

CMS Highlights

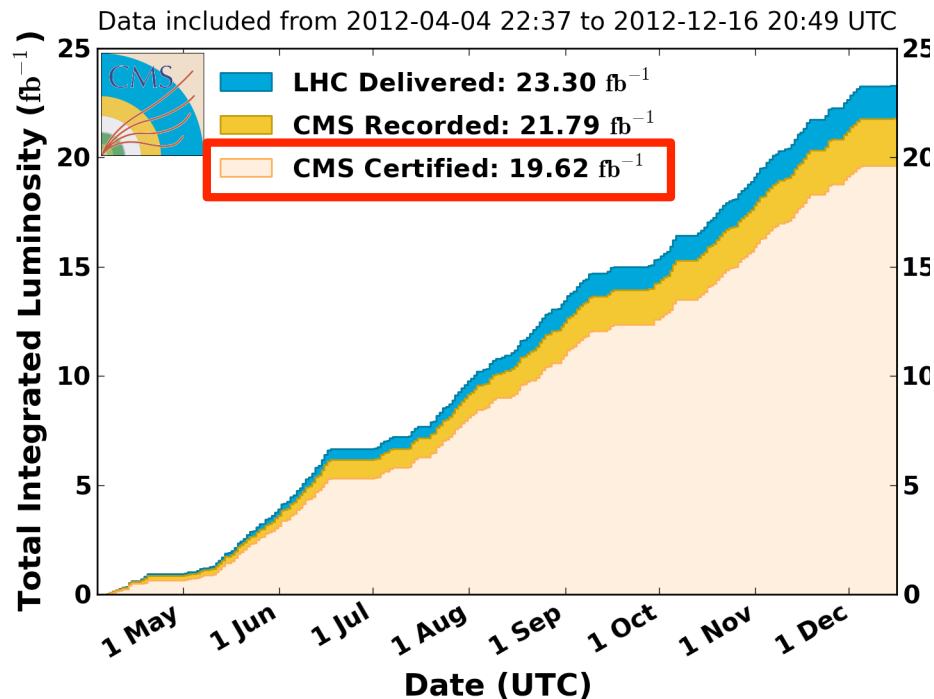


LHCC open session
March 13, 2013

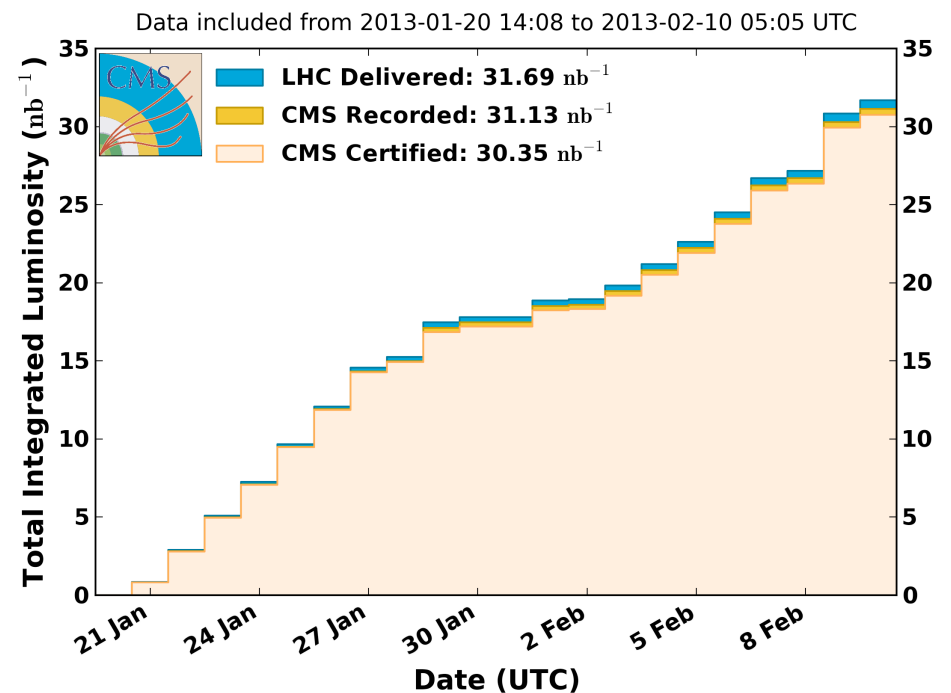
Colin Bernet (CERN/LLR),
on behalf of the CMS collaboration

p-p run, 2012

CMS Integrated Luminosity, pp, 2012, $\sqrt{s} = 8$ TeV



CMS Integrated Luminosity, pPb, 2013, $\sqrt{s} = 5.02$ TeV/nucleon



- **Congratulations** and **thanks** to the people working on the LHC
- 85 % of the delivered data are used for physics
- Important to control pileup in p-p run

c.f. Lucia Silvestris' slides @ last LHCC

<http://indico.cern.ch/getFile.py/access?contribId=4&sessionId=0&resId=0&materialId=slides&confId=216930>

Outline

Search for t + b resonances in leptonic final state	B2G-12-010	PHYS-APP
Search for T5/3 top partners	B2G-12-012	PAS-PUB
Search for excited tops	B2G-12-014	PHYS-APP
Search for stable charged particles	EXO-12-026	CWR
Search for ADD extra dimensions with dimuons	EXO-12-027	PAS-PUB
Search for ADD extra dimensions with dielectrons	EXO-12-031	PAS-PUB
Monojet search	EXO-12-048	PAS-PUB
Dijet mass 2012	EXO-12-059	PAS-PUB
W' to l nu	EXO-12-060	PAS-PUB
Z' full 2012 data	EXO-12-061	PAS-PUB
Study of exclusive gamma-gamma --> W W	FSQ-12-010	CWR
VH with Higgs to tautau	HIG-12-053	PHYS-APP
Higgs to gamma-gamma	HIG-13-001	PHYS-APP
Higgs to ZZ to 4 leptons	HIG-13-002	PAS-PUB
Higgs to WW to 2l2nu	HIG-13-003	PAS-PUB
Higgs to tau tau (SM)	HIG-13-004	PHYS-APP
Higgs to Zgamma targetting	HIG-13-006	PAS-PUB
Associated Higgs Production with H->WW	HIG-13-009	PAS-PUB
Measurement of W+charm	SMP-12-002	PAS-PUB
Measurement of Z/gamma + jet angular distributions	SMP-12-004	PAS-PUB
Measurement of WW production rate	SMP-12-005	CWR-ended
Zgamma cross section in MET+gamma channel at 7 TeV	SMP-12-020	CWR
Z PT differential cross section at 8 TeV	SMP-12-025	PHYS-APP
W+bb cross section at 7 TeV	SMP-12-026	PHYS-APP
Search for SUSY in all-hadronic events with b-jets	SUS-12-024	PAS-PUB
RPV stop search	SUS-13-003	PAS-PUB
Search for SUSY in single-lepton events with b-jets	SUS-13-007	PAS-PUB
W helicity in ttbar	TOP-12-015	PAS-PUB
W helicity in single top	TOP-12-020	PAS-PUB
LHC Combination note: W helicities	TOP-12-025	PHYS-APP
Differential ttbar cross-section (semi-leptonic)	TOP-12-027	PAS-PUB
Differential ttbar cross-section (di-leptonic)	TOP-12-028	PAS-PUB
Differential top mass measurements	TOP-12-029	PAS-PUB
t-tbar mass difference	TOP-12-031	PHYS-APP
R=BR(t->Wb)	TOP-12-035	PAS-PUB
t/tbar production ratio in single top	TOP-12-038	PHYS-APP

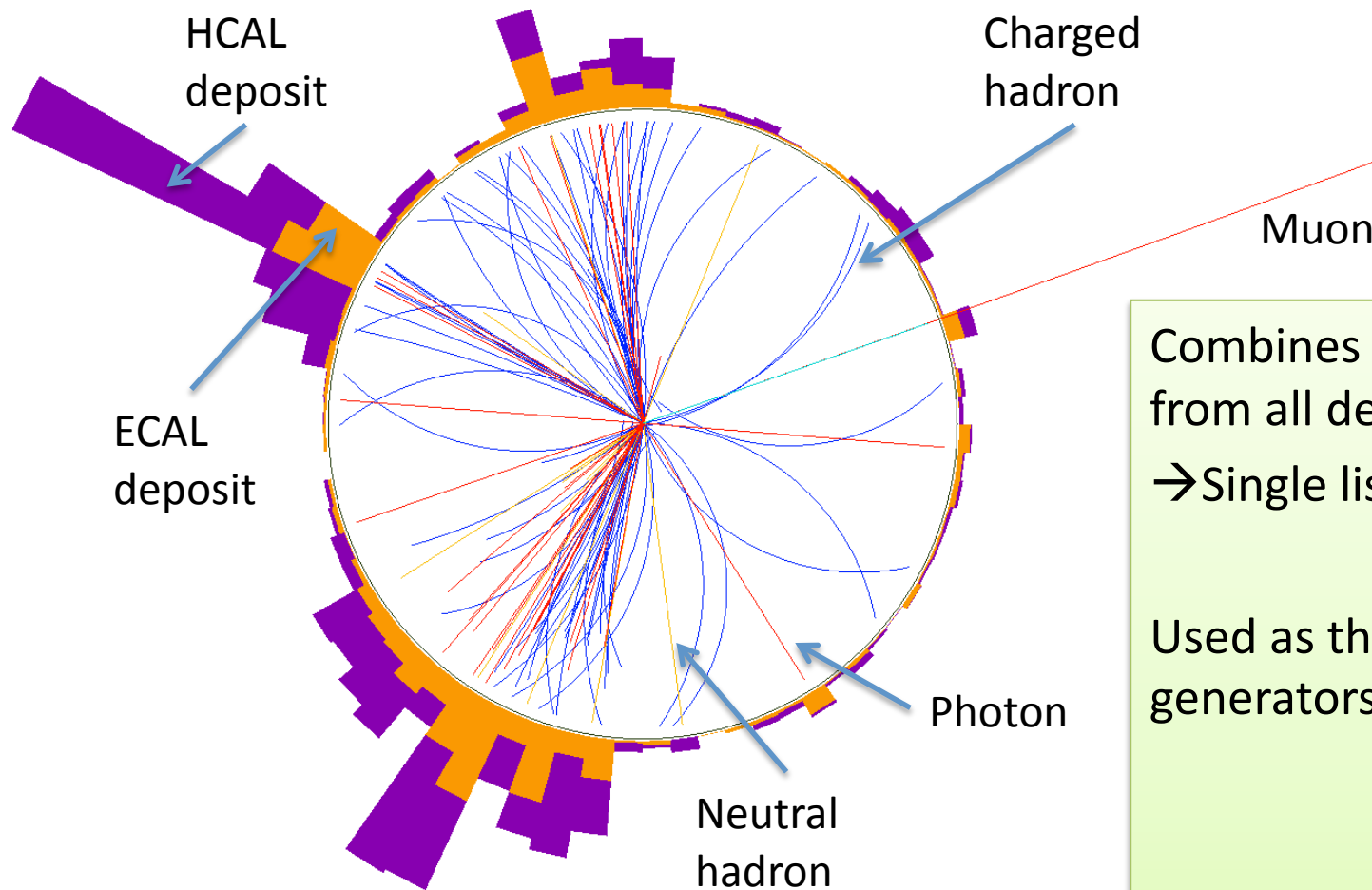
- Event reconstruction
 - Particle flow & effect of pileup
- Physics results shown today:
 - First look at p-Pb data
 - Top quark mass
 - Search for gluinos
 - Exotic searches
 - Higgs properties

36 Analyses approved for Moriond 2013

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults>

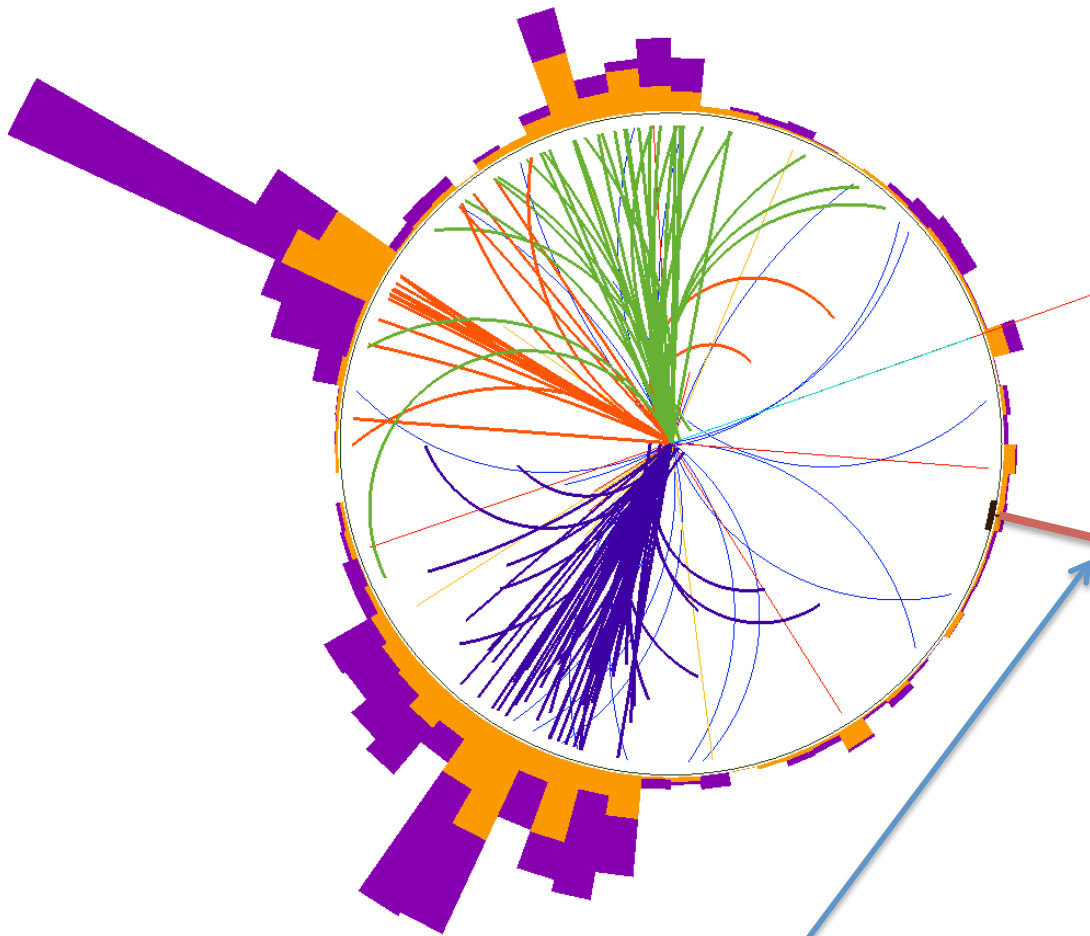
Particle flow event reconstruction

CMS PAS PFT-09-001



Combines information from all detectors
→ Single list of particles

Used as the particles from a generators



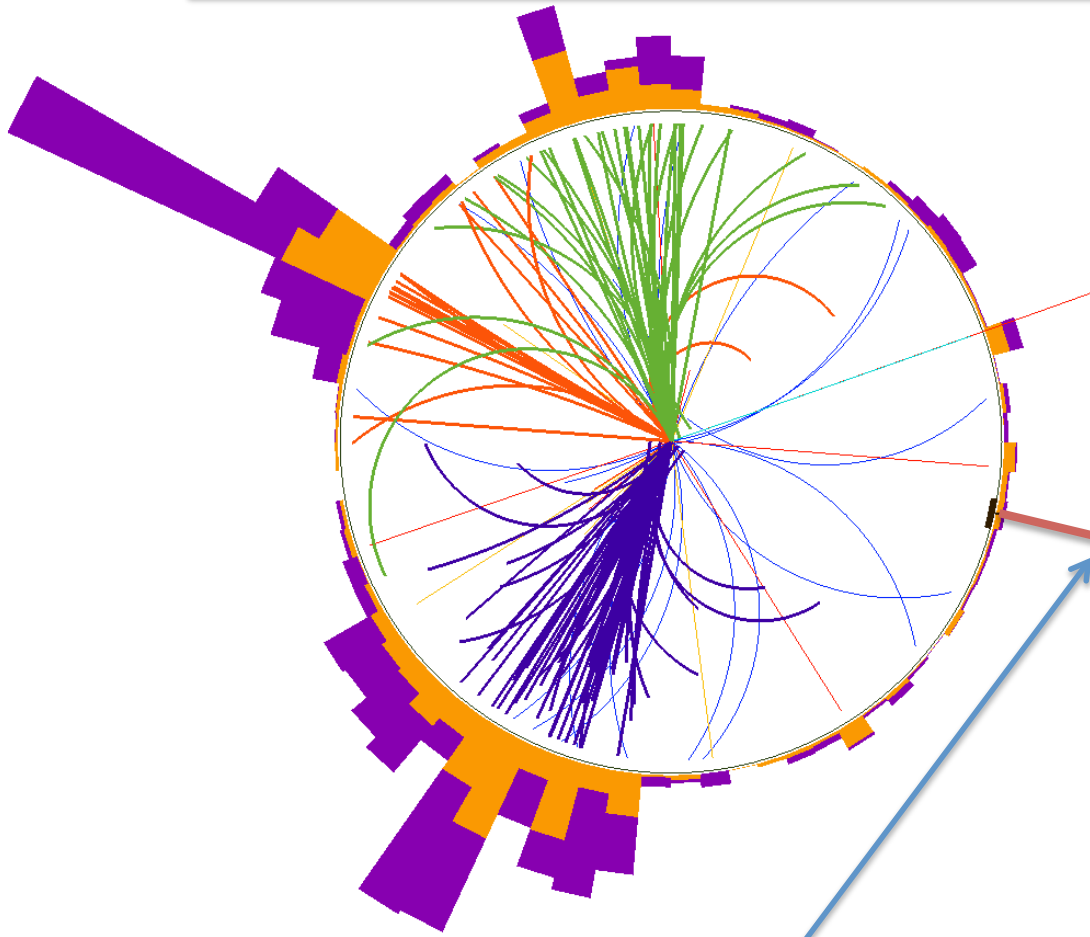
Combines information from all detectors
→ Single list of particles

Used as the particles from a generator to build:

- jets
- MET
- τ
- leptons
- isolation

$$\vec{MET} = - \sum_{\text{particles}} \vec{p}_T$$

- Factor 2 improvement on most physics objects
- Particle flow also running in the high level trigger



Combines information from all detectors
→ Single list of particles

Used as the particles from a generator to build:

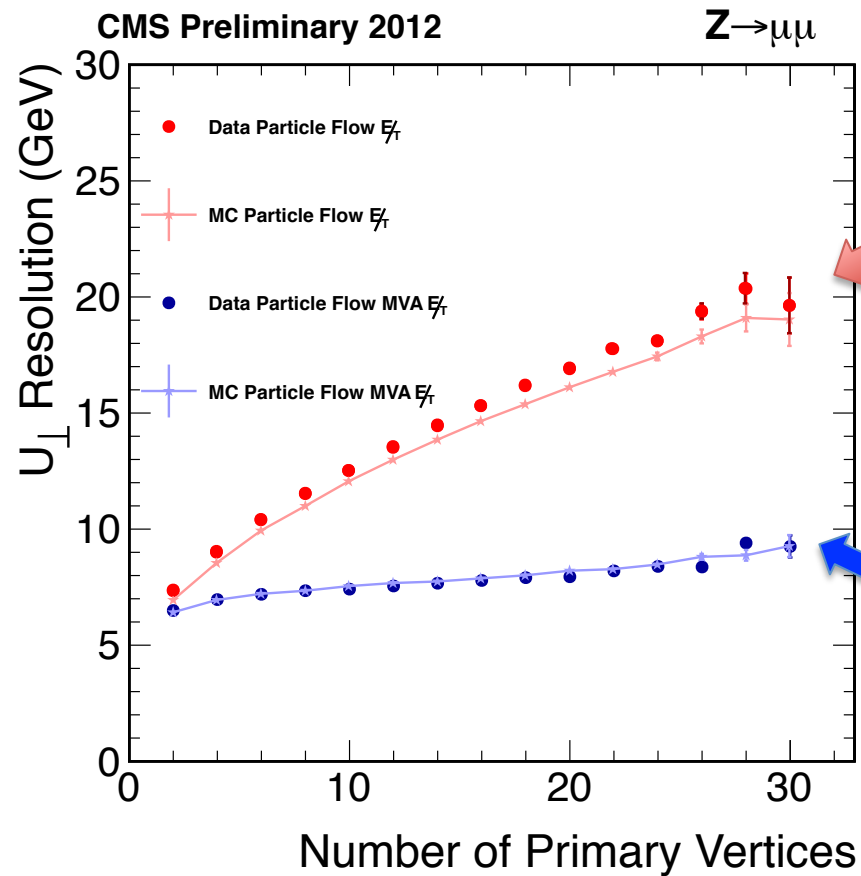
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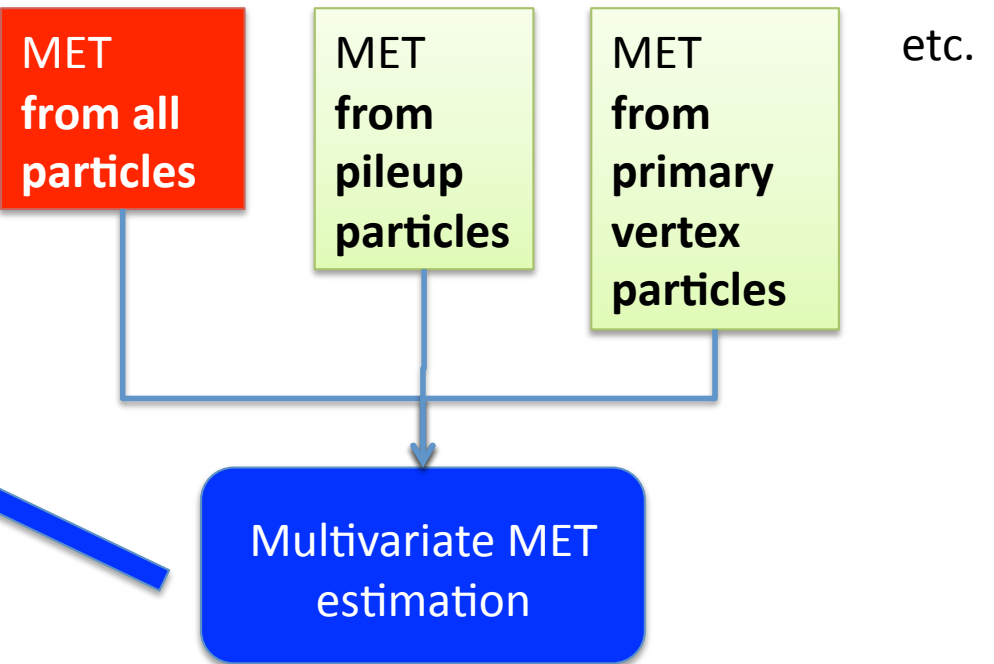


