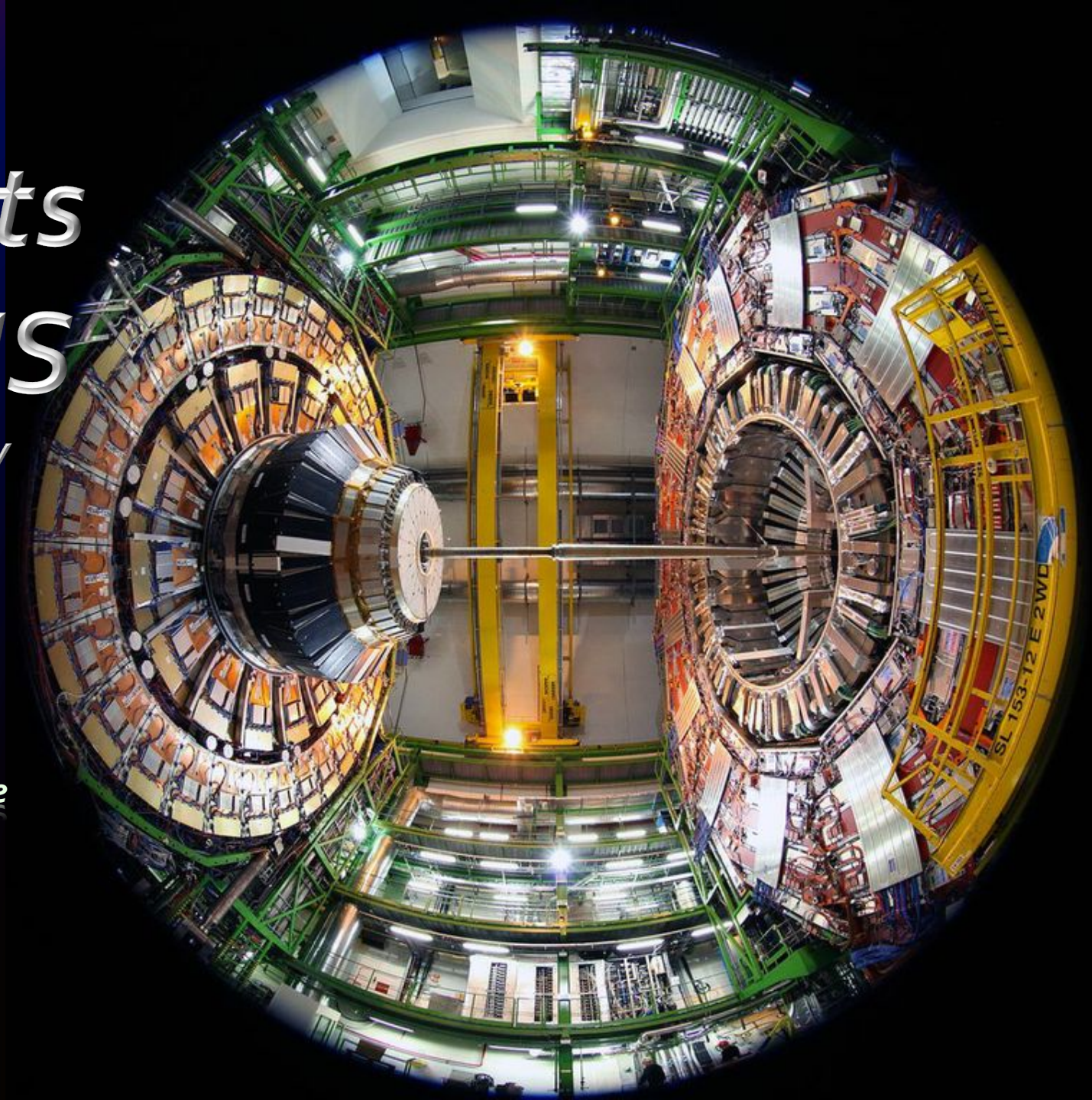
Highlights from CMS

And the discovery of a Higgs boson



Windows on the Universe
Quy Nhon, Vietnam

August 12, 2013

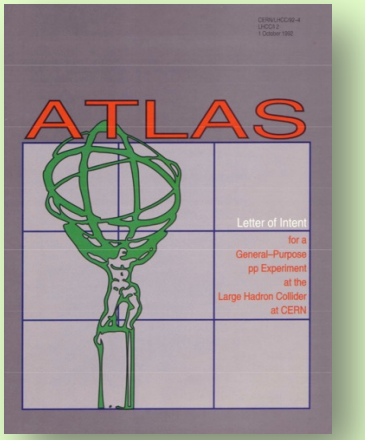
Joe Incandela
Santa Barbara/CERN

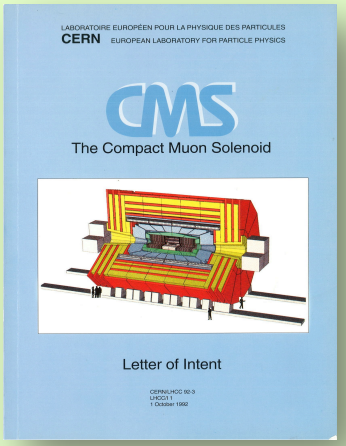
Timeline of the LHC Project (*en bref*)

1984 Lausanne workshop on a Large Hadron Collider in the LEP tunnel

1987 Rubbia "Long-Range Planning Committee" recommends LHC for CERN's future

1993 ATLAS and CMS selected by LHCC





1998 Construction begins (after approval of Technical Design Reports)

2008-9 First beams - First pp Collisions

2012 New boson discovered with mass ~125 GeV

Based on slide from Tejinder Virdee

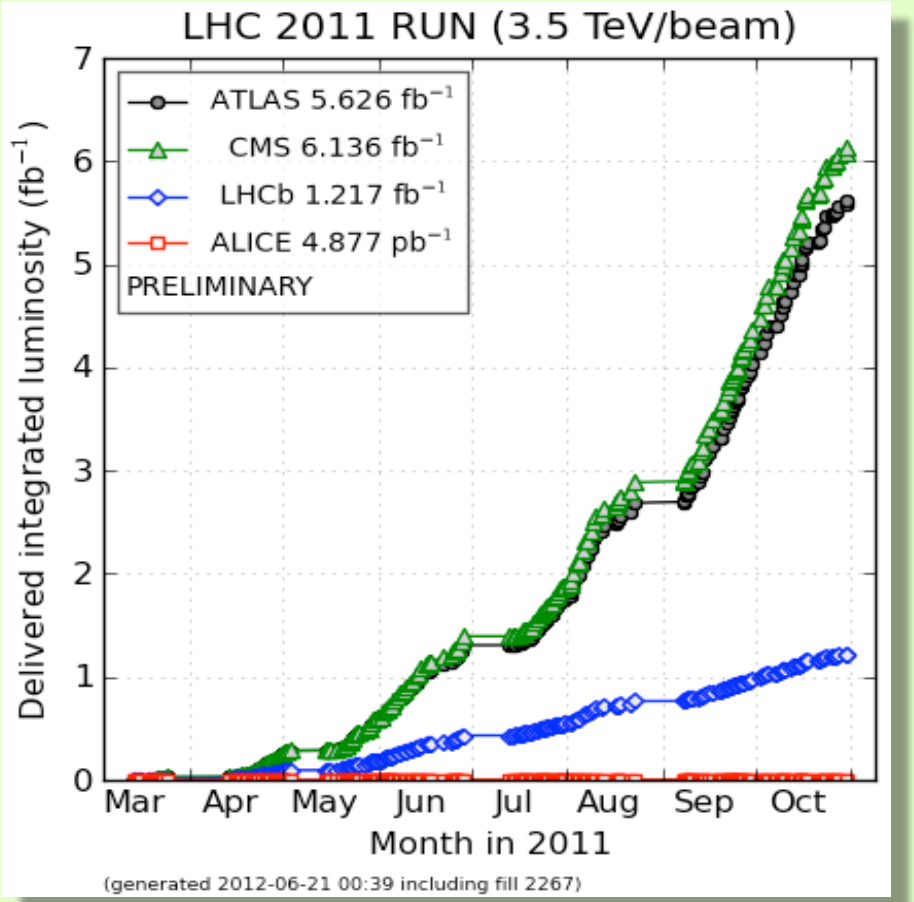
10 Sep. 2008: LHC inauguration

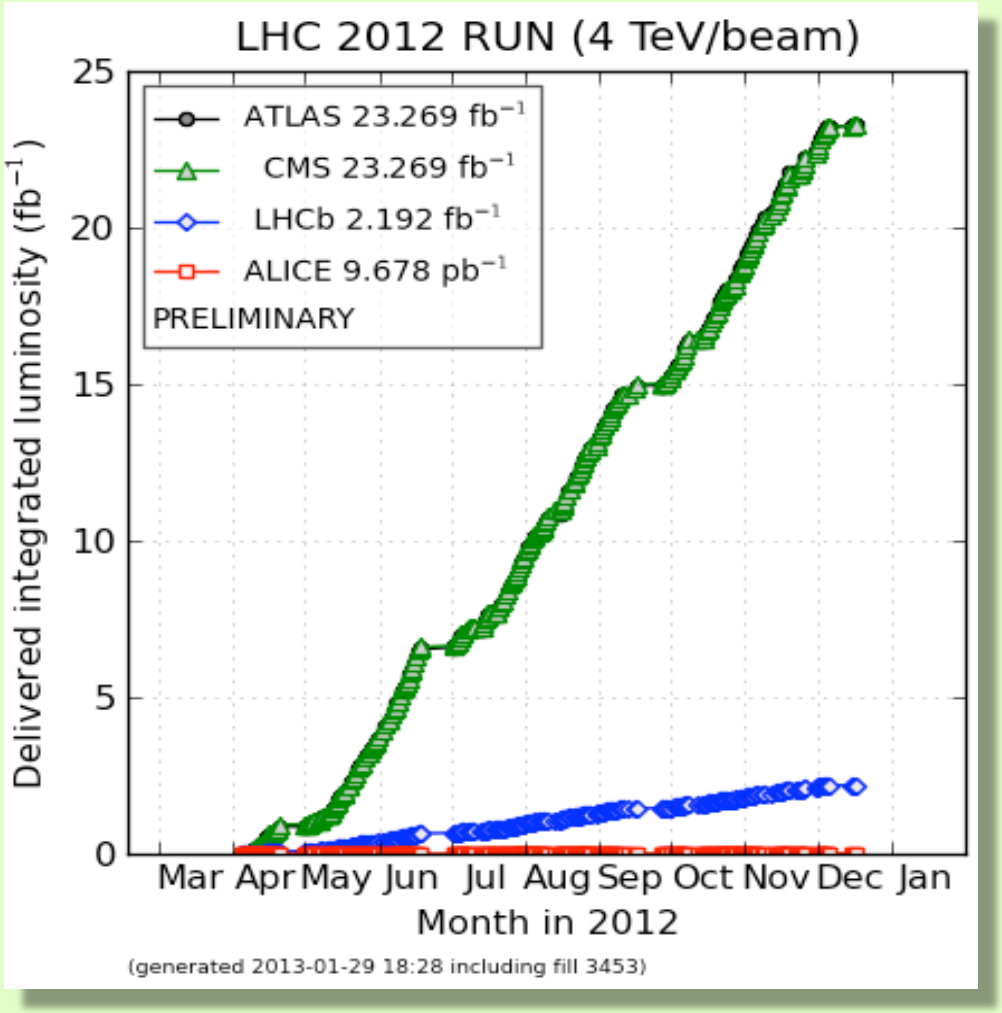
First (single) beams circulating in the machine

Six CERN DGs from conception to physics!
Schopper, Rubbia, Llewellyn Smith, Maiani, Aymar, Heuer (from right to left) with 5-year terms!!

And the LHC outperformed expectations

- Spectacular 3 years and ~30/fb delivered per ATLAS/CMS





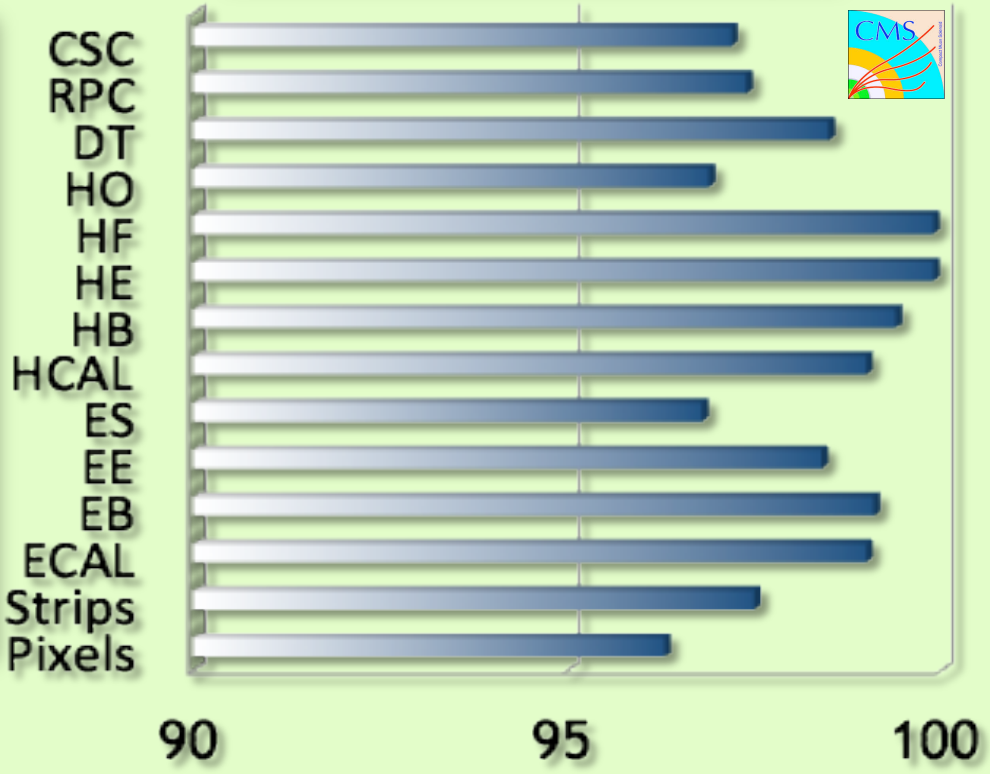
Spectacular Run 1 Detector Performance: 2009-2013

- The LHC detectors have worked extremely well !
  - Almost no degradation in performance
  - Some losses in performance were even recovered

ATLAS Performance in 2012

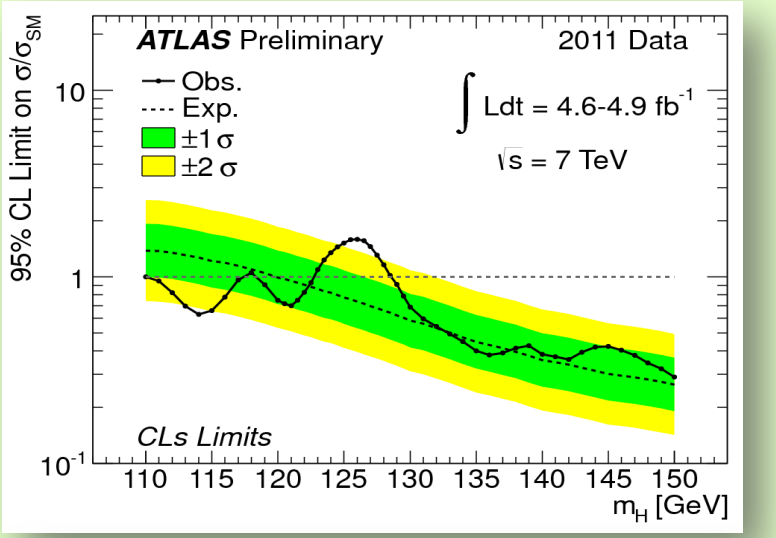
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	95.0%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	97.5%
LAr EM Calorimeter	170 k	99.9%
Tile calorimeter	9800	98.3%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo trigger	7160	100%
LVL1 Muon RPC trigger	370 k	100%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	96.0%
RPC Barrel Muon Chambers	370 k	97.1%
TGC Endcap Muon Chambers	320 k	98.2%

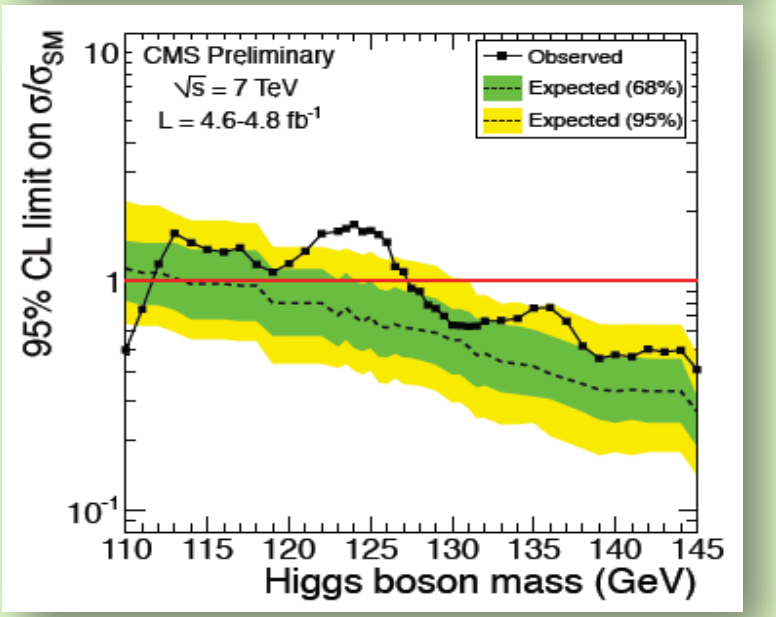
CMS Status in Feb 2013 (%)



Higgs Status Dec. 2011

- Small excesses at 125 GeV
- ATLAS and CMS couldn't celebrate yet…
  - Not unprecedented to have coincidences at low significance
  - $\gamma\gamma$ channel the main contributor
    - Very small signal on large background
- Important steps taken for 2012
  - Energy increased from $\sqrt{s}$= 3.5 TeV to 4 TeV and luminosity increased
    - Target 5σ sensitivity down to 110 GeV
  - 'Blind' the 2012 data
  - Extended run by ~2.5 months

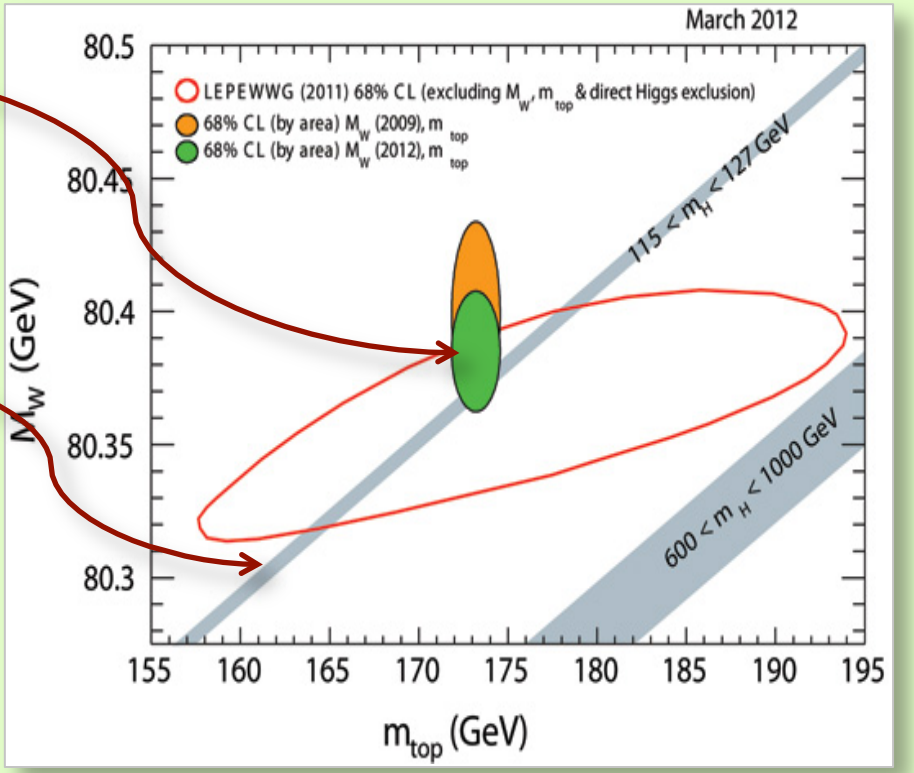


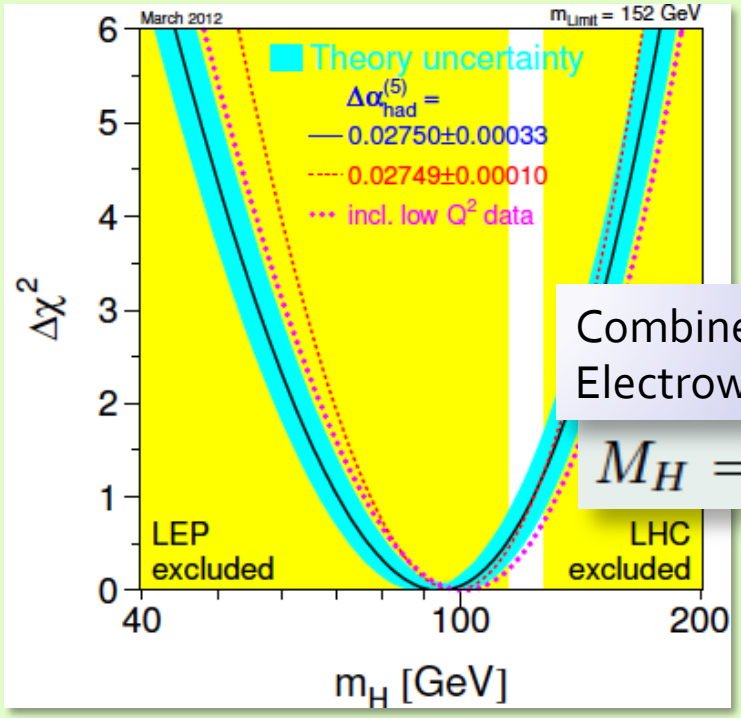


Status of Electroweak Measurements Winter2012

1. M_{top} vs. M_W
   - Tevatron M_W *Tour de Force!!*
     - $m_W = 80385 \pm 15$ MeV
       (World Ave – Mar 2012)

2. Colliders leave little space





Combined precision Electroweak data

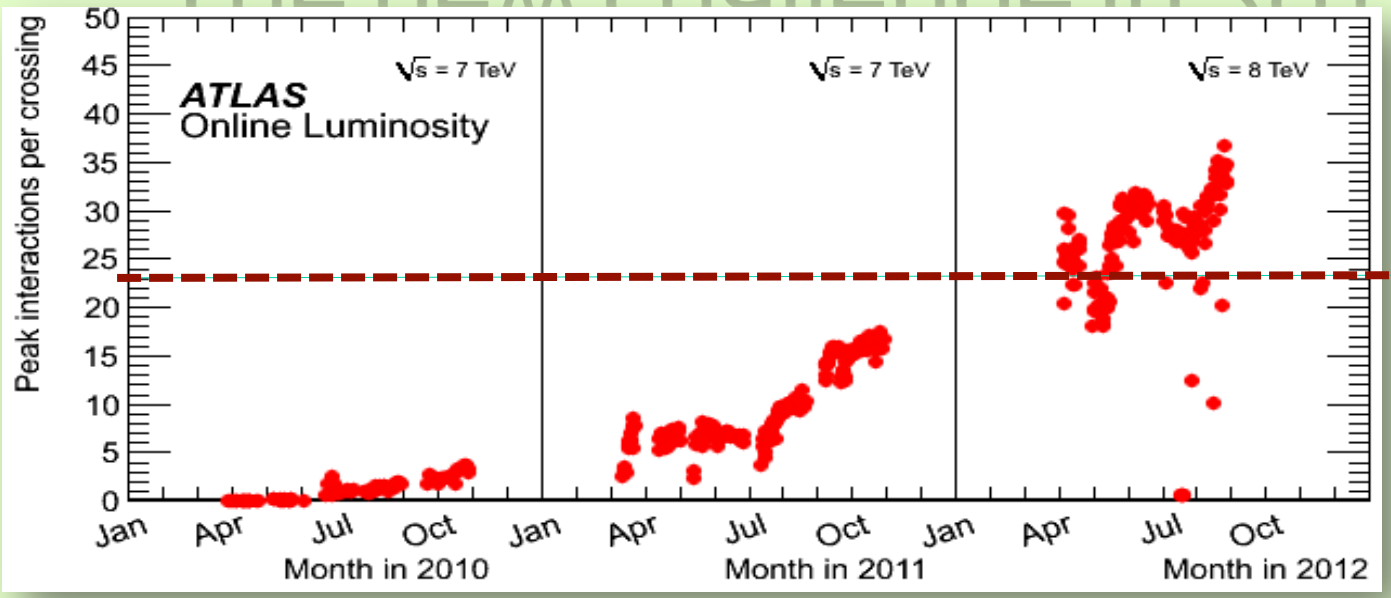
$$M_H = 94^{+29}_{-24}$$

This is the main story of 2011

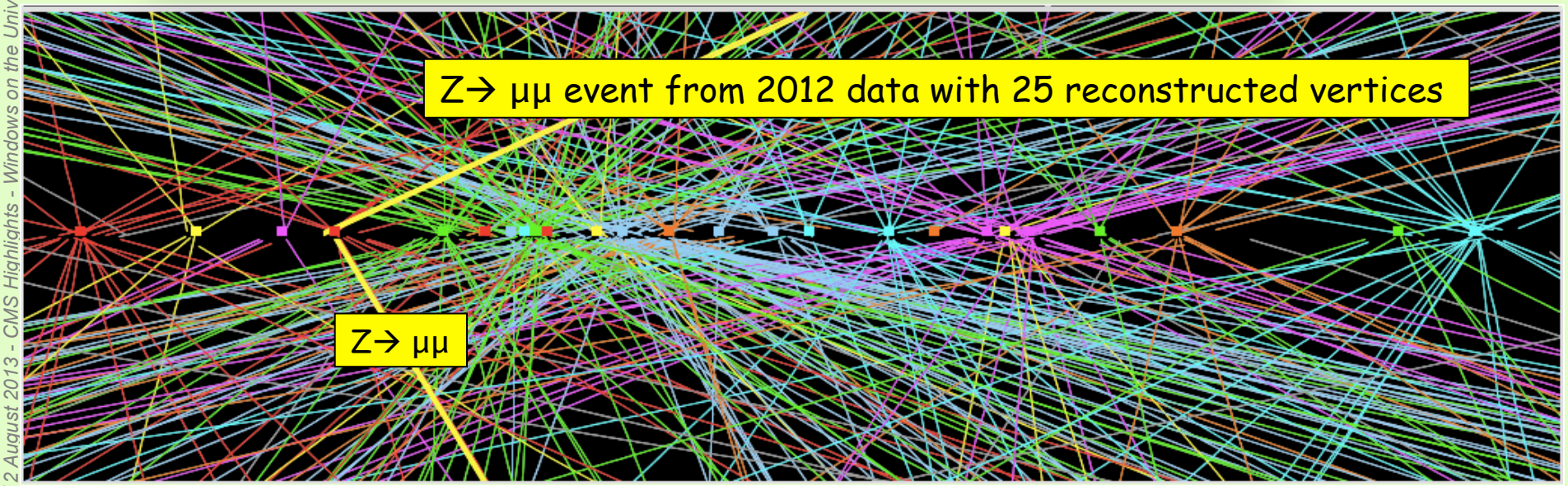
We eliminated >450 GeV of Higgs mass range.

Slide from spring 2012

The new challenge in 2012: Pileup

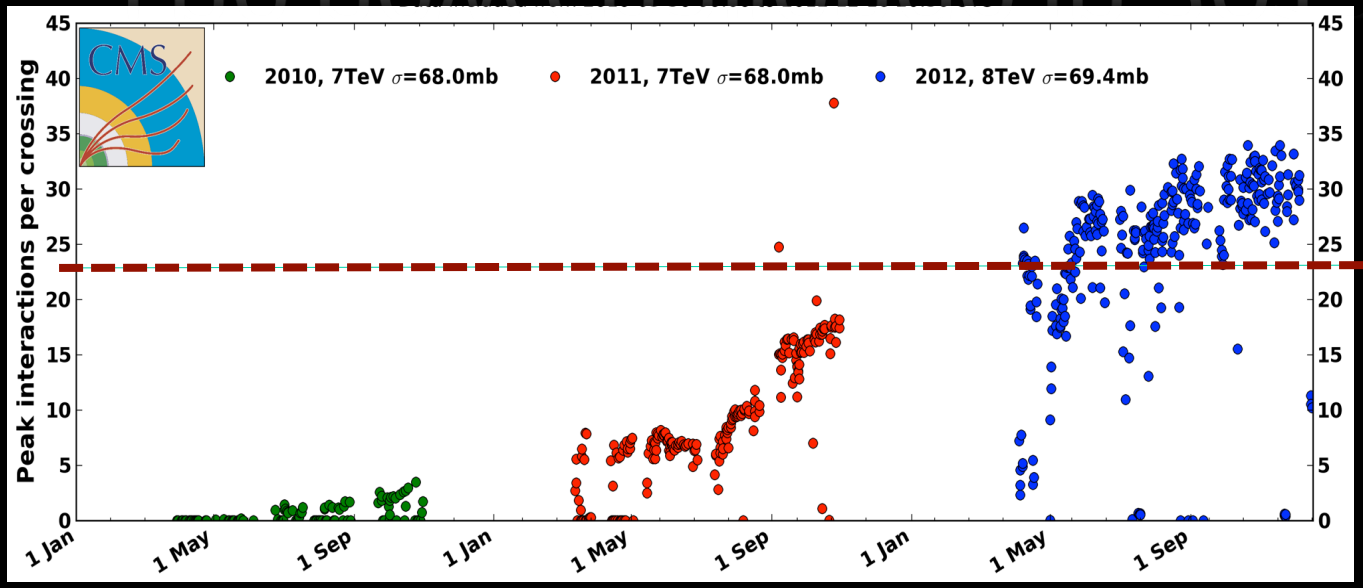


~Design value
(L=10^{34} @ 25 ns)



Slide courtesy Fabiola Gianotti

The new challenge in 2012: Pileup



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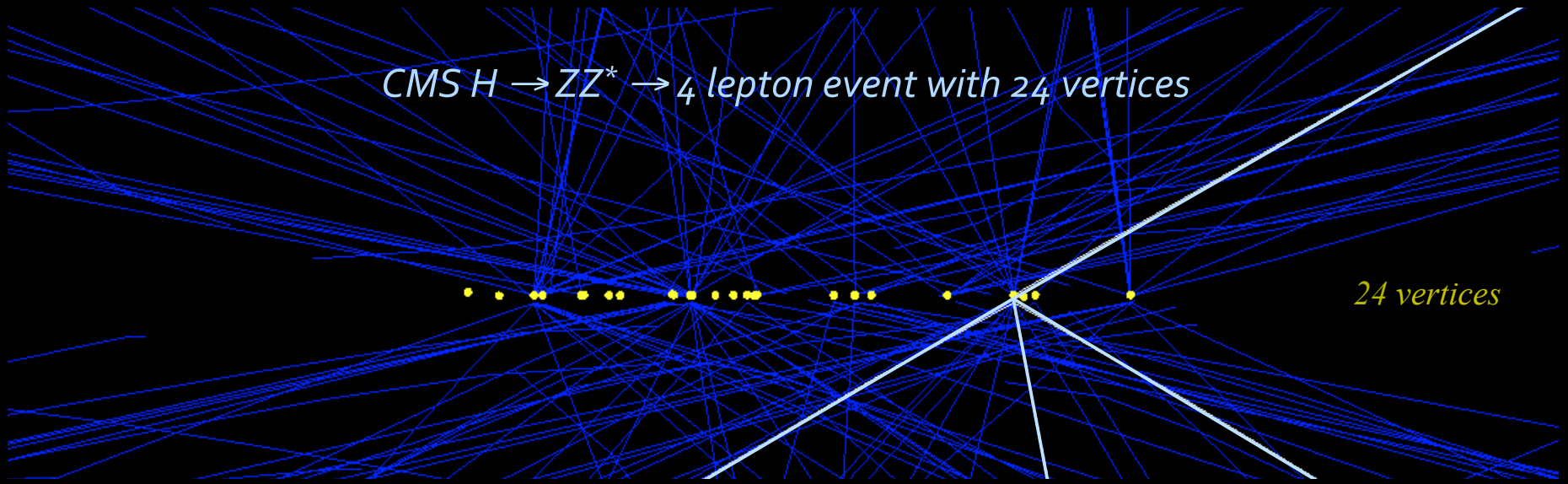
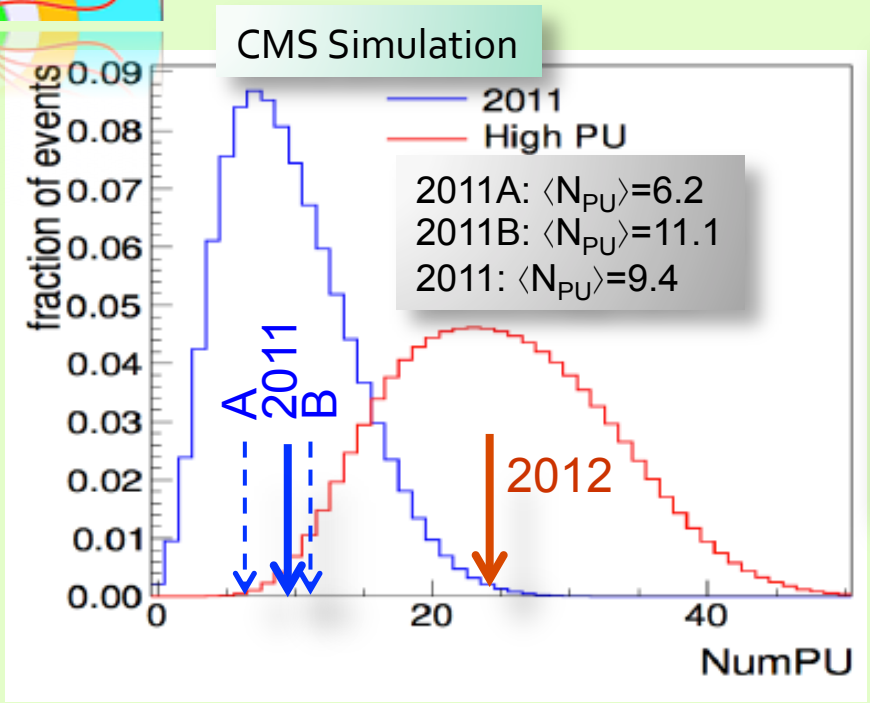
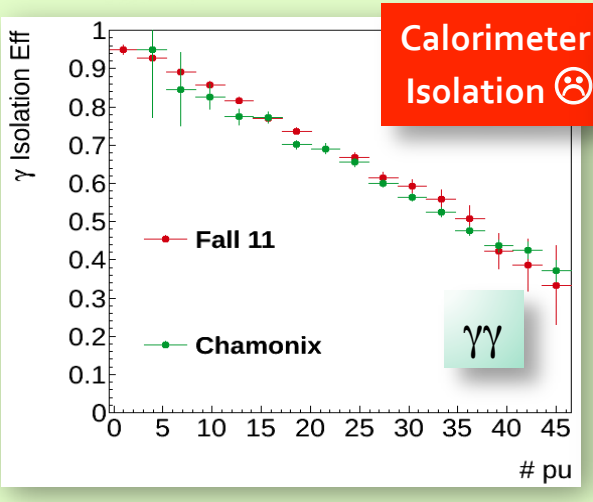
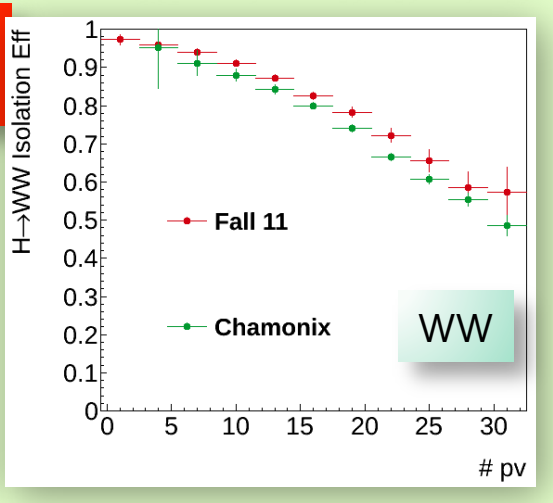
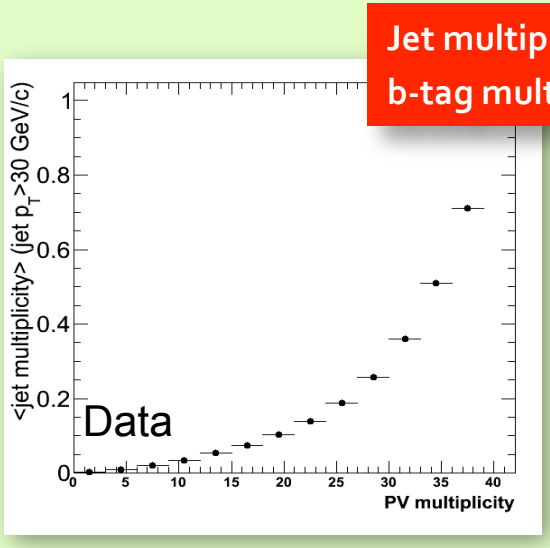


