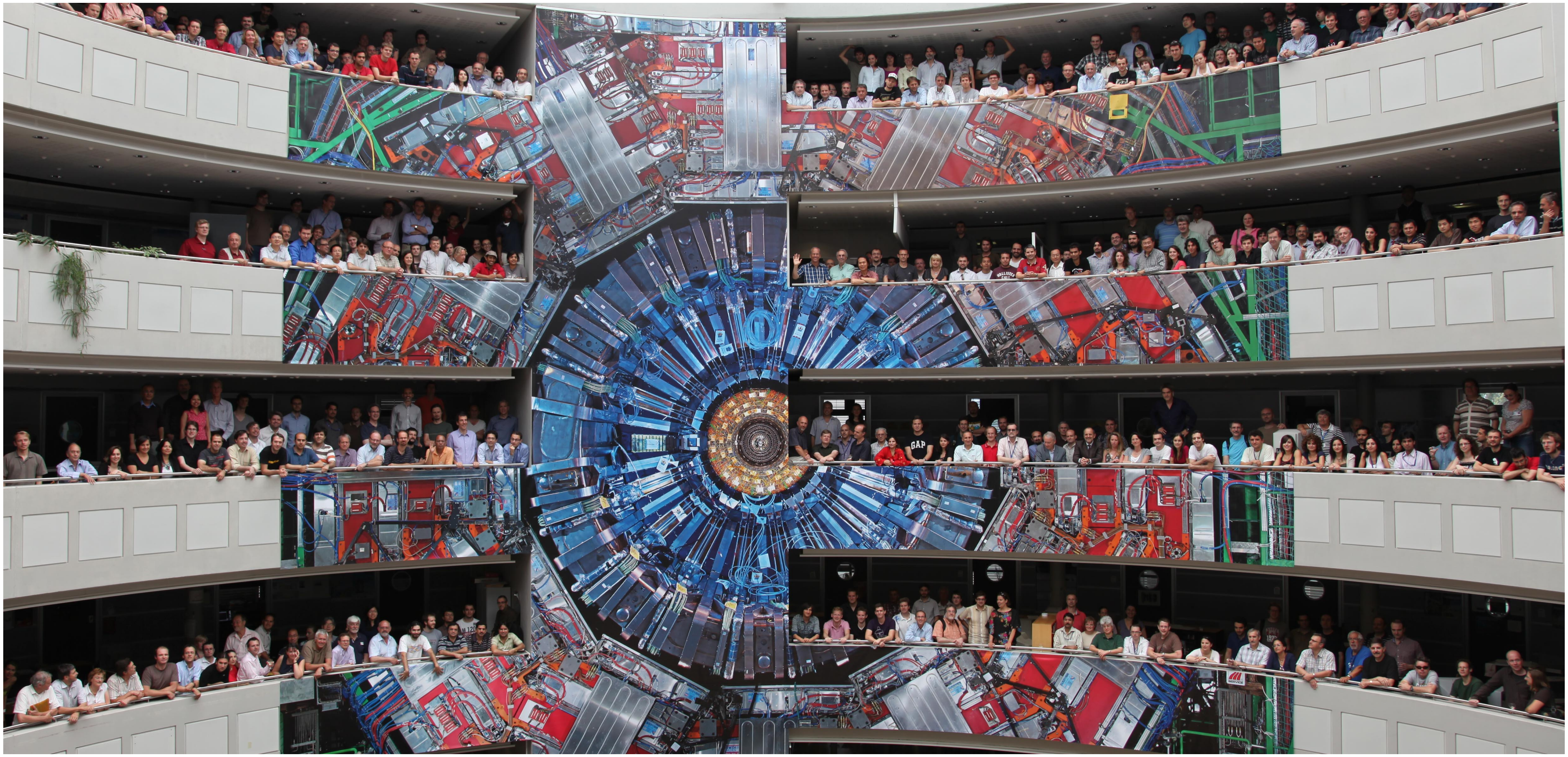


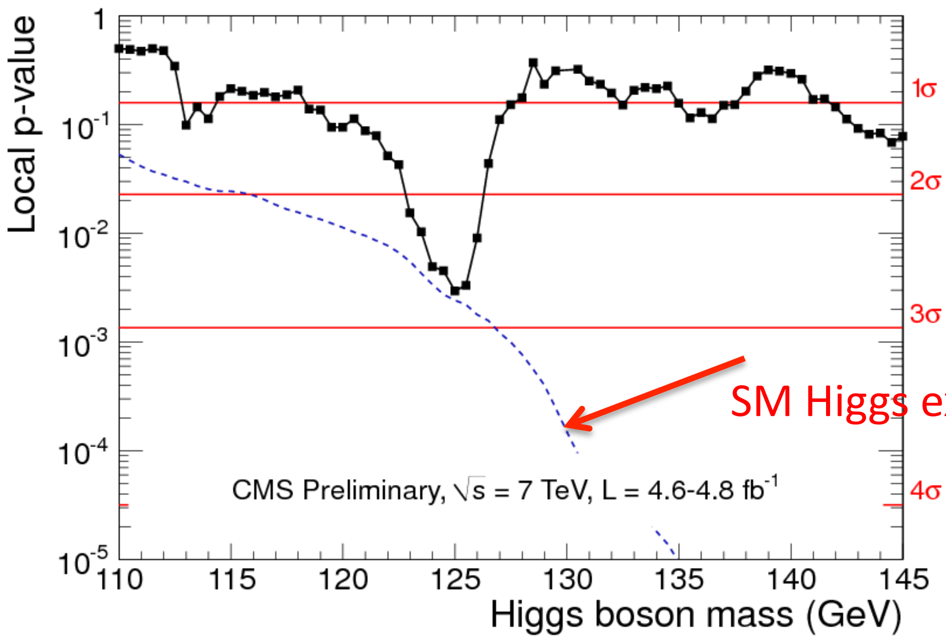
Higgs studies with the CMS detector at LHC

Guenakh Mitselmakher
University of Florida
HQP-13, Dubna, July 2013

Content

- My previous talk in Dubna
- Introduction: LHC and CMS
- SM rediscovery
- $H \to ZZ \to 4l$
- $H \to \gamma\gamma$.
- $H \to WW$
- $H \to \tau\tau$
- $H \to bb$
- Coupling constants (from all channels)
- Conclusion

CMS: Moriond 2012 Higgs significance
Dubna talk, May 17, 2012



Moriond'12: Combined significance (right scale)

– excess at 124 GeV close to SM Higgs expectation

Summary (Dubna talk, May 17, 2012)

- CMS reached SM Higgs exclusion sensitivity in the full mass range

- SM Higgs excluded by CMS at 95% CL for m_H = 127–600 GeV

  at 99% CL for m_H = 128–525 GeV

  ATLAS+CMS results leave only narrow window for SM Higgs: 122.5-127.5 GeV

- The excess at low masses remains.

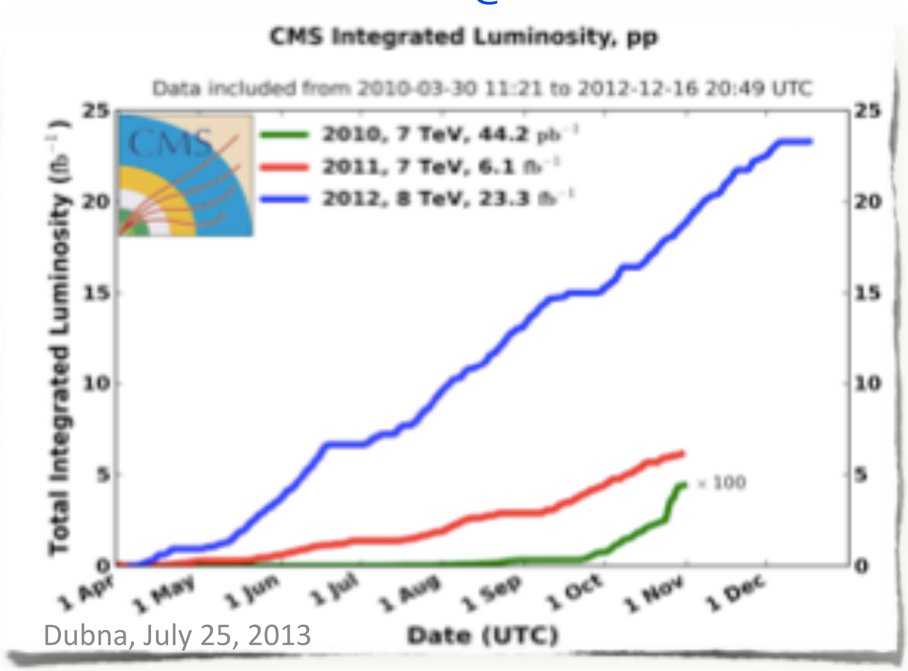
  It is consistent with SM Higgs, but it may well be bkgd fluctuation

  To ascertain the origin of the excess, more data are required.

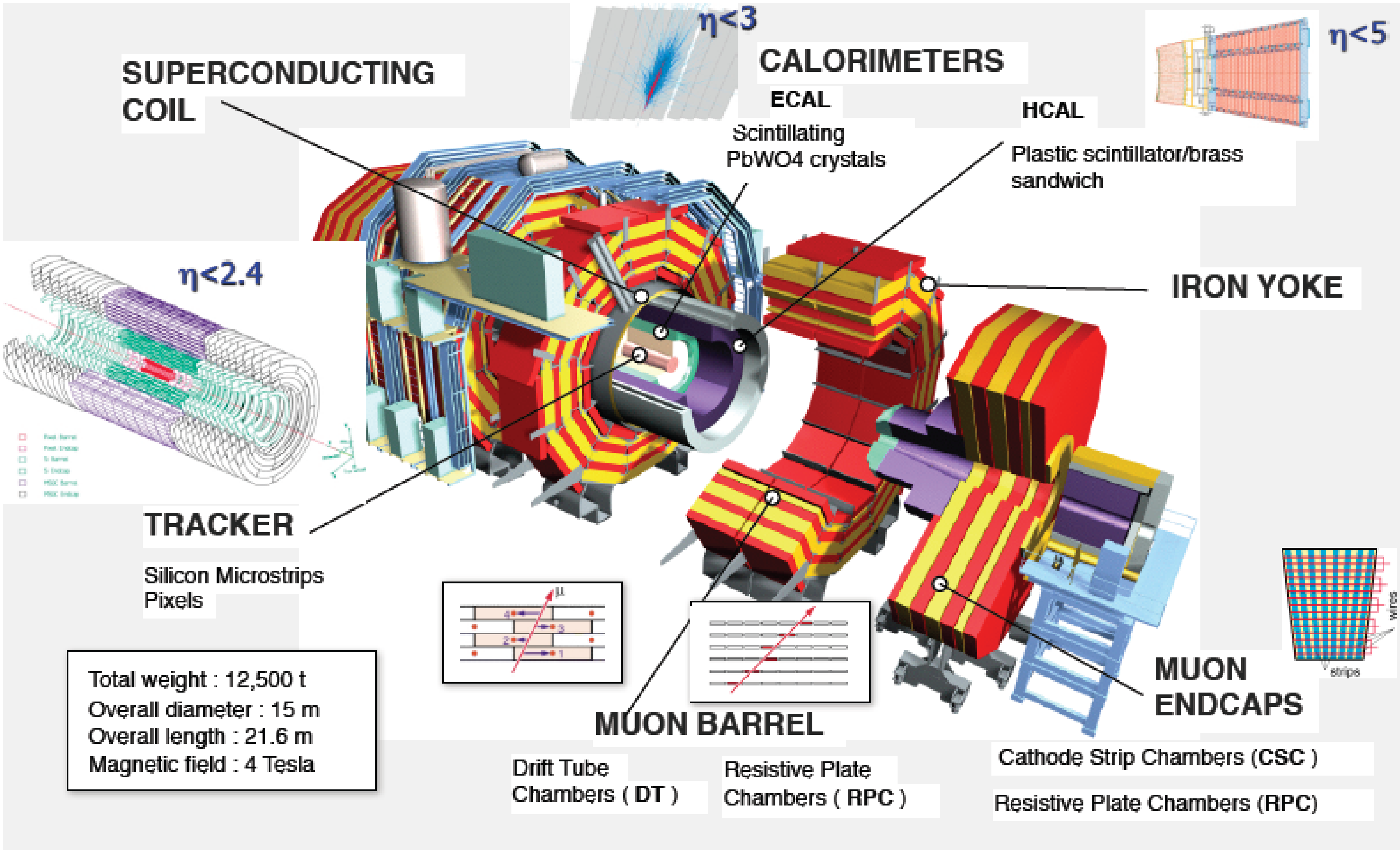
- 2012: with > 20 fb^{-1} per experiment next year, we expect to reach discovery sensitivity in the full mass range

LHC performance

pp collisions in CMS
2011: ~6 fb^{-1} @ 7 TeV
2012: ~23 fb^{-1} @ 8 TeV

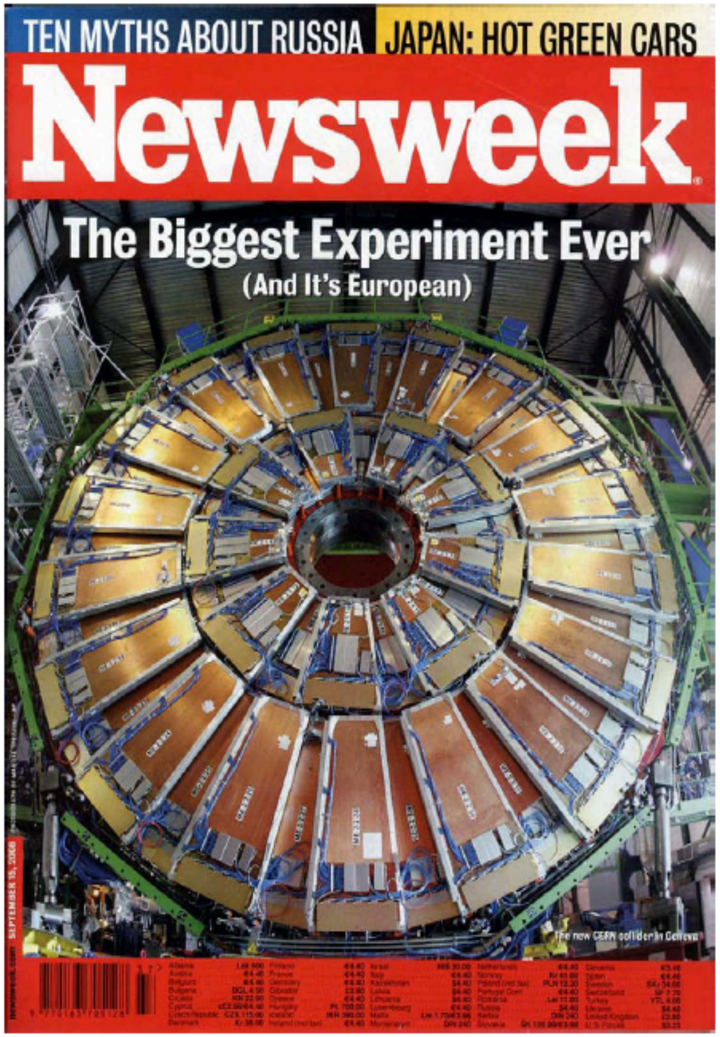


The Compact Muon Solenoid

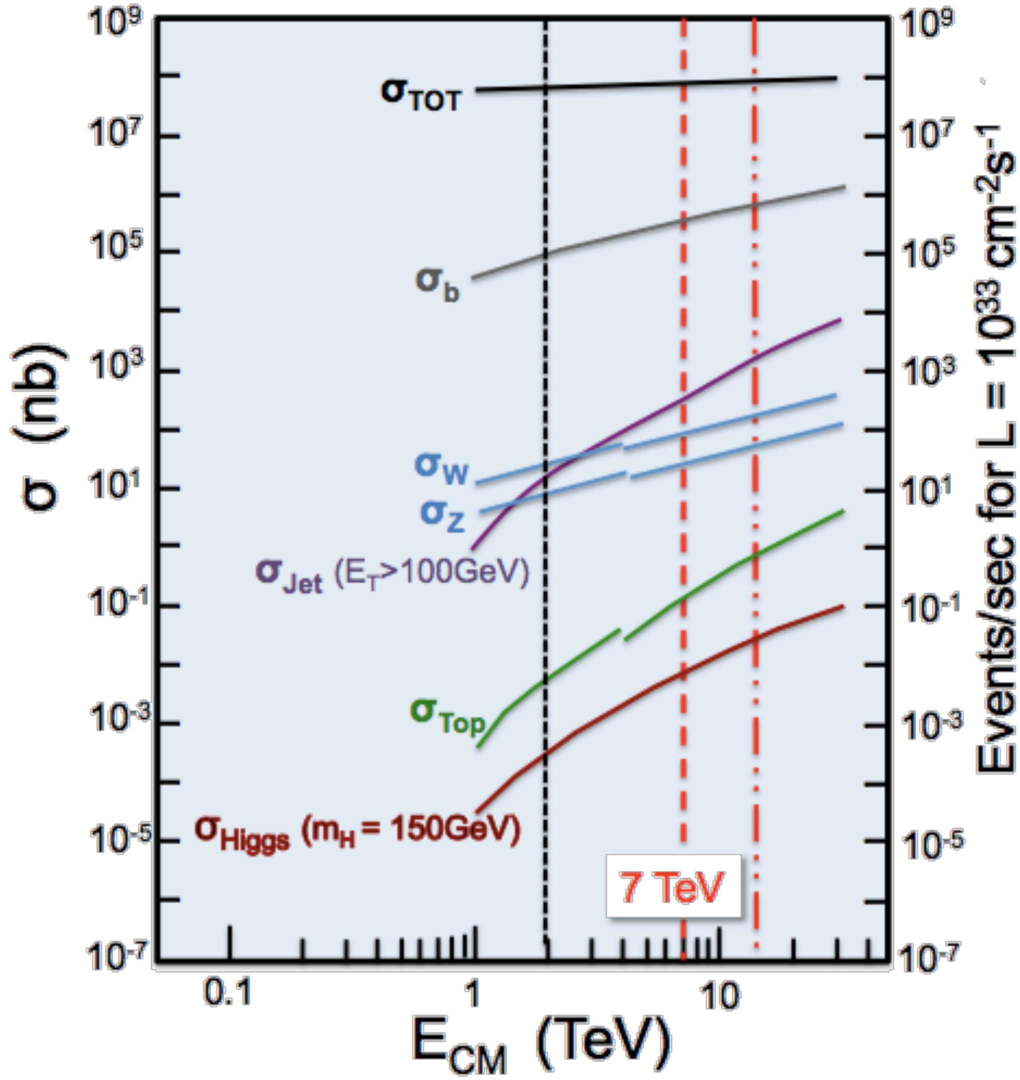


On a personal note: pictures of CMS Endcap Muon system.

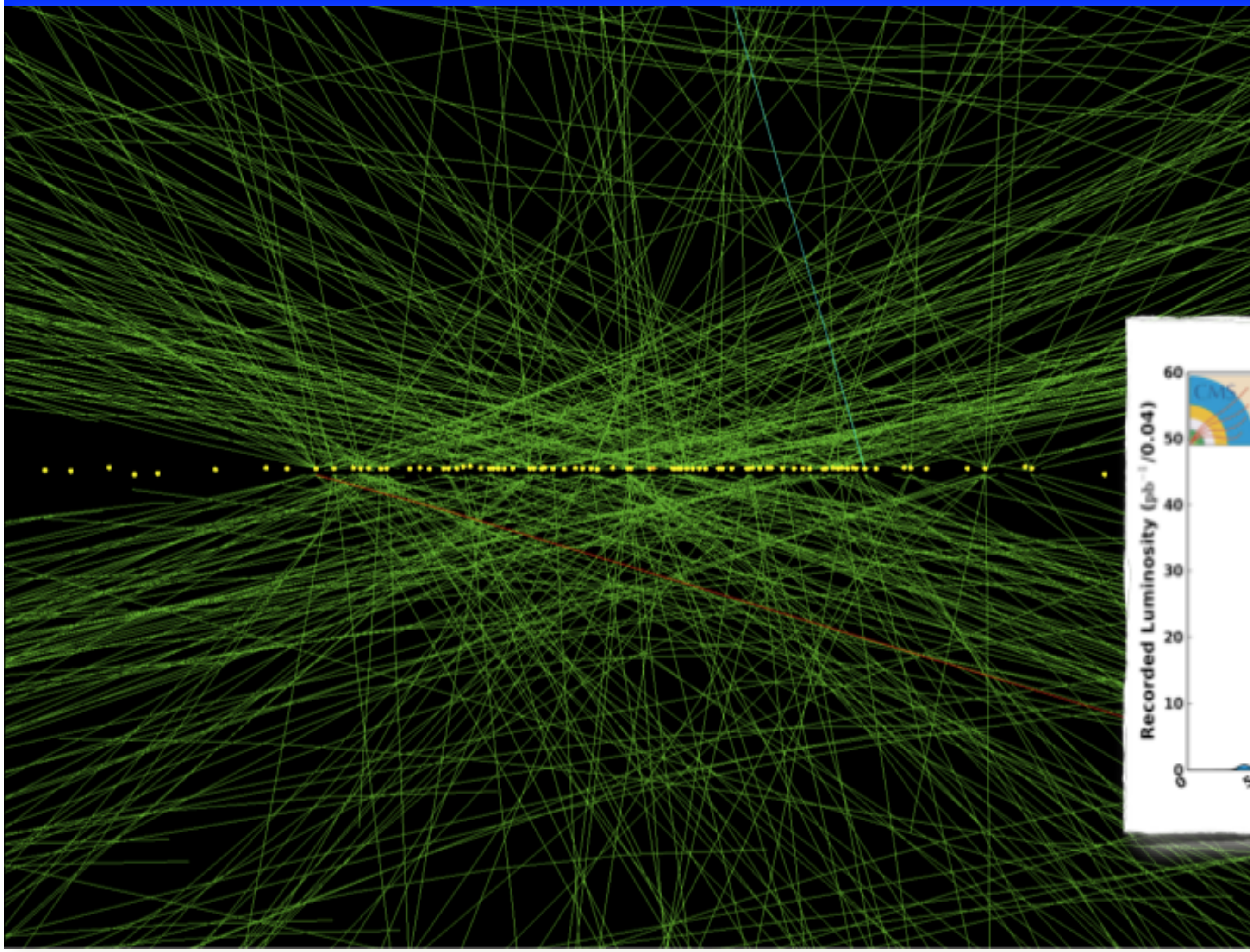
Performed beautifully (as did the rest of CMS)

