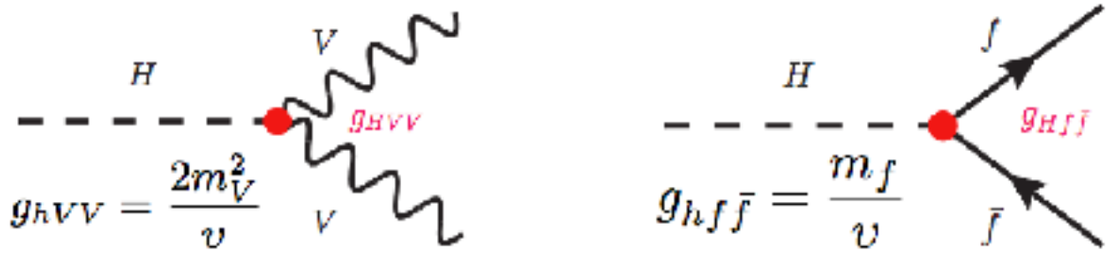
Activités du groupe ATLAS LPNHE Higgs-fermions

Paolo Francavilla, pour le groupe ATLAS LPNHE Higgs-fermions
Biennale du LPNHE, Tirrenia, Italie
Mercredi 5 octobre 2016

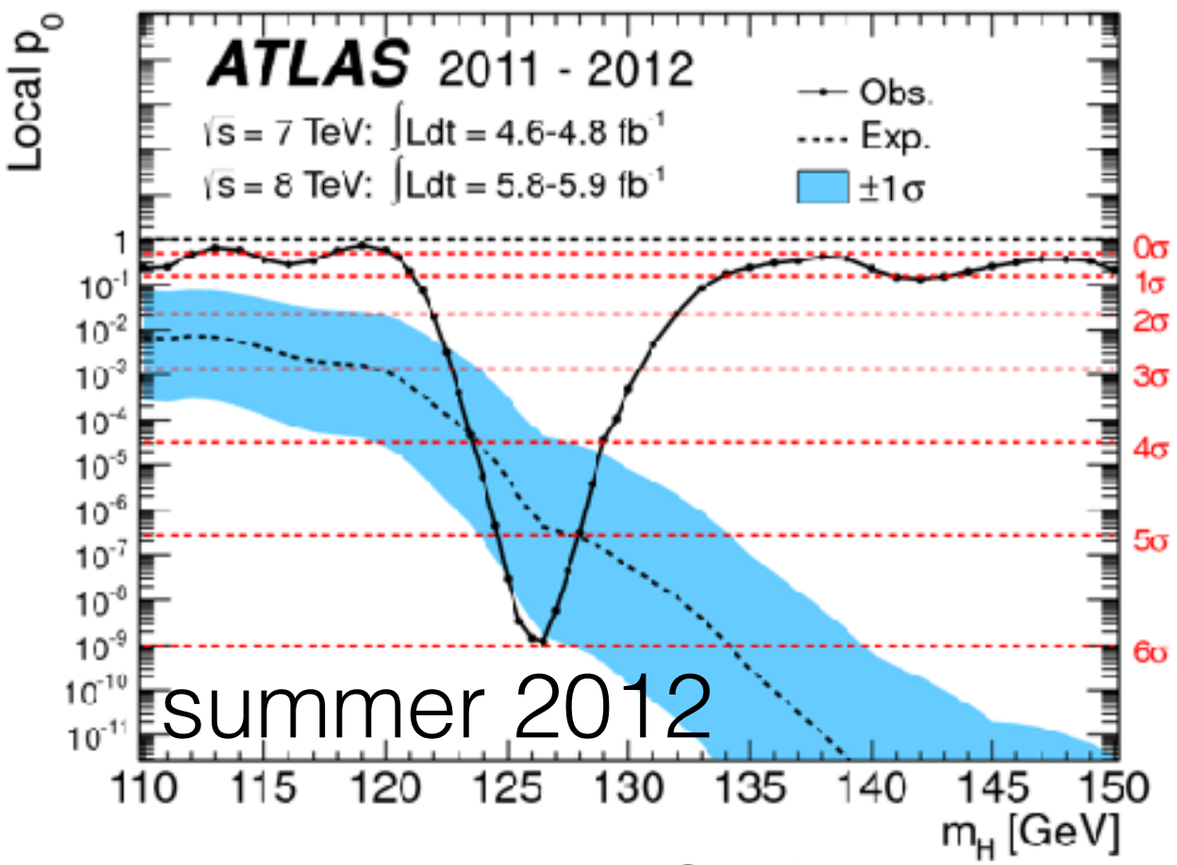
Higgs-fermion sector



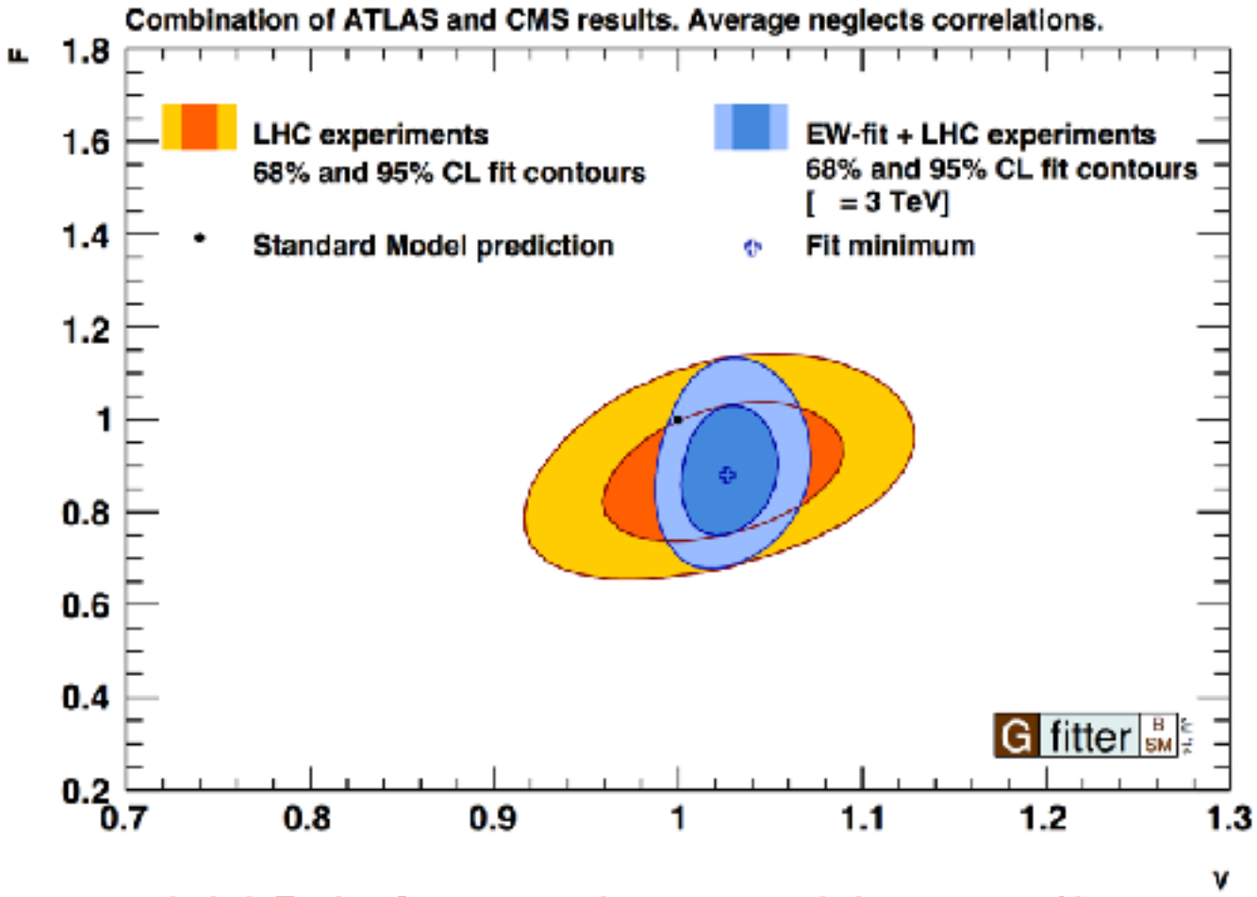
g_{hvv} coupling defined by symmetry breaking.

g_{hFF} coupling is ad hoc Yukawa coupling.
→ New physics scenarios predict changes in Yukawa couplings

Higgs boson discovery in 2012 from decay channels with bosons:
H→γγ*, *H→ZZ* and *H→WW



m_H=125.09 ± 0.24 GeV
Spin 0, CP-even
(other hypothesis excluded at 95% CL)



LHC information on H couplings with **fermions** is essential!

Higgs-quark sector

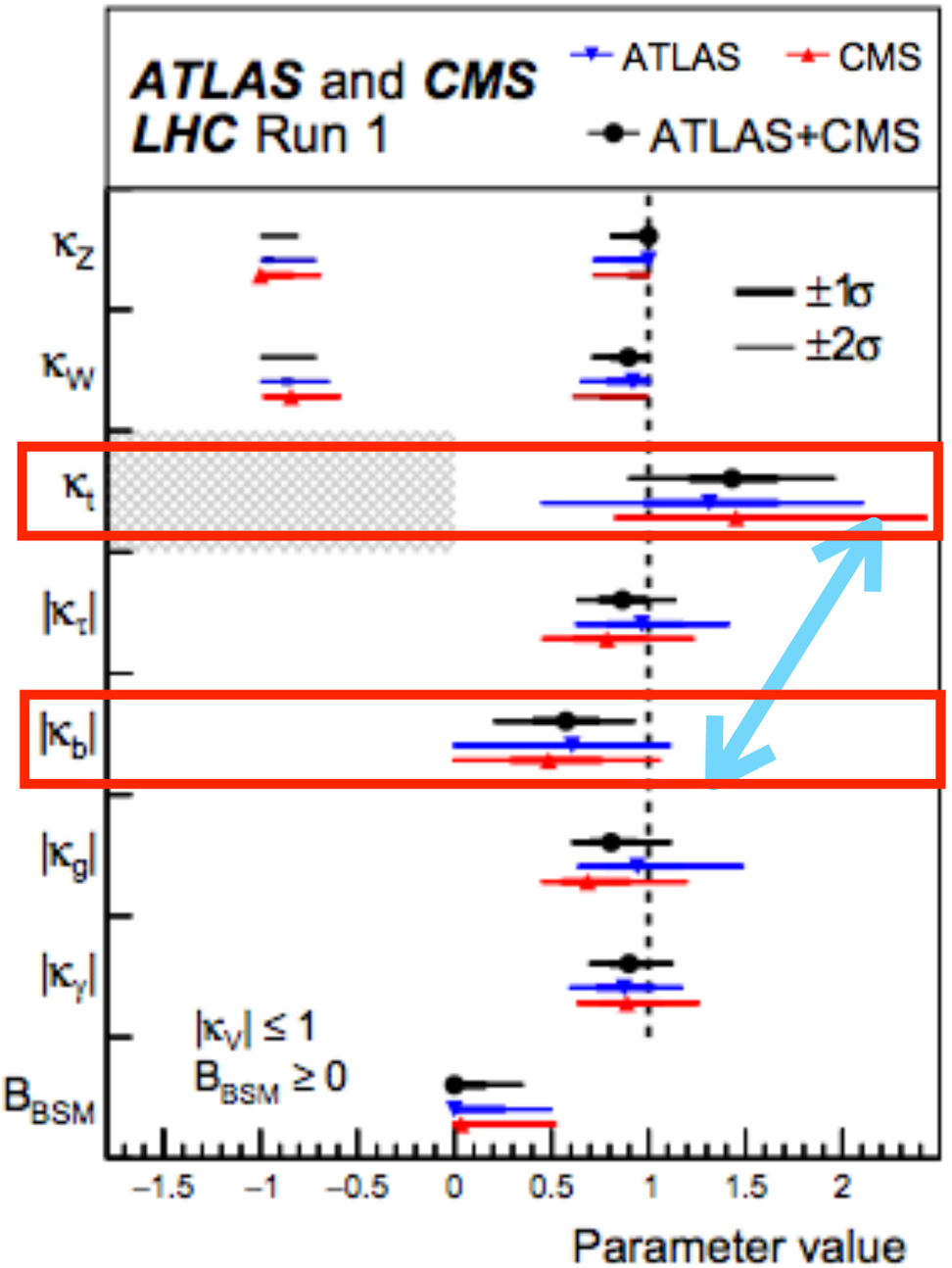
Getting access to the quark sector via

- $H \to bb$
  LPNHE leading in all the public results since 2014

- $pp \to ttH$
  Planning to get involved on this in the next 3 years

ATLAS and CMS LHC Run1

Production process	Measured significance (σ)	Expected significance (σ)
VBF	5.4	4.6
WH	2.4	2.7
ZH	2.3	2.9
VH	3.5	4.2
ttH	4.4	2.0
Decay channel		
$H \to \tau\tau$	5.5	5.0
$H \to bb$	2.6	3.7



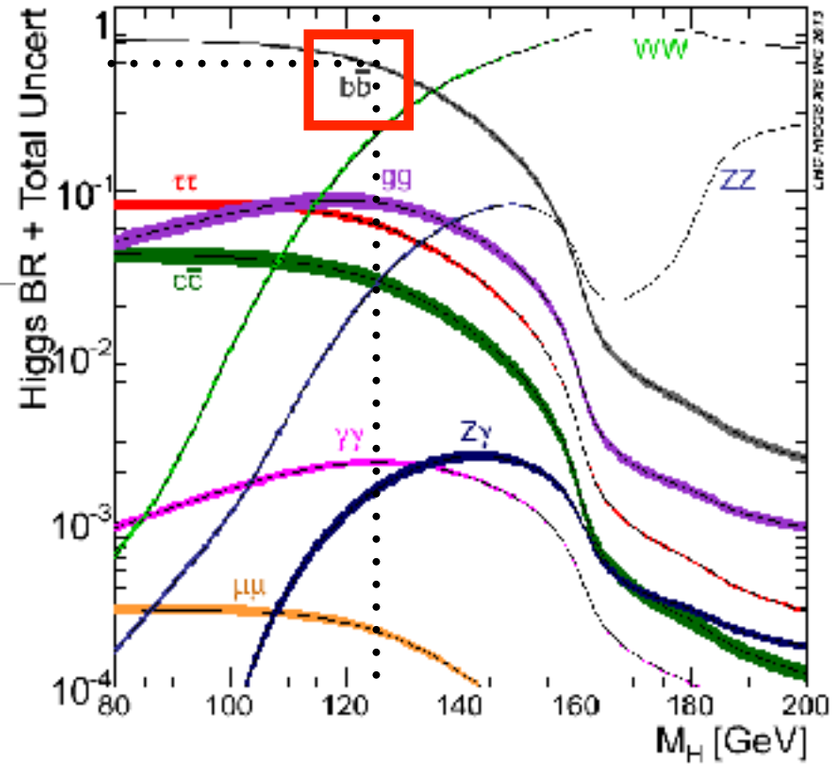
(not yet significant) deviations in the quark sector

NOTE: we do not have yet a solid observation for the more common Higgs decay mode

H→bb particularly appealing…

- *H→bb*, **(BR=~58%)**
  >Crucial to get an evidence of the coupling to the down-type quarks.
  >Direct measurement of Yukawa yb coupling
  >Significant contribution to total width
  >Large statistics in searches for rare or very rare processes

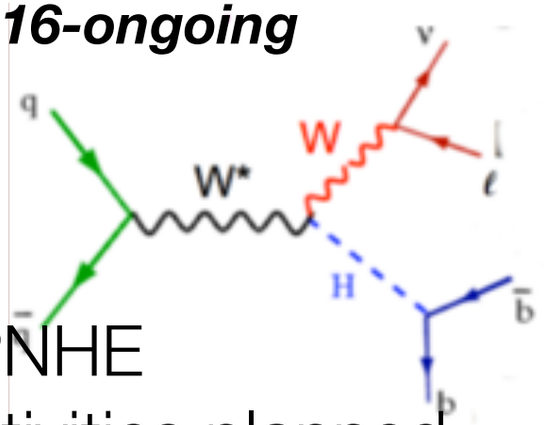
- **Backgrounds:**
  Overwhelming **multi-jet** production from strong interaction
  pp→WH and **pp→ZH** good handle to ***reduce them***.