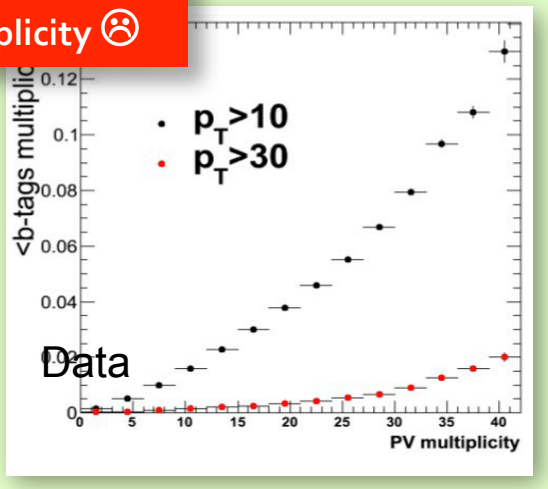
Pileup studies Feb 2012



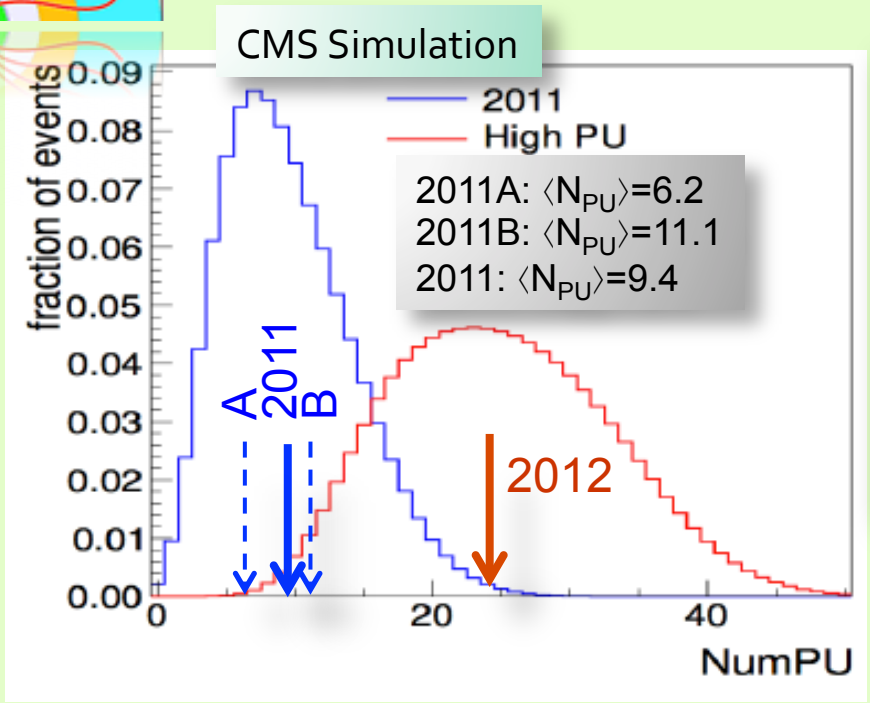


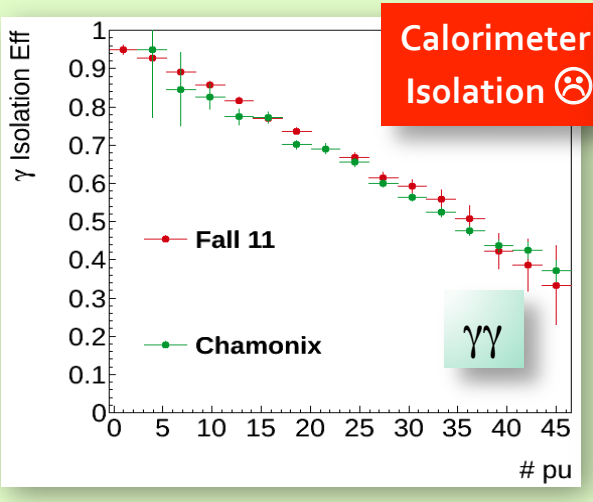


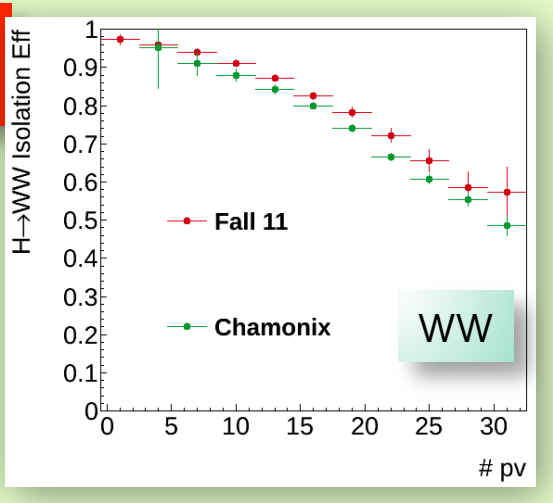


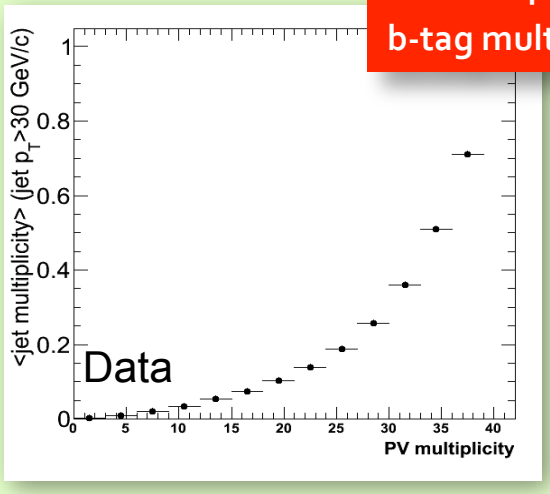


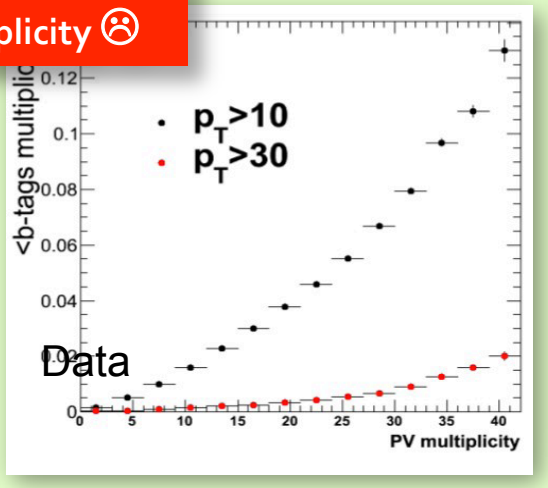
Pileup studies Feb 2012

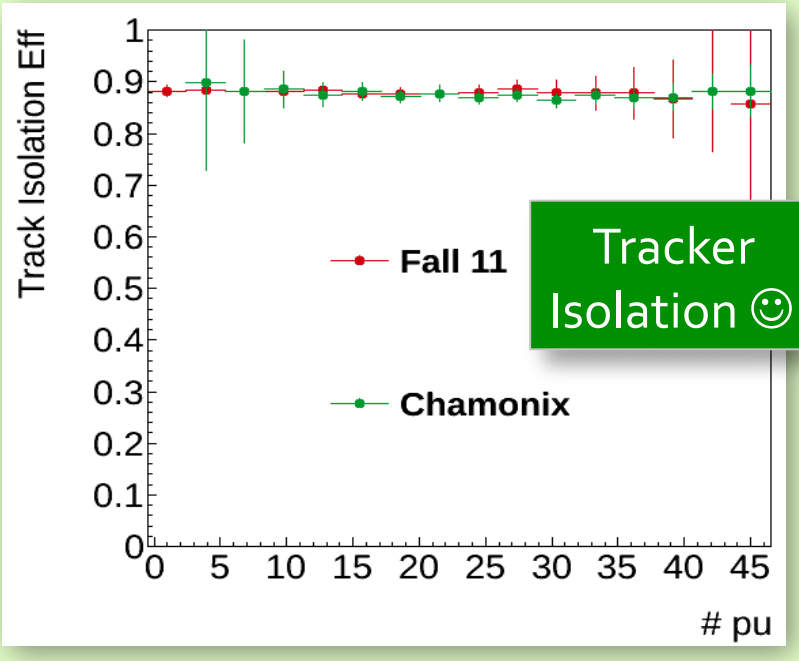






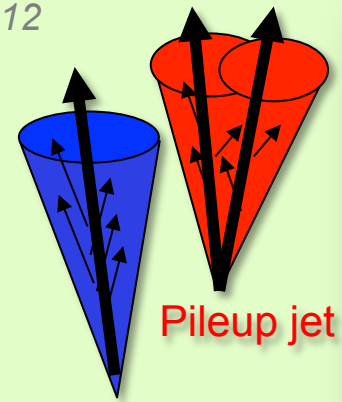


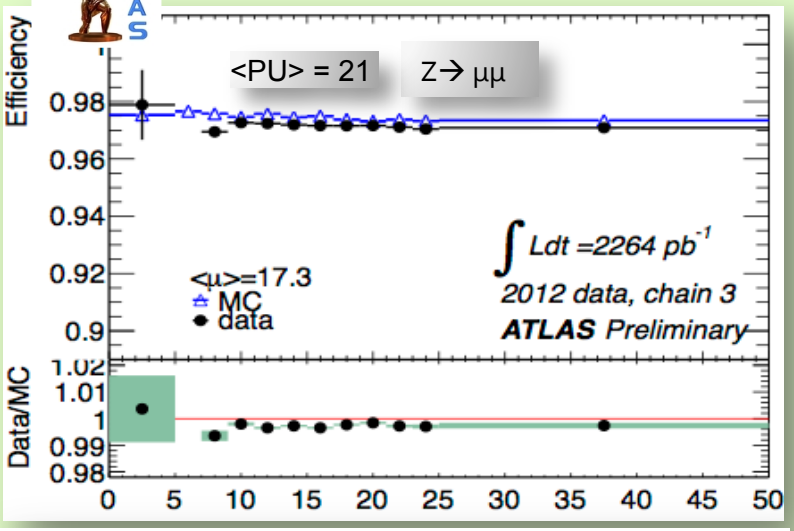


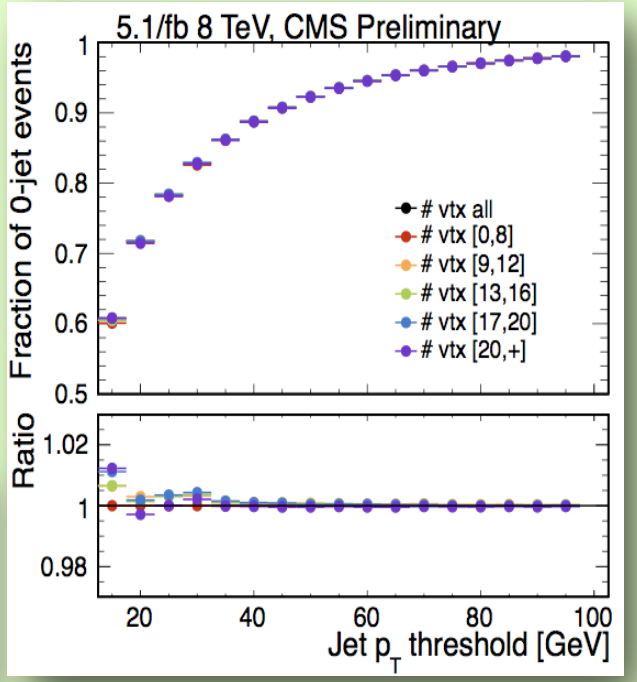


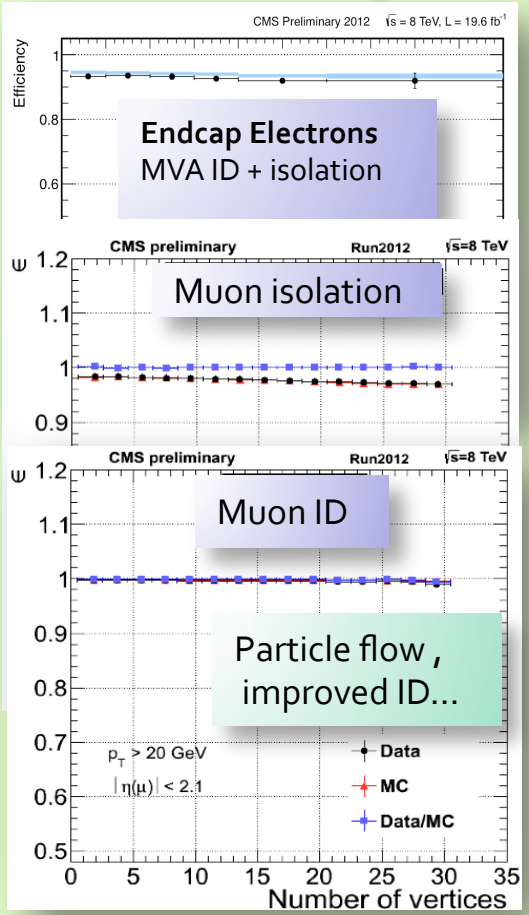
Taking control

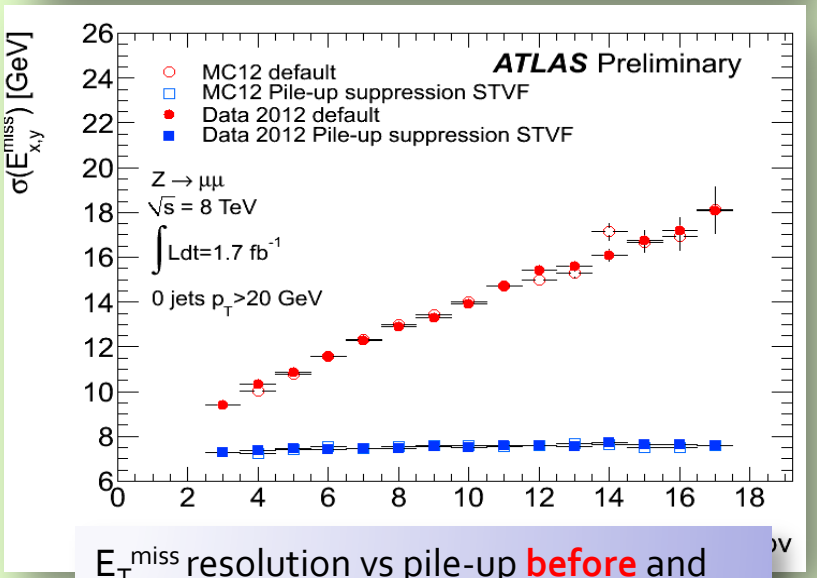
May-June 2012



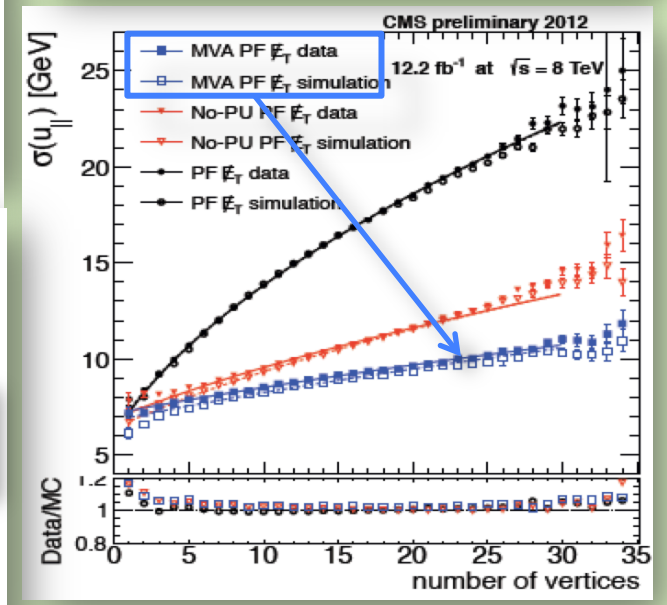






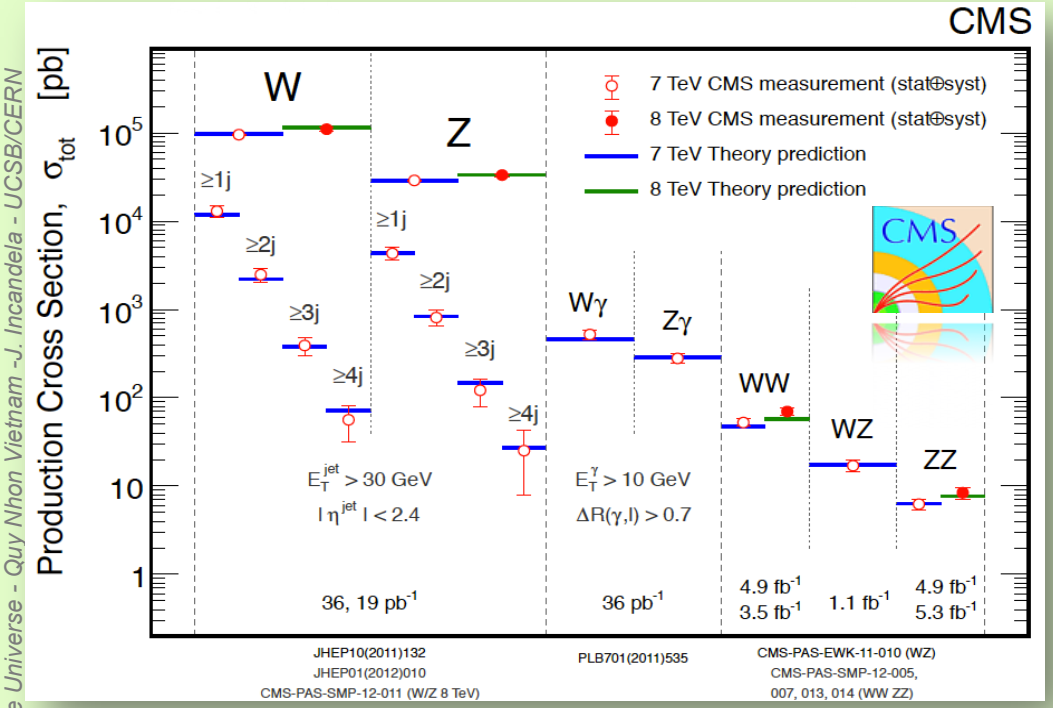


E_T^{miss} resolution vs pile-up **before** and **after** pile-up suppression using tracks



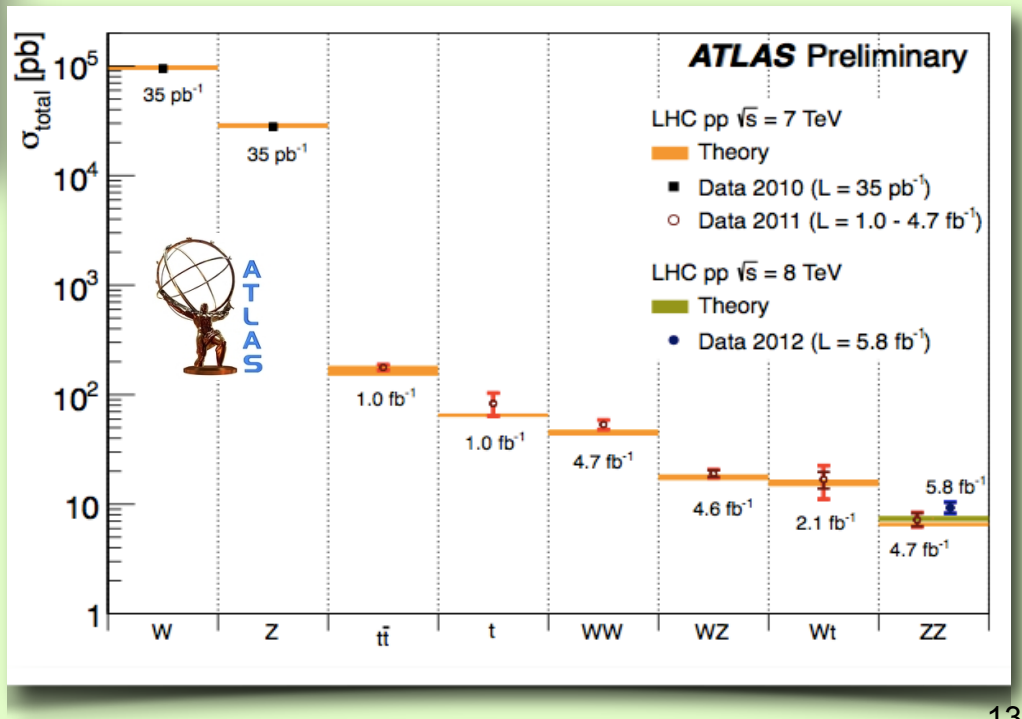
E_T^{miss} : PFlow and MVA regression

EWK measurements over >4 orders of magnitude



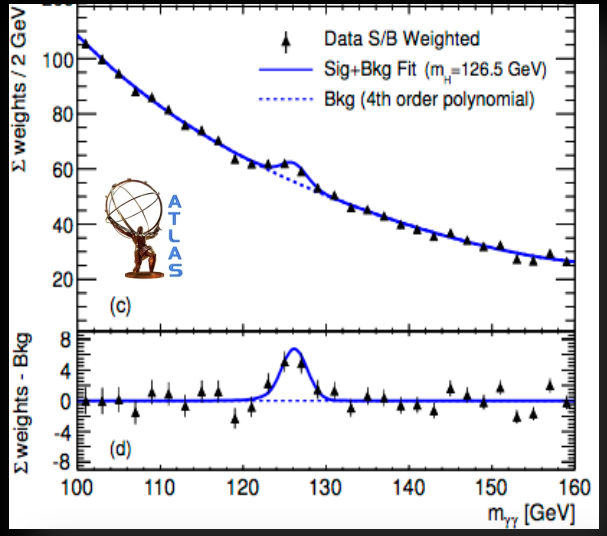
Good understanding of the detector
+ accurate theory predictions
→Precision SM measurements
→Excellent control of backgrounds

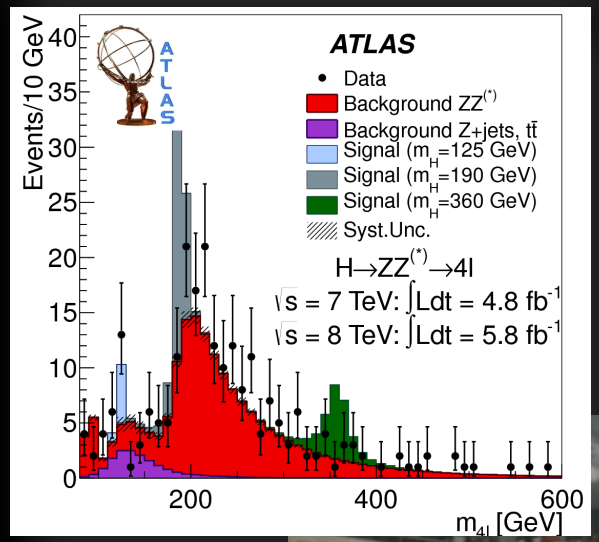
Ready to hunt for the Higgs

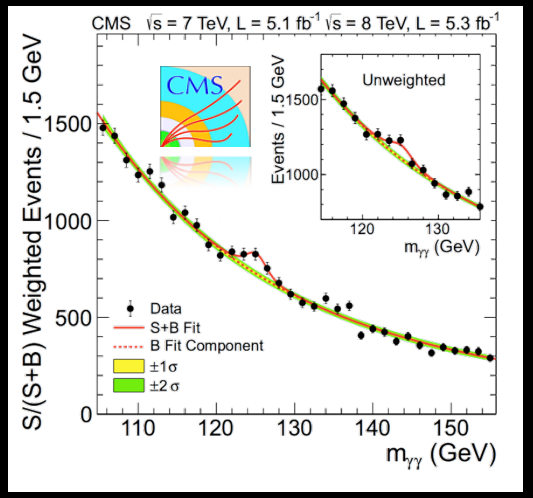


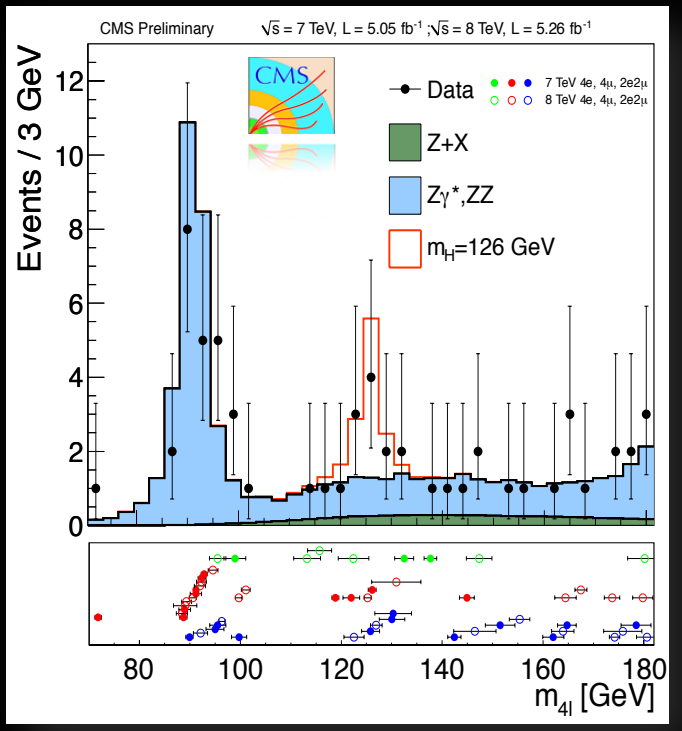
→ July 4th 2012

'Higgs-like' particle found



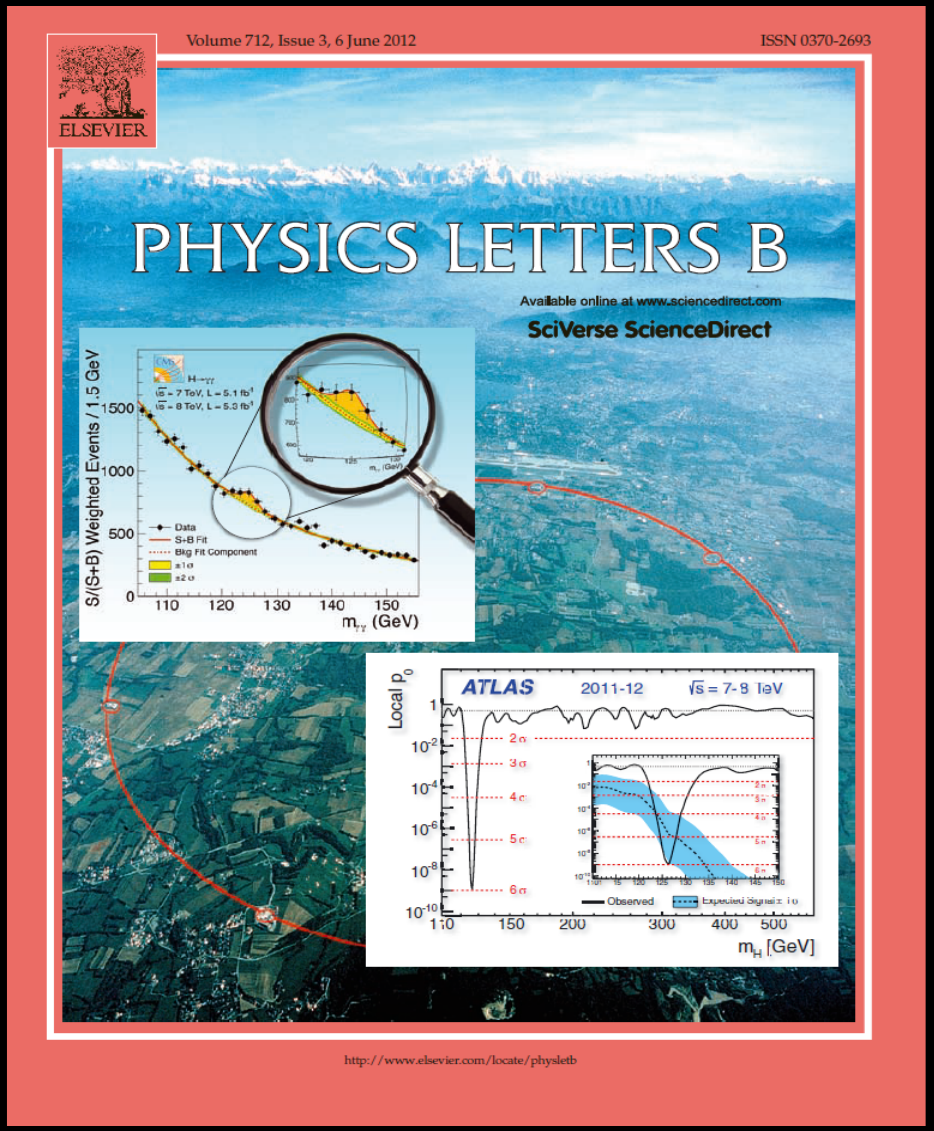


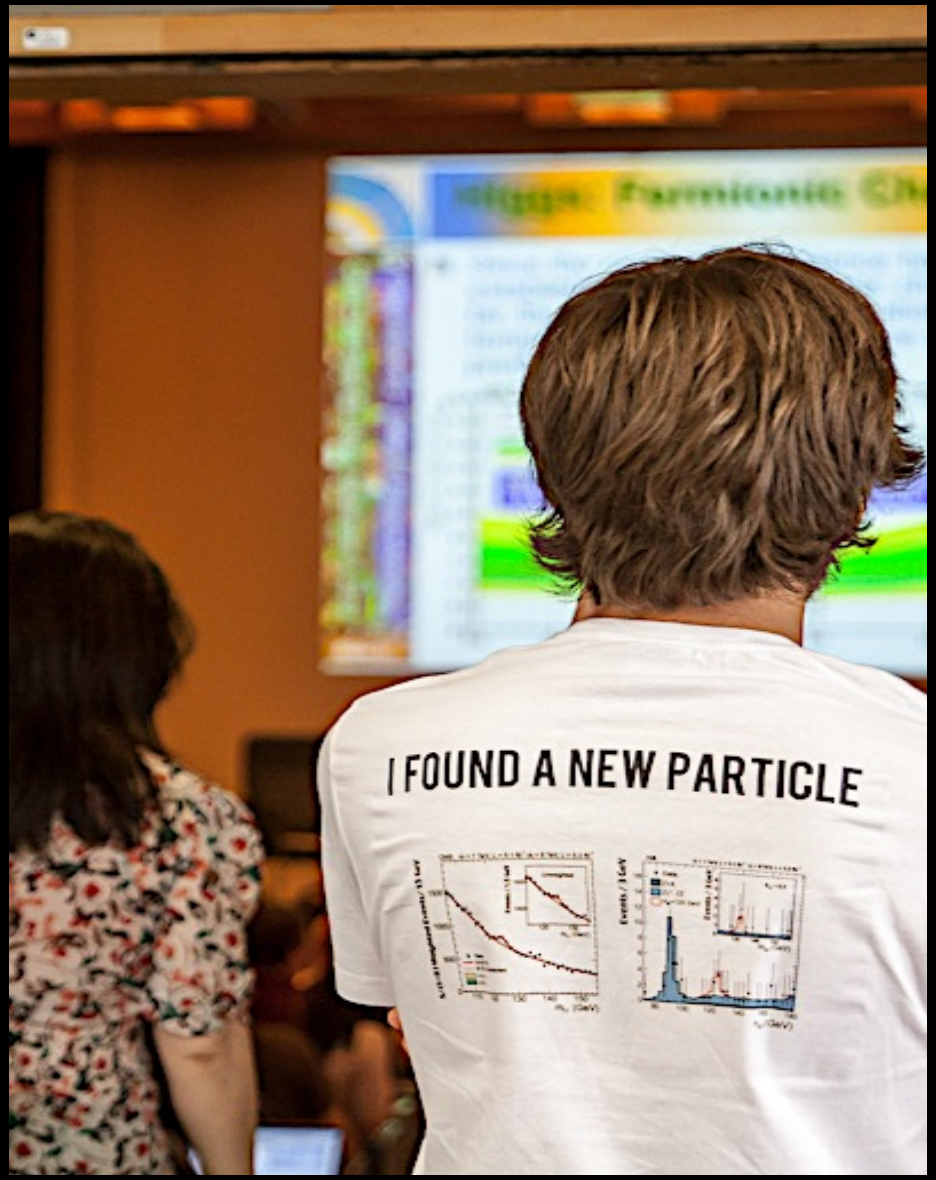




Phys. Lett. B 716 (2012) 1
Phys. Lett. B 716 (2012) 30

- 48 years
  - Since idea was hatched
- 20 years
  - To design and build
- 3 years
  - To acquire the data
- A generation
  - of work by thousands





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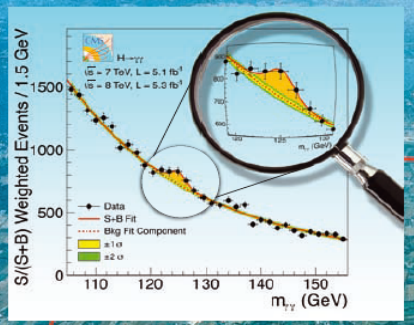

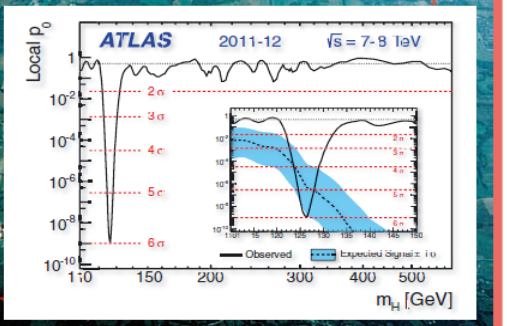

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BREAKTHROUGH of the YEAR
The HIGGS BOSON
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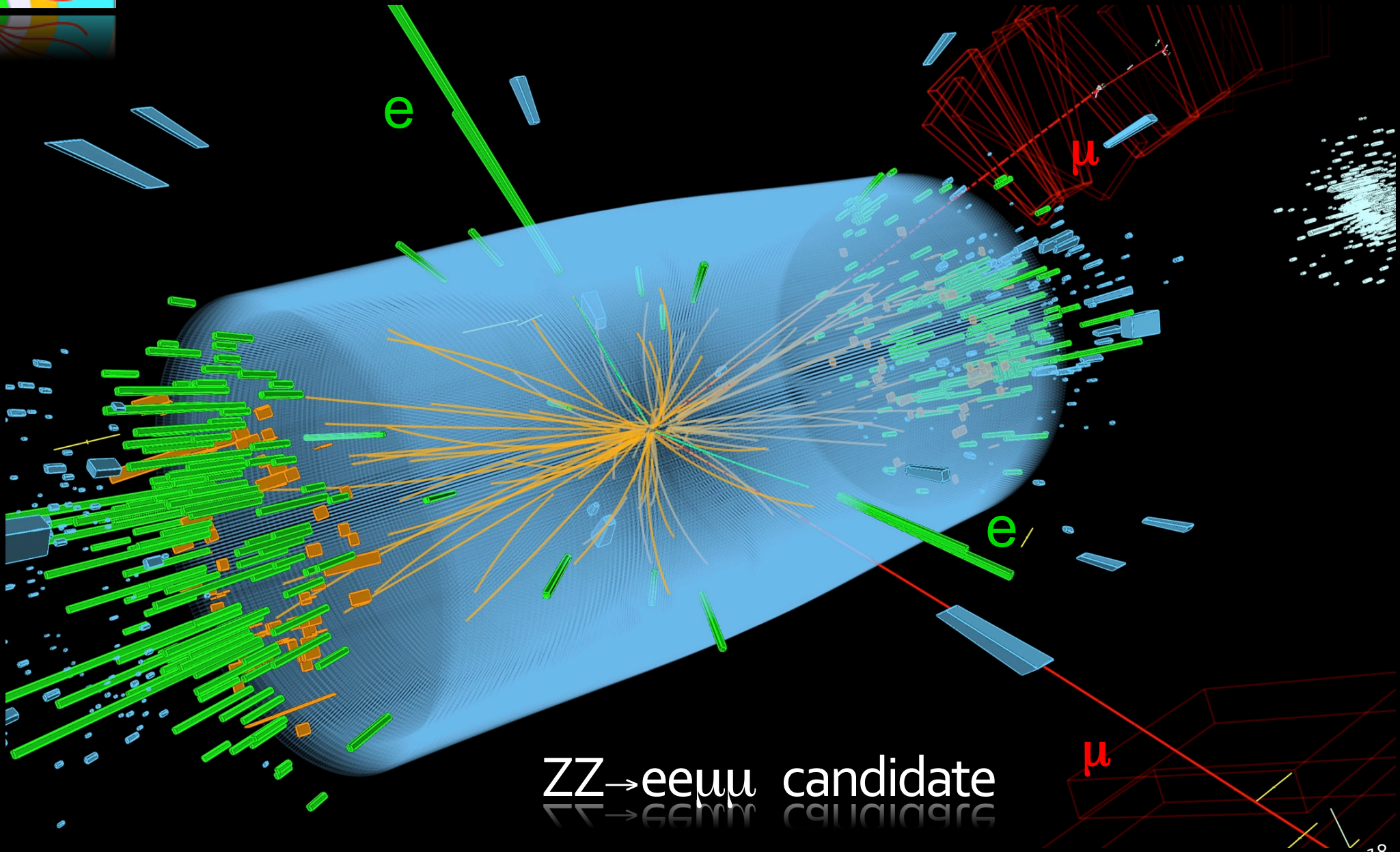
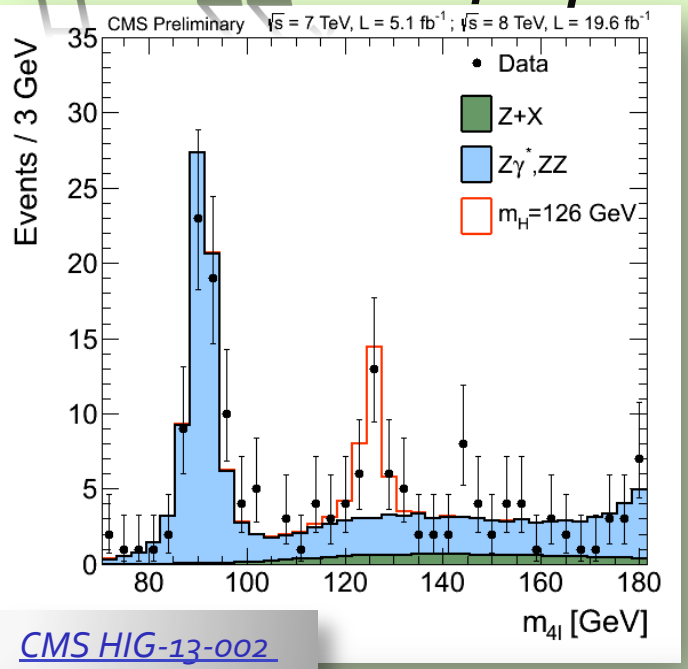
CMS Higgs Results Since 4th July 2012

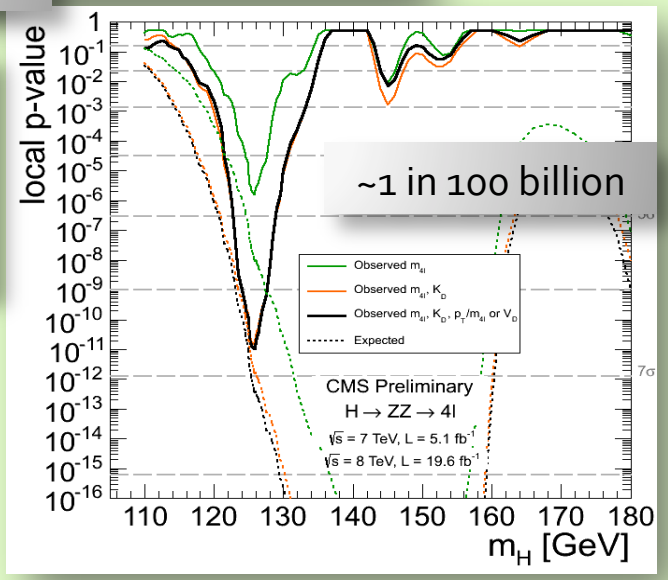


$ZZ \rightarrow ee\mu\mu$ candidate

$H \rightarrow ZZ^* \rightarrow 4$ leptons



CMS HIG-13-002



~1 in 100 billion

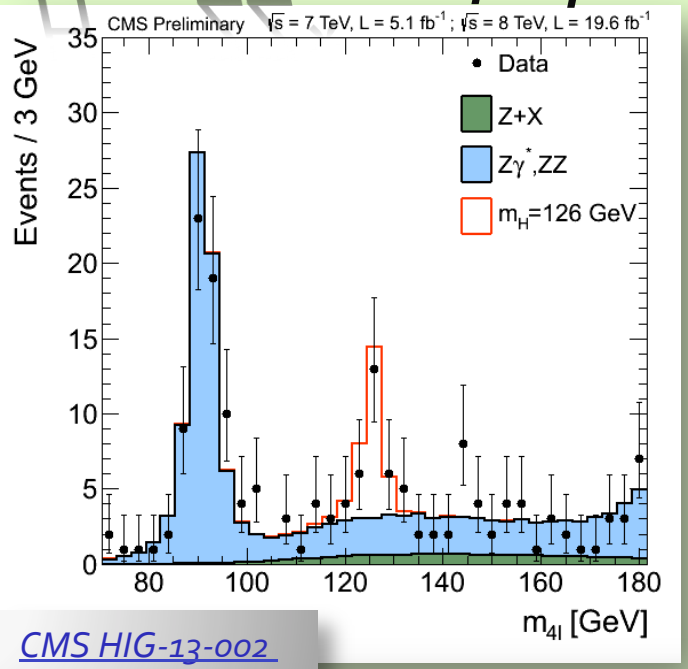
6.7 σ (expect 7.1)

Signal strength relative to the Standard Model:

$\mu = 0.92 \pm 0.28$

$m_H = 125.8 \pm 0.5 \pm 0.2$ (sys.)

$H \rightarrow ZZ^* \rightarrow 4$ leptons

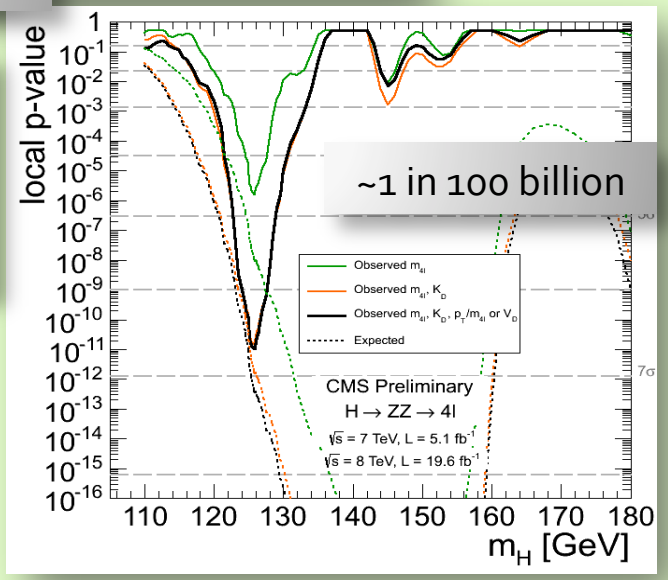


CMS HIG-13-002

6.7 σ (expect 7.1)

Signal strength relative to the Standard Model:

μ = 0.92 ± 0.28



~1 in 100 billion

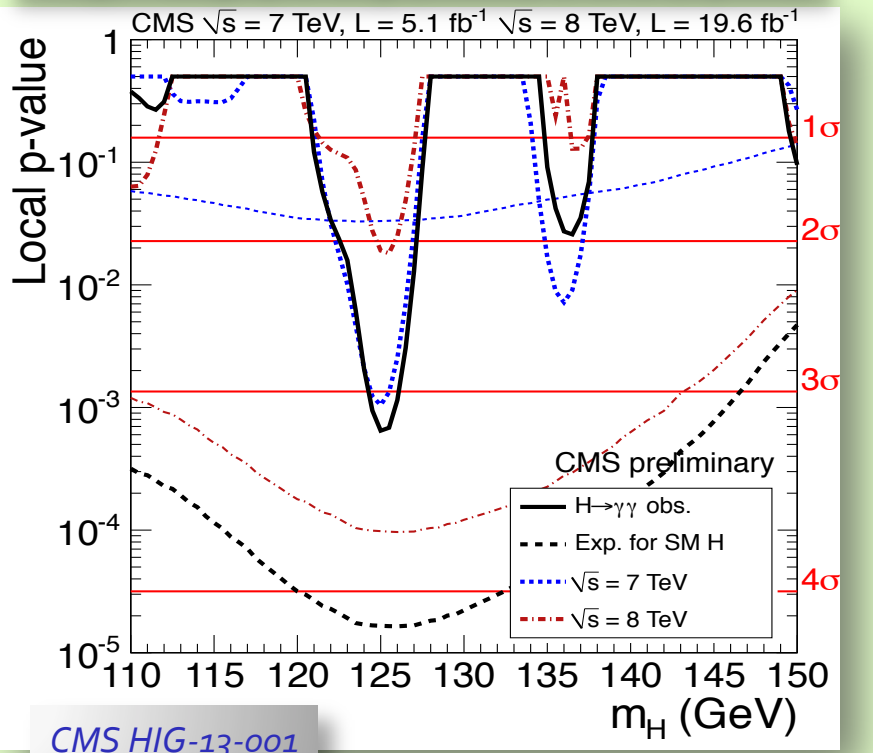
$m_H = 125.8 \pm 0.5 \pm 0.2$ (sys.)

$H \rightarrow \gamma\gamma$

Moriond 2013

CMS 3.2σ (expect 4.2σ)

$m_H = 125.4 \pm 0.5$ (stat.) $\pm$ 0.6 (syst.)



