Physics Goals and perspectives for CMS for Run II and III

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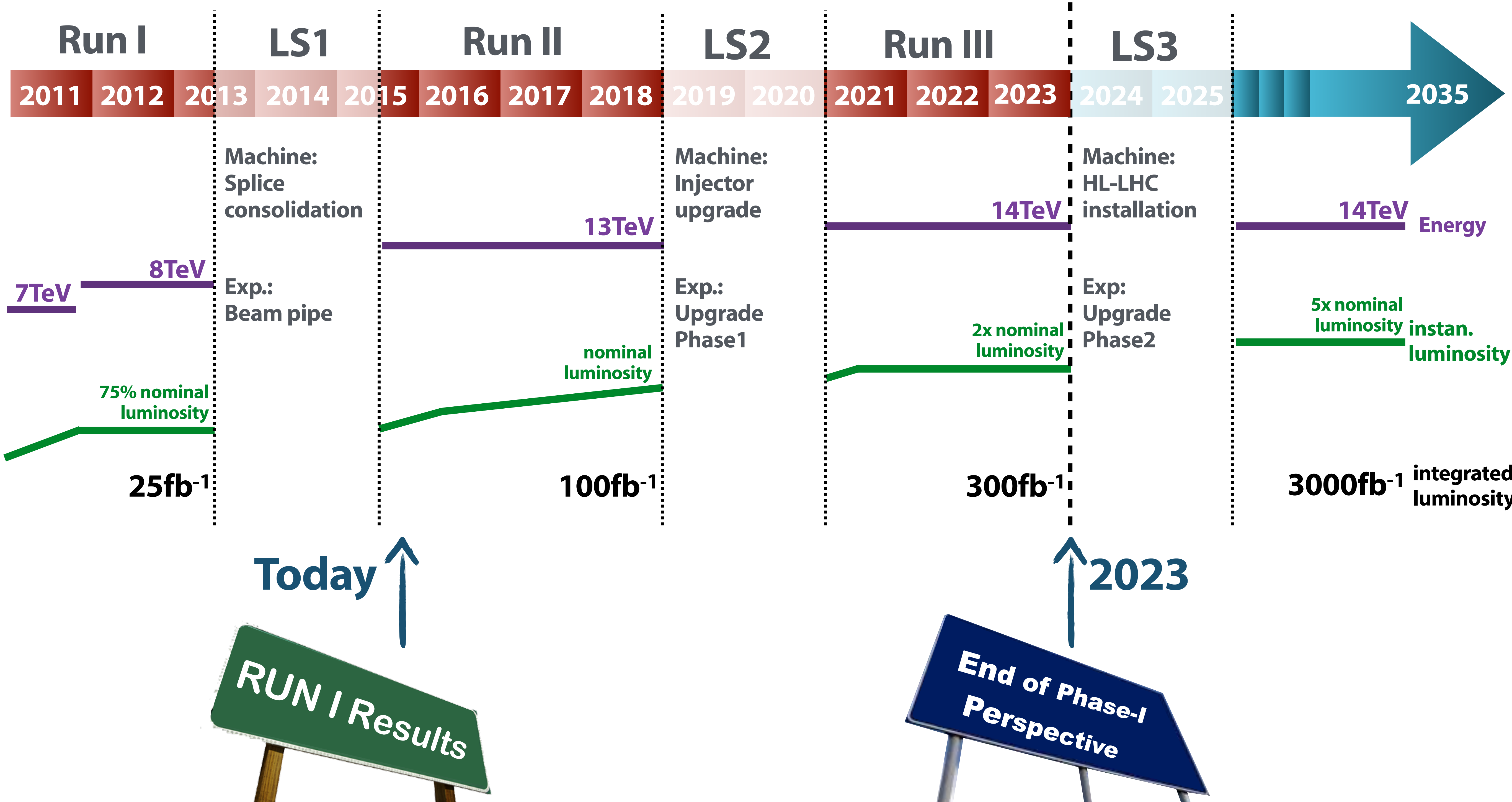
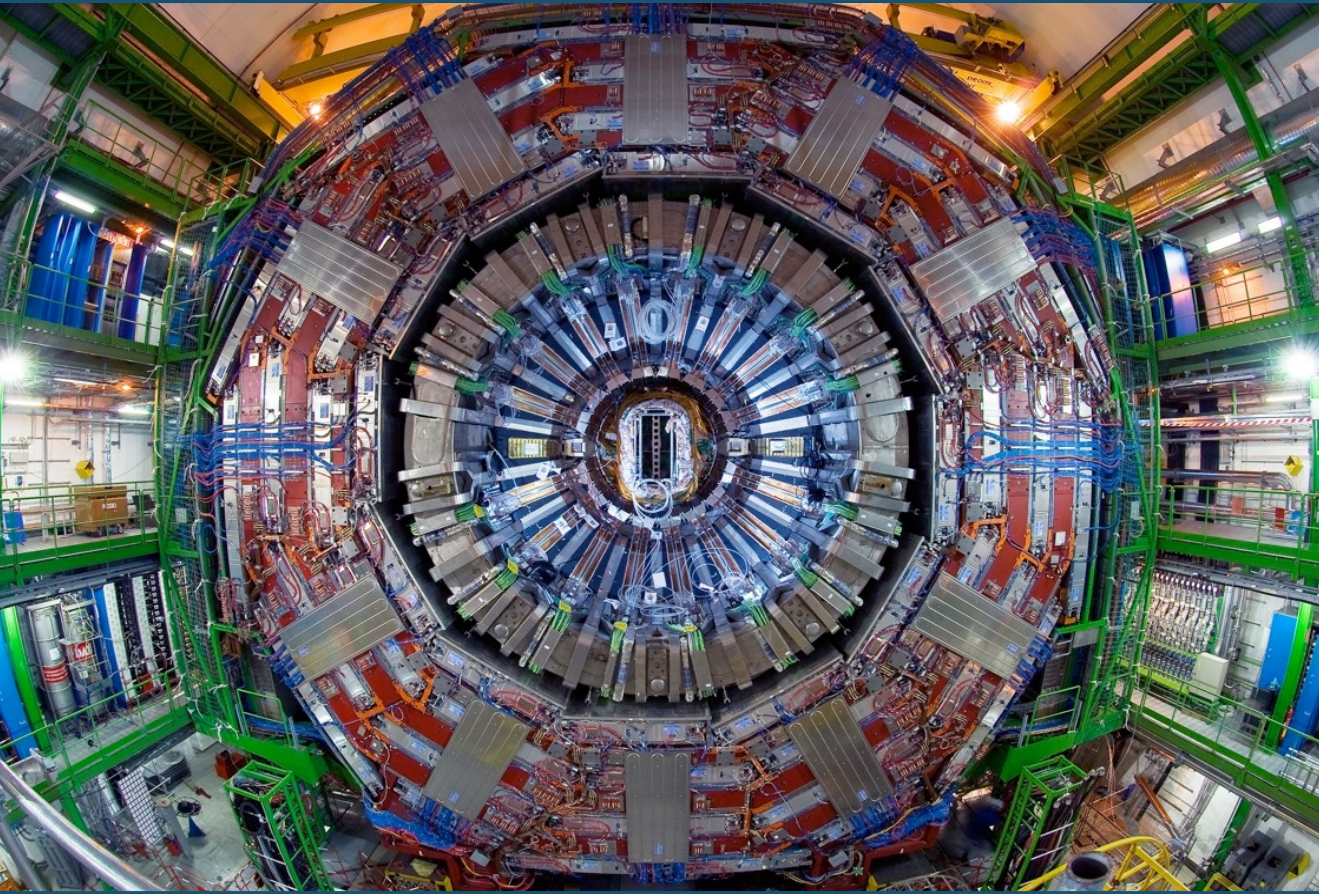
LHC and HL-LHC plans

LHC

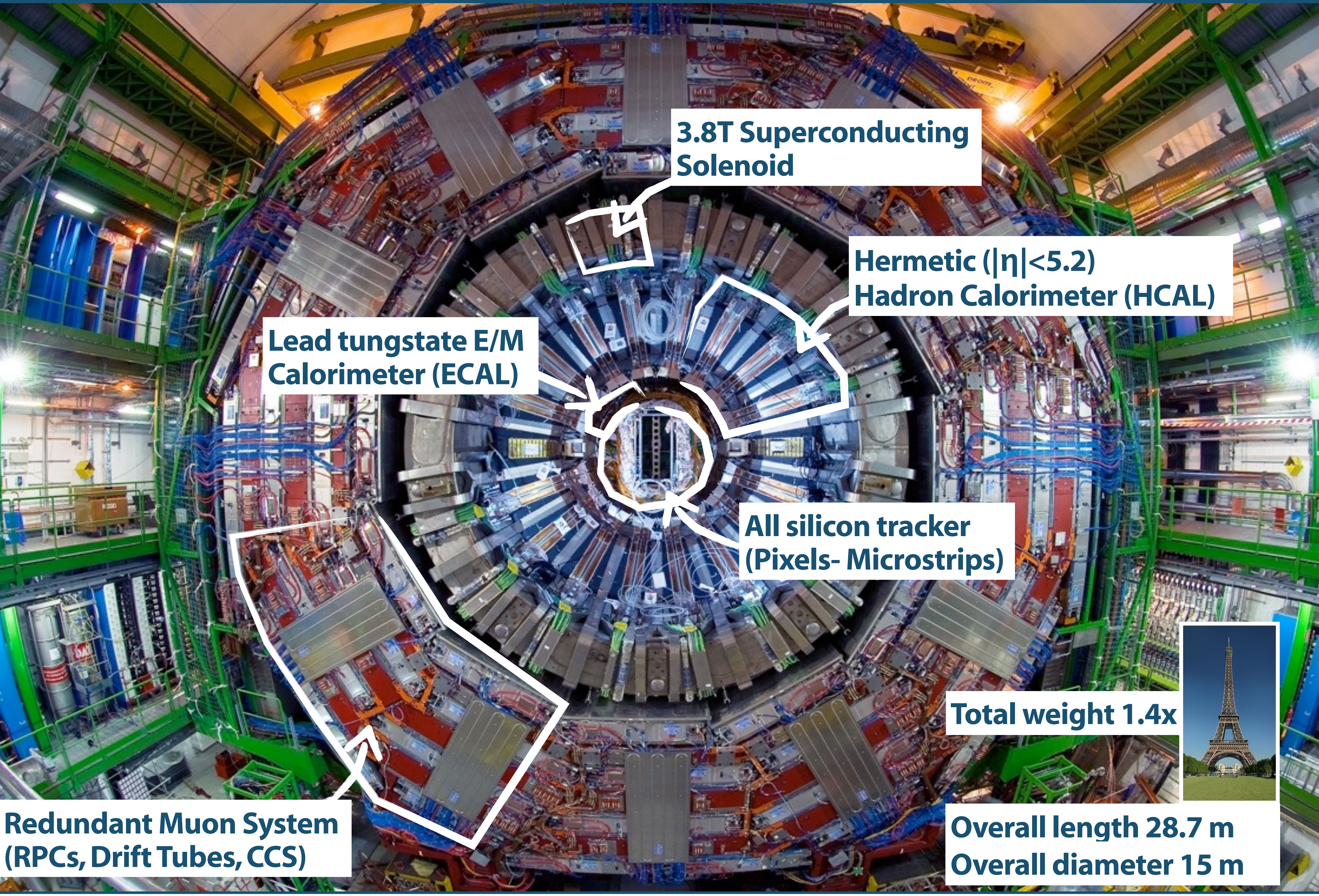
High Luminosity LHC



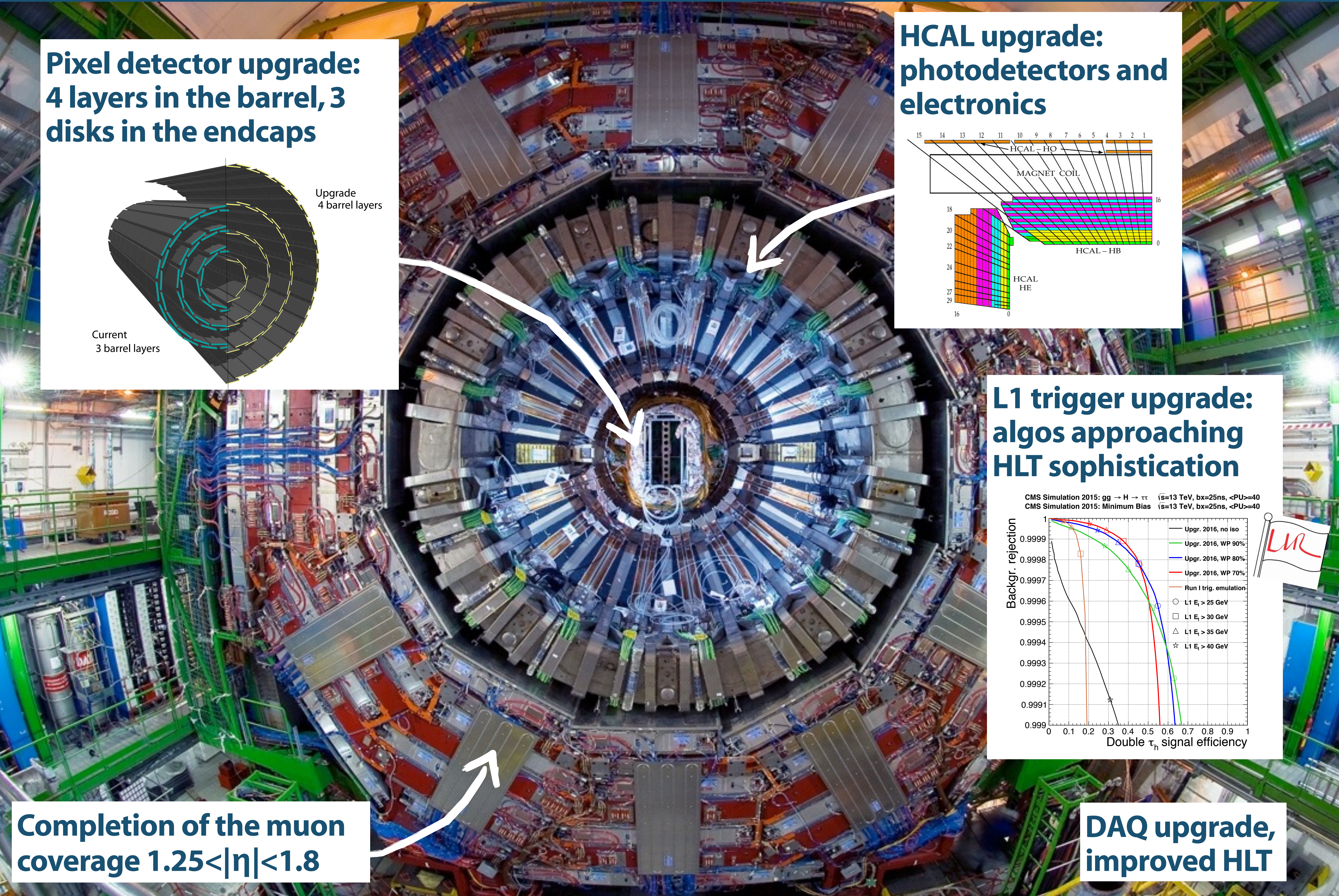
The CMS detector



The CMS detector



... after upgrade at the end of Phase-I



Pixel detector upgrade: 4 layers in the barrel, 3 disks in the endcaps

HCAL upgrade: photodetectors and electronics

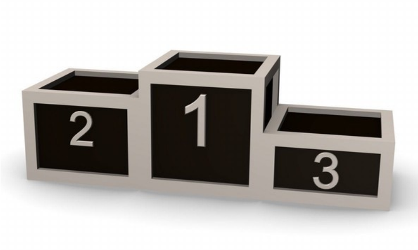
L1 trigger upgrade: algos approaching HLT sophistication