Vh in *ATLAS:* Three leptonic signatures

pp→WH

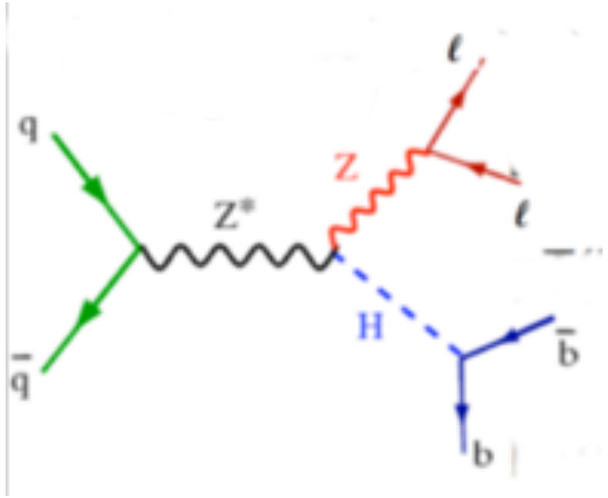
WH→lvbb (131 fb@8TeV)
2016-ongoing



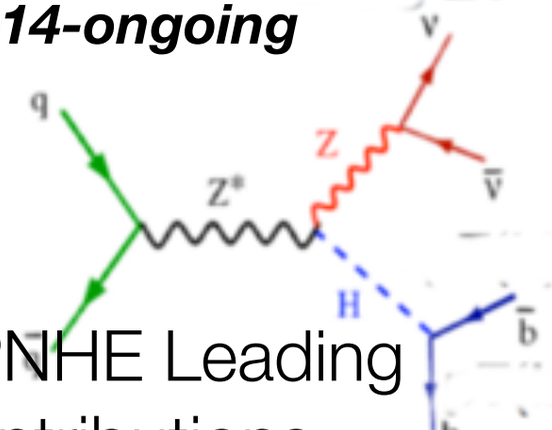
LPNHE
Activities planned

pp→ZH

ZH→llbb (15 fb@8TeV)



ZH→vvbb (44 fb@8TeV)
2014-ongoing

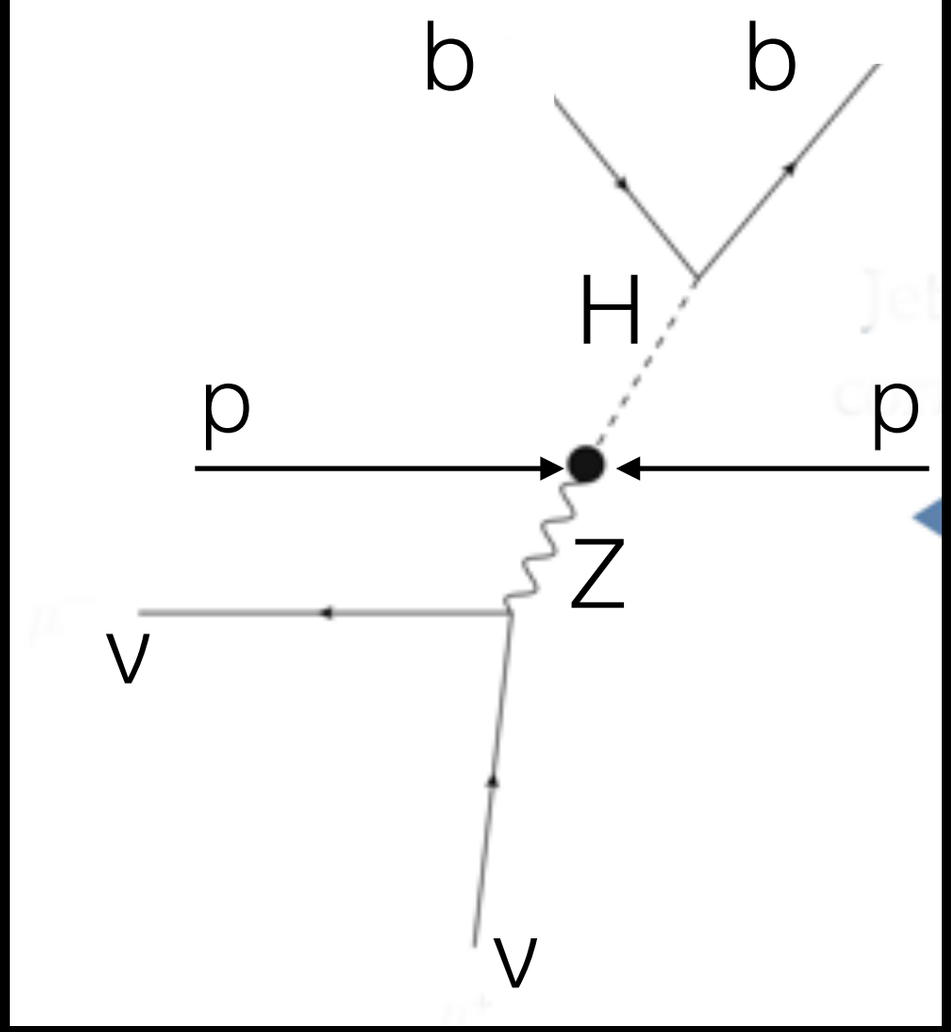


LPNHE Leading
contributions

Higgs boson decaying in b-quarks candidate in Run1

ATLAS EXPERIMENT
http://atlas.ch

pp→Zh→vvbb



ATLAS EXPERIMENT
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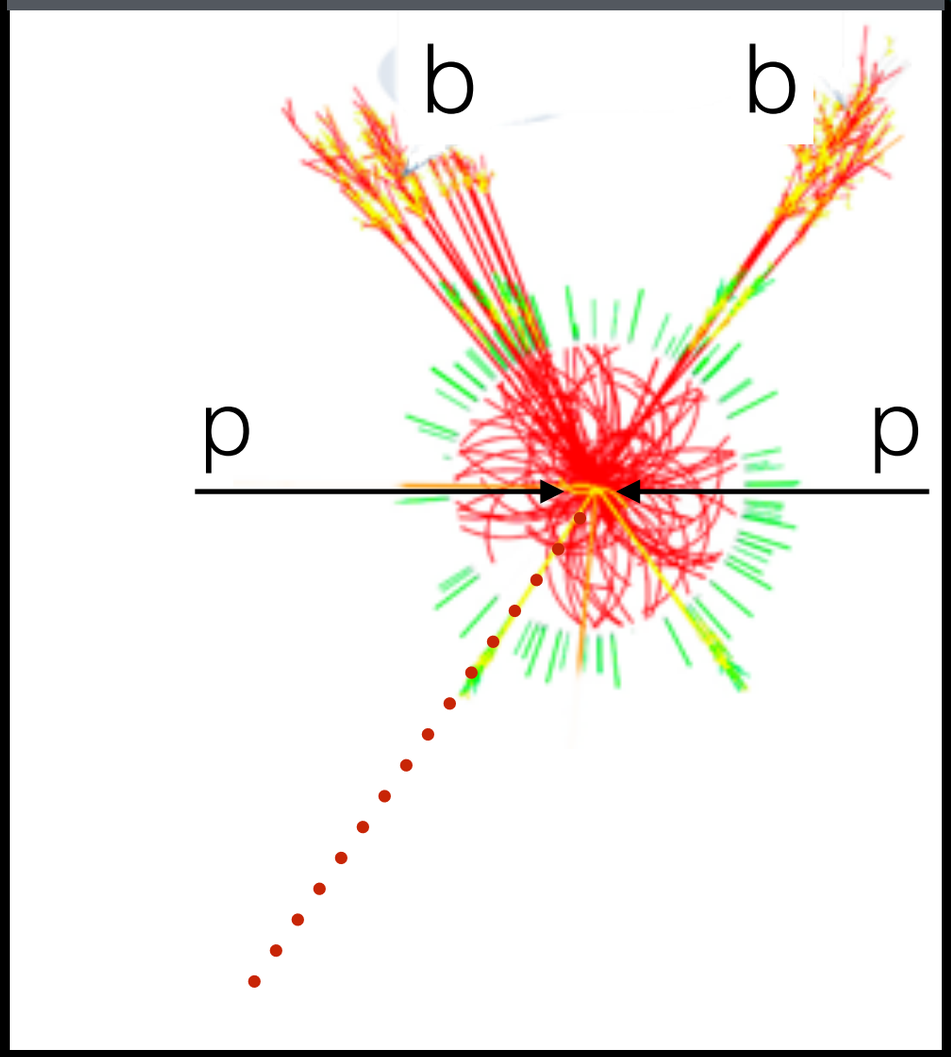
Higgs boson decaying in b-quarks candidate in Run1

Jet from b-quark:
clusters in calorimeter
and tracks from hadrons
footprint of b-quarks

pp→Zh→vvbb



Jet from b-quark

MET:
Missing Transverse Momentum
~ $\Sigma\vec{p}_T$ of particles not interacting
with the detector like neutrinos/neutralinos

Higgs boson decaying in b-quarks candidate in Run1

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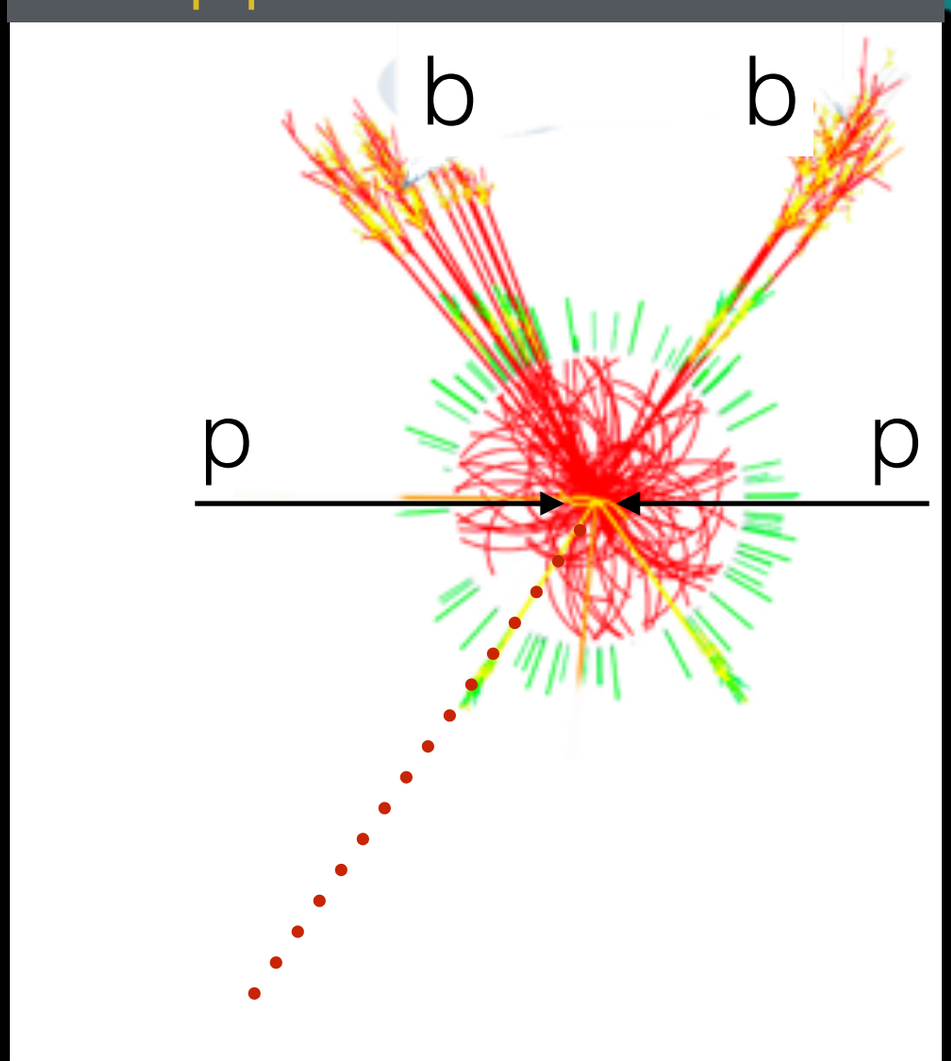
pp→Zh→ννbb



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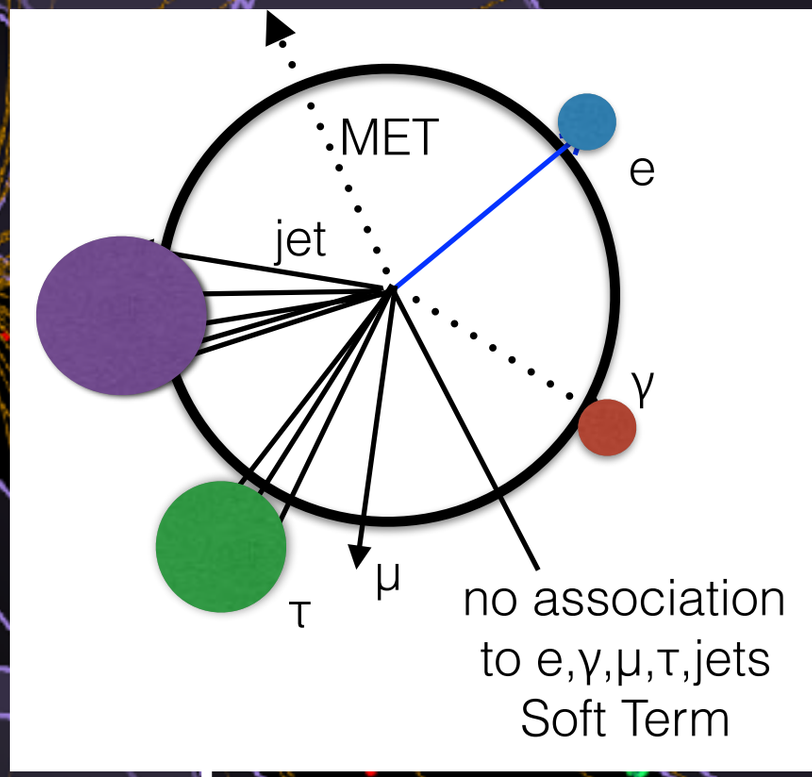


MET:
Missing Transverse Momentum
~ $\Sigma\vec{p}_T$ of particles not interacting
with the detector like neutrinos/neutralinos

Composition de l'equipe (I) - staff & post-docs

- Local contact: Giovanni MARCHIORI
- Liste des chercheurs participants:
  - 4 permanents

Name	Position	HDR	fraction du temps de recherche	Other activity @ LPNHE
Gregorio BERNARDI	DR	Yes	25%	directeur du labo
Giovanni CALDERINI	DR	Yes	40%	responsable du groupe ATLAS, R&D ATLAS upgrade
Sandro DE CECCO	MdC	Not yet	50%	responsable du groupe DarkSide
Giovanni MARCHIORI	CR	Yes	50%	ATLAS "H→γγ" et R&D ATLAS upgrade

  - 1 post-doctorant
    - Paolo FRANCAVILLA, H→bb (SM et BSM), financé par le labex ILP, 100%, Decembre 2013-Decembre 2016
  - 1 post-doc de 2 ans financé par l'ANR (projet Hbb+ttH@LHC), pas encore recruté

Composition de l'equipe (II) - students

- 5 students with diversified topics and sources of funding
  - good attractiveness of topic