CMS HIG-13-001

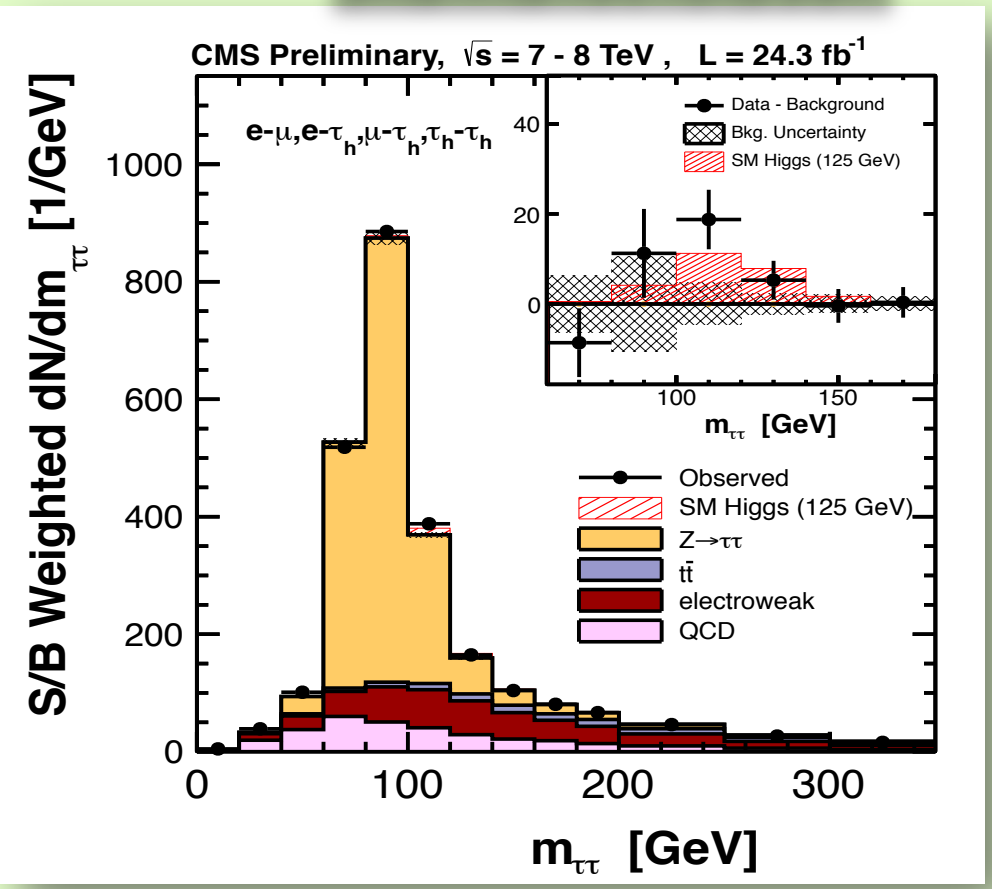
$m_H = 125.4 \pm 0.5 \pm 0.6$ (syst.)

With additional data, significance decreased relative to 4th of July!!

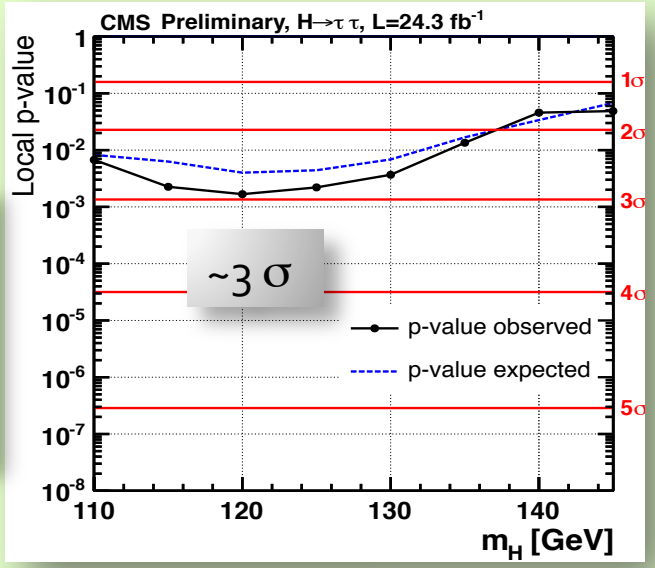
μ = 0.77 ± 0.27

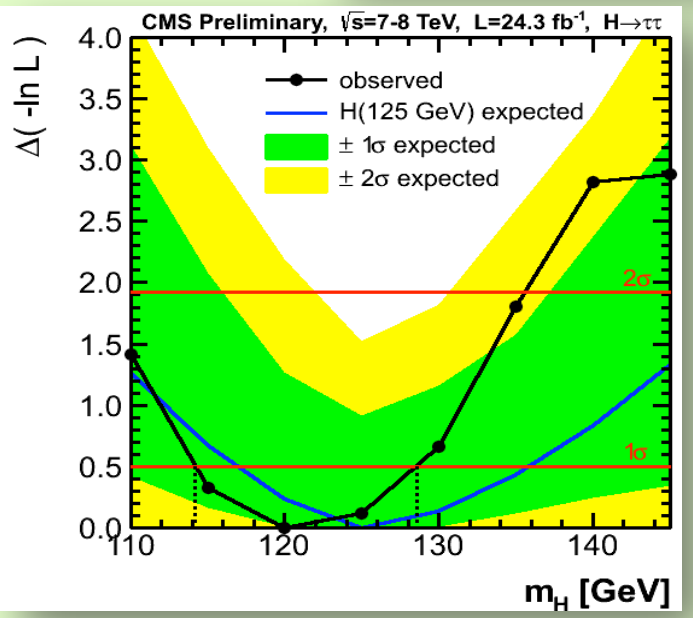
$H \rightarrow \tau\tau$

$\mu\tau_h$, $e\tau_h$, $e\mu$, $\tau_h\tau_h$, $\mu\mu$



First strong indication of decay to spin ½ particles

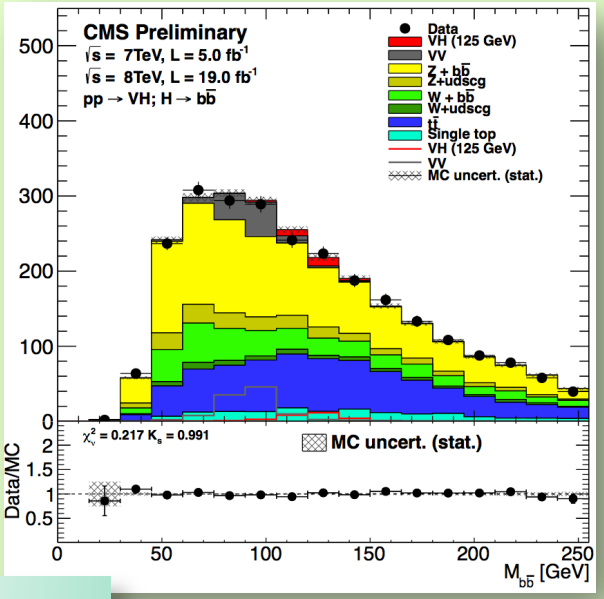


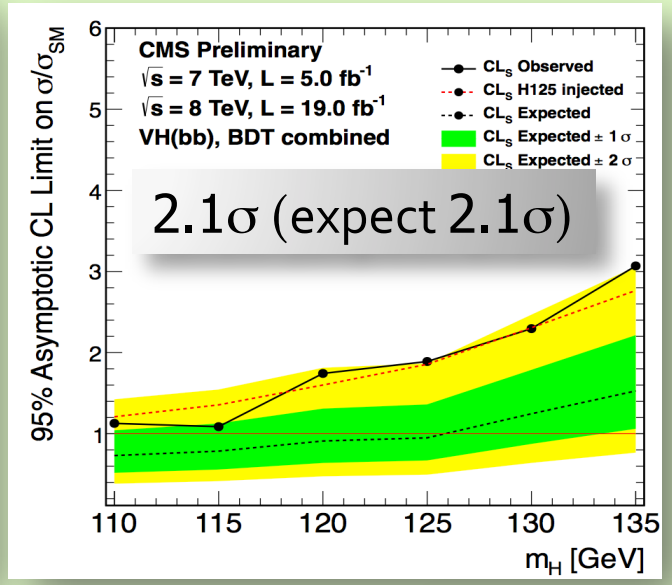


[CMS HIG-13-004]

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

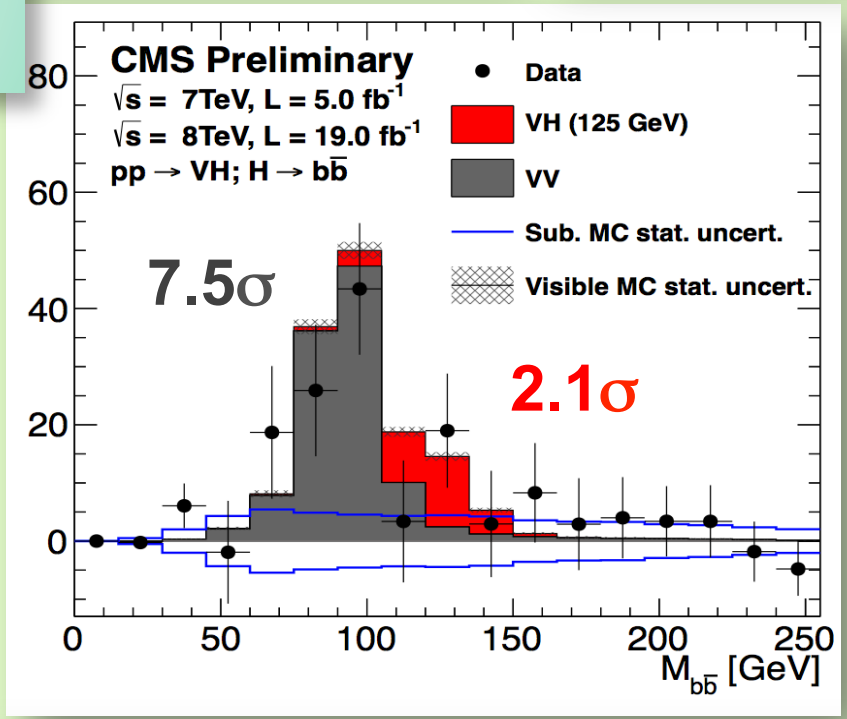
VH, H→bb̄

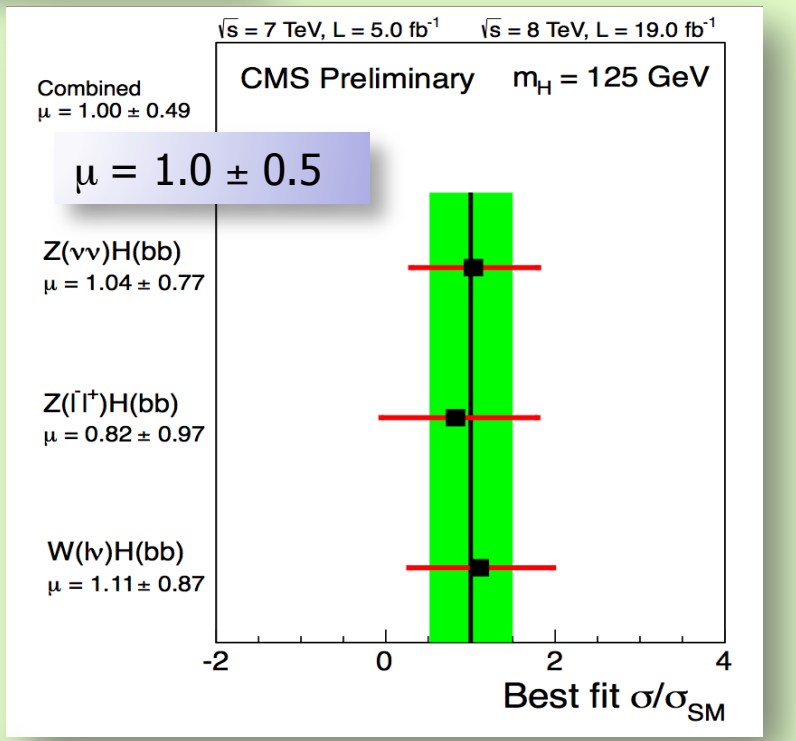




2.1σ (expect 2.1σ)

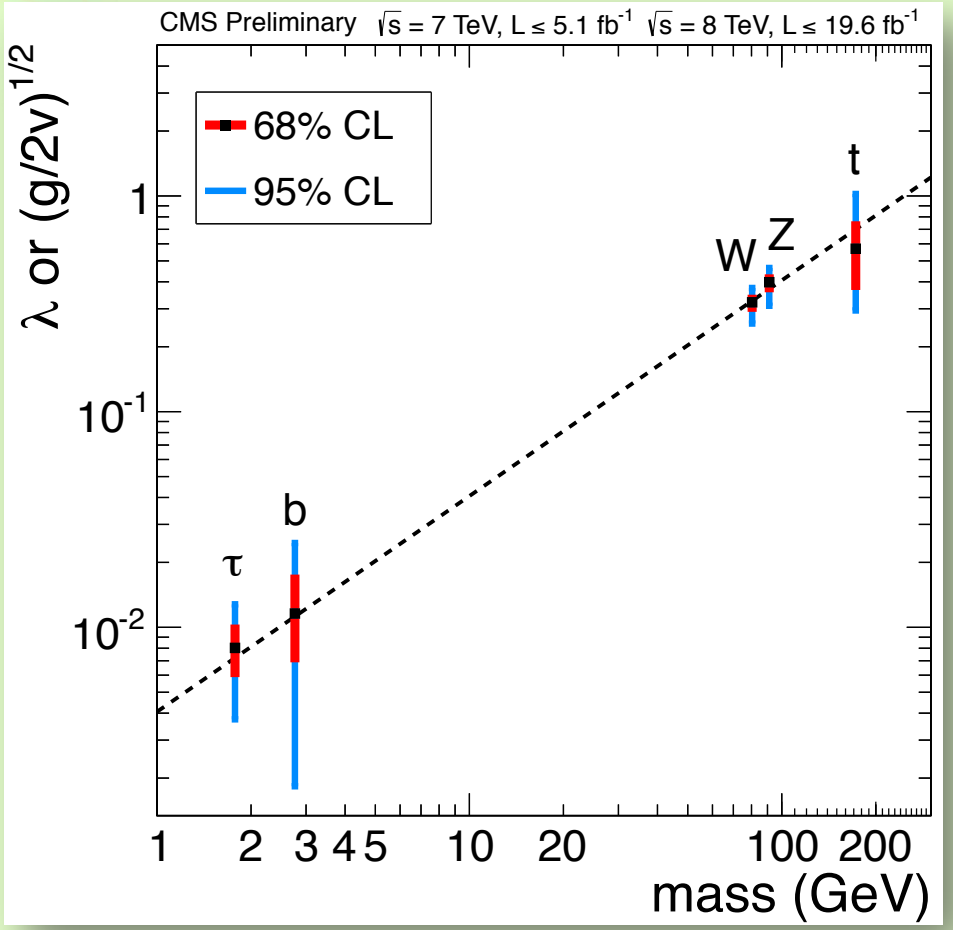
$M_{b\bar{b}}$ all subchannels





W(μν)H, W(eν)H, W(τν)H, Z(μμ)H, Z(ee)H and Z(νν)H

The 5 main decay modes



HIG-13-005

Decay	Expected	Observed	
ZZ	7.1 σ	6.7 σ	
γγ	3.9 σ	3.2 σ	
WW	5.3 σ	3.9 σ	
bb	2.2 σ	2.1 σ	3.4 σ
ττ	2.6 σ	2.8 σ	

m_H = 125.7

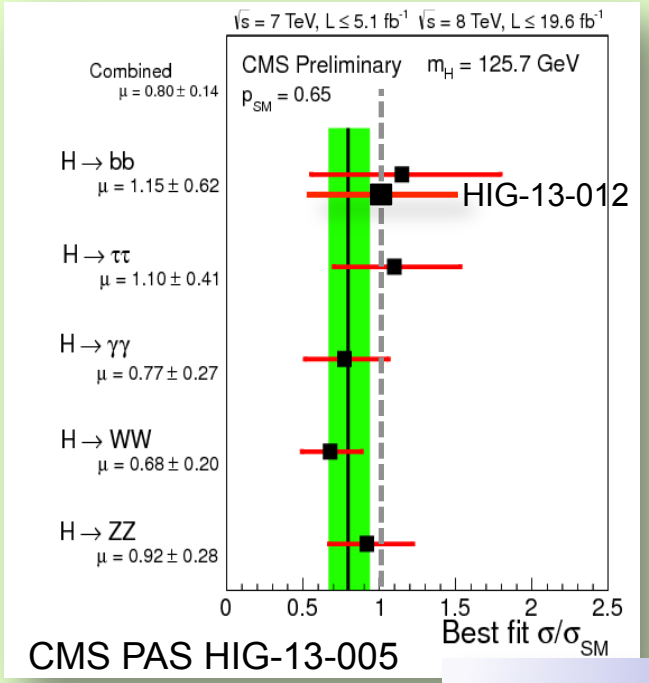
$b\bar{b}$: VH ⊕ VBF
WW: ggF⊕VH⊕VBF

Br(H→χχ) < 75% (91% exp.) @ 95% CL

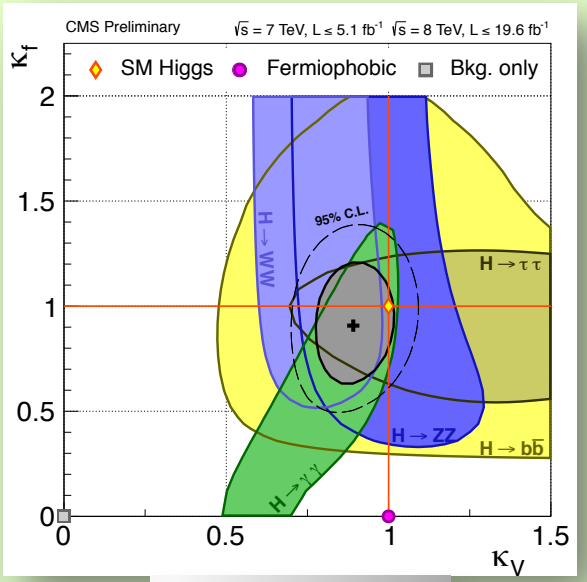
3.4σ Evidence for H→ $f\bar{f}$

σ/σ_{SM}, Mass ($\gamma\gamma \oplus ZZ$), Couplings, J^{PC}

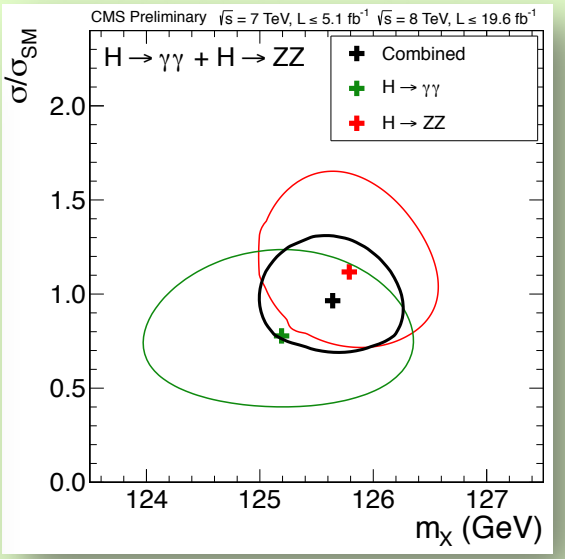
CERN April 15, 2013



μ=0.80±0.14



HIG-13-005



m = 125.7 ± 0.3 ± 0.3 GeV

$\mu = 0.80 \pm 0.14$

- *Negligible change for new VH(bb) result: $\mu = 1.15 \pm 0.62 \rightarrow 1.00 \pm 0.50$*

$m = 125.7 \pm 0.3 \pm 0.3$ GeV

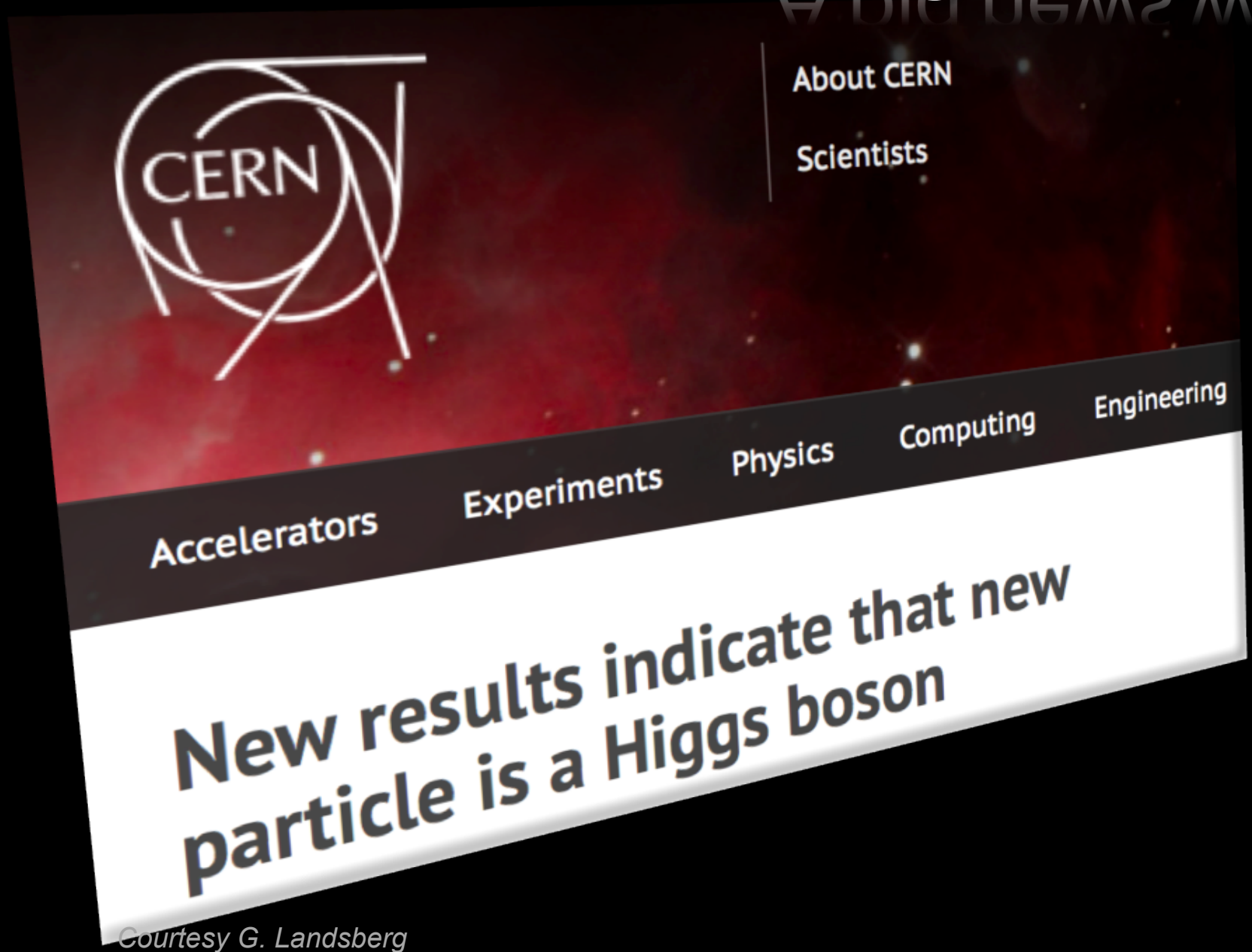
- 0.5% precision already

0^{++} is preferred over 2^{++}, 0^{-+} at 2.8, 3.3σ, respectively

A big news week!

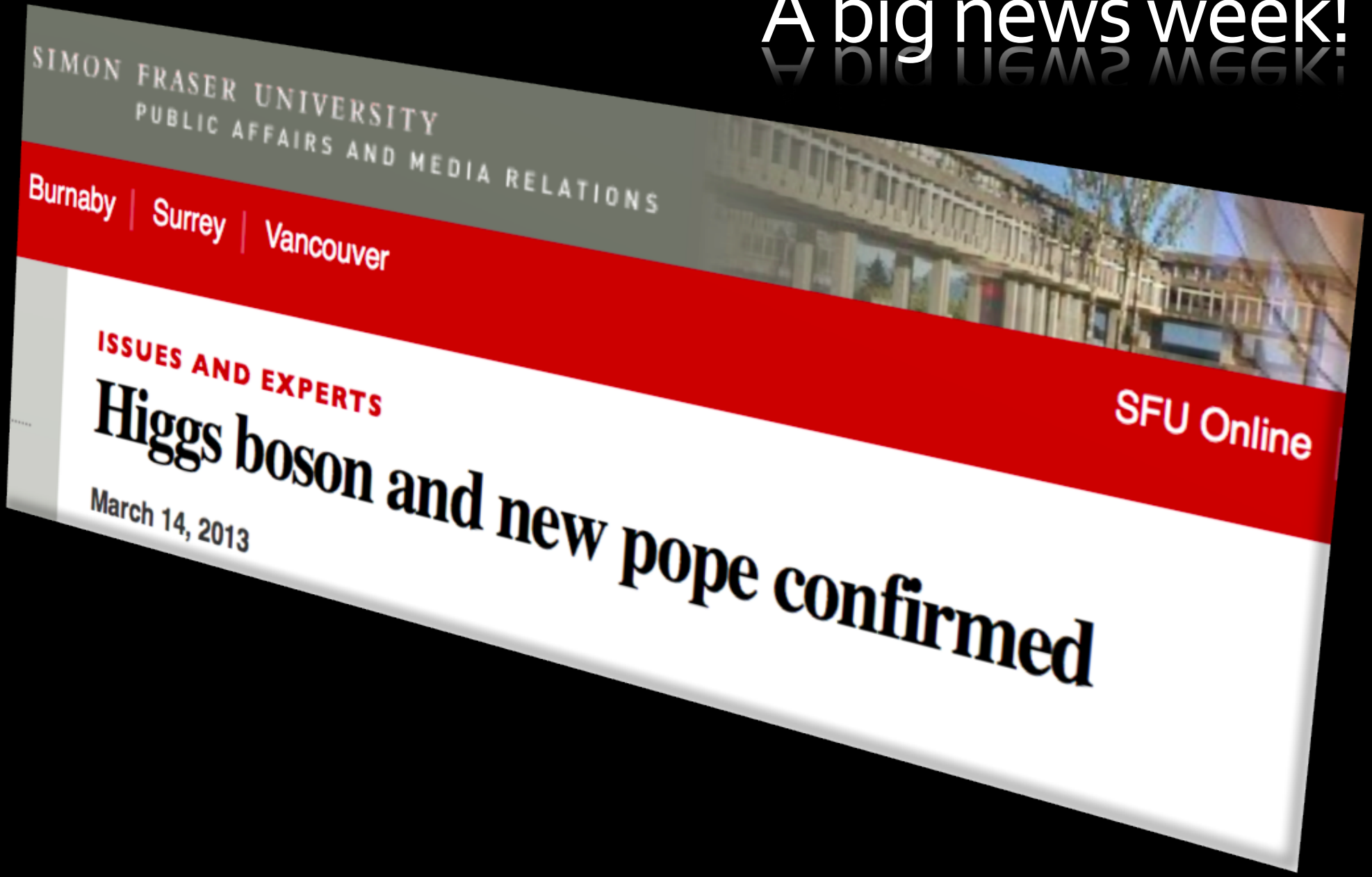
Courtesy G. Landsberg

A big news week!



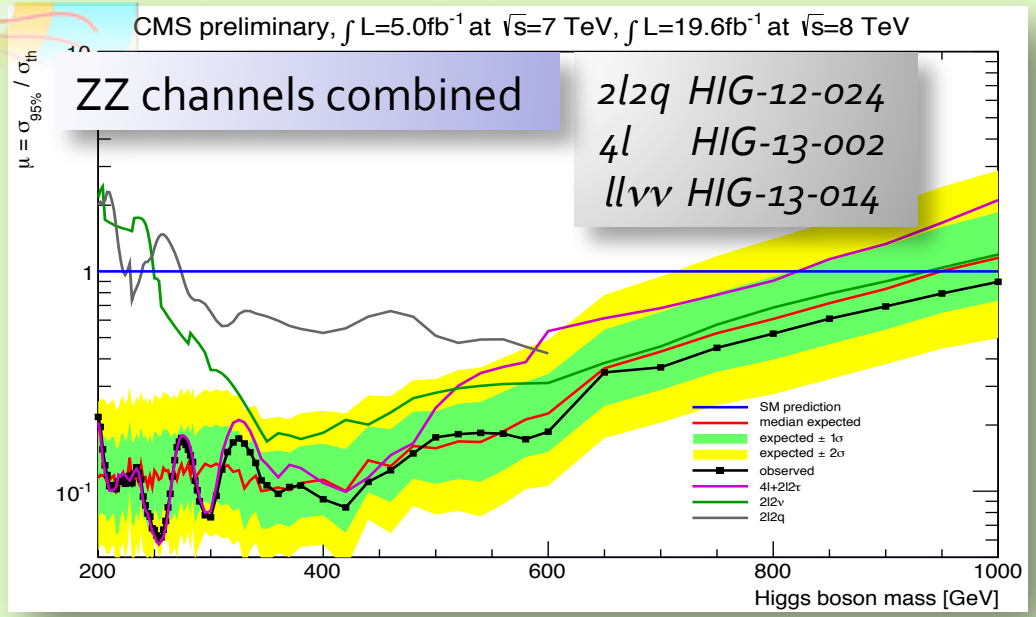
Courtesy G. Landsberg

A big news week!



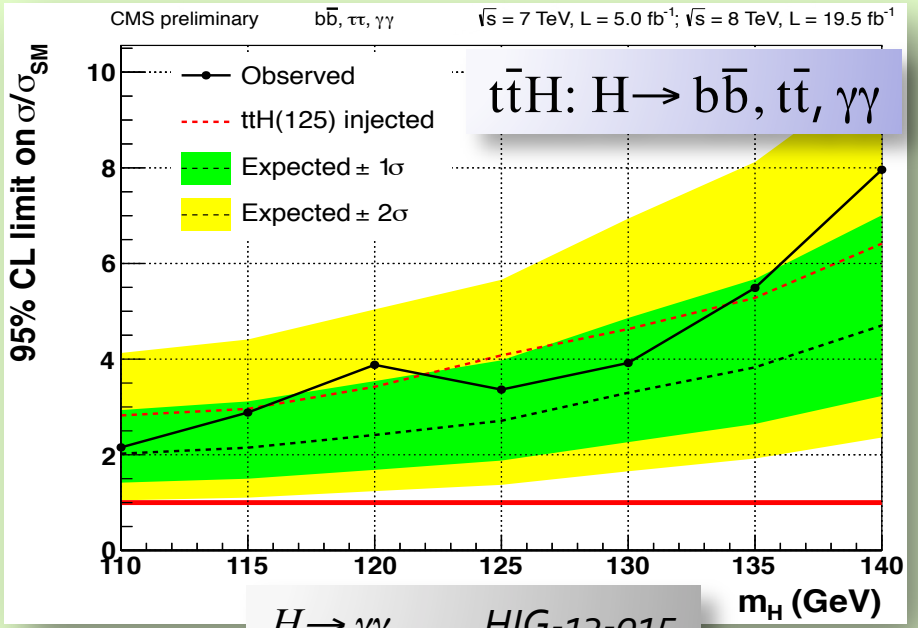
Courtesy G. Landsberg

High Mass Searches and new $t\bar{t}H$ results



ZZ channels combined

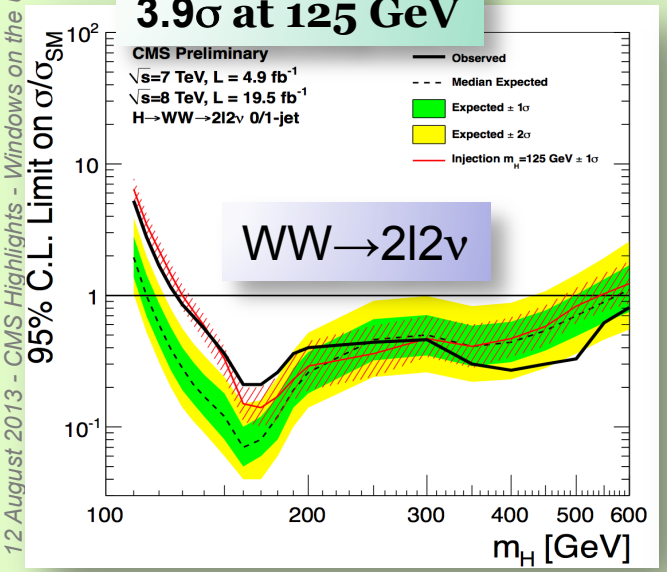
2l2q HIG-12-024
4l HIG-13-002
llνν HIG-13-014



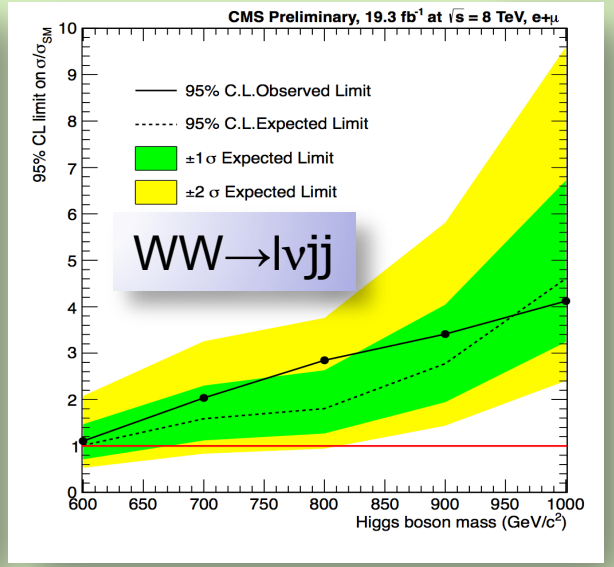
$t\bar{t}H$: $H \to b\bar{b}, t\bar{t}, \gamma\gamma$

$H \to \gamma\gamma$ HIG-13-015
$H \to b\bar{b}, t\bar{t}$ HIG-13-019
arXiv:1303.0763

3.9σ at 125 GeV



WW→2l2ν



WW→lνjj

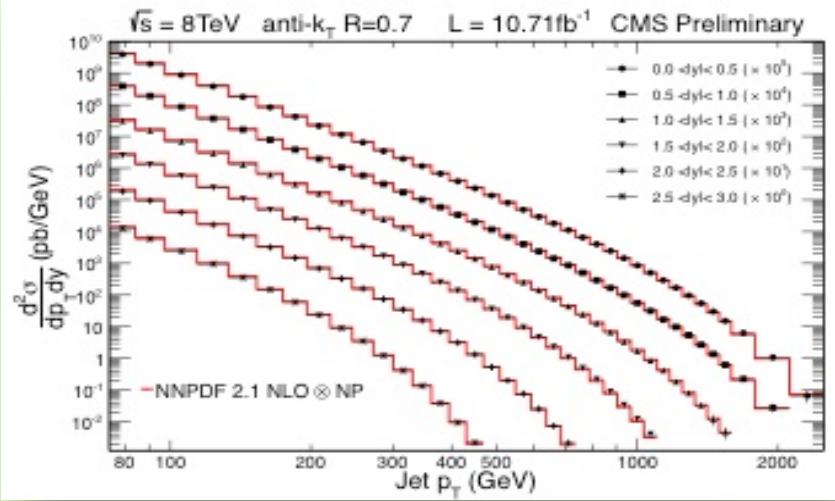
Interpretation in EW-singlet models and LHC XS WG benchmark models:
lνjj HIG-13-008
2l2ν HIG-13-014

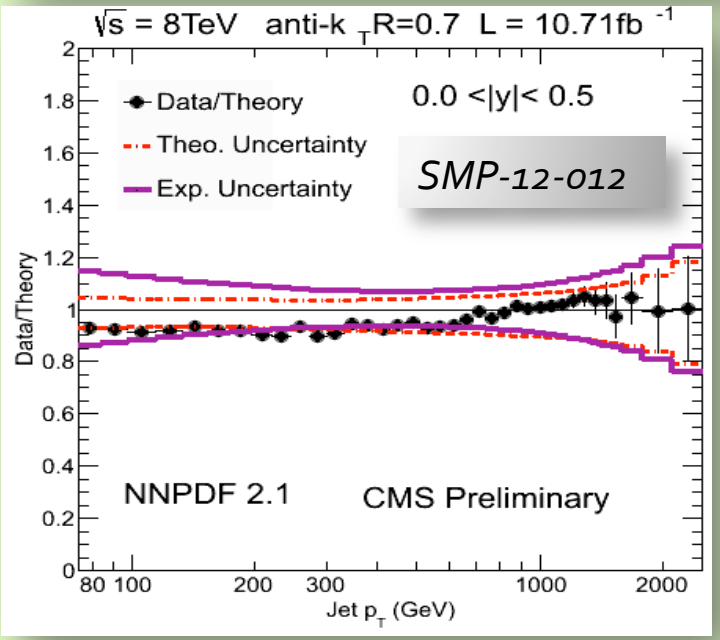
SM Physics

Current Highlights

Jet Physics Highlights

- First differential inclusive jet cross section measurement at 8 TeV
  - Important input to PDF fits





Jet Physics Highlights

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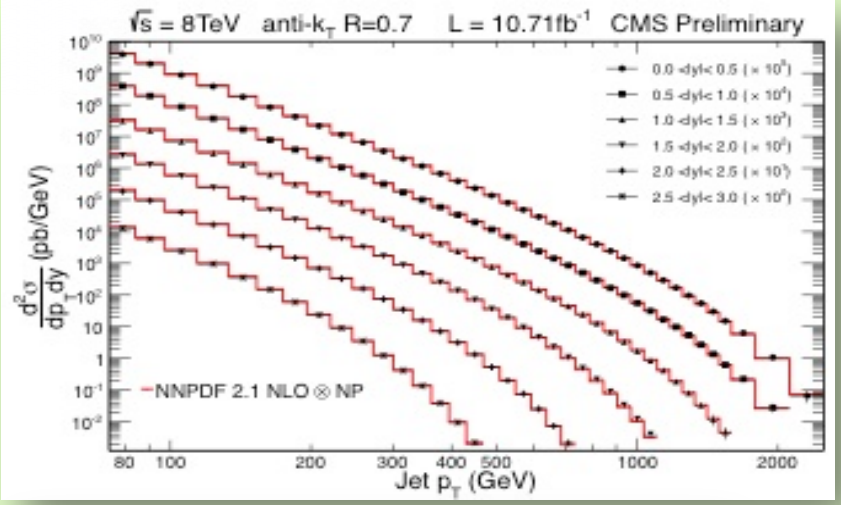
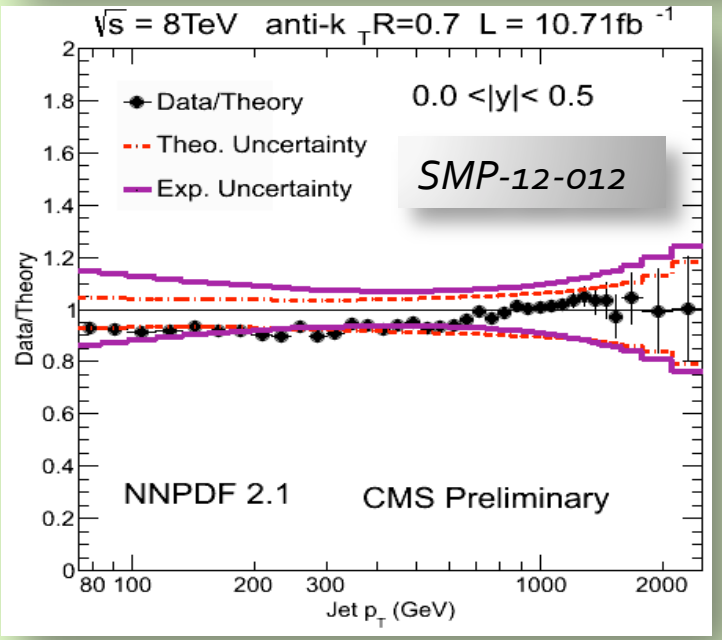
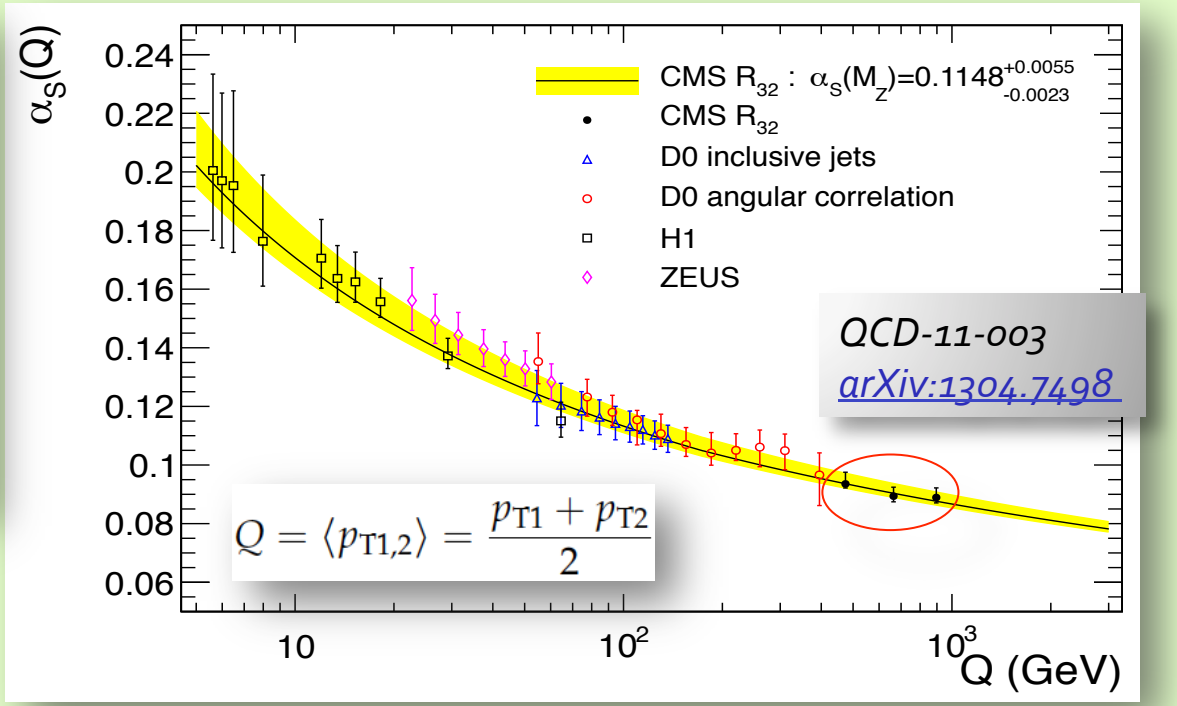




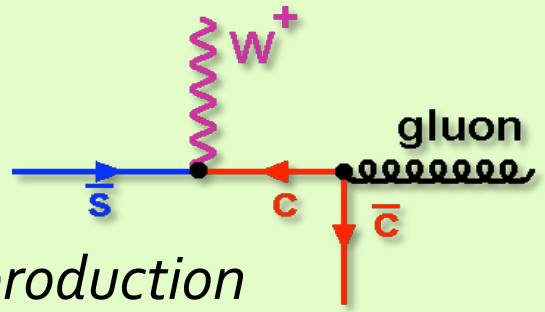


New α_S measurement via ratio R32:

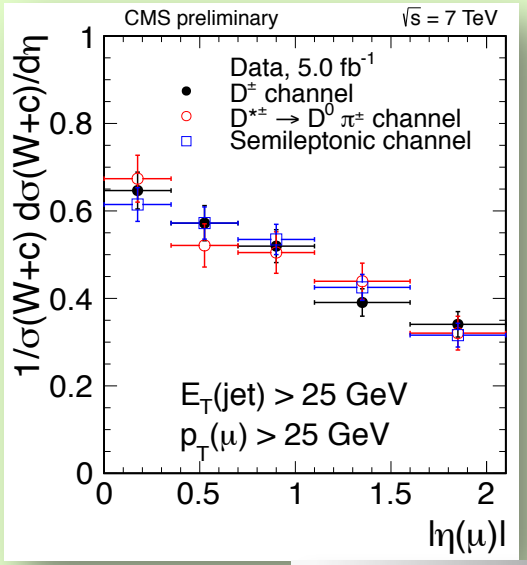
$\alpha_S(M_Z) = 0.1148 \pm 0.0014$ (exp.) ± 0.0018 (PDF) $^{+0.005}_{-0.0}$ (scale)

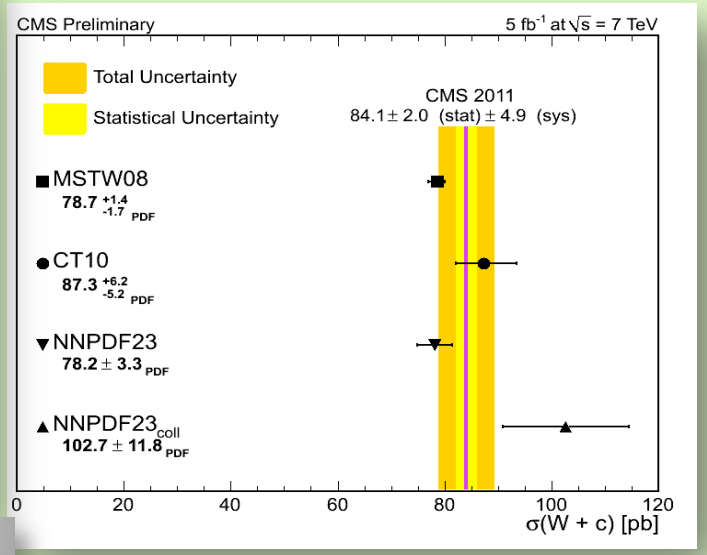
- Many theoretical uncertainties *(related to choice of renormalization and factorization scales, μ_r and m_f, or to non-perturbative effects)*, are reduced in the 3 to 2 jets cross sections ratio.