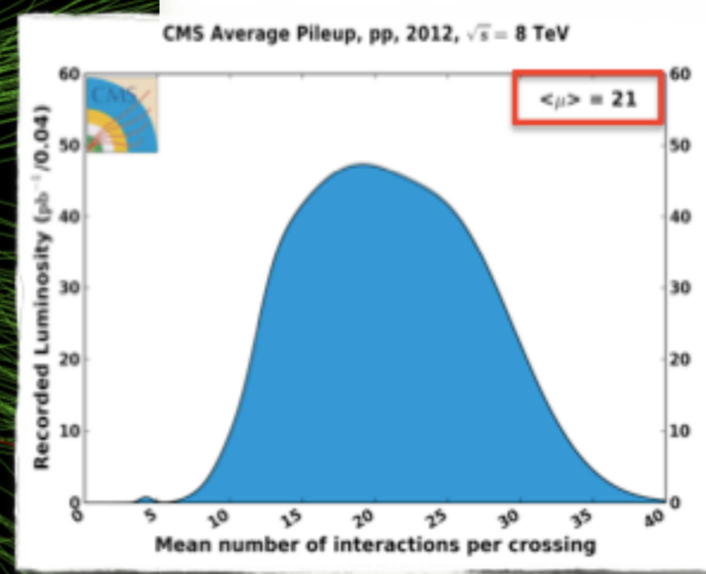


Standard Model: cross sections



A challenge in LHC experiments: “pileup”



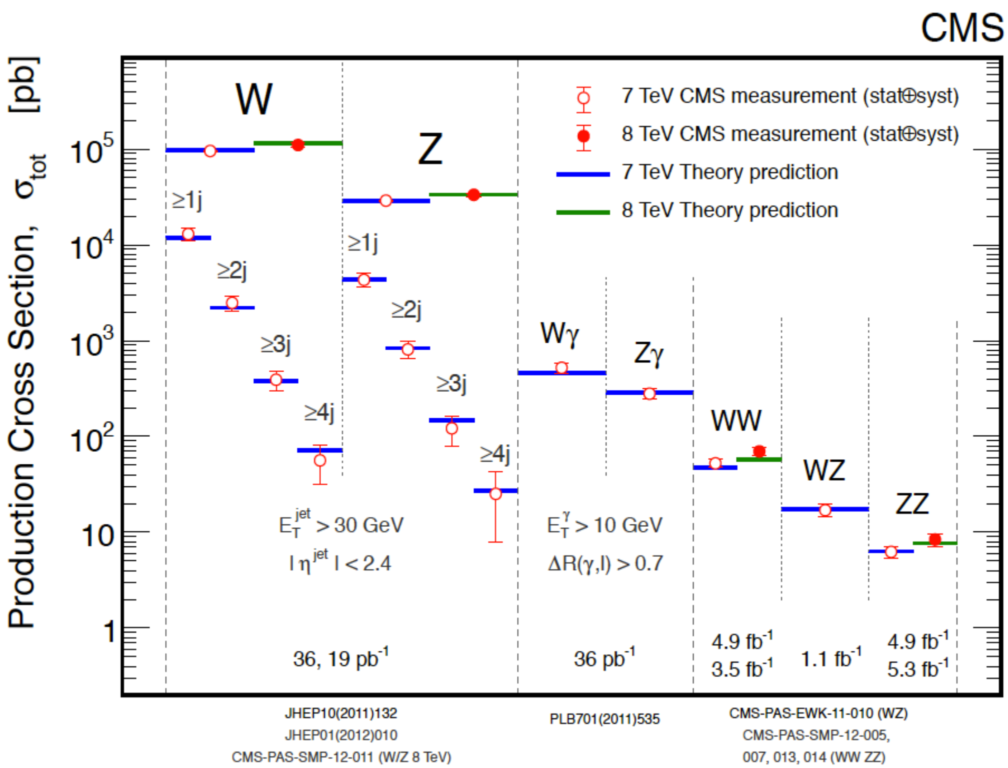


78 (!) reconstructed collision vertices
in one bunch crossing in CMS

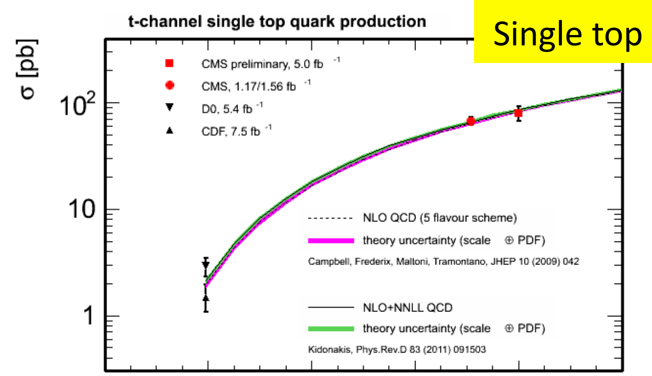
Before the Higgs studies…

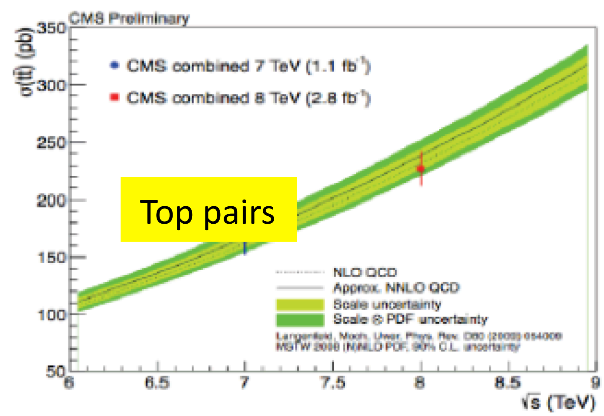
Rediscovery of the Standard Model in CMS

Electroweak Measurements



Top Quark Cross Sections





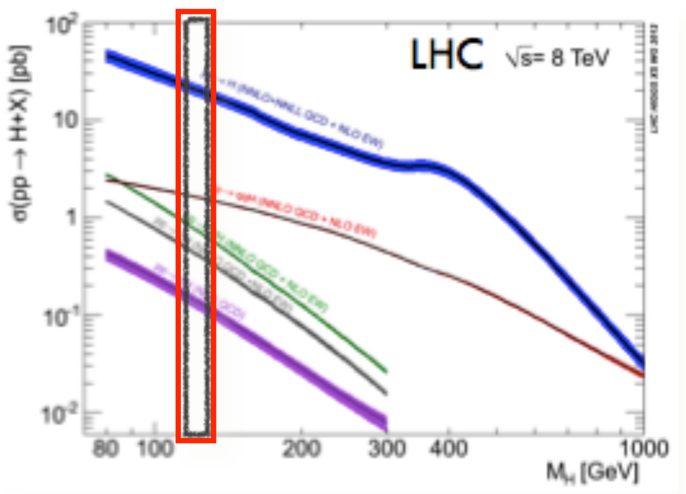
→Precise measurements of the SM processes necessary

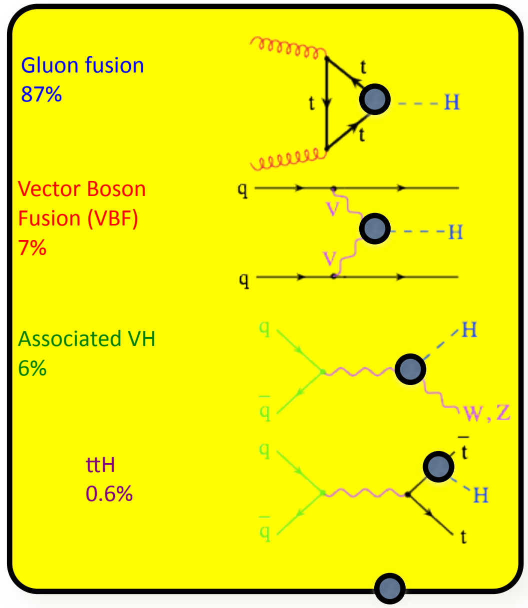
→Possible ONLY with excellent understanding of the detector

→Gives good knowledge of the backgrounds to the Higgs analyses

Predicted Higgs production and decay

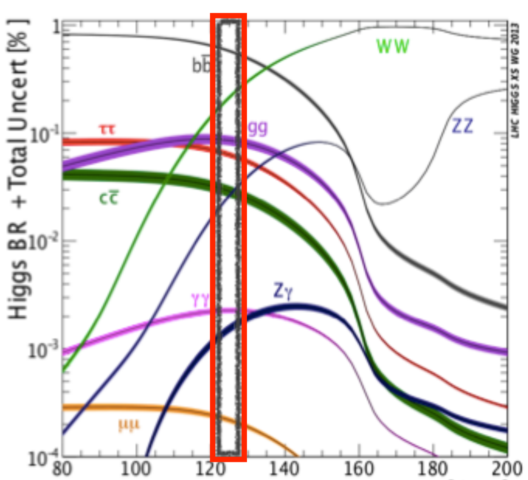
Production

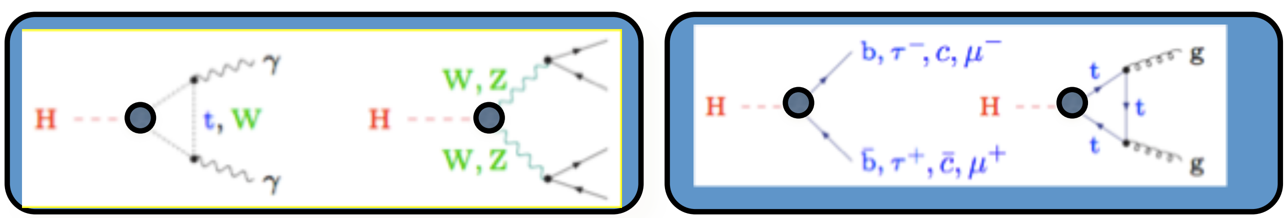




At Higgs mass
~125 Gev we have access
to several decay modes,
which allows
for detailed studies
Of couplings
We are lucky!

Decays





$\mathrm{BR}(h \to b\bar{b}) = 58\%$, $\mathrm{BR}(h \to WW^*) = 21.6\%$, $\mathrm{BR}(h \to \tau^+\tau^-) = 6.4\%$,
$\mathrm{BR}(h \to ZZ^*) = 2.7\%$, $\mathrm{BR}(h \to gg) = 8.5\%$, $\mathrm{BR}(h \to \gamma\gamma) = 0.22\%$,
$\mathrm{BR}(h \to c\bar{c}) = 2.7\%$

Higgses produced at LHC in numbers (more estimates)

- Number of Higgs particles produced in CMS in 2011-2012 = 550,000 (total CS 22 pb) x (25 fb-1)

- Contribution of different production mechanisms (wrt the total CS)
- ggF = 87%
- VBF = 7%
- VH = 5%
- ttH = 0.6%

- Decay modes (l = e or mu)
- BR(bb) = 57%
- BR(tautau) = 6%
- BR(WW->2l2v) = 22% x (0.22)^2 = 1.1%
- BR(gamgam) = 0.23%
- BR(ZZ->4l) = 2.8% x (0.06)^2 = 0.013%
- BR(mumu) = 0.022%

Higgs Studies in CMS

Processes/decays studied:

Results released | In progress

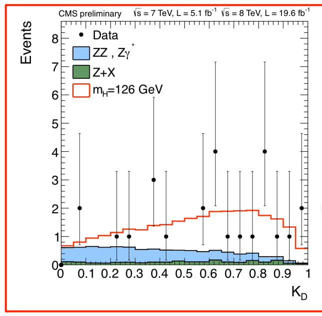
	untagged	VBF	VH	ttH
H-> gamgam				
H-> ZZ				
H->WW				
H-> bb				
H-> tau tau				
H-> Zgamma				
H-> mumu				
H-> invisible				

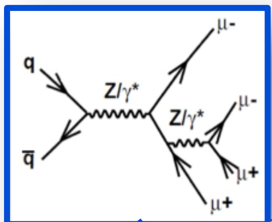
+ more exotic channels

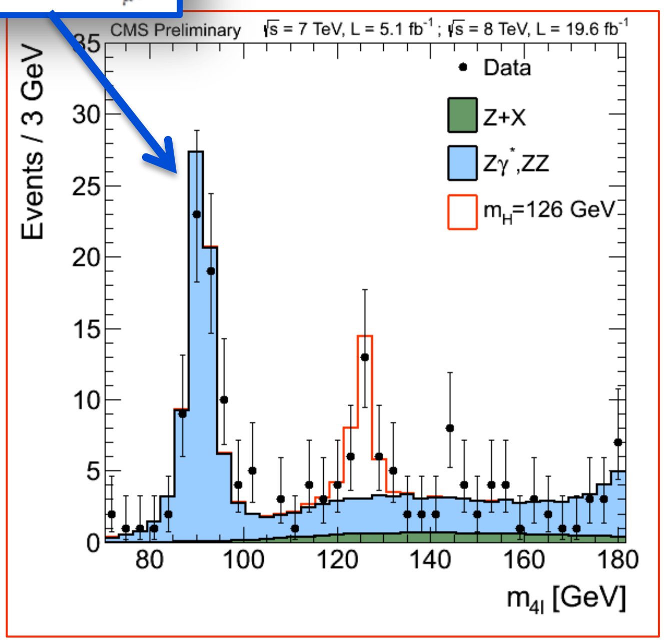
Main decay channels characteristics:

Channel	m_H range (GeV/c^2)	Data used 7+8 TeV (fb^{-1})	m_H resolution
H -> $\gamma\gamma$	110-150	5.1+19.6	1-2%
H -> tautau	110-145	4.9+19.6	15%
H -> bb	110-135	5.0+19.0	10%
H -> WW -> lnulnu	110-600	4.9+19.5	20%
H -> ZZ -> 4l	110-1000	5.1+19.6	1-2%

H → ZZ → 4l







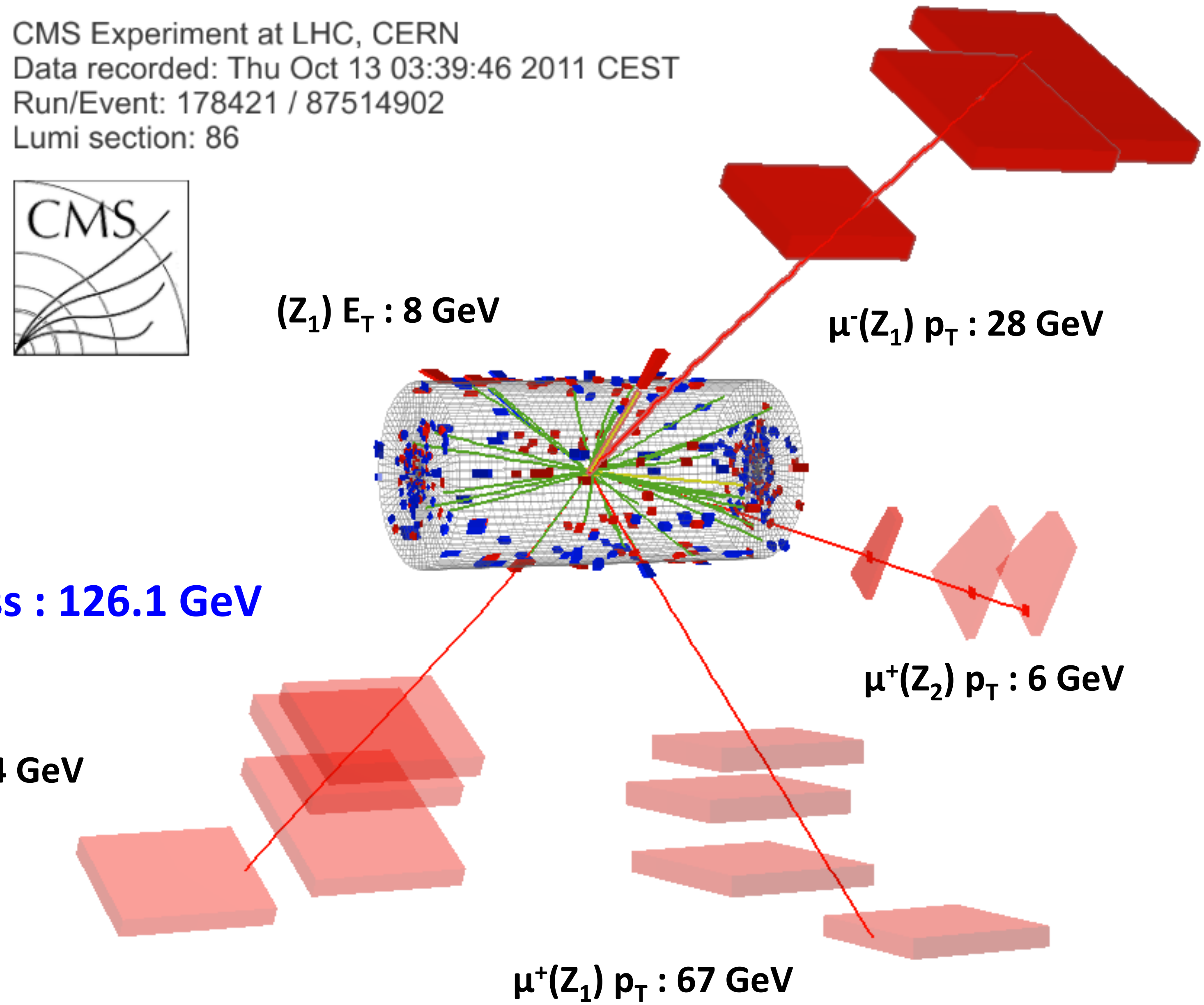
Analysis strategy:

- Four leptons
- **four-lepton mass** is the key observable
- split events into 4e, 4μ, 2e2μ channels:
  - different mass resolutions
  - different S/B rates (for reducible bkgd with "fake" leptons)
- CMS: add **ME-based discriminant K_D** (2nd observ.), more details about **K_D** later
- Backgrounds:
  - ZZ (dominant) from Monte Carlo (MC)
  - reducible (with non-isolated or "fake" leptons): from control region

Analysis features:

- high S/B-ratio (~2:1)
- but small event yield
- excellent mass resolution = 1-2%"
- "Standard candle" Z→4l decay peak nearby, natural validation of the discovered peak

4μ+γ computer event display



7 TeV DATA

4μ+γ Mass : 126.1 GeV

Higgs →4l : Signal/Background ratio ~ 2:1 observed: 25 events total (S+B)

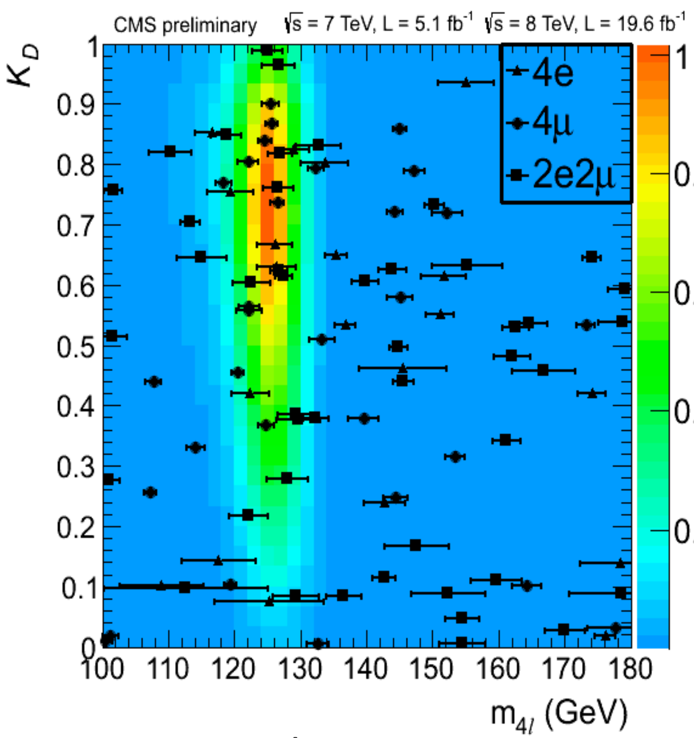
For 121.5 < m4l < 130.5 GeV

	4e	4μ	2e2μ
H(126) expected	3.0	6.7	8.9
ZZ expected	1.2	2.7	3.5
Z+X & top expected	0.6	0.5	0.9
Total Bkg	1.8	3.2	4.4
Signal+Bkg expected	4.8	9.9	13.3
Observed	5	8	12

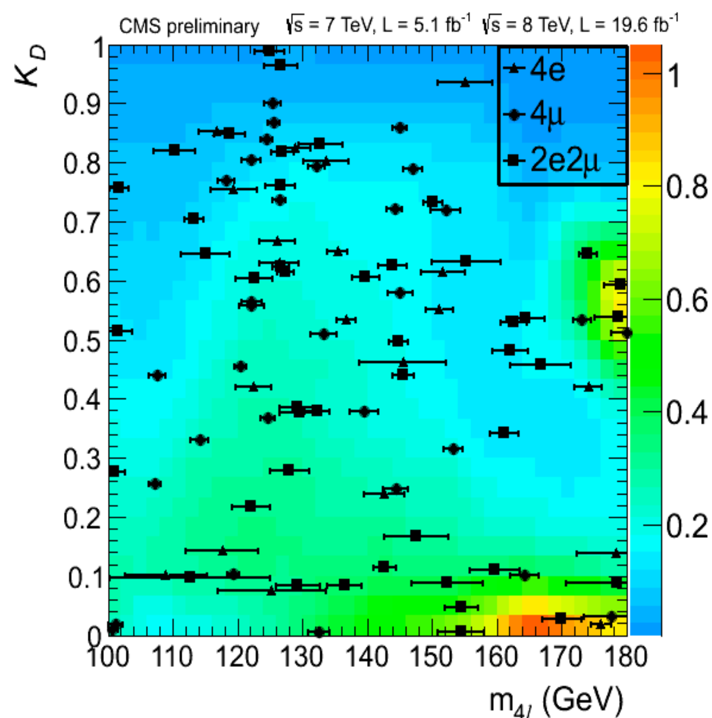
S/B improvement: Kinematic Discriminant

- To further improve signal to background ratio, we use a discriminant based on kinematic 4l information

$$\mathrm{KD} = \frac{\mathcal{P}_{\mathrm{sig}}}{\mathcal{P}_{\mathrm{sig}} + c \times \mathcal{P}_{\mathrm{bkg}}} = \left[1 + \frac{c \times \mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \vec{\Omega}|m_{4\ell})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \vec{\Omega}|m_{4\ell})}\right]^{-1}$$