Name	Year	Subject	Supervisor	Funding source	Time on project	Duration
Carlo PANDINI	3	SM VH et A→ZH, H→bb (0 lepton)	G. CALDERINI	ED STEP-UP	100%	10/2013 - 10/2016
Dilia PORTILLO	1	Recherche de matiere noire dans la signature mono-Higgs (H→bb + energie transverse manquante)	S. DE CECCO	labex ILP	100%	10/2015 - 10/2018
Changqiao LI	1	SM VH, H→bb (0+1 lepton)	G. MARCHIORI, Y. LIU (USTC - Chine)	FCPPL + CSC	100%	10/2015 - 10/2018
Louis D'ERAMO	0	H→bb (0 lepton): SM VH et nouvelles resonances	G. CALDERINI	ENS	100%	10/2016 - 10/2019
Ilaria LUISE	0	SM H→bb (VH 1 lepton + ttH)	G. BERNARDI, G. MARCHIORI	ED STEP-UP	100%	10/2016 - 10/2019

- Synergies with ATLAS Pixel R&D thesis

Audrey DUCOURTHIAL	1	Pixel R&D & H→bb projections	M. BOMBEN	ED STEP-UP	30%	10/2015 - 10/2018

Students technical work for ATLAS authorship

Name	Qualification task for ATLAS authorship	Status of qualification
Carlo PANDINI	Optimisation of bank of patterns for **FTK**	qualified
Dilia PORTILLO	Improvement of **MET** significance calculation	started
Changqiao LI	Measurement of **b-tagging** efficiency of calo and track jets	qualified
Louis D'ERAMO	Equalisation of **FTK** pattern performance in barrel-endcap transition	started
Ilaria LUISE	**Electron** identification optimisation/efficiency measurement	will start in October

- qualification work related to improvements related to physics analysis for the thesis or on R&D activities in which the LPNHE group is strongly involved
- important fraction of time during 1st year of PhD
- students qualified as ATLAS authors without delay so far

Performance and simulations

1 paper
1609.09324

1 public note (editor)
ATL-PHYS-PUB-2015-023

1 conf, note planned

Development of the new default MET definition (aka TST)

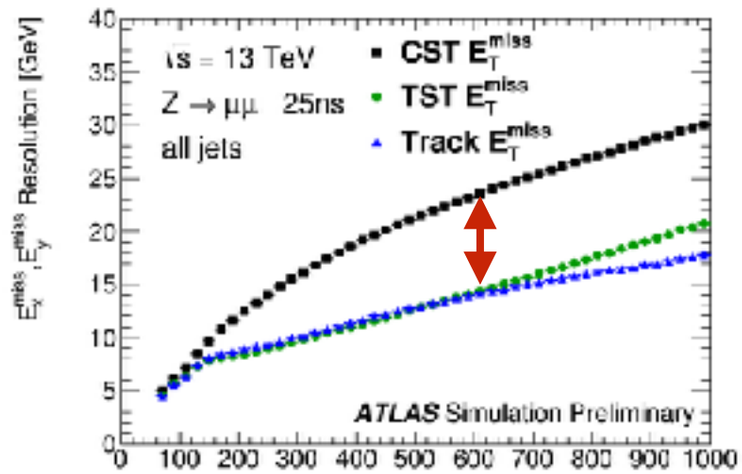
at the end of Run1 - still in use (***2013-2014***) **PF, DP, SdC**

> *Derivation of the systematics uncertainties for MET in Run1 (**2014**)*

> *Pre-recommendation on use of MET in Run2 in ATLAS (**2015**)*

> *Definition of the significance of the MET (**2016-ongoing**)*

Responsibilities: ATLAS MET convener (PF, *13-14*) *~15 people*



Studies on the MET trigger (*2016-ongoing*) **LdE,RjW** **1 conf note planned**

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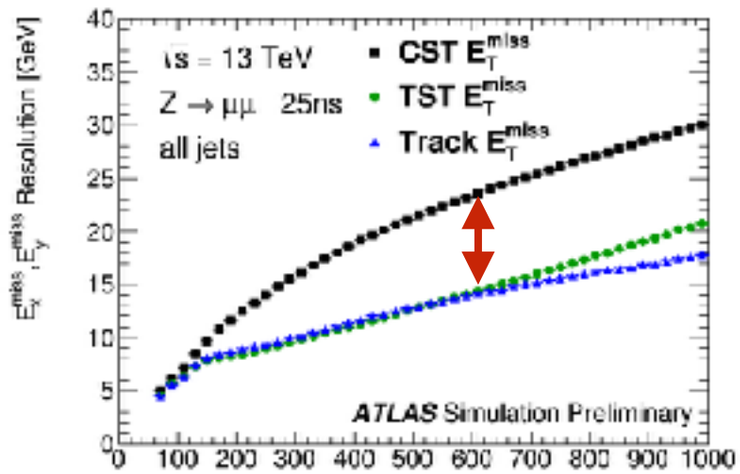

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B-tagging efficiency calibration with 2015 data (2015)

Data/MC b-tagging efficiency scale factors for different cone sizes and jet algorithm used in ATLAS **CL,GM**

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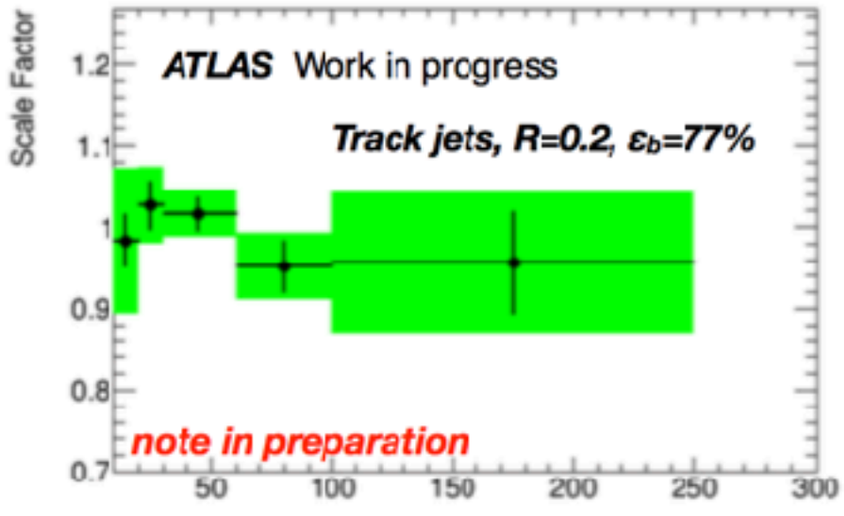

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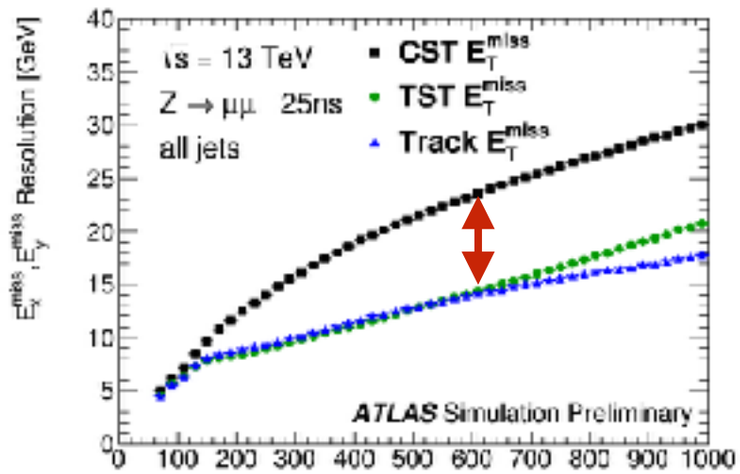

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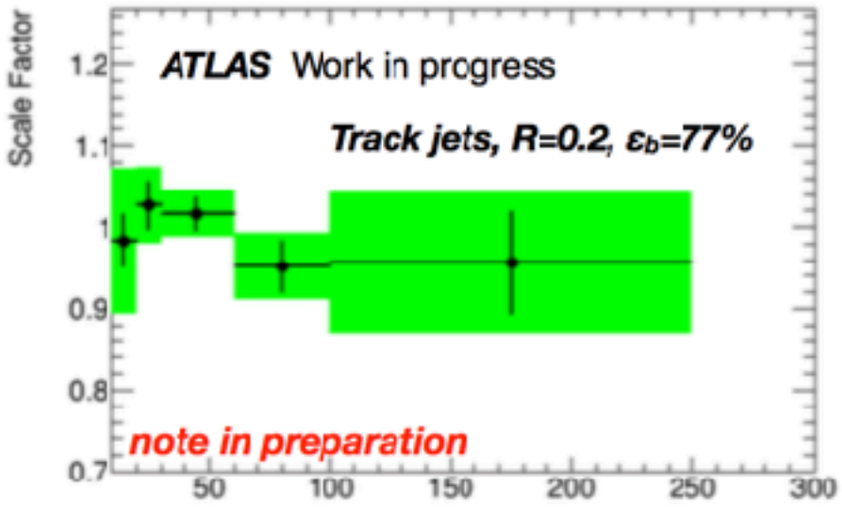


Monte Carlo simulations for signals and background (2014-ongoing) **CP,PF**

Work on the LHC Higgs Cross Section Working Group

2 public note in ATLAS ATL-PHYS-PUB-2014-022 ATL-PHYS-PUB-2016-002

2 contributions on the Higgs yellow report IV

Responsibilities: ATLAS MC validation convener (PF, 16-17) *~5 people*

Responsibilities: ATLAS Hbb convener (PF, 14-15) ~60 people

SM H→bb searches

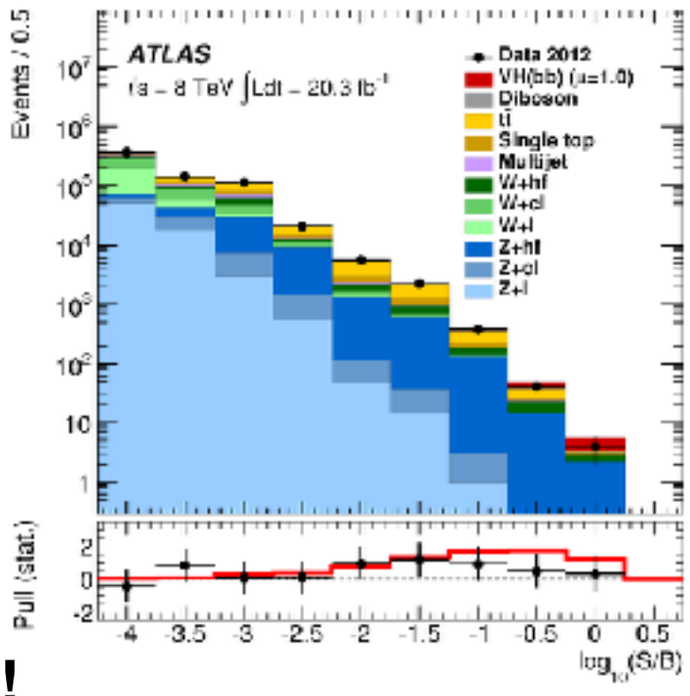
Expected sensitivity: **2.6σ**
Error on SM **expectation** for $\mu=\sigma/\sigma_{SM}$: **40%**

Observed significance: 1.4σ
VH **μ=0.51±0.40**
Weak hint of signal, no evidence yet.

Run 1

PF, CP, GC, GM
1 paper
JHEP01(2015)069
(editor of the supporting note)

Most sensitive analysis performed so far!!!



H→bb Global picture at the LHC Run1:

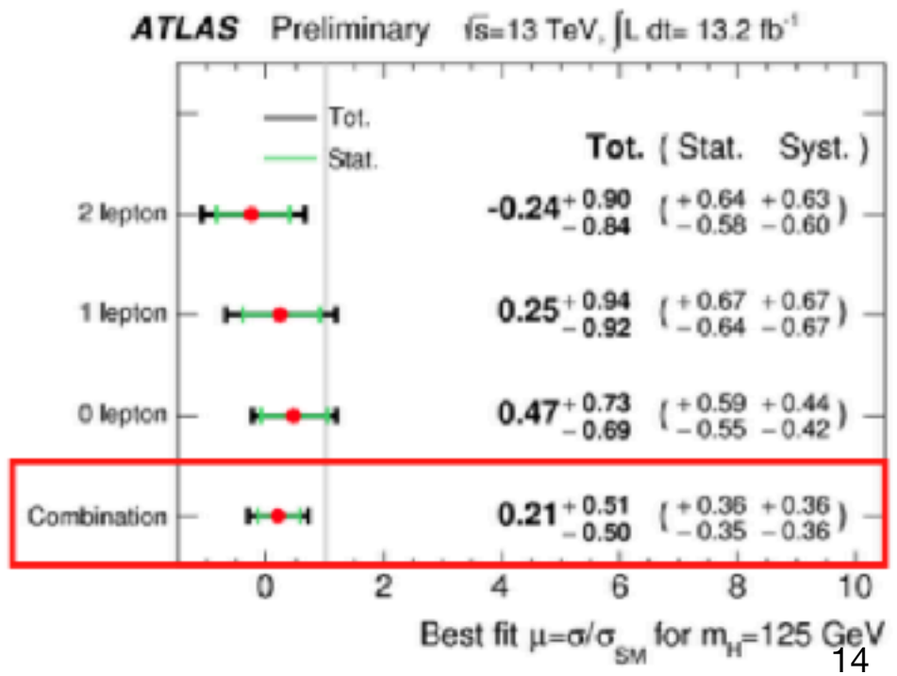
ATLAS H→*bb* combination (*VH*+*ttH*):
1.7 σ (2.7 σ), μ=0.63 ± 0.4

CMS *H→bb* combination (*VH*+*ttH*+VBF):
2.6 σ (2.6 σ), μ=1.0 ± 0.4

Run 2 - Preliminary

PF, CP, GC, GM, GB, CL
1 conf note ATLAS-CONF-2016-091

Very complex analysis done with the first 13.2 fb-1 of data collected at 13 TeV. First time at the LHC-Run2!!!



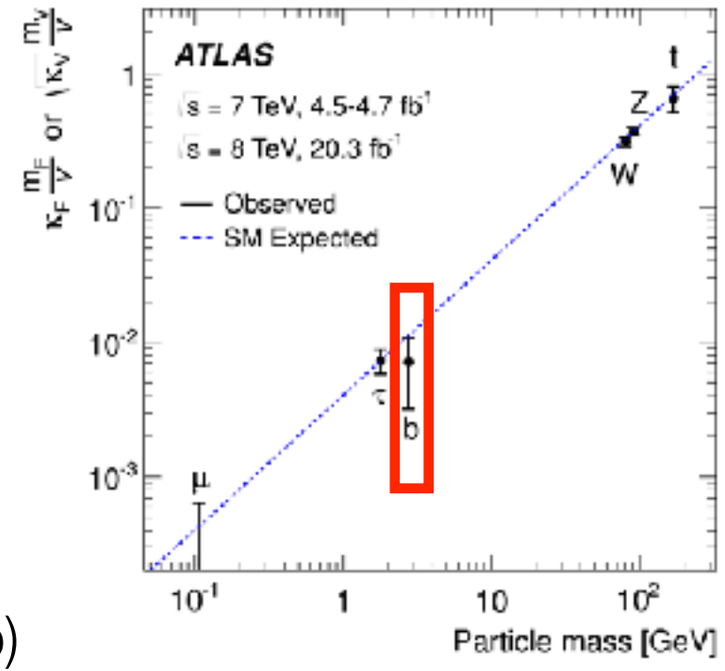
SM Higgs Combination

Run 1

CP

1 paper
EPJC (2016) 76:6

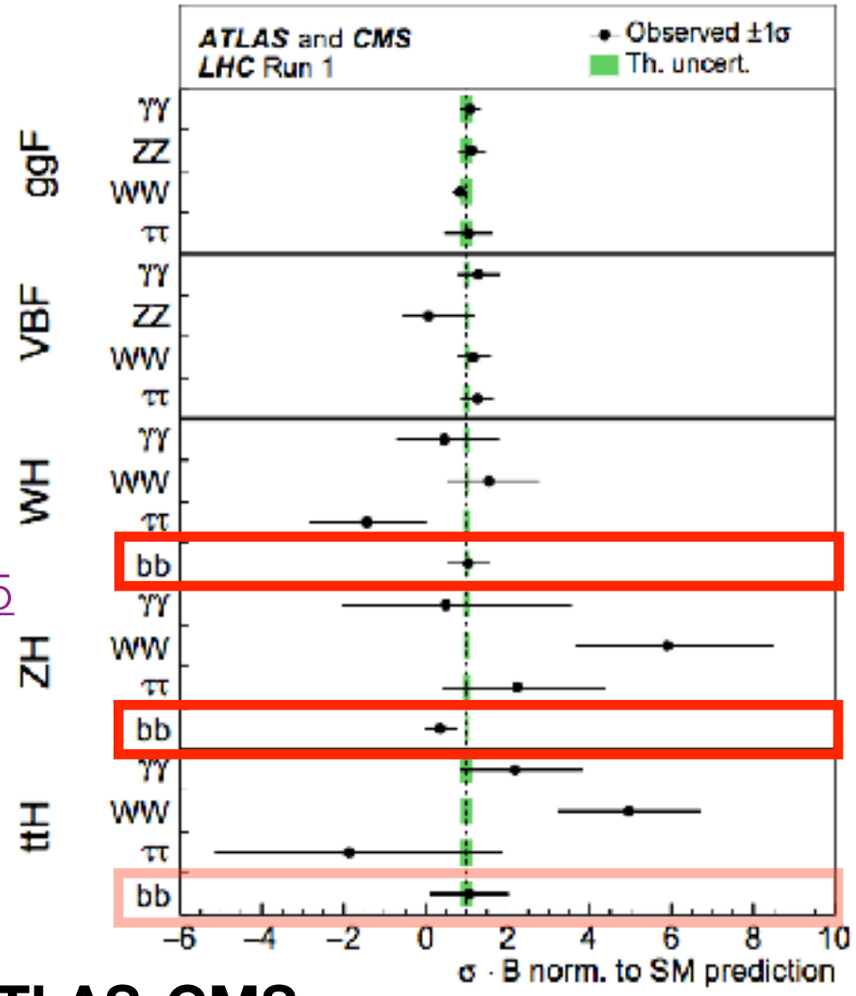
Combination with all the ATLAS Higgs analysis
Support for combining 7 TeV and 8 TeV for VH(bb)