V+jets Highlights



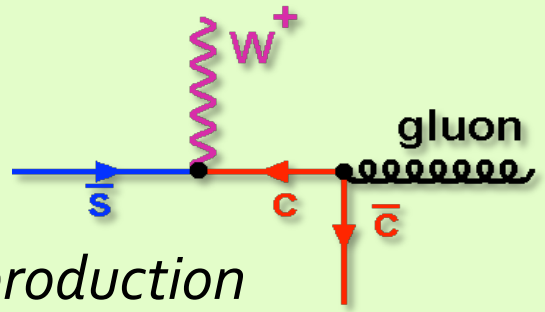
- *W+c production*
  - *Exclusive charm tagging via full reconstruction of D±, D*, and semi-leptonic decays*
- *Direct access to s-quark PDF*





SMP-12-002

V+jets Highlights



- *W+c production*
  - *Exclusive charm tagging via full reconstruction of D±, D*, and semi-leptonic decays*
- *Direct access to s-quark PDF*

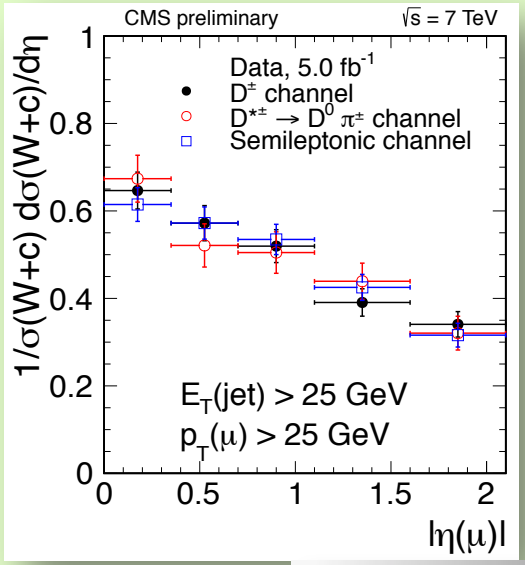
- σ x Br: $pp \to b\bar{b}W, W \to \mu\nu$ = 0.53 ± 0.12 pb
  - NLO prediction: 0.52 ± 0.03 pb

SMP-12-026

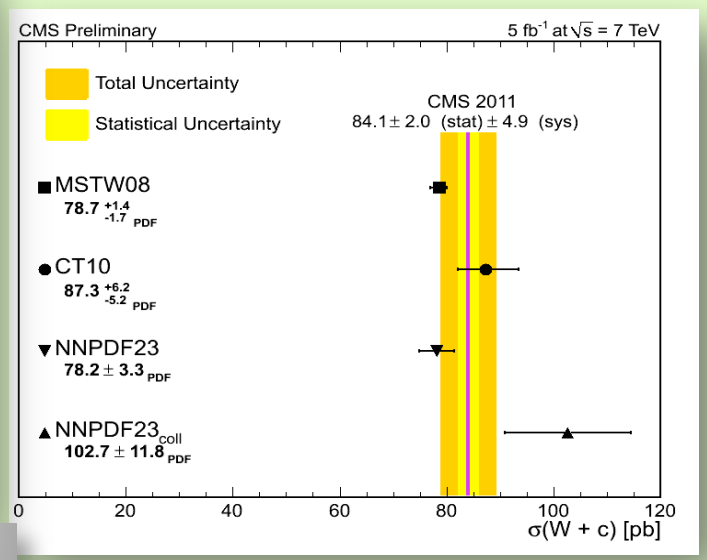
- σ x Br: $pp \to b\bar{b}Z, Z \to ll$ = 0.36 ± 0.07 pb

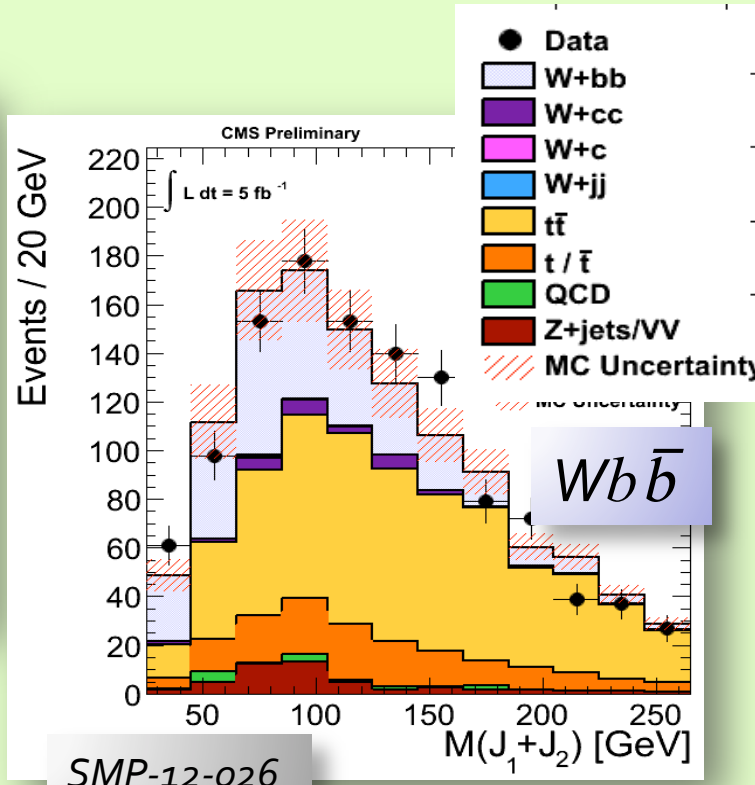
SMP-13-004

$\sqrt{s}$ = 7 TeV and p_T^b > 25 GeV



SMP-12-002

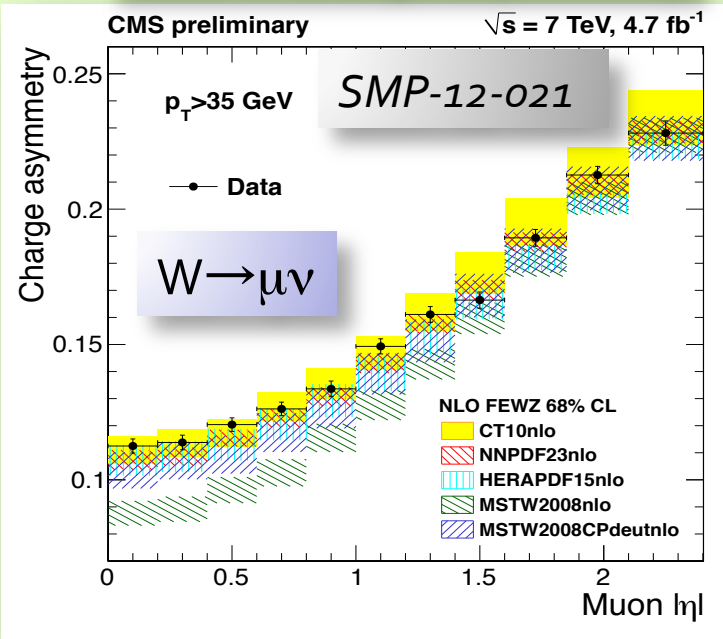




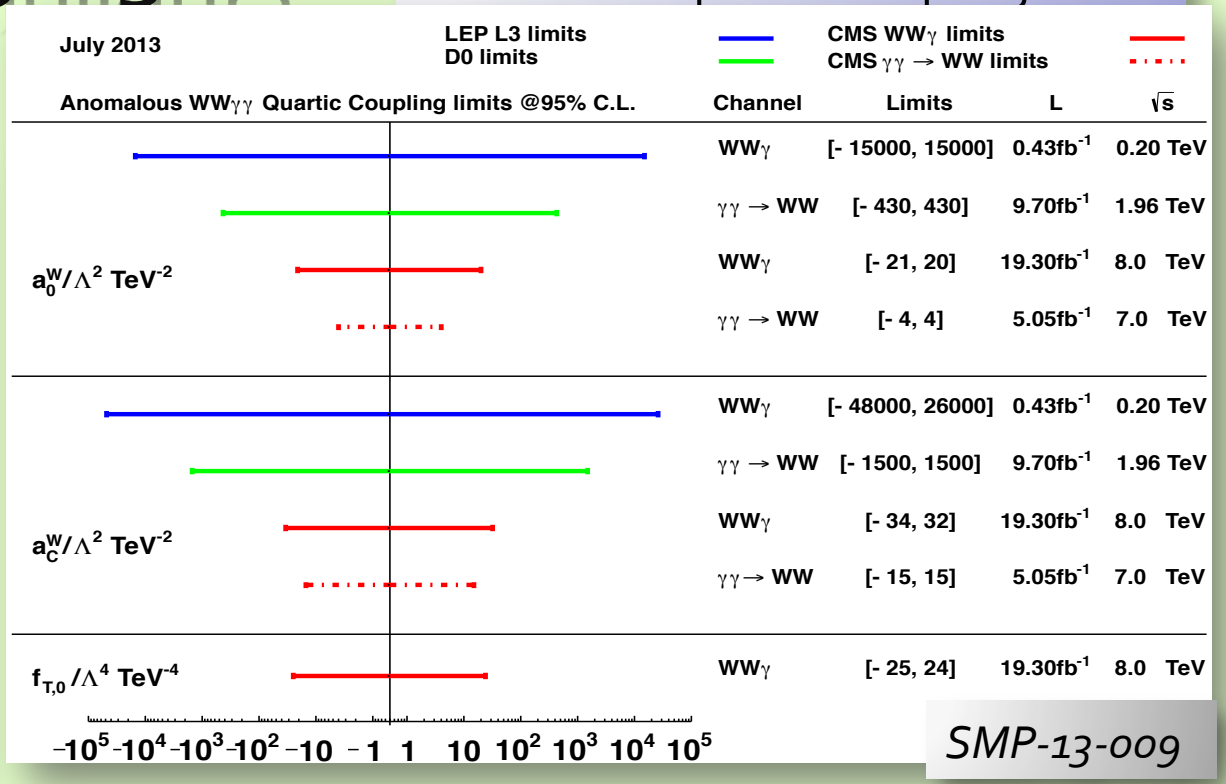
SMP-12-026

Electroweak Highlights

New W charge asymmetry

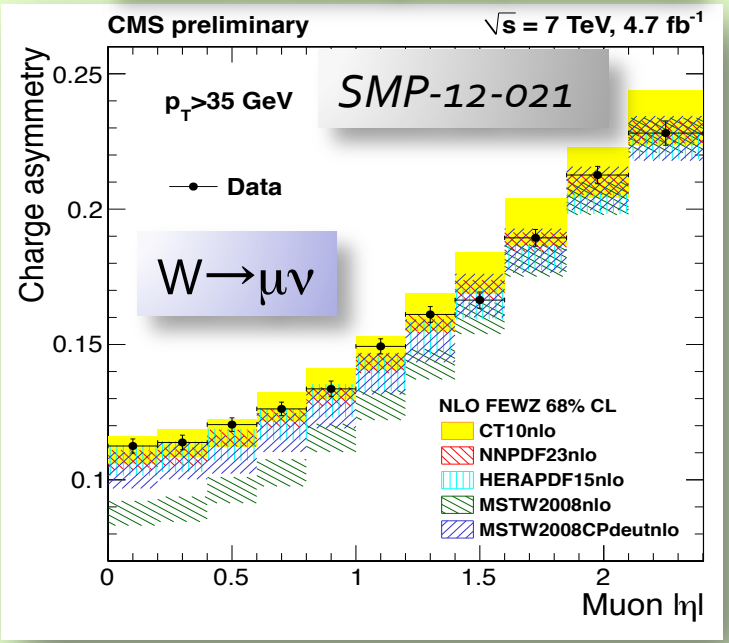


Anomalous quartic coupling limits

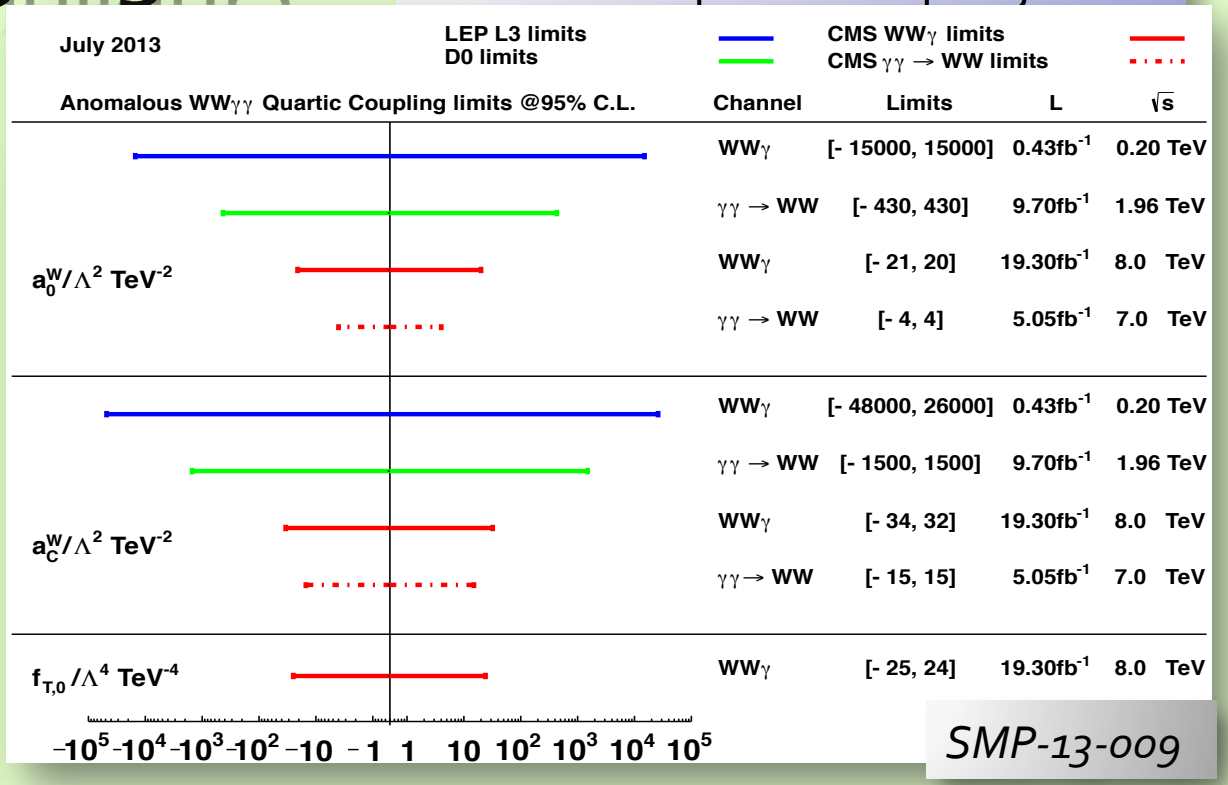


Electroweak Highlights

New W charge asymmetry



Anomalous quartic coupling limits



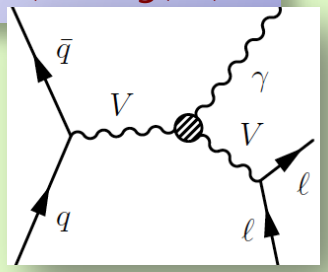
SMP-13-009

Precise Wγ and Zγ cross sections

Wγ: σ/σ_{SM} = 1.16 ± 0.11 (ex)± 0.06(th)

Zγ: σ/σ_{SM} = 0.98 ± 0.05 (ex)± 0.05(th)

EWK-11-009

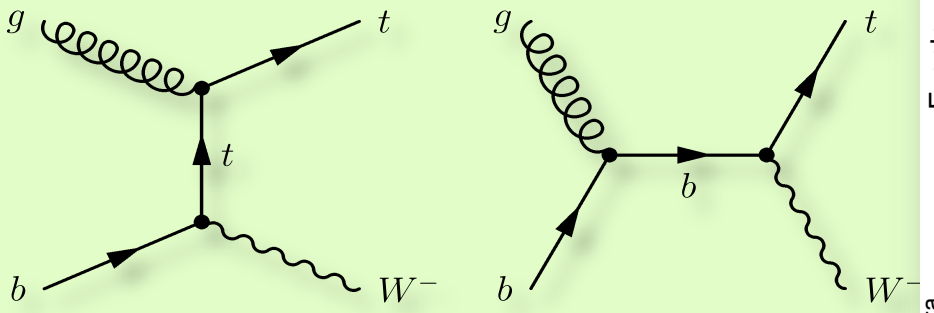


Stringent limits: Anomalous Trilinear Gauge Couplings

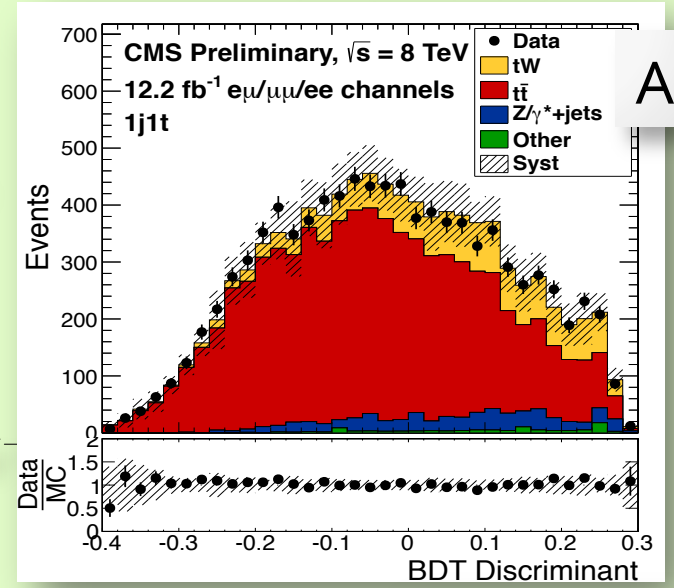
Coupling	95% CL Limit	95% CL Limit
WWγ	$-0.38 < k_\gamma < 0.29$	$-0.050 < \lambda_\gamma < 0.037$
Zγγ	$-0.010 < h_3^\gamma < 0.010$	$\lvert h_4^\gamma \rvert < 8.8\times10^{-5}$
ZZγ	$-0.0086 < h_3^Z < 0.0084$	$-8.0\times10^{-5} < h_4^Z < 7.9\times10^{-5}$

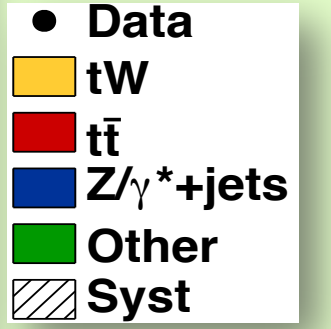
Observation of tW Production

LO Feynman diagrams:



All channels

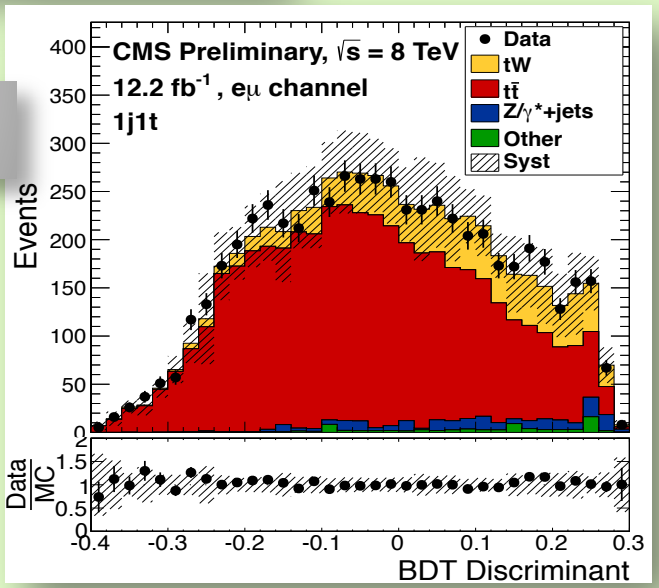




TOP-12-040

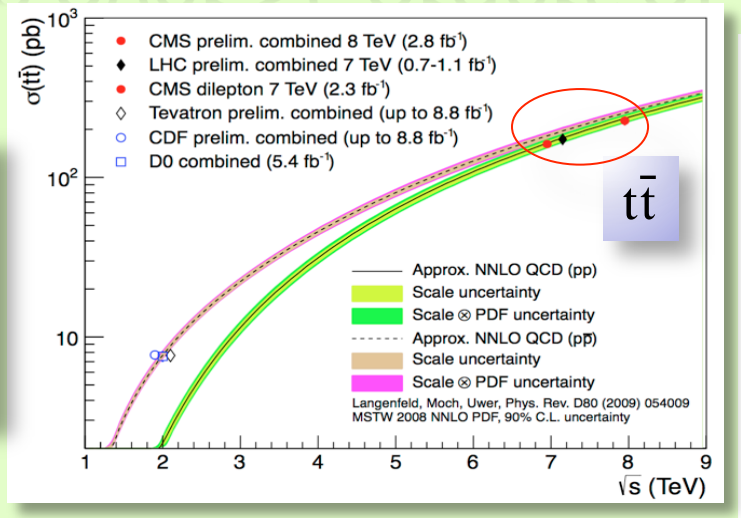
- Use W(lν) decays for both W's
  - Max sensitivity in eμ channel
- Selection based on BDT
  - Jet, b-jet multiplicity categories
- Observed 6σ (5.4σ expected)
  - $\sigma = 23.4^{+5.5}_{-5.4}$ pb
- $V_{tb} > 0.78$ @ 95% CL

eμ alone

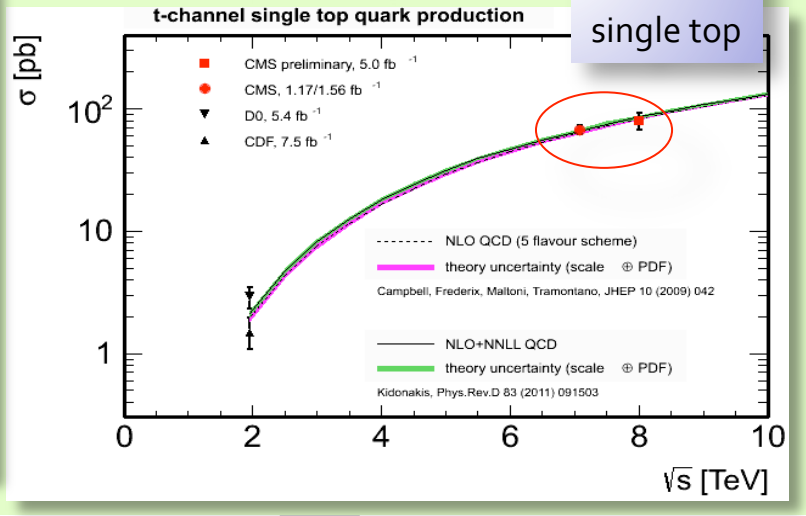


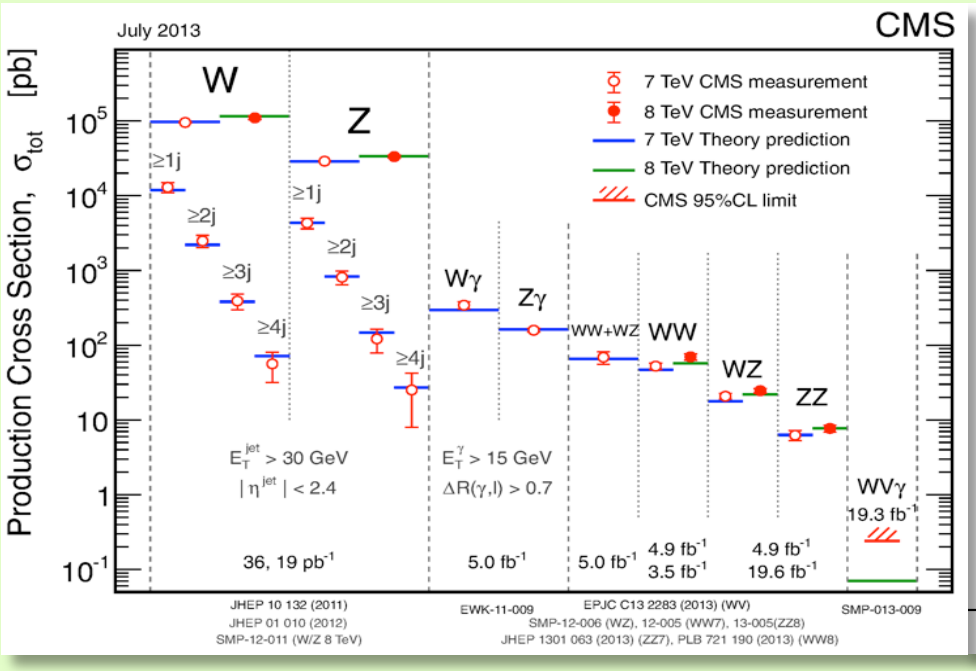
Measure over >5 orders of magnitude

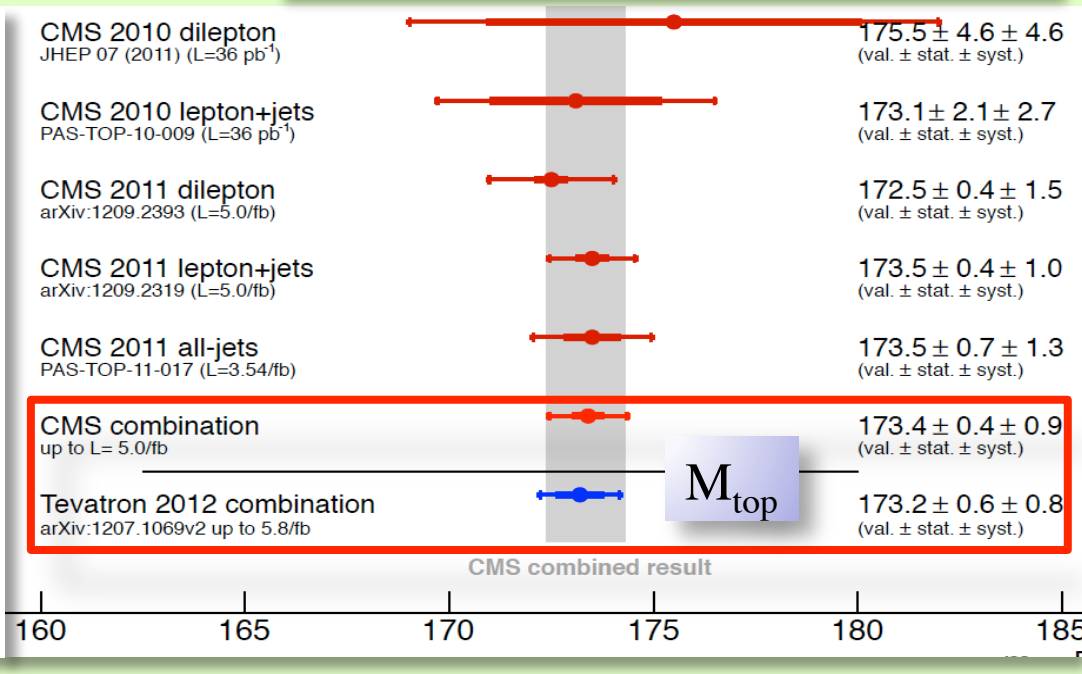
Many SM processes measured/probed with unprecedented precision/sensitivity



t channel single top



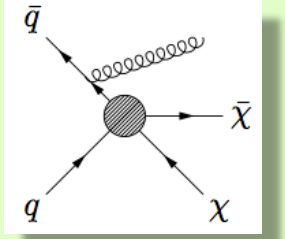




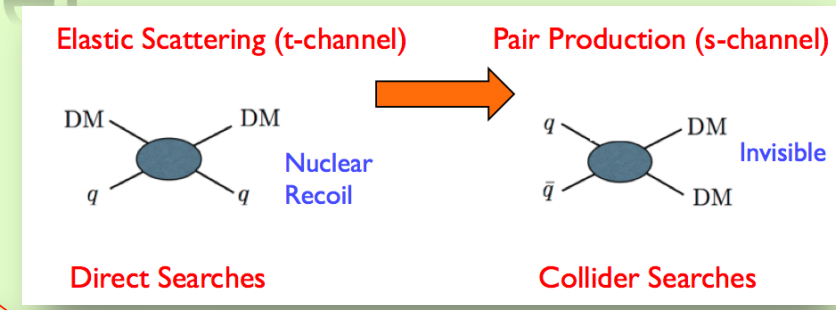
Searches for New Physics

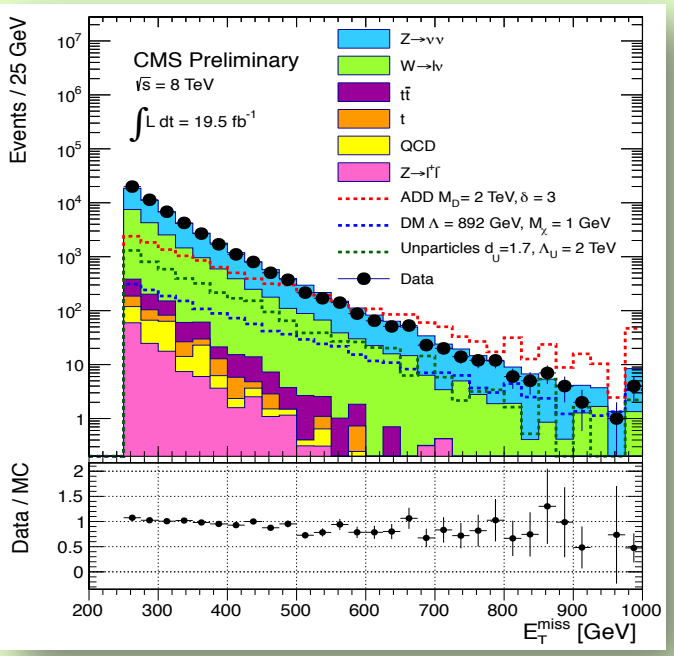
Current Highlights

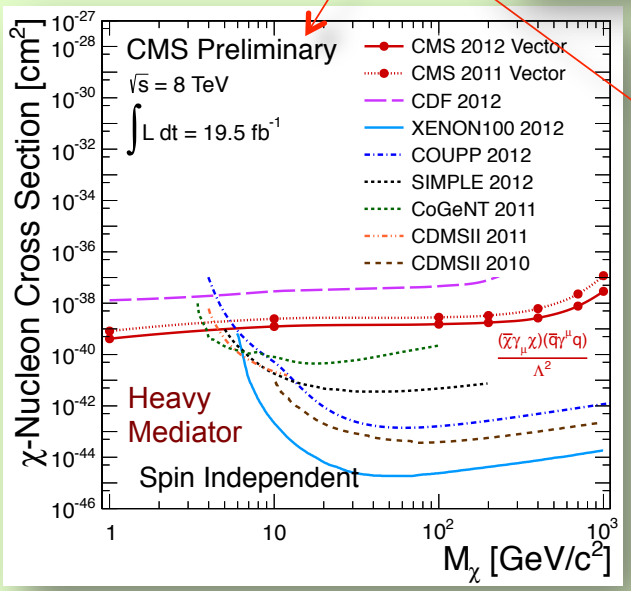
Dark matter

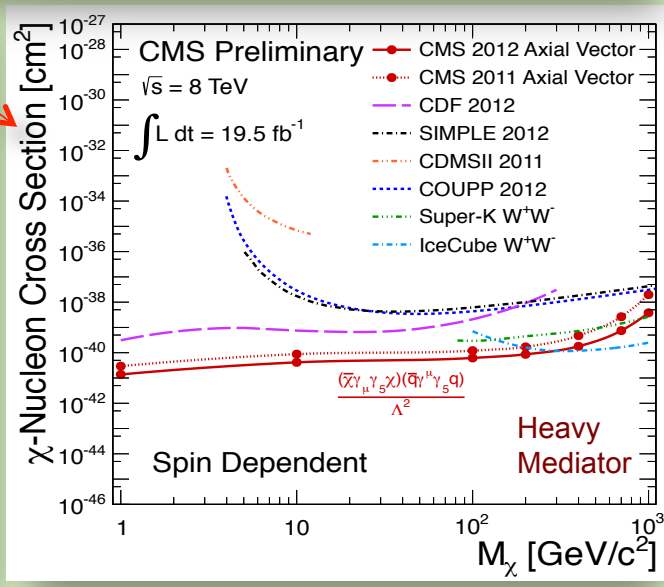


- Using monojets and mono-photons
  - Stringent DM limits for heavy mediators



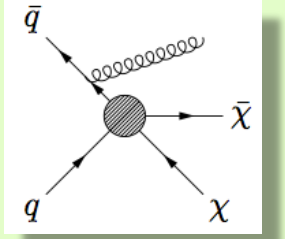






[CMS-PAS-EXO-12-048]

Dark matter



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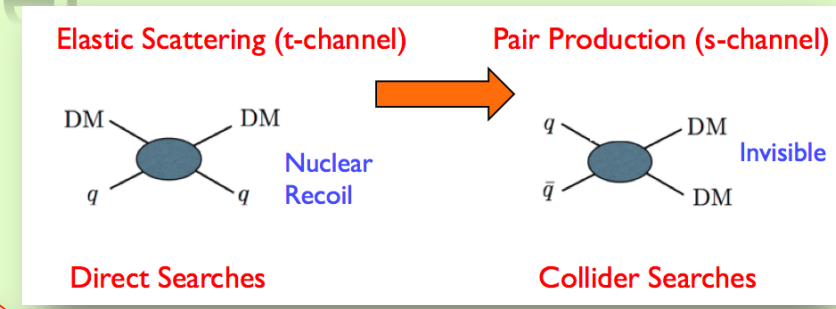
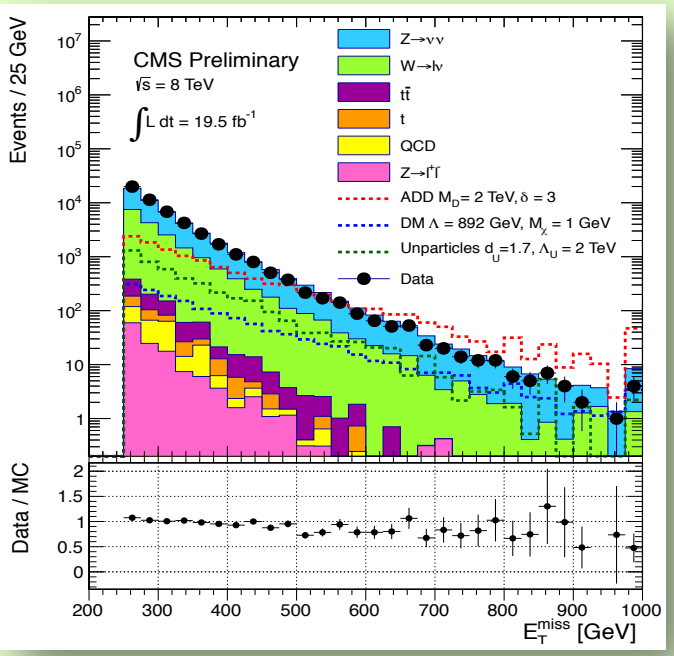
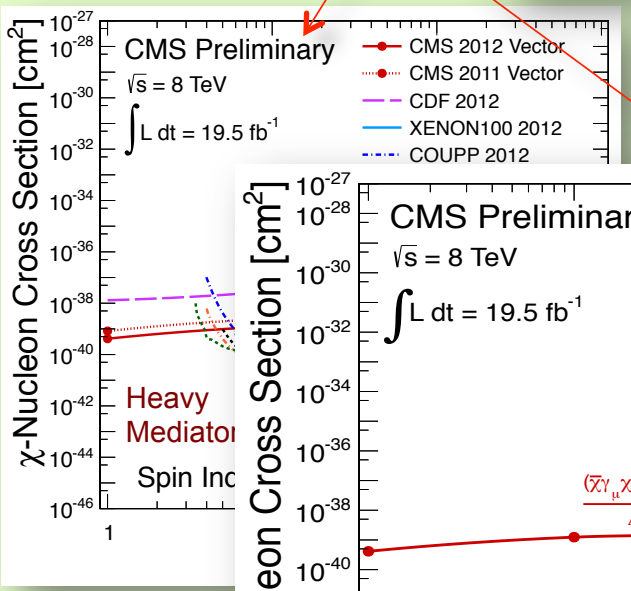
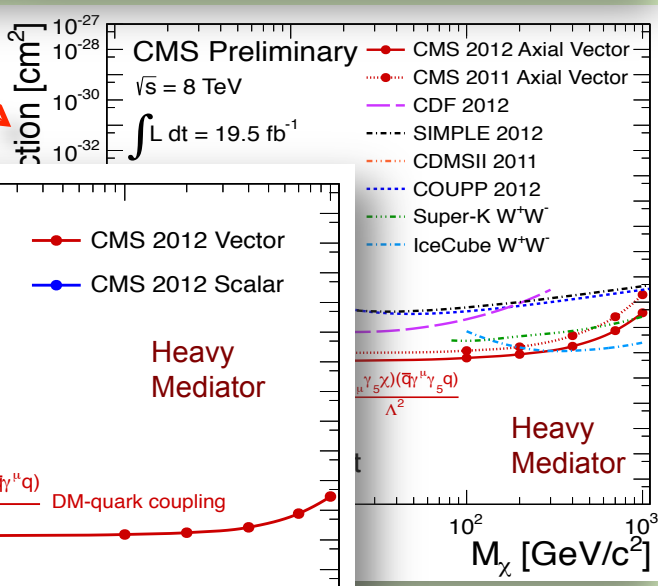
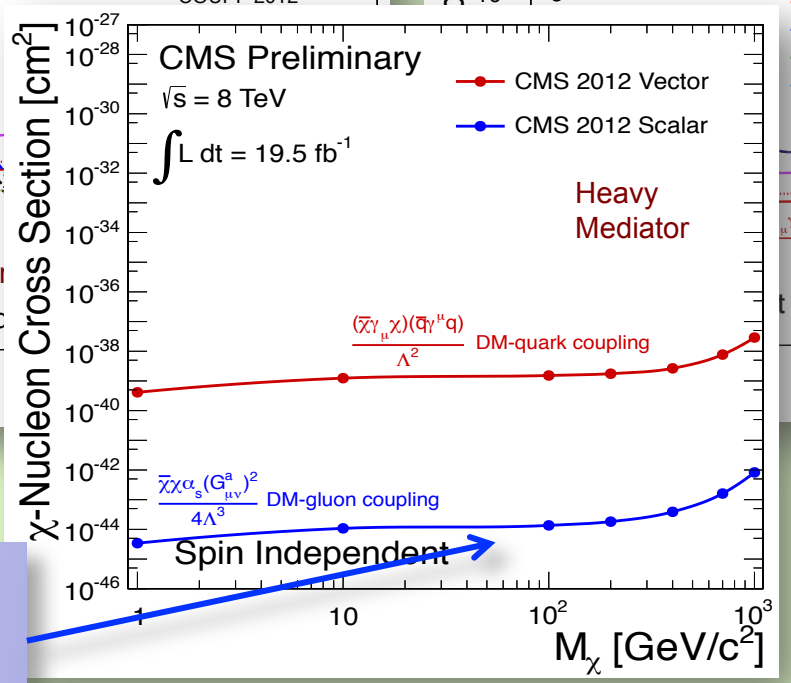
  - Stringent DM limits for heavy mediators









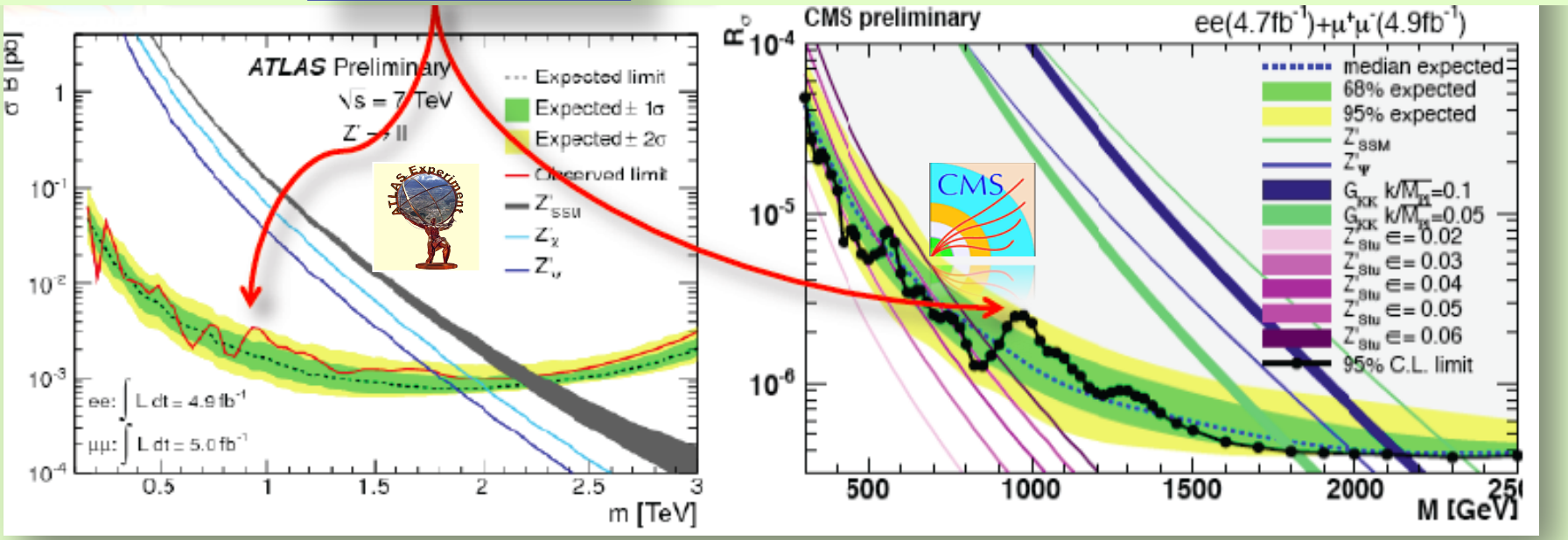


- Also sensitive to DM-gluon couplings

CMS-PAS-EXO-12-048

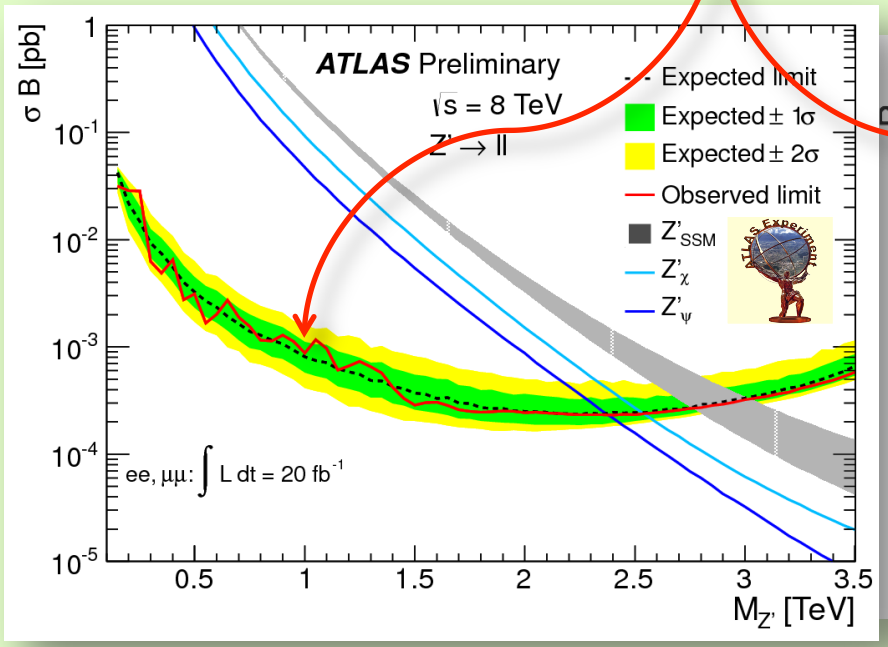
$Z' \rightarrow ll$: ca. Moriond 2012

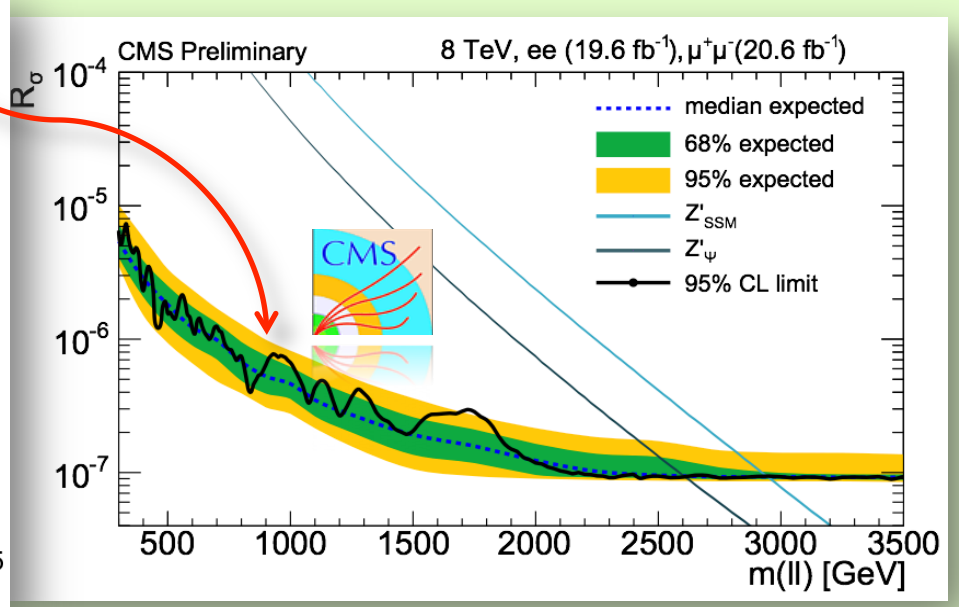
Going, going...