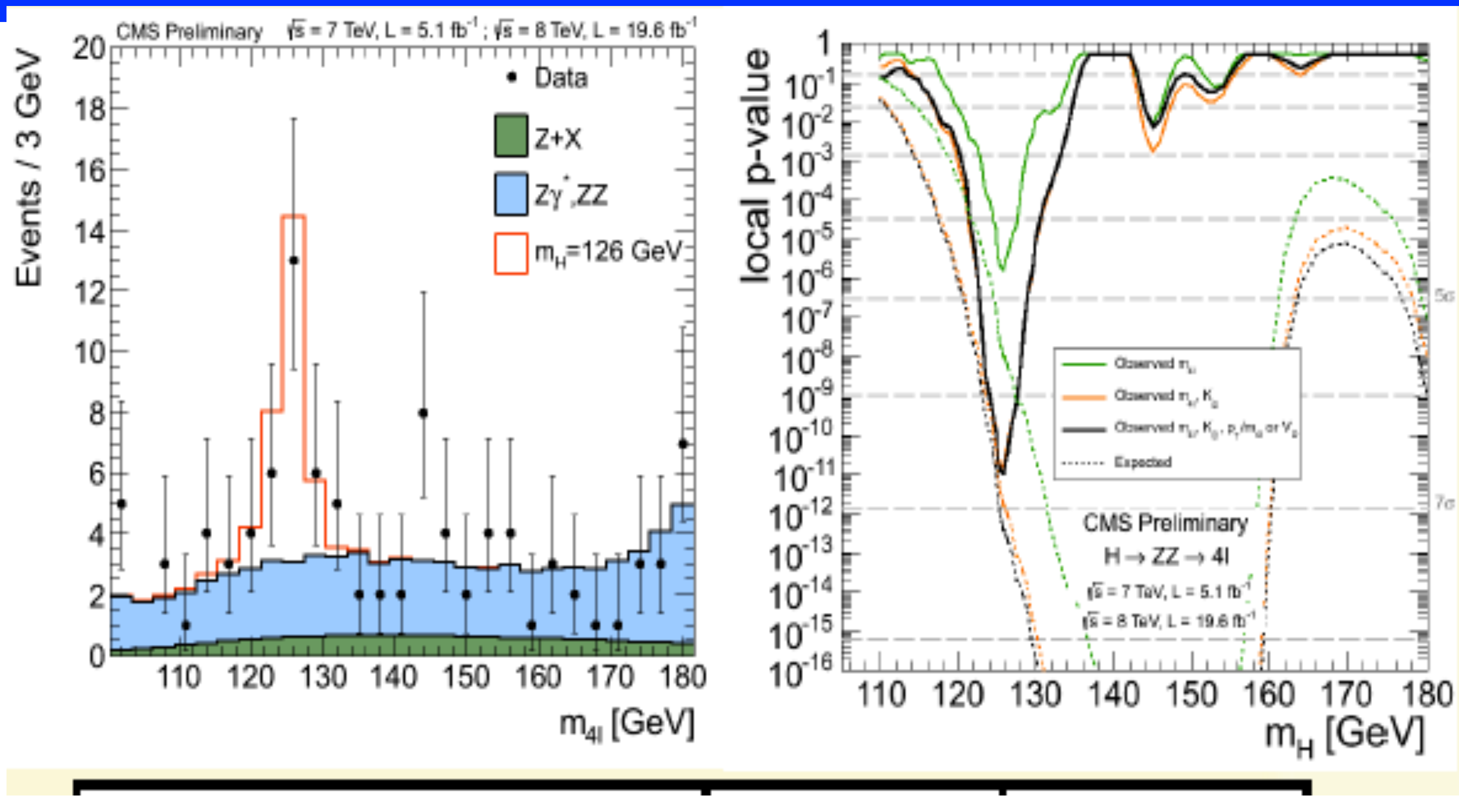


Higgs signal



ZZ^* background

Statistical significance of 4l peak



Expected significance : 7.2 σ

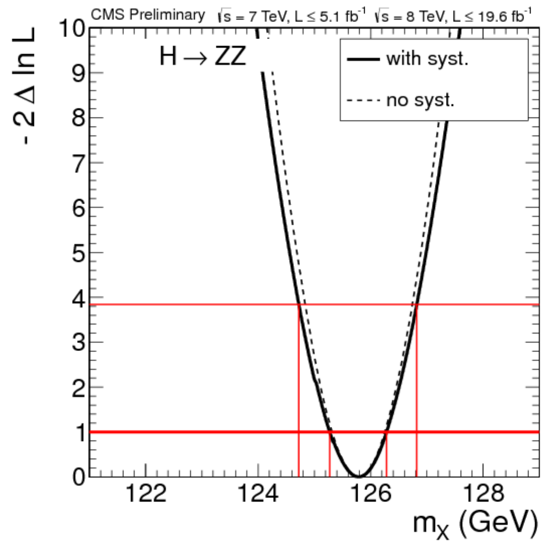
Observed significance: 6.7 σ

Includes kinematic discriminant weight, and per-event errors

More than 5 σ in a single decay channel,

Both for expected and observed!

New boson mass measurement from 4l channel



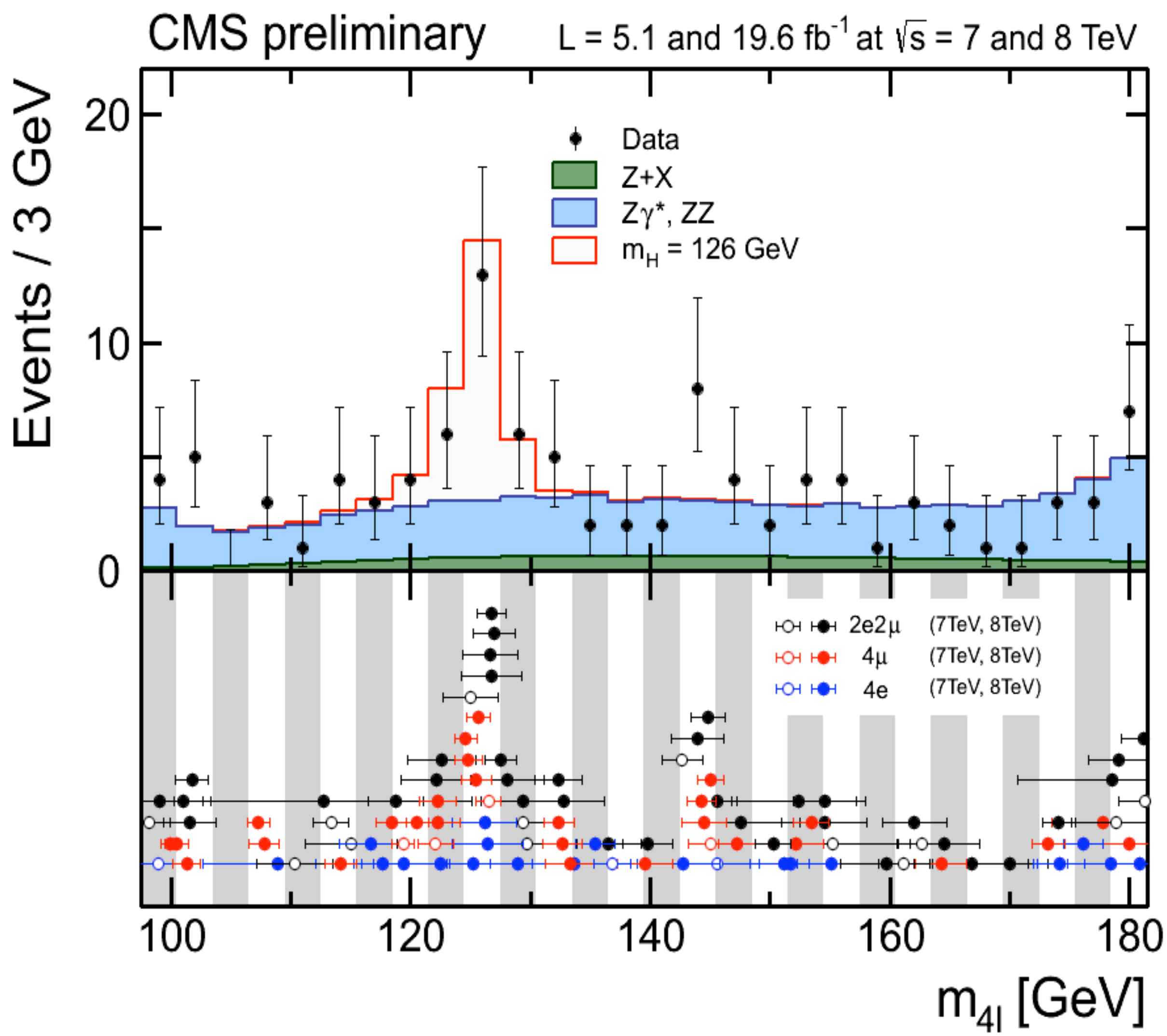
m_X = 125.8 ± 0.5 (stat) ±0.2 (syst) GeV

Statistics dominated! Can be significantly improved in the future

main sources of systematic uncertainties:

- electron energy scale: 0.3%
- muon energy scale: 0.1%

Individual 4l events including per-event mass errors



Spin and Parity J^P

- Use kinematic information to separate different spin-parity hypotheses J^P
- The following J^P considered (pure cases, no mixing):

J^P	production	description
0^+	$gg \to X$	SM Higgs boson
0^-	$gg \to X$	pseudoscalar
0_h^+	$gg \to X$	BSM scalar with higher dim operators (decay amplitude)
2^+_{mgg}	$gg \to X$	KK Graviton-like with minimal couplings
$2^+_{mq\bar{q}}$	$q\bar{q} \to X$	KK Graviton-like with minimal couplings
1^-	$q\bar{q} \to X$	exotic vector
1^+	$q\bar{q} \to X$	exotic pseudovector

:

Kinematic Discriminants for J^P separation

- Build two discriminants based on the complete Leading-Order Matrix Elements

  - one discriminant to separate signal from background, combined with mass information → D_{bkg}

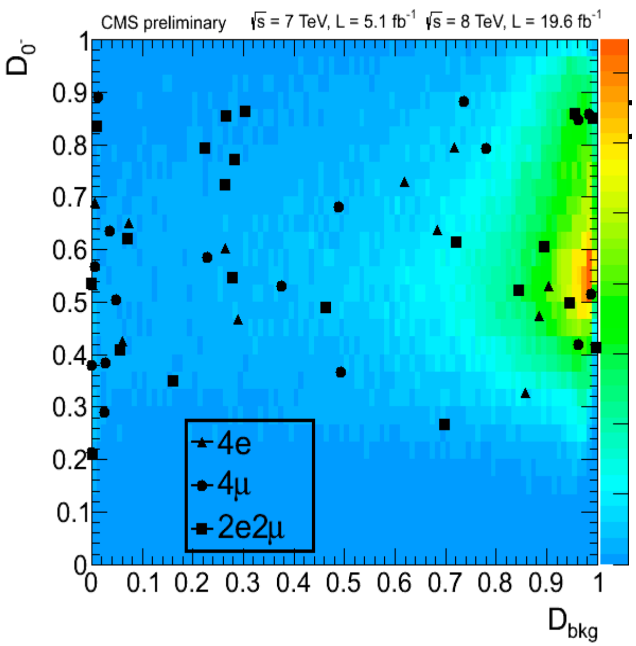
$$D_{\mathrm{BKG}} = \left[1 + c_{\mathrm{bkg}} \cdot \frac{|\mathcal{M}_{\mathrm{BKG}}(\vec{p}_i)|^2 \cdot pdf(m_{4\ell}|\mathrm{BKG})}{|\mathcal{M}_{\mathrm{Higgs}}(\vec{p}_i)|^2 \cdot pdf(m_{4\ell}|\mathrm{Higgs})}\right]^{-1}$$

  - another discriminant to separate the SM Higgs from alternative J^P hypothesis → D_{JP}

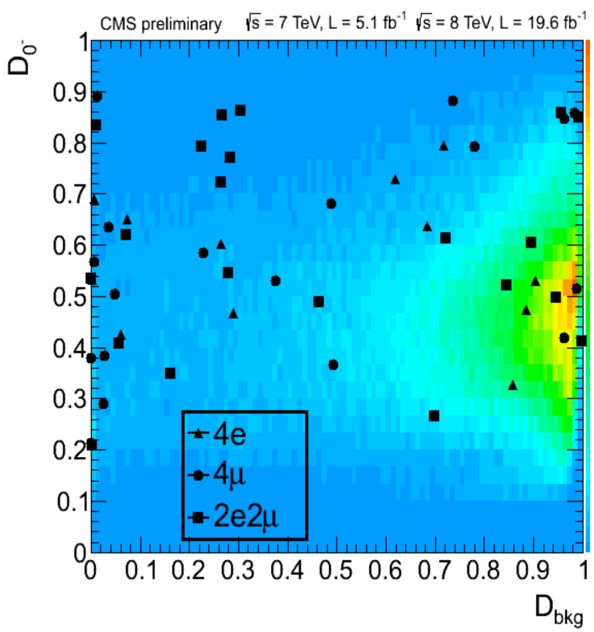
$$D_{\mathrm{J^P}} = \left[1 + c_{\mathrm{j^P}} \cdot \frac{|\mathcal{M}_{\mathrm{J^P}}(\vec{p}_i)|^2}{|\mathcal{M}_{\mathrm{Higgs}}(\vec{p}_i)|^2}\right]^{-1}$$

Example: comparison of 0$^+$ (Higgs) and 0$^-$ (with ZZ bckg included)

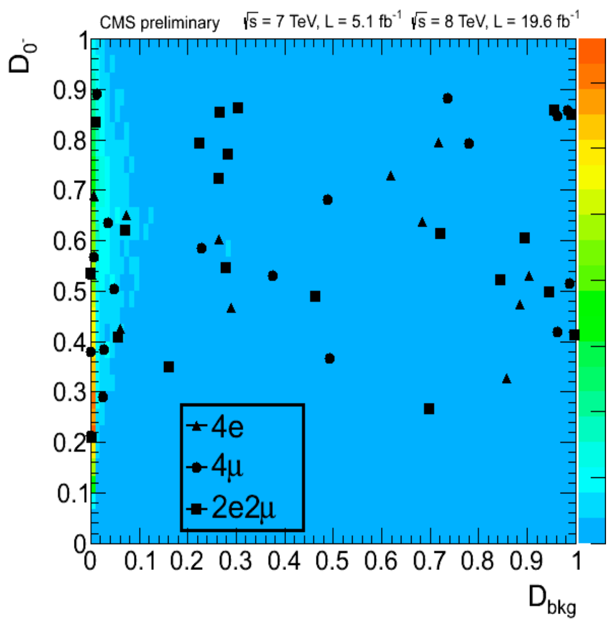
- Expected two dimensional distributions of (D_{JP}, D_{bkg}) for: a) the SM Higgs 0$^+$, b) pseudoscalar 0$^-$ and c) ZZ bkgd



Higgs **0$^+$**

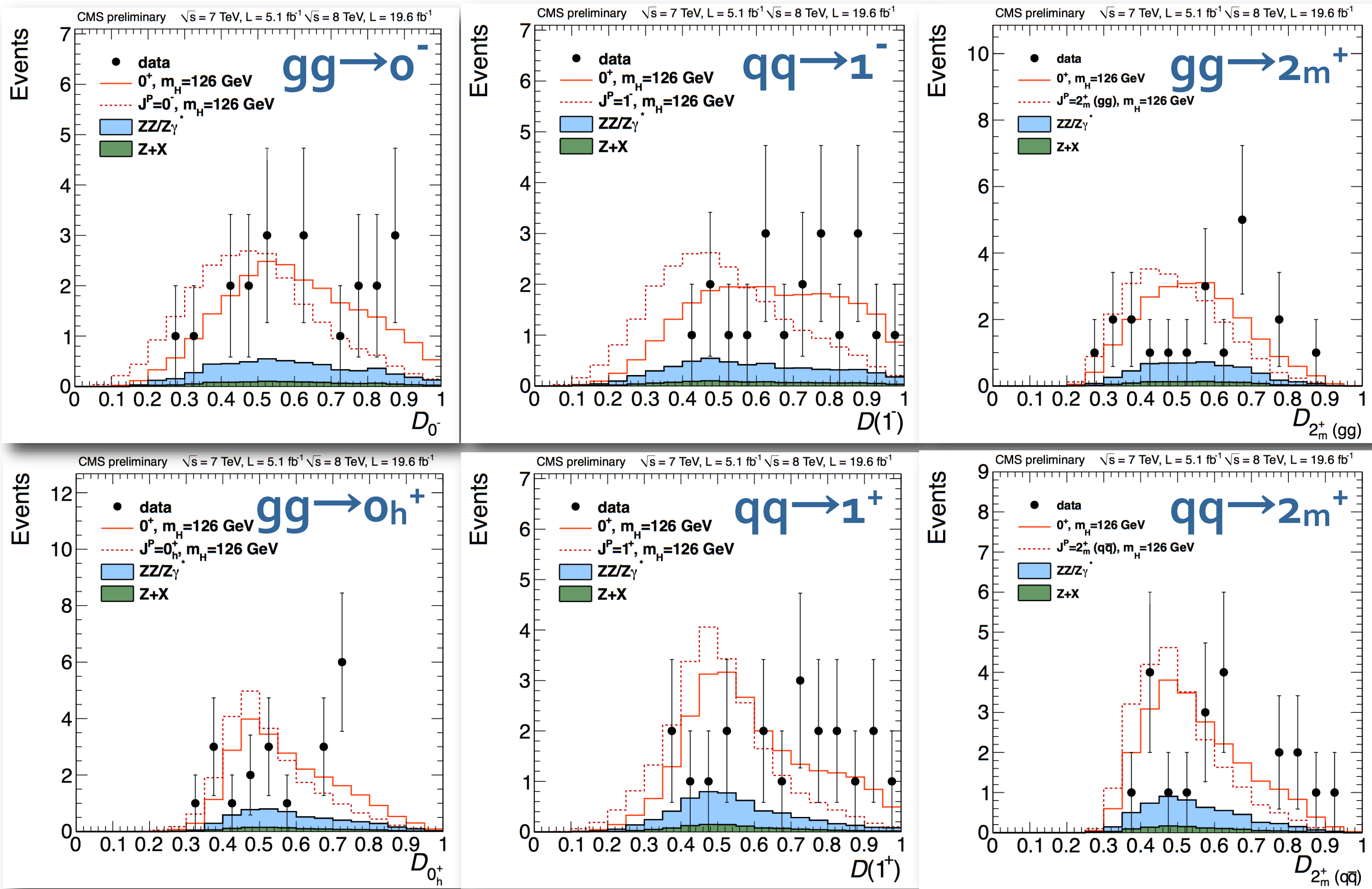


pseudoscalar **0$^-$**

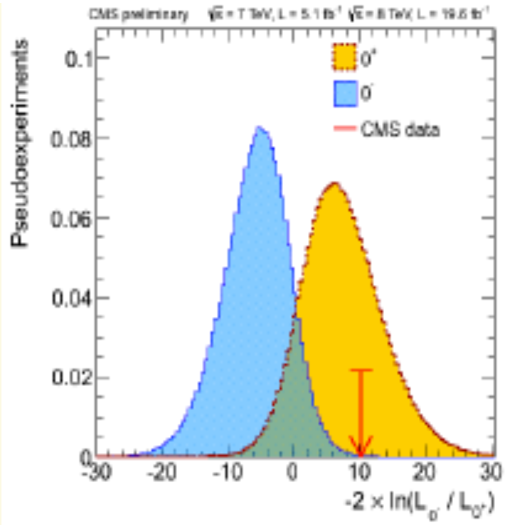


ZZ bkg

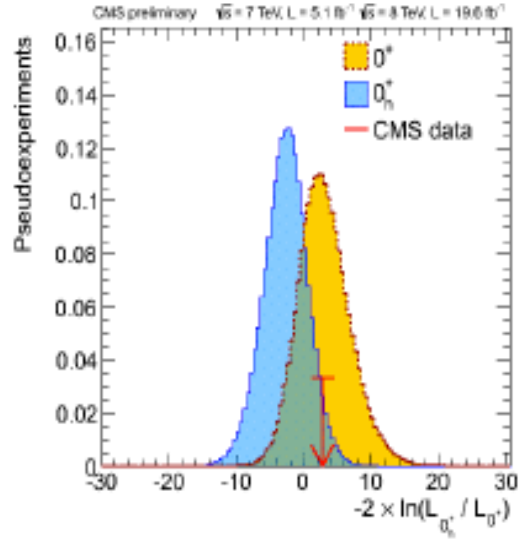
D_{JP} distributions (with D_{bkg}>0.5)



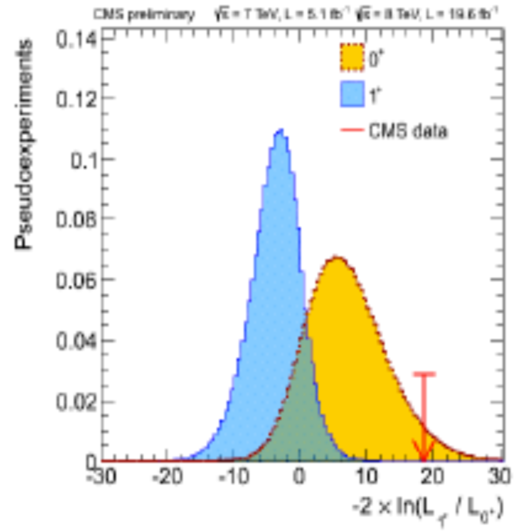
Confidence level (CL_s) : “exotic” J^P vs scalar



