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CMS recent results

…with 2010 and 2011 data

On behalf of the CMS Collaboration

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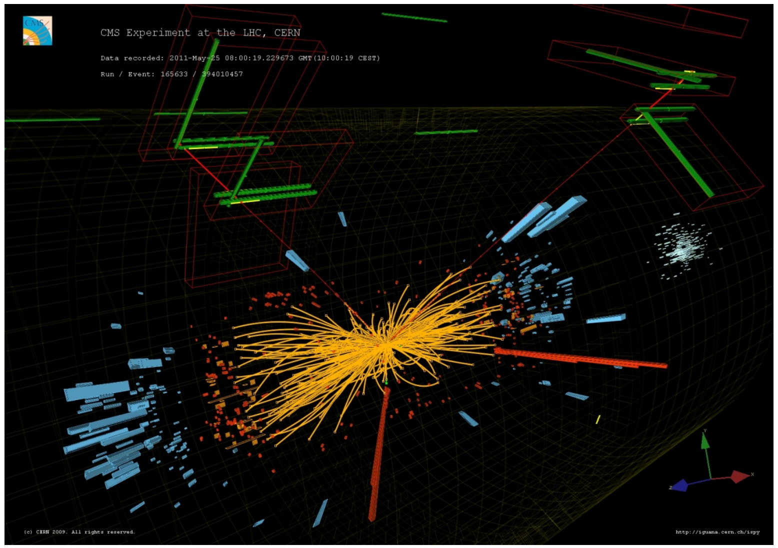
January 2012

Outline

- ***Introduction***
  - ***Physics motivation***
  - ***LHC and CMS***
- ***Results***
  - ***Top, electroweak, heavy flavours***
  - ***Higgs** (much of the material taken more or less directly from G. Tonelli's seminar 13.12.2011 at CERN)*
  - ***Beyond the Standard Model (SM)***
- ***Future***
- ***Summary***

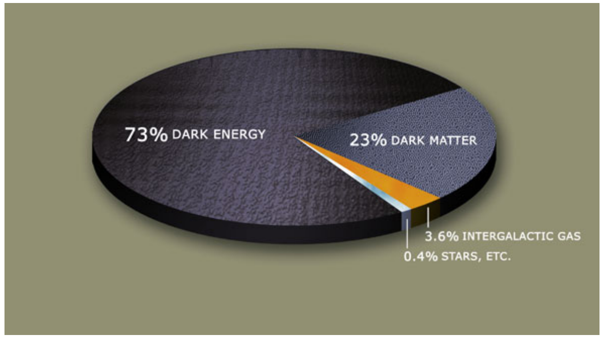
LHC physics goals

- **New particles or phenomena – rare/forbidden decays – precision measurements**
- **Higgs bosons – electroweak symmetry breaking**
- **Supersymmetry – solution to dark matter?**
- **Zoo of new particles – alternative theories beyond SM**
- **CP violation, very rare decays – SM or not?**
- **Precision measurements – indirect handle to physics at (even) higher energies**

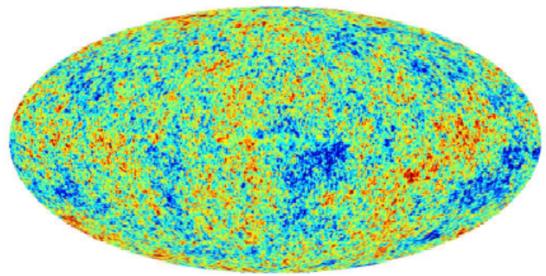


Evidence for physics beyond the Standard Model

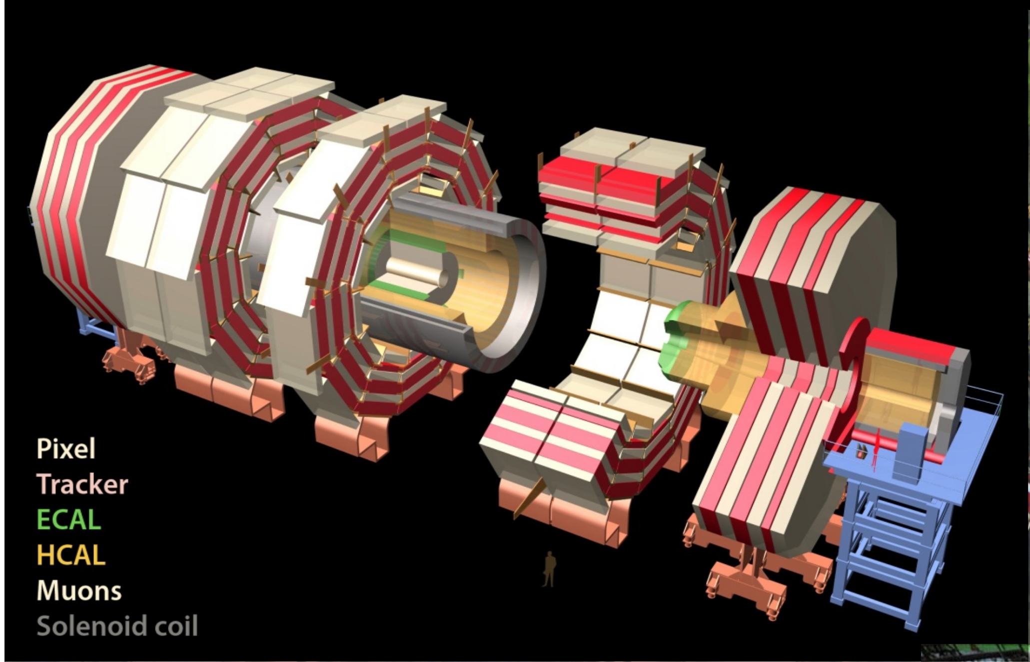
- Dark matter
- Neutrino masses
- Matter-antimatter asymmetry
- Accelerated expansion of the Universe

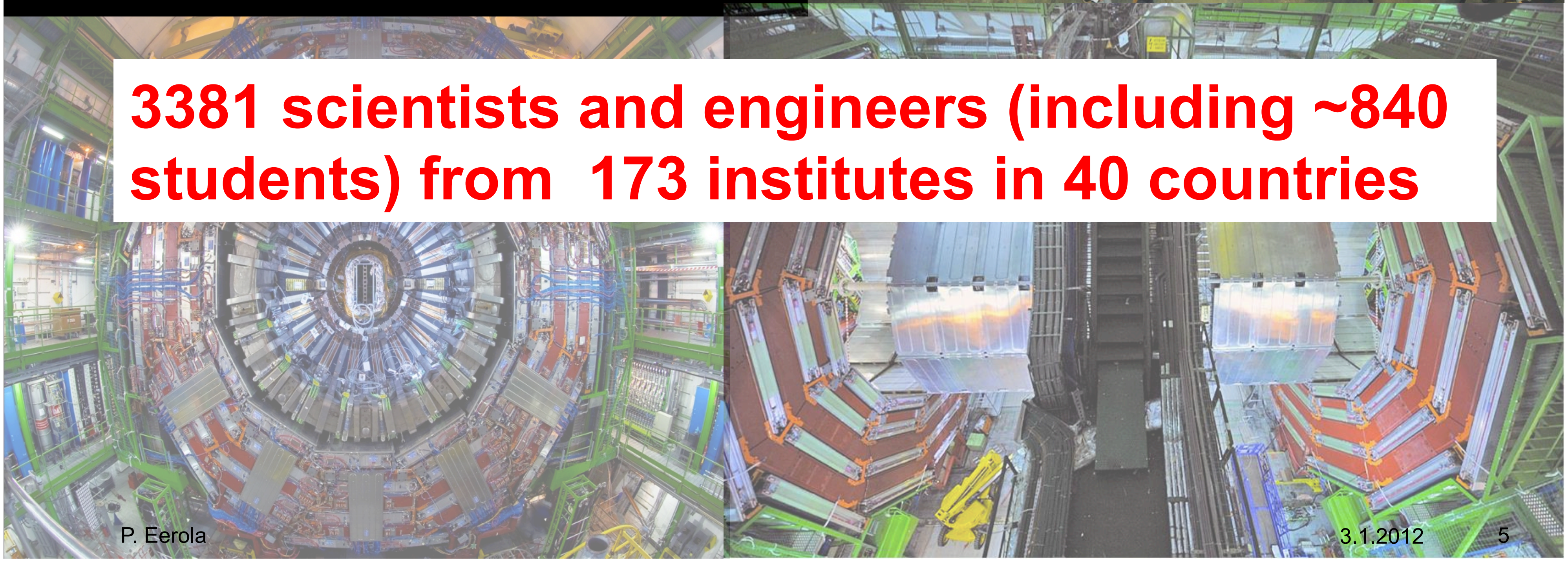


- Terascale physics: probe electroweak scale **10^{-19} m ← → TeV^{-1}**
- Why do we expect anything new to happen at this scale?
  - Some (new?) physics needed to break $SU(2)_L xU(1)_Y$ gauge invariance (electroweak symmetry breaking)
- Is TeV an indirect new scale?
  - Supersymmetry breaking at higher scale → effects at TeV-scale
  - Technicolor
- Is TeV a fundamental new scale?
  - Extra dimensions
  - Strings at TeV scale



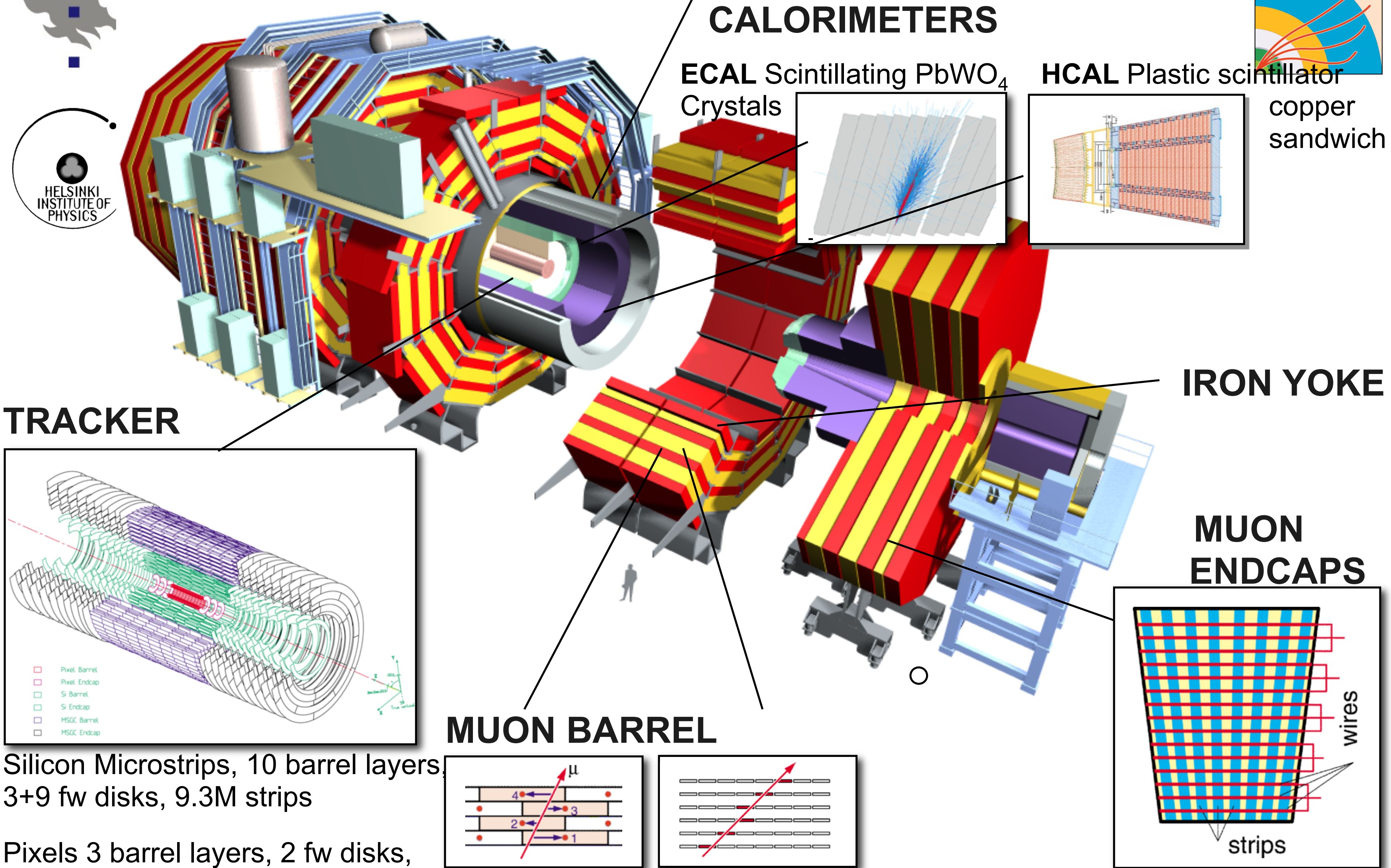
The CMS Collaboration





3381 scientists and engineers (including ~840 students) from 173 institutes in 40 countries

The CMS detector



Silicon Microstrips, 10 barrel layers, 3+9 fw disks, 9.3M strips

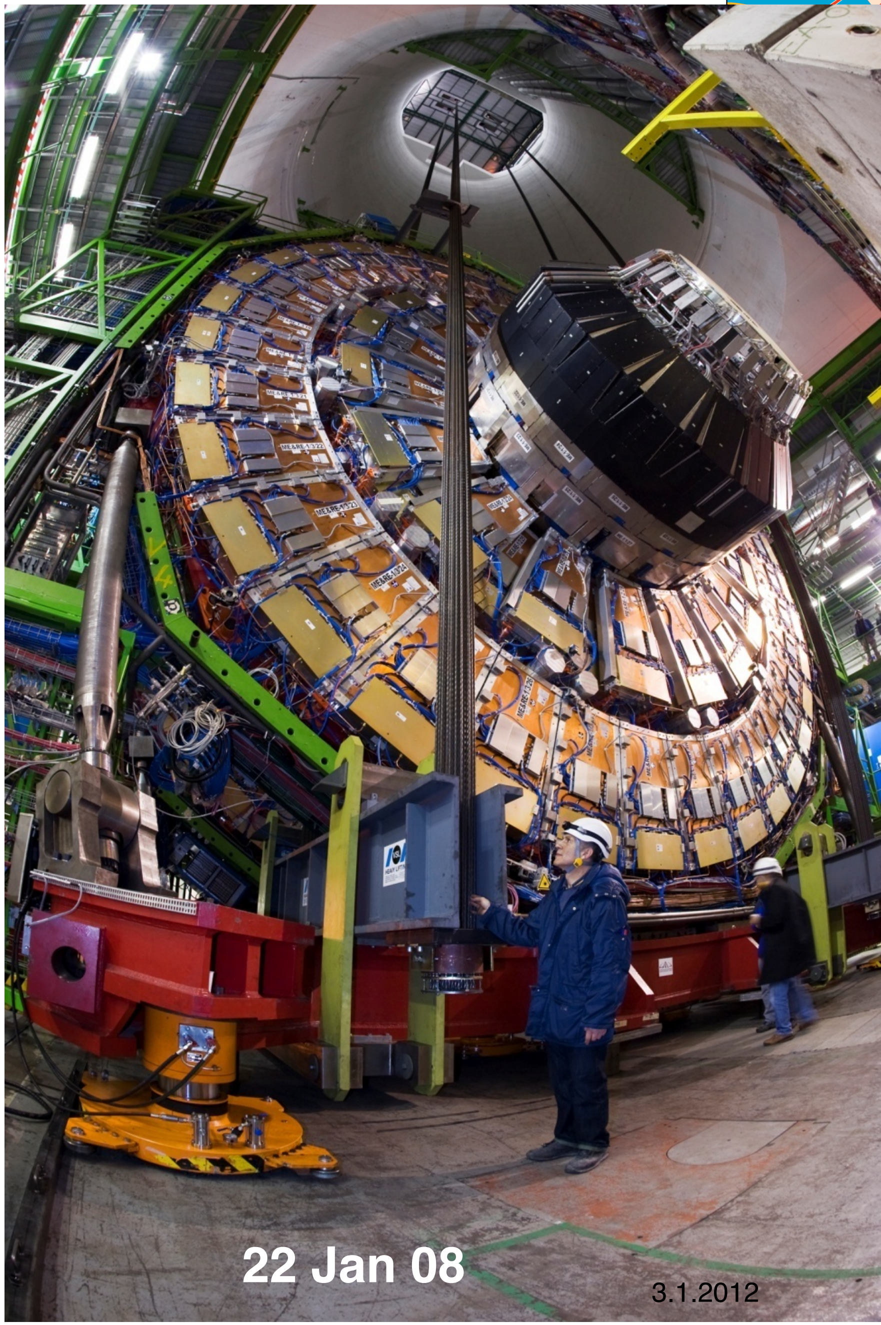
Pixels 3 barrel layers, 2 fw disks, 66M channels

Drift Tube Chambers (**DT**)

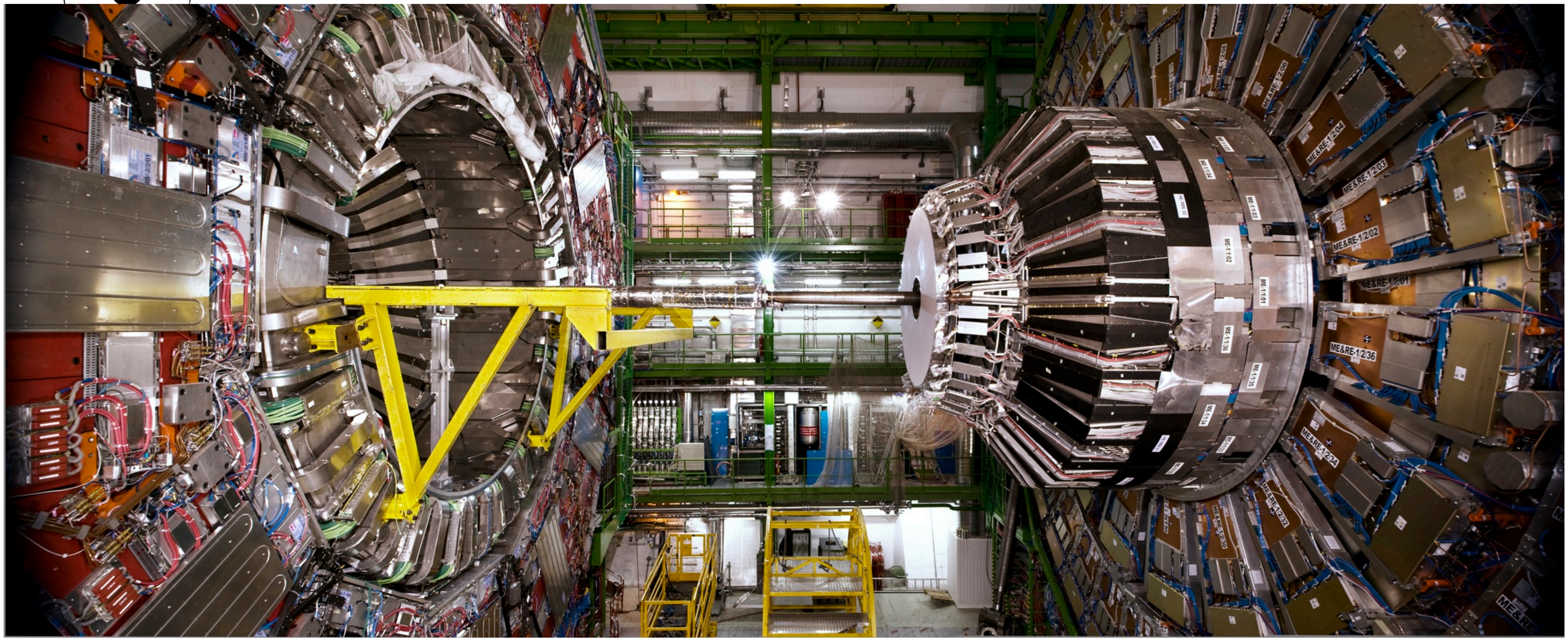
Resistive Plate Chambers (**RPC**)

Cathode Strip Chambers (**CSC**)
Resistive Plate Chambers (**RPC**)

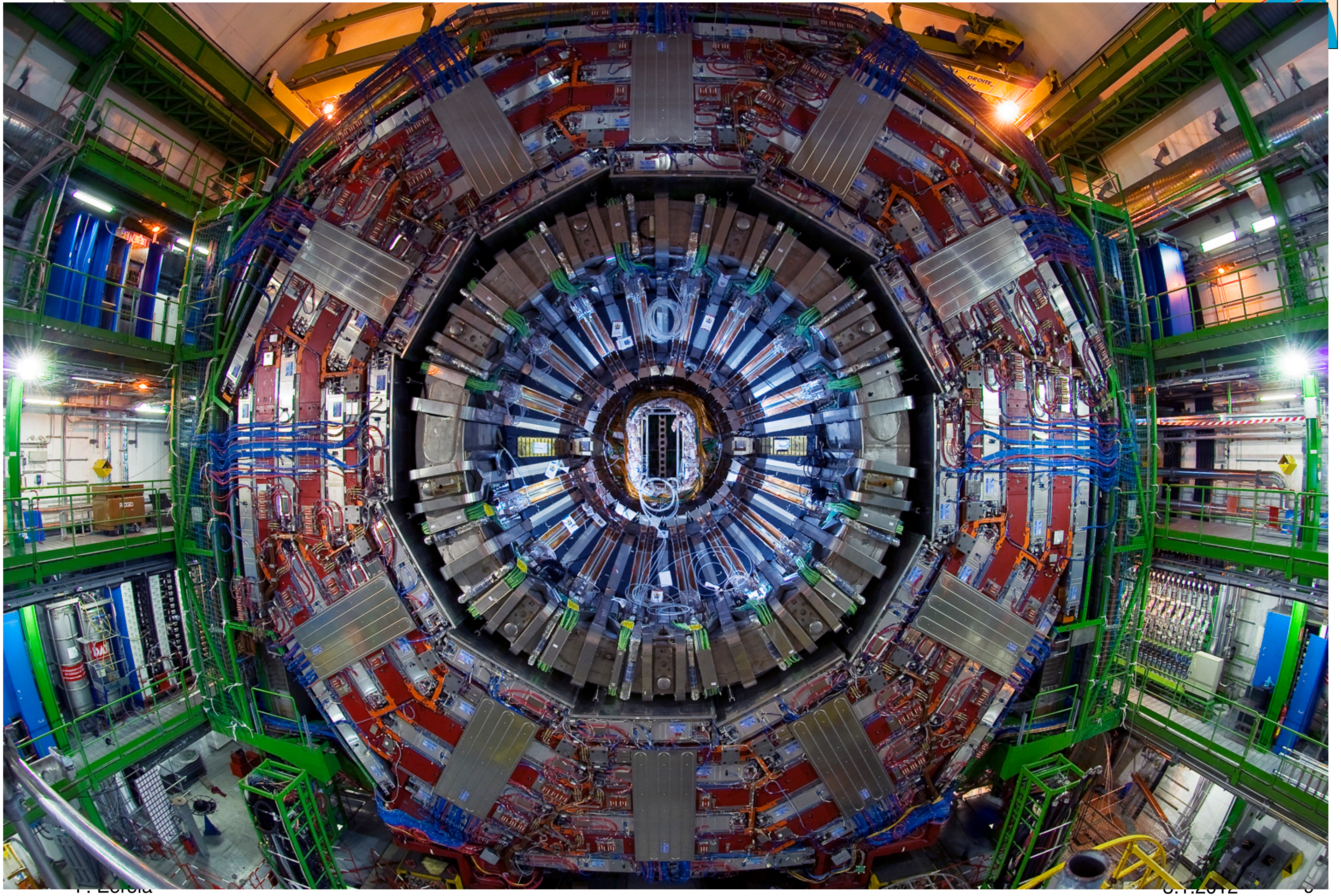
CMS: lowering of muon endcaps to the cavern



Beampipe assembly inside CMS

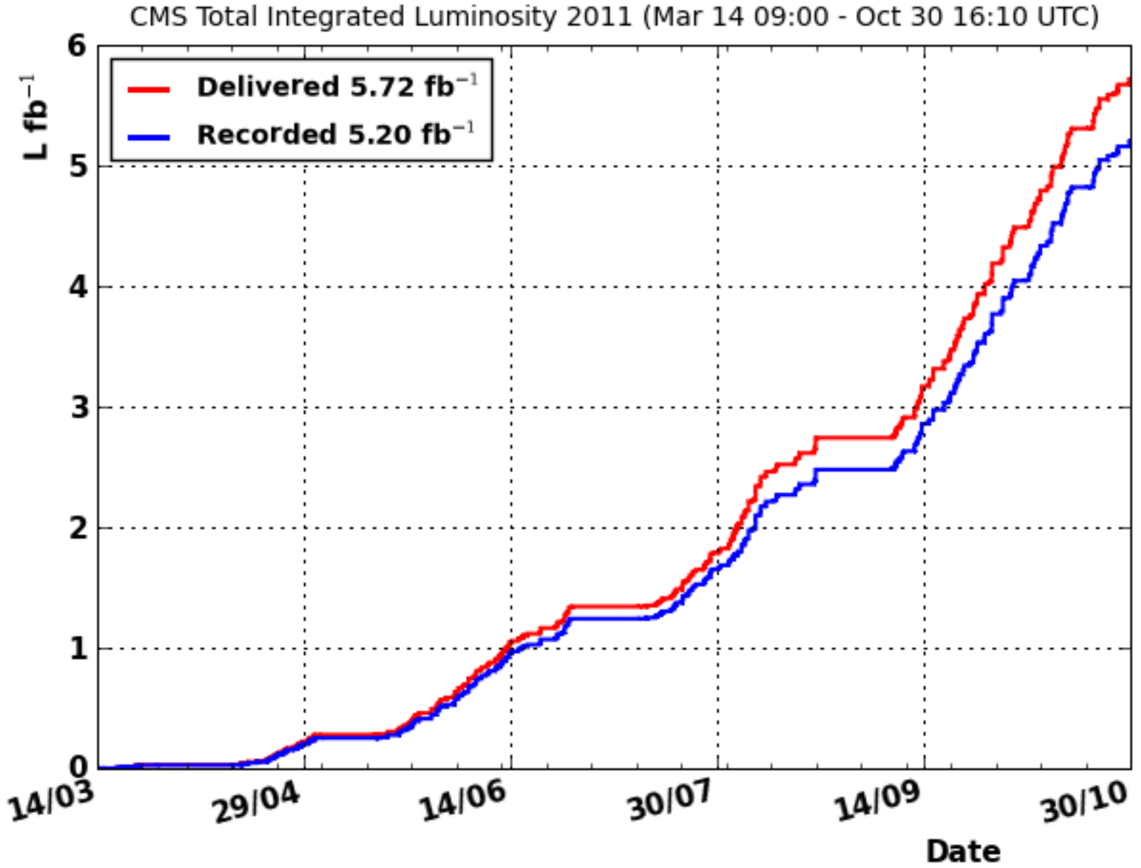


CMS after assembly



LHC: performance 2011

Amount of data 2011
x 140

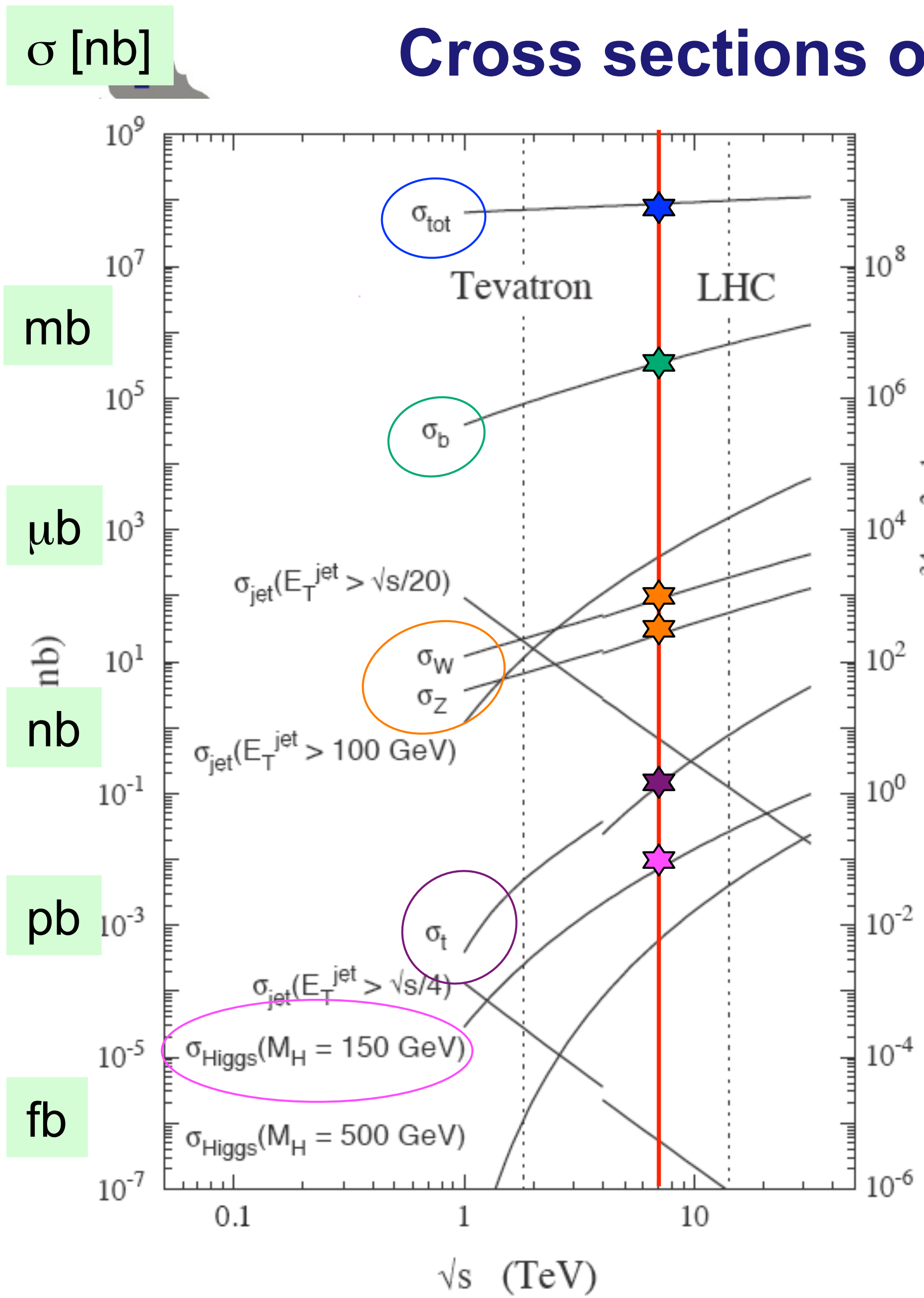


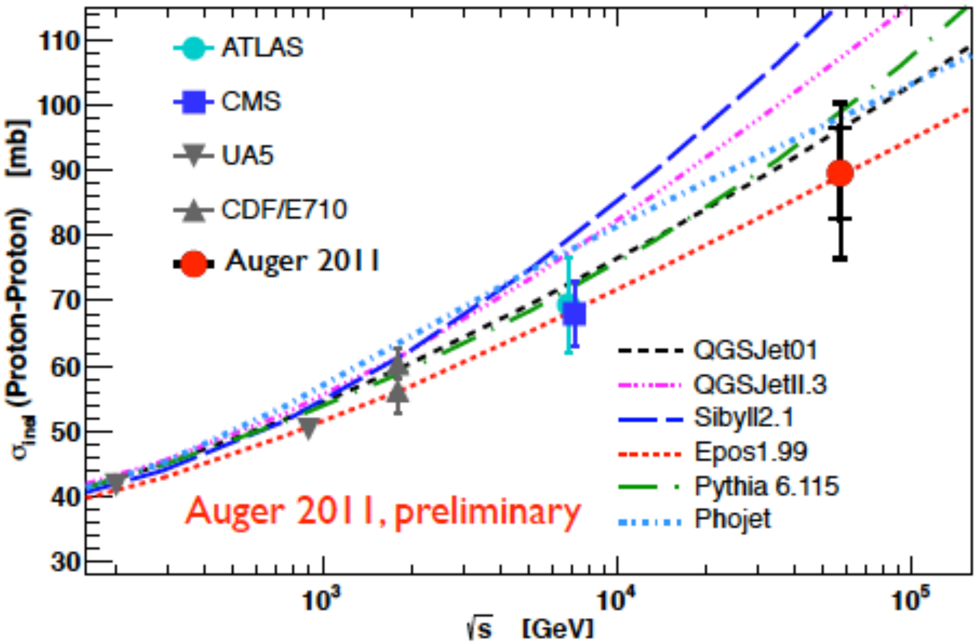
Amount of data 2010

5.72 fb^{-1} delivered by LHC and **5.2 fb^{-1}** recorded by CMS. Overall data taking efficiency **~91%. Average fraction of operational channels per subsystem >98.5%.** Uncertainty on the luminosity determination **4%**.