$Z' \rightarrow ll$: ca. Moriond 2013

gone





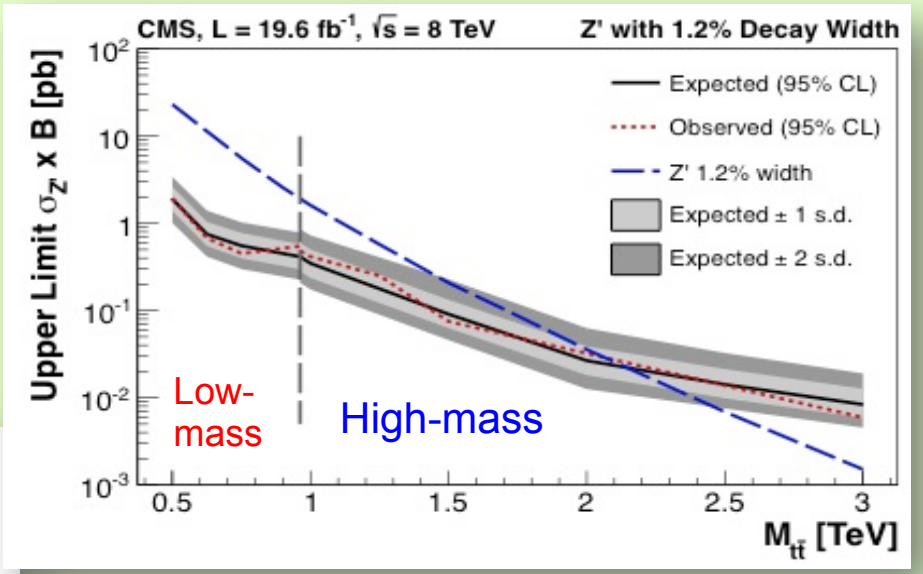
Heavy Resonances

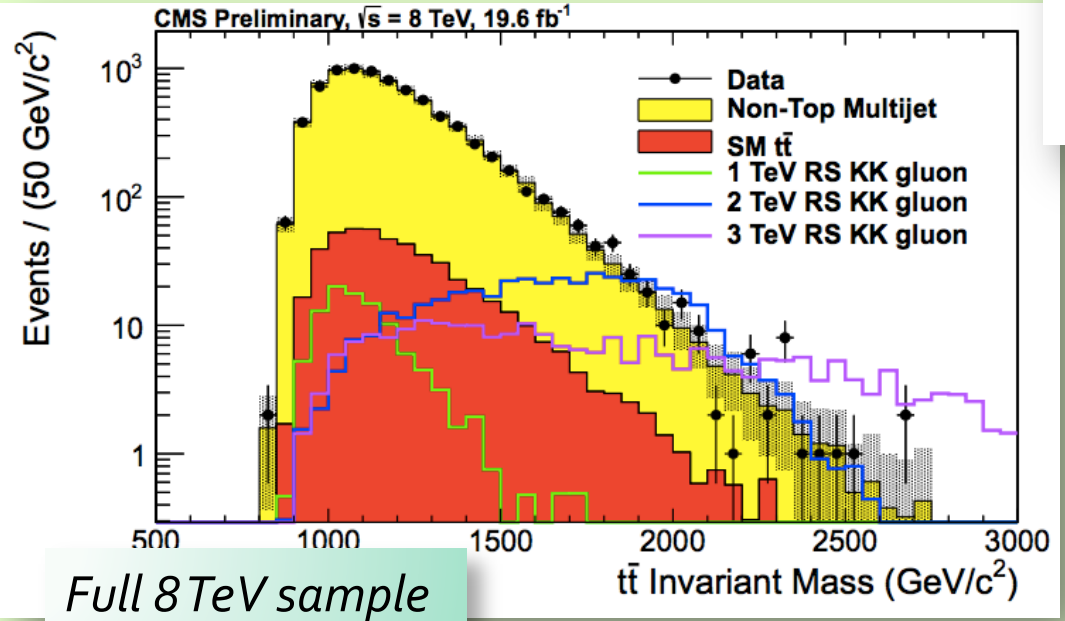
$Z' \rightarrow t\bar{t}$ (hadronic)

2 fat jets 140 < M < 250

$M_{Z'}$ > 1.6 (2.3) TeV for Γ =1.2 (10)%

$M_{g(KK)}$ > 1.8 TeV

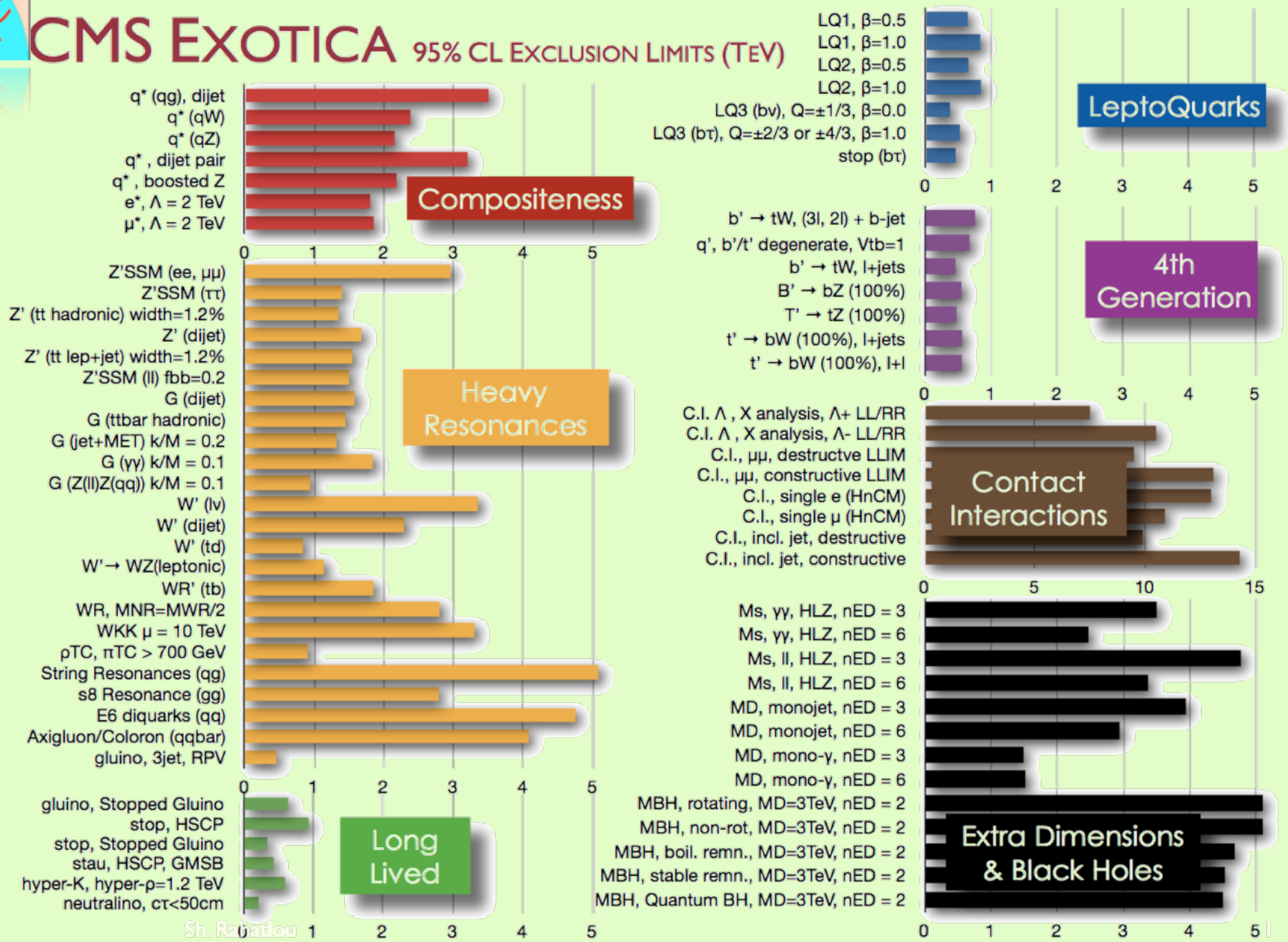




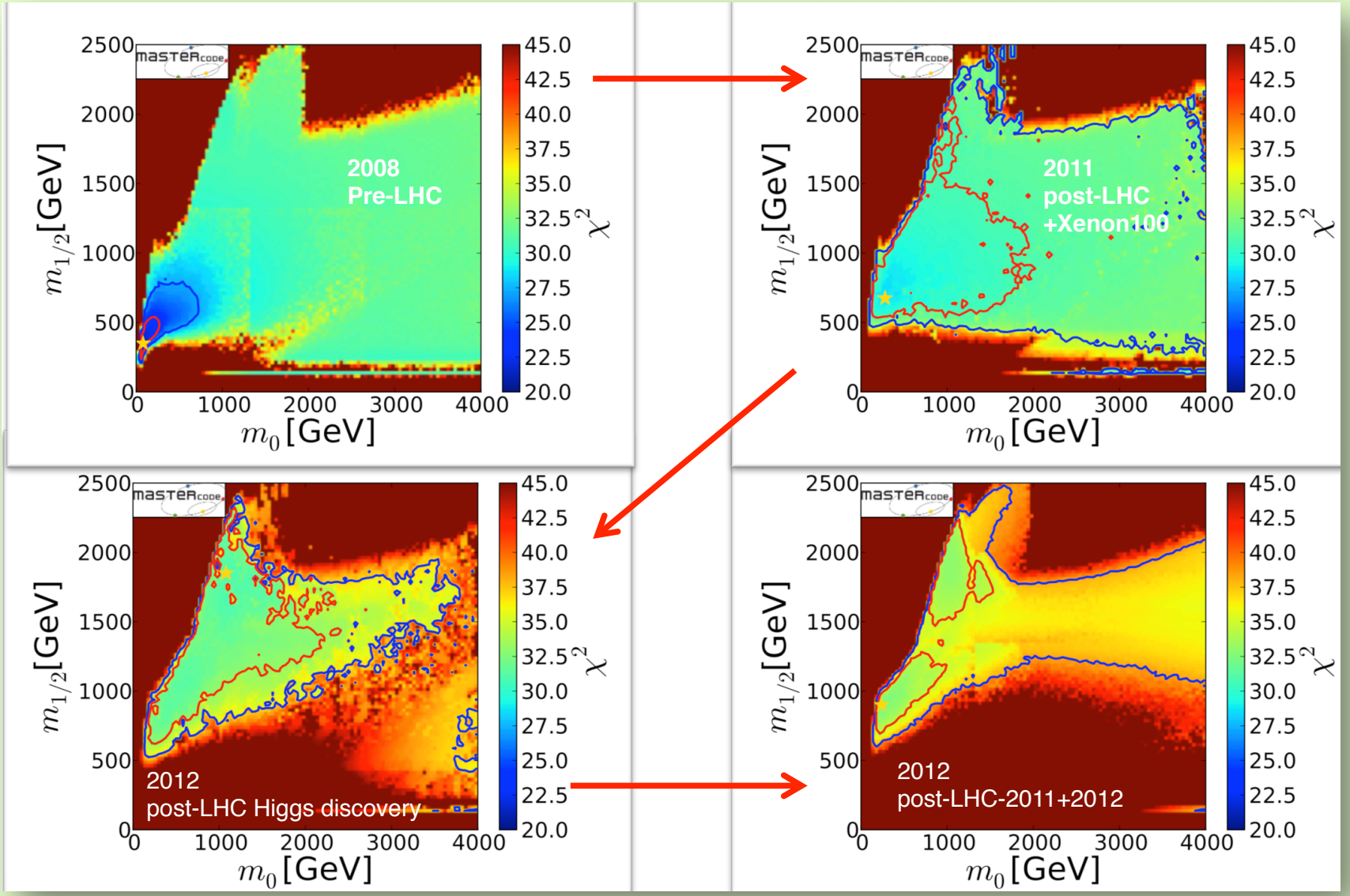
Full 8 TeV sample

- Combine L+jets+MET and Hadronic channels
  - Optimized separately for low-mass (non-boosted, M_{tt} < 1 TeV) and high-mass (boosted)

CMS EXOTICA 95% CL EXCLUSION LIMITS (TEV)

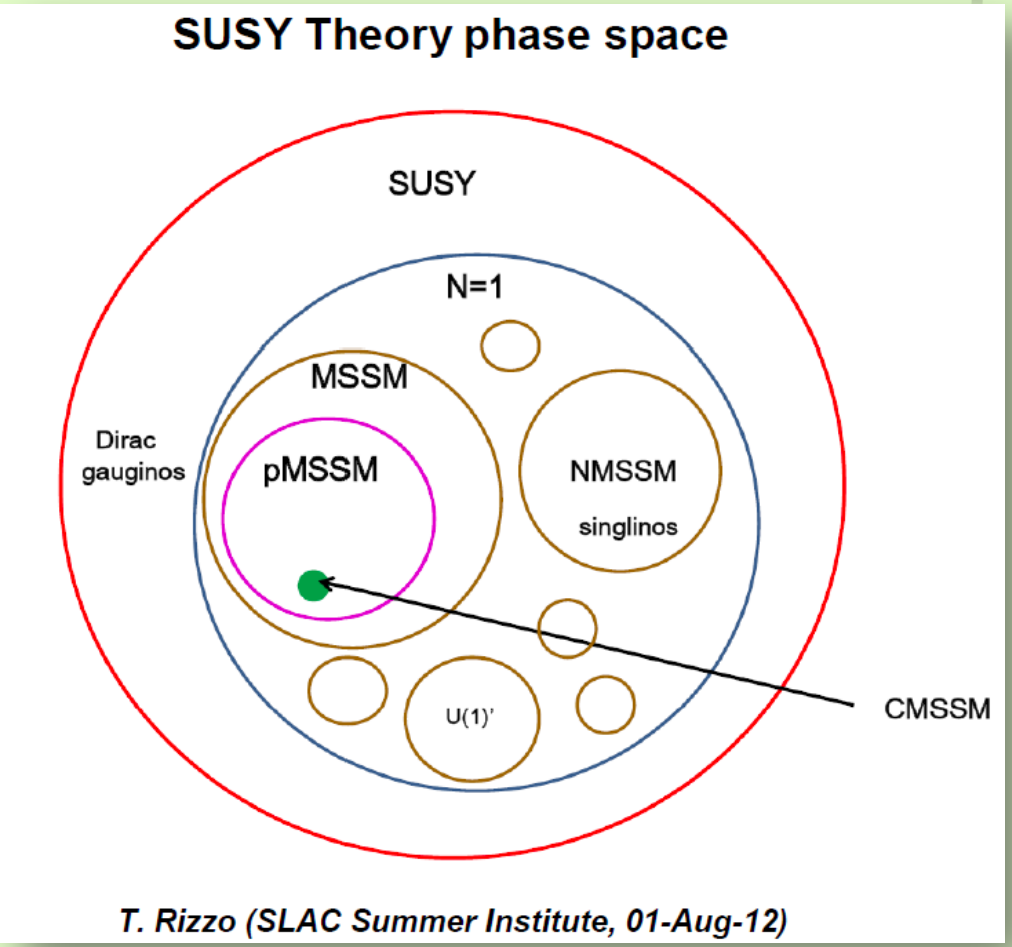


CMSSM Evolution



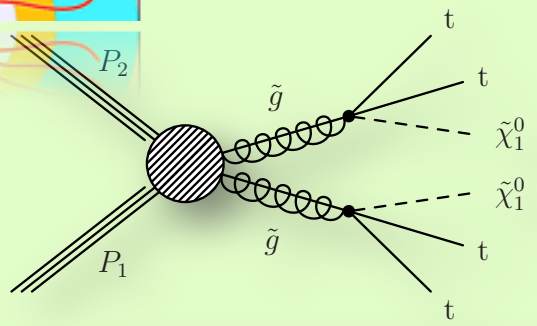
Courtesy Oliver Buchmueller, EPS 2013

CMSSM in context

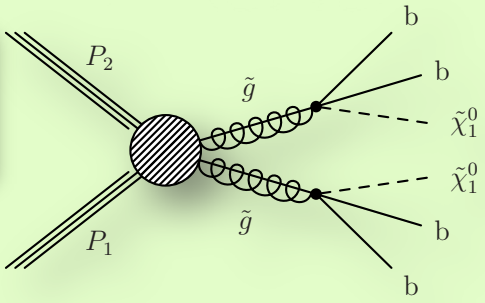


- LHC excludes squarks and gluinos > 1 TeV and > 1.8 TeV respectively in the CMSSM
  - But, this is only really probing a tiny part of a large parameter space

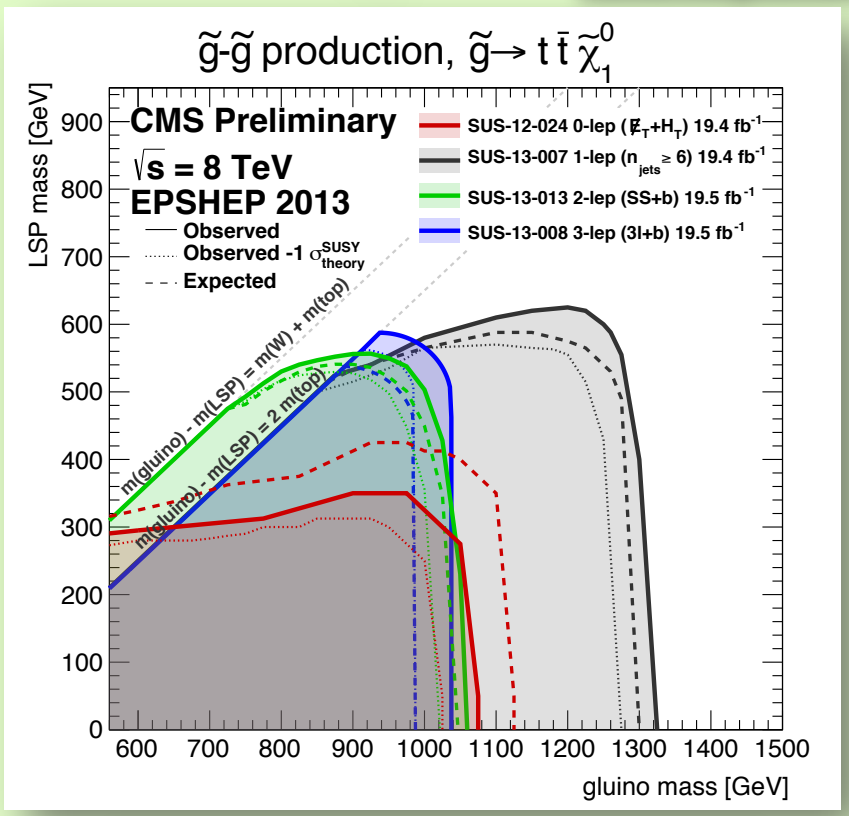
General SUSY searches: Simplified Model Spectra (SMS)



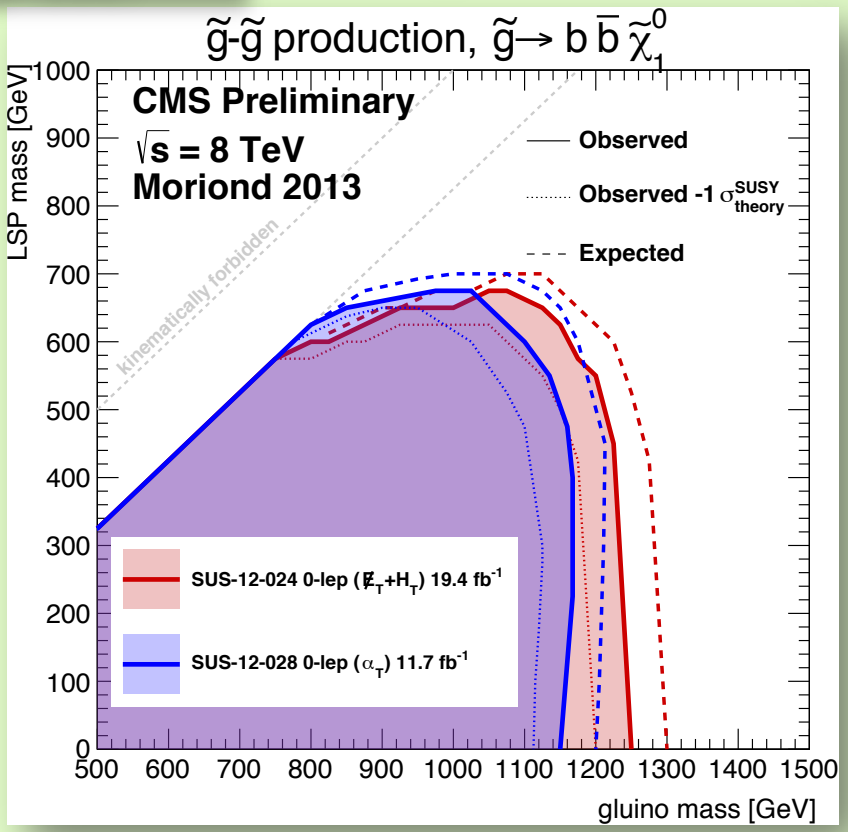
Gluinos decaying to stop or sbottom decaying to top or bottom + neutralino



Eliminating essentially all of the regions we can probe:



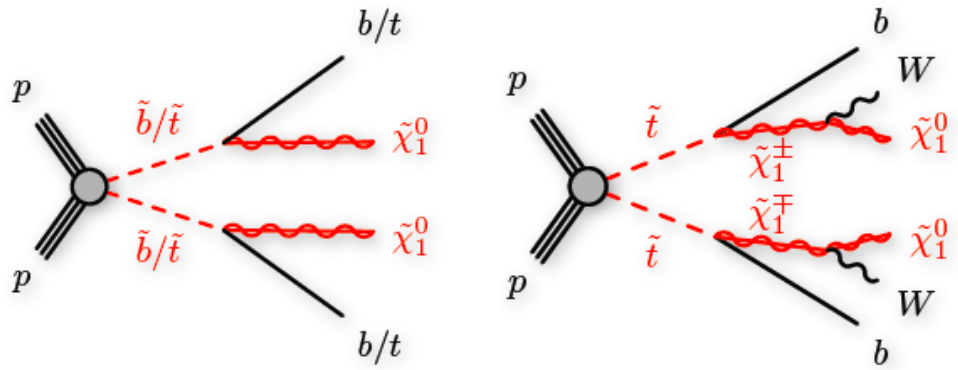
CMS PAS SUS-12-024, SUS-13-007
SUS-13-008, SUS-13-013