Completion of the muon coverage 1.25<|η|<1.8

DAQ upgrade, improved HLT

Number of submitted papers

438 papers have been submitted of by the CMS collaboration from the beginning of LHC



the most cited papers

Higgs

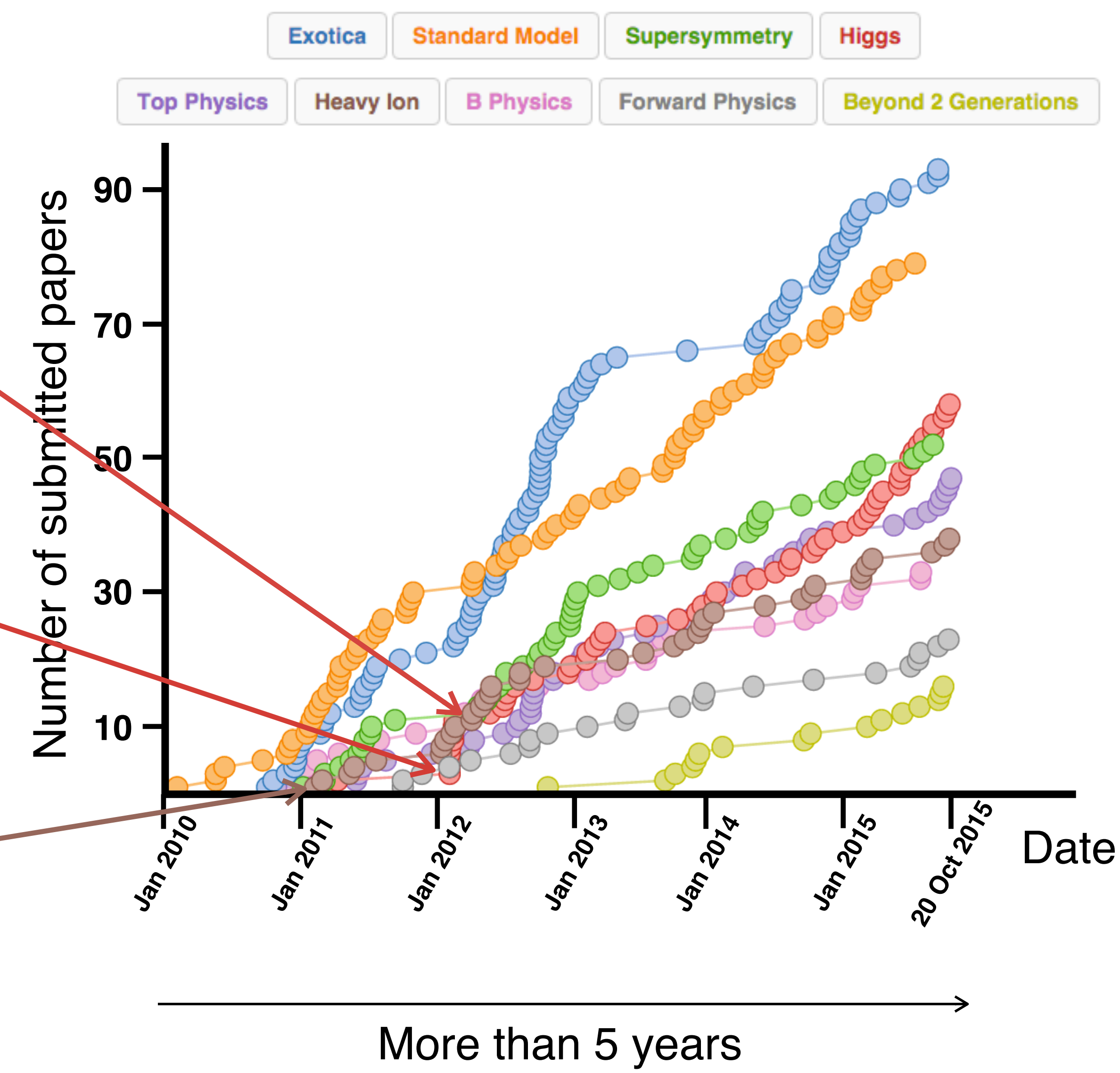
1st Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC
~5000 citations

Higgs

2nd Combined results of searches for the standard model Higgs boson in pp collisions at √s=7 TeV
~700 citations

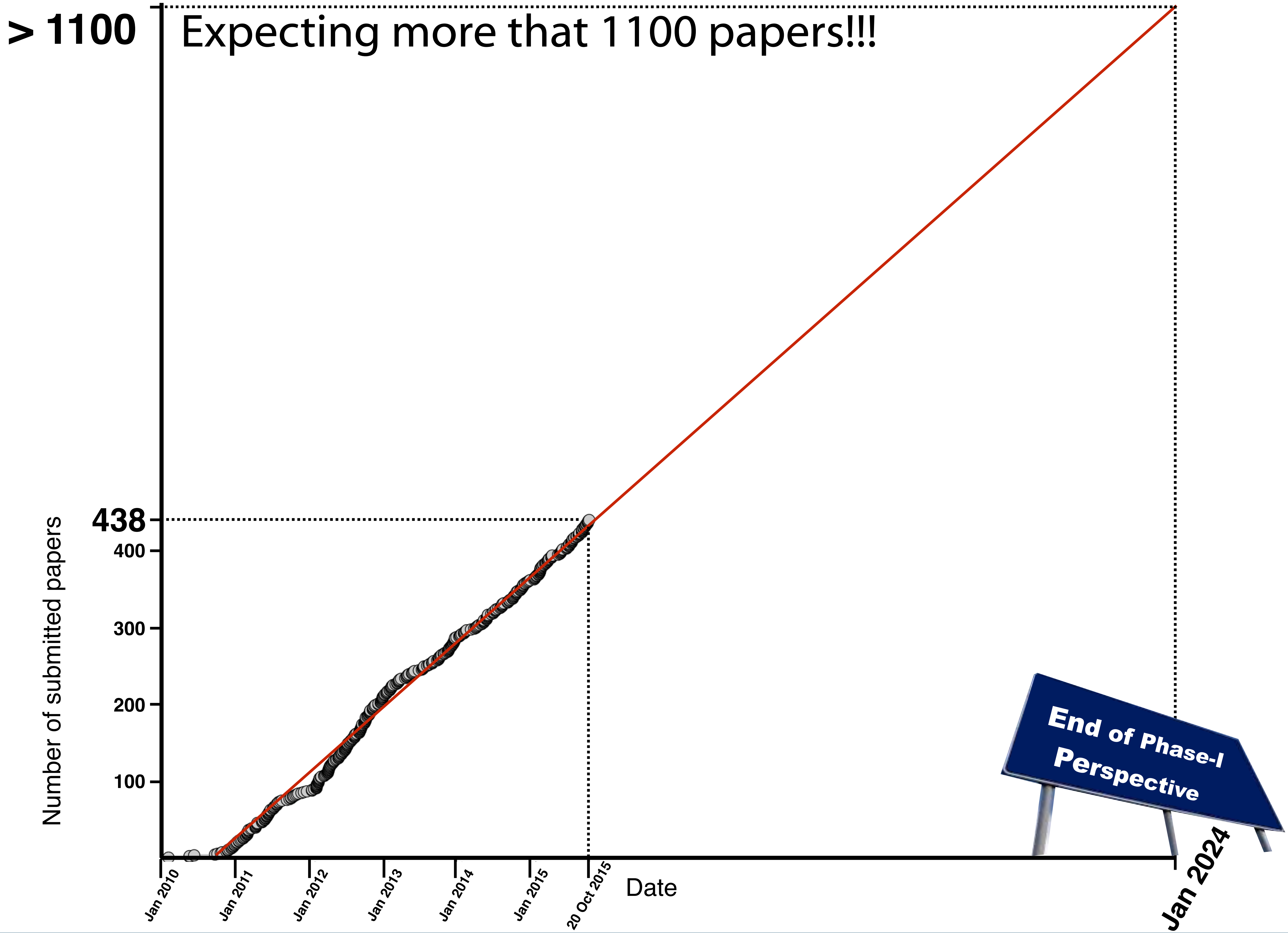
Heavy ion

3th Observation and studies of jet quenching in PbPb collisions at nucleon-nucleon center-of-mass energy = 2.76 TeV
~400 citations



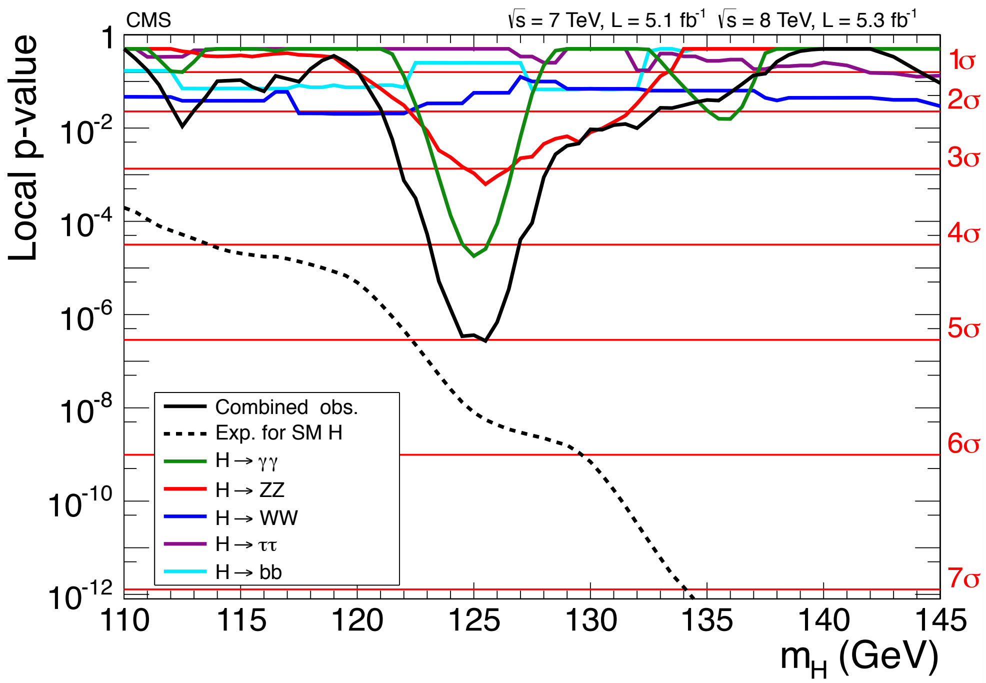
We have to discuss about perspectives …
let's see where we stand at the end of LHC Phase-I…

Number of papers that will be submitted



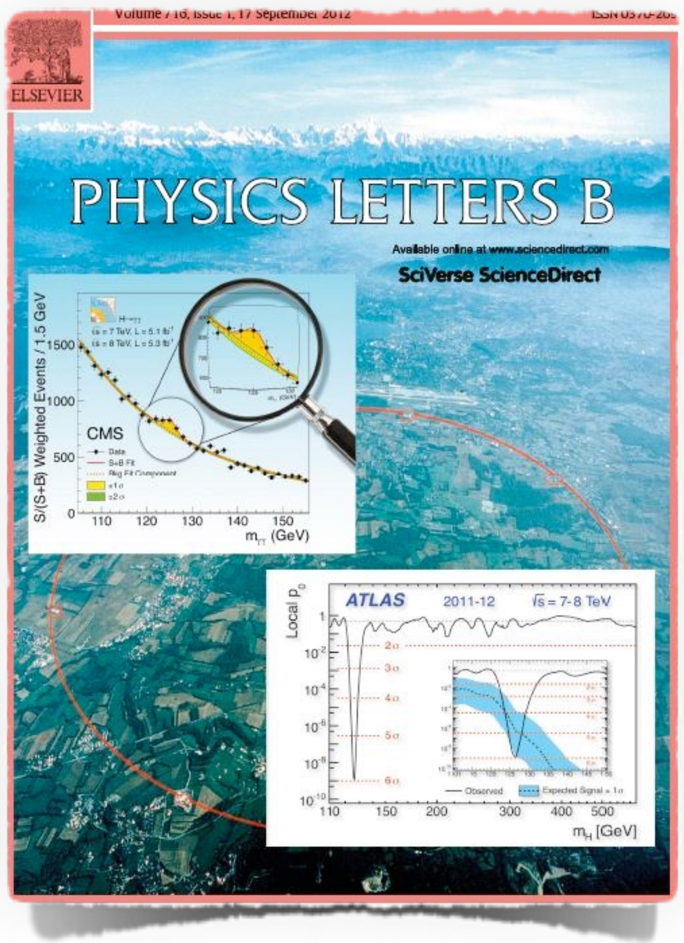
The (extended) scalar sector

4th July 2012: Higgs-dependence day



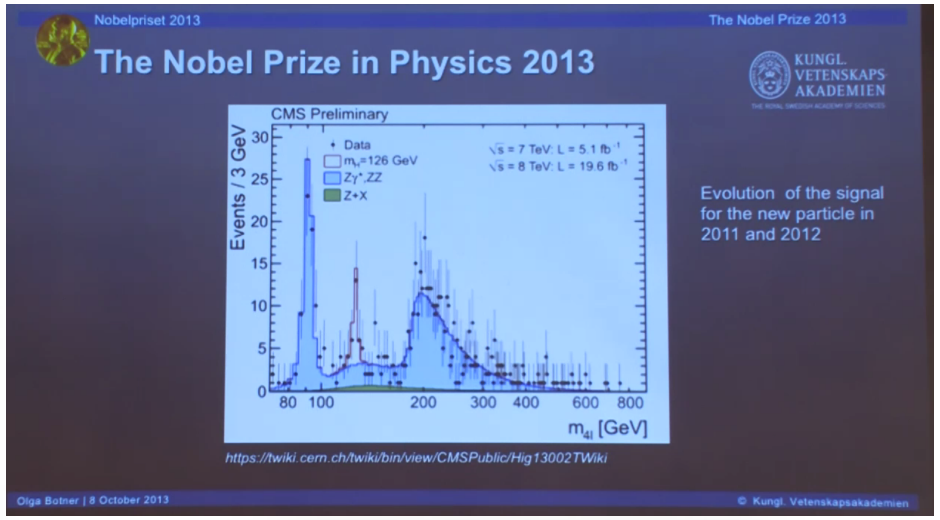
Discovery of a new boson

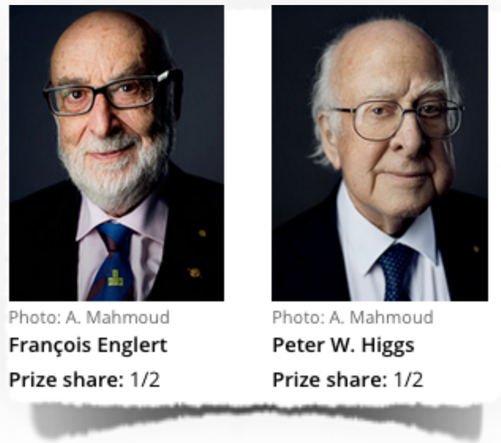
The white paper



~5000 citations and counting

The 2013 Nobel prize



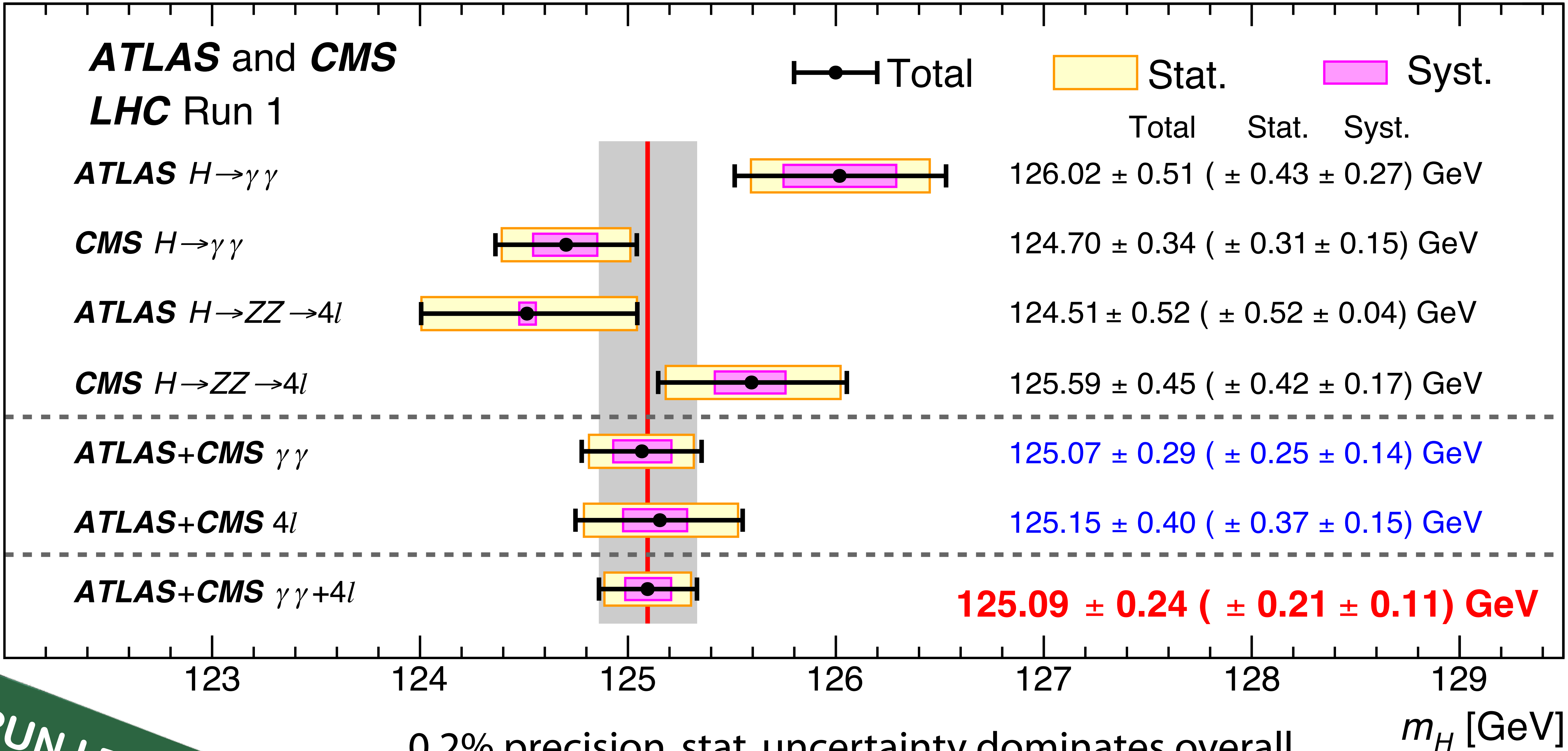


LLR was there!

