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Bundesministerium für Bildung und Forschung

CMS

CMS expectations/improvements from Run2 (with 30-100 and 300/fb)

29th September 2016

Adrian Perieanu

on behalf of the CMS collaboration

get precise or die tryin'!

CMS Higgs expectations & improvements from Run II

29th September 2016

Adrian Perieanu

on behalf of the CMS collaboration

a more realistic title


or
how far is the future
from us

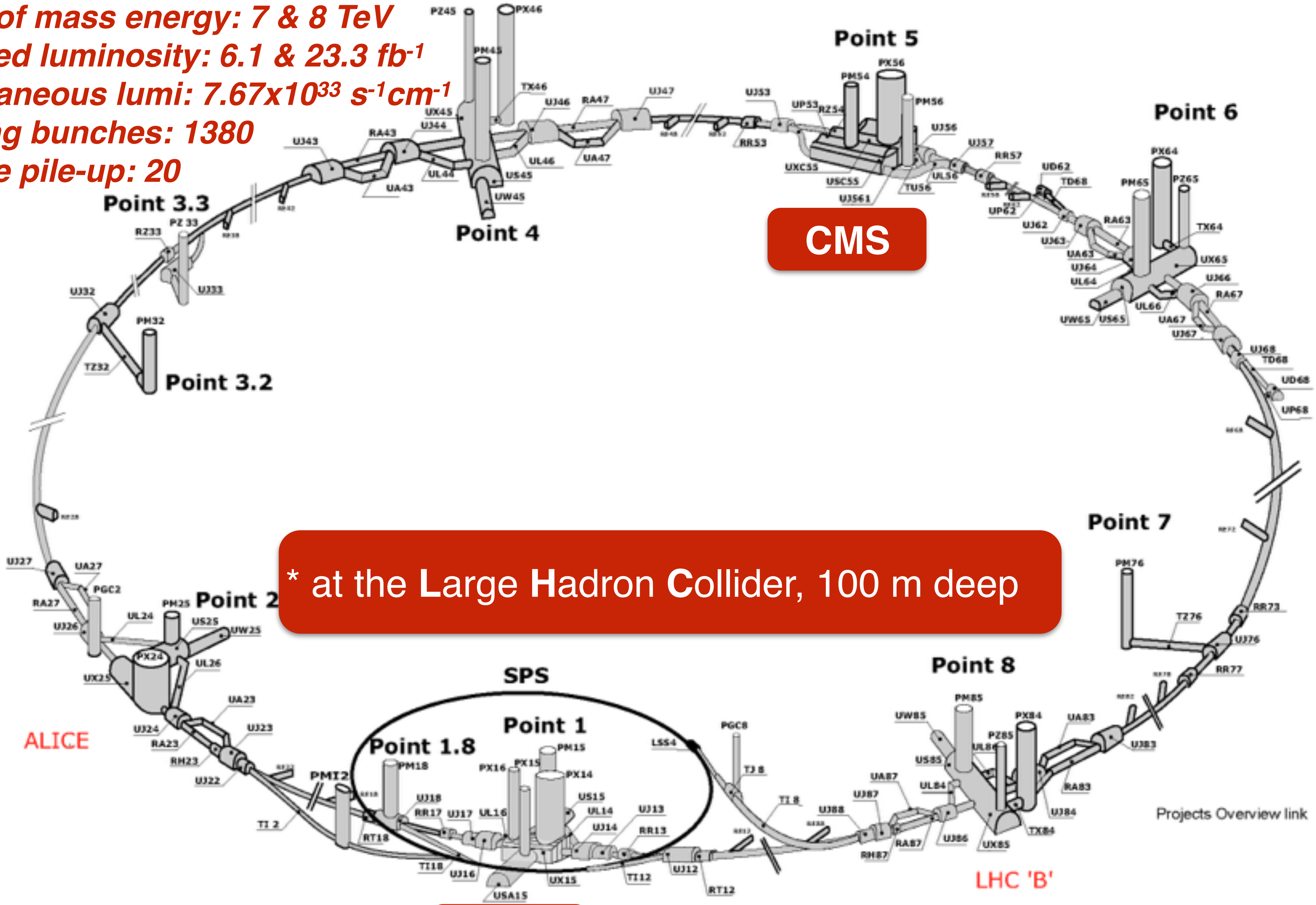
overview

* LHC time scale
* new CMS DNA: Run I vs. Run II
* Higgs after ~1/3 of the Run II
* expectations after Run II
* what comes next

because this conference is about precision, let’s clarify when and how much lumi. we will have

where it all (really) happens

Run I:
**** centre of mass energy: 7 & 8 TeV***
**** delivered luminosity: 6.1 & 23.3 fb^{-1}***
**** instantaneous lumi: 7.67x10^{33} s^{-1}cm^{-1}***
**** colliding bunches: 1380***
**** average pile-up: 20***



CMS

* at the **L**arge **H**adron **C**ollider, 100 m deep

ATLAS

where it all (really) happens

Run I:
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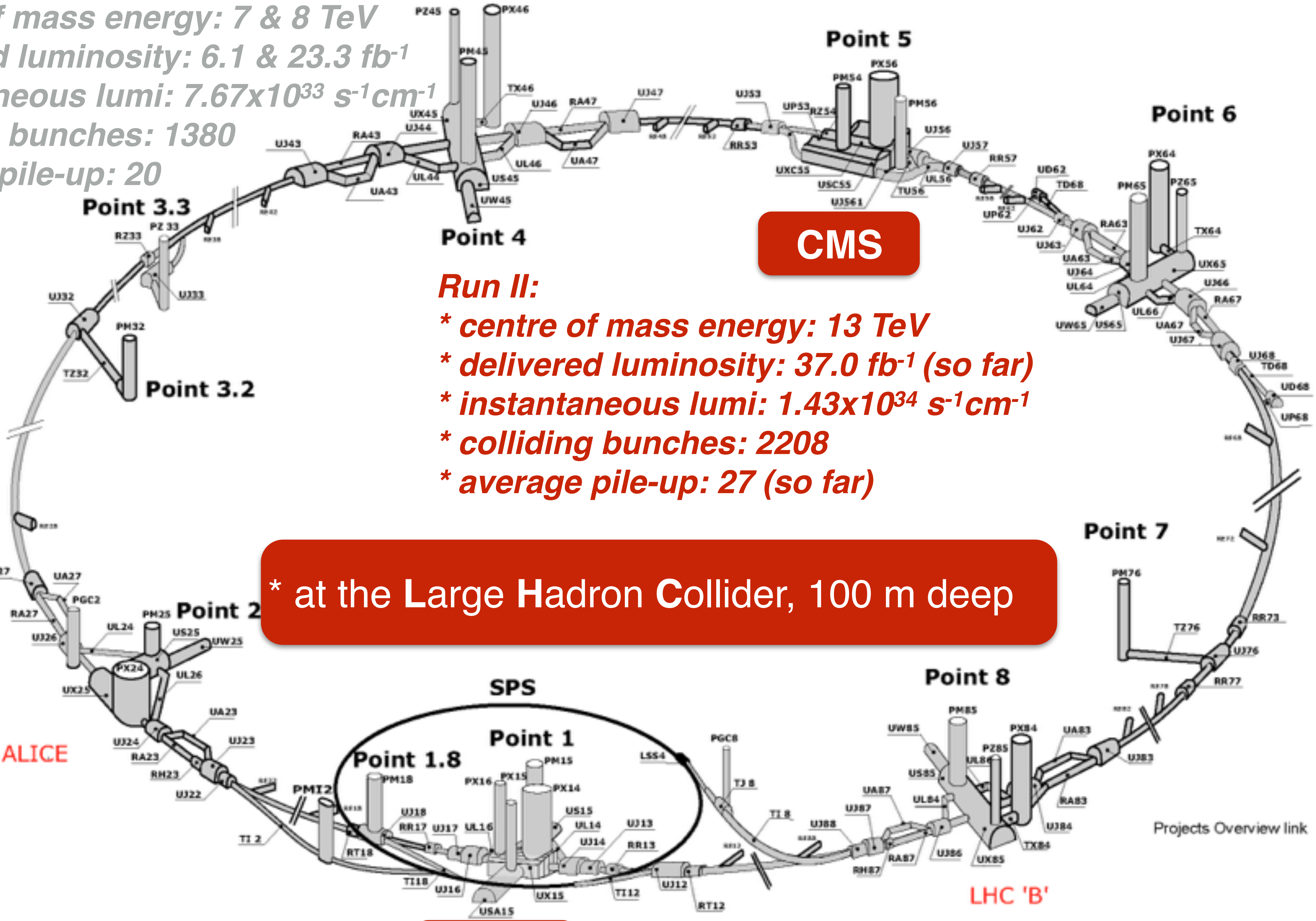
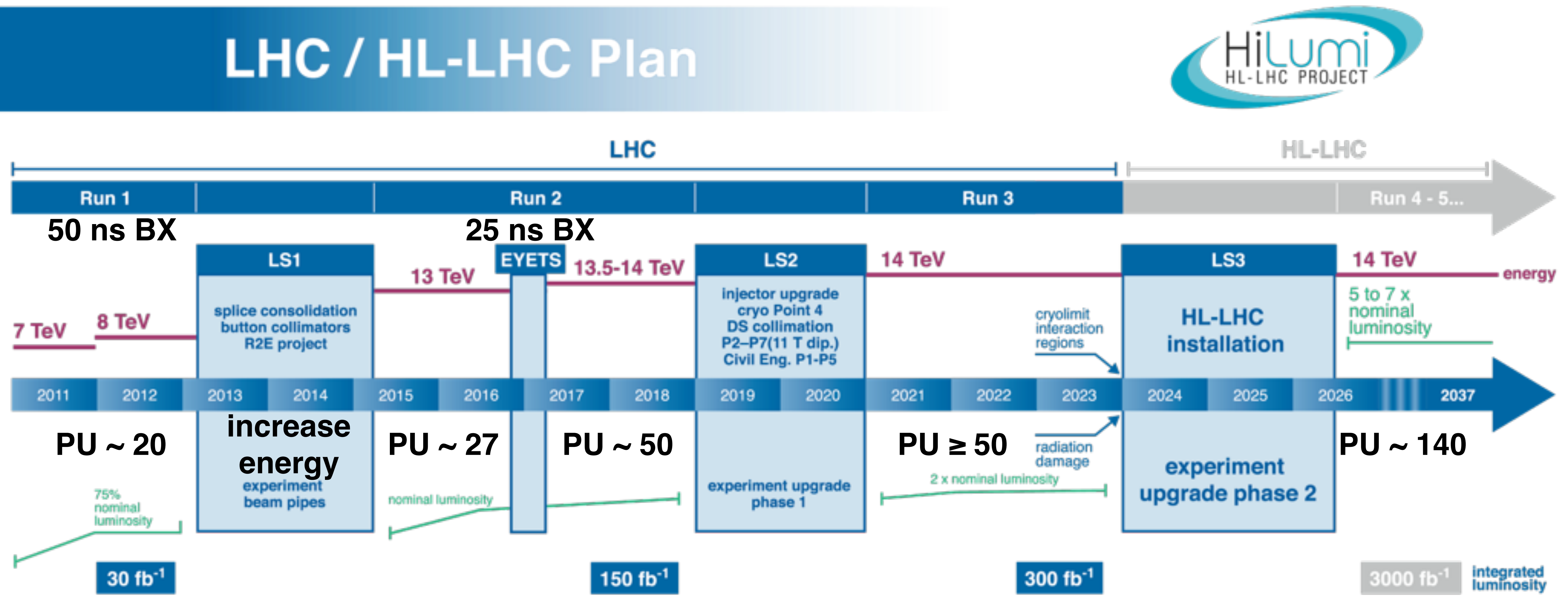


Run II:
**** centre of mass energy: 13 TeV***
**** delivered luminosity: 37.0 fb^{-1} (so far)***
**** instantaneous lumi: 1.43x10^{34} s^{-1}cm^{-1}***
**** colliding bunches: 2208***
**** average pile-up: 27 (so far)***

* at the **L**arge **H**adron **C**ollider, 100 m deep

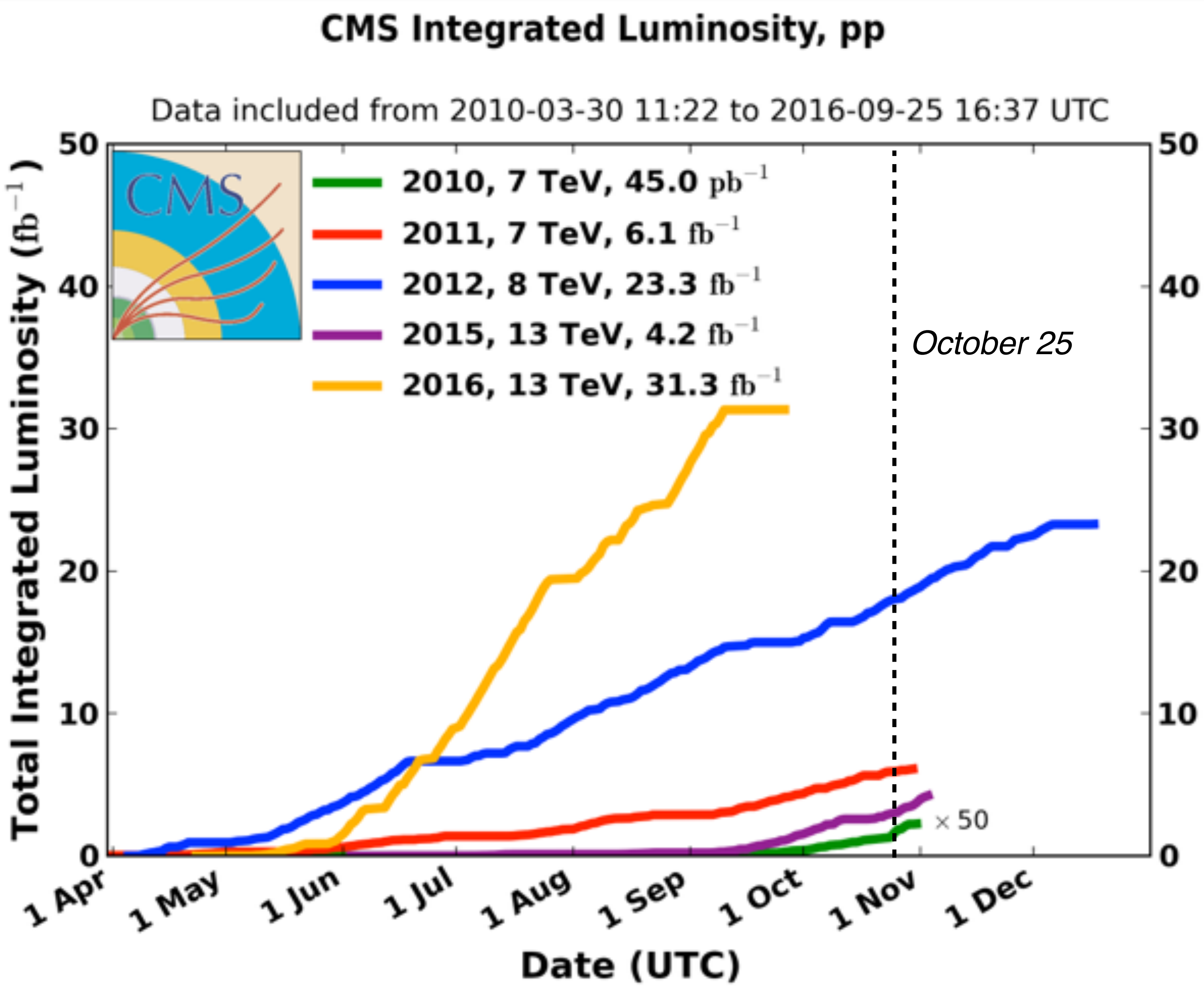
LHC: time scale



EYETS: Extended Year-End Technical Stop

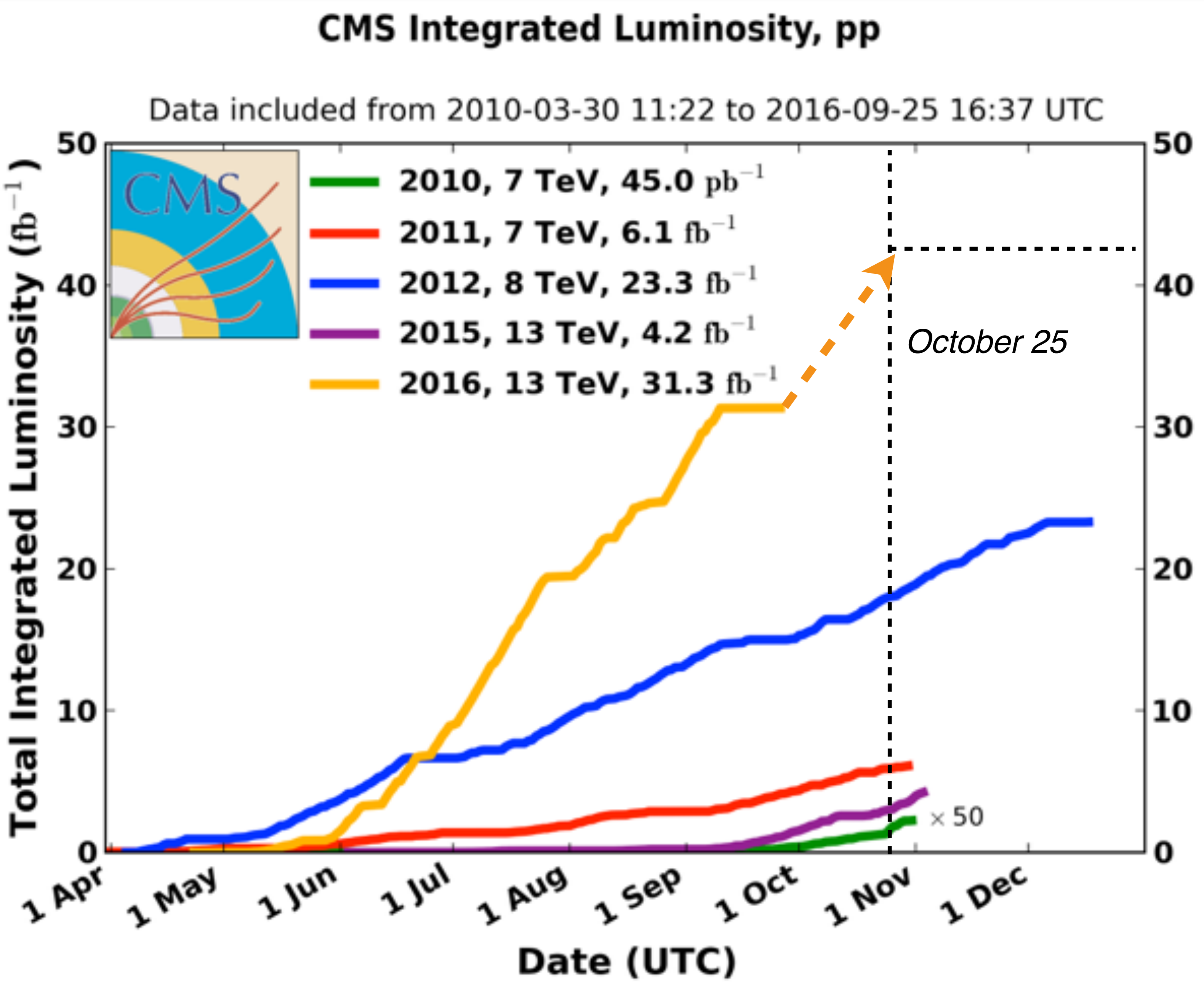
- experiments survived Run I and LS 1 without being damaged by their own constructors
- **new data at 13 TeV** start accumulating (slowly in 2015, amassing in 2016)
- we expect (hope) to get about **150 fb^{-1} after Run II** and **300 fb^{-1} after Run III**
- from **mid 2026** (probably 2027) we can talk about HL-LHC data: deliver **200 to 300 fb^{-1} a year**