CP

1 paper
JHEP 08 (2016) 045

Combination ATLAS-CMS

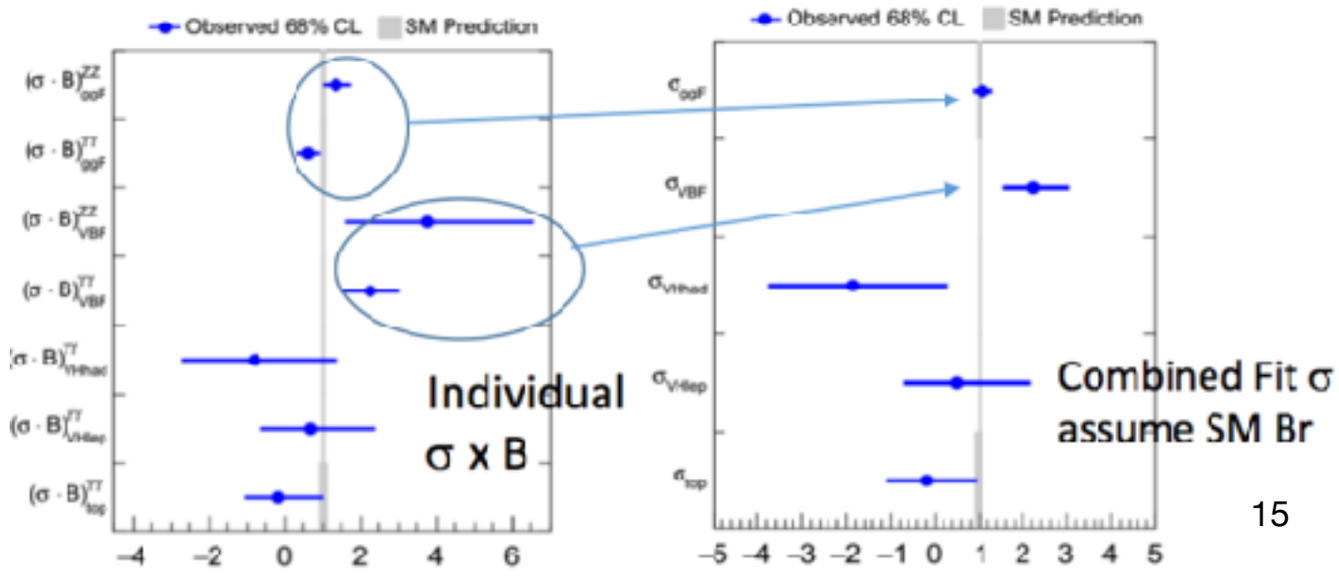


Run 2 - Preliminary

PF **1 conf note (editor)**
ATLAS-CONF-2016-081

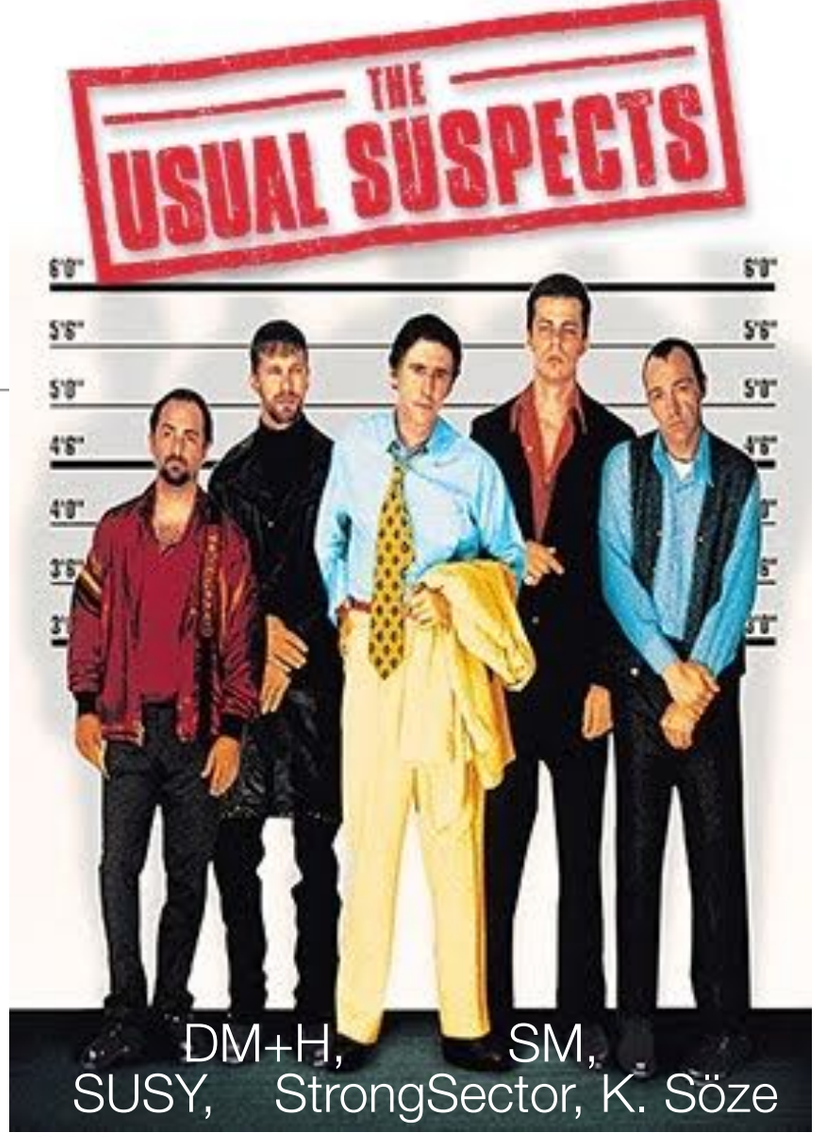
LHC-Run2 Higgs Combination (H→ZZ*→4l, H→γγ)
Observed local significance
- for total Higgs Production ~10σ
- for VBF-only: 4σ

Tests for the combinations of the Hbb channels ongoing



And if H is not SM? the usual suspects

- ***Strongly interacting sector at higher energies***
  - *H(125) is a"Low-energy" manifestation of new physics*
  - *Tower or new (vector) resonances at high mass*
- ***Supersymmetry***
  - *extensions of Higgs sector*
  - *coupling to up and down fermions can be different from SM*



Looking for new resonances:

- heavy vector bosons ***W', Z' → W/Z+H(125)***
  (i.e. in models with composite Higgs boson)
- heavy CP-odd scalar ***A → Z+H(125)***
  (i.e. in models with 2 Higgs doublets : 2hdm, SUSY-MSSM,…)

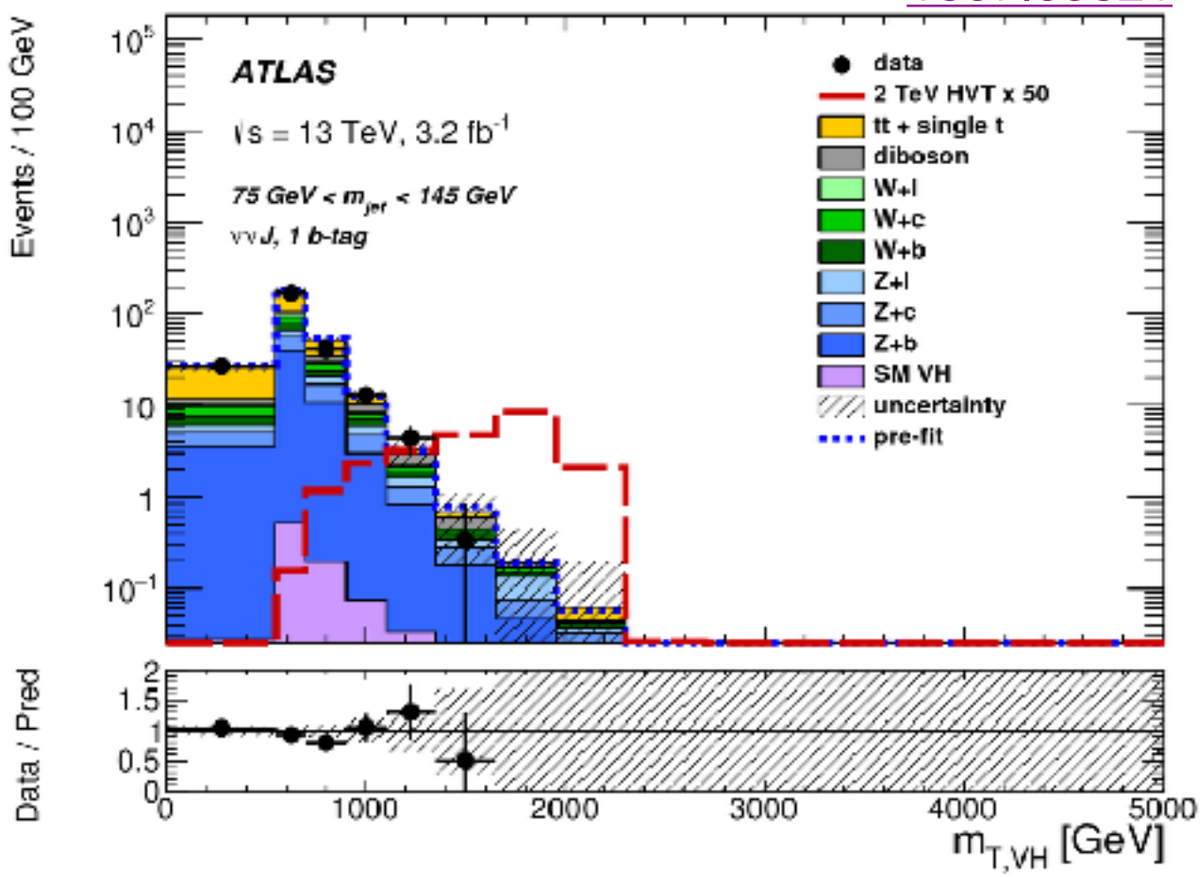
Responsibilities: ATLAS Hbb convener (PF, 14-15) ~60 people

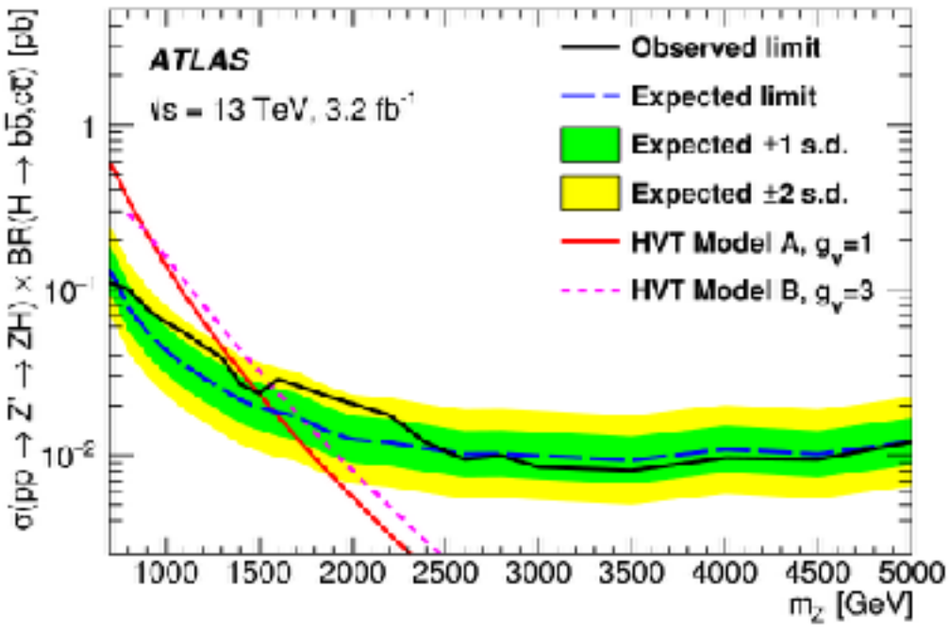
BSM H→bb searches (Resonances)

W', Z' →W/ZH (Run2)

1 conf note
ATLAS-CONF-2015-074
1 paper (editor)
1607.05621

PF, CP, GC, GM + all staff





No significant excesses found (yet)

- Almost 2 σ deviations (2 TeV)
- Surpassing Run1 results

A→ZH (Run2)

PF, CP, GC, GM + all staff

1 conf note (editor)
ATLAS-CONF-2015-074
Editor of the supporting note

No significant excesses found (yet)

- Couple of 2 σ deviations (260 GeV, 440 GeV)
- Extending up to 2 TeV

BSM H→bb searches (Dark Matter)