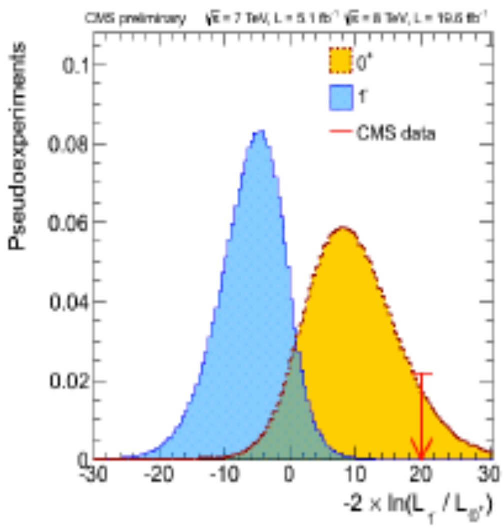
0^- : 0.16 %



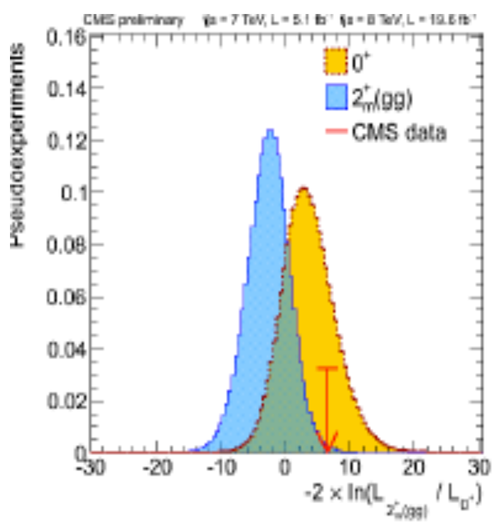
0^+_h : 8.1 %



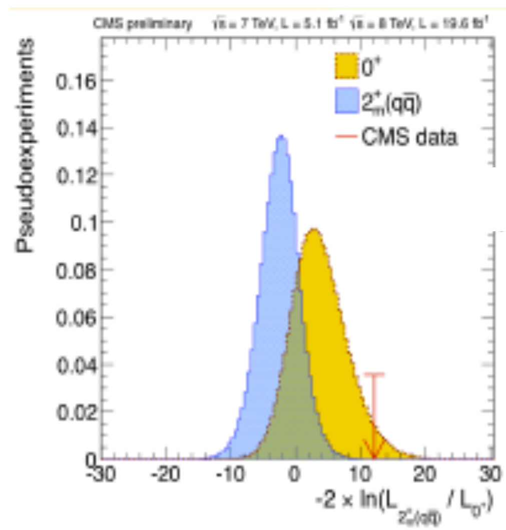
1^+ < 0.01 %



1^- < 0.01 %



2^+_{mgg} : 1.5 %



2^+_{mqq} < 0.1 %

Spin-parity: results

	Expected [σ]		Observed (μ from data)		
	μ=1	μ from data	P(q > Obs | alternative) [σ]	P(q > Obs | SM Higgs) [σ]	CLs [%]
$gg \to 0^-$	2.8	2.5	3.3	-0.5	0.16
$gg \to 0_h^+$	1.8	1.7	1.7	+0.0	8.12
$qq \to 1^+$	2.6	2.3	> 4.0	-1.7	< 0.01
$qq \to 1^-$	3.1	2.8	> 4.0	-1.4	< 0.01
$gg \to 2_m^+$	1.9	1.8	2.7	-0.8	1.46
$qq \to 2_m^+$	1.9	1.7	4.0	-1.8	0.09

The studied pseudo-scalar, spin-1 and spin-2 models are excluded at 95% CL or higher

Data is consistent with SM Higgs

Fit for CP-odd contribution

- Perform a fit for the fraction f_{a3} of a CP-odd contribution in the observed peak

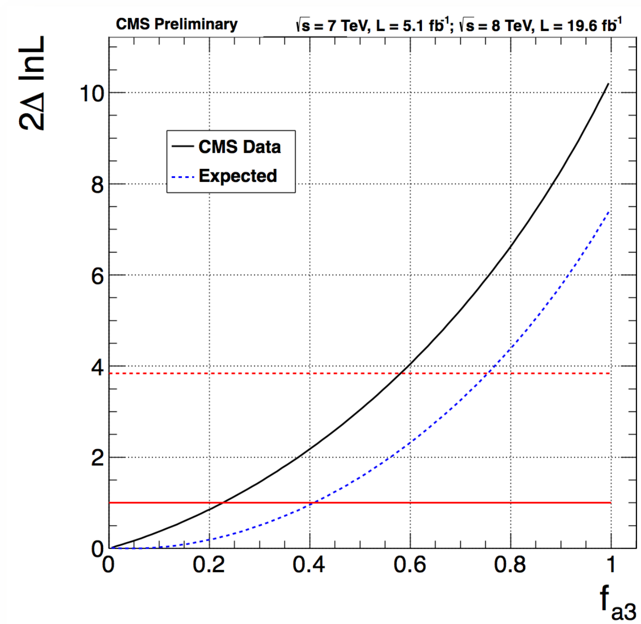
$$f_{a3} = \frac{|A_3^2|}{|A_1^2| + |A_3^2|}$$

$$A(X \to VV) = v^{-1} \epsilon_1^{*\mu} \epsilon_2^{*\nu} \left(a_1 g_{\mu\nu} m_H^2 + a_2 q_\mu q_\nu + a_3 \epsilon_{\mu\nu\alpha\beta} q_1^\alpha q_2^\beta \right) = A_1 + A_2 + A_3$$

(A2 contribution assumed to be 0)

  - decays of state 0_m^+ governed by the A1 amplitude
  - decays of state 0^- governed by A3 amplitude

- Fit the data for the ratio SM Higgs (A1) and 0- (A3) states
- Measurement of the f_{a3} fraction in data: $f_{a3} = 0.00^{+0.23}_{-0.00}$

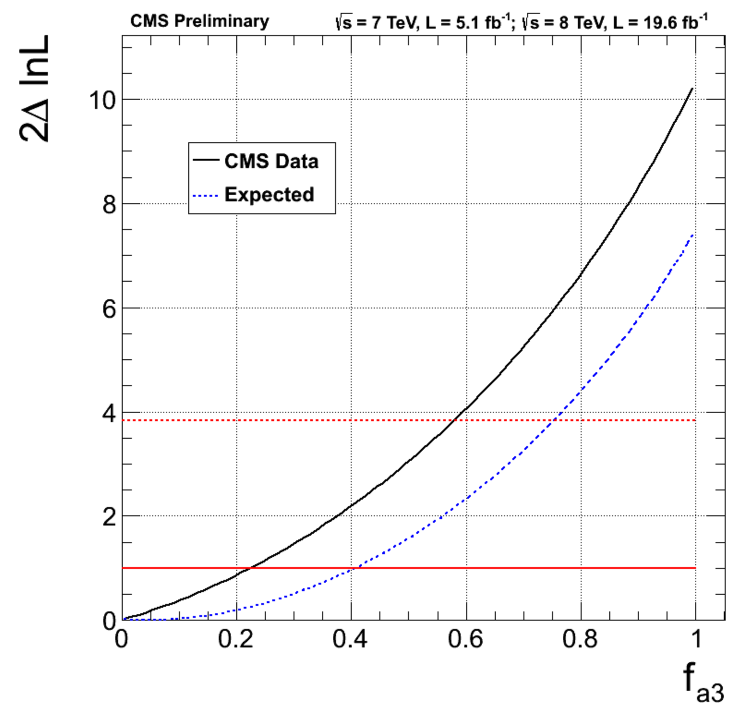


Is X126 one particle?

What if X126 is two bosons with near degenerate masses?

– What can we infer from kinematics of decays?
  - From the previous fit for CP-odd contribution **$f(0^-) < 0.58$ at 95% CL**
  - Non-zero $f(0^-)$ may be due to
    – a 0^- particle with a nearly the same mass;
    – a single particle $X = H(0^+) + A(0^-)$ with mixed CP-even/odd states

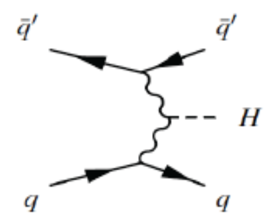
  - No public results on other $f(J^{CP})$ fractions



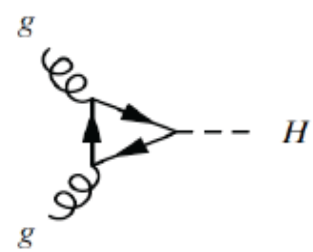
Tagging Vector-Boson Fusion: separation of production diagrams

To have sensitivity to couplings of the new particle with vector bosons, as well as with fermions, we split events into two categories:

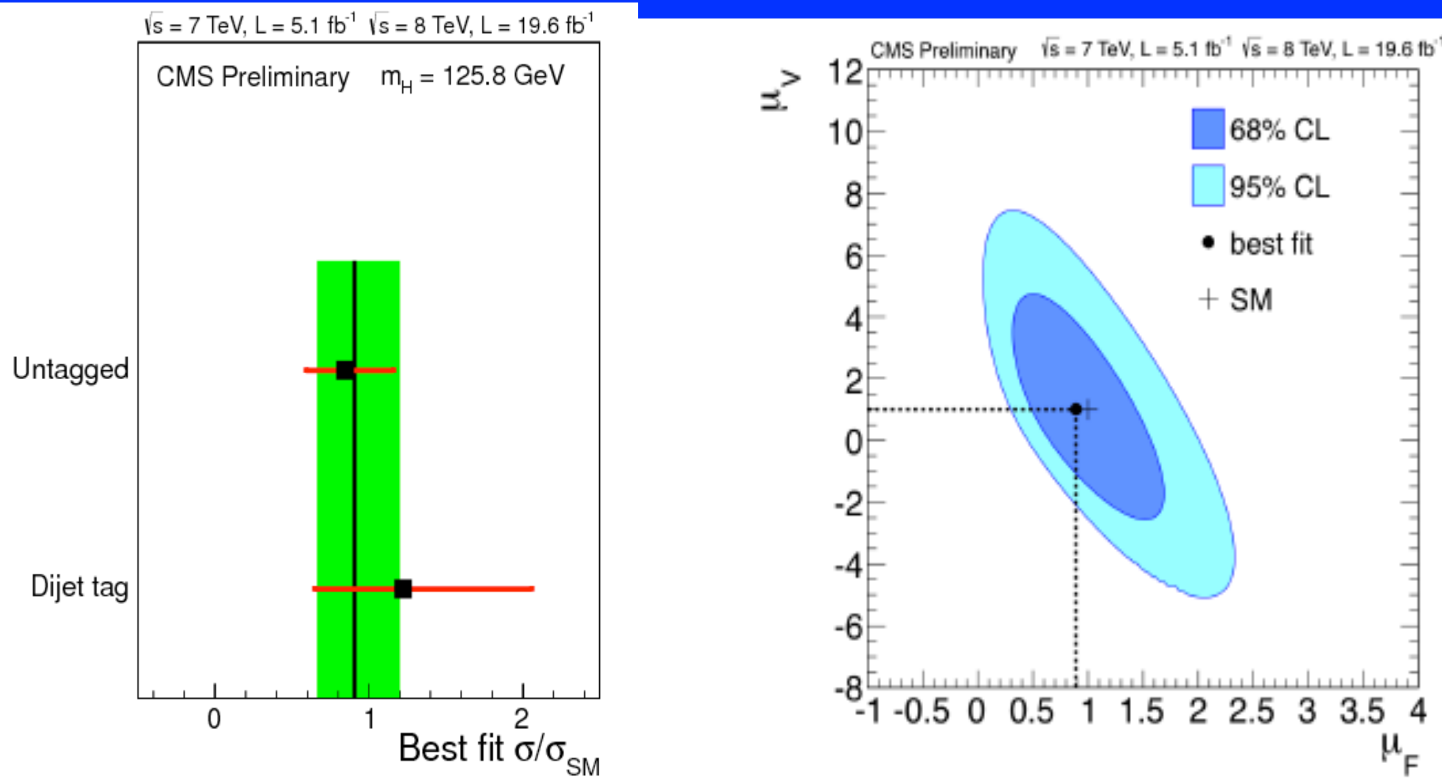
1) Di-jet tag (sensitive to coupling with vector bosons):
PT > 30 GeV, |n| < 4.7; Jet ID to reject fake jets from pileup



2) Untagged (majority of events, sensitive to couplings with fermions)

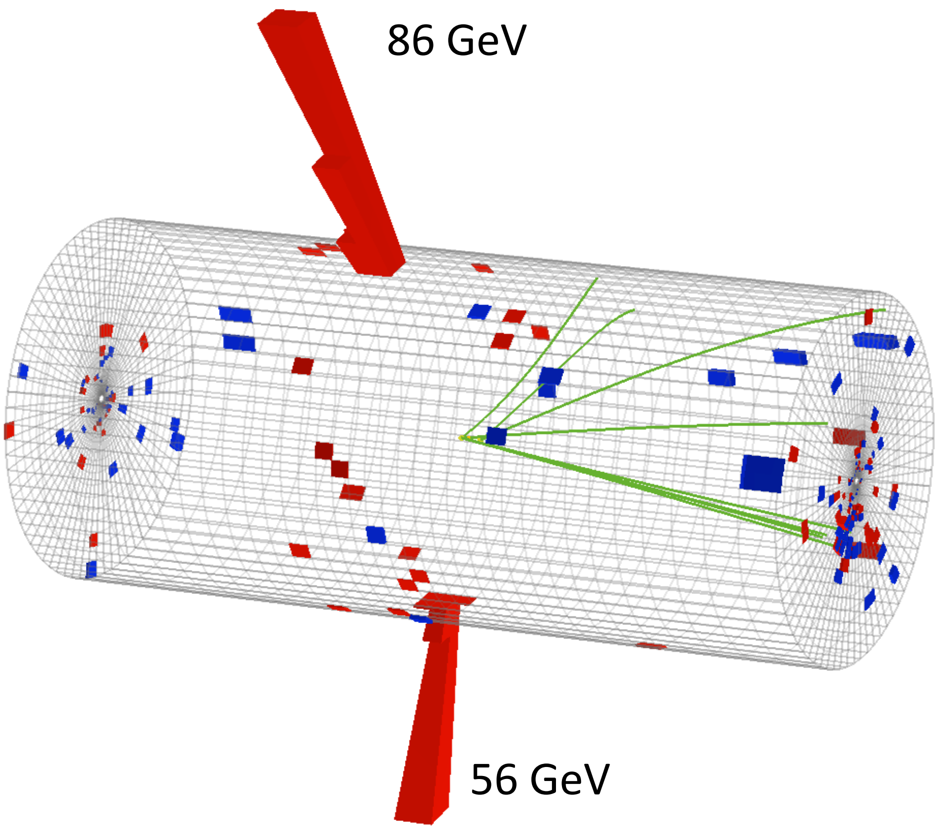


Signal strength, boson vs vector couplings



- Best fit signal strength in H→4l : **μ=0.91+0.30-0.24** is compatible with the Standard Model **(μ=1).**
- Couplings with bosons and fermions in 4l also compatible with the SM
- Statistical precision needs to be improved (particularly of boson couplings, which are still compatible also with zero)

The Decay H→ γγ



Analysis

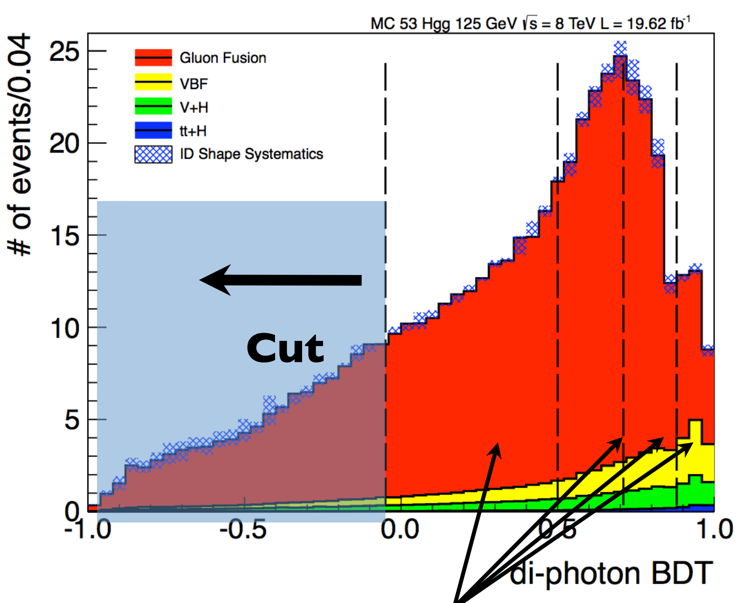
- Two high momentum photons
- Higgs is narrow (at low mass)
- Two photon resolution is excellent
- Large irreducible background from direct two photons
- Smaller "reducible" fake photon background

Key analysis features

- Energy resolution (calibration)
- Fake photon rejection
- Use of kinematics

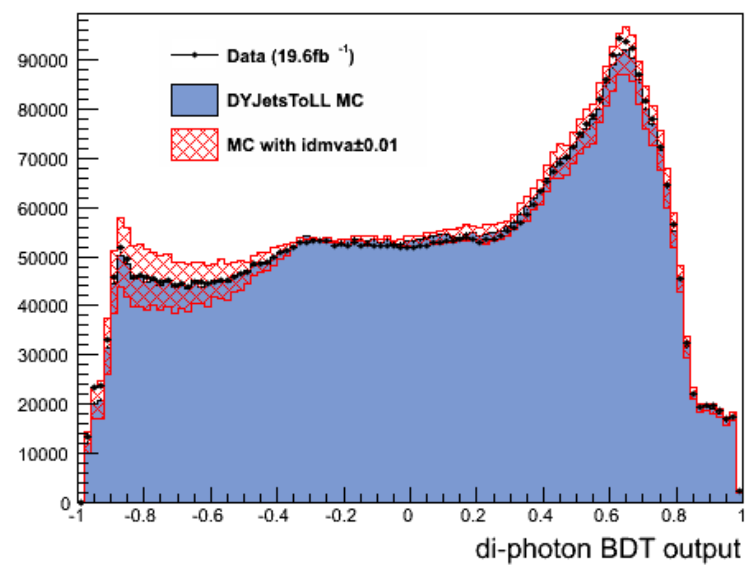
The Decay H→ γγ

- Two inclusive analyses:
  - PRIMARY — MVA: photons selected with an MVA. Variable in the MVA: photon kinematics, photon ID MVA score (shower shape, isolation), di-photon mass resolution. 4 MVA categories with different S/B
  - CROSS-CHECK — Cut-based: photons selected with cuts. 4 categories based on: γ in Barrel/Endcap, (un)converted γ. Each category has different mass resolution and S/B
- 3 VH channels (e, μ and MET tag) + VBF (2 dijet categories)



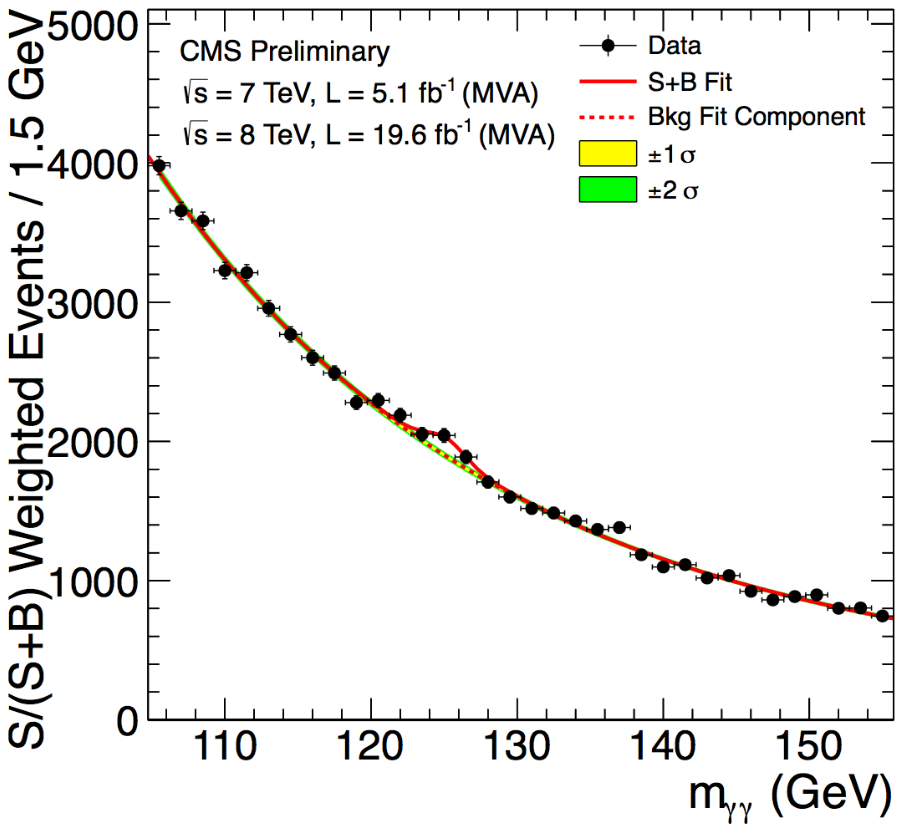
MVA Event categories

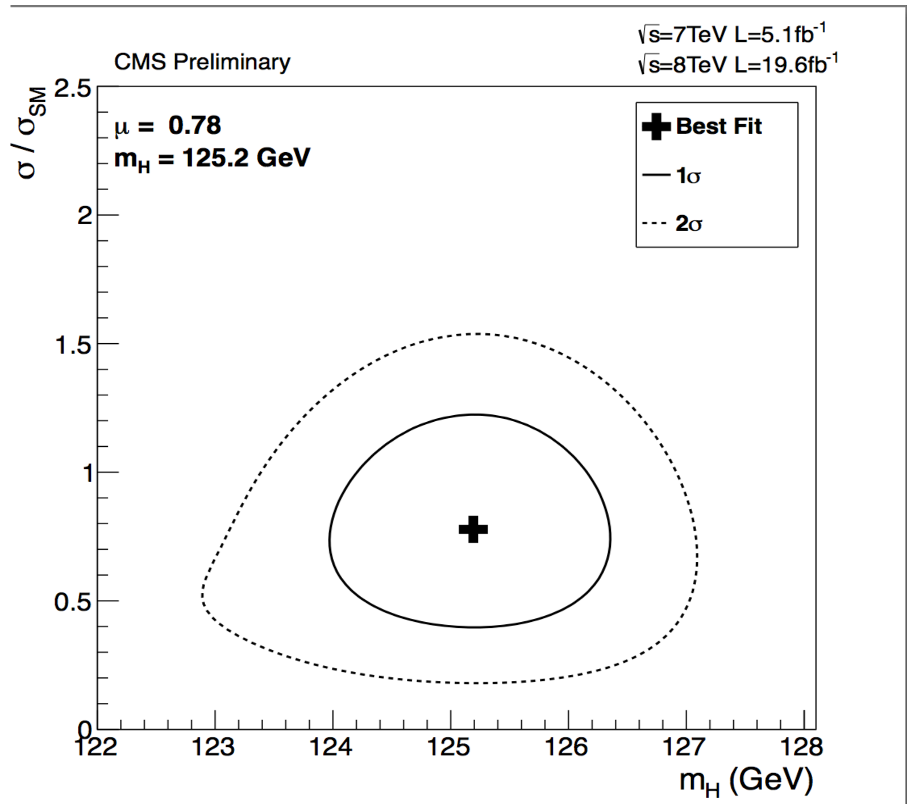
Output of the MVA validated using Z→ee (where e are reconstructed as γ)



The Decay H→ γγ

Multivariate (MVA) analysis

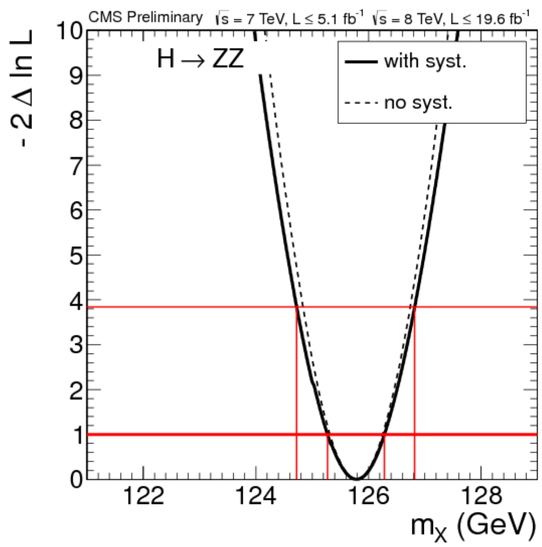


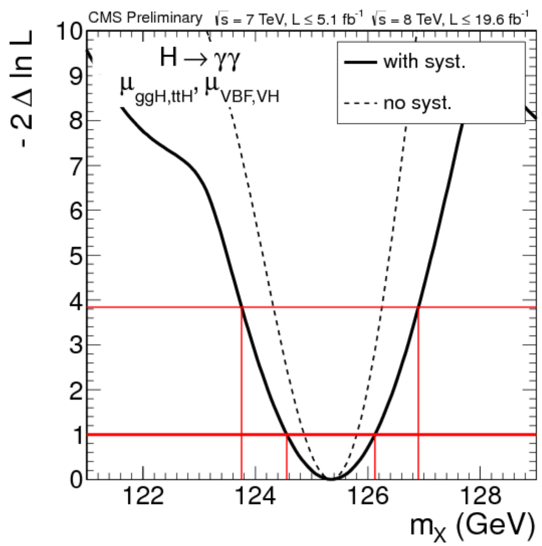


M_H=125.4 ± 0.5(stat.) ± 0.6(syst.)