Results

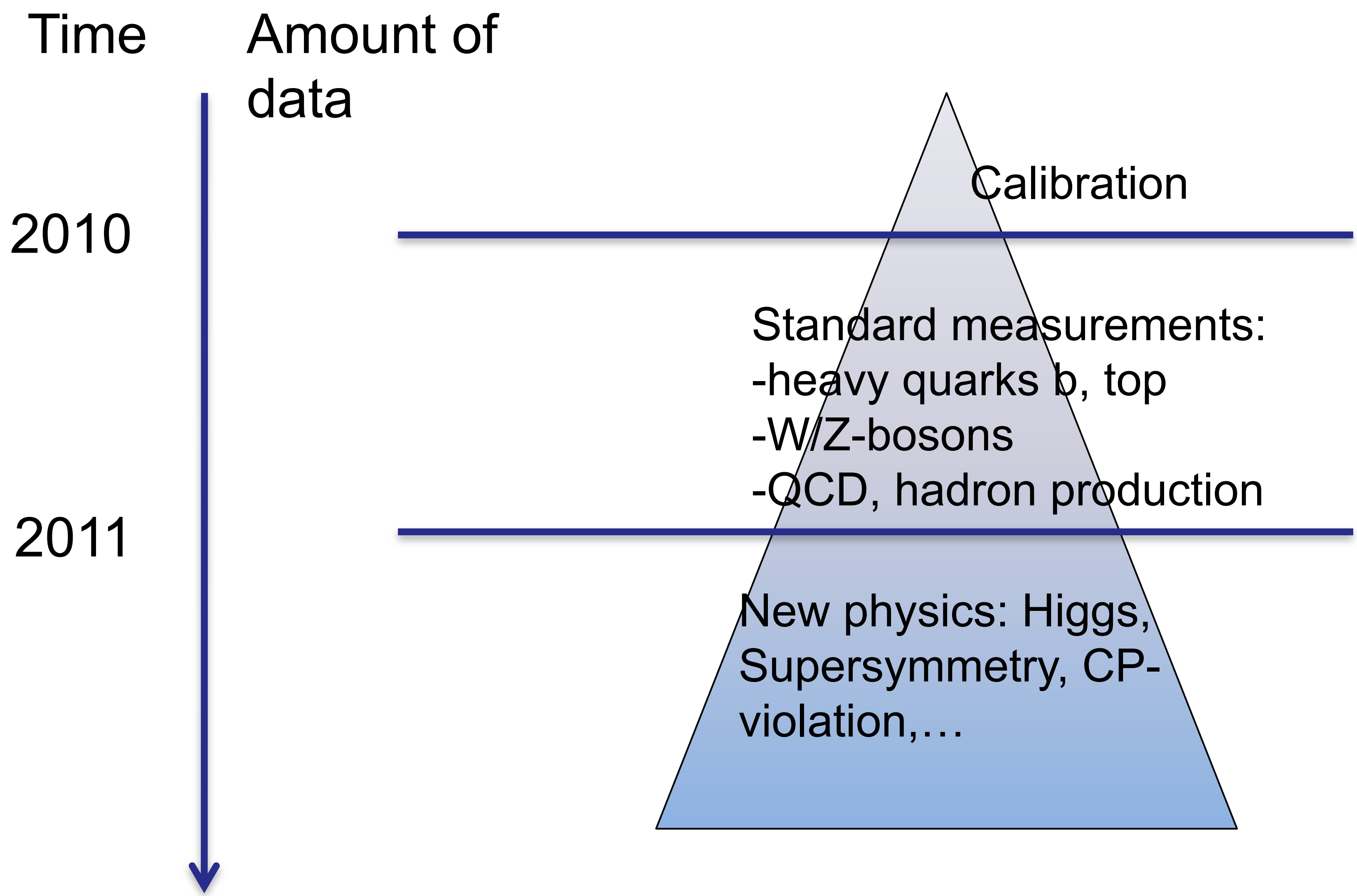
Cross sections of physics processes



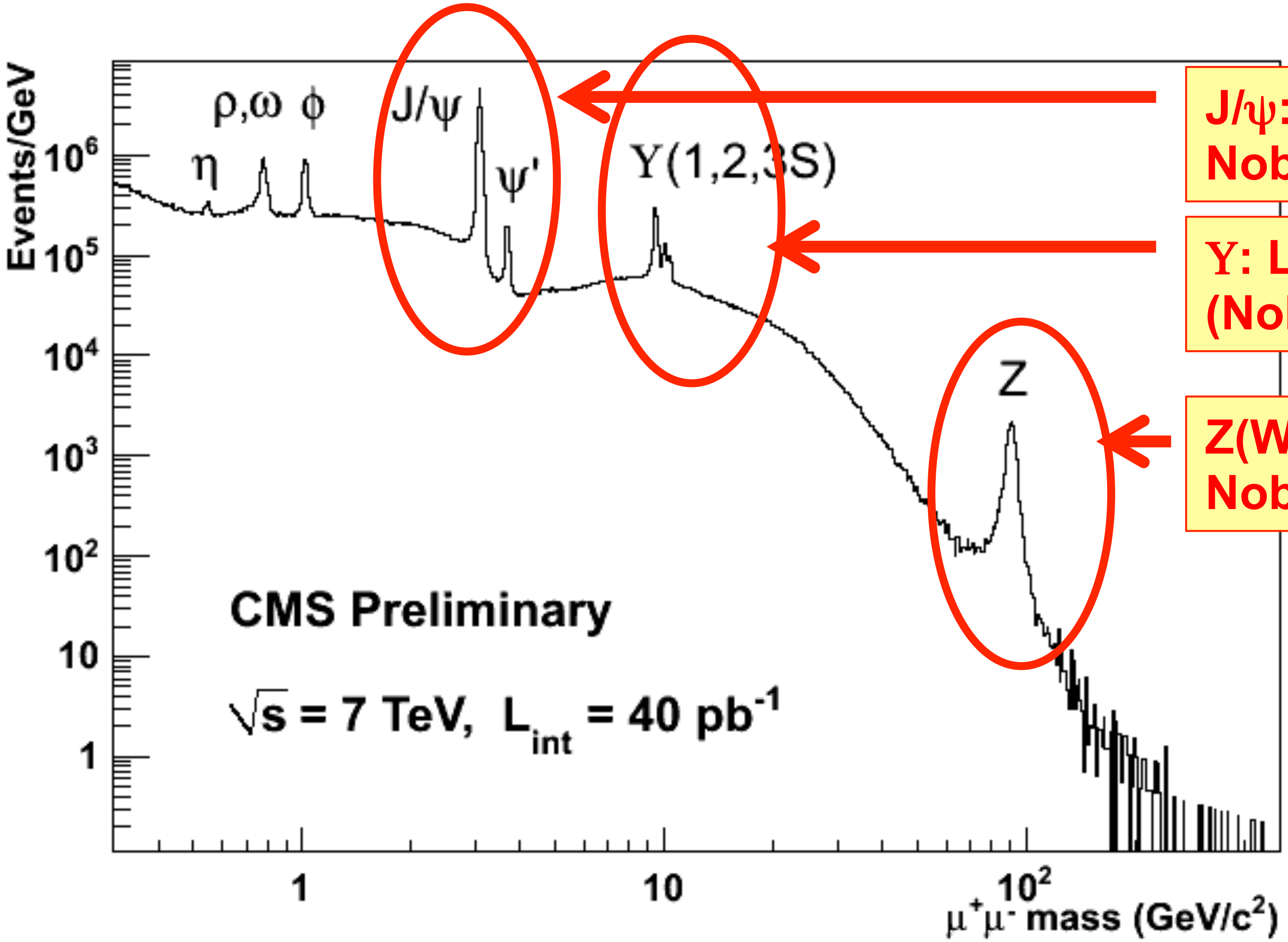


Total proton-proton production cross section

LHC physics 2010 →



Discovery → calibration → background

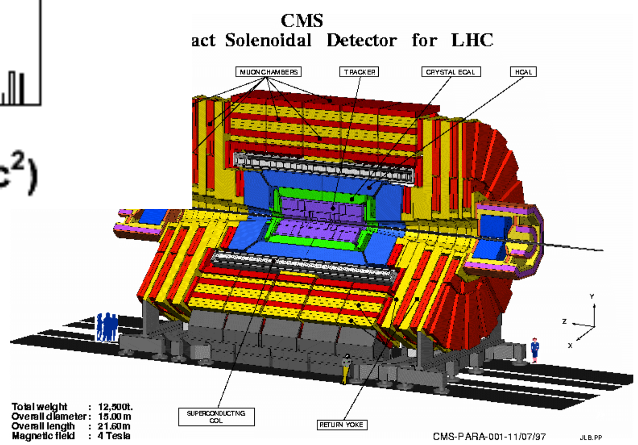


J/ψ: Richer, Ting 1974
Nobel 1976

Υ: Lederman et al 1977
(Nobel 2008 CKM – b-quark)

Z(W): Rubbia et al 1983
Nobel 1984

Invariant ($\mu^+\mu^-$) mass

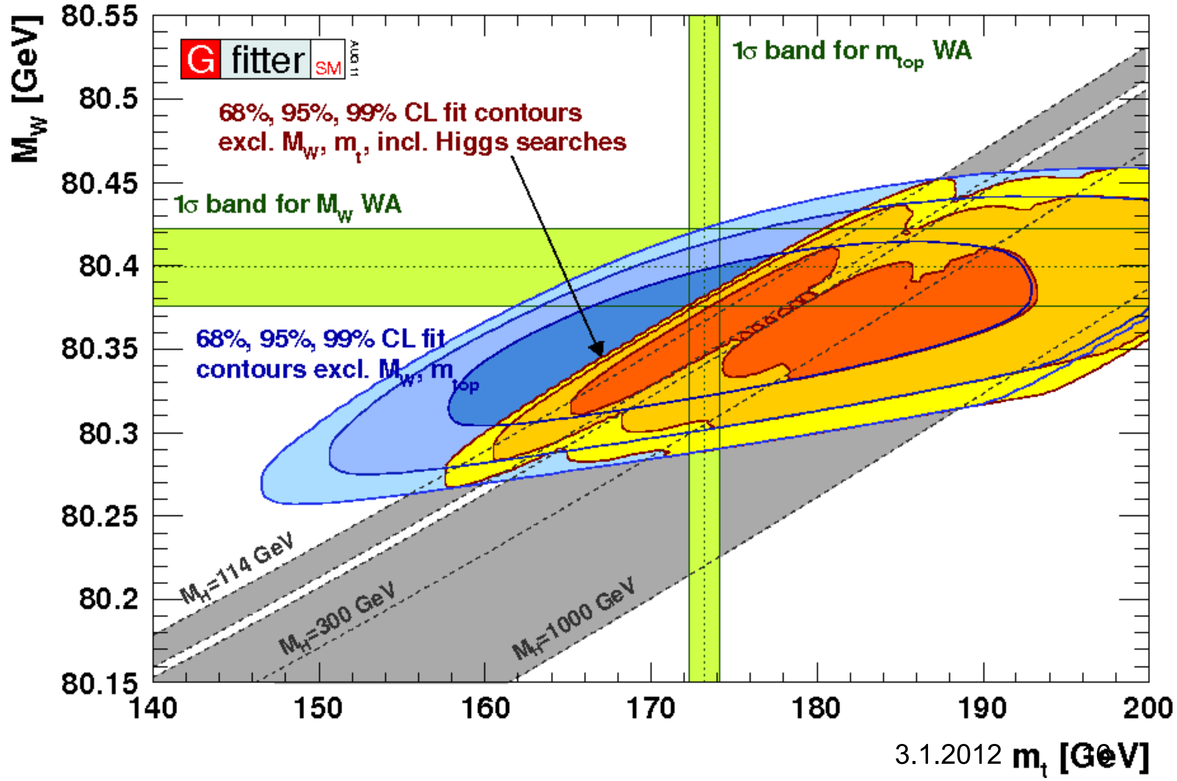


Selected Standard Model measurements

Top quark

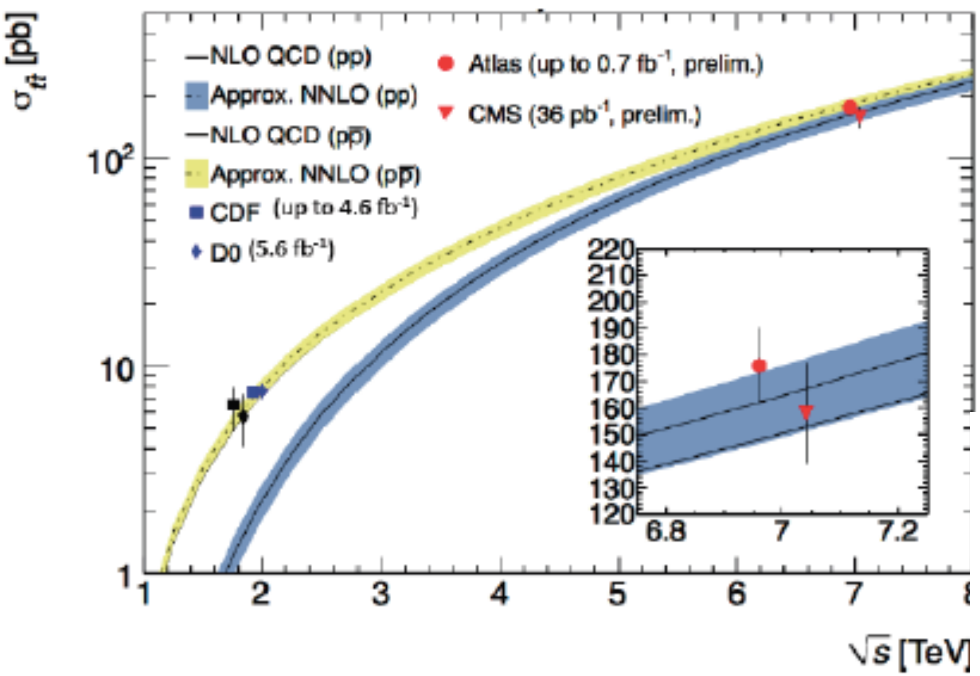
- Newest quark, found 1995 at Tevatron
- Heaviest known particle
  - **Precision measurements** needed: mass, intrinsic properties, cross section, decays, couplings
  - Find or exclude non-standard values

- **Sensitive to Higgs mass through electroweak loop corrections**
- Sensitive to other new particles
- Background to new particle searches

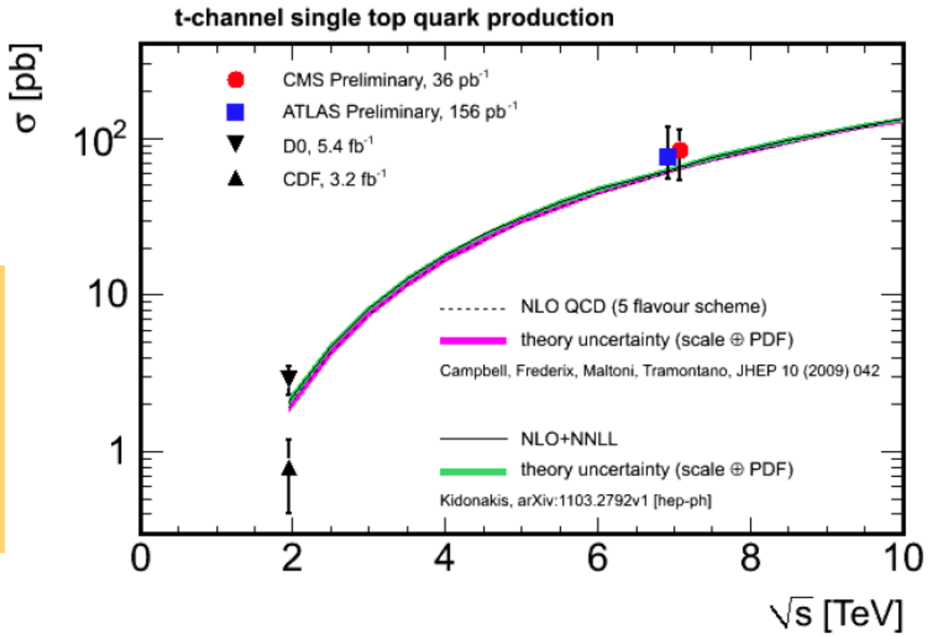


- **Cross section: new measurements at new energy**
- **Top mass and V_{tb}: measurements still worse than at Tevatron, improving soon**

Top-quark pair production cross section

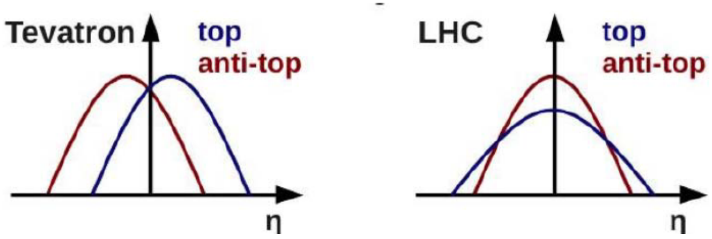


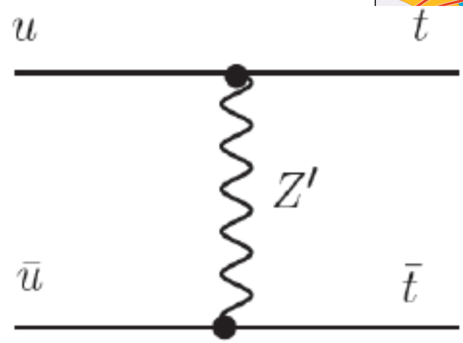
Single top-quark production
Sensitive to $|V_{tb}|$
Tevatron: $|V_{tb}|=0.88 \pm 0.07$
CMS: $|V_{tb}|=1.16 \pm 0.22$



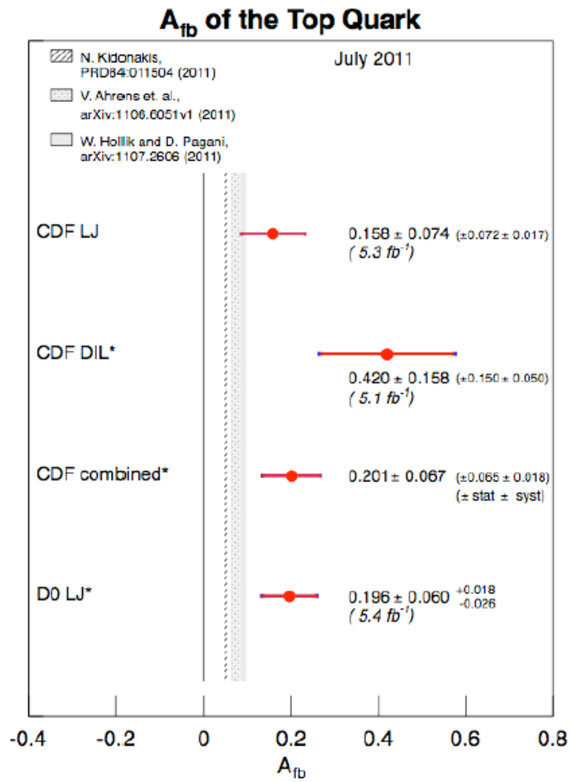
Top mass:
Tevatron
m_{top} = (173.2 ± 0.6 (stat.) ± 0.2 (syst.)) GeV
LHC
m_{top} = (173.4 ± 1.9 (stat.) ± 2.4 (syst.)) GeV

Top-quark forward-backward asymmetry A_{FB}

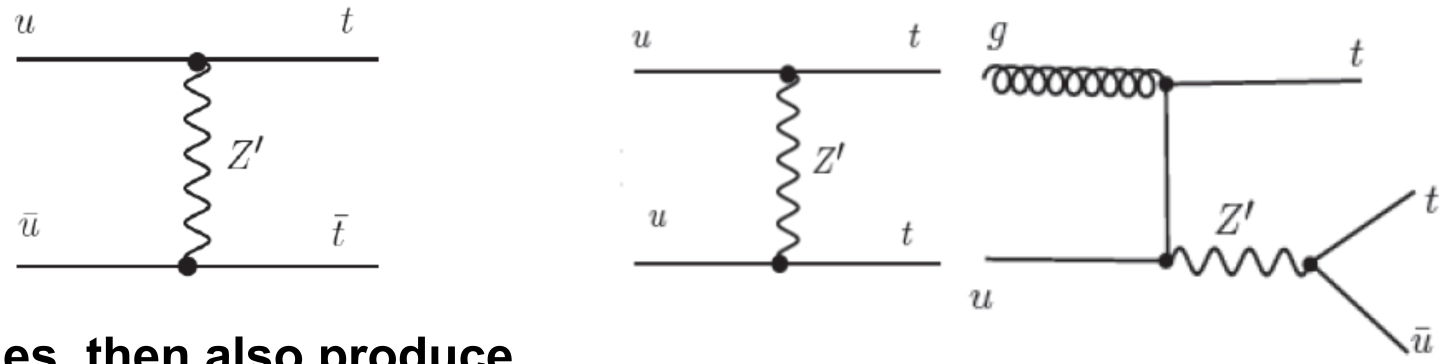




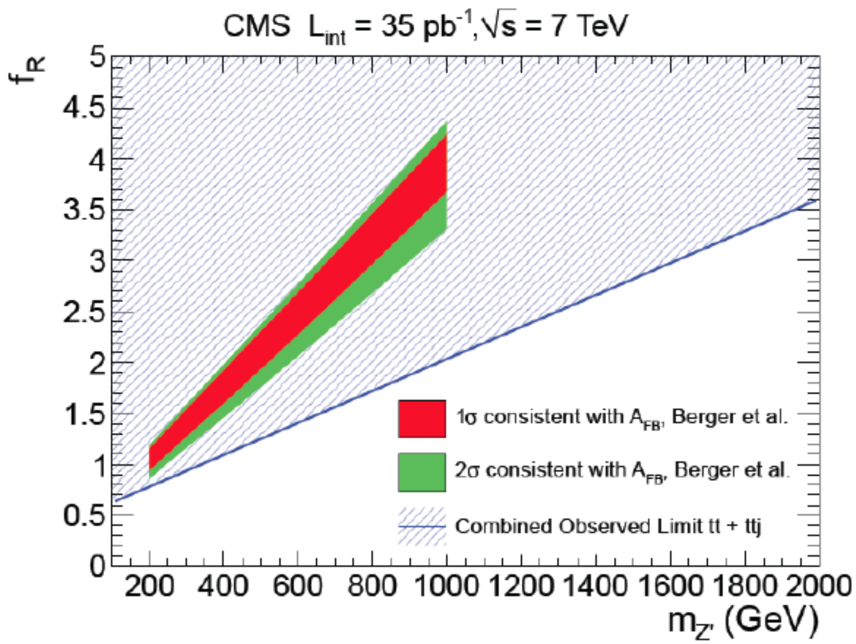
- **Tevatron ($p\bar{p}$ collider):**
  - SM: small asymmetry from higher order effects
  - **Measured asymmetry higher than expected, specially at high m_{tt} (CDF 3σ)**
  - Speculations about new particles $p\bar{p} \rightarrow X \rightarrow t\bar{t}$
- **LHC (pp collider):**
  - No forward-backward asymmetry due to symmetric initial state
  - Quarks have on average more momentum than antiquarks → boost difference → **central-decentral asymmetry** (but 85% from gg are symmetric)
  - Difficult measurement, but **ATLAS/CMS should be able to obtain same sensitivity as CDF**



Forward-backward asymmetry A_{FB} and same-sign top quarks



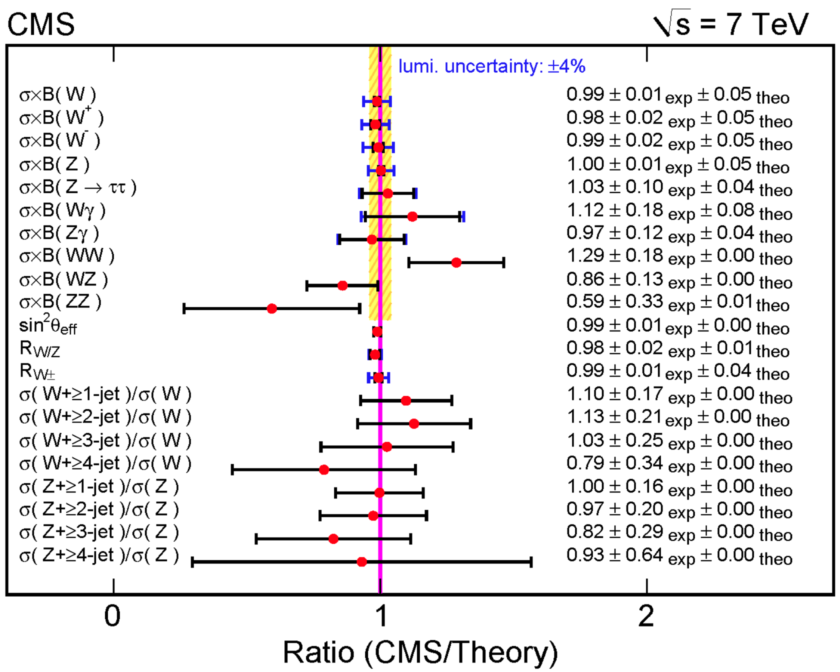
- **If new particles, then also produce same-sign top quarks**
- **CMS search: exclude region preferred by CDF A_{FB} results**



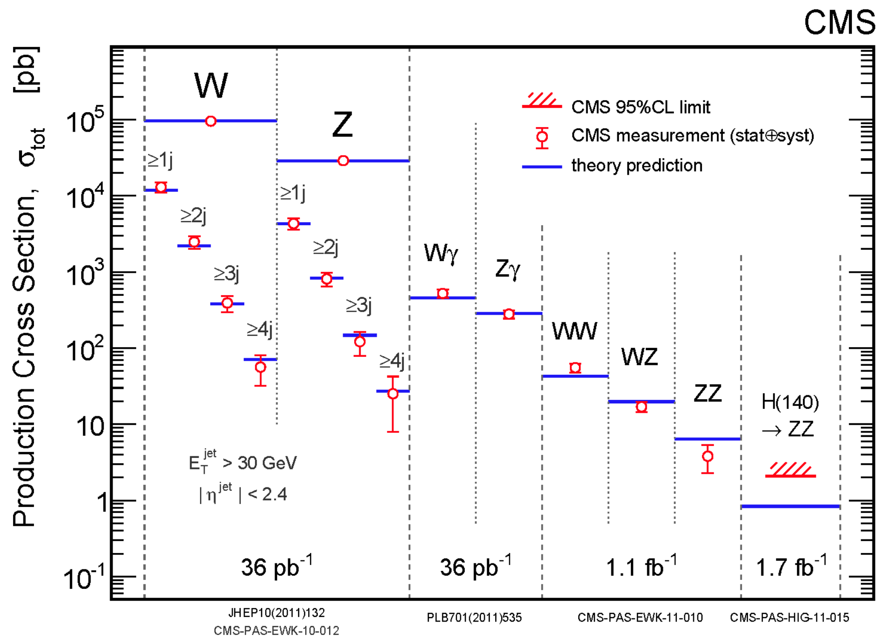
Electroweak measurements

- **W, Z, diboson production, W and Z couplings, W mass, W(Z)+jets**
  - **m_W sensitive to Higgs mass through electroweak loop corrections**
  - **Key background to SM Higgs searches**
  - No Higgs: WW cross section?
  - Triple gauge boson couplings
  - Unexpected signals like Wjj at CDF

All measurements agree with the Standard Model



Comparison to theory

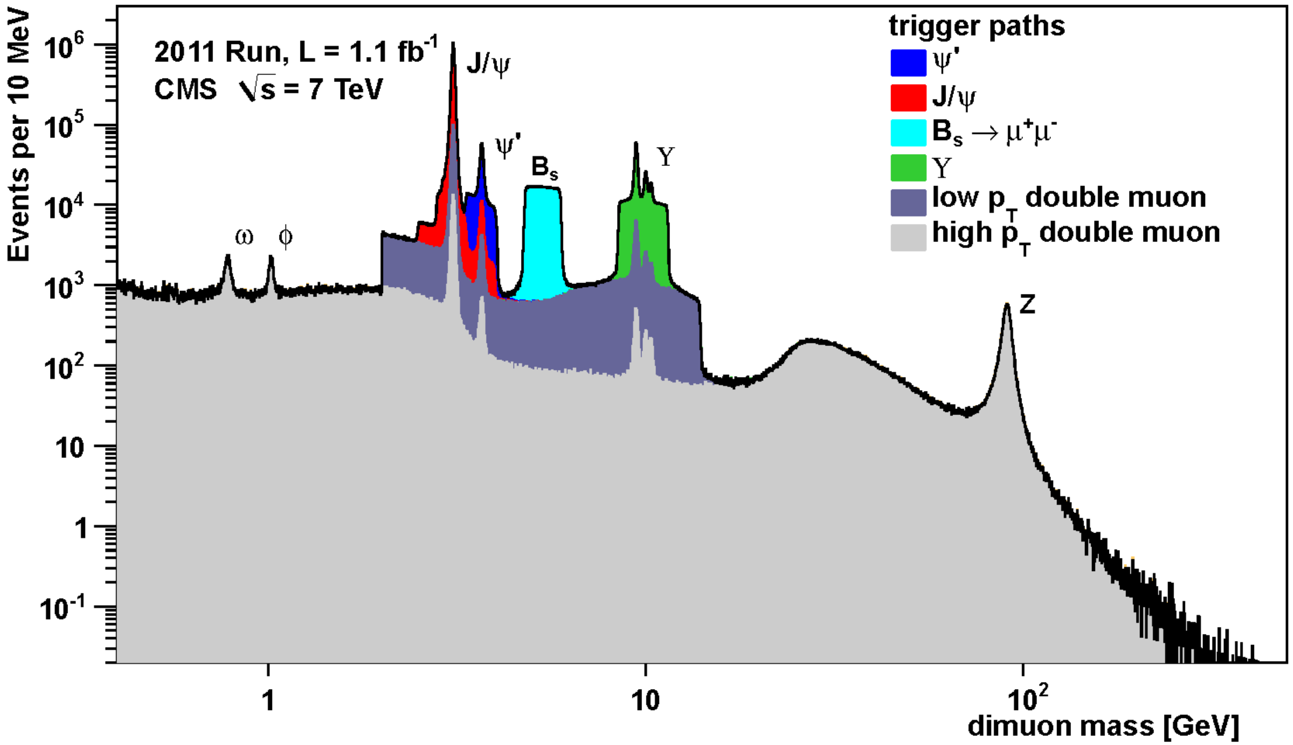


Production cross sections

Heavy flavours: physics with b quarks

B physics with CMS

- General purpose experiment: main challenges trigger bandwidth, no hadron triggers at level-1, no π/K separation
- → Concentrate on dilepton channels
- → Use highly "specialized" triggers: apply at High Level Trigger already as many selections as possible

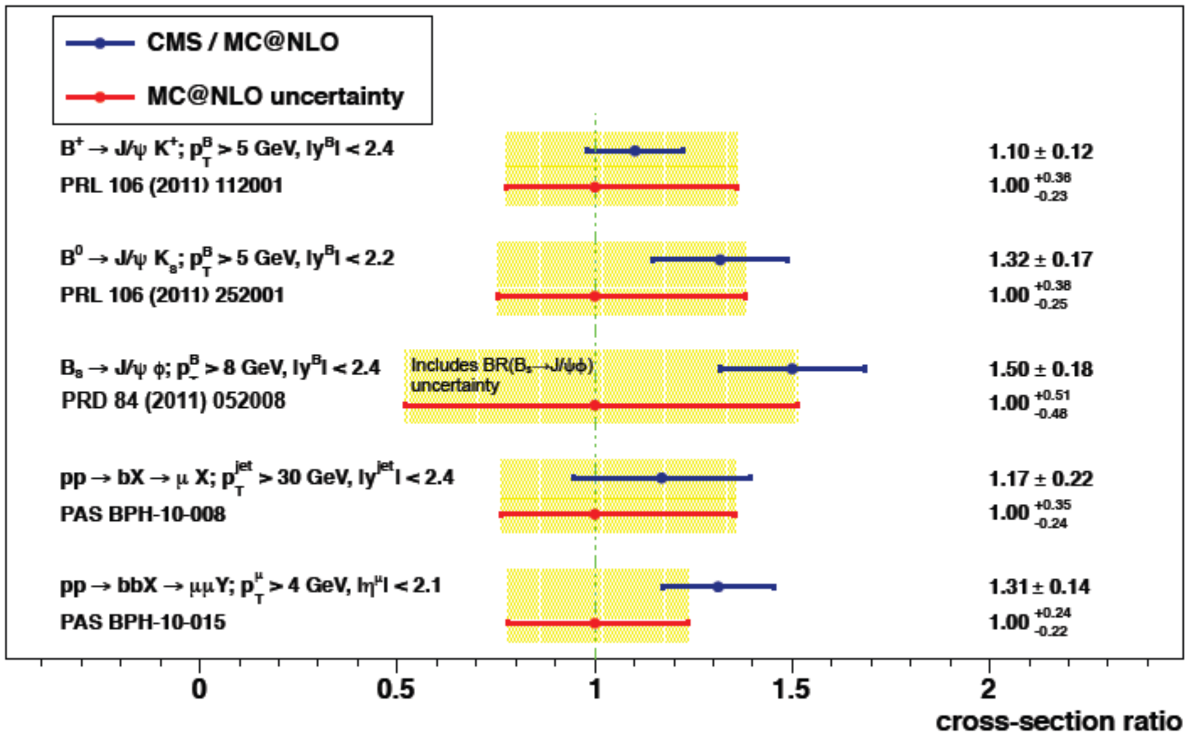


Cross section measurements

- Probing QCD in **different kinematical domains**
- All measurements confirming that **MC@NLO undershoots data at 7 TeV** (within uncertainties)
- CMS has also the first LHC result on **bb angular correlations**

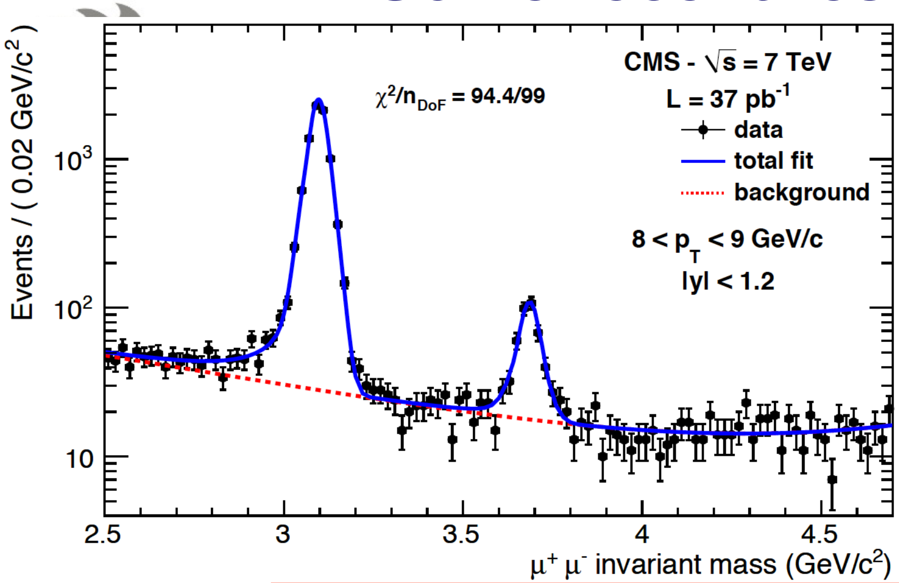
Exclusive $B \rightarrow J/\psi X$ decays

Inclusive $B \rightarrow$ muons



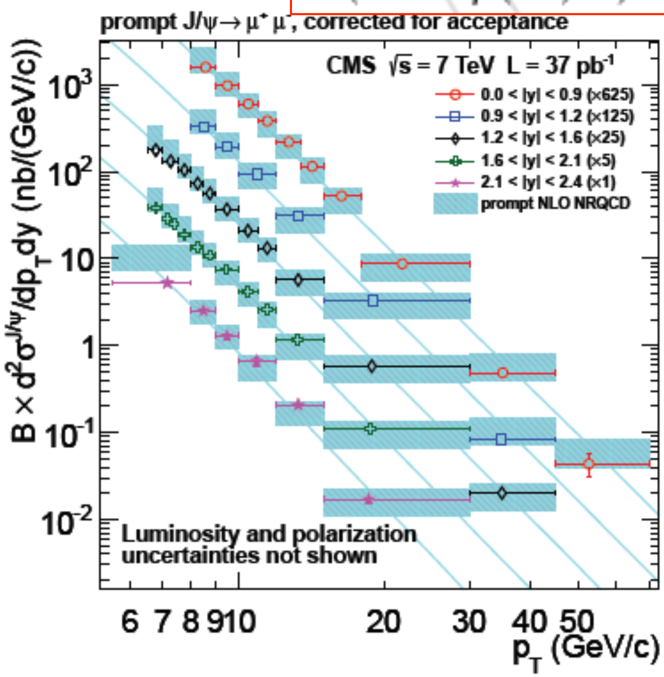
B^+ CMS PAS BPH-010-04, PRL 106, 112001 (2011); B^0 CMS PAS BPH-010-05, PRL 106, 252001 (2011); B_s CMS PAS BPH-010-013, PRD 84, 052008 (2011); inclusive CMS PAS BPH-10-008, CMS PAS 10-015

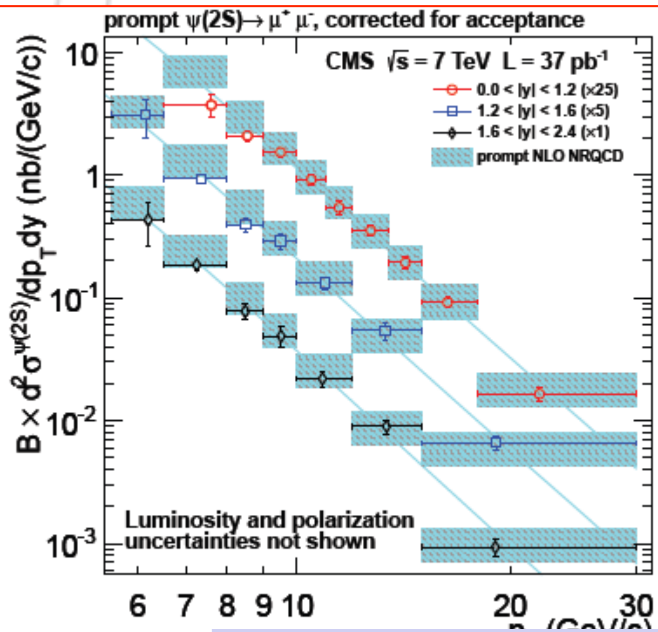
Some recent results: J/ψ and ψ(2S)

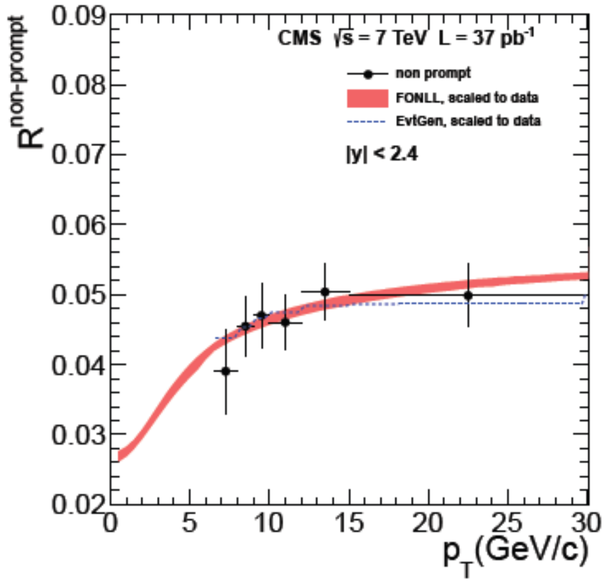


- ψ(2S) cleaner probe of NRQCD (no feed-down from heavier states)
- Differential cross-sections show good agreement with predictions
- Inclusive BR of B → ψ(2S) extracted from cross-section ratio, improving PDG uncertainty by a factor 3:

$$\mathcal{B}(B \to \psi(2S)X) = (3.08 \pm 0.12(\text{stat.} + \text{syst.}) \pm 0.13(\text{theor.}) \pm 0.42(\mathcal{B}_{\text{PDG}})) \cdot 10^{-3},$$







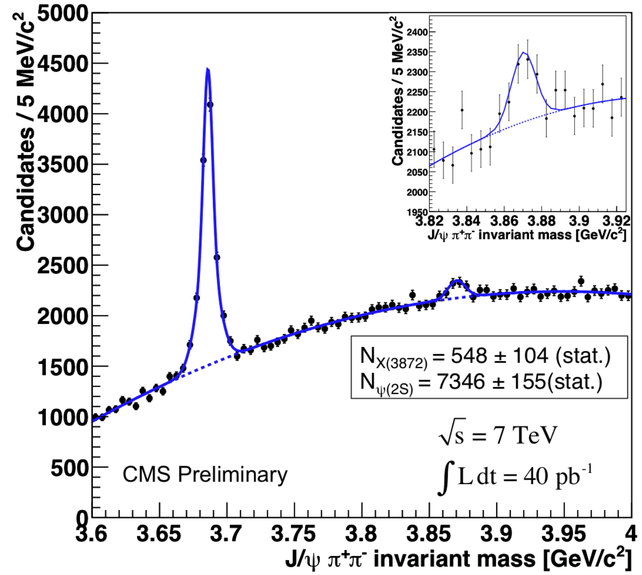
P. Eerola

CMS PAS BPH-010-14, arXiv:1111.1157

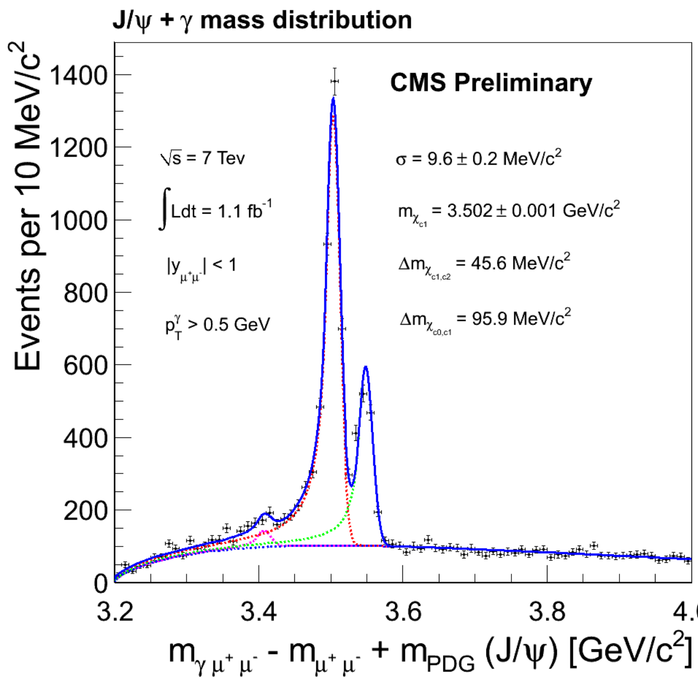
X(3872) and $\chi_{c0,c1,c2}$

Ratio of σxBR for X(3872)/ψ(2S) in the kinematic region p_T(X) > 8 GeV and |y(X)| < 2.2 is measured to be

R = 0.087 +/- 0.017(stat.) +/- 0.009(syst.)

