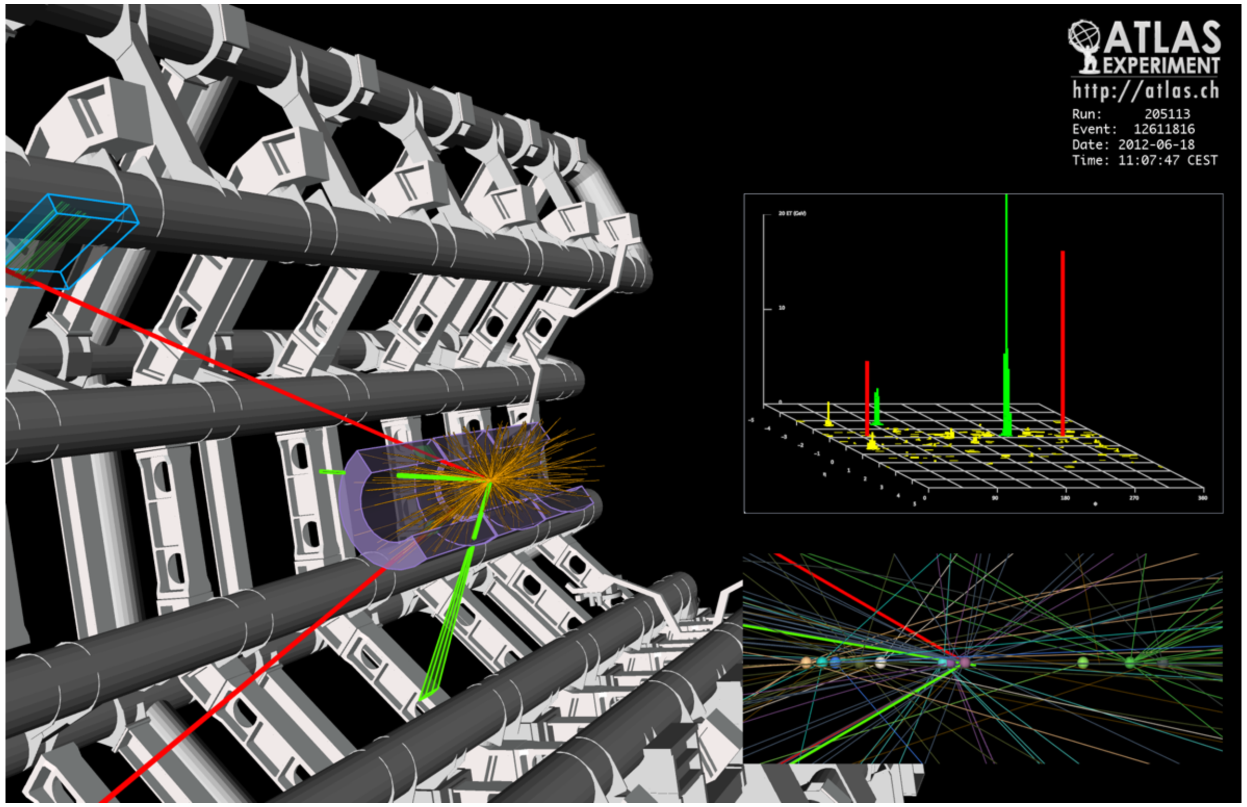
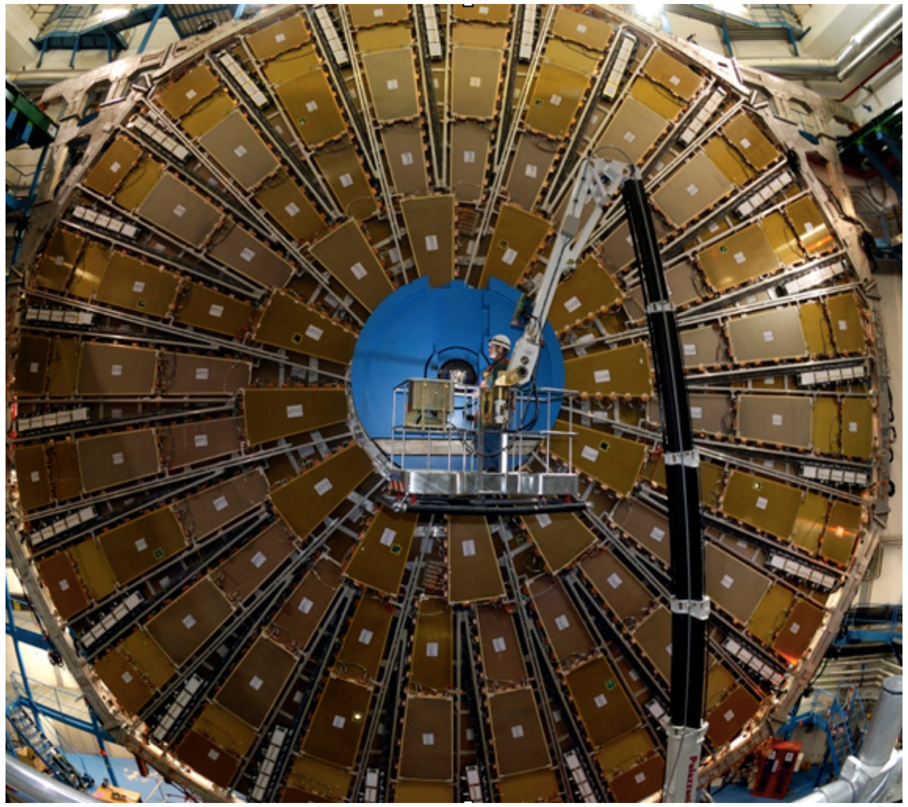
Higgs Particle properties from High-Energy experiments





Higgs modes in condensed matter and quantum gases

23rd June 2014 @ YITP, Kyoto University

Masaya ISHINO (Kyoto University)

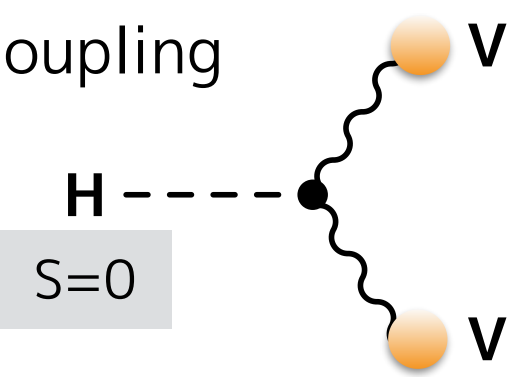
The Standard-Model in High-Energy phys.

fermion

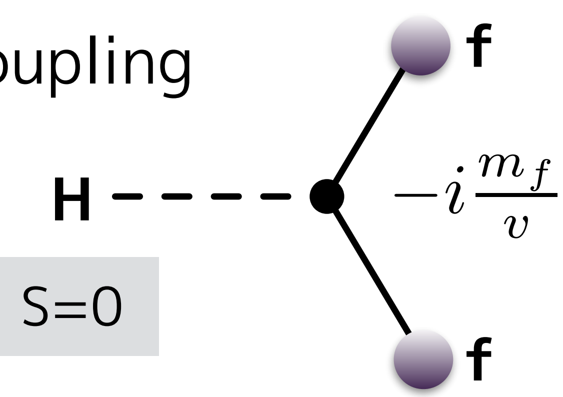
S=1/2

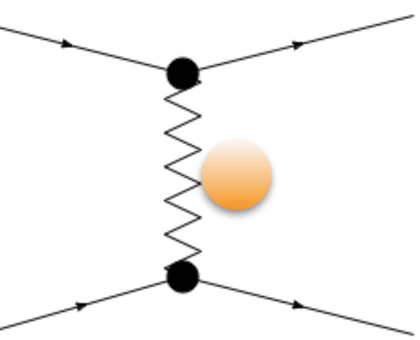
	leptons		quarks		
~0.0005 GeV	e	ν_e	d	u	~0.002 GeV
~0.1 GeV	μ	ν_μ	s	c	~1.5 GeV
~1.7 GeV	τ	ν_τ	b	t	173 GeV

HVV coupling



Hff coupling





vector-Boson (V)

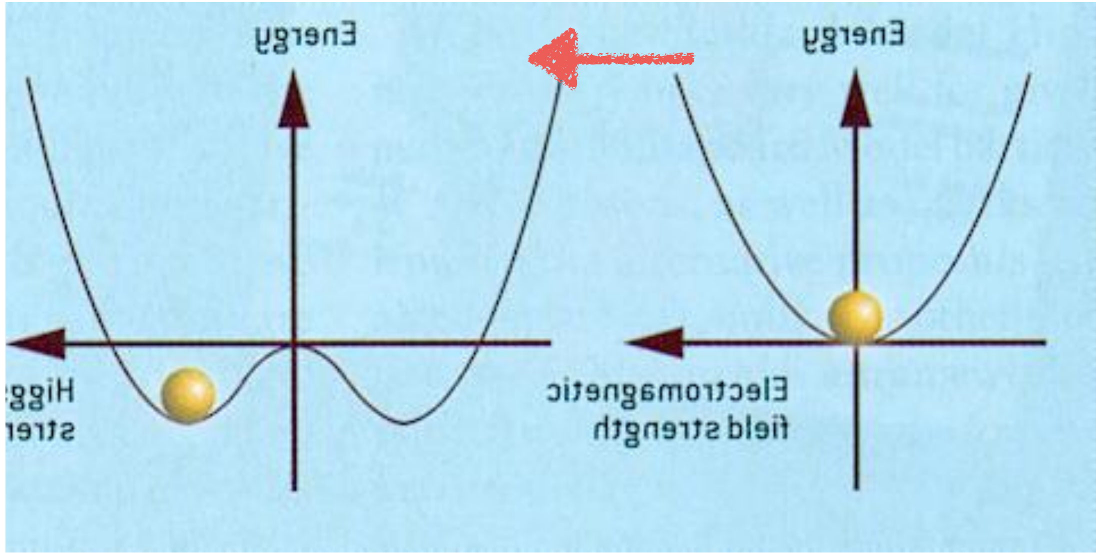
s=1

g m=0 Strong

γ m=0 Electro-Magnetic

$W^\pm$ ~81GeV, Z^0 ~90GeV Weak

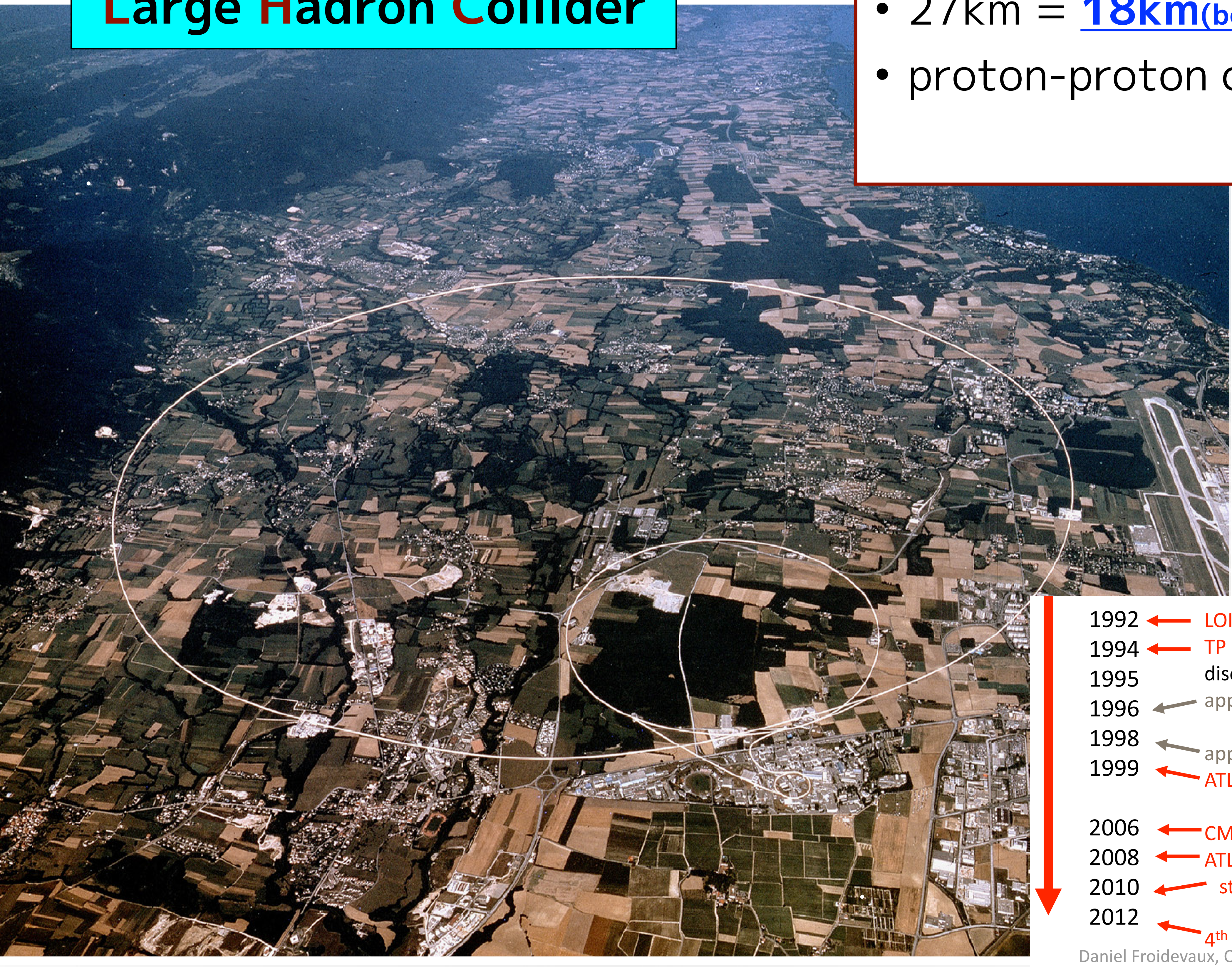
?



Electro-Weak symmetry, $SU(2)_L \times U(1)_Y$, is broken

The Key-Tool for discovery & measurements

Large Hadron Collider



- 27km = **18km(bent)** + 9km(straight)
- proton-proton collider **@ 14TeV**

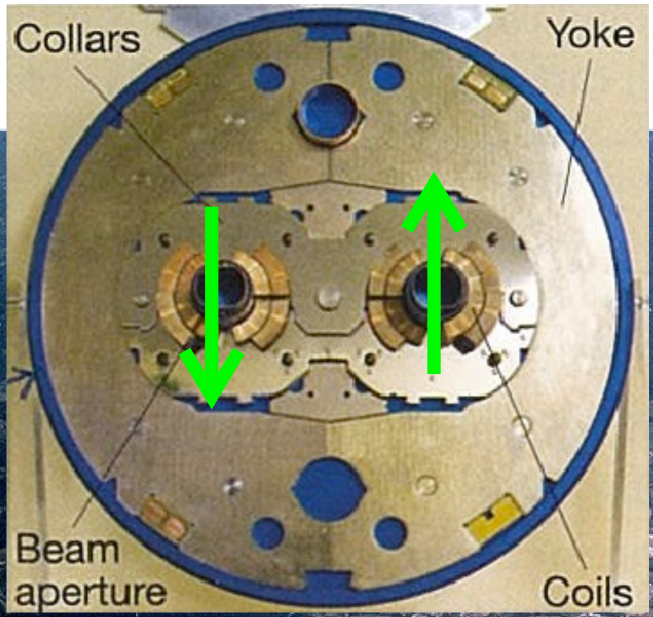
(@ 8TeV in 2012)