Higgs \rightarrow ZZ \rightarrow 4 lepton
candidate
24 vertices

Pileup control: MET



several kinds of particle-flow MET:



- **Multivariate MET almost insensitive to pileup**
- Also the case for lepton, photon, tau identification and isolation
- Pileup control algorithms applied in the HLT

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p-Pb, 2012

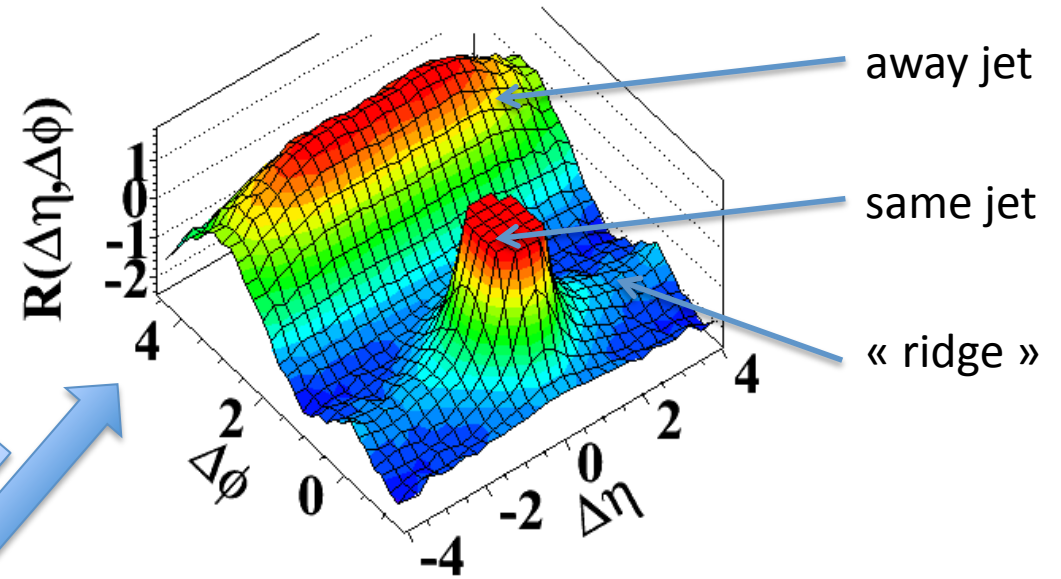
Reference
measurements for
heavy ion programme

compare Pb-Pb
p-p
p-Pb

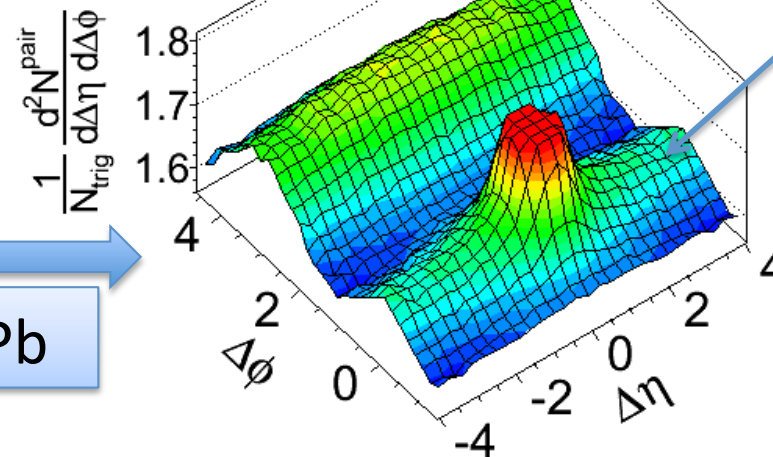
Example:

Angular correlation
between any pair of
particles

$N > 110, 1.0 \text{ GeV}/c < p_T < 3.0 \text{ GeV}/c$



CMS pPb $\sqrt{s_{NN}} = 5.02 \text{ TeV}, N_{\text{trk}}^{\text{offline}} \geq 110$
 $1 < p_T < 3 \text{ GeV}/c$



Top quark



The « X bison » field

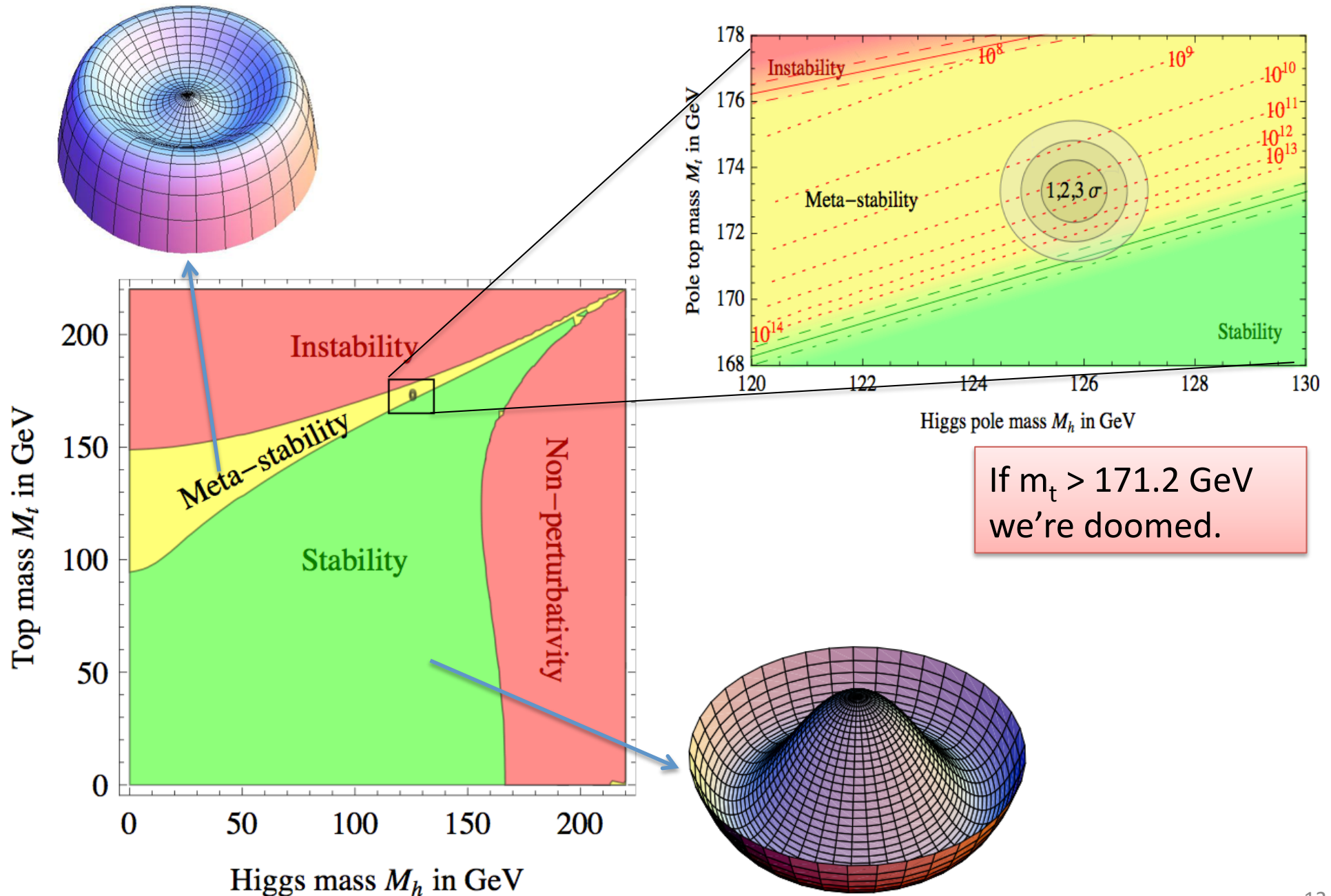


A light quark

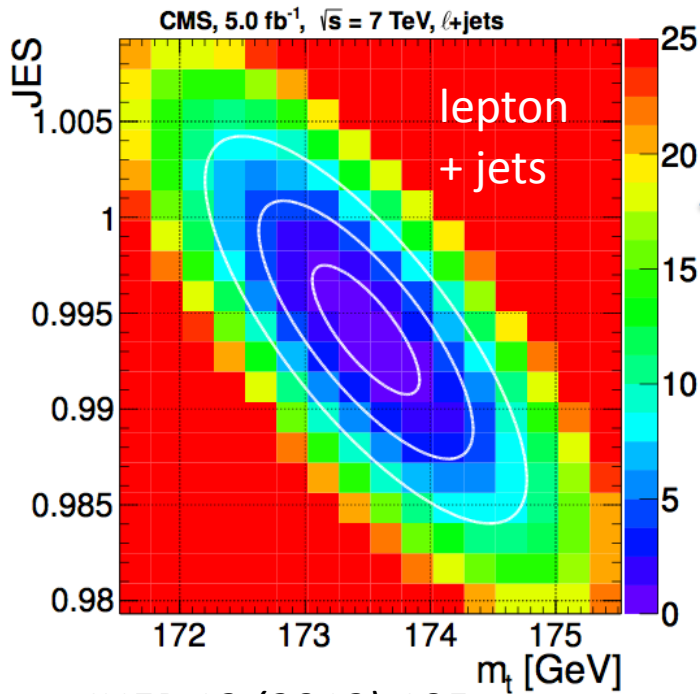


A top quark

Top mass: vacuum stability



Top mass systematic checks



JHEP 12 (2012) 105

Combined CMS:

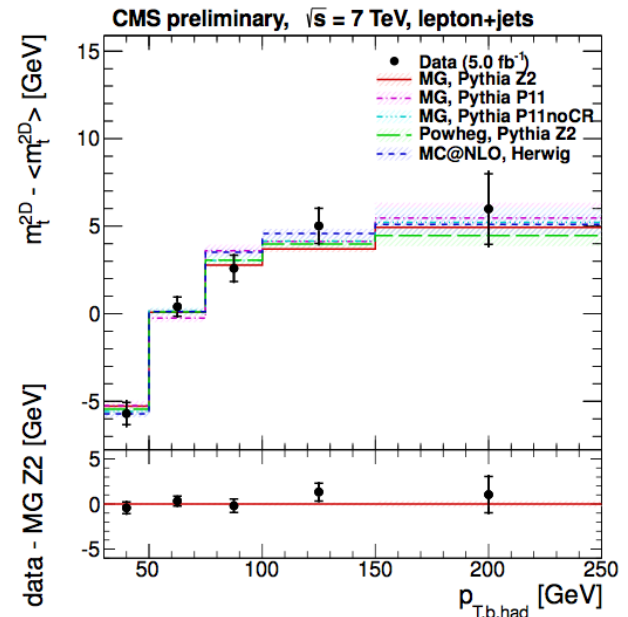
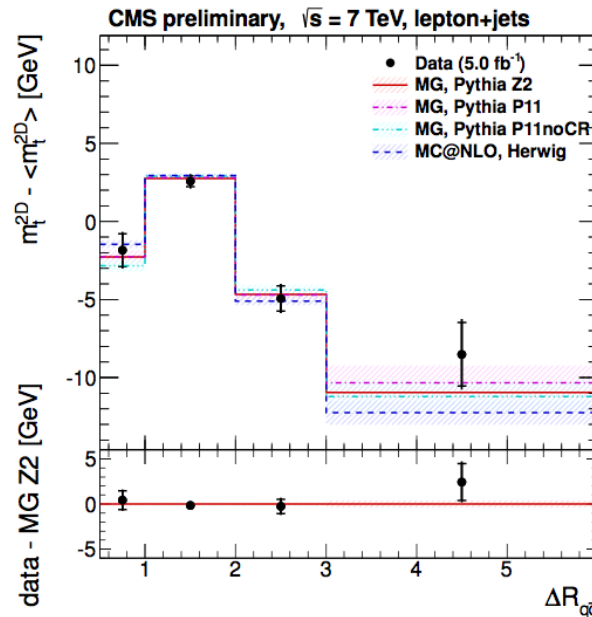
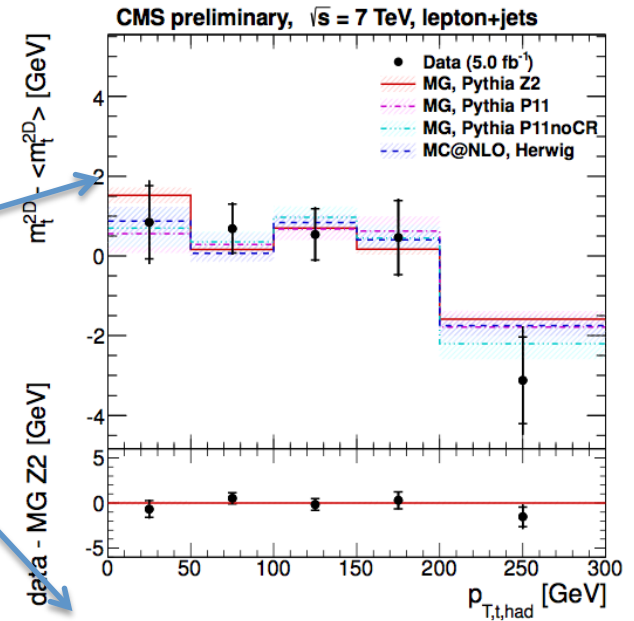
$m_t = 173.36$
 ± 0.38 (stat+JES)
 ± 0.91 (syst) GeV

Tevatron:

$m_t = 173.18$
 ± 0.56 (stat+JES)
 ± 0.75 (syst) GeV

m_t vs
 many
 kinematic
 variables

Simulation
 validated



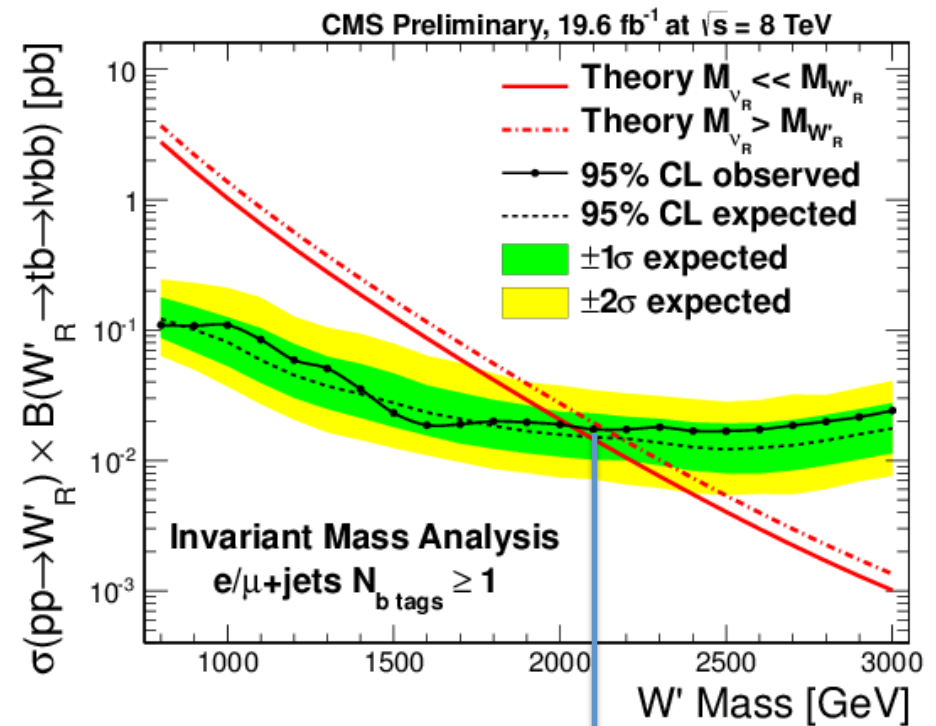
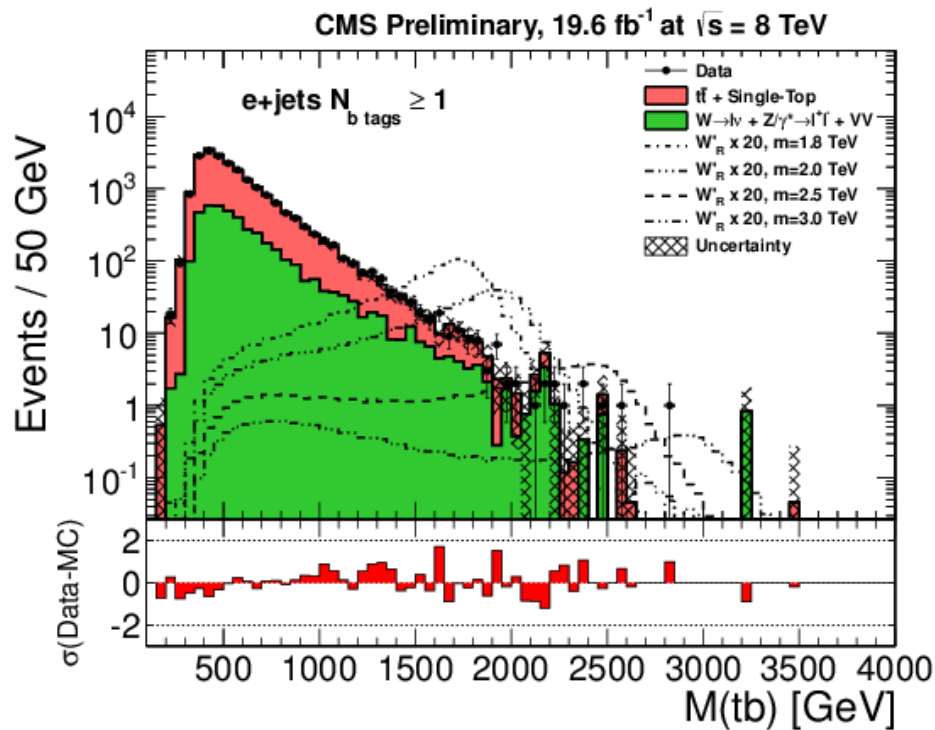
Beyond Standard Model



$W' \rightarrow t+b$ search

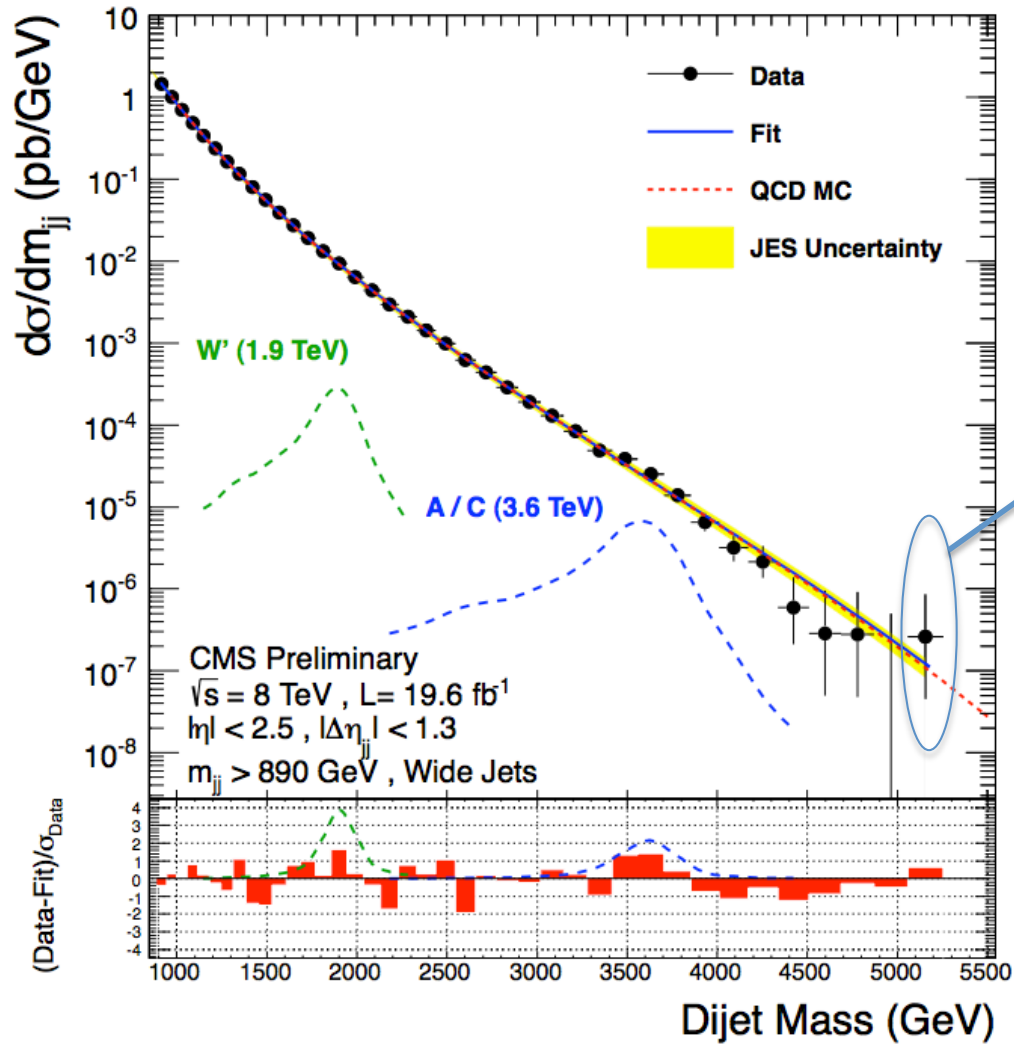
CMS PAS B2G-12-010

- Predicted by extradimensions, little Higgs, technicolor
- W from top decays leptonically