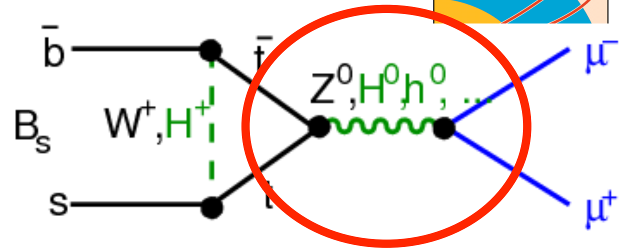


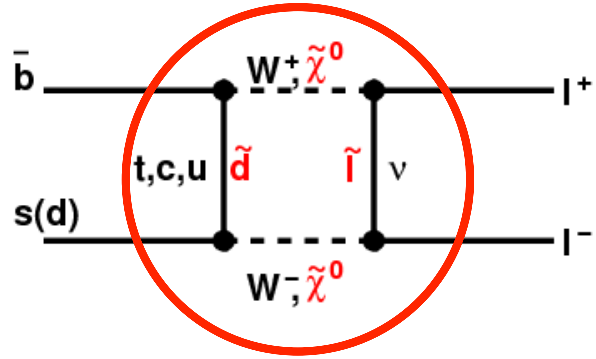
Reconstruction of χ_{c0}, χ_{c1}, χ_{c2} using converted photons



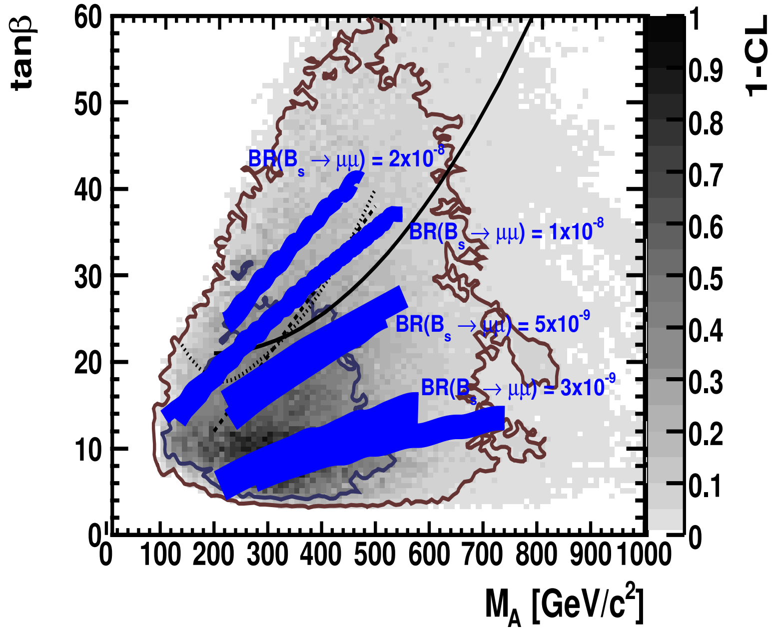
CMS PAS BPH-010-18; CMS DP 2011-011

Looking for new physics: very rare B decays



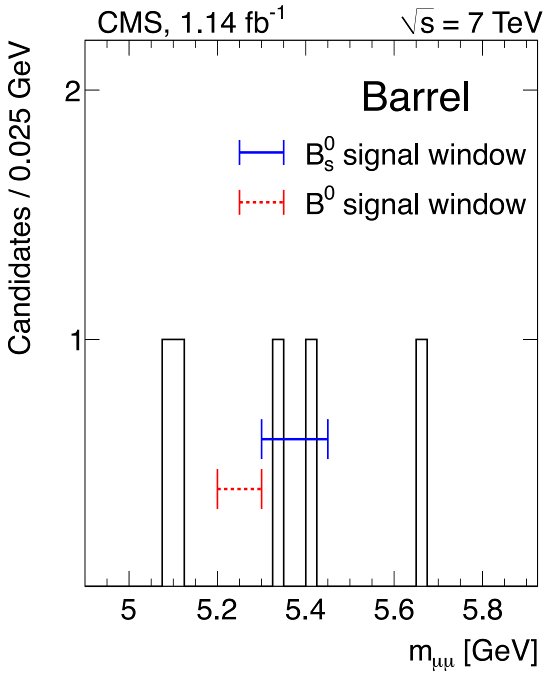


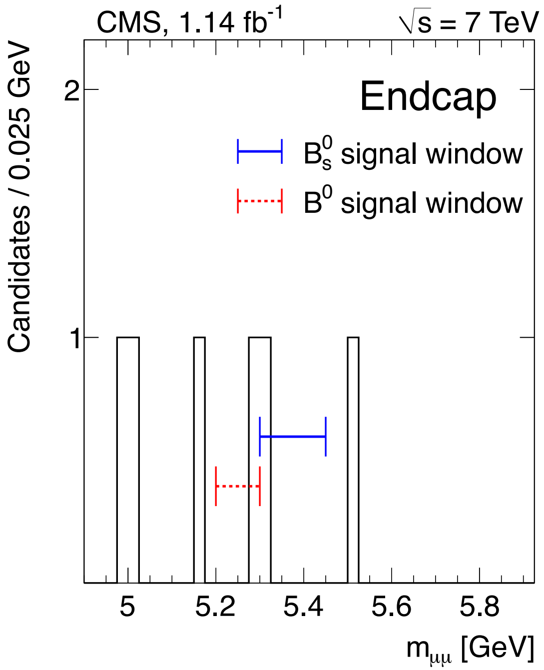
- **$B^0_s \rightarrow \mu^+\mu^-$**
- Very rare in the Standard Model due to GIM and helicity suppression: **$BR(B^0_s \rightarrow \mu^+\mu^-) = (3.2 \pm 0.2)\times10^{-9}$**
- Sensitive to physics beyond the Standard Model: **new particles entering in the loops**
- Eg. MSSM: $BR_{MSSM}(B_q \rightarrow \ell^+\ell^-) \propto \frac{m_b^2 m_\ell^2 \tan^6\beta}{m_A^4}$



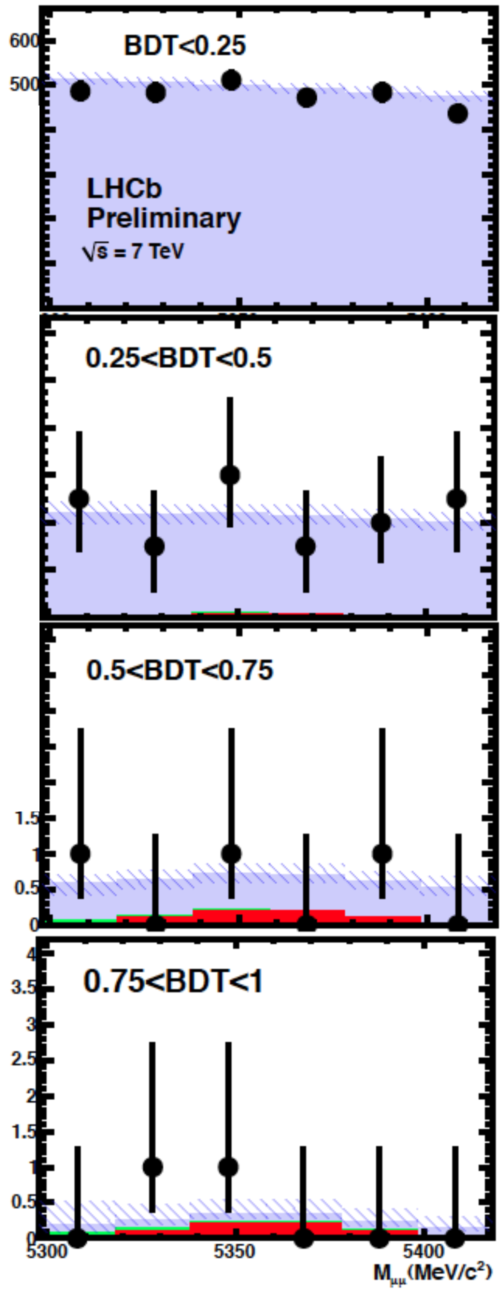
F. Mahmoudi, Eur.Phys.J.C64(2009)391 NUHM1

CMS results





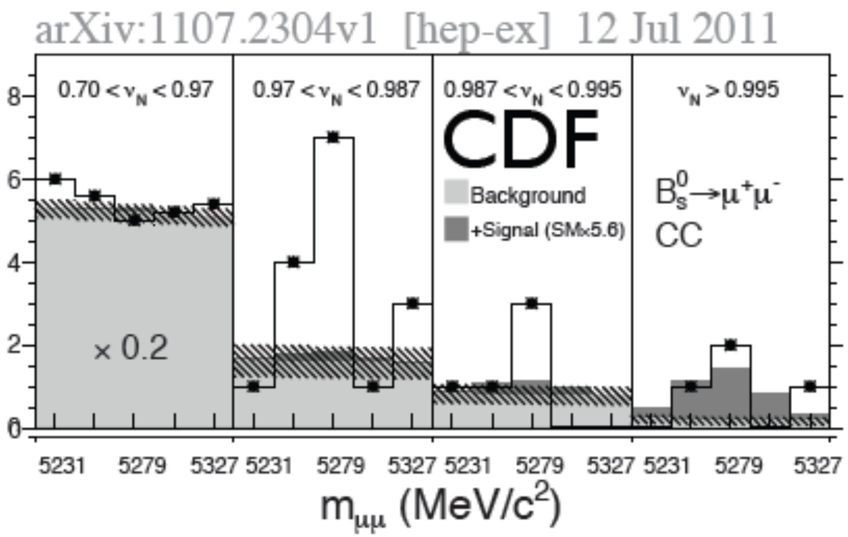
LHCb results



CMS PAS BPH-011-02
PRL 107, 191802 (2011)

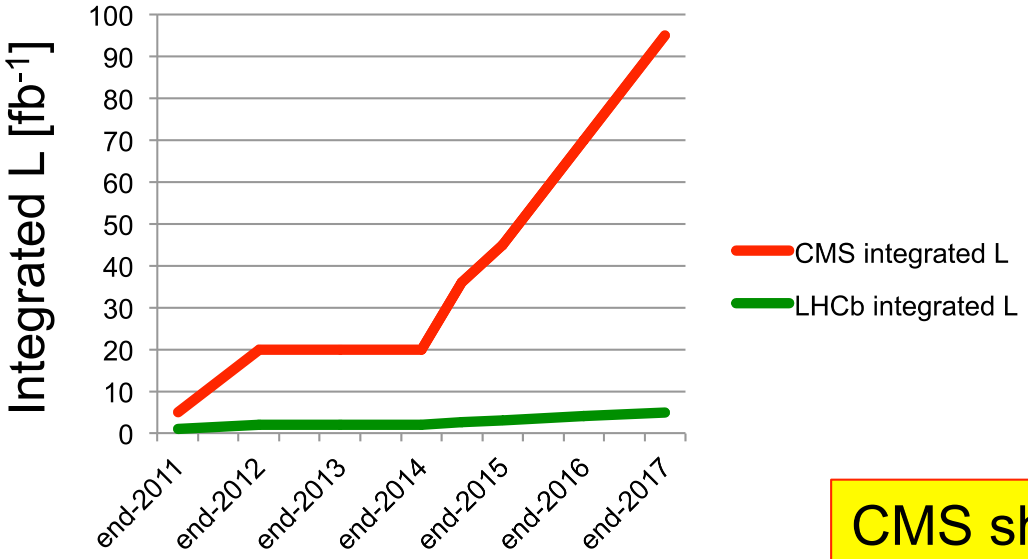
Results

- No signal → put upper limits
- LHCb: $BR(B^0_s \rightarrow \mu^+\mu^-) < 1.5 \times 10^{-8}$
- CMS: $BR(B^0_s \rightarrow \mu^+\mu^-) < 1.9 \times 10^{-8}$
- Combined: $BR(B^0_s \rightarrow \mu^+\mu^-) < 1.1 \times 10^{-8}$
- CDF: $BR(B^0_s \rightarrow \mu^+\mu^-) = (1.8^{+1.1}_{-0.9}) \times 10^{-8}$

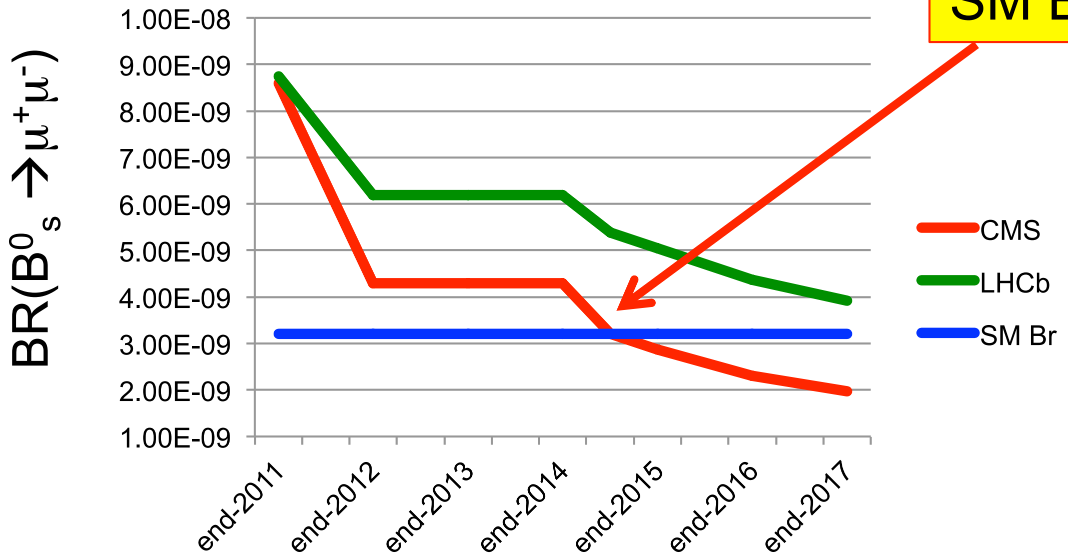


CMS+LHCb combined results
CMS PAS BPH-011-019, LHCb-ANA-2011-039

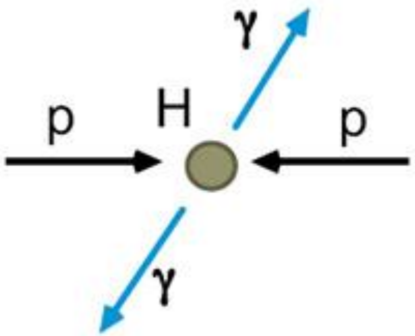
Prospects

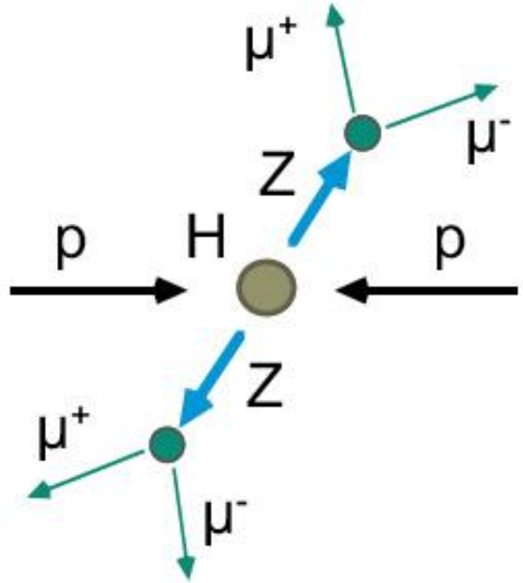


CMS should reach the SM BR mid-2015

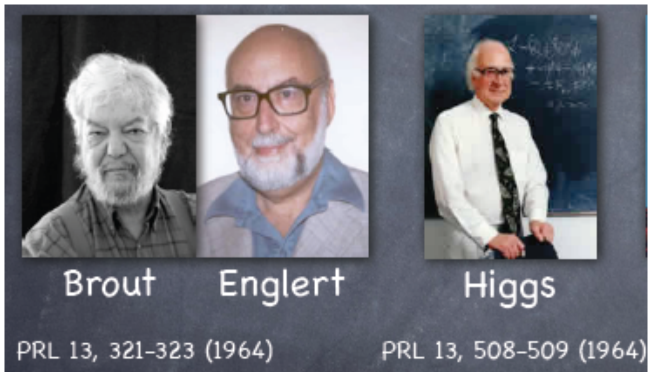


Higgs searches





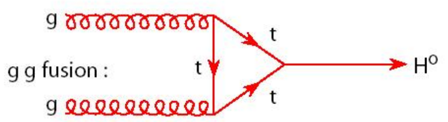
(Peter) Higgs in LHC



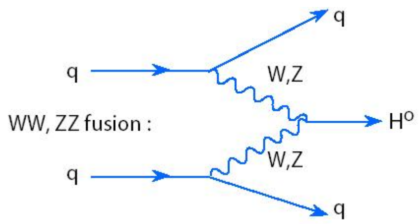
Brout-Englert-Higgs

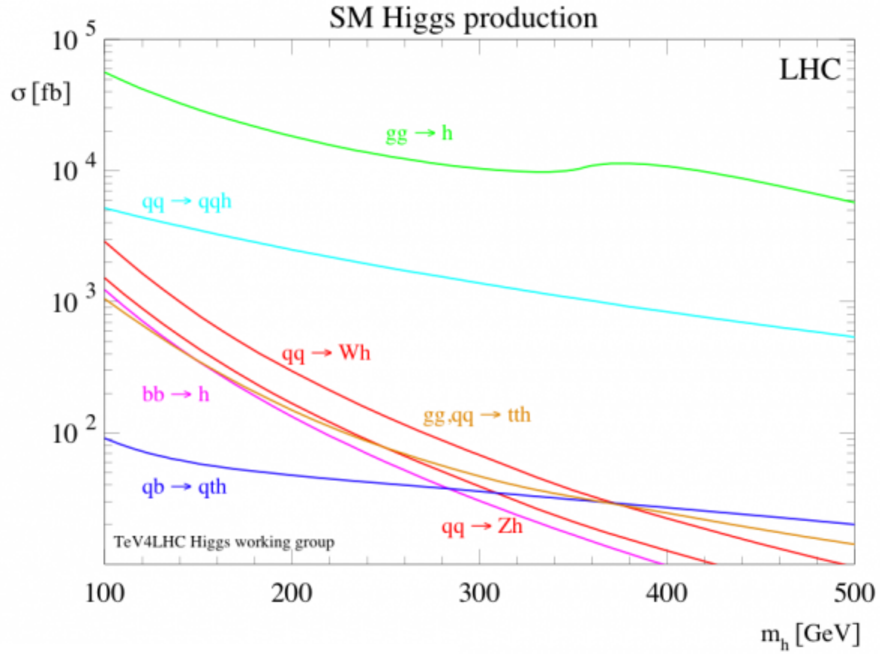
SM Higgs production at LHC

gg fusion (dominant)

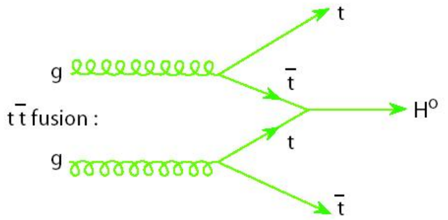


vector boson fusion

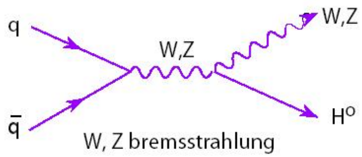


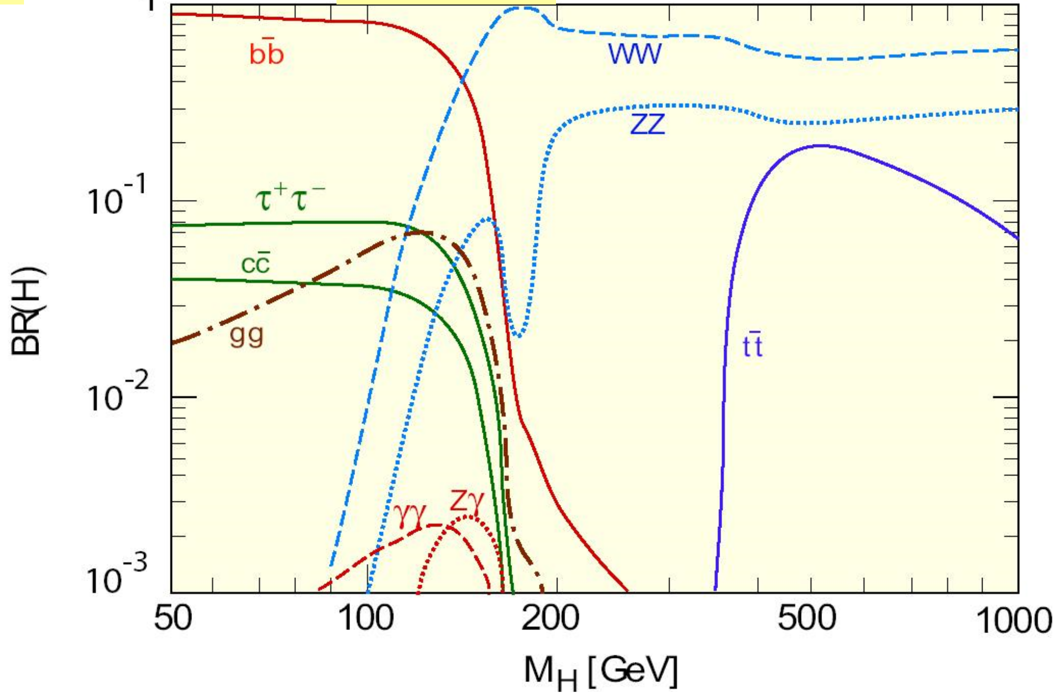


gg (qq) → ttH

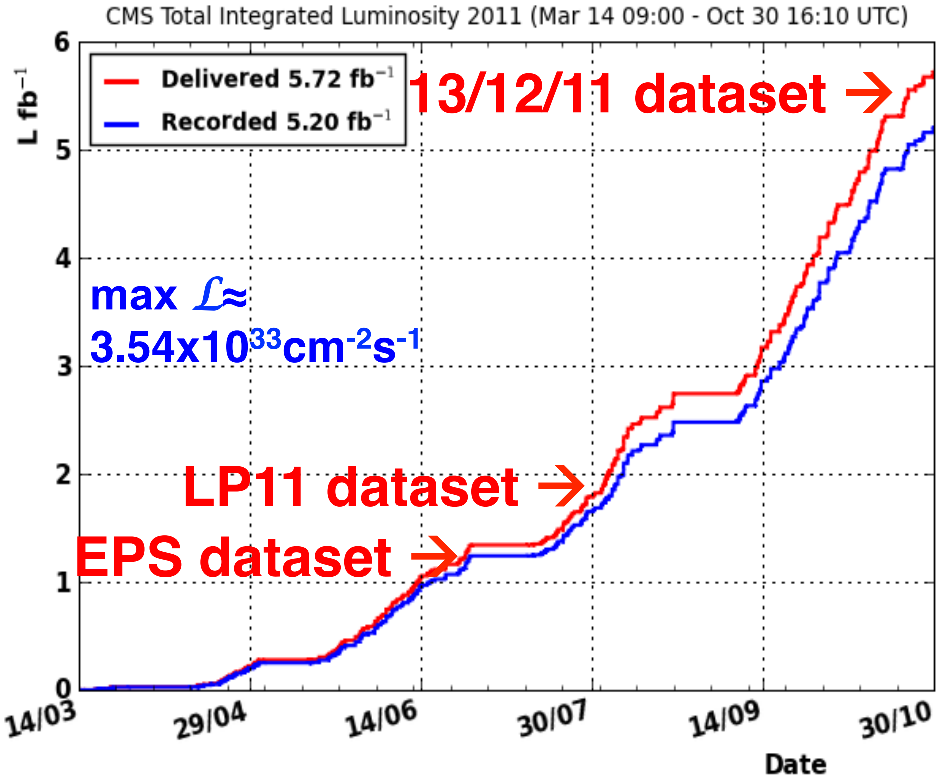


qq → VH



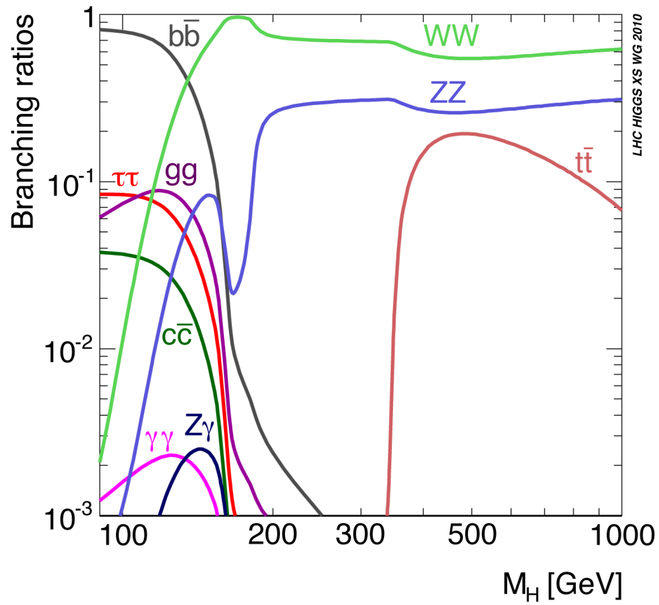


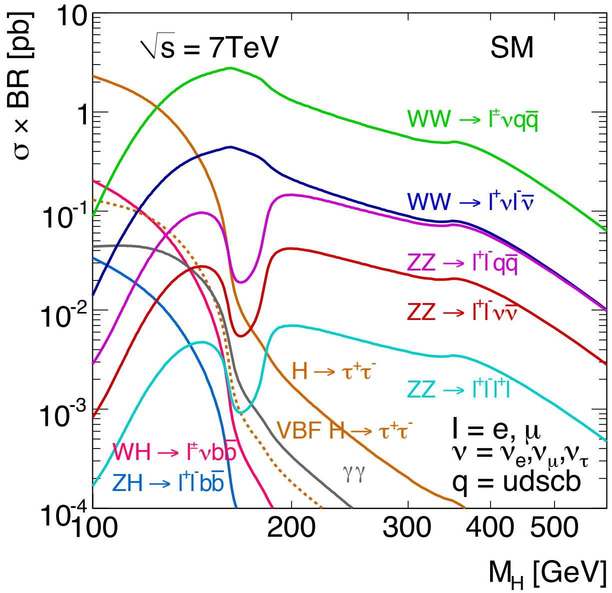
Data for Higgs results



Results use a large fraction of the full 2011 dataset.
Certified data for physics: "**Golden**" **4745 pb^{-1} (~92%),**
"**Muon**" **4965 pb^{-1} (~96%)**.

Decay modes analyzed with the full 2011 data set





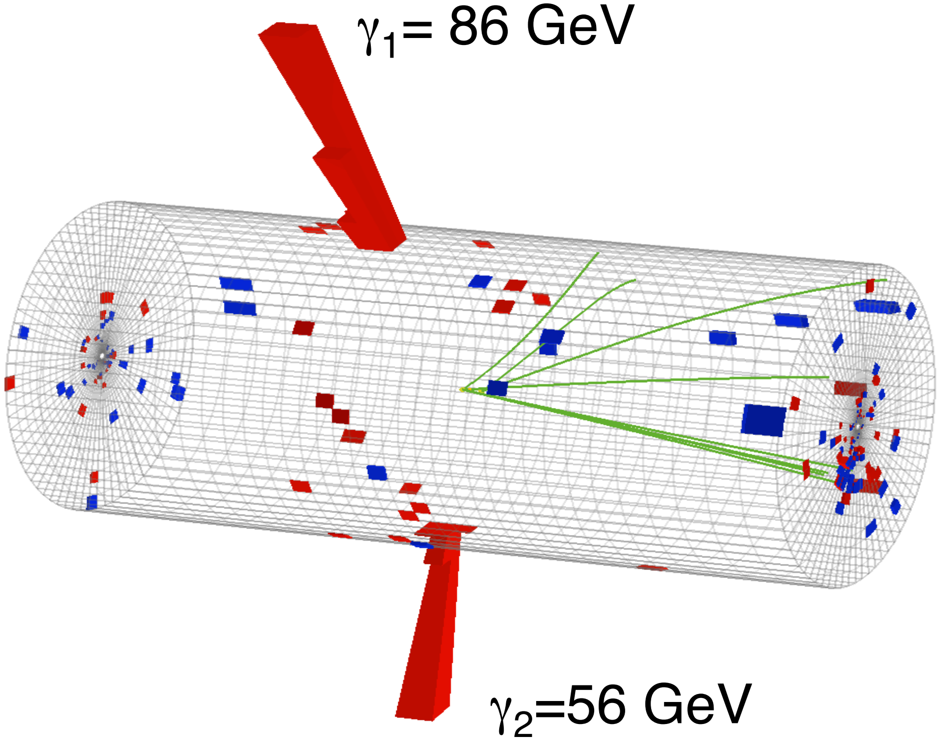
Mode	Mass Range	Data Used (fb^{-1})	CMS Document
H → γγ	110-150	4.7	HIG-11-030
H → bb	110-135	4.7	HIG-11-031
H → ττ	110-145	4.6	HIG-11-029
H →WW →2l 2ν	110-600	4.6	HIG-11-024
H → ZZ →4l	110-600	4.7	HIG-11-025
H → ZZ →2l2τ	180-600	4.7	HIG-11-028
H → ZZ →2l2j	130-165/200-600	4.6	HIG-11-027
H → ZZ →2l2ν	250-600	4.6	HIG-11-026

Decay modes

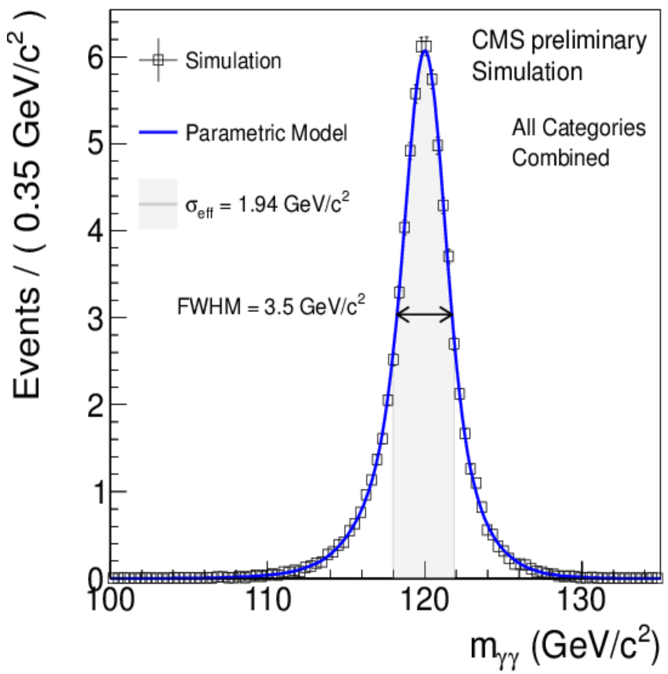
Channel	m_H range (GeV/c^2)	Lumi (fb^{-1})	sub-channels	m_H resolution
$H \to \gamma\gamma$	110–150	4.7	4	1.2–2.7%
$H \to \tau\tau$	110–145	4.6	9	20%
$H \to bb$	110–135	4.7	5	10%
$H \to WW \to \ell\nu\ell\nu$	110–600	4.6	5	20%
$H \to ZZ \to 4\ell$	110–600	4.7	3	1–2%
$H \to ZZ \to 2\ell 2\tau$	180–600	4.7	8	10–15%
$H \to ZZ \to 2\ell 2\nu$	250–600	4.6	2	7%
$H \to ZZ \to 2\ell 2q$	200–600 130–165	4.6	6	3%

Low mass Higgs search : H→ γγ

- + **Simple signal: 2 energetic, isolated γ.**
- + **Excellent mass resolution → narrow mass peak**
- \- Large and partly irreducible QCD background
- \- Challenges: vertexing with pileup, calibrations and transparency corrections for the crystals.