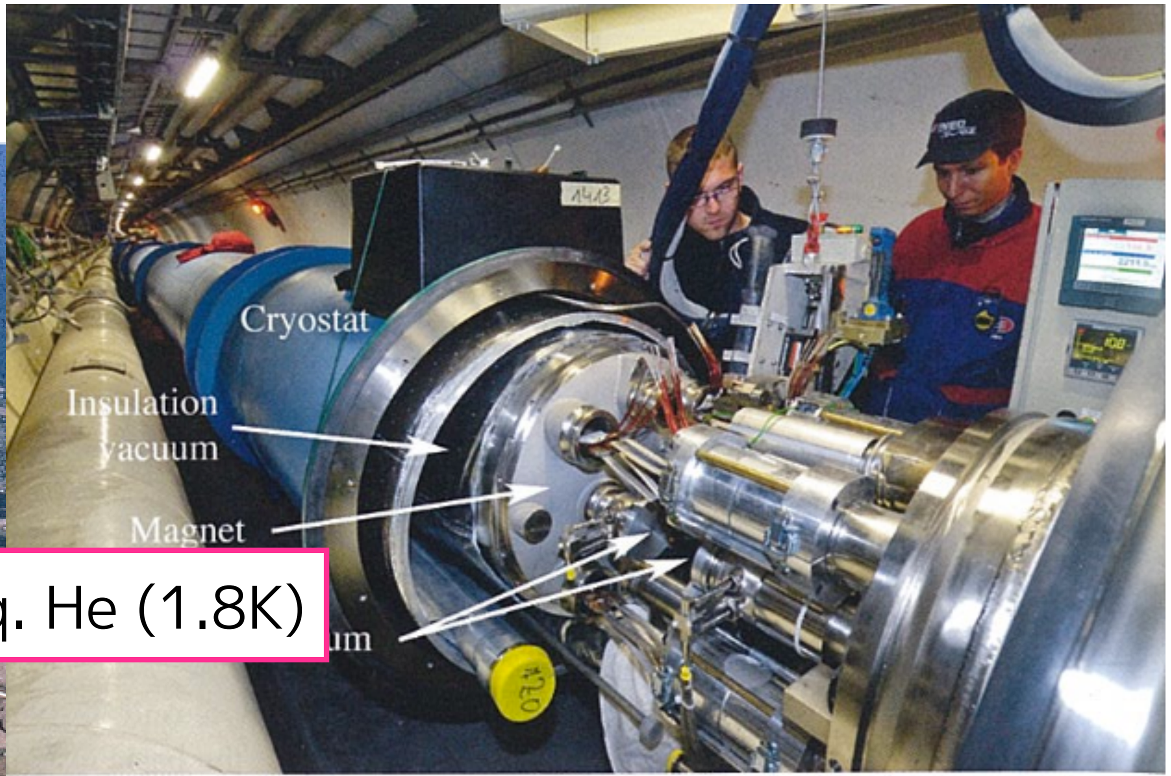
1992 LOI of 'large' LHC experiments
1994 TP of ATLAS and CMS approval of LHC (dece
1995 discovery of top by CDF and D0 (following evi
1996 approval of LHC in one step (december)
1998 approval of the 4 largest LHC experiments (A
1999 ATLAS Physics TDR CERN/LHCC/99-14 CERN
2006 CMS Physics TDR J. Phys. G: Nucl. Part. Phys.
2008 ATLAS Expected Performance arXiv:0901.051
2010 start-up at 3.5 + 3.5 TeV
2012 4th July discovery of boson

Courtesy

Daniel Froidevaux, CERN ATLAS SM Worshop, Bost

LHC & super-conducting magnets

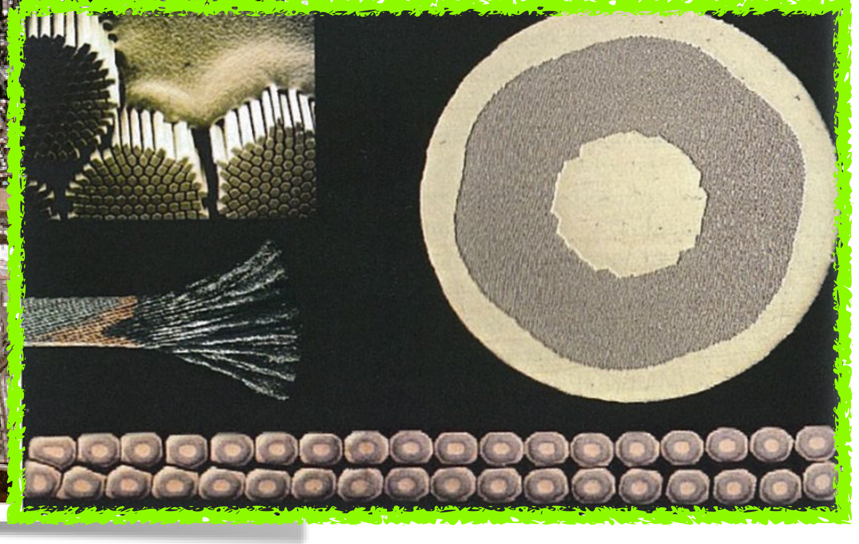




liq. He (1.8K)

B~8.3[T]

Nb-Ti conductor



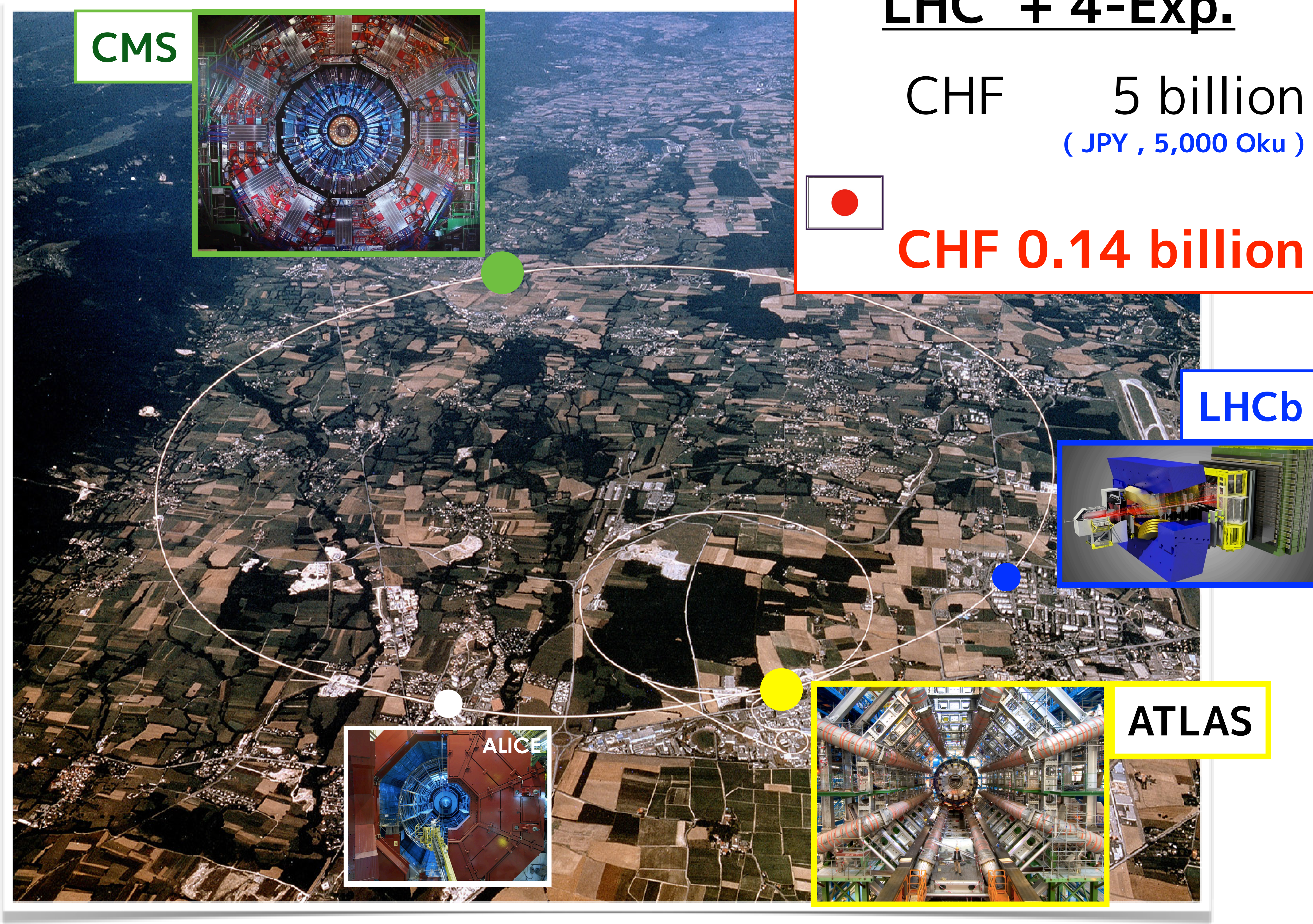
LHC & Experiments

LHC + 4-Exp.

CHF 5 billion

(JPY , 5,000 Oku)

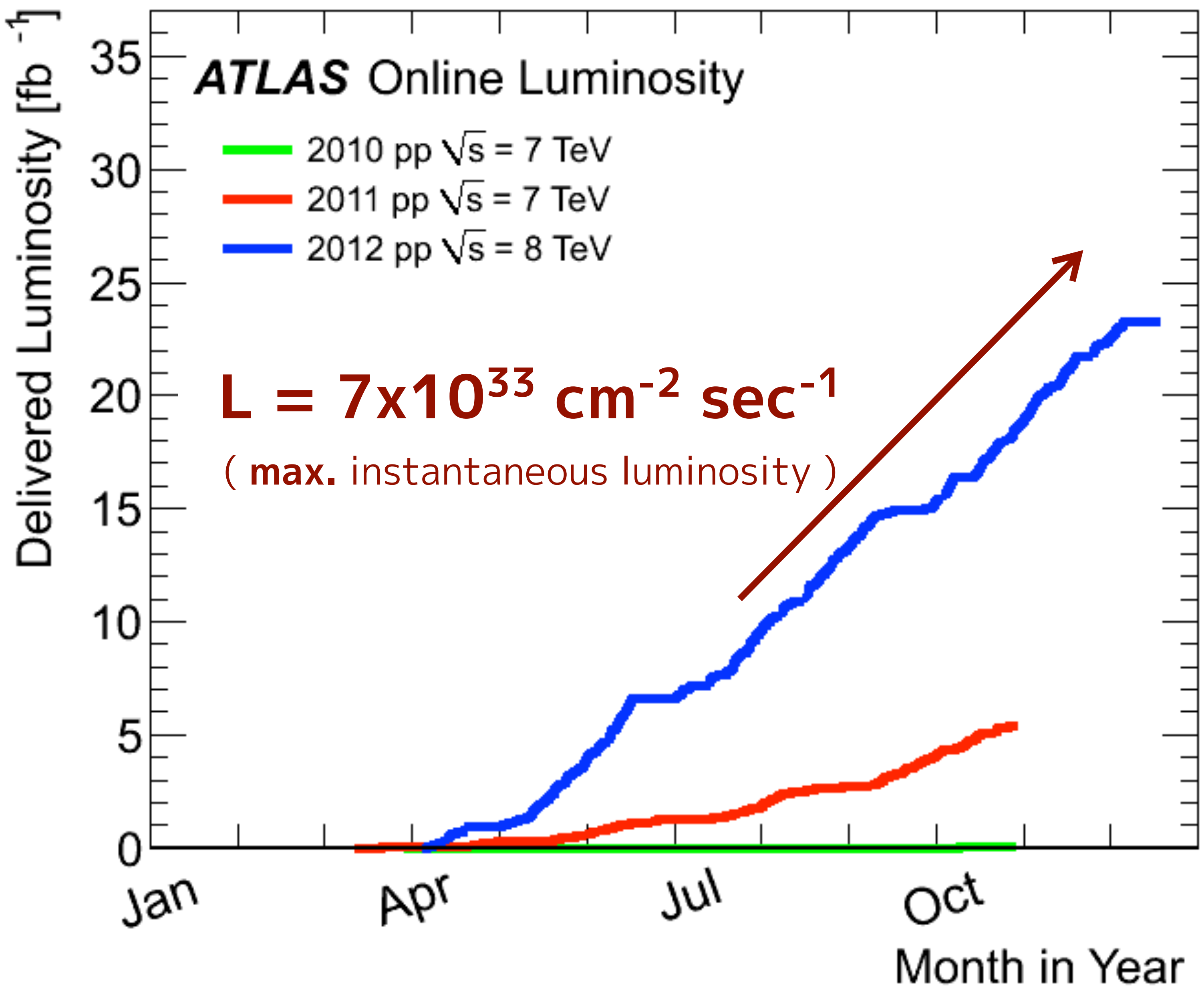
CHF 0.14 billion



LHC Operation Run-1 , **2010 - 2012**

Integrated Luminosity

2010 :	0.05 fb^{-1}
2011 :	5 fb^{-1} (**7TeV**)
2012 :	**23 fb^{-1}** (**8TeV**)



L = 7×10^{33} cm^{-2} sec^{-1}

(**max.** instantaneous luminosity)

# of events : $N = \sigma \cdot L$

e.g. Higgs

$\sigma_{pp \to H} = 22.3pb$ [8TeV , m_H=125GeV]

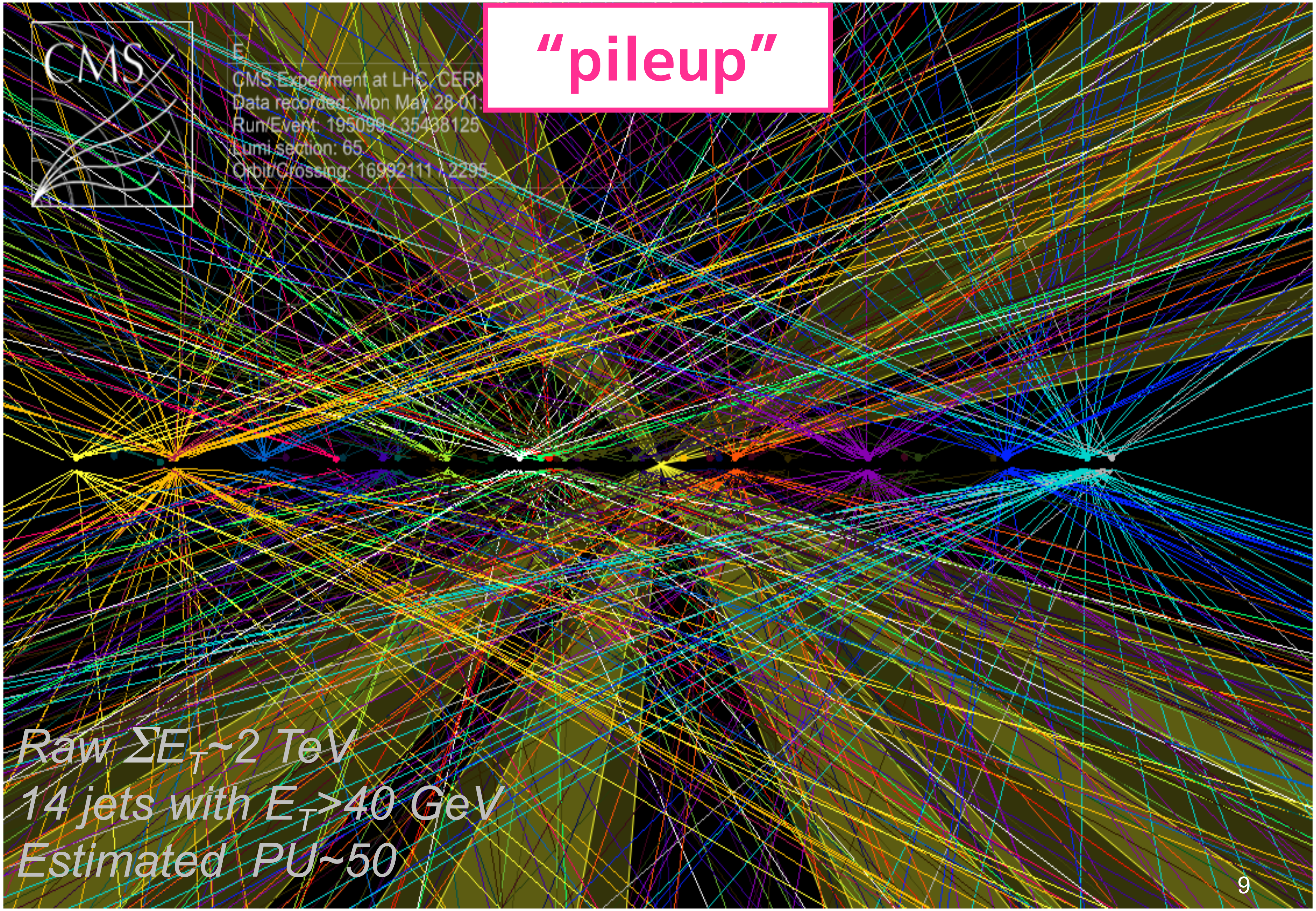
$(\sigma \cdot L) \times 1hour = 22.3 \times 10^{-36} \times 7 \times 10^{33} \times 3600 =$ **560 Higgs /hour**

(**$23fb^{-1}$** x 22.3pb ~ **500k Higgs in 2012**)

High-Energy & High-Luminosity

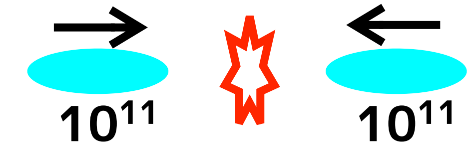
High-Luminosity comes at a price !!