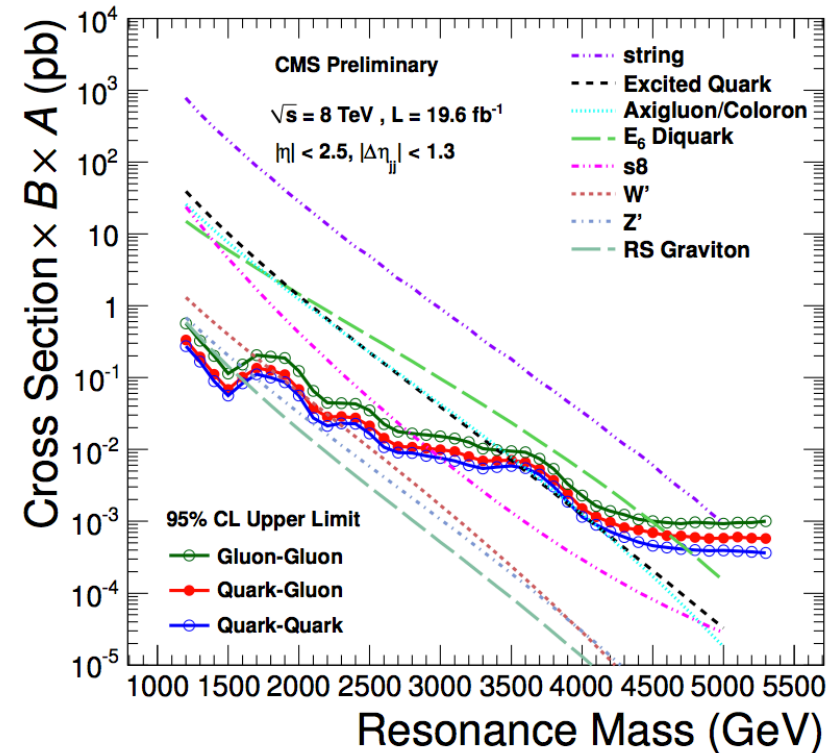
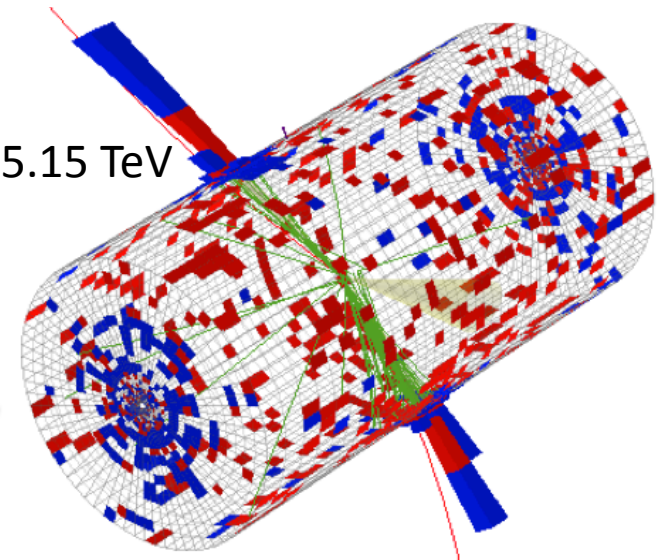


Exclude W' with $m < 2.1$ TeV

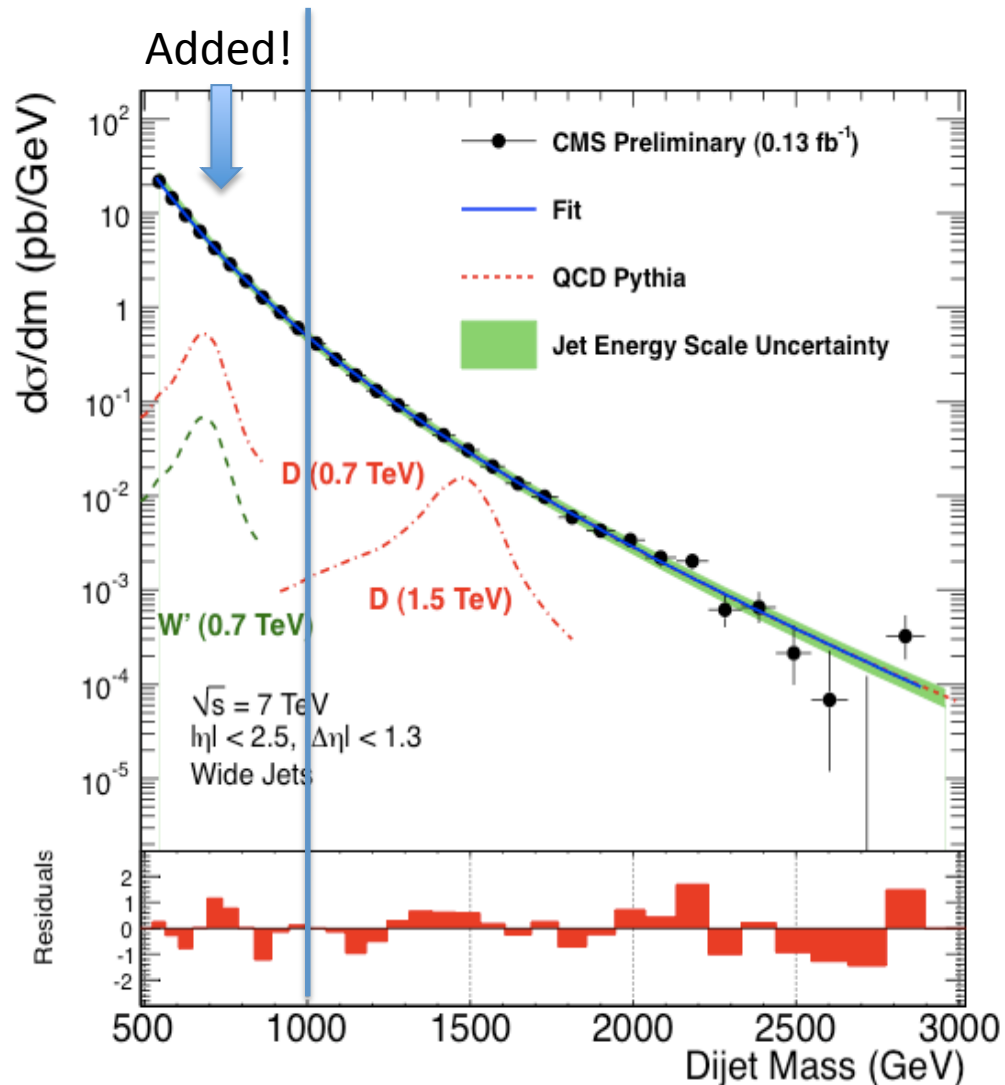
Dijet Resonance Search



Mass = 5.15 TeV



Dijet Resonance Search below 1 TeV



Data Scouting: $\sim 1\text{kHz}$

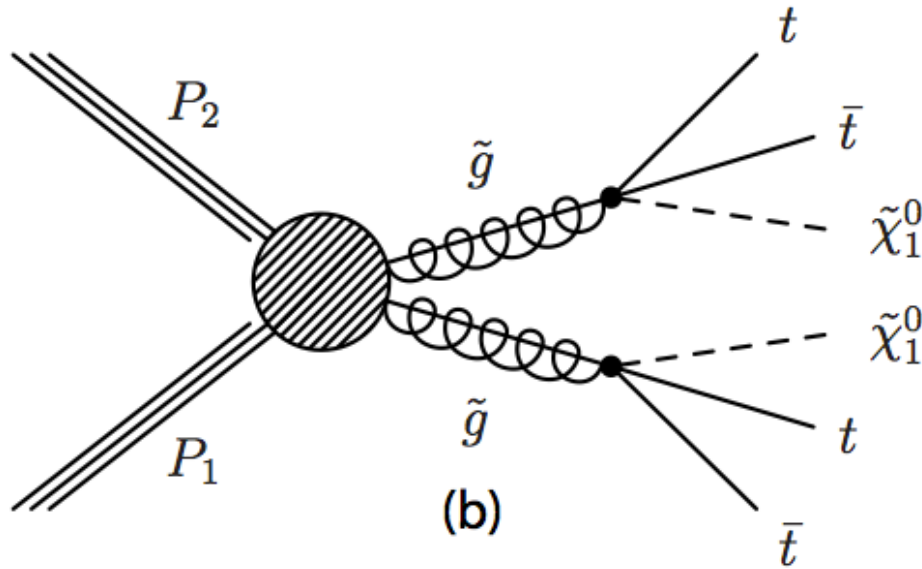
- Novel trigger and data acquisition strategy applied to physics analysis
- Trigger: $H_T > 250 \text{ GeV}$
 - Reduced event content:
 - HLT calorimeter jets only
 - no raw data
 - no offline reconstruction
 - Bandwidth (rate x size) under control

Data Parking: 300-600 Hz

- looser and new triggers
 - increased range for many analyses
- For the shutdown

SUSY: gluino \rightarrow top searches

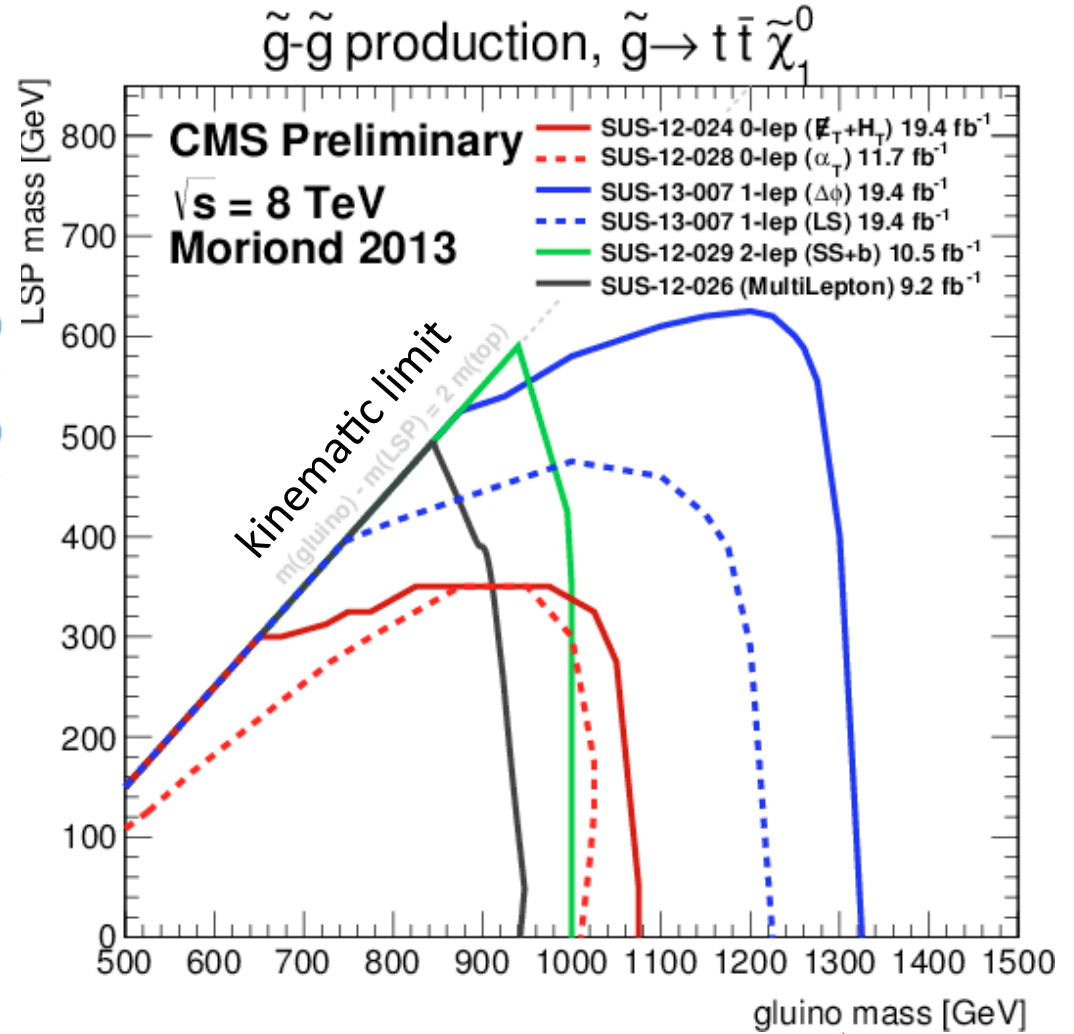
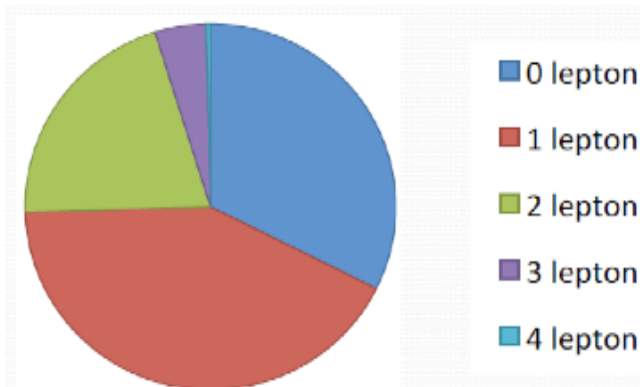
Limits in simplified susy models



- Assumptions:

$$m_{\tilde{t}} > m_{\tilde{g}}$$

$$\text{BR}(\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0) = 100\%$$



Exclude gluino with $m < 1.3 \text{ TeV}$

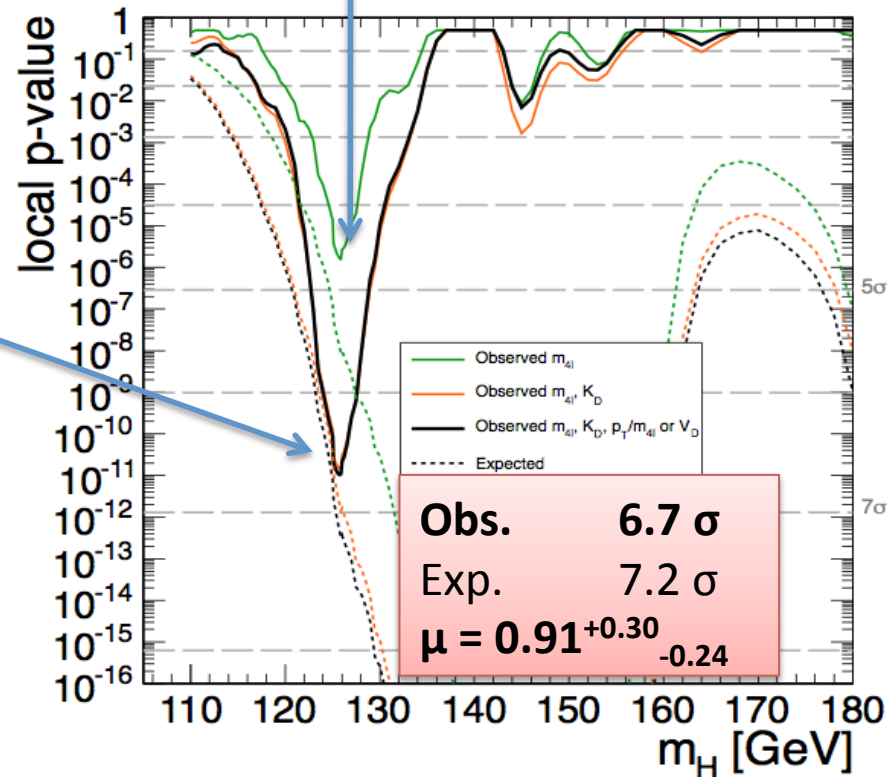
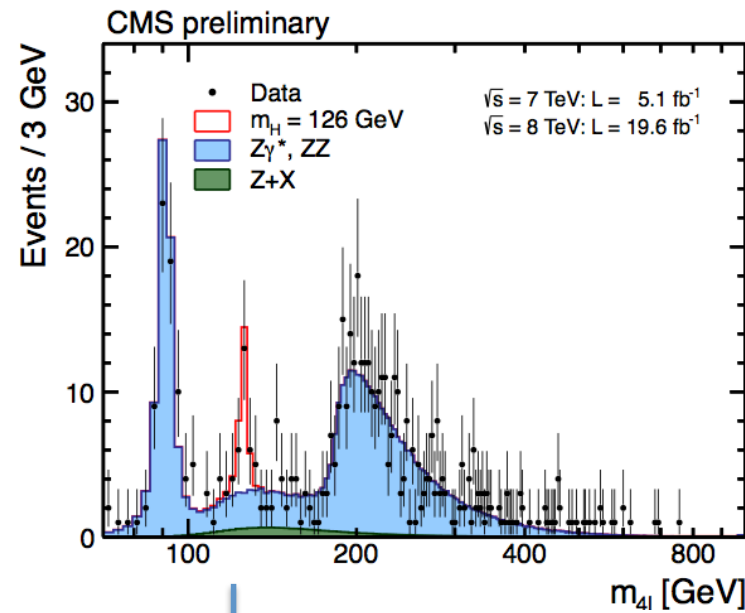
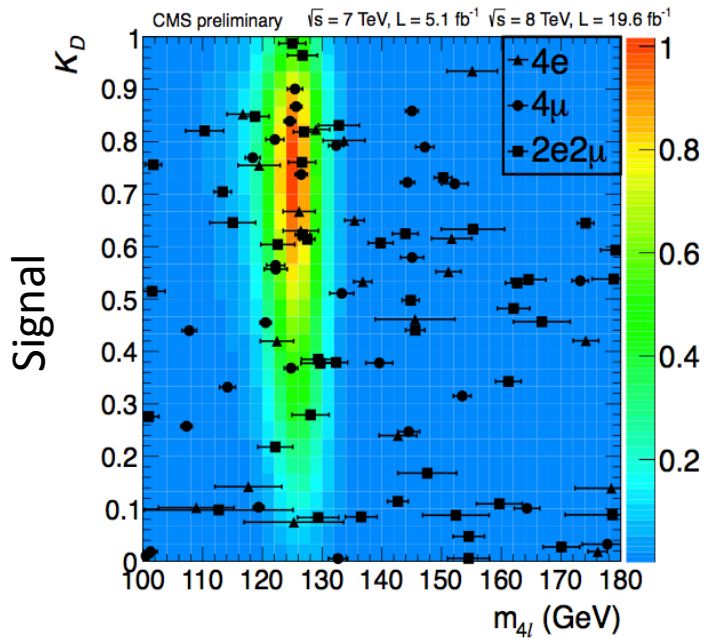
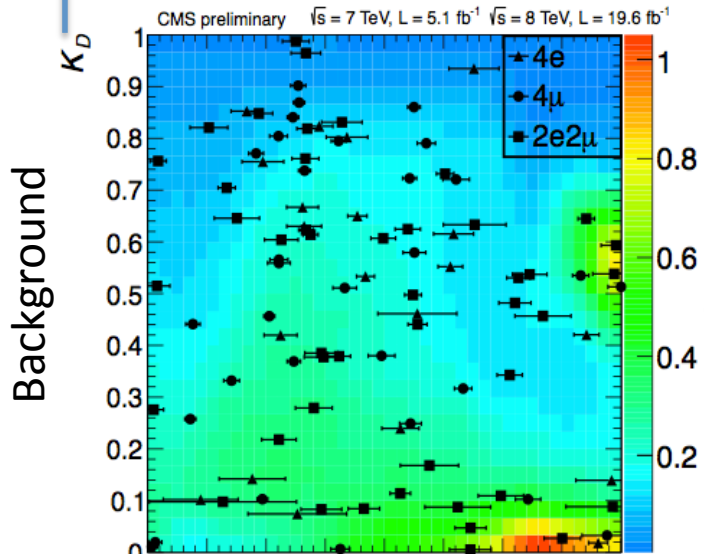
Higgs (Properties)



H → ZZ → 4 leptons

Matrix-element likelihood discriminant
 Built from lepton angles, m_{Z1} , m_{Z2}

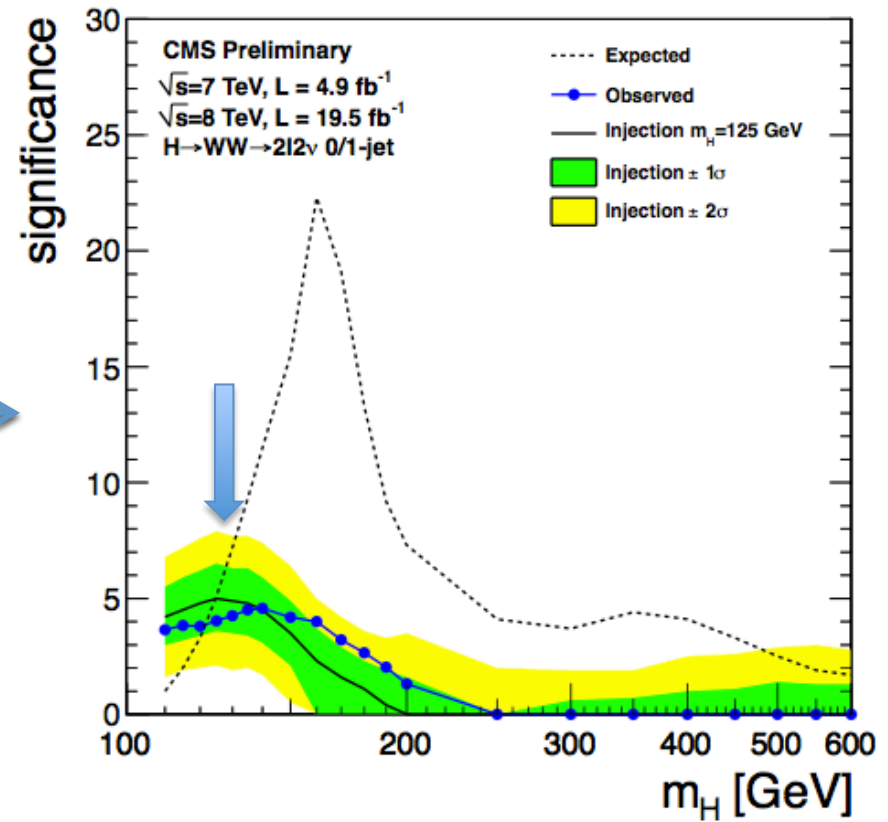
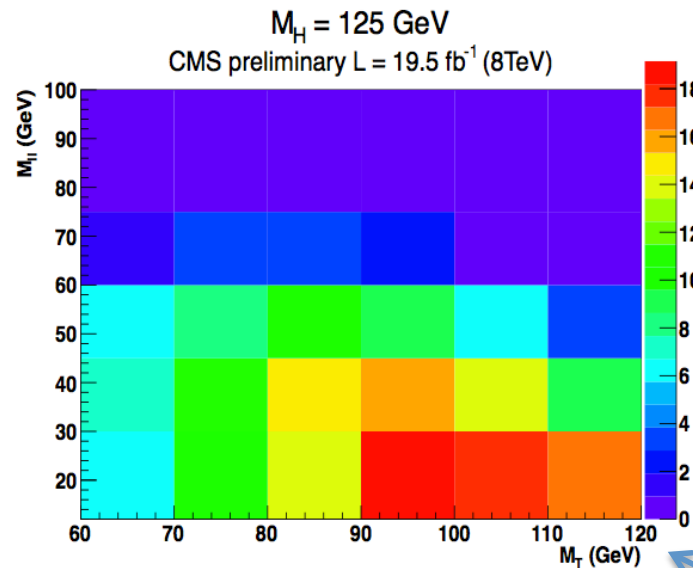
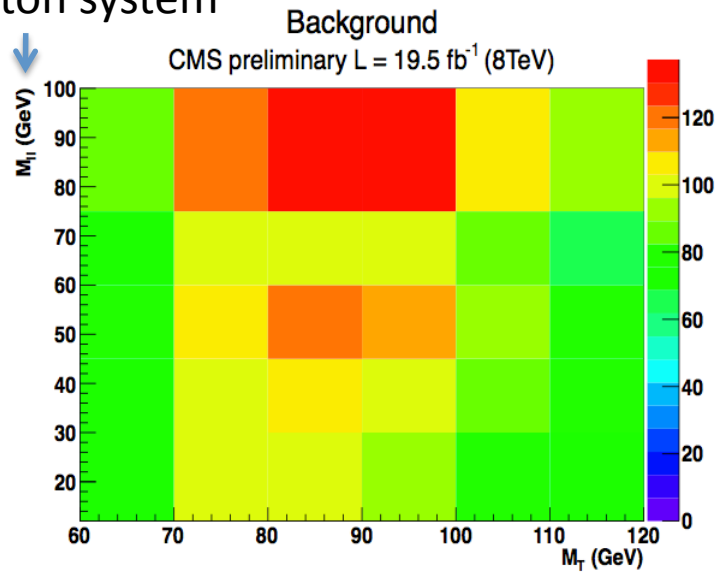
$$K_D = \frac{p_{\text{sig}}}{p_{\text{sig}} + p_{\text{bgd}}}$$