integrated luminosity at 13 TeV



* after a “conservative” and precocious start in 2015, LHC is doing an amazing job in 2016
* almost every week of running brings an increase in the instantaneous luminosity

integrated luminosity at 13 TeV



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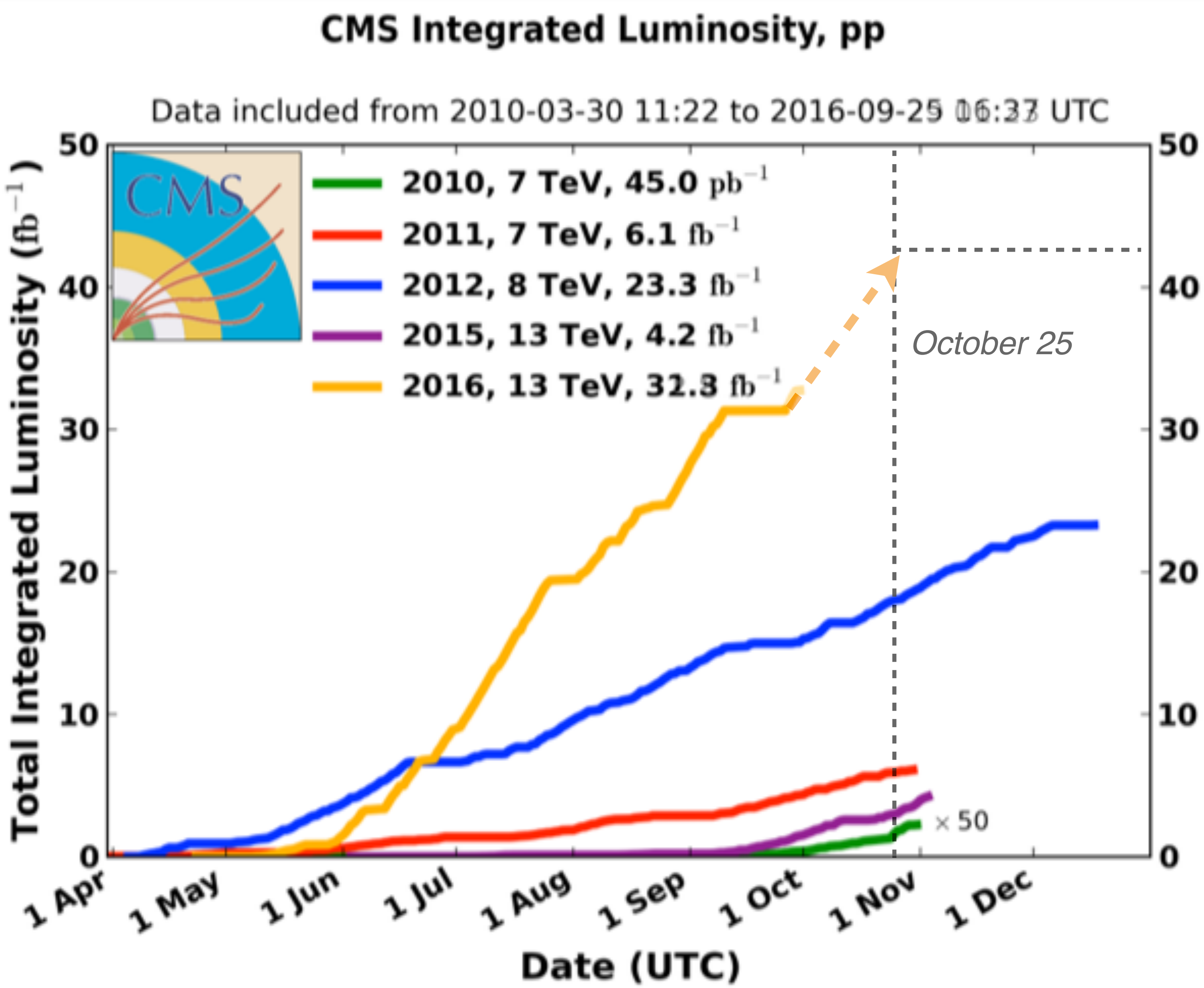
* probably the answer to everything is indeed 42 (**fb⁻¹**)…

integrated luminosity at 13 TeV



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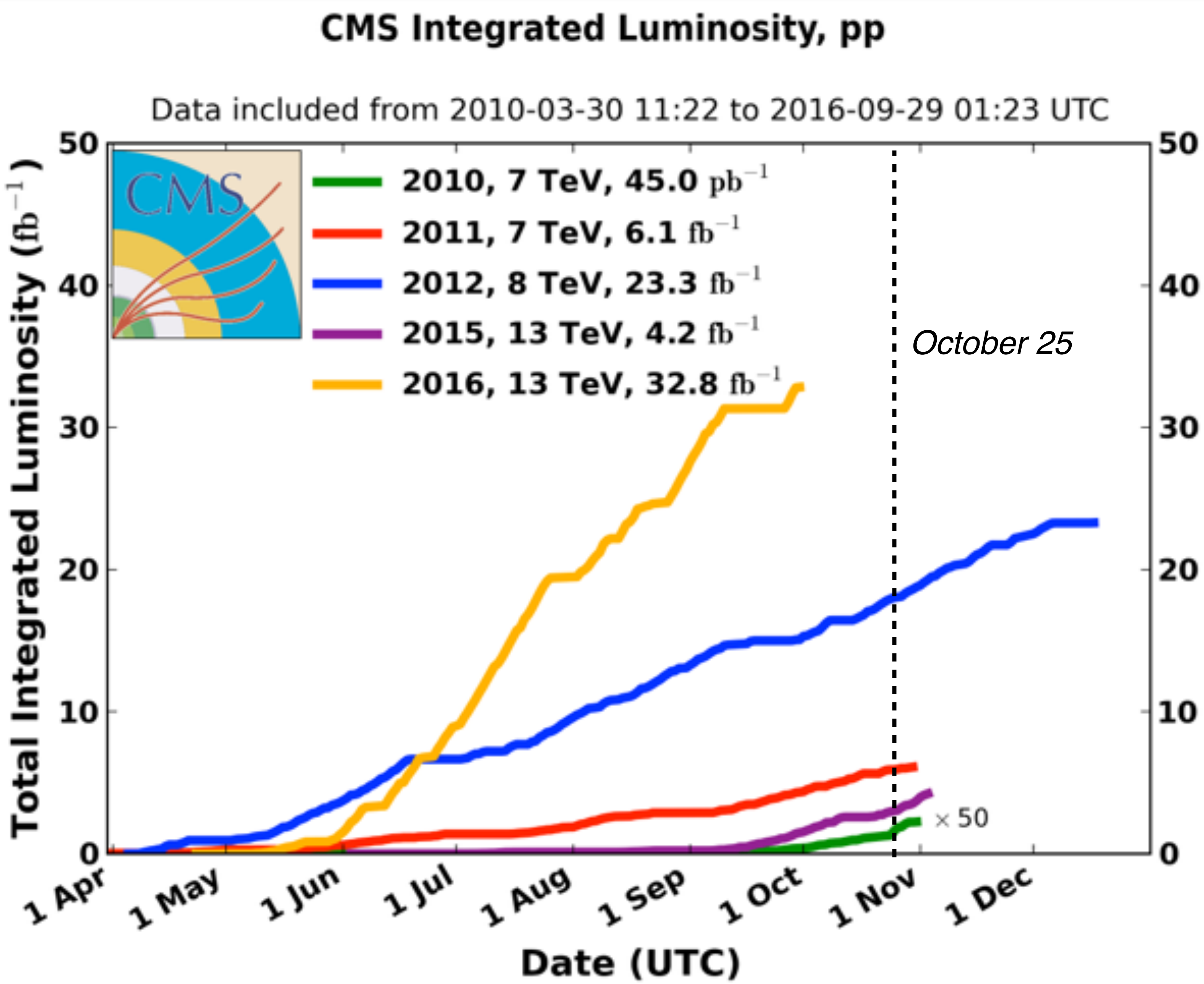
integrated luminosity at 13 TeV



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* almost every week of running brings an increase in the instantaneous luminosity
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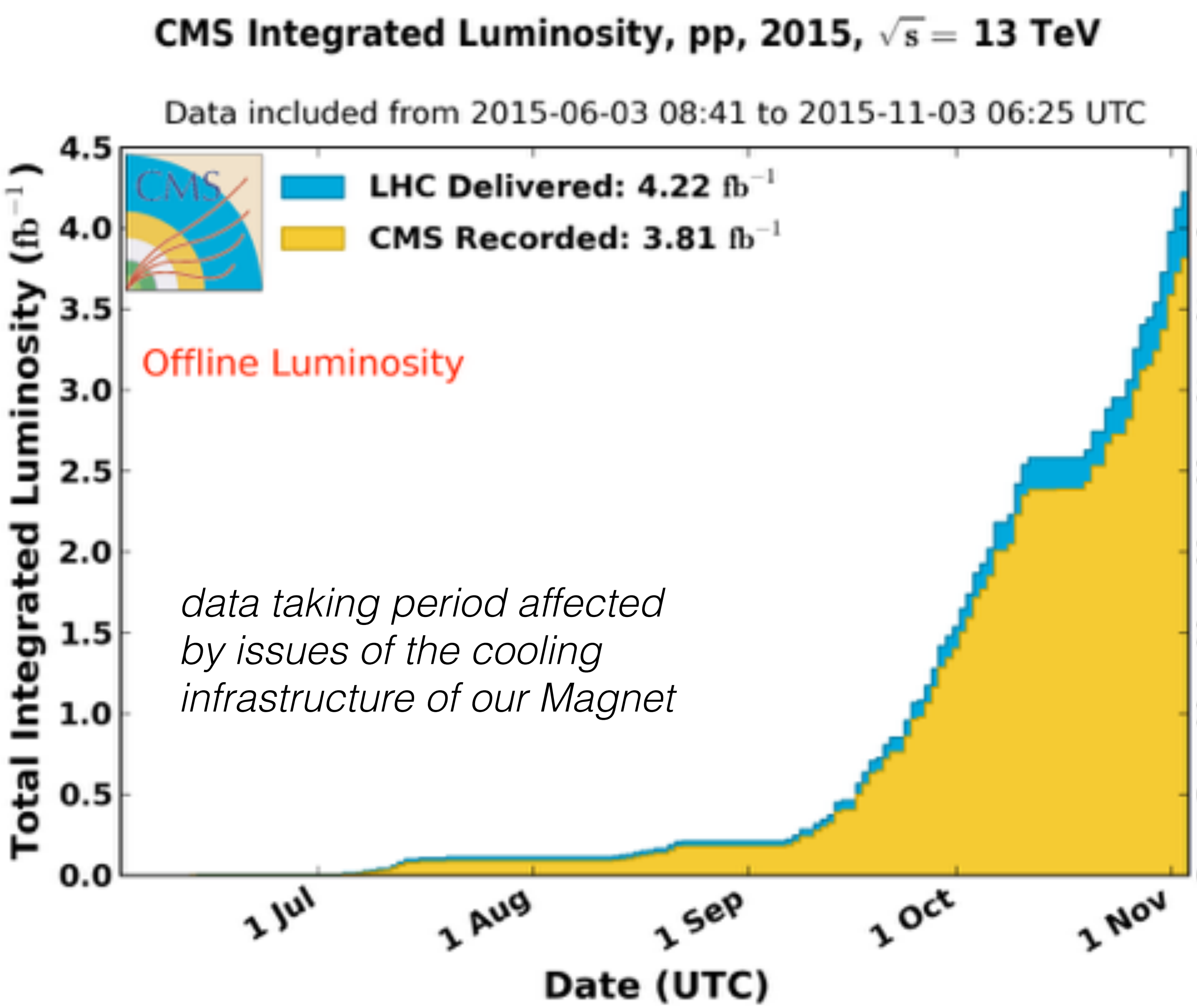
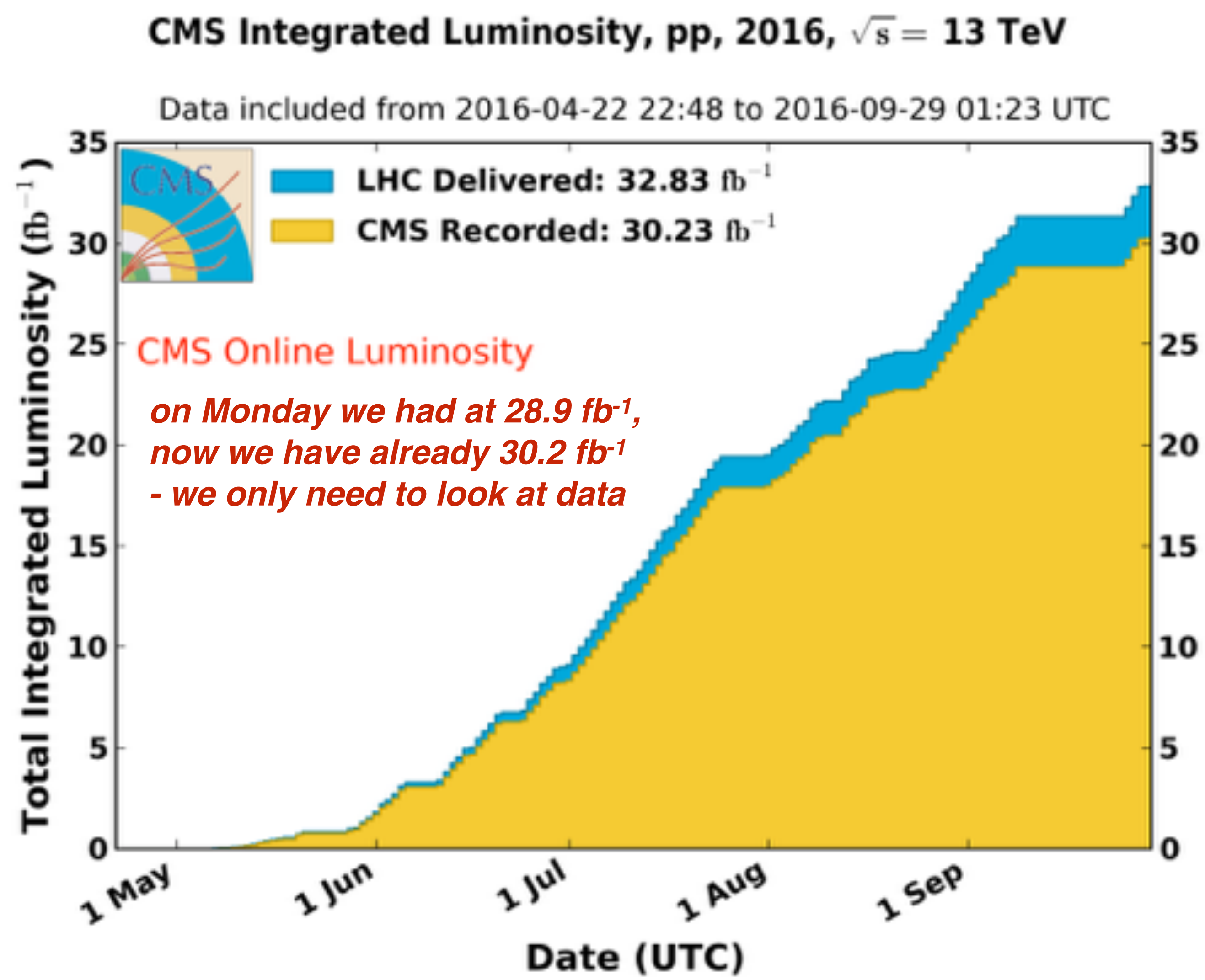
integrated luminosity at 13 TeV
- CMS -