50 interactions in one bunch-crossing



"pileup"

~10cm

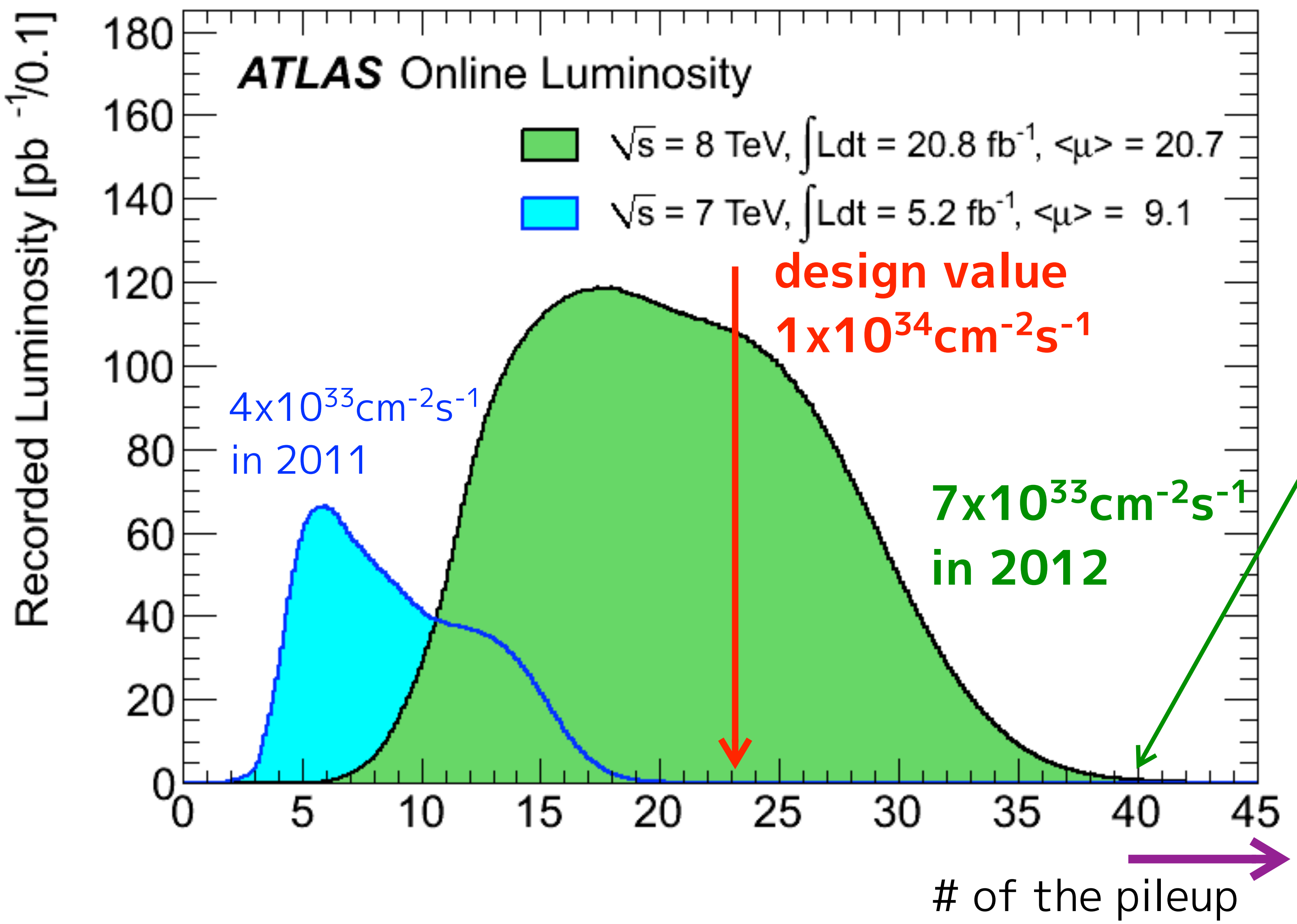


10^{11} protons 10^{11} protons

Φ~16μm
L~10cm

difficulties of Hadron-Collider

event **"pileup"**



side-effect to achieve **a similar Lumi.** with **half #** of the collision rate

(the collision rate of 20MHz instead of 40MHz)

challenges for the experiments

- Trigger
- Reconstruct (**e/γ** , **μ** , τ , jet , Missing-E_T , b-tag , …)
- …

EM (e,γ) Energy-Scale v.s. "pileup"

H Decay mode	ATLAS signal significance
H → **γγ**	**7.4σ**
H	**6.6σ**
H→ WW → **e** ν , μ ν	**3.8σ**
H → τ τ	**4.1σ**
VH → V , bb	limit < SM x 1.4

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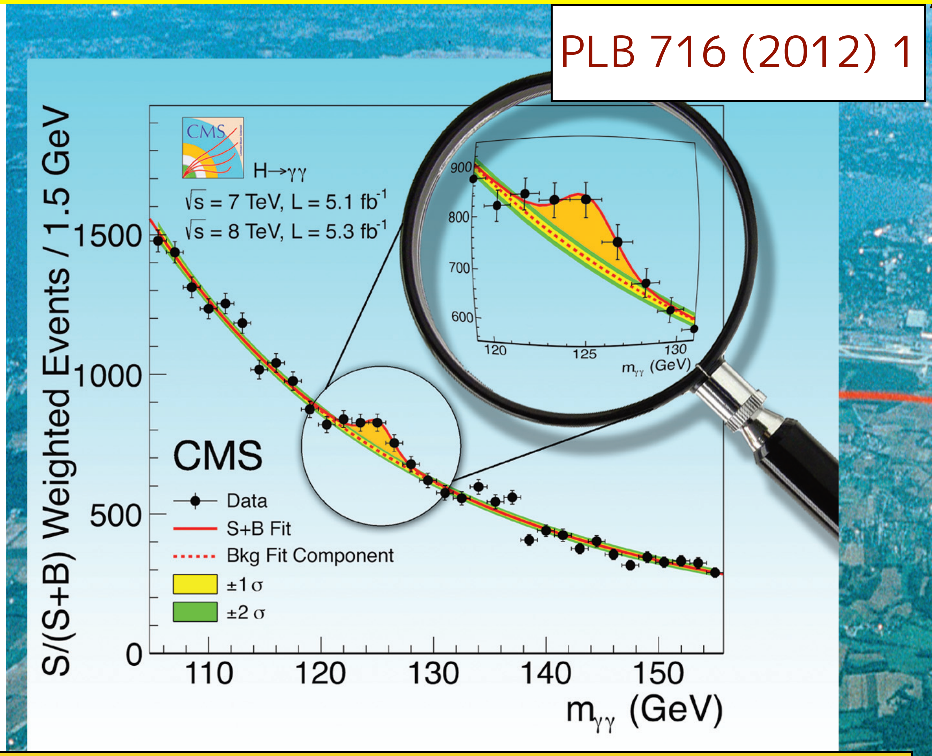
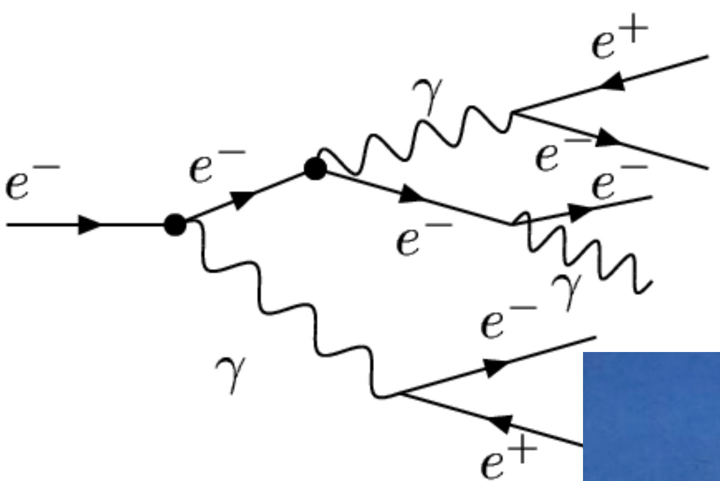


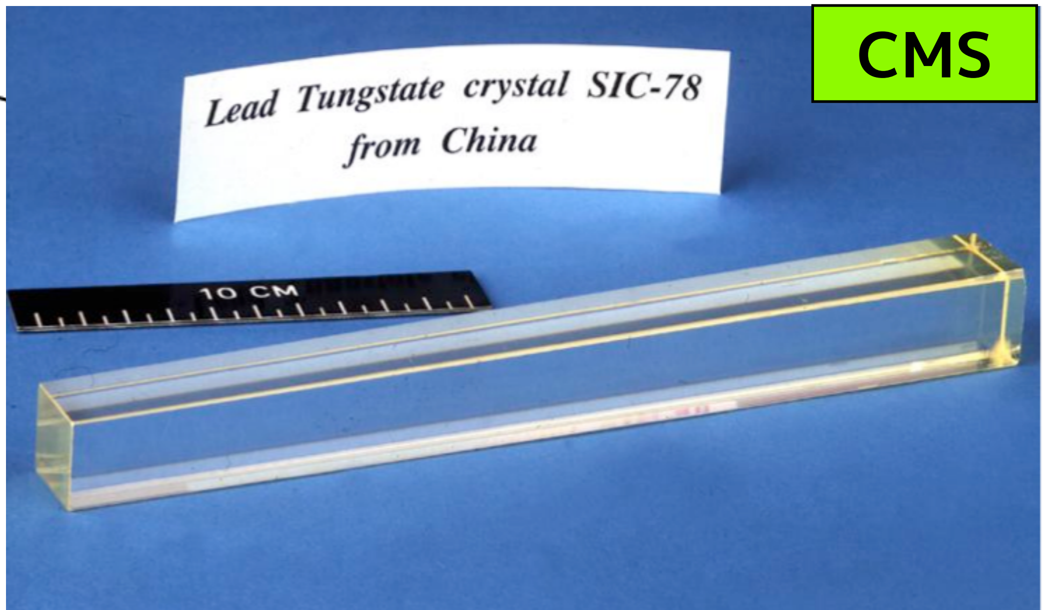
(Lorentz) Invariant Mass distribution



To measure **e/γ energy** is (one of) the key to the success for the Higgs measurements

as well as

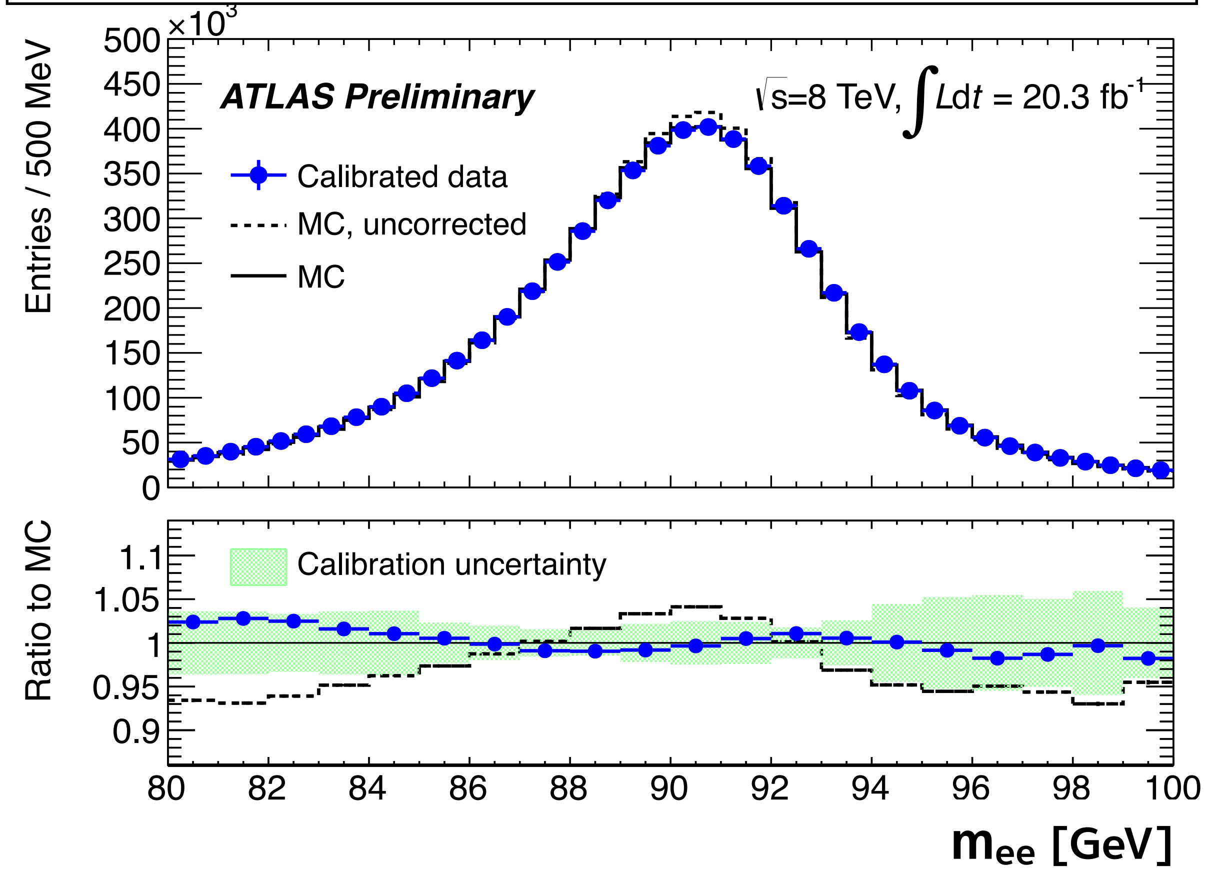
μ , τ , Jet , ..

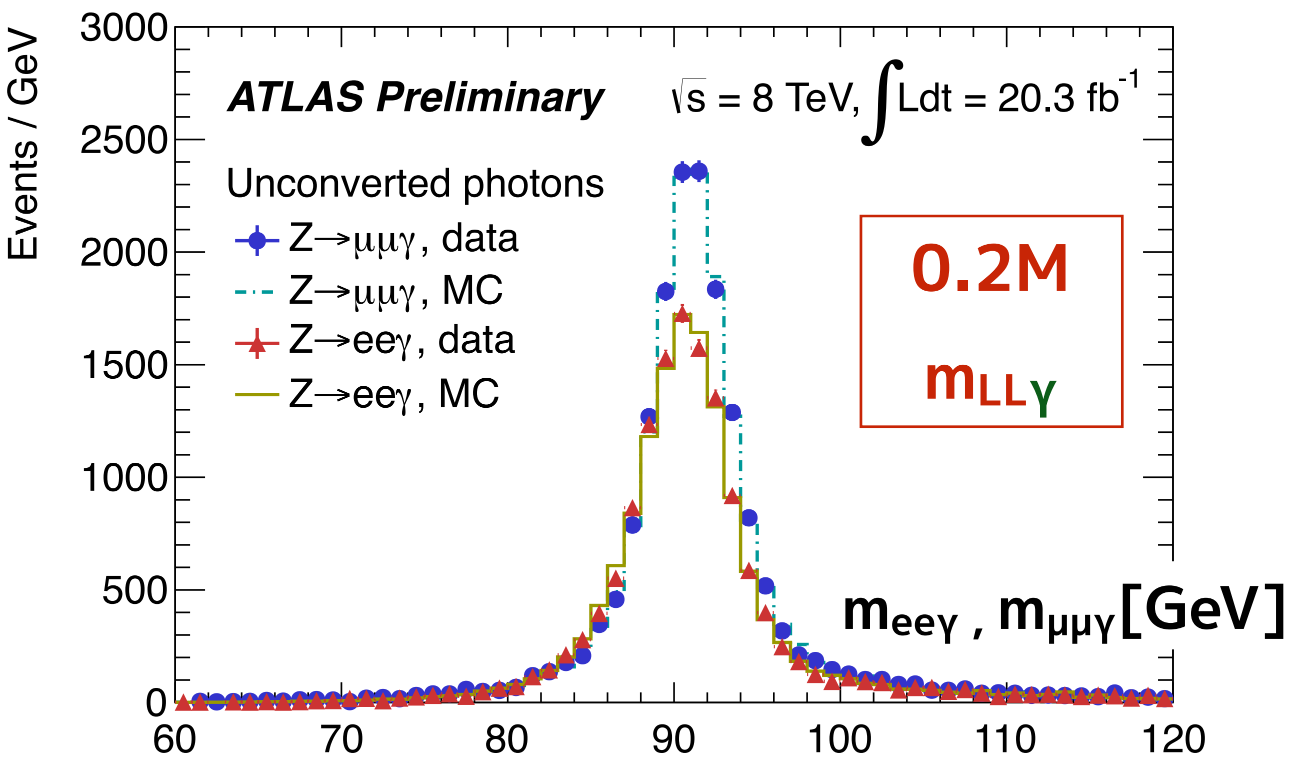


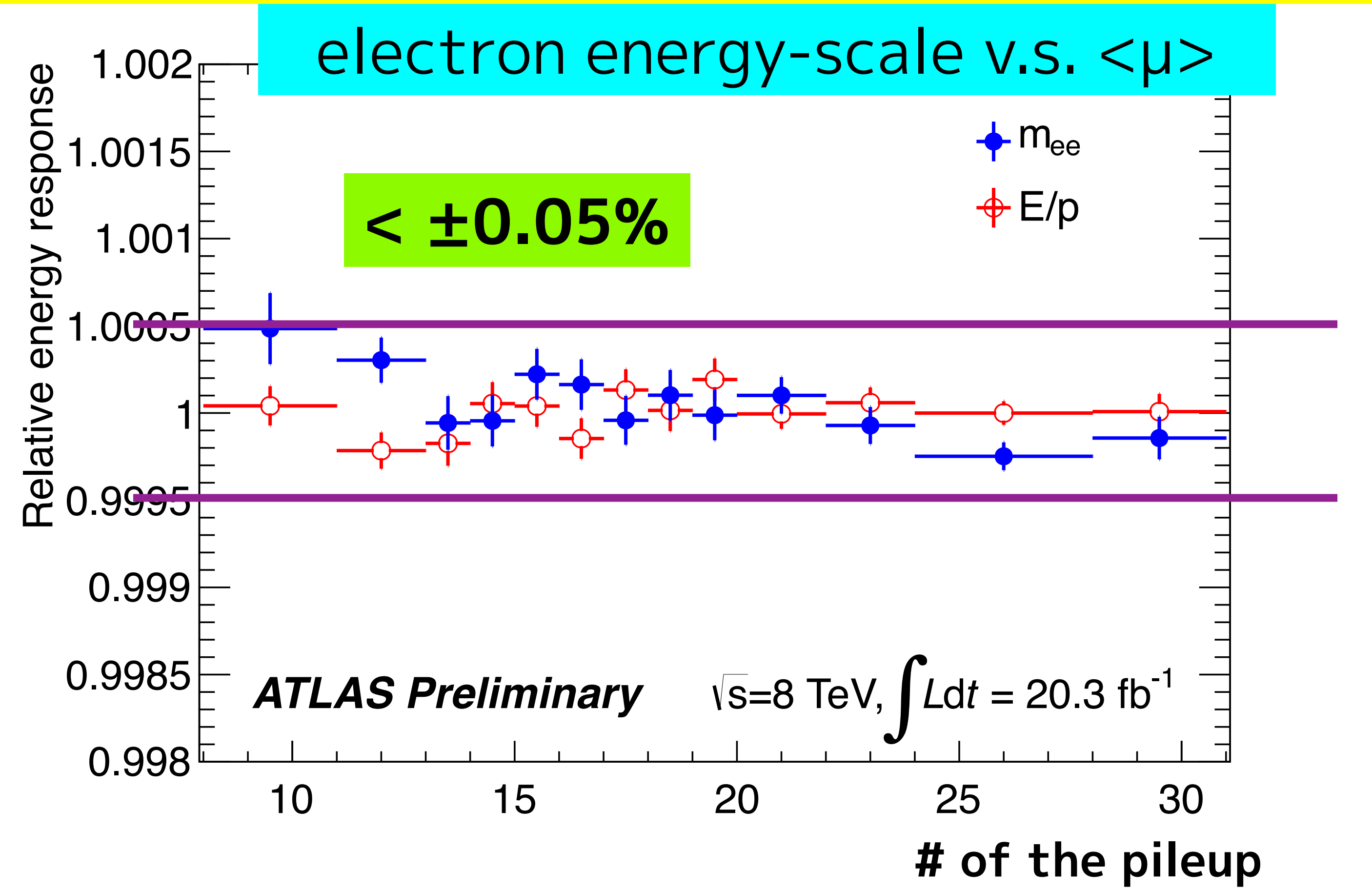
EM (e,γ) Energy-Scale v.s. "pileup"

