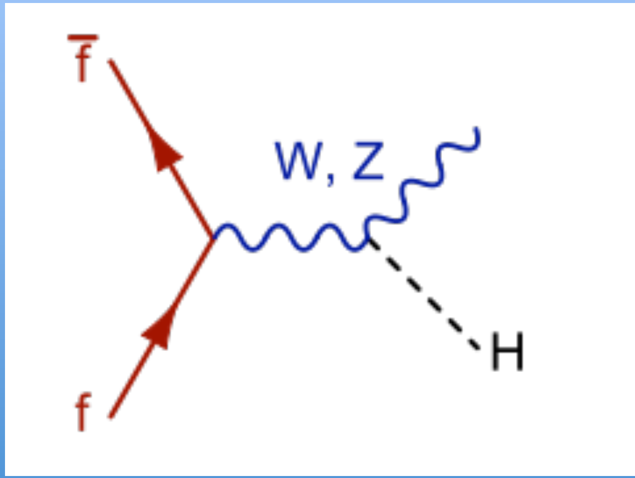
$$R_{inv} = \sigma^{BSM}_{ZH} B(H \to \text{invisible}) / \sigma^{SM}_{ZH}$$

topologies

VBF H



Z(2μ,2e)H



AN-12-403

AN-12-123
AN-13-116

in preparation:
- Z(2b) H – H(2b) group

not yet looked for:
- W(μ,e) H
- Z(2τ,2j) H: more challenging

VBF H

- AN-12-403 & PAS HIG-13-013 -

well written and (almost) complete documentation

C. Asawangtrakuldee, Q. Li, D. Wang

Peking University, Beijing, China

K. Mazumdar, S. Kumar

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P. Srimanobhas

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D. Colling, P. Dunne, A-M. Magnan, A. Nikitenko, J. Pela

Imperial College, London, UK

VBF H

- AN-12-403 & PAS HIG-13-013 -

VBF parked data to be used for the paper

online selection:

• triggers

- HLT_DiPFJet40_PFMETnoMu65_MJJ600VBF_LeadingJets
- HLT_DiPFJet40_PFMETnoMu65_MJJ800VBF_AllJets

• only 8 TeV data:

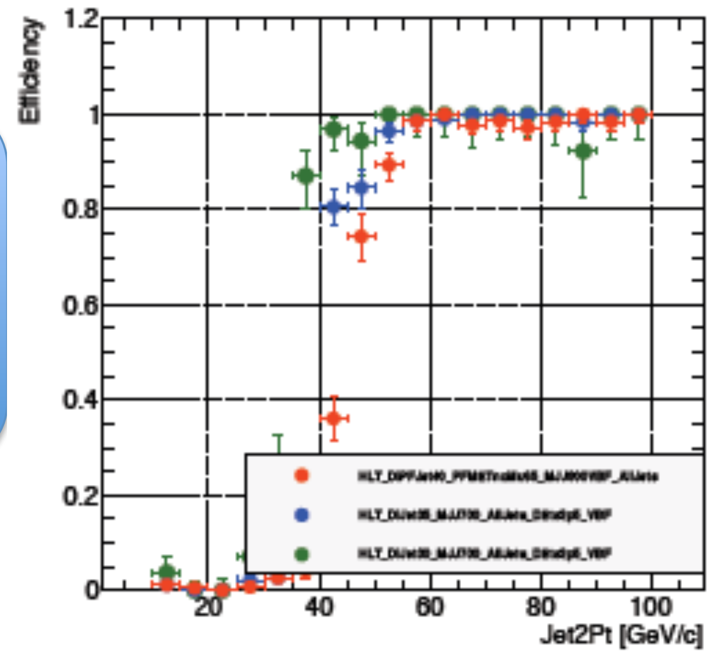
- integrated luminosity 19.6 fb^{-1}

the right way to determine trigger efficiencies

• **trigger efficiency calculated from an independent sample of events** collected using un-prescaled HLT IsoMu24 eta2p1 trigger

• invisible Higgs search triggers eff. become ~100%

- $p_{T\ jet}$ > 50 GeV, M_{jj} > 900 GeV, MET > 130 GeV



more trigger efficiency plots in back-up slides

MC

signal
(total SM VBF Higgs production)

Dataset	Cross-section [pb]
PYTHIA	
$H \to ZZ \to 4\nu$ ($m_H = 120$ GeV)	1.632
$H \to ZZ \to 4\nu$ ($m_H = 150$ GeV)	1.280
$H \to ZZ \to 4\nu$ ($m_H = 200$ GeV)	0.8685
$H \to ZZ \to 4\nu$ ($m_H = 300$ GeV)	0.4408
$H \to ZZ \to 4\nu$ ($m_H = 400$ GeV)	0.2543
POWHEG	
$H \to ZZ \to 4\nu$ ($m_H = 110$ GeV)	1.809
$H \to ZZ \to 4\nu$ ($m_H = 125$ GeV)	1.578
$H \to ZZ \to 4\nu$ ($m_H = 150$ GeV)	1.280
$H \to ZZ \to 4\nu$ ($m_H = 200$ GeV)	0.8685
$H \to ZZ \to 4\nu$ ($m_H = 300$ GeV)	0.4408
$H \to ZZ \to 4\nu$ ($m_H = 400$ GeV)	0.2543

background

Dataset	σ [pb]	Equivalent $\int L$ [fb^{-1}]
$(Z \to \nu\nu)$ + jets ($50 < H_T < 100$ GeV)	381.2	10.3
$(Z \to \nu\nu)$ + jets ($100 < H_T < 200$ GeV)	160.3	25.1
$(Z \to \nu\nu)$ + jets ($200 < H_T < 400$ GeV)	41.49	122
$(Z \to \nu\nu)$ + jets ($400 < H_T < \infty$ GeV)	5.274	191
$(W \to l\nu)$ + jets (inclusive)	37509 (NNLO)	2.0
$(W \to l\nu)$ + 1 jet	6662.78 (NNLO)	3.5
$(W \to l\nu)$ + 2 jet	2159.24 (NNLO)	15.8
$(W \to l\nu)$ + 3 jet	640.37 (NNLO)	24.3
$(W \to l\nu)$ + 4 jet	264.0 (NNLO)	50.7
$(Z/\gamma* \to ll)$ + jets ($M_{ll} > 50$)	3503.71 (NNLO)	8.6
$(Z/\gamma* \to ll)$ + jets ($p_T^Z > 100$ GeV)	40.5 (NNLO)	64.7
$(Z/\gamma* \to ll)$ + EWK jets ($M_{ll} > 50$, $M_{jj} > 200$ GeV)	0.45	1134
WW	54.838 (NLO)	182
WZ	33.21 (NLO)	301
ZZ	17.654 (NLO)	558
$t\bar{t}$ + jets	234 (NNLO)	28.8
t (t-channel)	56.4 (NLO)	66.6
t (tW-channel)	11.1 (NLO)	42.5
t (s-channel)	3.79 (NLO)	62.0
$\bar{t}$ (t-channel)	30.7 (NLO)	63.0
$\bar{t}$ (tW-channel)	11.1 (NLO)	42.5
$\bar{t}$ (s-channel)	1.76 (NLO)	79.5
QCD ($30 < \hat{p}_T < 50$ GeV)	6.6285328E7	0.00009
QCD ($50 < \hat{p}_T < 80$ GeV)	8148778.0	0.00073
QCD ($80 < \hat{p}_T < 120$ GeV)	1033680.0	0.0058
QCD ($120 < \hat{p}_T < 170$ GeV)	156293.3	0.038
QCD ($170 < \hat{p}_T < 300$ GeV)	34138.15	0.17
QCD ($300 < \hat{p}_T < 470$ GeV)	1759.549	3.4
QCD ($470 < \hat{p}_T < 600$ GeV)	113.8791	35.1
QCD ($600 < \hat{p}_T < 800$ GeV)	26.9921	148
QCD ($800 < \hat{p}_T < 1000$ GeV)	3.550036	1126
QCD ($1000 < \hat{p}_T < 1400$ GeV)	0.737844	2662
QCD ($1400 < \hat{p}_T < 1800$ GeV)	0.03352235	59700
QCD ($1800 < \hat{p}_T < \infty$ GeV)	0.001829005	534492

offline selection

PV:
- $|z| < 24$ cm
- $r < 2$ cm
- $N_{tracks} > 10$

- with r = 2 cm we risk to hit the beam pipe (see back-up slides)

- according to HCAL TDR the coverage goes up to $|\eta| < 5.0$
- looking for anti k_T jets with $R < 0.5$, jets acceptance should be $|\eta| < 4.3$ (max 4.5)

jets:
- anti k_T jets with $R < 0.5$
- pass PU jet ID (Loose MVA working point)
- 2 jets:

- $p_T > 50$ GeV
- $|\eta| < 4.7$ (inherited), $\eta_{j1} * \eta_{j2} < 0$
- $|\Delta\eta_{jj}| > 4.2$
- $M_{jj} > 1200$ GeV

topology:
- PF MET > 130 GeV

- event selected if it passes the MET filter

- $|\Delta\Phi_{jj}| < 1.0$ rad

(suppresses QCD multi-jet bkg.)

leptons veto:
- veto μ:

$p_T > 10$ GeV, $|\eta| < 2.1$, rel PF Iso < 0.2
- veto e:

$p_T > 10$ GeV, $|\eta| < 2.5$, rel PF Iso < 0.15

expected yields: 19.6 fb^{-1}

Cut	Process						
	$Z \to \nu\nu$	$W \to \ell\nu$	QCD	$t\bar{t}$	single t	VV	$H \to inv$ ($m_H = 125$ GeV)
Trigger	36408 ± 124	225189 ± 648	$(5.3 \pm 4.1) \times 10^8$	36412 ± 162	8517 ± 55	2518 ± 14	2447 ± 29
MET filters	36276 ± 124	224312 ± 647	$(5.3 \pm 4.1) \times 10^8$	36191 ± 161	8471 ± 55	2508 ± 14	2440 ± 29
e veto	36216 ± 124	186433 ± 581	$(5.3 \pm 4.1) \times 10^8$	27731 ± 141	6832 ± 49	2075 ± 13	2437 ± 29
μ veto	36206 ± 123	131046 ± 525	$(5.3 \pm 4.1) \times 10^8$	16071 ± 107	4261 ± 39	1407 ± 10	2437 ± 29
dijet $p_T > 50$ GeV	23406 ± 77	72685 ± 273	$(8.4 \pm 1.1) \times 10^6$	15389 ± 105	3600 ± 36	884 ± 8.3	1694 ± 24
$\eta_1 \cdot \eta_2 < 0$	16376 ± 65	45650 ± 206	$(3.8 \pm 0.3) \times 10^6$	7542 ± 75	2051 ± 27	427 ± 5.8	1602 ± 24
$\Delta\eta_{jj} > 4.2$	6754 ± 49	18814 ± 144	$(1.25 \pm 0.11) \times 10^6$	1035 ± 28	567 ± 14	133.9 ± 3.3	1291 ± 21
$\not{E}_T > 130$ GeV	2947 ± 30	4872 ± 64	4230 ± 1340	385 ± 17	132.8 ± 7.1	58.6 ± 2.1	838 ± 17
$M_{jj} > 1200$ GeV	1207 ± 17	1981 ± 40	1889 ± 715	163 ± 11	51.0 ± 4.4	16.2 ± 1.1	459 ± 13
$\Delta\phi_{jj} < 1.0$	235 ± 8.6	385 ± 18	10 ± 10	39.4 ± 5.5	13.7 ± 2.3	5.14 ± 0.64	190.6 ± 8.3

Powheg

most difficult background:
- QCD

main backgrounds:
- irreducible Z(2ν)+jets
- W+jets

signal:
- assuming 100% BR

expected yields: 19.6 fb^{-1}

m_H [GeV]	yield POWHEG qqH	eff [%] POWHEG qqH	eff [%] PYTHIA qqH	eff [%] POWHEG ggH
110	200.3 ± 9.0	0.561 ± 0.025	-	0.0047 ± 0.0017
120	-	-	0.635 ± 0.027	-
125	190.6 ± 8.3	0.611 ± 0.027	-	0.0029 ± 0.0012
150	183.6 ± 7.3	0.726 ± 0.029	0.750 ± 0.029	0.0085 ± 0.0022
200	140.7 ± 7.5	0.820 ± 0.044	0.960 ± 0.033	0.0083 ± 0.0022
300	93.3 ± 4.3	1.071 ± 0.049	1.387 ± 0.040	0.0290 ± 0.0041
400	66.2 ± 2.7	1.319 ± 0.055	1.555 ± 0.042	0.0380 ± 0.0046

qqH
- differences between Pythia and Powheg efficiencies (from 4% to 28%)
- not yet clear the reason

ggH
- less than 1% for mass bellow 200 GeV

background: Z(2ν)