$m_H = 125.8 \pm 0.5(\text{stat}) \pm 0.2(\text{syst}) \text{ GeV}$

H → WW

mass of di-lepton system



Obs. 4.0 σ
Exp. 5.1 σ
 $\mu = 0.81 \pm 0.21$

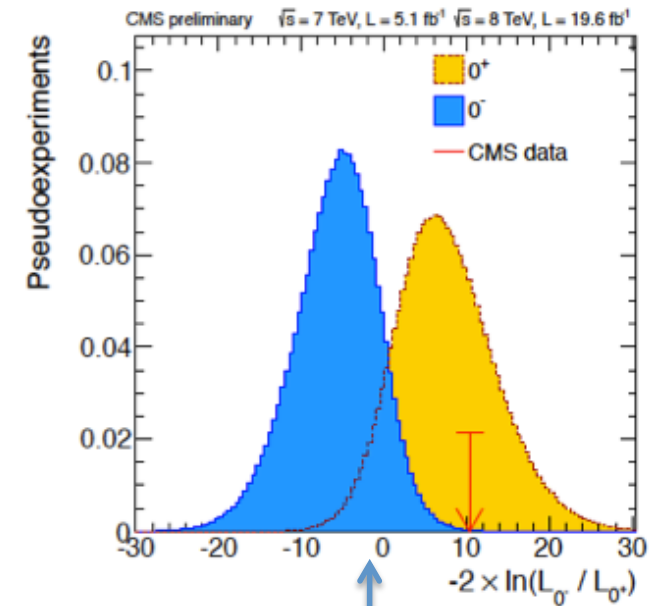
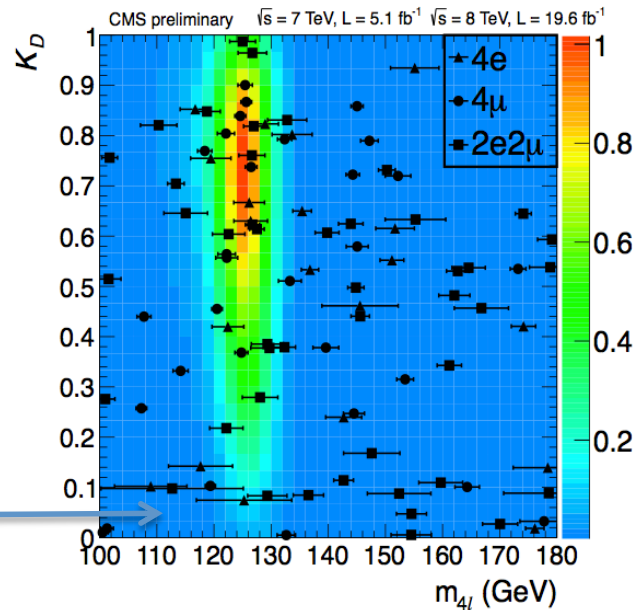
$$M_T = \sqrt{2p_T^{ll} E_T^{\text{miss}} (1 - \cos\Delta\phi)}$$

H → ZZ → 4 leptons: spin & Parity

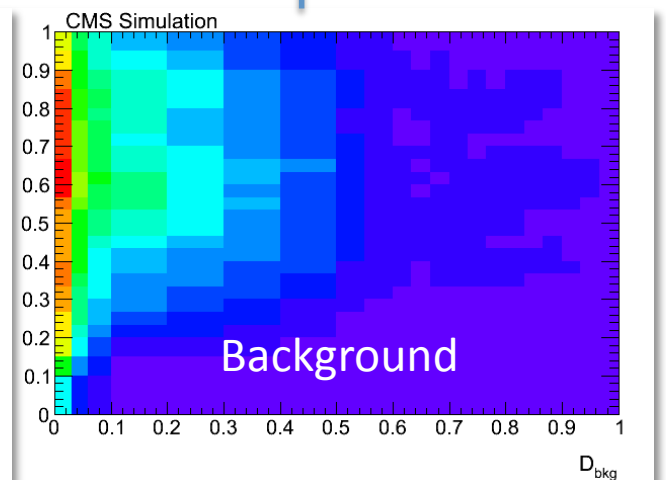
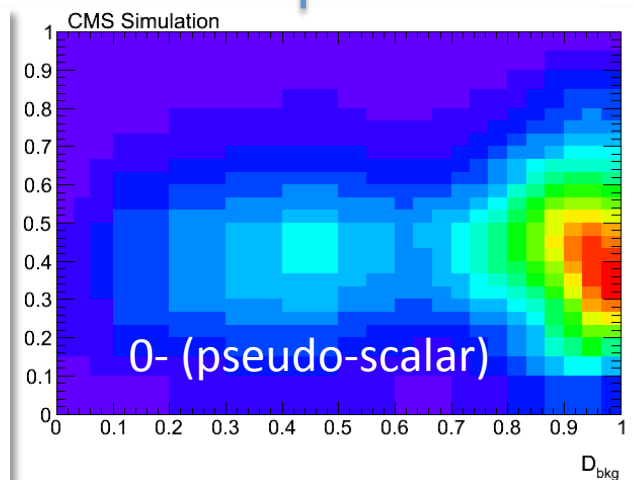
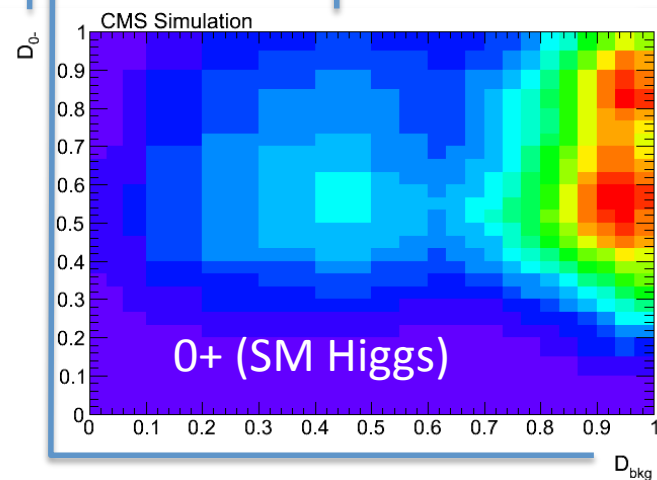
CMS PAS HIG-13-002

D_{JP} :
discriminates J^P
from 0^+ (SM Higgs)

D_{bkg} :
discriminates signal
from background
(K_D + mass)



Ratio of profile likelihoods:
Fit μ and nuisances

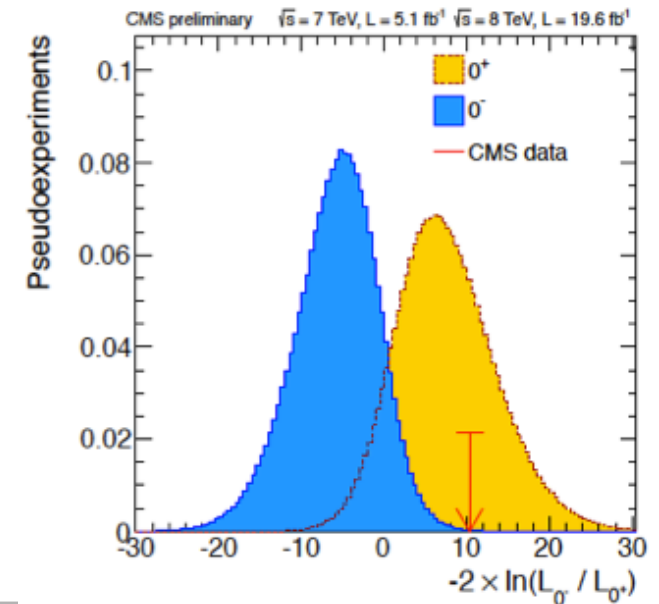


H → ZZ → 4 leptons: spin & Parity

CMS PAS HIG-13-002

Pseudo-scalar excluded at $> 3 \sigma$

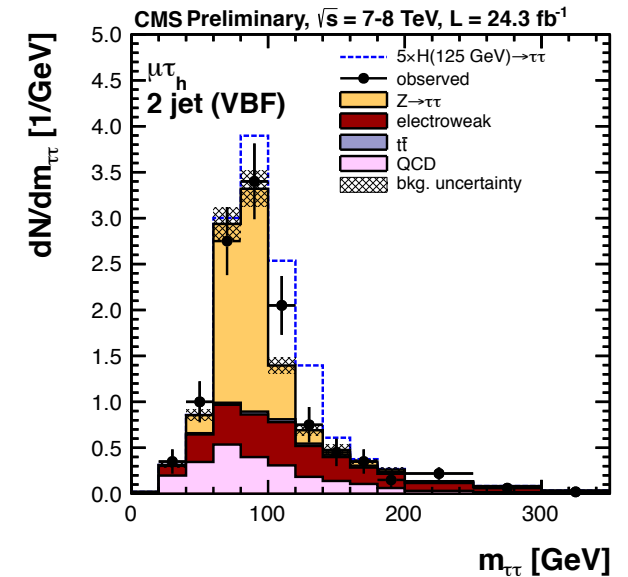
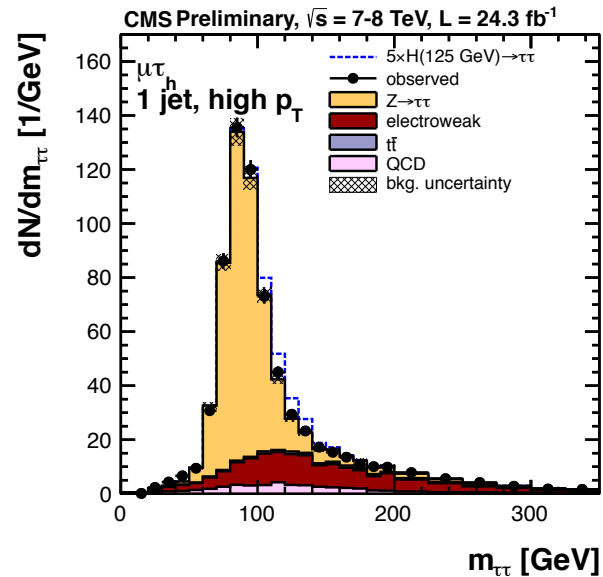
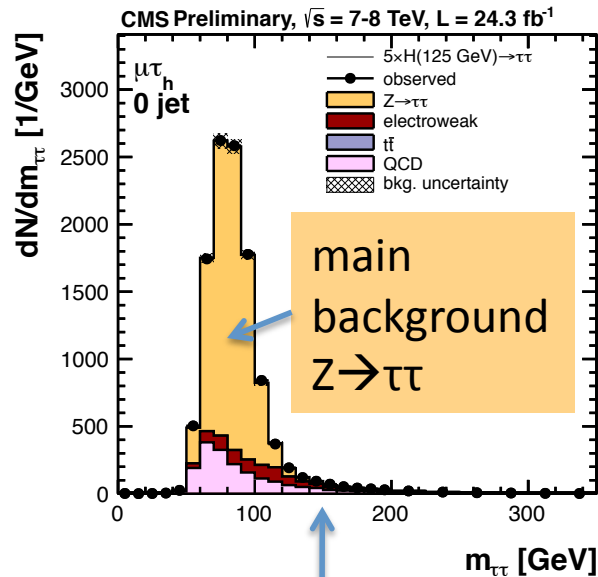
Spin 2: one model excluded at 4σ
the other is excluded @ 98.5% CL



	Expected [σ]		Observed (μ from data)		
	$\mu=1$	μ from data	P(q > Obs alternative) [σ]	P(q > Obs SM Higgs) [σ]	CLs [%]
gg → 0^-	2.8	2.6	3.3	-0.5	0.16
gg → 0_h^+	1.8	1.7	1.7	+0.0	8.1
qq → 1^+	2.6	2.3	> 4.0	-1.7	< 0.1
qq → 1^-	3.1	2.8	> 4.0	-1.4	< 0.1
gg → 2_m^+	1.9	1.8	2.7	-0.8	1.5
qq → 2_m^+	1.9	1.7	4.0	-1.8	< 0.1

H \rightarrow $\tau\tau$ search

5 channels: $\mu\tau_h$, $e\tau_h$, $e\mu$, $\tau_h\tau_h$, $\mu\mu$



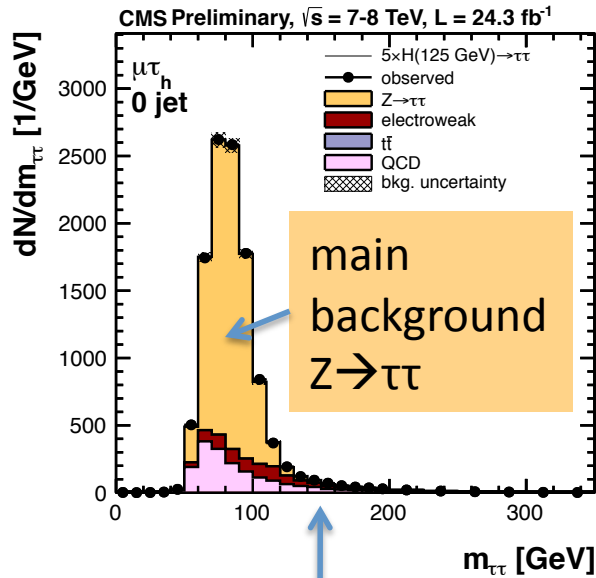
constrains
systematic errors
for sensitive
categories

Main systematic errors:
tau ID efficiency: 8%
tau energy scale: 3%

Combine the sensitive
categories of all channels
with a S/B weight

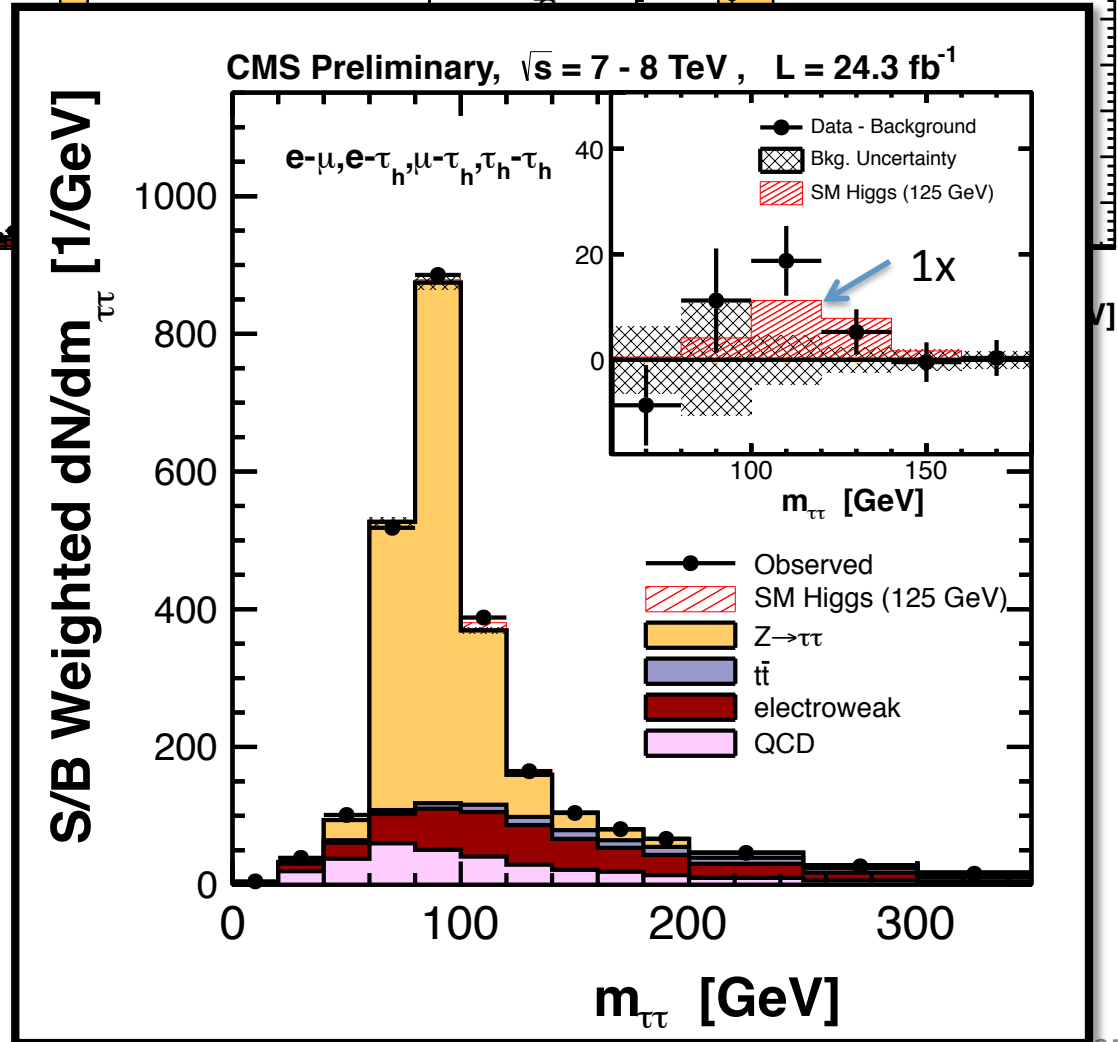
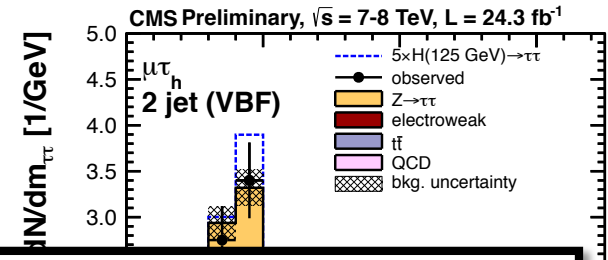
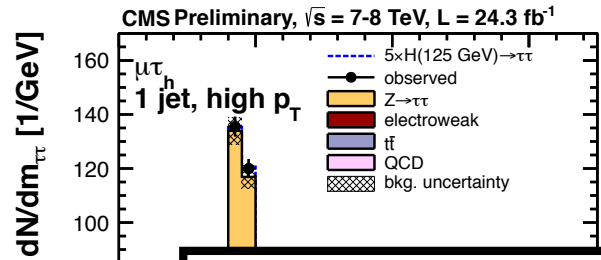
H \rightarrow $\tau\tau$ search

5 channels: $\mu\tau_h$, $e\tau_h$, $e\mu$, $\tau_h\tau_h$, $\mu\mu$

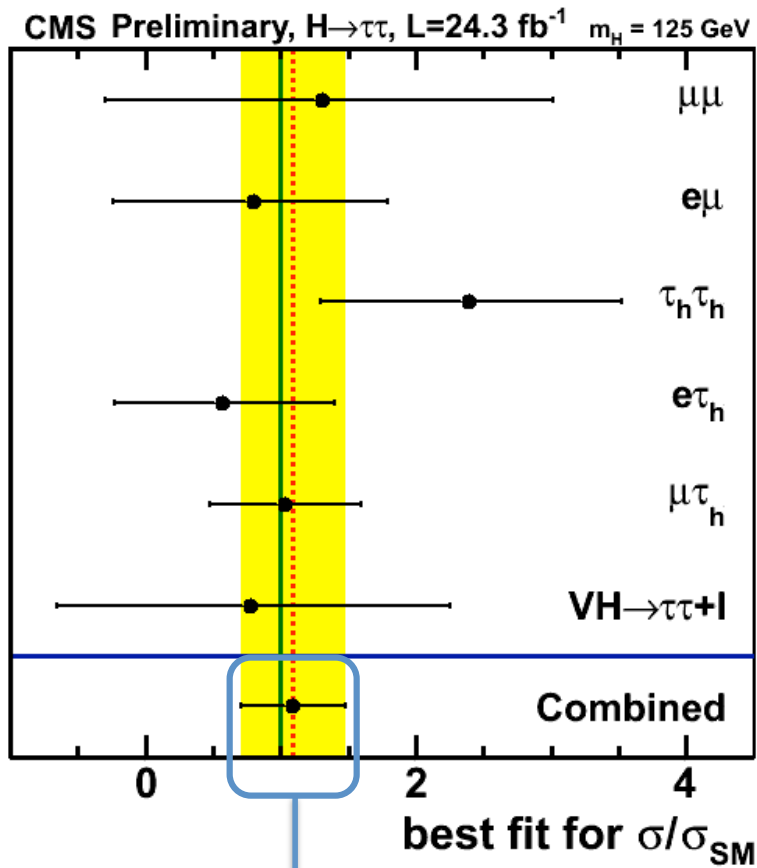


constrains systematic errors for sensitive categories

Main systematic errors:
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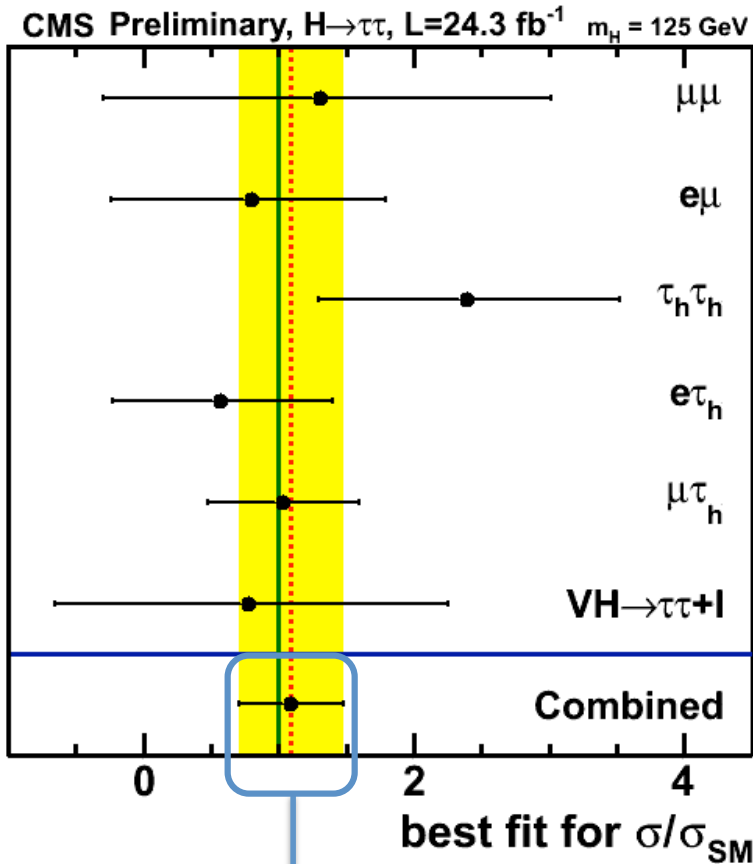
H \rightarrow $\tau\tau$ significance