Run 2 - Preliminary

DP, SdC

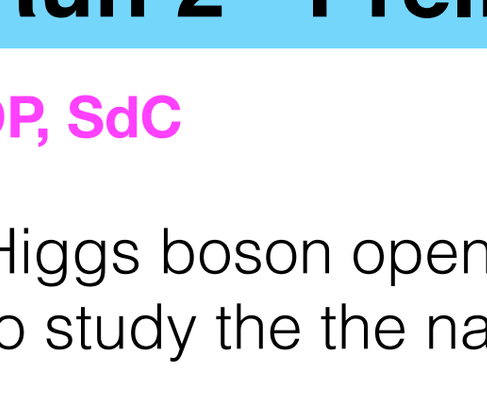
1 conf note
ATLAS-CONF-2016-019

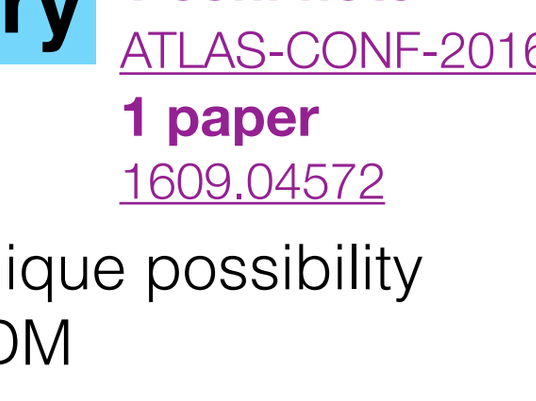
1 paper
1609.04572

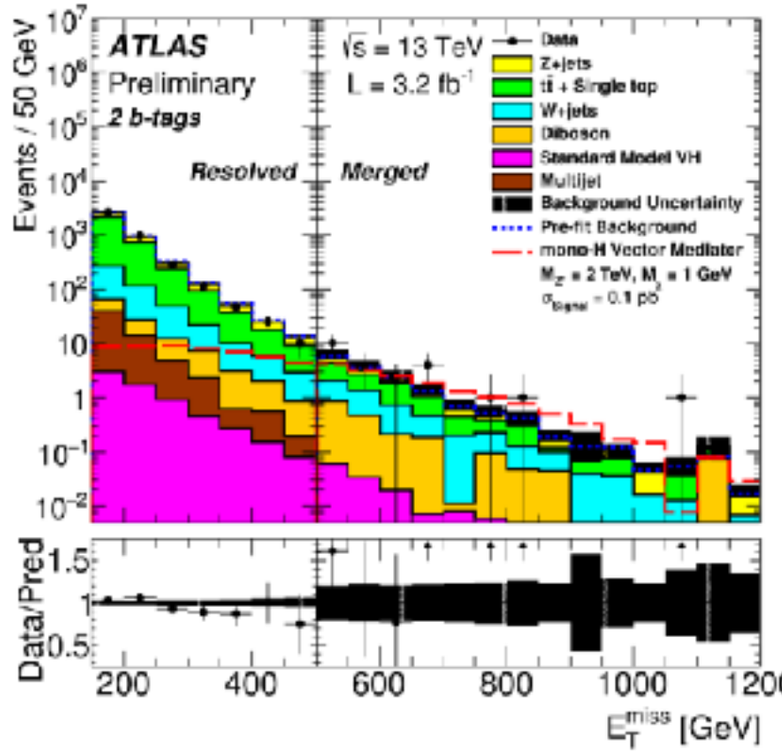
Higgs boson opens the unique possibility to study the the nature of DM

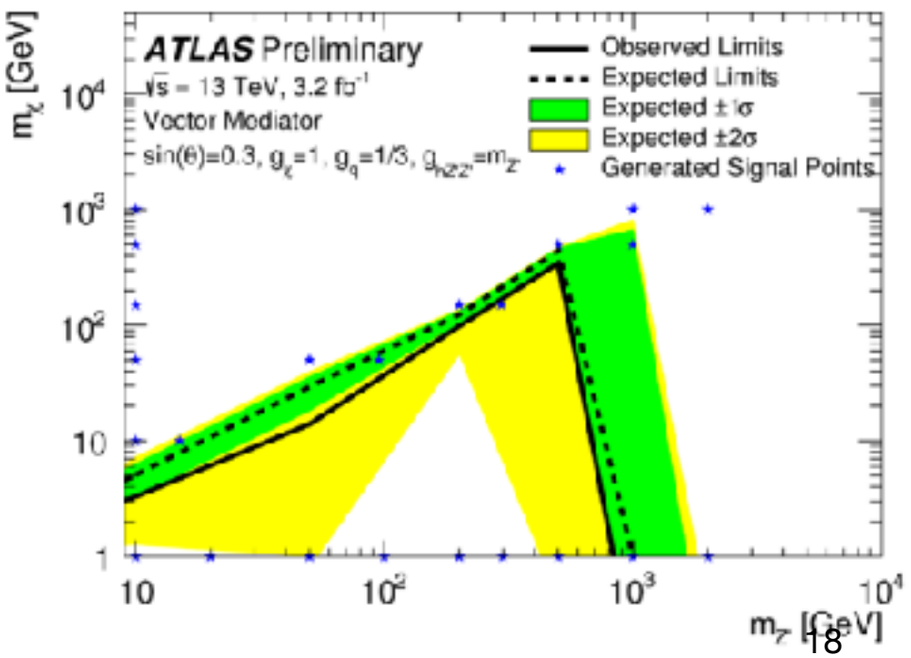
Unlikely that H “emitted" by initial partons

Assuming a BR ~58%, H→bb is the most sensitive among the Higgs decay channels
Synergy with LPNHE searches in DM+ H→γγ and DM +top

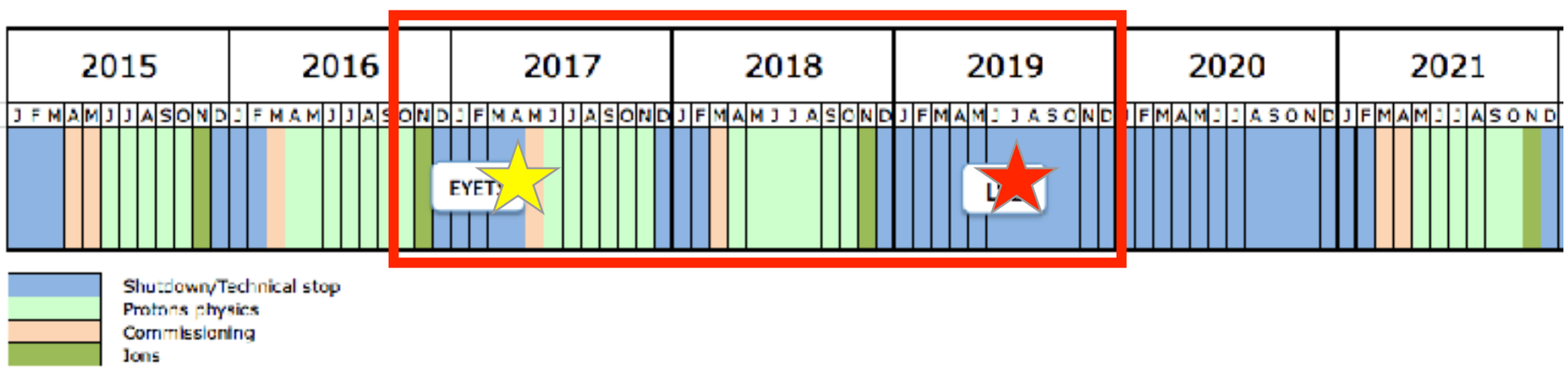








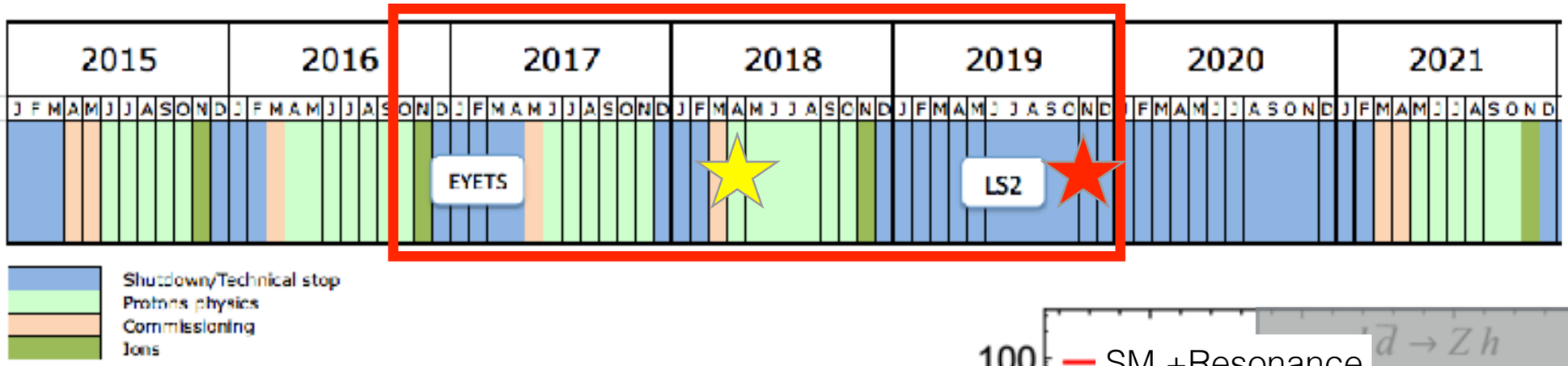
Prospectives (I): SM H→bb



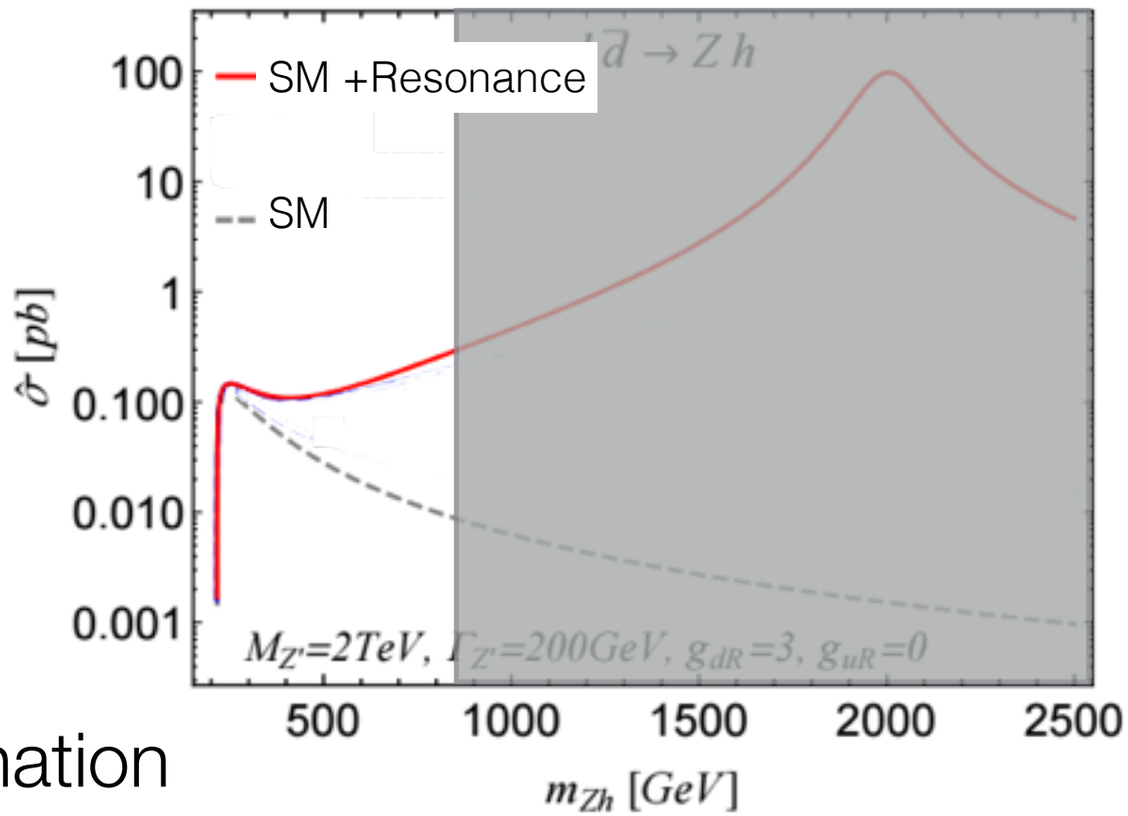
- ***Winter-Summer 2017:*** ★
  - Continue leading the **ZH(vvbb)** channel
  - Start the **WH(lvbb)** channel
  - **Analysis** with full 2016 dataset (~2 times the stat. analysed so far)
    SM VH combination with Run1: Expected *sensitivity:* ***> 3σ***
  - **VH(bb)-ttH(bb) combination ongoing (Summer 2017?)**

- ***Summer 2019:*** *Run2 legacy paper (100 fb-1)* ★
  Expected *sensitivity:* ***~ 5σ - precision ~20%***

Prospectives (II):
VH couplings with H→bb & combination

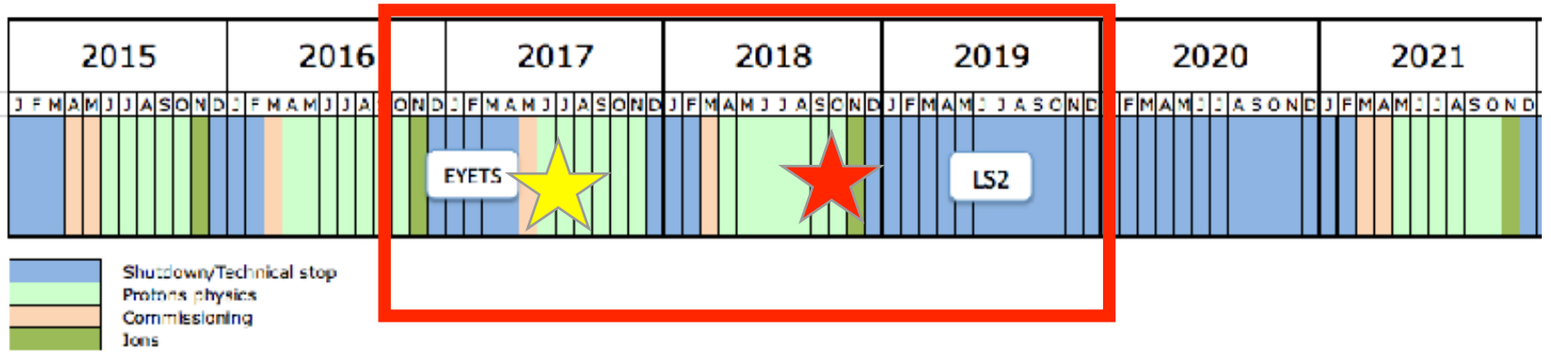


- ***Winter-Summer 2018:*** ★
  - Investigate the VH coupling structure using the H→bb
  - (maybe with Higgs Eff. Field Theory)



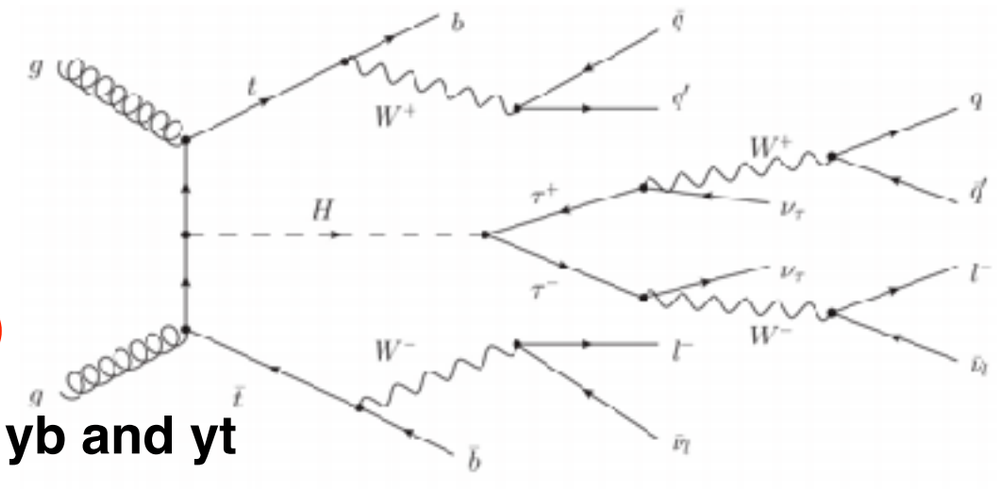
- ***Summer 2019 - Winter 2020:*** ★
  Likely ATLAS Run2 legacy Higgs combination
  Maybe ATLAS-CMS combination?
  (ATLAS+CMS stats at end 2018: ~200fb-1
  probably not before end 2022 for single experiment)

Prospectives (III): ttH and searches



SM ttH

- ***ttH very attractive*** ★
  >Direct measurement of Yukawa yt coupling (~1 in SM)
- Plan to use the experience in W(lν)H(bb) for tt(lνb jjb)H(bb)
- **Possible synergies with ttH(γγ) to disentangle effect of yb and yt**