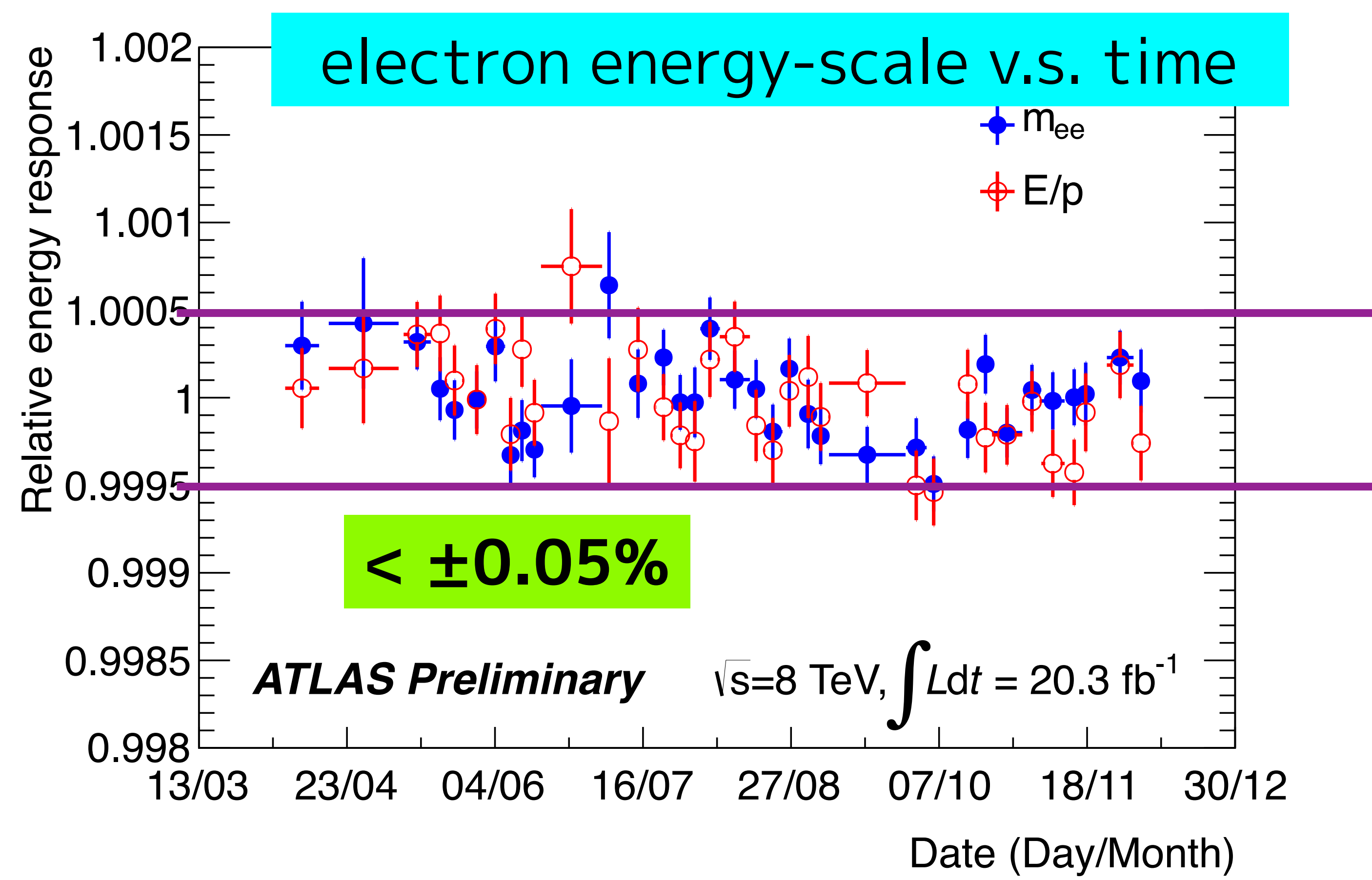
LHCP14 NEW !

"known mass" , Z→e⁺e⁻ (6.6M events)





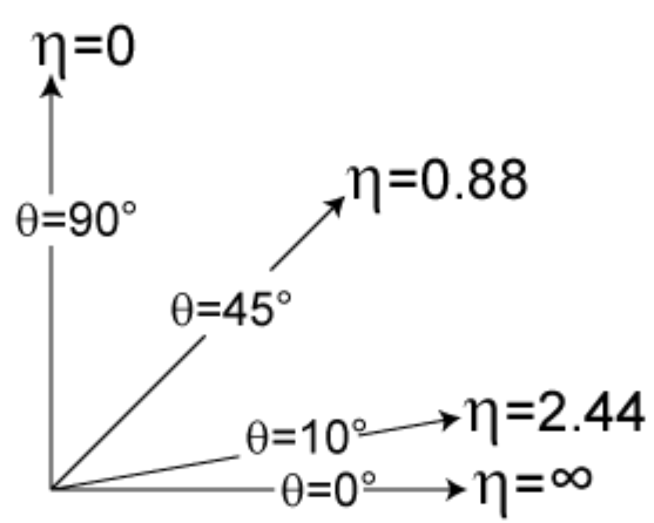


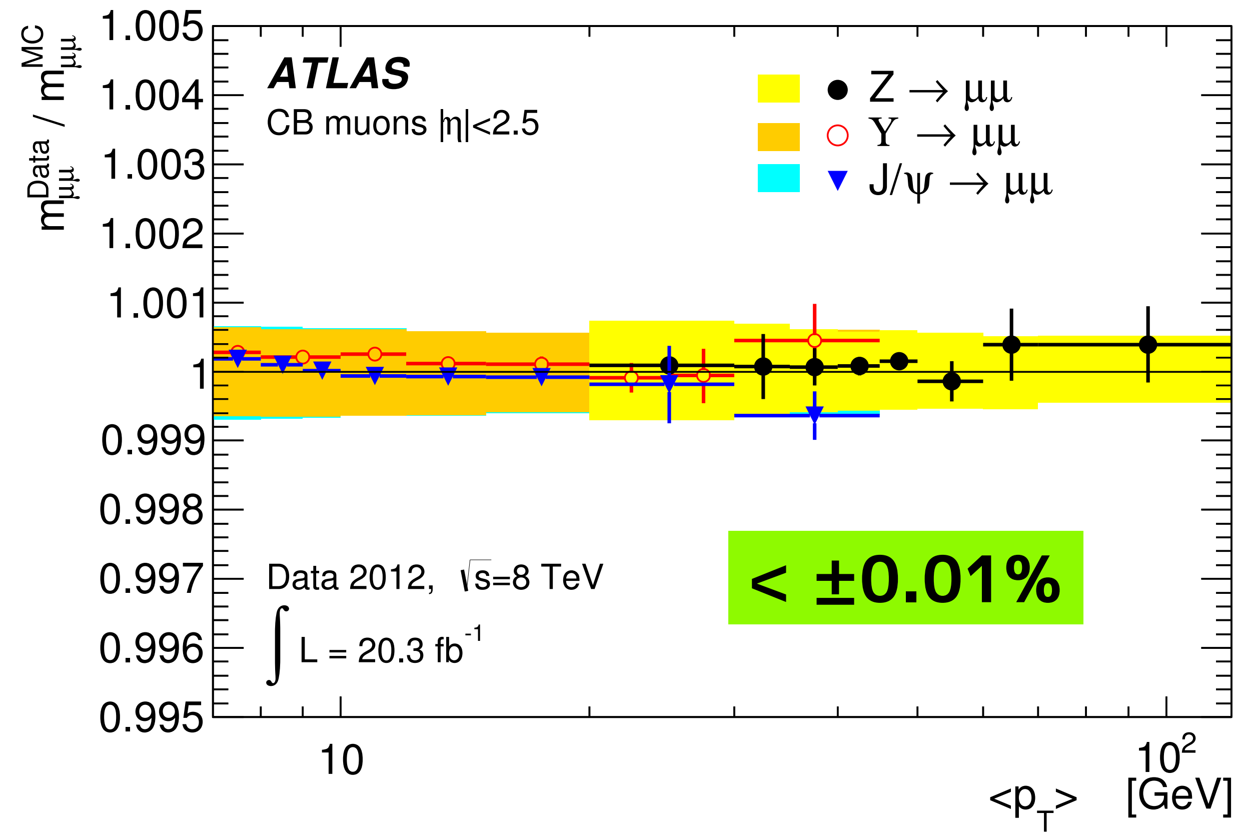


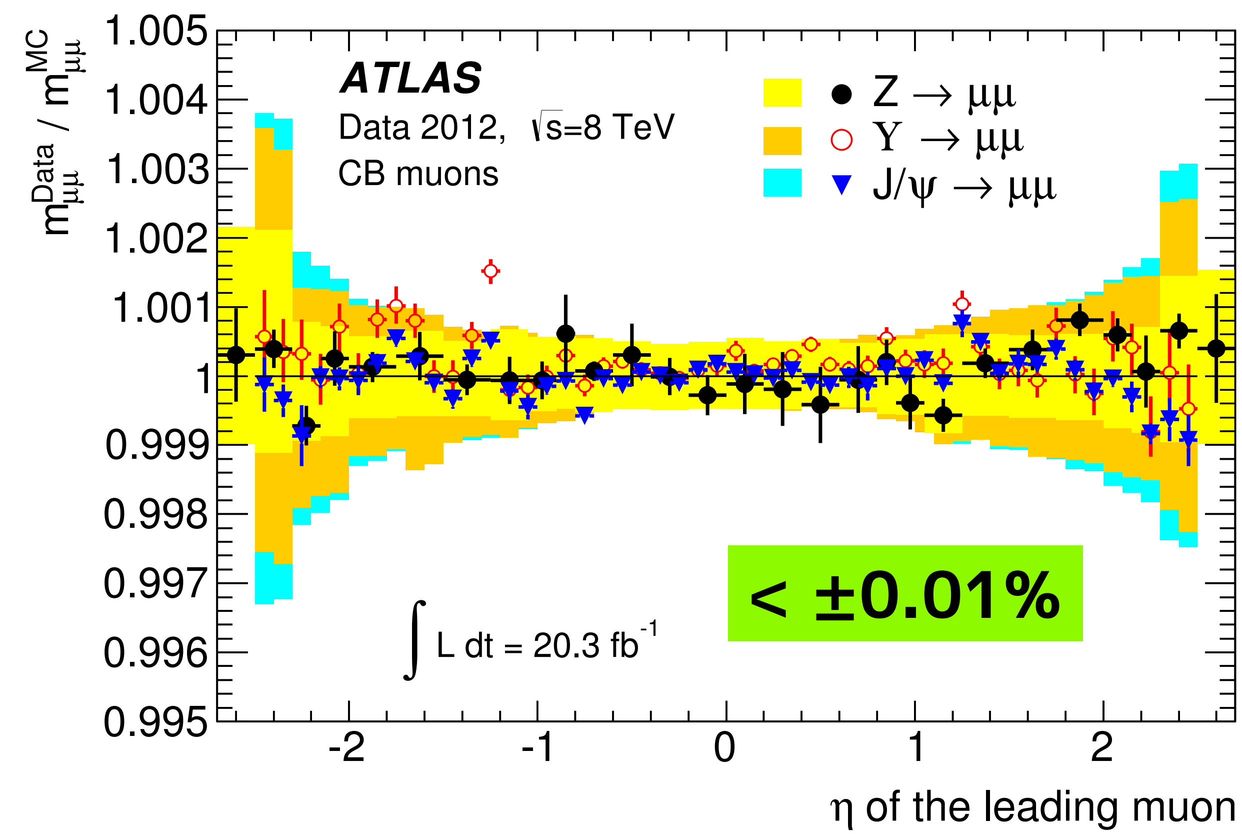
Muon (μ) Momentum-Scale

LHCP14 NEW !

H Decay mode	ATLAS signal significance
H → γγ	**7.4σ**
H	**6.6σ**
H → WW → e ν , **μ** ν	**3.8σ**
H → τ τ	**4.1σ**
VH → V , bb	limit < SM x 1.4