Higgs boson measured mass

In the SM the Higgs sector is determined by a single parameter $\boldsymbol{m_h}$

Once m_h is fixed the Higgs couplings are **determined**



0.2% precision, stat. uncertainty dominates overall,
syst. uncertainty has big energy scale contribution (can be improved)
Among the most precise parameters of the EWK fit

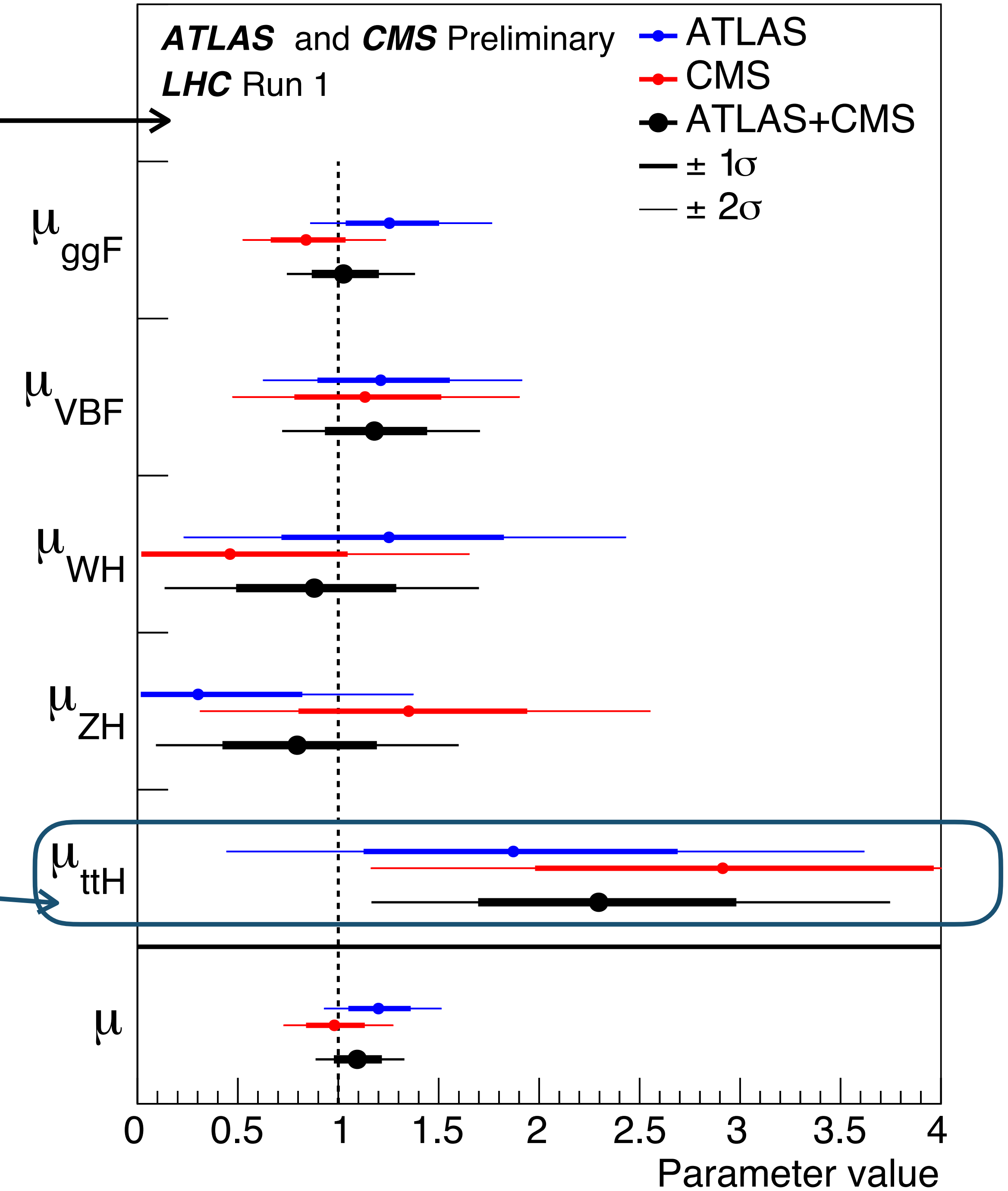
Higgs boson measured signal strengths

Properties of the Higgs boson are inferred correlating the event rates in all the channels

Predicted — Estimated — Measured

$$N^{cat} = \mu^{cat} \times \sum_{p,d} \left[(\varepsilon \cdot A)^{ch}_{pd} \cdot \sigma_p^{SM} \cdot BR_d^{SM} \cdot L \right] + Bkg^{ch}$$

Signal strength



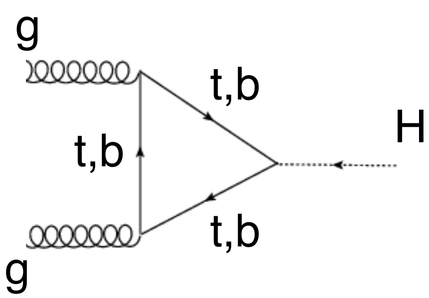
Signal strengths in different channels are consistent with 1 (SM). Largest difference in tth: **2.3σ excess with respect to SM** in both ATLAS/CMS

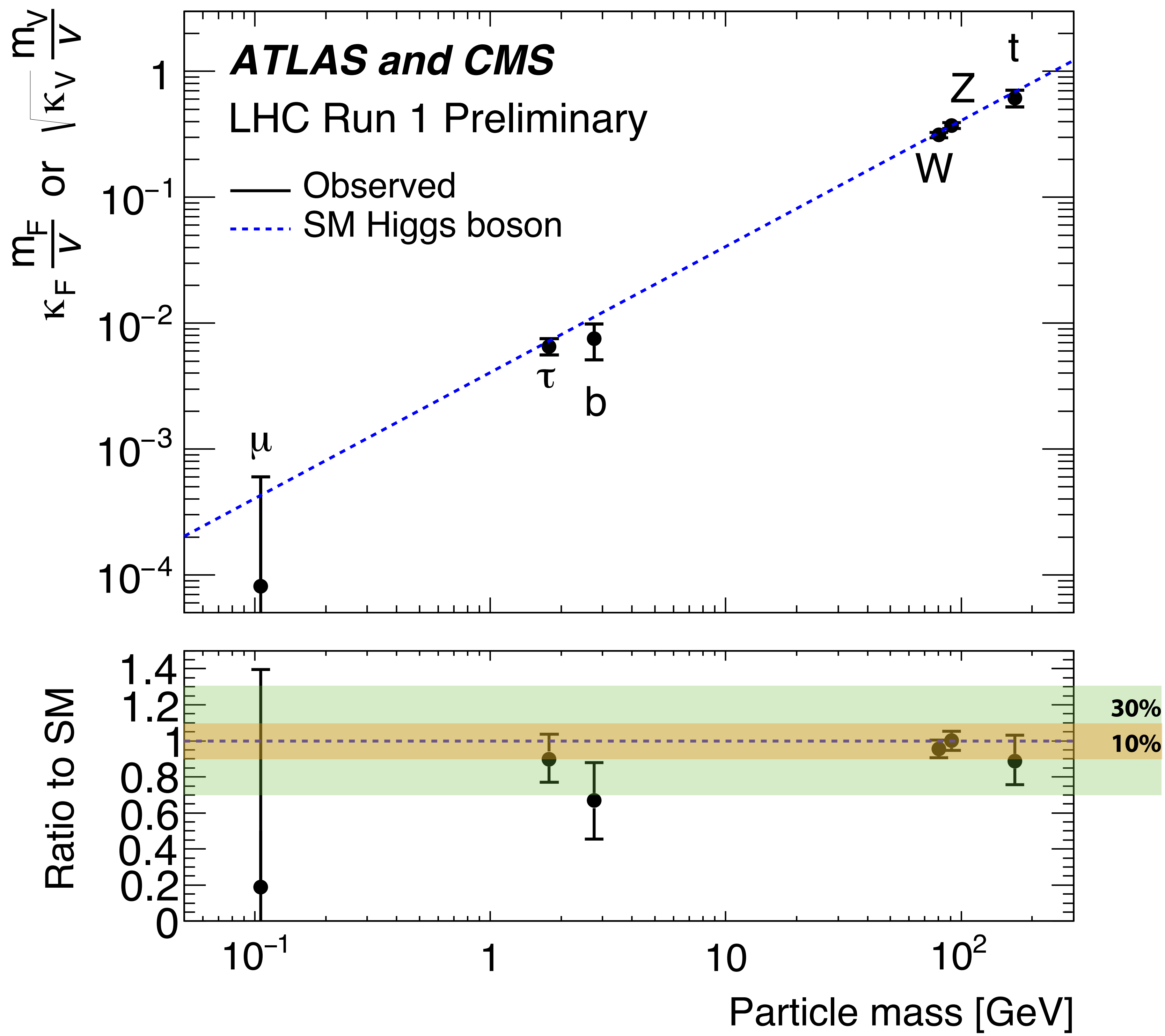
Higgs boson measured couplings

Simplest parametrisation of Higgs-couplings deviations from SM values

$$(\sigma \times BR)(ii \rightarrow h \rightarrow ff) = \sigma_{SM}(ii \rightarrow h) \times BR_{SM}(h \rightarrow ff) \times \frac{k_i^2 k_f^2}{k_H^2}$$

Assuming no BSM particles in the loops: i.e. assume SM for K_γ and K_g





Couplings to weak bosons and to fermions are verified at 10-30% precision only!

No sensitivity on K_μ!

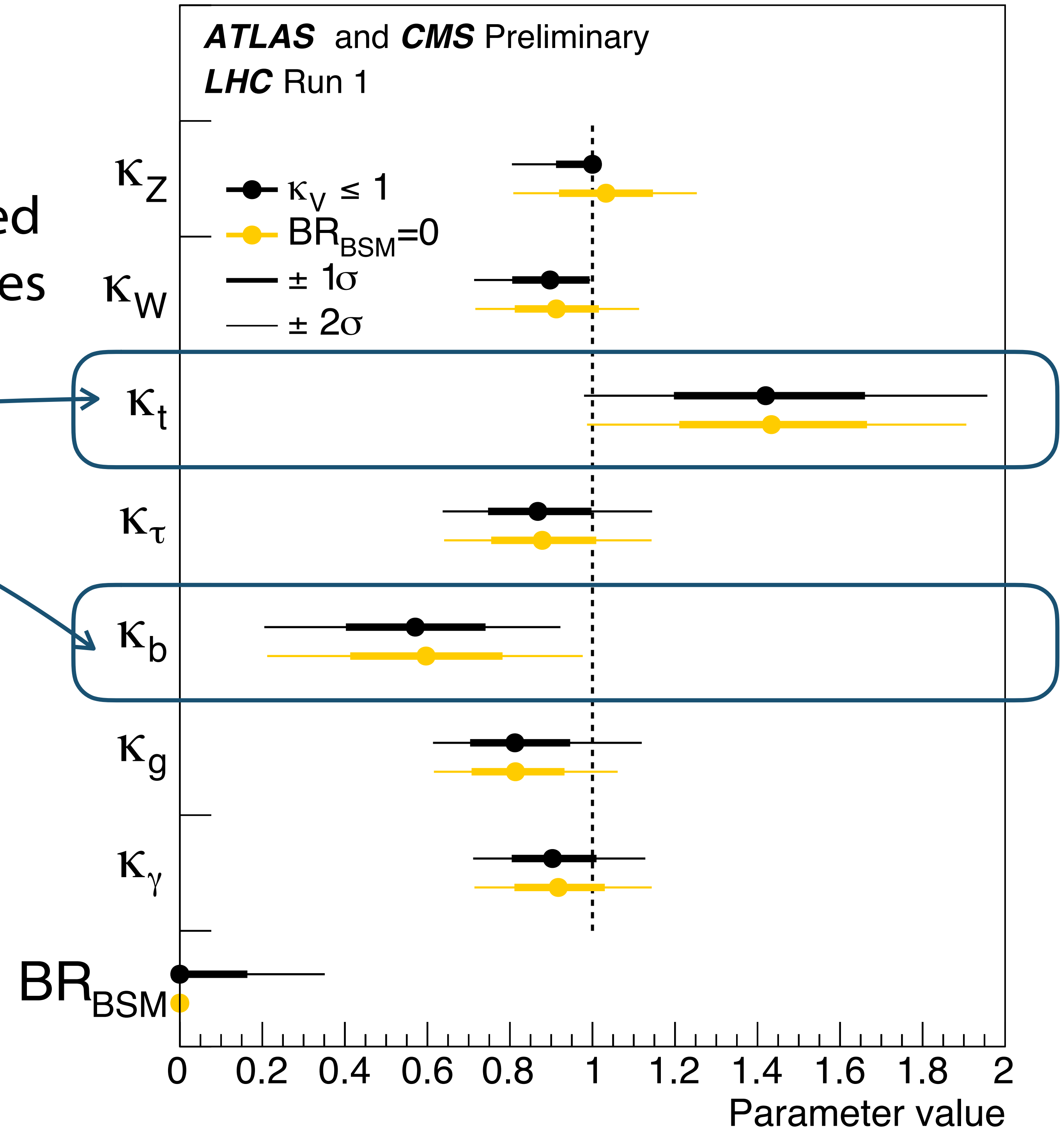
Higgs boson measured couplings

Simplest parametrisation of Higgs-couplings deviations from SM values

$$(\sigma \times BR)(ii \rightarrow h \rightarrow ff) = \sigma_{SM}(ii \rightarrow h) \times BR_{SM}(h \rightarrow ff) \times \frac{k_i^2 k_f^2}{k_H^2}$$

Allowing for BSM particles in the loops:
i.e. allow effective couplings for K_γ and K_g

$K_V \leq 1$ (2HDM) $\Rightarrow$ BR_{BSM} can be constrained
$BR_{BSM} = 0$ $\Rightarrow$ no decay in BSM particles



Some **tensions** (~ 2σ) seen from tth production and h → bb decays in both ATLAS and CMS. Tension at the level of 2.4σ is seen as well in BR_{bb}/BR_{ZZ}.

Rediscover the Higgs boson at 13 TeV

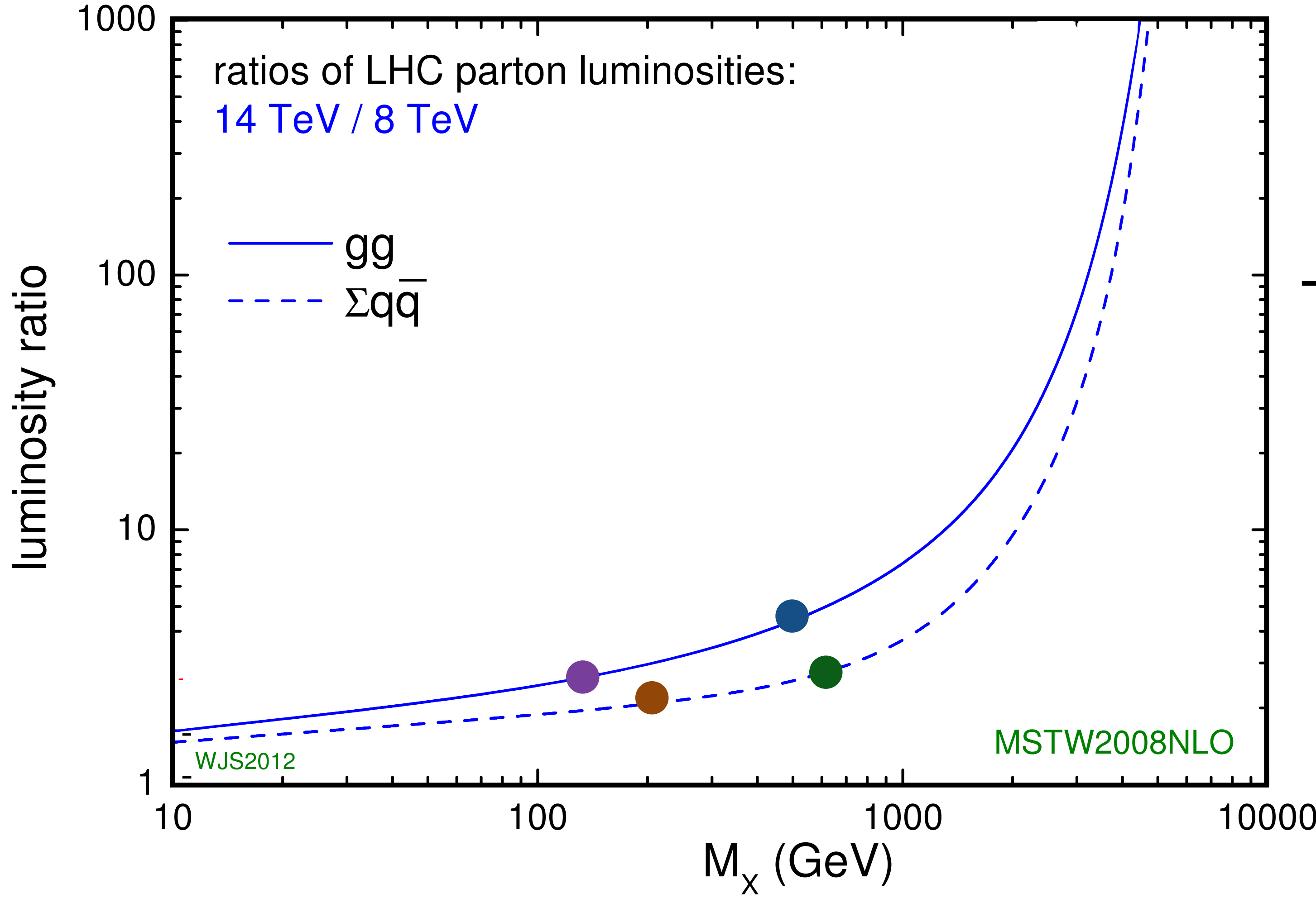
High precision Higgs boson coupling measurements

Follow the few tensions observed with Run1 data ($h \rightarrow bb$, tth, …)

Observe the Higgs boson in more exclusive production/decay modes

Look for additional Higgs-like particles or partners at high masses

LHC14 : the Higgs factory for rediscovery



	$\sigma_{14TeV}/\sigma_{8TeV}$	σ_{14TeV} [pb]
● gg→h	2.6(M_X=M_h)	49.5
● qq→qqh	2.6(high M_X)	4.2
● qq→Vh	2.1(M_X=M_V+M_h)	1.5/1
● gg→tth	4.7(M_X=2M_t+M_h)	0.6