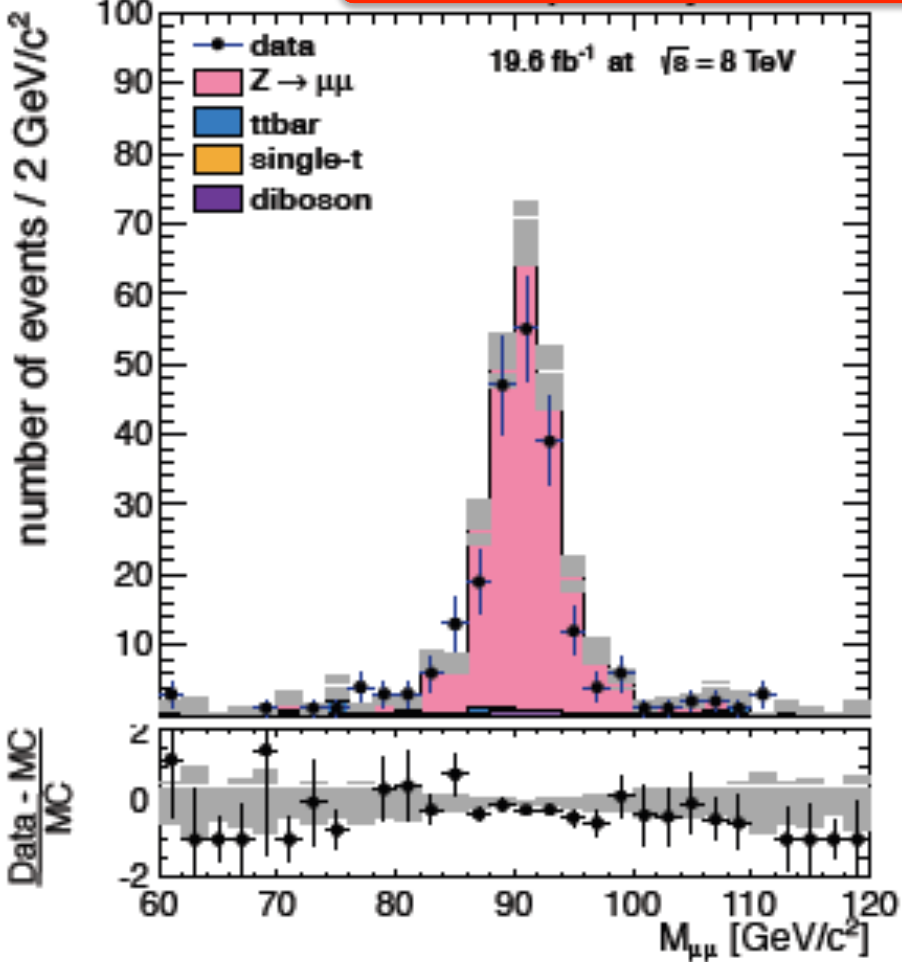
estimated from data: Z(2μ)

- 2 tight muons:
- $p_T > 20$ GeV, $|\eta| < 2.1$,
- $60 < M_{\mu\mu} < 120$ GeV
- 2 jets:
- $p_T > 50$ GeV, $|\eta| < 4.7$, $\eta_{j1} * \eta_{j2} < 0$
- $|\Delta\eta_{jj}| > 4.2$
- $M_{jj} > 1200$ GeV
- MET including Z > 130 GeV
- no lepton veto

number of Z(2ν) events in signal region:

$$(N^c_{obs} - N^c_{bkg}) \cdot \frac{\sigma(Z \to \nu\nu)}{\sigma(Z/\gamma^* \to \mu\mu)} \cdot \frac{\epsilon^S_{VBF}/\epsilon^C_{VBF}}{\epsilon_{\mu\mu}}$$

clear and well made plots



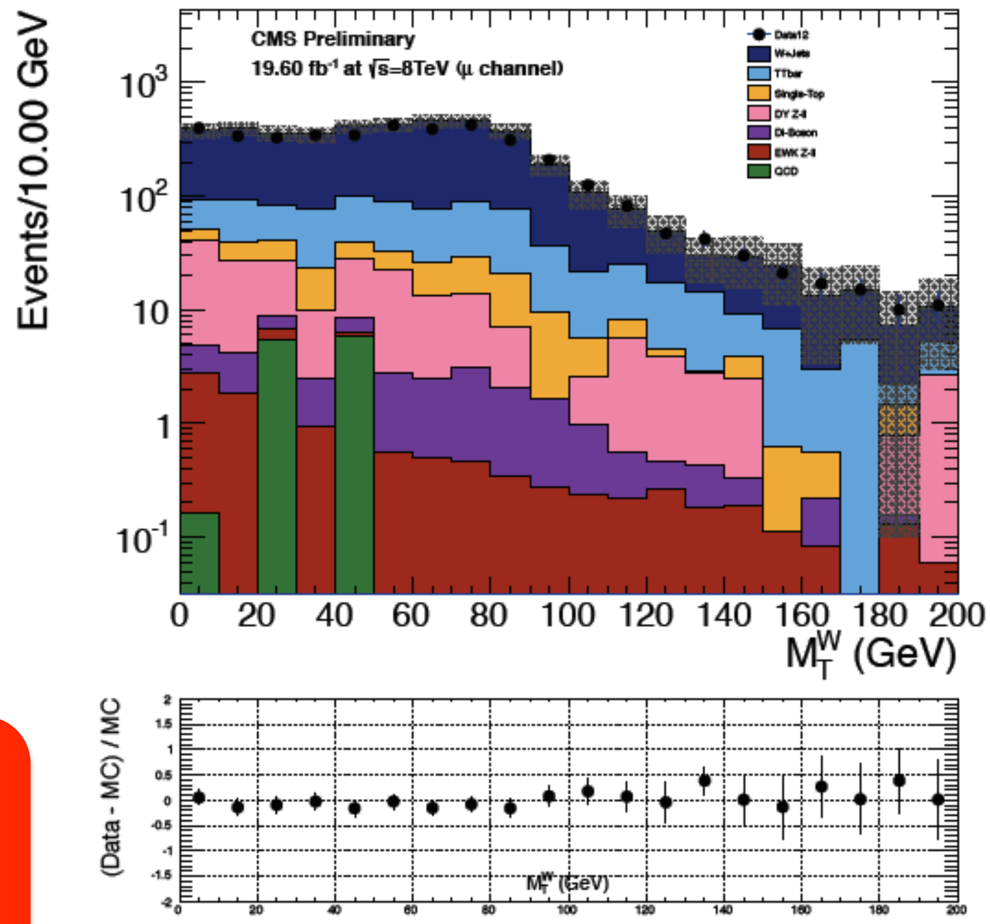
nice agreement between data and MC in the control region (see back-up slides)

background: W+jets

estimated from data: W(μ,e)

- one tight muon/electorn:
- p_T > 20 GeV, |η| < 2.1/2.5,
- 40 < M_T < 120 GeV
- veto on additional e and μ
- p_T > 10 GeV, |η| < 2.1/2.5
- 2 jets:
- p_T > 50 GeV, |η| < 4.7, $\eta_{j1} * \eta_{j2} < 0$
- $|\Delta\eta_{jj}| > 4.2$
- M_{jj} > 1200 GeV
- MET including W(μ,e) > 130 GeV

clear and well made plots



number of W+jets events in signal region:

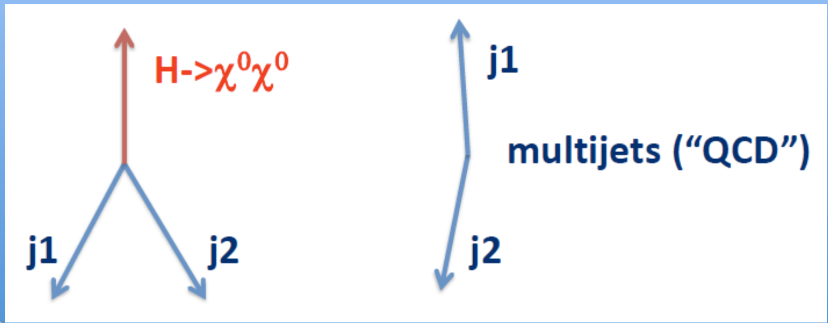
$$N_\ell^s = (N_{obs}^c - N_{bkg}^c) \cdot (\epsilon_{VBF}^S / \epsilon_{VBF}^C) \frac{1 - \epsilon_{\ell-veto}}{\epsilon_\ell}$$

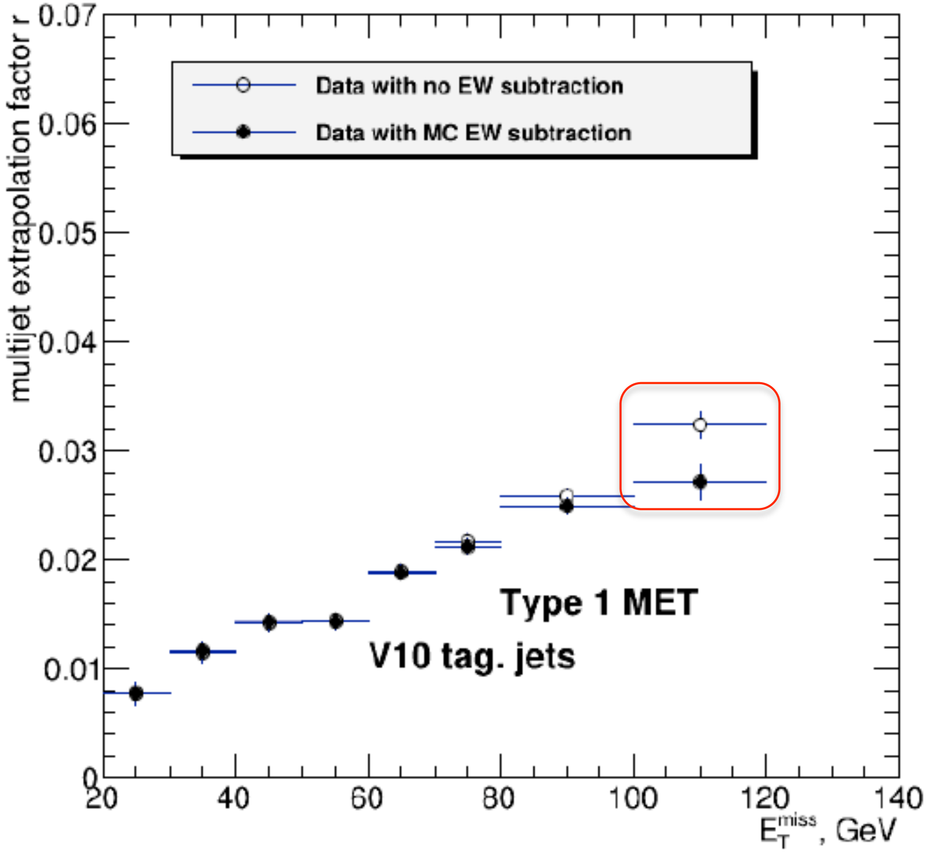
nice agreement between data and MC in the control region (see back-up slides)

background: QCD – method 1

estimated from data & MC:

- no MET selection
- large $\Delta\Phi_{jj} > 2.6$





number of QCD multijet events in signal region:

$$N_S^{\mathrm{multijet}} = (N_C - N^{\mathrm{non-multijet}}) \times r$$

with r(MET):

