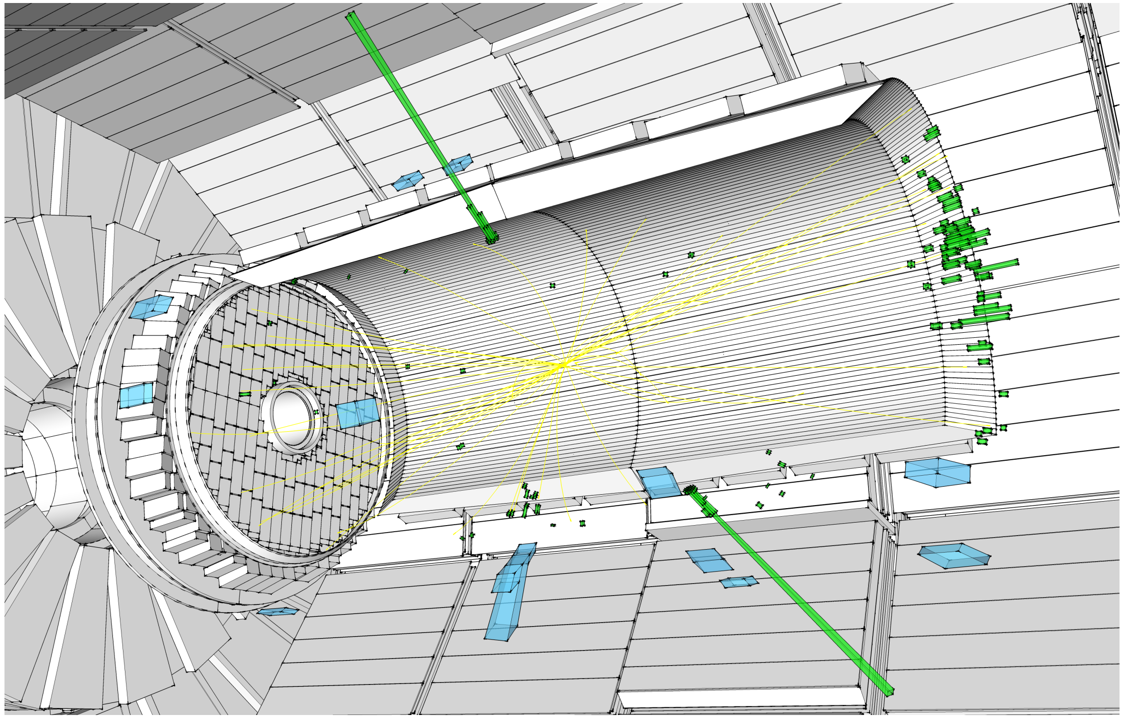
CMS (and LHC) status and preparation for Run 2

Jim Olsen, Luca Malgeri

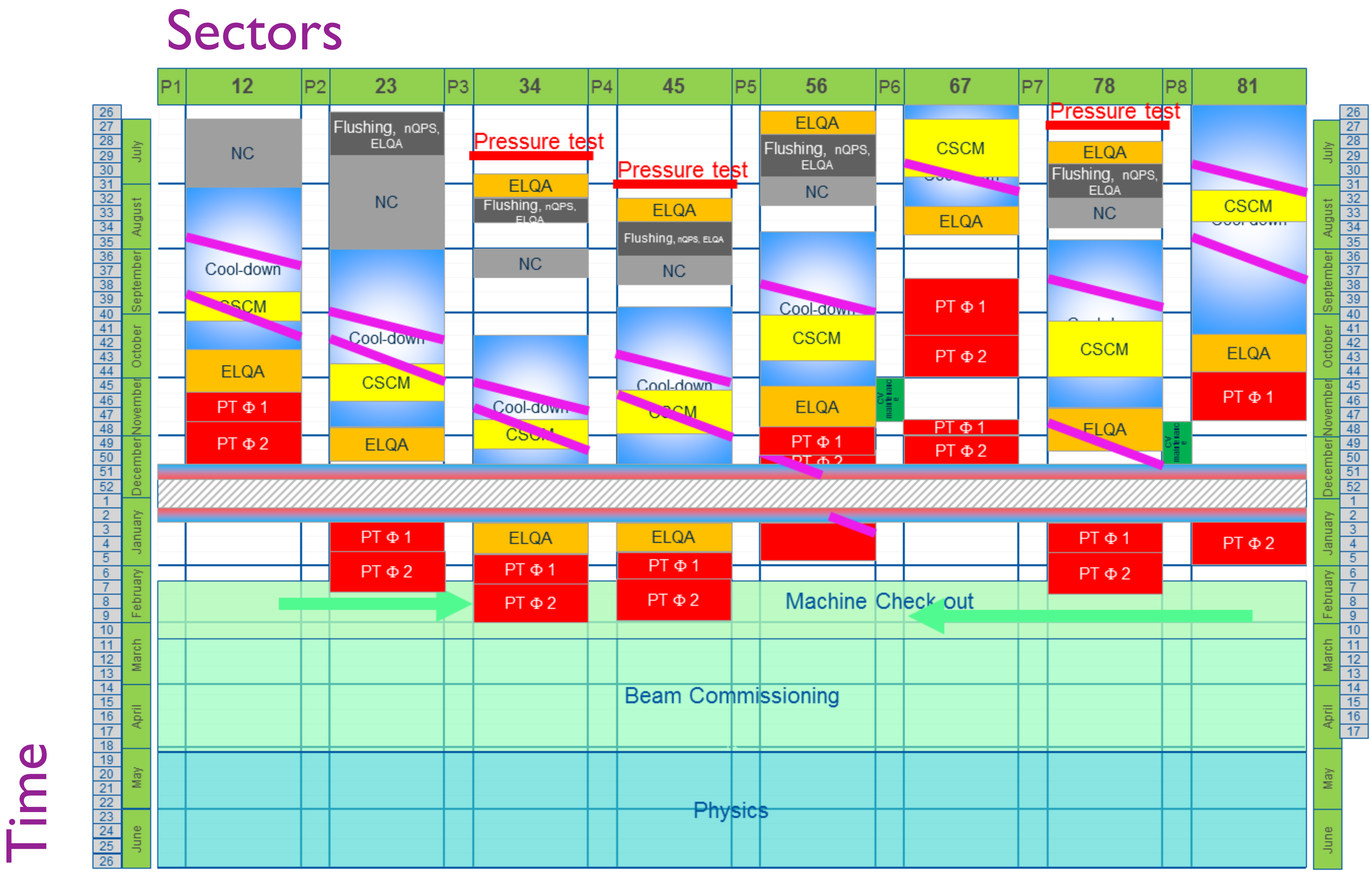


Outline

- LHC status, progress and plans
- CMS activities in the last two years:
  - detector status
  - commissioning activities
  - readiness for data taking
- Analysis status and prospects:
  - run1 end-game
  - preparation for Run2
  - exercising
  - effects under surveillance
- Outlook
- Backup:
  - Future prospects
  - Hot topic for run2: Dark Matter

What is going on at the LHC

Full program of activities in the LHC



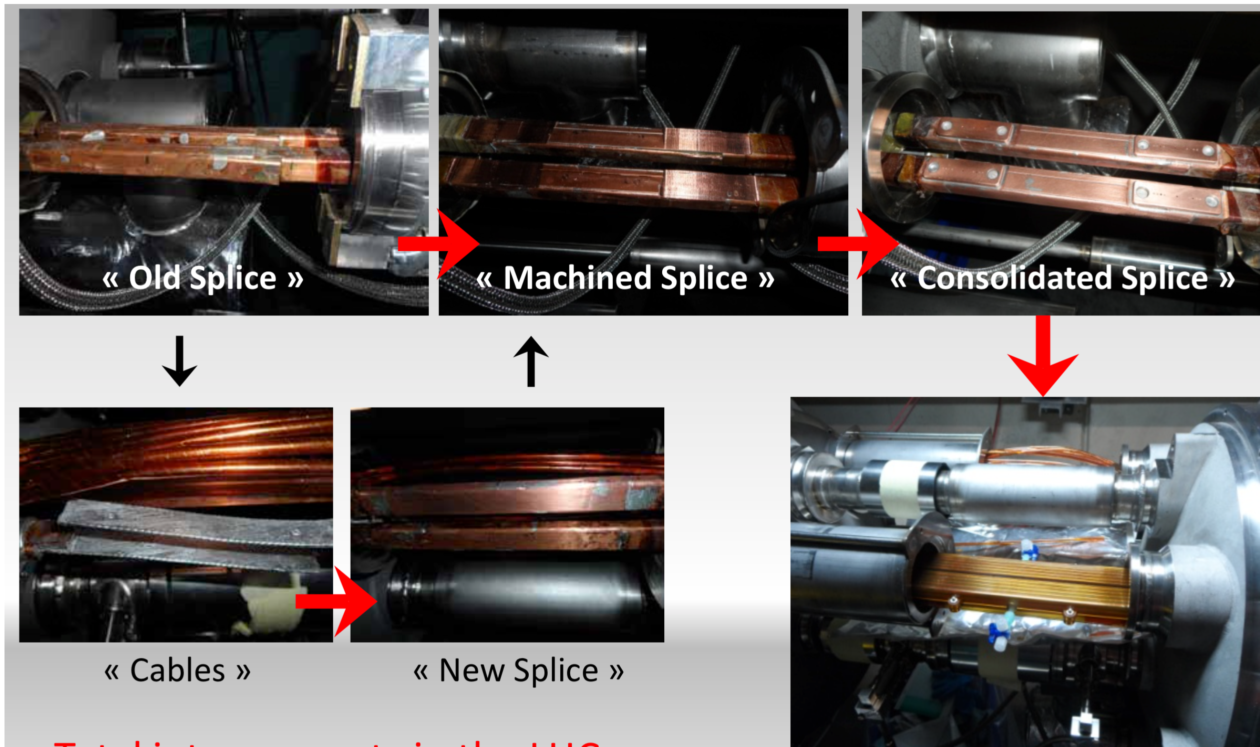
What has happened in the last two years

The main 2013-14 LHC consolidations

Splices consolidation campaigns

You might remember the incident occurred on Sep. 19th 2008 (destructive sequential quenching of ~100 magnets due to an electrical faults).

After a temporary fix able to keep LHC going up to 8 TeV, the LS1 was used to verify and repair all interconnection (among other things)



« Insulation box »

Courtesy of M. Lamont

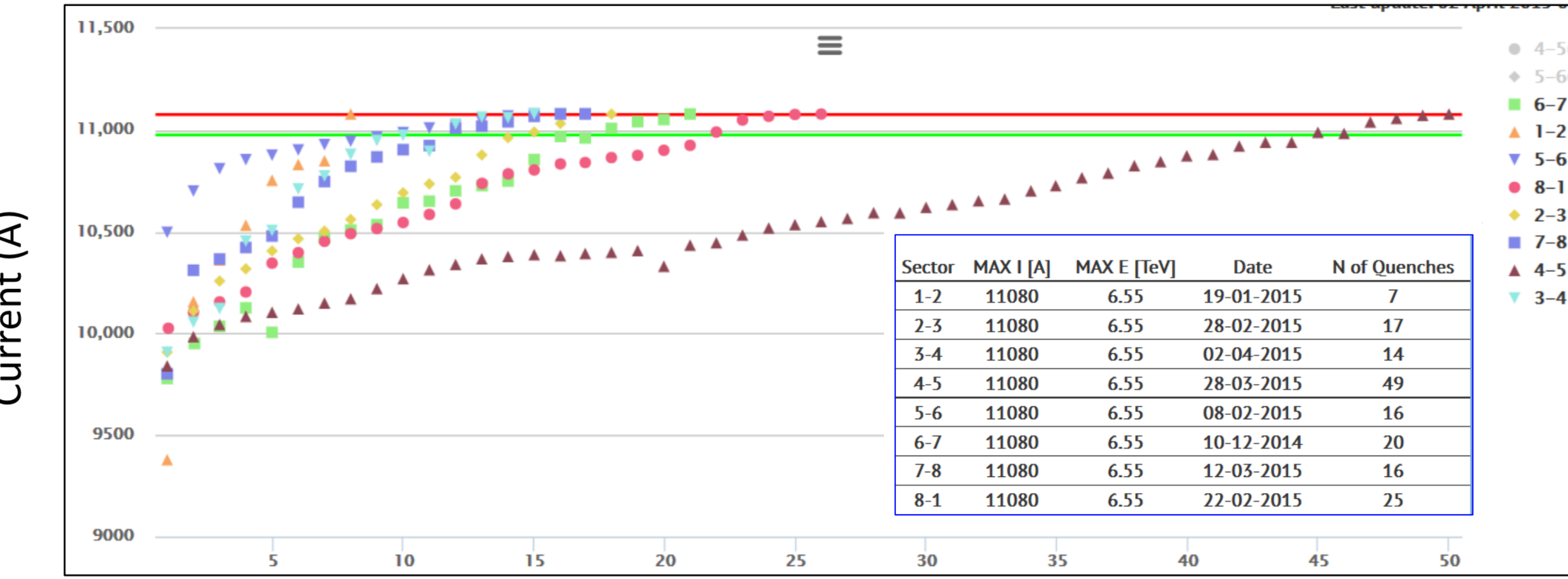
- Total interconnects in the LHC:
  - 1,695 (10,170 high current splices)
- Number of splices redone: ~3,000 (~ 30%)
- Number of shunts applied: > 27,000

And a lot more besides…

Powering test campaign

Magnets training by controlled quenches

http://hcc.web.cern.ch/hcc/



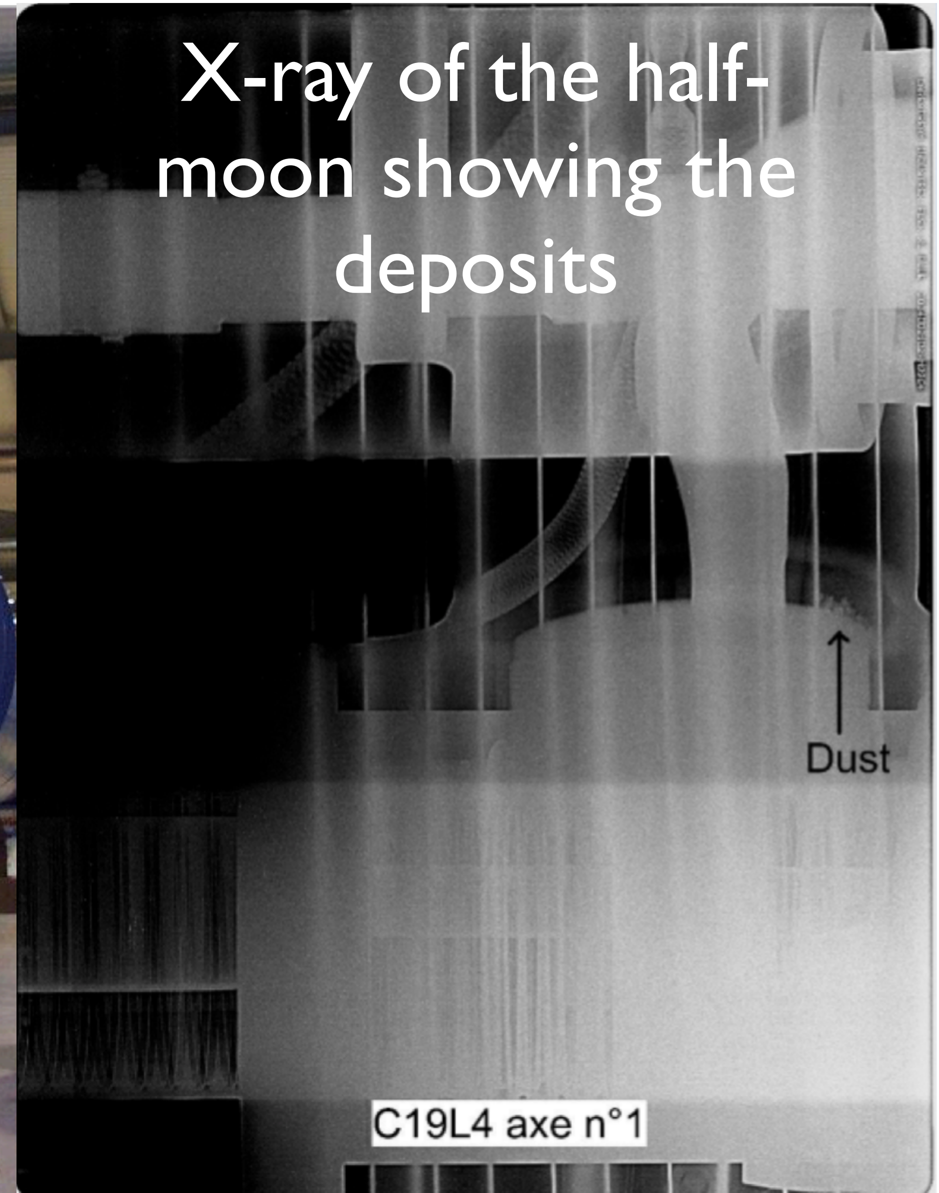
Sector	MAX I [A]	MAX E [TeV]	Date	N of Quenches
1-2	11080	6.55	19-01-2015	7
2-3	11080	6.55	28-02-2015	17
3-4	11080	6.55	02-04-2015	14
4-5	11080	6.55	28-03-2015	49
5-6	11080	6.55	08-02-2015	16
6-7	11080	6.55	10-12-2014	20
7-8	11080	6.55	12-03-2015	16
8-1	11080	6.55	22-02-2015	25

An hard work for some of the magnets (all coming from the same firm…) but finally all commissioned to 6.55 TeV with a 1% safety margin.

Suddenly another (small) incident

- During the last step of the quench (March 21st) re-training for sector 3-4 a fault to ground has developed
- Intensive investigation has shown that was located in the cold volume, not in the 'critical' magnet/busbar area, but in the 'protection diode 'pit which is located below the magnet body.
- In a few days it was decided to try to vaporize/burn the debris by capacitive discharge through the short.
  - if this didn't work, no other solution than warming up locally and clean up the diode (>6 weeks delay)

The short

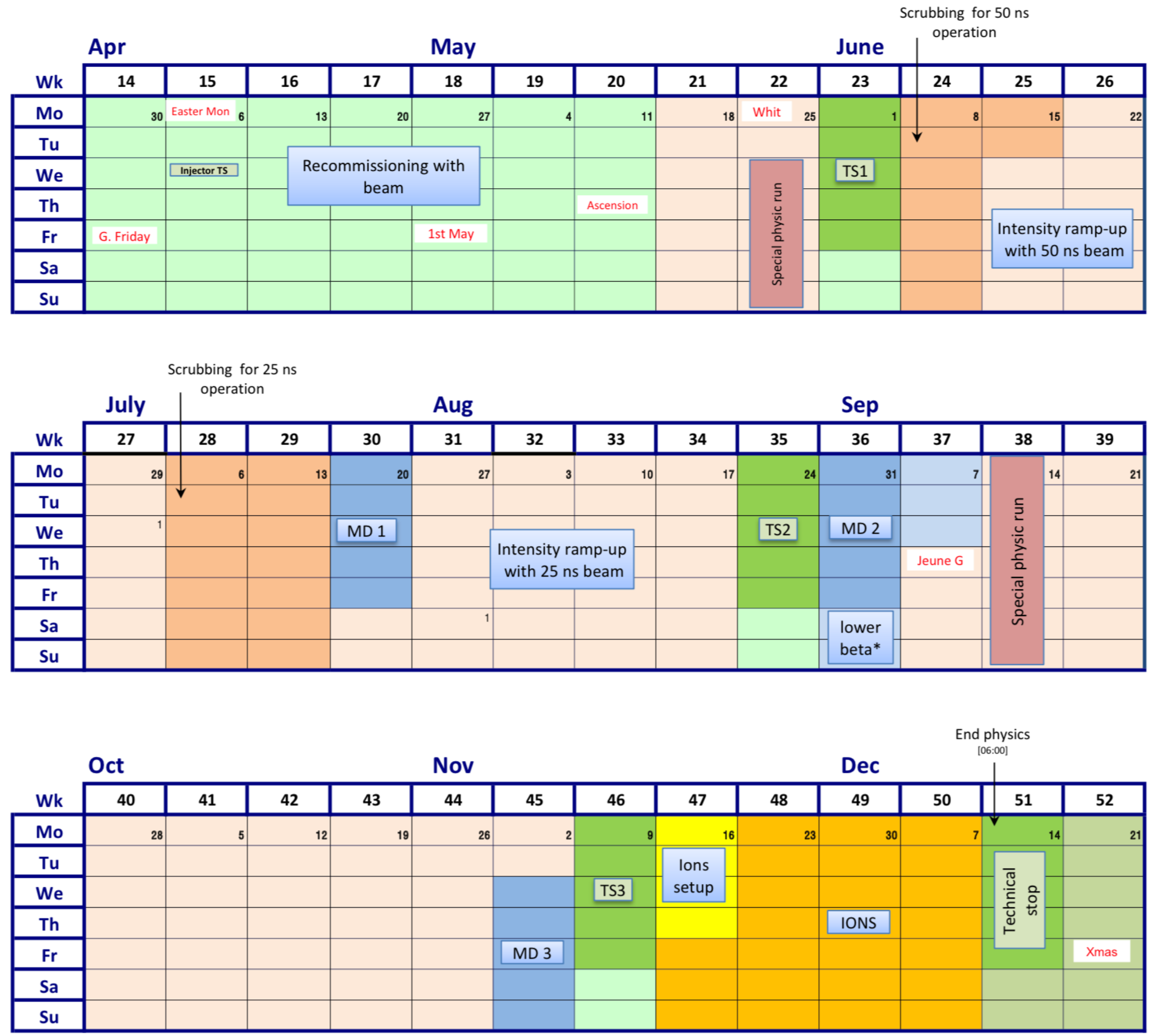


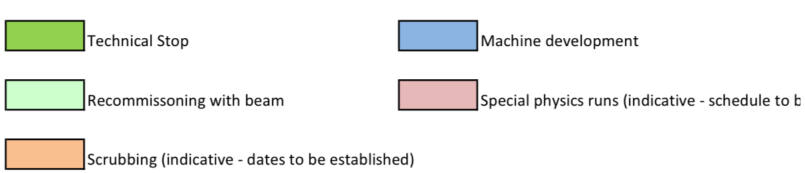
After the zap, no more short! Success!

Current machine plan

CAVEAT:
two days ago a new schedule has been proposed (w.r.t. the one shown here):

- two weeks delay in the start of 50 ns running period
- two/three weeks shorter running period 25ns
- keep all TS, special runs and HI runs

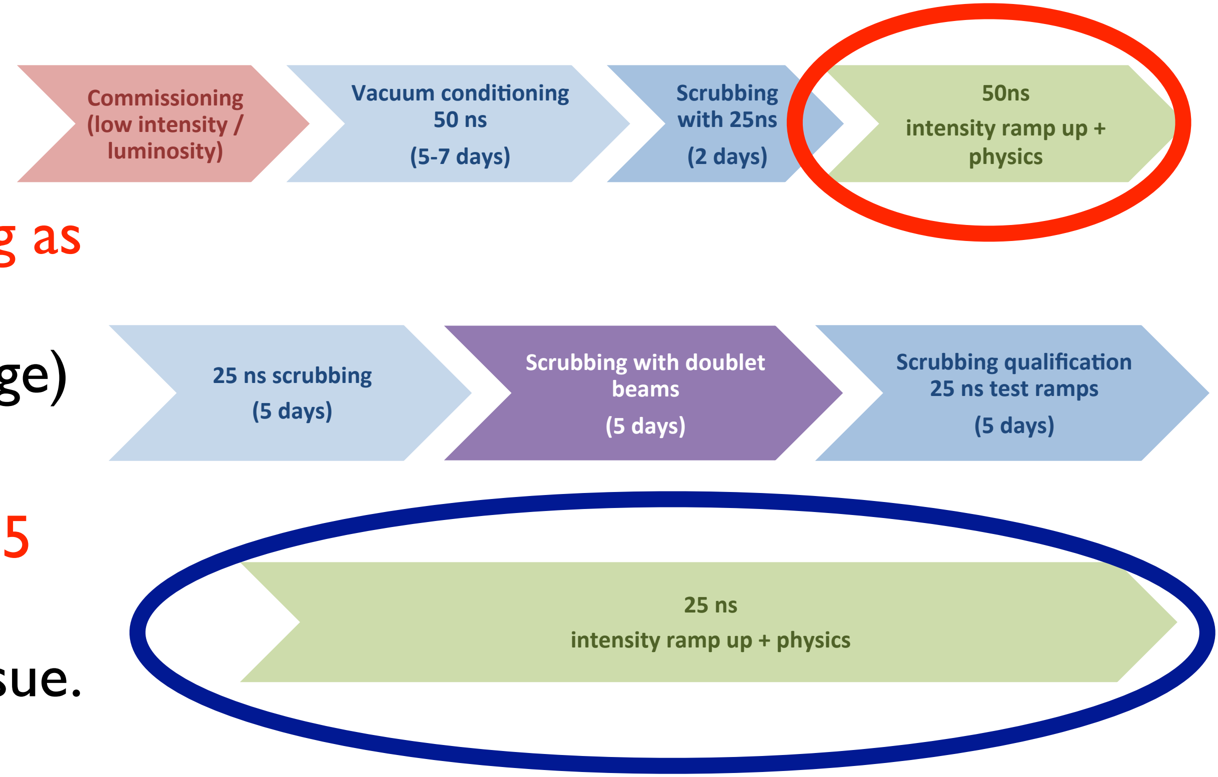




Current machine plan

In terms of running scenarios

- Energy=13 TeV (confirmed after powering tests)
- Possible physics run @50ns as big as 1fb^{-1}:
  - PU 30 ! (never so high in average)
  - potentially a discovery dataset
- Physics bulk @25ns, 10fb^{-1} in 2015
  - PU up to 45!
  - Out-of-time PU might be an issue.