Higgs boson candidates for 300 fb^{-1} at 14 TeV:

ggF	VBF	Wh	Zh	tth	total
14M	1.3M	0.5M	0.3M	0.2M	17M

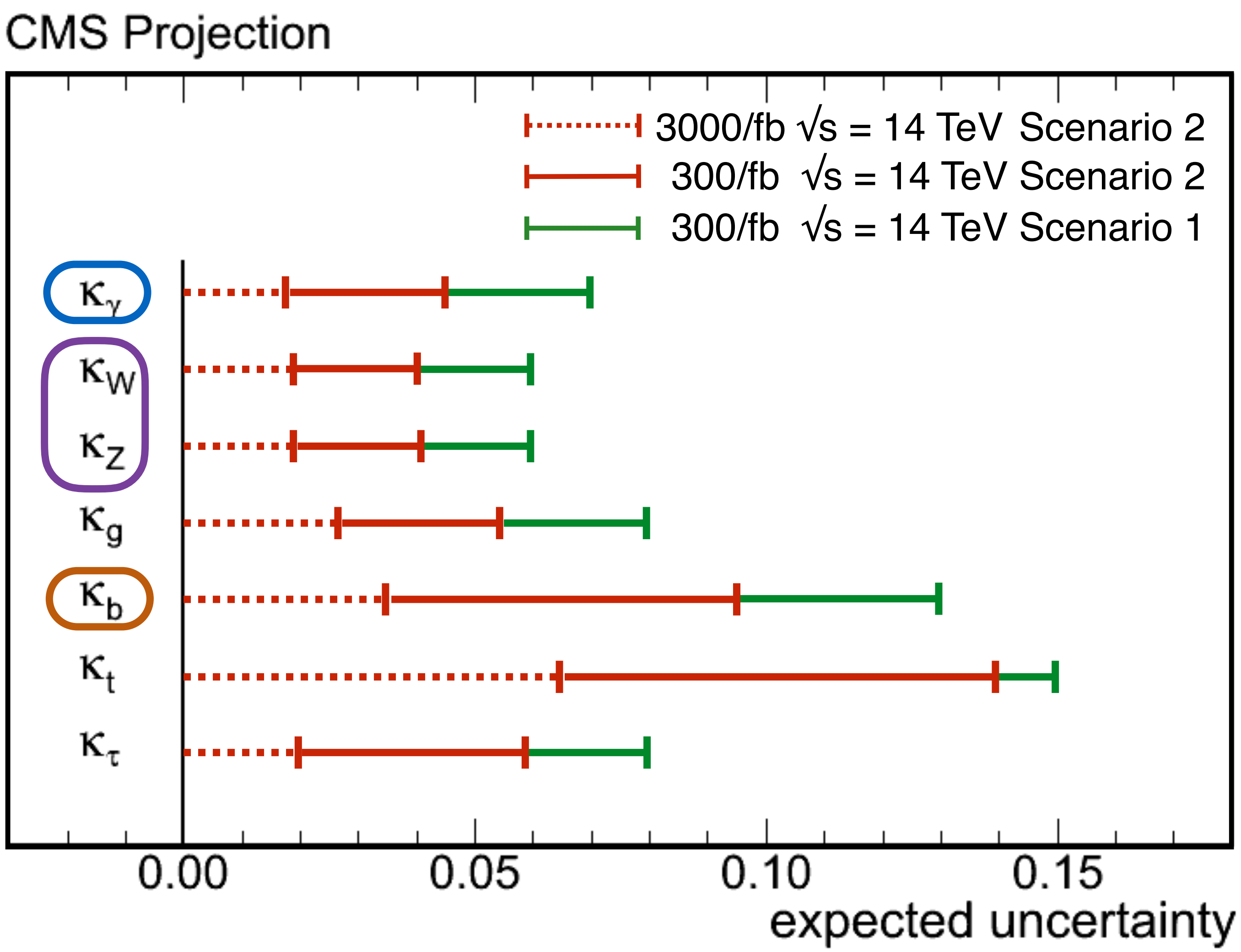
→ Access rare(r) Higgs boson production and decay modes

26K th candidates, 14K hh candidates

$BR_{h\to\mu\mu}$ = 0.021% $BR_{h\to Z\gamma}$ = 0.15% ($BR_{h\to Z\gamma\to ll\gamma}$ = 0.01%)

High precision coupling measurements

Expected uncertainties on Higgs boson couplings



Model	κ_V	κ_b	κ_γ
Singlet Mixing	$\sim 6\%$	$\sim 6\%$	$\sim 6\%$
2HDM	$\sim 1\%$	$\sim 10\%$	$\sim 1\%$
Decoupling MSSM	$\sim -0.0013\%$	$\sim 1.6\%$	$< 1.5\%$
Composite	$\sim -3\%$	$\sim -(3-9)\%$	$\sim -9\%$
Top Partner	$\sim -2\%$	$\sim -2\%$	$\sim +1\%$

arXiv:1401.6081

Generic size of Higgs boson coupling modifications from the SM values in classes of new physics models

Not another EWSB states accessible at LHC

Scenario 1 : uncertainties as in Run1

Scenario 2 : theoretical uncertainties/2
experiment systematic/sqrt($\mathcal{L}$)

.. and what about K_μ …

h →μμ

Main channel to measure Yukawa coupling to **2nd generation fermions**

$BR_{H\rightarrow\mu\mu} = 0.021\%$: ~100 events produced during RUN1 w.r.t. 3.4k events at LHC

The important path to the future

6 fb⁻¹ : reach RUN1 sensitivity (95%CL on $\sigma/\sigma_{SM} = 5$)

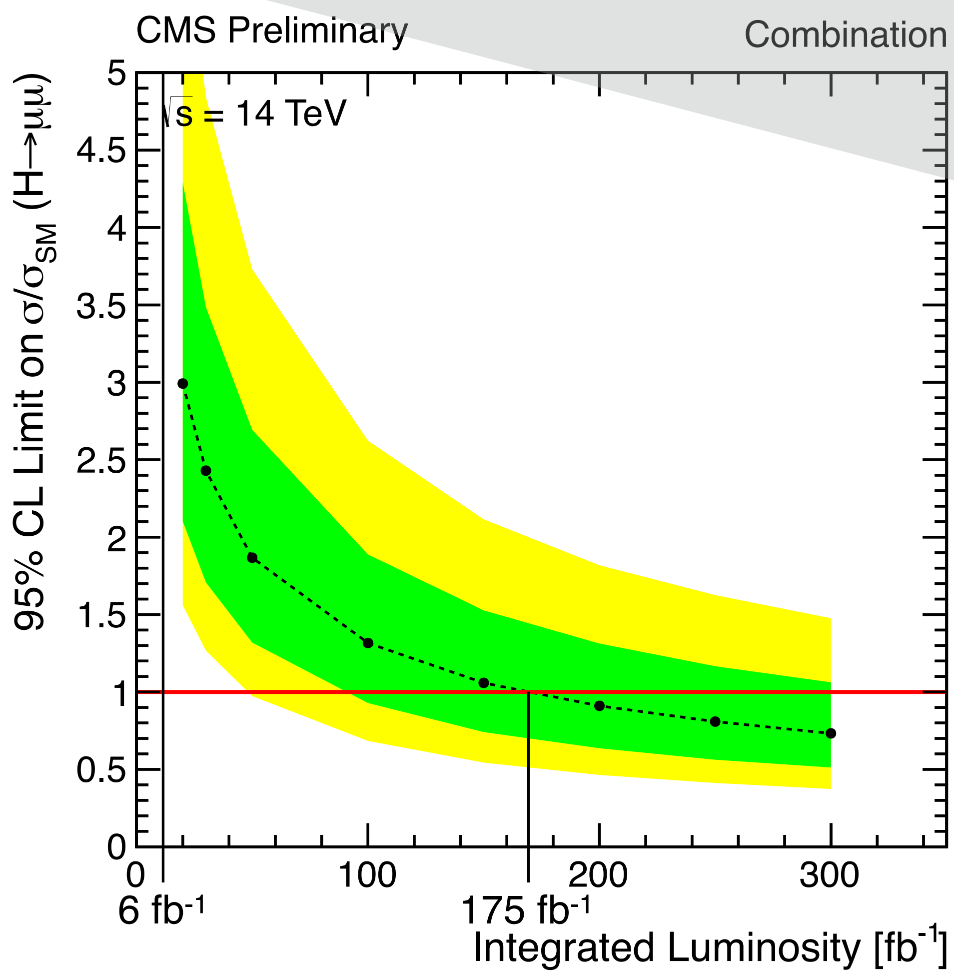
175 fb⁻¹ : excluded SM

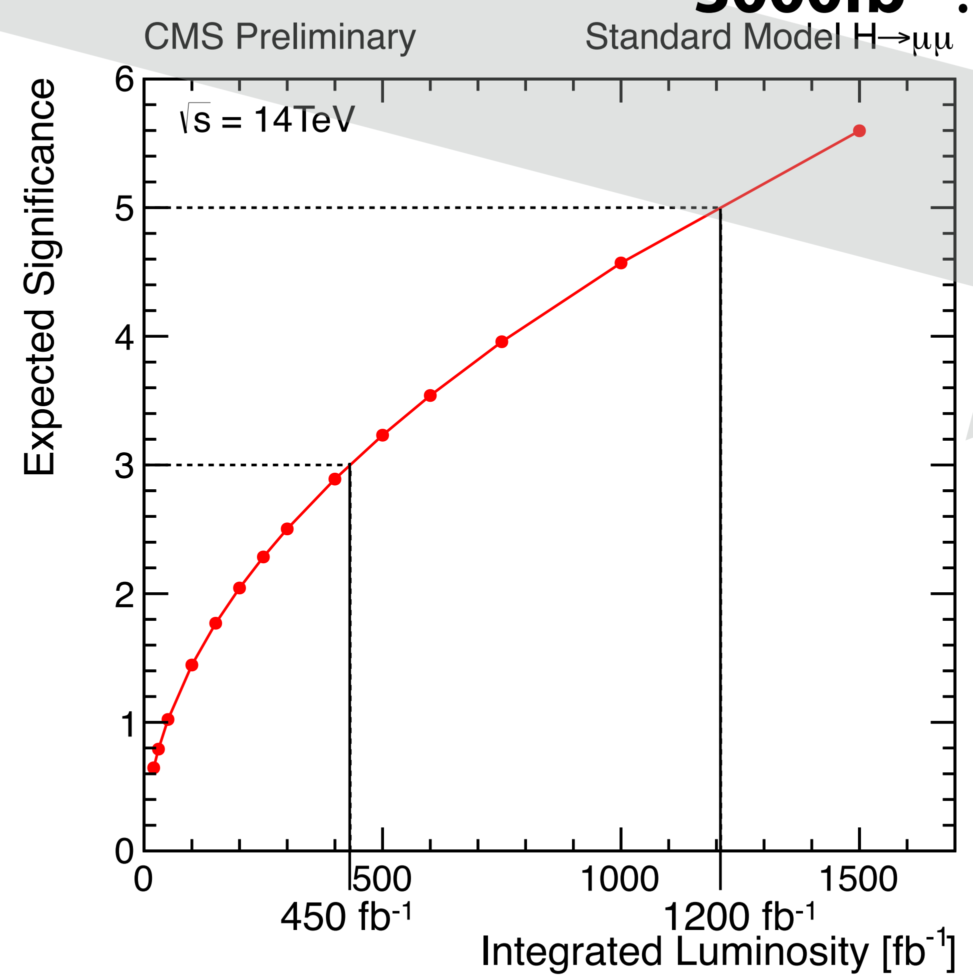
300 fb⁻¹ : 20% on K_μ

450 fb⁻¹ : reach 3σ significance

1200 fb⁻¹ : reach 5σ significance

3000fb⁻¹ : 5% on K_μ





$h \to J/\psi\gamma$ to access the Hcc coupling

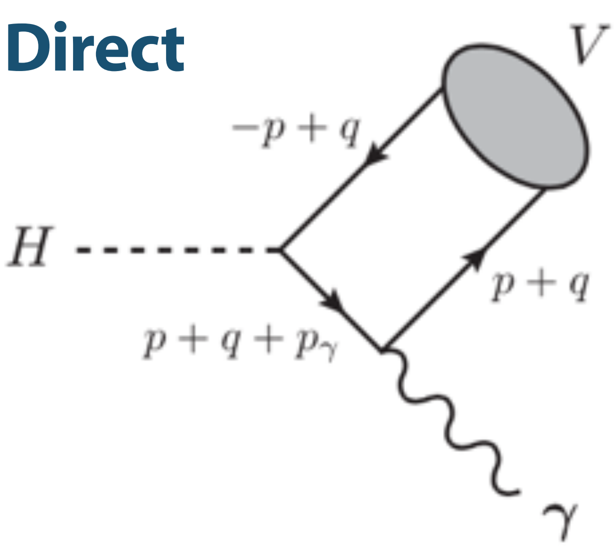
Another test to measure Yukawa coupling to **2nd generation fermions**

Why not $h \to cc$ ($BR_{H\to cc}$~2.9%)?

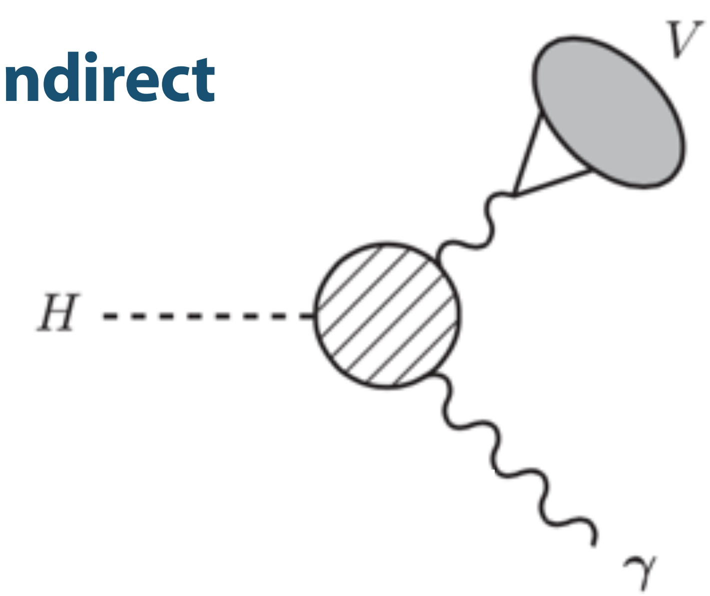
Sufficient statistics but huge QCD background and poor c-tagging performance

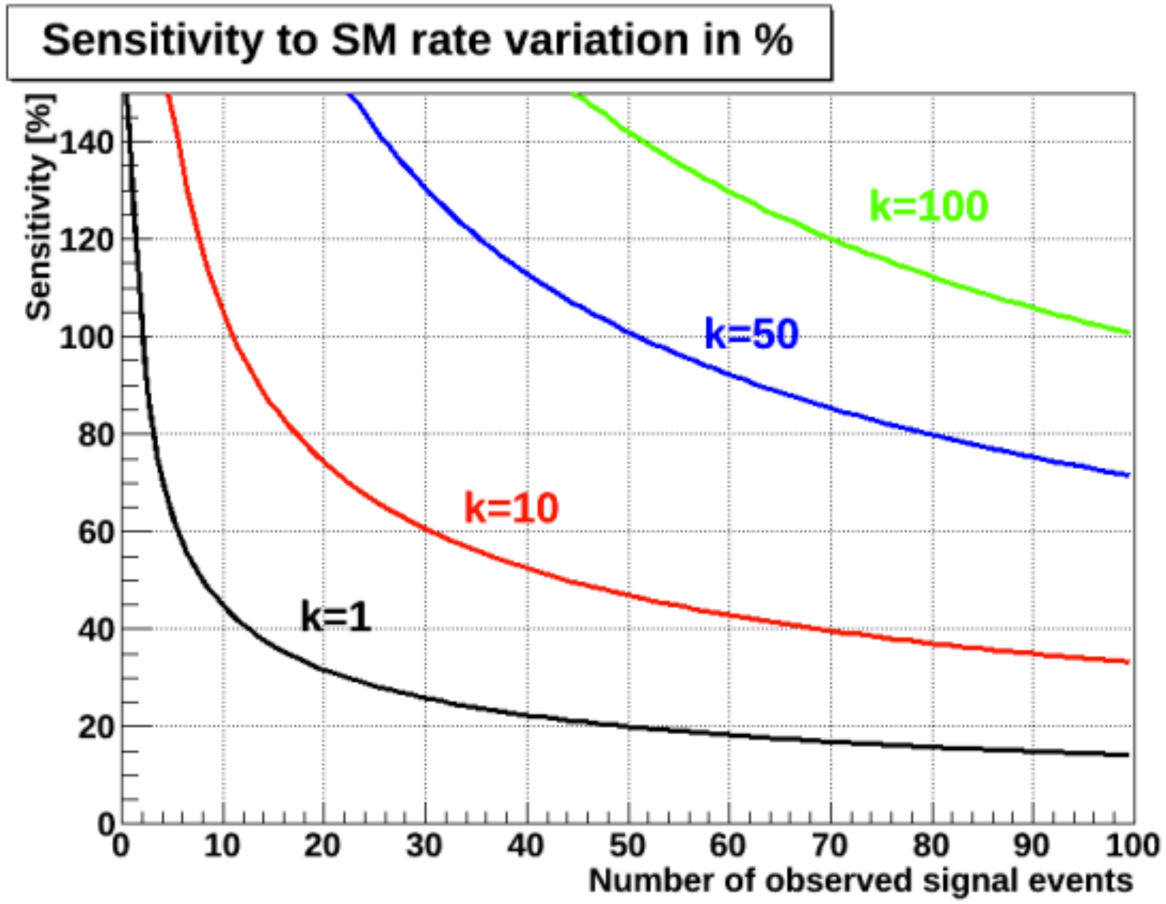
$h \to J/\psi\gamma$: exploit interference between direct (hcc mediated) amplitude and indirect one to gain insight into hcc