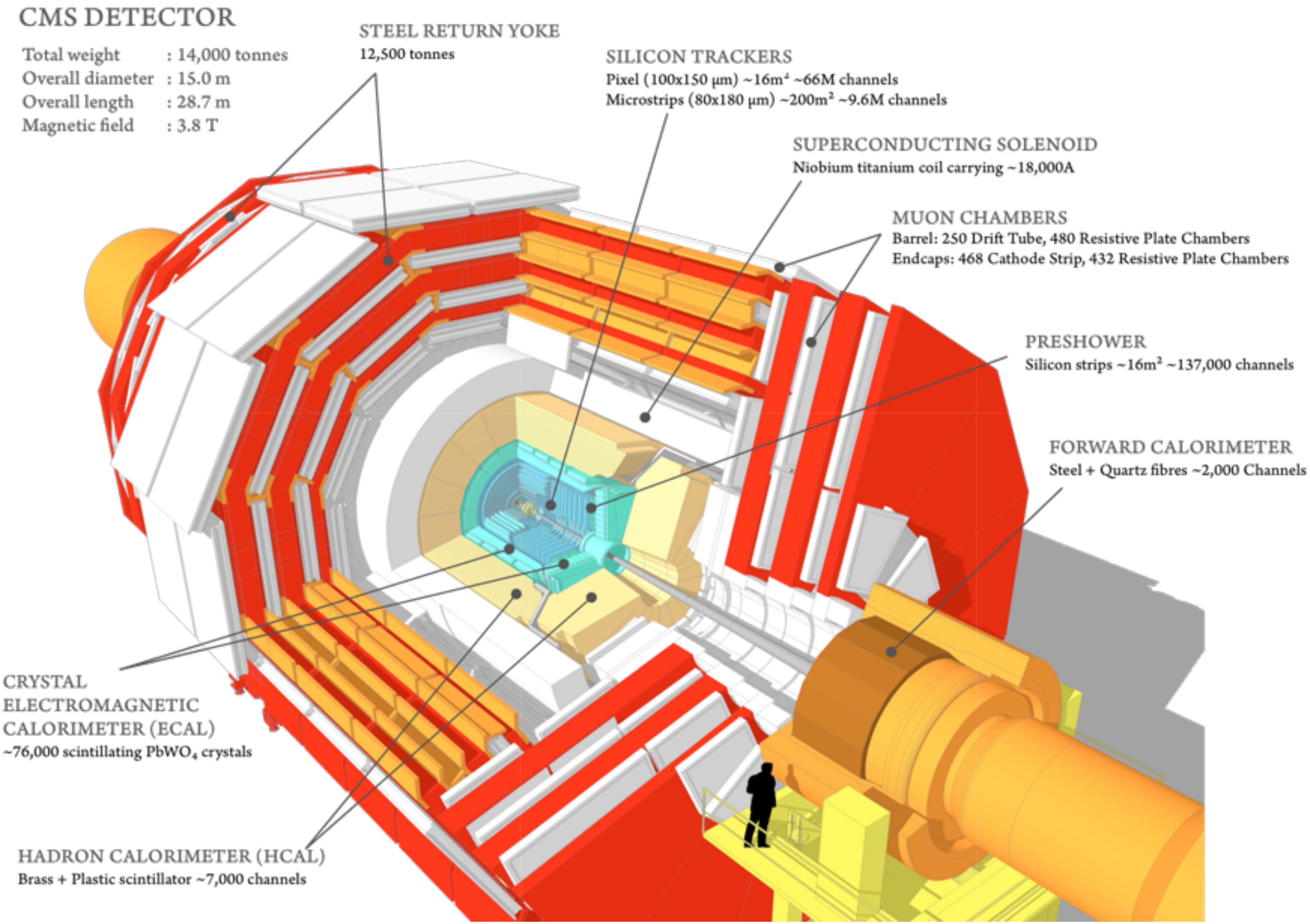
* for more realistic numbers for CMS:
— wanted lumi * data taking efficiency * data quality:
150 fb^{-1} * 90% * 96% **~ 130 fb^{-1}**

* still, if LHC team go wild (max inst. lumi. of $1.7x10^{34}$ $s^{-1}cm^{-1}$ and a Hübner factor of 90-95%) in 2018 and 2019, they might hit us even with 300 fb^{-1}

to summarise:

	lumi sum - planned - [fb^{-1}]	lumi sum - delivered - [fb^{-1}]	lumi sum - usable - [fb^{-1}]
Run I	30	29.4	24.8
Run II	150	37.0 and counting	130 (probably at the end)
Run III	300	to be seen	to be seen

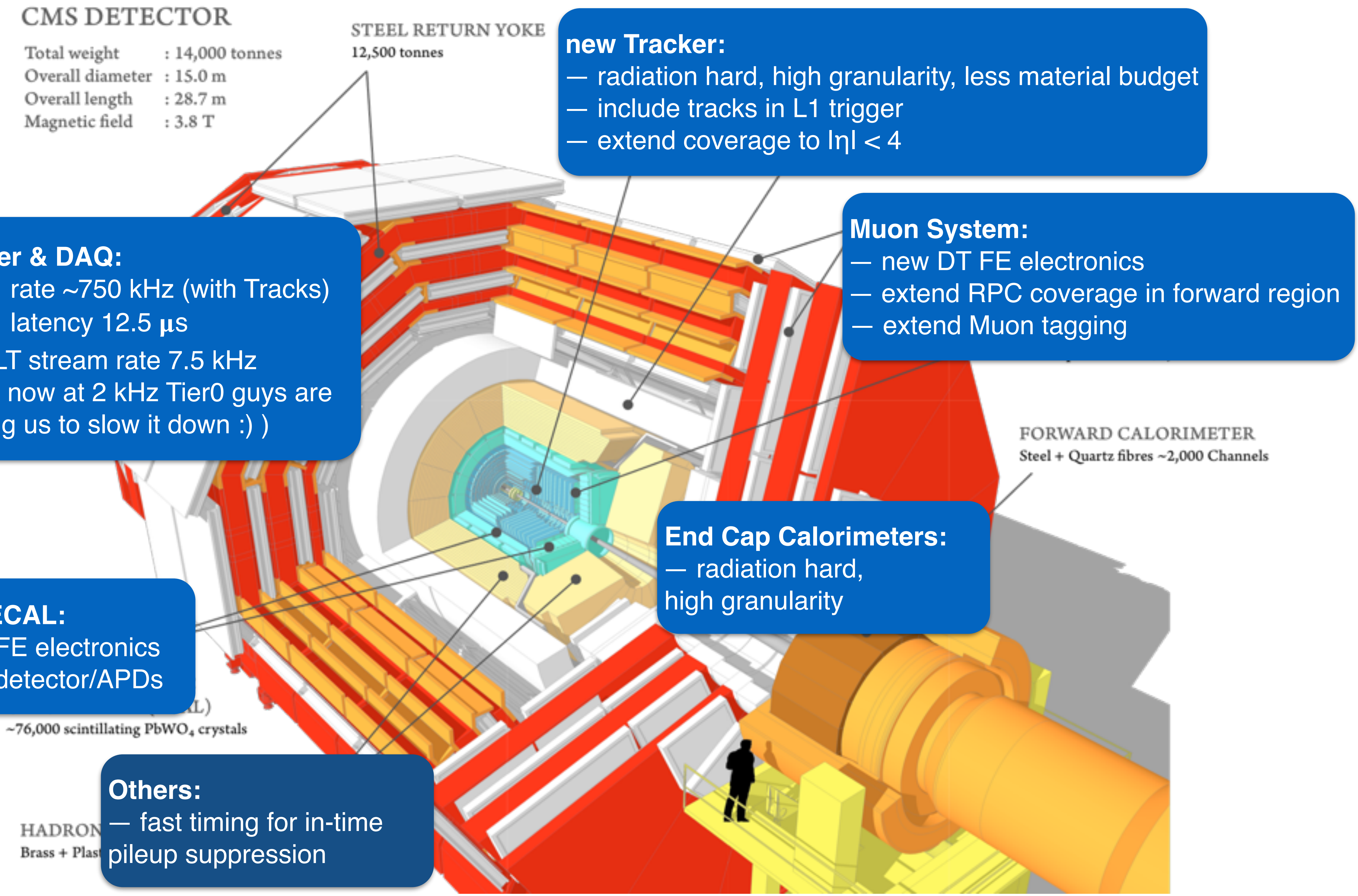
CMS: in Run I


CMS DETECTOR
Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T
STEEL RETURN YOKE
12,500 tonnes
SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels
SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers
PRESHOWER
Silicon strips ~16m² ~137,000 channels
FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating PbWO4 crystals
HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

and now forget the old CMS

CMS after EYETS, LS2 and LS3

— with new DNA —



new Tracker:
— radiation hard, high granularity, less material budget
— include tracks in L1 trigger
— extend coverage to $|\eta| < 4$

Muon System:
— new DT FE electronics
— extend RPC coverage in forward region
— extend Muon tagging

Tigger & DAQ:
— L1 rate ~750 kHz (with Tracks)
— L1 latency 12.5 µs
— HLT stream rate 7.5 kHz
(right now at 2 kHz Tier0 guys are calling us to slow it down :))

End Cap Calorimeters:
— radiation hard, high granularity

barrel ECAL:
— new FE electronics
— cool detector/APDs

Others:
— fast timing for in-time pileup suppression

in 2017 after EYETS:

* new PIXEL detector: 4 layers (EYETS)

* new PMT readout for Forward HCAL (EYETS)

* new L1 Trigger: running in parallel with current system (in place: LS1)

* new DAQ system: DAQ2 (in place: LS1)

* L1 & HLT accept already higher rates as in Run I

now that we know where we are standing with int. lumi. is time for Higgs

Higgs boson

H^0

$J = 0$

Mass $m = 125.09 \pm 0.24$ GeV

H^0 Signal Strengths in Different Channels

See Listings for the latest unpublished results.

Combined Final States $= 1.17 \pm 0.17 \quad (S = 1.2)$
$W W^* = 0.81 \pm 0.16$
$Z Z^* = 1.15^{+0.27}_{-0.23} \quad (S = 1.2)$
$\gamma\gamma = 1.17^{+0.19}_{-0.17}$
$b\overline{b} = 0.85 \pm 0.29$
$\mu^+\mu^- < 7.0$, CL = 95%
$\tau^+\tau^- = 0.79 \pm 0.26$
$Z\gamma < 9.5$, CL = 95%
$t\overline{t}H^0$ Production $= 2.5^{+0.9}_{-0.8}$

H^0 DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
invisible	<58 %	95%	–

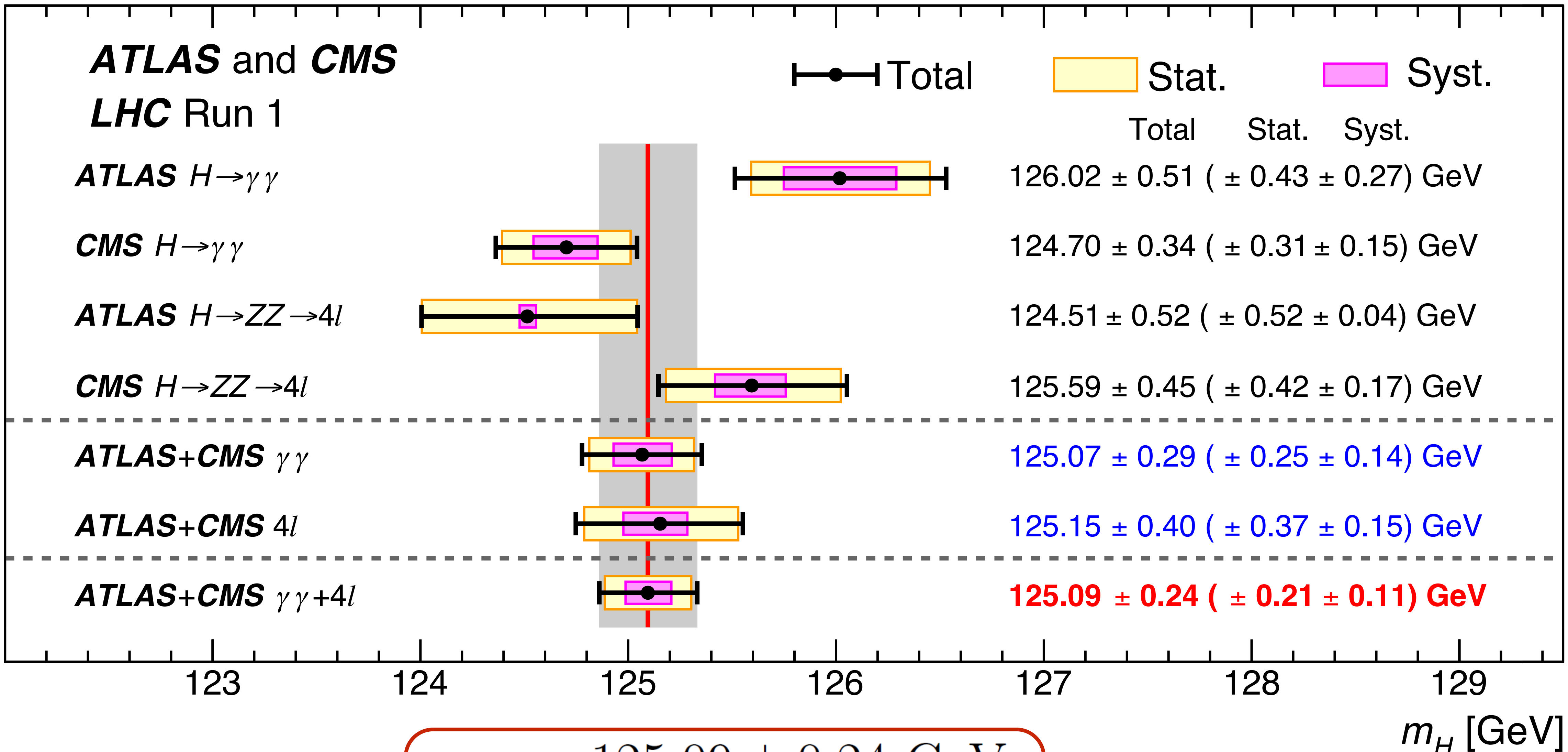
nowadays is easier to introduce it:
http://pdg.lbl.gov/2015/tables/rpp2015-sum-gauge-higgs-bosons.pdf

or more precise: a historical combination

* statistic uncertainty

$$m_H = 125.09 \pm 0.21(\text{stat.}) \pm 0.11(\text{scale}) \pm 0.02(\text{other}) \pm 0.01(\text{theory})\ \text{GeV}$$