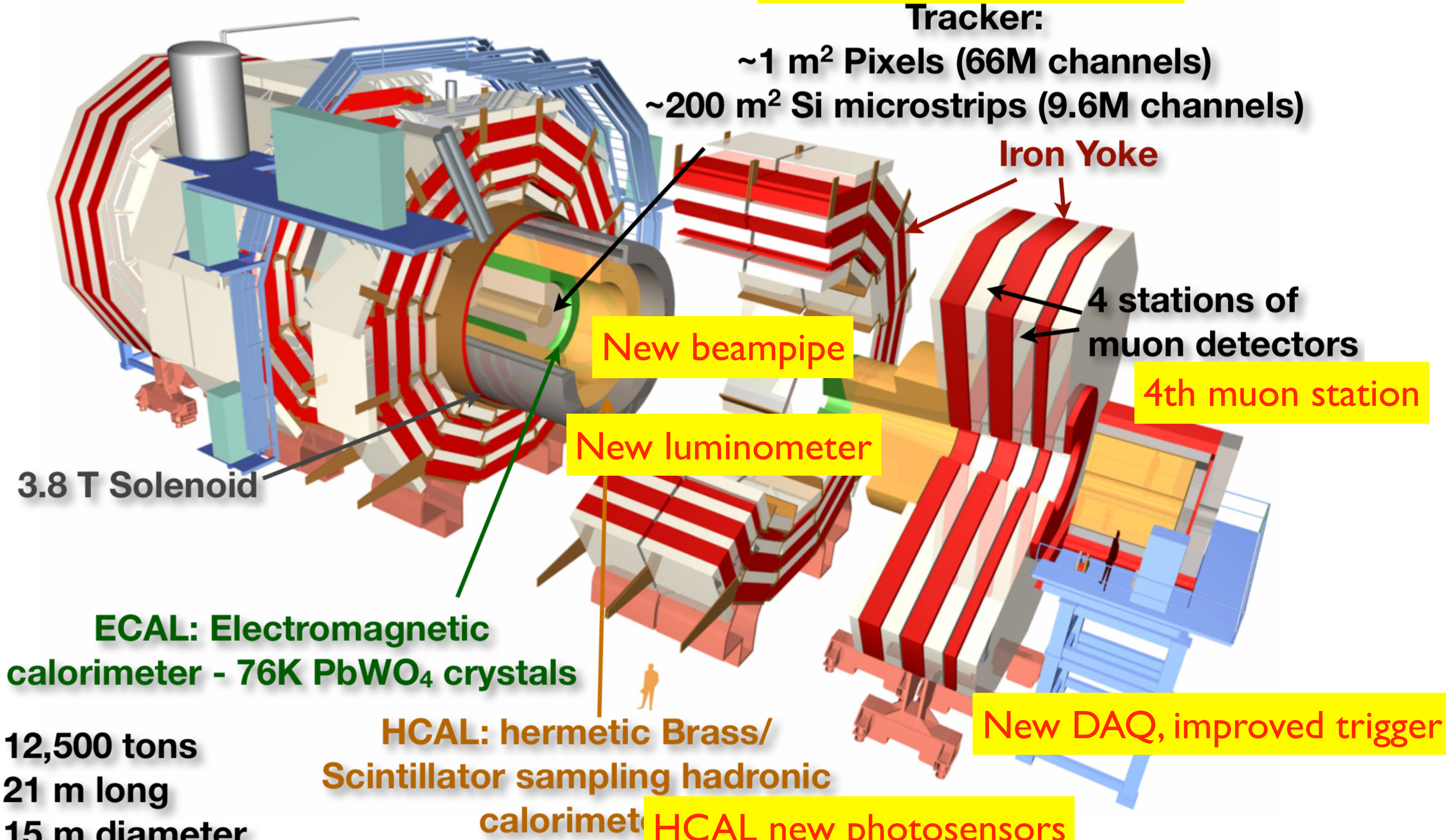


Period	N_{bunch} [10^{11}]	ε* [μm]	k	β* [cm]	L [$cm^{-2}s^{-1}$]	<μ>	Days(*)	∫L [fb^{-1}]
50 ns	1.2	2.2	≈1370	80	5.3×10^{33}	30	21	≈1
25 ns / 1	1.2	2.5	≈2500	80	8.1×10^{33}	26	44	≈4
25 ns / 2	1.2	2.5	≈2500	**40**	14.7×10^{33}	45	46	≈13

Toward Run 2:
Status of CMS commissioning

CMS detector

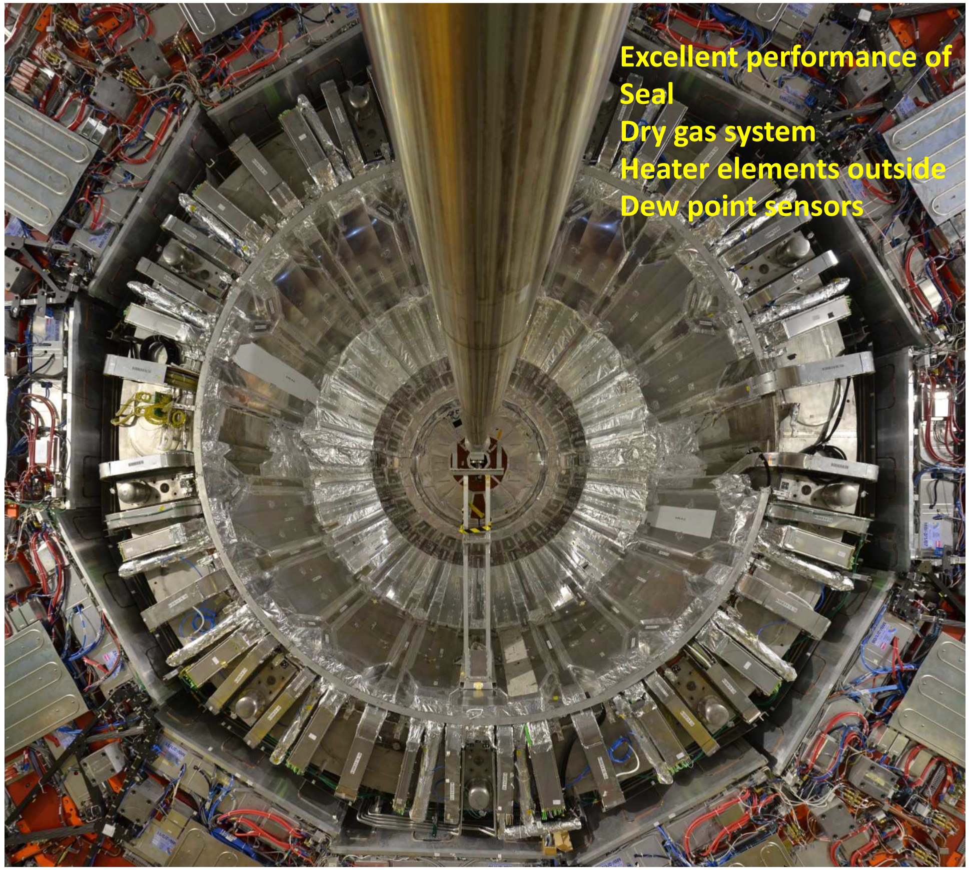
Interventions during shutdown



Tracker – Pixel

Pixel detector installed before Christmas

- Detector now centered 0:0
- Very dry environment
- Including 8 modules with upgrades components
- 99.2% of the detector is alive: better than during Run I (96.3%)
- Pixel calibration at T = -10°C completed



Calibration of strips at T = -15°C completed

- New additional dry air plant

Pixel Luminosity Telescope

Brand new luminosity detector

16/16 PLT telescopes (8 telescopes per end)

48/48 PLT sensors

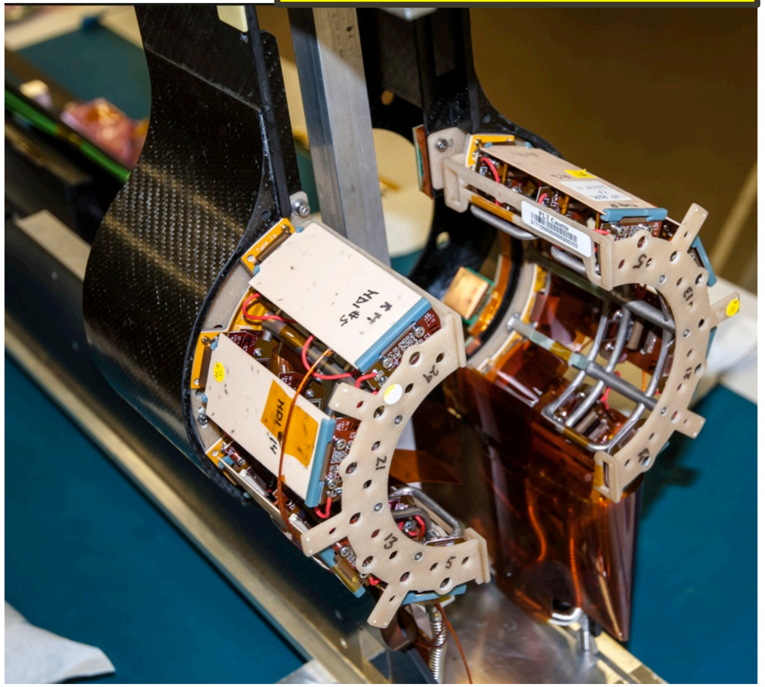
Target is 1% Statistical error/Bunch/s

Coincidence fast-OR of 3-plane telescopes.

Online and Offline luminometer

Innovative use of Titanium 3D Printed integrated cooling/support structure

PLT IP side of carriage



Calorimeters

ECAL: Detector reconstruction and calibration

- New ECAL local reconstruction algorithm with better out-of-time pileup (OOTP) rejection finalised for Run 2, both in offline and in HLT
- Calibration strategy for 2015 defined, algorithms being retuned for 13 TeV/ 25ns operation

HCAL: several improvements

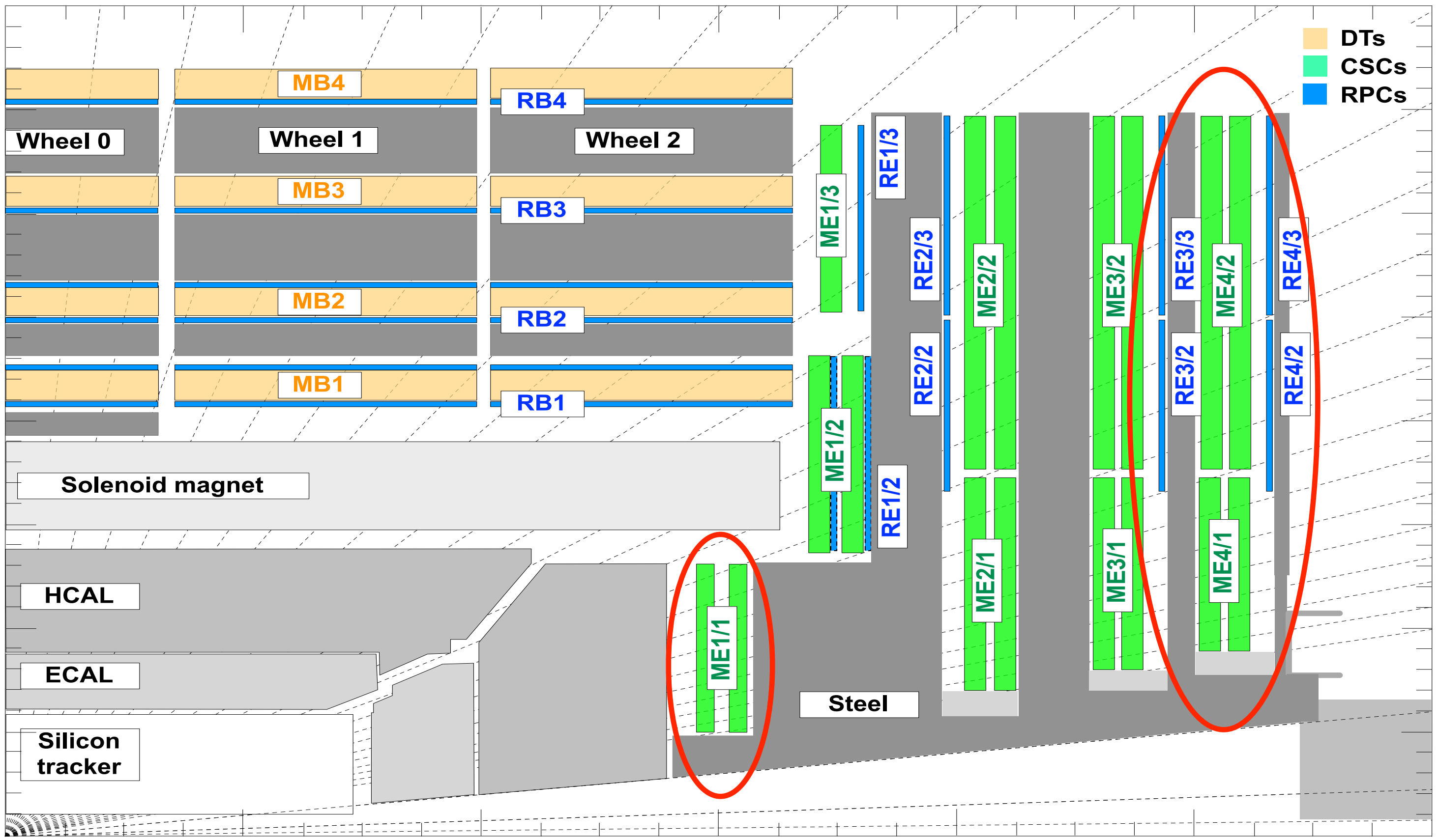
- Field-insensitive, high-performing SiPMs on entire Outer layer
- Multi-anode, thin-window PMTs in the forward
  - Reduction in anomalous signals
- Developed new HCAL local reconstruction algorithm with better OOTP rejection
- New or improved calibration methods available for all HCAL detectors, in particular
  - HO (new SiPMs) calibration performed with cosmics
  - HF (new PMTs) calibration using wire-source

Muon System

CMS Muon System has three sub-systems: Drift Tubes (DT), Cathode Strip Chambers (CSC), Resistive Plate Chambers (RPC)

Removal, revision, re-installation of ME1/1 chambers

4th muon station added: 72 (144) new CSC (RPC) chambers



DAQ and Trigger

New DAQ

- Acquire data from "legacy" and new back-end electronics
- New equipment (PC, 40/56 Gbps networking, Lustre storage)
- Operational, with performance at least as good as in Run 1

Trigger

- New High Level Trigger (HLT) nodes delivered
- Will provide CPU budget of 300 ms/event @ 100kHz
- New Trigger Control and Distribution System now operational

L1/HLT menus for 1.4 x 10^{34} Hz/cm^2 @ 25 ns ready

- Most challenging conditions: ~double energy, lumi, pileup (~40)
- Acceptance similar to that of 2012
- Optimized treatment of OOTP for ECAL and HCAL
- **Total rate fits in budget of 1.35kHz peak for 1kHz average offline rate**

First version of L1/HLT menus for 7 x 10^{33} Hz/cm^2 (25ns)

- More relaxed requirements at both L1 and HLT: lower thresholds and/or prescales; cpu/rate studies ongoing

First version of 5x10^{33} Hz/cm^2 (50ns) L1 and HLT menu available

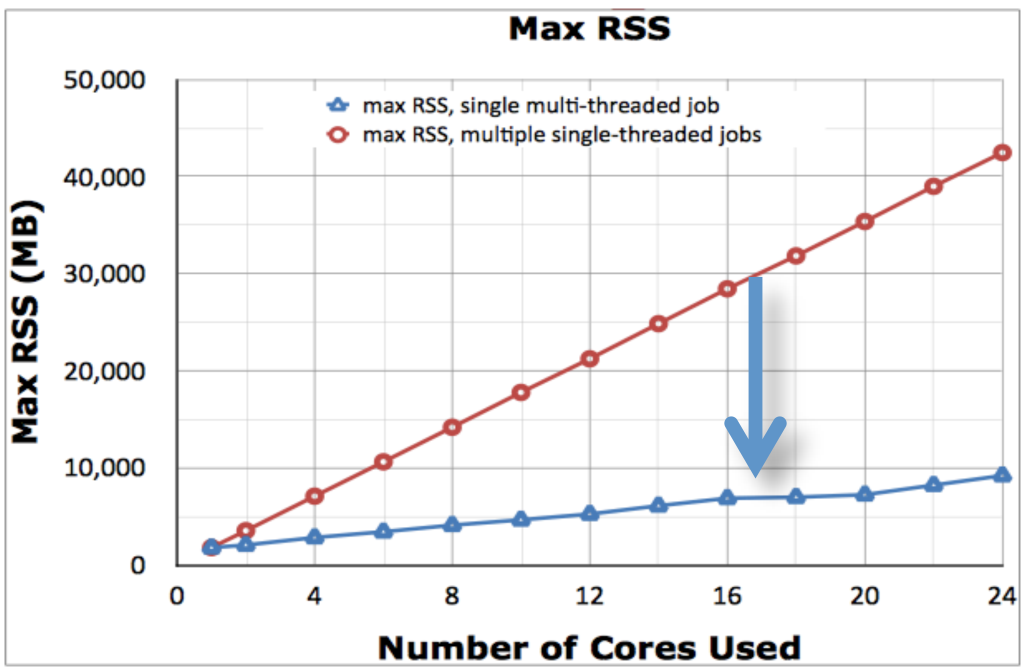
Computing/Offline for Run 2

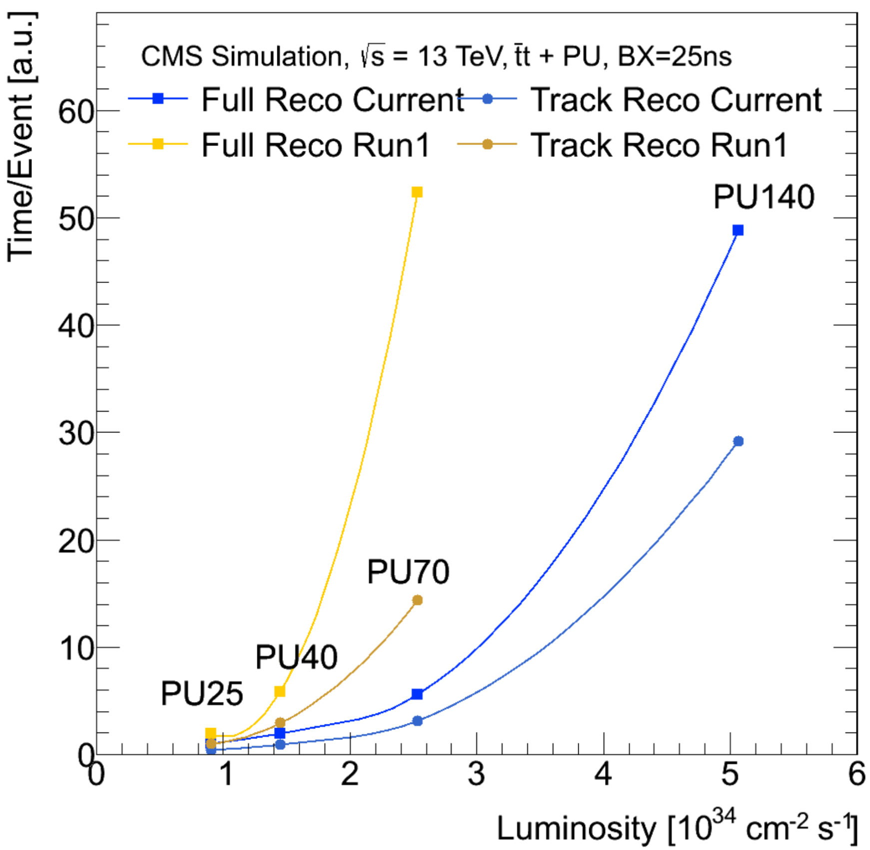
Next-generation framework based on multi-threading approach

Processing higher Run 2 trigger rates efficiently; lower memory usage

Developed "miniAOD" data format ~10 times smaller than what was used in Run 1: target ~80-90% of users

Several technical improvements in the reconstruction code (not impacting physics performance) allowed to reduce drastically the CPUtime/event (x2 reduction)





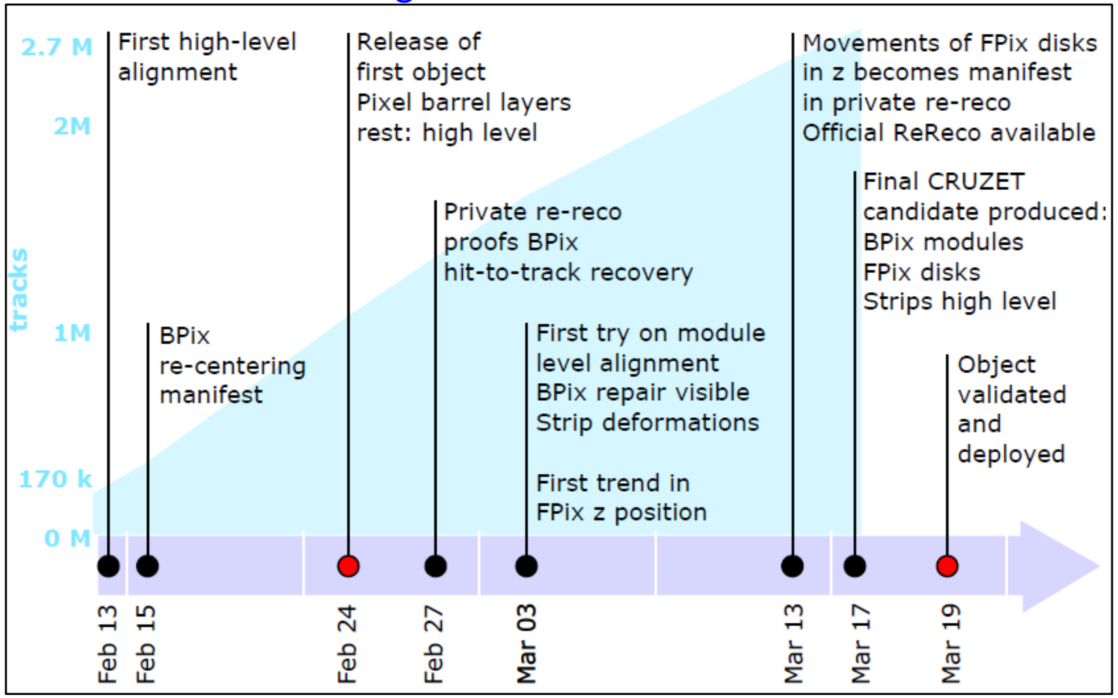
First data taking after two years

We had two cosmic run campaigns needed to provide a first alignment of the tracker.

Cosmic RUN at ZEro Tesla (CRUZET): 420 hours

The goal was 400 hours

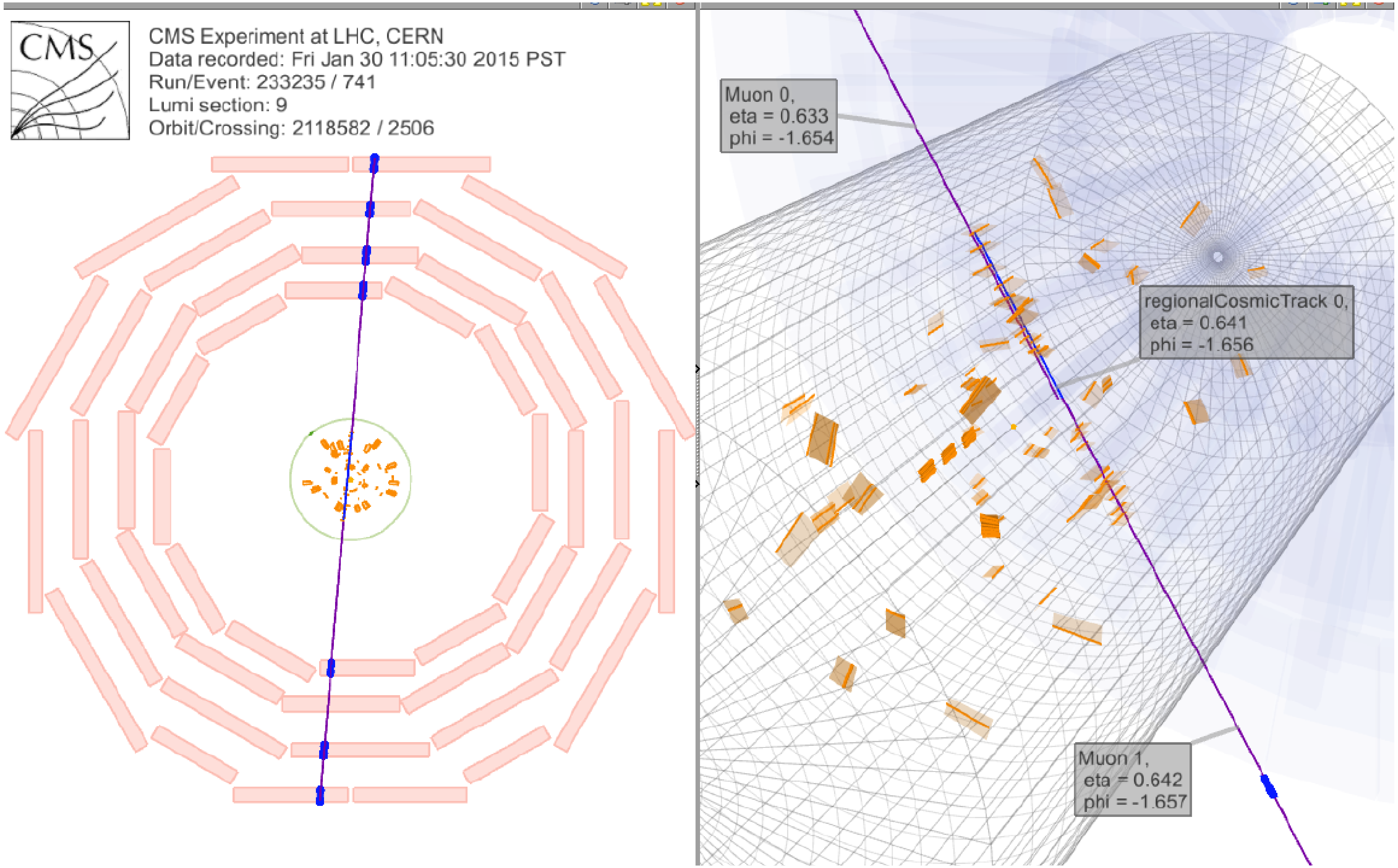
Timeline of Tracker Alignment achievements:



Cosmic RUN At Four Tesla (CRAFT): 200 hours

- B is actually 3.8T
- Ended on April 1st
- Minimal goal: 100 hours

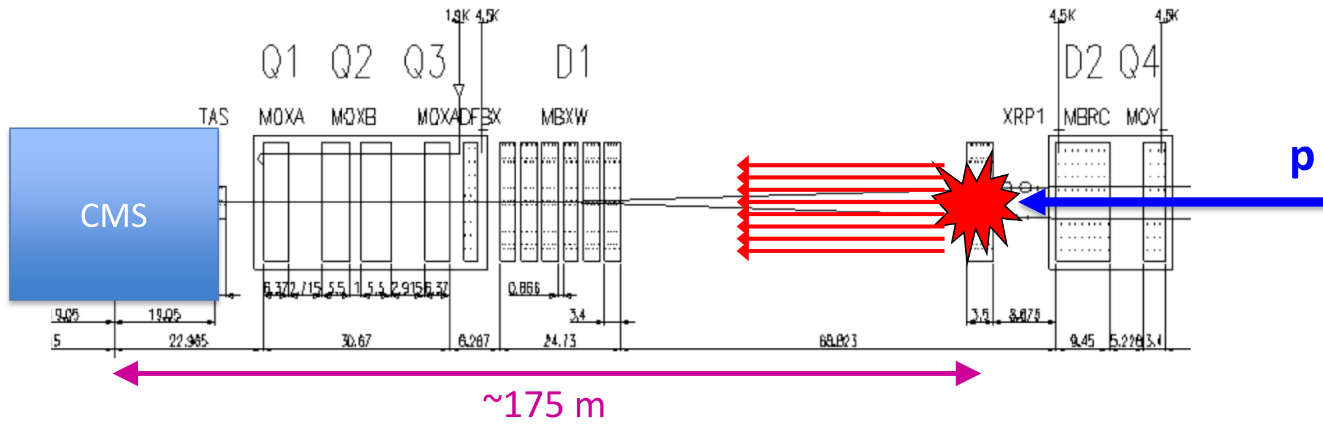
Example Cosmic Ray: Jan 30, 2015

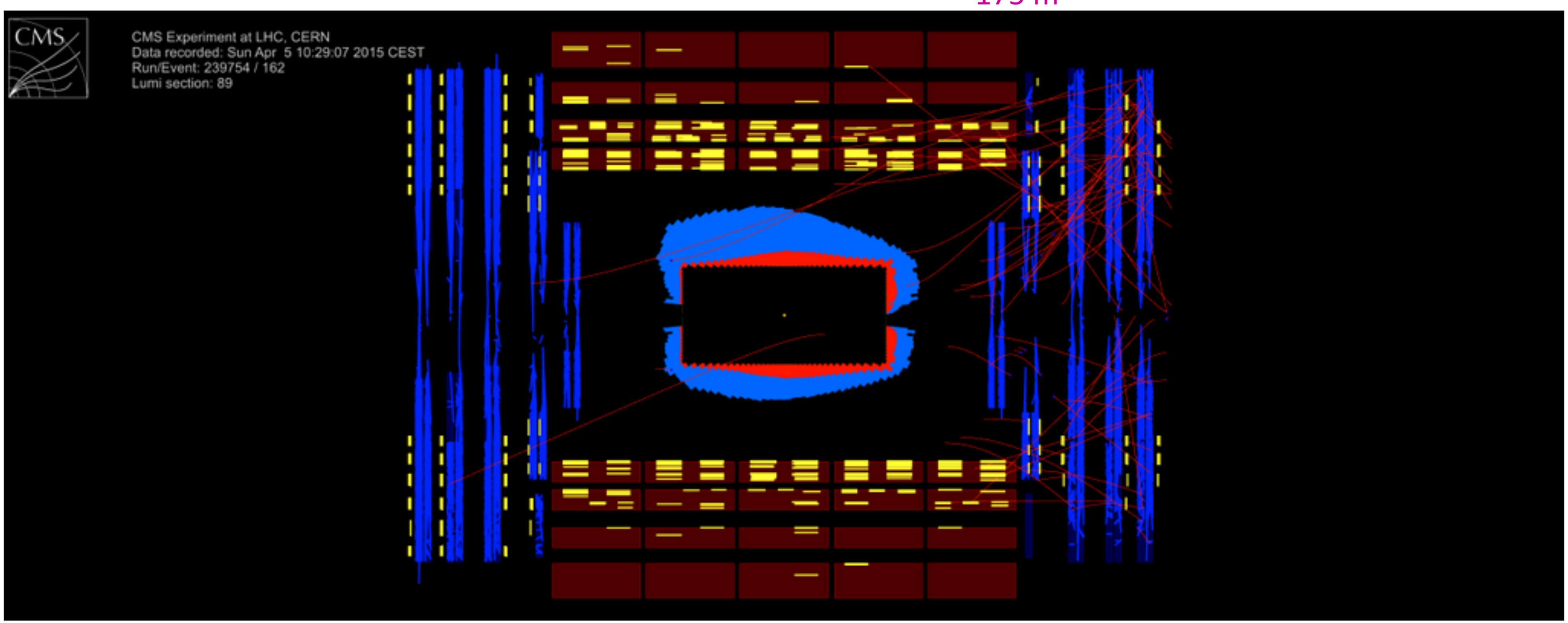


And then beam…(or better splashes)

5 April 2015 10:30: Beam-2 splash at CMS

~3 – 4 x 10^9 protons at 450 GeV/c hit TCT collimators ~175m upstream of CMS
(first splash was ~$10^{5\text{–}6}$ protons)





It's always fun to see a detector alive

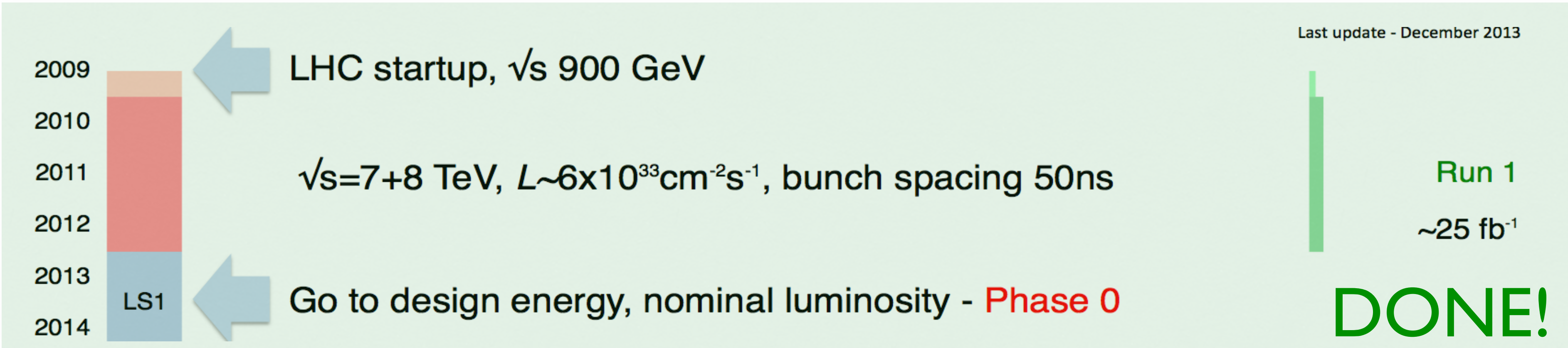
Status of CMS physics and preparation for Run2 analyses

LHC roadmap (as of Dec 2013)