Direct



Indirect





arXiv:1306.5770

BR_{direct} : 5×10^{-8}

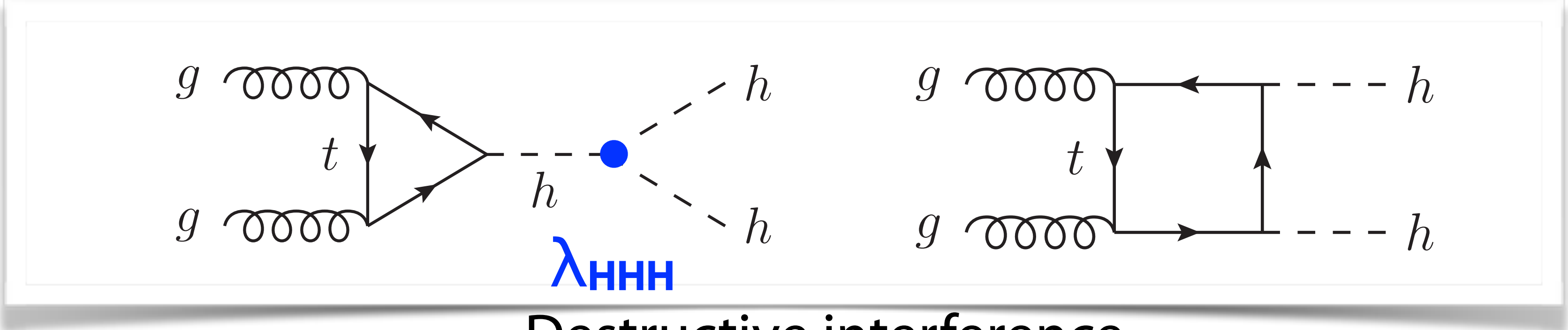
$BR_{indirect}$: 3.3×10^{-6}

BR_{TOT} : 2.5×10^{-6}

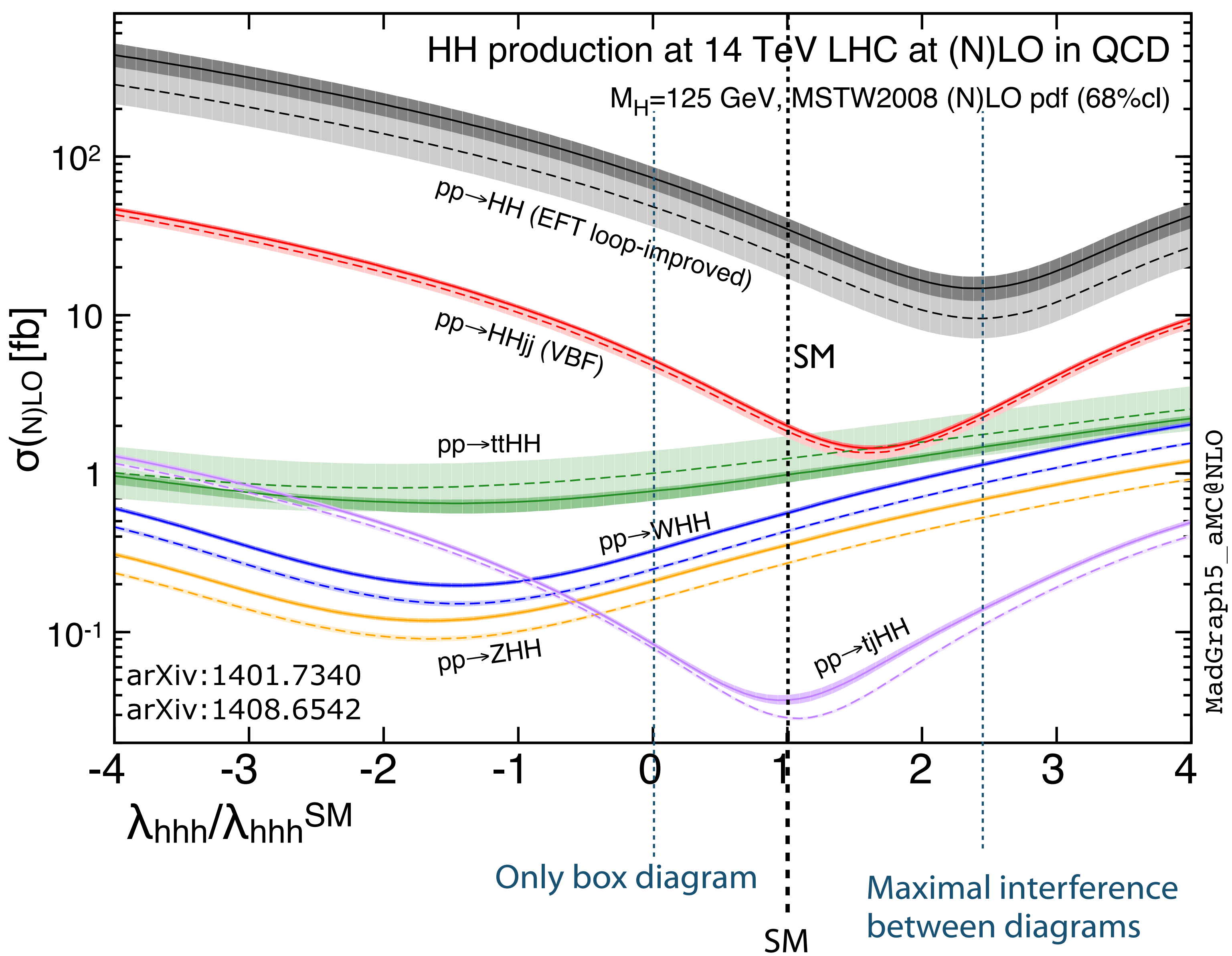
-30% from interference

Higgs boson pair production

hh production could ultimately allow to test the shape of the scalar potential, i.e. the self-coupling at the origin of the spontaneous EWK symmetry breaking



Destructive interference



At 14 TeV

gg→hh = 40.7 fb
VBF = 6.8 fb
tthh = 0.7 fb

About 100 events expected during PhaseI (300 fb-1)

$\lambda_{hhh}/\lambda_{hhh}^{SM}$	σ^{SM}
-4	12
0	2.2
1	1
2.45	0.42
20	105

Significant enhancements w.r.t. SM

hh : which final states?

Branching ratios and production mechanisms are decoupled effects
hh production has a phenomenologically rich set of final states

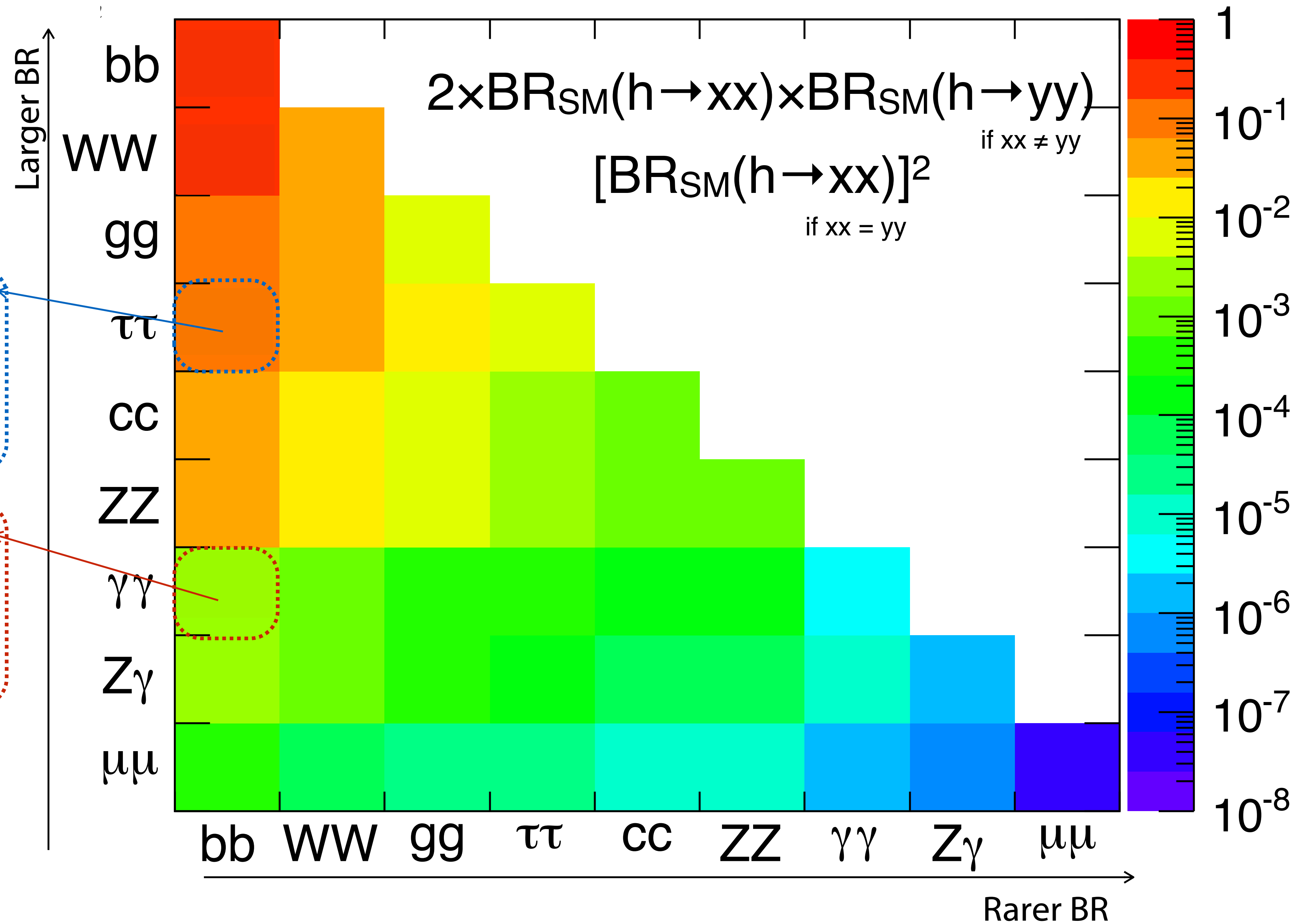
Most promising channels

bbττ

Excellent τ_h reconstruction
and τ_h/jet separation needed
Multivariate approach

bbγγ

Simple reconstruction …
but very low BR
Large background rates



→SM branching ratios (for m_h = 125 GeV) are used

HH results

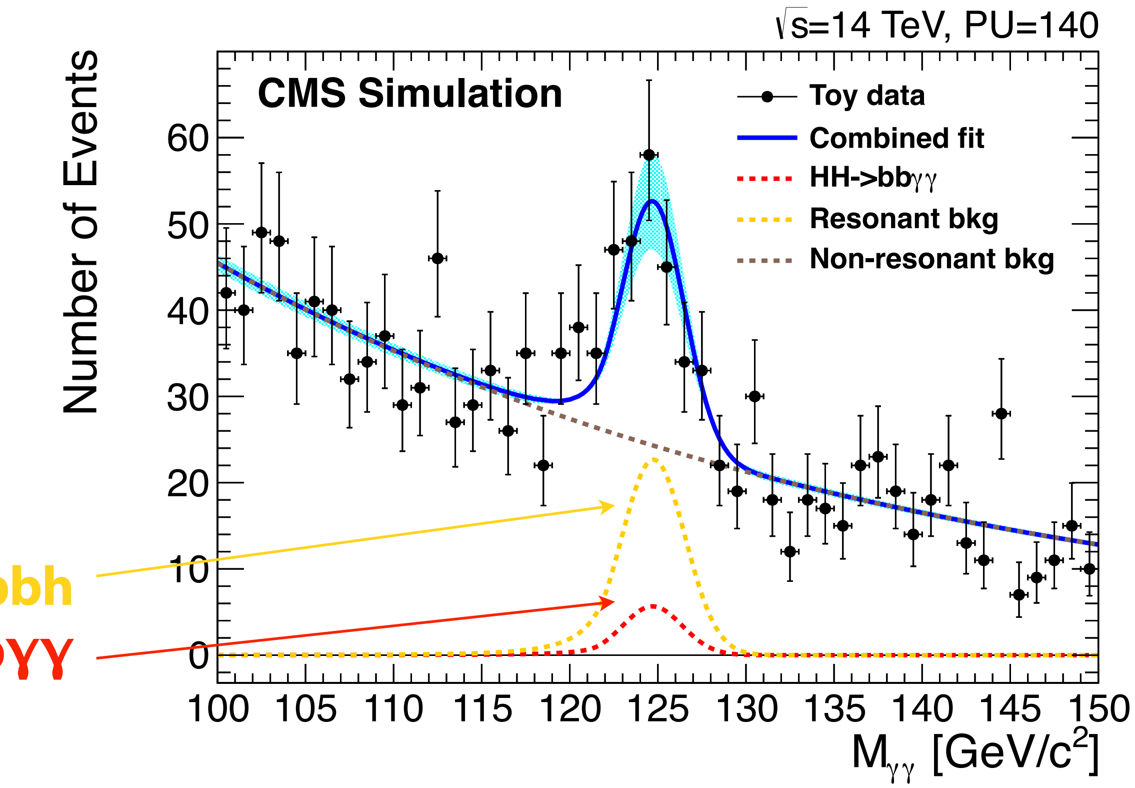
bbγγ

Be aware: prospective results for the end of HL-LHC

Di-photon mass distribution for the estimated signal and background contributions.
The data points show the result of a pseudo-experiment.

background : Zh,tth,bbh

signal : hh → bbγγ

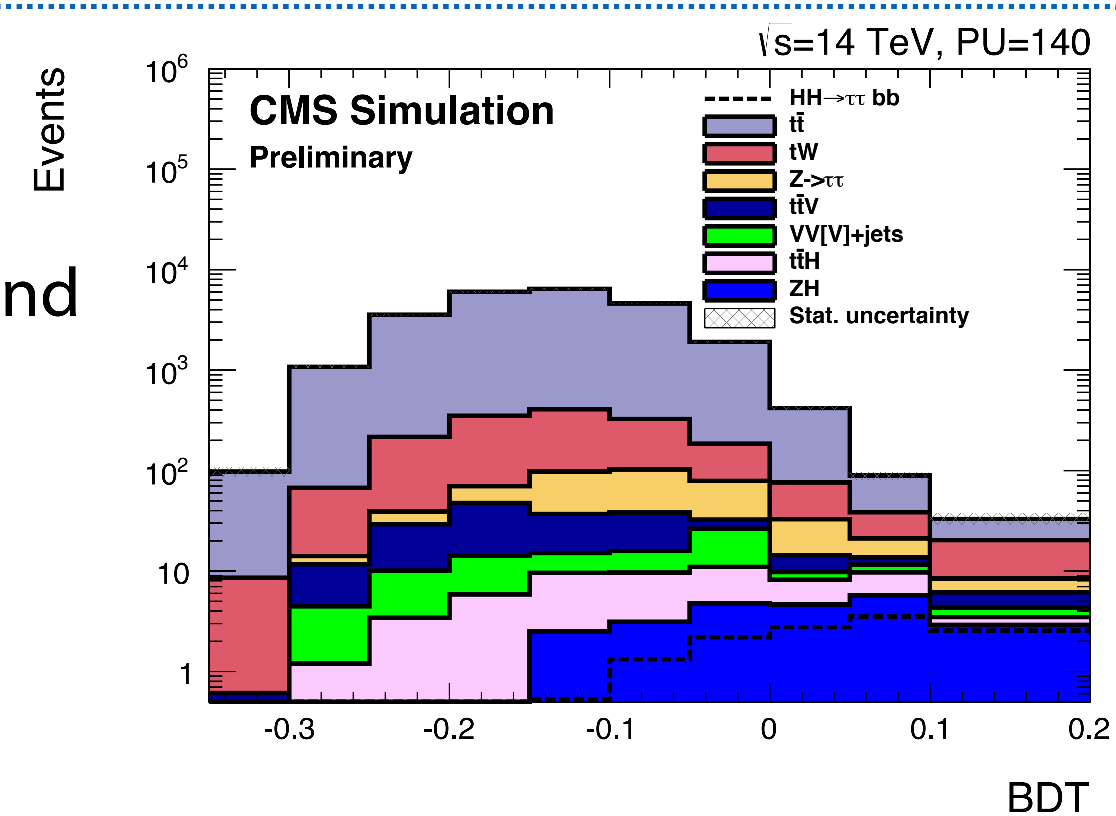


bbττ

Challenging analysis, overwhelming tt background

The most sensitive final states: $\tau_\mu\tau_h$ and $\tau_h\tau_h$

m_{T2} mass/BDT for signal extraction method



Assuming ~same performance in Phase-I/Phase-II it could be better

BSM Higgs bosons searches

The properties of Higgs boson at the current level of precision appear to almost in accord with the SM… but …

- the detailed structure of the Higgs sector is still unclear
- the SM cannot be a final theory of Nature
- some tensions have been seen from tth production and h→bb decays

Beyond the SM (2HDM, MSSM/nMSSM) might hold the answer

decay

Exotic Higgs boson decays
- Search for lepton flavour violating decays
- Search for decays into undetectable particles