All channels compatible

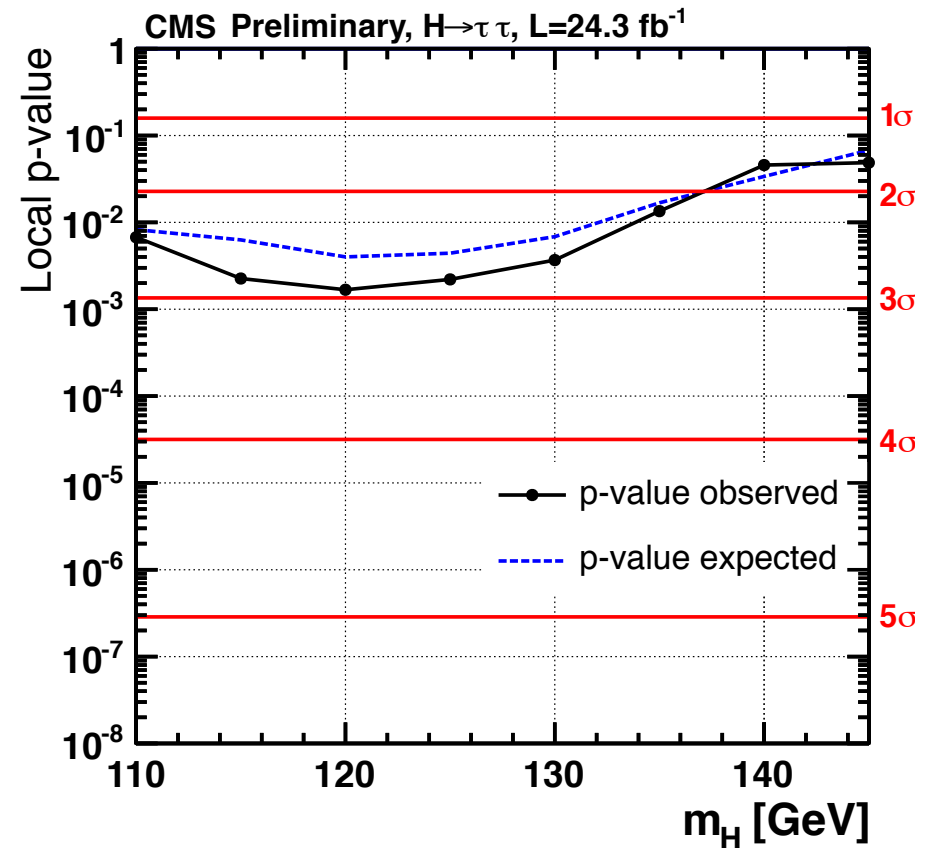
$\mu = 1.1 \pm 0.4$

H \rightarrow $\tau\tau$ significance



All channels compatible

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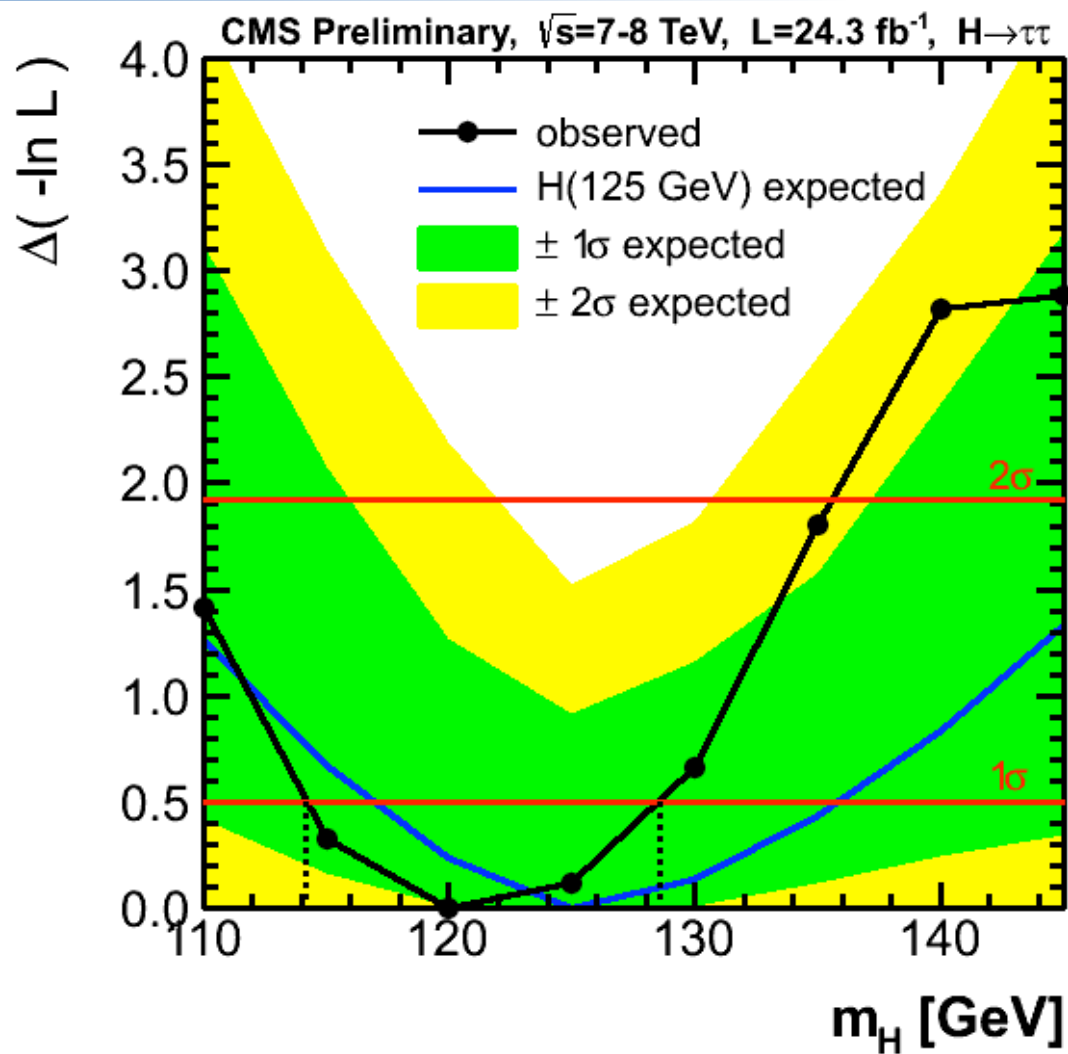


Maximum significance:
2.93 σ @ $m_H = 120$ GeV (2.65 exp.)

First Strong indication that the new boson couples to τ as the SM Higgs!

H $\rightarrow\tau\tau$ mass measurement

CMS PAS HIG-13-004

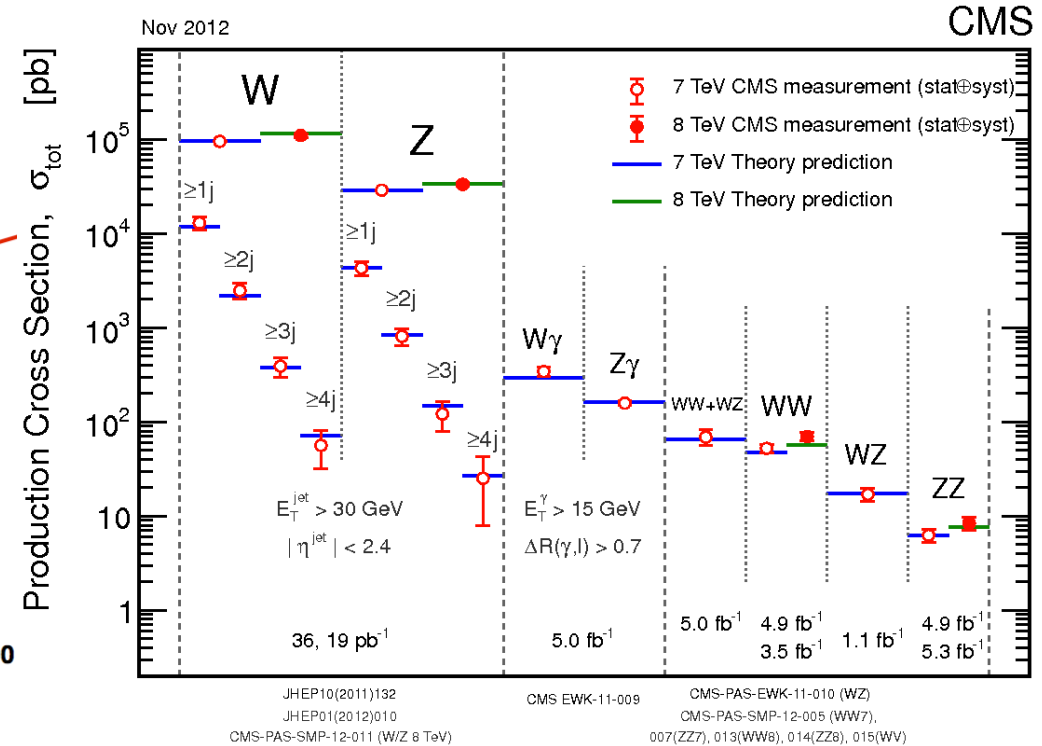
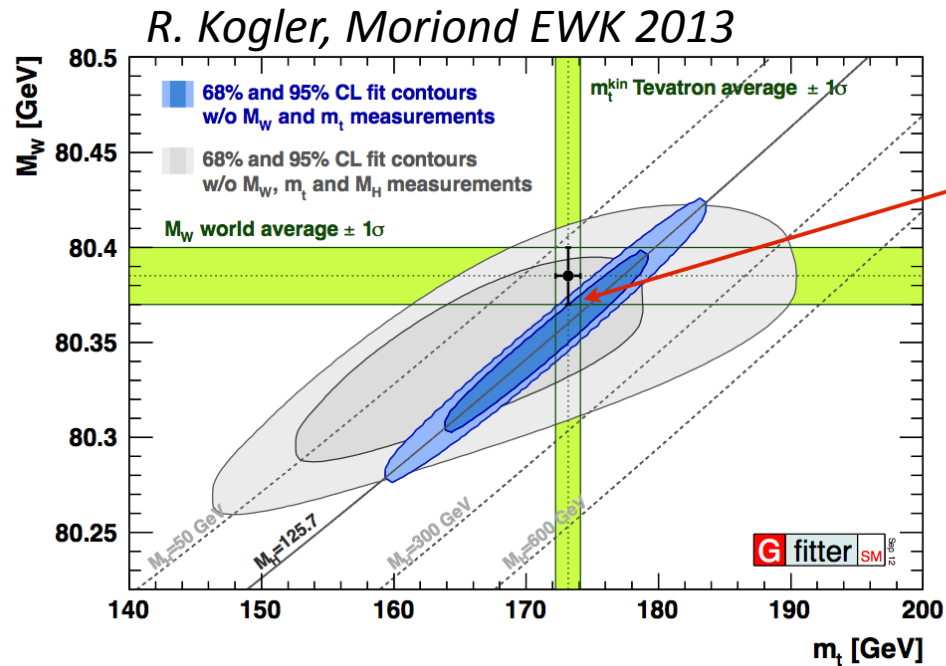


Compatible with:

- expectation for $m_H = 125$ GeV

- H $\rightarrow ZZ\rightarrow 4$ lepton mass measurement

Summary & Outlook



- It does look like the SM Higgs boson (spin, BR)
 - $H \rightarrow b\bar{b}$!
- No new physics, but stringent limits

- The standard model is now fully constrained
 - Standard model measurements!

Physics results for Moriond

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Search for ADD extra dimensions with dielectrons	EXO-12-031	PAS-PUB
Monojet search	EXO-12-048	PAS-PUB
Dijet mass 2012	EXO-12-059	PAS-PUB
W' to l nu	EXO-12-060	PAS-PUB
Z' full 2012 data	EXO-12-061	PAS-PUB
Study of exclusive gamma-gamma --> W W	FSQ-12-010	CWR
VH with Higgs to tautau	HIG-12-053	PHYS-APP
Higgs to gamma-gamma	HIG-13-001	PHYS-APP
Higgs to ZZ to 4 leptons	HIG-13-002	PAS-PUB
Higgs to WW to 2l2nu	HIG-13-003	PAS-PUB
Higgs to tau tau (SM)	HIG-13-004	PHYS-APP
Higgs to Zgamma targetting	HIG-13-006	PAS-PUB
Associated Higgs Production with H->WW	HIG-13-009	PAS-PUB
Measurement of W+charm	SMP-12-002	PAS-PUB
Measurement of Z/gamma + jet angular distributions	SMP-12-004	PAS-PUB
Measurement of WW production rate	SMP-12-005	CWR-ended
Zgamma cross section in MET+gamma channel at 7 TeV	SMP-12-020	CWR
Z PT differential cross section at 8 TeV	SMP-12-025	PHYS-APP
W+bb cross section at 7 TeV	SMP-12-026	PHYS-APP
Search for SUSY in all-hadronic events with b-jets	SUS-12-024	PAS-PUB
RPV stop search	SUS-13-003	PAS-PUB
Search for SUSY in single-lepton events with b-jets	SUS-13-007	PAS-PUB
W helicity in ttbar	TOP-12-015	PAS-PUB
W helicity in single top	TOP-12-020	PAS-PUB
LHC Combination note: W helicities	TOP-12-025	PHYS-APP
Differential ttbar cross-section (semi-leptonic)	TOP-12-027	PAS-PUB
Differential ttbar cross-section (di-leptonic)	TOP-12-028	PAS-PUB
Differential top mass measurements	TOP-12-029	PAS-PUB
t-tbar mass difference	TOP-12-031	PHYS-APP
R=BR(t->Wb)	TOP-12-035	PAS-PUB
t/tbar production ratio in single top	TOP-12-038	PHYS-APP

- Lots of interesting results available
- Apologies if I didn't have time to present your favourite result

36 Analyses approved for Moriond 2013

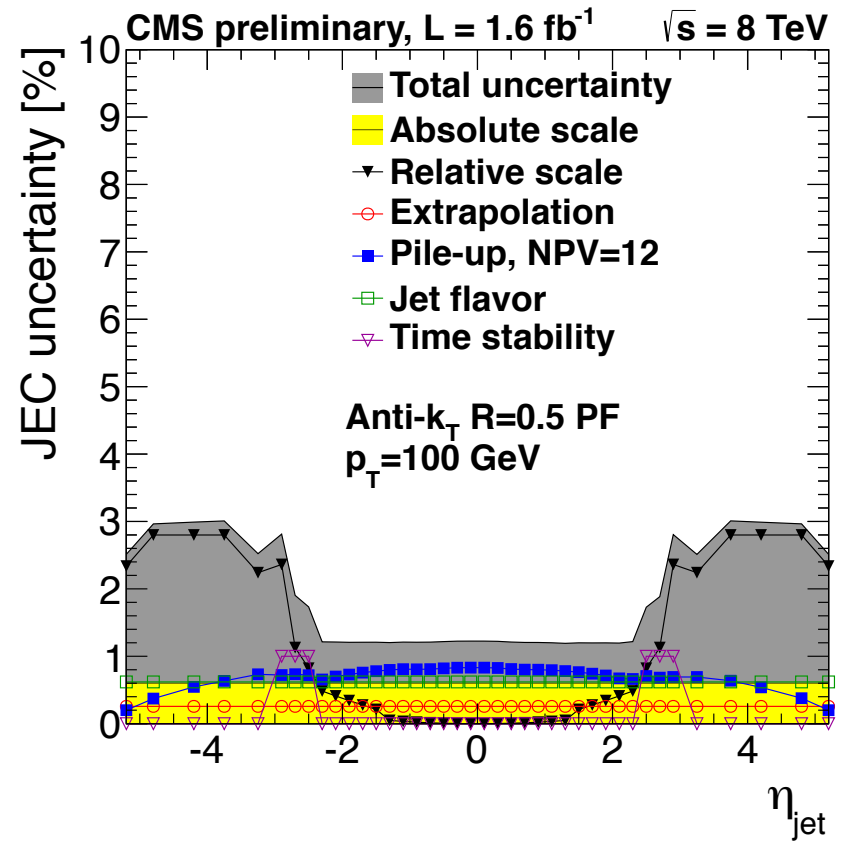
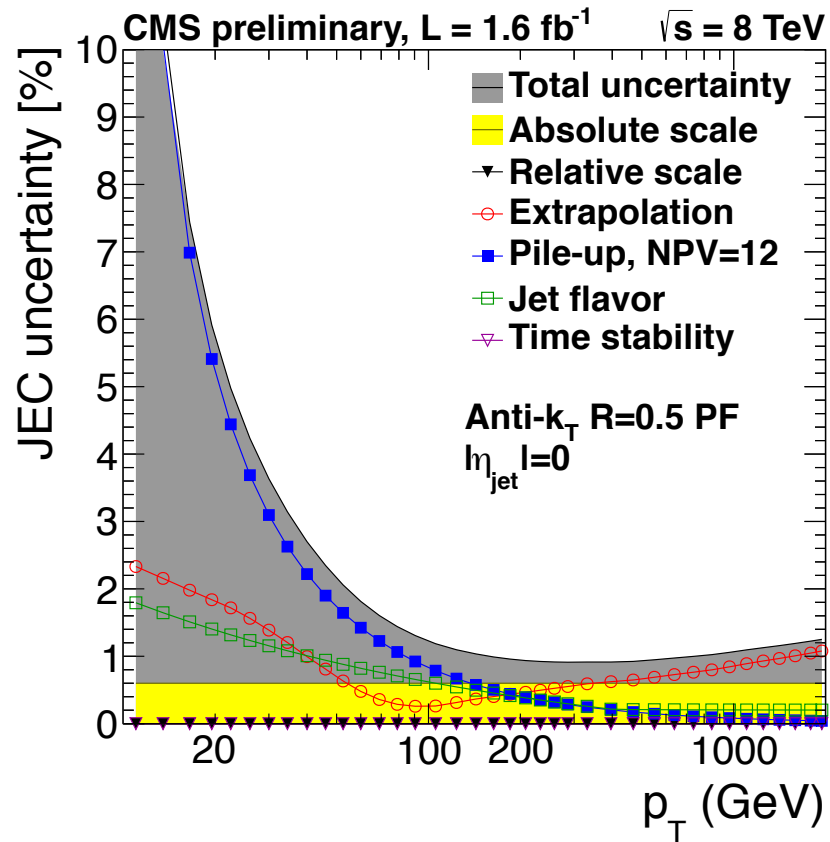
<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults>