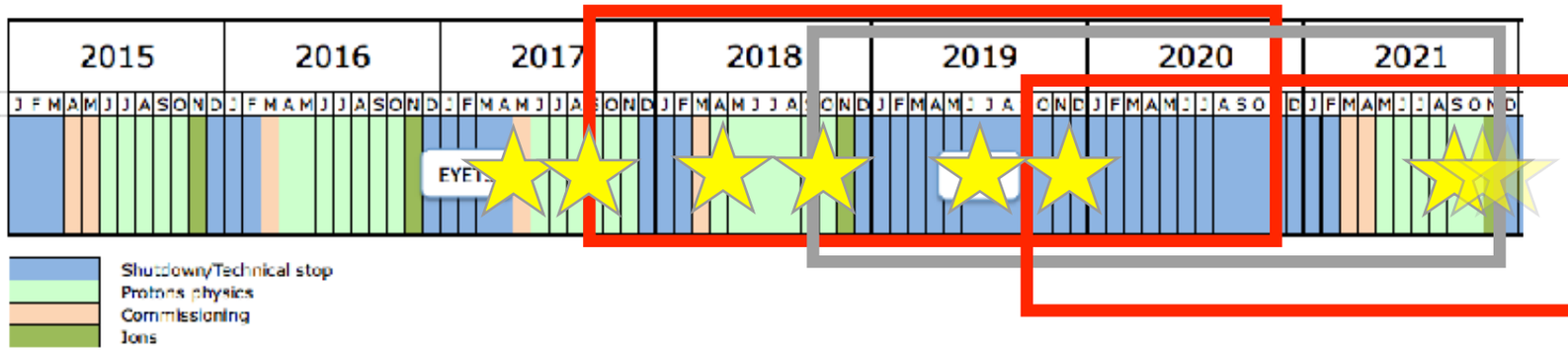


- NOTE: σ B higher than SM, but not yet significative - Interesting early on!
- **Likely starting this activity in 2017**, but already learning from the combination in 2016

BSM H→bb

- **Dark Matter searches will continue at least until end 2018** ★
  We will benefit from more statistics to cover the high energy regions
- **Resonance searches in VH(125) - interesting but depending on manpower**
  Likely update by next spring, and again at least at the end of 2018
  - CP odd resonance still interesting, both in searches with A→ZH(125), or with A→ZH(m!=125)
- **Possible involvement in double Higgs searches** (new resonances, or changes on trilinear coupling) **- interesting but depending on manpower**

Theses



- Very attractive physics case which open to a lot of different measurements of H in the SM, and searches BSM

- 2017/2020 - Run2 Analysis of Hbb and combinations

- 2018/2021 - ITK R&D + high-luminosity physics prospects

- 2019/2022 - Preparation for Run 3 and analysis of first Run3 data in Hbb and ttH analyses (SM and BSM)

Conclusions

- Very intriguing period for H-quark sector
- Observation of *pp→ttH, H→bb* important part of the physics program for the LHC-Run2
- Still important possibilities to have breakthrough surprises
  - deviations from the SM of the H-quarks couplings
  - deviations from the SM of the H-V couplings
  - observation of new resonances or DM involving the Higgs boson
- The results we expect in the next 3 years from this program will give crucial information on the nature of the Higgs boson discovered 4 years ago

Responsibilities

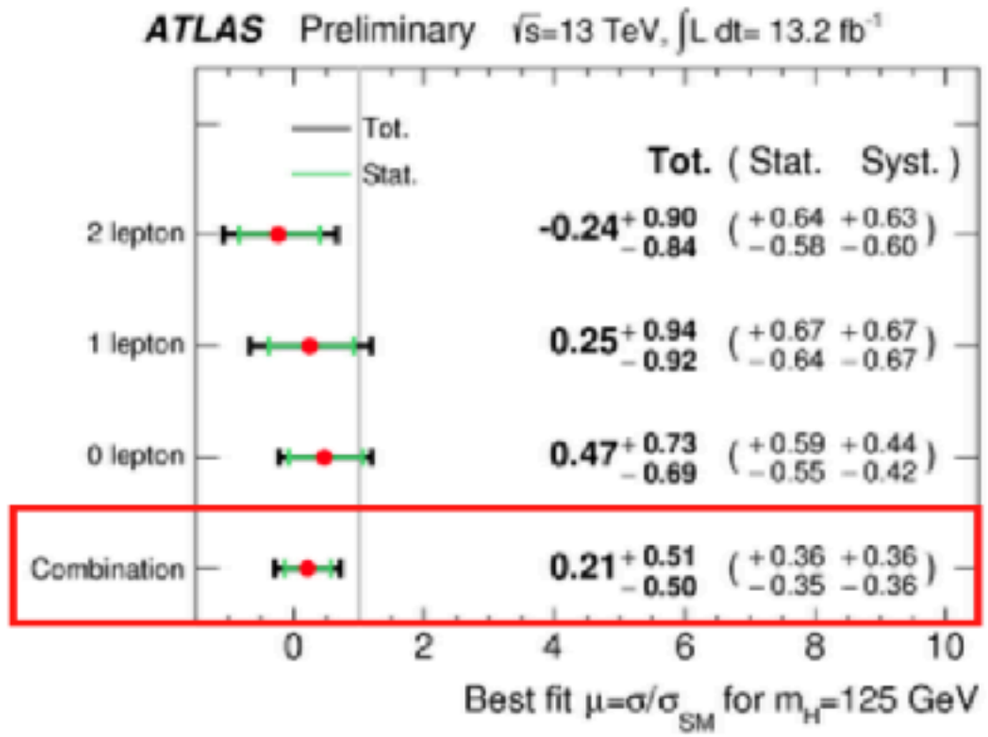
- **Coordination of ATLAS Hbb analysis working group**: PF, 10/2014-10/2015
- **Coordination of software framework development**: PF, 10/2014-08/2015
- **Coordinator of the ATLAS EtMiss working group**: PF, 4/2013-3/2014
- **Coordinator of the ATLAS MC validation working group:** PF, 10/2016 - 10/2017
- **Contacts** between ATLAS Hbb and 3 other ATLAS physics/performance groups:
  - MET: PF
  - e/γ: GM
  - ATLAS Higgs combination: PF
- **Editing of ATLAS papers (1), CONF notes (3), public notes (3), supporting notes (2)**
  - main supporting note (ATL-COM-PHYS-2014-051) of SM VH Run1 paper (**JHEP01(2015)069**): PF
  - VH resonance search w/ 2015 data, CONF note for 2015 CERN EOYE (**ATLAS-CONF-2015-074**) and paper: PF
  - A→Zh search w/ 2015 data: CONF note for Moriond 2016 (**ATLAS-CONF-2016-015**): PF
  - supporting note on signal and background modelling (**ATL-COM-PHYS-2015-1474**): CP
  - public note on MET expected performance in Run2 (**ATL-PHYS-PUB-2015-023**): PF
  - **Higgs@LHC xsection working group - report 4,** section on template cross sections: PF section on VH,VBF: CP

BACKUP

H→bb - Global picture

VH - Associated Production

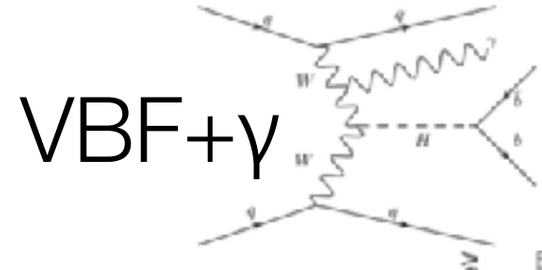
	Significance obs (exp) [σ]	Signal Strenght μ=σ/σ(SM)
ATLAS Run1	1.4 (2.6)	0.5±0.4
ATLAS Run2	0.42 (1.94)	0.2±0.5
CMS Run1	2.1 (2.5)	0.9±0.4
ATLAS+CMS Run 1	2.6 (3.7)	0.7±0.3

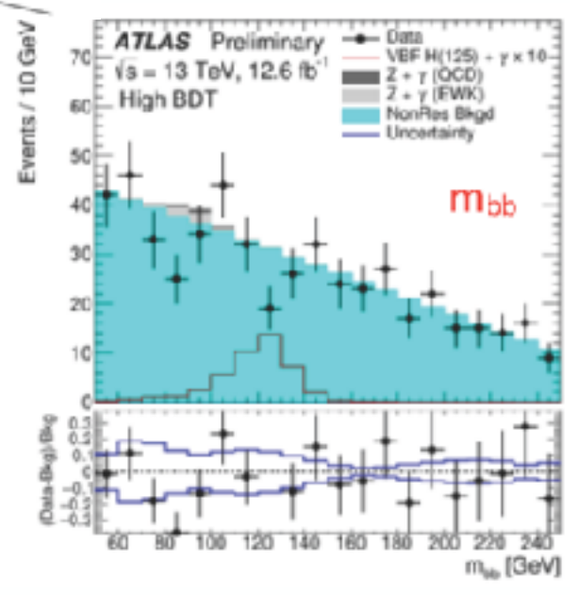


Vector Boson Fusion

	Limits on σ/σ(SM)	Signal Strenght μ=σ/σ(SM)
ATLAS Run1	4.4 (5.4)	-0.8±2.3
ATLAS (VBF+γ)Run2	4.0 (6.0)	-3.9±2.8
CMS Run1	5.5 (2.5)	2.8±1.6
CMS Run 2	3.0 (5.0)	-3.7±2.4
CMS Run1+Run2	3.4 (2.2)	1.3±1.2

VBF+γ

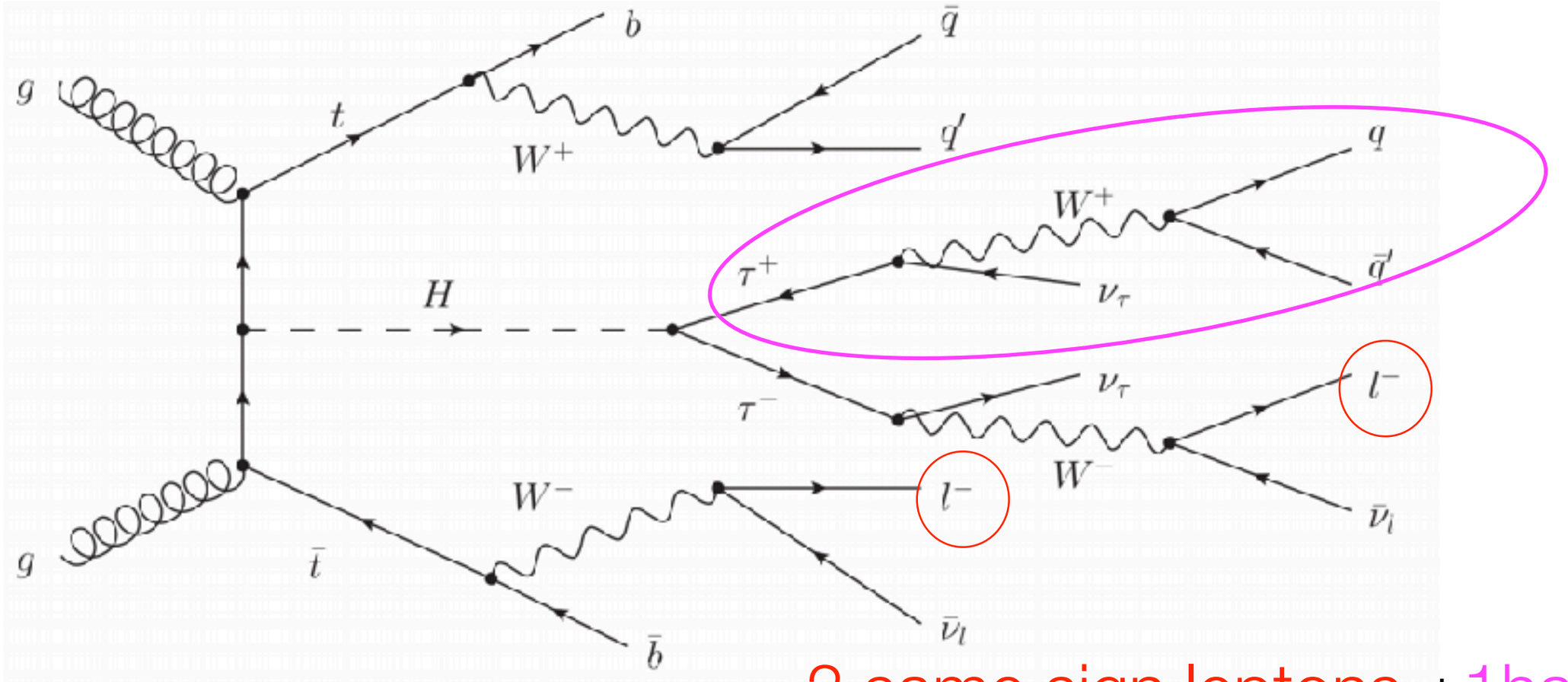




ttH

- Great interest because cross section increase by a factor 4 (Run1 sensitivity reached with ~5-6 fb-1 of 13 TeV data)

- Very rich set of decay modes



2 same sign leptons +1had τ

ttH

- Great interest because cross section increase by a factor 4 (Run1 sensitivity reached with ~5-6 fb-1 of 13 TeV data)

- Very rich set of decay modes

H decays:

bb

WW

ZZ

ττ

γγ

multileptons

2 same sign leptons +1had τ (ττ)
2 same sign leptons +0 had τ (WW)
3 leptons (WW)
4 leptons (ZZ)

ttH multilepton and γγ

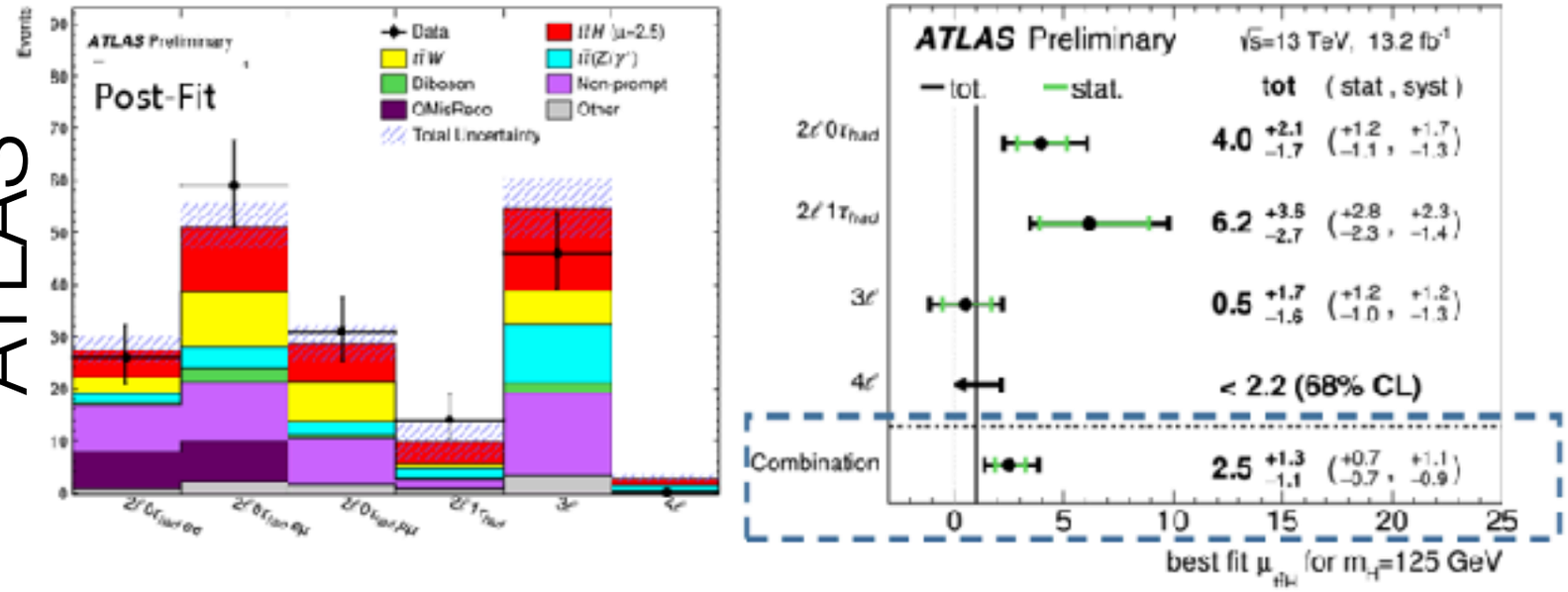
- Multileptons searches show signal strengths >1