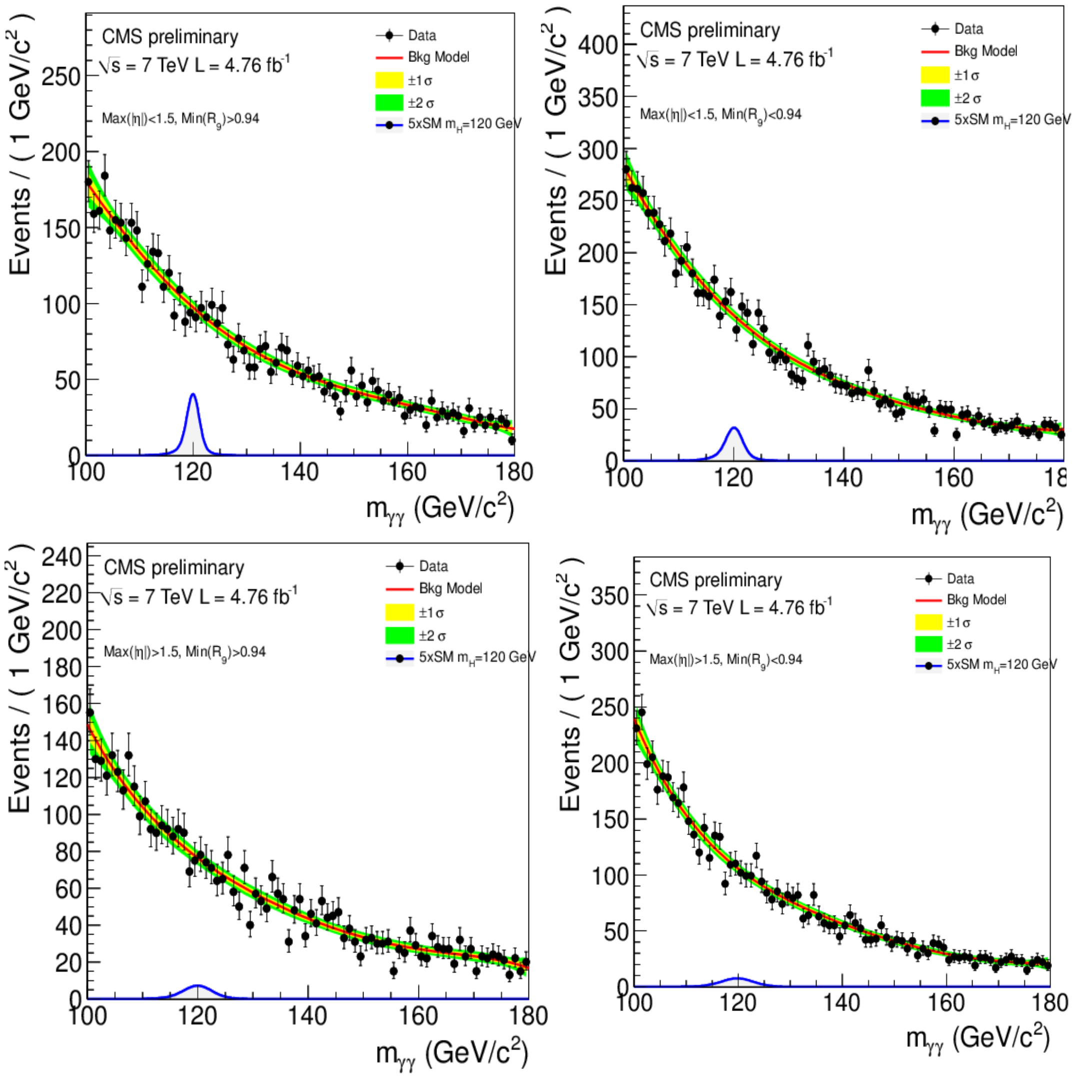


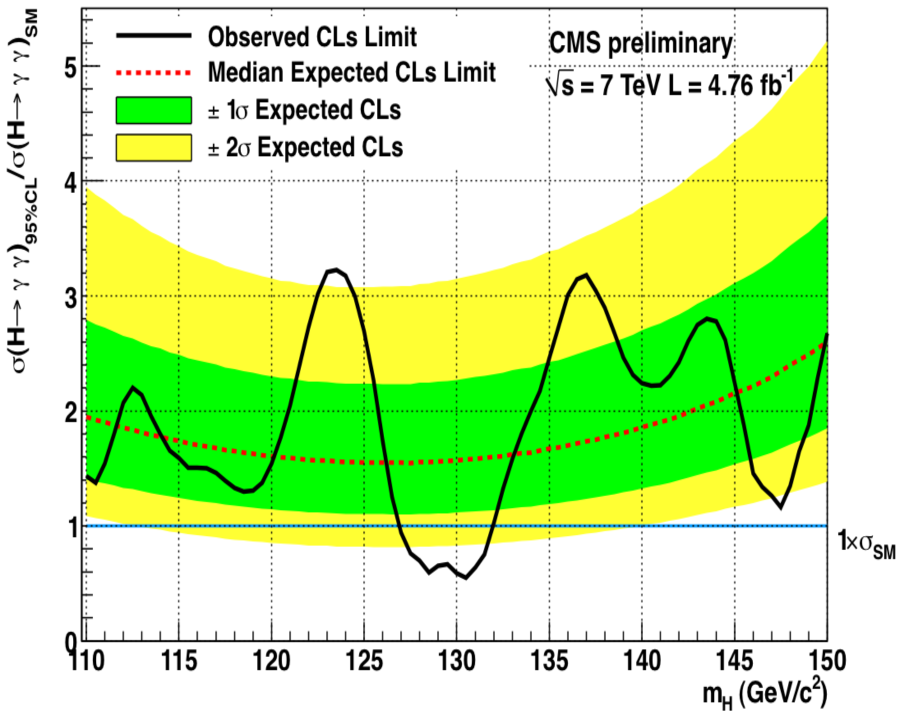
* Background: measured from $M_{\gamma\gamma}$ sidebands in data
* Calibration constants derived from Z→ee data



CMS PAS HIG-011-30

H→ γγ: data and exclusion limits



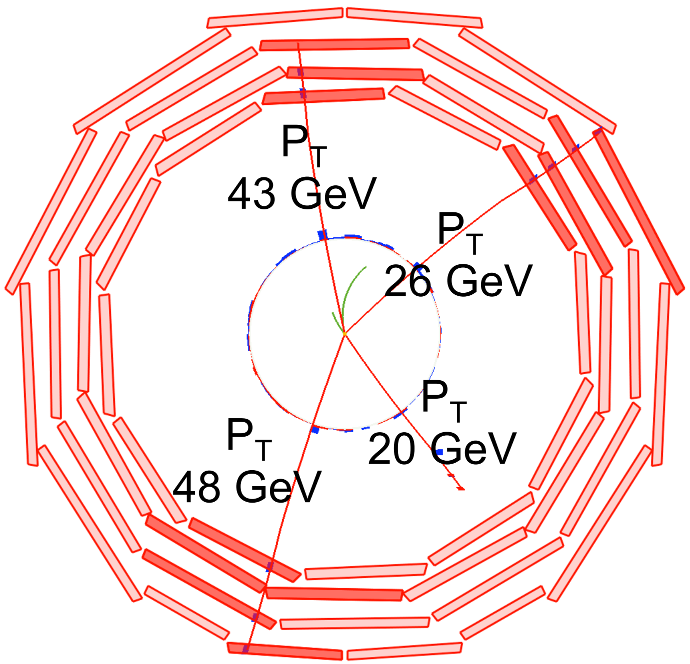


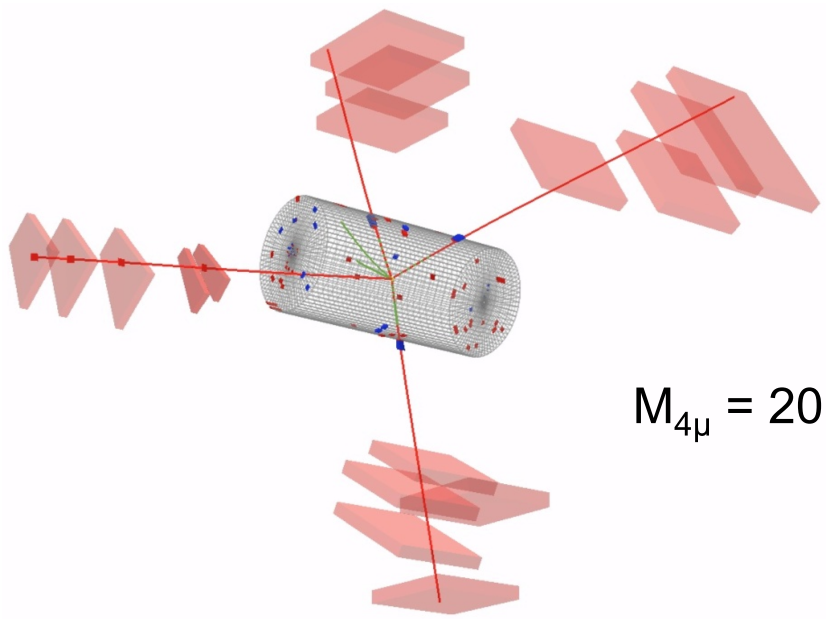
Critical point: background fit model. It has been shown that the structure/ shape of the observed limit is not due to the chosen background model.

Using 5th order polynomial fit to background: some loss in sensitivity but negligible bias.

Higgs decay to four leptons: H → ZZ$^{(*)}$ → 4e, 4μ, 2e+2μ

Observed event in CMS

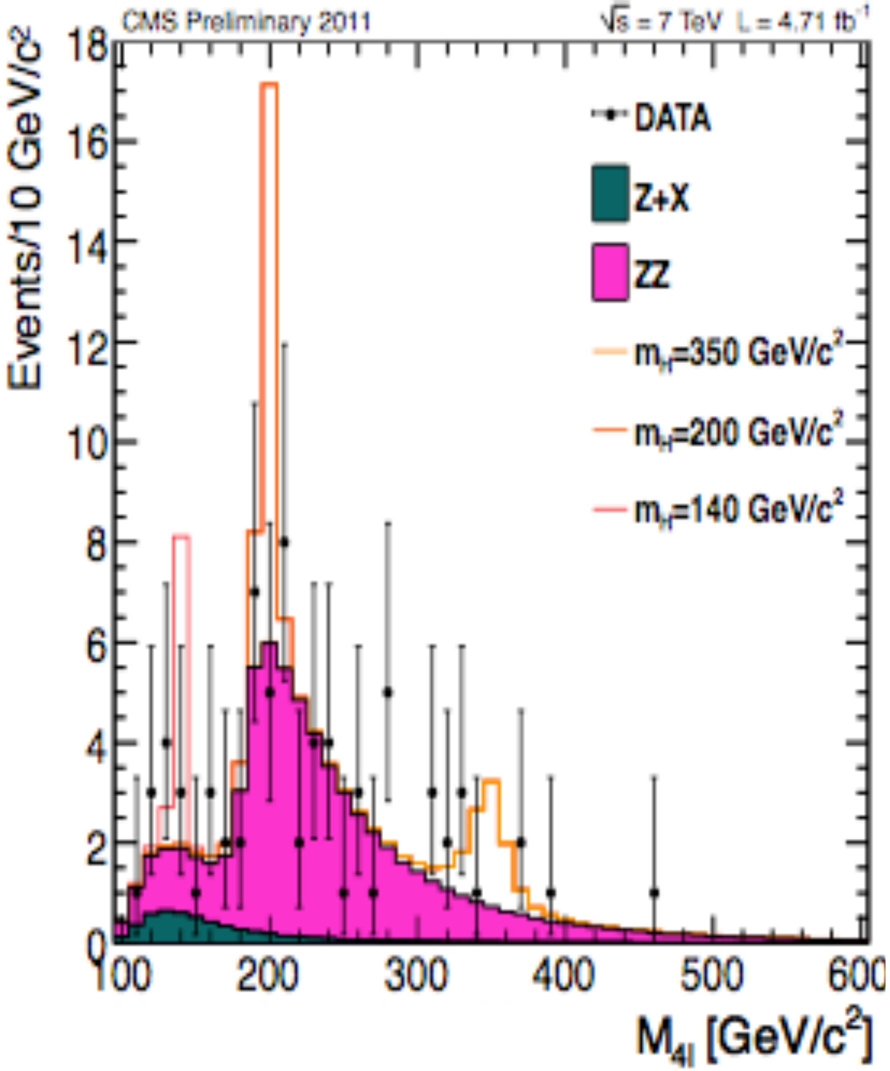




$M_{4\mu}$ = 201 GeV

CMS PAS HIG-011-25

Results: H → ZZ → 4leptons



Estimated background

Estimated Higgs signals

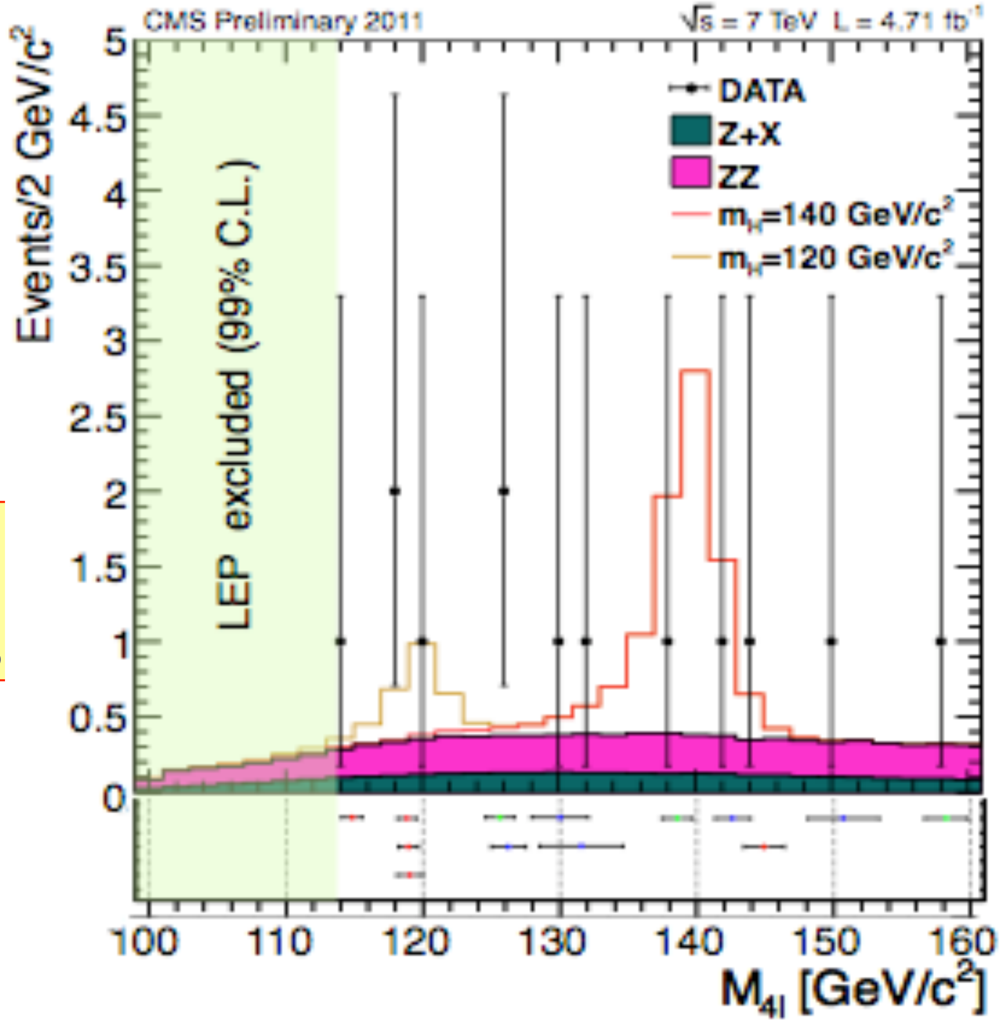
m_{4l} >100 GeV/c²
Observed events: 72
Expected events: 67.1 ± 6.0

Baseline	$4e$	4μ	$2e2\mu$
ZZ	12.27 ± 1.16	19.11 ± 1.75	30.25 ± 2.78
Z+X	1.67 ± 0.55	1.13 ± 0.55	2.71 ± 0.96
All background	13.94 ± 1.28	20.24 ± 1.83	32.96 ± 2.94
$m_H = 120$ GeV$/c^2$	0.25	0.62	0.68
$m_H = 140$ GeV$/c^2$	1.32	2.48	3.37
$m_H = 350$ GeV$/c^2$	1.95	2.61	4.64
Observed	12	23	37

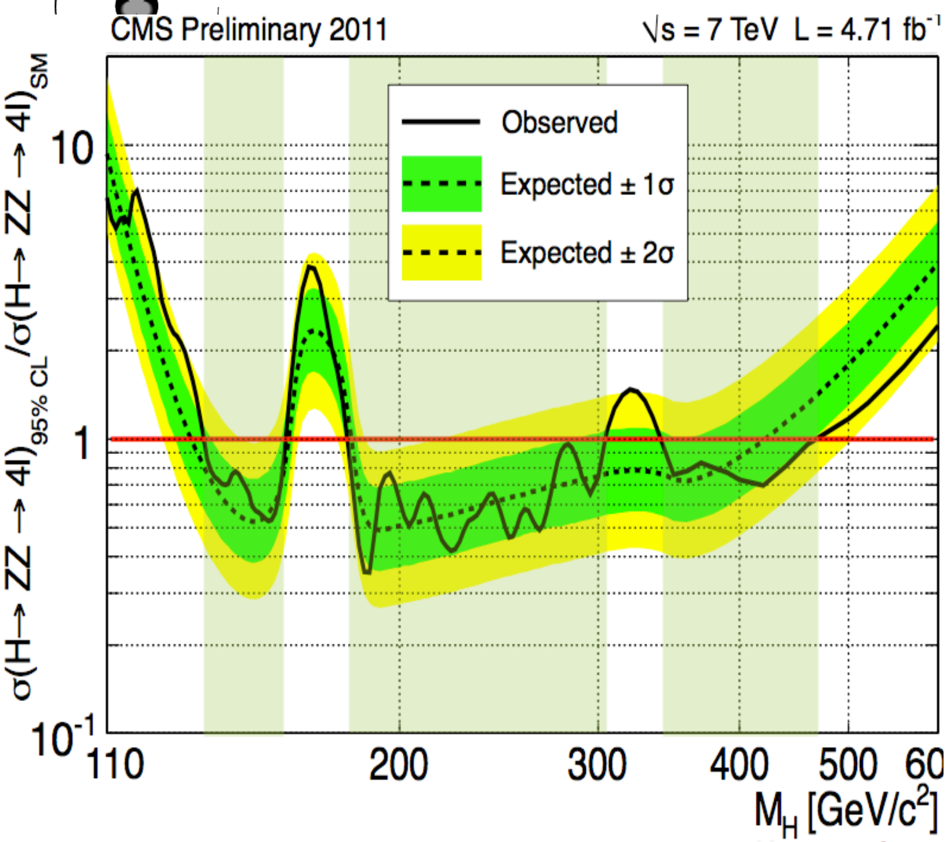
Low mass region

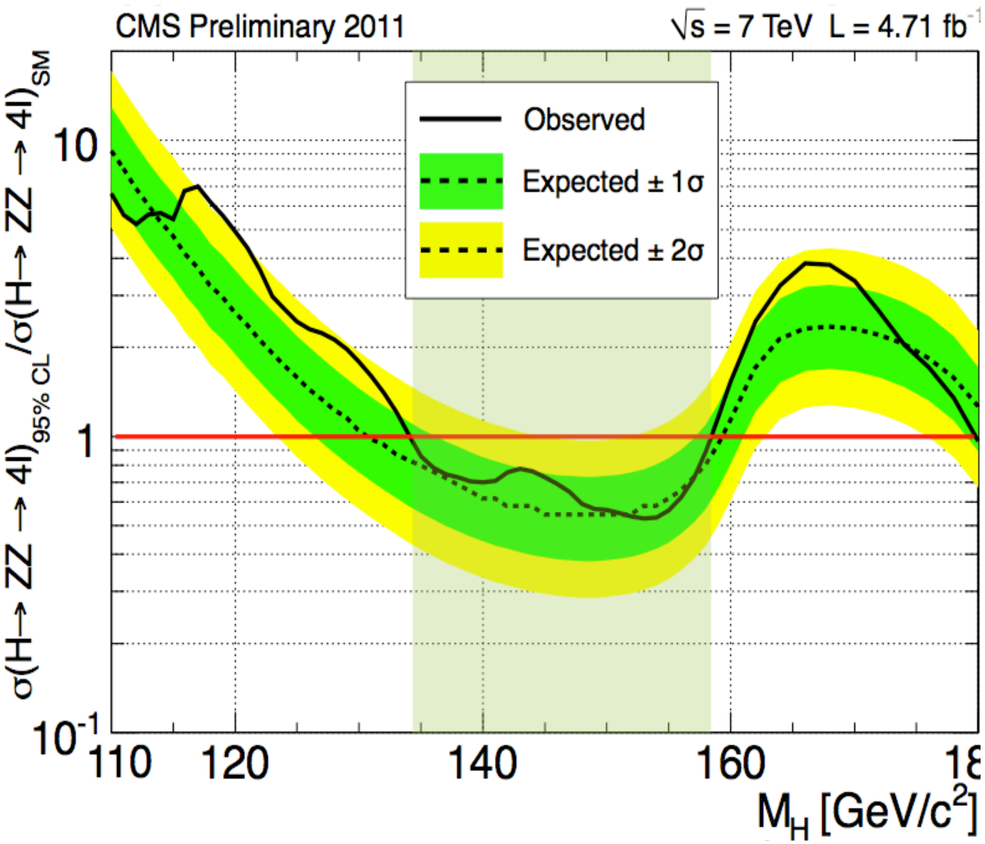
100 < m_{4l} < 160 GeV/c^2
Observed events: 13
Expected events: 9.5 ± 1.3

Final state:	4e	4μ	2e2μ
Obs. events:	3	5	5
Exp. events:	1.7	3.3	4.5



H→ZZ→4l: 95%CL exclusion limits

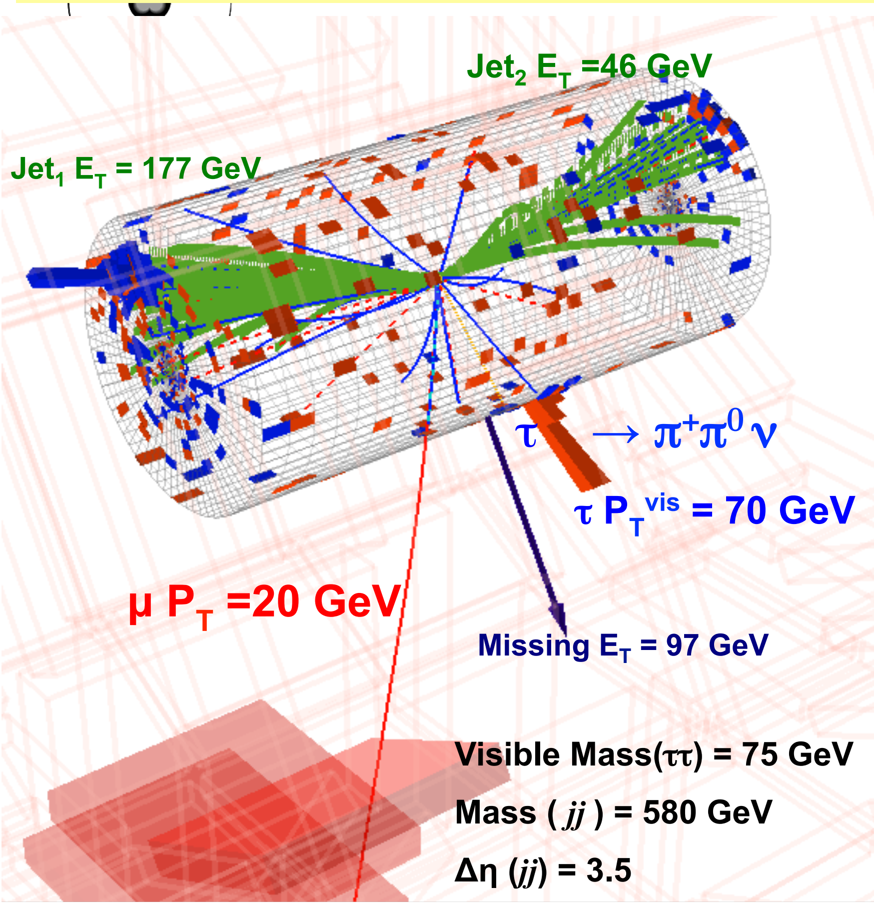


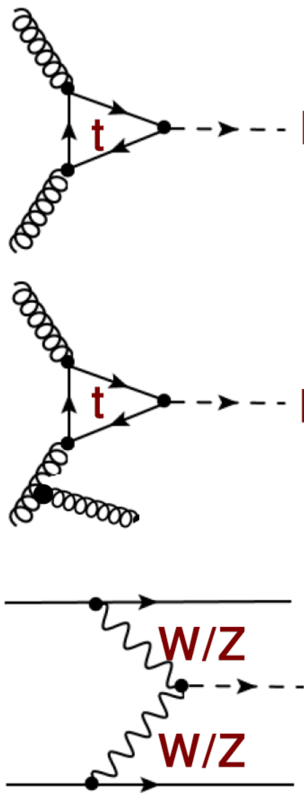


Expected range: $130 < M_H < 160$ GeV; $182 < M_H < 420$ GeV
Observed range: $134 < M_H < 158$ GeV; $180 < M_H < 305$ GeV; $340 < M_H < 460$ GeV

Low mass Higgs search : H→ $\tau\tau$

Gluon-fusion production dominant, but overwhelmed by Drell-Yan production of τ pairs.
Need additional handles:
→ VBF Higgs production,
→ high-p_T τ pairs from Higgs produced in association with a high-p_T jet (Boosted)





SM-0/1 jet
0 jets >30 GeV or 1 jet<150 GeV

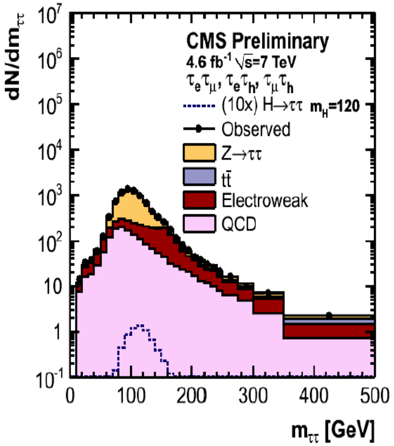
SM-Boosted
One jet Pt>150 GeV
No other jets>30 GeV

SM-VBF
>=2 Jets >30 GeV
$\Delta\eta$>4 , Mjj>400 GeV
No additional jets with Pt>30 in the rapidity gap

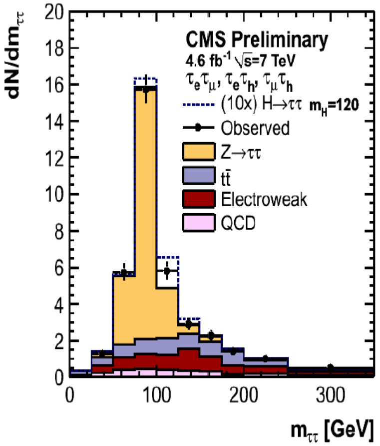
CMS PAS HIG-011-29

- $\tau\tau$ selection: $\mu+\tau_{had}$, $\mu+\tau_{had}$, μ+e
- **VBF mode cleanest, most sensitive**

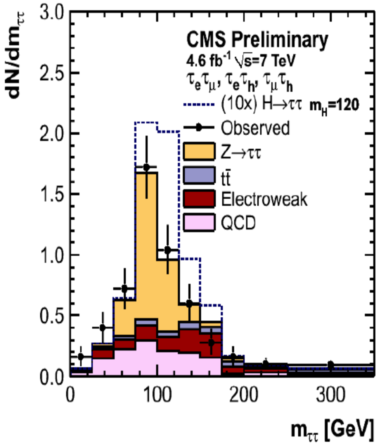
H→ ττ : results



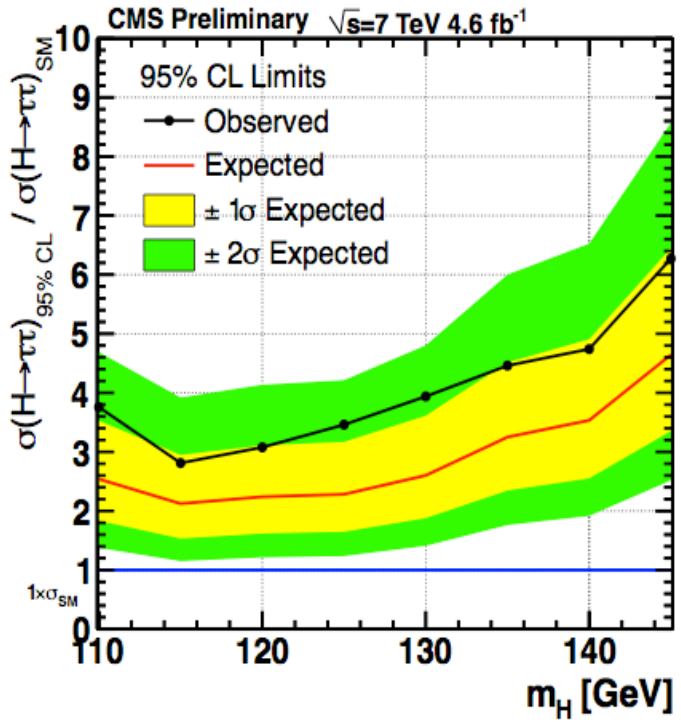
CMS Preliminary
4.6 fb-1 √s=7 TeV
τeτμ, τeτh, τμτh
(10x) H→ττ mH=120
Observed
Z→ττ
tt̄
Electroweak
QCD
dN/dmττ
mττ [GeV]



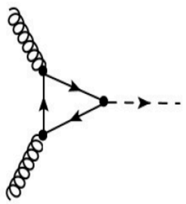
CMS Preliminary
4.6 fb-1 √s=7 TeV
τeτμ, τeτh, τμτh
(10x) H→ττ mH=120
Observed
Z→ττ
tt̄
Electroweak
QCD
dN/dmττ
mττ [GeV]

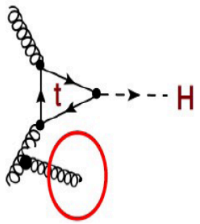


CMS Preliminary
4.6 fb-1 √s=7 TeV
τeτμ, τeτh, τμτh
(10x) H→ττ mH=120
Observed
Z→ττ
tt̄
Electroweak
QCD
dN/dmττ
mττ [GeV]

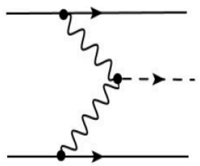


CMS Preliminary √s=7 TeV 4.6 fb-1
95% CL Limits
Observed
Expected
± 1σ Expected
± 2σ Expected
σ(H→ττ)95% CL / σ(H→ττ)SM
1×σSM
mH [GeV]



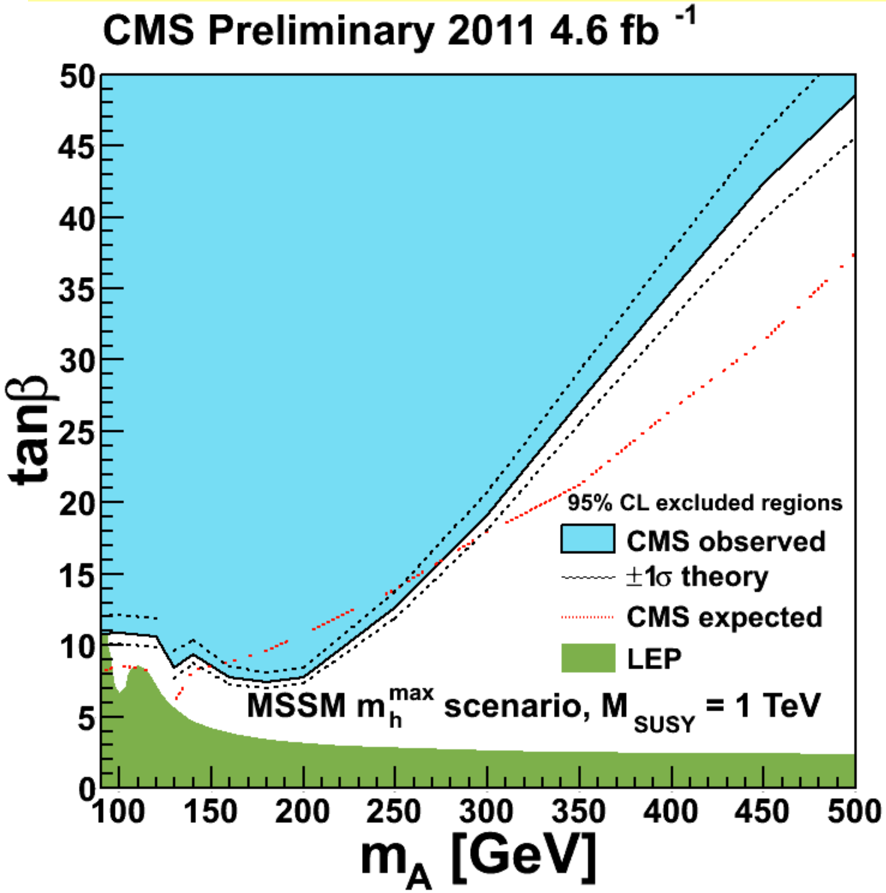


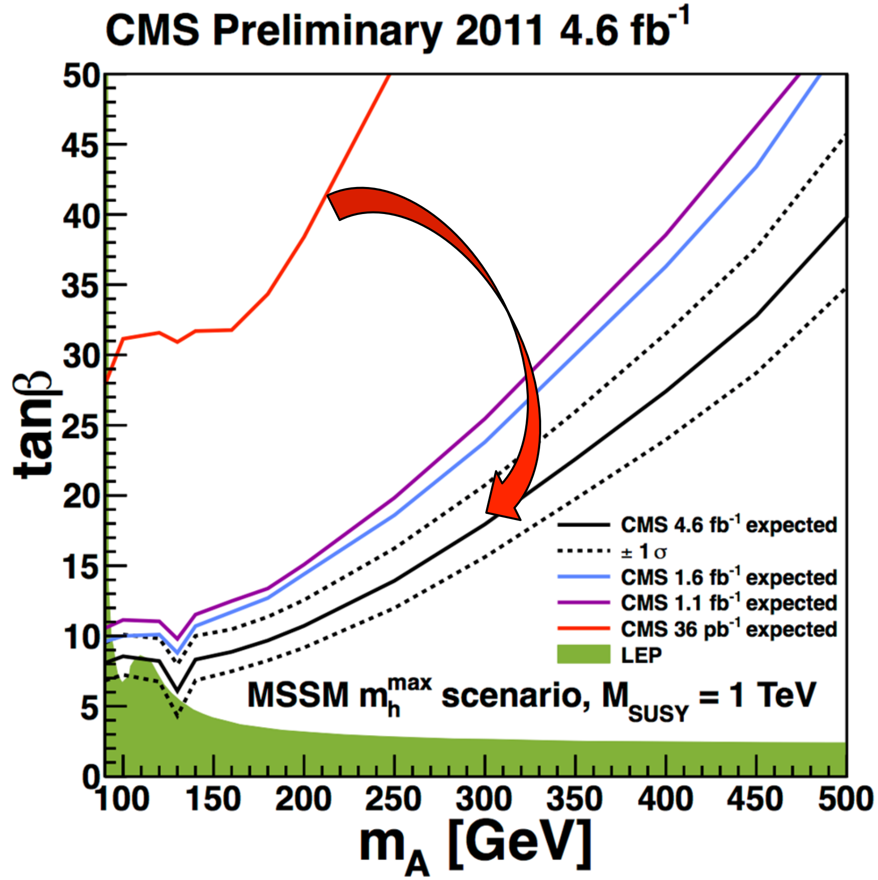
t
H



MSSM search $\phi \rightarrow \tau\tau$, ϕ = h, H, A

Main production processes:
- gluon fusion through a b quark loop
- direct bb annihilation from the b parton density ←→ increased probability for an associated b-tagged jet, additional handle to beat the background

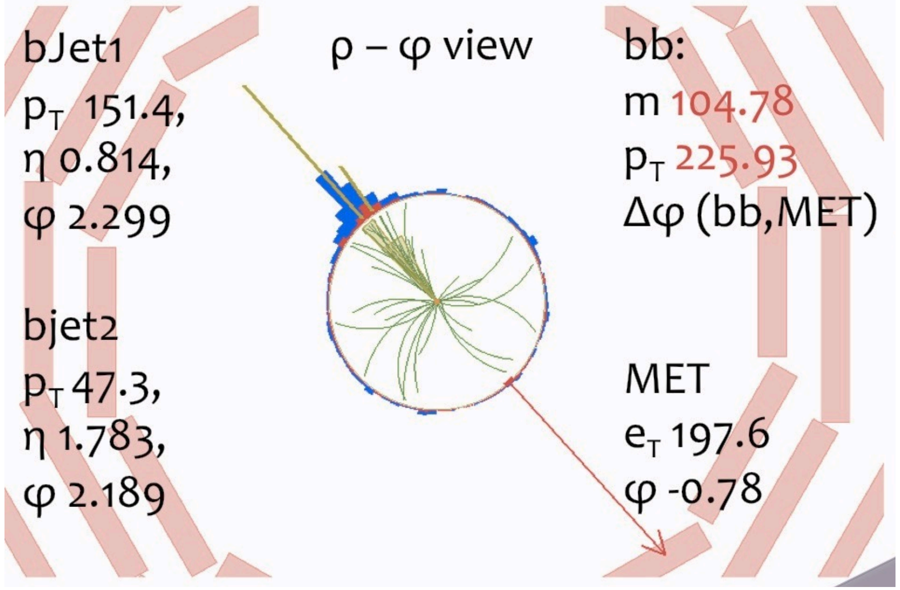


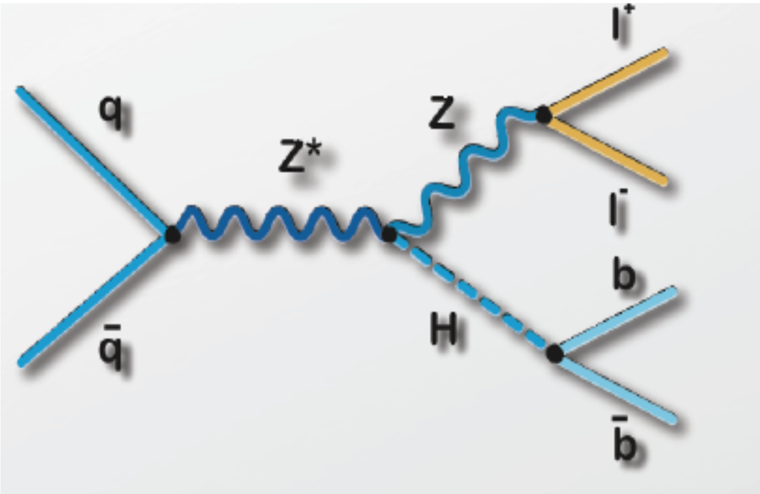


CMS PAS HIG-011-29

Low mass Higgs search : H→ bb

- gg→ H→ bb and VBF are dominant production modes but overwhelmed by enormous QCD di-jet background
- Best option: qq→ VH; H → bb
  - Major backgrounds are V+jets, VV, ttbar
- Use
  - **VH topology : ΔΦ(V,H) > 3**
  - **P_T(V)> 100-160 GeV (boosted W/Z)**
  - Tight b-tagging & MET quality
  - Backgrounds estimated from control data





5 sub channels

Z(→*ll*); H→bb, *l* = μ, e

W(→lν) ; H→bb, *l* = μ, e

Z(→νν); H→bb

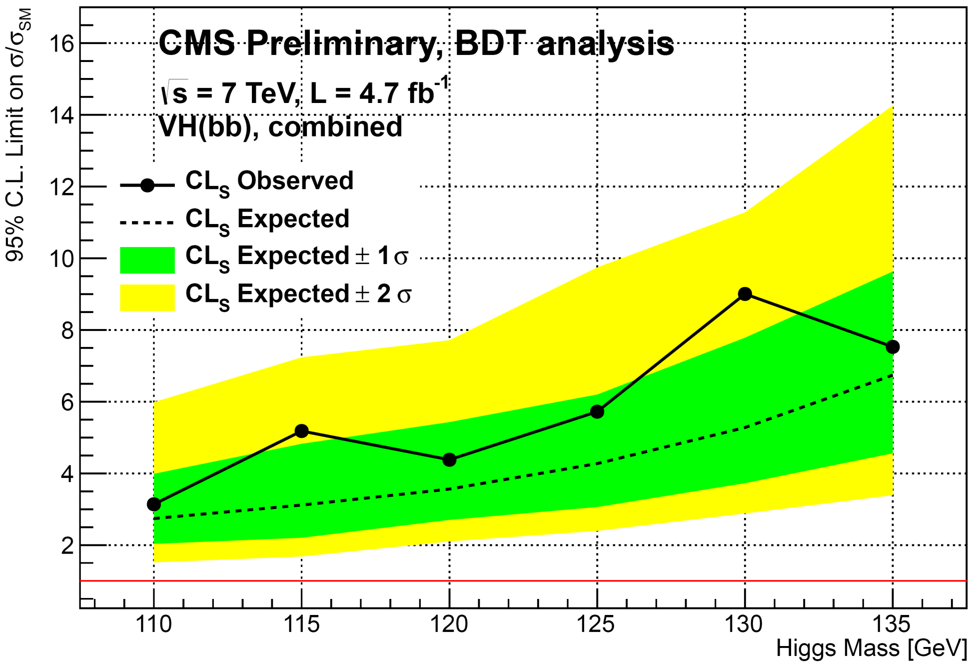
Extensive use of data driven methods to control the backgrounds.