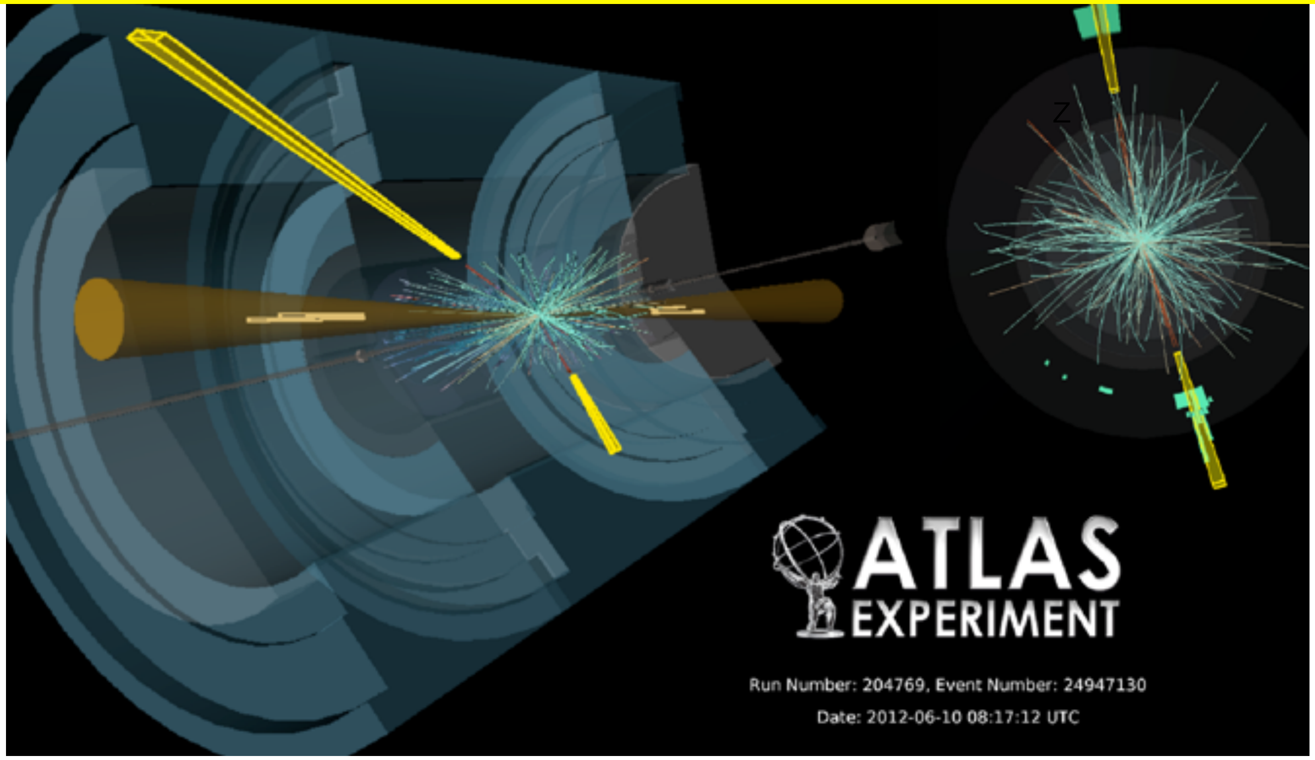


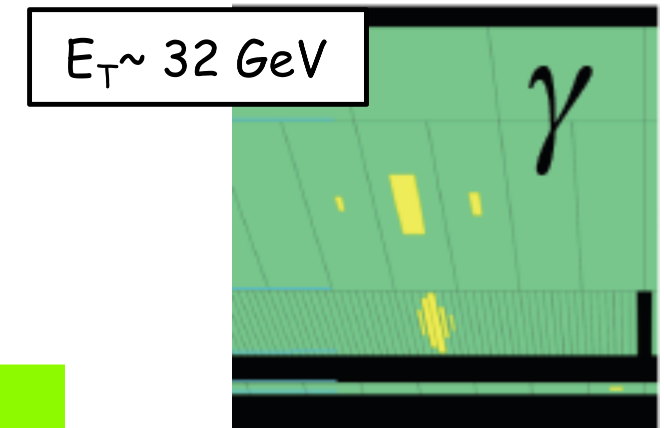
Higgs Property 1 : Mass

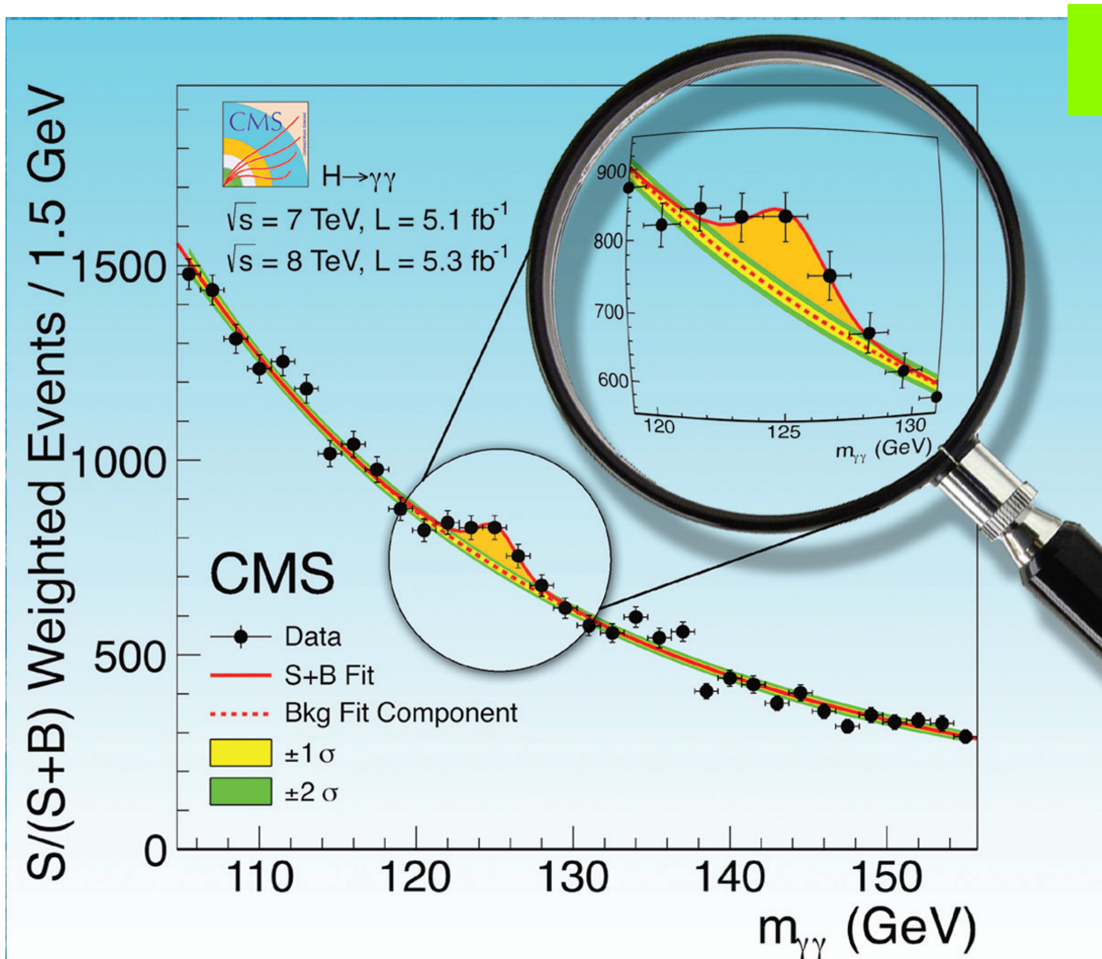
$H \rightarrow \gamma\gamma$

arXiv: 1406.3827

H Decay mode
$H \rightarrow \gamma\gamma$
H
~~$H \rightarrow WW \rightarrow e\,\nu$, $\mu\,\nu$~~
~~$H \rightarrow \tau\tau \rightarrow$ including ν~~
~~$VH \rightarrow V$, bb~~

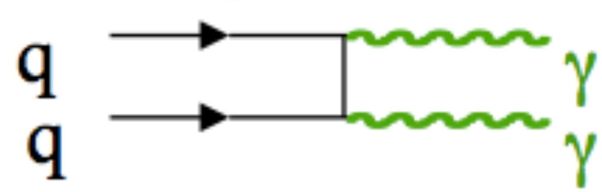




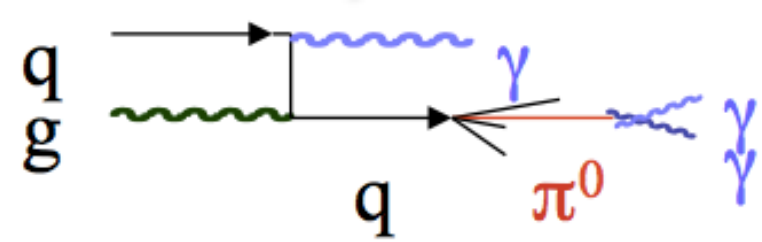


Bad S/N ratio ~ 3.4%

(a) γ-energy resolution : ($\Delta m_{\gamma\gamma}$ ~ 1.65 GeV)
(b) π^0/γ-separation to reduce **BG (π^0 jet)**



irreducible

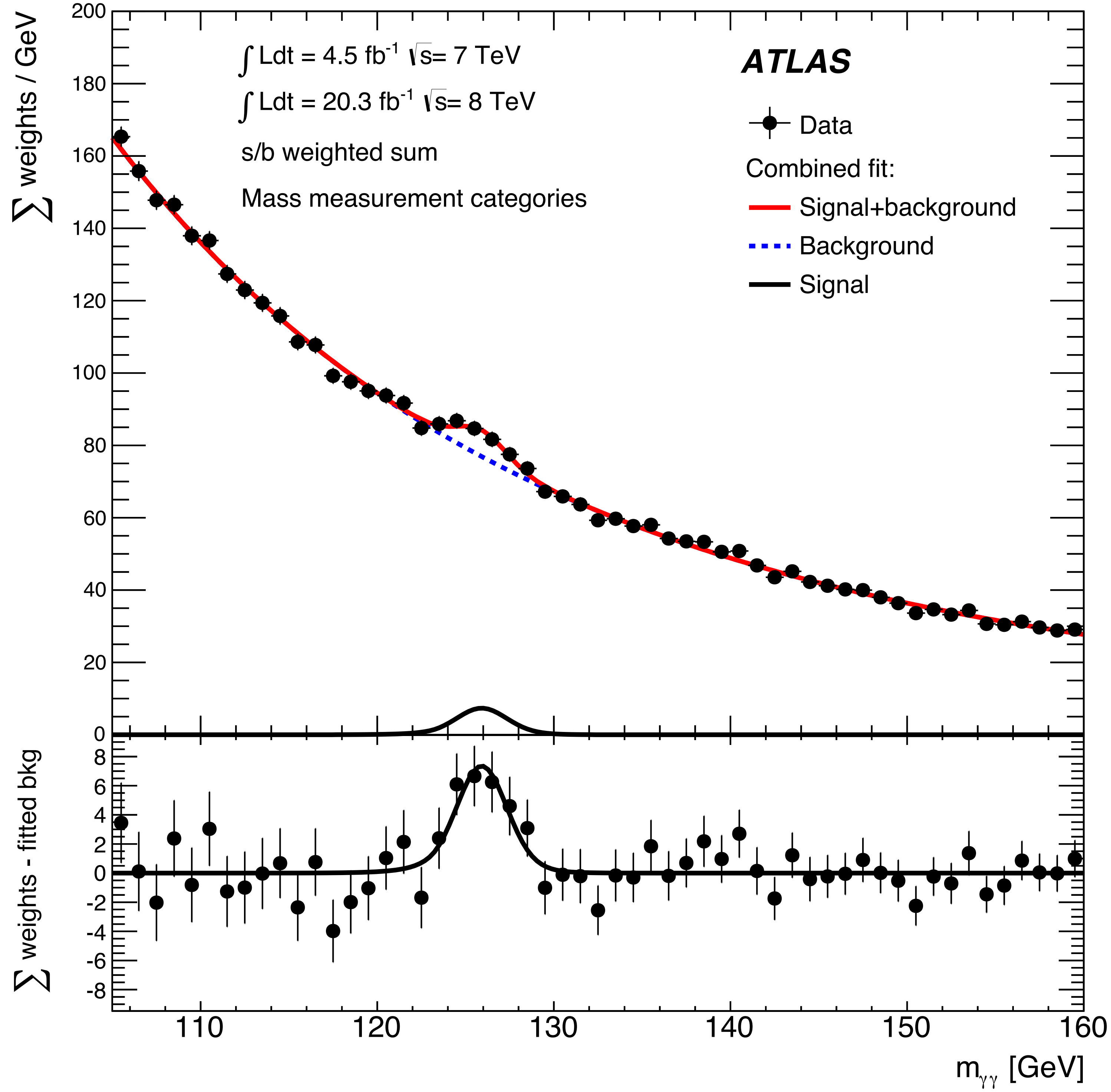


reducible

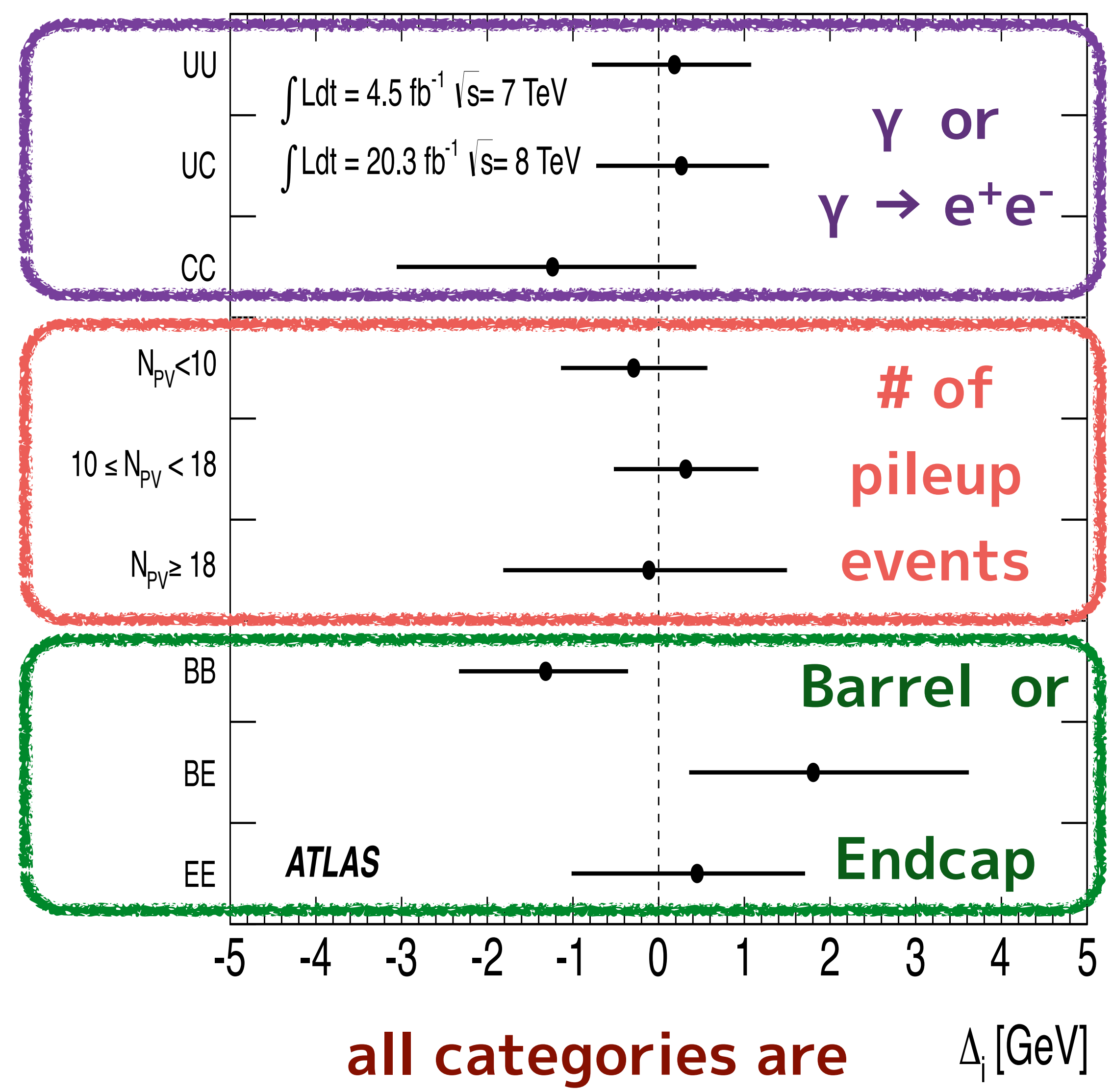
Higgs Property 1 : Mass

$H \to \gamma\gamma$

arXiv: 1406.3827



consistency check



all categories are consistent within **1.5σ**

$m_H = 125.98 \pm 0.42(\text{stat.}) \pm 0.28\ (\text{sys.})$ GeV

(previous $m_H = 126.8 \pm 0.2\ (\text{stat.}) \pm 0.7\ (\text{sys.})$ GeV)

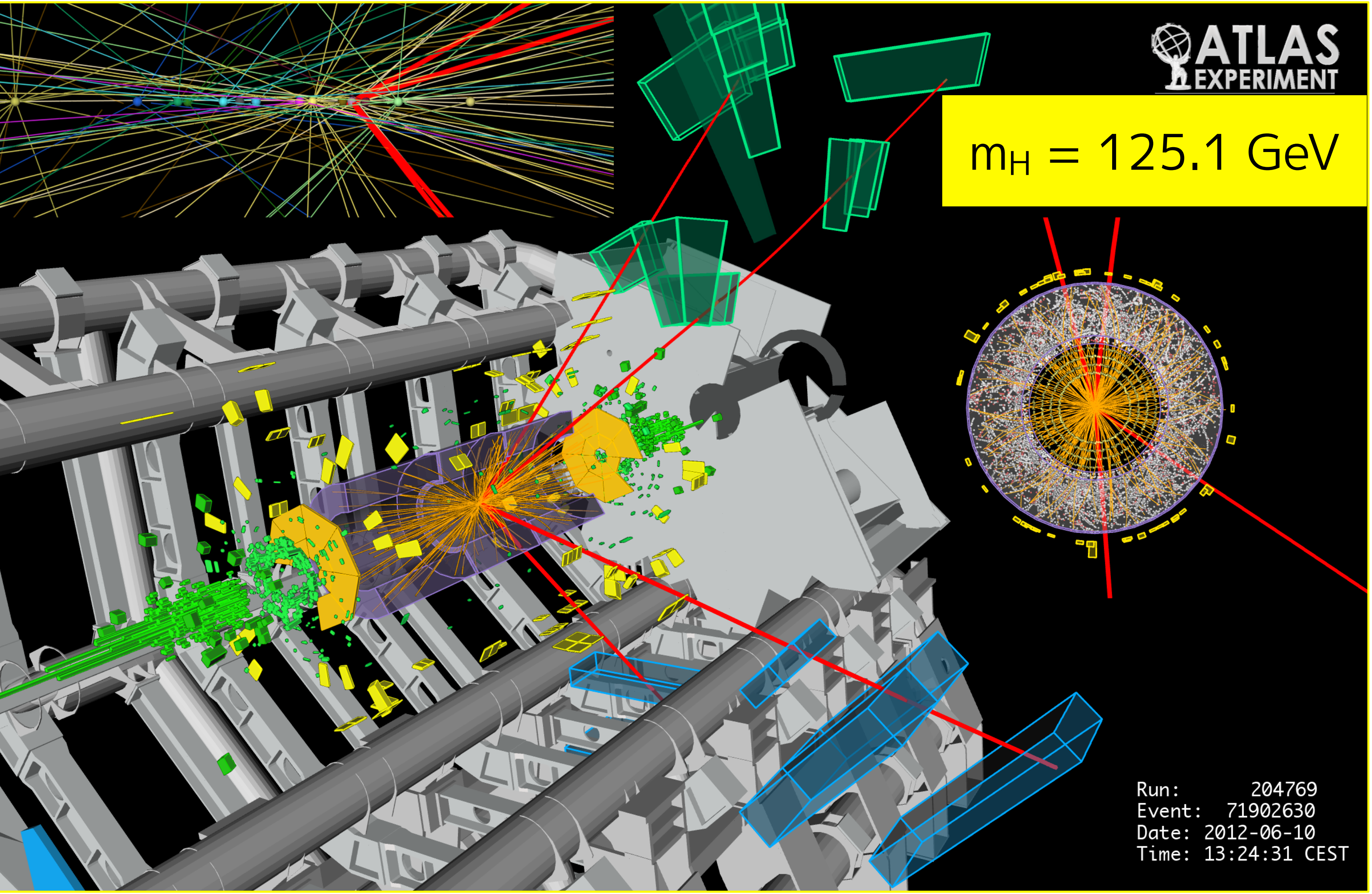
improvement:

γ-energy scale

Higgs Property 1 : Mass

$H \to ZZ^* \to 4L$

arXiv: 1406.3827



p_T (4μ)= 36.1, 47.5, 26.4, 71 .7GeV
m_{12}= 86.3 GeV, m_{34}= 31.6 GeV

4L : $p_T^{1,2,3,4}$ > 20, 15, 10, 6 GeV
✓m_{12} = 50 ~ 106GeV
✓m_{34} = 17.5 ~ 50 GeV

(ref. : mZ = 90GeV)

keep acceptance to low-momentum e/μ

σ x Br = 2.9 fb : Small !! [ref. : σ x Br ($H \to 2\gamma$) = 50 fb] (@ mH = 125 GeV)

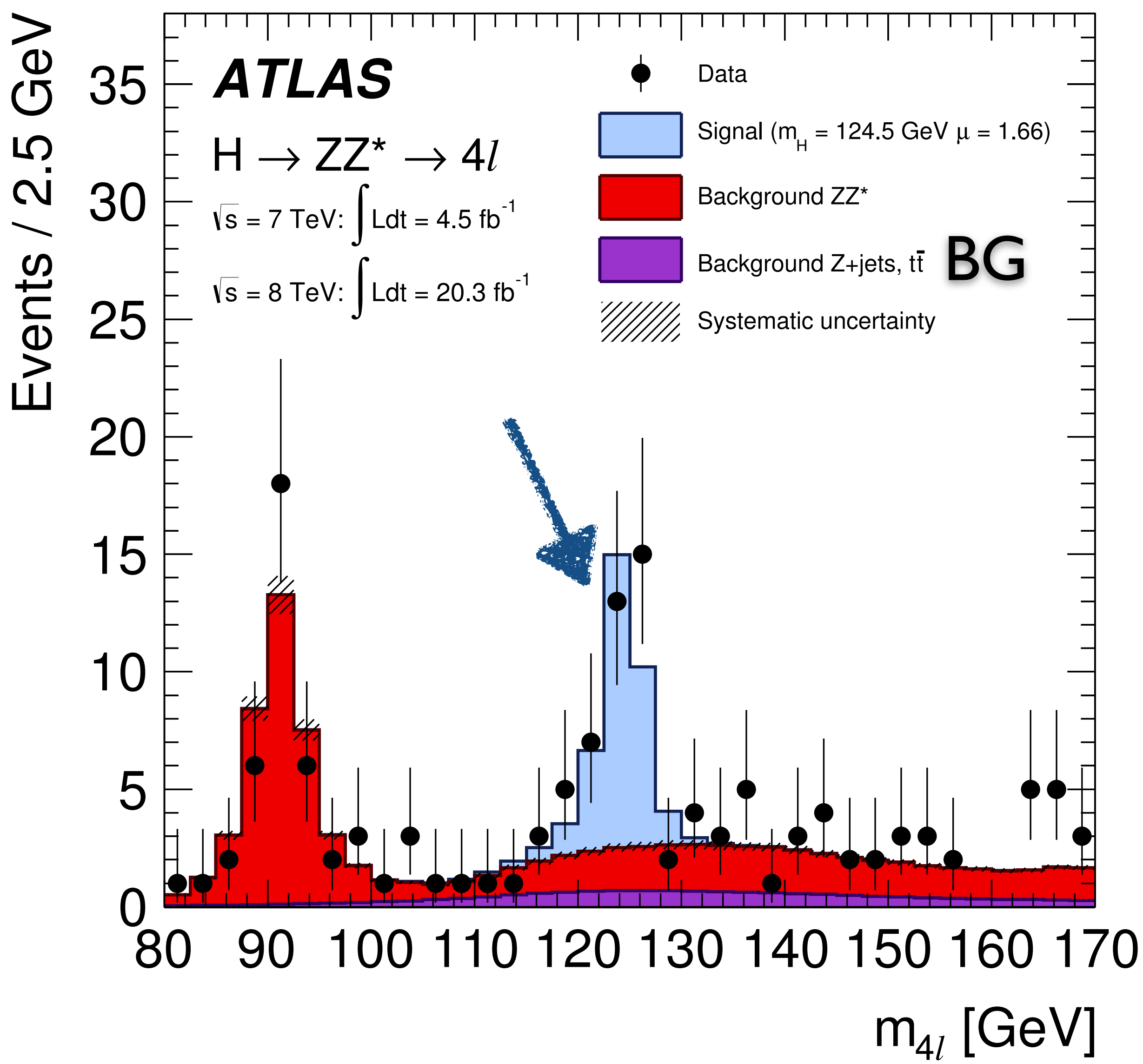
Hoever …

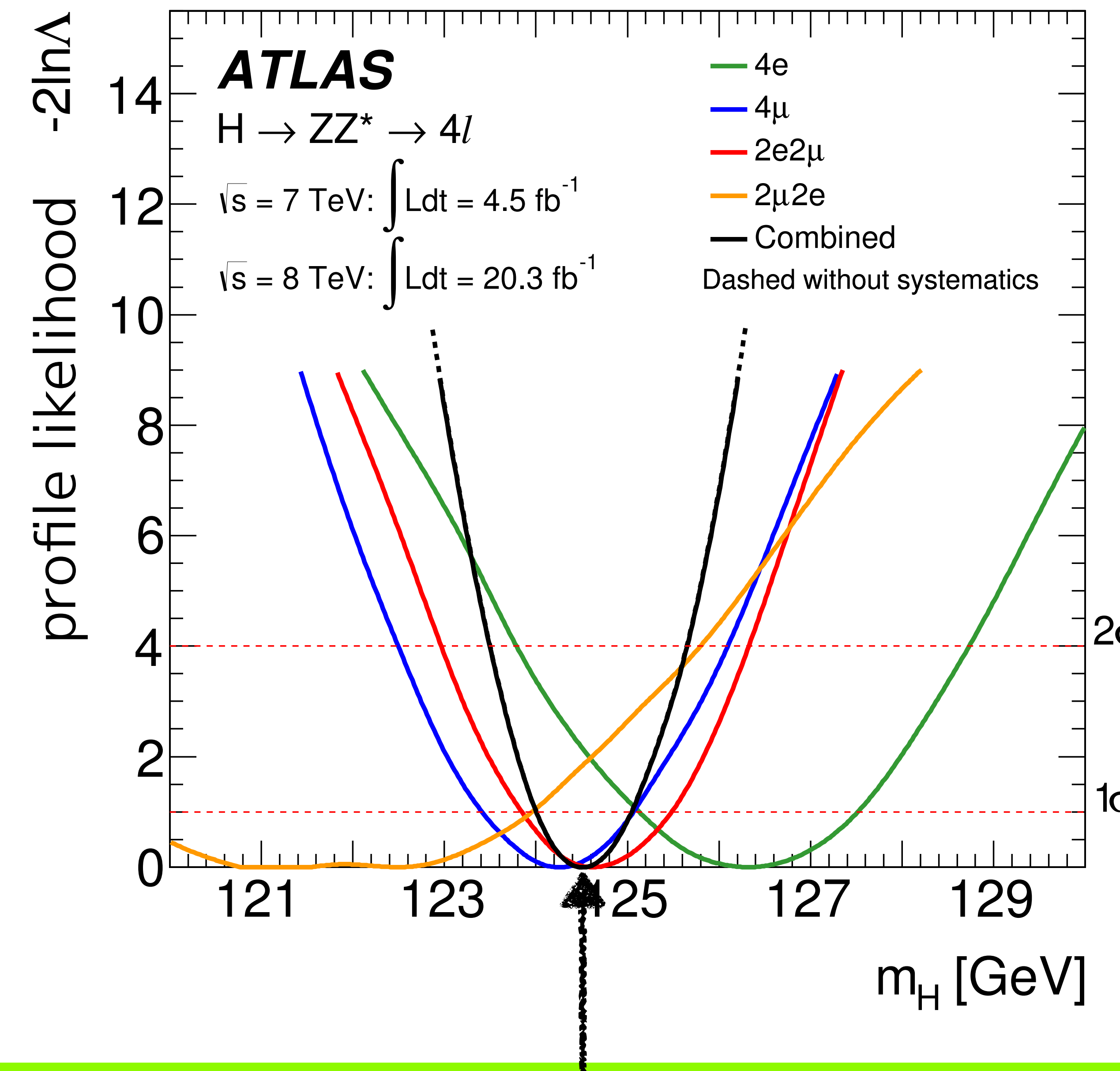
* invariant mass can be determined
* e / μ : clean signature : very good S/N ~ 1

Higgs Property 1 : Mass

$H \to ZZ^* \to 4L$

arXiv: 1406.3827





s+b

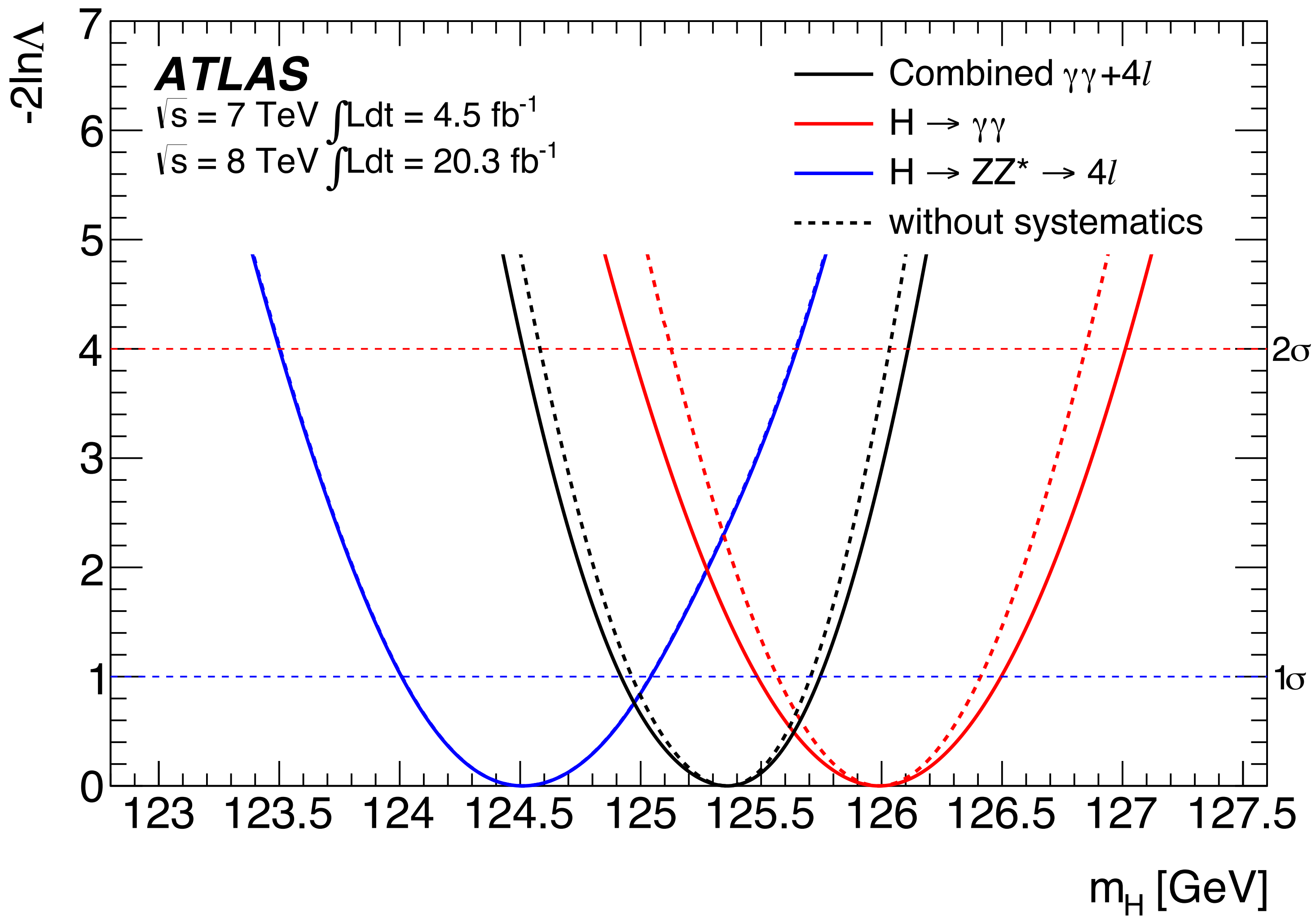
	s/b	expected	observed
4μ	1.7	9.80 ± 0.64	14
$2e2\mu$	1.5	6.72 ± 0.43	9
$2\mu 2e$	1.5	5.24 ± 0.35	6
$4e$	1.4	4.75 ± 0.32	8
total	1.6	26.5 ± 1.7	37

$m_H = 124.51 \pm 0.52(\text{stat.}) \pm 0.06\ (\text{sys.})$ GeV

compatibility among the m_H measurements from the four final states : 20%

Higgs Property 1 : Mass

arXiv: 1406.3827



the previous published result was

125.5 ± 0.2 (stat) $^{+0.5}_{-0.6}$ (sys.) GeV

Total uncertainty reduced by **~40%**

thanks to the better understanding

e/μ/γ performance

Table 5: Summary of Higgs boson mass measurements.

Channel	Mass measurement [GeV]
$H \to \gamma\gamma$	$125.98 \pm 0.42\,(\text{stat}) \pm 0.28\,(\text{syst}) = 125.98 \pm 0.50$
$H \to ZZ^* \to 4\ell$	$124.51 \pm 0.52\,(\text{stat}) \pm 0.06\,(\text{syst}) = 124.51 \pm 0.52$
Combined	$125.36 \pm 0.37\,(\text{stat}) \pm 0.18\,(\text{syst}) = 125.36 \pm 0.41$