Invisible Higgs boson decays

add. scalar

Low mass Higgs boson
- Search for pair production of new light bosons decaying into muons

High mass Higgs boson
- Search for pseudoscalar A boson decaying into a Z boson and h_{125} boson
- Search for scalar boson decaying into a VV bosons

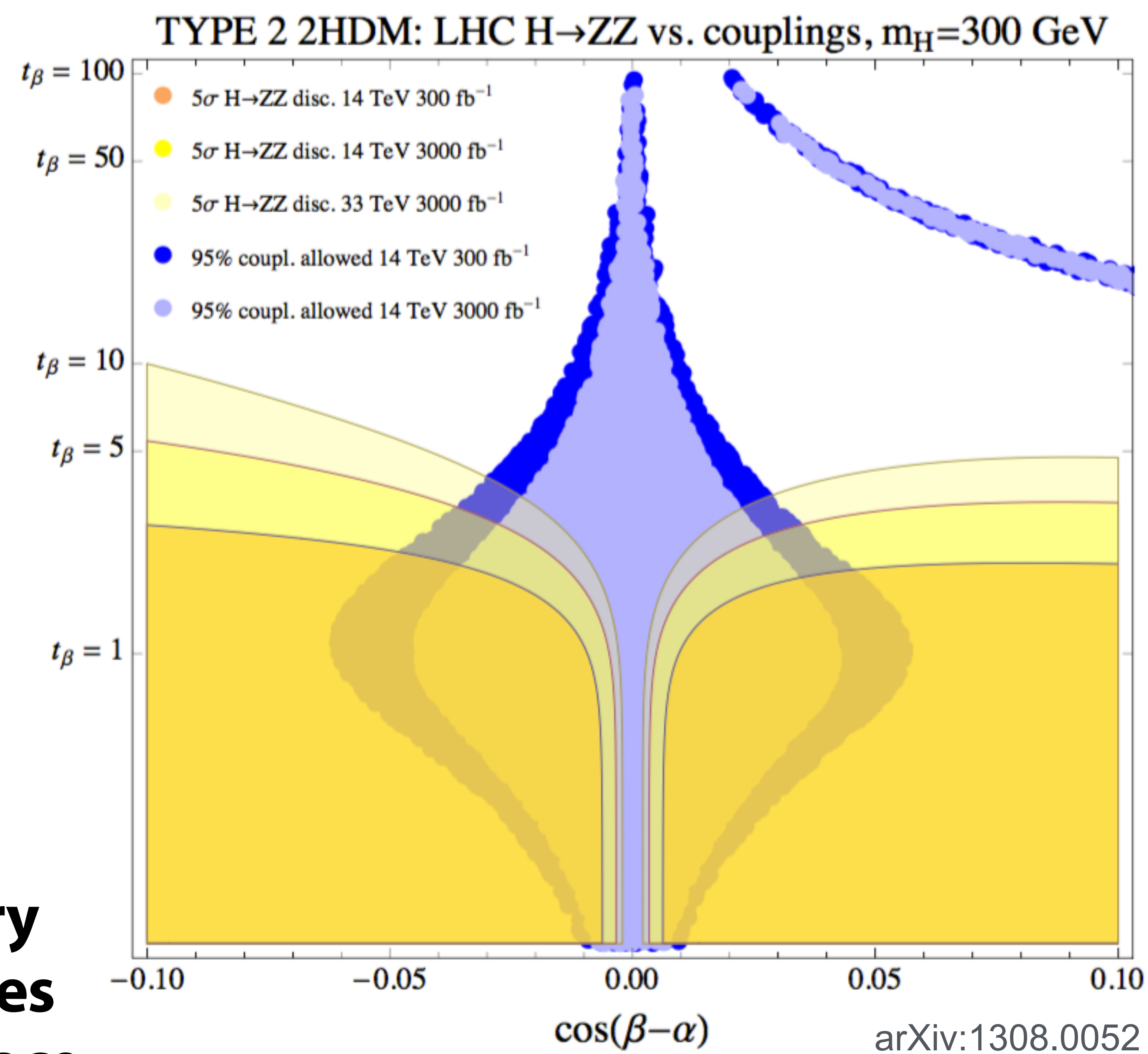
Search for additional Higgs bosons

Potential to exclude or discover heavy (scalar/pseudo-scalar) neutral Higgs bosons in the context of 2HDM

5σ discovery reach in direct searches at the LHC for a 300 GeV H decaying via H→ZZ→4l for the Type II 2HDM

Regions allowed at 95%CL by precision Higgs coupling measurements

The coupling measurements are very constraining, the direct search probes significant additional parameter space



arXiv:1308.0052

Type II model includes supersymmetry

Exotic decays

Lepton Flavour Violating decays (h→μτ) are not allowed in SM

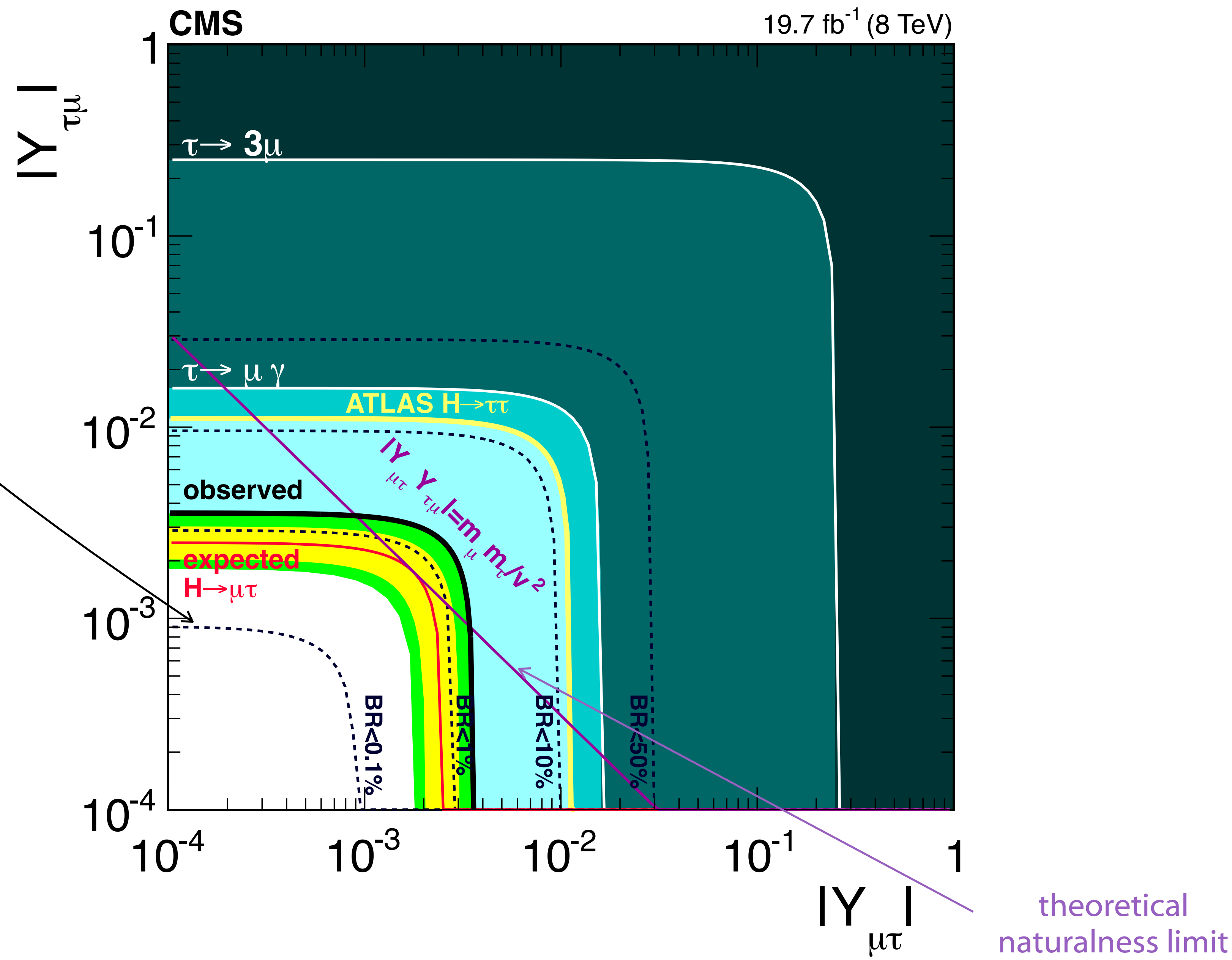
exception can occur in case it is a theory valid only to a finite mass scale

LFV decays can occur in 2HDM, and others…

$$\begin{pmatrix} y_{ee} & y_{e\mu} & y_{e\tau} \\ & y_{\mu\mu} & y_{\mu\tau} \\ & & y_{\tau\tau} \end{pmatrix}$$

With the Phase-I data BR < 0.1% will be probed

The slight excess of signal events (2.5σ) observed with RUN1 data will be monitored



Yukawa Couplings $Y_{\mu\tau}$ and $Y_{\tau\mu}$

97% C.L.: $\sqrt{|Y_{\mu\tau}|^2 + |Y_{\tau\mu}|^2} < 3.6 \times 10^{-3}$

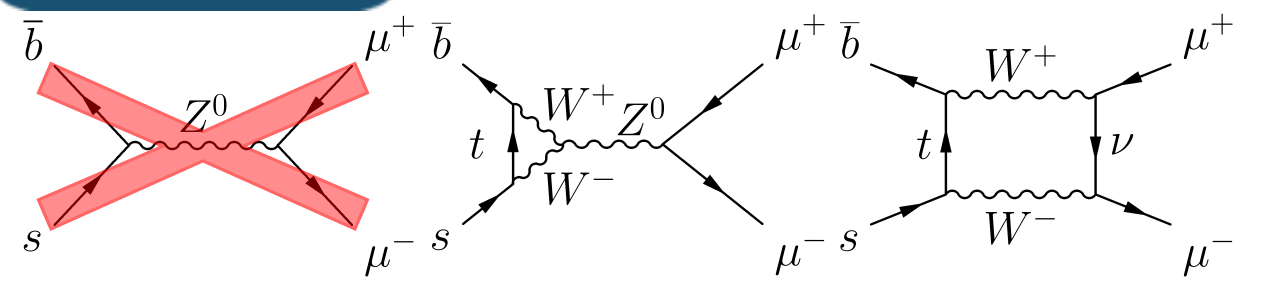
B-physics
Dark Matter
VBS
SUSY

$B_d^0/B_s^0 \to \mu\mu$

Flavour physics benefits from large cross-sections at the LHC

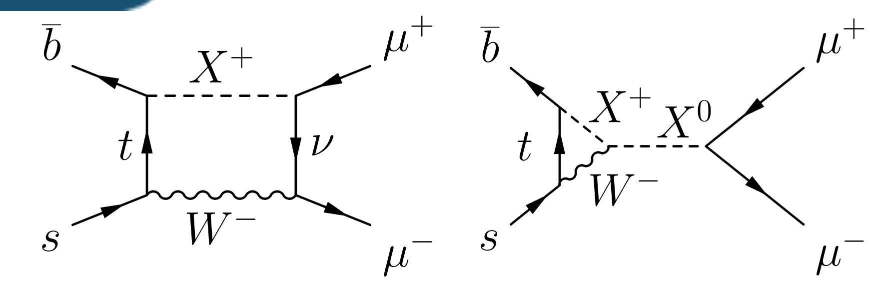
$B_d^0/B_s^0 \to \mu\mu$ decays are FCNC highly suppressed: $B(B_s^0 \to \mu\mu)_{SM} = (3.66 \pm 0.23) \times 10^{-9}$, $B(B_d^0 \to \mu\mu)_{SM} = (1.06 \pm 0.09) \times 10^{-10}$

SM diagrams



high order, helicity and CKM suppressed process

BSM diagrams

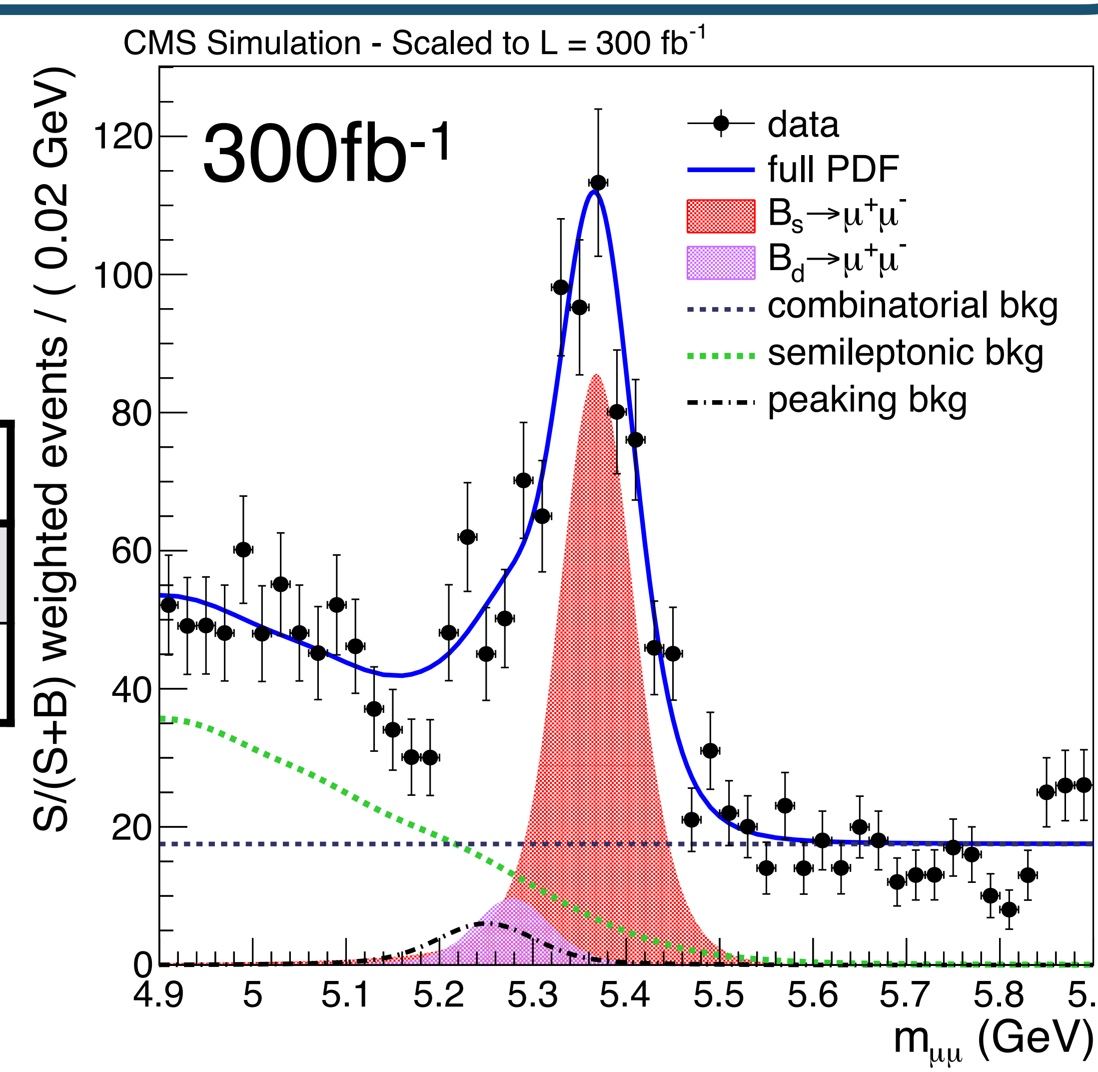


sensitive to NP in the loop (e.g. $X^+=H^+$ $X^0=h/H/A^0$)

The ratio of the branching fractions (R) of the two decay modes provides discrimination among BSM theories

L (fb^{-1})	num. B_s^0	num. B_d^0	$\delta\mathcal{B}/\mathcal{B}(B_s^0)$	$\delta\mathcal{B}/\mathcal{B}(B_d^0)$	R
20	16.5	2	35%	>100%	>100%
300	433	54	12%	45%	47%

Expect observation of B_d^0, improvement of >2 on the precision on R with 300 fb^{-1} and we will continue to combine with LHCb



The mystery of dark matter

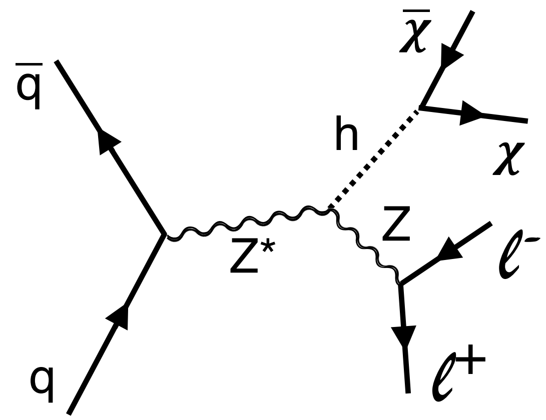
- Dark matter exists
- It is most likely a neutral, weakly-interacting, massive particle (WIMP)
- The energy scale of the interactions of dark matter must be close to 1 TeV

This could be a coincidence, but it might be a suggestion:

“models for the Higgs potential also solve the dark matter problem”