CMS PAS HIG-011-31

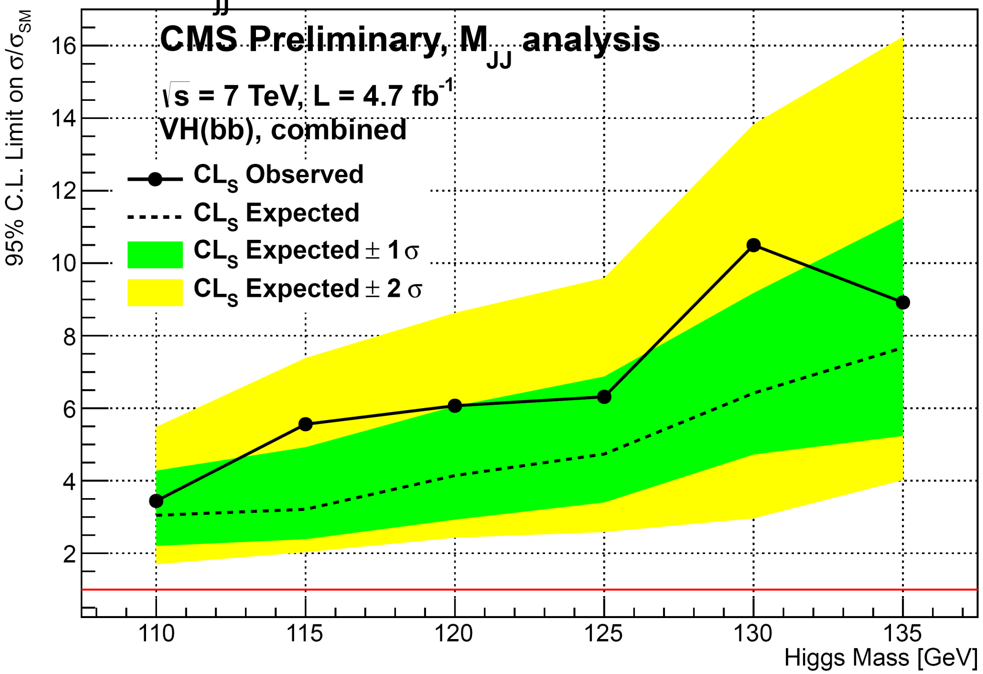
$H \rightarrow bb$: results

Results based on the invariant mass distribution of $H\rightarrow bb$ candidates (M_{jj}) or boosted decision tree (BDT)

BDT

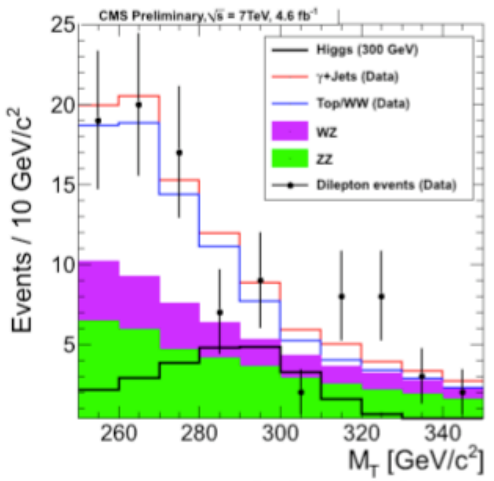


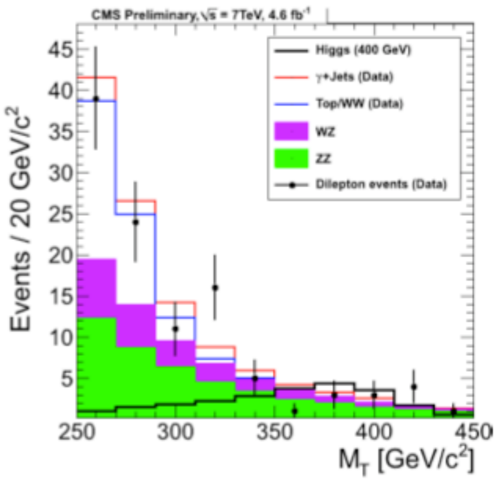
M_{jj}



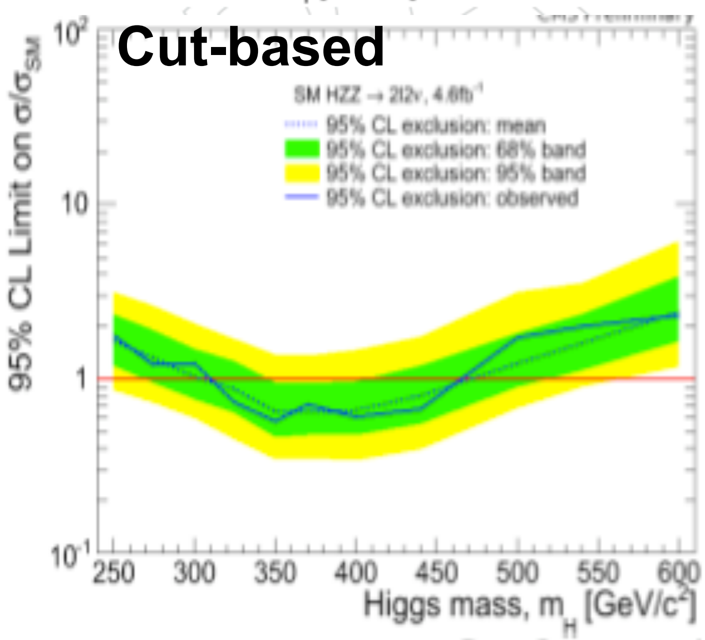
H → ZZ→ 2l2ν (high mass Higgs)

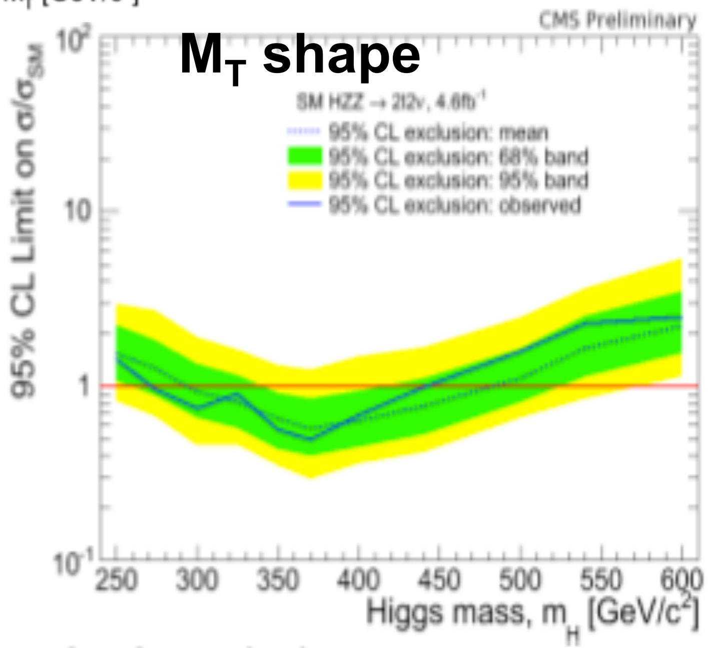
Results based on a cut-based analysis and a binned likelihood fit to the M_T distribution ("shape-based").





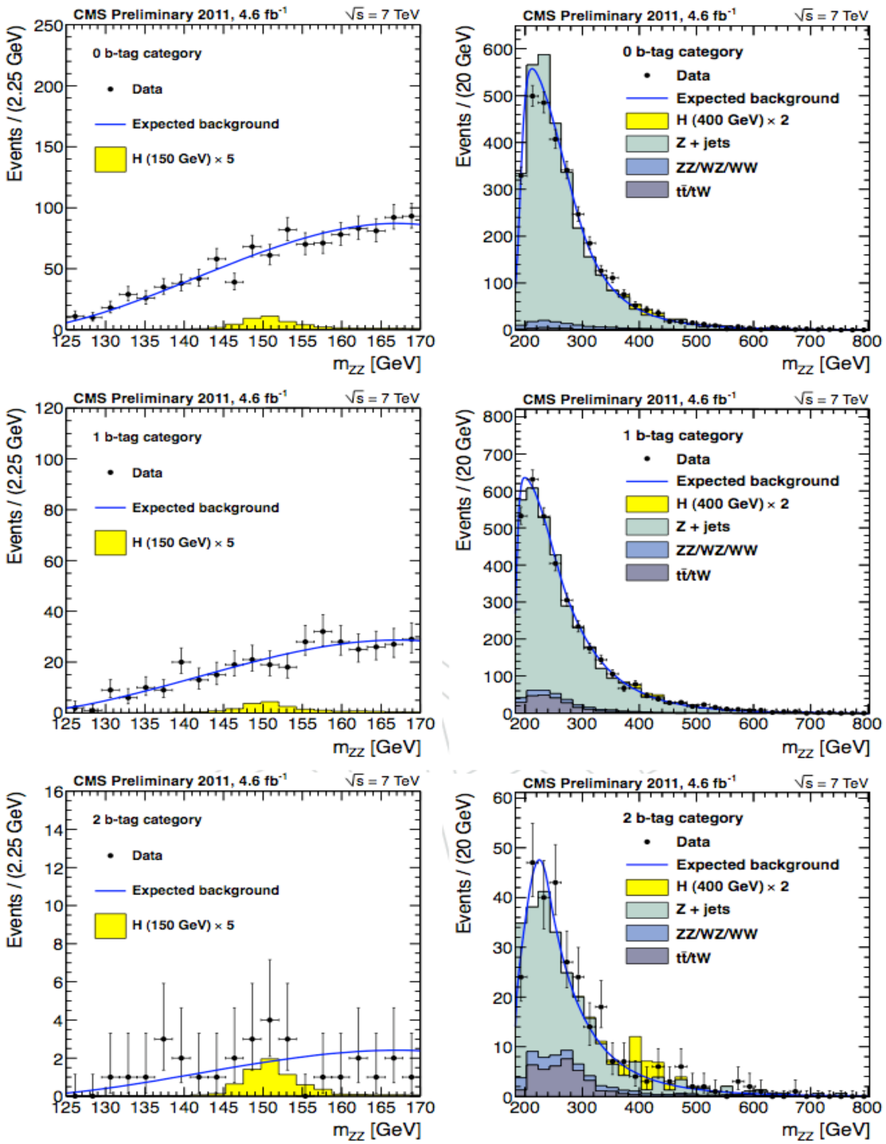
95%CL exclusion limits for a SM Higgs boson in the range 270-440 GeV (M_T shape based analysis)

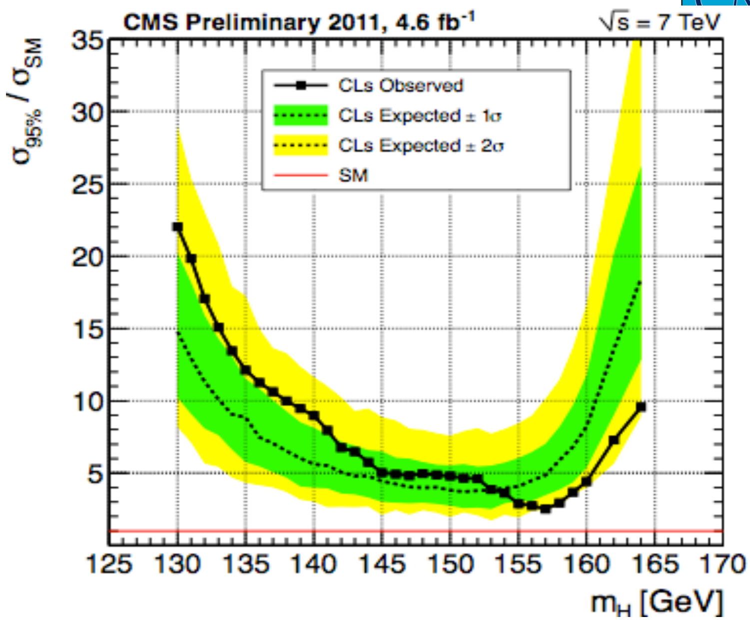


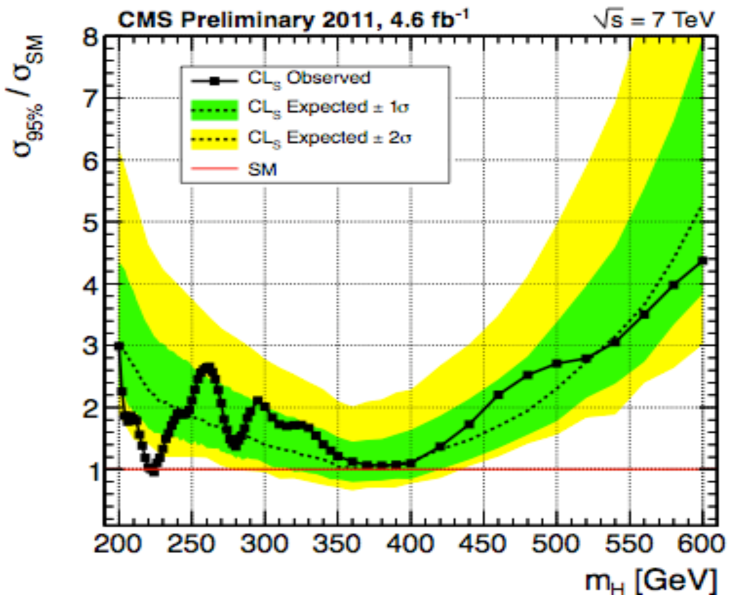


CMS PAS HIG-011-26

H →ZZ→2l 2q: results



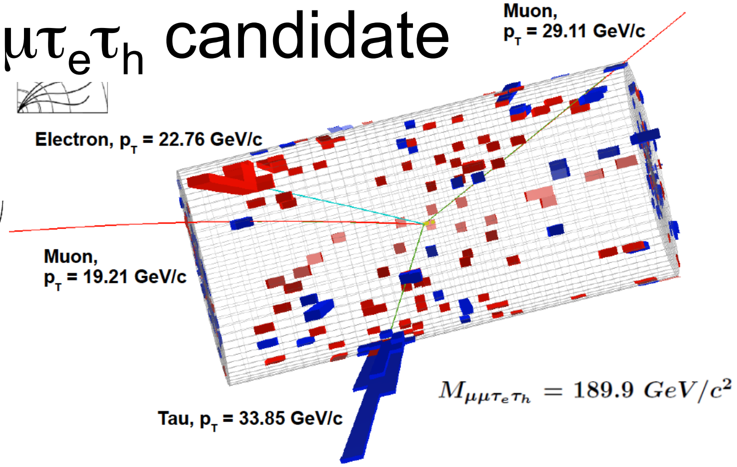


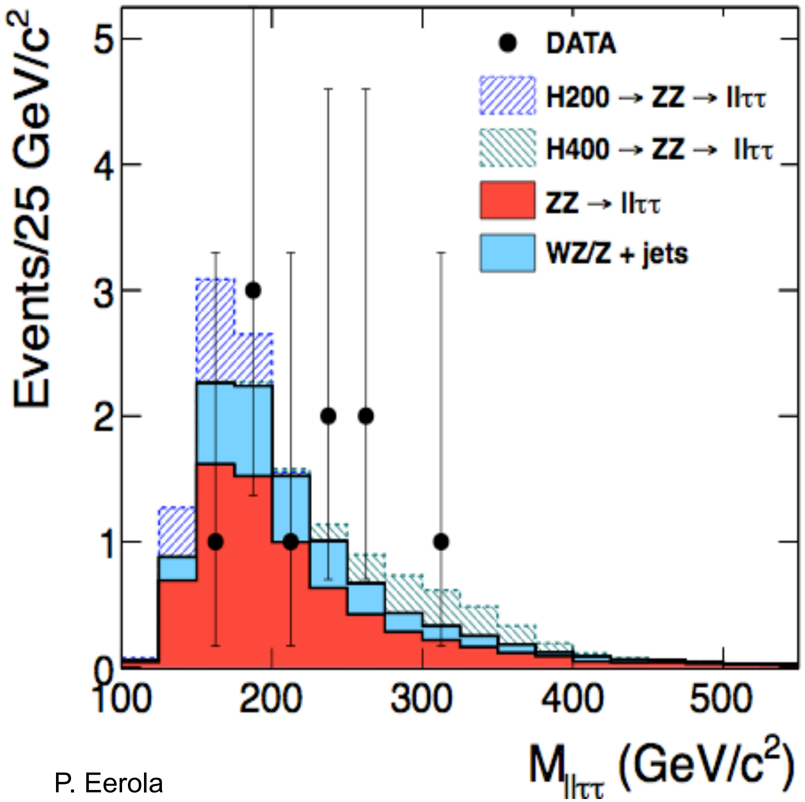


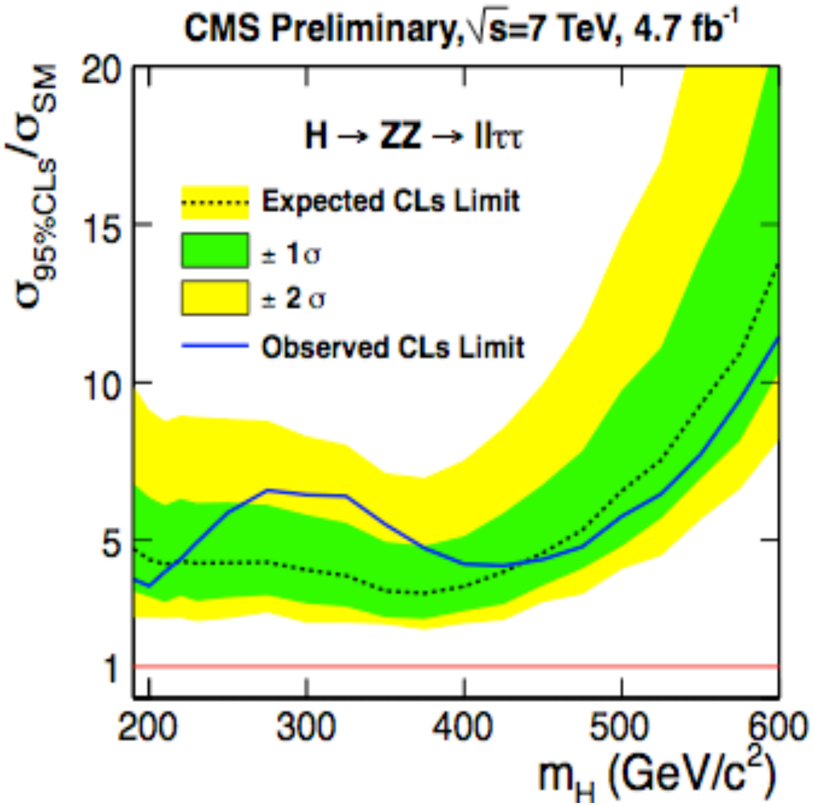
CMS PAS HIG-011-27

H →ZZ→2l 2τ (high mass Higgs)

$\mu\mu\tau_e\tau_h$ candidate





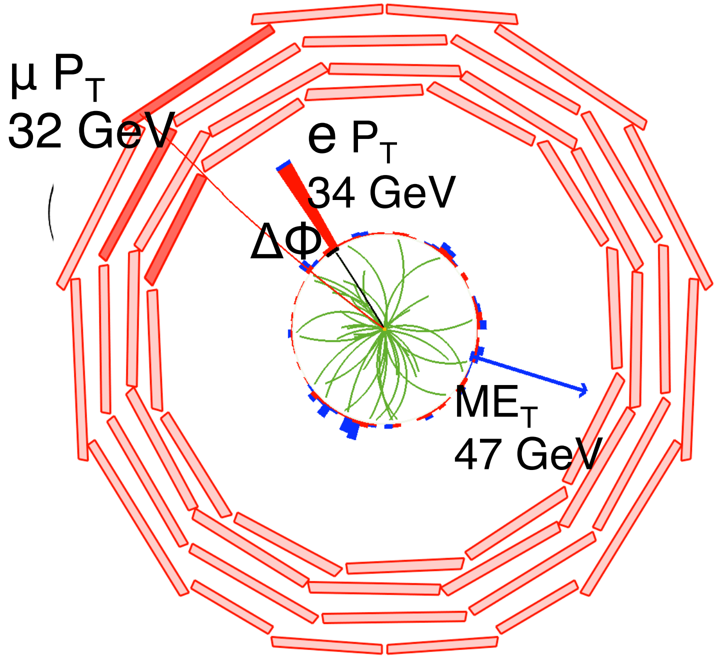


10 observed events, 10.3 expected background

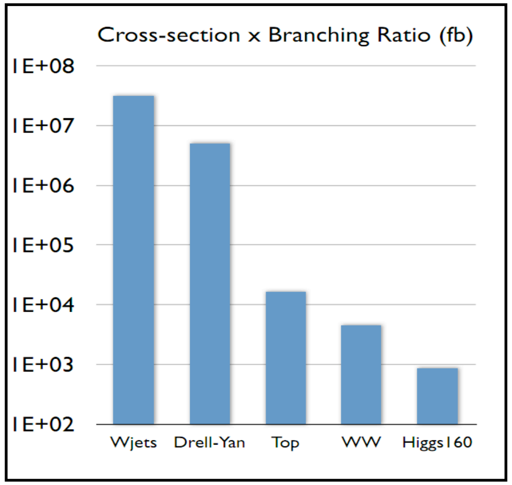
Background shapes are taken from MC simulation and normalized to the values obtained using data-driven techniques.

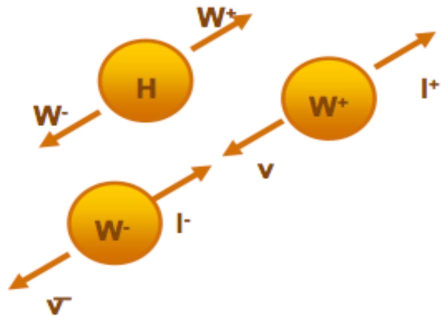
CMS PAS HIG-011-28

H→ WW → 2l 2ν



- **No signal mass peak (missing νν) ➔ Counting expt.**
- **Challenge is to remove & control large backgrounds**





- Signal characteristics:
  - Only 2 opposite sign, isolated leptons
  - significant ME_T➔ No mass peak
  - No b-jets, no additional low P_T μ
  - With additional 0, 1 or 2 jets (VBF)
  - Small ΔΦ (l^+l^-) ← Higgs scalarity

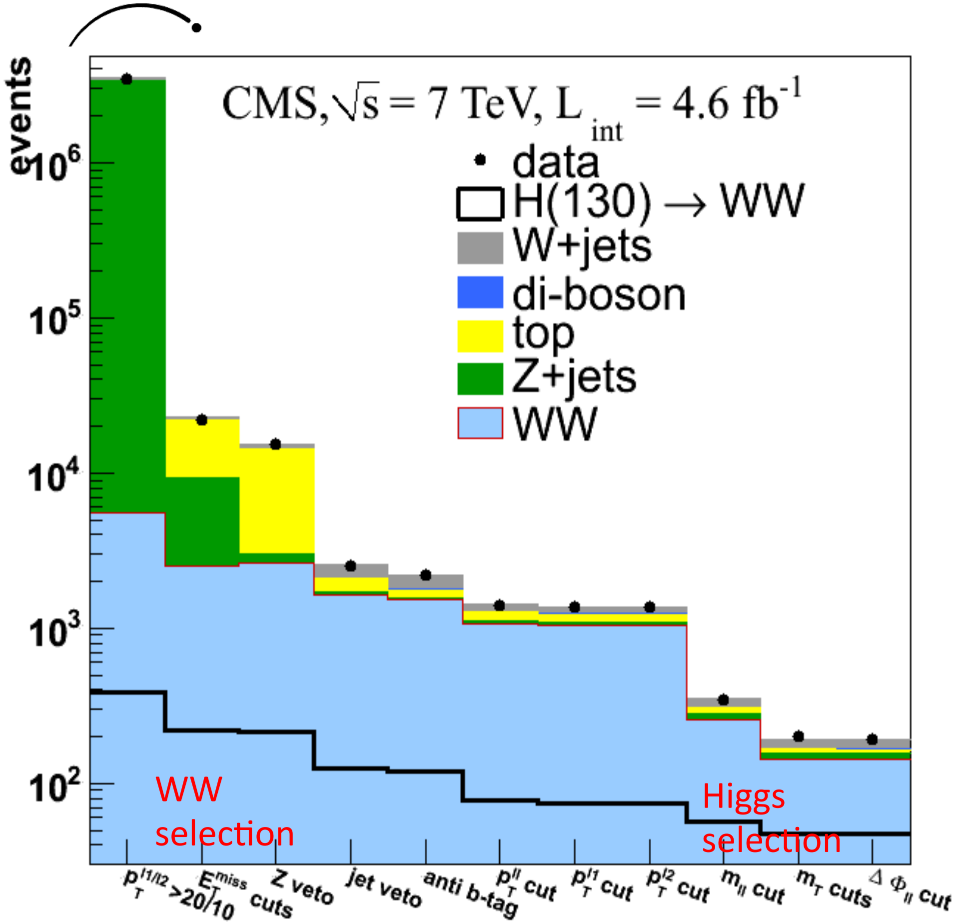
Major requirements:

- Lepton P_t > 15 GeV, tight ID & Isolation
- Large ME_T & Z → μμ, ee veto
- Classification by # of jets (P_T > 30 GeV) & b-jet veto
- Kinematic discriminants: M_{ll} & ΔΦ (l^+l^-)
- M_H–dependent cut optimization

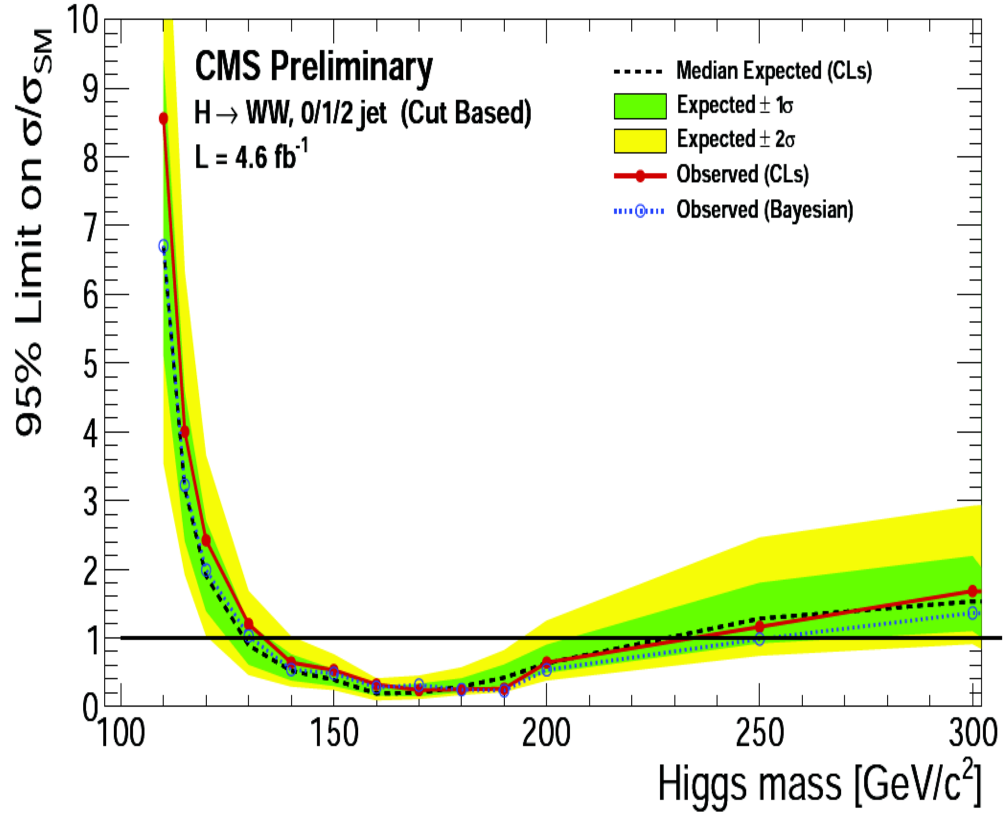
CMS PAS HIG-011-24

Data and limits in cut and count analysis

Results based on a cut-based analysis or a boosted decision tree.

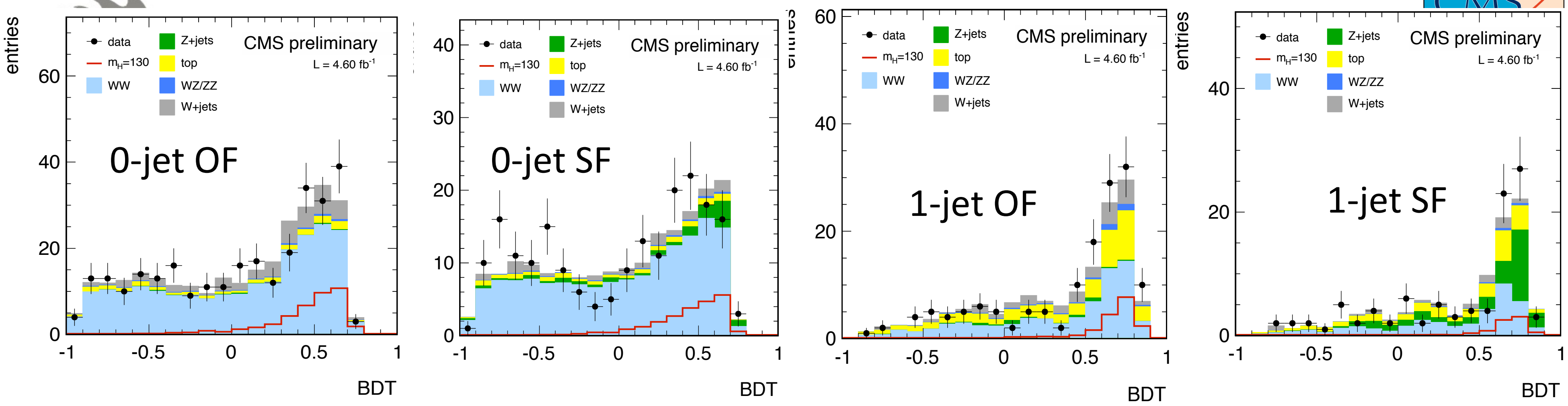


Data describes predicted background well.