ATLAS μ= 2.5 $^{+1.3}_{-1.1}$

CMS μ= 2.0 $^{+0.8}_{-0.7}$

- Interesting to see with the data collected this year

ATLAS



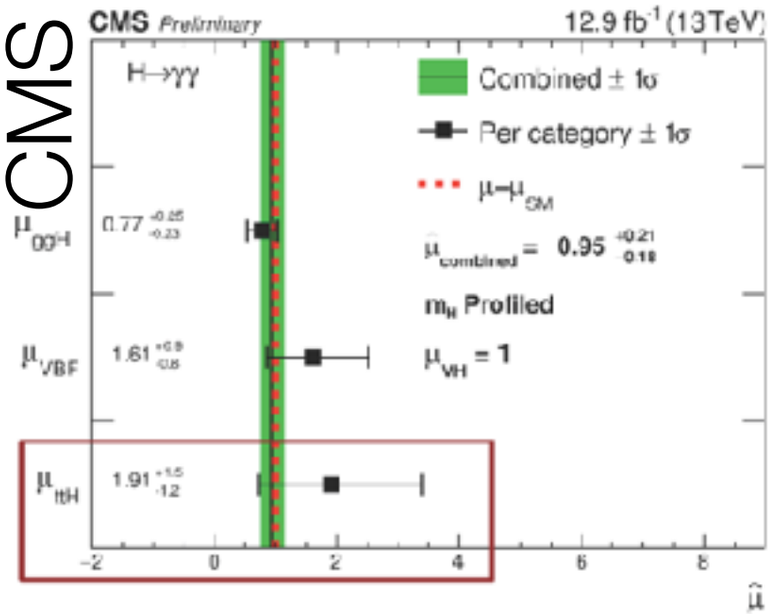
CMS

➢ Observed and expected asymptotic 95% CL upper limits on and best t value of the signal strength (2015+2016 datasets)

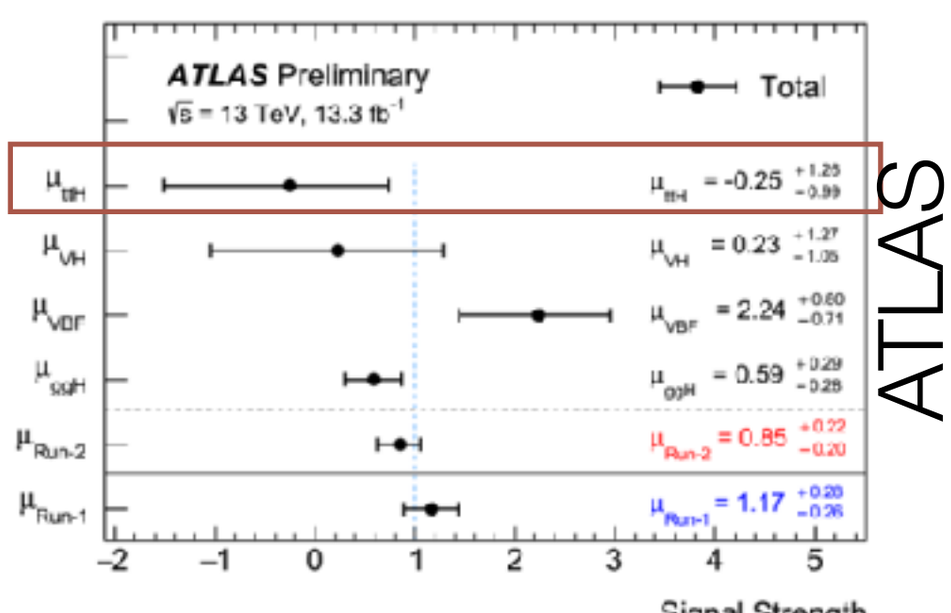
Category	Obs. limit	Exp. limit $\pm1\sigma$	Best fit μ $\pm1\sigma$
Same-sign dileptons	4.6	$1.7^{+0.9}_{-0.5}$	$2.7^{+1.1}_{-1.0}$
Trileptons	3.7	$2.3^{+1.2}_{-0.7}$	$1.3^{+1.2}_{-1.0}$
Combined categories	3.9	$1.4^{+0.7}_{-0.4}$	$2.3^{+0.9}_{-0.8}$
Combined with 2015 data	3.4	$1.3^{+0.6}_{-0.4}$	$2.0^{+0.8}_{-0.7}$

μ = 1.9 $^{+1.5}_{-1.2}$ (2016 dataset)

CMS



μ= - 0.25 $^{+1.26}_{-0.99}$

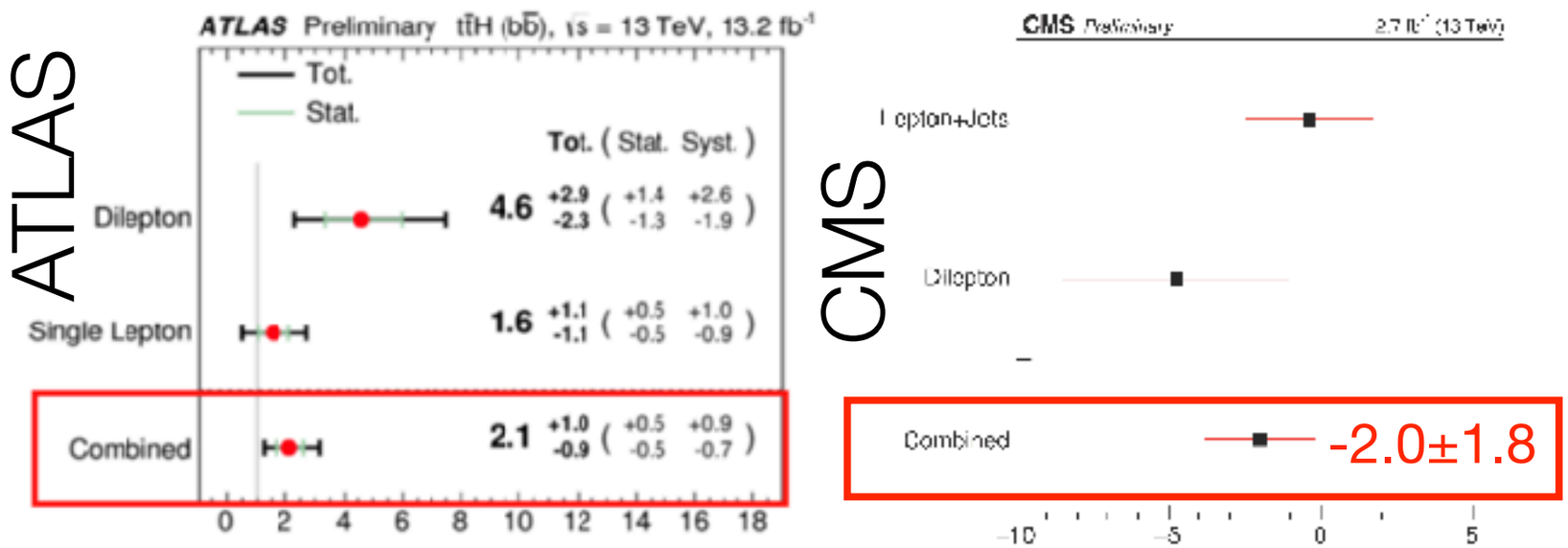


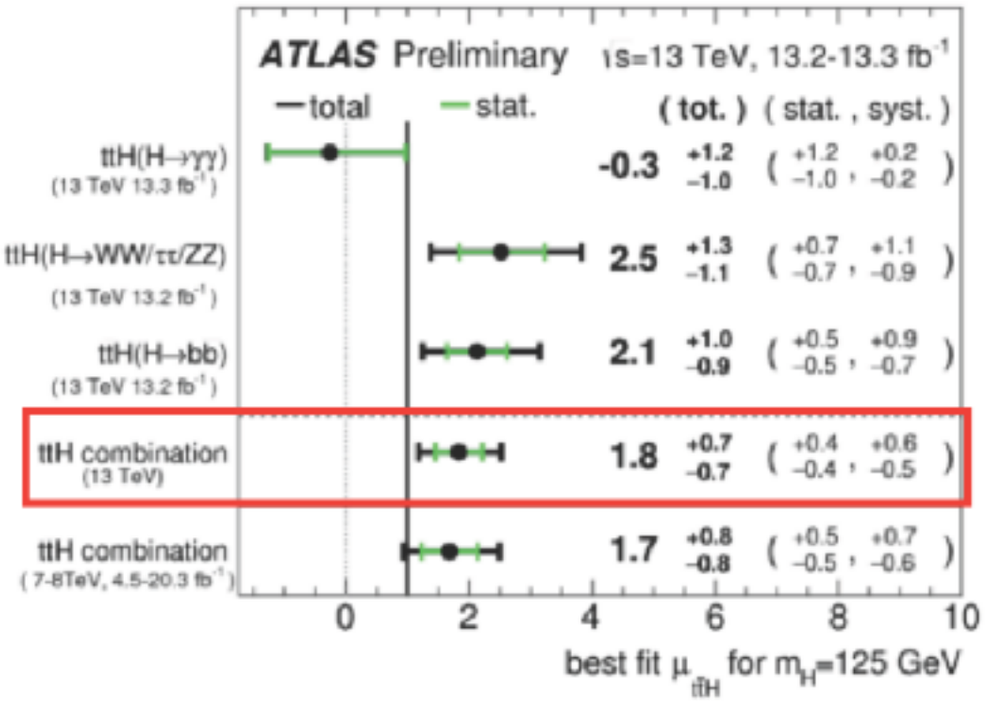
ATLAS

- γγ searches have opposite fluctuations in ATLAS and CMS

ttH bb
and combination

- Lower statistics analysed so far by CMS
- bb searches have opposite fluctuations in ATLAS and CMS

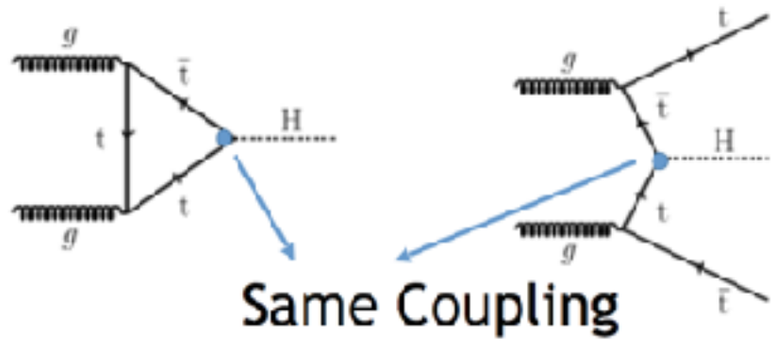




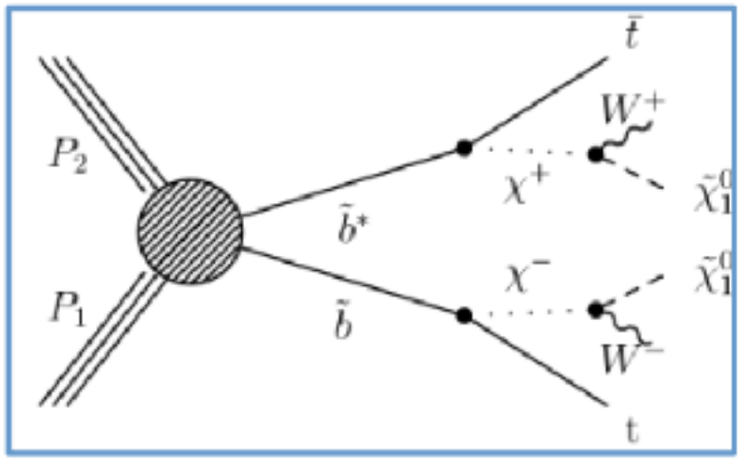
	Significance obs (exp) [σ]	Signal Strenght μ=σ/σ(SM)
ATLAS Run1	2.33 (1.53)	1.7±0.8
ATLAS Run2	2.8 (1.8)	1.8±0.7
CMS Run1	3.4 (1.2)	2.8±1.0
ATLAS+CMS Run 1	4.4 (2.0)	2.3±0.7

Signal strength bigger than 1 interesting to see the rest of the data

BSM searches - ttH multi lepton excess

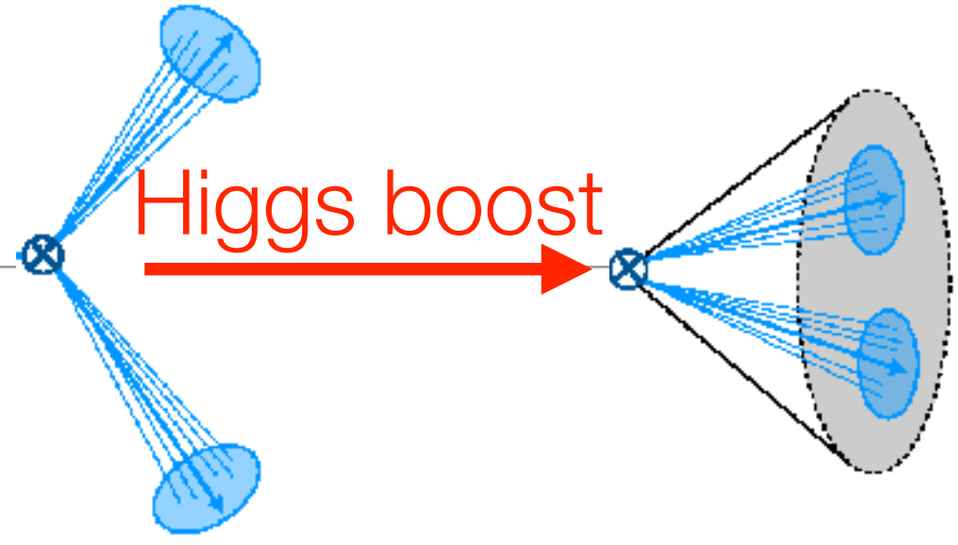


- Top quark coupling enhancement ?
  - Why not gluon-gluon fusion enhancement?
    Additional contributions necessary to suppress the ggh coupling
  - Possible benchmarks in SUSY NMSSM.
    For neutralino mass >250 GeV, the stop not yet excluded. Scenarios with stop masses ~ 300-800 GeV possible



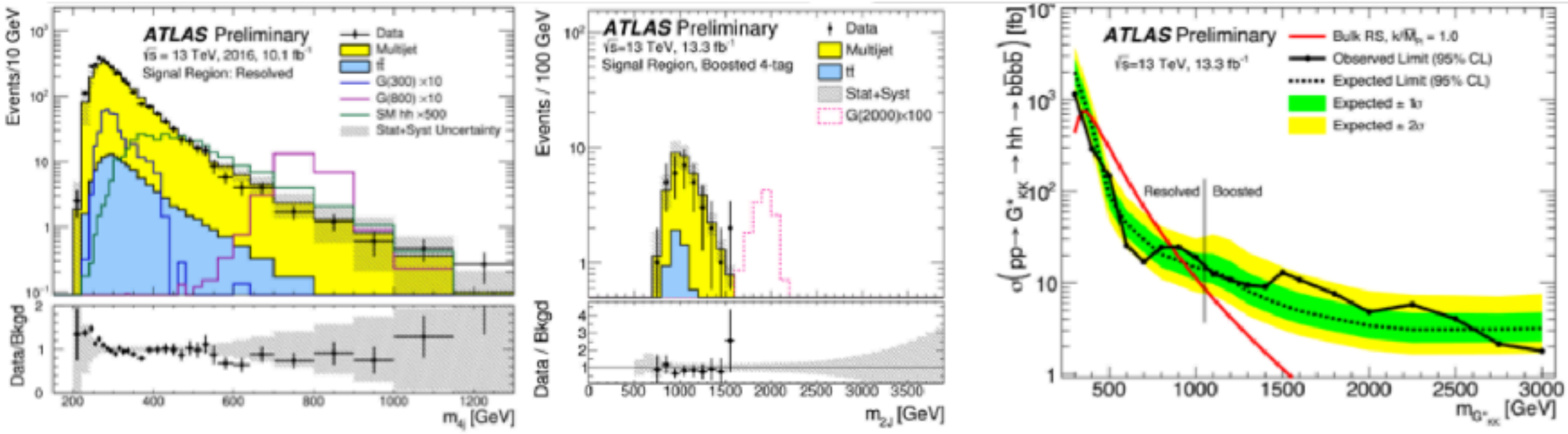
- New Physics 2t2W+MET final state?
  - first sign of sbottom? other channels should see excess, but still space to accommodate this possibility
- What if at higher luminosities all production and decay widths converge to the SM values ?
  - Decoupling : SM a good effective theory until high scales.
  - Alignment : Extended Higgs Sector present, but Higgs mass eigenvalues are aligned with the V.E.V. direction → Searches for new bosons (in NMSSM rich scenario)