Each event category is weighted by its S/(S+B)
(only for visualization purposes)

Mass measurement





- **A narrow resonance is seen with high significance in the two excellent mass resolution channels, ZZ(4l) and γγ**

ZZ(4l): m_X = 125.8 ± 0.5 (stat) ±0.2 (syst) GeV

main sources of systematic uncertainties:

- electron energy scale: 0.3%
- muon energy scale: 0.1%

γγ: m_X = 125.4 ± 0.5 (stat) ± 0.6 (syst) GeV

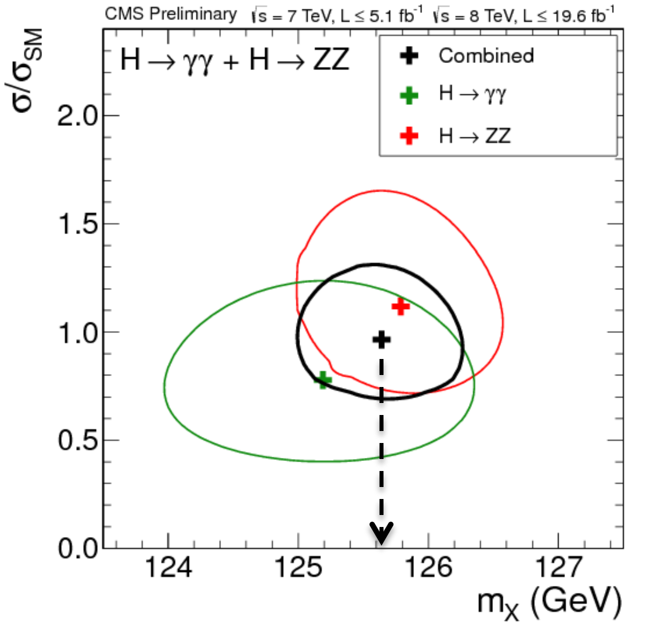
– main sources of systematic uncertainties:

- electron-photon extrapolation
- p_T scale extrapolation from $m_Z/2$ to $m_H/2$

- **Results are consistent with one particle X**

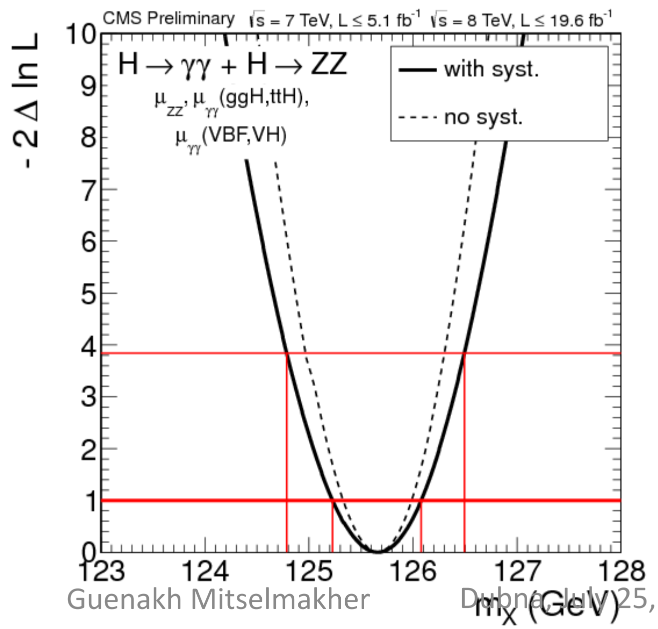
  → proceed with a combined mass measurement

Mass measurement



Assuming that we see one particle X,
one can combine the mass measurements
In two high resolution channels

- either assuming the SM Higgs-like relationship for relative production rates (top plot)

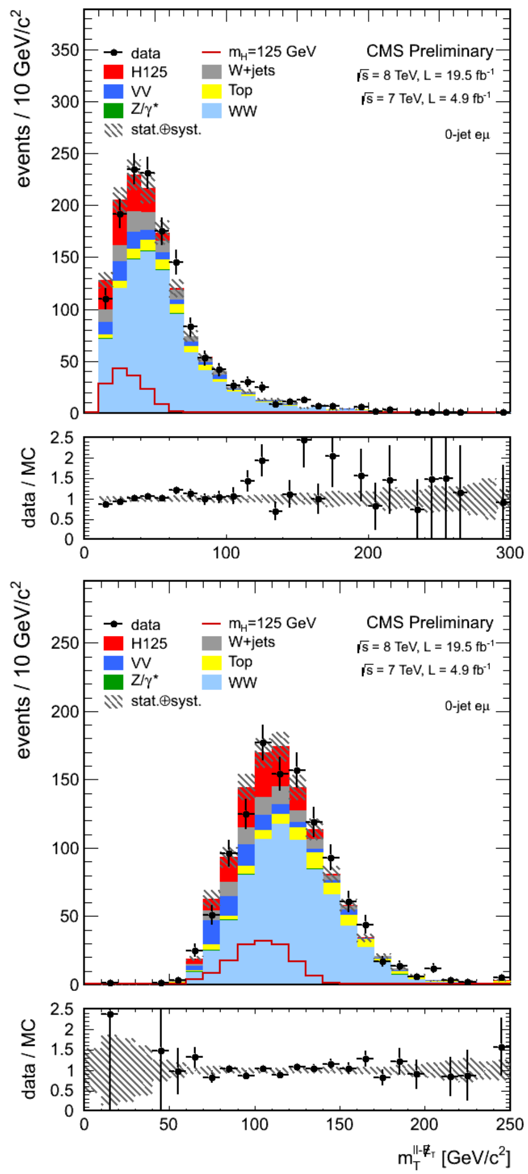


- or letting relative event yields float free in the almost-model-independent fit (bottom plot):

m_X = 125.7 ± 0.4 (0.3%) GeV

= 125.7 ± 0.3 (stat) ± 0.3 (syst) GeV

H → WW → lνlν

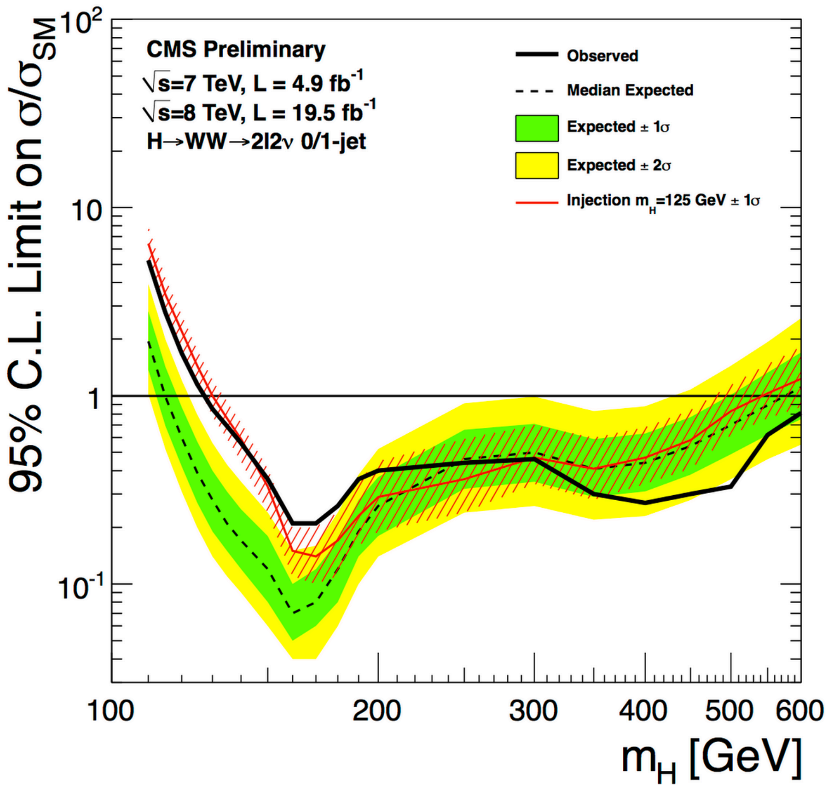


- Analysis strategy:
  - two prompt high-p_T leptons
  - MET
  - split events into ee, μμ, eμ channels:
    - different S/B rates: Drell-Yan in ee/μμ
  - split events further into 0/1-jet:
    - different S/B rates: ttbar in 1-jet
  - Backgrounds (for low mass Higgs):
    - WW, tt, W+jets, DY+jets, Wγ: from control regions
    - ZW, ZZ: from MC (very small contribution)

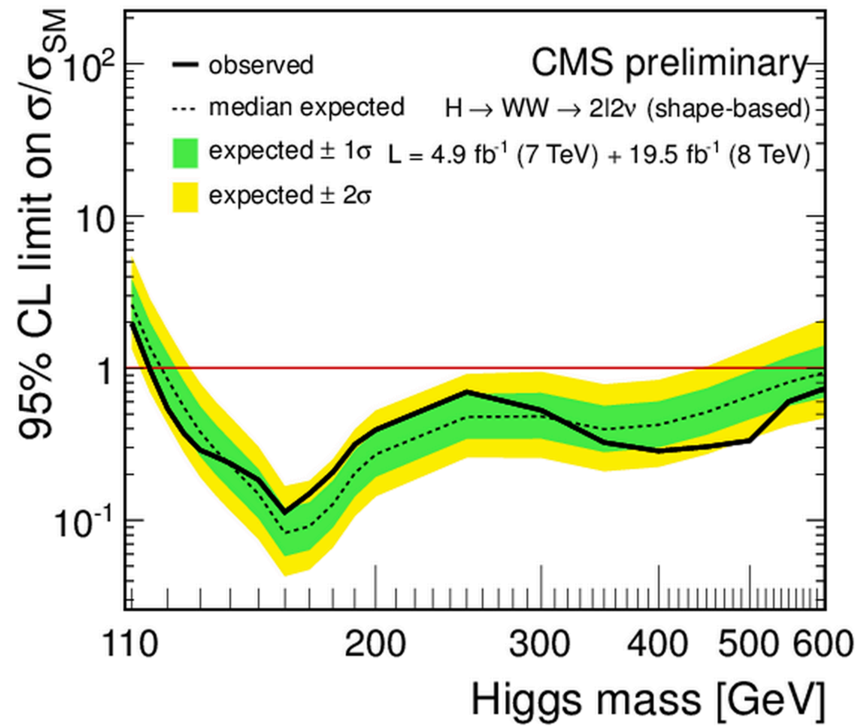
- Analysis features:
  - OK S/B-ratio
  - fair signal event yield (200 events)
  - poor mass resolution ≈20%

The Decay H → WW → 2l 2ν

Standard Analysis

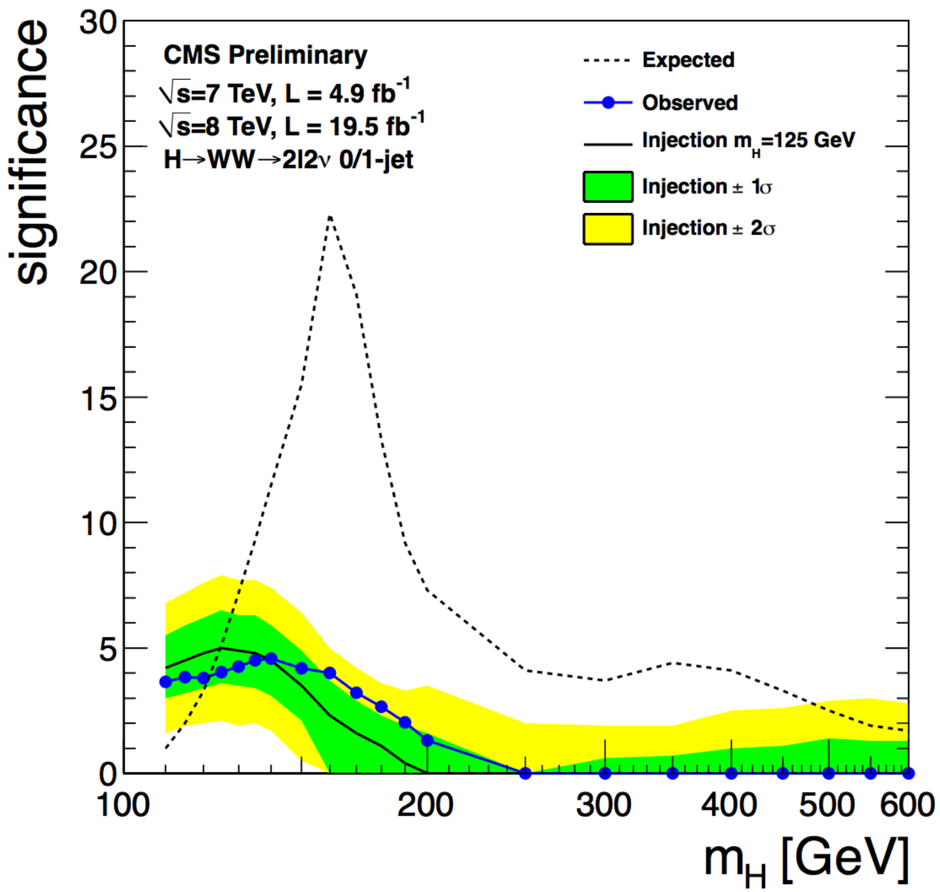


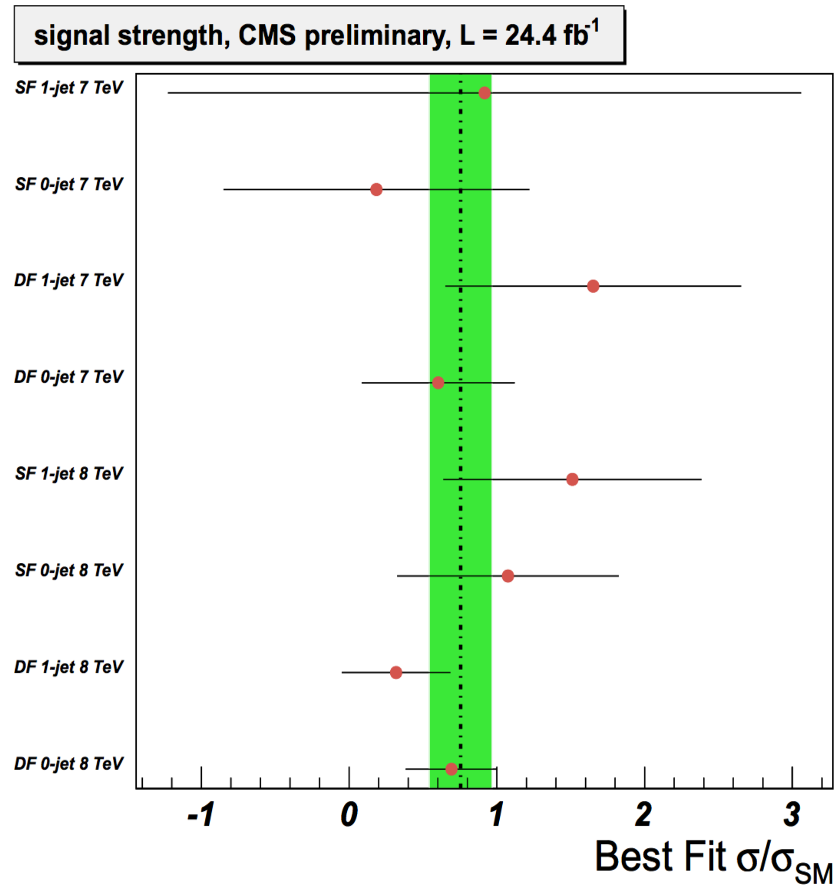
Using m_H = 125 GeV as a "background"



- Exclusion at 95% in the mass range 128-600 GeV
- Large excess in the low mass region
- When including M_H=125 GeV as part of the background, no significant excess is seen over the entire mass range

The Decay H → WW → 2l 2ν

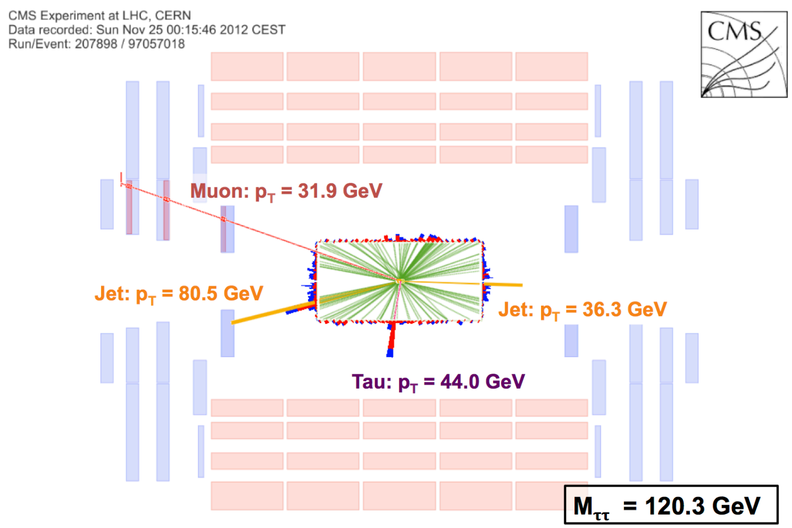


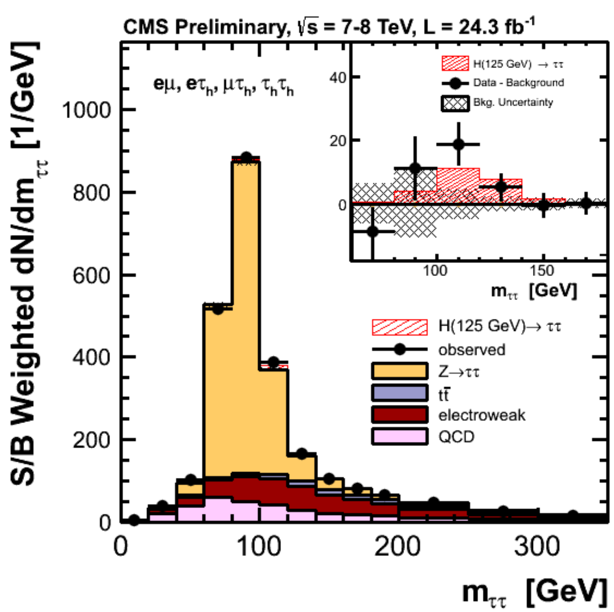


A 4.0σ (5.1σ) observed (expected) significance at m_H ~ 125 GeV

σ/σ_{SM} signal strength: 0.76 ± 0.21

$H \rightarrow \tau\tau$

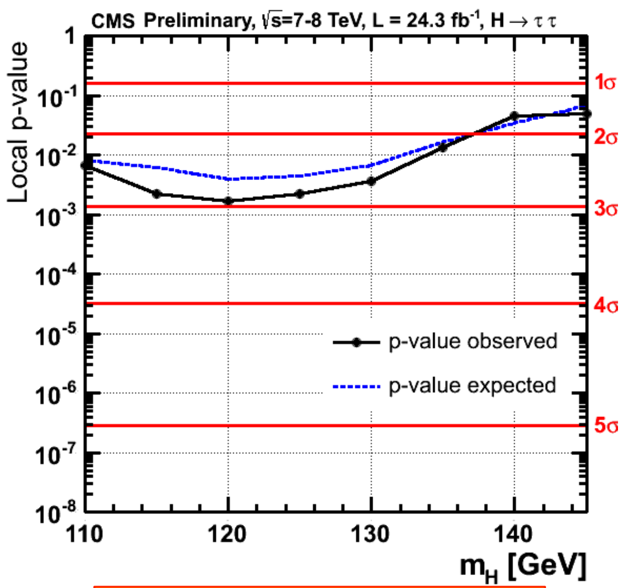




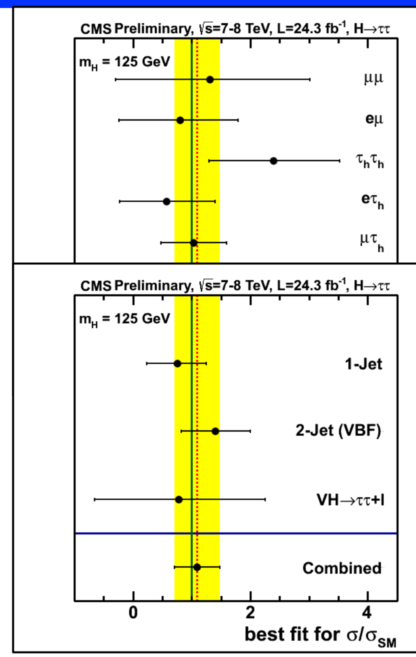
- **Analysis strategy:**
  - di-tau candidates: $e\tau_h$, $\mu\tau_h$, $e\mu$, $\mu\mu$, $\tau_h\tau_h$
  - MET
  - **DiTau mass (including MET)**: key distribution
  - split events into jet categories:
    - **2-jets (VBF-tag)**: best S/B-ratio
    - **1-jet (ggF, VH)**: acceptable S/B-ratio
    - untagged: control region (S/B≅0)
  - split 1-jet events further high/low p_T tau
    - different S/B rates
  - Backgrounds:
    - Z→ττ: Z→μμ (data) with a simulated μ-τ swap
    - Z→ee, W+jets, ttbar: MC for shapes, data for normalization
    - QCD: from control regions

- **Analysis features:**
  - low S/B-ratio
  - small signal event yield
  - Higgs is on falling slope of Z-decays
  - poor mass resolution ≈15%