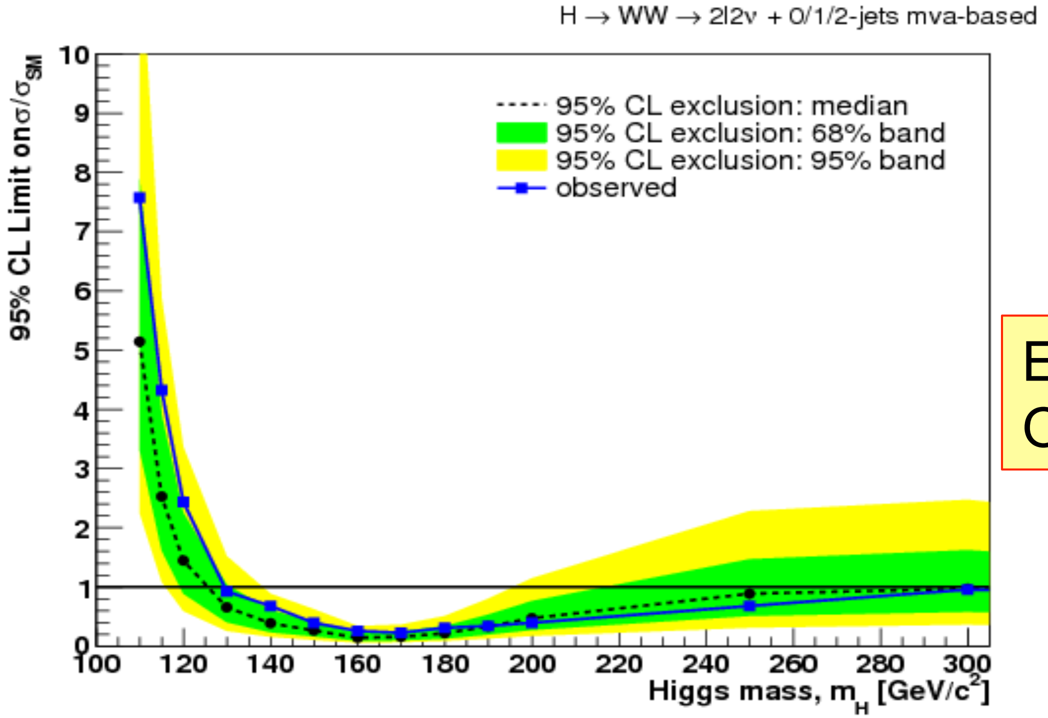


Expected range: $128 < M_H < 236$ GeV
Observed range: $132 < M_H < 238$ GeV

BDT shape comparison

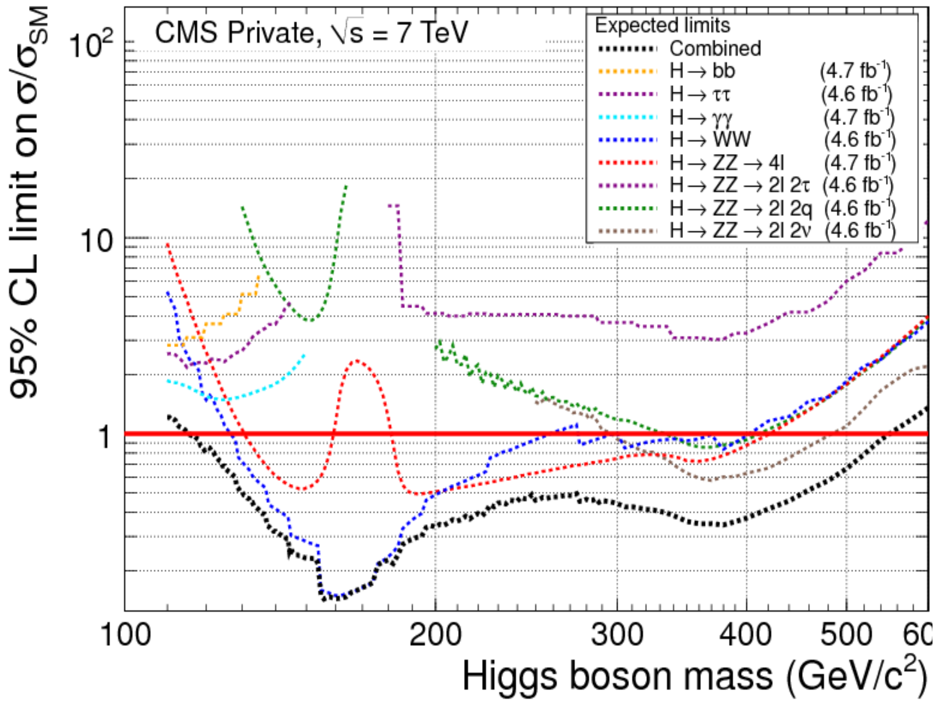


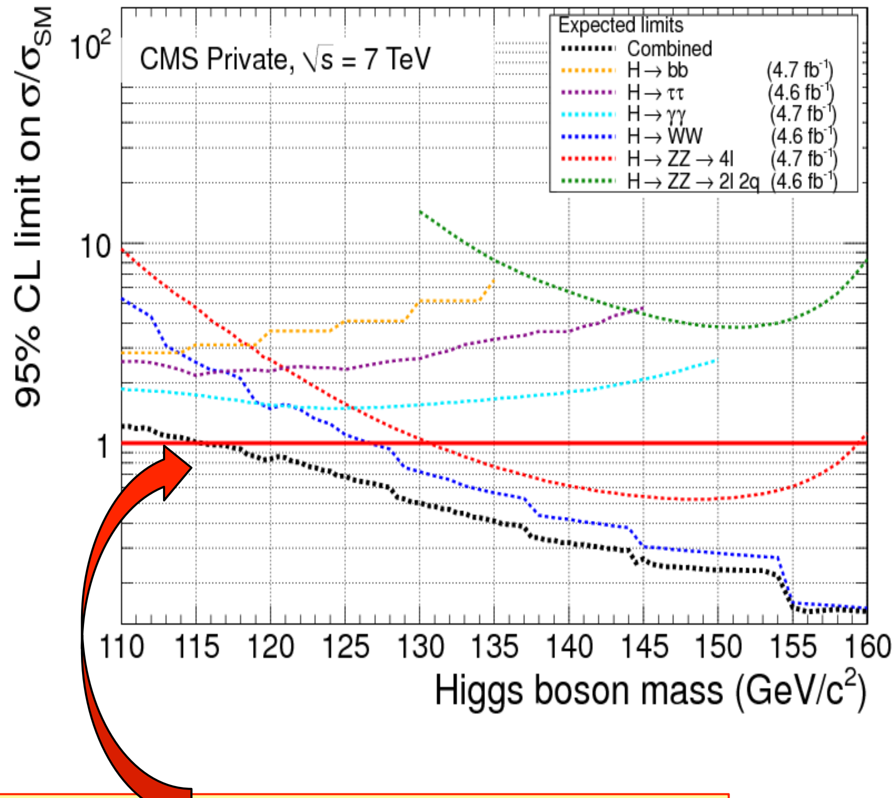
Opposite/same flavour (OF/SF) leptons



Expected range: 125 < M_H < 300 GeV
Observed range: 128< M_H < 300 GeV

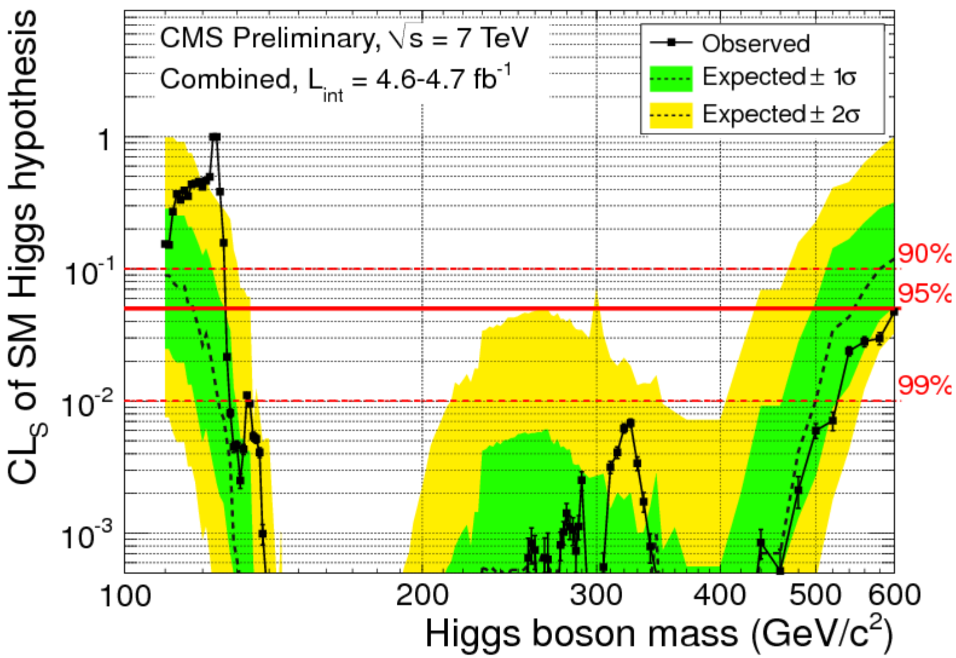
CMS combination and sensitivity @ 4.7 fb^{-1}

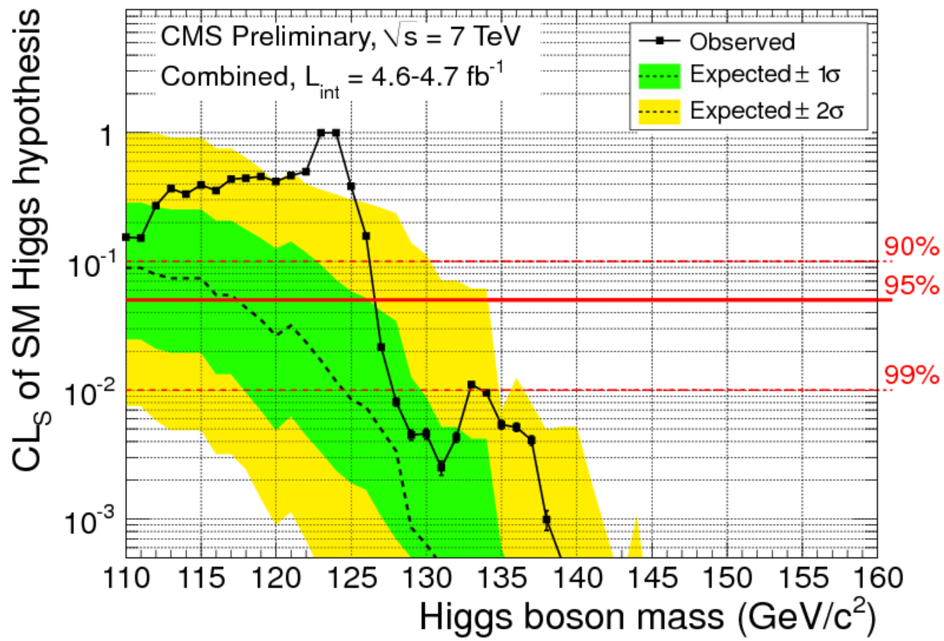




Very close or better than 1xSM in the full mass range.

CLs for SM Higgs

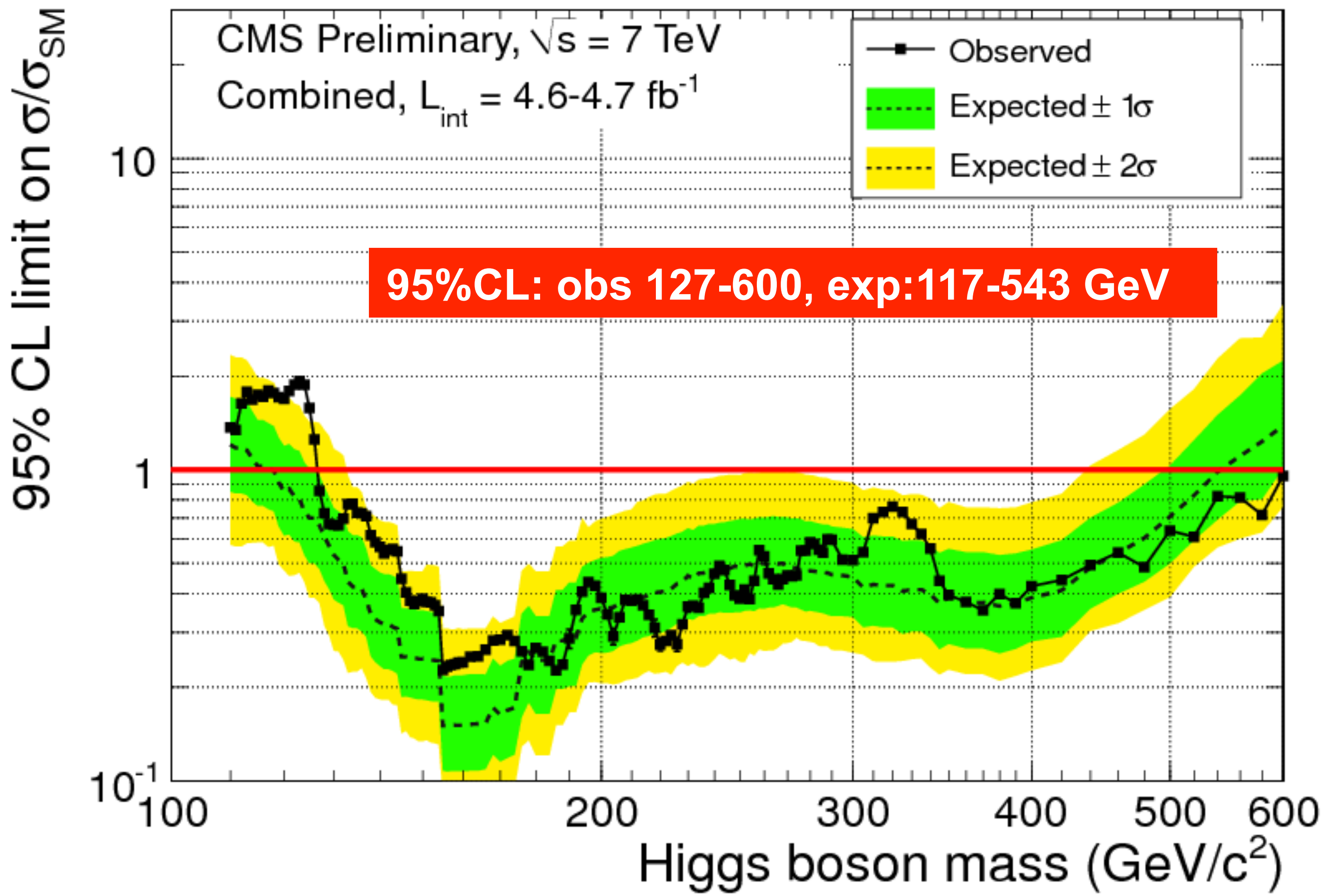




Preliminary exclusion limits

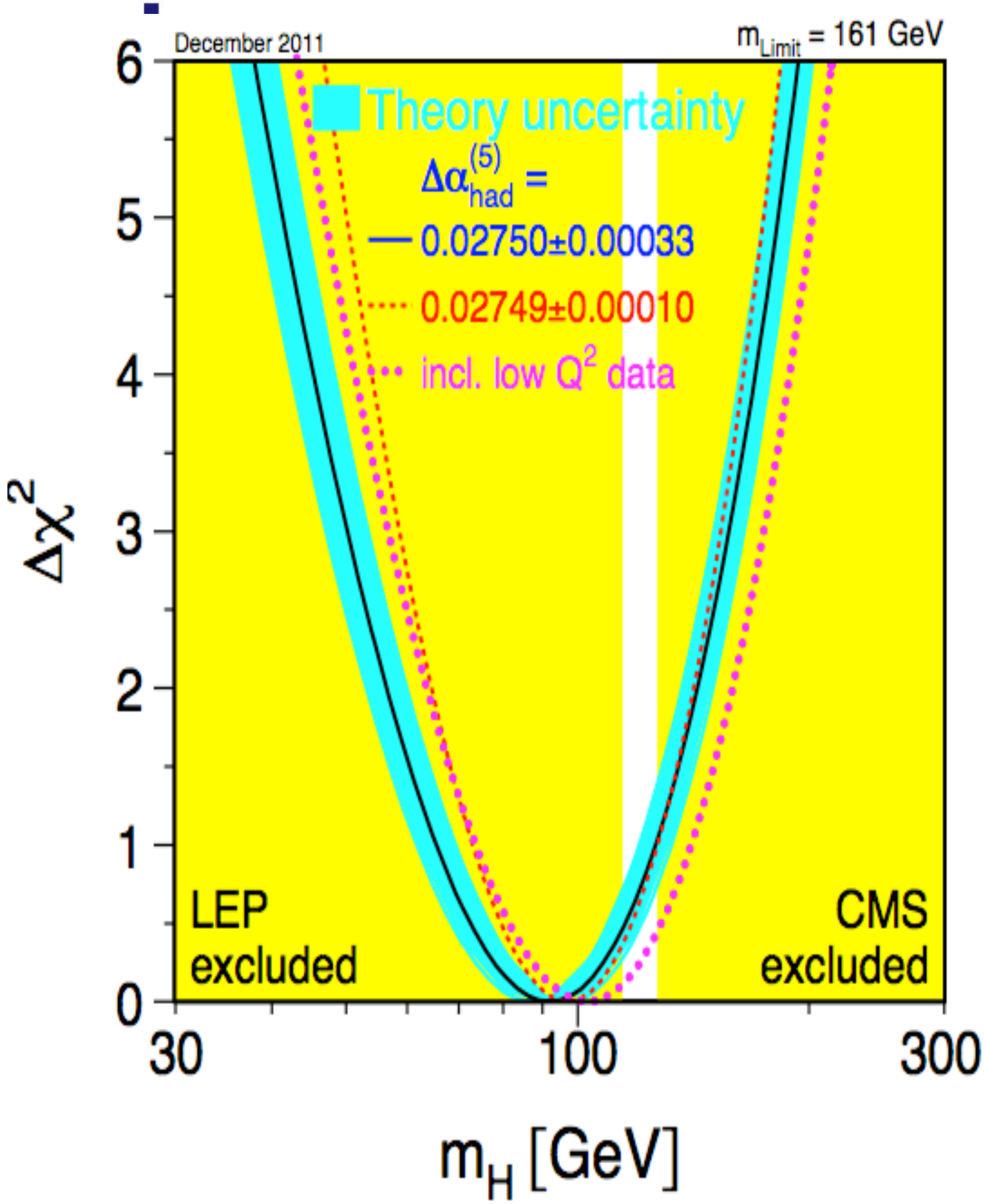
95% CL:	**obs 127-600,**	**exp:117-543**
99% CL:	**obs 128-525,**	**exp:125-500**

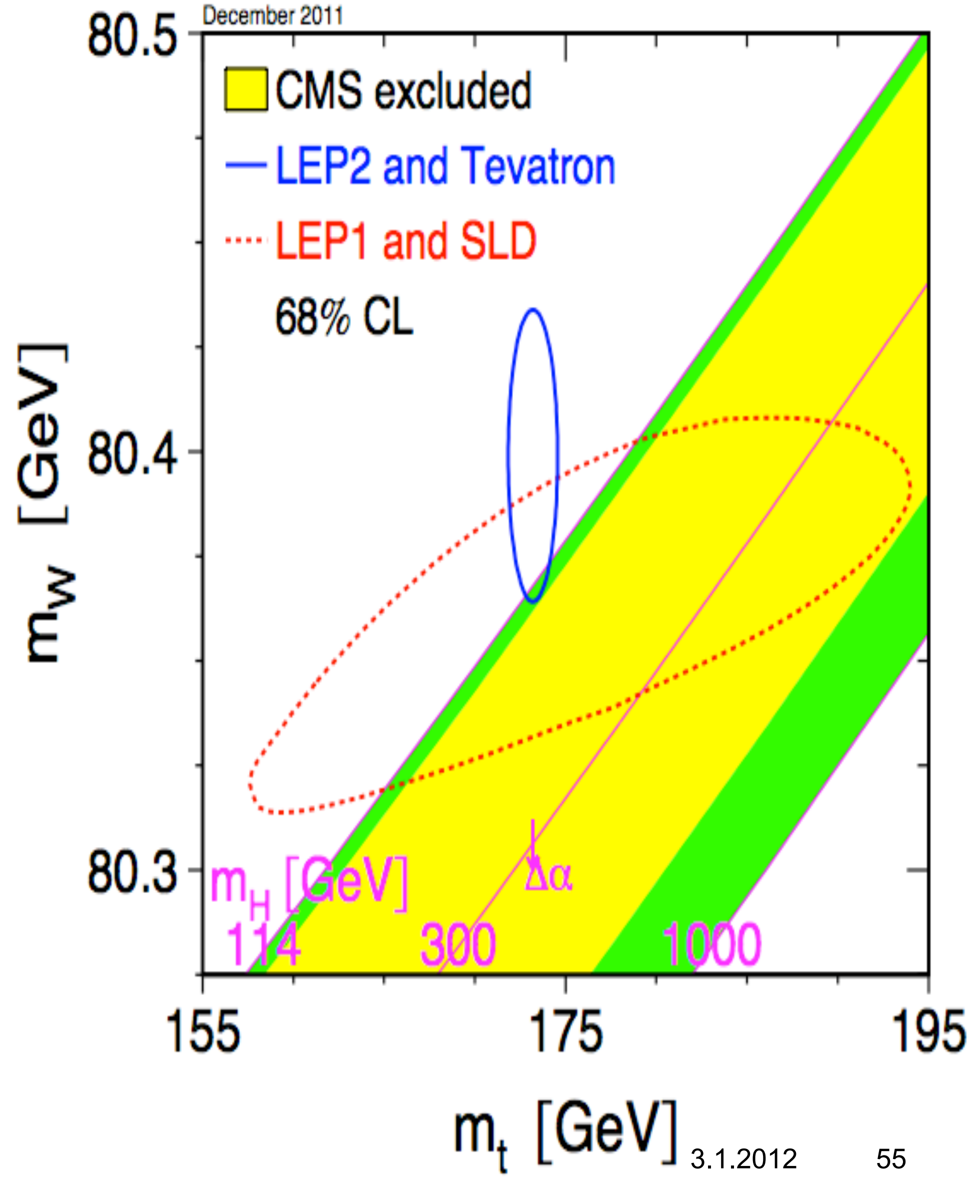
Limits on σ/σ_{sm} (CLs method)



CMS PAS HIG-011-32

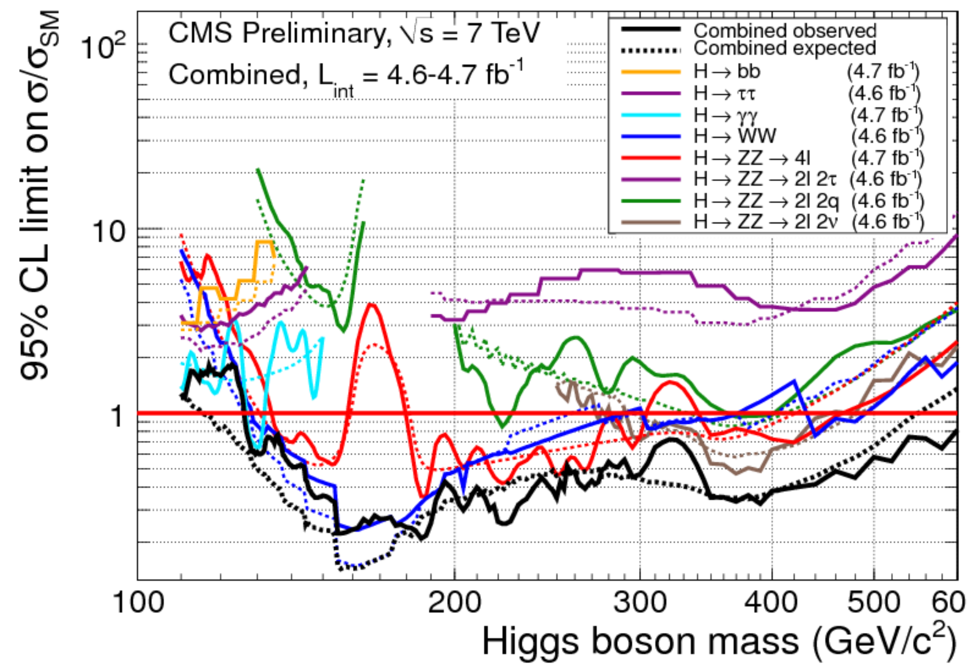
EWK fits together with CMS results

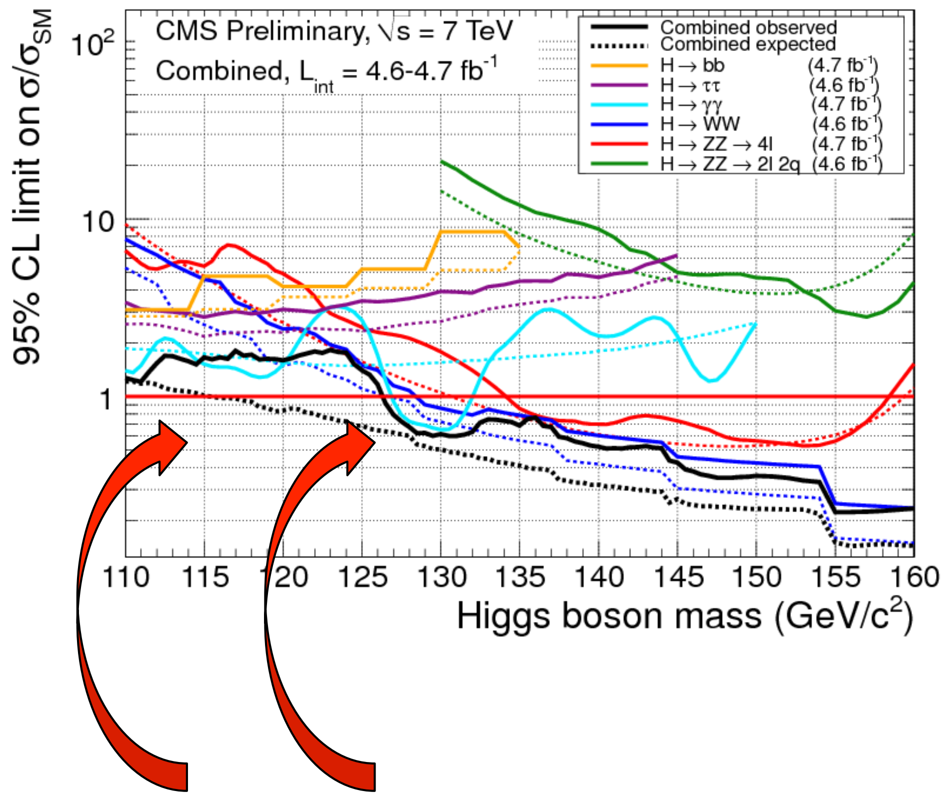




Limits by channel

Solid line = Observed limit ; Dashed line = Median Expected

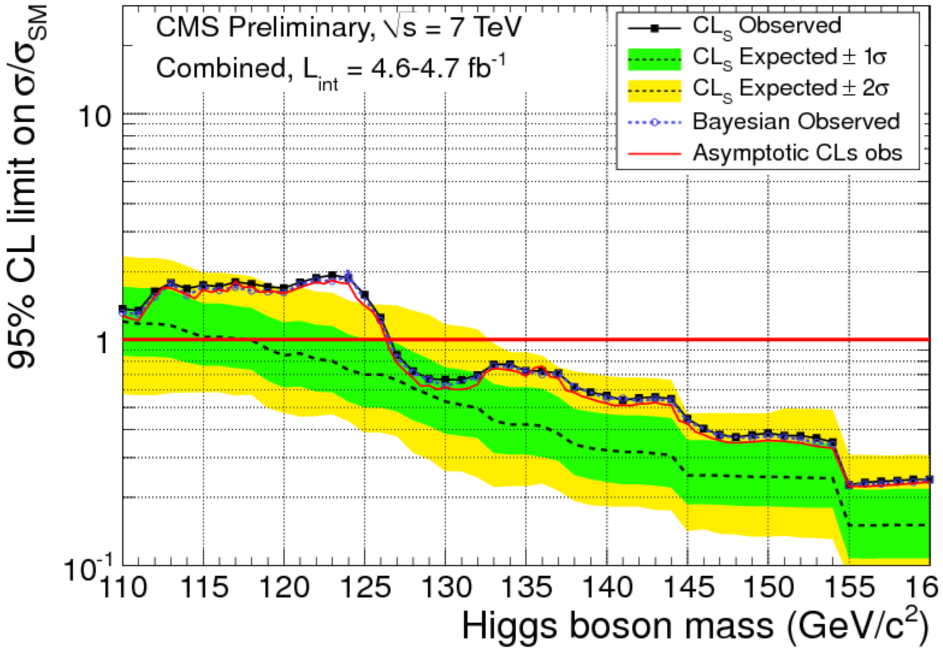


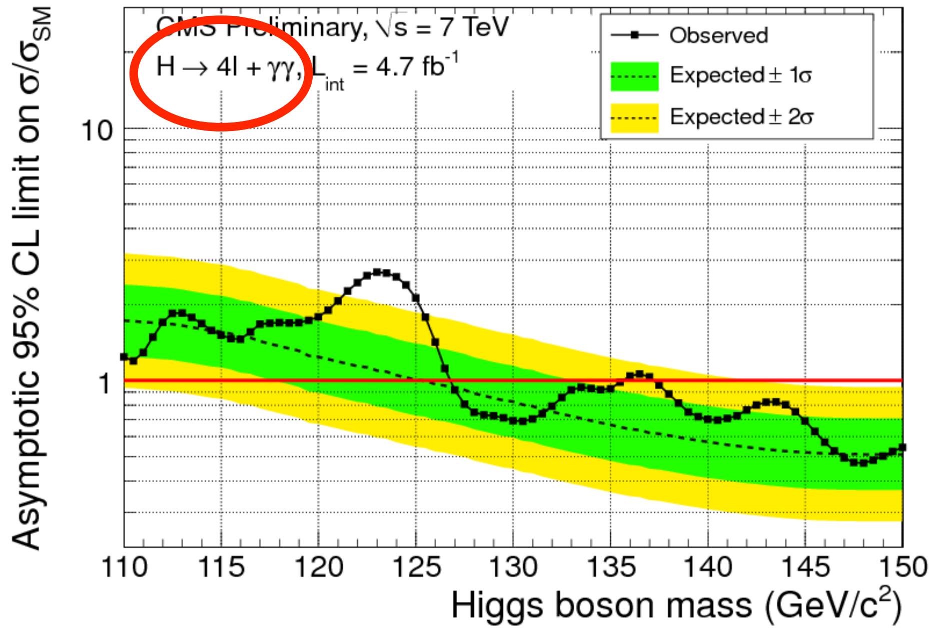


(Asymptotic CLs only)

Expected Observed

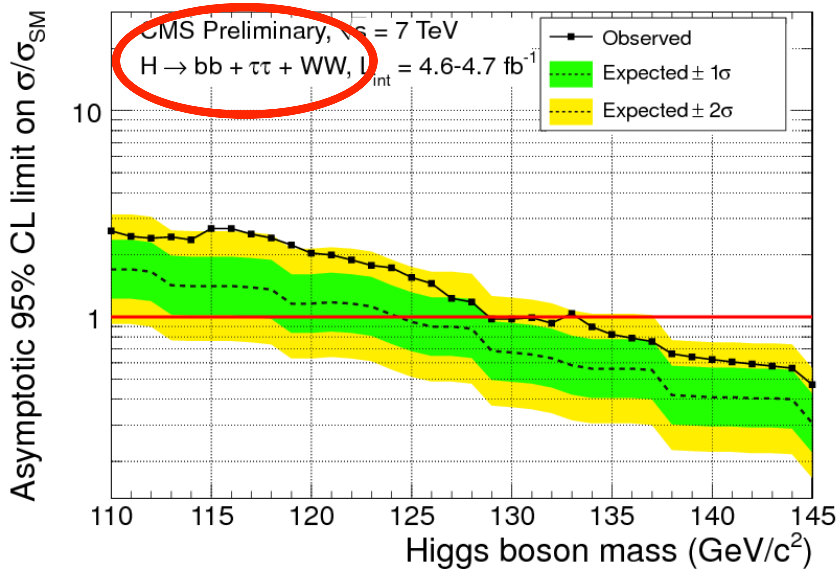
Zoom in the low mass region



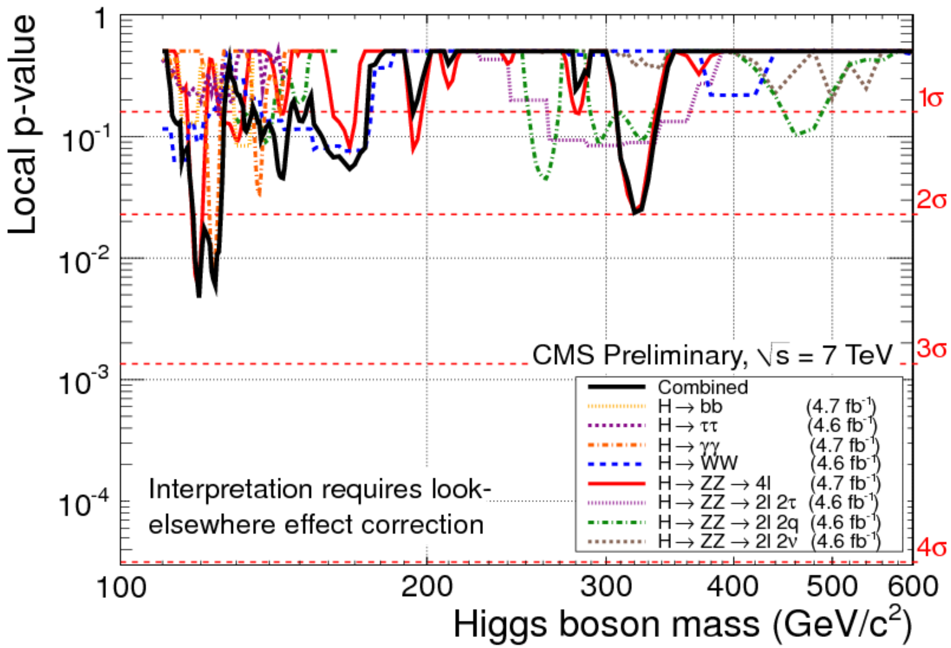


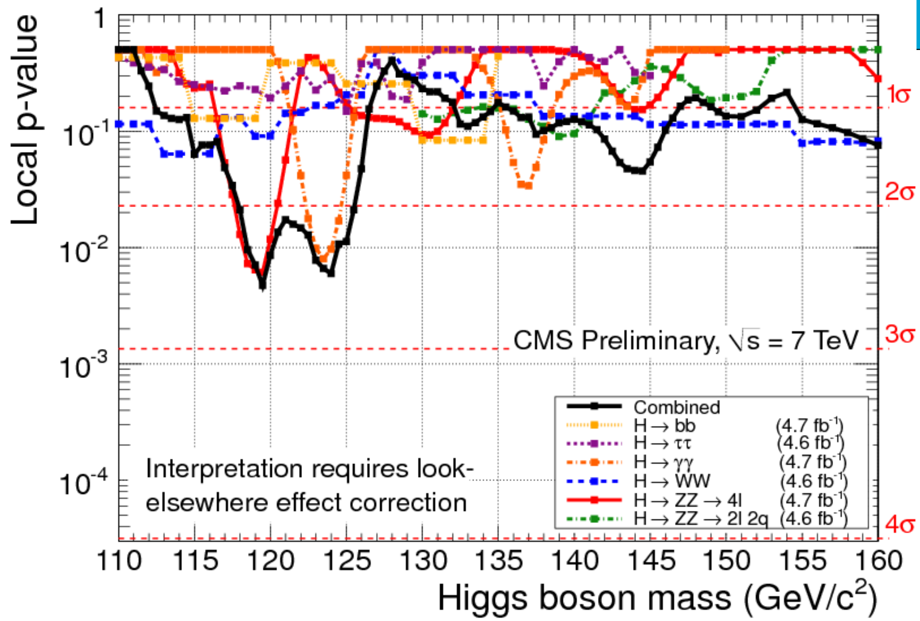
We cannot exclude the presence of the SM Higgs boson below 127 GeV because of a modest excess of events in the region between 115 and 127 GeV.

A broad excess driven by the low resolution channels, modulated by the localized excesses seen by the high resolution channels (H→4l+γγ).



Local and global p-values





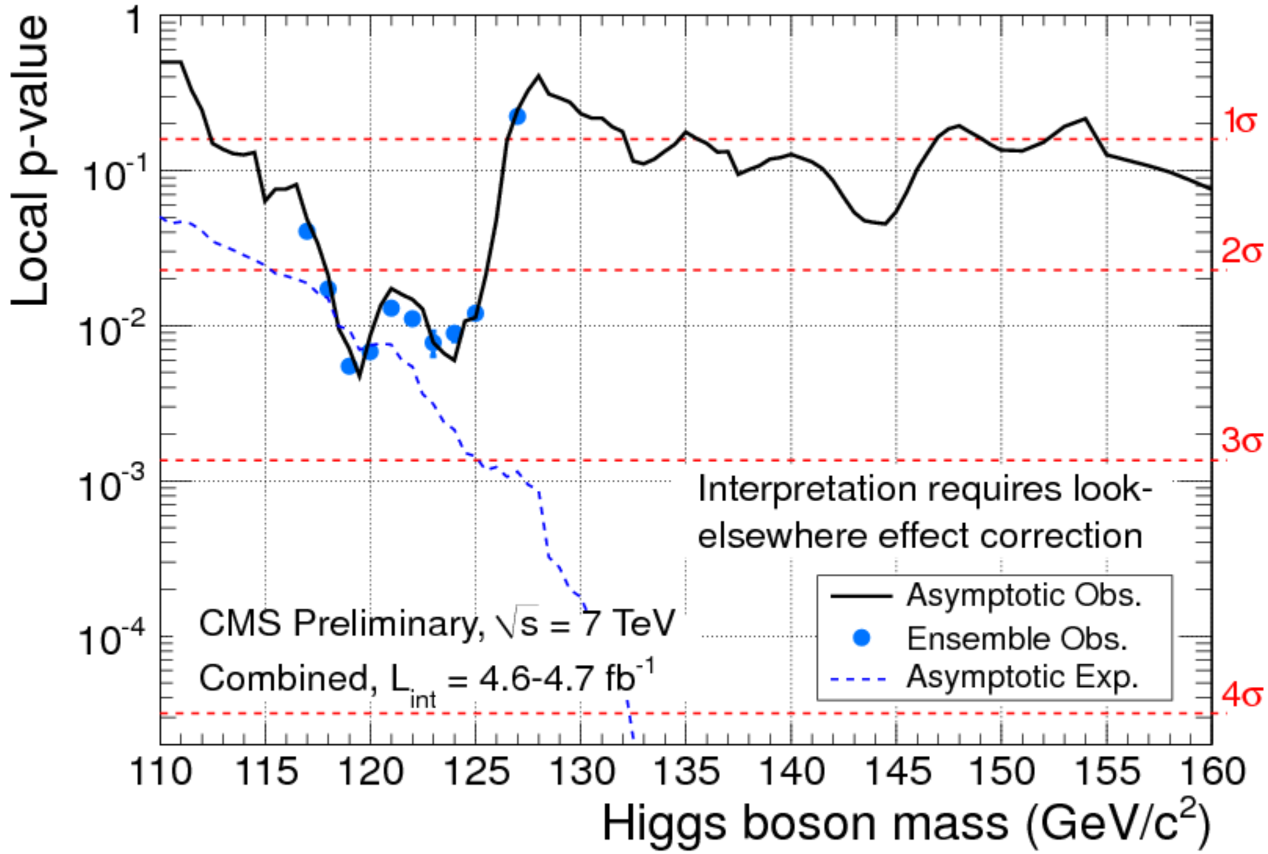
Maximum local significance **2.6σ.**

LEE-corrected significance (full mass range: 110-600GeV)= **0.6σ**

LEE-corrected significance (low mass range: 110-145GeV)= **1.9σ**

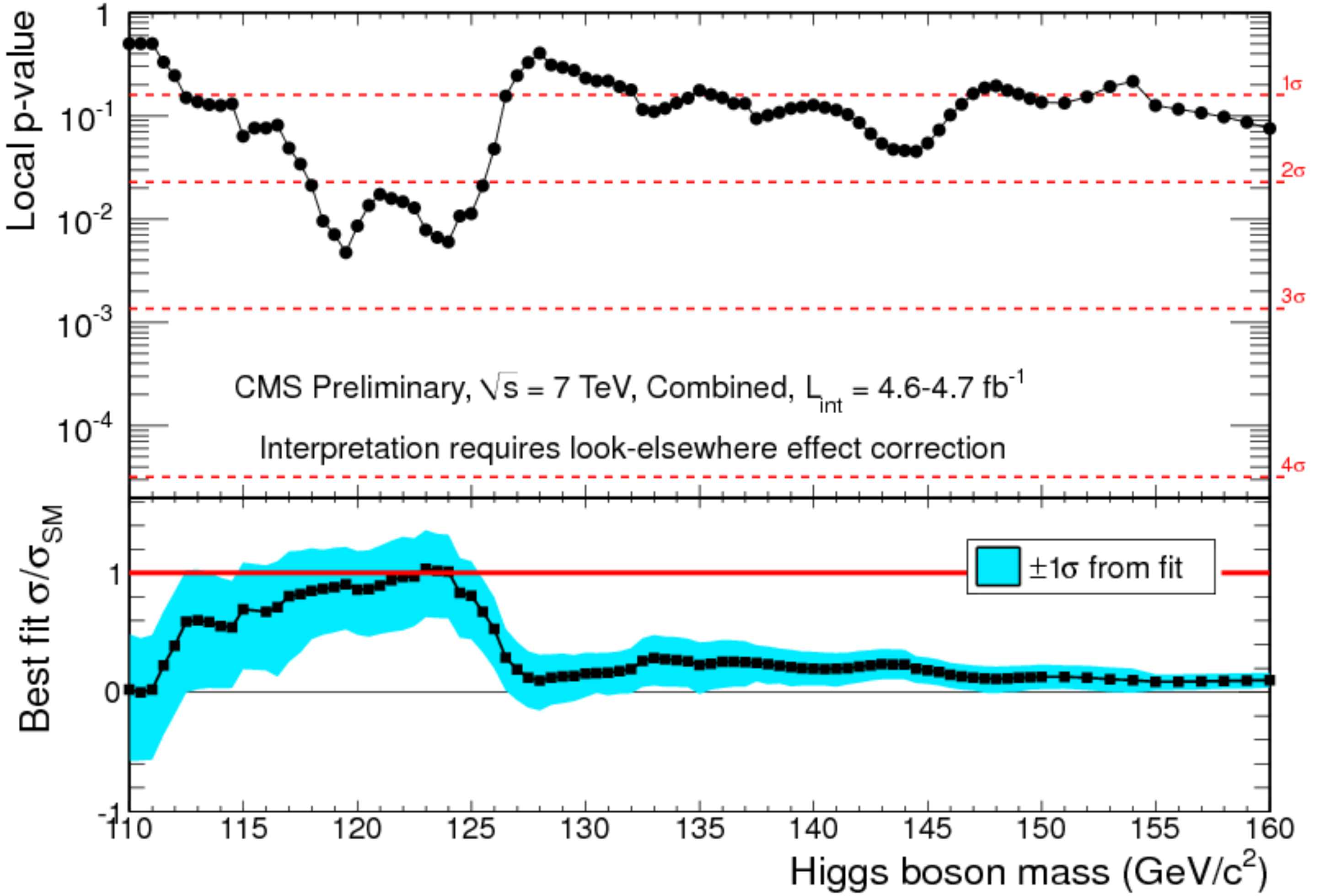
The excess we see in the low mass region has a modest statistical significance and can be definitely interpreted as a fluctuation of the background.