Double Higgs searches



- Main interest: searches of new resonances
  - i.e. H→2h(125) or spin-2 Kaluza-Klein gravitons
- In addition, pp→2h(125) foreseen in SM (and depends on the Higgs self coupling)
- Novel detectors (ATLAS - insertable b-layer)
  and experimental techniques (jet sub-structures) critical for these searches

Example - ATLAS: pp→(X)→2h(125)→4b



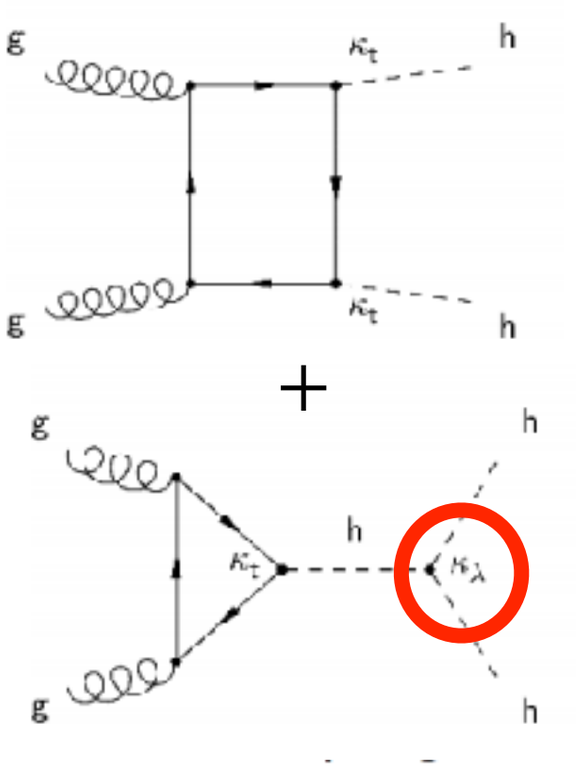
- **Results:**
- 95% CL limit is (pp → hh → bbbb) < 330 fb
- **Excluded mass range:**
- observed: 360 GeV < $m(G_{KK})$< 860 GeV

29 x the SM, expected may be somewhat larger

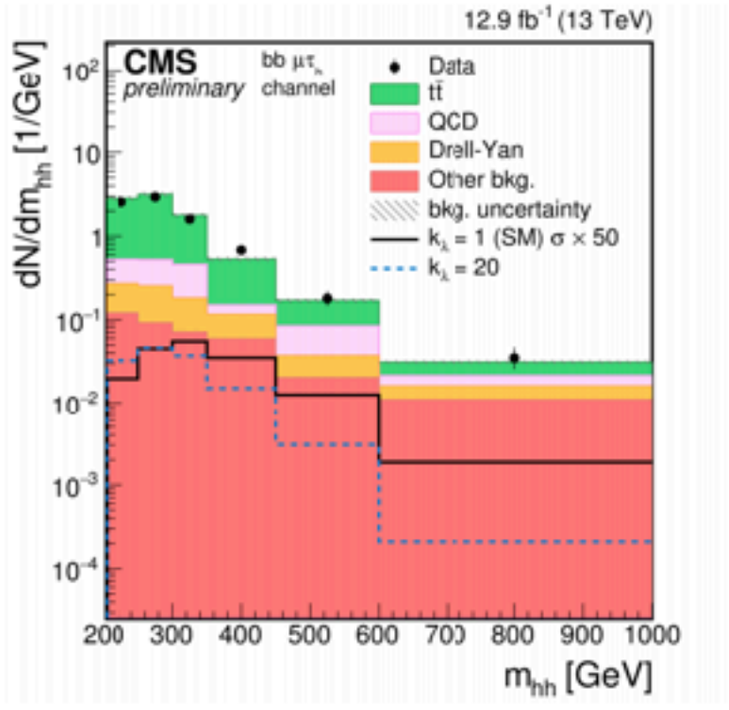
Double Higgs searches

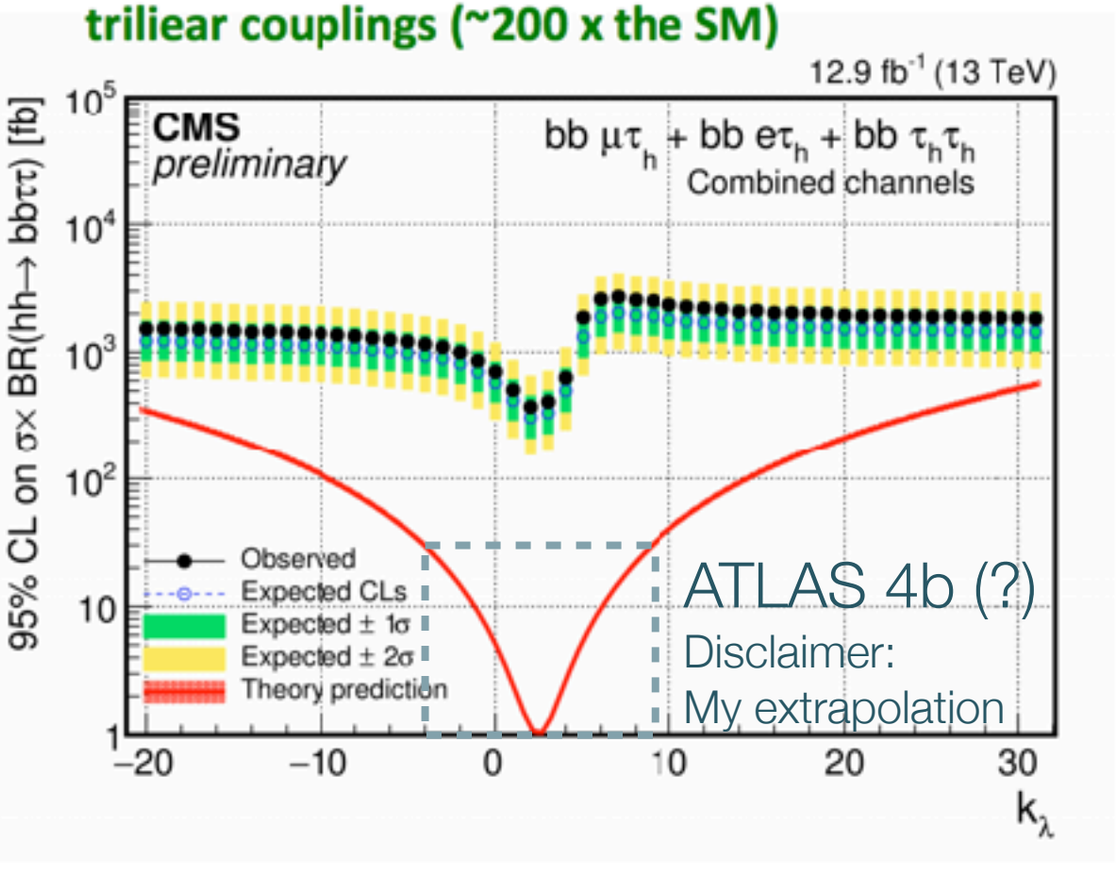
- Resonant and non-resonant searches have been performed at 13 TeV in different channels using 2015 data (3 fb-1).

- Among the others, CMS updated the pp→(X)→2h(125)→2b2τ (13 fb-1)

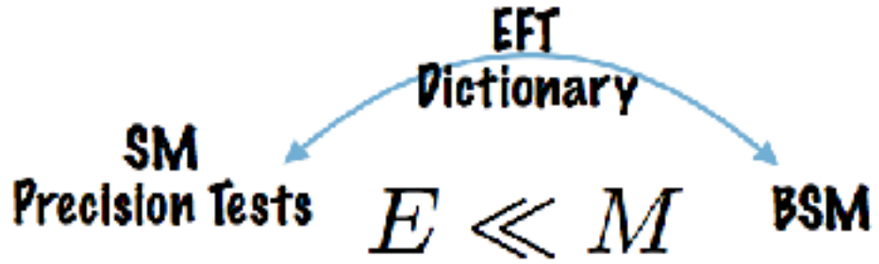


$$k_\lambda = \lambda_{hhh}/\lambda_{hhh}^{SM}$$



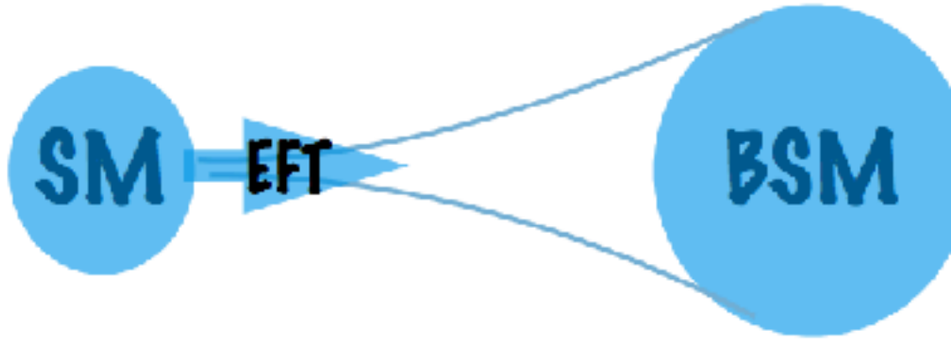


Effective field theory, couplings & Co.

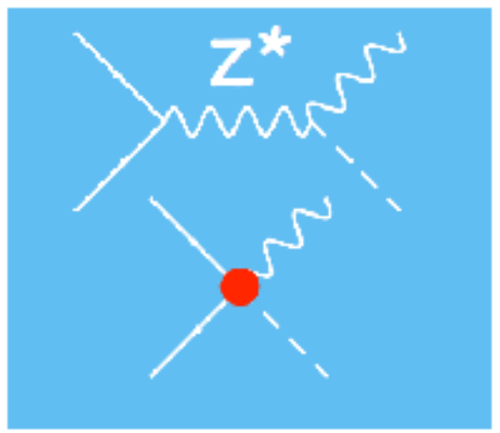


$$\mathcal{L}_{BSM} \xrightarrow[(E \ll M)]{} \mathcal{L}_{\text{eff}} \simeq \mathcal{L}_4 + \mathcal{L}_6 + \cdots$$

$$\sum_i c_i \frac{\mathcal{O}_i}{M^2}$$



- If new physics beyond the LHC reach, departures from SM couplings are still possible.
- EW precision measurements on Z resonance (LEP),
  Triple gauge coupling measurements
  Higgs measurements
- Measures modifications of SM couplings at the mZ or mH scale
- Measures E-growing effects E> mZ, mH
  i. e. measure m(VH) in associated production.

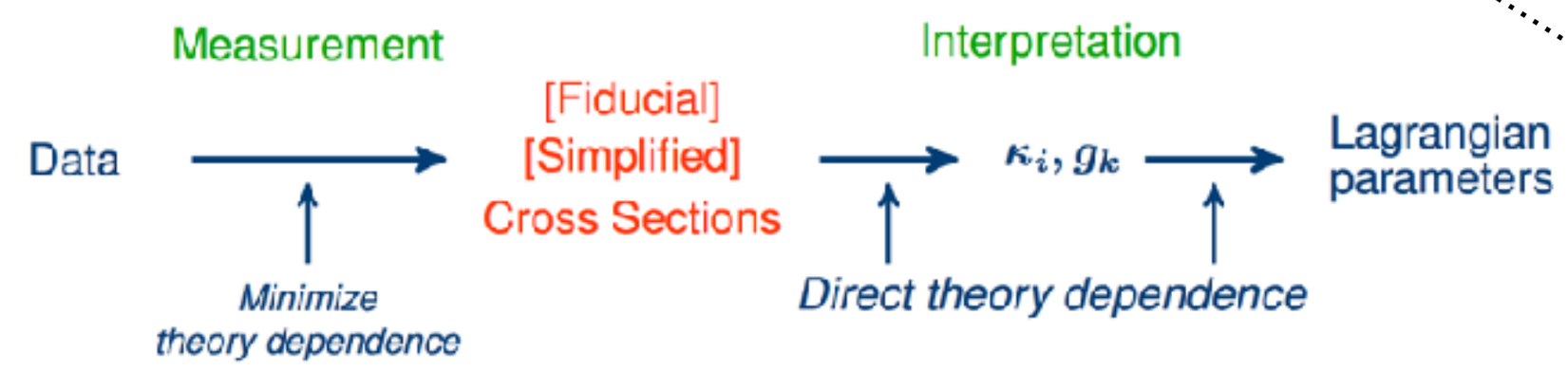


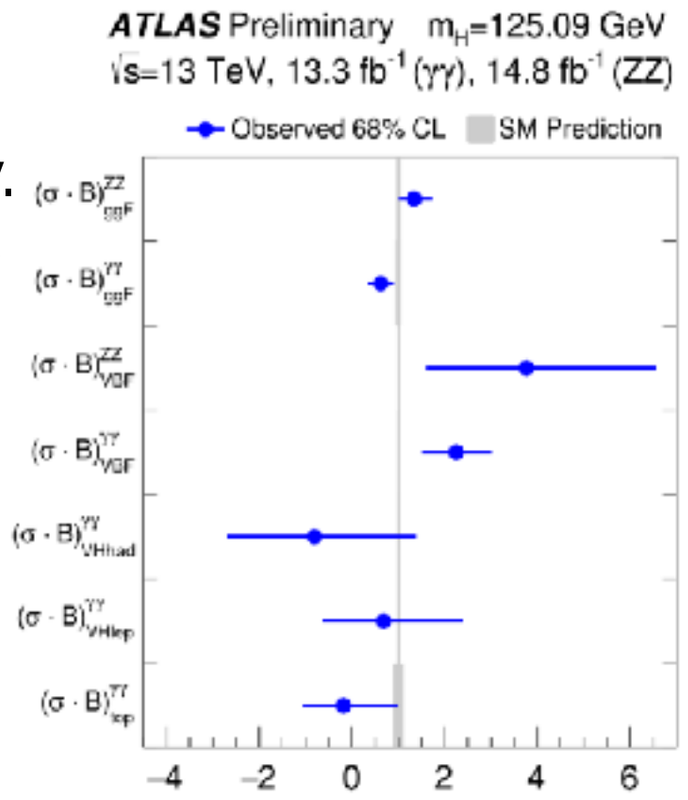
$$\sim \frac{1}{E^2}$$

$$\sim const$$

Near future - Template cross sections

like this, but divided in kinematic bins i.e. pT(H>200 GeV) sensible to BSM dev.





- Fiducial differential cross sections natural candidate

- However Higgs is special: **several production mechanism and decay modes**, and we gain from combining all the information. **Deviations in these could highlight new physics!**

- Not for all the decay modes a fiducial differential cross sections is easy to perform (what if we use MVA?)

- Proposal to have an additional framework to combine the Higgs measurements:
  Simplified Template Cross Sections

  - provide more **finely-grained measurements**, while at the same time allowing and **benefitting from the global combination** of the measurements in all decay channels

  - make a measurement in **kinematic bins** covered by the experimental setup, **limiting extrapolations**.

  - **reduce** the impact of the **theory assumptions/bias folded in the measurement**