Higgs bosons invisible decays

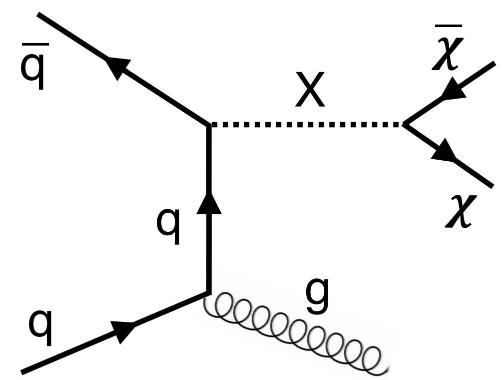
For $m_{DM} < m_h/2$



profiting of VBF and VH production modes

Mono-mania

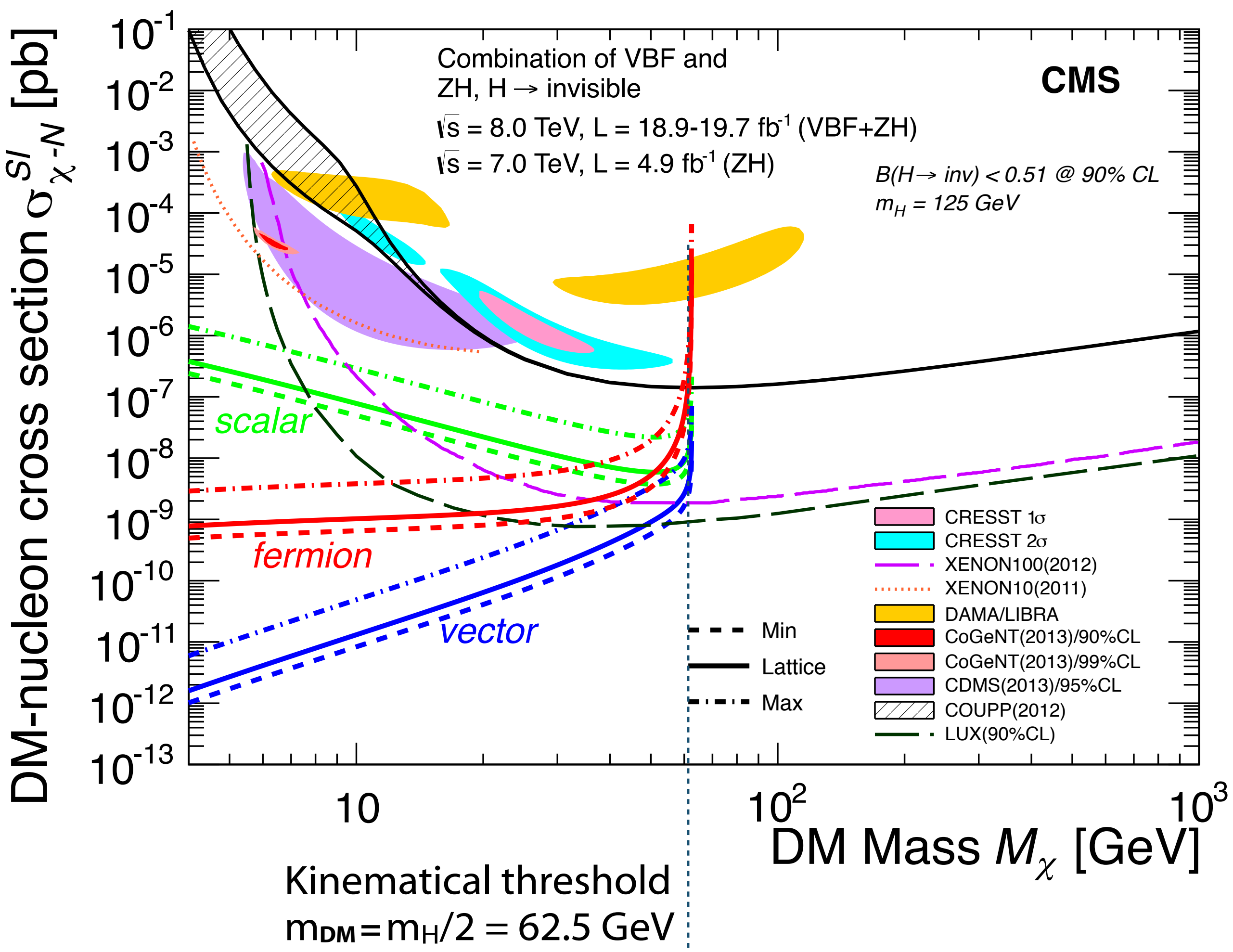
For every m_{DM} value



X is a mediator here example of a spin-1 mediator

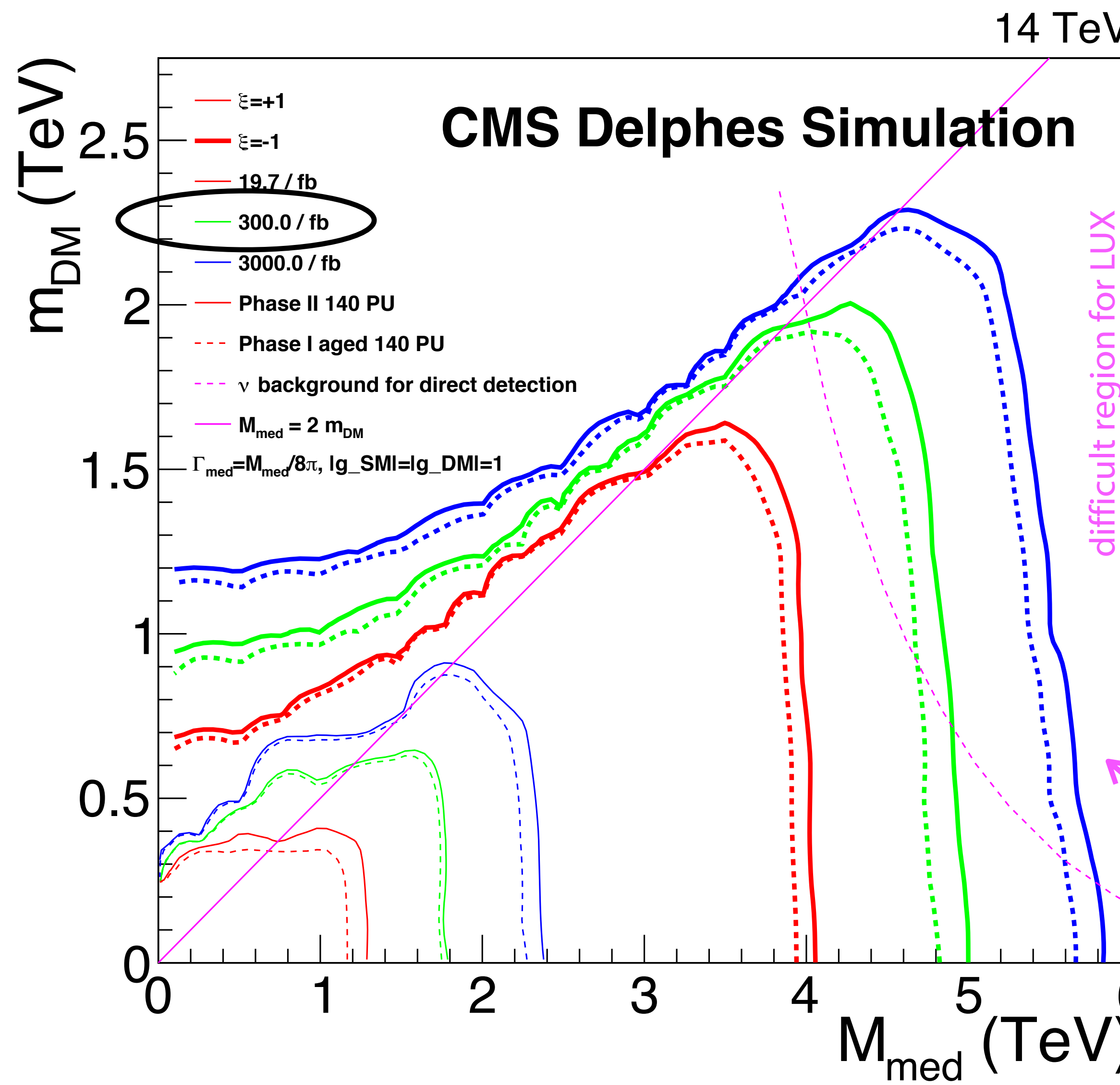
Dark matter : results

Higgs bosons invisible decays



RUN1 results are already better then the direct searches experiments (LUX, XENON, …)

Single lepton channel (W+DM)

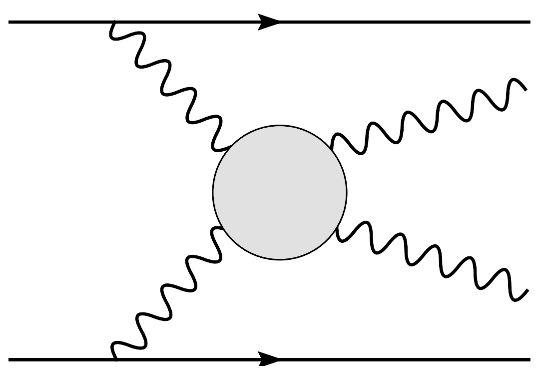


Region that is difficult to exclude with direct searches experiments (LUX, XENON, …), due to the ν background will be covered by LHC starting as soon as **$300 fb^{-1}$** will be collected

LHC and CMS will be the most sensitive dark matter detection apparatuses

Assess VBS sensitivity using same-sign WW, WZ, ZZ

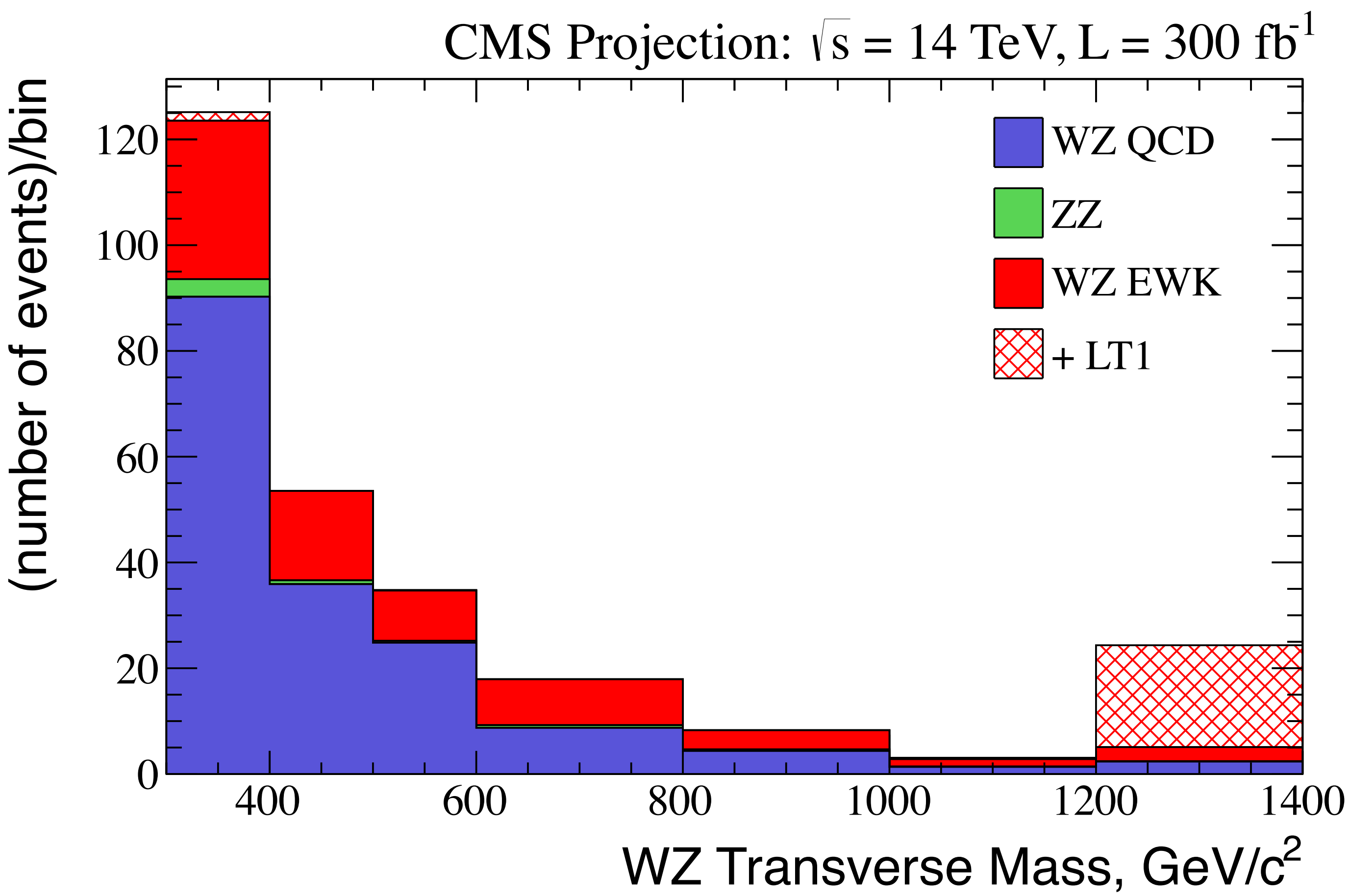
EWK scattering cross-section
non-unitarized scenarios simulated as the absence of Higgs
anomalous couplings in the EFT approach

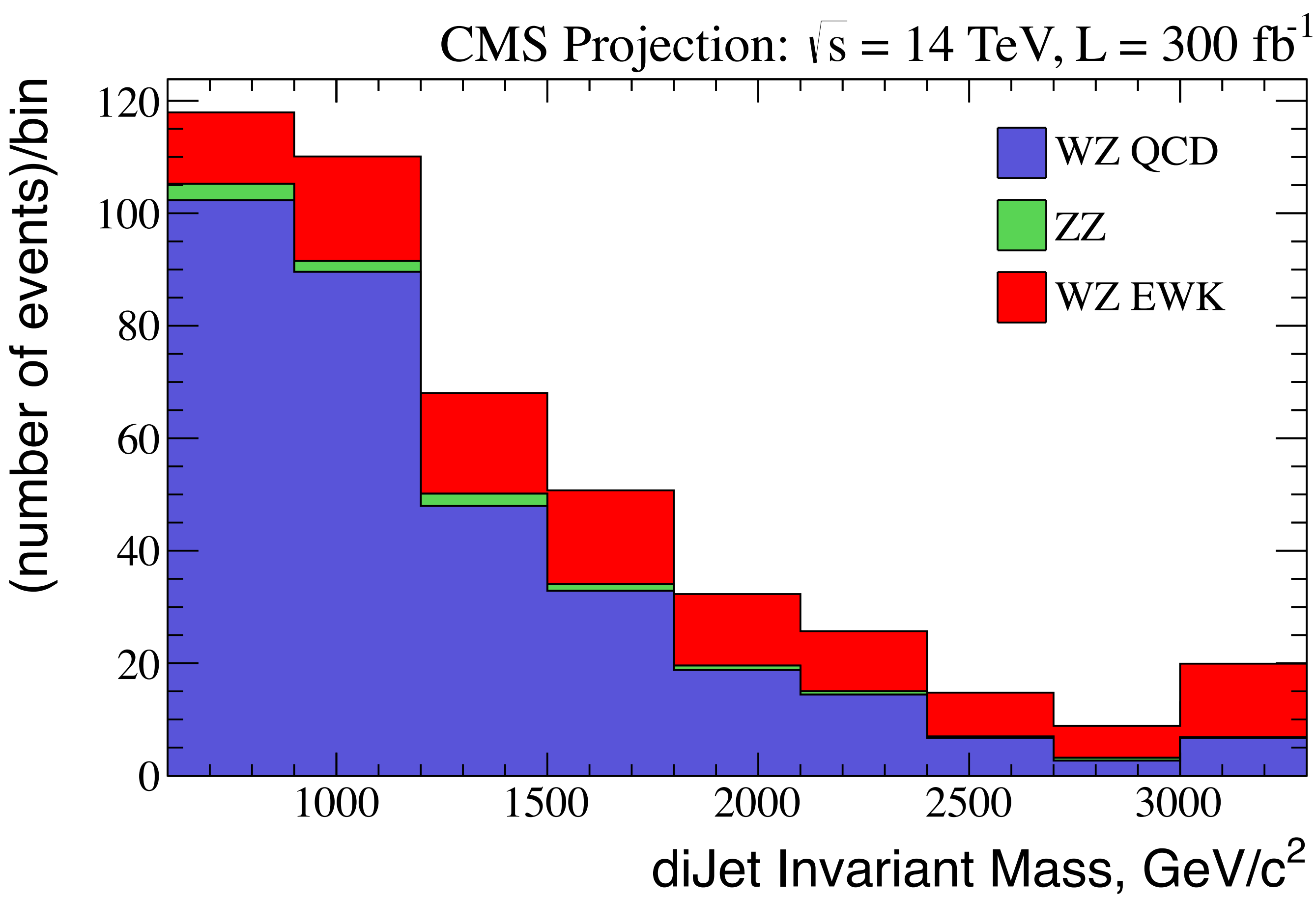


WZjj VBS process at 14 TeV

Establish quartic self-couplings and constraint aQGC

Significance	3σ	5σ
SM EWK	75 fb^{-1}	185 fb^{-1}
f_{T1}/Λ^4 at 300fb^{-1}	0.8 TeV^{-4}	1.0 TeV^{-4}