Anatomy of the excess: Observed and Expected



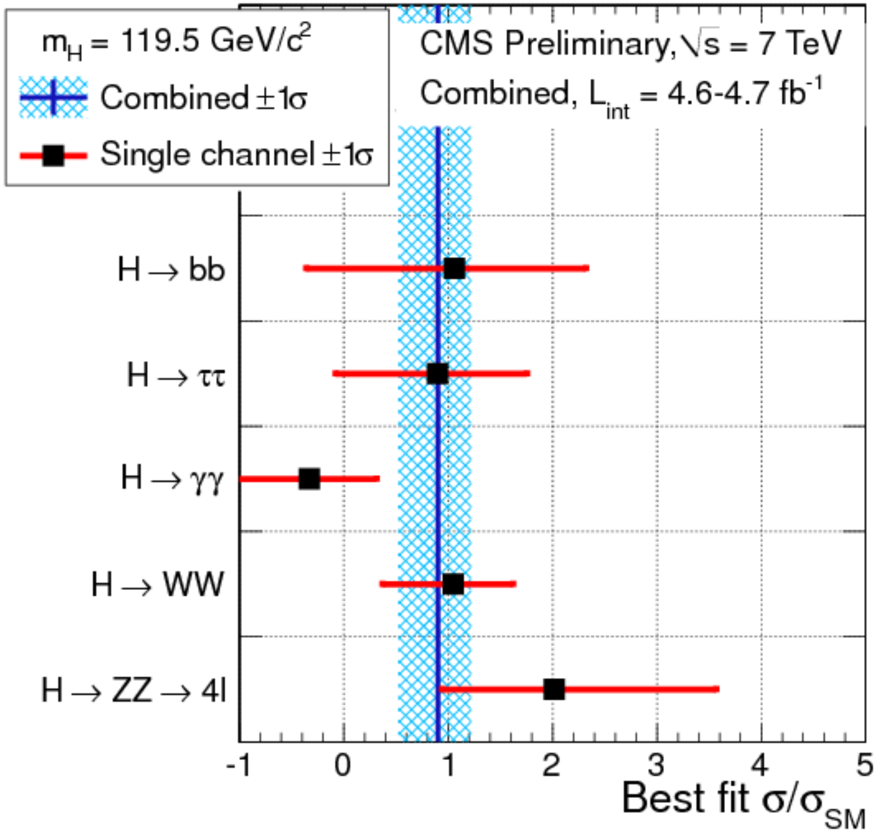
Dashed line: expected p-values for a SM Higgs boson.
A SM Higgs boson is expected to yield a modest p-value (2-3σ median value) in the range 115-127 GeV.

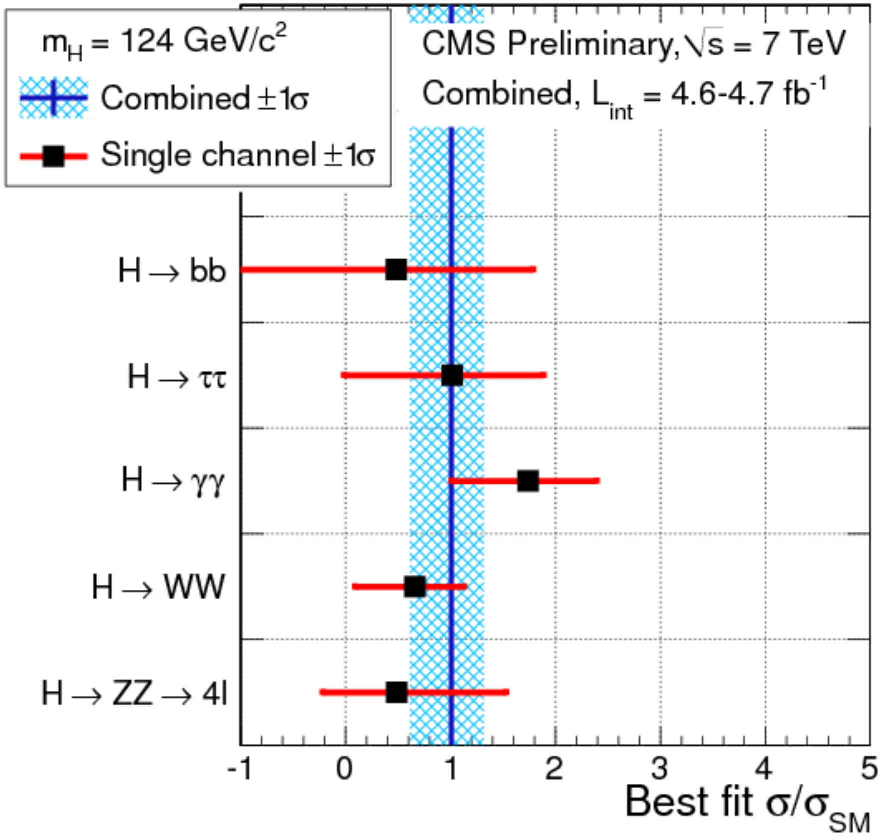
Anatomy of the excess: best fit σ/σ_{sm}



Fitted σ/σ_{SM} compatible with 1 in the full low mass range. Median value touching 1 at a mass of 124 GeV and below.

Anatomy of the excess
Best fit σ/σ_{sm} of the various channels

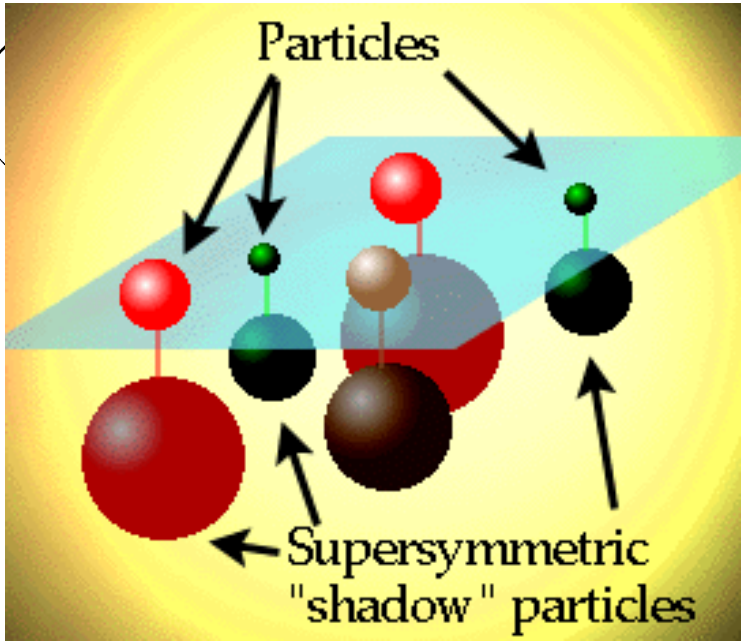


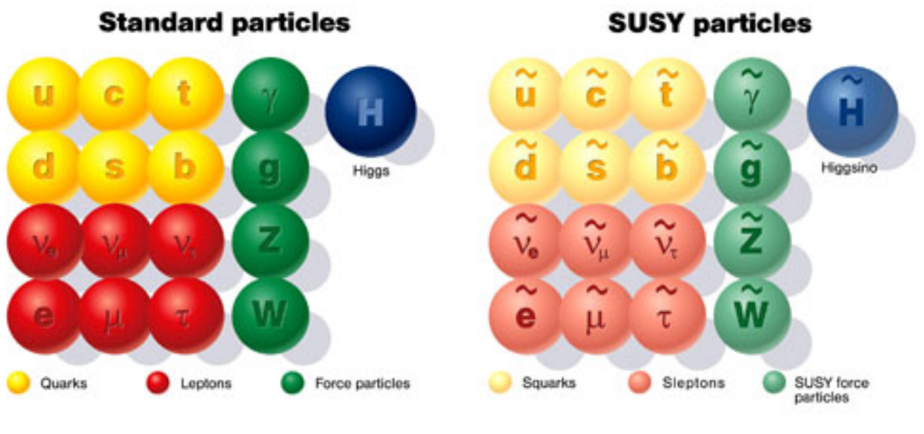


Excess quite consistently seen in all individual channels ±1σ in the low mass region.

Searching for Supersymmetry and other New Physics

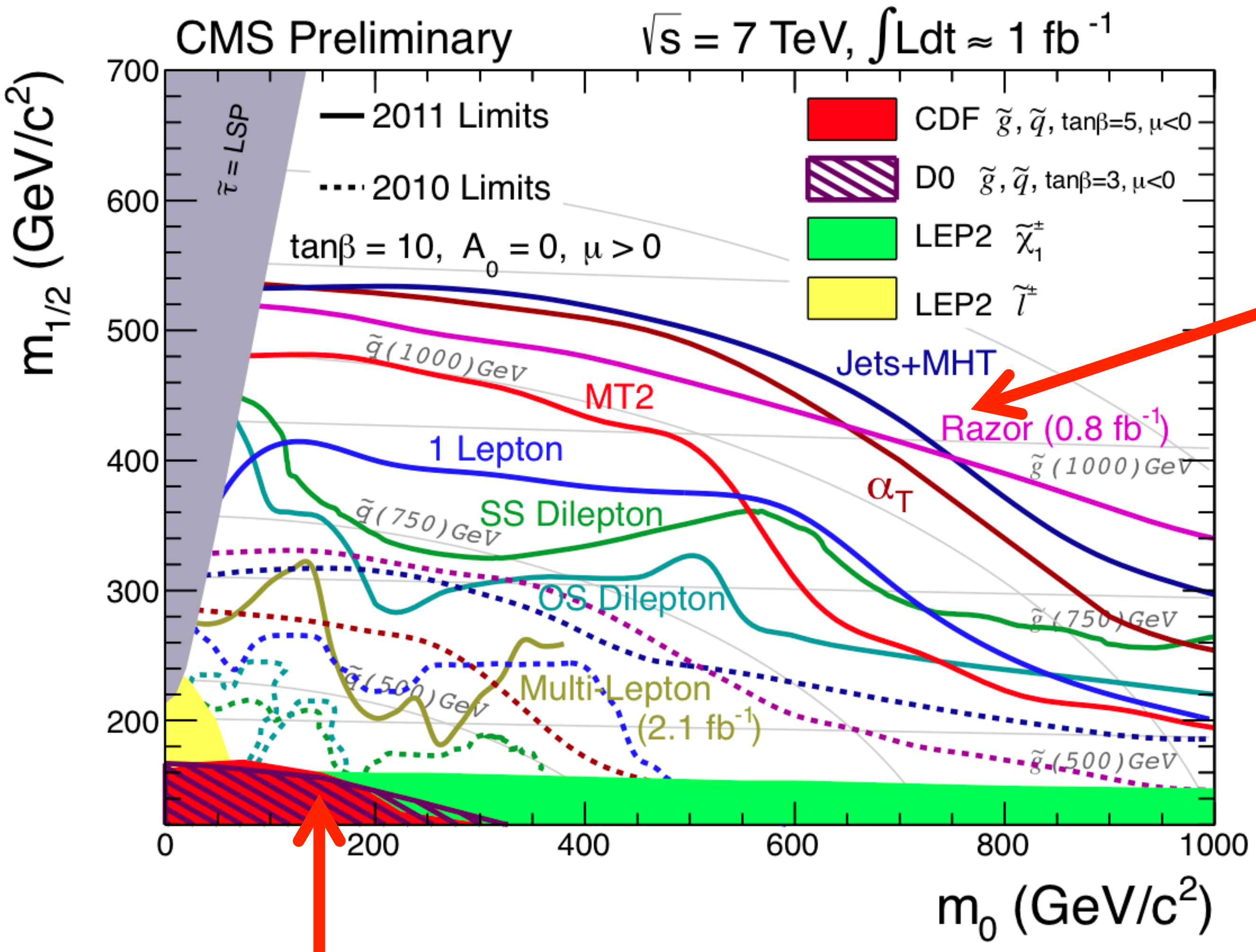
Supersymmetry - SUSY





- Unified theory
- Elegant way of solving the hierarchy problem of the Standard Model (radiative corrections to Higgs mass grow to very large values)
- Lightest SUSY particle the ”best” candidate for dark matter

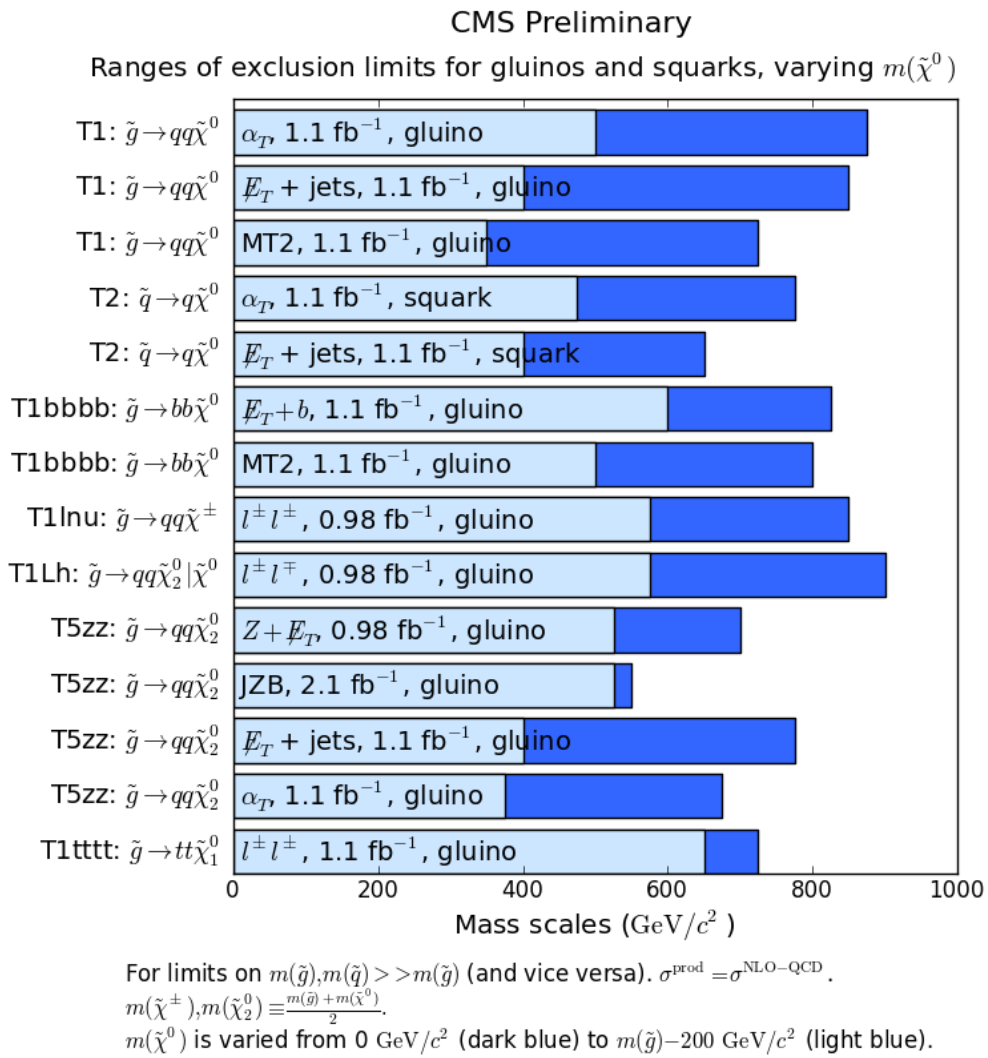
Supersymmetric particles: nothing so far



Excluded range

LHC: much larger parameter space excluded than at Tevatron

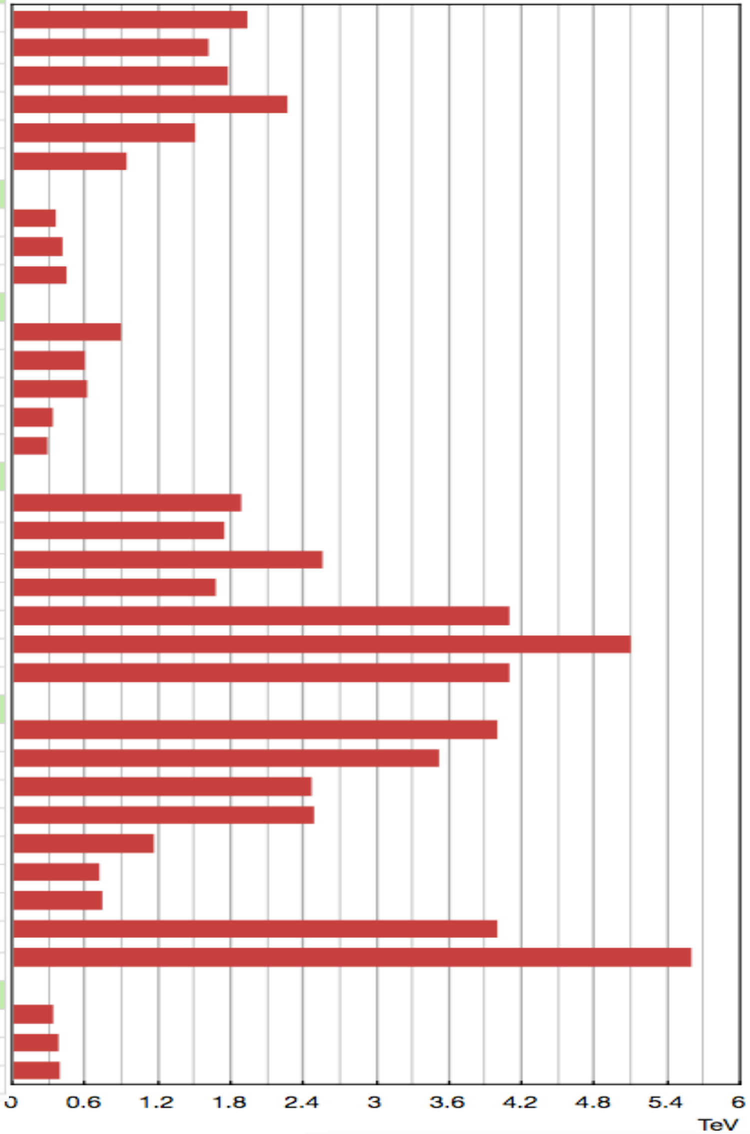
Excluded SUSY mass ranges



Range of excluded mass scale in Simplified Model Spectra from several 2011 CMS SUSY searches

…no other new particles either…

	Limits in TeV	
		Heavy Bosons
Z'_{SSM} ll	1.94	2011
Z'_{Ψ} ll	1.62	2011
G_{KK} ll k/M = 0.1	1.78	2011
W' lν	2.27	2011
W' dijet	1.51	2011
G_{KK} γγ k/M = 0.1 (2010)	0.945	2010
		4th Generation
$M_{b'}$, b' ⇒ tW (2010)	0.361	2010
$M_{t'}$, t' ⇒ tZ (100%)	0.417	2011
$M_{t'}$, t' ⇒ bW (100%), l+jets	0.45	2011
		Heavy Stable Particles
M_{gluino}, HSCP	0.899	2011
M_{gluino}, Stopped Gluino	0.601	2011
M_{stop}, HSCP	0.620	2011
M_{stop}, Stopped Gluino	0.337	2011
M_{stau}, HSCP	0.293	2011
		Large Extra Dimensions
M_s, γγ, GRW (2010)	1.89	2010
M_s, μμ, GRW (2010)	1.75	2010
M_D, monojet, n_{ED} = 2 (2010)	2.56	2010
M_D, monojet, n_{ED} = 6 (2010)	1.68	2010
M_{BH}, rotating, M_D=3.5 TeV, n_{ED} = 2	4.1	2011
M_{BH}, non-rot, M_D=1.5 TeV, n_{ED} = 6	5.1	2011
String Ball M, M_D=2.1, M_s=1.7, g_s=0.4	4.1	2011
		Compositeness and Contact Interactions
String Resonances	4.0	2011
E_6 diquarks	3.52	2011
Axigluon/Coloron	2.47	2011
q* , dijet	2.49	2011
q* , boosted Z	1.17	2010
e*, Λ = 2 TeV	0.720	2010
μ*, Λ = 2 TeV	0.745	2010
C.I. Λ , dijet mass (3 pb^{-1})	4.0	2010
C.I. Λ , Χ analysis	5.6	2010
		LeptoQuark
LQ1, β=0.5 (2010)	0.340	2010
LQ1, β=1.0 (2010)	0.384	2010
LQ2, β=1.0 (2010)	0.394	2010



Why nothing so far?

- **M. Peskin, Lepton-Photon conference Aug 2011:** ***"SUSY is a beautiful idea. It is a theory with only weak couplings, in which all effects can be computed explicitly, that provides solutions to many of the important problems of particle physics, including electroweak symmetry breaking, grand unification, and dark matter…."***
- ***"It is time to give up on the cMSSM. But what should replace it:"***
  - ***"1. Find a type of SUSY model in which the mass scale is least constrained"***
  - ***"2. Accept that the theory of electroweak symmetry breaking might involve strong interactions"***

Consequences:

- **1. option:**
  - **Not all the SUSY particles need to have masses near the 100 GeV scale, only Higgsinos and top**

    → look for 3rd generation SUSY particles, stop, sbottom
- **2. option:**
  - **The Higgs is composite with strong interactions**

    → a general feature is the appearance of partners of W, Z, top (W', Z', T)
- **3. option:**
  - **The Standard Model is consistent up to the Planck scale (10^{19} GeV)**
  - **→ consistency with 125 GeV Higgs?**
  - **Peskin: "*We must confront the possibility that we have come to the end of our ability to understand physics microscopically*"**

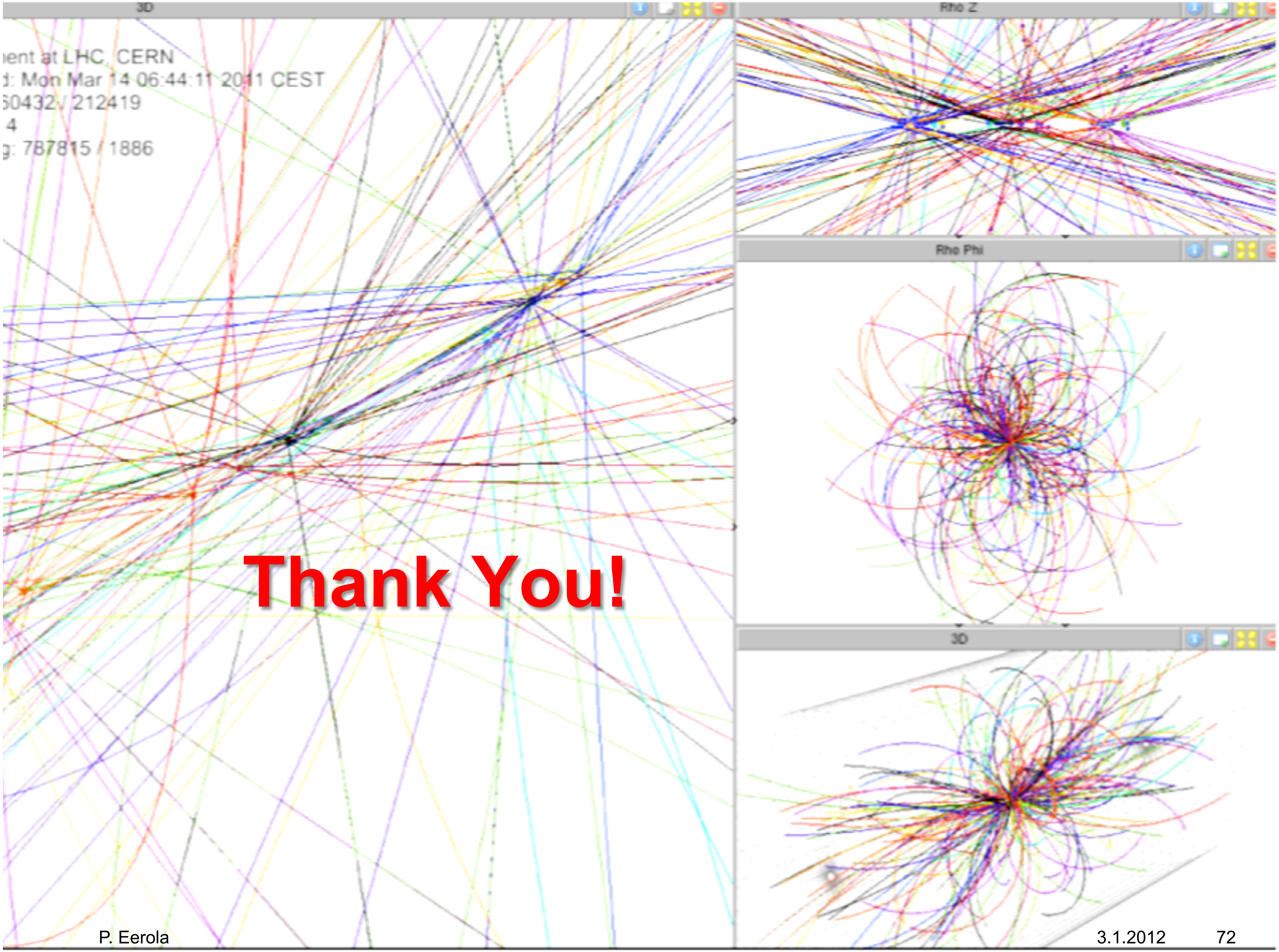
LHC: future?

- 2010-2012 – 7 TeV
- 2013-2014 – shutdown, improve magnets
- 2015-2017 → 14 TeV, L to 10^{34} $cm^{-2}s^{-1}$
- 2017-2018 – shutdown, replacements of inner parts of detectors
- 2019-2021 – 14 TeV, L > 10^{34} $cm^{-2}s^{-1}$?
- 2022 – shutdown, major upgrades
- …continue past 2030…?

Summary

- LHC: enormous amounts of new results in a new energy domain
- The accelerator and the experiments have been working in a fantastic way
- Very rapid take-over of physics leadership
- No signs of new physics yet, Supersymmetry being constrained more and more…
- Standard Model is the final answer??
- Some of the Tevatron 2-3σ effects disfavoured

- Higgs bosons:
- CMS has reached a sensitivity of around or better than 1xSM in the full mass range of our current exploration (115-600 GeV). 95% CL exclusion limit (127-600) GeV.
- CMS is not able to exclude the presence of the SM Higgs below 127 GeV because of a modest excess of events between 115 and 127 GeV
- Excess appears in five independent channels
- The excess is most compatible with a SM Higgs hypothesis in the vicinity of 124 GeV and below
- The statistical significance (2.6σ local and 1.9σ global after correcting for the LEE in the low mass region) is not sufficient
- Results consistent either with a background fluctuation or with the presence of the SM Higgs boson
- Refined analyses and additional data in 2012 will definitely give an answer

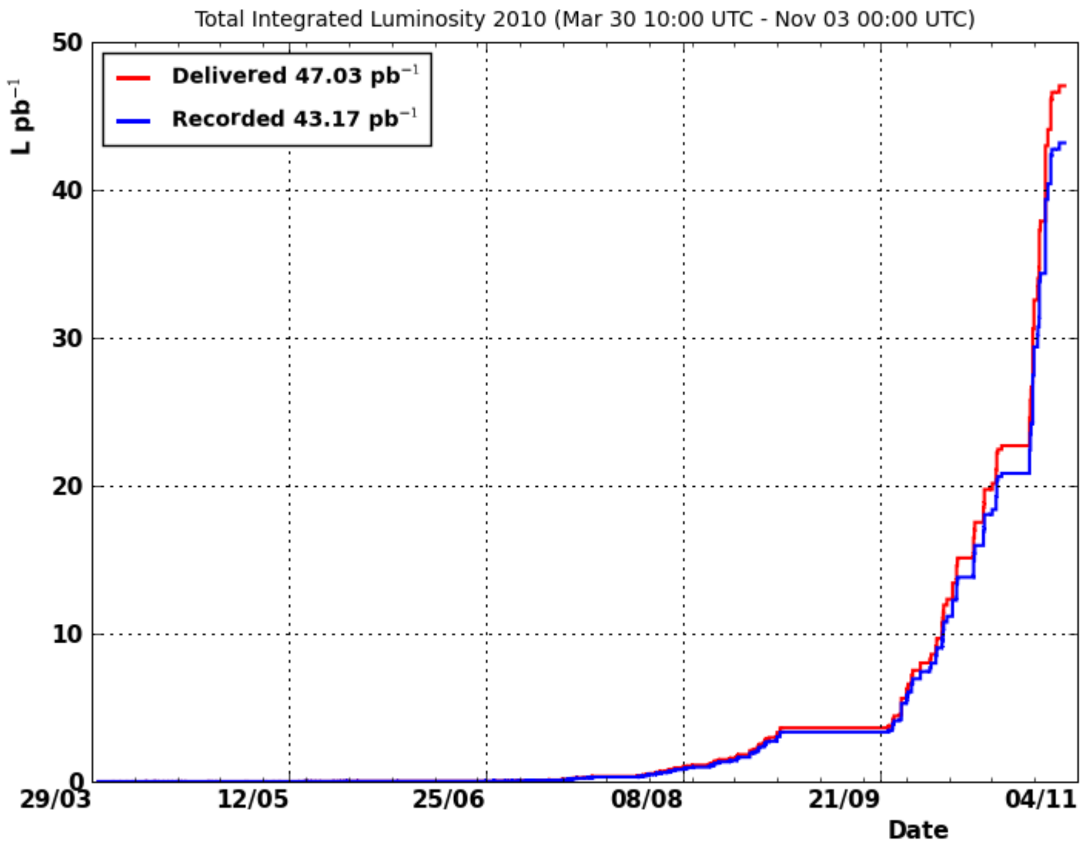

3D
ent at LHC, CERN
Mon Mar 14 06:44:11 2011 CEST
212419
787815 / 1886
Rho Z
Rho Phi
3D

Thank You!

Back-up material

LHC: performance 2010

Amount of data 2010



Luminosity: quick user's guide

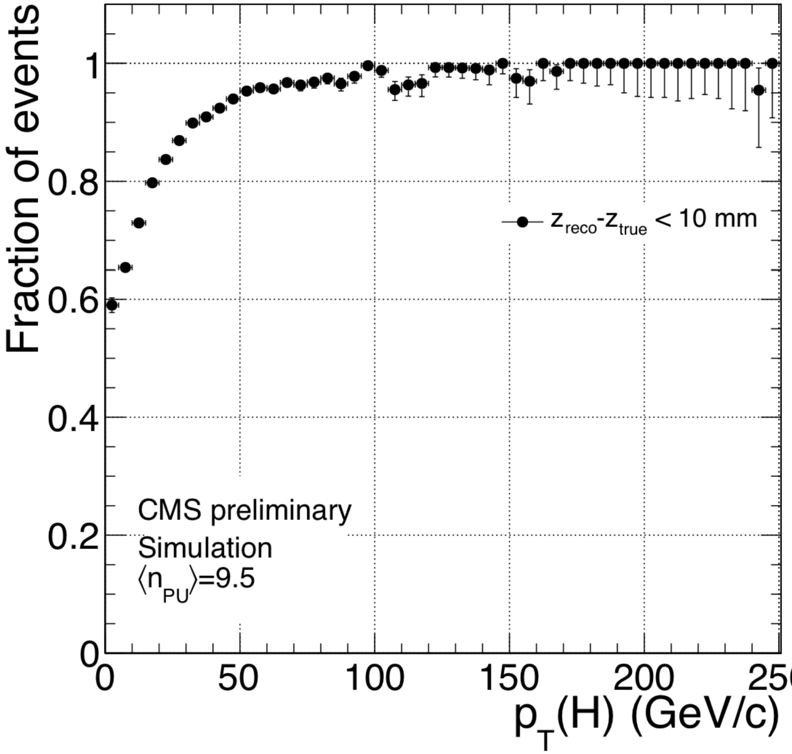
- Integrated luminosity: $\mathcal{L} = \int L\,dt$
- **N(number of events) = σ(cross section) x $\mathcal{L}$(int. luminosity)**
- Example:
  - Top-quark production cross section at LHC: σ **~ 165 pb = 165 000 fb**
  - 2011: LHC $\mathcal{L}$ = **5 fb^{-1}**
  - **N = σ x $\mathcal{L}$ = 165 000 fb x 5 fb^{-1} =825 000 events in 2011**
- 1 barn = 10^{-24} cm^2
- t=10^7 s, L=10^{32} cm^{-2} s^{-1} → $\mathcal{L}$ = 10^7s x 10^{32} cm^{-2} s^{-1} = (10^{-39} cm^2)$^{-1}$ = (10^{-15} 10^{-24} cm^2)$^{-1}$ = (1 fb)$^{-1}$ = 1 fb^{-1}

- t=10^7 s ("1 year"), L=10^{34} cm^{-2} s^{-1} (design L) →$\mathcal{L}$ = 100 fb^{-1}
- In 2011, the effective "year" (= time in stable beams) was t=5x10^6 s, and the collected integrated luminosity was $\mathcal{L}$ = 5 fb^{-1} → average L during the year was L = 10^{33} cm^{-2} s^{-1}

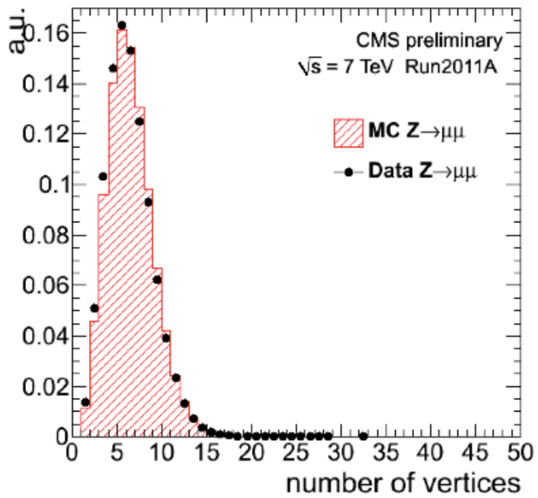
LHC

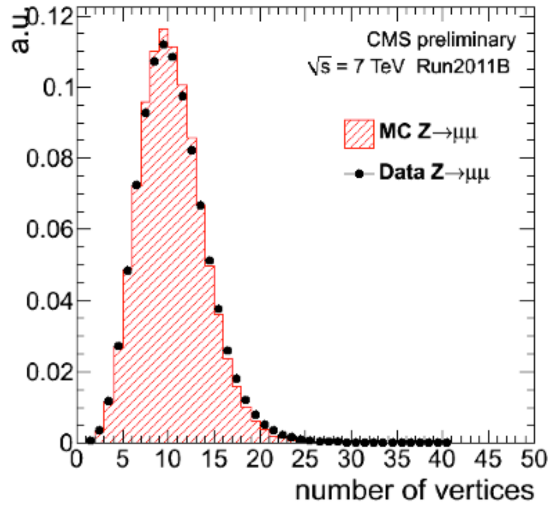
Collider at CERN, pp, 7 TeV (14 TeV), started 2009

$H \rightarrow \gamma\gamma$



Fraction of Higgs vertices found within 10 mm of their true location, for a MC signal sample (m_H = 120 GeV/c^2), as a function of the Higgs p_T. The distribution of the number of interactions per bunch crossing (nPU) in the MC is adjusted to be the same as in the data by weighting the events.