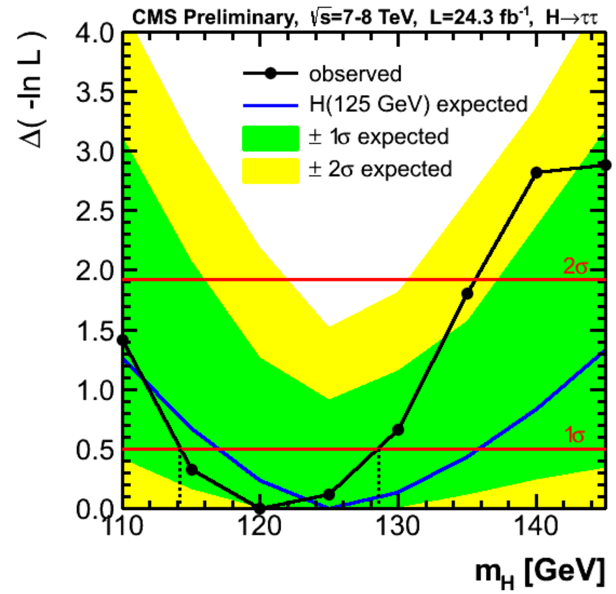
H → ττ: CMS results



Z_{obs} = 2.9 σ
Z_{exp} = 2.6 σ (m = 125)



μ = 1.1 ± 0.4
(m = 125 GeV)

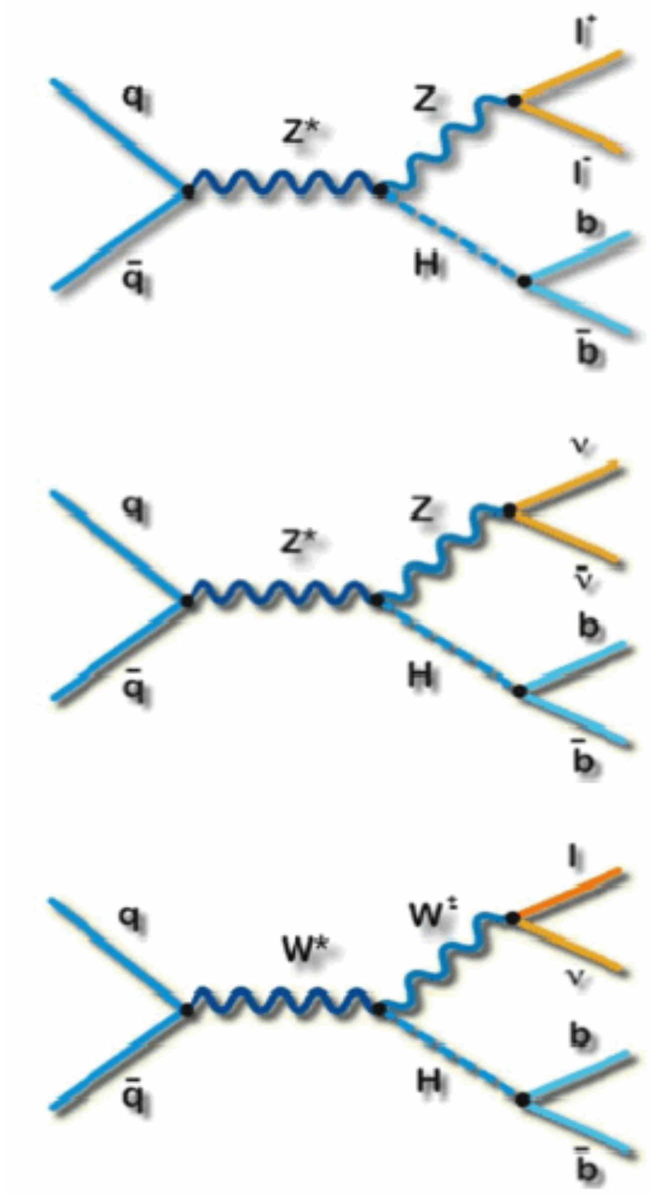


$m_X = 120^{+9}_{-7}$ GeV

Points to note:

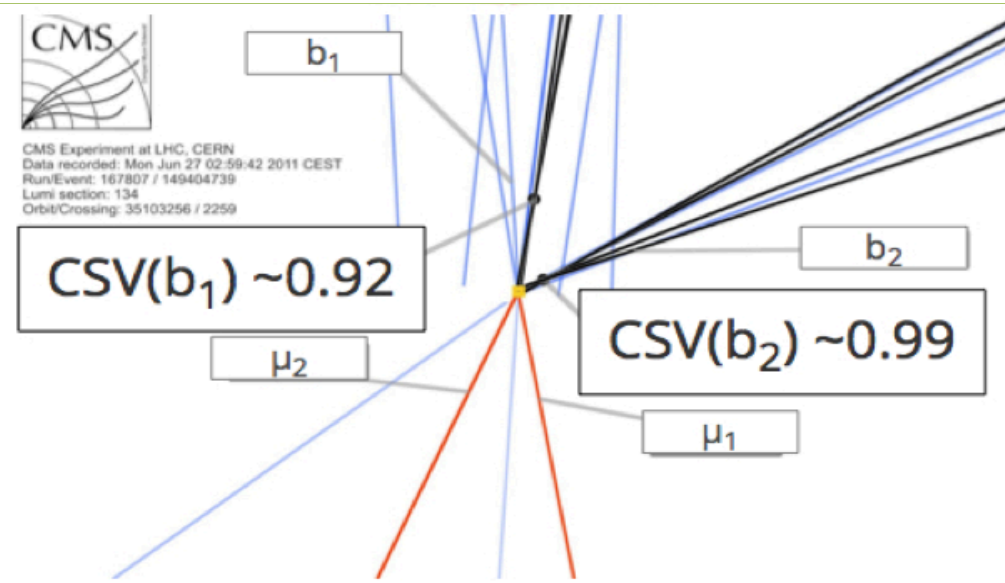
- broad access (poor mass resolution), consistent with **SM Higgs rate**
- close to reaching a 3σ-sensitivity
- despite poor mass resolution, the TauTau channel is **not completely mass-blind**

The Decay H→bb



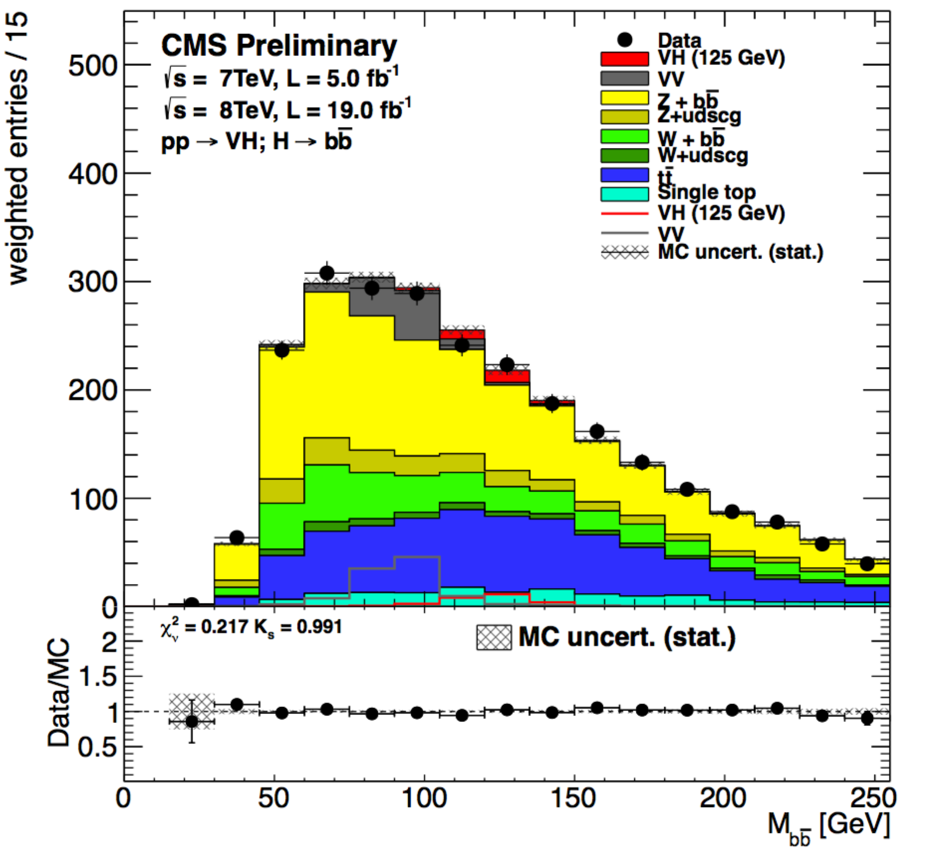
Analysis

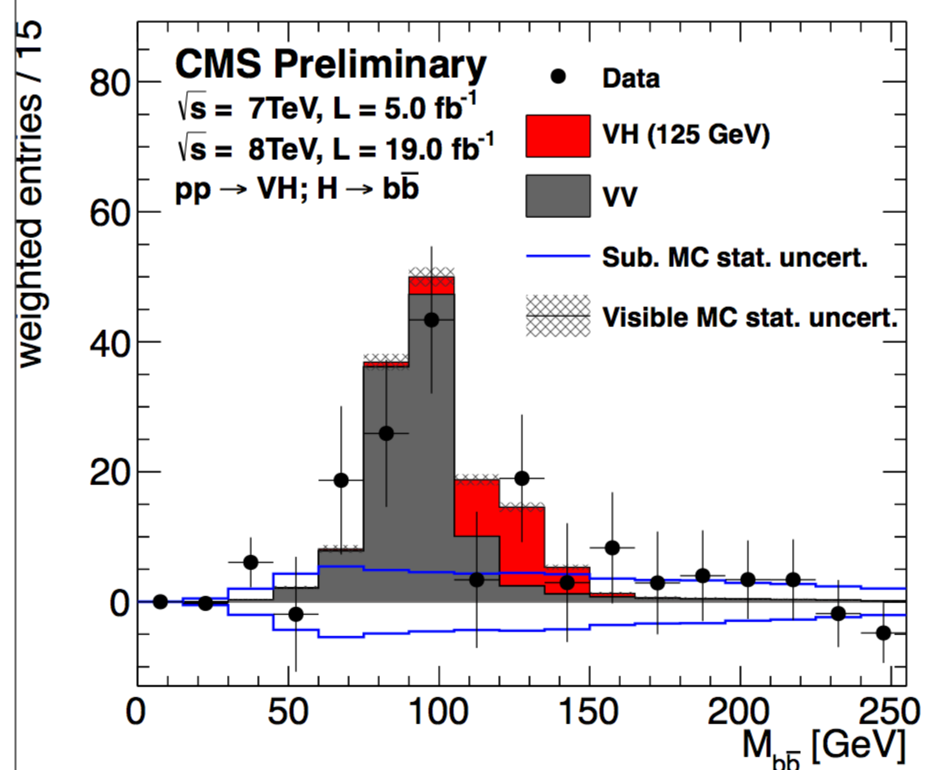
- By far the largest number of Higgs decays
- But lots of QCD background (jets)
- Trigger based on leptons and missing E_T
- b-jets identified through displaced tracks
- Go to high p_T where Higgs is enhanced
- Main background W/Z+jets and top



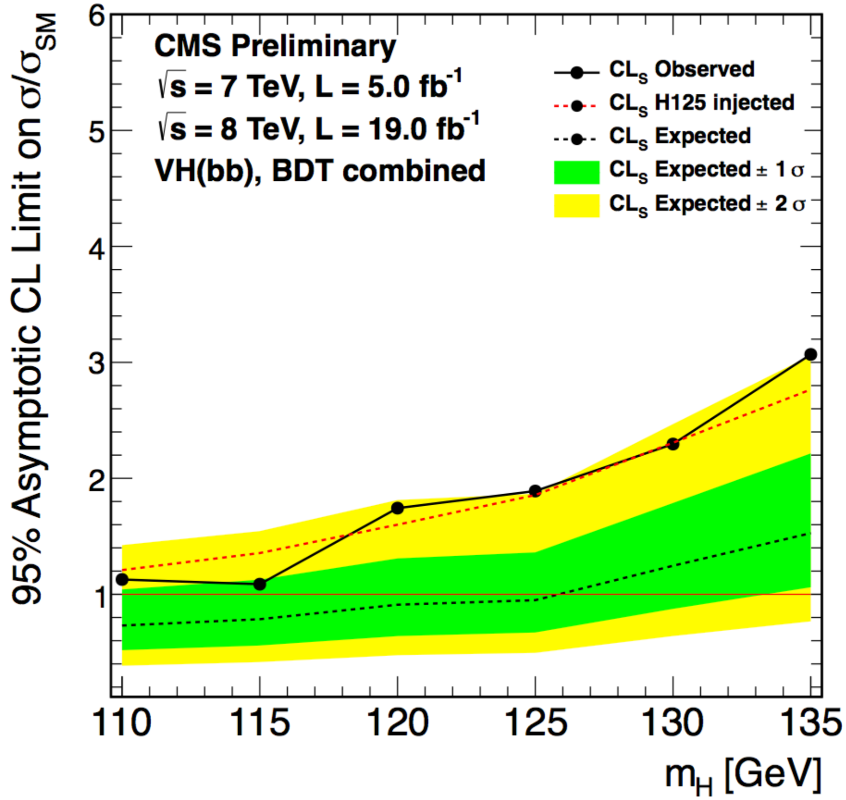
The Decay H→bb

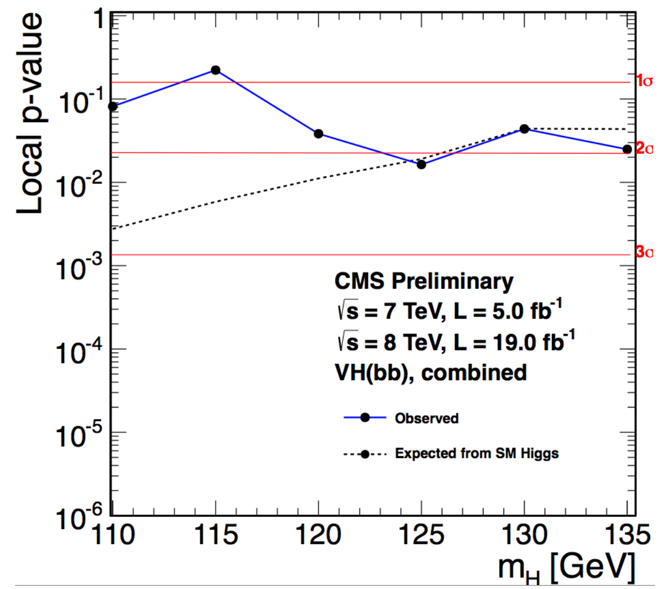
M_{bb} for all categories and 7+8 TeV

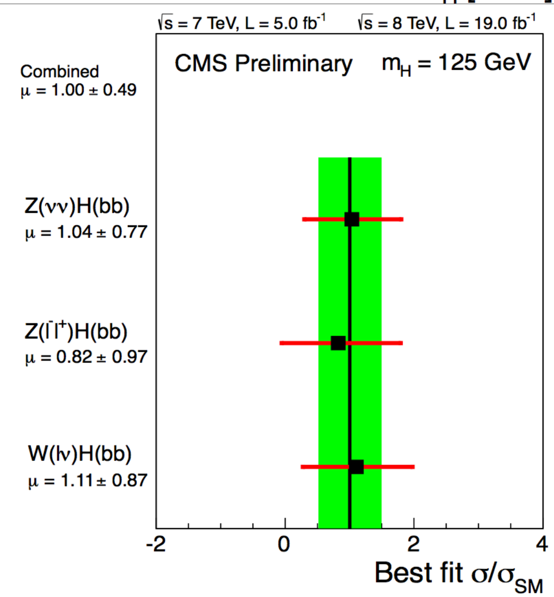




The Decay H→bb







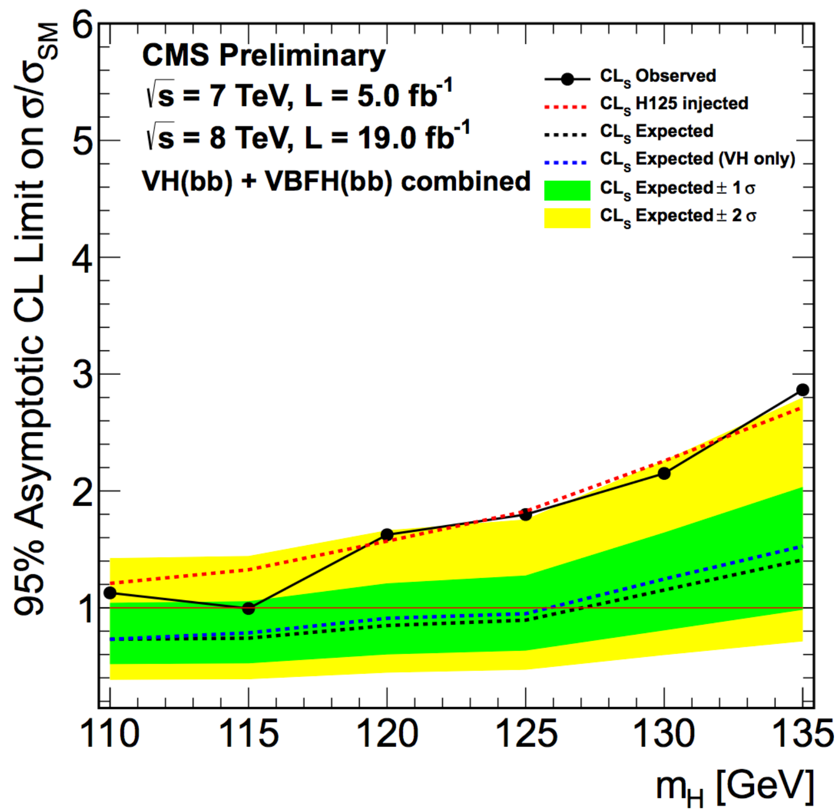
For 125 GeV:

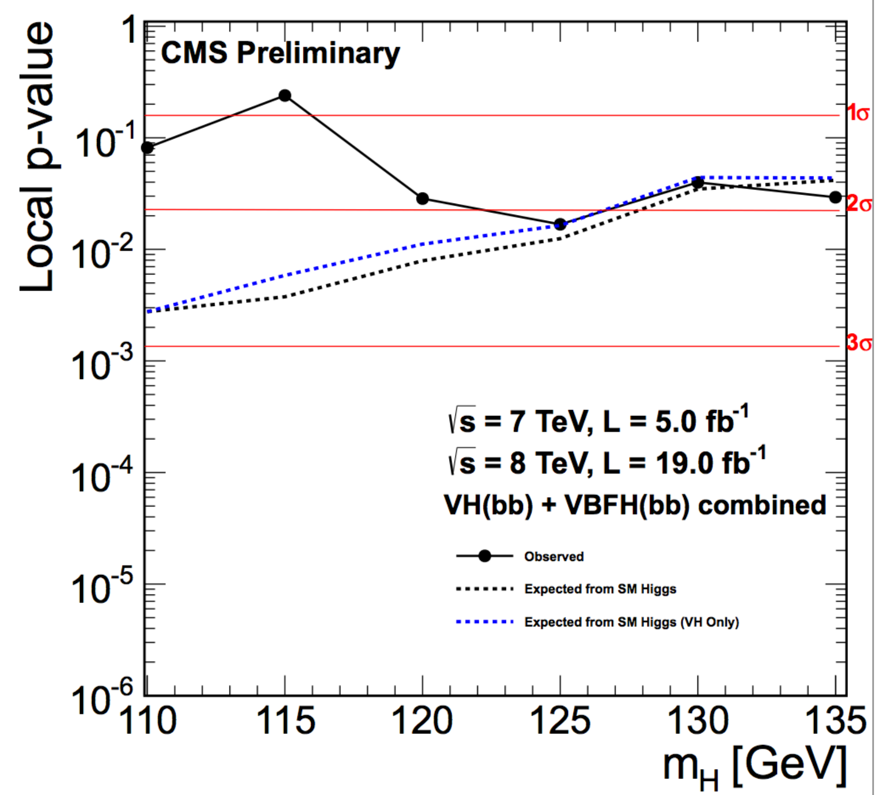
- Significance = 2.1σ (2.1σ expected)
- Signal strength $\mu = 1.0 \pm 0.5$

Mild excess observed in data.

H→bb Channel Combination

Combine the results of the VBF and VH processes for H→bb





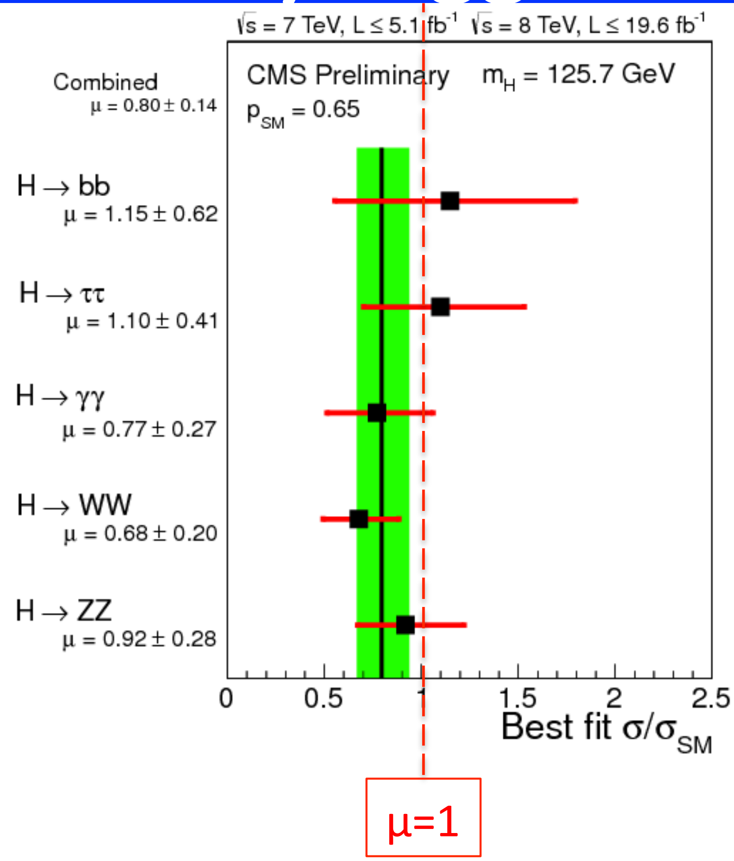
- 95% CL limit observed (expected) at 125 GeV: 1.79 (0.89)
- Significance observed (expected) at 125 GeV : 2.1σ (2.2σ)
- Signal strength at 125 GeV: μ= 0.97± 0.48

Significance of the excess near 125 GeV (also compared with ATLAS)

	ATLAS		CMS		
	expected	**observed**	expected	**observed**	observed
H→ZZ	4.4	**6.6**	7.1	**6.7**	
H→γγ	4.1	**7.4**	3.9	**3.2**	
H→WW	3.8	**3.8**	5.3	**3.9**	
H→ττ	1.6	**1.1**	2.6	**2.8**	3.4
H→bb	1.0	**0**	2.2	**2.0**	
combined	7.3	**10**	stopped computing		

Higgs signal is > 5 sigma in expected (and observed) in single ZZ→4l channel in CMS

Consistency of event yields in 5 main (most informative) Higgs decay channels



CMS best-fit signal strength

$\mu = 0.80 \pm 0.14$

Is X126 the SM Higgs boson? (using event yields from different channels)

- In the following slides will check compatibility of event yields in different channels with the expectations for the SM Higgs boson by recasting the event yields into measurements of couplings in several ways.