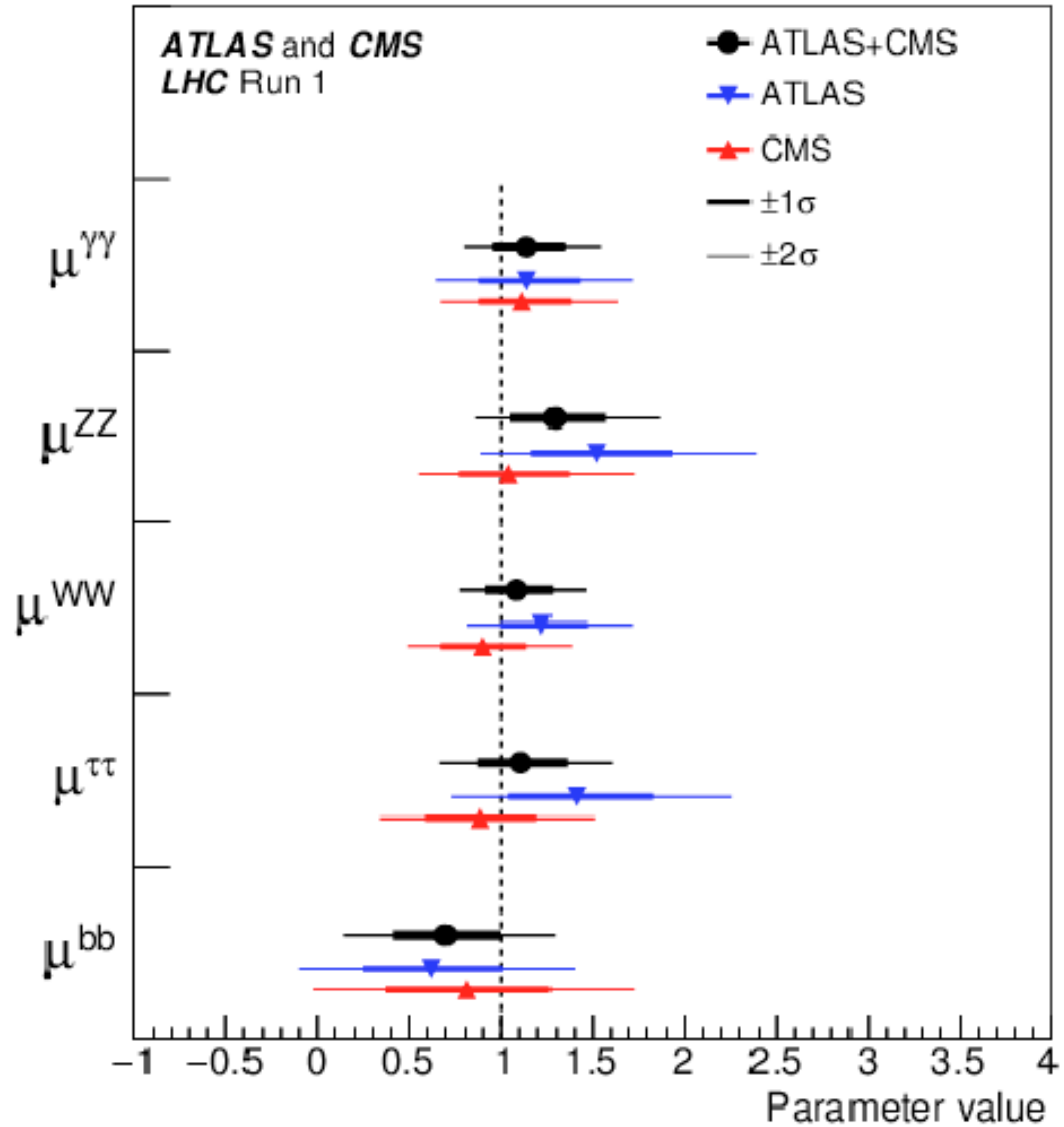
* energy scale and resolution



$$m_H = 125.09 \pm 0.24\ \text{GeV}$$

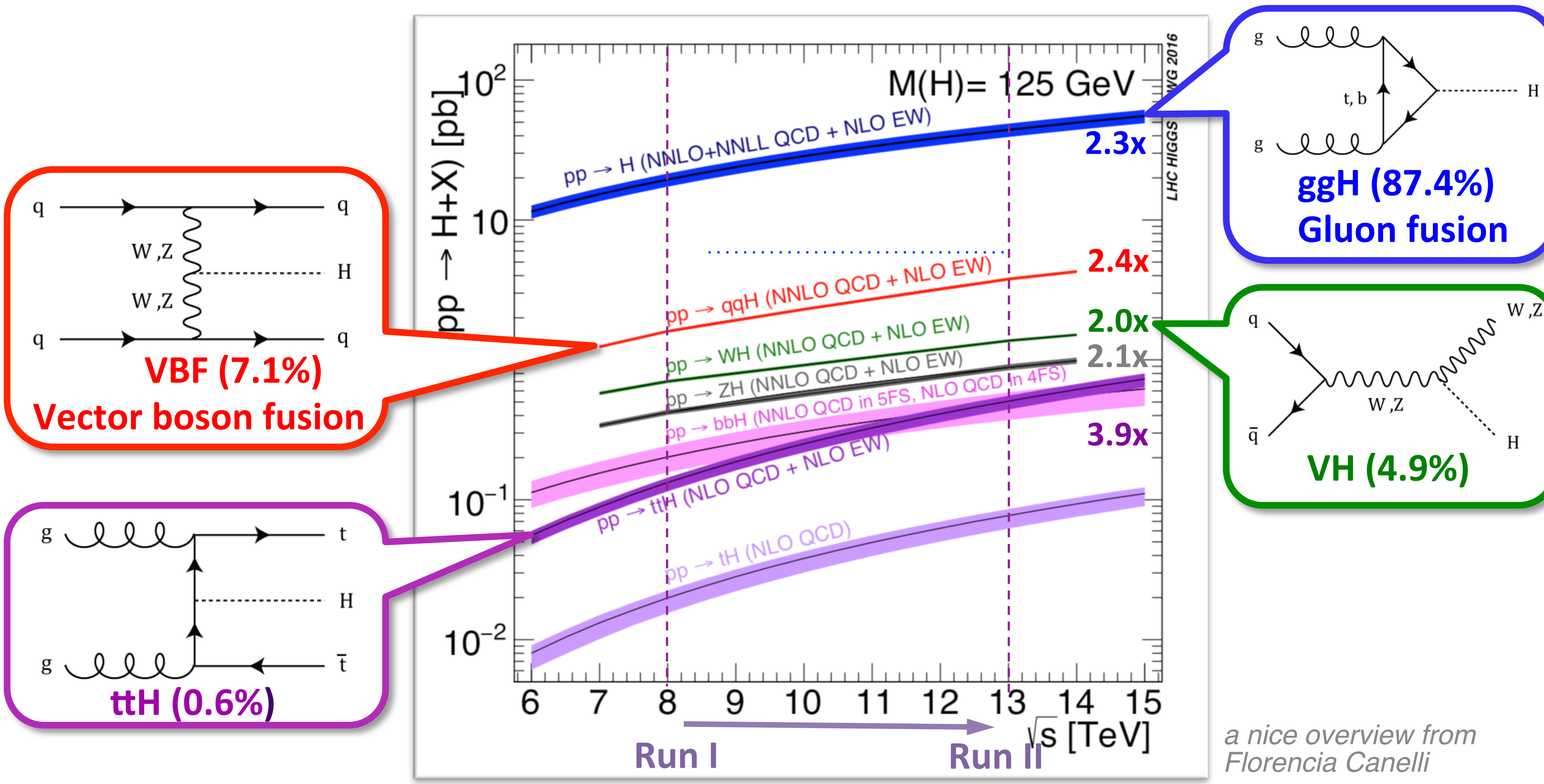
* overall: 0.19% precision

Higgs decay signal strengths: combination



*** we should definitely do this again after the Run2**

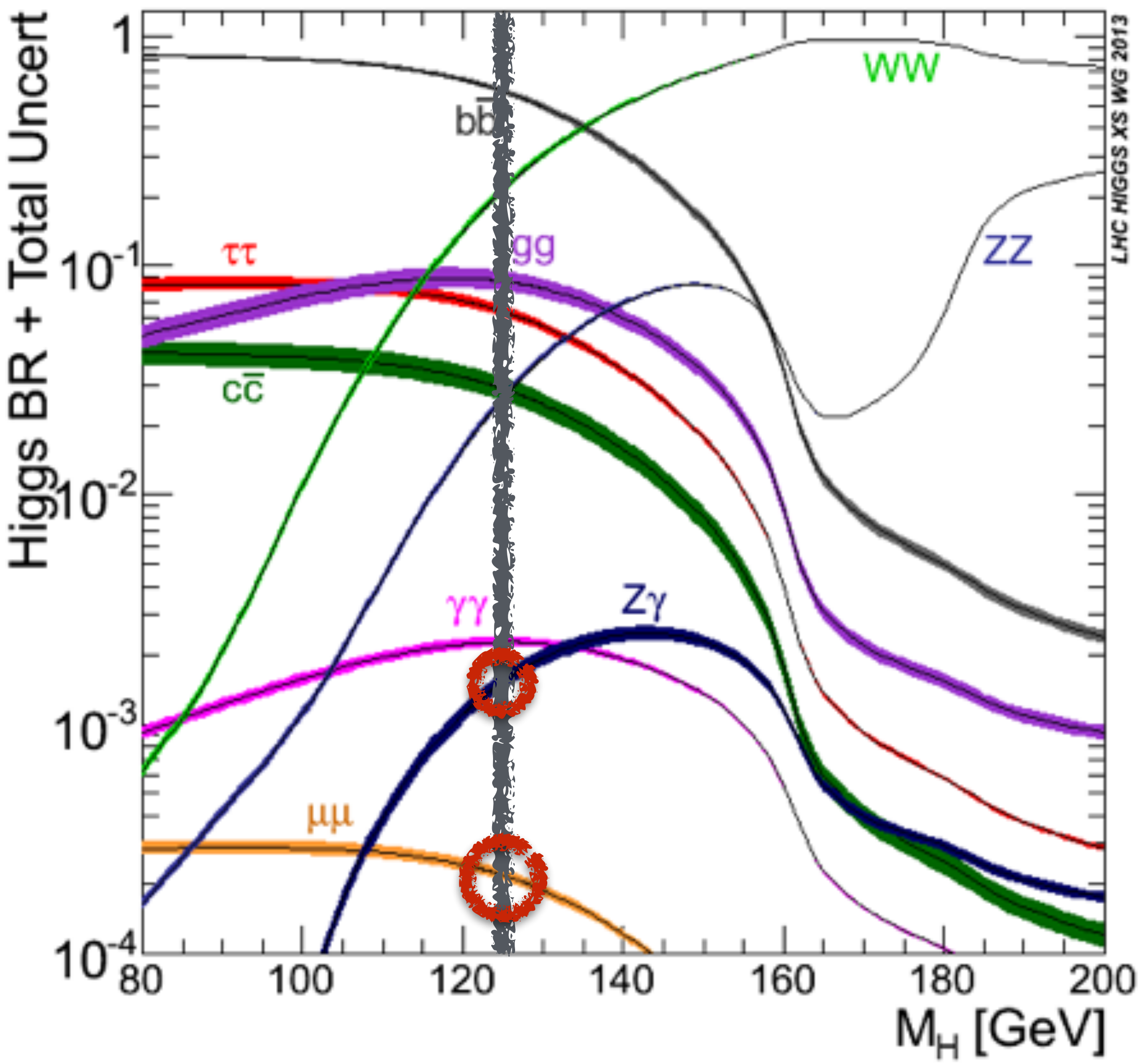
Higgs production at LHC



a nice overview from Florencia Canelli

*** we need to measure: VBF, VH, and ttH - production cross-sections**

Higgs decays
— overview —



*** look at rare decays: $\mu\mu$ and $Z\gamma$**

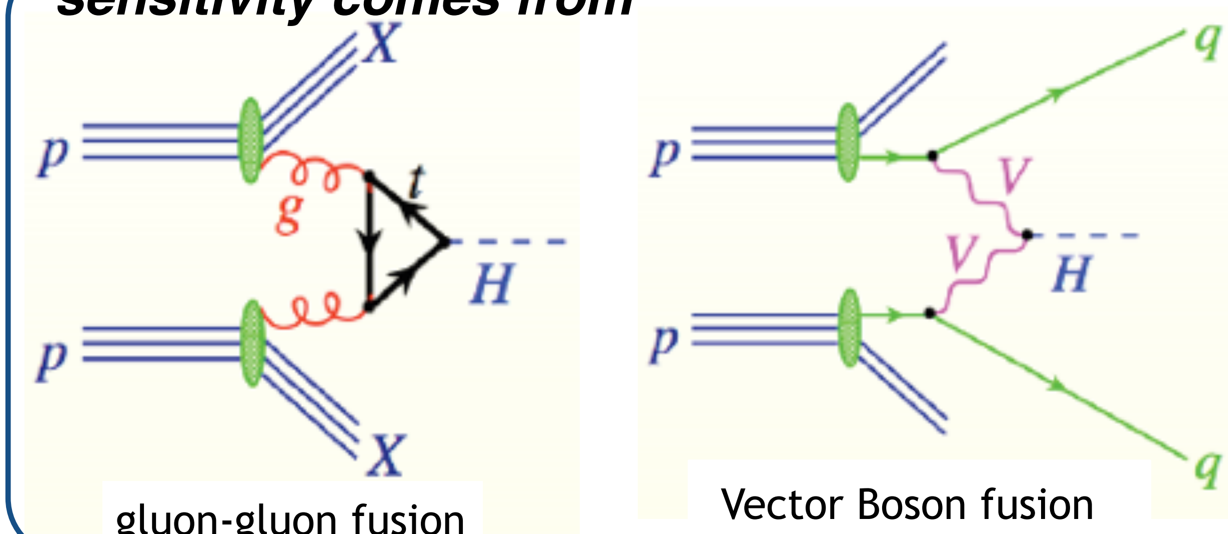
*** check for exotic decays like LFV: $\mu\tau$, $e\tau$, $e\mu$**

what do we know from CMS in Run I ?

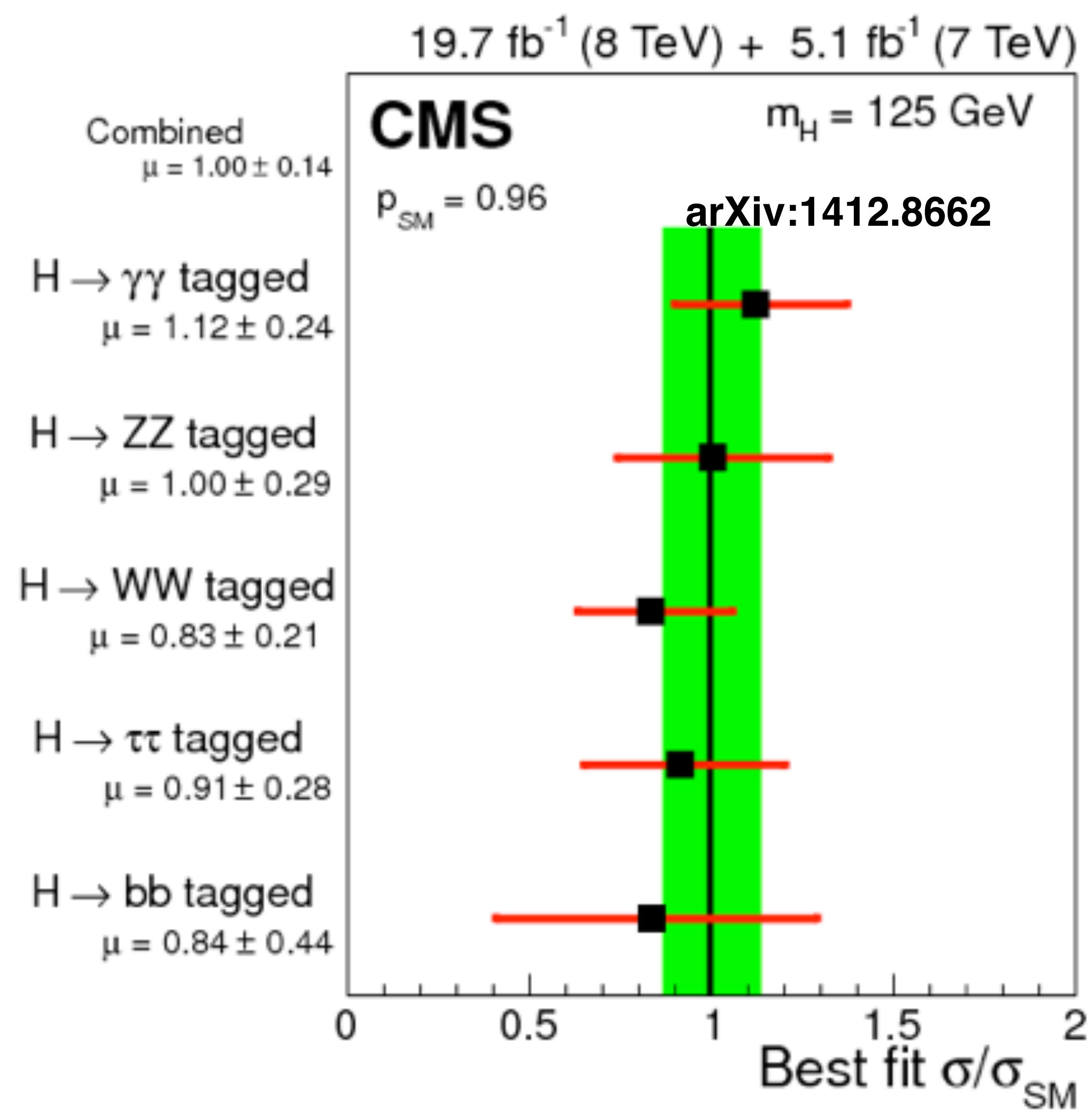
- Significance (m_H = 125.0 GeV)

Combination	Expected (post-fit)	Observed
$H \to ZZ$ tagged	6.3 σ	6.5 σ
$H \to \gamma\gamma$ tagged	5.3 σ	5.6 σ
$H \to WW$ tagged	5.4 σ	4.7 σ
$H \to \tau\tau$ tagged	3.9 σ	3.8 σ
$H \to bb$ tagged	2.6 σ	2.0 σ
$H \to \mu\mu$ tagged	<0.1 σ	0.4 σ

sensitivity comes from:

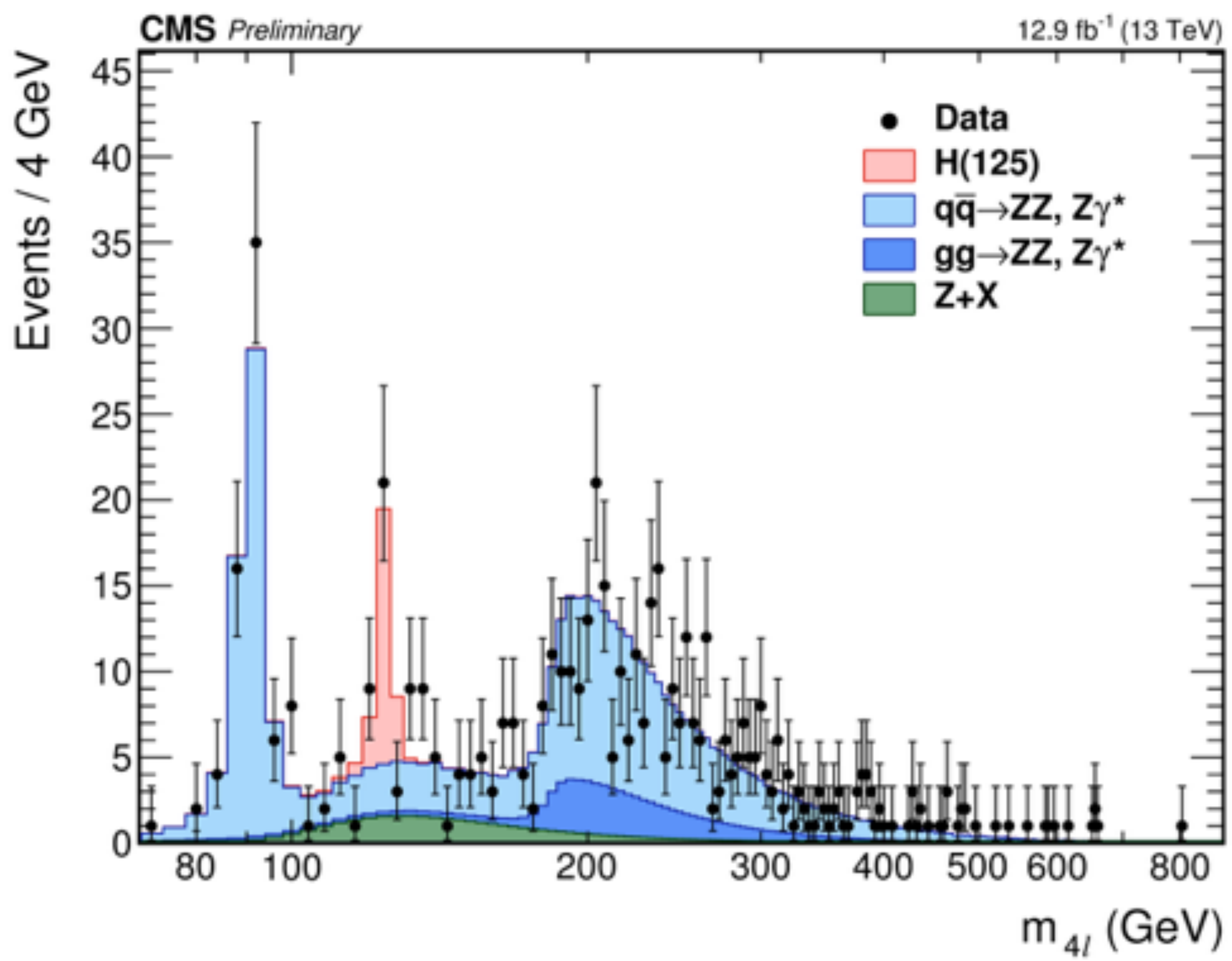


- combined signal strength: **μ = 1.00 ± 0.14**

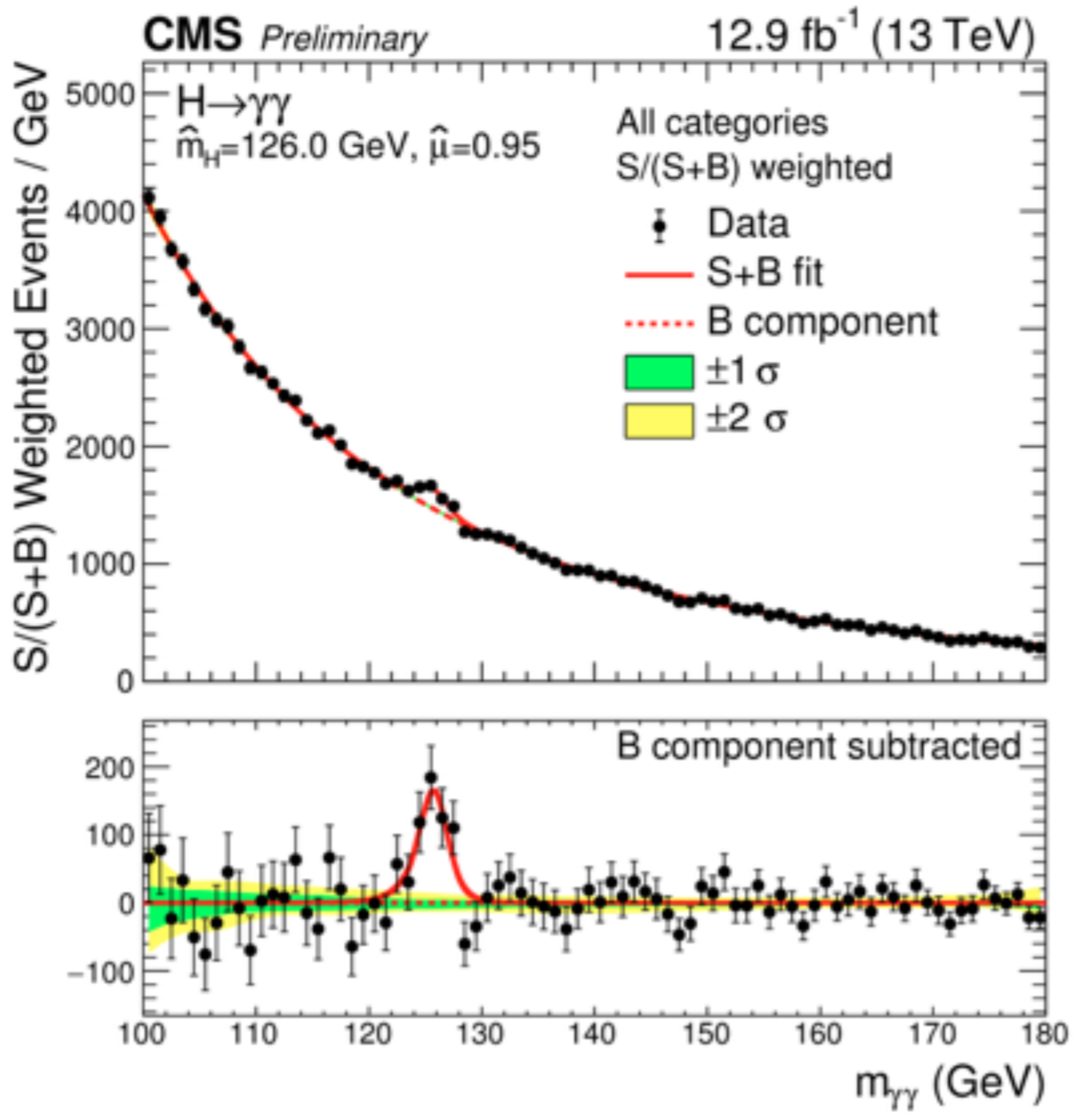


what do we know from CMS in Run II, so far?

CMS HIG-16-033

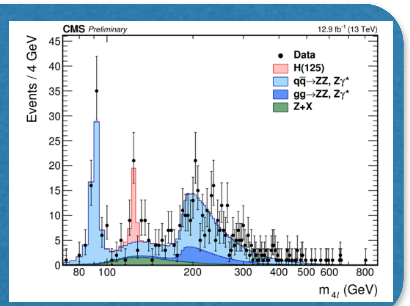


CMS HIG-16-020

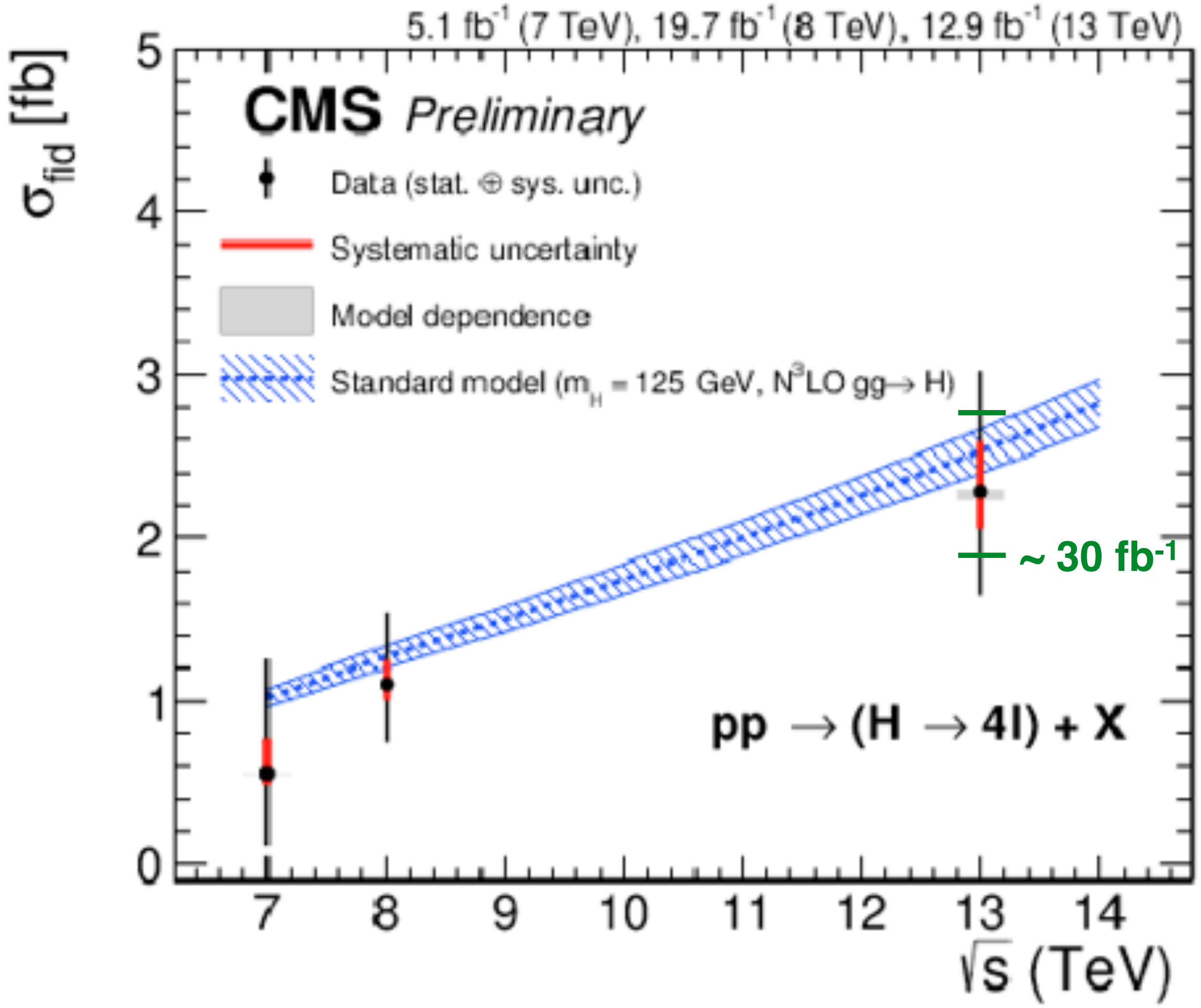


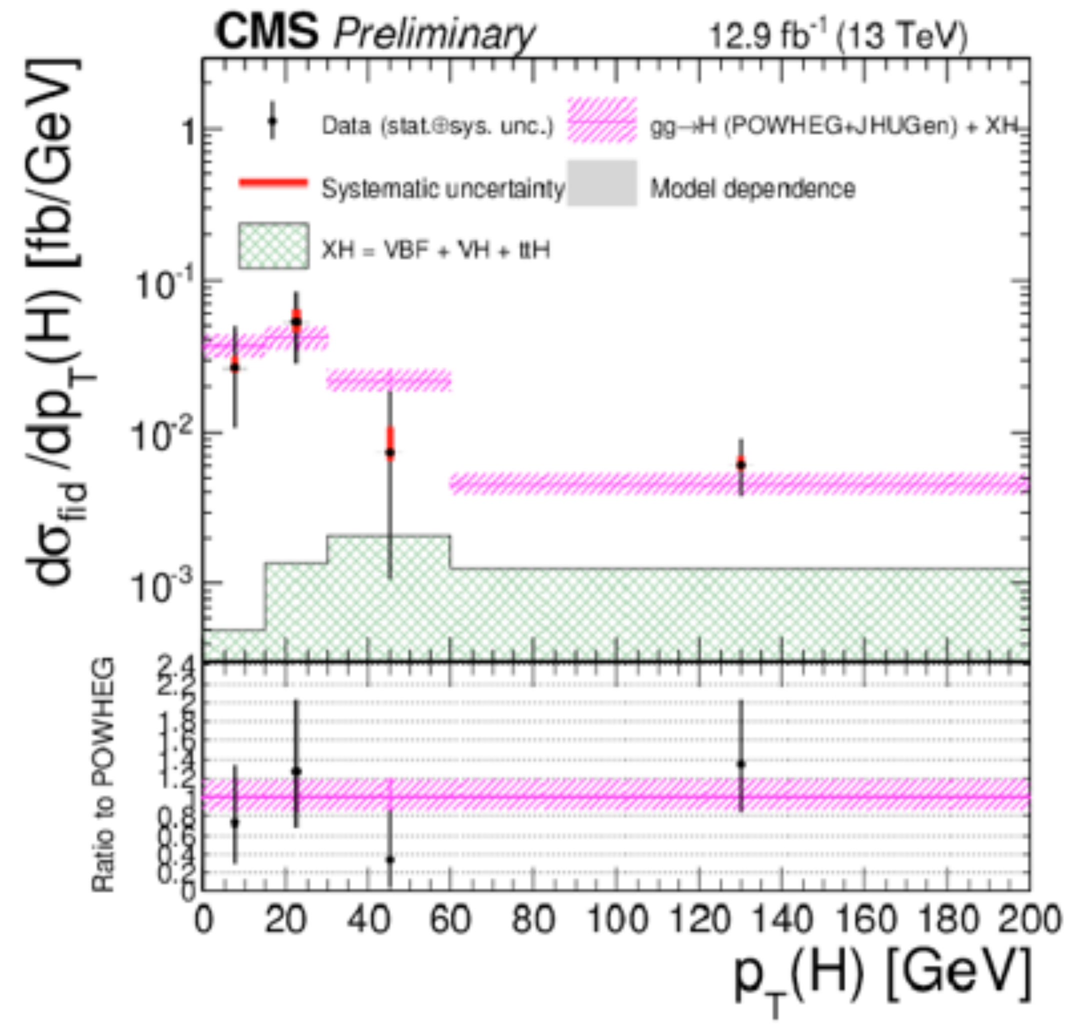
Higgs is still there!

where we can go: h ➛ ZZ*



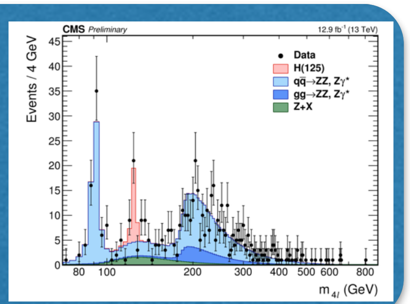
* fiducial cross-section:
$\sigma_{fid}=2.29^{+0.74}_{-0.64}(stat)^{+0.30}_{-0.23}(syst)^{+0.01}_{-0.05}(model\ dep.)$ fb
$\sigma^{SM}_{fid}=2.53 \pm 0.13$ fb
* with 30 fb-1 we can reduce uncertainties by ~1/3, scaled with √L





* differential cross-sections: $d\sigma/dp_T$

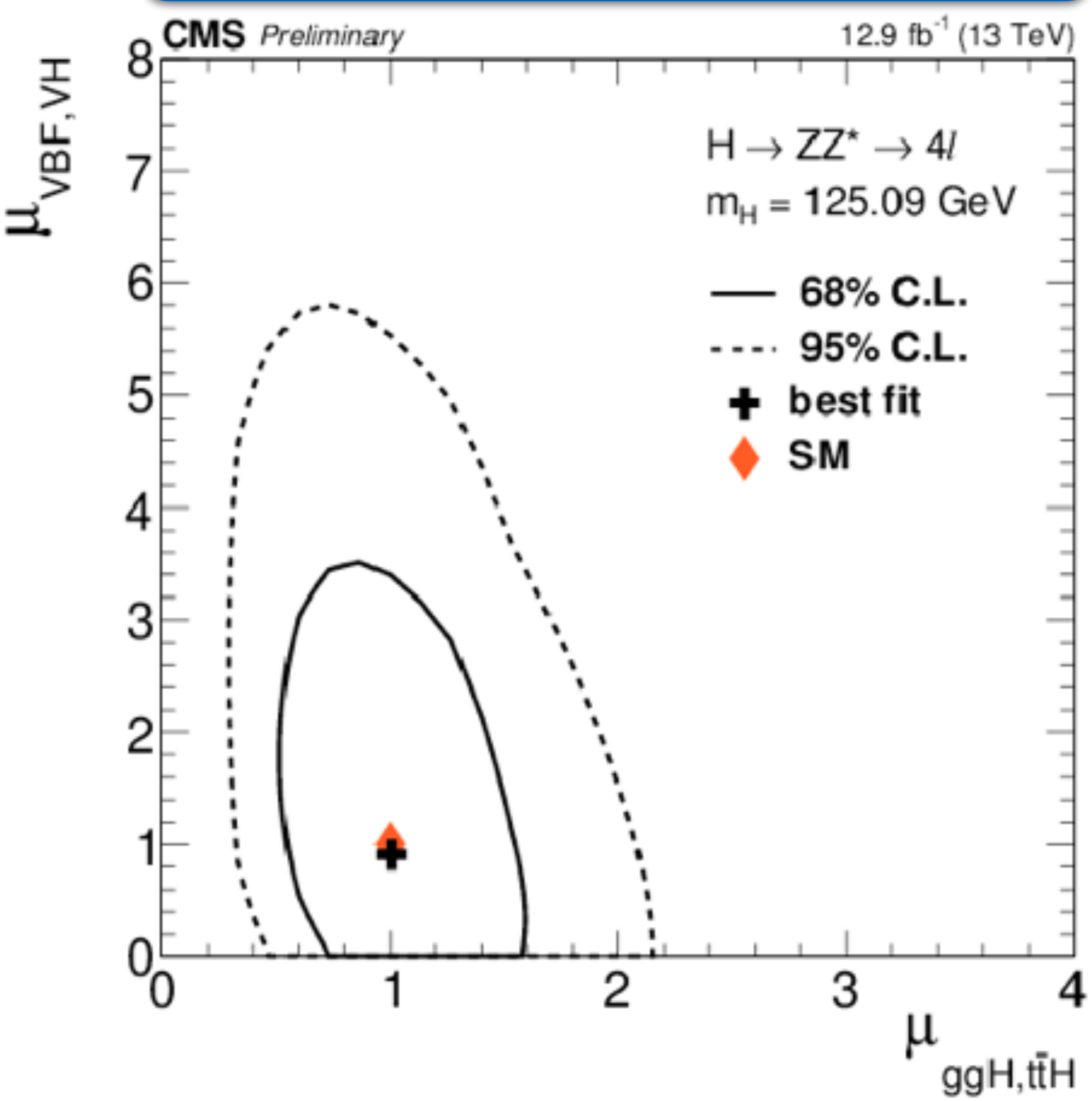
where we can go: h ➛ ZZ*



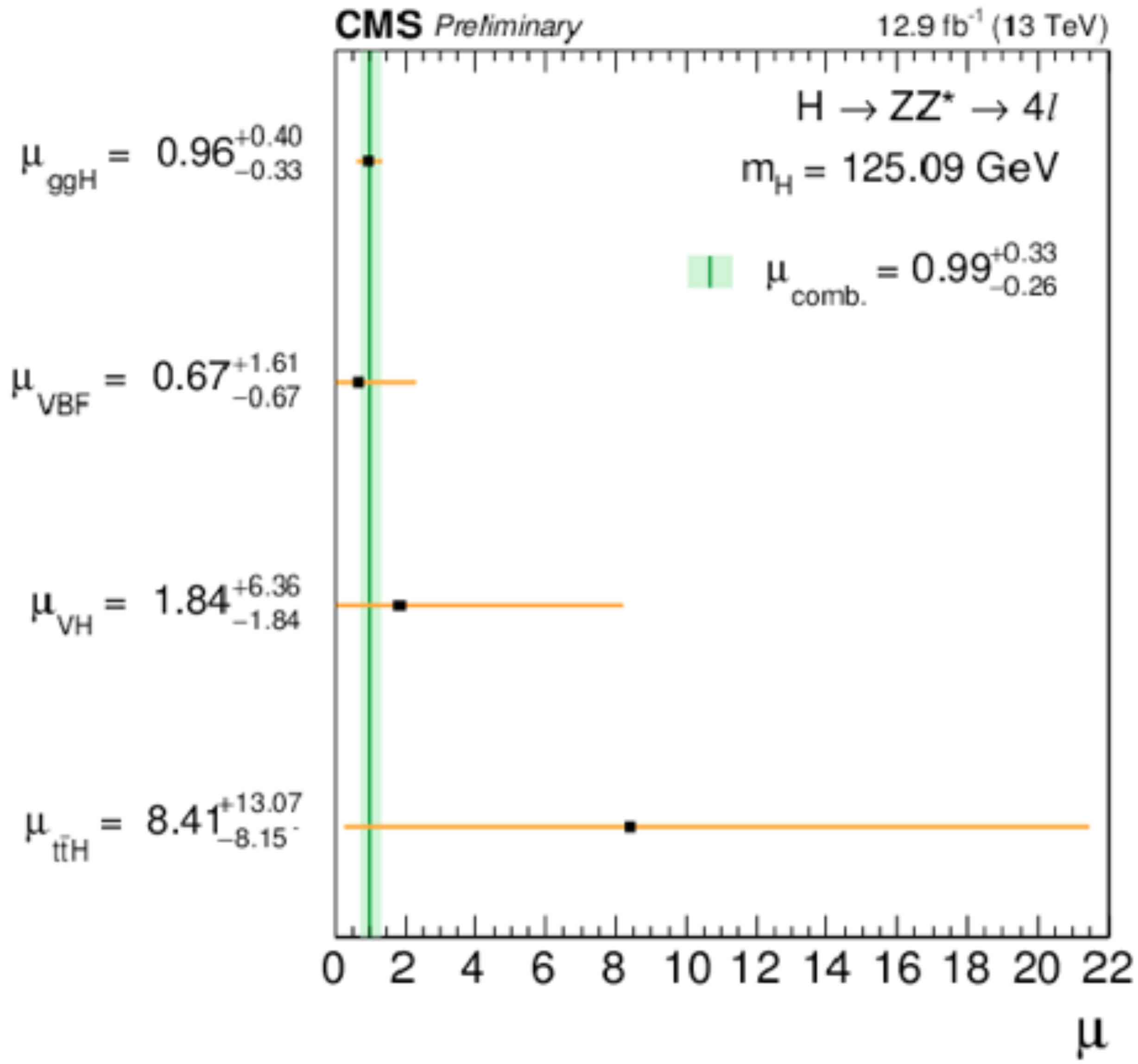
2D likelihood scan assuming m_h:

* $\mu_{ggH,\ ttH} = 1.00^{+0.39}_{-0.32}$

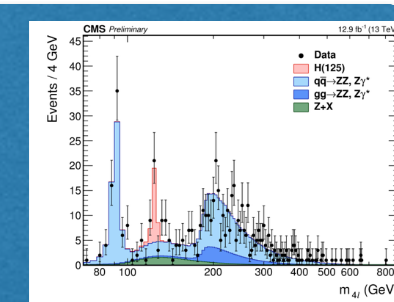
* $\mu_{VBF,VH} = 0.91^{+1.56}_{-0.91}$



*** individual production modes**

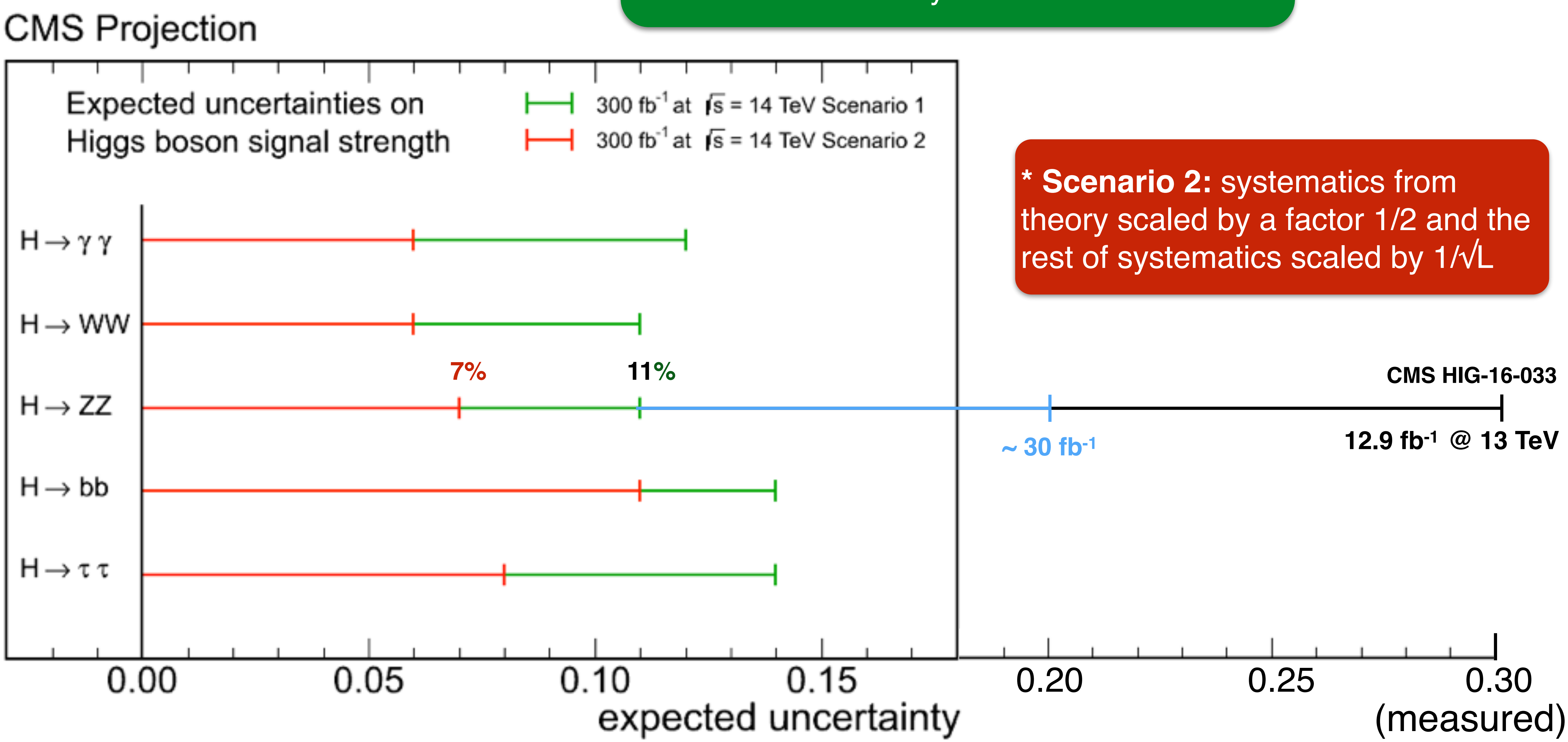


where we can go: h → ZZ*

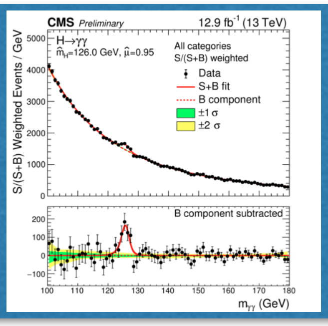


*** Scenario 1:** same systematics as in Run I

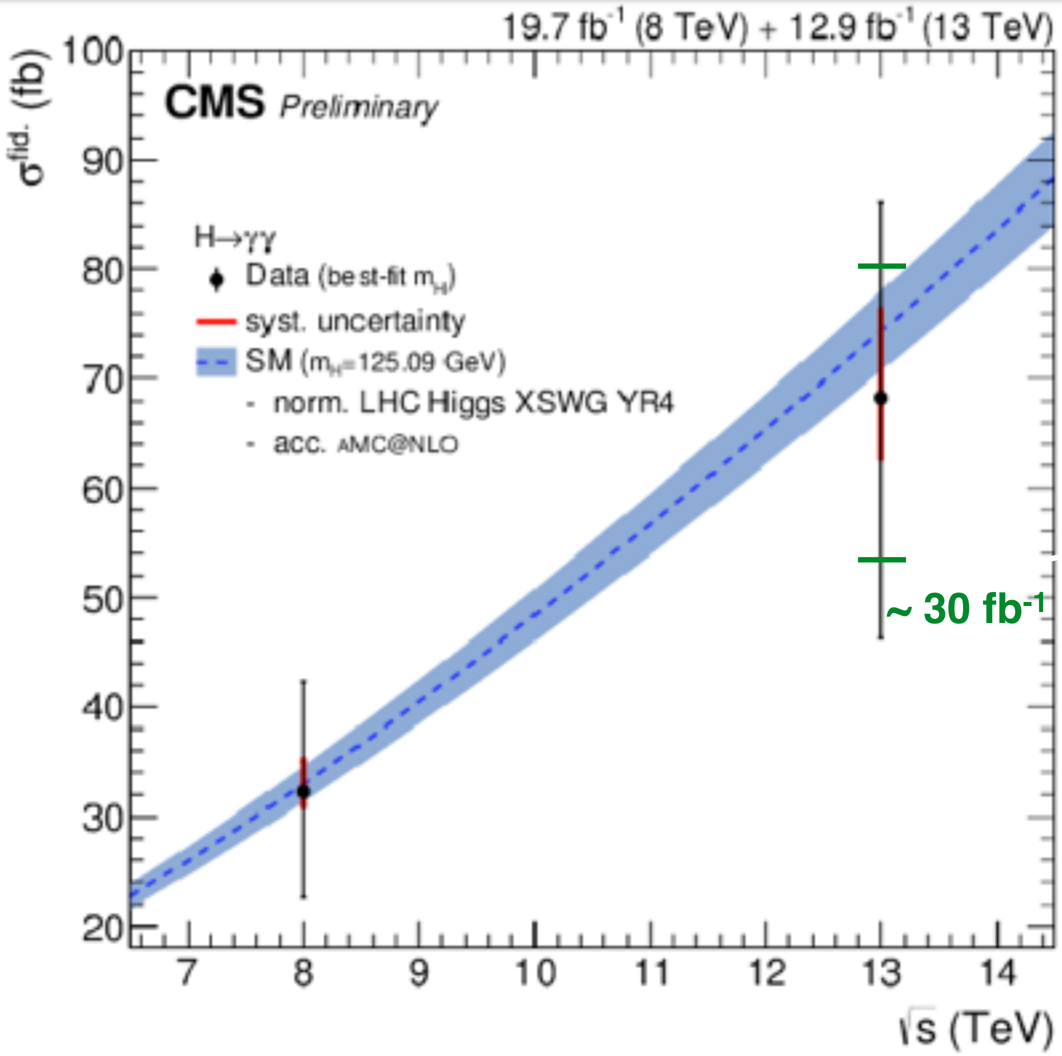
*** Scenario 2:** systematics from theory scaled by a factor 1/2 and the rest of systematics scaled by 1/√L

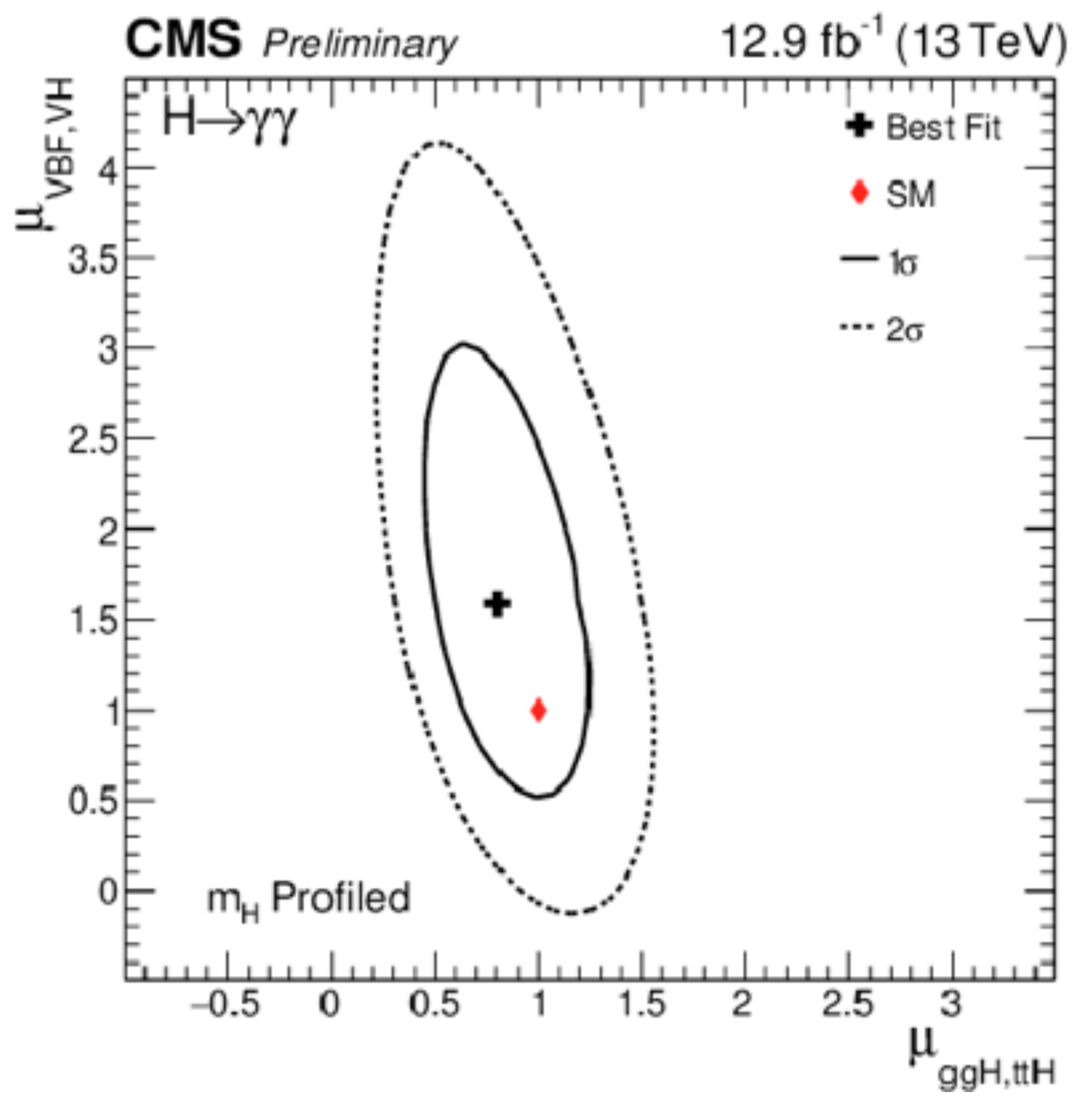


where we can go: h ➝ γγ



* fiducial cross-section:
$\sigma_{fid}=69^{+12}_{-22}(stat)^{+8}_{-6}(syst)$ fb
$\sigma^{SM}_{fid}=73.8 \pm 3.8$ fb
* with 30 fb-1 we can reduce uncertainties by ~1/3, scaled with √L

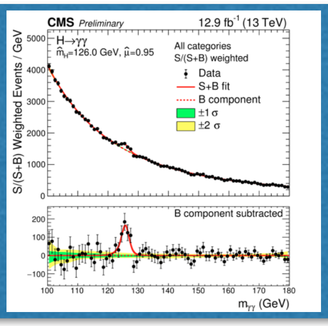




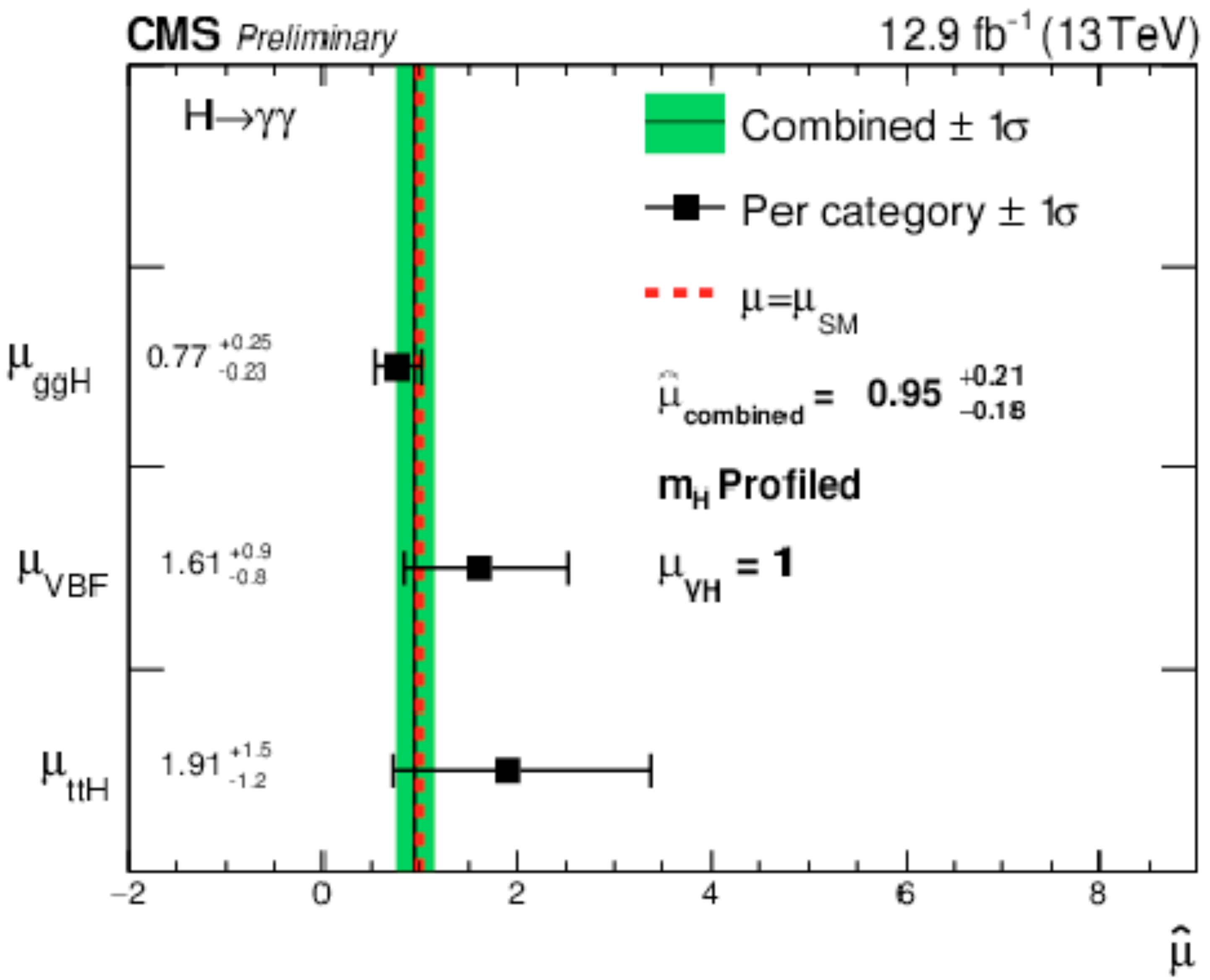
2D likelihood scan profiling m_h:

* $\mu_{ggH,\,ttH} = 0.80^{+0.14}_{-0.18}$
* $\mu_{VBF,VH} = 1.59^{+0.73}_{-0.45}$