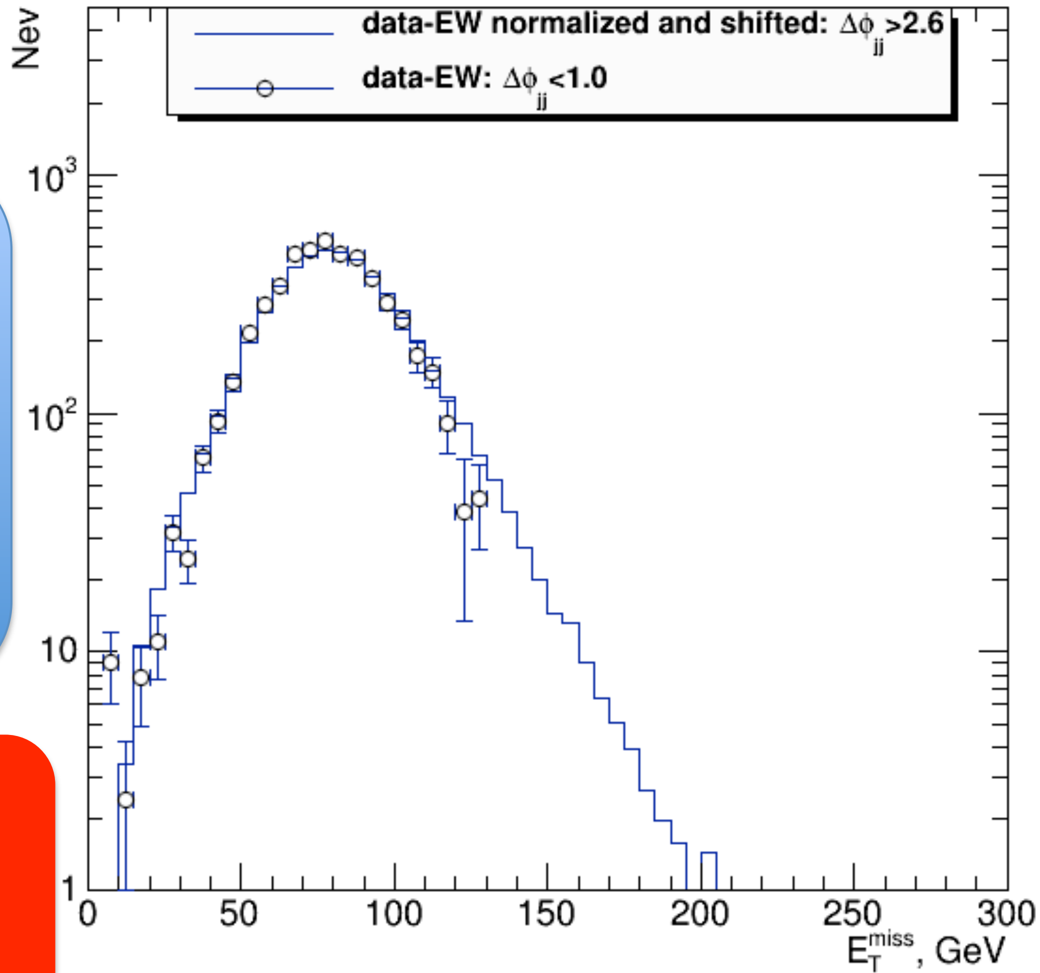
$$\frac{N_{\mathrm{data}}(\Delta\phi_{jj} < 1.0) - N^{\mathrm{non-multijet}}(\Delta\phi_{jj} < 1.0)}{N_{\mathrm{data}}(\Delta\phi_{jj} > 2.6) - N^{\mathrm{non-multijet}}(\Delta\phi_{jj} > 2.6)}$$

not easy to control extrapolation from low MET (35/70 GeV) to higher values > 130 GeV

background: QCD – method 2

estimated from data & MC:
- MET shape in QCD control region (no MET cut)
- N_{ev} signal region with MET < 130 GeV, subtract EW
- N_{ev} QCD in signal region with MET > 130 GeV:

measured MET shape and N_{ev} QCD in signal region (MET< 130 GeV)



- an additional jet veto (p_T > 20 GeV) in tracker acceptance can reduce QCD contribution by a factor of 5
- signal efficiency still needs to be check

- up to 120 GeV very nice agreement
- but there is a shift of 10 GeV that still needs to be explained ☺

systematic uncertainties

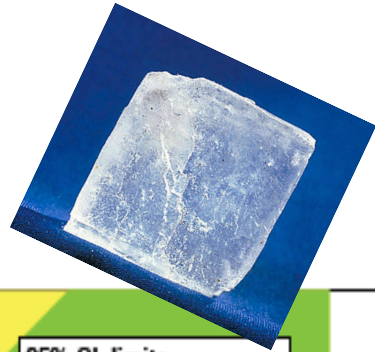
Source	Uncertainty on background
Statistics in Z region	25%
Statistics in $W-e$ region	10%
Statistics in $W-\mu$ region	5%
W MC statistics	10%
Luminosity	4%
Jet energy scale	3%
Jet energy resolution	*not included yet*
Unclustered energy scale	*not included yet*

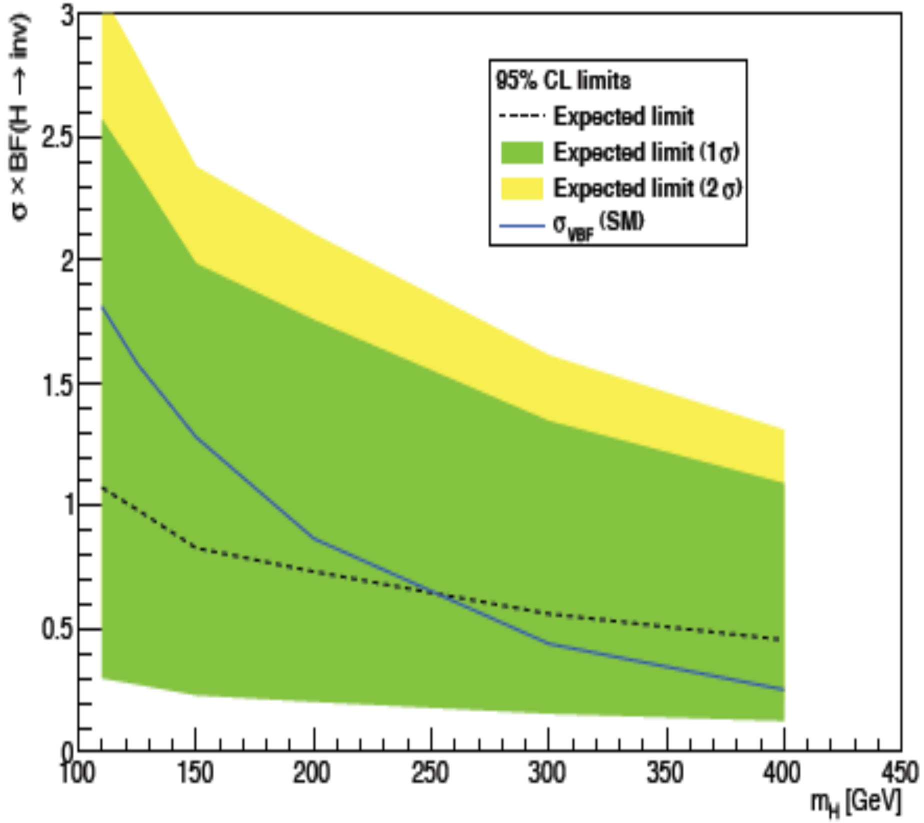
Source	Uncertainty on signal efficiency
Jet energy scale	10%
Jet energy resolution	*not included yet*
Unclustered energy scale	*not included yet*

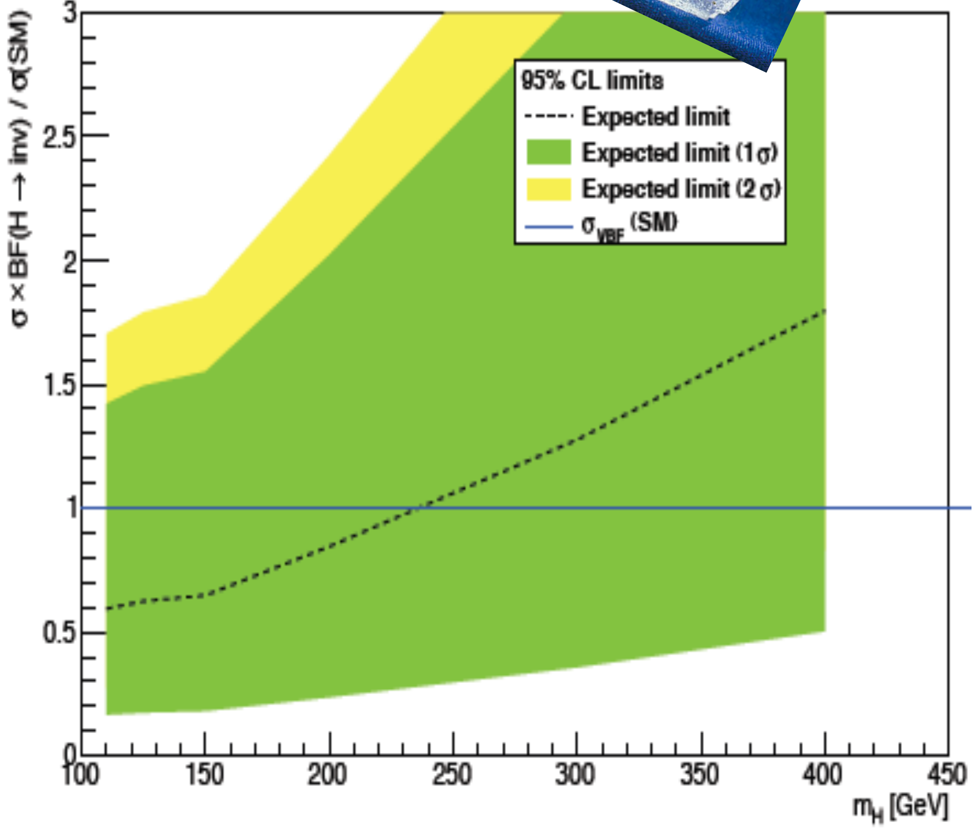
- still missing the PDF uncertainty
- all systematic uncertainties should come with the next update

expected limits

- QCD method 1 -







- asymptotic CL_S:

95% CL expected limit on the invisible BR for 125 GeV: 62%

- exclude additional Higgs bosons with 100% invisible BR and masses below 250 GeV

Z(2μ,2e)H

- AN-12-123 & AN-13-013 -

we are working on it

we can benefit much more from an improved version of the documentation

AN-13-116

A. Apyan [a], G. Bauer [a], M. Chan [a], L. Di Matteo [a], V. Dutta [a], G. Gómez-Ceballos [a], M. Goncharov [a], M. Klute [a], I. Kravchenko [b], A. Levin [a], S. Nahn [a], Ch. Paus [a], D. Ralph [a], K. Sumorok [a], S. Tkaczyk [c], R. Wolf [a], M. Yang [a], M. Zanetti [a]

well written and (almost) complete documentation

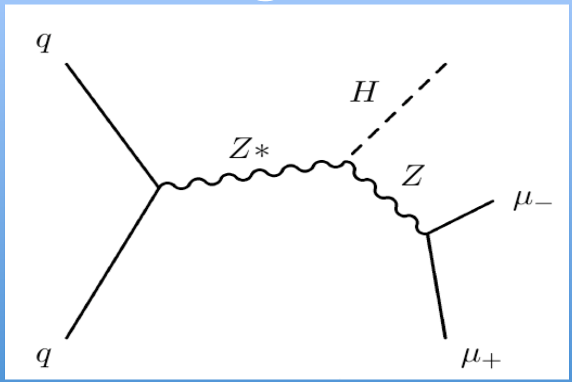
AN-12-123

E. Barberis, .D. Bortoletto, G. Cerminara, M. Cervantes Valdovinos, M. Chasco, B. Clerbaux, M. Manelli, P. Merkel, L. Pernie, L. Quertenmont, T. Seva, P. Silva, D. Trocino, P. Vanlaer, J. Wang, R.-J. Wang, D. Wood

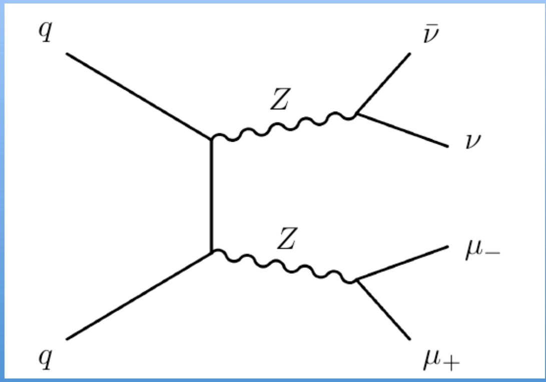
in the next slides the AN-12-123 will be presented

Z(2μ,2e)H

signal



irreducible background



Dataset	$\int \mathcal{L}$ [pb^{-1}]	Run range
7 TeV		
/PD/Run2011A-HZZ-08Nov2011-v1/AOD	2312	160431-173692
/PD/Run2011B-HZZ-19Nov2011-v1/AOD	2739	175860-180252
Total for the 2011 dataset	5051	
8 TeV		
/PD/Run2012A-13Jul2012/AOD	890	190459-193621
/PD/Run2012B-13Jul2012/AOD	4430	193834-195947
/PD/Run2012C-24Aug/AOD	490	197774-198913
/PD/Run2012C-PromptReco-v2/AOD	6390	198913-200601
/PD/Run2012D-PromptReco-v1/AOD	7380	203768-208686
Total for the 2012 dataset	19580	

primary data sets:

- Single Mu
- Double Mu
- Double Electron

Z(2μ,2e)H: trigger

need to complete description of trigger efficiency treatment

Channel	Dataset Name	2011 p_T thresholds [GeV/c, GeV/c]	2012 p_T thresholds [GeV/c, GeV/c]
ee	DoubleElectron	17, 8	17, 8
$\mu\mu$	DoubleMu	7, 7 13, 8 17, 8	17, 8
$e\mu$	MuEG	17 (μ), 8 (e) 17 (e), 8 (μ)	17 (μ), 8 (e) 17 (e), 8 (μ)
γ	Photon,SinglePhoton, DoubleElectron	20,30,50,75,90 125,135,200	22,36,50,75,90 (EB only) 135,150,160,250,300