Last update - December 2013

Years	Period	Description	Run / Integrated luminosity
2009		LHC startup, $\sqrt{s}$ 900 GeV	
2010–2012		$\sqrt{s}$=7+8 TeV, L~6x10^{33}cm^{-2}s^{-1}, bunch spacing 50ns	Run 1 ~25 fb^{-1}
2013–2014	LS1	Go to design energy, nominal luminosity - Phase 0	
2015–2018		$\sqrt{s}$=13~14 TeV, L~1x10^{34}cm^{-2}s^{-1}, bunch spacing 25ns	Run 2 ~75-100 fb^{-1}
2018–2019	LS2	Injector + LHC Phase I upgrade to ultimate design luminosity	
2020–2022		$\sqrt{s}$=14 TeV, L~2x10^{34}cm^{-2}s^{-1}, bunch spacing 25ns	Run 3 ~350 fb^{-1}
2023–2025	LS3	HL-LHC Phase II upgrade: Interaction Region, crab cavities?	
2025 … 2035?		$\sqrt{s}$=14 TeV, L~5x10^{34}cm^{-2}s^{-1}, luminosity levelling	~3000 fb^{-1}

Where do we stand



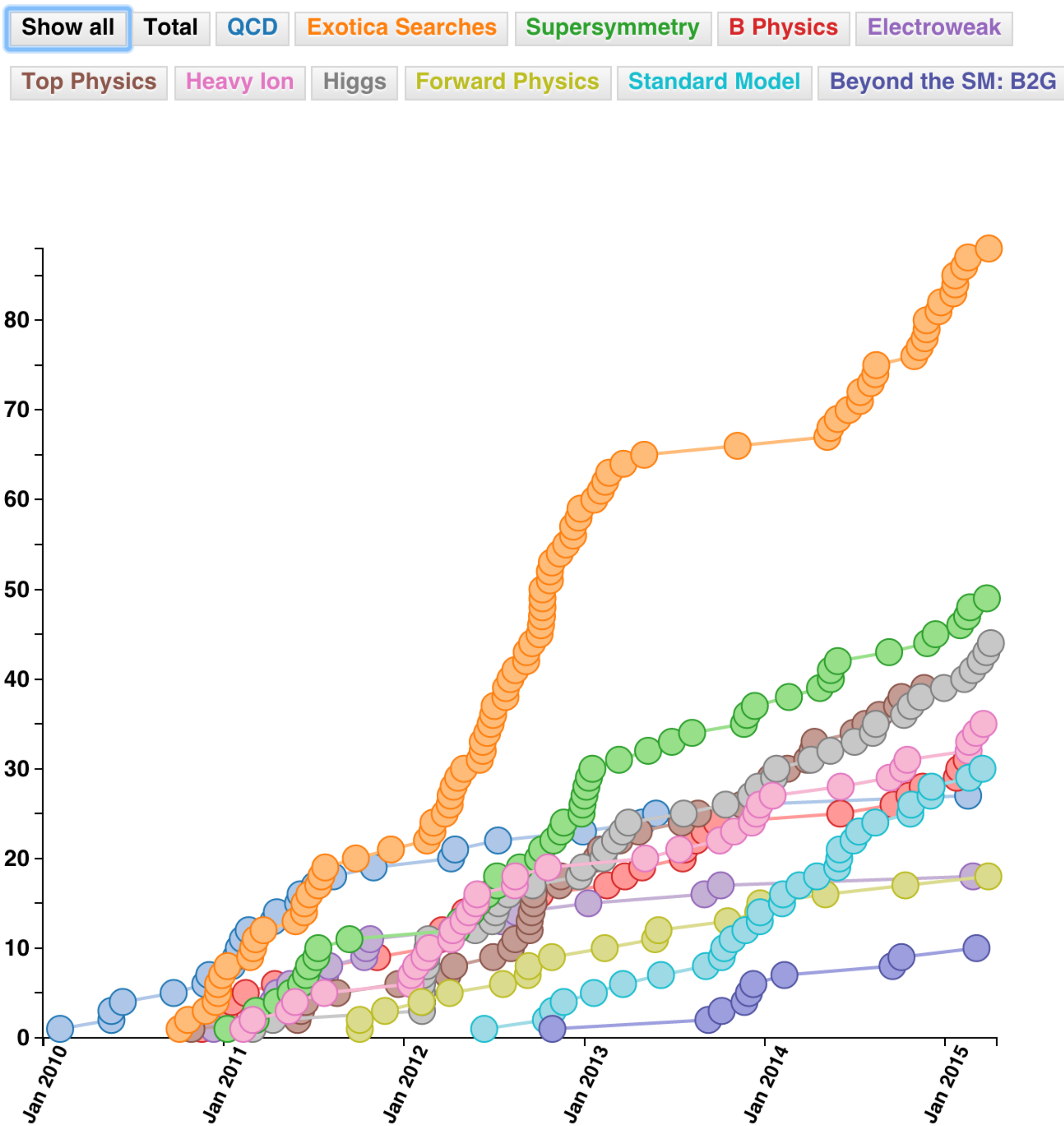
Standard Model complete: Higgs discovery!

- Bosonic decays established to more than 5 σ
- Fermionic decays observed
- Spin structure extensively tested (even though not able yet to firmly exclude other possibilities than 0+)
- (Some) couplings known to 10-20 %

Standard Model extensive tests at multiTeV scale

- Long list of of measurements at 7-8 TeV (none of them showing signs of BSM physics)
- Entered the precision physics arena
- Rare processes sensitive to New Physics, like $Bs \to \mu\mu$ decay, probed and showing no interesting discrepancies

Run 1 Pub and Analysis Status



Pub rate steady in LS1, few submissions / week

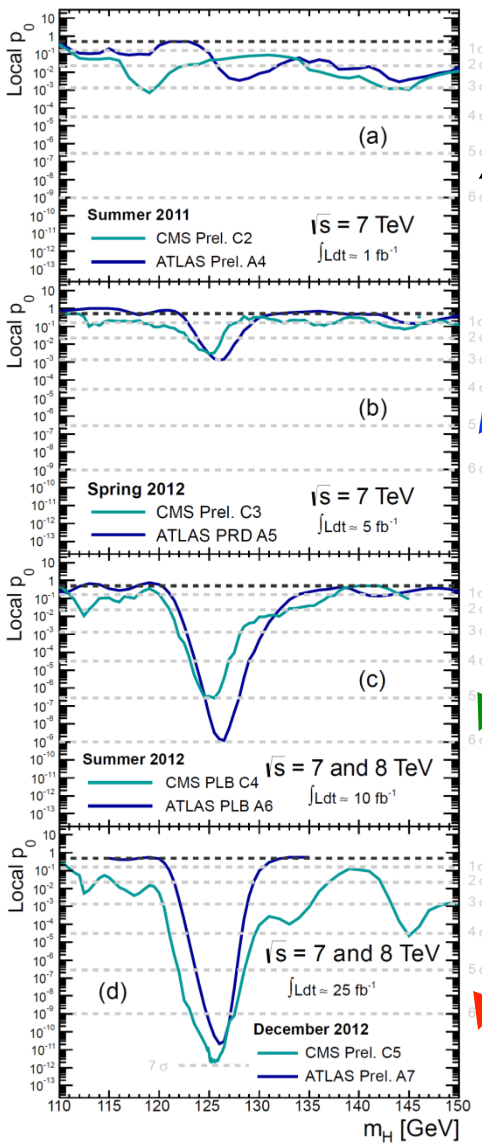
388 papers submitted:
- +23 CRAFT based
- +24 in-or-post final review
- +8 PubDraft

Bulk of remaining Run 1 measurements targeting publication by summer (to avoid overlap with Run 2)

Where do we stand

Higgs: mission accomplished

From PDG



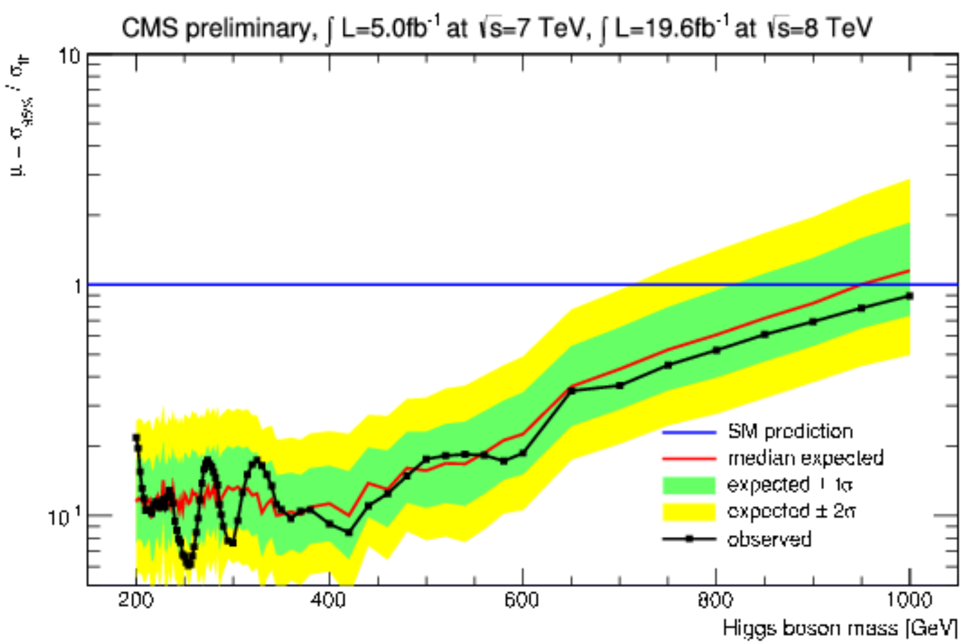
Summer 2011: drops in the bucket

End of 2011: tantalizing hint, the trail begins

Summer 2012: discovery! 5σ from both experiments

End of 2012: confirmation! Measurement era begins

…and we did not find a SM-like Higgs boson anywhere else:



Where do we stand

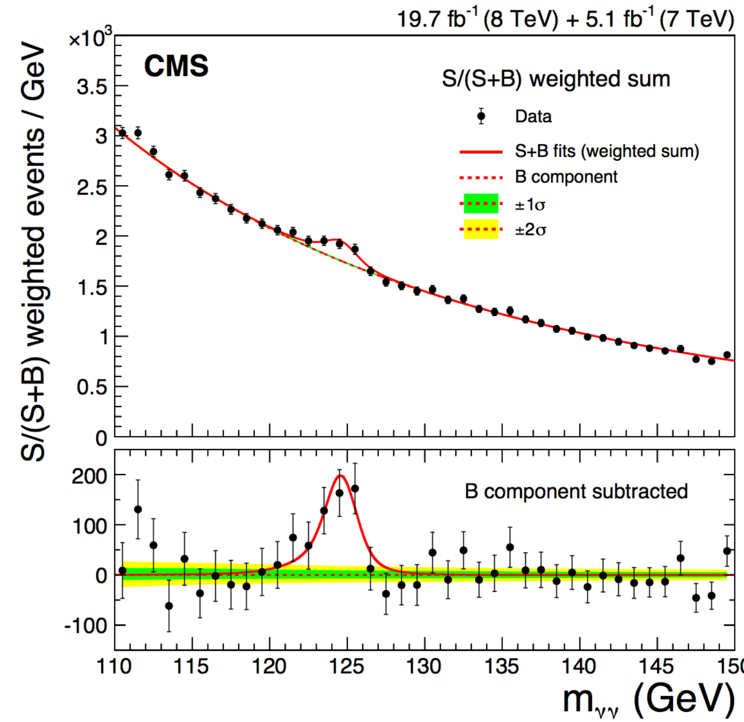
Higgs: mission accomplished

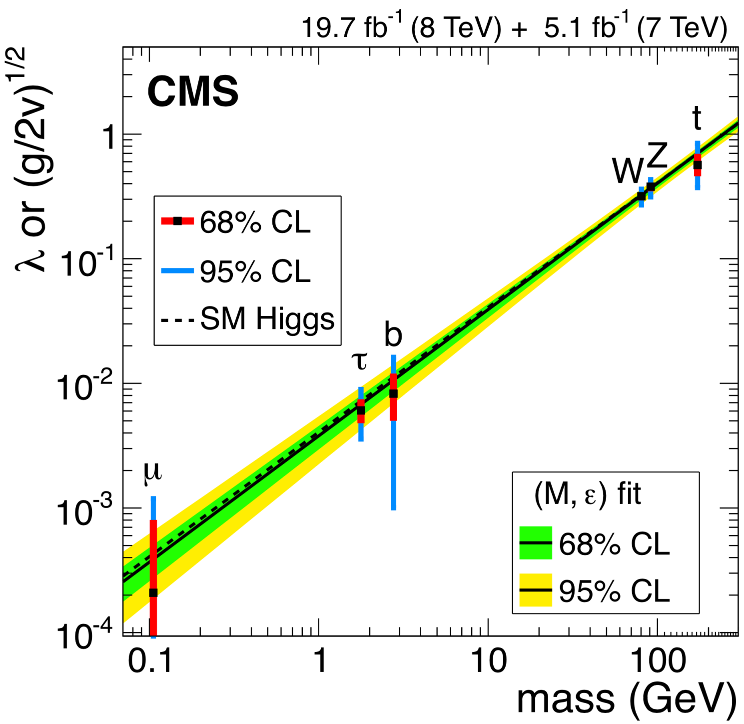
All "big 5" channels published.
Full combo submitted for publication:

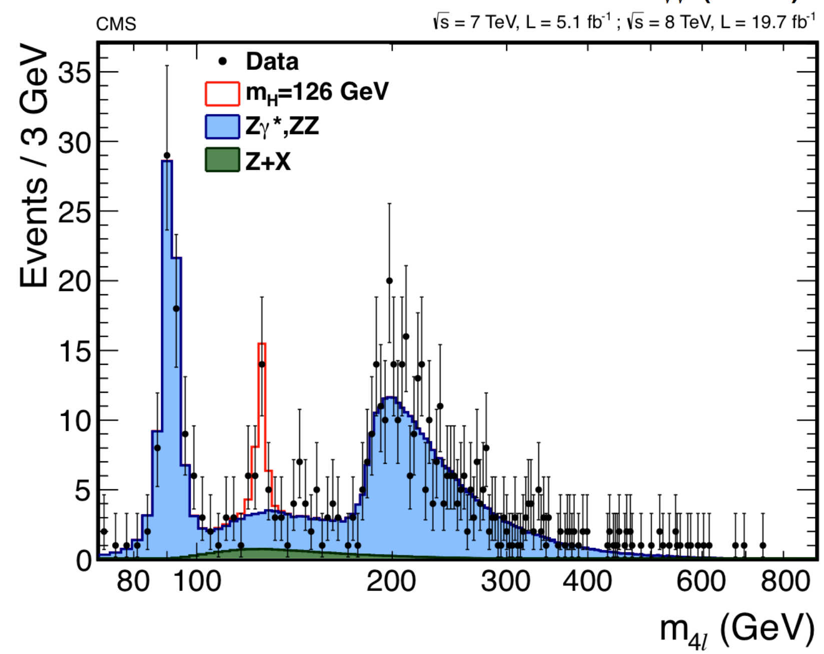
http://arxiv.org/abs/arXiv:1412.8662

$$m_{\mathrm{H}} = 125.03\,^{+0.26}_{-0.27}\,(\mathrm{stat.})\,^{+0.13}_{-0.15}\,(\mathrm{syst.})\ \mathrm{GeV}$$

$$\mu = 1.00^{+0.14}_{-0.13}\ \left[\pm 0.09(\mathrm{stat.})^{+0.08}_{-0.07}(\mathrm{theo.}) \pm 0.07(\mathrm{syst.})\right]$$



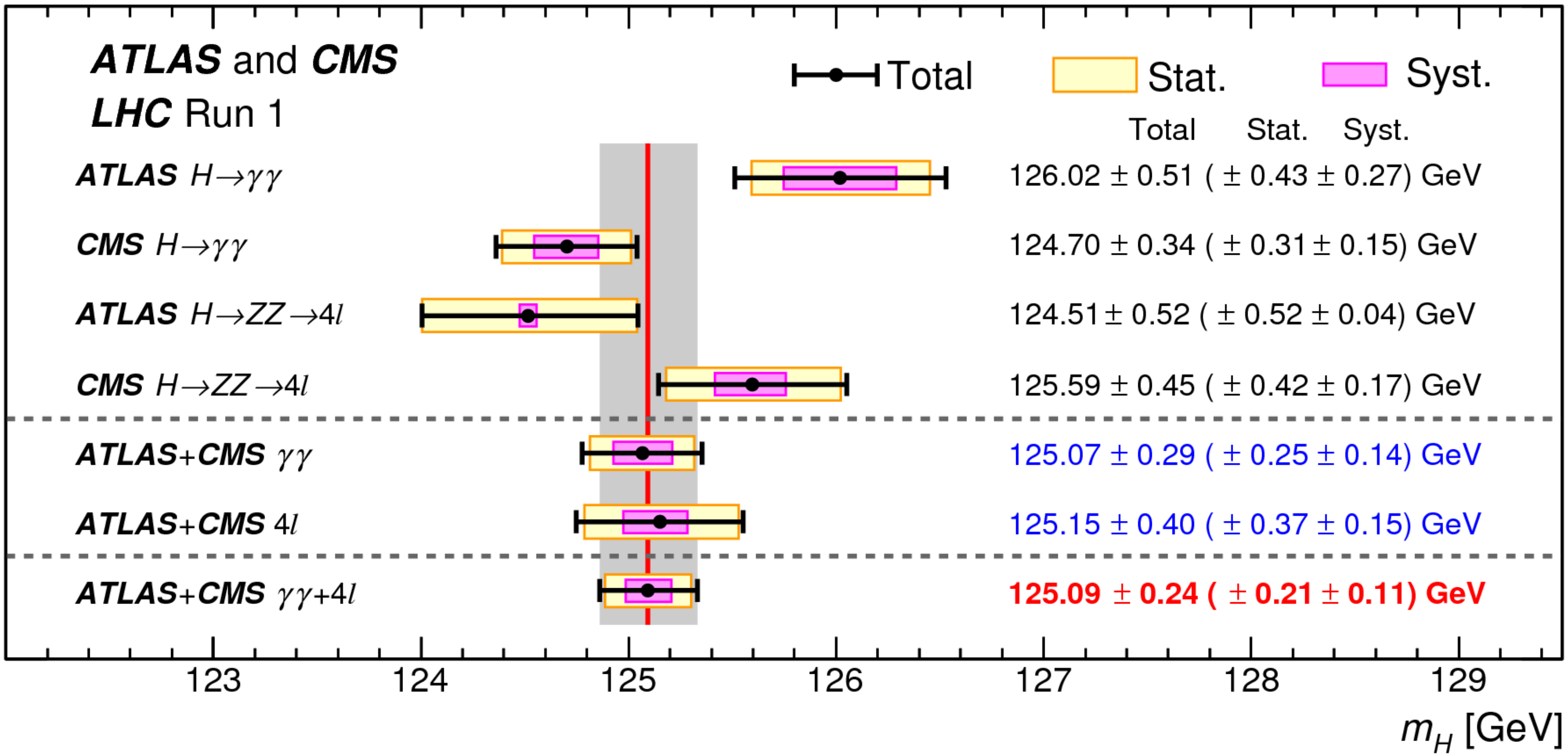




Where do we stand: LHC Higgs Mass Comb.

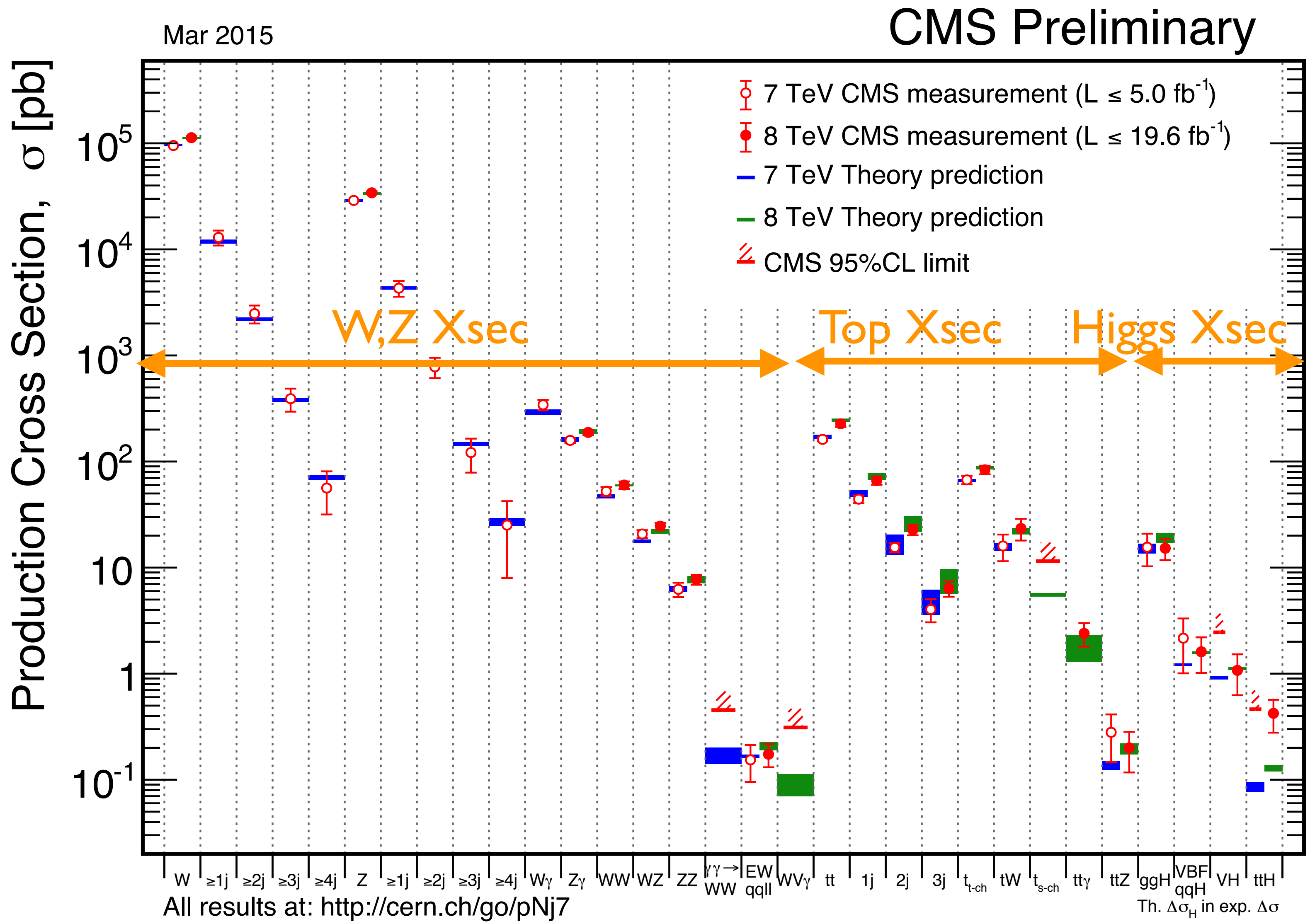
We have approved the first ATLAS-CMS Higgs mass combination.

The joint paper was submitted to PRL on March 26.