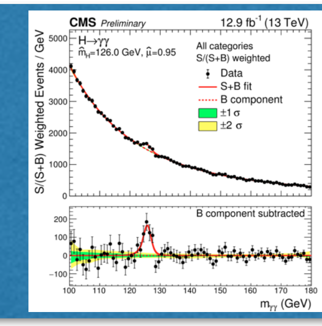
where we can go: h ➛ γγ



* individual production modes



where we can go: h ➝ γγ



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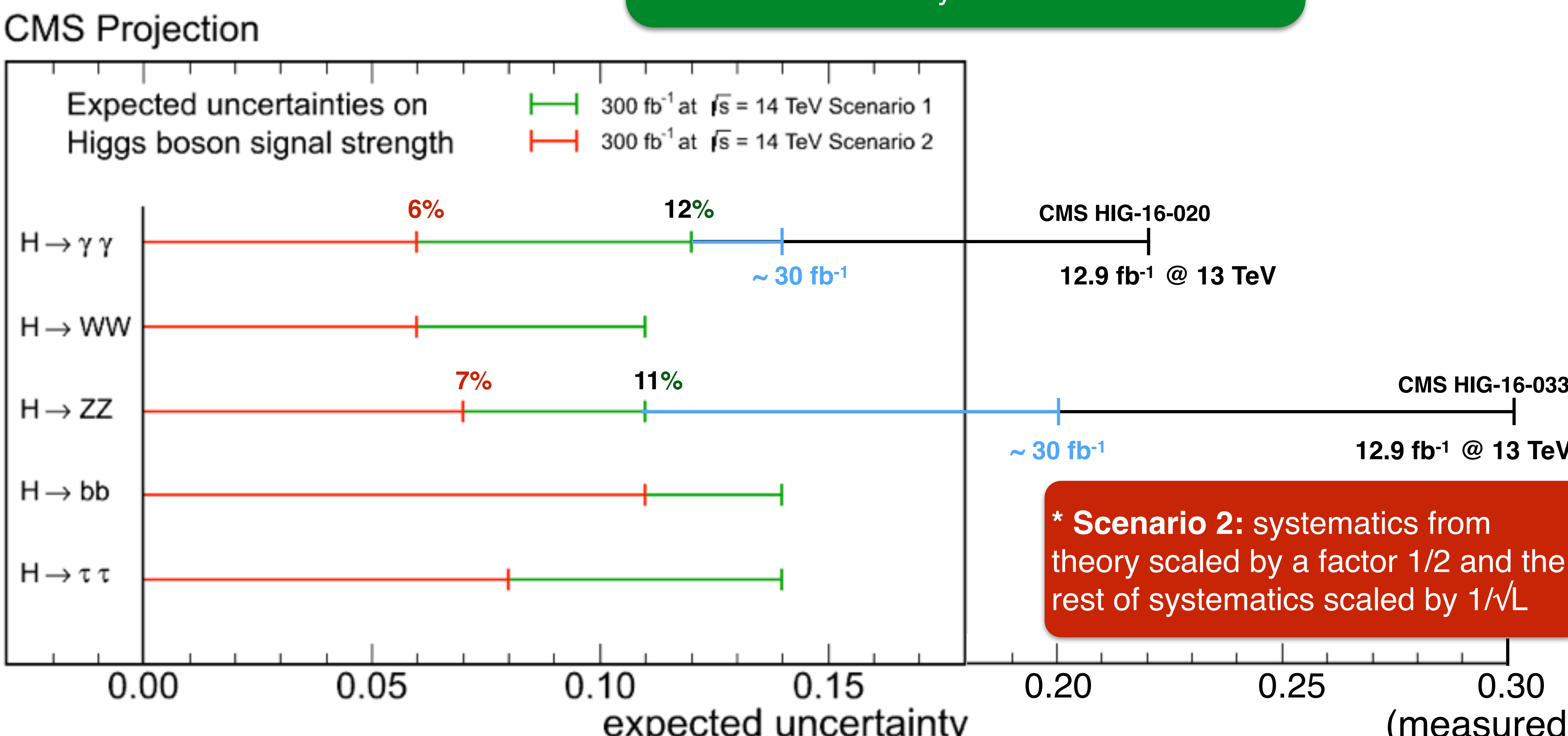


*** Scenario 2:** systematics from theory scaled by a factor 1/2 and the rest of systematics scaled by 1/√L

where we can go: couplings

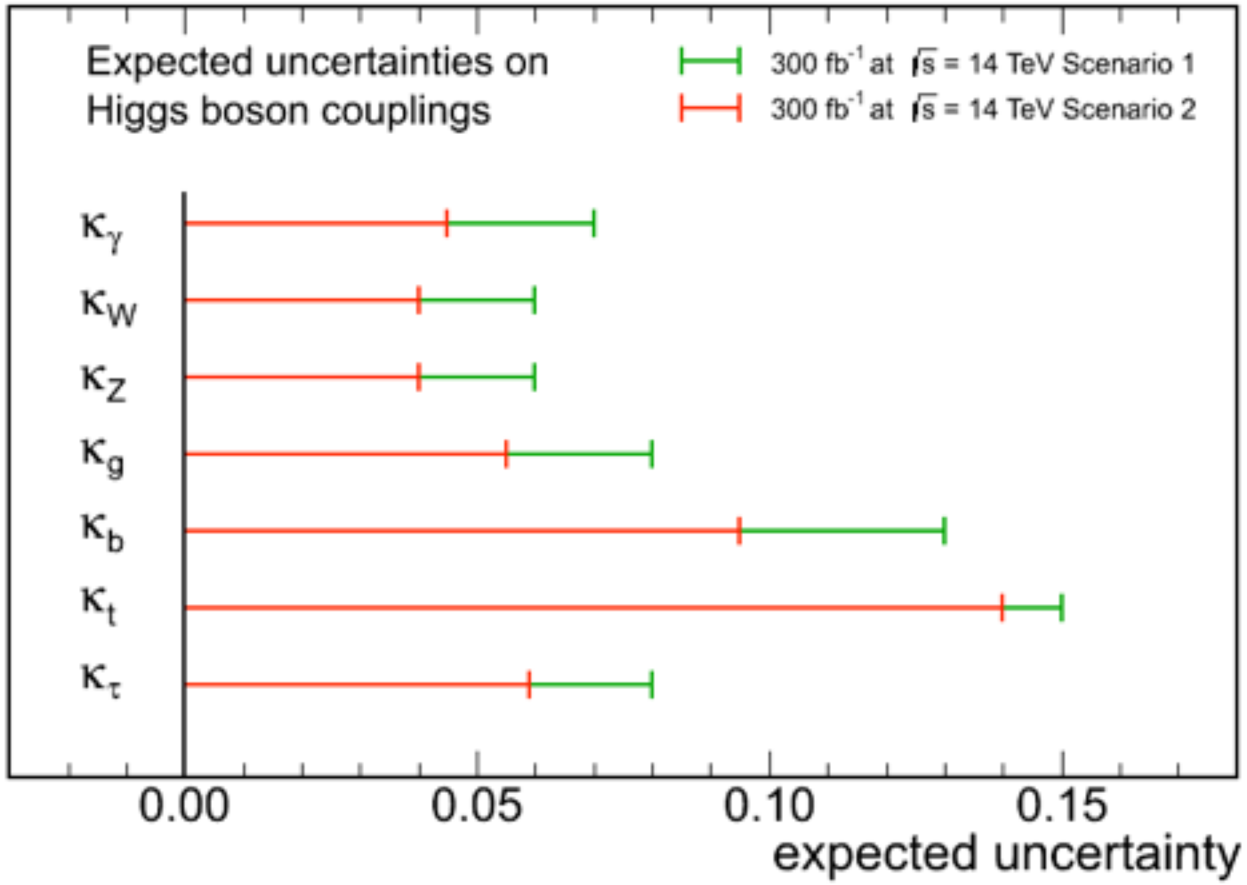
reduced coupling parameters

$$Y_V = \kappa_V \frac{m_V}{v}$$

$$Y_f = \kappa_f \frac{m_f}{v}$$

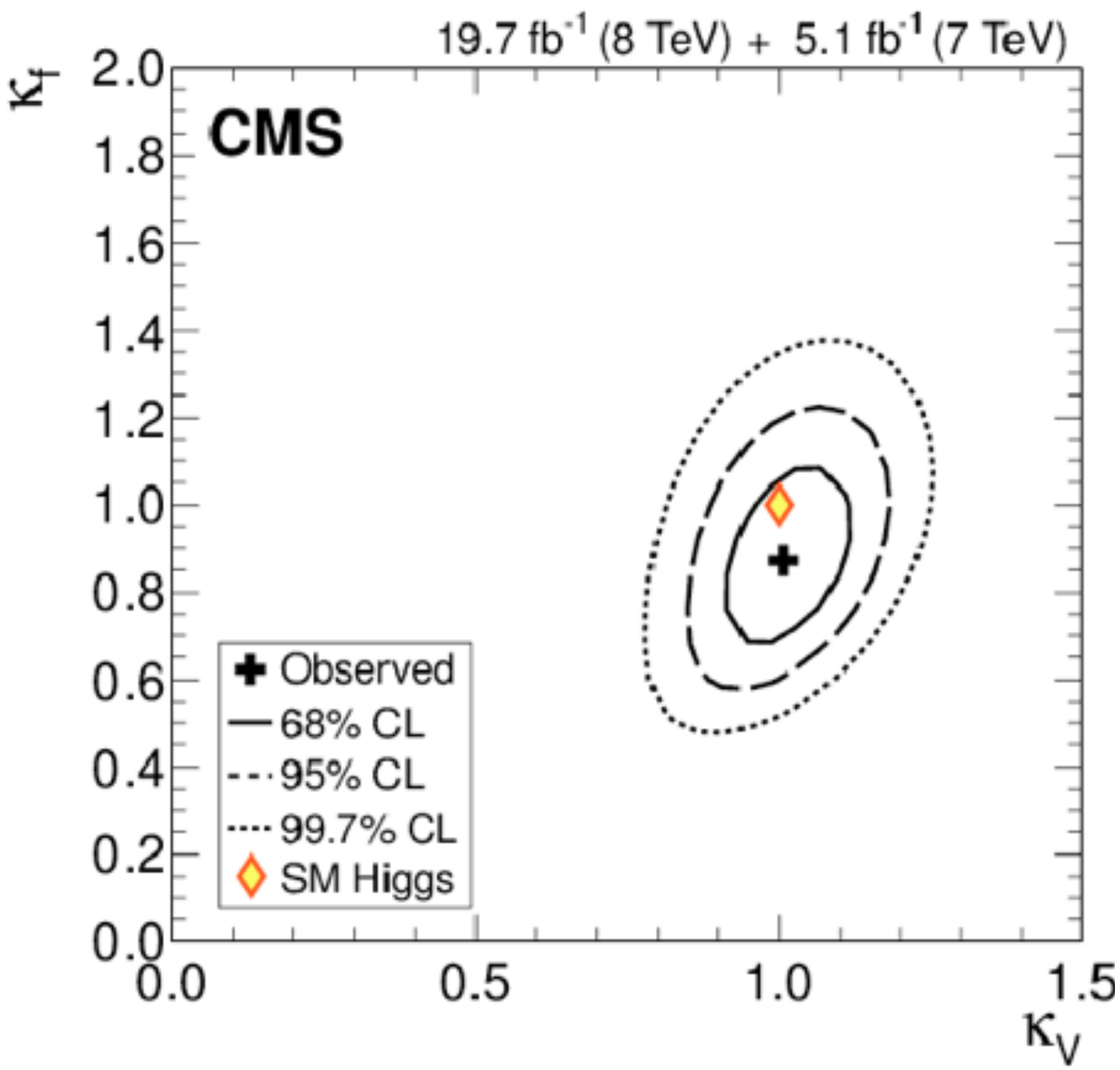
L (fb^{-1})	κ_γ	κ_W	κ_Z	κ_g	κ_b	κ_t	κ_τ	$\kappa_{Z\gamma}$	$\kappa_{\mu\mu}$	BR_{SM}
300	[5, 7]	[4, 6]	[4, 6]	[6, 8]	[10, 13]	[14, 15]	[6, 8]	[41, 41]	[23, 23]	[14, 18]

CMS Projection

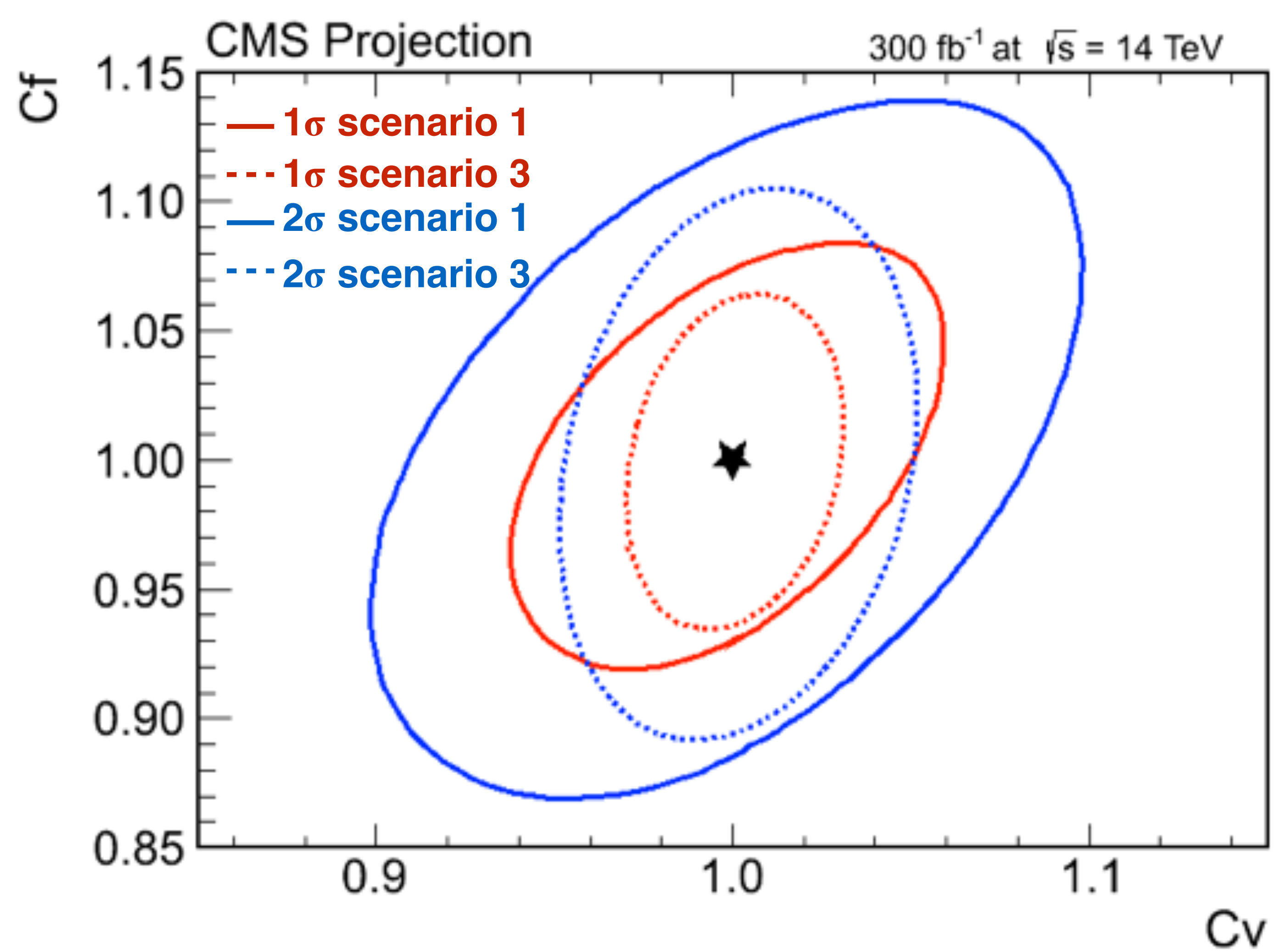


where we can go: couplings

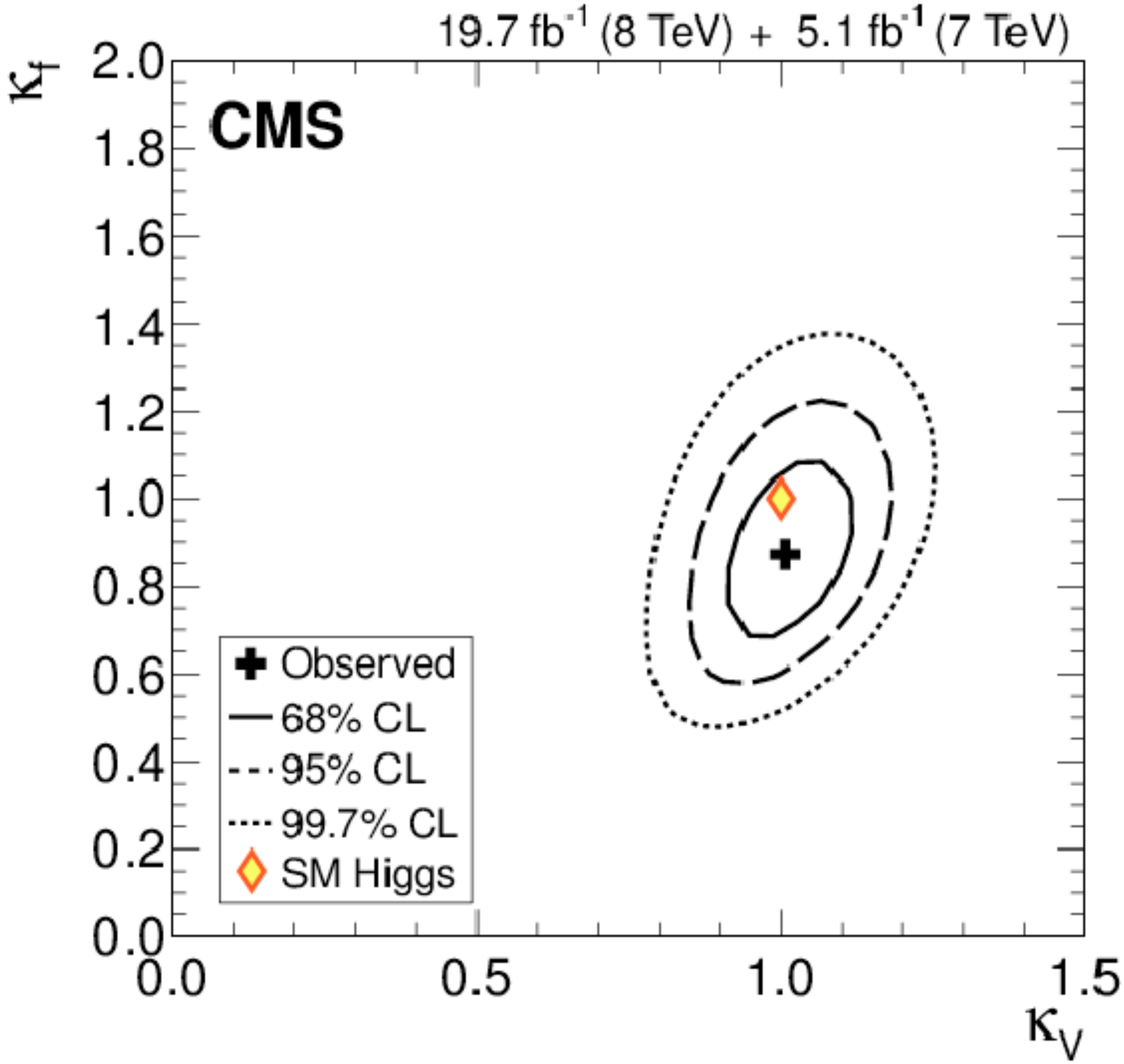
* from Run I we know:



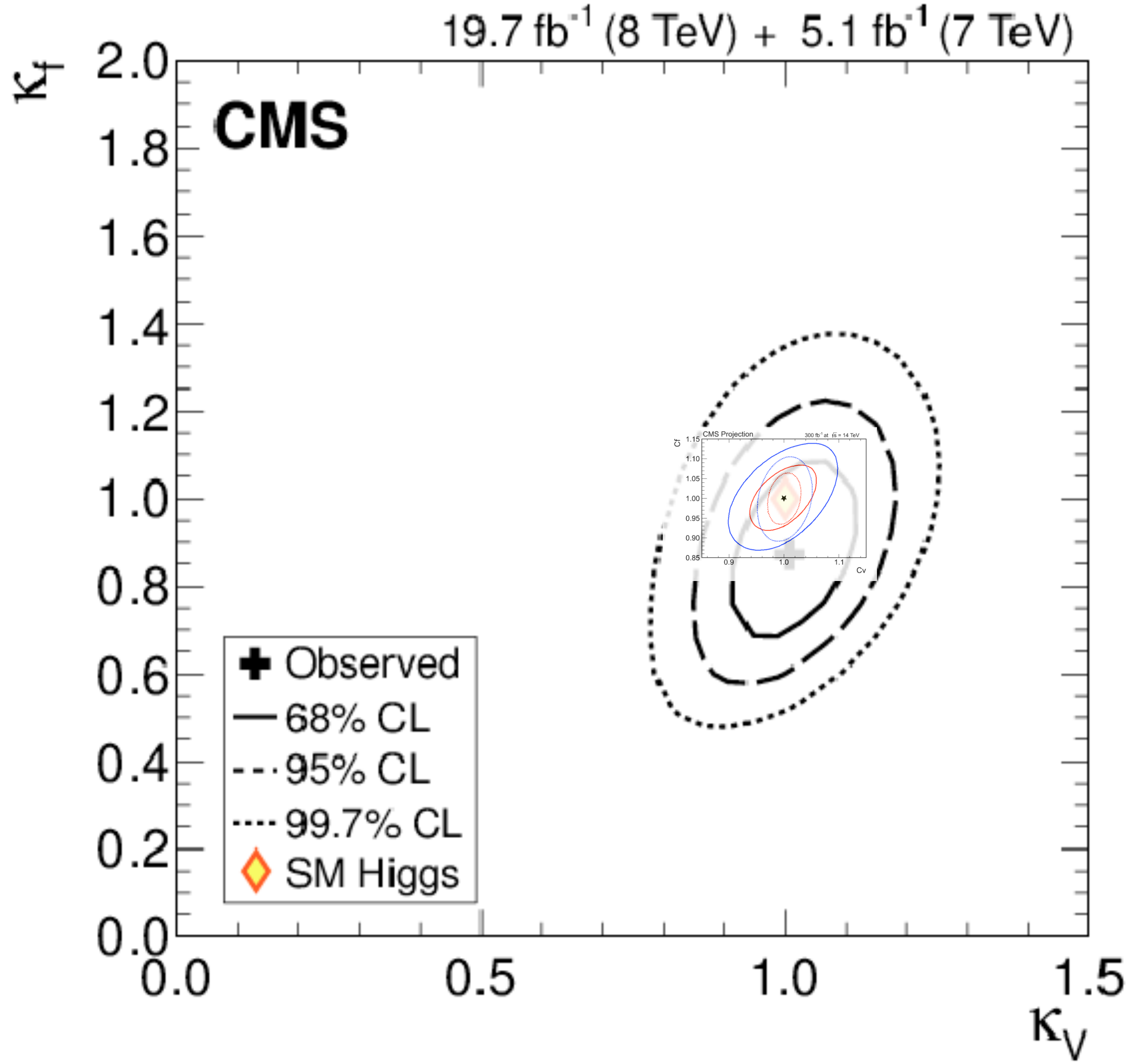
* for 300 fb^{-1} experimental systematics as in Run I, w/o theory uncertainty (scenario3):
— $\sigma(C_V) \approx$ 3-6%
— $\sigma(C_f) \approx$ 5-10%



where we can go: couplings
— let's make an overlay exercise —

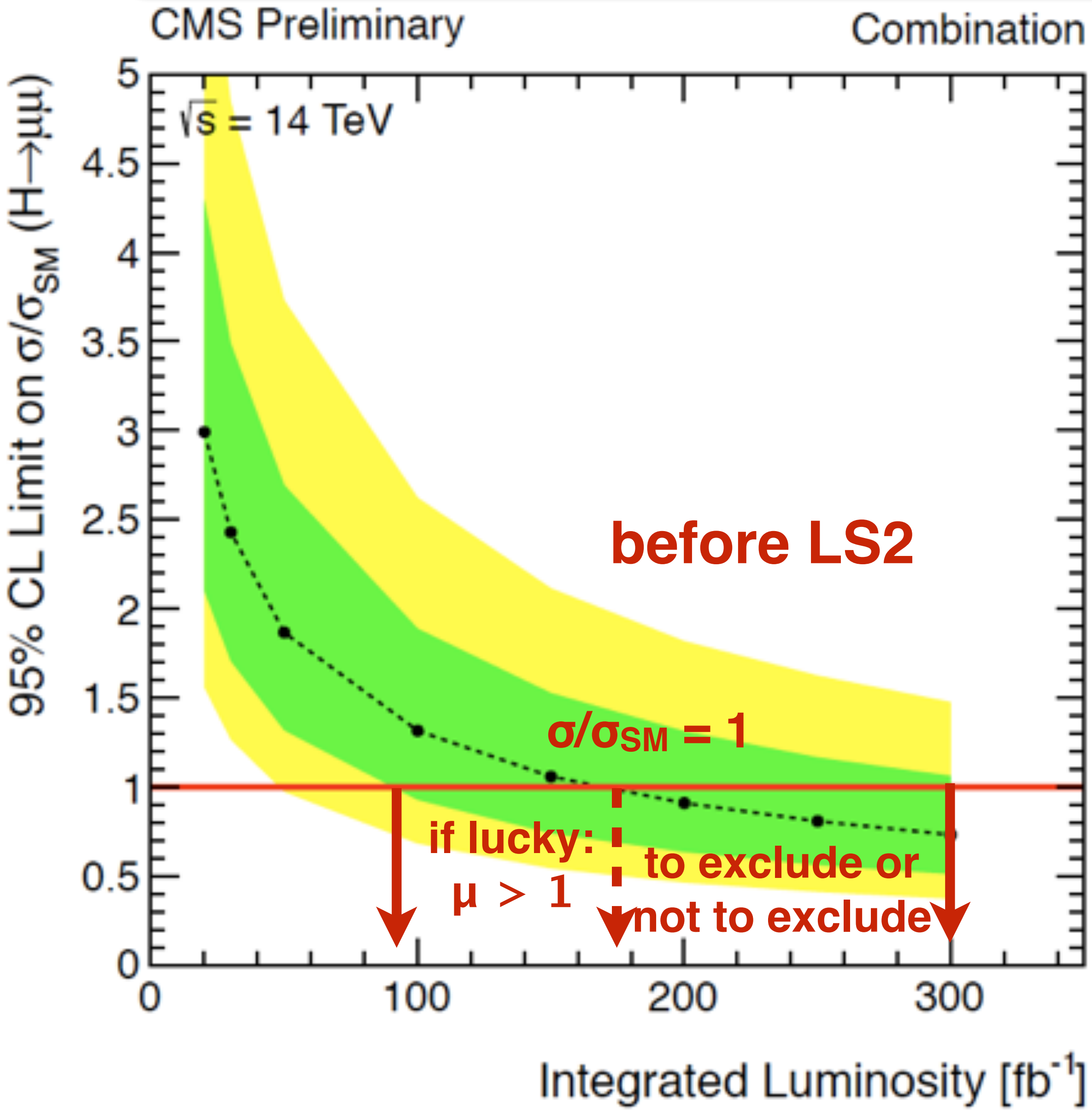


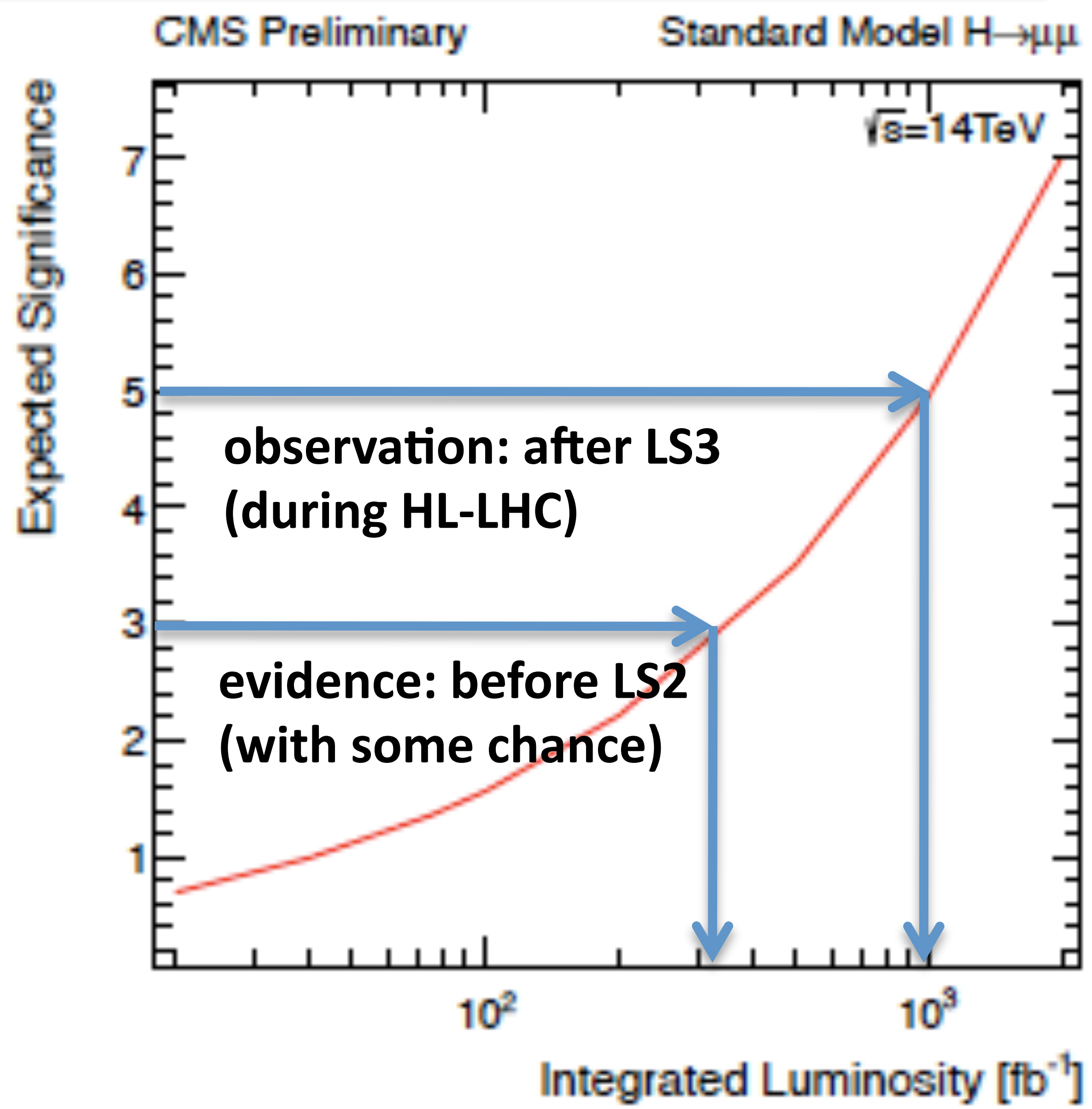
where we can go: couplings
— let's make an overlay exercise —



let’s not forget about rare decays

Higgs rare decays
— dimuon decay —





* SM sensitivity should be reached before LS2

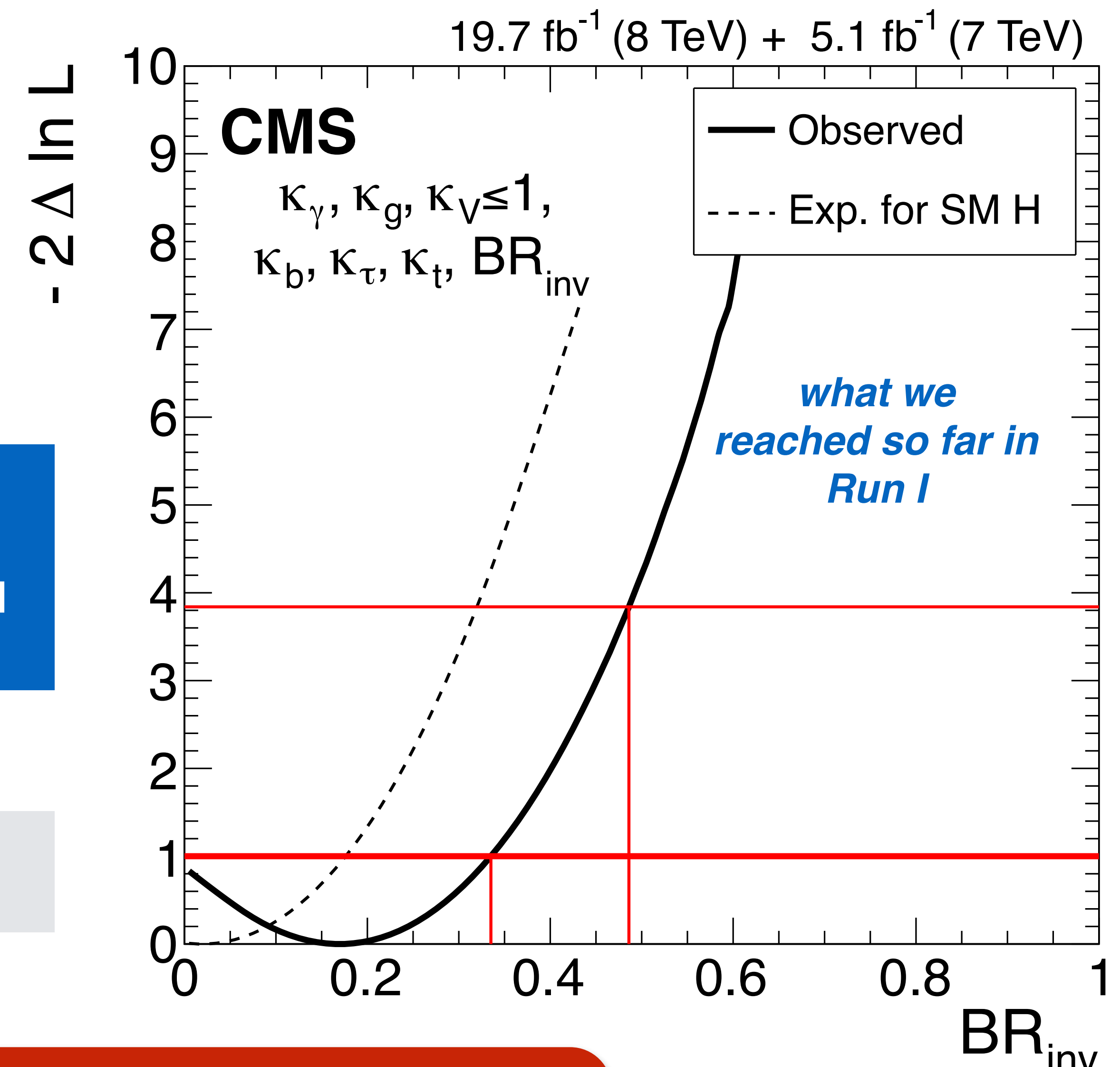
* observation (> 5σ) expected with HL-LHC

Higgs rare decays

— invisible —

* direct access: VBF and ZH production
* indirect access: combined coupling fit

95% CL upper limit	Z h (inv.) after 300 fb^{-1}	Z h (inv.) after 3000 fb^{-1}
Scenario 1	28%	17 %
Scenario 2	17%	6.4%



* together with the VBF channel, the ZH(inv) can help us to constrain even more the BSM physics
* additional input will be coming from the mono jet and mono photon searches

conclusions & outlook

* LHC is doing an amazing job this year

* CMS is keeping the pace with data taking and the Higgs analyses

* next winter we will have analysed the 2015/2016 data and better projections based on 30 (42) fb-1

* Run II is not the end of the story - the big game will be HL-LHC

* we will have a new CMS detector: improved/new analyses

* many studies are now trying to understand how to improve sensitivity with HL-LHC data set

maybe we are already in the future… we just do not know it, yet

backup