- backgrounds measurement
- control of some backgrounds

Z(2μ,2e)H: MC samples

since long time I have not seen such a complete overview

- signal samples (Pythia):

SM Higgs in association with Z boson
- Z decays into lepton pairs (2e, 2μ, 2τ)

Process	Dataset	σ
	7 TeV	
$W \to \ell\nu$	/WJetsToLNu_TuneZ2_7TeV-madgraph-tauola/F11-S6-v1	31314 ± 1558
$Z \to \ell\ell$	/DYJetsToLL_TuneZ2_M-50_7TeV-madgraph-tauola/F11-S4-v1	3048 ± 132
$t\bar{t}$	/TTJets_TuneZ2_7TeV-madgraph-tauola/F11-S4-v1	165^{+8}_{-11}
Single top	/T_TuneZ2_tW-channel-DR_7TeV-powheg-tauola/F11-S6-v1	7.87 ± 0.59
	/Tbar_TuneZ2_tW-channel-DR_7TeV-powheg-tauola/F11-S6-v1	7.87 ± 0.59
	/T_TuneZ2_t-channel_7TeV-powheg-tauola/F11-S6-v1	$41.92^{+1.8}_{-0.9}$
	/Tbar_TuneZ2_t-channel_7TeV-powheg-tauola/F11-S6-v1	$22.6^{+0.84}_{-1.04}$
	/T_TuneZ2_s-channel_7TeV-powheg-tauola/F11-S6-v1	$3.19^{+0.14}_{-0.12}$
	/Tbar_TuneZ2_s-channel_7TeV-powheg-tauola/F11-S6-v1	$1.44^{+0.06}_{-0.07}$
Di-bosons	/ZZJetsTo2L2Nu_TuneZ2_7TeV-madgraph-tauola/F11-v1	$6.83^{+0.30}_{-0.21} \times 0.0386$
	/WWJetsTo2l2Nu_TuneZ2_7TeV-madgraph-tauola/F11-S6-v1	$52.4 \pm 2.0_{stat} \pm 4.7_{syst} \times 0.105$
	/WZJetsTo3LNu_TuneZ2_7TeV-madgraph-tauola/F11-S6-v1	$18.5^{+1.0}_{-0.8} \times 0.033$
	8 TeV	
$W \to \ell\nu$	/WToENu_TuneZ2star_8TeV_pythia6/S12-S50-v1 /WToMuNu_TuneZ2star_8TeV_pythia6/S12-S50-v1 /WToTauNu_TuneZ2star_8TeV_pythia6_tauola_cff/S12-S50-v1	12085
$Z \to \ell\ell$	/DYJetsToLL_M-50_TuneZ2Star_8TeV-madgraph-tarball/S12-S52-v2	35041
$t\bar{t}$	/TTJets_MassiveBinDECAY_TuneZ2star_8TeV-madgraph-tauola/S12-v1	225
Single top	/Tbar_tW-channel-DR_TuneZ2star_8TeV-powheg-tauola/S12-S52 $(\bar{t})$	11.2
	/T_tW-channel-DR_TuneZ2star_8TeV-powheg-tauola/S12-S52 (t)	11.2
	/Tbar_t-channel_TuneZ2star_8TeV-powheg-tauola/S12-S52 $(\bar{t})$	55.5
	/T_t-channel_TuneZ2star_8TeV-powheg-tauola/S12-S52 (t)	30.0
	/Tbar_s-channel_TuneZ2star_8TeV-powheg-tauola/S12-S52 $(\bar{t})$	3.9
	(t)	1.76
Dibosons	/ZZJetsTo2L2Nu_TuneZ2star_8TeV-madgraph-tauola/S12-S52-v3	$8.384^{+0.37}_{-0.24} \times 0.0386$
	/WWJetsTo2L2Nu_TuneZ2star_8TeV-madgraph-tauola/S12-S52-v1	$69.9 \pm 2.8_{stat} \pm 6.4_{syst} \times 0.105$
	/WZTo3LNu_TuneZ2star_8TeV_pythia6_tauola/S12-S52-v1	$22.9^{+1.2}_{-0.9} \times 0.033$

Z(2μ,2e)H: MC samples

Process	Dataset	σ (pb)
	7 TeV	
γ+jets	G_Pt-30to50_TuneZ2_7TeV_pythia6/F11_S6_V9B-v1	1.67×10^4
	G_Pt-50to80_TuneZ2_7TeV_pythia6/F11_S6_V9B-v1	2.72×10^3
	G_Pt-80to120_TuneZ2_7TeV_pythia6/F11_S6_V9B-v1	4.47×10^2
	G_Pt-120to170_TuneZ2_7TeV_pythia6/F11_S6_V9B-v1	84.2
	G_Pt-170to300_TuneZ2_7TeV_pythia6/F11_S6_V9B-v1	22.6
	G_Pt-300to470_TuneZ2_7TeV_pythia6/F11_S6_V9B-v1	1.49
	G_Pt-470to800_TuneZ2_7TeV_pythia6/F11_S6_V9B-v1	0.132
	G_Pt-800to1400_TuneZ2_7TeV_pythia6/F11_S6_V9B-v1	3.48×10^{-3}
	G_Pt-1400to1800_TuneZ2_7TeV_pythia6/F11_S6_V9B-v1	1.26×10^{-5}
QCD	QCD_Pt-20to30_EMEnriched_TuneZ2_7TeV-pythia6/F11_S6_V9B-v1	2502660
	QCD_Pt-30to80_EMEnriched_TuneZ2_7TeV-pythia6/F11_S6_V9B-v1	3625840
	QCD_Pt-80to170_EMEnriched_TuneZ2_7TeV-pythia6/F11_S6_V9B-v1	142813.8
	QCD_Pt-170to250_EMEnriched_TuneZ2_7TeV-pythia6/F11_S6_V9B-v1	3263.4
	QCD_Pt-250to350_EMEnriched_TuneZ2_7TeV-pythia6/F11_S6_V9B-v1	368.0
	QCD_Pt-350_EMEnriched_TuneZ2_7TeV-pythia6/F11_S6_V9B-v1	55.0
$Z\to\nu\nu$	ZGToNuNuG_TuneZ2_7TeV-madgraph/S4-v2	3.425
	ZJetsToNuNu_50_HT_100_7TeV-madgraph/F11_S6_V14B-v1	309.5
	ZJetsToNuNu_100_HT_200_7TeV-madgraph/F11_S6_V14B-v1	125.2
	ZJetsToNuNu_200_HT_inf_7TeV-madgraph/F11_S6_V14B-v1	32.92
$W\gamma$	WGToEEG_TuneZ2_7TeV-madgraph/F11_S6_V14B-v1	114.7
	WGToMuMuG_TuneZ2_7TeV-madgraph/F11_S6_V14B-v1	114.6
	WGToTauNuG_TuneZ2_7TeV-madgraph-tauola/F11_S6_V14B-v1	104.6
	8 TeV	
γ+jets	G_Pt-30to50_TuneZ2star_8TeV_pythia6_Z2/S12-S52-v1	1.99×10^4
	G_Pt-50to80_TuneZ2star_8TeV_pythia6/S12-S52-v1	3.32×10^3
	G_Pt-80to120_TuneZ2star_8TeV_pythia6/S12-S52-v1	5.58×10^2
	G_Pt-120to170_TuneZ2star_8TeV_pythia6/S12-S52-v1	108
	G_Pt-170to300_TuneZ2star_8TeV_pythia6/S12-S52-v1	30.1
	G_Pt-300to470_TuneZ2star_8TeV_pythia6/S12-S52-v1	2.14
	G_Pt-470to800_TuneZ2star_8TeV_pythia6/S12-S52-v1	0.212
	G_Pt-800to1400_TuneZ2star_8TeV_pythia6/S12-S52-v1	7.08×10^{-3}
QCD	QCD_Pt-30to80_EMEnriched_TuneZ2star_8TeV-pythia6/S12-S52-v1	4677993
	QCD_Pt-80to170_EMEnriched_TuneZ2star_8TeV-pythia6/S12-S52-v1	183295
	QCD_Pt-170to250_EMEnriched_TuneZ2star_8TeV-pythia6/S12-S52-v1	4587
	QCD_Pt-250to350_EMEnriched_TuneZ2star_8TeV-pythia6/S12-S52-v1	557
	QCD_Pt-350_EMEnriched_TuneZ2star_8TeV-pythia6/S12-S52-v1	89

offline selection

- with r = 2 mm we finally can keep the beam pipe safe

PV:
- $|z| < 24$ cm
- $r < 2$ mm
- $N_{Ndf} > 4$

- very clear lepton selection, everyone from CMS can reproduce the analysis

two leptons selection:
- oppositely charged
- tight μ:
  - $p_T > 20$ GeV, $|\eta| < 2.1$
  - rel Iso < 0.15 (2011), rel PF Iso < 0.2 (2012)
- medium e (2012) and WP80 e (2011):
  - $p_T > 20$ GeV, $|\eta| < 2.5$
  - rel Iso < 0.1 (2011), rel PF Iso < 0.15 (2012)

- M_{ll} compatible with the Z mass

- **veto on additional μ and e**
  - $p_T > 3/10$ GeV, $|\eta| < 2.1/2.5$
- **jet veto**
  - no jet with $p_T > 30$ GeV & $|\eta| < 5.0$
- **b-jet veto**
  - no jet with $p_T > 20$ GeV and $d_{CSV} > 0.244$

topology (optimized selection):
- $|m_{ll} - 91| < 17.5$ GeV
- $p_{TZ} > 80$ GeV
- reduced MET > 110 GeV
- $|\Delta\Phi_{MET\text{-}j}| > 2.6$ rad
- MET balance $0.8 < MET/p_{TZ} < 1.2$
- $M_T > 220$ GeV

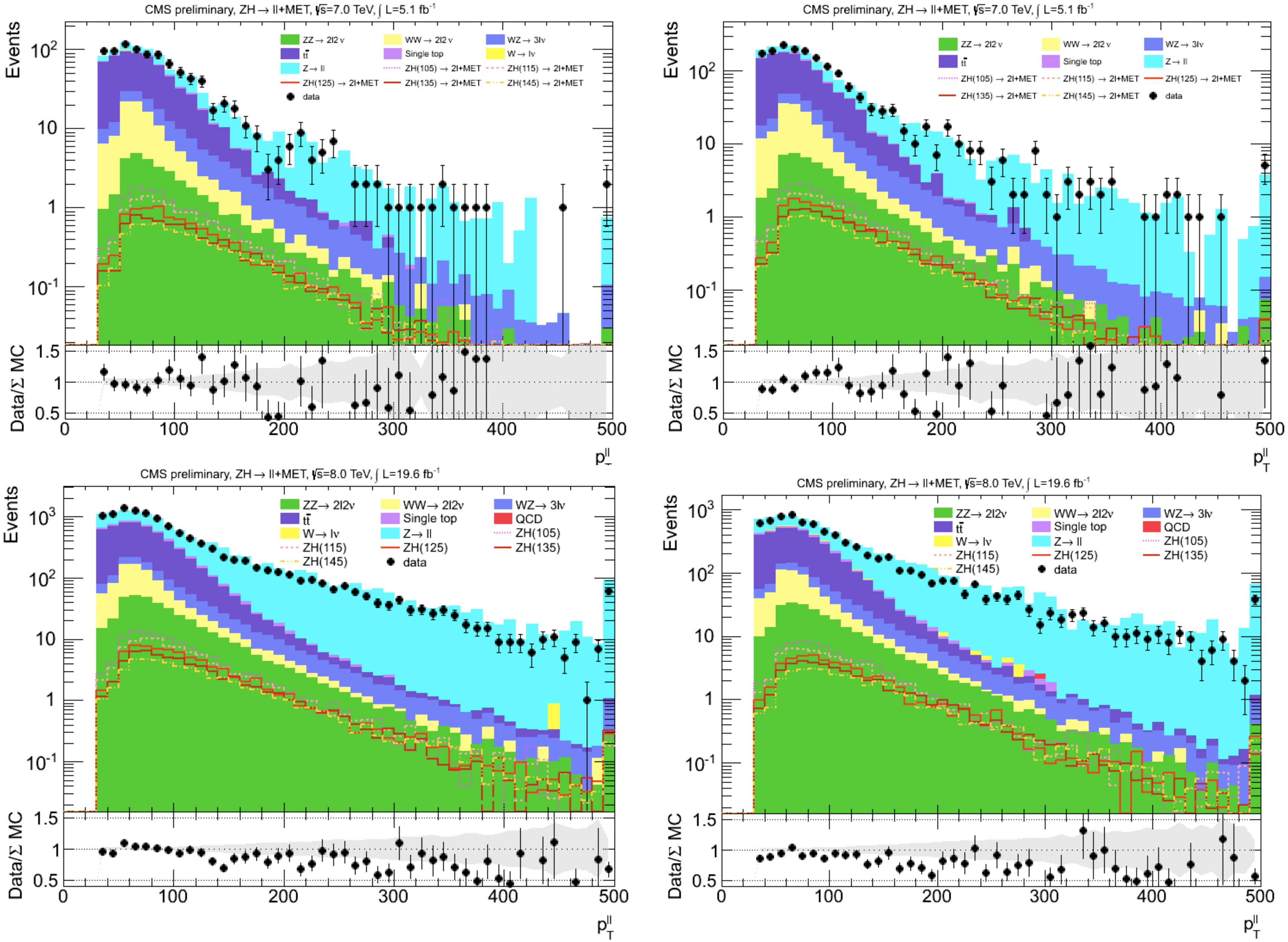
- needs to be updated in AN

dilepton p_T spectra before ZH optimization

ee μμ

7TeV

8TeV



lepton selection

both analyses claim using same type of leptons, however looking at the signal overlap we noticed large differences at this basic level