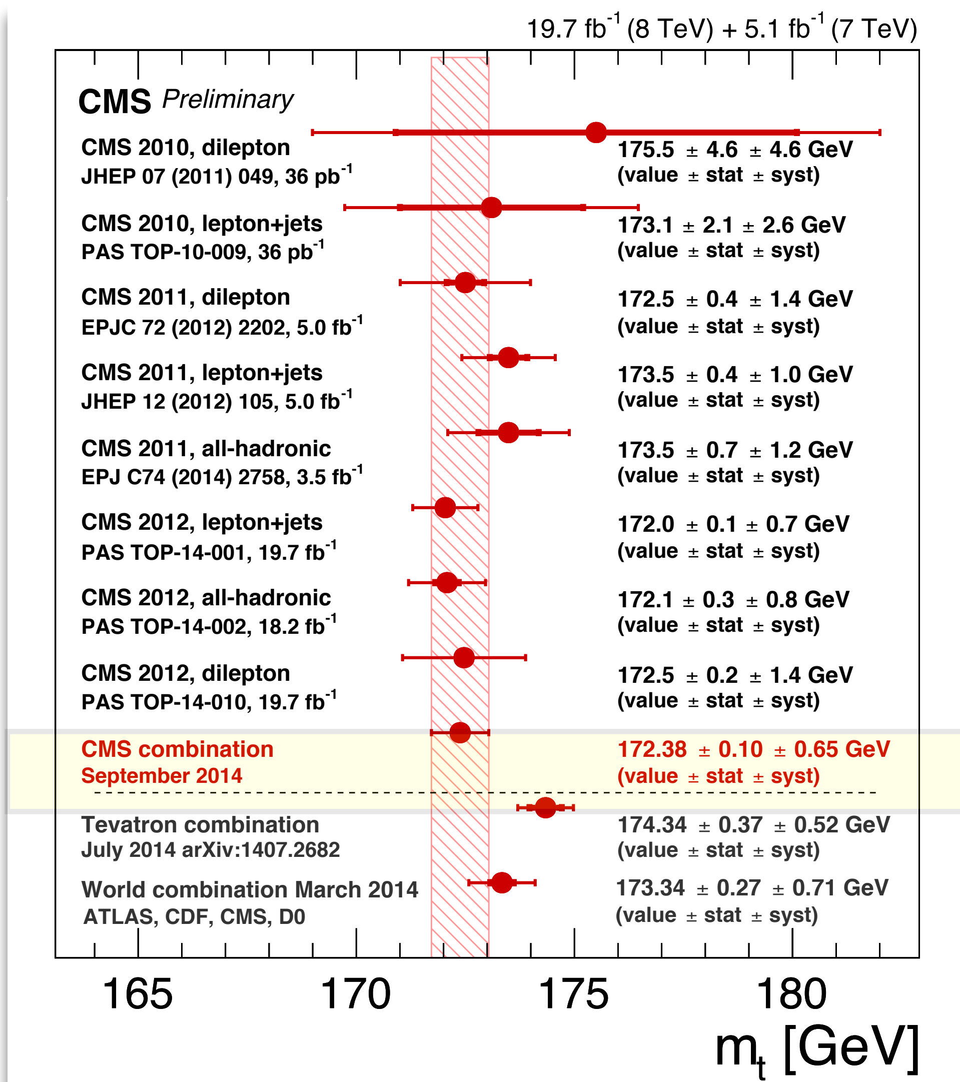
Where do we stand

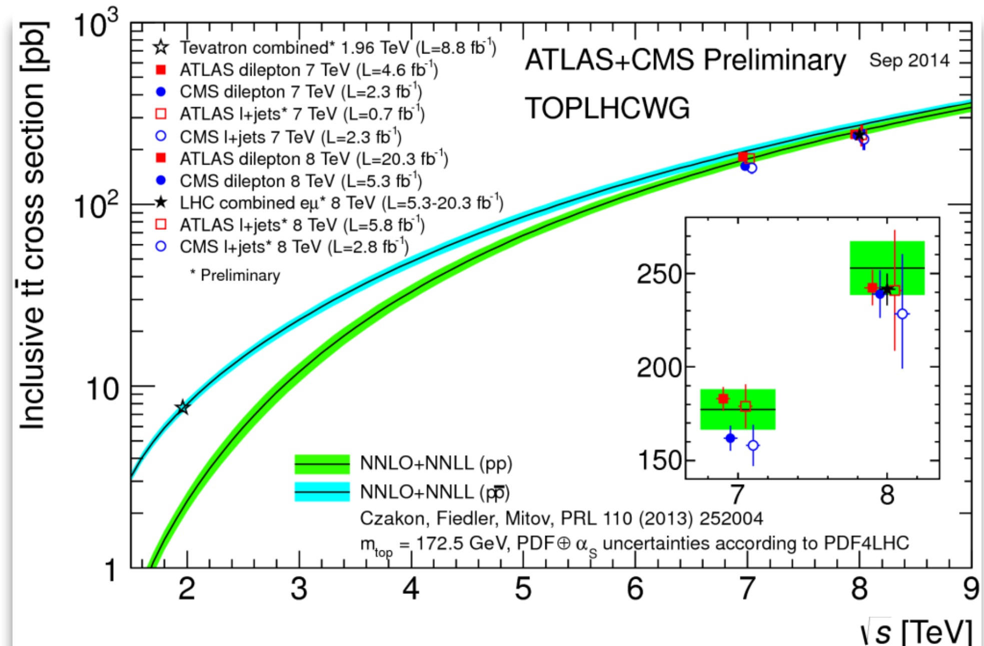
Standard Model: as healthy as ever

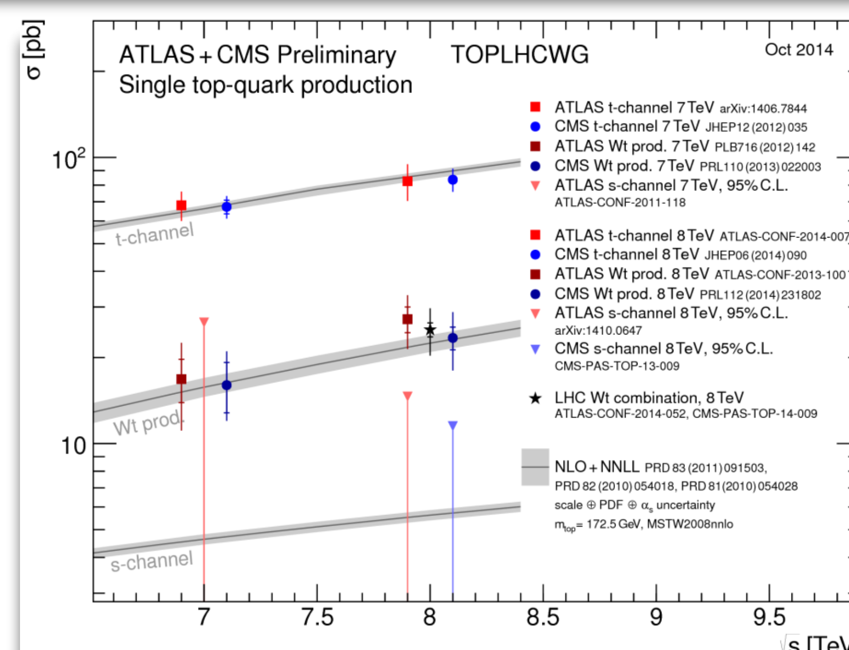


Where do we stand

Top quark measurements





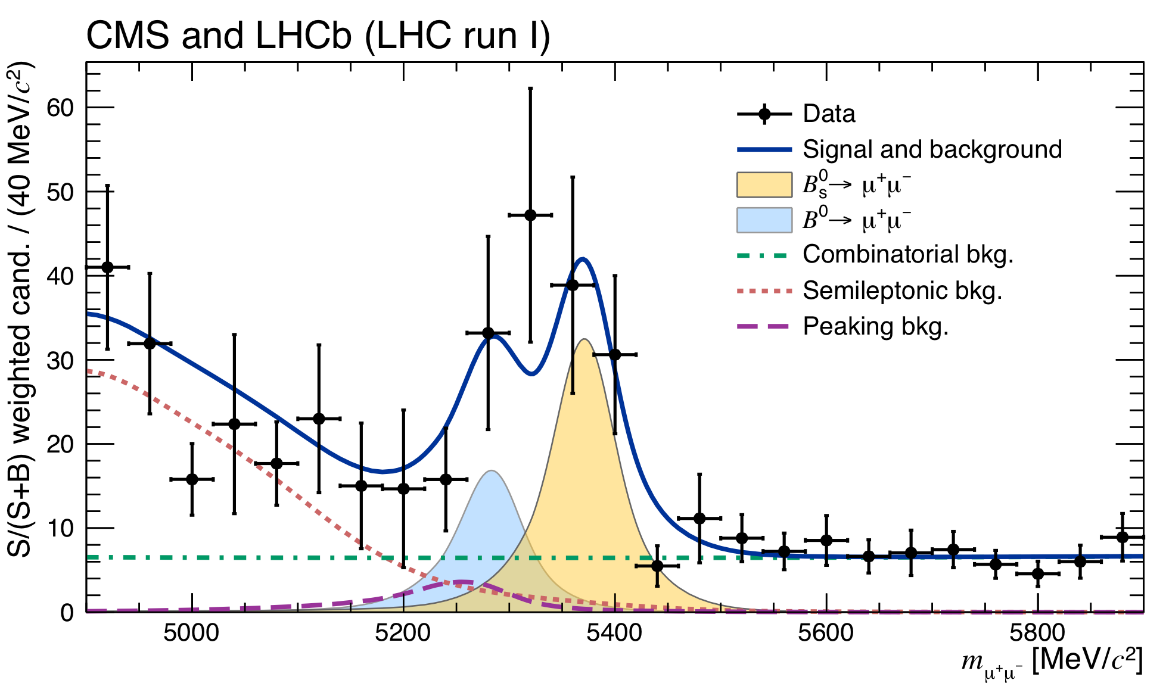


- (almost) world leading measurement
- fully dominated by theory and JES syst

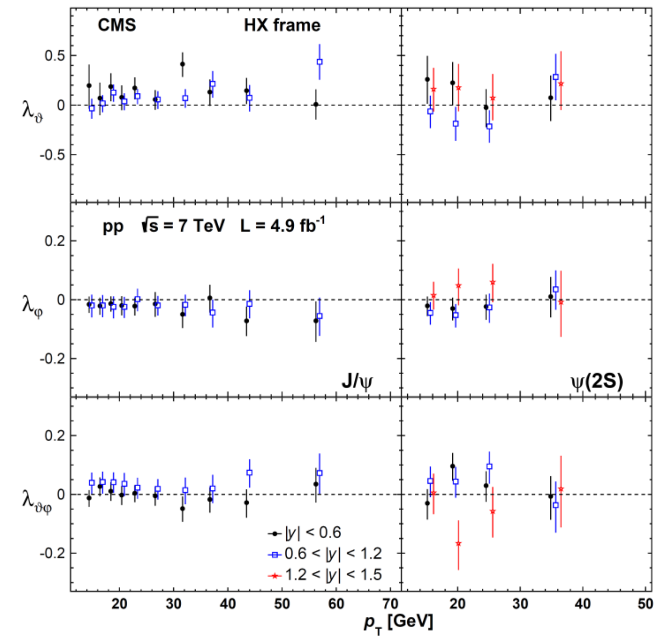
Where do we stand

B physics and quarkonia

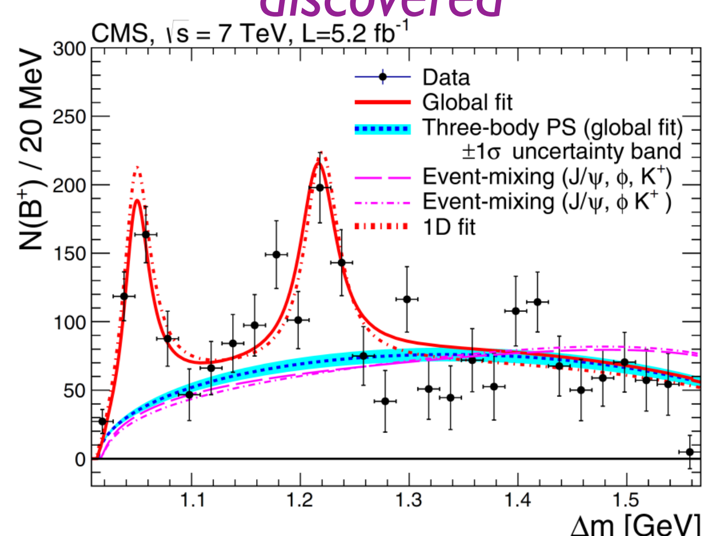
$B_{(s)} \rightarrow \mu\mu$
- first observation !
- combined "Nature" paper with LHCb recently submitted: http://arxiv.org/abs/1411.4413



J/ψ and ψ(2S) polarization



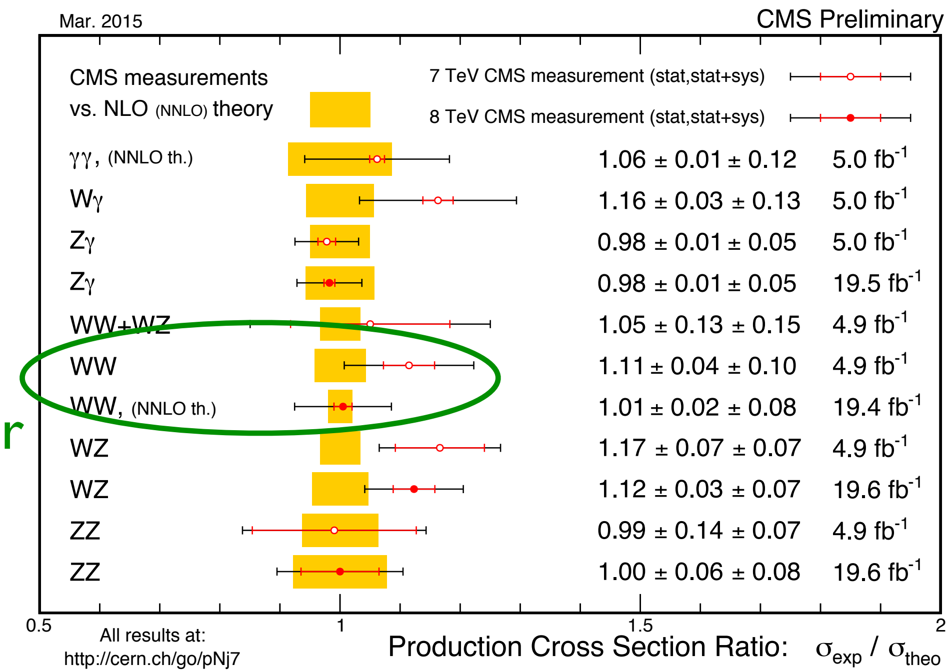
New states continuously discovered



Where do we stand

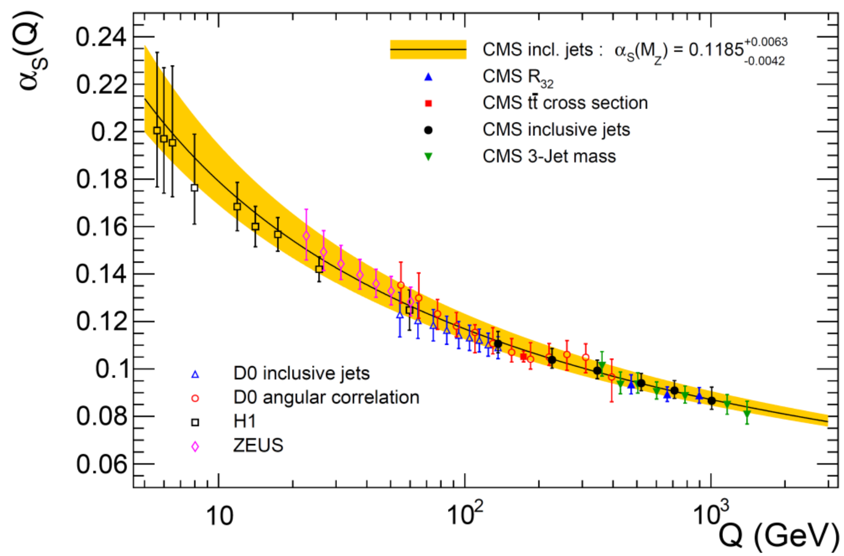
Precision QCD and SMP measurements

Diboson cross sections

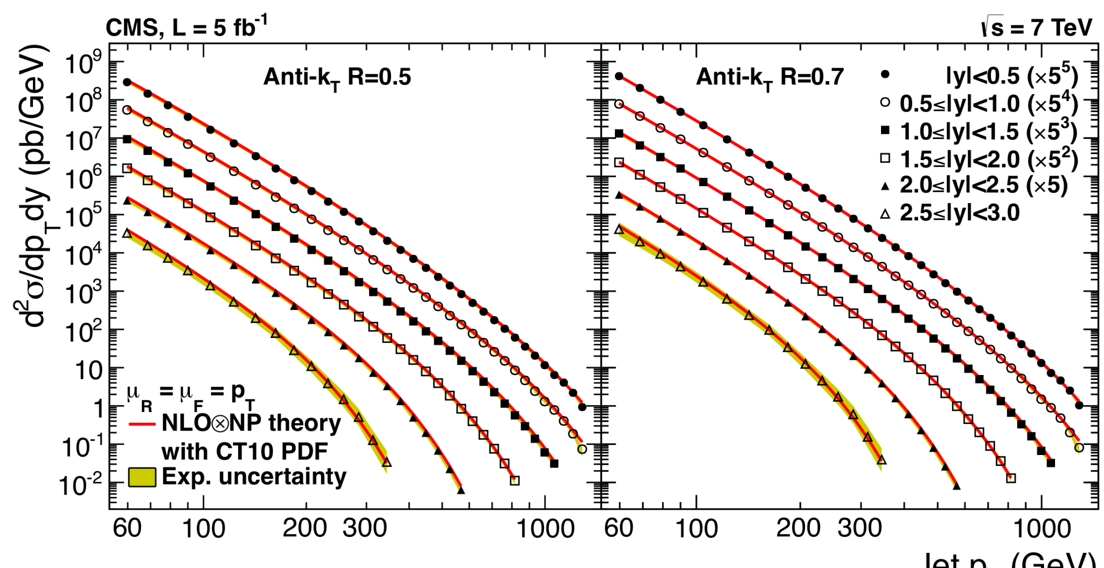


Remember the WW anomaly?

Running $\alpha_S(Q)$ measurements with different techniques



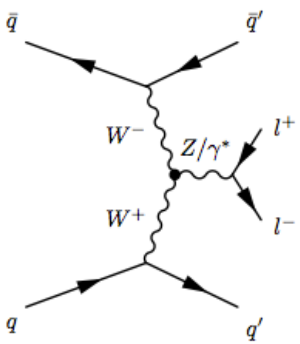
Differential jet production cross section

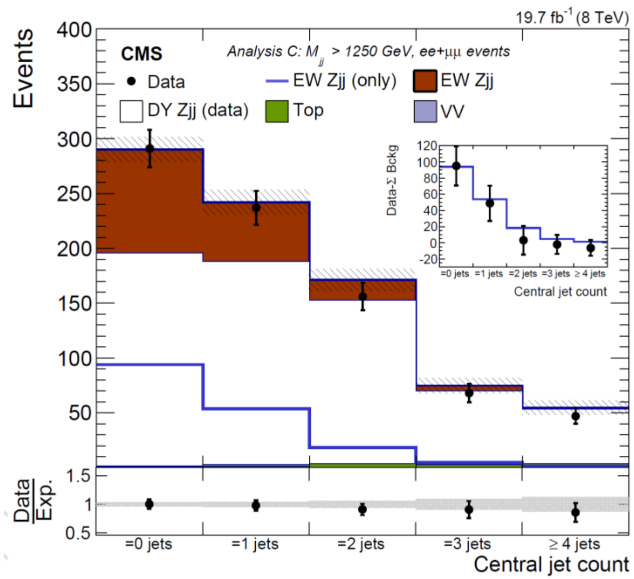


Where do we stand

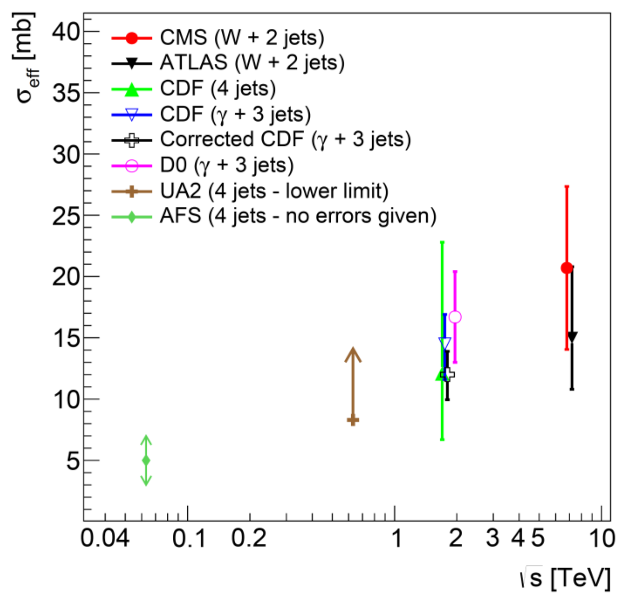
Forward and Heavy Ion Physics

Z production in VBF

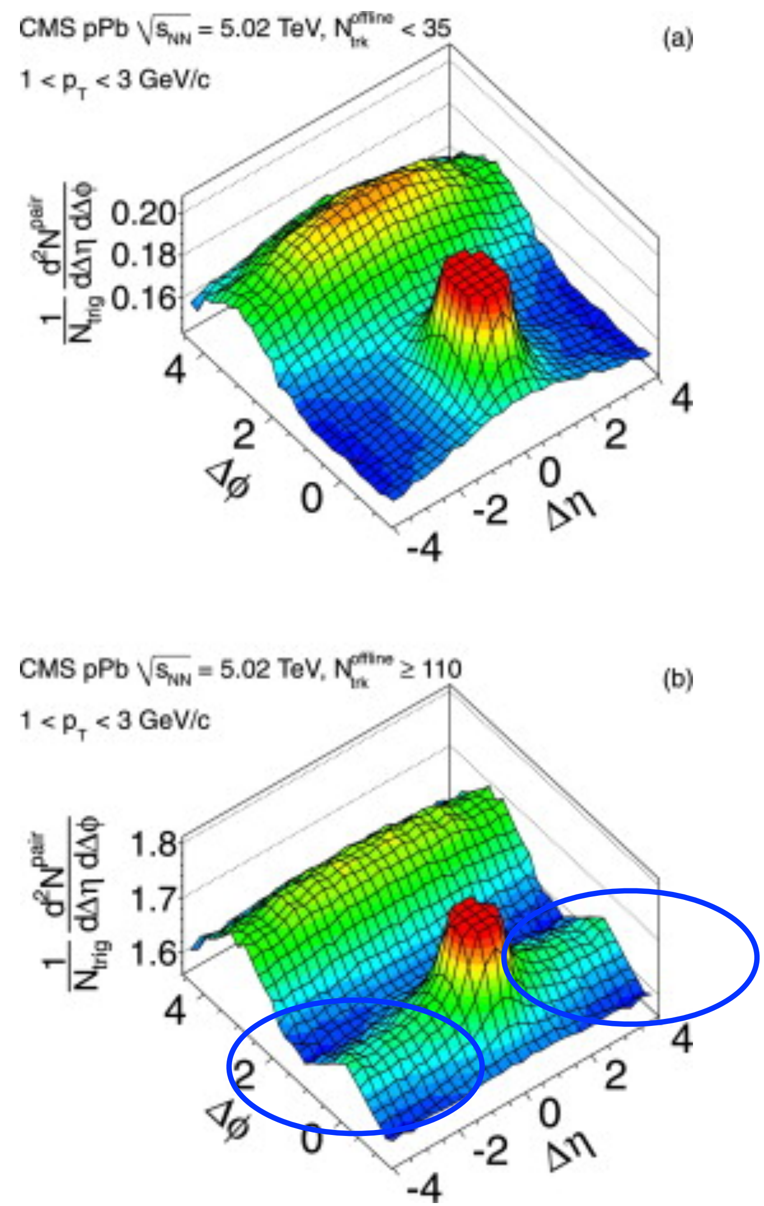




Multiparton interactions (more than one hard scatter in the same pp collision, in this case W + jj)



The famous ridge



Where do we stand

All NP searches were unfortunately null

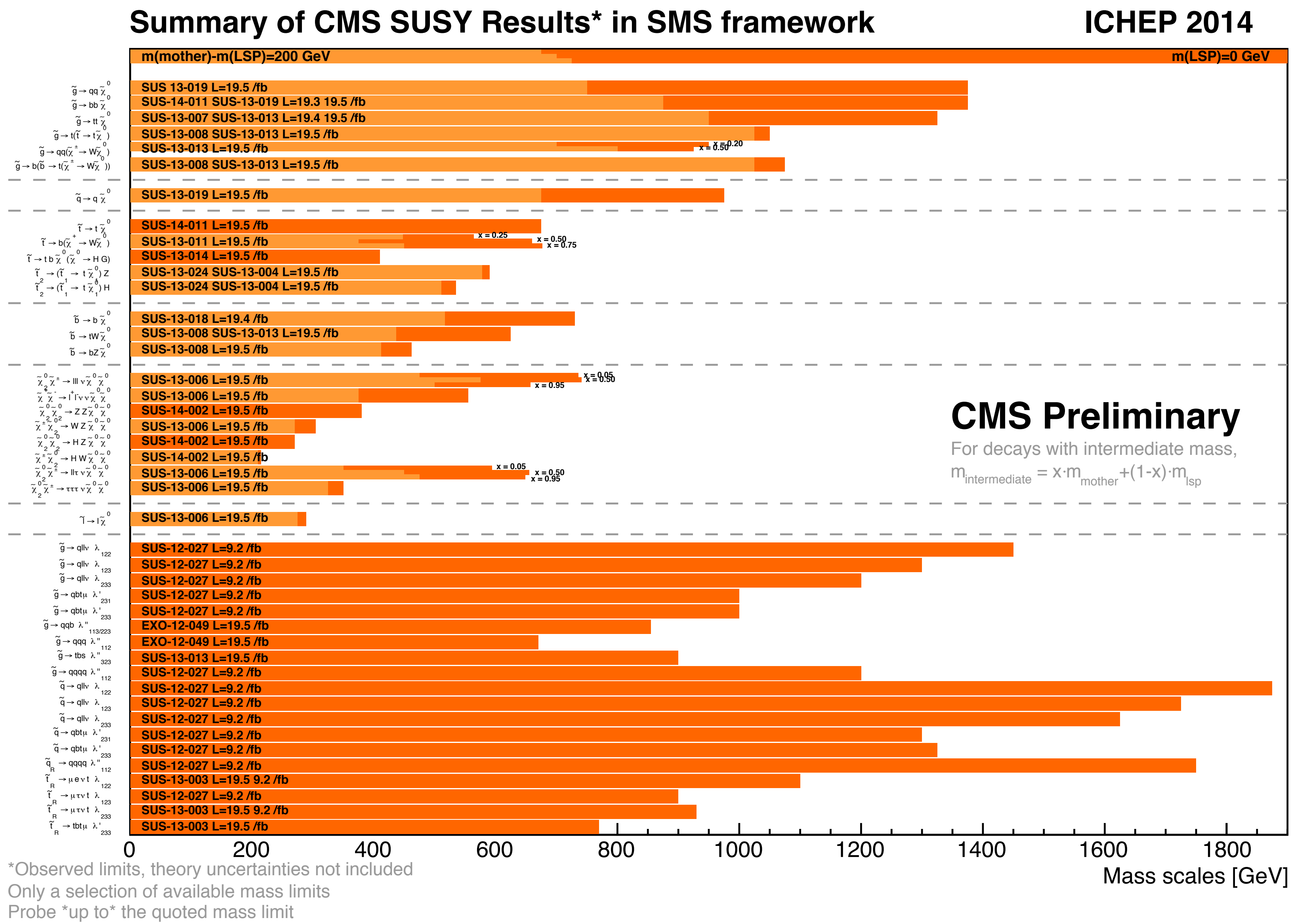
SuSy

gluino exclusions ~1.3 TeV

stop/sbottom ~700 GeV

EWKino ~300 GeV

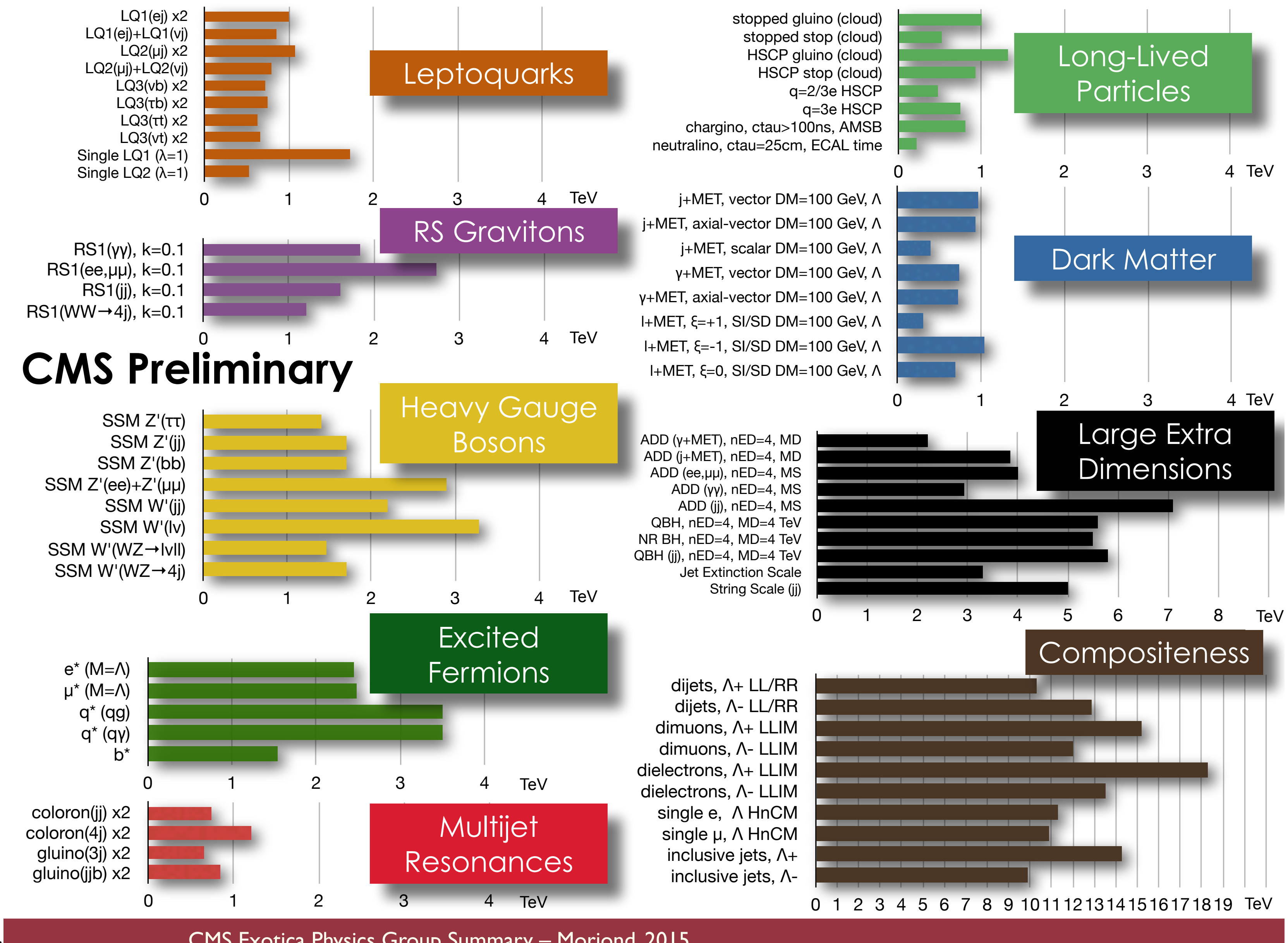
CAVEAT: several assumptions behind these limits



Where do we stand

All NP searches were unfortunately null

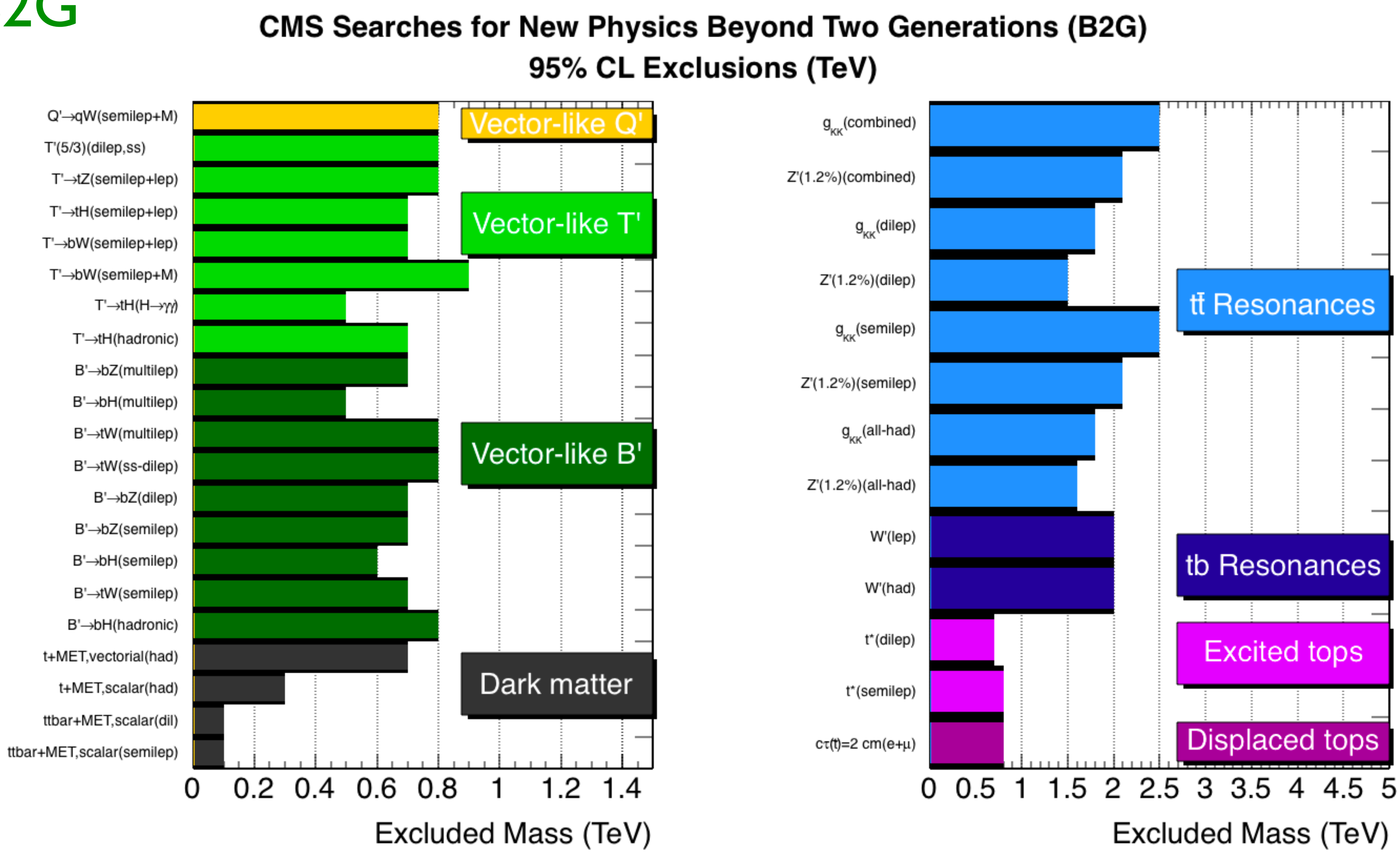
Exotica



Where do we stand

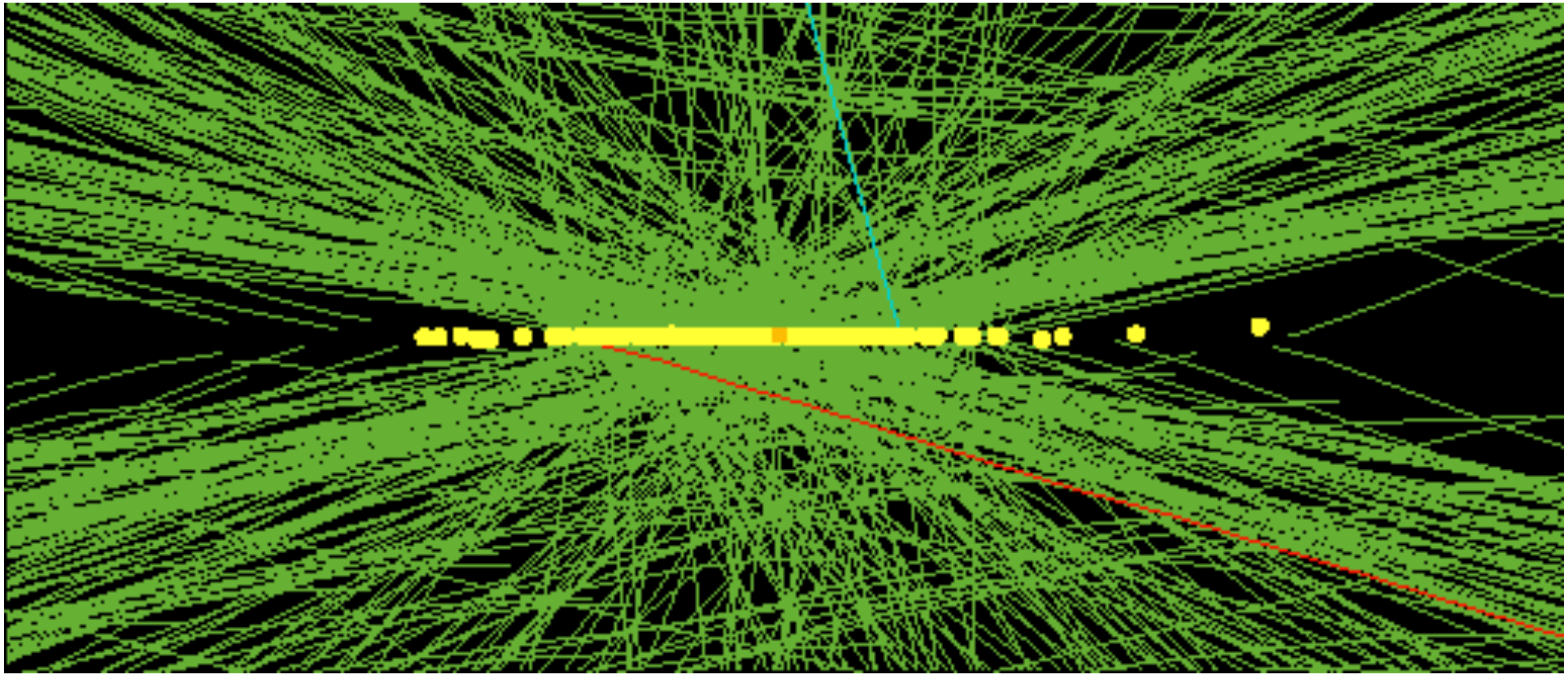
All NP searches were unfortunately null

B2G



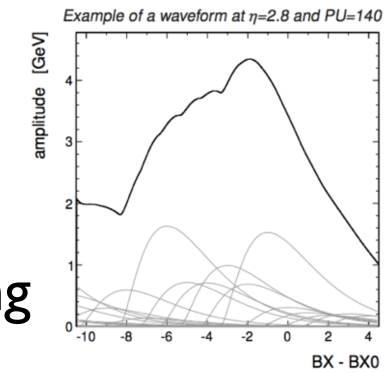
How we are preparing for physics in Run2