Back-up

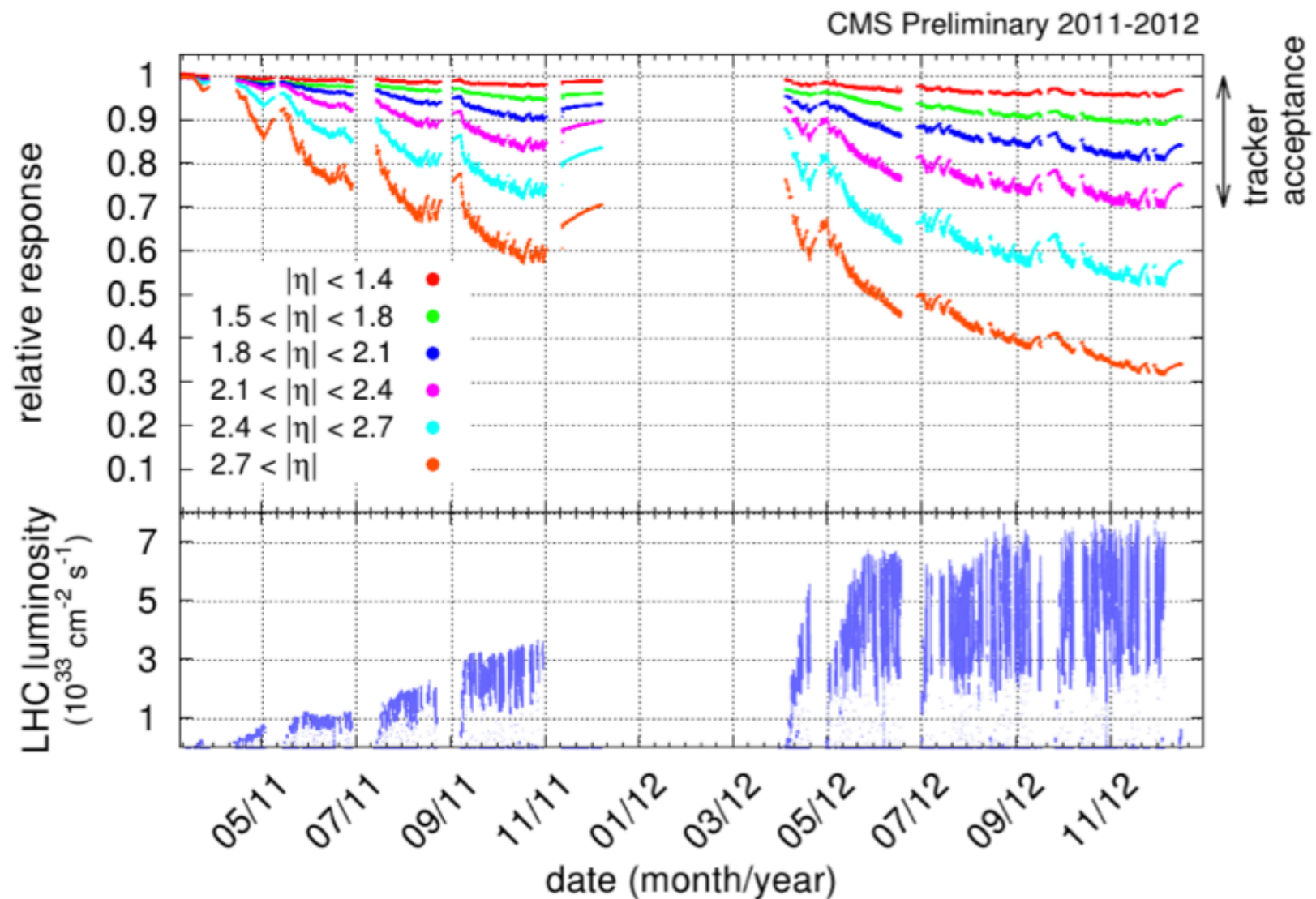
Needed backup slides

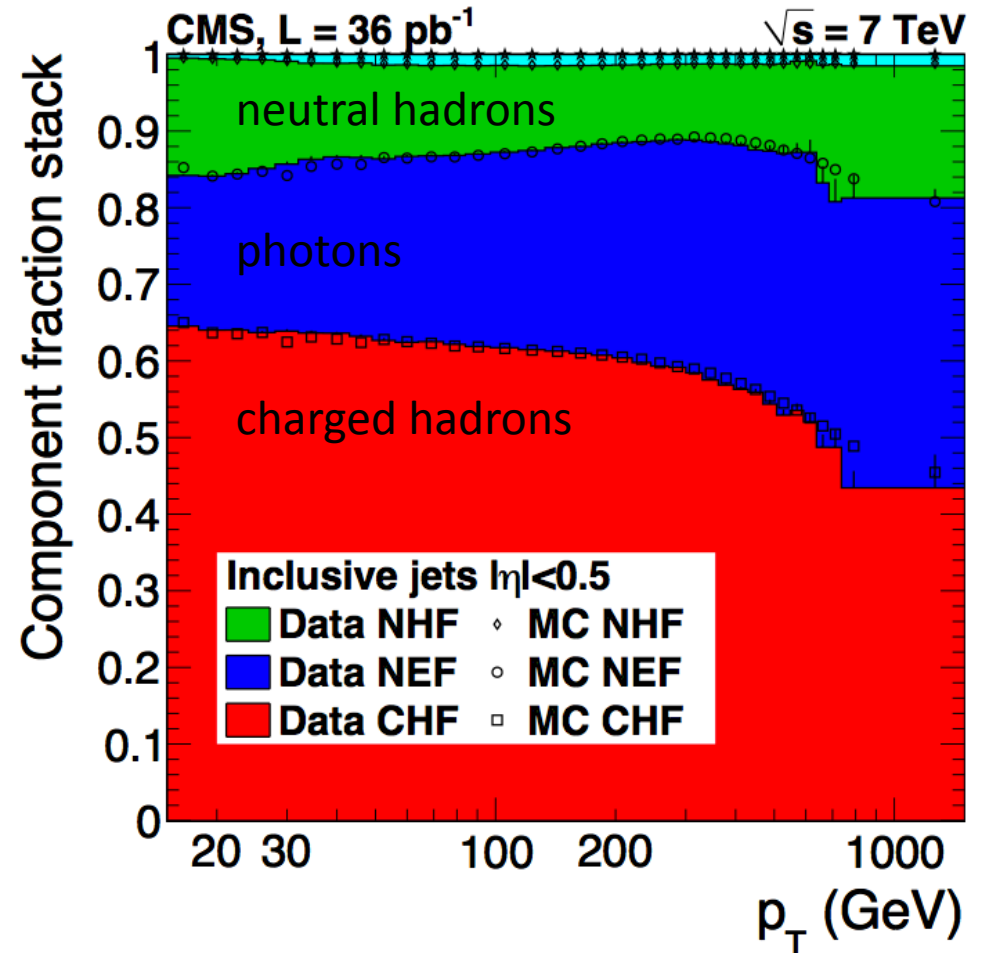
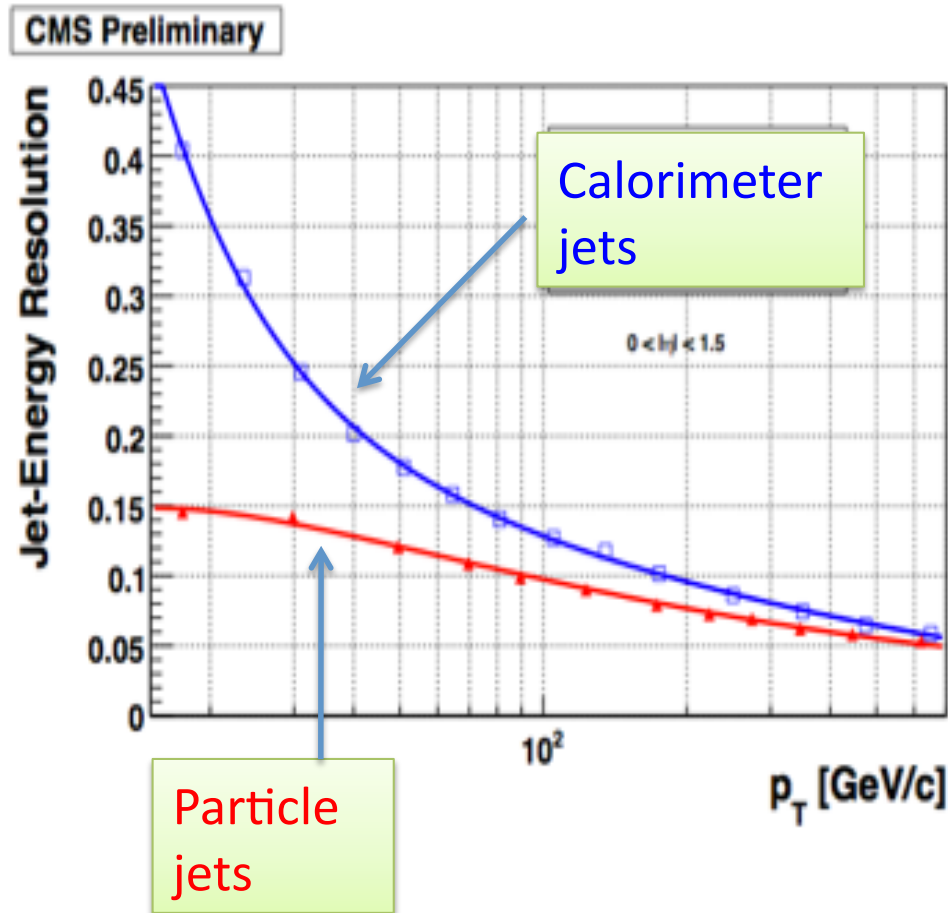
- crystal response monitoring plot
- ECAL intercalibration, response, resolution for Z (backup $H \rightarrow gg$)
- tau ID slide from Valentina
- mtautau slide from Valentina
 - or make one myself
- selections for all analyses presented here, except tau tau

JES uncertainty



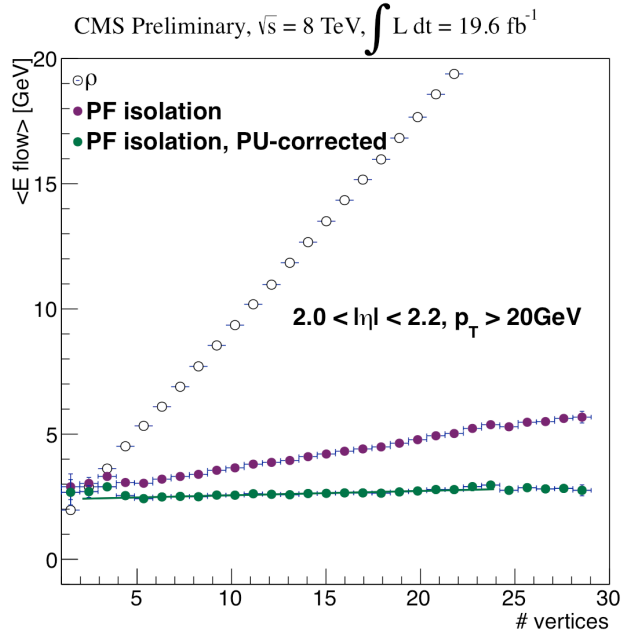
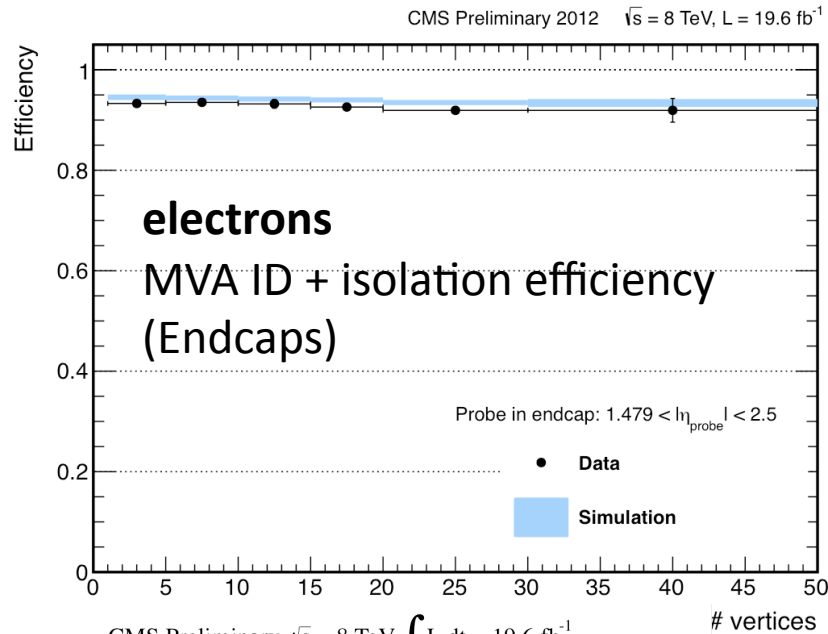
History of relative response



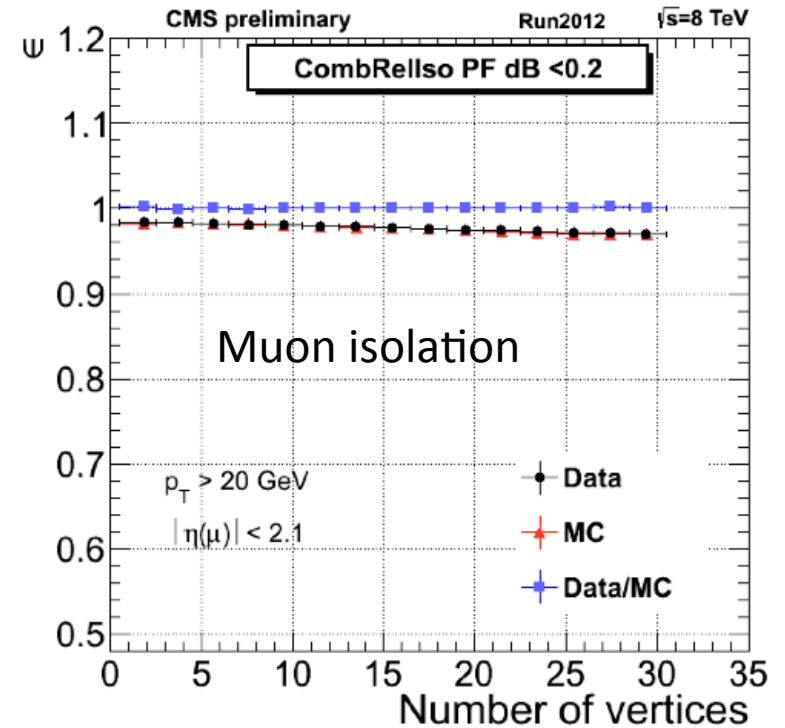
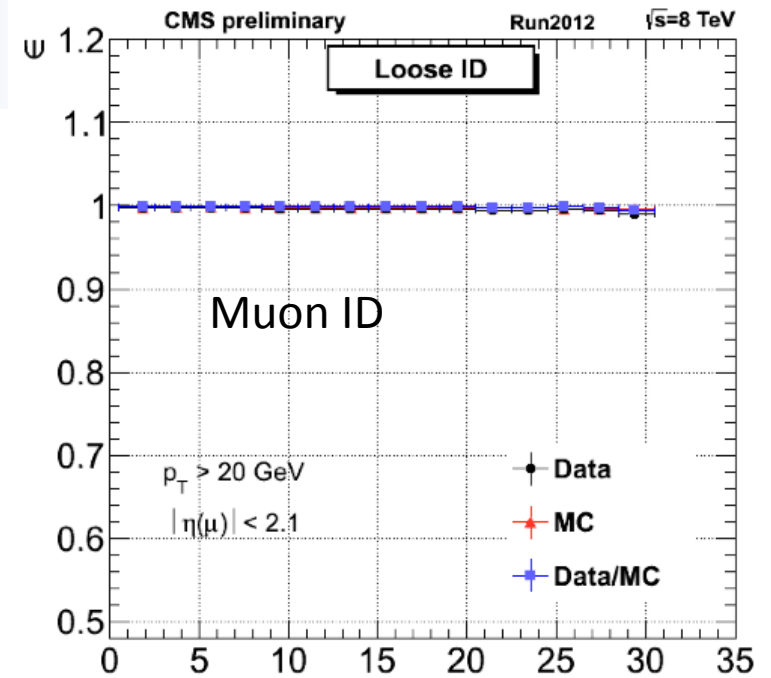


- Factor 2 improvement on most physics objects
- Particle flow also running in high level trigger

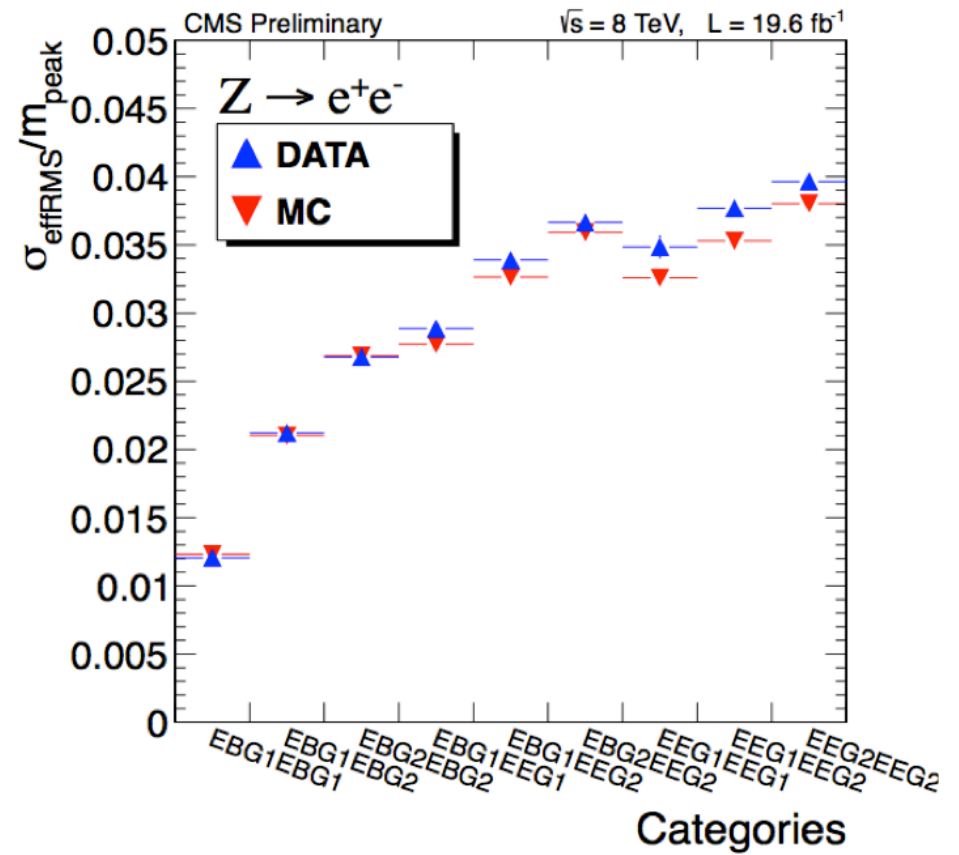
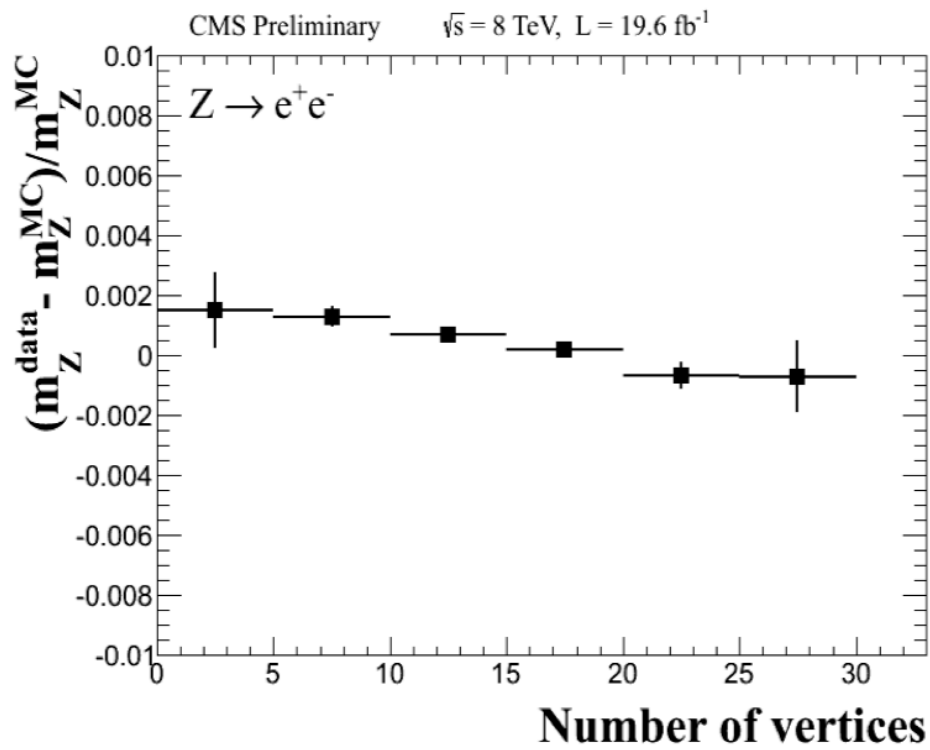
PU control: leptons



Leptons
almost
insensitive
to pileup

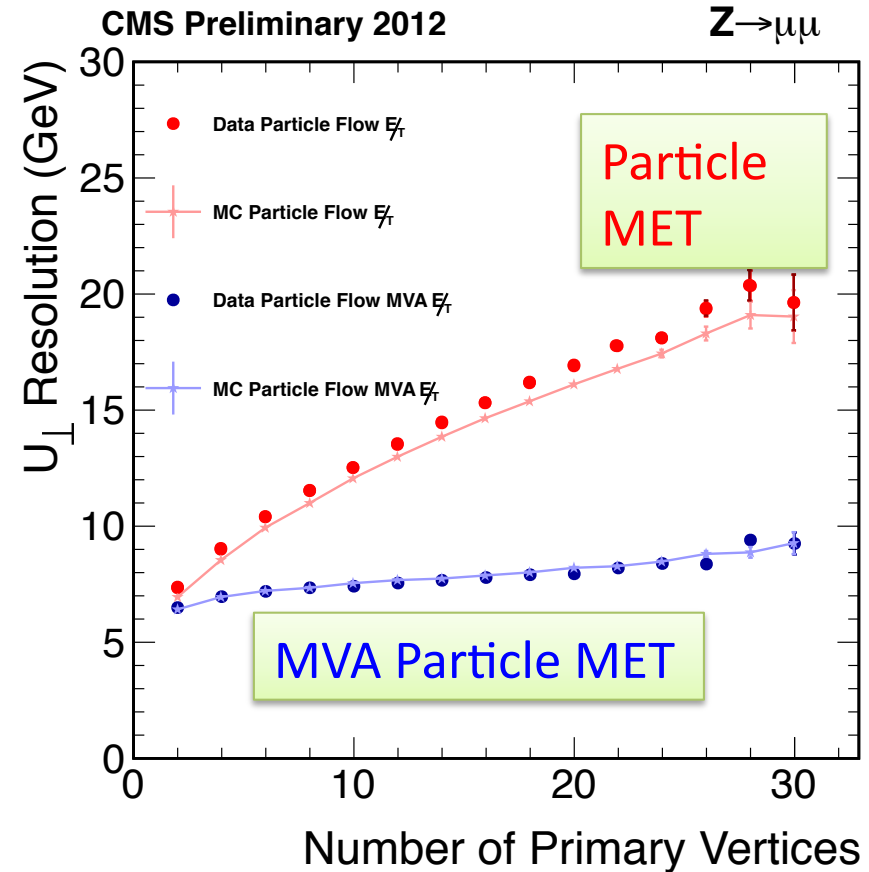
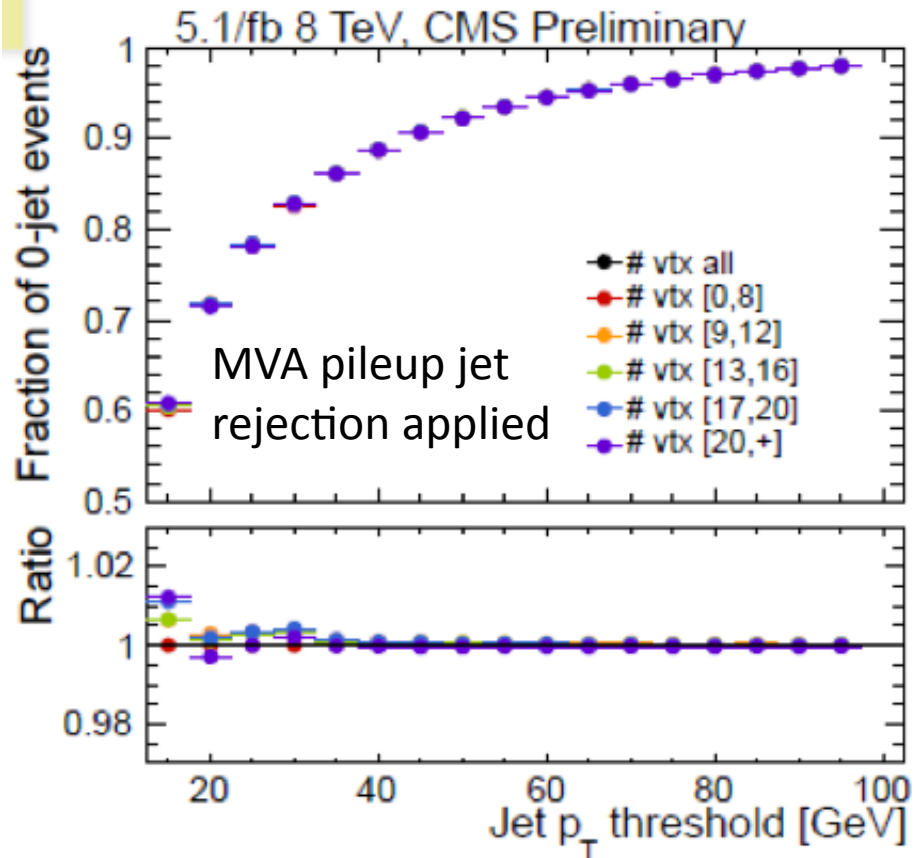
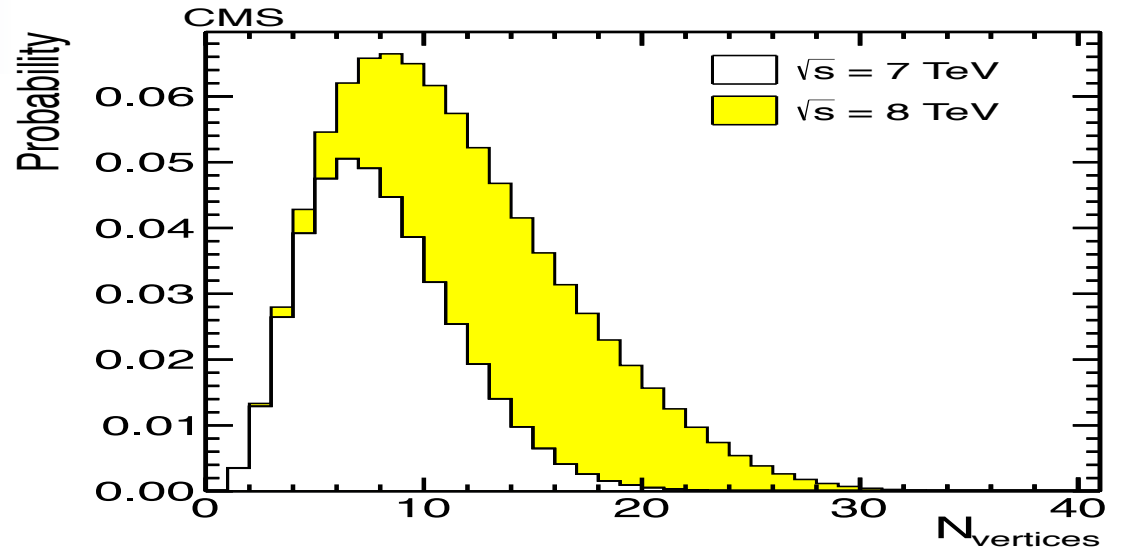