Higgs Property 2 : Couplings

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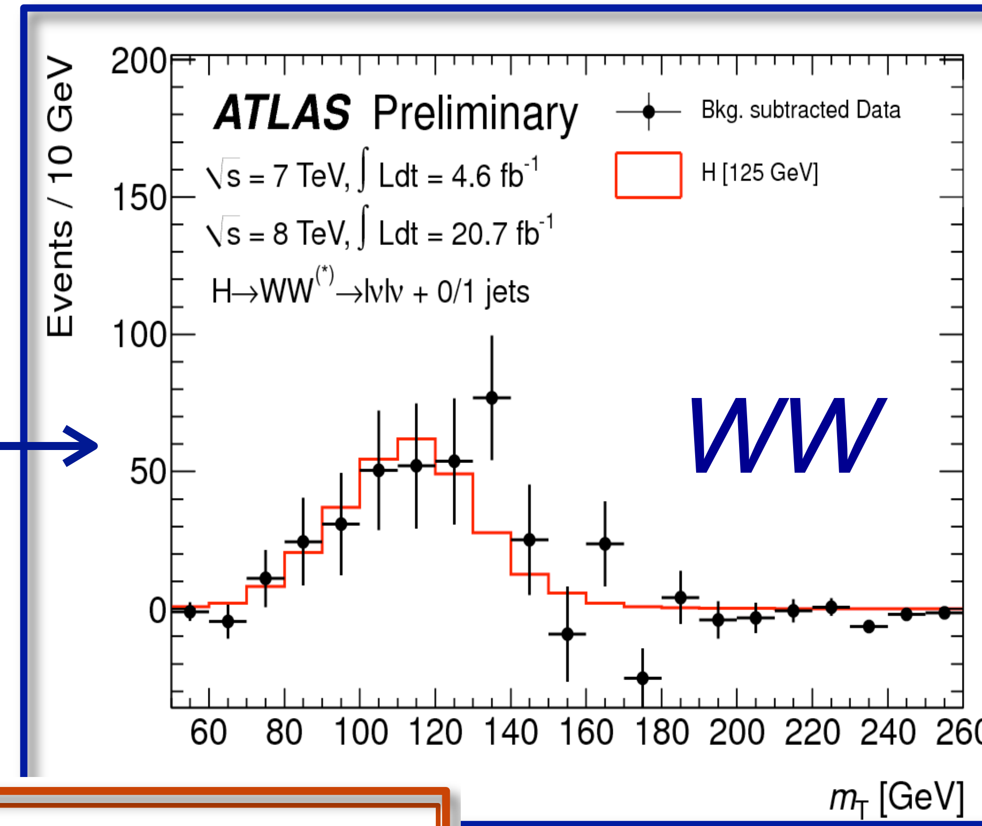
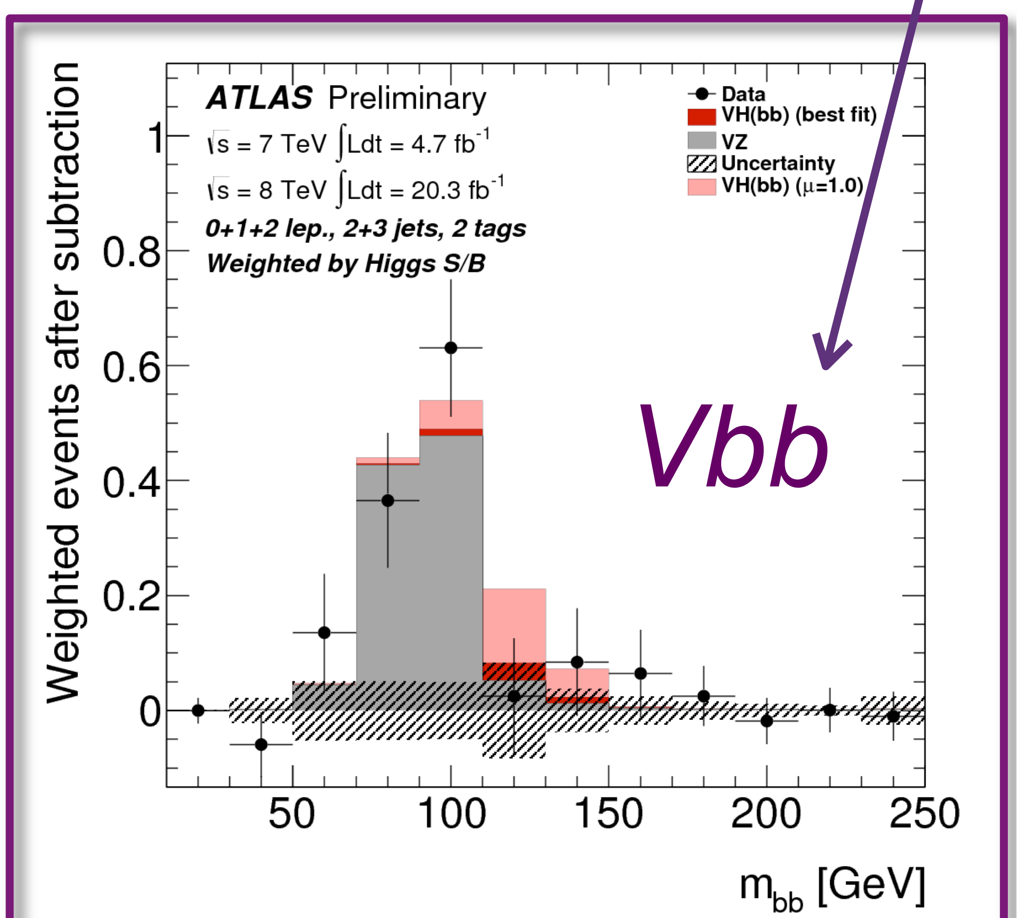
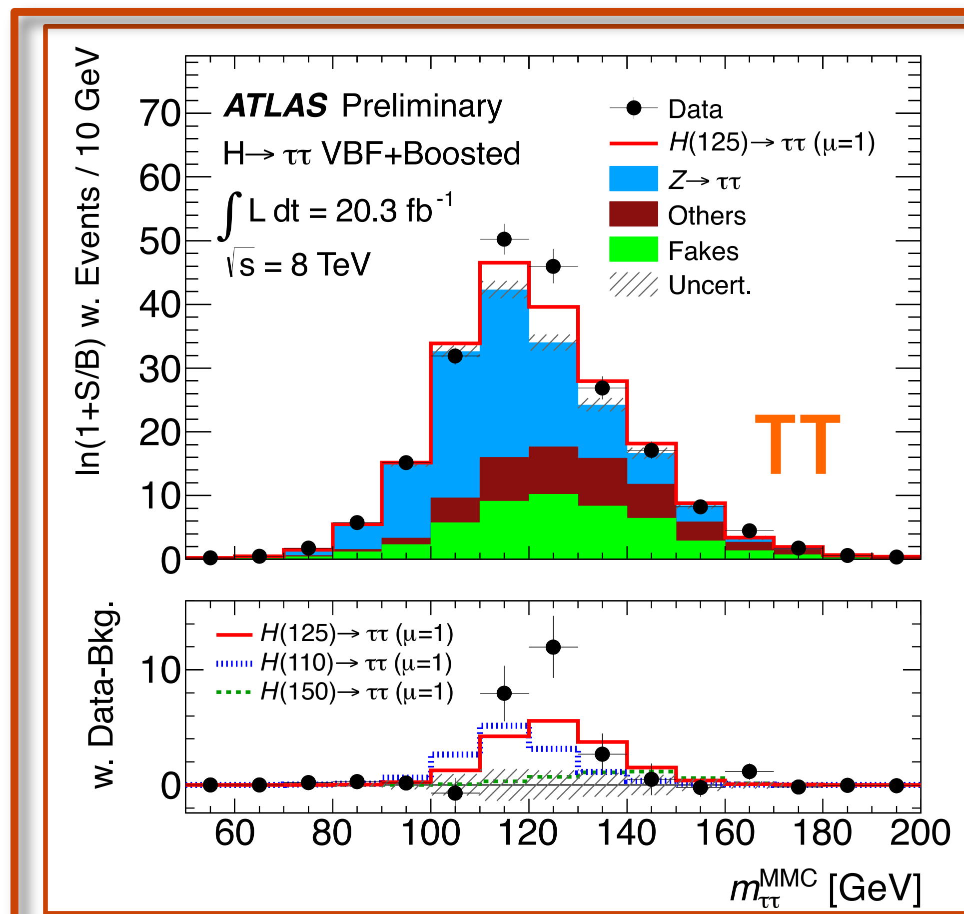
H Decay mode	ATLAS signal significance
H → γγ	**7.4σ**
H	**6.6σ**
H → WW → Lν , Lν	**3.8σ**
H → τ τ	**4.1σ**
VH → V , bb	limit < SM x 1.4



ATLAS-CONF-2013-079





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Higgs Property 2 : Couplings

signal strength : μ

$$\mu = \frac{\sigma \cdot BR}{(\sigma \cdot BR)_{SM}}$$

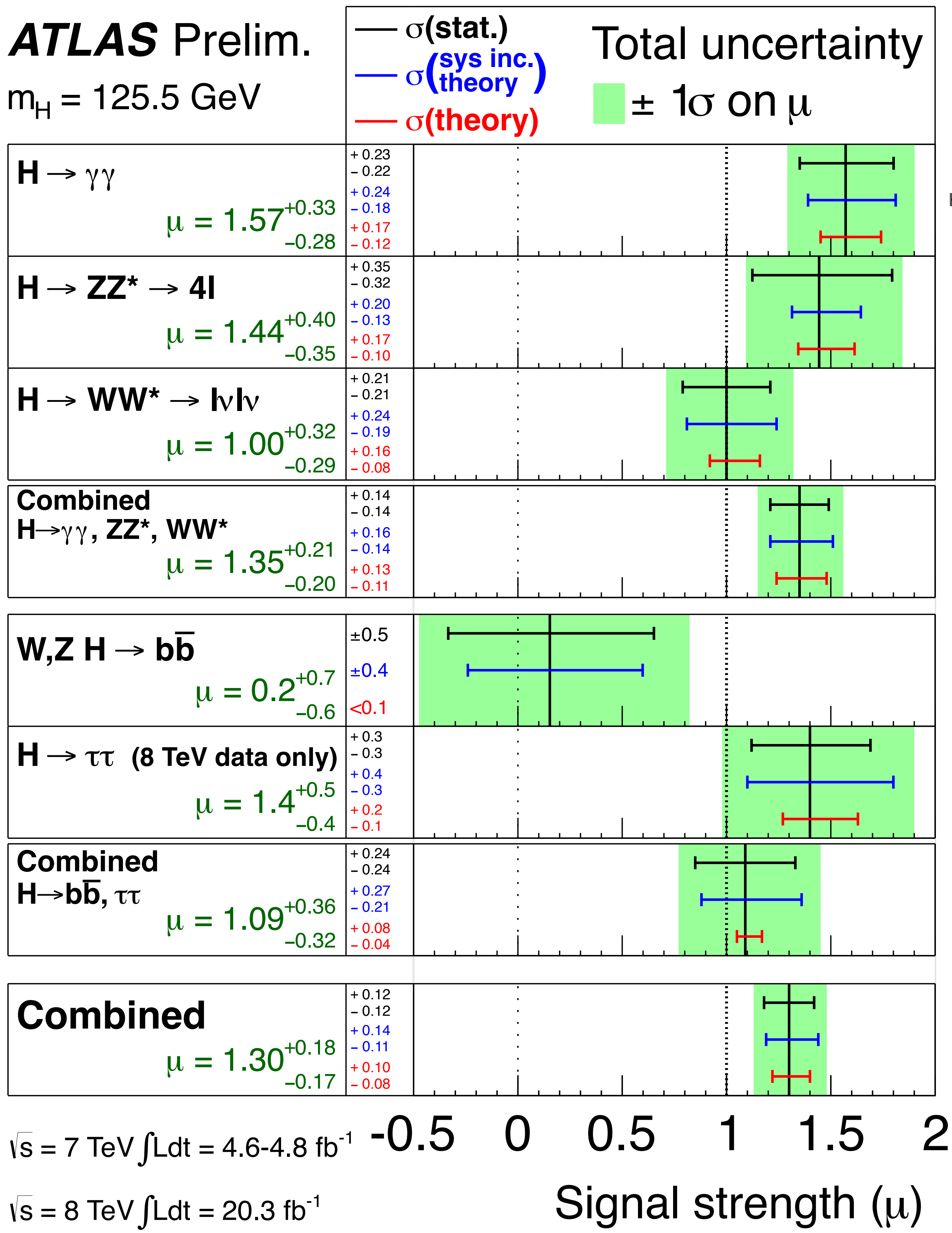
for all productions & decay modes

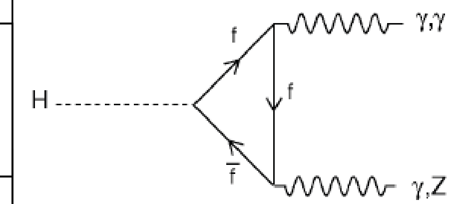
μ=1 ⇔ consistent with SM

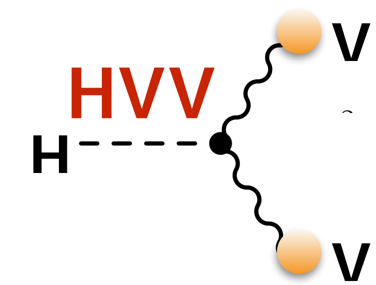
the compatibility between the results and SM (μ=1) : ~7%

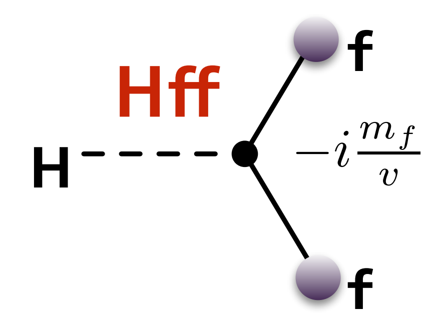
$\mu = 1.30 \pm 0.12\ ^{+0.14}_{-0.11}$

theoretical uncertainty (QCD Λ , PDF) ~ exp. uncertainty









3.7σ

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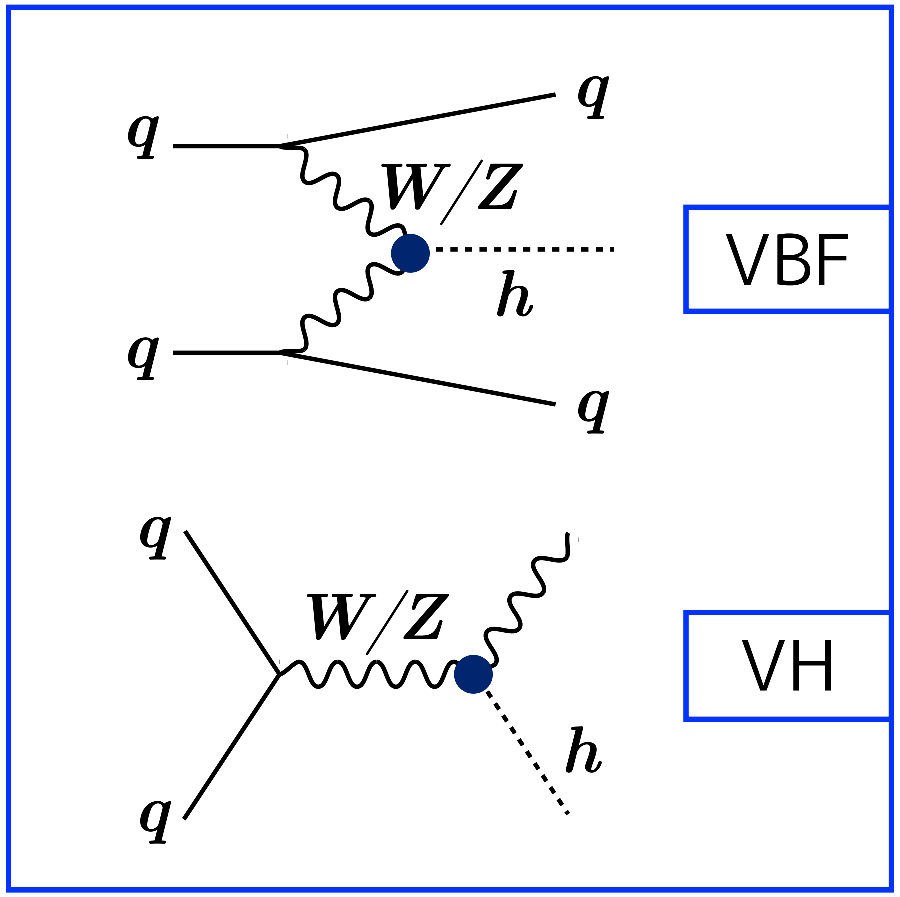
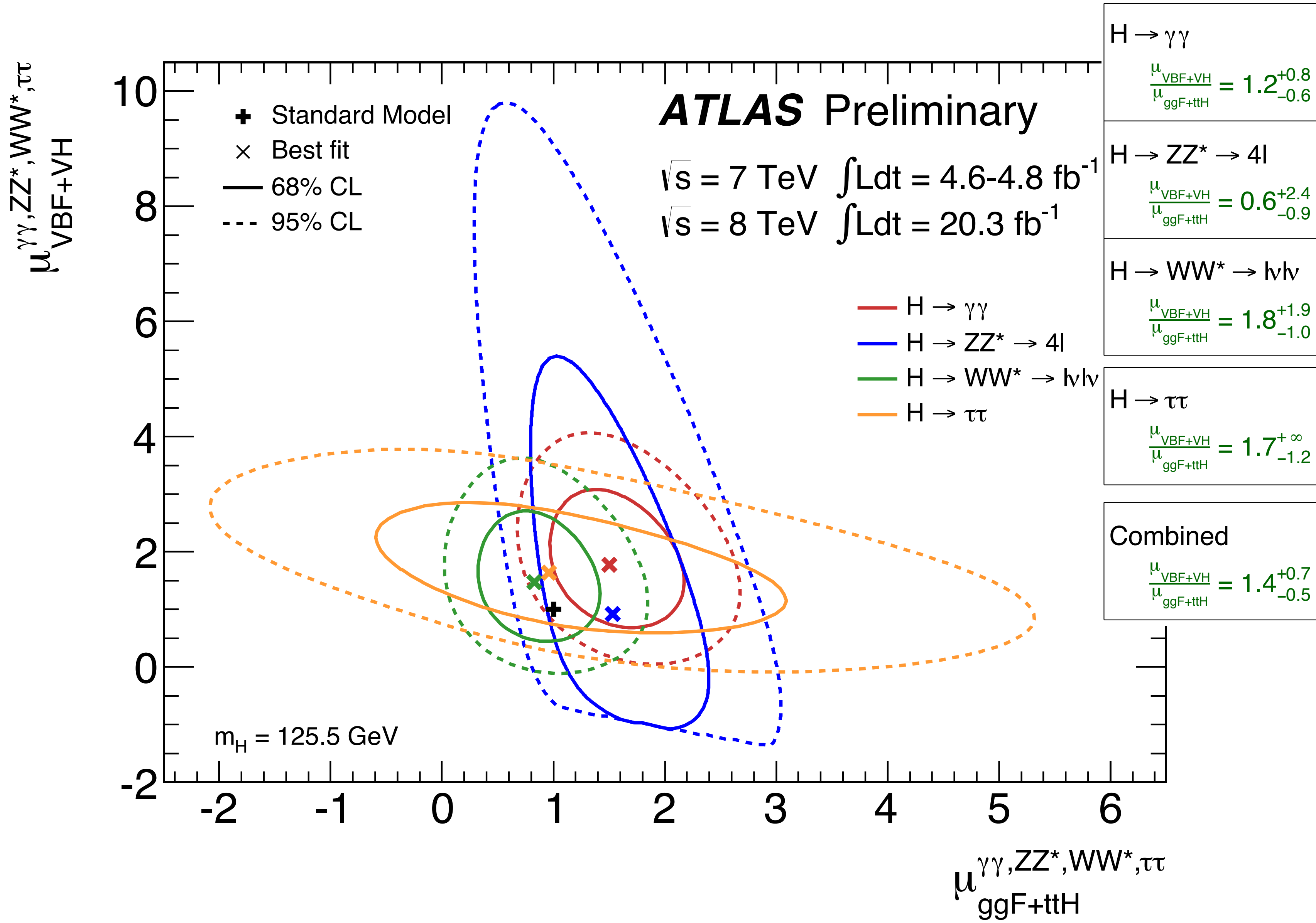
Higgs Property 2 : Couplings