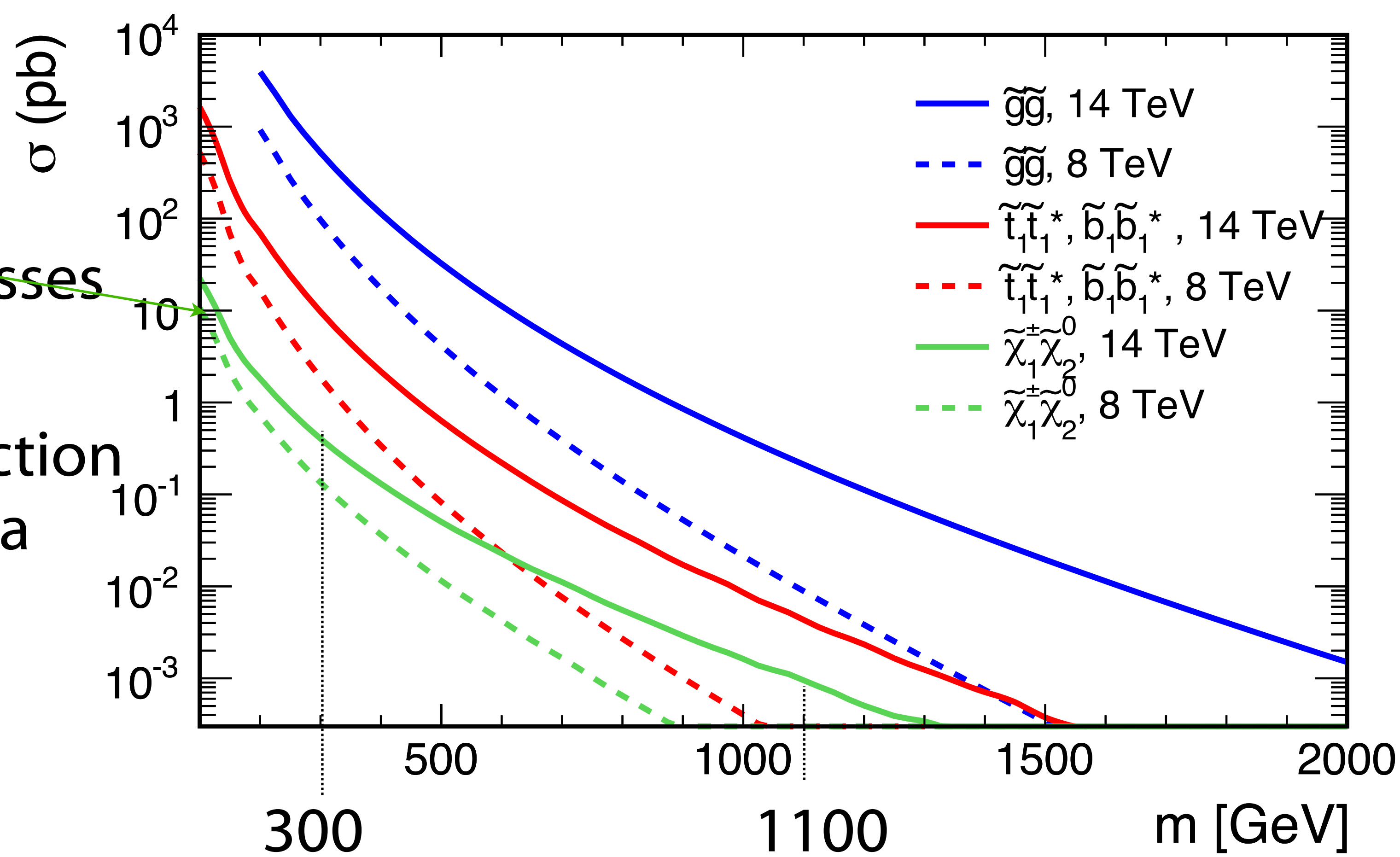


Motivation for SUSY has never been stronger, discovery of the Higgs gives new urgency to find "natural" explanation for gauge hierarchy

The sensitivity to new physics increases significantly with an increase in the center-of-mass energy of the collisions

The smallest cross section **pp→χ$^{\pm}$χ^{0}** ranges from 1pb to 1fb, going from masses of 300 to 1100 GeV.

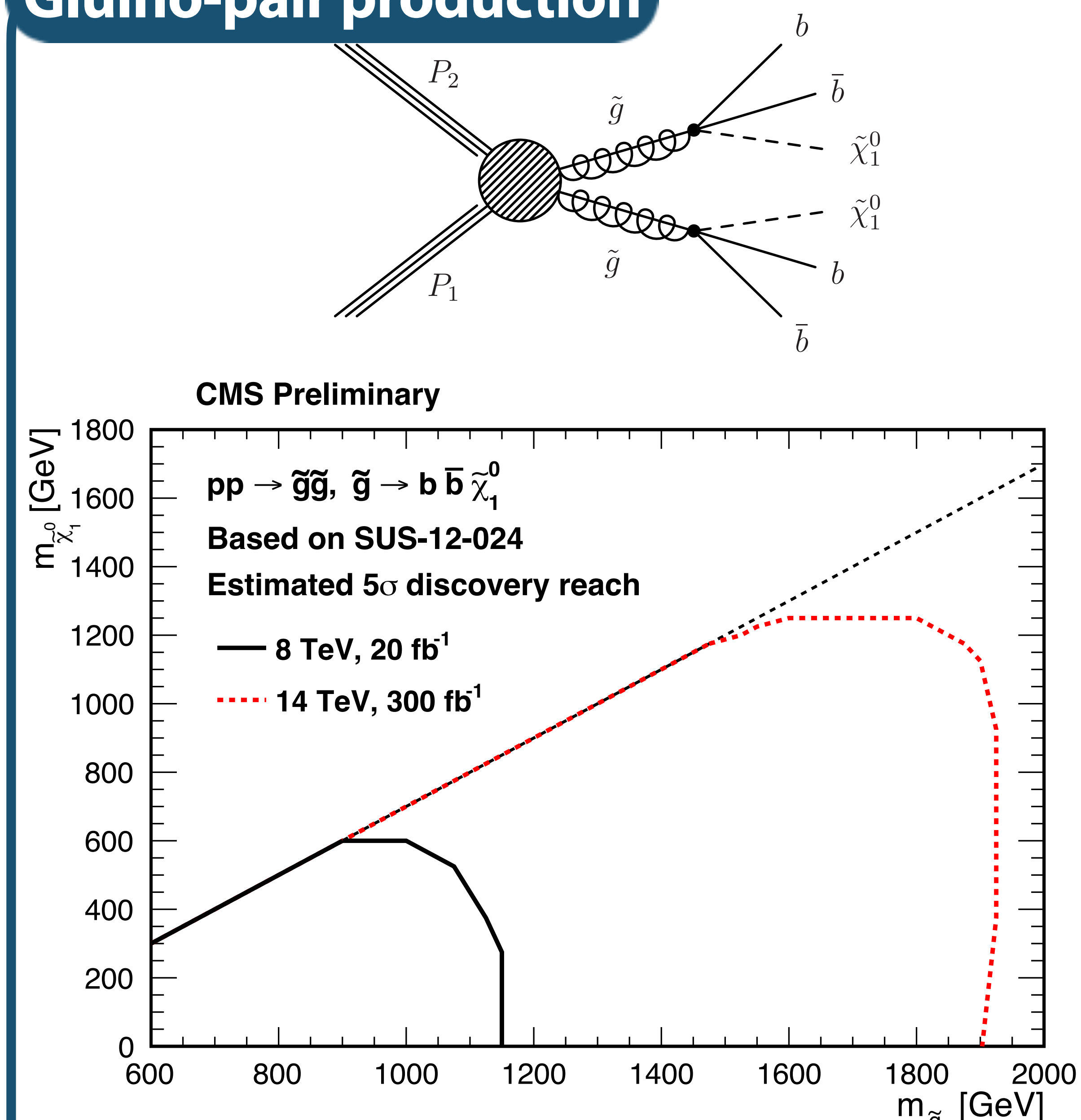
Moving from 8 TeV to 13 TeV the production cross sections will increased more than a factor 10



SUSY simplified models

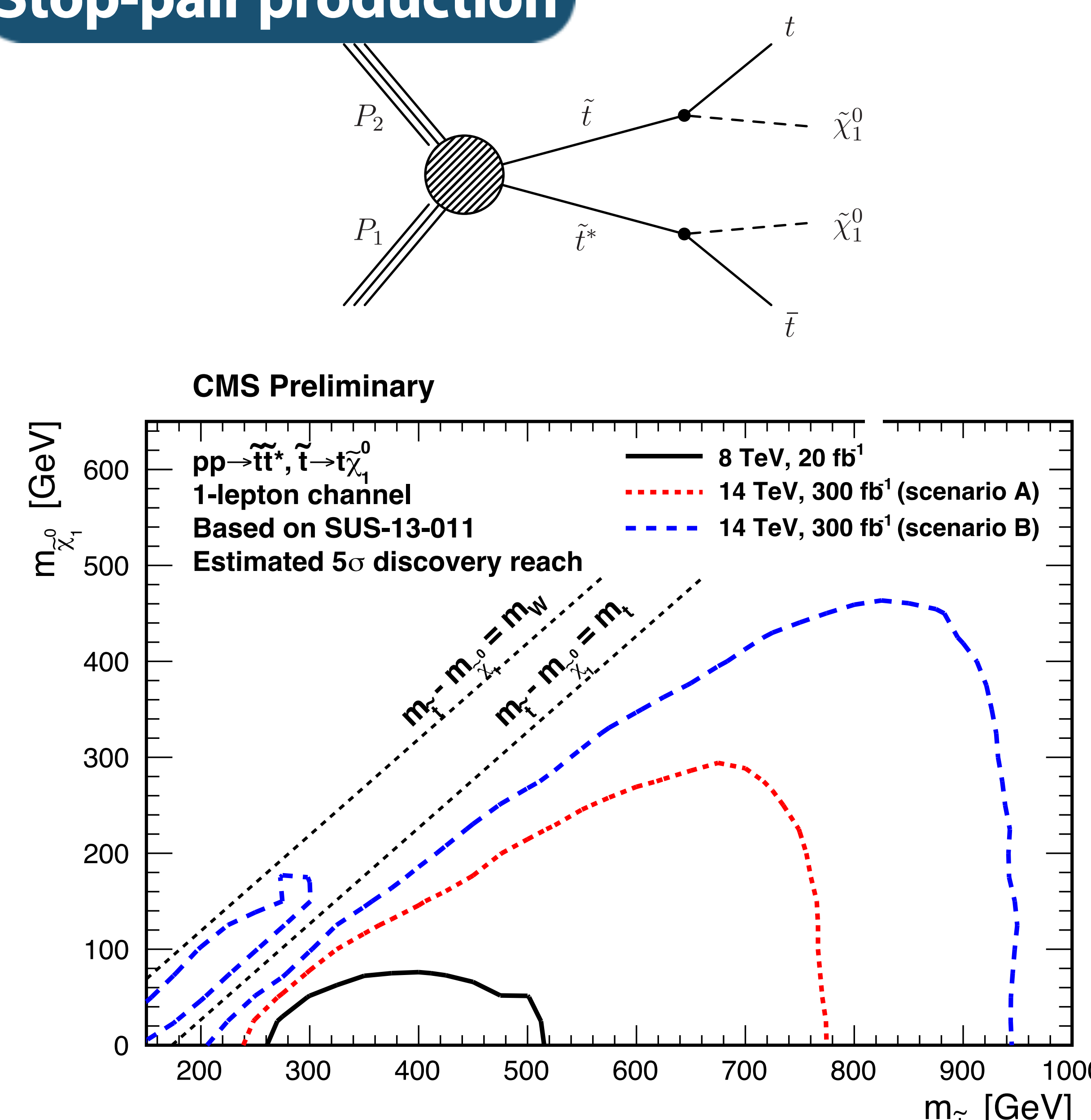
Naturalness predicts light third-generation masses and also gluinos not much heavier than 1 TeV → it will be discovered or ruled out at LHC

Gluino-pair production



Improvements

Stop-pair production



Improvements

Sizeable improvement on the sensitivity for all the models

Discovering SUSY

Exploring SUSY model space

Exploring experimental signature space

Analysis	Luminosity (fb^{-1})	Model NM1	NM2	NM3	STC	STOC
all-hadronic (H_T-H_T^{miss}) search	300					
	3000					
all-hadronic (M_{T2}) search	300					
	3000					
all-hadronic $\tilde{b}_1$ search	300					
	3000					
1-lepton $\tilde{t}_1$ search	300					
	3000					
monojet $\tilde{t}_1$ search	300					
	3000					
$m_{\ell^+\ell^-}$ kinematic edge	300					
	3000					
multilepton + b-tag search	300					
	3000					
multilepton search	300					
	3000					
ewkino WH search	300					
	3000					

$< 3\sigma$ | $3 - 5\sigma$ | $> 5\sigma$

SUSY EWK searches

Different types of SUSY models lead to different patterns of discoveries in different final states after different amounts of data.

LHC has the unique opportunity to discover SUSY before the end of the Phase1

HL-LHC measurements will then be crucial to illuminate LHC discovery, and thus answer fundamental questions about gauge hierarchy or dark matter.

Objectives for CMS-LLR group

Maintain the leadership in the critical analysis channels related to EWSB

- h_{125} precision measurement
- search of addition higgs bosons (2HDM)
- Higgs boson self-coupling either to shape the Higgs boson potential and study the ttH coupling
- use h_{125} as a portal for the dark matter sector
- study unitary at high mass (VBS)

Conclusions

The discovery of the h boson at 125 GeV opens up new avenus at the LHC

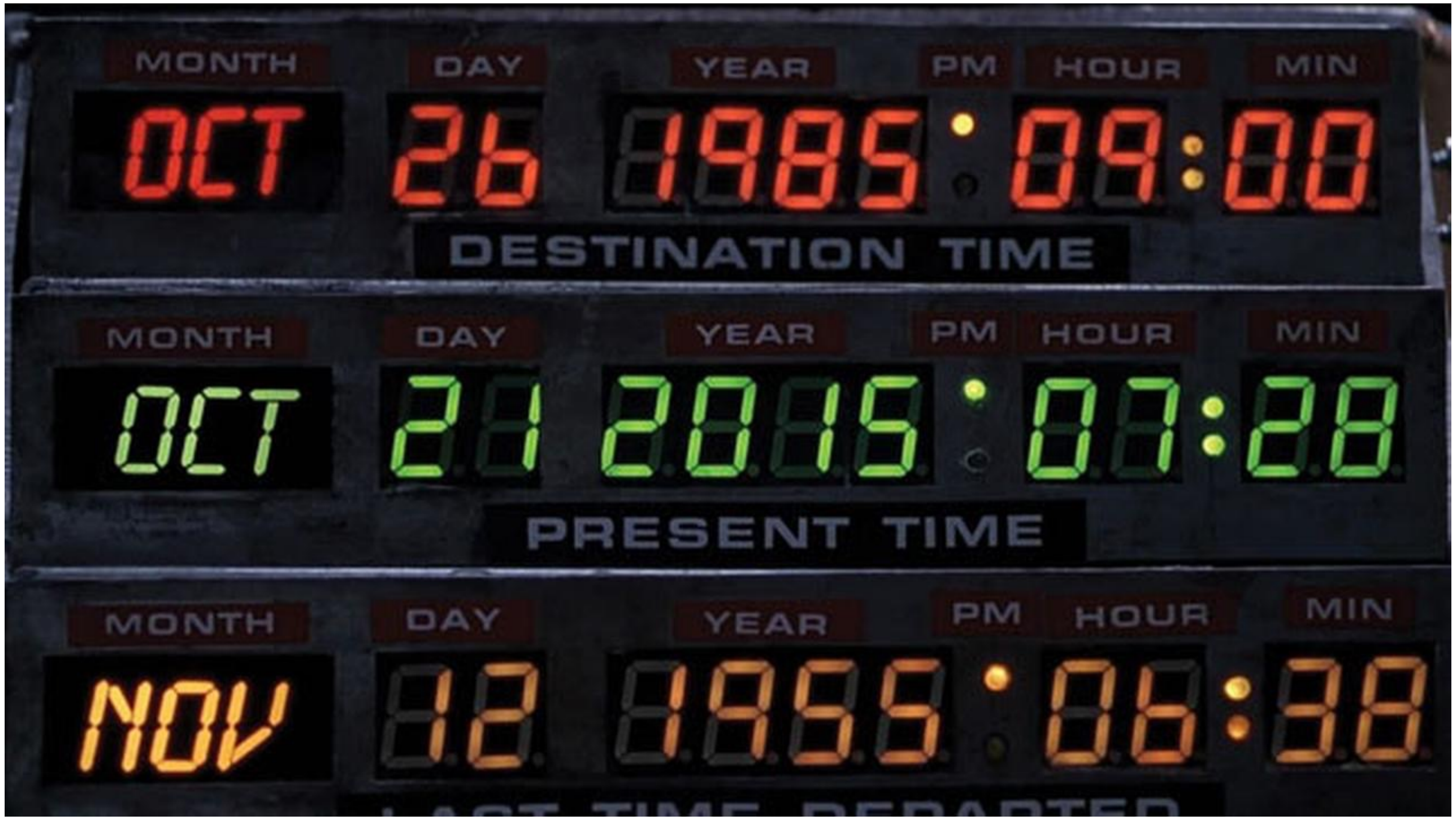
The specific mass value at 125 GeV is a challenge for many SUSY theories of models with extended scalar sector needed to « stabilize » the Higgs boson mass

Considerable progress is expected during Run II and III at the LHC (reaching 300 fb^{-1} of integrated luminosity) on:

- Higgs boson precision coupling measurements
- measure Higgs boson Yukawa coupling to 2nd generation fermions
- Higgs boson pair production
- BSM Higgs bosons searches
- $B_d^0/B_S^0 \rightarrow \mu\mu$
- Dark matter
- SUSY
- VBS
- …

Finally to sum up

The physics goals and for CMS are discussed just the right day…



… the day that Doc and Marty are coming for the past

Considering that 7:28 in California are 16:28 in Paris they should be arrived just in time for this….