Electron scale & resolution



PU control: jets, MET

- Sensitivity of jets and MET to pileup almost eliminated
- Pileup control algorithms running at HLT



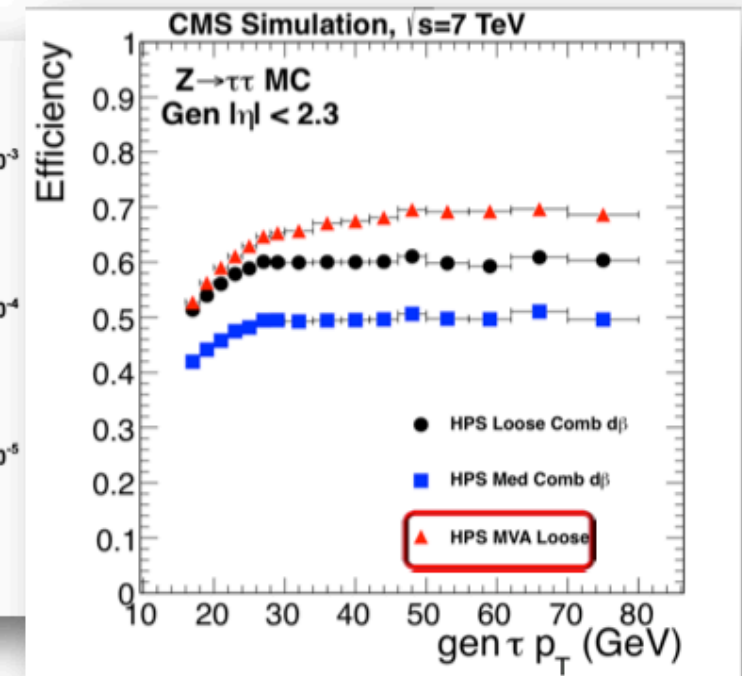
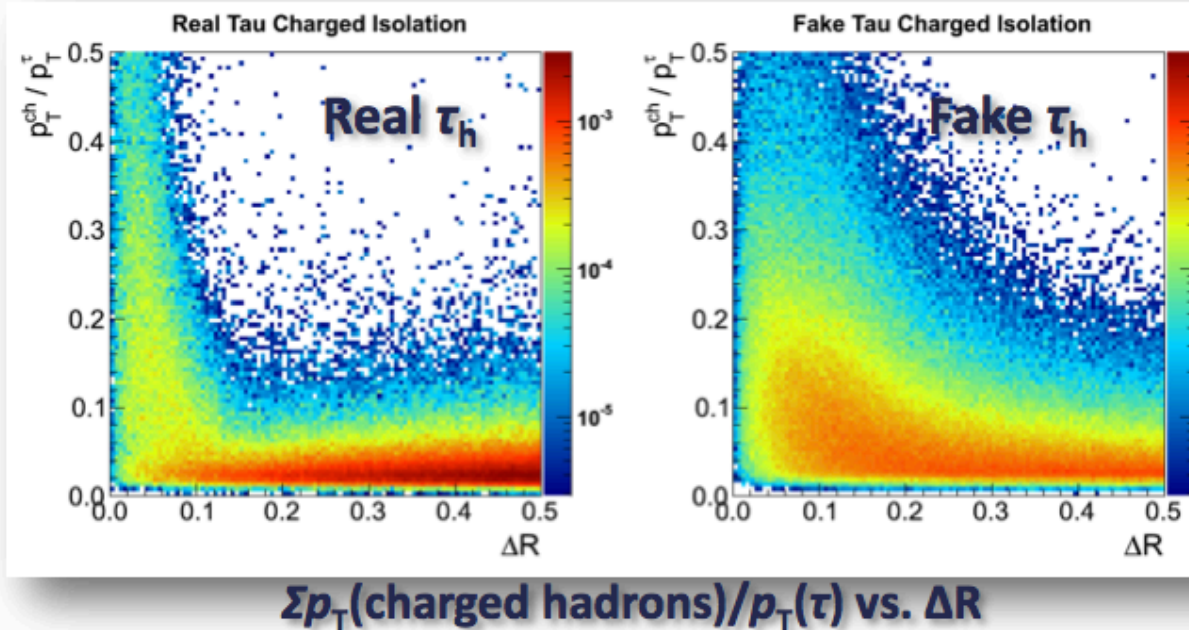
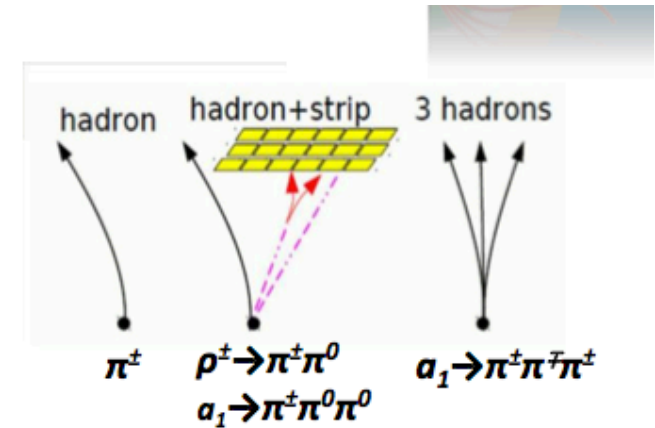
Tau identification

Identification:

- Reconstructed based on decay modes: charged hadrons + ECAL deposits

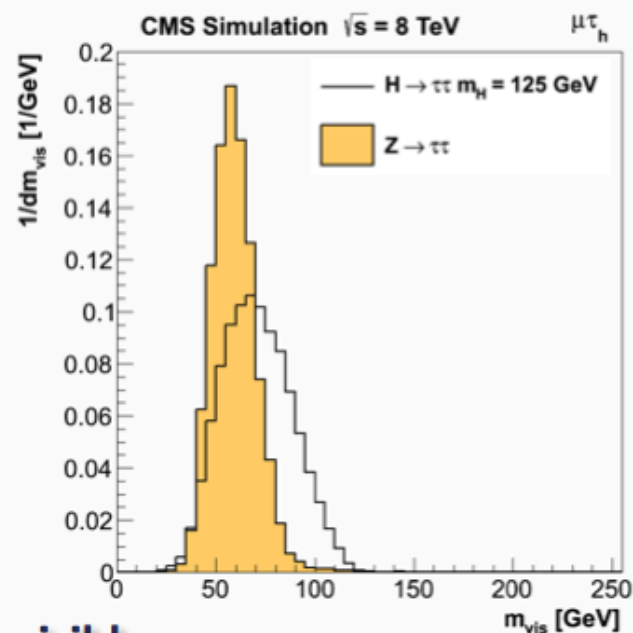
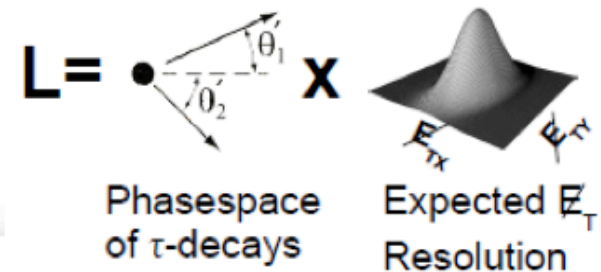
Isolation: **New in 2012**

- Multivariate isolation using relative Σp_T of particle-flow candidates in concentric rings around τ

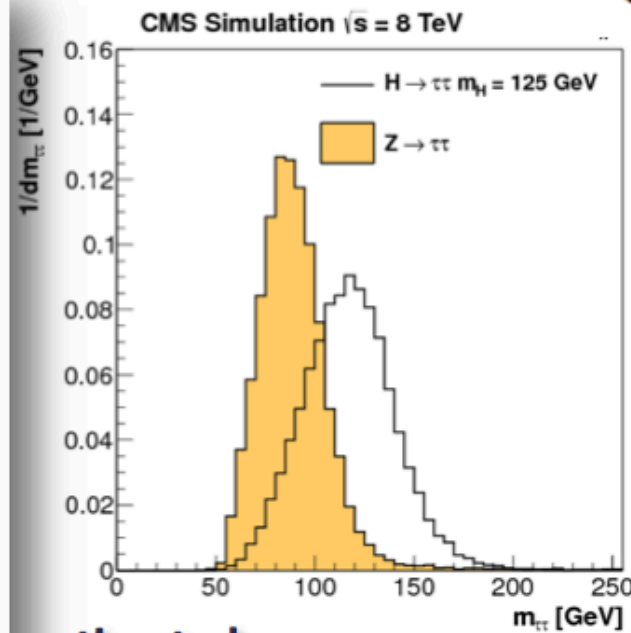


$m_{\tau\tau}$ reconstruction

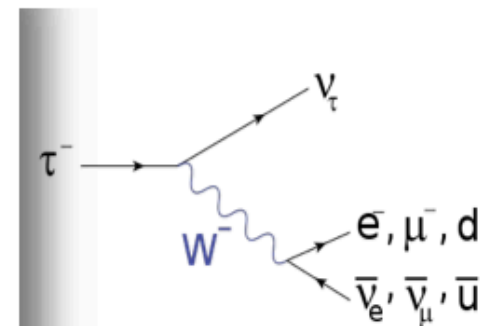
- Maximum likelihood method used
- Estimated on event-by-event basis using four-momenta of visible decay products, E_x^{miss} , E_y^{miss} , expected E_T^{miss} resolution
- Nuisance parameters integrated out
- 15-20% resolution on reconstructed $m_{\tau\tau}$



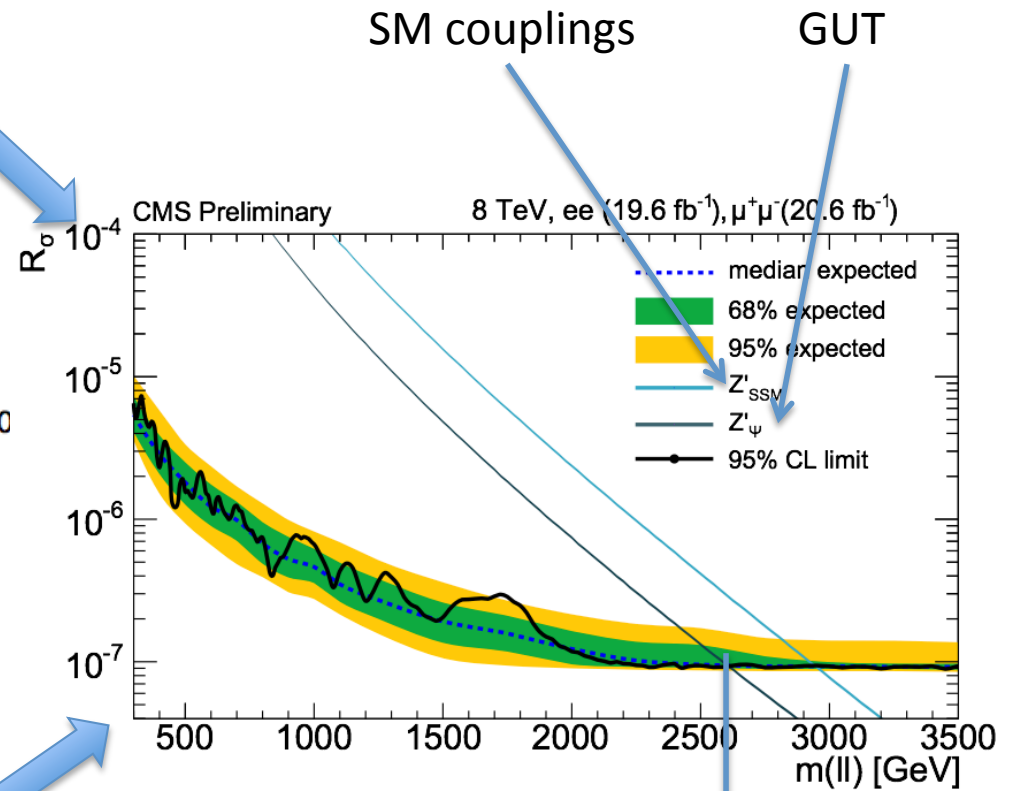
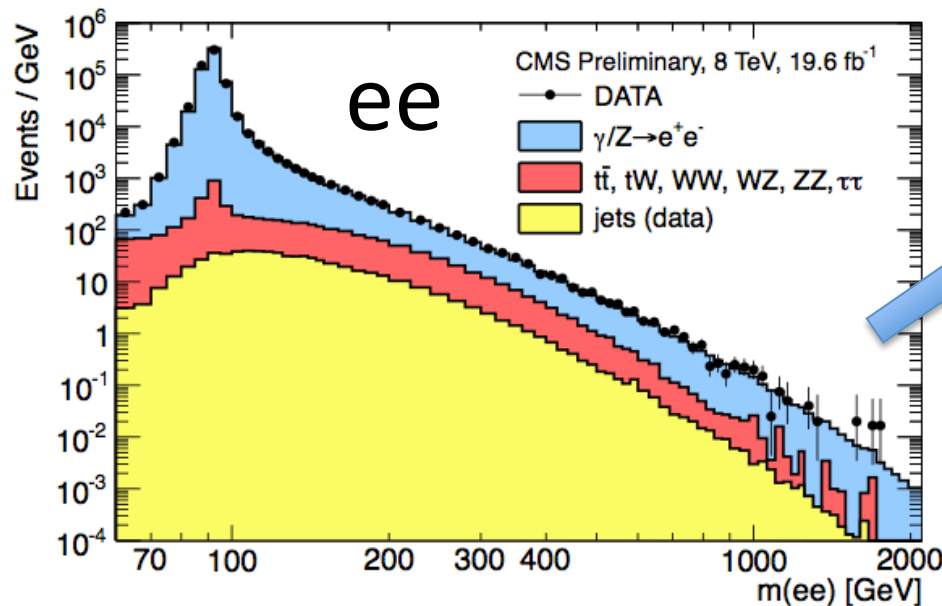
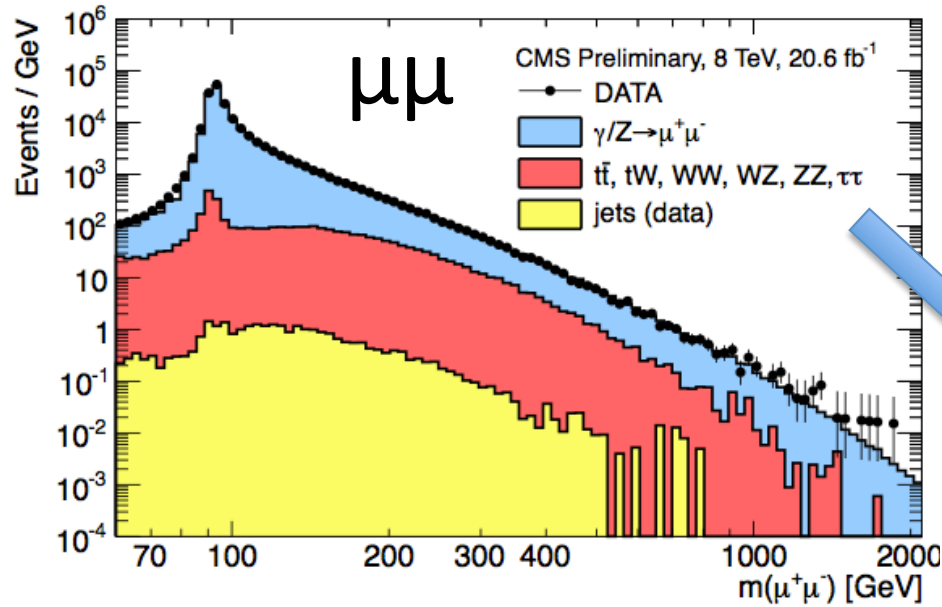
visible mass



estimated $m_{\tau\tau}$

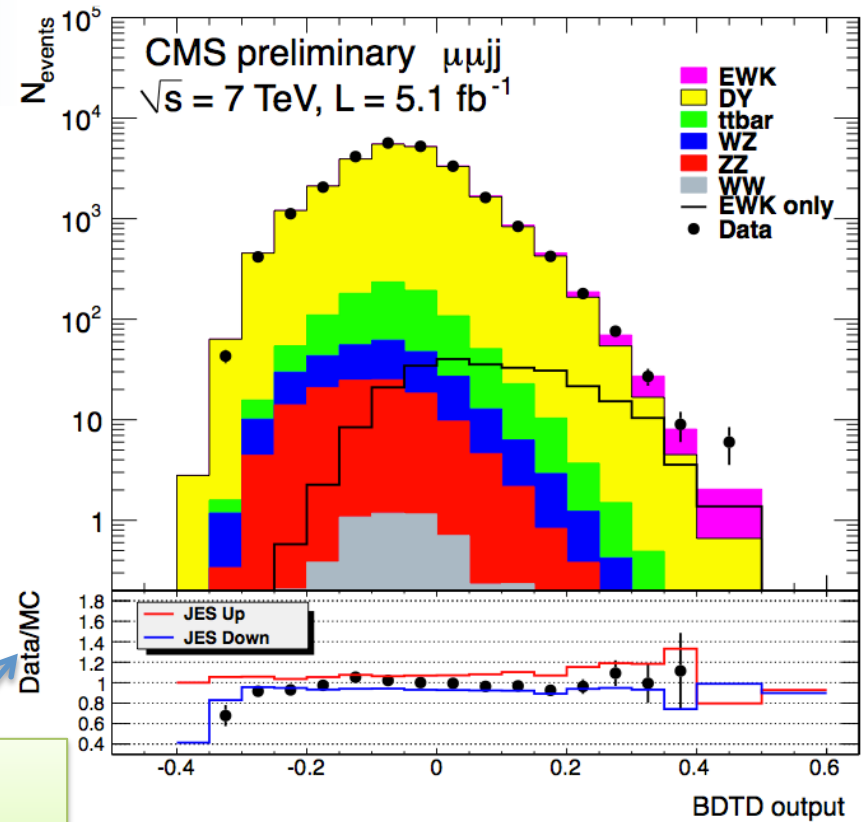
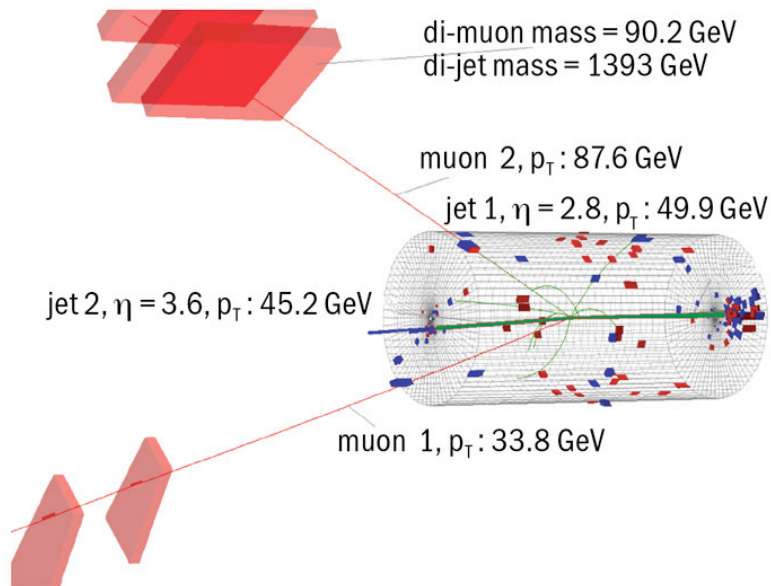
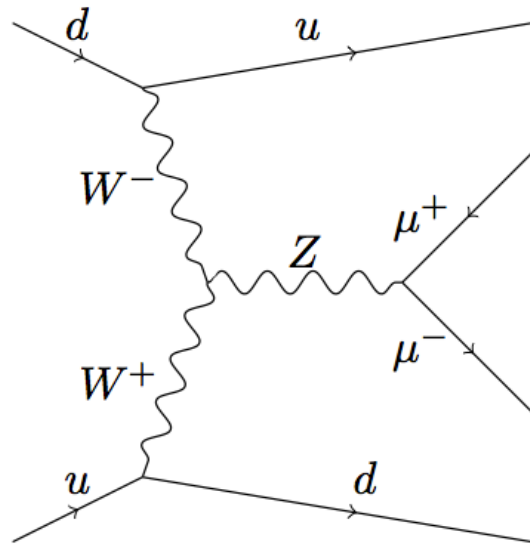


dilepton resonance search



Exclude W' with $m < 2.6$ TeV

EWK Z production



data / sig + bkg.