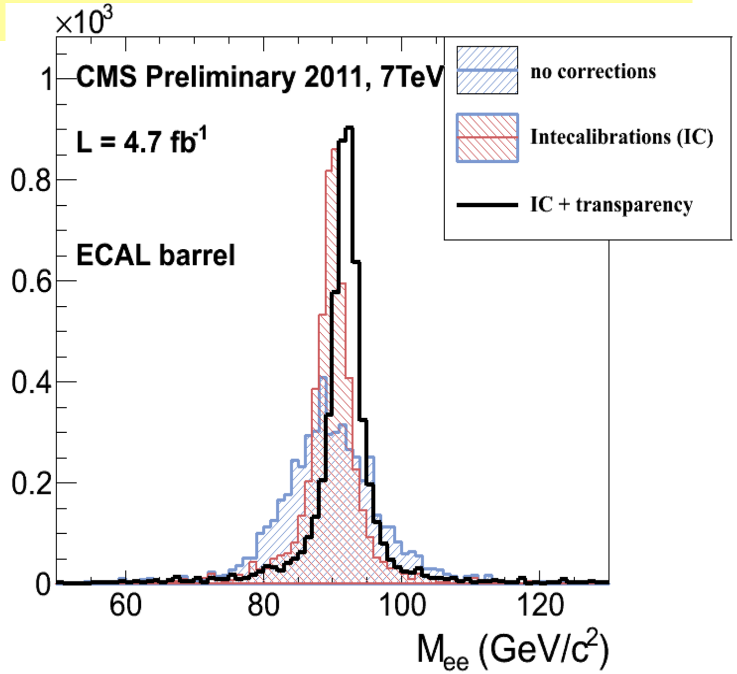


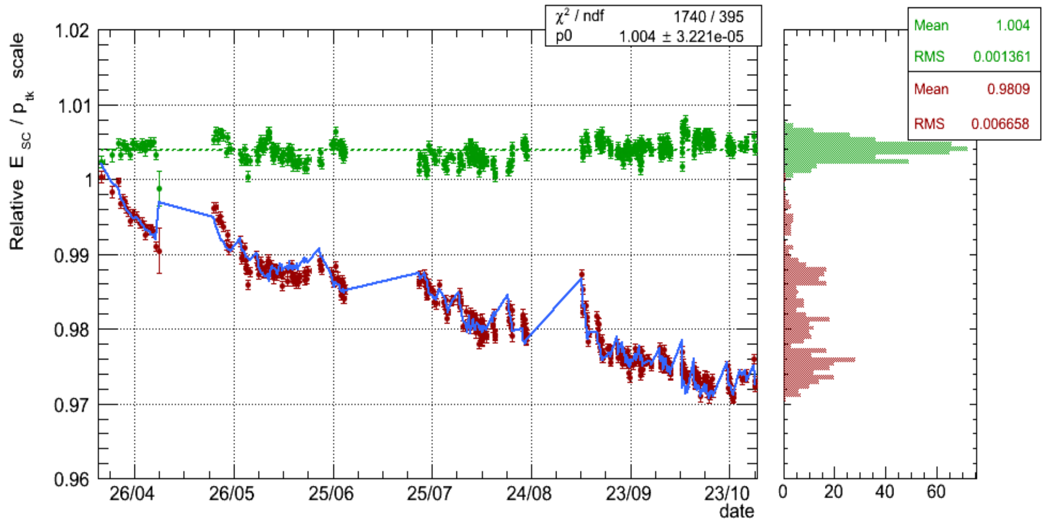
Distribution of the number of reconstructed vertices for events with a Z decaying to 2 muons in the data (points) and MC after having applied the reweighting on the number of simulated in-time pile-up events (filled histogram). Left: 2011A - up until late August, during which time the average instantaneous luminosity and consequent pileup was lower, and right: 2001B, when the instantaneous luminosity was higher.

Improvemens in Photon Energy Resolution

Comprehensive energy resolution studies made with Z →ee, W →eν and E/p, π^o intercalibrations and laser signals for transparency corrections

Effect of laser corrections and intercalibration on barrel-barrel Z→ee
Resolution in data improves typically by 10%, EB, |η|>1, R9>0.94
Additional smearing in data for the best EB category: 0.99 ±0.01 GeV

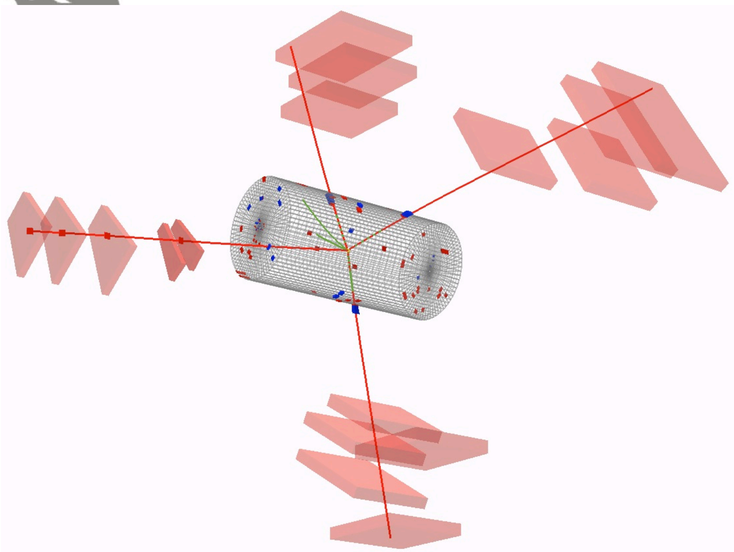


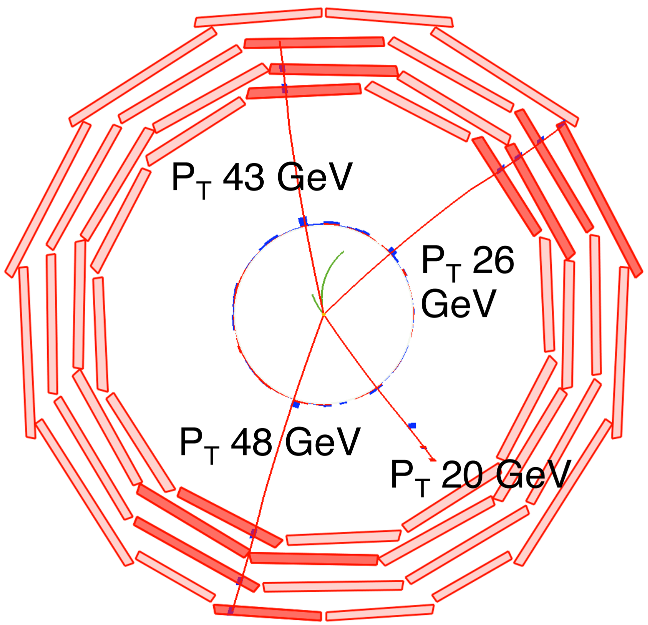


Energy scale for W→eν and Z→ee stable throughout 2011 at the level of 0.1 GeV.

EB inter-calibration and transparency correction fully understood for the entire 2011 data set.

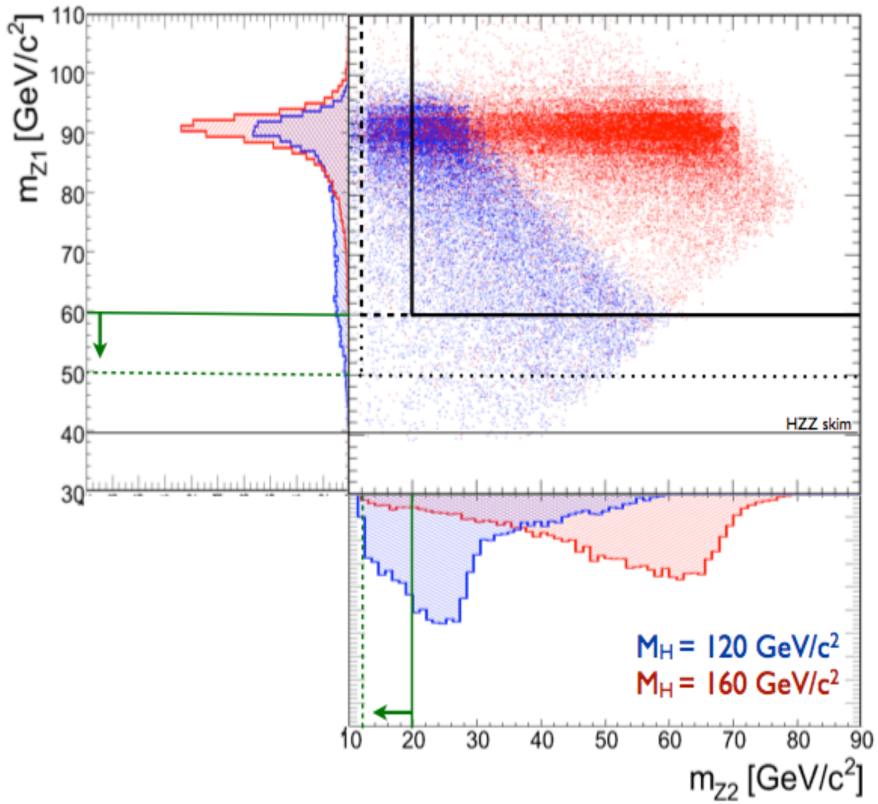
H → ZZ →4e, 4μ, 2e2μ



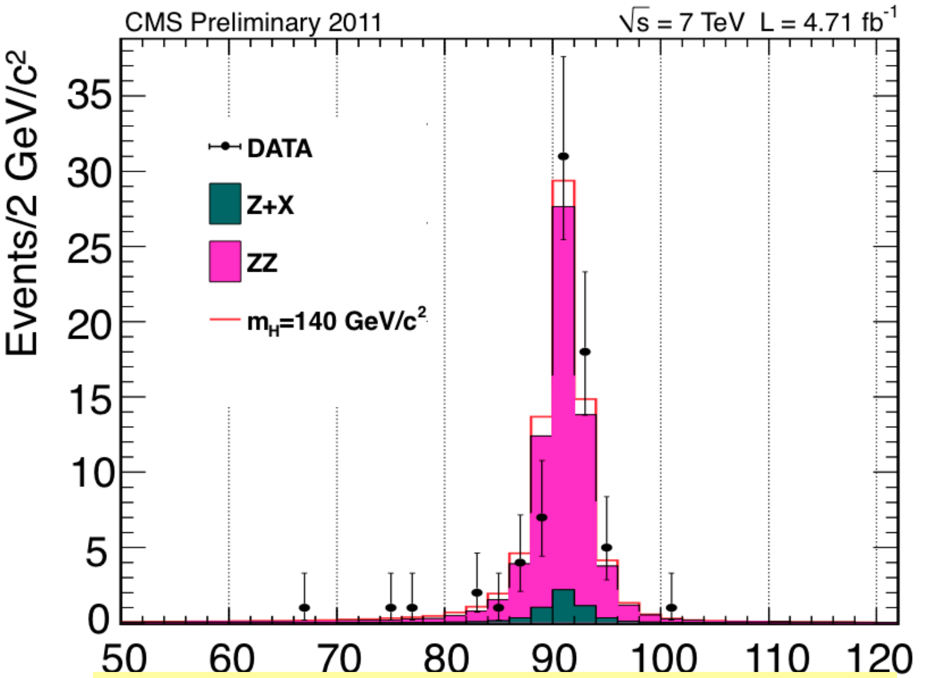


Improved sensitivity at low Higgs masses

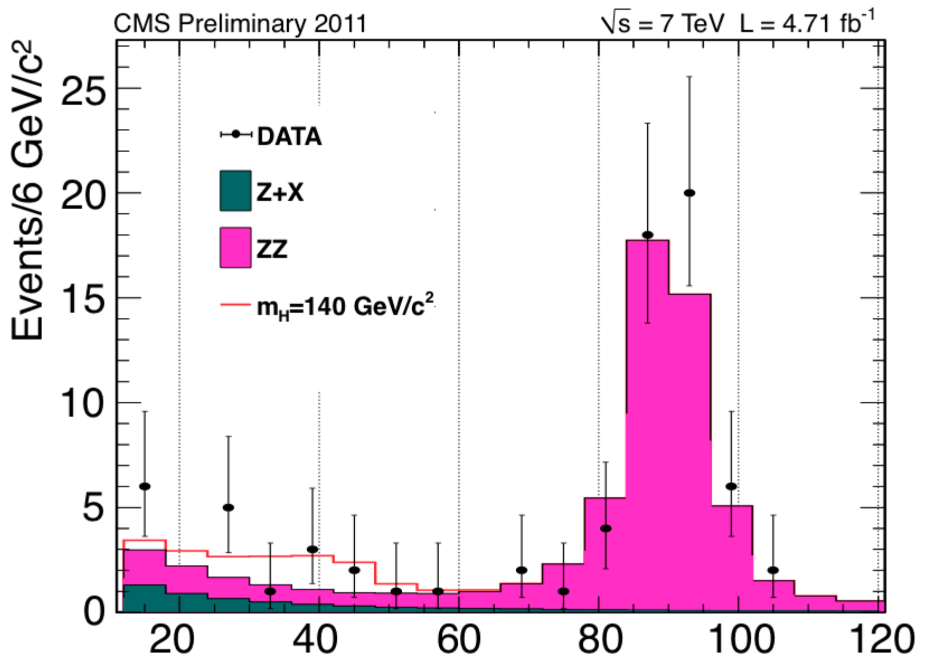
- Reduce MZ_1 cut from 60 → 50GeV
- Reduce MZ_2 cut from 20 → 12GeV



H→ZZ→4l



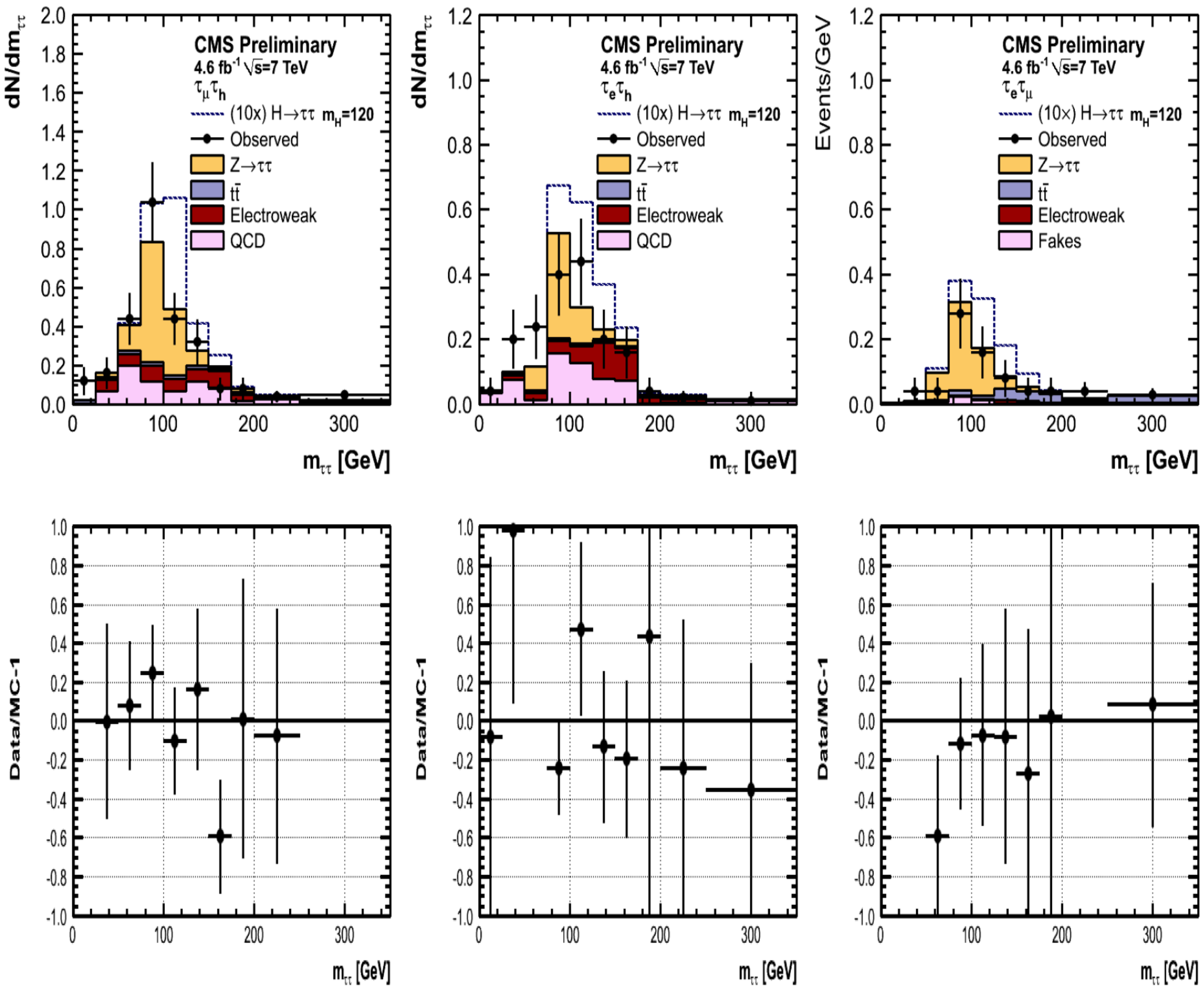
Distribution of the reconstructed mass of the first lepton pair (M_{Z1}) in the sum of the 4l channels. Points represent the data, shaded histograms represent the signal and background expectations. The samples correspond to an integrated luminosity of L = 4.71 fb^{-1}.

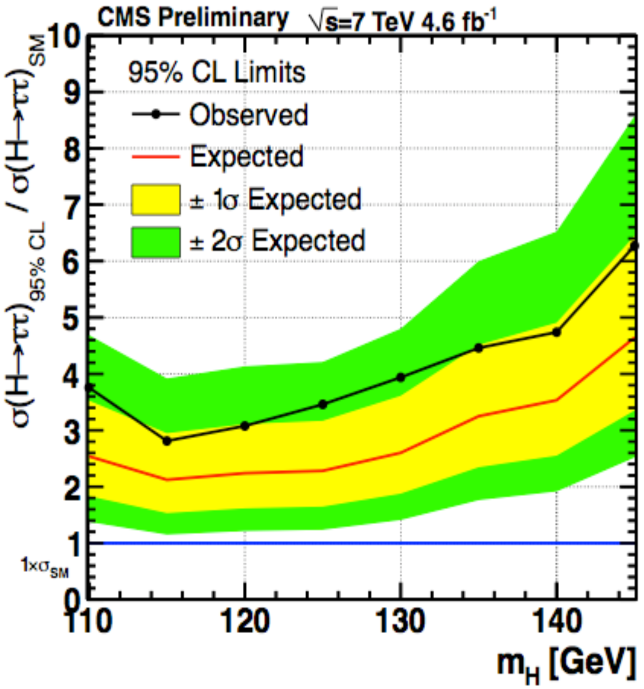


Distribution of the reconstructed mass of the second lepton pair (M_{Z2}) in the sum of the 4l channels. Points represent the data, shaded histograms represent the signal and background expectations. The samples correspond to an integrated luminosity of L = 4.71 fb^{-1}.

H→ ττ : data and limits

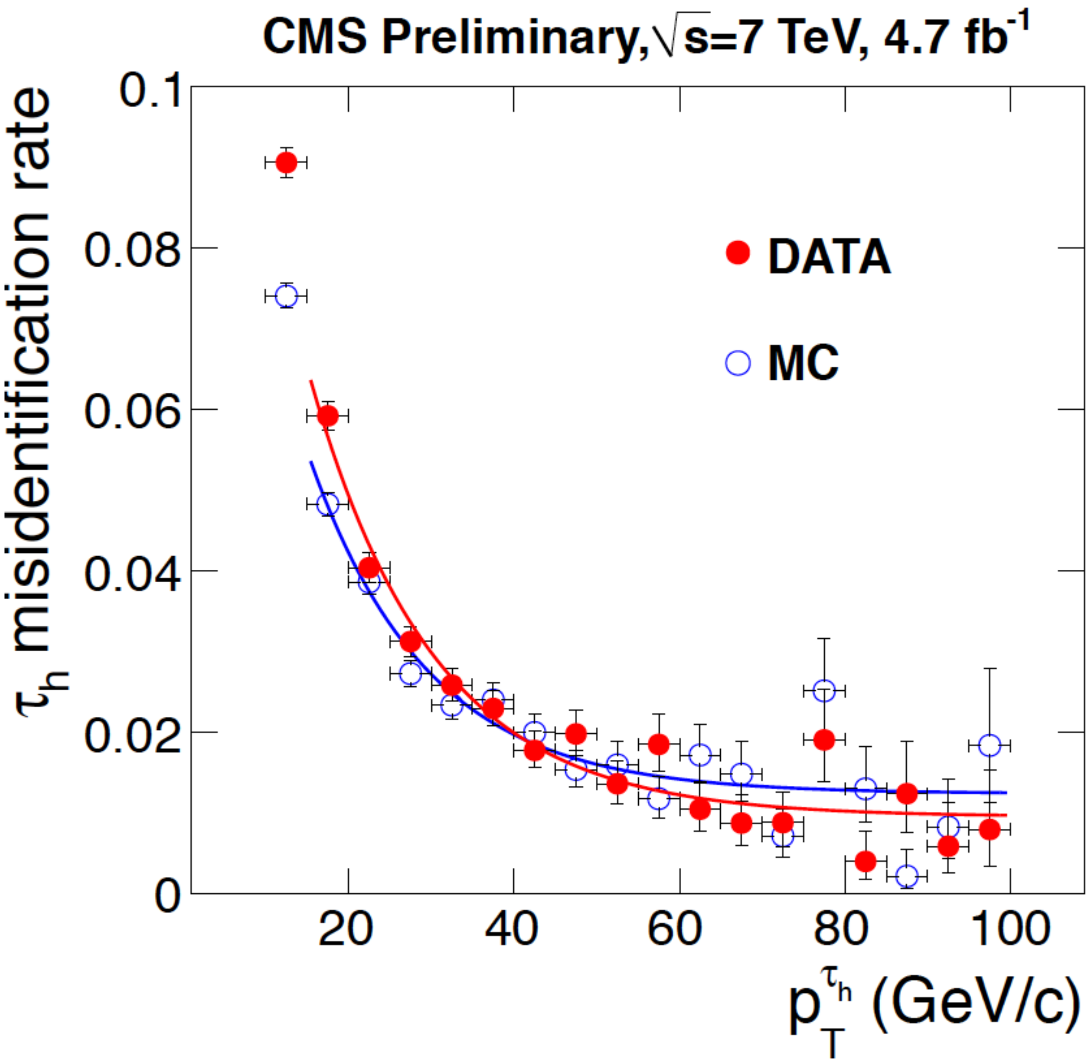
data in VBF Channels





Significant improvement in sensitivity since LP' 11

H→ττ



Data to MC comparison for the hadronic tau fake rate.

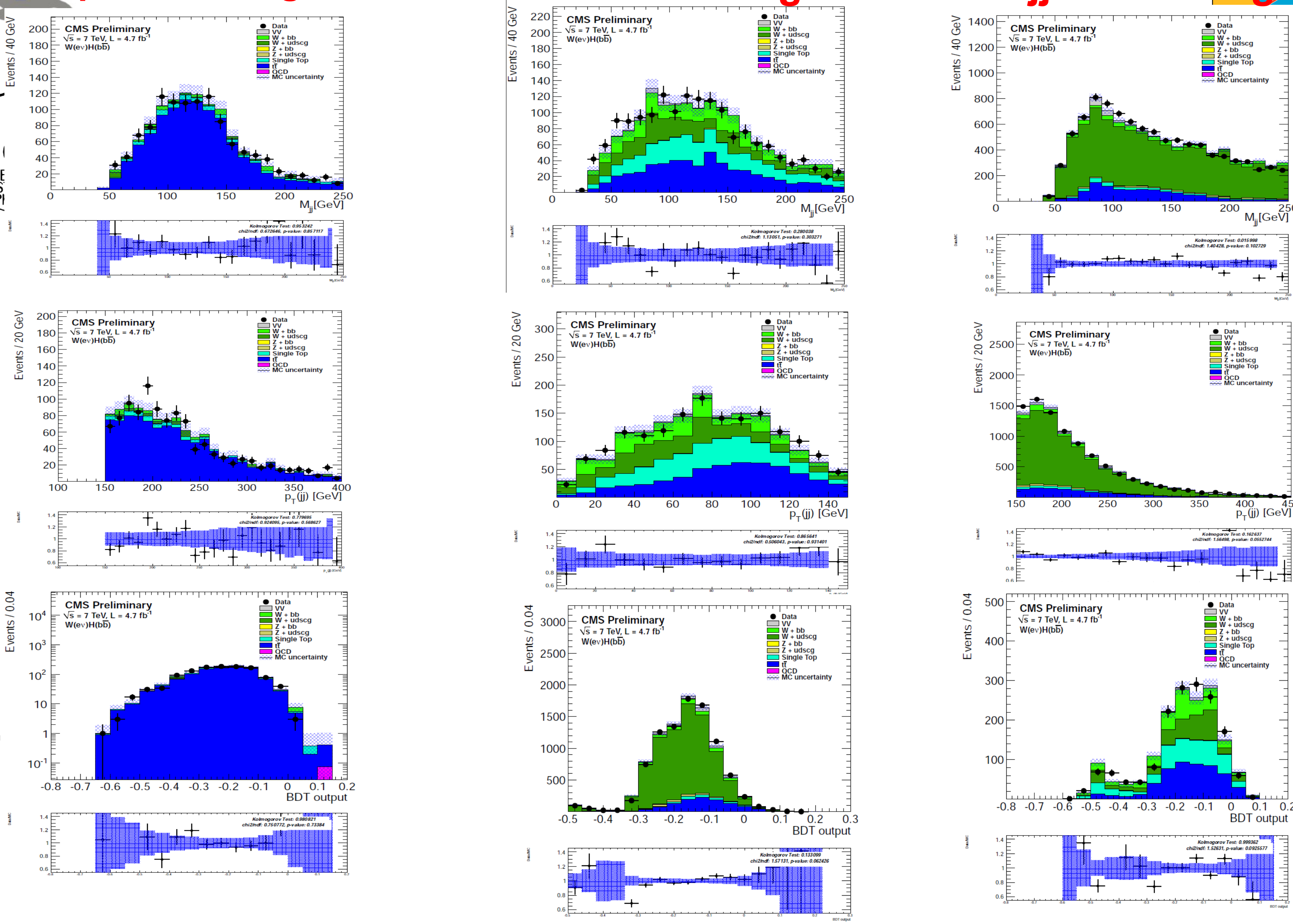
H→bb: Example of control regions in WH analysis

Top control region | **W+bb control region** | **W+jj control region**

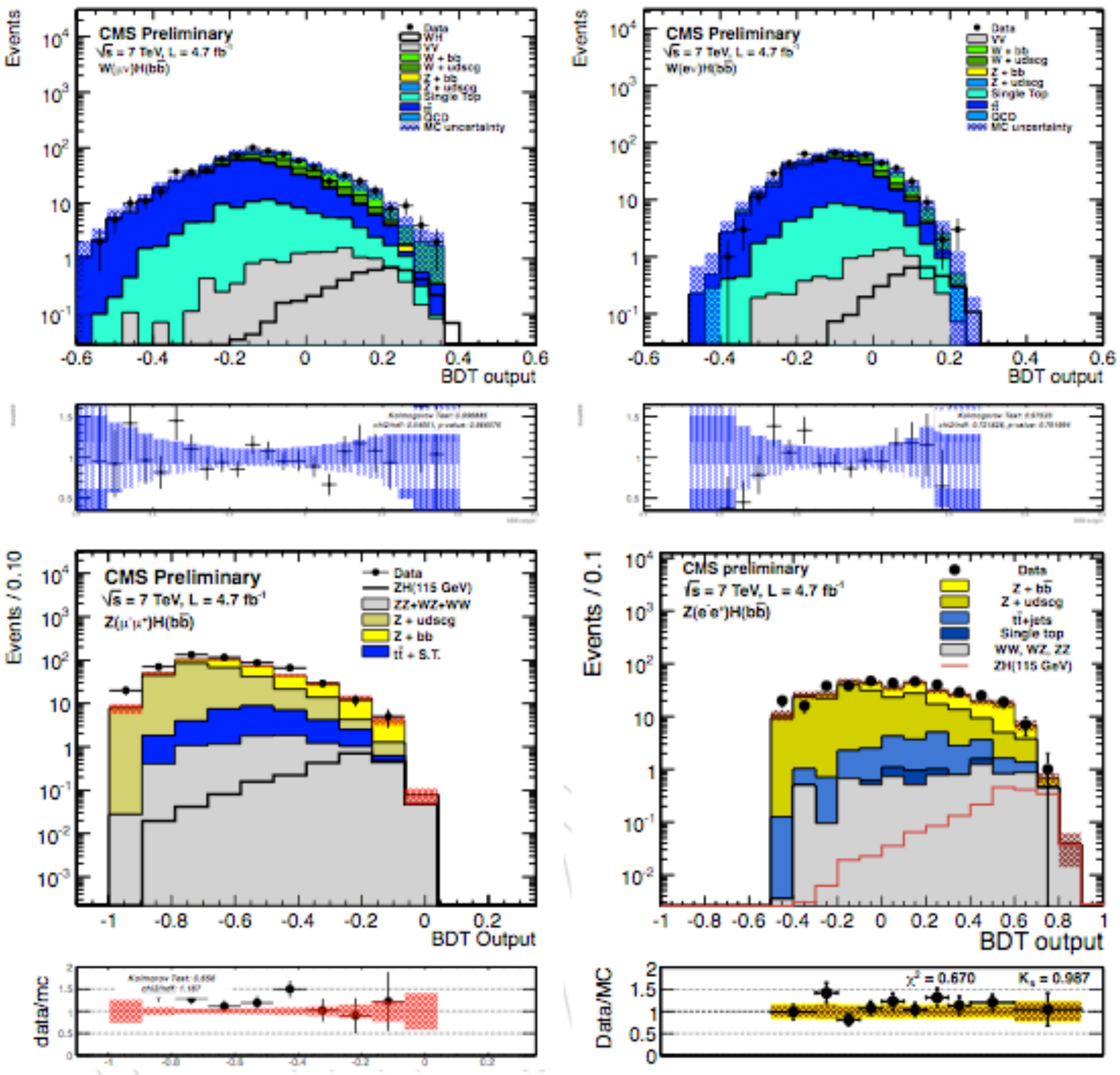
M_{jj}

pT_{jj}

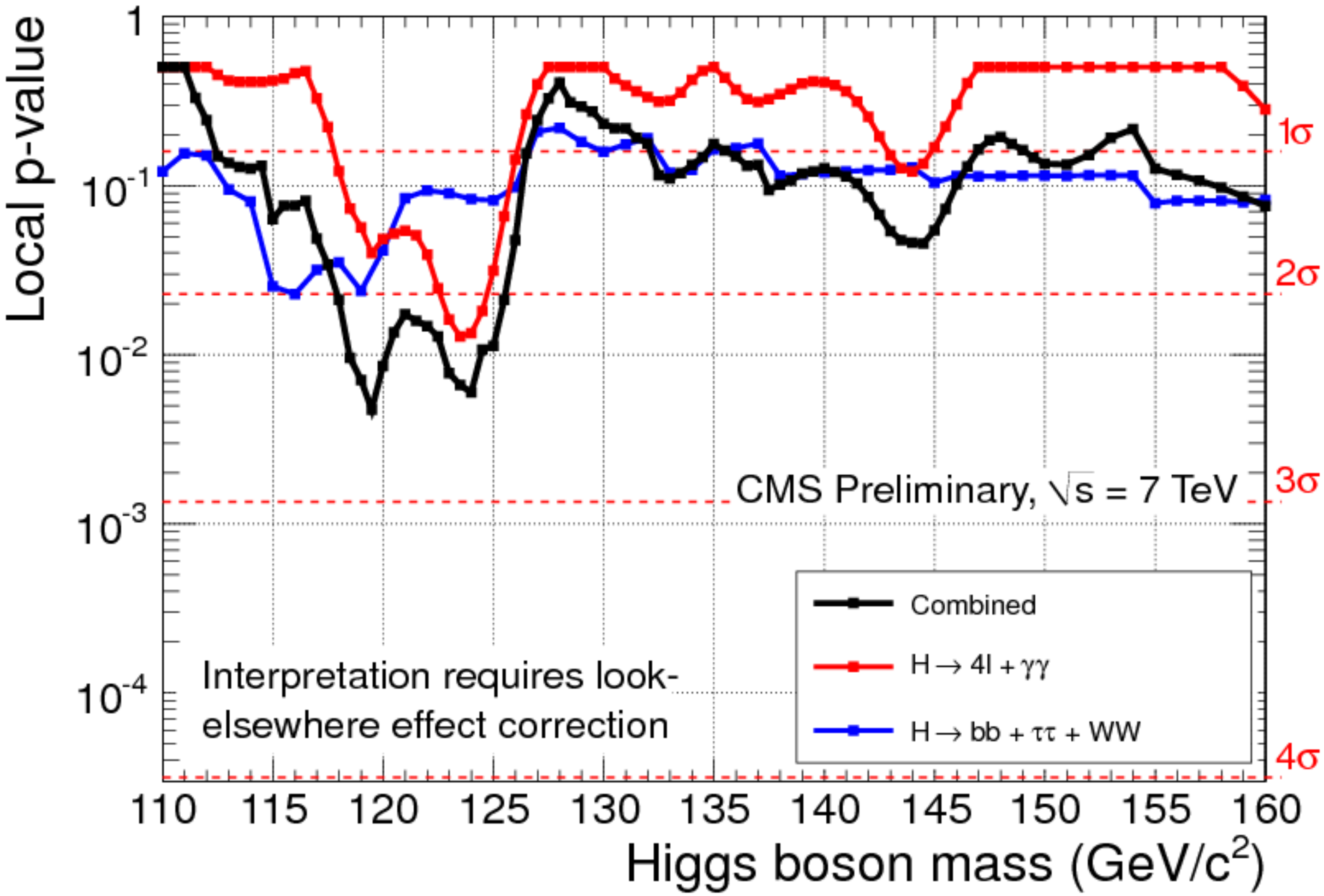
BDT



H→bb


CMS Preliminary
√s = 7 TeV, L = 4.7 fb⁻¹
W(μν)H(bb̄)
BDT output
Events
CMS Preliminary
√s = 7 TeV, L = 4.7 fb⁻¹
W(eν)H(bb̄)
BDT output
Events
CMS Preliminary
√s = 7 TeV, L = 4.7 fb⁻¹
Z(μ⁻μ⁺)H(bb̄)
Data
ZH(115 GeV)
ZZ+WZ+WW
Z + udscg
Z + bb
tt̄ + S.T.
Events / 0.10
BDT Output
data/mc
CMS preliminary
√s = 7 TeV, L = 4.7 fb⁻¹
Z(e⁻e⁺)H(bb̄)
Data
Z + bb̄
Z + udscg
tt̄+jets
Single top
WW, WZ, ZZ
ZH(115 GeV)
Events / 0.1
BDT output
Data/MC
χ² = 0.670
K_s = 0.987

Anatomy of an excess: p-values for the high and the low-resolution channels



Higgs Sensitivity : 1, 2, 5 and 10 fb^{-1} @ 7 TeV

Vivek Sharma, Lepton-Photon conference, Aug 2011