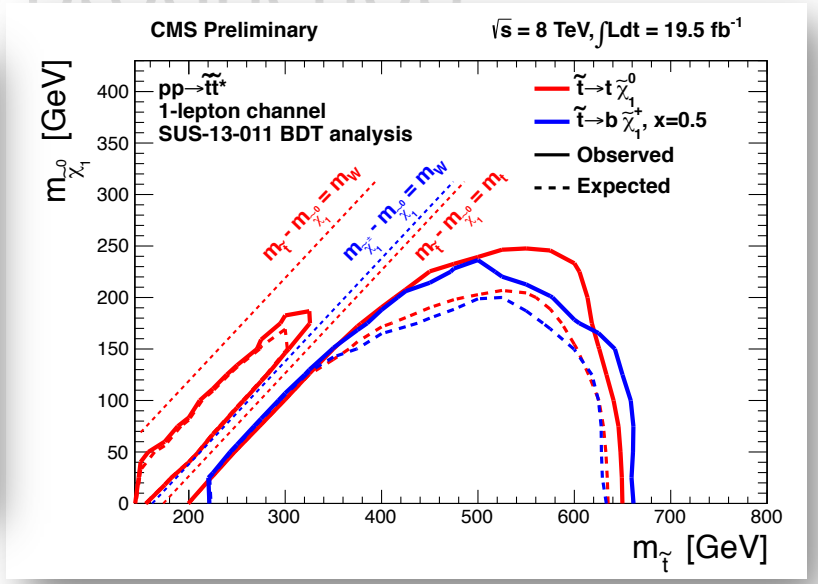
CMS PAS SUS-12-024, SUS-12-028

Direct 3rd generation production

Direct $\tilde{b}/\tilde{t}$ pair production

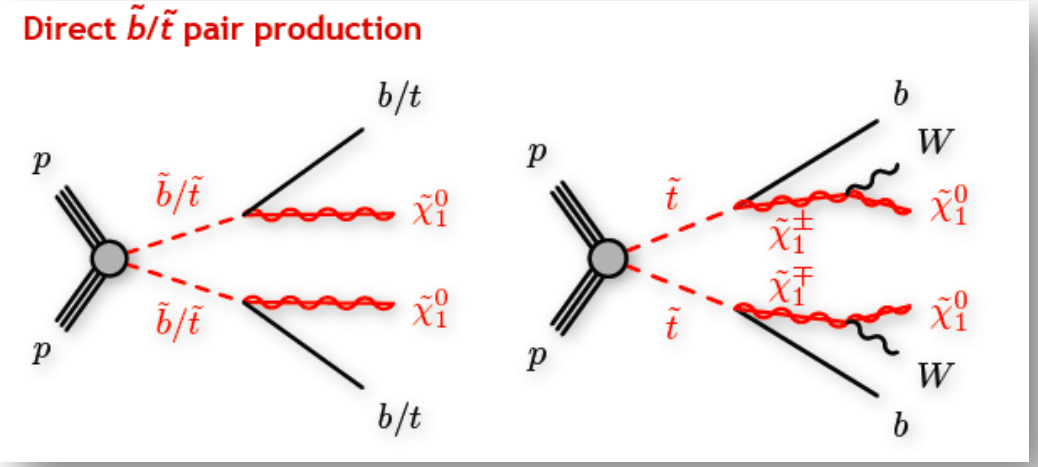


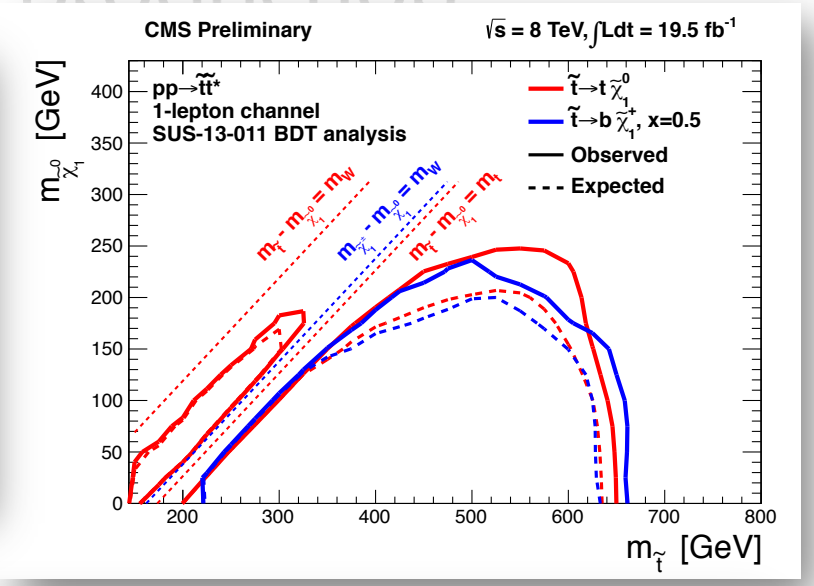
Sensitivity depends on mass hierarchy



SUS-13-007

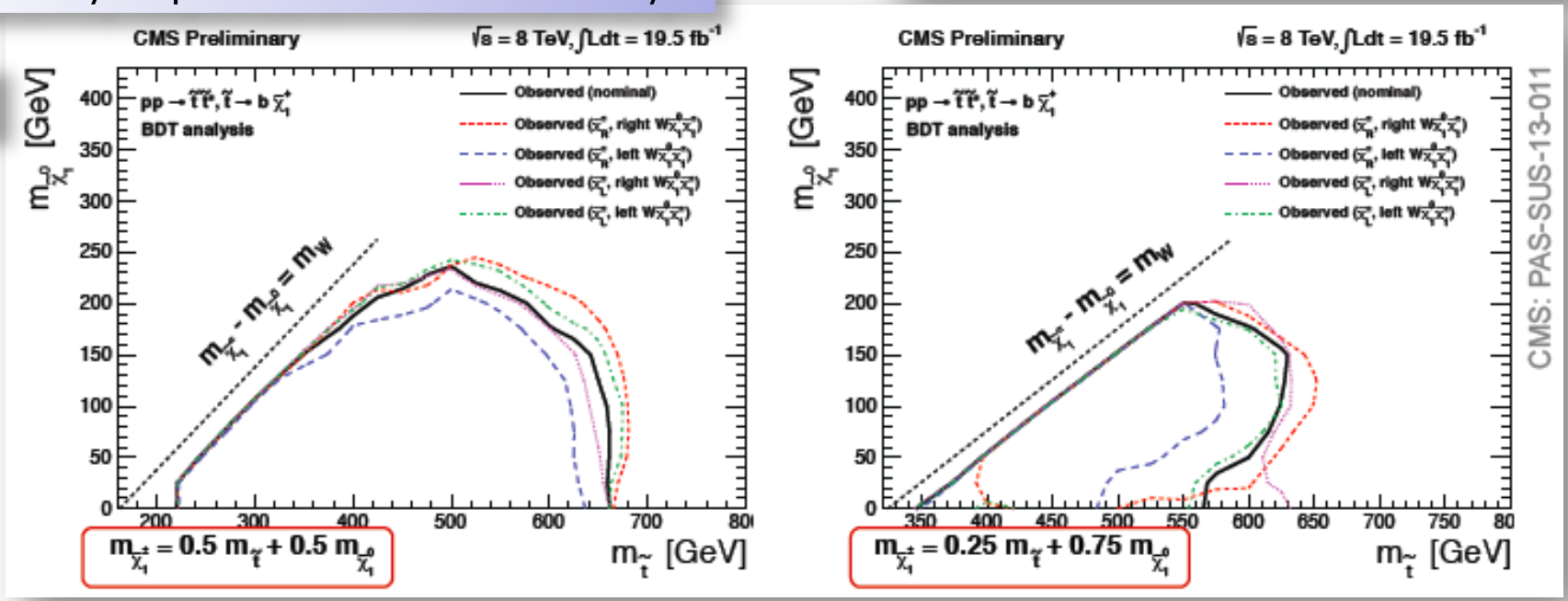
Direct 3rd generation production



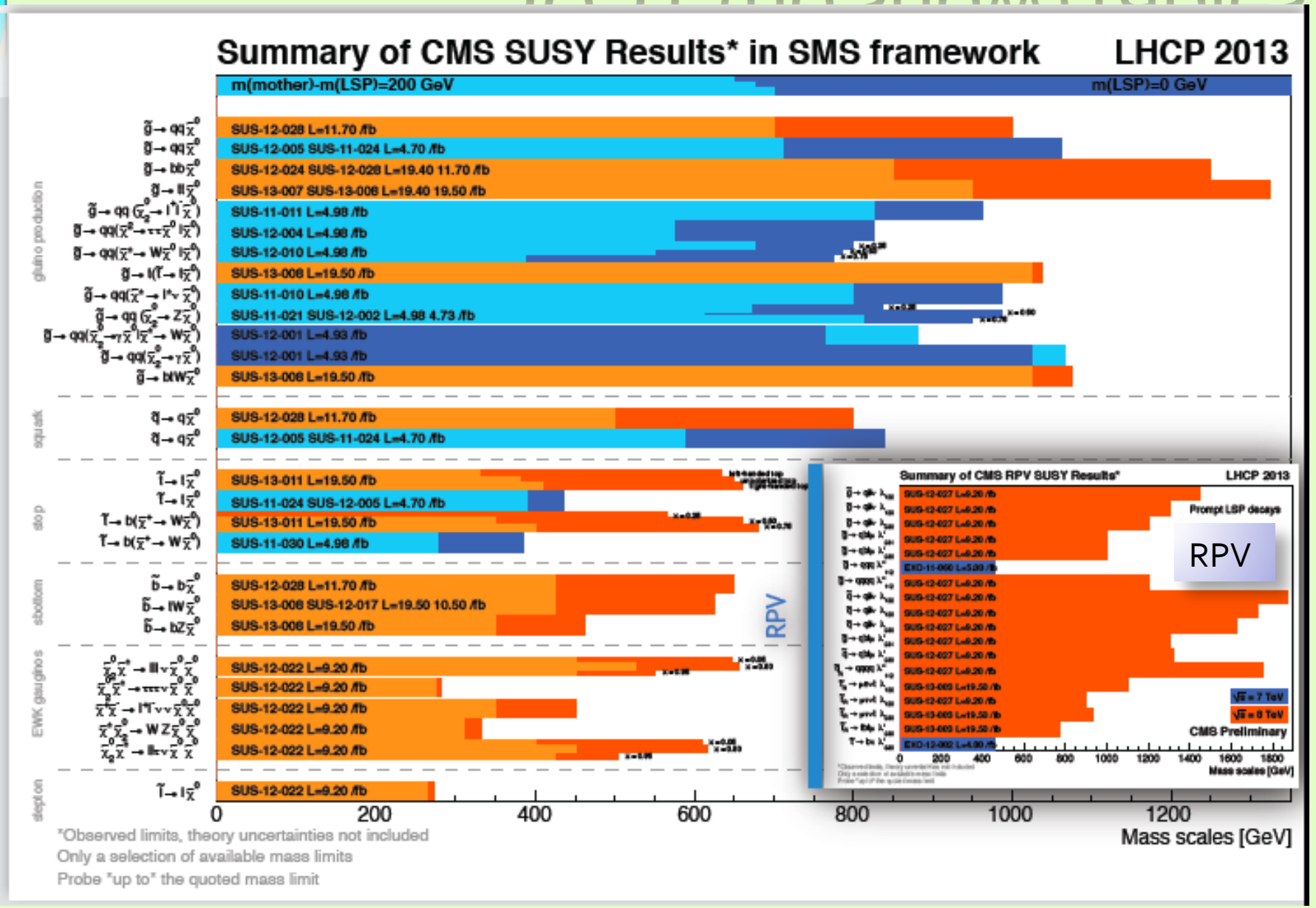


Sensitivity depends on mass hierarchy

SUS-13-007

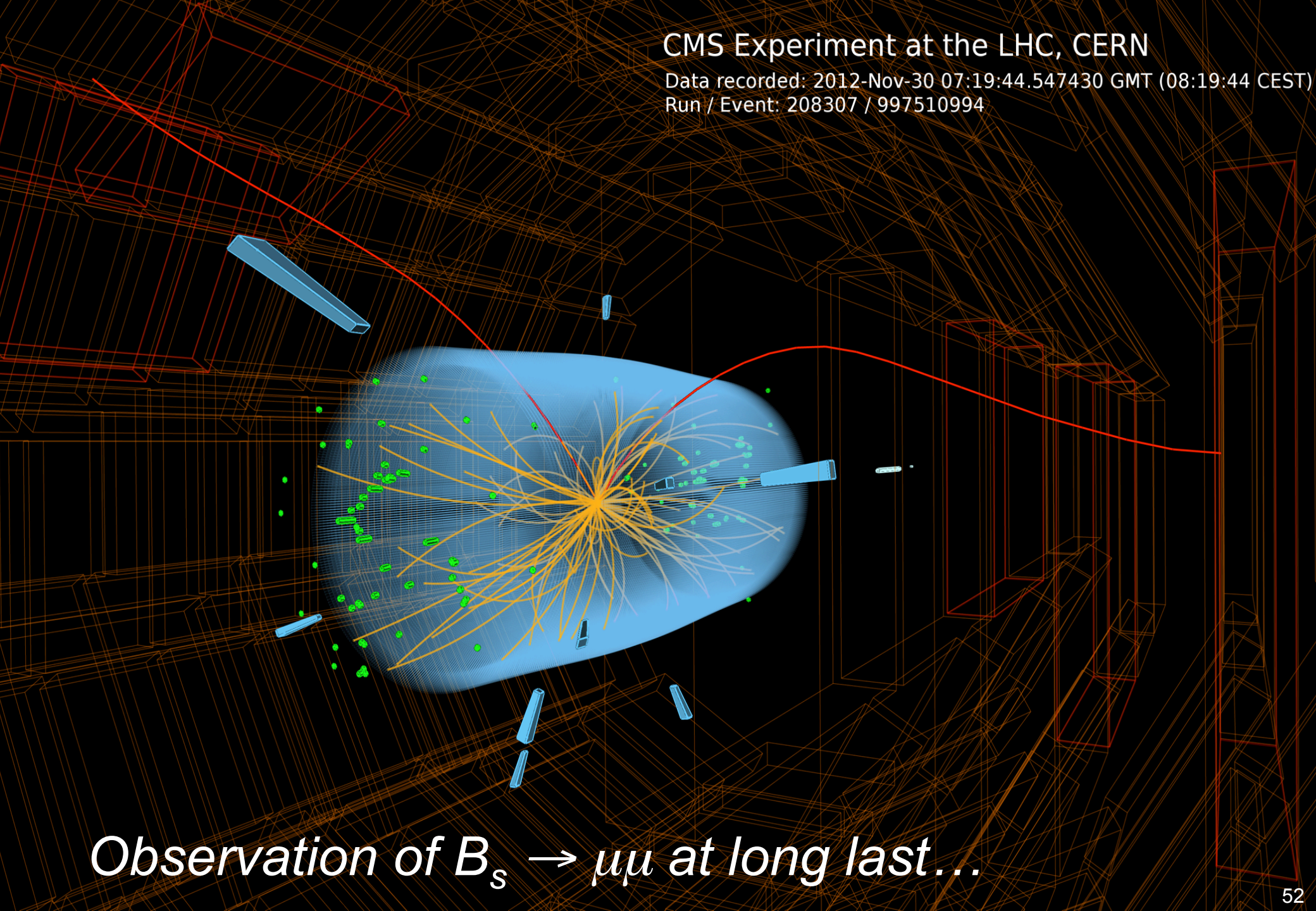


SUSY (no show) tables



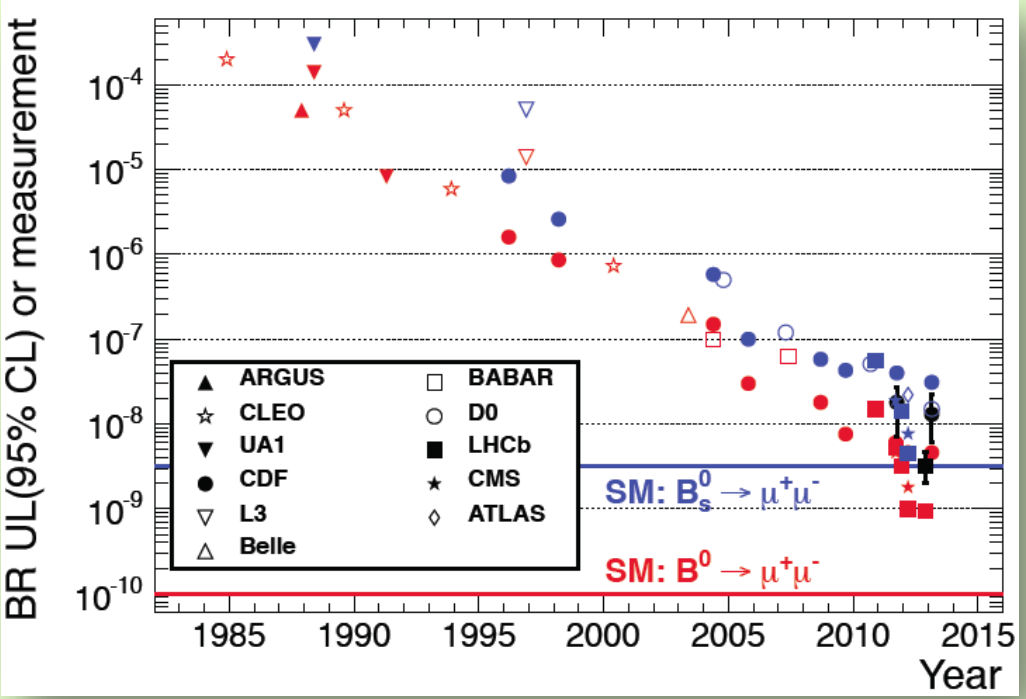
B Physics

Current Highlights



Observation of $B_s \rightarrow \mu\mu$ at long last…

30 years searching: $B_{d/s} \rightarrow \mu\mu$

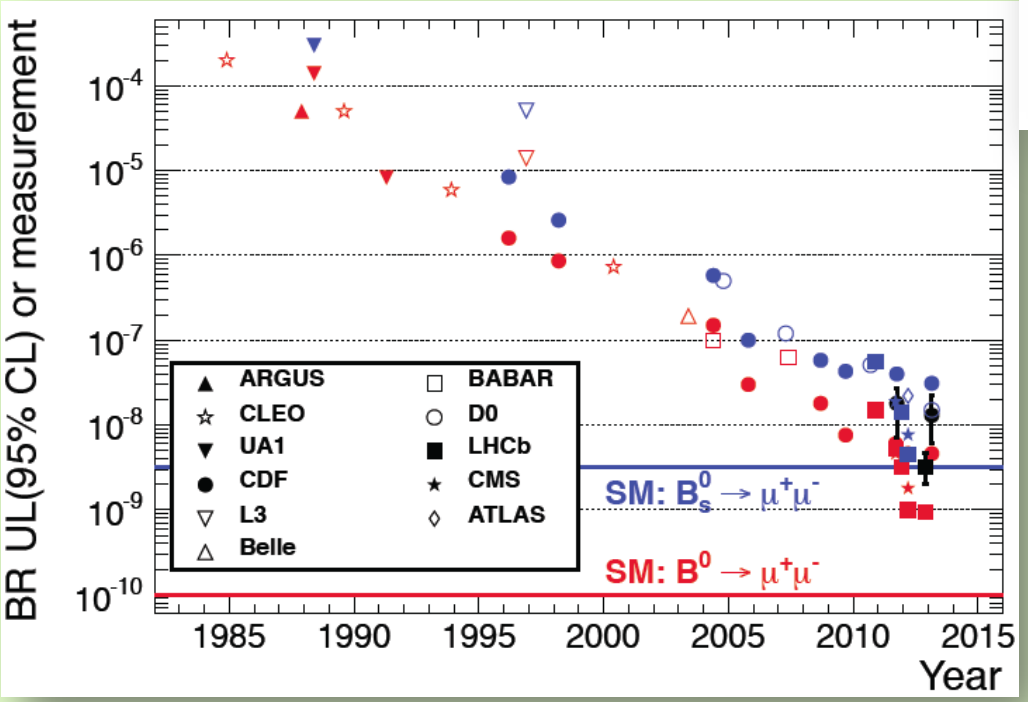


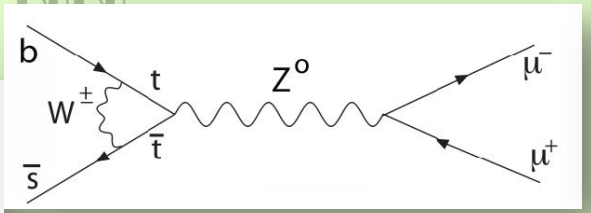
$$BR(B_S \rightarrow \mu\mu) = \left(3.2^{+1.4}_{-1.2}\ (\text{stat})^{+0.5}_{-0.3}\ (\text{syst})\right) \times 10^{-9}$$ LHCb 3.5 σ evidence

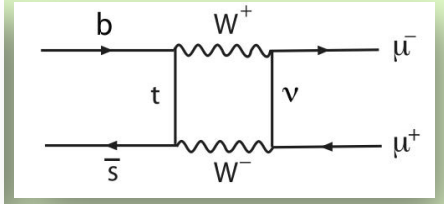
$$BR(B_d \rightarrow \mu\mu) < 8.4 \times 10^{-10}\ @95\%\ \text{CL}$$ ATLAS+CMS+LHCb best upper limit on $B_d \rightarrow \mu\mu$

Ca. Moriond 2013

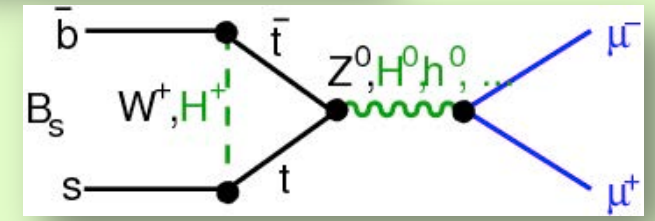
30 years searching: $B_{d/s} \rightarrow \mu\mu$

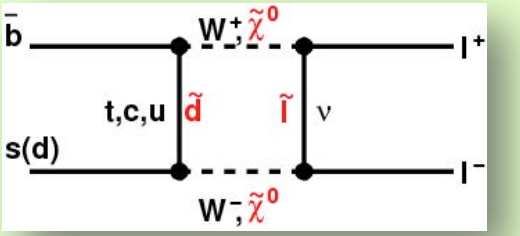






- $BR(B_s \rightarrow \mu\mu) = (3.56 \pm 0.18) \times 10^{-9}$
  - SM time integrated
- Forbidden at tree level
- Helicity suppressed
  - *Cabibbo enhancement of $B_s \rightarrow \mu\mu$ over $B_d \rightarrow \mu\mu$ since $|V_{td}| < |V_{ts}|$*
  - A good place to look for enhancements from new physics via loop/box contributions



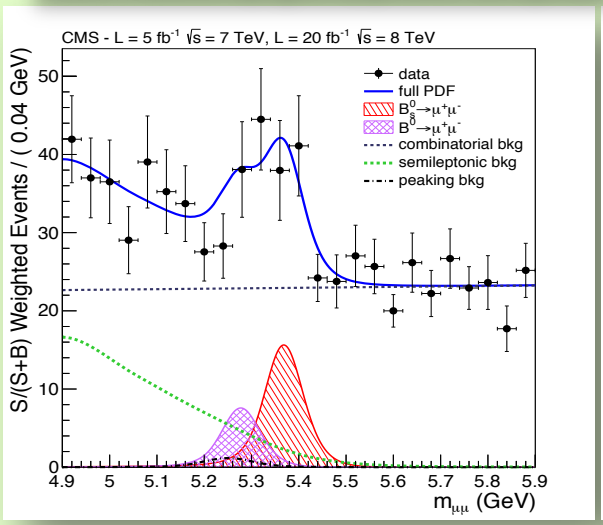


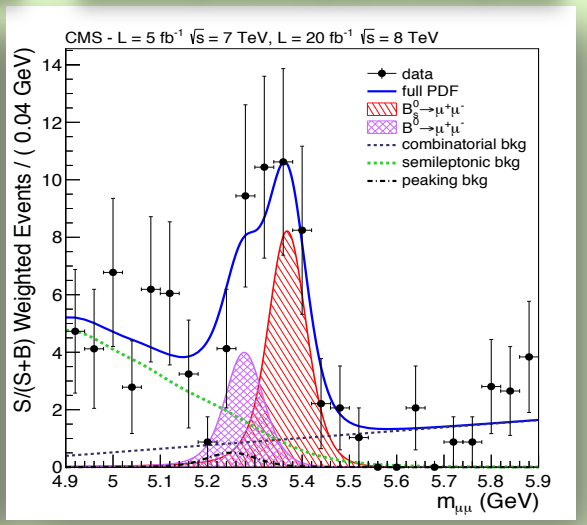
$B_{d/s}(\mu\mu)$ Results

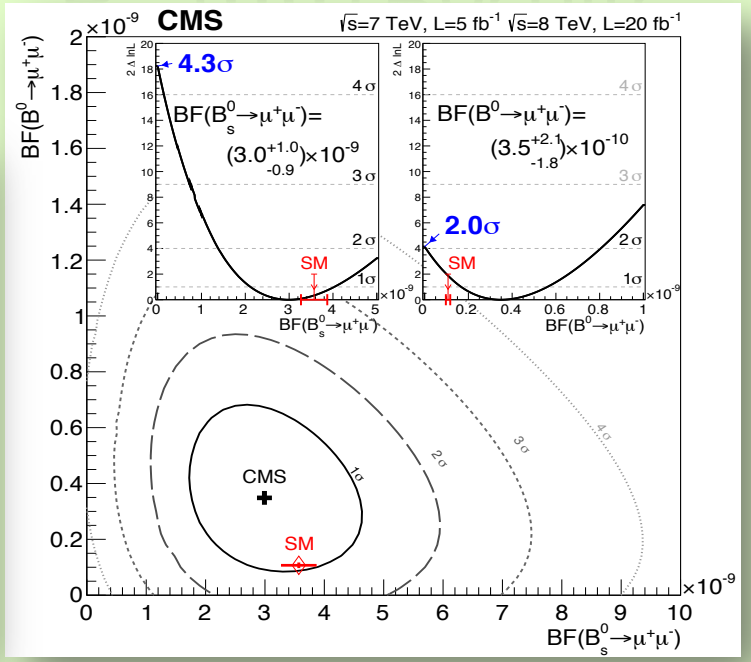
arXiv:1307.5025, PRL

1D+cat: 4.3σ (4.8σ exp.)

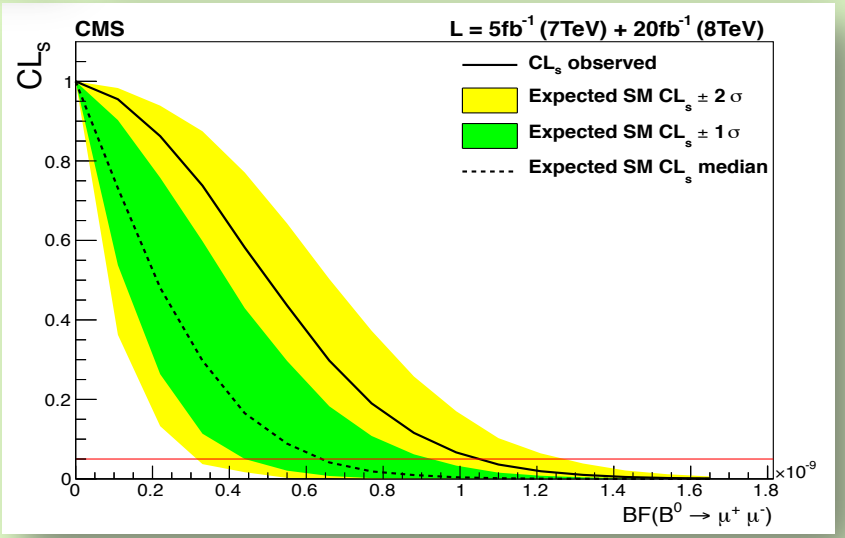
1D: 4.8σ (4.7σ exp.)







- The results:
  - $B(B_s \to \mu\mu) = (3.0^{+1.0}_{-0.9}) \times 10^{-9}$
  - $B(B_d \to \mu\mu) < 1.1 \times 10^{-9}$ (9.2×10^{-10})
    - $B(B_d \to \mu\mu) = (3.5^{+2.1}_{-1.8}) \times 10^{-10}$
    - Significance ~2σ



Combination for an Observation

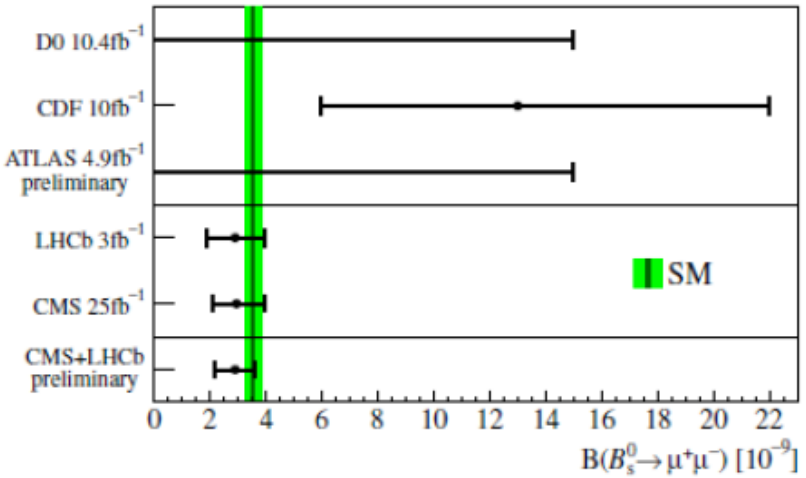
BPH-13-007
LHCb-CONF-2013-012

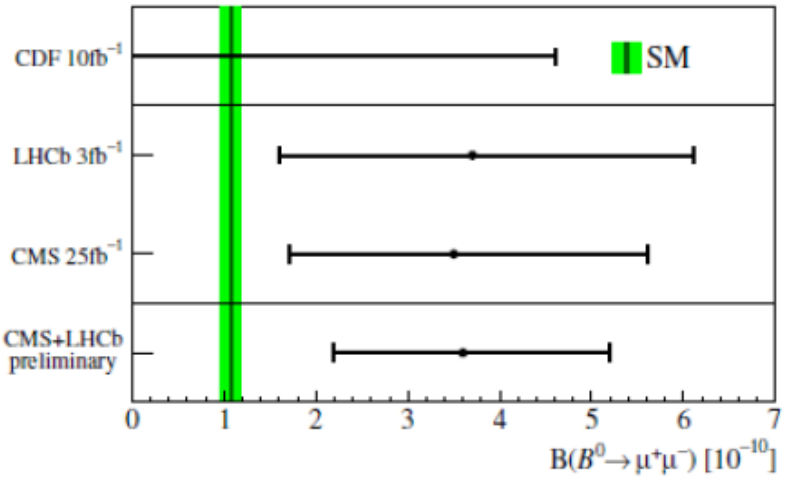
- Several methods used, giving compatible results
- Method based on pseudo experiments, modelling distribution with variable-width Gaussian function (suggested by R. Barlow arXiv:physics/0406120):

preliminary

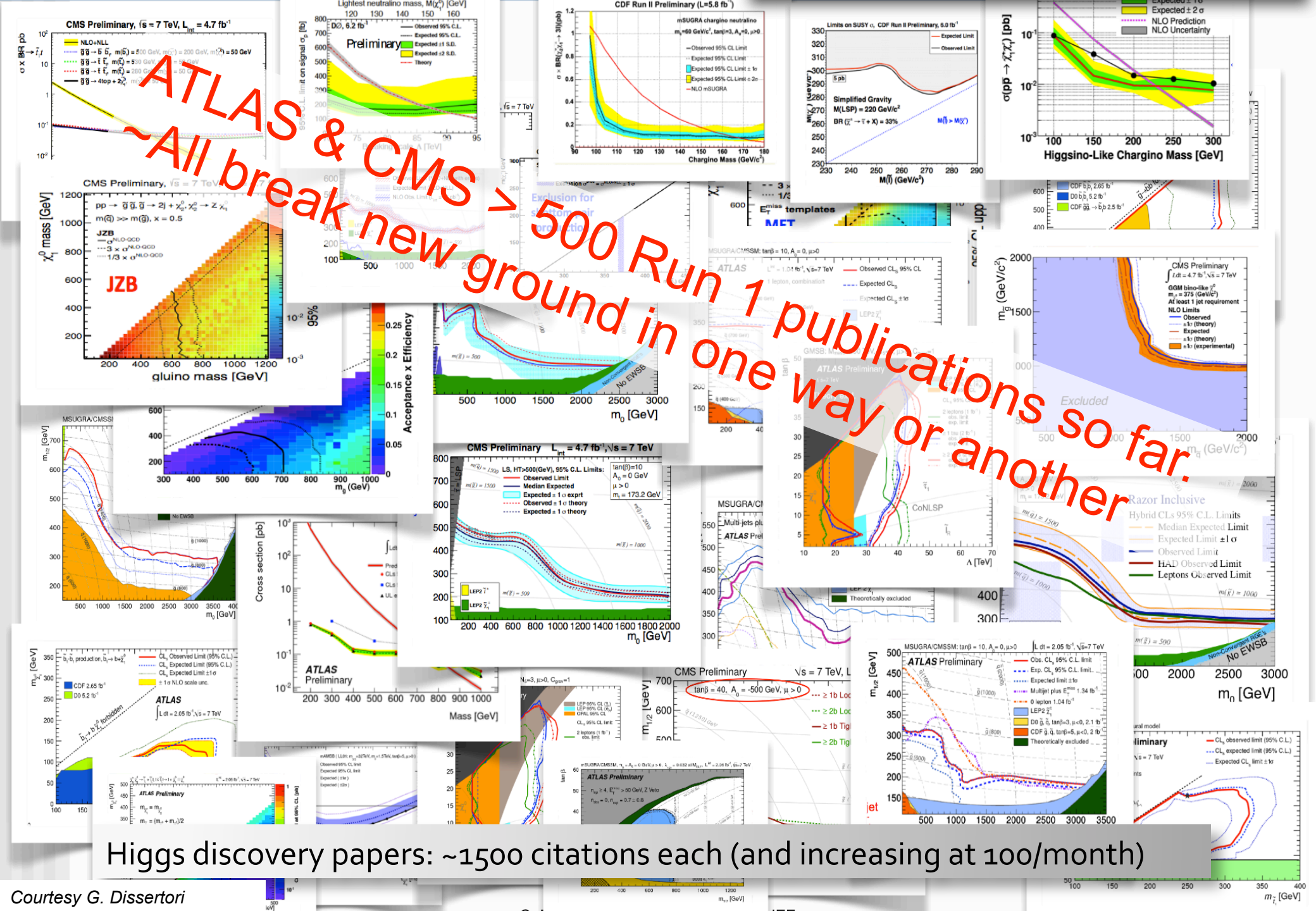
$$BR(B_S^0 \to \mu^+\mu^-) = (2.9 \pm 0.7) \times 10^{-9}$$ Observation!!

$$BR(B^0 \to \mu^+\mu^-) = (3.6^{+1.6}_{-1.4}) \times 10^{-10}$$ Not statistically significant



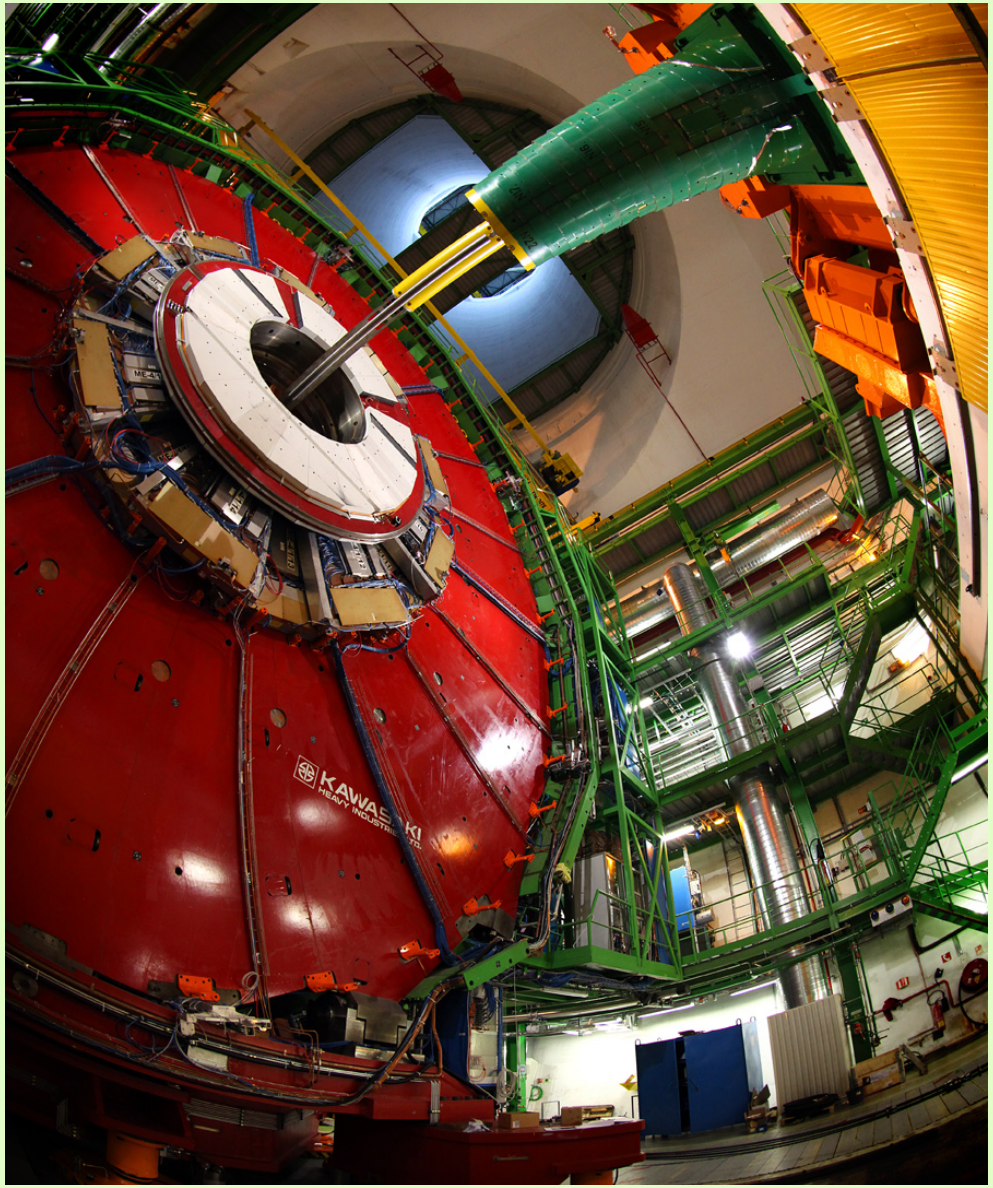


Courtesy of Justine Serrano (LHCb CERN Seminar August 6, 2013)


ATLAS & CMS > 500 Run 1 publications so far.
~All break new ground in one way or another
Higgs discovery papers: ~1500 citations each (and increasing at 100/month)
Courtesy G. Dissertori

What's next?

- Run 1 has been a success
  - More results to come this year
- Run 2 and beyond
  - Extend searches and precision measurements significantly
- Lots more to come…
  - The LHC is a Higgs (and top, W, Z …) factory, superb for precision measurements and for uncovering rare physics




CMS
June 2013 - photo by
Michael.Hoch@CERN.ch

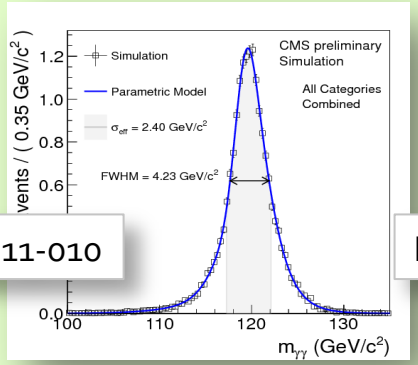

The End

ECAL response and m(γγ) resolution

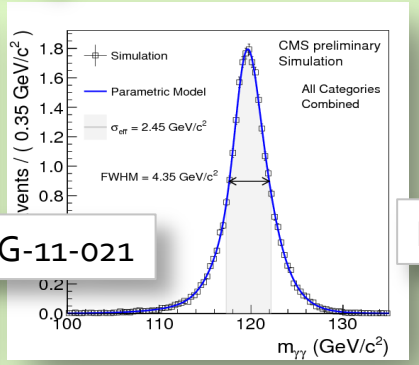
7 TeV: 25% improvement over one year

EPS – Jul 2011	LP – Aug 2011	Moriond – Feb 2012	ICHEP – Jul 2012
FWHM = **4.23 () GeV**	**4.35 GeV**	**3.29 GeV**	**3.2 GeV (σ~1.3 GeV)**

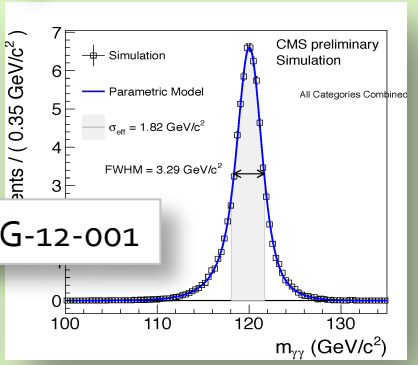
HIG-11-010



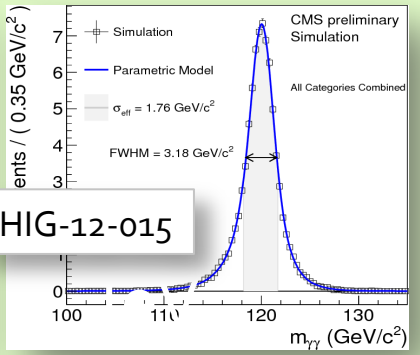
HIG-11-021



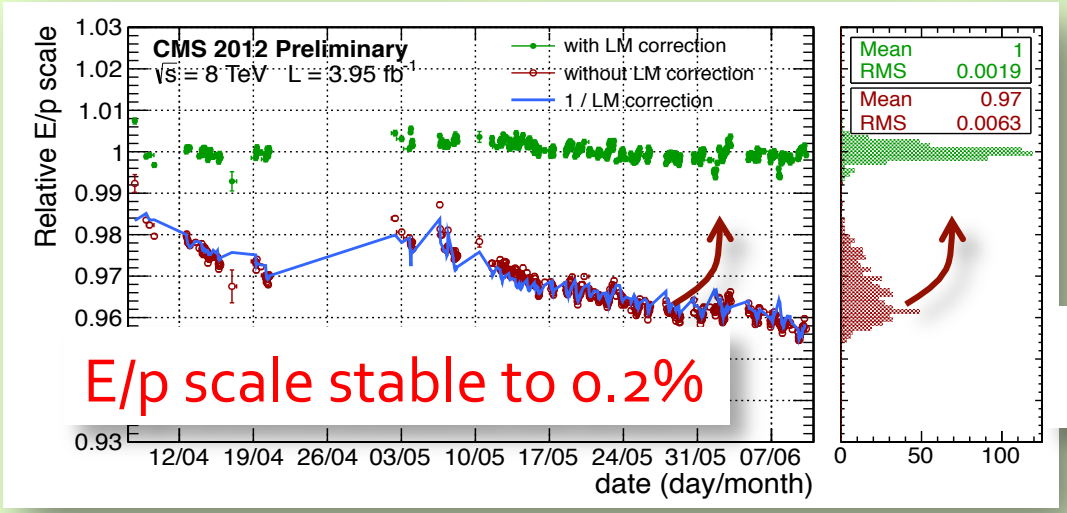
HIG-12-001



HIG-12-015

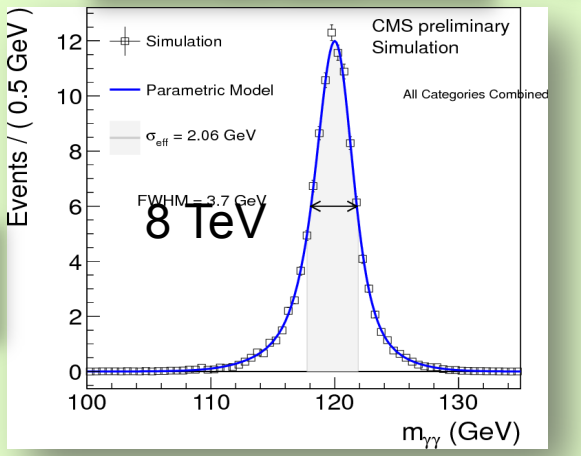


Even better performance



CMS-DP-2012-015

3.7 GeV

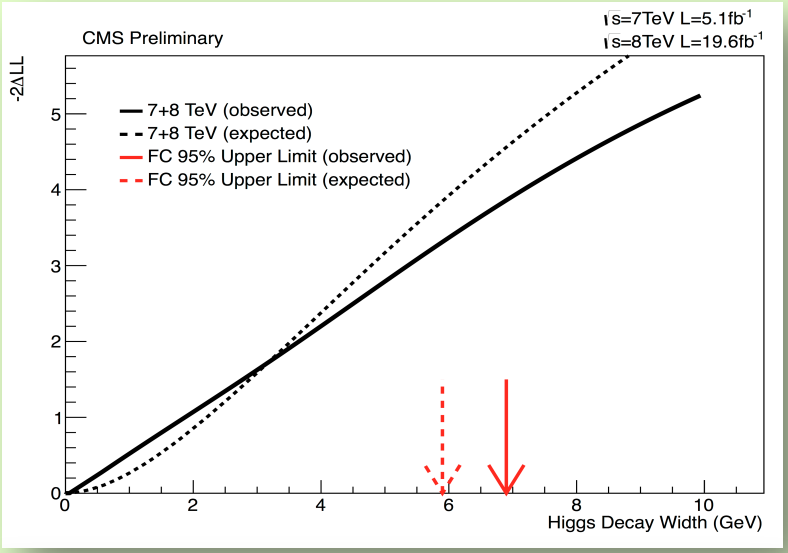


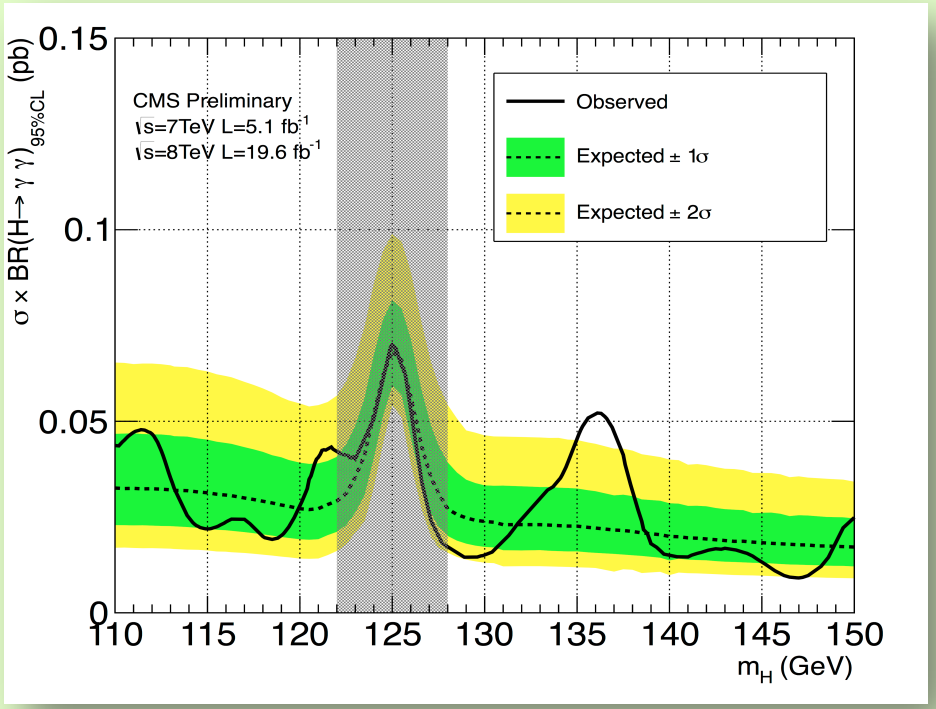
Laser calibration: Automated 48-hour calib. loop.

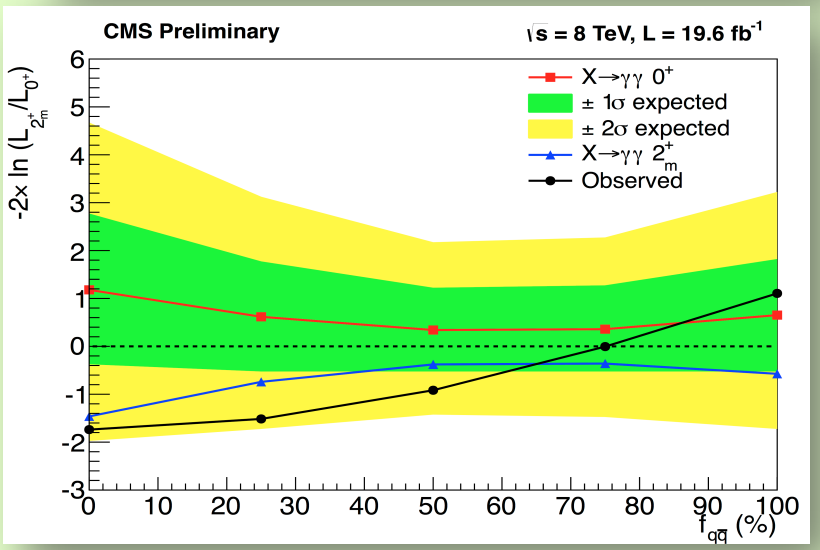
Higgs Properties in H(γγ)

HIG-13-016

- H(γγ) analyses are used to
  - Look for additional Higgs'
  - Set a limit on the Higgs width
  - Study the Higgs spin-parity

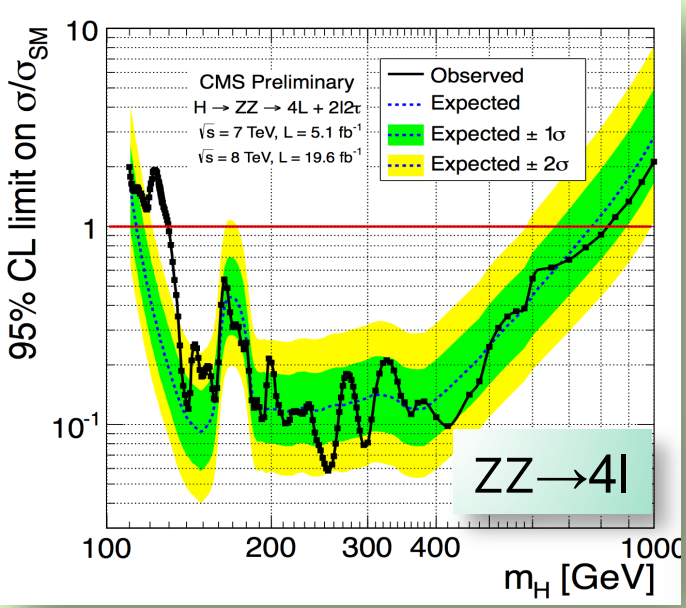


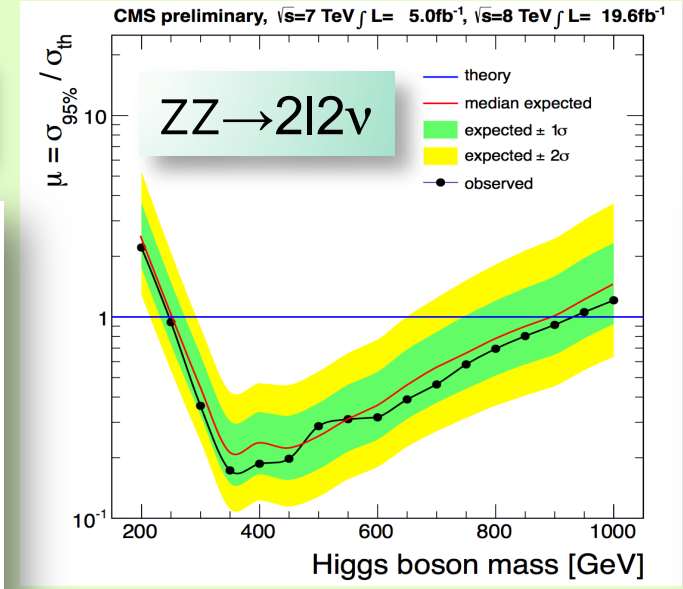


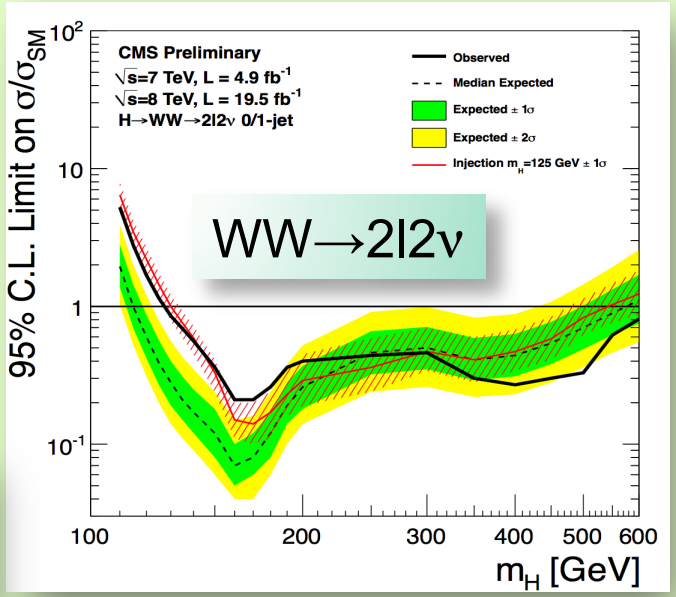


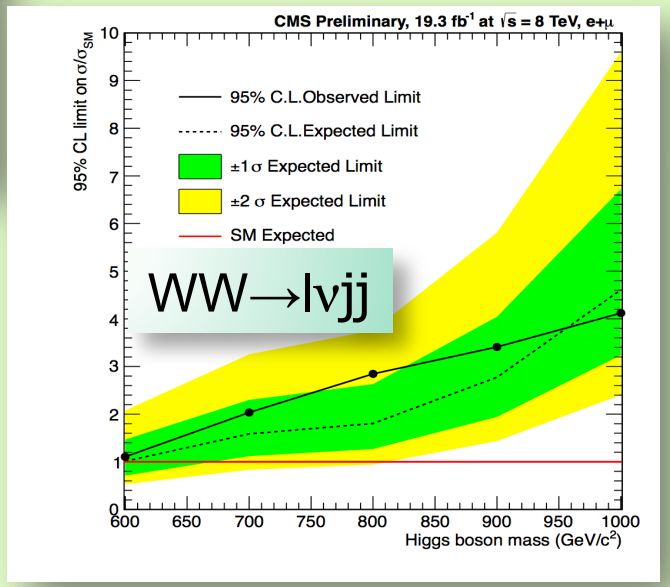
High Mass Higgs Searches

Sensitivity to ~ 1 TeV









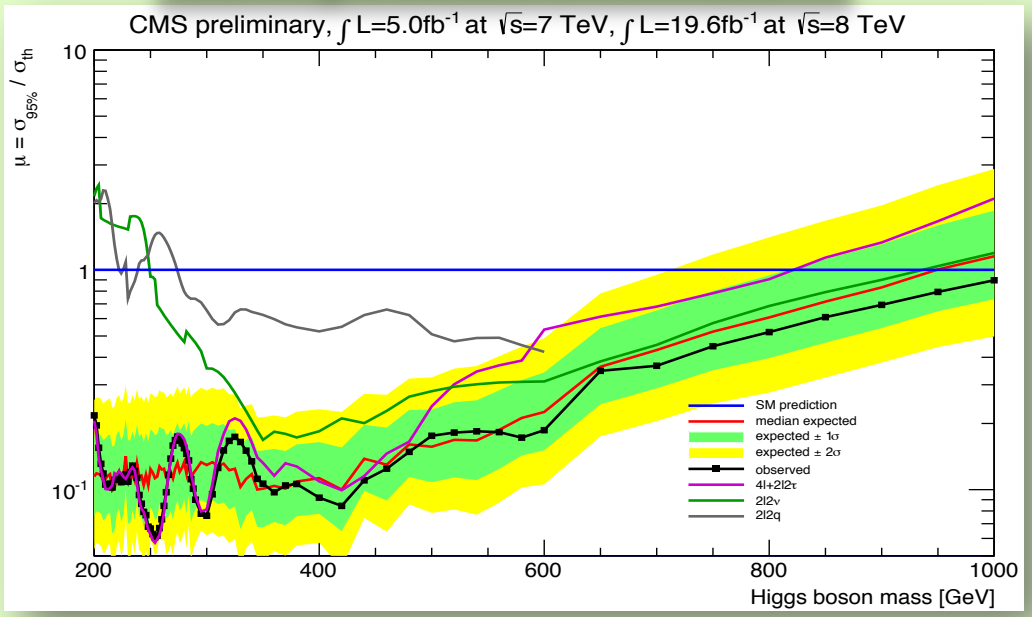
Interpretation of data in EW-singlet models and LHC XS WG benchmark models:

CMS-PAS-HIG-13-008

CMS-PAS-HIG-13-014

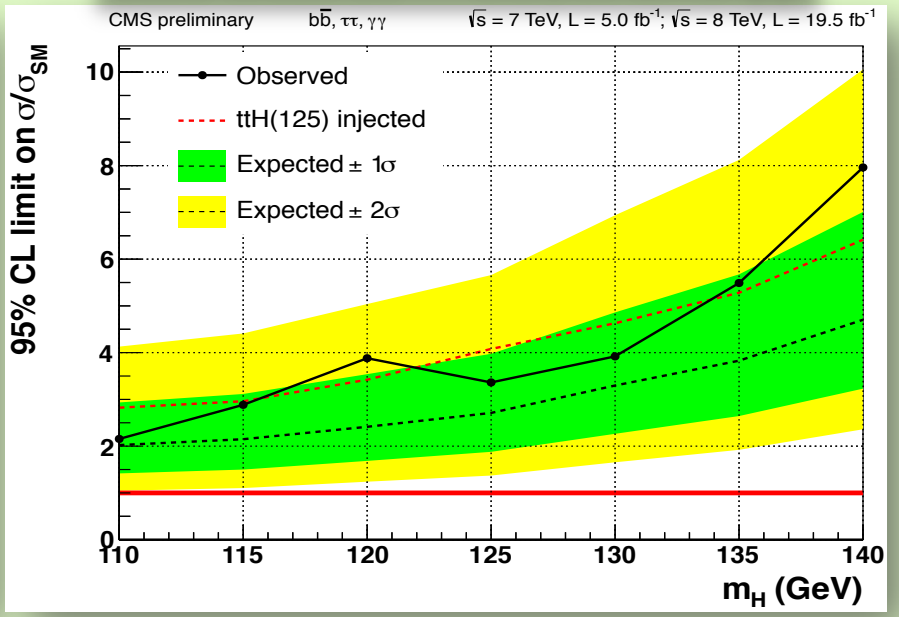
New mini-combinations

ZZ high mass channels



HIG-12-024
HIG-13-002
HIG-13-014

$t\bar{t}H$ with $H \to b\bar{b}$, $t\bar{t}$ and $\gamma\gamma$

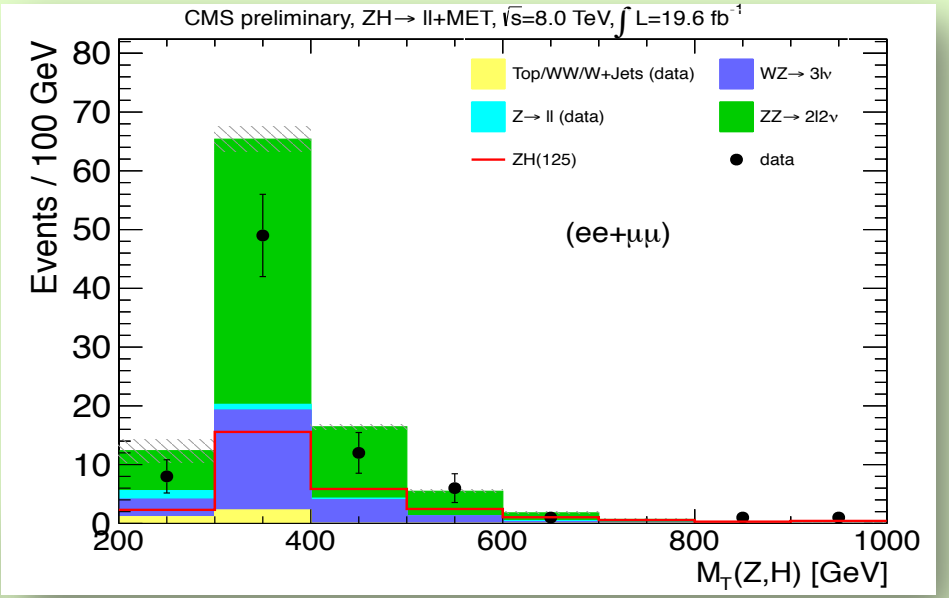


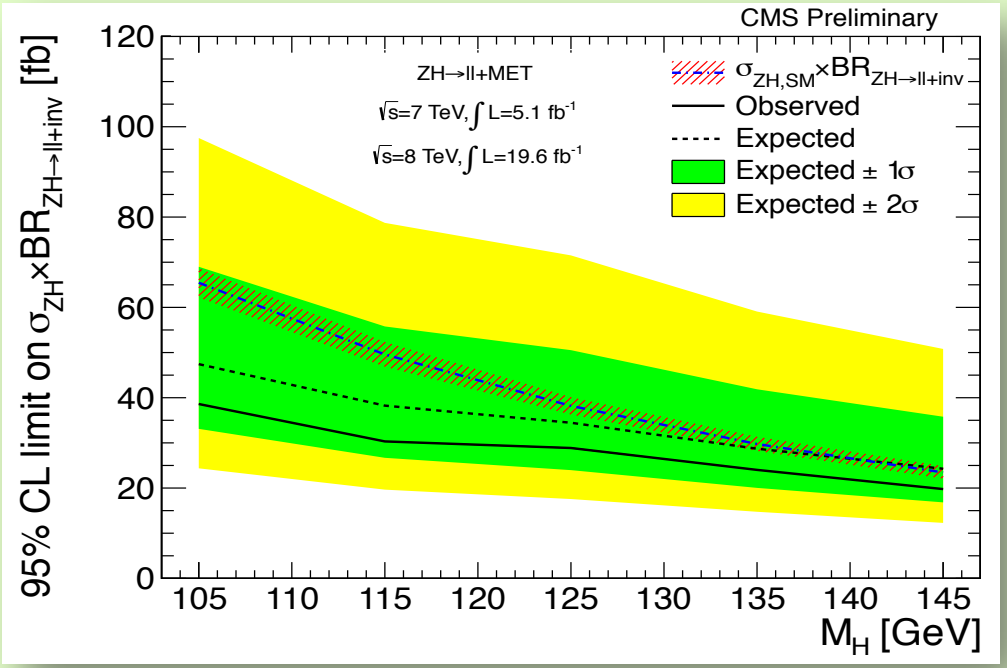
HIG-12-015
HIG-13-019
arXiv:1303.0763

More channels under study – reported soon

Invisible Higgs

- New ZH analysis
  - Z decaying leptonically and Higgs decaying invisibly
  - Use transverse mass as the discriminating variable
  - CMS (5+20 fb^{-1}):
    - **Br(H→χχ) < 75%** (91% exp.) @ 95% CL, m_H = 125 GeV

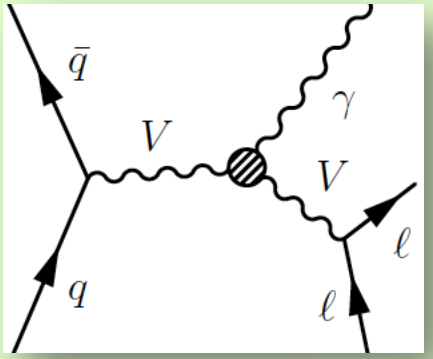


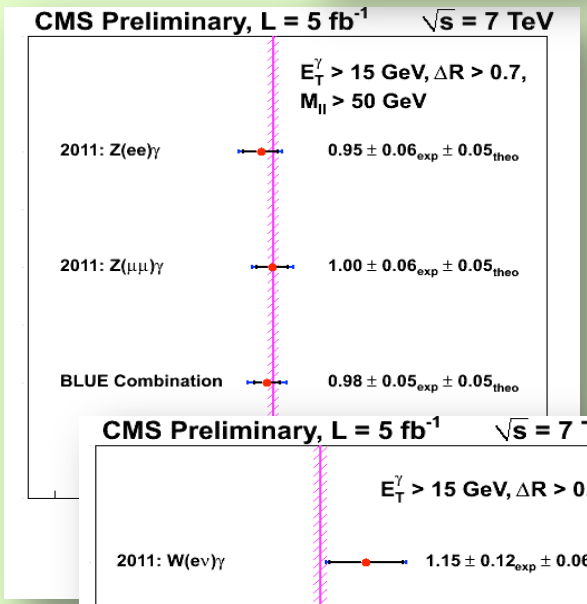


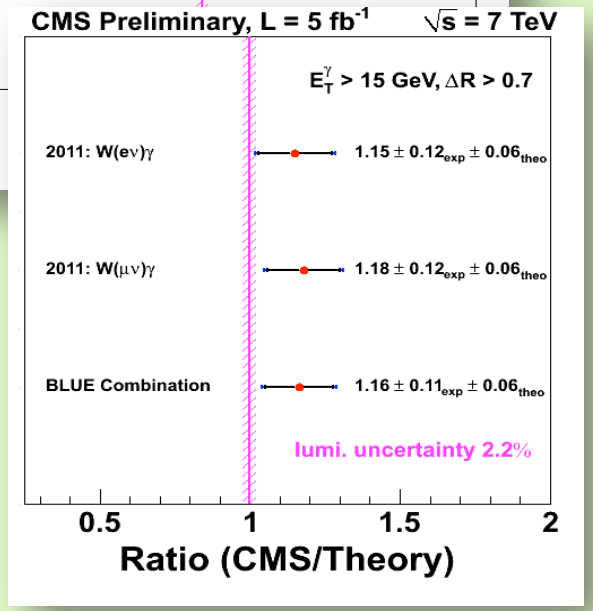
HIG-13-018

Triple Gauge Couplings

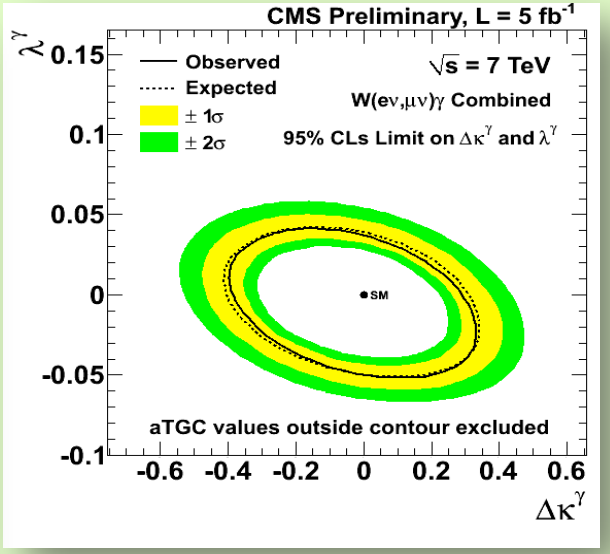
- Precision measurement of Wγ and Zγ production cross section and
  - Most stringent limits on anomalous WWγ and Zγγ couplings to date

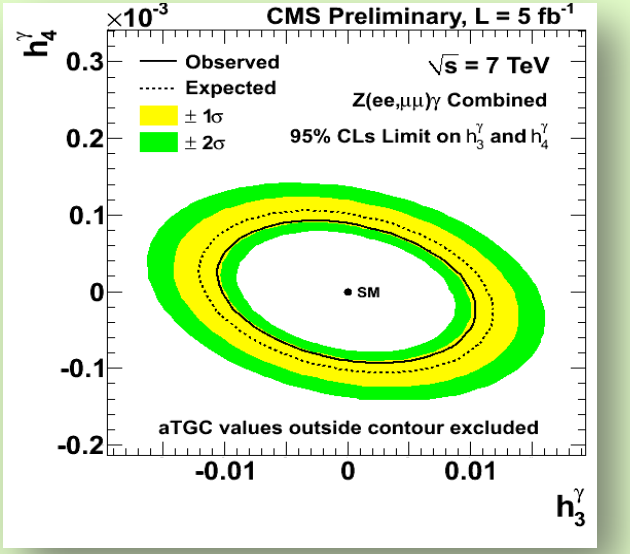






Coupling	95% CL Limit	95% CL Limit
WWγ	$-0.38 < k_\gamma < 0.29$	$-0.050 < \lambda_\gamma < 0.037$
Zγγ	$-0.010 < h_3^\gamma < 0.010$	$\lvert h_4^\gamma \rvert < 8.8\times10^{-5}$
ZZγ	$-0.0086 < h_3^Z < 0.0084$	$-8.0\times10^{-5} < h_4^Z < 7.9\times10^{-5}$





EWK-11-009

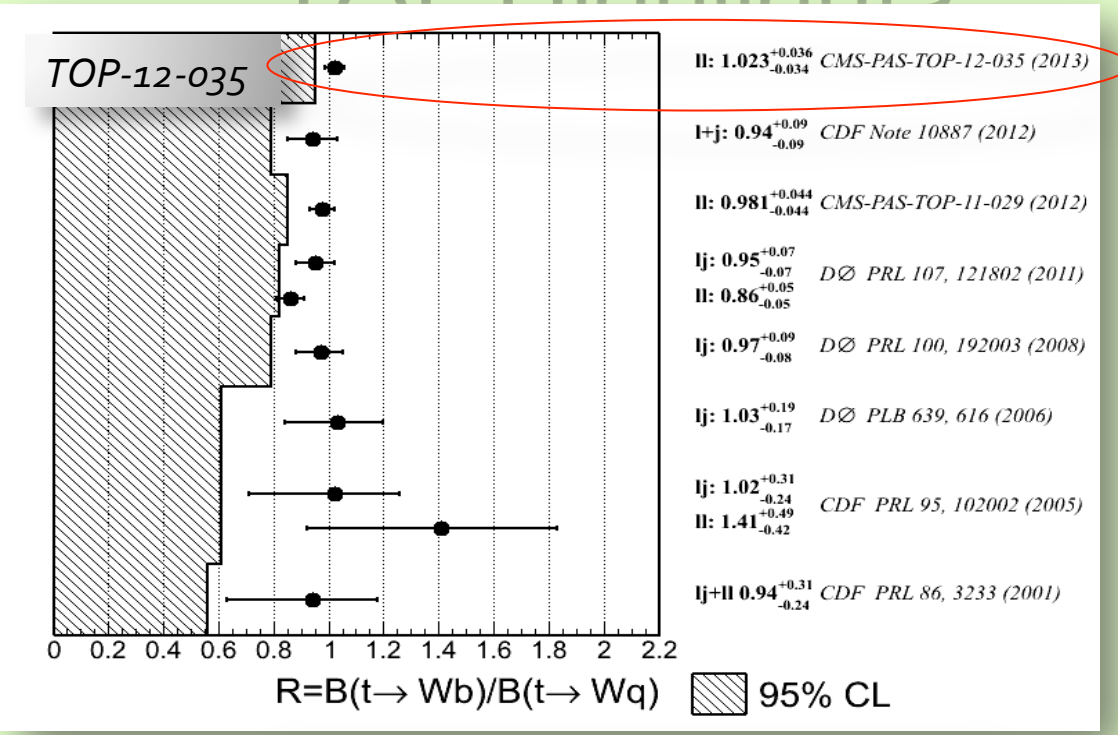
TOP Highlights

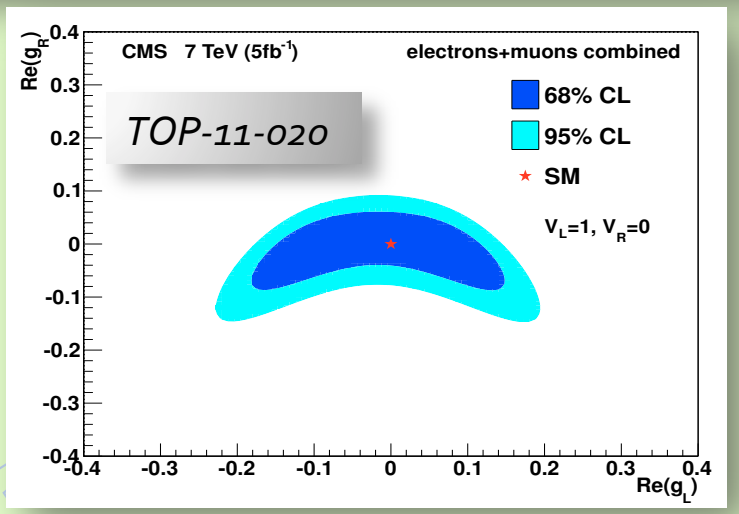
- R=Br(t→Wb)/Br(t→Wq)
  - R = 1.023 +0.036 –0.034

- Search for FCNC t→Zq:
  - Br(t →Zq) < 0.07% @ 95% CL

TOP-12-037

- New W helicity
  - In single-top and $t\bar{t}$ dileptons





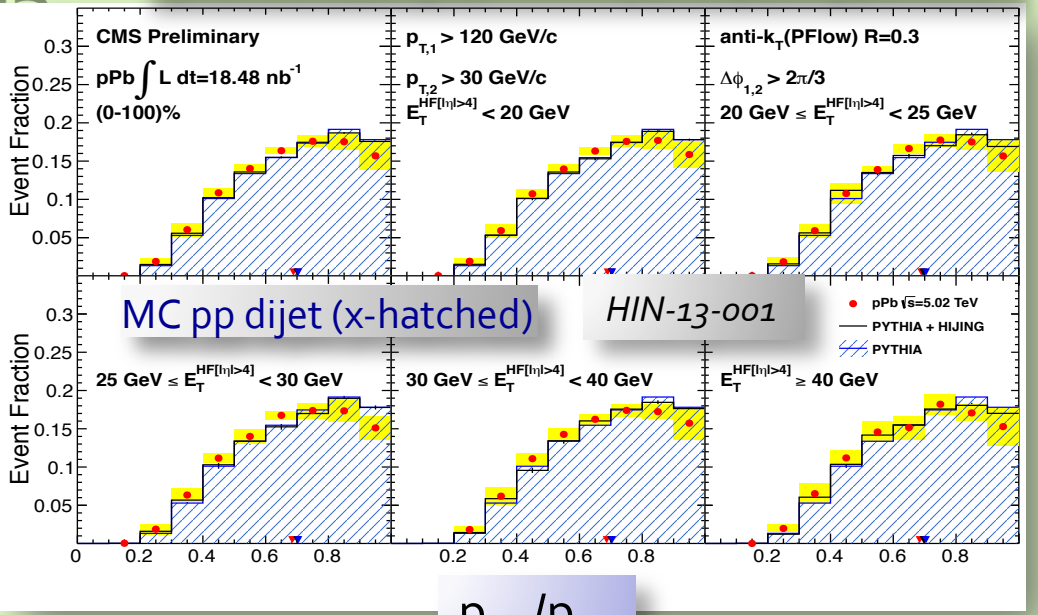
Heavy Ions

Current Highlights

Jets in pPb Collisions

pPb: increasing $E_T^{HF(\eta>4)}$ ~ participating partons

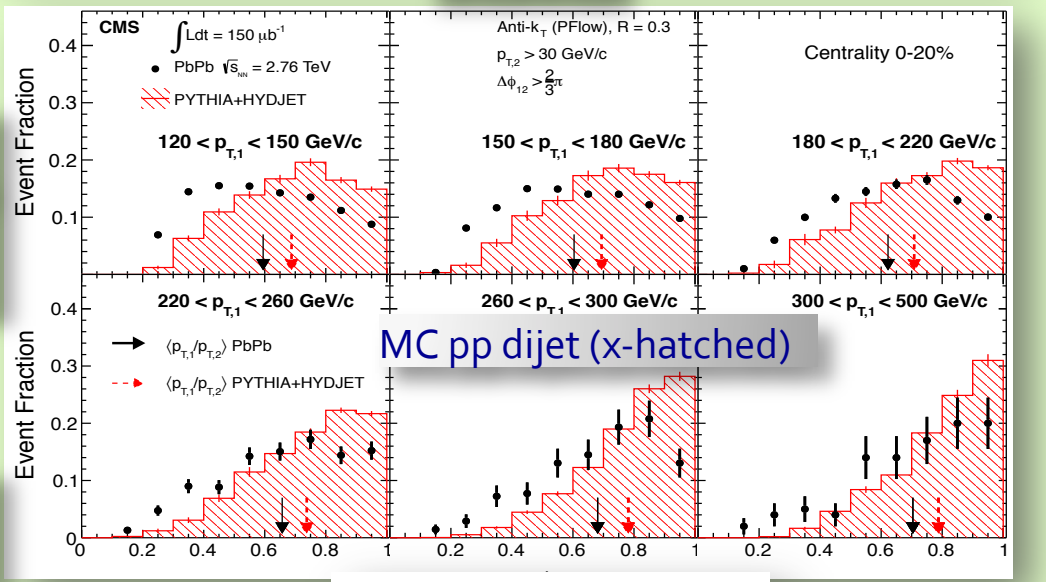
- No jet quenching in pPb
  - Supports idea of quenching as due to interactions with a hot dense 'partonic medium', rather than initial state or flow effects



MC pp dijet (x-hatched)

HIN-13-001

$p_{T,2}/p_{T,1}$



PbPb: Dijet asymmetry A_J 0-20% centrality, bins of increasing $p_{T,1}$

MC pp dijet (x-hatched)

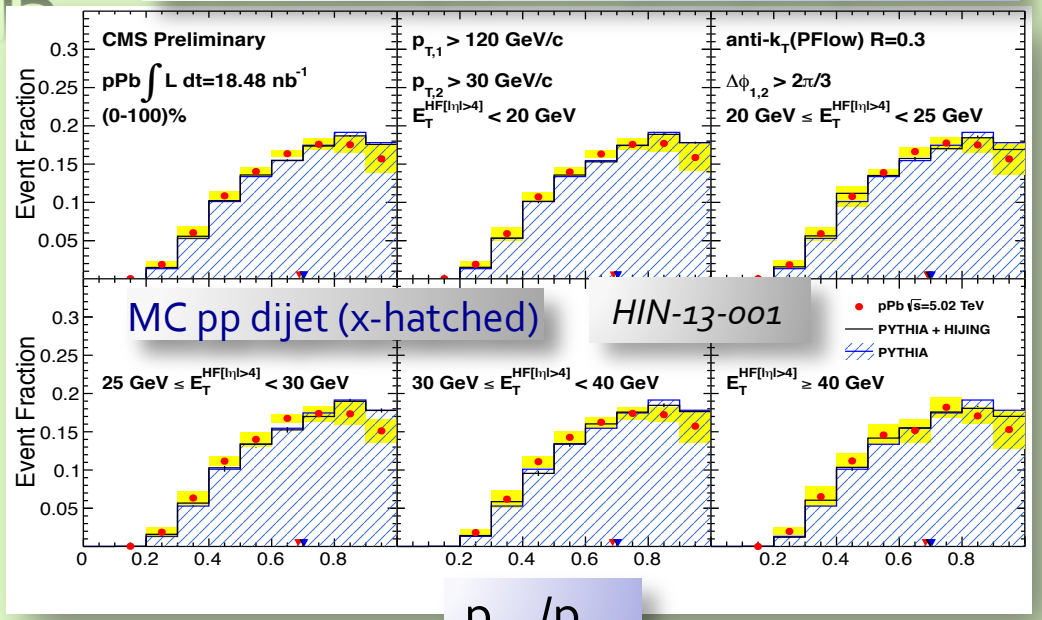
HIN-11-013
arXiv:1202.5022

$A_J = (p_{T,1}-p_{T,2})/(p_{T,1}+p_{T,2})$

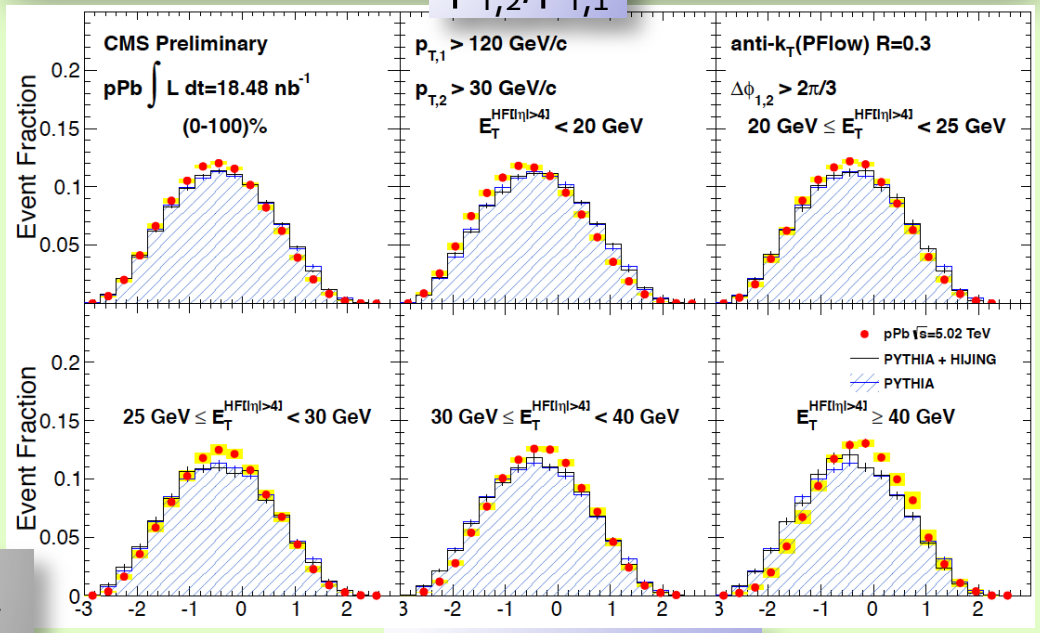
Jets in pPb Collisions

pPb: increasing $E_T^{HF(\eta>4)}$ ~ participating partons

- No jet quenching in pPb
  - Supports idea of quenching as due to interactions with a hot dense 'partonic medium', rather than initial state or flow effects
- Dijet η
  - Correlated with Feynman x in the Pb nucleus
  - Sensitive to nuclear PDF



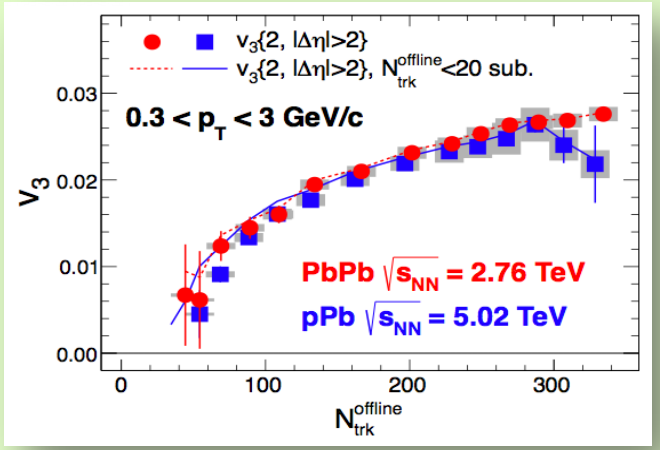
$p_{T,2}/p_{T,1}$



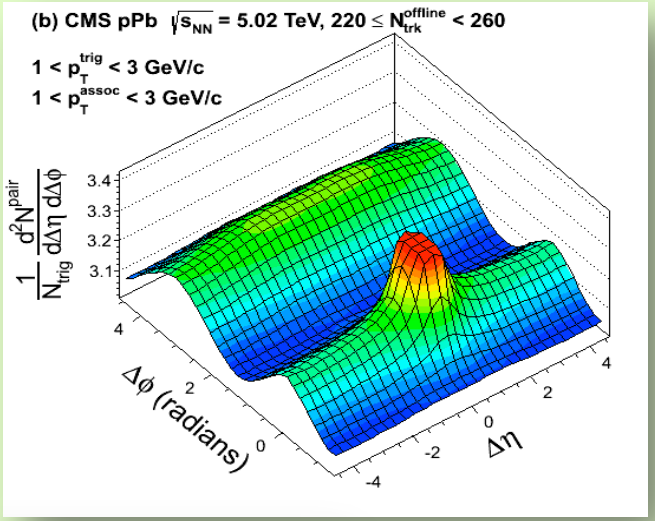
η Dijet = (η1+η2)/2

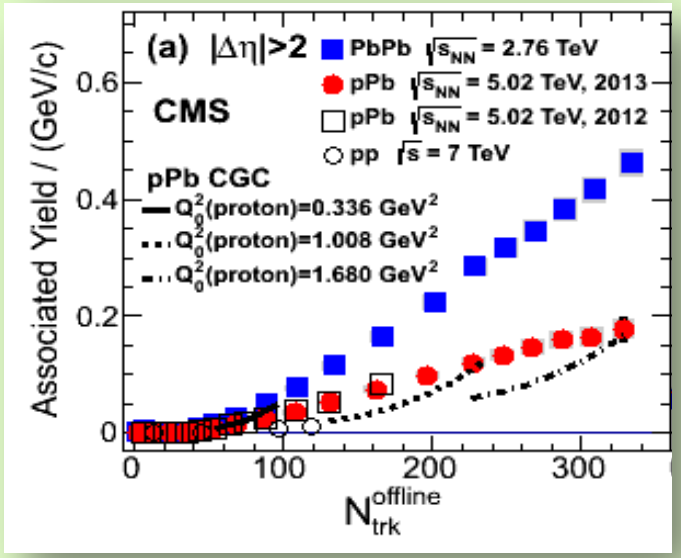
Ridge in High-Multiplicity pPb

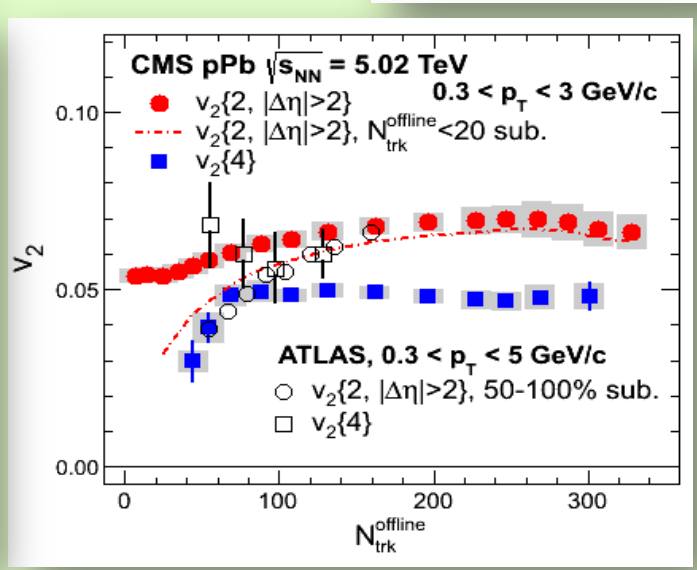
- 2 and 4-particle correlations and multipole harmonics (v_2,v_3) studied
  - Striking similarities across collision systems (pPb, PbPb) for the same multiplicity



HIN-13-002
arXiv:1305.0609



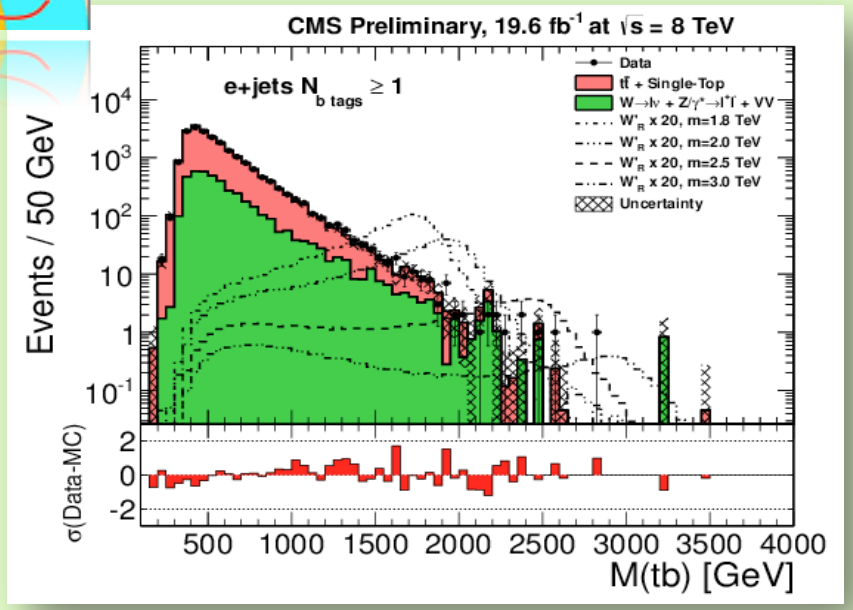


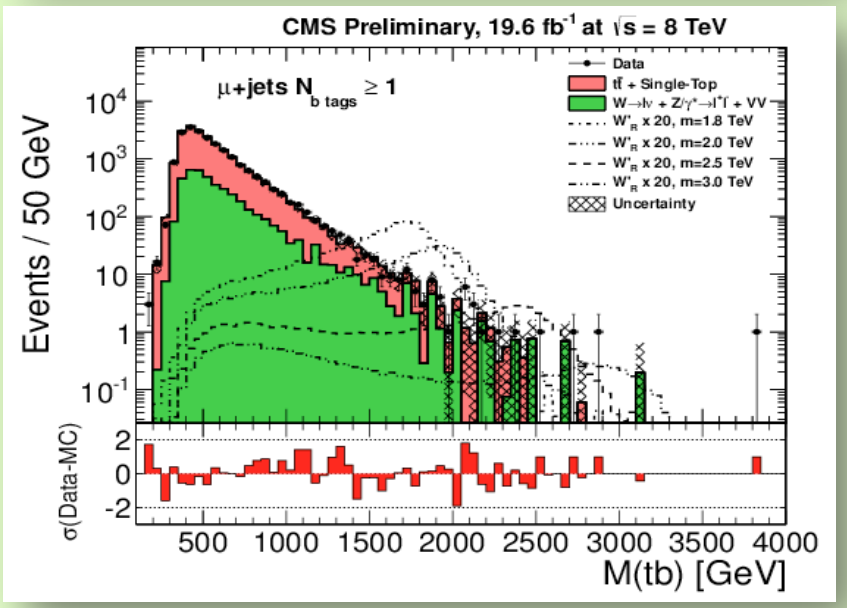


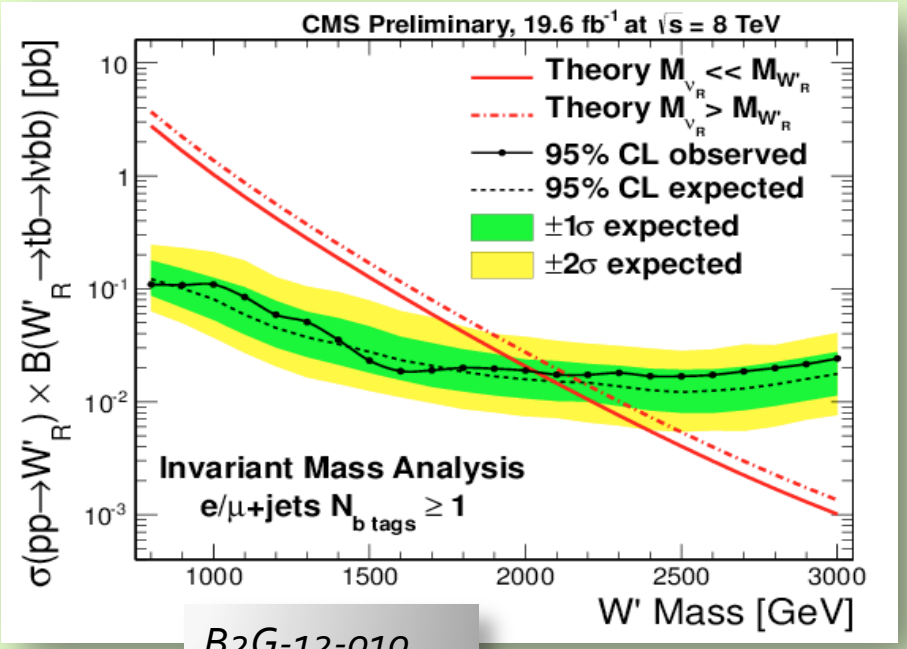
Hydrodynamic expansion of a strongly coupled medium is presently the only theory that covers all observations

BSM Searches: W′(tb)

- Probing $W_{R,L}$ as well as arbitrary couplings
  - Full 8 TeV statistics
  - Limits as high as 2.1 TeV are set for W_R and W_L without interference





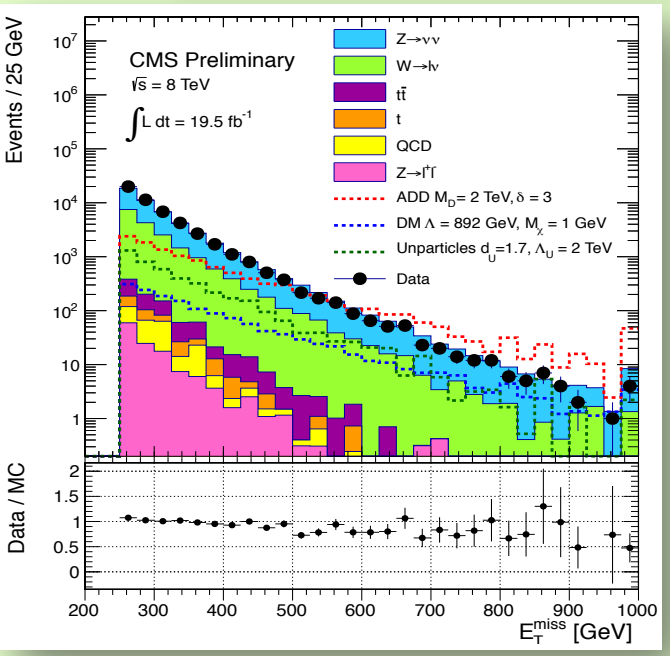


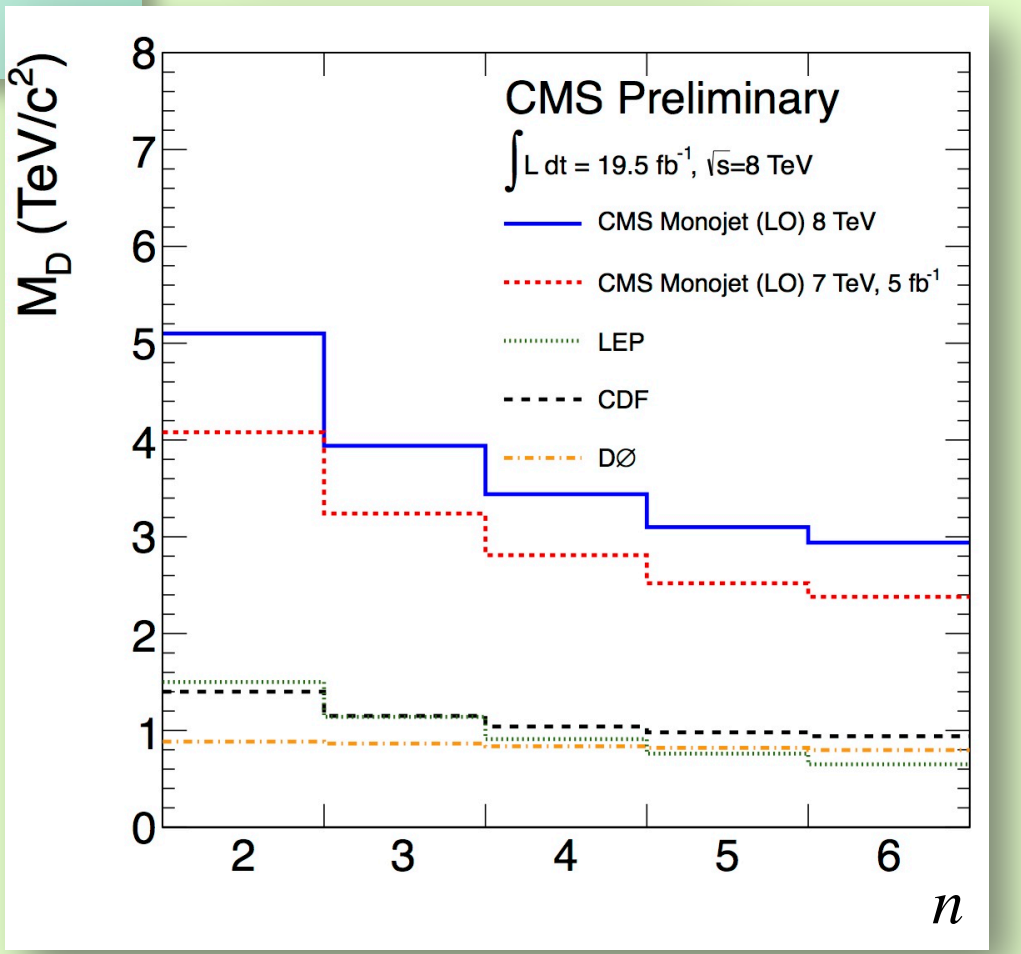
B2G-12-010

Extra Dimensions

- Can also look for evidence of KK Gravitons
  - ADD Extra Dimensions

$$M_{Pl}^2 \sim M_D^{2+n} R^n$$

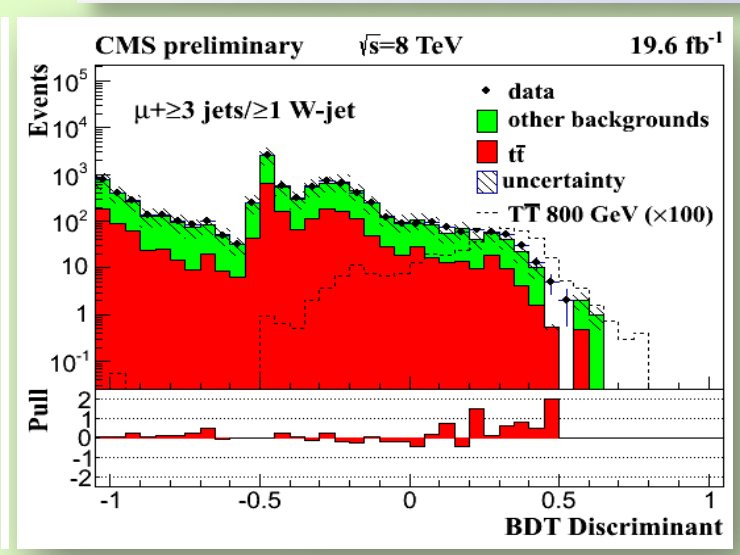


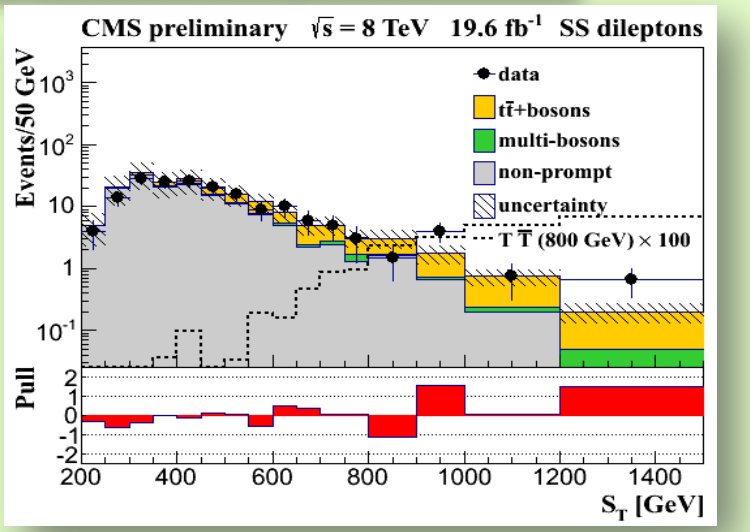


CMS-PAS-EXO-12-048

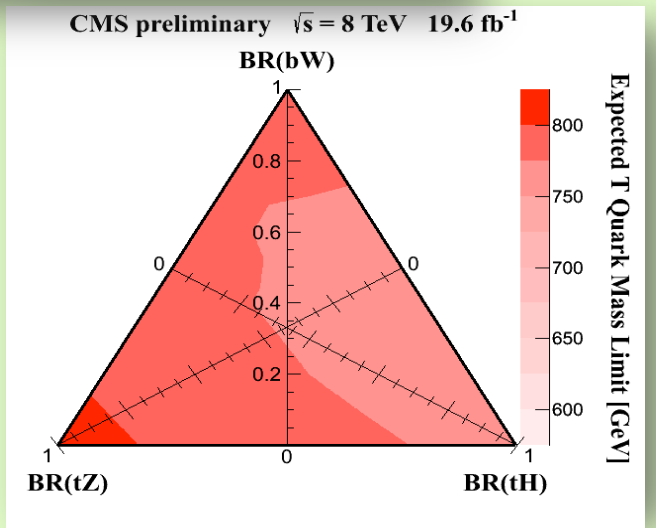
Search for Top Partners

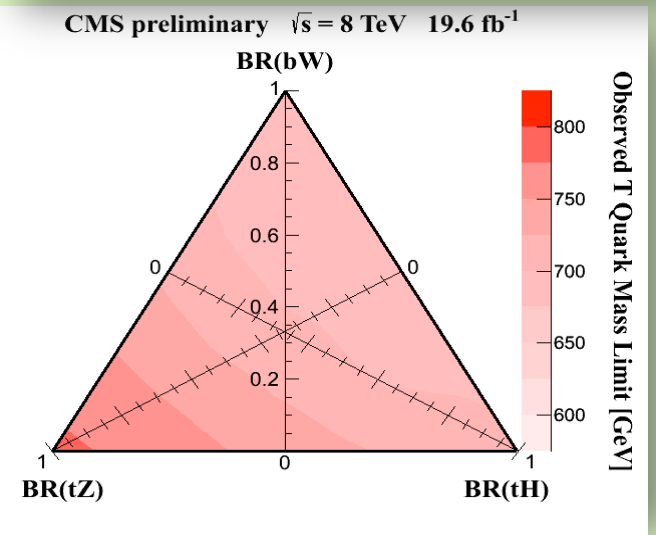
- Search for vector-like T quark in various possible decay modes in the combinations of l+jets and dileptons