1st measurement

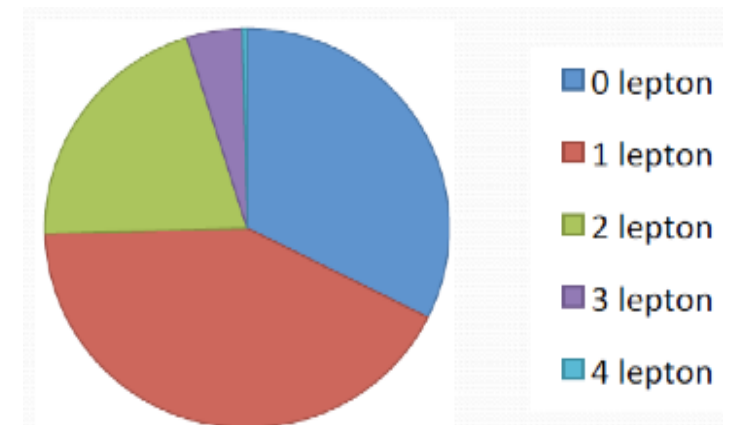
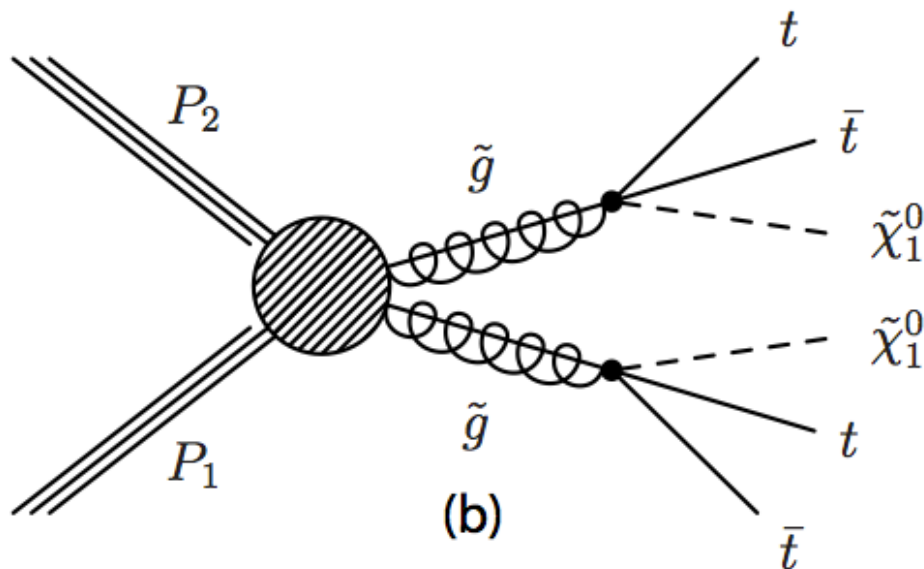
$$\begin{aligned}
 \sigma(\text{EWK Z}+2\text{jets}) &= 154 \pm 24 \text{ (stat.)} \\
 &\quad \pm 46 \text{ (exp. syst.)} \\
 &\quad \pm 27 \text{ (th. syst.)} \\
 &\quad \pm 3 \text{ (lum.) fb}
 \end{aligned}$$

Good agreement with NLO calculation:
 $\sigma(\text{EWK Z}+2\text{jets}) = 166 \text{ fb}$

Supersymmetry

$m_H = 125$ GeV requires in the MSSM:

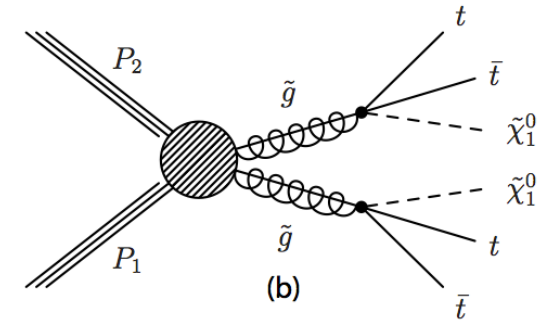
- light gluino
- large stop mixing \rightarrow heavy stop2 and light stop1



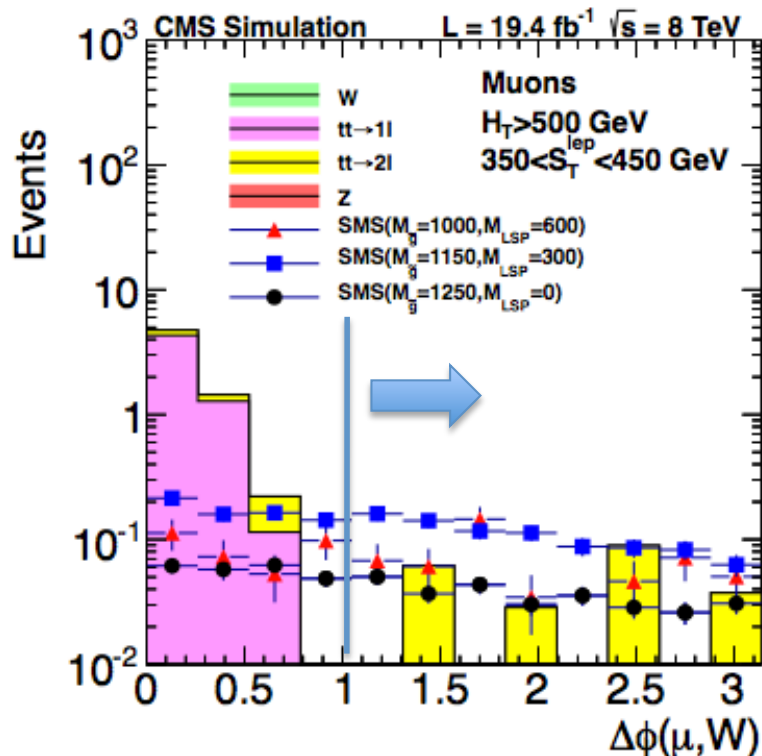
1 lepton + ≥ 6 jets + ≥ 2 b jets

- $\Delta\Phi$ between:
 - lepton,
 - $W = \text{lepton} + \text{MET}$.
- Background prediction from 1b jet data control sample.

Correction factor from simulation
 $\sim 1.0 \pm 1.5$



$$R_{\text{ctl} \rightarrow \text{sig}}(N_b \geq 1) \cdot K_{\text{MC}}(N_b \geq 3) \cdot N_{\text{ctl}}(N_b \geq 3) = N_{\text{sig}}(N_b \geq 3)$$

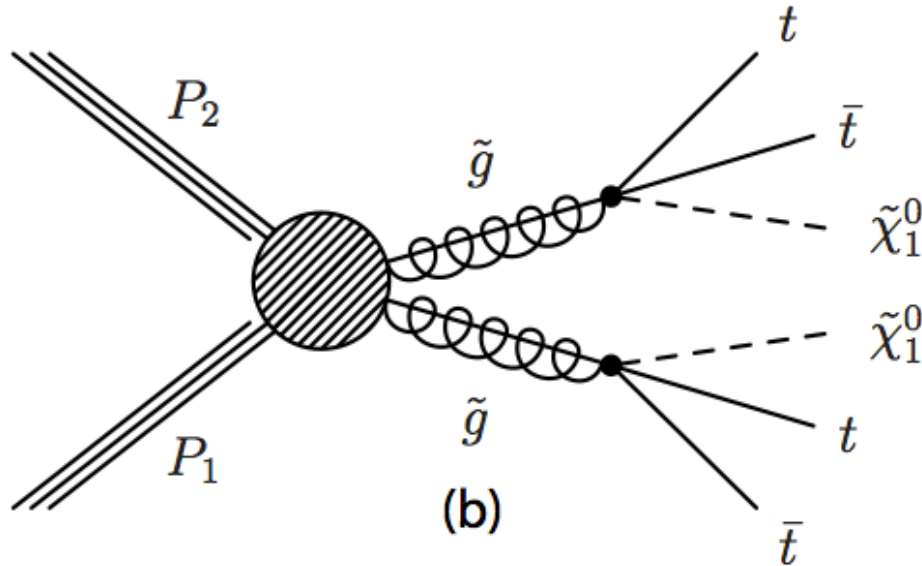


		S_T^{lep} [GeV]	control reg. data	prediction	observation
$N_b = 2$	Muons	[250,350]	141	6.00 ± 2.40 (2.23)	9
		[350,450]	24	1.37 ± 1.19 (1.12)	2
		>450	9	0.0 ± 0.66 (0.66)	0
	Electr.	[250,350]	112	3.83 ± 1.84 (1.75)	9
		[350,450]	28	2.74 ± 2.02 (1.86)	2
		>450	9	0.0 ± 0.42 (0.42)	0
$N_b \geq 3$	Muons	[250,350]	28	1.92 ± 0.95 (0.84)	0
		[350,450]	13	0.57 ± 0.58 (0.52)	0
		>450	2	0.0 ± 0.22 (0.22)	0
	Electr.	[250,350]	45	1.89 ± 1.03 (0.94)	4
		[350,450]	7	0.85 ± 0.80 (0.70)	0
		>450	0	0.0 ± 0.08 (0.08)	0

No observed excess \rightarrow limits

1 lepton + ≥ 6 jets + ≥ 2 b jets

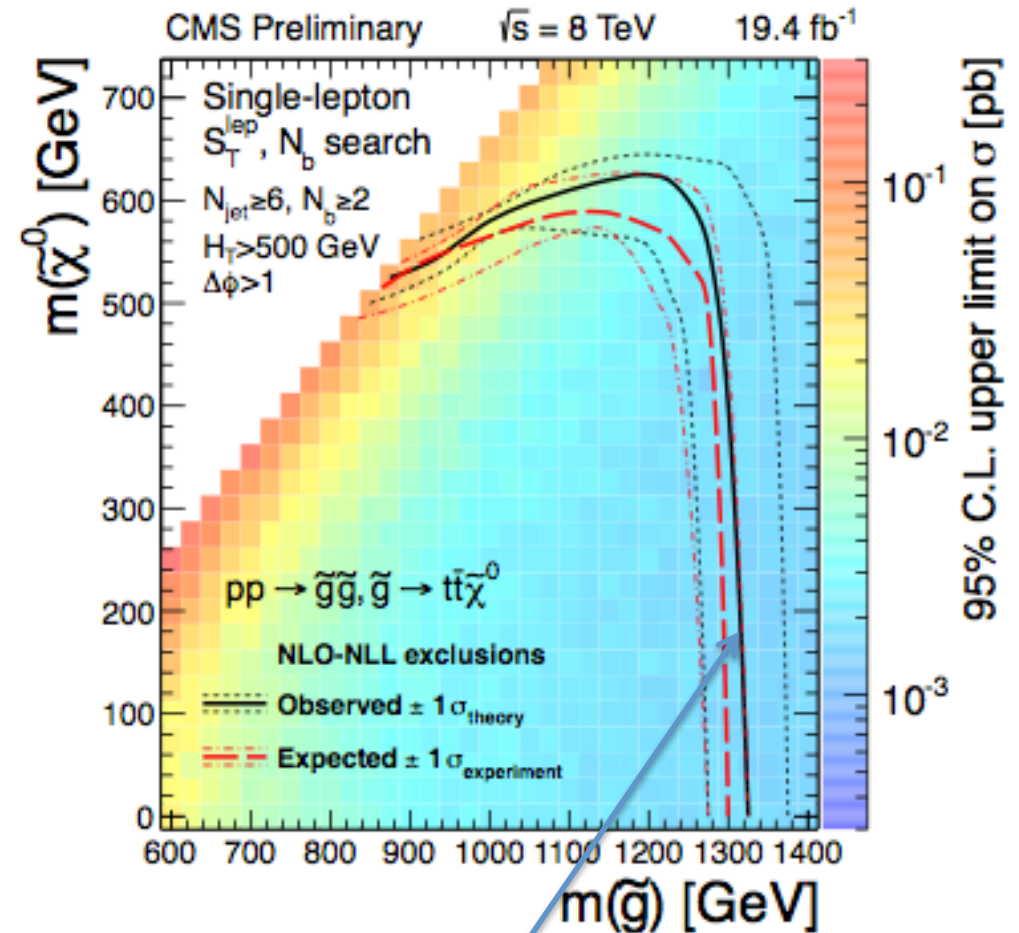
Limits in simplified susy models



- Assumptions:

$$m_{\tilde{t}} > m_{\tilde{g}}$$

$$\text{BR}(\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0) = 100\%$$



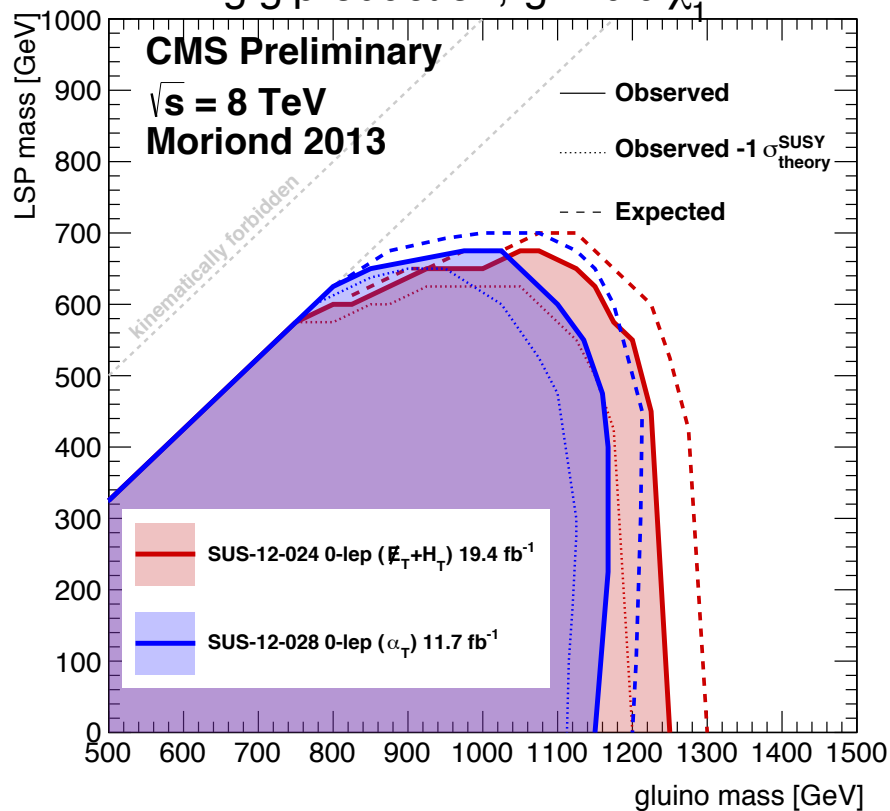
1 lepton + ≥ 6 jets + ≥ 2 b jets

Limits on cross-section: allow theorists to test models

Other SUSY searches

gluino \rightarrow bb neutralino

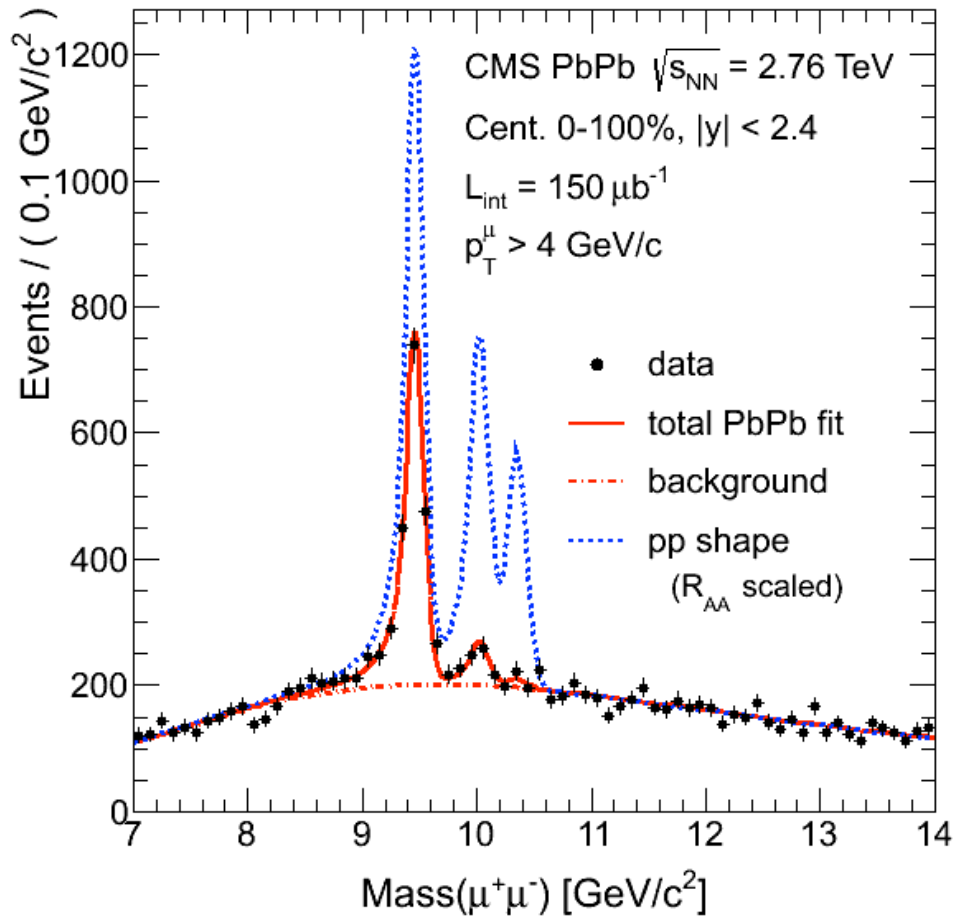
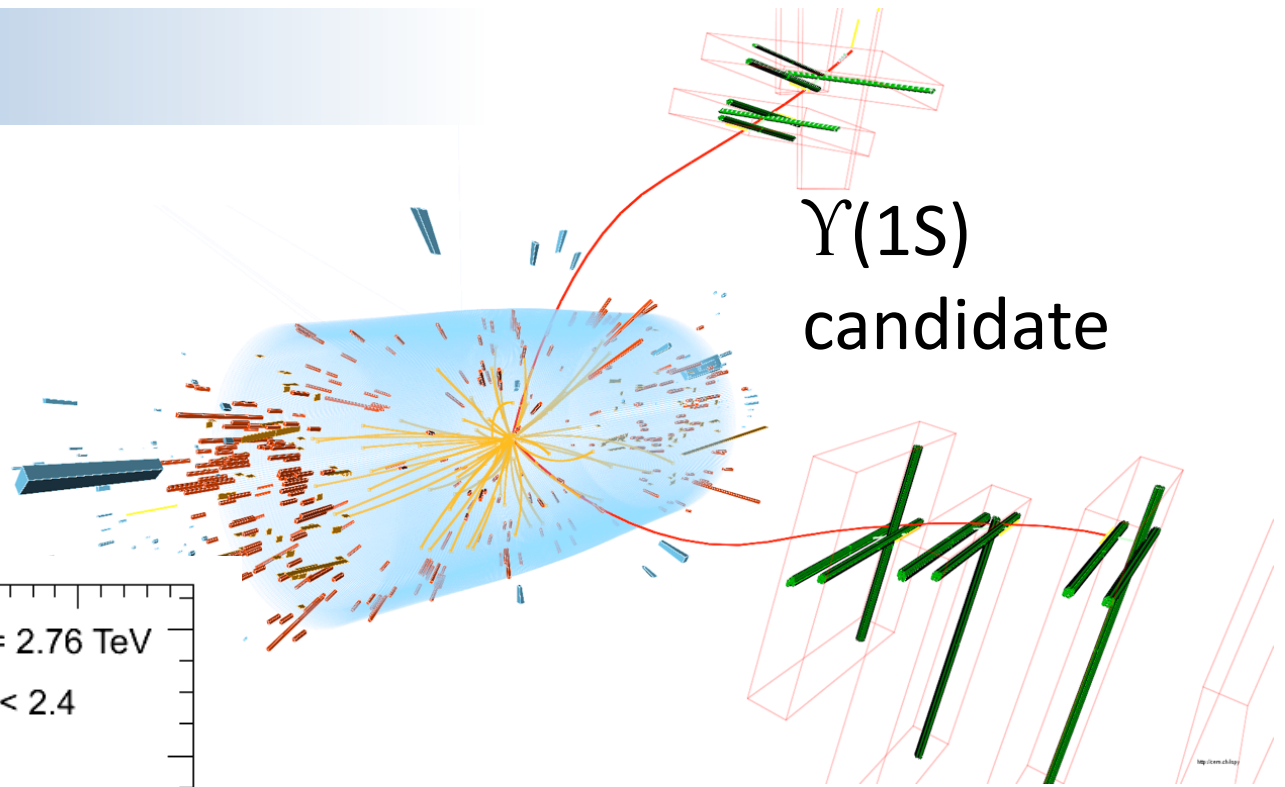
$\tilde{g}\text{-}\tilde{g}$ production, $\tilde{g}\rightarrow b\bar{b}\tilde{\chi}_1^0$



- Also:
 - search for direct stop production
 - search for sleptons and charginos
 - inclusive squark and gluino searches
 - ...

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS>

p-Pb, 2012



p-Pb reference measurements:

No production of a dense medium in p-Pb events (?)

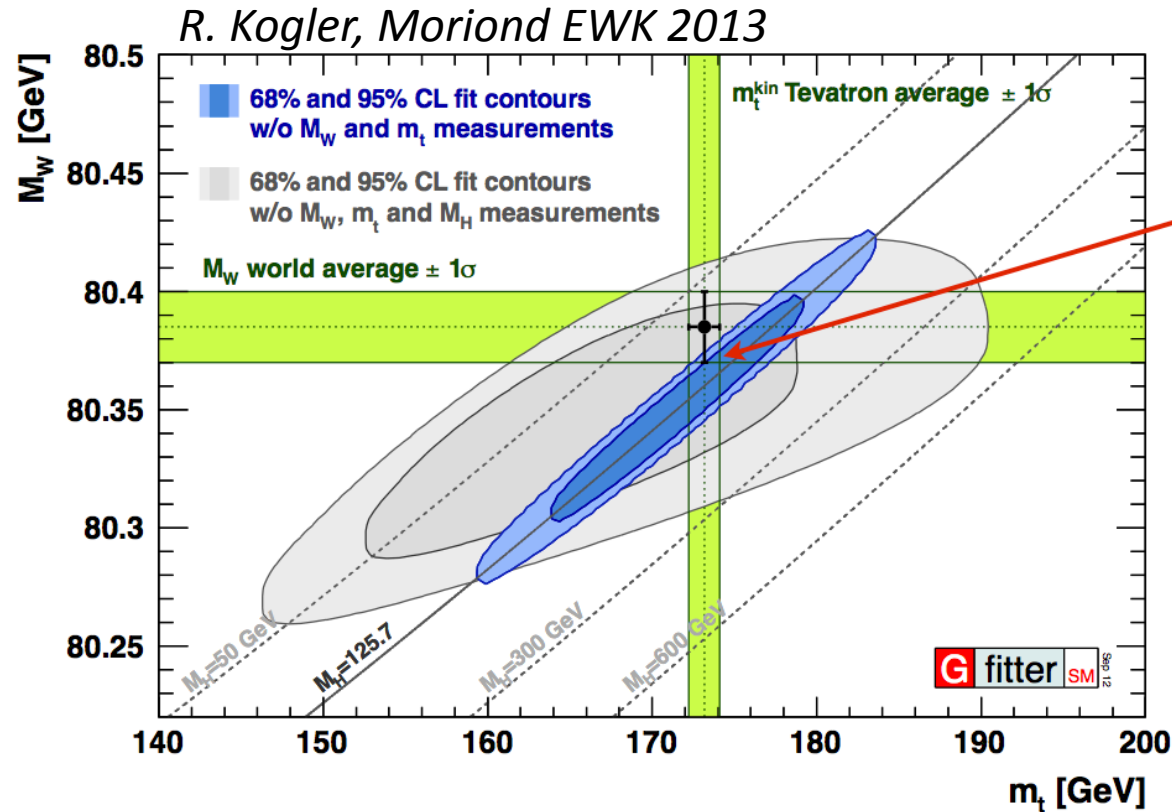
e.g.

Check $\Upsilon(1S)$ suppression in p-Pb

Top mass: the ideogram method

- Slide could be put in back up

Standard Model



Once M_H is fixed, we cornered the SM!

Effects of new physics through loop corrections!

⇒ improve measurements of EW precision observables

+ Important measurements for all analyses, e.g.

- di-boson cross-section
- Z+bb cross-section
- Parton distribution functions (pdfs)

Constraints on pdfs using $Z p_T$