- reading the ANs selection lepton seems to be the same
- lack of information in one AN stops us in judging which selection is optimal

for 125 GeV mass point:

analysis	all ev.	common	different
1	1731	1463	268 (18.3%)
2	1887	1463	424 (28.9%)

- 25% different lepton selection
- 32% due to MET cut
- 14% due to jet veto
- 10% due to b-jet veto.

reduced MET: one slide from Daniele

Selection

Reduced MET (I)

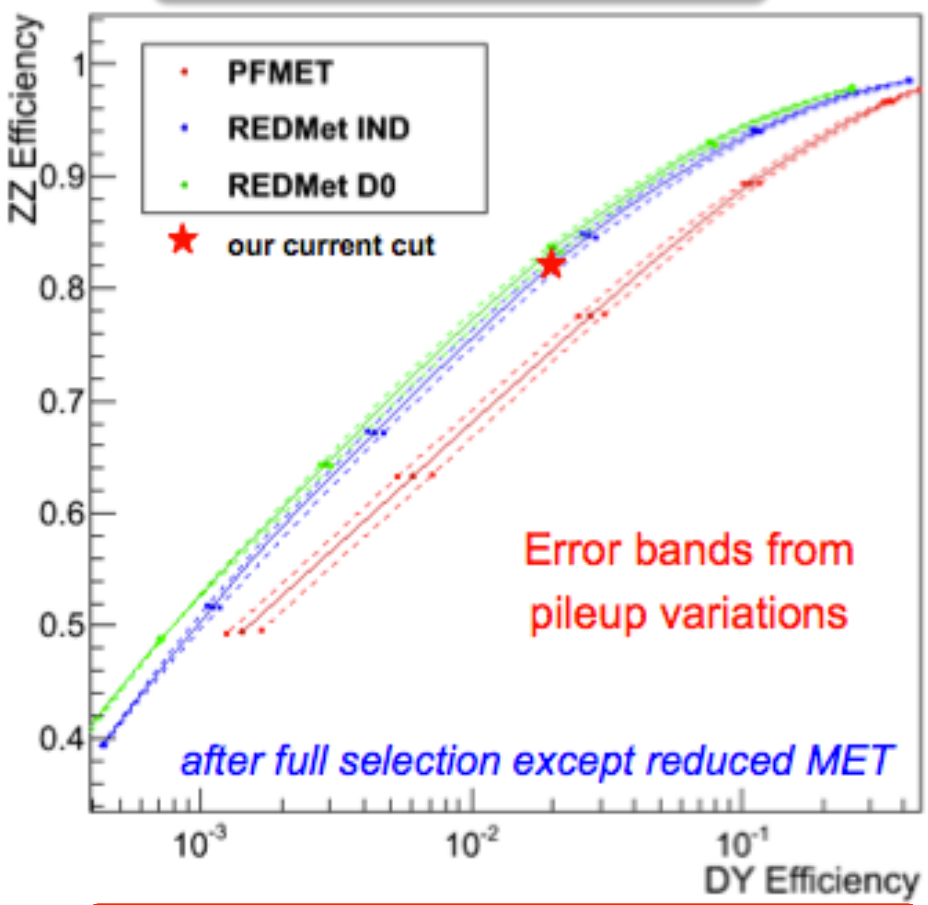
- MET is the main handle to reduce DY background
  - DY process does not include neutrinos: MET only comes from detector effects, like jet mis-measurements or hadrons escaping detection
- Define a variable that is less affected by jet resolution and mismeasurement than the standard MET
  - Basic idea: start from dilepton p_T, subtract hadronic recoil
- Two estimates of hadronic recoil
  - "clustered" recoil R^C: sum of all jets p_T
  - "unclustered" recoil R^U: sum of all hadron candidates
- Decompose all terms in two directions: parallel and orthogonal to dilepton p_T
  - real MET shows mostly in parallel component
  - orthogonal projection dominated by jet/MET resolution
- Each component of redMET is defined as $\text{redMET}_i = p_{T,i}^{\ell\ell} + \min(R_i^C, R_i^U)$

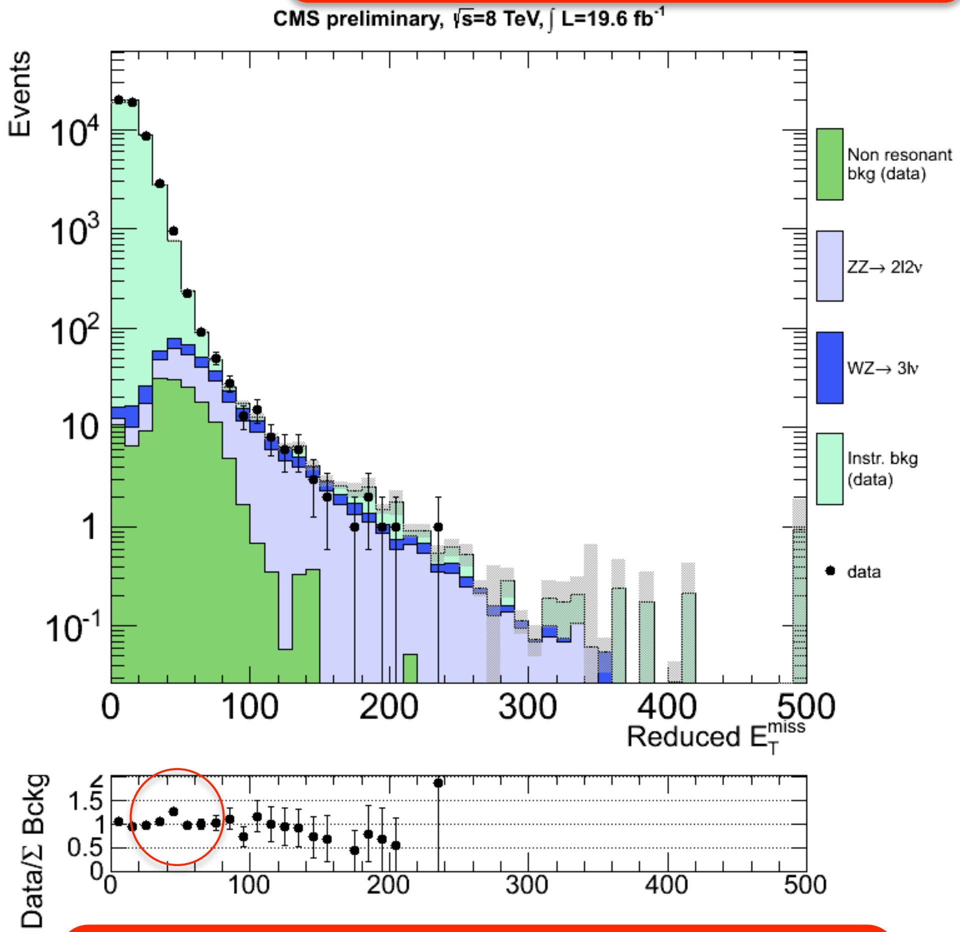
$$\text{redMET} = \sqrt{\text{redMET}_{/\!/}^2 + \text{redMET}_{\perp}^2}$$

reduced MET: single γ data

relatively clear plots, maybe not so well done as for VBF H(inv)

from ZZ->2l2v (AN-12-148)

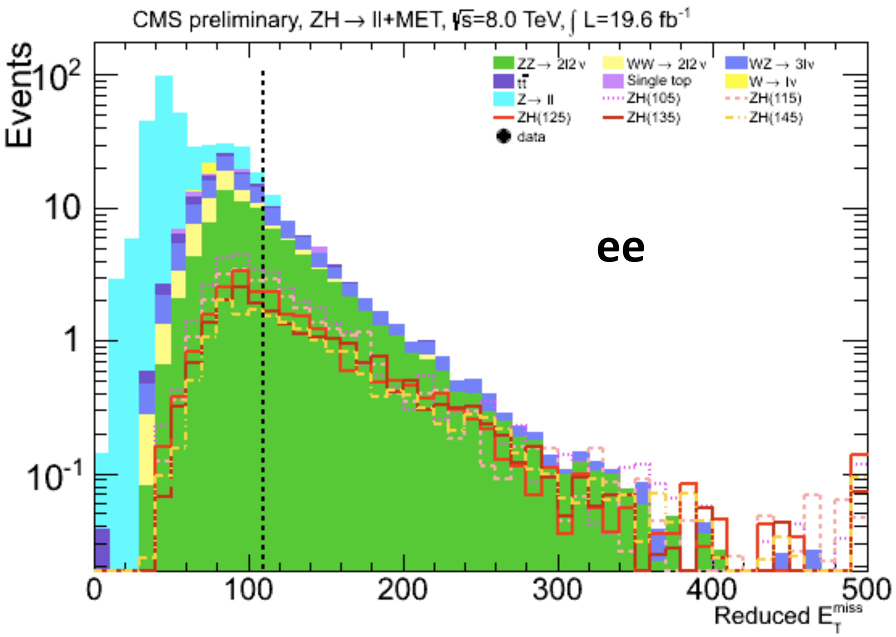


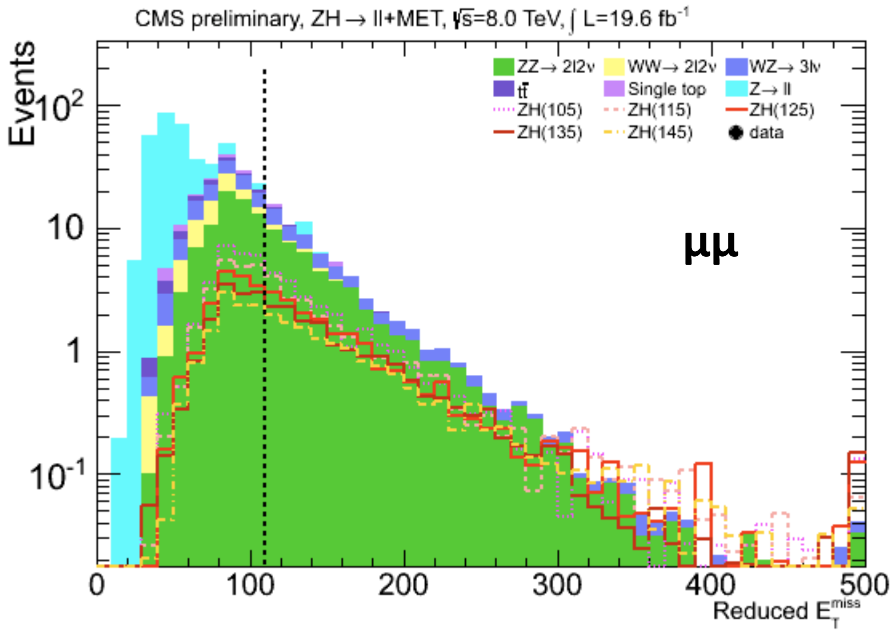


same plot(s) still to be done for ZH(inv)

not yet sure if the ~30% deviation is within MC errors, but it is in only one bin and much more reliable for DY+jets estimation

reduced MET: signal region





top and WW backgrounds

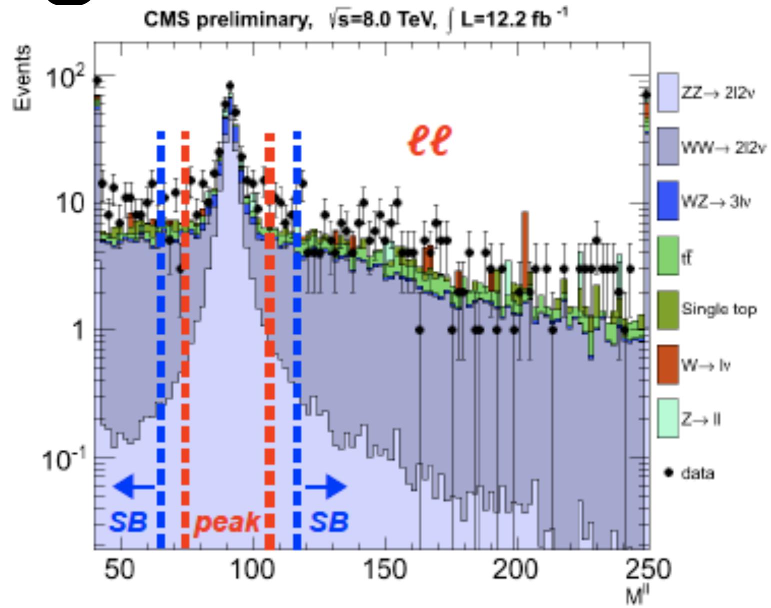
estimation:

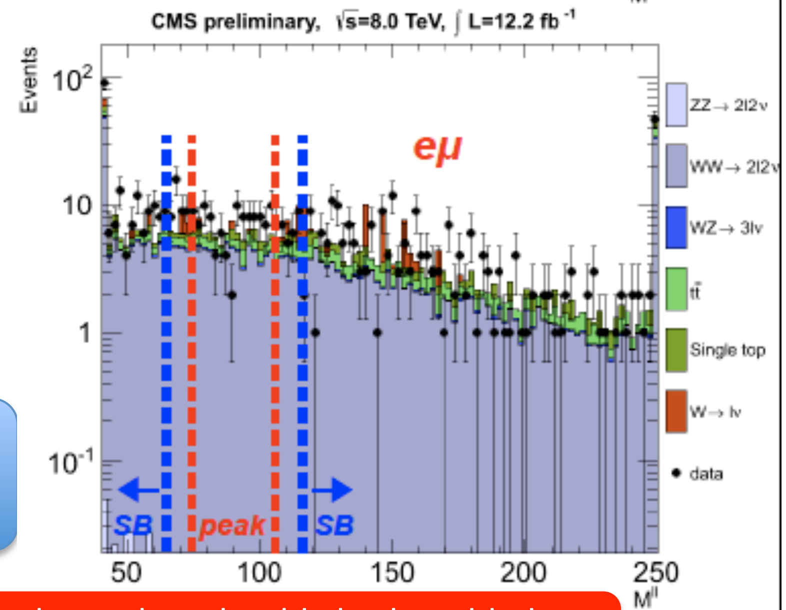
$$N^{\text{peak}}_{ee/\mu\mu} = \alpha_{ee/\mu\mu} \times N^{\text{peak}}_{e\mu}$$

$$\alpha_{ee/\mu\mu} = N^{\text{SB}}_{ee/\mu\mu} / N^{\text{SB}}_{e\mu}$$

$\alpha_{\mu\mu} = 0.673 \pm 0.035$
$\alpha_{ee} = 0.405 \pm 0.035$
predicted background events:
$N_{\mu\mu} = 10.8 \pm 2.7 \pm 0.8$
$N_{ee} = 6.5 \pm 1.6 \pm 1.0$

relative uncertainties on α are assigned as systematic uncertainties on the background estimations





these plots should also be added to AN (taken from a previous talk)

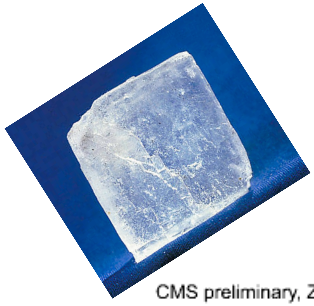
systematic uncertainties

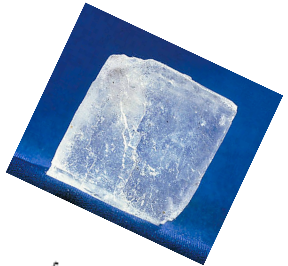
* shape errors are used in limit calculation

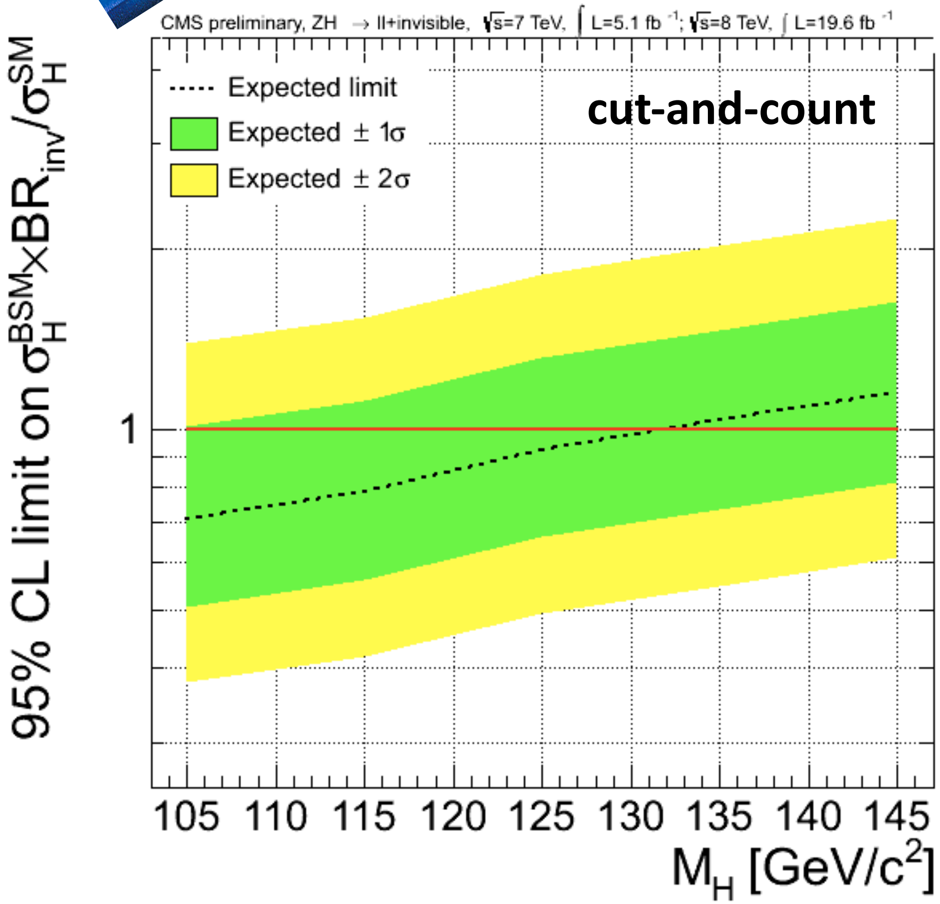
Source of uncertainty	ZH	ZZ	Z/γ^*	Top/WW/W+j	WZ
(*) MC statistics: ZH	3-4	-	-	-	-
(*) MC statistics: ZZ	-	1.6-3.5	-	-	-
(*) MC statistics: WZ	-	-	2.8-5.8	-	-
(*) MC statistics: DY	-	-	-	55-70	-
(*) Ctrl. sample statistics: NRB	-	-	-	-	53-100
(*) b-tagging Efficiency	0.2	0.15	3.2	-	0.25
Lepton Trigger, ID, Iso	3	3	3	-	3
(*) Pile Up	0.3	0.15	3.4	-	0.2
(*) Unclustered E_T^{miss}	0.6	1	37.1	-	3.3
QCD scales VV	-	6.7	-	-	7.7
QCD scales ZH	7	-	-	-	-
Signal Acceptance	1.8	1.8	1.8	-	1.8
$Z/\gamma^* \rightarrow \ell\ell$ normalization	-	-	100	-	-
Top & WW & W+j normalization	-	-	-	25	-
(*) Jet Energy Scale, Resolution	2	2	-	-	3
Luminosity	2.2-4.4	2.2-4.4	2.2-4.4	-	2.2-4.4
PDF_qqbar	3.5	3.1	-	-	4.6
(*) Lepton Momentum Scale	1	1	1	-	1

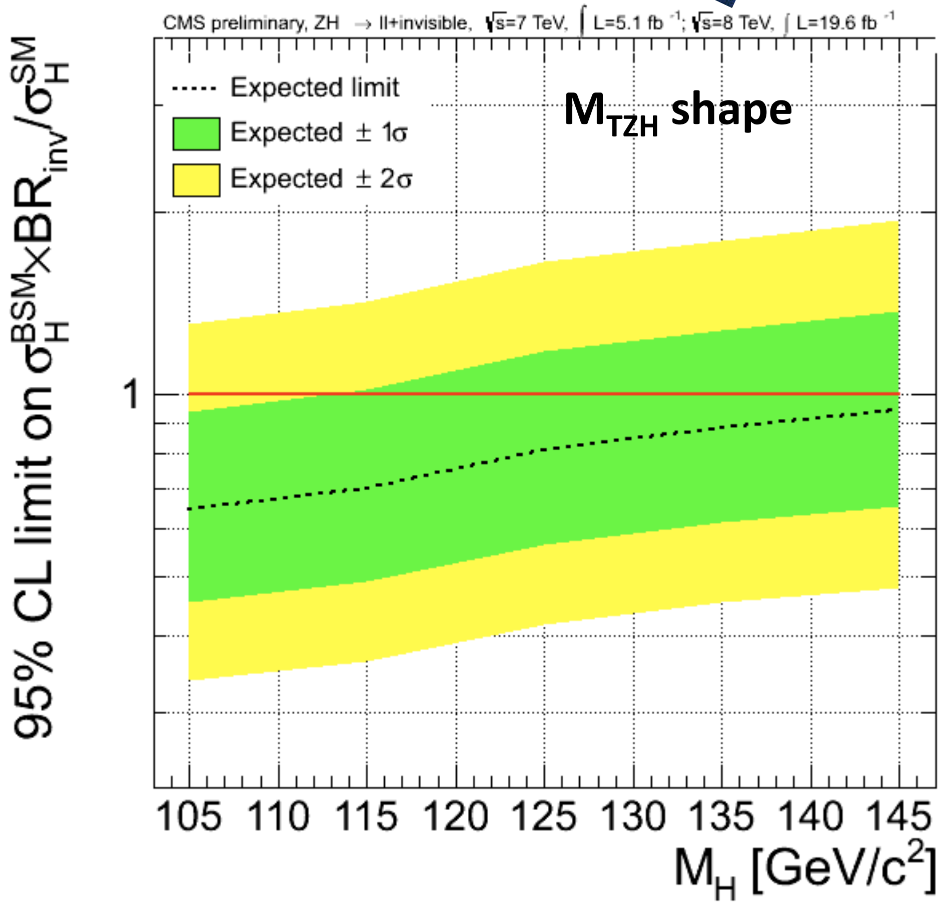
a PDF systematic uncertainty of 6.9 for ZH is reported in the independent analysis – need to synchronize theoretical uncertainties

expected limits









- upper limit for BR H(inv) at 125 GeV: shape (cut-and-count) is 79% (89%) – post-fit 0 & 1 jet ($20 < p_T < 30$ GeV)

- latest numbers, not included in the AN, 86% (97%) with a tighter MET balance – pre-fit 0 jet only
- ATLAS 84%

in the next slides the AN-13-113 will be presented

final call

if we did not yet make it clear, we really need the ANs to be complete

we would like to have both analyses in the PAS:

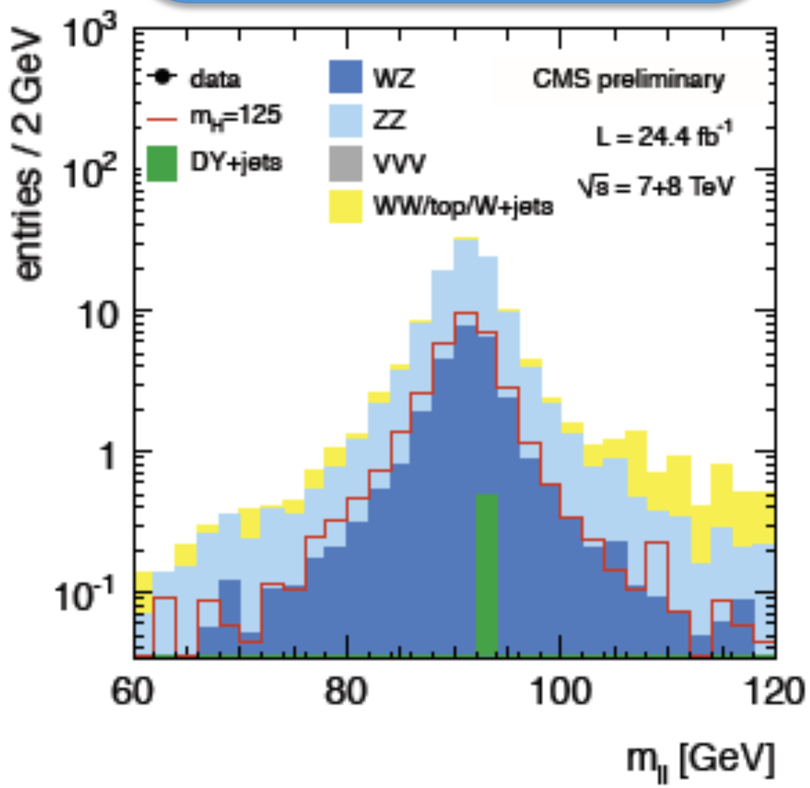
• they are independent concerning background estimation and signal optimization