Object ID Challenges
(most of them due to Pile-up, in time and out of time)



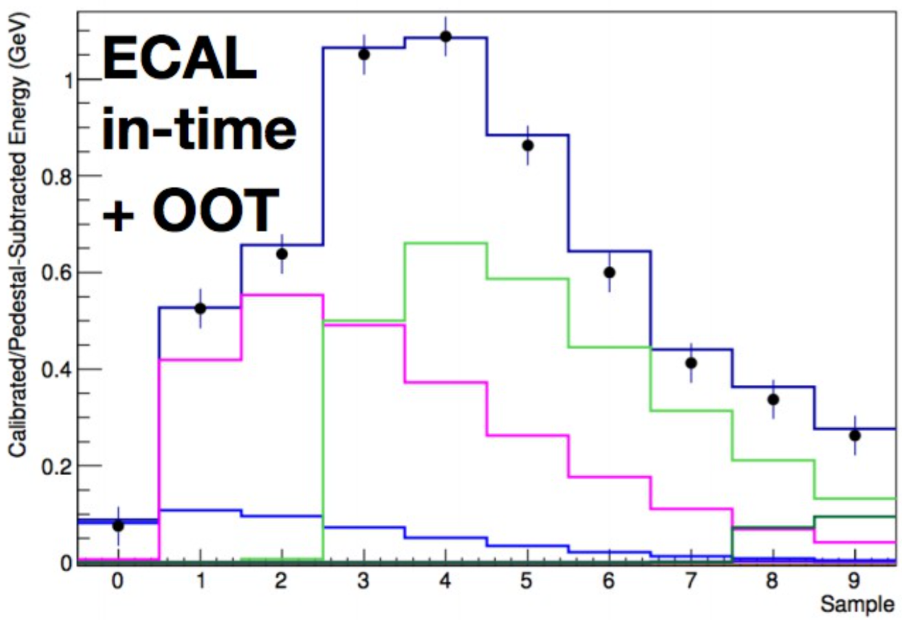
Challenges and new tools for 2015

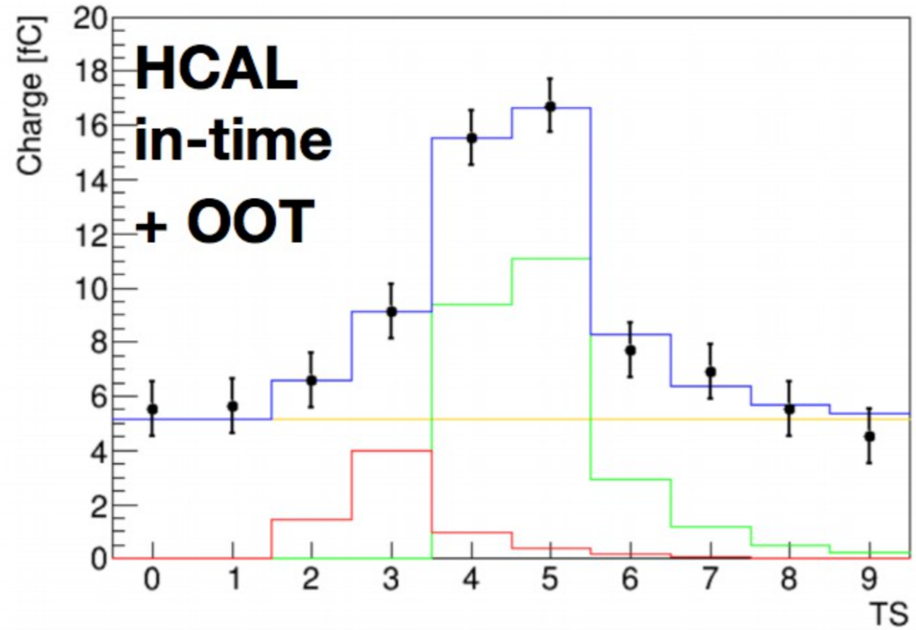
Pile up in 2015 will reach another frontier:



- Out of time (OOT) pileup is a totally new story
  - need to adapt reconstruction to 25ns running
  - need to identify OOT pileup hit at low level by using the timing information in the calorimeters
  - work quite advanced already in ECAL and HCAL and close to final

Fitting techniques with templates based on overlapping pulses used both in ECAL and HCAL



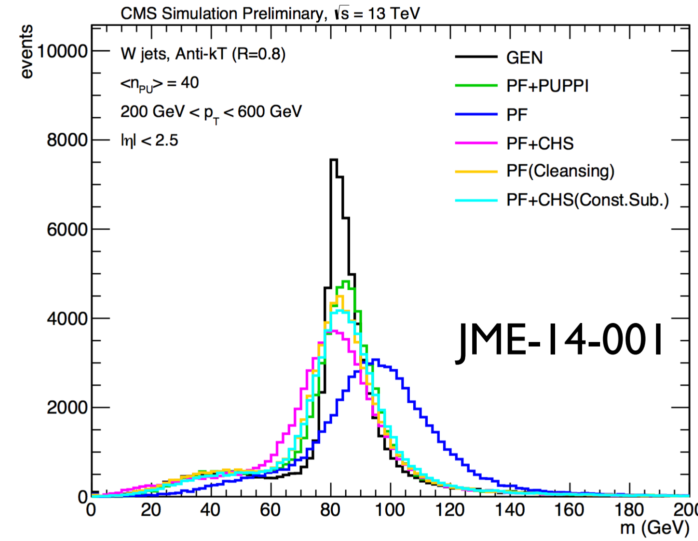


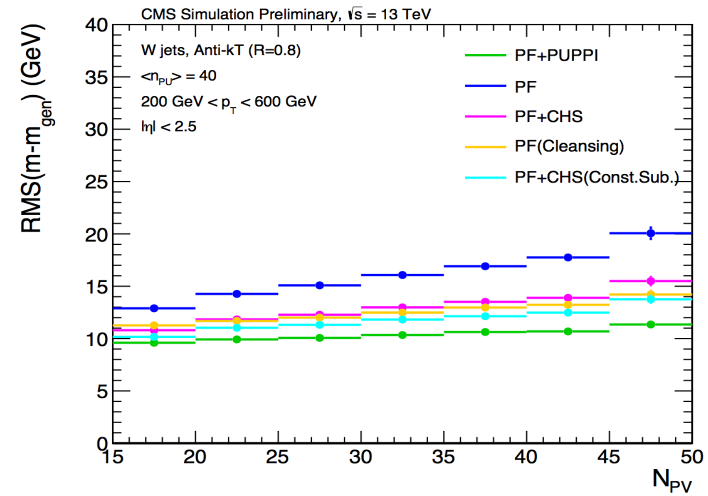
Pile up in 2015 will reach another frontier:

- In time pile up (PU) can get as high as 40 in average
  - in 2012 we have collected less than 1% of our luminosity with PU>35
- new techniques are being developed at high level reco using mostly information from Particle Flow objects
  - most of them associate a weight to all particle candidates corresponding to the probability to come from a PU collision:

$$w_i = \frac{\Sigma log \frac{p_{Tj}}{\Delta R_{ij}}(LV)}{\Sigma log \frac{p_{Tj}}{\Delta R_{ij}}(LV) + \Sigma log \frac{p_{Tj}}{\Delta R_{ij}}(PU)}$$

  - in a simple approach the weight comes from the distance of the neutral particle w.r.t. to candidates associated to the primary vertex
  - more sophisticated approach (PUPPI) add to the weight many other observables

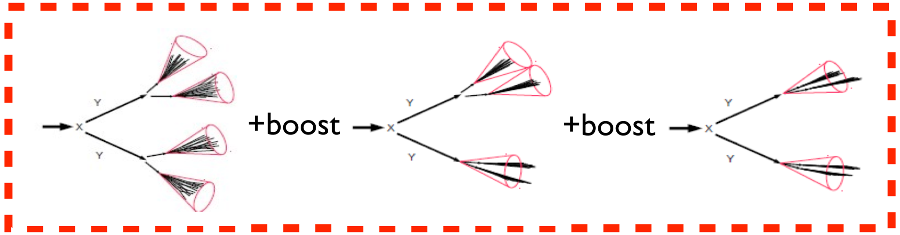


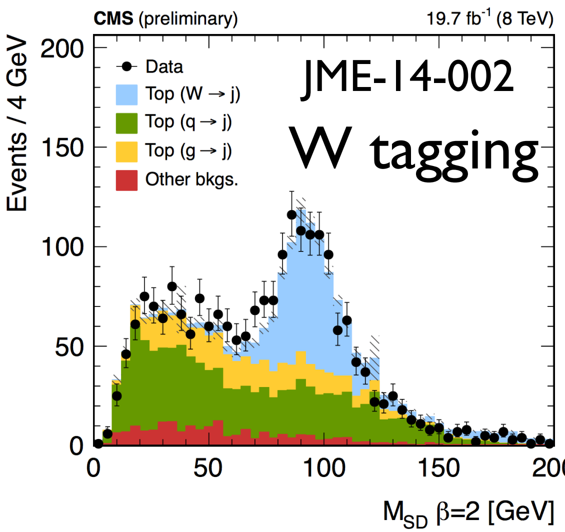


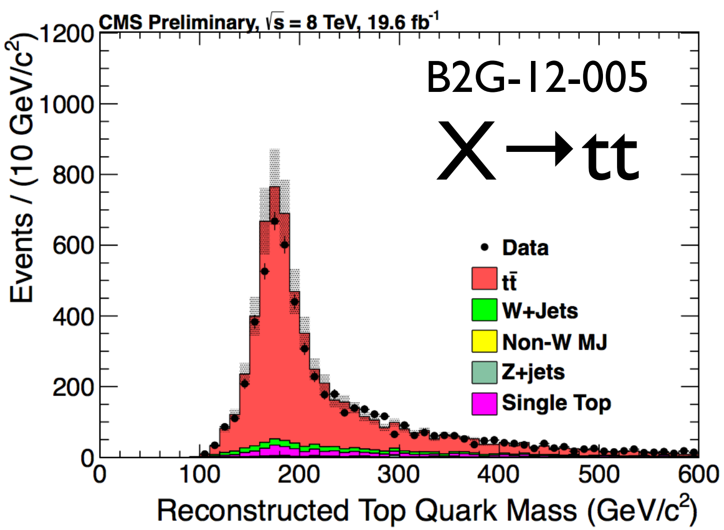
We will need also new tools

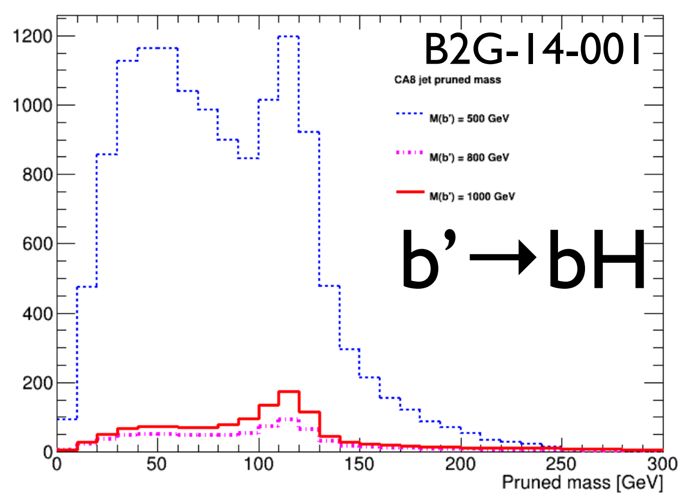
Many searches for new physics will be based on high mass resonances or boosted Higgs/top in order to maximally profit of the increased energy:

- tools to analyse boosted topologies are needed
- W, Z, Higgs, top tagger (from monojets signatures)
- b-tag and substructure id
- few searches already published





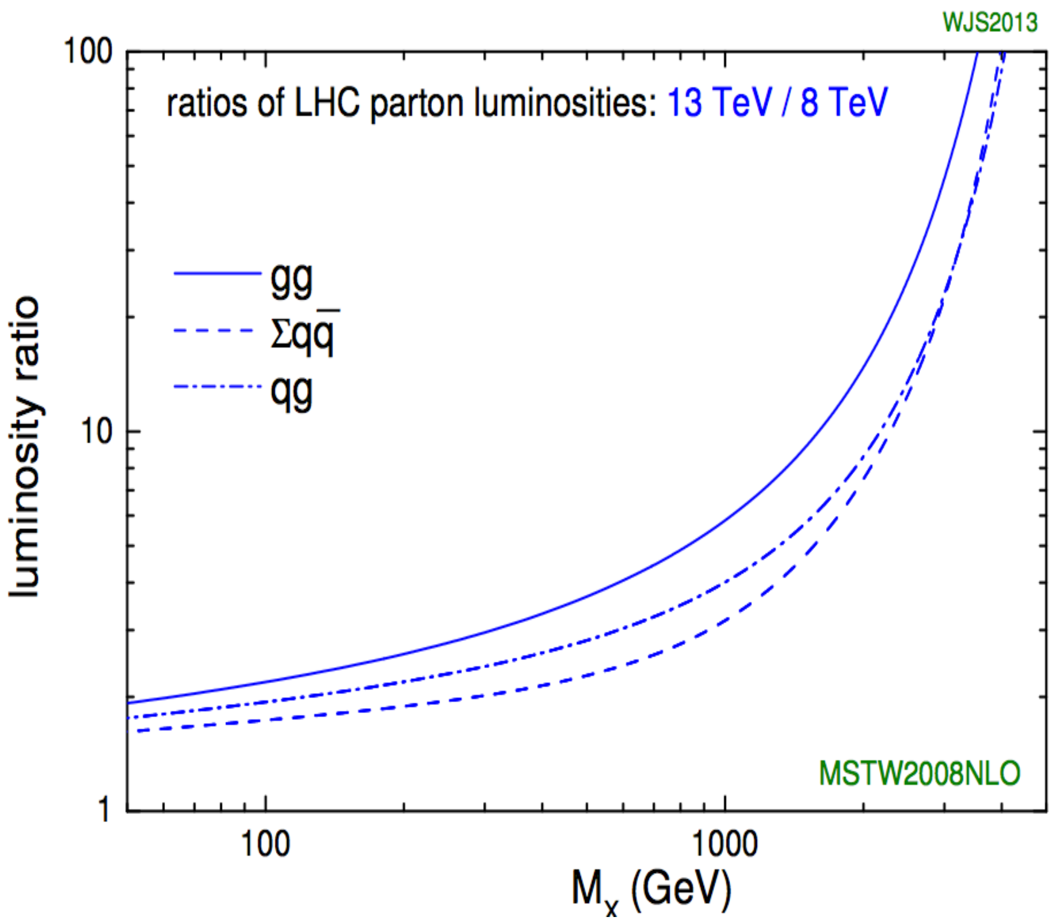




Analysis Challenges

Toward Run 2 planning

Then optimizing in terms of physics potential matched to available luminosity



The larger the scale the sooner we will overcome Run1 reach

- direct extrapolation from Stirling plot (i.e. when will we exceed the 8 TeV discovery potential?)
- Explore corner of phase space left hidden in our 8 TeV data (low missing Et, low pt leptons, long-lived, etc.) but for this we need a lot of ingenuity and flexibility at trigger and data processing level
- Precision physics:
  - test that bkgs for searches are well modelled (including our MC tuning)
  - Indirect searches.

How do we plan for Run2

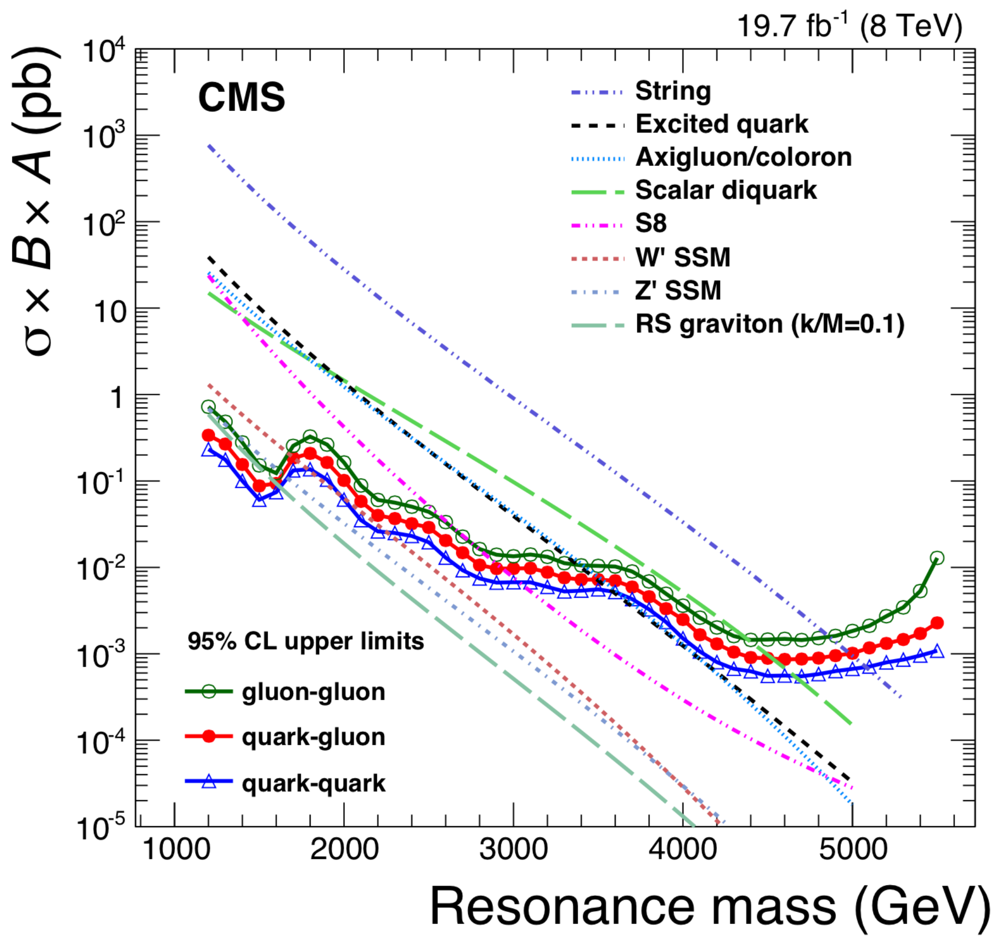
Going backward along the line of effective luminosity ratio

dijet resonances → x100 (M= 4-5 TeV)

we will be in an unexplored region literally on day 1 !

arXiv:1501.04198

- Search for strongly produced resonances or micro black holes decaying into dijets
- current limits ~4-5 TeV
- Effective integrated luminosity at 13 TeV to overcome current limits : <100 pb^{-1}



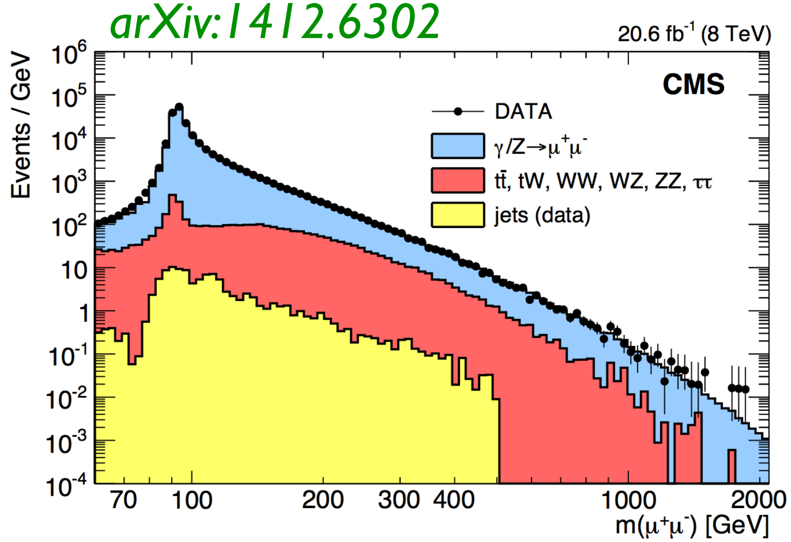
How do we plan for Run2

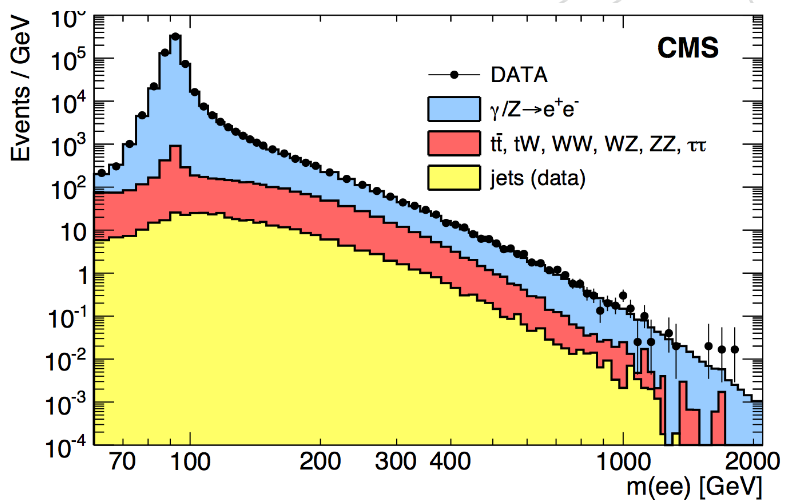
Going backward along the line of effective luminosity ratio

Z'→ x13 (M= 3 TeV)

we will be in an unexplored region with 1-2 fb^{-1} !

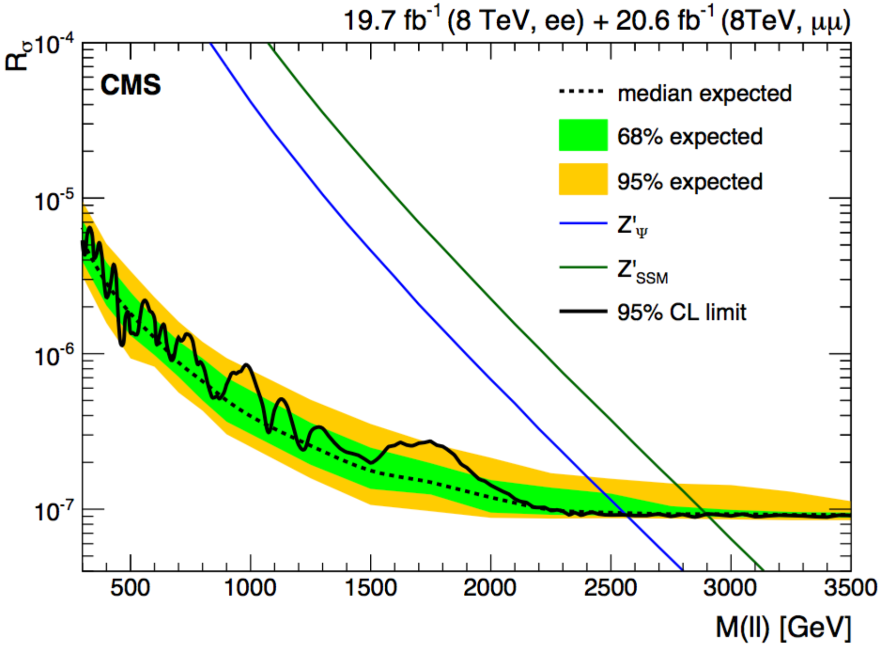
arXiv:1412.6302





Needs:

- high energy lepton id and reco
- boosted topologies (for other channels)



How do we plan for Run2

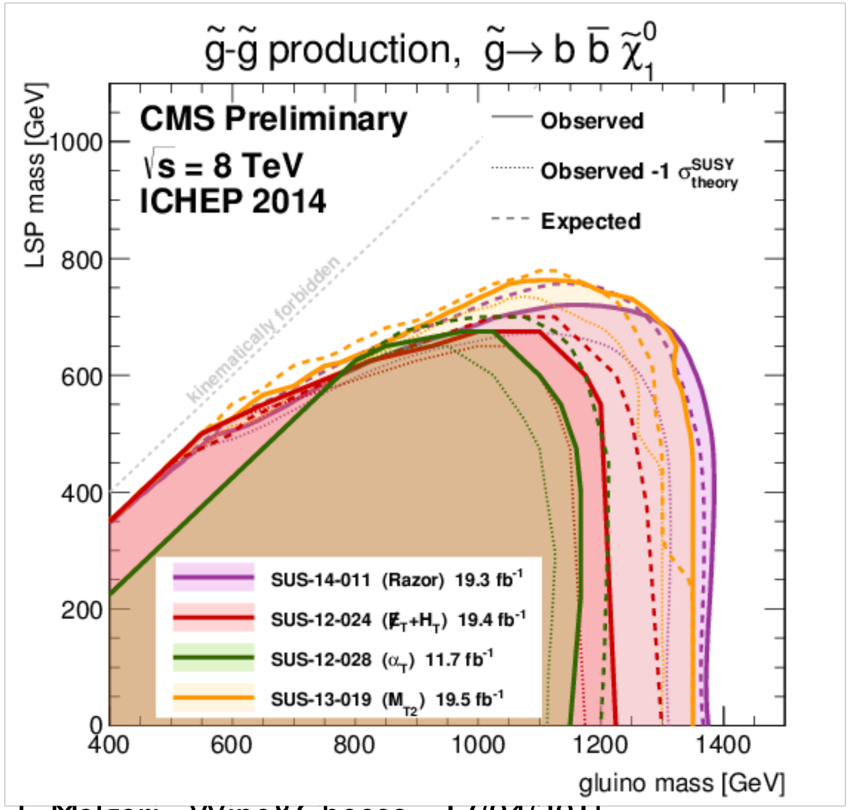
Going backward along the line of effective luminosity ratio

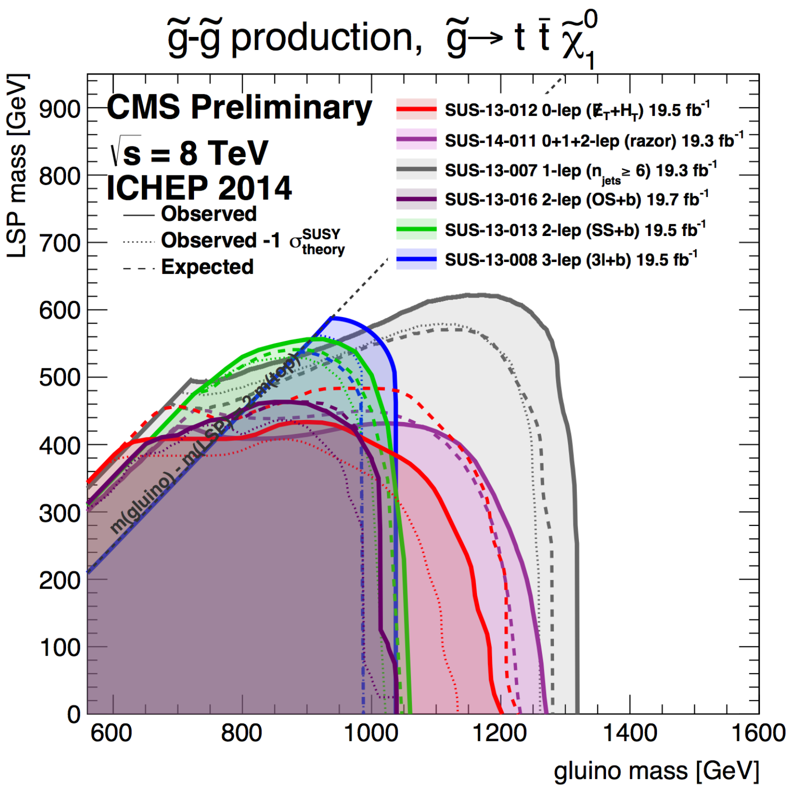
gluino pair→ x ~30 (M = 1.5 TeV)

we will be in an unexplored region with 1 fb^{-1} !