Production × Decay parameterization

8 independent parameters to describe all currently relevant decays and production mechanisms:

$$\sigma(xx \to H) \cdot BR(H \to yy) \propto \frac{\Gamma_{xx} \cdot \Gamma_{yy}}{\Gamma_{TOT}}$$

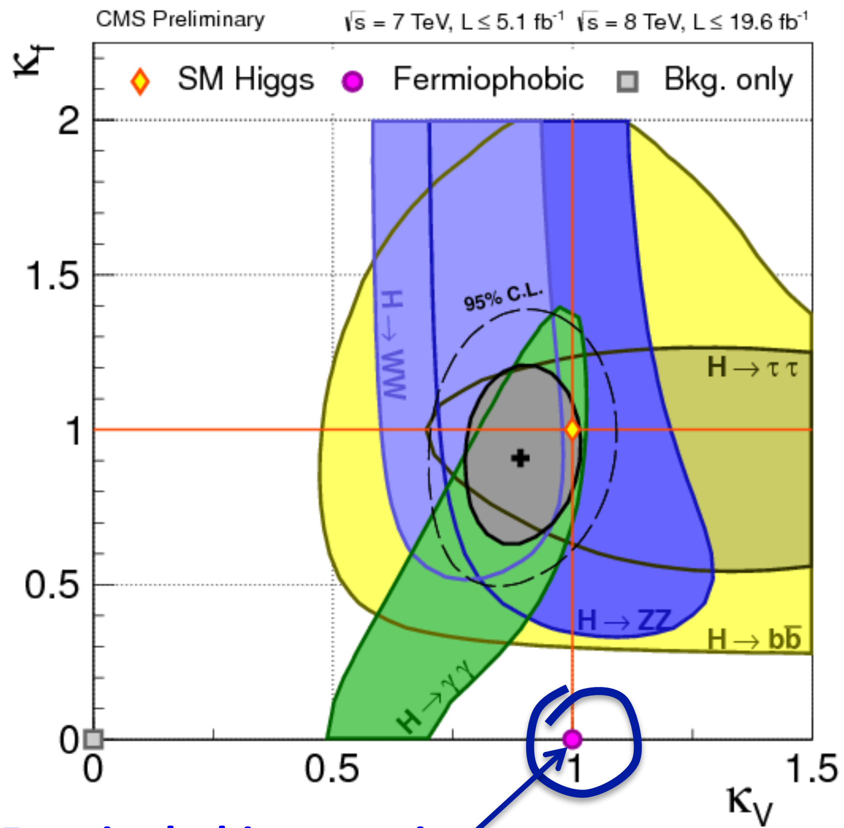
- Γ_{WW}
- Γ_{ZZ}
- Γ_{bb}
- $\Gamma_{\tau\tau}$
- $\Gamma_{\gamma\gamma}$ (loop induced)
- Γ_{gg} (loop induced)
- Γ_{tt}
- Γ_{TOT} (including H → "invisible")
- **Zγ** and **μμ** still have too little sensitivity to affect anything in the combination

	untagged	VBF-tag	VH-tag	ttH-tag
WW	✔	✔	✔	
ZZ	✔	✔		
bb			✔	✔
ττ	✔	✔	✔	
γγ	✔	✔	✔	

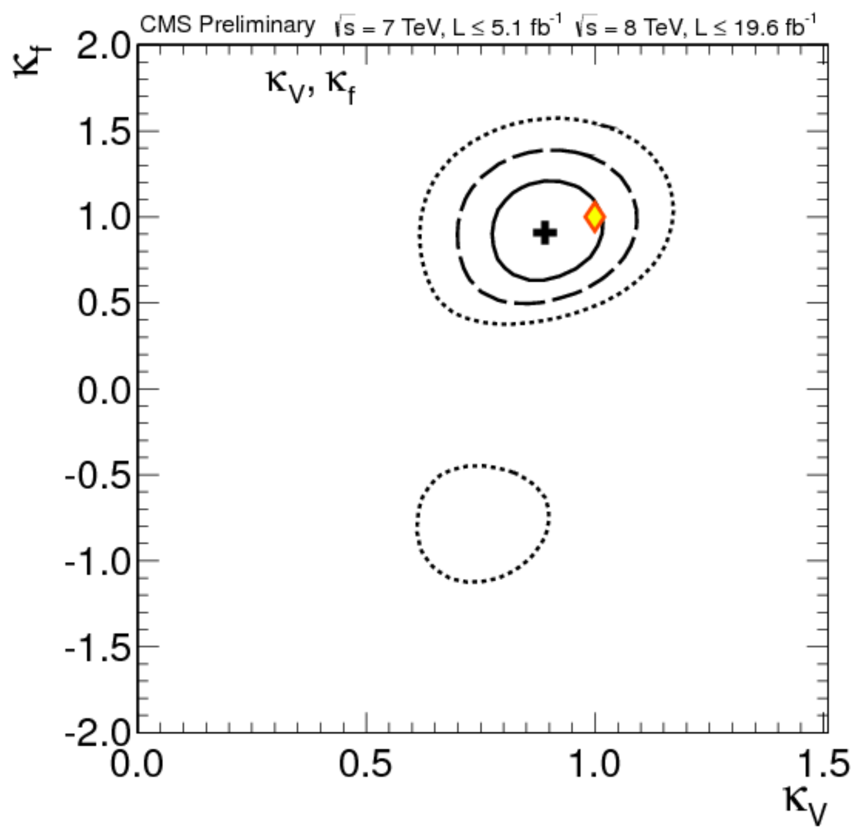
Introduce scaling factors *κ* w.r.t. the S/M Higgs couplings

Since statistics is small, will check compatibility with SM fitting smaller number than of couplings, making different assumptions

Two parameters: κ_V and κ_F



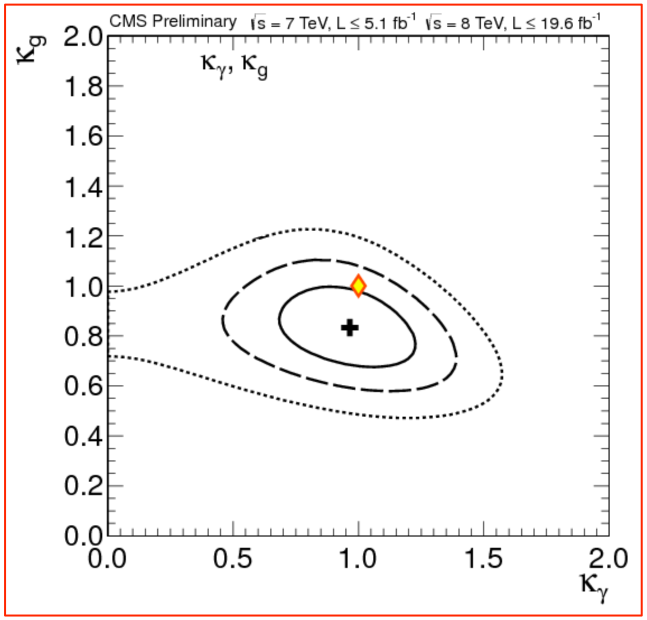
Fermiophobic scenario is reliably excluded

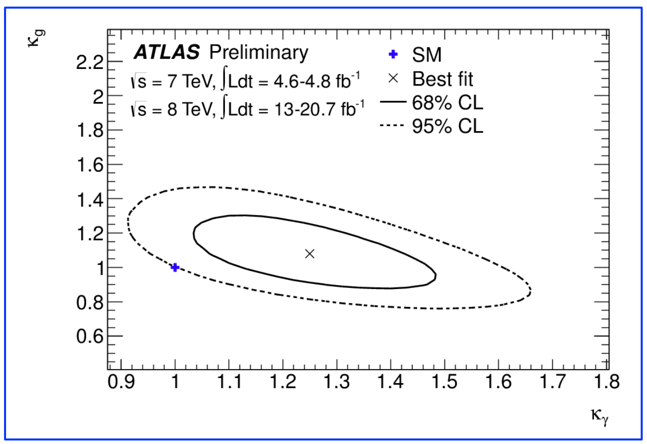


Data are consistent with $(\kappa_V; \kappa_F)=(1; 1)$

The previously seen global minimum of the likelihood in the (+; –) quadrant is gone, since the γγ-channel is no more enhanced

1. Look for new physics in loops: κ_g and κ_γ



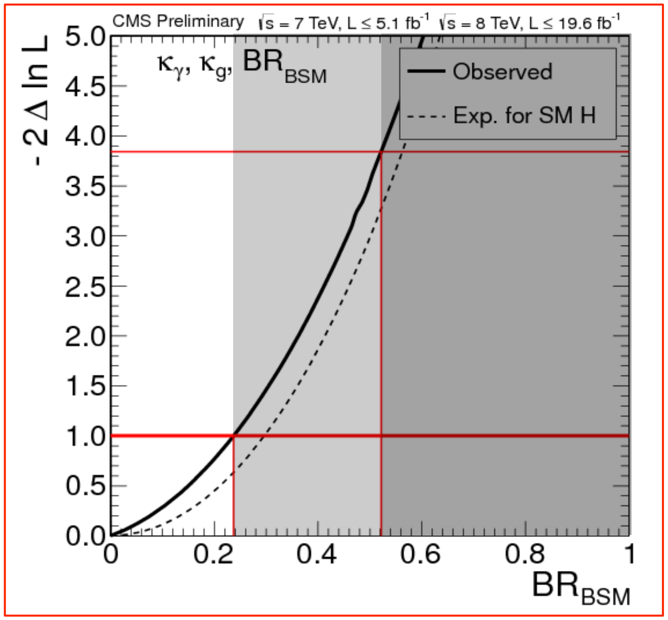


Two-parameter fit

- use all channels
- assume tree-level couplings = SM
- assume BR(BSM)=0
- **Fit for: κ_γ , κ_g**

Data are consistent with (κ_γ; κ_g)=(1; 1)

2. Look for new physics: BR(BSM), κ_g , κ_γ



Three-parameter fit

- use all channels
- assume tree-level couplings = SM
- allow for BR(BSM) ≠ 0
- **Fit for: BR("invisible"), κ_γ , κ_g**

CMS: BR(BSM) < 0.52 at 95% CL

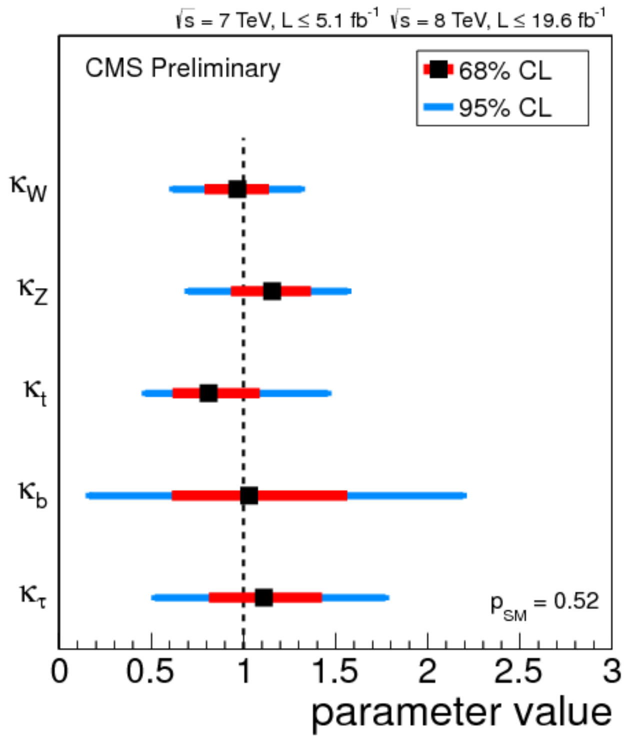
3a. CMS: 5 parameter model

Fit 5 of 8 independent parameter describing all currently relevant decays and production mechanisms:

- Γ_{WW} → κ_W
- Γ_{ZZ} → κ_Z
- Γ_{tt} → κ_t
- Γ_{bb} → κ_b
- $\Gamma_{\tau\tau}$ → κ_τ

Assume that:

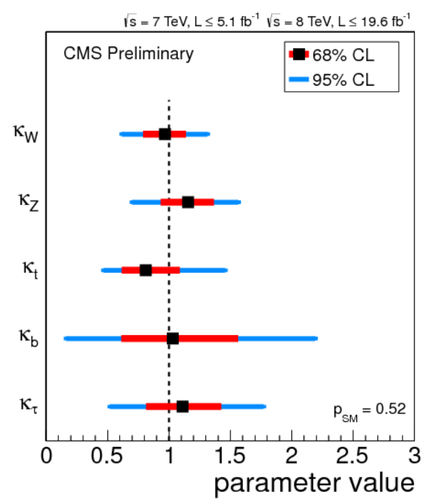
- $\Gamma_{\gamma\gamma}$ (loop is resolved) → κ_W, κ_t
- Γ_{gg} (loop is resolved) → κ_t, κ_b
- **BR(BSM)=0**

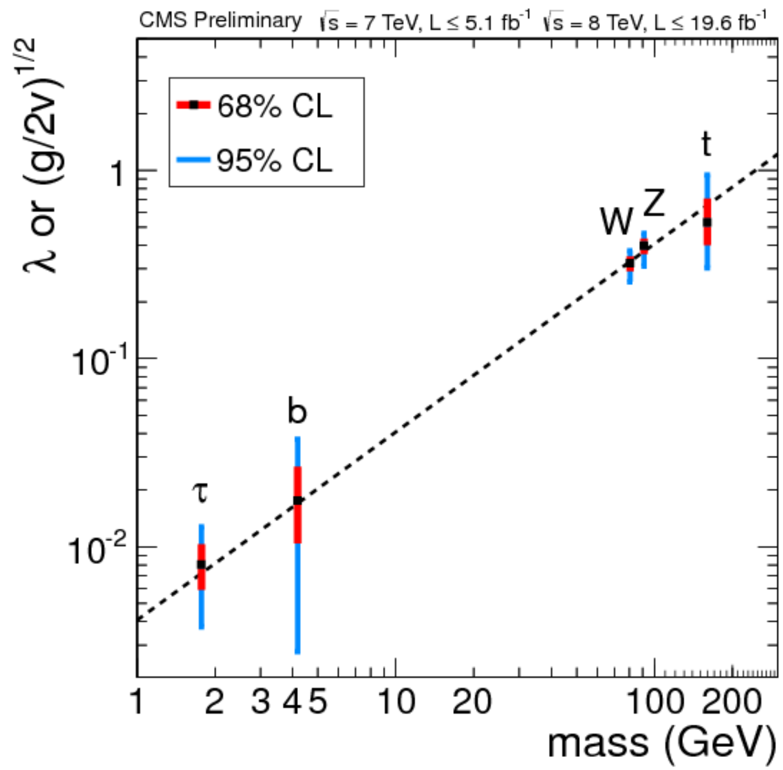


- Assume couplings to the 1st, 2nd, 3rd generations are modified the same way

3b. CMS: 5 parameter model

- Scale SM couplings by measured scale factors and plot modified couplings vs particle masses:
  - λ_f(Yukawa coupling) ~ m_f
  - $(g_V/2vev)^{0.5}$ ~ m_V



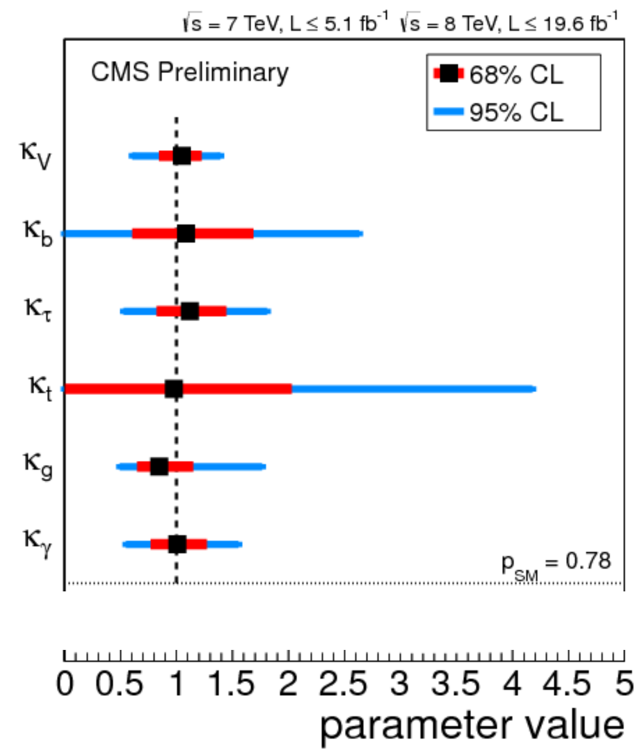


Note: the magnitude of couplings we try to assess range by a factor of 100!
A test with 20+% accuracy is actually a very respectable test. Note that experimental information about 1st and 2nd generation is not accurate yet and not on the plot.

4. CMS: 6 parameter model

8 independent parameters to describe all currently relevant decays and production mechanisms:

- Γ_{ZZ} → κ_V
- Γ_{WW}
- $\Gamma_{\tau\tau}$ → κ_τ
- Γ_{bb} → κ_b
- $\Gamma_{\gamma\gamma}$ (loop induced) → κ_γ
- Γ_{gg} (loop induced) → κ_g
- Γ_{tt} → κ_t
- assume **BR(BSM)=0**
- Couplings to the 1st and 2nd generations are not measure accurately yet, so take from SM



Summary

- In a **combined search** for the SM Higgs boson in CMS, **a significant excess of events near m_H=126 GeV** persists
- The following decay channels contribute to the sensitivity: **ZZ, γγ, WW, ττ, bb**
- **New boson's mass as measured by CMS is: 125.7 ± 0.4 GeV**
- **Is X126 the SM Higgs boson?**
  - **event yields in all individual channels are consistent with the SM Higgs boson**
  - **couplings agree with the SM Higgs boson** with the current statistical accuracy
  - **no significant modifications for loop-induced couplings (deviations < 2σ)**
  - **BR(H→BSM) < 0.5 (approx.) at 95%CL**
  - **100% pure $J^{CP} = 0^-$, $1^\pm$, 2^+_m states are excluded at >99% CL**
  - **CP-odd fractional contribution: $f(0^-)$ < 0.58 at 95% CL**
- **Still a lot of room for deviation from the SM Higgs exists: the precision of the measurements is in many cases statistically dominated, and can be significantly improved in the future years**

Backup slides

ZZ->4L J^{CP} analysis: discriminants

- Analysis considers alternative signal+background hypotheses, where signal *X* can be either gg→H or *xx* → J^{CP}

  - Construct two ME-based discriminating observables:

    where ME are complete LO matrix elements, and $m_X = m_{4\ell}$

$$KD(\mathrm{H;ZZ}) = \frac{|ME_{\mathrm{H}}(gg \to H \to 4\ell)|^2}{|ME_{\mathrm{ZZ}}(q\bar{q} \to 4\ell)|^2}$$

$$KD(J^{CP};\mathrm{ZZ}) = \frac{|ME_{J^{CP}}(xx \to J^{CP} \to 4\ell)|^2}{|ME_{\mathrm{ZZ}}(q\bar{q} \to 4\ell)|^2}$$

  - Extend KDs to include discriminating information from four-lepton mass:

$$D(H;\mathrm{ZZ}) = \frac{|ME_X(xx \to H \to 4\ell)|^2 \cdot pdf(m_{4\ell} \mid m_H)}{|ME_{\mathrm{ZZ}}(q\bar{q} \to 4\ell)|^2 \cdot pdf(m_{4\ell} \mid ZZ)}$$

$$D(J^{CP};\mathrm{ZZ}) = \frac{|ME_{J^{CP}}(xx \to J^{CP} \to 4\ell)|^2 \cdot pdf(m_{4\ell} \mid m_{J^{CP}})}{|ME_{\mathrm{ZZ}}(q\bar{q} \to 4\ell)|^2 \cdot pdf(m_{4\ell} \mid ZZ)}$$

  - Without any loss of information, one can change "variables":

$$D(\mathrm{H;ZZ})$$

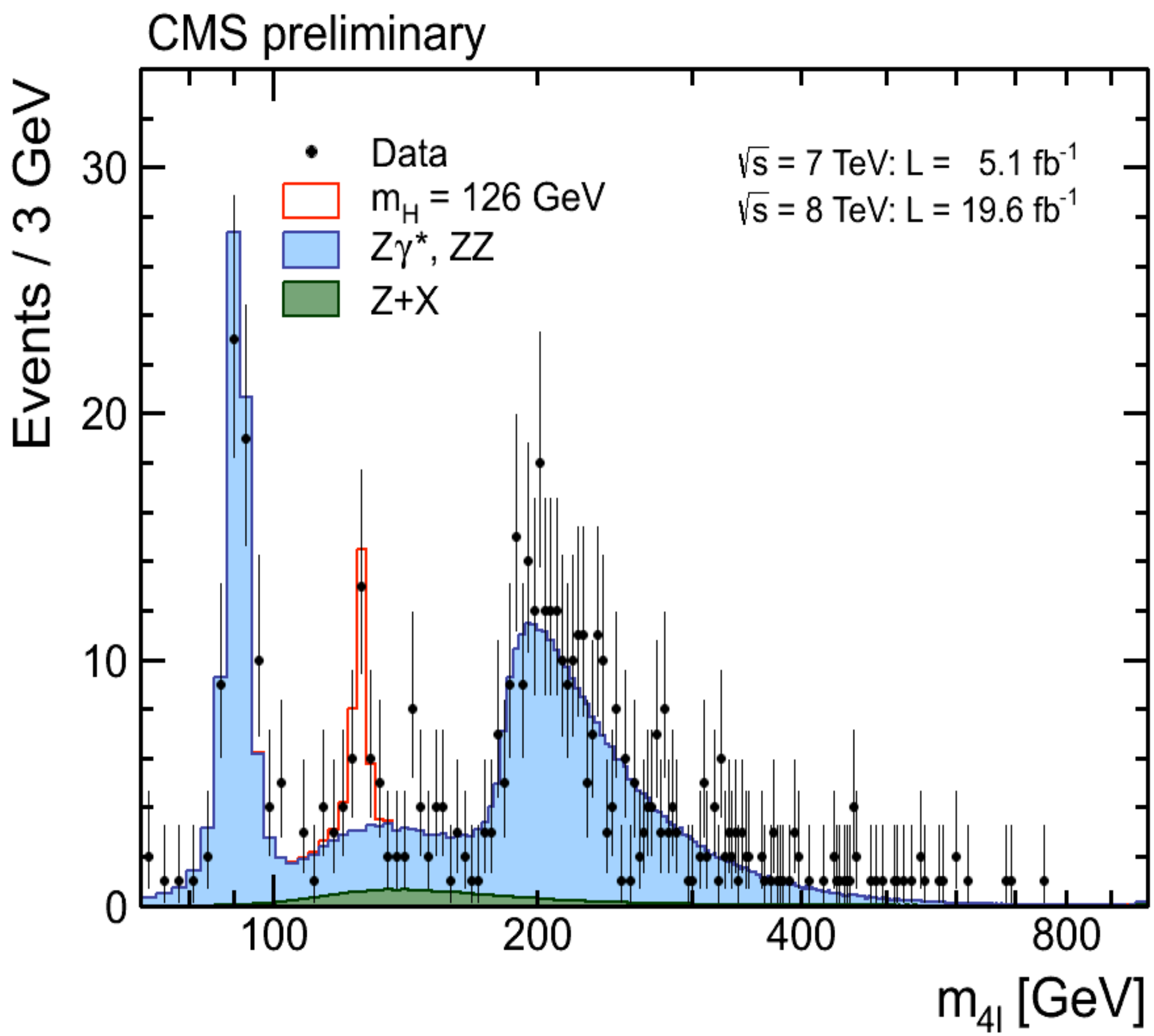
$$D(J^{CP};\mathrm{H}) = \frac{D(\mathrm{J^{CP};ZZ})}{D(\mathrm{H;ZZ})} = \frac{|ME_{J^{CP}}(xx \to \mathrm{J^{CP}} \to 4\ell)|^2}{|ME_{\mathrm{H}}(gg \to \mathrm{H} \to 4\ell)|^2}$$