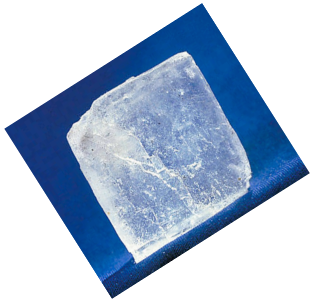
independent analysis:

• optimization using
- PFMET > 120 GeV
- $\Delta\Phi$(Z-MET) > 2.7 radians
- $|\mathrm{MET} - p_{TZ}|/p_{TZ} < 0.25$

systematic uncertainties

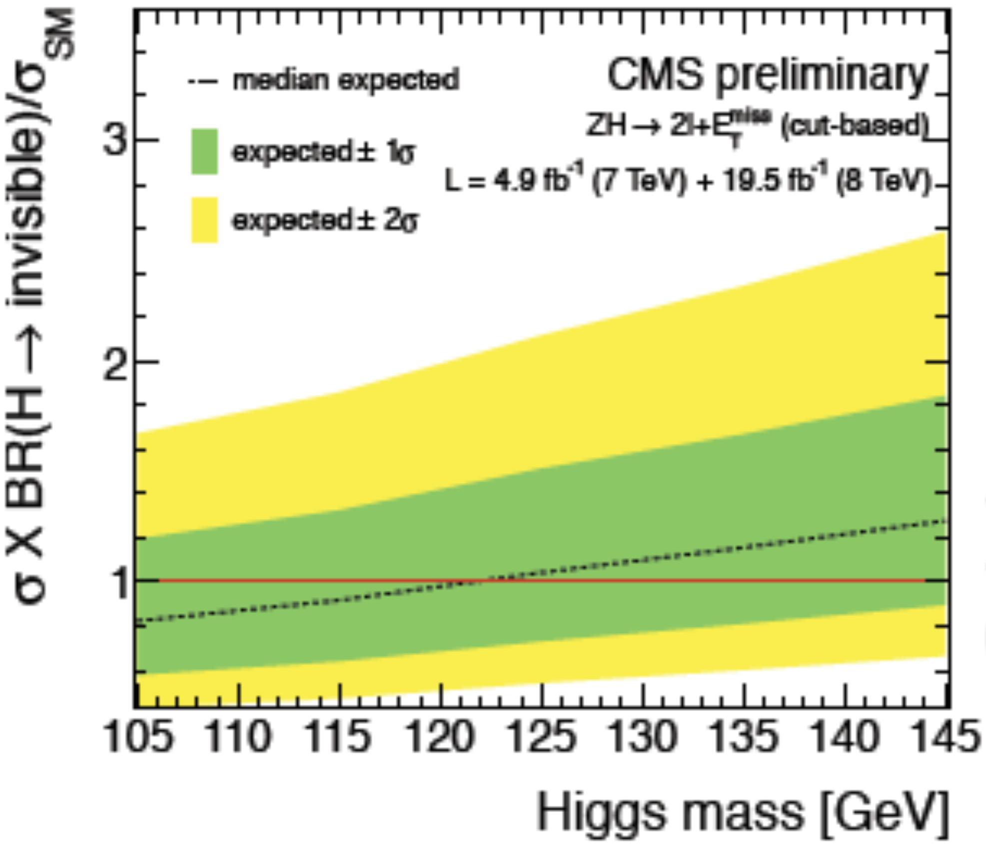
source	ZH	Z/γ^*	VVV	WZ	ZZ	W^+W^-+top+$Z/\gamma^* \to \tau^+\tau^-$	W + jets
luminosity	4.4	-	4.4	4.4	4.4	-	-
lepton efficiency	3.6	-	3.6	3.6	3.6	-	-
momentum resolution	0.2	-	0.7	0.1	0.3	-	-
E_T^{miss}	0.5	-	1.4	0.6	0.1	-	-
JES	1.8	-	9.4	3.7	2.1	-	-
Underlying event	3.0	-	-	-	-	-	-
PDF	6.9	-	-	5.0	6.0	-	-
QCD scales VH	7.0	-	-	-	-	-	-
QCD scales VV	-	-	-	10.7	6.5	-	-
QCD scales VVV	-	-	50.0	-	-	-	-
$Z/\gamma^* \to \ell^+\ell^-$ normalization	-	100.0	-	-	-	-	-
W^+W^-+top normalization	-	-	-	-	-	101.0	-
W + jets normalization	-	-	-	-	-	-	25.8
MC statistics	2.5	-	12.5	2.3	1.1	-	55.4

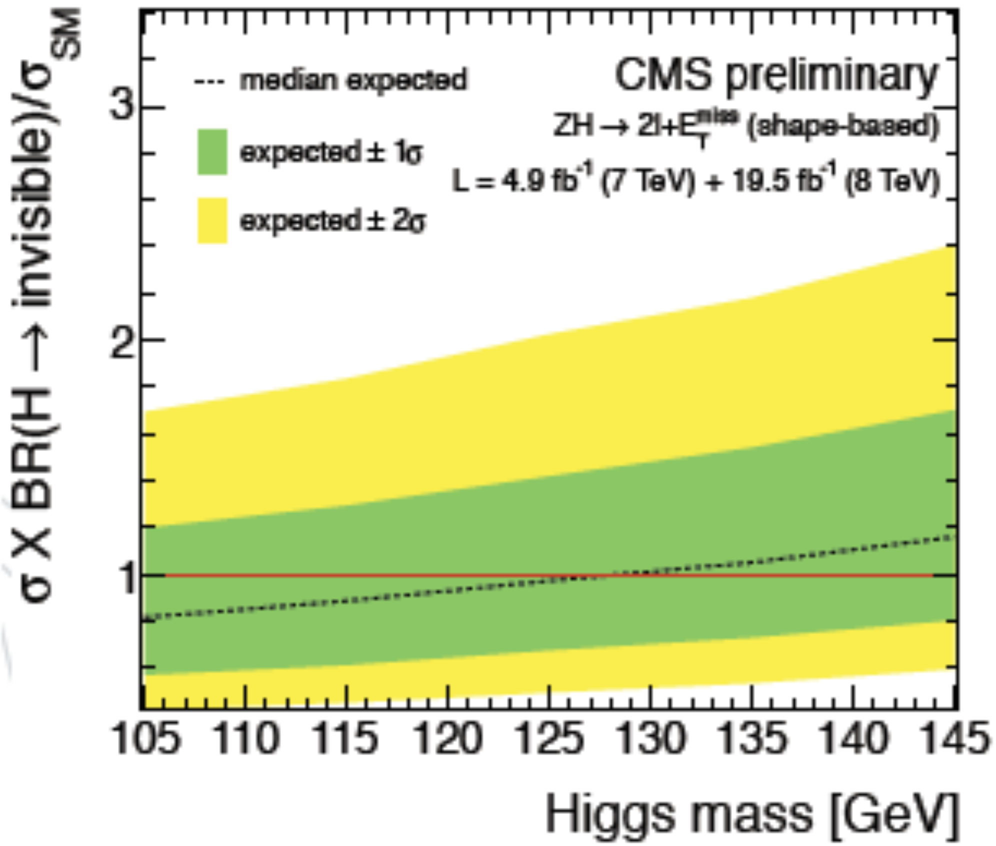




expected limits

- independent analysis -





- upper limit for BR H(inv) at 125 GeV: shape (cut-based) is ~98% (>100%)
- read from the plot

we can learn more out of the differences

b-jet veto:

- **AN-12-123**

- $p_T > 20$ GeV, $|\eta| < 2.4$, $d_{CSV} > 0.244$
- veto on soft e and μ

- **AN-13-116**

method1:
- soft muons $p_T > 3$GeV,
(impact parameter conditions too hard for muon from a b-decay)
method2:
- b-jets with 10(?) < p_T < 30 GeV and $d_{TCHE} > 2.1$
(we would need for 2012 b-tag eff. and misidentification rates)

MET:

- **AN-12-123**

- reduced MET (more robust)

- **AN-13-116**

- PF MET

Z+jets background:

- **AN-12-123**

- obtained from single γ data after reweighting p_T spectrum to Z one

- **AN-13-116**

- extrapolated from DY+jets after removing other contributions

it would be good to understand which approach gives best sensitivity relative to the targeted background

summary

• **both channels: VBF H and ZH are on a good path for preliminary results**

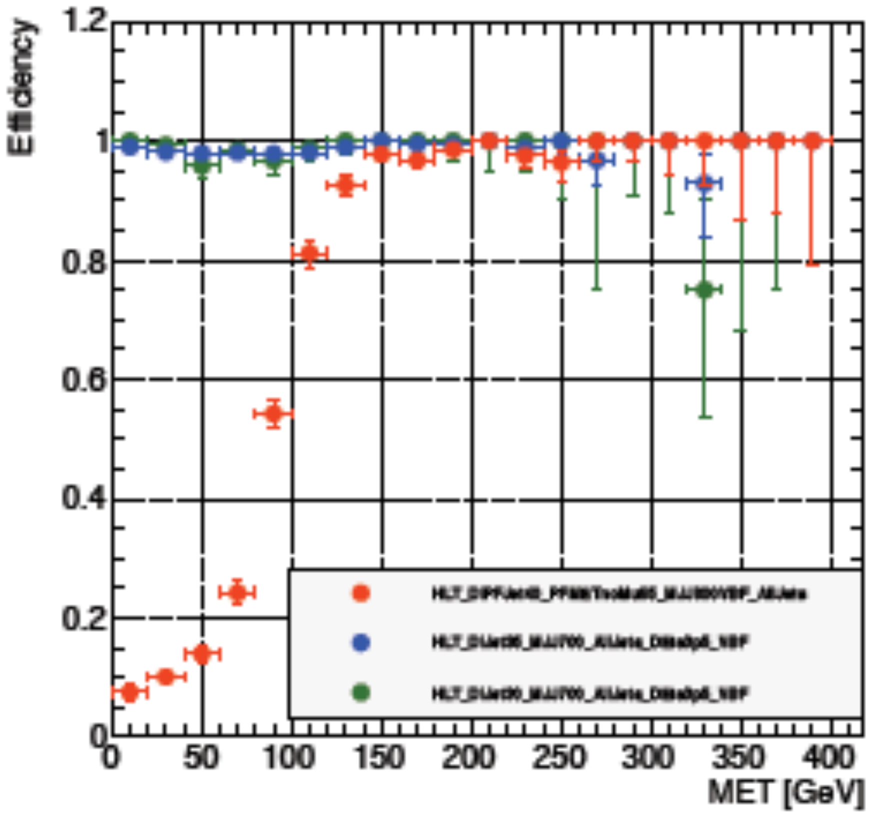
• **VBF H:**
- QCD background estimation still needs some work
- otherwise only very few details need to be added to AN
- and some systematic uncertainties still need to be finished
- **expected limit on BR: 62%**