Need to understand (very early in the run):

- missing Et, lepton efficiencies
- btag, ttbar background



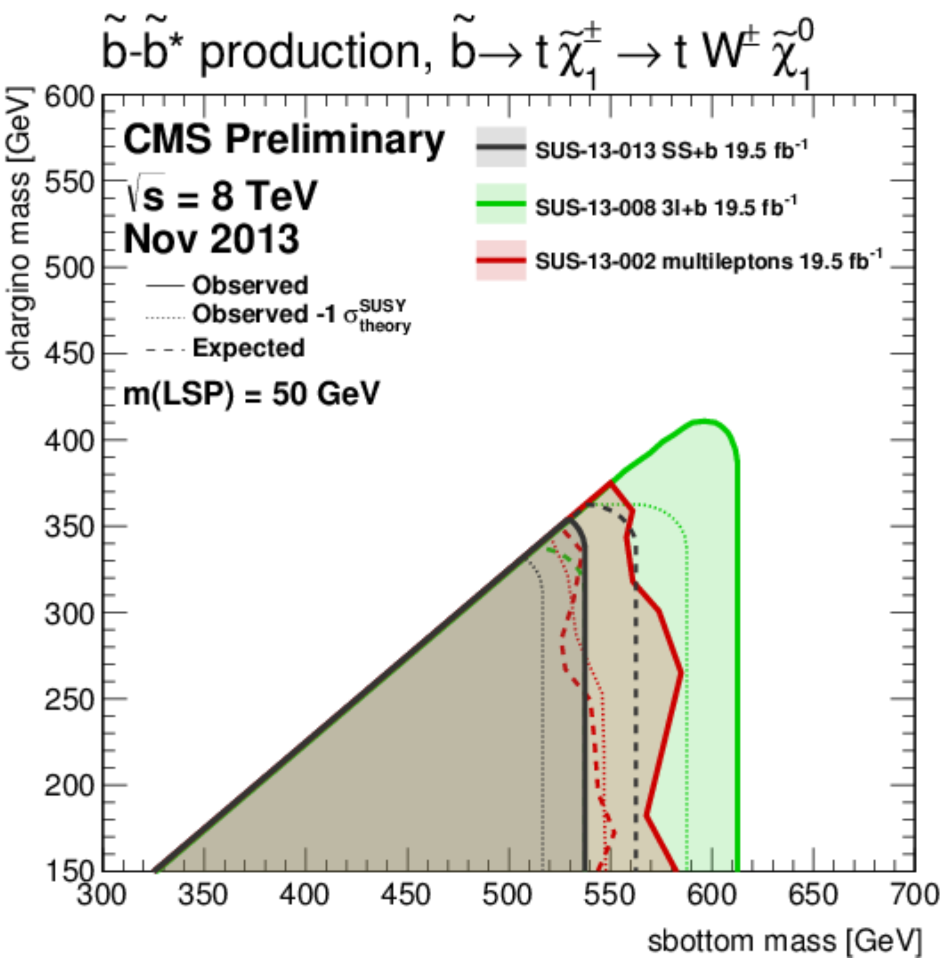


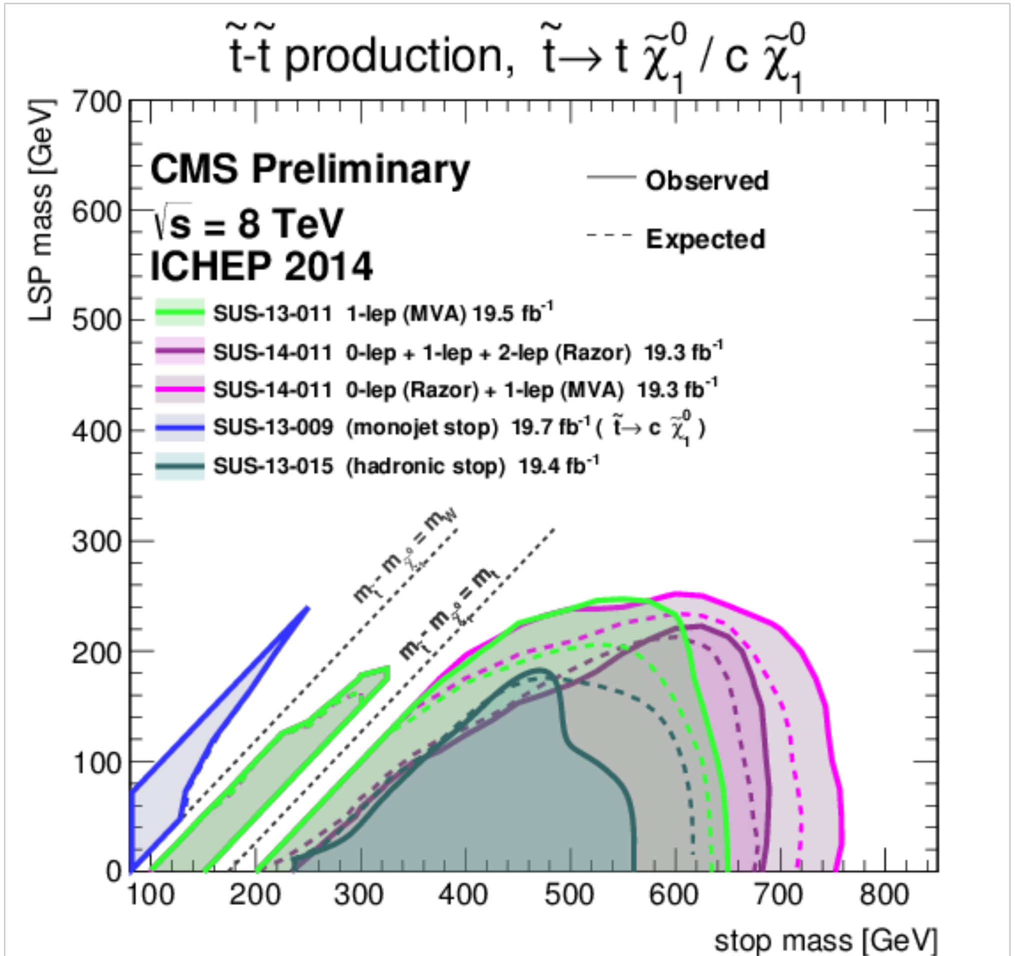
How do we plan for Run2

Going backward along the line of effective luminosity ratio

stop/sbottom pair → x6 (M = 0.7 TeV)

we will be in an unexplored region with 4 fb^{-1} !





How do we plan for Run2

Going backward along the line of effective luminosity ratio

ttH → x4

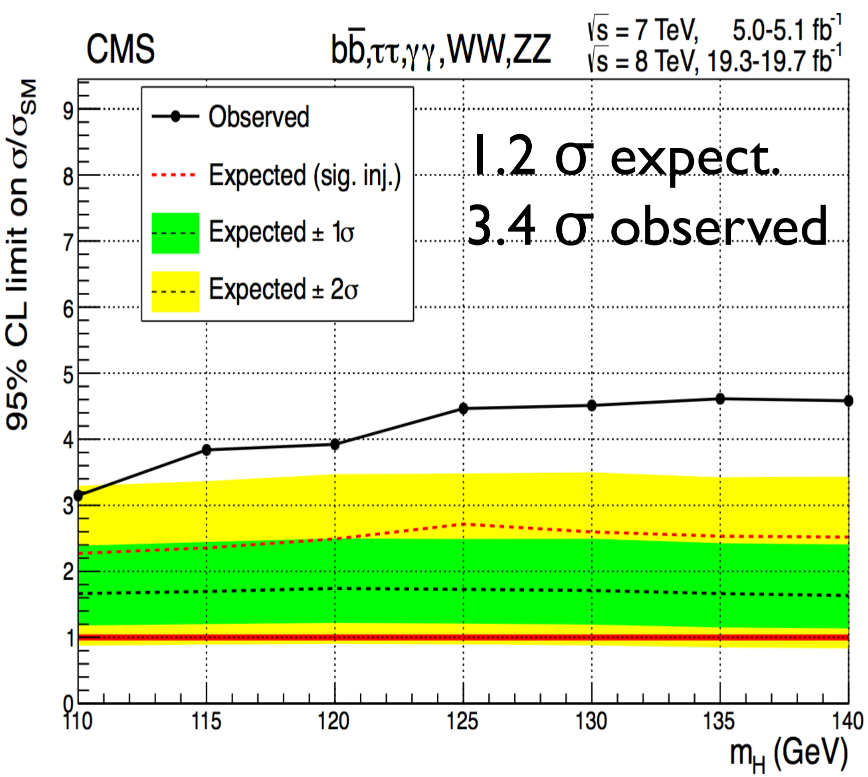
ttH can probably pass the "observation" threshold already with ~10fb^{-1} @13TeV

The other Higgs process will get a boost around 2x (i.e. ~10fb^{-1} to equal our current knowledge)

JHEP09(2014)087

Experimentally extremely challenging (all possible final states considered including multileptons!)

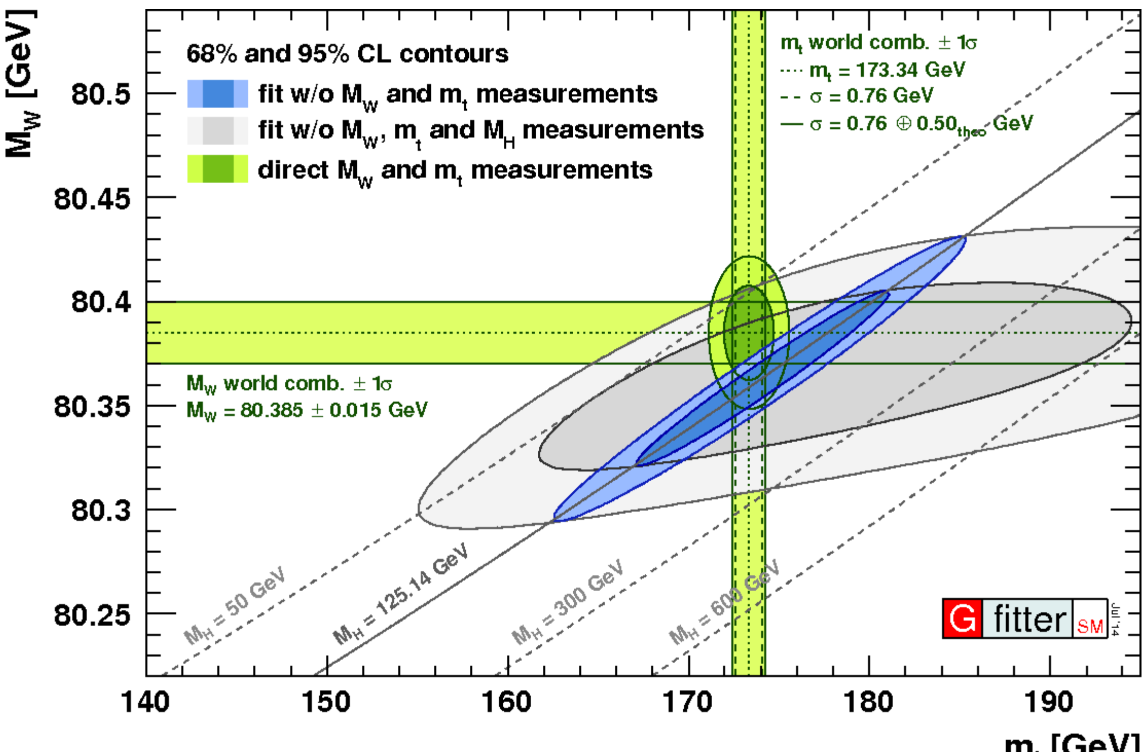
$t\bar{t}$H Channel	Measured μ	95% CL upper limits on $\mu = \sigma/\sigma_{SM}$ ($m_H = 125.6$ GeV)				
			Expected			
	Observed	Observed	Median Signal-injected	Median	68% CL range	95% CL range
$\gamma\gamma$	$+2.7^{+2.6}_{-1.8}$	7.4	5.7	4.7	[3.1, 7.6]	[2.2, 11.7]
$b\bar{b}$	$+0.7^{+1.9}_{-1.9}$	4.1	5.0	3.5	[2.5, 5.0]	[1.9, 6.7]
$\tau_h\tau_h$	$-1.3^{+6.3}_{-5.5}$	13.0	16.2	14.2	[9.5, 21.7]	[6.9, 32.5]
4l	$-4.7^{+5.0}_{-1.3}$	6.8	11.9	8.8	[5.7, 14.3]	[4.0, 22.5]
3l	$+3.1^{+2.4}_{-2.0}$	7.5	5.0	4.1	[2.8, 6.3]	[2.0, 9.5]
Same-sign 2l	$+5.3^{+2.1}_{-1.8}$	9.0	3.6	3.4	[2.3, 5.0]	[1.7, 7.2]
Combined	$+2.8^{+1.0}_{-0.9}$	4.5	2.7	1.7	[1.2, 2.5]	[0.9, 3.5]



New physics from precision physics in Run2

We should not forget that Standard Model precision physics IS a discovery tool:

- history has shown us that indirect searches via SM tests are a powerful way to get hints on new physics
- with the discovery of the Higgs (assuming it is the SM Higgs) we have closed the parameter space of the SM and precision measurements become even more powerful
- in addition, the represent an intrinsic "calibration/validation" tool for all our analyses.



- We (LHC/CMS) are already doing pretty well in M_{top}.
- M_W might be the next (big) challenge. Tevatron did great and much better than expected
- Need to keep an eye on it and prepare for Run2!

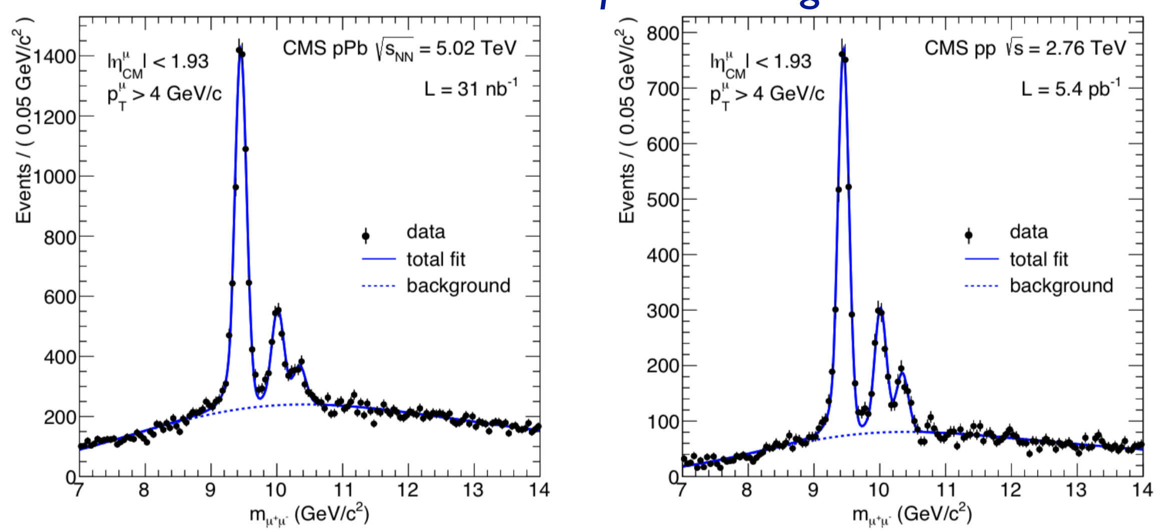
The 2015 Ion Period will be the first high luminosity Pb run in the LHC Ion program

- Peak Lumi: 3.7×10^{27} $cm^{-2}s^{-1}$, interaction rate ~30kHz
- 8 times higher than the 2011 PbPb interaction rate, and 4 times higher than the LHC design value!

Physics emphasis of the CMS HI Group for Run 2: Exploiting the high p_T reach of the high luminosity Ion LHC

- Z^0-jet, photon-jet correlations
- TeV-scale jet quenching
- Differential studies of pathlength/system-size/flavor dependence
  - photon-jet correlations vs photon pT, centrality, event plane
  - b jets, charmonium, and bottomonium production

http://arxiv.org/abs/1312.6300



Exercising

How do we plan for Run2: exercising (PHYS14)

Since last summer we have performed two dress rehearsal:

- CSA14 (Computing, Software and Analysis) challenge:
  ~1 billion MC events samples targeting the physics performance of the new software and exercising the updated workflow
- PHYS14: a full "simulation" of data taking (300M events generated) targeting early analyses in 2015:

Target early (search) analyses:

EXO:
- Z' (ee/μμ)
- monojet
- Dijet

SUS:
- gluino all-hadronic
- same sign di-lepton
- single lepton

B2G:
- Z'->ttbar,
- W'->tb
- T'->bH, T'->tH

Several configurations tested:

- BX25, PU20, 1/fb alignment, 0.7e34 trigger table
- BX50, PU30+tails, 1/fb alignment, 0.7e34 trigger table
- BX50, PU4, 1/fb alignment, 0.7e34 trigger table (for SMP, etc and low-PU running)

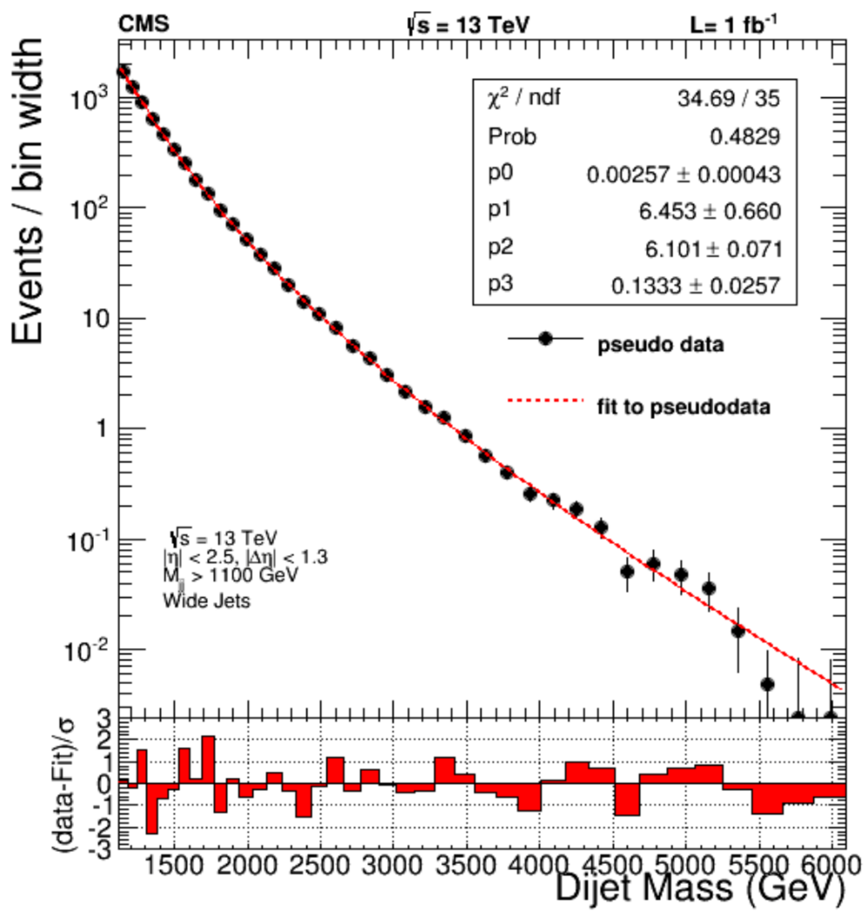
Produced miniAOD in parallel with RECO step

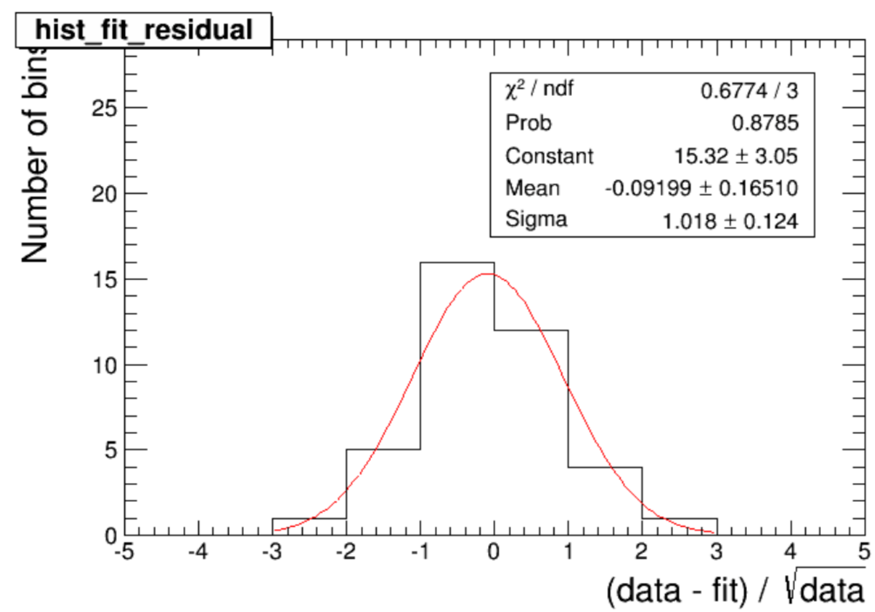
Dijet: background and shape fit

- Variable mass binning that corresponds to the estimated dijet mass resolution
- Pseudo dataset corresponding to 1/fb
- Pythia8 QCD MC PHYS14
- Likelihood fit, range 1.1 to 6 TeV

The standard parametrization gives good fit results

$$\frac{p_0\left(1-\frac{x}{13000}\right)^{p_1}}{\left(\frac{x}{13000}\right)^{p_2+p_3\log\left(\frac{x}{13000}\right)}}$$





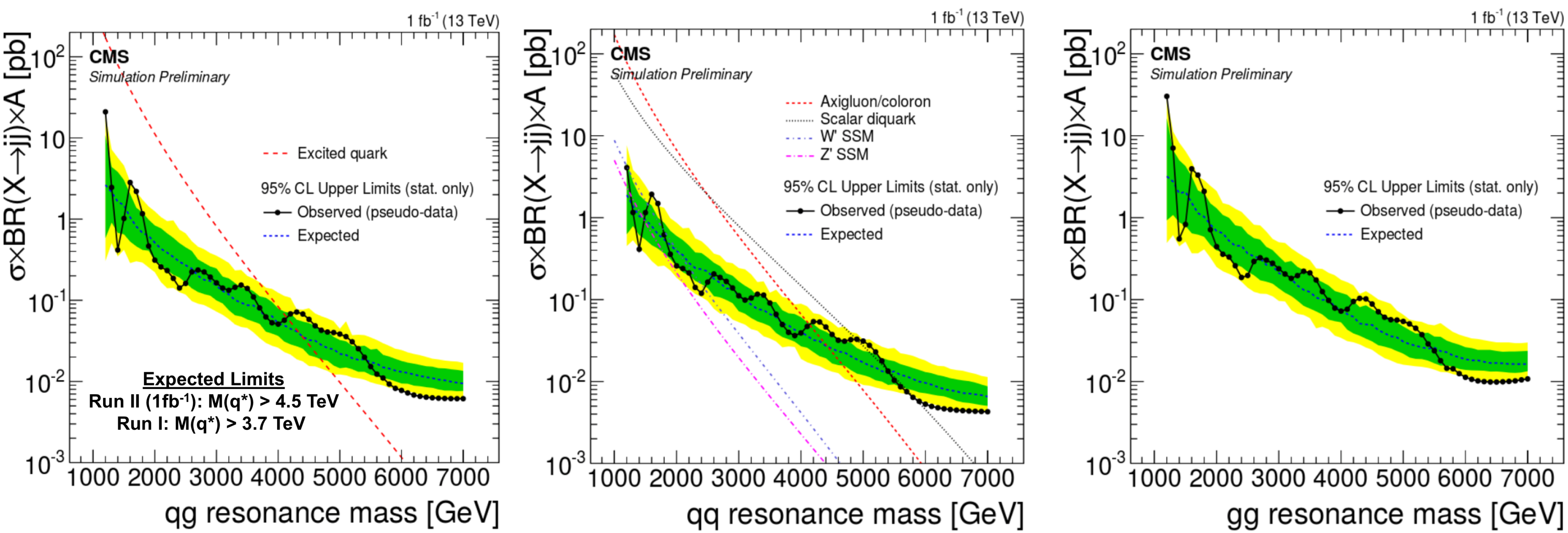
PHYS14 exercise example

Dijet: expected reach

Expected q* mass limit: 4.5 TeV

– Exceeds Run I expected (3.7 TeV) & observed limit (3.5 TeV).

Expected limits for Axigluons & Scalar diquarks also greater than in Run I



Run2 (and 3) "analysis" menu

Starter (up to 1-5 fb^{-1})

SM: W/Z inclusive Xsec, ttbar Xsec, di-bosons,
inclusive jets
dN/dη, underlying event
dijet resonances
heavy neutrinos, excited quarks
W',Z'
Gluino search

} Re-establish SM

} Start exploring

Main course (up to 10 fb^{-1})

stop,sbottom searches
Higgs physics 2012 program (including ttH ?)
Vector Like Quarks, boosted top
EWK SuSy

Dessert (up to 300 fb^{-1})

Precision Higgs physics
HH scattering? WW scattering?
Rare processes (Bd?)
(but all depends if something is found before)

… and clearly watch closely all our past "discrepancies"…

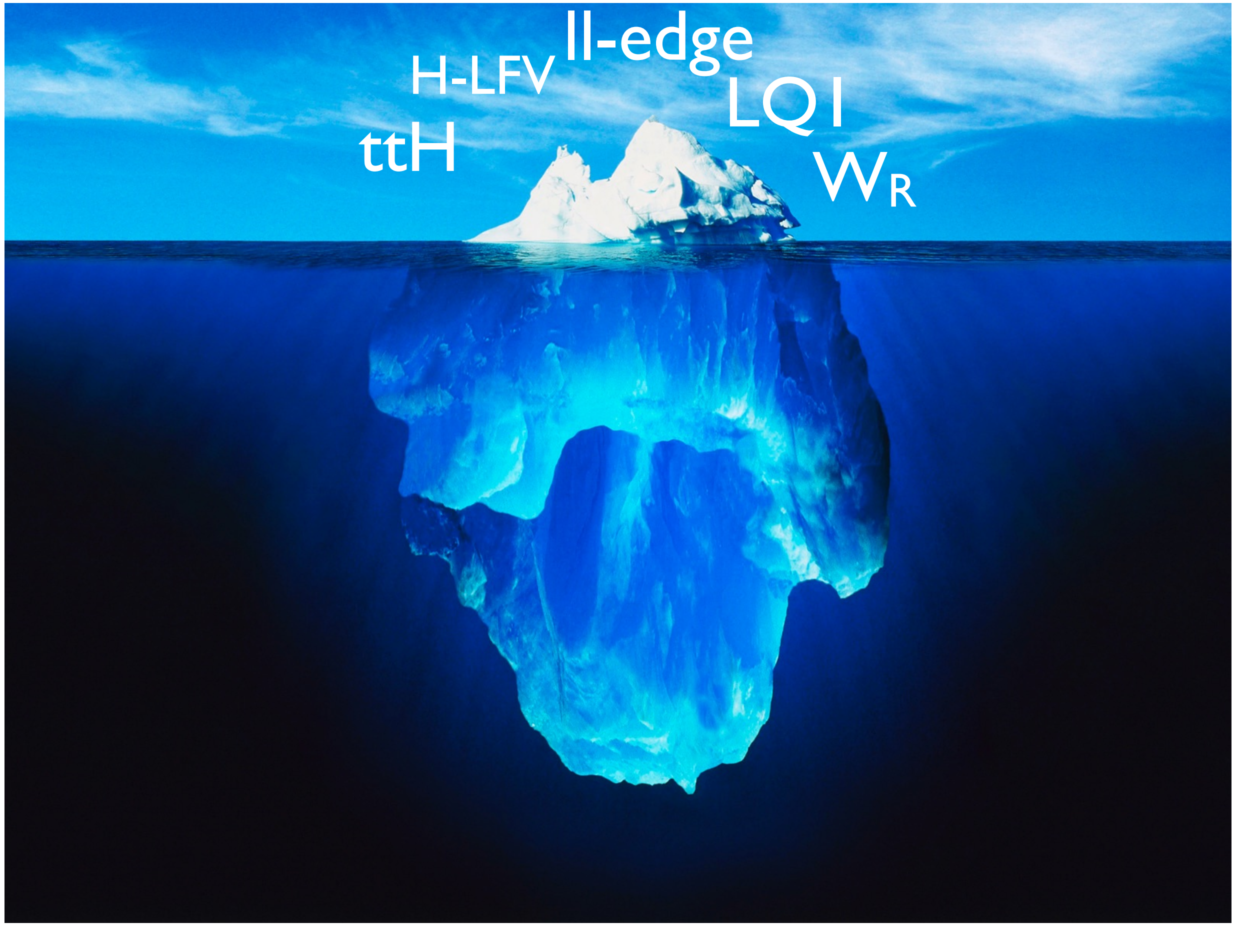
↳

Tip of the iceberg(s)?

We don't have to exclude that we have already seen the tip of the iceberg and watch carefully for all our >2σ deviations.