B2G-12-015

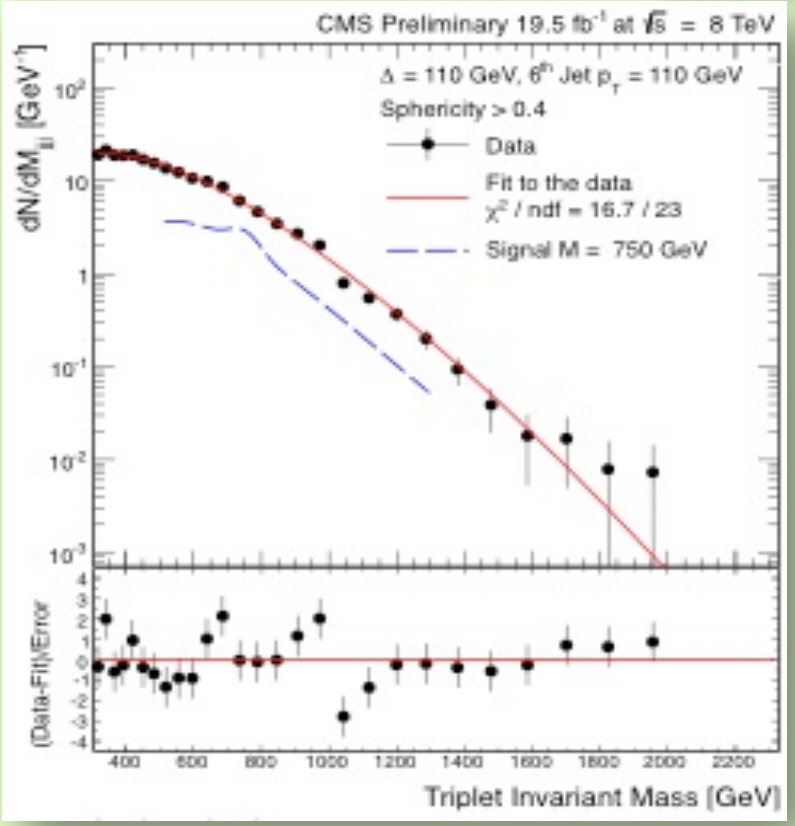


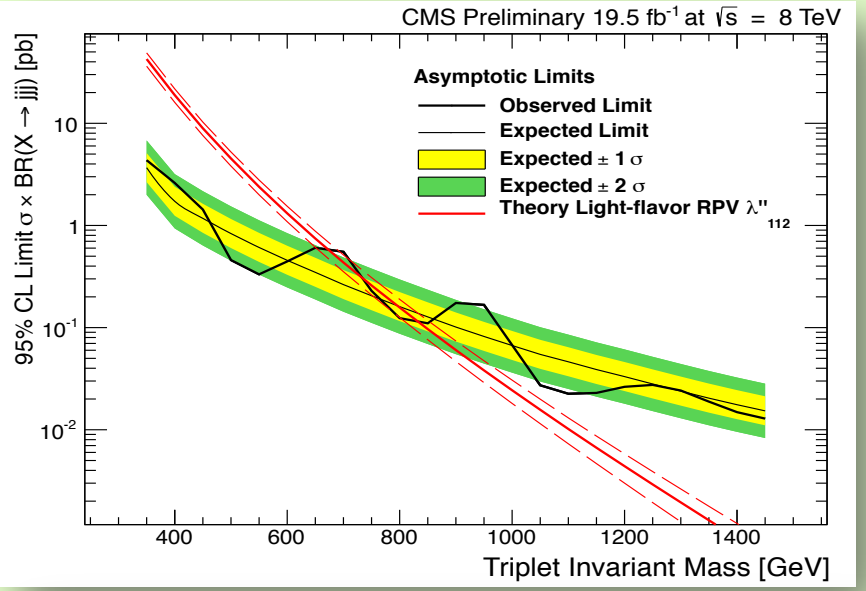


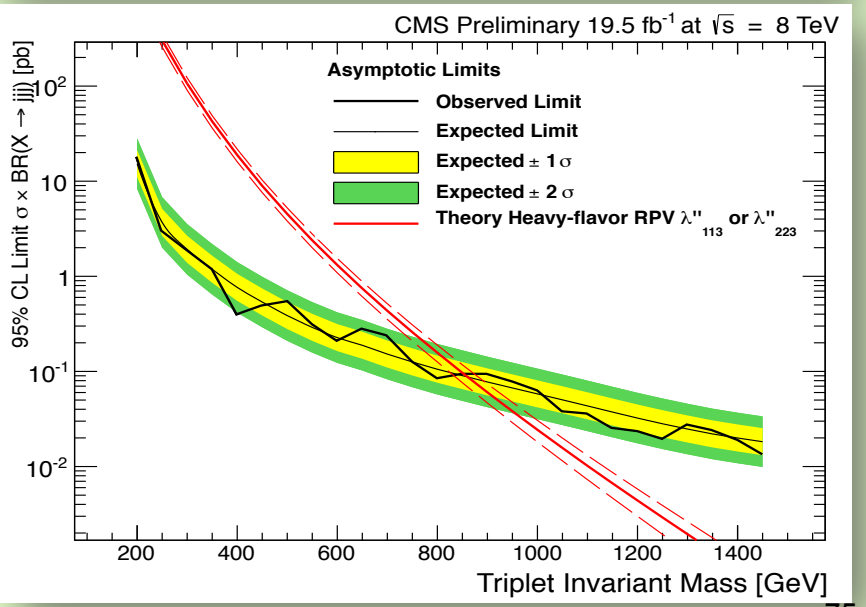
RPV Gluinos in 3 jets

- Search for RPV decays of a gluino in 3 jets (either qq′q″ or bqq′)

EXO-12-049

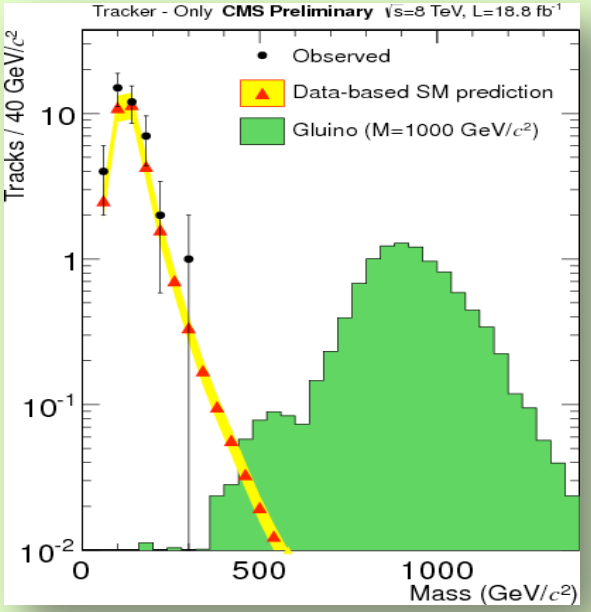


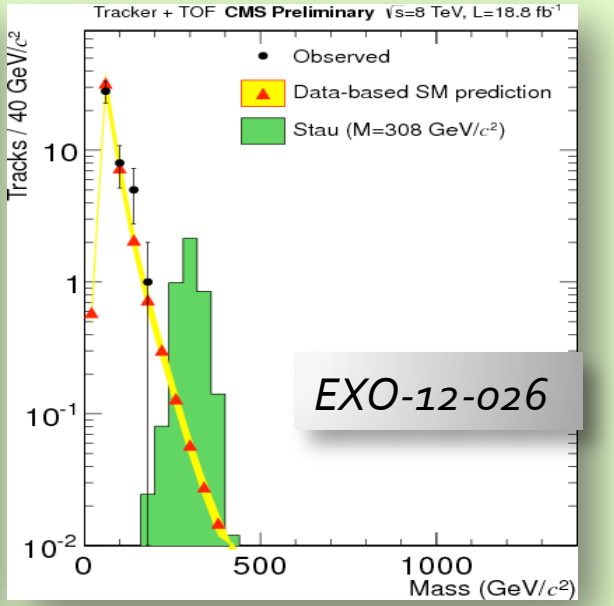


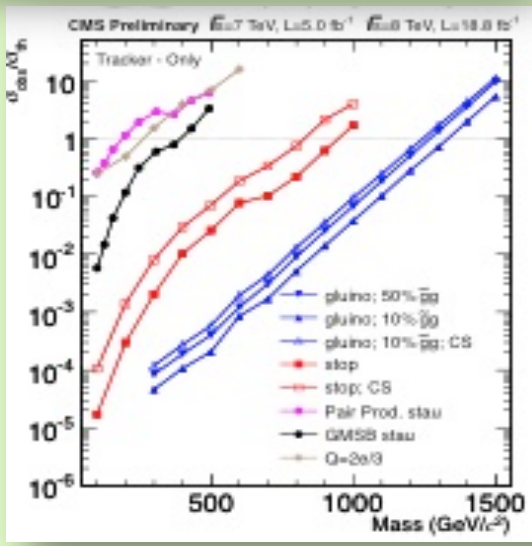


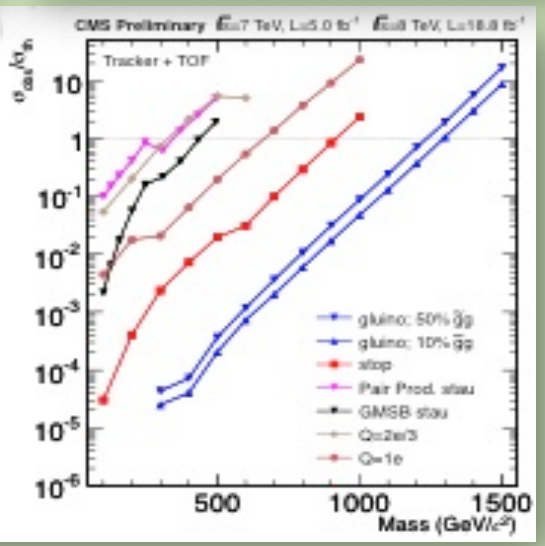
Searches for Long-Lived SUSY

- Extends HSCP search to full 8 TeV statistics
  + 7 TeV reanalysis
- Background prediction
  - Use absence of correlation between p_T spectrum and the mass as determined from ionization
- Strong limits
  - Gluinos, stops, and staus
    - Use combination of tracker +TOF and tracker-only analyses





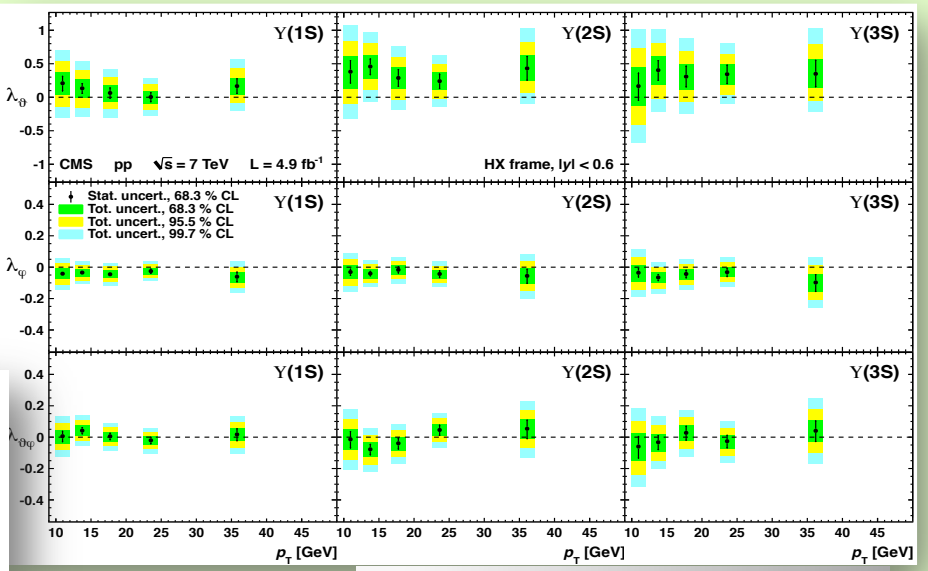




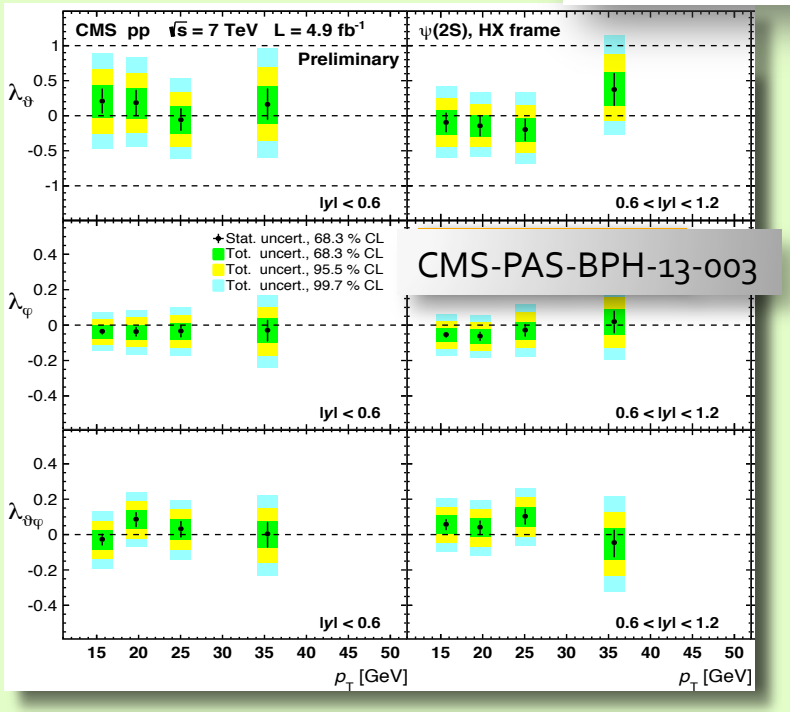
Ψ/Υ Polarization, Λ_b lifetime

- 1st meas. of Υ(nS) polarization at the LHC
  - Now extended to Ψ(2S) polarization measurement
- No evidence for large polarizations
  - An issue for NRQCD that needs to be resolved!

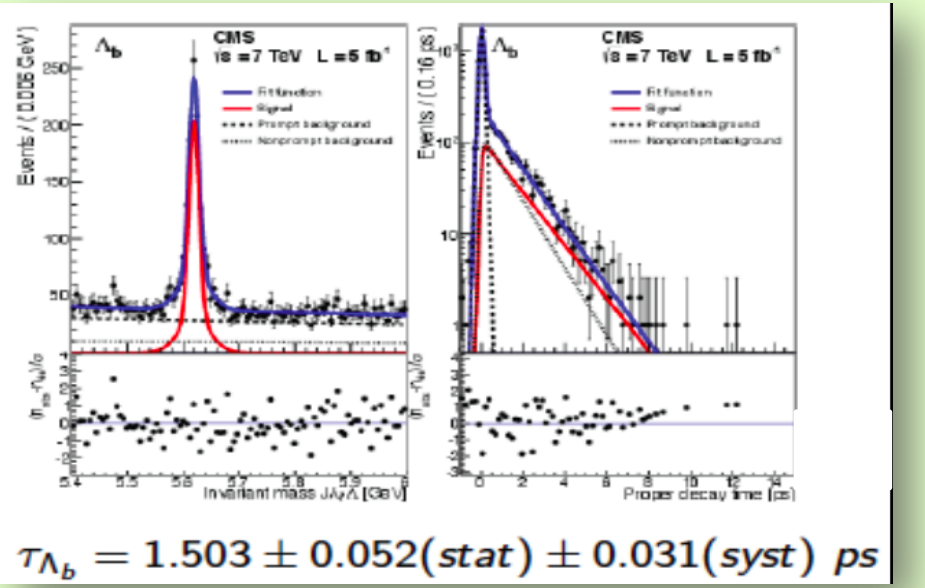
$$\frac{dN}{d\Omega} \propto 1 + \lambda_\theta \cos^2\theta + \lambda_\varphi \sin^2\theta \cos 2\varphi + \lambda_{\theta\varphi} \sin 2\theta \cos\varphi$$



PRL 110 (2013) 081802



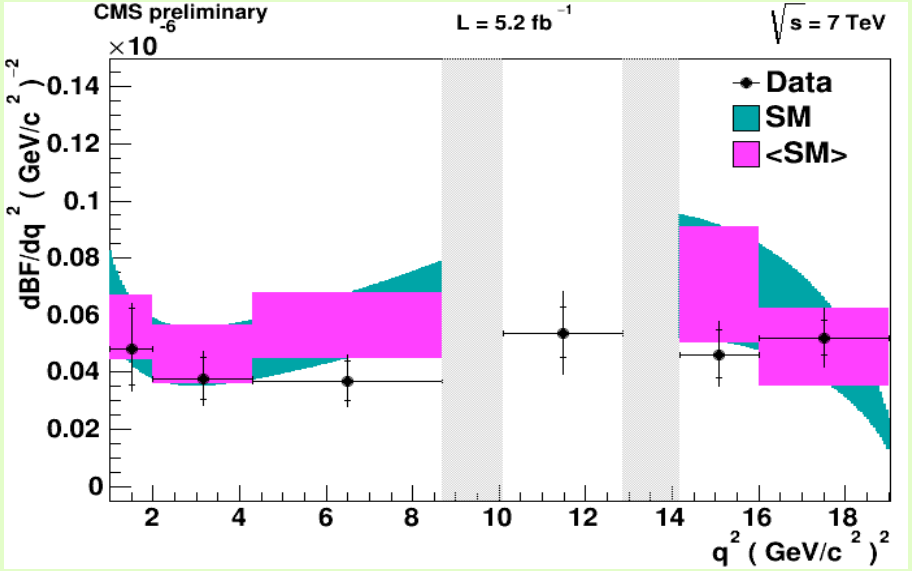
CMS-PAS-BPH-13-003



$$\tau_{\Lambda_b} = 1.503 \pm 0.052(stat) \pm 0.031(syst)\ ps$$

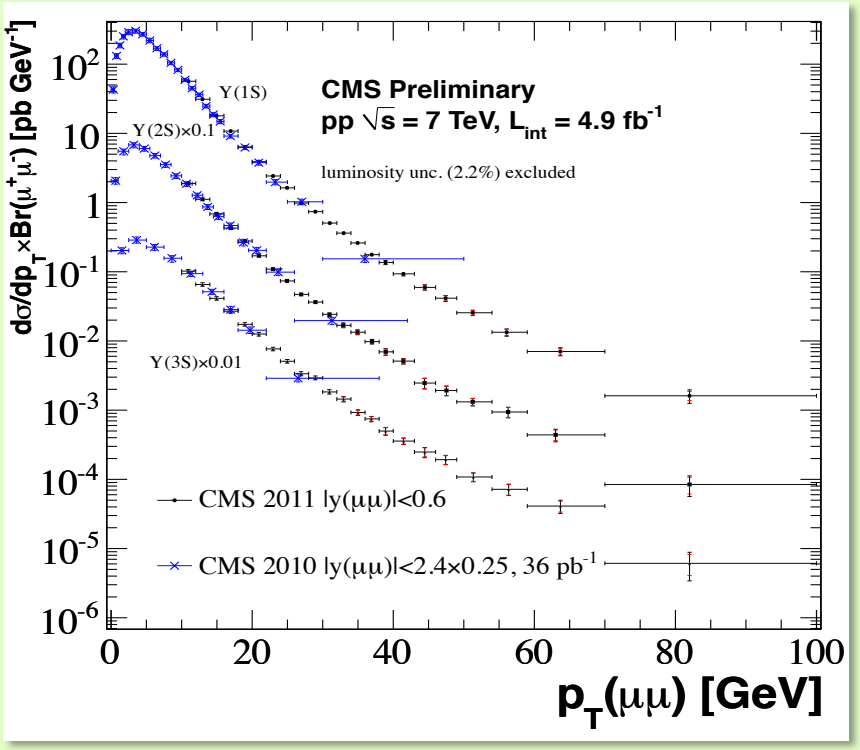
Recent Highlights

- Full angular analysis of $B^0 \rightarrow \mu^+\mu^- K^{*0}$
  - And determination of differential branching fraction as a function of $m_{\mu\mu}^2$



BPH-11-009

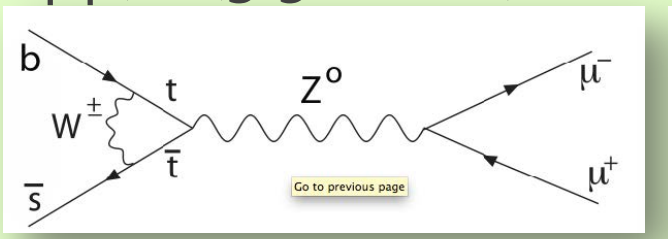
- Υ(nS) $d\sigma/dp_T$
  - 7 TeV data sample

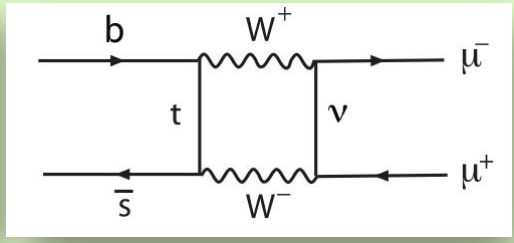


BPH-12-006

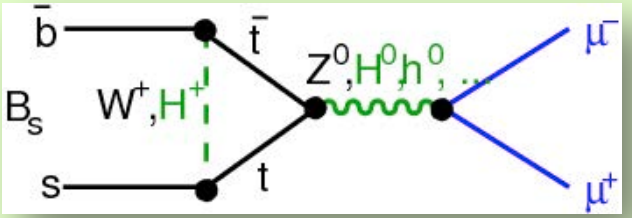
A portal to physics beyond the SM

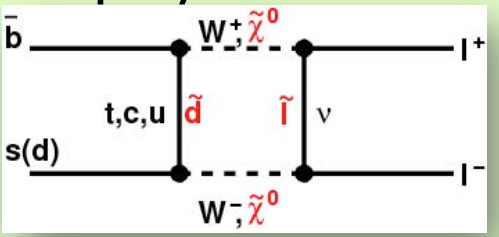
- SM time integrated BR($B_s \to \mu\mu$) = (3.56±0.18)×10^{-9}
  - Forbidden at tree level
  - Involves FCNC's
  - Helicity suppressed
  - Cabibbo enhancement of $B_s \to \mu\mu$ over $B_d \to \mu\mu$ since $|V_{td}| < |V_{ts}|$



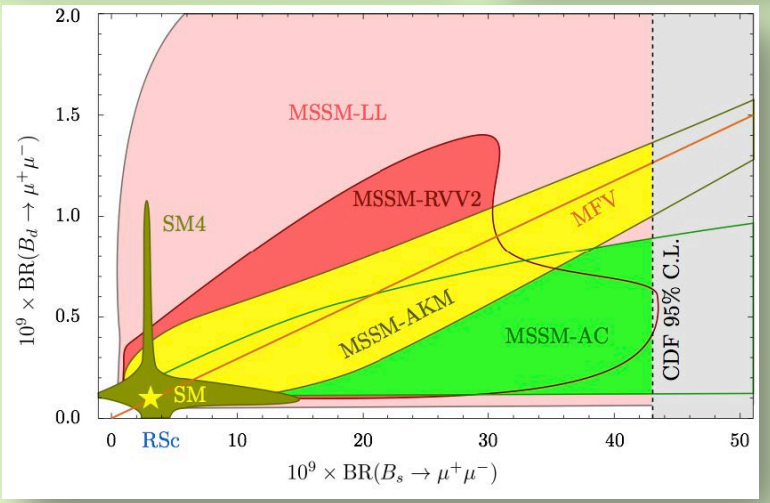


- A good place to look for enhancements from new physics
  - via loop/box contributions





- 2HDM: BR(Bs/d→μμ) ∝ $\tan^4\beta$ and m(H+)
  - *J. R. Ellis et al, JHEP 05 (2006) 063*
- MSSM: BR(Bs/d→μμ) ∝ $\tan^6\beta$
  - *J.Parry, Nucl. Phys. B 760 (2007) 38*
- Leptoquarks
  - *S. Davidson and S. Descotes-Genon*
  - *JHEP 11 (2010) 073*
- 4th generation top
  - *Wei-Shu Hou, Masaya Kohda, Fanrong Xu,*
  - *Phys. Rev. D87, 094005 (2013).*

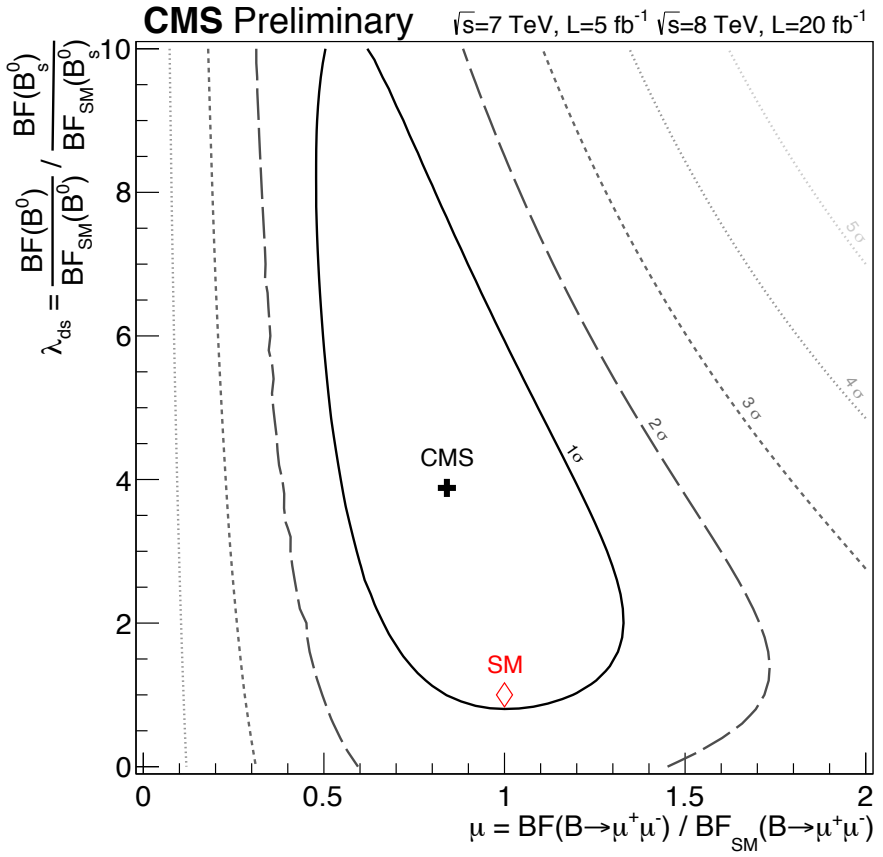


Courtesy Fabrizio Palla (LHCb CERN Seminar August 6, 2013)

Alternative parameterization for SM compatibility check

Test how the BRs are compatible with the SM expectations

- $BR_{SM}(B_s \to \mu\mu) = (3.56 \pm 0.18) \times 10^{-9}$
- $BR_{SM}(B_d \to \mu\mu) = (1.07 \pm 0.10) \times 10^{-10}$



$$\mu = \frac{\mathrm{BR}(B_S \to \mu\mu)}{\mathrm{BR}_{SM}(B_S \to \mu\mu)}$$

$$\lambda_{ds} = \frac{\mathrm{BR}(B_d \to \mu\mu)}{\mathrm{BR}_{SM}(B_d \to \mu\mu)} \Big/ \frac{\mathrm{BR}(B_S \to \mu\mu)}{\mathrm{BR}_{SM}(B_S \to \mu\mu)}$$

Simultaneous fit

$$\mu = 0.84^{+0.31}_{-0.25}; \lambda_{ds} = 3.9^{+3.7}_{-2.2}$$

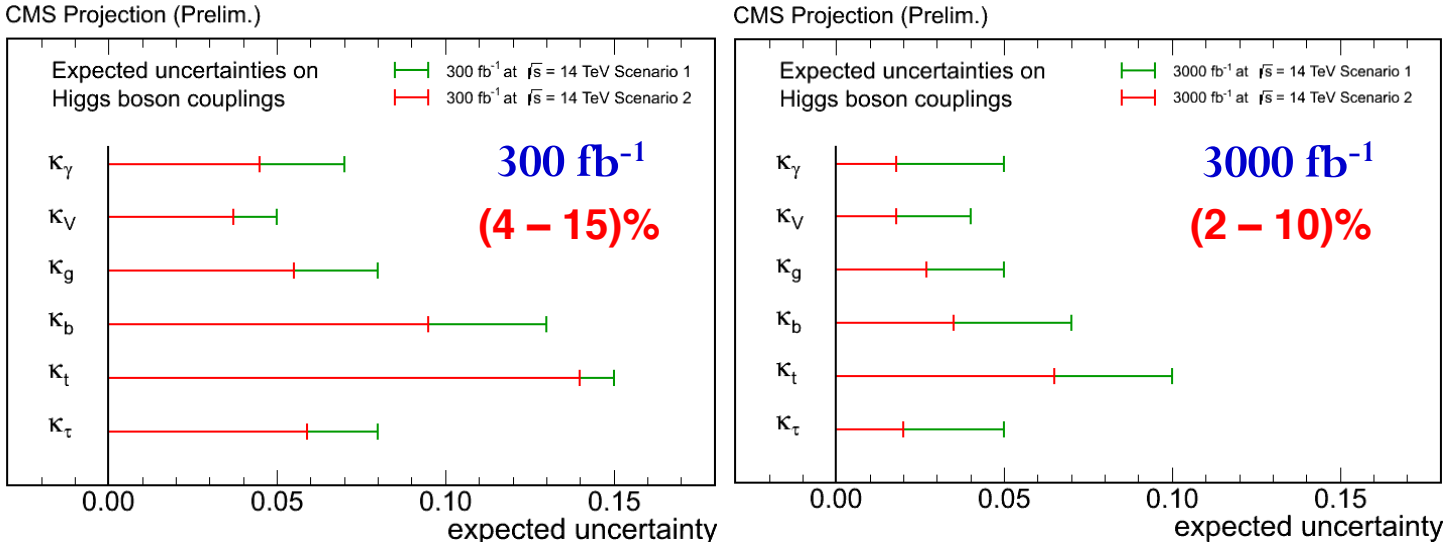
Fit for μ (fix lambda to SM)

$$\mu = 1.01^{+0.31}_{-0.26}$$

Fit for λ_{ds} (fix μ to SM)

$$\lambda_{ds} = 3.1^{+2.0}_{-1.7}$$

New CMS Higgs projections for 300(0) fb^{-1}



Numbers in brackets are % uncertainties on coupling deviations for [scenario 2, scenario 1]

L (fb^{-1})	κ_γ	κ_V	κ_g	κ_b	κ_t	κ_τ
300	[5, 7]	[4, 5]	[6, 8]	[10, 13]	[14, 15]	[6, 8]
3000	[2, 5]	[2, 3]	[3, 5]	[4, 7]	[7, 10]	[2, 5]

Goal: ultimate precision of ~5% or better

July 1, 2013 J. Olsen – Snowmass Energy Frontier Workshop 31

Bracket precision estimates

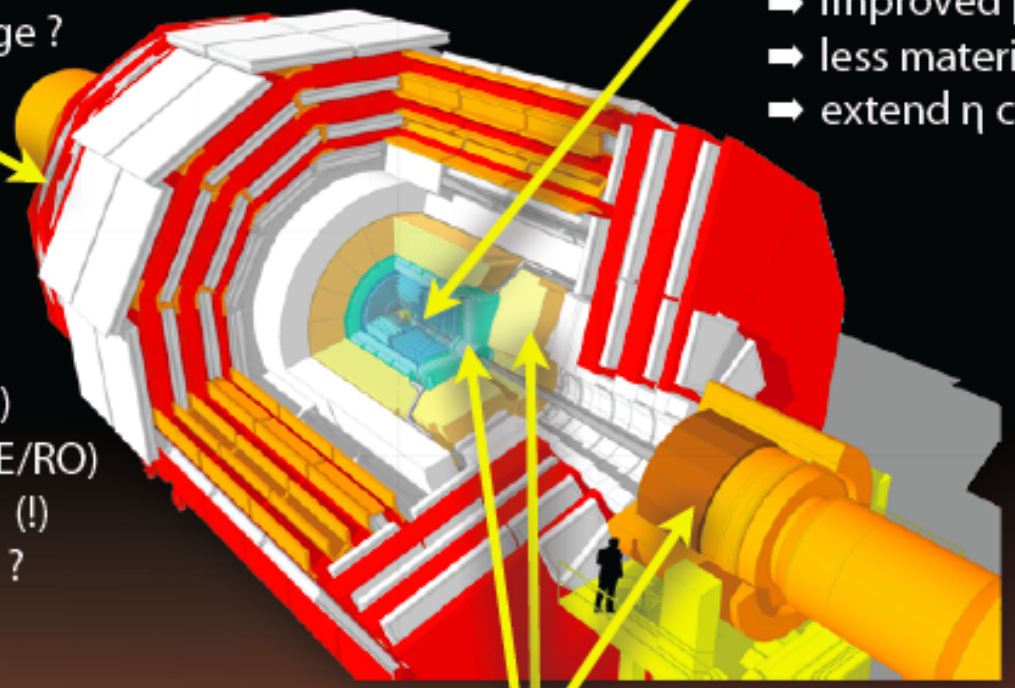
1. Systematics unchanged
2. Theory uncertainties reduced ½, all other systematics ~ $1/\sqrt{(\int L dt)}$

Upgrades target precision Higgs measurements with pileup ~140!! (25 ns and L = 5x10^{34} cm^{-2}s^{-1})

CMS Phase-2 Upgrades

- Muons
  - ➡ complete RPCs in forward region with new technology, GEM or GRPCs
  - ➡ extend η coverage ?

- new Inner Tracker
  - ➡ radiation hardness
  - ➡ better granularity and faster links
  - ➡ improved precision
  - ➡ less material
  - ➡ extend η coverage ?

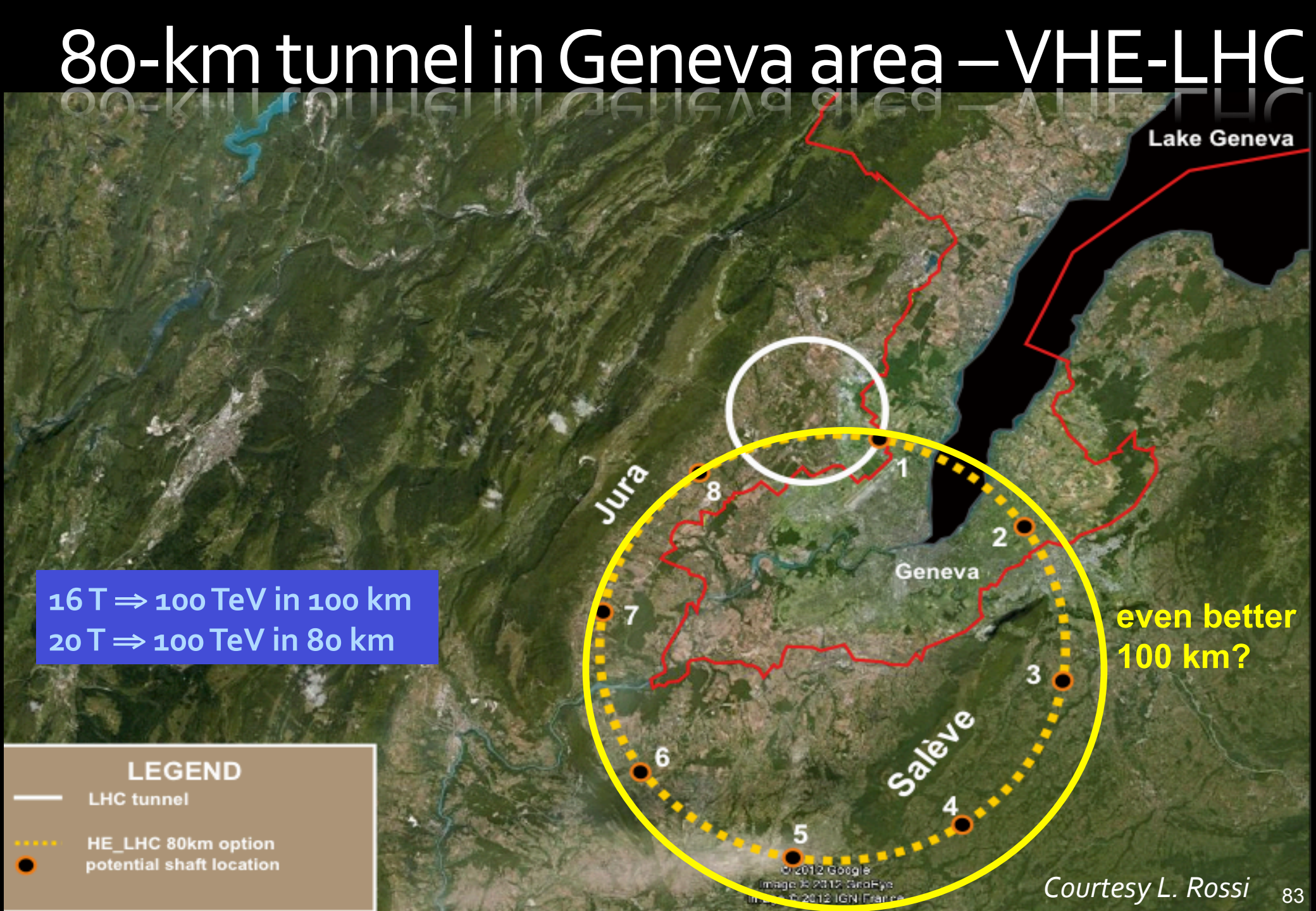


- T/DAQ
  - ➡ Level-1 at 1 *MHz* (?) (requires all new FE/RO)
  - ➡ Tracking at Level-1 (!)
  - ➡ HLT output 10 *kHz* ?

Technical Proposal in 2014

- upgrade/replace Forward Calorimeters
  - ➡ extend η coverage ?
  - ➡ mitigate pileup effects with tracking and precise timing

80-km tunnel in Geneva area – VHE-LHC



Courtesy L. Rossi