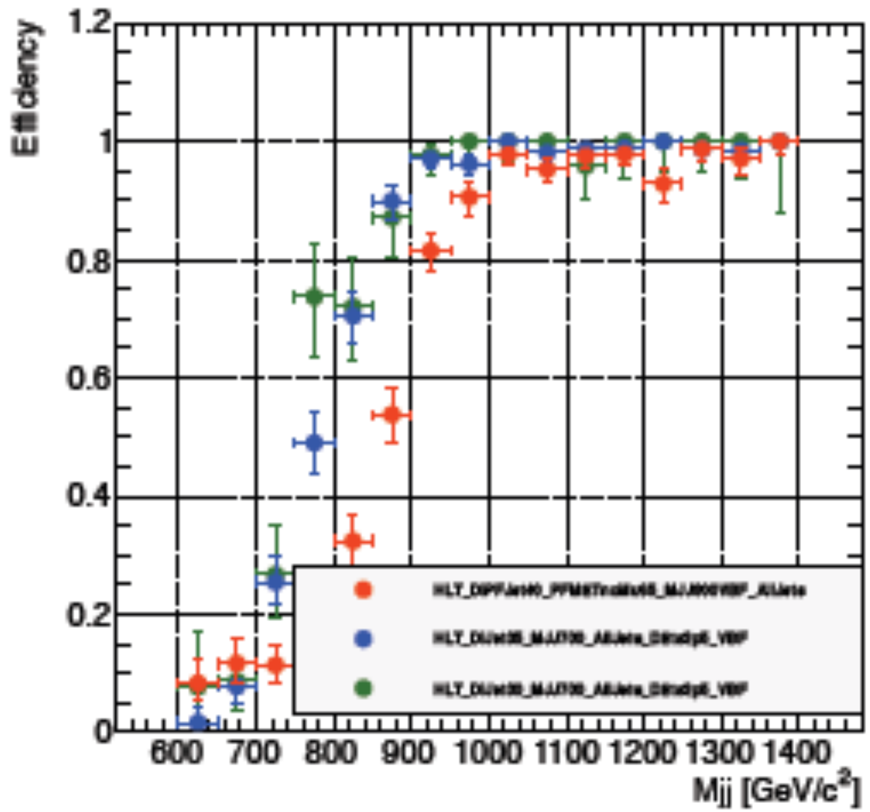
• **Z H:**
- some of the plots need a bit of work
- we have two independent analysis, but we cannot really use them if we do not have all details
- we need more completed analyses documentation
- here the **CMS result will be the one of the most sensitive approach**
- **expected limit from the shape analysis: 79% (86%)**

we think than we can give also a CADI entry for the ZH channel

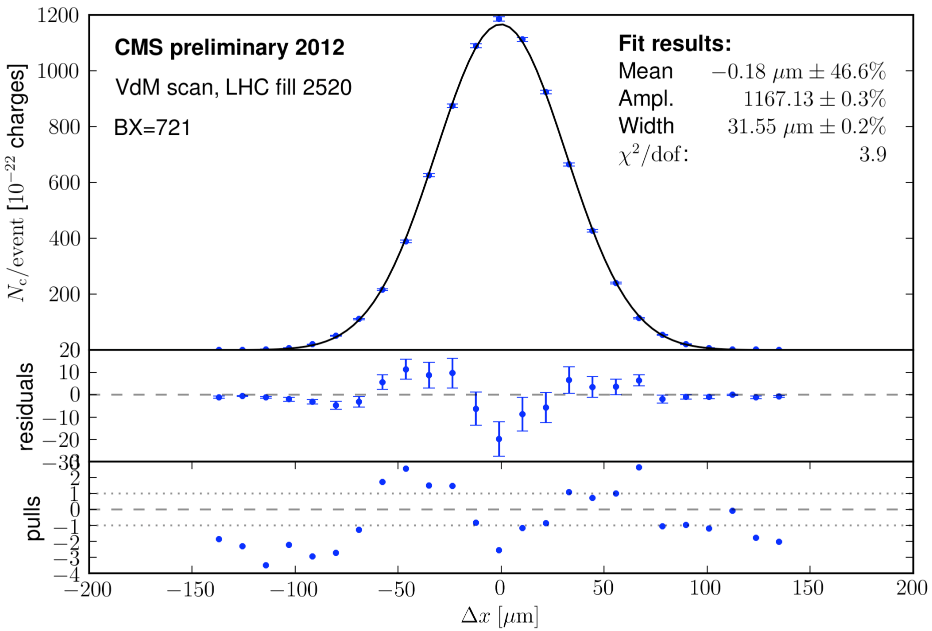
back-up

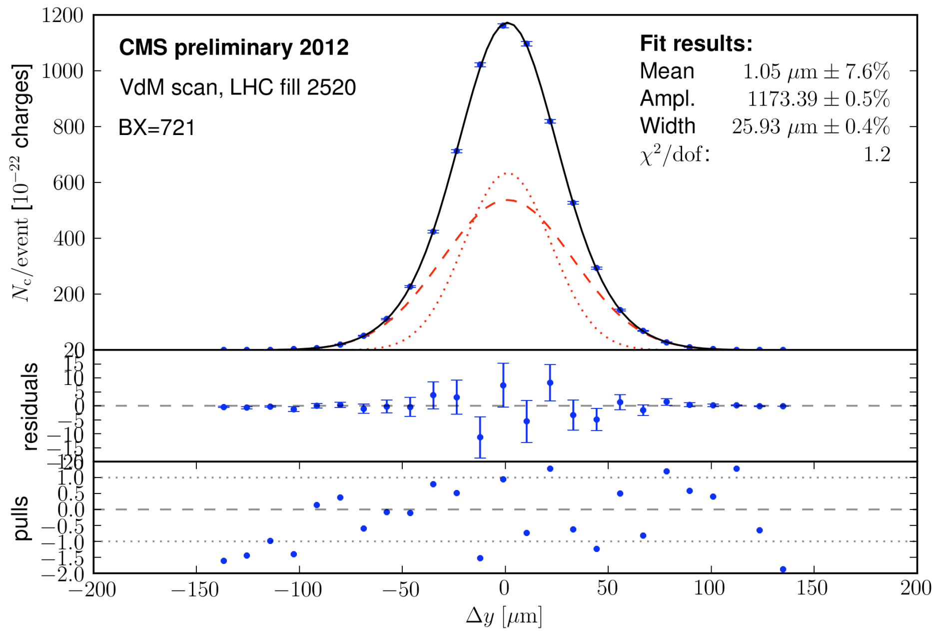
VBF H: trigger efficiency



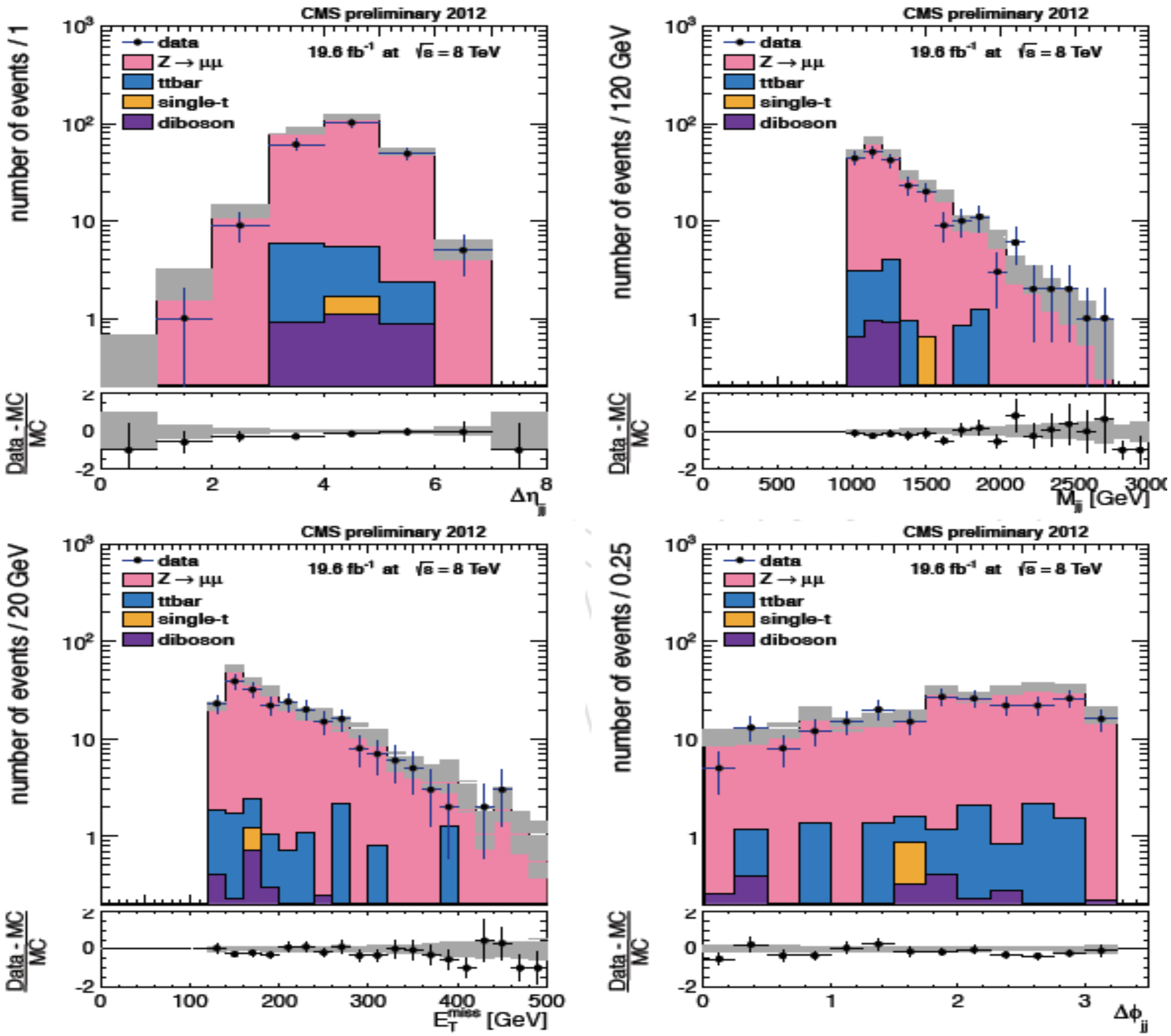


beam position

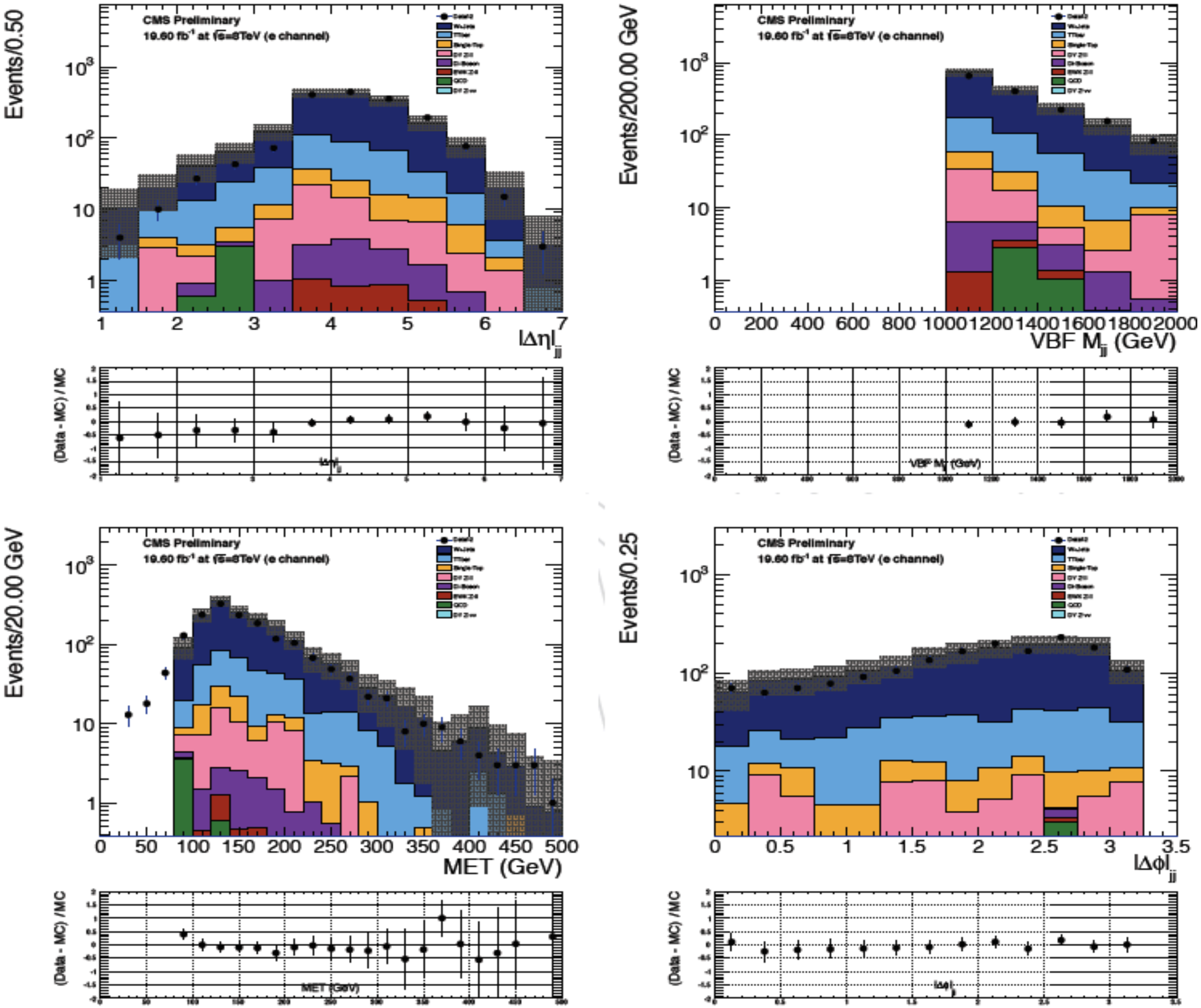




background: Z(2ν)



background: W(e)+jets



background: W(μ)+jets