CAVEAT 1: many of them have been subject to the scrutiny of the community and generated some heat. No suitable explanations has been found that would accommodate at least two of them with a single NP source

CAVEAT 2: no detailed statistics evaluation has been made so far (we should probably do it) but out of >300 results the probability of having few 3σ-ish deviation is NOT negligible (and actually is a sign of good health)



For more details: W&C Jan 16th, J.P. Chou

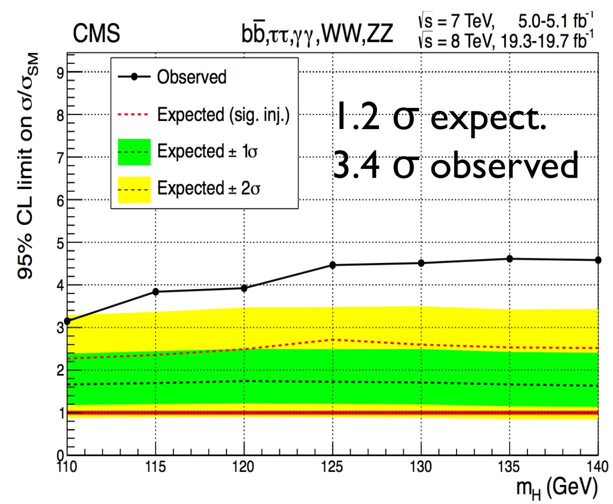
Tip of the iceberg(s)?

List of effect to keep under strict surveillance

In the Higgs arena we have a couple of effects to monitor:

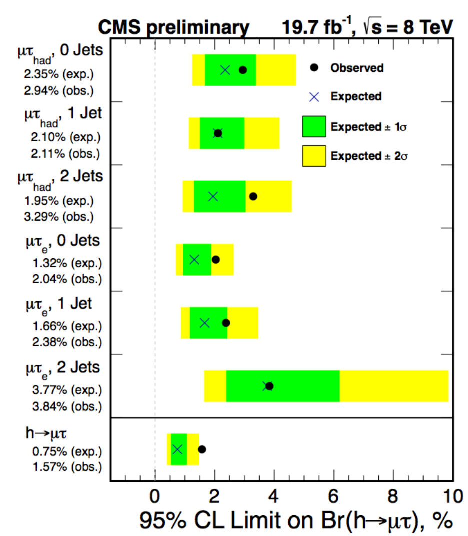
ttH:

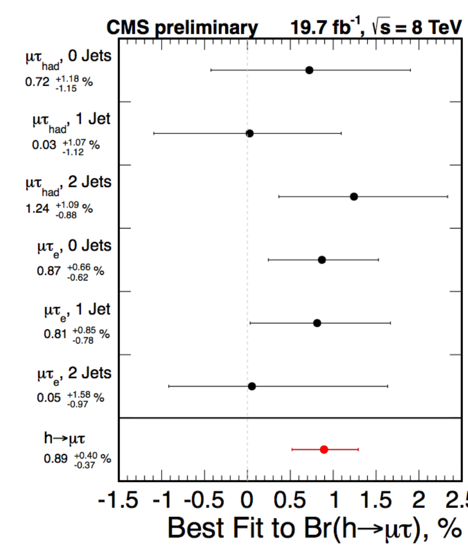
- we see more than what we expect
- excess is located in multilepton final state



Higgs lepton flavor violating decays:

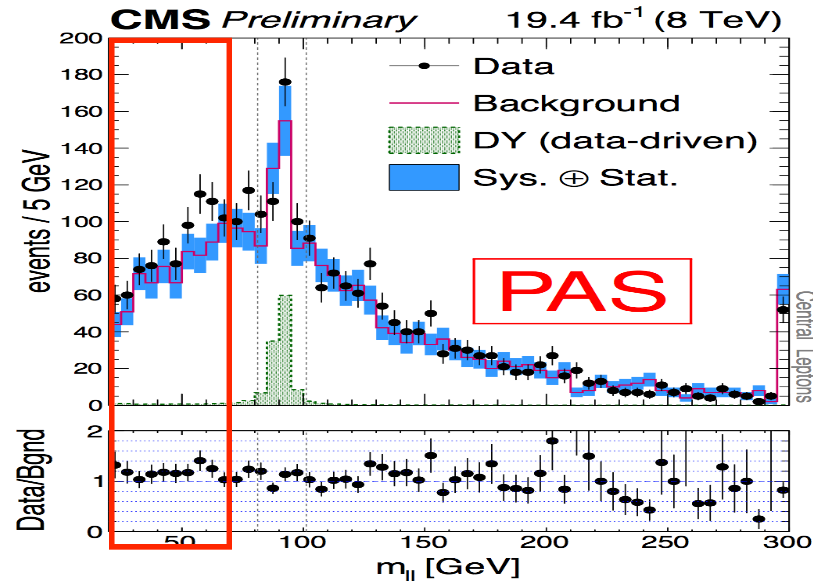
- in the search for $H\rightarrow\mu\tau$ we see an excess of ~2.5σ
- both hadronic and leptonic taus are affected





Tip of the iceberg(s)?

List of effect to keep under strict surveillance

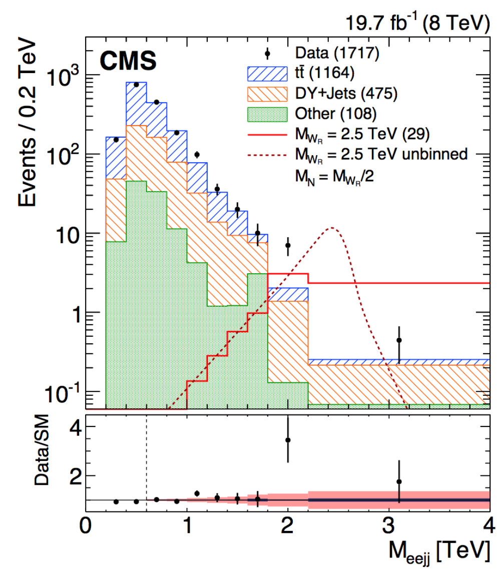


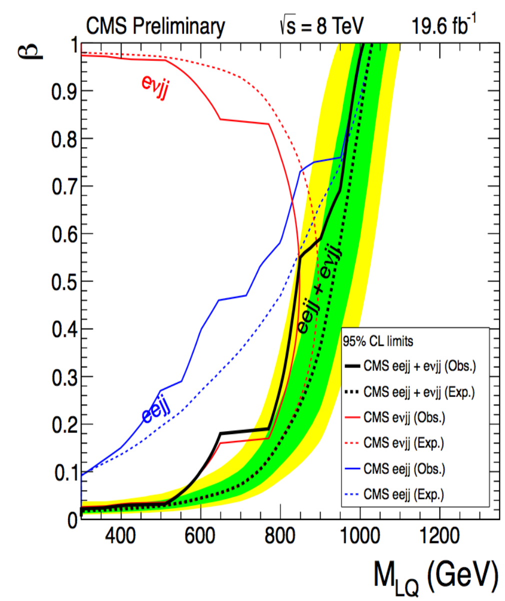
The di-lepton edge analysis (SUS-12-019)

- There is an excess (2.6 σ)visible on the low di-lepton invariant mass that was first shown during Lisbon is CMS Week 2012.
- Any plausible hypothesis of new physics is not corroborated by evidence in other channels.

The "electron excesses":

- There is an excess (2.8 σ @2.1 TeV) visible on the eejj invariant mass in the search for W_R (but not in μμjj !)
- Another excess is observed in both eejj and evjj channel in leptoquarks searches
- The correlation between the two is minimal but has generated a lot of literature:
  - http://arxiv.org/pdf/1407.4466v1.pdf
  - http://arxiv.org/pdf/1407.5384v1.pdf
  - http://arxiv.org/pdf/1407.6908v1.pdf
  - http://arxiv.org/pdf/1408.1082v1.pdf





Conclusions and outlook

After the Higgs discovery and the closing of the SM space we are now living an exciting starting of a journey towards a "terra incognita".

Sebastian Munster. Cosmographia, 1544

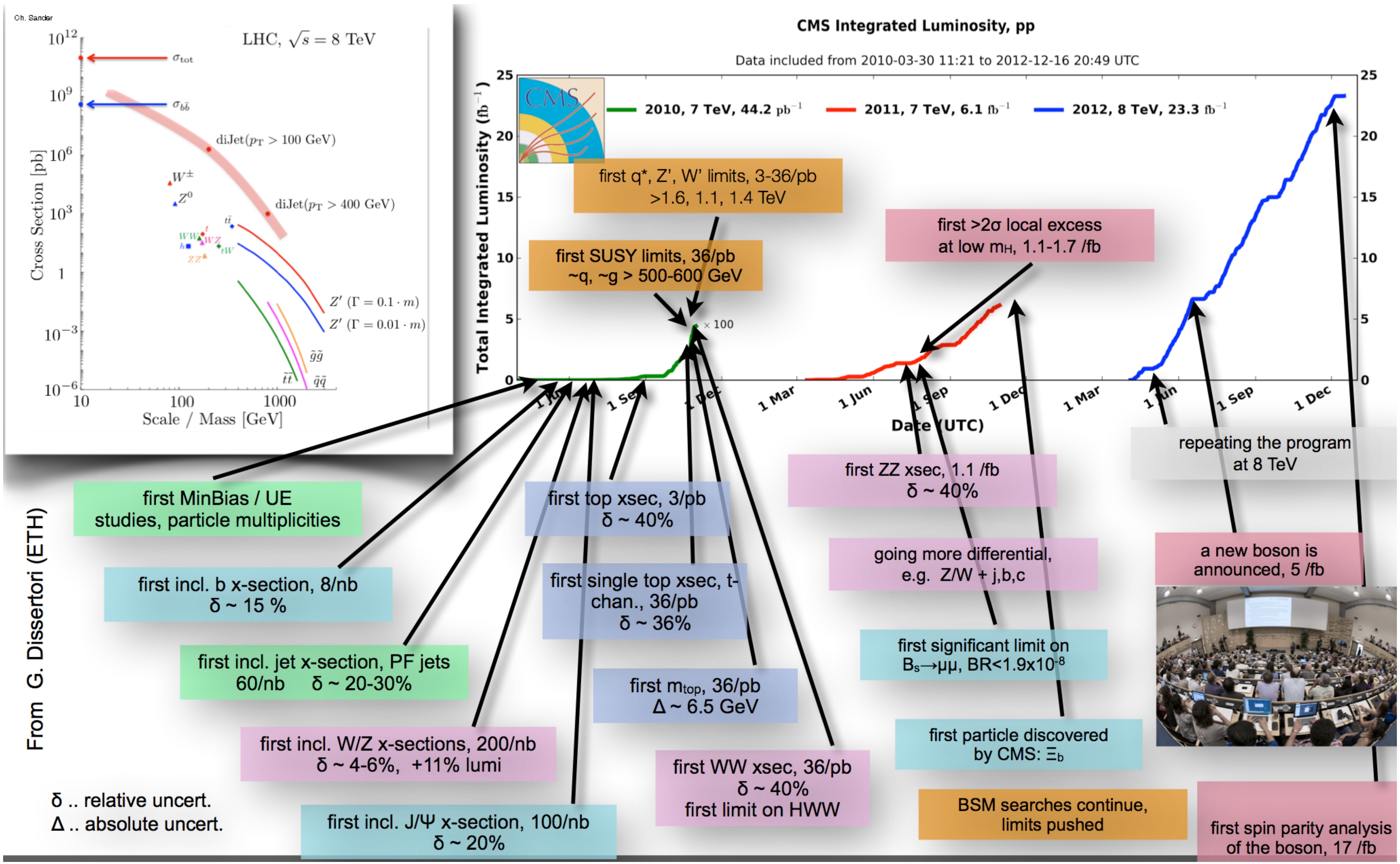
- We don't know yet what we should expect, but there are good reasons to believe that we will see new forms of "life"
- Some of them might be already among us, but too few to be noticed

- Preparation is essential:
  - the LHC has done a fantastic work in preparing for run2 (as usual)
  - the detector and the software have been re-commissioned/improved to get ready for it
  - an analyses program has been tailored for the expected lumi ramp-up:
    - ➡diversifying search approaches also to fill up holes left in Run1(DM, soft leptons, …)
    - ➡building a complete SM program (no one can claim a discovery without having understood the main bkg)

The wait is over and we are more than ready to start!

BACKUP

Not much different than the recent past

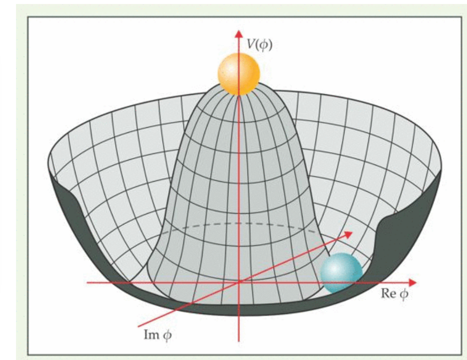


The fundamental questions after run 1

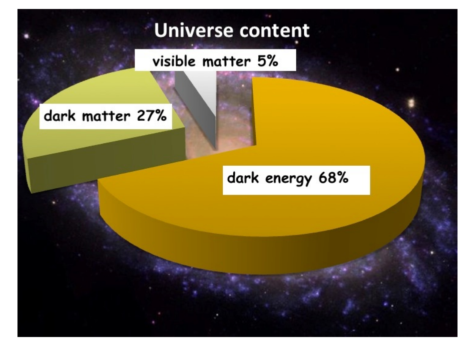
The LHC was designed, and destined, to answer some fundamental questions:

Replaced

1) Is the 125GeV Higgs "the" (only) Higgs?
- How does it get its job done?
- What is its role in BSM?



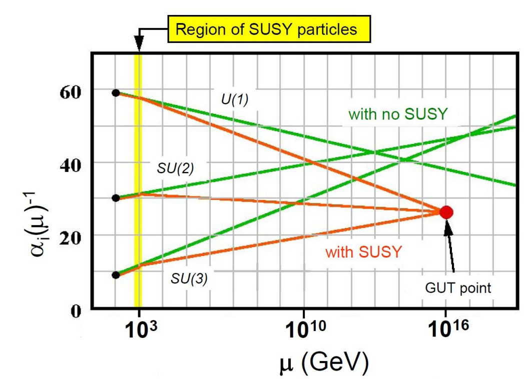
2) Why is gravity so weak w.r.t. all other interactions?
- Do we live in a 4d world?
- what kind of physics we should expect at Mpl?
- is the SM holding until then?



3) What is the origin of dark matter?
- Is it linked to any of the other questions above?

4) What is the origin of matter-antimatter asymmetry?

5) Can we invoke Occam's razor and focus on common solutions for most of the questions above?
- Or, equivalently, is SuSy realized in nature?



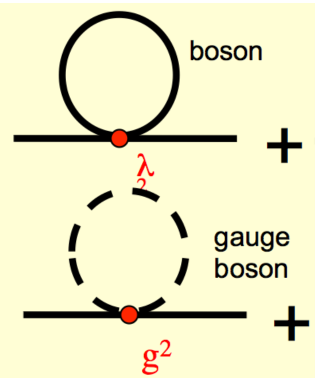
How the Higgs changed the picture?

A short reminder, why we are so obsessed by SuperSymmetry:

1)it solves/mitigate the hierarchy problem and regularize the Higgs mass (otherwise divergent)

- the mass of the Higgs gets quadratically divergent loop corrections:

$$\delta m^2{}_H = \delta m_H^2{}^{top} + \delta m_H^2{}^{W,Z} + \delta m_H^2{}^{self}$$



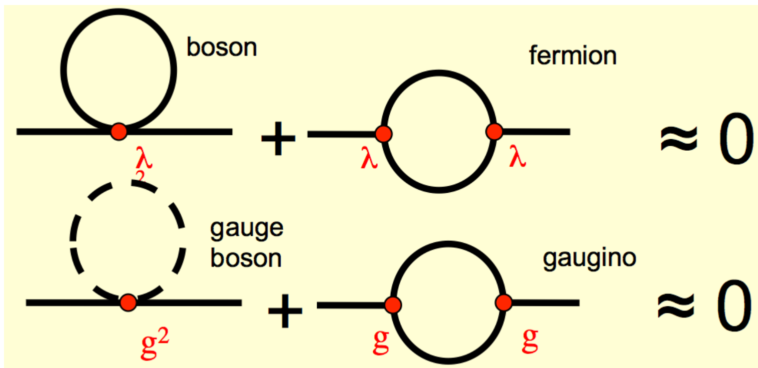
... ≈ m(planck)

or any arbitrarely large scale

... ≈ m(planck)

- we need a "natural" cancelling term with negative contribution: arXiv:1110.6926, J. Ruderman et al.

$$\delta m_{H_u}^2 = -\frac{3y_t^2}{8\pi^2}\left(m_{Q_3}^2 + m_{u_3}^2 + |A_t|^2\right)\ln\left(\frac{\Lambda}{m_{\tilde{t}}}\right)$$



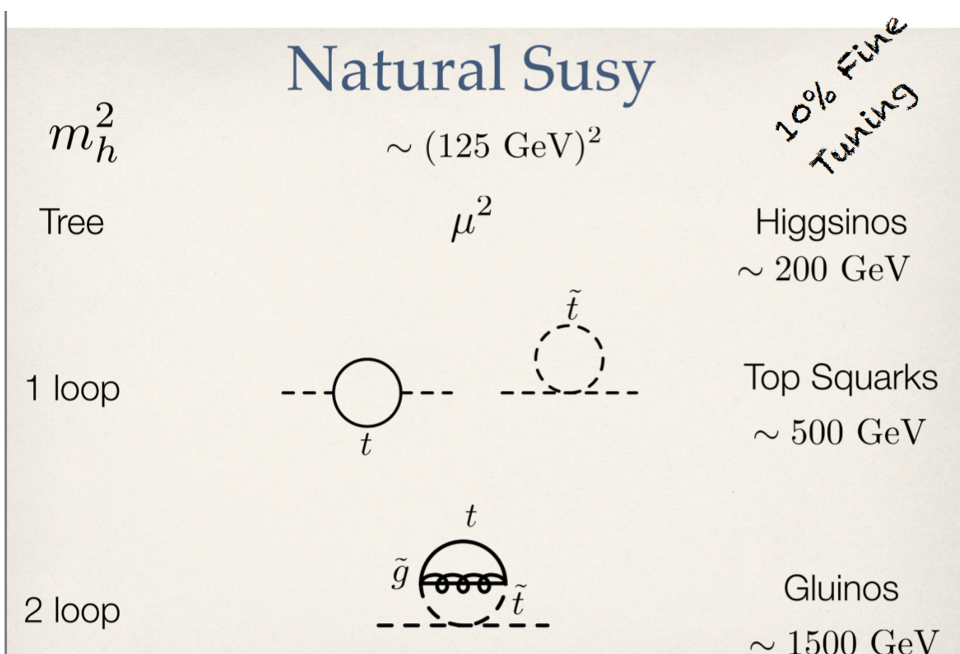
A short reminder, why we are so obsessed by SuperSymmetry:

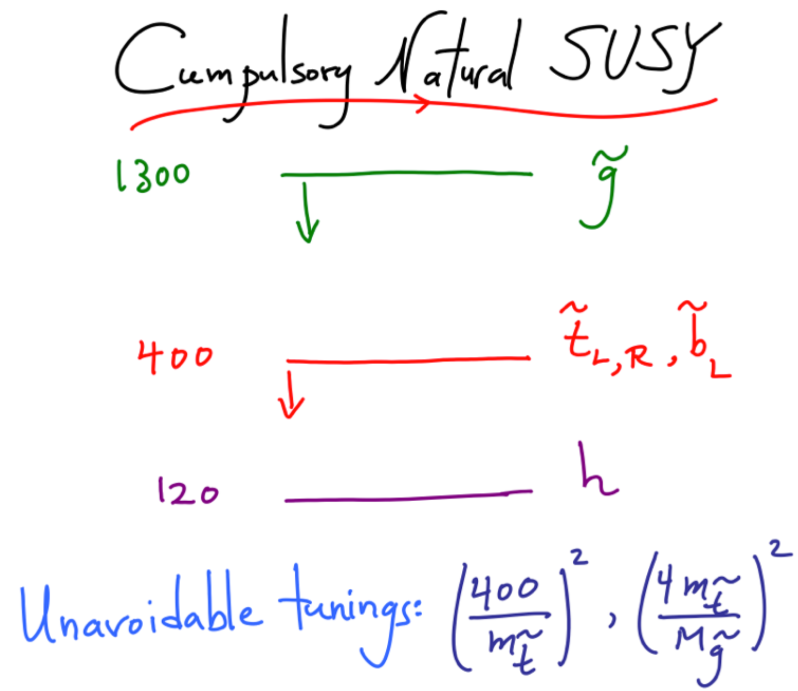
1)it solves/mitigate the hierarchy problem and regularize the Higgs mass (otherwise divergent)

- but in turns, a light stop requires a not too heavy gluino (two loop corrections):

$$\delta m^2_{H_u}|_{gluino} = -\frac{2}{\pi^2} y_t^2 \left(\frac{\alpha_s}{\pi}\right) |M_3|^2 \log^2\left(\frac{\Lambda}{\text{TeV}}\right)$$

- + additional constraints on Higgsinos.....





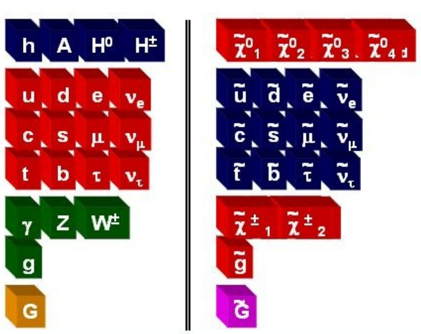
Nima Harkani-Hamed SavasFest 2012

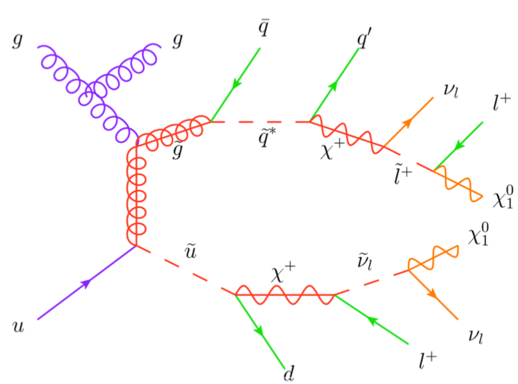
A short reminder, why we are so obsessed by SuperSymmetry:

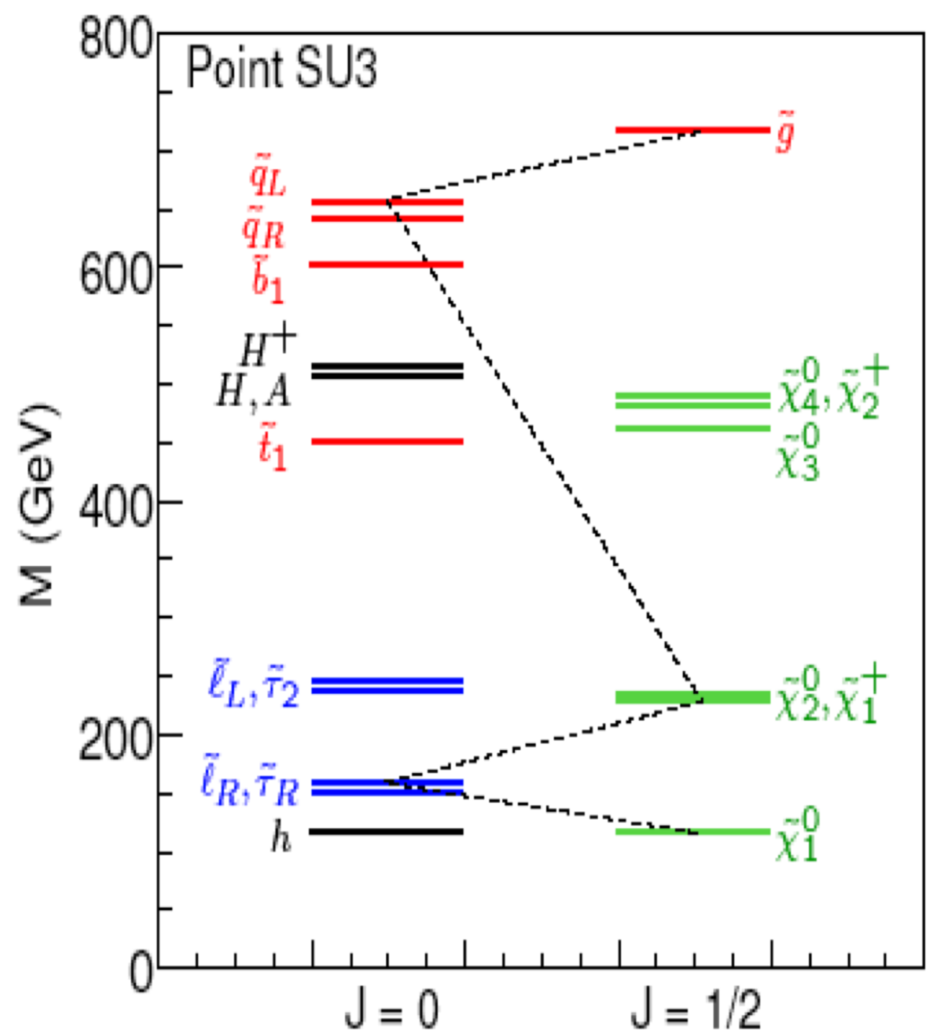
2)it gives a natural candidate for dark matter, at least in its R-parity conserved realization:

$$R_P=(-1)^{3B+L+2S}$$

- =+1 SM particles
- =-1 SuSy particles
- SuSy particles produced in pairs
- LSP is stable (and neutral)

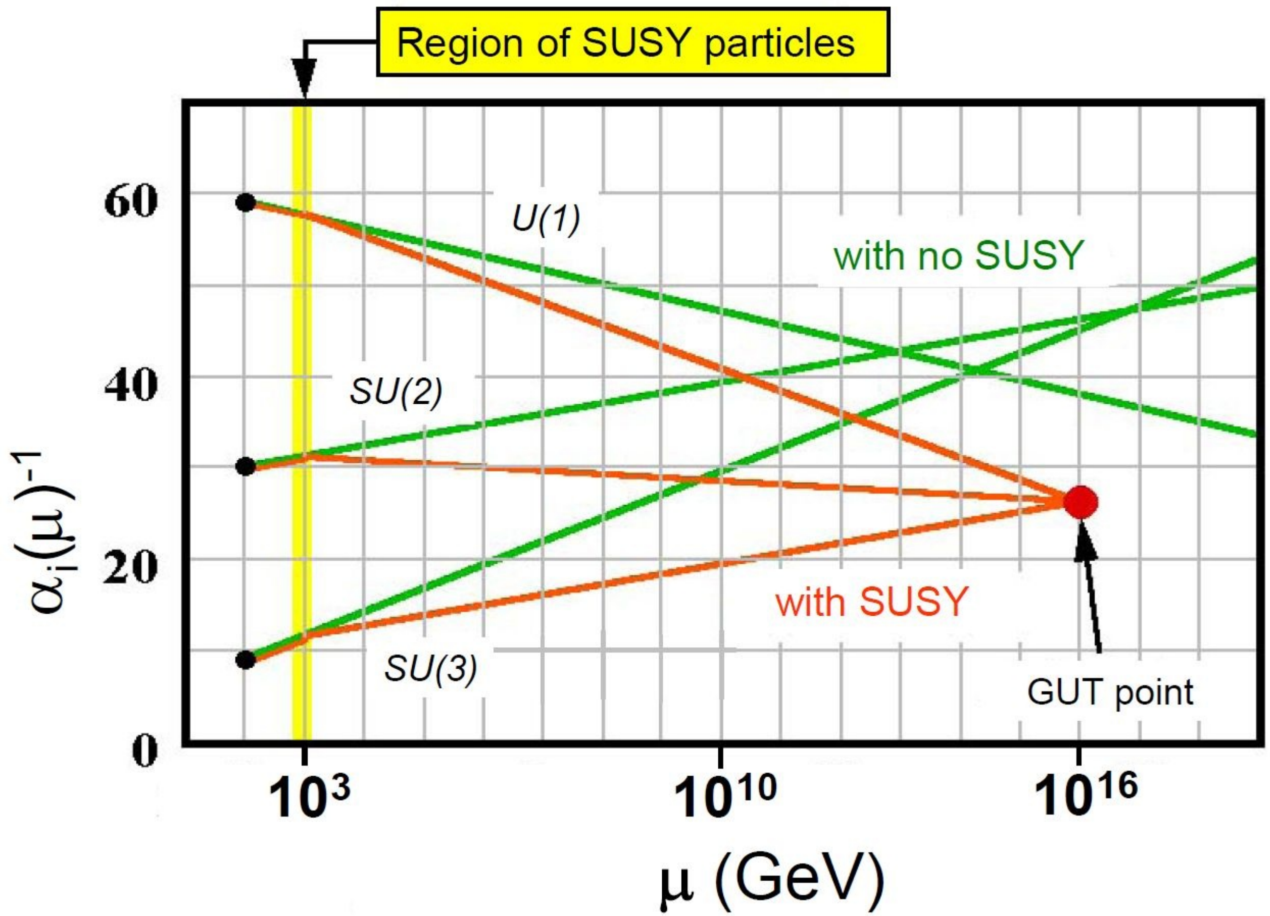






A short reminder, why we are so obsessed by SuperSymmetry:

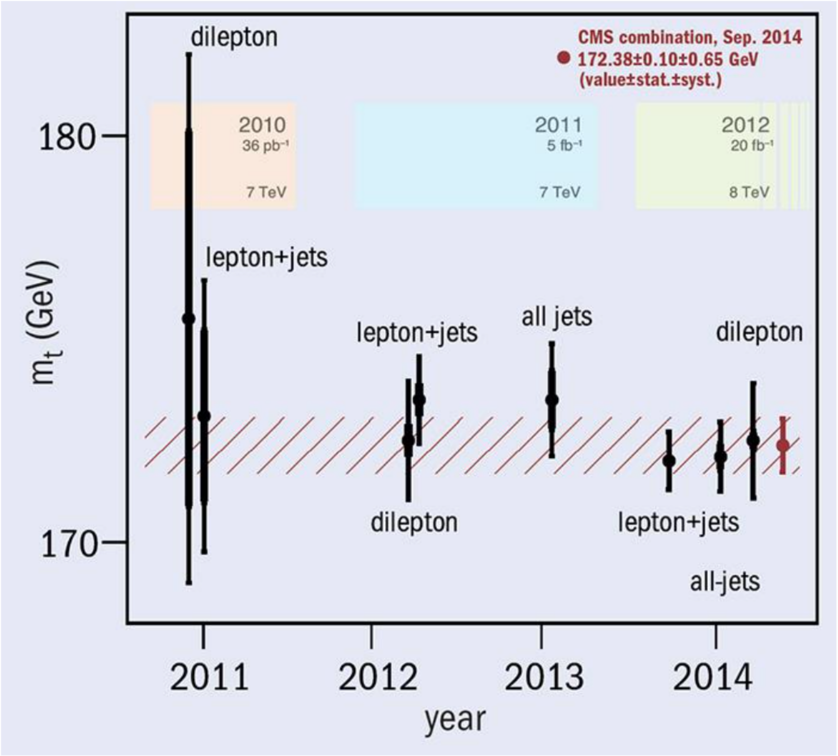
3) and it also gives an handle on unification of couplings at high energy

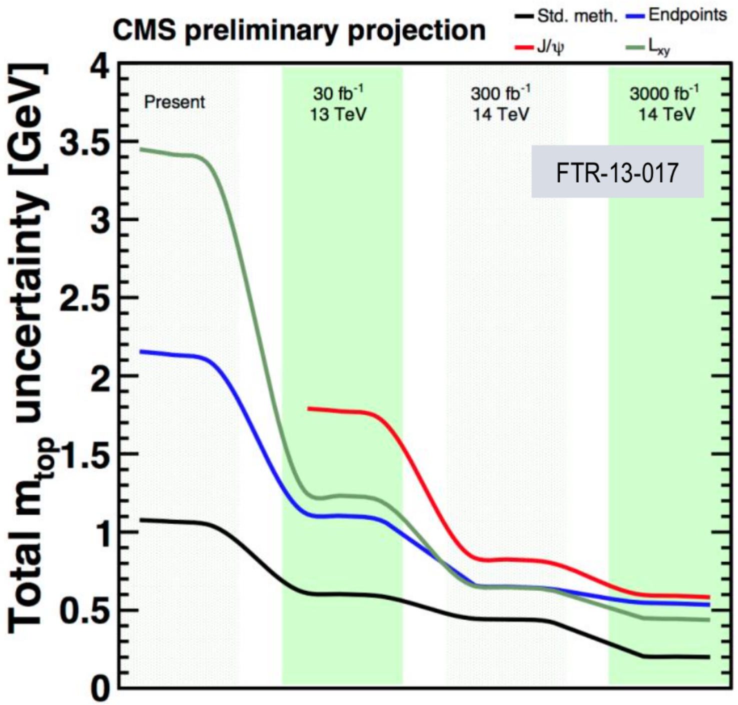


Top mass plans for Run2 (and beyond)

- < 15/pb: help commissioning software, object ID, MC tools and tunes
  - MC tunes with UE in ttbar? JES calibration using in-situ JES fit in ttbar?
- 15/pb: profit from increased statistics & improved MC tools and tunes

CERN Courier, Dec 2014





Longer term (End of Run3 ~300 fb^{-1})

CMS and ATLAS white papers: arXiv:1307.7135 and 1307.7292

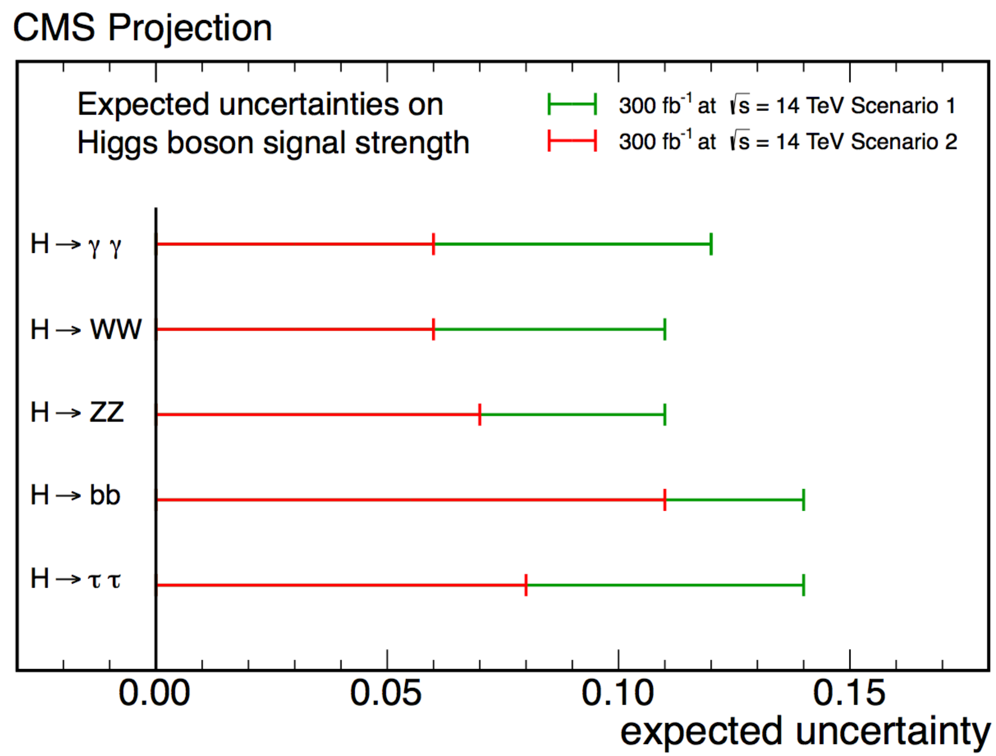
Higgs Physics expectations

- ~5 M Higgs events produced
- ~50 K events useful for precision measurements (x 40 w.r.t. now)

Physics subjects

- Higgs precision measurement
  - Mass (100 MeV reachable?)
  - Cross-sections
  - Couplings

    ➡ H → μμ might be measured at 30% level
- Possible (but very difficult) $W_L W_L$ scattering ?



L (fb^{-1})	κ_γ	κ_W	κ_Z	κ_g	κ_b	κ_t	κ_τ	$\kappa_{Z\gamma}$	$\kappa_{\mu\mu}$	BR_{SM}
300	[5, 7]	[4, 6]	[4, 6]	[6, 8]	[10, 13]	[14, 15]	[6, 8]	[41, 41]	[23, 23]	[14, 18]
3000	[2, 5]	[2, 5]	[2, 4]	[3, 5]	[4, 7]	[7, 10]	[2, 5]	[10, 12]	[8, 8]	[7, 11]

Assumptions on systematic uncertainties:

Scenario 1: no change
Scenario 2: theory unc. / 2, rest goes like 1/√L

Longer term (End of Run4 ~3000 fb^{-1})

CMS and ATLAS white papers: arXiv:1307.7135 and 1307.7292

Higgs Physics expectations

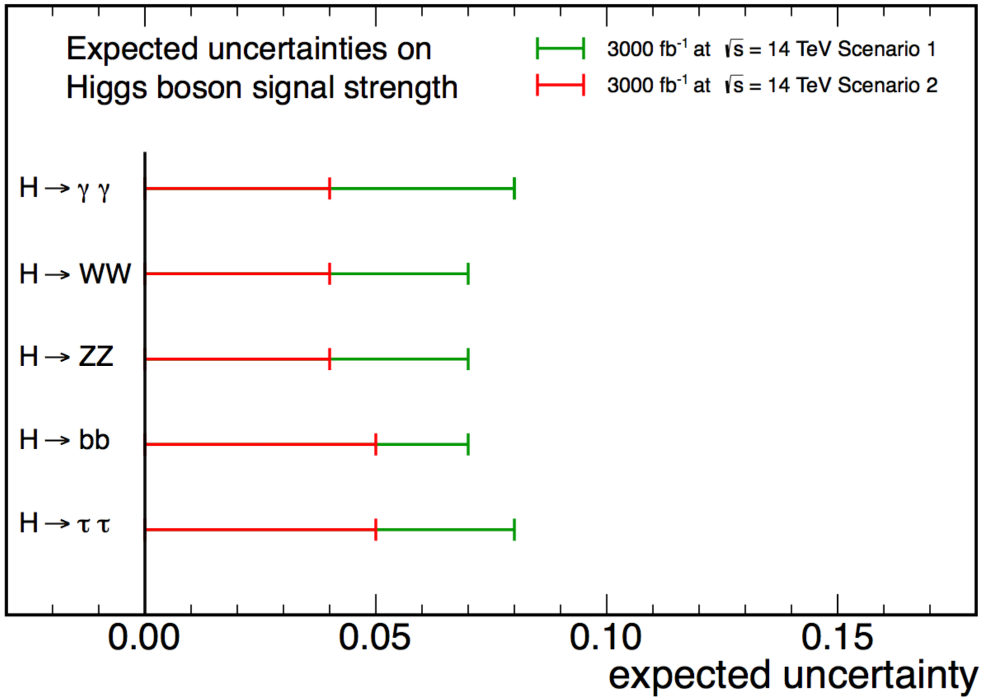
- 50 M Higgs events produced
- 500 K events useful for precision measurements (x 400 w.r.t. now)

Physics subjects

- Higgs precision measurement
  - Mass (100 MeV syst. limited?)
  - Cross-sections
  - Couplings

  ➡ $H \rightarrow \mu\mu$ might be measured at 10% level ?
- Possible (but very difficult) $W_L W_L$ scattering ?

CMS Projection



L (fb^{-1})	κ_γ	κ_W	κ_Z	κ_g	κ_b	κ_t	κ_τ	$\kappa_{Z\gamma}$	$\kappa_{\mu\mu}$	BR_{SM}
300	[5, 7]	[4, 6]	[4, 6]	[6, 8]	[10, 13]	[14, 15]	[6, 8]	[41, 41]	[23, 23]	[14, 18]
3000	[2, 5]	[2, 5]	[2, 4]	[3, 5]	[4, 7]	[7, 10]	[2, 5]	[10, 12]	[8, 8]	[7, 11]

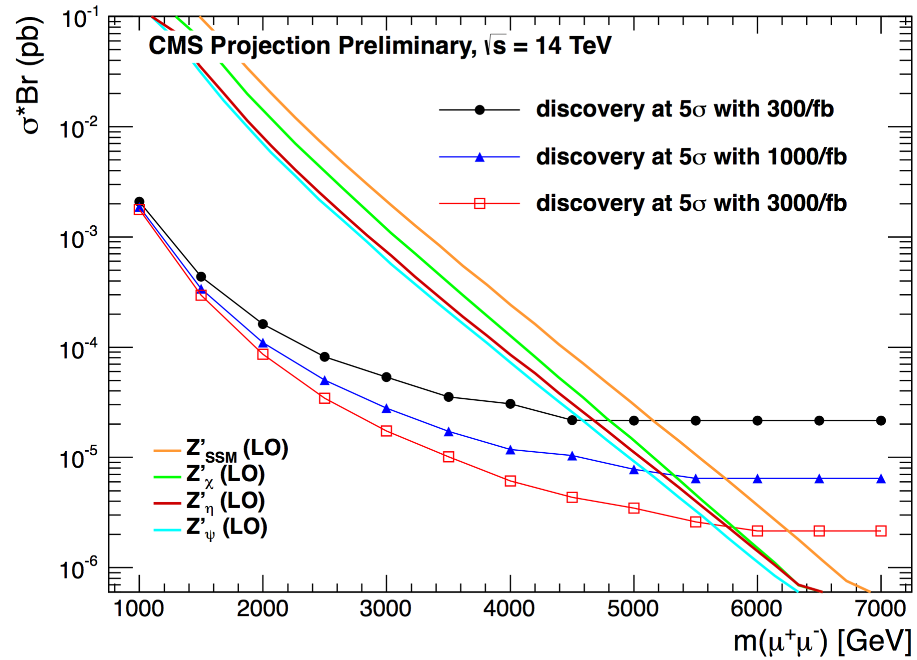
Assumptions on systematic uncertainties:

Scenario 1: no change

Scenario 2: theory unc. / 2, rest goes like $1/\sqrt{L}$

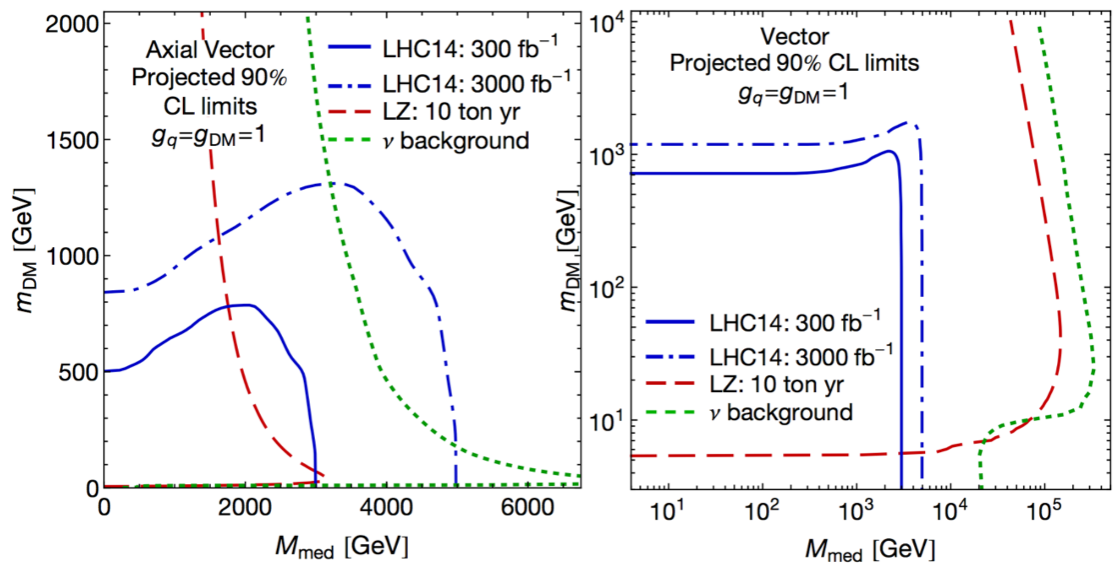
Exotica searches

- Di-lepton resonances reach can extend up to 5-6 TeV in both ee and μμ channels



- In the Dark Matter sector we can be competitive, and complementary to, new generation direct searches:
  - excluding on the low m_{DM} vs M_{med} region up to 500 vs 3000 GeV

O. Buchmuller et al.



Longer term (End of Run2 ~300 fb^{-1})

CMS and ATLAS white papers: arXiv:1307.7135 and 1307.7292

SuSy searches expectations

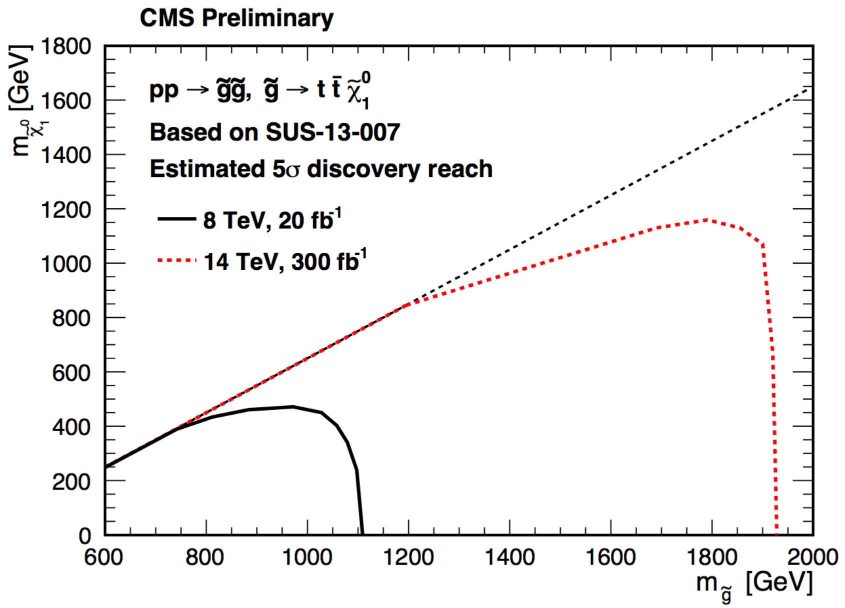
In strongly produced SuSy scenario we could reach:

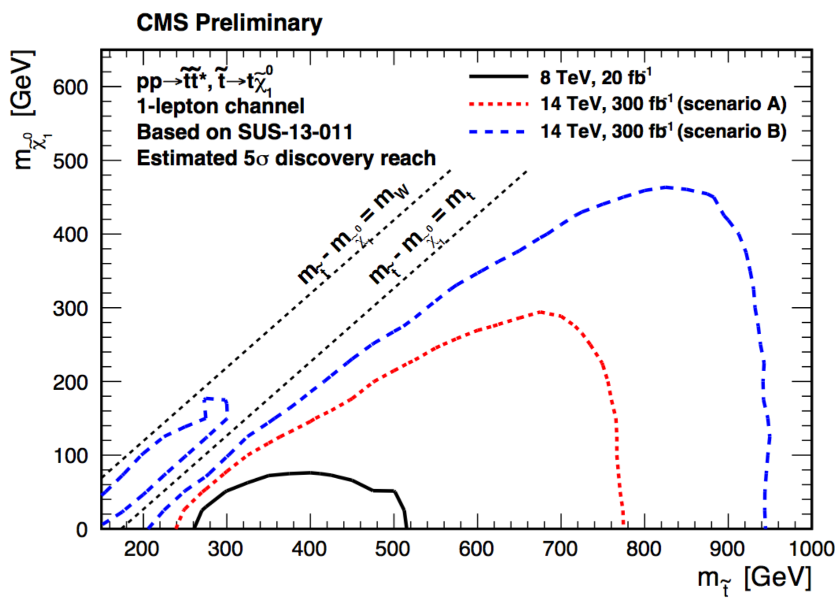
- gluino limits up to 1.8 TeV
- stop limits up to 800 GeV

Systematics driven by bkg uncertainties:

- scenario A: simple scaling from now
- scenario B: reduction as $1/\sqrt{R_{bkg}}$

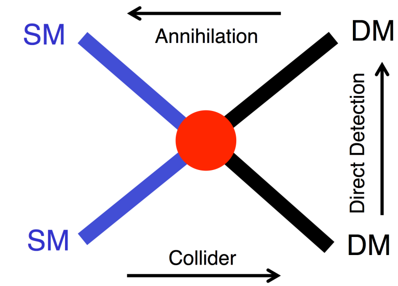
Similar improvements in sbottom searches.

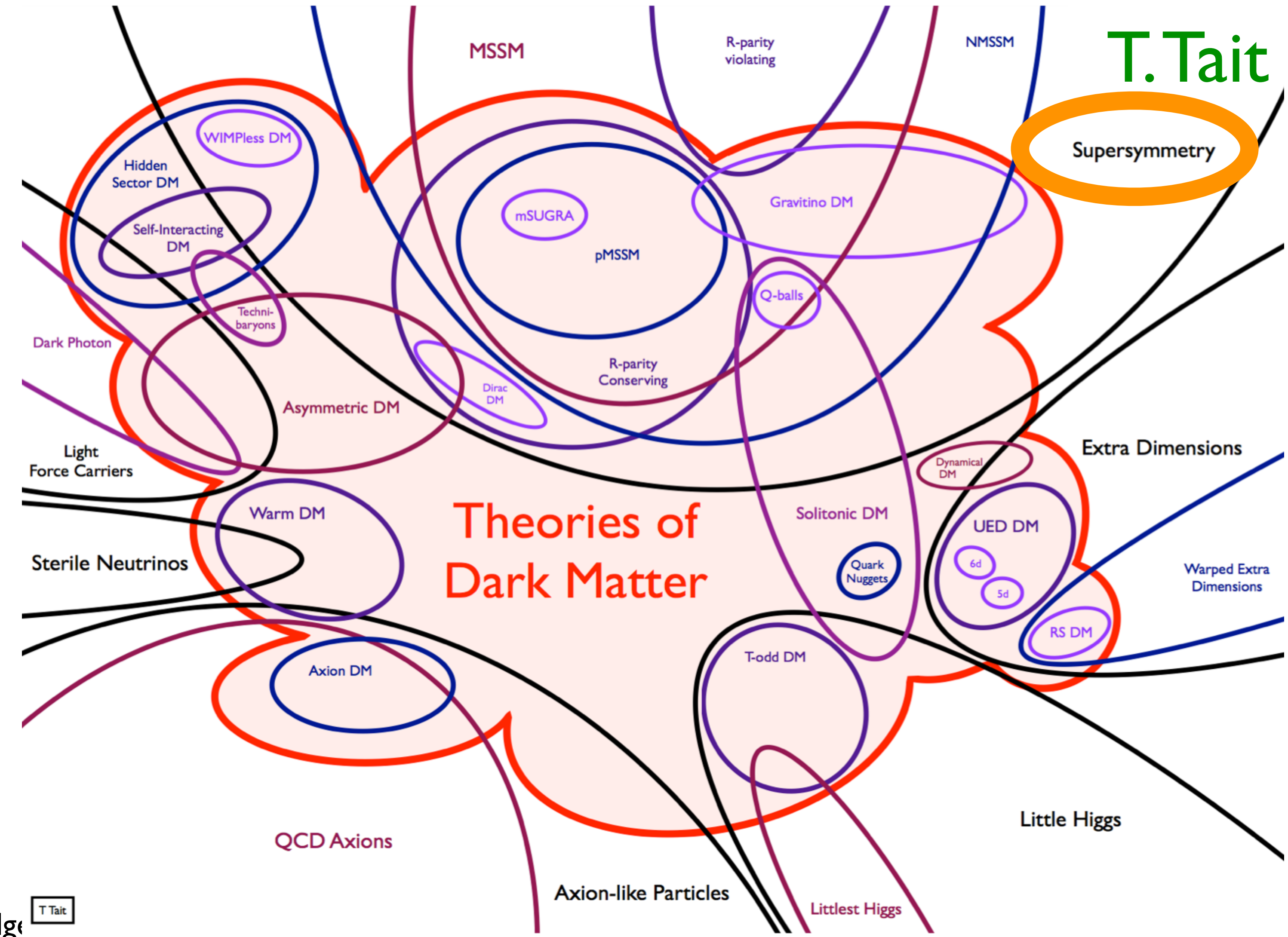




A general (i.e. not SuSy) look at DM searches

Besides specific neutralinos searches in the SuSy framework we have to continue and extend the panorama for "generic" DM searches.



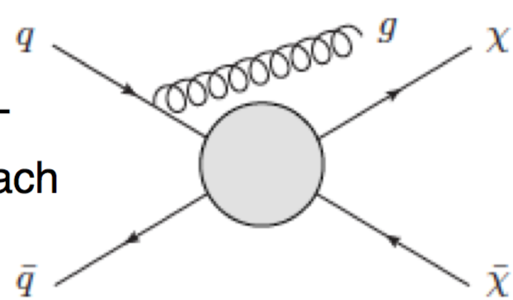


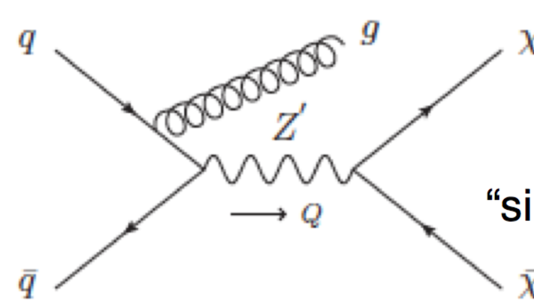
Complementarity with direct detection one step further:

- evolution from EFT towards simplified models with propagator mass as parameter

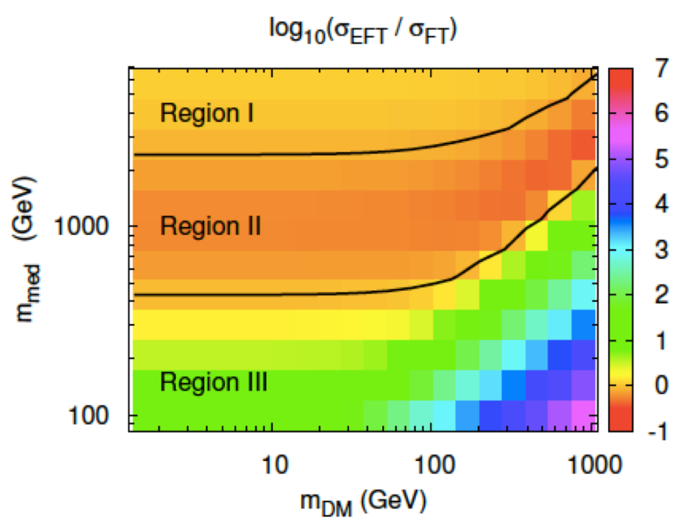
Recent work from OB, M.Dolan,C.McCabe: arXiv:1308.6799
➢ Compare Effective Field Theory (EFT) with Full Theory (FT)

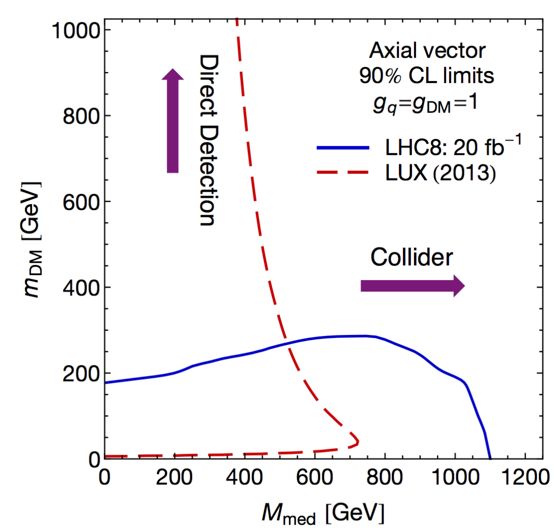
EFT approach





FT
one diagram
"simplified model"





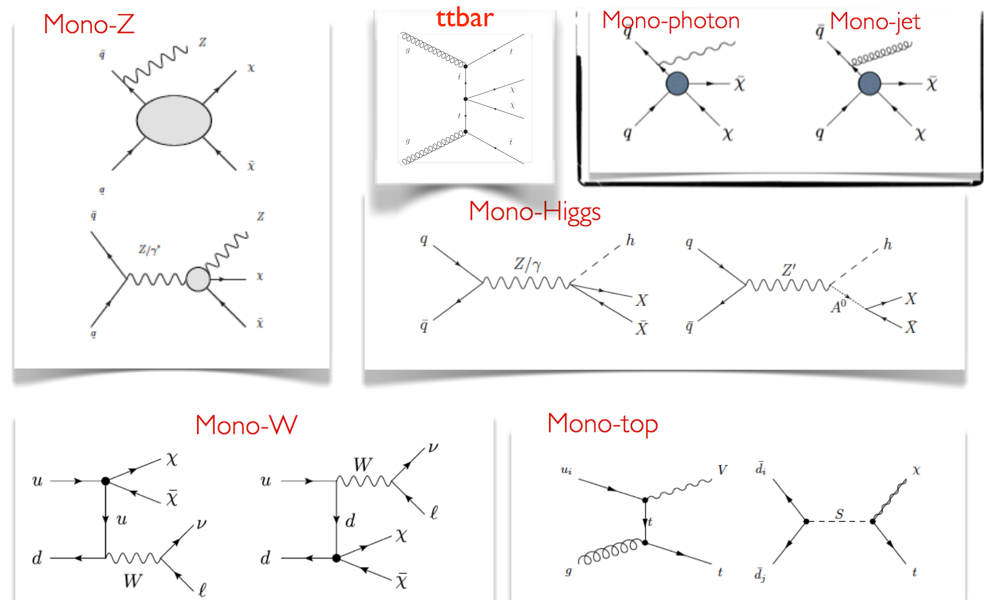
- need to keep both approaches to be as extensive as possible in our searches

A general (i.e. not SuSy) look at DM searches

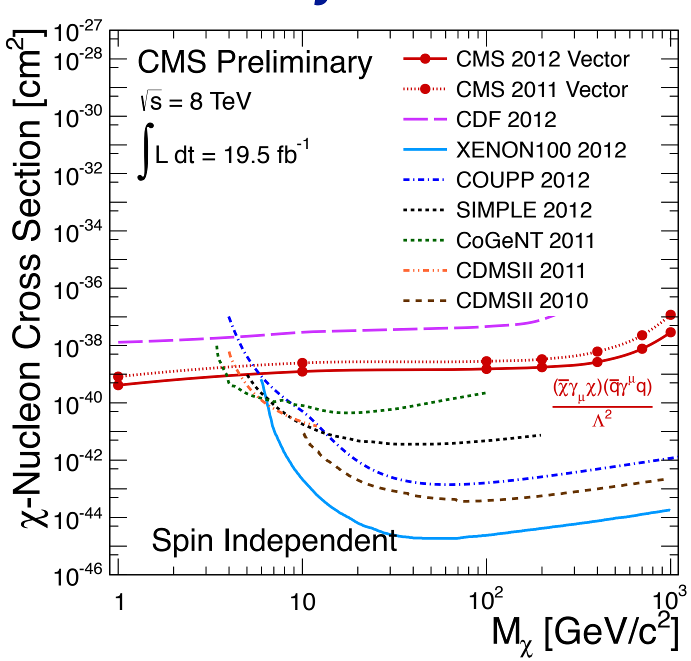
Colliders searches historically based on mono-"something", usually ISR tagging.

Higgs is entering in the game and might play a leading role in Run2:

- mono-Higgs searches
- invisible/undetectable Higgs decays



Mono-jet limits



ttbar limit