  - And again without any loss of information, compress discriminants to be between 0 and 1

$$D_{bkg} = \frac{1}{1 + const \cdot D(\mathrm{H;ZZ})}$$

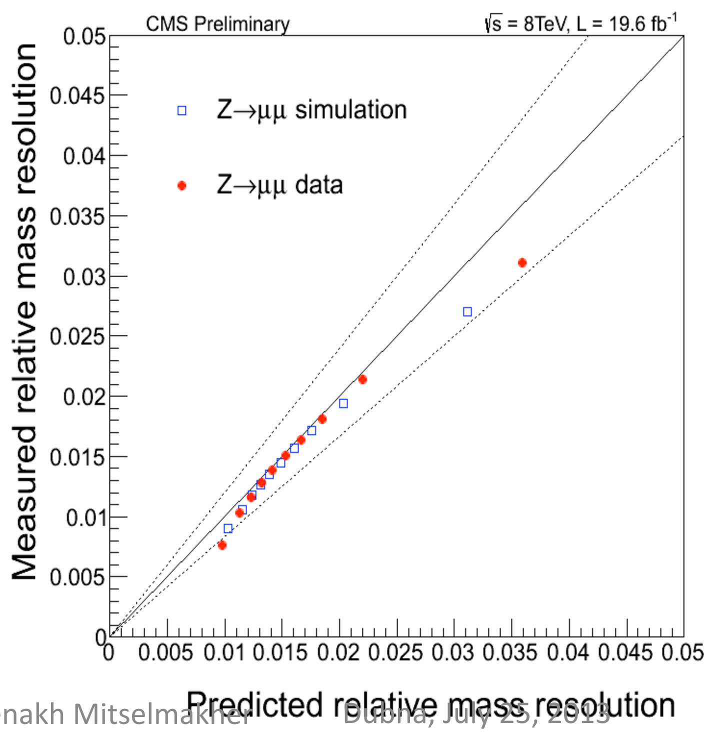
$$D_{J^{CP}} = \frac{1}{1 + const \cdot D(J^{CP};\mathrm{H})}$$

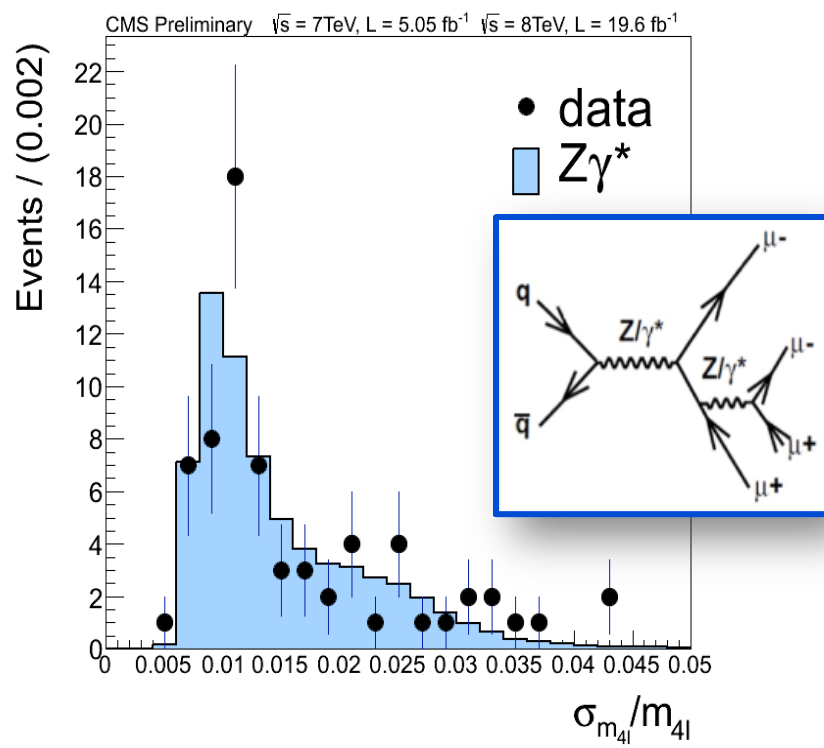
Full statistics in 4l channel color-filled: SM background



Per-event mass errors

- To improve precision of the mass measurement, we estimate per-event mass uncertainty and KD
- Per-event mass uncertainty validated using Z→ll data
- Additional cross-check performed using the Z→4l decays:





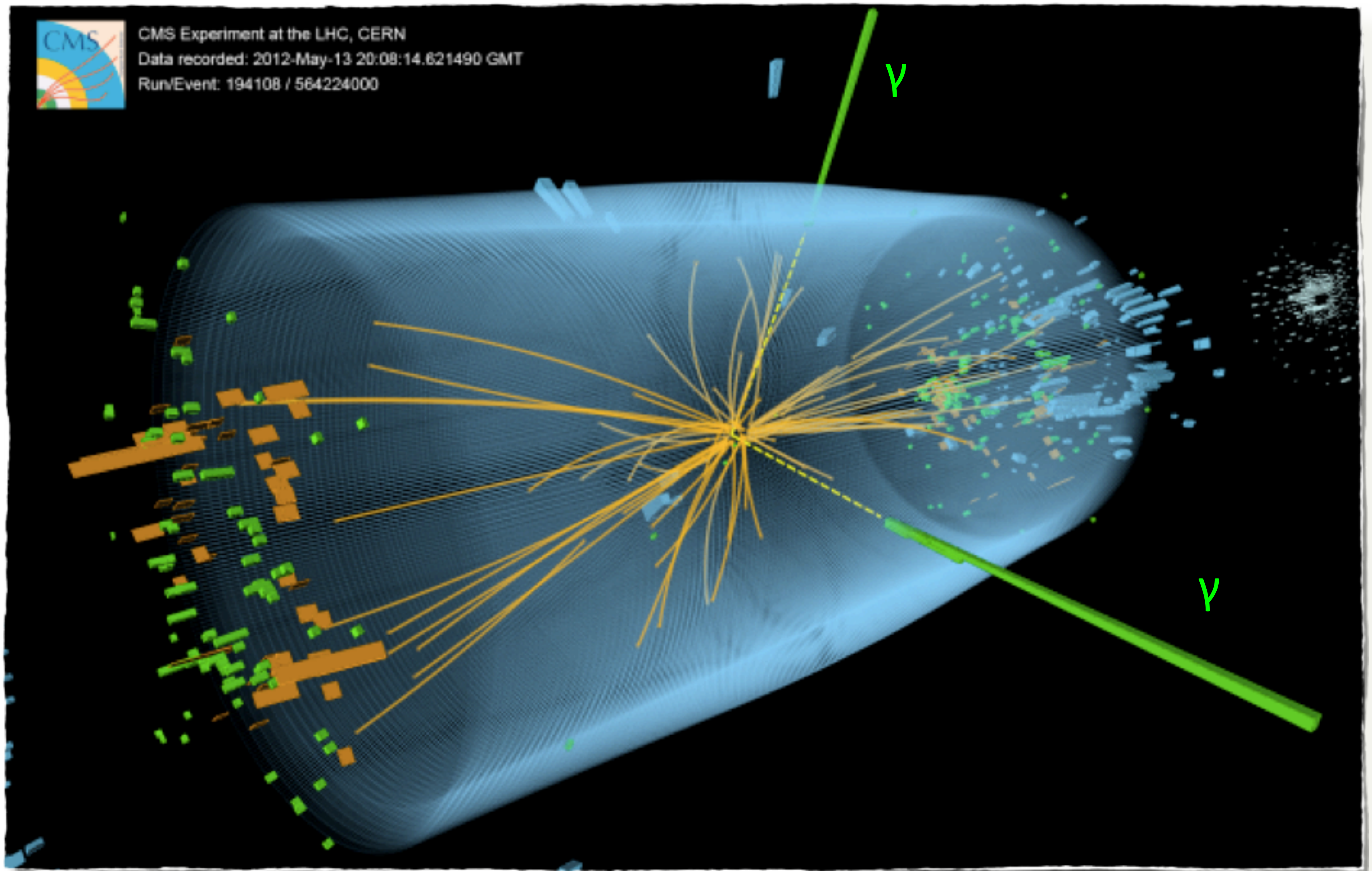
Test statistics

Signal model parameters a (signal strength modifier μ can be one of them) are evaluated from a scan of the profile likelihood ratio $q(a)$:

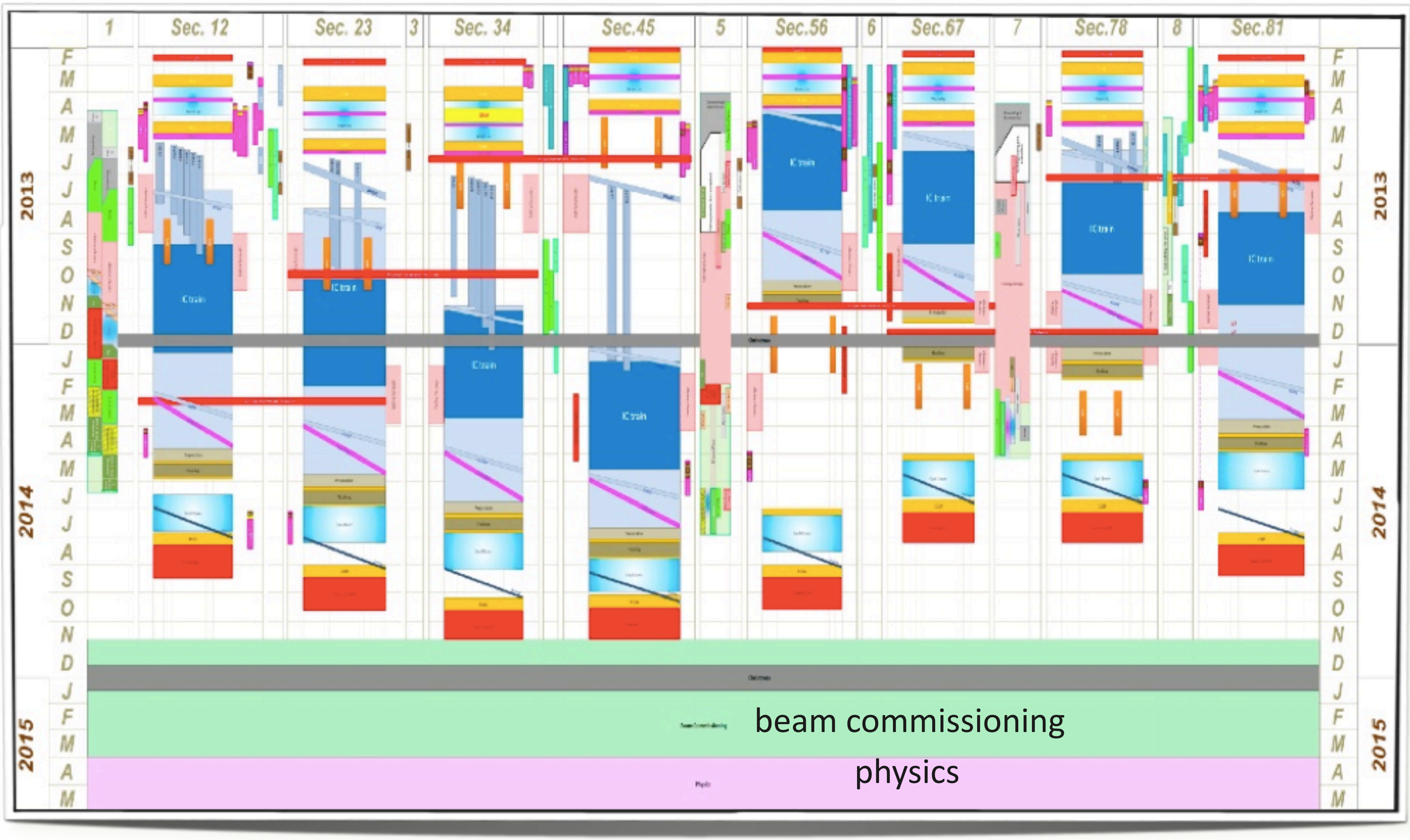
$$q(a) = -2 \ln \frac{\mathcal{L}(\text{obs} \,|\, s(a) + b, \hat{\theta}_a)}{\mathcal{L}(\text{obs} \,|\, s(\hat{a}) + b, \hat{\theta})}, \qquad (6)$$

Parameters $\hat{a}$ and $\hat{\theta}$ that maximize the likelihood, $\mathcal{L}(\text{obs} \,|\, s(\hat{a}) + b, \hat{\theta}) = \mathcal{L}_{\text{max}}$, are called the best-fit set. The 68% (95%) CL on a given parameter of interest a_i is evaluated from $q(a_i) = 1$ (3.84) with all other unconstrained model parameters treated in the same way as the nuisance parameters. The 2D 68% (95%) CL contours for pairs of parameters are derived from $q(a_i, a_j) = 2.3$ (6). One should keep in mind that boundaries of 2D confidence regions projected on either parameter axis are not identical to the 1D confidence interval for that parameter.

H => γγ


CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000
γ
γ

LHC schedule :)



References

Channel	Conference note	L	Date
Spin Combination	ATLAS-CONF-2013-040	up to 25 fb-1	16/04/2013
Couplings Combination	ATLAS-CONF-2013-034	up to 25 fb-1	14/03/2013
Higgs to Diphoton spin	ATLAS-CONF-2013-029	21 fb-1	13/03/2013
Higgs to WW(lvlv) spin	ATLAS-CONF-2013-031	21 fb-1	11/03/2013
Higgs to WW(lvlv)	ATLAS-CONF-2013-030	25 fb-1	11/03/2013
2HDM WW(lvlv)	ATLAS-CONF-2013-027	13 fb-1	11/03/2013
Combined of Mass	ATLAS-CONF-2013-014	up to 25 fb-1	05/03/2013
Higgs to Diphoton	ATLAS-CONF-2013-012	25 fb-1	05/03/2013
Higgs to 4 leptons	ATLAS-CONF-2013-013	25 fb-1	05/03/2013
ZH (invisible decays)	ATLAS-CONF-2013-011	18 fb-1	05/03/2013
Higgs to dimuon	ATLAS-CONF-2013-010	21 fb-1	05/03/2013
Higgs to Zgamma	ATLAS-CONF-2013-009	25 fb-1	05/03/2013

May-2013	Full 8 TeV dataset: VBF H, H -> bb	TWiki, PAS
May-2013	Full 8 TeV dataset: ttH, H -> gamma gamma	TWiki, PAS
May-2013	Full 7+8 TeV dataset: VH, H -> bb	TWiki, PAS
May-2013	Full 8 TeV dataset: H -> WW -> lnuJ	TWiki, PAS
May-2013	Full 7+8 TeV dataset: H -> ZZ -> 2l2nu	TWiki, PAS
Apr-2013	Moriond Higgs Combination	TWiki, PAS
Mar-2013	Full 7+8 TeV dataset: H -> gamma gamma	TWiki, PAS
Mar-2013	Full 7+8 TeV dataset: H -> ZZ -> 4l	TWiki, PAS
Mar-2013	Full 7+8 TeV dataset: H -> WW -> 2l2nu	TWiki, PAS
Mar-2013	Full 7+8 TeV dataset: H -> tau tau	TWiki, PAS
Mar-2013	Full 7+8 TeV dataset: H -> Z gamma	TWiki, PAS
Mar-2013	Full 7+8 TeV dataset: H -> WWW -> 3l3nu	TWiki, PAS
Mar-2013	Full 7+8 TeV dataset: VH -> tau tau	TWiki, PAS

LHC in 2015

Potential performance

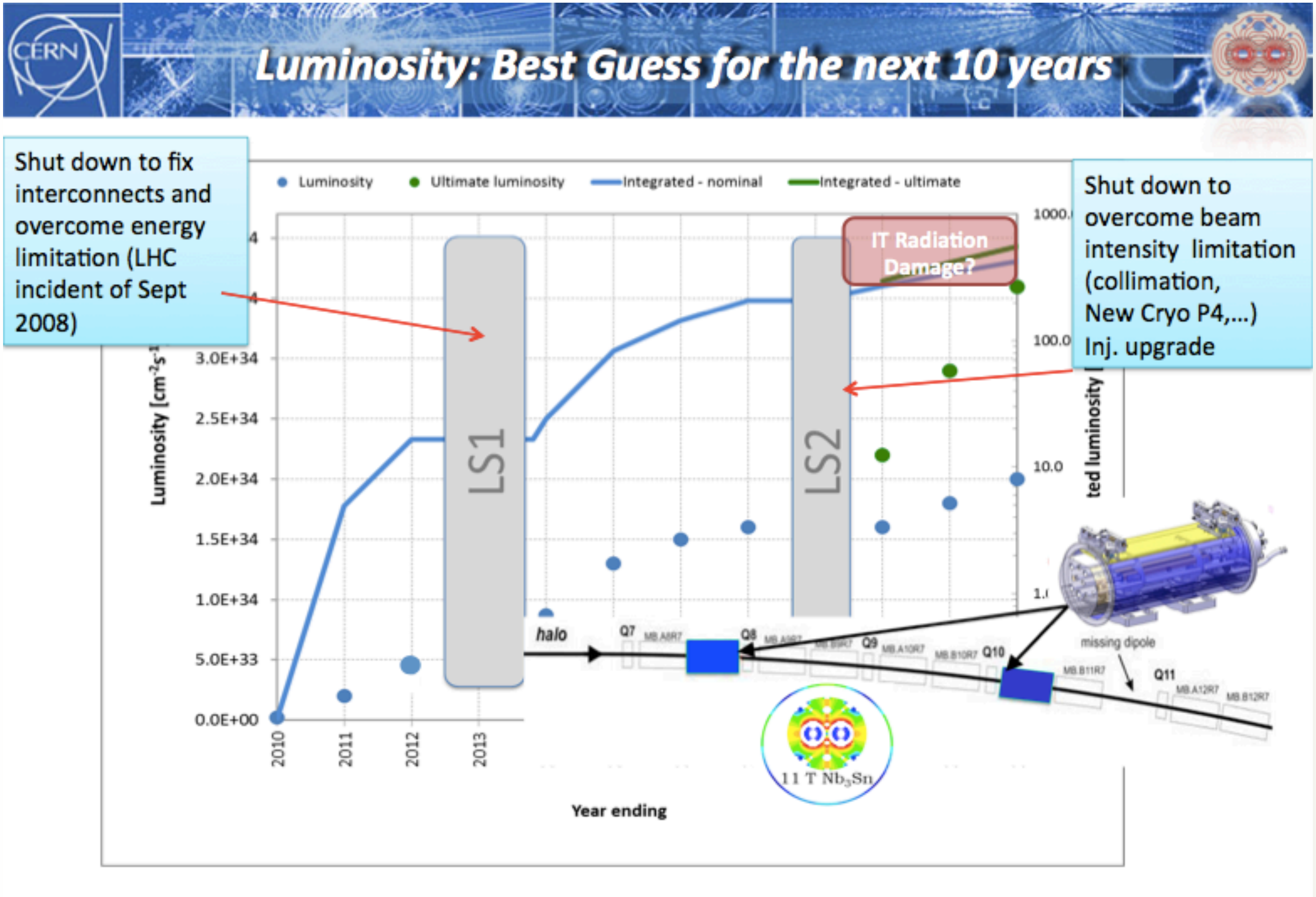
	Number of bunches	Ib LHC FT[1e11]	Collimator scenario	Emit LHC (SPS) [um]	Peak Lumi [$cm^{-2}s^{-1}$]	~Pile-up	Int. Lumi [fb^{-1}]
25 ns	2760	1.15	S1	3.5 (2.8)	9.2e33	21	24
25 ns low emit	2320	1.15	S4	1.9 (1.4)	1.6e34	43	42
50 ns	1380	1.6	S1	2.3 (1.7)	1.7e34 level 0.9e34	76 level 40	~45*
50 ns low emit	1260	1.6	S4	1.6 (1.2)	2.2e34	108	...

- 6.5 TeV
- 1.1 ns bunch length
- 150 days proton physics, HF = 0.2
- 70 mb visible cross-section
- * different operational model – caveat - unproven

All numbers approximate

LHCP 2013
Sergio Bertolucci CERN

LHC 10 yrs



CERN
Luminosity: Best Guess for the next 10 years
Shut down to fix interconnects and overcome energy limitation (LHC incident of Sept 2008)
Luminosity
Ultimate luminosity
Integrated - nominal
Integrated - ultimate
Shut down to overcome beam intensity limitation (collimation, New Cryo P4,...) Inj. upgrade
IT Radiation Damage?
Luminosity [cm⁻²s⁻¹]
3.0E+34
2.5E+34
2.0E+34
1.5E+34
1.0E+34
5.0E+33
0.0E+00
1000.
100.0
10.0
LS1
LS2
2010
2011
2012
2013
Year ending
halo
Q7
Q8
Q9
Q10
Q11
missing dipole
11 T Nb_3Sn