signal strength : μ

$$\mu = \frac{\sigma \cdot BR}{(\sigma \cdot BR)_{SM}}$$

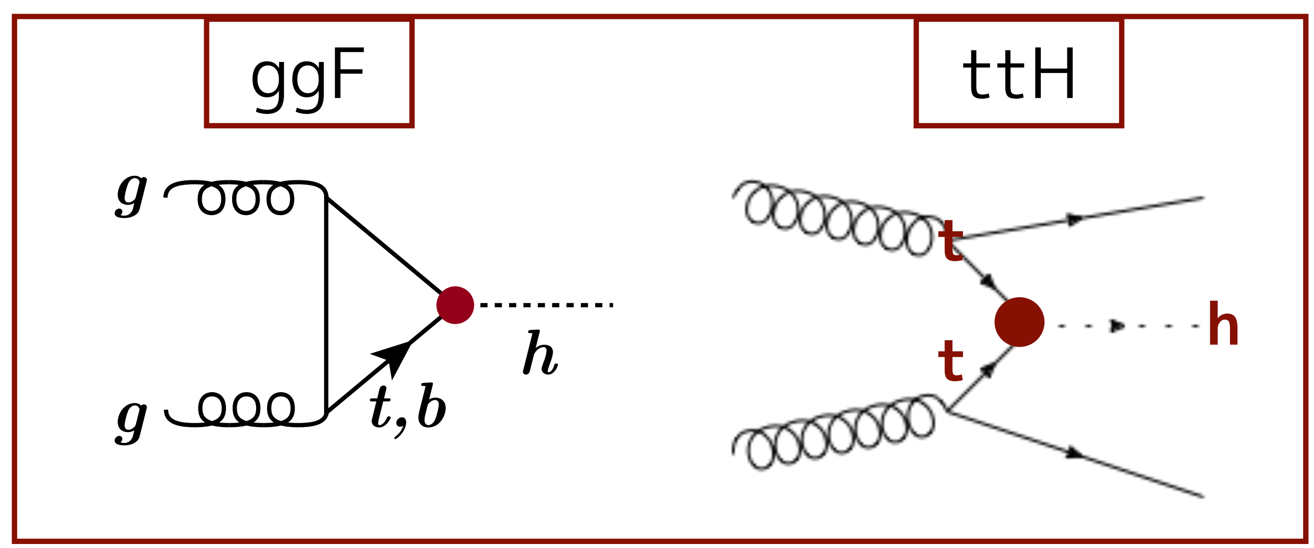




Production 1
Gauge Boson

Production 2
fermion

H → the same final state



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Higgs Property 2 : Couplings

coupling scale factor : κ

Basic assumptions

observed signals originate from

a single resonance at m=125.5GeV

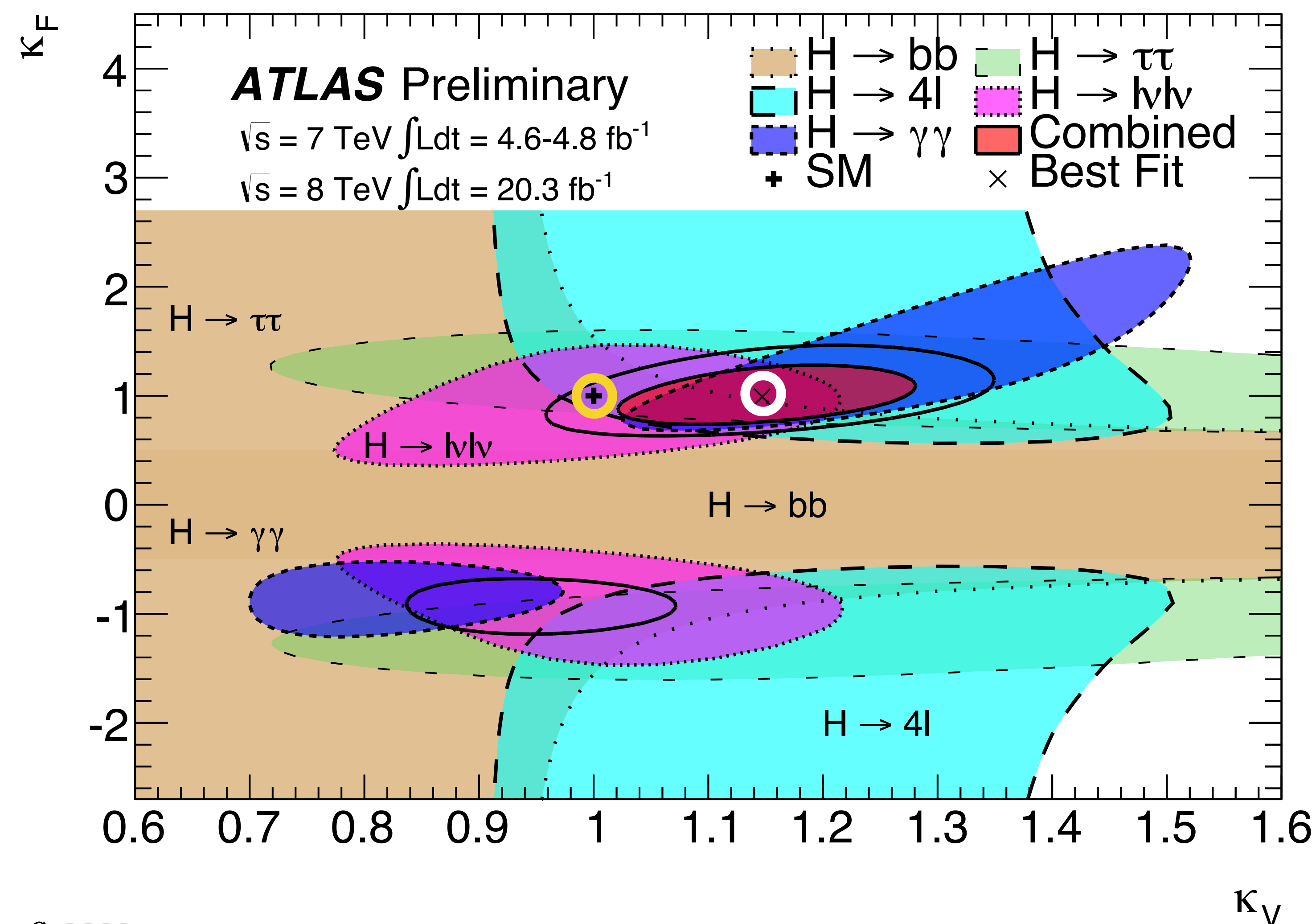
$$(\sigma \cdot BR)(i \to H \to f) = \frac{\sigma_i \cdot \Gamma_f}{\Gamma_H}$$

(zero-width approximation)

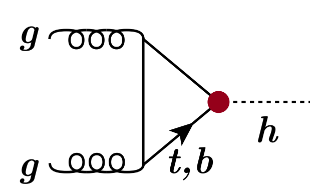
Coupling deviation from SM are defined

as multiplicative modifiers : **K**

{ Fermion v.s. Vector } Coupling



$$\kappa_i^2 = \frac{\sigma_i}{\sigma_i^{SM}} \qquad \kappa_f^2 = \frac{\Gamma_f}{\Gamma_f^{SM}}$$



$$\frac{\sigma \cdot Br(gg \to H \to \gamma\gamma)}{\sigma_{SM}(gg \to H) \cdot Br_{SM}(H \to \gamma\gamma)} = \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

$$\kappa_V = 1.15 \pm 0.08$$
$$\kappa_F = 0.99^{+0.17}_{-0.15}.$$

P^{SM}=10%

Higgs Property 3 : Spin & Parity

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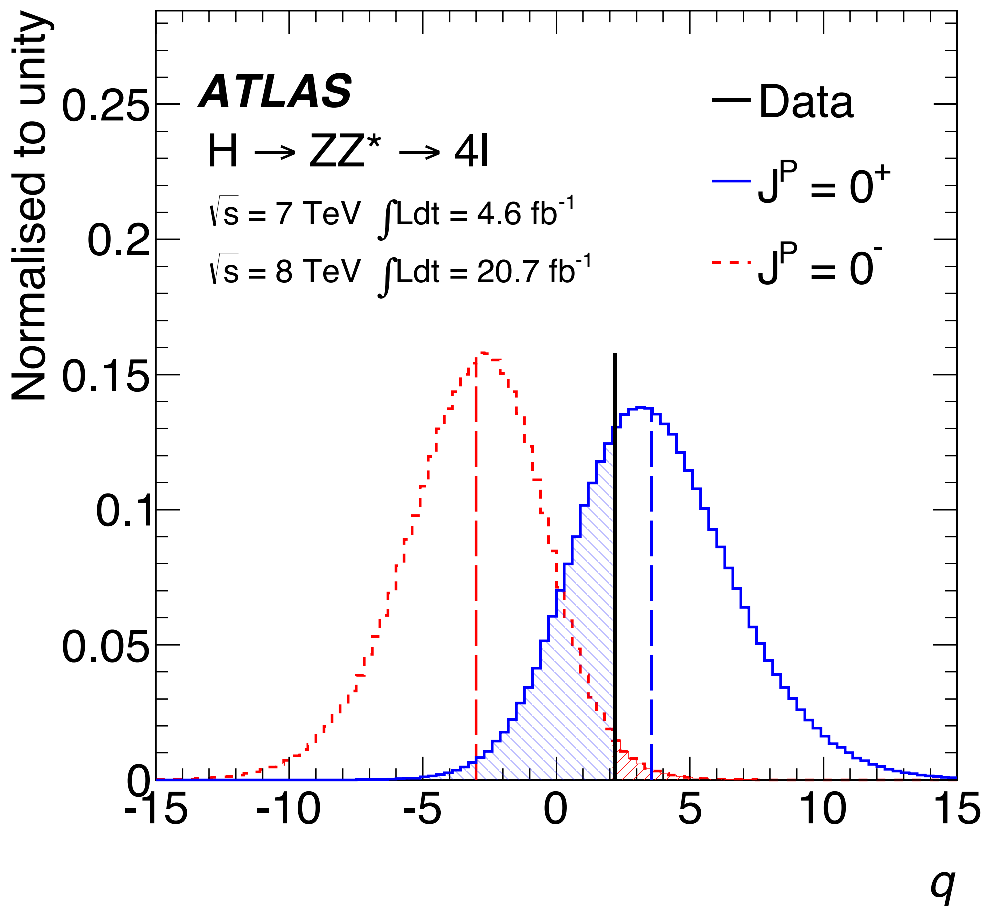

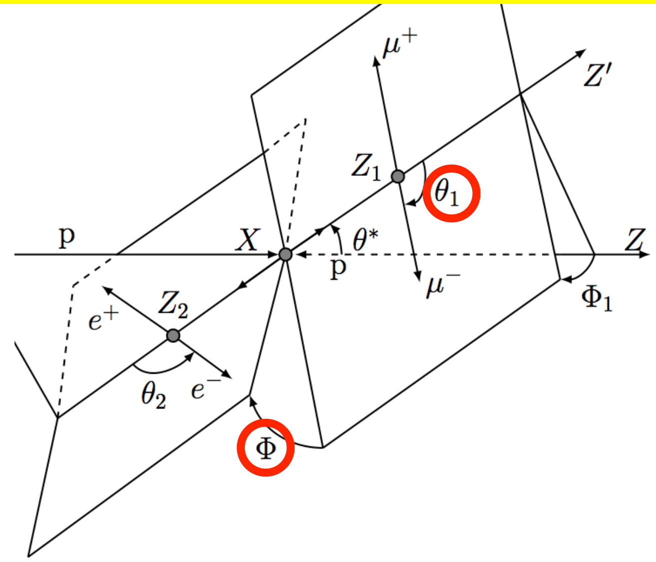

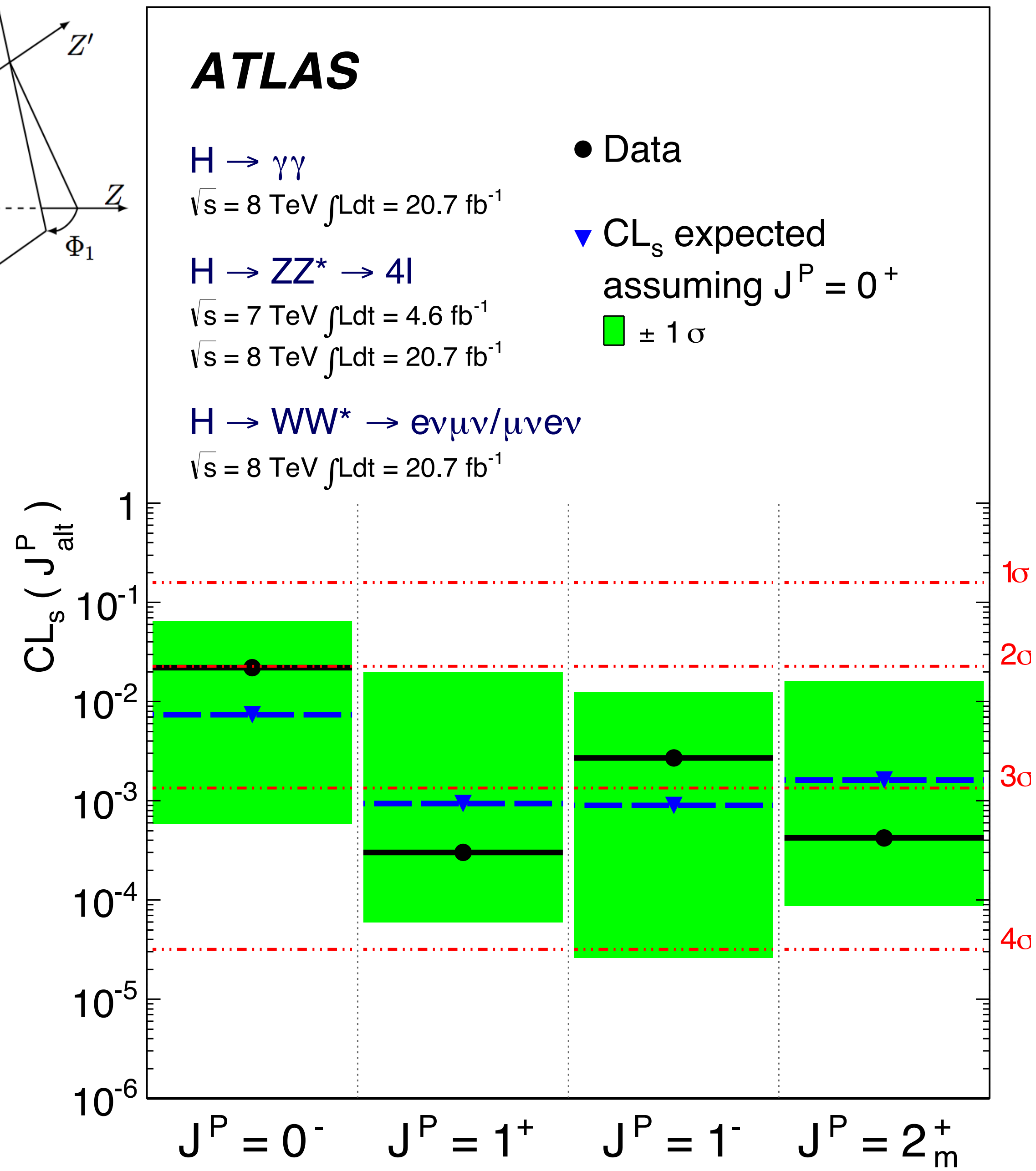

0	ZZ	97.8% CL
0	ZZ , WW	99.97% CL
0	ZZ , WW	99.7% CL
0	γγ , ZZ , WW	> 99.9% CL

0^- , 1^+ , 1^- , 2^+ , all tested spin hypotheses disfavored compared to 0^+ at > 97.8%

Conclusion

[0] A Higgs Boson is discovered

Couple to Vector-Bosons , Fermions

EW symmetry breaking

[1] **m_H** (updated)

$125.36 \pm 0.37(\text{stat.}) \pm 0.18(\text{sys.})$ GeV

[2] The strength of **coupling** to Vector-Bosons , Fermions are consistent with the SM-Higgs

[3] **Spin-Parity** of **0^+** is favored

0^-, 1^+, 1^-, 2^+ hypotheses , disfavored compared to 0^+ at > 97.8%